Seeing Particles

Mike Albrow, Fermilab

Fundamental Particles are VERY VERY SMALL tiny .....

How can we possibly "see" them ?

We will see that:

The elementary particles of matter are MUCH too small to see directly with the eye.

But we can still see them with the *brain*, using many kinds of "artificial eyes"

Using (usually) electric charge of particles to shake up atoms

Then a tiny effect can be amplified and become visible:

droplet, bubble, spark, glow, light emission, electron avalanche ...

Aurora: Particles from the Sun making the atmosphere glow.

Strange and beautiful

Norse explanations AD 1230: Fluorescent glaciers or oceans?
Flares from the Sun?? !!

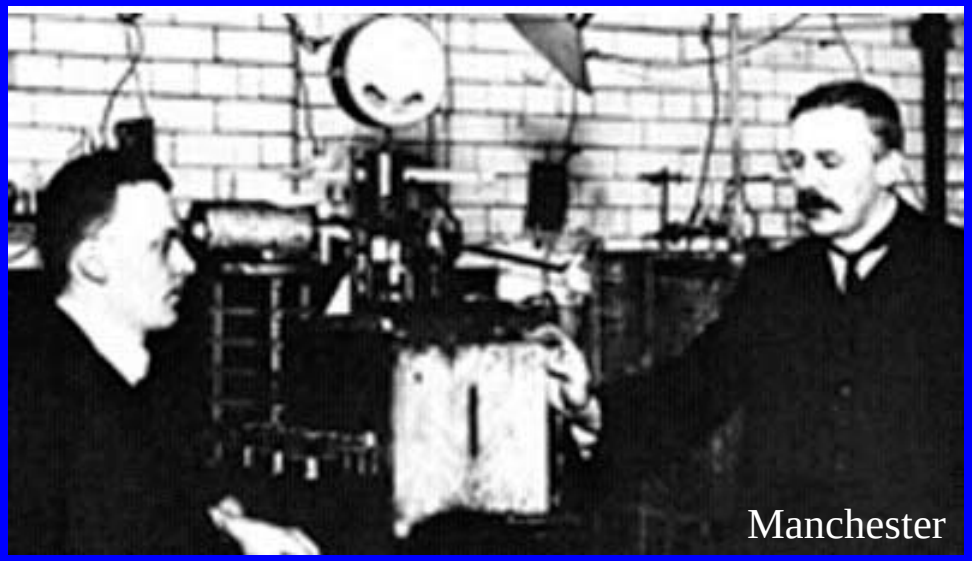
Aurora over Fermilab!

Radium glows in the dark! Atomic energy.

2 NP!

Zinc sulphide "scintillates" (sparkles)

Elster & Geitel (school teachers) & Crookes (X-rays)



Geiger **Rutherford, NP**

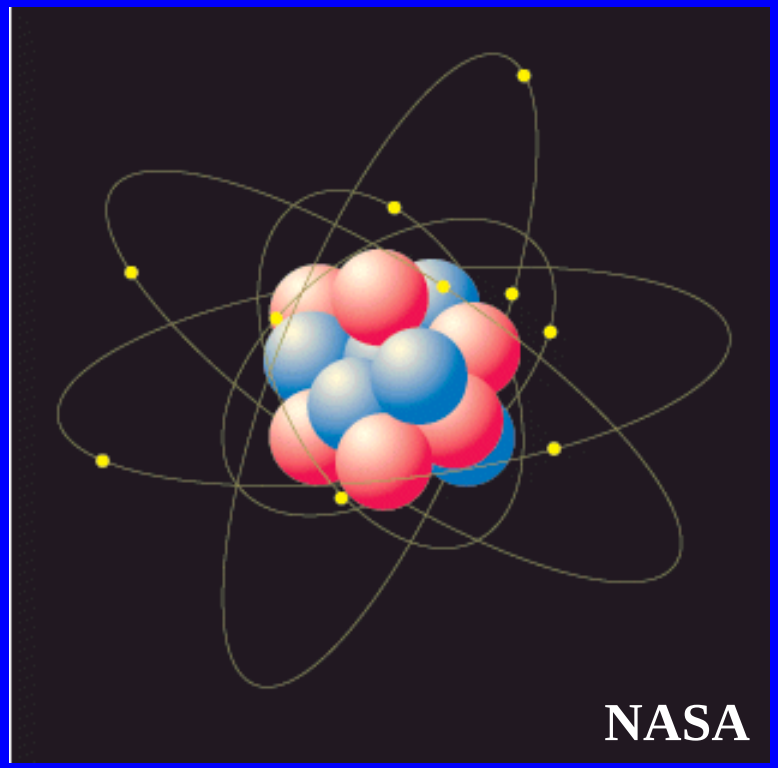
NP (chemistry)

Alpha particles bounce back - NUCLEUS

(luminous watch – radium girls)

Atomic nucleus (?)

Atom with orbiting electrons.
"NASA-ESIP project for schools"

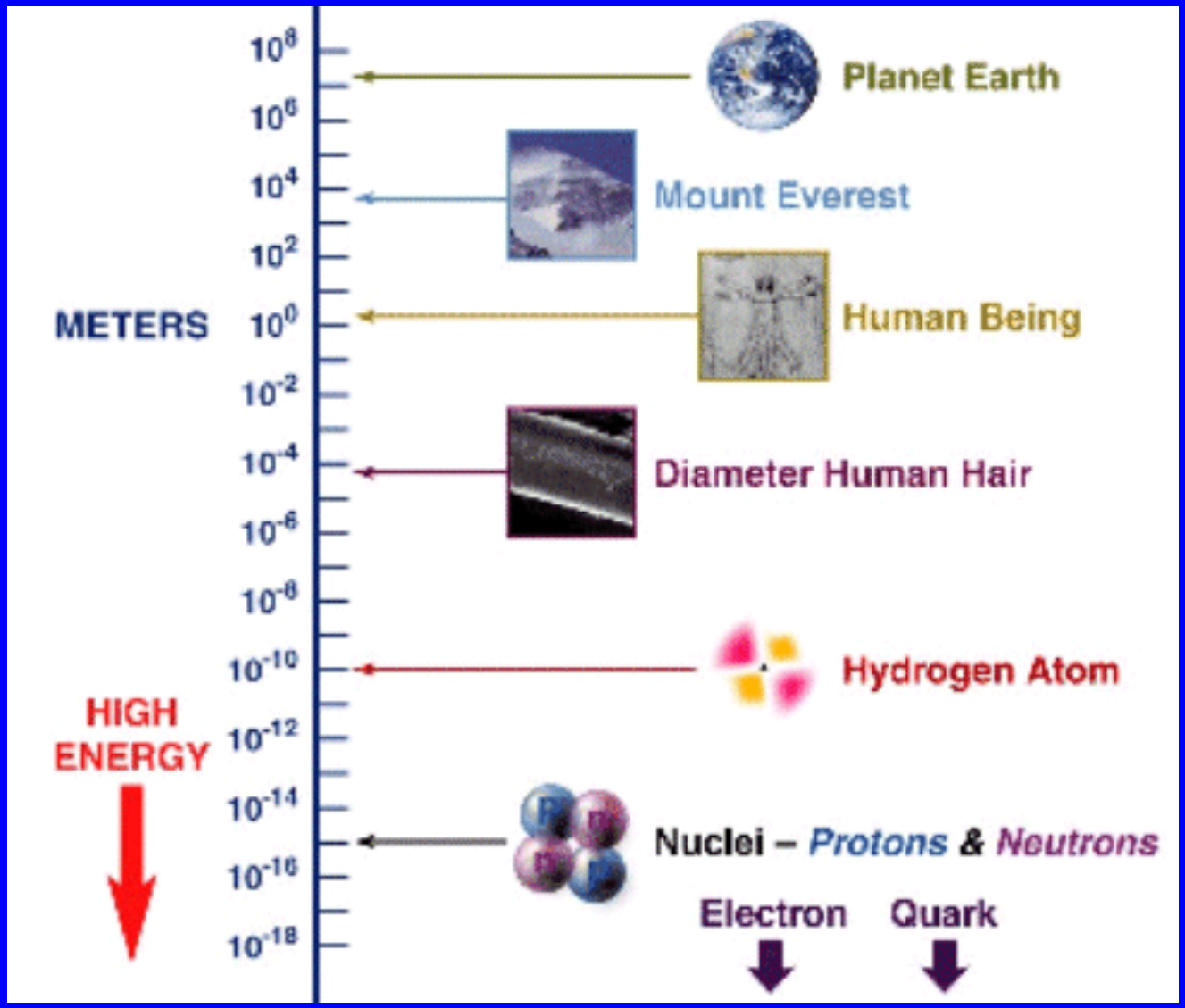


Nucleus is as small as a gnat sitting on this windowsill.
And that's hydrogen!

NO !!

Proton & neutron
not hard little balls

… and actually electron is not localized, it's a "probability wave"



$(10^5)^3 = 10^{15}$

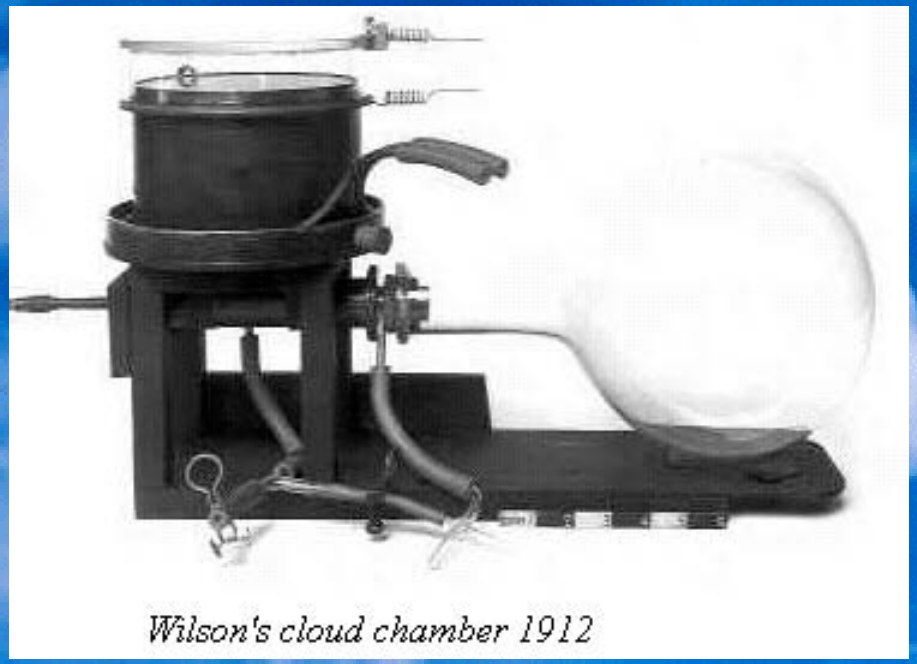
Volume ratio: 1/1000th of a trillionth!

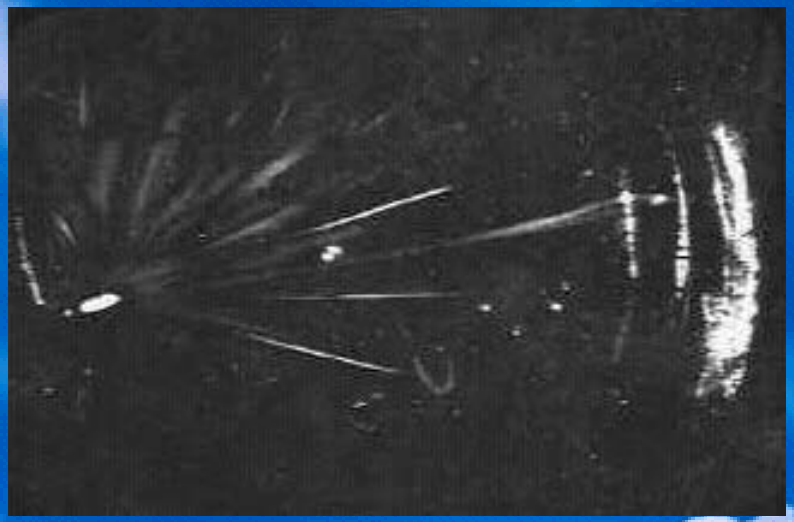
or a millionth of a billionth!

Atom's Nucleus is to Hair as Hair is to Earth

English Lake District

C.T.R.Wilson, NP

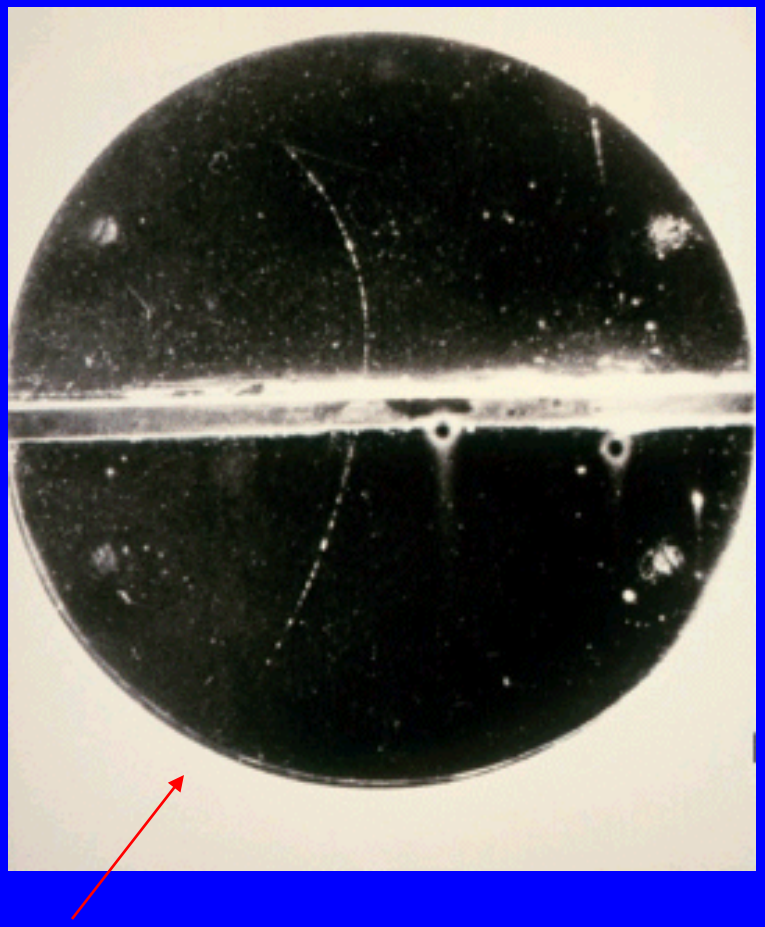




Electron tracks from X-rays in Wilson's cloud chamber

Cloud Chamber: Discovery of the Positron (antimatter) 1932

e^+

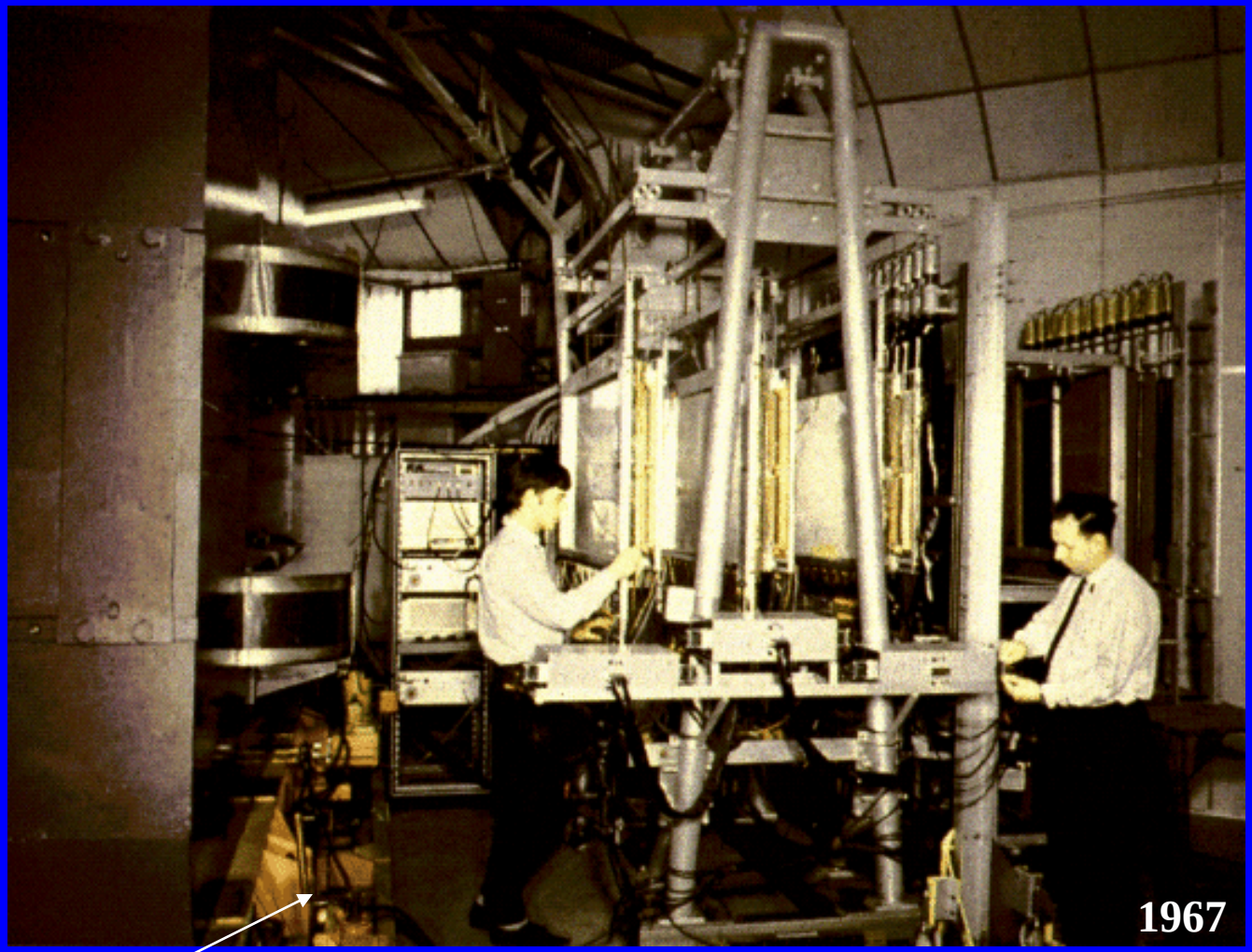


6 mm lead

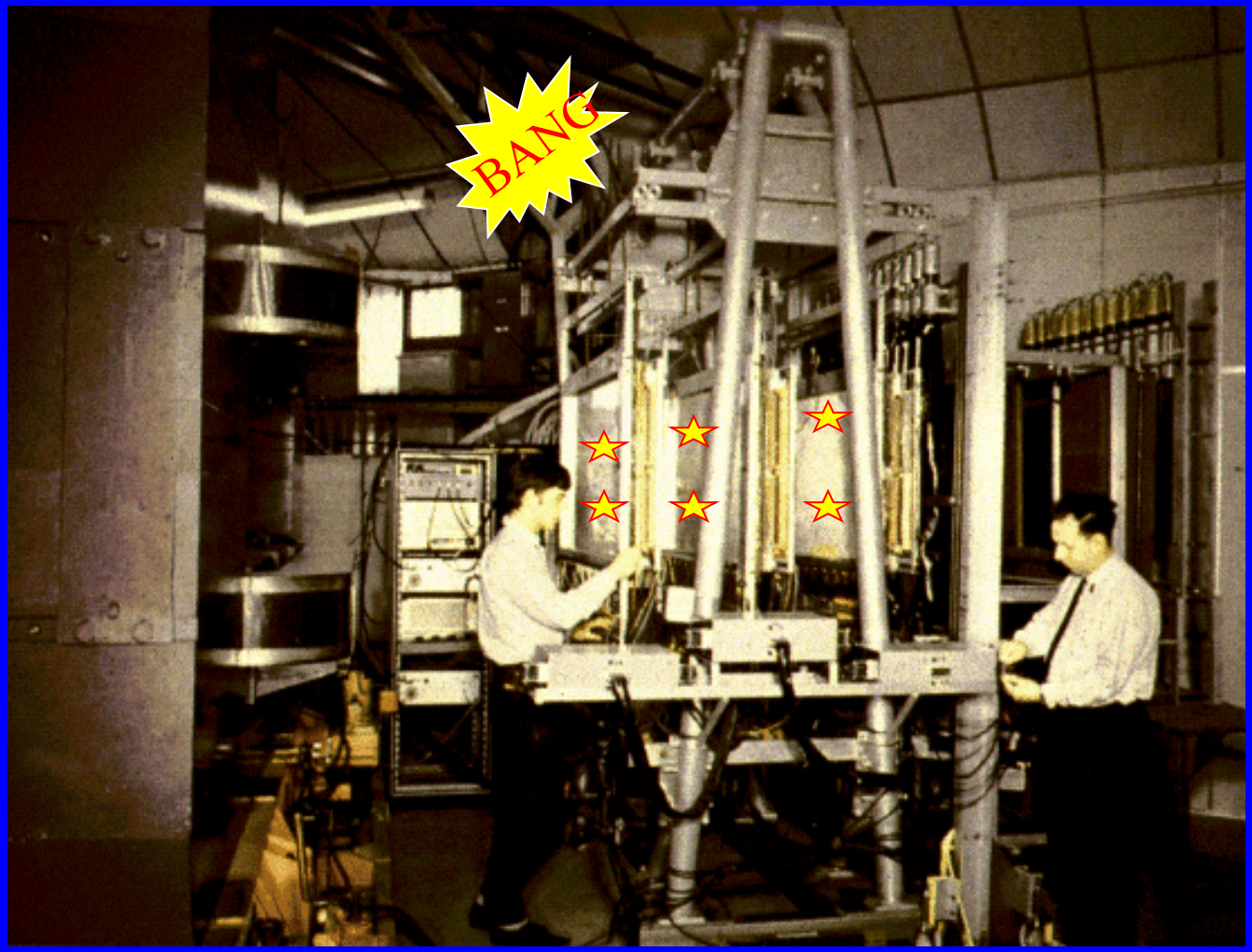
PET scan:
Positron
Emission
Tomography

Carl Anderson, NP

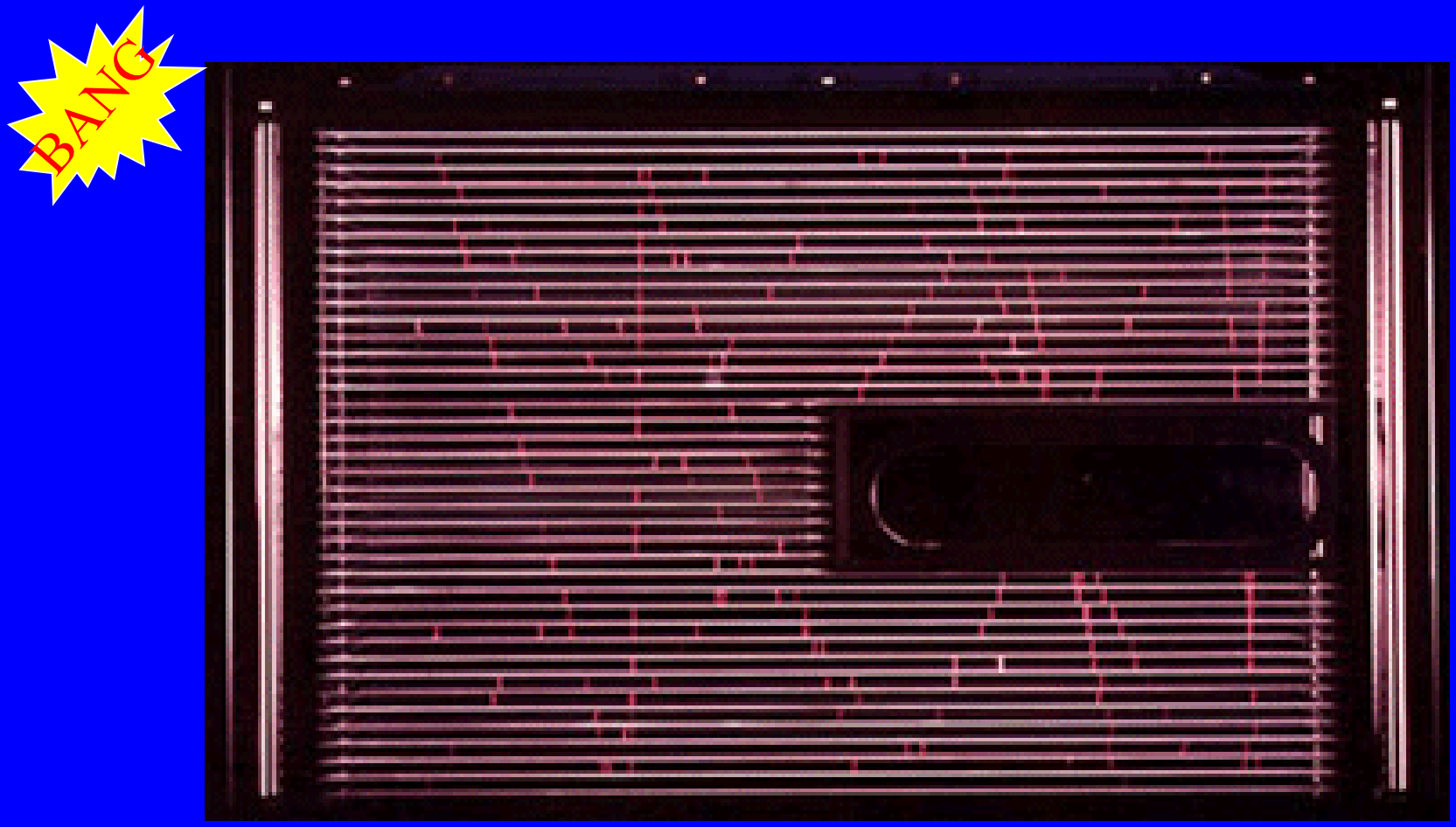
Spark chambers



Spark chambers



Spark Chamber: High Voltage between plates in gas



Cosmic rays!

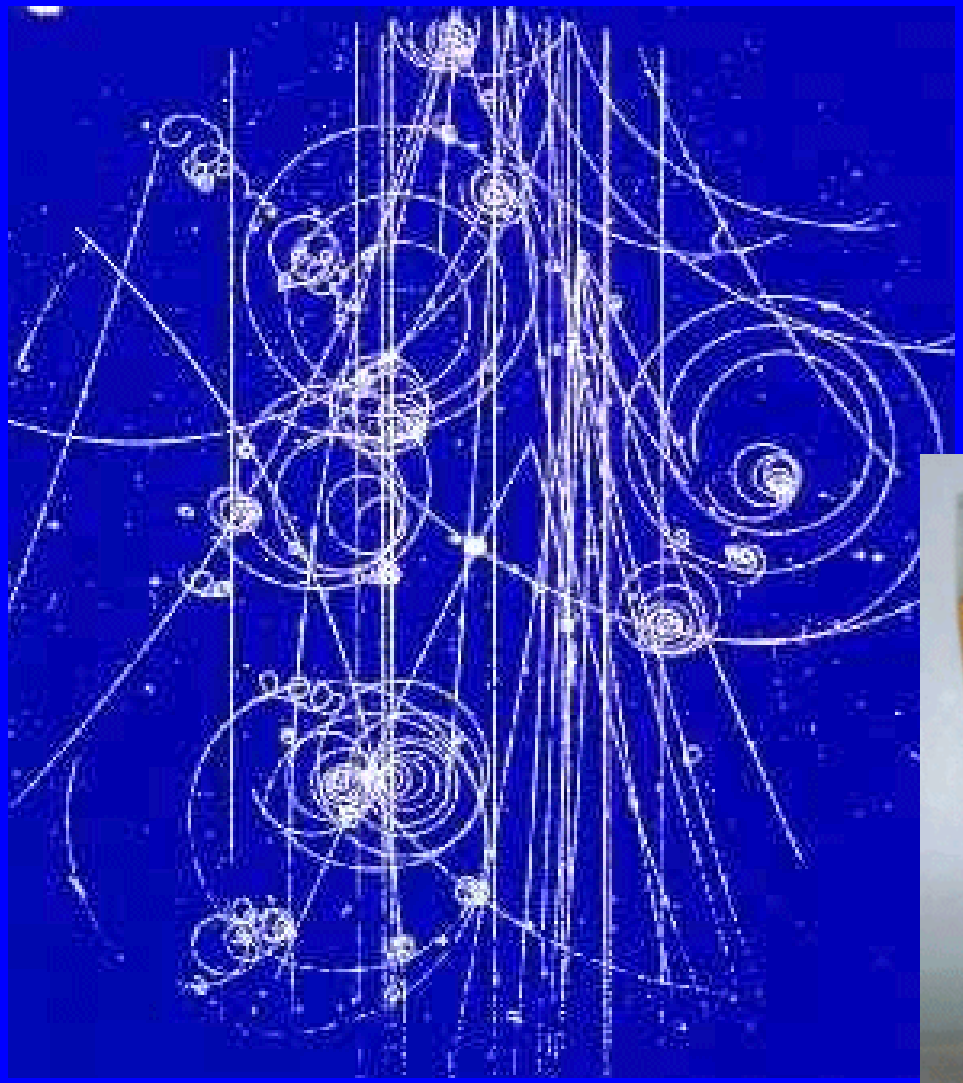
Bubble Chamber

Bubbles in a glass – grow on a "defect" … or ionization

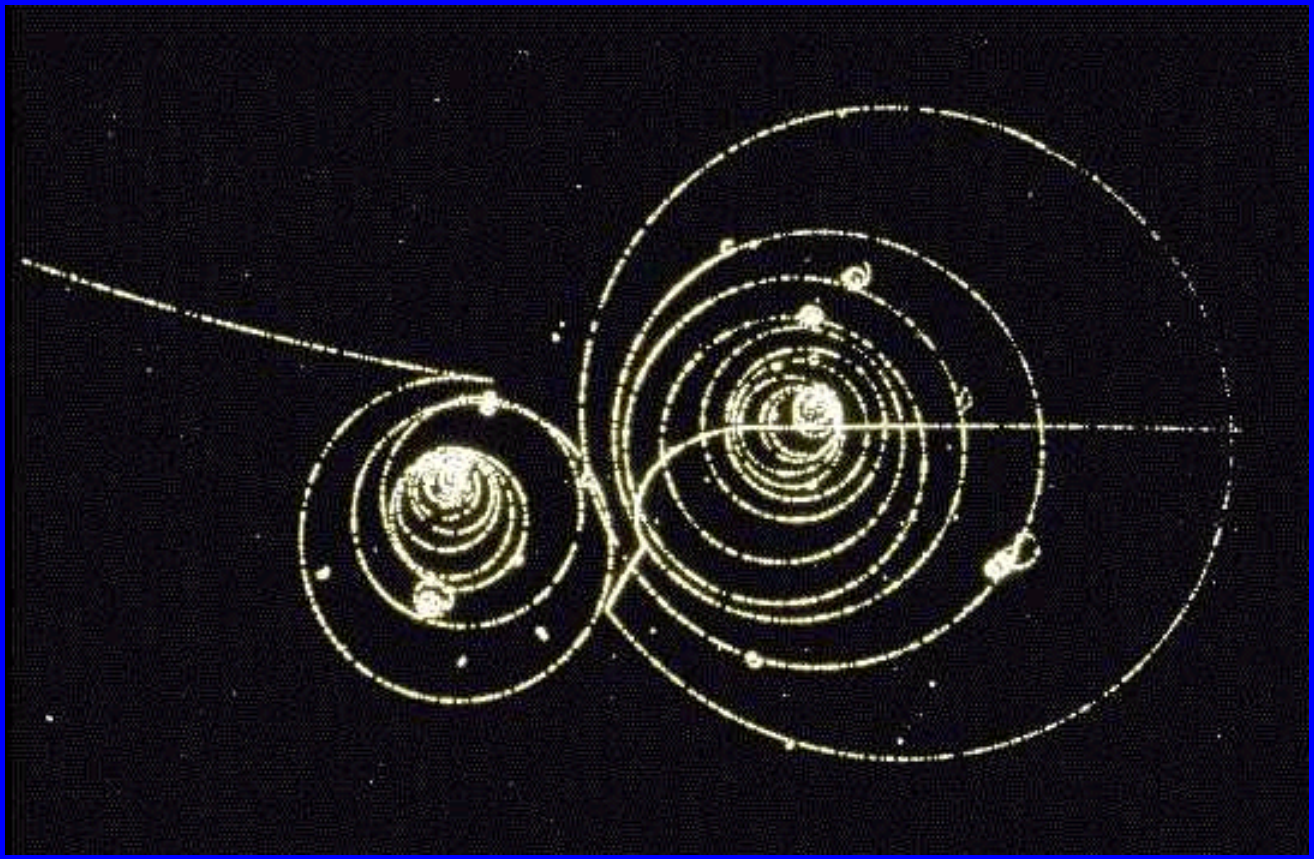
Expand – photograph - compress

1952

Donald Glaser, NP



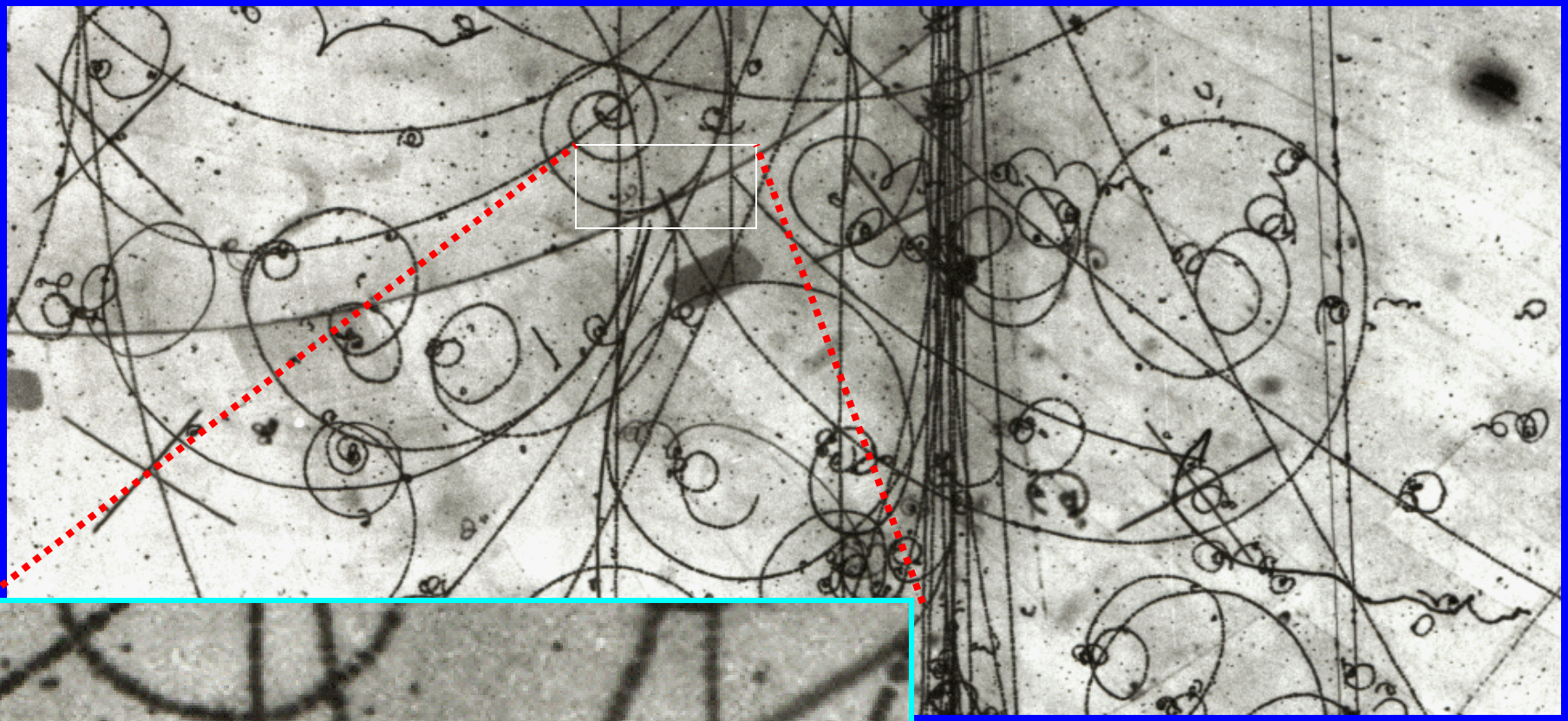
CHEERS

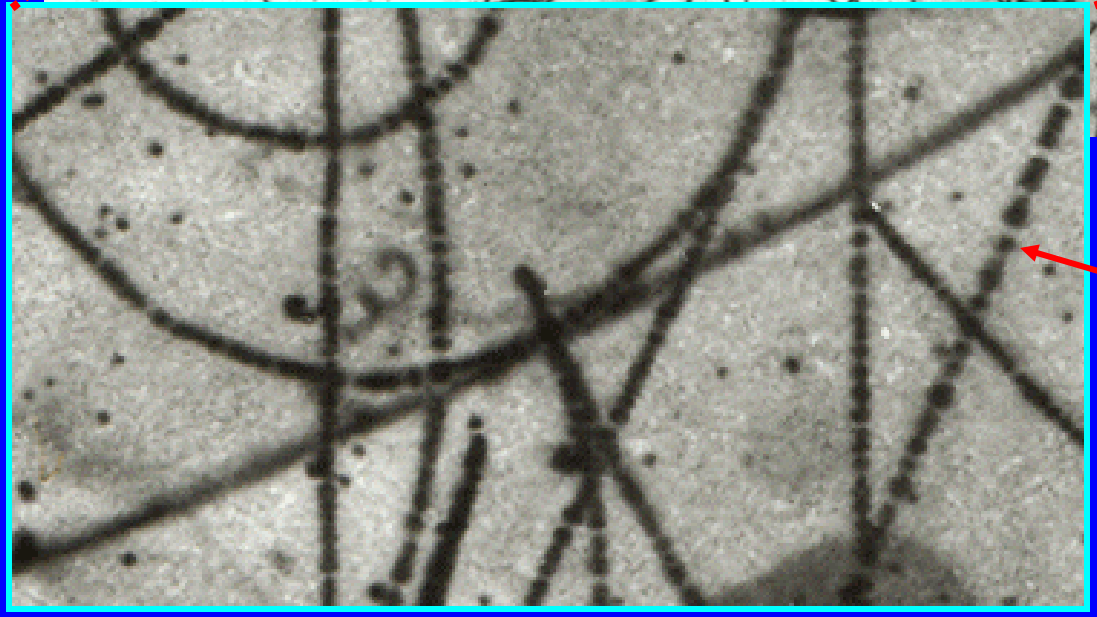


It lived in here

Fermilab 15’ bubble chamber (retired)

Fermilab 15' Neon Bubble Chamber: neutrino-nucleus collision





An atom is 1 million times smaller than this bubble.

Atom → electron + ion
"amplification"

Streamer Chamber at CERN, Proton Antiproton Collider

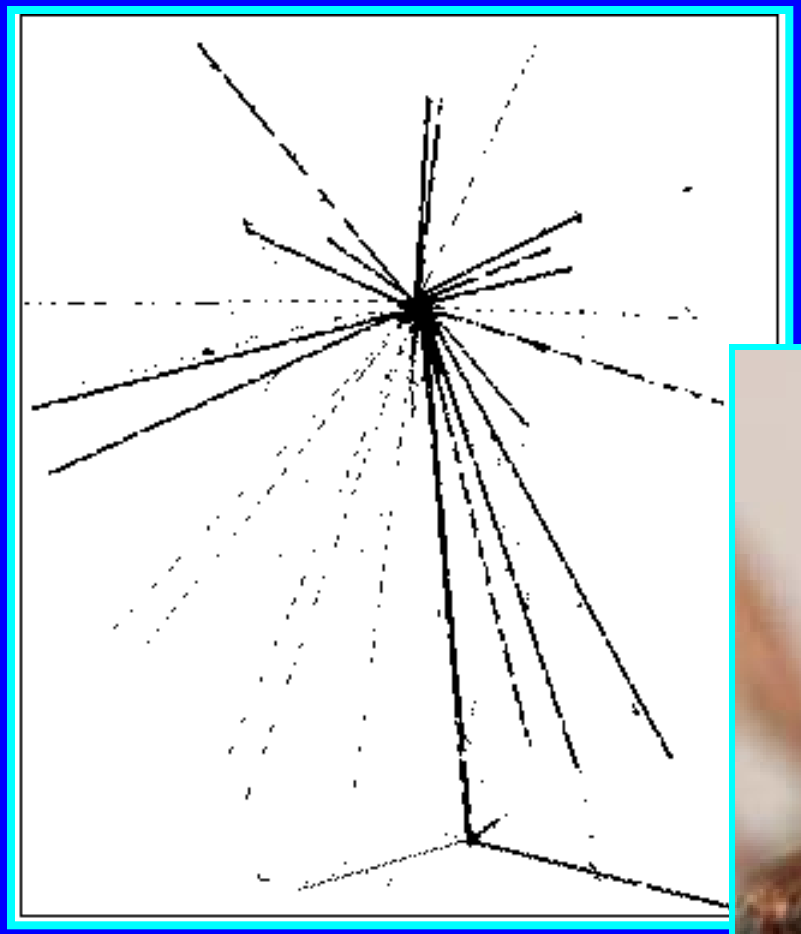
Stereo pair:

500 kiloVolts for 10 nanoseconds (0.00000001 sec)

BIG BANG!

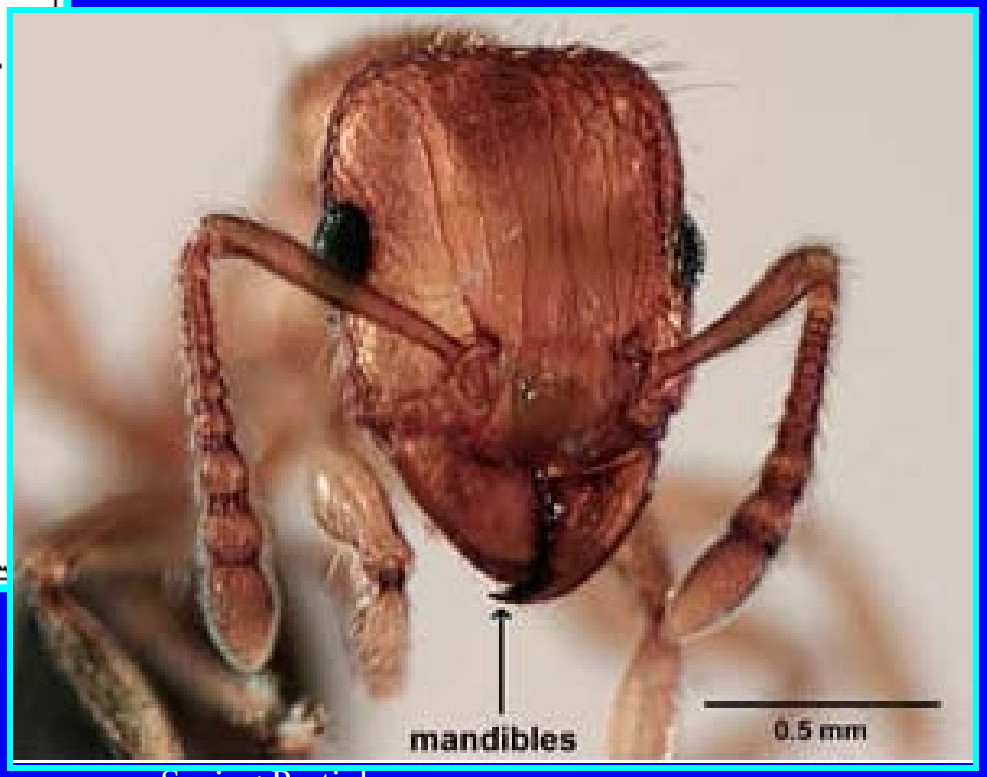
Photographic emulsions

| ← 1 mm → |



Ant's head

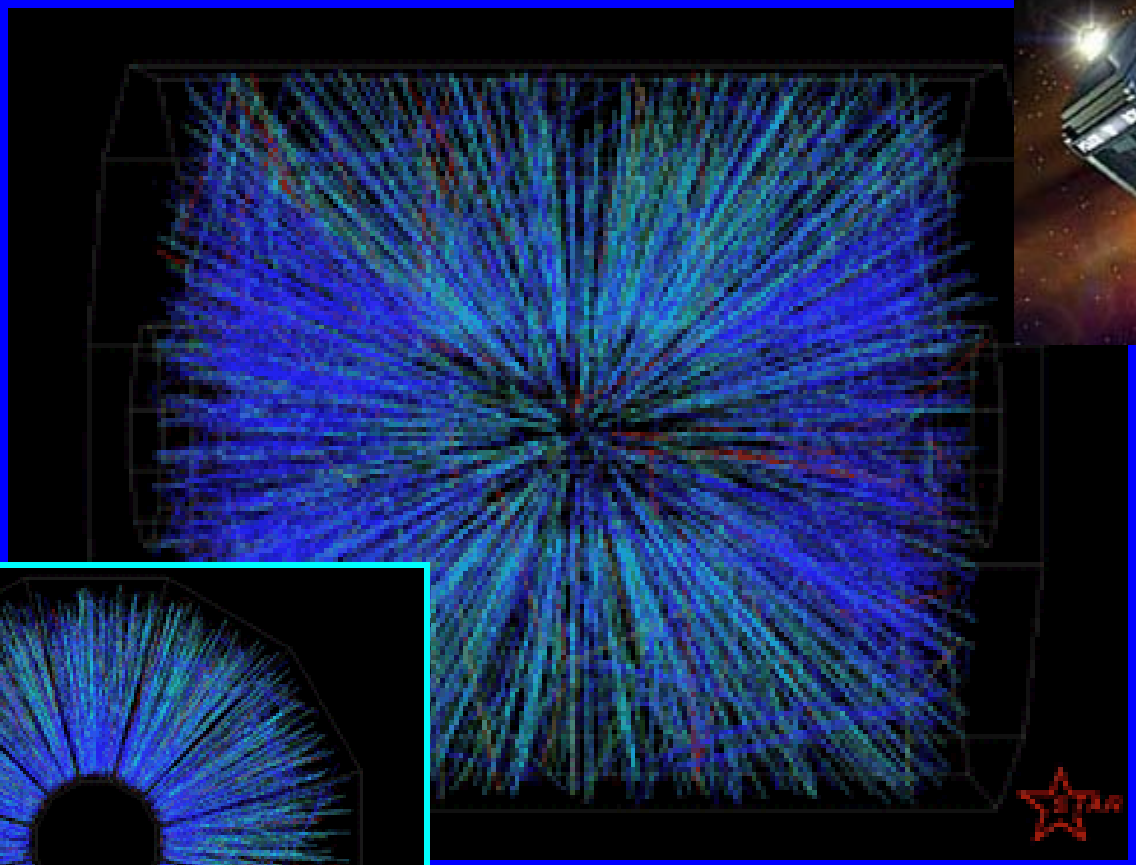
| ← 1 mm → |



"Time Projection Chamber"

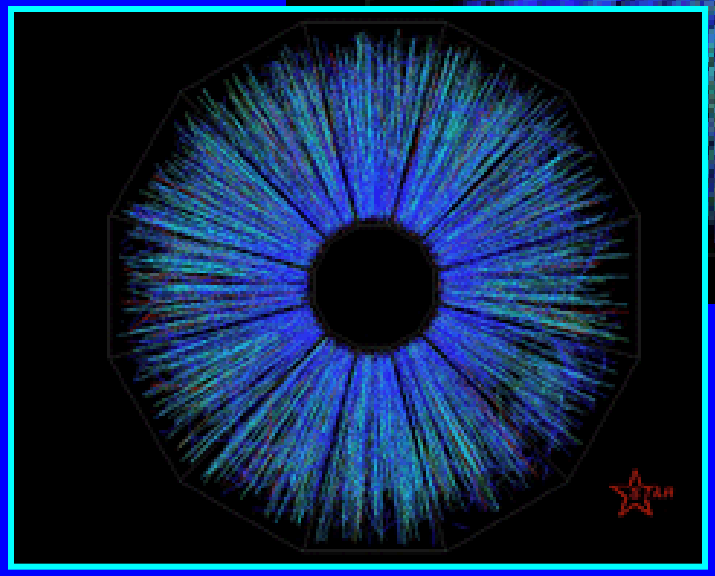
Electrons drift in gas: position → time

Dr. Who



Gold nucleus

Gold nucleus



STAR experiment at Brookhaven National Lab

Drift Chamber:
Wires in gas connected to computers

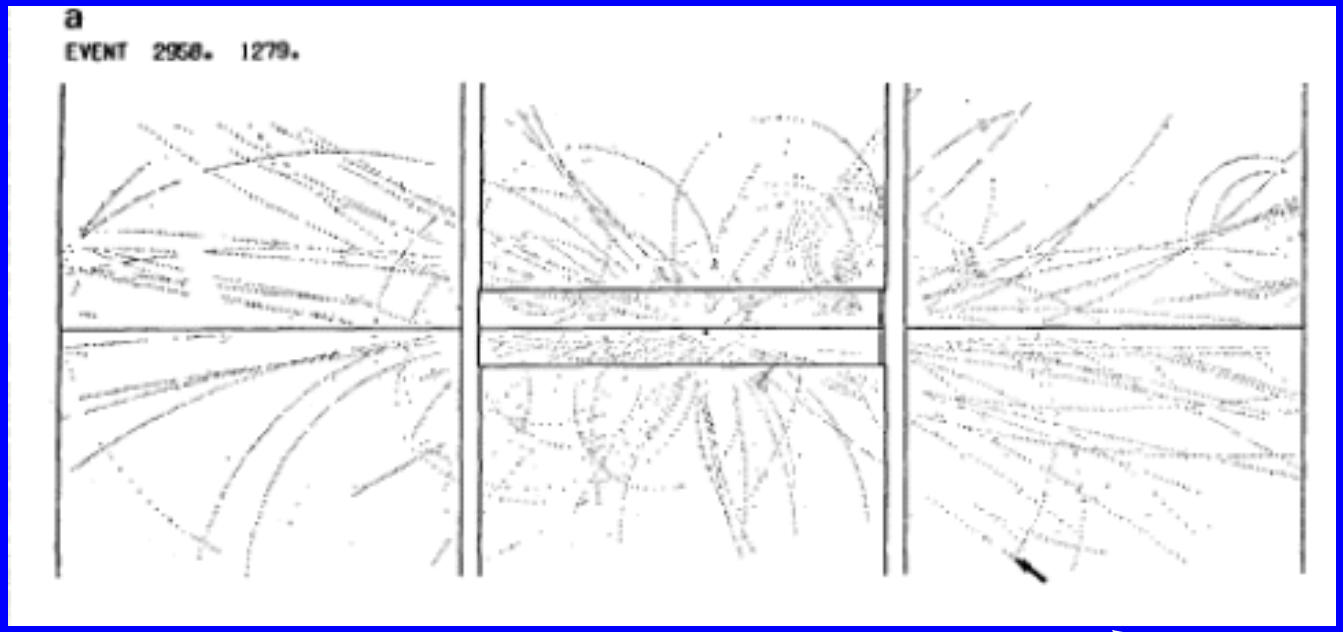
Discovery of W & Z particles (1983)

Experiment UA1 (CERN)
Carlo Rubbia, NP
Simon van der Meer, NP

UA1 Drift Chamber

Every point is a measurement on a wire.

Magnetic fields makes particles bend.



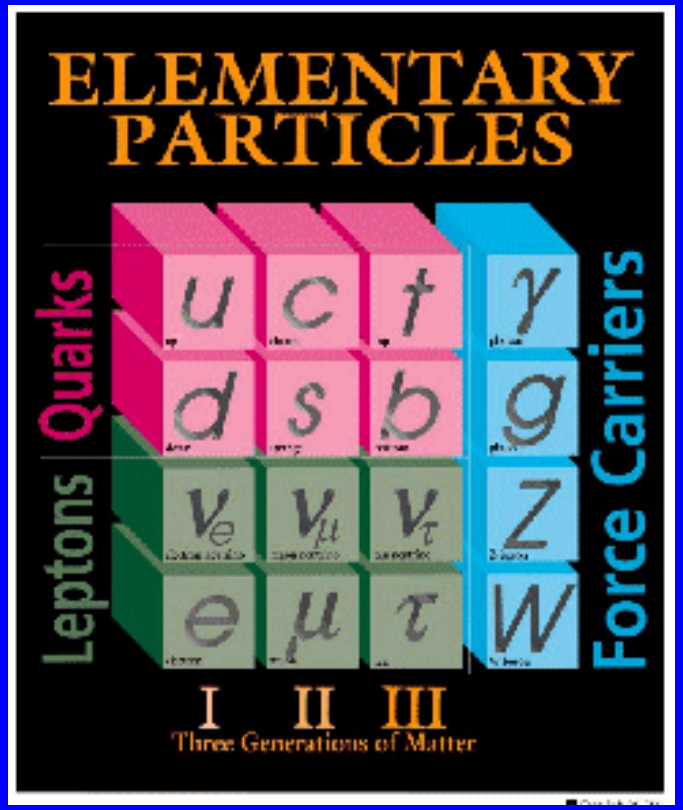
High energy electron from W decay

Fermilab Accelerators

www.fnal.gov

Tevatron, 4 miles around,
Superconducting magnets.
Highest energy collisions
until last December!

“Standard Model”



Looks neat, but don’t be fooled!

Why 3 generations/families?

How do they get those masses?

Is there a new field & particle: Higgs?

Why is the Universe all matter?

Are the forces unified at small distances?

How does gravity fit in. Graviton?

Are there super-symmetric partners?

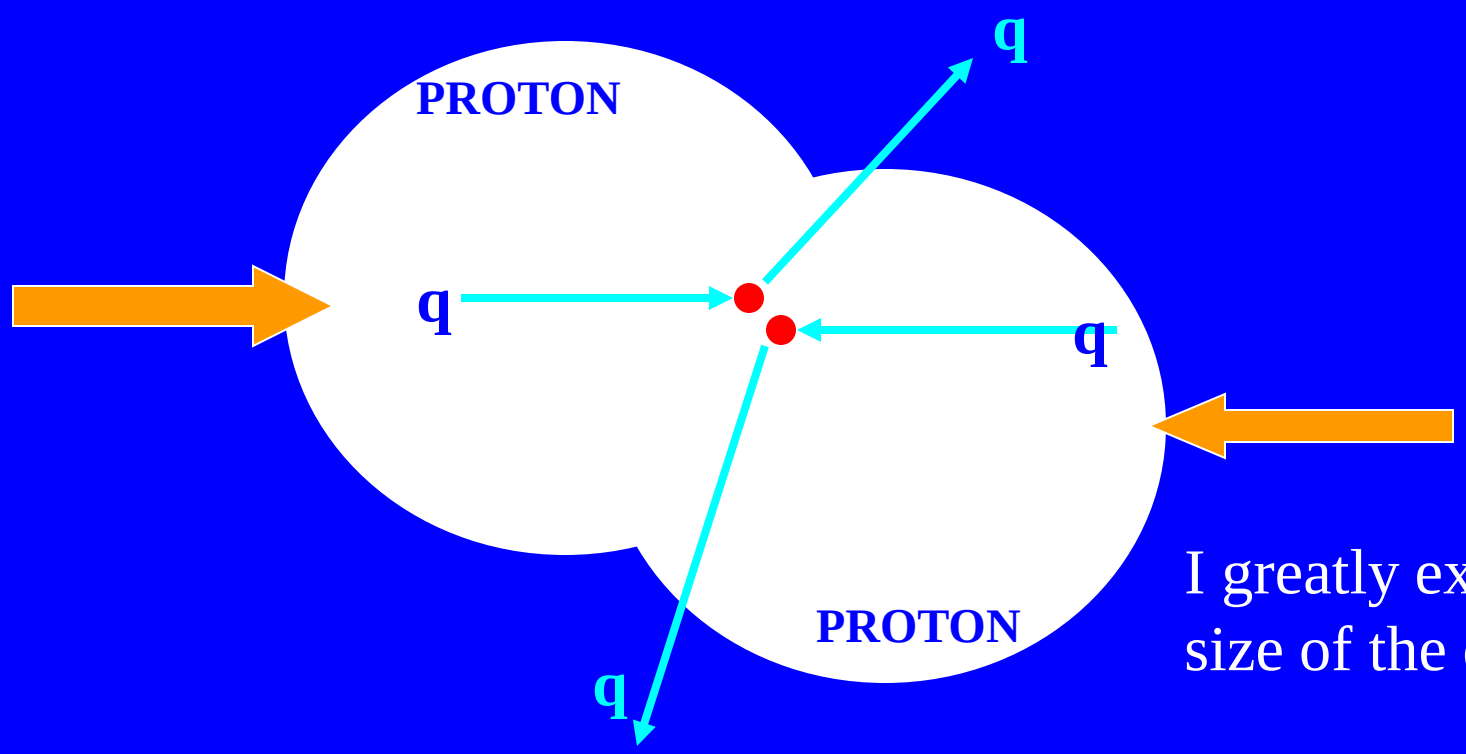
Are there “dark matter” particles?

Are there more than 3 space dimensions?

What if anything is “dark energy”?

Seeing Quarks : much smaller than protons!

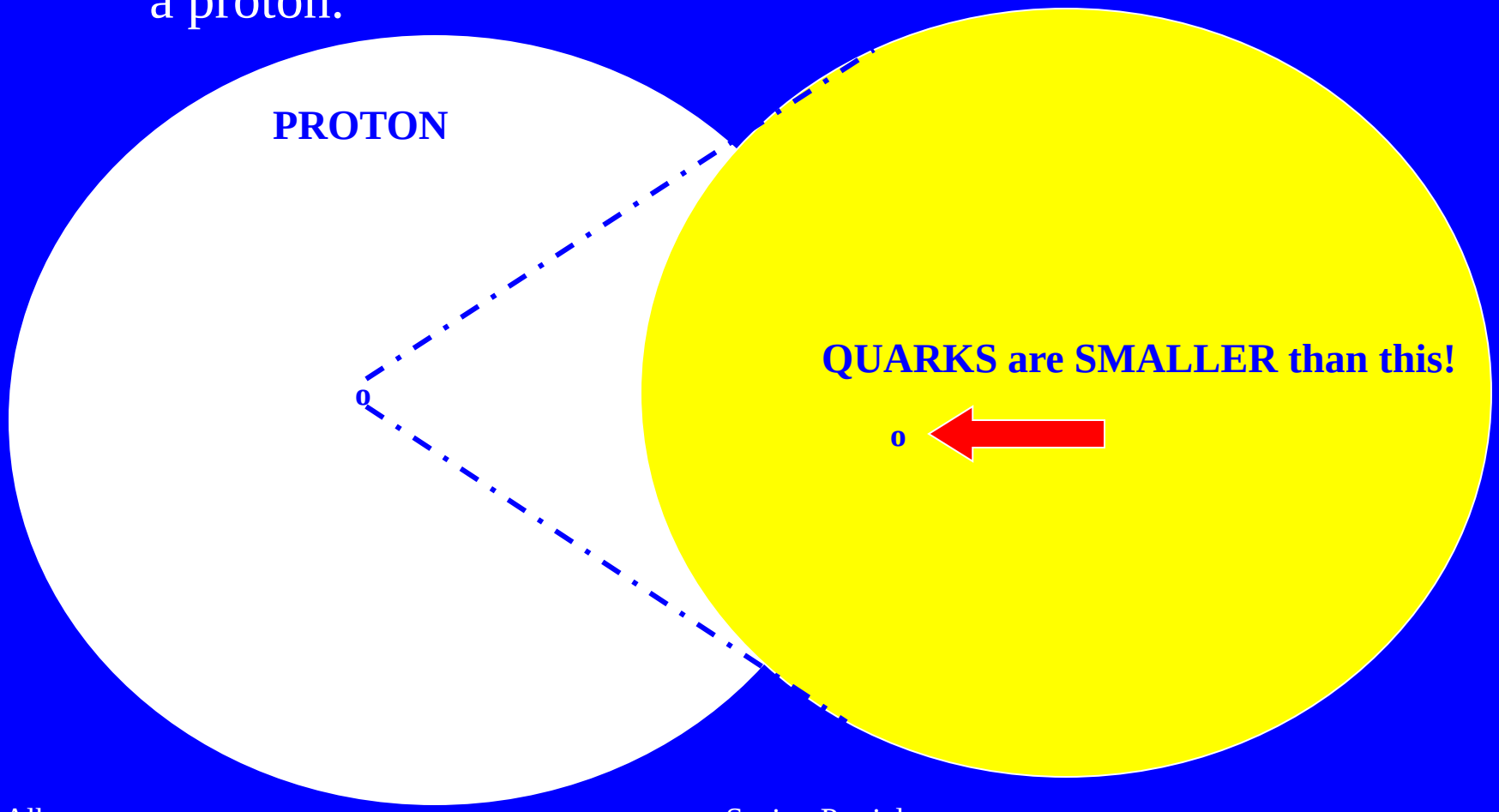
QUARK transforms itself
into a spray (jet) of free particles



I greatly exaggerate the
size of the quarks!

Thus we can “see” the **top and bottom** quarks and others (**up, down, strange, charmed**!)

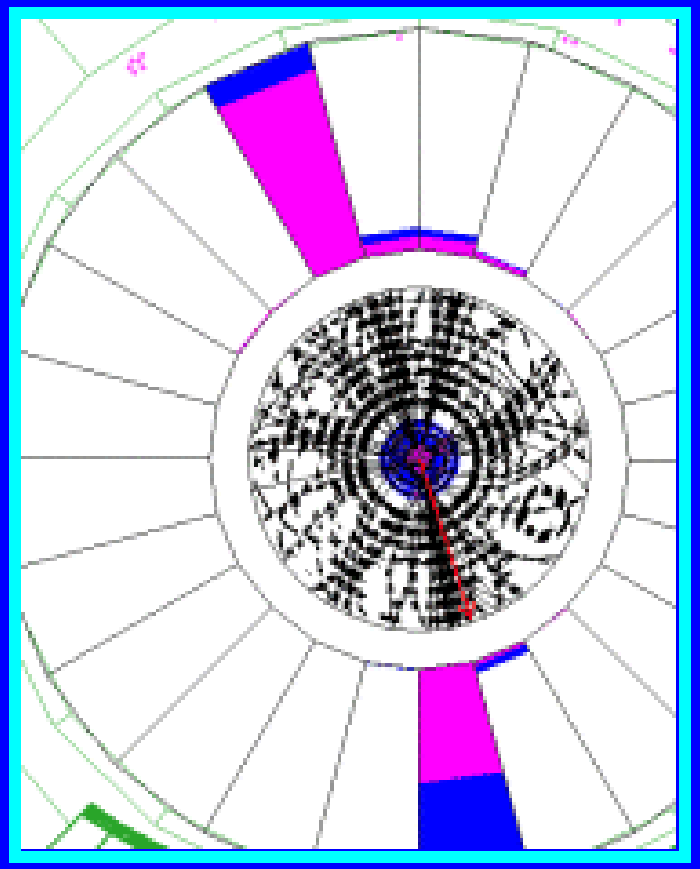
We can see that they are ***at most*** 1/5,000th the size of a proton.



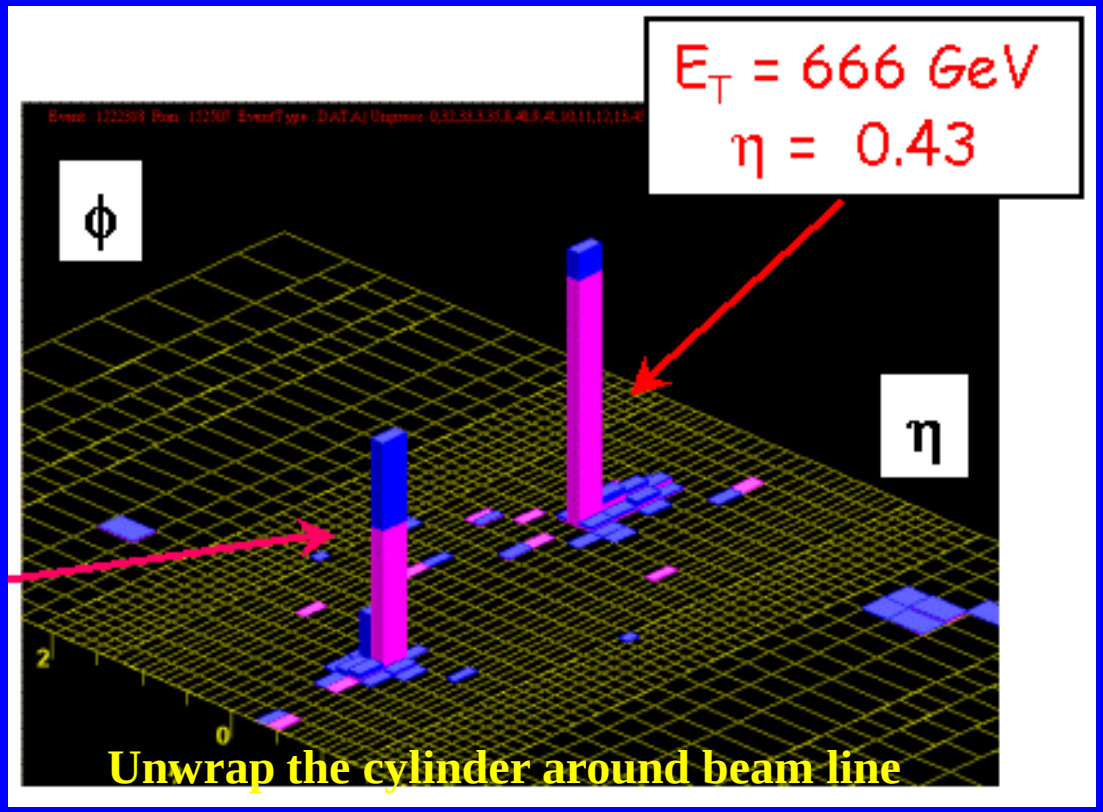
CDF
Fermilab

Quarks in protons can scatter – but turn into jets (sprays) of particles on way out

"See" tracks in wires+gas chamber



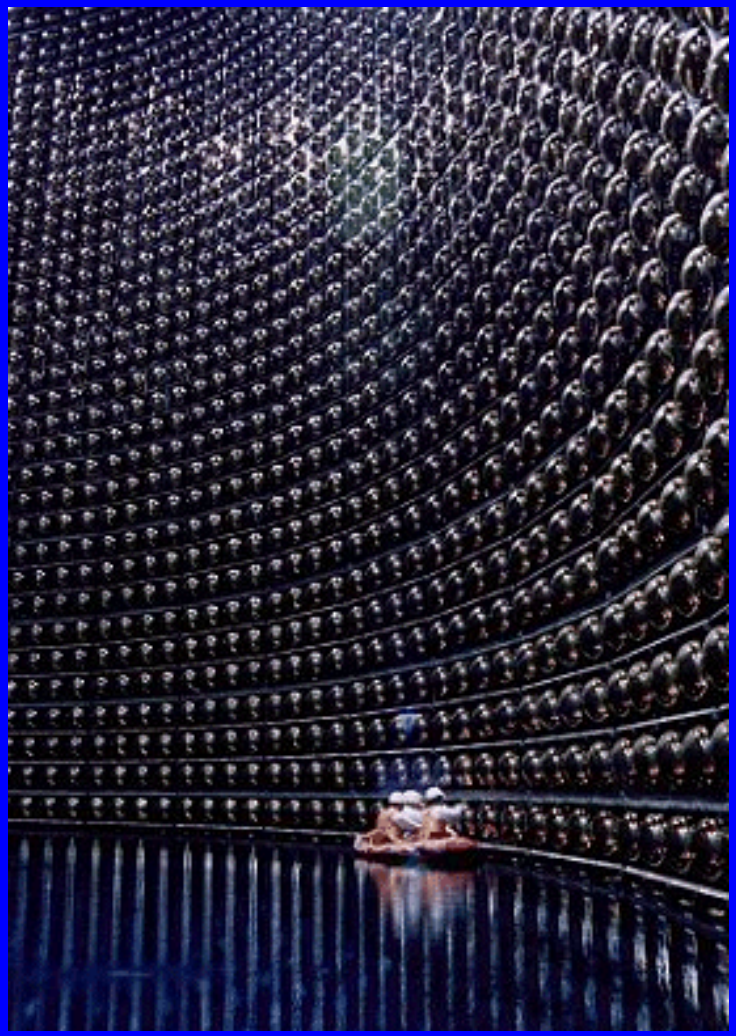
"See" jets in lead-iron-plastic multilayer sandwich



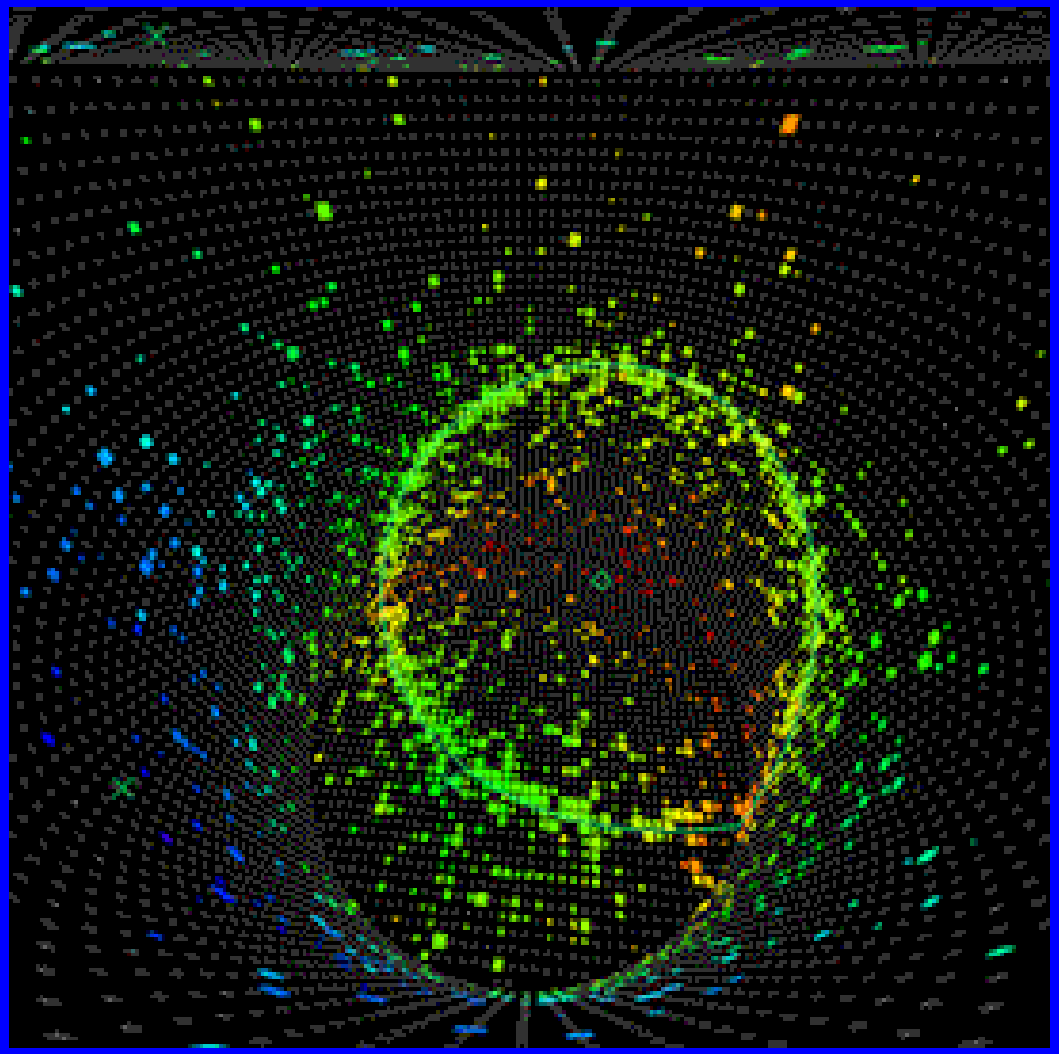
Diameter quarks (much?) less than about 1/5000th proton size !

Neutrinos!

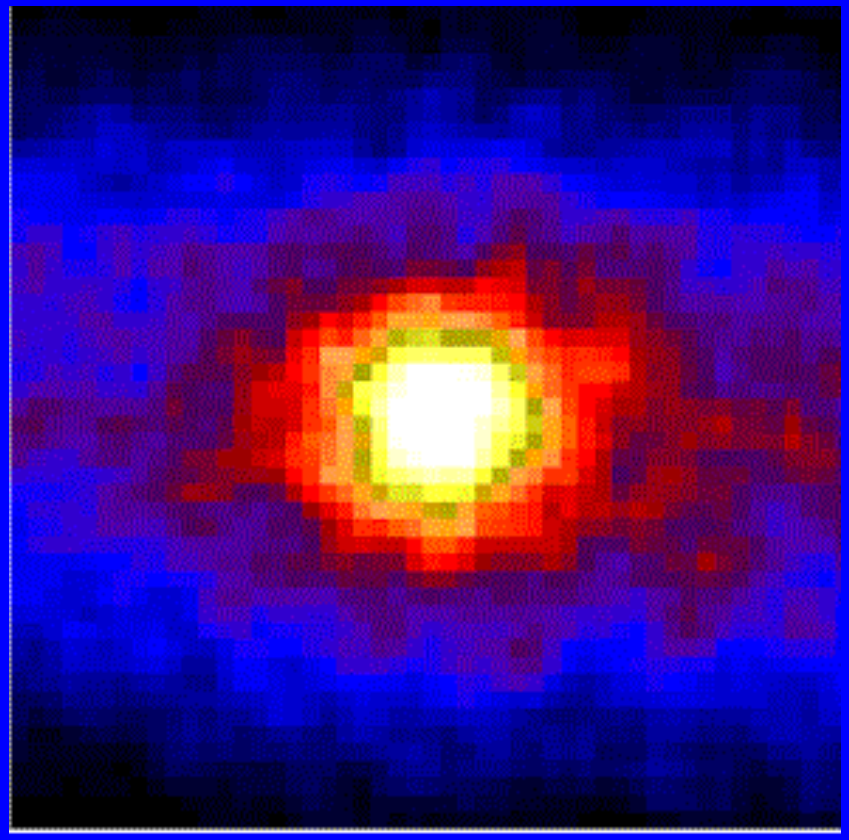
Deep underground
Neutrino telescope



Neutrino interacts (rare!)
Light emitted in ring



The Sun at night, seen with neutrinos through the Earth!

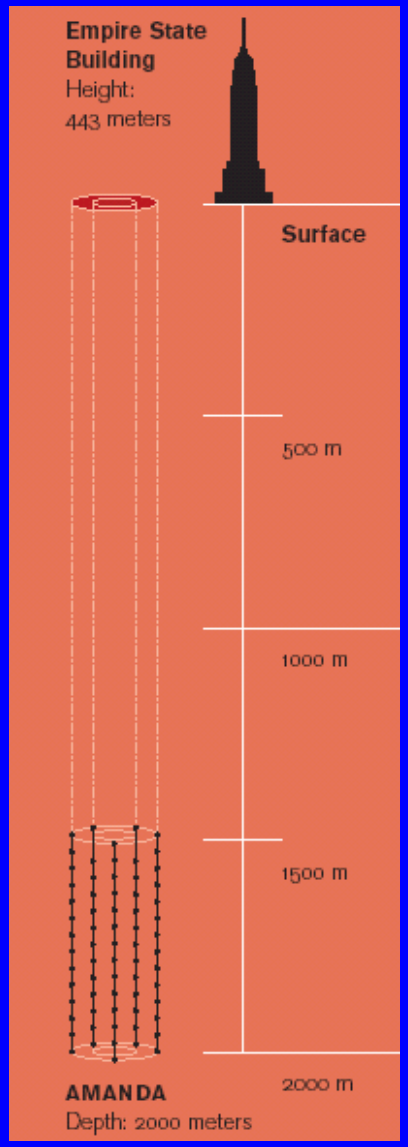


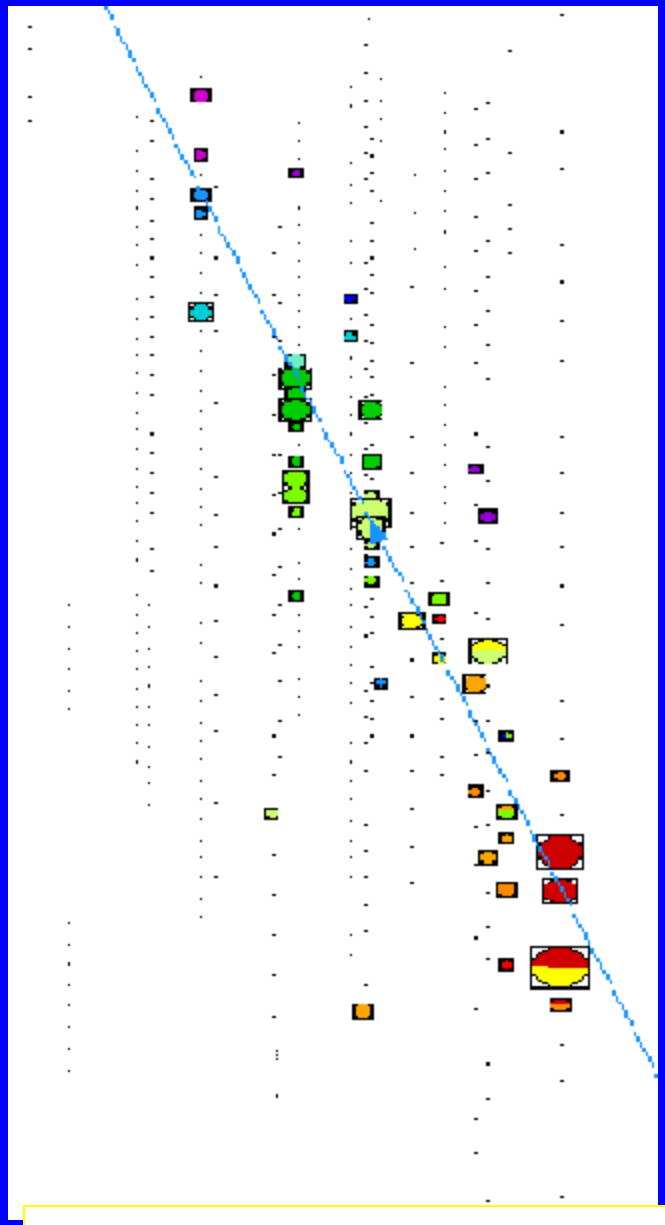
SuperKamiokande, Japan

& we can “see” Fermilab through the Earth from N. Minnesota!
(very blurry though!)

AMANDA (Antarctica)

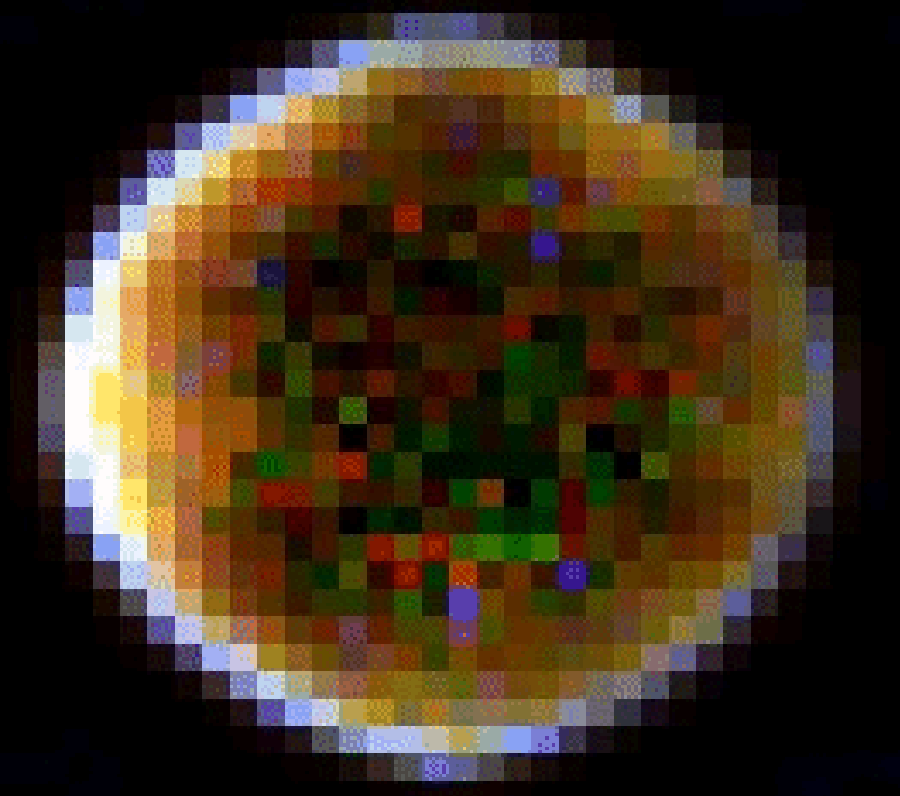
2 km ICE





Next: ICECUBE, ~ 1 km x 1 km

The Earth, seen from space in gamma-rays



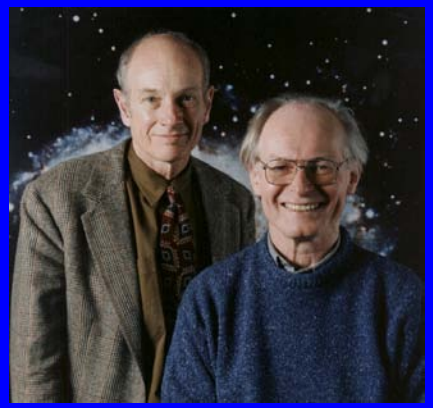
Cosmic ray showers in the atmosphere!

APOD 050331

AUGER Cosmic Ray Observatory (Fermilab + many others)

Most energetic particles ever "seen"

Jim Cronin, NP
Alan Watson



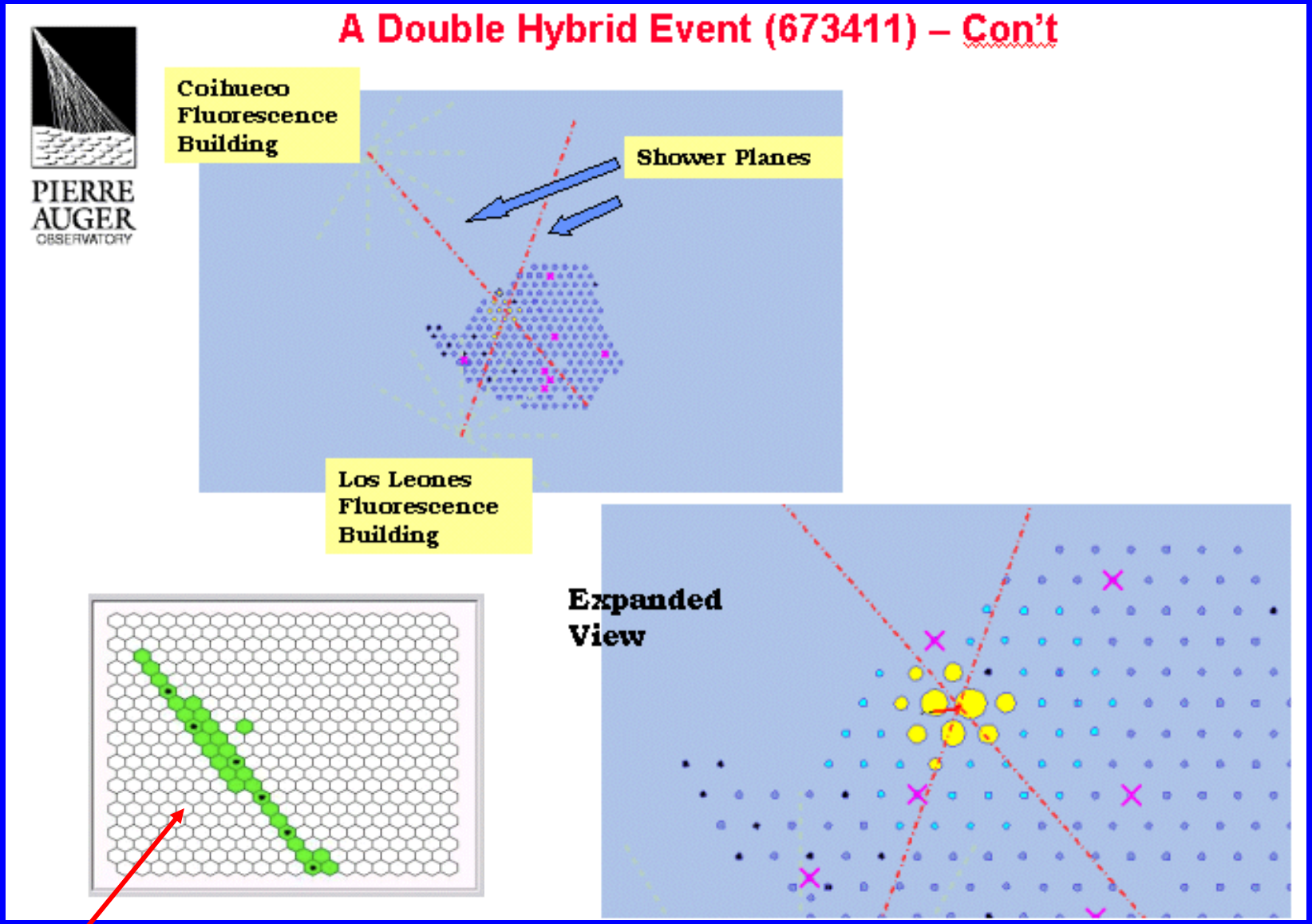
Atmosphere "glows"

Tanks 1.5 km apart

100,000,000,000,000,000,000 x 1 volt
100,000,000 x Fermilab's beam

(& we're still here)

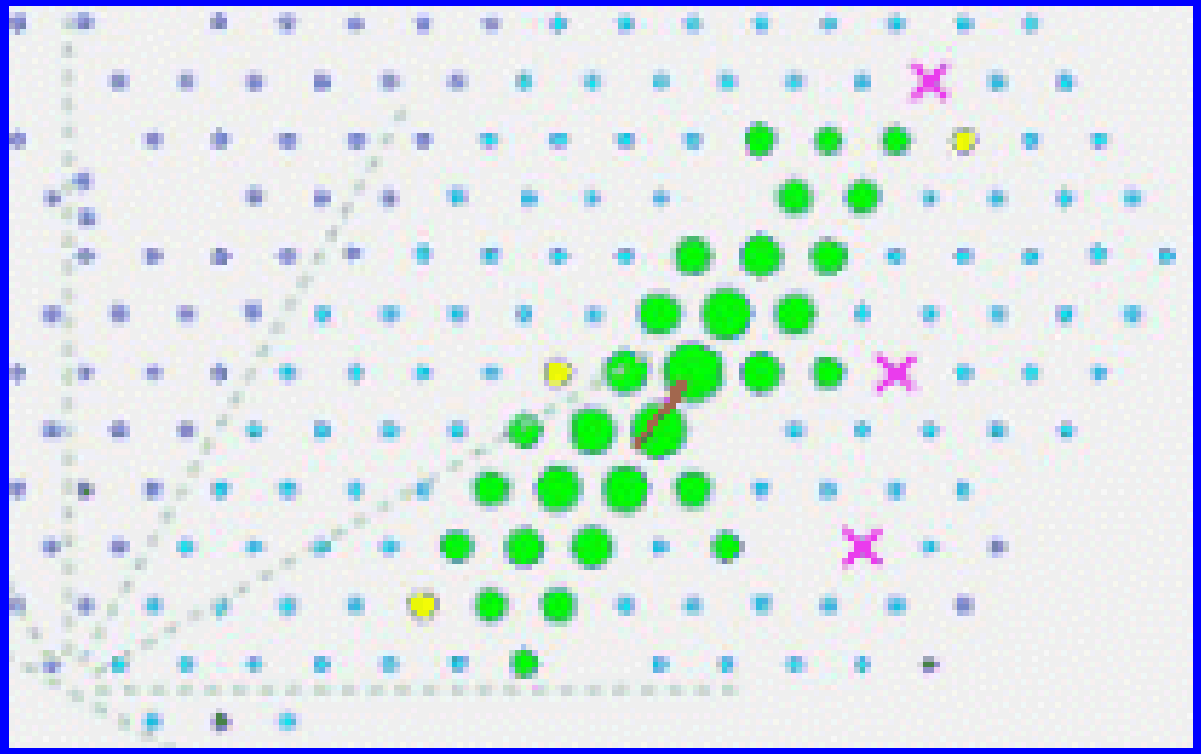
A Double Hybrid Event (673411) – Con't



Trail of light in sky (flash)

What is it? Where from?

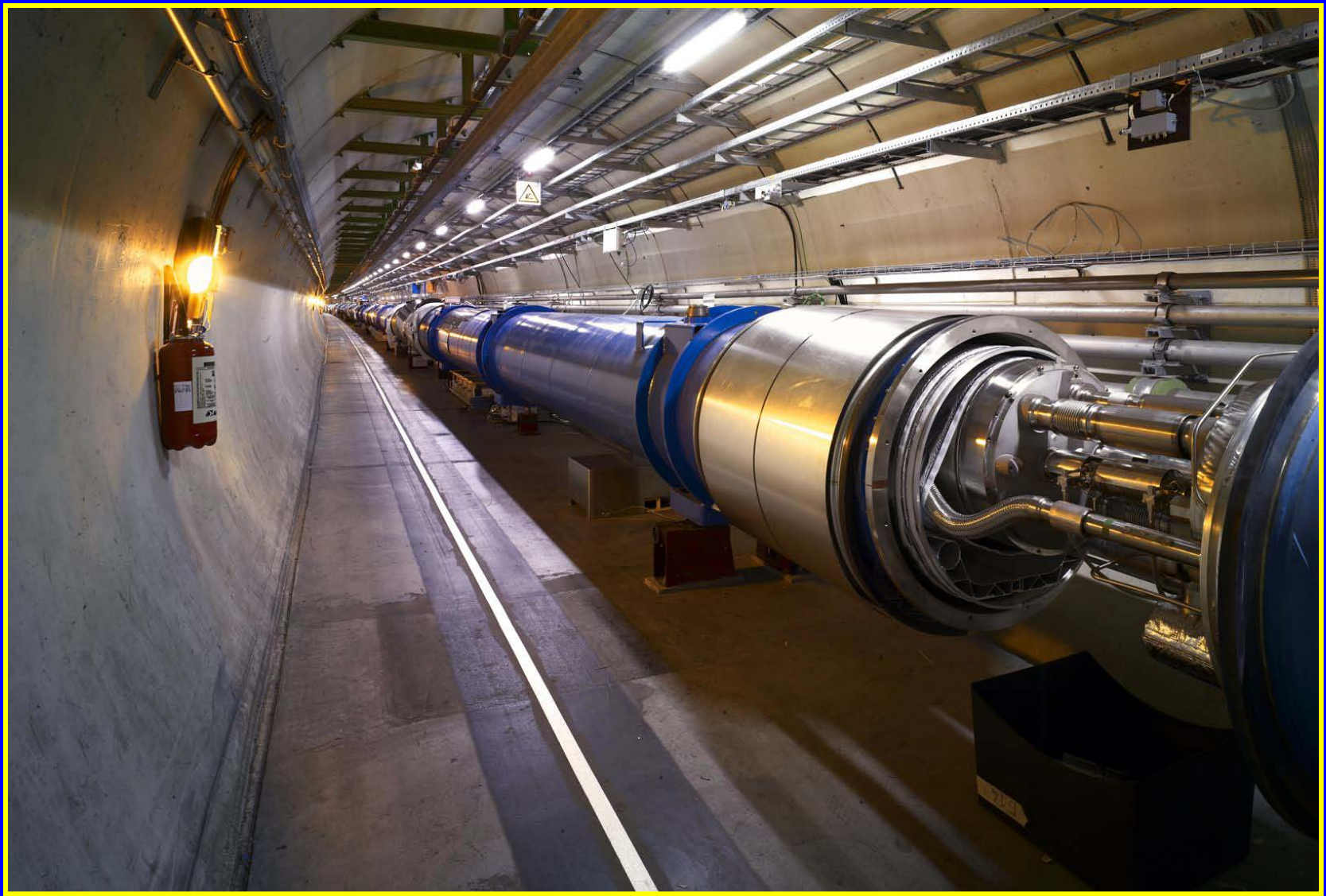
Nearly horizontal cosmic ray shower
Almost most energetic particle “seen”
Green blobs are water tanks with flashes



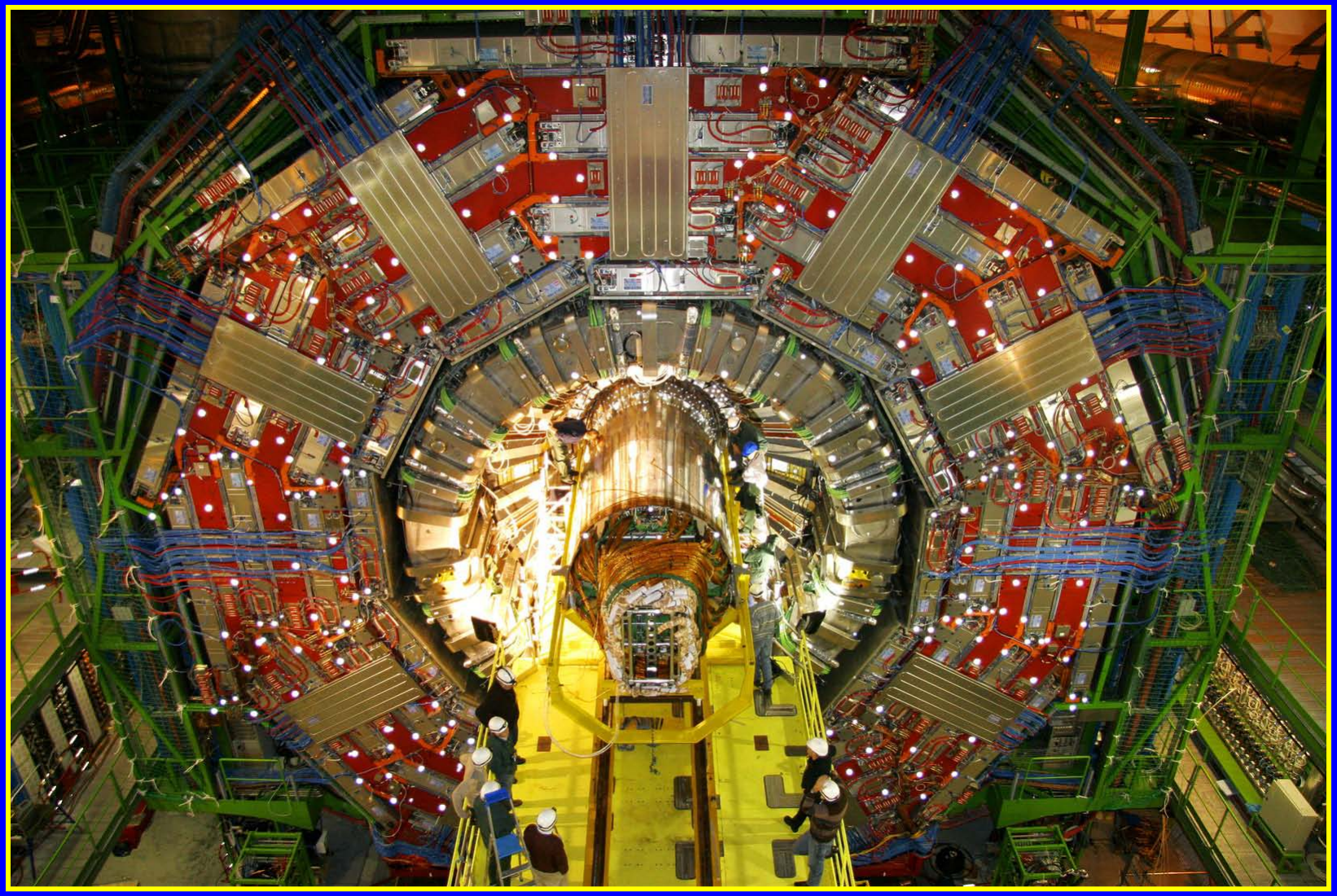
14 km

AUGER, Event 762577 5th May 04

The Large Hadron Collider, LHC: 27km of 2K superconducting magnets
CERN Geneva Switzerland & France : All European countries, since 1950s

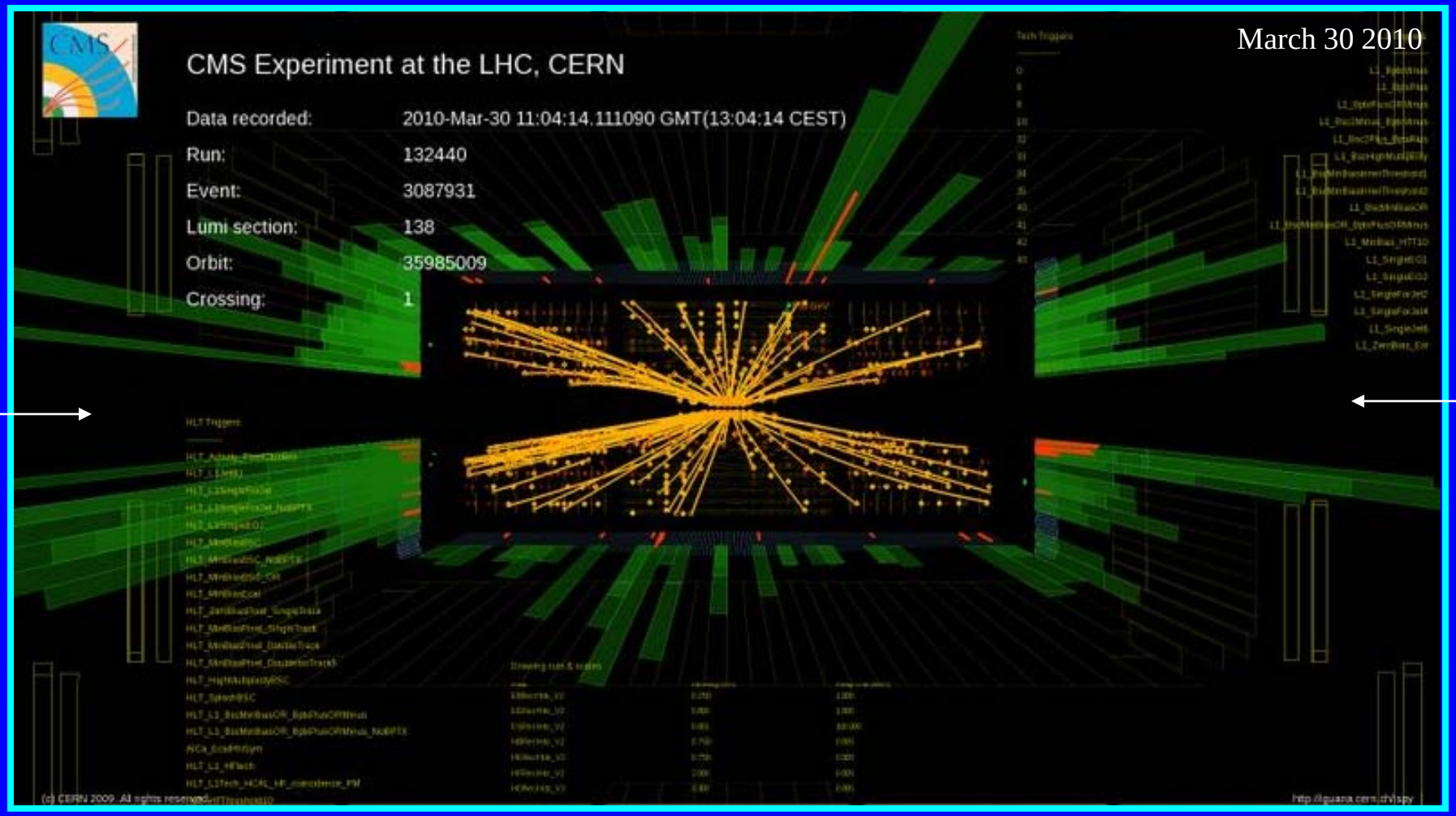


The “Compact” Muon Spectrometer. ATLAS is still bigger!



12,500 tons, 80,000 crystals of lead-tungstate (98% metal yet transparent!)
700,000 electronic channels! In 1 sec will write “10,000 Encyclopaedia Brittanicas”

Proton-proton collisions at 7000 GeV (Tevatron is 1960 GeV)



Tracks fitted to hit tiny (1/10th mm) pixels in silicon wafers

100 years ago we first could “see” individual particles:
sparkles in zinc sulphide, tracks in a cloud chamber.

With accelerators, progressing more than a million-fold in energy,
at the bottom rung so far we find quarks, smaller than:
0.000 000 000 000 000 000 5 the diameter of a hair.

Lots of questions, mysteries : masses, space dimensions, new forces…

The start-up of the Large Hadron Collider at CERN in the last few months, will let us zoom in one more step to the very small!

We have good reasons to expect exciting new discoveries …
but we do not yet know what! (Many, too many, ideas!!)

So:

The elementary particles of matter are MUCH too small to see directly with the eye.

But we can still see them with the *brain*, using many kinds of "artificial eyes"

Using (usually) electric charge of particles to shake up atoms

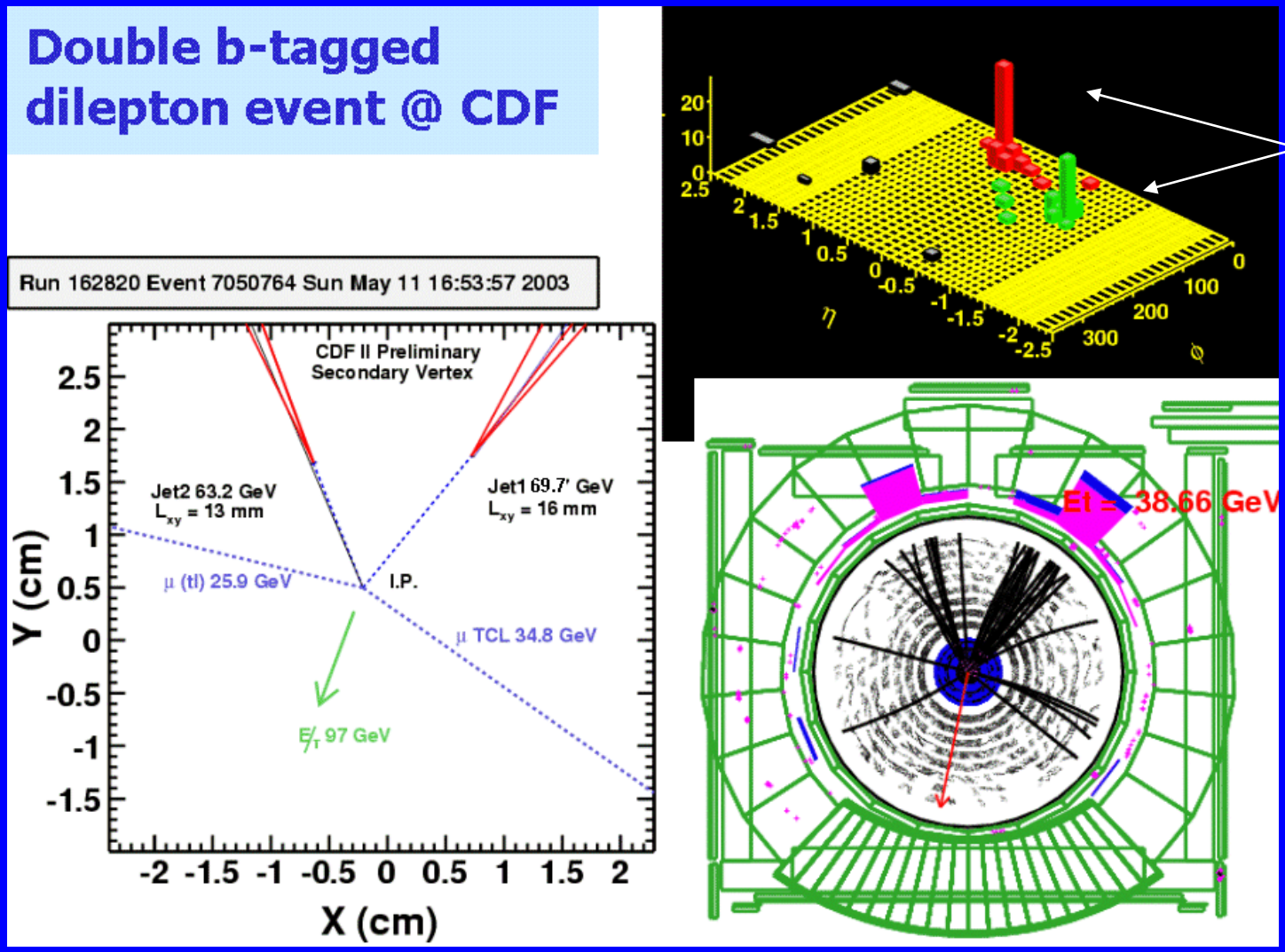
Then a tiny effect can be amplified and become visible:

droplet, bubble, spark, glow, light emission, electron avalanche ...

Thank you!

Questions?

Observation of top-quark pair production at Fermilab

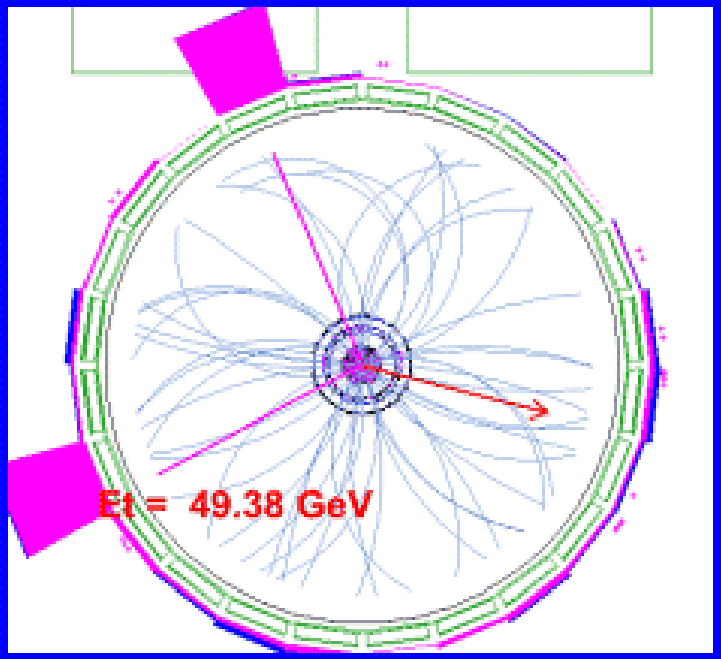


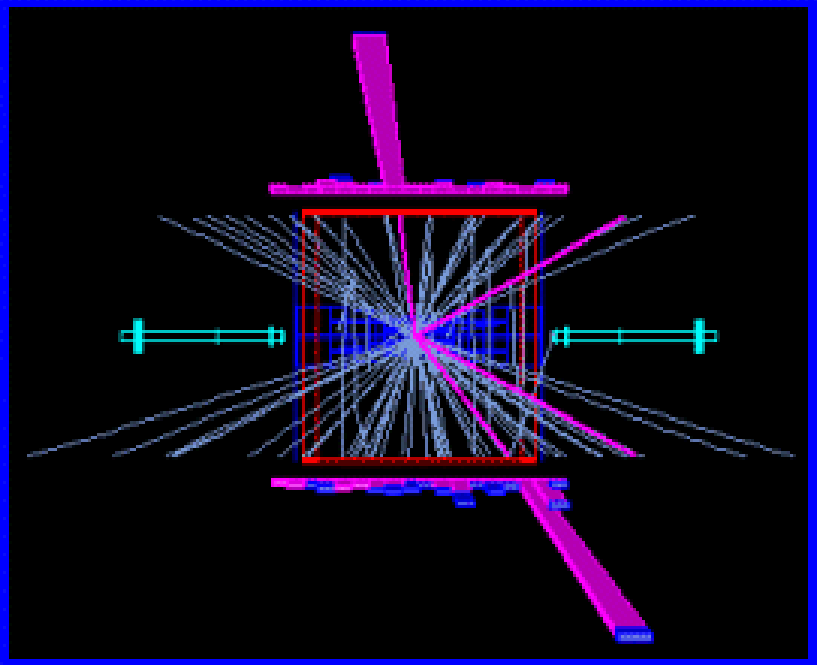
Jets or sprays of particles from bottom quarks

ZOOM IN : silicon microstrip detector

At Fermilab: Proton-Antiprotons Collide
Highest Energy anywhere
0.9999995 x speed of light

Drift Chamber of CDF





Two Z-bosons, each about 100 x mass of proton
+ more than 70 other particles created