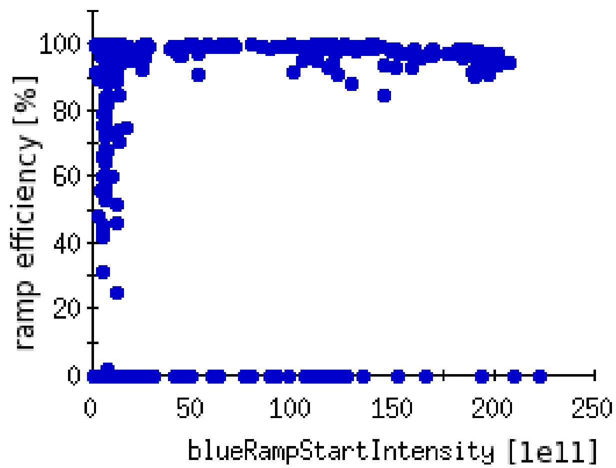
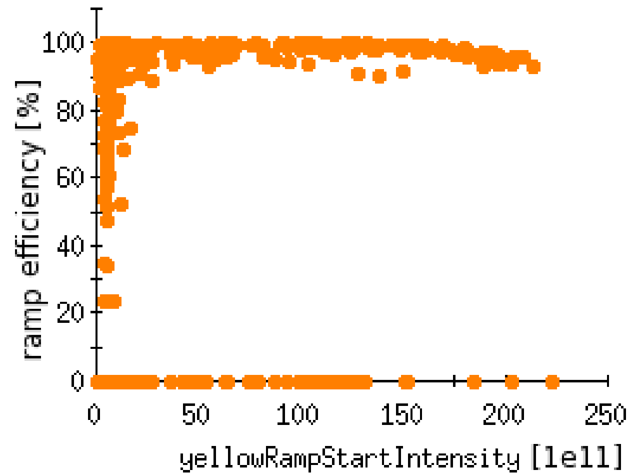
High intensity protons in RHIC

Christoph Montag

Contents

Ramp efficiency



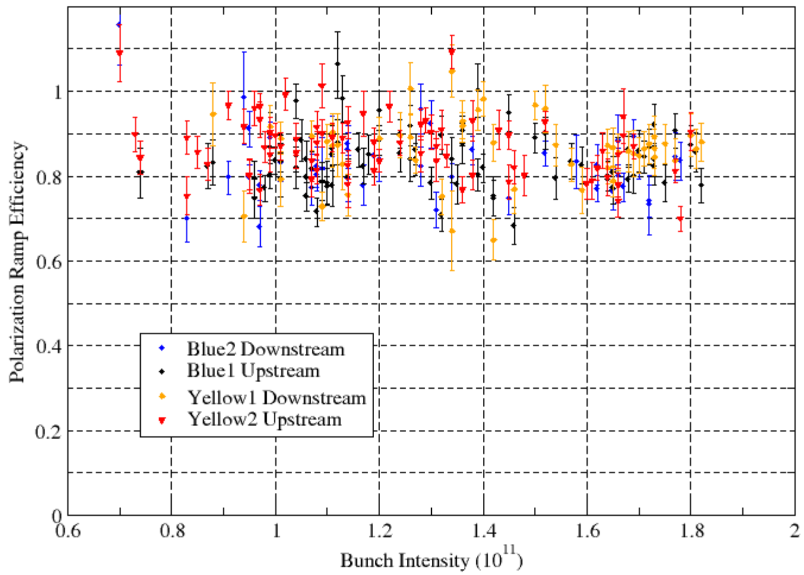


Blue and Yellow ramp efficiencies in percent vs. total beam intensity in Run-11
95 percent ramp efficiency at 2e11 protons/bunch

Losses occur predominantly during final squeeze - high intensity bunches have larger emittance out of AGS, and may be blown up by electron cloud

Polarization transmission on the ramp

$$\eta = \frac{P_{\text{250 GeV store}}}{P_{\text{injection}}}$$



Polarization transmission on the ramp is independent of intensity

Radiation safety

- Accelerator Safety Envelope (ASE) is being increased to 5e13 protons/beam at 250 GeV, or 4.5e11 protons/bunch in 109 bunches/beam
- Fences around ventilation shafts will be installed next summer, as well as improved shielding walls
- Upgrades need to be reviewed
- For short commissioning tests temporary precautions can be reviewed and approved

Sufficiently high limits will be in place by Run-13

RHIC beam dump

- RHIC beam dump was designed for 1e11 protons in 56 bunches per beam, with a safety factor of 2
- In Run-10, 250 GeV beam aborts at 1.2e11 in 109 bunches/beam caused magnet quenches downstream of the dump - not unexpected since safety factor 2 was exceeded
- Based on GEANT simulations, the wall thickness of the beam pipe for the circulating RHIC beam next to the dump ws increased to increase the safe limit by a factor 2 for Run-11

- Replacing the beam pipe raised concerns about exposing activated carbon to air

- Beam pipe was thickened by inserting 20 short (5 inches) sleeves

- No magnet quenches were observed during Run-11, with bunch intensities up to 2e11/bunch

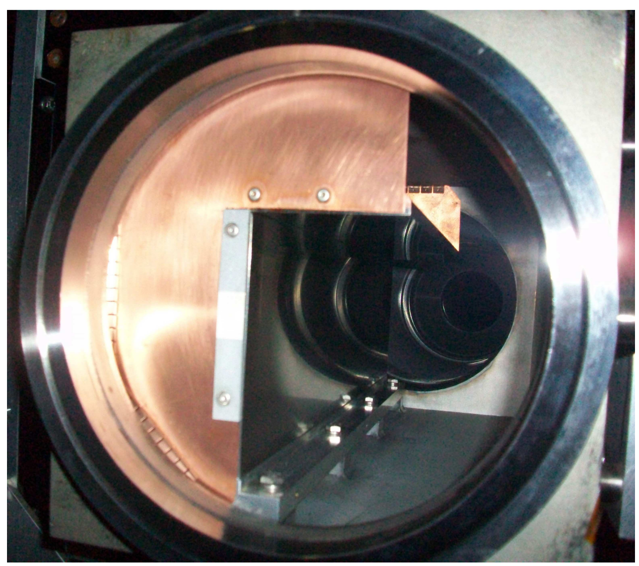
- OK up to 2.5e11/bunch according to simulations, need to learn whether 3e11/bunch causes problems

Beam dump is well understood, and predictive power of simulations is high
Can be studied experimentally with unpolarized protons
If needed, further upgrades can be designed and implemented

Collimation system

- Present two-stage system of one-sided collimators proven to reduce detector backgrounds sufficiently for intensities up to 2e11/bunch

- Recently inspected Yellow primary collimator shows flat surface with no damage



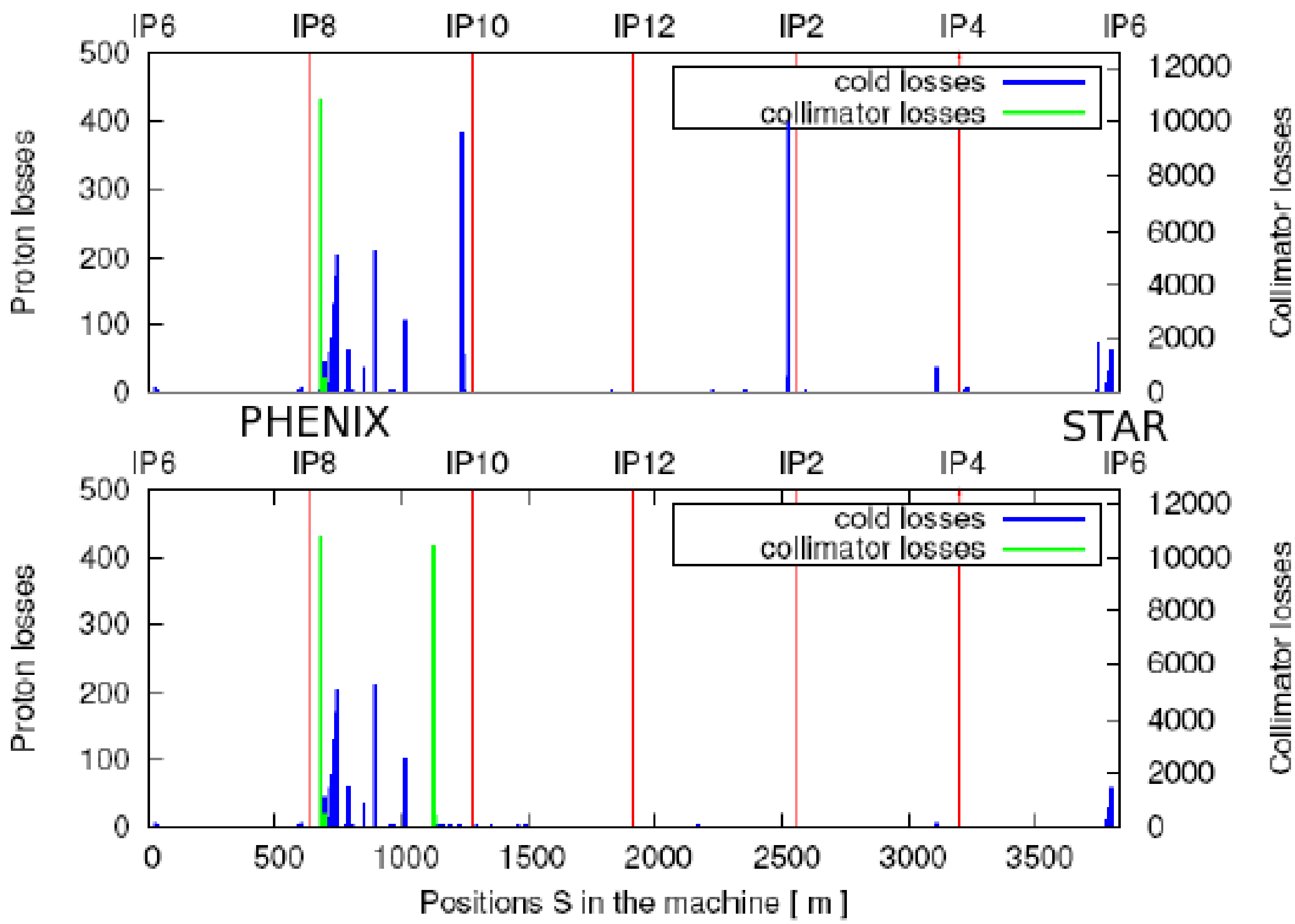
- Assuming that backgrounds scale linearly with intensity, both STAR and PHENIX expect no problems at 3e11/bunch

- Upgraded system with double-sided collimators and newly located secondary collimators is being investigated in simulations as a back-up

- Double-sided collimator system less sensitive to orbit changes

Loss pattern from BLUE horizontal collimators

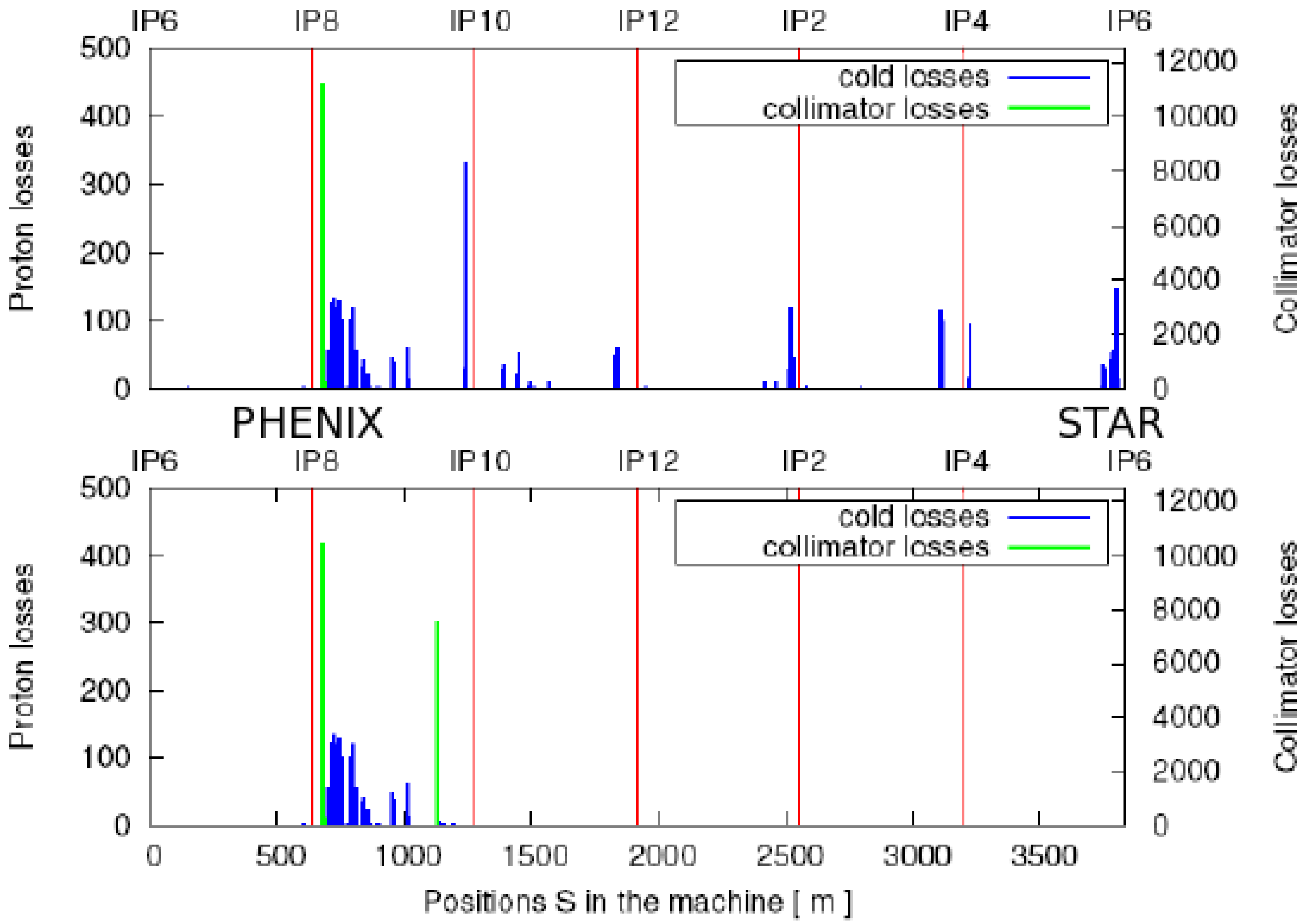
Beam direction left-to-right



Comparison of longitudinal loss patterns between the current RHIC collimation system (top) and its proposed upgrade (bottom) for Blue Horizontal.

Loss pattern from BLUE vertical collimators

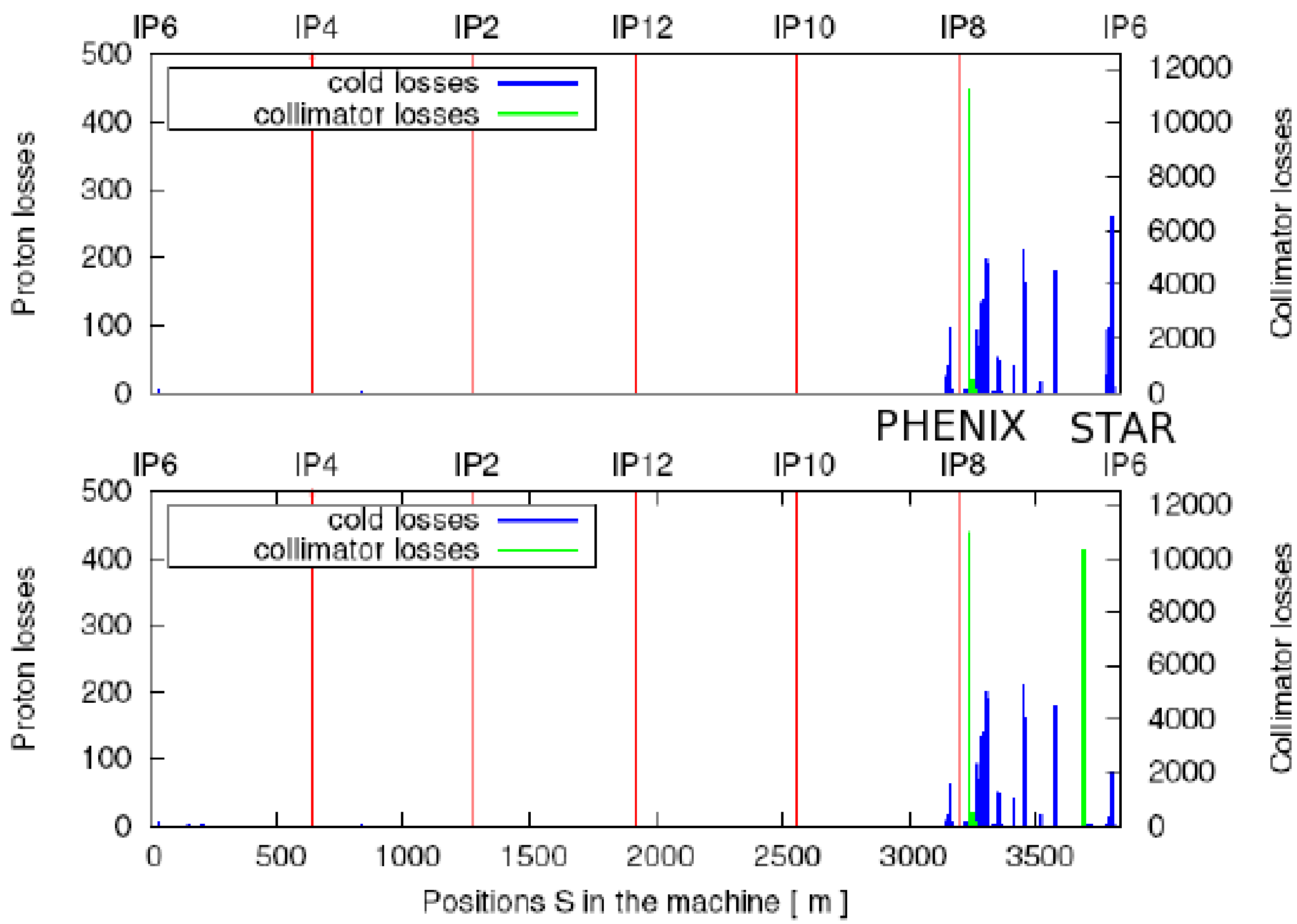
Beam direction left-to-right



Comparison of longitudinal loss patterns between the current RHIC collimation system (top) and its proposed upgrade (bottom) for Blue Vertical.

Loss pattern from YELLOW horizontal collimators

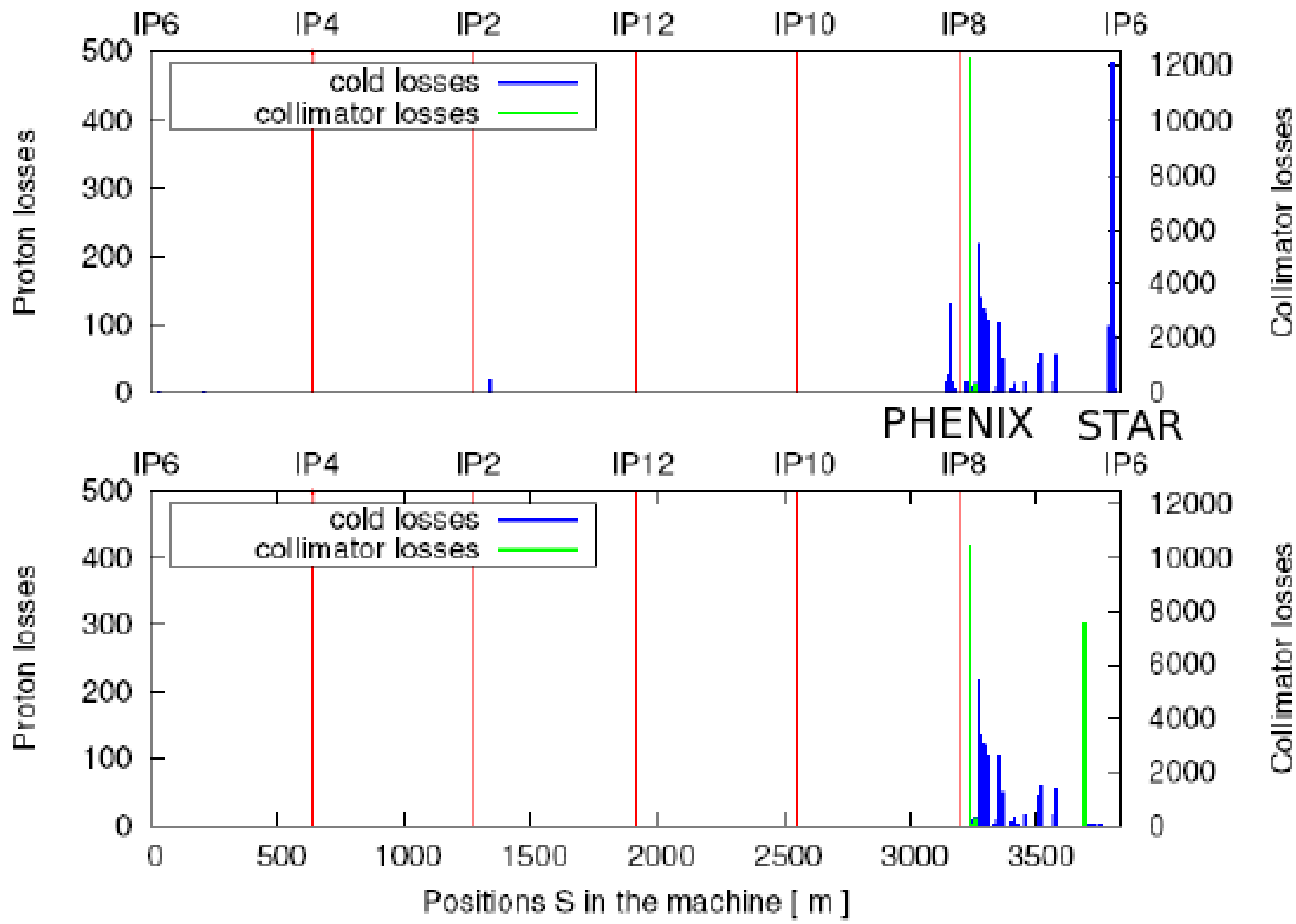
Beam direction left-to-right



Comparison of longitudinal loss patterns between the current RHIC collimation system (top) and its proposed upgrade (bottom) for Yellow Horizontal.

Loss pattern from YELLOW vertical collimators

Beam direction left-to-right



Comparison of longitudinal loss patterns between the current RHIC collimation system (top) and its proposed upgrade (bottom) for Yellow Vertical.

- Upgraded system would significantly reduce losses around the ring and in triplet upstream of STAR

- Effect of showers generated by new secondary collimators upstream of STAR in YELLOW ring to be investigated

- Installation of new secondary collimators in ”missing magnet” location (dispersion suppressor) costly and labor intensive but feasible

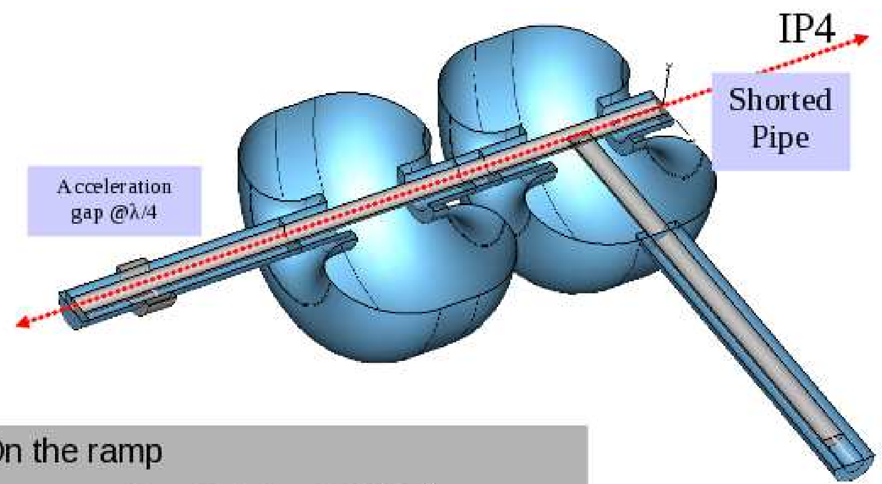
Can be studied experimentally with unpolarized protons
In case present system turns out to be insufficient at high intensity, an upgrade scenario has been developed

RF system

Three RF systems in RHIC:

1. 9 MHz system for injection and ramp
2. 28 MHz system for store (after rebucketing)
3. 197 MHz system for store (after rebucketing)

9 MHz RF



On the ramp

- Max B-dot = 0.015 T/s
- Vrf = 20 kV
- Elong.=0.66 eVs
- Frf = 9.3 MHz (120 bunches)

- New system, still being optimized
- Purpose of the system is to improve longitudinal injection matching from AGS
- Longer bunches during ramp have smaller peak current

Modifications for Run-12

- Re-designed cavity with lower impedance by lowering Q from 2400 to 642 (no copper plating)

- Very powerful amplifier now better matched for this low-Q cavity

- Spark gap protection allows higher feedback gains to fight instabilities

- Fast feedback reduces cavity $R/Q = 34.5\,\Omega$ by factor 30

- Shunt impedance is $(34.5 \cdot 642/30)\,\Omega = 738\,\Omega$

- Cavity induced voltage per beam with 3e11 in 120 short bunches ($I = 0.9\,\mathrm{A}$) is
$U_{\mathrm{ind.}} = 0.9 \cdot 738\,\mathrm{V} = 664\,\mathrm{V} << U_{\mathrm{RF}} = 20\,\mathrm{kV}$

Induced voltage is small compared to cavity voltage

28 MHz RF

- Not involved in injection and ramping
- Used offset frequency technique so cavity is always active on the ramp, but does not couple to the beam (M. Brennan)
- Mechanical tuner does not have to move when cavity is coupled to the beam
- Fundamental beam loading limit is 9e11 protons/bunch

Further studies required to determine transient beam loading effects and higher order mode-driven instabilities

197 MHz RF

- System was limited by power dissipation in couplers
- Separating common cavities (common to both beams) increases the beam intensity limit by a factor 4 (power scales quadratically with beam current) to 4e11/bunch
- Acceptable 197 MHz voltage expected to be limited by off-momentum dynamic aperture

Entire RF system expected to be able to handle 3e11 protons/bunch, but further studies are required on the 28 MHz system to confirm this

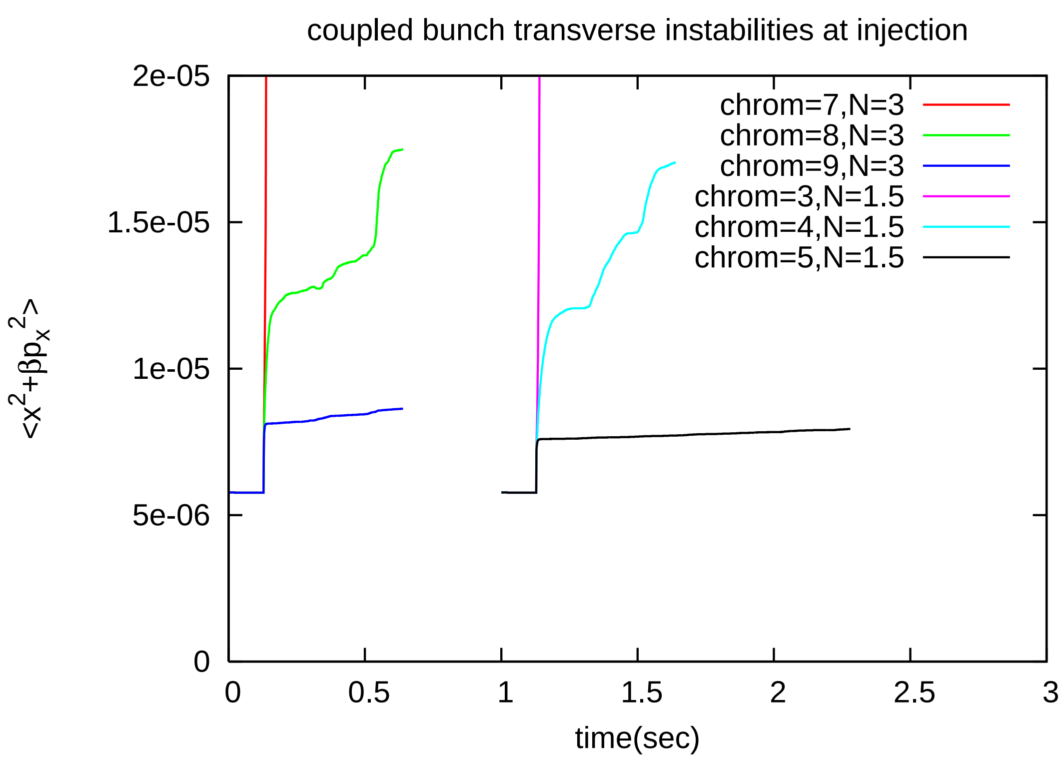
Instabilities

- With proton bunch intensities up to 2e11, never experienced any coherent instabilities that were not easily overcome by chromaticity corrections

- Simulations of coherent instabilities at injection
  - transverse impedance:
    * space charge (direct and image currents)
    * resistive wall
    * BPMs, abort kicker, and unshielded bellows
  - longitudinal impedance: broadband, yielding correct $|Z/n|$

Simulation results for coherent instabilities at injection

14 ns FWHM bunch length



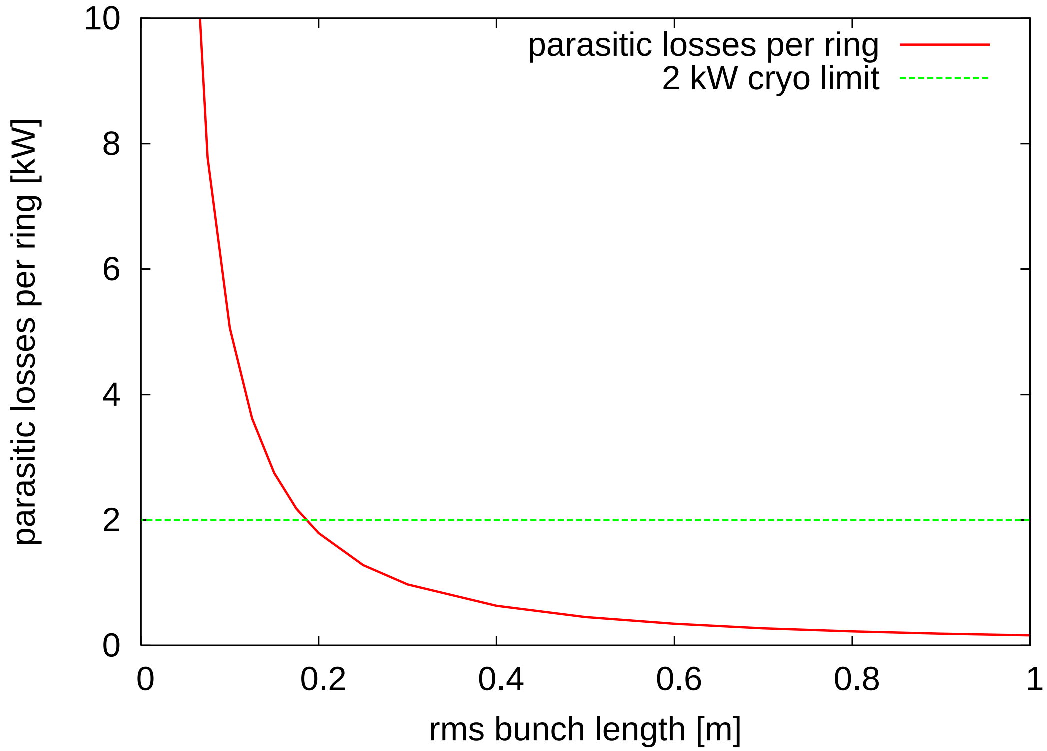
Injection situation expected to be worst due to low synchrotron frequency (5 Hz) and small γ

- Electron cloud induced dynamic pressure rise may cause emittance growth below instability threshold (Zhang and Ptitsyn, PRST-AB 11, 051001 (2008))

- Threshold has increased over the years (scrubbing?), from 1.3e11 in Run-6 to $\geq$ 2e11 in Run-11. In-situ NEG coating will make this a non-issue

To be studied experimentally with unpolarized protons in Run-12, measuring bunch-by-bunch BTFs for different intensities

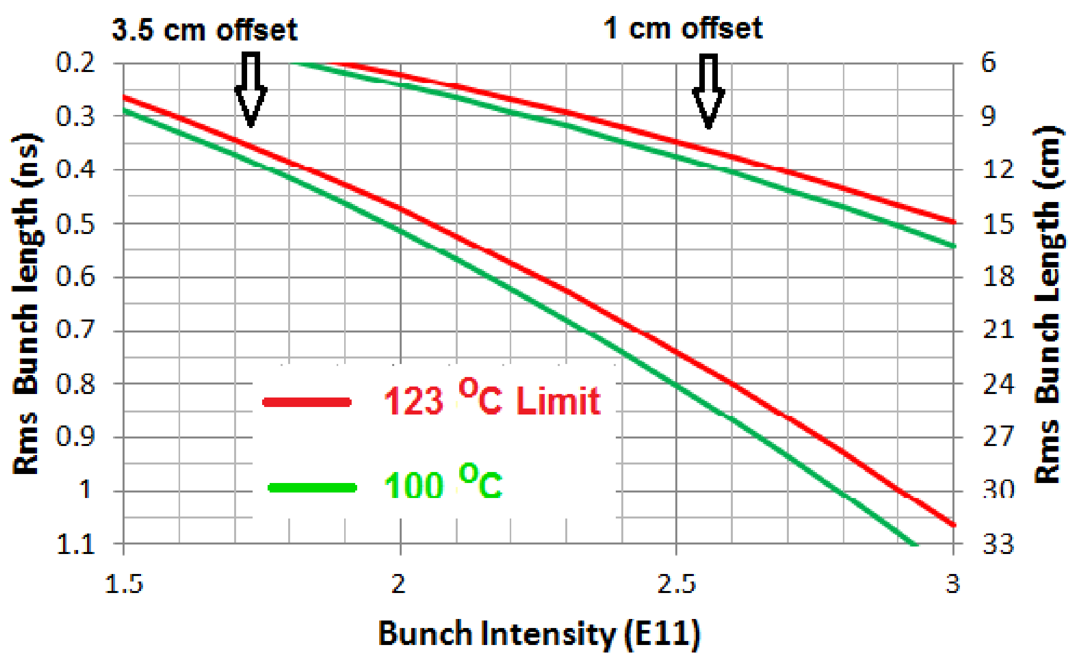
Resistive wall heating



At 3e11/bunch need to limit bunch length to $\sigma_s \geq 20\,\text{cm}$
For shorter bunches in-situ beampipe coating is required
(M. Blaskiewicz talk)

Cryogenic BPM cables

Preliminary estimates of RHIC operational limits due to cryogenic BPM cable heating (specified maximum 123 degrees C).



- 3.5 cm orbit offset is limited by beam pipe radius; 1 cm maximum offset requires orbit interlock system

- Using orbit feedback maximum offsets below a millimeter are routinely achieved. Need interlock for accidents.

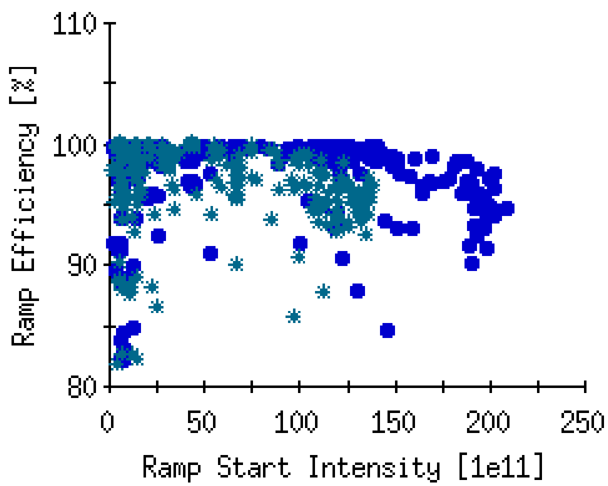
At 3e11/bunch, rms bunch length as low as $\sigma_s = 17$ cm is permissible
Shorter bunches require new cryogenic BPM cables; upgrade requires two summer shutdowns, starting next year

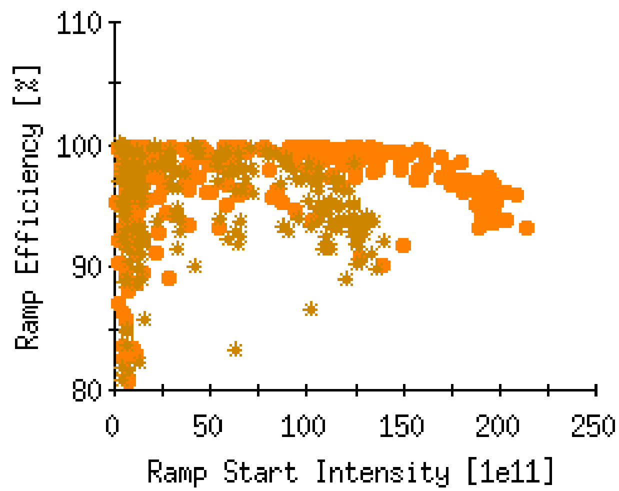
Summary

- Ramp efficiency: No problem due to lower emittance from AGS
- Radiation safety: 4.5e11 protons/bunch allowed by FY2013
- RHIC beam dump: Likely OK, sufficient understanding to design upgrade if necessary
- Collimation system: Most likely OK, upgrade as back-up
- RF system: Likely no problem; 28 MHz system requires further studies
- Instabilities: To be studied experimentally during Run-12
- Resistive wall heating: OK at 3e11 with $\sigma_s \geq 20\,\mathrm{cm}$
- Cryogenic BPM cables: OK at 3e11 with $\sigma_s \geq 20\,\mathrm{cm}$ and 1cm orbit interlock

Back-up slides

Ramp efficiency in Run-11 vs. Run-9



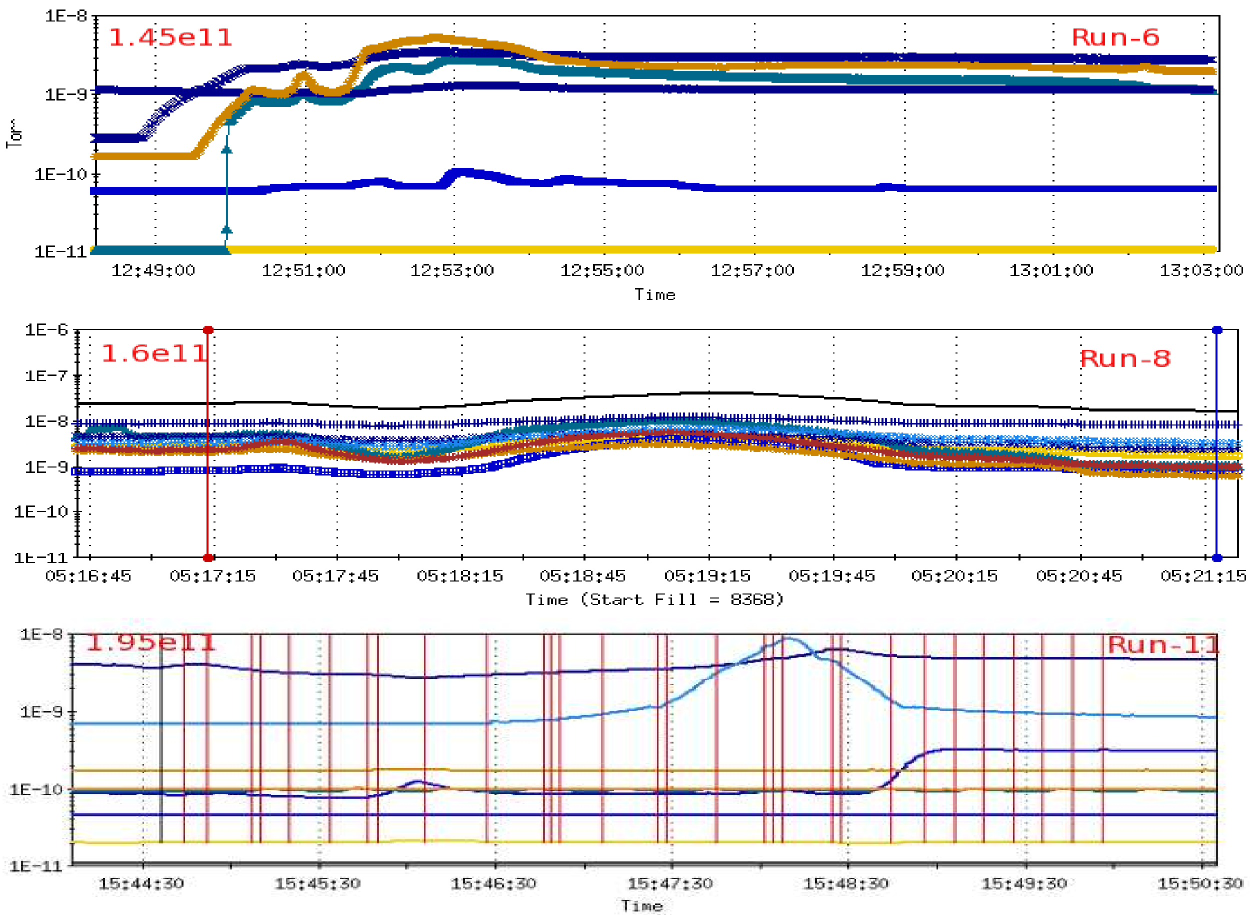


Blue and Yellow ramp efficiencies in percent vs. total beam intensity in Run-9

95 percent ramp efficiency at 1.3e11 protons/bunch

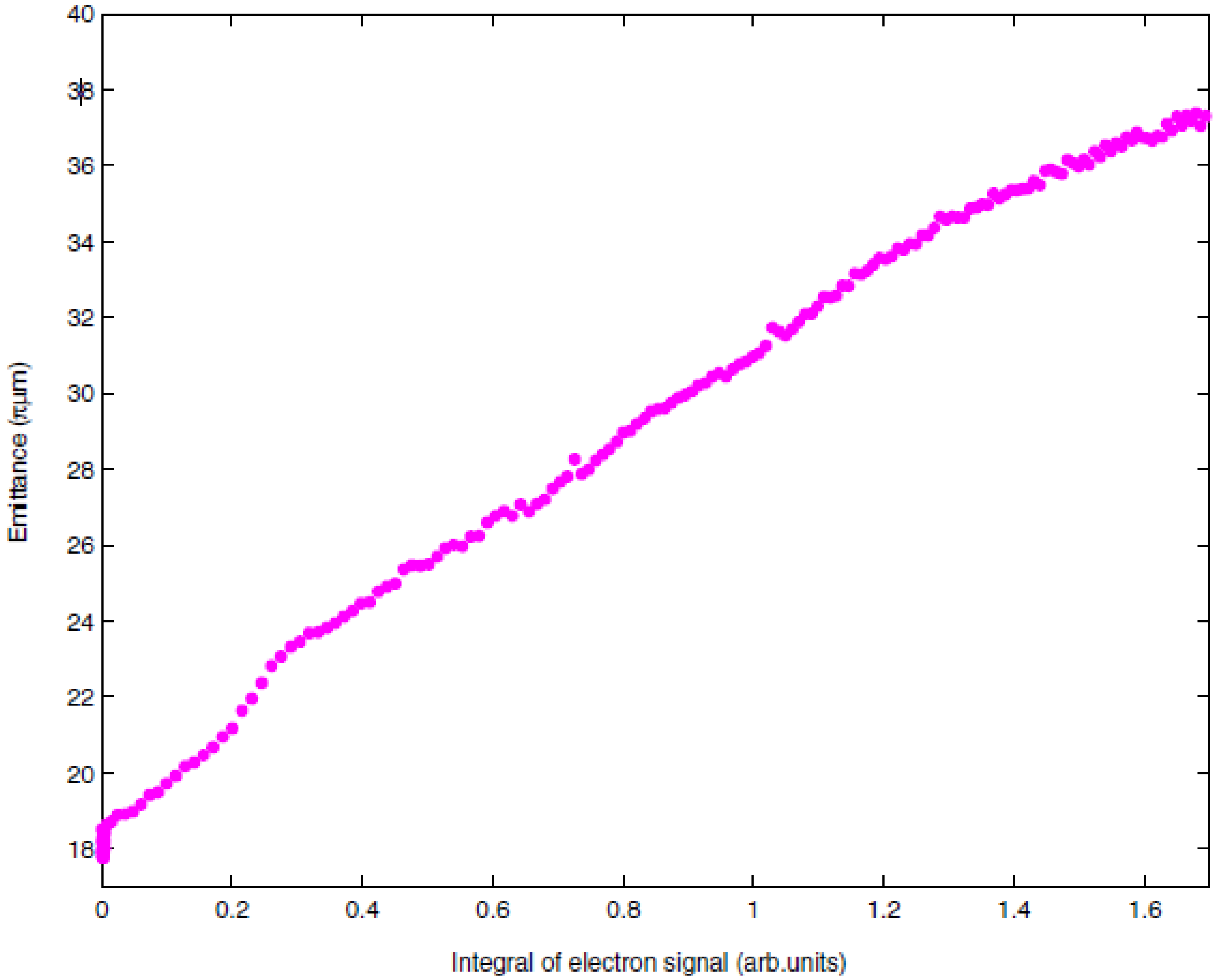
Significant improvement in Run-11, with 95 percent at 2e11

Vacuum pressures on ramps in different runs



Similar pressure bumps at ever higher bunch inteisities over time

Blue ring vertical emittance growth vs. integrated electron signal



BPM and cryo limits