RHIC performance in Run-8, upgrades, and projections for Run-9 and beyond

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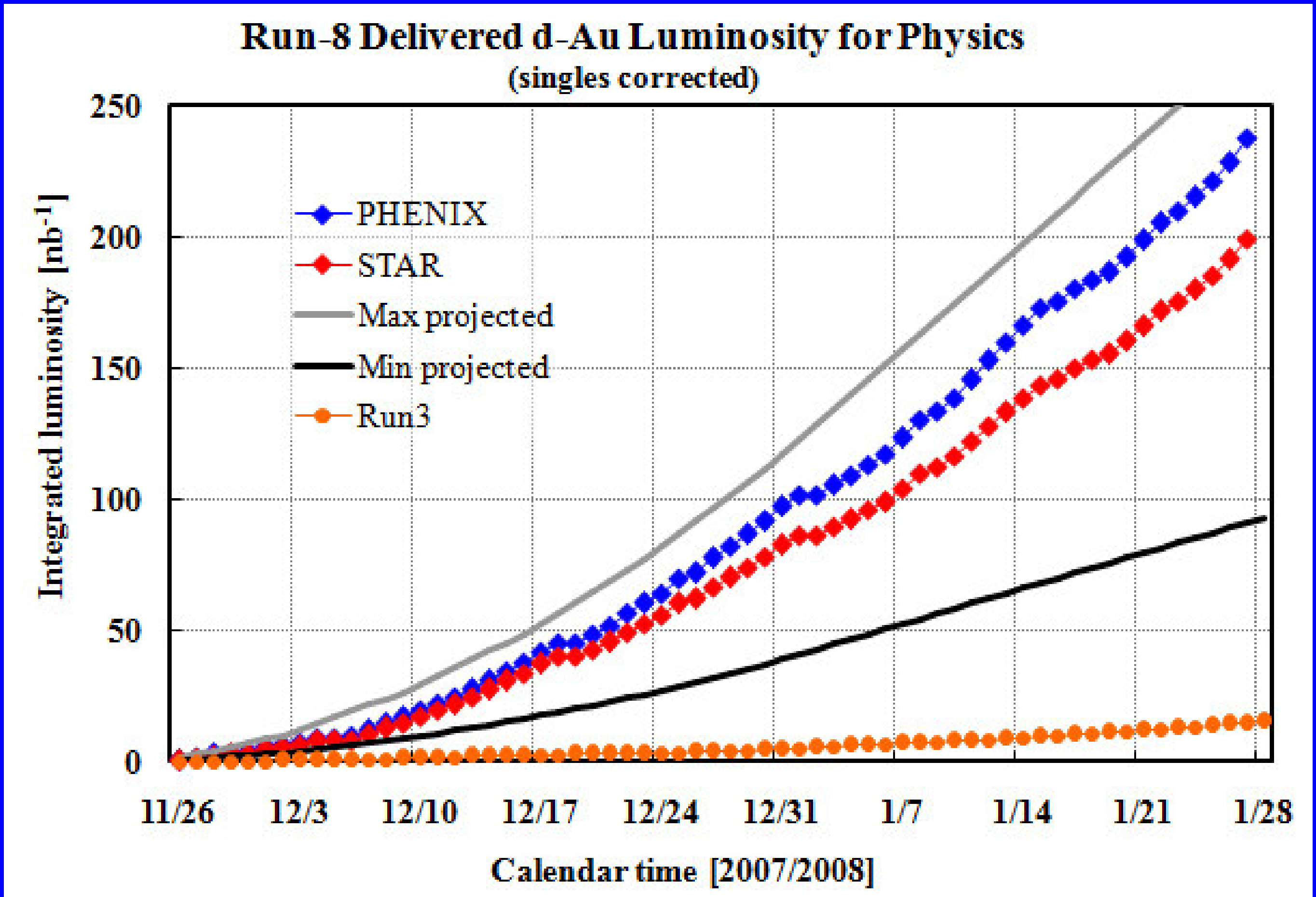
Outline

1. Run-8 performance (d-Au, p↑-p↑)
2. Upgrades plans
   - **for heavy ions**
   - **for polarized protons**
3. Projections for Run-9 (Au-Au, p↑-p ↑)
4. 5-year projections (Au-Au, p↑-p ↑)
5. Projection for low-energy operation (Au-Au)

Run-8 d-Au operation (Run Coordinator: C. Gardner)



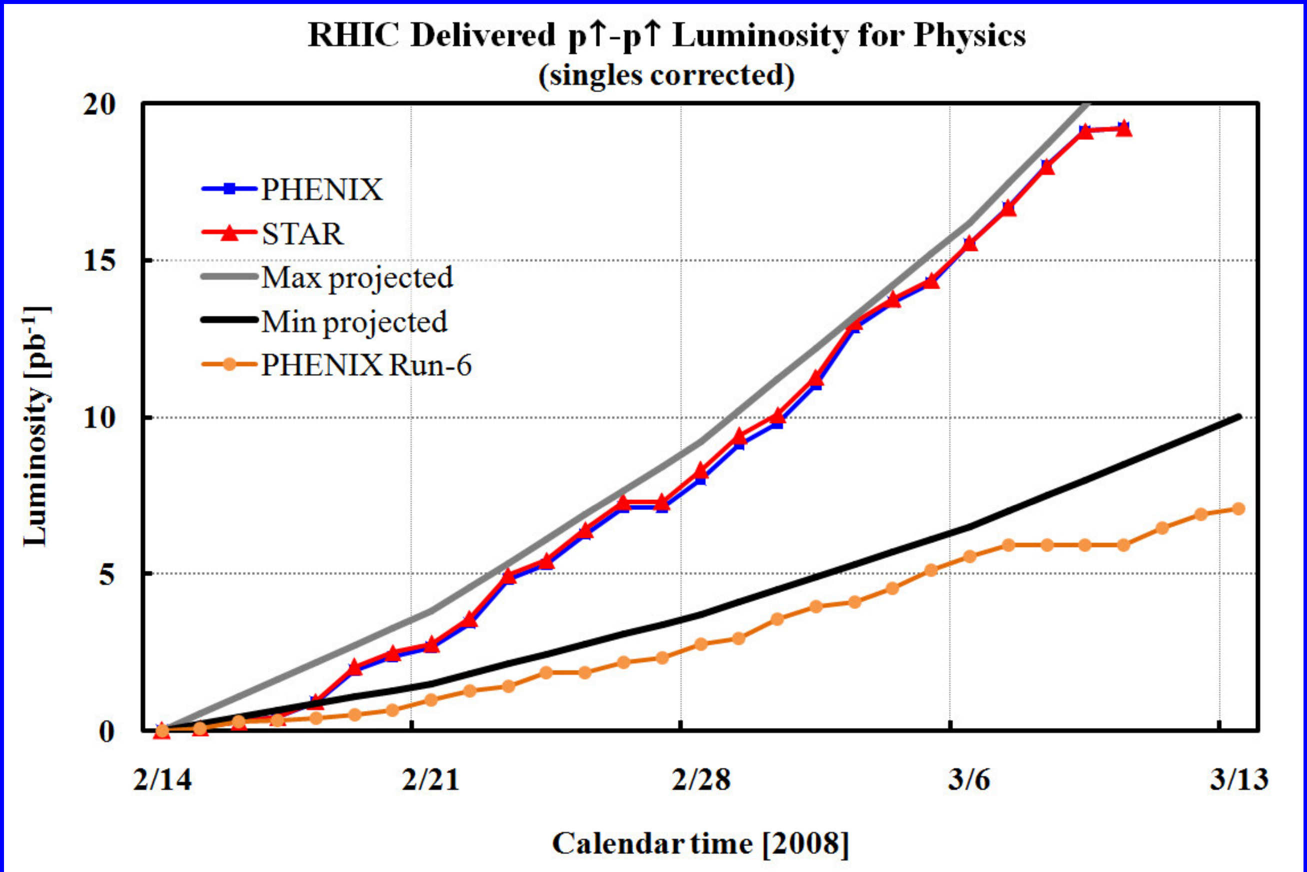
Delivered 10× more luminosity than in Run-3

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

Other improvement:
- long. stoch. cooling
- IBS 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

Run-8 p↑-p↑ luminosity (Run Coordinator: C. Montag)



Followed maximum $\mathcal{L}$ projection through 3.5 weeks, yielding a **15% increase in average store $\mathcal{L}$ over end of Run-6**.

However,
- could not test all limits in time available
- tested a near integer WP, abandoned due to 10 Hz triplet vibrations
- tested β^*=0.65 m (design)

no of bunches	ions/bunch [10^9]	β^* [m]	emittance [μm]	$\mathcal{L}_{peak}$ [$cm^{-2}s^{-1}$]	$\mathcal{L}_{store\ avg}$ [$cm^{-2}s^{-1}$]	L_{week} [pb^{-1}]
111	150	1.0	20-25	35×10^{30}	23×10^{30}	7.5

Run-8 p↑-p↑ operation – polarization

Source

- $\mathcal{P}$ = 80-82% in Run-8 after 85-89% in Run-7
  (but changes in 200 MeV polarimeter between Run-7 and Run-8)
- Aim for $\mathcal{P}$ = 85% in Run-9

AGS

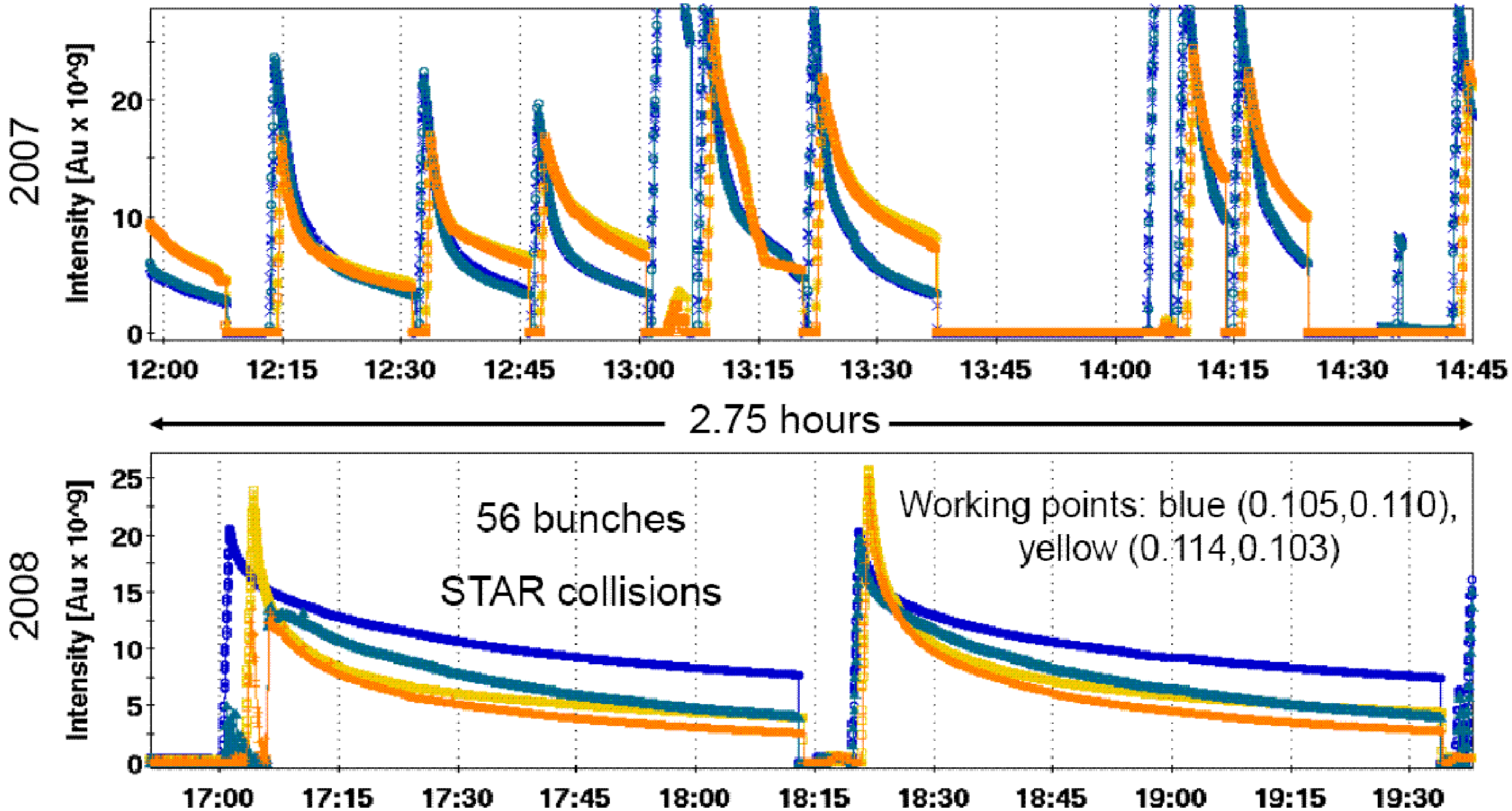
- Tested stronger snake and near integer horizontal tune in Run-7
- Tested injection on the fly (no flat bottom) in Run-8
- In both cases significant intensity dependent polarization
- Returned to Run-6 setup with $\mathcal{P}$ = 55% at extraction vs. $\mathcal{P}$ = 65% in Run-6
  (half of the loss due to source, other half due to only 10 days of tuning)

RHIC

- About 10% (absolute) lower $\mathcal{P}$ than in Run-6, more problems in Yellow
- Learned that orbit angle through snakes needs better control

Run-8 low energy Au-Au operation

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

[T. Satogata, RHIC Retreat 2008]

Run-8 low energy Au-Au operation

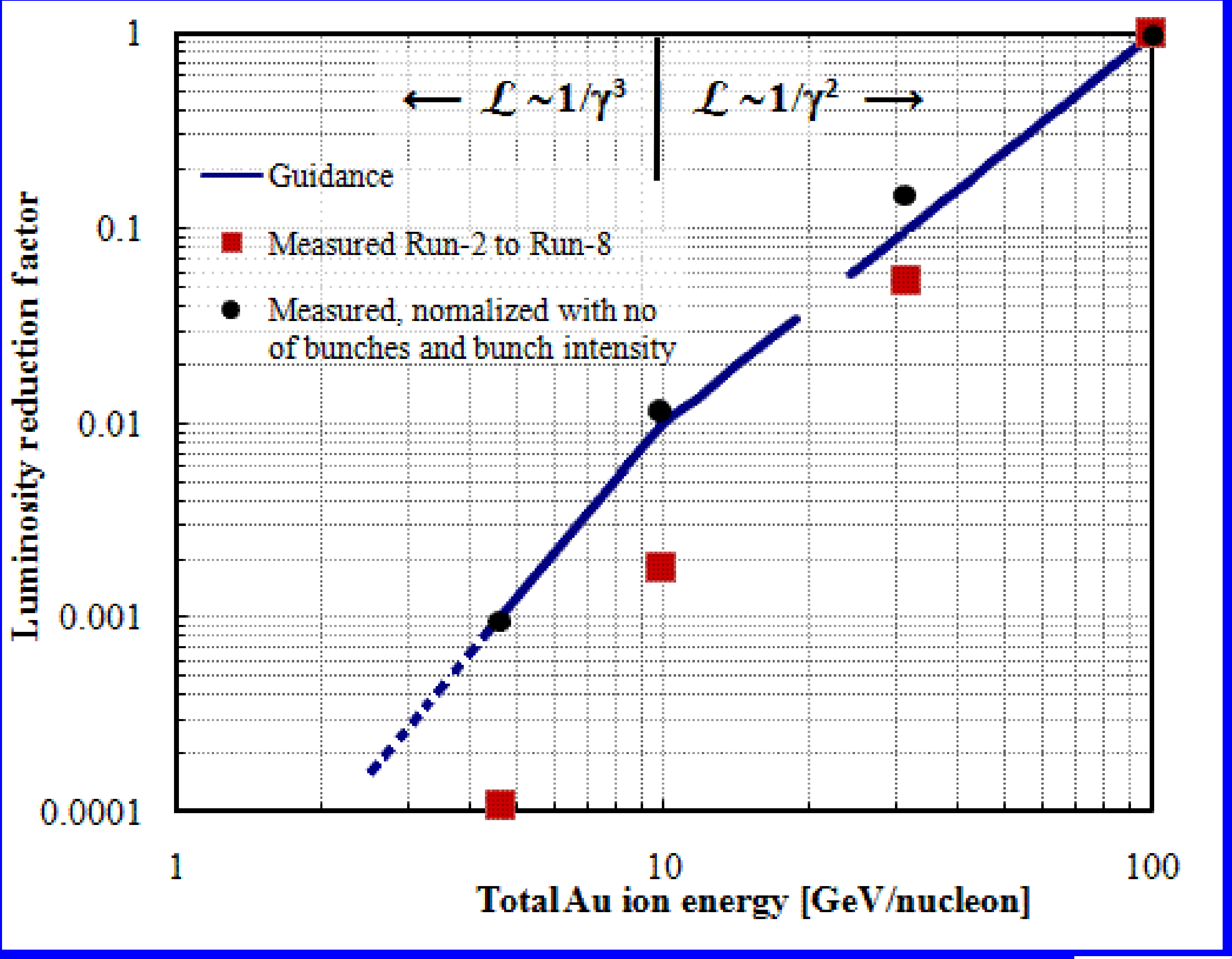
4.6 GeV/nucleon

- $\mathcal{L}_{max} = 3.5\times10^{23}\text{cm}^{-2}\text{s}^{-1}$, $\mathcal{L}_{avg} = 1.2\times10^{23}\text{cm}^{-2}\text{s}^{-1}$
- With $h = f_{rf}/f_{rev} = 366$ not possible to simultaneously give collisions to both STAR and PENIX
- Should be possible to increase bunch intensity and number of bunches each by about a factor 2

2.5 GeV/nucleon

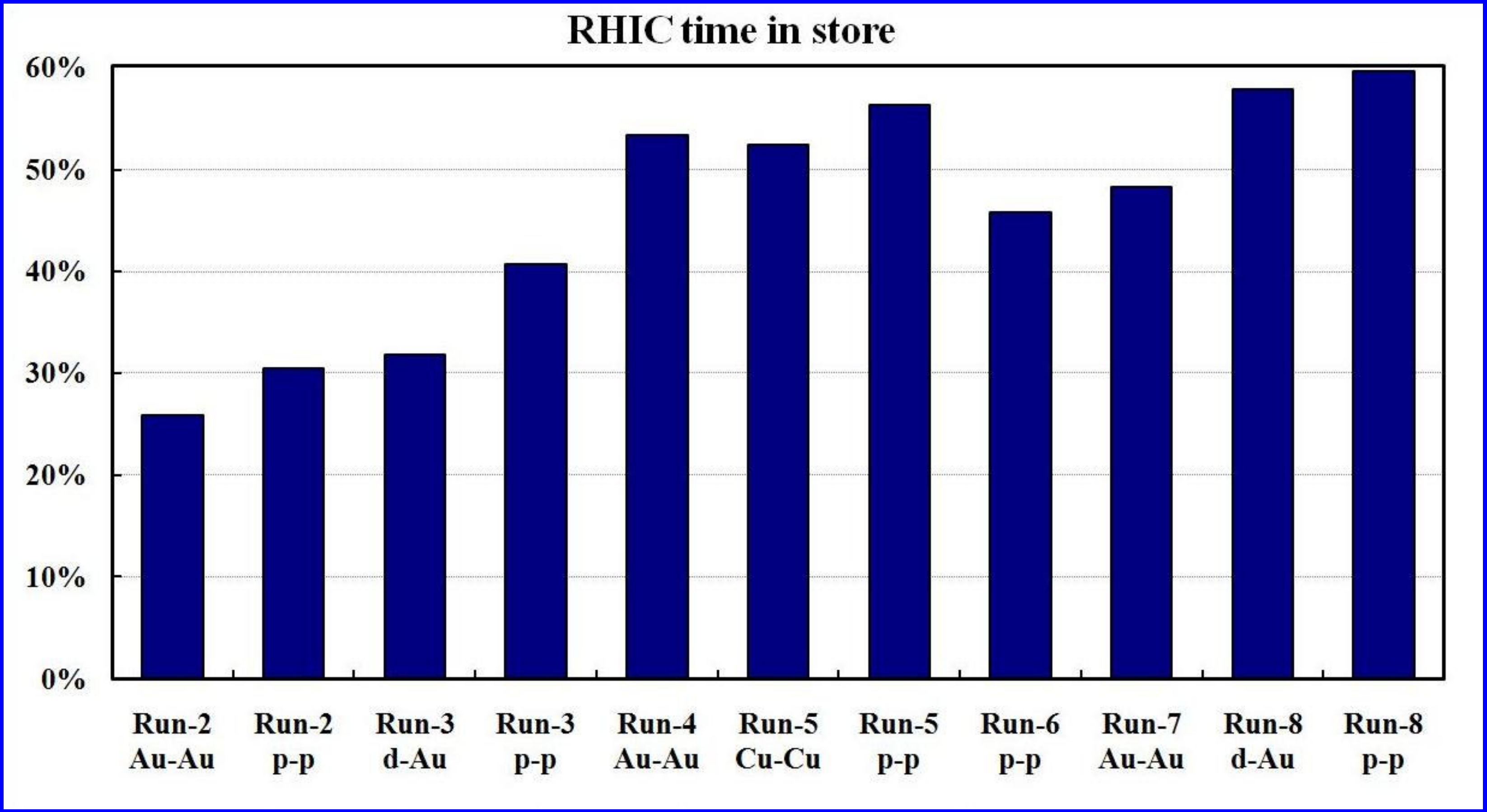
- Stored some beam in Yellow (Blue ps failure prevented injection)
- Only 10% injection efficiency, very nonlinear lattice, orbit corrections very difficult, bunched beam lifetime only second
- Need to obtain better magnetic field error data (possibly new cold measurements in SMD), nonlinear online model for orbit correction

Luminosity scaling with energy



Run-8 time in store (as fraction of calendar time)

After 2 difficult years, time in store increased again. Improvements from many systems, large part from main and IR power supplies.



Reached goal of 60% time in store with protons in Run-8, but did not do rotator ramps for most part of the run (~2% of calendar time).

Luminosity and polarization goals

Parameter	unit	**Achieved**	**Enhanced design**	**Next $\mathcal{L}$ upgrade**
Au-Au operation		**(2007)**		**(≥ 2011)**
Energy	GeV/nucleon	100	100	100
No of bunches	…	103	111	111
Bunch intensity	10^9	1.1	1.0	1.0
Average $\mathcal{L}$	**10^{26}cm^{-2}s^{-1}**	**12**	**8**	**40**
p↑- p↑ operation		**(2006/08)**	**(≥ 2010)**	**(≥ 2012)**
Energy	GeV	100	100 (250)	250
No of bunches	…	111	111	111
Bunch intensity	10^{11}	1.5	2.0	2.0
Average $\mathcal{L}$	**10^{30}cm^{-2}s^{-1}**	**23**	**60 (150)**	**300**
Polarization $\mathcal{P}$	**%**	**60**	**70**	**70**

Upgrades for heavy ion luminosity (Au-Au)

Main limits: IBS, transition instabilities

- Reduction in β^* (from 80cm to 50cm, +70%)
- Lattice with reduced IBS (+25%)
- Blue longitudinal stochastic cooling (+15%)
- Transverse stochastic cooling (+400%)
- Transverse damper / scrubbing (+40%)
- 56MHz SRF (+30-50%)

potential luminosity increases
(not all independent, cannot simply multiply)

- EBIS, begin commissioning FY10 (reliability, U, $^3He\uparrow$)

Stochastic cooling & 56 MHz SRF – upgrade plan

FY07: Yellow longitudinal sc operational in Au-Au

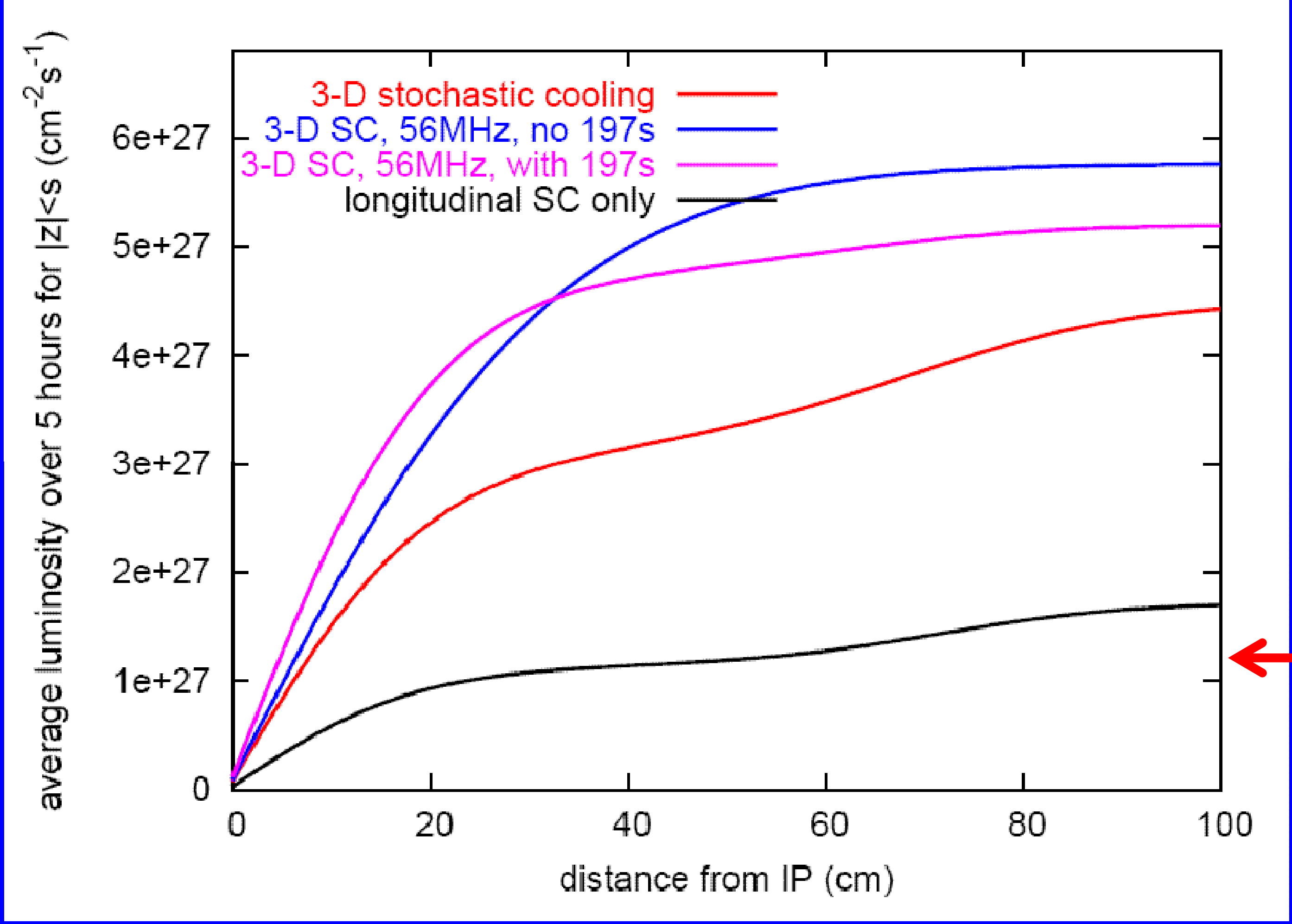
FY08: Yellow longitudinal sc used again in d-Au
Blue longitudinal sc installed, 56 MHz SRF AIP start

FY09: Yellow longitudinal sc upgrade
Yellow transverse sc test: **Cooling in one plane sufficient?**
(transverse cooling can be tested in principle with low intensity proton bunch, longitudinal-transverse interaction via IBS cannot)

FY10: 1st transverse plane sc operational

FY11: 2nd transverse plane sc operational
56 MHz SRF commissioning

Stochastic cooling & 56 MHz SRF – luminosity increase



Achieved in Run-7

Yellow longitudinal stochastic cooling only.

Calculation by M. Blaskiewicz.

Upgrades for polarized protons

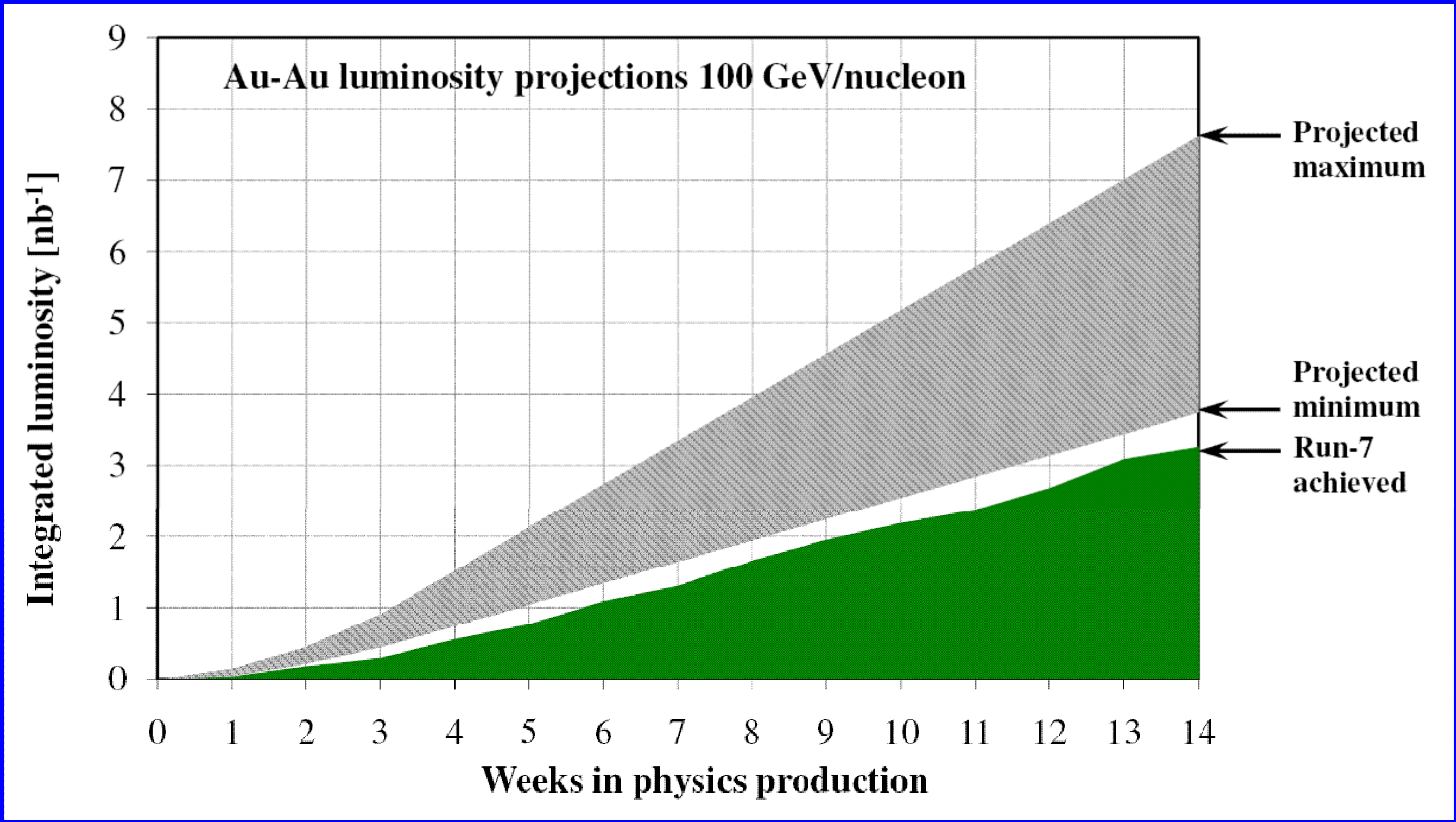
Main limits: beam-beam, p↑-operation

potential luminosity gains
(not all independent, cannot simply multiply)

- Reduction in β^* (from 100cm to 50cm, +70% at σ_s=1m)
- Nonlinear chromaticity correction (+30%)
- LEBT/MEBT/Booster modifications for p↑ (+20%)
- 9 MHz cavity (+25% at β^* = 1m)
- Horizontal tune jumps in AGS ($\mathcal{P}$ +5% absolute)
- Orbit control in RHIC snakes (avoids $\mathcal{P}$ loss in RHIC)
- Mitigate 10 Hz triplet vibration (+5-10%)
  (passive or active stabilization of cold masses, removal of driving term, orbit feedback)
- Near integer working point (+40%)
  (requires mitigation of 10 Hz triplet vibrations)
- 56 MHz cavity (operational flexibility)

- Spin flipper (R&D)
- Electron lens (R&D)
- Coherent electron cooling (R&D)

Run-9 projections Au-Au

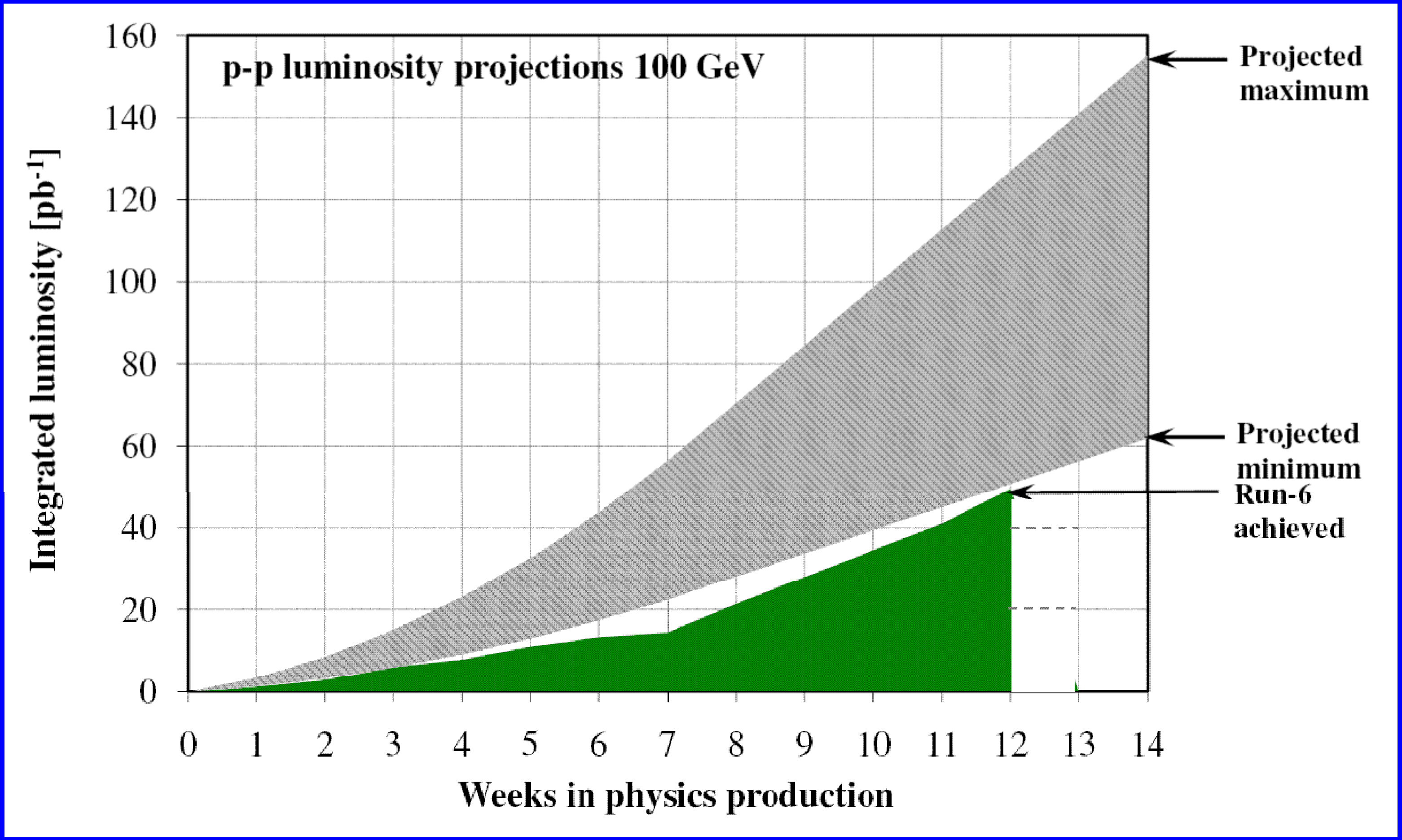


Main improvements for $\mathcal{L}$:

β^*, Blue longitudinal stochastic cooling, IBS lattice, time in store

<u>Need about 6 weeks in physics to test transverse stochastic cooling.</u>

Run-9 projections p↑-p↑

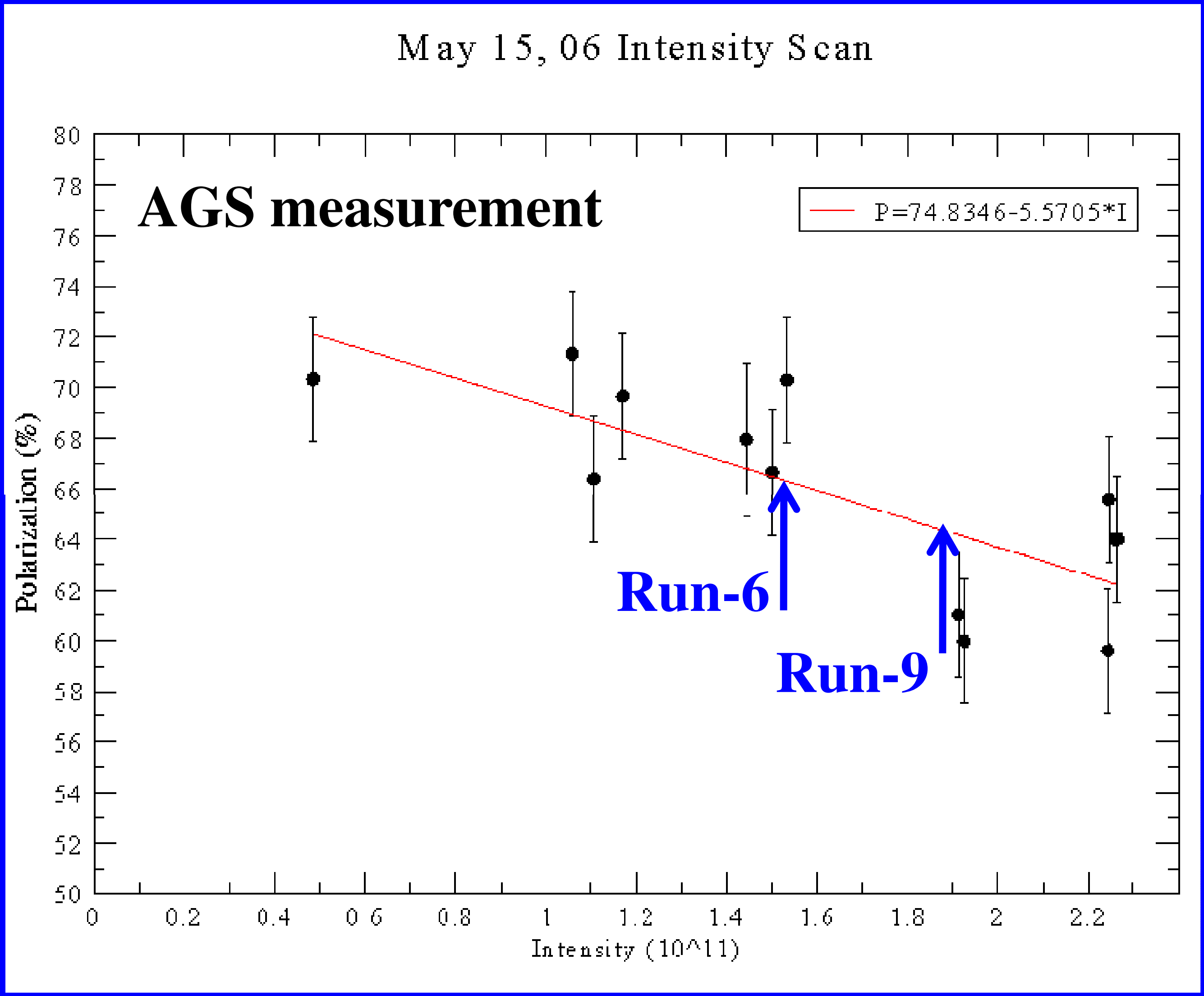


Main improvements:

for $\mathcal{L}$: β^*, 9 MHz rf system, bunch intensity

for $\mathcal{P}$: LEBT/MEBT/Booster injection modification, possibly AGS hor. tune jumps, RHIC orbit control (particularly snakes)

Run-9 projections p↑-p↑



Expect for Run-9:

AGS:
Min $\mathcal{P}$ = 55%
Max $\mathcal{P}$ = 65%

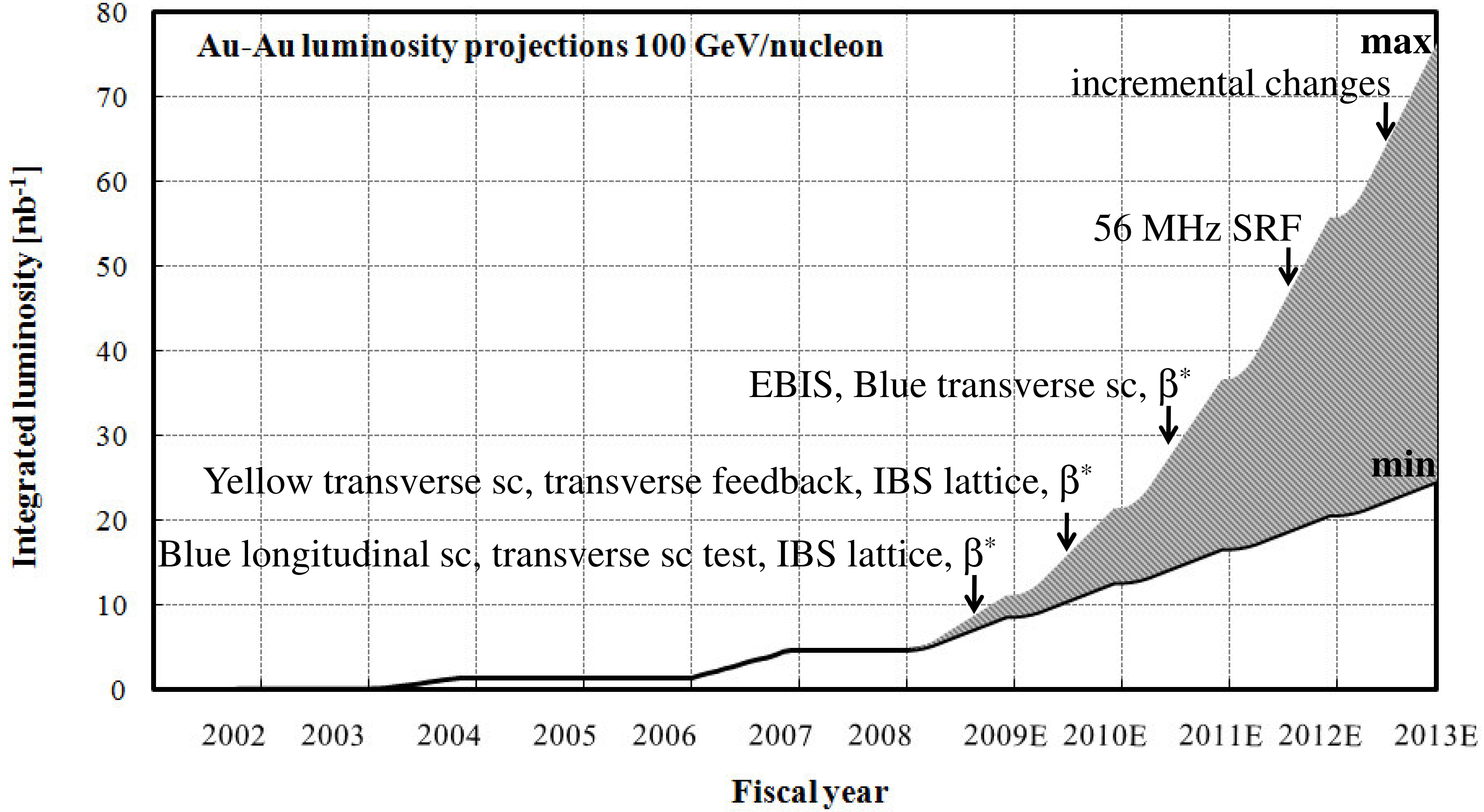
RHIC:
Min $\mathcal{P}$ = 50%
Max $\mathcal{P}$ = 60%

[courtesy H. Huang and A. Zelenski]

5-year projections Au-Au

5-year projections for Au-Au luminosity assuming 12 weeks of physics in every year

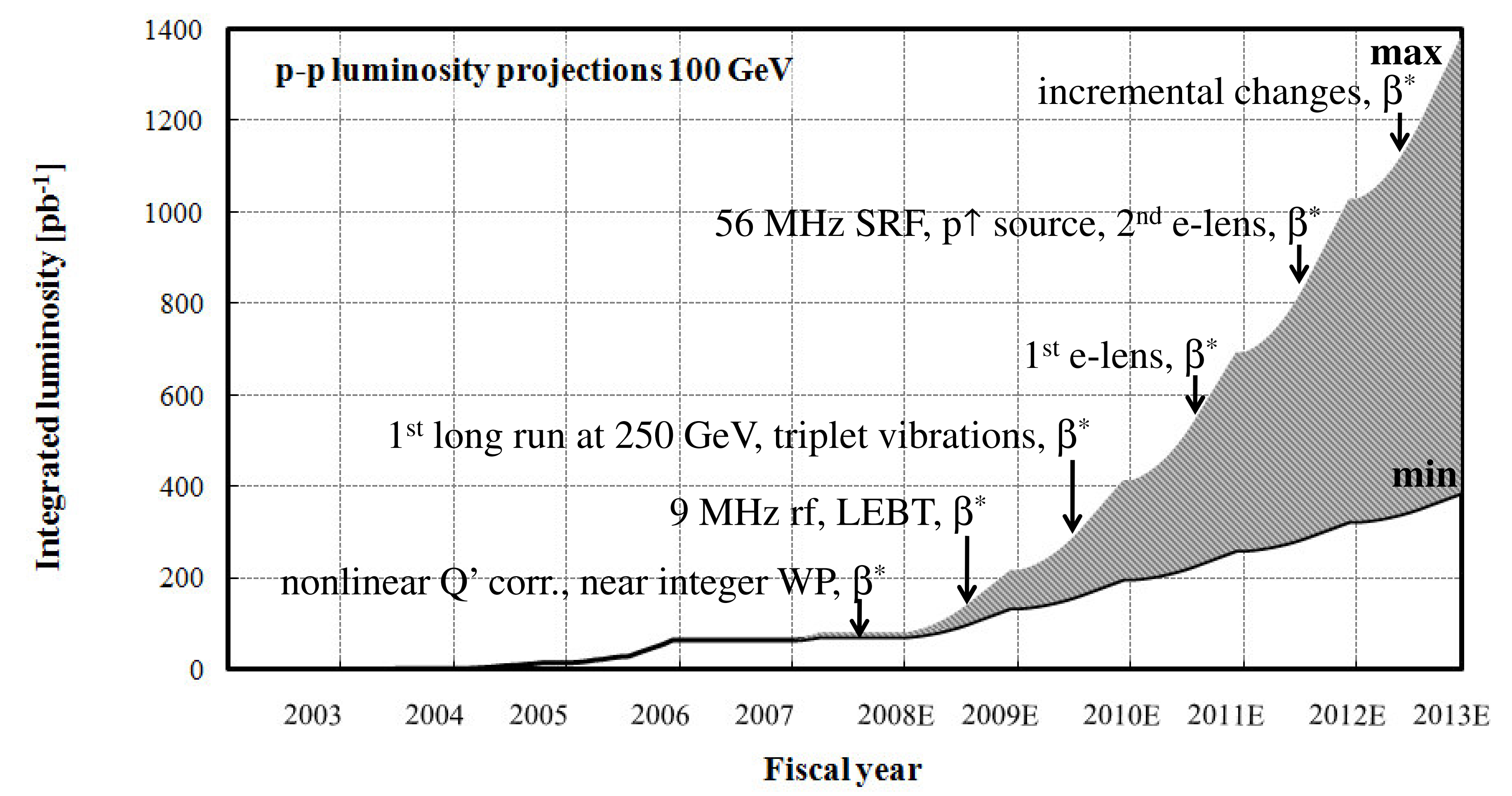
min: no performance increase max: success of all major upgrade projects



5-year projections p↑-p↑

5-year projections for p↑-p↑ luminosity assuming 12 weeks of physics in every year

min: no performance increase   max: success of all major upgrade projects



Low energy Au-Au operation – allowed energies

- Need $h = f_{rf}/f_{rev}$ divisible by 3 for any experiment to operate
- Need h divisible by 9 for both experiments to operate

h divisible by 9 → (h = 360)

Run-8 → (h = 366)

h	Allowed $\sqrt{s_{NN}}$ [GeV]	h	Allowed $\sqrt{s_{NN}}$ [GeV]
360	16.7-107	375	6.3-6.7
363	11.4-15.0	378	5.8-6.1
366	9.0-10.5	381	5.45-5.7
369	7.7-8.6	384	5.15-5.38
372	6.9-7.4	387	4.91-5.1

← Run-8 (h = 387)

[T. Satogata, RHIC Retreat 2008, BNL C-A/AP/309 (2008)]

Low energy Au-Au operation – $\mathcal{L}$ upgrade options

0. Improvements in the longitudinal emittance (AGS)

- For all options (E. Pozdeyev)

1. E-cooling in RHIC

- $\mathcal{L}$ is limited by space charge, assume space charge limit $\Delta Q_{sc} = 0.05$
- Expect 3-6× more $\mathcal{L}$ (lowest to higher γ) when operating at space charge limit with non-magnetized beam [A. Fedotov et al., C-A/AP/307]

– **With dc beam (Fermilab Pelletron)**
  - \$1.7M (direct) + \$2M (non-CAD labor), ~ 3 yrs, ~ 3-6× more $\mathcal{L}$ (low to higher γ)

– **With rf beam (56 MHz SRF gun, 703 SRF gun – under construction)**
  - \$3.6M (direct) + \$1M (non-CAD labor), ~ 3 yrs, ~ 3-6× more $\mathcal{L}$ (low to higher γ)

2. Top-off mode

– Replace 1-4 RHIC bunches every AGS cycle, beam stays in RHIC only 3-7 min
– Needs modification of RHIC injection and extraction kickers (appears feasible)
– Needs experiments to stay on during continuous refill (likely ok, test desirable)
– ~\$0.5-1.0M (not well estimated), ~ 1 yr, ~ 2-3× more $\mathcal{L}$

Summary

Run-8

- 10× larger delivered d-Au luminosity than Run-3
- With 3.5 weeks in physics, only modest (15%) increase in average p↑-p↑ luminosity, lower polarization than in Run-6

Run-9, aim for:

- ~2× larger luminosity (both Au-Au and p-p)
- Slight increase in $\mathcal{P}$ over Run-6, more stable $\mathcal{P}$ in RHIC

5-year outlook, aim for:

- 3.5× larger Au-Au luminosity
- 5× larger p↑-p↑ luminosity (excl. γ-gain, incl. lower β* at 250 GeV), $\mathcal{P}$ +10% absolute

Low energy Au-Au operation

- Demonstrated operation at 4.6 GeV/nucleon (some beam stored at 2.5 GeV/nucleon)
- Studying e-cooling in RHIC and top-off mode for $\mathcal{L}$ increase