

RHIC Upgrades

Possible upgrades for heavy ions:

- Increase luminosity.
- Increase atomic number: $\text{Au}^{197} \rightarrow \text{U}^{238}$.
(Needs new EBIS.)
- Increase energy.

Possible upgrades for protons:

- Increase luminosity.
- Increase c.m. energy: 500 GeV \rightarrow 650 GeV.
- Add polarized jet polarimeter for absolute polarization measurement.
(Note: Rotators for STAR & PHENIX are in original scope.)

eRHIC

- Electron-Heavy Ion collisions
- Polarized electron-proton collisions



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RHIC Retreat: 16 Nov., 2000

Luminosity Upgrade Options for RHIC

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Definitions and Conventions:

- Emittance, ϵ is 95%, normalized area (with π): $\sigma_x = \sqrt{\frac{\beta_x \epsilon}{6\pi\gamma\beta}}$.
- Beam-beam parameter (tune shift per IR):

$$\xi = N \frac{r\beta^*}{4\pi\gamma\sigma^{*2}} = \frac{3r}{2} \frac{N}{\epsilon}.$$

for M bunches of N ions per bunch. Classical radius $r = \frac{Z^2 e^2}{4\pi\epsilon_0 A M_0 c^2}$.
Assume a maximum value of beam-beam tune shift

$$\Delta Q_c = 0.024 = 6 \times 0.004 \quad \text{or} \quad \xi_c = 0.004.$$

This gives a maximum gold bunch intensity of

$$N_c = 2.6 \times 10^9 \left(\frac{\epsilon}{15\pi \mu\text{m}} \right) \left(\frac{\xi_c}{0.004} \right).$$

IR Optics

- At IP: $\beta(s) = \beta^* + s^2/\beta^*$.
⇒ Effective triplet distance:

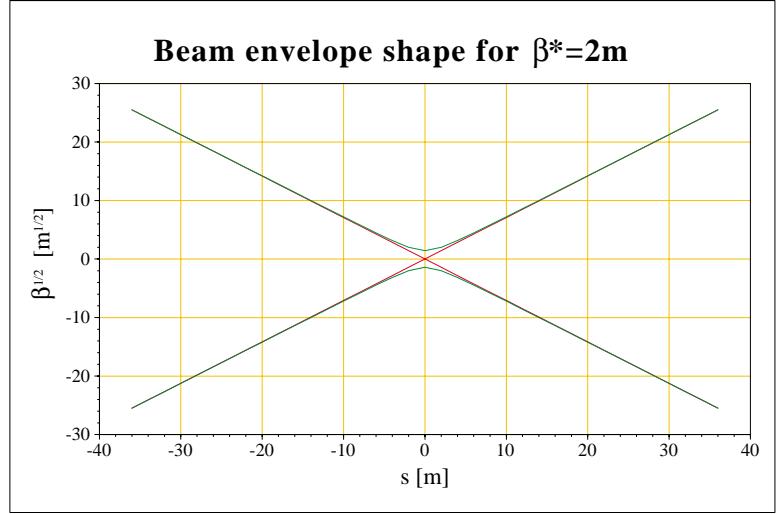
$$\hat{s} \simeq \sqrt{\hat{\beta}\beta^*} = 36 \text{ m.}$$

Beam size at triplet: $\hat{\sigma} \simeq \sigma' \hat{s}$, where

$$\sigma'^* = \hat{\sigma}' = \sqrt{\frac{\epsilon}{6\pi\beta^*\gamma\beta}}.$$

- We require an aperture of $a = n\sigma$ at triplet ($n \gtrsim 8$), so

$$\sigma'^* \leq \frac{a}{n\hat{s}} \simeq 226 \text{ } \mu\text{rad}, \quad \text{for } n = 8.$$



Luminosity Dependence

- To maximize luminosity, we can write

$$L = f_{\text{rev}} \frac{MN^2}{4\pi\sigma^{*2}} = \frac{M}{120} \left(\frac{\xi}{.004} \right)^2 \left(\frac{\sigma'^*}{266 [\mu\text{rad}]} \right)^2 4.6 \times 10^{28} [\text{cm}^{-2}\text{s}^{-1}]$$

which is independent of ϵ and β^*

Three Cases for Heavy Ion Collisions

1. **RDM**: Reference Design Manual (60 bunches $\times 10^9$ ions & $\beta^* = 2$ m).
2. **RDM+**: Case 1 upgraded to 120 bunches and $\beta^* = 1$ m.
3. **RHIC II**: Adds electron cooling to reduce emittance and cancel IBS.

Parameters for Heavy Ion Collisions

Scheme		RDM	RDM+	RHIC II
Initial Emittance (95%), ϵ	$[\pi\mu\text{m}]$	15	15	15
Final Emittance (95%), ϵ	$[\pi\mu\text{m}]$	40	40	< 6*
IP beta function, β^*	[m]	2.0	1.0	1.0
Number of bunches, M		60	120	120
Bunch population, N	$[\times 10^9]$	1.0	1.0	1.0
Beam-beam parameter per IR, ξ		.0016	.0016	.004*
Angular beam size, σ'^*	$[\mu\text{rad}]$	108	153	95
RMS beam size, σ^*	$[\mu\text{m}]$	216	150	95
Peak Luminosity, L_0	$[10^{27}\text{cm}^{-2}\text{s}^{-1}]$	0.8	3.2	8.3
Average Luminosity, $\langle L \rangle$	$[10^{27}\text{cm}^{-2}\text{s}^{-1}]$	0.2 [†]	0.8 [†]	7 [‡]

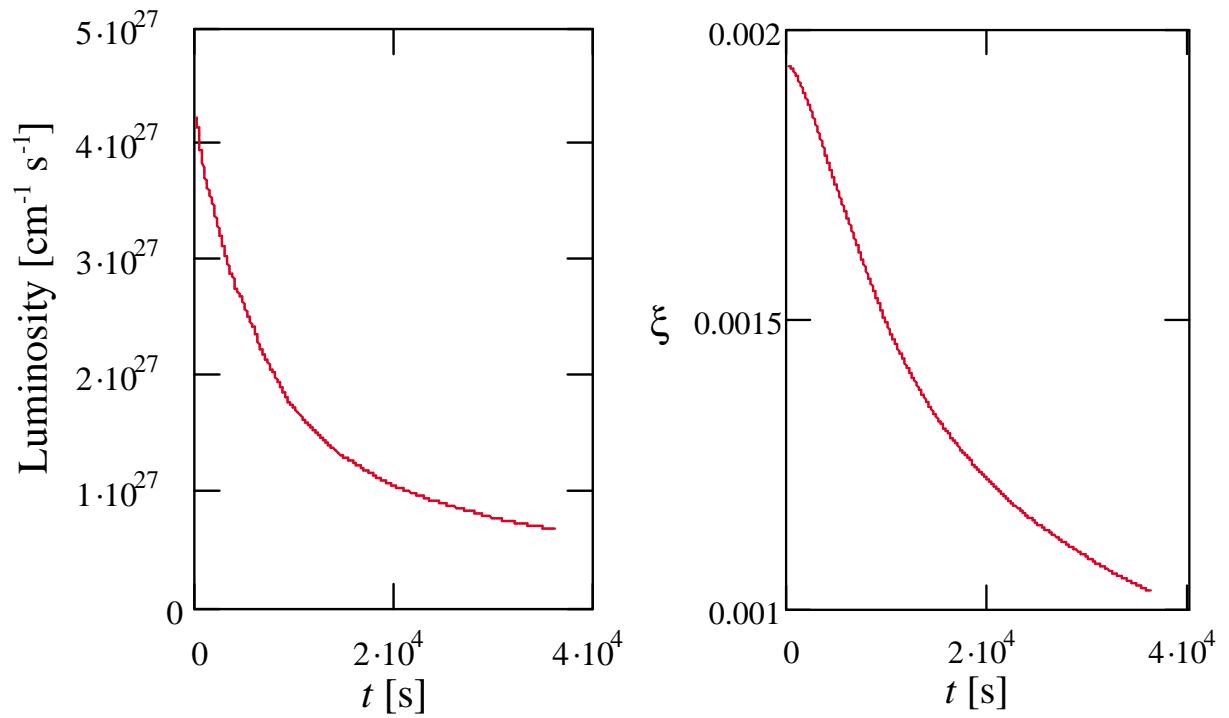
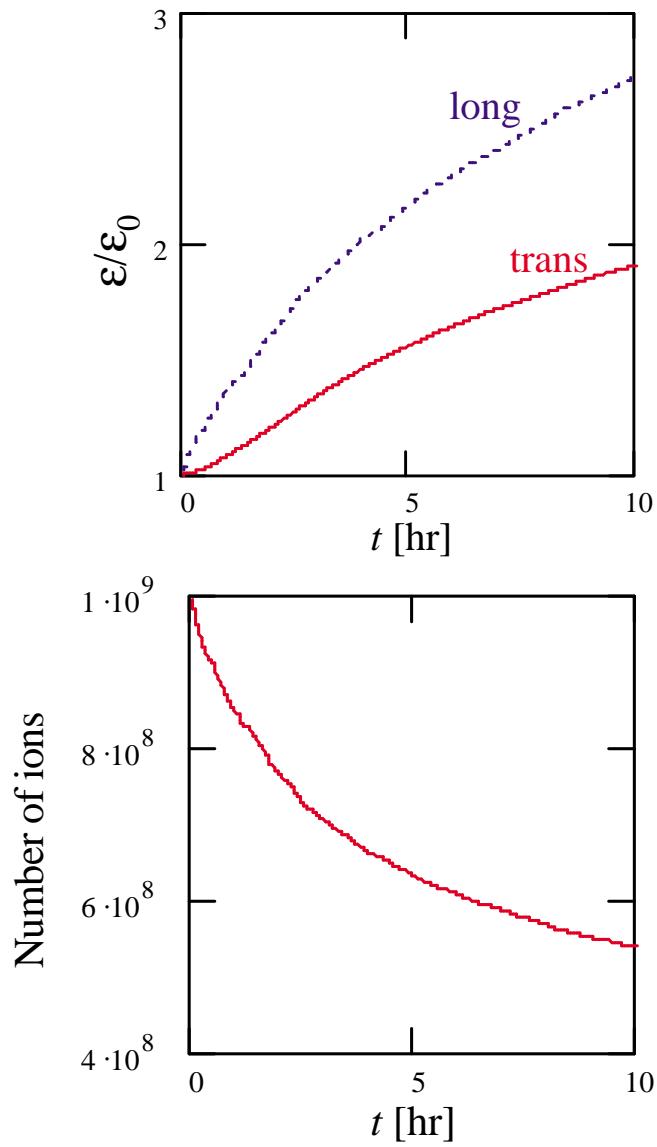
* RHIC II assumes **electron cooling** to reduce the emittance and counteract IBS.

† Luminosity average over 10 hr for RMD and RDM+.

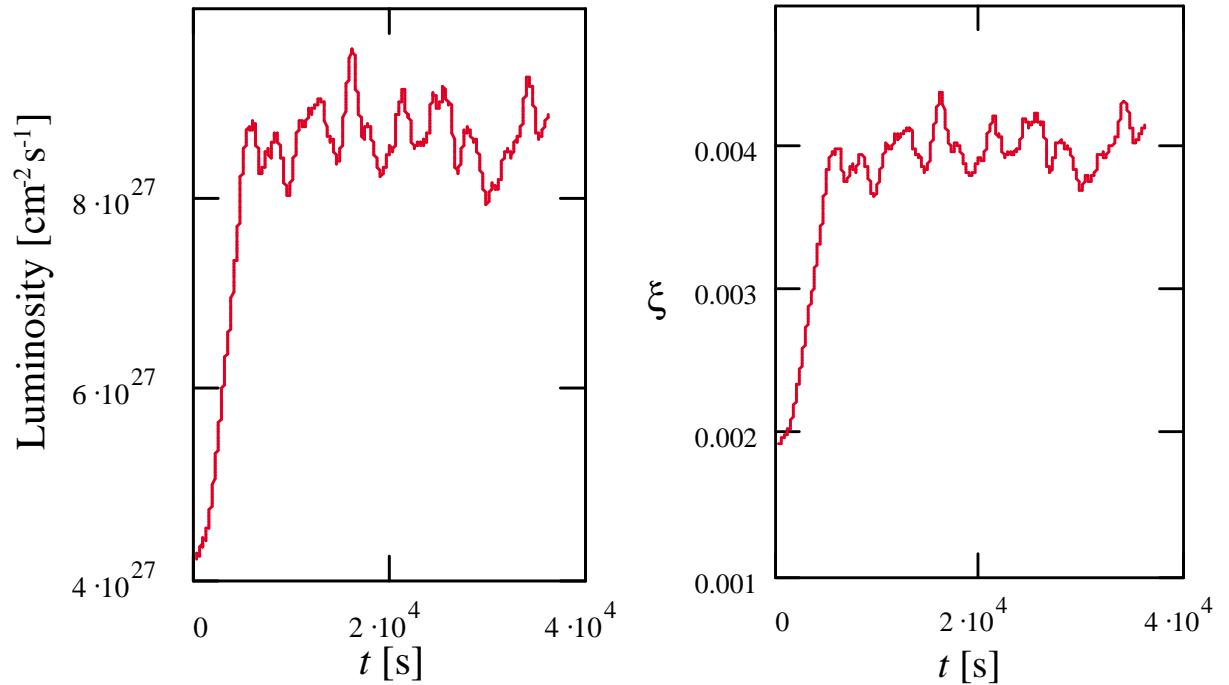
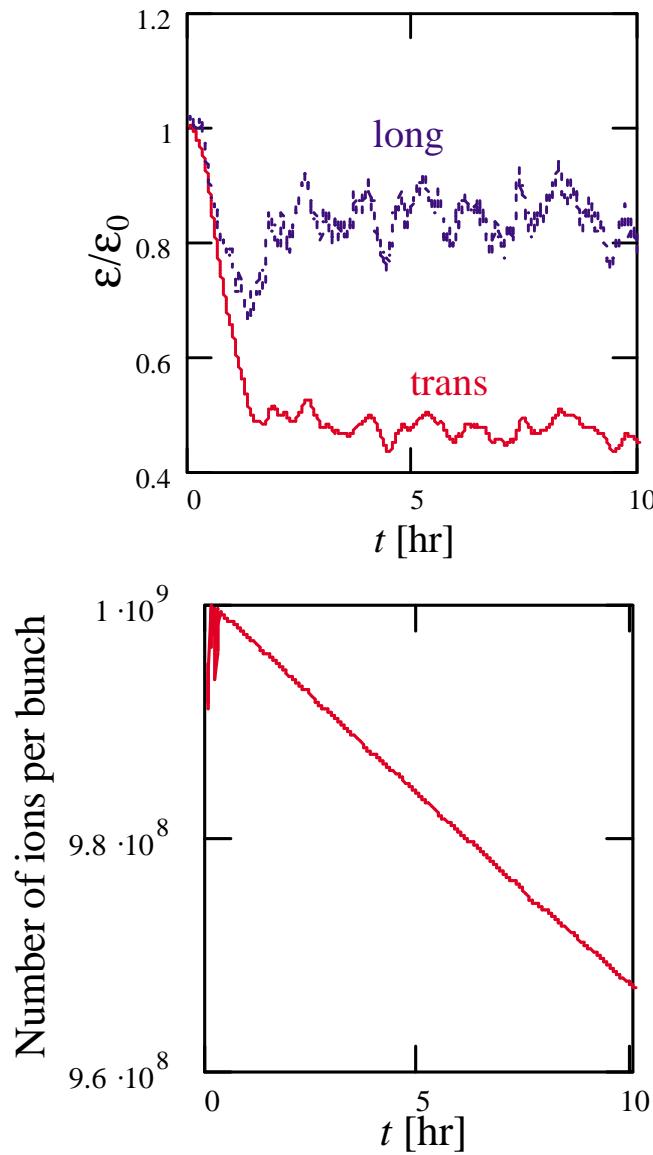
‡ Luminosity average over 5 hr for RHIC II since burn-off is high.

Electron Cooling of HI beam

- 50 MeV electron beams:
 - Electron current 10 mA (0.6 mA peak, $\sigma_z \sim 20$ cm).
 - Superconducting e^- linac
- Cool ion beam down to tune shift limit ($\xi \sim 0.004$).
 $\epsilon = 15\pi \rightarrow 6\pi \mu\text{m}$ in about 1.5 hr
- Solenoidal transport for electrons 30 m of 1 T
 - Between Q3–Q4 at Sector 11.
Helical motion of electrons can reduce recombination.
Cooling comes from average trajectory of electrons.
- BINP (Parkhomchuk...) preparing cooler design for RHIC.
 - Report expected at end of December.
- As particles burn off from collisions: keep $L(t)$ and ξ constant.
 \Rightarrow Squeeze: $\epsilon \propto \beta^* \propto N$.



Without cooling we see emittance growth due to IBS and a fairly rapid decrease in luminosity.



With cooling we see the emittance and luminosity reach equilibrium. This calculation ignores burn-off of beam and only assumes losses due to IBS.

Beam Burn-off due to Collision Losses

- For constant emittances, $L(t) \propto N^2$.
- At high luminosity, Au collisions (100 GeV/n) – losses dominated* by
 - bound electron-positron production
 - Coulomb dissociation

$$\sigma = \sigma_{\text{pair}} + \sigma_{\text{dis}} = 212 \pm 10 \text{ b.}$$

- For $n_i = 6$ IP's the particle loss rate per bunch is

$$\frac{dN}{dt} = -\frac{n_i}{M} L(t) \sigma.$$

Solving for constant emittance gives

$$L(t) = L_0 \left(1 + \frac{n_i L_0 \sigma}{MN_0} t\right)^{-2},$$
$$\langle L \rangle = L_0 \left(1 + \frac{n_i L_0 \sigma}{MN_0} t\right)^{-1}.$$

* Baltz et al., Phys. Rev. E **54**, 4233 (1996).

To hold luminosity constant $L_0 = 8.3 \times 10^{27} \text{ cm}^{-2}\text{s}^{-1}$,

- $N = 1 \rightarrow 0.5 \times 10^9$ in 4.7 hr (drops linearly).
- $\beta^* = 1 \rightarrow 0.5 \text{ m}$ (lower limit of current optics).
- $\epsilon = 6\pi \rightarrow 3\pi \mu\text{m}$.



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Parameters for Proton Collisions

Scheme		RDM	RDM+	RHIC II
Emittance (95%), ϵ	[$\pi\mu\text{m}$]	20	20	12*
IP beta function, β^*	[m]	2.0	1.0	1.0
Number of bunches, M		60	120	120
Bunch population, N	[10^{11}]	1.0	2.0	2.0
Beam-beam parameter per IR, ξ		.0037	.0073†	.012‡
Angular beam size, σ'^*	[μrad]	79	112	86
RMS beam size, σ^*	[μm]	158	112	86
Peak Luminosity, L_0	[$10^{31}\text{cm}^{-2}\text{s}^{-1}$]	1.5	24	40

* For RHIC II assumes electron cooling at injection to reduce emittance.

† For RDM+ assumes only collisions at 3 IR's.

‡ For RHIC II assumes only collisions at 2 IR's.

Summary

- First upgrade **RDM+**:
 - Double number of bunches.
 - Squeeze IR's to $\beta^* = 1$ m.
 - $4 \times$ design luminosity for Au collisions.
 - $16 \times$ design luminosity for p collisions at ≤ 3 IR's.
- Next upgrade **RHIC II** for Au:
 - Use electron cooling to combat IBS and reduce emittance of ion beams.
 - $35 \times$ design luminosity over 5 hr.
 - Reduce emittance and β^* as intensity drops.
- Next upgrade **RHIC II** for p:
 - Increase ξ to 0.012 by colliding at only two IR's
 - $40 \times$ design luminosity.