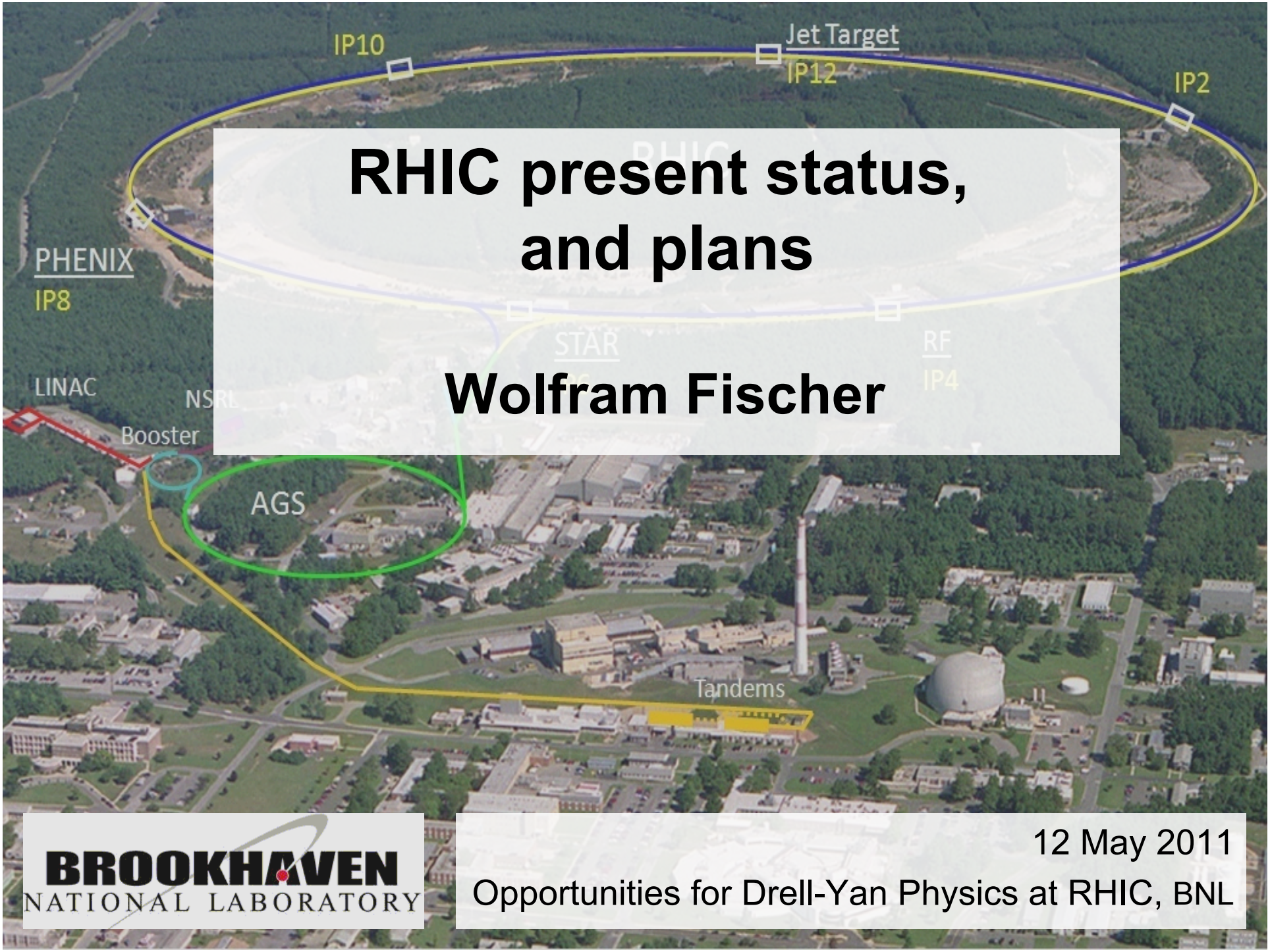


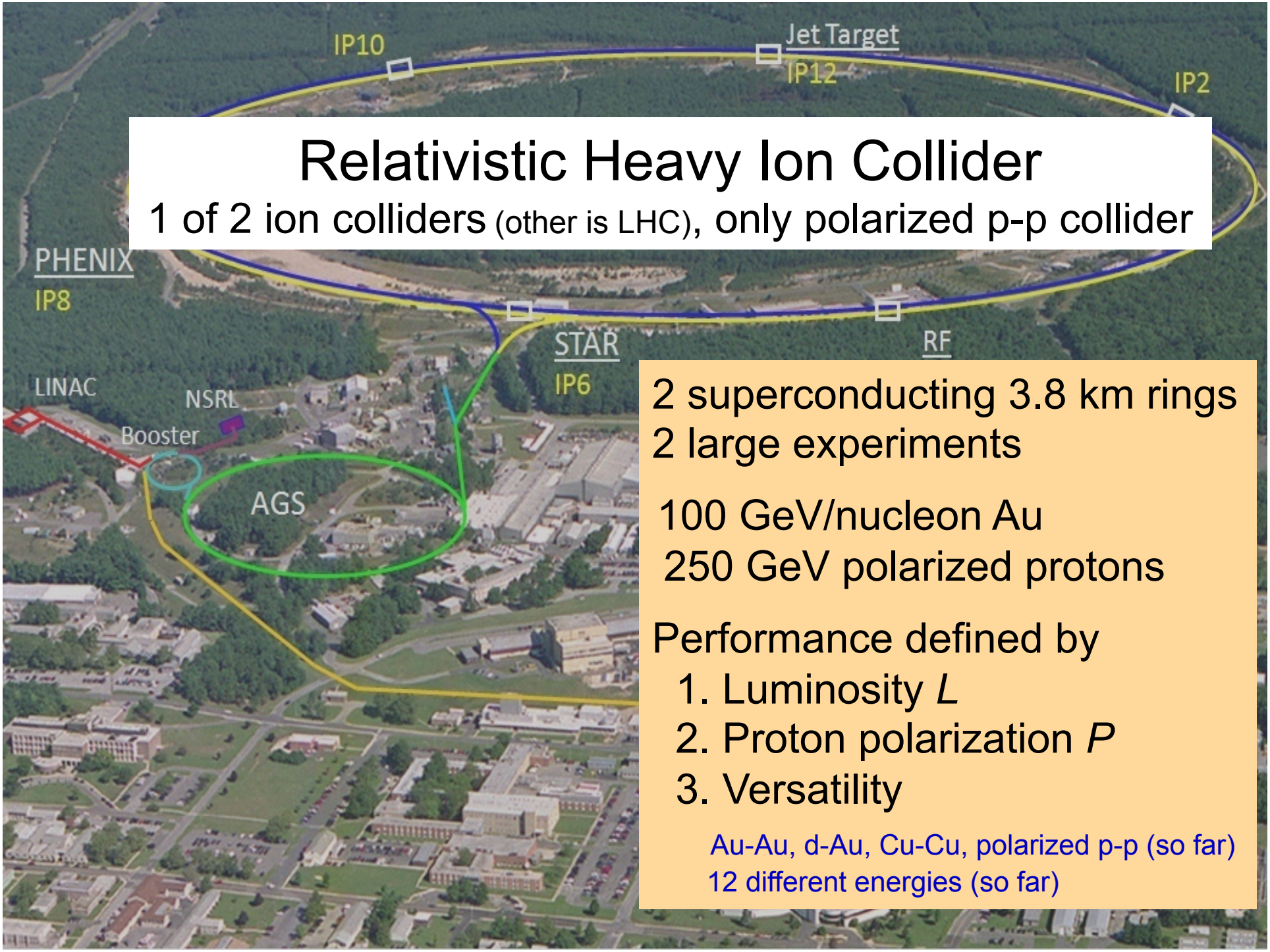
RHIC present status, and plans

Wolfram Fischer

BROOKHAVEN NATIONAL LABORATORY

12 May 2011

Opportunities for Drell-Yan Physics at RHIC, BNL



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 Au
250 GeV polarized protons

Performance defined by

1. Luminosity *L*
2. Proton polarization *P*
3. Versatility

Au-Au, d-Au, Cu-Cu, polarized p-p (so far)
12 different energies (so far)

Content

1. Run-11 polarized proton performance

   Impact of A_nDY, future operation

2. Future developments for polarized protons

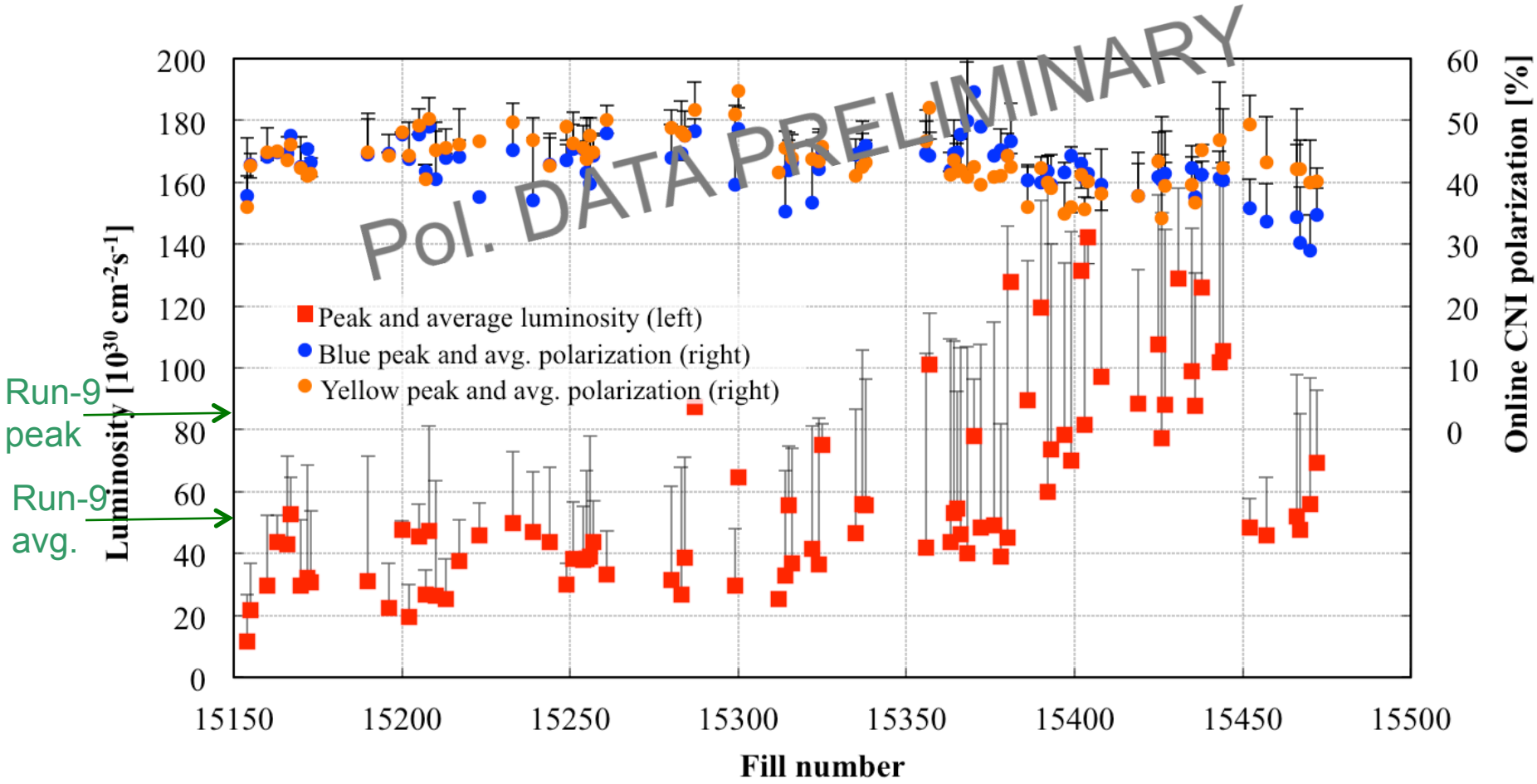
3. Asymmetric collisions (d-Au and p-Au)

4. Energy upgrade

5. Polarized ^{3}He (p-^{3}He, ^{3}He-^{3}He)

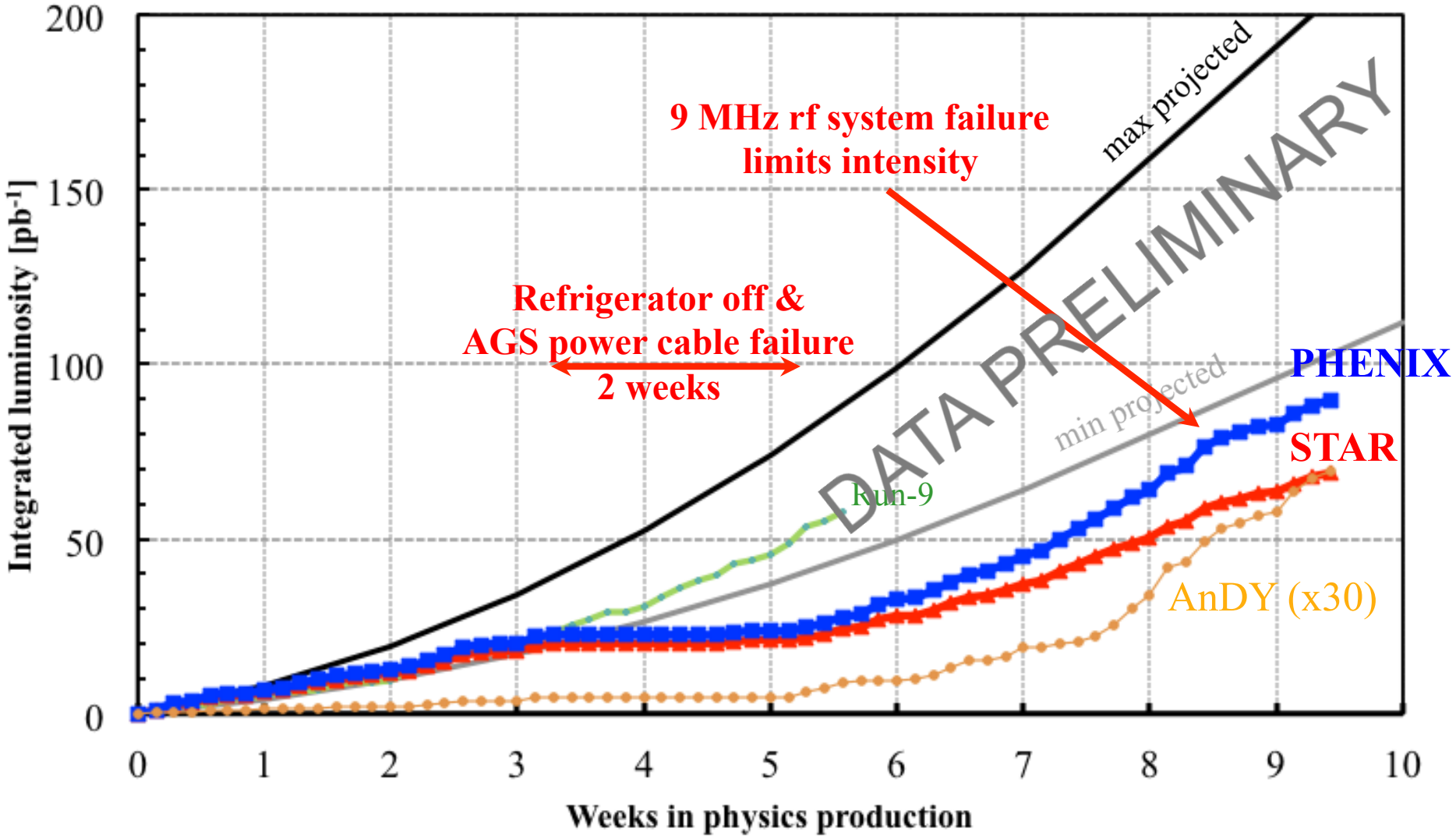
Run-11 250 GeV store overview – polarization and luminosity

Run Coordinator: Haixin Huang

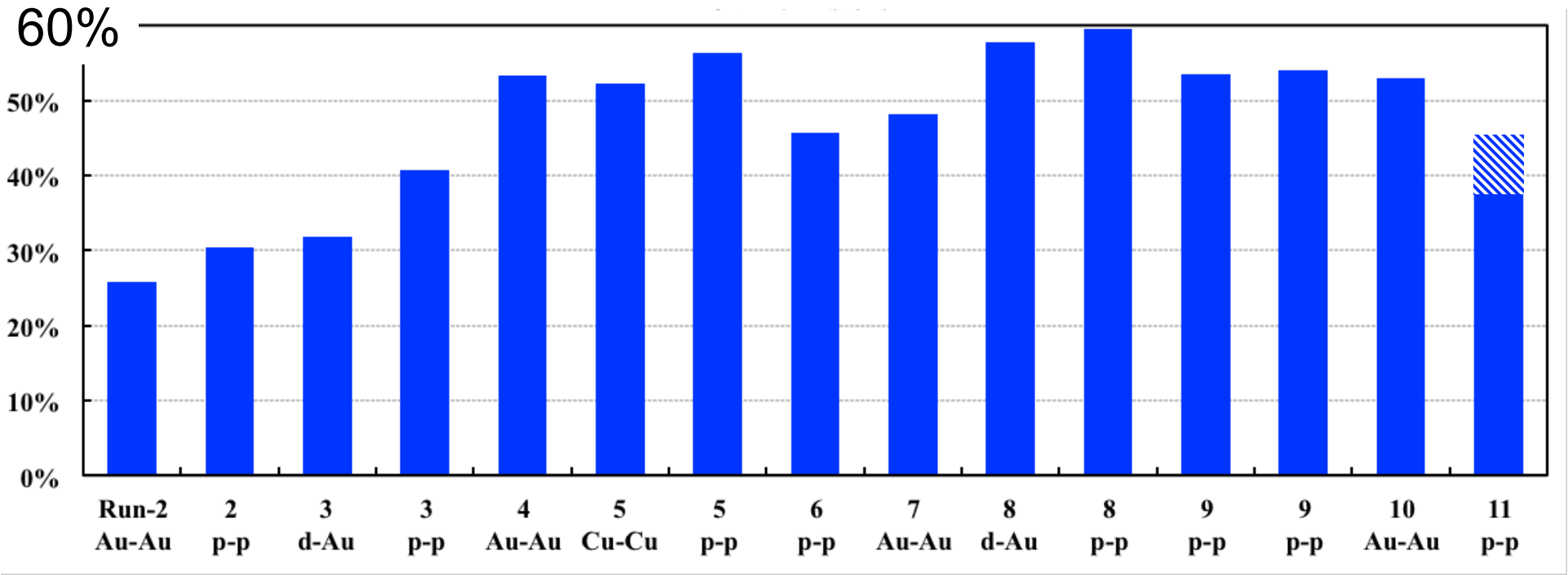


Run-11 polarized proton luminosity √s = 500 GeV

Run Coordinator: Haixin Huang



Run-11 polarized proton time-in-store (% of calendar time)



- Time-in-store lower than in previous runs
- No common reason identified for reduced time-in-store
- 2 largest events (refrigerator off, AGS power cable) account for 9%
- Effect on performance stronger than linear (scheduling difficult, less time for implementation of improvements, more time re-establishing machine)

Unusual events in 250 GeV polarized proton Run-11

- Total of 6 snow days during start-up (>20 h excused time in January)
- Fast emittance growth in Blue ring (intermittently observed in 2007 and 2009, tracked down to loose wire in dump kicker thyratron module B), delayed physics by about ½ week
- Breaker trip on 03/07/11 leads to refrigerator shut-off and helium venting in 2:00 and 6:00 service buildings, loss of about 3.5 tons of He, after repair encounter difficulties in purchasing replacement He, operation re-established on 03/17/11 – 219h downtime
- Power cable failure shut-down most of AGS equipment and part of building 911 – 78h downtime
- New 9 MHz RF system breaks 1 week before run end (current shield for bellows failing leading to overheating), cutting luminosity in half

Run-11 peak polarization and luminosity

Run Coordinator: Haixin Huang

		Run-9 achieved	Run-11 achieved	Run-11 projections
Polarization P	%	35★	**46★**	35–50★
Peak luminosity L_{peak}	$10^{30}\,cm^{-2}s^{-1}$	85	**145***	85–170
Avg. store luminosty L_{avg}	$10^{30}\,cm^{-2}s^{-1}$	55	**90***	55–100
Luminosity per week L_{week}	pb^{-1}	18	**25**	18–35
Time-in-store	%	53	**37** (46**)	55

★ Online H-jet measurement (average over transverse profile)

* Average of 6 best stores.

** Excluding down time due to refrigerator and AGS power cable failure.

- Good progress with peak performance
- Overall performance held back by reduced reliability
- Established operation of A_nDY with small impact on STAR/PHENIX

Main improvements for polarized protons in Run-11

AGS

- Magnets surveyed and adjusted horizontally (*P*+)
- Horizontal tune jump quads operational (reduced *P* profiles, *P* +5%)
- Access Control System rebuild after fire on 11/09/11

RHIC

- Magnets surveyed and adjusted vertically (*P*+)
- New auto-transformer in Blue to reduce flattop-to-ramp MMPS transients (needed for 9 MHz rf, had done Yellow previously) (*P*+)
- Yellow snake installed in sector 9 after repair
- Inserts installed in beam dump (19 pieces, 12.7 cm long), allowed for higher intensity, at limit in Run-9 (Q4 quench without) (*L*+)
- 2 common storage cavities moved to sector 3,
  2 more cavities installed => allows for permanent 9 MHz cavity (*L*+)

Main improvements for polarized protons in Run-11

RHIC

- 2 storage cavities permanently converted to 9 MHz,
  1 bouncer cavity install in each ring (9 MHz) (*P*+, *L*+)
- Current limit for tq increased from 100 A to 140A IR6 to IR8 (*L*+)
- Collimation on ramp with continuous set point changes (*L*+)
- RHIC CNI polarimeters with new electronics (mitigates rate dependence)
- First H-jet polarization measurement at injection

RHIC beam and optics control

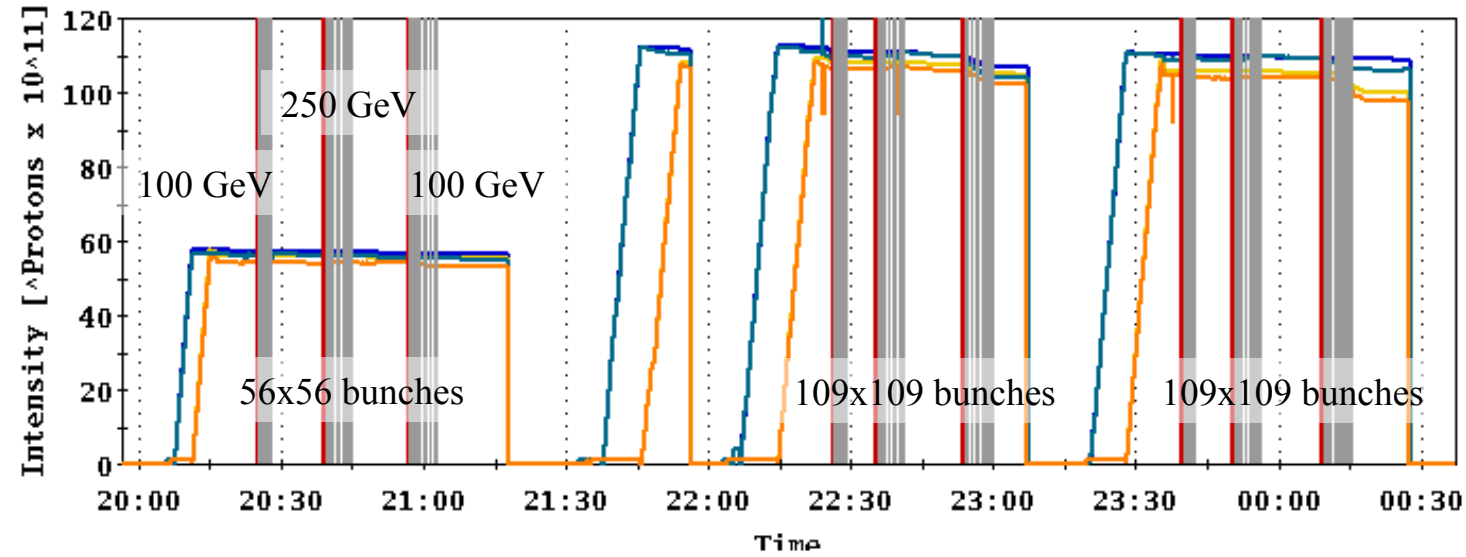
- All ramps with orbit, tune, and coupling feedback (*P*+, *L*+)
- Ramps Q_v = 0.673 (near low order resonance) (*P*+)
- Radial loop control via all BPMs (previously only 2) (*P*+, *L*+)
- Octupoles on ramp to suppress instabilities (*L*+)
- Operational use of 10 Hz orbit feedback in store (*L*+)
- First use of beta-beat correction in operation (*L*+)

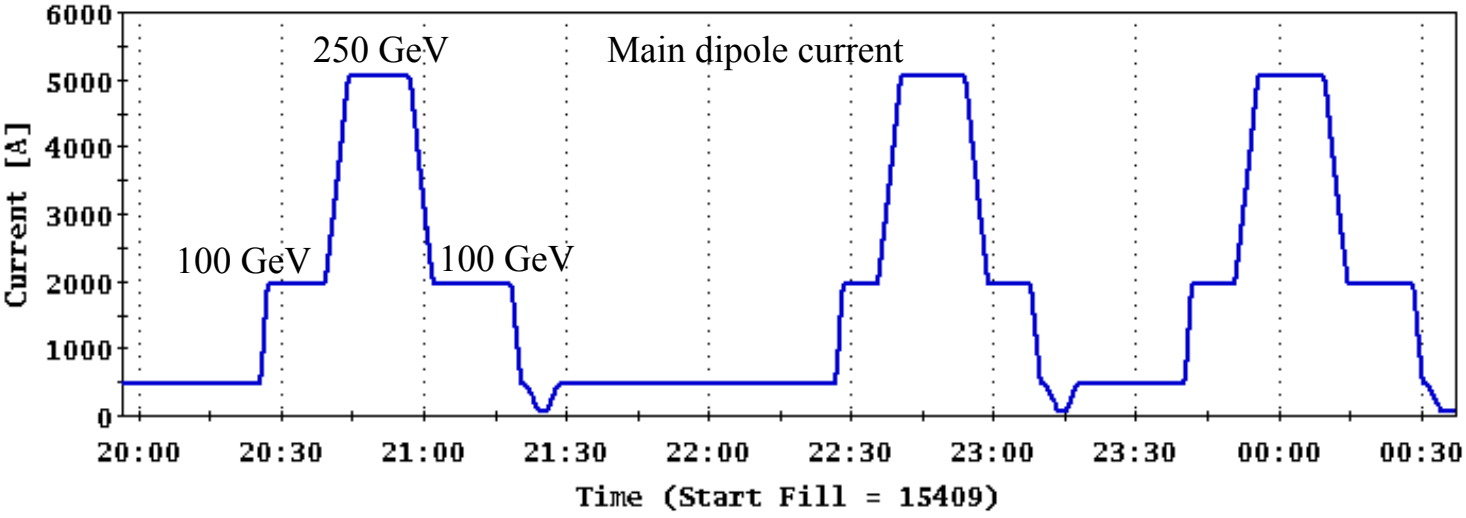
[**Note: also have upgrade for heavy ions, particularly for stochastic cooling.**]

Down ramp with polarized protons in Run-11

Setup and 3 up and down ramps with up to 109x109 bunches in only 2 shifts

(simultaneous orbit/tune/coupling/chromaticity feedback essential)

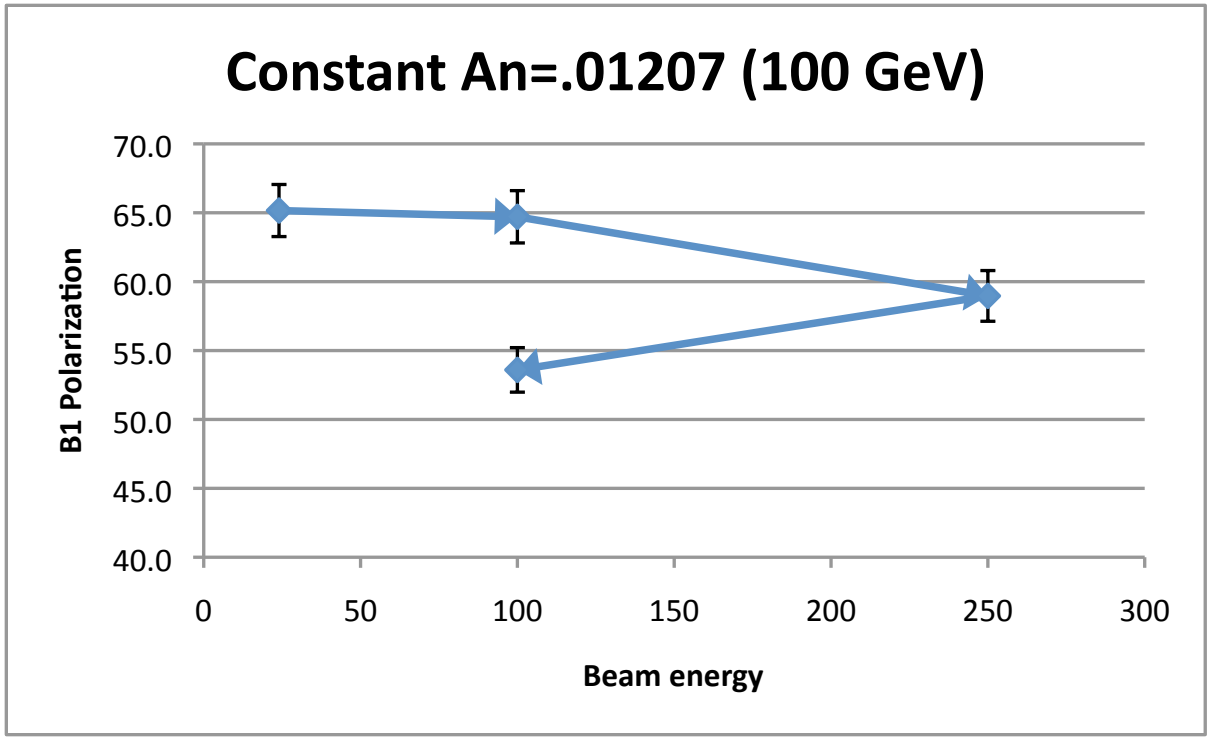




Down ramp with polarized protons in Run-11

Summary T. Roser

- From H-jet calibration of pC polarimeter at 100 GeV and 250 GeV there is ~30% (relative) loss of polarization between 100 GeV and 250 GeV (~65% -> 45%)
- Varying many parameter on energy ramp that should change polarization if there is a polarization loss had no effect on polarization (snake currents, vertical tune, horizontal tune, vertical chromaticity, momentum spread, blue vs. yellow)
- Up/down ramp will independently measure polarization loss between 100 GeV and 250 GeV



100 GeV:
$R_{up}/R_{down} = 0.80 \pm 0.02$

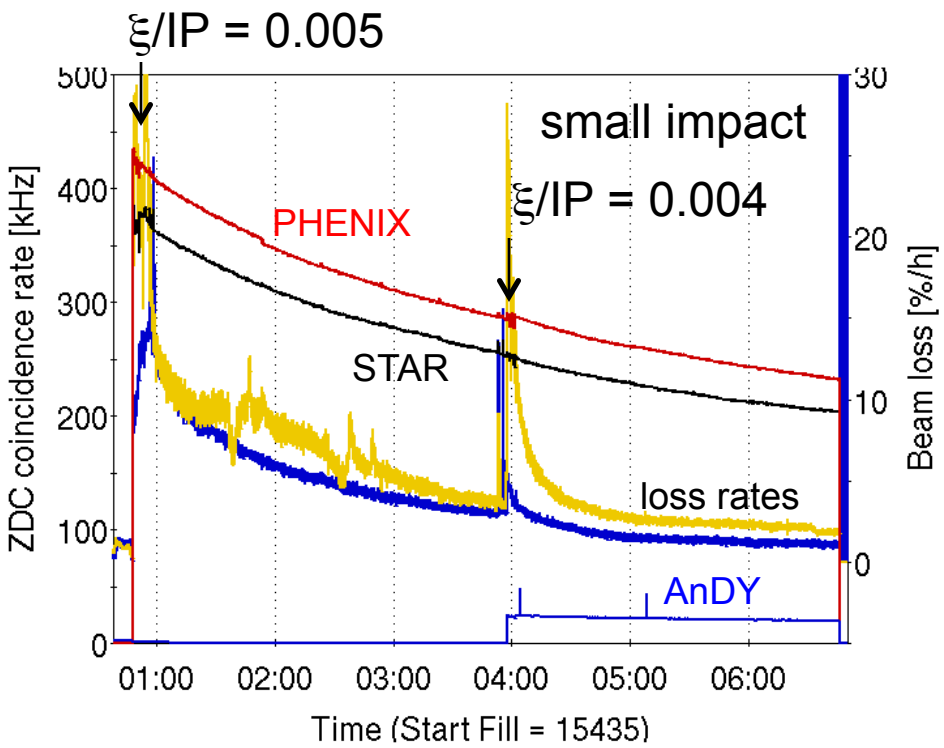
Pol. trans. on up ramp:
0.89 ± 0.01

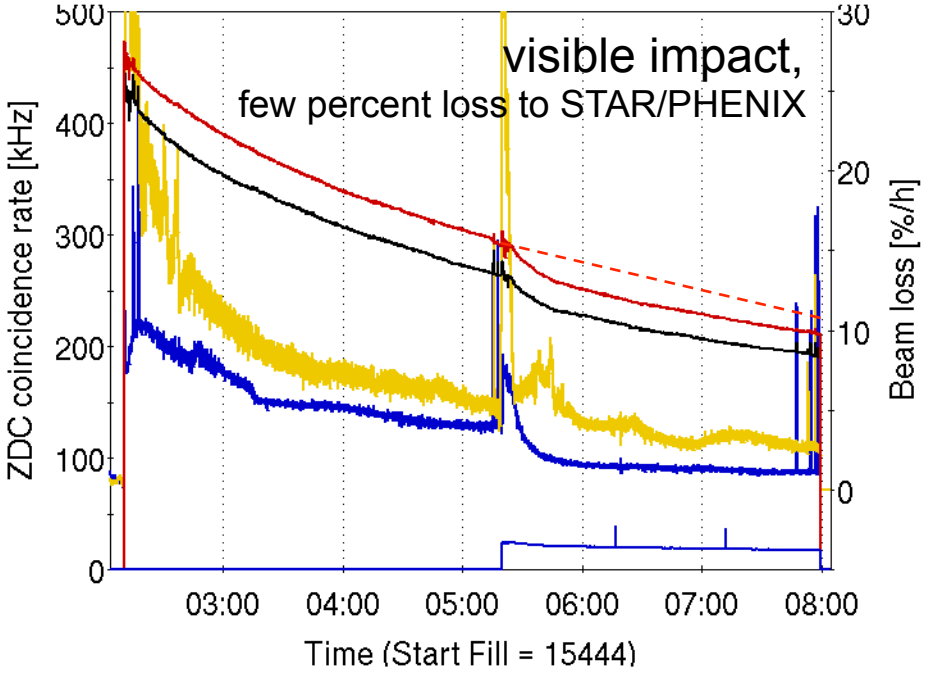
If P(250) = 46 % then
P(100) ~ P(24) = 52% ??

If P(24) ~ P(100) = 65% then
P(250) = 58%

A_nDY in Run-11 (250 GeV pp)

- Beam envelope function β^* = 3.0 m at IP2
- Reduced IP2 crossing angle from initially 2.0 mrad to zero
- Added 3rd collision with following criteria (last instruction):
  1. $N_b \leq 1.5 \times 10^{11}$
  2. Beam loss rate <15%/h in both beams
  3. Not before first polarization measurement 3h into store





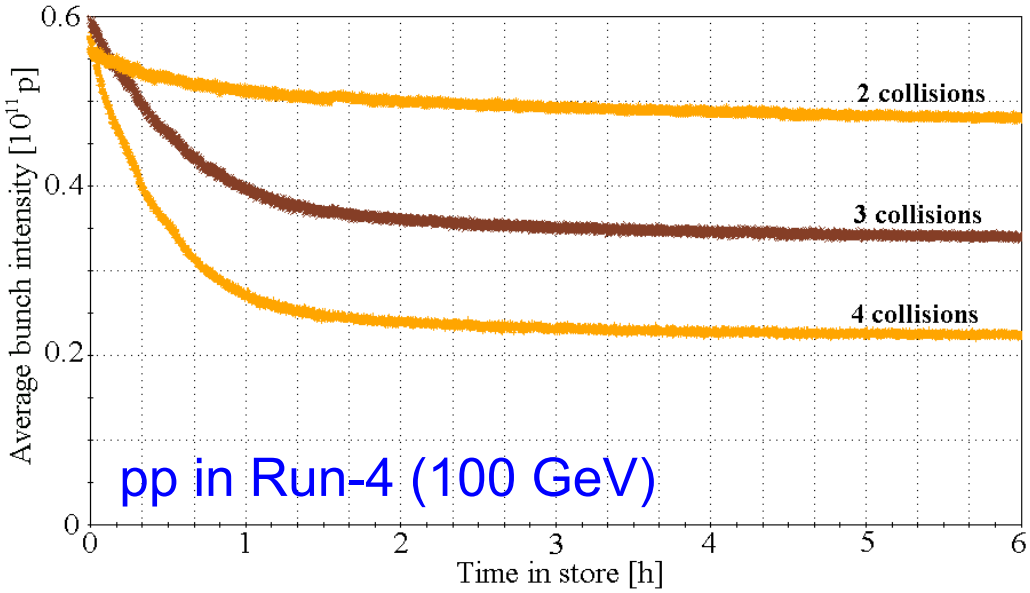
Future operation of A_nDY

- Can reduce β^* at IP2
  - have run with β^* = 2.0 m previously for BRAHMS
  - β^* = 1.5 m probably ok, needs to be tested
- Longer stores
  - 10h instead of 8h in Run-11 (depends on luminosity lifetime and store-to-store time)
- Collide earlier in store when conditions are met
  - needs coordination with polarization measurement, PHENIX and STAR
- Electron lenses (see later) if A_nDY runs beyond Run-13
  - increases max beam-beam tune spread, currently $\Delta Q_{max,bb} \approx 0.015$
  - can be used for to increase $\xi \sim N_b/\varepsilon$ and/or number of collisions

Run-11 luminosity at A_nDY:
max ~0.3 pb^{-1}/store

With improvements:
~3x increase,
~10 pb^{-1}/week

[all preliminary]



Future upgrades for polarized protons

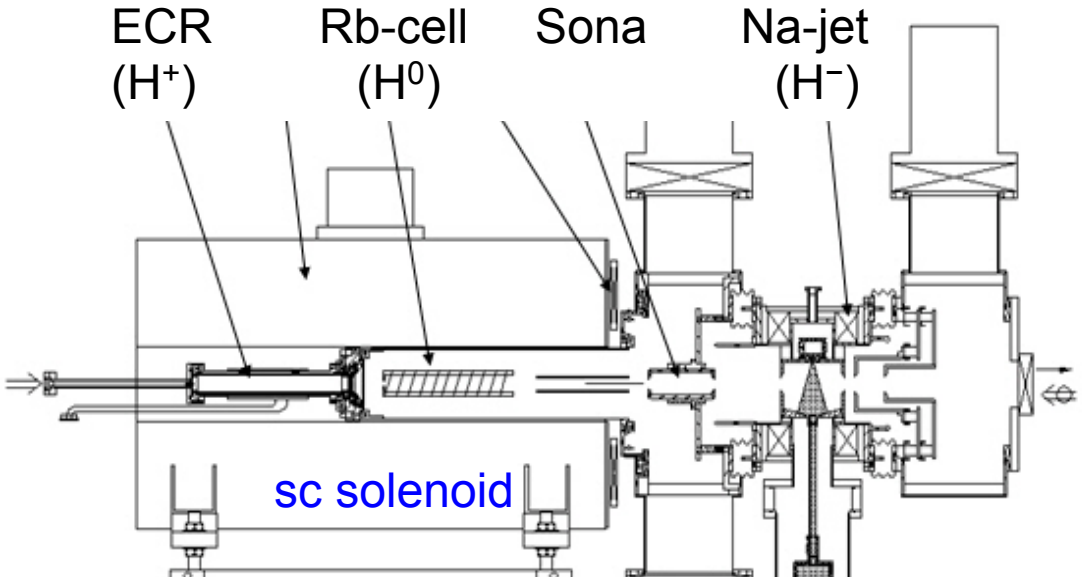
- Power supplies upgrades/replacements (*T*)
- Reliability upgrades in other areas (*T*)
- 9 MHz upgrade for more intensity (*L*)
- Different tunes (*P*,*L*) (near-integer tune is option since 10 Hz feedback operational)
- Spin flipper (*P*)
- Lower β^* (*L*) (requires $\Delta\beta/\beta$ and Q''/Q''' correction)
- Polarized source upgrade (*P*, *L*) [Run-13]
- Electron lenses, partial head-on beam-beam compensation (*L*) [Run-13]
- 56 MHz SRF (*L*) [Run-14]
- Instrumentation upgrades (*L*,*P*)
- In-situ beam pipe-coating coating (*L*)

Focus of this year's RHIC Retreat

Optically Pumped Polarized H⁻ source (OPPIS)

Current OPPIS

A. Zelenski, PST2009



- 29.2 GHz ECR source used for primary H^+ generation
- source was originally developed for dc operation

RHIC OPPIS produces reliably 0.5-1.0 mA polarized H^- ion current.

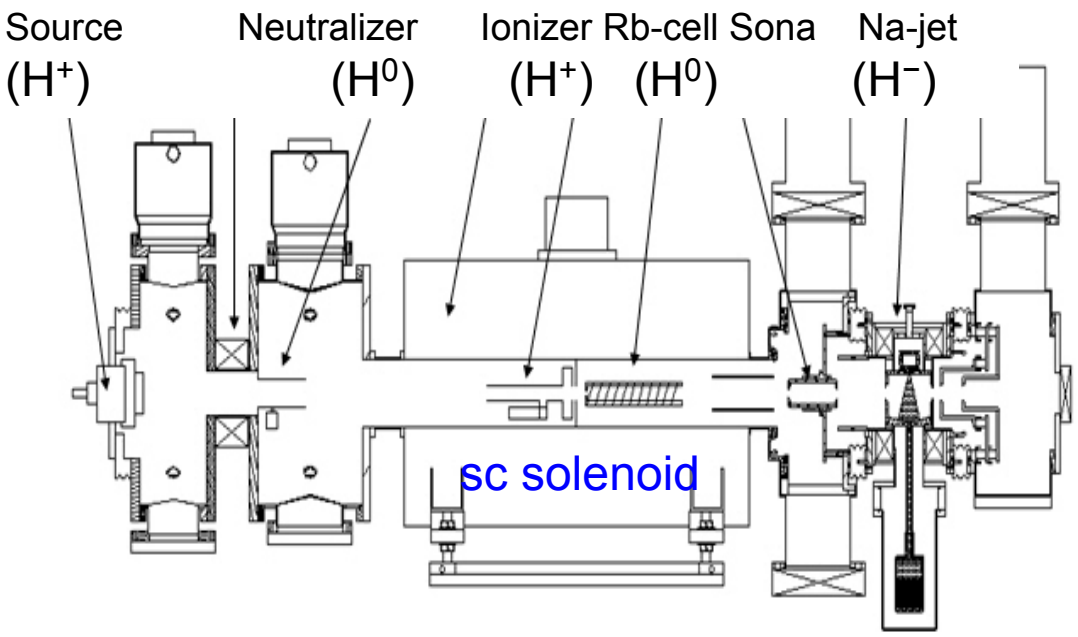
Polarization at 200 MeV:
P = 80-85%.

Beam intensity (ion/pulse) routine operation:

Source - 10^{12} H^-/pulse
Linac - 5×10^{11}
AGS - $1.8\text{-}2.0\times10^{11}$
RHIC - 1.8×10^{11}/bunch

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

Upgraded OPPIS (Run-13)



10x intensity increase was demonstrated in a pulsed operation by using a very high-brightness Fast Atomic Beam Source instead of the ECR source

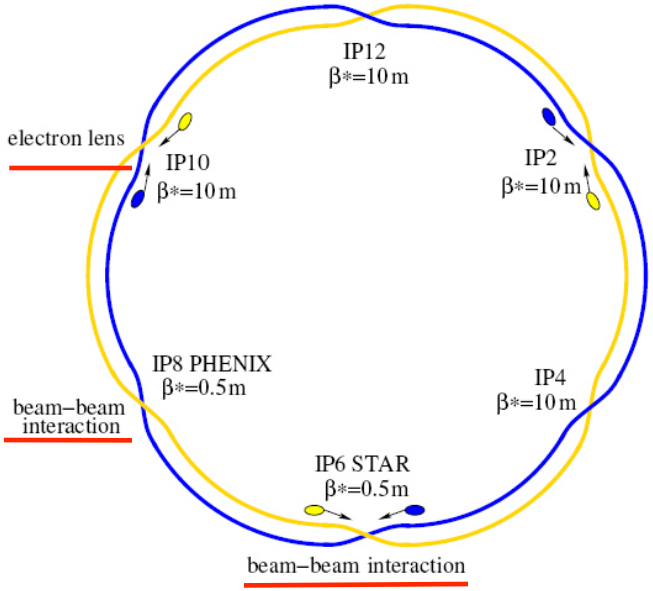
Goals:

1. H^- 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

Electron lenses – partial head-on beam-beam compensation



Polarized proton luminosity limited by head-on beam-beam effect ($\Delta Q_{bb,max}$ ~ 0.02)

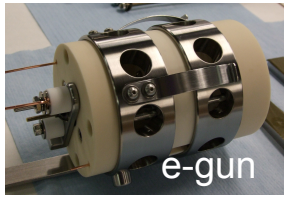
Basic idea:

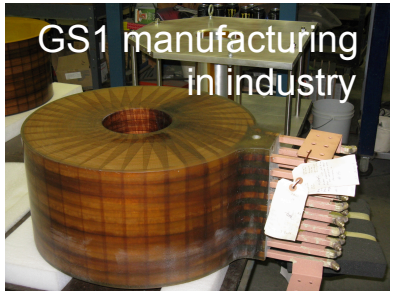
In addition to 2(3) beam-beam collisions with **positively** charged beam have another collision with a **negatively** charged beam with the same amplitude dependence.

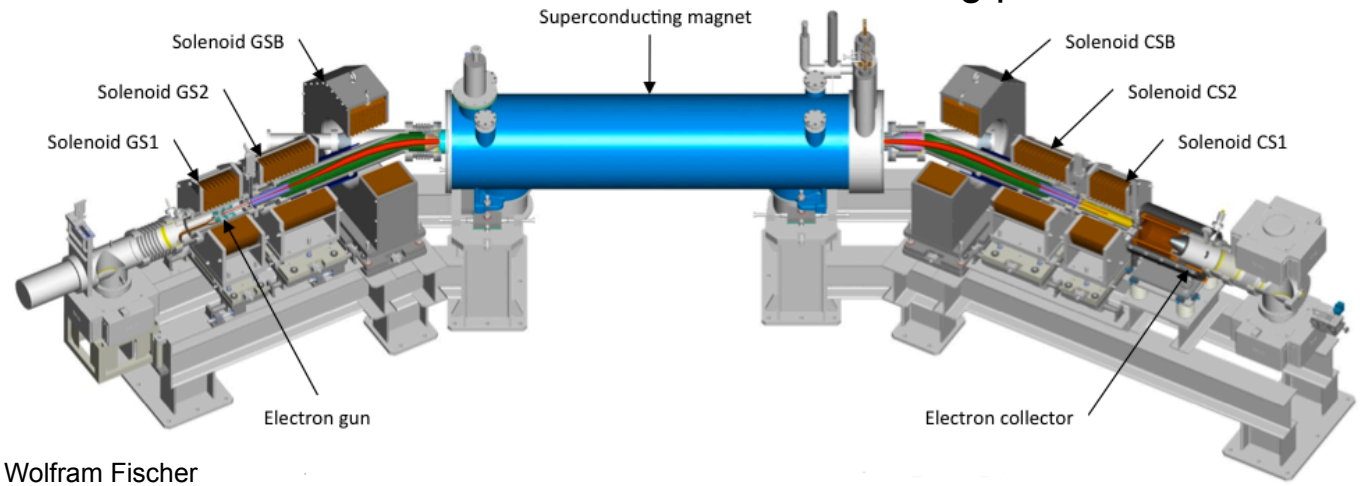
Exact compensation for:

- short bunches
- $\Delta\psi_{x,y}$ = kπ between p-p and p-e collision
- no nonlinearities between p-p and p-e
- same amplitude dependent kick from p-p, p-e
- only approximate realization possible

Expect up to 2x more luminosity
with OPPIS upgrade
Commissioning planned for Run-13



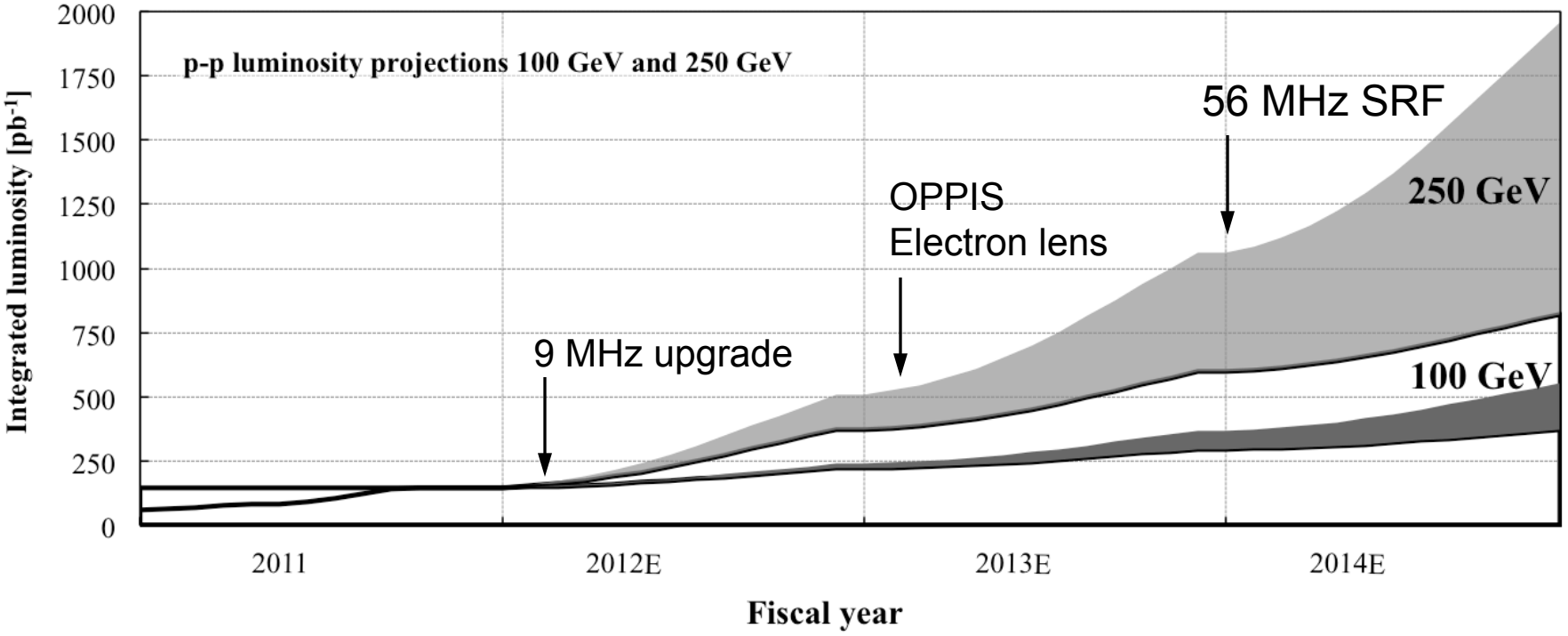




Summary – RHIC luminosity and polarization goals

Parameter	Unit	Achieved	Upgraded	
Au-Au operation		(2010)	(>=2012)	
Energy	GeV/nucleon	100	100	
No of bunches	…	111	111	
Bunch intensity	10^9	1.1	1.0	
Average *L*	**10^{26}cm^{-2}s^{-1}**	**20**	**40**	
p↑- p↑ operation		(2011)	(>=2012)	(>=2014)
Energy	GeV	100 / 250	100 / 250	250
No of bunches	…	109	109	109
Bunch intensity	10^{11}	1.3 / 1.65	1.3 / 1.5	2.0
Average *L*	**10^{30}cm^{-2}s^{-1}**	**24 / 90**	**30 / 150**	**60 / 300**
Polarization *P*	**%**	**55 / 46**	**70**	**70**

Polarized proton projections Run-12 to Run-14



[Assume 12 weeks of physics per run, 8 weeks linear luminosity ramp up.]

Asymmetric collisions (d-Au)

- Operated d-Au in Run-3 (2002/03) and Run-8 (2007/08) at full energy
  - 101.9 GeV/nucleon d on 100.0 GeV/nucleon Au ($\gamma_d = \gamma_{Au} = 107.4$)
- Future gains in d-Au operation from
  - 3-D stochastic cooling of Au beam
  - reduction in β^*, increase in bunch intensity and number of bunches
- For energy scan need to match Lorentz factor γ of both beams

		Run-8 achieved	≥ Run-12 Max projections
Peak luminosty L_{peak}	10^{28} cm^{-2}s^{-1}	25	37
Avg. store luminosty L_{avg}	10^{28} cm^{-2}s^{-1}	12.5	22
Luminosity per week L_{week}	nb^{-1}	40	75
Time-in-store	%	58	55

Asymmetric collisions (p-Au)

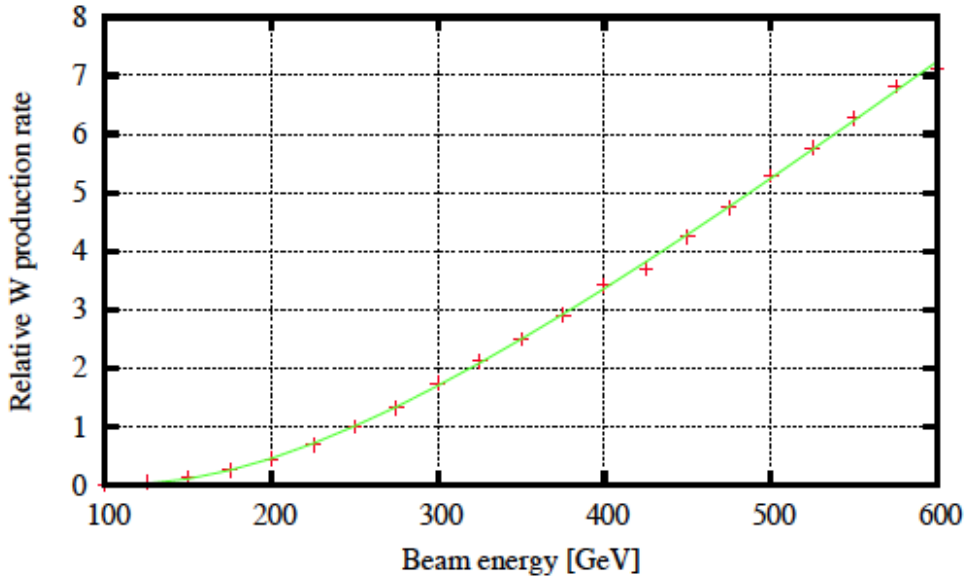
- p-Au was considered in RHIC design (D. Trbojevic), no operation yet
  100.8 GeV p on 100.0 GeV/nucleon Au ($\gamma_p = \gamma_{Au} = 107.4$)
- **Need to translate DX magnets horizontally by 4.33 cm**
  p are bent stronger than Au^{79+}
- For energy scan need to match Lorentz factor γ of both beams

Parameter	unit	p-Au		p-Au	
No of bunches	…	111	111	111	111
Ions/bunch, initial	10^9	100	1.0	200	1.2
Average beam current/ring	mA	139	110	278	132
Stored energy per beam	MJ			0.36	0.42
β^*	m	0.85		0.60	
Hour glass factor	…	1.00		0.91	
Beam-beam parameter ξ/IP	10^{-3}	4.3	1.7	5.2	3.5
Peak luminosity	10^{28} cm^{-2}s^{-1}	30		95	
Average / peak luminosity	%	60		60	
Average store luminosity	10^{28} cm^{-2}s^{-1}	18		57	
Time in store	%	55		55	
Maximum luminosity/week	nb^{-1}			189	
Minimum luminosity/week	nb^{-1}	60			

Energy upgrade – W. MacKay, BNL C-A/AP/422

Motivations:

1. Increase in W production cross section
2. eRHIC

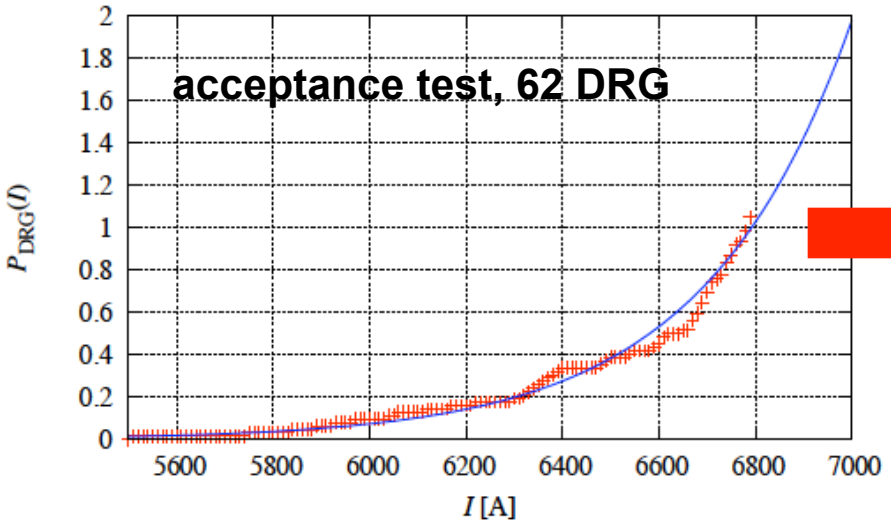


Main issues:

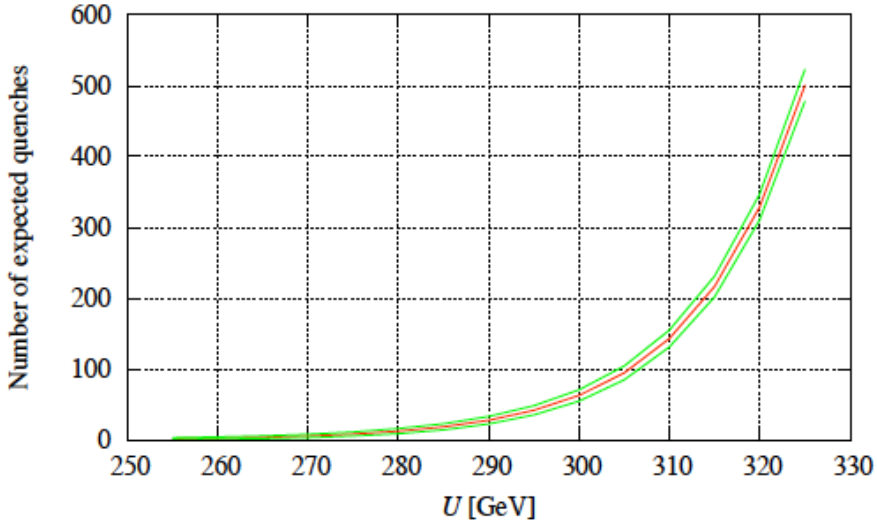
- Quench performance of magnets (DX, arc dipoles and quads, IR quads)
- Crossing angles at IPs and luminosity
- Polarization
- Current feedthroughs
- Power supplies and transformers
- Dump kicker (strength, pre-fires)
- Reliability generally reduced at higher energies

Energy upgrade – W. MacKay, C-A/AP/422

observed quenches in arc dipoles



estimated # of training quenches



Conclusion:

- 10% increase to 275 GeV (+45% in σ_W) feasible with current magnets
  - about 20 DX, 10 other training quenches, more cooling at some current leads
- Requires some hardware upgrades (dump kicker, power supplies)
- Effect on polarization still needs study
- Energies >275 GeV require too many training quenches
  - hundreds of arc dipole training quenches alone for 325 GeV

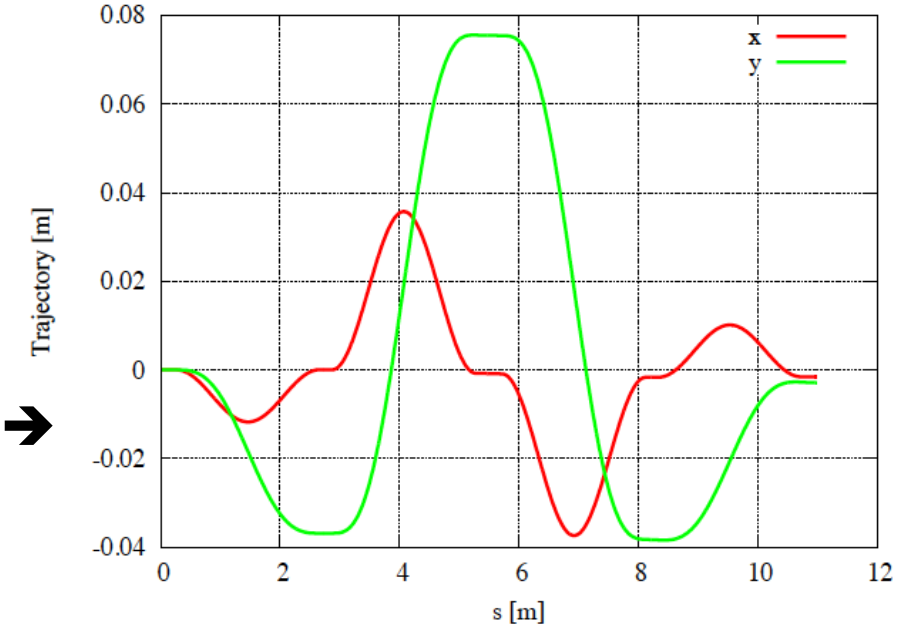
Polarized d

- Polarized neutrons for RHIC and eRHIC could be in deuterons (d = $^{2}H^{1+}$) or $^{3}He^{2+}$

	p	$^{2}_{1}H^{+}$	$^{3}_{1}H^{+}$	$^{3}_{2}He^{+2}$
M [GeV/c^2]	0.938272	1.875613	2.808921	2.808391
μ/μ_N	2.792847	0.857438	2.972962	-2.127498
$G = (g-2)/2$	1.792847	-0.142987	7.918171	-4.183963

- d very difficult at high energy (i.e. RHIC)
- Currently no technical solution for maintaining and rotating polarized deuterons (G = −0.14) in RHIC
- Siberian snake with B_{out} = 33.5 T, B_{in} = 101.6 T

Orbit excursion in snake for deuterons ➔



[W. MacKay, CAD MAC-05, 09/15/2010]

Polarized ^{3}He

[Summary W. MacKay, CAD MAC-05, 09/15/2010]

- Deuterons not good in RHIC — perhaps in a figure-8 ring.

- He^3 looks promising: no real show stoppers.
  - Source: $^3He^{+2}$ OPPIS source — proposal: Milner/Zelenski
    See Anatoli Zelenski's presentation.
  - $|G\gamma|_{max}$ is higher for He^3:
    - More and Stronger resonances in all rings.
  - ^{3}He polarimeters need to be developed.
  - AGS cold snake may be sufficient at lower field.
    AGS warm snake (fixed field) might be too strong ($\sim 14\%$).
  - AGS injection and extraction spin-matching: not too bad.
    - Booster to AGS may need matching (depends on AGS snakes).
  - RHIC snakes and rotators will work with lower fields.
  - Lower injection rigidity for RHIC should be OK.
    - Injection orbit excursions reduced.

Polarized ^{3}He source R&D

- Plans to start working on ^{3}He source (MIT – R. Milner, Mainz)

- 3 possibilities discussed to use EBIS (A. Zelenski, J. Alessi et al.):
  1. ^{3}He production outside EBIS
     limits on field gradients
  2. ^{3}He production inside EBIS
     space and maintenance issues, P source measurement
  3. Injection of $^3He^+$ into EBIS

- In all cases EBIS ionizes to $^3H^{2+}$
- Aim for 2.5×10^{11} ions from EBIS, 1×10^{11}/bunch in RHIC
- Could collide ^{3}He-^{3}He or p-^{3}He at $\gamma_{max} = 178$
  (^{3}He with 166.2 GeV/nucleon, p with 167.5 GeV)

Summary – RHIC performance

- Run-11 p^p^ results:
  - P > 46%, L_{peak} = 150x10^{30}cm^{-2}s^{-1}, L_{avg} = 85x10^{30}cm^{-2}s^{-1}
    (all new records for peak performance, and all within Run-11 projections)
  - Integrated luminosity below expectation due to down time
  - A_nDY tested, ran with relatively small impact on STAR/PHENIX
- Main hardware upgrades for p^p^ (commissioning planned for Run-13)
  - Polarized source: P +5%, intensity +order of magnitude
  - Electron lenses : up to 2x more luminosity with source upgrade
- Asymmetric collisions (d-Au and p-Au)
  - Expect up 2x more luminosity for future d-Au operation rel. to Run-8
  - p-Au possible with change of DX location ($\gamma_p = \gamma_{Au} = 107.4$)
- Limited energy upgrade possible, 10% to 275 GeV protons
  - Effect on polarization still needs study, requires hardware upgrades
- Polarized ^{3}He (p-^{3}He, ^{3}He-^{3}He)
  - Polarized ^{3}He source R&D has started (with MIT, using EBIS)
  - Acceleration and storage in RHIC should be possible
  - ^{3}He polarimetry at high (esp. absolute) needs R&D