# Tevatron Run II in Fermilab


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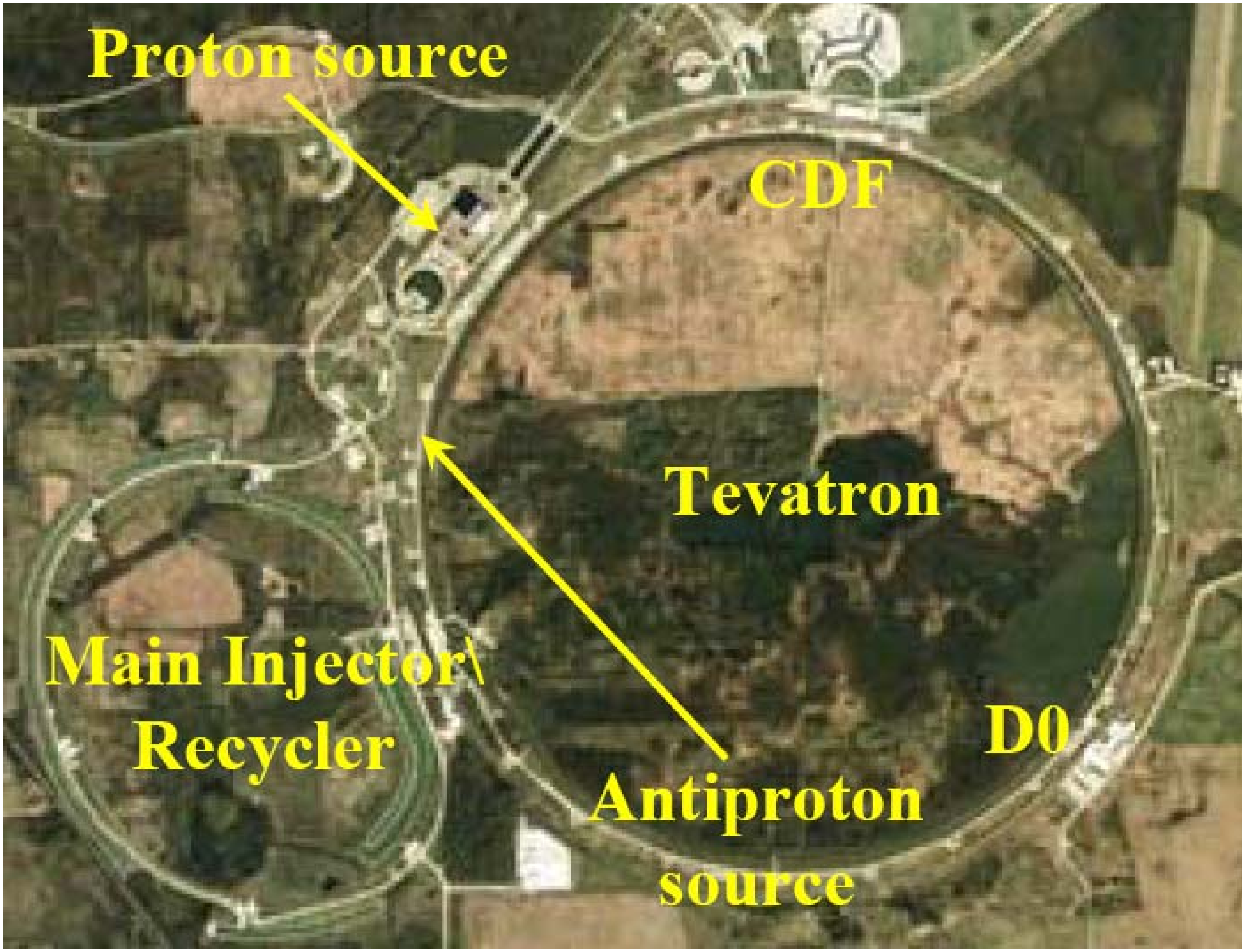
Fermilab

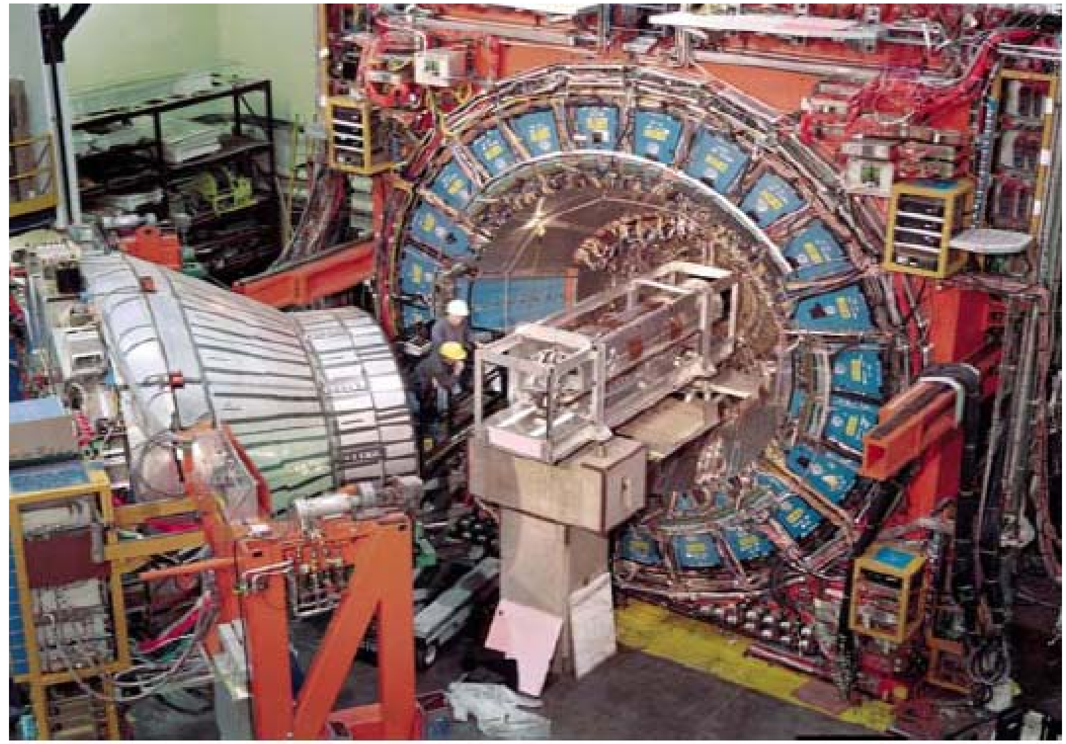
# Tevatron is a $\mathbf{P}-\overline{\mathbf{P}}$ Collider Operating at 980 GeV

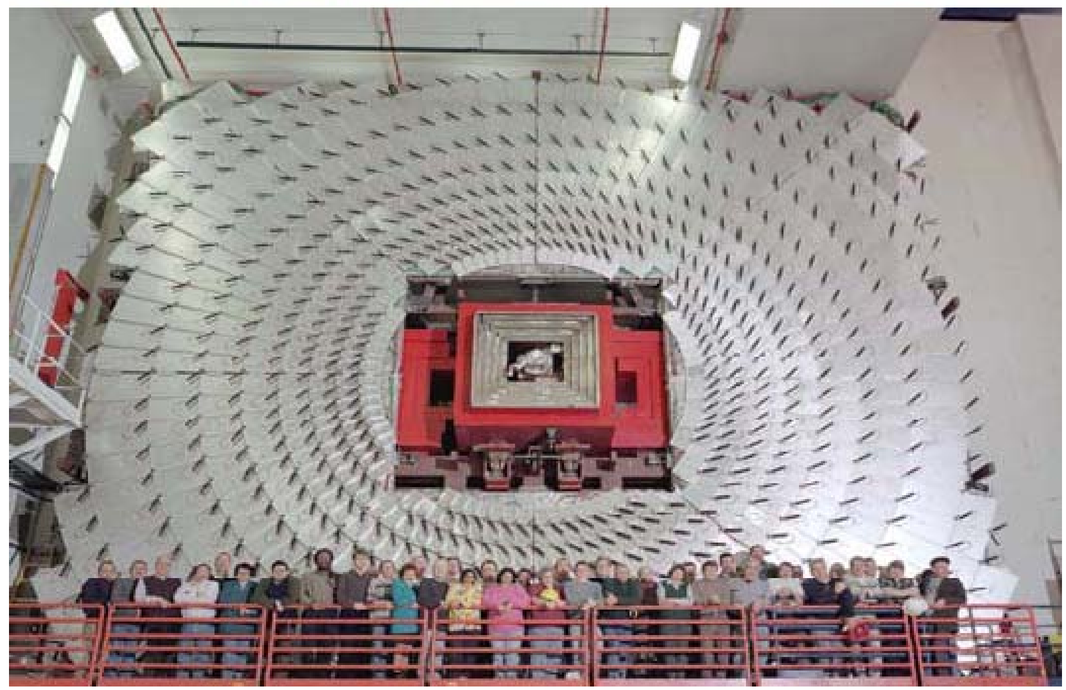



- $H^-$ source, 35mA
- Electrostatic accel. 750 keV
- Linac, 0.4 GeV
- Booster, 0.4–8 GeV
- Main injector, 8-150 GeV
- Debuncher, 8 GeV
- Accumulator, 8 GeV
- Recycler,8 GeV
- Tevatron, 980 GeV

# Physics Program

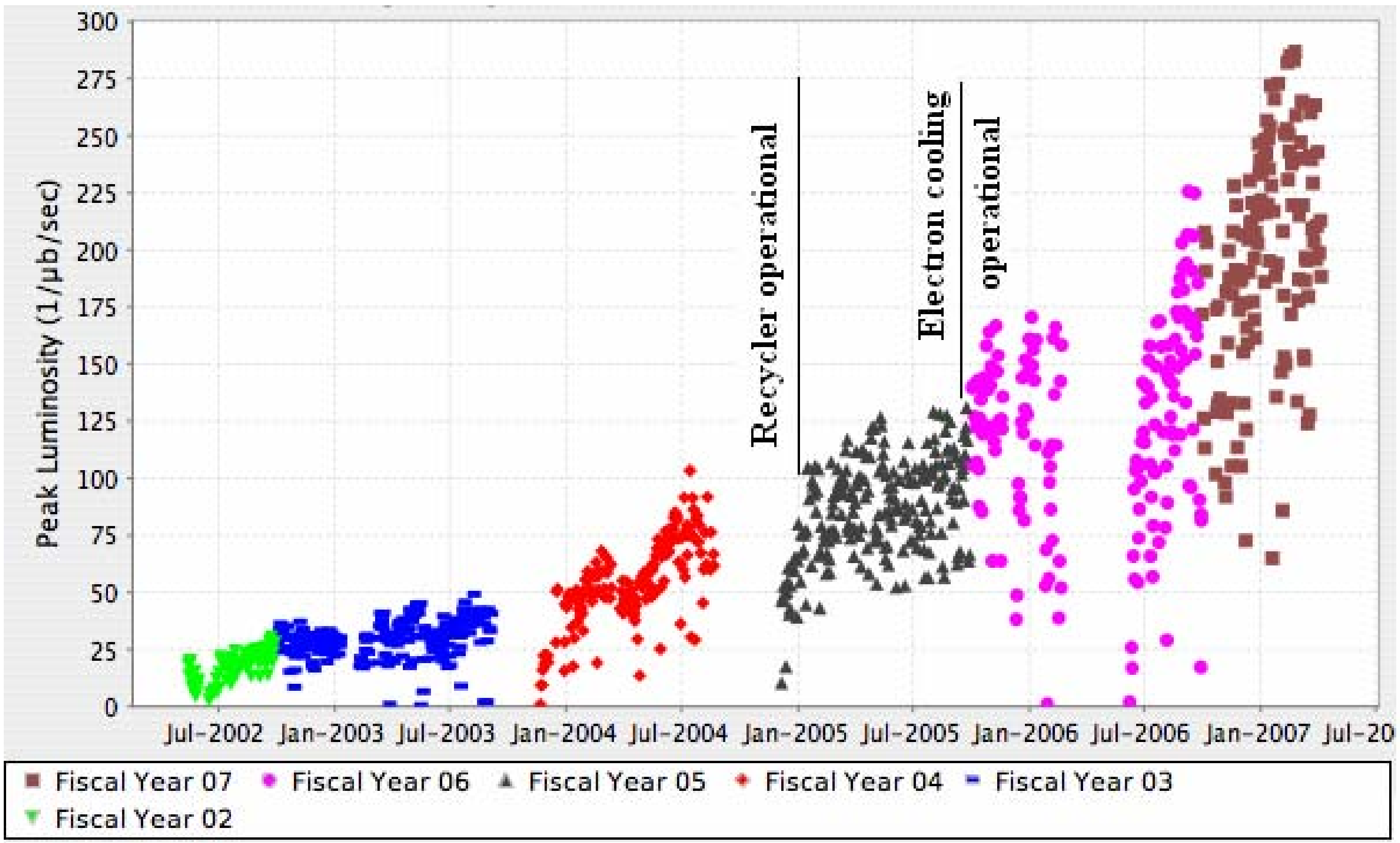
- Highest energy collider
- Two detectors
  - 1500 collaborators + students and postdocs
- The greatest high energy physics before LHC is operational
  - Higgs boson search
  - B-physics
  - Extra-dimensions
  - …
- Success critically depends on the luminosity growth





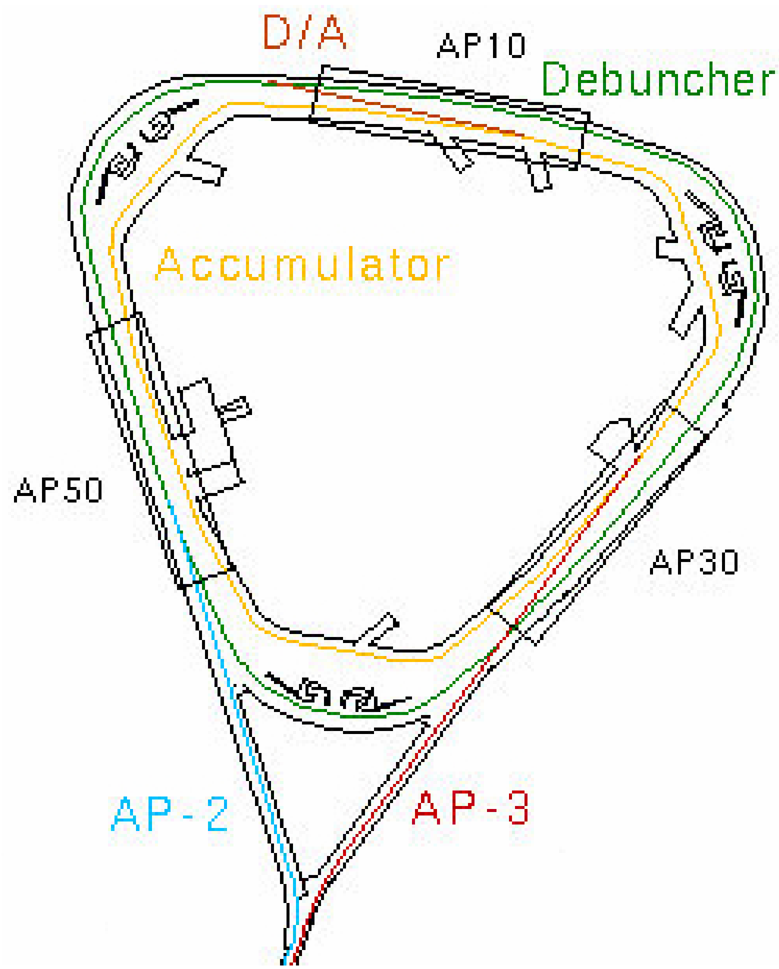
# Tevatron Luminosity

- Proton-antiproton collider luminosity is supported by ability
  - To stack and store antiprotons and
  - To cool them to small emittances
- Both electron and stochastic coolings are important
  - Stochastic cooling – stacking and precooling (large – $\varepsilon$, small – $N_p$)
  - Electron cooling – final cooling (small – $\varepsilon$, large – $N_p$)



# Antiproton Production (simplified review of operations)

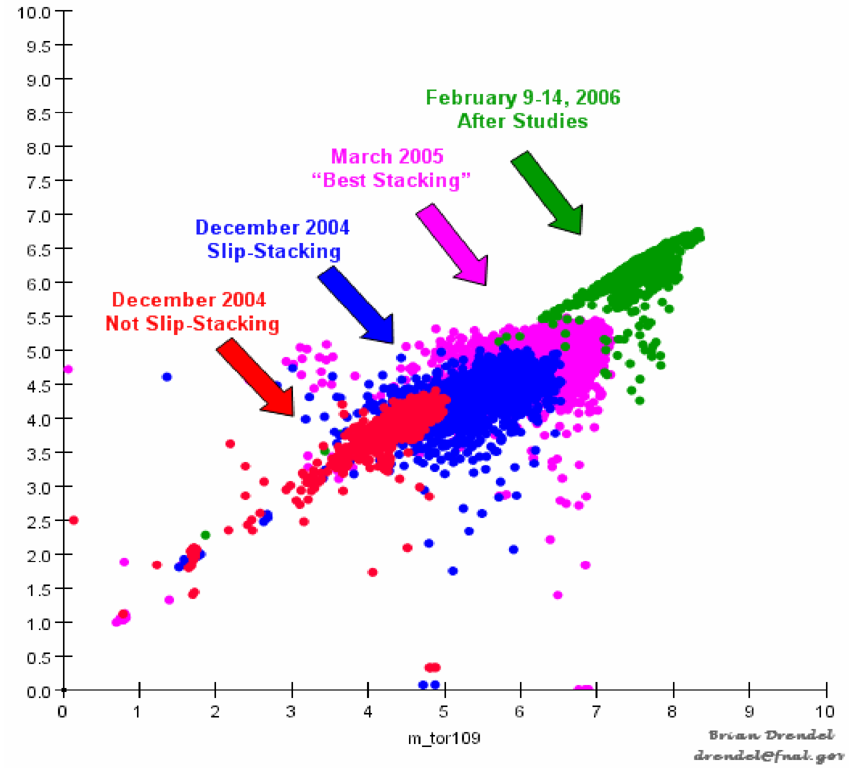
- Every 2.4 seconds $8\cdot10^{12}$ protons at 120 GeV from MI injector sent to the target of about 10 cm length (medium Z - inconel, nickel)
- Li lens located at ~25 cm from target (center-to-center) reduces initially large angular spread
- 8 GeV antiprotons and other secondaries ($\mu$, $\pi$, …) are transported to Debuncher; $N_{pbar}\sim2\cdot10^8$, $\Delta p/p\sim\pm2.2\%$, $\varepsilon\sim35$ mm mrad
- Bunch rotation and adiabatic debunching
- After stochastic L&$\perp$ cooling in Debuncher antiprotons are sent to Accumulator
- In Accumulator Stochastic cooling is used for stacking and for core cooling (long. H and V)



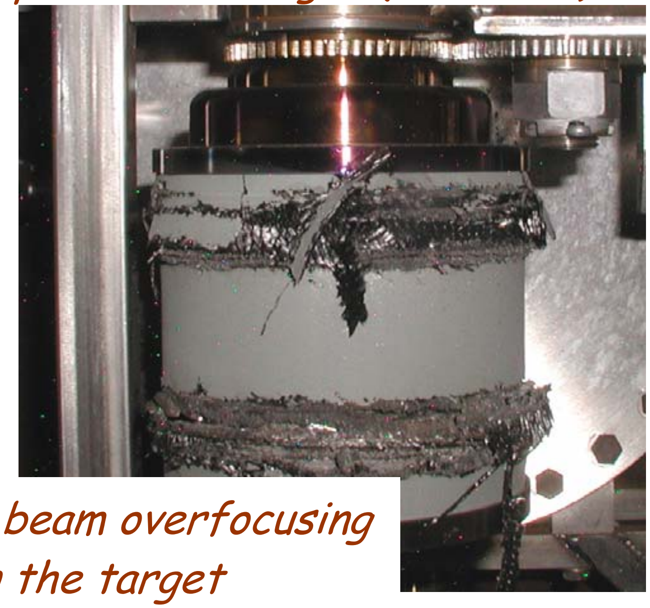

- After storing $\sim5\cdot10^{11}$ $\bar{p}$ in Accumulator (~2.5 hour) they are sent to Recycler
- $\sim3\cdot10^{12}$ $\bar{p}$ are stored in Recycler (~24 hour) and then sent to Tevatron

## Protons on Target

- Strong effort to improve operation of proton accelerators (Jun.05- Feb.06)
- In 2006 we achieved the number of protons on target required by the final Run II parameters
  - It satisfies present and future Run II requirements
- Other improvements
  - Beam position stabilization on target
  - Optics correction for better focusing of proton on the target
    - Rms beam size of ~200 μm is limited by target damage



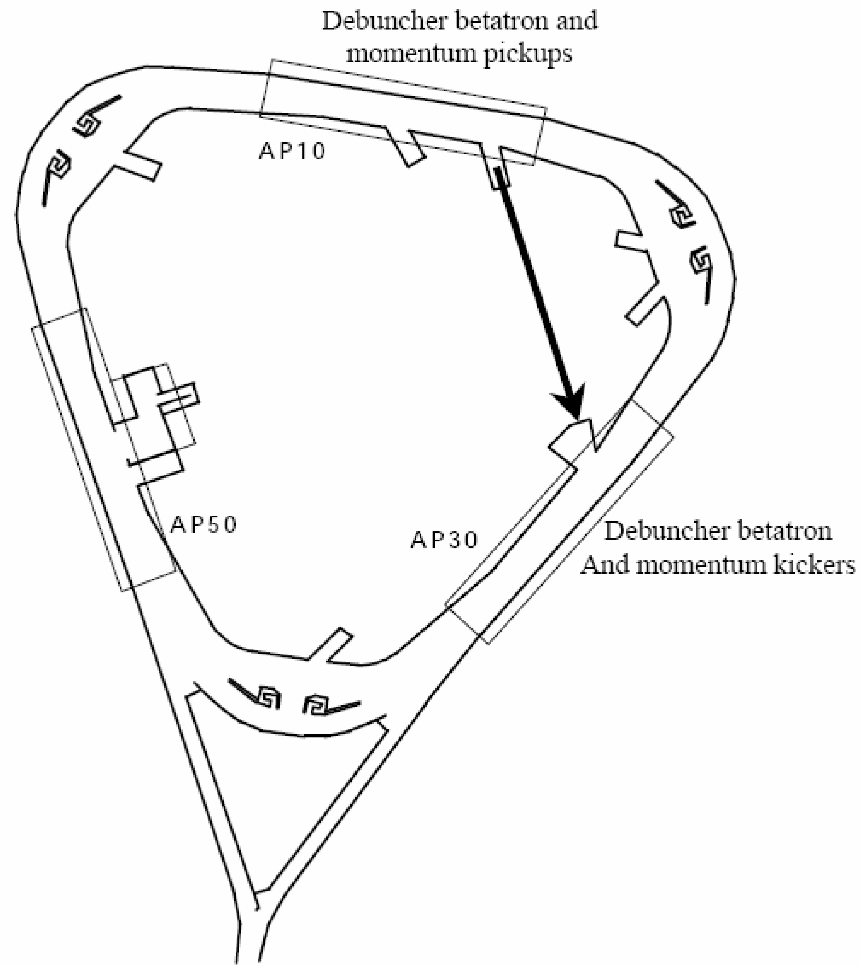

*$N_{pbar}$ at Debuncher entrance (arb. units) on number of protons on target (units $10^{12}$)*

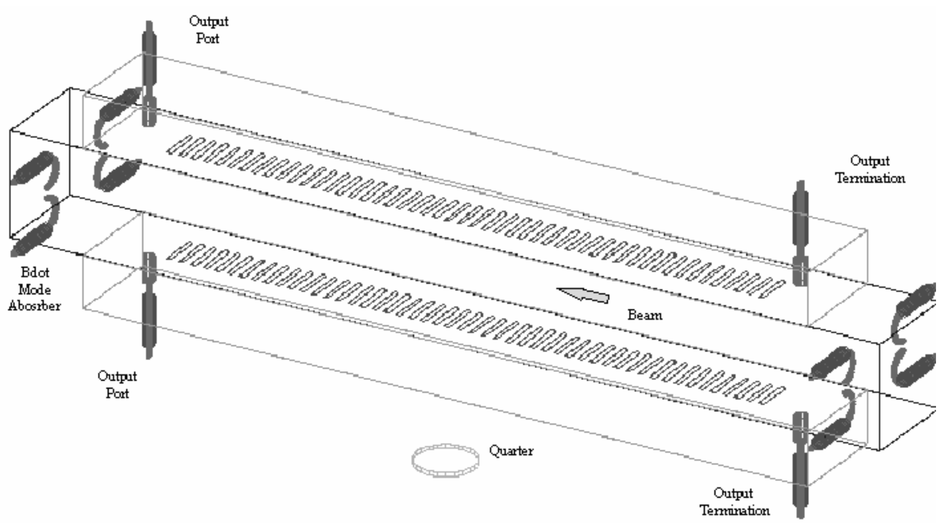


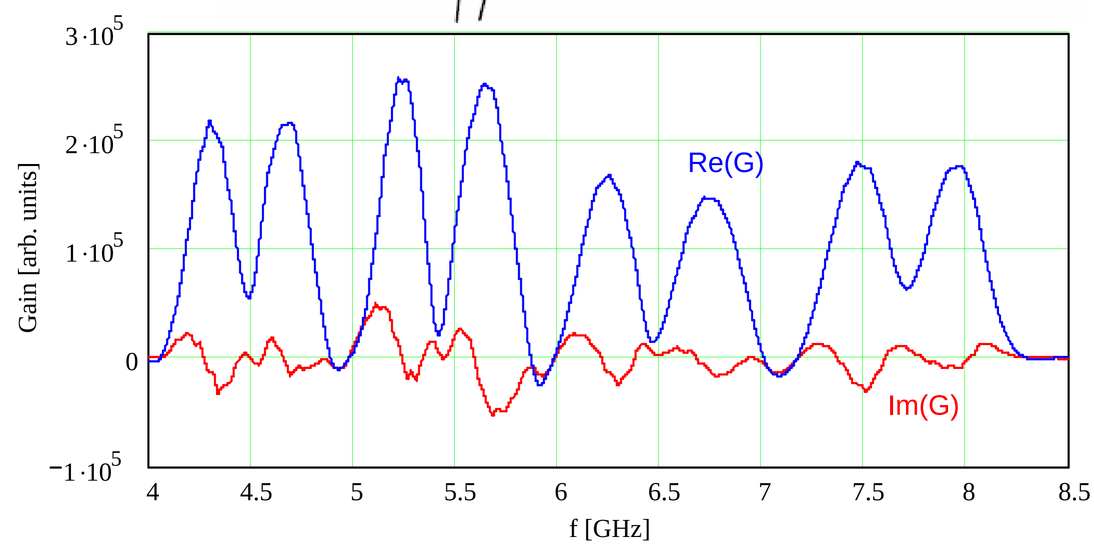
*Result of beam overfocusing on the target*

# Cooling in Debuncher

- 3 cooling systems (L, H, V)
  - 4-8 GHz band
  - L system uses the same pickups and kickers as H&V but in Σ mode instead of Δ mode (filter cooling)
- Each system has 4 sub-bands
  - Pickups of each subband are split into 2 additional subbands
- Cryogenic wave-guide pickups and preamplifiers

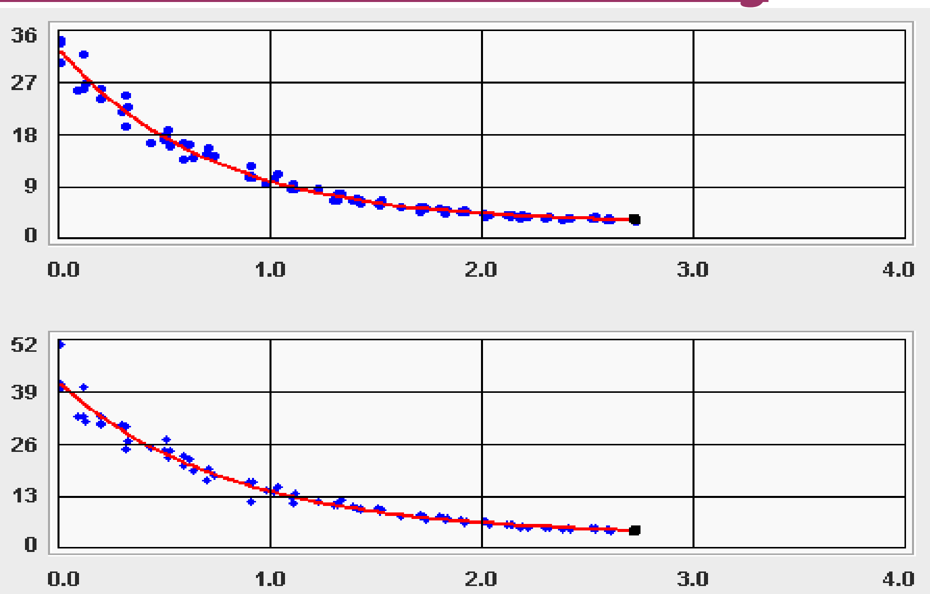


- Debuncher cooling is power limited
  - Wave guide kickers are used. Total power is:
    - ~1.6 kW for each of H&V systems (16 of 100 W TWTs)
    - 3.2 kW for L system (32 of 100 W TWTs)
  - We ramp the gain of transverse systems to keep power at maximum during entire cooling cycle of ~2.4 s

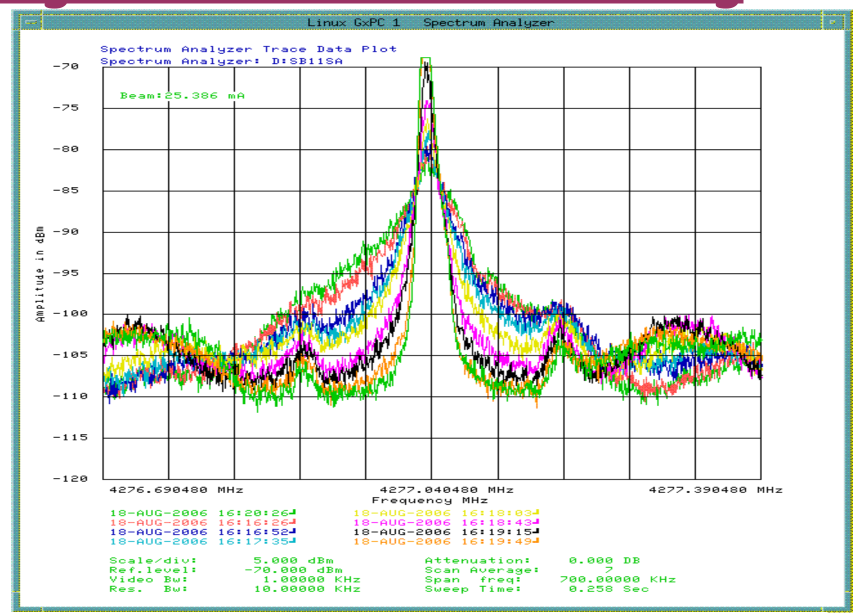
## Transverse Debuncher cooling

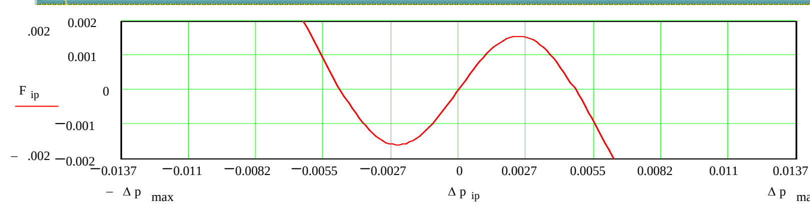



| | Initial | Decrement | Base | at 2 sec |
|---|---|---|---|---|
| X plane: | 32.508 | 0.719 | 2.06 | 3.946 |
| Y plane: | 40.884 | 0.811 | 2.508 | 5.762 |

*X & Y 95% emittances on time*

## Longitudinal Debuncher cooling

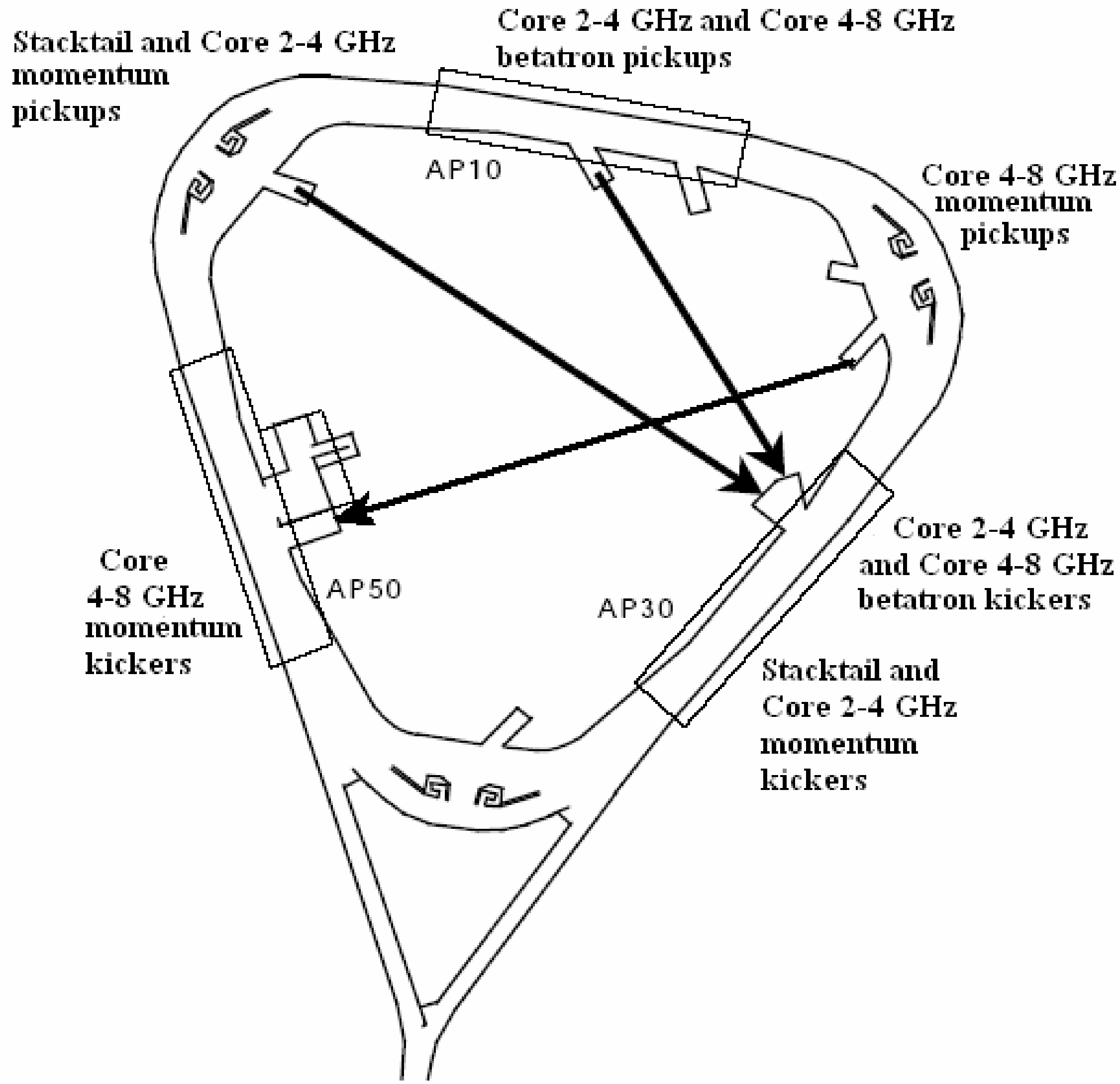



*Top: Spectra at 0, 0.2, 0.4, 0.6, 0.8, 1, 1.2, 1.6, 2 s*
*Bottom: Computed dependence of $F_{||}(\Delta p/p)$*

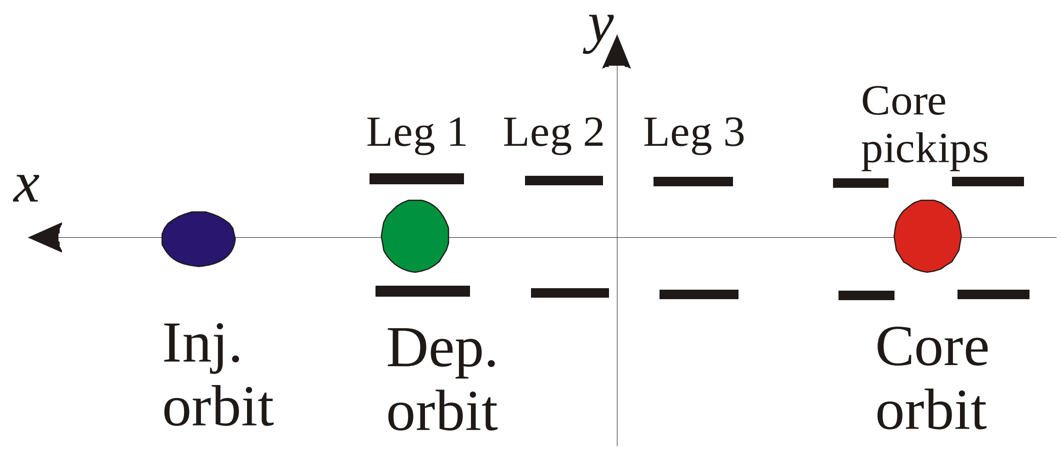
# Cooling and Stacking in Accumulator

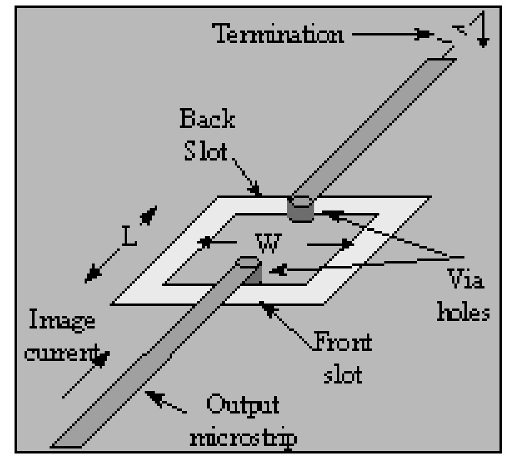
- 5 cooling systems
  - Core cooling
    - H & V – 4-8 GHz
    - Longitudinal: 2-4 GHz and 4-8 GHz
  - Stack-tail - 2-4 GHz
- Stack-tail system moves injected antiprotons to the core
  - Presently it is a major limitation of stacking rate increase
  - All stacking rate improvements of last two years are related to improvements of the stack-tail cooling (every time it is the last bottle neck to be opened)

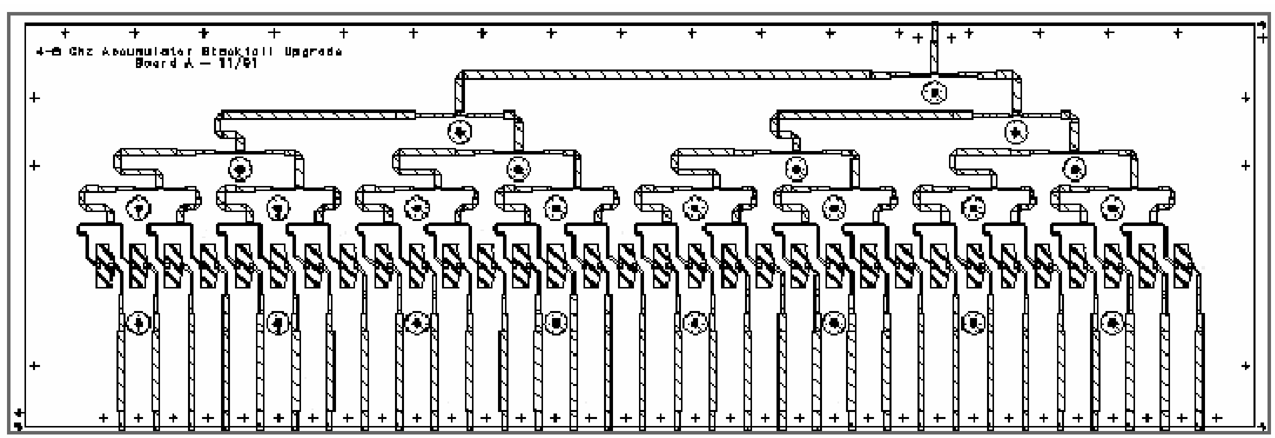


# Stack-tail

- Pickups are located at large dispersion (~9.1 m) while kickers are at zero dispersion (Palmer cooling)
- Stack-tail has 3 pickups located at different radial positions to make desired dependence of gain on the momentum
- Pickups and kickers are built on the same technology
  - Planar loops
  - Printed circuit board technology
  - Works good at small frequencies (f≤4 GHz)
- Outside of pickup aperture its sensitivity drops exponentially. That allows one to form desired gain profile on particle position with small number of pickups
- Notch filters perform additional suppression of the gain on the core (40 Db dynamic range)

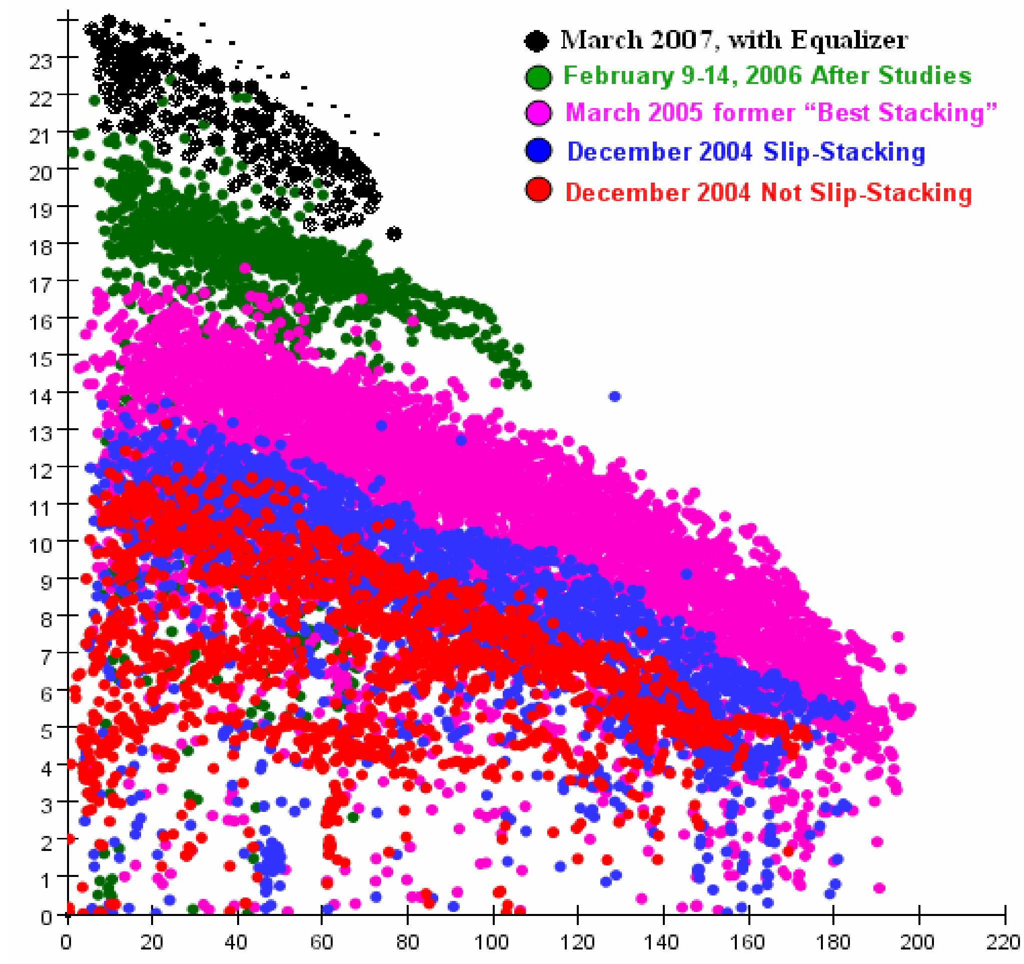


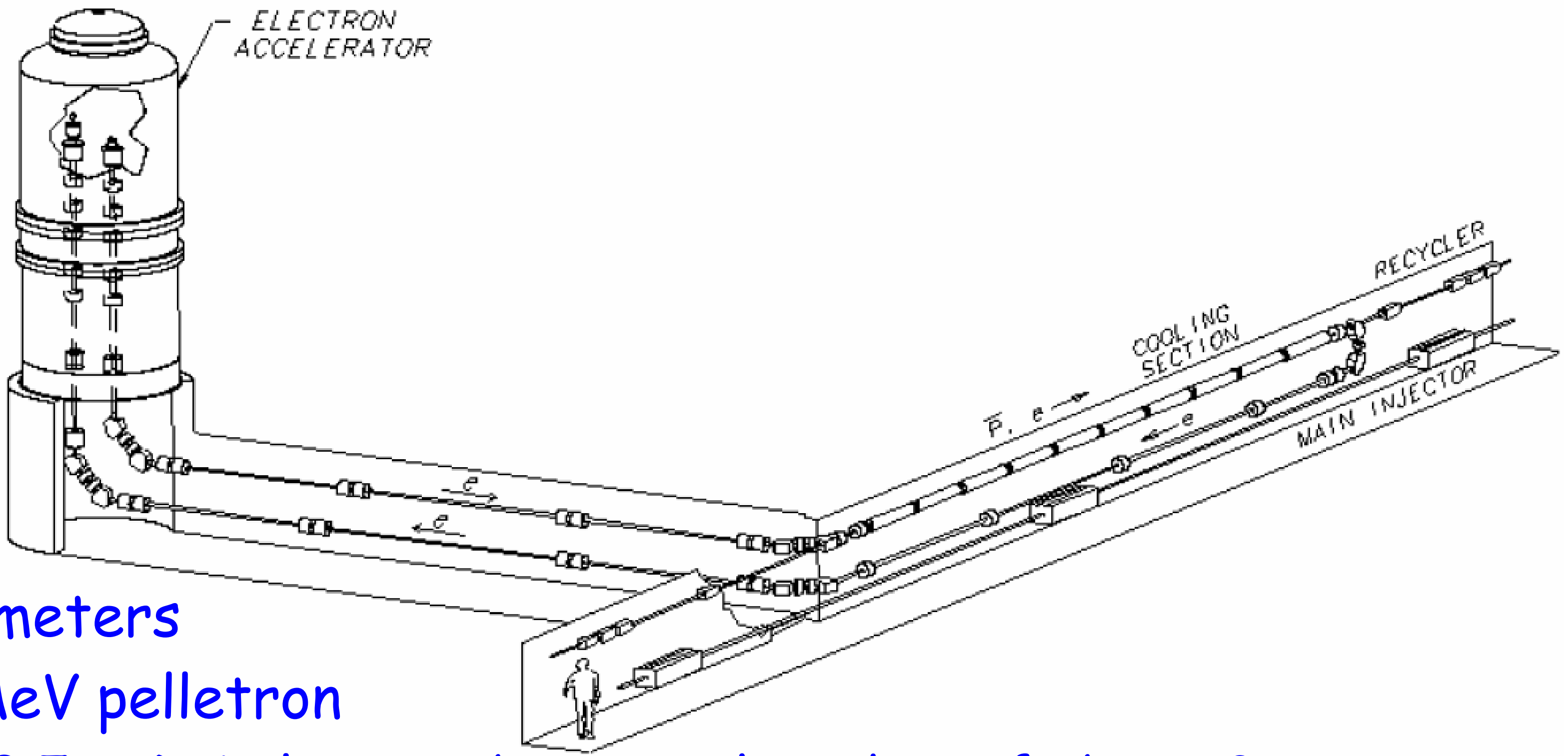
# Sequence of stack-tail upgrades

- **Past**
  - February 2006 – Larger gain of 4-8 long. core cooling; 18->20 mA/hour
  - October 2006 – Flipping gain polarity to correct the phase intercept; 20->22 mA/hour
  - March 2007 – Installation of prototype equalizer; 22->24 mA/hour
- **Future**
  - May 2007 - Optics upgrade in Accumulator (20% slip-factor increase, 15% acceptance increase)
  - June 2007 - Installation of final equalizer
  - July 2007 – Debuncher cooling improvements
- Aim – Peak stacking rate of 30 mA/hour ≡ $30 \cdot 10^{10}$ pbars/hour by the end of FY-2007



# Electron Cooling

- In comparison with stochastic cooling the electron cooling performance is not affected by number of antiprotons
  - The only way to form sufficiently dense pbar beam
- Simultaneous operation of electron and stochastic coolings




- Main Parameters
  - 4.34 MeV pelletron
  - Up to 0.5 A DC electron beam with radius of about 2 mm
  - Magnetic field in the cooling section: 100 G
  - Interaction length – 20 m (out of 3319 m of Recycler circumference)

# Electron Cooling (2)

## What makes Fermilab electron cooler unique?

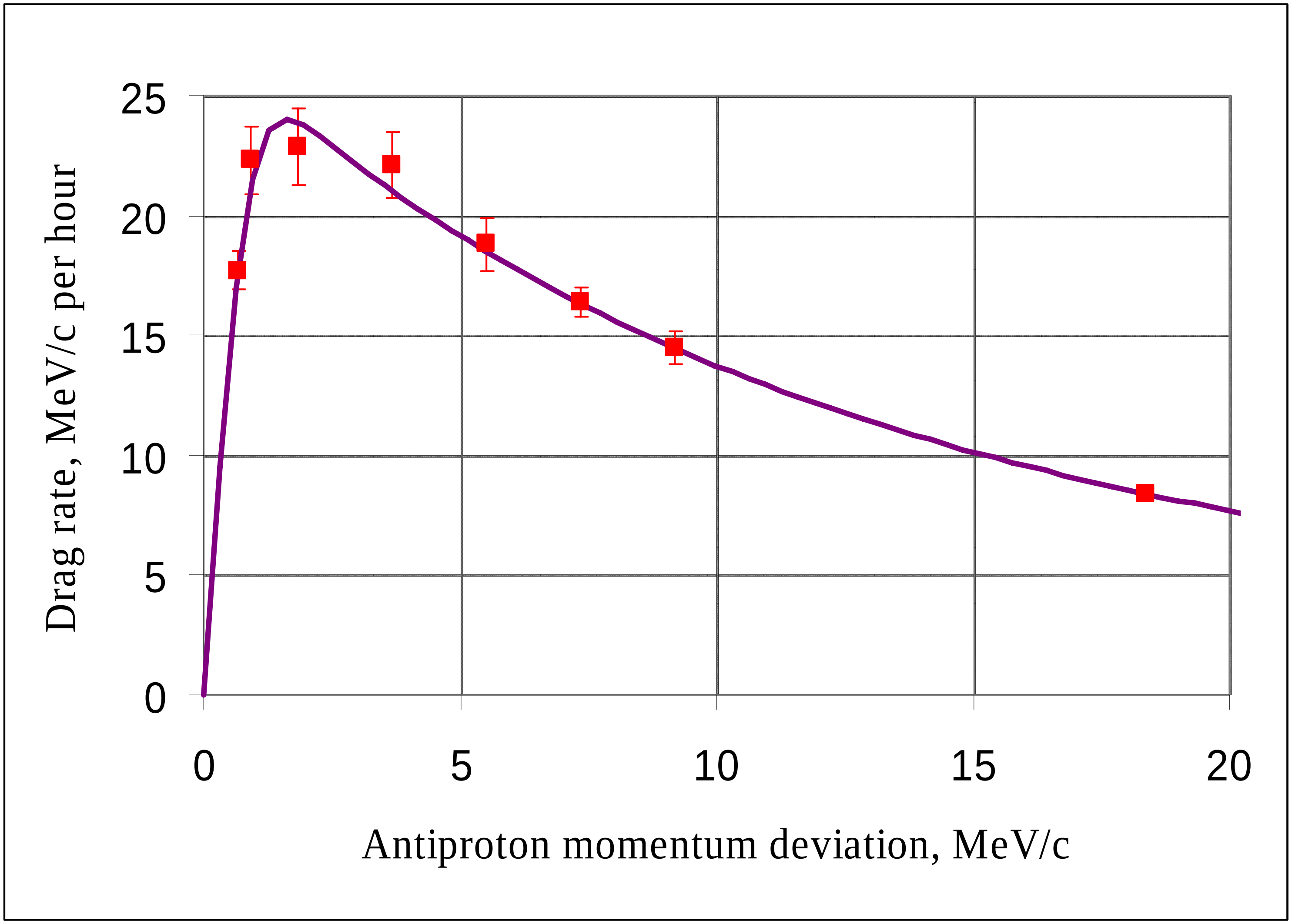
- No strong longitudinal magnetic field accompanying electron beam all the way from gun to collector
  - Angular-momentum-dominated beam transport line
  - Phase advance Q~6
  - Fully coupled motion
  - Length of beam transport~70 m
  - Difficulties of optics commissioning similar to large machines
- Cooling with low-magnetic field – something that had never been tested before, B=100 G
- 15 times higher energy than any cooler before (GSI ~0.3 MV)

*Pelletron*

*Cooling section*

# Electron Cooling (3)

## Longitudinal cooling force




*Drag rate as a function of the antiproton momentum deviation. $I_b$=0.1A, electron beam is on axis. The solid line is a fit by a non-magnetized formula with electron current density of 1.2 A/cm$^2$, rms electron angle in the cooling section of 0.19 mrad, and rms electron energy spread of 370 eV. The Coulomb logarithm in the simulation is taken equal to 10.*