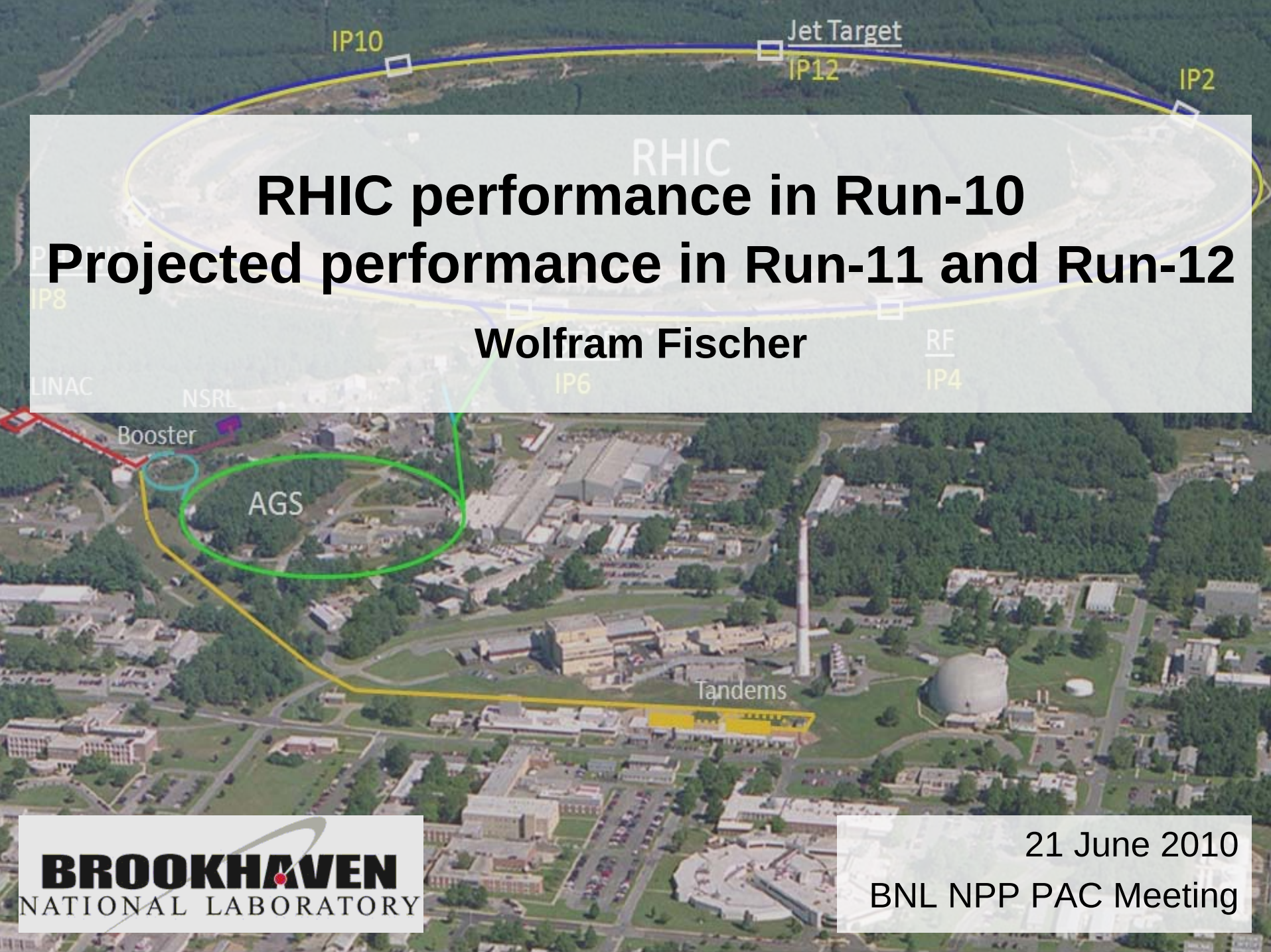


RHIC performance in Run-10
Projected performance in Run-11 and Run-12

Wolfram Fischer

BROOKHAVEN NATIONAL LABORATORY

21 June 2010

BNL NPP PAC Meeting

Content

RHIC Au-Au performance in Run-10

- High E: s_{NN} = 200 GeV
  (high = 100 GeV/nucleon)
- Medium E: s_{NN} = 62.4, 39 GeV
  (high > medium > low)
- Low E: s_{NN} = 7.7, 5.75, 5.0 GeV
  (low = below nominal injection)

Projected performance in Run-11

- Heavy ions (Au at various energies, U at high energy)
- Polarized protons at s = 500 GeV

Projected performance in Run-12

RHIC luminosity and polarization goals

Parameter	Unit	Achieved	Enhanced design	Next *L* upgrade
Au-Au operation		(2010)		(≥2012)
Energy	GeV/nucleon	100	100	100
No of bunches	…	111	111	111
Bunch intensity	10^9	1.1	1.0	1.0
Average *L*	**10^{26}cm^{-2}s^{-1}**	**20**	**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 *L*	**10^{30}cm^{-2}s^{-1}**	**24 / 55**	**30 / 150**	**300**
Polarization *P*	**%**	**55 / 34**	**70**	**70**

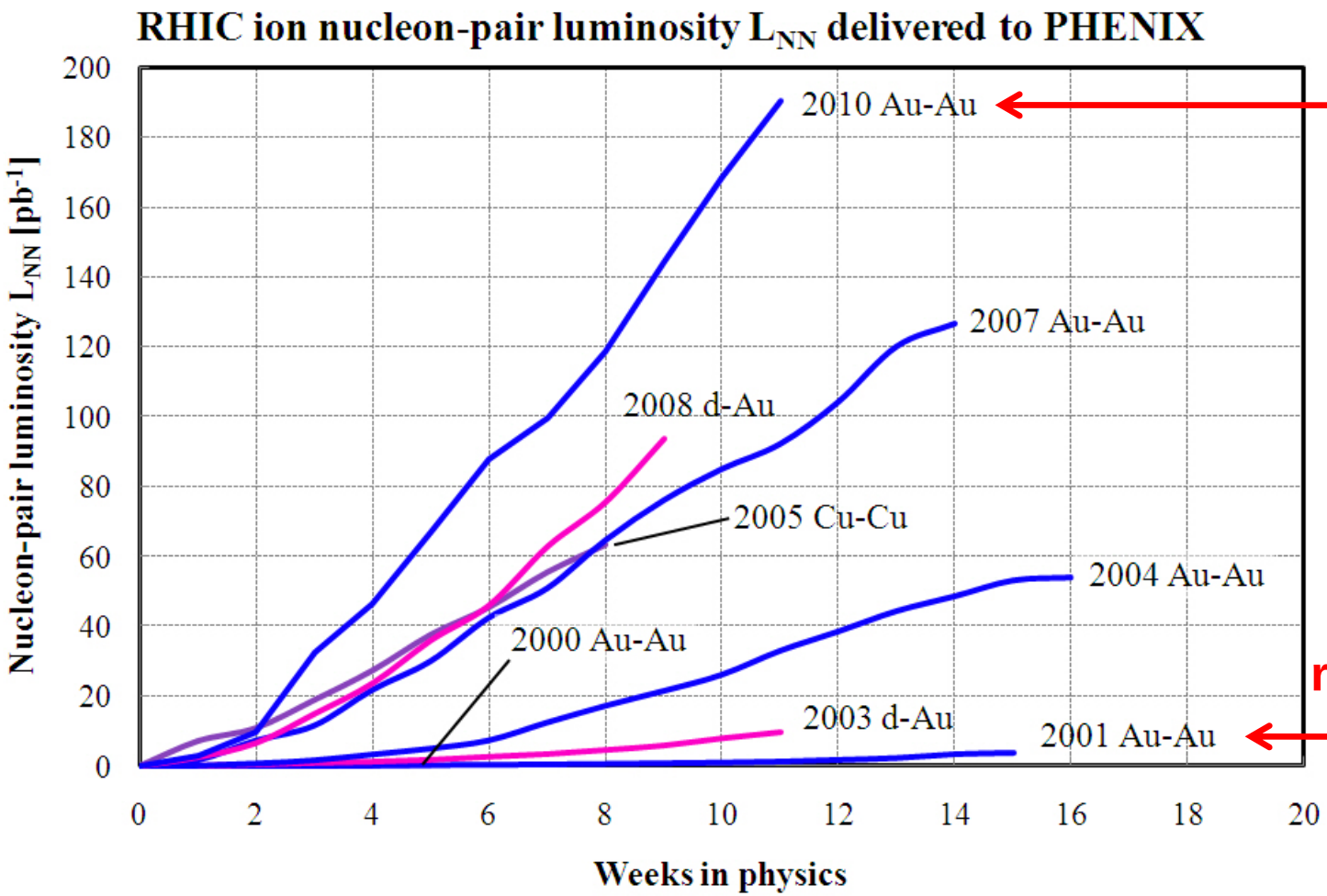
Had previously a goal of 60 here – but low luminosity lifetime with low β^*.

Run-10 main upgrades and events

- Yellow 10 o'clock snake out for repair
- Start-up ramp-up in 3.5 weeks
  (1.5 weeks longer than plan – largely due to unfinished shut-down work)
- Lattice with higher phase advances in both rings (IBS suppression)
- Separation of γ_{tr} by 1.2 units (e-cloud reduction at transition)
- 2 mrad crossing angle in all IPs without collision (DX training reduction)
- New auto transformer in Yellow (reduction of flattop-to-ramp main magnet power supply transients – test for pp in Run-11)
- Tune and coupling feedback on every development ramp
- First successful ramp (ever in any accelerator) with simultaneous orbit, tune, coupling and chromaticity feedbacks
- Tested 1 Hz orbit feedback (ramp and store)
- Tested 10 Hz orbit feedback (store) (counteracts mechanical triplet vibrations)
- First use of Yellow dipole feedback at transition
  (more reproducible transition crossing)
- Started with $\beta^* = 60$ cm, raised to 70 cm due to chromatic abberations
- First use of vertical stochastic cooling, simultaneous with longitudinal

RHIC heavy ions – luminosity evolution

$L_{NN} = L\ N_1 N_2$ (= luminosity for beam of nucleons, not ions)

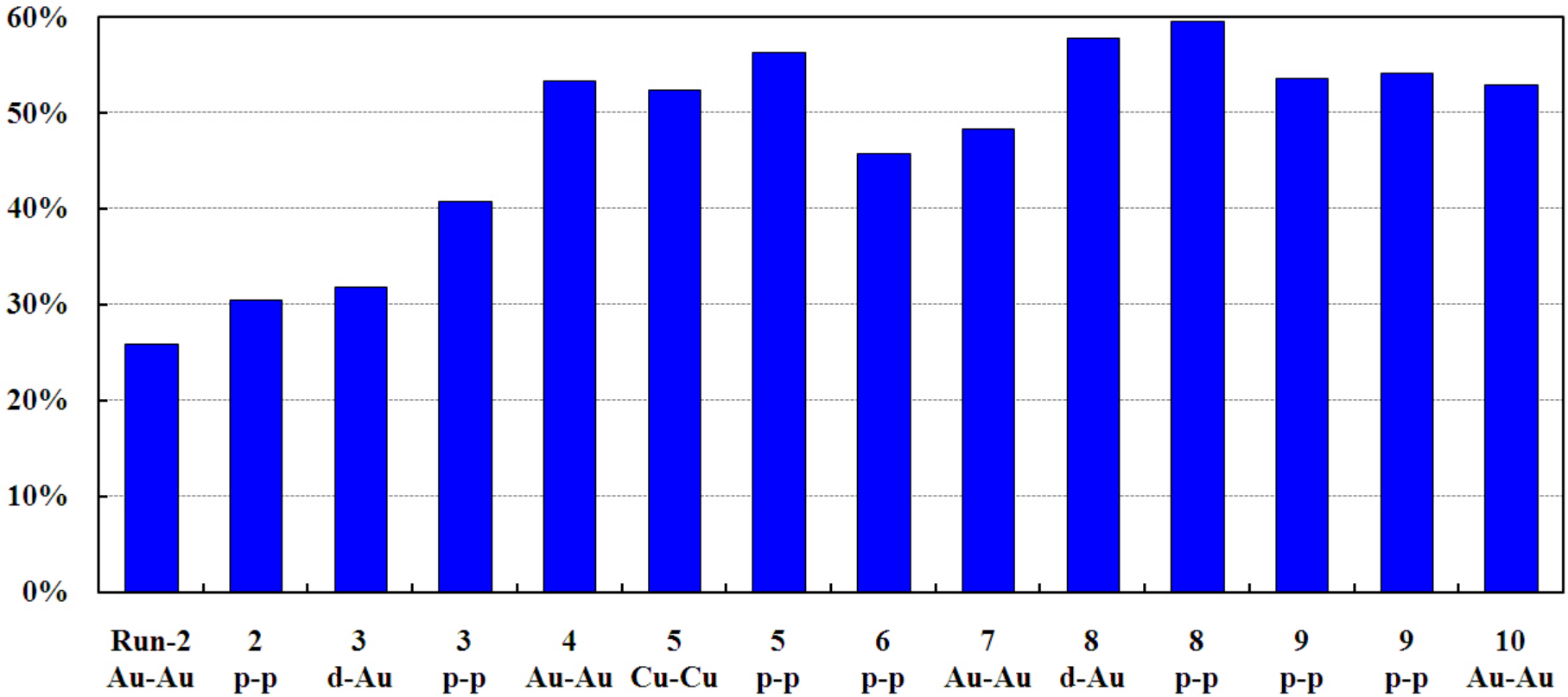


10x design in 2010

Run Coordinator: K. Brown

reached design in 2001

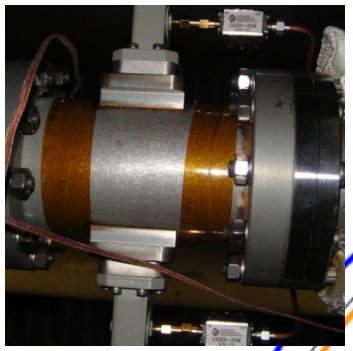
RHIC calendar time in store (high energy parts only)



Time in store settled around 55% of calendar time.
Expect to hold this value in the future.

RHIC – 3D stochastic cooling for heavy ions

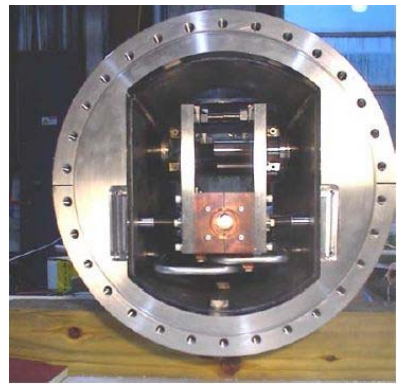
longitudinal pickup



Y h+v pickups

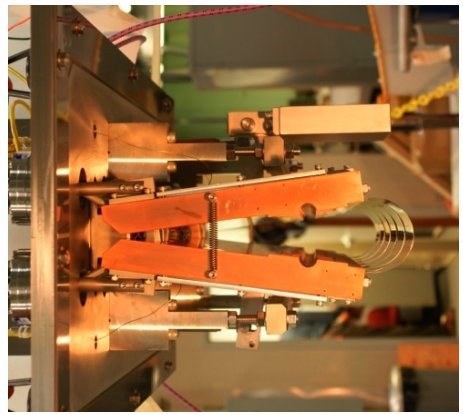
B h+v kickers

longitudinal kicker (closed)



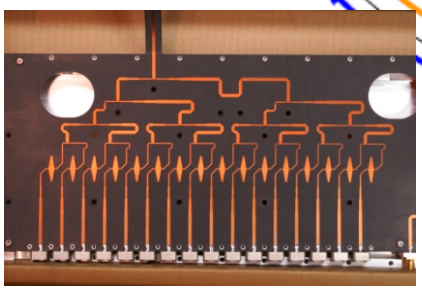
Fiber Optic Links, transverse

MicroWave Links, longitudinal



horizontal kicker (open)

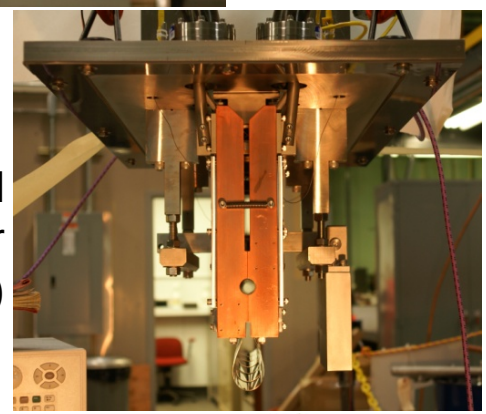
horizontal and vertical pickups



B h+v pickups

Y h+v kickers

vertical kicker (closed)



5-9 GHz, cooling times ~1 h

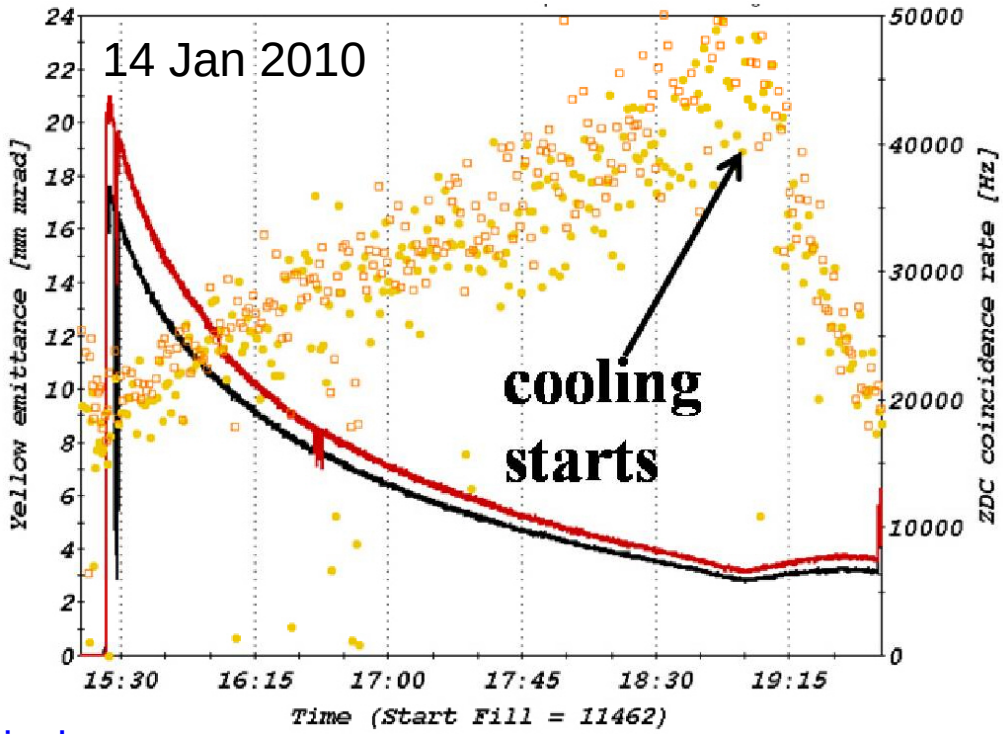
M. Brennan, M. Blaskiewicz, F. Severino, Phys. Rev. Lett. **100** 174803 (2008); PRST-AB, PAC, EPAC

RHIC – bunched beam stochastic cooling for heavy ions

M. Brennan
M. Blaskiewicz et al.

- **Longitudinal cooling since 2007**
- **First transverse (vertical) cooling in 2010**

- **So far stochastic cooling increased average store luminosity by factor 2**
- **Expect another factor 2 with full 3D cooling**



Issues:

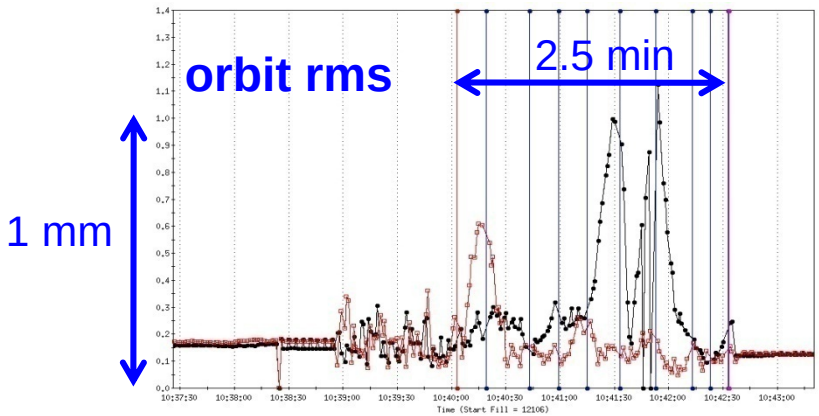
- Vacuum leaks at feedthroughs
- Mechanical motion of long. kickers
- Cross-talk between Blue and Yellow vertical system (addressed by 100 MHz shift in Blue)
- Construction, installation, and commissioning of horizontal systems

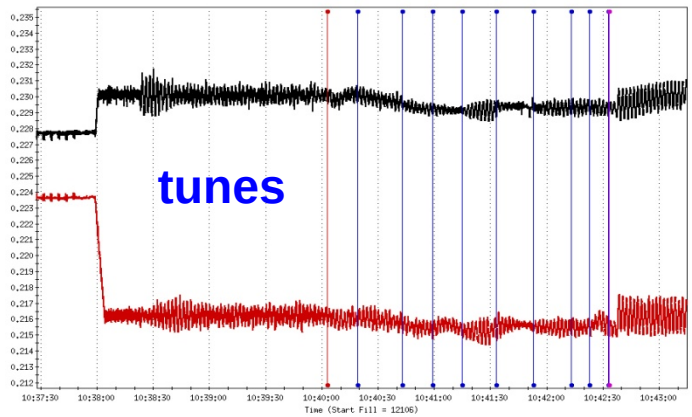
Upgrades for heavy ions and polarized protons – feedbacks

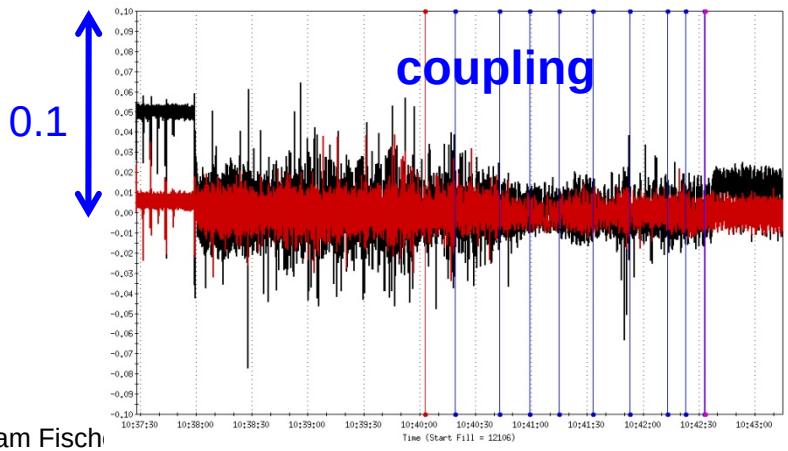
- 1 Hz global orbit feedback (ramp and store)
- 1 Hz orbit, tune, coupling, chromaticity feedback (ramp)
- 10 Hz local orbit feedback (store)

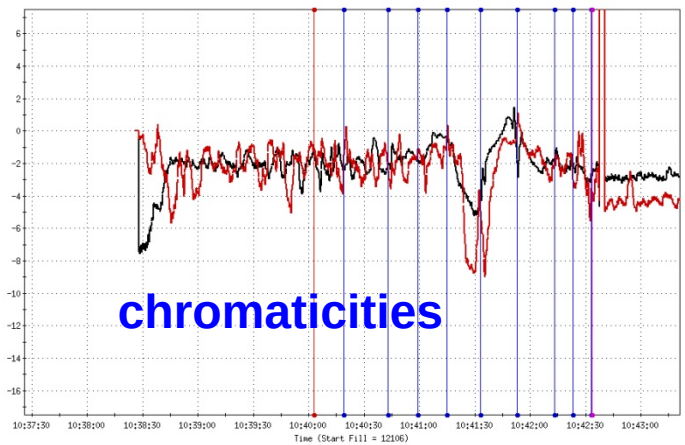
M. Minty
A. Marusic
R. Michnoff
et al.

First ramp with simultaneous orbit, tune, coupling and chromaticity feedback (both beams)



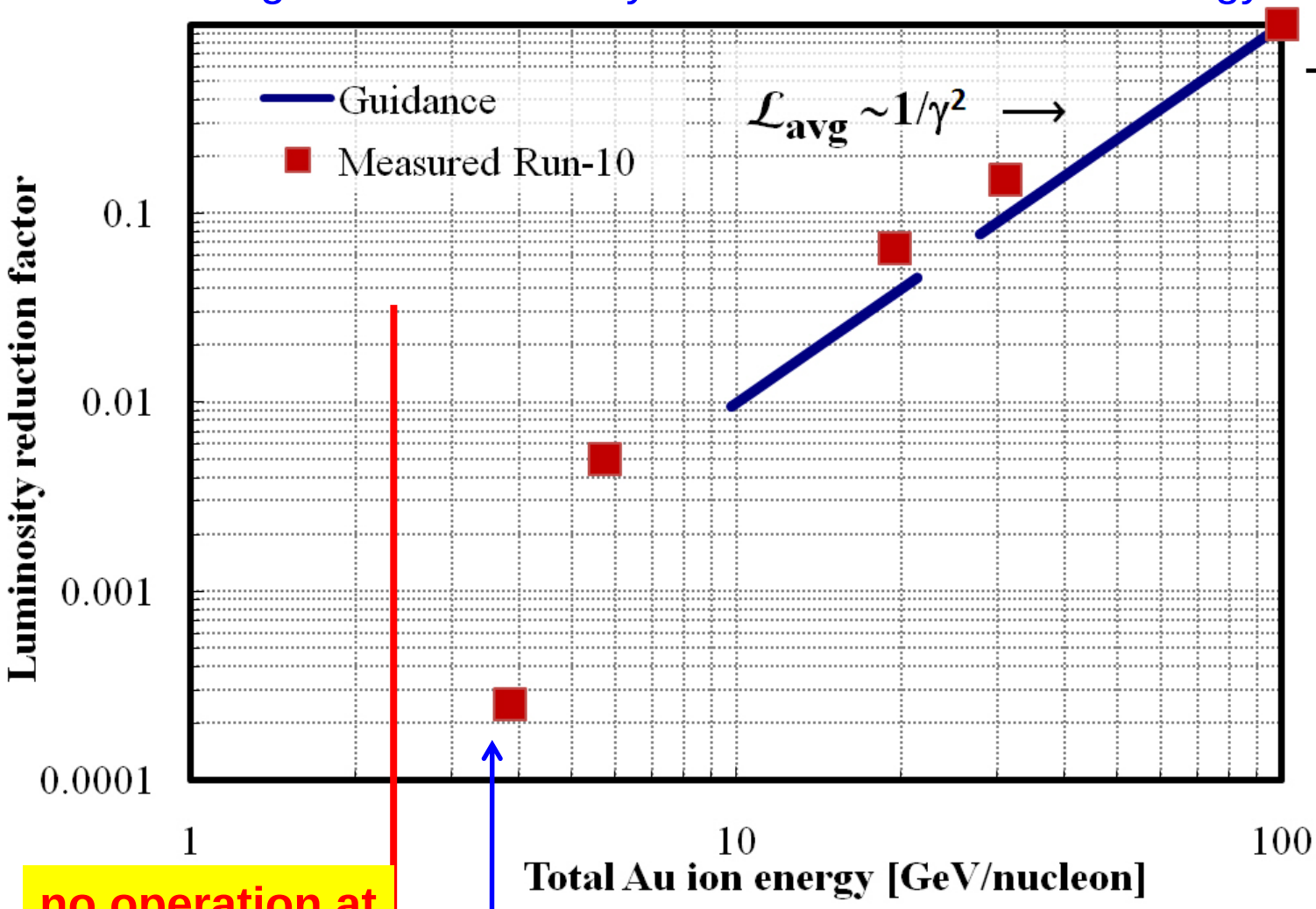






Run-10 Au-Au medium and low energies

Average store luminosity as a function of beam energy



T. Satogata, G. Marr, A. Drees, et al.

no operation at or below here (2.5 GeV/nucleon)

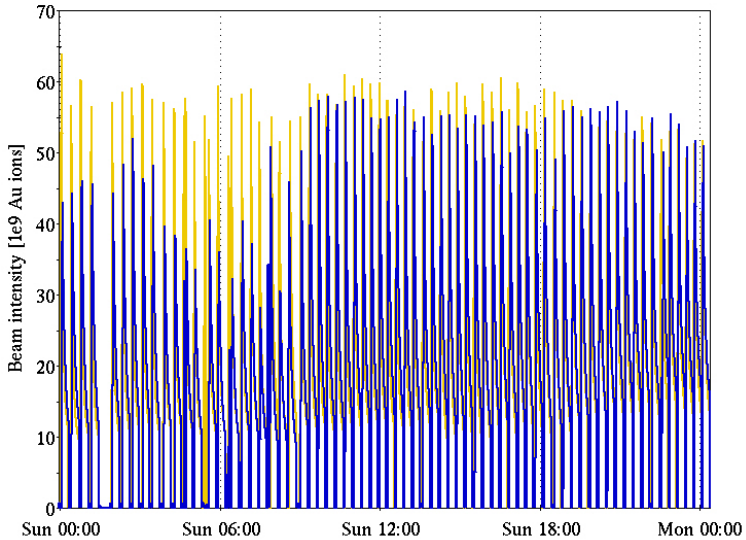
3.85 GeV/nucleon (not fully analyzed, large error, probably too low)

RHIC – low energy heavy ion operation (T. Satogata et al.)

In search of critical point in QCD phase diagram, energy scan now extends below nominal injection energy (which is already 30% below design)

Effects to contend with (numbers for 20% nominal ($B\rho$)

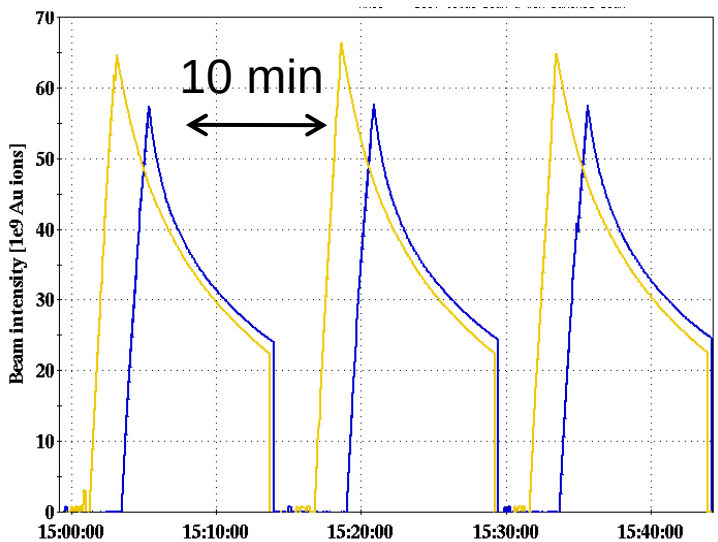
- Large beam sizes **(longitudinal and transverse) controlling losses becomes critical**
- Large magnetic field errors **(b_3 ~ 10, b_5 ~ 6 units from persistent currents in superconducting magnets)**
- Intrabeam scattering **(debunching ~min)**
- Space charge **($\Delta Q_{Laslett}$ ~ 0.1 – new regime for collider)**
- Beam-beam **(ξ/IP ~ 0.003)**
- Low event rates **(~ 1 Hz)**



Full energy injection allows for short stores

- At 38% of nominal injection ($B\rho$)

- **Could not operate at 20% of nominal injection (s_{NN} = 5 GeV)**
- **Need guidance for importance of increased luminosity (factor 3-6) at low s_{NN} for electron cooling effort**



Run-11 and Run-12 working assumptions

(from BUPs, subject to discussion and change)

Requests for Run-11

- Au-Au : s_{NN} = 200 GeV
- Au-Au : s_{NN} = 18, 27 GeV
- U-U : s_{NN} 200 GeV
- p -p : s = 500 GeV
- p -p : s = 500 GeV (pp2pp)
- IP2 DY test : 3rd collision with proton beams

Preferred order for machine:

Au-Au, U-U, p -p (aware that PHENIX prefers to start with p -p)

Requests for Run-12

- Au-Au : s_{NN} = 200 GeV
- p -p : s = 500 GeV
- p-p (unpolarized) : s = 62.4, 39, 27, 22.4 GV

Run-11 upgrades for heavy ions

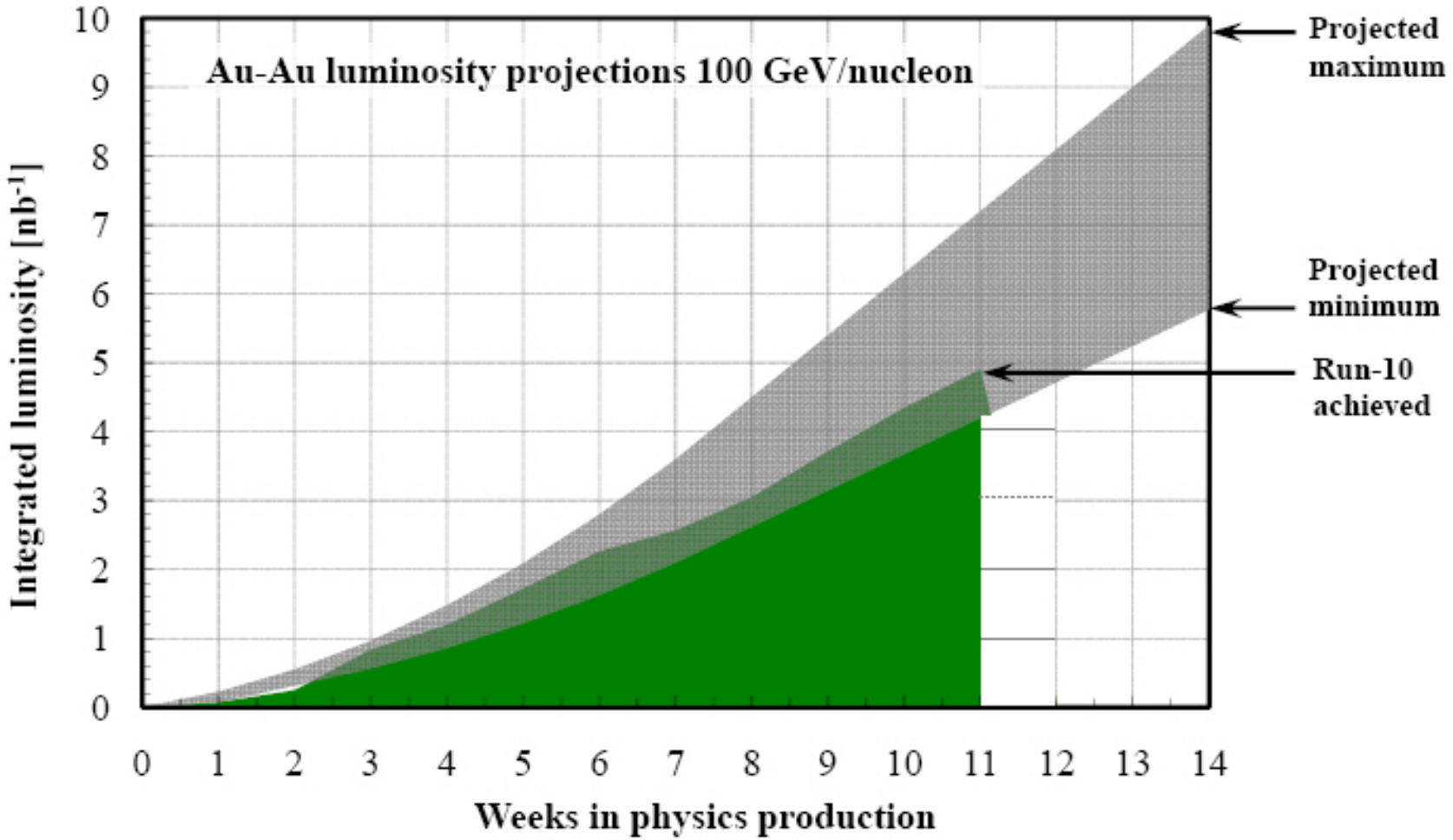
Run Coordinator
Greg Marr

- Upgrade of longitudinal and vertical stochastic cooling systems (address feedthrough vacuum problems, mechanical problems, Blue-Yellow cross-talk of vertical planes)
- Construction of horizontal stochastic cooling systems

  expect stochastic cooling at s_{NN} = 200 GeV to perform as good as in Run-10, but may not be able to complete all planned shut-down work

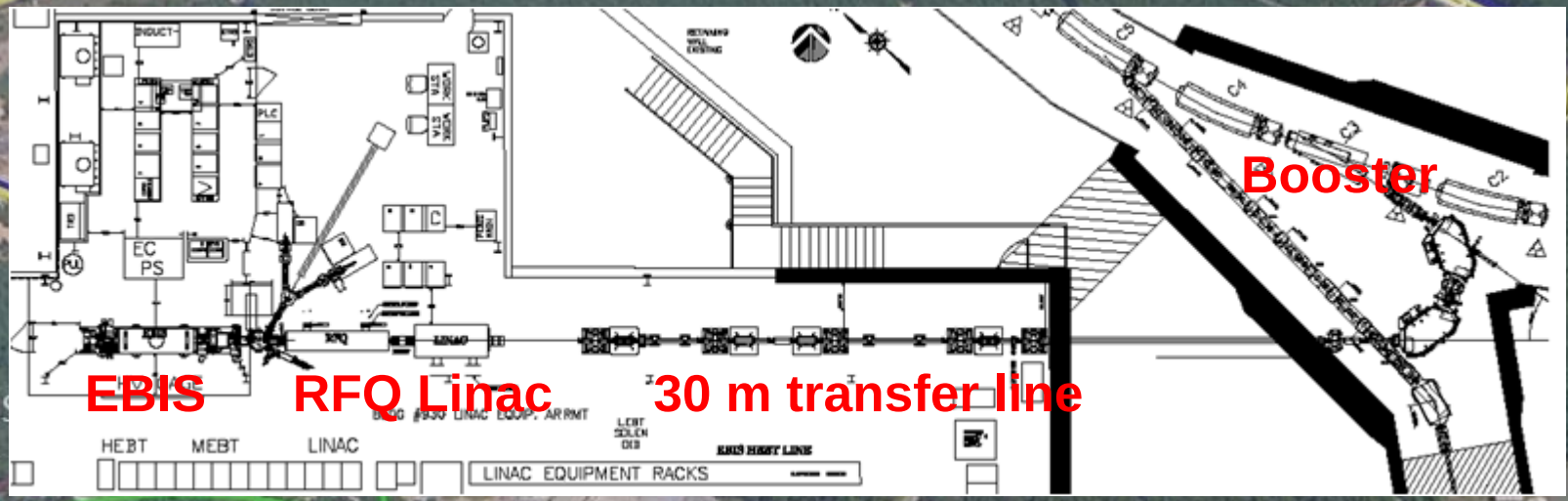
- Correction of chromatic lattice abberations in design stage (needed to reduce β^* further, so far only beam based)
- Improved feedbacks (orbit, tune, coupling, chromaticity) on ramp (reduce ramp setup time)
- Improved store orbit feedback (improves stability of store conditions)
- Beam dump upgrade (needed for higher intensity)
- New Be beam pipe in PHENIX (smaller ID – 40 mm vs. 76 mm now)

Run-11 Au-Au luminosity projections 100 GeV/nucleon



Assume 6 weeks to ramp-up for min, and 8 weeks for max.
[For energy scaling see previous slide.]

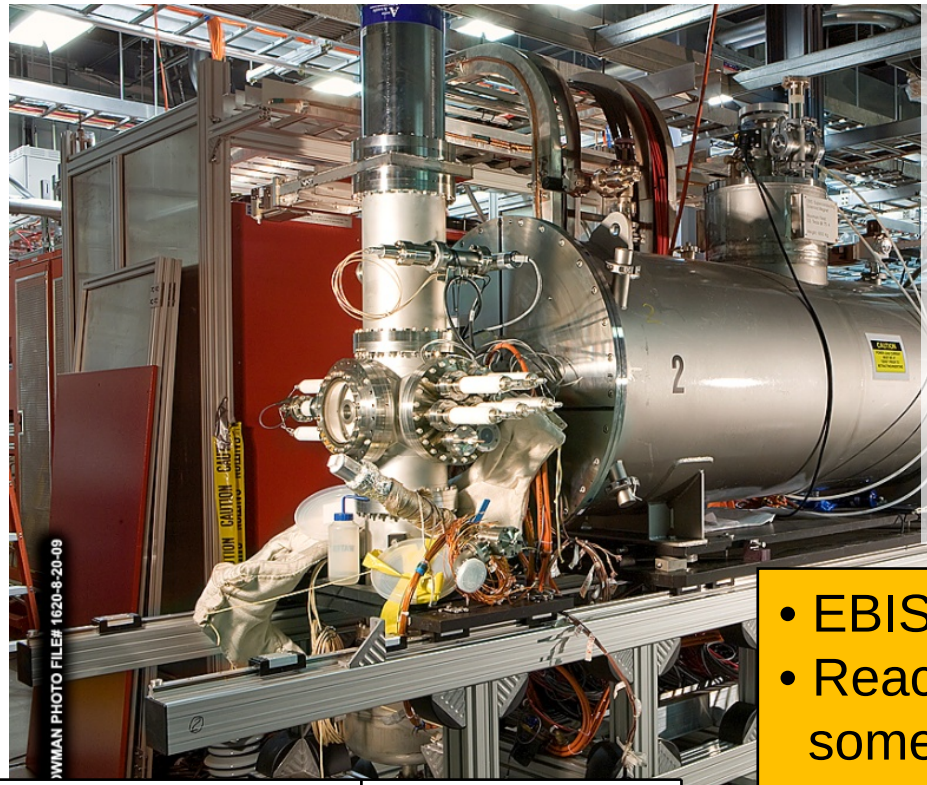
Electron Beam Ion Source (EBIS) (J. Alessi et al.)



PHENIX
IP8
LINAC
EBIS
Booster
AGS
860 m transfer line
Tandems
ions currently from electrostatic Tandem accelerators (~40 years, several upgrades)

Electron Beam Ion Source (EBIS) (J. Alessi et al.)

10 A electron beam creates desired charge state
in trap within 5 T superconducting solenoid

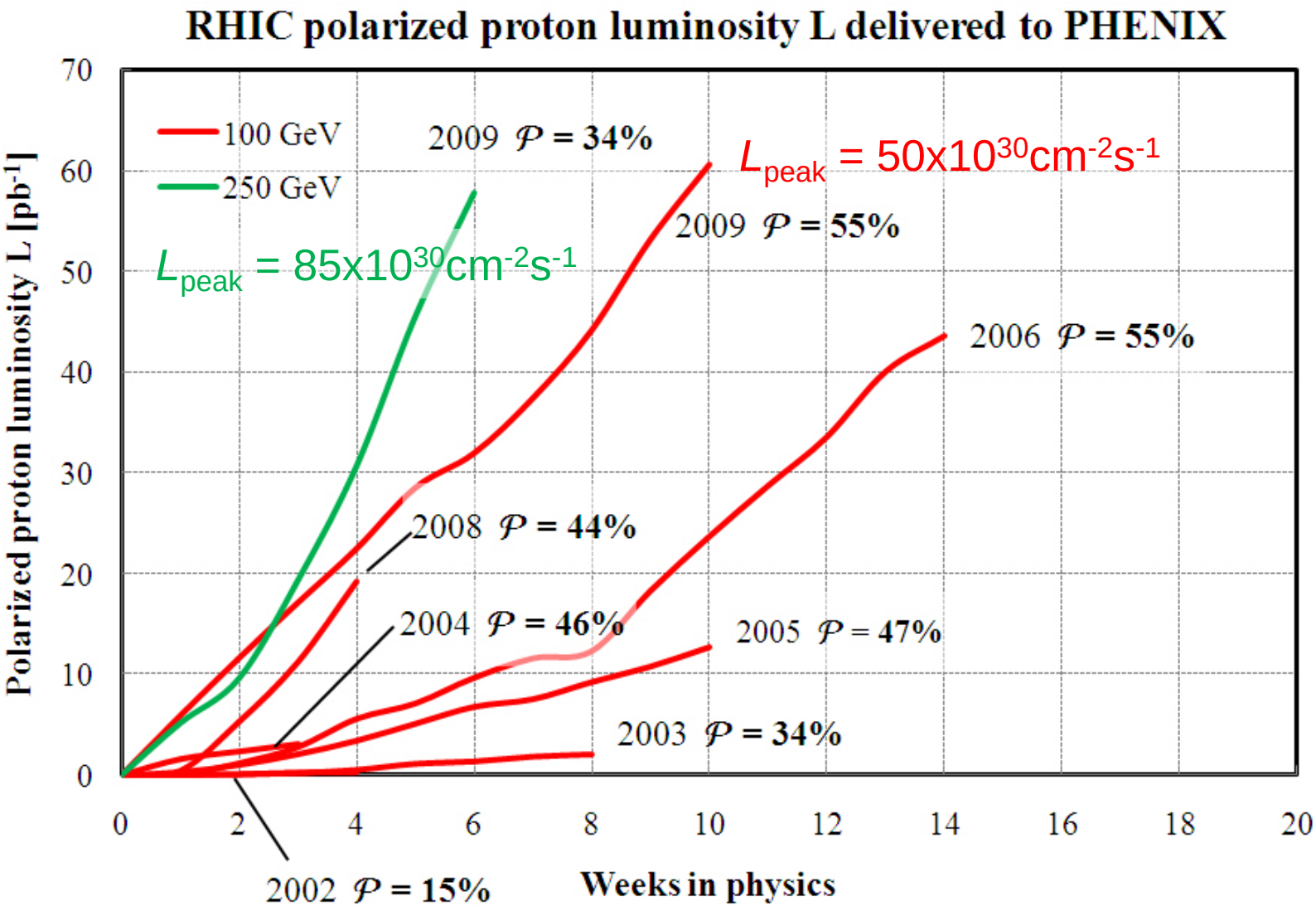


- Simple, modern, low maintenance
- Lower operating cost
- Can produce any ions (noble gases, U, $He^{3\uparrow}$)
- Higher Au injection energy into Booster
- Fast switching between species, without constraints on beam rigidity
- Short transfer line to Booster (30 m)
- Few-turn injection (now about 50)
- No stripping needed before the Booster, resulting in more stable beams

Ions	He - U
Q / m	≥1/6
Current	> 1.5 emA
Pulse length	10 μs (1-turn injection)
Repetition rate	5 Hz
Output energy	2 MeV/nucleon
Time to switch species	1 second

- EBIS under commissioning
- Reached 50% of design Au intensity in trap, some beam transported through HEBT
- Expect U available for RHIC in Run-11, for 25-50% of Au-Au luminosity
- For short U-U run same (Bρ) as for of Au-Au at 100 GeV/nucleon allows for faster setup 96.6 GeV/nucleon for U
- Tandems still available for operation

RHIC polarized protons – luminosity and polarization



$FOM = LP^n$, $n = 4$ (long. P), 2 (trans. P), 1 (DY)

RHIC protons – polarization and luminosity limits

1. **AGS : proton bunches with high intensity, high polarization and low emittance**
   - polarized source upgrade (under way)
   - AGS horizontal tune jump system (tested in 2009-10)

2. **RHIC: polarization transmission to 250 GeV**
   - acceleration near 2/3 resonance (tested in 2010)

3. **RHIC: intensity transmission to 250 GeV**
   - beam dump system modifications (thicker beam pipe in dump)
   - Yellow ramp transmission (9 MHz rf system)

4. **RHIC: peak luminosity and luminosity lifetime**
   - reached lower β^* limit at 100 GeV (not necessarily a problem at 250 GeV)
   - electron lenses allow for larger beam-beam parameter

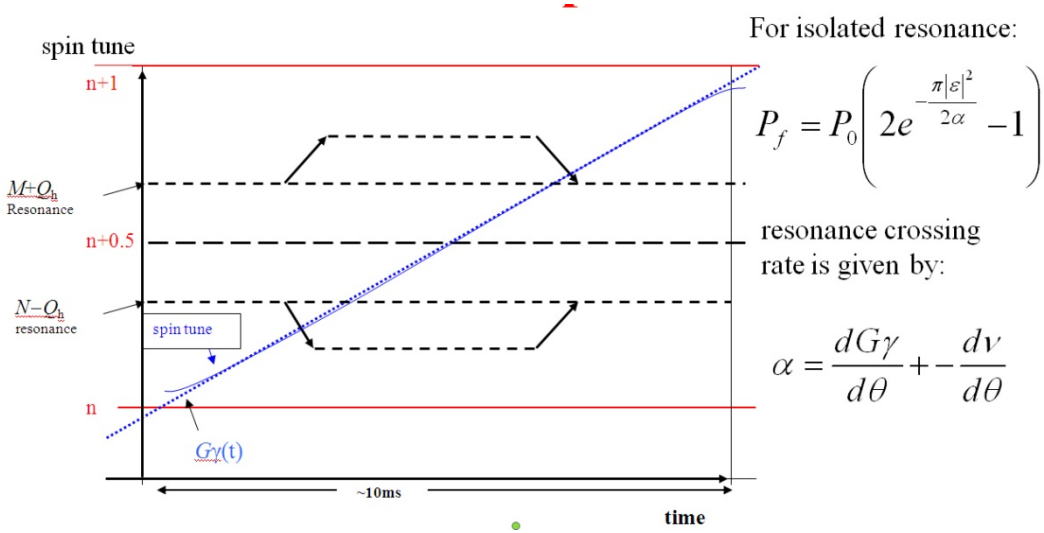
Run-11 upgrades for p -p performance

Run Coordinator:
Haxin Huang

- AGS horizontal tune jump system
  (up to 5% more polarization if successful)
- Possibly RHIC injection at lower energy
  (avoid last depolarizing intrinsic resonance in AGS)
- 9 MHz rf system (including 2 longitudinal dampers)
  (preservation of both longitudinal and transverse emittance, ramp transmission)
- RHIC MMPS flattop-to-ramp and ramp-to-flattop switchover
  (transients lead to beam loss and problems with 9 MHz system)
- Ramp feedbacks (orbit, tune, coupling, chromaticity)
- Global 1 Hz orbit feedback (tighter tolerances at IPs and collimators)
- 10 Hz orbit feedback at store (background reduction)
- CNI Polarimetry (new electronics, removes limits of rate dependence)
- β^* reduction from 0.70 m to 0.65 m
- Beam dump modification (Q4 quenched with high intensity dumps)
- Spin flipper (re-commissioning after modifications)

Horizontal tune jump system in AGS (H. Huang et al.)

- 2 partial snakes prevent depolarization from low-order resonances
- Stable spin direction with partial snakes is off-vertical, horizontal depolarizing resonances appear (82, causing 5% polarization loss)
- Horizontal tune jump system installed in the AGS ($\Delta Q = 0.04$, 100ms)
- Critical for success: jump timing, emittance preservation
- Completed tests:
  - Demonstrated better polarization at $G\gamma=7.5$ (extraction at $G\gamma=45.5$)
  - Polarization maximization with timing scans
  - Demonstrated emittance preservation ($\Delta\varepsilon/\varepsilon$ few percent) with β-beat correction (Q near integer)



For isolated resonance:

$$P_f = P_0\left(2e^{-\frac{\pi|\varepsilon|^2}{2\alpha}} - 1\right)$$

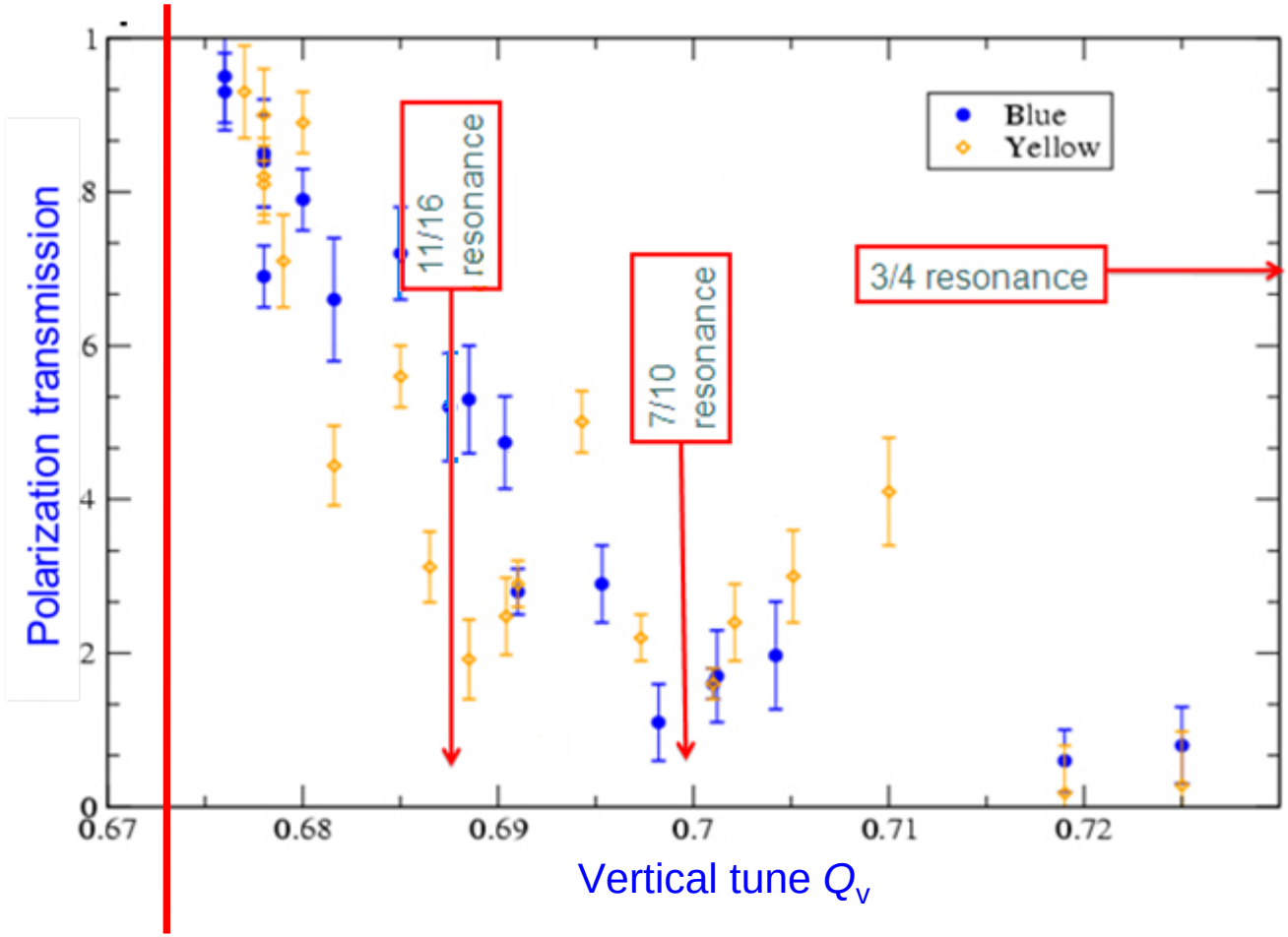
resonance crossing rate is given by:

$$\alpha = \frac{dG\gamma}{d\theta} + - \frac{d\nu}{d\theta}$$

RHIC polarized protons – acceleration to 250 GeV near Q_v = 2/3

Had only 34% polarization at 250 GeV (57% at 100 GeV)

M. Bai et al.



Need upgrade to main PS to reduce transients between ramp and flattop supplies (for 2011)

Tested acceleration with intense Au beam with **tune 0.005 away from 2/3**
Simulations (X. Gu, Y. Luo) compared Au with p lattice DA

RHIC polarized protons – 9 MHz system

A. Zaltsman et al.

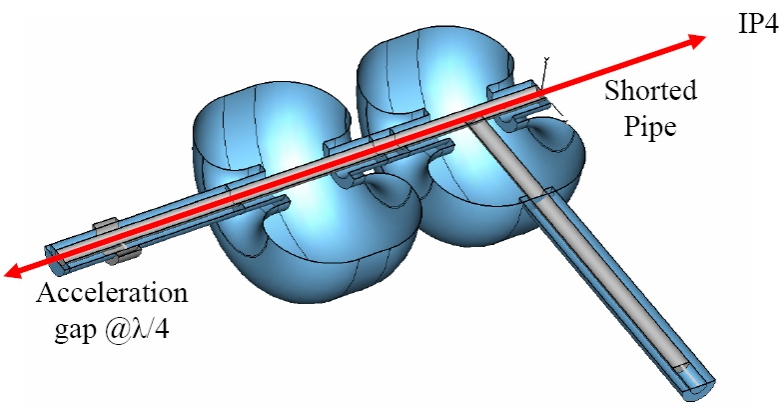
Problem:

- **Inject close to and above transition in 28 MHz system (h = 360)**
- **Longitudinally matched bunches are short**
  emittance growth from e-cloud
- **Unmatched bunches have 4x larger longitudinal emittance**
  luminosity loss from hourglass effect and vertex size

Solution:

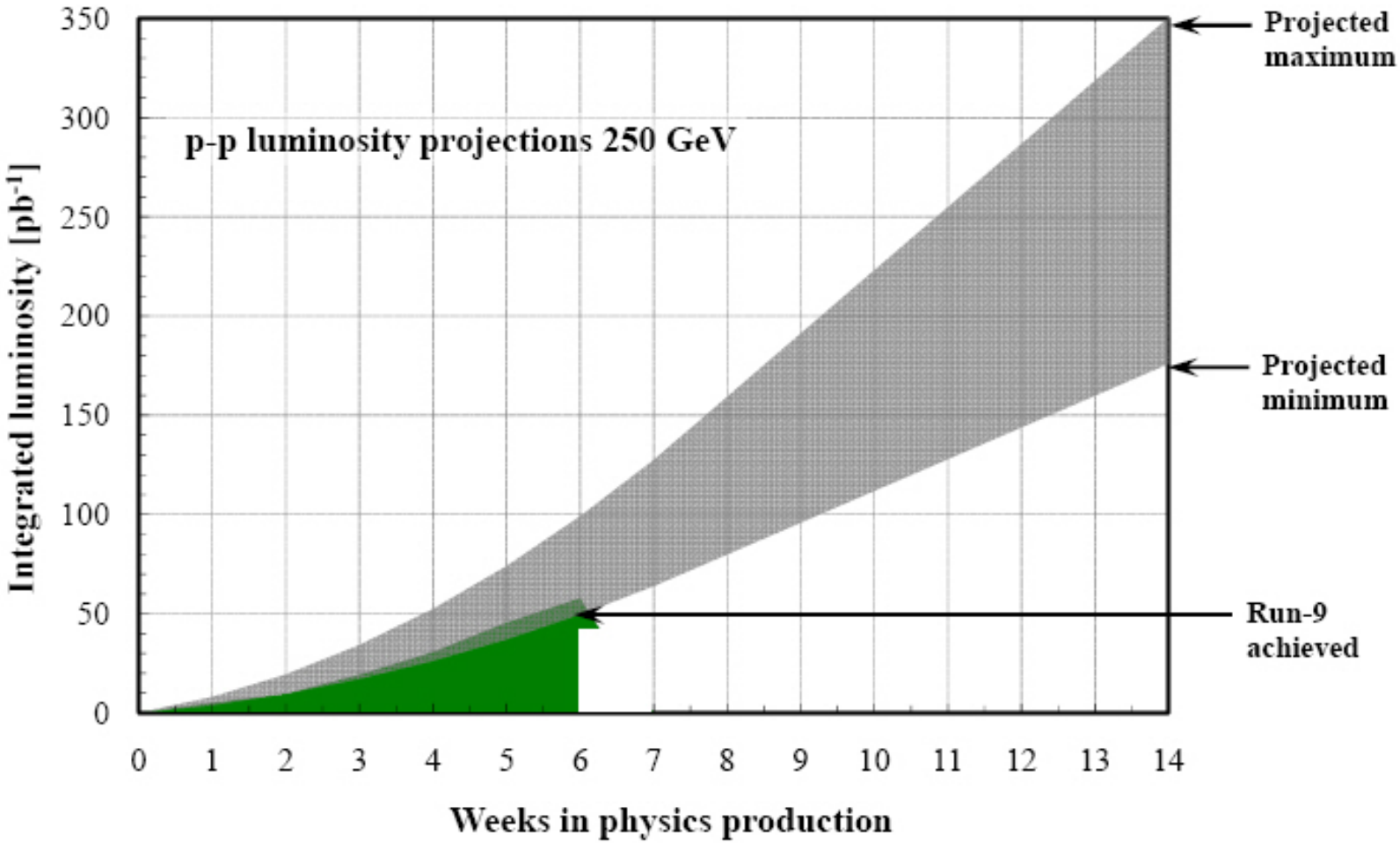
Use a 9 MHz system (h = 120) allows to accelerate long bunches that preserve both the longitudinal and transverse emittance

Cavity Concept:
use the shield inside the common cavities
to make a 9 MHz resonator



- common to both beams
- 9 MHz, 25 kV
- tested in 2009
- need independent long. dampers in both beam
- will use again in 2011

Run-11 p -p luminosity projections 250 GeV



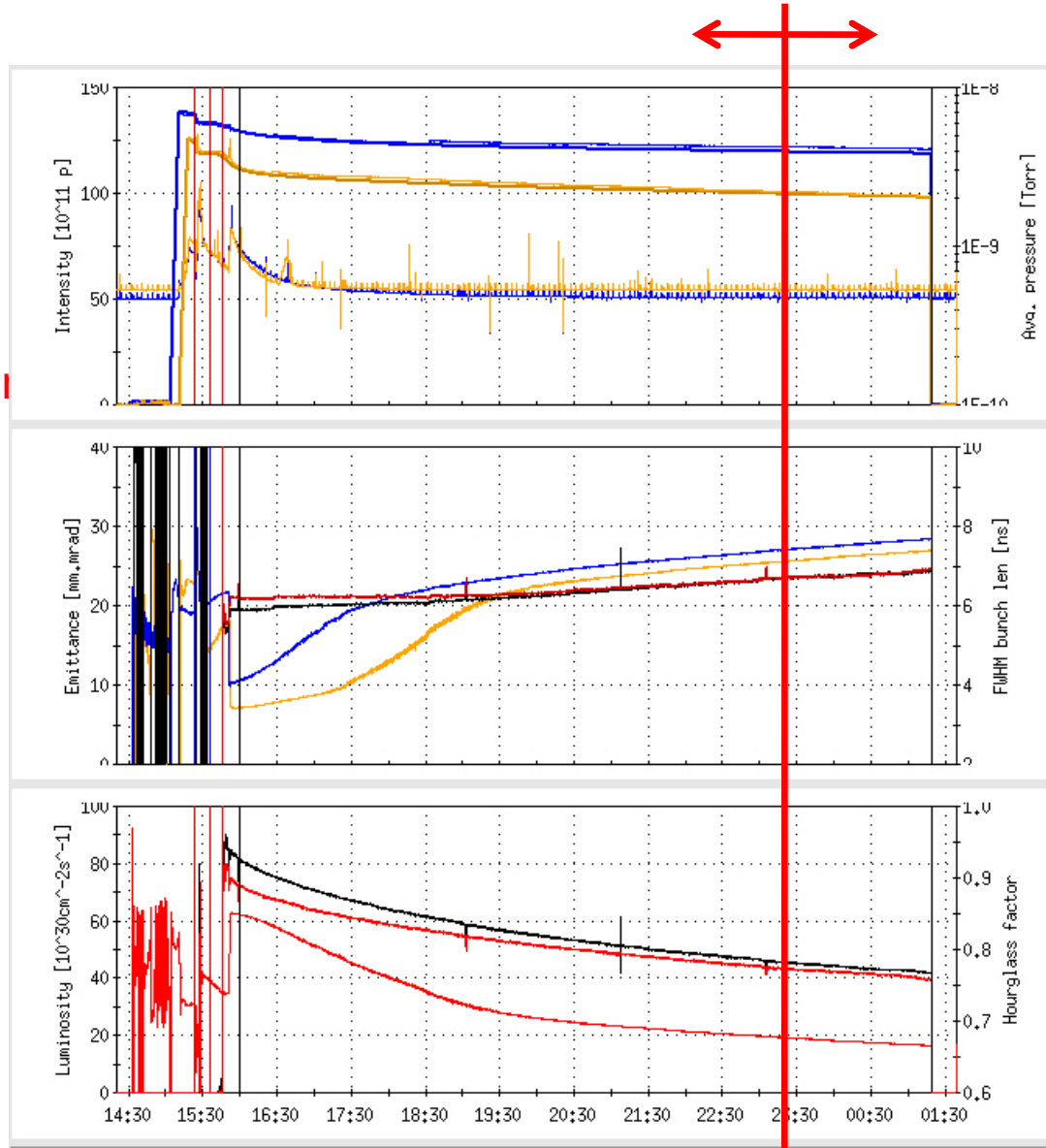
Expect store polarization of 35-50%,
and average store luminosity of up to 100 10^{30}cm^{-2}s^{-1}.

Drell-Yan experiment proposal 1 – colliding beams

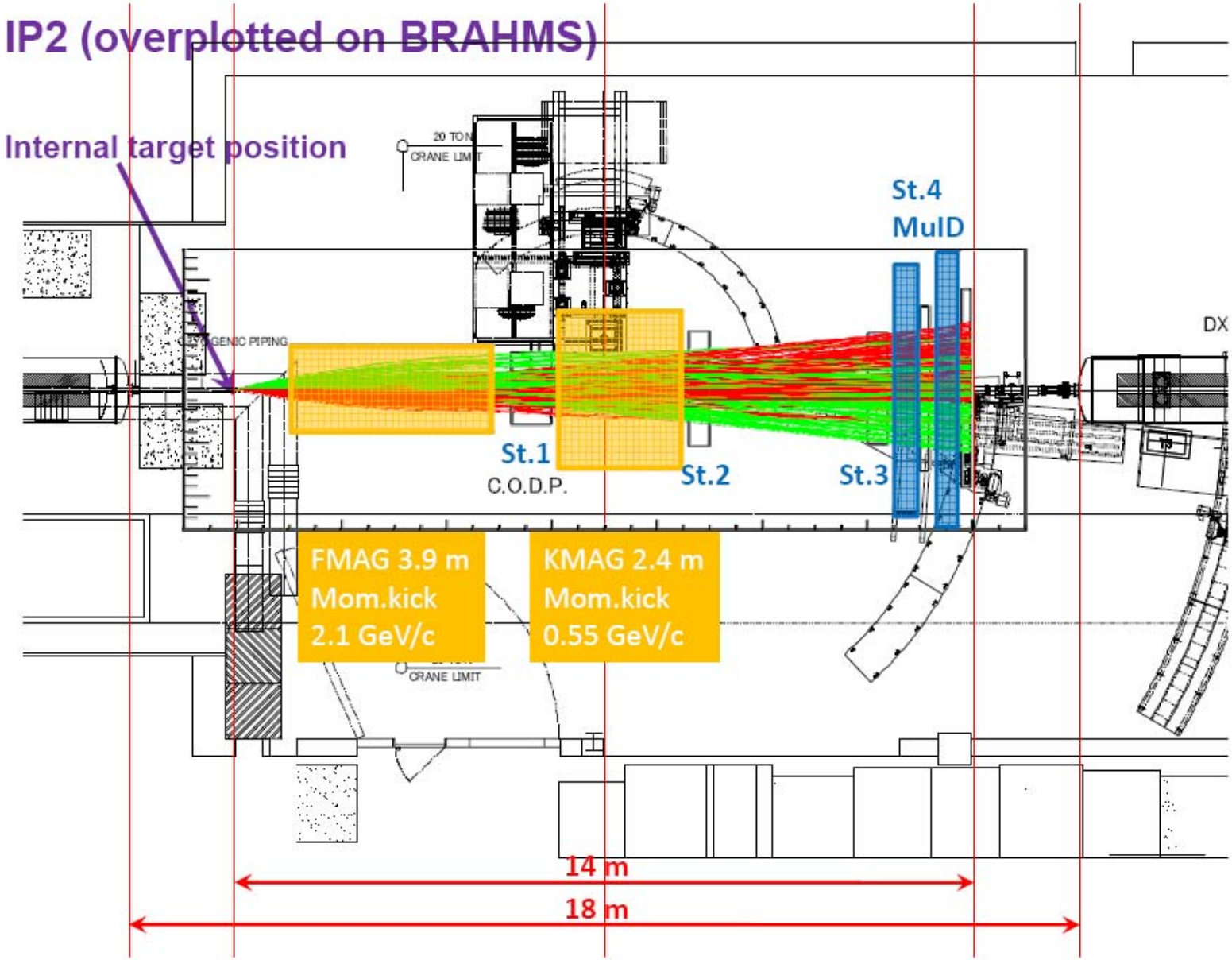
- Colliding beams in IP2
  - $\beta^* = 2$m may be possible, needs upgrade of some IR correctors
    (PS for 6-poles, skew 6-poles, perhaps 8-, 10-, 12-poles correctors) – I

Can test impact of 3rd collision

- Beam-beam parameter ξ_{tot} (= beam-beam tune spread) is limited (to 0.015-0.020)
- Each collision contributes equally ξ_{tot} N ξ_{IP}
  - ξ_{IP} N_b/ε_n (independent of E, β^*)
- Add 3rd collision later in store when ξ_{IP} is reduced due to intensity loss and emittance increase



Drell-Yan experiment proposal 2 – internal target



Drell-Yan experiment proposal 2 – internal target

- 2 dipoles (11 and 3 mrad bend) with same polarity need compensation
  (RHIC orbit corrector has 0.3 mrad, at locations with larger β-functions) – needs study
- β* = 2m may be possible, needs upgrade of some IR correctors
  (PS for 6-poles, skew 6-poles, perhaps 8-, 10-, 12-poles correctors) – needs study

Cluster or pellet H target with 10^{15} atoms/cm^2

- Continuous operation
- Calculated beam lifetime τ 15 h (D. Trbojevic, internal note)
- Need to reduce target density by about factor 5
  (τ 50 h without target)

Internal H target with 10^{17} atoms/cm^2,

- End-of-store operation, 15 min
- Beam lifetime τ = 0.15 h (scaled from above),
  (no problem for STAR/PHENIX except for extra time per store, of order τ)

Phase-2 with 168 bunches would require substantial upgrades (before eRHIC), may get more luminosity after source upgrade and higher bunch intensity

Run-12 upgrades and performance

Heavy ions

- Finish stochastic cooling upgrades and construction
  Full 3D cooling (horizontal + vertical + longitudinal)
  L_{avg} = 40 $10^{26}cm^{-2}s^{-1}$ (2 Run-10, 20 design value)
- β^* reduction
- Feedbacks

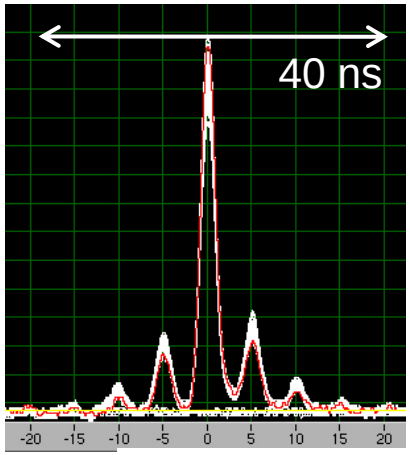
Polarized protons

- Finish upgrades from Run-10 if any (long list)
- β^* reduction, increase in bunch intensity
- Further upgrades need guidance from Run-11

Luminosity and polarization

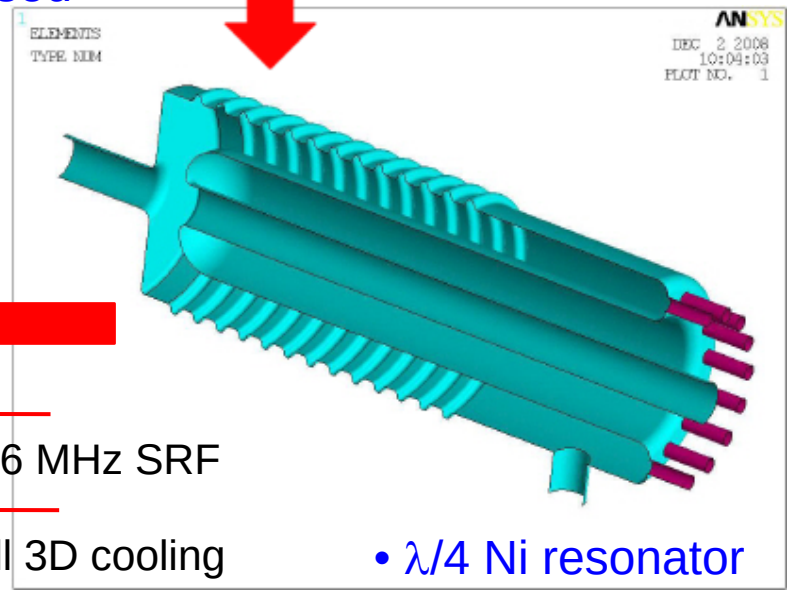
- Au-Au at s_{NN} = 100 GeV: **0.6 – 1.3 nb^{-1}/week** (full 3d stochastic cooling)
- p -p at s = 100 GeV: **8 – 10 pb^{-1}/week** (Run-9 performance), ***P*** **≥ Run-9 value**
- p -p at s = 250 GeV: **18 – 56 pb^{-1}/week, *P* ≥ Run-11 value**

56 MHz SRF for heavy ions – under construction (I. Ben-Zvi et al.)



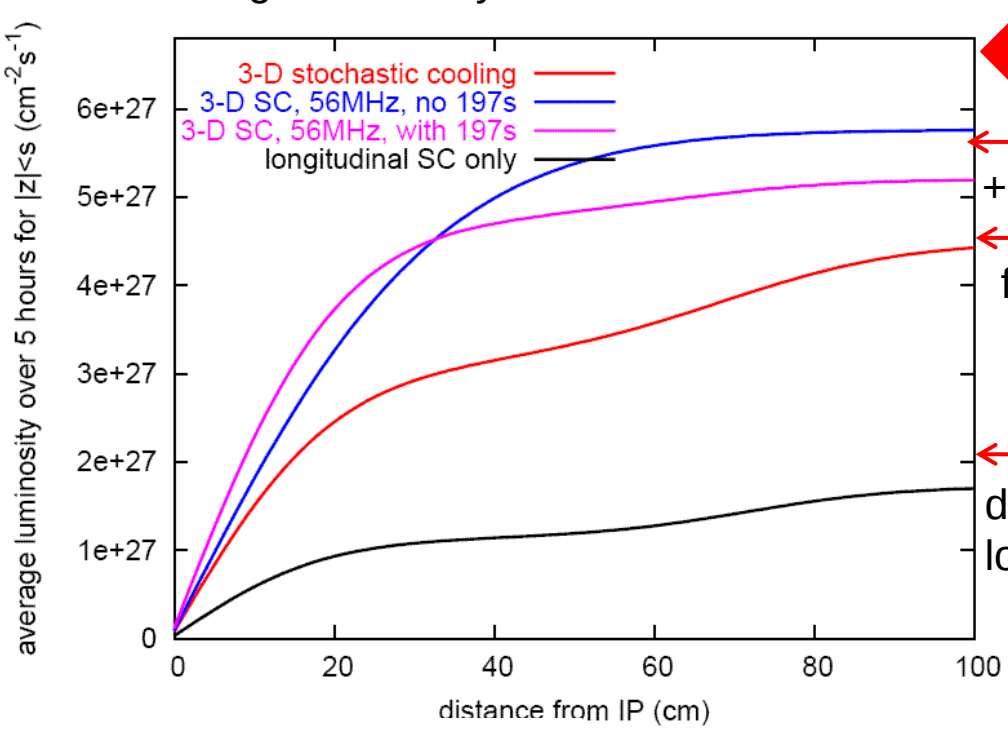
Longitudinal profile at end of store
- even with cooling ions migrate into neighboring buckets
- can be reduced with increased focusing

Run-13



- $\lambda/4$ Ni resonator
- common to both beams
- beam driven
- 56 MHz, 2 MV

Average luminosity vs. vertex size



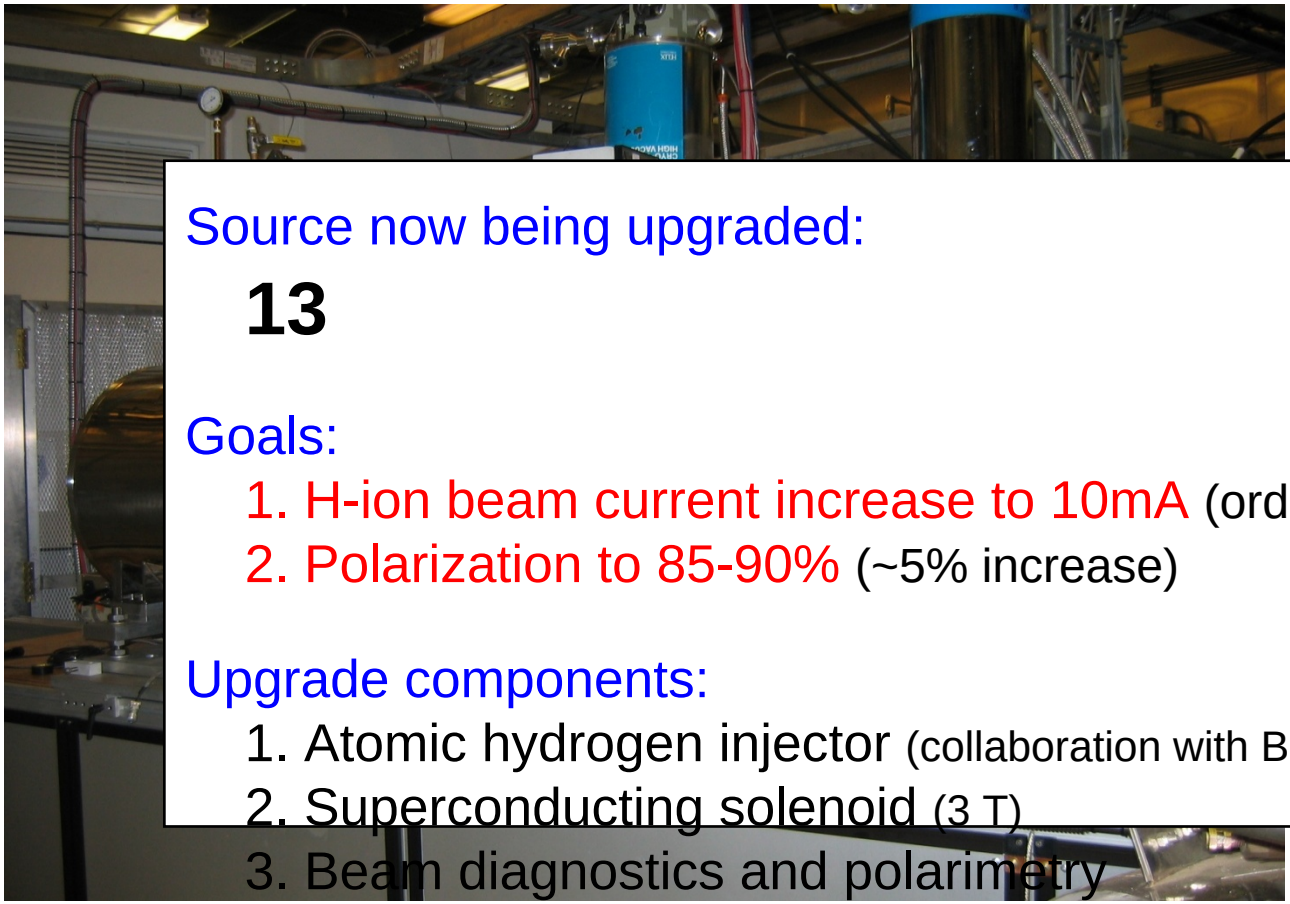
+ 56 MHz SRF

full 3D cooling

demonstrated 2010 long. + ver. cooling

Calculations by M. Blaskiewicz

Optically Pumped Polarized H^- source at RHIC (A. Zelenski)



RHIC OPPIS produces reliably 0.5-1.0 mA
urrent.

0 MeV:

n/pulse)

/pulse

0x10^{11}

RHIC - 1.5x10^{11}/bunch

Source now being upgraded: **Run-13**

Goals:

1. H-ion beam current increase to 10mA (order of magnitude)
2. Polarization to 85-90% (~5% increase)

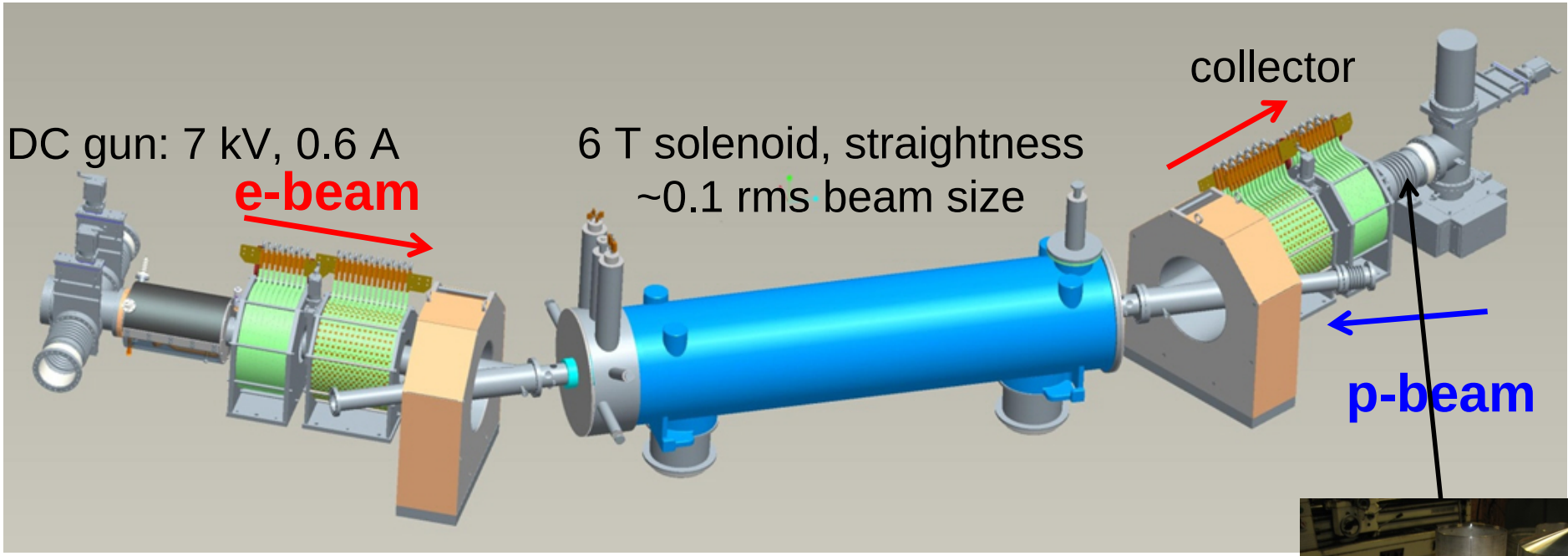
Upgrade components:

1. Atomic hydrogen injector (collaboration with BINP Novosibirsk)
2. Superconducting solenoid (3 T)
3. Beam diagnostics and polarimetry

- 29.2 GHz ECR source used for primary proton beam generation
- source was originally developed for dc operation
- 10x intensity increase was demonstrated in a pulsed operation by using a very high-brightness Fast Atomic Beam Source instead of the ECR source

Electron lenses in RHIC – under construction

Run-13



electron collector

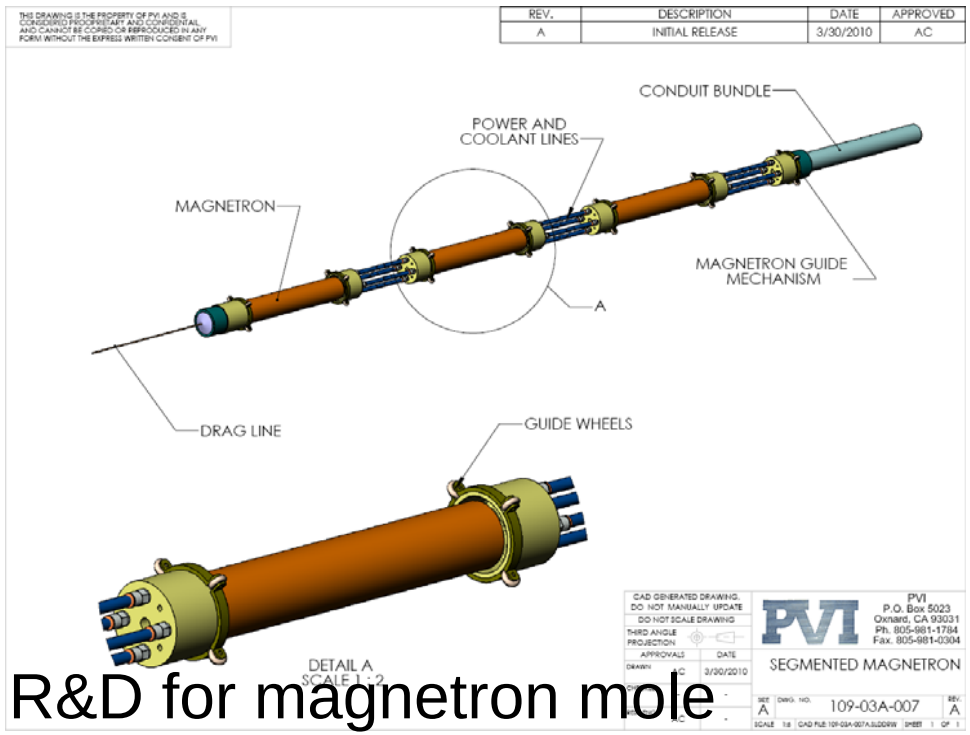
- partial compensation of head-on beam-beam
- goal of 2x luminosity increase together with source upgrade (allowing for higher bunch intensity with good polarization)
- critical: relative beam alignment (Tevatron experience) requires straight solenoid field lines, good instrumentation (bremsstrahlung monitor – C. Montag, D. Gassner et al.)

Upgrades for heavy ions and polarized protons – in situ-coating

- Electron clouds limit
  - Ion intensity (through instability at transition)
  - Proton emittance at injection, and intensity
- Warm parts are largely coated with NEG
- Cold arcs are stainless steel, not coated

Need in-situ coating for arcs

A. Hershkovich et al.



R&D for magnetron mole

Test tube coated with Cu

Summary

Au-Au performance in Run-10

- Au-Au at s_{NN} = 200 GeV: **0.65 nb^{-1}/week** (longitudinal + vertical stochastic cooling)
- Energy scan with s_{NN} = 62.4, 39, 7.7, 11.5 GeV
- No collider operation at s_{NN} = 5 GeV
- Need guidance for importance of increased luminosity (factor 3-6) at low s_{NN}

Projections for Run-11

- Au-Au at s_{NN} = 200 GeV: **0.6 – 0.9 nb^{-1}/week**
- Au-Au energy scaling established with Run-10 data
- U beam available from EBIS (Tandems still available)
  (luminosity likely lower than Au-Au, prefer s_{NN} = 193 GeV for short run)
- p -p at s = 250 GeV: **18 – 32 pb^{-1}/week, 35-50% polarization**
- p -p test of 3rd colliding experiment in IP2 possible

Projections for Run-12

- Au-Au at s_{NN} = 100 GeV: **0.6 – 1.3 nb^{-1}/week** (full 3d stochastic cooling)
- p -p at s = 100 GeV: **8 – 10 pb^{-1}/week** (Run-9 performance)**, *P* ≥ Run-9 value**
- p -p at s = 250 GeV: **18 – 56 pb^{-1}/week, *P* ≥ Run-11 value**