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
Energy

\[ E = Mc^2 \]

protons

+1

938 MeV/c^2

+1

anti-protons
electric charge

-1

mass

938 MeV/c^2

baryon number

-1

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

$e^+$ bends right, while $e^-$ bends left in a magnetic field
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.]
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
- $b, t, \nu_\tau$ 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 \textit{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.)
\[ p + p \rightarrow W^+ + X \quad \text{or} \quad u + \bar{d} \rightarrow W^+ \]

Protons and anti-protons are bags of quarks (and anti-quarks) and gluons. We study the interactions of these smaller constituents \textit{inside} the original particles.
$p + \bar{p} \rightarrow W$ and $Z^0$ at CERN 1983

Simon Van der Meer: stochastic cooling of antiprotons
Carlo Rubbia: led experiment discovered $W$ and $Z^0$
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
velocity = 0 ⟷ 0.04 c

LINAC 400 MeV
0.71 c

Booster 8 GeV
0.994 c

(Recycler 8 GeV)

Main Injector 150 GeV
0.994 c ⟷ 0.99998 c

Antiproton “Bottle”
@ 8 GeV

Tevatron 1000 GeV = 1 TeV
0.99998 c ⟷ 0.9999995 c

your tour today!
produce only $\sim 1$ 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 $\alpha \propto 1/\text{momentum}$)
calorimetry (# shower particles is proportional to energy)
decays: reconstruct mass of unseen parent particles
CDF and D-Zero Experiments
Using anti-matter in our daily lives!

**Positron Emission Tomography** (PET scan)

isotope \( ^{11}\text{C} \rightarrow \) sugars (bio.)

20 min. \( ^{11}\text{B} + e^+ + \nu_e \rightarrow e^- \rightarrow \gamma + \gamma \)

momentum conservation:

(remember from physics class)

de 2 \( \gamma \)-rays are back-to-back co-linear **annihilation**

\[
2 E_\gamma = 2 m_e c^2 = 2(0.511 \text{MeV})
\]

ring of \( \gamma \)-ray detectors

images radioactive salt

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

a blunt object, a tool for precision measurement, raw energy for discovery, collides fundamental particles without internal structure