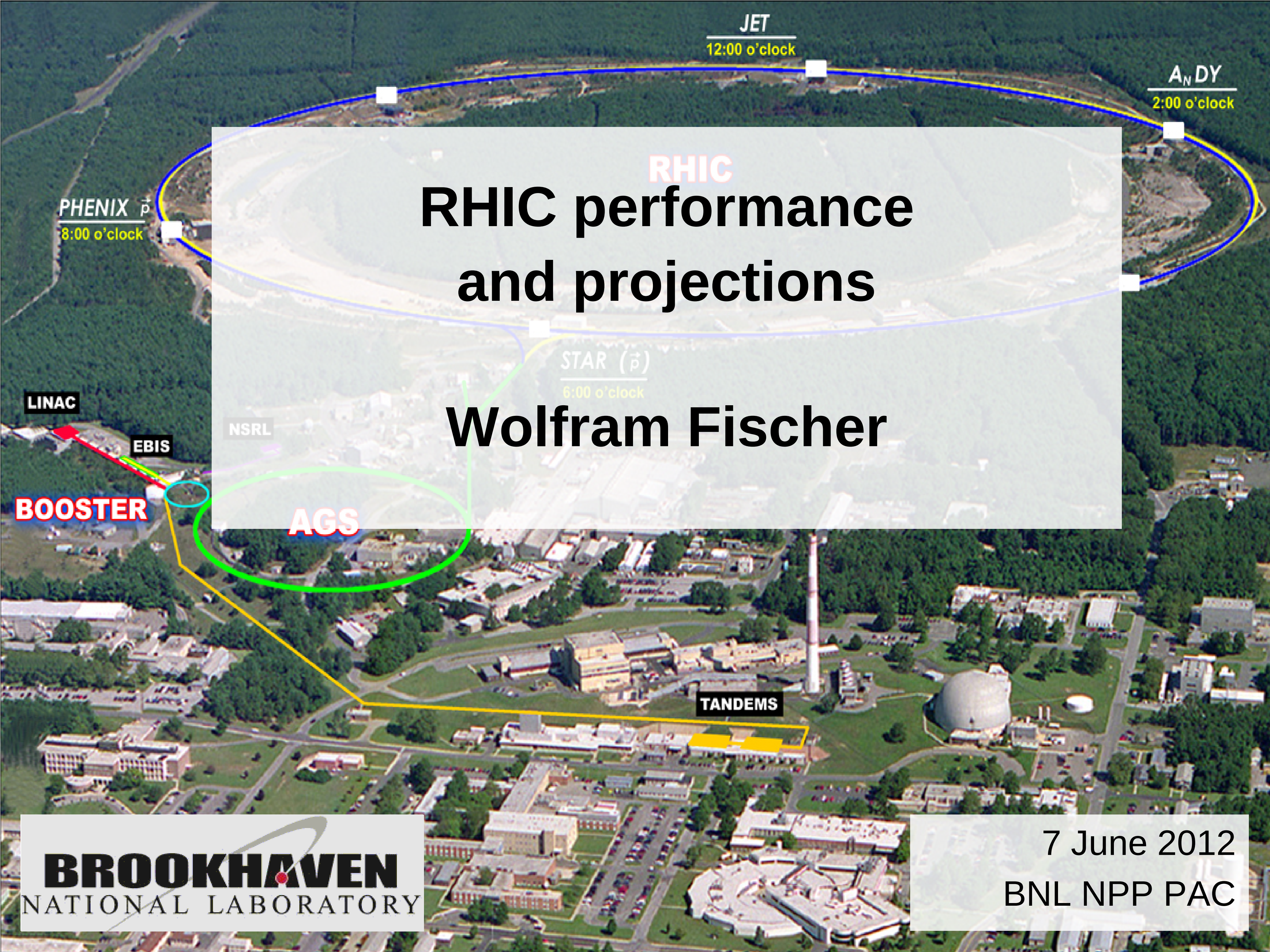
RHIC performance and projections

Wolfram Fischer



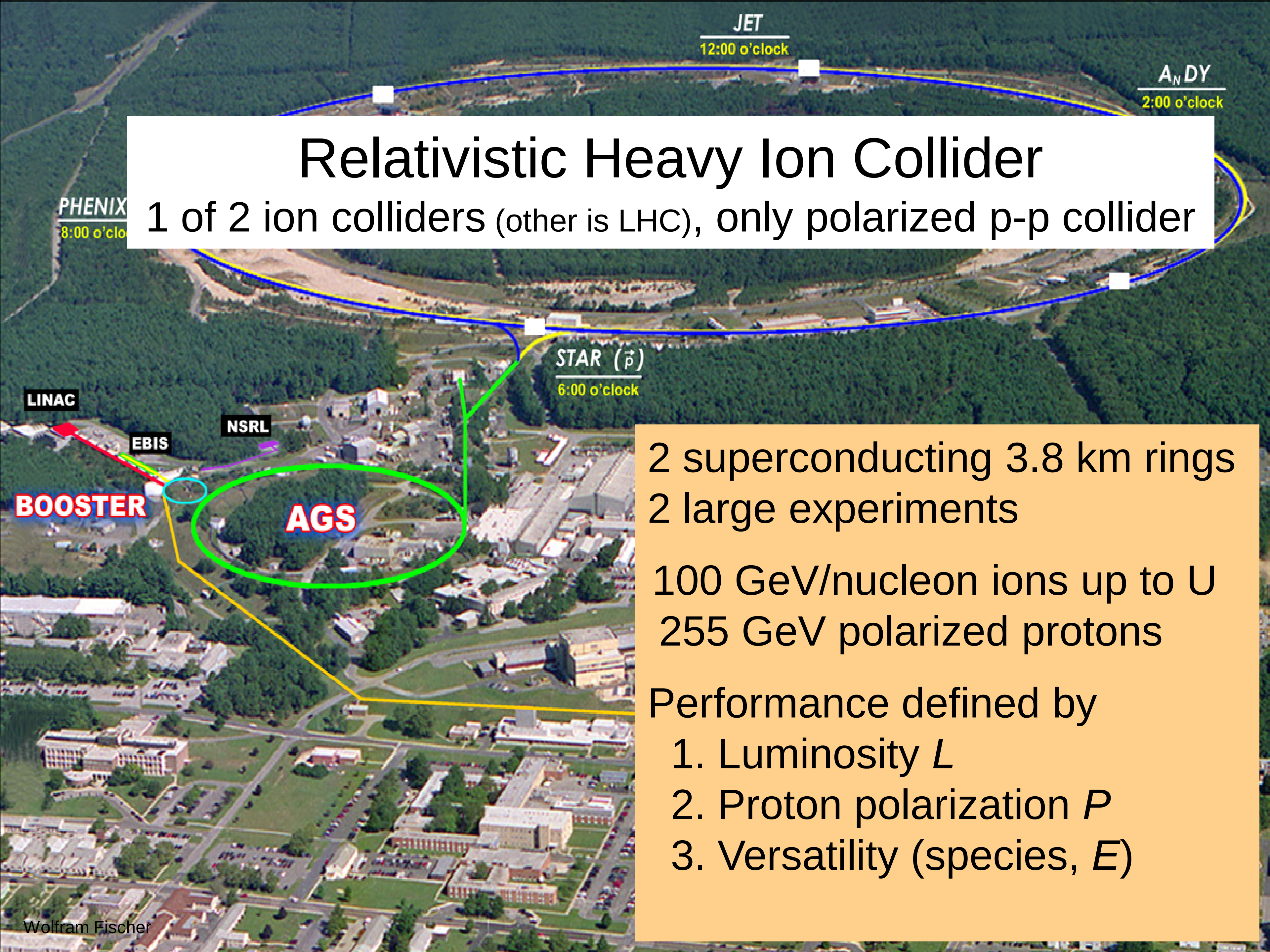
BROOKHAVEN NATIONAL LABORATORY

7 June 2012

BNL NPP PAC

Relativistic Heavy Ion Collider

1 of 2 ion colliders (other is LHC), only polarized p-p collider



2 superconducting 3.8 km rings
2 large experiments

100 GeV/nucleon ions up to U
255 GeV polarized protons

Performance defined by

1. Luminosity *L*
2. Proton polarization *P*
3. Versatility (species, *E*)

Wolfram Fischer

Content

Run-12 overview

- Polarized protons, $\sqrt{s}$ = 200, 510 GeV
- Uranium-uranium $\sqrt{s_{NN}}$ = 193 GeV,
  copper-gold $\sqrt{s_{NN}}$ = 200 GeV

Heavy upgrades and projections

- Luminosity with stochastic cooling & 56 MHz SRF
- Energy scan and low energy cooling

Polarized proton upgrades and projections

- Polarization and luminosity with source upgrade
- Luminosity with RHIC electron lenses
- R&D for polarized ^{3}He

2012 RHIC Run (23 weeks of cryo ops) – most varied to date

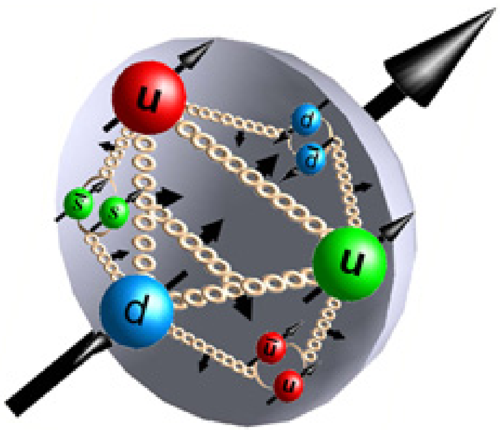
100 GeV polarized protons

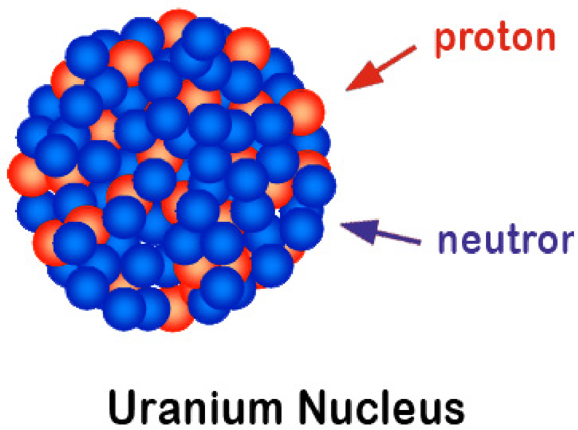
new records for L_{peak}, L_{avg}, P

255 GeV polarized protons

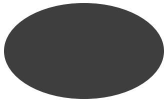
highest energy polarized proton beam

new records for L_{peak}, L_{avg}, P





96.4 GeV/nucleon uranium-uranium



heaviest element in collider, shape

stochastic cooling: $L_{max} > L_0$ 1st time in hadron collider!

all ions lost through burn-off 1st time in hadron collider!

100 GeV/nucleon copper-gold

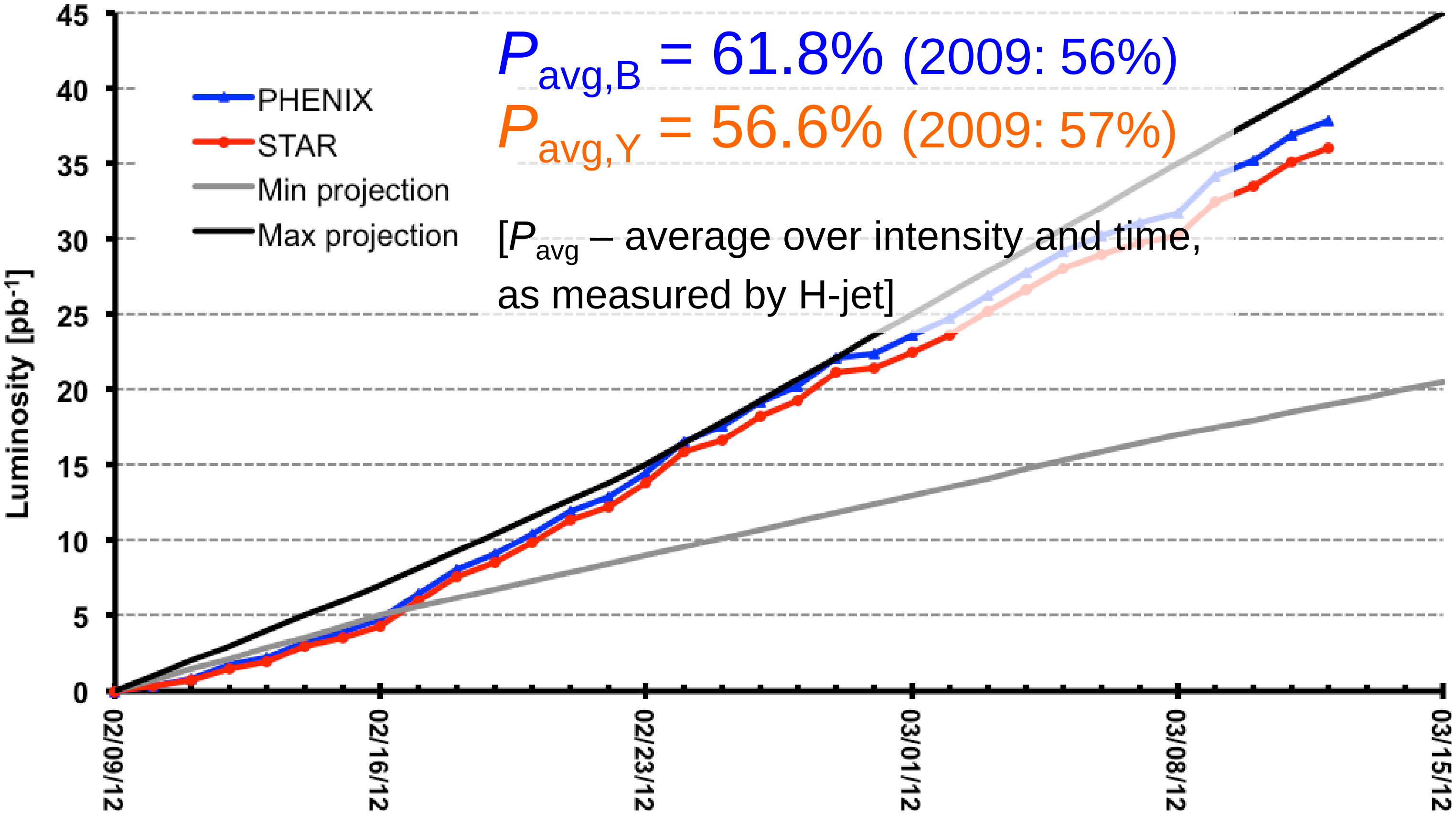
new species combination

possibly 2.5 GeV/nucleon gold-gold test (2 days)

lowest energy to date, 20% of nominal injection E

Run-12 – Polarized protons 100 GeV

Run Coordinator: V. Schoeffer



$P_{avg,B}$ = 61.8% (2009: 56%)

$P_{avg,Y}$ = 56.6% (2009: 57%)

[P_{avg} – average over intensity and time, as measured by H-jet]

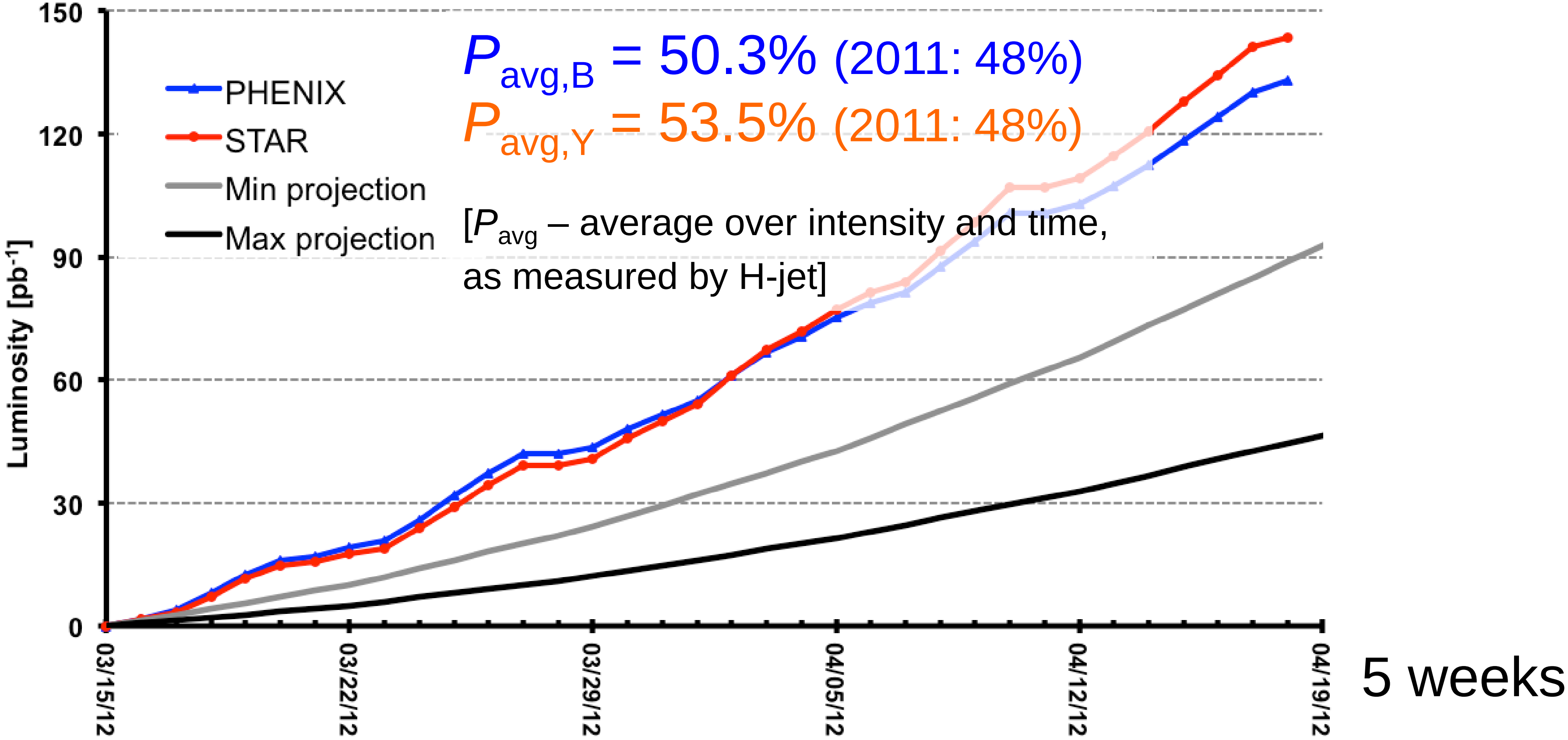
5 weeks

New: 2 new Landau cavities installed in RHIC; AGS horizontal alignment; 9 MHz system upgraded; AGS horizontal tune jump timing improved; operation from new Main Control Room; down ramp does not stop at injection any more, ramp from park to injection with 2x ramp speed compared to previous runs (saves 2.9 min per ramp)

Polarization details at www.phy.bnl.gov/cnipol (D. Smirnov)

Run-12 – Polarized protons 255 GeV

Run Coordinator: V. Schoeffer



New: same as for 100 GeV; increased store energy to increase polarization lifetime; snakes ramp between 100 GeV and 255 GeV; scan of snake spin rotation axis angle and spin rotation angle; test of longitudinal injection damper; test of Landau phase error compensation (phase error from Booster) compensation

Polarization details at www.phy.bnl.gov/cnipol (D. Smirnov)

Polarization profiles and quantities of interest

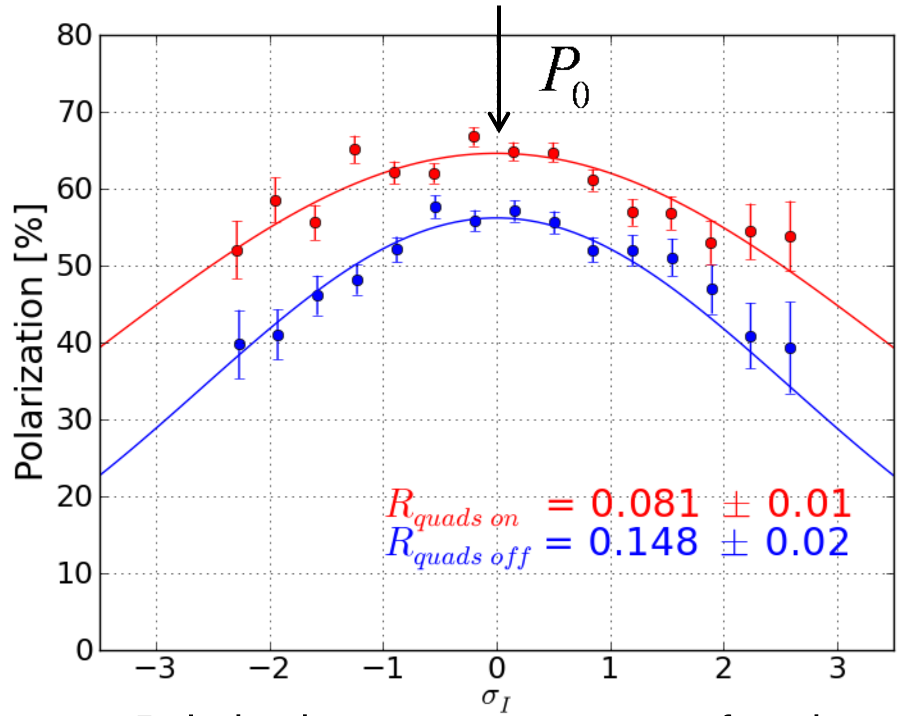
- Polarization can be characterized by

  P_0 center value

  $R = \frac{\sigma_I^2}{\sigma_P^2}$ profile parameter (no profile with R=0, can have R_x, R_y, R_s)

- Polarization P_{avg} measured by H-jet is averaged over <u>intensity</u> and time

$$P_{avg} = \frac{P_0}{(1+R_x)(1+R_y)(1+R_s)}$$



Polarization measurements as function of transverse position, with ultra-thin carbon target, at AGS extraction

- Luminosity-averaged quantities of interest for experiments:

$$\langle P_B \rangle, FOM_B = L\langle P_B^2 \rangle$$ single-spin experiments

$$\langle P_B \cdot P_Y \rangle, FOM = L\langle P_B^2 \cdot P_Y^2 \rangle$$ double-spin experiments

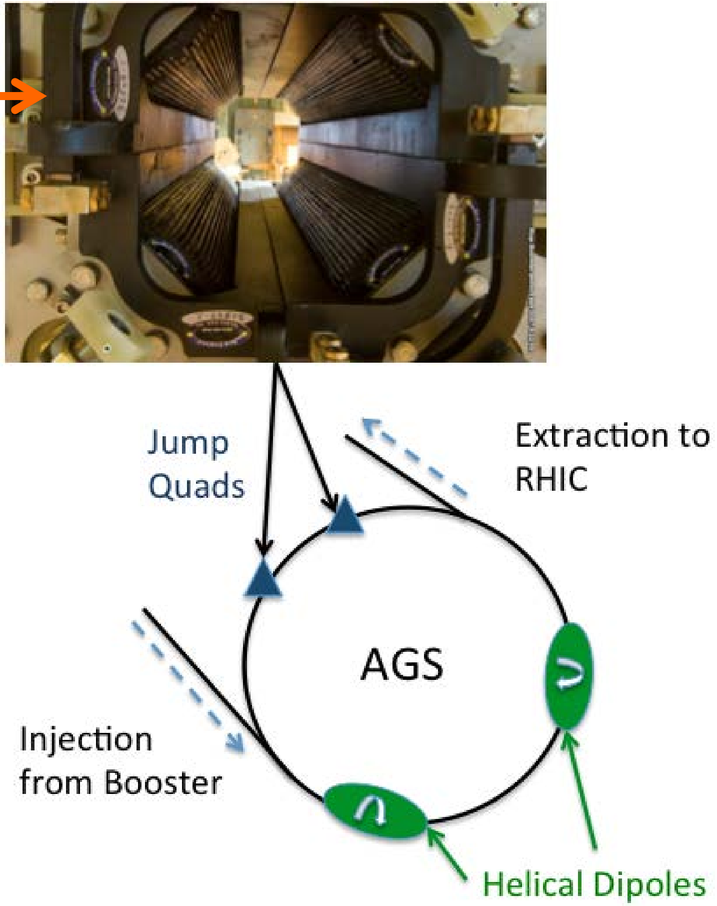
RHIC Polarization status

2 types of depolarizing resonances

- Imperfection resonances (from vertical closed orbit errors): $G\gamma = k$
- Intrinsic resonances (from vertical betatron motion): $G\gamma = kP \pm Q_v$
- G – anomalous magnetic moment (+1.79 for p, −4.18 for ^{3}He)

Recent improvements (2011-2012)

- 80 horizontal tune jumps in AGS
  (weak horizontal resonances)
- AGS and RHIC re-alignment
- Operation with 9 MHz rf system (low $\delta p/p$)
- Acceleration near 2/3 (only 0.006 off; need orbit, tune, coupling feedback on every ramp)
- pC-polarimeter upgrade (rate dependence)

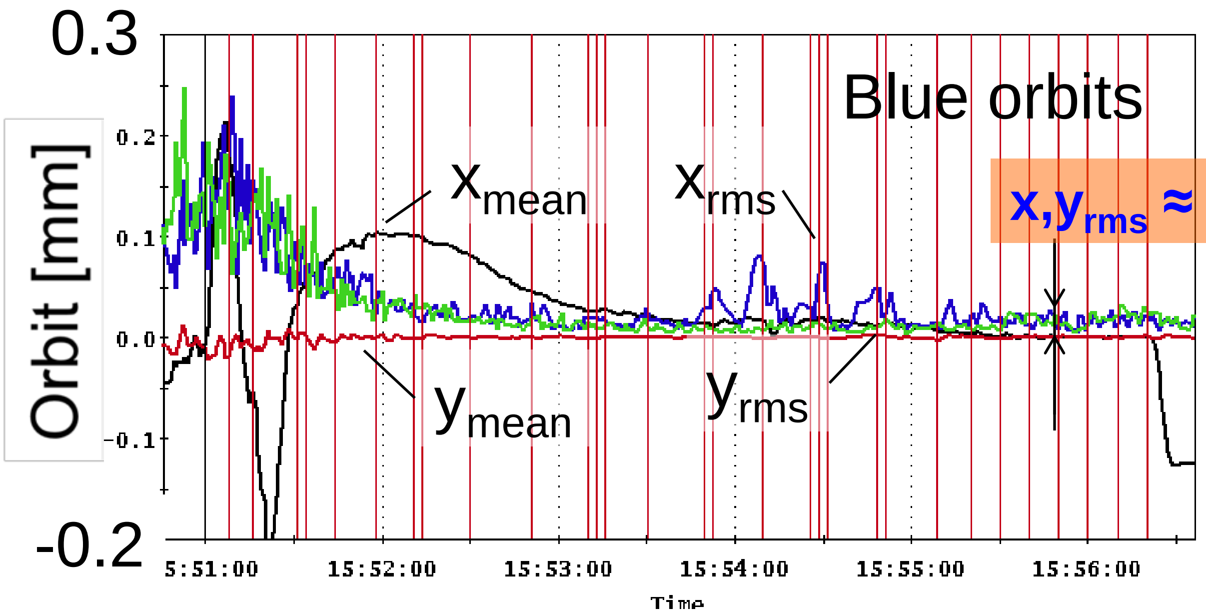


Future improvements

- Polarized source upgrade
- Possibly more RHIC snakes (also for ^{3}He♒)

Beam control improvement – feedbacks on ramp

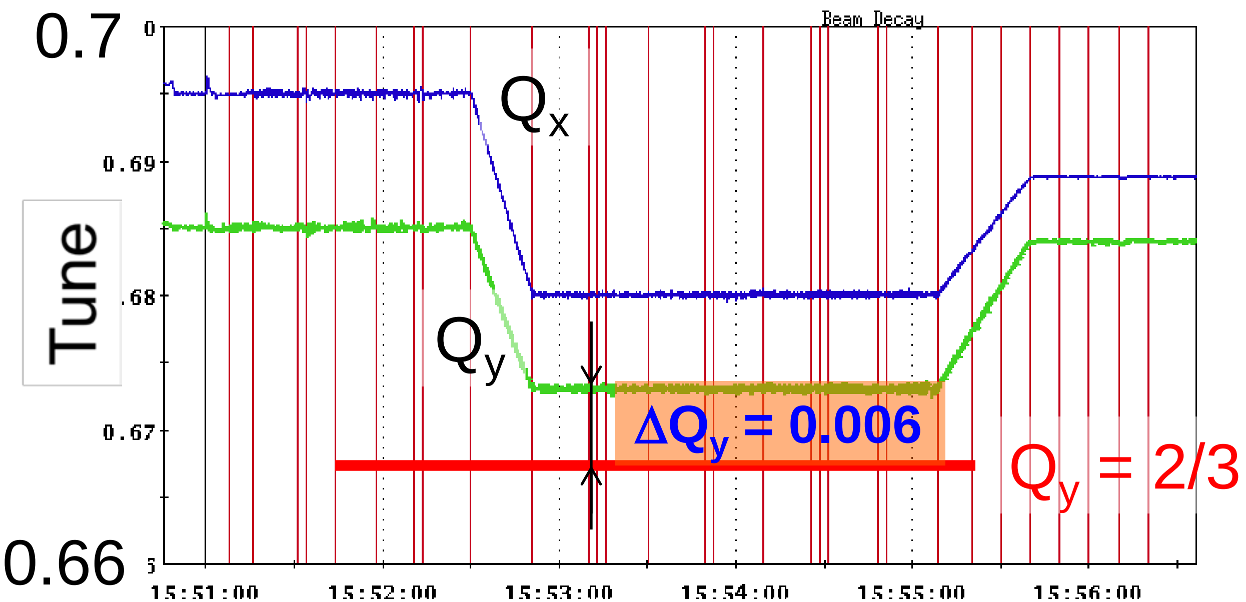
M. Minty,
A. Marusic et al.



x,y_{rms} ≈ 20 μm (!) ≈ 3% of rms size

Orbit feedback on every ramp allows for

- Smaller y_{rms} (smaller imperfection resonance strength)
- Ramp reproducibility (have 24 h orbit variation)



Tune/coupling feedback on every ramp allows for

- Acceleration near $Q_y = 2/3$ (better P transmission compared to higher tune)

Polarization tests during Run-13 (M. Bai et al.)

Polarization lifetime at store (0.5-1.0%/h loss at 100 and 250 GeV)

- Energy change from 250 to 255 GeV => no difference
- Depolarization of non-colliding beam on/off the strongest snake resonance (=11/16) => no difference
- Spin tune change ±0.01=> no difference
- Snake spin rotation angle scan ±10 deg => small effect for –10 deg

Depolarization during energy and rotator ramps

- Orbit effect of last 2 strong intrinsic resonances
  => small effect for large orbit error
- Contribution of final β^*-squeeze => no difference
- Snake spin rotation angle => 5% (absolute) gain in Yellow
- Spin tune change ±0.01 => no difference

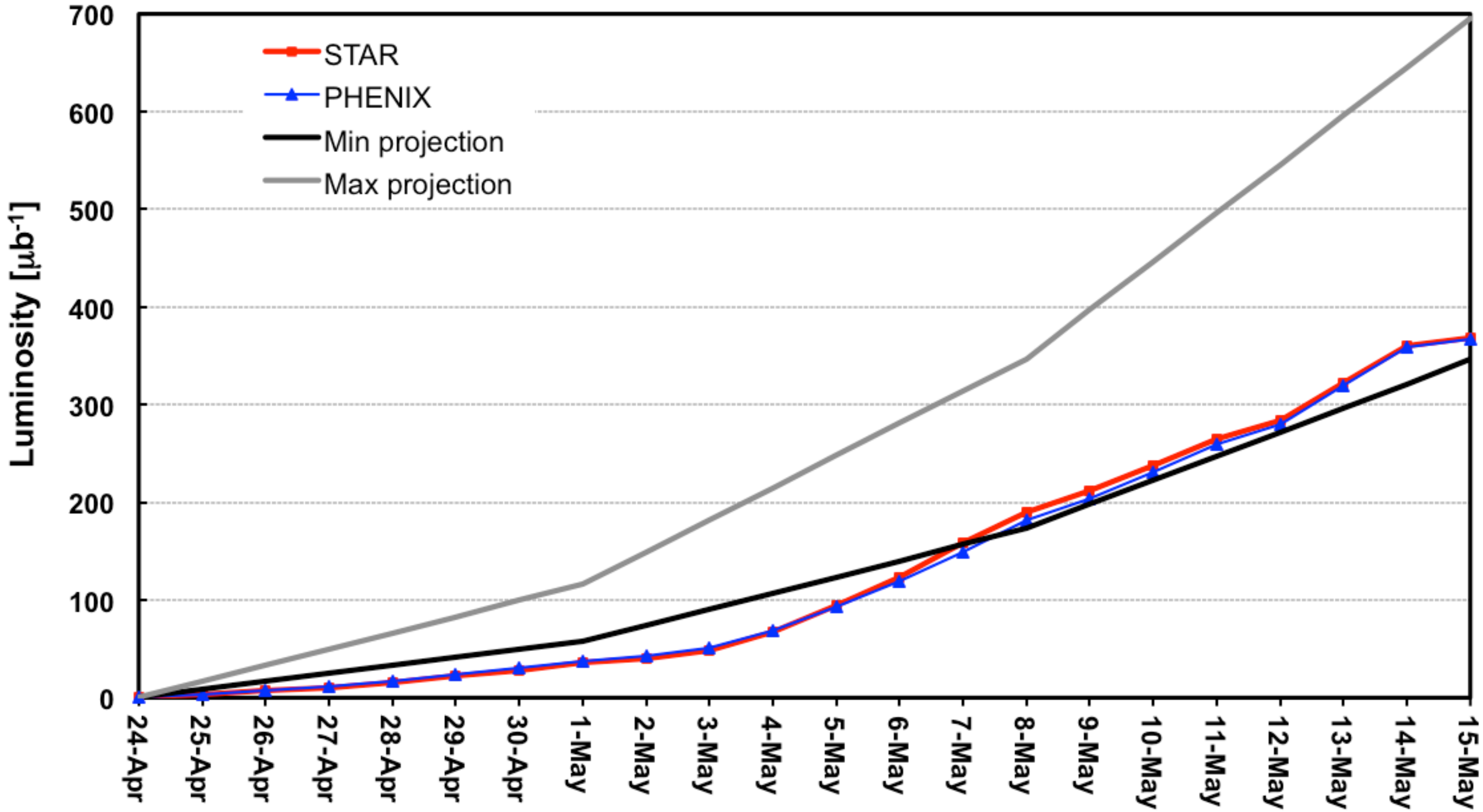
Absolute polarization at injection with H-jet

- 10 h for measurement in Yellow only (background minimization)
- P_{avg} = (63±4.4)%

=> Unlikely that large polarization gains can be made by further parameter changes (depolarization due to many small effects)

Run-12 – Uranium-uranium 96.4 GeV/nucleon

Run Coordinator: Y. Luo

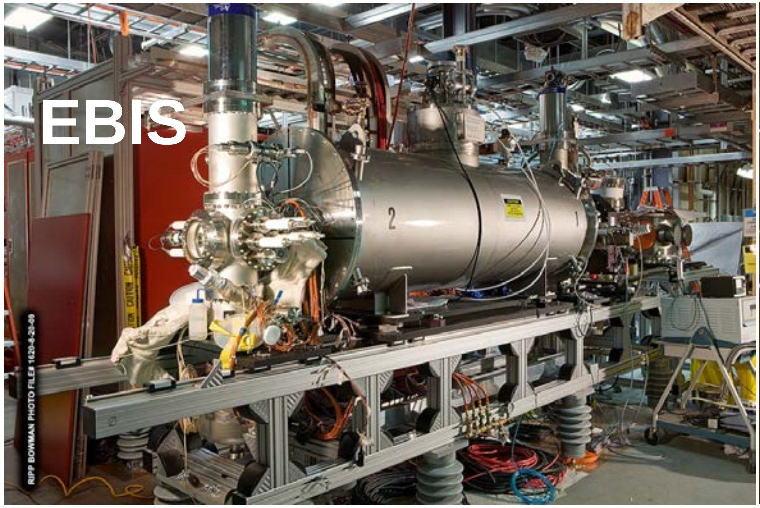


3 weeks

New: first use of EBIS for RHIC operation; first U-U operation in a collider; used standard lattice to increase off-momentum dynamic aperture; first use of Blue and Yellow horizontal stochastic cooling (resulting in 3D cooling in both rings); due to small beam size need micro-vernier scan every 1/2 h

Electron Beam Ion Source (EBIS)

- Inject single charge ion from primary source (e.g. hollow cathode source)
- 10 A electron beam creates desired charge state in trap (5 T sc solenoid)
- Source for high-charge state, high brightness ion beams
- Accelerated through RFQ and linac, injected into AGS Booster
- All ion species including noble gas, uranium and polarized ^{3}He



Operated for NASA Space Radiation Laboratory in 2011-12 with

- He^{+}, He^{2+}, Ne^{5+}, Ne^{8+}, Ar^{10+}, Kr^{18+}, Ti^{18+}, Fe^{20+}, Ta^{33+}, Ta^{38+}

Operated for RHIC in 2012 with

- U^{39+} (not possible previously), Cu^{11+}, Au^{31+}

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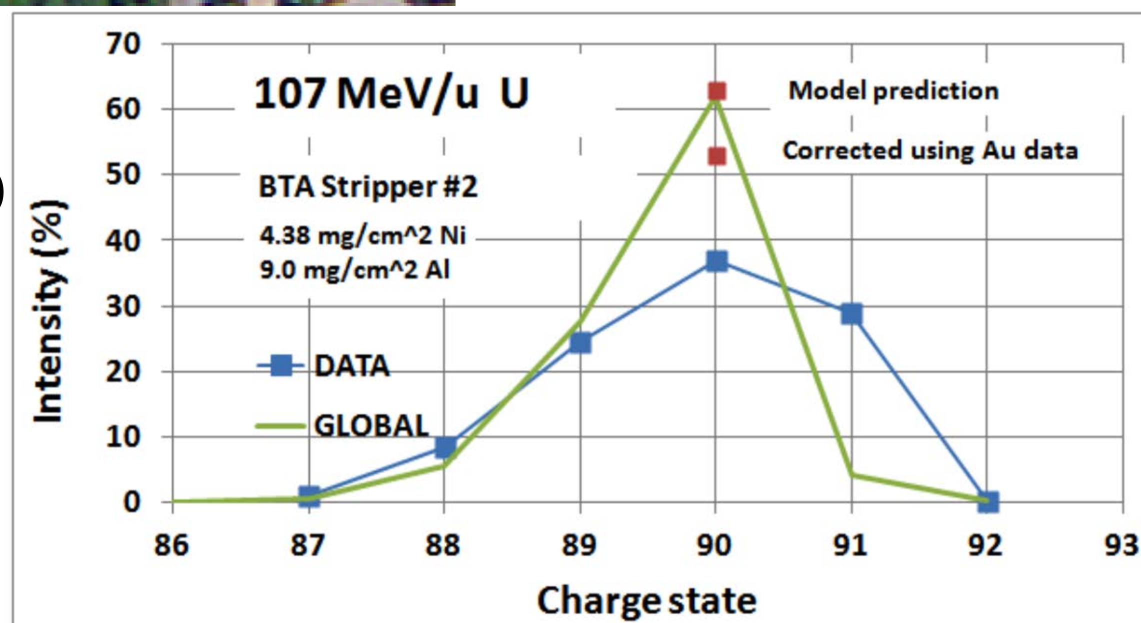
Preparation of U beams for RHIC

EBIS out: U^{39+}

AGS-to-RHIC transfer line
Stripping foil:
Al_2O_3 (5.2 mg/cm^{2})
E_{kin} = 8.51 GeV/nucleon
U^{90+} ♑ U^{92+} (99.9% of intensity)

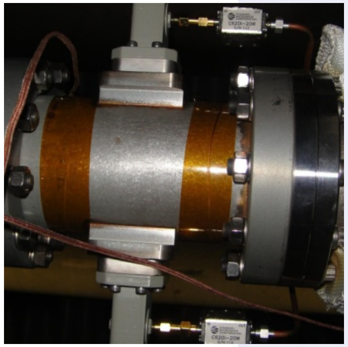
P. Thieberger, K. Zeno

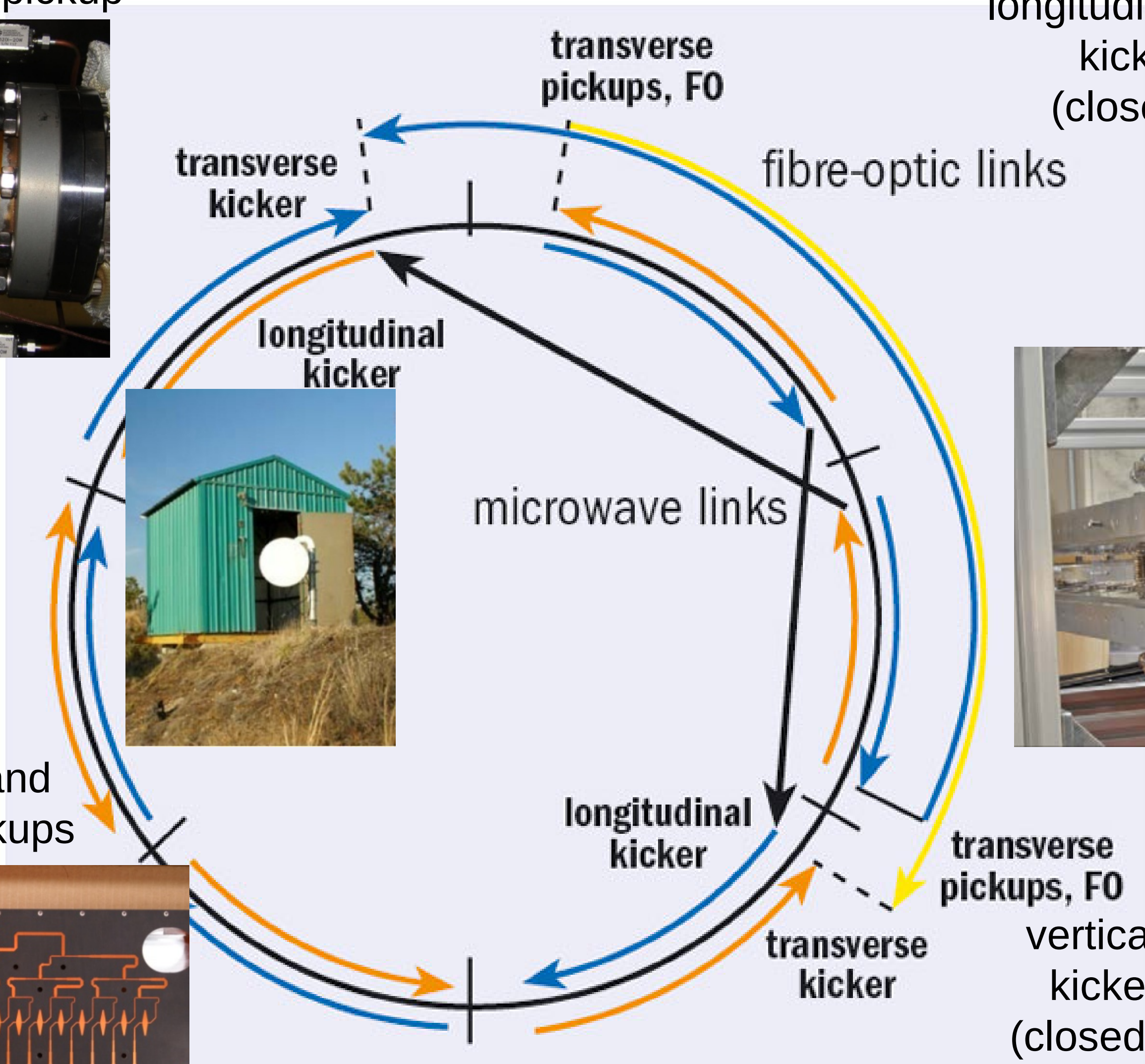
Booster-to-AGS transfer line
Stripping foil:
Ni (4.4 mg/cm^{2}) + Al (9.0 mg/cm^{2})
E_{kin} = 107 MeV/nucleon
U^{39+} ♑ U^{90+} (35% of intensity)
(had expected >50% based on GLOBAL)



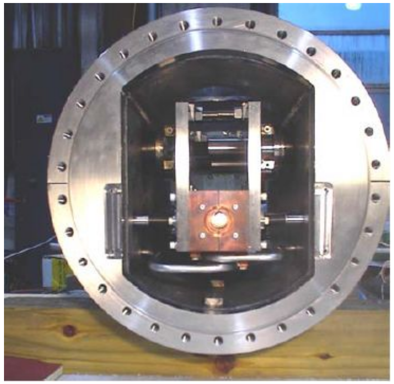
Now have full 3D stochastic cooling for heavy ions

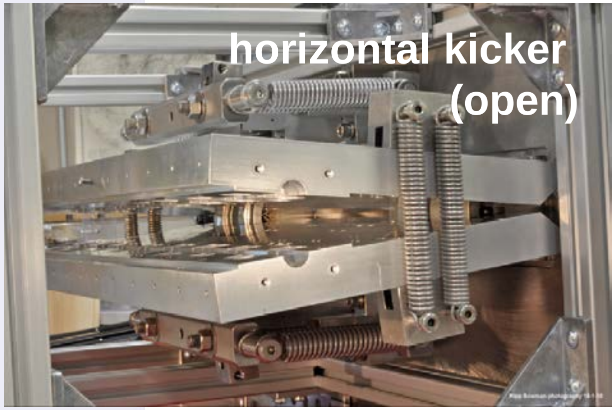
longitudinal pickup



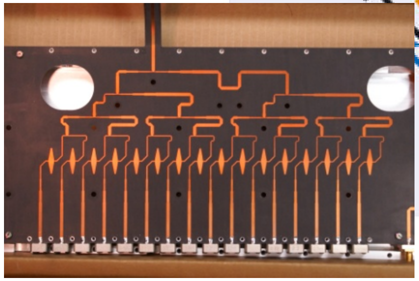


longitudinal kicker (closed)

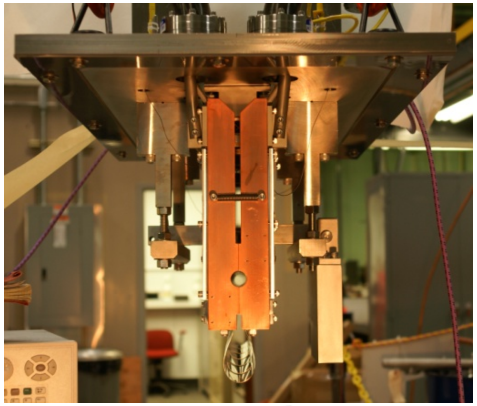




horizontal and vertical pickups

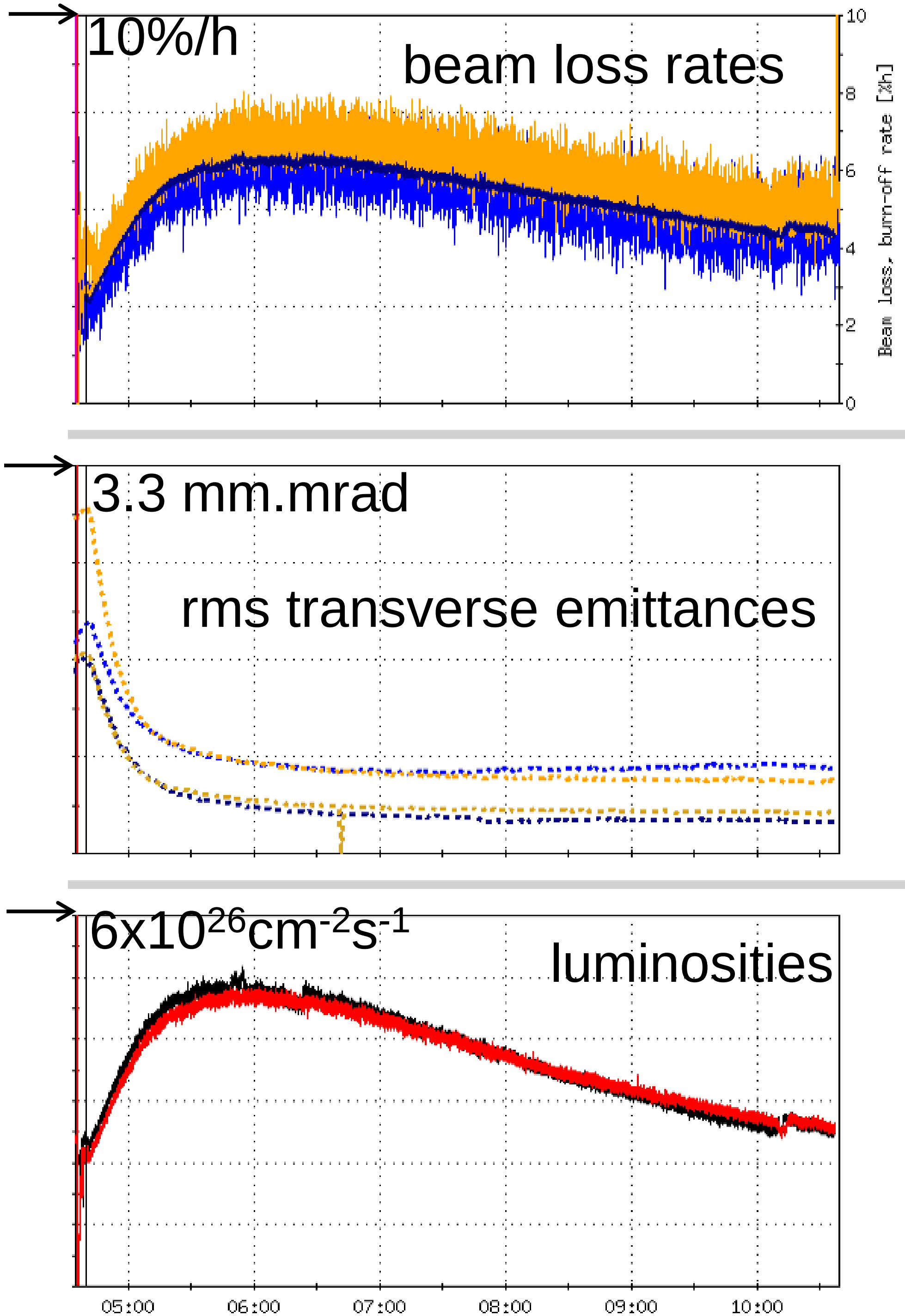


vertical kicker (closed)



5-9 GHz, cooling times ~1 h

M. Brennan, M. Blaskiewicz, F. Severino, PRL **100** 174803 (2008); PRSTAB, PAC, EPAC



U-U store – new mode in 2012

All beam loss though luminosity (burn-off)!

cross sections [b]:

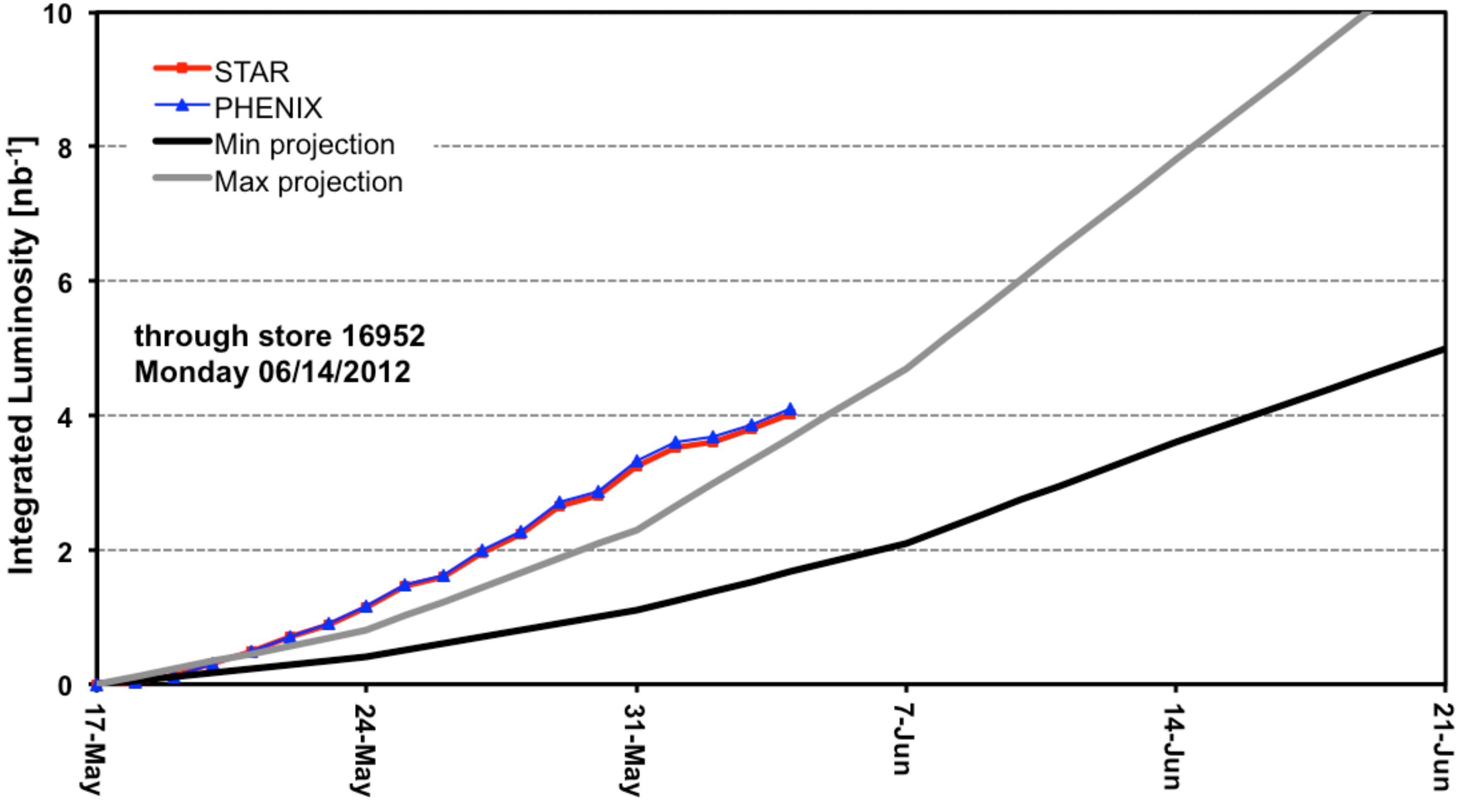
	Au-Au	U-U
BFPP	117	329
EMD	99	160

3D stochastic cooling leads to new feature in hadron collider:

$$L_{max} > L_{initial}$$

Run-12 – Copper-gold 100 GeV/nucleon (still running)

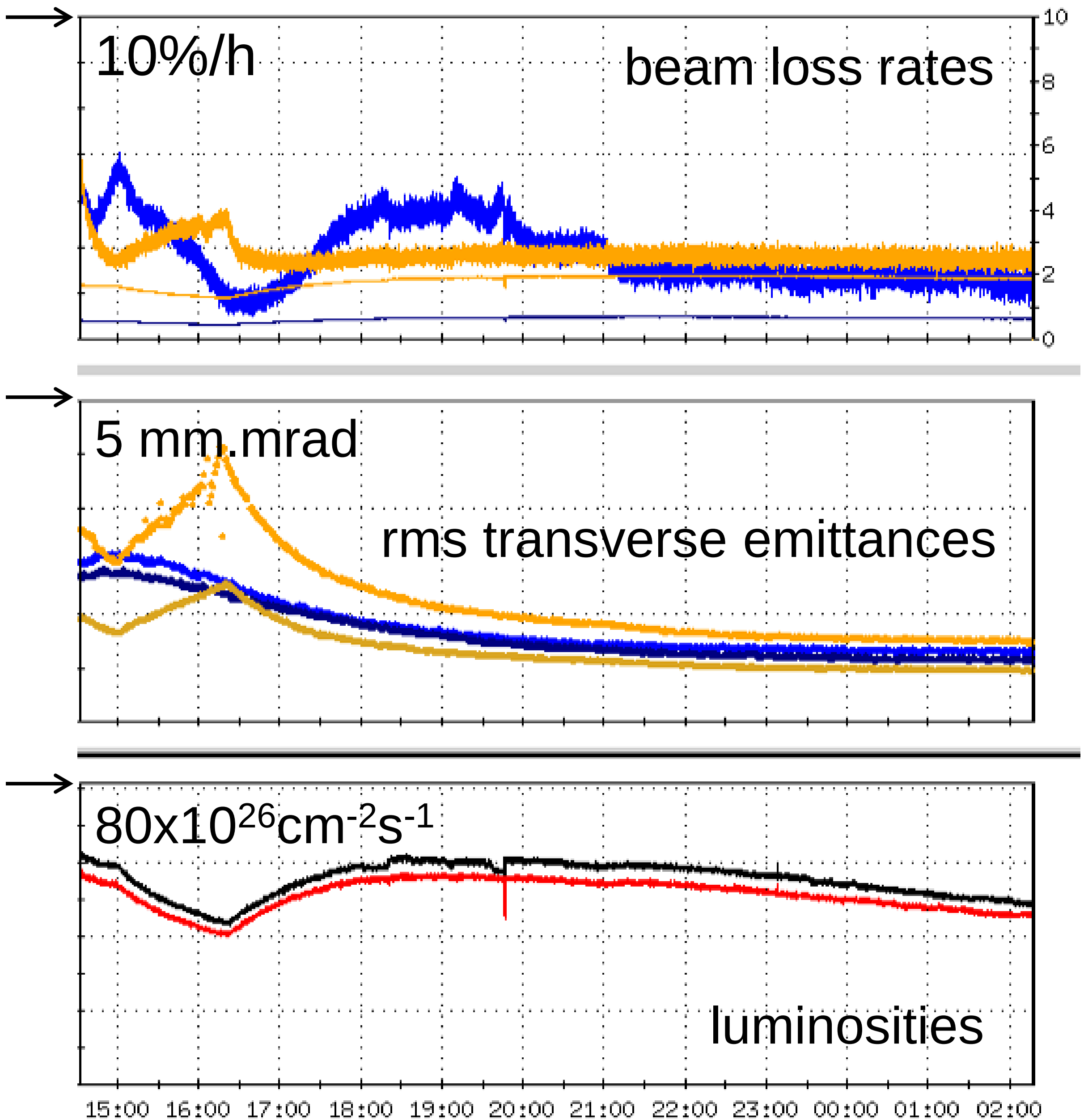
Run Coordinator: Y. Luo



5 weeks

New: first Cu-Au operation in a collider; used standard lattice to increase off-momentum dynamic aperture; first use of Blue and Yellow horizontal stochastic cooling (resulting in 3D cooling in both rings)

Cu-Au store – new mode in 2012



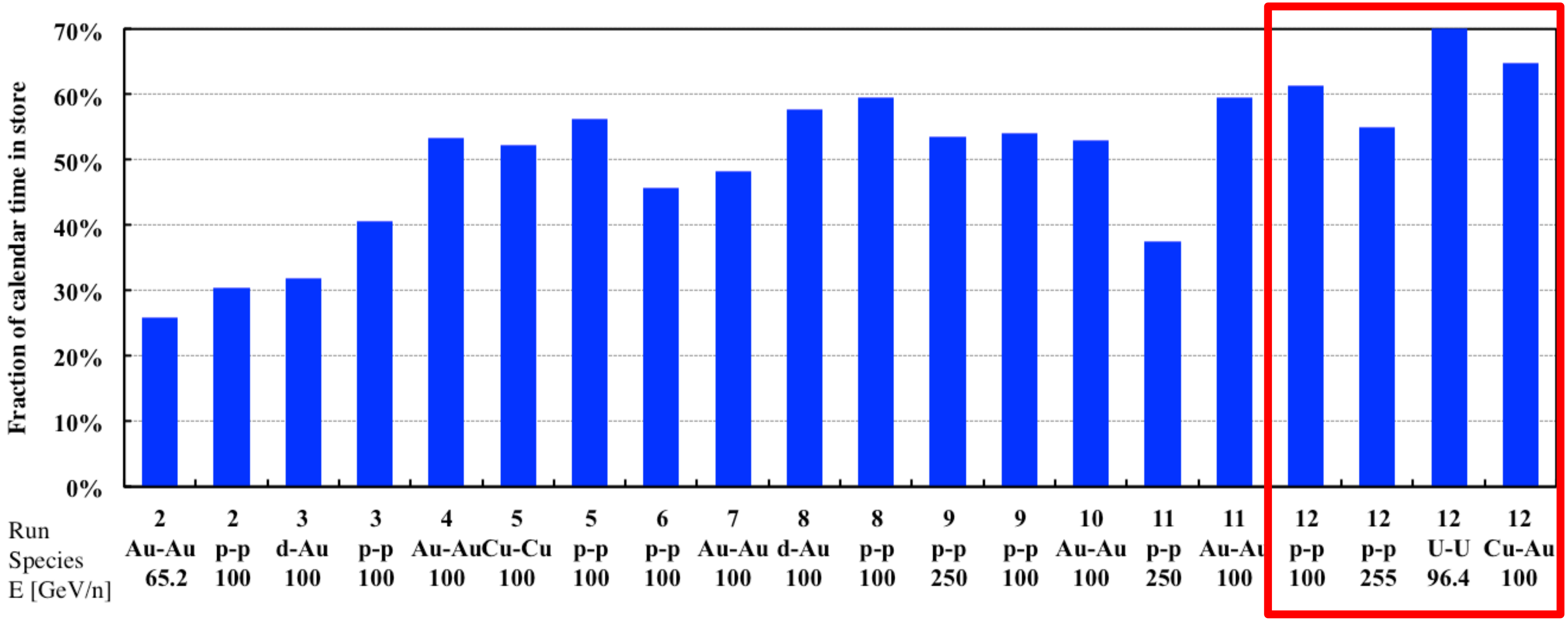
Cu and Au have different

- intrabeam scattering growth rates ($\sim Z^4 N_b / A^2$)
  $r_{IBS,Au} \approx 2x\ r_{IBS,Cu}$
- cooling rates ($\sim 1/N_b$)
  $r_{SC,Au} \approx 3x\ r_{SC,Cu}$

Optimization of Cu/Au cooling rates:
Overcooling of one beam creates large loss rate in other beam

14 h store length

Time-in-store as fraction of calendar time



As of 06/03/12

- Run-12 with low failure rates in all systems
- Highest time-in-store ratios to date
  (even with increased APEX time during 255 GeV protons compared to Run-11)

RHIC ions – 6 species and 15 energies to date

$^{238}\mathrm{U}^{92+}-^{238}\mathrm{U}^{92+}$ ♑ first time in 2012, 3 weeks physics, complete

96.4 GeV/nucleon

$^{197}\mathrm{Au}^{79+}-^{197}\mathrm{Au}^{79+}$

3.85, 4.6, 5.75, 9.8, 13.5, 19.5, 27.9, 31.2, 65.2, 100.0 GeV/nucleon

$^{63}\mathrm{Cu}^{29+}-^{197}\mathrm{Au}^{79+}$ ♑ first time in 2012, 5 weeks, under way

99.9/100.0 GeV/nucleon

$^{63}\mathrm{Cu}^{29+}-^{63}\mathrm{Cu}^{29+}$

11.2, 31.2, 100.0 GeV/nucleon

$\mathrm{d}-^{197}\mathrm{Au}^{79+}$

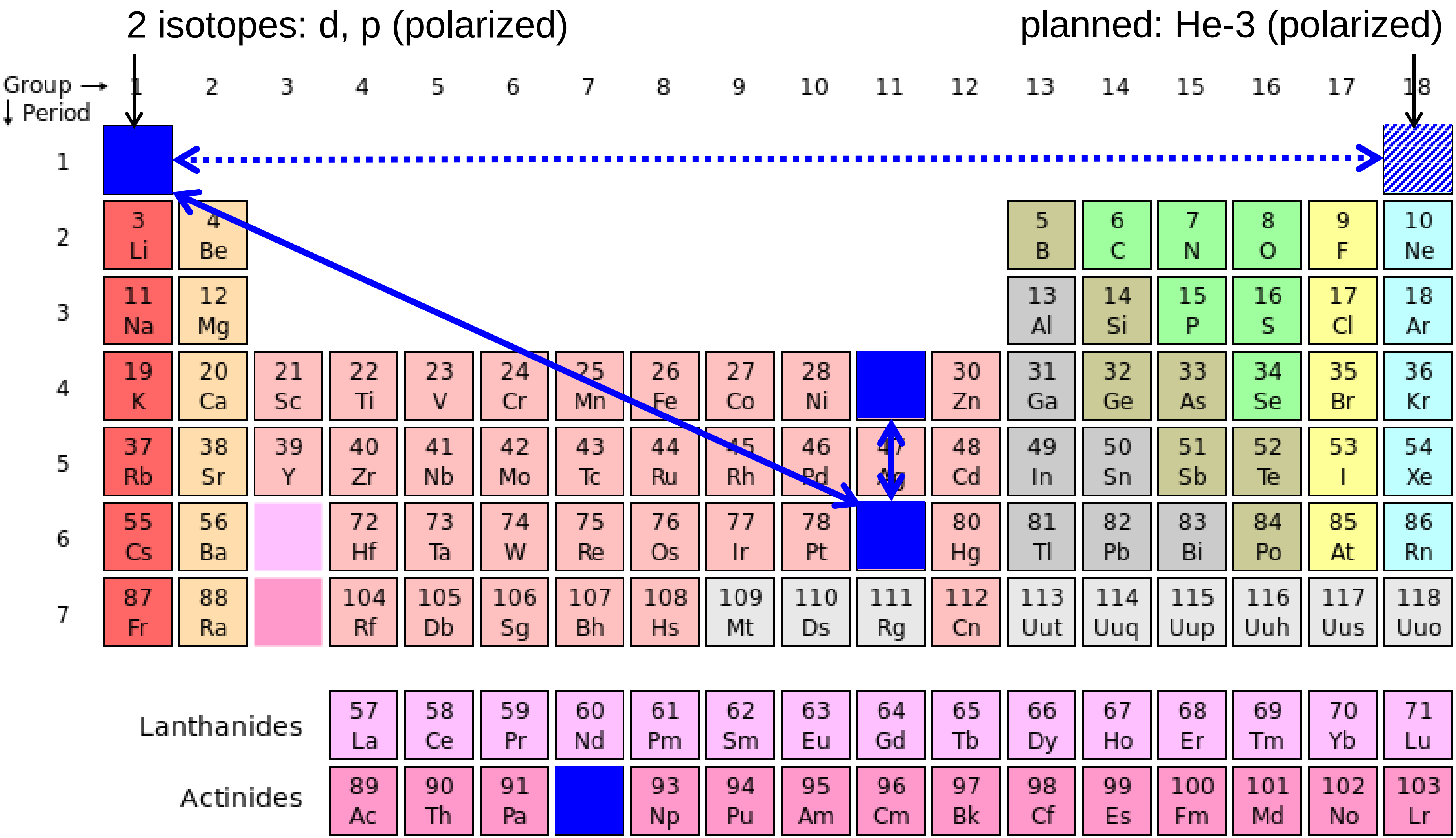
100.7/100.0 GeV/nucleon

p♒−p♒

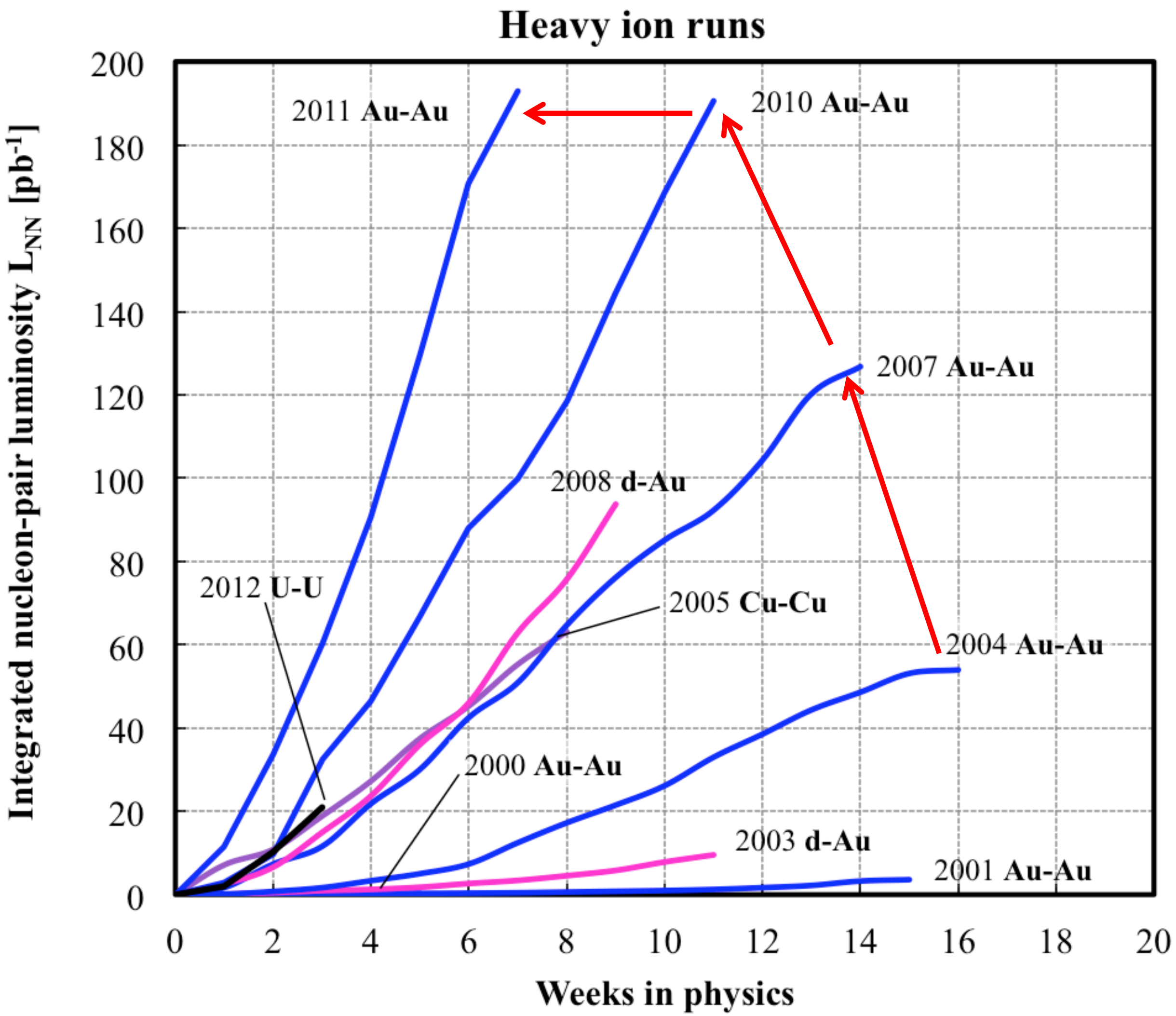
31.2, 100.2, 204.9, 249.9, 254.9 GeV

Can collide any species from protons (polarized) to uranium – with each other or with another species

RHIC ions – 6 species and 15 energies to date



RHIC heavy ions – luminosity evolution to date



<L> = 15x design in 2011

About 2x increase in L_{int}/week each

- Run-4 to Run-7
- Run-7 to Run10
- Run-10 to Run-11

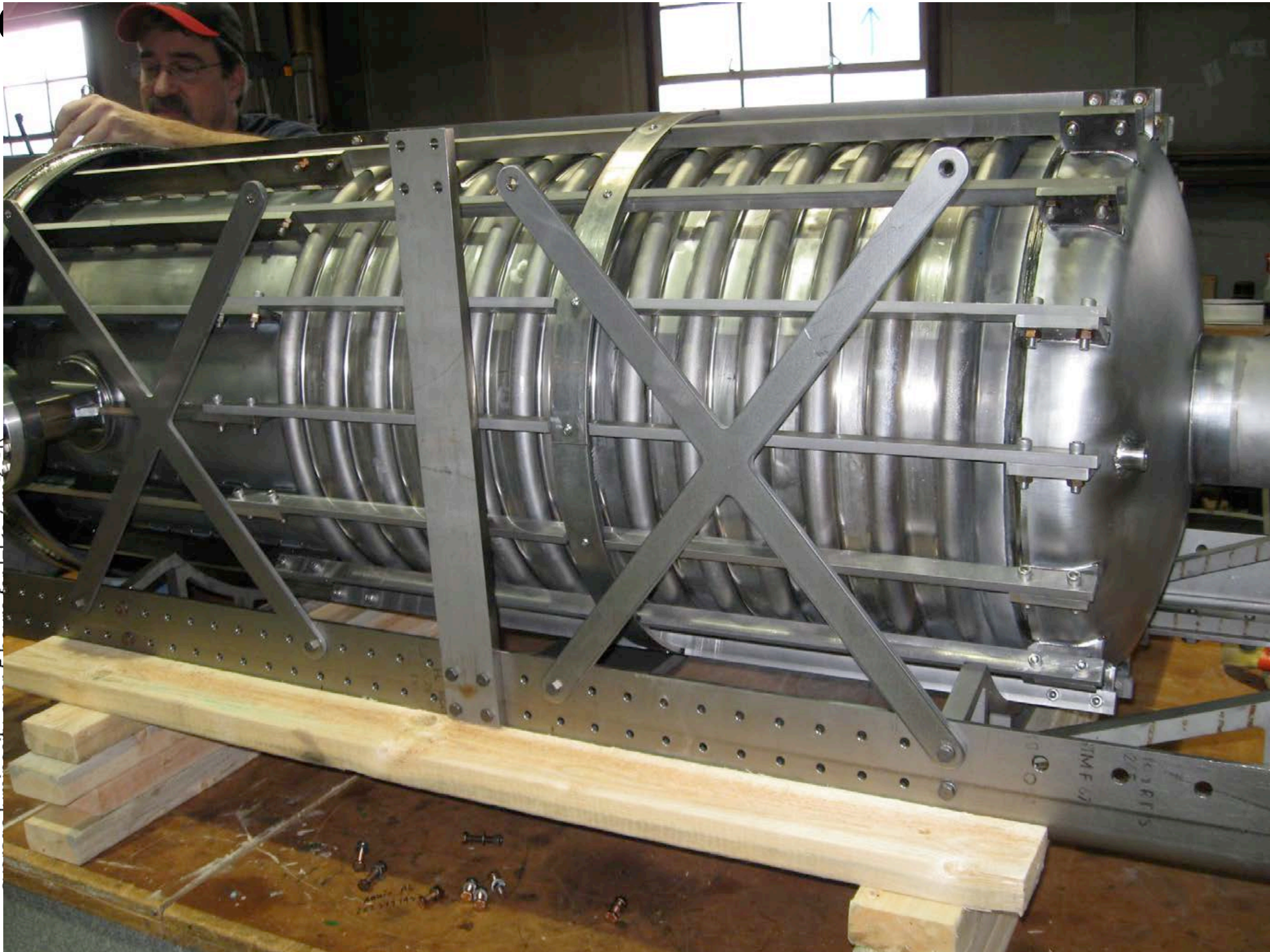
Rate of progress will slow down – burn off 50% of Au beam in collisions already

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

5… al.)

…ng

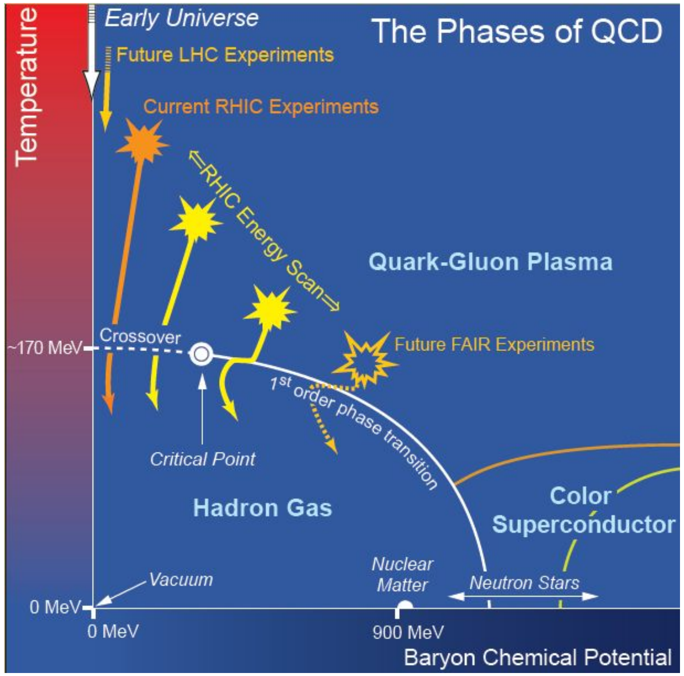
…14



Calculation by M. Blaskiewicz

RHIC – Au-Au energy scan

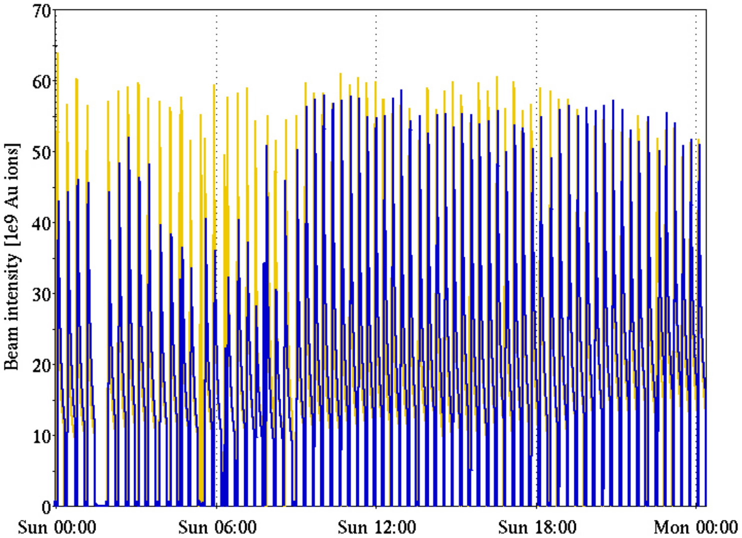
US NSAC report 2007



Energy scan – extends below nominal injection energy in search of critical point in QCD phase diagram

Effects to contend with (#s for 20% nominal ($B\rho$)):

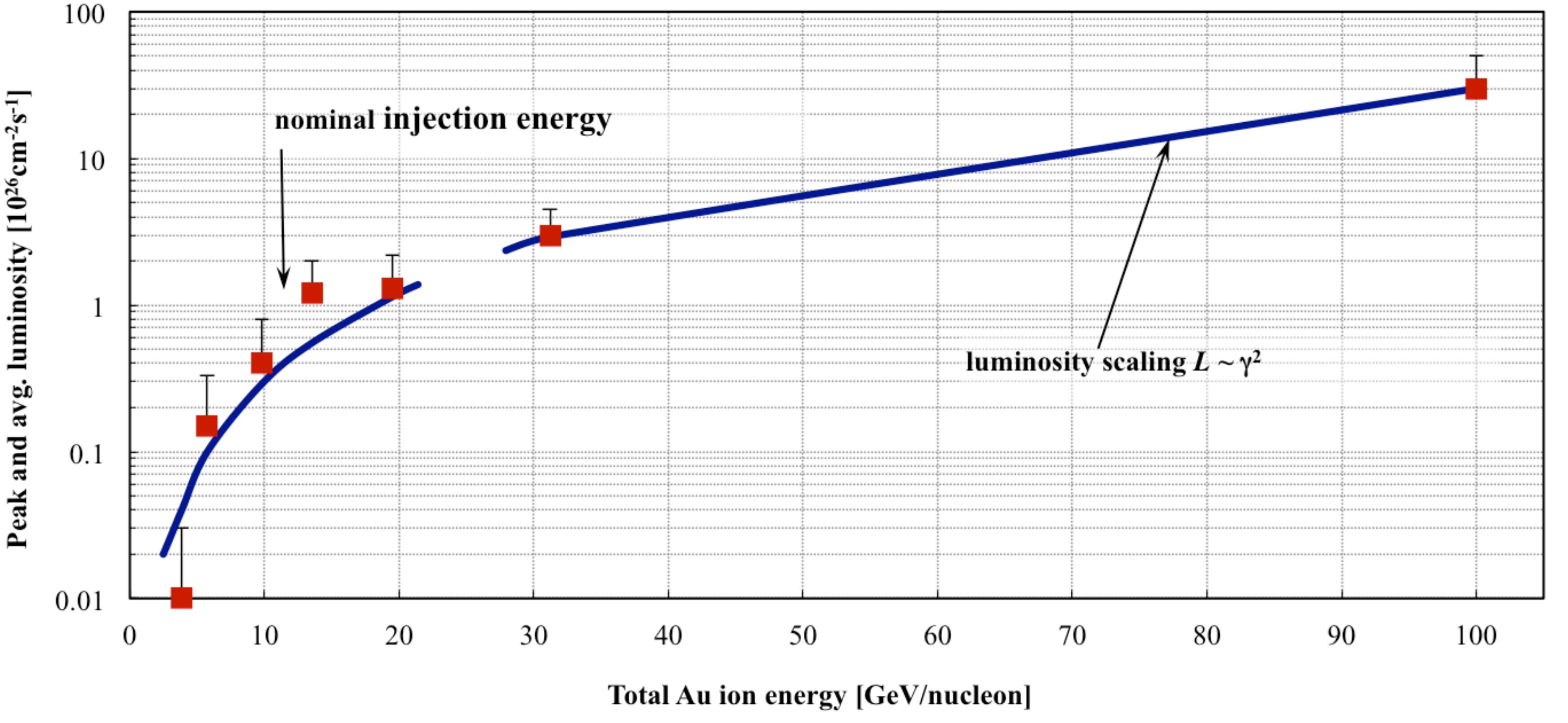
- Large beam sizes **(longitudinal and transverse)** **controlling losses becomes critical**
- Large magnetic field errors **(b_3 ~ 10, b_5 ~ 6 units from persistent currents in superconducting magnets)**
- Intrabeam scattering **(debunching ~min)**
- Space charge **($\Delta Q_{Laslett}$ ~ 0.1 – new 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 ($B\rho$)
- **May operate at 20% of nominal injection ($B\rho$)**

Au-Au energy scan to date



Peak and average luminosities fall faster than $1/\gamma^2$ at lowest energies
Need cooling at low energies to significantly increase luminosities

e-cooling for low energy collider operation (A. Fedotov et al.)

Fermilab Pelletron (cooled 8 GeV pbar for Tevatron use) usable –

scheduled for decommissioning in 3/2012, so far have not requested transfer

Alternative option with e- beam from 112 MHz SRF gun

Cooling into space charge limit

$\Delta Q_{sc} \sim 0.05$ (new collider regime)

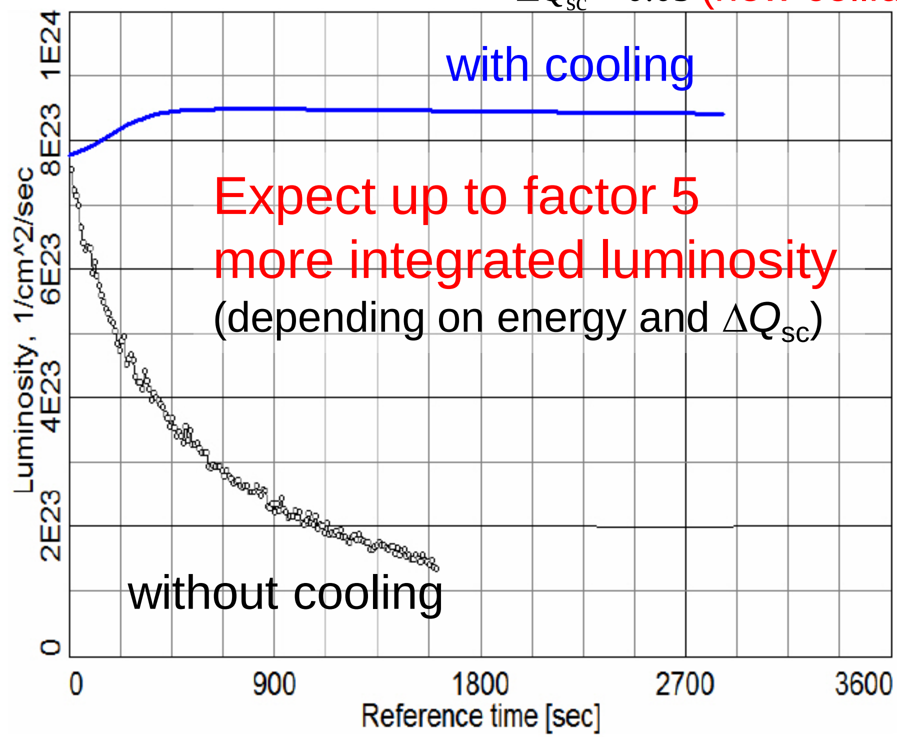
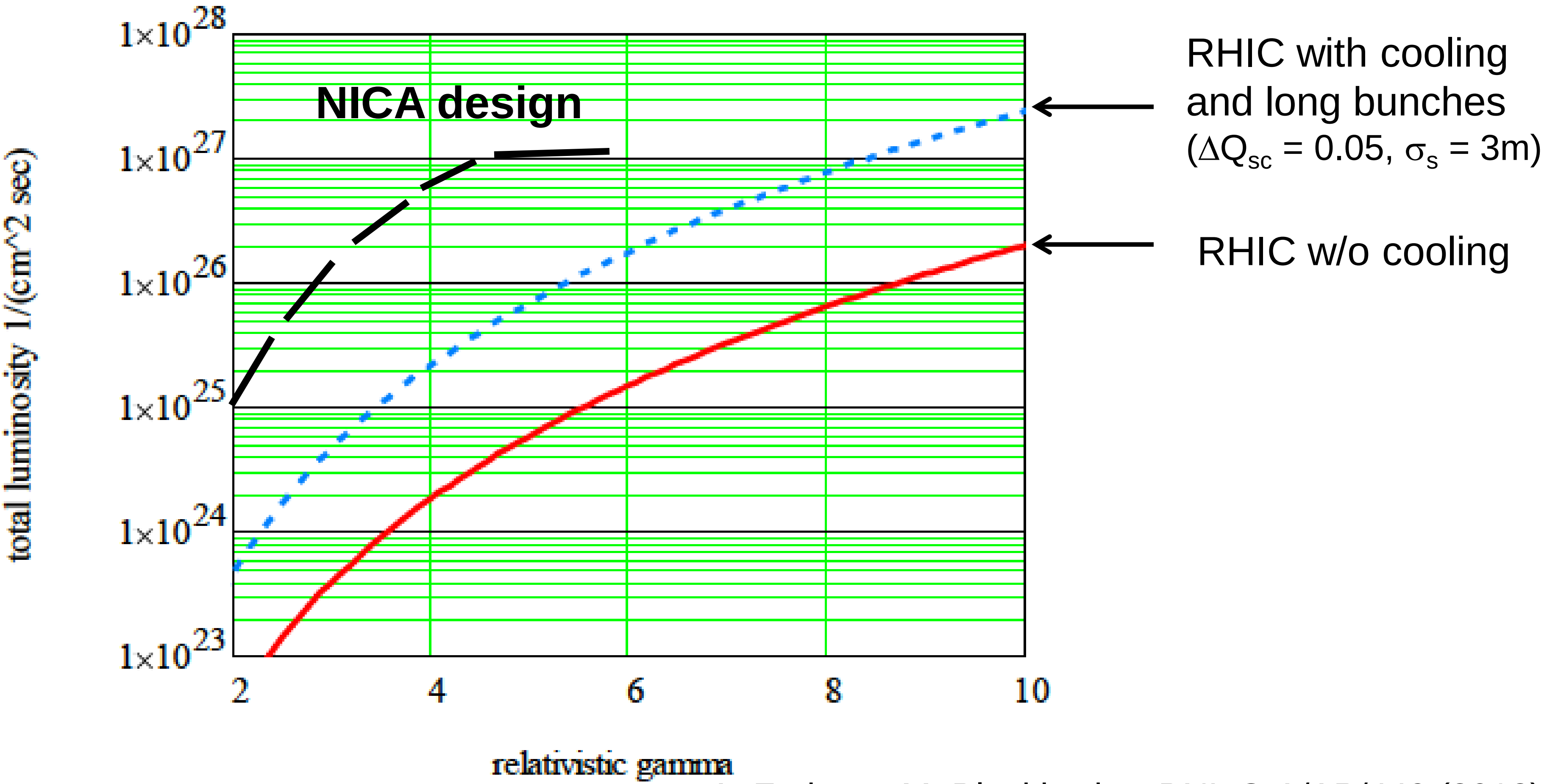


Figure 4. Simulation of luminosity with (blue line) and without (black dots) electron cooling at γ=2.7.

A. Fedotov, M. Blaskiewicz, BNL C-A/AP/449 (2012)

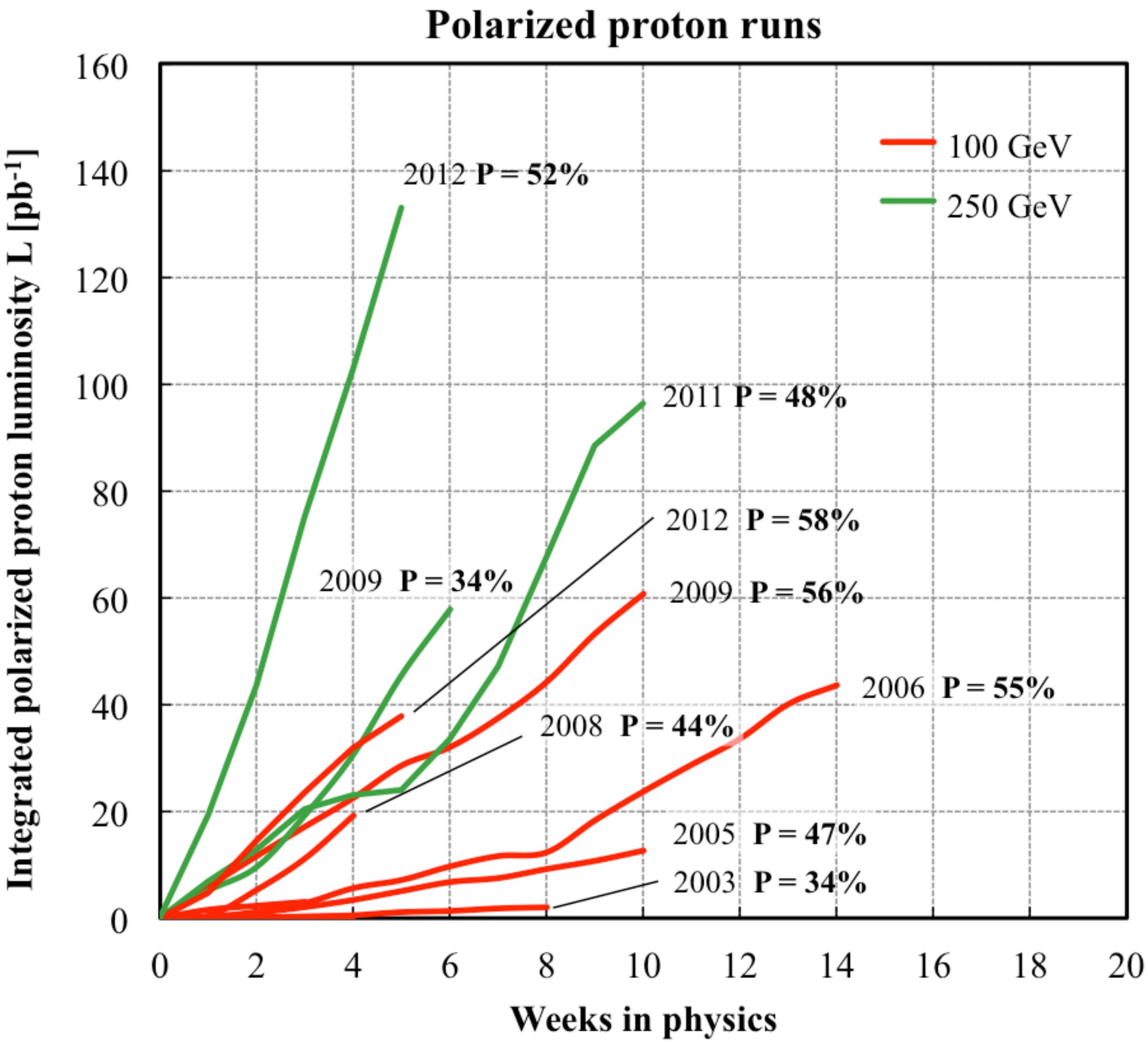
Low energy operation with cooling AND long bunches

Additional gain by operating with long bunches (at space charge limit)



A. Fedotov, M. Blaskiewicz, BNL C-A/AP/449 (2012)

RHIC polarized protons – luminosity and polarization



At 255 GeV in 2012

L_{avg} = 105x10^{30}cm^{-2}s^{-1}

P_{avg} = 52%

L_{avg} +15% relative to 2011

P_{avg} +8% relative to 2011

$FOM = LP^2$

(single spin experiments)

$FOM = LP^4$

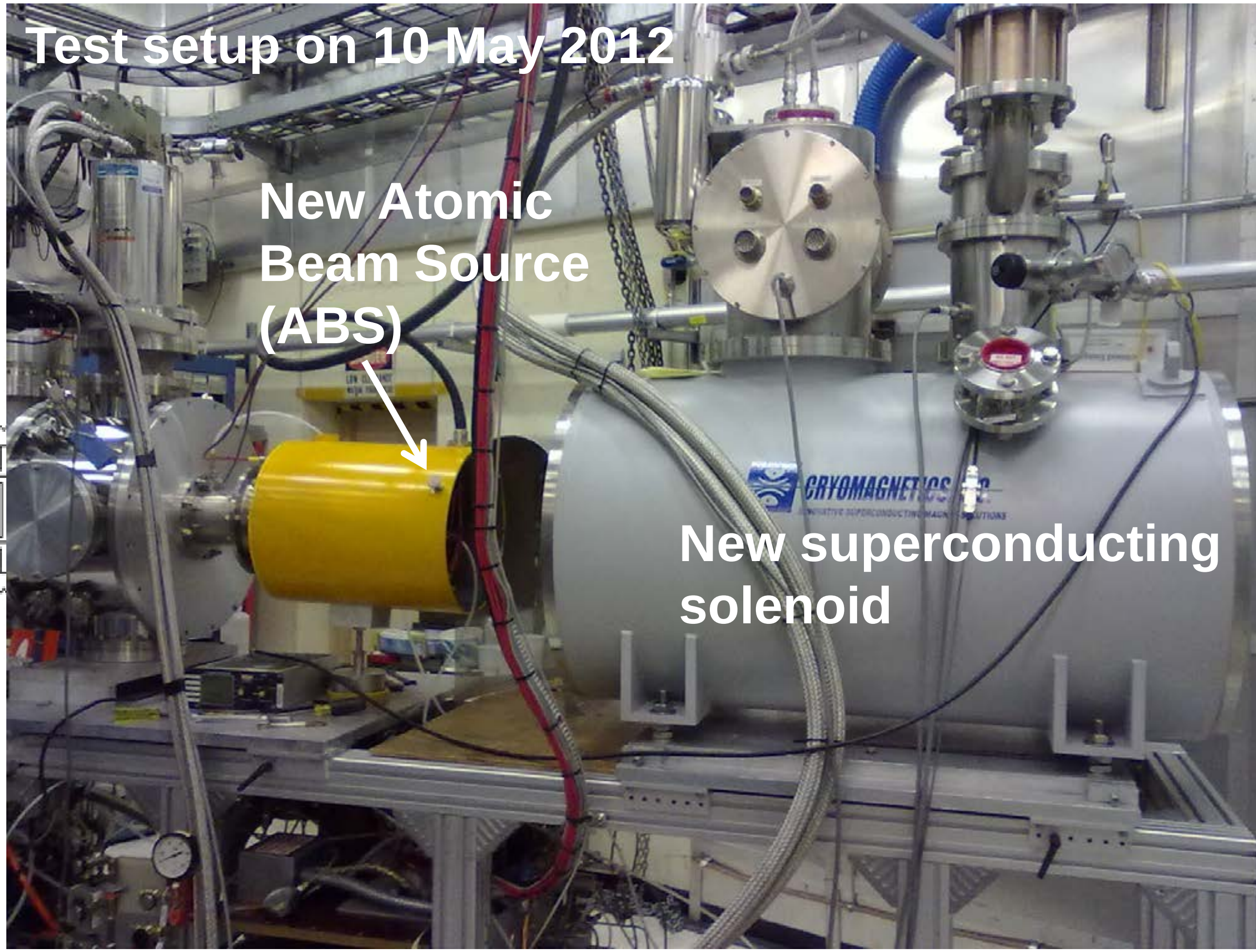
(double spin experiments)

Wolfram Fischer

Optically Pumped Polarized H⁻ source (OPPIS) – A. Zelenski

Upgraded OPPIS (2013)

Source
(H^+)



Goals:

eam current
e to 10mA
f magnitude)
rization to 85-
5% increase)

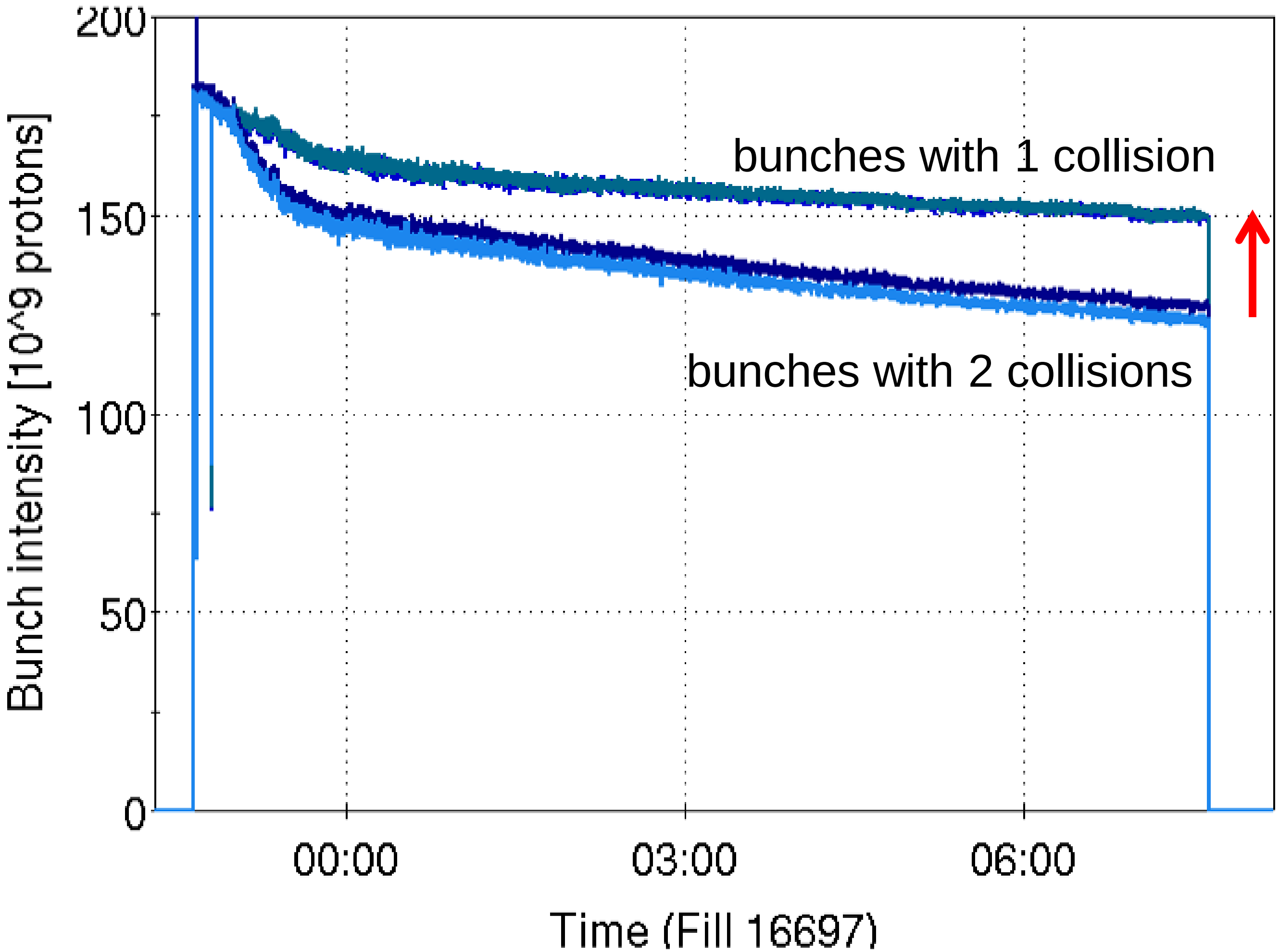
components:

hydrogen
(collaboration
P Novosibirsk)
onducting
d (3 T)
liagnostics
arimetry

=> 10x intensity from ABS was accelerated through Linac

Motivation

Bunch intensity in 2012 polarized proton physics store



Goal:

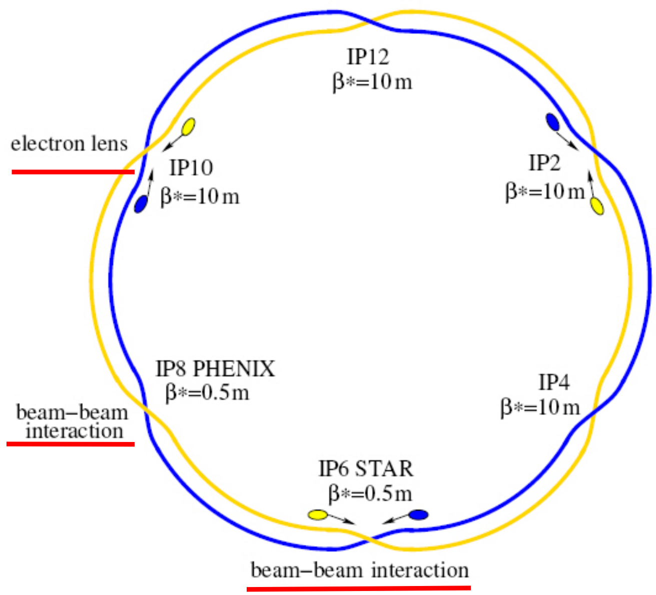
Compensate for 1 of 2 beam-beam interactions with electron lenses

Then increase bunch intensity
$\Rightarrow$ up to 2× luminosity

Need new polarized proton source − under construction, A. Zelenski

$$L \propto N_b^2$$

Electron lenses – partial head-on beam-beam compensation

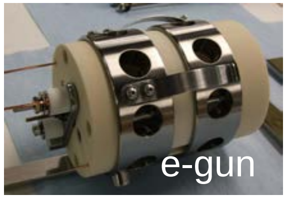


Basic idea:

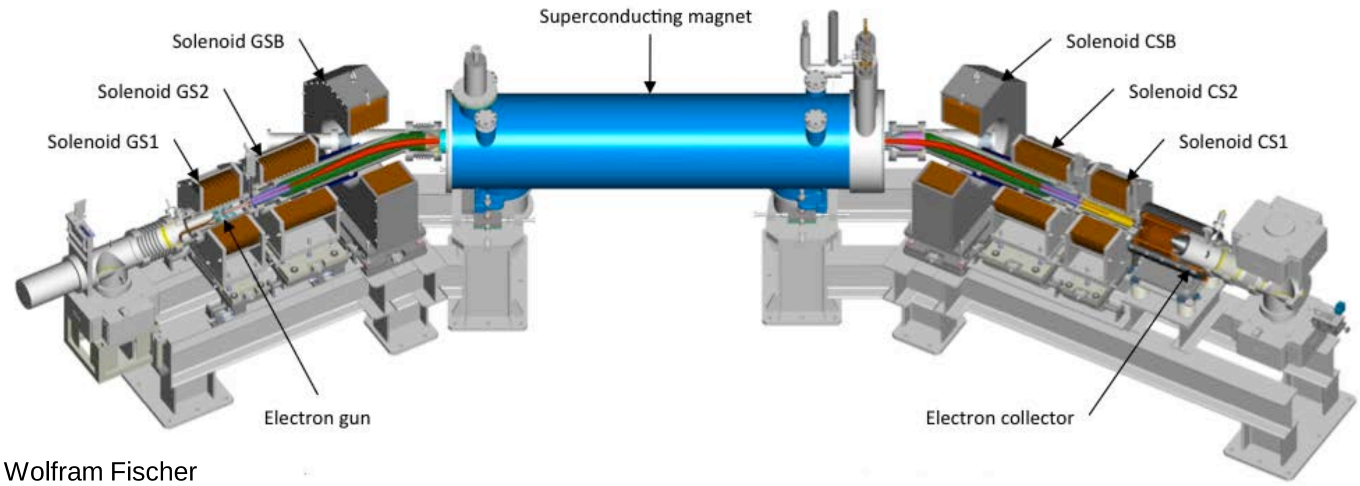
- 2 beam-beam collisions with **positively** charged beam
- Add collision with a **negatively** charged beam – with matched intensity and same amplitude dependence

Compensation of nonlinear effects:

- e-beam current and shape
  => reduces tune spread
- $\Delta\psi_{x,y} = k\pi$ between p-p and p-e collision
  => reduces resonance driving terms



Installation in 2012
Expect up to 2x more luminosity



Polarized ^{3}He – Workshop 28-30 September 2011

Workshop program

- $^{3}\text{He}^{2+}$ source, $^{3}\text{He}^{2+}$ beams from EBIS
- $^{3}\text{He}^{2+}$ in Booster/AGS
- $^{3}\text{He}^{2+}$ in RHIC and EIC
- Polarimetry (low and high energy)
- Physics with $^{3}\text{He}^{2+}$ beams (theory and experiments)

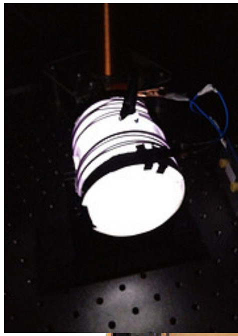
Overview
Agenda
Call for Abstracts
View my abstracts
Submit a new abstract
Timetable
Contribution List
Book of abstracts
Registration

Dates: from 28 September 2011 08:00 to 30 September 2011 18:00
Timezone: US/Eastern
Room: Brookhaven Center, Bldg. 30
Dr. Aschenauer, Elke
Additional info: Guest Information System (GIS)
If you have a current BNL Appointment and a valid BNL Guest Number or you have a pending Guest Registration (GR) Number, it is not necessary to complete

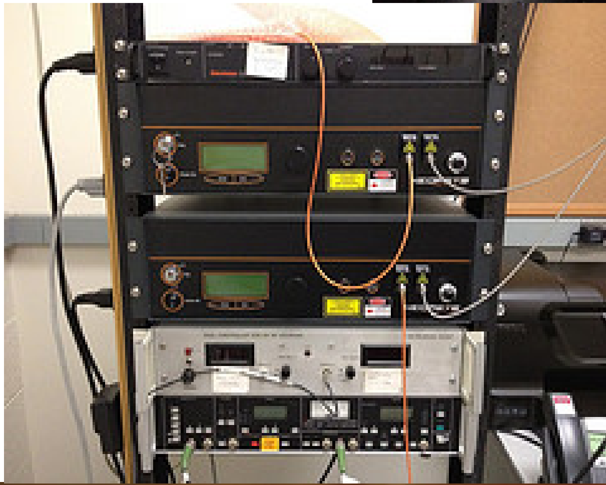
Development of Polarized ^3He Ion Source for RHIC

BNL-MIT Collaboration http://he3.xvm.mit.edu/

R. Milner, C. Epstein, MIT



- Spec.: deliver $^3He^{++}$ at ≈ 3 x 10^{12} atoms/sec with 70% polarization
- Concept: polarize ^3He gas in glass cell using MEOP in fringe field of ≈ 5 Tesla EBIS solenoid and feed into EBIS
- MEOP technology under development at MIT
  - two Keopsys 10 Watt lasers operational
  - data acquisition system operational
  - 20 liters of ^3He gas ordered
  - glass systems under construction
- Goal: to test principle of source using spare EBIS solenoid within the next year



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Polarized ^{3}He in RHIC – plan under development

- Polarized ^{3}He source developed at MIT (R. Milner)
- Polarized ^{3}He beams from EBIS
- Polarimeter after EBIS linac at 2 MeV/nucleon
- Un-polarized ^{3}He from EBIS:
  - Injection into Booster at low rigidity
  - Acceleration in Booster, AGS, RHIC?
  - Test carbon polarimeters

Plan acceleration of unpolarized ^{3}He in Booster and AGS after RHIC Run ends

- Acceleration of polarized ^{3}He in Booster and transfer to AGS
  - Vertical tune in Booster < 4.19 !!
- Measure polarization at AGS injection energy, no depolarization?
- Accelerate ^{3}He in AGS and measure polarization on ramp and extraction
- Calibrate A_N of carbon polarimeter at extraction energy with up/down ramp?
- Transfer to RHIC and calibrate carbon polarimeter in RHIC (which ring?)
- Absolute polarization measurement at RHIC injection with pol. ^{3}He jet/cell
- Accelerate in RHIC and measure polarization on ramp and at store energy
  - May need 4 more snakes in Blue ring
- Calibrate A_N of carbon polarimeter at store energy with up/down ramp
- Absolute polarization measurement at RHIC store with pol. ^{3}He jet/cell

Possible running modes Run-13 and Run-14 (BUPs)

Run-13

- 500 GeV p-p (STAR, PHENIX) ~10 weeks
- 200 GeV p-p (PHENIX) ~3-4 weeks
- 30 GeV p-p (PHENIX) ~1.5 weeks
- 200 GeV Au-Au (STAR) ~ 4 weeks

Run-14

- 200 GeV Au-Au (STAR, PHENIX) ~6-8 weeks
- 200 GeV p-p (STAR, PHENIX) ~4 weeks
- 200 GeV d-Au (PHENIX) ~6 weeks

RHIC luminosity and polarization goals

parameter	unit	achieved		goals			
Au-Au operation		**2011**		**≥ 2014** 3D stochastic cooling + 56 MHz SRF			
energy	GeV/nucleon	100		100			
no colliding bunches	…	111		111			
bunch intensity	10^9	1.3		≥ 1.1			
avg. luminosity	$10^{26}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$	**30**		**40**			
p↑-p↑ operation		**2012**		**≥ 2013**		**≥ 2014** source + e-lenses	
energy	GeV	100	255	100	250	100	250
no colliding bunches	…	– 107 –		– 107 –		– 107 –	
bunch intensity	10^{11}	1.6	1.7	1.6	2.0	1.8	2.5
avg. luminosity	$10^{30}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$	**33**	**105**	**30**	**150**	**60**	**300**
avg. polarization*	%	**58**	**52**	**– 60 –**		**– 70 –**	

*Intensity and time-averaged polarization as measured by the H-jet. Luminosity-averaged polarizations, relevant in single-spin colliding beam experiments, are higher. For example, for intensity-averaged P = 48% and $R_x = R_y = 0.2$ (250 GeV, 2011), the luminosity-averaged polarization is P = 52%.

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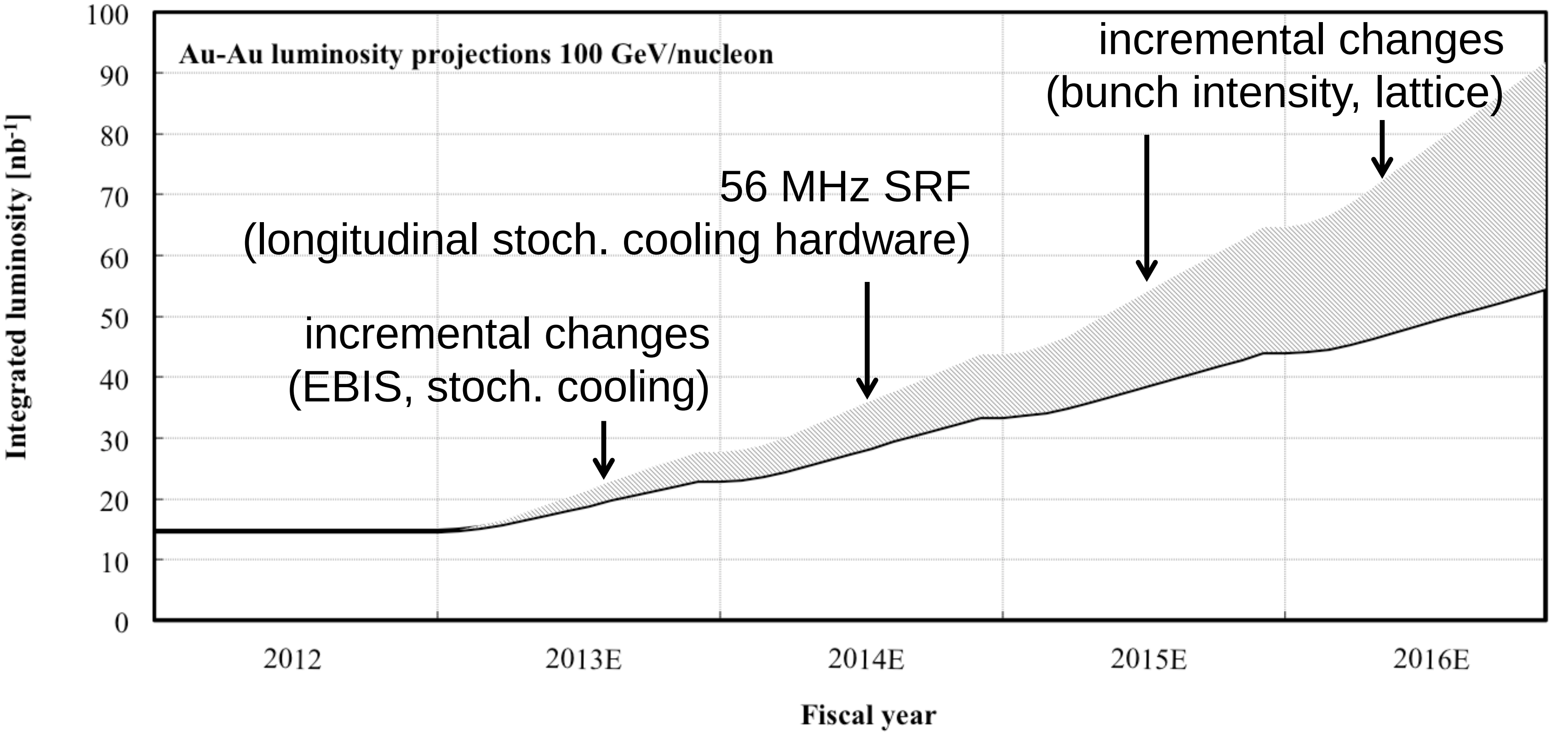
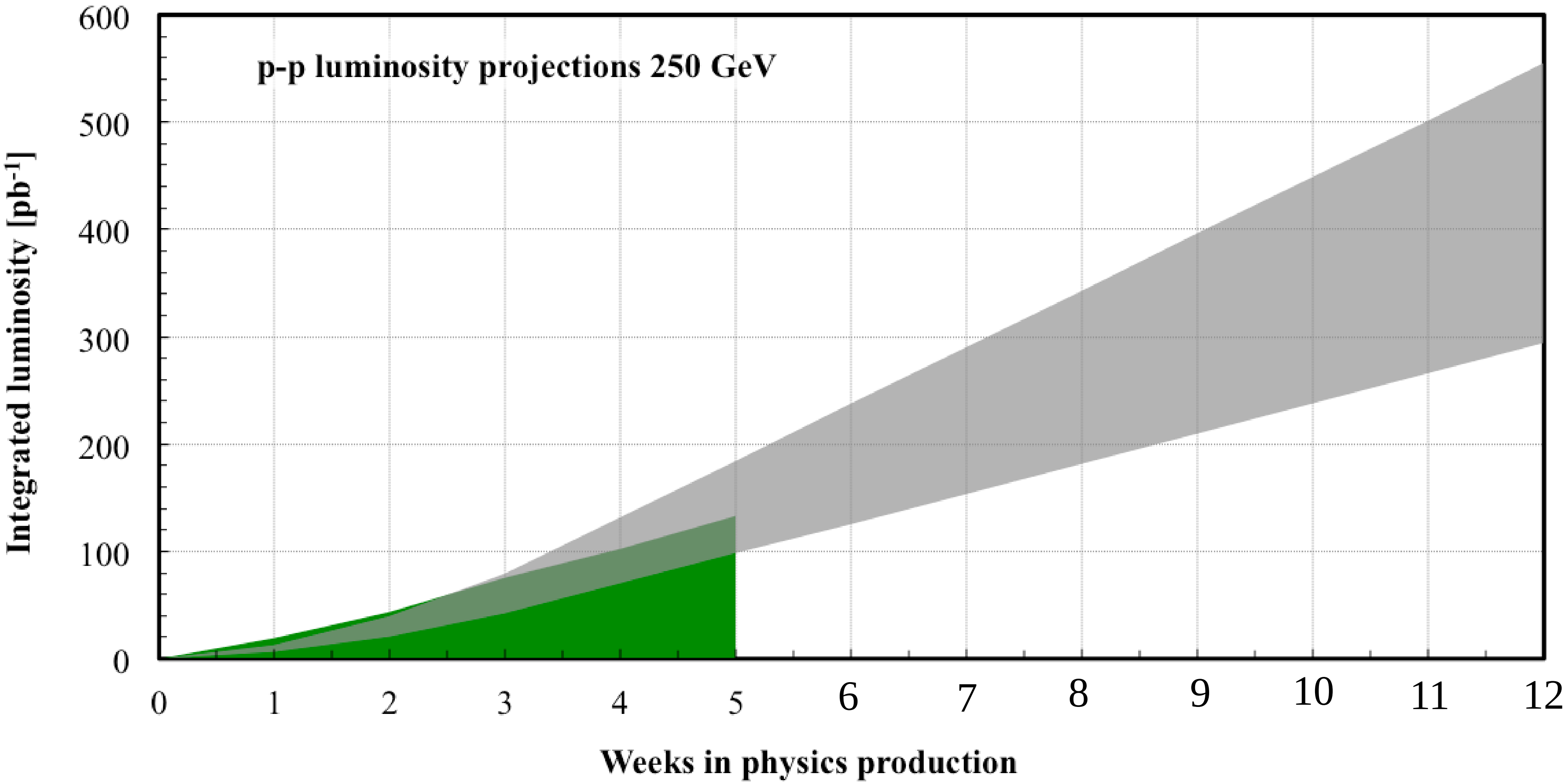
Projections projection for Au-Au



[Note: assume 12 weeks of physics, 8 weeks of ramp-up, start at ¼ of max]
[Note 2: last projections from 14 October 2011 still valid – close to peak performance goals for both polarized protons and heavy ions, will update after Run-12]

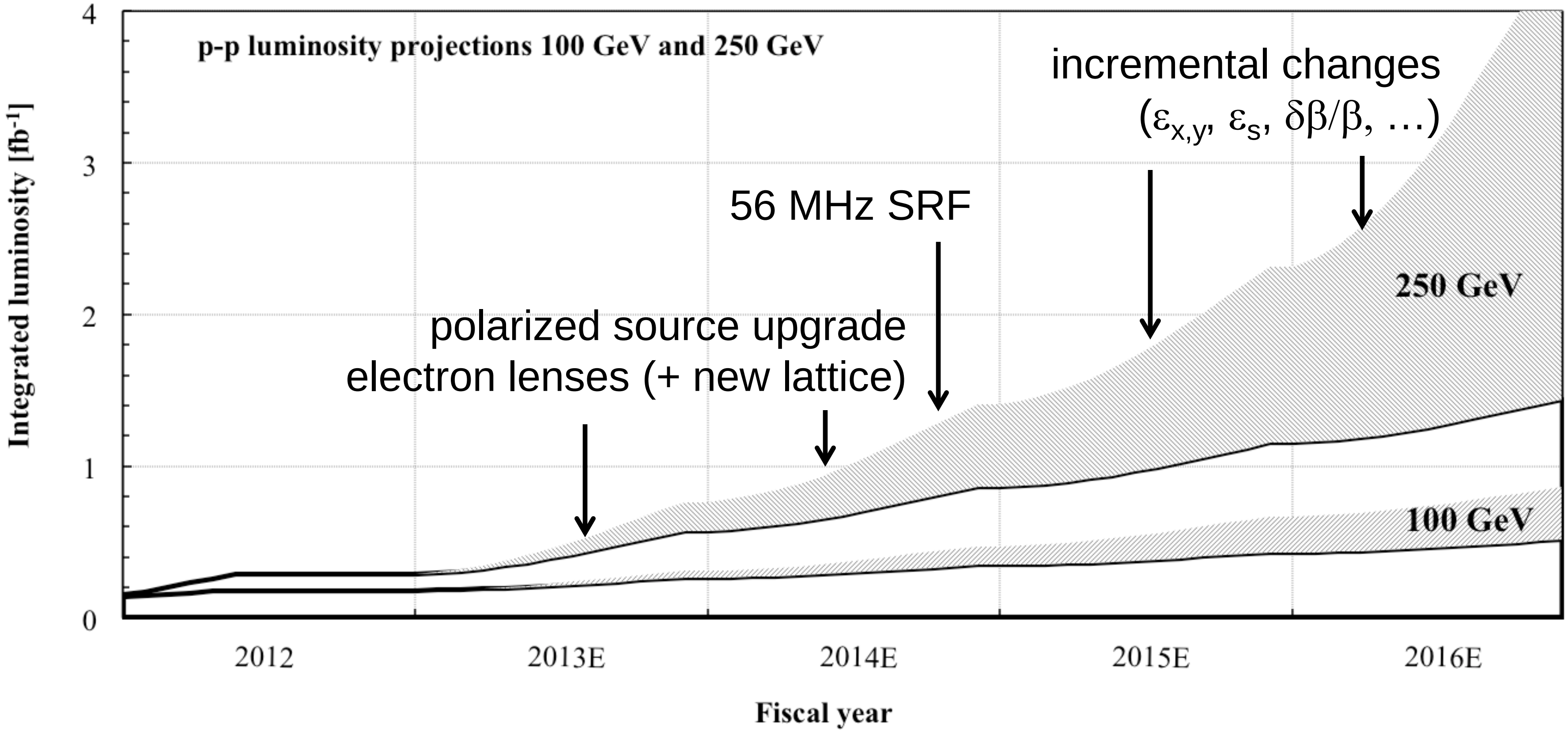
Polarized proton projection for Run-13



Polarization (as measured by H-jet): 50-60%

New: lattice (for e-lens, new phase shifter ps), partial or full source upgrade, e-lens (largely commissioning in Run-13)

Projections for polarized protons

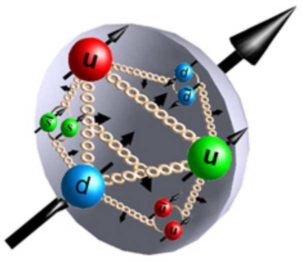


[Note1:assume 12 weeks of physics, 8 weeks of ramp-up, start at ¼ of max]
[Note 2: last projections from 14 October 2011 still valid – close to peak performance goals for both polarized protons and heavy ions, will update after Run-12]

RHIC status and upgrades

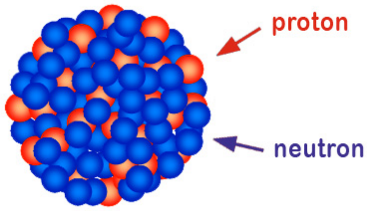
Run-12

- Polarized protons at $\sqrt{s}$ = 200, 510 GeV
  new records for $\sqrt{s}$, L_{peak}, L_{avg}, P
- First U-U collisions at $\sqrt{s_{NN}}$ = 193
  3D stochastic cooling => 5x L_{avg} 5x, only burn-off losses
- First Cu-Au collisions $\sqrt{s_{NN}}$ = 200 GeV



Run-13 – upgrades mainly for polarized protons

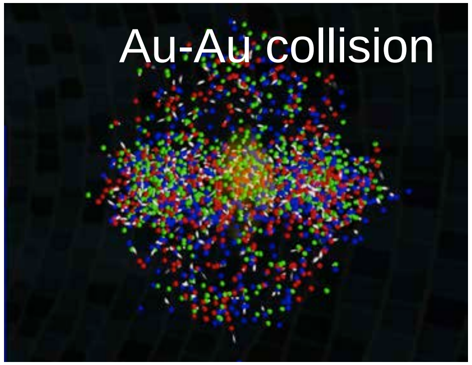
- Polarized source upgrade (partial or full)
  10x intensity, +5% P
- Electron lenses
  requires new lattice, commissioning in Run-13



Uranium Nucleus

Run-14 – upgrades mainly for heavy ions

- 56 MHz SRF, +30-50% L
- Long. stochastic cooling hardware (pickup, kickers)



Low-energy cooling possible for Au-Au
up to $\sqrt{s_{NN}}$ = 20 GeV with Pelletron; up to ~10x L;
≥ 2017 – limited by funding, technical resources, personnel