CERN

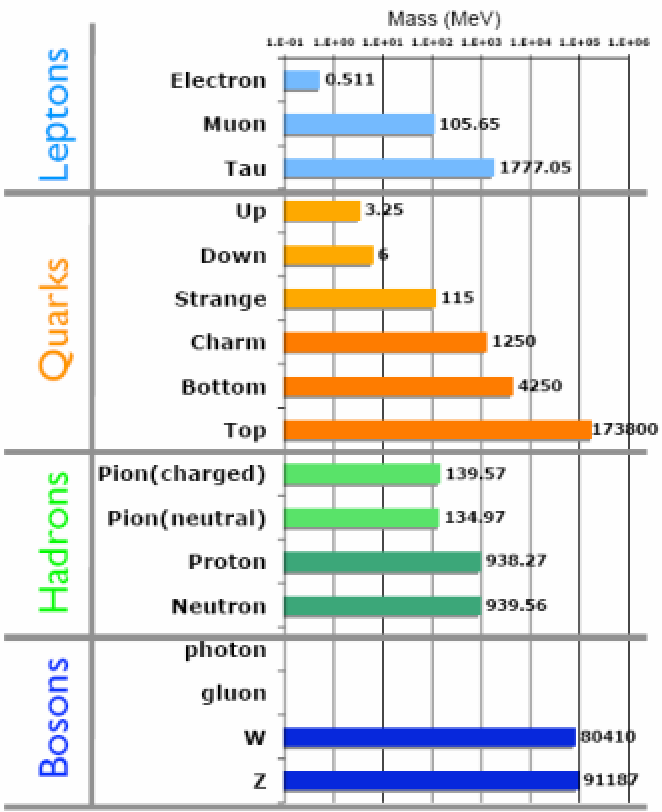
European Organization for Nuclear Research
Organisation Européenne pour la Recherche Nucléaire

American Physical Society
Anaheim CA 30th April 2011

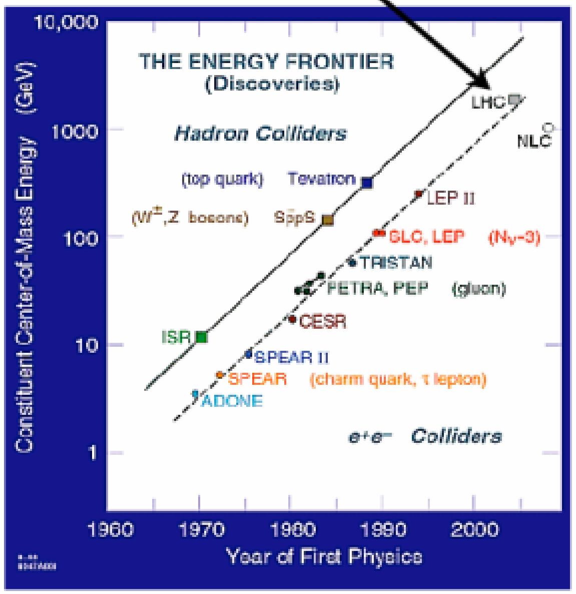
Proton-Antiproton Colliders

Lyndon Evans/CERN

History/energy line vs discovery



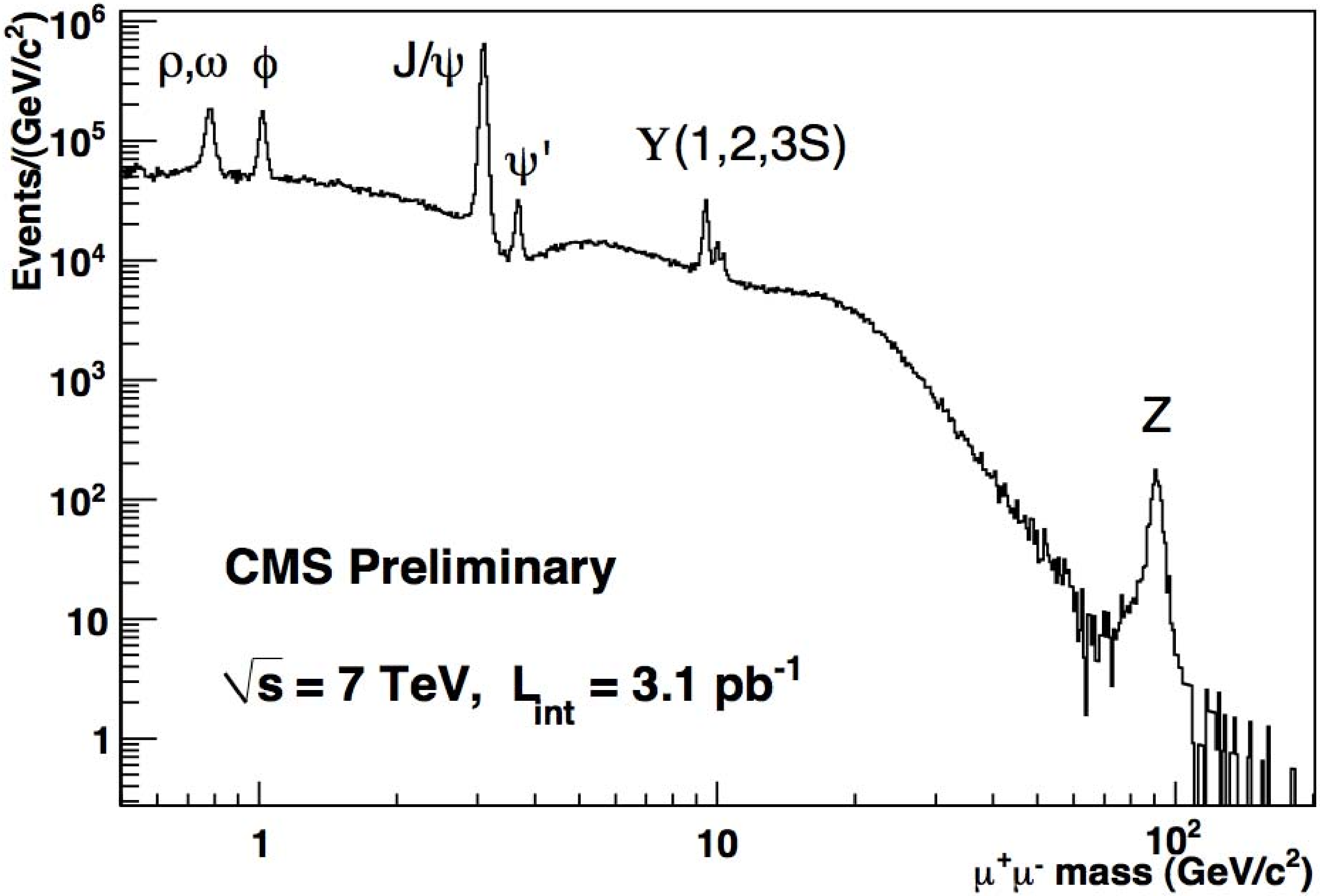
Higgs and super-symmetry ?
Or something else maybe



Behind the history plot is hidden the technological development required for each step

Obs: you can notice different particle species used in the different colliders electron-positrons and hadron colliders (either $\bar{p}$-p as Tevratron, p-p as LHC)

CMS Muon Pairs Mass



Proton - Antiproton Colliders

In 1976, Rubbia, Kline and McIntyre proposed that the CERN SPS and the Fermilab Main Ring could be converted into proton-antiproton colliders to search for the W and Z bosons.

In order to achieve this, it was first necessary to develop the technology for the production, accumulation and cooling of intense antiproton beams.

Joseph Liouville (1809 – 1882)

Beam Cooling

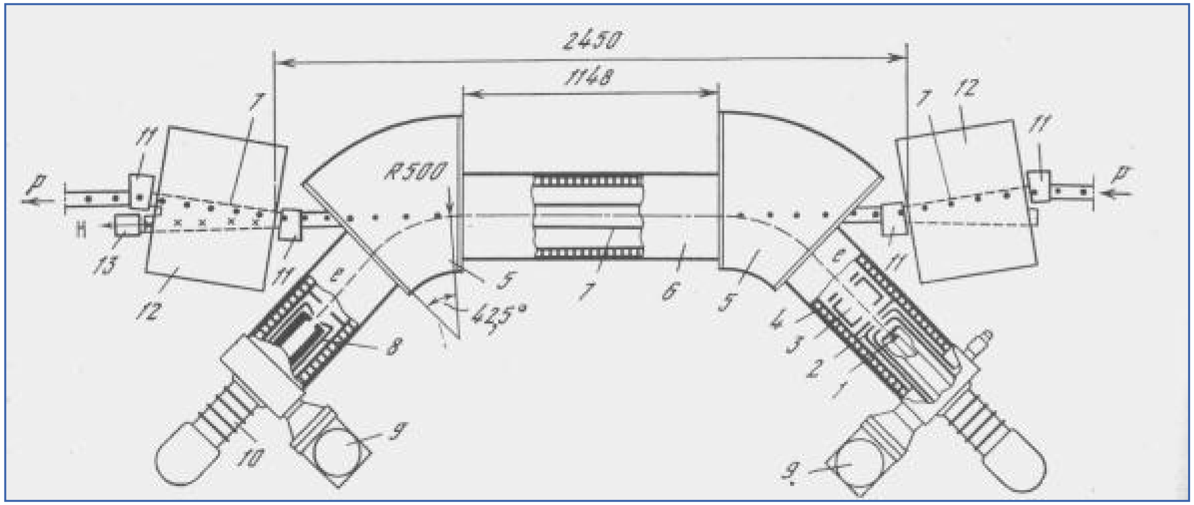
Liouville's theorem states that the phase space density of a particle beam cannot be changed under the action of conservative forces if the beam is considered to be a continuous medium.

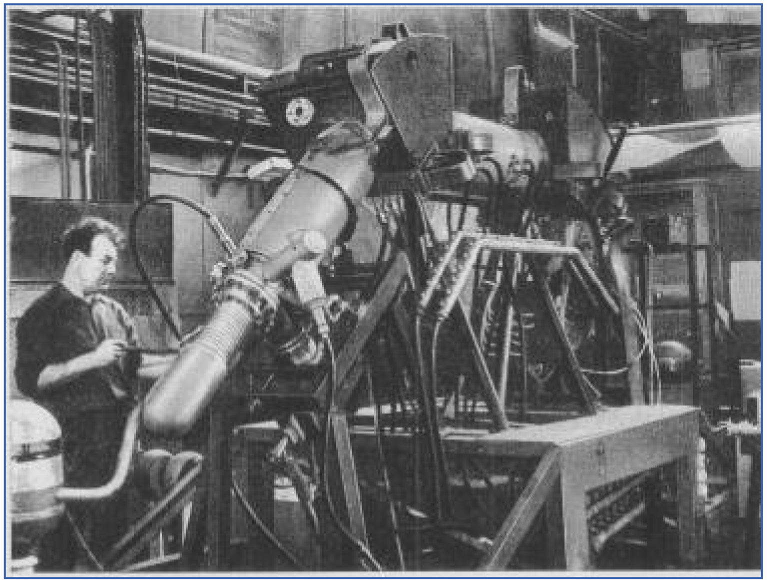
Electron beams are naturally cooled by the emission of synchrotron radiation.

In the 1960's, Budker proposed the cooling of protons by their interaction with a cold electron beam (non-conservative) Coulomb collisions.

In 1972 (from work done in 1968), Van der Meer discovered the principle of stochastic cooling, which makes use of the fact that the beam is not a continuous medium.

Electron Cooling





Electron Cooling

- Fast
- Most suited for low- β beams. Very effective for heavy ions and is used to cool the Pb ion beam for LHC. Until recently it was not possible to cool antiprotons produced at high energy.
- Effective at cooling beams that are already cool. Not good for cooling antiprotons directly from production target.

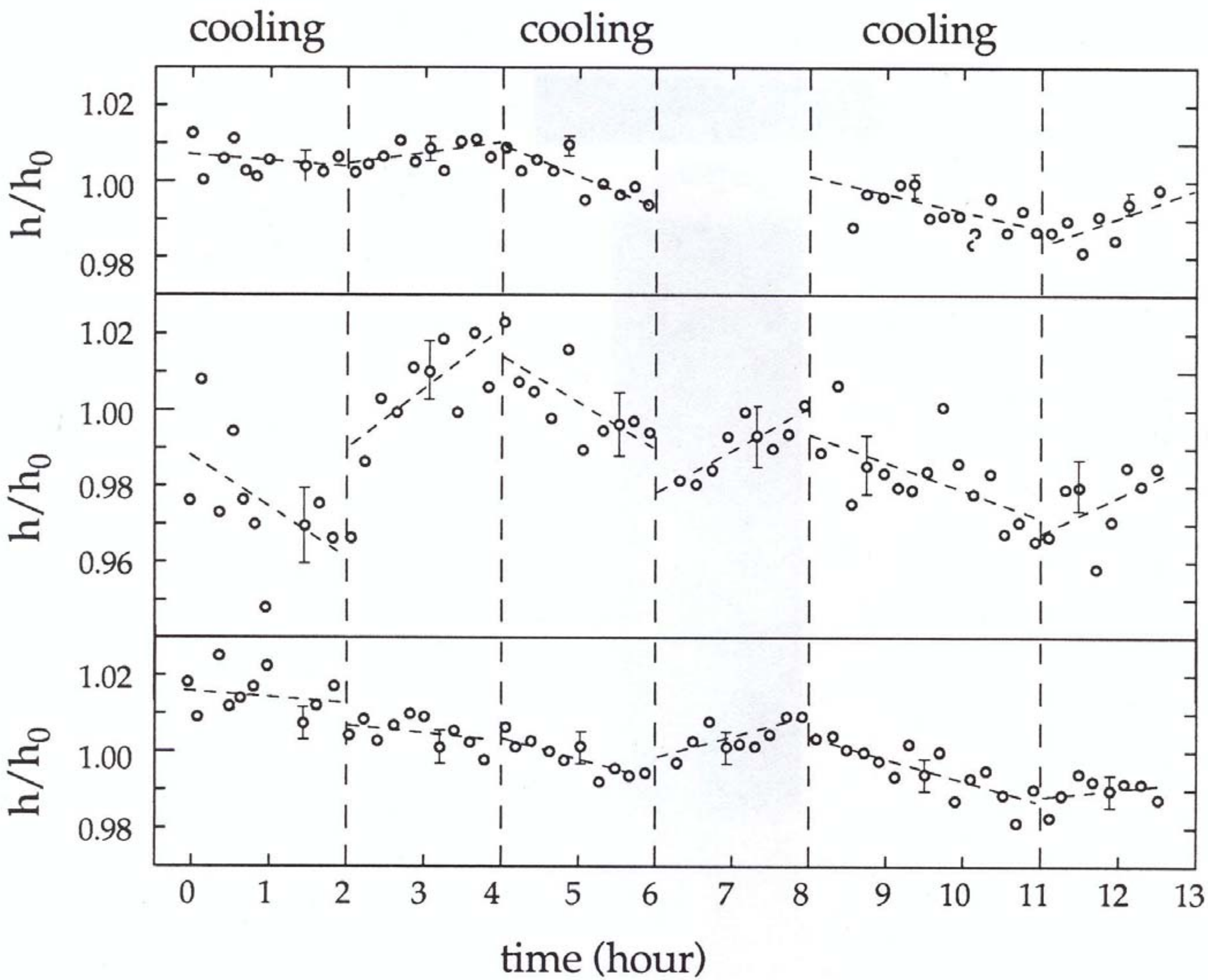
The Intersecting Storage Rings (1971-1984)

- First hadron storage rings
- First observation of Schottky noise
- First demonstration of stochastic cooling

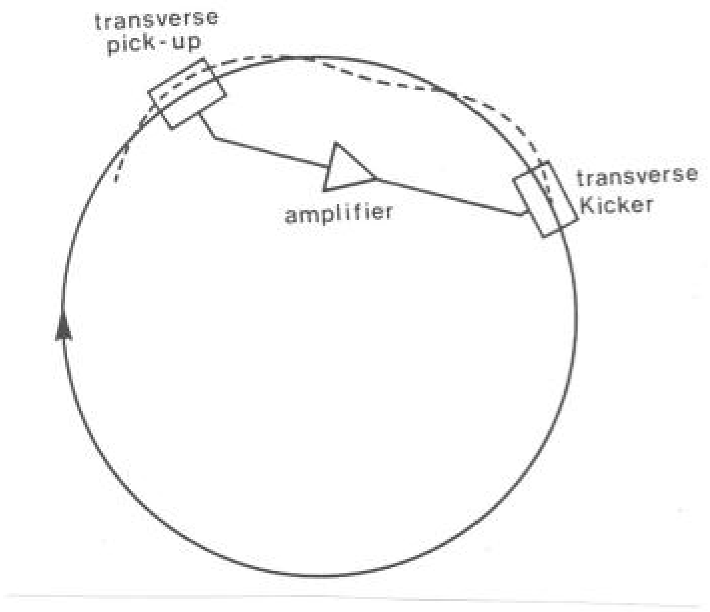
S. van der Meer

FINAL NOTE

This work was done in 1968. The idea seemed too far-fetched at the time to justify publication. However, the fluctuations upon which the system is based were experimentally observed recently. Although it may still be unlikely that useful damping could be achieved in practice, it seems useful now to present at least some quantitative estimation of the effect.


cooling
cooling
cooling
h/h0
1.02
1.00
0.98
0.96
0 1 2 3 4 5 6 7 8 9 10 11 12 13
time (hour)

Stochastic Betatron Cooling



$$\bar{x} = \frac{\sigma_S}{\sqrt{N_S}} \qquad \frac{1}{\tau} = \frac{W}{2N}$$

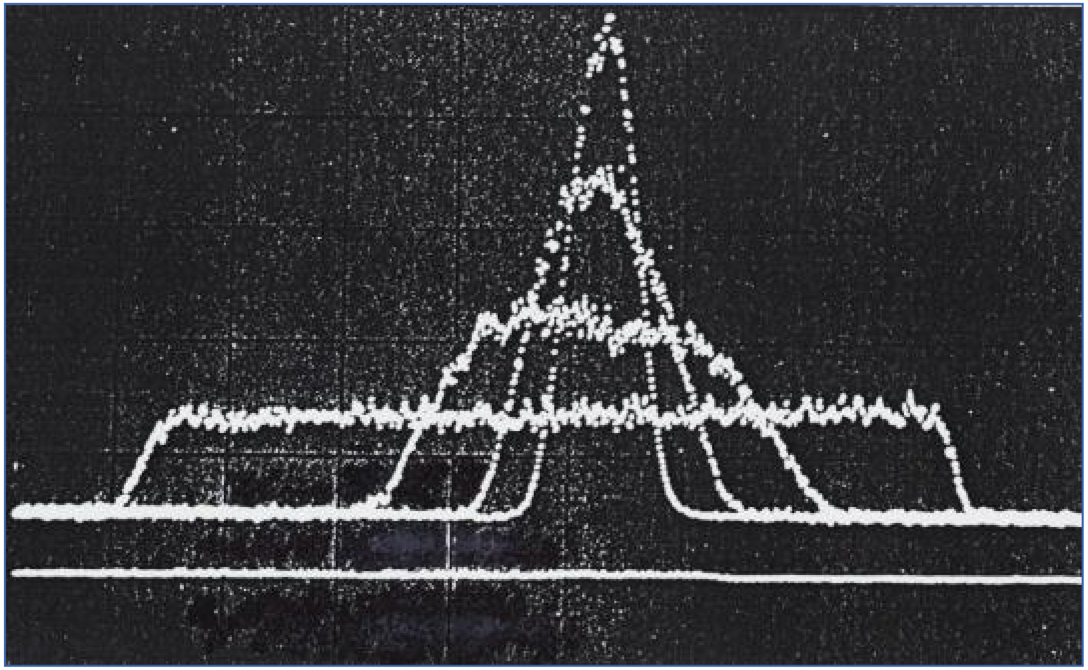
No mixing from pickup to kicker

Good mixing from kicker to pickup

1977 Initial Cooling Experiment (ICE)

- In 1977 the (g-2) ring at CERN was converted into a machine on which stochastic cooling could be tested in detail.
- In parallel, the theory of stochastic cooling was developed by Sacherer, Hereward, Van de Meer and Mohl.
- In May 1978 ICE achieved cooling for the first time in all 3 dimensions
- In June the ppbar project was submitted to CERN Council for approval.

Momentum Cooling in ICE



Schottky scan after 1, 2 and 4 min.

Signal height proportional to the square root of density and width proportional to Δ p/p.

The Fermilab position

- **Fermilab was in the middle of the construction of the Doubler (now the Tevatron), the world’s first large superconducting machine.**

- **In November 1978 it was decided that this would remain top priority and that colliding beams would be in the Tevatron and not the Main Ring.**

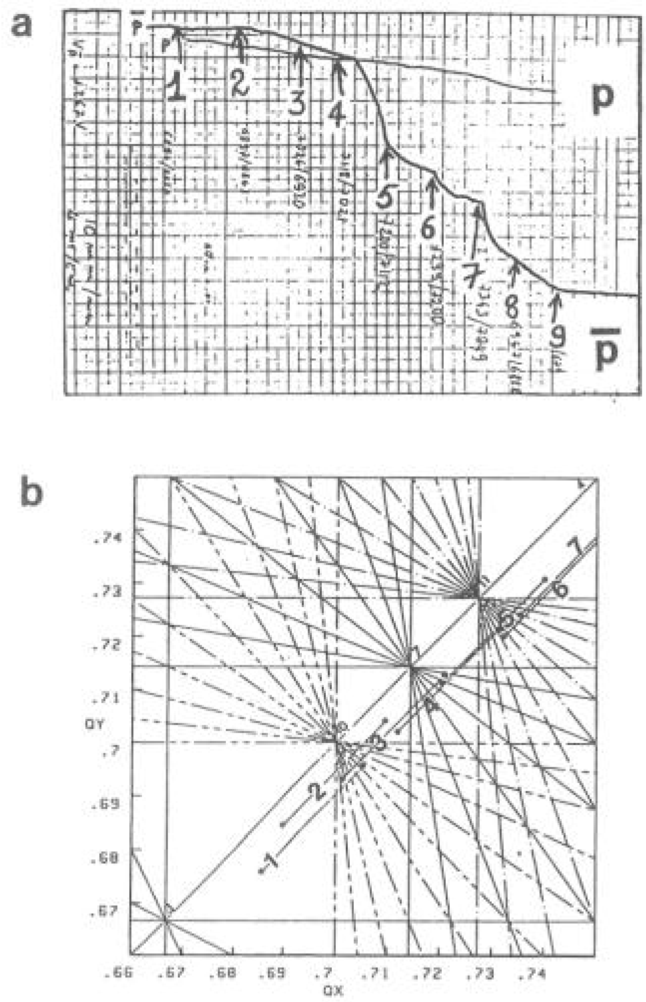
The Antiproton Accumulator

Proton – Antiproton Colliders

- The acceleration and storage of intense proton and antiproton colliding beams create many problems which have to be resolved in order to produce luminosity.
- They include:

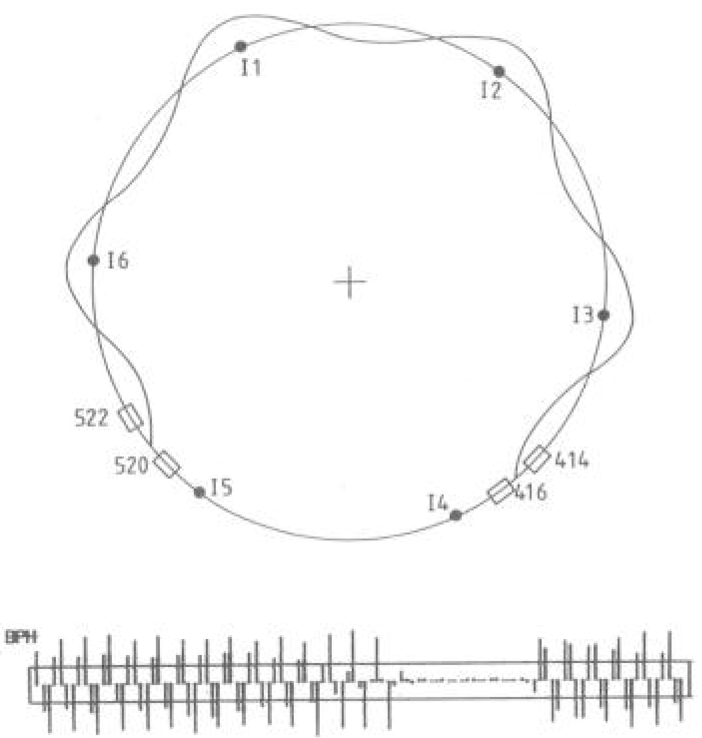
- **Beam stability**
- **RF noise**
- **Intrabeam scattering**
- **Low-beta optics**
- **The beam-beam interaction.**

The Beam – Beam Interaction

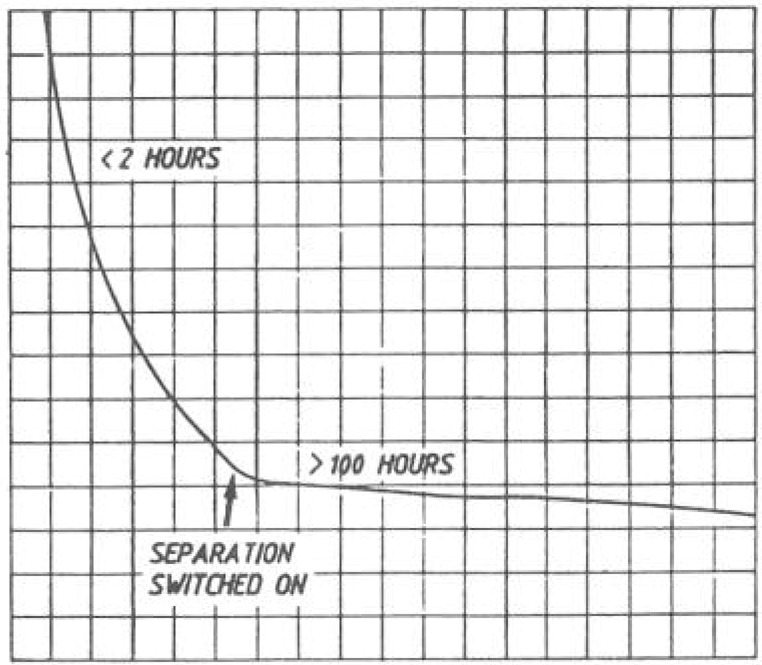


Beam Separation and Lifetime

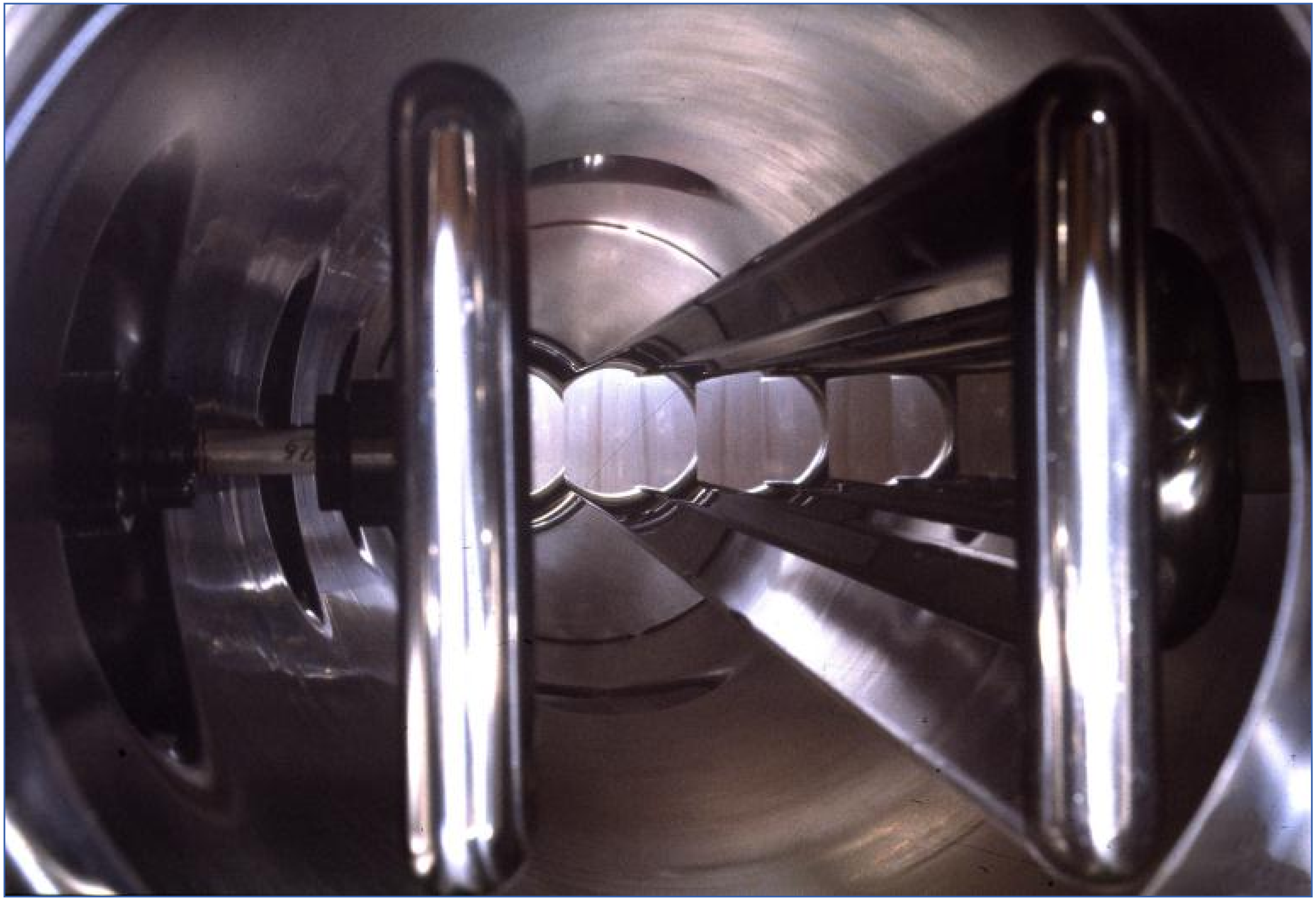
a.



b.



Electrostatic Separator

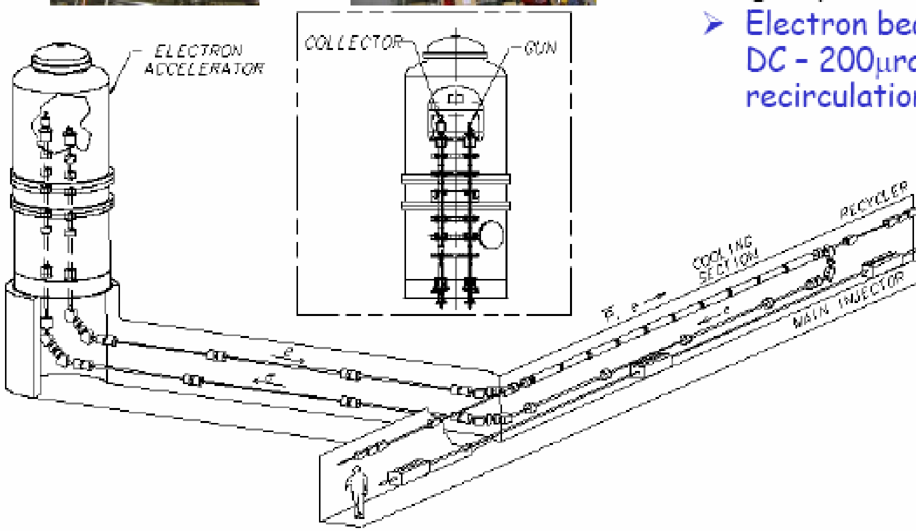


High Energy Electron Cooling

Fermilab
Accelerator Division

Recycler Electron Cooling

- The maximum antiproton stack size in the Recycler is limited by
  - Stacking Rate in the Debuncher-Accumulator at large stacks
  - Longitudinal cooling in the Recycler
- Longitudinal stochastic cooling of 8 GeV antiprotons in the Recycler is being replaced by Electron Cooling
  - Electron beam: 4.34 MeV - 0.5 Amps DC - 200μrad beam spread - 99% recirculation efficiency

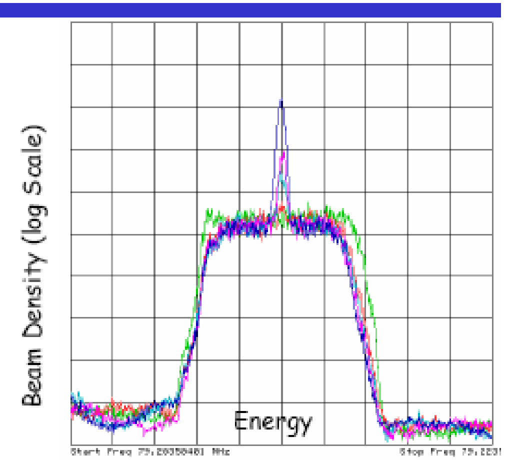


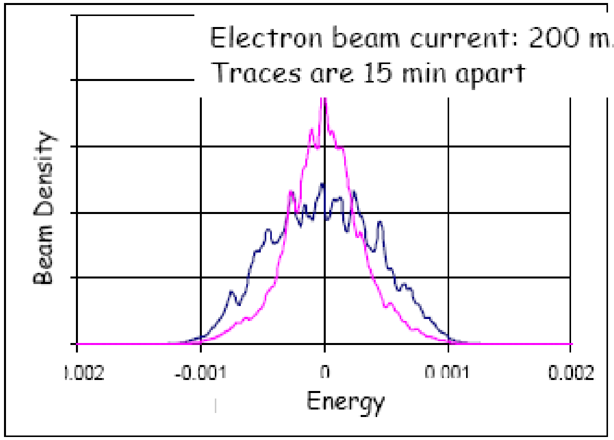
High Energy Electron Cooling

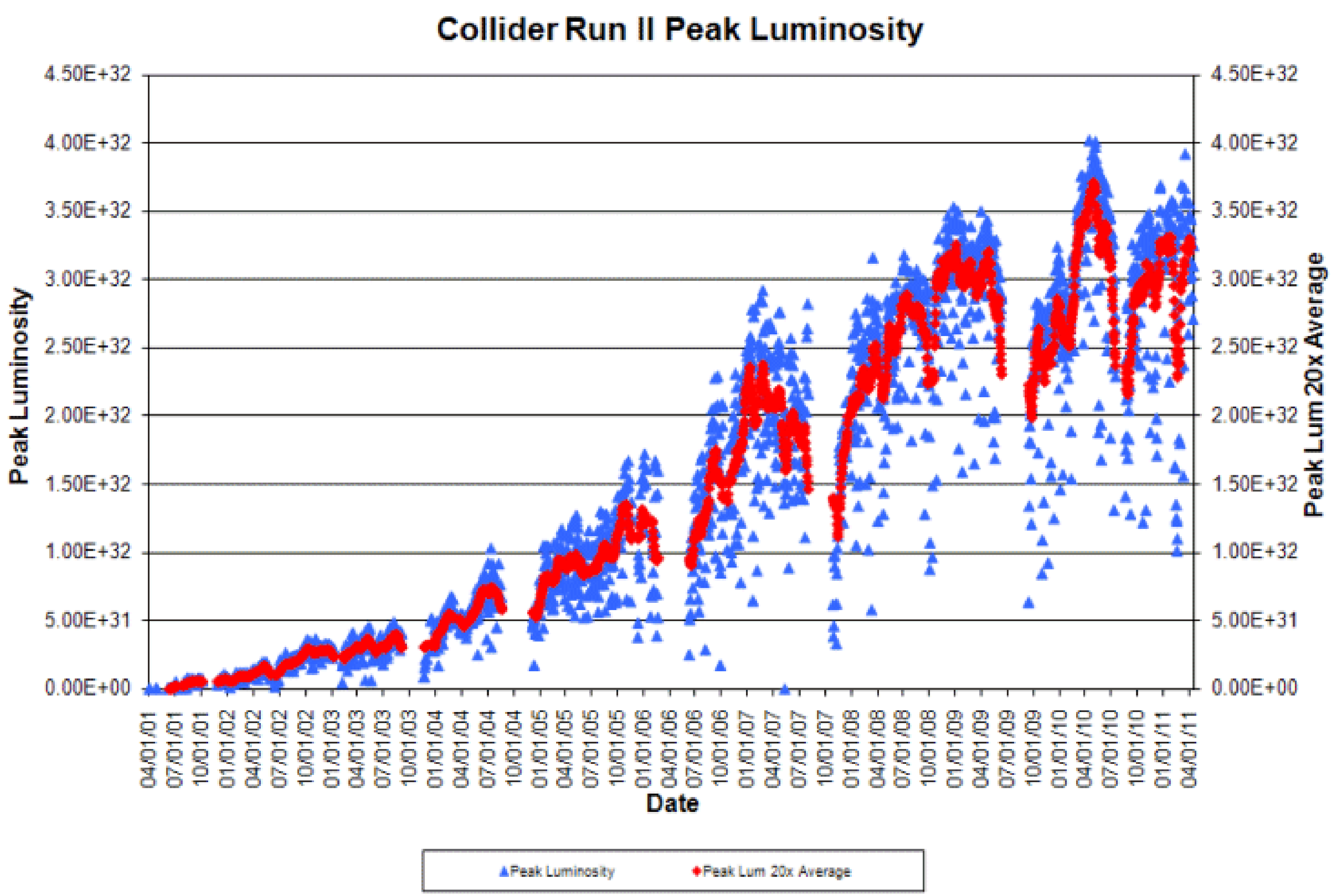
Fermilab
Accelerator Division

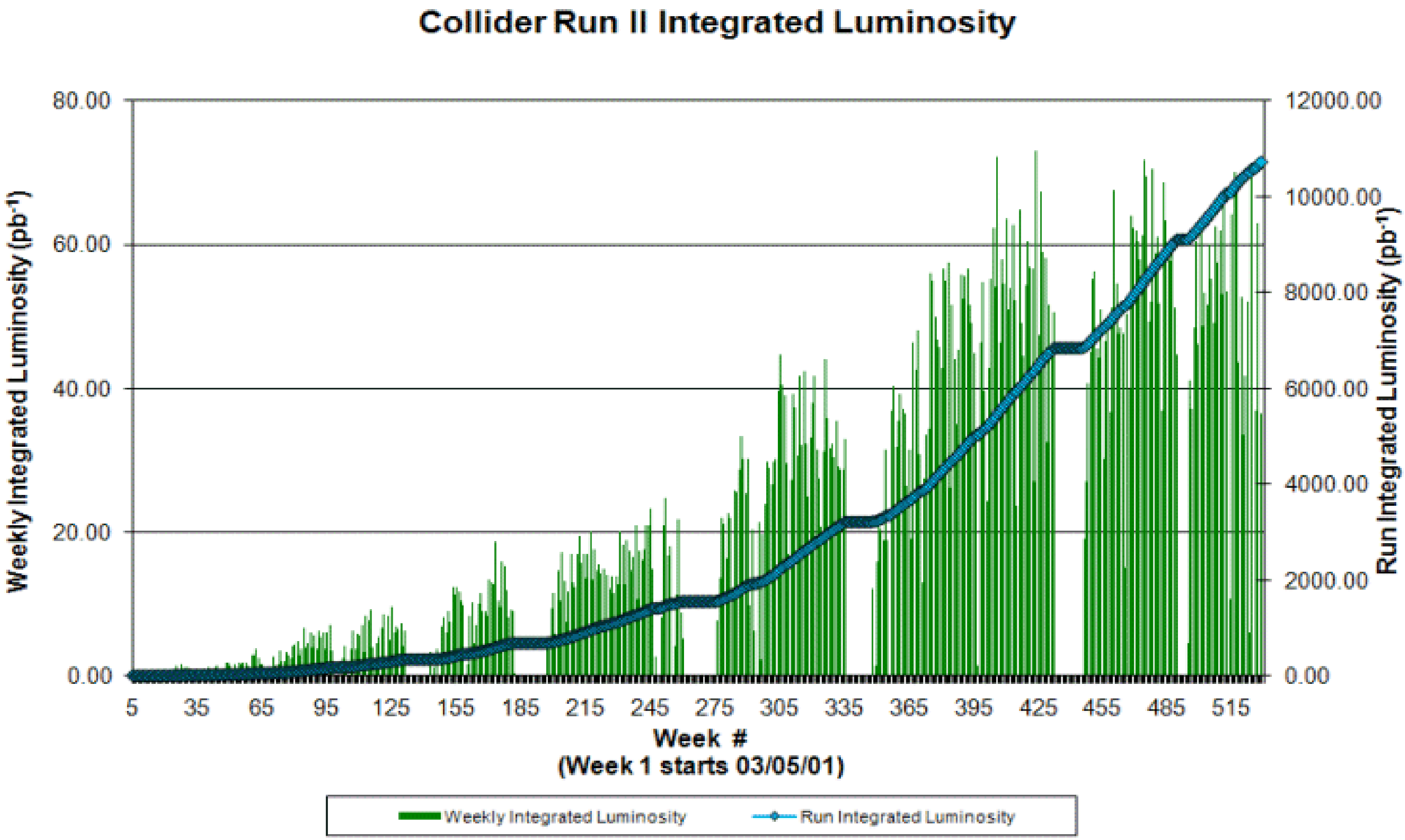
Recycler Electron Cooling

- Electron cooling commisioning
  - Electron cooling was demonstrated in July 2005 two months ahead of schedule.
  - By the end of August 2005, electron cooling was being used on every Tevatron shot
- Electron cooling goals
  - Can presently support final design goal of rapid transfers (30eV-Sec/2hrs)
  - Can presently reliably support stacks of 250×10^{10} (FY06 design goal)
  - Have achieved 500 mA of electron beam which is the final design goal.





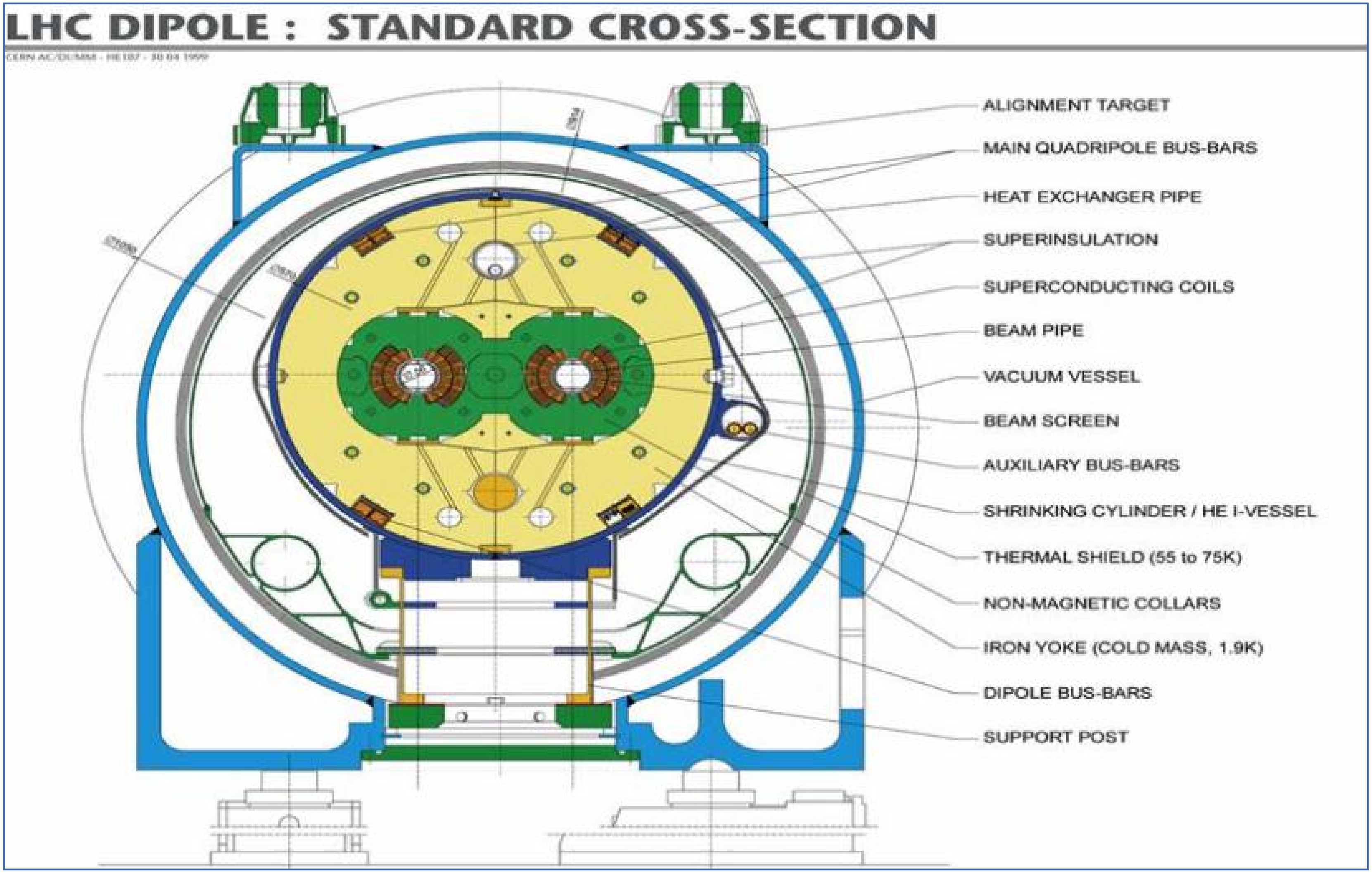

Collider Run II Peak Luminosity
Peak Luminosity
Peak Lum 20x Average
0.00E+00
5.00E+31
1.00E+32
1.50E+32
2.00E+32
2.50E+32
3.00E+32
3.50E+32
4.00E+32
4.50E+32
Date
04/01/01 07/01/01 10/01/01 01/01/02 04/01/02 07/01/02 10/01/02 01/01/03 04/01/03 07/01/03 10/01/03 01/01/04 04/01/04 07/01/04 10/01/04 01/01/05 04/01/05 07/01/05 10/01/05 01/01/06 04/01/06 07/01/06 10/01/06 01/01/07 04/01/07 07/01/07 10/01/07 01/01/08 04/01/08 07/01/08 10/01/08 01/01/09 04/01/09 07/01/09 10/01/09 01/01/10 04/01/10 07/01/10 10/01/10 01/01/11 04/01/11
Peak Luminosity
Peak Lum 20x Average



Collider Run II Integrated Luminosity
Weekly Integrated Luminosity (pb-1)
Run Integrated Luminosity (pb-1)
80.00
60.00
40.00
20.00
0.00
12000.00
10000.00
8000.00
6000.00
4000.00
2000.00
0.00
5 35 65 95 125 155 185 215 245 275 305 335 365 395 425 455 485 515
Week #
(Week 1 starts 03/05/01)
Weekly Integrated Luminosity
Run Integrated Luminosity

The Large Hadron Collider

The Large Hadron Collider



Conclusions

- The developments leading to the successful conversion of the two high energy accelerators to proton - antiproton colliders has taken the art of manipulating and controlling particle beams to new heights and have made the most fundamental discoveries in the last quarter of the 20^{th} century.

- The lessons learned have been essential for the design of the LHC. However, due to the need for an increase of two orders magnitude in luminosity, the use of antiprotons is no longer an option. The final closure of the Tevatron collider will end an exciting and productive chapter in the development of accelerator technology.