

# Day 27, 19.04.2018 Particle Physics 2

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# housekeeping

The end game: next slide

**Particle Physics:** 

**Readings:** Oerter and Hobson

Hobson\_PP.pdf is chapter 17 out of Hobson

Homework #12 is all from MasteringPhysics - normal due date

Feynman Diagram rules

3 movies in the lecture slide directory - you'll need them for homework and the final

they are: primitiveDiagrams\_X. mp4



## where X = 0,1,2

# last 2 weeks & final

Homework #13 will be assigned 4/21 and due 4/28 - normal rotation

On-line final exam will be assigned Sunday, 4/29 and due Tuesday night, May 1

will cover material since midterm plus the last week of class

There is 1 more 10 point quiz (stay tuned)...

only the shadow knows when

## Remember when I was sick?

been trying to catch up, but not going to make it. Hence:

### Final Exam day:

- 1. You'll arrive at 0745 on May 4, here. I know.
- 2. I'll provide bagels. You supply liquids.
- 3. We'll have a quiz.
- 4. I'll finish with about a 1 hour grand finale, lalapalooza, mind-bending lecture
- 5. You'll do your Feynman Diagram Project
- 6. There will be no poster project this year



I'm willing to rethink this

# honors project began

https://qstbb.pa.msu.edu/storage/Homework\_Projects/honors\_project\_2018/

contains:

the first instructions: the plan & tutorial the second instructions -v2 uploaded, added a missing student the data, assigned by name in the second instructions - see next

dates:

complete first part, March 16

analyze data by April 24 and hand in complete writeup at the final exam



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# the data

# should have been in zipped format

rather, somehow they were unzipped in some process

fixed: now

https://qstbb.pa.msu.edu/ storage/Homework\_Projects/ honors\_project\_2018/

	Name	Last modified	Size	Description
	Parent Directory		-	
	ISP220_inspirationaltalk.pdf	2018-03-01 07:10	4.3M	Portable Document Format file
POF	MinervaInstructions1_2018.pdf	2018-03-01 07:10	2.3M	Portable Document Format file
Pop	MinervaInstructions2_2018_2.pdf	2018-04-09 22:11	112K	Portable Document Format file
	Zpathintro.mp4	2018-03-01 07:16	274M	
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### Index of /storage/Homework\_Projects/honors\_project\_2018

# I need a Section 2

to test the Z-path uploading machinery and instructions



## particles in time

An anti-electron...coming into an initial state to a node:



*is the same thing as* An electron coming **out** of an **initial** state (?)



An anti-electron...coming **out** of a **final** state:



*is the same thing as* An electron coming **into** a **final** state (?)



## Yes, this makes sense

# Nope, this makes no sense...time-backwards

## Yes, this makes sense

# Nope, this makes no sense...time-backwards

# primitive diagrams

## are general

but this is completely general...for any charged fermion:



f could be electron, positron, proton, antiproton...and more – any electrically charged **f**ermion.

Their diagrams are identical.



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## Primitive Diagram Scorecard

your first entry

Primitive Diagrams	TIME always	;	
f f f			QED
2	3		Weak Int
6	7		eractions
4	5		Strong Interactions
8	9		Higgs
10	11		Interactions
rmion, spin 1/2, e.g., electron Vector Boson, spin 1, e	.g., photon gluon, spin	1 scalar Boson, spin 0, e.g., F	figgs Boson

# beta decay

the inaugural non-QED interaction

Weak Force

Fermi Theory of Beta Decay

uses the Dirac ideas of quantum electrodynamics

particle creation and annihilation



m<sub>neutron</sub> > m<sub>proton</sub> a smidgen.



## a free neutron has a lifetime of about 11 minutes. He sent the paper to *Nature*, but it was rejected:

"it contained speculations which were too remote from reality"



## from his original paper for different nuclear species parameters

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# exchange force

the modern view:

if there's a force...there's a field

if there's a field...there's a particle

# eld ticle

we know one force...so far electromagnetism electricity magnetism united by Relativity remember?



The modern idea:

The force of electromagnetism is "propagated" by the photon.

Multiple names: "propogator" "Intermediate Vector Boson"

## I'll call the photon: the "Messenger Field for Electromagnetism"

# charge independence

the force that holds the protons and neutrons together

is the same between n-n, p-p, n-p

**Strong Force** 

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## the STRONG force

## overwhelms the electromagnetic force

## but only over a very short range...





uncertainty certainly to the rescue

brilliant observation by Yukawa

maybe there's a quantum that is active only over the size of a nucleus: "U"

another exchange force/particle?



Suppose U travels at c within a nucleus...  $\Delta t = \Delta x/c$ 

Then Uncertainty could estimate U's mass...  $\Delta E \Delta t = h/4\pi$ 

$$m_{\scriptscriptstyle U} = \Delta E/c^2$$

 $m_U \approx 100 \times 10^6 eV = 100 MeV$ 

# the Yukawa particle

## is the pion



These coupling strengths are large - strong.

In technical terms we call this...the strong interaction.

If we ignore electromagnetism...the proton & the neutron are very much alike - we can treat them as being the same particle

neutrons and protons

act like they are identical particles

the electric charge?

as a force...Yukawa's force is 100 times the electromagnetic

For nuclear forces: treat p and n as identical and differing only by a "quantum number" called "Isospin"



A neutron... is a "nucleon" with "isospin down" is a "nucleon" with "isospin up" A proton...

They go together...within the strong, nuclear force.

How?





+ 1/2

- 1/2

# jargon alert:nucleonrefers to:either a proton or a neutronentomology:from "nucleus"...the "-on" tends to be a<br/>particle nameexample:"nucleon force"



## by 1950 the forces were identified

## "strong"

## as evidenced by the pion (refined later)

## "electromagnetic"

as evidenced by the exchange of photons among electrically charged particles

"weak"

as originally evidenced by neutron beta decay, and subsequently pion, muon, and other hadronic decays

## "gravitational"

the weakest of all...quantum theory of gravity still a mystery



# FAMILIES

## Nature prefers

like-particles



Lepton Families

electrons and a neutrino

muons and a neutrino

taus and a neutrino

These sorts of patterns are a huge deal.

Q



# by 1955

	N(1535)	$S_{11}$	****	$\Delta(1750)$	P
	N(1650)	$S_{11}$	****	$\Delta(1900)$	$S_{2}$
	N(1675)	D15	****	$\Delta(1905)$	F
	N(1680)	F15	****	∆(1910)	P
	N(1700)	D13	***	$\Delta(1920)$	P
	N(1710)	$P_{11}$	***	$\Delta(1930)$	D
	N(1720)	$P_{13}$	****	<b>∆</b> (1940)	D
	N(1900)	P <sub>13</sub>	**	$\Delta(1950)$	F
	N(1990)	F <sub>17</sub>	**	$\Delta(2000)$	F
	N(2000)	F <sub>15</sub>	**	$\Delta(2150)$	S
	N(2080)	D13	**	$\Delta(2200)$	G
	N(2090)	S <sub>11</sub>	*	$\Delta(2300)$	
	N(2100)	$P_{11}$	*	$\Delta(2350)$	
	N(2190)	G17	****	$\Delta(2390)$	
	N(2200)	D15	**	$\Delta(2400)$	
	N(2220)	$H_{19}$	****	$\Delta(2420)$	
	N(2250)	$G_{19}$	****	$\Delta(2750)$	
	N(2600)	1,11	***	$\Delta(2950)$	

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A(1670)

A(1690)

A(1800) A(1810) A(1820)

A(1830)

A(1890)

A(2000) A(2020) A(2100) A(2110)

A(2325) A(2350) A(2585)

 $P_{01}$   $S_{01}$   $P_{01}$   $S_{01}$   $S_{01}$   $P_{01}$   $F_{05}$   $D_{05}$ 

 $P_{03}$ 

F<sub>07</sub> G<sub>07</sub> F<sub>05</sub> D<sub>03</sub> H<sub>09</sub>

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Σ(1775)

 $\Sigma(1840)$   $\Sigma(1880)$   $\Sigma(1915)$   $\Sigma(1940)$ 

 $P_{33}$   $P_{33}$   $S_{31}$   $P_{31}$   $S_{31}$   $F_{35}$   $P_{33}$   $D_{35}$   $D_{33}$   $F_{35}$   $F_{35}$   $F_{31}$   $D_{35}$   $S_{31}$   $F_{35}$   $F_{37}$   $F_{3$ 

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 $P_{11}$ 

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 $S_{11}$ 

 $D_{15}$ 

F<sub>15</sub> D<sub>13</sub> P<sub>11</sub>

 $P_{13}$ 

 $P_{13}$ 

F<sub>17</sub> F<sub>15</sub>

D13

 $S_{11}$ 

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G17

V(2700) K<sub>1.13</sub> \*\*

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N(2100) N(2190)

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 $D_{13}$   $S_{11}$   $P_{11}$   $D_{13}$   $S_{11}$   $P_{11}$   $D_{15}$   $P_{13}$ 

 $\Xi(1690)$ 

 $\Xi(1820)$ 

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 $\Xi(2120)$  $\Xi(2250)$  $\Xi(2370)$ 

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Ω-

 $I^{G}(J^{PC}$ 

 $1^{-}(2^{-})$  $0^{-}(1^{-})$ 

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N(1700)

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N(2000)

N(2080)

N(2090)

N(2100) N(2190) N(2200)

 $D_{13}$ 

 $P_{11}$   $P_{13}$   $P_{13}$   $F_{17}$   $F_{15}$   $D_{13}$   $S_{11}$   $P_{11}$   $G_{17}$ 

 $D_{15}$ 

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 $\eta_b(1S)$ • T(1S)

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χ<sub>b1</sub>(1P)

T(25)

T(1D)

χ<sub>b0</sub>(2P)

χ<sub>b1</sub>(2P)
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*Υ*(35)

T(45)

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NON-qq CA

N(1440) N(1520) N(1535)

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 $F_{01}^{01}$   $S_{01}^{03}$   $S_{01}^{01}$   $F_{05}^{05}$   $P_{03}^{03}$ 

F<sub>07</sub> G<sub>07</sub> F<sub>05</sub>

r 01

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 Σ (1670)

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 Σ (1690)

\*  $\Sigma(1750)$ \*  $\Sigma(1770)$ \*\*\*\*  $\Sigma(1775)$ \*\*\*\*  $\Sigma(1775)$ 

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A(1810)

A(1820) A(1830) A(1890) A(2000)

A(2020) A(2100) A(2110)

888

E(2250)

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**Ξ**(2500)

Ω(2250)<sup>-</sup> Ω(2380)<sup>-</sup>

Ω(2470)

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# things wer meschat's so

"		er		<b>e</b>		a	ry	
• $\pi^{\pm}$ • $\pi^{0}$ • $\eta$	$1^{-}(0^{-})$ $1^{-}(0^{-}+)$ $0^{+}(0^{-}+)$	<ul> <li>π<sub>2</sub>(1670)</li> <li>φ(1680)</li> <li>ρ<sub>3</sub>(1690)</li> </ul>	$1^{-}(2^{-}+)$ $0^{-}(1^{-}-)$ $1^{+}(3^{-}-)$	• K <sup>±</sup> • K <sup>0</sup> • K <sup>0</sup> <sub>5</sub>	$\frac{1/2(0^{-})}{1/2(0^{-})}$ $\frac{1/2(0^{-})}{1/2(0^{-})}$			

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$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	$\begin{array}{c c c c c c c c c c c c c c c c c c c $	<ul> <li>\$\phi(1020)\$</li> </ul>	$0^{-}(1^{-})$	X(1835)	??(? - +)'	<ul> <li>K:(1430)</li> </ul>	1/2(0+)	BOTTOM,	STRANGE
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	$\begin{array}{c c c c c c c c c c c c c c c c c c c $	<ul> <li>h<sub>1</sub>(1170)</li> </ul>	$0^{-(1^{+}-)}$	<ul> <li></li></ul>	$0^{-}(3^{-}-)$	• K:(1430)	1/2(2+)	$(B = \pm 1,$	$S = \mp 1$
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	$\begin{array}{c} 1(1260) & 1-(1++) \\ f_{1}(120) & 0^{+}(2++) \\ f_{1}(120) & 0^{+}(2++) \\ f_{1}(125) & 0^{+}(2++) \\ f_{1}(125) & 0^{+}(0++) \\ f_{1}(125) & 0^{+}(0++) \\ f_{1}(125) & 0^{+}(0++) \\ f_{1}(130) & 1^{-}(0-+) \\ f_{2}(130) & 1^{-}(0-+) \\ f_{2}(130) & 1^{-}(0-+) \\ f_{2}(130) & 1^{-}(0-+) \\ f_{2}(130) & 1^{-}(0++) \\ f_{3}(130) & 1^{-}(0++) \\ f_{4}(1330) & 7^{-}(1+-) \\ f_{4}(1330) & 7^{-}(1+-) \\ f_{4}(1330) & 7^{-}(1+-) \\ f_{4}(1330) & 7^{-}(1+-) \\ f_{4}(1330) & 1^{-}(2++) \\ f_{4}(1330) & 0^{+}(0++) \\ f_{5}(1420) & 0^{+}(1++) \\ f_{2}(1430) & 0^{+}(2++) \\ f_{4}(1430) & 0^{+}(2++) \\ f_{4}(130) & 0^{+}(1++) \\ f_{4}(120) & 0^{+}(2++) \\ f_{4}(130) & 0^{+}(2++) \\ f_{4}(1450) & 1^{-}(1) \\ g_{4}(1450) & 1^{-}(1) \\ g_{4}(1450) & 1^{-}(1) \\ g_{4}(250) & 1^{+}(3) \\ g_{4}(250) & 0^{+}(2++) \\ f_{4}(150) & 0^{+}(0++) \\ f_{4}(150) & 0^{+}(1++) \\ g_{5}(2300) & 0^{+}(2++) \\ f_{4}(150) & 0^{-}(1+) \\ g_{4}(240) & 0^{+}(2++) \\ g_{5}(2400) & 0^{+}(2(2++) \\ g_{6}(2400) & 1^{-}(2(1-)) \\ D_{6}(2400) & 1^{-}(2(1-)) \\ D_{6}($	<ul> <li>b<sub>1</sub>(1235)</li> </ul>	1+(1+-)	$\eta_2(1870)$	$0^+(2^{-+})$	K(1460)	1/2(0-)	<ul> <li>B<sup>0</sup></li> </ul>	0(0-)
$\begin{array}{c} f_{1}(127) \\ f_{1}(128) $	$\begin{array}{c} f_{(1270)} & (+2^+) \\ f_{(1285)} & (+1^+) \\ f_{(1285)} & (+1^+) \\ f_{(1295)} & (+1^+) \\ f_{(1295)} & (+1^+) \\ f_{(1201)} & (+$	<ul> <li>a)(1260)</li> </ul>	$1^{-}(1^{+})$	a(1900)	1+(1)	K (1460)	1/2(0)	B.	0(1-)
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$\begin{array}{c} \gamma_{1}(1285) & 0^{+}(1^{+}+) \\ \eta(1295) & 0^{+}(0^{-}+) \\ \gamma_{1}(1300) & 1^{-}(0^{-}+) \\ \gamma_{2}(1300) & 1^{-}(0^{-}+) \\ \gamma_{3}(1300) & 1^{-}(0^{-}+) \\ \gamma_{4}(1300) & 1^{-}(0^{+}+) \\ \gamma_{4}(1300) & 1^{-}(0^{+}+) \\ \gamma_{4}(1300) & 1^{-}(1^{+}+) \\ \gamma_{4}(1400) & 1^{-}(1^{+}+) \\ \gamma_{4}(1400) & 0^{+}(1^{+}+) \\ \gamma_{4}(1400) & 0^{+}(1^{+}+) \\ \gamma_{4}(1400) & 0^{+}(1^{+}+) \\ \gamma_{4}(1400) & 0^{+}(1^{+}+) \\ \gamma_{4}(1420) & 0^{-}(1^{-}-) \\ \gamma_{4}(1450) & 1^{-}(0^{+}+) \\ \gamma_{4}(1450) & 1^{-}(1^{+}-) \\ \gamma_{4}(1450) & 0^{-}(1^{+}-) \\ \gamma_{4}(1450) & 0^{-}(1^{-}-) \\ \gamma_{$	<ul> <li>£(1270)</li> </ul>	$0^+(2^+)$	6(1910)	$0^+(2^++1)$	N2(1580)	1/2(2)	B* (5850)	2(2?)
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$\begin{array}{c} \gamma_{(1285)} & 0^{+}(0^{-}) \\ \gamma_{(1280)} & 1^{-}(0^{-}) \\ z_{2}(1300) & 1^{-}(0^{-}) \\ z_{3}(1300) & 1^{-}(0^{-}) \\ z_{4}(1300) & 1^{-}(2^{+}) \\ h_{1}(1380) & 7^{-}(1^{+}) \\ h_{1}(1380) & 7^{-}(1^{+}) \\ \tau_{1}(1400) & 1^{-}(1^{-}) \\ \tau_{1}(1400) & 1^{-}(1^{-}) \\ \tau_{1}(1400) & 0^{-}(1^{-}) \\ \tau_{1}(1402) & 0^{+}(1^{+}) \\ f_{1}(120) & 0^{+}(2^{+}) \\ f_{1}(120) & 0^{+}(2^{+}) \\ f_{1}(130) & 0^{+}(2^{+}) \\ f_{1}(150) & 0^{-}(1^{-}) \\ z_{1}(1640) & 1^{-}(1^{+}) \\ z_{1}(1640) & 1^{-}(1^{+}) \\ z_{1}(1640) & 1^{-}(1^{+}) \\ z_{2}(1670) & 0^{-}(3^{-}) \\ z_{2}$	<ul> <li>6 (1285)</li> </ul>	$0^{+}(1^{+}+)$	• fs(1950)	$0^{+}(2^{+}+)$	K(1630)	1/2(1)	D <sub>s</sub> j(0000)	-(- )
$\begin{array}{c} \eta(1300) & 1-(0-+) \\ \pi(1300) & 1-(0-+) \\ \delta_{0}(2020) & 0^{+}(0^{+}+) \\ \delta_{0}(2020) & 0^{+}(0^{+}+) \\ \delta_{1}(1300) & 1-(2^{+}+) \\ \eta(1405) & 0^{+}(0^{+}+) \\ \pi(1405) & 0^{+}(0^{+}+) \\ \pi(1402) & 0^{-}(1) \\ f_{1}(1320) & 0^{+}(1^{+}+) \\ \delta_{1}(2130) & 0^{+}(2^{+}+) \\ \delta_{1}(1320) & 0^{-}(1^{-}-) \\ f_{2}(130) & 0^{+}(2^{+}+) \\ \delta_{1}(130) & 0^{+}(1^{+}+) \\ \delta_{2}(1200) & 0^{+}(0^{+}+) \\ \delta_{2}(1200) & 0^{+}(0^{+}+) \\ \delta_{2}(1200) & 0^{+}(0^{+}+) \\ \delta_{2}(1200) & 0^{+}(0^{+}+) \\ \delta_{1}(1300) & 0^{-}(1^{-}-) \\ f_{2}(1430) & 0^{-}(1^{-}-) \\ f_{2}(1450) & 1^{+}(1^{-}-) \\ \eta(1475) & 0^{+}(1^{+}+) \\ f_{2}(1220) & 0^{+}(2^{-}a^{+}+) \\ f_{2}(1500) & 0^{+}(0^{+}+) \\ f_{3}(1220) & 0^{+}(2^{-}a^{+}+) \\ f_{4}(1300) & 0^{+}(0^{+}+) \\ f_{5}(12300) & 0^{+}(0^{+}+) \\ f_{5}(1565) & 0^{+}(2^{+}+) \\ f_{4}(1550) & 0^{-}(1^{-}-) \\ \delta_{1}(1500) & 0^{-}(1^{-}-) \\ \delta_{1}(1500) & 0^{-}(1^{-}-) \\ \delta_{1}(1500) & 0^{-}(1^{-}-) \\ \delta_{2}(1500) & 0^{-}(1^{-}-) \\ \delta_{2}(1500) & 0^{-}(1^{-}-) \\ \delta_{3}(1670) & 0^{-}(1^{-}-) \\ \delta_{3}(1670) & 0^{-}(1^{-}-) \\ \delta_{3}(1670) & 0^{-}(3^{-}-) \\ \end{array}$ $\begin{array}{c} + R (1800) & 1/2(2^{+}) \\ K_{3}(100) & 1/2(2^{+}) \\ K_{3}(2302) & 1/2(2^{+}) \\ K_{3}(2300) & 1/2(2^{+}) \\ Further States \\ \end{array}$ $\begin{array}{c} + R (1800) & 1/2(2^{+}) \\ K_{3}(1230) & 1/2(2^{+}) \\ K_{3}(1230) & 1/2(2^{+}) \\ K_{3}(120) & 0^{-}(1^{-}-) \\ K_{3}(120) & 1/2(2^{+}) \\ K_{3}(120) & 0^{-}(1^{-}-) \\ Further States \\ \end{array}$ $\begin{array}{c} + R (1800) & 1/2(2^{+}) \\ K_{3}(120) & 0^{-}(1^{-}) \\ K_{3}(120) & 0^{-}($	$\begin{array}{c} \eta(1300) & 1^{-}(0^{-}) \\ \pi(1300) & 1^{-}(2^{-}) \\ \delta_{2}(2100) & 0^{+}(2^{+}) \\ \delta_{3}(1700) & 1/2(2^{-}) \\ \kappa_{3}(1700) & 1/2(2^{-}) \\ \kappa_{3}(1700) & 1/2(2^{-}) \\ \kappa_{3}(1830) & 2^{-}(1^{+}) \\ \kappa_{4}(2030) & 1^{-}(4^{+}) \\ \pi_{1}(1400) & 1^{-}(1^{-}) \\ \pi_{1}(1400) & 1^{-}(1^{-}) \\ \pi_{1}(1402) & 0^{-}(1^{-}) \\ \kappa_{1}(1200) & 0^{+}(0^{+}) \\ \kappa_{1}(1200) & 0^{+}(0^{+}) \\ \kappa_{1}(1200) & 0^{-}(1^{-}) \\ \kappa_{1}(1200) & 0^{+}(2^{+}) \\ \kappa_{1}(1200) & 0^{+}(2^{+}) \\ \kappa_{1}(1200) & 0^{+}(2^{+}) \\ \kappa_{1}(1200) & 0^{+}(2^{+}) \\ \kappa_{2}(2100) & 1^{-}(1^{-}) \\ \kappa_{2}(2200) & 0^{+}(0^{+}) \\ \kappa_{2}(2200) & 0^{+}(0^{+}) \\ \kappa_{2}(2200) & 0^{+}(0^{+}) \\ \kappa_{1}(2200) & 0^{+}(2^{+}) \\ \kappa_{2}(2200) & 0^{+}(2^{+}) \\ \kappa_{2}(2200) & 0^{+}(2^{+}) \\ \kappa_{1}(2300) & 0^{+}(2^{+}) \\ \kappa_{2}(2300) & 1^{-}(2^{-}) \\ \kappa_{1}(1500) & 0^{-}(1^{-}) \\ \kappa_{2}(2400) & 1^{-}(2^{+}) \\ \kappa_{2}(240) & 1^{-}(2^{+}) \\ \kappa_{2}(240) & 1^{-}(2^{+}) \\ \kappa_{2}(240) & 1^{-}(2^{+}) \\ \kappa_{2}(1P) & 0^{+}(1^{+}) \\ \kappa_{2}(2P) & 0^{-}(1^{-}) \\ \kappa_{2}(240) & 1^{-}(2^{+}) \\ \kappa_{2}(2P) & 0^{-}(1^{-}) \\ \kappa_{2}$	<ul> <li>n(1295)</li> </ul>	$0^{+}(0^{-}+)$	m(1990)	1+(3)	A1(1650)	1/2(1.)	BOTTOM,	CHARMED
$\begin{array}{c} \lambda_{2}(130) & 1-(2++) \\ \delta_{2}(130) & 1-(2++) \\ \delta_{3}(120) & 1-(2++) \\ h_{1}(130) & 7-(1+-) \\ \kappa_{4}(2040) & 1-(4++) \\ \kappa_{4}(2050) & 0^{+}(4++) \\ \kappa_{5}(1200) & 1-(2++) \\ \kappa_{5}(1200) & 1-(2++) \\ \kappa_{5}(1200) & 1-(2++) \\ \kappa_{5}(1200) & 0^{+}(0++) \\ \kappa_{5}(1200) & 0^{+}(1++) \\ \kappa_{5}(1200) & 0$	$\begin{array}{c} h_{1}(320) & 1-(2++) \\ s_{2}(1320) & 0^{+}(0^{+}) \\ t_{6}(2020) & 0^{+}(0^{+}) \\ t_{6}(2020) & 0^{+}(0^{+}) \\ h_{1}(330) & 2^{-}(1^{-}) \\ h_{1}(330) & 1^{-}(0^{+}) \\ t_{1}(1400) & 1^{-}(1^{-}) \\ t_{1}(1400) & 1^{-}(1^{-}) \\ t_{1}(1420) & 0^{+}(1^{+}) \\ t_{1}(1420) & 0^{+}(1^{+}) \\ t_{1}(1420) & 0^{+}(1^{+}) \\ t_{1}(1420) & 0^{+}(1^{+}) \\ t_{2}(1430) & 0^{+}(2^{+}) \\ t_{2}(1430) & 0^{+}(2^{+}) \\ t_{2}(1450) & 1^{-}(0^{-}) \\ t_{2}(1430) & 0^{+}(2^{+}) \\ t_{2}(1450) & 1^{-}(0^{-}) \\ t_{1}(150) & 0^{+}(0^{-}) \\ t_{1}(150) & 0^{+}(0^{+}) \\ t_{1}(1510) & 0^{+}(1^{+}) \\ t_{1}(1510) & 0^{+}(1^{+}) \\ t_{1}(1525) & 0^{+}(2^{+}) \\ t_{1}(1510) & 0^{+}(1^{+}) \\ t_{2}(1464) & 1^{-}(1^{-}) \\ s_{2}(1665) & 0^{+}(2^{+}) \\ t_{2}(1646) & 1^{-}(1^{-}) \\ s_{2}(1660) & 1^{-}(1^{-}) \\ s_{2}(1660) & 0^{-}(1^{-}) \\ s_{3}(1670) & 0^{-}(1^{-}) \\ s_{3}(1670) & 0^{-}(3^{-}) \\ \end{array}$ $\begin{array}{c} b_{2}(2x0) & 0^{+}(2x+1) \\ t_{2}(2x0) & 0^{+}(2x+1) \\ t_{3}(1640) & 1^{-}(1^{-}) \\ s_{3}(1670) & 0^{-}(3^{-}) \\ \end{array}$ $\begin{array}{c} b_{2}(2x0) & 0^{+}(2x+1) \\ t_{2}(2x0) & 0^{-}(1^{-}) \\ t_{3}(1670) & 0^{-}(3^{-}) \\ \end{array}$ $\begin{array}{c} b_{2}(2x0) & 0^{+}(2x+1) \\ t_{3}(2x0) & 0^{-}(2x+1) \\ t_{3}(2x0) $	<ul> <li>π(1300)</li> </ul>	$1^{-}(0^{-}+)$	• £(2010)	$0^{+}(2^{+}+)$	• A (1000)	1/2(1)	(B = C	$= \pm 1$ )
$\begin{array}{c} \lambda_{1}(1370) & 0^{+}(0^{+}) \\ h_{1}(1380) & 7^{-}(1^{+}) \\ h_{1}(1380) & 7^{-}(1^{+}) \\ \pi_{1}(1400) & 1^{-}(1^{+}) \\ \pi_{2}(2100) & 1^{-}(2^{+}) \\ \pi_{2}(2100) & 1^{-}(2^{+}) \\ f_{1}(1420) & 0^{+}(1^{+}) \\ \mu_{2}(150) & 0^{+}(0^{+}) \\ h_{2}(150) & 0^{+}(0^{+}) \\ h_{2}(150) & 1^{+}(1^{-}) \\ \mu_{2}(150) & 1^{+}(1^{-}) \\ \mu_{2}(225) & 0^{+}(0^{+}) \\ \mu_{2}(225) & 0^{+}(0^{+}) \\ \mu_{2}(225) & 1^{+}(2^{-}) \\ \lambda_{3}(1300) & 0^{+}(0^{+}) \\ \mu_{2}(225) & 1^{+}(2^{-}) \\ \lambda_{4}(1500) & 0^{+}(0^{+}) \\ \mu_{2}(2250) & 1^{+}(3^{-}) \\ \mu_{2}(2250) & 1^{+}(3^{-}) \\ \mu_{2}(2300) & 0^{+}(2^{+}) \\ \mu_{2}(2300) & 1^{+}(2^{+}) \\ \mu_{2}(2300) & 1^{+}(2^{+}) \\ \mu_{2}(2400) & 1^{+}(2^{+}) \\ \mu_{2}(2400)^{0} & 1^{+}(2^{+}) \\ \mu_{2}(25) & 0^{-}(1^{-}) \\ \mu_{2}(2400)^{0} & 1^{+}(2^{+}) \\ \mu_{2}(2400)^{0} & 1^{+}(2^{+}) \\ \mu_{2}(2400)^{0} & 1^{+}(2^{+}) \\ \mu_{2}(250) & 0^{-}(1^{-}) \\ \mu_{2}(2400)^{0} & 1^{+}(2^{+}) \\ \mu_{2}(2400)^{0} & 1^{+}(2^{+}) \\ \mu_{2}(25) & 0^{-$	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	<ul> <li>a)(1320)</li> </ul>	1-(2++)	6(2020)	$0^{+}(0^{+}+)$	• N2(1770)	1/2(2)	<ul> <li>B<sup>±</sup><sub>c</sub></li> </ul>	0(0-)
$\begin{array}{c} \lambda_{1}(130) & (-1)^{-} \\ \tau_{1}(1400) & (-1)^{-} \\ \tau_{1}(1400) & (-1)^{-} \\ \tau_{1}(1402) & (-1)^{-} \\ \tau_{1}(1402) & (-1)^{-} \\ \tau_{1}(1402) & (-1)^{-} \\ \tau_{1}(1402) & (-1)^{-} \\ \tau_{1}(1420) & (-1)^{-} \\ \tau_{1}(1500) & (-1)^{-} \\ \tau_{1}(1200) & ($	$\begin{array}{cccccc} & \chi_{2}(250) & 1 & (4+1) \\ \pi_{1}(1400) & 1^{-}(1-+) \\ \pi_{1}(1400) & 1^{-}(1-+) \\ \pi_{1}(1402) & 0^{+}(1++) \\ f_{1}(1420) & 0^{+}(1++) \\ f_{1}(1420) & 0^{-}(1) \\ \mu_{1}(1430) & 0^{+}(2++) \\ \mu_{1}(1430) & 0^{+}(2++) \\ \mu_{1}(1450) & 1^{-}(1) \\ \pi_{1}(1450) & 1^{-}(1) \\ \pi_{1}(1500) & 0^{+}(0++) \\ f_{1}(2220) & 0^{+}(2++) \\ f_{2}(2250) & 0^{+}(2++) \\ f_{2}(2300) & 0^{+}(2++) \\ f_{3}(1640) & 1^{-}(1++) \\ \pi_{2}(1645) & 0^{-}(1) \\ \pi_{1}(1640) & 1^{-}(1++) \\ \pi_{2}(1645) & 0^{-}(2++) \\ \pi_{2}(1645) & 0^{-}(2++) \\ \pi_{2}(1645) & 0^{-}(2++) \\ \pi_{2}(1645) & 0^{-}(2++) \\ \pi_{2}(1645) & 0^{-}(1) \\ \pi_{3}(1670) & 0^{-}(3) \\ \end{array}$	<ul> <li>f<sub>0</sub>(1370)</li> </ul>	$0^{+}(0^{+}+)$	• a:(2040)	$1^{-(4^{++})}$	• K <sub>3</sub> (1780)	1/2(3)	- ·	
$\begin{array}{c} \pi_{1}(1400) & 1^{-}(1^{-}) \\ \pi_{1}(1400) & 0^{+}(0^{-}) \\ f_{1}(120) & 0^{+}(0^{-}) \\ f_{1}(120) & 0^{-}(1^{-}) \\ f_{2}(120) & 0^{+}(0^{+}) \\ f_{2}(120) & 0^{+}(2^{+}) \\ f_{2}(120) & 0^{+}(2^{+}+) \\ f_{2}(120) & 0^{+}(0^{+}) \\ f_{2}(120) & 0^{+}(1^{+}+) \\ f_{2}(160) & 1^{-}(1^{-}) \\ f_{2}(160) & 0^{-}(1^{-}) \\ h_{1}(159) & 0^{-}(1^{-}) \\ h_{1}(159) & 0^{-}(1^{-}) \\ h_{2}(1670) & 0^{-}(3^{-}) \\ \end{pmatrix} \\ Further States \\ \hline \begin{array}{c} 0 \\ Further States \\ \hline \begin{array}{c} 0 \\ Further States \\ \hline \end{array}$	$\begin{array}{c} \pi_1(1400) & 1 - (1 - +) \\ \pi_1(1400) & 1 - (1 - +) \\ \pi_1(1400) & 0^+ (0^- +) \\ f_0(1200) & 0^+ (0^+ +) \\ f_0(1200) & 0^- (1^) \\ g_0(1^+ (0^+ +) \\ g_0(100) & 0^- (1^) \\ g_0(1^+ (0^+ +) \\ g_0(100) & 0^- (1^) \\ $	h (1380)	7-(1+-)	• £(2050)	$0^+(4^++1)$	<ul> <li>R<sub>2</sub>(1820)</li> </ul>	1/2(2)	cc	5
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	$\begin{array}{c} \pi_{1}(1405) & 0^{+}(0^{-}+) \\ f_{1}(1420) & 0^{+}(1^{+}+) \\ f_{2}(150) & 0^{+}(2^{+}+) \\ f_{2}(150) & 0^{+}(2^{+}+) \\ f_{3}(1420) & 0^{-}(1^{-}-) \\ f_{3}(1430) & 0^{+}(2^{+}+) \\ f_{4}(1450) & 1^{-}(0^{+}+) \\ f_{4}(1250) & 0^{+}(2^{+}+) \\ f_{4}(1250) & 0^{+}(2^{+}+) \\ f_{4}(1250) & 0^{+}(2^{+}+) \\ f_{4}(1250) & 0^{+}(2^{+}+) \\ f_{4}(1250) & 0^{+}(0^{-}+) \\ f_{4}(1250) & 0^{+}(0^{-}+) \\ f_{4}(1250) & 0^{+}(0^{+}+) \\ f_{4}(1250) & 0^{+}(0^{+}+) \\ f_{4}(1250) & 0^{+}(0^{+}+) \\ f_{4}(1250) & 0^{+}(1^{+}+) \\ f_{4}(1250) & 0^{-}(1^{-}-) \\ h_{1}(1595) & 0^{-}(1^{+}-) \\ h_{4}(1595) & 0^{-}(1^{+}-) \\ h_{4}(1660) & 1^{-}(1^{+}+) \\ f_{4}(2510) & 0^{+}(6^{+}+) \\ f_{4}(2510) & 0^{+}(6^{+}+) \\ f_{4}(1260) & 0^{-}(1^{-}-) \\ h_{4}(1650) & 0^{-}(1^{-}-) \\ h_{4}(160) & 0$	<ul> <li>π1(1400)</li> </ul>	1-(1-+)	To(2100)	1-(2-+)	K (1830)	1/2(0)	• $\eta_c(1S)$	$0^{+}(0^{-+})$
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$\begin{array}{c} \eta_1(30) & 0^+(0^+) \\ \eta_1(420) & 0^-(1^-) \\ \xi_1(130) & 0^+(2^+) \\ \lambda_3(1450) & 1^-(0^+) \\ \rho_1(150) & 0^+(2^+) \\ \rho_1(150) & 1^+(1^-) \\ \rho_1(150) & 0^+(0^+) \\ \eta_1(175) & 0^+(0^-+) \\ \eta_2(225) & 0^+(2^-+) \\ \eta_2(225) & 0^+(2^-+) \\ \eta_2(225) & 0^+(2^-+) \\ \eta_2(225) & 0^+(2^-+) \\ \eta_2(225) & 0^+(2^++) \\ \eta_2(225) & 0^+(2^++) \\ \eta_2(225) & 0^+(2^++) \\ \eta_2(25) & 0^-(1^) \\ \eta_2(240) & 1/2(0^-) \\ \eta_2(240) & 1/2(0^-) \\ \eta_2(240) & 1/2(1^-) \\ \eta_2(240) & 1/2(1^-) \\ \eta_2(240) & 1/2(1^+) \\ \eta_2(240) & 1/2(1^+) \\ \eta_2(240) & 1/2(2^+) \\ \eta_3(1670) & 0^-(3^) \\ \eta_3(1670) & 0$	<ul> <li>n(1405)</li> </ul>	$a^{+}(a^{-}+)$	6(2100)	$0^{+}(0^{+}+)$	R <sub>0</sub> (1950)	1/2(0 ' )	<ul> <li>J/\u03c6(15)</li> </ul>	$0^{-}(1^{-})$
$\begin{array}{c} \gamma_{1}(126) & 0^{-}(1) \\ \gamma_{2}(130) & 0^{+}(2++) \\ \delta_{0}(2150) & 1^{+}(1) \\ f_{0}(220) & 0^{+}(0^{+}) \\ \rho_{1}(2220) & 0^{+}(2^{-}r^{4}++) \\ \gamma_{1}(2220) & 0^{+}(2^{-}r^{4}++) \\ \gamma_{1}(2220) & 0^{+}(2^{-}r^{4}++) \\ \gamma_{1}(2220) & 0^{+}(2^{-}r^{4}++) \\ \gamma_{1}(2225) & 0^{+}(0^{-}+) \\ \gamma_{1}(1475) & 0^{+}(0^{-}+) \\ \gamma_{1}(1500) & 0^{+}(0^{+}+) \\ f_{1}(1510) & 0^{+}(1^{+}+) \\ f_{2}(1505) & 0^{-}(1^{+}-) \\ \gamma_{1}(1555) & 0^{-}(1^{+}-) \\ \gamma_{1}(1565) & 0^{-}(1^{+}-) \\ \gamma_{1}(1560) & 1^{-}(1^{-}+) \\ \gamma_{1}(1550) & 0^{-}(1^{-}-) \\ \gamma_{1}(1640) & 1^{-}(1^{+}+) \\ f_{2}(1560) & 0^{-}(1^{-}-) \\ \gamma_{1}(1640) & 1^{-}(1^{+}+) \\ \gamma_{2}(1645) & 0^{-}(1^{-}-) \\ \gamma_{2}(1645) & 0^{-}(1^{-}-) \\ \gamma_{2}(1645) & 0^{-}(1^{-}-) \\ \gamma_{2}(1645) & 0^{-}(1^{-}-) \\ \gamma_{3}(1670) & 0^{-}(3^{-}-) \\ \end{array}$ $\begin{array}{c} \gamma_{1}(1600) & 1^{-}(1^{-}+) \\ \gamma_{2}(1645) & 0^{-}(1^{-}-) \\ \gamma_{2}(1645) & 0^{-}(1^{-}-) \\ \gamma_{3}(1670) & 0^{-}(3^{-}-) \\ \gamma_{3}(1670) & 0^{-}(3^{-}-) \\ \gamma_{2}(1645) & 0^{-}(1^{-}-) \\ \gamma_{3}(1670) & 0^{-}(3^{-}-) \\ \gamma_{2}(1645) & 0^{-}(1^{-}-) \\ \gamma_{3}(1670) & 0^{-}(3^{-}-) \\ \gamma_{3}(167$	$\begin{array}{c} f_1(125) & 0 & (1-7) \\ f_2(130) & 0^+(2^+) \\ a_0(1450) & 1^-(0^+) \\ a_0(1450) & 1^-(0^+) \\ f_1(220) & 0^+(2 \ or \ 4^+) \\ \eta(225) & 0^+(0^-+) \\ \eta(2150) & 0^+(0^+) \\ \eta(225) & 0^+(0^-+) \\ g_2(250) & 1^+(3^) \\ f_1(150) & 0^+(0^++) \\ f_1(150) & 0^+(0^++) \\ f_2(2300) & 0^+(2^++) \\ f_2(1525) & 0^+(2^++) \\ f_2(1525) & 0^+(2^++) \\ f_2(1525) & 0^-(1^+-) \\ a_1(1600) & 1^-(1^++) \\ f_2(1565) & 0^+(2^++) \\ \eta_2(2350) & 1^+(5^) \\ a_6(2450) & 1^-(6^++) \\ f_6(2510) & 0^+(6^++) \\ \hline \\ f_2(1640) & 0^-(2^+-) \\ g_1(1640) & 0^-(1^) \\ g_1(1640) & 0^-(1^) \\ g_2(1645) & 0^-(1^) \\ g_2(2460) & 1/2(1^+) \\ g_2(2460) & 1/2(2^+) \\ g_2(250) & 0^-(1^) \\ g_2(2460) & 1/2(2^+) \\ g_2(250) & 0^-(1^) \\ g_2(25$	<ul> <li>6 (1420)</li> </ul>	$0^{+}(1^{+})$	6(2150)	$0^+(2^++)$	$K_{2}^{*}(1980)$	1/2(2+)	<ul> <li>χ<sub>c0</sub>(1P)</li> </ul>	$0^{+}(0^{+}+)$
$\begin{array}{c} b_{1}(130) & 0^{+}(2^{+}+) \\ f_{0}(130) & 1^{-}(0^{+}+) \\ s_{0}(1450) & 1^{-}(0^{+}+) \\ \rho_{1}(150) & 1^{+}(1^{-}-) \\ \eta_{1}(225) & 0^{+}(2^{-}+) \\ \eta_{2}(225) & 1^{+}(3^{-}-) \\ \rho_{3}(2250) & 1^{+}(3^{-}-) \\ \rho_{3}(2250) & 1^{+}(3^{-}-) \\ \rho_{3}(2250) & 0^{+}(2^{+}+) \\ f_{4}(1510) & 0^{+}(1^{+}+) \\ f_{4}(1510) & 0^{+}(1^{+}+) \\ f_{4}(1520) & 0^{+}(2^{+}+) \\ f_{4}(155) & 0^{-}(1^{-}-) \\ h_{1}(1595) & 0^{-}(1^{+}-) \\ \sigma_{1}(1600) & 1^{-}(1^{-}+) \\ \sigma_{1}(1600) & 1^{-}(1^{-}+) \\ \sigma_{1}(1600) & 1^{-}(1^{-}+) \\ \sigma_{1}(1600) & 1^{-}(1^{-}+) \\ \sigma_{3}(1670) & 0^{-}(3^{-}-) \end{array} \right) \xrightarrow{b_{1}(2250) & 1^{+}(5^{-}-) \\ a_{1}(1640) & 1^{-}(1^{+}+) \\ f_{5}(1640) & 0^{+}(2^{+}+) \\ \omega(1650) & 0^{-}(1^{-}-) \\ \omega_{3}(1670) & 0^{-}(3^{-}-) \end{array} \right) \xrightarrow{b_{1}(2350) & 1^{+}(5^{-}-) \\ \sigma_{1}(1645) & 0^{-}(1^{-}-) \\ \sigma_{2}(2400)^{0} & 1/2(1^{-}) \\ \sigma_{1}(2420)^{0} & 1/2(1^{-}) \\ \sigma_{1}(2420)^{0} & 1/2(1^{-}) \\ \sigma_{1}(2420)^{0} & 1/2(1^{-}) \\ \sigma_{2}(2400)^{0} & 1/2(1^{+}) \\ \sigma_{2}(2460)^{0} & 1/2(2^{+}) \\ \sigma_{3}(1670) & 0^{-}(3^{-}-) \end{array} \right) \xrightarrow{b_{1}(15) \\ f_{1}(5) & 0^{-}(1^{-}-) \\ \sigma_{2}(2460)^{\pm} & 1/2(2^{7}) \\ \sigma_{2}(2460)^{\pm} & 1/2(2^{7}) \\ \sigma_{2}(2460)^{\pm} & 1/2(2^{7}) \\ \sigma_{1}(2420)^{0} & 1/2(1^{+}) \\ \sigma_{2}(2460)^{\pm} & 1/2(2^{7}) \\ \sigma_{2}(2460)^{\pm} & 1/2(2^{7}) \\ \sigma_{2}(2460)^{\pm} & 1/2(2^{7}) \\ \sigma_{3}(217)^{\pm} & 0(0^{+}) \\ \sigma_{3}(227) & 0^{+}(1^{+}+) \\ \sigma_{3}(22P) & 0^{+}(1^{-}+) \\ \sigma_{3}(22P) & 0^{+}(1^{-}+) \\ \sigma_{3}(2460)^{\pm} & 0^{+}(1^{+}) \\ \sigma_{3}(2460)^{\pm} & 0^{+}(1^{+}) \\ \sigma_{3}(22P) & 0^{+}(1^{-}+) \\ \sigma_{3}(22P) & 0^{+}(1^{-}+) \\ \sigma_{3}(2P) & 0^{+}(1^{-}+) \\ \sigma_{3}(2P) & 0^{+}(1^{-}+) \\ \sigma_{3}(2P) & 0^{+}(1^{-}-) \\ \sigma_{3}(2EP) & 0^{+}(1^{-}+) \\ \sigma_{3}(2EP) & 0^{+}(1^{-}$	$\begin{array}{c c c c c c c c c c c c c c c c c c c $	• (1420)	$0^{-}(1^{-})$	o(2150)	$1^{+}(1^{-})$	<ul> <li>K<sup>*</sup><sub>4</sub>(2045)</li> </ul>	$1/2(4^+)$	<ul> <li>χ<sub>c1</sub>(1P)</li> </ul>	$0^{+}(1^{+})$
$\begin{array}{c} \gamma_{1}(230) & 1-(0++) \\ \gamma_{0}(1450) & 1^{+}(1) \\ \gamma_{1}(1475) & 0^{+}(0-+) \\ \gamma_{1}(225) & 0^{+}(0-+) \\ \gamma_{1}(250) & 1^{+}(3) \\ f_{0}(1500) & 0^{+}(0++) \\ f_{1}(1510) & 0^{+}(1++) \\ f_{1}(1510) & 0^{+}(1++) \\ f_{2}(230) & 0^{+}(2++) \\ f_{2}(1525) & 0^{+}(2++) \\ f_{2}(1525) & 0^{+}(2++) \\ f_{2}(1525) & 0^{+}(2++) \\ f_{2}(1555) & 0^{-}(1+-) \\ s_{1}(1600) & 1^{-}(1-+) \\ f_{2}(1600) & 1^{-}(1-+) \\ f_{2}(1640) & 1^{-}(1++) \\ f_{2}(1640) & 0^{-}(2++) \\ f_{2}(1640) & 0^{-}(2++) \\ \gamma_{2}(1645) & 0^{-}(1) \\ s_{3}(1670) & 0^{-}(3) \end{array} \right) \xrightarrow{P_{1}(1641)} Further States \\ \hline \begin{array}{c} N_{1}(225) & 0^{+}(2++) \\ f_{2}(210) & 0^{+}(2++) \\ 0^{-}(210) & 0^{+}(2++) \\ 0^{-}(210) & 0^{-}(21) \\ 0^{-}(200)^{0} & 1/2(1-) \\ 0^{-}(2400)^{0} & 1/2(1-) \\ 0^{-}(2400)^{0} & 1/2(1-) \\ 0^{-}(2400)^{0} & 1/2(1-) \\ 0^{-}(2400)^{0} & 1/2(1-) \\ 0^{-}(2400)^{0} & 1/2(1^{+}) \\ 0^{-}(2400)^{0} & 1/2(1^{+}) \\ 0^{-}(2400)^{0} & 1/2(1^{+}) \\ 0^{-}(2400)^{0} & 1/2(1^{+}) \\ 0^{-}(2400)^{0} & 1/2(2^{+}) \\ 0^{-}(2400)^{0} & 1/2(2^{+}) \\ 0^{-}(2400)^{0} & 1/2(2^{+}) \\ 0^{-}(2400)^{0} & 1/2(2^{+}) \\ 0^{-}(2400)^{0} & 1/2(2^{+}) \\ 0^{-}(2400)^{0} & 1/2(2^{+}) \\ 0^{-}(2400)^{0} & 1/2(2^{+}) \\ 0^{-}(2640)^{\pm} & 1/2(2^{-}) \\ 0^{+}(2400)^{\pm} & 1/2(2^{-}) \\ 0^{+}(2400)^{\pm} & 1/2(2^{-}) \\ 0^{+}(2400)^{\pm} & 1/2(2^{-}) \\ 0^{+}(2400)^{\pm} & 1/2(2^{-}) \\ 0^{+}(2400)^{0} & 1/2(2^{+}) \\ 0^{+}(2400)$	$\begin{array}{c} \lambda_0(1350) & 0 & (1-1) \\ \lambda_0(1450) & 1-(0++) \\ \rho(1450) & 1+(1) \\ \eta(1475) & 0^+(0-+) \\ \eta(225) & 0^+(0-+) \\ \eta(2250) & 1^+(3) \\ f_0(1500) & 0^+(0++) \\ f_0(1500) & 0^+(0++) \\ f_1(1500) & 0^+(1++) \\ f_2(1525) & 0^+(2++) \\ f_1(1565) & 0^-(1+-) \\ \eta_2(250) & 1^+(5) \\ h_1(1595) & 0^-(1+-) \\ \eta_2(210) & 1^-(1++) \\ f_2(1640) & 1^-(1++) \\ f_2(1640) & 0^+(2++) \\ \psi_2(1645) & 0^+(2++) \\ \psi_2(1645) & 0^-(1) \\ \psi_2(10) & 1^-(1-+) \\ \psi_2(10) & 1^-(1-+) \\ \eta_2(1645) & 0^-(1) \\ \psi_2(10) & 0^-(3) \\ \end{array}$ $\begin{array}{c} \lambda_{10} \lambda_{1$	£(1430)	$0^+(2^+)$	£(2200)	$0^{+}(0^{+}+)$	$K_2(2250)$	1/2(2-)	$h_c(1P)$	?*(?**)
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	$\begin{array}{c} 1 \\ \rho(1450) \\ \rho(1450) \\ \eta(1475) \\ \eta(147$	<ul> <li>a.(1450)</li> </ul>	1-(0++)	f.(2220)	$0^{+}(2 \text{ or } 4^{+})$	$K_3(2320)$	$1/2(3^{+})$	<ul> <li>χ<sub>c2</sub>(1P)</li> </ul>	$0^{+}(2^{++})$
$\begin{array}{c} \mu(1475) \\ \eta(1475) \\ f_{0}(1500) \\ \eta(1475) \\ f_{0}(1500) \\ \eta(1475) \\ f_{0}(1510) \\ \eta(1475) \\ f_{0}(1520) \\ \eta(1475) \\ \eta(1510) \\ \eta(1475) \\ \eta(1$	$\begin{array}{c c c c c c c c c c c c c c c c c c c $	<ul> <li>a(1450)</li> </ul>	$1^{+}(1^{-}-)$	p(2225)	$0^+(0^-+)$	K <sup>*</sup> <sub>5</sub> (2380)	$1/2(5^{-})$	<ul> <li>η<sub>c</sub>(2S)</li> </ul>	0+(0 - +)
$\begin{array}{c} \eta_{(170)} & 0 & (0 & (0 & +) \\ f_{0}(150) & 0^{+}(0 & +) \\ f_{1}(1510) & 0^{+}(1 & +) \\ f_{2}(1525) & 0^{+}(2 & +) \\ h_{1}(1595) & 0^{-}(1 & -) \\ h_{1}(1595) & 0^{-}(1 & -) \\ h_{1}(1595) & 0^{-}(1 & -) \\ a_{6}(2450) & 1^{-}(6 & +) \\ f_{2}(2300) & 0^{+}(2 & +) \\ f_{2}(2510) & 0^{+}(6 & +) \\ f_{3}(2510) & 0^{+}(6 & +) \\ f_{4}(2510) & 0^{+}(6 & +) \\ f_{2}(2610) & 0^{+}(6 & +) \\ f_{2}(1640) & 0^{+}(2 & +) \\ f_{2}(1645) & 0^{-}(1 & -) \\ h_{2}(1645) & 0^{-}(1 & -) \\ h_{2}(1650) & 0^{-}(1 & -) \\ h_{3}(1670) & 0^{-}(3 & -) \\ \end{array}\right) \\ \hline \begin{array}{c} Further States \\ Further State \\ Furthe$	$ \begin{array}{c} \gamma_1(1350) & 0^+(0^++) \\ f_1(1510) & 0^+(1^++) \\ f_2(1525) & 0^+(2^++) \\ f_2(1525) & 0^+(2^++) \\ f_2(1565) & 0^+(2^++) \\ h_1(1595) & 0^-(1^+-) \\ \pi_1(1600) & 1^-(1^-+) \\ a_b(2450) & 1^-(6^++) \\ f_b(2510) & 0^+(6^++) \\ f_b(2510) & 0^-(6^++) \\ f_b(2510) & 0^-(6^++) \\ f_b(2510) & 0^+(6^++) \\ \hline \\ D^+(2010)^{\pm} 1/2(0^-) \\ D^+(2010)^{\pm} 1/2(0^+) \\ D^+_0(2400)^{0} 1/2(1^+) \\ D^+_0(2$	<ul> <li>p(1475)</li> </ul>	$a^{+}(a^{-}+)$	0 (2250)	1+(3)	$K_4(2500)$	$1/2(4^{-})$	<ul> <li>ψ(25)</li> </ul>	0-(1)
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	$ \begin{array}{c} f_{1}(1550) & 0^{+}(1^{+}) \\ f_{1}(1510) & 0^{+}(1^{+}) \\ f_{2}(1525) & 0^{+}(2^{+}) \\ f_{2}(1565) & 0^{+}(2^{+}) \\ h_{1}(1595) & 0^{-}(1^{+}) \\ \pi_{1}(1600) & 1^{-}(1^{-}) \\ \pi_{1}(1600) & 1^{-}(1^{+}) \\ a_{1}(1640) & 1^{-}(1^{+}) \\ f_{2}(2150) & 0^{+}(6^{+}) \\ \pi_{2}(1645) & 0^{-}(2^{-}) \\ & 0^{-}(1^{-}) \\ f_{2}(1645) & 0^{-}(1^{-}) \\ & \omega_{3}(1670) & 0^{-}(3^{-}) \end{array} \right) \\ \begin{array}{c} THER \ LIGHT \\ \hline \\ Further \ States \\ \end{array} \right) \\ \begin{array}{c} D^{\pm} & 1/2(0^{-}) \\ D^{0} & 1/2(0^{-}) \\ D^{0} & 1/2(0^{-}) \\ D^{0} & 1/2(0^{-}) \\ D^{0} & 1/2(0^{-}) \\ D^{0}(2400)^{0} & 1/2(1^{-}) \\ D^{0}(2400)^{0} & 1/2(0^{+}) \\ D^{0}(2400)^{0} & 1/2(1^{+}) \\ D^{1}(2420)^{0} & 1/2(2^{+}) \\ D^{1}(2420)^{0} & 1/2(2^{+}) \\ D^{1}(2420)^{0} & 1/2(2^{+}) \\ D^{1}(2400)^{0} & $	• £(1500)	$0^{+}(0^{+}+)$	6(2300)	$n^{+}(2^{+}+)$	K(3100)	?!(?!!)	<ul> <li>ψ(3770)</li> </ul>	$0^{-}(1^{-})$
$\begin{array}{c} f_{2}(1535) & 0 + (2 + +) \\ f_{2}(1555) & 0^{+}(2 + +) \\ h_{1}(1595) & 0^{-}(1 + -) \\ \pi_{1}(1600) & 1^{-}(1 - +) \\ a_{1}(1640) & 1^{-}(1 + +) \\ f_{2}(2350) & 1^{+}(5) \\ a_{6}(2450) & 1^{-}(6 + +) \\ f_{6}(2510) & 0^{+}(6 + +) \\ \pi_{1}(1640) & 0^{+}(2 + +) \\ f_{6}(2510) & 0^{+}(6 + +) \\ \pi_{1}(1640) & 0^{-}(1) \\ f_{6}(2510) & 0^{+}(6 + +) \\ \pi_{1}(1650) & 0^{-}(1) \\ \phi_{1}(2400)^{0} & 1/2(1^{-}) \\ \phi_{1}(2400)^{0} & 1/2(1^{-}) \\ D_{0}^{+}(2400)^{0} & 1/2(0^{+}) \\ D_{0}^{+}(2400)^{0} & 1/2(0^{+}) \\ D_{0}^{+}(2400)^{0} & 1/2(1^{-}) \\ D_{0}^{+}(2400)^{0} & 1/2(1^{-}) \\ D_{0}^{+}(2400)^{0} & 1/2(1^{-}) \\ D_{0}^{+}(2400)^{0} & 1/2(2^{+}) \\ D_{0}^{+}(2400)^{0} & 1/2(2^{+}) \\ D_{0}^{+}(2400)^{0} & 1/2(2^{+}) \\ D_{1}(2420)^{0} & 1/2(2^{+}) \\ D_{1}(2420)^{0} & 1/2(2^{+}) \\ D_{2}^{+}(2460)^{0} & 1/2(2^{+}) \\ D_{2}^{+}(2460)^{0} & 1/2(2^{+}) \\ D_{2}^{+}(2460)^{0} & 1/2(2^{+}) \\ D_{2}^{+}(2460)^{0} & 1/2(2^{+}) \\ D_{2}^{+}(2400)^{0} & 1/2(2^{+}) \\$	$\begin{array}{c} f_{2}(1525) & 0 + (2^{+}) \\ f_{2}(1525) & 0^{+}(2^{+}) \\ f_{3}(1565) & 0^{+}(2^{+}) \\ h_{1}(1595) & 0^{-}(1^{+}) \\ \pi_{1}(1600) & 1^{-}(1^{-}) \\ a_{5}(2450) & 1^{-}(6^{+}) \\ a_{1}(1640) & 1^{-}(1^{+}) \\ f_{5}(1640) & 0^{+}(2^{+}) \\ \pi_{2}(1645) & 0^{-}(2^{-}) \\ \phi_{3}(1670) & 0^{-}(3^{-}) \end{array} \right) \xrightarrow{V} \begin{bmatrix} 0 & (4^{+}) \\ f_{5}(2510) & 0^{+}(6^{+}) \\ f_{5}(2510) & 0^{+}(6^{+}) \\ \phi_{3}(2350) & 1^{-}(6^{+}) \\ f_{5}(2510) & 0^{+}(6^{+}) \\ f_{5}(2510) & 0^{+}(6^{+}) \\ \phi_{2}(240)^{0} & 1/2(1^{-}) \\ D^{+}(200)^{1} & 1/2(1^{-}) \\ D^{+}(2400)^{0} & 1/2(1^{+}) \\ D^{+}(2400)^{0} & 1/2(1^{+}) \\ D^{+}(2400)^{1} & 1/2(2^{+}) \\ D^{+}($	6 (1510)	$0^+(1^+)$	• (2300) € (2300)	$0^{+}(4^{+}+)$	CHAR	MED	<ul> <li>X(3872)</li> </ul>	0 <sup>?</sup> (? <sup>?+</sup> )
$\begin{array}{c} r_{2}(1565) \\ f_{2}(1565) \\ f_{2}(1565) \\ f_{2}(1565) \\ f_{2}(1565) \\ f_{2}(1565) \\ f_{2}(1565) \\ f_{2}(1-1) \\ f_{3}(1640) \\ f_{4}(2+1) \\ f_{3}(1640) \\ f_{4}(2+1) \\ f_{3}(1640) \\ f_{4}(2+1) \\ f_{3}(1650) \\ f_{4}(2+1) \\ f_{4}(165) \\ f_{4}(2+1) \\ f_{5}(1640) \\ f_{5}(2+1) \\ $	$\begin{array}{c c c c c c c c c c c c c c c c c c c $	f'(1525)	$0^+(2^++)$	• f (2340)	$0^{+}(2^{+}+)$	(C =	+1)	<ul> <li>χ<sub>c2</sub>(2P)</li> </ul>	$0^{+}(2^{+})$
$\begin{array}{c} p_{1}(1305) & 0 & (2 - 1) \\ h_{1}(1595) & 0 & (1 - 1) \\ a_{1}(1400) & 1 & (1 - 1) \\ a_{1}(1400) & 1 & (1 + 1) \\ f_{2}(1640) & 0 & (2 + 1) \\ \hline f_{2}(1640) & 0 & (2 + 1) \\ \hline f_{2}(1640) & 0 & (1 - 1) \\ \hline f_{2}(1650) & 0 & (1 - 1) \\ \hline g_{2}(1650) & 0 & (1 - 1) \\ \hline g_{2}(1650) & 0 & (1 - 1) \\ \hline g_{2}(1650) & 0 & (1 - 1) \\ \hline g_{2}(1650) & 0 & (1 - 1) \\ \hline g_{2}(1650) & 0 & (1 - 1) \\ \hline g_{2}(1650) & 0 & (1 - 1) \\ \hline g_{2}(1650) & 0 & (1 - 1) \\ \hline g_{2}(1650) & 0 & (1 - 1) \\ \hline g_{2}(1670) & 0 & (3 - 1) \\ \hline g_{2}(170) & 0 & (3 - 1) \\ \hline g_{2}(170) & 0 & (3 - 1) \\ \hline g_{2}(170) & 0 & (3 - 1) \\ \hline g_{2}(170) & 0 & (3 - 1) \\ \hline g_{2}(170) & 0 & (3 - 1) \\ \hline g_{2}(170) & 0 & (3 - 1) \\ \hline g_{2}(170) & 0 & (3 - 1) \\ \hline g_{2}(170) & 0 & (3 - 1) \\ \hline g_{2}(170) & 0 & (3 - 1) \\ \hline g_{2}(170) & 0 & (3 - 1) \\ \hline g_{2}(170) & 0 & (3 - 1) \\ \hline g_{2}(170) & 0 & (3 - 1) \\ \hline g_{2}(170) & 0 & (3 - 1) \\ \hline g_{2}(170) & 0 & (3 - 1) \\ \hline g_{2}(170) & 0 & (3 -$	$\begin{array}{c} \mu_{1}(350) & 0 & (2 - 7) \\ h_{1}(1595) & 0 - (1 - 7) \\ a_{1}(1600) & 1 - (1 + 4) \\ f_{1}(1640) & 0 + (2 + 4) \\ \hline & \eta_{2}(1645) & 0 + (2 - 4) \\ \hline & \psi_{2}(1645) & 0 - (1 - 7) \\ \hline & \psi_{3}(1670) & 0 - (3 - 7) \end{array} \right) \xrightarrow{p_{3}(2500) & 1 - (6 + 4) \\ f_{6}(2510) & 0 + (6 + 4) \\ \hline & \eta_{2}(1645) & 0 + (2 - 4) \\ \hline & \psi_{1}(1640) & 0 - (1 - 7) \\ \hline & \psi_{2}(1645) & 0 - (1 - 7) \\ \hline & \psi_{2}(1645) & 0 - (1 - 7) \\ \hline & \psi_{2}(1645) & 0 - (1 - 7) \\ \hline & \psi_{2}(1645) & 0 - (1 - 7) \\ \hline & \psi_{3}(1670) & 0 - (3 - 7) \end{array} \right) \xrightarrow{p_{3}(2500) & 1 - (6 + 4) \\ \hline & \mu_{2}(2400)^{0} & 1/2(1^{-}) \\ \hline & \psi_{2}(2400)^{0} & 1/2(0^{+}) \\ \hline & \psi_{2}(2400)^{0} & 1/2(1^{+}) \\ \hline & \psi_{2}(2460)^{0} & 1/2(2^{+}) \\ \hline & \psi_{3}(1670) & 0 - (3 - 7) \end{array} \right) \xrightarrow{p_{3}(2500) & 0 - (1 - 7) \\ \hline & \psi_{3}(1670) & 0 - (3 - 7) \\ \hline & \psi_{3}(1670) & 0 $	£ (1565)	$0^+(2^+)$	o (2350)	$1^{+}(5^{-}-)$	(c -	+-/	Y(3940)	? <sup>?</sup> (? <sup>??</sup> )
$\begin{array}{c} \mathfrak{m}_{1}(1639) & \mathfrak{l}^{-}(1-r) \\ \mathfrak{a}_{1}(1640) & \mathfrak{l}^{-}(1+r) \\ \mathfrak{a}_{1}(1640) & \mathfrak{0}^{-}(2+r) \\ \mathfrak{f}_{2}(1640) & \mathfrak{0}^{+}(2+r) \\ \mathfrak{f}_{2}(1645) & \mathfrak{0}^{+}(2-r) \\ \mathfrak{w}_{3}(1670) & \mathfrak{0}^{-}(3-r) \end{array} \xrightarrow{\mathbf{b}} \begin{array}{c} \mathfrak{b} \mathcal{D}^{-}(2007)^{0} & \mathfrak{1}/2(1-r) \\ \mathfrak{b}^{-}(2010)^{\pm} & \mathfrak{1}/2(0+r) \\ \mathfrak{b}^{-}(2010)^{\pm} & \mathfrak{1}/2(2+r) \\ b$	$\begin{array}{c} \pi_{1}(1500) & 1^{-}(1-+) \\ a_{1}(1640) & 1^{-}(1++) \\ f_{5}(1640) & 0^{+}(2++) \\ \hline & \eta_{2}(1645) & 0^{+}(2-+) \\ & \omega_{1}(550) & 0^{-}(1) \\ & \omega_{3}(1670) & 0^{-}(3) \end{array} \xrightarrow{h_{0}(2+30)} \begin{array}{c} \mu_{1}(2+) \\ \hline & \mu_{1}(2+1) \\ \hline & \mu_{2}(1645) \\ & \omega_{3}(1670) \\ & 0^{-}(3) \end{array} \xrightarrow{h_{0}(2+30)} \begin{array}{c} \mu_{1}(2+) \\ \hline & \mu_{1}(2+2) \\ \hline & \mu_{2}(2400)^{0} & 1/2(1^{-}) \\ & \mu_{2}(2400)^{0} & 1/2(1^{+}) \\ & \mu_{2}(2400)^{0} & 1/2(1^{+}) \\ \hline & \mu_{2}(2400)^{0} & 1/2(1^{+}) \\ \hline & \mu_{2}(2400)^{0} & 1/2(1^{+}) \\ & \mu_{2}(2400)^{0} & 1/2(1^{+}) \\ \hline & \mu_{2}(240)$	h (1595)	$0^{-}(1^{+}-)$	a: (2450)	1-(6++)	• D⊥	1/2(0 )	<ul> <li>ψ(4040)</li> </ul>	$0^{-}(1^{-})$
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	$\begin{array}{c c c c c c c c c c c c c c c c c c c $	<ul> <li>π<sub>1</sub>(1555)</li> <li>π<sub>2</sub>(1600)</li> </ul>	$1^{-}(1^{-}+)$	£(2510)	$0^+(6^+)$	• D* (2007)[	1/2(0)	<ul> <li>ψ(4160)</li> </ul>	0-(1)
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	$\begin{array}{c c c c c c c c c c c c c c c c c c c $	a (1640)	1 - (1 + +)	76(2310)	0 (0 )	• D*(2007)*	1/2(1-)	Y(4260)	? <sup>?</sup> (1)
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	$\begin{array}{c c} \eta_{2}(1640) & 0 & (2 & -1) \\ & \eta_{2}(1645) & 0^{+}(2 & -1) \\ & \omega(1650) & 0^{-}(1 & -1) \\ & \omega_{3}(1670) & 0^{-}(3 & -1) \end{array} \end{array} \begin{array}{c c} Further States \\ \hline Further States \\ & \mu_{3}(1670) & 0^{-}(3 & -1) \end{array} \end{array} \begin{array}{c c} Further States \\ \hline D_{0}^{1}(2400)^{\pm} & 1/2(0^{+}) \\ & D_{1}(2420)^{\pm} & 1/2(1^{+}) \\ & D_{1}(2420)^{\pm} & 1/2(1^{+}) \\ & D_{1}(2430)^{0} & 1/2(1^{+}) \\ & D_{2}^{1}(2460)^{0} & 1/2(2^{+}) \\ & \mu_{3}(150) & 0^{-}(1 & -1) \\ & D_{1}(2430)^{0} & 1/2(1^{+}) \\ & D_{2}^{1}(2460)^{\pm} & 1/2(2^{+}) \\ & D_{2}^{1}(240)^{\pm} & 0/2(2^{+}) \\ & D_{2}^{1}(240)^{\pm} & D_{2}^{1}(240)^{\pm} \\ & D_{2}^{1}(240)^{\pm} & D_{2}^{1}($	£(1640)	$0^+(2^+)$	OTH	ER LIGHT	• D*(2010)*	1/2(1)	<ul> <li>ψ(4415)</li> </ul>	0-(1)
$\begin{array}{c} p_{1}(1943) & 0 & (2 & 1) \\ \omega(1650) & 0^{-}(1 & -) \\ \omega_{3}(1670) & 0^{-}(3 & -) \end{array} \\ \end{array} \\ \begin{array}{c} \mu_{1}(2450) & 0^{-}(1 & -) \\ \omega_{3}(1670) & 0^{-}(3 & -) \end{array} \\ \end{array} \\ \begin{array}{c} \mu_{1}(2420)^{0} & 1/2(1^{+}) \\ D_{1}(2420)^{0} & 1/2(1^{+}) \\ D_{2}(2430)^{0} & 1/2(2^{+}) \\ D_{2}(2460)^{0} & 1/2(2^{+}) \\ D_{2}(2460)^{0} & 1/2(2^{+}) \\ D_{2}(2460)^{0} & 1/2(2^{+}) \\ D_{2}(2460)^{\pm} & 1/2(2^{+}) \\ D_{2}(2460)^{\pm} & 1/2(2^{+}) \\ D_{2}(2460)^{\pm} & 1/2(2^{+}) \\ D_{2}(260)^{\pm} & 0(0^{-}) \\ D_{2}^{\pm} & 0(0^{-}) \\ D_{2}^{\pm} & 0(0^{-}) \\ D_{2}^{\pm} & 0(7^{+}) \\ D_{2}(217)^{\pm} & 0(0^{+}) \\ D_{2}(1260)^{\pm} & 0(1^{+}) \\ \end{array} \\ \begin{array}{c} \mu_{1}(1260)^{\pm} & \mu_{2}(1260)^{\pm} \\ D_{2}(1260)^{\pm} & 0(1^{+}) \\ D_{2}(1260)^{\pm} & 0(1^{+}) \\ D_{2}(1260)^{\pm} & 0(1^{+}) \\ D_{2}(1260)^{\pm} & 0(1^{+}) \\ \end{array} \\ \begin{array}{c} \mu_{1}(1260)^{\pm} & \mu_{2}(1260)^{\pm} \\ D_{2}(1260)^{\pm} & 0(1^{+}) \\ D_{2}(1260)^{\pm} & D_{2}(1^{+}) \\ D_{2}(1260)^{\pm} & D_{2$	$\begin{array}{c} & \eta_{2}(1043) & 0 & (2 & 7) \\ & \bullet \omega(1650) & 0^{-}(1 & -) \\ & \bullet \omega_{3}(1670) & 0^{-}(3 & -) \end{array} \\ \end{array} \\ \begin{array}{c} & \omega_{3}(1670) & 0^{-}(3 & -) \\ & \bullet \omega_{3}(1670) & 0^{-}(3 & -) \end{array} \\ \end{array} \\ \begin{array}{c} & \omega_{3}(1670) & 0^{-}(3 & -) \\ & \bullet \omega_{3}(1670) & 0^{-}(3 & -) \\ \end{array} \\ \begin{array}{c} & \omega_{3}(1670) & 0^{-}(3 & -) \\ & & \omega_{3}(1670) & 0^{-}(1 & -) \\ & & & \omega_{3}(1670) & 0^{-}(1 & -) \\ & & \omega_$	n (1645)	$0^{+}(2^{-}+)$	Further Sta	tes	D <sub>0</sub> (2400) <sup>5</sup>	1/2(0 ' )		-
$\begin{array}{c} b_{1}(2630) & 0 & (1 - 1) \\ & \omega_{3}(1670) & 0^{-}(3) \end{array} \\ & & \omega_{3}(1670) & 0^{-}(3) \end{array} \\ & & & b_{1}(2420)^{\pm} & 1/2(1^{+}) \\ & & b_{1}(2420)^{\pm} & 1/2(1^{+}) \\ & & b_{1}(2430)^{0} & 1/2(1^{+}) \\ & & b_{2}^{*}(2460)^{0} & 1/2(2^{+}) \\ & & b_{2}^{*}(2460)^{0} & 1/2(2^{+}) \\ & & b_{2}^{*}(2460)^{\pm} & 1/2(2^{+}) \\ & & b_{2}^{*}(25) & 0^{-}(1^{-}) \\ & & b_{2}^{*}(280)^{\pm} & 0(0^{-}) \\ & & b_{2}^{*}(280)^{\pm} & 0(0^{+}) \\ & & b_{2}^{*}(280)^{\pm}$	$ \begin{array}{c} \omega_{2}(1650) & 0 & (1 - 1) \\ \bullet \omega_{3}(1670) & 0^{-}(3) \\ \end{array} \\ \begin{array}{c} \omega_{3}(1670) & 0^{-}(3) \\ \end{array} \\ \end{array} \\ \begin{array}{c} \omega_{3}(1670) & 0^{-}(3) \\ D_{1}(2420)^{\pm} & 1/2(2^{7}) \\ \end{array} \\ \begin{array}{c} \omega_{2}(2460)^{0} & 1/2(1^{+}) \\ \bullet D_{2}^{*}(2460)^{0} & 1/2(2^{+}) \\ \end{array} \\ \begin{array}{c} \omega_{2}(2460)^{0} & 1/2(2^{+}) \\ \end{array} \\ \begin{array}{c} \omega_{2}(2460)^{\pm} & 1/2(2^{+}) \\ \end{array} \\ \begin{array}{c} \omega_{2}(2460)^{\pm} & 1/2(2^{+}) \\ \end{array} \\ \begin{array}{c} \omega_{2}(2460)^{\pm} & 1/2(2^{7}) \\ \end{array} \\ \begin{array}{c} \omega_{2}(260)^{\pm} & 1/2(2^{7}) \\ \end{array} \\ \begin{array}{c} \omega_{2}(260)^{\pm} & 0 \\ \end{array} \\ \end{array} \\ \begin{array}{c} \omega_{2}(260)^{\pm} & 0 \\ \end{array} \\ \begin{array}{c} \omega_{2}(260)^{\pm} & 0 \\ \end{array} \\ \end{array} \\ \begin{array}{c} \omega_{2}(260)^{\pm} & 0 \\ \end{array} \\ \end{array} \\ \begin{array}{c} \omega_{2}(260)^{\pm} & 0 \\ \end{array} \\ \begin{array}{c} \omega_{2}(260)^{\pm} & 0 \\ \end{array} \\ \end{array} \\ \begin{array}{c} \omega_{2}(260)^{\pm} & 0 \\ \end{array} \\ \end{array} \\ \begin{array}{c} \omega_{2}(260)^{\pm} & 0 \\ \end{array} \\ \end{array} \\ \begin{array}{c} \omega_{2}(260)^{\pm} & 0 \\ \end{array} \\ \end{array} \\ \begin{array}{c} \omega_{2}(260)^{\pm} & 0 \\ \end{array} \\ \end{array} \\ \begin{array}{c} \omega_{2}(260)^{\pm} & 0 \\ \end{array} \\ \end{array} \\ \end{array} \\ \begin{array}{c} \omega_{2}(260)^{\pm} & 0 \\ \end{array} \\ \end{array} \\ \end{array} \\ \begin{array}{c} \omega_{2}(260)^{\pm} & 0 \\ \end{array} \\ \end{array} \\ \begin{array}{c} \omega_{2}(260)^{\pm} & 0 \\ \end{array} \\ \end{array} \\ \begin{array}{c} \omega_{2}(260)^{\pm} & 0 \\ \end{array} \\ \end{array} \\ \end{array} \\ \begin{array}{c} \omega_{2}(260)^{\pm} & 0 \\ \end{array} \\ \end{array} \\ \end{array} \\ \begin{array}{c} \omega_{2}(260)^{\pm} & 0 \\ \end{array} \\ \end{array} \\ \end{array} \\ \begin{array}{c} \omega_{2}(260)^{\pm} & 0 \\ \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \\ \begin{array}{c} \omega_{2}(260)^{\pm} & 0 \\ \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \\ \begin{array}{c} \omega_{2}(260)^{\pm} & 0 \\ \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \\ \begin{array}{c} \omega_{2}(260)^{\pm} & 0 \\ \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \\ \\ \begin{array}{c} \omega_{2}(260)^{\pm} & 0 \\ \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \\ \\ \end{array} \\ \end{array} \\ \end{array}$	• 1/2(1645)	$0^{-}(1^{-})$			$D_0^{\bullet}(2400)^{\pm}$	1/2(0+)	DI	b
$\begin{array}{c} D_{1}(2420)^{\pm} & 1/2(7^{2}) \\ D_{1}(2430)^{0} & 1/2(1^{+}) \\ D_{2}(2460)^{0} & 1/2(2^{+}) \\ D_{2}(2460)^{0} & 1/2(2^{+}) \\ D_{2}(2460)^{\pm} & 1/2(2^{+}) \\ D_{2}(2460)^{\pm} & 1/2(2^{+}) \\ D^{*}(2640)^{\pm} & 1/2(2^{+}) \\ D^{*}(2640)^{\pm} & 1/2(7^{2}) \\ \hline \\ $	$\begin{array}{c} D_{1}(2420)^{\pm} & 1/2(2^{+}) \\ D_{1}(2430)^{0} & 1/2(1^{+}) \\ D_{2}(2430)^{0} & 1/2(1^{+}) \\ D_{2}(2460)^{0} & 1/2(2^{+}) \\ D_{2}(2460)^{\pm} & 1/2(2^$	• $\omega(1650)$	0 (1 )			<ul> <li>D<sub>1</sub>(2420)<sup>0</sup></li> </ul>	$1/2(1^+)$	$\eta_b(1S)$	0+(0 - +)
$\begin{array}{c ccccc} D_{1}(2430)^{o} & 1/2(1^{+}) & & & & & & & & & & & & & & & & & & &$	$\frac{D_{1}(2430)^{0}  1/2(1^{-})}{D_{2}^{*}(2460)^{0}  1/2(2^{+})}  \underbrace{\times_{b0}(1P)  0^{+}(0^{+}^{+})}{\chi_{b1}(1P)  0^{+}(1^{+}^{+})} \\ D_{2}^{*}(2460)^{\pm}  1/2(2^{+})  \underbrace{\times_{b2}(1P)  0^{+}(2^{+}^{+})}{D^{*}(2640)^{\pm}  1/2(2^{?})}  T(25)  0^{-}(1^{-}^{-})} \\ \hline \\ $	• \$\mu_3(1070)	0 (3 )			$D_1(2420)^{\pm}$	1/2(?*)	<ul> <li>T(15)</li> </ul>	0-(1)
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	$\frac{\begin{array}{c} D_2^*(2460)^0 & 1/2(2^+) \\ D_2^*(2460)^{\pm} & 1/2(2^+) \\ D_2^*(2460)^{\pm} & 1/2(2^7) \\ \hline \\ D_2^*(2640)^{\pm} & 1/2(2^7) \\ \hline \\ $					$D_1(2430)^0$	$1/2(1^+)$	• $\chi_{b0}(1P)$	$0^{+}(0^{+}^{+})$
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	$\frac{\begin{array}{c} D_2^*(2460)^{\pm} & 1/2(2^+) \\ D^*(2640)^{\pm} & 1/2(2^7) \\ \hline \\ $					<ul> <li>D<sup>*</sup><sub>2</sub>(2460)<sup>0</sup></li> </ul>	$1/2(2^+)$	<ul> <li>χ<sub>b1</sub>(1P)</li> </ul>	$0^{+}(1^{++})$
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	$\frac{D^{*}(2640)^{\pm}  1/2(?^{7})}{CHARMED, STRANGE} + \frac{T(2S)}{(C = S = \pm 1)} + \frac{T(2S)}{(C = S $					<ul> <li>D<sup>*</sup><sub>2</sub>(2460)<sup>±</sup></li> </ul>	$1/2(2^+)$	<ul> <li>χ<sub>b2</sub>(1P)</li> </ul>	0+(2++)
$\begin{array}{c c} \hline & & & & & & & & & & & & & & & & & & $	$\begin{array}{c c} \hline CHARMED, STRANGE \\ (C = S = \pm 1) \\ \hline D_{5}^{\pm} & 0(0^{-}) \\ P^{\pm} & 0(2^{7}) \\ \hline \end{array} \begin{array}{c} \gamma(1D) & 0^{-}(2^{-}) \\ \hline \chi_{b0}(2P) & 0^{+}(0^{+}+) \\ \hline \chi_{b1}(2P) & 0^{+}(1^{+}+) \\ \hline \chi_{b2}(2P) & 0^{+}(2^{+}+) \\ \hline \chi_{b2}(2P) & 0^{-}(2^{+}-) \\ \hline \chi_{b2}(2P) & 0^{+}(2^{+}+) \\ \hline $					$D^{*}(2640)^{\pm}$	1/2(? <sup>f</sup> )	<ul> <li>T(25)</li> </ul>	0-(1)
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	$\begin{array}{c} \hline \begin{array}{c} \hline (C = S = \pm 1) \\ \hline (C = S = \pm 1) \\ \hline D_{S}^{\pm} & 0(0^{-}) \\ P^{\pm} & 0(7^{2}) \\ \hline \end{array} & \begin{array}{c} \chi_{b0}(2P) & 0^{+}(0^{+}+1) \\ & \chi_{b1}(2P) & 0^{+}(1^{+}+1) \\ & \chi_{b2}(2P) & 0^{+}(2^{+}+1) \\ & \chi_{b2}(2P) & 0^{+}(2^{+}+1) \\ \hline \end{array}$					CHARMED	STRANCE	T(1D)	0-(2)
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	$\begin{array}{cccc} \bullet & & & & \\ \hline & & & & \\ \bullet & & & & \\ \bullet & & & & \\ \bullet & & & &$					(C = S	= +1)	<ul> <li>χ<sub>b0</sub>(2P)</li> </ul>	$0^{+}(0^{+}+)$
$\begin{array}{c ccccc} \bullet & D_{3}^{-} & 0(0^{-}) \\ \bullet & D_{3}^{+\pm} & 0(7^{2}) \\ \bullet & D_{3}^{+\pm} & 0(7^{2}) \\ \bullet & \mathcal{T}(3S) & 0^{-}(1^{-}) \\ \bullet & \mathcal{T}(4S) & 0^{-}(1^{-}) \\ \bullet & \mathcal{T}(4S) & 0^{-}(1^{-}) \\ \bullet & \mathcal{T}(4S) & 0^{-}(1^{-}) \\ \bullet & \mathcal{T}(10860) & 0^{-}(1^{-}) \\ \bullet & \mathcal{T}(10860) & 0^{-}(1^{-}) \end{array}$	$\begin{array}{cccc} \bullet D_s^+ & 0(0^-) & \bullet \chi_{b2}(2P) & 0^+(2^++) \\ \bullet D^{*\pm} & 0(7^7) & \bullet \chi_{b2}(2P) & 0^-(2^++) \\ \bullet \chi_{b2}(2P) & 0^+(2^++) \\$					(c = 5)	)	<ul> <li>χ<sub>b1</sub>(2P)</li> </ul>	$0^{+}(1^{++})$
$\begin{array}{c cccc} \bullet D_{s}^{} & 0(7') & \bullet T(3S) & 0^{-}(1) \\ \bullet D_{s0}^{+}(2317)^{\pm} & 0(0^{+}) & \bullet T(4S) & 0^{-}(1) \\ \bullet D_{s1}(2460)^{\pm} & 0(1^{+}) & \bullet T(10860) & 0^{-}(1) \\ \bullet T(10860) & 0^{-}(1) \end{array}$	$0.07^{-1}$ $0.07^{-1}$ $0.07^{-1}$					• D <sub>s</sub>	0(0-)	<ul> <li>χ<sub>b2</sub>(2P)</li> </ul>	$0^{+}(2^{++})$
$\begin{array}{c c} \bullet D_{s0}^{*}(2317)^{\pm} & 0(0^{+}) \\ \bullet D_{s1}(2460)^{\pm} & 0(1^{+}) \\ \bullet \mathcal{T}(10860) & 0^{-}(1^{-}) \\ \bullet \mathcal{T}(10860) & 0^{-}(1^{-}) \end{array}$	• (35) 0 (1					• D <sup>**</sup> <sub>5</sub>	0(?')	<ul> <li> <i>τ</i>(35)     </li> </ul>	0-(1)
• $D_{s1}(2460)^{\pm}$ $0(1^{+})$ • $T(10860)$ $0^{-}(1^{-})$	$\bullet D^*_{s0}(2317)^{\pm} 0(0^{-}) \bullet \gamma(4S) 0^{-}(1^{-})$					<ul> <li>D<sup>*</sup><sub>s0</sub>(2317)<sup>±</sup></li> </ul>	0(0+)	<ul> <li> <i>Υ</i>(45)     </li> </ul>	0-(1)
	$\bullet D_{s1}(2460)^{\pm} 0(1^{+}) \bullet T(10860) 0^{-}(1^{-})$					<ul> <li>D<sub>s1</sub>(2460)<sup>±</sup></li> </ul>	$0(1^+)$	<ul> <li> <i>Υ</i>(10860)     </li> </ul>	0-(1)
• $D_{s1}(2536)^{-1}$ $0(1^+)$ • $\gamma(11020)$ $0^-(1^-)$	$\bullet D_{s1}(2536)^{\pm} 0(1^{+}_{-}) \bullet \tau(11020) 0^{-}(1^{-}_{-})$			1		<ul> <li>D<sub>\$1</sub>(2536)<sup>±</sup></li> </ul>	$0(1^{+})$	<ul> <li> <i>Υ</i>(11020)     </li> </ul>	$0^{-}(1^{-})$

$\begin{array}{c} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 $	2(160)         ****       Δ(170)         ****       Δ(170)         ****       Δ(190)         ****       Δ(190)         ****       Δ(191)         ****       Δ(192)         ****       Δ(193)         ****       Δ(194)         ****       Δ(194)         ***       Δ(195)         ***       Δ(200)	$\begin{array}{c} 0) & F_{33} & \cdots \\ 0) & S_{31} & \cdots \\ 0) & D_{33} & \cdots \\ 0) & P_{31} & * \\ 0) & S_{31} & * \\ 0) & S_{31} & * \\ 0) & P_{31} & \cdots \\ 0) & P_{33} & \cdots \\ 0) & D_{35} & \cdots \\ 0) & D_{33} & * \\ 0) & D_{33} & * \\ 0) & F_{37} & \cdots \\ 0) & F_{35} & \cdots \\ 0) & $	A(1403)       S01         A(1520)       D01         A(1600)       P01         A(1670)       S01         A(1690)       D02         A(1810)       P01         A(1810)       P01         A(1830)       D02         A(1830)       D03         A(2020)       F05	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$\begin{array}{c} & P_{11} \\ P_{11} \\ P_{13} \\ P_{11} \\ P_{11} \\ P_{11} \\ P_{13} \\ P_{$	$\begin{array}{c} = \\ = \\ = \\ (1530) \\ = \\ = \\ (1620) \\ = \\ = \\ (1640) \\ = \\ = \\ (1640) \\ = \\ = \\ (1640) \\ = \\ = \\ (1640) \\ = \\ = \\ (1640) \\ = \\ = \\ (1640) \\ =$	P11       ****         P13       ****         ***       ***         ***       ***         ***       ***         ***       ***         ***       ****         ***       ****         ****       ****         ****       ****         ****       ****         ****       ****         ****       ****         ****       ****         ****       ****         ****       ****         ****       ****         ****       ****         ****       ****         ****       ****	e	
				LIGHT UI ( $S = C$	NFLAVORED T = B = 0	IG ( IPC)	STR (5 = ±1,	ANGE C = B = 0) $K P^{D}$ )	BC (E
		_	• $\pi^{\pm}$ • $\pi^{0}$ • $\eta$ • $f_{0}(600)$ • $q(770)$	$\begin{array}{c} 1^{-}(0^{-}) \\ 1^{-}(0^{-}) \\ 0^{+}(0^{-}+) \\ 0^{+}(0^{+}+) \\ 1^{+}(1^{-}-) \end{array}$	• $\pi_2(1670)$ • $\phi(1680)$ • $\rho_3(1690)$ • $\rho(1700)$ • $\rho(1700)$	$\frac{1^{-}(2^{-}+)}{1^{-}(2^{-}+)}$ $\frac{1^{-}(2^{-}+)}{1^{+}(3^{-}-)}$ $\frac{1^{+}(1^{-}-)}{1^{-}(2^{+}+)}$	) • $K^{\pm}$ ) • $K^{0}$ ) • $K^{0}_{L}$ • $K^{0}_{L}$	$\frac{1/2(0^{-})}{1/2(0^{-})}$ $\frac{1/2(0^{-})}{1/2(0^{-})}$ $\frac{1/2(0^{-})}{1/2(0^{+})}$	• B <sup>±</sup> • B <sup>0</sup> • B <sup>±</sup> /B <sup>0</sup> AD • B <sup>±</sup> /B <sup>0</sup> /B <sup>0</sup> MIXTURE
2.11 *** 3.13 ** 3.13 ** 4 7 7 7 7 7 7 7 7 7 7 7 7 7	$\begin{array}{c} \cdot \pi^{\pm} \\ \pi^{0} \\ \cdot \pi^{0} \\ \cdot$	I-(0-) I-(0-) I-(0-) I-(0-) I-(0-) I-(0-) I-(0-) I-(0-) I-(0-) I-(0-) I-(1-)	• $h_0(600)$ • $\rho(770)$ • $\omega(782)$ • $\pi/(988)$ • $h_0(980)$ • $\phi(980)$ • $\phi(1020)$ • $h_1(1170)$ • $h_1(1235)$ • $a_1(1260)$ • $f_2(1270)$ • $f_1(1285)$ • $\pi(1300)$ • $\sigma_2(130)$ • $\sigma_2(130)$ • $h_1(1-1)$ • $f_1(1420)$ • $f_2(1430)$ • $\phi(1450)$ • $\rho(1450)$ • $p(1450)$ • $p(1450)$ • $f_2(1525)$ • $h_1(1500)$ • $f_2(1565)$ • $h_1(1505)$ • $\pi_1(1600)$ • $a_1(1640)$ • $f_2(1645)$ • $\omega_3(1670)$	$ \begin{array}{c} 0 + (0 + 1) \\ 1 + (1) \\ 0 - (1) \\ 0 + (0 + +) \\ 1 - (0 + +) \\ 0 - (1) \\ 0 - (1) \\ 0 - (1 + -) \\ 1 - (1 + +) \\ 0 + (1 + +) \\ 0 + (1 + +) \\ 0 + (1 + +) \\ 0 + (1 + +) \\ 0 + (0 + +) \\ 1 - (2 + +) \\ 0 + (0 + +) \\ 1 - (2 + +) \\ 0 + (0 + +) \\ 1 - (2 + +) \\ 0 + (1 + +) \\ 0 - (1) \\ 0 + (2 + +) \\ 0 + (1 + -) \\ 0 + (2 + +) \\ 0 + (2 + +) \\ 0 + (2 + +) \\ 0 + (2 + +) \\ 0 + (2 + +) \\ 0 + (2 + +) \\ 0 - (1) \\ 0 + (2 + +) \\ 0 - (1) \\ 0 - (3) \\ 0 - (3) \\ \end{array} $	<ul> <li>ρ(1700)</li> <li>a)(1700)</li> <li>a)(1700)</li> <li>f<sub>0</sub>(1710)</li> <li>η(1760)</li> <li>π(1800)</li> <li>f<sub>0</sub>(1810)</li> <li>X(1835)</li> <li>φ<sub>3</sub>(1870)</li> <li>p<sub>1</sub>(1900)</li> <li>f<sub>2</sub>(1910)</li> <li>f<sub>2</sub>(1950)</li> <li>p<sub>1</sub>(1900)</li> <li>f<sub>2</sub>(1910)</li> <li>f<sub>2</sub>(2150)</li> <li>f<sub>3</sub>(2200)</li> <li>f<sub>2</sub>(220)</li> <li>f<sub>2</sub>(220)</li> <li>f<sub>2</sub>(2300)</li> <li>f<sub>2</sub>(2300)</li> <li>f<sub>2</sub>(2300)</li> <li>f<sub>2</sub>(2300)</li> <li>f<sub>2</sub>(2300)</li> <li>f<sub>2</sub>(2300)</li> <li>f<sub>2</sub>(2300)</li> <li>f<sub>2</sub>(2300)</li> <li>f<sub>2</sub>(2300)</li> <li>f<sub>3</sub>(2450)</li> <li>f<sub>6</sub>(2510)</li> <li>OTH</li> <li>Further State</li> </ul>	1+(1) 1-(2++) 0+(0++) 0+(0++) 0+(2++) 0+(2++) 0+(2++) 0+(2++) 0+(2++) 0+(2++) 1+(1) 0+(2++) 0+(	) $K_{2}^{U}$ $K_{1}^{*}(800)$ $K_{1}^{*}(800)$ $K_{1}^{*}(1270)$ $K_{1}^{*}(1400)$ $K_{1}^{*}(140)$ $K_{1}^{*}(140)$ $K_{1}^{*}(140)$ $K_{2}^{*}(180)$ $K_{1}^{*}(1650)$ $K_{1}^{*}(1650)$ $K_{1}^{*}(1650)$ $K_{1}^{*}(1650)$ $K_{1}^{*}(1650)$ $K_{2}^{*}(170)$ $K_{1}^{*}(190)$ $K_{2}^{*}(190)$ $K_{2}^{*}(190)$ $K_{1}^{*}(230)$ $K_{3}^{*}(190)$ $K_{3}^{*}(230)$ $K_{3}^{*}(230)$ $K_{3}^{*}(230)$ $K_{3}^{*}(230)$ $K_{4}^{*}(200)^{0}$ $D^{*}(2400)^{0}$ $D^{*}(2400)^{0}$ $D_{1}^{*}(2420)^{0}$ $D_{1}^{*}(2400)^{0}$ $D_{2}^{*}(2400)^{0}$ $D_{3}^{*}(2400)^{0}$ $D_{3}^{*}(2400)^{0}$ $D_{3}^{*}(2400)^{0}$ $D_{3}^{*}(2400)^{0}$ $D_{3}^{*}(2400)^{0}$ $D_{3}^{*}(2400)^{0}$ $D_{3}^{*}(2400)^{0}$ $D_{3}^{*}(2400)^{0}$ $D_{3}^{*}(2400)^{0}$ $D_{3}^{*}(2460)^{0}$ $D_{3}^{*}(2460)^{0}$ $D_{3}^{*}(2460)^{0}$ $D_{3}^{*}(2460)^{0}$ $D_{3}^{*}(2460)^{0}$ $D_{3}^{*}(2460)^{0}$ $D_{3}^{*}(2460)^{0}$ $D_{3}^{*}(2450)^{0}$ $D_{3}^{*}(2450)^{0}$ $D_{3}^{*}(2450)^{0}$ $D_{3}^{*}(2460)^{0}$ $D_{3}^{*}(2450)^{0}$ $D_{3}^{*}(2530)^{0}$ $D_{3}^{*}(250)^{0}$ $D_{3}^{$	$1/2(0^{-})$ $1/2(1^{+})$ $1/2(1^{+})$ $1/2(1^{+})$ $1/2(1^{-})$ $1/2(2^{-})$ $1/2(1^{-})$ $1/2(1^{-})$ $1/2(1^{-})$ $1/2(1^{-})$ $1/2(2^{+})$ $1/2$	$\begin{array}{c} & \mathbb{B}^+_{, B^+}/B^+_{, M} \\ \text{MIXTURE} \\ & \mathbb{W}_{cb} \text{ and } \mathbb{V}_{, t} \\ & \mathbb{W}_{cb} \text{ and } \mathbb{V}_{, t} \\ & \mathbb{B}^+_{, t} \\ & \mathbb{B}^+$
	$\tau_{2}^{(1525)}$ $f_{2}^{(1565)}$ $h_{1}^{(1595)}$ $\cdot \pi_{1}^{(1600)}$ $\sigma_{1}^{(1640)}$ $\cdot \eta_{2}^{(1645)}$ $\cdot \omega^{(1650)}$ $\cdot \omega_{3}^{(1670)}$	$ \begin{array}{c} 0 + (2 + - \\ 0^{-}(1 + - \\ 1^{-}(1 - + ) \\ 1^{-}(1 + + ) \\ 0^{+}(2 + + ) \\ 0^{+}(2 - + ) \\ 0^{-}(1 ) \\ 0^{-}(3 ) \end{array} $	f <sub>6</sub> (2510) OTHER L Further States	0 <sup>+</sup> (6 <sup>++</sup> ) IGHT	$\begin{array}{c} D^{*}(2007)^{0} \\ D^{*}(2007)^{0} \\ D^{*}(2010)^{\pm} \\ D^{*}_{0}(2400)^{0} \\ D^{*}_{0}(2400)^{0} \\ D_{1}(2420)^{0} \\ D_{1}(2420)^{0} \\ D^{*}_{2}(2460)^{0} \\ D^{*}_{2}(2460)^{\pm} \\ D^{*}(2640)^{\pm} \\ \hline \\ CHARMEE \\ (C = 1) \\ CHARMEE \\ C = 1 \\ C$	$\begin{array}{c} 1/2(1^{-}) \\ 1/2(1^{-}) \\ 1/2(0^{+}) \\ 1/2(0^{+}) \\ 1/2(1^{+}) \\ 1/2(2^{+}) \\ 1/2(2^{+}) \\ 1/2(2^{+}) \\ 1/2(2^{+}) \\ 1/2(2^{+}) \\ 1/2(2^{+}) \\ 1/2(2^{+}) \\ 1/2(2^{+}) \\ 0(0^{-}) \\ 0(0^{-}) \\ 0(0^{+}) \\ 0(0^{+}) \\ 0(1^{+}) \\ 0(1^{+}) \\ 0(7^{2}) \end{array}$	• $\psi(4160)$ Y(4260) • $\psi(4415)$ • $b\bar{b}$ $\eta_b(1S)$ • $T(1S)$ • $\chi_{b0}(1P)$ • $\chi_{b1}(1P)$ • $\chi_{b2}(1P)$ • $\chi_{b2}(2P)$ • $T(1D)$ • $\chi_{b2}(2P)$ • $\chi_{b1}(2P)$ • $\chi_{b2}(2P)$ • $T(3S)$ • $T(4S)$ • $T(1020)$	$\begin{array}{c} 0 & (1 & -) \\ 2^{?}(1) \\ 0 - (1) \\ 0^{-}(1) \\ 0^{+}(0 + +) \\ 0^{+}(0 + +) \\ 0^{+}(1 + +) \\ 0^{-}(1) \\ 0^{+}(2 + +) \\ 0^{+}(2 + +) \\ 0^{+}(2 + +) \\ 0^{+}(2 + +) \\ 0^{+}(2 + +) \\ 0^{-}(1) \\ 0^{-}(1) \\ 0^{-}(1) \\ 0^{-}(1) \\ 0^{-}(1) \end{array}$	14014-99

jargon alert:	hadron	
	refers to:	any particle that Strong Force
	entomology:	αδρόσ "hadros" "I
	example:	proton and neutinot electron, not

## interacts via the

## arge", "massive"

ron *photon* 

jargon alert:	lepton	
	refers to:	originally, an elec neutrino
	entomology:	"λεπτός" (leptos)
	example:	electron, muon,

## ctron, muon,

# ), "fine, small, thin" neutrino, tau!

## The Particle Zoo?



jargon alert:	particle qua	ntum number
	refers to:	quantities that are inh particles, which are coordinate or decays
	entomology:	historical to Bohr and
	example:	electric charge, baryo number, isospin

## S

# herently a part of onserved in interactions

## Schroedinger

## n number, lepton

## something like these will never happen:

**Q:** 

**Q**:

## so, you'll always see:

total electric charge at the beginning equals total charges at the end



## Strangeness, S

strangeness seems to come in pairs

assign "strangeness" empirically.





and yet you *do* see:

$$\Lambda \to p + \pi^-$$

S: -1 0 0

**Production** of a subset of all baryons seems to require them to come in pairs. Strong interactions conserve Strangeness

**Decay** of those same baryons...notsomuch Weak interactions change Strangeness by 1 unit

Strong interaction 0

## Weak interaction

# the dominant Baryons

		Deet Massa						
Particle	Symbol	MeV/c <sup>2</sup>	spin	Q	В	S	Lifetime	modes
proton	p	938.3	1/2	+1	+1	0	> 10 <sup>31</sup> y	
neutron	n	939.6	1/2	0	+1	0	920	$pe^-\bar{\nu}_e$
Lambda	$\Lambda^0$	1115.6	1/2	0	+1	-1	2.6 x 10 <sup>-10</sup>	$p\pi^-, n\pi^0$
Sigma	$\Sigma^+$	1189.4	1/2	+1	+1	-1	0.8 x 10 <sup>-10</sup>	$p\pi^0, n\pi^+$
Sigma	$\Sigma^0$	1192.5	1/2	0	+1	-1	6 x 10 <sup>20</sup>	$\Lambda^0\gamma$
Sigma	$\Sigma^{-}$	1197.3	1/2	-1	+1	-1	1.5 x 10 <sup>-10</sup>	$n\pi^-$
Delta	$\Delta^{++}$	1232	3/2	+2	+1	0	0.6 x 10 <sup>23</sup>	$p\pi^+$
Delta	$\Delta^+$	1232	3/2	+1	+1	0	0.6 x 10 <sup>23</sup>	$n\pi^+, \ p\pi^0$
Delta	$\Delta^0$	1232	3/2	0	+1	0	0.6 x 10 <sup>23</sup>	$n\pi^0$
Delta	$\Delta^{-}$	1232	3/2	-1	+1	0	0.6 x 10 <sup>23</sup>	$n\pi^-$
Xi	$\Xi^0$	1315	1/2	0	+1	-2	2.9 x 10 <sup>-10</sup>	$\Lambda^0\pi^0$
Xi	[I]	1321	1/2	-1	+1	-2	1.64 x 10 <sup>-10</sup>	$\Lambda^0\pi^-$
Omega	$\Omega^{-}$	1672	3/2	-1	+1	-3	0.82 x 10 <sup>-10</sup>	$\Xi^0\pi^-, \ \Lambda^0K^-$



# the dominant Mesons

Particle	Symbol	anti- particle	Rest Mass MeV/c <sup>2</sup>	spin	Q	В	S	Lifetime
Pion	$\pi^+$	$\pi^{-}$	139.6	0	+1	0	0	2.6 x 10 <sup>-8</sup>
Pi-zero	$\pi^0$	$\pi^0$	135	0	0	0	0	920
Kaon	$K^+$	$K^{-}$	493.7	0	+1	0	+1	1.24 x 10 <sup>-8</sup>
K-short	$K_S^0$	$K_S^0$	497.7	0	0	0	+1	0.89 x 10 <sup>-10</sup>
K-long	$K_L^0$	$K_L^0$	497.7	0	0	0	+1	5.2 x 10 <sup>-8</sup>
Eta	$\eta^0$	$\eta^0$	548.8	0	0	0	0	< 10 <sup>-18</sup>
Eta-prime	$\eta^0$ ′	$\eta^0$ ′	958	1	0	0	0	
Rho	$\rho^+$	$ ho^-$	770	1	+1	0	0	0.4 x 10 <sup>23</sup>
Rho-naught	$ ho^0$	$ ho^0$	770	1	0	0	0	0.4 x 10 <sup>23</sup>
Omega	$\omega^0$	$\omega^0$	782	1	0	0	0	0.8 x 10 <sup>22</sup>
Phi	$\phi$	$\phi$	1020	1	0	0	0	20 x 10 <sup>-23</sup>





# patterns emerged

## to Murray Gell-Mann & (independently) Yuval Ne'eman in 1964



$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	$(S = C + B = 0)$ $f^{G}(J^{PC})$ $f^{G}(J^{PC})$	STRANGE $S = \pm 1, C = B = 0$ ) $I(J^{P})$ BOTTOM $(B = \pm 1)$ $I^{G}(J^{PC})$
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	(A30) $1/2(0^+)$ BOTTOM, STRANGE           (430) $1/2(0^+)$ $(B = \pm 1, S = \mp 1)$ (430) $1/2(2^+)$ $B_s^0$ $0(0^-)$ (430) $1/2(2^-)$ $B_s^0$ $0(0^-)$ (580) $1/2(2^-)$ $B_s^*$ $0(1^-)$ (580) $1/2(1^+)$ $BOTTOM, CHARMED$ (680) $1/2(1^-)$ $(B = C = \pm 1)$
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	$\begin{array}{cccccccccccccccccccccccccccccccccccc$
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	$\begin{array}{c} \hline (2-24) \\ \hline \gamma(3940) \\ (277)^{0} \\ 1/2(0^{-}) \\ 1/2(0^{-}) \\ 007)^{0} \\ 1/2(1^{-}) \\ 010)^{\pm} \\ 1/2(1^{-}) \\ 400)^{0} \\ 1/2(0^{+}) \\ 400)^{\pm} \\ 1/2(0^{+}) \\ \hline b\overline{b} \end{array}$
$ \begin{array}{c c} & \omega_{1}(1650) & 0^{-}(1^{-}-1) \\ & & \omega_{3}(1670) & 0^{-}(3^{-}-1) \end{array} \end{array} \begin{array}{c c} & D_{0}(2400)^{-} & 1/2(0^{+}) \\ & & D_{1}(2420)^{0} & 1/2(1^{+}) \\ & D_{1}(2420)^{0} & 1/2(1^{+}) \\ & & D_{1}(2430)^{0} & 1/2(1^{+}) \\ & & D_{2}^{*}(2460)^{0} & 1/2(2^{+}) \\ & & D_{2}^{*}(2460)^{\pm} & 1/2(2^{+}) \\ & & D_{2}^{*}(2460)^{\pm} & 1/2(2^{+}) \\ & & D_{2}^{*}(2460)^{\pm} & 1/2(2^{+}) \\ \end{array} $	$\begin{array}{c cccc} \bullet & \omega(1650) & 0^{-}(1) \\ \bullet & \omega_3(1670) & 0^{-}(3) \\ \end{array} \qquad \qquad$	$\begin{array}{cccccccccccccccccccccccccccccccccccc$



# **5 ed** Ne'eman in 1964

# family arrangements





# quarks

## the mathematical description of such patterns
# 1964



### Murray Gell-Mann

1929 -

theoretician

Nobel Laureate 1969

genius

### Yale at age of 15. PhD from MIT at age of 22.

Speaks at least 13 languages fluently. Studies linguistics now, among other things.

Unraveled many of the organization puzzles of the particle zoo: strangeness an empirical mass formula relating them

Worries a lot now about the nature of physical law.

A not-so-good TED lecture on mathematical Beauty in physics...link below.

Not known for his humility.

http://www.ted.com/talks/murray gell mann on beauty and truth in physics.html

# Gell-Mann found that the patterns work

### if every particle is composed of smaller bits

up down strange

Gell-Mann's original pattern for quarks. Changed...

with fractional electric charge:

charge of up quark: charge of down quark: charge of strange quark:

### "Quarks"

FINNEGANS WAKE BY JAMES IOYCE ER AND

+2/3 e -1/3 e -1/3 e

# fundamental particles, circa...now

quarks and leptons

hadrons are composite: made of quarks

electrons and cousins are fundamental on their own

# quarks on their own

Baryons & Mesons differ by quark-content Baryons are made of 3 quarks Mesons are made of 1 quark and 1 antiquark

40

# Quarks

- 1964 version
- fundamental fermions

in same league as electrons and neutrinos



Quark	Symbol	Rest Mass MeV/c <sup>2</sup>	spin	Q	В	S
up	u	1.7 - 3.3	1/2	+2/3	1/3	0
down	d	4.1 - 5.8	1/2	-1/3	1/3	0
strange	S	101	1/2	-1/3	1/3	-1



### proton

### electric charge = +1

Quark	Symbol	Rest Mass MeV/c <sup>2</sup>	spin	Q	В	S
up	U	1.7 - 3.3	1/2	+2/3	1/3	0
down	d	4.1 - 5.8	1/2	-1/3	1/3	0
strange	S	101	1/2	-1/3	1/3	-1



d

# proton electric charge = +1

Quark	Symbol	Rest Mass MeV/c <sup>2</sup>	spin	Q	В	S
up	u	1.7 - 3.3	1/2	+2/3	1/3	0
down	d	4.1 - 5.8	1/2	-1/3	1/3	0
strange	S	101	1/2	-1/3	1/3	-1



+2/3

-1/3

### neutron

### electric charge = 0

Quark	Symbol	Rest Mass MeV/c <sup>2</sup>	spin	Q	В	S
up	U	1.7 - 3.3	1/2	+2/3	1/3	0
down	d	4.1 - 5.8	1/2	-1/3	1/3	0
strange	S	101	1/2	-1/3	1/3	-1



d

neutron

### electric charge = 0

Quark	Symbol	Rest Mass MeV/c <sup>2</sup>	spin	Q	В	S
up	U	1.7 - 3.3	1/2	+2/3	1/3	0
down	d	4.1 - 5.8	1/2	-1/3	1/3	0
strange	S	101	1/2	-1/3	1/3	-1



+2/3

-1/3





### discovered at Brookhaven within a year the "Omega minus" was discovered at Brookhaven National Lab S $\Lambda^0$ $\Lambda$ + 0 D -1 $\sum *0$ **Ξ**\*0 -2 $\mathbf{T}\mathbf{0}$ -3 $-\frac{1}{2}$ <u>1</u> 2 <u>1</u> 2 3 <u>1</u> 2 -1 0 1 -1 1 0 Ι



### most famous bubble chamber picture in history, 1964



The event in question is shown in Fig. 2, and

$$= \Omega^{-} + K^{+} + K^{0}$$

$$= \Sigma^{0} + \pi^{-}$$

$$= \Lambda^{0} + \pi^{0}$$

$$= \int_{-}^{-} \gamma_{1} + \gamma_{2}$$

$$= \int_{-}^{+} e^{+} + e^{-}$$

$$= e^{+} + e^{-}$$

$$= \int_{-}^{+} \pi^{-} + p.$$

$$= (1)$$

particle:	Omega minus						
	symbol:	$\Omega^{-}$					
	charge:	-1					
	mass:	1672.45 MeV/c <sup>2</sup>					
	spin:	3/2					
	category:	Fermion, baryon,					

### I = 0, B=1, S=-3

# the dominant Baryons

Particle	Symbol	Rest Mass MeV/c <sup>2</sup>	spin	Q	В	S	Lifetime	dominant decay modes
proton	p	938.3	1/2	+1	+1	0	> 10 <sup>31</sup> y	
neutron	n	939.6	1/2	0	+1	0	920	$pe^-\bar{\nu}_e$
Lambda	$\Lambda^0$	1115.6	1/2	0	+1	-1	2.6 x 10 <sup>-10</sup>	$p\pi^-, n\pi^0$
Sigma	$\Sigma^+$	1189.4	1/2	+1	+1	-1	0.8 x 10 <sup>-10</sup>	$p\pi^0, n\pi^+$
Sigma	$\Sigma^0$	1192.5	1/2	0	+1	-1	6 x 10 <sup>20</sup>	$\Lambda^0\gamma$
Sigma	$\Sigma^{-}$	1197.3	1/2	-1	+1	-1	1.5 x 10 <sup>-10</sup>	$n\pi^-$
Delta	$\Delta^{++}$	1232	3/2	+2	+1	0	0.6 x 10 <sup>23</sup>	$p\pi^+$
Delta	$\Delta^+$	1232	3/2	+1	+1	0	0.6 x 10 <sup>23</sup>	$n\pi^+, \ p\pi^0$
Delta	$\Delta^0$	1232	3/2	0	+1	0	0.6 x 10 <sup>23</sup>	$n\pi^0$
Delta	$\Delta^{-}$	1232	3/2	-1	+1	0	0.6 x 10 <sup>23</sup>	$n\pi^-$
Xi	$\Xi^0$	1315	1/2	0	+1	-2	2.9 x 10 <sup>-10</sup>	$\Lambda^0\pi^0$
Xi	[I]	1321	1/2	-1	+1	-2	1.64 x 10 <sup>-10</sup>	$\Lambda^0\pi^-$
Omega	$\Omega^{-}$	1672	3/2	-1	+1	-3	0.82 x 10 <sup>-10</sup>	$\Xi^0\pi^-, \ \Lambda^0K^-$

quark content
uud
ddu
uds
uus
uds
dds
иии
uud
udd
ddd
USS
dss
SSS

### mesons

Quark	Symbol	Rest Mass MeV/c <sup>2</sup>	spin	Q	В	S
up	U	1.7 - 3.3	1/2	+2/3	1/3	0
down	d	4.1 - 5.8	1/2	-1/3	1/3	0
strange	8	101	1/2	-1/3	1/3	-1

### a little different

	Particle	Symbol	anti- particle	Rest Mass MeV/c <sup>2</sup>	spin	Q	В	S
The pion:	Pion	$\pi^+$	$\pi^{-}$	139.6	0	+1	0	0

$$\pi^{+} = \begin{pmatrix} u & \& & \bar{d} \\ 0 & +1 & +2/3 & +-(-1) \\ 0 & 1/3 & +-(1/3) \\ 0 & 0 & 0 \end{pmatrix}$$

 $\pi^+ = u\bar{d}$ 



### a similar thing happens for the mesons



meson quark content





# the dominant Mesons

Particle	Symbol	anti- particle	Rest Mass MeV/c <sup>2</sup>	spin	Q	В	S	Lifetime	dominant decay modes	quark content
Pion	$\pi^+$	$\pi^{-}$	139.6	0	+1	0	0	2.6 x 10 <sup>-8</sup>	$\mu^+ u_\mu$	$u \overline{d}$
Pi-zero	$\pi^0$	$\pi^0$	135	0	0	0	0	920	$2\gamma$	$\frac{1}{\sqrt{2}}(u\bar{u}+d\bar{d})$
Kaon	$K^+$	$K^{-}$	493.7	0	+1	0	+1	1.24 x 10 <sup>-8</sup>	$\mu^+\nu_\mu, \pi^+\pi^0$	$u\overline{s}$
K-short	$K_S^0$	$K_S^0$	497.7	0	0	0	+1	0.89 x 10 <sup>-10</sup>	$\pi^+\pi^-, 2\pi^0$	$dar{s},sar{d}$
K-long	$K_L^0$	$K_L^0$	497.7	0	0	0	+1	5.2 x 10 <sup>-8</sup>	$\pi^{\pm}\ell^{\mp}\nu_{\ell}$	$dar{s},sar{d}$
Eta	$\eta^0$	$\eta^0$	548.8	0	0	0	0	< 10 <sup>-18</sup>	$2\gamma, \pi^+\pi^-\pi^0$	$uar{u}, dar{d}, sar{s}$
Eta-prime	$\eta^0$ ′	$\eta^0$ ′	958	1	0	0	0		$\pi^+\pi^-\eta$	$uar{u}, dar{d}, sar{s}$
Rho	$\rho^+$	$ ho^-$	770	1	+1	0	0	0.4 x 10 <sup>23</sup>	$\pi^+\pi^-, 2\pi^0$	$u \overline{d}$
Rho-naught	$ ho^0$	$ ho^0$	770	1	0	0	0	0.4 x 10 <sup>23</sup>	$\pi^+\pi^-$	$uar{u}, dar{d}$
Omega	$\omega^0$	$\omega^0$	782	1	0	0	0	0.8 x 10 <sup>22</sup>	$\pi^+\pi^-\pi^0$	$uar{u}, dar{d}$
Phi	$\phi$	$\phi$	1020	1	0	0	0	20 x 10 <sup>-23</sup>	$K^+K^-, K^0\bar{K}^0$	$s\overline{s}$

# spins work out

### add up the spins

Keep track of quark spins:

for example, a couple of baryons:

 $u \uparrow u \downarrow d \uparrow$  total spin: 1/2 p

 $\Delta^+$   $u \uparrow u \uparrow d \uparrow$  total spin: 3/2

for example, a couple of mesons:

$$\pi^+ \qquad u \uparrow \bar{d} \downarrow$$

 $\rho^+ \qquad u \uparrow \bar{d} \uparrow$ 

spin +1/2  $q\uparrow$ spin –1/2  $q\downarrow$ 

total spin: 0

total spin: 1

# there are still

### 100's more baryons and mesons

what's up with that? you're asking

A model of "quark molecules"...

Molecules can have vibrational and rotational excited states...

So can quarks.

is a state with the same quark content as a proton  $N^*$ but which has a high orbital angular momentum

> dU U

Other states can be well-modeled by assuming relative vibrational modes..

d

you can tell a particle physicist by the books that we carry

"I laughed, I cried"



# the now jargon

### gets a little more straightforward



### Hadrons: particles made of quarks.

Baryons: particles made of 3 quarks.

now defined:

now defined:

**Mesons**: particles made of 1 quark and 1 antiquark.

a variety of consequences

### became apparent

One could begin to understand particle decays and reactions in terms of pseudo-Feynman diagrams\* like this:

 $\pi^+ + p \rightarrow \pi^+ + p$  Fermi had produced "resonances" that suggested that something was "in between" the initial and final states

$$\pi^+ + p \to \Delta^{++} \to \pi^+ + p$$



scatterings
now are
thought of
diferently

by following the lines...

 $\pi^+ + p \to \Delta^{++} \to \pi^+ + p$ 

### Feynman Diagram, pre-1964:

### in quark language:











how about a strong interaction decay?

a little nonintuitive.  $\Delta^0 \to \pi^- + p$ 

the old way:



the quark way:



3 quarks

### some quark-creation required!



### stay tuned.

# is the world made of actual quarks?

or is this just a convenient organizing scheme

that's all Gell-Mann thought

But evidence started to accumulate that surprised everyone

quarks are indeed as real as electrons.

### First piece of convincing evidence:

we can bang on them

individually...Feynman saw this first.



64

### remember. the crucial thing in order to "see" something?

# wavelength has to be about the size of the object

### larger the momentum

the smaller the spatial resolving capability

65

### scattering of an electron from a nucleus

slow electron, long wavelength photon





### "sees" the whole nucleus





### scattering of an electron from a nucleus

fast electron, medium-short wavelength photon

M



### "sees" an individual proton in the nucleus

67

### scattering of an electron from a nucleus

very fast electron, very-short wavelength photon



"sees" an individual quark in a proton or neutron That's how we became convinced in 1969 – the same sort of backwards scattering as Rutherford's







### The Nobel Prize in Physics 1990

Jerome I. Friedman, Henry W. Kendall, Richard E. Taylor

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### The Nobel Prize in Physics 1990



Jerome I. Friedman Prize share: 1/3



Henry W. Kendall Prize share: 1/3



Photo: T. Nakashima Richard E. Taylor Prize share: 1/3

The Nobel Prize in Physics 1990 was awarded jointly to Jerome I. Friedman, Henry W. Kendall and Richard E. Taylor "for their pioneering investigations concerning deep inelastic scattering of electrons on protons and bound neutrons, which have been of essential importance for the development of the quark model in particle physics".

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particle:	up quark	up quark							
	symbol:	U							
	charge:	+2/3							
	mass:	1.7 to 3.3 MeV/c <sup>2</sup>							
	spin:	1/2							
	category:	Fermion, I=+1/2,							

### B=1/3, S=0

particle:	down quark	
	symbol:	d
	charge:	-1/3
	mass:	4.1 to 5.8 MeV/c <sup>2</sup>
	spin:	1/2
	category:	Fermion, I=–1/2,

### B=1/3, S=0

particle:	strange quark	
	symbol:	S
	charge:	-1/3
	mass:	101 MeV/c <sup>2</sup>
	spin:	1/2
	category:	Fermion, $I=-1/2$ ,

### B=1/3, S=-1
# shifting gears

### the weak interaction needs a boson



## the quantum relativistic field theory theme song:







### this kind of magic:



If there's a field,

### If there is a force...there's a field





# there's a quantum to go with it.

## **Because Nature** is Clumpy.

## for the electromagnetic interaction:

the force is the electromagnetic force

the field is E & B

the clumpiness – the <u>quantum</u> – is:

The photon:  $\gamma$ 



# nteraction: tic force

Well, the Weak Force must have a field ...yadda yadda yadda



If there's a field,

### If there is a force...there's a field



# there's a quantum to go with it.

## **Because Nature** is Clumpy.

### for weak interaction:

the field must be a weak field...& Massive & electrically charged

the clumpiness - the quantum - must be Something else.

here's a weak interaction

## neutron beta decay



the weak interaction here changes the bottom and the top of these doublets

Manipulate the graph in the now familiar way:





the muon decay is the same sort of

> in that second way of looking at it:



# do it again?

### can a "photon" be forced to exist that governs the weak interaction?

### It was a dream that the electromagnetic interaction



could have a weak interaction counterpart.



Feynman and Murray Gell-Mann worked out a consistent theory based on the idea of a "heavy" photon with electric charge.

"W" for "Weak"

Notice that f and f' and  $W^{\pm}$  all have to have their electric charges assigned so that electric charge is conserved.

temporary entries into your table of primitive diagrams



so, a new primitive diagram

 $\begin{pmatrix} \gamma \\ \chi \\ W \end{pmatrix}$  pretend this is primitive for a moment.

### Neutron beta decay:

## for the Weak Interaction







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keep track of the charge flow

### there are 2 W charged states



 $n \to p + W^- \to p + e^- + \bar{\nu}_e$ 

+1 + -1 = +1 + -1 + 0**Q:** 

So:  $W^-$  lowers the electrical charge by 1 W + raises the electrical charge by 1



# = 0

here is where those weak "doublets" in come

the Weak Interaction connects them The particle doublets that we know so far:



Notice, that all of these transitions change the electric charge as well as the particle type



### making these transitions is the W Boson's job.

"deep inelastic scattering"

hitting quarks individually

of course in a statistical fashion

neutrinos do it too...



analyses of these reactions,  $\nu N \to \mu X \qquad eN \to eX$ 

confirm the point-like (?) nature of quarks

confirm their apparent loose-binding within nucleons (in a second)

confirm their fractional electric charges!



SO, new a primitive diagram

for the Weak Interaction with quarks, to go with the leptons





 $\bar{\nu}_e$ 



instead of what I had before:

there are still weak interactions

including transitions among quarks

The particle doublets that we know so far:



Notice, that all of these transitions change the electric charge as well as the particle type



### making these transitions is the W Boson's job.

there are still weak interactions

## including transitions among quarks

The particle doublets in quark language:



Notice, that all of these transitions change the electric charge as well as the particle type





making these transitions

NOW...your second entry into your

table of primitive diagrams



particle:	charm quark		
	symbol:	С	
	charge:	+2/3	
	mass:	1,270 MeV/c <sup>2</sup>	
	spin:	1/2	
	category:	Fermion, I=0, B=	

### =1/3, S=0, C=+1

SO, decays we've seen

just put in the decaying quark and let the other "spectator quarks"

come along for the ride

$$\pi^+ \to \mu^+ + \nu_\mu$$

responsible for making neutrino beams from proton accelerators



Strong interaction, again: The original question about nuclei... now in play for quarks: what holds the quarks inside of the baryons and mesons?

94

Gross, Politzer, and Wilczek

### 2004

"asymptotic freedom" in strong interactions

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Nobel Medal for Physics	David J. Gross	
Articles in Physics	H. David Politzer	
Video Interviews	Frank Wilczek	
Video Nobel Lectures	-	
Nobel Prize in Chemistry		
Nobel Prize in Physiology or Medicine	( and	
Nobel Prize in Literature	4	9
Nobel Peace Prize		1-
Prize in Economic Sciences		1 -
Nobel Laureates Have Their Say		A A-

David J. Gross

The Nobel Prize in Physics 2004 was Politzer and Frank Wilczek "for the d of the strong interaction".

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Nobel Prize Award Ceremonies

Nomination and Selection of

	Home	A-Z		
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	2012			
ur 🔹	Prize category: Physics			
sics 2004 blitzer, Frank Wilczek				
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id Politzer s awarded jointly	Frank Wilczek to David J. Gross, H. David	ł		
liscovery of asym	ptotic freedom in the theor	y		

H. Davi

it's the glue that holds everything together virtually

Predicted the existence of the Strong Messenger Particle: the **Gluon** 

0000

my gluon



# third entry into your

## table of primitive diagrams



# there are two amazing things

about gluons

# thing 1

### they self-interact



a photon propagates the electromagnetic force...but it does not have an electric charge



the gluon propagates the strong force...and it DOES have a "strong charge"

This has significant consequences...almost magical

fourth and fifth entries into your

## table of primitive diagrams



# thing 2

their force field is the opposite of electromagnetism, or gravity



force of attraction or repulsion for electromagnetic fields







# ah, but the gluon is odd



force of attraction for gluon fields



g

the further away you get, the **STRONGER** the quark-quark attraction is!

## pull apart 6 em

### called

### quark confinement



The energy in the field is so high...that it pops a new quark-antiquark pair out of the vacuum.

We don't see individual quarks or gluons

they make more quarks and gluons

and interact very quickly into a cascade of particles

"quark-gluon jets"





# "hard" quark production



Date: 2010-07-18 11:05:54 CEST







particle:	gluon	
	symbol:	g
	charge:	0
	mass:	0
	spin:	1
	category:	Strong Vector Bo












# why does the proton weigh?









## gluons

# **Field Energy**









# when you step on the scale

### you measure the earth's attraction

to the gluons' mass-energy in your protons and neutrons

and you use the non-quantum Newton's theory to do it

your "weight" is a quantum relativistic field theoretic thing

# ction ns and neutrons theory to do it

here's the elementary particles story

circa 1975

## the messengers

### spin 1 Bosons

circa 1980

the photon "propagates the electromagnetic force"

the W Boson

"propagates the weak force"

0000

the gluon

"propagates the strong force"

say tuned.

particle:	bottom quark			
	symbol:	b		
	charge:	-1/3 e		
	mass:	4.5 GeV/c <sup>2</sup> = 4.5 p		
	spin:	1/2		
	category:	Fermion, quark		



the

"top quark" was discovered in 1995

by two experiments at Fermilab

with MSU faculty and students intimately involved

VOLUME 74, NUMBER 14 PHYSICAL REVIEW LETTERS 3 APRIL 1995 **Observation of the Top Quark** The D0 Collaboration reports on a search for the standard model top quark in pp collisions at  $\sqrt{s} = 1.8$  TeV at the Fermilab Tevatron with an integrated luminosity of approximately 50 pb<sup>-1</sup>. We have searched for rī production in the dilepton and single-lepton decay channels with and without tagging of b-quark jets. We observed 17 events with an expected background of 3.8 ± 0.6 events. The probability for an upward fluctuation of the background to produce the observed signal is 2 × 10<sup>-6</sup> (equivalent to 4.6 standard deviations). The kinematic properties of the excess events are consistent with top quark decay. We conclude that we have observed the top quark and measured its mass to be  $199^{+19}_{-21}$  (stat) ±22 (syst) GeV/e<sup>1</sup> and its production cross section to be 6.4 ± 2.2 pb. PACS numbers: 14.65.Ha, 13.85.Qk, 13.85.Ni VOLUME 74, NUMBER 14 PHYSICAL REVIEW LETTERS 3 APRIL 1995 Observation of Top Quark Production in  $\overline{p}p$  Collisions with the Collider Detector at Fermilab We establish the existence of the top quark using a 67 pb-1 data sample of pp collisions at  $\sqrt{3}$  = 1.8 TeV collected with the Collider Detector at Fermilab (CDF). Employing techniques similar to those we previously published, we observe a signal consistent with ti decay to WWbb, but inconsistent with the background prediction by  $4.8\sigma$ . Additional evidence for the top quark is provided by a peak in the reconstructed mass distribution. We measure the top quark mass to be 176 ± 8(stat) ± 10(syst) GeV/c<sup>2</sup>, and the *ii* production cross section to be 6.8<sup>+1.6</sup>/<sub>2.4</sub> pb. PACS numbers: 14.65.Ha, 13.85.Qk, 13.85.Ni

February 24th, 11AM, we submitted our discovery paper to Physical Review Letters

March 2, 1995 the announcement was made at Fermilab



particle:	top quark			
	symbol:	t		
	charge:	+2/3 e		
	mass:	172.0±2.2 GeV/c <sup>2</sup>		
	spin:	1/2		
	category:	Fermion, quark		

### <sup>2</sup> = 172 p



# the weak interactions

### still operate with the increased doublet sets

### The complete (circa 2000) particle doublets:

Q  
+2/3 
$$\begin{pmatrix} u \\ d \end{pmatrix}$$
  $\begin{pmatrix} c \\ s \end{pmatrix}$ 

$$\begin{array}{c} \mathbf{0} \\ \mathbf{-1} \end{array} \begin{pmatrix} \nu_e \\ e \end{pmatrix} \qquad \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}$$





### the weak interactions

### still operate with the increased doublet sets

The complete (circa 2000) particle doublets:



 $\begin{array}{c} \mathbf{0} \\ \mathbf{-1} \end{array} \begin{pmatrix} \nu_e \\ e \end{pmatrix} \longrightarrow W \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix} \longrightarrow W \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix} \searrow W$ 

the modern picture

of the elementary particle patterns

circa 2000

and still current

the lepton families...lepton "doublets"

### and their interactions: 🗶 no, 🖌 yes.

leptons	$ u_e $	e	$ u_{\mu}$	$\mu$	$ u_{ au}$	au
strong 0000 g	×	×	×	×	×	×
electromagnetic $\gamma$	×		×		×	
weak MM W						
gravitational						

 $\begin{pmatrix} \nu_e \\ e^- \end{pmatrix} \quad \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix} \quad \begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix}$ 

the modern picture

### of the elementary particle patterns

circa 2000

the quark families...quark "doublets"

### and their interactions: 🗶 no, 🖌 yes.

quarks	U	d	С	S	t	b
strong $g$						
electromagnetic						
weak $\mathcal{W}$						
gravitational						





### The Particle Zoo?



### The Particle Zoo? tamed.



# shifting gears

the weak and electromagnetic forces are one.





### "phase transitions"

### not a subject of **Particle Physics**

we thought

but we stole a theory from materials scientists

when there has been a symmetry change, that's essentially the definition of a phase change: Pierre Curie

before: every direction is identical





### what a physicist sees is a change of symmetry





after: now there are special directions

there are basically 2 kinds

1st Order nucleation

2d Order continuous



Boiling starts in various locations inside of liquid water

Other kinds of phase transitions happen uniformly throughout the substance.

you probably are mostly familiar with: freezing melting boiling

These "2nd Order," phase transitions are continuouseverywhere:

crystallization changes of density magnetism superconductivity superfluidity plasma transition electron gases Bose gases