Update on Run II Luminosity Progress and Projections

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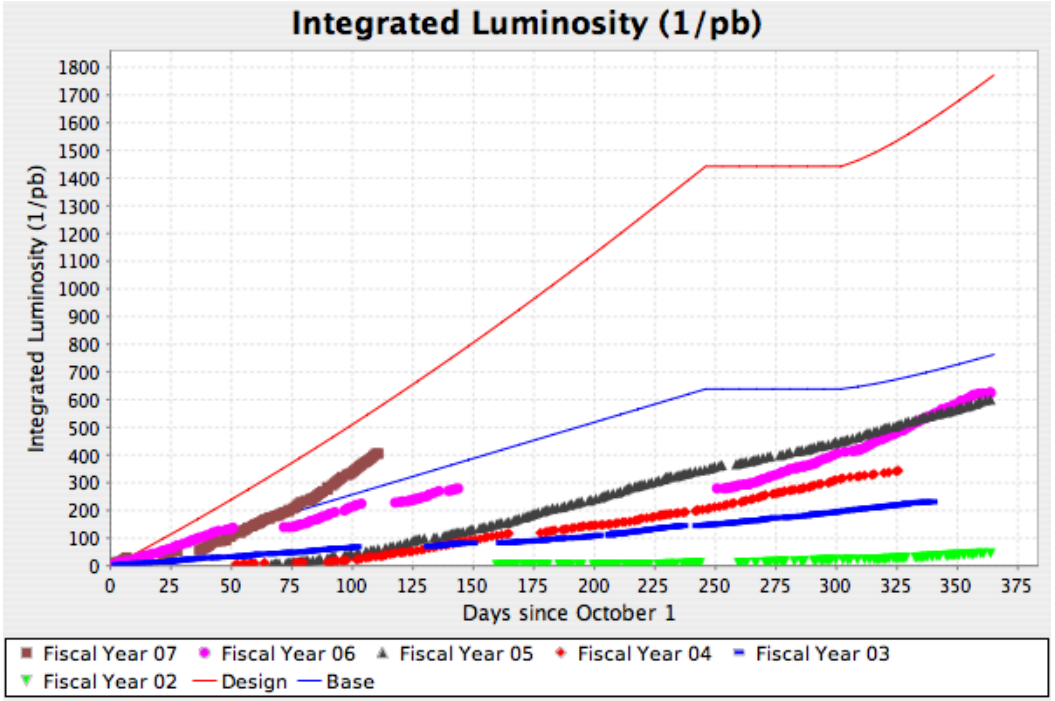
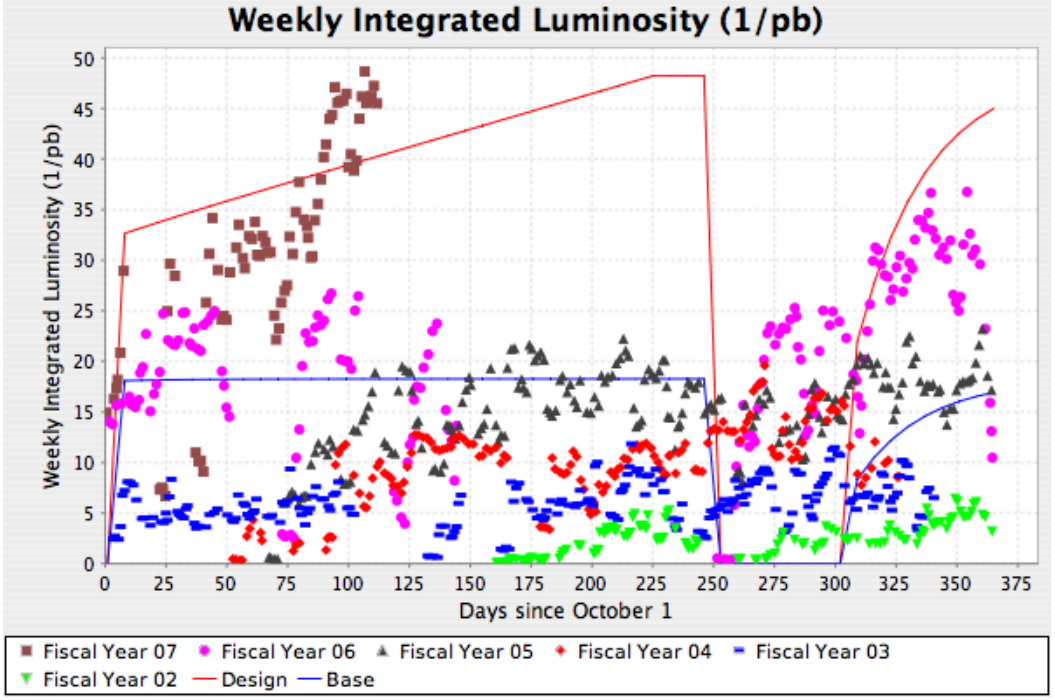
FNAL, D0

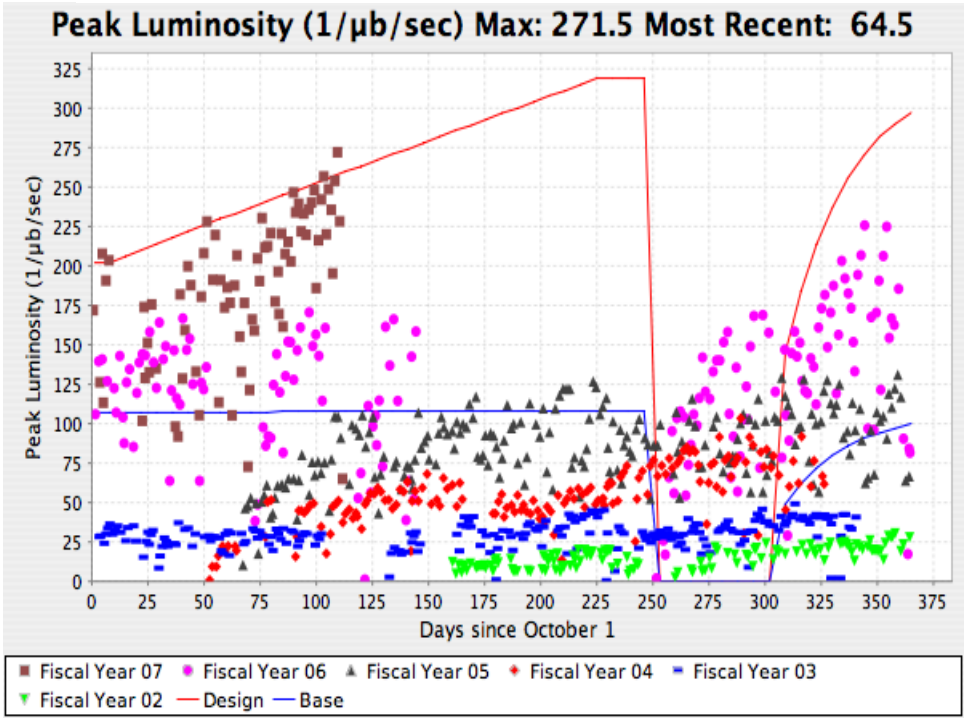
January 26, 2007

Present Collider Status



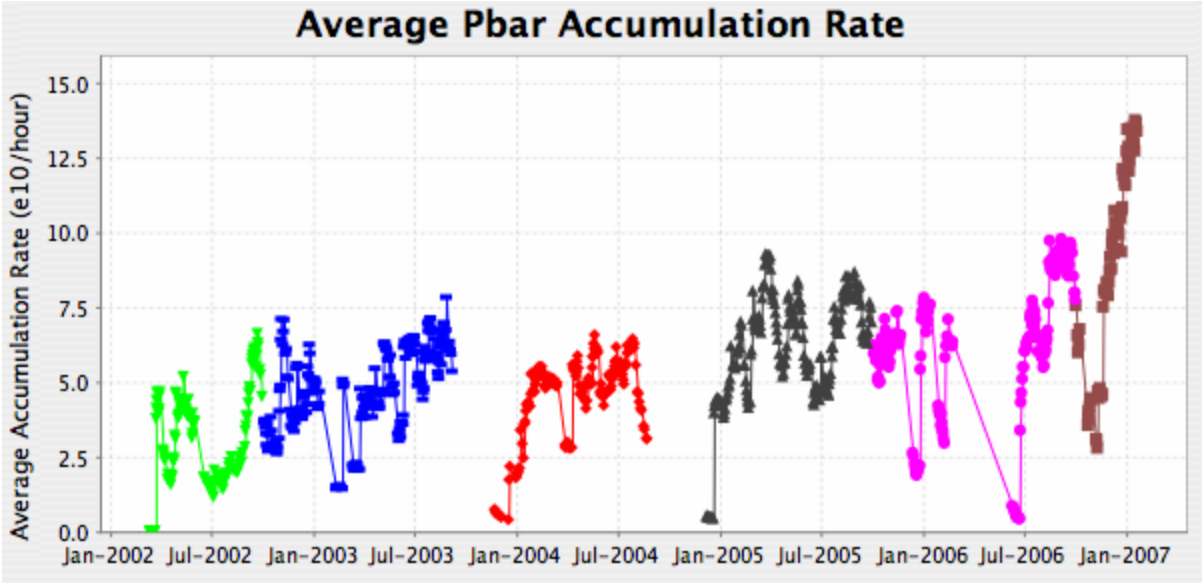


- Expectations for 2007 presented at September D0 meeting were 1.5 fb^{-1}
- Already achieved performance presents a strong evidence that we should meet this goal
- Taking into account expected gains in pbar production we should overpass it

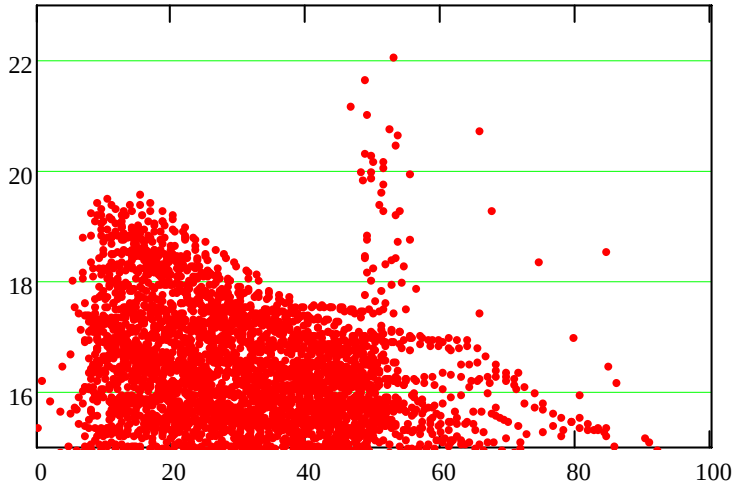


What was done?

- Improvement in antiproton production and transport of ~45% yielded the same improvement in luminosity integral
  - Stack-tail gain correction and pbar source tuning ~12%
  - Fast transfers ~10%
  - Recycler to HEP transport ~6%
  - Reliability & unaccounted ~ 11%
  - Multiplying: 1.12 * 1.1 * 1.06 * 1.04 = 1.45

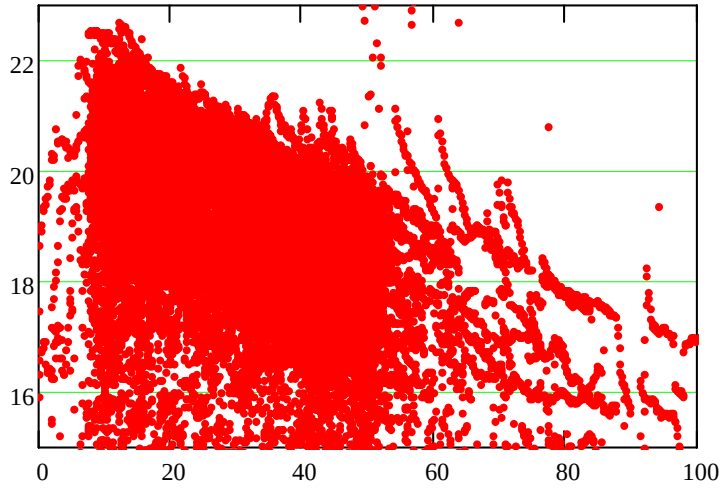


Stacking rate, mA/h, Aug.18-Sep.18, 2006



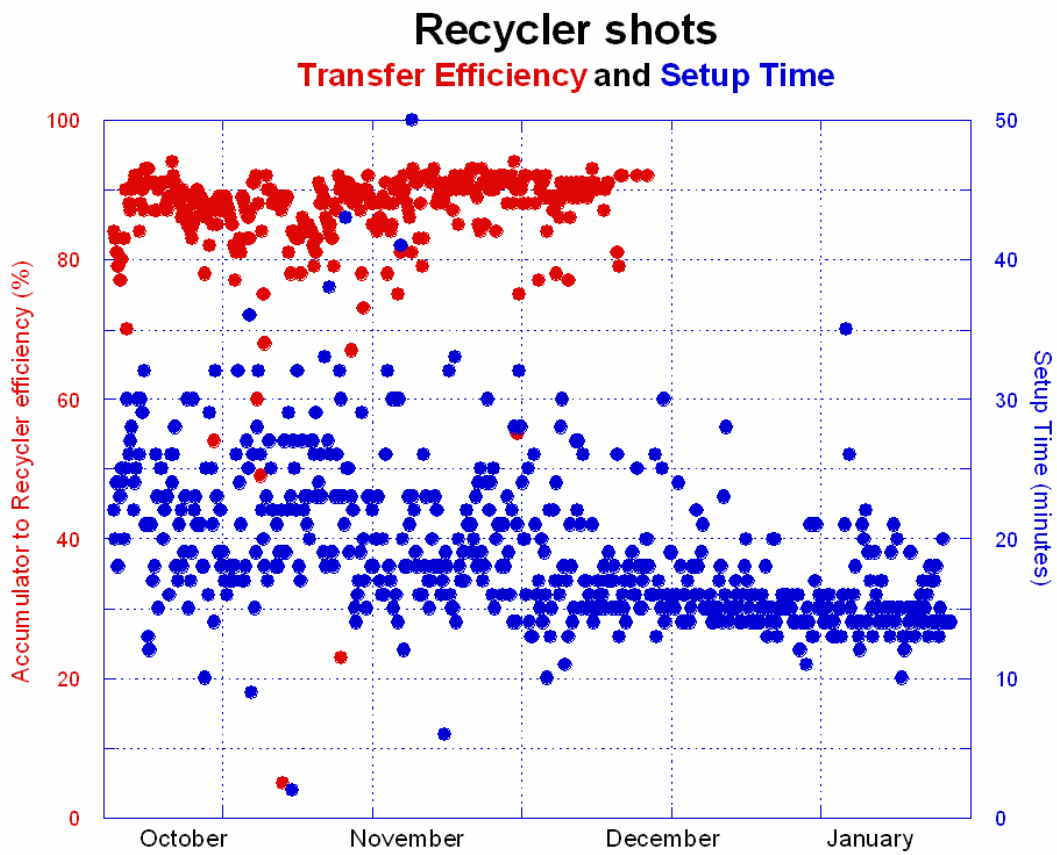
Stack size, mA

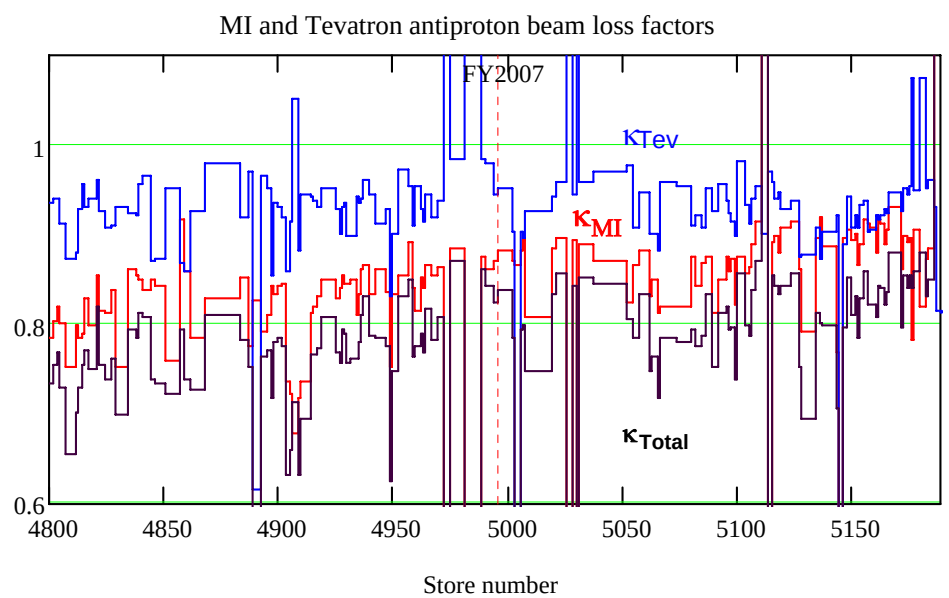
Stacking rate, mA/h, Jan.04-Jan.20, 2007



Stack size, mA

- This growth has been supported by Tevatron tuning
  - Mainly minor tune adjustments
- What was invisible but will play role in the future
  - Lithium lens upgrade ~10-15%





Update on Major objectives of the upgrade

- Peak production rate in Accumulator
  - Maximum gain is expected from
    - Lithium lens - done
    - Stochastic cooling !!! – great progress in understanding, visible results in 1-2 months for stack-tail. Debuncher cooling is next.
    - Optics in Accumulator – design work will start in March and will be finished before summer shutdown
- Fast transfers from Accumulator to MI
  - Maximum gain is expected from – progresses well, has to be finished by the end of March
    - ⇒ Smaller antiproton loss at transfers
    - ⇒ Less time spent for transfers
- Tevatron improvements
  - New working point – Power supply delivery is delayed by 3.5 month to mid January. Second order chromaticity correction has to be finished by the end of February. Decision on new working point will follow. Input from D0 and CDF is expected by this time

- Break-down of the luminosity goal
  - **Increase the peak antiproton production in the antiproton source** - is expected to be achieved before summer shutdown
    - **20 -> 30 mA/hour (× 1.5)**
    - That implies

Number of protons on target: $8 \cdot 10^{12}$ /pulse (already achieved)
Antiproton yield: $25 \cdot 10^{-6}$ pbar/p (already achieved in Debuncher)
Cycle time: 2.4 s

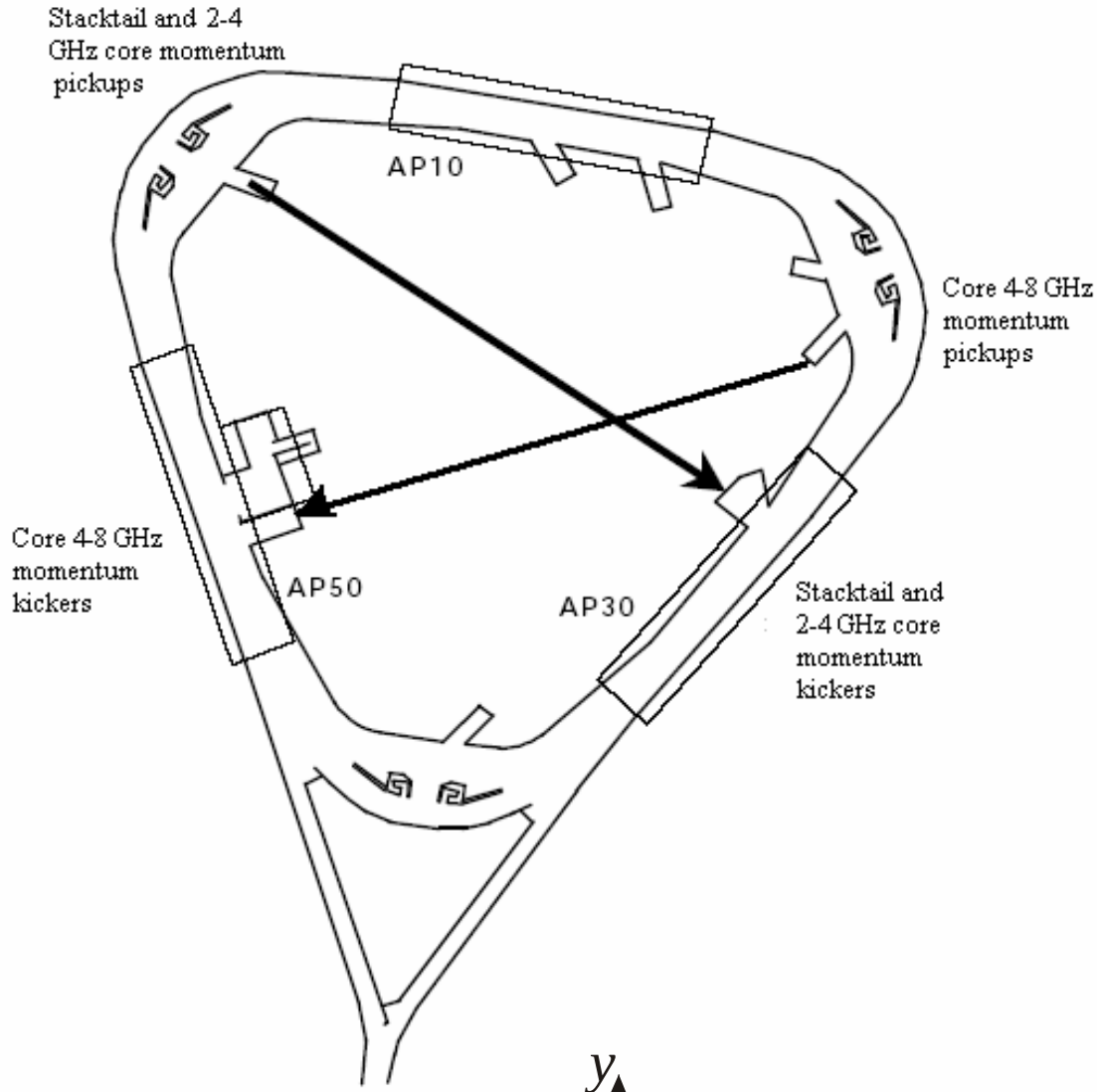
  - **Increase of average production to Recycler** - almost finished
    - **9 -> 16 mA/hour (1.5×1.05×1.05×1.10 = 1.8)**
    - That implies high efficiency Fast transfers (× 1.2)
      - Accumulator-to-MI loss: 90 -> 95% (× 1.05)
      - Transfer time: 20 min -> (<5 min) (× 1.05)
      - Operational improvements(no shot effect on pbar-
      - production, stability of parameters) should reduce
      - downtime in Pbar source: 75% -> 82% (× 1.10)
  - **Tevatron improvements (1.8 × 1.10 = 2)** – ready to go
    - **New working point (× 1.1)**
- Additional Goals not mentioned in September goals
  - Recycler has to support operation with 600E10 antiprotons – looks realistic by the end of FY'07

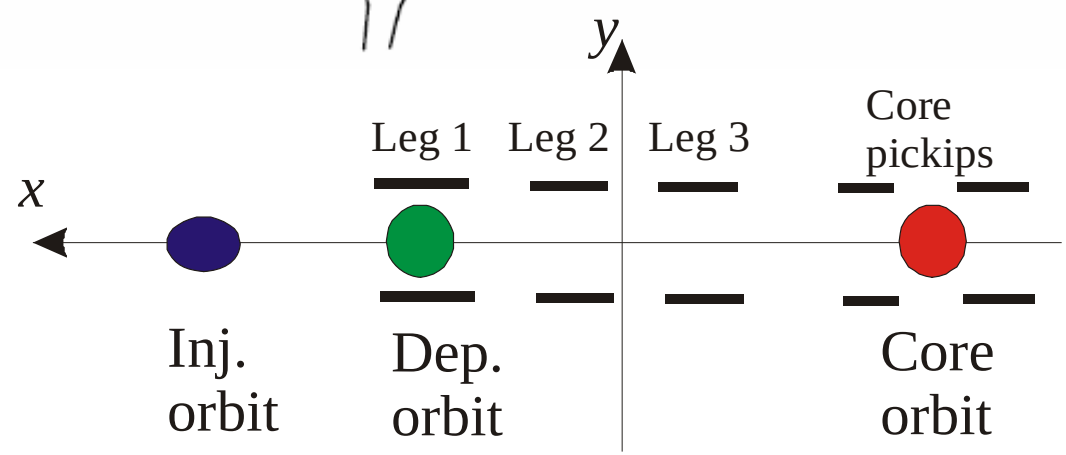
Upgrade of Stack-tail in Accumulator

- Presently the stack-tail is a major limitation for stacking rate increase
- Great progress in understanding of its operation since September
  - We built detailed model of the system
    - Model is based on beam measurements and includes all important phenomena and limitations
  - Measured maximum stacking rate of 22 mA/hour coincides well with the model predictions
- A few changes in the system will be introduced
  - Installation of equalizer
  - Repositioning of stack-tail pickups
  - Swapping stack-tail and longitudinal core cooling pickups
  - Installation of electronics for stack-tail gain ramps
- This upgrade will be also supported by Debuncher cooling upgrade
  - Installation of additional notch filters in both transverse and longitudinal systems

Stack-tail Hardware

- Pickups are located at large dispersion (~9.1 m) while kickers are at zero dispersion
- Stack-tail has 3 pickups located at different radial positions to make desired dependence of gain on the momentum
- Outside of pickup aperture its sensitivity drops exponentially. That allows one to form desired gain profile on particle position with small number of pickups

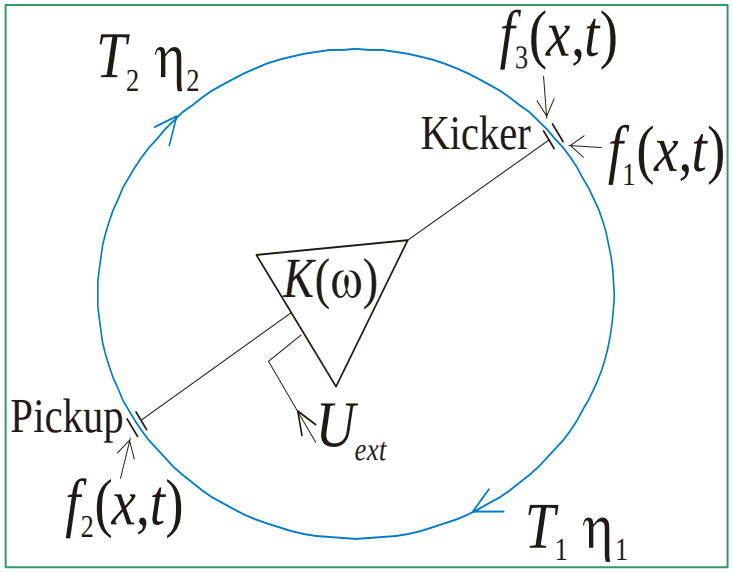




Stack-tail Model

- Evolution of particle distribution is described by Fokker-Planck equation

$$\boxed{\frac{\partial \psi}{\partial t} + \frac{\partial}{\partial x}\left(F(x)\psi\right) = \frac{1}{2}\frac{\partial}{\partial x}\left(D(x)\frac{\partial \psi}{\partial x}\right)} \quad .$$



$$F(x) = f_0 \sum_{n=-\infty}^{\infty} \frac{G_1(x,\omega_n)}{\varepsilon(\omega_n)}\left(1 - A(\omega_n)e^{-i\omega_n T_0}\right)e^{i\omega_n T_2 \eta_2 x}$$

$$D(x) = \sum_{n=-\infty}^{\infty} \frac{1}{\left|\varepsilon(\omega_n)^2\right|}\left[\frac{2\pi e^2 P_{Unoise}(\omega_n)}{T_0{}^2\left(\gamma\beta^2 mc^2\right)^2}\left|\frac{Z_k(\omega_n)}{Z_{ampl}}\right|^2 + f_0\left|G_1(x,\omega_n)\left(1 - A(\omega_n)e^{-i\omega_n T_0}\right)\right|^2 \frac{\psi(x)}{|n\eta|}\right] \quad .$$

$$\varepsilon(\omega) = 1 + \left(1 - A(\omega)e^{-i\omega T_0}\right)\int_{\delta\to 0_+} \frac{d\psi(x)}{dx}\frac{G_1(x,\omega)e^{i\omega T_2 \eta_2 x}}{e^{i\omega T_0(1+\eta x)} - (1-\delta)}dx \ ,$$

where: $\int \psi(x)dx = N \quad , \quad \omega_n = n\omega_0(1 - \eta x)$

- Taking into account that the betatron size in the pickup is much smaller than the synchrotron size we can factorize the gain for each system or leg:

$$G_1(x,\omega) = G_x(x)G_\omega(\omega), \quad \text{so that} \quad \mathrm{Im}(G_x(x)) = 0$$

Van der Meer solution

- Assuming that the total gain of the system can be factorized

$$G(x,\omega) = G_x(x)G_\omega(\omega) \ , \quad G_x(x) = G_0 \exp(-x/x_d)$$

- and looking for a static solution with constant flux one arrives that the maximum flux is

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

where the effective bandwidth is:

$$W = \sqrt{\frac{\left(\int_0^\infty \mathrm{Re}(G_\omega(2\pi f))df\right)^2}{\int_0^\infty |G_\omega(2\pi f)|^2 \frac{df}{f}}}$$

- For the rectangular gain function

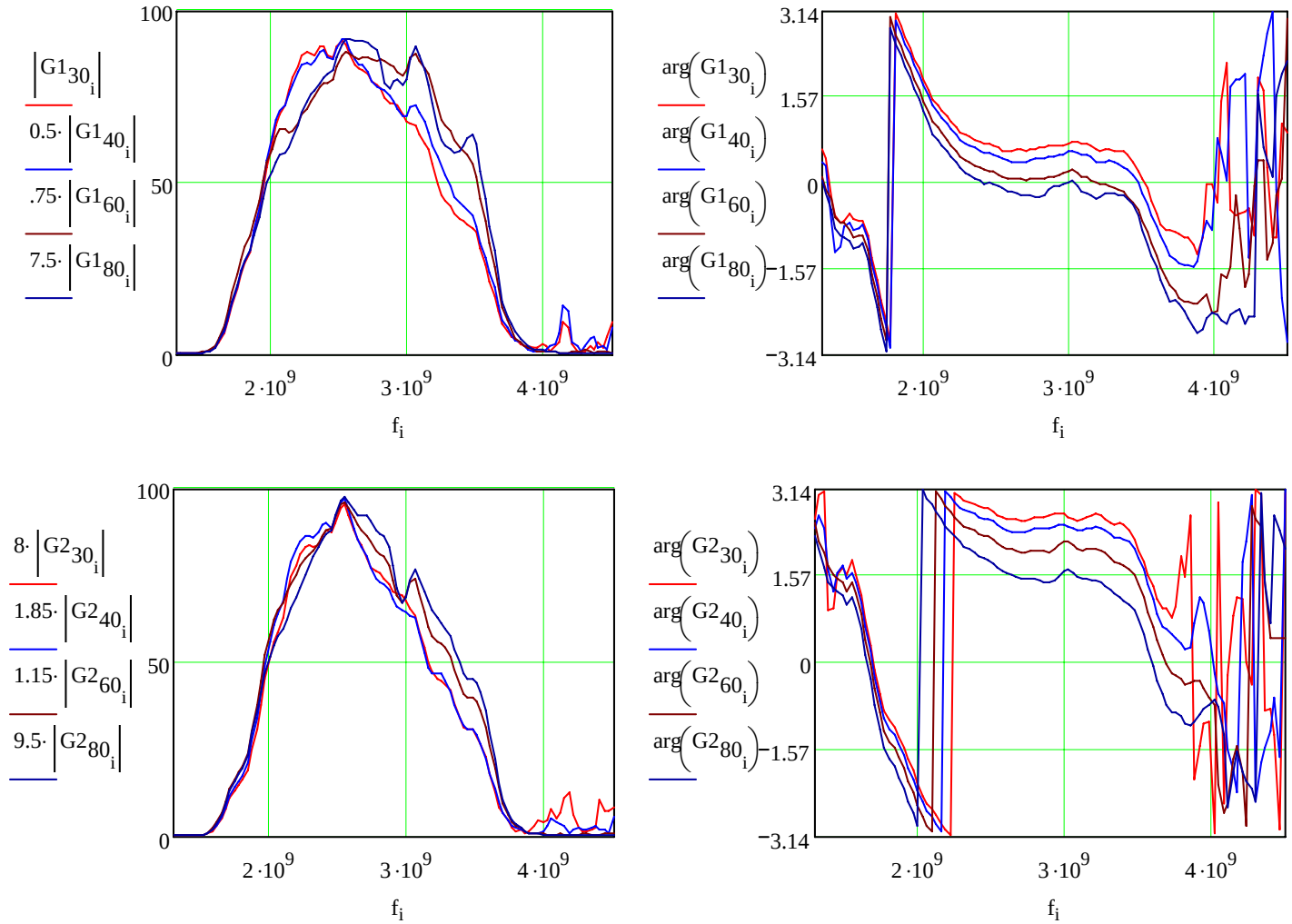
$$G_\omega(2\pi f) = \begin{cases} G_{opt} \ , & f \in [f_{\min}, f_{\max}] \\ 0 \ , & otherwise \end{cases}$$

that yields

$$W = \frac{(f_{\max} - f_{\min})}{\sqrt{\ln(f_{\max}/f_{\min})}}$$

- The gain of real system cannot be factorized and is not exponential through entire stack-tail region
  - Solving complete Fokker-Plank equation is required to understand the system and to predict its behavior

System gain was measured by open loop measurements for narrow beam at beam revolution harmonics without notch filters



Leg 1 frequency response depends on beam position in pickup (summing of 2 pickups or too many loops?)

Leg 2 shows this feature in much smaller scale

Phase shift with beam momentum is only 0.82 of expected for perfectly symmetric lattice

$$\Delta t = T_0\eta_0 \frac{\Delta p}{p_0}, \quad \Delta t_{pk} = T_{pk}\eta_{pk} \frac{\Delta p}{p_0}, \quad \Delta t_{kp} = T_{kp}\eta_{kp} \frac{\Delta p}{p_0}$$

$$T_0\eta_0 = T_{pk}\eta_{pk} + T_{kp}\eta_{kp}$$

η_{pk}=0.82, η_{kp}=1.18 – pickup data

η_{pk}=0.86, η_{kp}=1.14 – OptiM

$T_{pk} = T_{kp} = T_0/2$

Stack-tail Upgrade

- Parts to be upgraded
  - Displacement of stack-tail pickups and switching-on the legs 3 pickup
  - Installation of equalizer to optimize the gain profile (present band-pass filters need to be removed)

Pickup displacements and changes to the gains

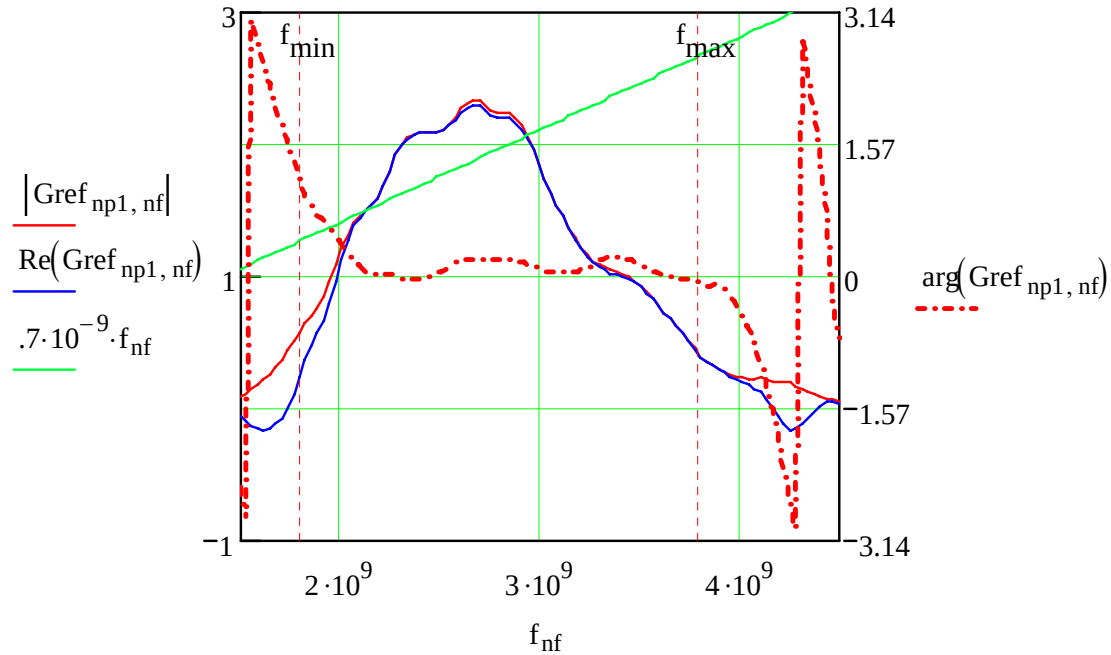
present/upgrade	Leg 1	Leg 2	Leg 3	Core cooling 2-4 GHz	Core cooling 2-4 GHz
f_0-628000, Hz	830/823	845/836	NA/852	890	890
Position, mm	10.7/18.4	-5.7/4.4	-23.9[†]/-13.8	-60.0	-60.0
Gain rel. to Leg 1	1/1	0.25/0.48	NA/0.1	0.010/0.006	0.030/0.019
Number of loops	256	48	16	0.010/0.006	0.030/0.019
Electronics gain relative to Leg 1	1/1	0.58/1.11	NA/0.4	NA	NA
Maximum stacking rate, mA/hour	22 / 30[‡]				

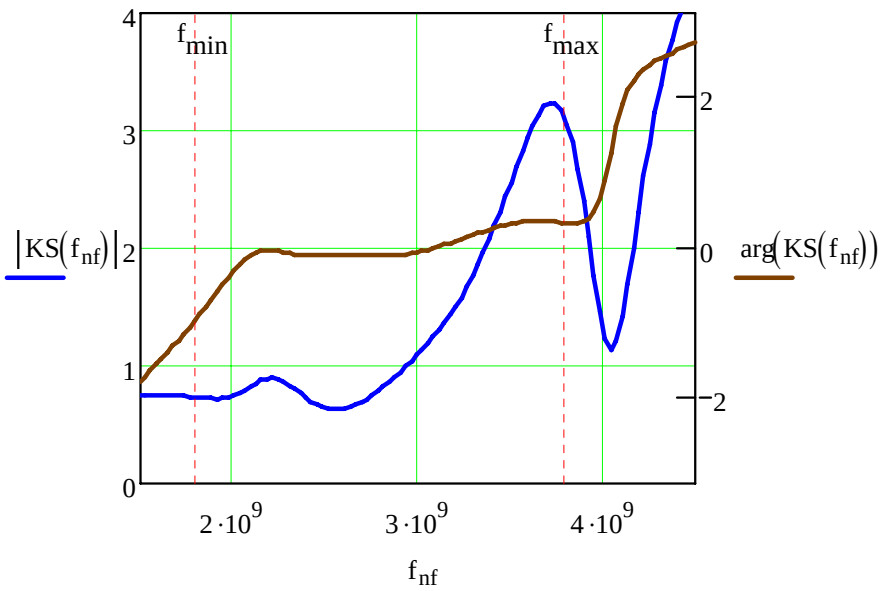
[†] It is not used presently. Bound up to the Leg2

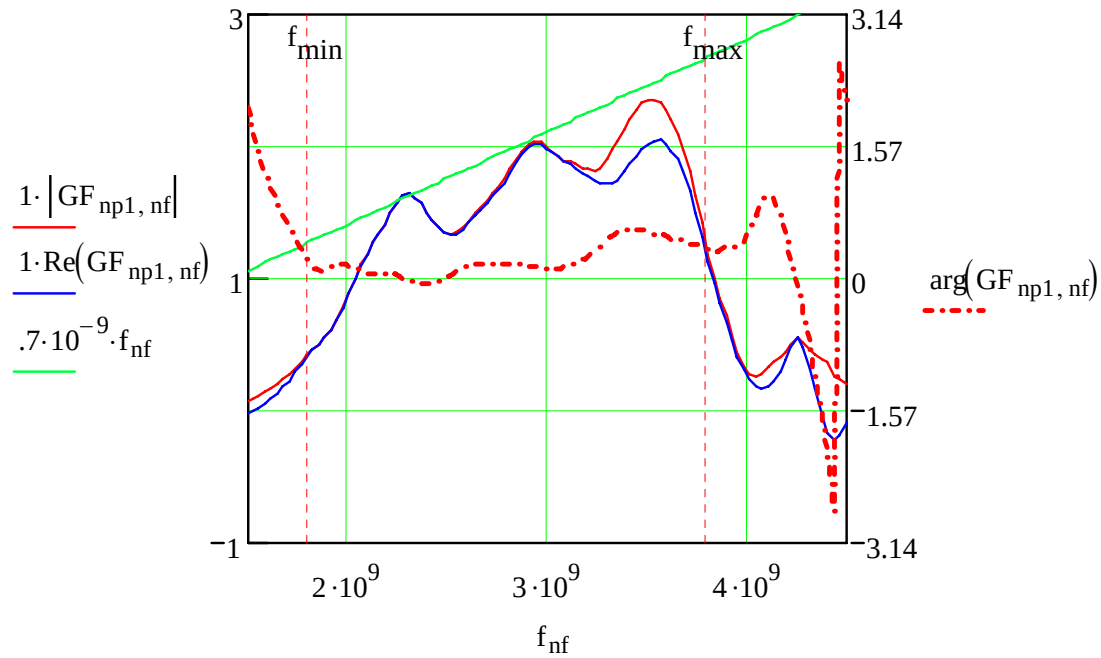
[‡] This number is expected to be better after equalizer design will be complete

Stack-tail Upgrade (continue)

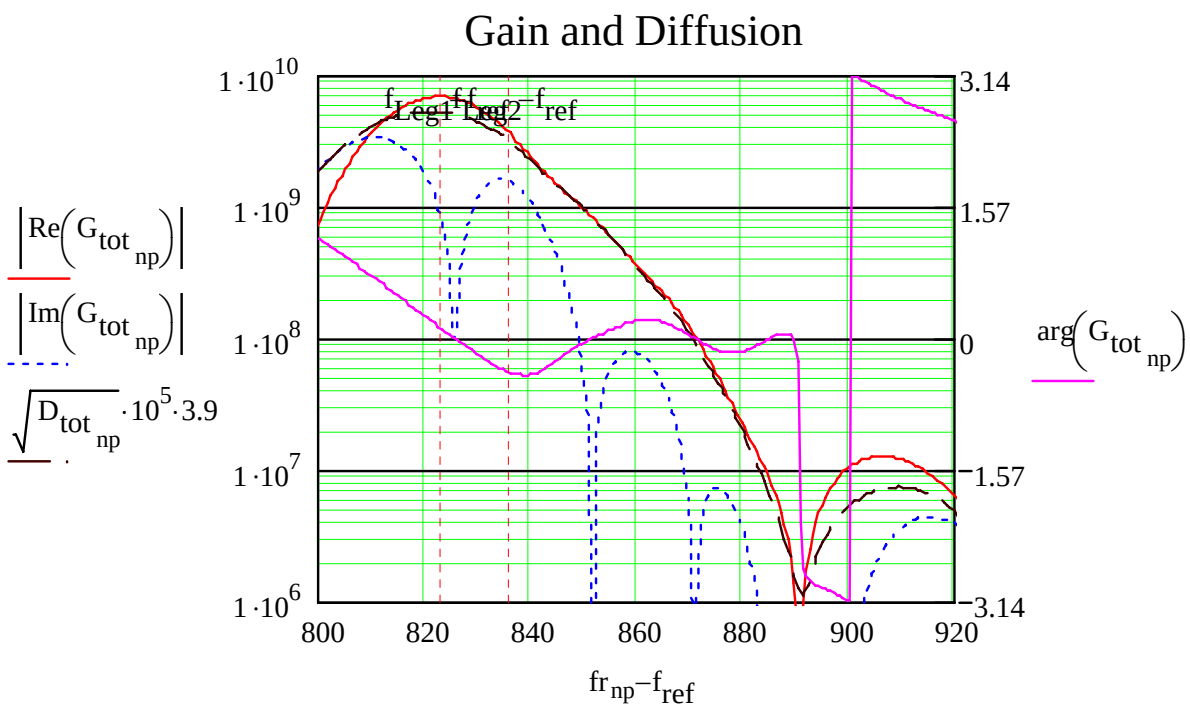
- Equalizer corrects the gain and phase of the system
- To demonstrate a possibility to correct phase and amplitude the equalizer prototype is designed of three resonators and a two modified notch filters
- Real microwave design progresses well

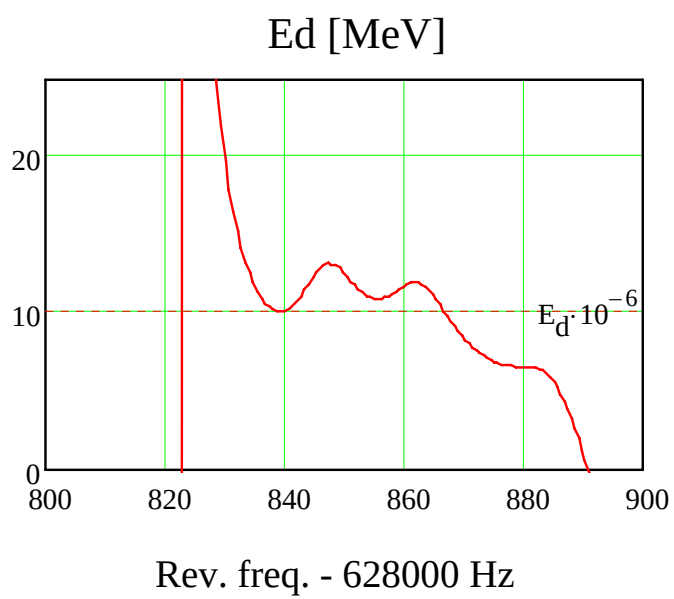


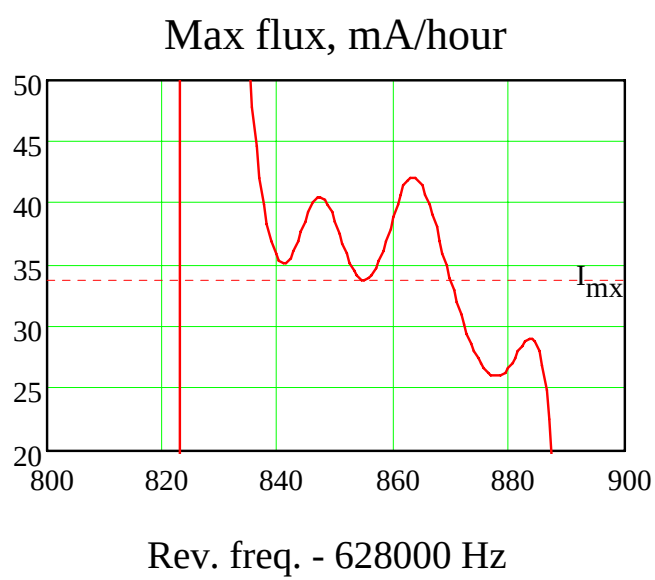




Parameters of the upgraded system







Other stack-tail issues

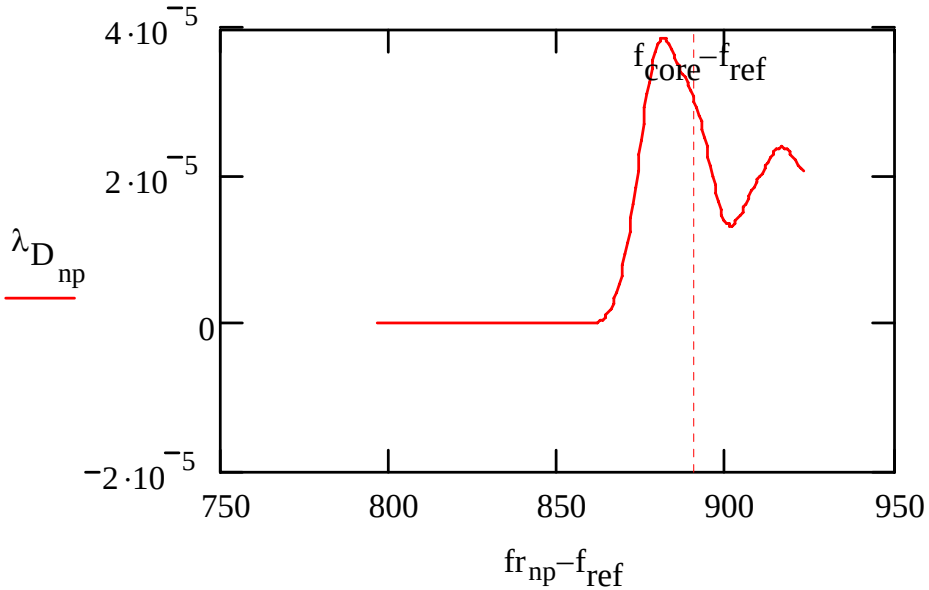
- Transverse emittance growth excited by the stack-tail

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

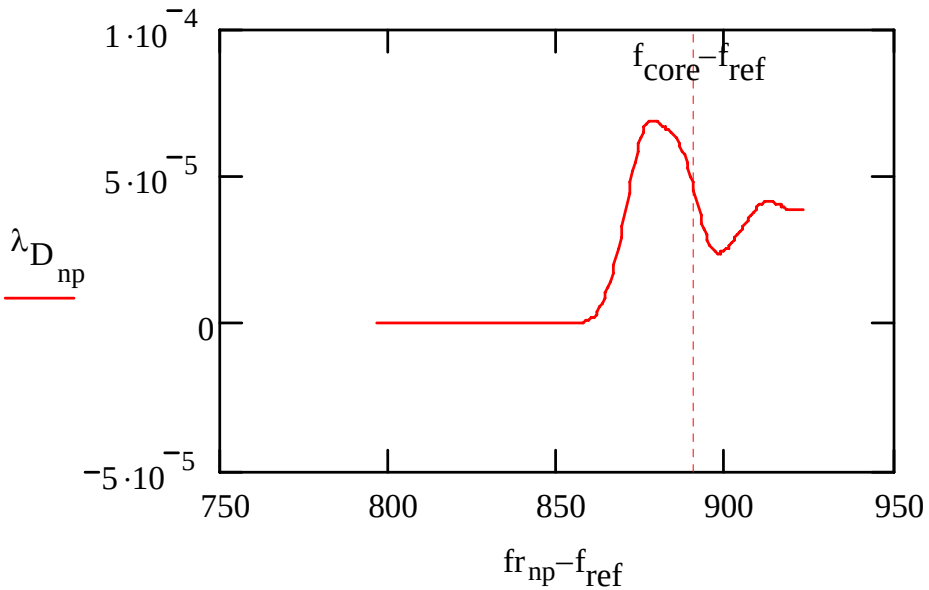
  - Dispersion mismatch
  - Kicker offset
  - Parametric heating
    - Is addressed by swapping core cooling and stack-tail kickers and switching of 4 of 31 kickers
- Installation of equalizer results in 1.8 times larger power required to run on optimal gain
  - Gain ramp
  - Improvement of longitudinal cooling in Debuncher

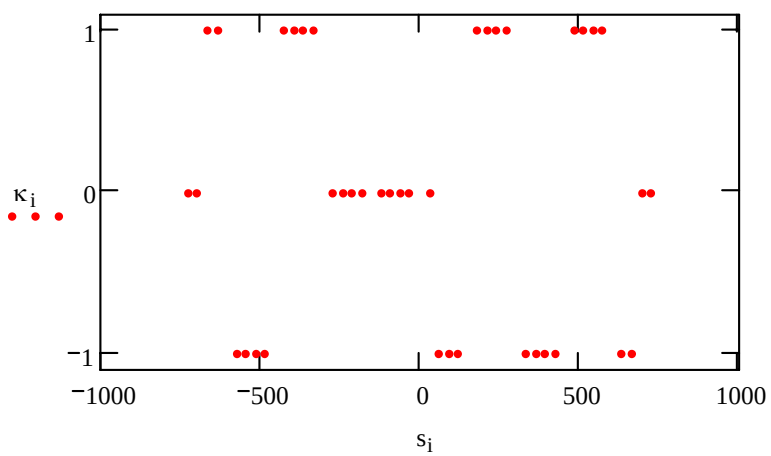
Expected Emittance Growth after Upgrade

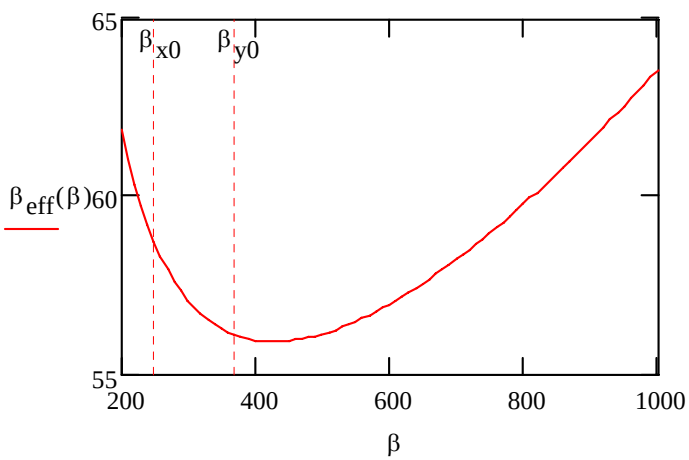
Now



After upgrade

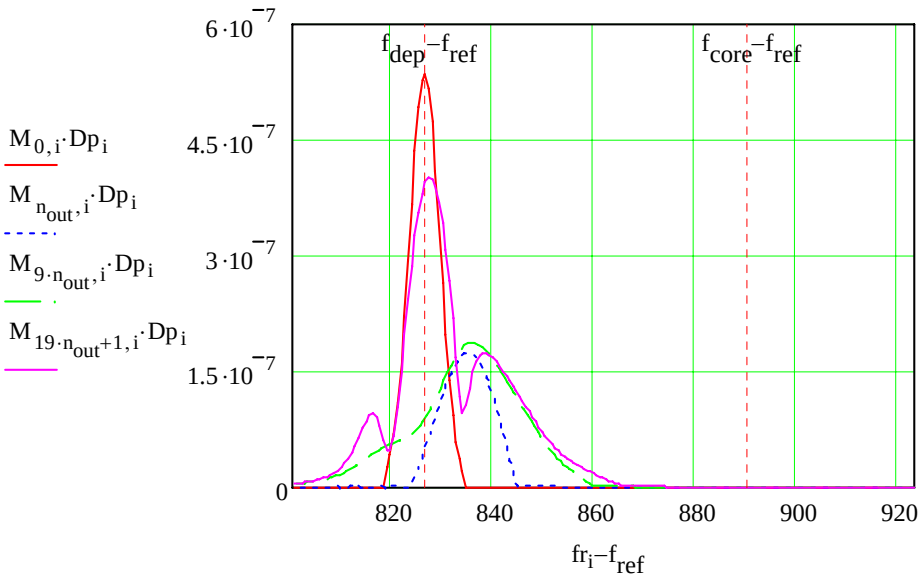




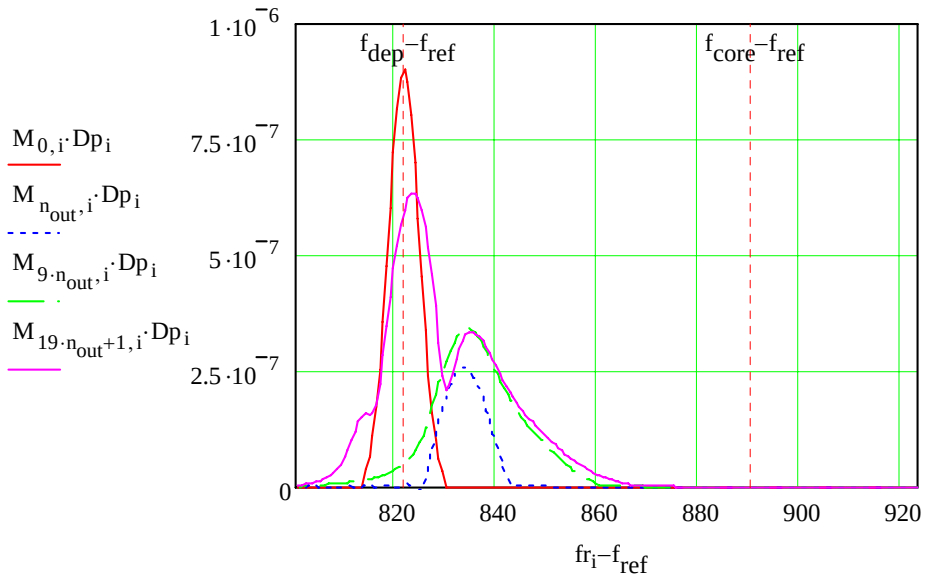


Horizontal emittance growth rate due to parametric heating, 2 kickers at each end are off, corresponding growth times are 7.1 and 4.0 hours correspondingly for present system and after equalizer installation

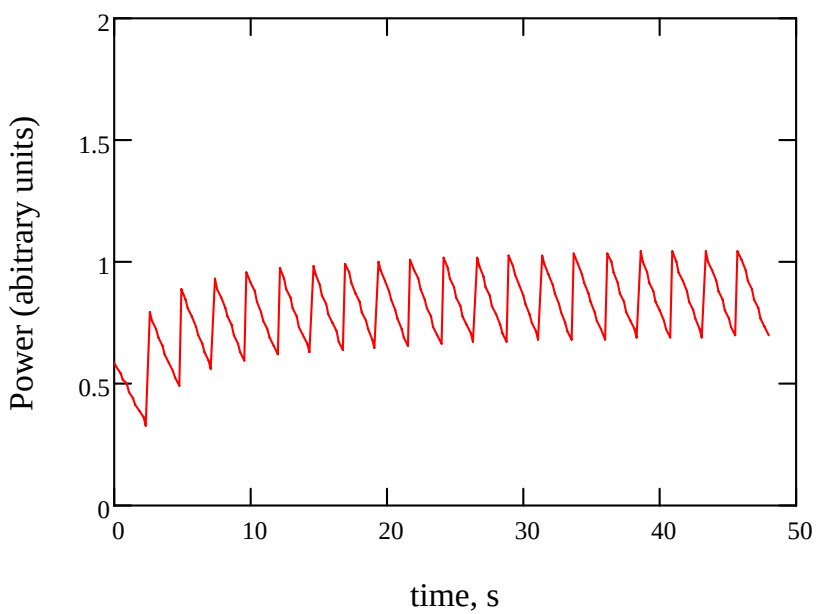
Present

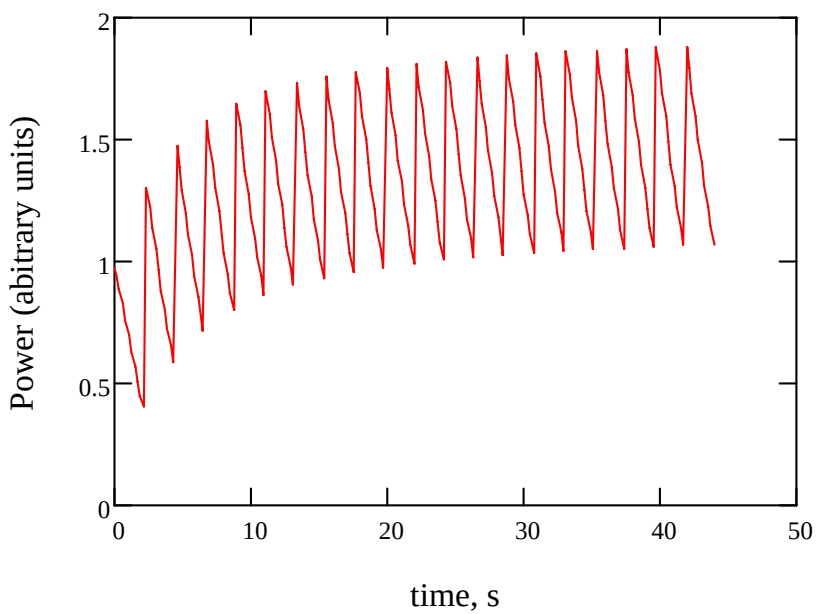


After equalizer installation



Spectral power density summed over all bands as function of revolution frequency





Dependence of total power on time

Conclusions

- AD has been able to follow the planned luminosity integral goal which was anticipated 3.5 year ago
  - Last 4 months certainly support this plan
  - Luminosity integral of 7-8 fb^{-1} by the end of FY2009 looks quite realistic goal
    - It is not clear yet - can we actually overpass it?
- The stacking rate goal of 30 mA/hour looks realistic
  - Results should be visible within 2-3 months
  - Such stacking rate supports luminosity integral of 60 pb^{-1}/week which corresponds to 2.2 - 2.4 fb^{-1}/year
  - Peak luminosity will exceed $3 \cdot 10^{32}$ $cm^{-2}s^{-1}$ soon
- Strong effort supporting further Run II improvements is required for the whole 2007
  - It is not clear how much beyond
- It is highly desirable to take a decision on the peak luminosity acceptable for both collaborations and the necessity of luminosity leveling by the end of March