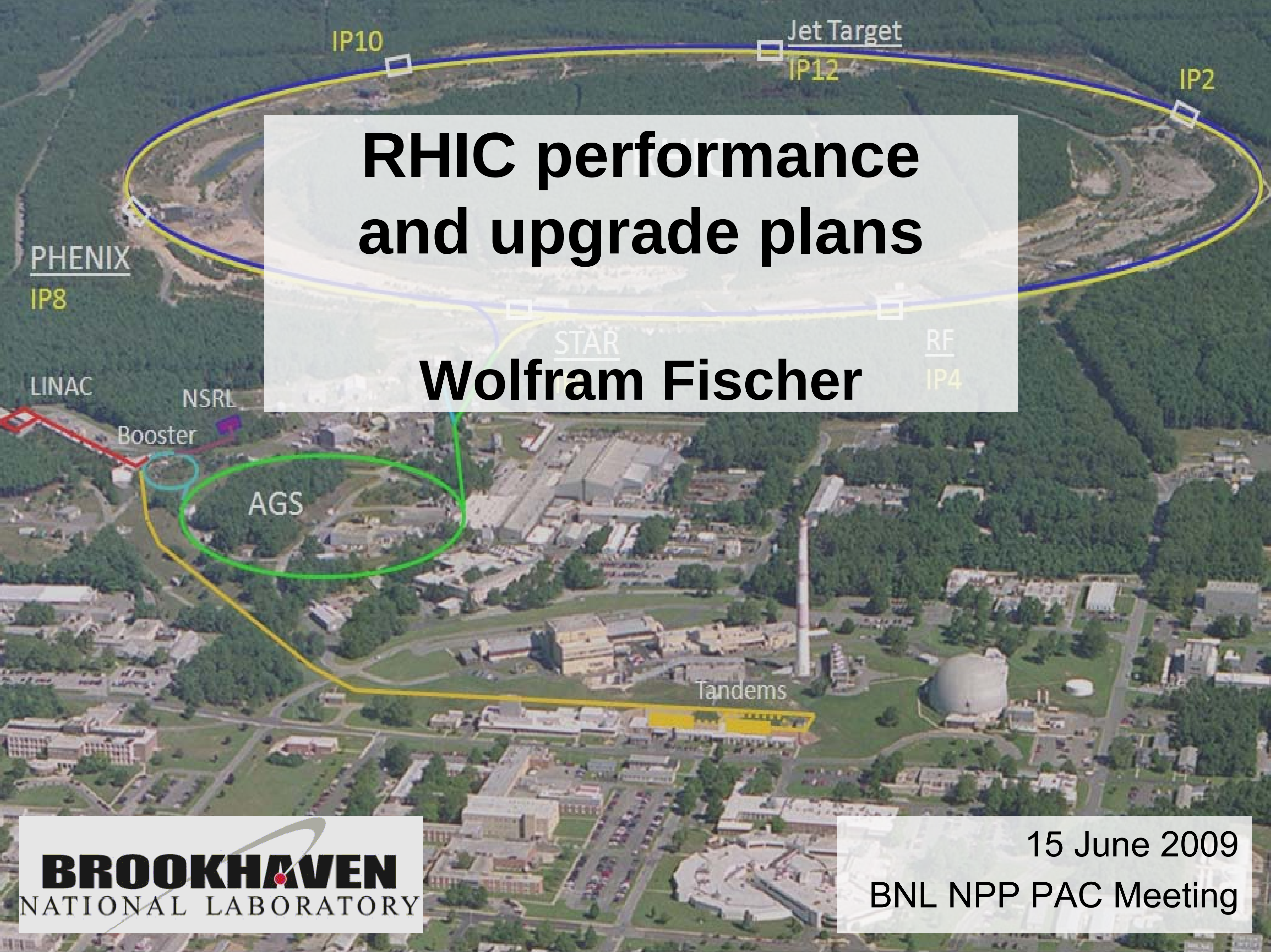
RHIC performance and upgrade plans

Wolfram Fischer



BROOKHAVEN NATIONAL LABORATORY

15 June 2009
BNL NPP PAC Meeting

Content

Heavy ion operation

- Run-7 (Au-Au) / Run-8 (d-Au) performance
- Run-10 upgrade plans and projections
  - High energy (100 GeV/nucleon)
  - Low energy (□ 10 GeV/nucleon)
- Longer-term upgrade plans

Polarized proton operation

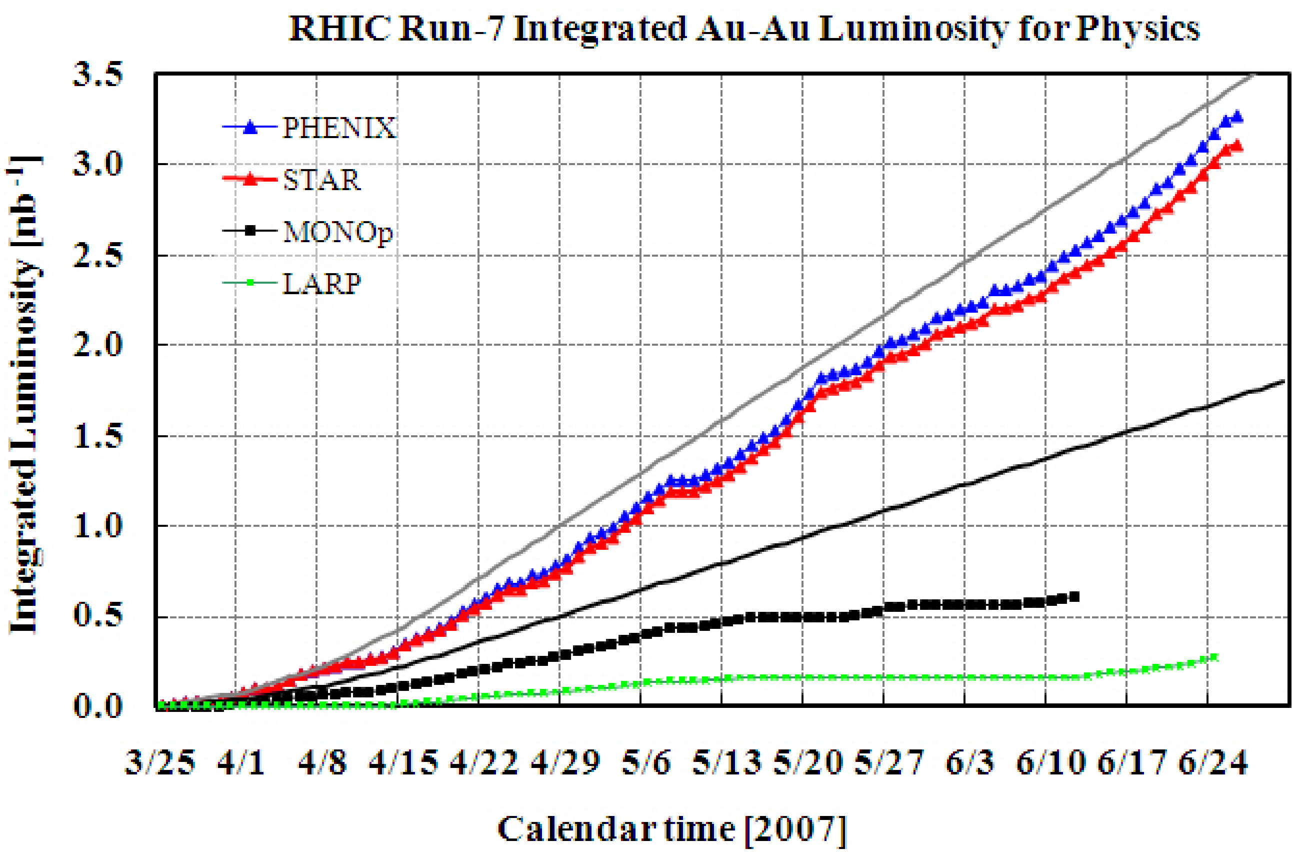
- Run-9 performance
- Run-11 upgrade plans and projections
- Longer-term upgrade plans

Luminosity and polarization goals

Parameter	unit	Achieved	Enhanced design	Next L upgrade
Au-Au operation		(2007)		(2012)
Energy	GeV/nucleon	100	100	100
No of bunches	…	103	111	111
Bunch intensity	10^9	1.1	1.0	1.0
Average L	10^{26}cm^{-2}s^{-1}	**12**	**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.

Run-7 Au-Au Run Coordinator: A. Dress

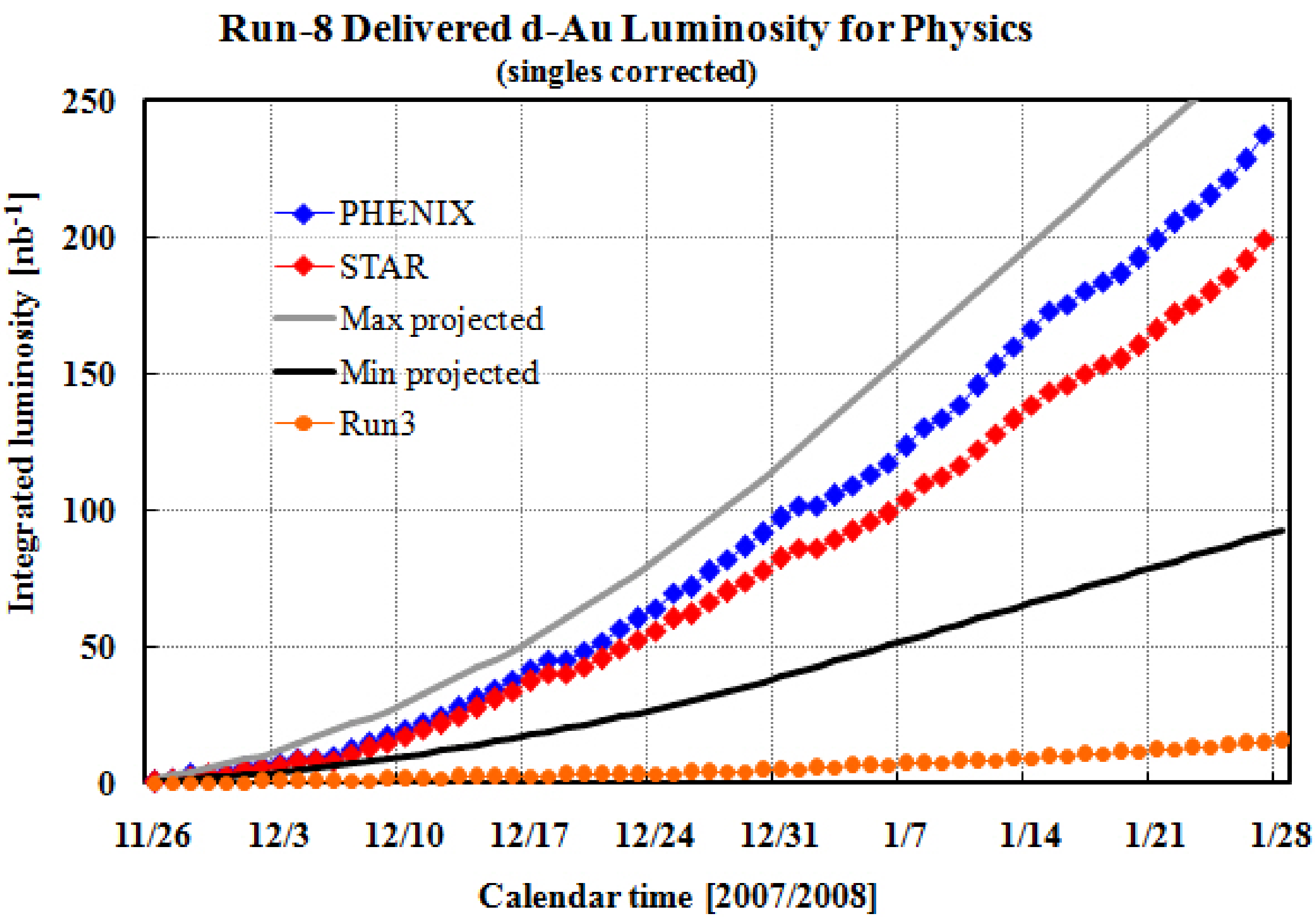


Delivered 2.6 more luminosity than in Run-4

Main improvements:
- new stripping foils (BtA and AtR)
- Au^{31+} in AGS
- 2.3x no of bunches
- reduction in β^*
- first use of long. stochastic cooling in Yellow

no of bunches	ions/bunch [10^9]	β^* [m]	emittance [μm]	L_{peak} [$cm^{-2}s^{-1}$]	$L_{store\ avg}$ [$cm^{-2}s^{-1}$]	L_{week} [μb^{-1}]
103	1.1	0.83/0.77	17-35	30×10^{26}	12×10^{26}	380

Run-8 d-Au   Run Coordinator: C. Gardner



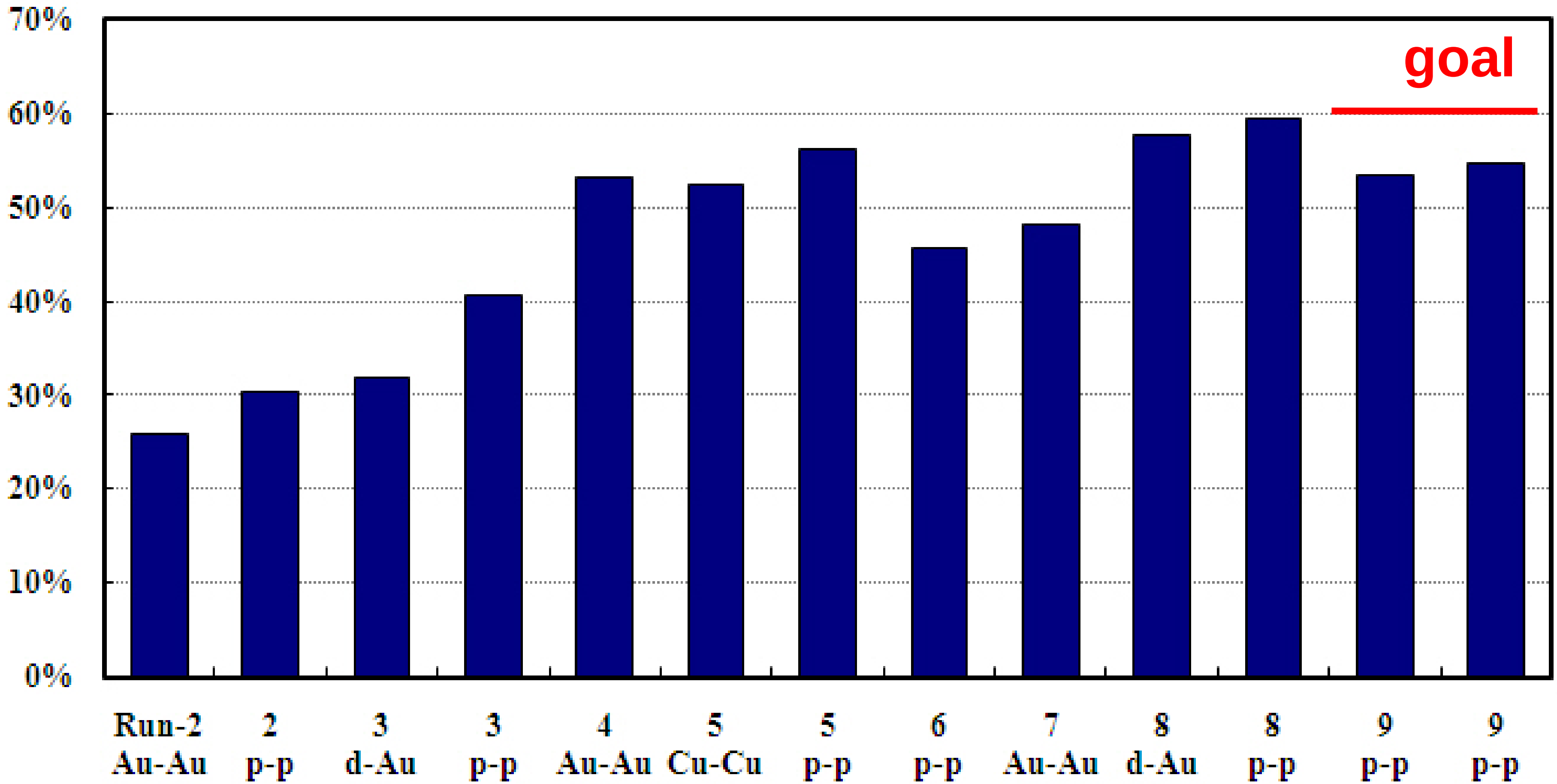
Delivered 10 more luminosity than in Run-3

About a factor 2 from:
- β^* reduction
- no of bunches
- time in store

Other improvement:
- long. stoch. cooling
- IBS suppression lattice
- …

no of bunches	ions/bunch $[10^9]$	β^* [m]	emittance [µm]	L_{peak} $[cm^{-2}s^{-1}]$	$L_{store\ avg}$ $[cm^{-2}s^{-1}]$	L_{week} $[nb^{-1}]$
95	100d/1.0Au	0.85	17-30	25×10^{28}	12.5×10^{28}	40

RHIC calendar time in store



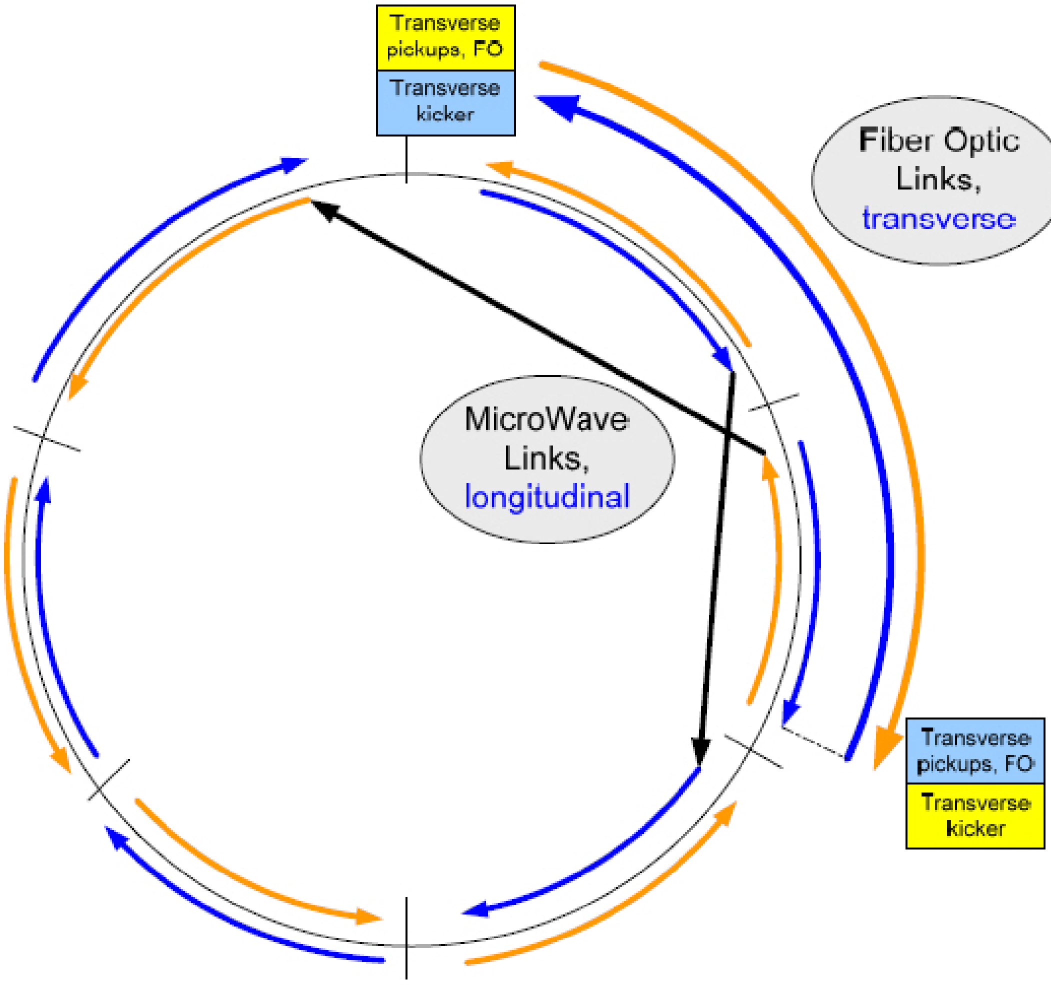
After improvements in Run-8, time in store fell back in Run-9. Should assume 55% on average for future runs.

Heavy ion operation – upgrades for Run-10

Run Coordinator: Kevin Brown

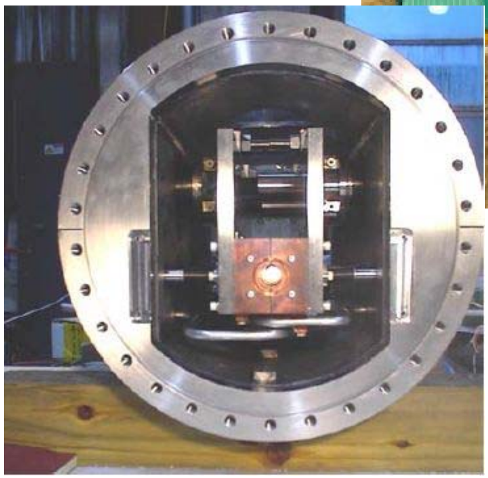
- Stochastic cooling:
  - Yellow longitudinal – upgraded
  - Blue longitudinal – first time in heavy ion operation
  - Yellow vertical – first time in heavy ion operation
  - Blue vertical – first time use
- Lattice changes compared to Run-7/Run-8
  - β^* reduction possibly as low as 0.5 m
  - Lattice with reduce IBS growth rate (like Run-8/Au)
- No significant change in transition crossing scheme foreseen so far
  - Will be main limit for intensity
- Ongoing effort to maintain/improve reliability

Run-10 stochastic cooling in RHIC



J.M. Brennan
M. Blaskiewicz

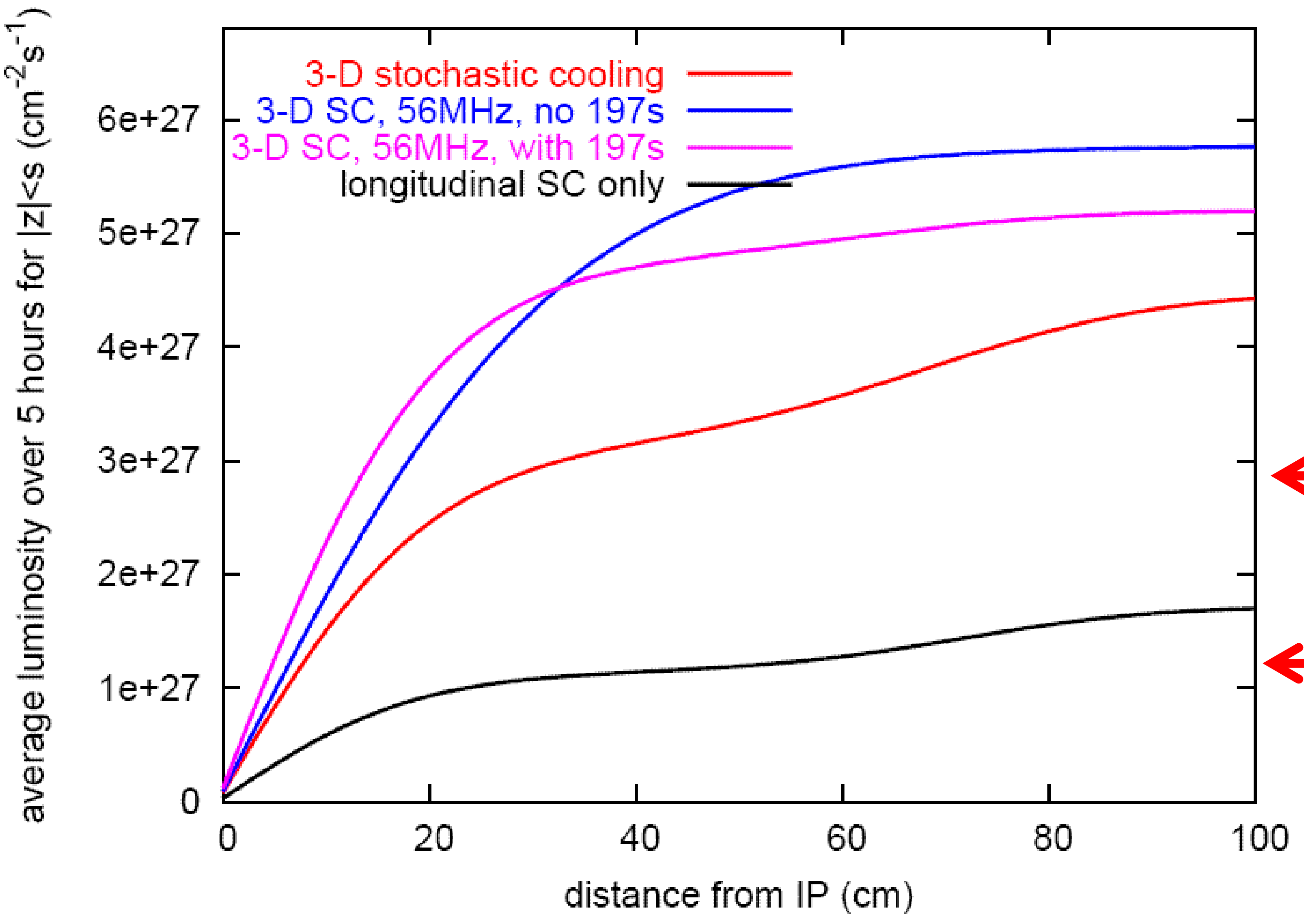
Microwave link



Longitudinal kicker

4 systems to (re)commission – at least 1 week per system

Stochastic cooling & 56 MHz SRF – luminosity increase



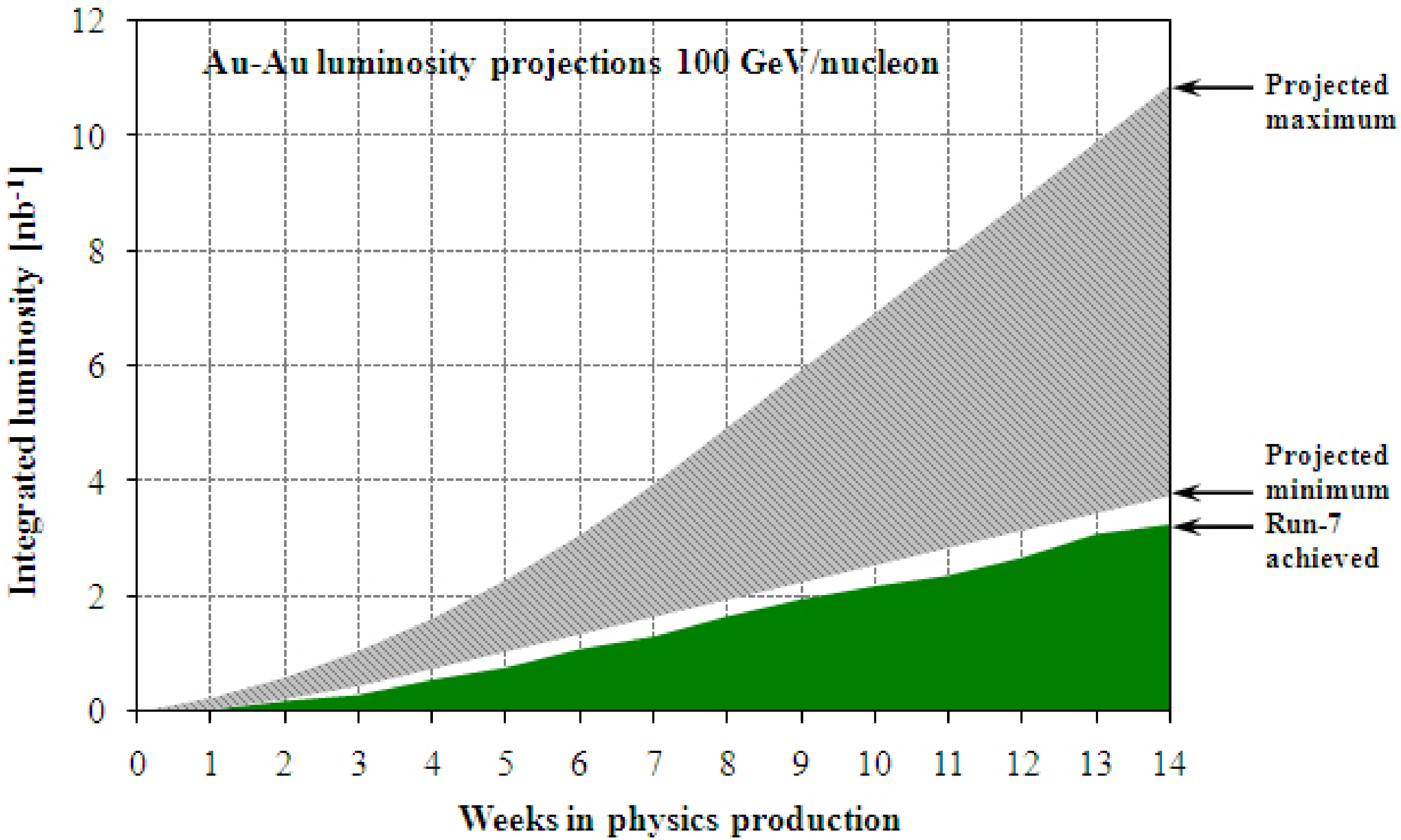
Max Run-10 expectation

Achieved in Run-7

Yellow longitudinal stochastic cooling only.

Calculation by M. Blaskiewicz.

Run-10 Au-Au luminosity projections 100 GeV/nucleon

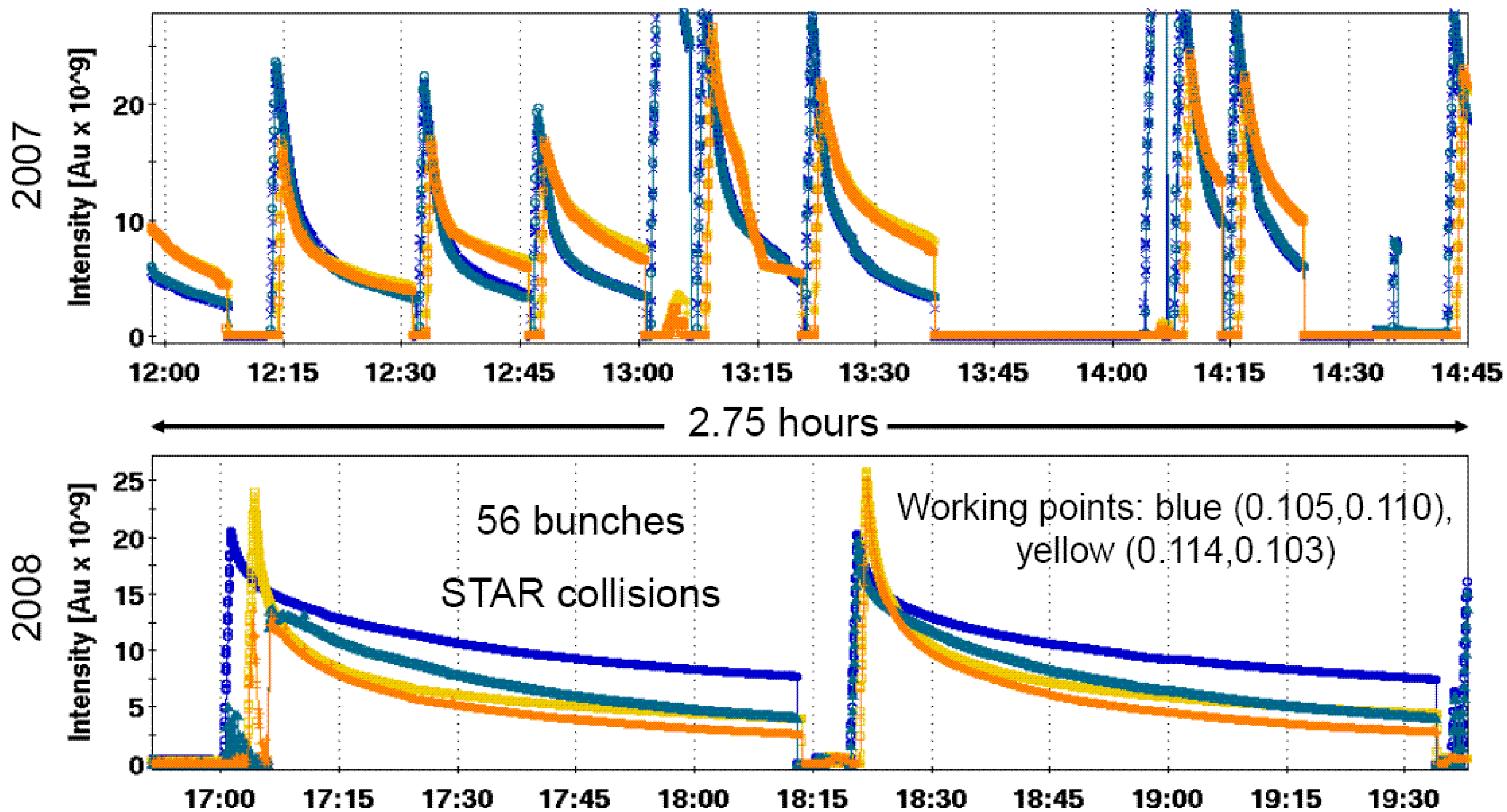


Assume 4 weeks to ramp-up for min, and 8 weeks for max.

Run-10 Au-Au low energy operation

Run Coordinator: Todd Satogata

2007 vs 2008 Low Energy Test: Beam Lifetime



- 2008 blue beam lifetime: 3.5 minutes (fast), 50 minutes (slow)
- Sextupole reversal and elimination of octupoles clearly helped beam lifetime
- Injection efficiency and yellow beam lifetime can clearly benefit from further tuning

Run-10 low energy projections – T. Satogata, CPOD

- From $\sqrt{s_{NN}}$ = 9 GeV 2008 experience and expected tuning improvements
  - Assumes 75% time in physics during running time
  - Event rates scale as γ^3 below injection, γ^2 above injection ($\sqrt{s_{NN}}$ = 23.5 GeV)
- Every additional $\sqrt{s_{NN}}$ data point close to doubles required total run time
- $\sqrt{s_{NN}}$ = 12 GeV precludes optimized luminosity at both experiments
- Also like 3 days development time for electron cooling projections
- There is no ordering preference between 200 GeV and low energy runs

$\sqrt{s_{NN}}$ [GeV]	μ_B [MeV]	<Event Rate> [Hz]	Days/ Mevent	# events	# beam days phys+setup
5.0	535	0.7	21	5M	105+5
6.1	470	1.4	11.3	5M	57+4
7.7	405	2.7	5.7	5M	29+3
8.8	370	4	3.9	5M	19+2
12	295	--	--	--	--
18	210	>30	0.5	5M	3+1
28	145	>60	<<1	5M	1+2

Total **Integrated** run time

(33 weeks)

(17 weeks)

(9 weeks)

(4 weeks)

(1 week)

From K. Rajagopalan (2006), STAR Beam Use Proposal (2007)

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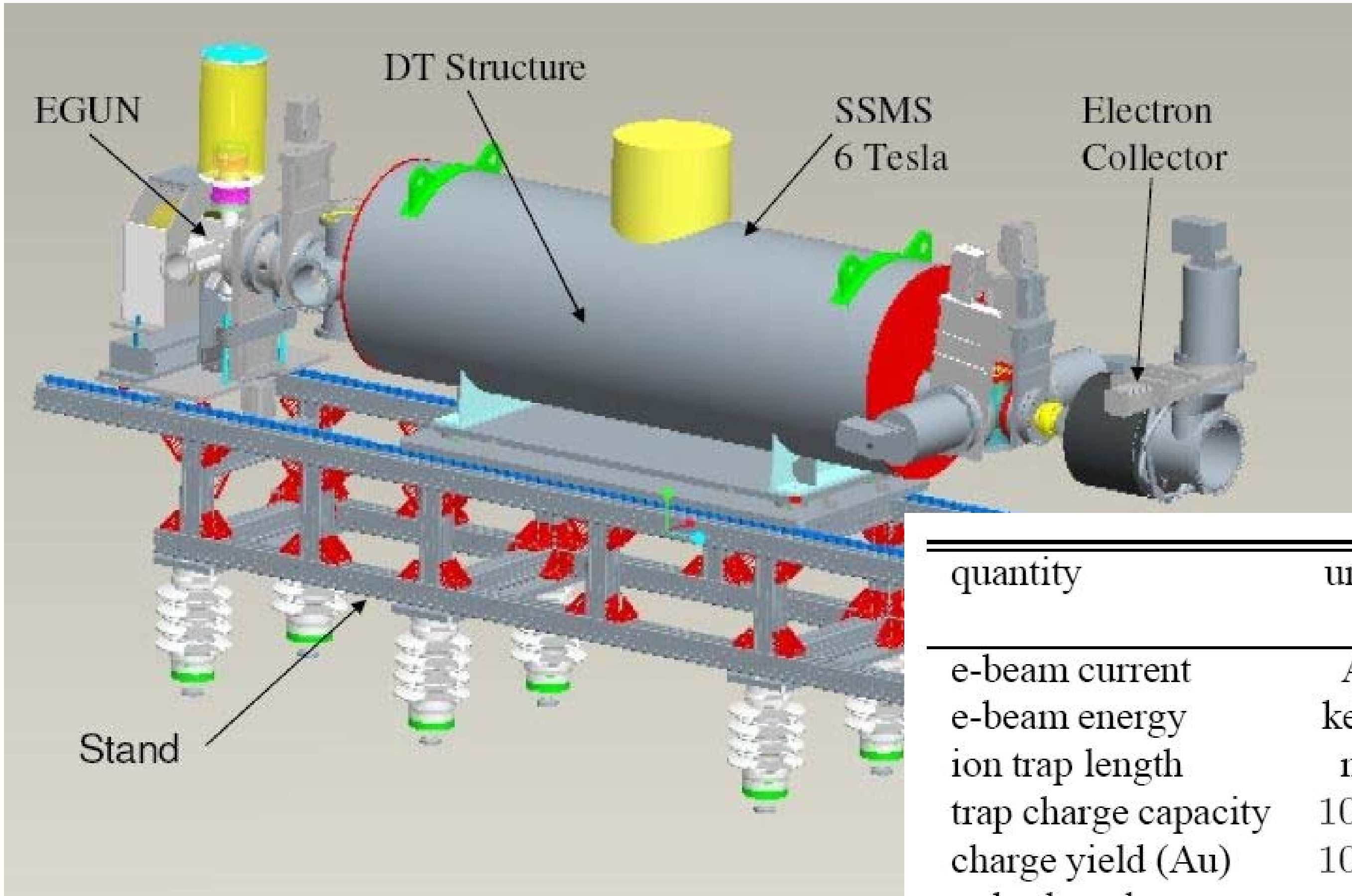
Heavy ions – further upgrade plans

- **EBIS**
  - CD-4 planned for September 2010
  - Lower intensity U operation later in Run-11 may be possible
- **Horizontal stochastic cooling**
  - Received $4M from stimulus funds
  - Completion planned for end of 2011
  - Should reduce the transverse cooling times by factor 2
- **56 MHz Superconducting RF**
  - Shorter vertex and reduced longitudinal migration
  - 30-50% increase in luminosity depending on vertex cut
  - Expect operation in 2012
- **Transition crossing feedback**
  - Electron cloud enhanced fast transverse instability at transition is main intensity limit
  - Fast transverse feedback needs R&D (also pursued for SPS, US LARP/CERN)
- **Electron cooling for low energy operation**
  - Use of Fermilab pbar cooler, expect 3-6□ more L (low to higher γ)
  - With start in 2009, completion □2014

Electron Beam Ion Source (EBIS)

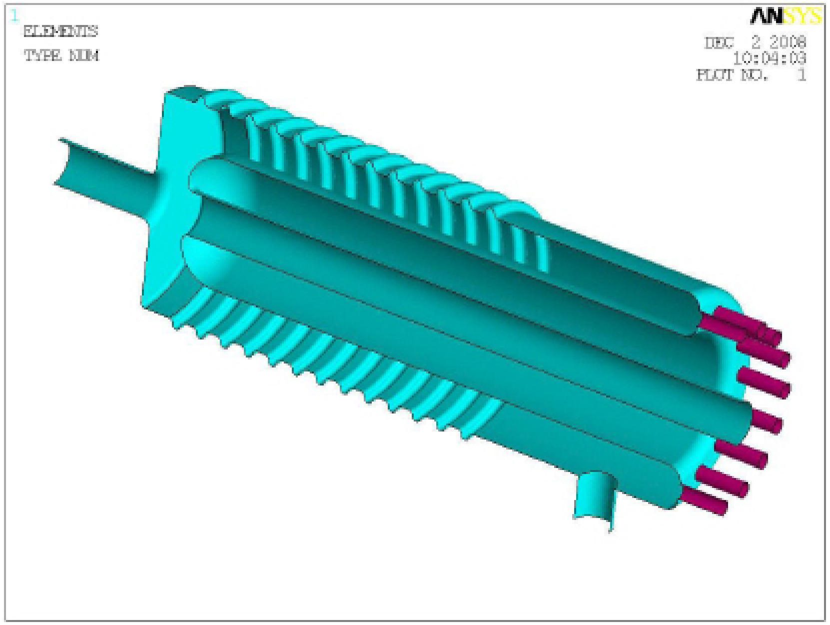


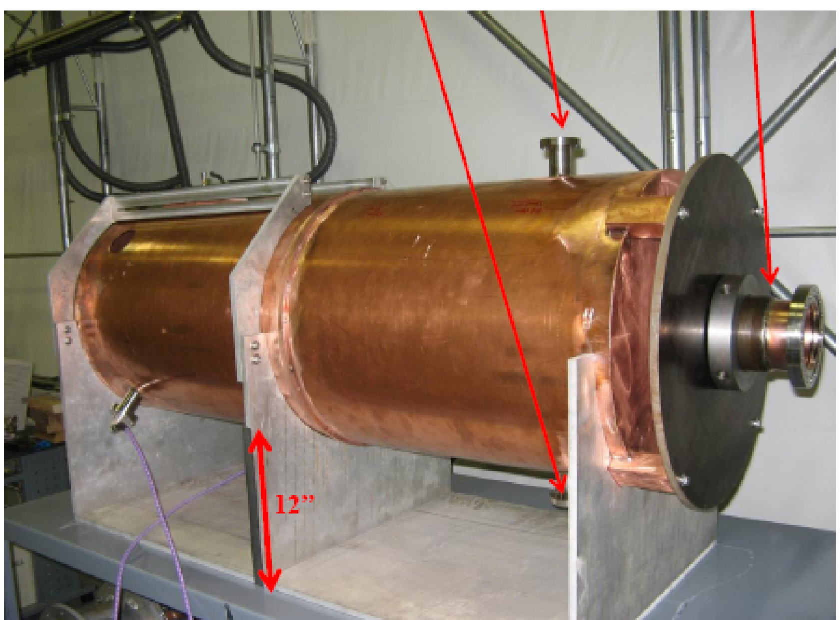
J. Alessi et al.

quantity	unit	RHIC EBIS	Test EBIS achieved
e-beam current	A	10	10
e-beam energy	keV	20	20
ion trap length	m	1.5	0.7
trap charge capacity	10^{11}	11	5.1
charge yield (Au)	10^{11}	5.5 (10 A)	3.4 (8 A)
pulse length	μs	≤ 40	20
yield Au^{32+}	10	3.4	> 1.5

CD-4 planned for Sep. 2010
Lower intensity U operation in 2011 possible
Full intensity operation in 2012

56 MHz SRF   I. Ben-Zvi et al.





- quarter wave Ni resonator
- common to both beams, IR4
- beam driven
- 56 MHz, 2 MV
  gives large bucket area
- better longitudinal
  containment of Au ions
- 30-50% more luminosity
  at 100 GeV/nucleon Au

- Expect operation in Run-12

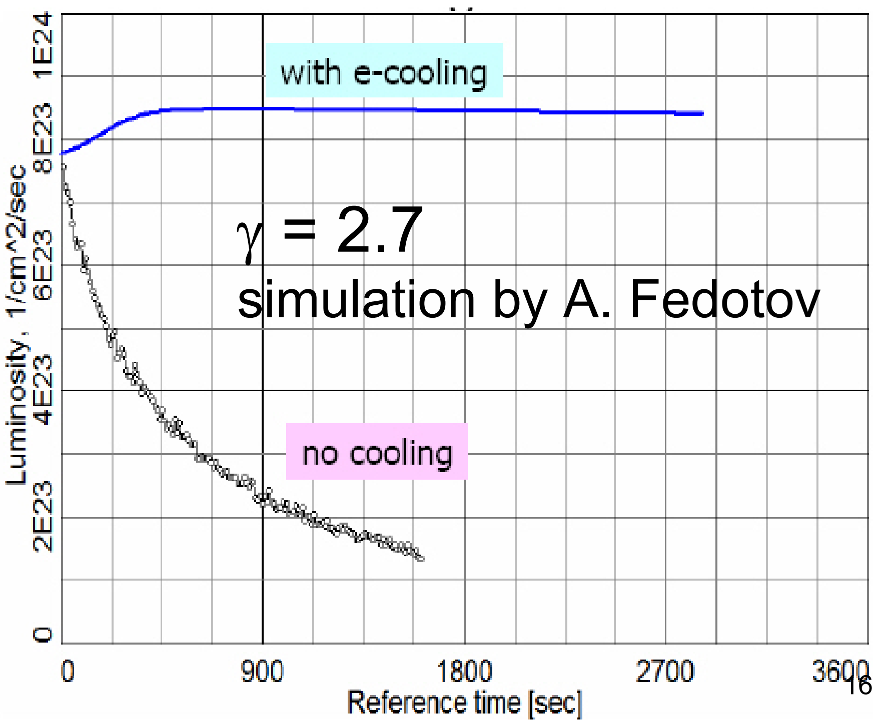
□ Copper prototype

Low energy electron cooling

Fermilab Pelletron

- Can use Fermilab Pelletron as e-source
- Expect factor 3-6 gain in integrated L

  beams are space charge dominated, assume ΔQ_{sc} = 0.05, may be too conservative
- Likely required for very low energies
- Need to finish other AIPs to release engineering resources
- With start in 2009, could be operational in 2014



Luminosity and polarization goals

Parameter	unit	Achieved	Enhanced design	Next L upgrade
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Energy	GeV	100 / 250	100 / 250	250
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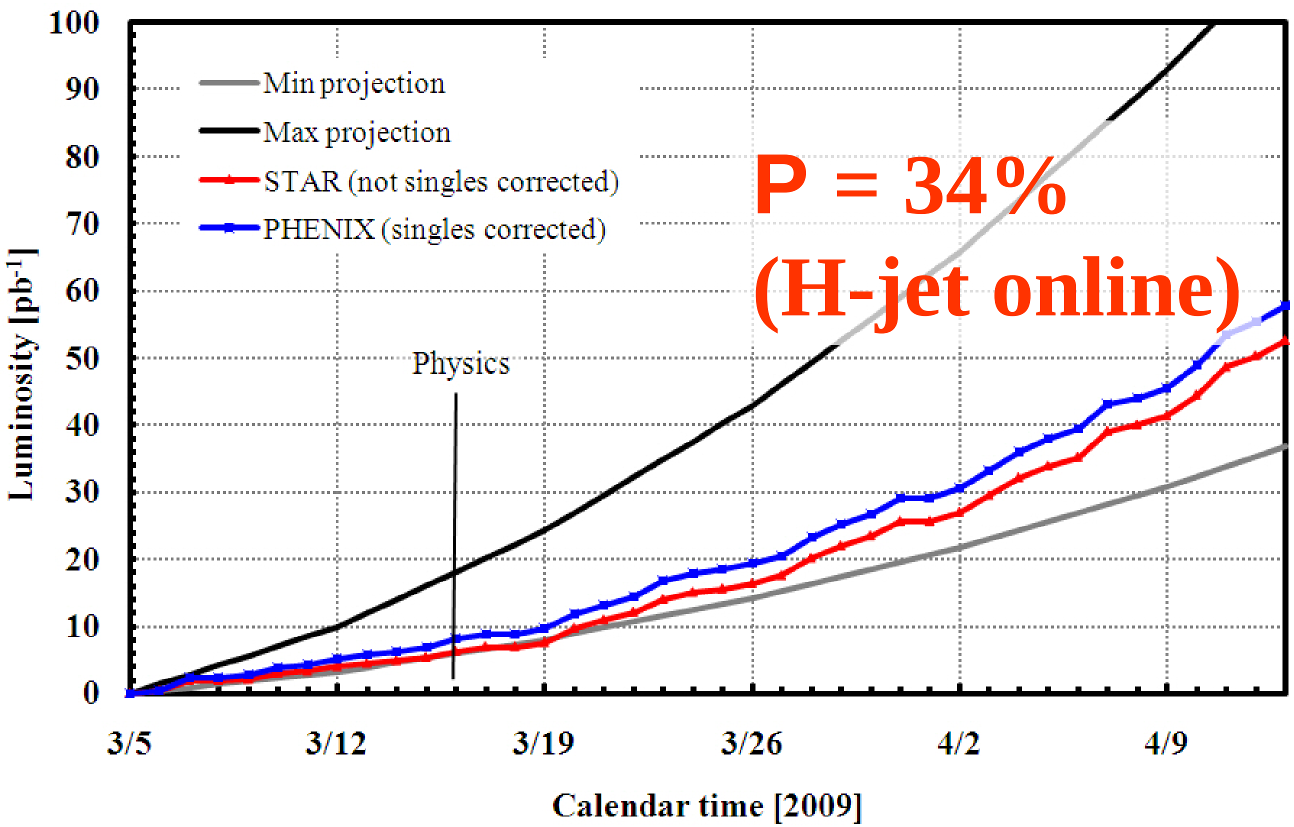
Bunch intensity	10^{11}	1.3 / 1.1	1.3 / 1.5	2.0
Average L	**10^{30}cm^{-2}s^{-1}**	**24 / 55**	**30 / 150**	**300**
Polarization P	**%**	**55 / 34**	**70**	**70**

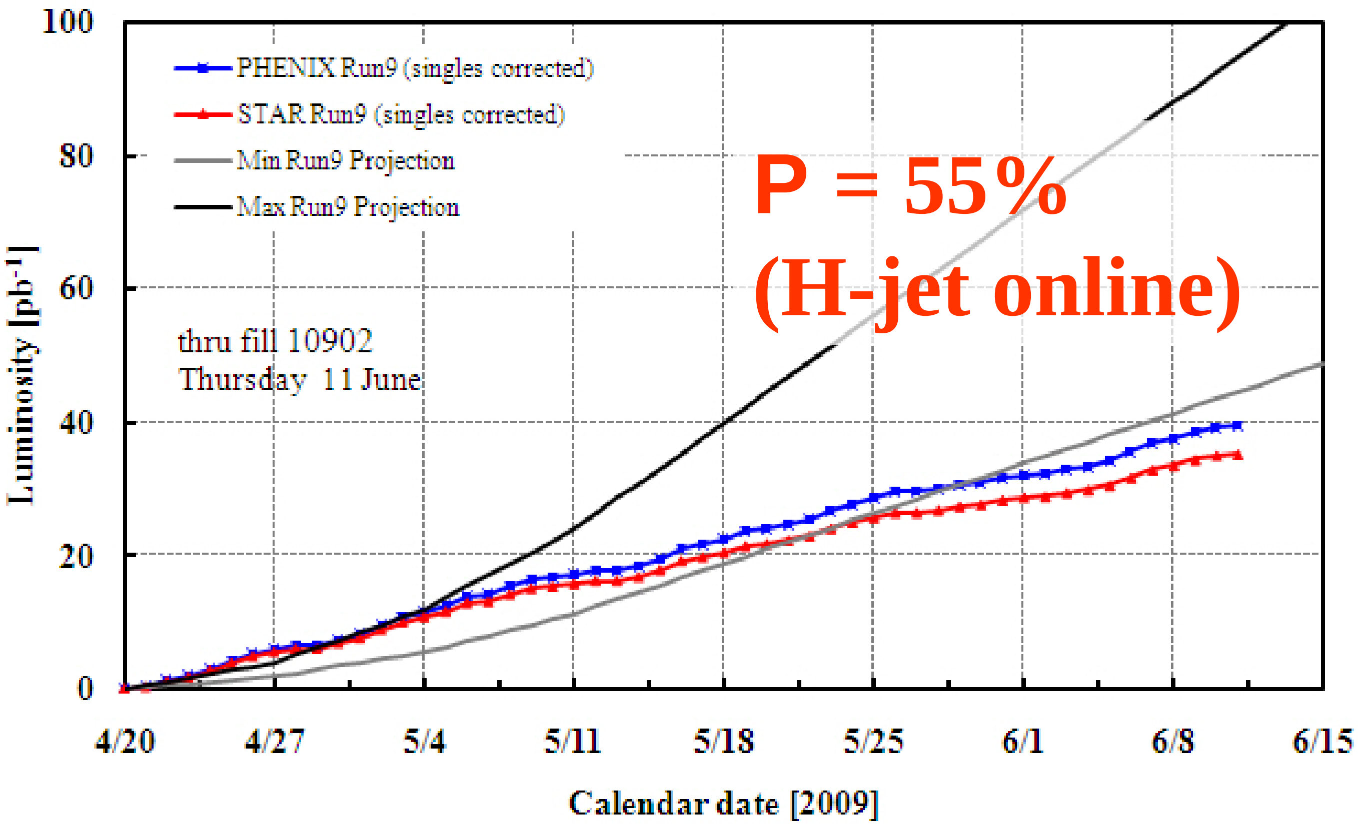
Run-9 250 GeV p -p Run Coordinator: M. Bai



First collider operation with polarized protons at 250 GeV

no of bunches	ions/bunch $[10^9]$	β^* [m]	emittance [μm]	L_{peak} $[cm^{-2}s^{-1}]$	$L_{store\ avg}$ $[cm^{-2}s^{-1}]$	L_{week} $[pb^{-1}]$
109	110	0.7	18-23	85×10^{30}	55×10^{30}	18.4
Average store polarization: 33% in Blue, 36% in Yellow (online H-jet measurements)						

Run-9 100 GeV p -p   Run Coordinator: C. Montag



Little progress compared to Run-6 / Run-8

- L_{peak} higher by up to 40% (lower ε and β^*)

- DOES NOT lead to increased L_{avg}

no of bunches	ions/bunch $[10^9]$	β^* [m]	emittance [μm]	L_{peak} $[cm^{-2}s^{-1}]$	$L_{store\ avg}$ $[cm^{-2}s^{-1}]$	L_{week} $[pb^{-1}]$
109	1.1	0.7	14-20	42	20	6.0
Average store polarization: 56 in Blue, 57 in Yellow (online H-jet measurements)						

Main limits for p -p performance and possible solutions

1. **AGS : proton bunches with high intensity, high polarization and low emittance**
   - horizontal tune jump system
   - source upgrade

2. **RHIC: polarization transmission to 250 GeV**
   - near integer working point, requires 10 Hz orbit feedback

3. **RHIC: luminosity lifetime at 100 GeV**
   - reached lower β^* limit at this energy (not necessarily a problem at 250 GeV)

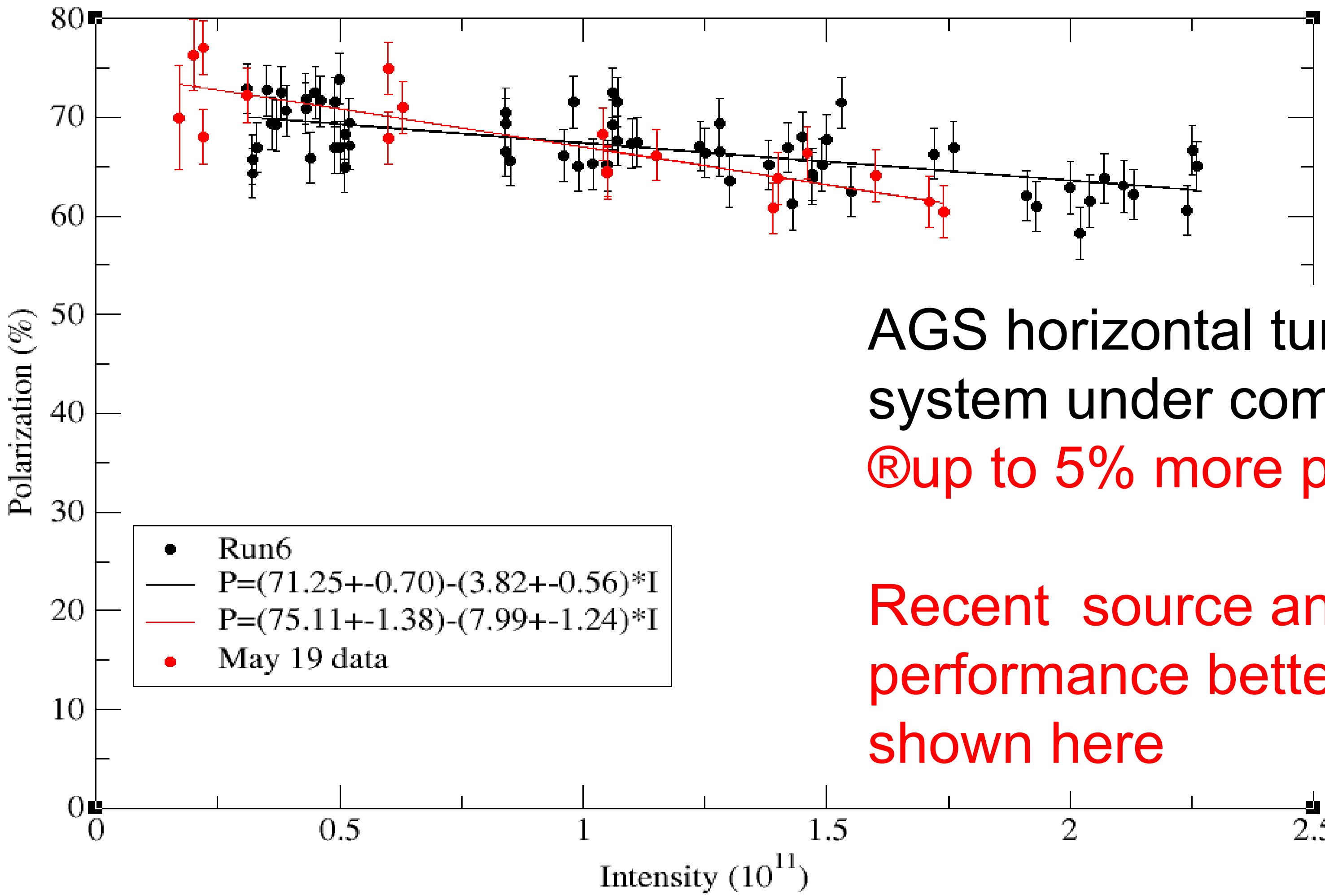
4. **RHIC: Yellow ramp transmission for high intensities**
   - 9 MHz rf system

Further upgrades for p -p performance

- Global 10 Hz orbit correction system
  required to operate near integer working point
- Polarimetry
  CNI polarimeter (rate dependence, setup time)
  additional PHENIX style polarimeter in IP10 with additional collision)
- More reliable orbit correction in store
  tighter tolerances at 250 GeV (collisions, collimators) due to smaller beam sizes
- Collimation efficiency
- β^* reduction to 0.5 m
- Beam dump
  Q7 quenched with normal beam dumps
- Spin flipper
  need full commissioning
- Intensity limits on ramp
  Limits from e-cloud(?) at beginning of ramp
  Limits from beam losses (flattop-ramp ps switchover, beta-squeeze, …)
- 24 h vertical orbit motion
- Maintain/improve reliability
- Electron lenses (increase of beam-beam parameter – now at limit)
  increase of beam-beam parameter – now at limit

Polarized protons from AGS

Intensity dependent polarization in AGS in Run-6 and Run-9



AGS horizontal tune jump system under commissioning
®up to 5% more polarization

Recent source and AGS performance better than shown here

Courtesy H. Huang

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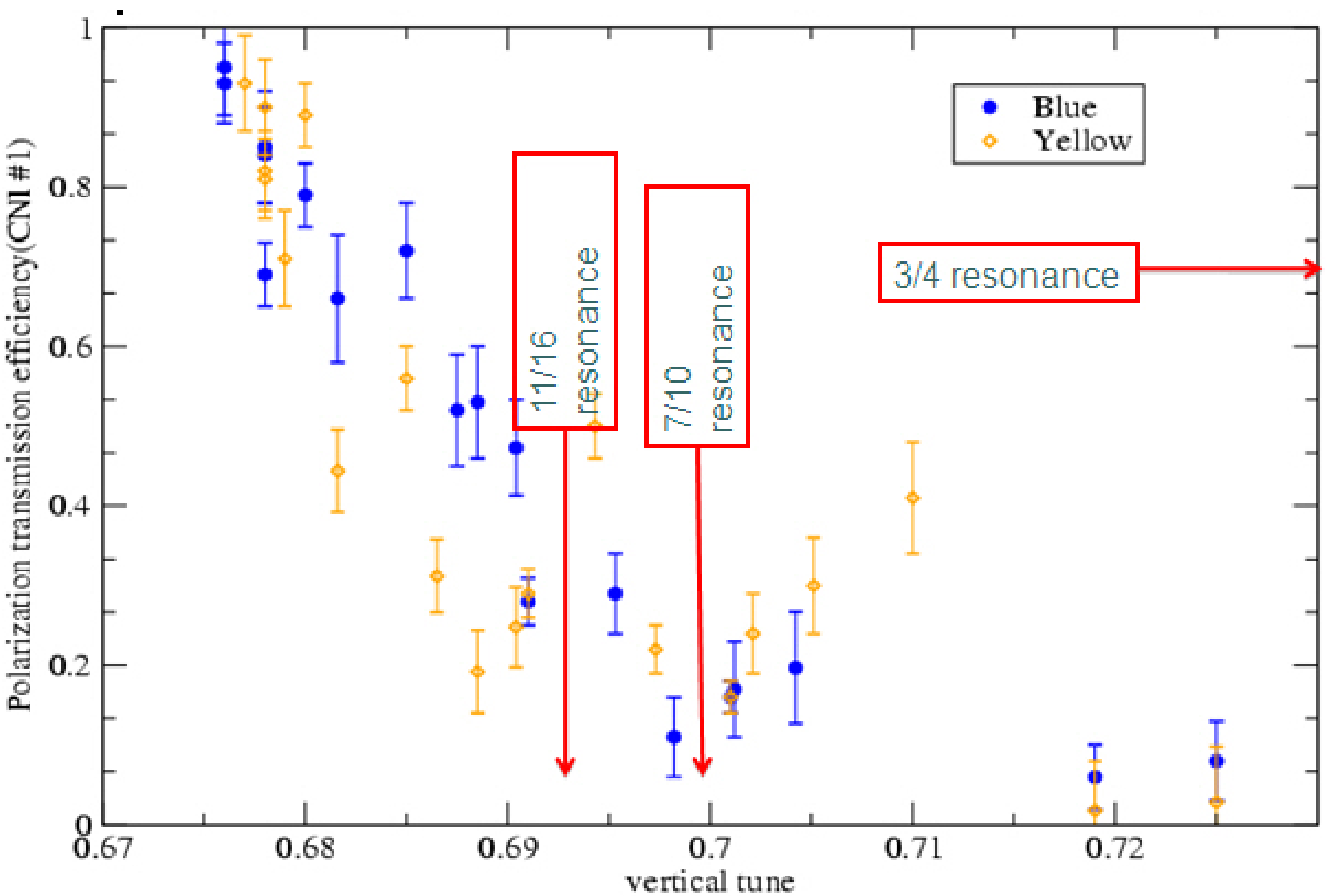
RHIC polarization transmission to 250 GeV



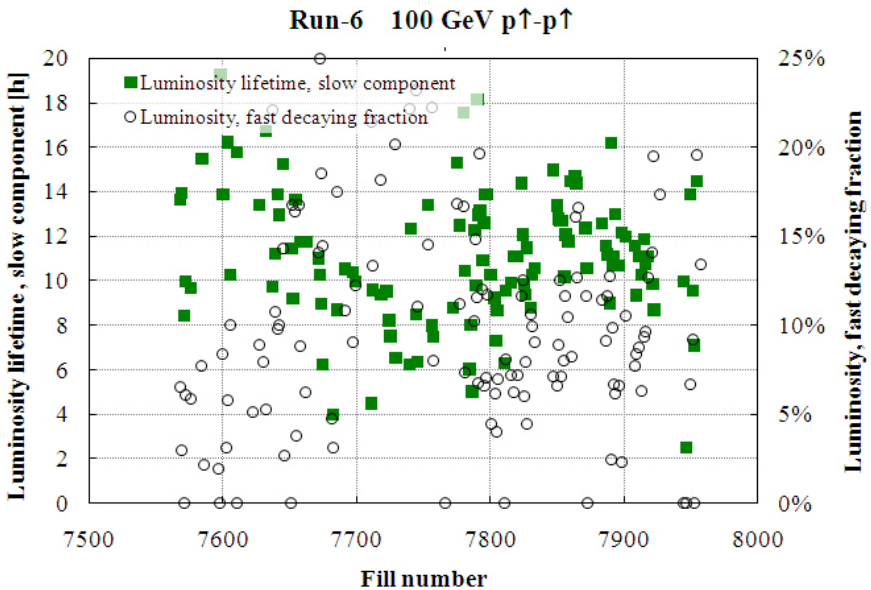
At current working point very limited tune space between 2/3 (beam loss) and 7/10 (polarization loss) on ramp.
Explore near-integer working point (requires 10 Hz orbit feedback).

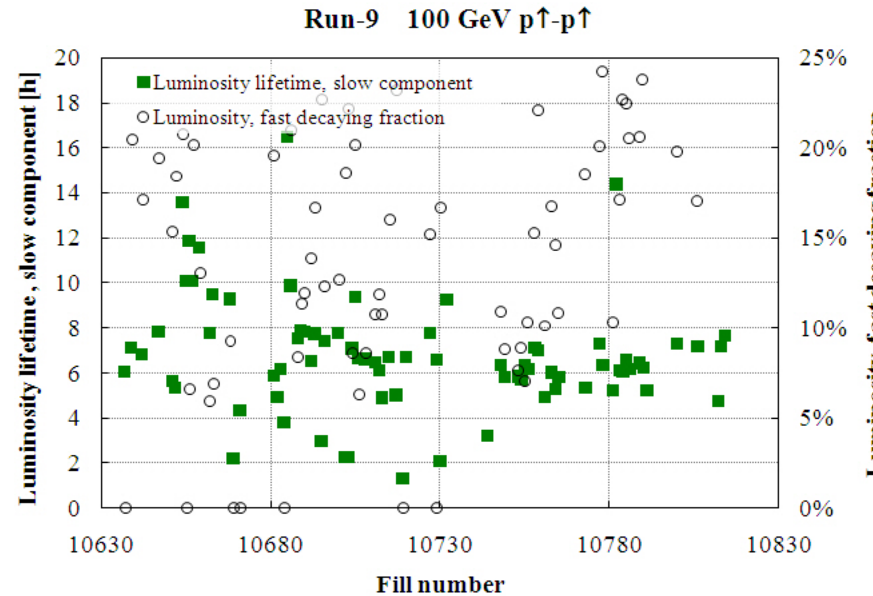
Courtesy M. Bai

RHIC luminosity lifetime at 100 GeV

Luminosity fitted to L(t) = A1*exp(-t/t1) + A2*exp(-t/t2)   [first 3h]

[fast decay, t1□0.5h]   [slow decay]



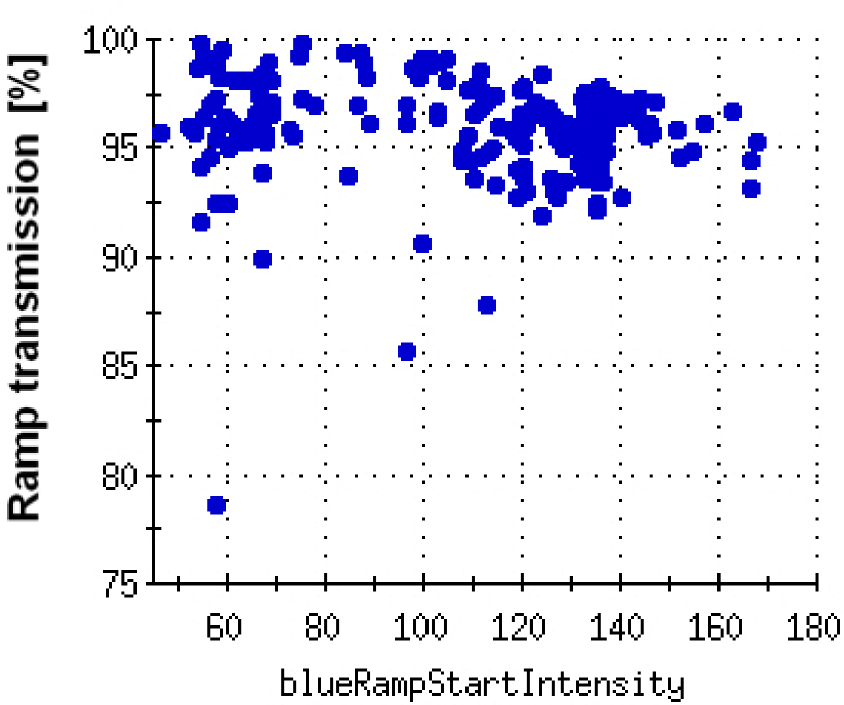


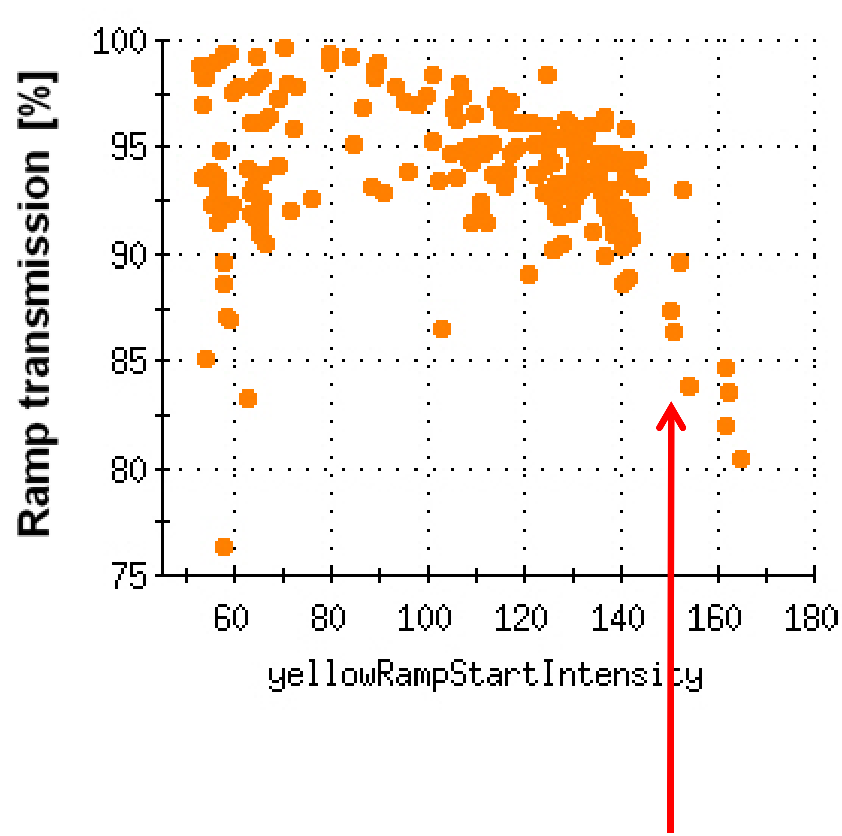
β^* = 1.0 m   1.0 m   0.7 m

		Run-6	Run-8	Run-9
A1/(A1+A2)	[%]	9.4	10.9	20.0
t2	[h]	12.9	12.9	7.2

Re-established beam lifetimes with β^* = 1.0
=> Reached lower β^* limit at 100 GeV

RHIC Yellow ramp transmission

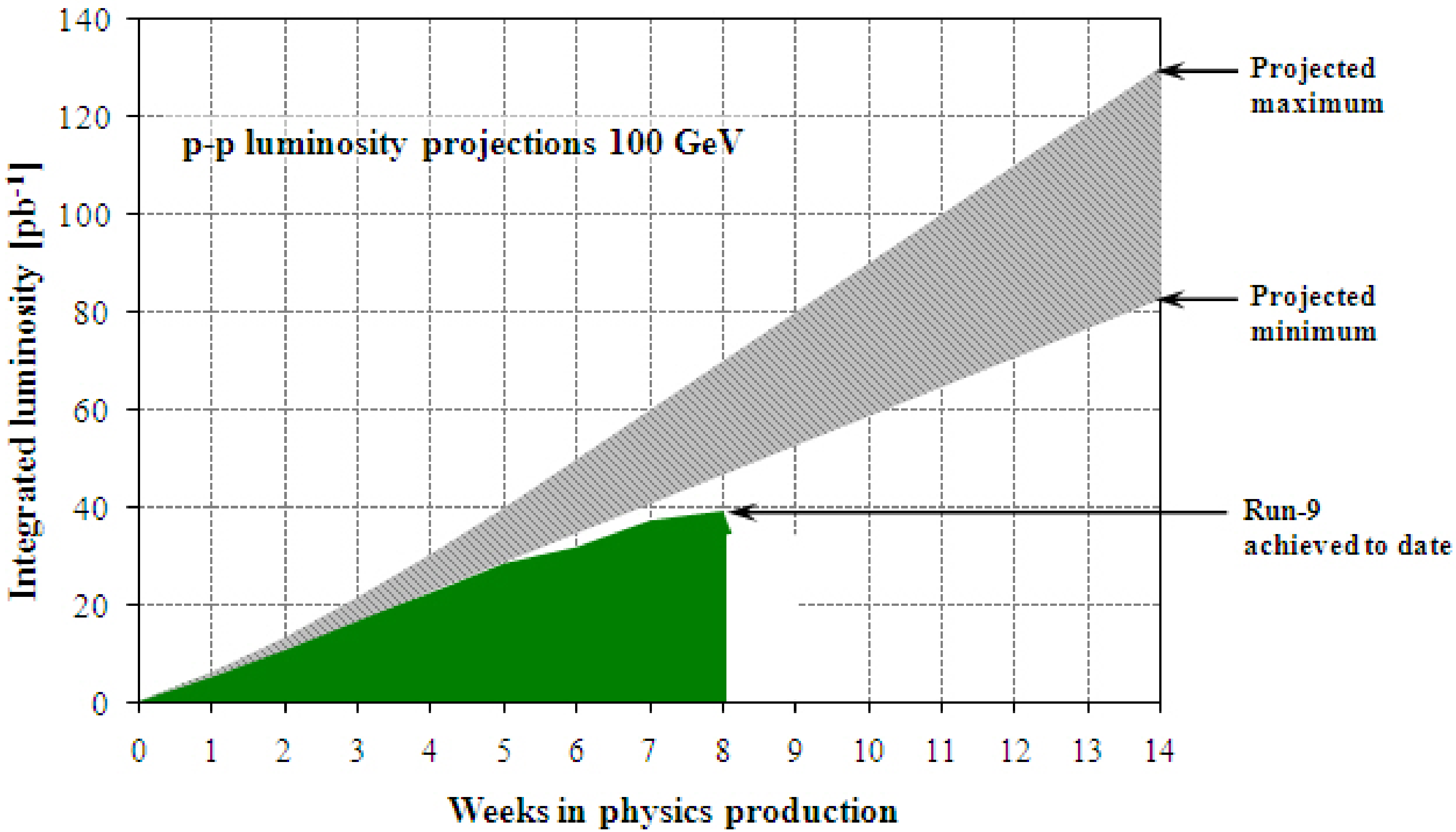




Sharp drop in Yellow ramp transmission for □ 150□10^{11} p

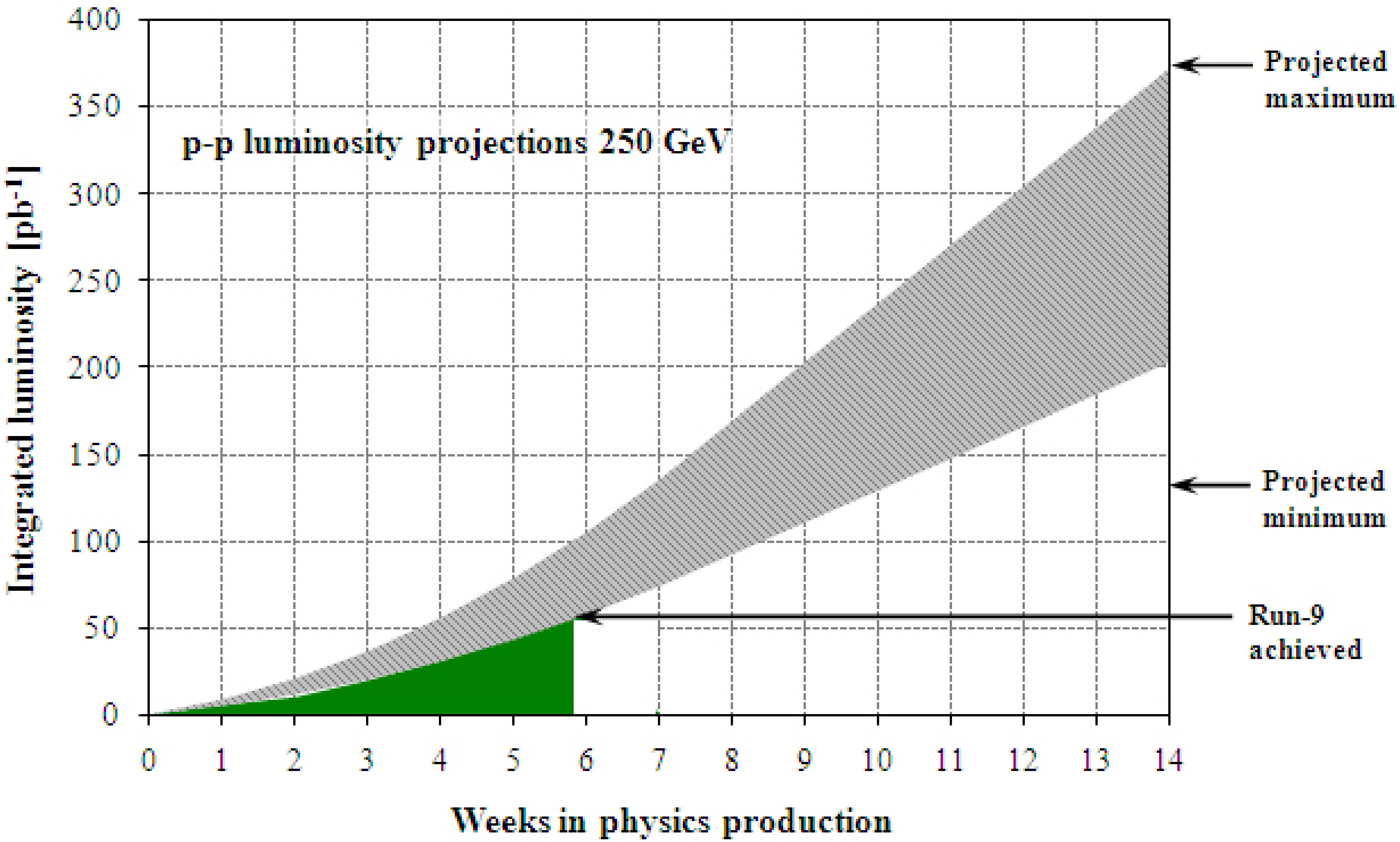
Better transmission for same intensity in fewer bunches suggest electron clouds as contributing mechanism, can be mitigated with 9 MHz rf

Run-11 p -p luminosity projections 100 GeV



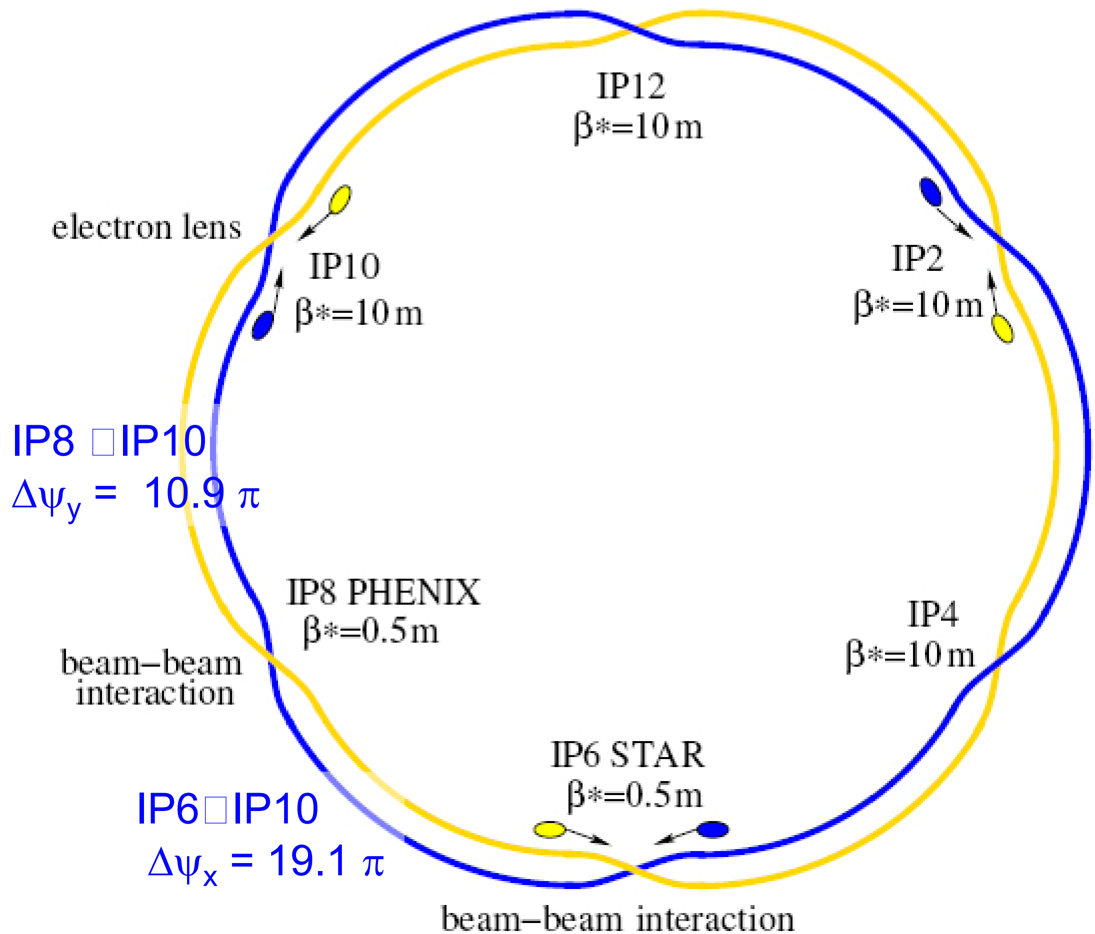
Expect store polarization of 50-65%,
and average store luminosity of up to 30 10^{30}cm^{-2}s^{-1}.

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}.
Higher polarization likely requires new working point.

Electron lenses in RHIC



Basic idea:

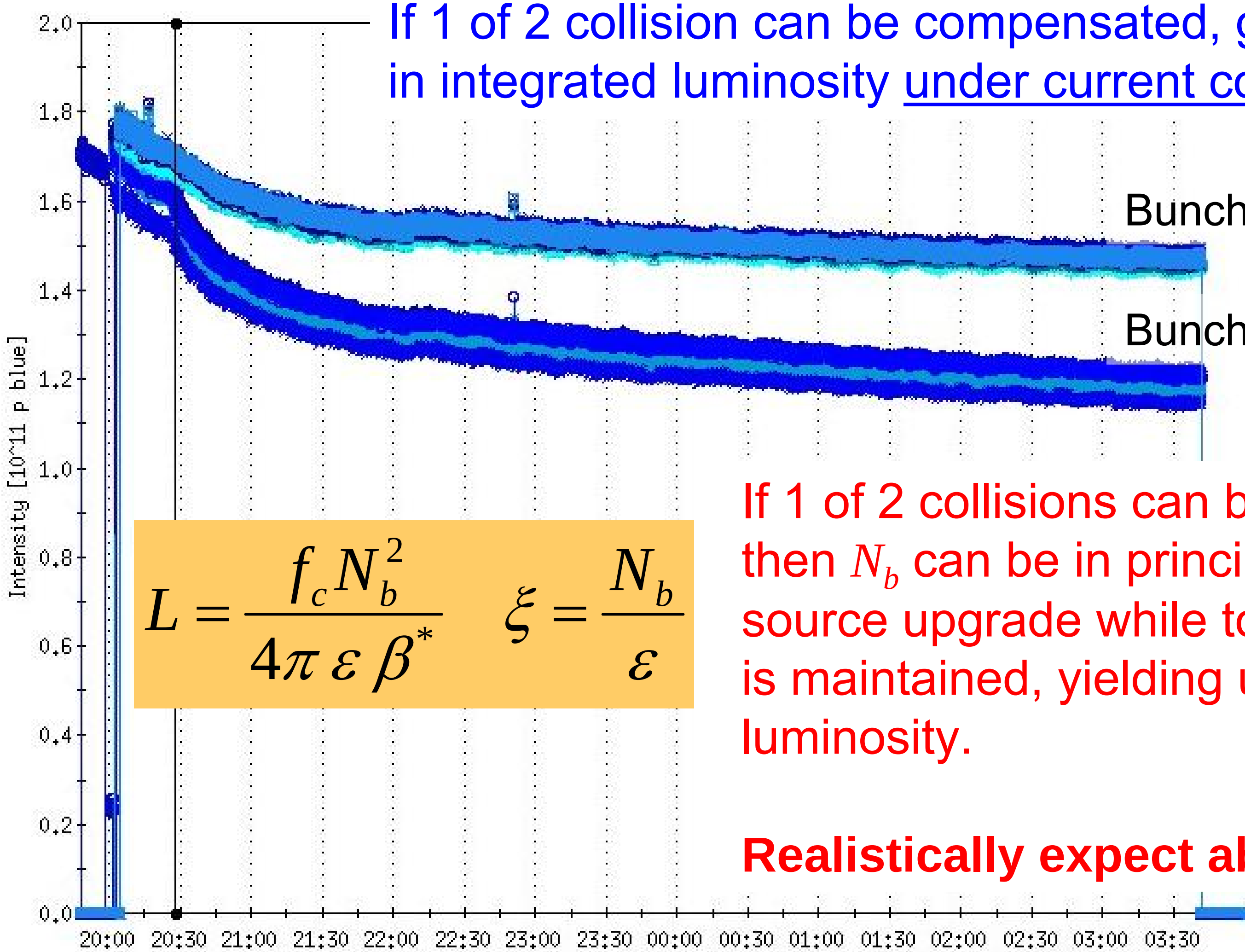
In addition to beam-beam collisions in IP6 and IP8 (with **positively** charged beam) have another collision at IP10 (with a **negatively** charged beam) with the same amplitude dependence.

Aim to remove effect of on beam-beam collision.

[Y. Luo and W. Fischer, "Outline of using an electron lens for the RHIC …", BNL C-AD/AP/284 (2007)]

Electron lenses – estimate of luminosity gain

If 1 of 2 collision can be compensated, gain up to □50% in integrated luminosity under current conditions



$$L = \frac{f_c N_b^2}{4\pi \varepsilon \beta^*} \qquad \xi = \frac{N_b}{\varepsilon}$$

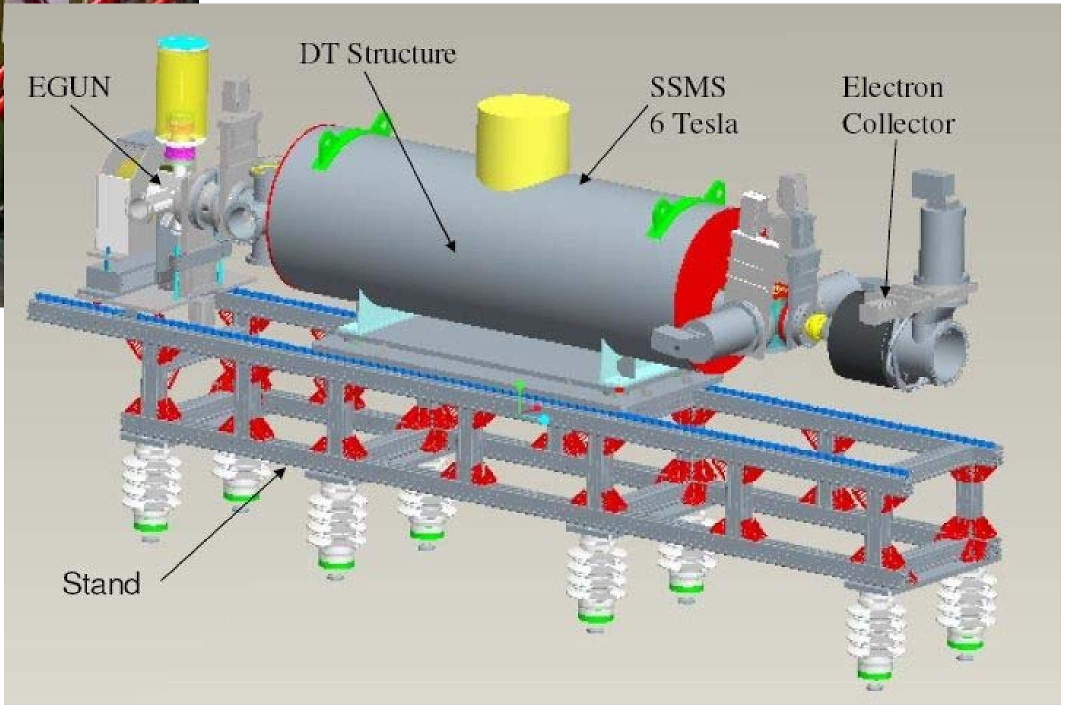
If 1 of 2 collisions can be compensated, then N_b can be in principle doubled with a source upgrade while total beam-beam ξ is maintained, yielding up to a factor 4 in luminosity.

Realistically expect about factor 2.

Electron lenses in RHIC

Tevatron e-lens

EBIS



Currently specifying e-lens solenoid in terms of length, strength and field quality.

E-lens main technical challenge is relative beam alignment.

Summary

Heavy ion operation

- For 100 GeV/nucleon in Run-10: **0.4 – 1 nb^{-1}/week**
  - Longitudinal and vertical stochastic cooling in both rings
- β^* reduction from 0.85 m to 0.50 m
- For □ 10 GeV/nucleon in Run-10: **table on slide 12**

  (storage rf system can be used with Au down to 19.5 GeV/nucleon)
- Longer-term upgrades:
- EBIS (2011)
- Horizontal stochastic cooling in both rings (2012)
- 56 MHz superconducting RF (2012, 30-50% increase in luminosity)
- Electron cooling for low energy operation (2014)

Polarized proton operation

- For 100 GeV in Run-11: **6 – 10 pb^{-1}/week, P = 50 – 65%**
- For 250 GeV in Run-11: **18 – 34 pb^{-1}/week, P = 35 – 50%**
  - AGS horizontal tune jump system
  - Near integer working point (requires 10 Hz orbit feedback)
  - 9 MHz rf system
- Longer-term upgrade:
  - Polarized source upgrade (2012)
  - Electron lenses (2012)