Optimizing the electron beam parameters for head-on beam-beam compensation in RHIC

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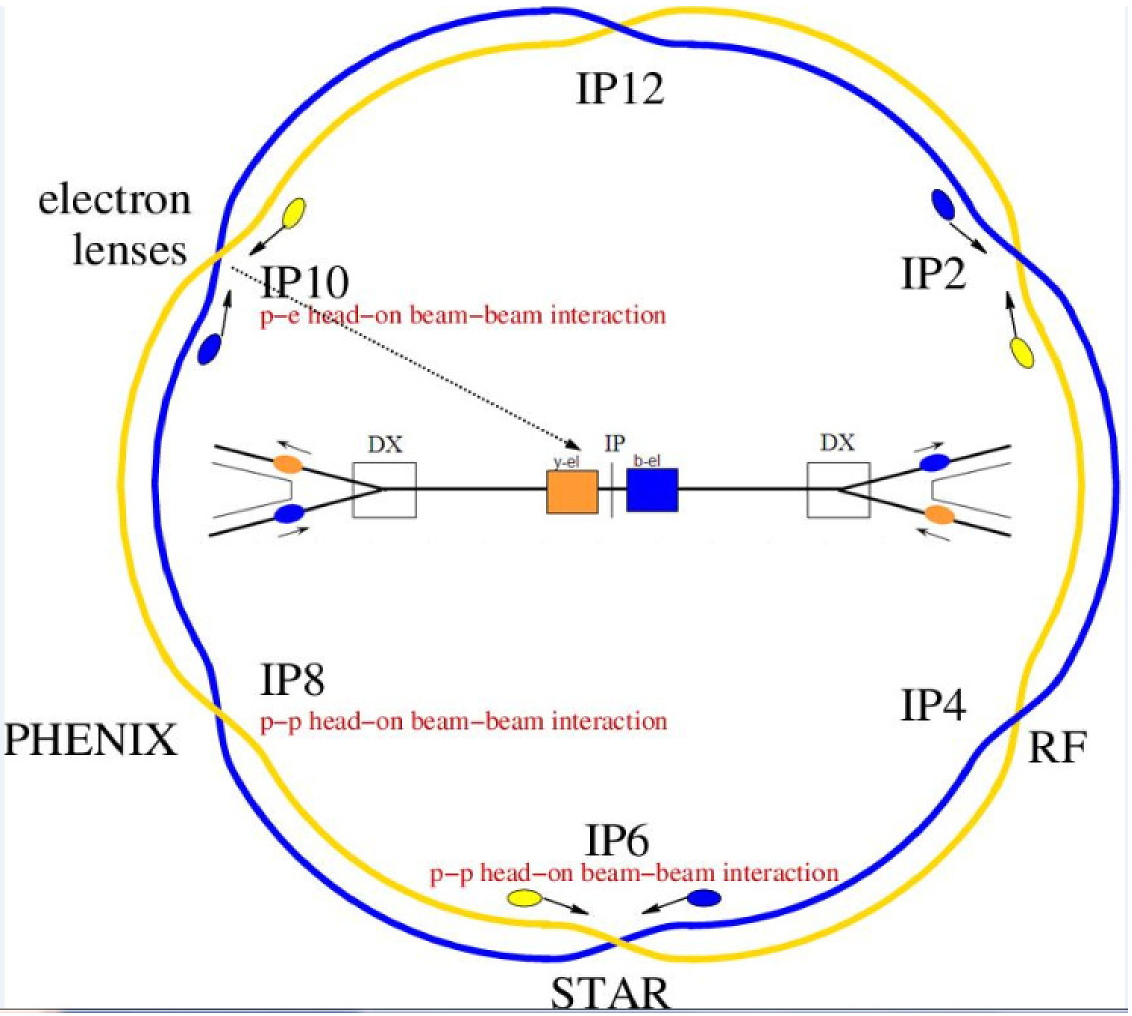
The goal of this numeric simulation study is to guide electron lens design efforts for head-on beam-beam compensation in RHIC.

Head-on Beam-beam compensation in RHIC



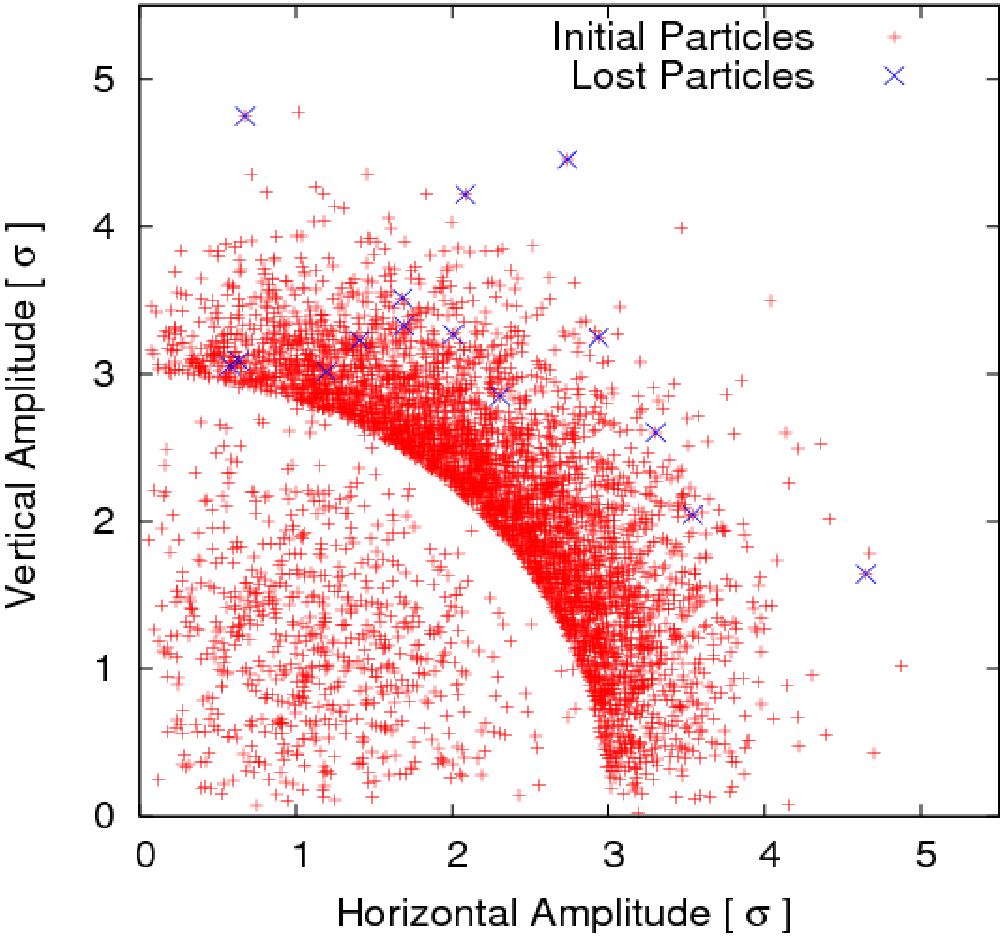
- RHIC working point for polarized proton between 2/3 and 7/10
- Not enough space for beam-beam tune spread for $>2\times10^{11}$/bunch
- Upgrade program aims at up to 3×10^{11}/bunch with new polarized source
- Requires head-on beam-beam compensation with e-lenses (under construction)

Other Posters: MOP209, TUP207, TUP208, THP055 , THP062,THP063, THP100

Simulation for RHIC beam-beam compensation

- Beam-beam tracking study tools
  - single particle:
    - tune/amplitude diffusion
    - resonance driving terms
    - dynamic aperture (DA)
  - multi-particle:
    - particle loss (easily observable)
    - emittance growth
- In the following simulations
  - Focus on proton particle loss calculation
  - Proton particles are tracked element by element
  - 6-D optical and 6-D beam-beam treatment
  - 4,800 macro-particles tracked up to 2×10^6 turns (24 seconds)

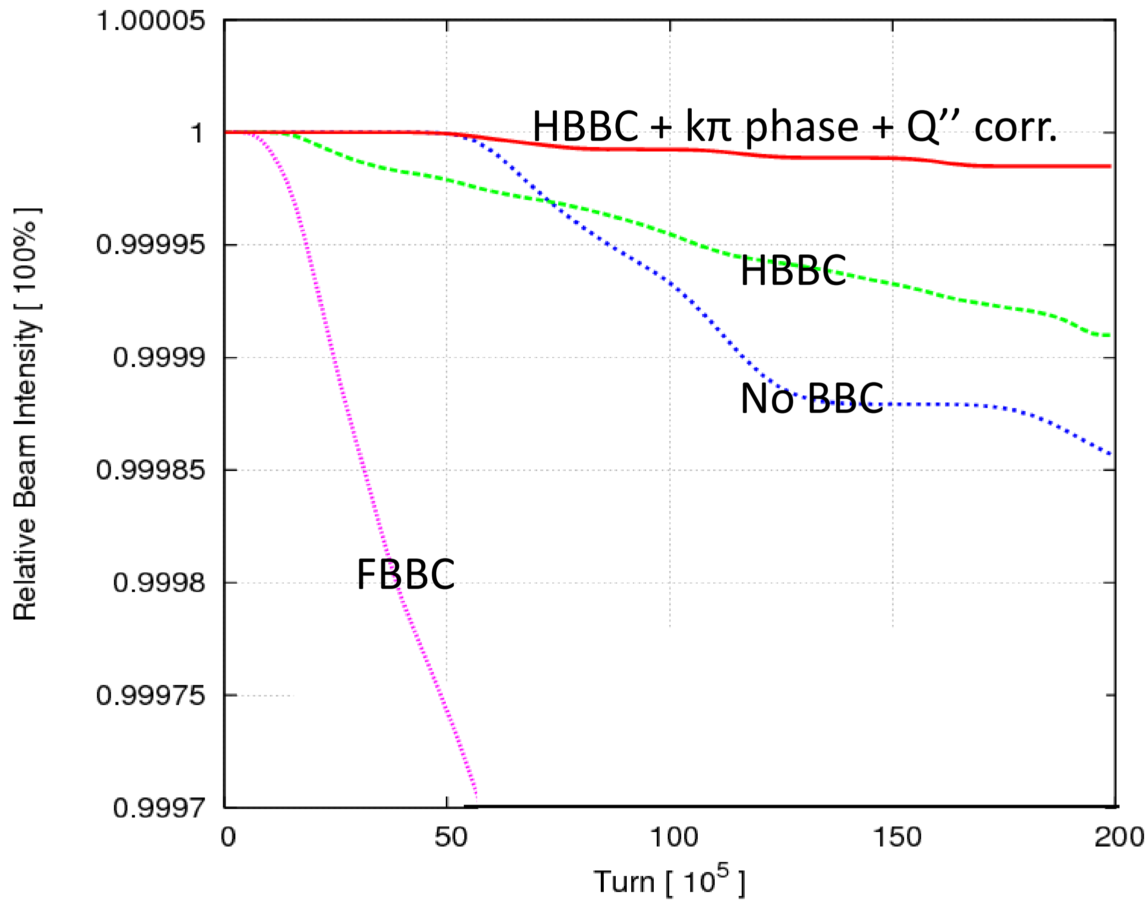
Particle loss rate simulation calculation



- ❑ We use a Hollow Gaussian distribution of proton particles to detect small proton loss.
- ❑ Only track proton particles above a boundary. Particles below boundary are assumed stable. The boundary should be chosen carefully.
- ❑ With initial Hollow Gaussian distribution, there are more macro-particles in the tail of Gaussian distribution and more particle loss in simulation.

Example : only track macro-particles whose transverse or longitudinal amplitudes > 3σ.
4,800 macro-particles represent about 66,269 particles of a solid Gaussian distribution.

Nominal Case – Half beam-beam compensation

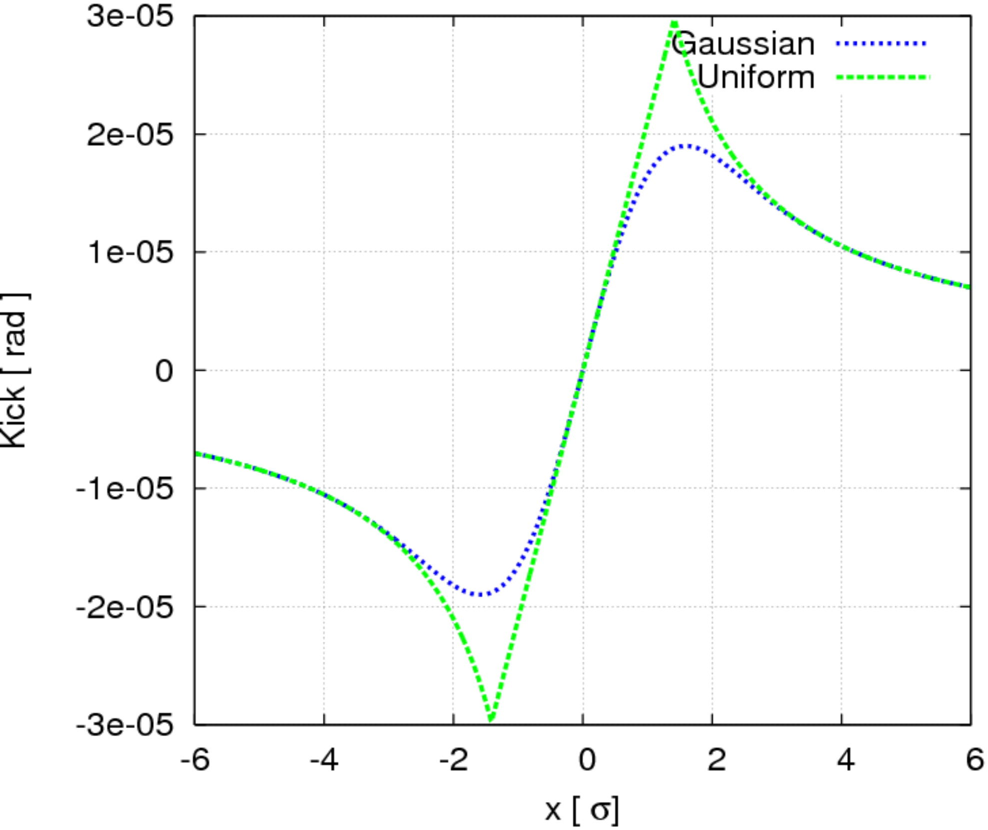


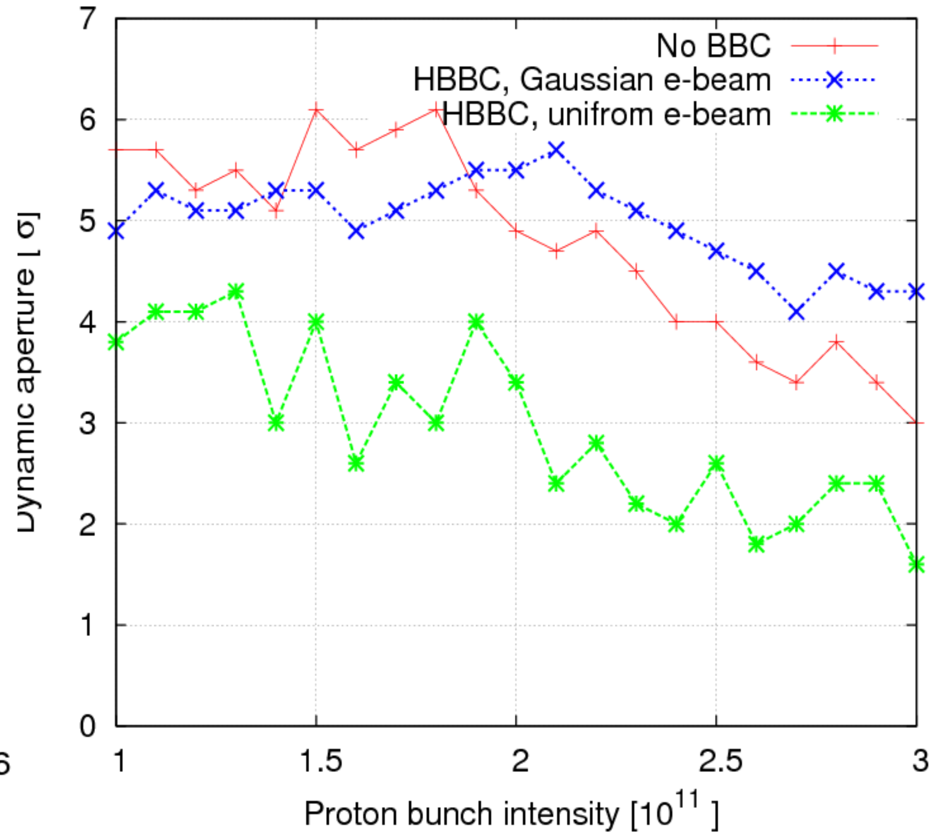
Np=2.5 × 10^{11}/bunch, Tunes (28.67, 29.68)

- ❑ Full and half head-on beam-beam compensation (FBBC and HBBC) compensate full and half beam-beam parameter.
- ❑ From simulation, HBBC improves proton beam lifetime. However, FBBC reduces proton beam lifetime since it introduces more nonlinearities.
- ❑ The kπ phase advances between IP8 and the center of e-lens further increase the proton lifetime on top of HBBC.

Please also consult Poster: THP062, THP063 (Montag)

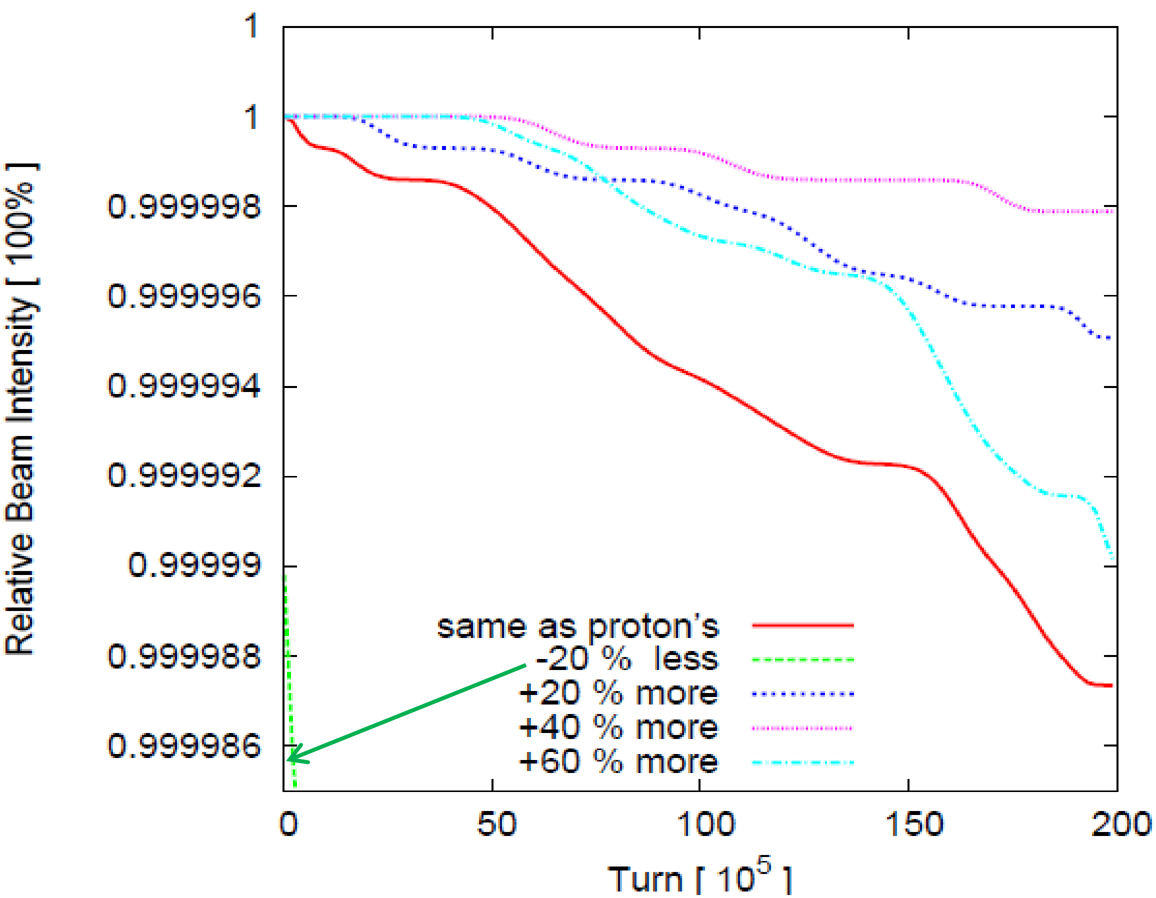
Transverse profile of electron beam





- ❑ For example, here we compare round Gaussian and uniform distributions.
- ❑ Simulation shows that a round uniform distribution of electron beam is not a good choice for head-on beam-beam compensation in RHIC. This is consistent to the Tevatron e-lens experience.

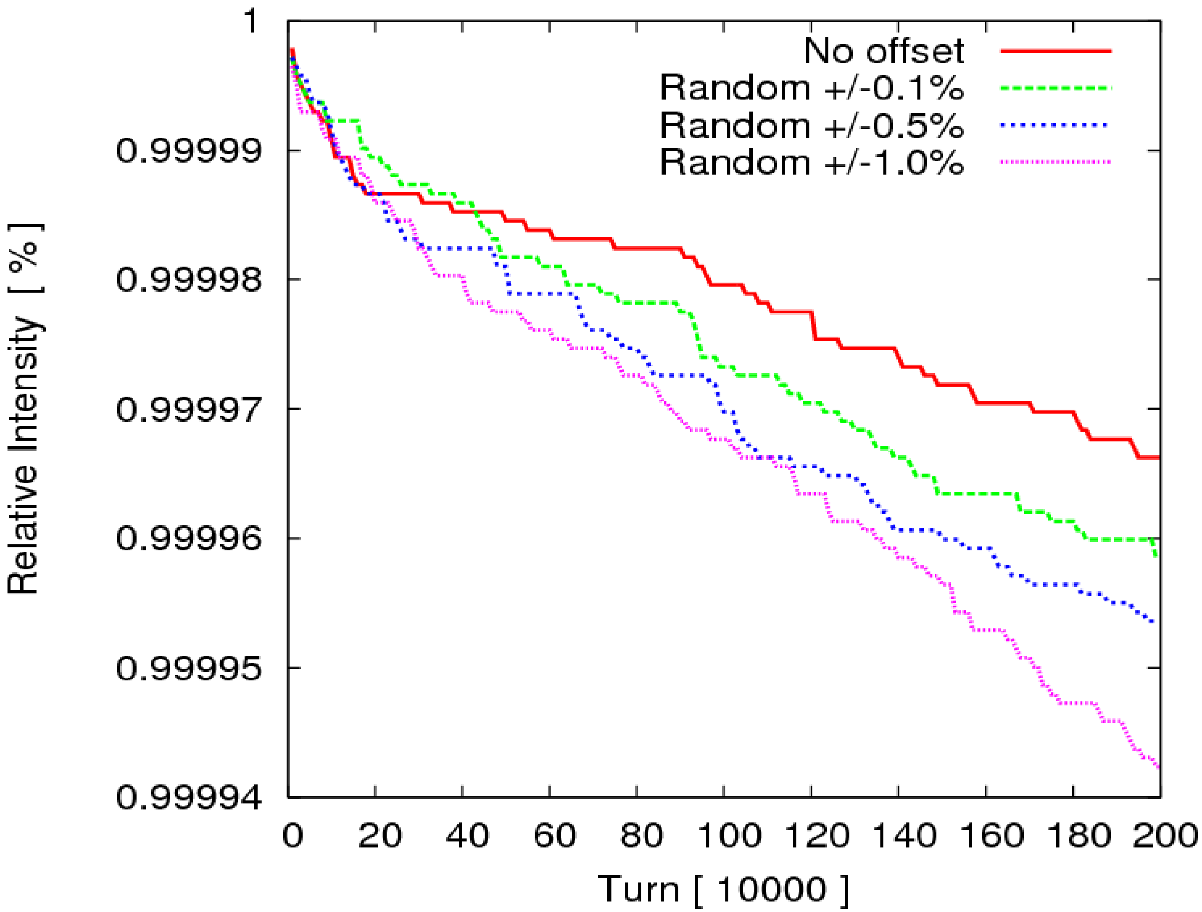
Beam size of electron beam



- ❑ In the simulation study we kept the electron bunch intensity 2.5×10^{11}.
- ❑ Smaller electron beam size than proton beam reduces proton lifetime. It agrees with many colliders' operation experiences that the beam with larger size will be hurt.
- ❑ Bigger electron beam-size than the proton beam reduces the beam-beam tune spread compensation strength.

Please also consult Poster: TUP055 (Fischer)

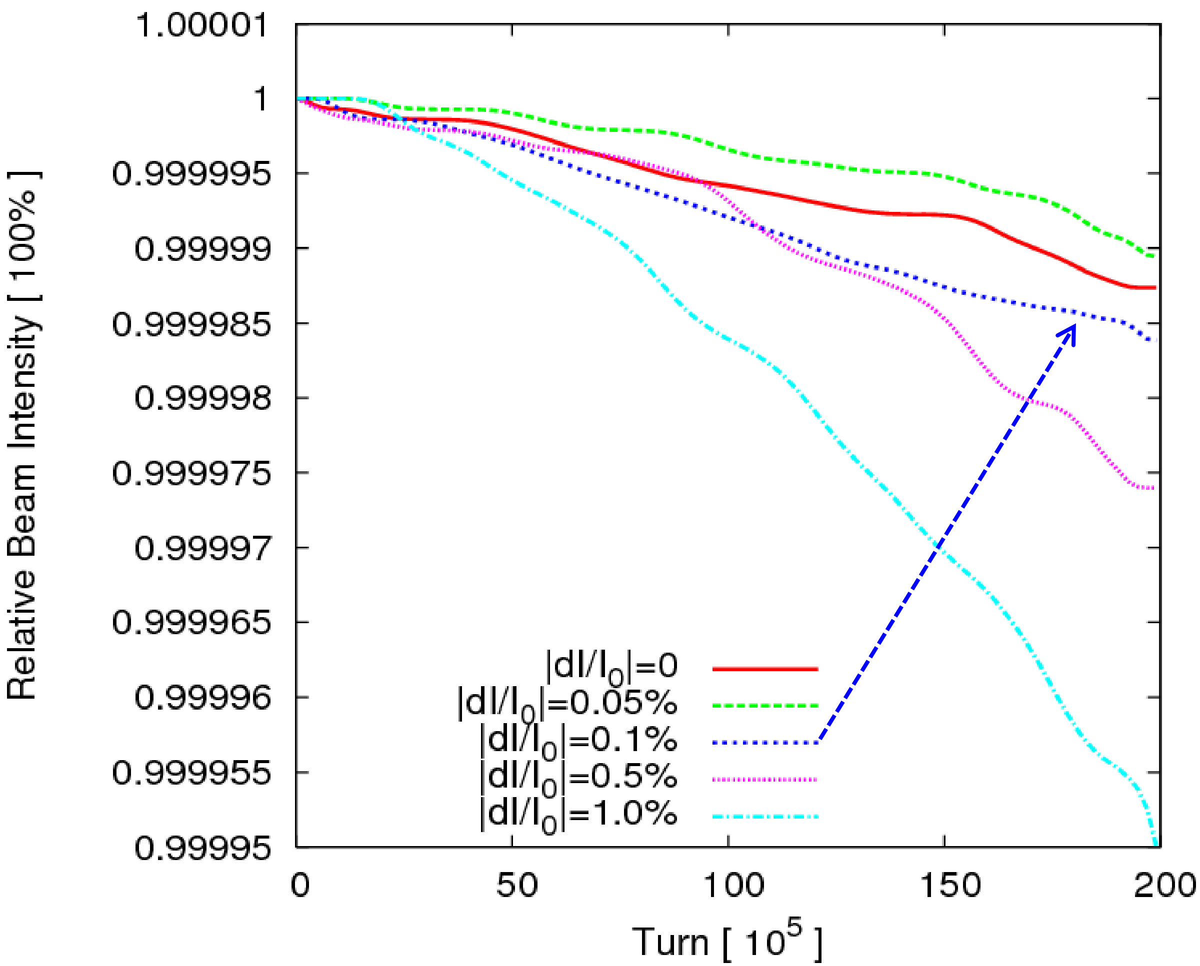
Random error in electron beam size



- ❑ Noise in electron gun power supplies can introduce random error in electron beam size.
- ❑ From simulation we conclude that below 1% random noise in electron beam size is tolerable for proton beam lifetime.
- ❑ In the RHIC e-lens design, the noise in the electron gun power supplies will be better than 1000 ppm (0.1%).

Please also consult Poster: TUP100 (Pikin)

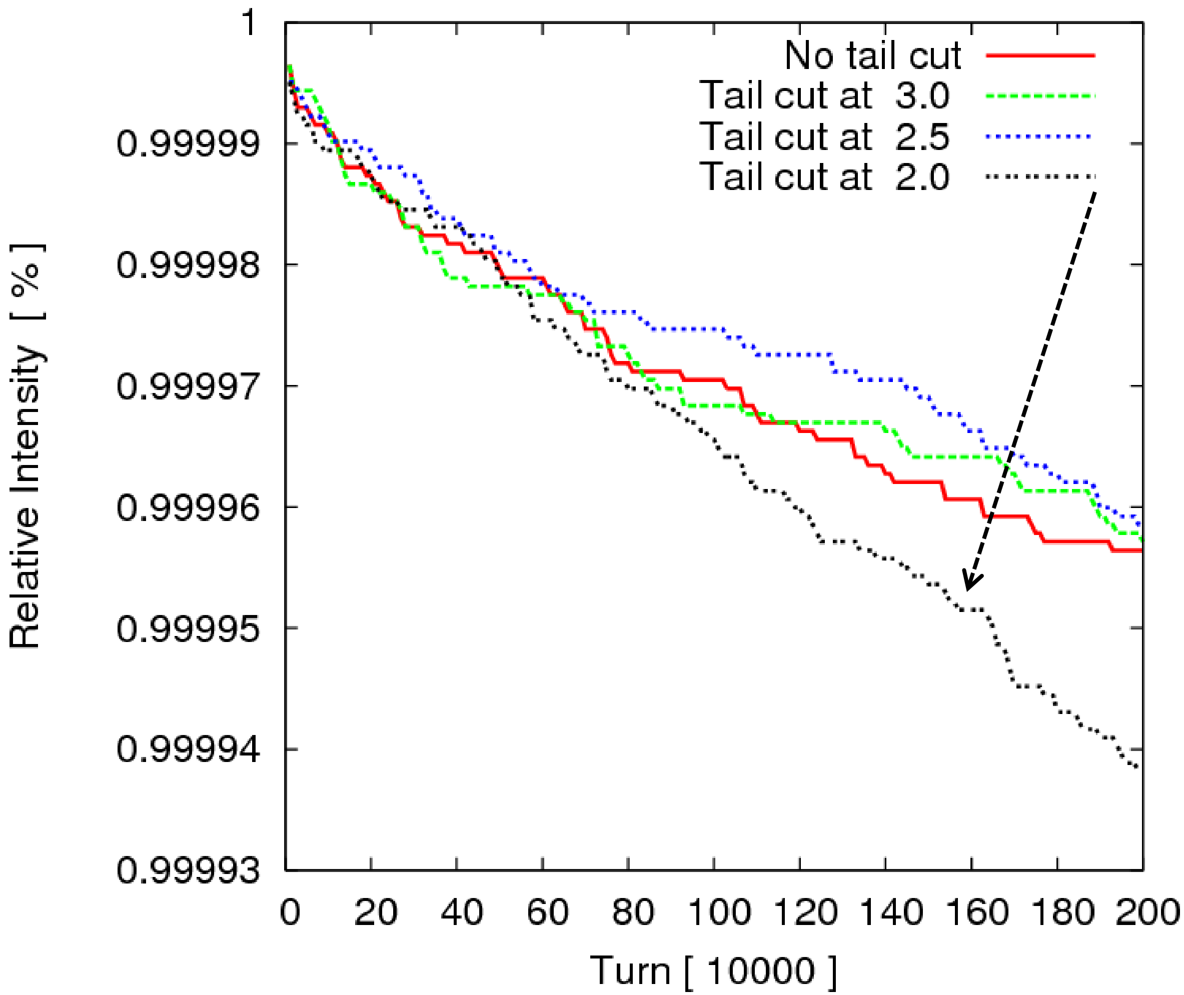
Random error in electron beam current



- ❑ Noise in electron beam current also comes from electron gun power supply noises.
- ❑ Based on simulation, less than 0.1% random errors in electron beam current is acceptable.
- ❑ 0.1% noise level is also consistent with Tevatron e-lens's experimental findings.

Please also consult Poster: TUP100 (Pikin)

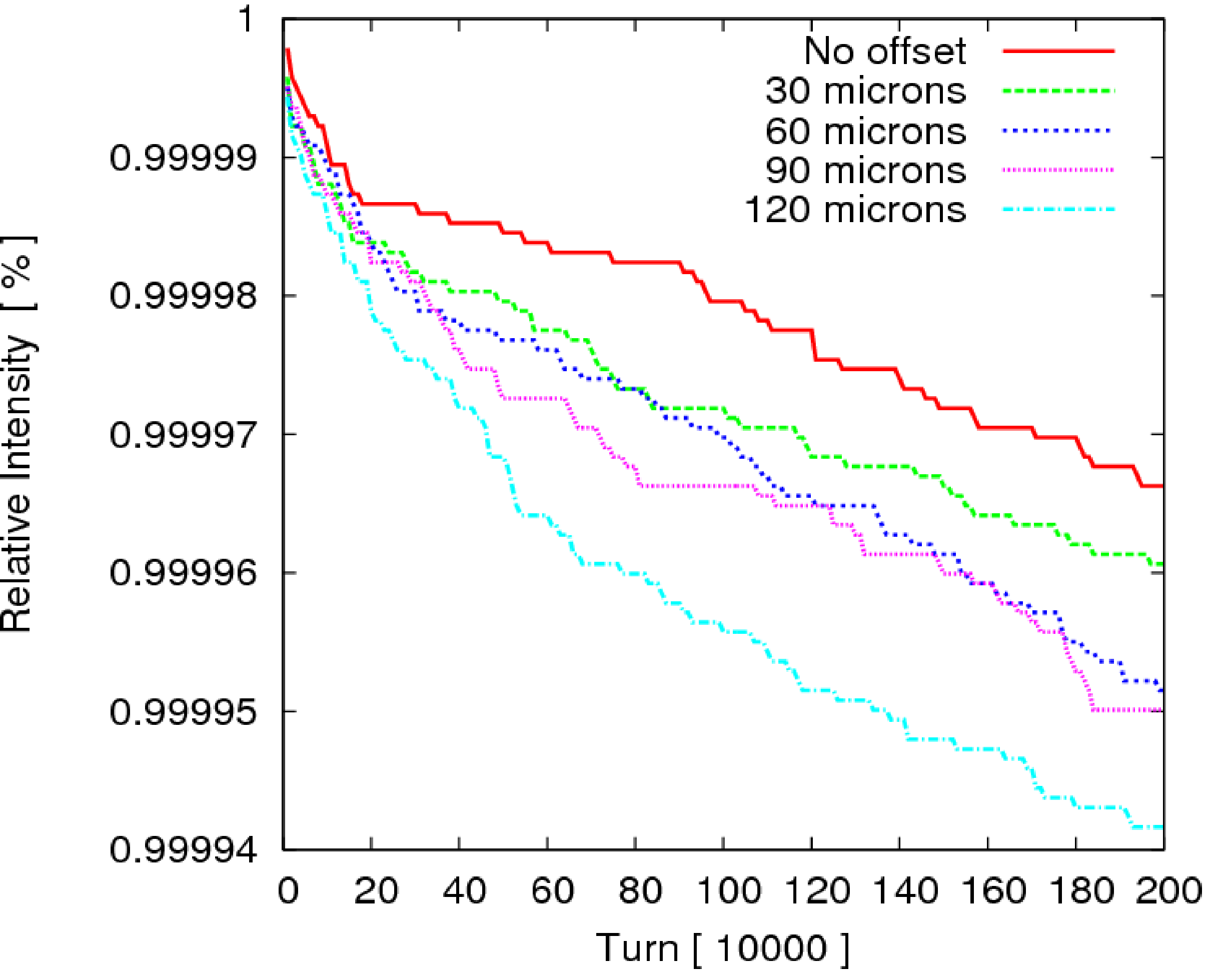
Truncated Gaussian electron beam



- ❑ Electron beam cannot be Gaussian due to finite cathode size.
- ❑ Based on simulation, when Gaussian tail is truncated below 2.5σ, the proton particle loss is visibly enhanced.
- ❑ In the current RHIC electron gun design, we have a good Gaussian fit up to 2.8σ (based on electron gun simulation).

Please also consult Poster: TUP100 (Pikin)

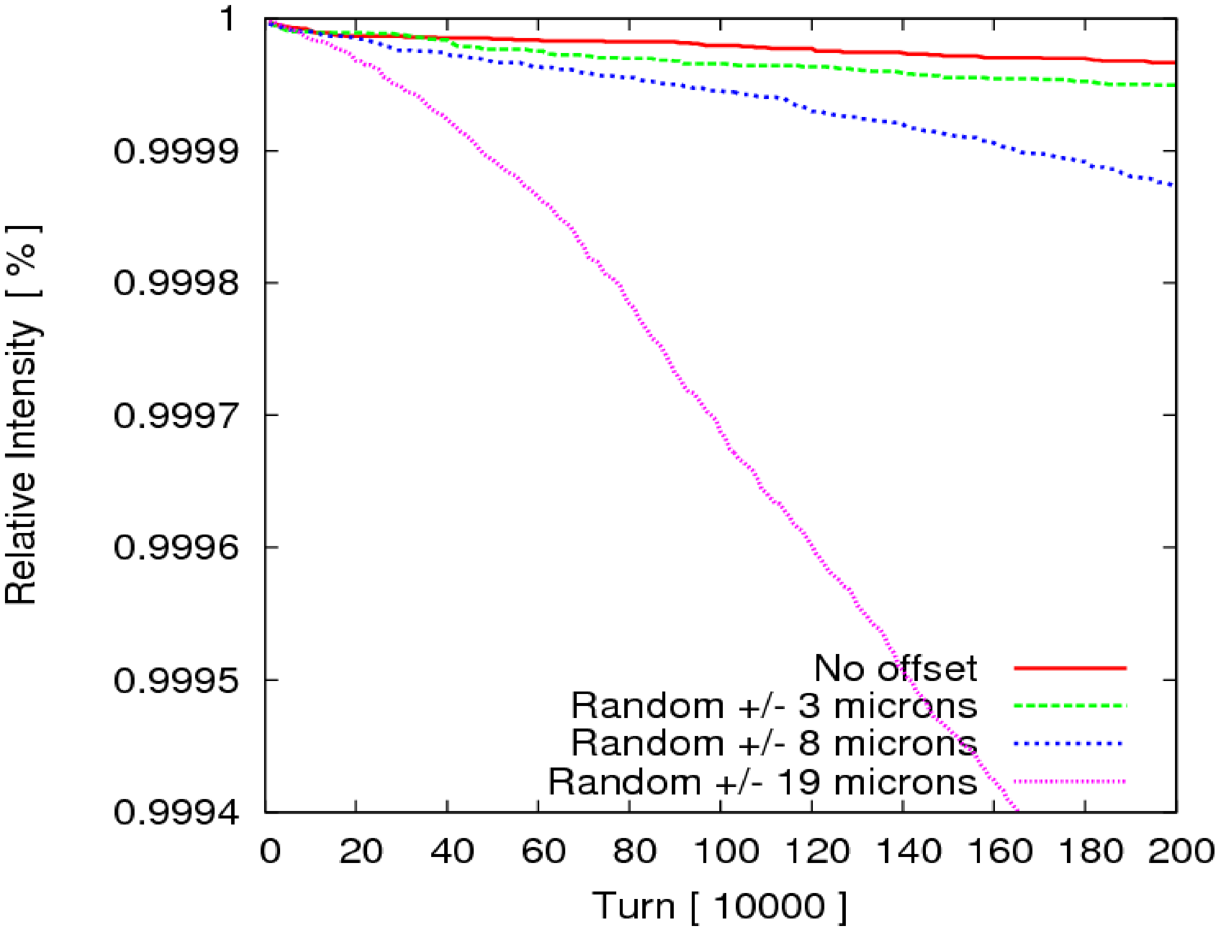
Transverse offset of electron beam



- ❑ Offset of electron w.r.t. proton beam center will reduce compensation strength and induce beam-beam nonlinearity.
- ❑ In e-lens design, we set the static offset error of electron beam less than 30 µm which is tenth of 1 rms beam size.
- ❑ BPM, halo monitor, Bremsstralung monitor will be used for e-p alignment.

Please also consult Posters: TUP055(Fischer), MOP209(Thieberger)

Random offset of electron beam



- ❑ Random noise in electron beam current severely reduces proton beam lifetime.
- ❑ ±3µm, ±8µm, ±19µm offsets correspond to three levels of steering power supply current noises.
- ❑ Based on simulation, we set the acceptable random offset of electron offset below 8 µm.

Please also consult Posters: TUP208, TUP207 (Gu)

Summary

- To upgrade the RHIC luminosity, two electron lenses are under construction to partially compensate the head-on beam-beam effect. Installation is planned for 2012.

- Numeric simulation studies are performed to guide the RHIC electron lens design. Static and random errors in various electron beam parameters are scanned and their tolerances are determined.

- Based on simulation studies, and experience from hadron collider operation and the Tevatron electron lenses
  - electron beam should have good Gaussian fit to >= 2.5σ.
  - noise in electron beam current and size should be < 0.1%.
  - static and random offset errors of electron w.r.t. proton beam center should be less than 30 μm and 8 μm respectively.