RHIC electron lenses

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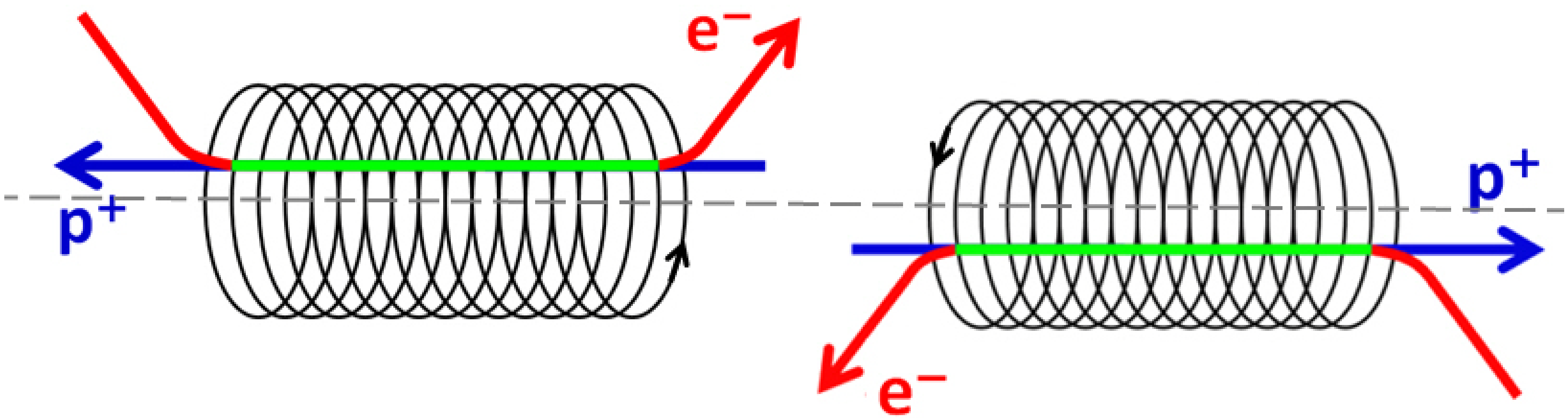
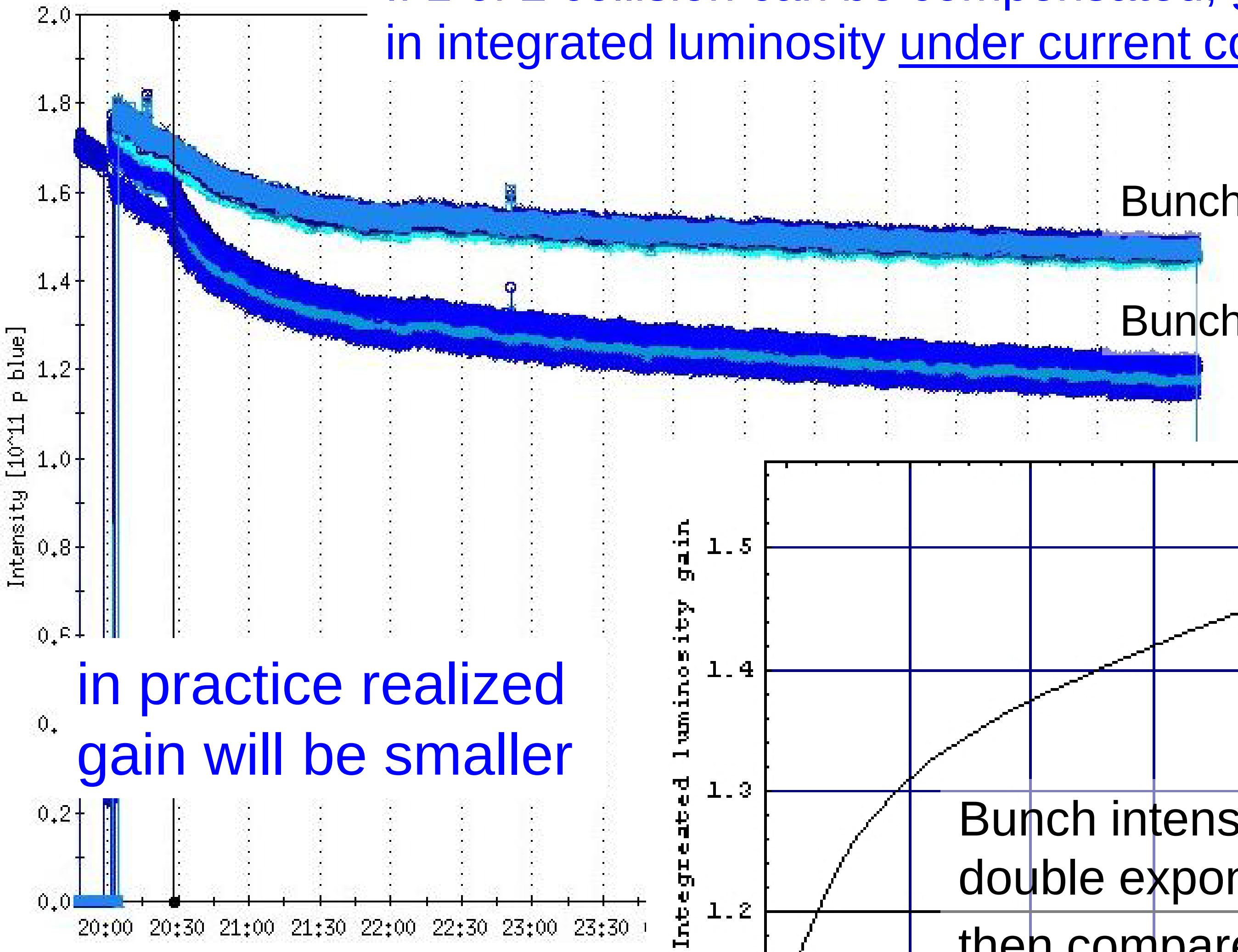


BROOKHAVEN NATIONAL LABORATORY

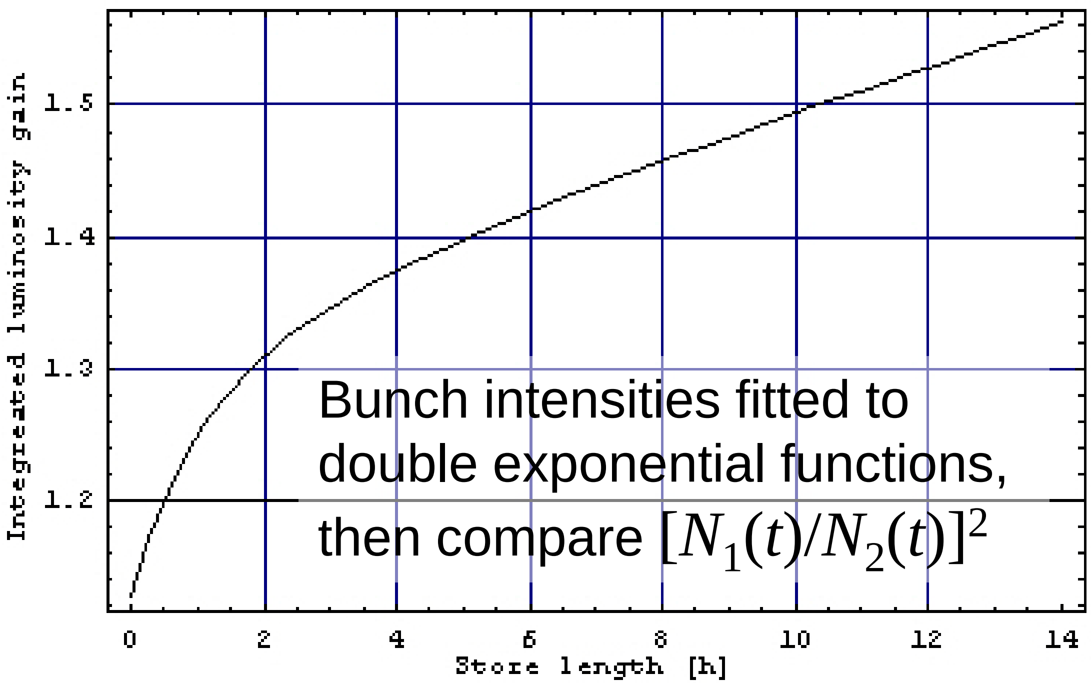
17 July 2009
RHIC Retreat, Mystic

Head-on beam-beam effect and luminosity in RHIC

If 1 of 2 collision can be compensated, gain up to □50% in integrated luminosity <u>under current conditions</u>



in practice realized gain will be smaller



Bunch intensities fitted to double exponential functions, then compare $[N_1(t)/N_2(t)]^2$

Head-on beam-beam effect and luminosity in RHIC

More luminosity can be gained with an increase in the bunch intensity:

$$L = \frac{f_c N_b^2}{4\pi \varepsilon \beta^*}$$

If 1 of 2 collisions can be compensated, then N_b can be doubled while total beam-beam $\xi \sim N_b/\varepsilon$ is maintained

This would yield theoretically a factor 4, expect in practice about a factor 2.

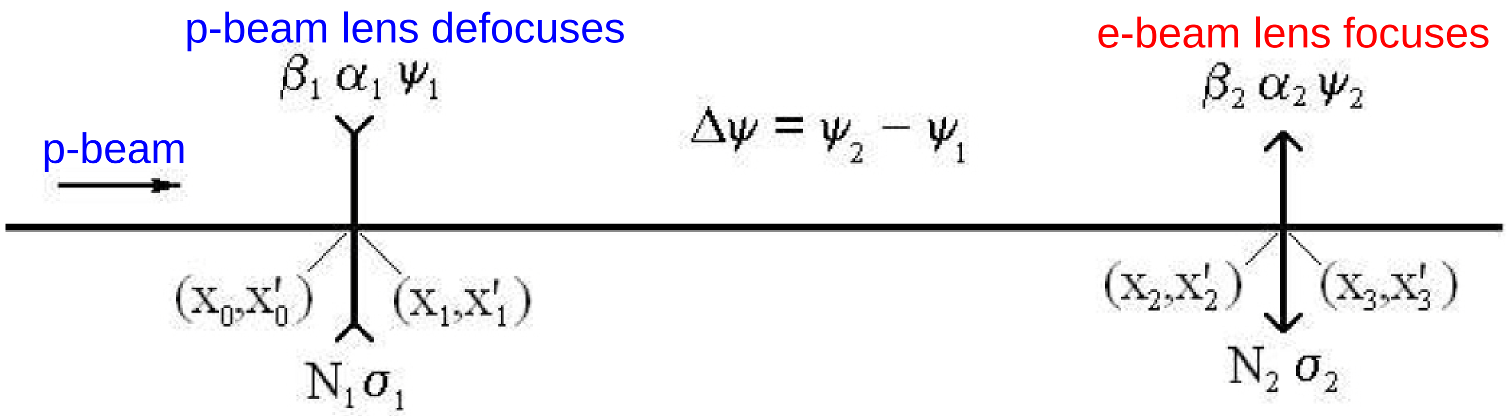
Increase of bunch intensity requires:

1. Upgrade of the polarized proton source
   approximately 3-year effort, started (A. Zelenski)
2. Upgrades in RHIC
   improvements to deal with larger stored energy, collimation, and dump, started process to enlarge Accelerator Safety Envelope for 2x intensity

Luminosity and polarization goals

Parameter	unit	**Achieved**	**Enhanced design**	**Next $\mathcal{L}$ upgrade**
Au-Au operation		**(2007)**		**(□ 2012)**
Energy	GeV/nucleon	100	100	100
No of bunches	…	103	111	111
Bunch intensity	10^9	1.1	1.0	1.0
Average $\mathcal{L}$	**10^{26}cm^{-2}s^{-1}**	**12**	**8**	**40**
p↑- p↑ operation		**(2009)**	**(□ 2011/12)**	**(□ 2014)**
Energy	GeV	100 / 250	100 / 250	250
No of bunches	…	109	109	109
Bunch intensity	10^{11}	1.3 / 1.1	1.3 / 1.5	2.0
Average $\mathcal{L}$	**10^{30}cm^{-2}s^{-1}**	**24 / 55**	**30 / 150** →	**300**
Polarization $\mathcal{P}$	**%**	**55 / 34**	**70**	**70**

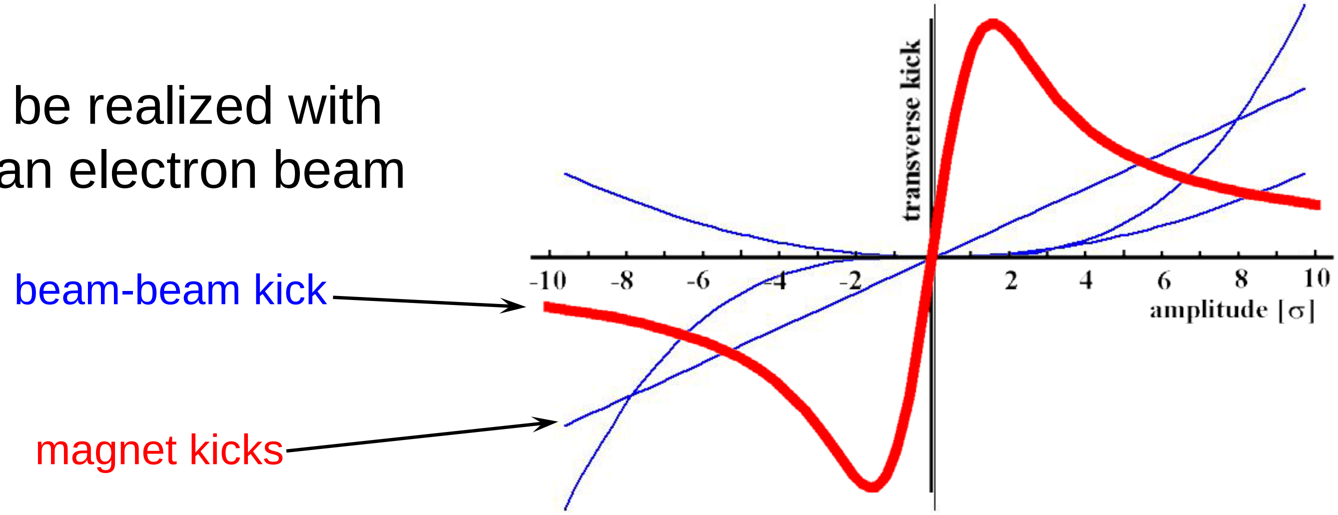
Beam-beam compensation concept with electron lens



Exact compensation if $x_3(N_1,N_2) = x_3(0,0)$ and $x'_3(N_1,N_2) = x'_3(0,0)$:

1. Same amplitude dependent force in p-beam and e-beam lens, and
2. Phase advance between p-beam and e-beam lens is $\Delta\Psi = k\pi$, and
3. No nonlinearities between p-beam and e-beam lens

Condition 1 cannot be realized with magnets, requires an electron beam

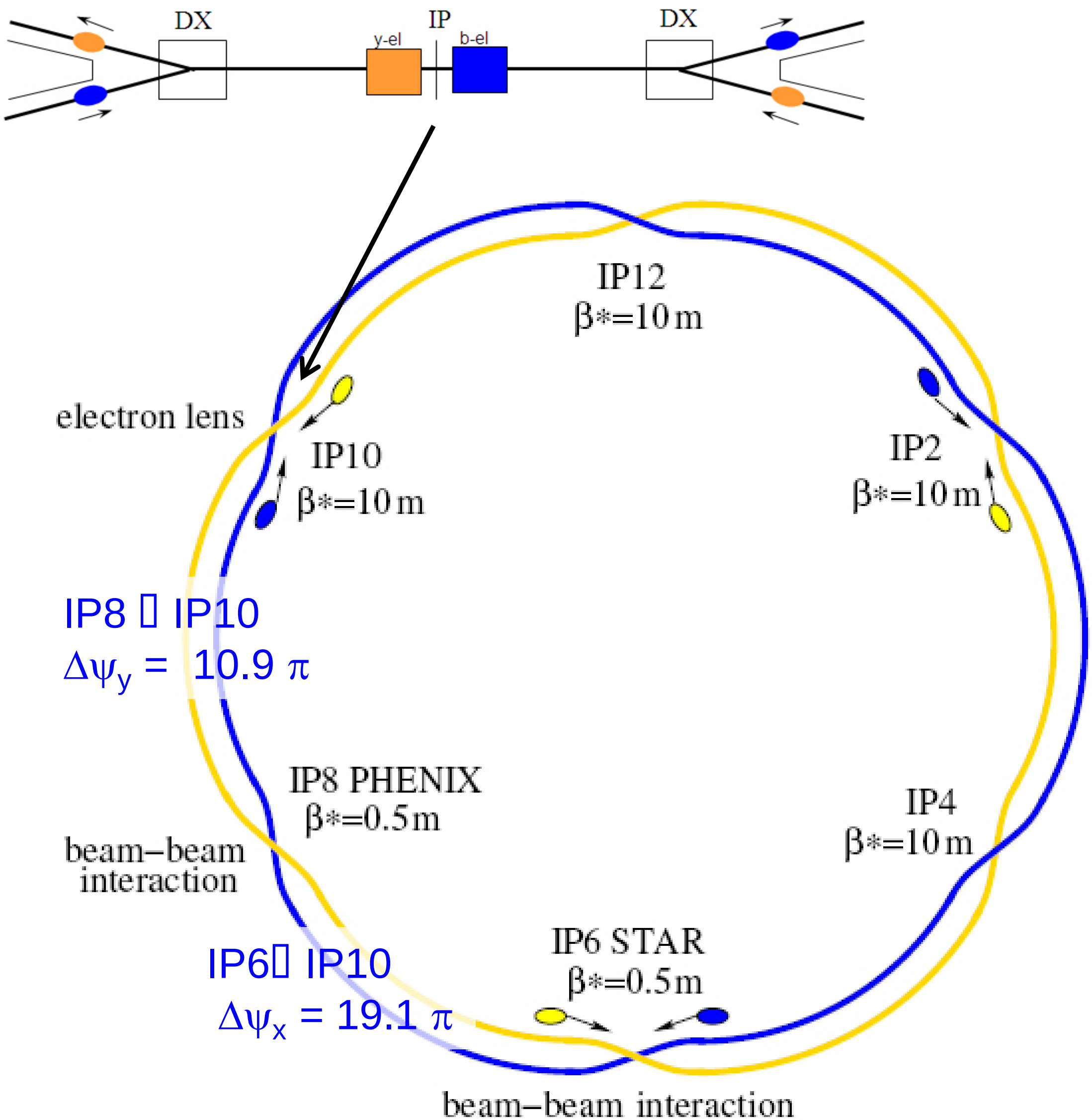


History of head-on beam-beam compensation (HOBBC)

- Compensation schemes (S. Peggs, Handbook):
  1. Direct space charge compensation (4 beams)
  2. Indirect space charge compensation (electron lenses) ⟵ **considered for RHIC**
  3. Betatron phase cancellation between neighboring IPs

- Proposals/studies of head-on beam-beam compensation to date:
  - COPPELIA → 4-beam (J.E. Augustine, HEACC, 1969)
  - DCI → 4-beam (G. Arzelia et al., HEACC, 1971) → **only real attempt so far failed because of coherent instabilities**
  - CESR → e-lens (R. Talman, unpublished, 1976)
  - SSC → e-lens (E. Tsyganov et al., SSCL-PREPRINT-519 ,1993)
  - LHC → e-lens (E. Tsyganov et al., CERN SL-Note-95-116-AP, 1995)
  - Tevatron → e-lens (Shiltsev et al., PRST-AB, 1999)
  - e^+e^- collider → 4-beam (Y. Ohnishi and K. Ohmi, Beam-Beam'03, 2003)

Electron lenses in RHIC

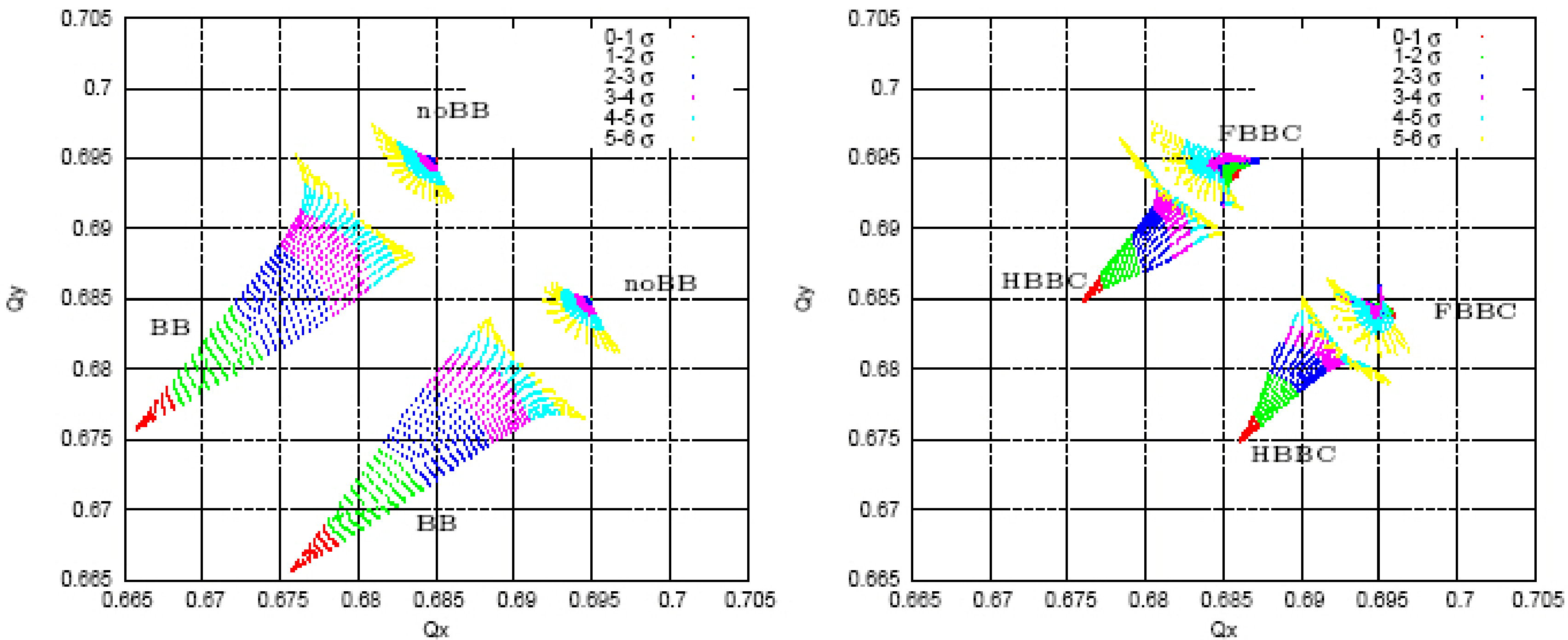


- Both lenses near IP10, between DX magnets ($\beta_x = \beta_y$)
- Blue and Yellow beams ver. separated like in other IPs
- Solenoids of different polarity (minimizes effect on linear coupling and spin)
- default $\Delta\phi_x$ □ $k\pi$, IP6 □ IP10
  default $\Delta\phi_y$ □ $k\pi$, IP8 □ IP10
  (C. Montag working on lattice optimization)

[Y. Luo and W. Fischer, "Outline of using an electron lens for the RHIC …", BNL C-AD/AP/284 (2007)]

Electron lens simulations – Y. Luo et al.

E-lens compresses tune footprints

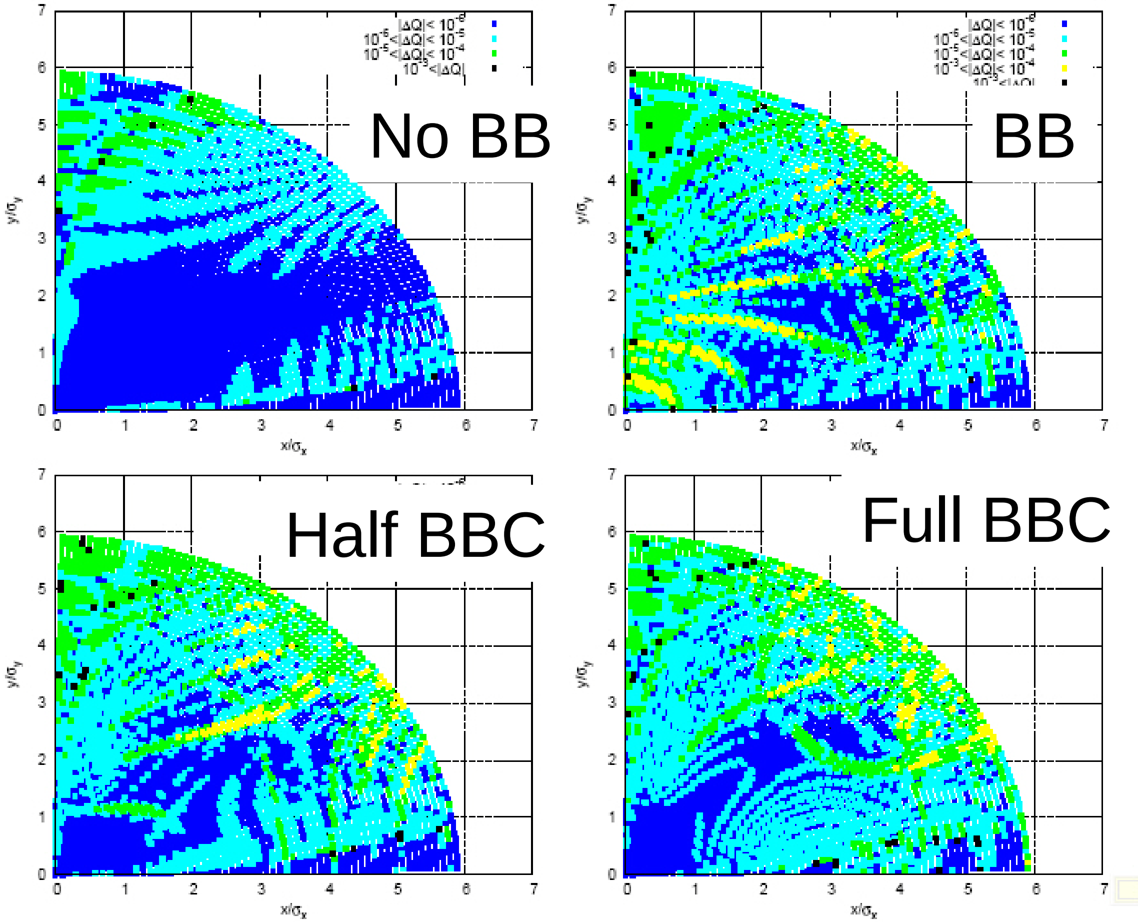


Tune footprint compression is not sufficient for better beam lifetime.
Full compensation folds footprint – known to be problematic.
 Use only partial compensation.

[Y. Luo, W. Fischer, and N. Abreu, "Stability of single particle motion with head-on beam-beam compensation in the RHIC", BNL C-AD/AP/310 (2008).]

Electron lens simulations – Y. Luo et al.

E-lens reduces tune diffusion in core (<3σ), increases in tail (>4σ)



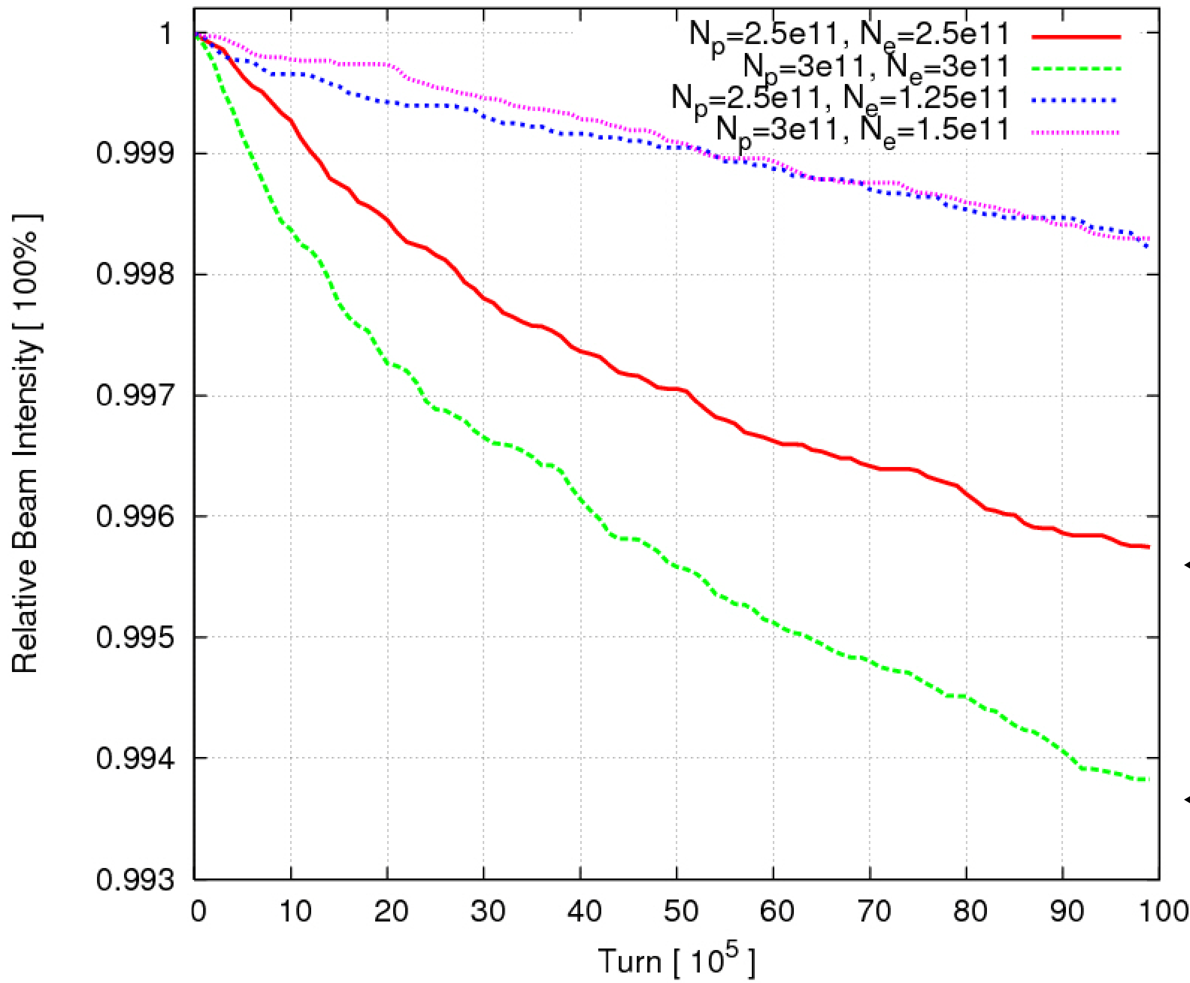
Tune change over
2 successive periods
of 1024 turns

$$|\Delta Q| = \sqrt{|\Delta Q_x|^2 + |\Delta Q_y|^2}$$

[Y. Luo, W. Fischer, and N. Abreu, "Stability of single particle motion with head-on beam-beam compensation in the RHIC", BNL C-AD/AP/310 (2008).]

Beam lifetime simulations for electron lenses – RHIC

Scan of electron lens strength Y. Luo et al. PAC09, MO4RAC05



Half HOBBC
N_b = 2.5, 3$\square$10[11]
τ = 19.7 h

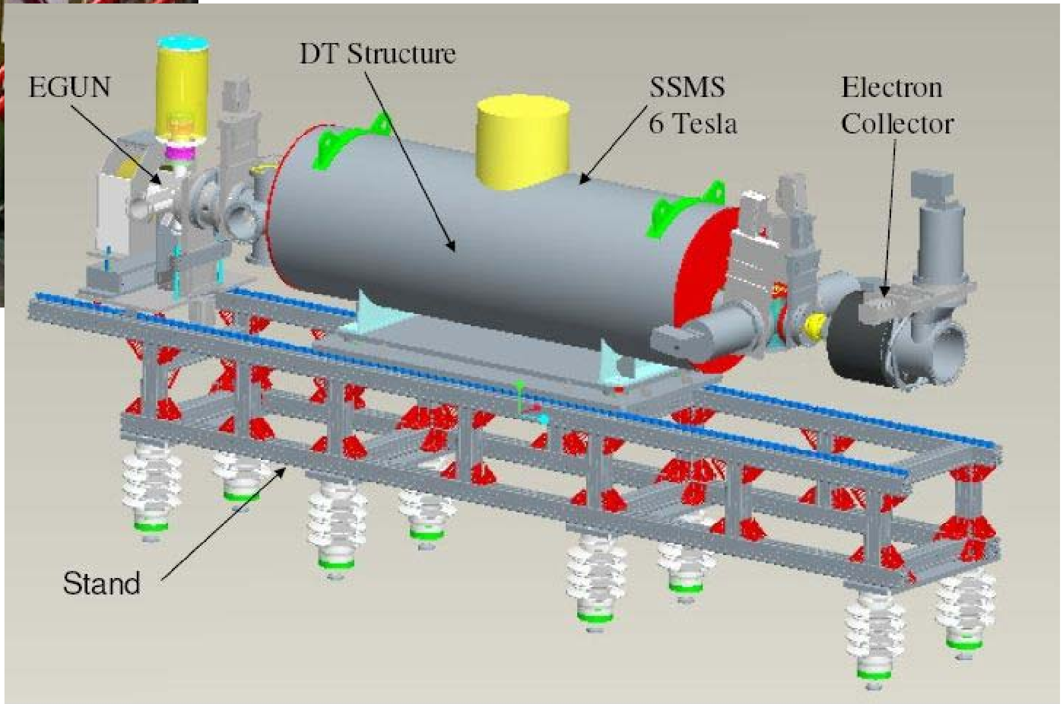
Full HOBBC
N_b = 2.5$\square$10[11]
τ = 8.5 h

Full HOBBC
N_b = 3$\square$10[11]
τ = 5.7 h

Best results with half compensation (avoids footprint folding).

Electron lenses in RHIC

 Tevatron e-lens



BNL EBIS

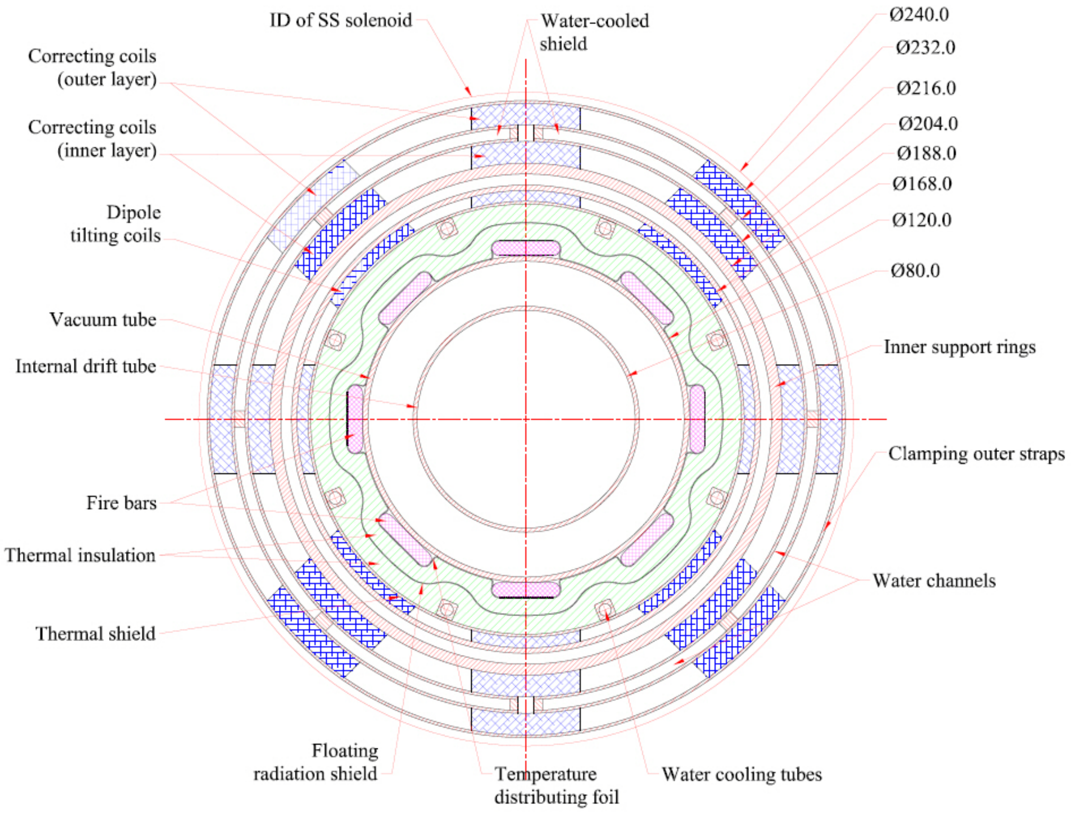
Head-on beam-beam compensation with electron lenses

- Design considerations driven by p-beam
  - RHIC beam size: σ = 0.25 mm rms (β_{xy} □ 10-20 m)
- Solenoid strength
  - Magnetic compression of electron beam to p-beam □ 6 T
  - Solenoid field lines straight within ~0.2 σ (□50 μm)
- Electron gun parameters
  - Small RHIC beam sizes with possible magnetic compression from 0.2 T on gun to 6 T in electron lens requires current densities of 14 A/cm^2, need IrCe cathodes for good lifetime (A. Pikin)
- Alignment of proton and electron beam
  (found to be of critical importance in Tevatron)
  - Straightness of solenoid field (□50 μm)
  - Instrumentation (BPMs, “luminosity” monitors – probably bremsstrahlung)

Electron lens main solenoids

Main solenoids:

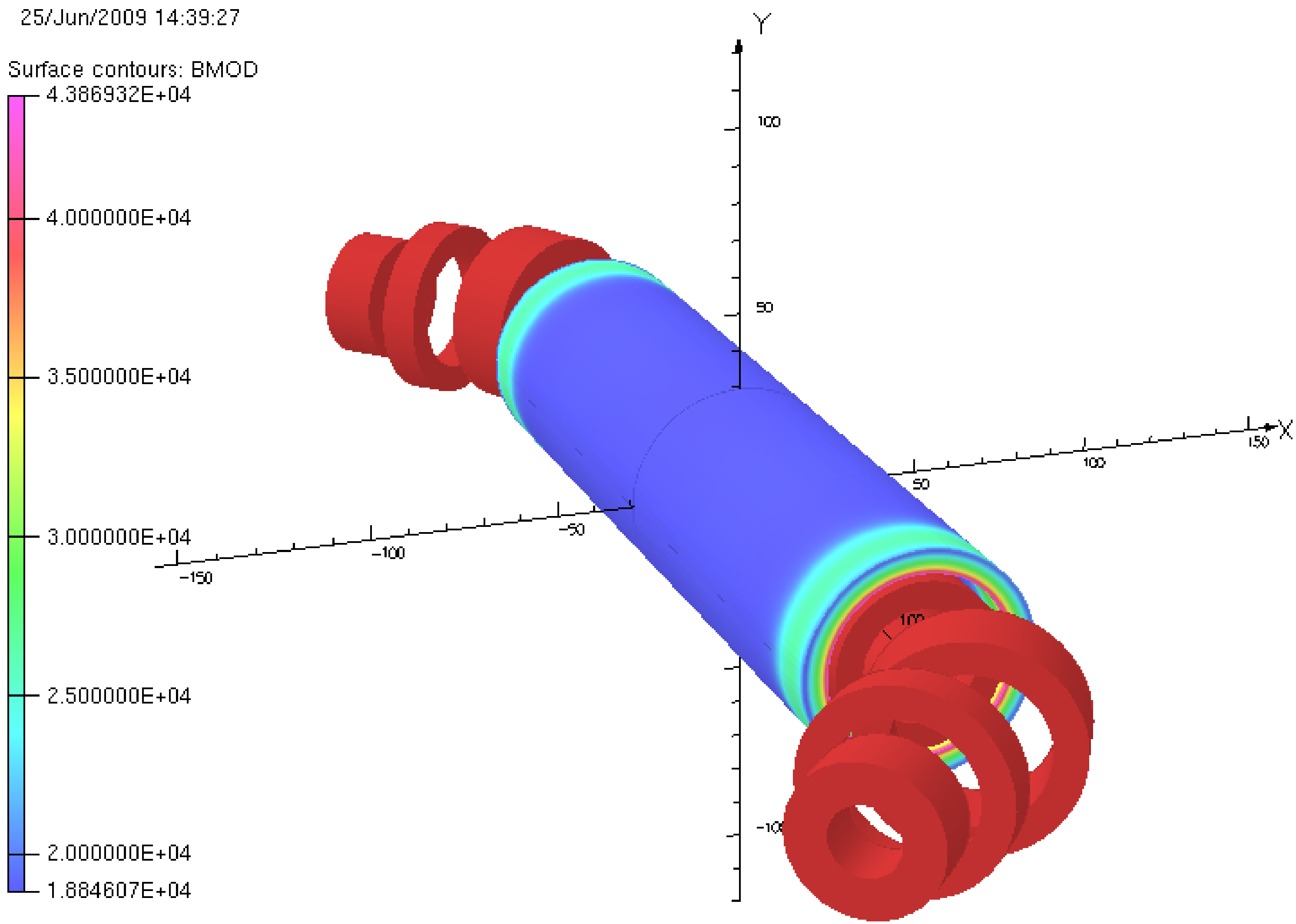
- 2.5 m long
  (2 m good field region)
- 6 T (superconducting)
- ID 250 mm
- Warm insert with
  - field correction
    (up to 10 correctors/plane)
  - orbit correction
  - angle correction



Draft by S. Pikin

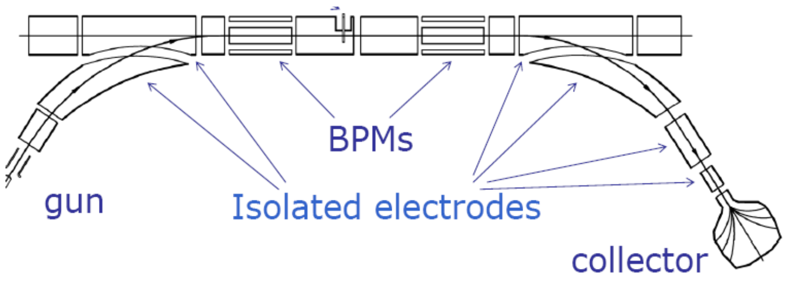
- Field line straightness 50 μm

Mechanical force calculations – W. Meng, S. Pikin



Instrumentation – D. Gassner

Relative beam alignment was of critical importance in Tevatron.



For accurate relative beam alignment would like to have "luminosity" monitor based on

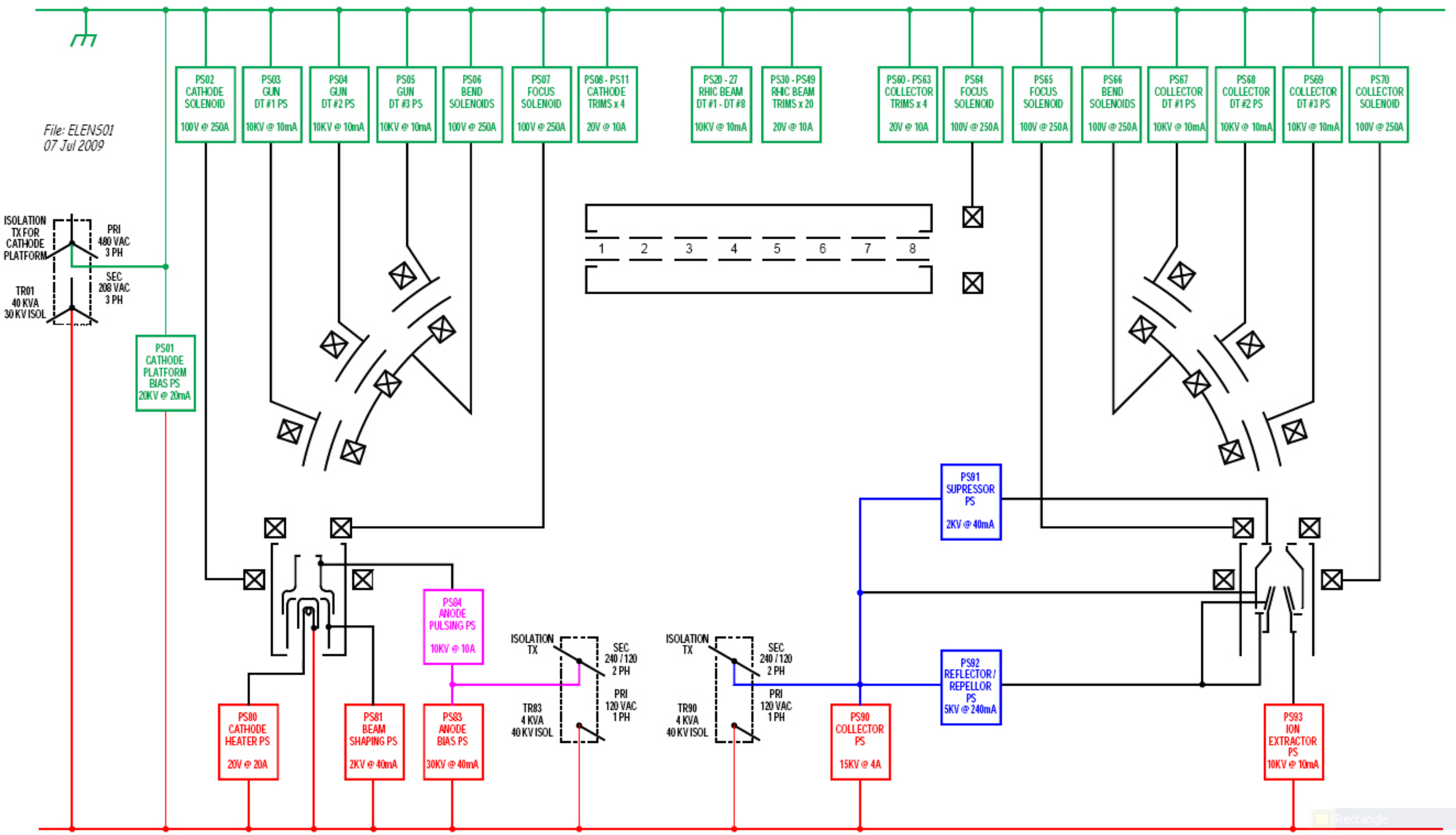
- bremsstrahlung, or
- back-scattered electrons

(C. Montag, W. Nakel)

RHIC Electron Lens Instrumentation Related Parameters Table

Parameter	Expected Value/Range	Accuracy	Resolution	Comments
RHIC beam position	Ave, 1 Hz	10 um	1 um	2 similar beams in common pipe, opposite directions.
E-beam position	Ave, 1 Hz	10 um	1 um	10 micron, need to modulate to measure position.
RHIC orbit stability	1/min	10 um?		Closed loop, RHIC local bumps, stable, low drift.
RHIC Beam Current	2e11/ bunch	10mA	1mA	Detect rate of beam decay, existing likely OK.
E-Beam Current	1 Amp, <0.1% ripple	0.1% 1mA	.001% 100uAmp	Gun & Collector toroids No direct beam measurement
RHIC Emittance bunch-by bunch	10pi mm-mrad		1pi mm-mrad	During commissioning & set-up. Bunch by bunch in RHIC?
RHIC Emittance Average	10pi mm-mrad		1pi mm-mrad	During operations store HF Schottky, IPM, CNI, etc.
Luminosity	Low-level gamma or Bremsstrahlung			For optimizing alignment Expect few counts/min.

PS layout – R. Lambiase



RHIC electron lenses – cost and schedule

25 Jun 2009	Received $4M (including $1M for labor) through ARRA (American Recovery and Reinvestment Act of 2009)
Aug 2009	Solenoids including power supply ready to order
Jan 2010	Gun and collector ready to order
Feb 2010	Beam transport system ready to order
May 2010	Diagnostics ready to order
Nov 2010	Solenoid acceptance test
Mar 2011	Control system specified
Jun 2011	Begin tunnel installation
Dec 2011	Tunnel installation complete

U.S. LARP

Collaboration with US LHC Accelerator Research Program (LARP) and CERN on beam-beam simulations and Tevatron beam tests

[▯0.25 LARP FTEs each for simulation at FNAL, SLAC, LBNL]

RHIC electron lenses – summary

- Plan to partially compensate head-on beam-beam effect with one electron lens per ring, located near IP10
- Technical challenge is to align the relatively small e- and p-beams (implications for straightness of solenoid field lines and instrumentation)
- Expect luminosity gain of up to a factor 2 together with polarized source upgrade (A. Zelenski) and RHIC upgrades for higher intensity
- Plan to complete tunnel installation at end of 2011, and start commissioning in Run-12