spring training has begun. all is well now.

Daft Punk week (don’t judge)

Happy Valentine’s Day

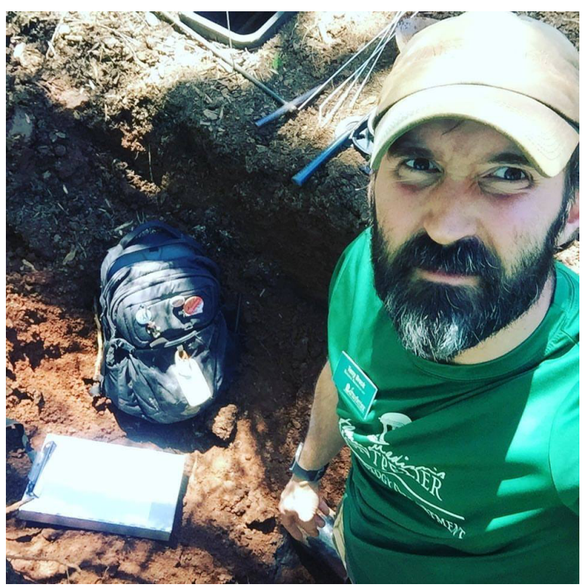
PREVENTION, OUTREACH, & EDUCATION (POE) DEPARTMENT IS...

RECRUITING PEER EDUCATORS FOR FALL 2019

Peer educators help educate and empower students through knowledge of sexual assault, relationship violence, stalking, and more. Flexible hours and PAID position, great for resumes and leadership experience.

APPLY HERE: HTTPS://BIT.LY/POEAPPS

EDUCATE & EMPOWER



hi

Day 10, 14.02.2019

Particle Accelerators and Detectors

housekeeping

Lectures forever now: Gotta come to class

question about anything? I'll make a movie for you:

Midterm…before Spring Break

available: Saturday, 23 February midnight

due: Tuesday, 26 February midnight

covering: material beginning through HW4 content

#attempts = 1

weight = 2 x HW

Some LON-CAPA

still!

I've not adjusted grades for the Kepler problem yet

LON-CAPA "essay" question fields

> You must paste in images separately

amnesty

> I did re-open the closing dates for all of the LON-CAPA reading questions for a brief window-of-reprieve
>
> Saturday, February 9 midnight until tomorrow, February 15, 11pm

February 2019

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
27	28	29	30	31	1	2
		yadda yadda yadda				HW2
3	4	5	6	7	8	9
		lessons 10,11,12		lesson 13	HW2 due	HW3
10	11	12	13	14	15	16
		lecture		lecture	HW3 due	HW4
17	18	19	20	21	22	23
		lecture		lecture	HW4 due	HW5
24	25	26	27	28	1	2
←	midterm	→ lecture		lecture	HW5 due	

Eastern Time Time Zone


KEEP
CALM
AND
LET'S
REVIEW

You might want to remember this:

a changing B field creates an E field

a changing E field creates a B field

accelerated charges produce electromagnetic radiation

"Lorentz Force"

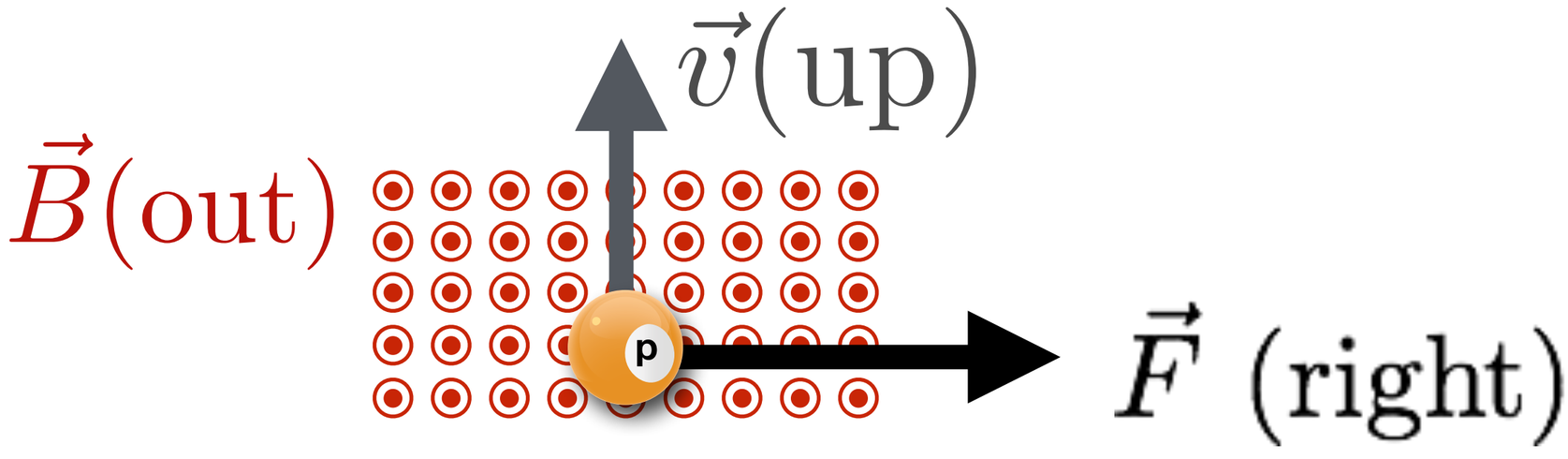
Electric fields accelerate + charged particles along the E field lines

F = QE

Magnetic fields accelerate + charged particles toward a center of a circle - a centripetal force

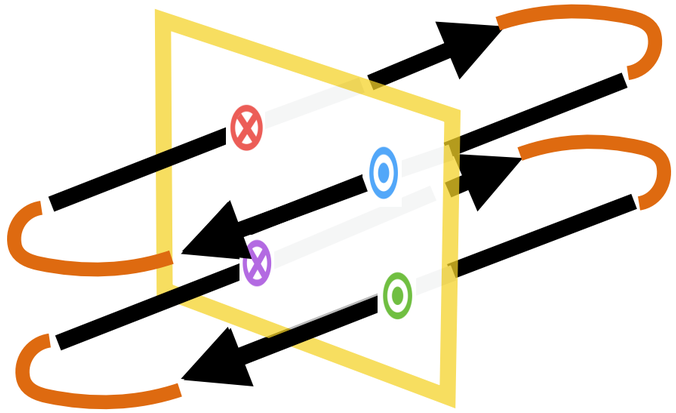
considered as forces on particles, F = QvB

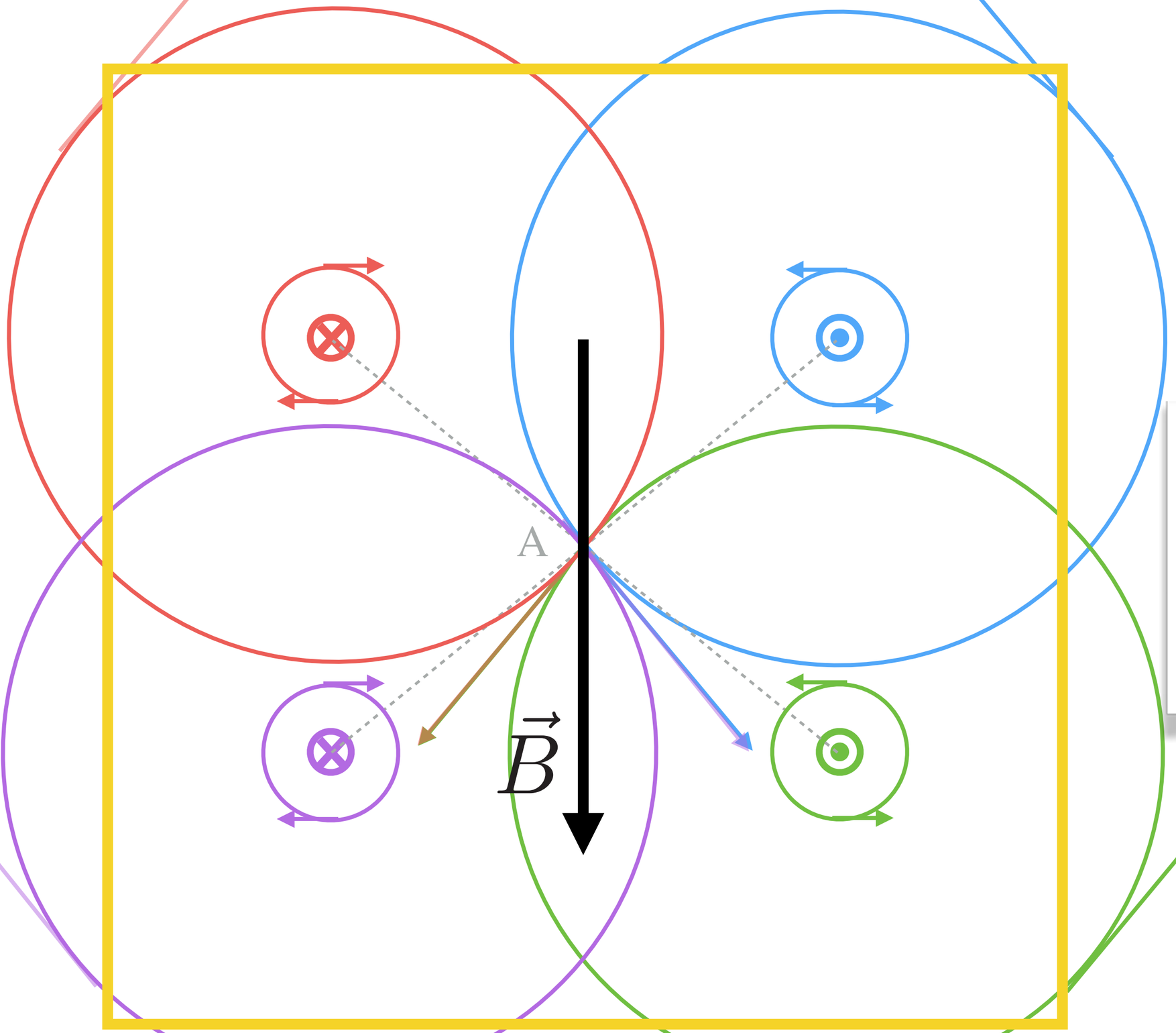
perpendicular to v and B, right hand pointing in F (for +Q)

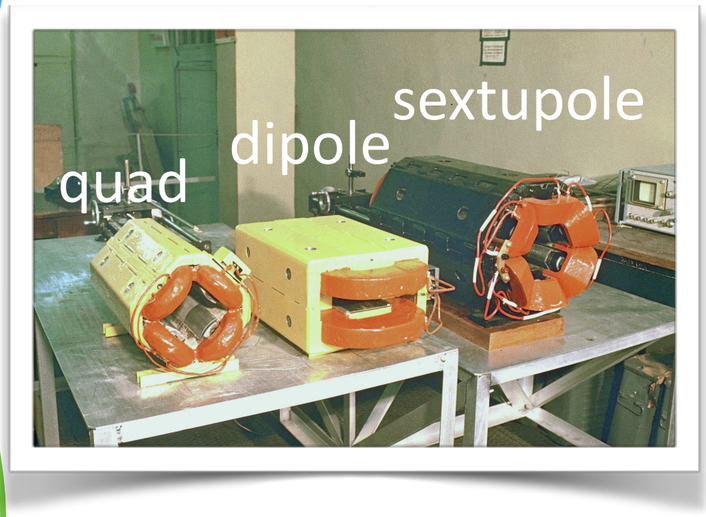


Lorentz Force: **F** = Q**E** + QvB(**perpendicular**)

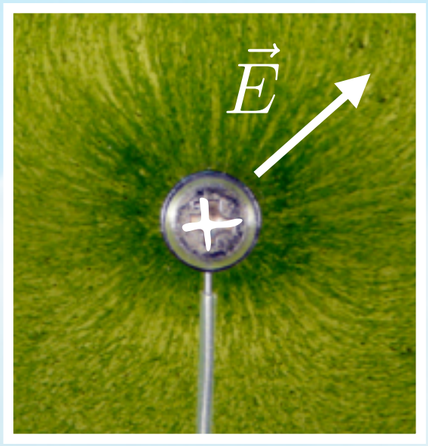
dipole beam magnet



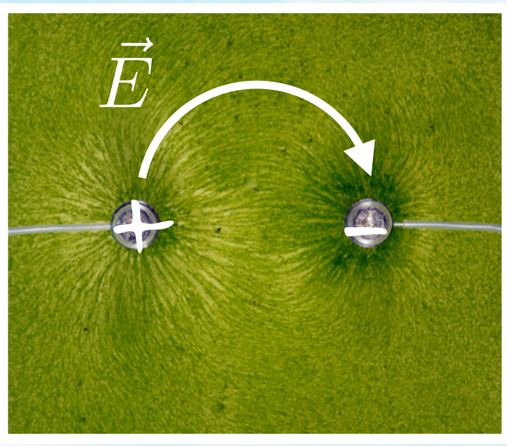




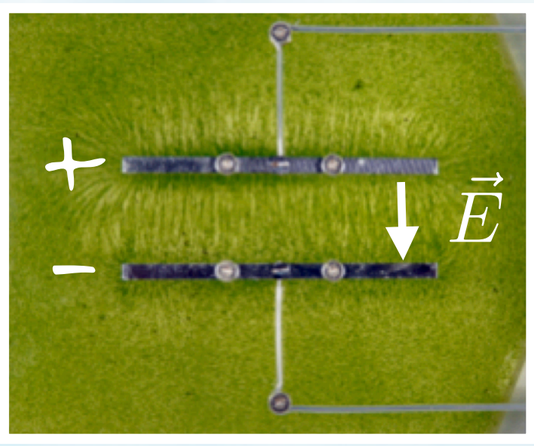
field configurations



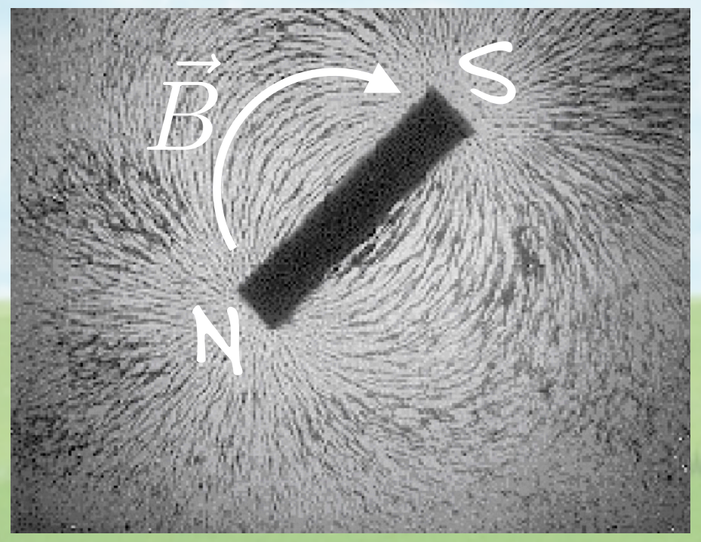
single electric charge



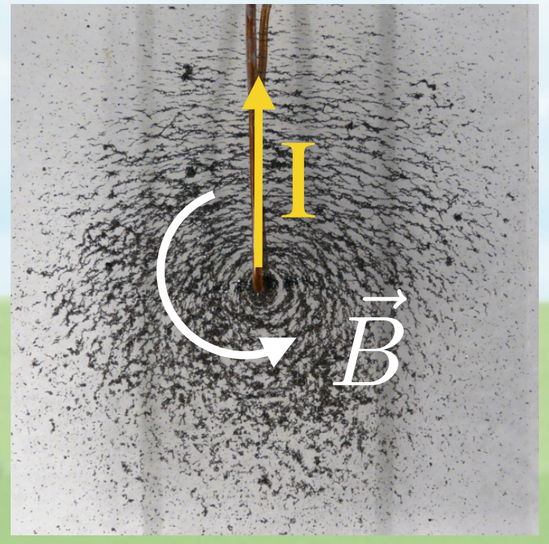
two opposite charges



parallel plates oppositely charged

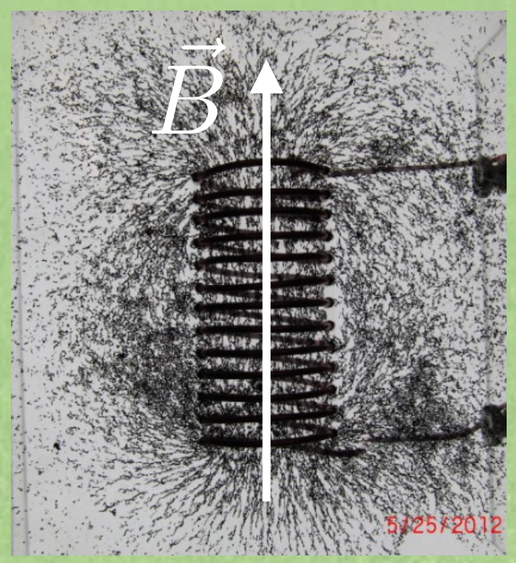


bar magnet

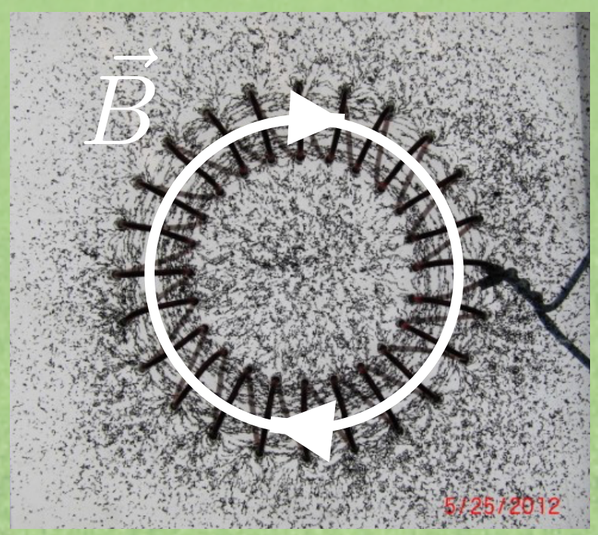


single current

current loop



solenoid



toroid

review, cont.

charges in motion

an electric charge at rest: what fields? electric

an accelerating electric charge: what fields? electric & magnetic

we say that an accelerating electric charge

radiates an electromagnetic wave

a changing electric field creates: a changing magnetic field

a changing magnetic field creates: a changing electric field

"conservation law" means "before = after"

$K_0 + U_0 = K + P$ expresses energy conservation

$p_{A,i} + p_{B,i} = p_A + p_B$ expresses momentum conservation


in 1895
the wheels came off

a series of

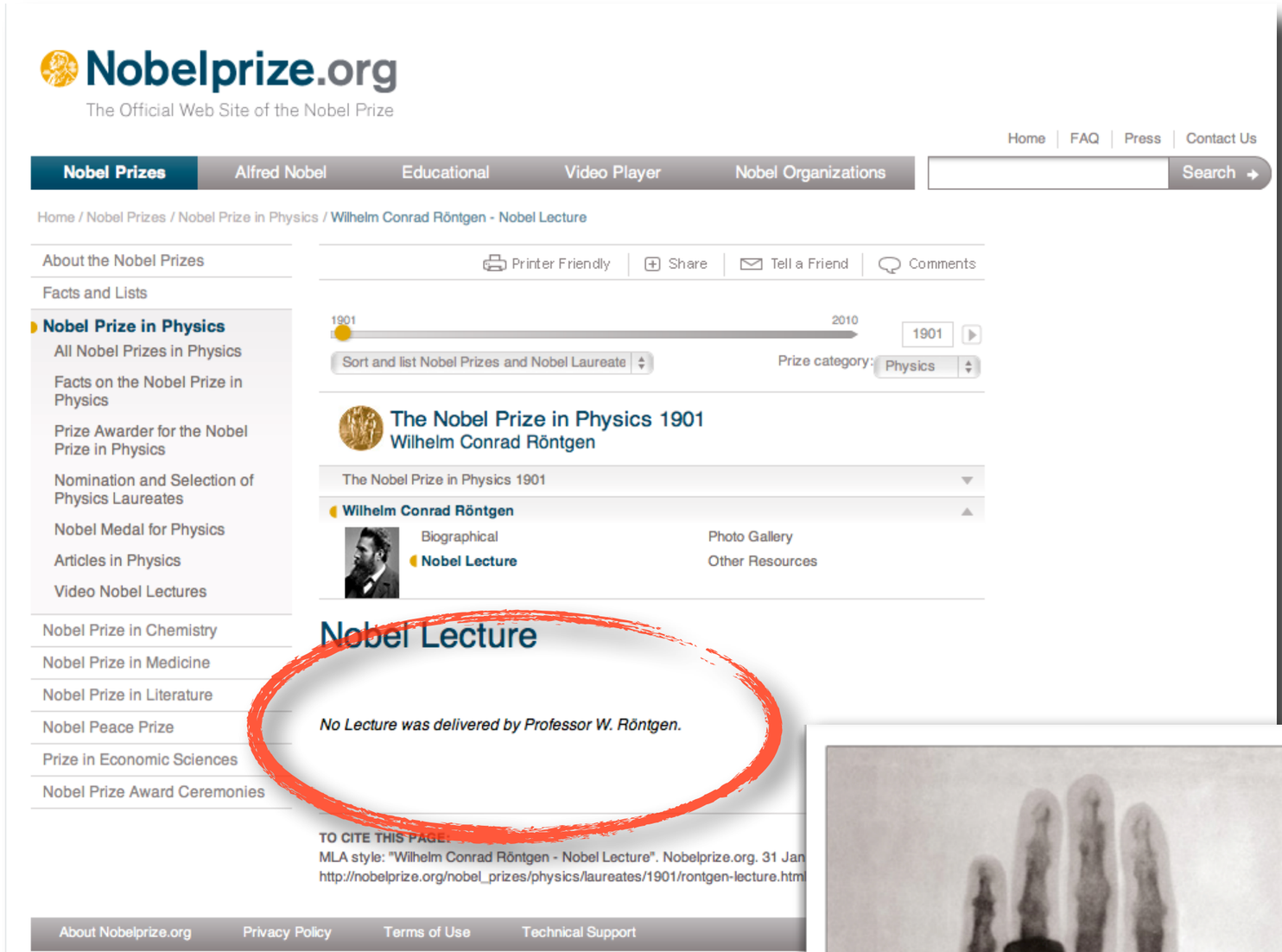
our first Nobel

1 talk

1 publication

no profit

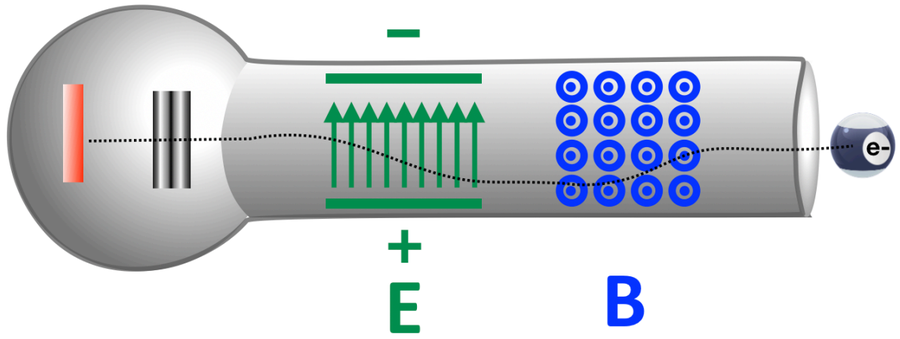
suffered terribly during WWI



then

it got strange

Nobel 1906



The Nobel Prize in Physics 1906
J.J. Thomson

Share this:

The Nobel Prize in Physics 1906

Joseph John Thomson

Prize share: 1/1

The Nobel Prize in Physics 1906 was awarded to J.J. Thomson *"in recognition of the great merits of his theoretical and experimental investigations on the conduction of electricity by gases".*

Share this:

is page
"The Nobel Prize in Physics 1906". *Nobelprize.org.* Nobel Media AB 2014. Web. 10
http://www.nobelprize.org/nobel_prizes/physics/laureates/1906/>

particle:	**electron**
symbol:	e
charge:	$-1e$
mass:	$m_e = 9.0 \times 10^{-31}$ kg ~ 0.0005 p
spin:	1/2
category:	fermion, lepton

what’s in store

learn about accelerators...

learn about detectors

the particle game

Particle accelerators give kinetic energy to particles,

which collide and create new forms of matter,

which we detect in apparatus we design and build.

and which we compare to theories.

our currency is “events”

each captured collision is an event

Tools of the trade

Particle Accelerators

beam: **cyclotron**

beam:	nuclei
source:	ion source
acceleration:	electrostatic
energy:	few 100 MeV/nucleon
location:	physics research: MSU, Canada, Germany, Japan, Britain, France

beam:

linear accelerator aka “LINAC”

beam:	*e or p*
source:	pre-accelerator (C-W)
acceleration:	RF
energy:	10’s GeV beam energy
location:	Fermilab, CERN, SLAC

what's a particle accelerator?

a device designed to:

accelerate elementary particles to interesting energies

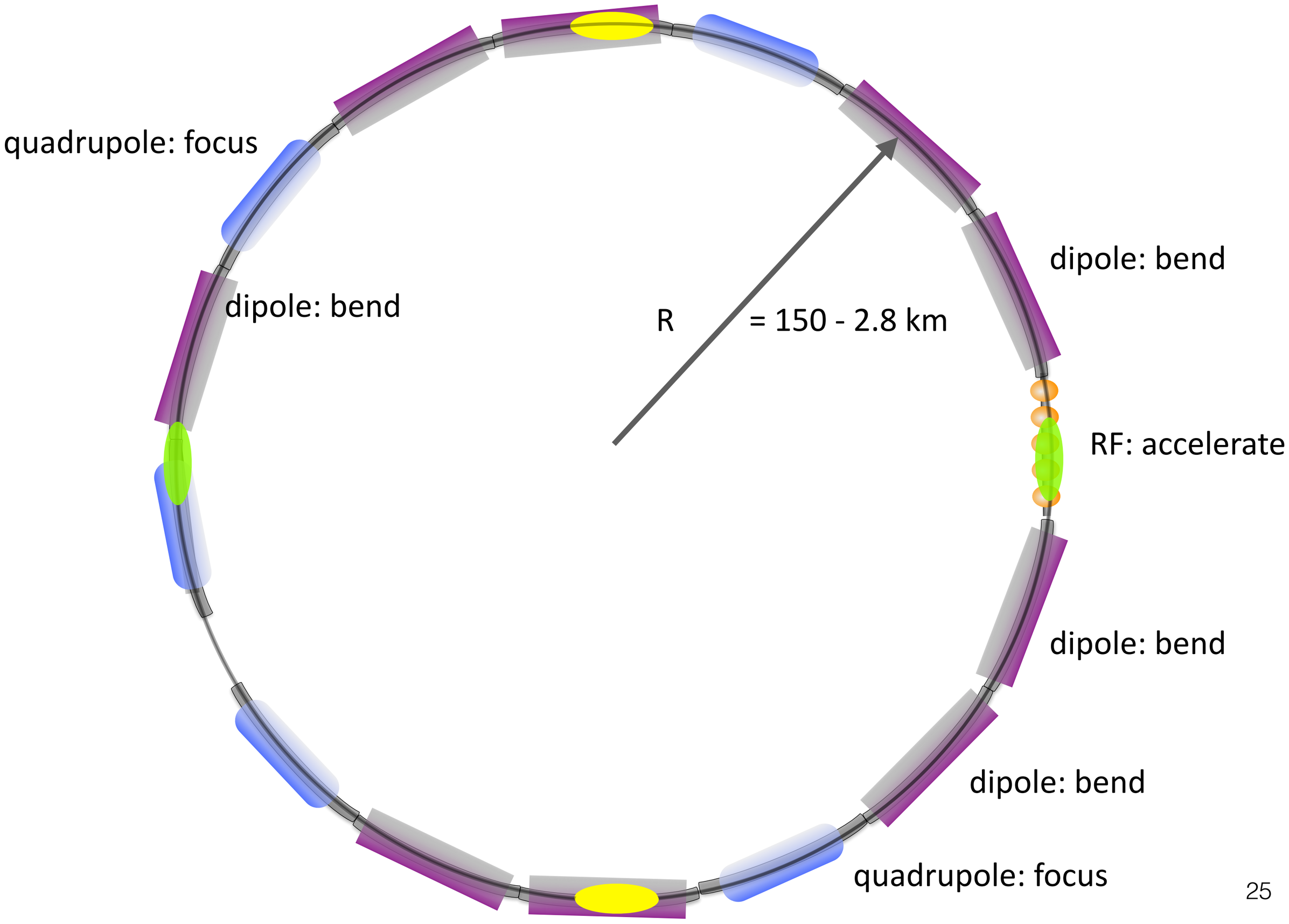
&

bend them where you want them to go

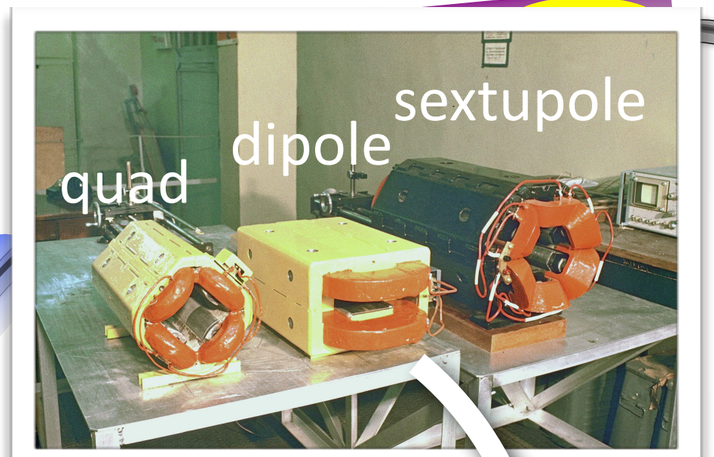
beam: **synchrotron**

beam:	*e, p, $\bar{p}$, heavy nuclei, or μ*
source:	LINACs
acceleration:	RF
energy:	10's GeV - few TeV beam energy
location:	CERN (p, Nuclei), Fermilab(μ), SLAC (e), other US and international labs

cartoon of a synchrotron



cartoon of a synchrotron



quadrupole: focus
392, LHC

dipole: bend
1232 LHC, 15m long

LHC dipole

cutaways of:

final focus

collisions!

final focus

R = 2.8 km, LHC

dipole: bend

RF: accelerate

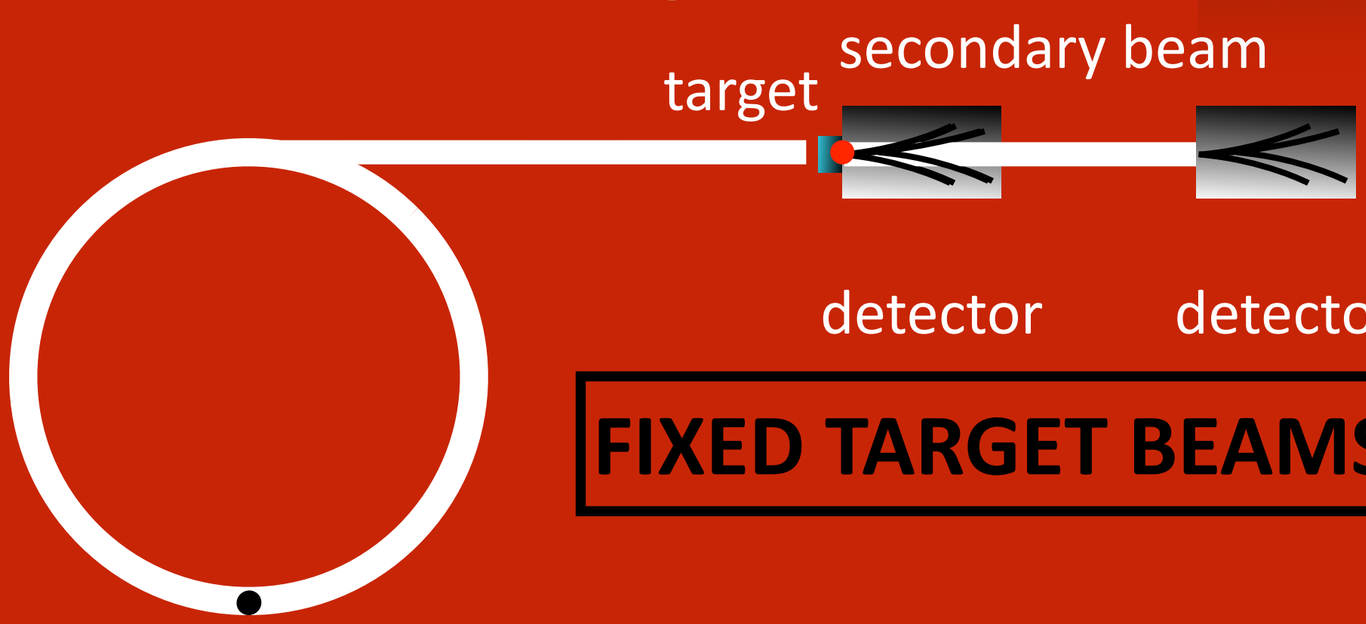
dipole: bend

dipole: bend

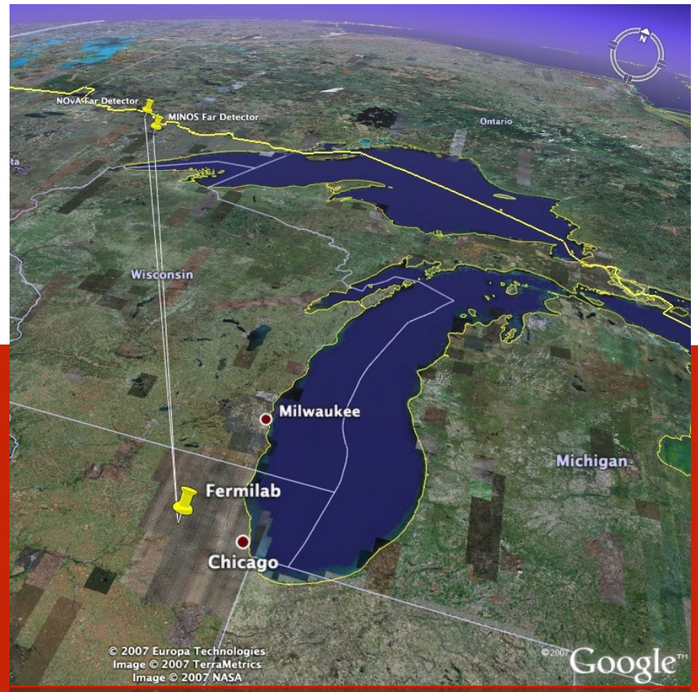
quadrupole: focus

two basic kinds of arrangements:

Fixed Target Beams and Colliding Beams



FIXED TARGET BEAMS



Fermi National Accelerator Laboratory
Batavia, IL

jargon alert: **fixed target experiment (aka "FT")**

refers to: a beam of particles impinges on a stationary target

entomology: obvious

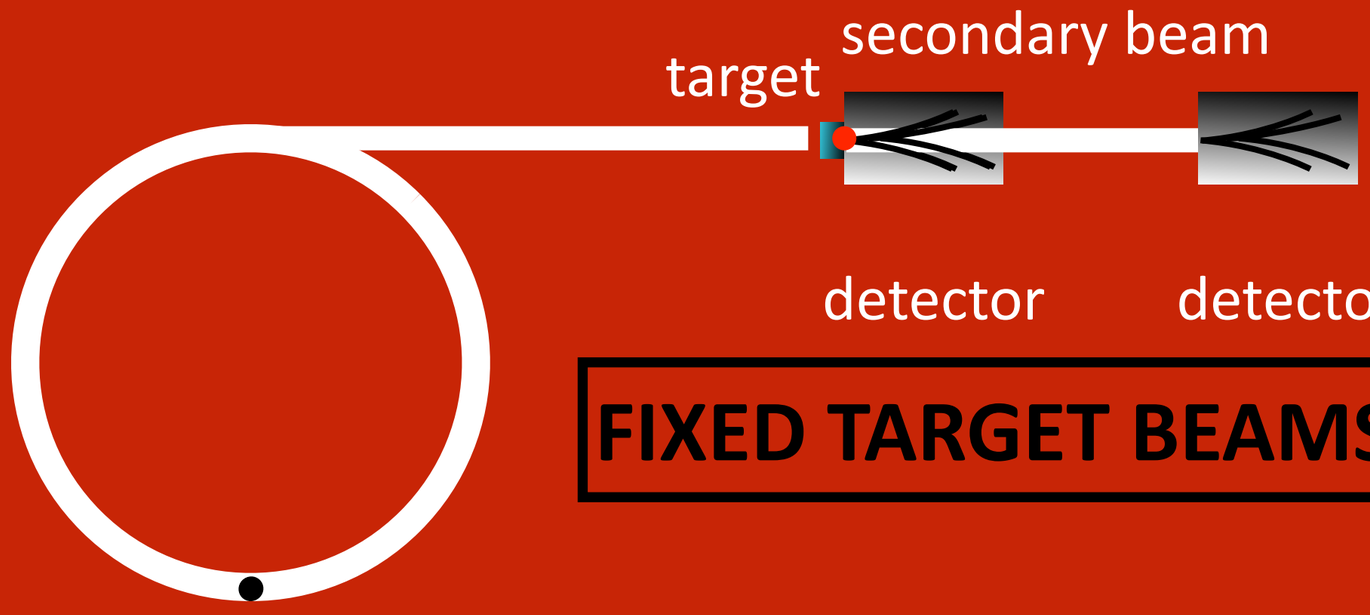
example: SLAC fixed target experiments, all neutrino experiments

Large Hadron Collider
Geneva, CH

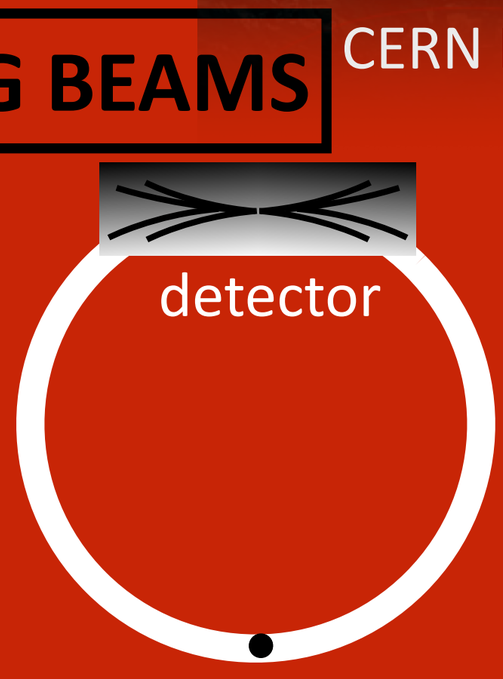
CERN LHC

two basic kinds of arrangements:

Fixed Target Beams and Colliding Beams



FIXED TARGET BEAMS



COLLIDING BEAMS

jargon alert: **colliding beam facility (aka “collider”)**

refers to: two beams are brought to head-on collisions

entomology: obvious

example: Fermilab Tevatron, LHC, SLAC colliders

4 life-stages of particle beams

Liberate the beam particle

- from a “source”: for protons, a bottle of hydrogen

Get it moving

- for protons, historically: through a “Cockroft Walton accelerator”

Accelerate it to high energy

- successive stages of linear and circular accelerators
- like booster rockets

Create a collision

- extract beams and collide with a machined target
- or collide counter-rotating beams in an accelerator

1932: John Cockroft & Ernest Walton

took on the task of making a proton accelerator

the 800 pound Gorilla: Ernest Rutherford

They made a “voltage multiplier” and used it to accelerate protons

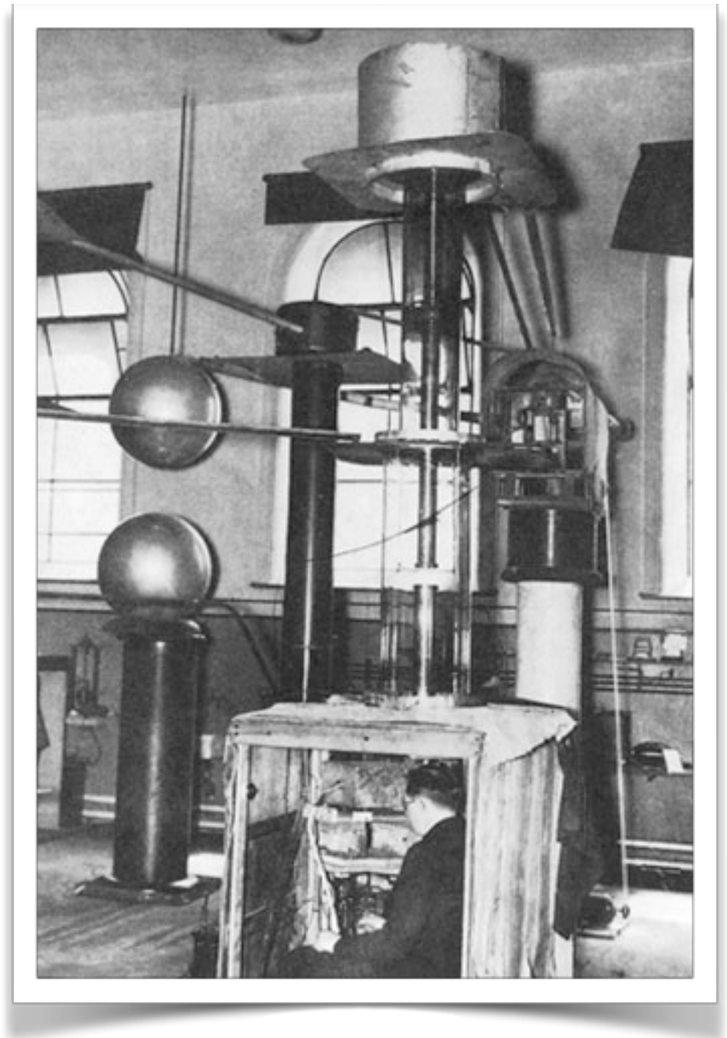
beam:

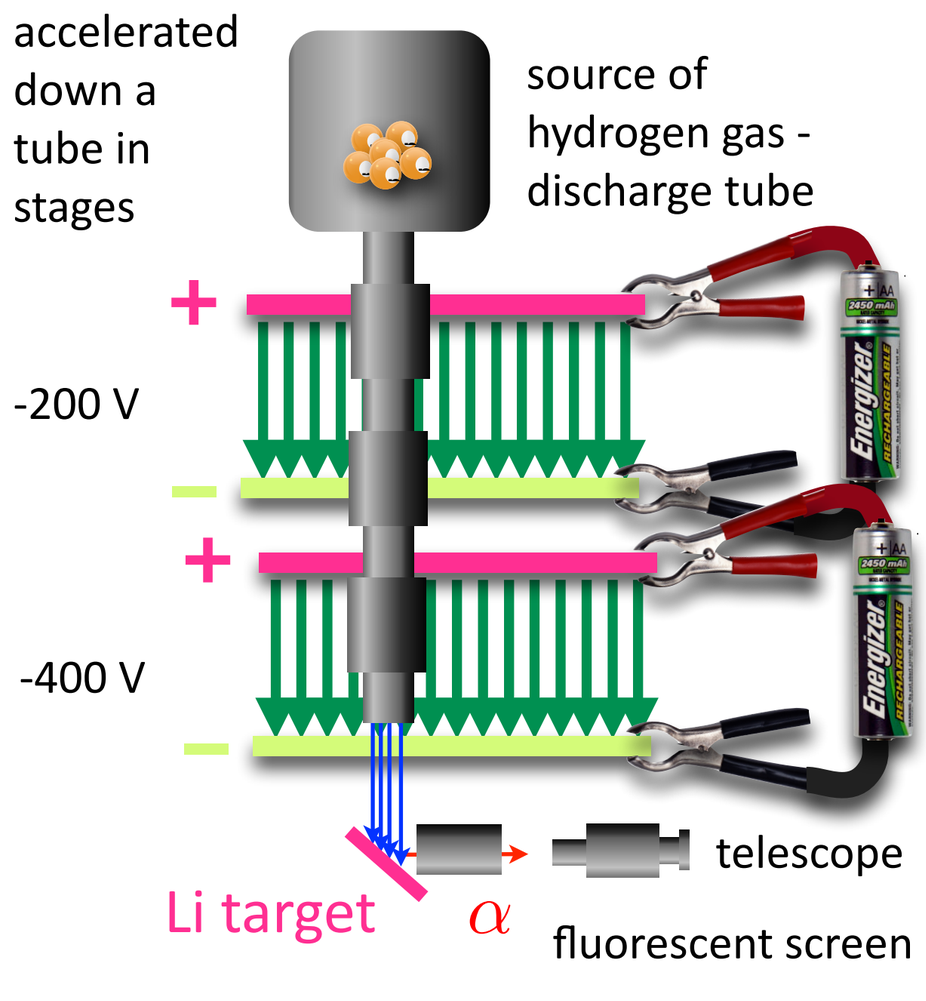
Cockcroft-Walton Accelerator

beam:	protons
source:	hydrogen
acceleration:	electrostatic
energy:	few 100 - 1000 keV
location:	most proton syncrotrons

Cockloft-Walton Accelerator 1932

invented it and then did "award-winning" experiments





Their voltage multiplication circuit became a standard way to accelerate electrons/protons - in a TV

at first, a slow beam, then a medium beam, then a high beam

they could produce beams of **micro-**Amps

4 life-stages of particle beams

- Liberate the beam particle
  - from a "source": for protons, a bottle of hydrogen
- Get it moving
  - for protons, historically: through a "Cockroft Walton accelerator"
- Accelerate it to high energy
  - successive stages of linear and circular accelerators
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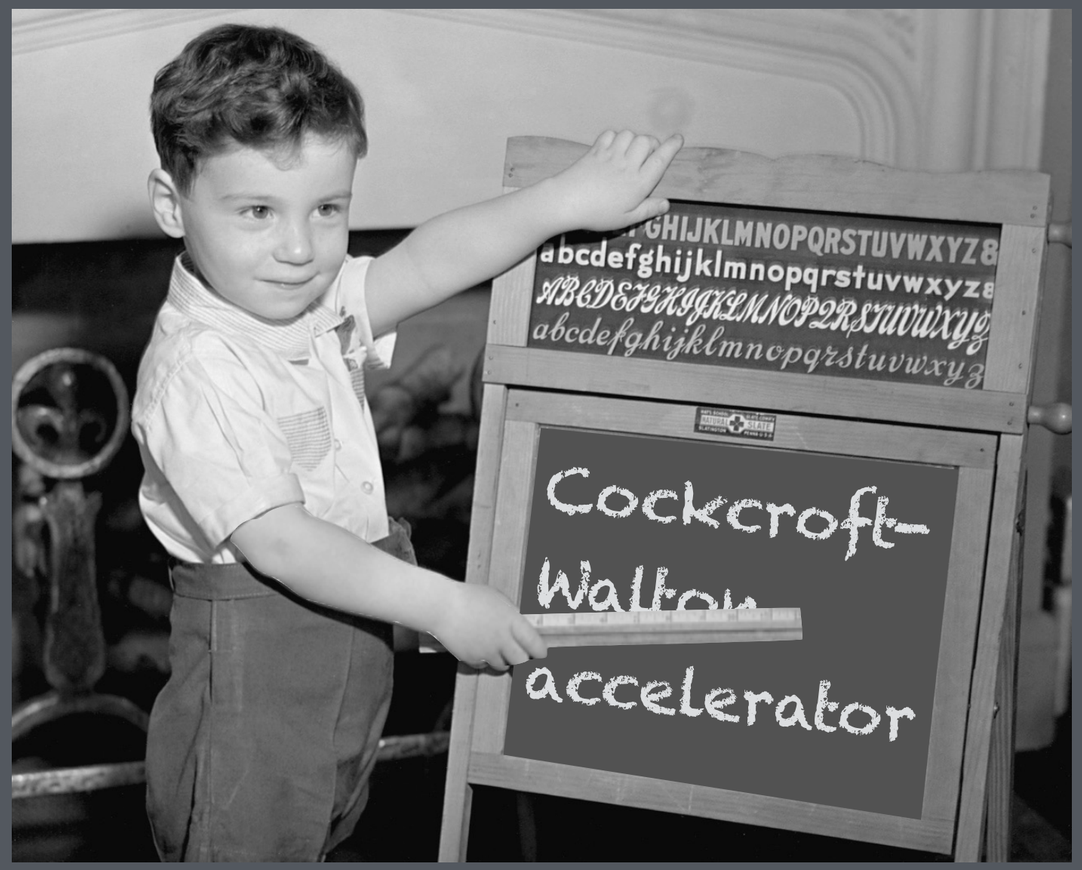
  - extract beams and collide with a machined target
  - or collide counter-rotating beams in an accelerator

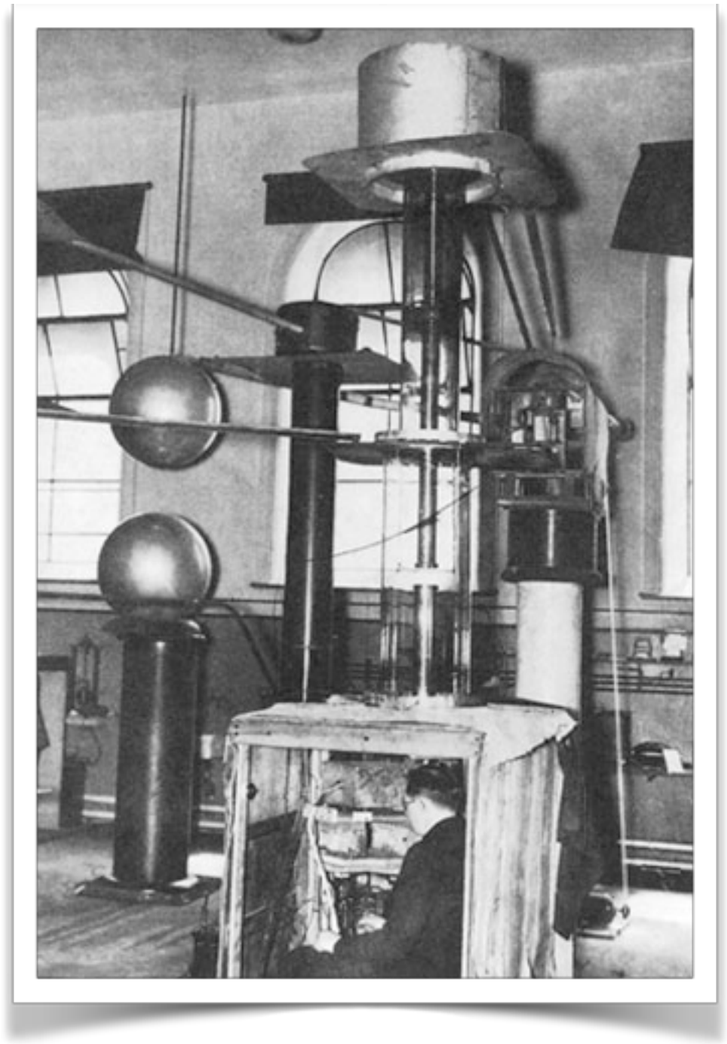


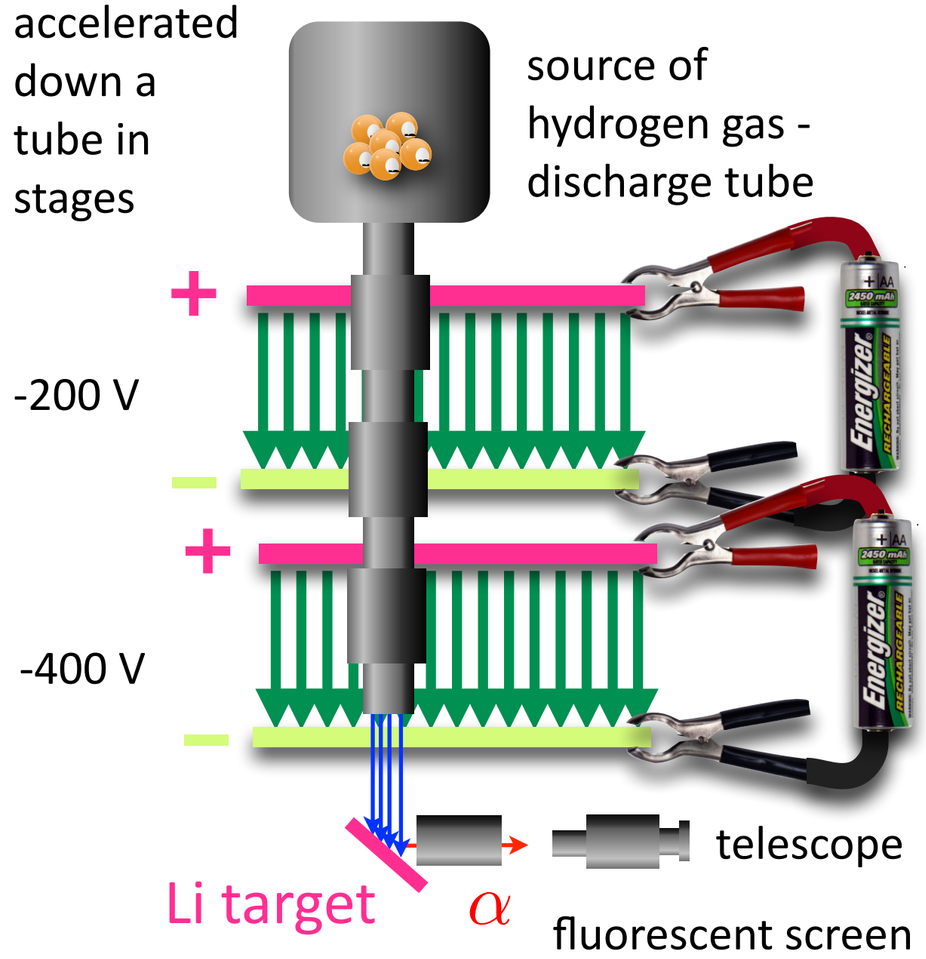
how many protons in the Cockcroft-Walton experiment?

they were able to produce 1 micro-Ampere of proton current

Cockloft-Walton Accelerator 1932

invented it and then did "award-winning" experiments





Their voltage multiplication circuit became a standard way to accelerate electrons/protons - in a TV

at first, a slow beam, then a medium beam, then a high beam

they could produce beams of micro-Amps…

6.25×10^{12} protons/second

6,250,000,000,000 protons/second

1951 Nobels

The Nobel Prize in Physics 1951
John Cockcroft, Ernest T.S. Walton

Share this:

John Cockcroft - Biographical

John Douglas Cockcroft was born at Todmorden, England, on May 27th, 1897. His family had for several generations been cotton manufacturers.

He was educated at Todmorden Secondary School and studied mathematics at Manchester University under Horace Lamb in 1914-1915. After serving in the First World War in the Royal Field Artillery he returned to Manchester to study electrical engineering at the College of Technology under Miles Walker. After two years apprenticeship with Metropolitan Vickers Electrical Company he went to St. John's College, Cambridge, and took the Mathematical Tripos in 1924. He then worked under Lord Rutherford in the Cavendish Laboratory.

He first collaborated with P. Kapitsa in the production of intense magnetic fields and low temperatures. In 1928 he turned to work on the acceleration of protons by high voltages and was soon joined in this work by E.T.S. Walton. In 1932 they succeeded in transmuting lithium and boron by high energy protons. In 1933 artificial radioactivity was produced by protons and a wide variety of transmutations produced by protons and deuterons was studied. In 1934 he took charge of the Royal Society Mond Laboratory in Cambridge.

In 1929 he was elected to a Fellowship in St. John's College and became successively University demonstrator, lecturer and in 1939 Jacksonian Professor of Natural Philosophy.

In September 1939 he took up a war-time appointment as Assistant Director of Scientific Research in the Ministry of Supply and started to work on the application of radar to coast and air defence problems. He was a member of the Tizard Mission to the United States in the autumn of 1940. After this he was appointed Head of the Air Defence Research and Development Establishment. In 1944 he went to Canada to take charge of the Canadian Atomic Energy project and became Director of the Montreal and Chalk River
s until 1946 when he returned to England as Director of the
esearch Establishment, Harwell.

59 he was scientific research member of the U.K.
and has since continued this function on a part time
Churchill College, Cambridge, followed in October
ncellor of the Australian National University,
dent of the Institute of Physics, the Physical Society
sh Association for the Advancement of Science

doctorates from some 19 universities and is a
ber of many of the principal scientific societies. In
nours and awards have also been bestowed upon him.

The Nobel Prize in Physics 1951
John Cockcroft, Ernest T.S. Walton

Share this:

Ernest T.S. Walton - Facts

Ernest Thomas Sinton Walton

Born: 6 October 1903, Dungarvan, Ireland

Died: 25 June 1995, Belfast, Northern Ireland

Affiliation at the time of the award: Trinity College, Dublin, Ireland

Prize motivation: "for their pioneer work on the transmutation of atomic nuclei by artificially accelerated atomic particles"

Field: accelerator physics, nuclear physics

Prize share: 1/2

Split the Atom for the First Time

Ernest Rutherford used alpha particles from radioactive elements to study nuclear reactions and managed to convert nitrogen to oxygen. However, only very few reactions could be achieved with alpha particles from radioactive elements. Ernest Walton and John Cockcroft developed a device, an accelerator, to make more penetrating radiation. Using an electric field, protons were accelerated to high velocities. In 1932 they bombarded lithium with protons and the lithium nucleus broke-up and two alpha particles were produced.

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To cite this page
MLA style: "Ernest T.S. Walton - Facts". *Nobelprize.org.* Nobel Media AB 2014. Web. 11 Feb 20
16. <http
lprize.org/nobel_prizes/physics/laureates/1951/walton-facts.html>

2 labs

2 accelerators

Fermilab in Batavia, IL

CERN in Geneva, Switzerland

4 life-stages of particle beams

Liberate the beam particle

- from a "source": for protons, a bottle of hydrogen

Get it moving

- for protons, historically: through a "Cockroft Walton accelerator"

Accelerate it to high energy

- successive stages of linear and circular accelerators
- like booster rockets

Create a collision

- extract beams and collide with a machined target
- or collide counter-rotating beams in an accelerator

‘‘Tevatron’’

proton-antiproton collider at Fermilab

1987–2011

laboratory: **Fermi National Accelerator Laboratory**

location: Batavia, IL

established: 1967

notable directors: Bob Wilson, Leon Lederman*, John Peoples, Mike Witherell, Pier Oddone, Nigel Lockyer

type of lab: fixed target: neutrinos, hadrons

* Nobel Prize

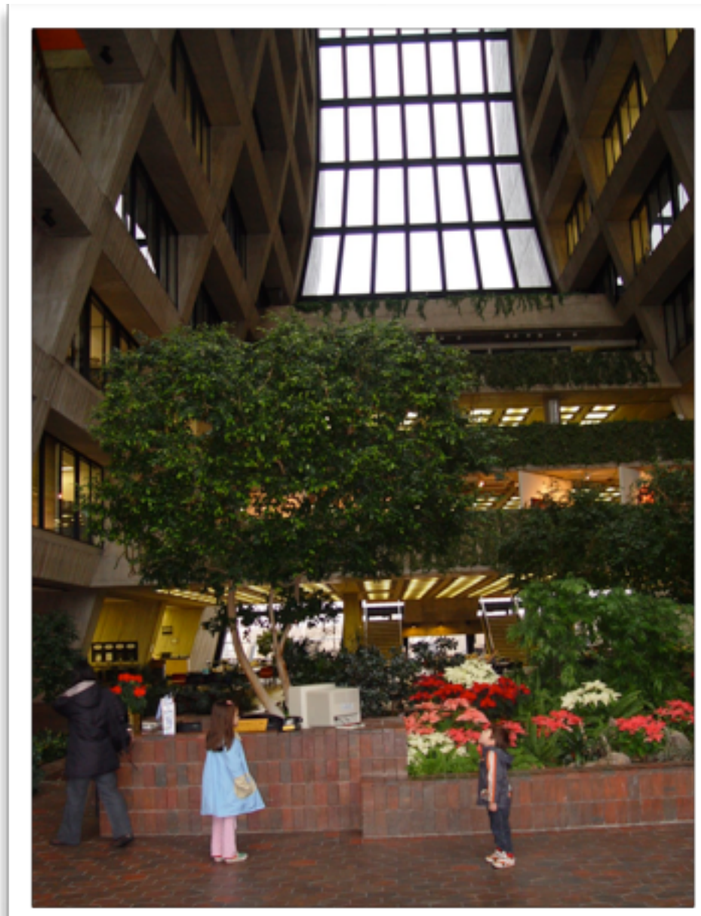
beam: **proton-antiproton collider**

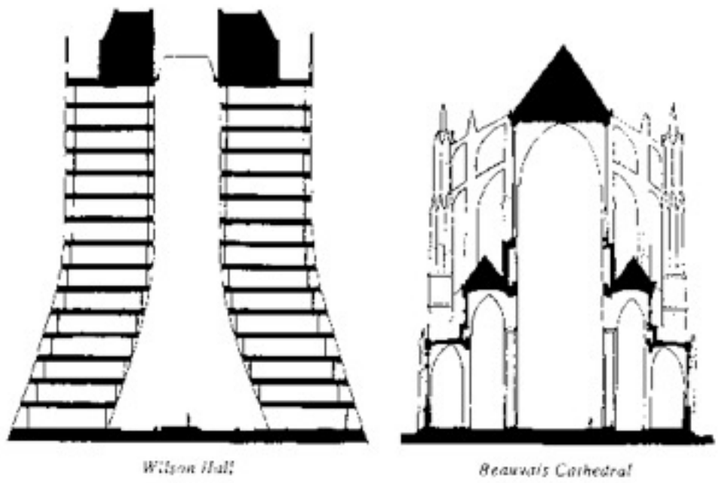
beam:	protons and antiprotons
source:	hydrogen and secondary targets
acceleration:	electrostatic + RF
energy:	CERN SppS: 540, 630, 900 GeV cms
location:	Fermilab: 1960 GeV cms
	CERN: Geneva, Switzerland

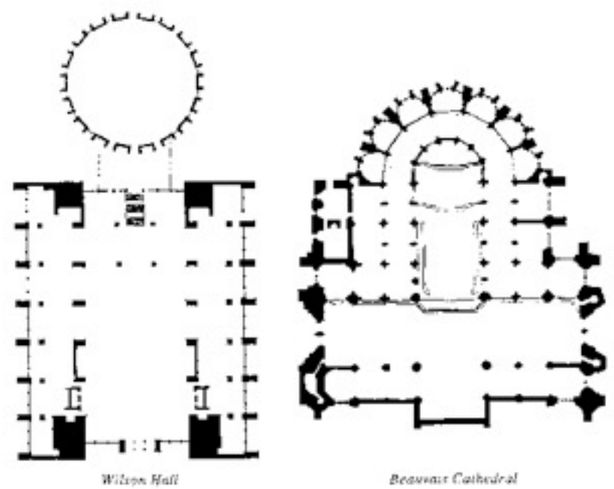
Fermilab's my particle physics home

I've worked there since 1975

Batavia was in my high school athletic conference!



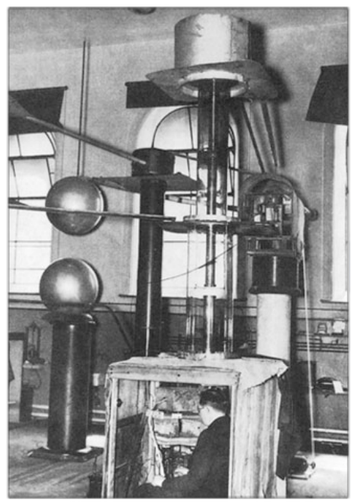




Cockcroft-Walton accelerators

traditional first stage

6.88 liters internal volume
5 x 10^{25} atoms/bottle
1 bottle lasts a year
Such a bottle cost $200 in the year 2000



750 keV, DC

4 life-stages of particle beams

Liberate the beam particle
- from a "source": for protons, a bottle of hydrogen

Get it moving
- for protons, historically: through a "Cockroft Walton accelerator"

Accelerate it to high energy
- successive stages of linear and circular accelerators
- like booster rockets

Create a collision
- extract beams and collide with a machined target
- or collide counter-rotating beams in an accelerator

LINACs

traditional second stage

4 life-stages of particle beams

Liberate the beam particle

- from a "source": for protons, a bottle of hydrogen

Get it moving

- for protons, historically: through a "Cockroft Walton accelerator"

Accelerate it to high energy

- successive stages of linear and circular accelerators
- like booster rockets

Create a collision

- extract beams and collide with a machined target
- or collide counter-rotating beams in an accelerator

450 MeV

Booster

1/3 circular stages

4 life-stages of particle beams

Liberate the beam particle

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Get it moving

- for protons, historically: through a “Cockroft Walton accelerator”

Accelerate it to high energy

- successive stages of linear and circular accelerators
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Create a collision

- extract beams and collide with a machined target
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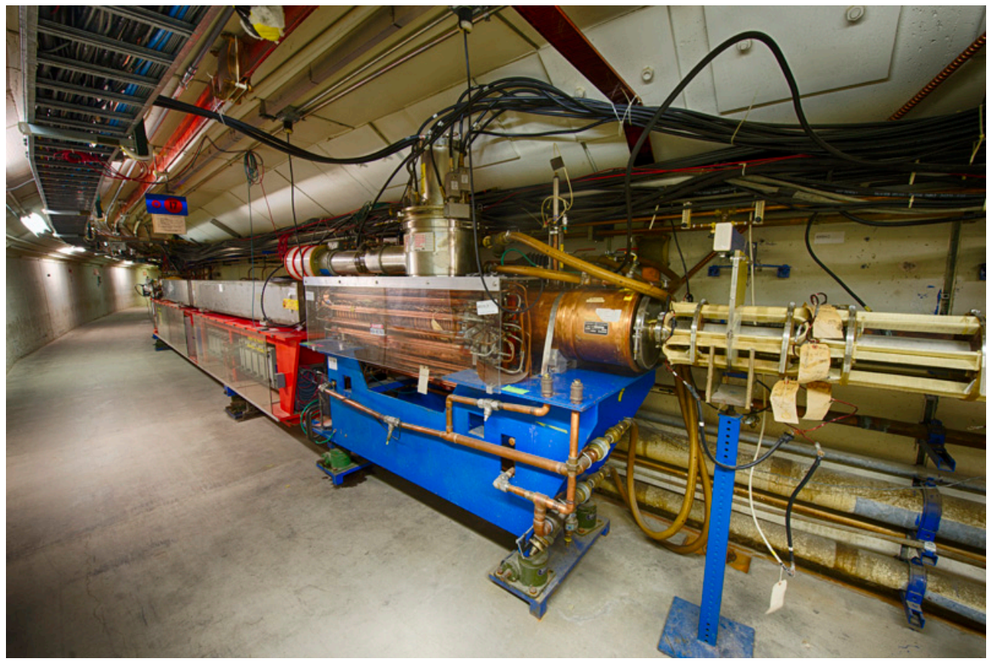

8 GeV

Main Injector

2/3 circular stages

4 life-stages of particle beams

Liberate the beam particle

- from a “source”: for protons, a bottle of hydrogen

Get it moving

- for protons, historically: through a “Cockroft Walton accelerator”

Accelerate it to high energy

- successive stages of linear and circular accelerators
- like booster rockets

Create a collision

- extract beams and collide with a machined target
- or collide counter-rotating beams in an accelerator

150 GeV

Congressman (Dr) Bill Foster
Illinois's 11th congressional district

Tevatron

3/3 circular stages

4 life-stages of particle beams

Liberate the beam particle

- from a “source”: for protons, a bottle of hydrogen

Get it moving

- for protons, historically: through a “Cockroft Walton accelerator”

Accelerate it to high energy

- successive stages of linear and circular accelerators
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Create a collision

- extract beams and collide with a machined target
- or collide counter-rotating beams in an accelerator

2000 GeV

Large Hadron Collider, aka “LHC”

proton-proton collider at CERN

2008-2035

laboratory: **European Organization for Nuclear Research (CERN*)**

location: Geneva, Switzerland

established: 1954

notable directors: Edoardo Amaldi, Felix Bloch**, Victor Weisskopf, John Adams, Leon van Hove, Carlo Rubbia**, Chris Llewellyn Smith, Luciano Maiani, Rolf Heuer

type of lab: fixed target: neutrinos, hadrons

collider: p-$\overline{p}$, e-$\overline{e}$, p-p, heavy ions

* originally: *Conseil Européen pour la Recherche Nucléaire*

** Nobel Prize

beam: **proton-proton collider**

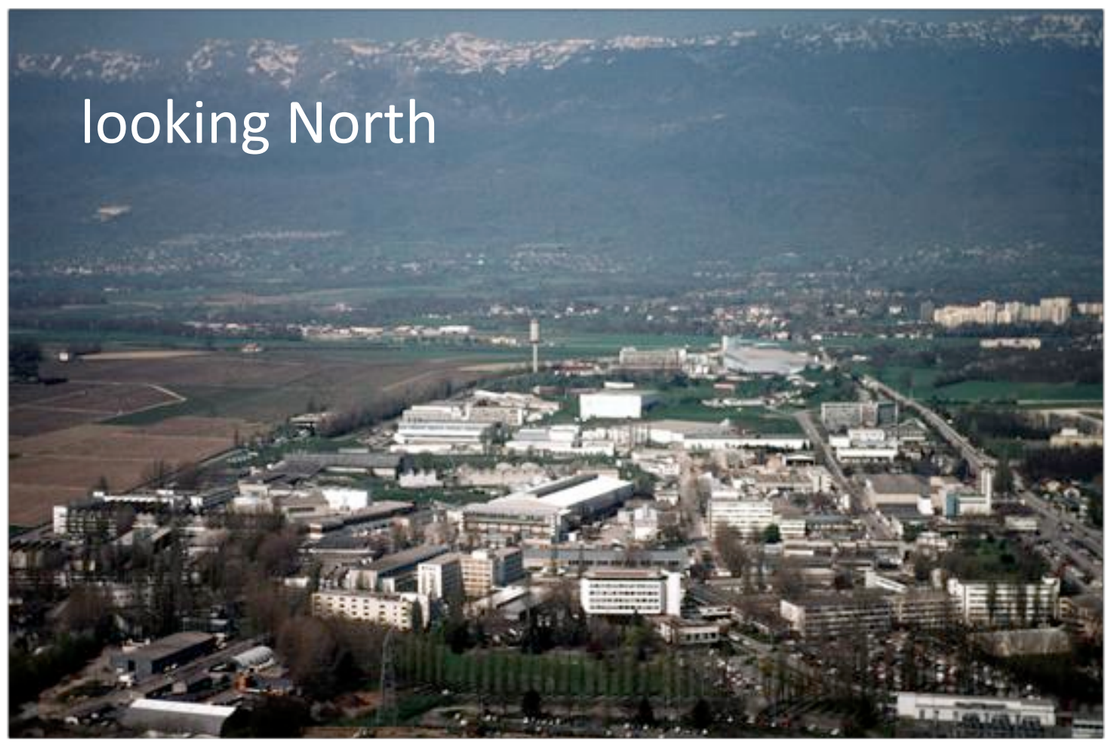
beam:	protons
source:	hydrogen
acceleration:	electrostatic + RF
energy:	“ISR,” 62GeV* & LHC 14,000GeV
location:	CERN: Geneva, Switzerland Fermilab: Batavia, IL

*1971 - 1984

CERN


looking North

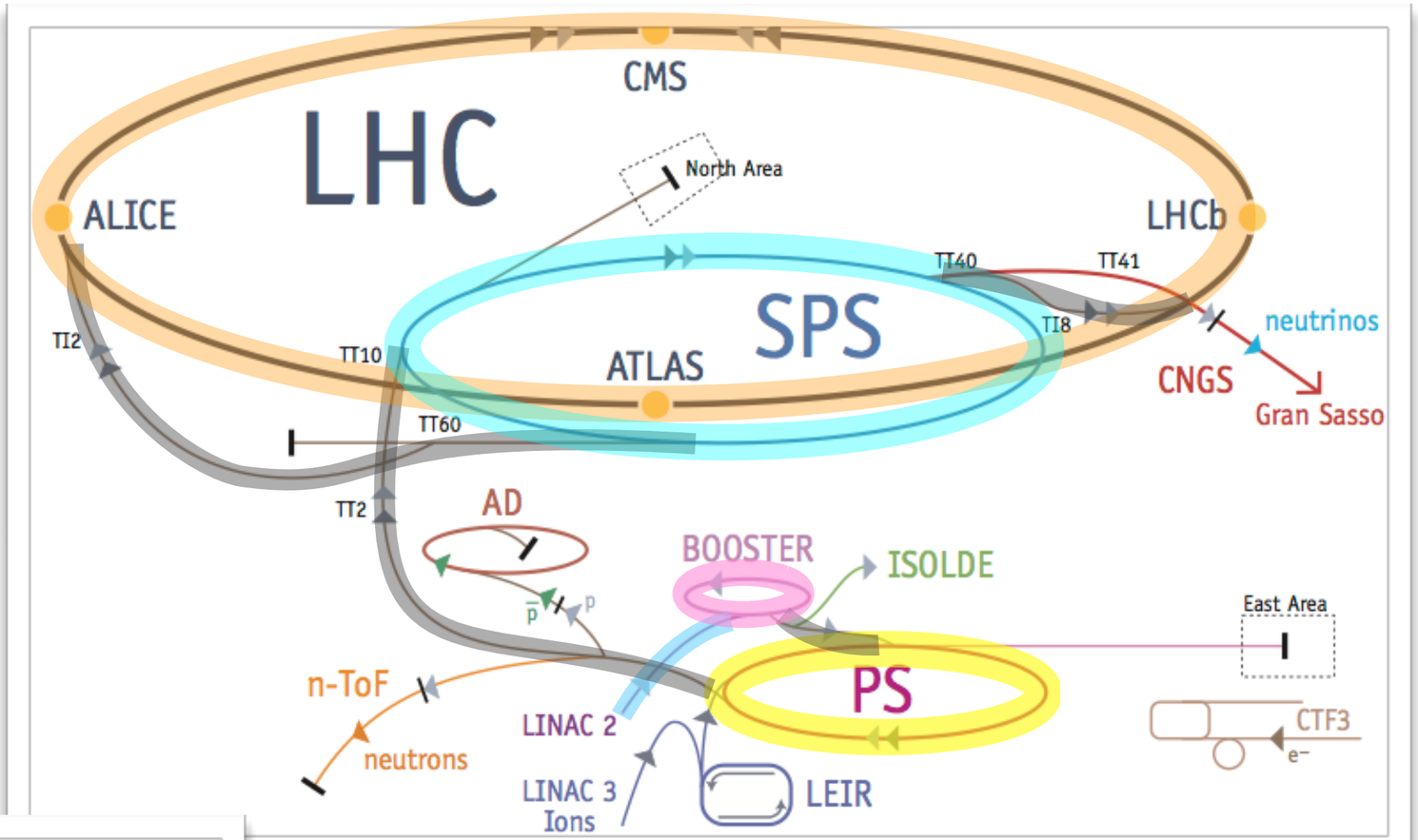

fresh
Vector
POPCORN


looking North


looking South

from the bottle

LHC complex



4 life-stages of particle beams

Liberate the beam particle

- from a "source": for protons, a bottle of hydrogen

Get it moving

- for protons, historically: through a "Cockroft Walton accelerator"

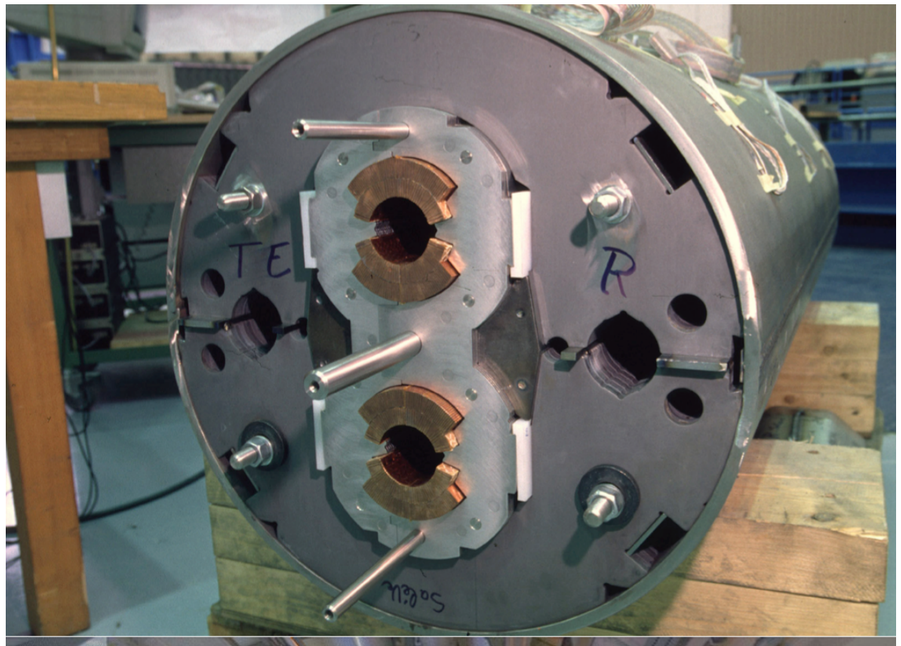
Accelerate it to high energy

- successive stages of linear and circular accelerators
- like booster rockets

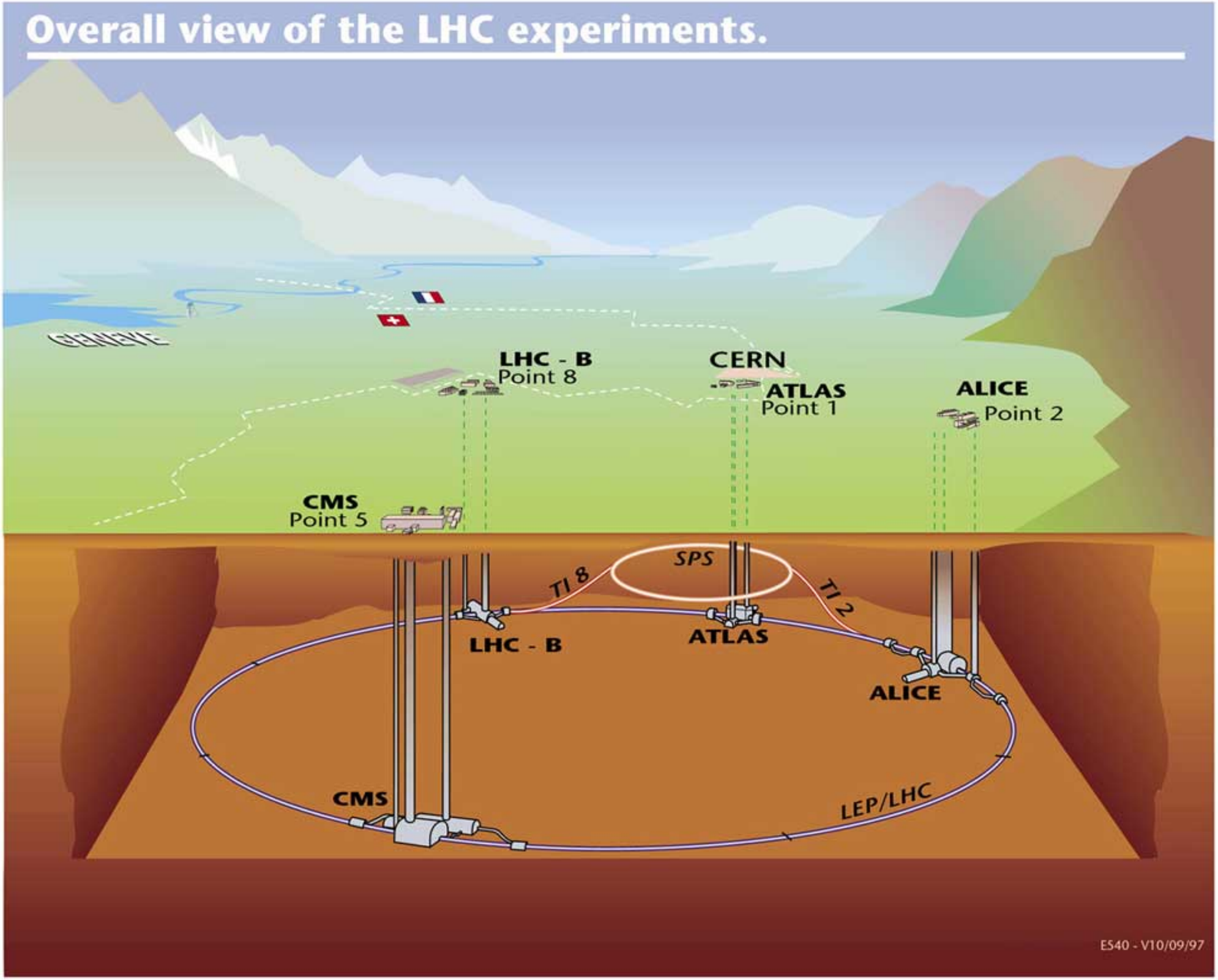
Create a collision

- extract beams and collide with a machined target
- or collide counter-rotating beams in an accelerator

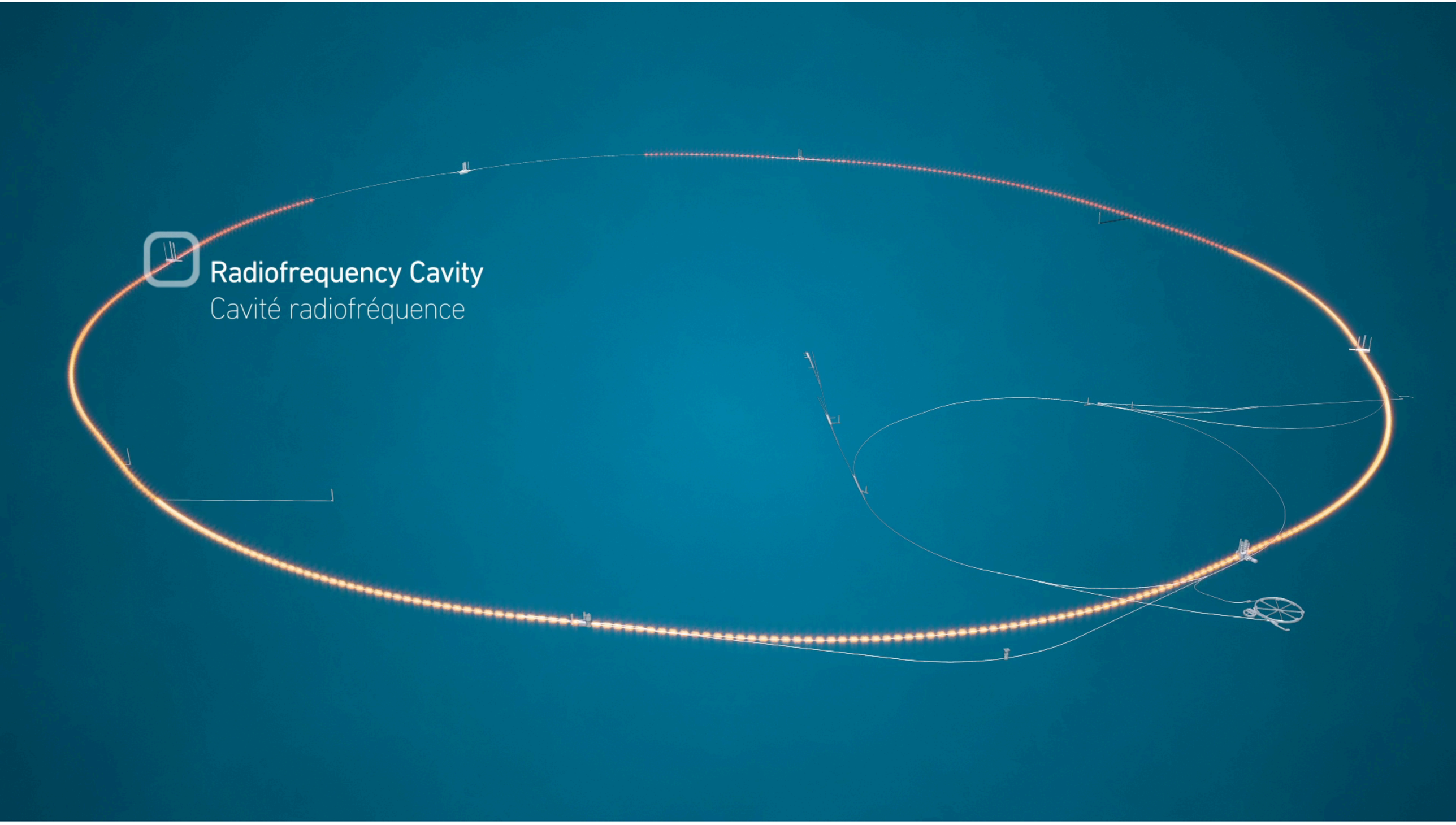
Large Hadron Collider, aka LHC



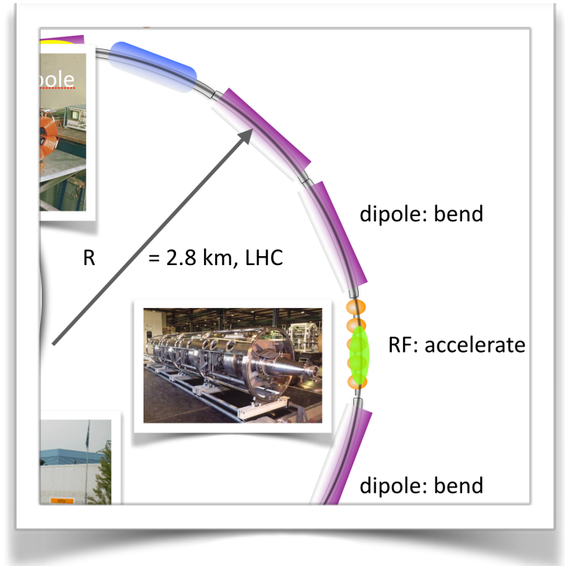
Overall view of the LHC experiments.



‘‘RF’’ and ‘‘dipoles’’



“buckets” of protons



E field @400 MHz frequency...?

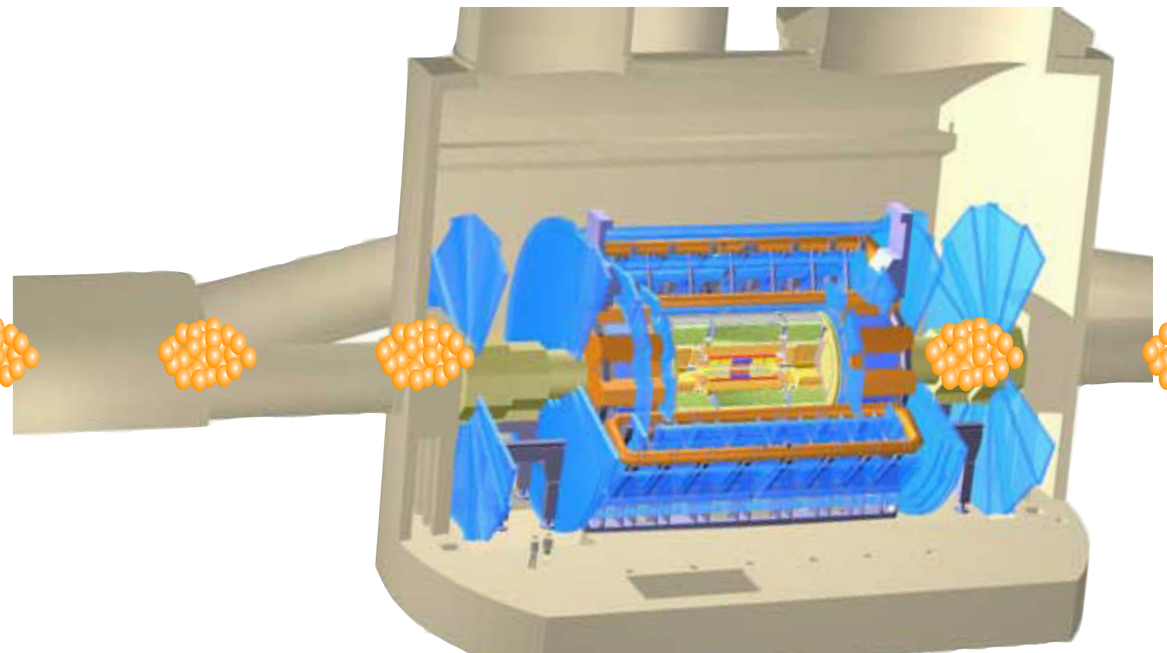
400 MHz means 400 x 10^6 cycles per second

or a E-field push every $\frac{1}{400 \times 10^6} = 0.25 \times 10^{-8} = 2.5$ nanoseconds

about every 10th bucket is filled

25 nsec

2.5 nsec



‘‘RF’’ and ‘‘dipoles’’

LHC dipole magnets

HUGE

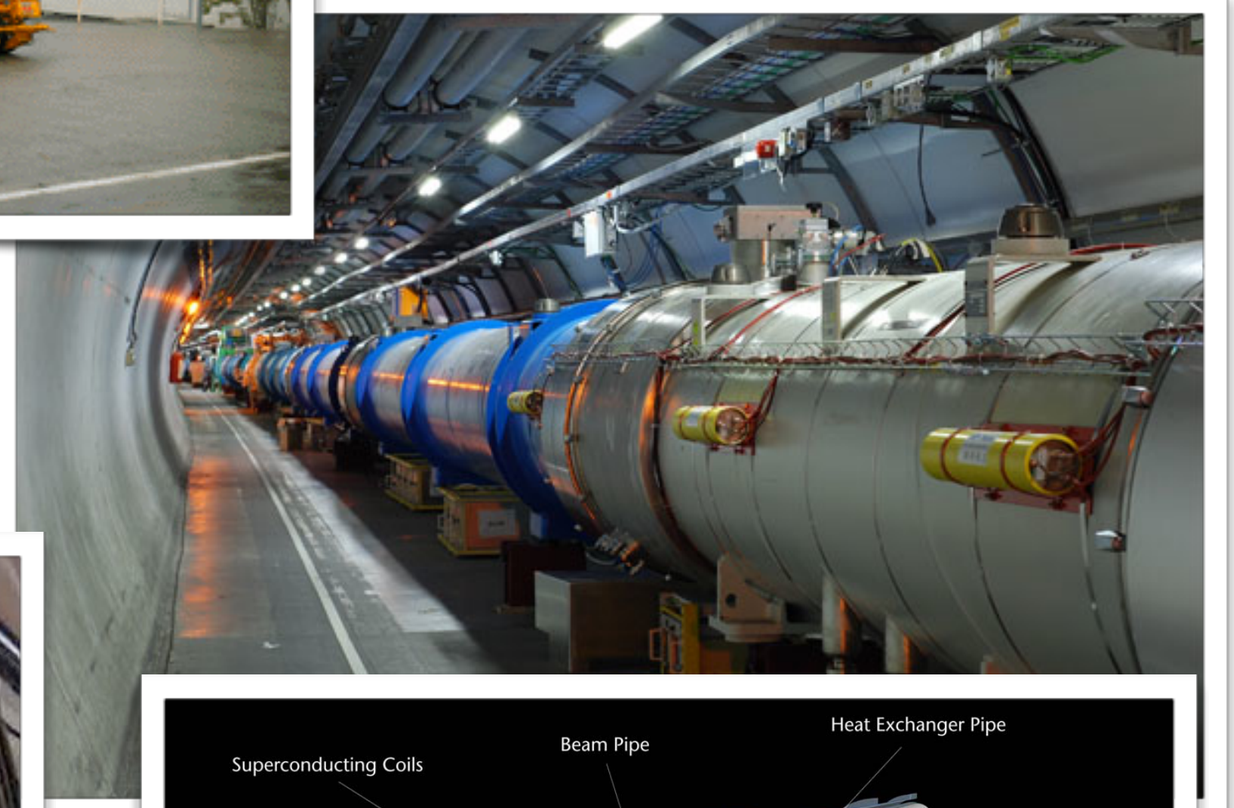
50 tons

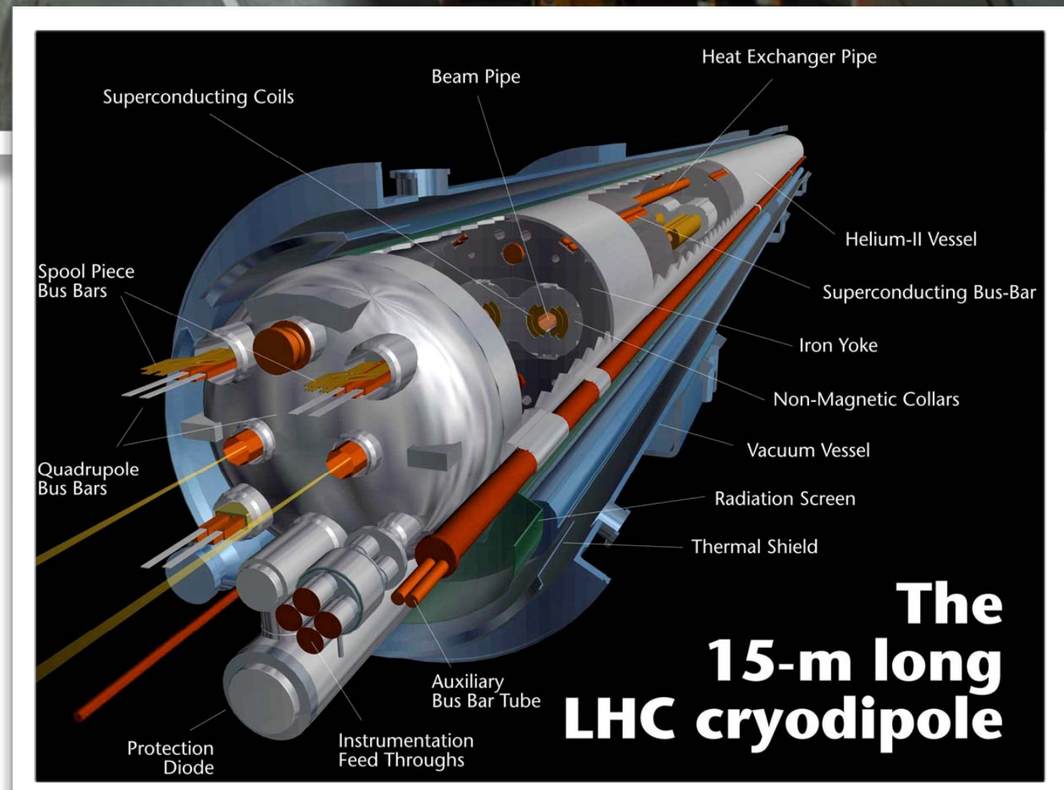
30 feet long

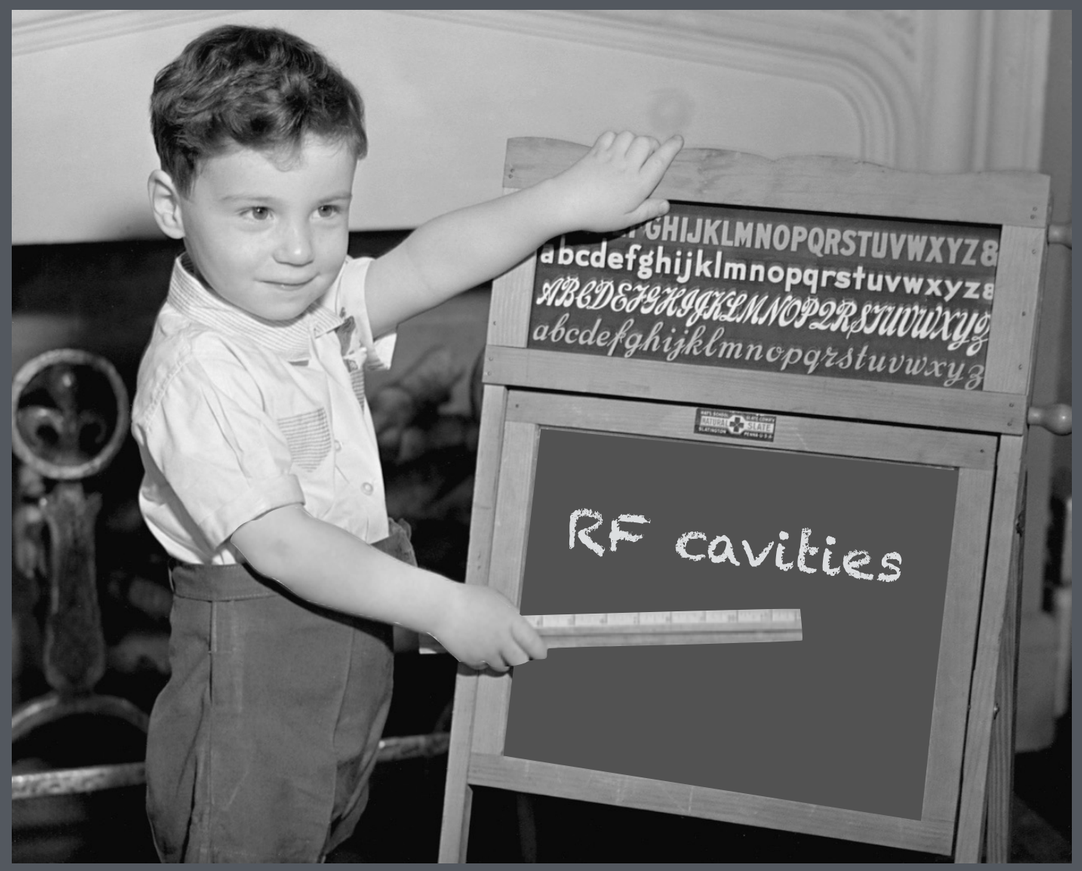
*superconducting, operating at 3C above absolute zero

LHC has 9000 magnets overall

1232 dipoles



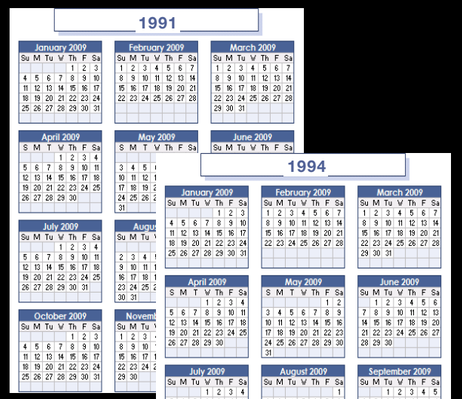




What is the energy boost given to each proton in the LHC RF cavities?

in Joules and eV

assume that the potential is 16 MV



1991: LHC proposal

1994: ATLAS proposal

LHC program

... decades

the disaster

53 50 ton, 15m long magnets were removed and
10 km of beam pipe had to be cleaned

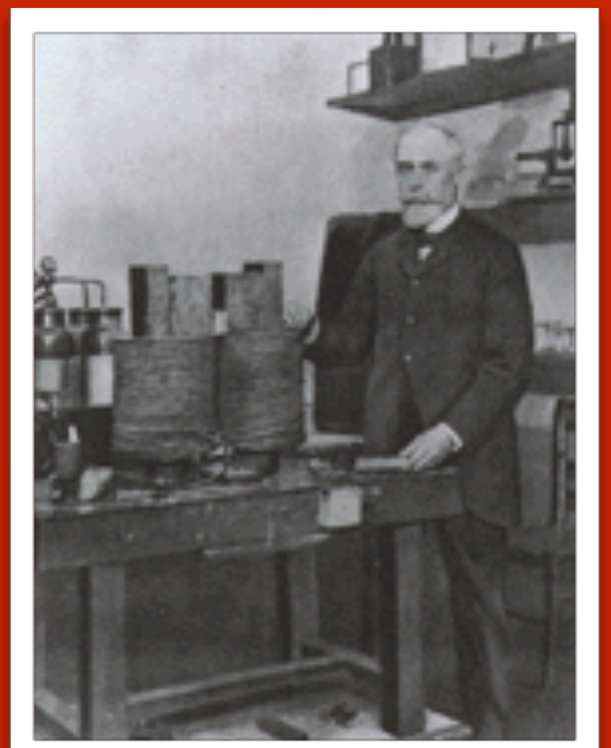
13 months...and we were back at half
of the design-energy


X (m)
X (cm)
LegoPlot Projection
Missing ET= 3 GeV
Constant (1-1)
Height of tallest tower:
Cells: 1 GeV
AOD: 4 GeV
17.0

then it got stranger

1896 Antoine-Henri Becquerel

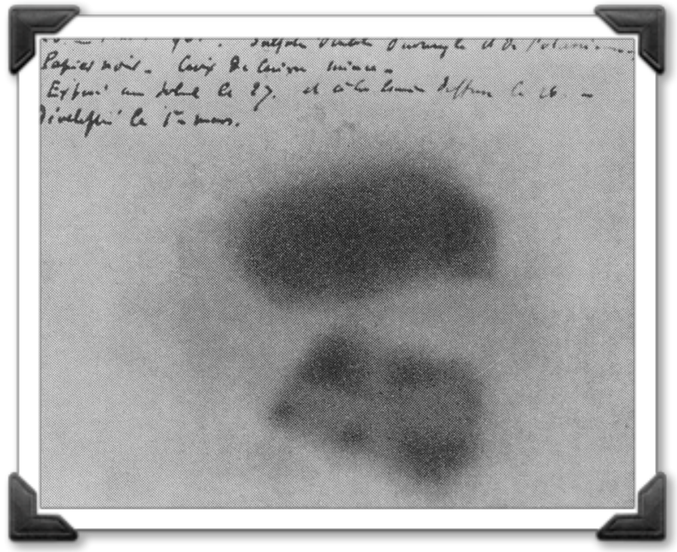
1852-1908



In the audience when X-rays were announced...

Expert in phosphorescence...thought X-rays were phosphorescence. wrong.

Wrapped up piece of Uranium when it got cloudy in Paris. When he unwrapped it:



Energy created out of nothing?

“Becquerel Rays”...didn’t catch on.

But: the idea of matter spontaneously emitting energy did!

He studied it and found the emanations ionized air and could be deflected by a magnet...so, it consisted of charged particles & not X-rays

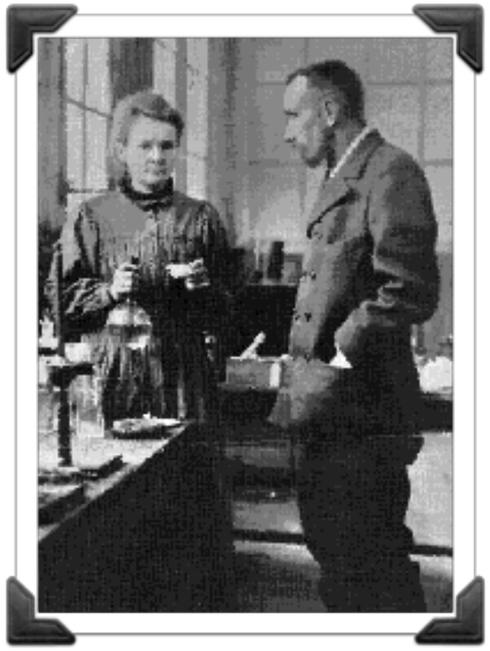
then it got even stranger still

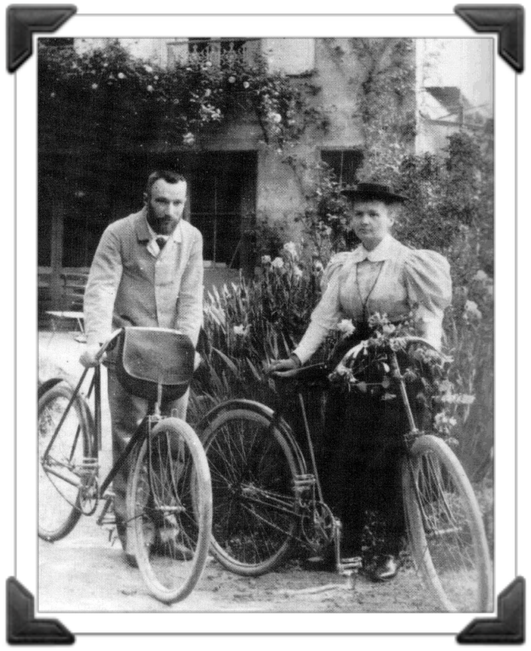
1898
Marie
Skodowska
Curie

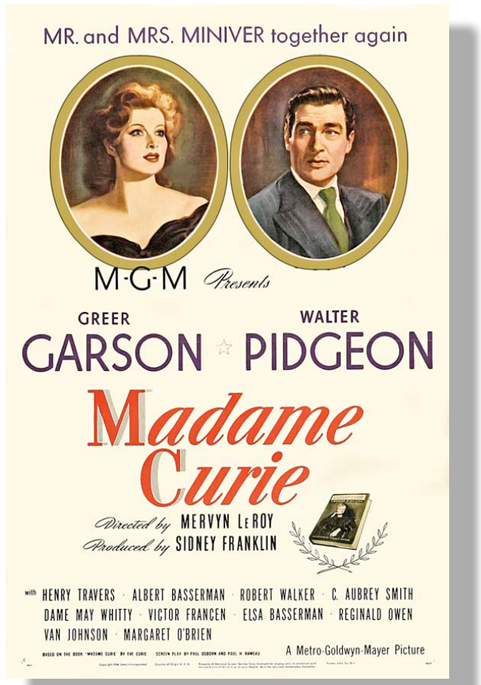
1857-1934

believe it or not

true-love stories in physics are rare!







set out to quantify

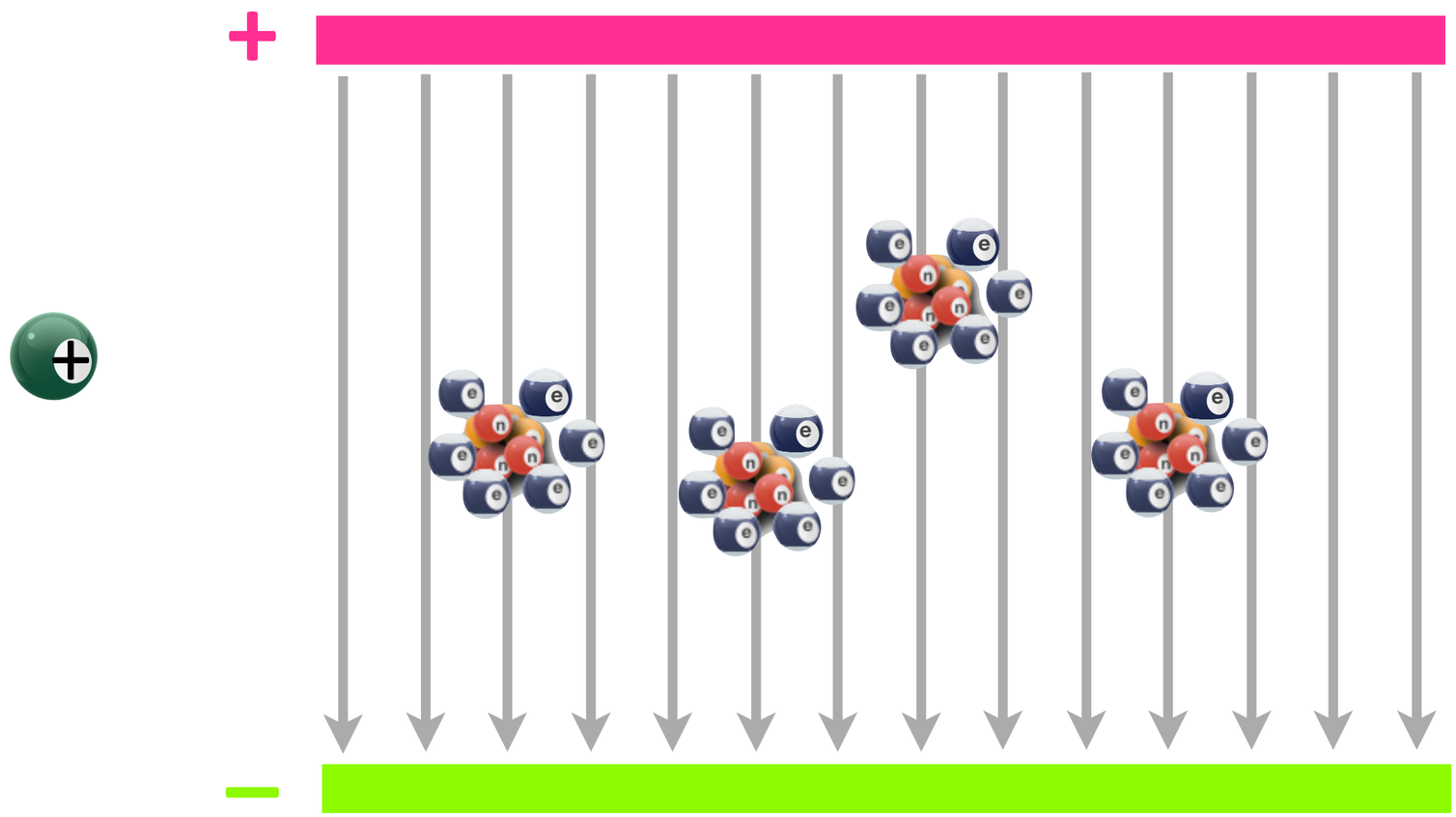
Becquerel rays

Marie built a new kind of apparatus for her PhD thesis

Ionizing radiation: Becquerel had found that the phenomenon of Uranium emissions would cause air to become **ionized**.

Madame Curie used that idea:

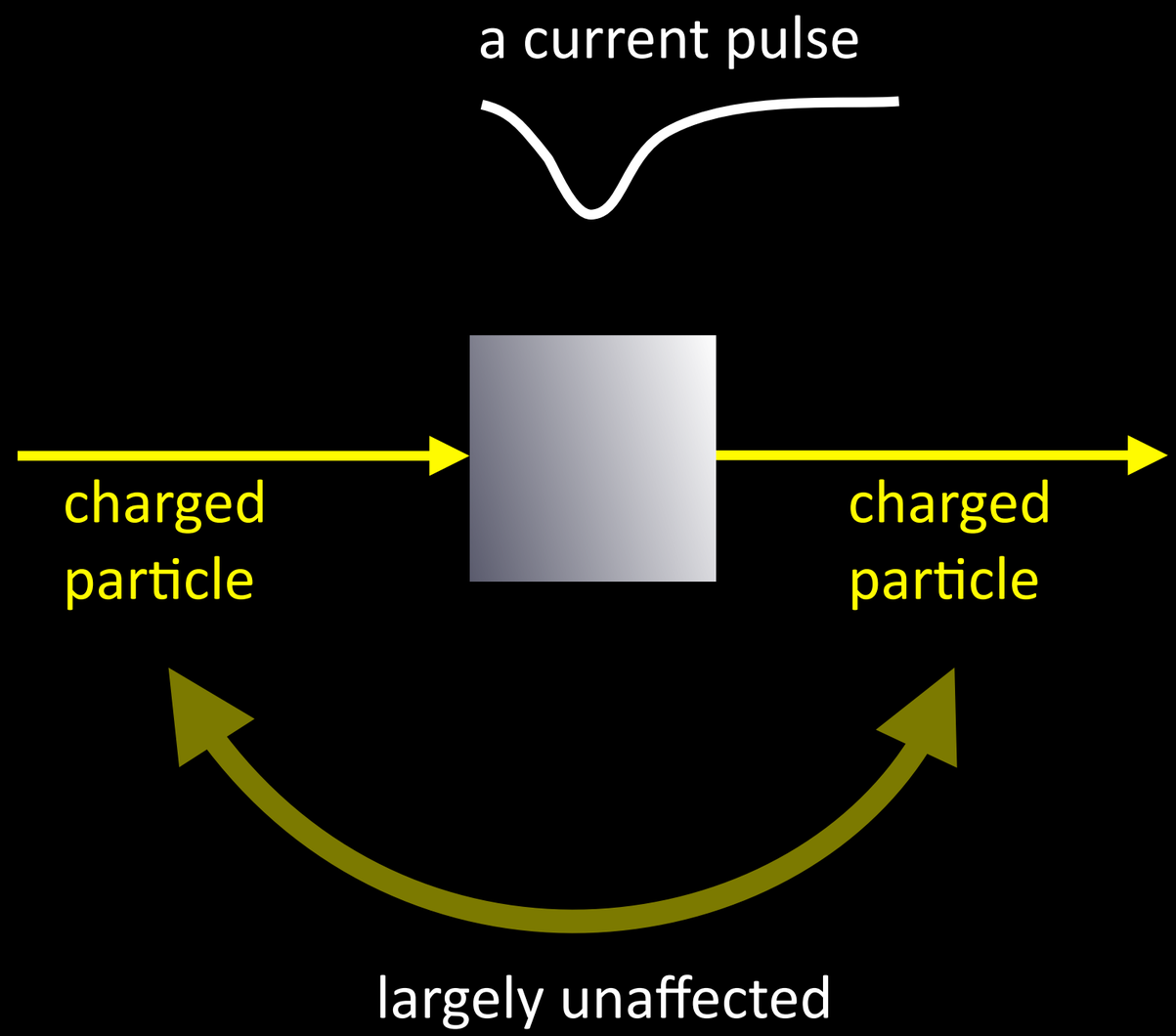
a current!



our first detector

Ionization Detector

*indicates the **location** and **time** of passage of a charged particle*



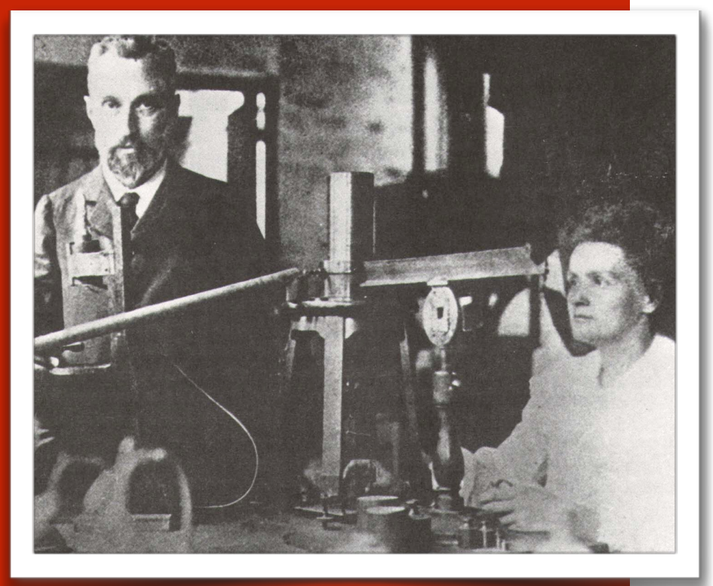

WARNING

piezo electricity

apply a force to some crystals

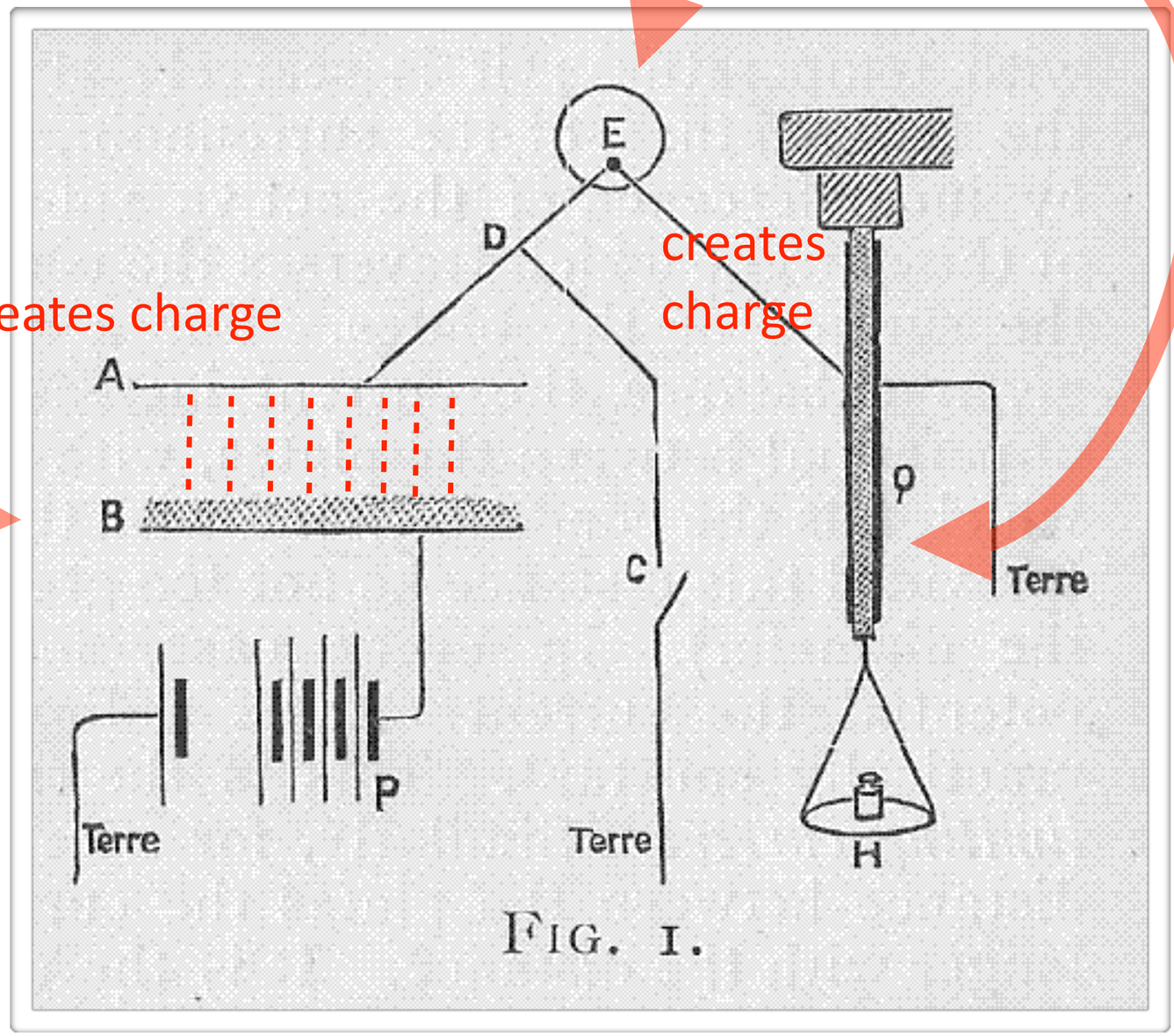
get a voltage

Discovered by Pierre Curie and his brother



balance is created by adjusting the weight

piezo electric crystal - & a weight



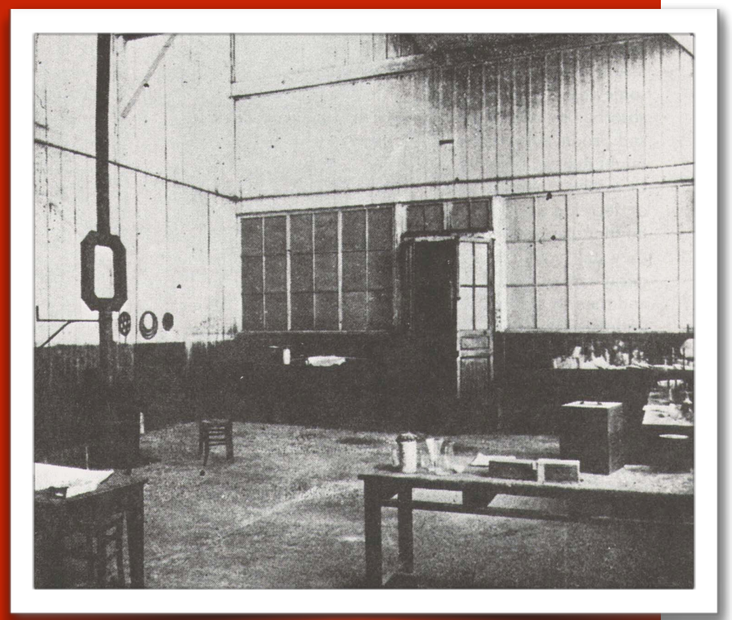
a radioactive substance inside of a parallel-plate capacitor

they found something else

They found a surprising thing:
pitchblend…an ore which contains concentrations of UO_2
was *more radioactive than uranium by itself*

"This fact is a very remarkable and leads one to believe that these minerals contain an element which is much more active than uranium."

She and Pierre began the systematic study of the relative radioactivity of whatever they could chemically isolate in the pitchblend



Announced the discovery of Po (Polonium) and Ra (Radium).
Then...they had to find it.

1900, 3 years later:

Nobel 1903

tragically Pierre kille a street accident 1

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1901 — 2010 — 1911

Sort and list Nobel Prizes and Nobel Laureate | Prize category: Chemistry

The Nobel Prize in Chemistry 1911
Marie Curie

- **The Nobel Prize in Chemistry 1911**
- Marie Curie

Marie Curie, née Sklodowska

The Nobel Prize in Chemistry 1911 was awarded to
her services to the advancement of chemistry by th
radium and polonium, by the isolation of radium and
compounds of this remarkable element".

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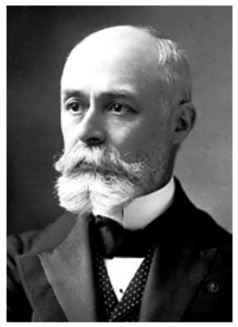
1901 — 2010 — 1903

Sort and list Nobel Prizes and Nobel Laureate | Prize category: Physics

The Nobel Prize in Physics 1903
Henri Becquerel, Pierre Curie, Marie Curie

- **The Nobel Prize in Physics 1903**
- Henri Becquerel
- Pierre Curie
- Marie Curie



Antoine Henri Becquerel

Pierre Curie

Marie Curie, née Sklodowska

The Nobel Prize in Physics 1903 was divided, one half awarded to Antoine Henri Becquerel *"in recognition of the extraordinary services he has rendered by his discovery of spontaneous radioactivity"*,the other half jointly to Pierre Curie and Marie Curie, née Sklodowska *"in recognition of the extraordinary services they have rendered by their joint researches on the radiation phenomena discovered by Professor Henri Becquerel"*.

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their daughter also…

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The Nobel Prize in Chemistry 1935

Frédéric Joliot, Irène Joliot-Curie

- **The Nobel Prize in Chemistry 1935**
- Frédéric Joliot
- Irène Joliot-Curie

Frédéric Joliot **Irène Joliot-Curie**

The Nobel Prize in Chemistry 1935 was awarded jointly to Frédéric Joliot and Irène Joliot-Curie *"in recognition of their synthesis of new radioactive elements"*

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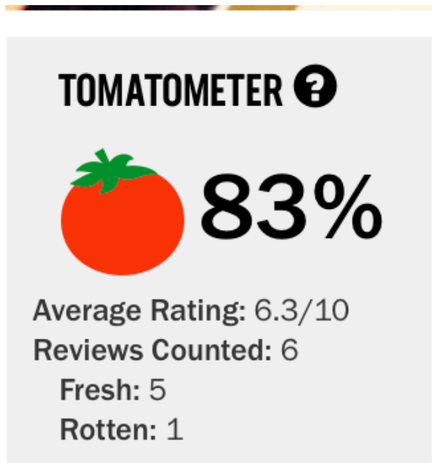
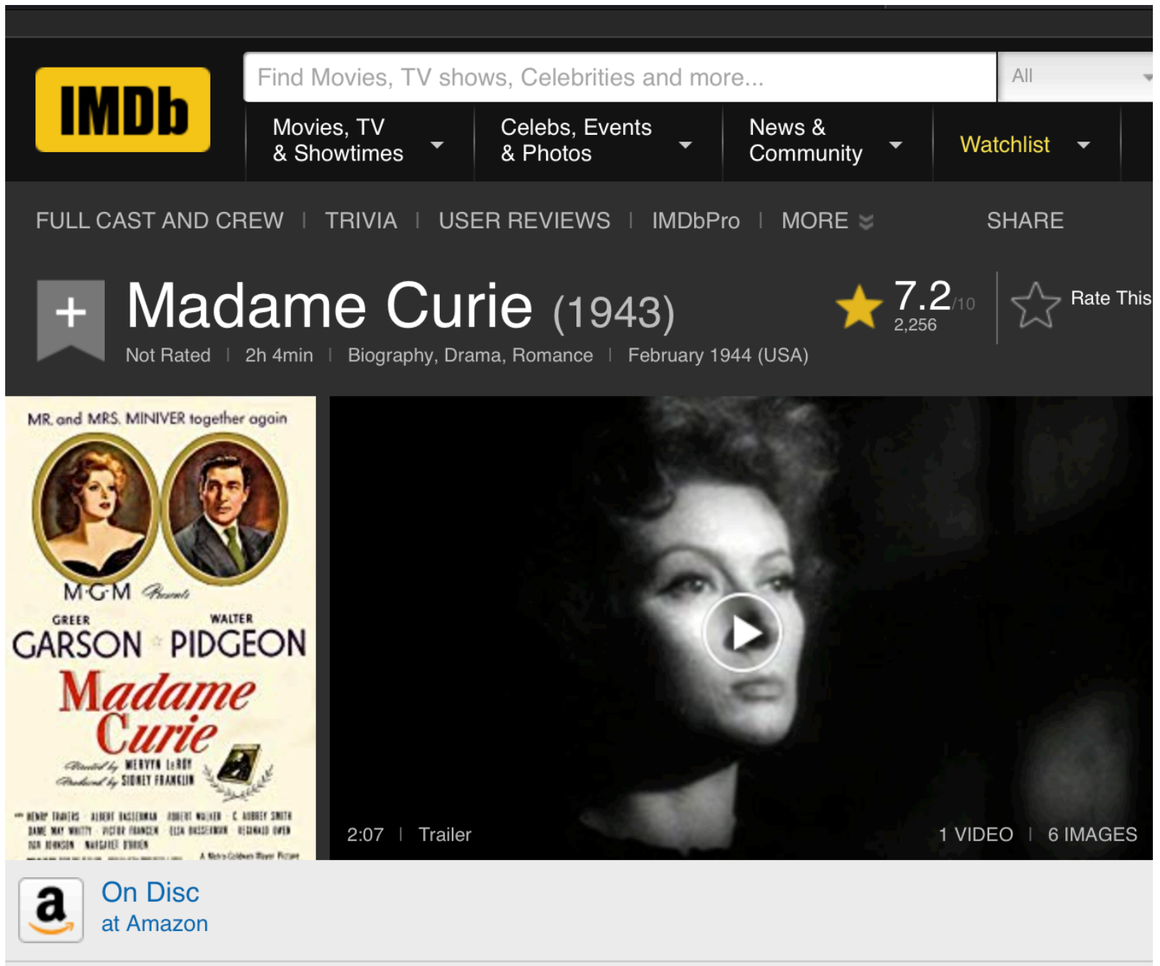




Academy Awards [edit]

Nominations[7]

- Outstanding Motion Picture: Metro-Goldwyn-Mayer
- Best Actor: Walter Pidgeon
- Best Actress: Greer Garson
- Best Art Direction (Black-and-White): *Art Direction:* Cedric Gibbons, Paul Groesse; *Interior Decoration:* Edwin B. Willis, Hugh Hunt
- Best Cinematography (Black-and-White): Joseph Ruttenberg
- Best Music (Music Score of a Dramatic or Comedy Picture): Herbert Stothart
- Best Sound Recording: Metro-Goldwyn-Mayer Studio Sound Department, Douglas Shearer, Sound Director

part of Paris still

famous photograph Solvay Conference 1927

updated:

Italian Physical Society in Trento, 2017

Tools of the trade

Particle Detectors

4 kinds of detectors

Ionization Detector

DIGITAL

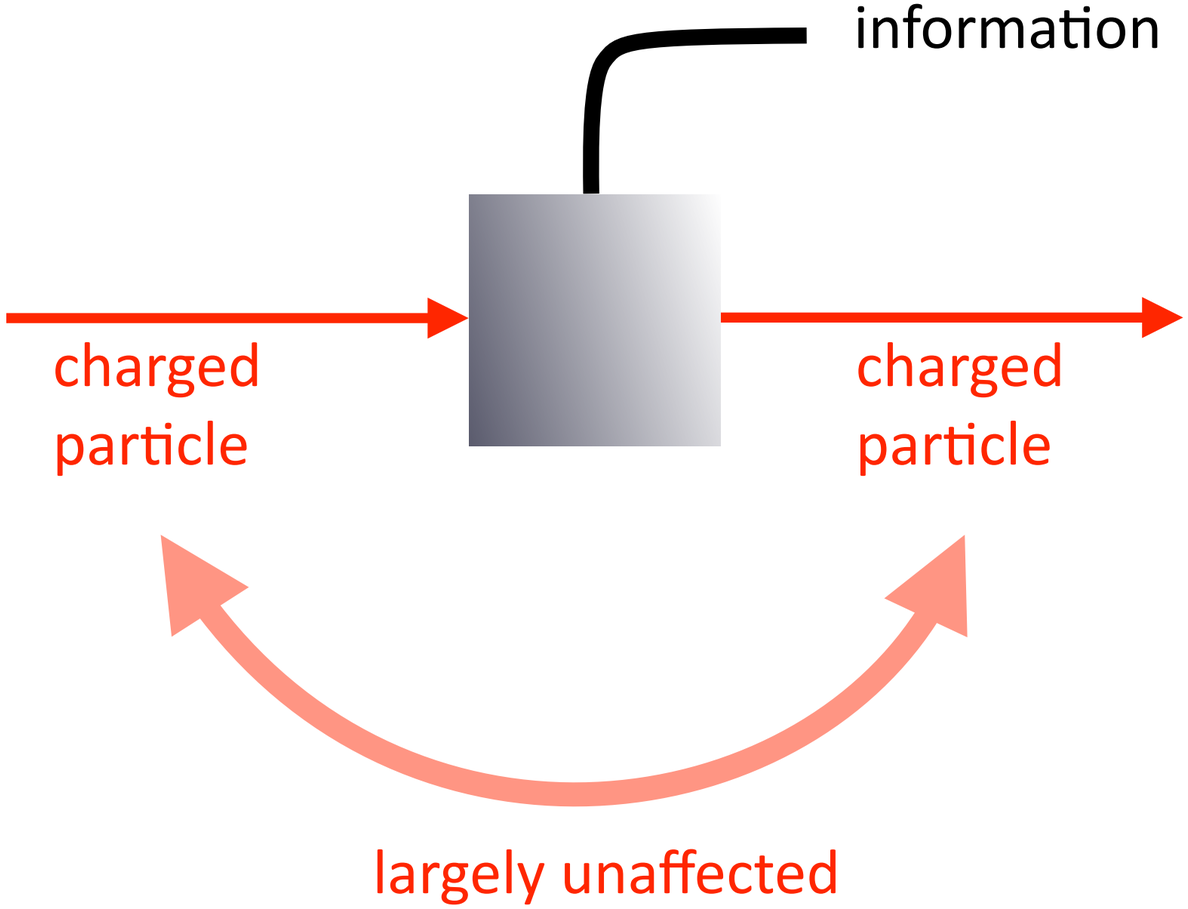
a current pulse

time

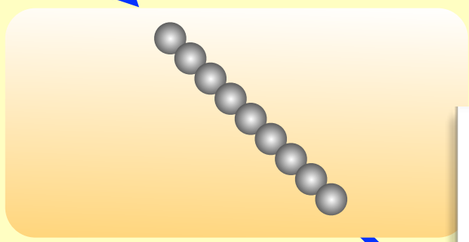
pulse heights digitized

time

information

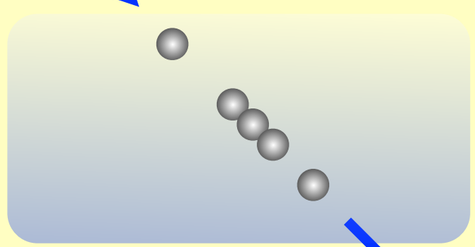


etching in an emulsion



Emulsion

bubbles in a gas or liquid



Cloud Chamber

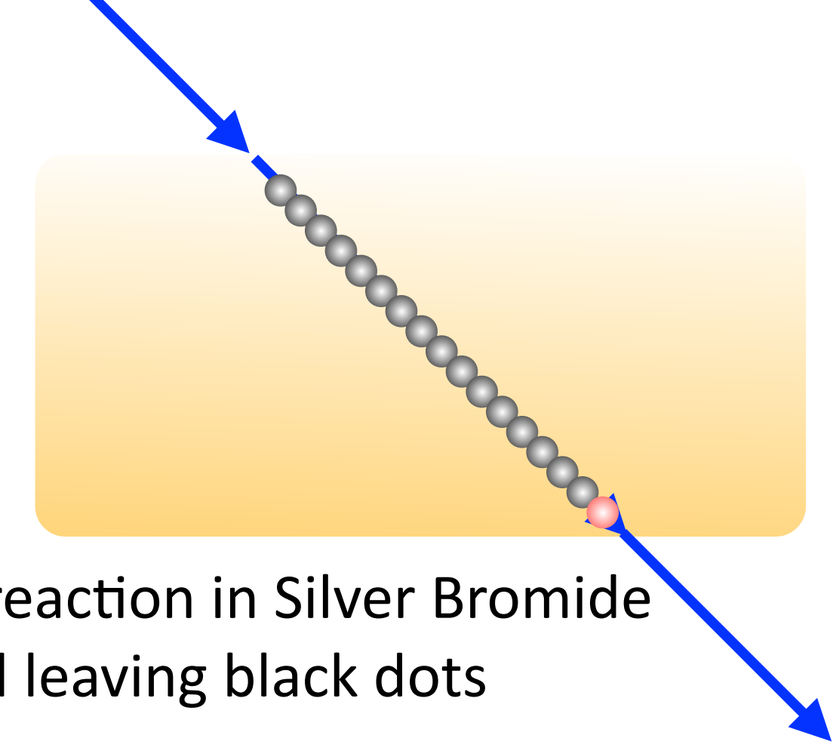
Bubble Chamber

VISUAL

emulsion

thick, photographic film

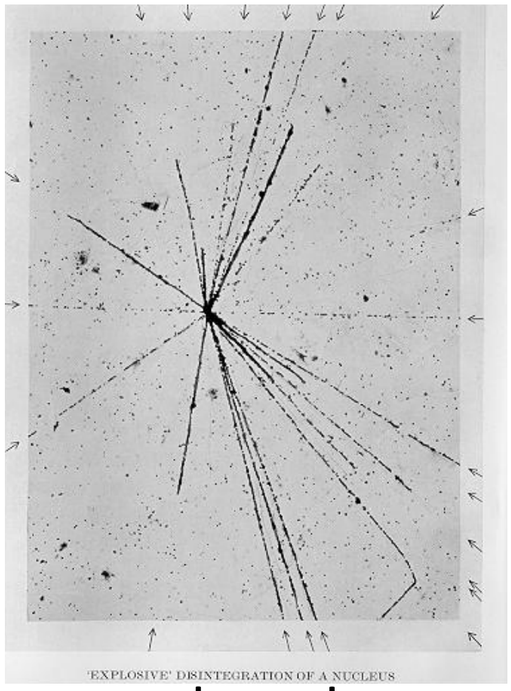
with excess silver



emulsion bulk

chemical reaction in Silver Bromide developed leaving black dots

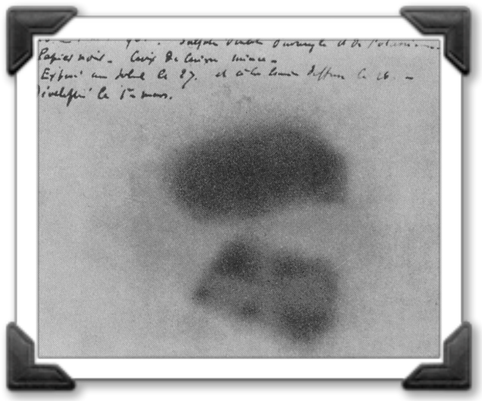
Microscope!
(now with automated optical scanners)



a nuclear decay

cosmic rays:
- mountain tops
- balloon flights

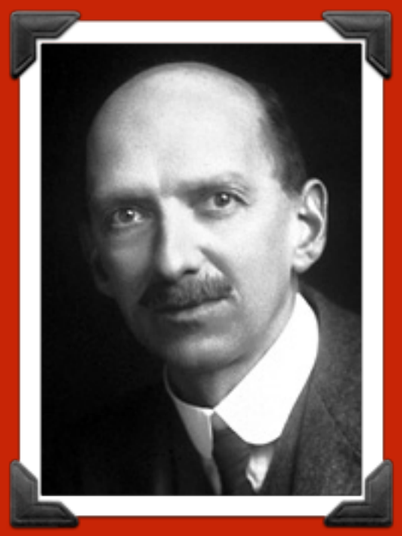
Becquerel's observation essentially an emulsion!



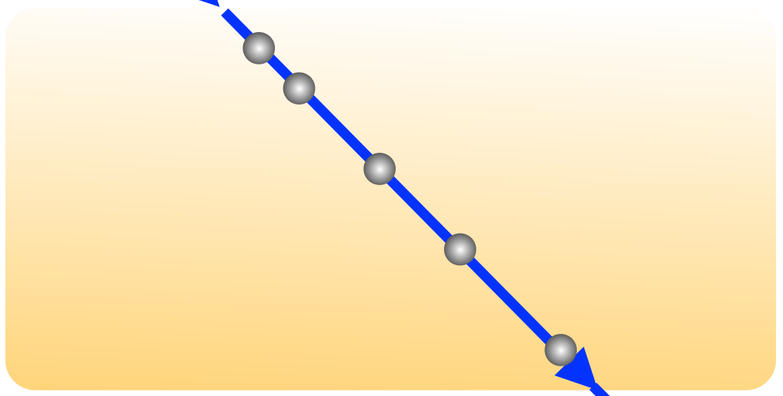
cloud chamber

bubbles in a gas

invented by Charles Thomson Rees Wilson 1895 working for JJ at Cavendish Labs



Nobel Prize 1927

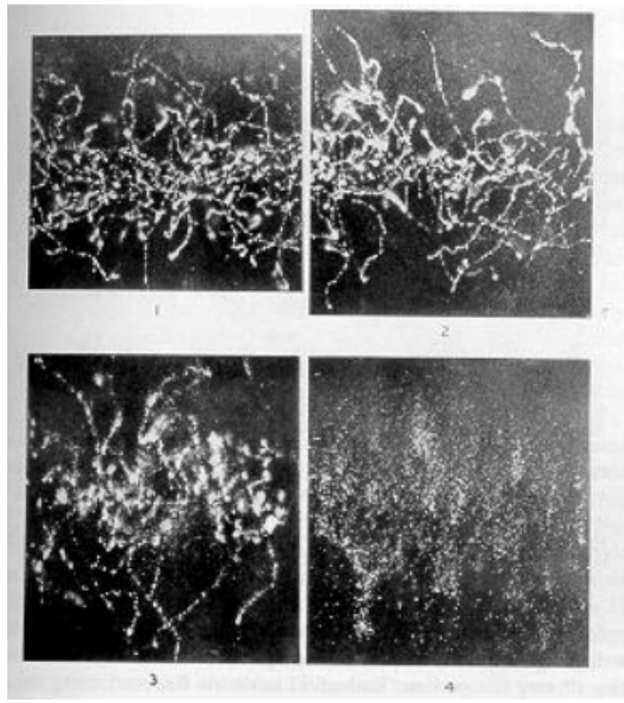


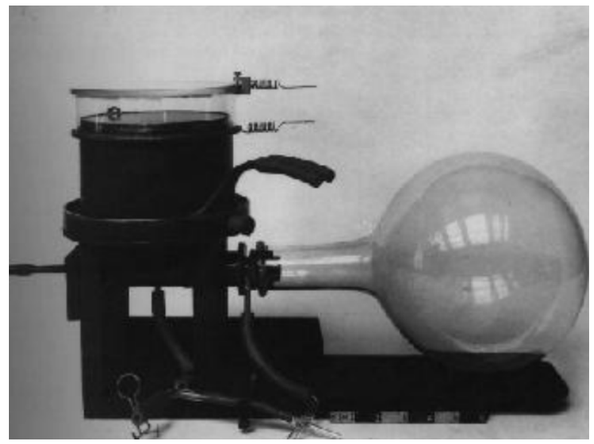
cloud chamber volume

a gas that's "supersaturated"...ready to bubble
charged particle supplies the localized heat

then, photographed

Wilson looking at X-rays 1912





1911 Cloud Chamber

bubble chamber

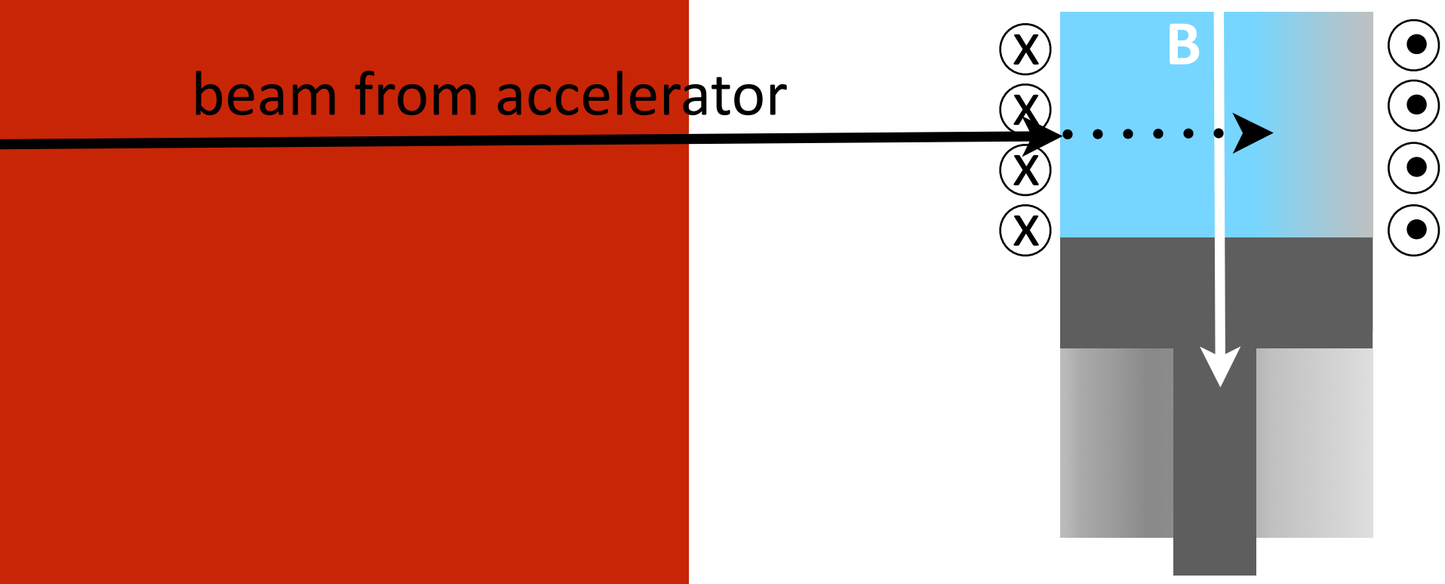
bubbles in a liquid

invented by Donald Glaser

In 1952 Donald Glaser had a beer in Ann Arbor

The sudden release of pressure causes bubbles to occur in the liquid.

Idea for the "**Bubble Chamber**"...our last visual particle detector.



typically a cryogenic liquid, like liquid Hydrogen, or a Hydrogen-Neon mixture.

which then *really wants* to boil

Piston is lowered... reducing pressure in liquid

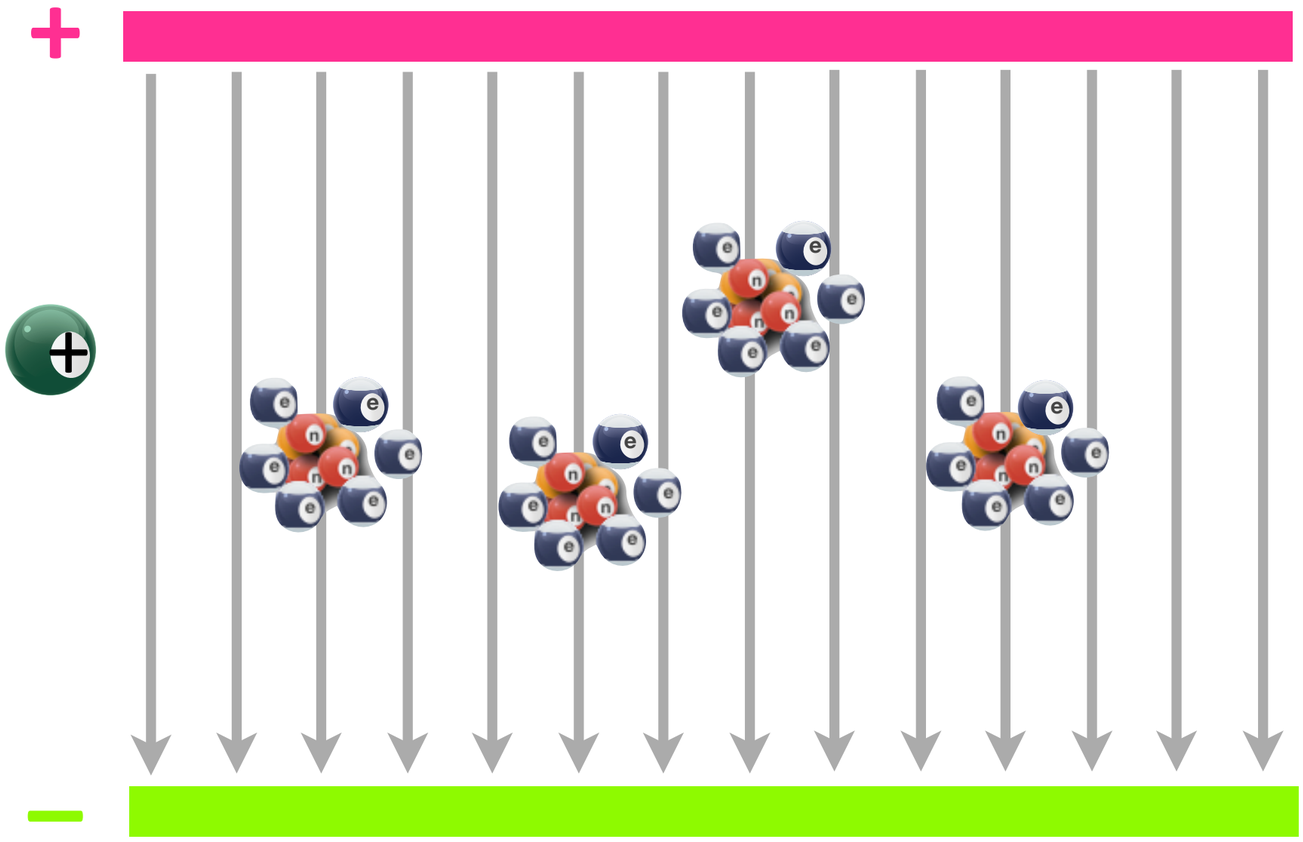
Photograph taken and analyzed by humans

you'll get to know them

Nobel Prize 1960

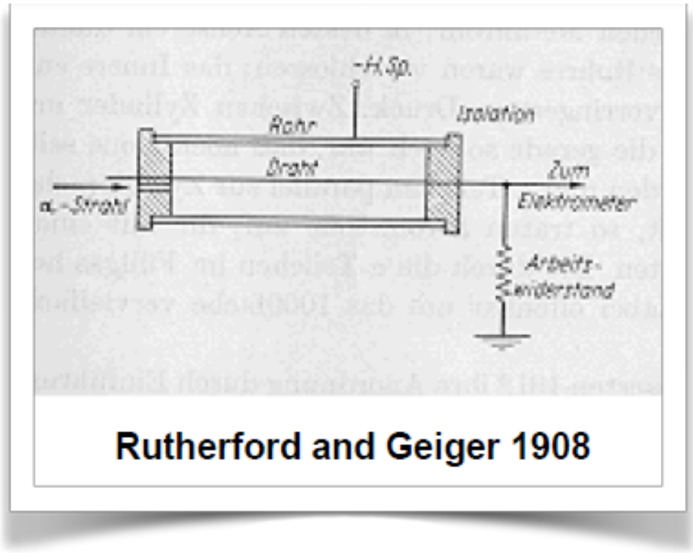
ionization detector

a current!



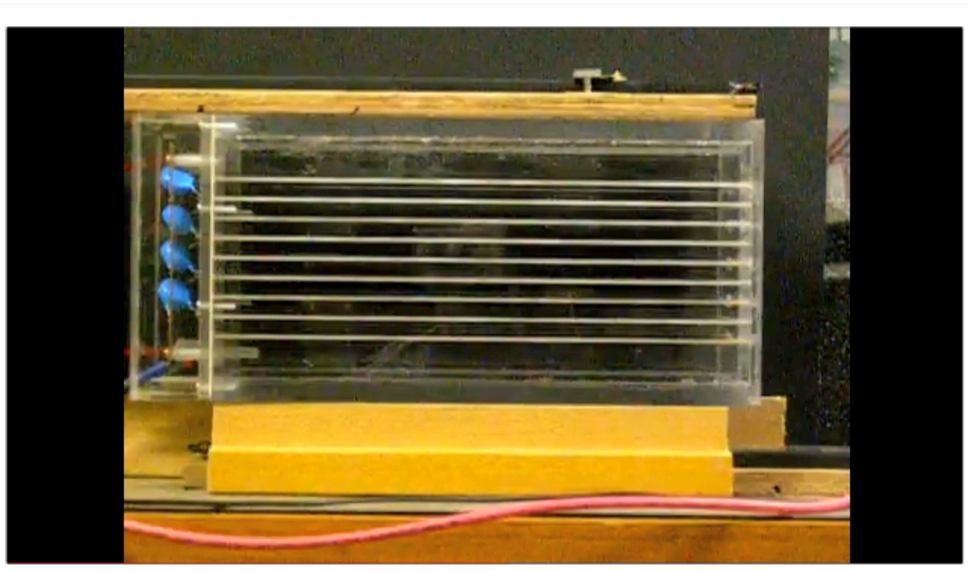
current could be
proportional to the charge
that went through

“current” could be a spark!



Rutherford and Geiger 1908

Geiger Counter



“spark chamber”

http://www.youtube.com/watch?v=cAIKp0cu7UM&feature=mfu_in_order&list=UL

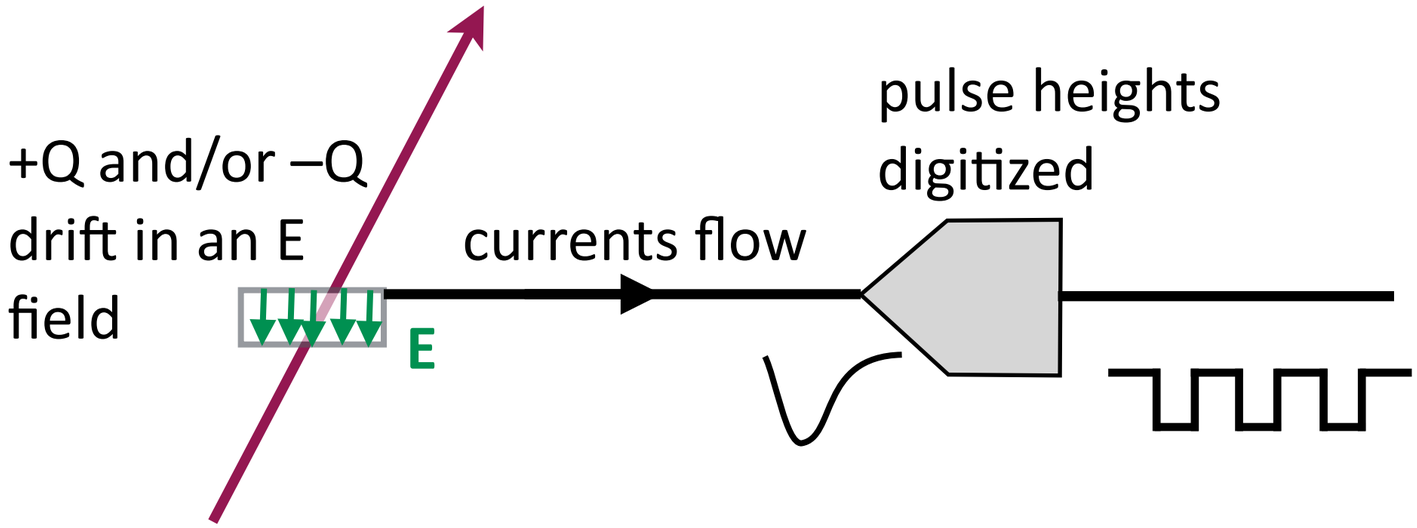
ionization detectors

same basics

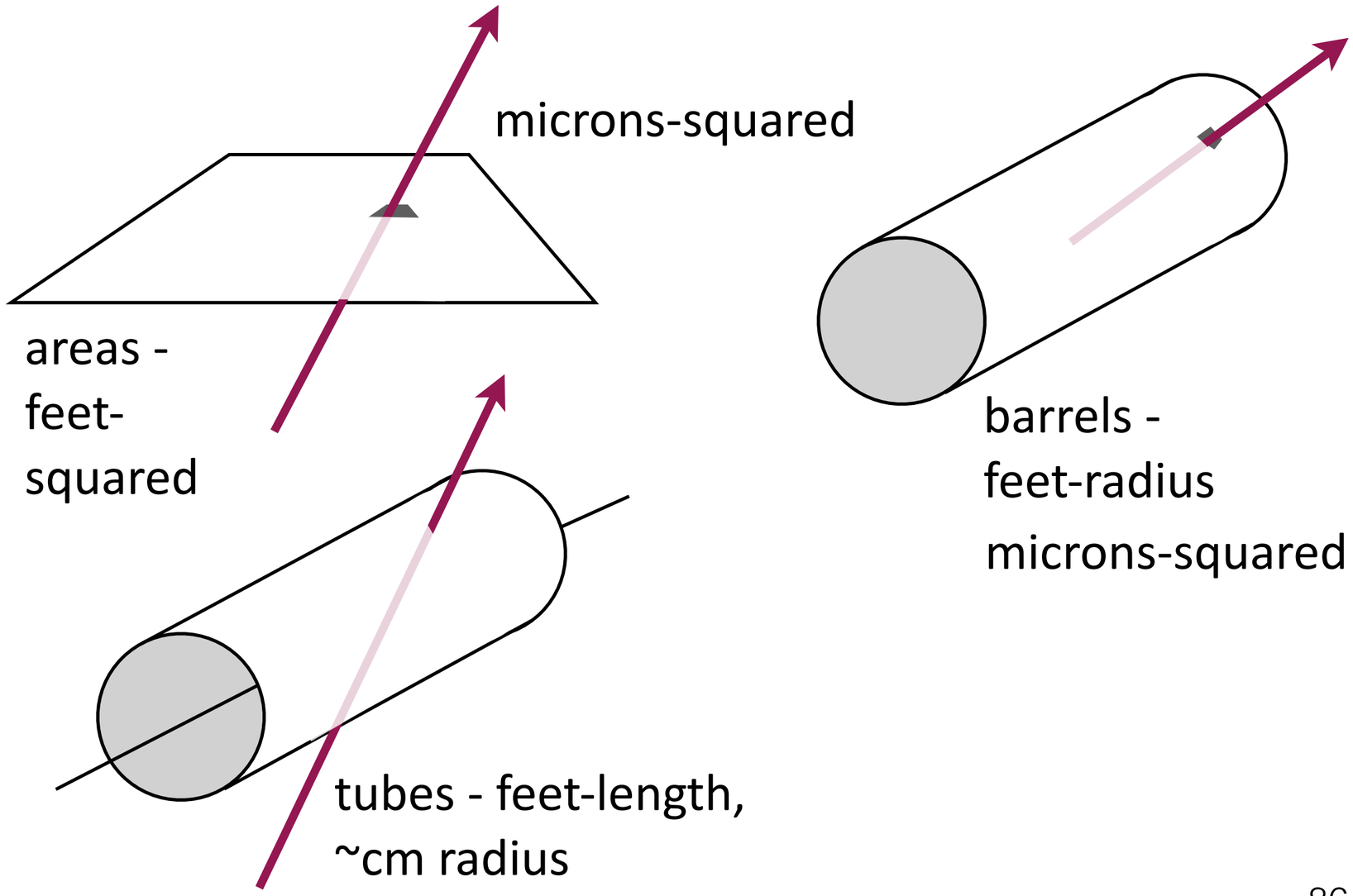
charged or neutral particle passes through a medium

dislodges electric charges

which become a current

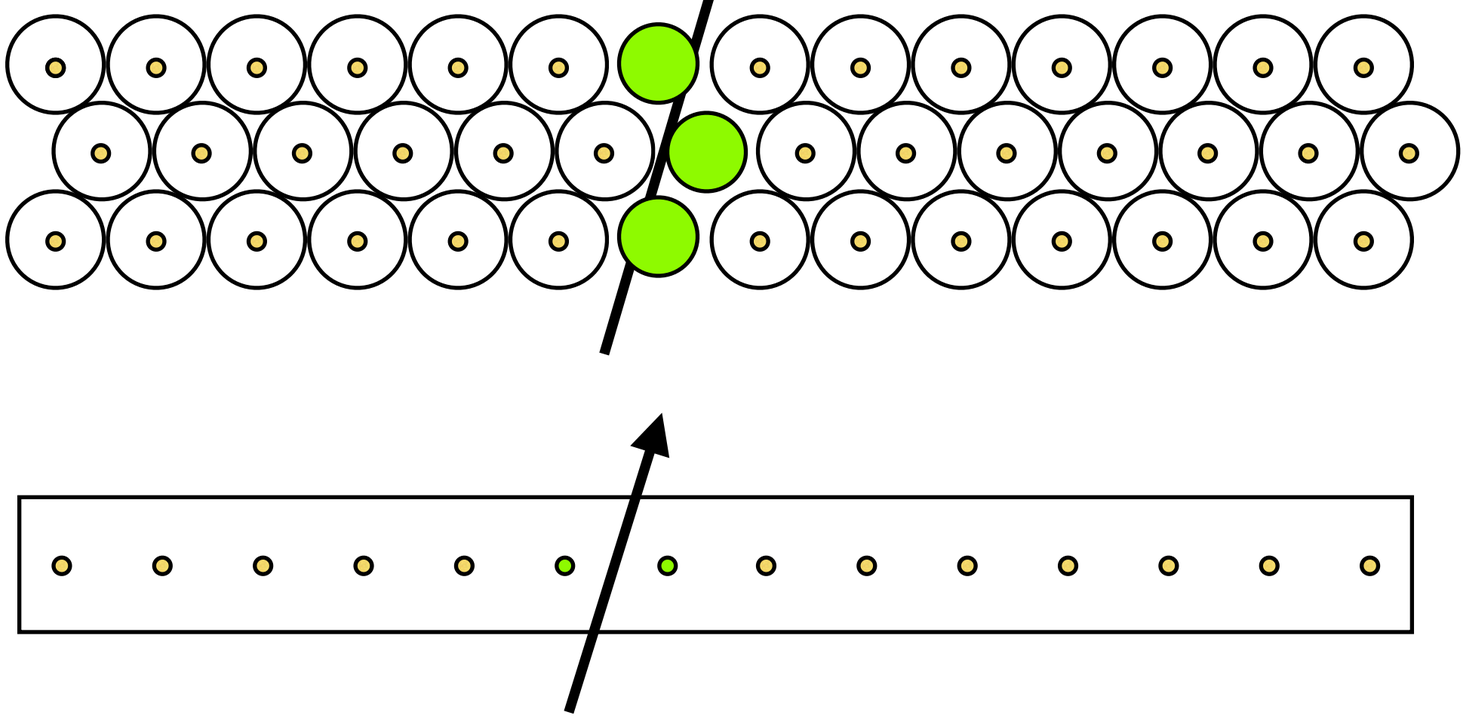


Many different geometries - limited by $ vs mission

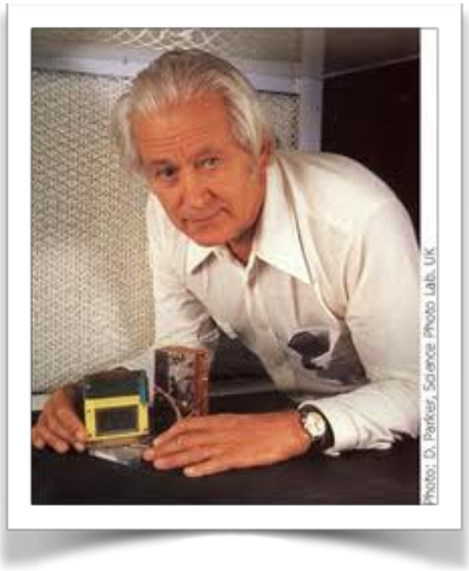


ganging them together

along with early logic circuits, 1928-29

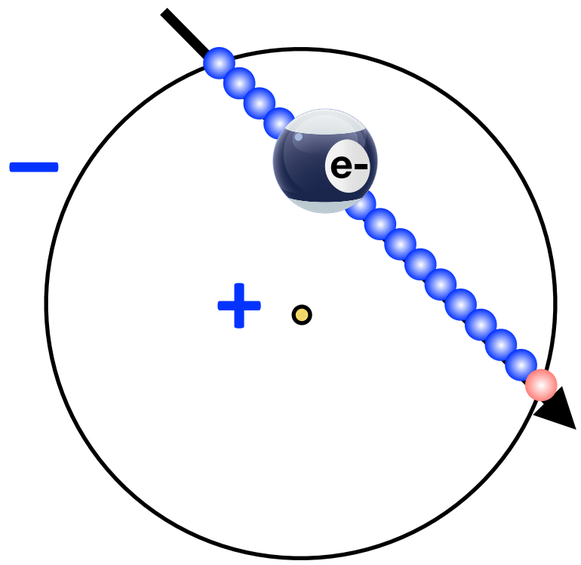


multiwire proportional chamber



Georges Charpak

Nobel Prize
1992



electrons drift towards + and positive ions towards –

causing more ionizations, so large pulse on wire

combine with a magnetic field

particle moves in a circle

radius is proportional to the B magnitude

precisely tailor the B field

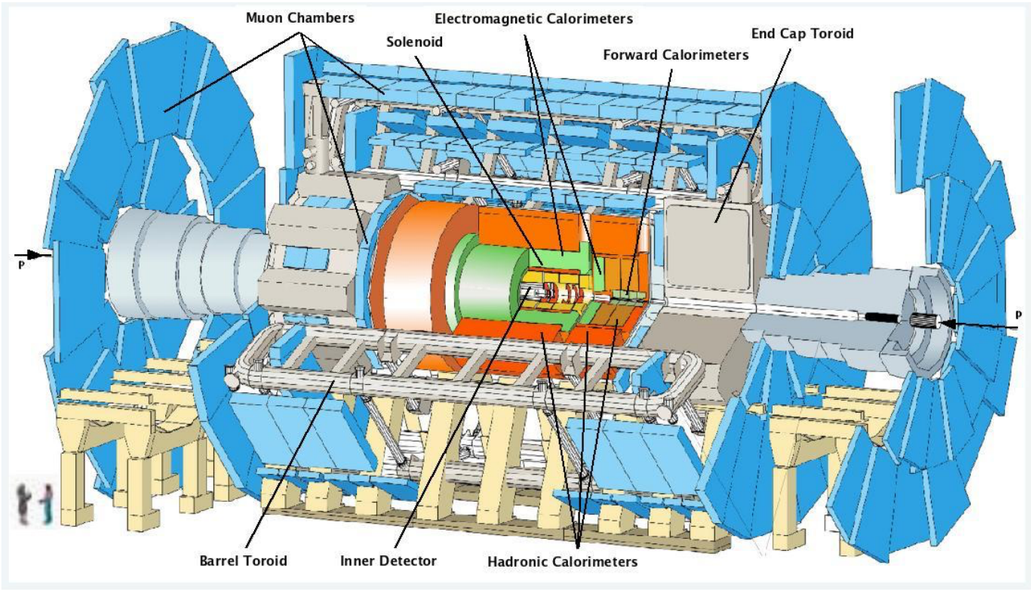
build precision space-measuring ion detectors and fit tracks to measure R

“tracking”

Try possible track shapes

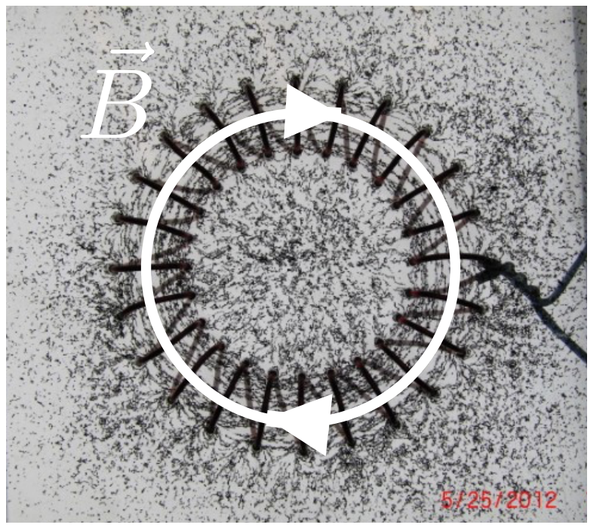
pick the one that fits best - that gives you the momentum

B

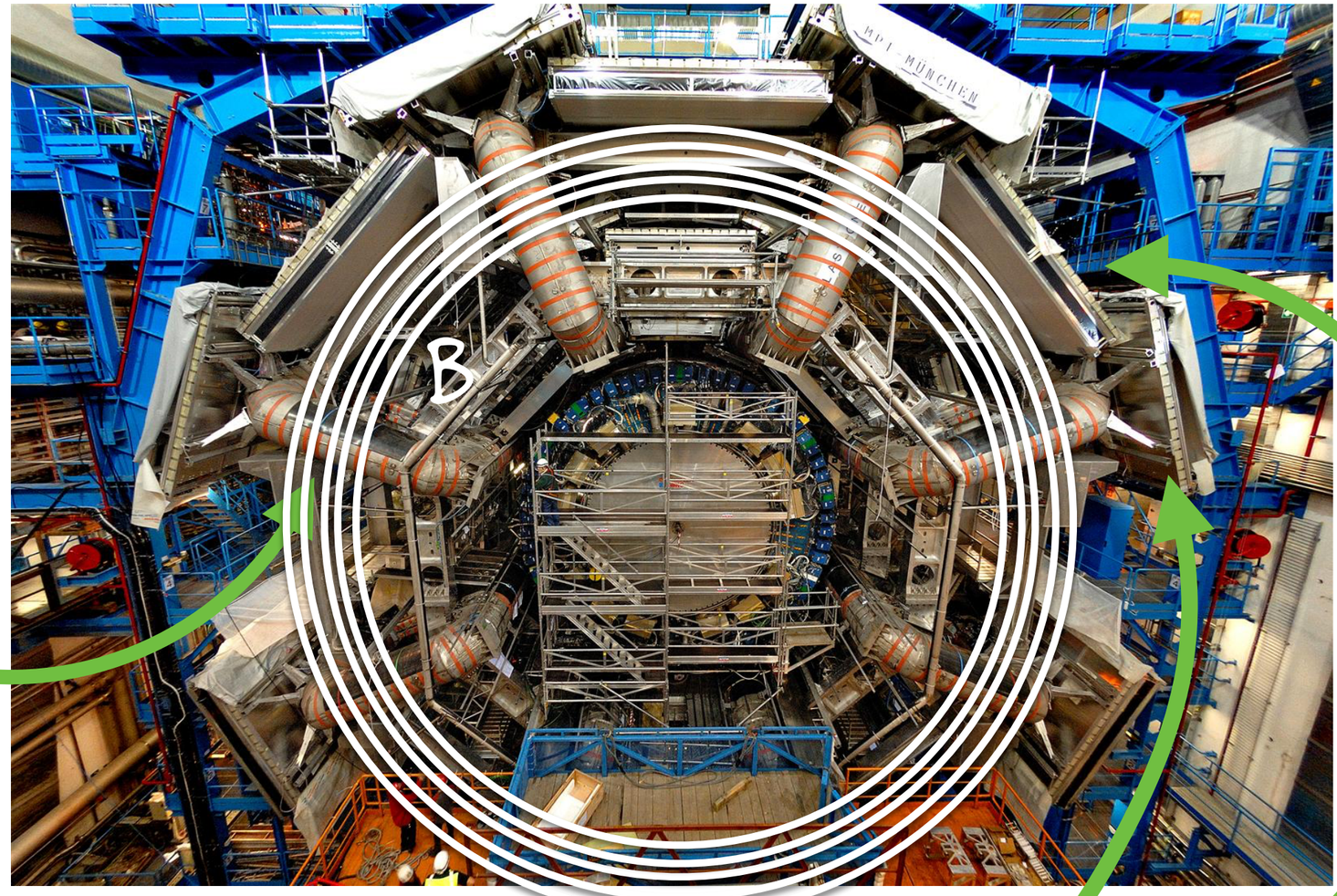


ATLAS "muon spectrometer"

barrel toroids



toroid



1200 "Monitored Drift Tube" chambers
400,000 individual tubes, 1-3 meters long

particle physics jobs

Beam physicists and beam engineers

mathematically model, design, construct, and operate accelerators

Theoretical particle physicists

mathematically model nature:

the most fundamental constituents and how they interact*

and...what their observable consequences might be

exceedingly rare processes

Experimental particle physicists

build the detectors required in order to:

confirm or disconfirm theoretical models and/or look for the unexpected

analyze the data and present the results

*indivisible bits of matter and energy

we're going to watch:

different paths from ideas to models to outcomes

theorists

mix theoretical ideas with current understanding

trying solve a problem or simply exploring mathematics

model "Nature"

predict an outcome

same?

confirmation!

different?

disconfirmation

OR a surprise discovery

experimenters

construct beams and detectors to confront

actual Nature

an *actual* outcome

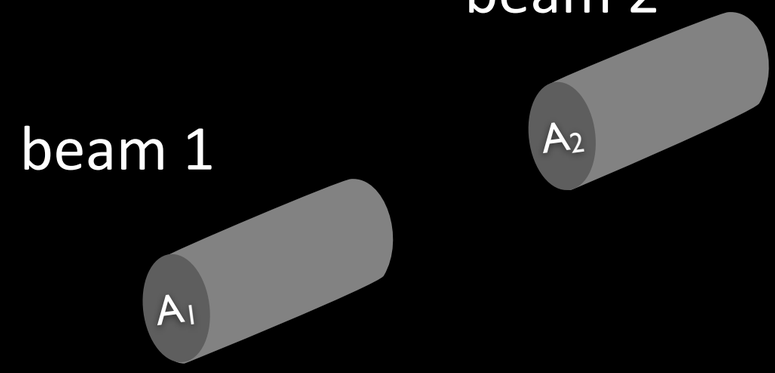
ingredients: beams

what do we need?

maximize opportunity for collisions

largest number of beam particles

squeezed into the smallest overlapping areas

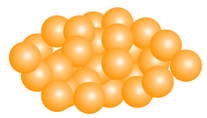


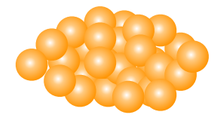
At Fermilab, beams were 30 x 10^{-6} m across
At LHC, beams are 16 x 10^{-6} m across

for something to happen

protons have to hit one another

within the bunches





Two probabilities at work here:

The likelihood that two protons will overlap

and

If they overlap, the likelihood that they will react

for something to happen

protons have to hit one another

within the bunches

how many protons there are: the beam

the probability of the scatter: Nature!

Two probabilities at work here:

The likelihood that two protons will overlap

and

If they overlap, the likelihood that they will react

theory about producing X

$$A + B \rightarrow X + \text{other stuff}$$

models predict how many X are produced from particular initial states

(# of A and B) • (the probability that A + B would create X)

our situation is:

$$p + p \rightarrow X + \text{other stuff}$$

back to the weird

0

1887

Albert Michelson (1852-1931)

and

Edward Morley

The Nobel Prize in Physics 1907
Albert A. Michelson

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The Nobel Prize in Physics 1907

Albert Abraham Michelson
Prize share: 1/1

The Nobel Prize in Physics 1907 was awarded to Albert A. Michelson *"for his optical precision instruments and the spectroscopic and metrological investigations carried out with their aid".*

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<http://www.nobelprize.org/nobel_prizes/physics/laureates/1907/>

We remember him for the most important measurement of nothing ever.