RHIC Progress and Future

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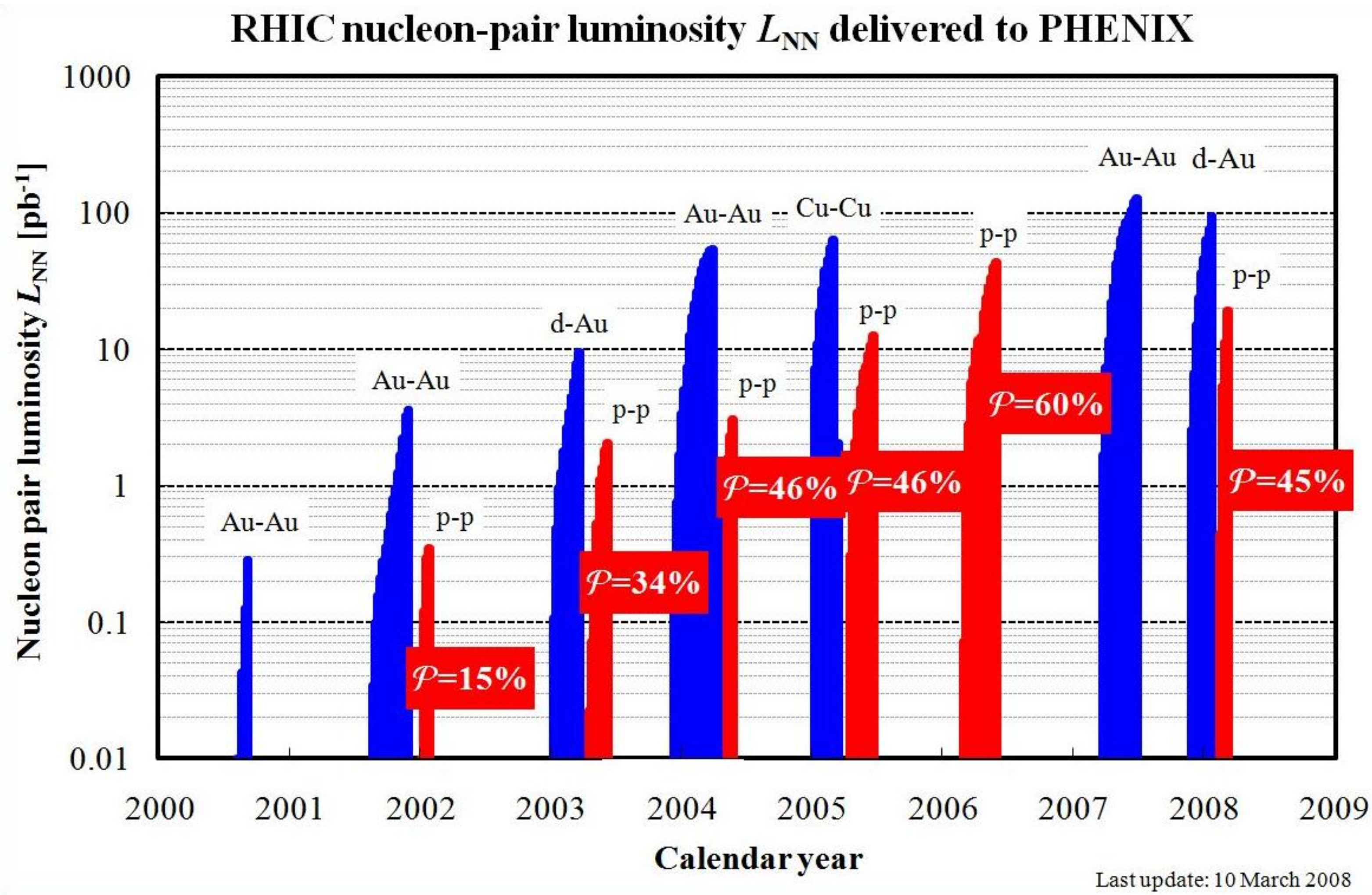
Delivered Luminosity and Polarization

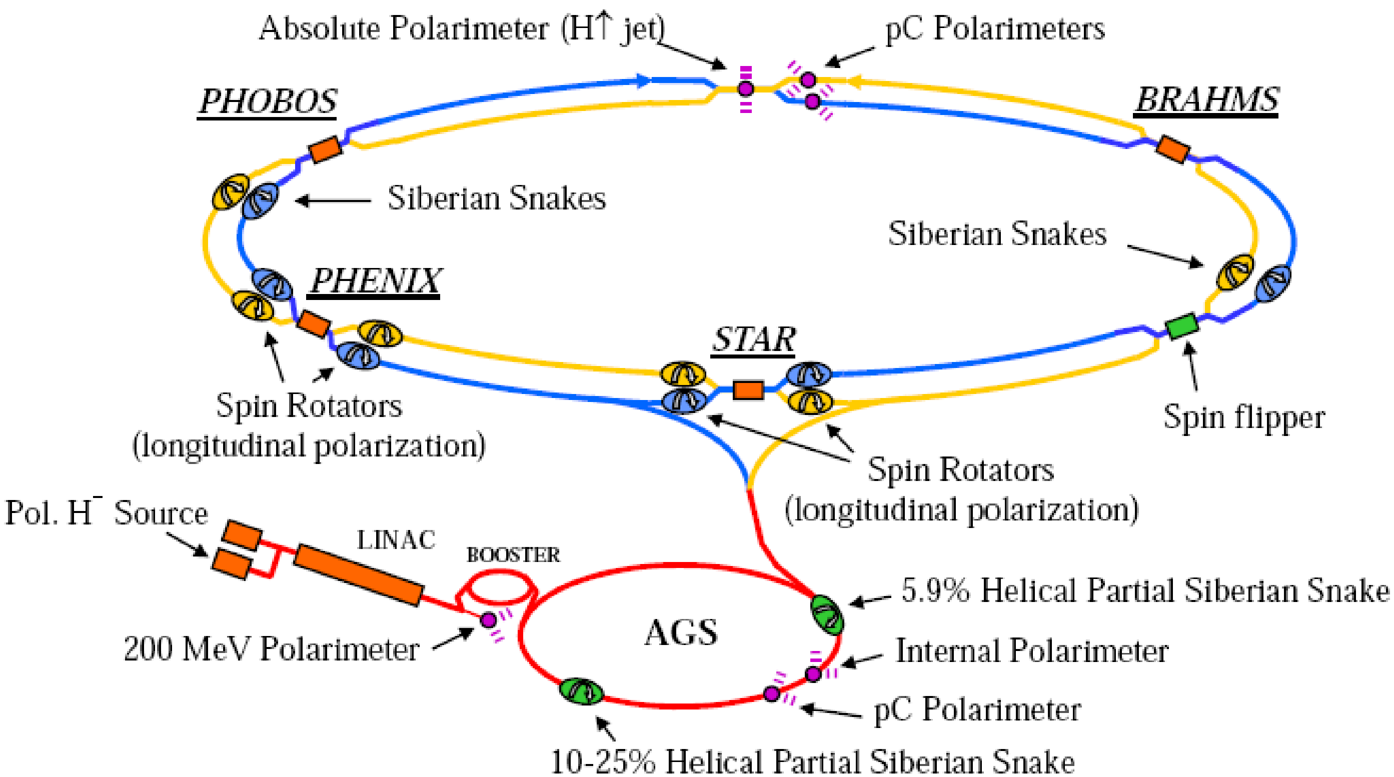


Achieved RHIC Parameters

mode	no. of bunches	ions/bunch $[10^9]$	β^* [m]	pol. %	$\mathcal{L}_{\text{store avg.}}$ $[\text{cm}^{-2}\text{sec}^{-1}]$	$A_1 A_2 \mathcal{L}_{\text{store avg.}}$ $[\text{cm}^{-2}\text{sec}^{-1}]$	$A_1 A_2 \mathcal{L}_{\text{peak}}$ $[\text{cm}^{-2}\text{sec}^{-1}]$
Au-Au	103	1.1	0.8		$12 \cdot 10^{26}$	$46 \cdot 10^{30}$	$120 \cdot 10^{30}$
Cu-Cu	37	4.5	0.9		$80 \cdot 10^{26}$	$32 \cdot 10^{30}$	$79 \cdot 10^{30}$
d-Au	103	100/1.0	0.85		$13 \cdot 10^{28}$	$51 \cdot 10^{30}$	$99 \cdot 10^{30}$
$\vec{p}$-$\vec{p}$ 100 GeV	111	1.35	1.0	60	$20 \cdot 10^{30}$	$20 \cdot 10^{30}$	$35 \cdot 10^{30}$

Nucleon-pair luminosity $A_1 A_2 \mathcal{L}$ treats nucleons of nuclei independently and allows for comparison of luminosities of different species

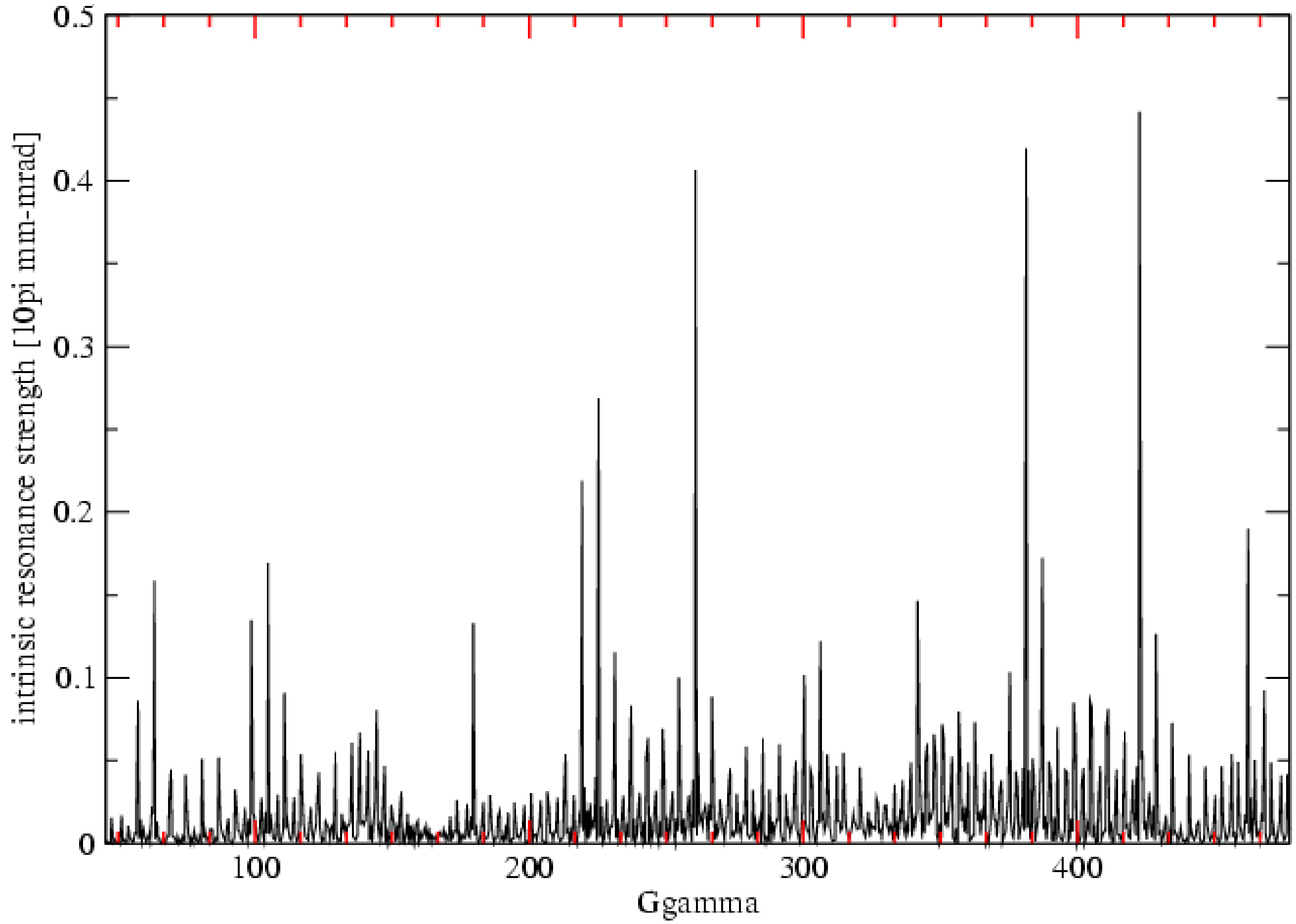
New Developments I: $\vec{p}$-$\vec{p}$ at 250 GeV



Two full Siberian snakes to overcome ≈ 1000 depolarizing resonances in RHIC

Two partial Siberian snakes in AGS

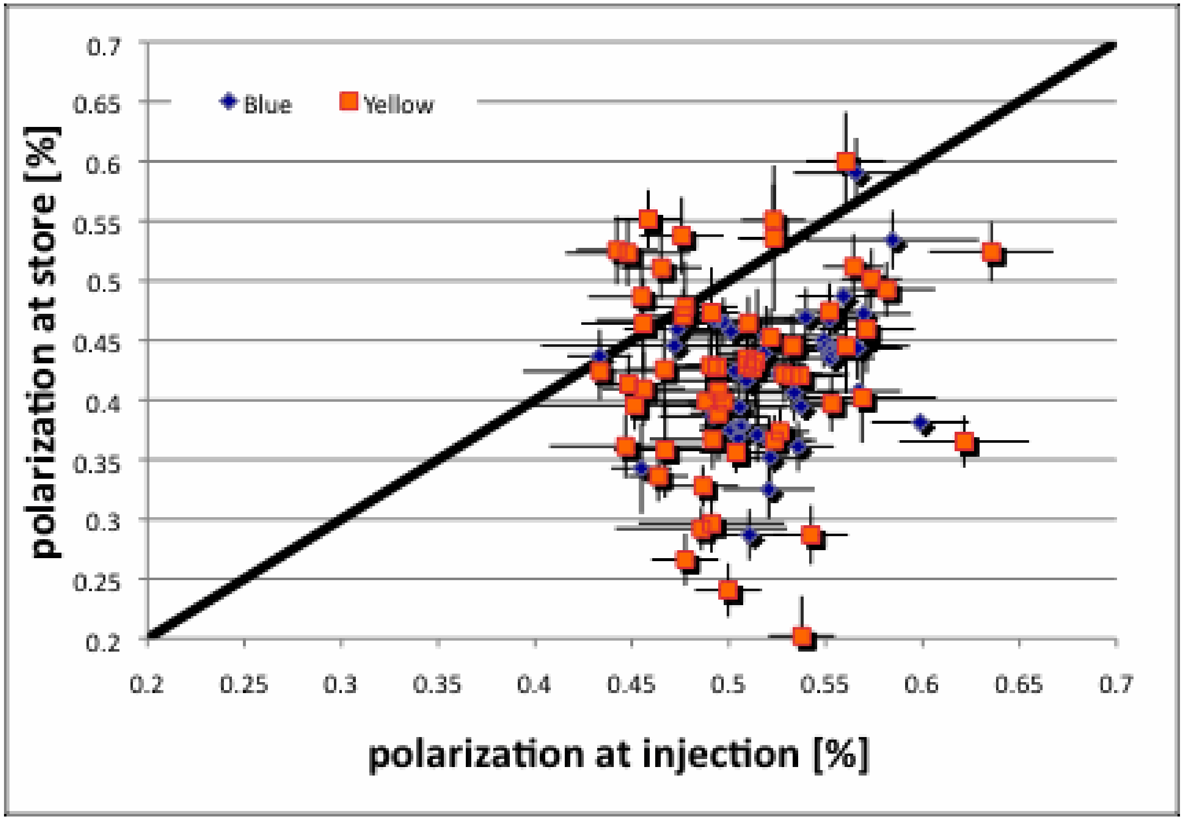
Intrinsic spin resonances up to 250 GeV



Beyond 100 GeV, resonances are two times stronger then below 100 GeV

Image courtesy of Mei Bai

Store polarization vs. injected polarization



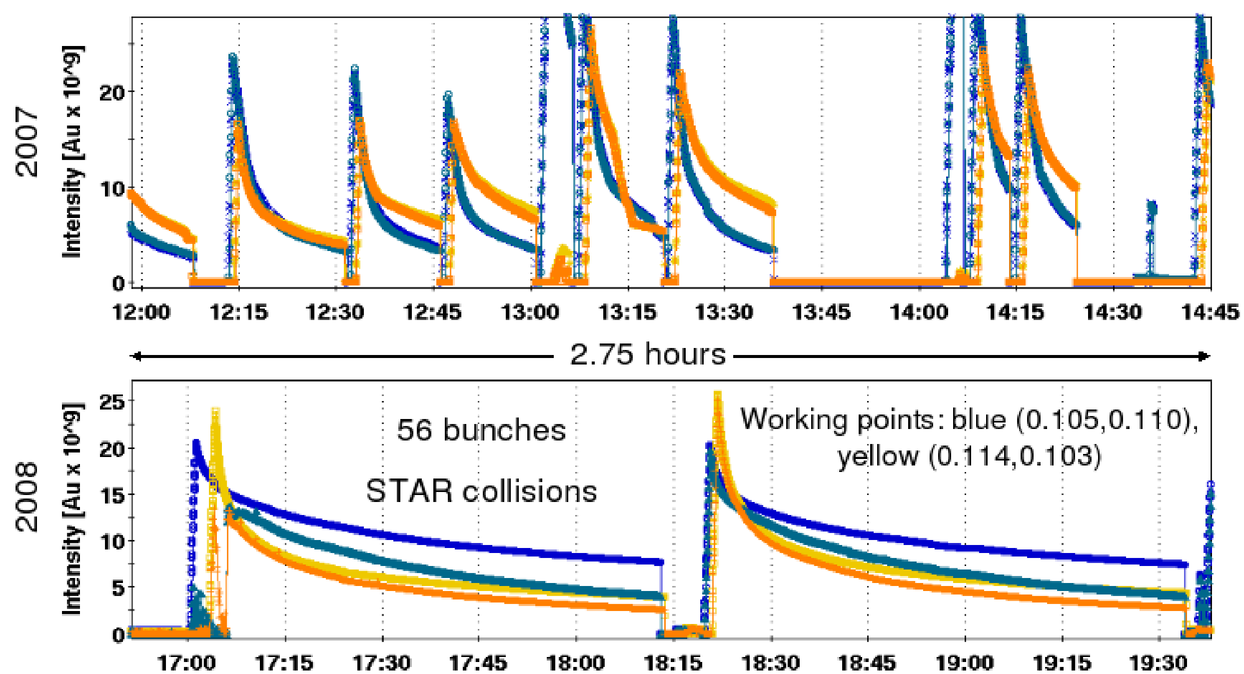
Average polarization at store (without rotators) is 42 %, after 50 % at injection

Image courtesy of Mei Bai

New Developments II: Low-energy Au-Au

- Search for critical point of nuclear phase transition
- Energy scan between 2.5 GeV/n and 25 GeV/n
- Two different beam energies tested so far, 4.6 GeV/n and 2.5 GeV/n.
- Different harmonic numbers due to limited tunability of RHIC RF: $h = 366$ at 4.6 GeV/n, $h = 387$ at 2.5 GeV/n.
- Defocusing sextupoles at opposite polarity to compensate dipole b_2.
- Low-energy physics run planned for 2010.

Beam lifetimes at 4.6 GeV/n

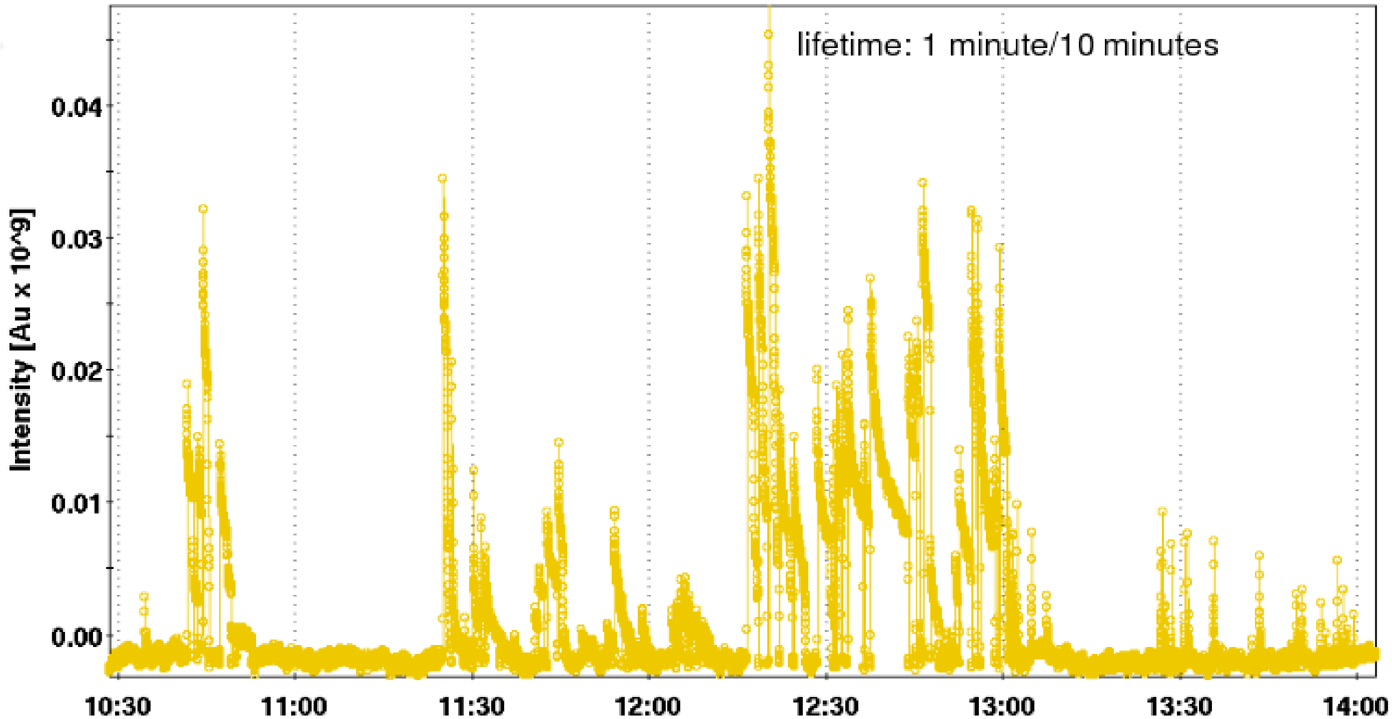


2008 blue beam lifetime: 3.5 min (fast), 50 min (slow)

High luminosity with electron cooling of low energy Au beams in RHIC in the future

Image courtesy of Todd Satogata

Beam activity at 2.5 GeV/n

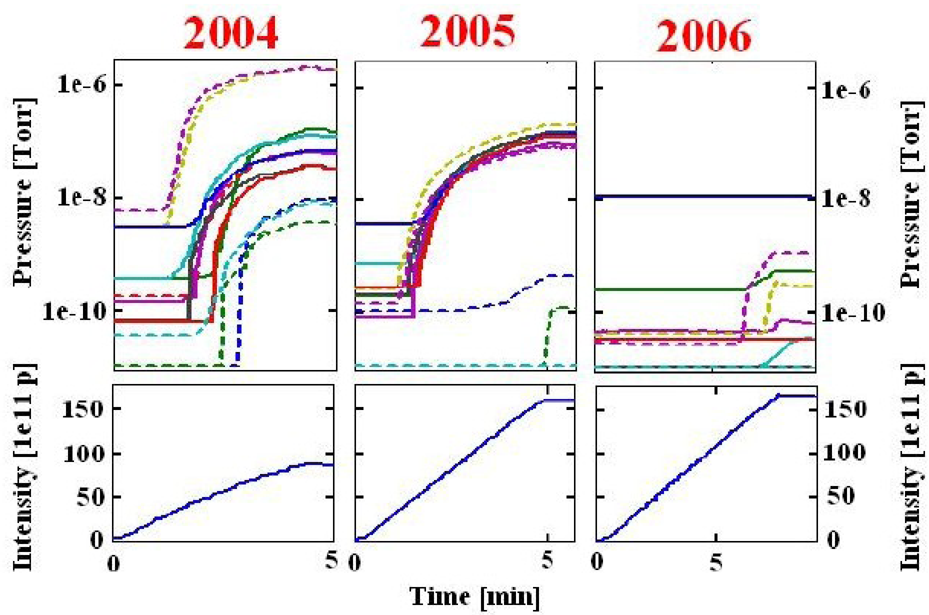


Beam liftime: 1 min (fast), 10 min (slow)

Blue ring unavailable due to power supply failure

Image courtesy of Todd Satogata

Intensity Limitation I: Dynamic Pressure Rise



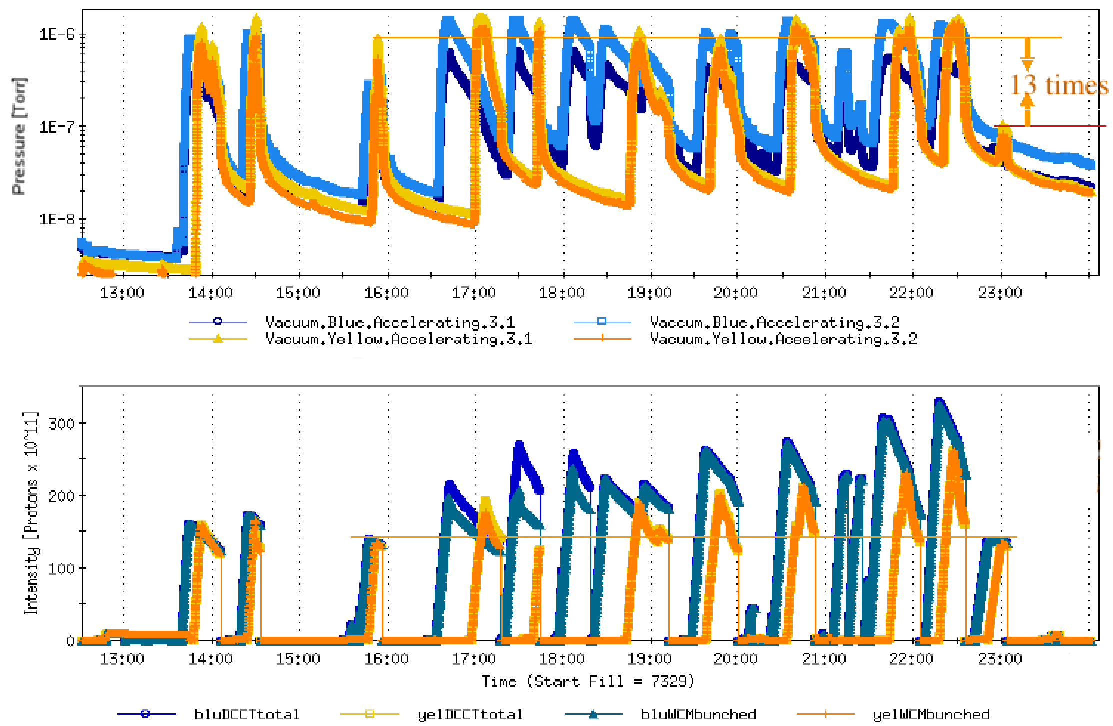
Dynamic pressure rise during beam injection, caused by electron clouds

Vacuum system upgrades:

- Installed 500 m of NEG coated pipes in warm sections
- Reduced pressure in cold sections to 10^{-7} Torr before cool-down

Image courtesy of Thomas Roser

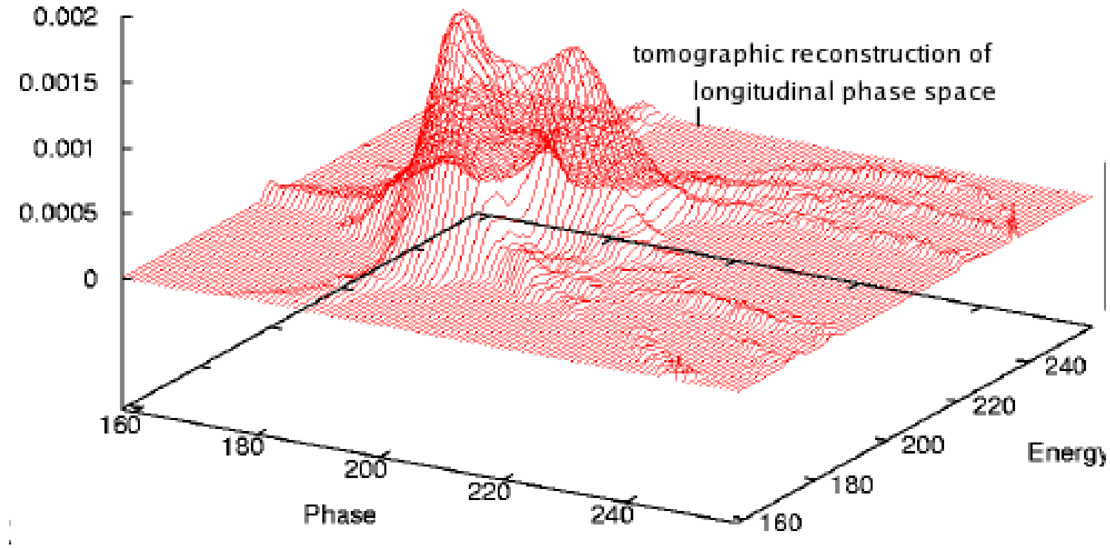
Beam scrubbing



- After six hours of scrubbing with high intensity beams at injection, pressure rise at cavities is factor 13 lower than before
- Improved beam lifetime at injection

Image courtesy of Haixin Huang

Intensity Limitation II: Fast Instability Near Transition



- Fast transverse instability, growth time $\approx 15\,$msec
- High sensitivity around transition due to required zero-crossing of chromaticities
- Effect of broadband impedance and electron clouds
- Cures: octupoles, adjust crossing time of zero chromaticity, suppress electron clouds, chromaticity jump

Luminosity Lifetime Improvement I: IBS lattice

Limited luminosity lifetime requires frequent refills

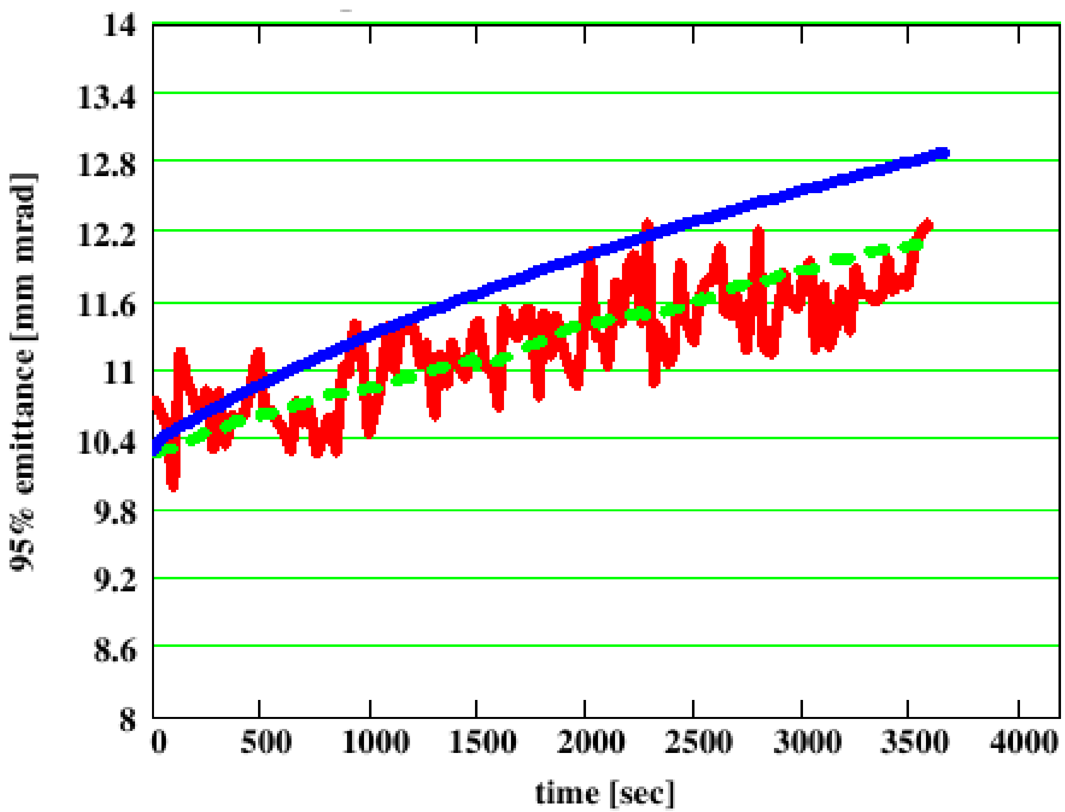
Increased focusing decreases IBS rate:

$$\begin{aligned}
\tau_{||}^{-1} &\approx \frac{r_i c N_i \Lambda}{8\beta^3\gamma^3\epsilon_x^{3/2}\langle\beta_\perp^{1/2}\rangle\sigma_x\sigma_p^2} \\
\tau_x^{-1} &= \frac{\sigma_p^2}{\epsilon_x}\left\langle\frac{D_x^2 + (D_x'\beta_x + \alpha_x D_x)^2}{\beta_x}\right\rangle\tau_{||}^{-1} \\
\mathcal{H} &= \gamma_x D_x^2 + 2\alpha_x D_x D_x' + \beta_x {D_x'}^2
\end{aligned}$$

Reducing $\mathcal{H}$ by higher phase advance in FODO cells reduces transverse IBS rate

Ultimately will need full energy cooling

Experimental results for $\phi = 92^\circ$ phase advance



Blue: Simulation with $\phi = 82^\circ$

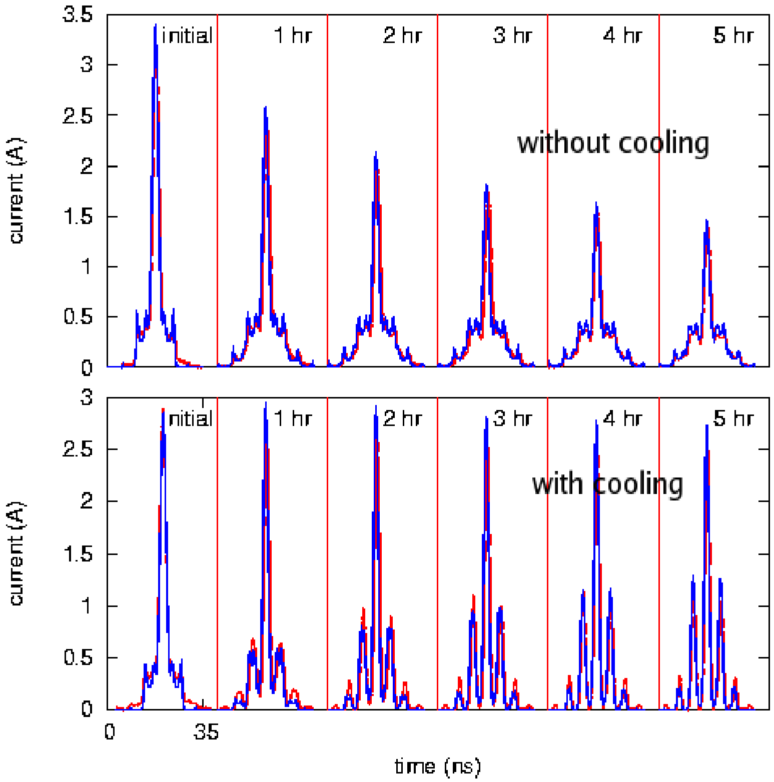
Green: Simulation with $\phi = 92^\circ$

Red: Measured emittance, at $\phi = 92^\circ$

Image courtesy of Alexei Fedotov

Luminosity Lifetime Improvement II: Stochastic Cooling

Longitudinal bunch profile evolution

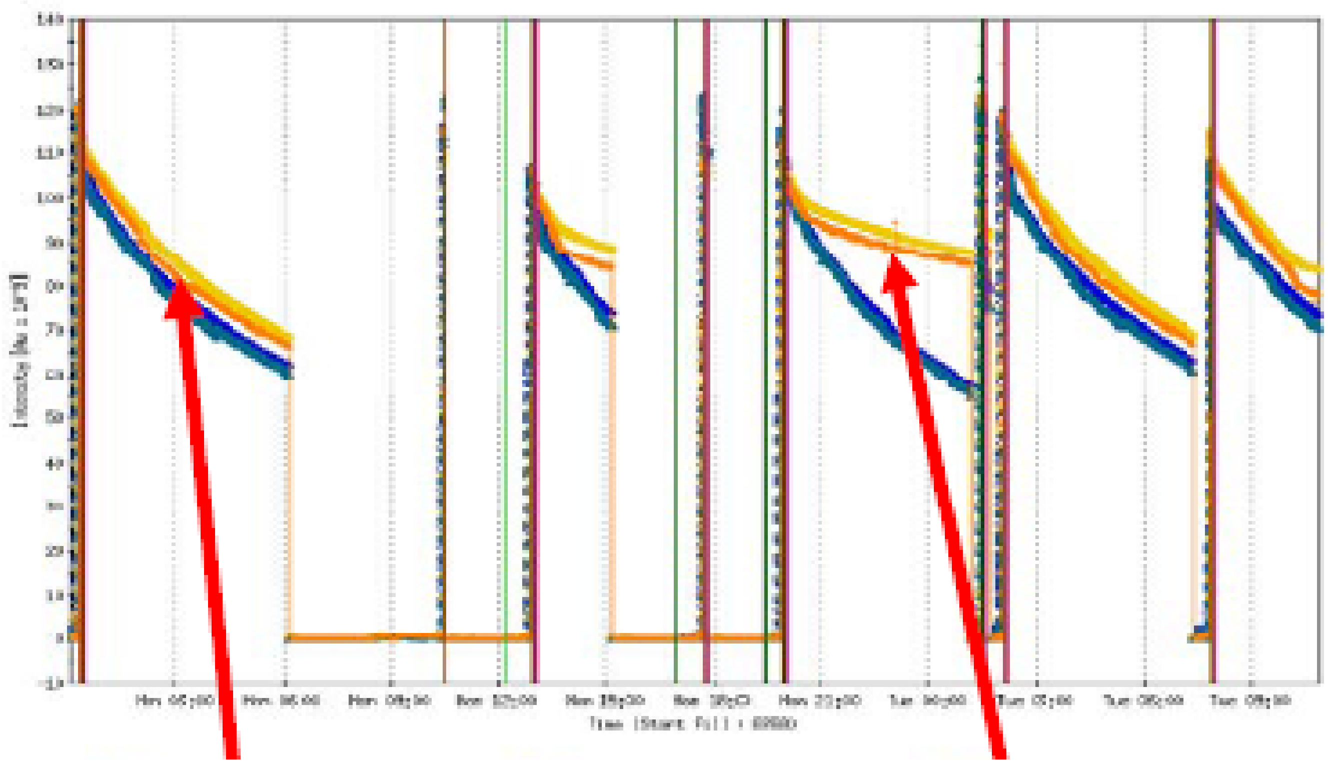


Red: Simulation

Blue: Measurement

Image courtesy of Mike Blaskiewicz

Effect of longitudinal stochastic cooling on Yellow beam lifetime

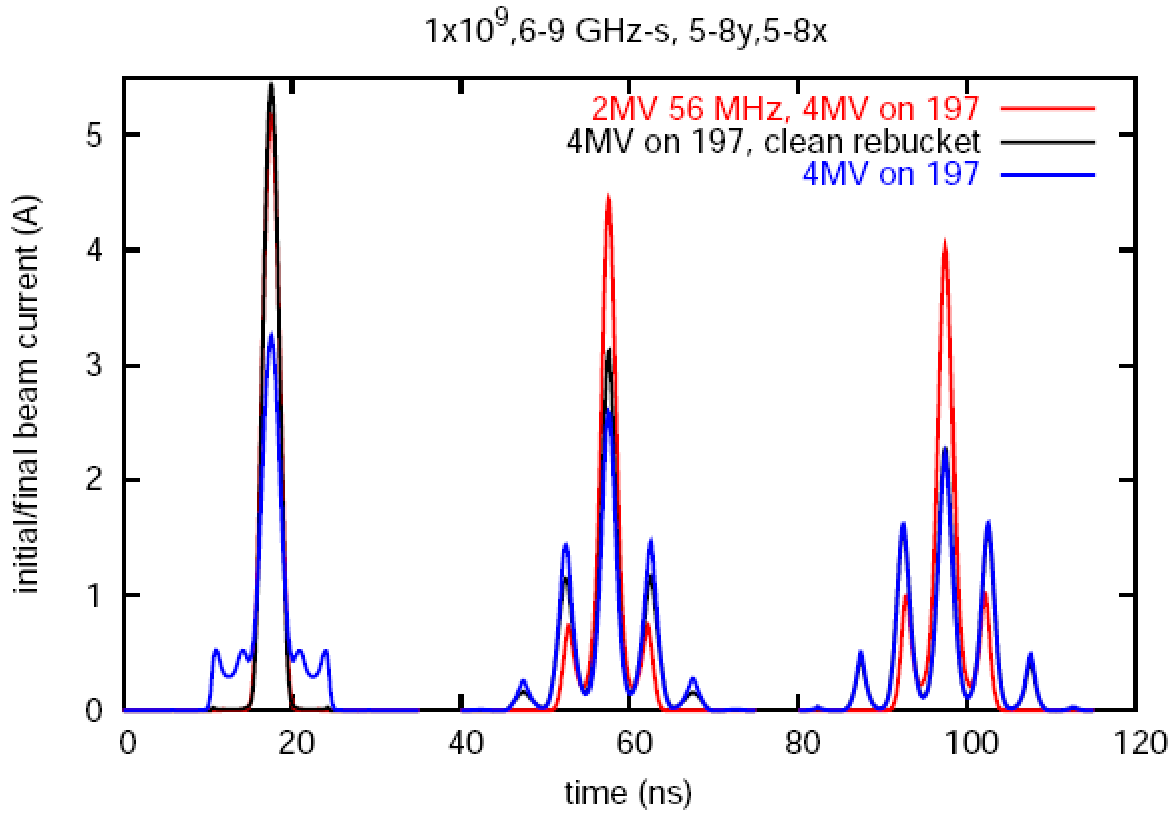


without cooling with cooling

IBS leads to debunching; debunched particles continuously removed from abort kicker gap

Image courtesy of Mike Brennan

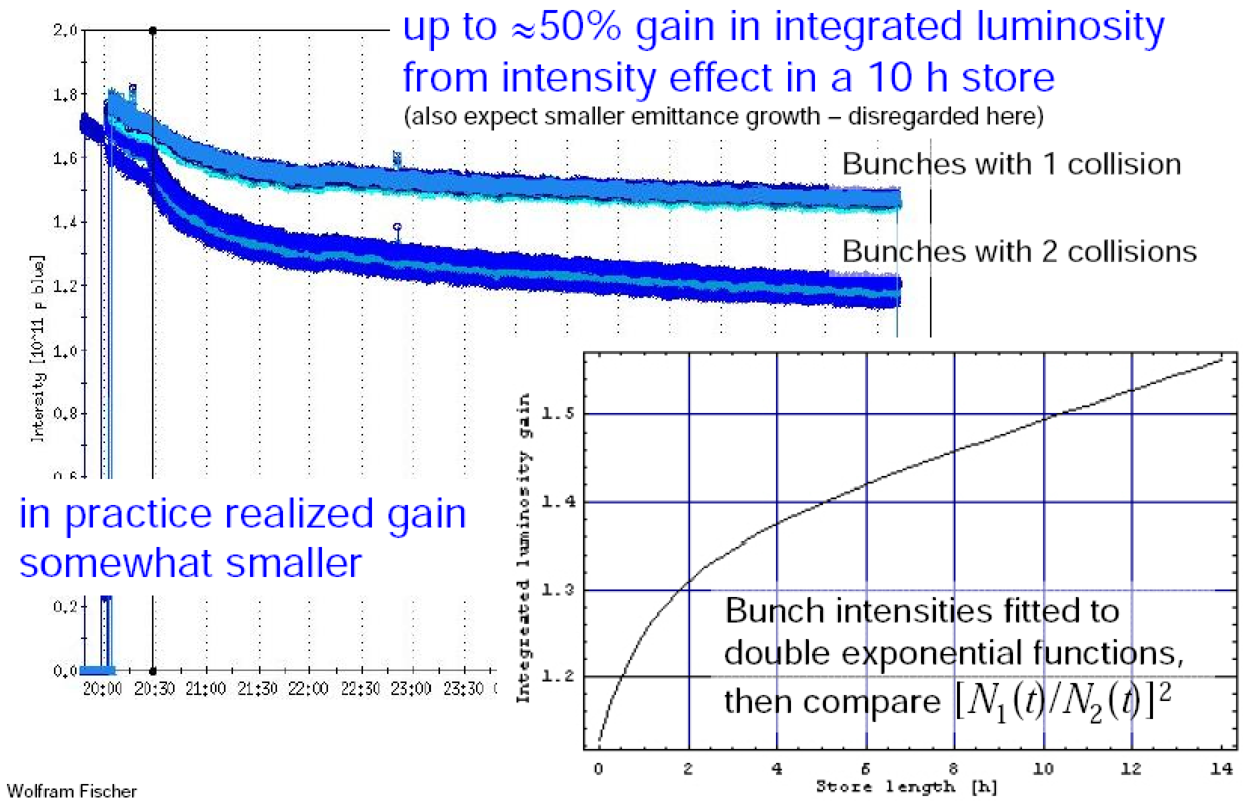
Luminosity Lifetime Improvement III: 56 MHz SRF



- Shorter bunches in conjunction with stochastic cooling
- Scheduled for 2012

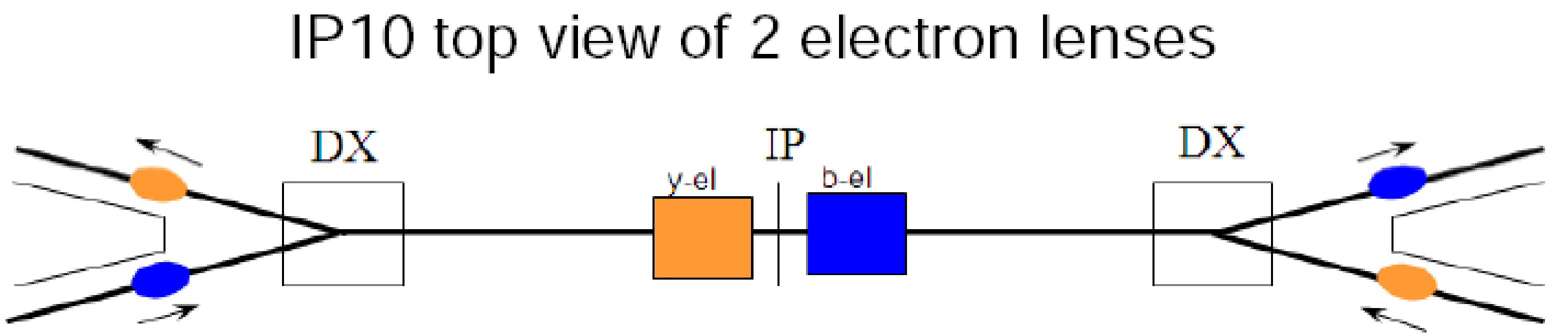
Image courtesy of Mike Blaskiewicz

Proton Luminosity Limitation I: Beam-Beam



Proton beam lifetime is limited by beam-beam effect; bunches with one collision have longer lifetime than bunches with two.

Image courtesy of Wolfram Fischer

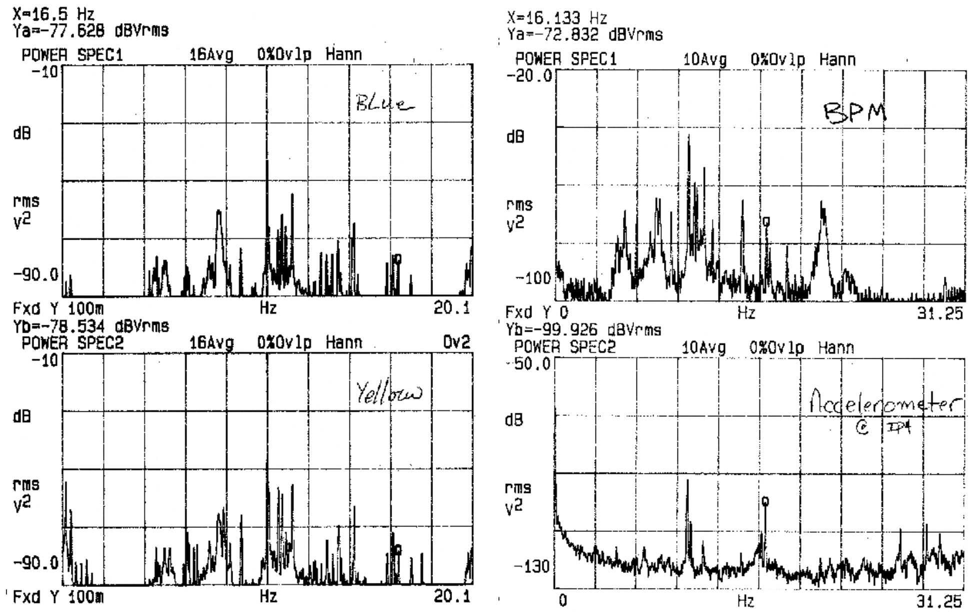


Idea:

- Compensating one collision point by an electron lens in each beam increases lifetime
- Tune footprint shrinks due to beam-beam compensation
- Allows for higher intensities/larger beam-beam tuneshift; therefore higher luminosity
- Scheduled for 2011

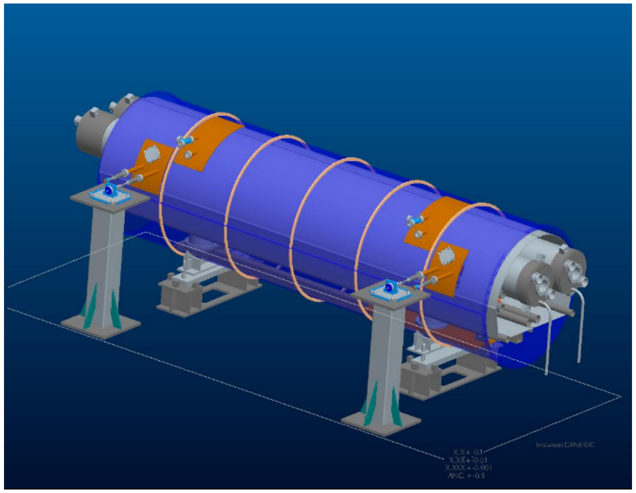
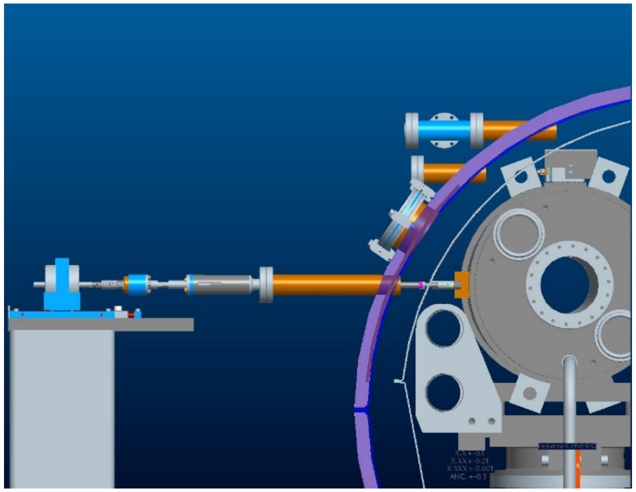
Image courtesy of Wolfram Fischer

Proton Luminosity Limitation II: 10 Hz Orbit Oscillations



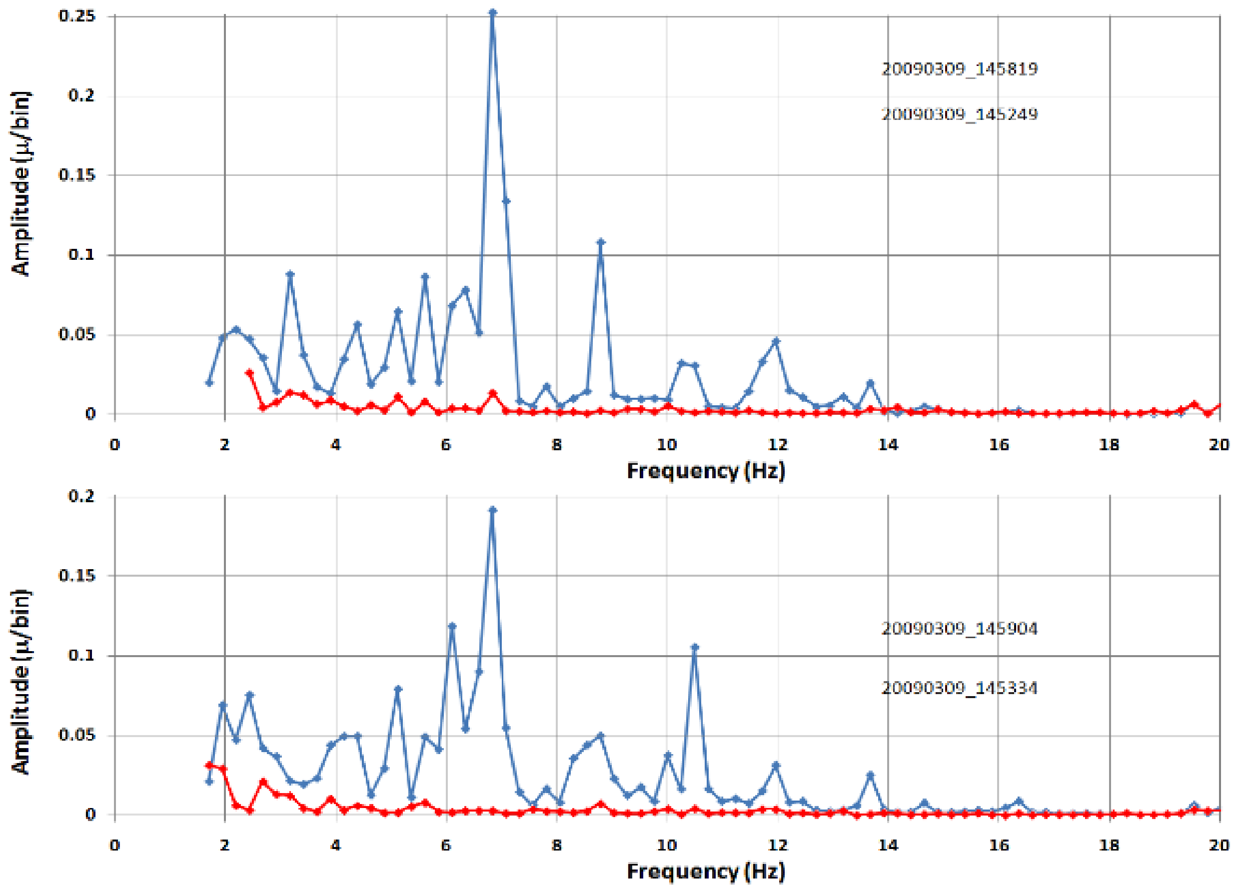
- Both beams oscillate at $\approx 10\,\text{Hz}$, caused by helium flow driven mechanical triplet vibrations
- Modulated beam-beam offsets may lead to emittance growth
- Enhanced beam jitter prevents running at near-integer tunes, where a larger beam-beam parameter could be reached

Active mechanical damping system to stabilize triplet vibrations

- Based on geophones or accelerometers as vibration sensors, and electro-mechanical actuators outside the cryostat
- One test setup at a single cold mass in one triplet
- Alternative design: fast orbit feedback based on mechanical vibration measurements
- To be installed on all cold masses in both low-β IRs over next few years, beginning in summer shutdown 2009

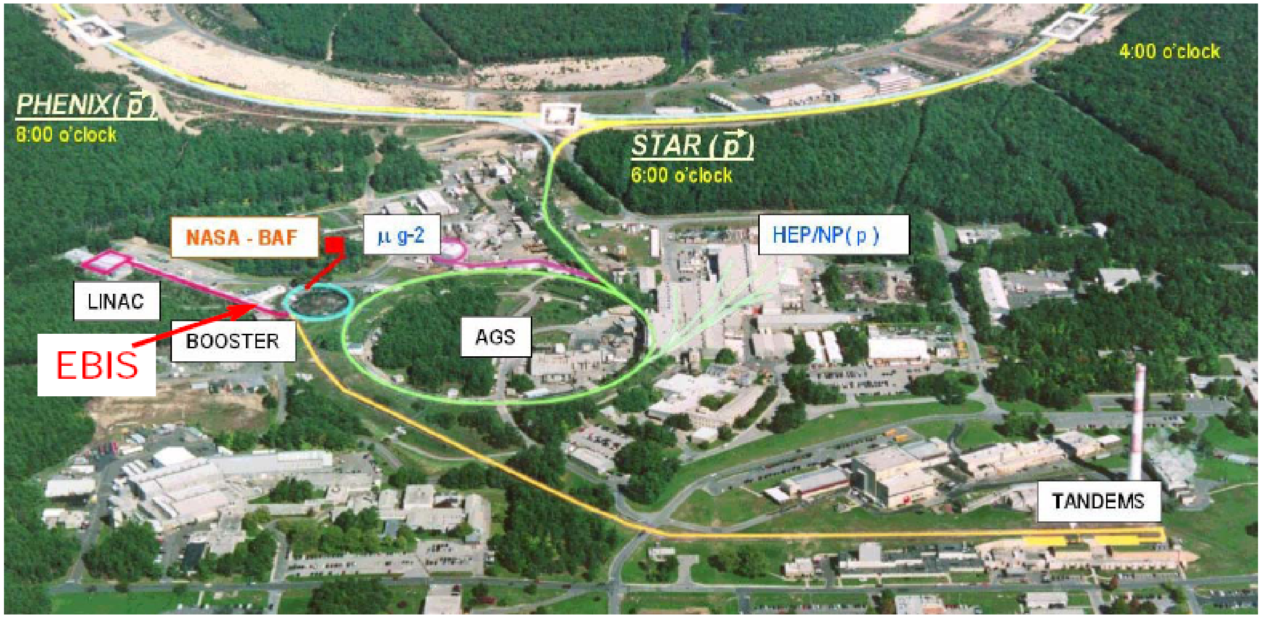
Images courtesy of Peter Thieberger



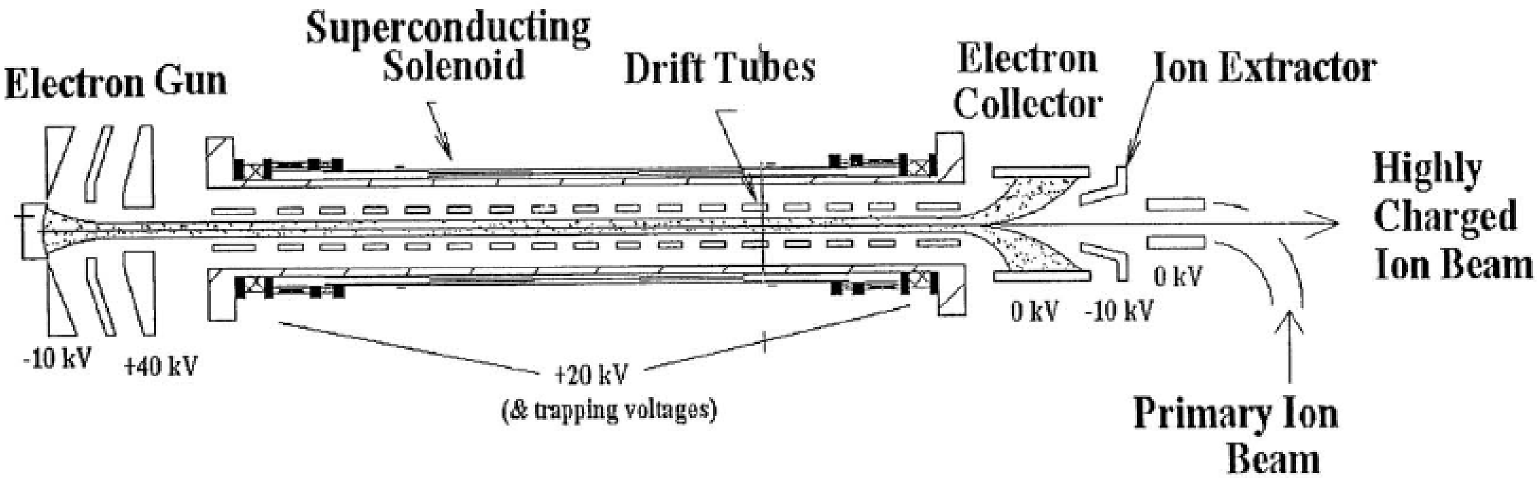
Vibration spectra of one triplet cold mass, with and without active damping

Image courtesy of Peter Thieberger

Future Upgrades I: EBIS



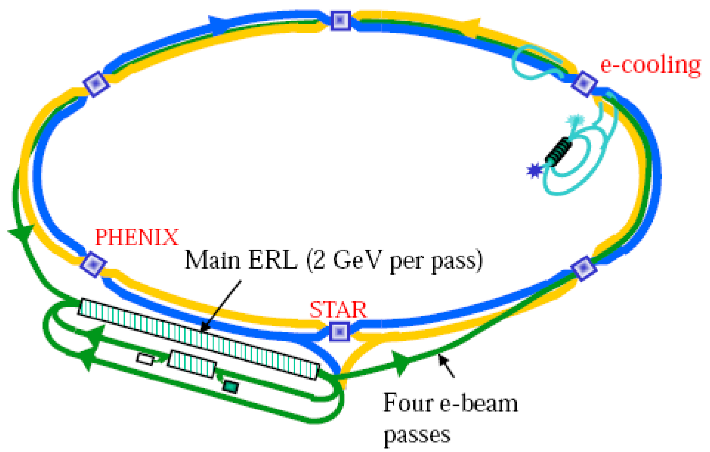
- Currently, all ions other than protons are injected into Booster by two Tandem Van-de-Graaffs some 800 m away
- Tandem maintenance is costly due to many mechanical parts
- Electron-beam ion source (EBIS) at the existing 200 MeV linac will replace the Tandems

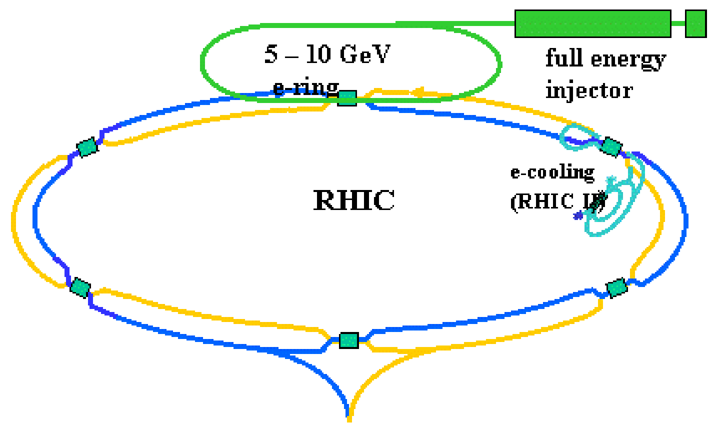


- Any ion species can be generated at any desired charge state
- Pulse-to-pulse switching of species possible – important for parallel running with Nasa Space Radiation Lab (NSRL) at Booster
- Under construction, CD-4 scheduled for September 2010

Image courtesy of Jim Alessi

Future Upgrades II: eRHIC





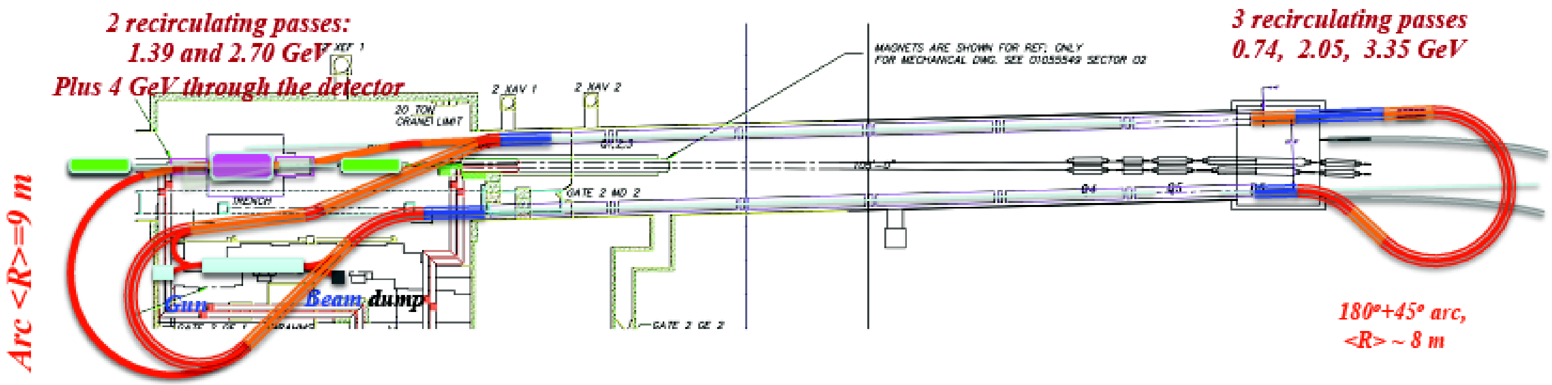
- RHIC-based electron-ion collider with 10 – 20 GeV polarized electrons on 250 GeV protons, or 100 GeV/n ions

- $\mathcal{L} = 10^{33} - 10^{34}\,\text{cm}^{-2}\text{sec}^{-1}$

- Main design: ERL-based linac-ring scheme

- Fallback: ring-ring scheme

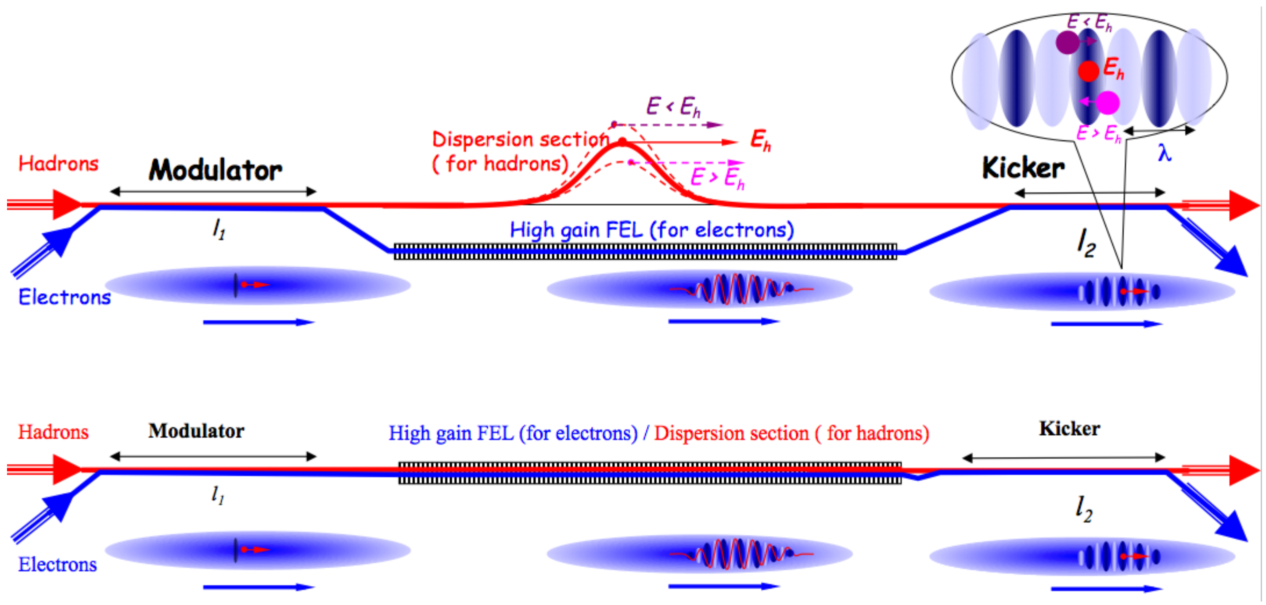
Staged approach towards eRHIC



- 4 GeV ERL to be installed in IR2, colliding with 250 GeV polarized protons in RHIC
- Installation almost entirely in existing RHIC tunnel and detector building, to reduce cost of civil engineering
- Almost all hardware could be re-used in full-scale eRHIC

Image courtesy of Vladimir Litvinenko

Future Upgrades III: Coherent Electron Cooling

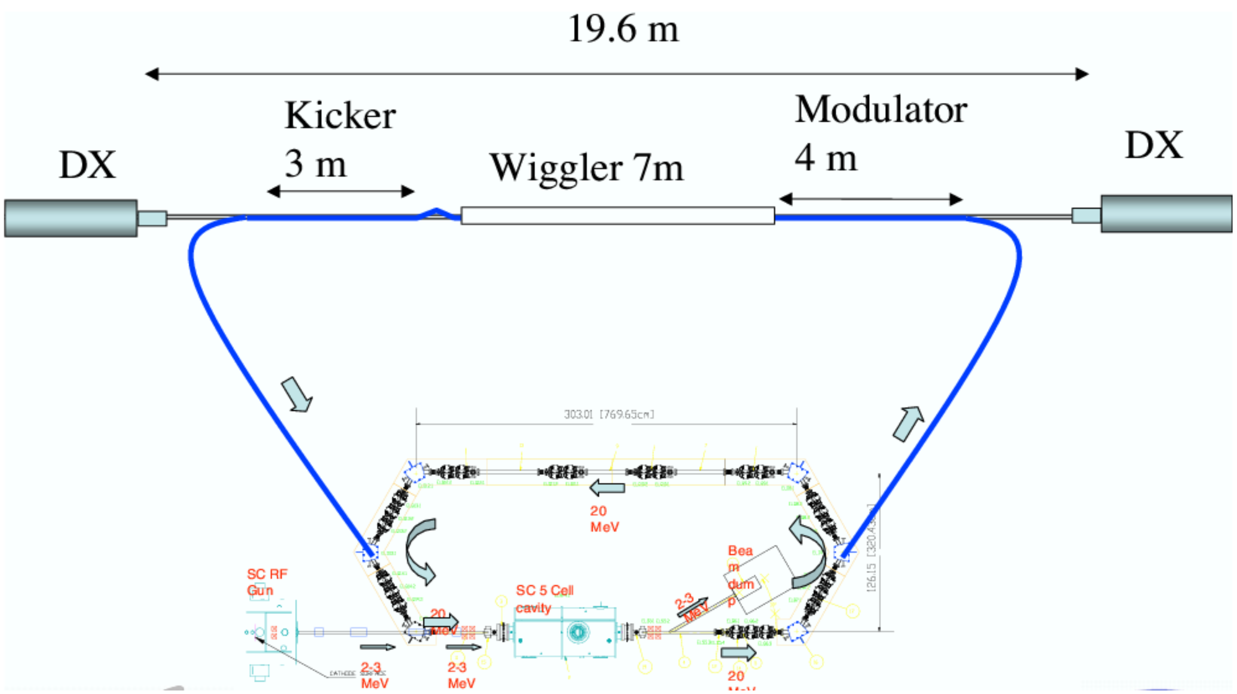


- Suggested almost 30 years ago by Y. Derbenev

- High gain FEL amplification at optical wavelengths makes it feasible

Image courtesy of Vladimir Litvinenko

Proof-of-principle experiment at RHIC



- Installation in one RHIC IR
- Utilizes BNL Test-ERL
- Demonstrate coherent electron cooling of 40 GeV proton beam in 2012

Image courtesy of Vladimir Litvinenko

Summary

- RHIC performance has continuously improved over past 9 years
- Future performance improvements require upgrades that are currently under way
- Converting RHIC into an electron-ion collider seems a natural next big step
- RHIC has a bright, exciting future