U.S. DEPARTMENT OF ENERGY

Fermilab

Status of Tevatron Run II

Valeri Lebedev

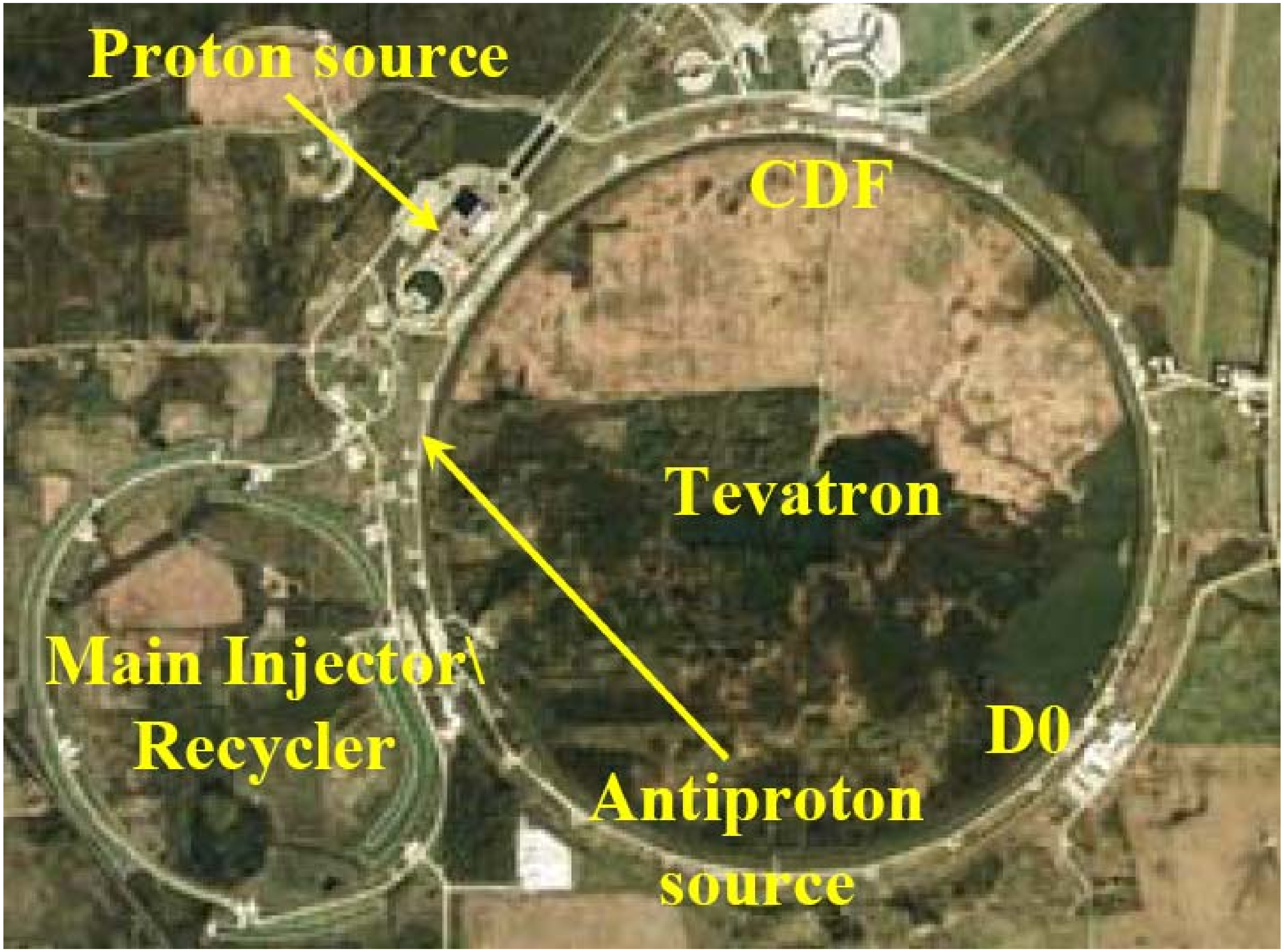
for Accelerator Part of Run II

Contents

- Introduction
- Physics program
- Luminosity performance and projections
- Antiproton production and stacking
- Antiproton Cooling and Accumulation in Recycler
- Tevatron (More details in “Recent Tevatron Operational Experience” by Alexander Valishev, Friday 10:00)
- Conclusions

- Presentation focus is shifted to Accelerator physics issues
- Operational strategy and details are in “Optimization of Integrated Luminosity of the Tevatron” by Consolato Gattuso, Monday 17:15

Tevatron - $P - \bar{P}$ Collider Operating at 980 GeV

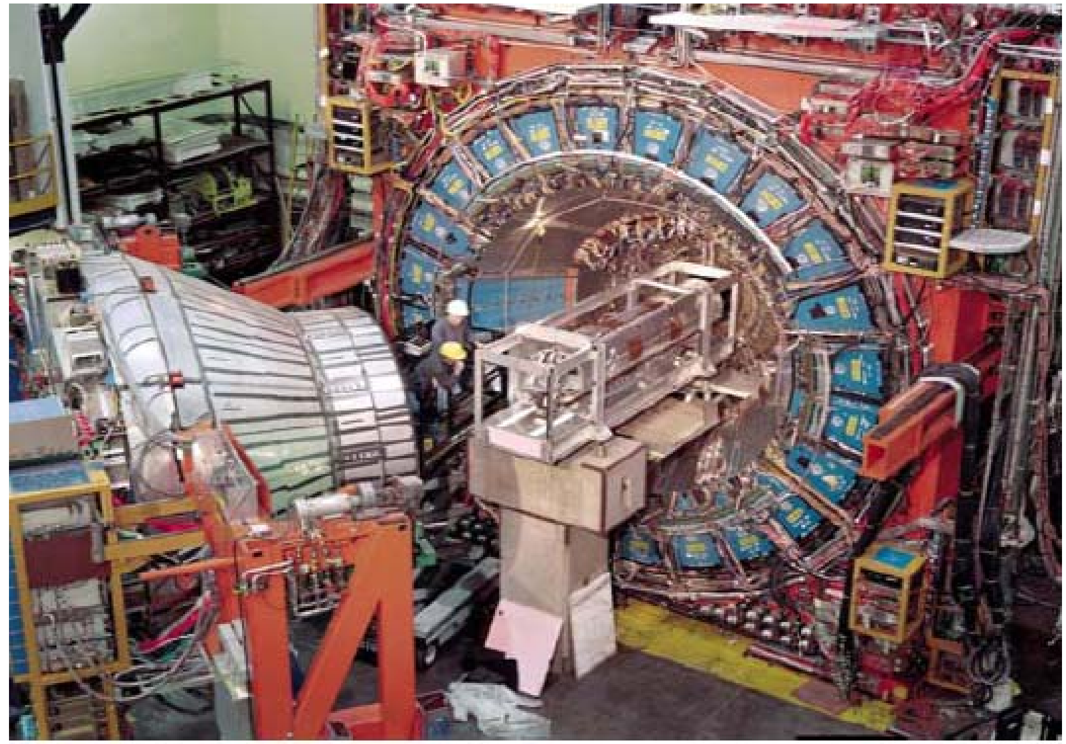


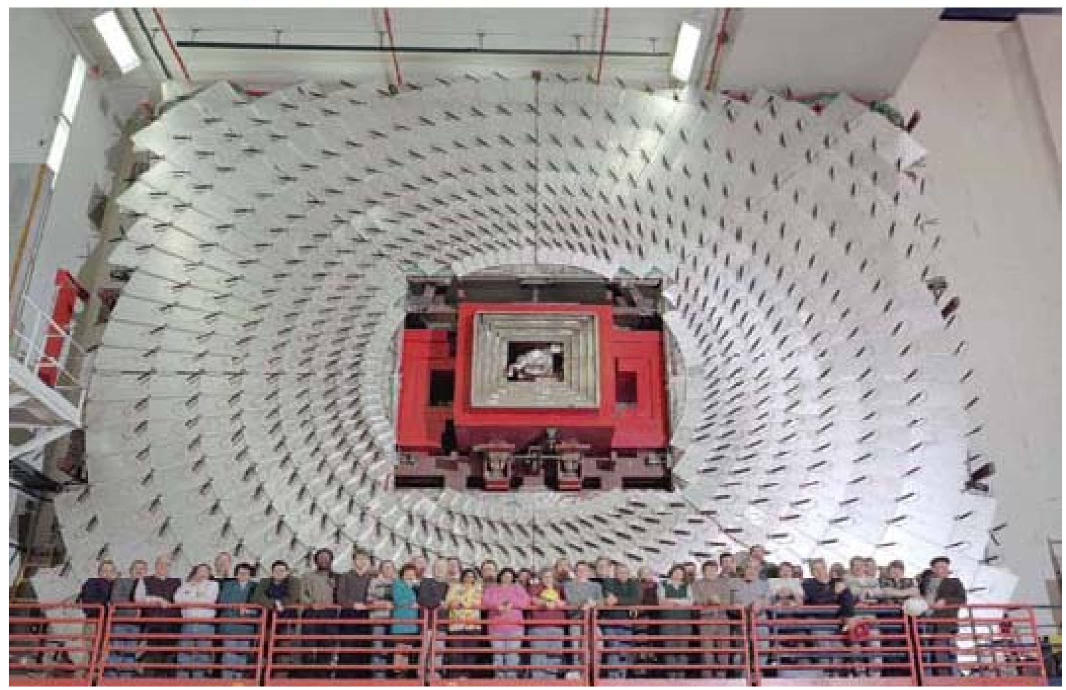
- H^- source, 35mA
- Electrostatic accel. 750 keV
- Linac, 0.4 GeV
- Booster, 0.4–8 GeV
- Main injector, 8-150 GeV
- Debuncher, 8 GeV
- Accumulator, 8 GeV
- Recycler,8 GeV
- Tevatron, 980 GeV

- Run I: 1992 – 1996, $\int Ldt = 0.187\ fb^{-1}$, (t-quark)
- Run II: started in the summer of 2001, ends – FY2010 ->2011?
  - Present $\int Ldt = 6.5\ fb^{-1}$, (Higgs ?)

Physics Program

- Highest energy collider
- Greatest discovery opportunities before LHC
- Two detectors
  - 1500 collaborators + students and postdocs
  - 60 PhDs last year
- The greatest high energy physics before LHC is operational
  - Higgs boson search
    - Single top
  - W & Z bosons
  - B-physics
  - …
- Success critically depends on the luminosity growth

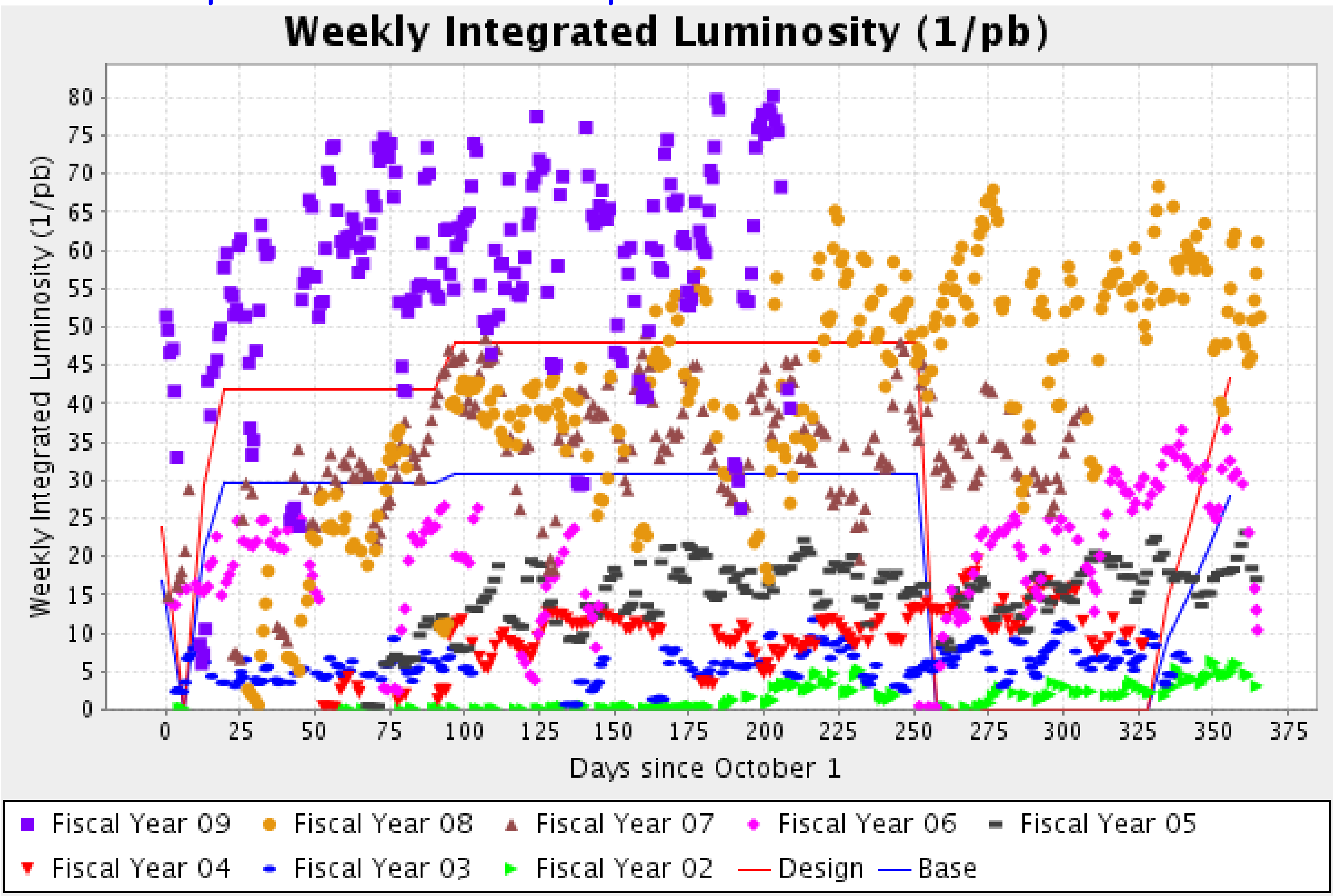


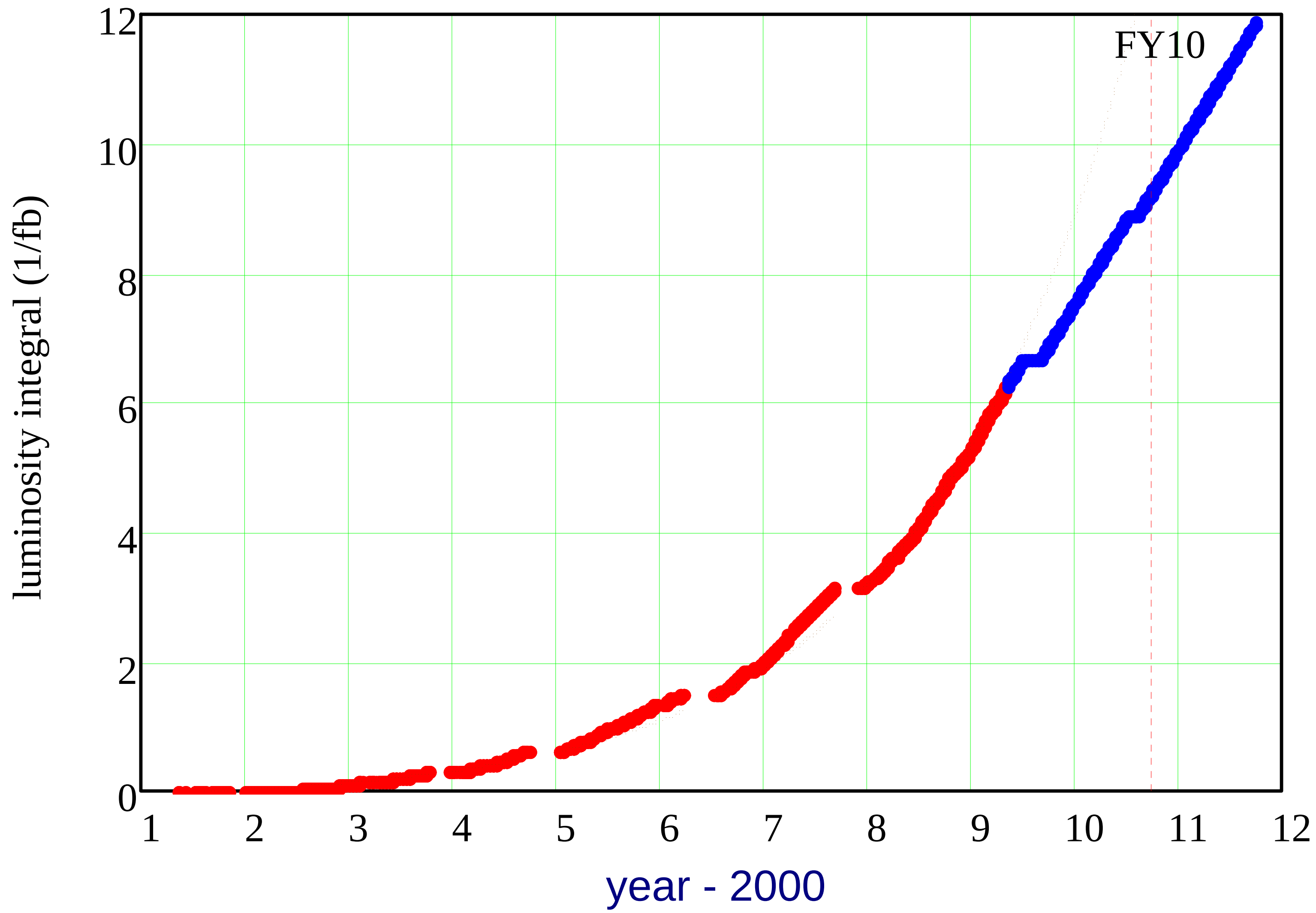


Luminosity Performance and Projections

Collider status and plans

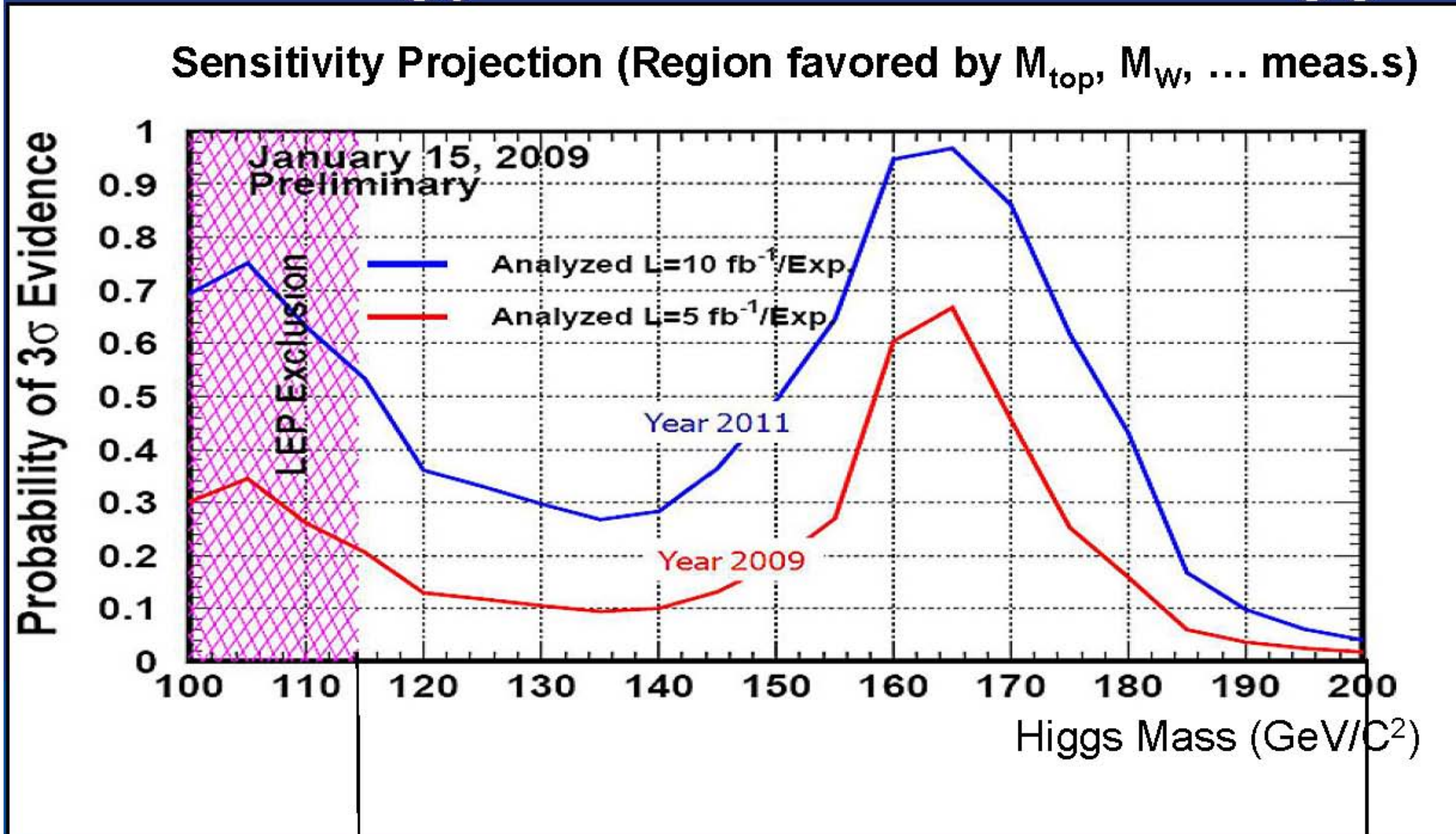
- We are close to the design luminosity set at DoE review in 2003
  - Minor improvements are still possible

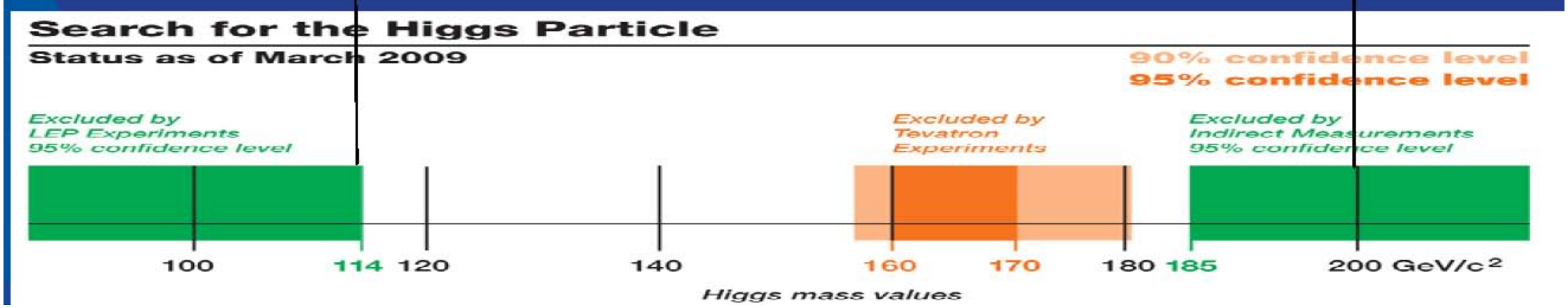




- Luminosity doubling every 1 year and 5 months
- Data analysis ~1.5 year behind (~3 fb)
- We plan to operate to the end of FY'10 (1.5 year)
  - Further Run II extension depends on pace of LHC commissioning

The Energy Frontier: Tevatron Higgs





Present and Planned Collider Parameters

- Original Run II plans were based on high energy physics request (15 fb^{-1})
- Realistic Operational scenario was build in 2003* (8.5 fb^{-1} by end of FY'09)
  - Actual pace of the machine performance followed sufficiently close

	Typical for April '03	Planned Run II	Typical for April '09
Average pbar production rate, 10^{10}/hour	5.3	**32†**	**21**
Pbar transfer efficiency, stack to HEP	59%	80%	80%
Number of protons per bunch, 10^{10}	20	27	28
Number of pbars per bunch, 10^{10}	2.2	13	8.3
Emit. norm. 95%, $(\varepsilon_x+\varepsilon_y)/2$, $p/\bar{p}$, mm mrad	20/20	**18/18‡**	**18/8**
Bunch length, proton/antiproton , cm	62/58	50/50	50/45
Initial luminosity, 10^{30} $cm^{-2}s^{-1}$	35	290	320
Store duration, hour	20	15.2	~16
Shot setup time, hour	2	2	1.5
Store hours per week	110	97	~110
Luminosity integral per week, $pbarn^{-1}$	4.7	55	55

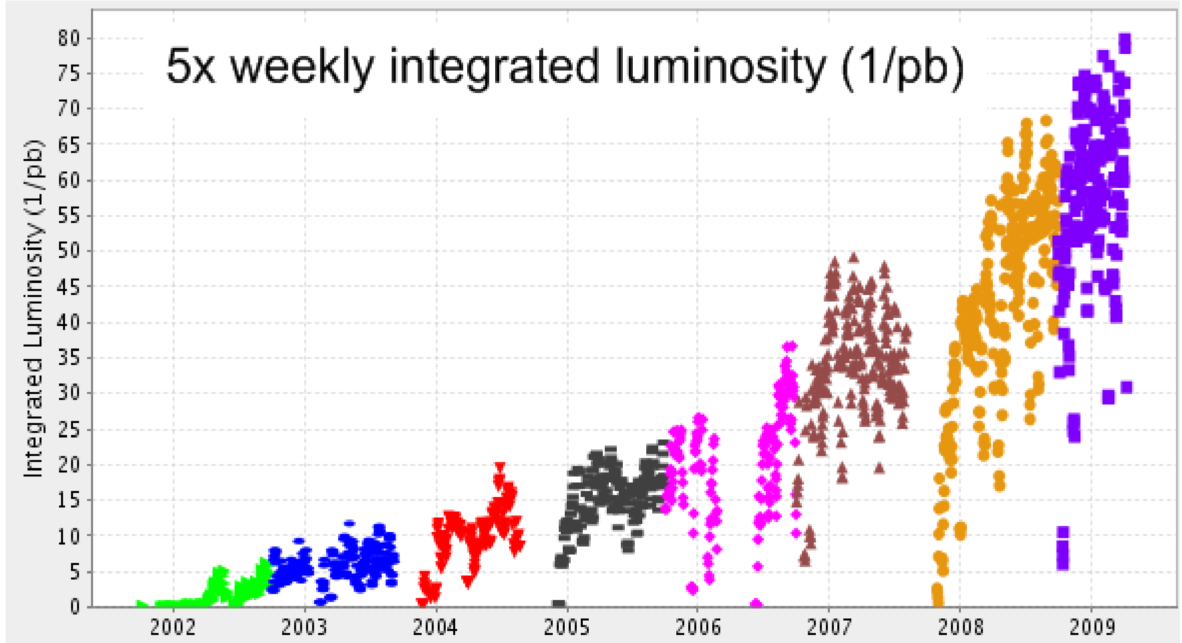
* DoE review of June 2003

† 80% availability for antiproton stacking is assumed

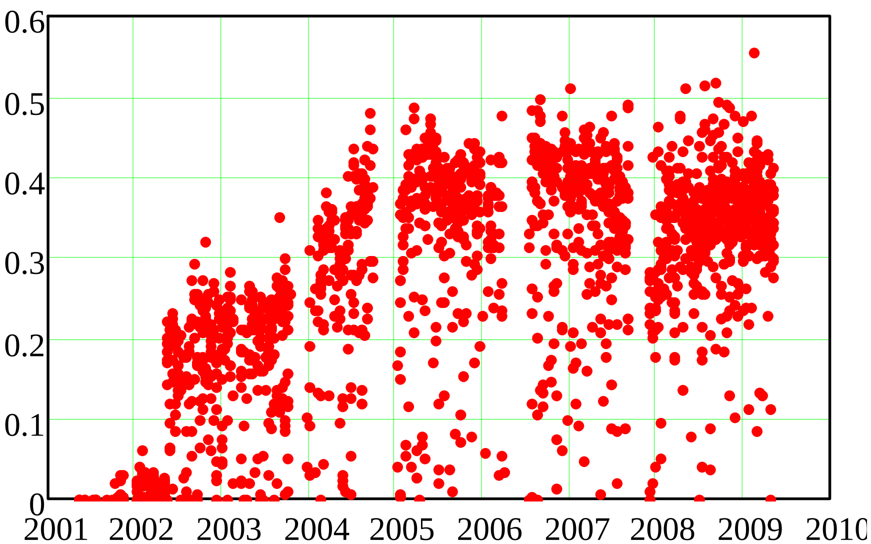
‡ **Assumed to be limited by beam-beam effects**

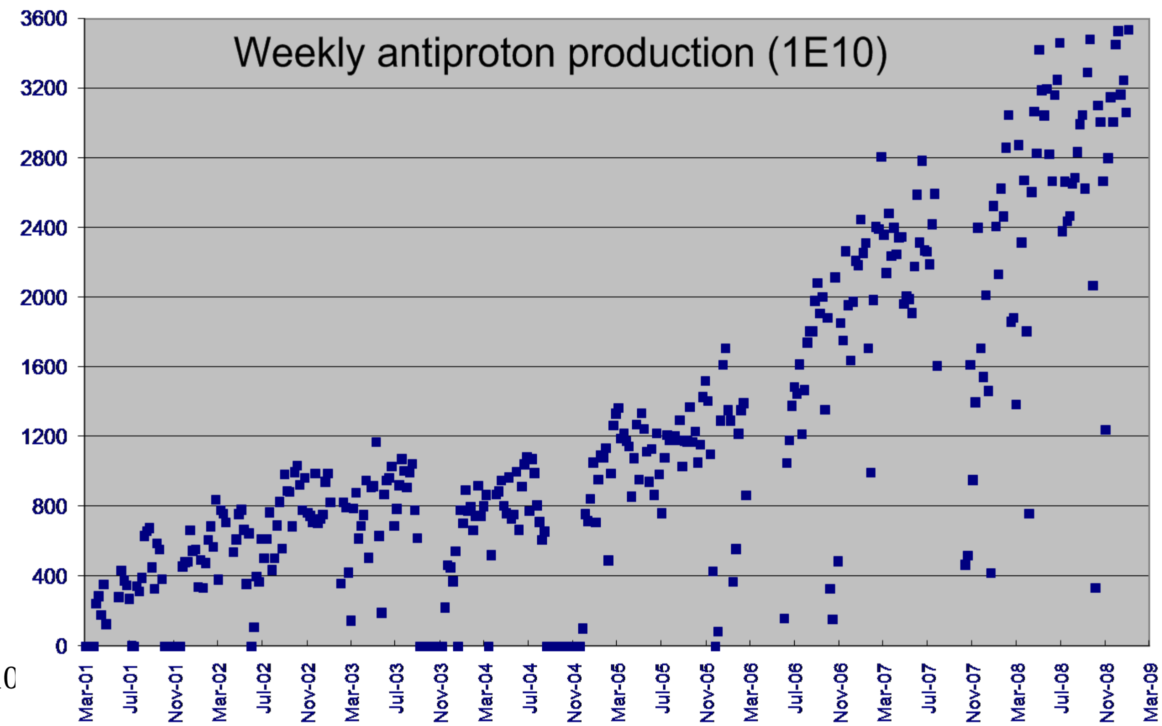
Luminosity Constituents

- Antiproton production
- Loss at transfers
- Luminosity in Tevatron
  - ~40% pbars are burned in nuclear interactions
  - Major limitations
    - Initial phase density of proton beam
    - IBS
    - Beam-beam effects



Antiproton utilization factor





Antiproton Production and Stacking*

- Pbar production on the target looks good
  - Desired proton intensity on target achieved in 2006 ($8\cdot10^{12}$ every 2.2 s)
  - New lithium lens (diffusion bonded); Oct.2006; gradient: 57→75 kG/cm
  - New target; Feb. 2009; Better lifetime
- Antiproton fluxes
  - Antiprotons injected to Debuncher: $\sim38\cdot10^{10}$ hour^{-1} ($2.3\cdot10^{8}$ every 2.2 s)
    - Antiproton yield of $3\cdot10^{-5}$ is in a good agreement with expectations
  - Antiprotons injected to Accumulator $\sim36\cdot10^{10}$ hour^{-1} ($2.1\cdot10^{8}$ every 2.2 s)
    - ~5% pbars are outside of cooling range after debunching
  - Peak stacking rate: $\sim30\cdot10^{10}$ hour^{-1}
    - Stacking rates linearly drops with stack size
- Stacking rate limitations in Accumulator
  - Bandwidth of the stacktail
  - Beam momentum spread coming from Debuncher
  - Stacktail power
    - intermodulation distortions
  - Transverse and longitudinal heating

* More details see in the poster 3246: Pasquinelli, et.al. “Progress in Antiproton Production at the Fermilab Tevatron Collider”

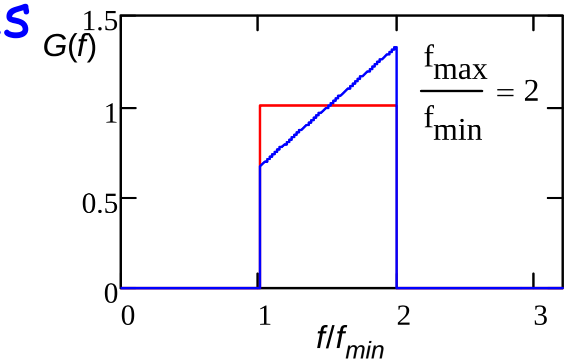
Effective bandwidth of stochastic cooling system

- Evolution of Long. distribution is described by Fokker-Planck eq.

$$\frac{\partial f}{\partial t}+\frac{\partial}{\partial x}\left(F(x)f\right)=\frac{1}{2}\frac{\partial}{\partial x}\left(D(x)\frac{\partial f}{\partial x}\right)$$

$$F(x)=f_0\sum_{n=-\infty}^{\infty}\frac{G(x,\omega_n)}{\varepsilon(\omega_n)}e^{i\omega_n T_2\eta_2 x},\quad D(x)=N\psi(x)f_0\sum_{n=-\infty}^{\infty}\frac{1}{|n\eta|}\left|\frac{G(x,\omega_n)}{\varepsilon(\omega_n)}\right|^2,\quad \omega_n=n\omega_0(1-\eta x)$$

where $x=\frac{\Delta p}{p}$ and we neglected noise of electronics



- $F(x)\propto \mathrm{Re}(G),\quad D(x)\propto |G|^2 \Rightarrow$ Effective bandwidth

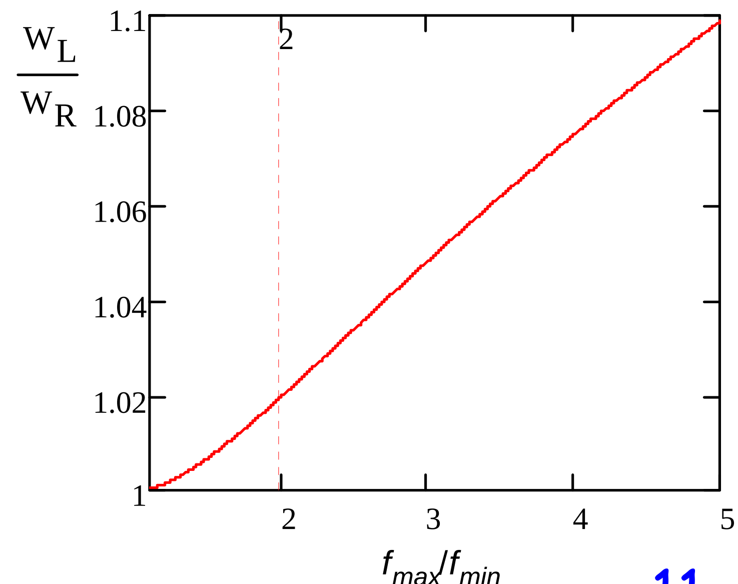
$$W_{eff}(x)=\int_0^\infty \mathrm{Re}\left(G(x,2\pi f)\right)df \Bigg/ \sqrt{\int_0^\infty \left|G(x,2\pi f)\right|^2\frac{df}{f}}$$

- ♦ Rectangular gain function

$$G_\omega(2\pi f)=\begin{cases}G_0\ , & f\in[f_{\min},f_{\max}]\\ 0\ , & otherwise\end{cases}\Rightarrow\quad W_R=\frac{f_{\max}-f_{\min}}{\sqrt{\ln(f_{\max}/f_{\min})}}$$

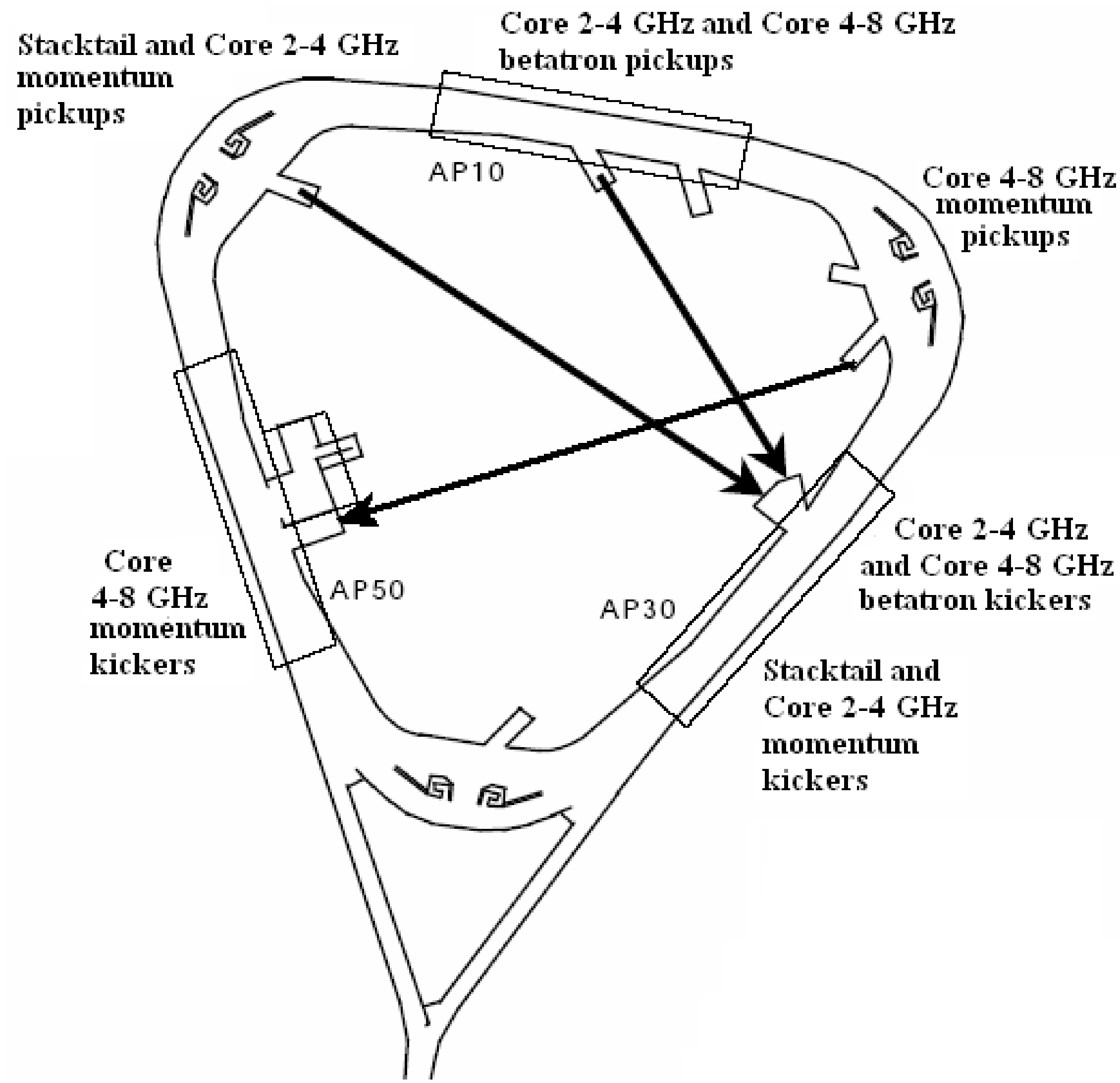
- ♦ Linear gain function (G~f)

$$G_\omega(2\pi f)=\begin{cases}af\ , & f\in[f_{\min},f_{\max}]\\ 0\ , & otherwise\end{cases}\Rightarrow\quad W_L=\sqrt{\frac{f_{\max}^2-f_{\min}^2}{2}}$$

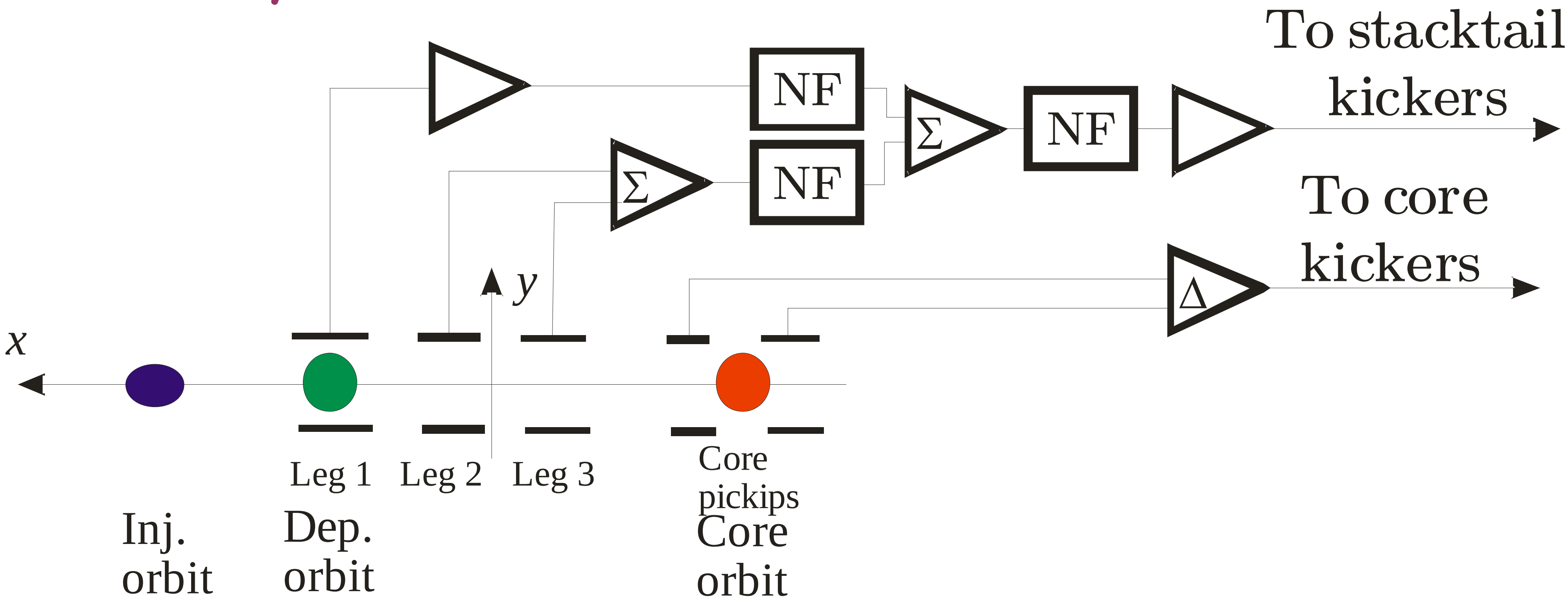


Cooling and Stacking in Accumulator

- 5 cooling systems
  - Core cooling
    - H & V – 4-8 GHz
    - Longitudinal: 2-4 GHz and 4-8 GHz
  - Stacktail - 2-4 GHz
- Stacktail system moves injected antiprotons to the core
  - Presently it is a major limitation of stacking rate increase
  - All stacking rate improvements of the last three years are closely related to operation and improvements of the Stacktail system
    - It is the last bottle neck limiting the staking rate



Stacktail system



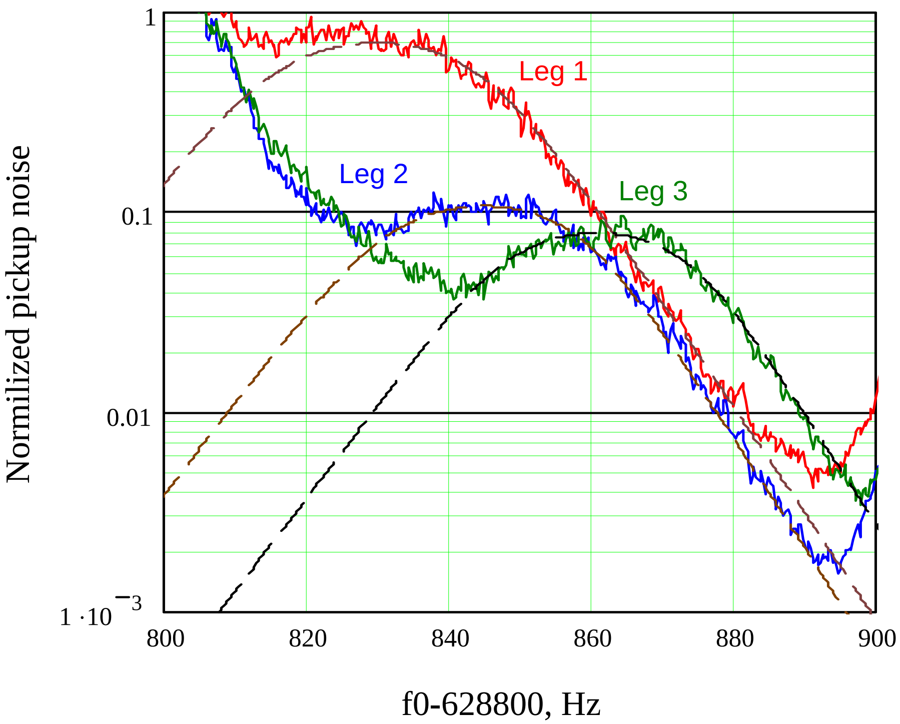
- System of 3 pickups which signals are added with right gains and delays and come through 3 notch filters makes the exponential gain profile in the stacktail area

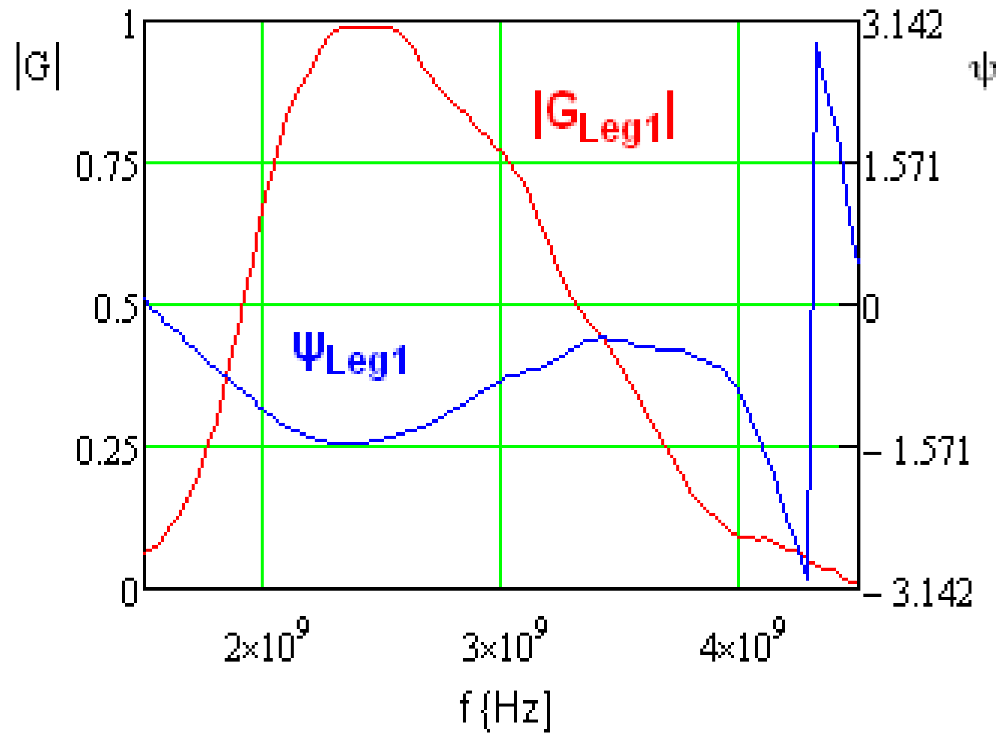
$$G(x,\omega) \approx G_{\omega}(\omega)\exp(-x / x_d)$$

- Van der Meer solution yields the maximum flux

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

Measurements of Stack-tail Parameters

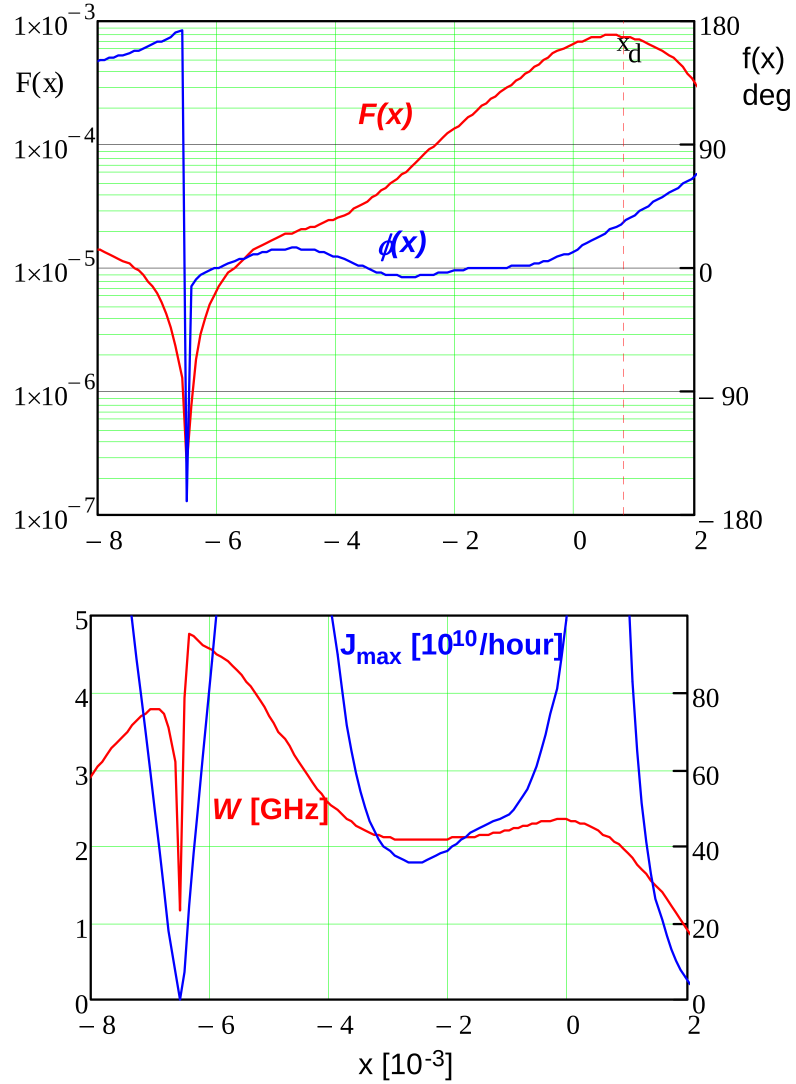




- Model takes into account nonlinearity of slip factor
- Dependence of pickup sensitivity on the beam coordinate corresponds to the earlier test-bench measurements
- Frequency response for each of three legs was measured on the revolution frequency harmonics in 1.5 – 5 GHz range with notch filters off at a few radial beam positions
  - Notch filters were measured separately

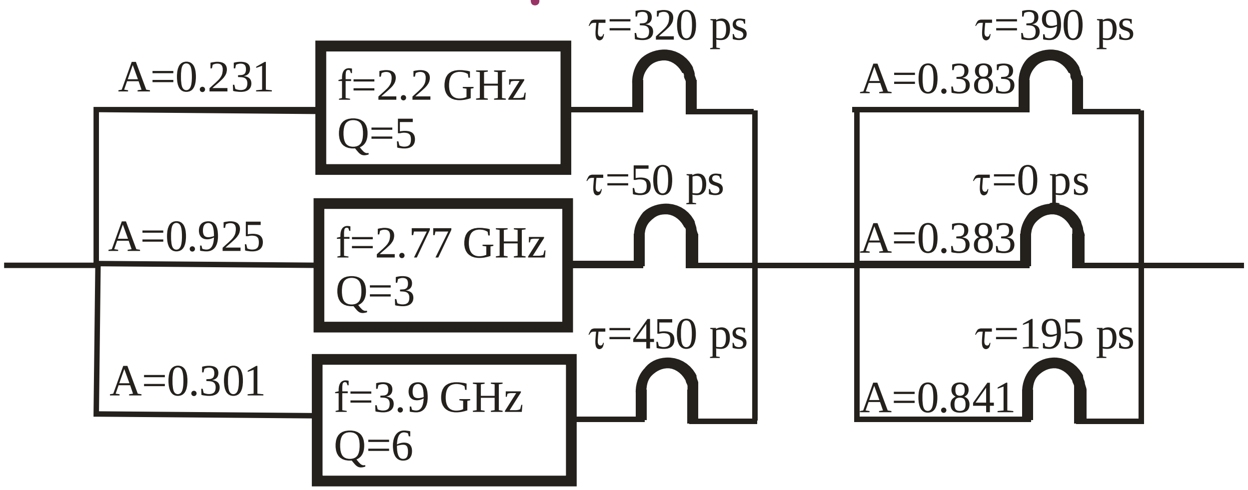
Stack-tail Model

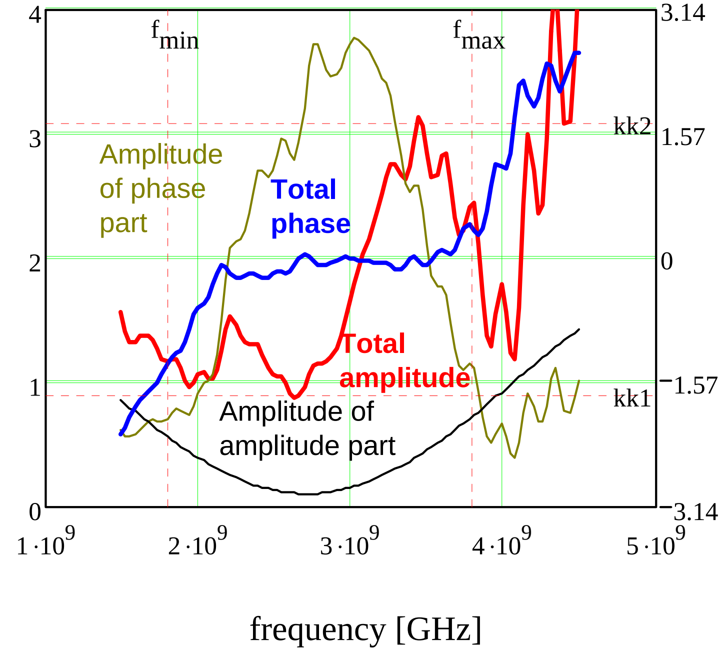
- Wiring all pieces together (including core cooling) one obtains $G(x,\omega)$
- Static model computes
  - cooling force: $G(x)$
  - Inverse rate of cooling force change: $E_d \equiv p\, x_d$
  - Effective bandwidth, $W(x)$
  - Van der Meer flux, $J_{max}(x)$
- Dynamic model solves Fokker-Planck equation for particle distribution
- Detailed modeling has been absolutely essential to chose upgrade path
  - Equalizers for gain correction
    - Stacktail
    - Longitudinal core, 4-8 GHz
  - Slip-factor increase (optics)
  - Gain profile optimization in the model (3 notch filters, 3 gains, 3 delays)
    - Final empiric tuning is still required (few picoseconds accuracy!!!)



Dependences on momentum for the cooling force, its phase, effective bandwidth and Van der Meer flux

Test Stacktail equalizer





Test Equalizer specifications

- Phase part corrects phase
- Amplitude part corrects amplitude so that to get the desired total amplitude

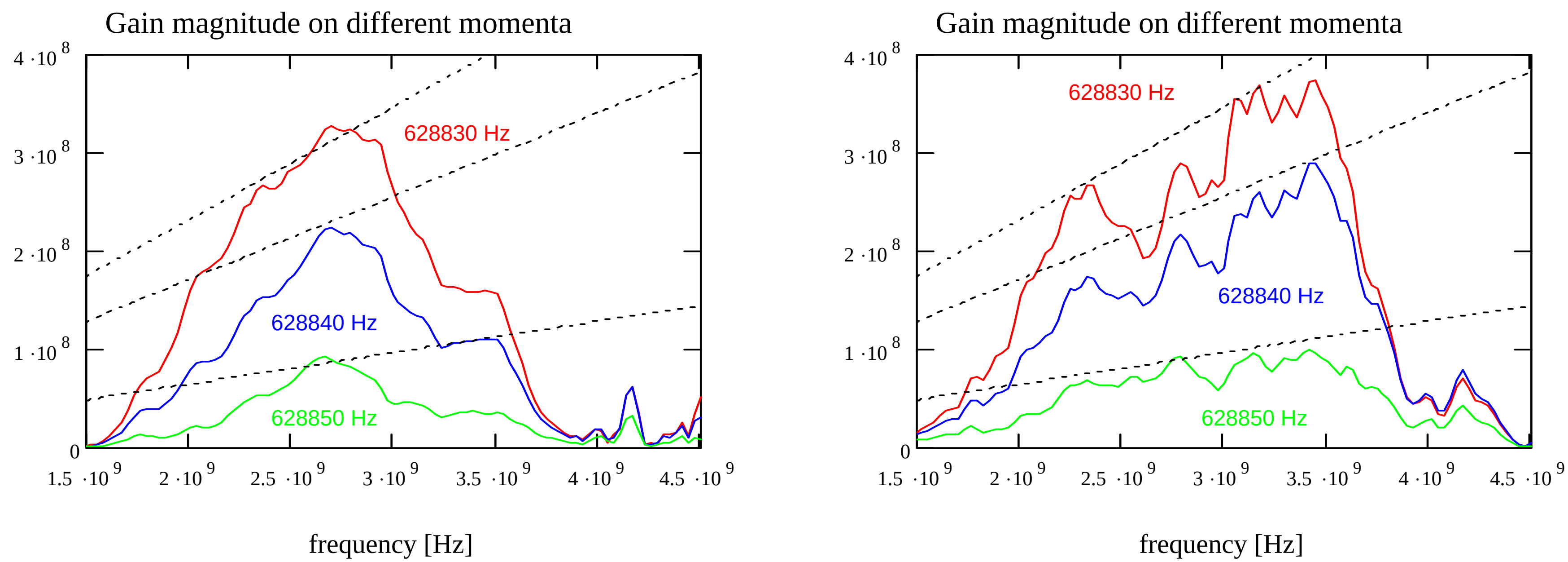
$$K_i(\omega) = \frac{A_i}{1 + iQ_i \dfrac{\omega^2 - \omega_i^2}{\omega\omega_i}}, \quad i = 1,2,3$$

$$K_A(\omega) = 1 + 0.91\cos(\omega\tau), \quad \tau = 195\ ps$$

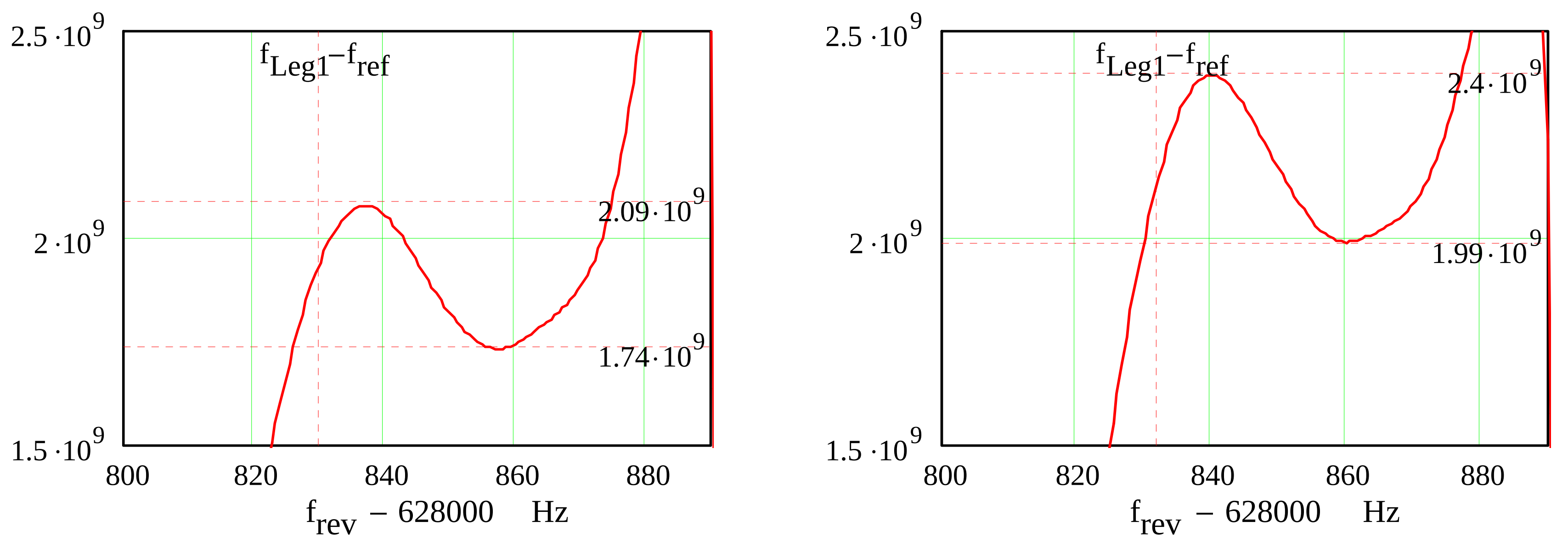
$$K_{tot}(\omega) = K_A(\omega)\big(K_1(\omega) + K_2(\omega) + K_3(\omega)\big)$$

- Final equalizer has 5 resonators and one-stage amplitude correction

Stacktail equalizer (continue)

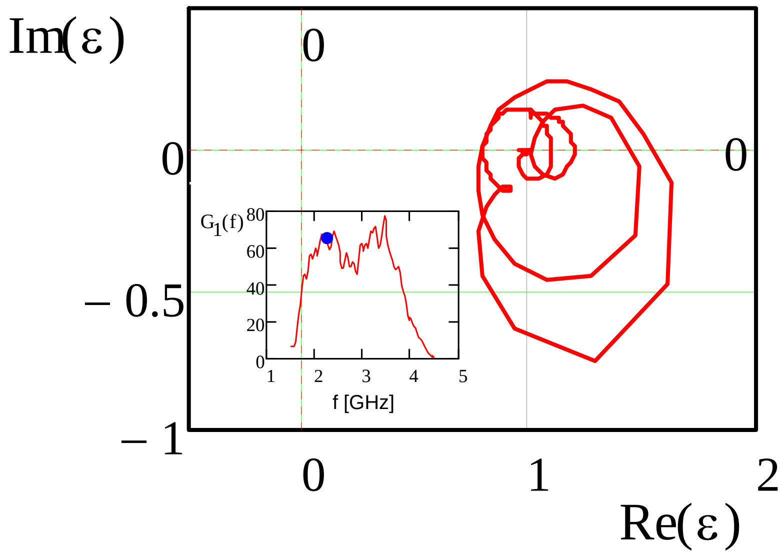


Dependence of stacktail gain on frequency before and after installation of the equalizer



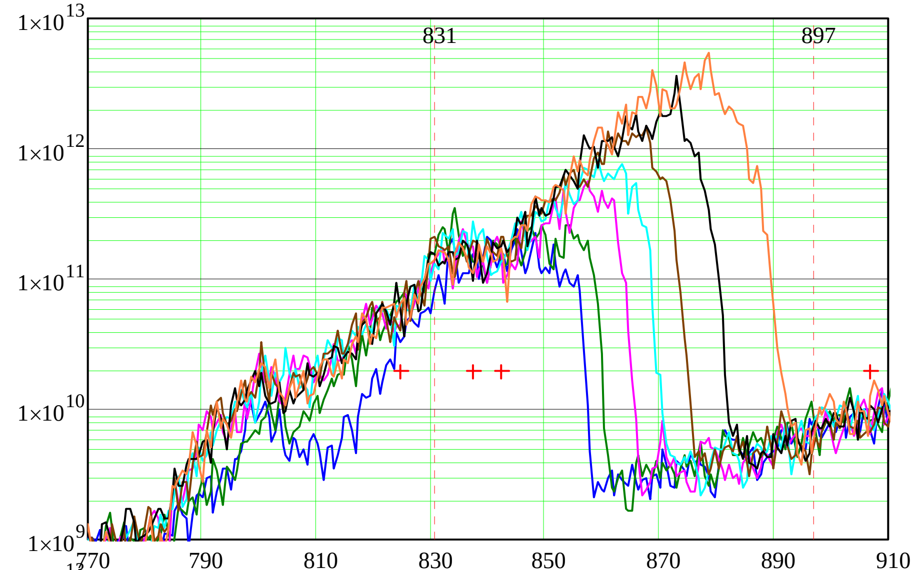
Dependence of effective bandwidth before and after installation of the equalizer (~15% growth)

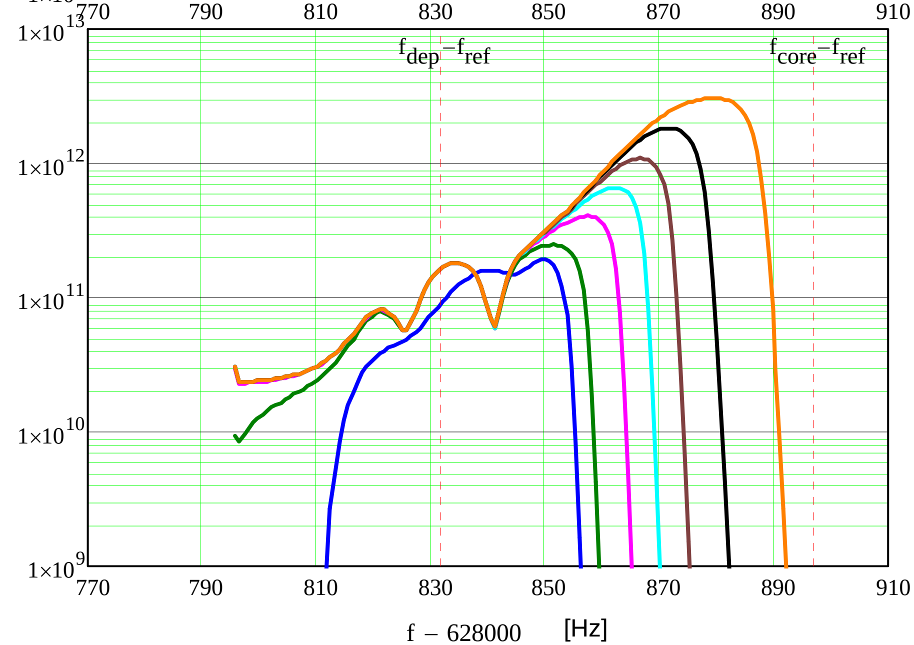
Stacking Simulations versus Stacking Measurements



Stability diagram at 0.22 s of cycle 46; f=2.25 GHz (cycle period – 2.2 s)

- Comparison of measurements and simulations resulted absolute value for the system gain
  - Signal suppression is close to optimum
- Good predictions for stacking rate for known speed of stack propagation
  - Back streaming

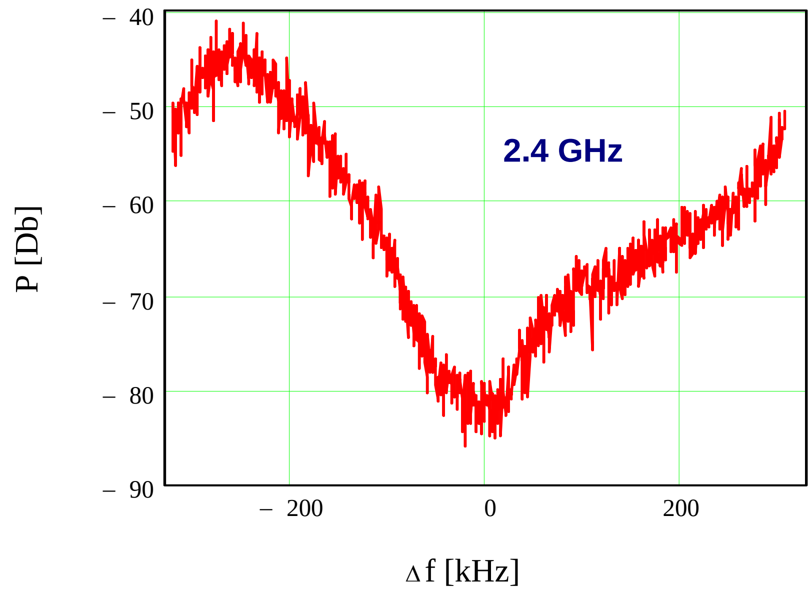




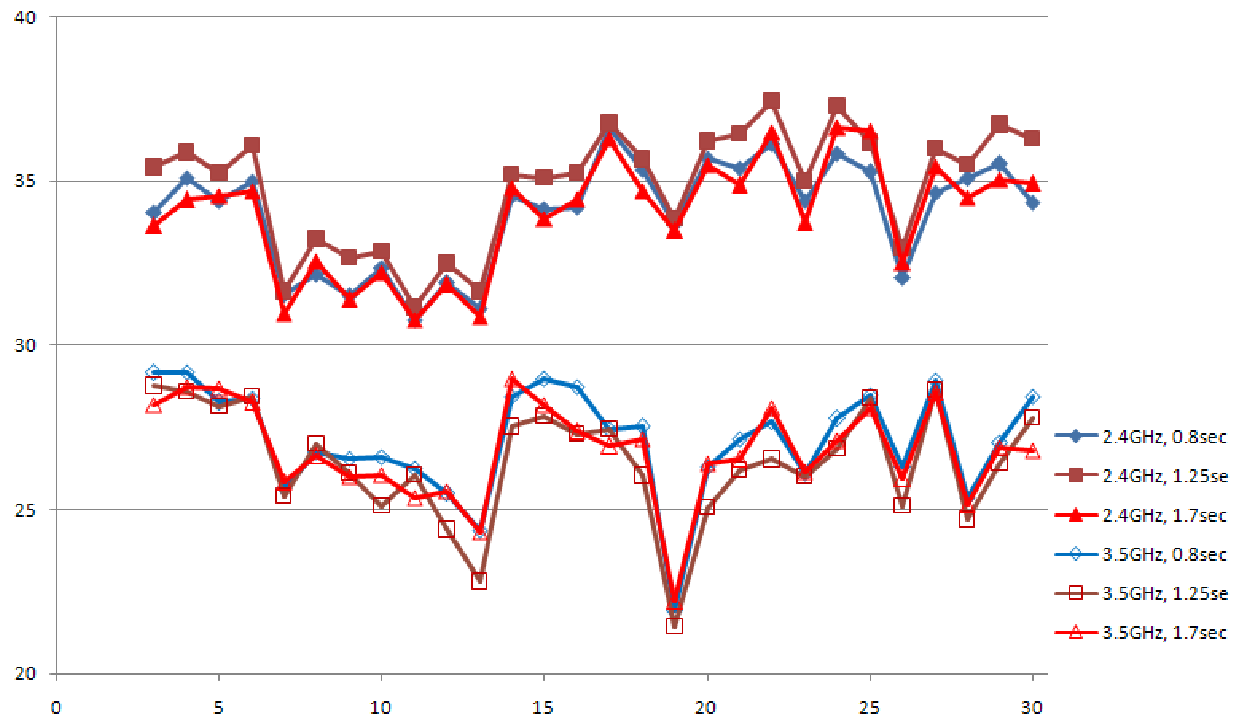
First 100 s of stacking; curves are built at 0.88 s in cycle 1, and 0.22 s in cycles 2,4,7,12,22 and 46

Longitudinal Core Heating

- Longitudinal core blowup requires decrease of stacktail gain
  $\Rightarrow$ decrease of stacking rate
- Installation of stacktail equalizer worsened the problem
- Drawbacks of the equalizer
  - Decreased signal-to-noise ratio due to larger gain at band edges
    - Not a problem for S-to-N ~15-20 Db
  - Increased effects of intermodulation distortions due to larger power for the same gain
    - Real problem

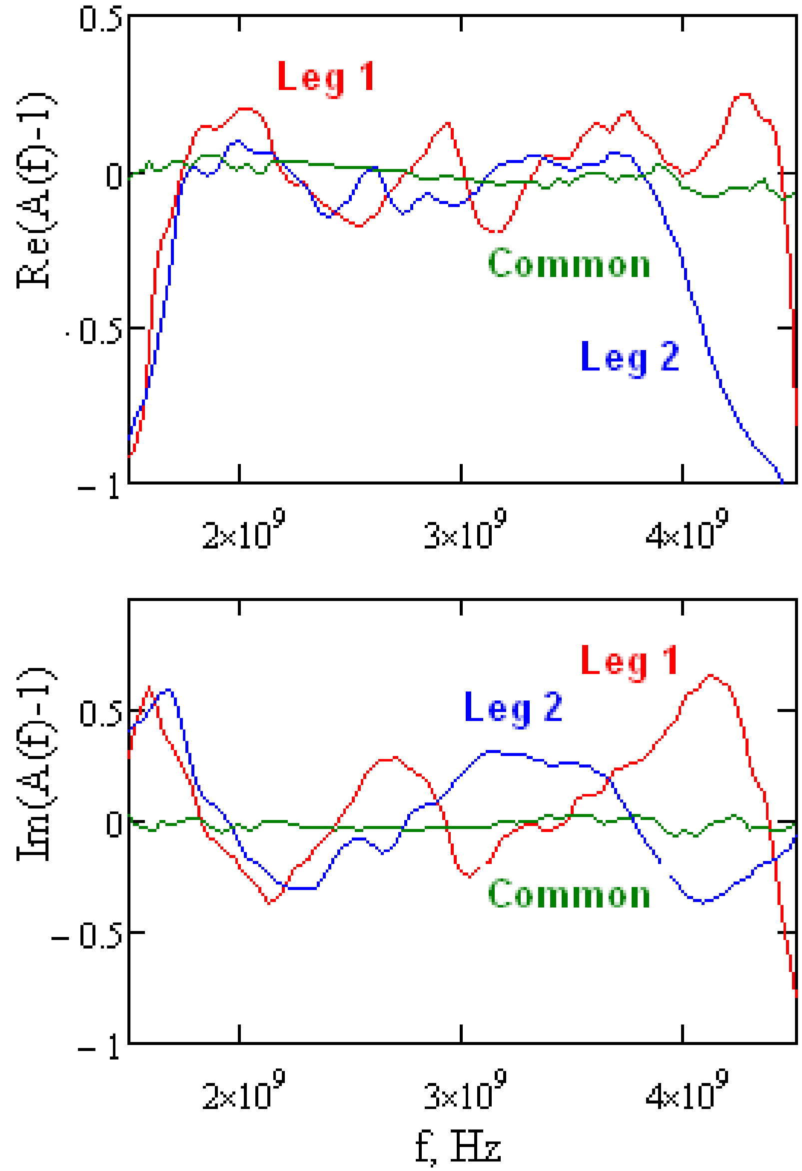


Schottky noise at a TWT exit in one revolution harmonic



Notch depth at different times in cycle for 2.4 and 3.5 GHz

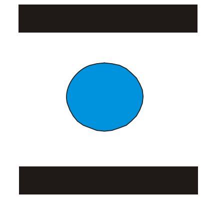
- Drawbacks of Stack-tail equalizer (continue)
  - Core instability at low frequency band edge (~1.8 GHz)
    - Shallow notches at the band edges for BAW notch filters
- Mitigation of longitudinal core heating
  - Core 4-8 GHz equalizer
    - ~30% bandwidth increase
    - ~1.7 times better cooling
  - One of three BAW notch filters was replaced by SC NF
    - No core instability
- Finite notch depth of 25-35 Db is set by intermods
  - It is a major reason of longitudinal heating
  - No easy/affordable solution



Comparison of BAW and SC notch filters; $K(\omega) = 1 - A(\omega)e^{-i\omega T_0}$

Transverse core heating

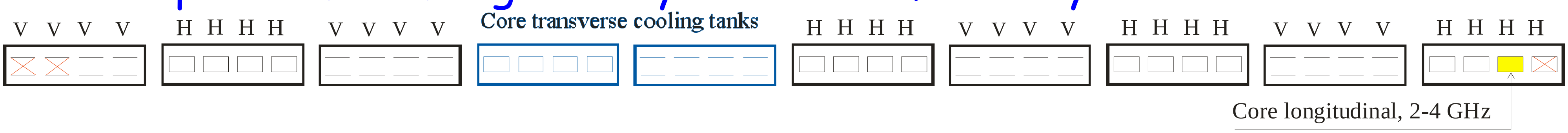
- Stacktail is a longitudinal system
  - However its kickers also produce transverse quadrupole kicks



$$U(x,y) = U_0\left(1 \pm \frac{x^2 - y^2}{2a_{eff}^{\;2}}\right), \quad a_{eff} \approx 1.87\ \mathrm{cm}$$

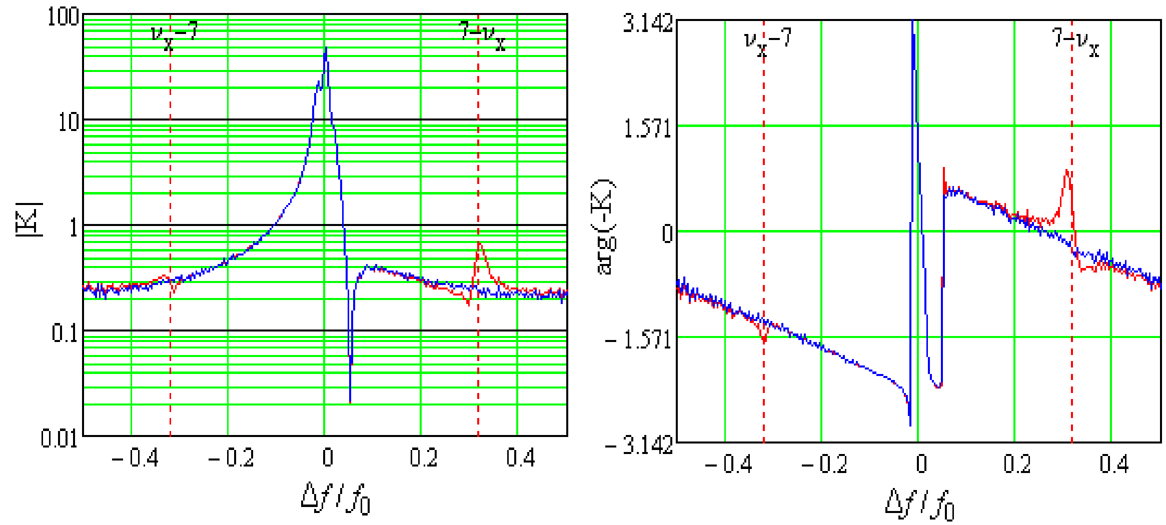
Panofsky-Wenzel theorem $\Rightarrow$ $E_x \propto \frac{dU(x,y)}{dx} = U_0 \frac{x}{a_{eff}^{\;2}}$

- The problem is mitigated by 90° rolls of nearby kickers

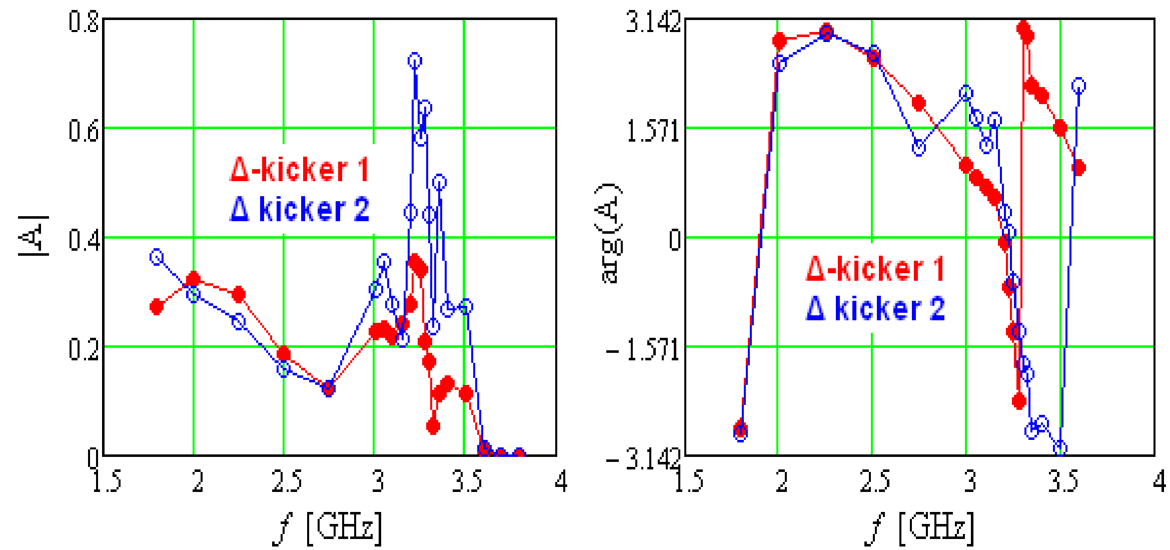


- Large betatron phase advance along kicker straight results in insufficient compensation and transverse emittance growth due to
  - Not perfectly zeroed dispersion in the kicker straight
  - Offset of kicker electrical center relative to the beam center
    - kicker electrical center varies with frequency
  - Parametric heating (kickers at ends heat more)
    - It is addressed by swapping core cooling and stack-tail kickers and switching of 3 of 31 kickers

- Open loop stacktail measurements exhibited that the kicker electrical center depends on frequency
  - Resonance at 3.25 GHz, $x_0 \approx 2$ mm, $Q \approx 27$,
- It results in emittance growth which cannot be suppressed by kicker centering
  - Δ-kickers with correct amplitude and phase response could be used but
    - Long measurement time
    - Building equalizers
    - Not practical because ⊥ response changes with time
- Presently
  - Kicker centering
  - Stack size reduction; ♦ Better ⊥ core cooling due to equalizers (still in work)



Stacktail open loop measurements at 2.25 GHz (span= f_0)
red – original measurements,
blue – the same with transverse response being removed



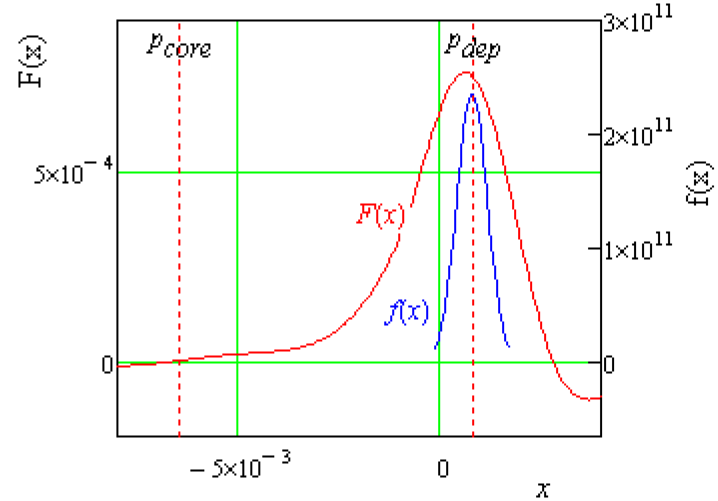
Amplitudes of Δ-kickers required for compensation of dipole part of transverse kicks

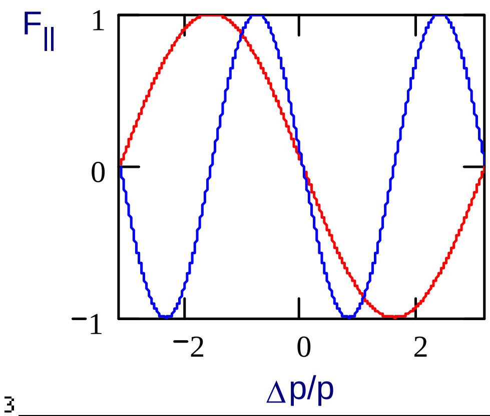
Cooling in Debuncher

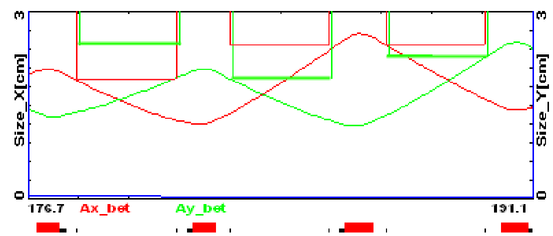
- If not well tuned both ⊥ and L coolings reduce stacking rate
  - ⊥ - to fit the beam to smaller accumulator acceptance (33 →8 mm mrad)
  - L – to fit the beam mom. spread into flattop of cooling force
- Both ⊥ and L coolings are power limited
  - Weak dependence of cooling force on eff. bandwidth:

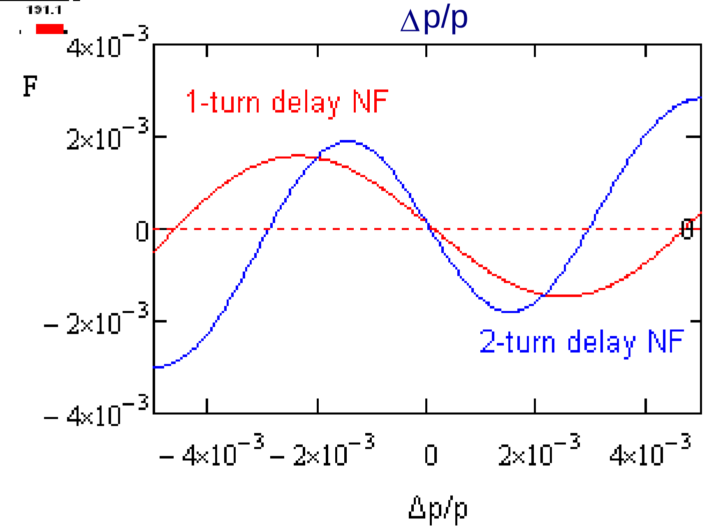
    $F \propto \sqrt{W}$ instead of $F \propto W^2$

    ⇒ little help from equalizers
- ⊥ cooling
  - Notch filters for bands 3 & 4 reduced common mode signals and effect of thermal noise
  - Optics adjustments improved phase advances and balanced β-functions ($A_{beam} = A_{pickups/kicker}$)
- Longitudinal cooling
  - Better balancing of notch filter legs
  - Two turn delay notch filter switched on at 1 s of 2.2 s cycle(doubled gain for the same power)



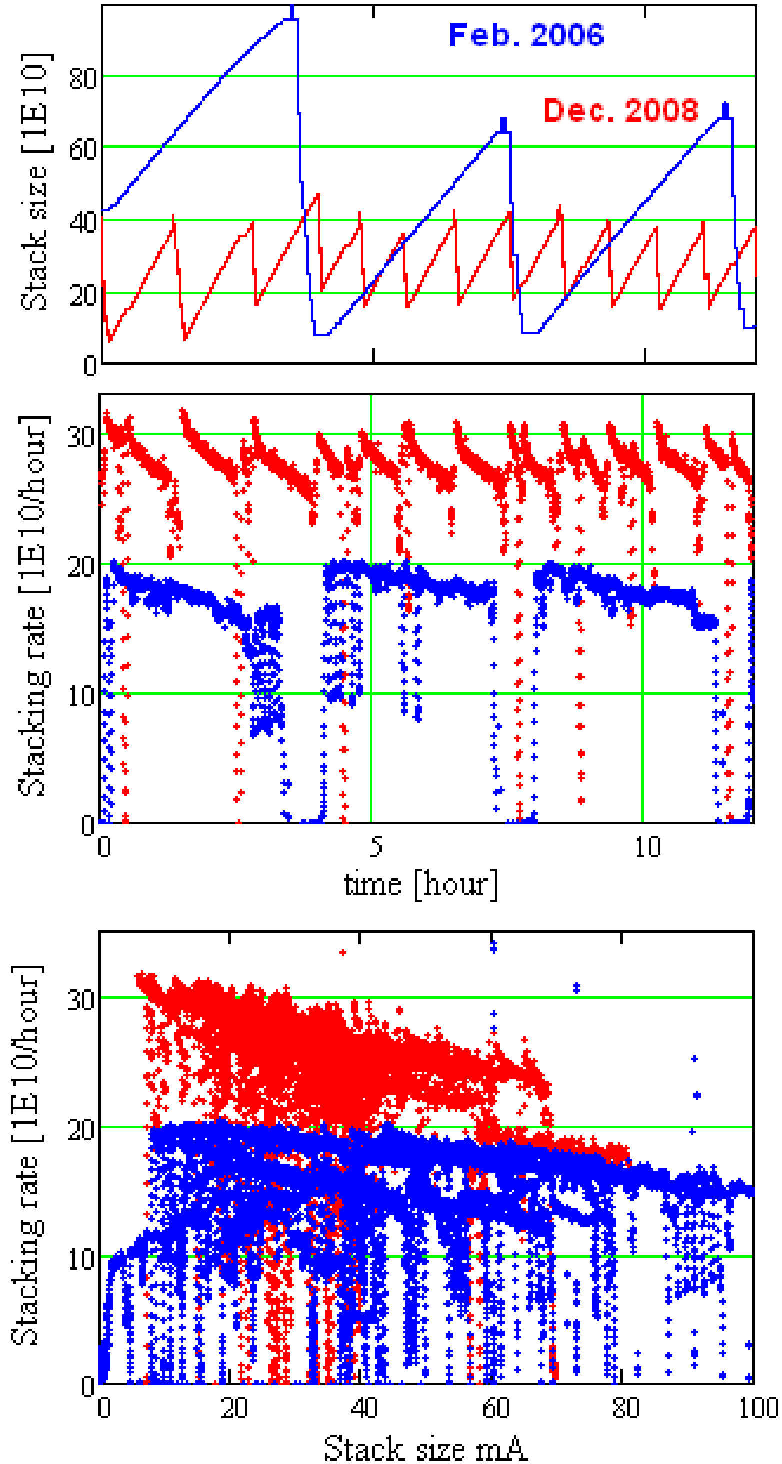






Fast transfers

- Three stage antiproton cooling
  - Debuncher - $2\cdot10^8$ (20 μA)
  - Accumulator - $4\cdot10^{11}$ (0–40 mA)
  - Recycler - $4\cdot10^{12}$ (0–50 mA)
    - + electron cooling
- Accumulator-to-Recycler transfers
  - Shortening time
    - ~50 min → ~0.5 min
  - Improving transfer efficiency
    - ~90% → ~96%
  - Further shortening of stacking cycle is going
    - Additional 3-5% improvement for antiprotons delivered to Recycler



Antiproton Cooling and Accumulation in Recycler

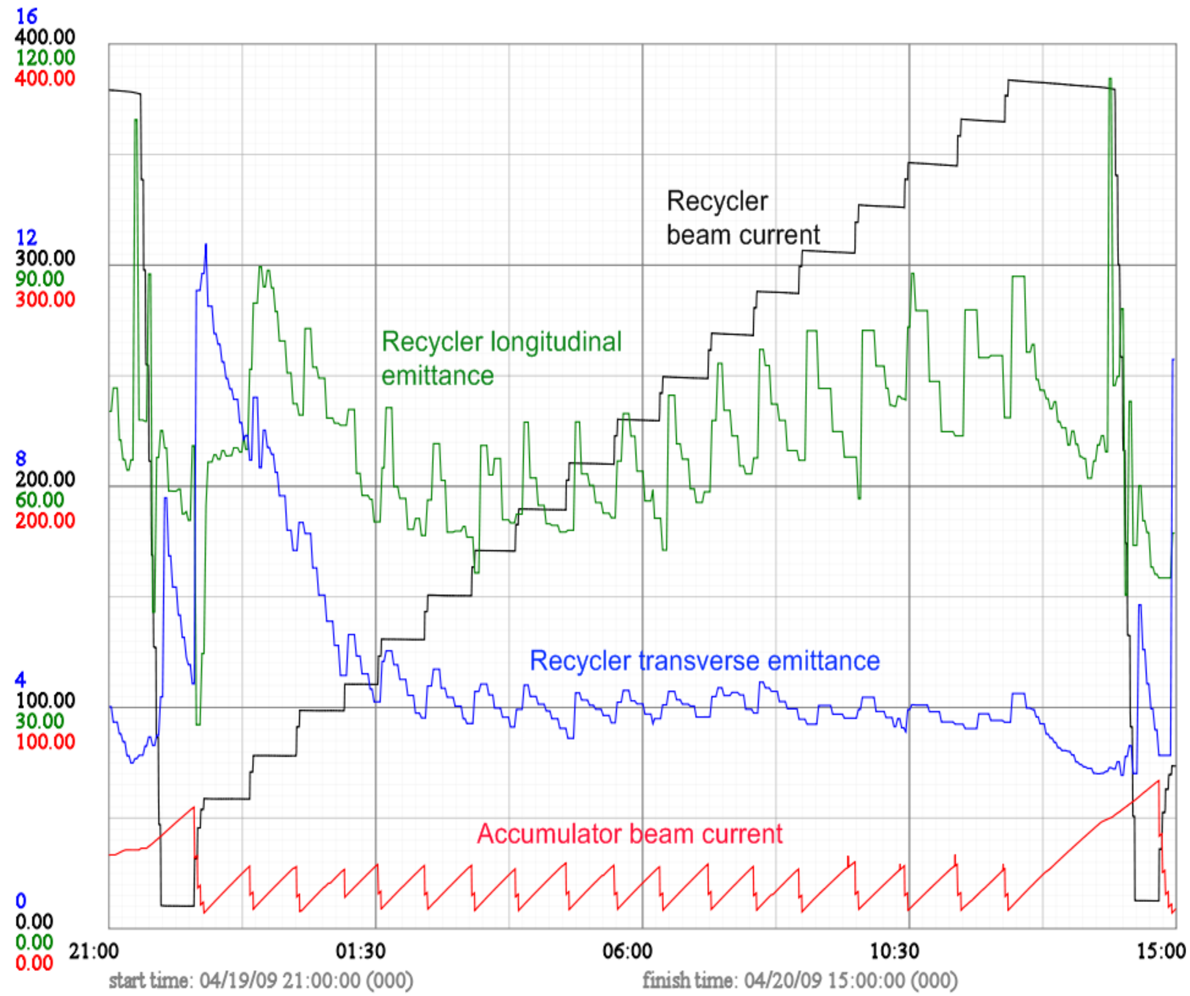
- Recycler ring
  - 3.3 km circumference antiproton accumulator operating at 8 GeV
  - Stochastic cooling
    - $\perp$: 2-4 GHz, limited by band overlap
    - ||: 1-2 GHz
  - Electron cooling
    - 100 mA, r_b~2.5 mm, 4.3 MeV, 20 m
- Stochastic & electron coolings supplement each other
  - Electron cooling is
    - extremely efficient for particles with small amplitudes
    - allows to get small emittances with large number of particles
    - but is not effective for particles with large amplitudes
  - St. cooling cools large amplitude particles $\Rightarrow$ improves lifetime

Pelletron

Cooling section

Recycler operating scenario

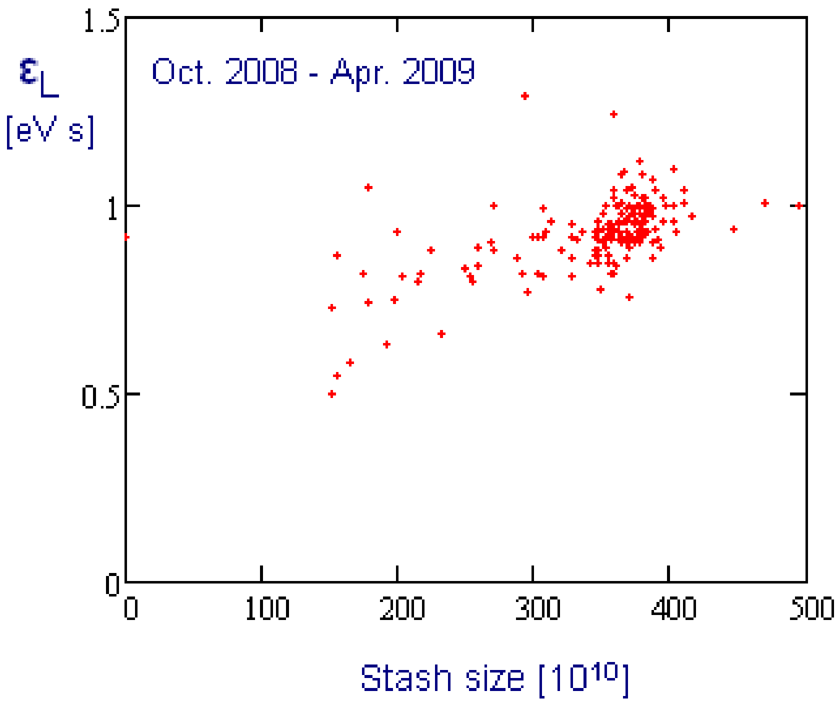
- Barrier buckets keep beam in one ~1.5 km bunch
- RR operates below transition
  $\Rightarrow$ IBS makes equal temperatures for all three planes
- IBS temperature exchange ~6 times faster than IBS heating
  - for ε=2 mm mrad
    τ_{rel} ~ 0.2 hour
    τ_{IBS} ~ 1.2 hour
- In normal operating conditions the cooling time is ~2 hour (see picture)
  - 7 min - for small emittances



Typical cycle of Recycler operation; Transverse emittance computed as average of H&V emittances measured by Schottky monitor. It exceeds the flying wire measurements by ~1.5 times because of non-Gaussian tails created by fast drop of electron cooling efficiency with betatron amplitudes

Beam lifetime in Recycler

- Beam lifetime due to residual gas scattering is ~700 hour
  - It is affected by beam intensity and previous history of beam manipulations (tails)
- To prevent overcooling and subsequent lifetime decrease the electron beam is offset by 2 mm (=> 0.5 mm at shot setup)
  - $\Delta\nu_{SC} \approx 0.03$ => ≈ 0.06 (at shot setup)
- Requirement to limit $\Delta\nu_{SC}$ yields that the transverse emittances should grow with beam intensity
  - IBS results in the proportional growth of longitudinal emittance
- Total beam loss in Recycler is ~4% (effective lifetime ~200 ->300 hour)
  - + ~4 loss in Accum.-to-Rec. transfers
- Recent shortening of cooling cycle and change of RF manipulations reduced this loss by almost 2 times



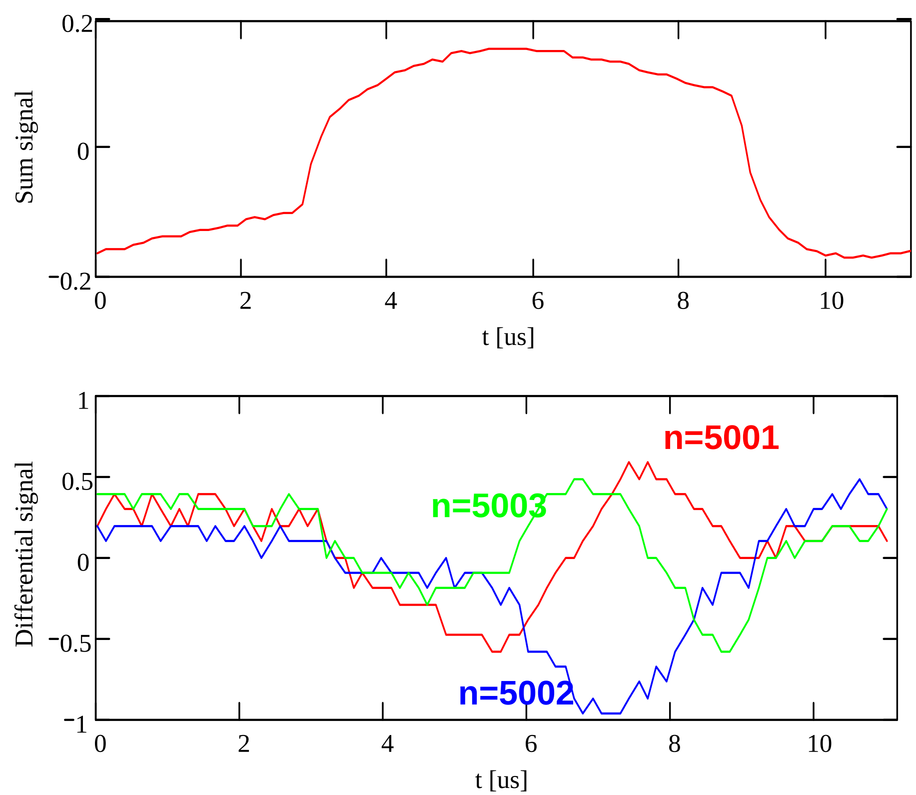
Dependence of longitudinal emittance in MI, 8 GeV, on stash size

Beam transverse stability in Recycler

- If not damped the instability will be mainly driven by wall resistivity
  - At lowest mode the instability growth rate ~$1.5\cdot10^{-3}$ turn^{-1} ($3.6\cdot10^{12}$part.)
- Beam space charge separates coherent and incoherent tunes and suppresses Landau damping
- Stability boundary for Gaussian distribution (Burov, Lebedev, 2008)

$$\sigma_p\left|\xi + n\eta\right| \approx \frac{0.6\Delta\nu_{SC}}{\ln\left(\Delta\nu_{SC}/\mathrm{Im}(\Delta\nu_{coh_n})\right)}$$

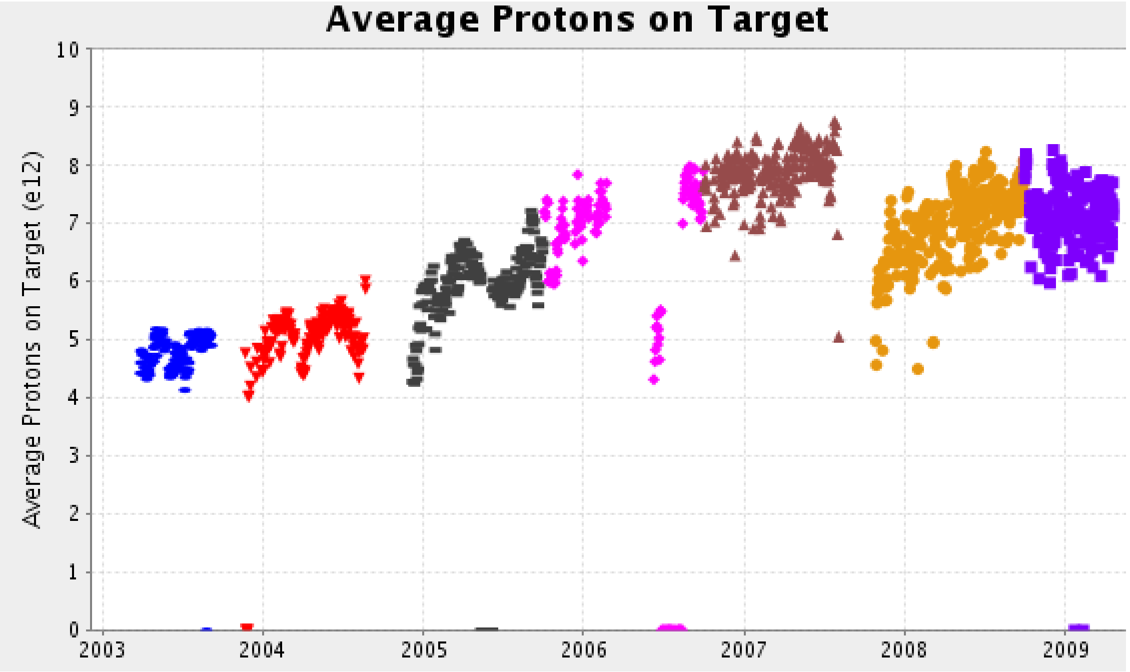
  - Depends on the coherent tune shift only logarithmically
- High frequency modes are stabilized by Landau damping
- Low frequency modes are stabilized by transverse dampers (H & V)
  - FPGA based digital damper with 212 MHz sampling rate and ~70 MHz bandwidth



Sum and difference BPM signals

Main Injector

- Design proton intensity on the pbar production target was achieved in 2006
  - Now MI delivers beam to pbar (70 kW) and NuMI (300 kW) in the same 2.2 s cycle



- Beam directed to Tevatron is intentionally scraped at 8 GeV in MI.
  - It results in an increase of brightness ($N_p / \varepsilon_\perp$) and
  - Removes protons with large betatron amplitudes
    - which would be lost in Tevatron due to beam-beam effects
- To accelerate antiprotons through transition
    - 2.5 MHz Recycler bunch is split to ~five 53 MHz bunches at 8 GeV
    - and then coalesced to one 53 MHz bunch at 150 GeV
  - This procedure results in doubling longitudinal emittance and 8% loss in MI with consecutive ~2-4% loss in Tevatron
  - We are considering ways to mitigate this problem

Tevatron

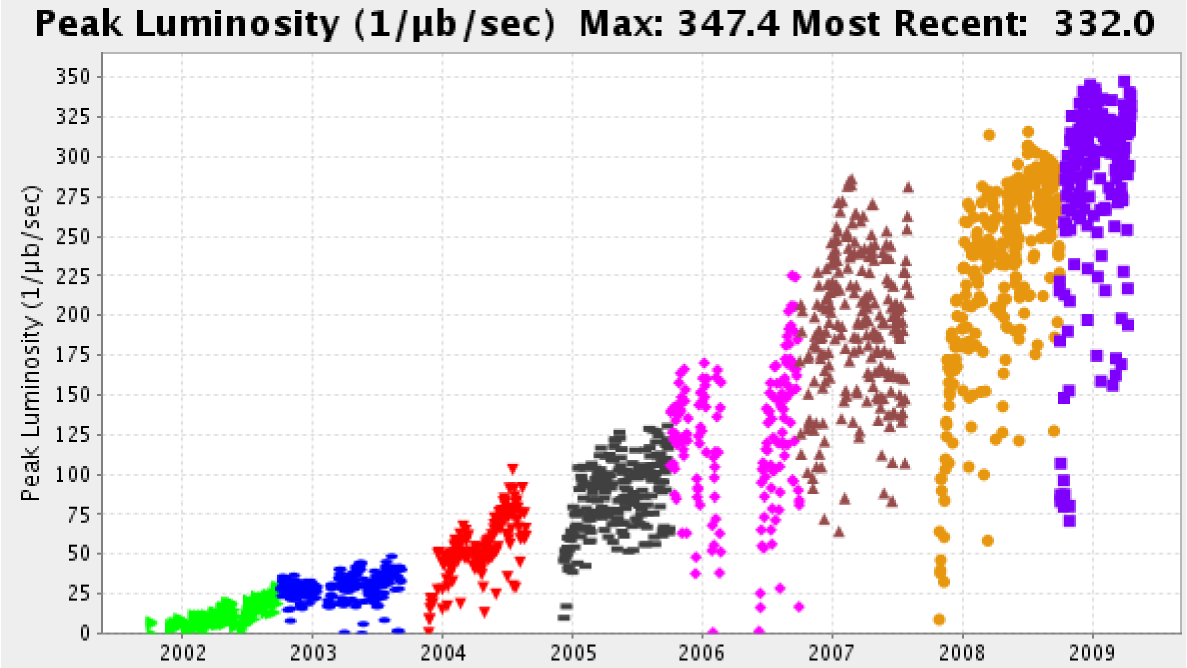
Recent improvements*

- Making Tevatron more stable
  - better orbit stabilization
  - persistent current compensation
  - stable operations, in particular, shot from the same pbar stash
- Good understanding and correction of linear and non-linear optics
  - β^*=35→28 cm – further reduction is limited by
    - aperture and non-linearity of FF quads
    - Gain of ∫Ldt is reduced by hour glass effect (σ_s ~ 45 → 65 cm)
  - Compensation of second order chromaticity (β-function chromaticity)
  - Coupling correction during acceleration
- Opening limiting aperture in vicinity of CDF (summer 2007)
- Intentional pbar emittance blow up before squeeze (6 →8 mm mrad)
- Operational improvements in the squeeze
- Shortening shot setup time: ~2 hour → 1 hour
  - Two proton bunches are accelerated in one cycle
  - Instrumentation and software improvements

* More details see in the presentation FR1PBC04 (Friday 10.00): Valishev, "Recent Tevatron Operational Experience"

Peak luminosity

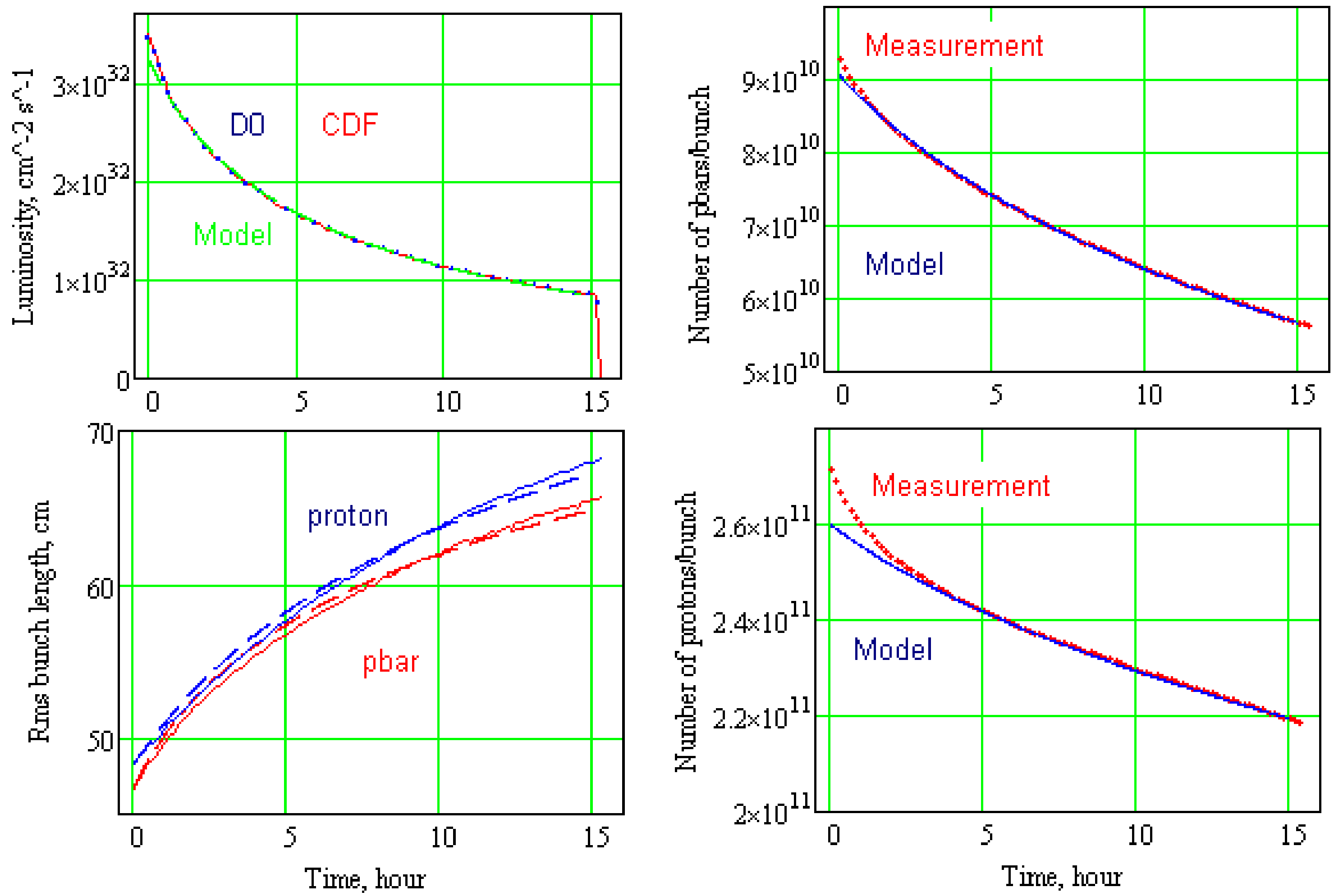
- Typically the peak Tevatron luminosity is ~$3.3 \cdot 10^{32}$ $cm^{-2}s^{-1}$
  - 11.5 collisions per IP ($\sigma_{inelastic}$=60 mb)
  - ♦ that exceeds the peak luminosity where detectors were expected to operate (2003)
  - ♦ Both CDF&D0 are close to the maximum but do not know how much more they can digest
    - $4 \cdot 10^{32}$ $cm^{-2}s^{-1}$ is not excluded



- Luminosity evolution model developed in 2003 describes stores comparatively well
  - ♦ It predicts that if we limit the peak luminosity the only way to increase the integrated luminosity is an increase of antiproton production and a decrease of antiproton loss

Luminosity evolution model

- The model ignores the beam-beam effects
  - Comparison to meas. shows that usually they result in ≤10% loss in $\int L dt$
- All tune shifts (protons, pbars, X, &Y) are ~0.02-0.025 at store beginning
  - Protons suffer more from beam-beam effects because of larger emit.
- Model predicts that operation with larger number of antiprotons but the same $L_{initial}$ should result larger luminosity integral



Conclusions

- Growth of luminosity integral would not be possible if increased antiproton production would not be supported by operational improvements in Tevatron and other machines
- The success is based on advances in the accelerator physics, as well as, on the excellence and advances in engineering, instrumentation and machine operation
- It took 8 years. What has been setting the pace?
  - Large scale of the complex
  - Operational status of the collider limits time for studies
  - Each store for hadron collider is unique (no damping)
    - store comparison is not straight forward
    - statistics is important to see an improvement
  - Antiproton production limits how frequently one can do another trial
  - Large number of steps in the collider shot setup
    - error at any place affects the final result
- Tevatron operates at the design luminosity
  - Minor improvements are still possible
  - Luminosity integral will be approximately doubled by the end of FY"11

Backup Viewgraphs

Collider History

- 1986-1987 Engineering Run
  - .05 pb^{-1}
- 1988-1989
  - 9.2 pb^{-1}
- Run Ia (1992-1993)
  - 32.2 pb^{-1}
- Run Ib (1994-1996)
  - 154.7 pb^{-1} (196 pb^{-1} cumulative)
- Run II (2001-2011)
  - 12,000 pb^{-1} planned (60 times of Run I)

17 steps up in '02-05 → 1.1717 = 15 times (V. Shiltsev)

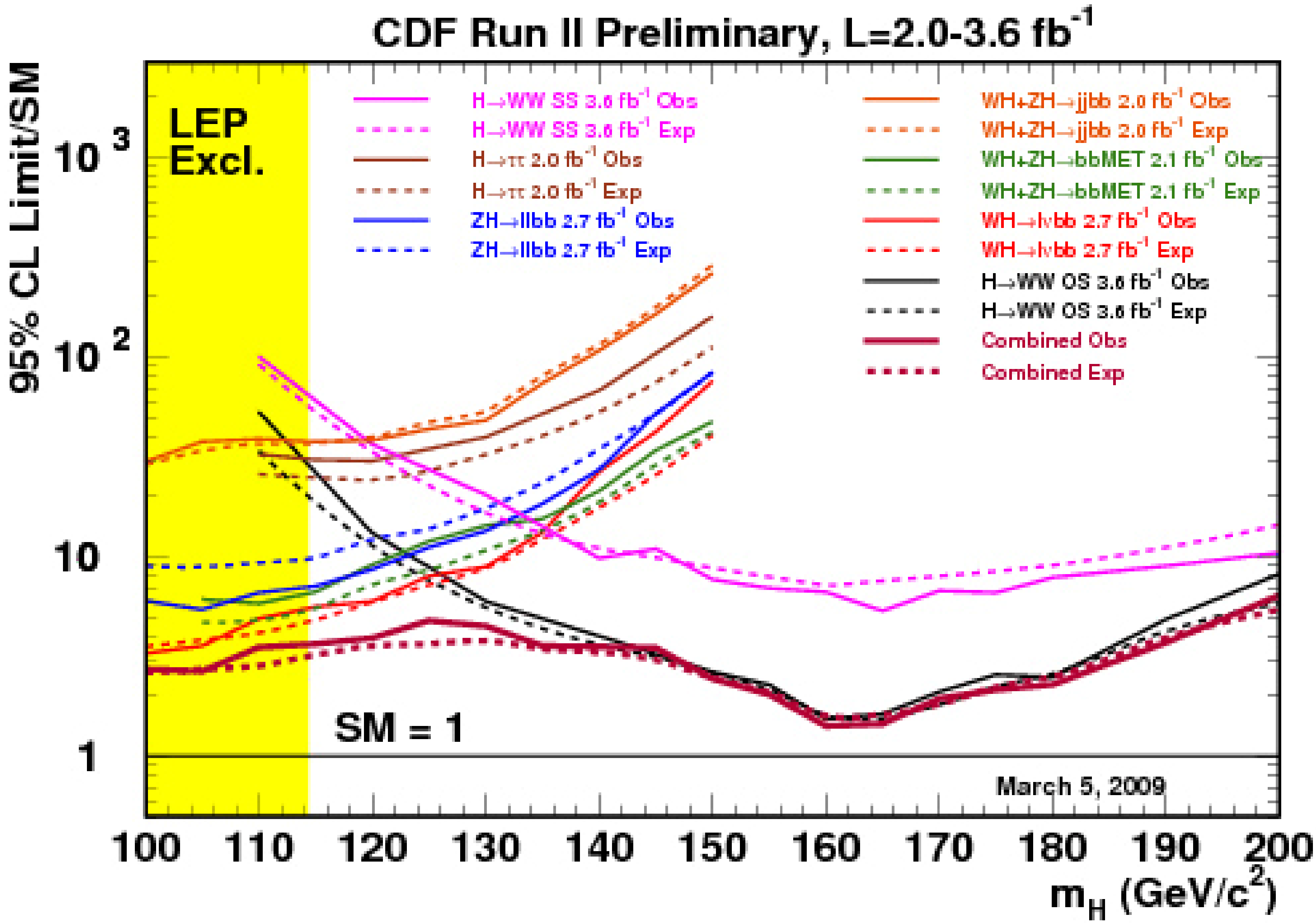
Optics AA->MI lines fixed	Dec'01	~25 %
New LB squeeze helix, TEL-1 abort	Mar'02	~40 %
"New-new" injection helix	May'02	~15 %
AA Shot lattice vs IBS	July'02	~40 %
Tev BLT/inst. dampers at injection	Sep'02	~10 %
Pbar coalescing improved in MI	Oct'02	~5 %
C0 Lambertsons Removed	Feb'03	~15 %
S6 circuit tuned/SEMs removed	June'03	~10 %
"5 star" helix on ramp	Aug'03	~2 %
Reshimming/Alignment	Nov'03	~12 %
Longer Stores/ MI dampers	Feb'04	~19 %
2.5MHz AA → MI trnsf/Cool shots	April'04	~8 %
Reduction of beta* to 35 cm	May'04	~26 %
Shots from Recycler	July'04	~20%
Slip Stacking in MI	Mar'05	~20%
Tev Octupoles at 150 GeV	April'05	~5%
Reduction of beta* to 28 cm	Sep'05	~8 %

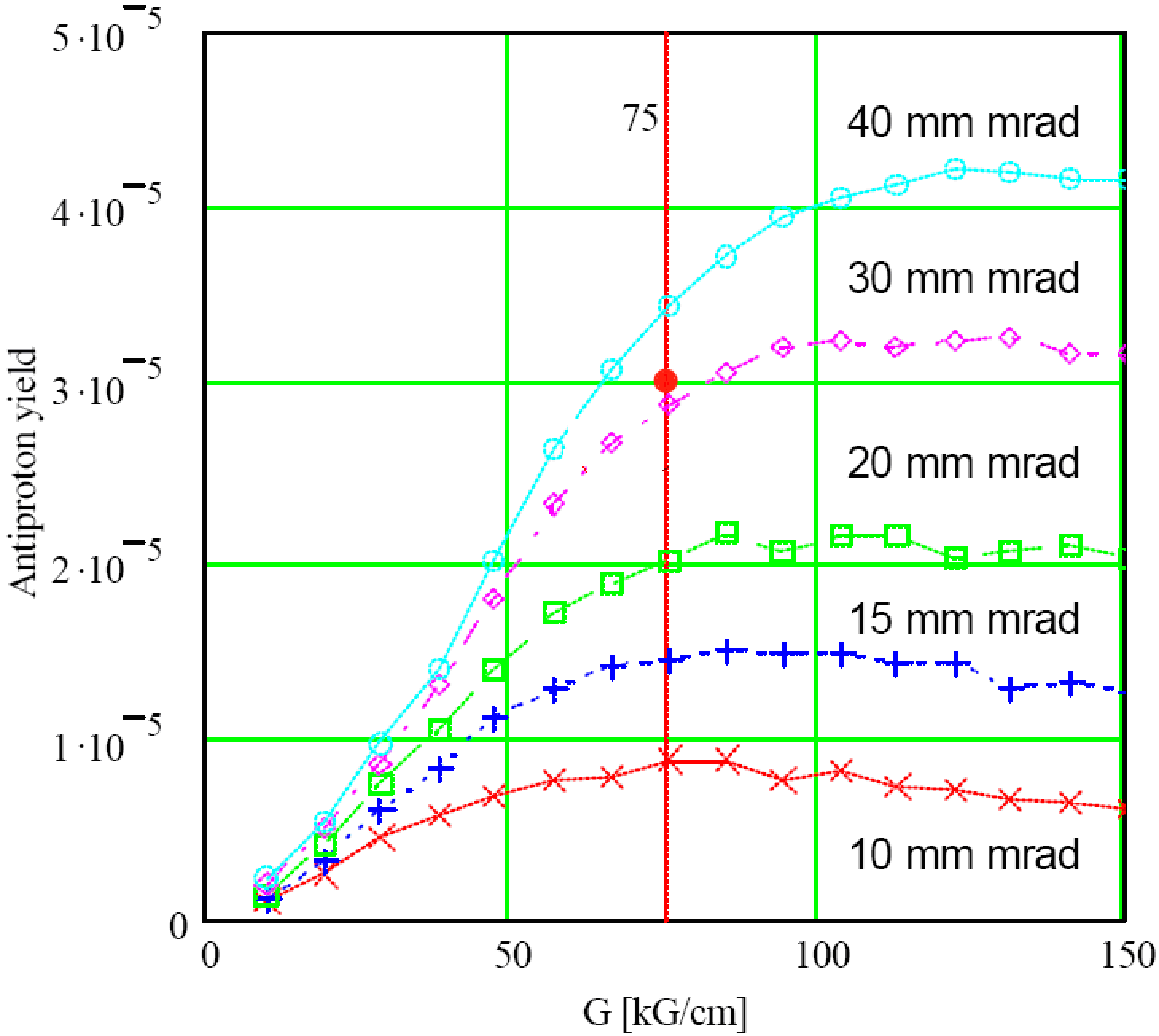
2006 improvements

Pbar production task force	Feb'06	~10 %
Tevatron 150 GeV helix→ more p's	June'06	~10 %
Tev collision helix → lifetime	July'06	~15 %
New RR WP →emittances	Sep'06	~25 %

Sequence of major events for the Antiproton source

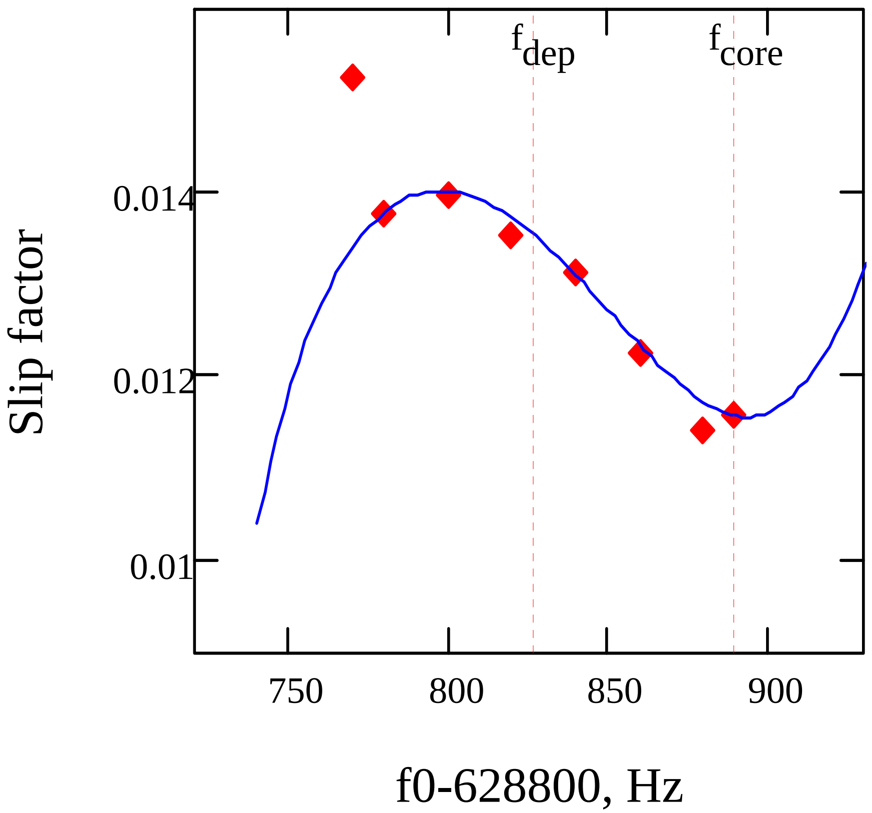
- Dec'05-Deb. optics and steering
- Feb'06 – Larger gain for 4-8 long. core cooling; 18->20 mA/hour
- July–Aug/06 - Tuning injector chain - pre-shutdown param. restored
- Oct. 1, 2006 - Stacktail polarity flip ⇒ peak st. rate: 20 ⇒ 22 mA/hour
- Dec'06 - New Li-lens
- March"07: Equalizer prototype for stacktail: 22 ⇒ 24 mA/hour
  - First attempt - March 12, 2007
  - Installation wit reduced gain at high *f* - March 19, 2007
  - Final installation - March 23, 2007
- April 3, 2007: Legs 2 & 3 pulled away
- May 16, 2007: Accumulator optics change
- May 4, 2007, Leg 3 is fully operational
  - New lithium lens lost – May 24, 2007
- June 4, 2007: Final Equalizer for stacktail
- July 18, 2007 – Notch filter #3: BAW (Bulk Acoustic Wave) ⇒SC
- August, 2007 – Equalizer for longitudinal core
- 2008, Double notch filter in Debuncher

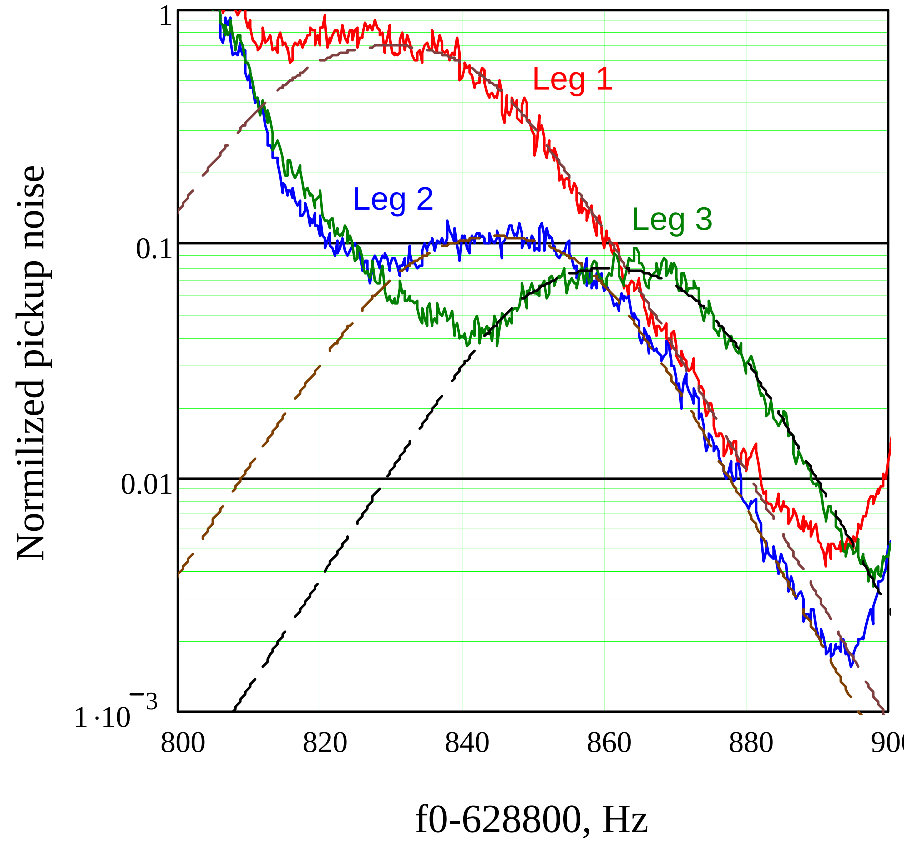

CDF Run II Preliminary, L=2.0-3.6 fb^{-1}
95% CL Limit/SM
LEP Excl.
H→WW SS 3.6 fb^{-1} Obs
H→WW SS 3.6 fb^{-1} Exp
H→ττ 2.0 fb^{-1} Obs
H→ττ 2.0 fb^{-1} Exp
ZH→llbb 2.7 fb^{-1} Obs
ZH→llbb 2.7 fb^{-1} Exp
WH+ZH→jjbb 2.0 fb^{-1} Obs
WH+ZH→jjbb 2.0 fb^{-1} Exp
WH+ZH→bbMET 2.1 fb^{-1} Obs
WH+ZH→bbMET 2.1 fb^{-1} Exp
WH→lνbb 2.7 fb^{-1} Obs
WH→lνbb 2.7 fb^{-1} Exp
H→WW OS 3.6 fb^{-1} Obs
H→WW OS 3.6 fb^{-1} Exp
Combined Obs
Combined Exp
SM = 1
March 5, 2009
10^3
10^2
10
1
100
110
120
130
140
150
160
170
180
190
200
m_H (GeV/c^2)



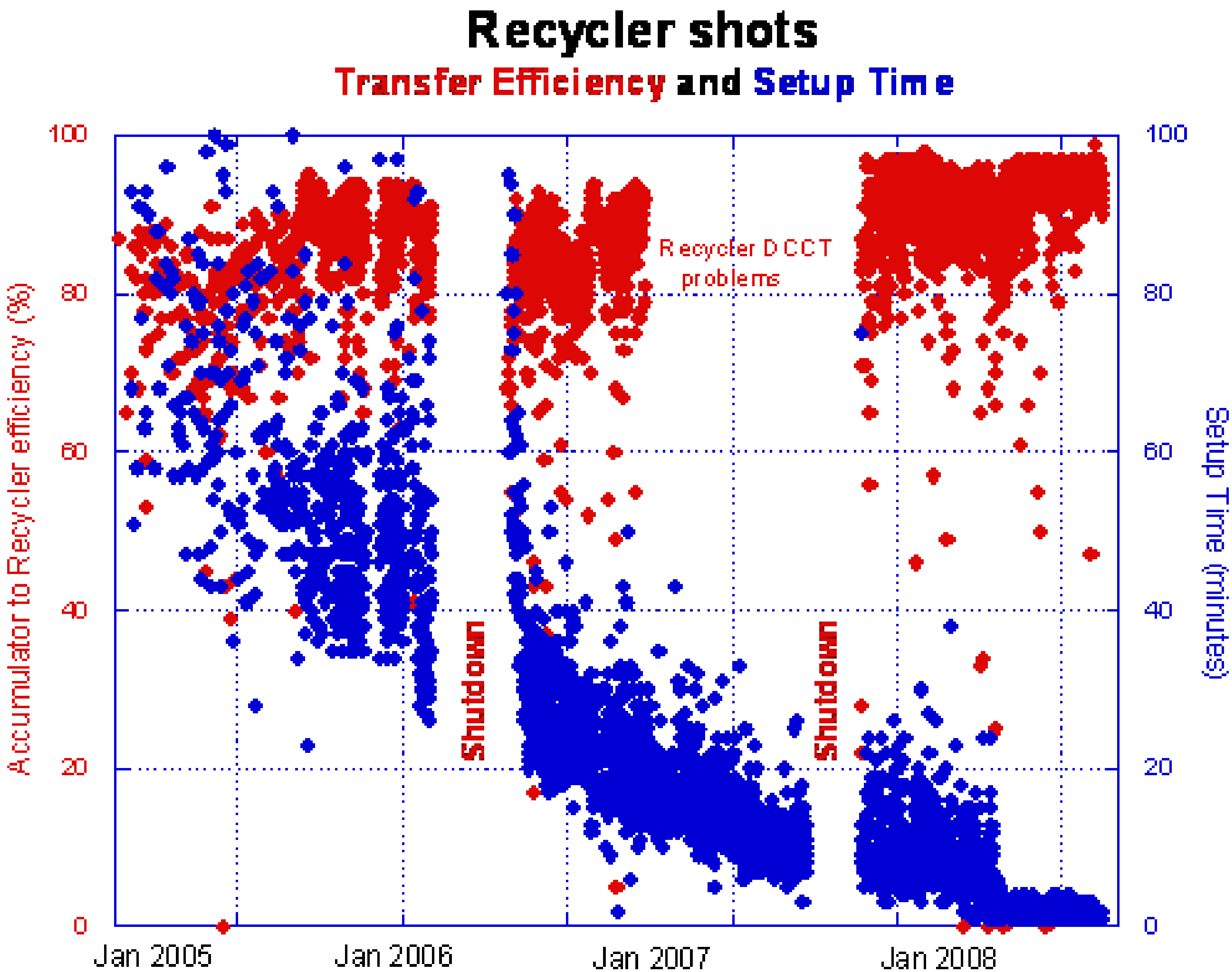
Dependence of Computed Antiproton yield on Debuncher acceptance and lithium lens gradient

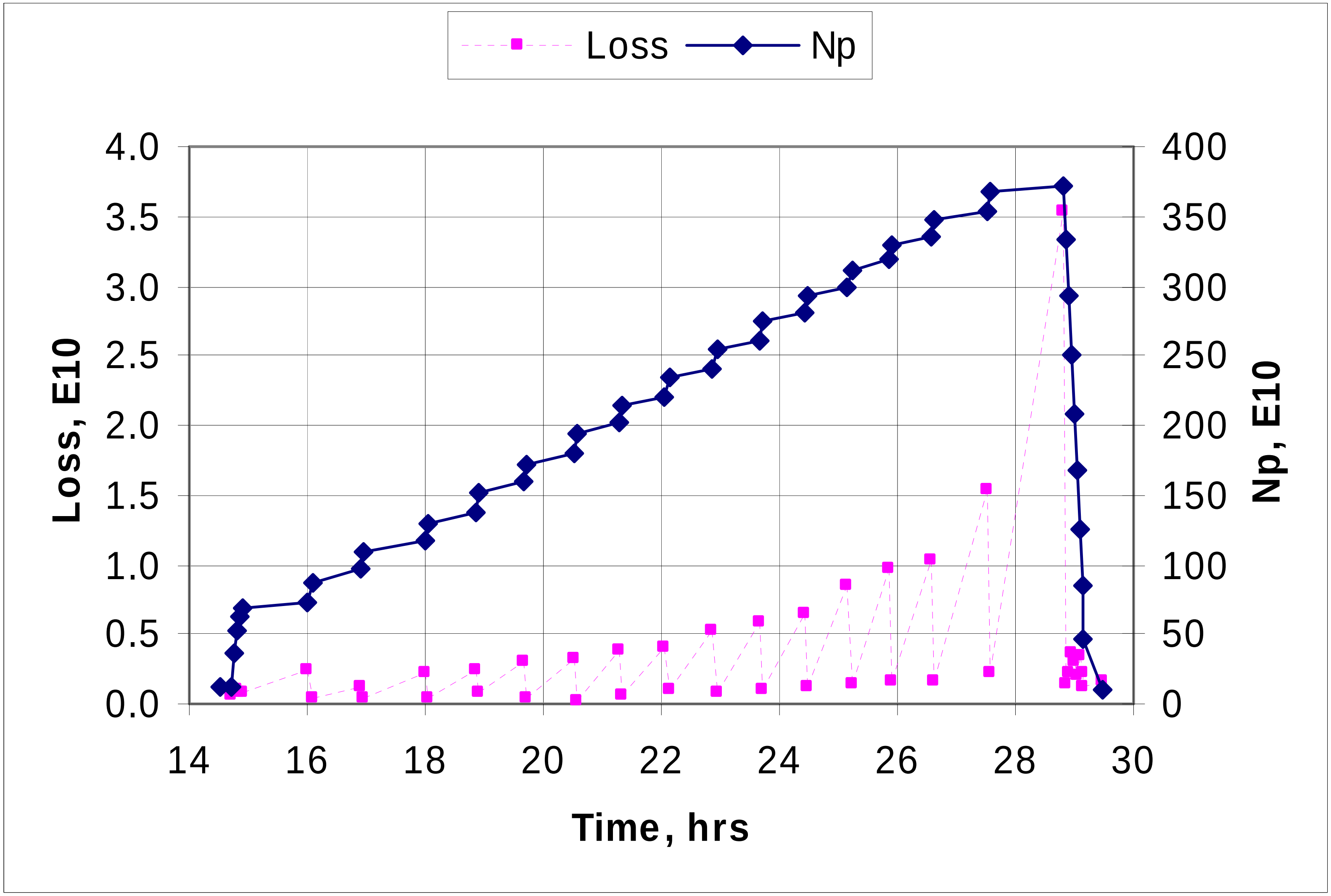
Measurements of Stack-tail Parameters and Numerical Model





- Measured dependence of slip factor on the momentum is fitted by polynomial
  - Decent coincidence with Accumulator optics model
  - Non-linearity of η is amplified by ~2 times due to proximity to γ_{tr}
- Dependence of pickup sensitivity on the beam coordinate corresponds to the earlier test-bench measurements


Recycler shots
Transfer Efficiency and Setup Time
Accumulator to Recycler efficiency (%)
Setup Time (minutes)
100
80
60
40
20
0
Jan 2005
Jan 2006
Jan 2007
Jan 2008
Shutdown
Shutdown
Recycler DCCT problems



- Record stash 498E10 (19-Apr-09, for shot #6987)
  - Partial mining; no hard limits for the stash size
    - Life time does degrade
- Example: losses between transfers while stashing for #6990

Courtesy of A. Shemyakin