Antiproton Production at Fermilab

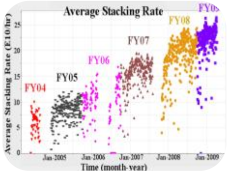
V. Nagaslaev (FNAL)

DPF-09, Detroit

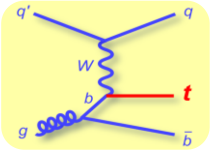
Antiproton Production at Fermilab: Outline

Introduction to the machine operation

Overview of the machine development in last 5 years



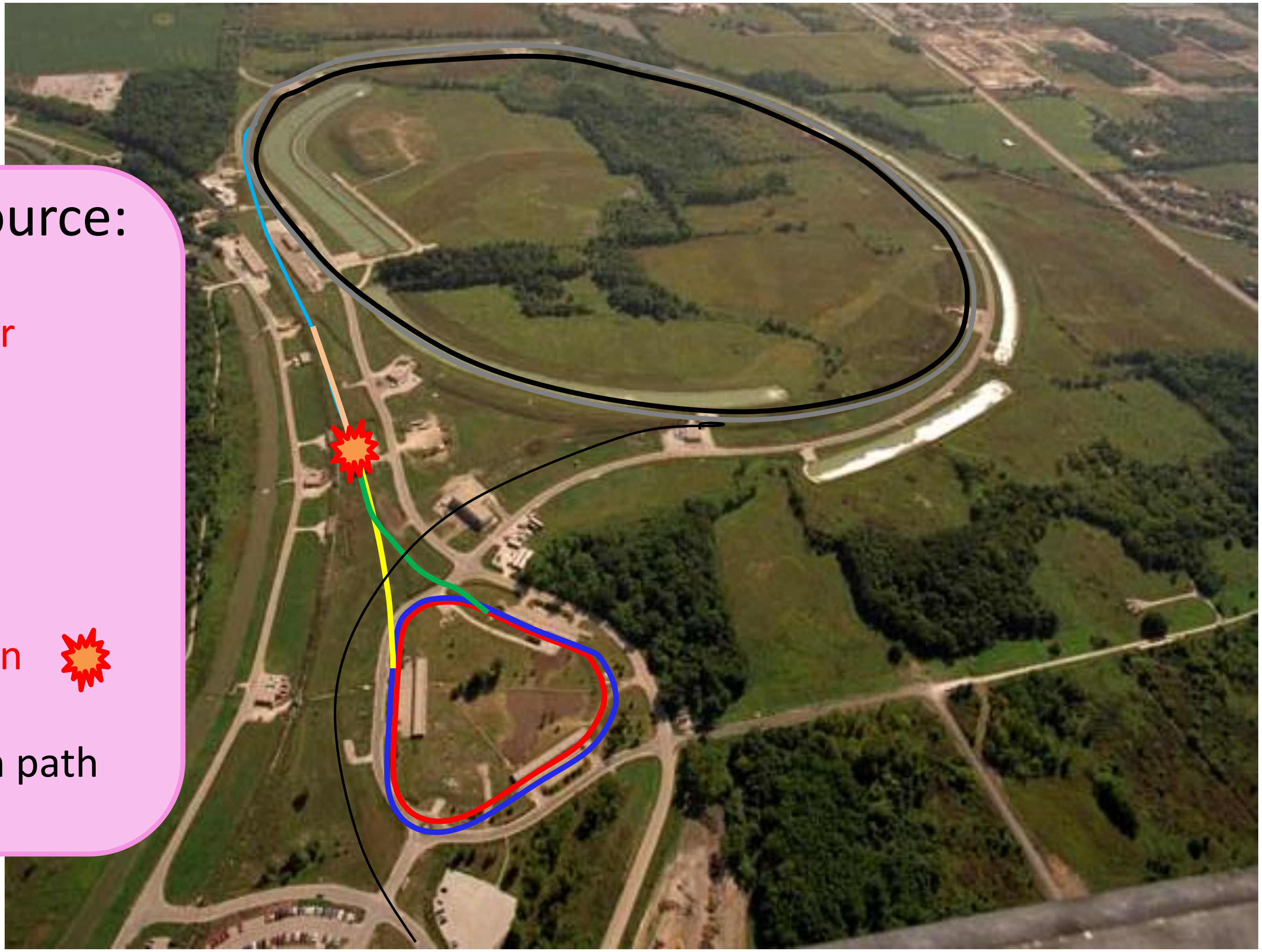
Current machine performance



Experimental options with antiprotons

Introduction: Machine operation

Introduction: Antiproton Source



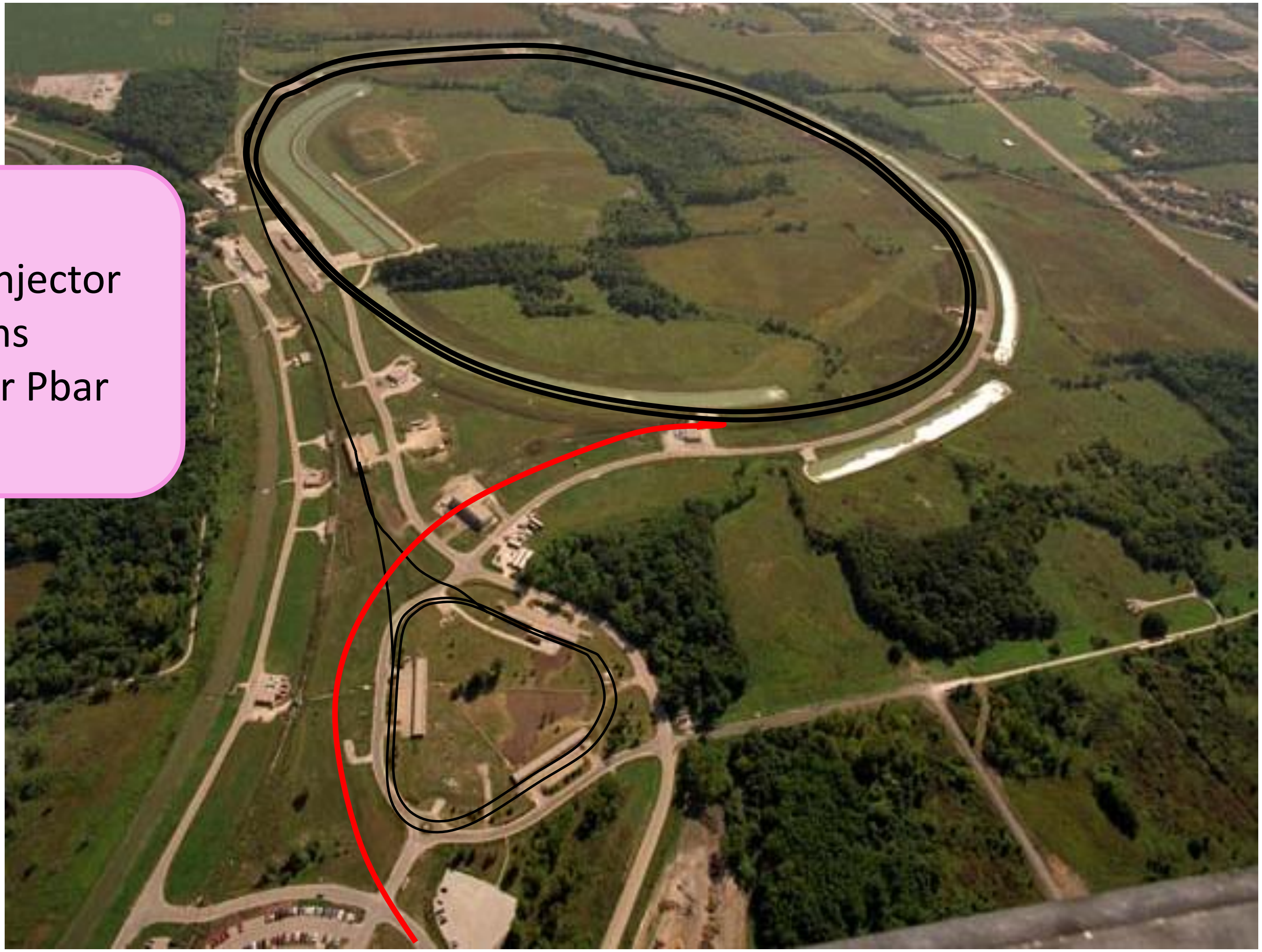
Antiproton Source:

Accumulator
Debuncher
AP1 line
AP3 line
AP2 line
D/A line
Target station

~2.4 km of beam path

Introduction: Machine operation: MI-8 line

Booster to Main Injector
8 GeV protons
~8E12 protons for Pbar



Introduction: Machine operation: Main Injector

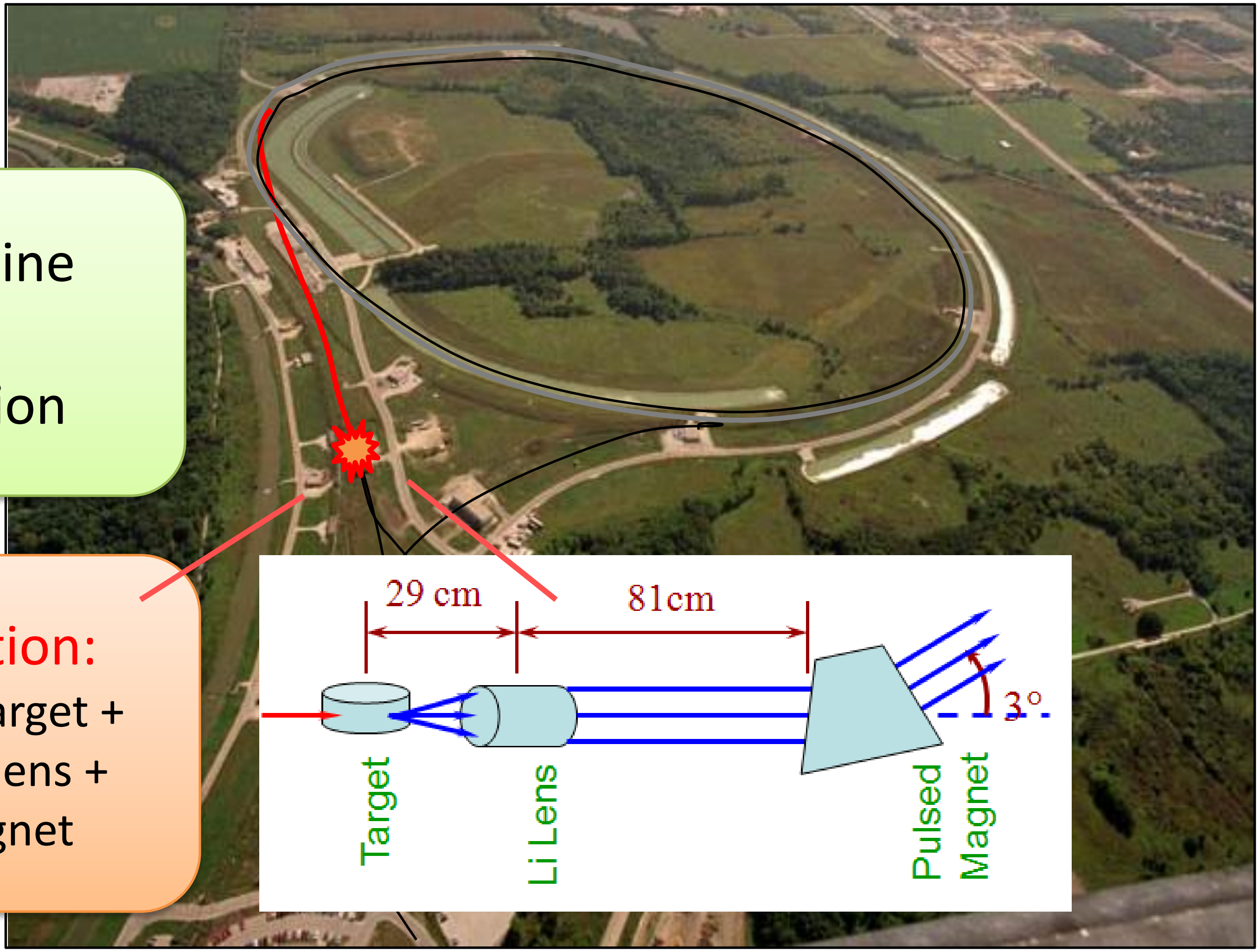
Main Injector:
Acceleration to 120 GeV
2.2 sec cycle

Introduction: Machine operation: P1-P2-AP1 line

Transport line
(P1-P2-AP1)
to the
Target station

Target station:
Ni (Inconel) target +
Li collection lens +
Pulsed magnet

Introduction: Machine operation: P1-P2-AP1 line



Transport line to the Target station

Target station:

Ni (Inconel) target +
Li collection lens +
Pulsed magnet

Introduction: Machine operation: AP2 line

Antiproton transport to the Debuncher
(AP2)
($\bar{p}$ + ...)

Introduction: Machine operation: Debuncher

Debuncher ring:

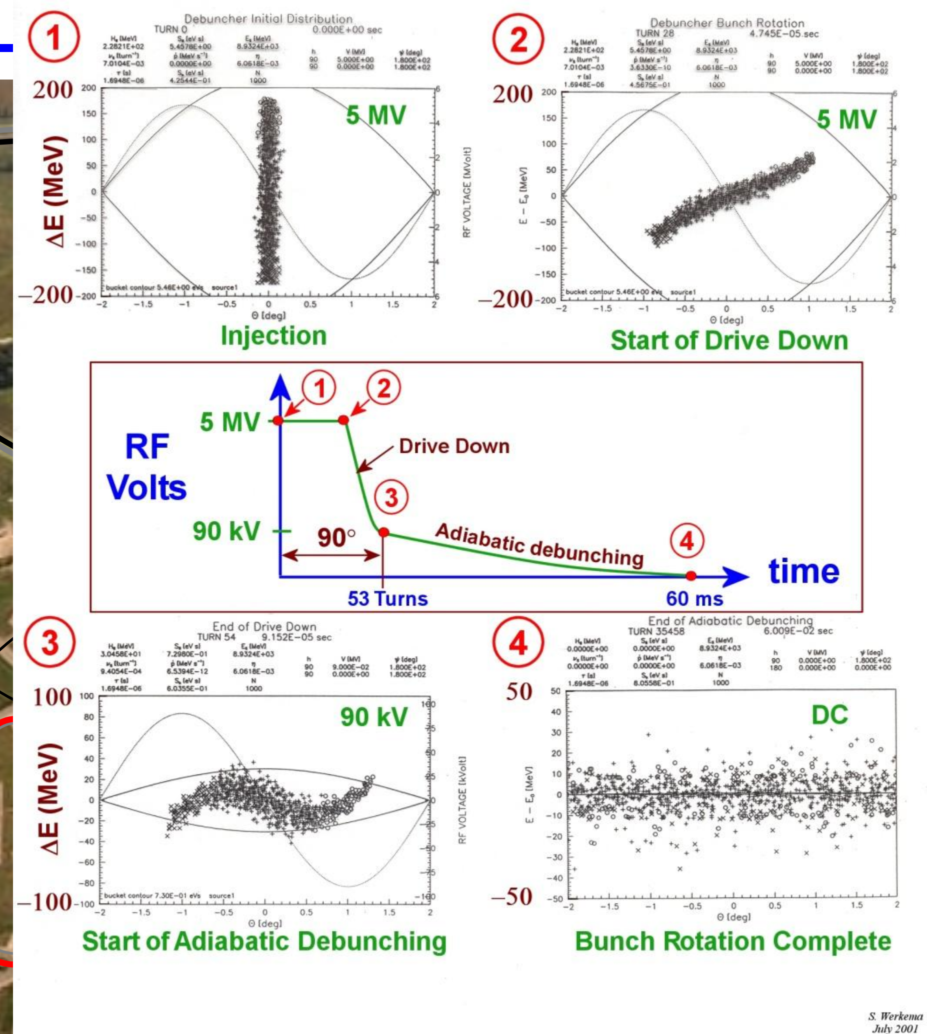
~2e8 pbars/cycle

Large acceptance

Fast compression (2sec):

- Adiabatic debunching
- Stochastic cooling
- ~10x10x10

Introduction: Machine operation: Debuncher



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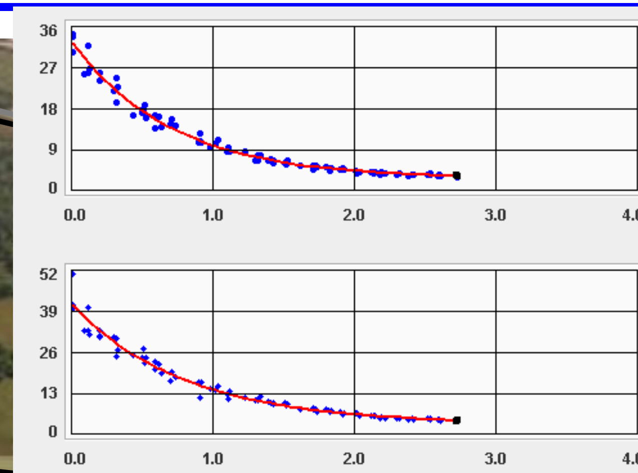
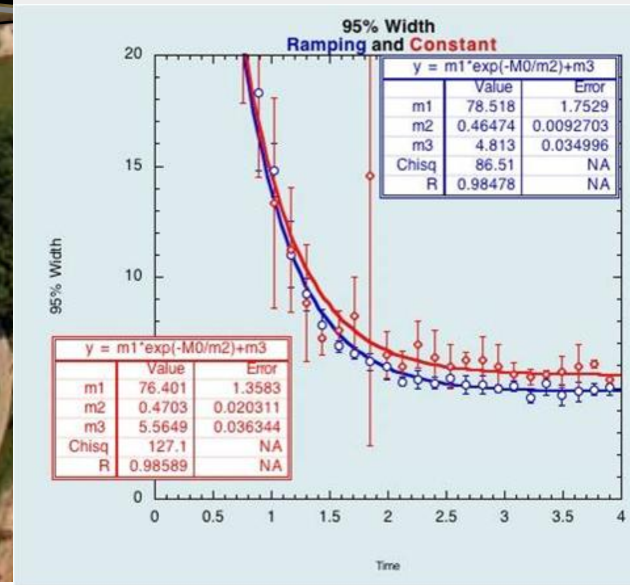




Introduction: Machine operation: Accumulator

Accumulator ring:

Inject to +80 MeV

RF move to deposition

Moving to Core: -60 MeV

with Stochastic cooling

RF unstack for extraction

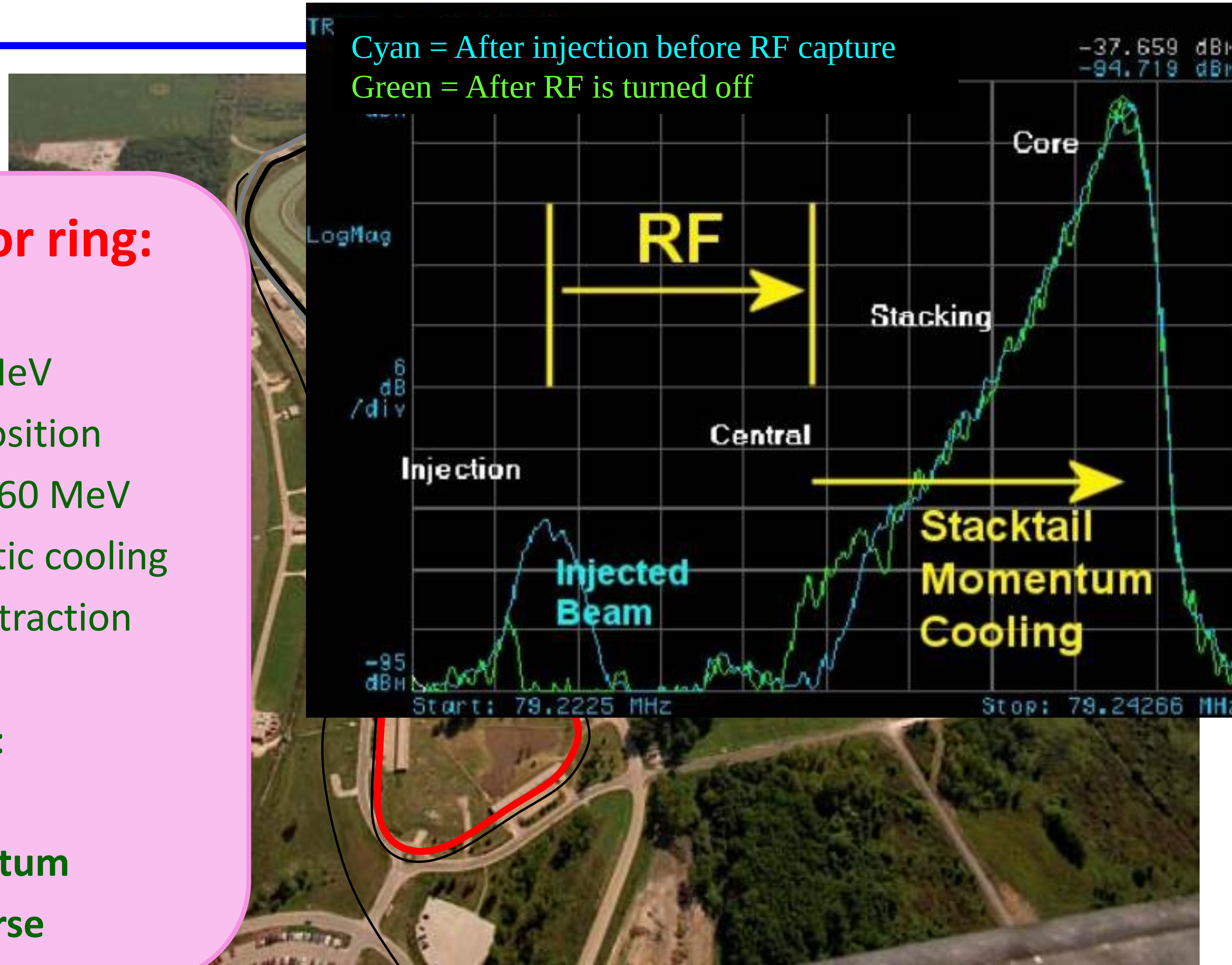
Stochastic cooling:

Stack- tail momentum

Core momentum

Core transverse

Introduction: Machine operation: Accumulator



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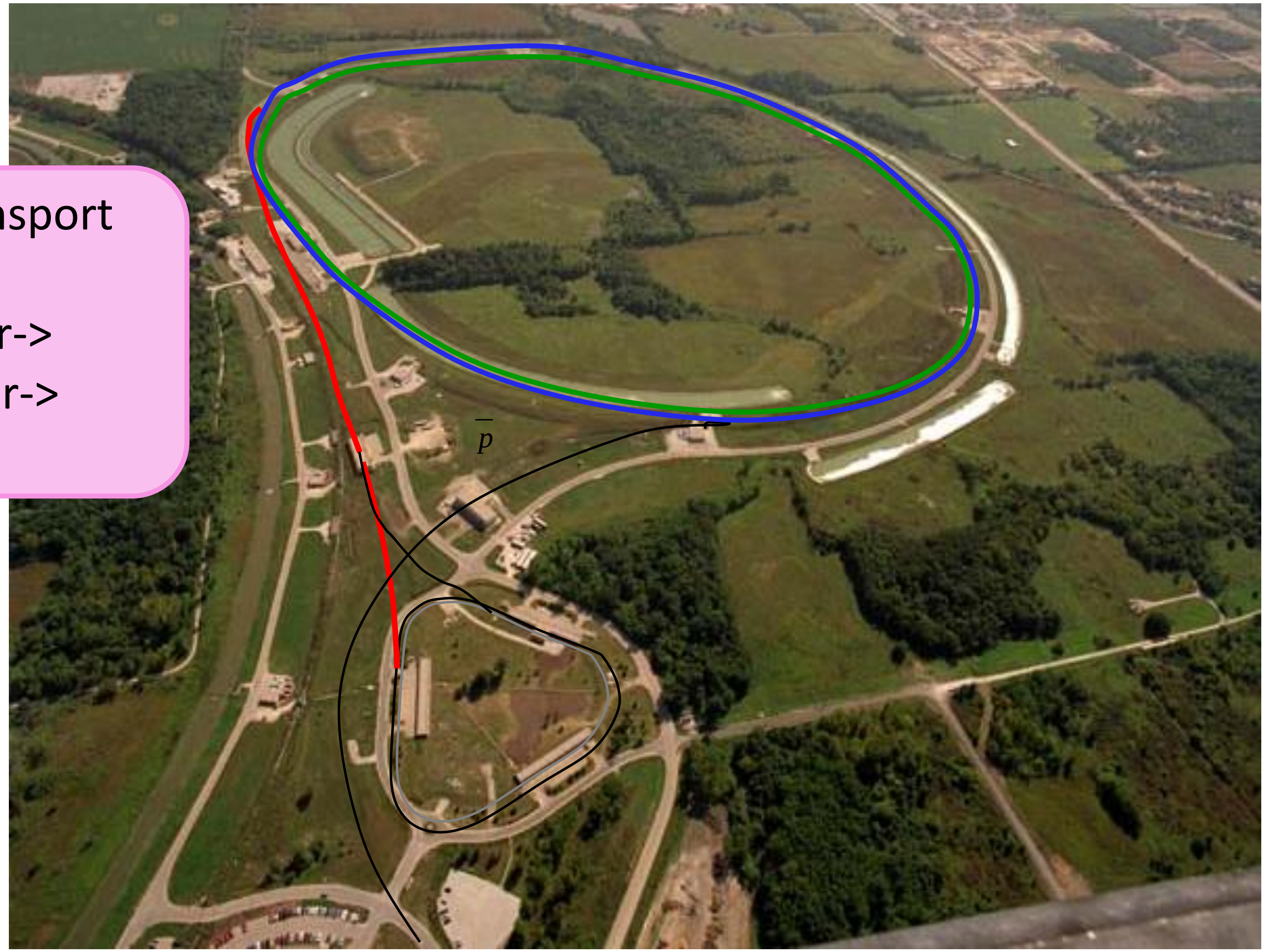
Core transverse

Introduction: Machine operation: AP3-AP1-P2-P1

Antiproton transport

Accumulator->
Main Injector->
Recycler



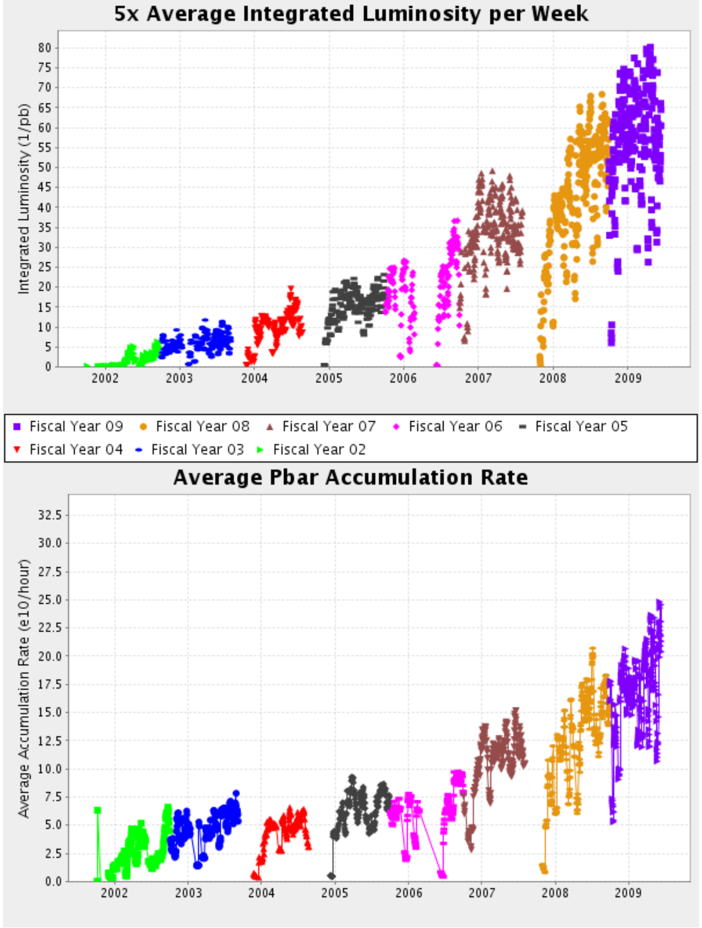
Antiproton Source parameters

Beam momentum	8.9 GeV/c
Peak stacking rate	27.6 e10/hr
Average stacking rate	24 e10/hr
Average production efficiency	22 e-6 $\bar{p}/p$
Typical stack size	25 e10
Maximum stack size	310 e10
Stacking cycle	2.2 sec
Time between transfers	50 min
Total beam compression	10^7
Transfer to RR efficiency	96%

(Terminology: "1mA" = 10^{10} pbars)

Main machine developments since 2005

There's been a remarkable progress with the Tevatron integrated luminosity since the beginning of Run-II. A crucial factor in this progress was the growth of antiproton production capability. Average weekly production has grown a factor of 3.5 since 2005.



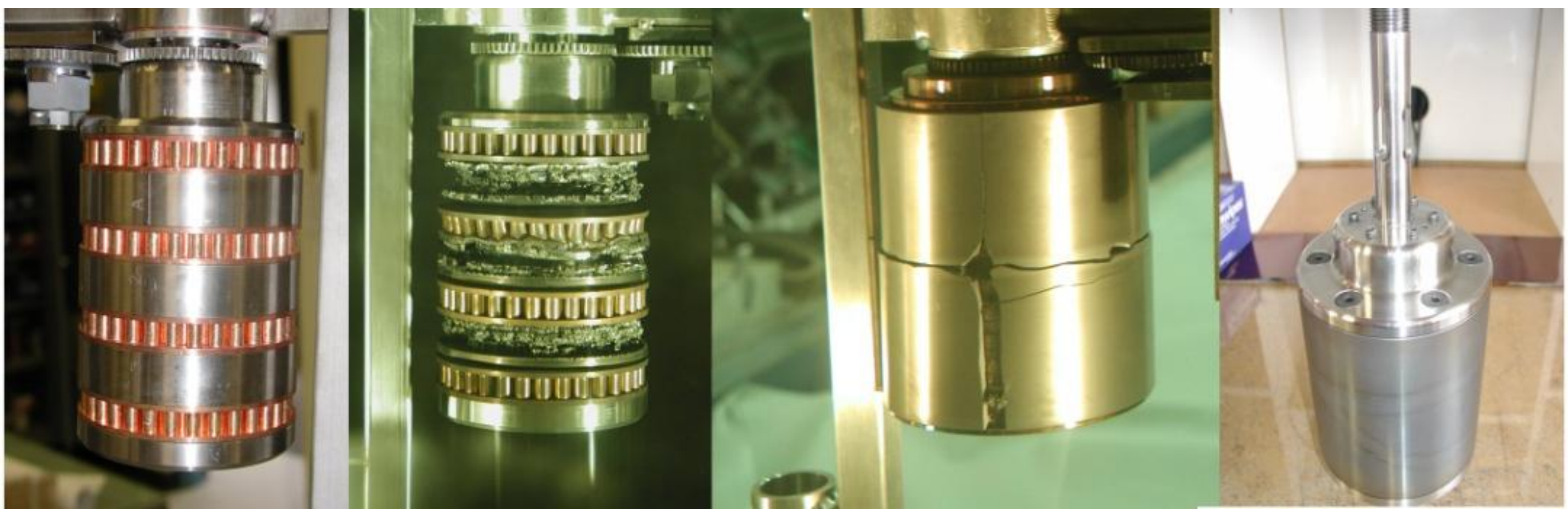
Main improvements since 2005:

- Target and collection lens
- AP2/Debuncher acceptance
- Debuncher stochastic cooling
- Accumulator stochastic cooling
- Lattice (optics) modifications
- Rapid transfers

  (no luxury of incremental changes)

Production target

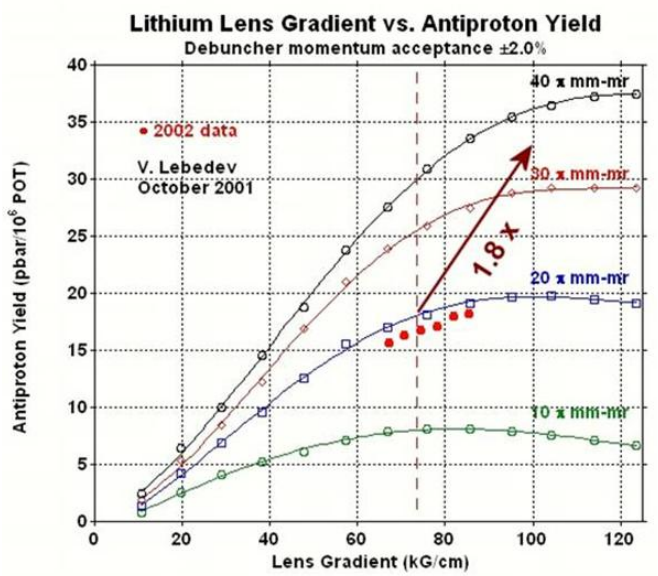
- Optimum yield with narrow beam spot, ~170u
- After implementing slip-stacking in MI – issues with target lifetime
- Engineering team working on the target design
- Eventually come up with a reliable solution, including the target, motion and cooling
- Beam sweeping
- Target is rotated by 15 degrees after each pulse

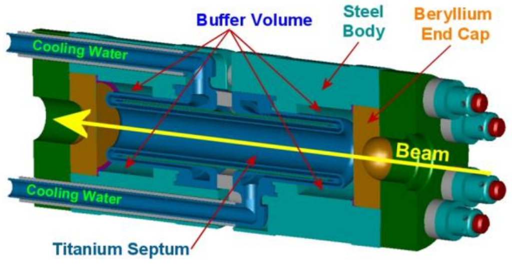


Previous design Latest design-B Latest design-C

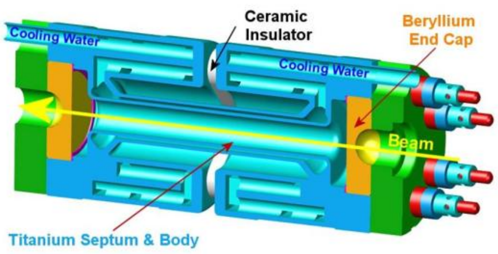
Collection lens

- Li cylinder, r=10mm, L=15cm
- Focusing by axial current (600kA)
- Extreme heat and mechanical load
- Lifetime issues at high gradients
- New design developed:
    - Titanium body
    - Diffusion bonding
    - More efficient cooling
    - New transformer design





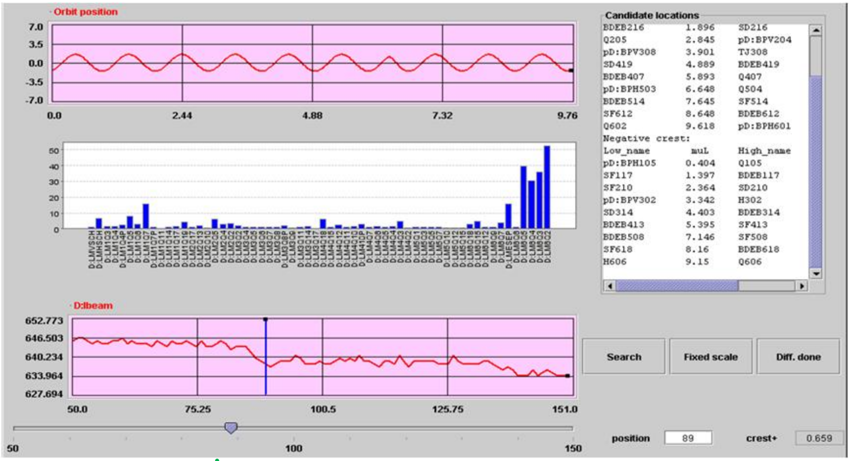
Old design



New design

AP2/Debuncher acceptance

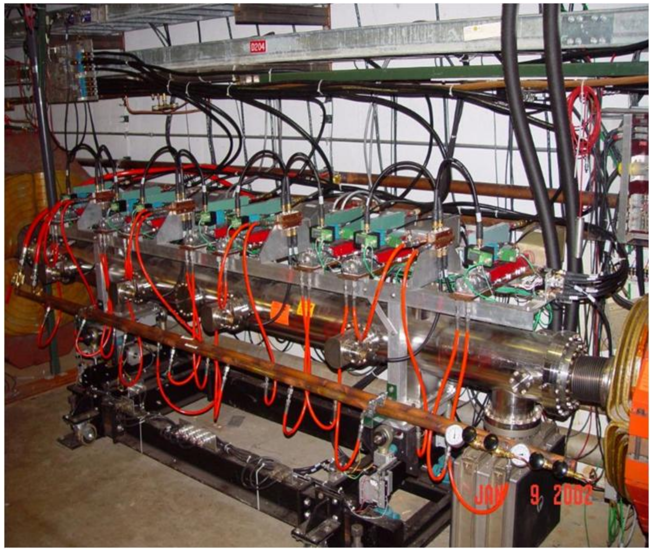
- Run-II: goal – increasing AP2/Debuncher acceptance to 35π/35π (H/V)
- March 2005 Debuncher acceptance 30π/25π (H/V)
- A lot of work before 2005 to build new hardware and instrumentation
- Requested 2 weeks of studies in December; Tevatron failure for 3 weeks:
  - studies in shifts around the clock (Study-O-Rama)
  - component centering, correcting orbits
  - aperture limitations searches (new method)
- Got 2 more weeks in January 2006
  - searches continued
  - removed Debuncher Schottkys
  - installed new trims in AP2
  - lattice studies



- Extraction kicker was modified to improve aperture
- New lattice was developed shortly after, and that completed the goal
- Design acceptance ~40π/40π, actual (measured) 35π/35π

Debuncher Stochastic cooling

- fast – 2 sec cycle time
- wide acceptance in dP
- very low signal – cryogenic
- 8 PU bands, 4 kicker bands, 4-8 GHz
- Total kicker power 10kW

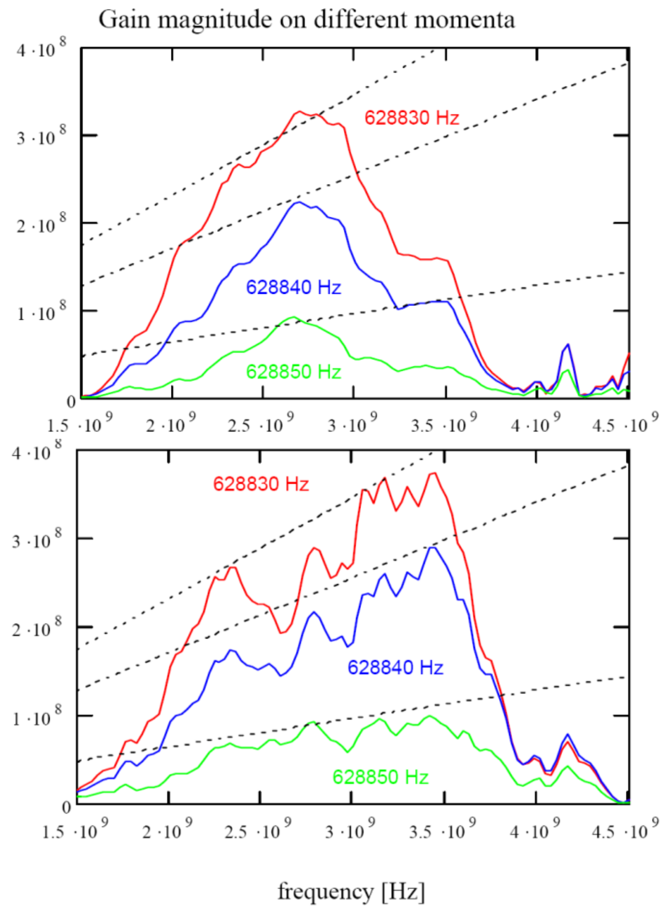


Debuncher stochastic cooling kicker tank

- Run-II upgrade: bands 3&4 tanks added
- Main improvement after upgrade: Double turn notch filter
  - switched in at 1 sec
  - 10% reduction of final energy spread

Accumulator stochastic cooling

- 4 systems:
  - StackTail Momentum 2-4 GHz
  - Core Momentum 2-4 GHz
  - Core Momentum 4-8 GHz
  - Core Betatron 4-8 GHz
- Main focus: StackTail
- 2006: switched focus from CM 2-4 to CM 4-8
- Detailed studying – numerical model developed
- Optimization, reconfiguration
  - Hybrid flip,
  - "Leg 3" resurrected
- 2007 – new equalizer
- Strong limitation: ST heating the Core
- Swapping 2 ST kicker tanks with 2 CM tanks
- Notch filter #3, BAW → SC, increased depth
- Equalizer for Core momentum
- New optics (increased eta)



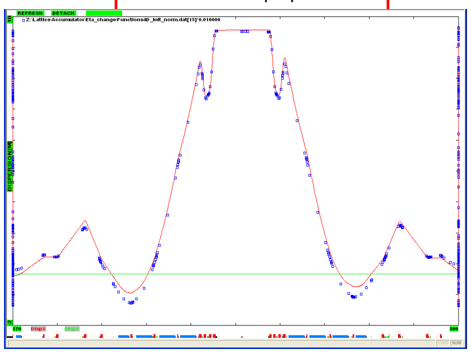
System gain versus frequency
before and after new equalizer installed

Lattice modifications

Accumulator:

- Slip factor increase by 15%:
- helps stochastic cooling

$$J_{\max} = T_0 |\eta| W^2 x_d$$



- dispersion variation in "wells"

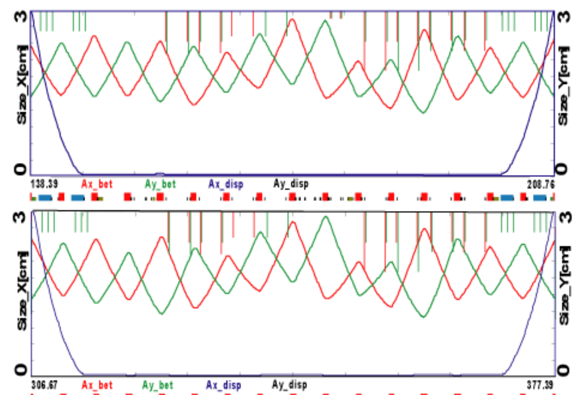
- Address transverse heating:
  - Mitigate heating resonances
  - Suppress dispersion in straights
  - Lower beta-functions (IBS)
- Apertures:
  - Reduce beam size at tight locations

Debuncher :

- Increase machine acceptance
- Correct P-K phase advances for SC

2005 : 30π/25π mm·mrad

2006: 35.3π/34.6π mm·mrad



Eliminated the need in replacing B4 cooling tanks

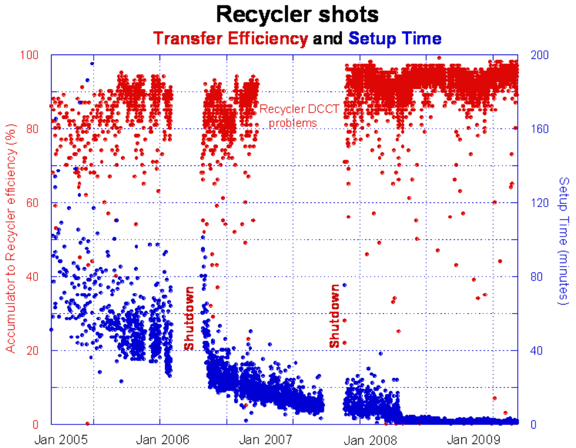
Rapid Transfers

Speeding up transfers:

- More time for stacking (13%)
- Smaller optimal stack size

Challenges:

- Thousands of devices involved
- Incremental changes
- Intelligent procedure
- Transfer efficiency

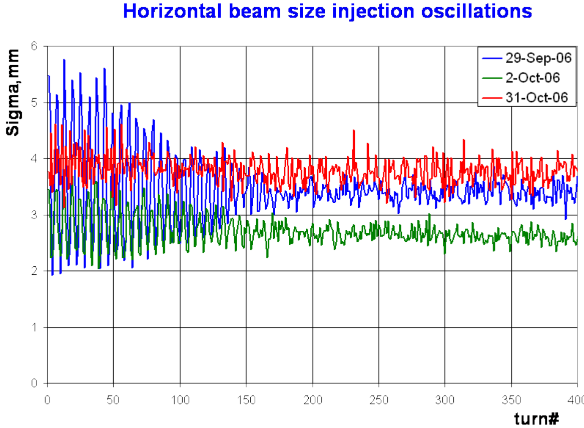


New hardware:

- BPM upgrade
- ramping magnets in AP1
- RF modifications – shorter bunches

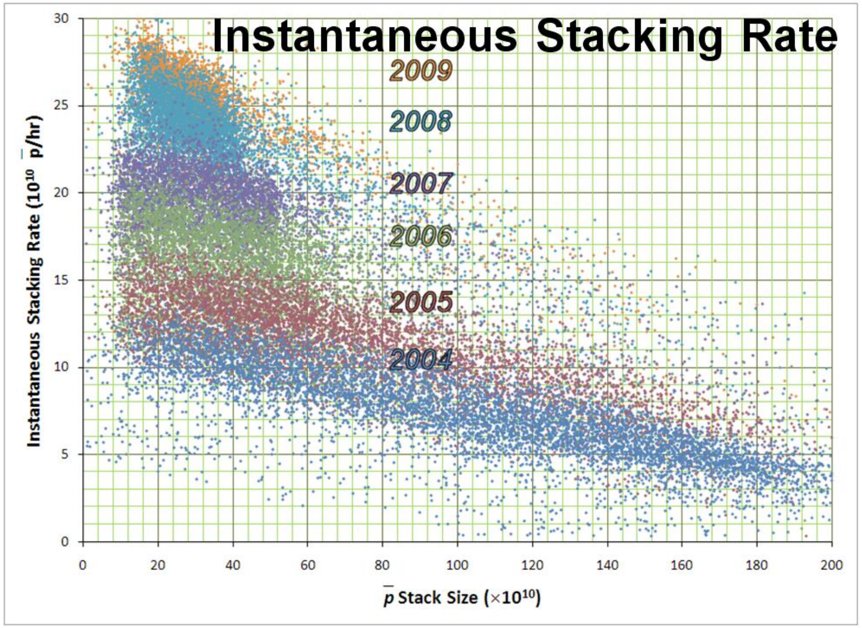
Transfer efficiency:

- Orbit monitoring
- MI injections damper
- Optics modifications
- 2006: 75%-95%
- Now: routinely 96%



Antiproton source performance

- 2005 start combination shots to TeV
- 2006 only RR shots
- 2005-2006: AP2/Deb acceptance
- after 2006:
    - Stochastic cooling
    - Target
    - Lens
- 2006 also: start of Rapid Transfer effort



World's antimatter production

	FNAL	CERN	GSI FAIR
Average production rate [e10/hr]	24		
Peak production rate [e10/hr]	27	7.5	3.5
Ready to start Experiments	2011	-	2015

What are we going to do with this facility when Run-II ends?

- Scope of this question spans beyond Fermilab
- We have not yet passed the decision point
- HEP community should think about it again – NOW!

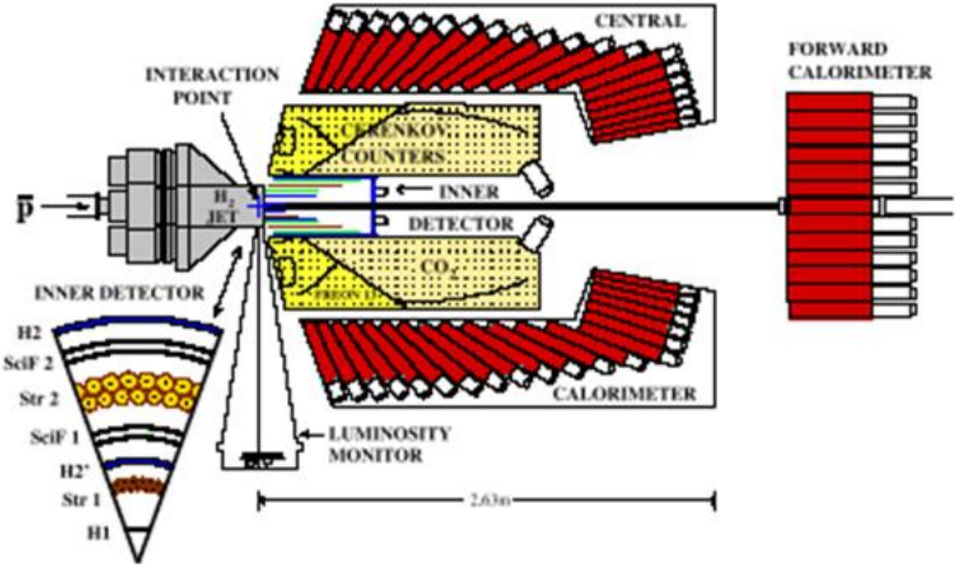
Experimental options: In the past

E760 (1990-1991)
E835 (1996-2000)

Charmonium experiments

Charmonium physics
and continuum cross-sections

Precision measurements of number of parameters, still leading in PDG tables



Detector pit is empty now!

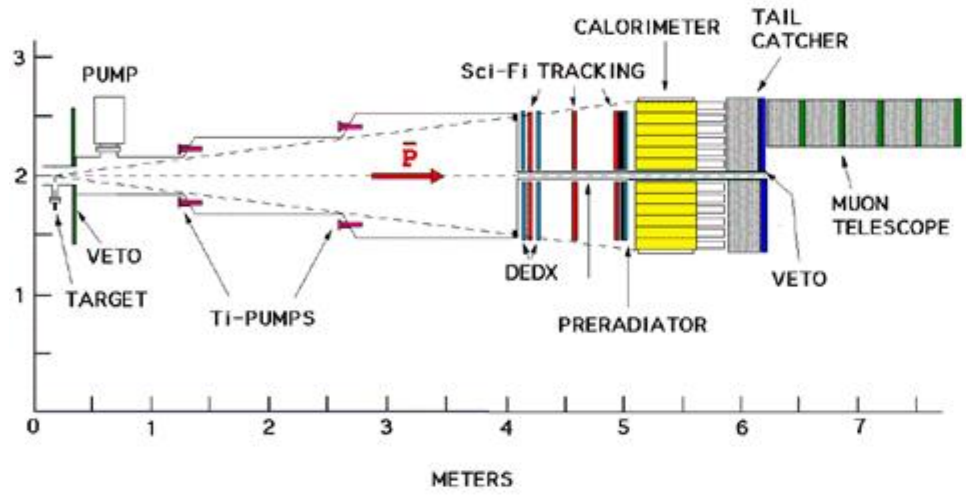
Experimental options: In the past

APEX (T861/E868, 1995-1996)

Antiproton lifetime experiment

$\bar{p} \rightarrow e + X$ (7 modes)

$\bar{p} \rightarrow \mu + X$ (6 modes)



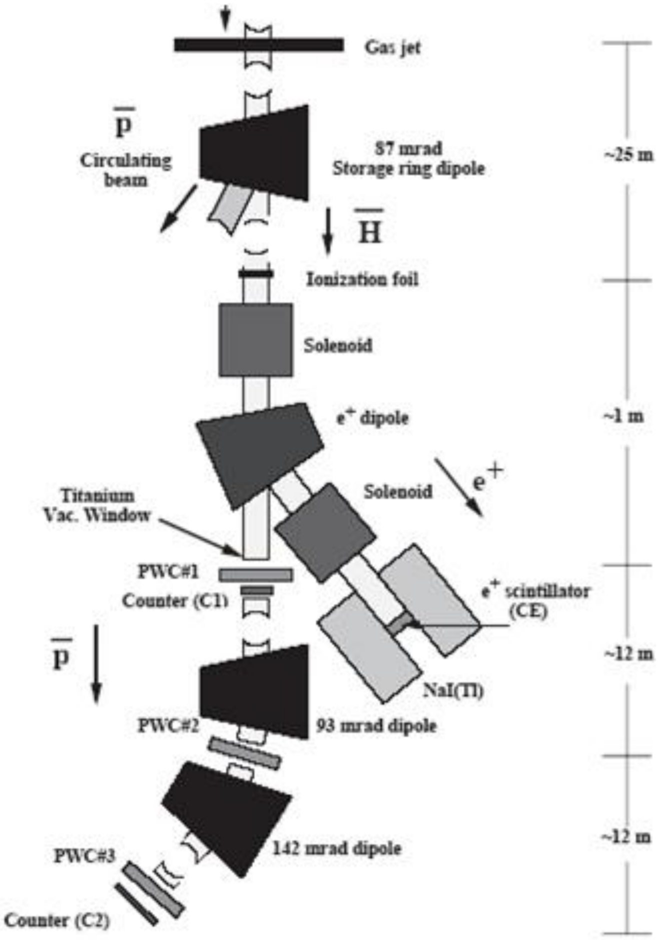
Experimental options: In the past

E862 (1996-1997)

Production of relativistic antihydrogen

Production and successful detection with no background has been demonstrated.

Experiment has been proposed to fine spectroscopic measurements including the Lamb shift (1-5% level)



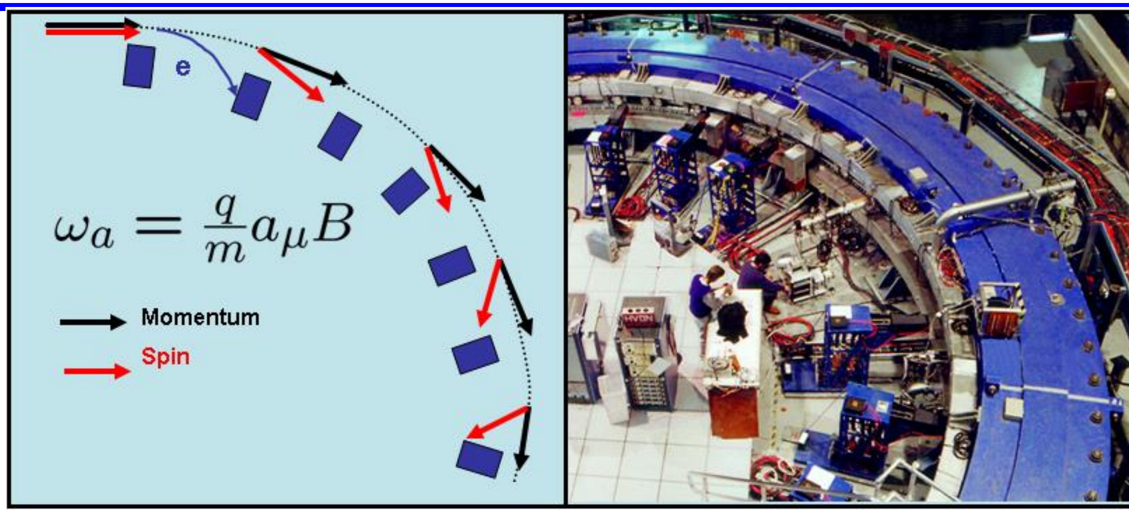
Experimental options

What can be done now?

Precision measurements with Charmonium	Precision measurements of XYZ states	Measurements of continuum
Searches (excited C, exotics, glueballs)	Asymmetries in Hyperon Decays (CP-violation)	Rare hyperon decays
Relativistic Antihydrogen (Lamb shift)	Open Charm	…many others!

For details see Dan Kaplan's talk at the parallel session "Hadron spectroscopy I"

Experimental options: g-2



- Using Fermilab beams to continue BNL g-2 experiments
- Valuable experiment at low cost and short time scale
- Potential: to improve experimental uncertainty from 0.54ppm to 0.14ppm

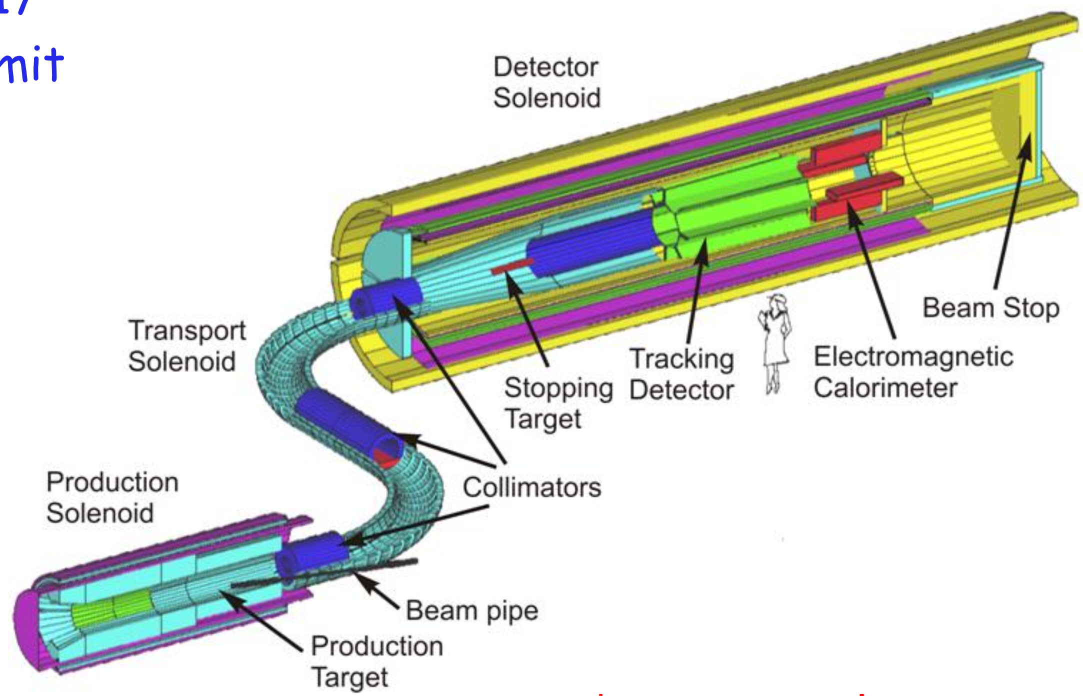
- Proposed to run parasitically with neutrino programs and before mu2e
- Use 8 GeV protons for 3.1 GeV pion production on the Pbar target
- Using Debuncher in a beam line mode
- Advantage of large Debuncher aperture and long decay path
    - Few technical challenges
    - Hardly compatible with antiproton program
    - Challenge to squeeze between Run-II and mu2e and low budget

Experimental options: mu2e

$$\mu^- N \to e^- N$$

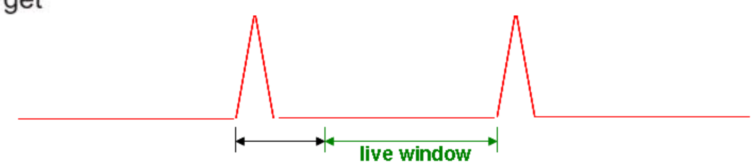
Charged Lepton Flavor Violation

- In 2 years running : Rμe ~ 2e-17
- 4 orders lower than current limit
- Many models predict   e-15



Using Pbar Source:

- Natural time structure
- Slow spill extraction
    - Challenges of high intensity
    - High radiation issues
    - Extinction at $<10^{-9}$
    - End of the antiproton program



Options other than using the Pbar source are possible!

Conclusions

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2. Fermilab antiproton program is now and will be the world most powerful source of antiproton production for decades
3. Rich physics with antiprotons may become available, with plenty of opportunities for PhD research
4. Interest and input from physics community is important

Backup

Experimental options: Alternatives

Project X, ICD-II (presented at NuFact-09)