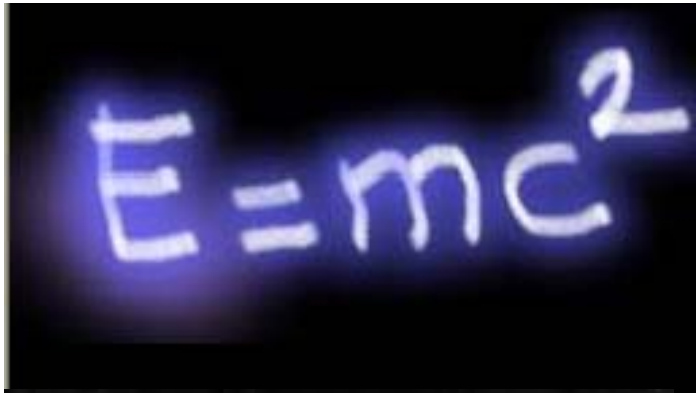
Anti-matter at Fermilab!

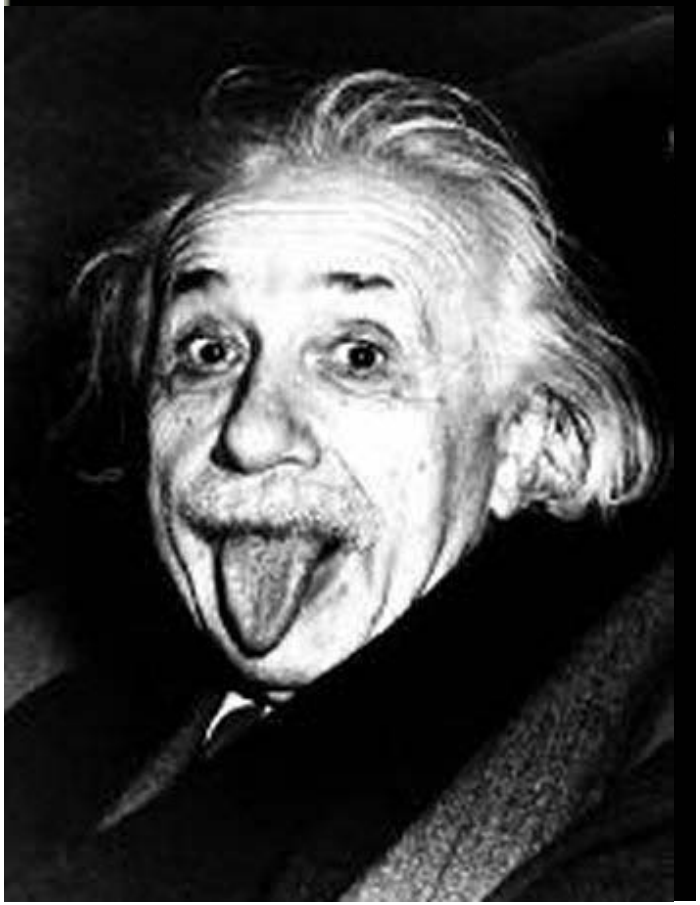
home of the world's highest energy particle accelerator

Peter H. Garbincius – May 21, 2006

at Fermilab – since 1976

- **what's the matter?**
- **history of anti-matter**
- **anti-protons = just a tool**





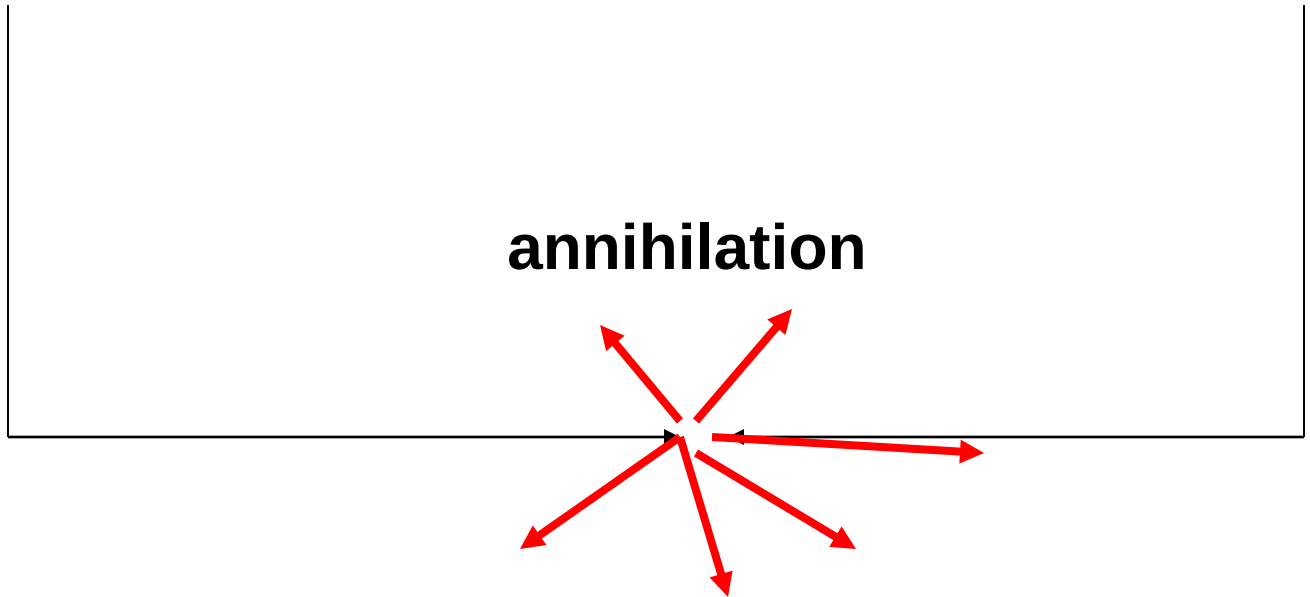
1905

1928

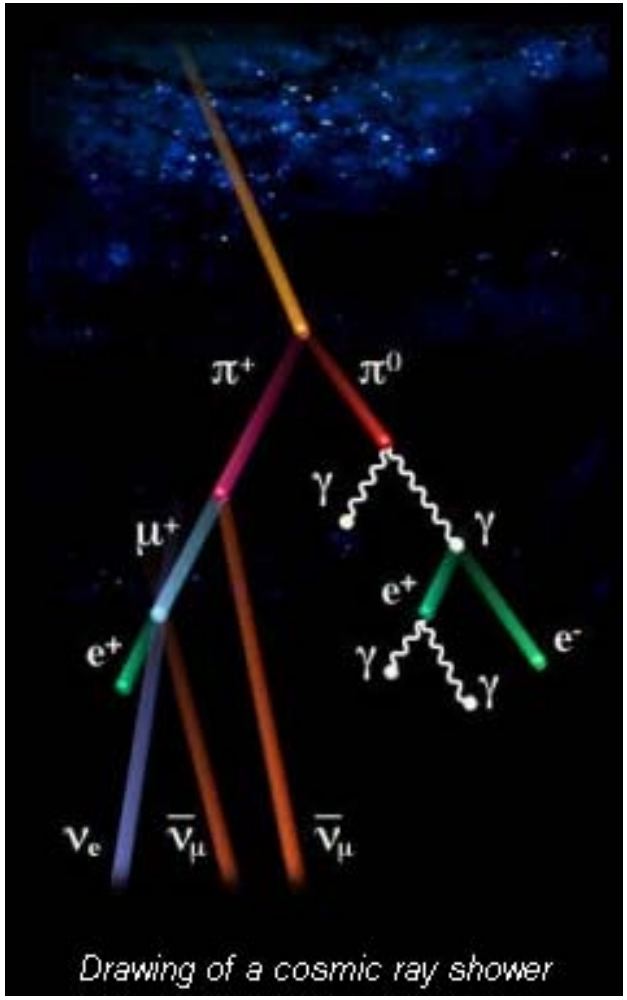
Energy

$E = Mc^2$

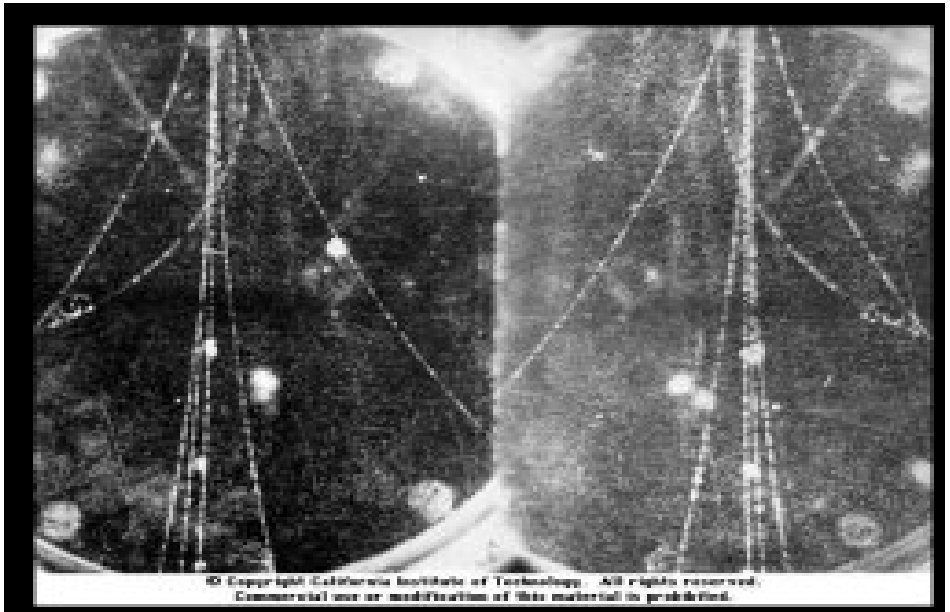
protons		anti-protons
+1	electric charge	-1
938 MeV/c^2	mass	938 MeV/c^2
+1	baryon number	-1



First observation (1933) of anti-matter positrons (positive electrons) e^+



Drawing of a cosmic ray shower


A small cosmic-ray shower of positive and negative electrons

e^+ bends right, while e^- bends left in a magnetic field

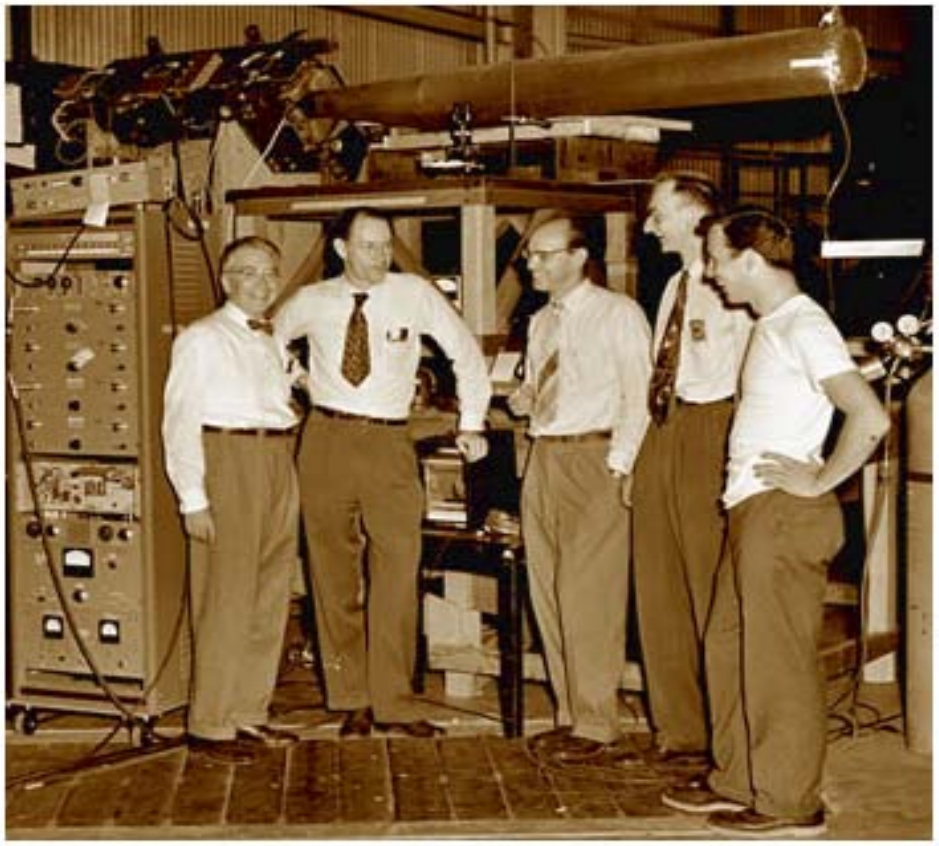
50, 100 & 150 Years Ago

FROM SCIENTIFIC AMERICAN

Lysenko Retreats ▪ Consumers Benefit ▪ Neptune's Realm Photographed

JUNE 1956

THE ANTIPROTON—"Since it was apparent that creation of the antiproton required tremendous energy, the most likely place to look for it was in cosmic rays. On a few occasions investigators found events which seemed to signal the generation of an antiproton, but there was never sufficient information to identify it with certainty. When the Bevatron at the University of California began to bombard a target made of copper with six-Bev (billion electron volts) protons, the next problem was to detect and identify any antiprotons created. A plan for the search was devised by Owen Chamberlain, Thomas Ypsilantis and the authors of this article. Tracks of about 20 antiprotons have now been detected in emulsions by observers in Berkeley. —Emilio Segrè and Clyde E. Wiegand" [*Editors' note: Emilio Segrè won a Nobel Prize in Physics in 1959.*]



From left, Emilio Segrè, Clyde Wiegand, Edward Lofgren, Owen Chamberlain, and Thomas Ypsilantis, members of the team that discovered the antiproton

1955

What is the universe made of, and how does it work?

What is this made of, Daddy?

What's inside of that?

What's that made of?

What inside of that?

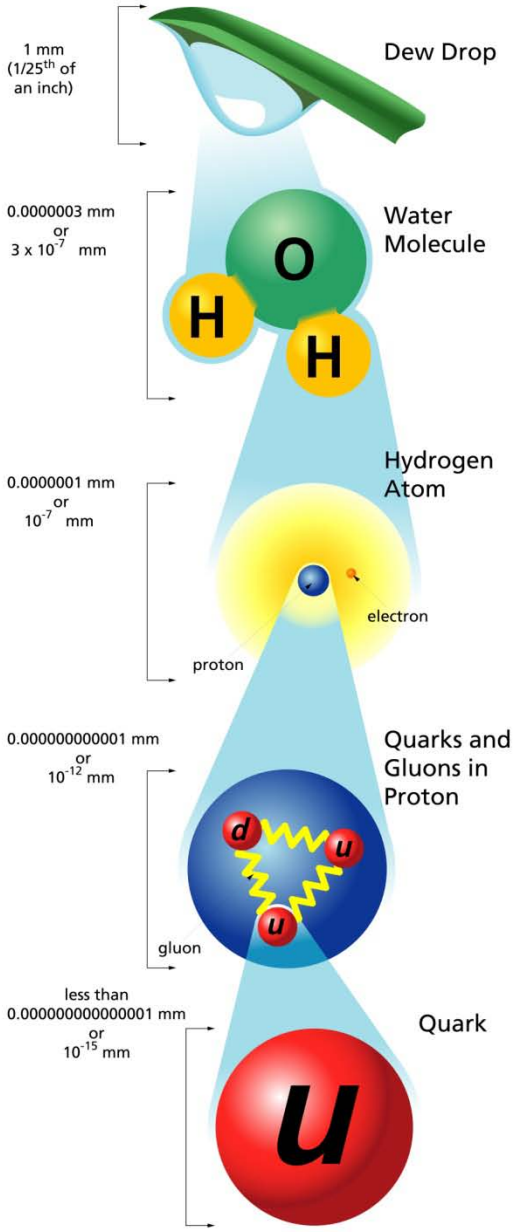
. . . .

Questions of

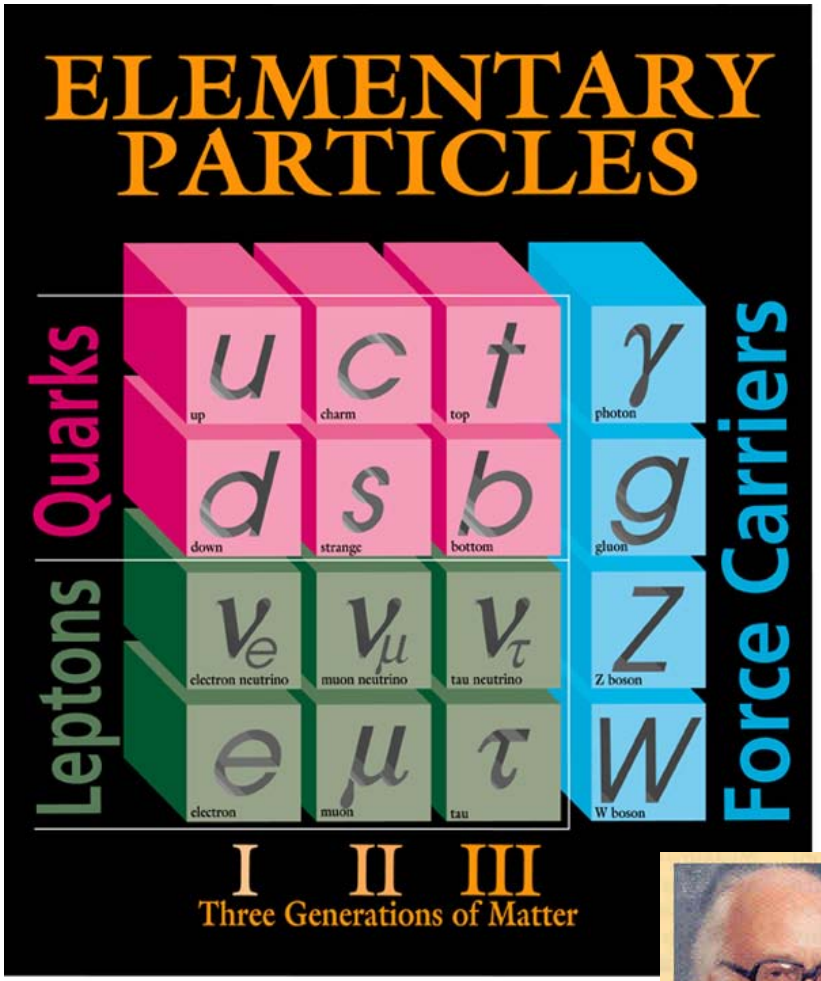
little children →

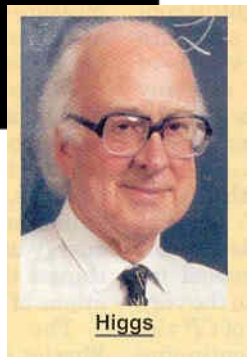
ancient Greeks (atoms) →

today's physicists



Our "Periodic Table"





Quarks, Leptons, & Forces

b, t, ν_τ discovered at FNAL

Electromagnetism
Strong Nuclear Force
Weak Nuclear Force
(radioactive decay)
Gravity is too weak for us

fundamental particles
no size – without parts
can't break them apart
(at least with today's accelerators)

“In the beginning…”

12-15 billion years ago, at the Big-Bang

energy → equal amounts of matter & anti-matter

the early universe was completely ***symmetric!***

somehow that symmetry was lost…***how***

We look at the universe and we see only matter,

well, maybe a little bit of anti-matter produced

in well-understood interactions….for example,

in cosmic ray interactions,

γ-rays hitting interstellar

molecules, etc.

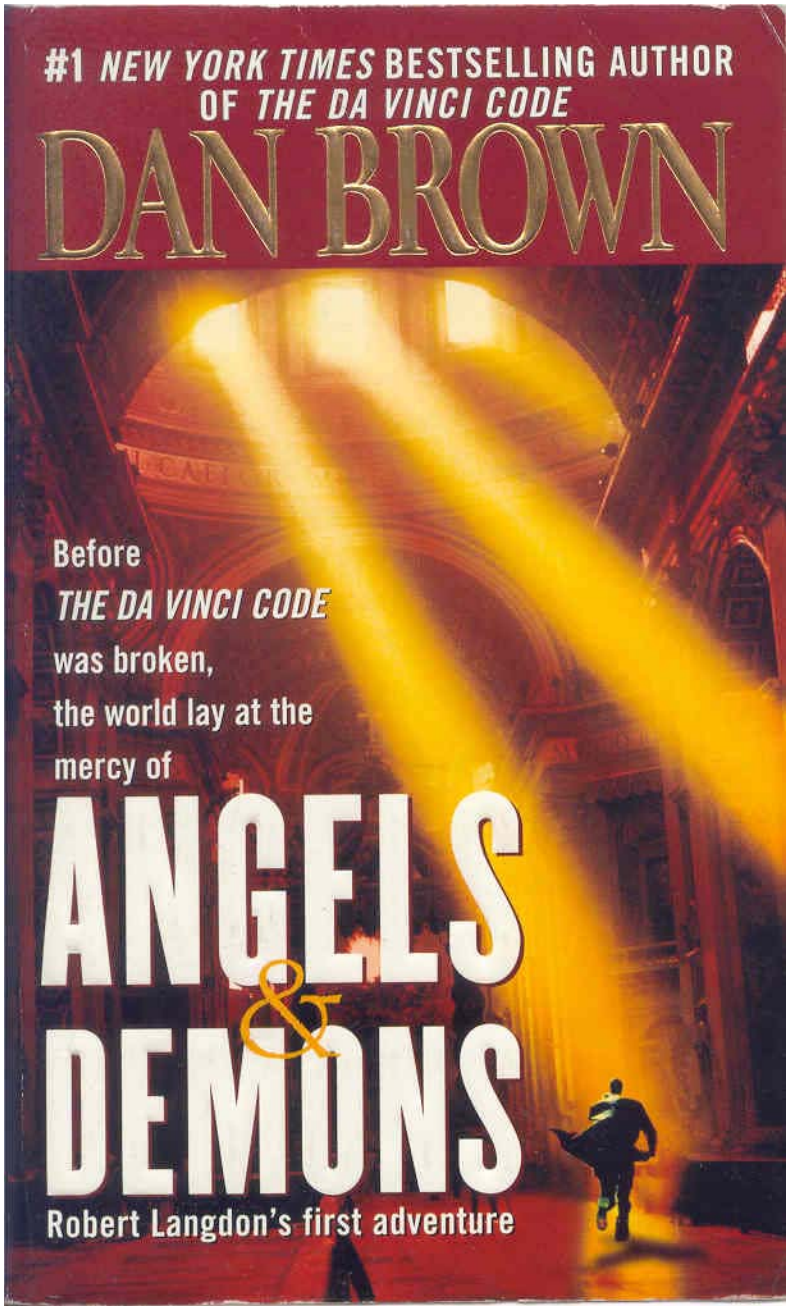
So what’s the matter with the anti-matter?

If you want anti-matter, you have to ***produce*** it!

No, I'm not doing a book review!

Only problem with story is the *economics* of producing anti-matter, it's just too expensive!

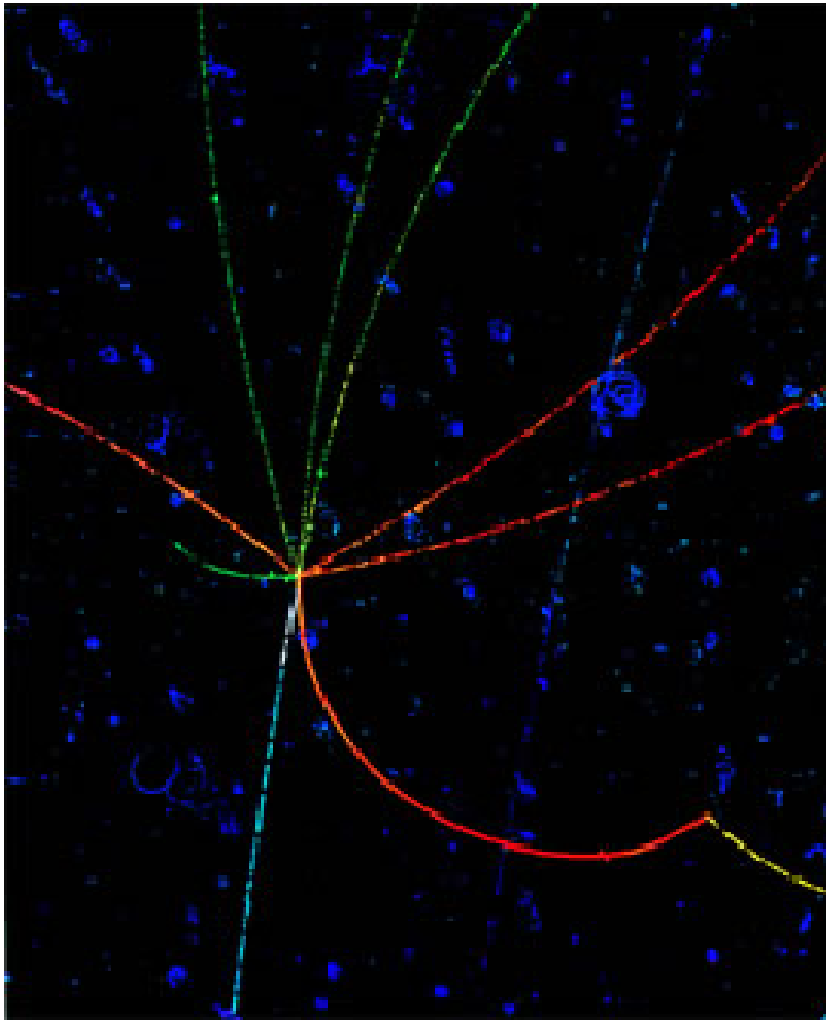
In 20 years, Fermilab, we've produced lots of antiprotons & science, but only a few nano-grams, or a few billionths of gram



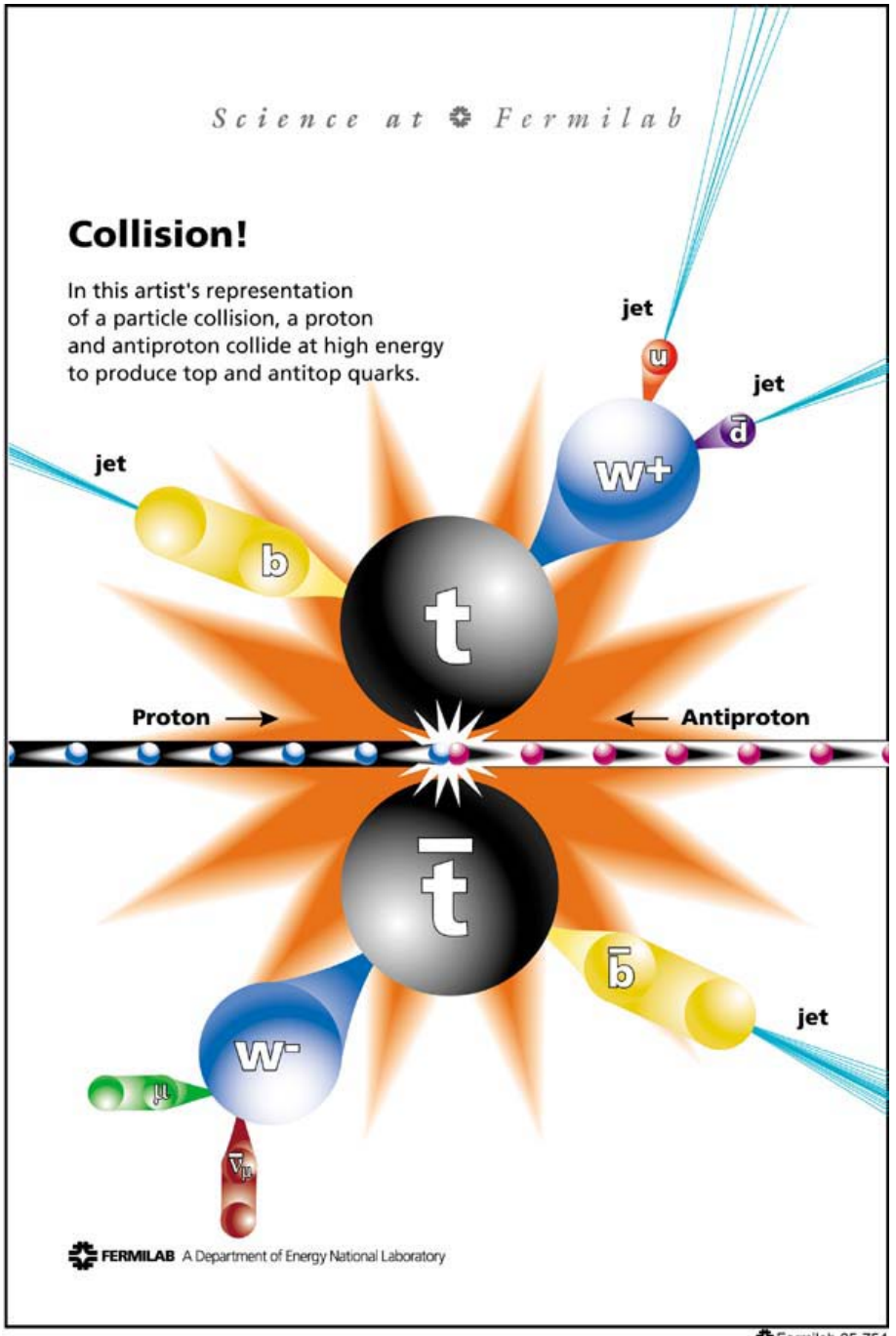
Why do we want ***anti-protons*** at Fermilab?

- Interesting in their own right, we study their properties and interactions, are they the same as protons (but opposite Q, B, etc.)?
  quarks in proton = anti-quarks in anti-proton
- As a source of high energy ***anti-quarks*** _
  some interactions just happen via ***q-q***
- Only need ***one accelerator ring*** (engineering) accelerate and collide protons & anti-protons in the same ring…***but*** need special pbar source,

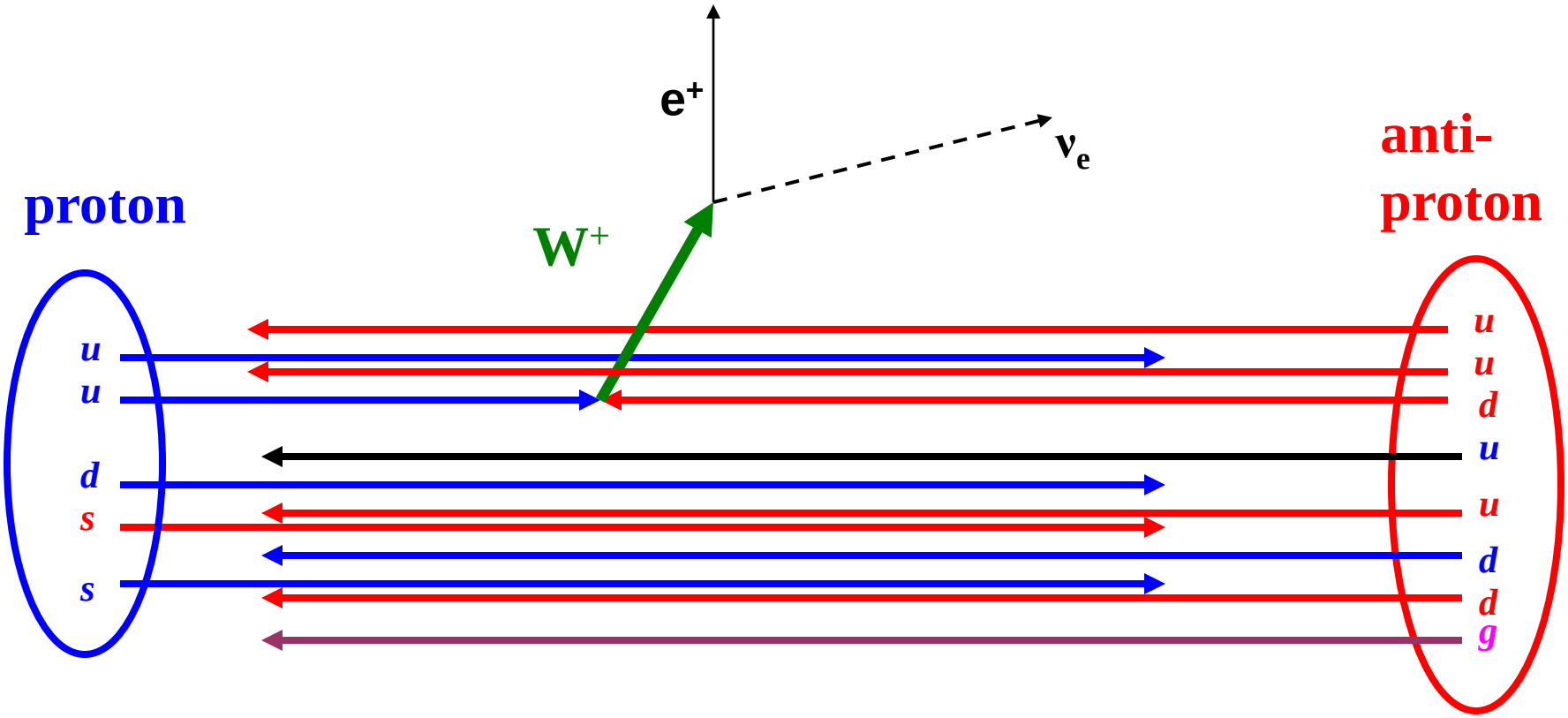
but that's a big but…



An antiproton (blue) enters a bubble chamber from bottom left and strikes a proton. The released energy creates four positive pions (red) and four negative pions (green). The yellow streak at the far right is a muon, a decay product of the adjacent pion. (The dark blue curlicues are low-energy electrons knocked from atoms not involved with the antiproton.)



$$p + \bar{p} \rightarrow W^+ + X \quad \text{or} \quad u + \bar{d} \rightarrow W^+$$



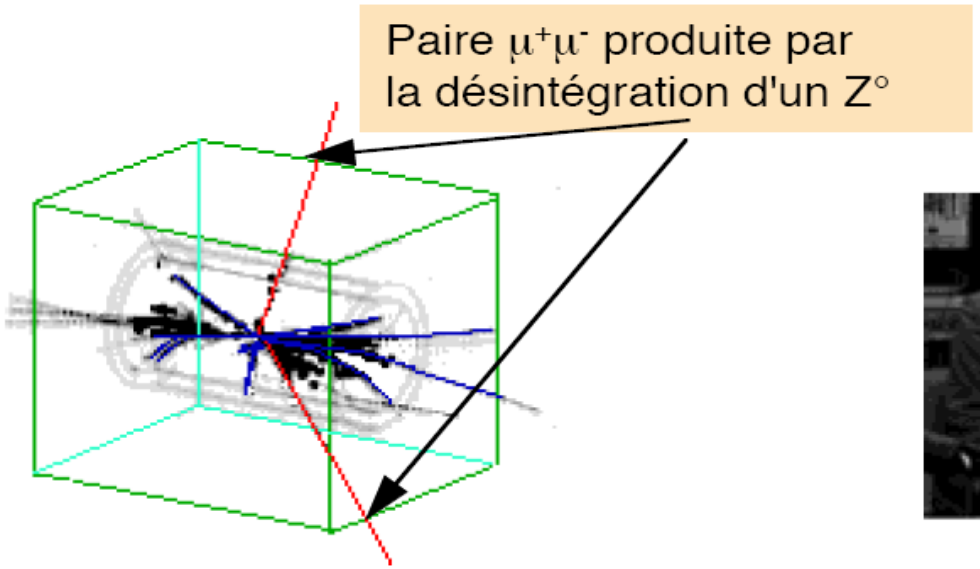
protons and anti-protons are bags of quarks (and anti-quarks) and gluons

we study the interactions of these smaller constituents *inside* the original particles

$p + \bar{p} \rightarrow W$ and Z^0 at CERN1983

Simon Van der Meer: stochastic cooling of antiprotons

Carlo Rubbia: led experiment discovered W and Z^0



Simon Van der Meer et Carlo Rubbia

The general scheme for doing Elementary Particle Physics

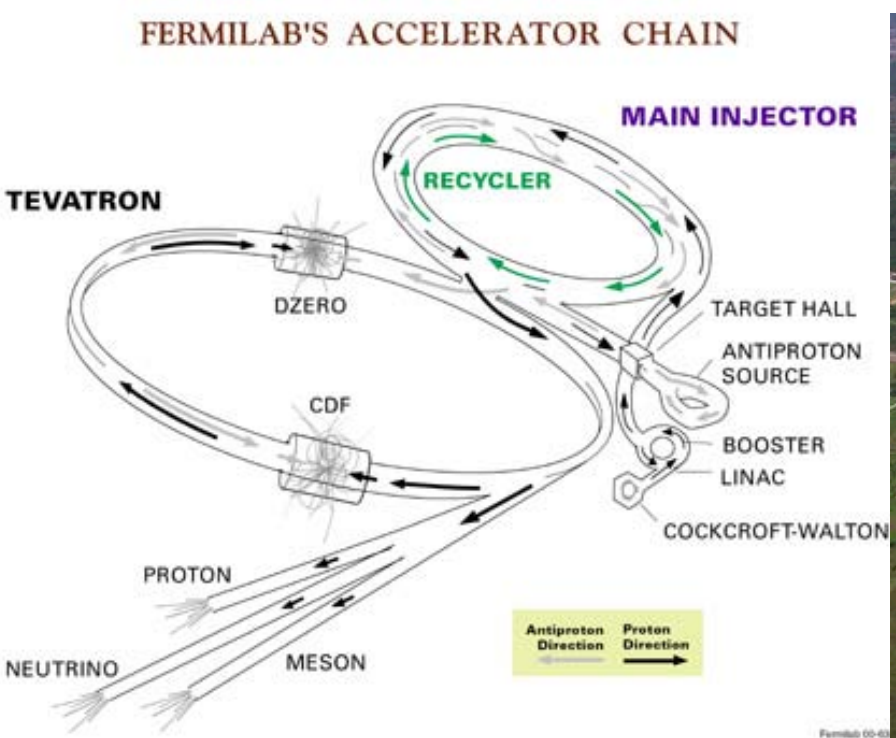
Accelerators give protons lots of energy to make beams of antiprotons, neutrinos, *etc*.

Collide these beams with protons/neutrons to make interesting "new particles" $E=mc^2$

Study their interactions, properties, & decays with large detectors

Fermilab Accelerator Complex

http://www-bd.fnal.gov/public/



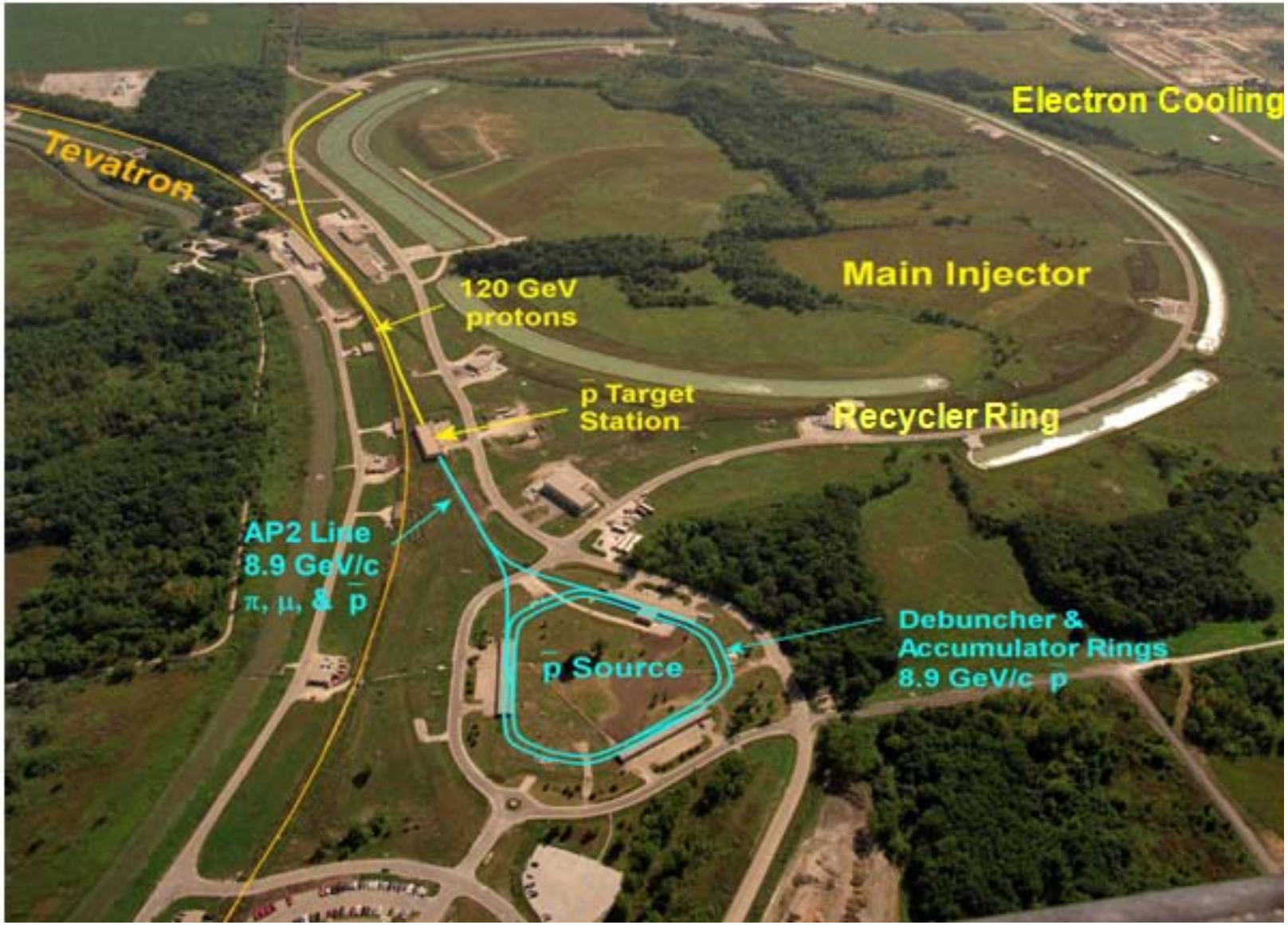
Cockcroft-Walton 750 KeV — **LINAC 400 MeV** — **Booster 8 GeV**

velocity = 0 → ***0.04 c*** → ***0.71 c*** → ***0.994 c***

(Recycler 8 GeV) **your tour today!**

Main Injector 150 GeV — **Antiproton "Bottle"** — **Tevatron 1000 GeV = 1 TeV**

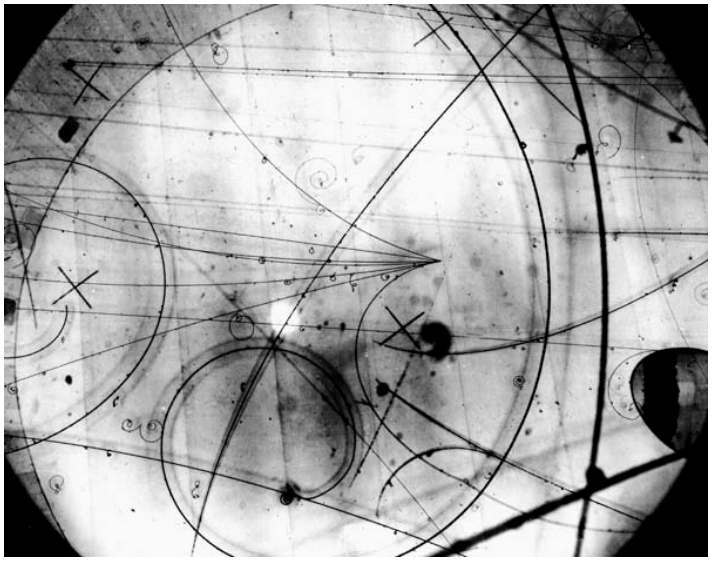
0.994 c → ***0.99998 c*** ***@ 8 GeV*** ***0.99998 c*** → ***0.9999995 c***

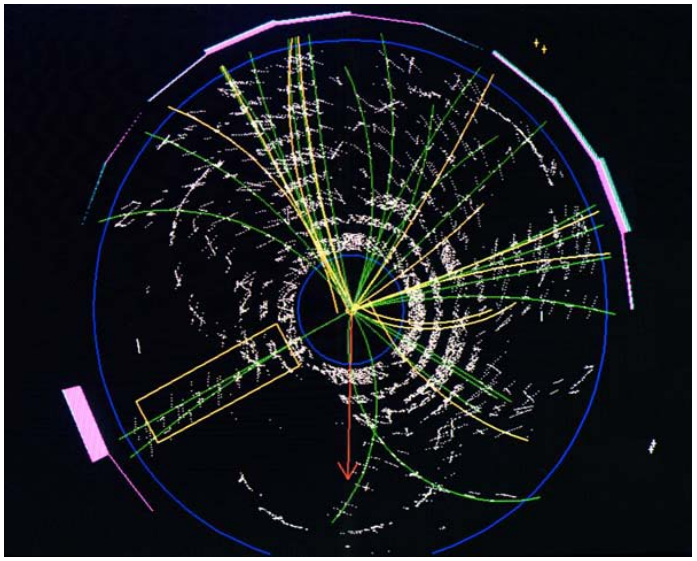


produce only ~1 anti-proton per 10^6 p

How do you “see” such tiny particles?

Q: How do you see the wind? **A: Indirectly**





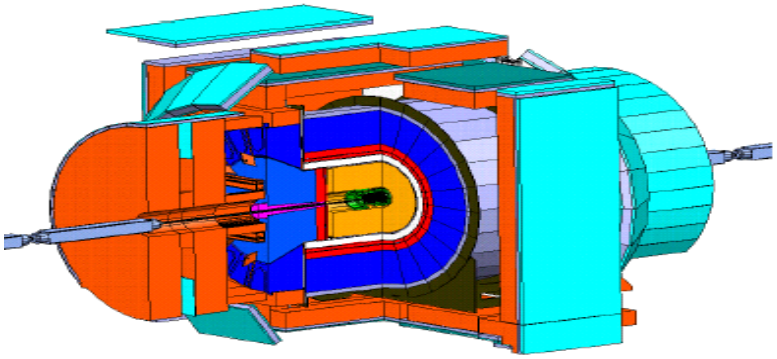
tracks in optical bubble chamber & electronic detectors

tracks bending in magnetic-field (bend α 1/momentum)

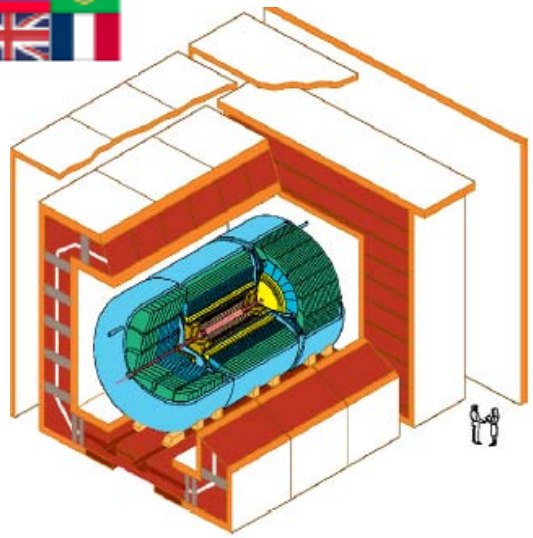
calorimetry (# shower particles is proportional to energy)

decays: reconstruct mass of unseen parent particles

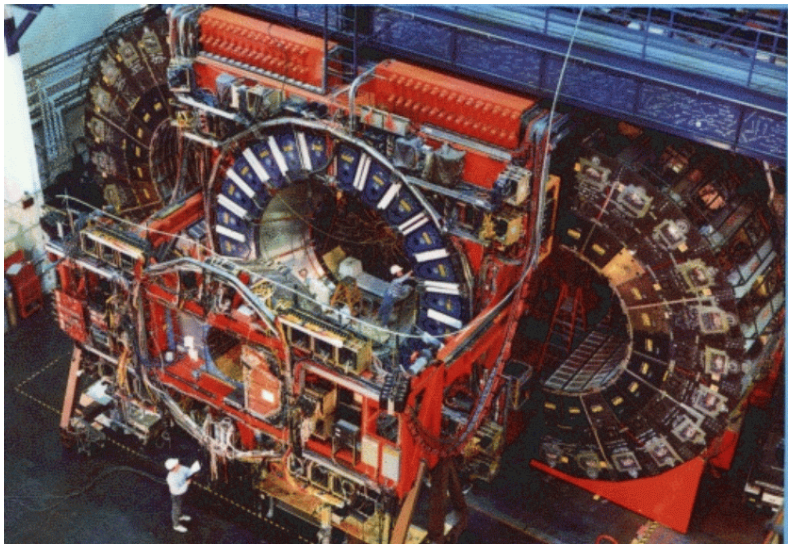
CDF and D-Zero Experiments



CDF Detector



DØ Detector



Using anti-matter in our daily lives!

Positron ***E***mission ***T***omography (***PET*** scan)

isotope $\mathbf{C^{11}}$ => sugars (bio.)

20 min. $\mathbf{\rightarrow B^{11} + e^{+} + \nu_e}$

then $\mathbf{e^{+} + e^{-} \rightarrow \gamma + \gamma}$

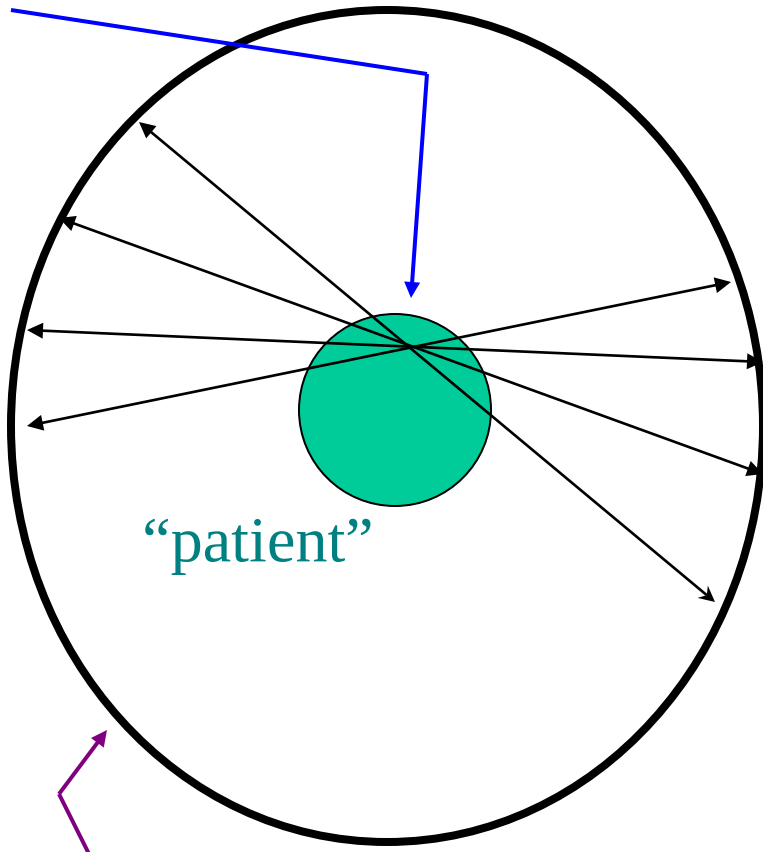
momentum conservation:

(remember from physics class)

the 2 γ-rays are back-to-back

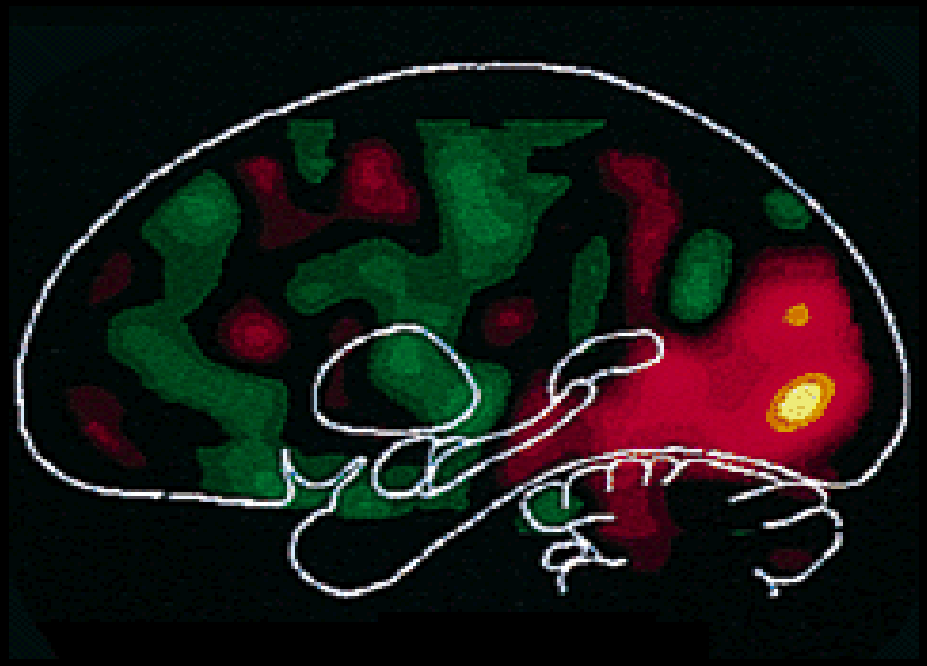
co-linear ***annihilation***

$2\ E_\gamma = 2\ m_e c^2 = 2(0.511 MeV)$

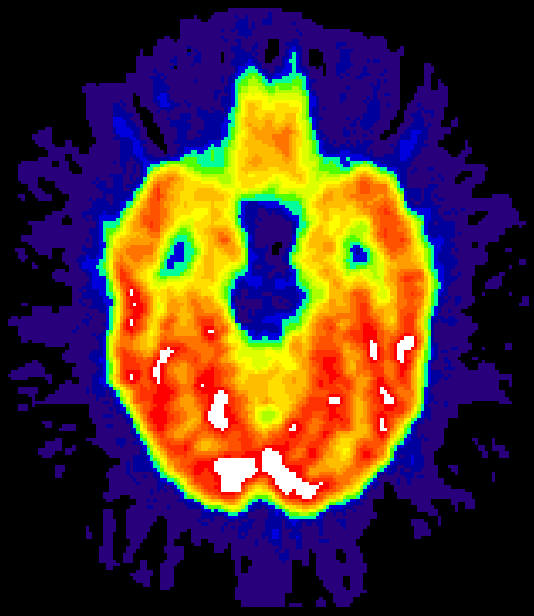


ring of γ-ray detectors
images radioactive salt

examples of PET scans



*PET scan of a brain "in action": the person is **seeing** words*

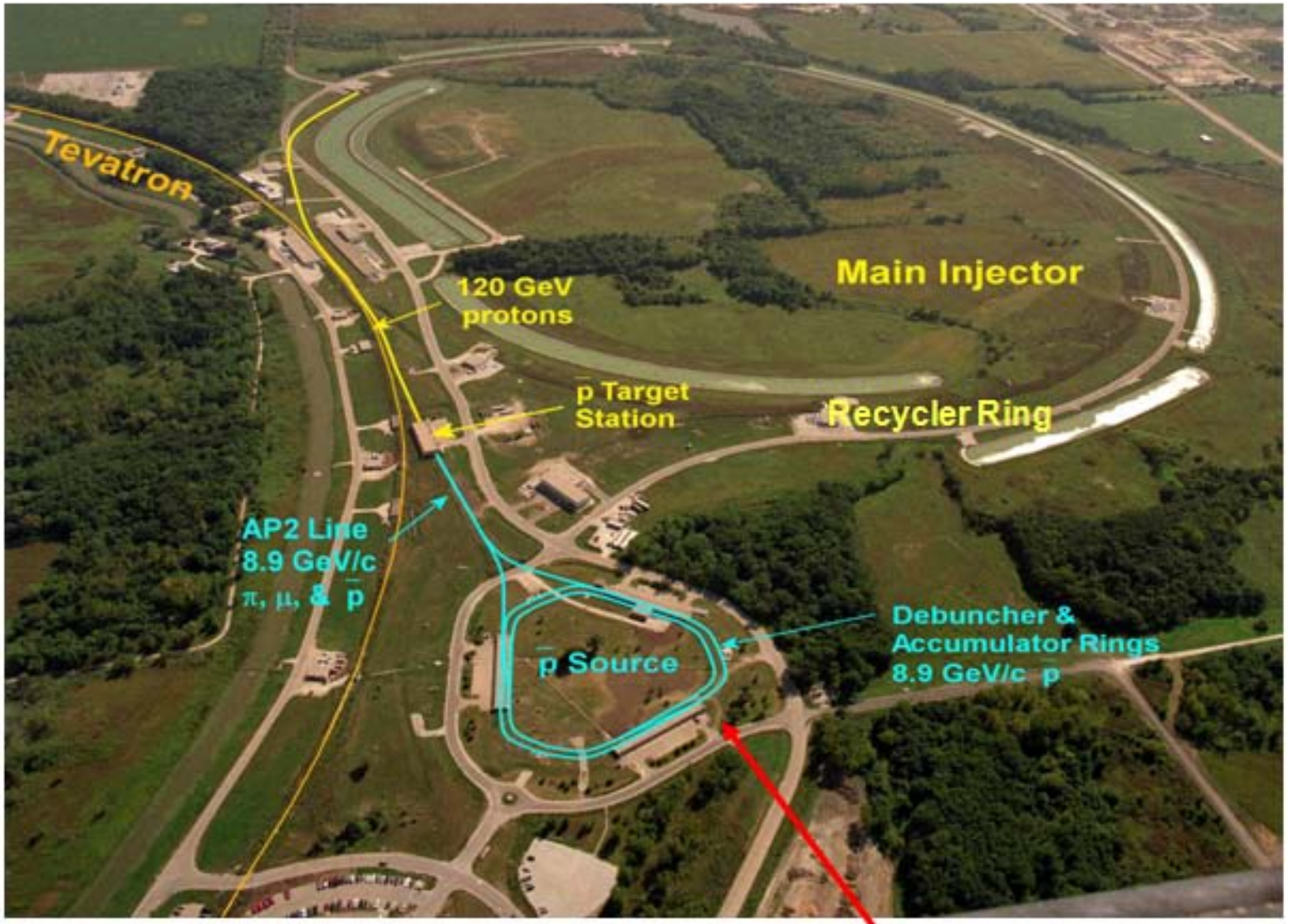


Pet scan of the brain of a physicist

thinking about…..physics

The accelerator complex is *off* for maintenance and upgrades

- You have the opportunity of visiting one of our accelerators, the anti-proton source
- You will be guided by the physicists and engineers who care for & feed the pbar source
- Not a radiation area, no beam today, and no residual radiation, because there were so few antiprotons while anti-proton source was in operations through February 22, 2006.



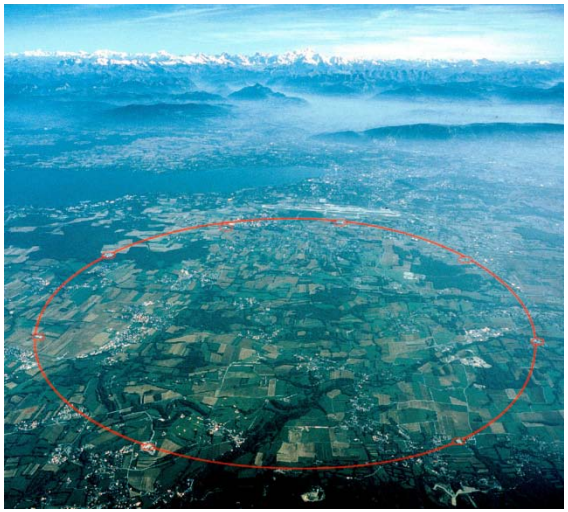
You will be going here

End of Presentation

The future – what will Fermilab do next?

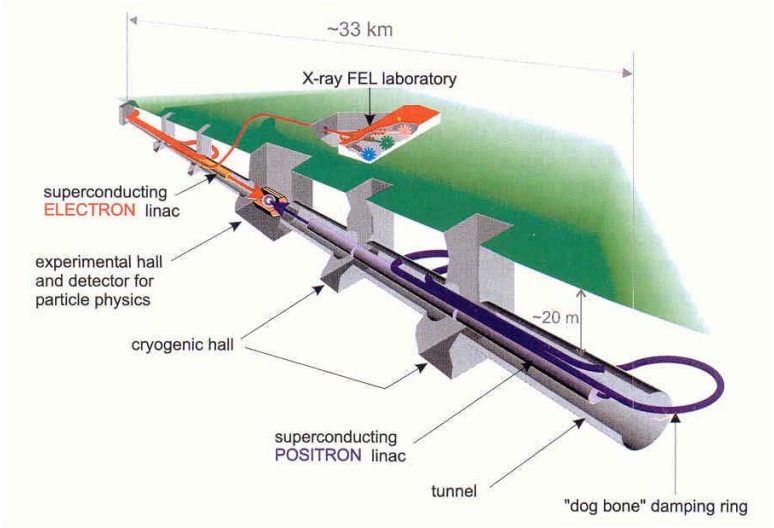
2 TeV proton-antiproton collider (6 km, ~15 yrs old)

CERN is now building
14 TeV pp collider in
27 km tunnel (~2007)

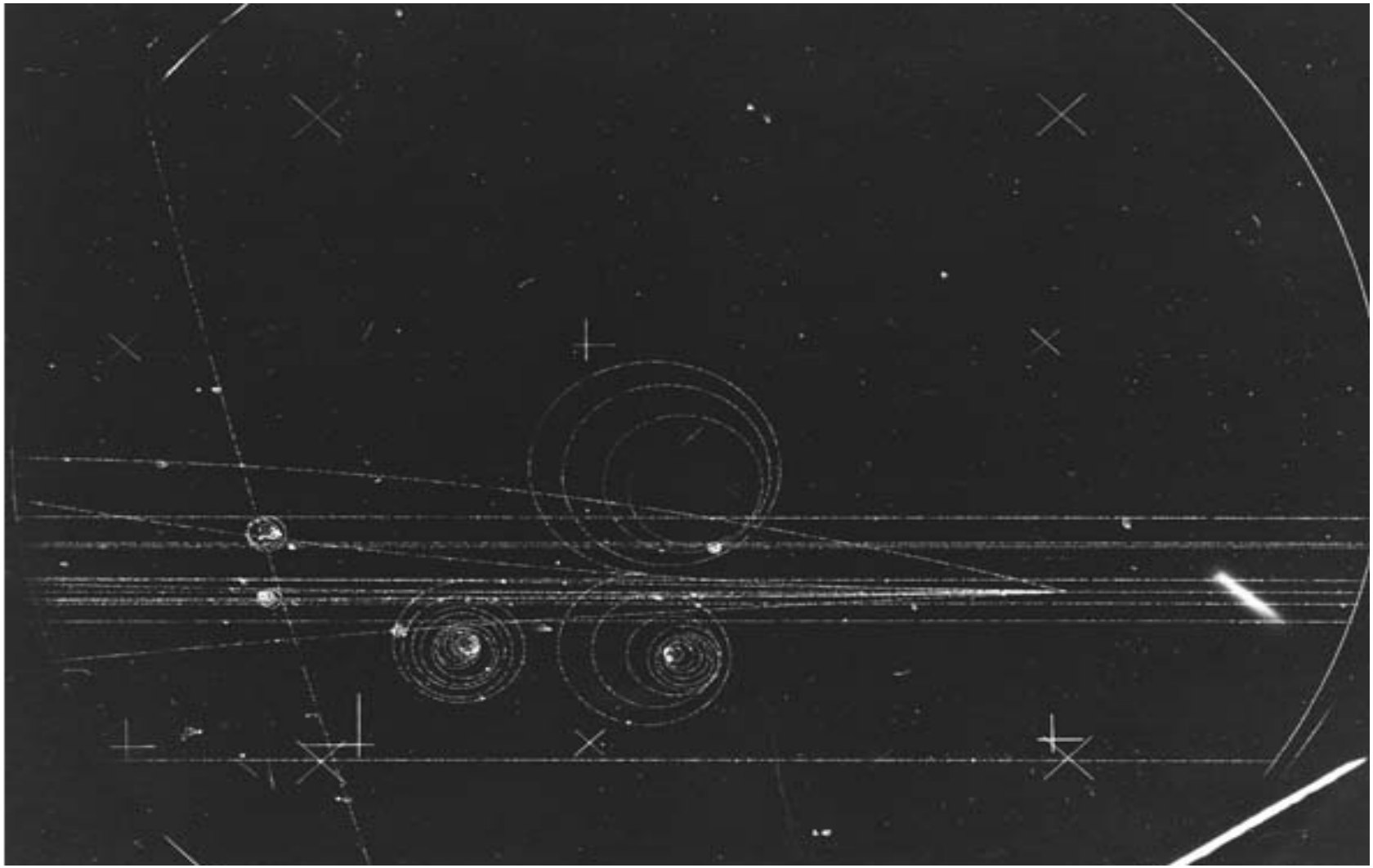


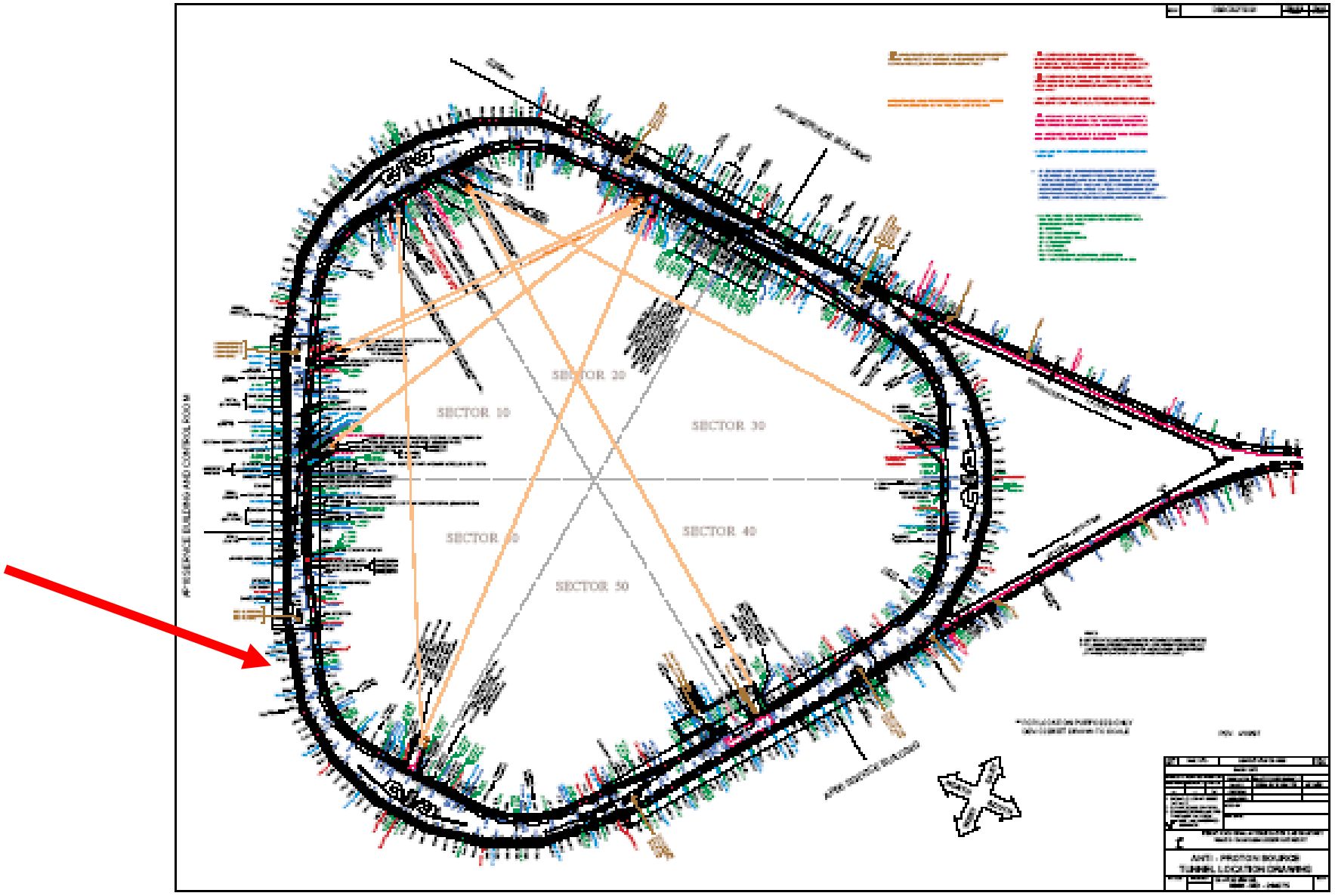
a blunt object,
raw energy for discovery,
collide bags of particles

a 0.5-1 TeV e^+e^- Linear Collider
is under consideration
by Europe, Japan, and U.S.



a tool for precision measurement,
collides fundamental particles
without internal structure




SECTOR 20
SECTOR 10
SECTOR 30
SECTOR 40
SECTOR 50
ANTI - PROTON SOURCE
TUNNEL LOCATION DRAWING