RHIC Upgrades

Possible upgrades for heavy ions:

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

Possible upgrades for protons:

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

eRHIC

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

Luminosity Upgrade Options for RHIC

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Contents

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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

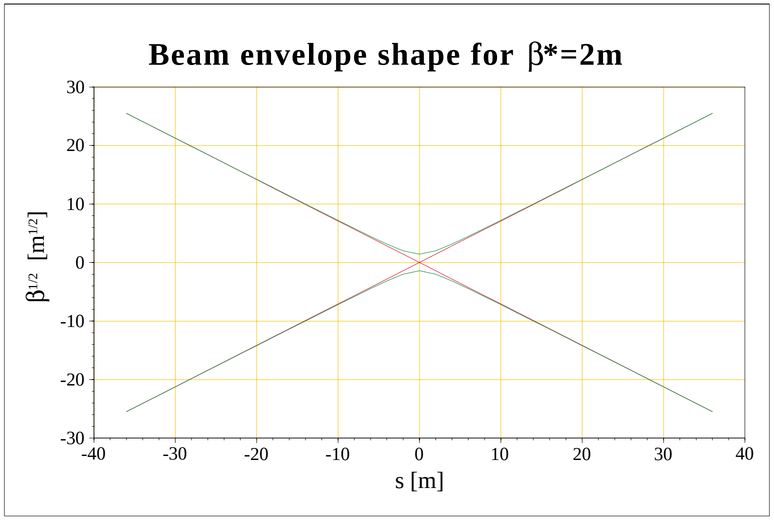
$$N_c = 2.6 \times 10^9 \left(\frac{\epsilon}{15\pi\ \mu\text{m}} \right) \left(\frac{\xi_c}{0.004} \right).$$

IR Optics

- At IP: $\beta(s) = \beta^* + s^2/\beta^*$.
  $\Rightarrow$ 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

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

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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	$[\pi\mu\mathrm{m}]$	15	15	15
Final Emittance (95%), ϵ	$[\pi\mu\mathrm{m}]$	40	40	$< 6^*$
IP beta function, β^*	[m]	2.0	1.0	$1.0 \rightarrow 0.5$
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'^*	$[\mu\mathrm{rad}]$	108	153	95
RMS beam size, σ^*	$[\mu\mathrm{m}]$	216	150	95
Peak Luminosity, L_0	$[10^{27}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	0.8	3.2	8.3
Average Luminosity, $\langle L \rangle$	$[10^{27}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	$0.2^\dagger$	$0.8^\dagger$	$7^\ddagger$

*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 A peak, $\sigma_z \sim 20$ cm).
  - Superconducting e^- linac
  - ✓ These parameters are very close to TJNAF's energy recovery linac.
- Cool ion beam down to tune shift limit ($\xi \sim 0.004$).
  $\epsilon = 15\pi \longrightarrow 6\pi$ μm in about 1.5 hr
- V. Parkhomchuk (BINP in Novosibirsk) preparing cooler design for RHIC.
  - Report expected at end of December.
- Solenoidal transport for electrons 30 m of 1 T
  - In Q3–Q4 straight section at Sector 11.
    Helical motion of electrons can reduce recombination.
    Cooling comes from average trajectory of electrons.

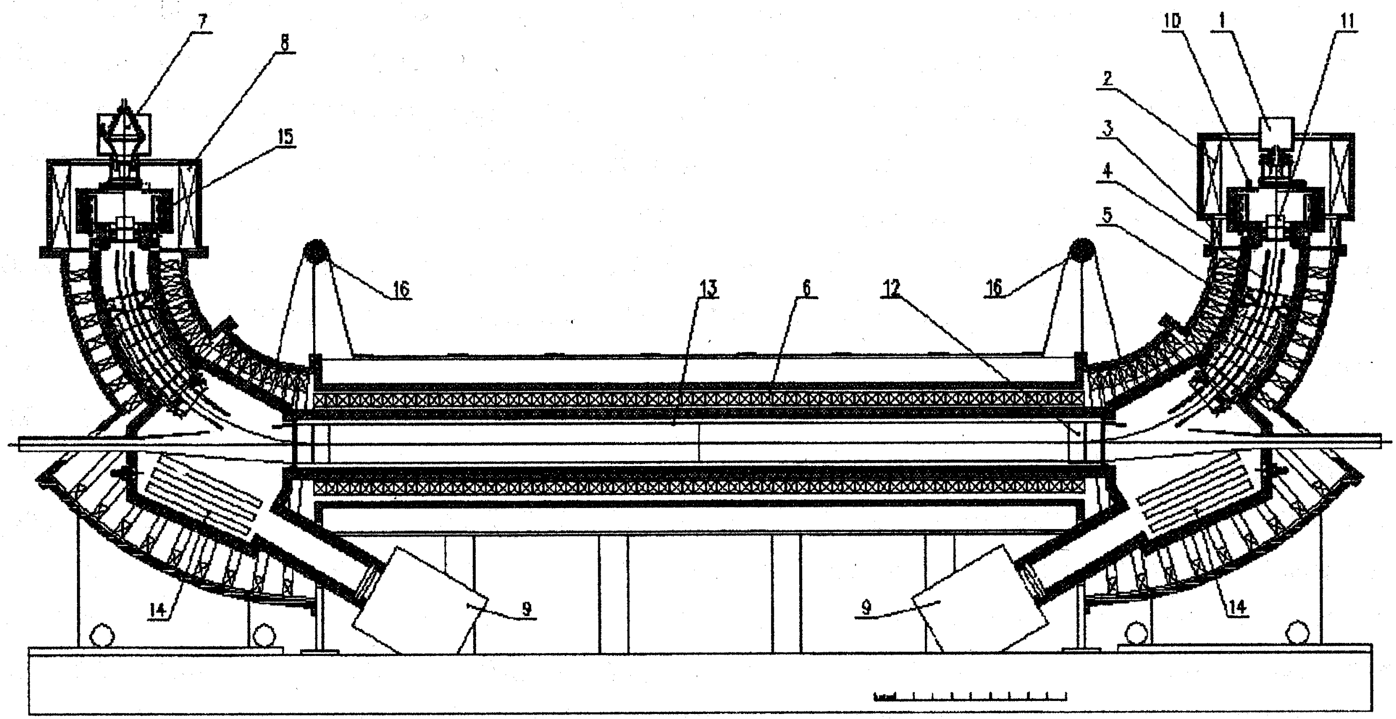
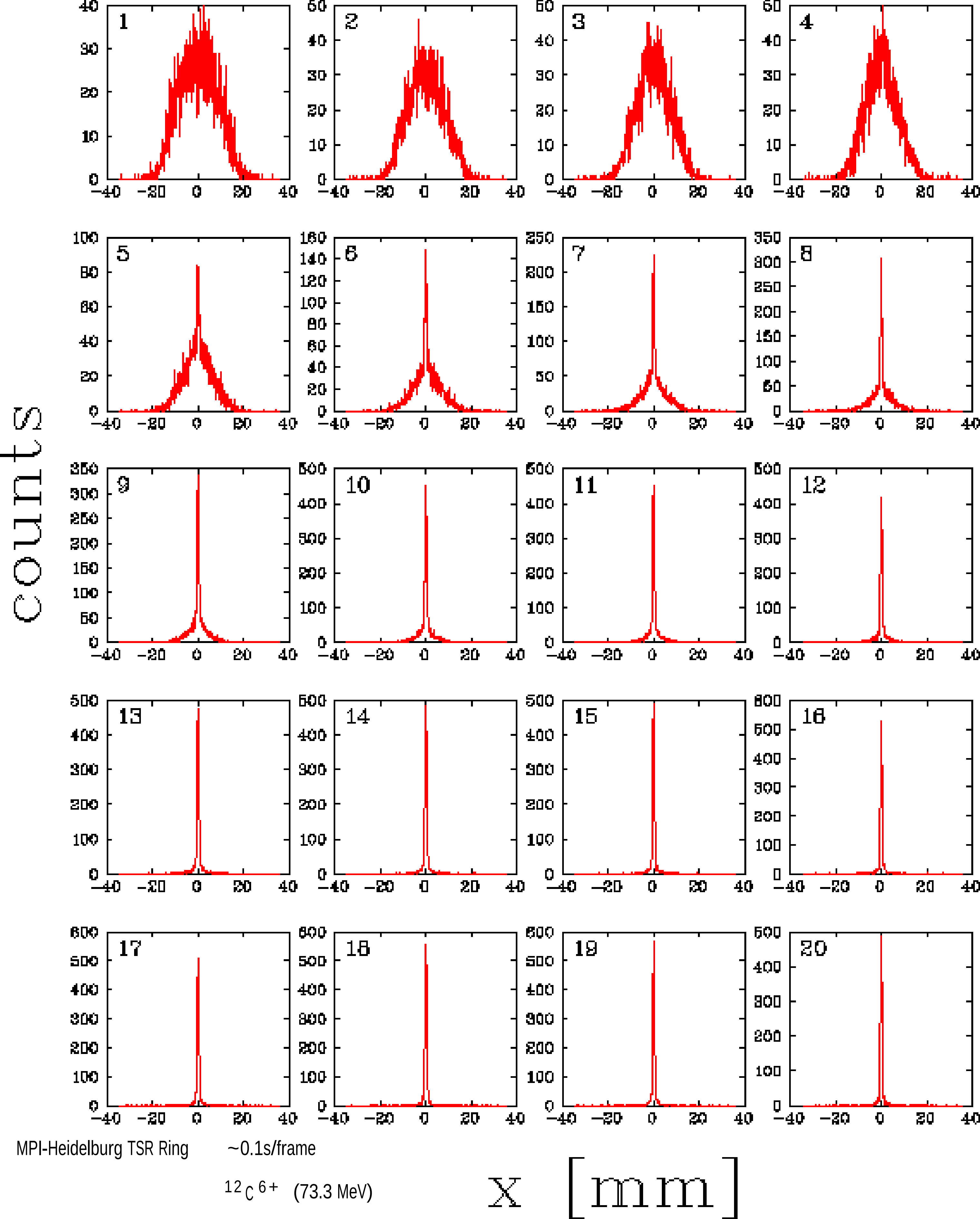


Figure 8: General arrangement of the EX-35 electron cooling device at an electron energy of 35 keV. 1-electron gun, 2-the main solenoid of the gun, 3-an additional solenoid of the gun, 4-the electrostatic deflector, 5-toroid, 6-the main solenoid, 7-collector, 8-the main solenoid of the collector, 9- ion pumps, 10-compensation coil, 11-titanium sputter, 12-pickup electrodes, 13-vacuum chamber, 14-getter pumps, 15- heating jackets, 16 -hinge, 17 - cooling system of the collector.


counts
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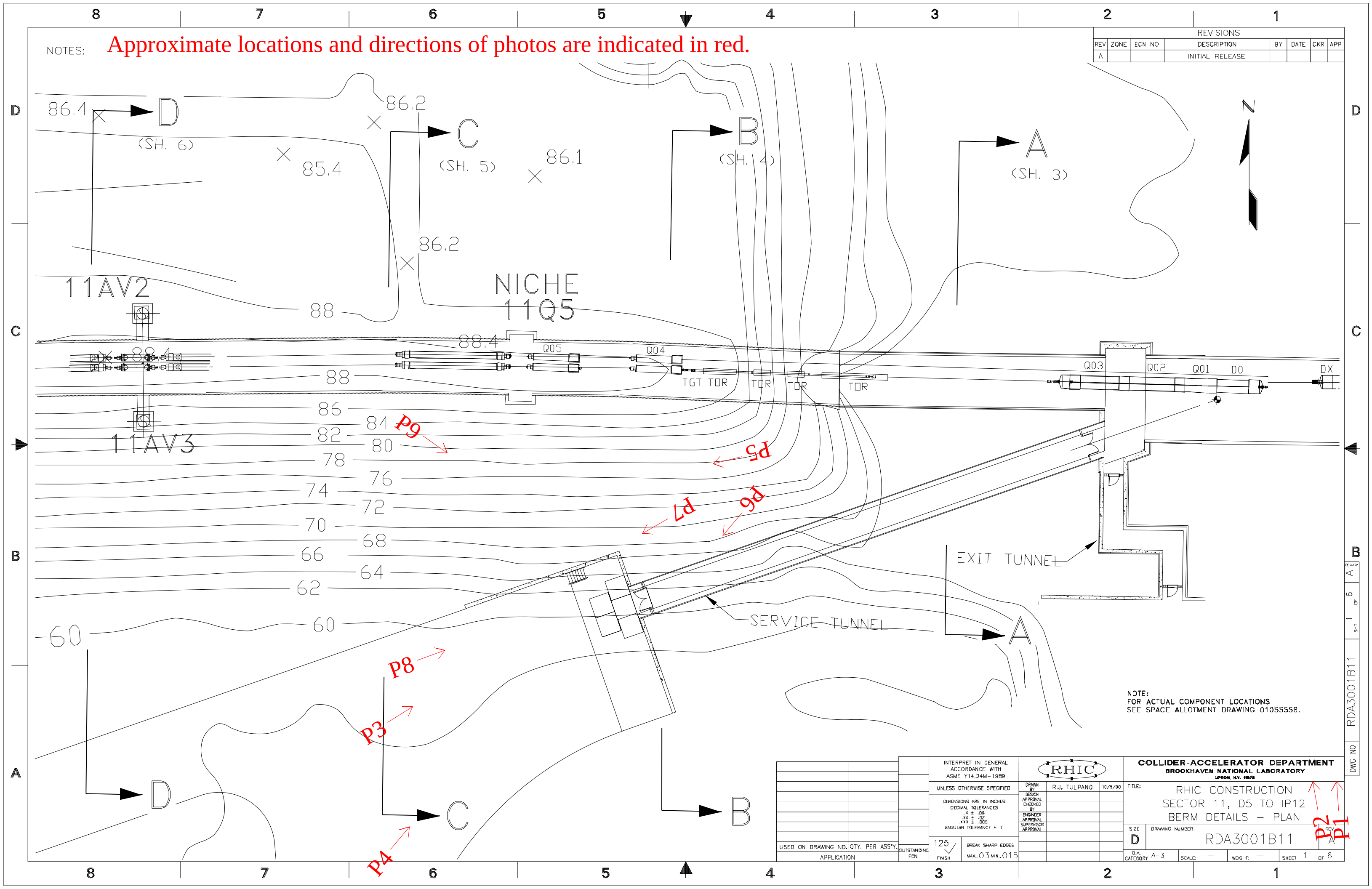
$^{12}C^{6+}$ (73.3 MeV)



http://www.agsrhichome.bnl.gov/RHIC/luminosity/upgrade/ecool/site.html

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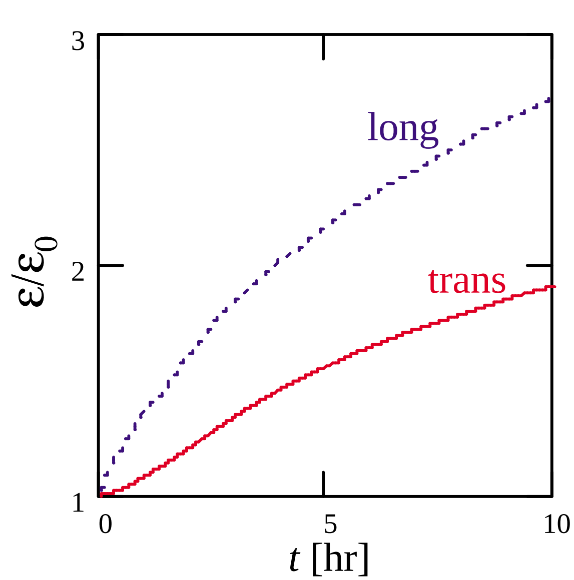
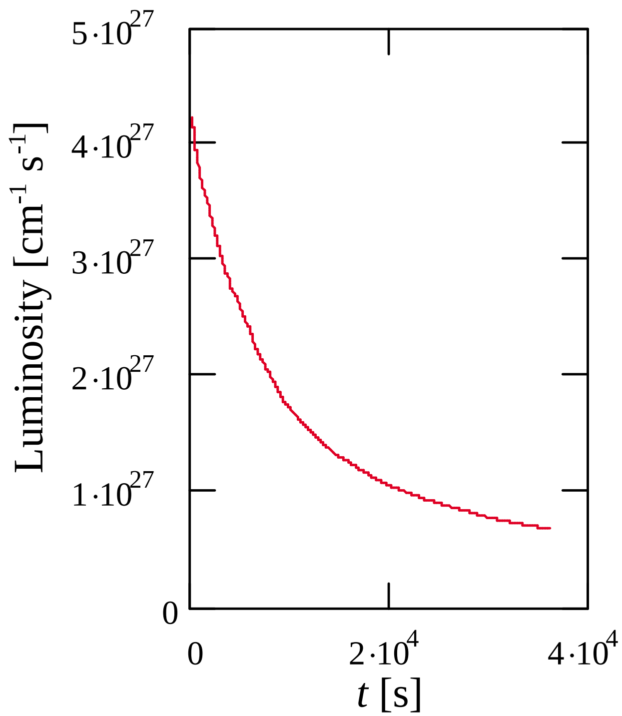
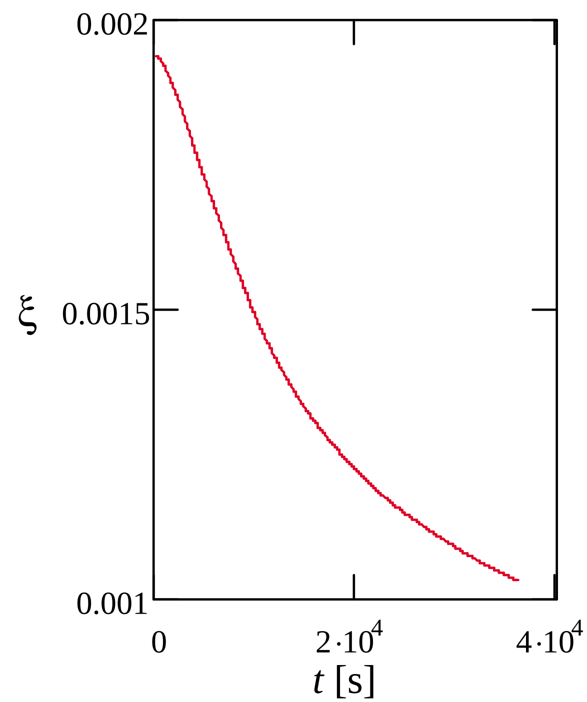
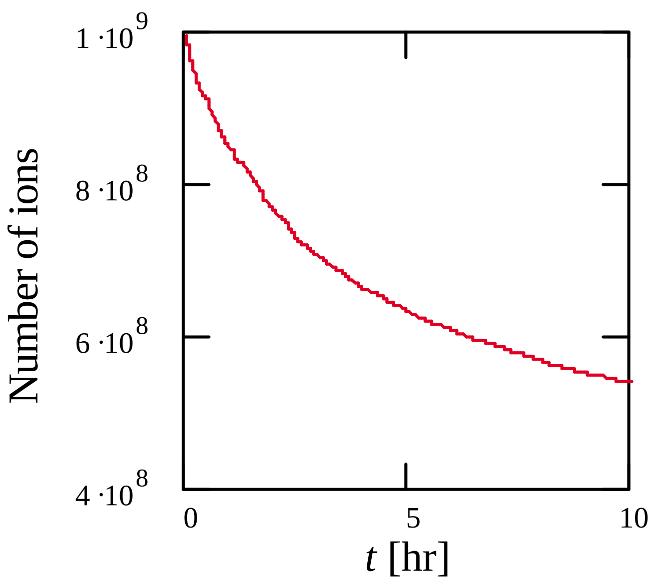
Waldo MacKay
RHIC Upgrades: 8 Dec., 2000

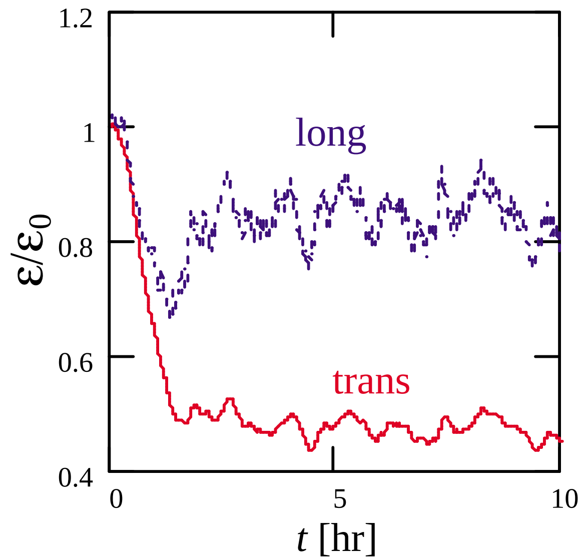


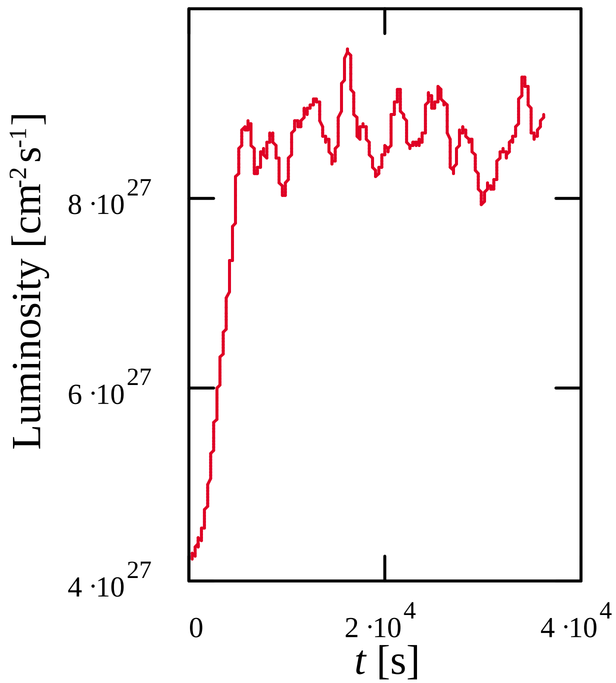


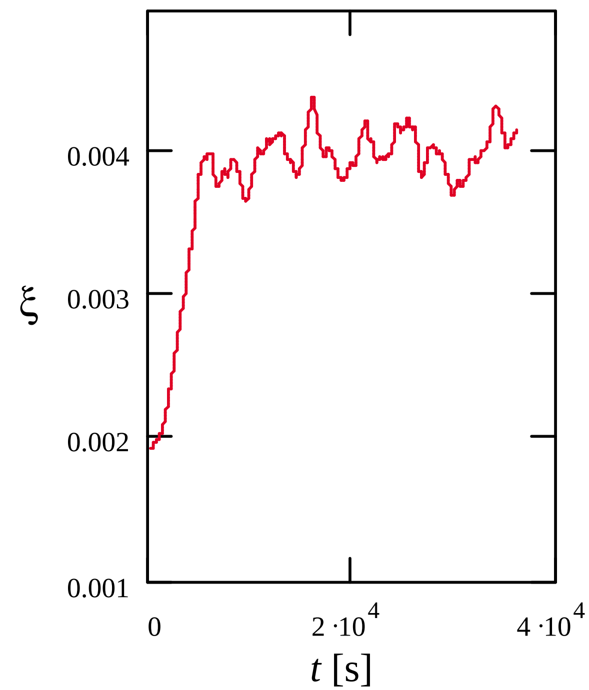


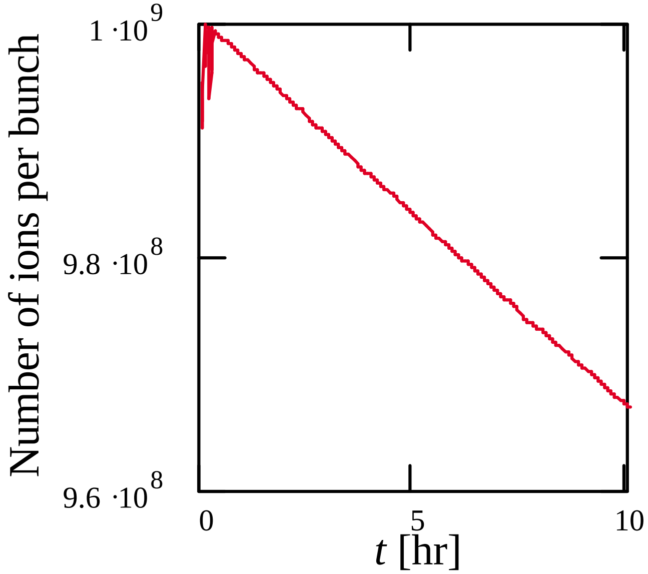


Without cooling we see emittance growth due to IBS and a fairly rapid decrease in luminosity.









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

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

- 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

$$L(t) = L_0 \left(1 + \frac{n_i L_0 \sigma}{M N_0} t\right)^{-2},$$

$$\langle L \rangle = L_0 \left(1 + \frac{n_i L_0 \sigma}{M N_0} t\right)^{-1}.$$

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

To hold luminosity and tune shift constant:

$$L_0 = 8.3 \times 10^{27}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$$

$$\xi = 0.004$$

$\Rightarrow$ Squeeze: $\epsilon \propto \beta^* \propto N$.

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

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'^*	$[\mu\text{rad}]$	79	112	86
RMS beam size, σ^*	$[\mu\text{m}]$	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.

R&D and Installation

- R&D
  - Develop SC electron gun and linac.
    Leads to eRHIC and linac for FEL.
  - Final design of e^- linac and transport.
  - Design of SC solenoid: length & alignment issues.
  - ◦ Study cooling with bunched e^- beam at existing cooler ring.

- Install e^- linac outside tunnel:
  - New building for linac.
  - RHIC downtime: A few months to install solenoid & transport.
  - Linac commissioning is independent of RHIC schedule.

Summary

- First upgrade RDM+:
  - Double number of bunches.
  - Squeeze IR's to $\beta^* = 1\,\text{m}$.
  - 4×design luminosity for Au collisions.
  - 16×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×design luminosity over 5 hr.
  - Reduce emittance and β^* as intensity drops.
  - Keeps total beam intensity at RDM+ level.

- Next upgrade RHIC II for p:
  - Increase ξ to 0.012 by colliding at only two IR's
  - 40×design luminosity.