RHIC Operation and Plans for Upgrades

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C-AD Machine Advisory Committee Meeting
10 March 2004

1. Challenges for RHIC operation
2. Enhanced luminosity goals
3. Run-4 statistics
4. Luminosity limitations
5. Summary

1. More flexibility than at other hadron colliders
   - Variation in particle species, also asymmetric
     - → So far Au+Au, d+Au, p+p, others possible
   - Variation in energy
     - → Au+Au at 10, 66, 100 GeV/u
     - → p↑ +p↑ at 100 GeV (250 GeV planned in year after next)
   - Variation in lattice
     - → Low β* in most cases (1-3 m)
     - → Large β* for small angle scattering experiments (>10 m)
     - → Polarity change in large experimental magnets about every 2 weeks
2. Four experiments (2 large, 2 small), different preferences
   - Need to avoid that any one experiment becomes bottleneck
3. Short runs (~30 weeks/year), with multiple modes
   - Significant amount of set-up time required
4. Short luminosity lifetime with heavy ions (~ few hours)
   - Fast refills essential

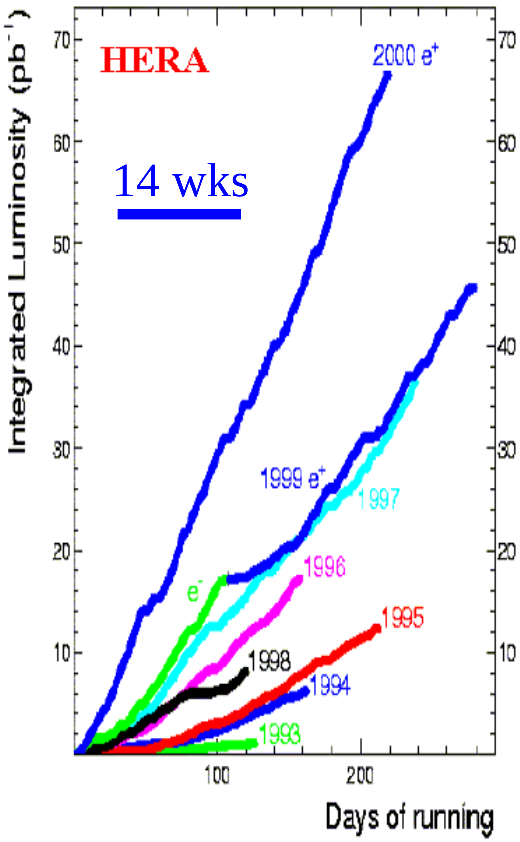
Heavy ion and polarized proton program until 2008:

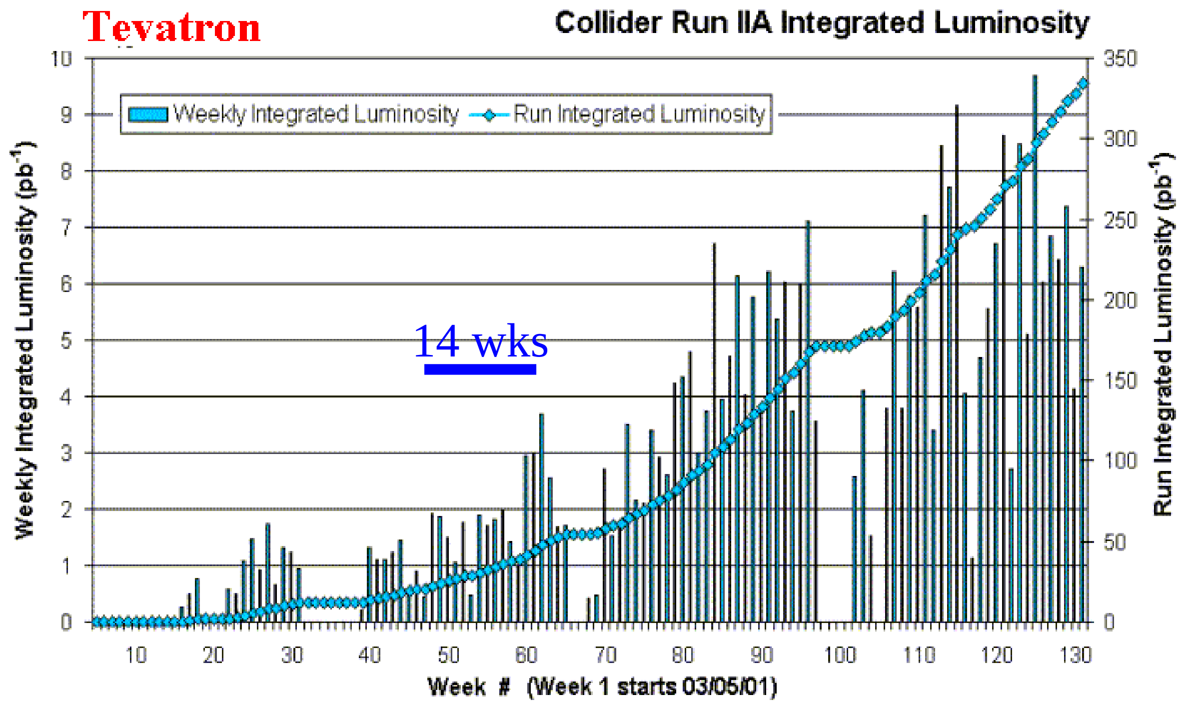
Heavy Ions	Physics Data Goals for Experiments
1.	A 200 GeV Au Au run (>300 μb^{-1}) in 2004 to follow-up on high p_T results, and get the first sizeable sample of J/ψ.
2.	Energy scan run: Au Au at 1 or 2 lower energies. 50-100 μb^{-1} total
3.	Species scan run: 1 – 2 lighter ions at 200 GeV. 3-6 nb^{-1} total
4.	A long Au Au run at 200 GeV in 2007 or 2008, with upgraded detector capability for open charm and particle i.d. at high p_T (≥2000 μb^{-1})
Polarized Protons	
1.	15-20 weeks of "development" in 2004 – 2005 (this would include physics data, but is required primarily to get the luminosity and polarization up to required levels).
2.	Full-capability spin data at 200 GeV. ≥150 pb^{-1}

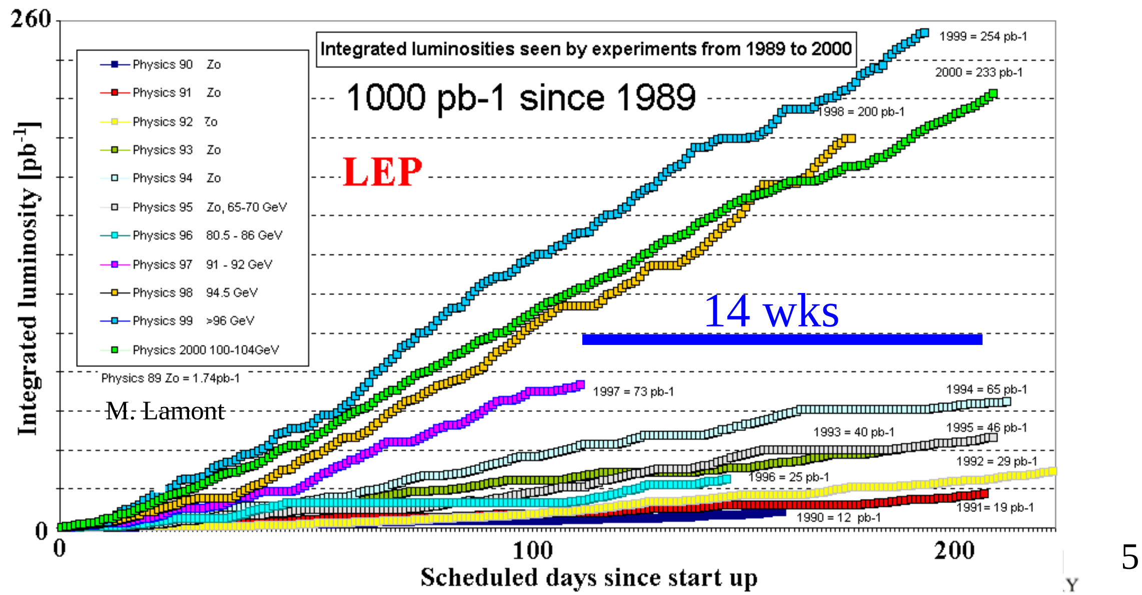
current Run ← (row 1)

Table 1. Minimal running requirements for the period 2004 – 2008: Note that the sample sizes indicated here are for delivered integrated luminosities. The actual recorded data samples used in physics analysis will be smaller by factors of 2-3.

RHIC Planning Group, "Twenty-Year Planning Study for the Relativistic Heavy Ion Collider Facility at Brookhaven National Laboratory", BNL-71881-2003 Informal Report (2003).







Common features

- long runs (>14 wks/yr)
- non-linear increase after shut-downs
- many years for substantial increases

RHIC is of comparable complexity

- **Enhanced Luminosity Goals**
  (before e-cooling, about to be reached when RSVP starts, 2008)

  – For Au-Au, average per store, 4 IRs
  $L = 8\cdot 10^{26} cm^{-2}s^{-1}$ at 100GeV/u

  4× design
  2× achieved

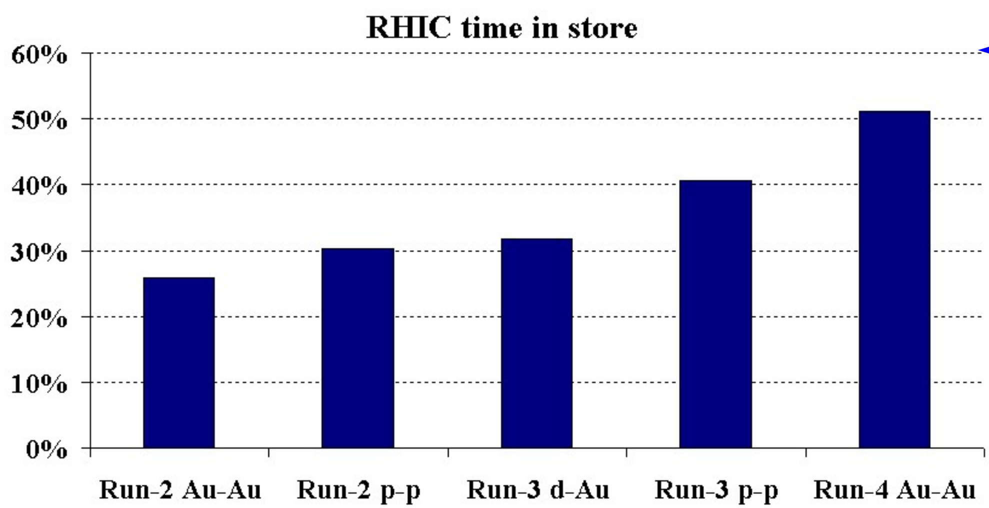
  – For p↑ -p↑ average per store, 2 IRs
  $L = 6\cdot 10^{31} cm^{-2}s^{-1}$ at 100GeV
  $L = 1.5\cdot 10^{32} cm^{-2}s^{-1}$ at 250GeV
  with **70% polarization**

  16× design
  10× achieved

Achieved parameters

Mode	No of bunches	Ions/bunch [10^9]	β* [m]	Emittance [μm]	$\mathcal{L}_{peak}$ [$cm^{-2}s^{-1}$]	$\mathcal{L}_{store\ ave}$ [$cm^{-2}s^{-1}$]	L_{week}
Au-Au [Run-4]	45	1.1	1	15-40	15×10^{26}	5×10^{26}	169 μb^{-1}
d-Au [Run-3]	55	110/0.7	1	15	12×10^{28}	3×10^{28}	4.5 nb^{-1}
p↑ -p↑ [Run-3]	55	70	1	20-30	6×10^{30}	3×10^{30}	0.6 pb^{-1}
Au-Au design	56	1	2	15-40	9×10^{26}	2×10^{26}	50 μb^{-1}
p-p design	56	100	2	20	5×10^{30}	4×10^{30}	1.2 pb^{-1}
p↑ -p↑ design	112	200	1	20	80×10^{30}	65×10^{30}	20 pb^{-1}

[best store or week]



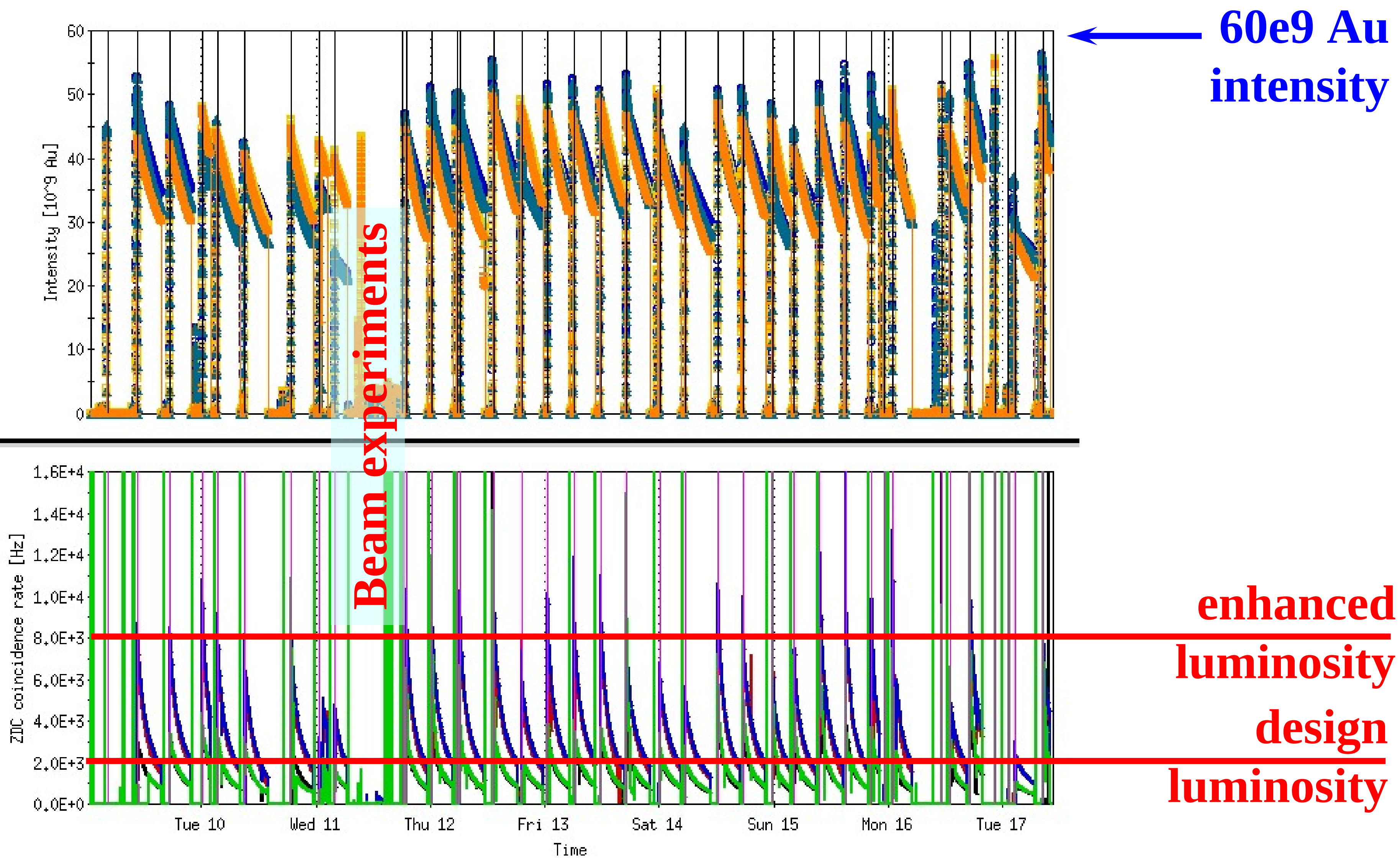
target

[incl. beam experiments and maintenance]

- 2 weeks for cool-down, 1 week for warm-up
- For each mode (Au-Au, p↑ -p↑ , d-Au, etc.)
  - 2 weeks of start-up
    [machine operation 24h/day]
  - 3 weeks of ramp-up
    [machine operation 16h/day, experimental set-up 8h/day]
  - Continuous luminosity development in production
    [up to 8h/day, until no further progress is possible]
- 11h/wk beam experiments, 6h/wk maintenance

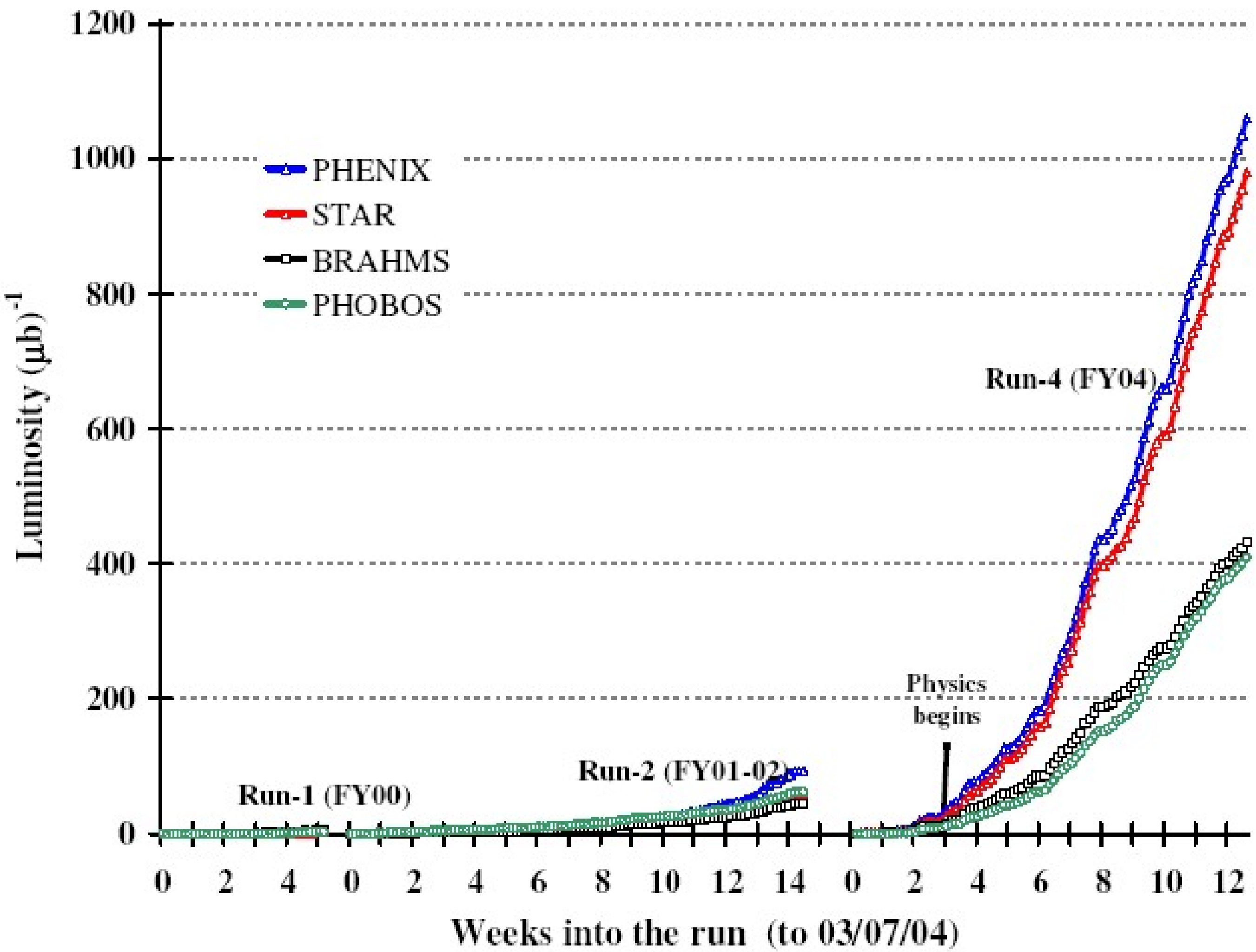
Assumptions under review:
→ Cool-down faster in Run-4
→ Needed only 4 weeks for start-up and ramp-up in Run-4
→ Potential for another week of saving in the next few years

Week 9 Feb to 17 Feb [66% of calendar time in store]



Delivered 1060 $(\mu b)^{-1}$ to Phenix
169 $(\mu b)^{-1}$ best week

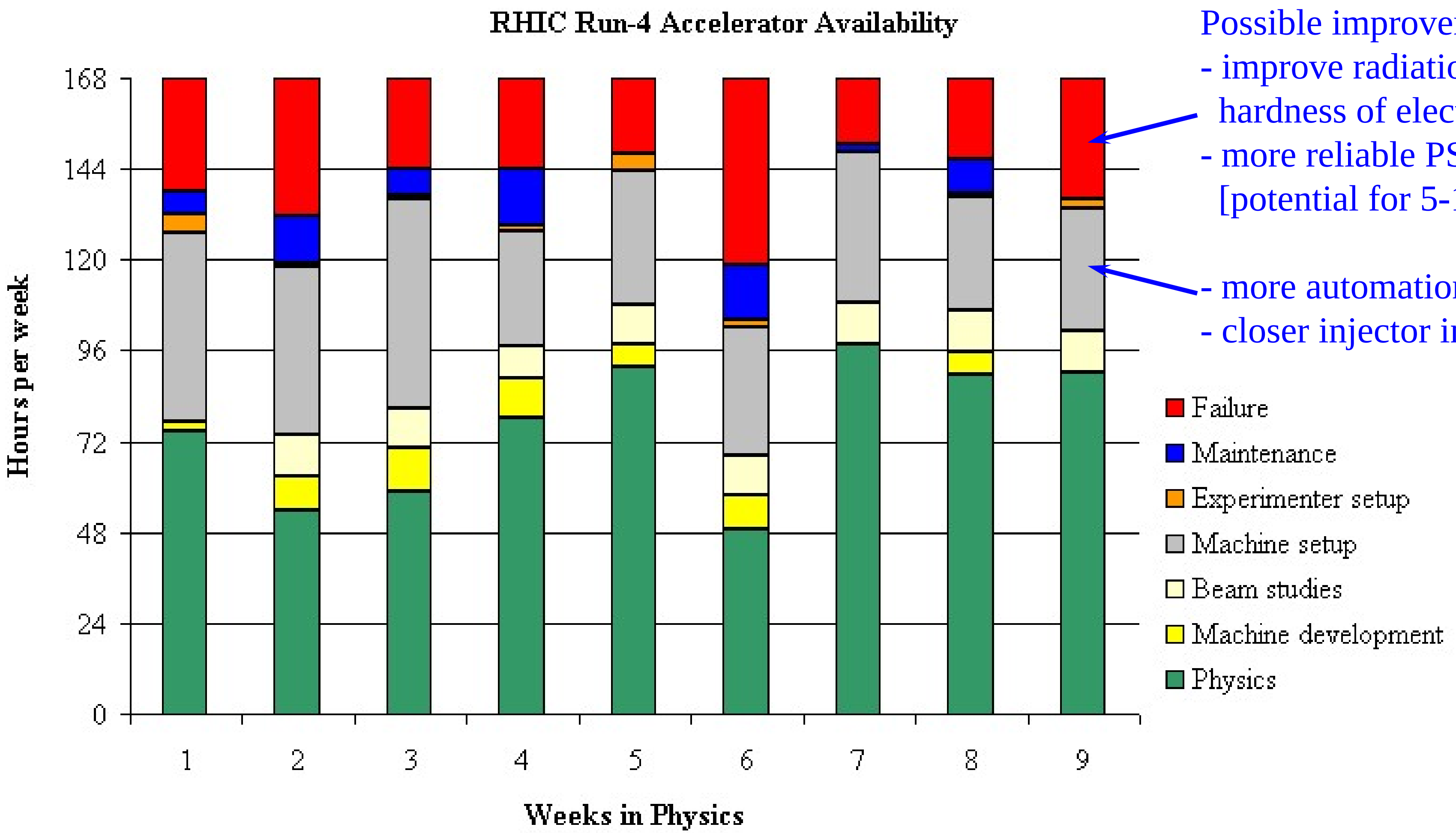
As of 03/07/04 24:00
Star × 0.9
Phobos × 0.3
Brahms × 0.4



maximum projection

physics target

minimum projection



Possible improvements:
- improve radiation hardness of electronics
- more reliable PS [potential for 5-10h/wk]

- more automation
- closer injector integration

1. Bunch intensity increases
   → More consistent injector performance (J. Alessi, L. Ahrens, K. Zeno, …)
   → Extra bunch merge in Booster (M. Brennan, M. Blaskiewicz, …)
2. Collimation
   → Secondary collimators in both rings (A. Drees, …)
3. Shielding
   → More shielding at Phenix and Brahms (K. Yip, C. Pearson, …)
4. Vacuum
   → More baking, NEG coated pipes for tests (D. Hseuh, S.Y. Zhang, …)
5. Reduced failures, recovery and maintenance time
   → Less quenches, less abort kicker pre-fires, no ice balls on current leads, faster down ramps, less corrector failures, AtR cooling, …
   (M . Bai, G. Ganetis, D. Bruno, L. Ahrens, J. Sandberg, A. Zhang, A. Pendzick, …)
6. More automation
   → Elog entries, injection set-up, orbit correction after every ramp, steering for luminosity maximization, collimator setting, continuous gap cleaning, …
   (J. van Zeijts, T. Satogata, W. Fischer, V. Ptitsyn, T. D'Ottavio, A. Drees, …)

Many improvements, leading to 1-30% more luminosity each

1. Vacuum (electron clouds, desorption from beam loss)
   - Vacuum instabilities
   - Experimental background
   - → Use optimized bunch patterns
   - → Installation of NEG coated pipes in warm regions
2. Intrabeam scattering (Au)
   - Leads to luminosity lifetime of a few hours
   - → Fast refills needed to increase average luminosity
   - → Ultimately need cooling at full energy (stochastic, electron)
3. Beam-Beam (p)
   - Limits number of experiments to 2 (out of 4)
   - → Possibly new working point
4. Instabilities
   - Vulnerable near transition (short bunches, no ξ -jump)
   - → Good chromaticity control on ramp, octupoles for transition crossing

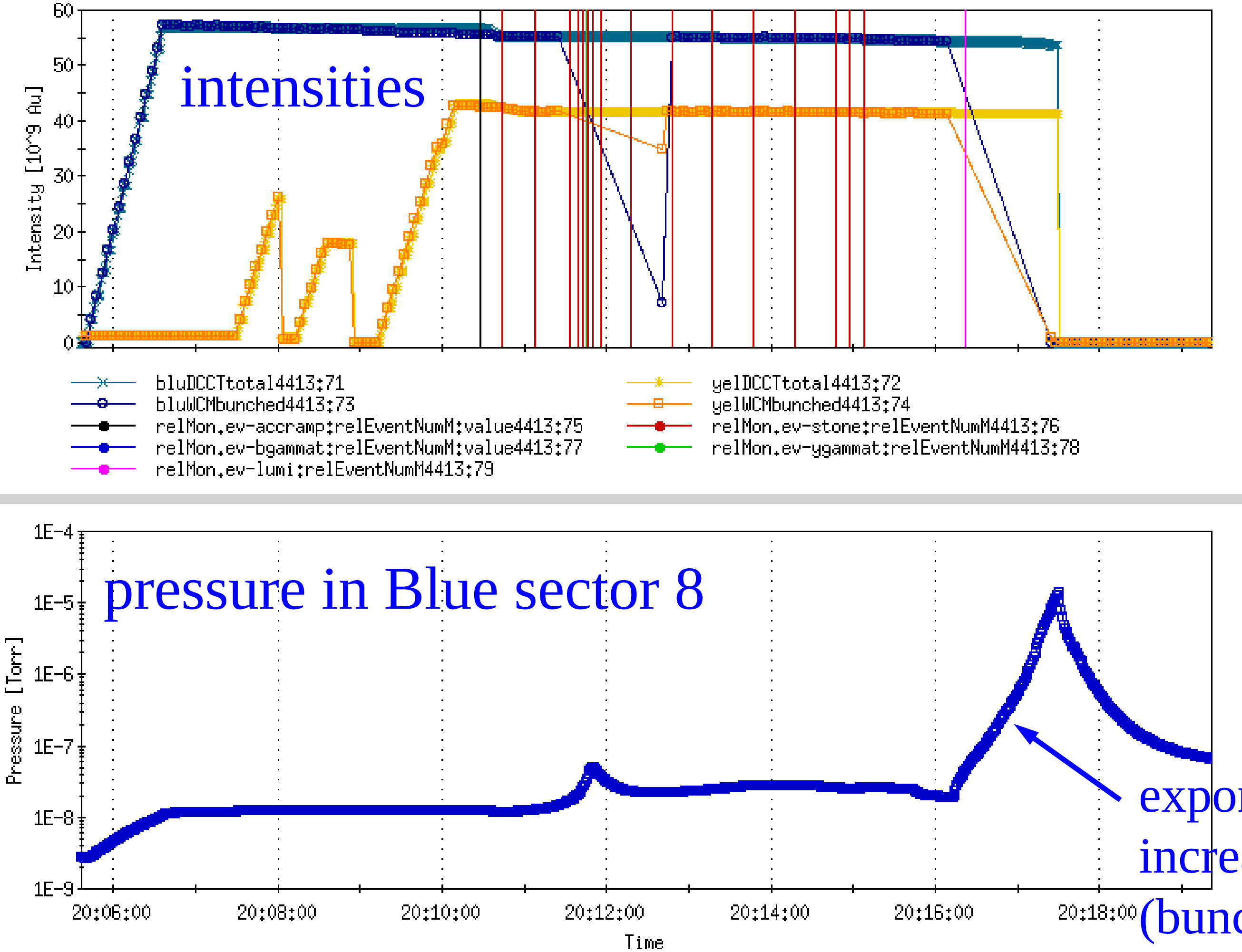
$$\mathcal{L} \propto N_{bunch}\, N_{Blue} N_{Yellow}$$

1. Maximize bunch intensity N_{Blue}
2. Maximize bunch number N_{bunch} for Blue
   (until Blue vacuum breaks down in sector 8, after rebucketing)
3. Determine max Yellow bunch intensity N_{Yellow} for N_{bunch}
   (unit Yellow vacuum breaks down in sector 4, after rebucketing)
4. Reduce bunch number
   (until Phobos background problem becomes acceptable)
5. Adjust bunch number if available bunch intensity changes
   (store-by-store if needed)
6. Optimize store length to maximize average luminosity

→ Machine runs close to 4 limits simultaneously

[bunch intensity, Blue vacuum, Yellow vacuum, Phobos background]

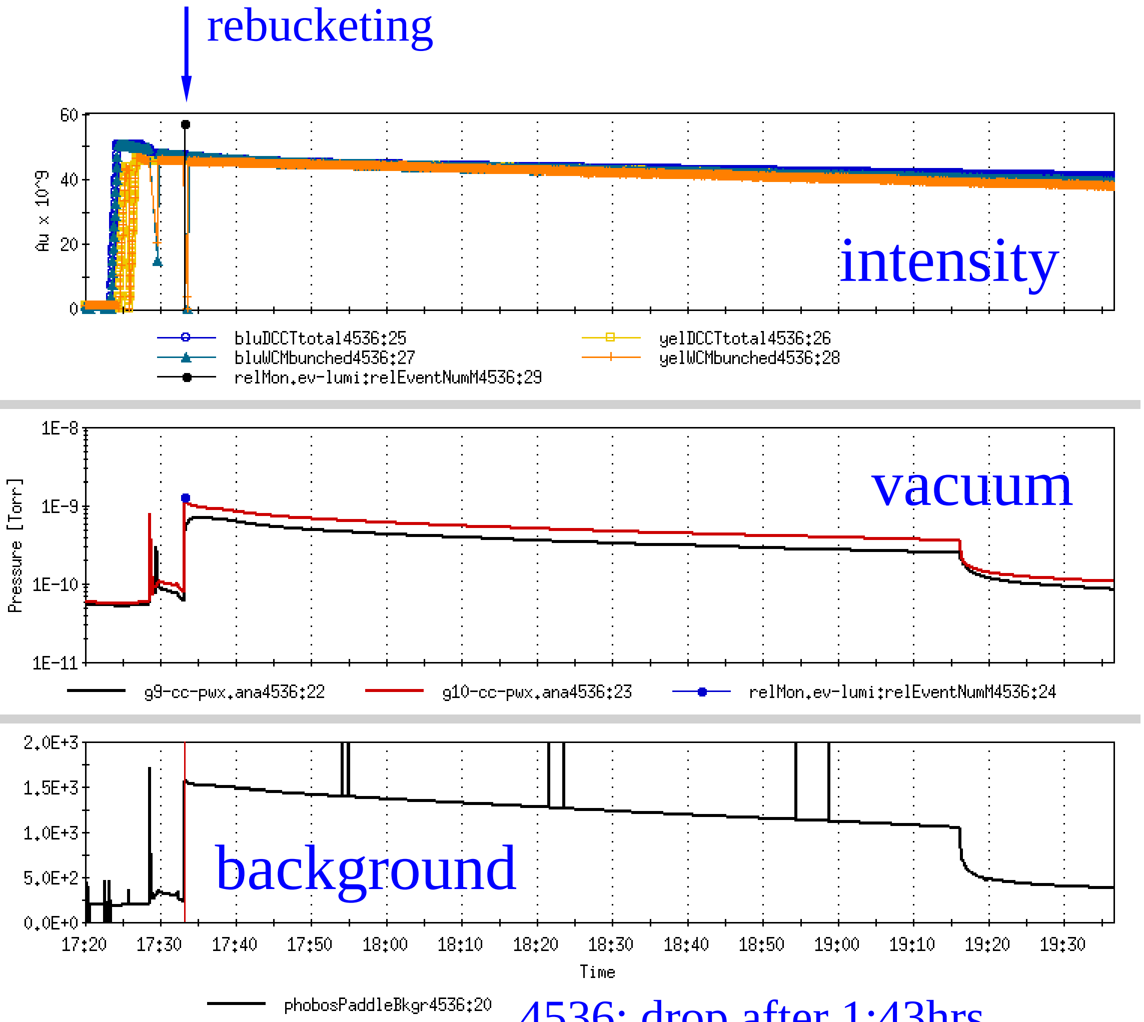
- Beam intensities in both rings are limited by vacuum instabilities
- Machine operates as closely as possible at these limits



exponential pressure increase after rebucketing (bunch length shortened)

PHOBOS background increase after rebucketing, drops after minutes to 2 hours

→ Some relieve from reduction of bunch number

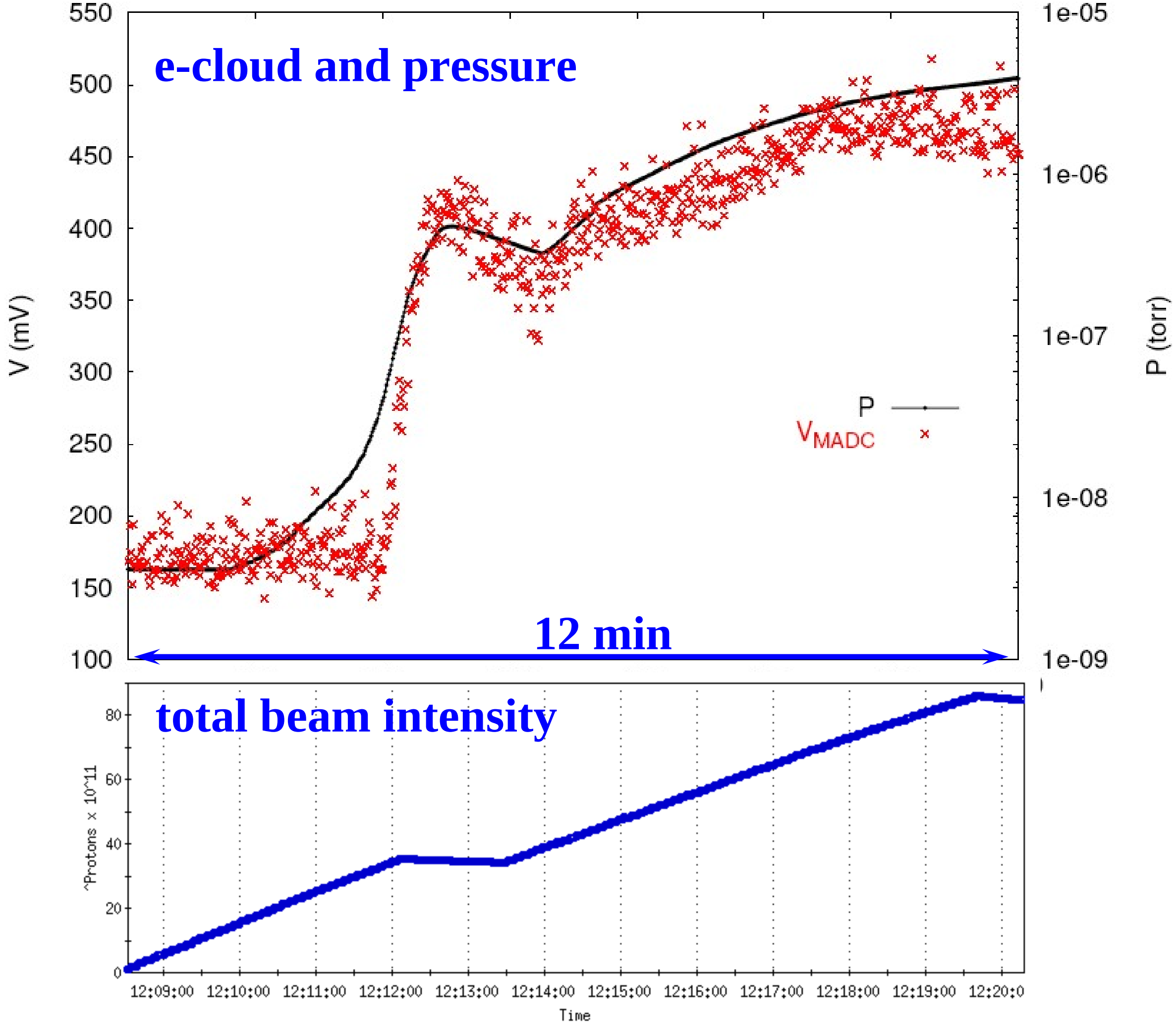


4536: drop after 1:43hrs

Electron cloud and pressure rise

$86 \cdot 10^{11}$ p^+ total, $0.78 \cdot 10^{11}$ p^+/bunch, 110 bunches, 108 ns spacing

U. Iriso-Ariz



Clear connection between e-cloud and pressure at injection

Estimate for η_e assuming pressure caused by e-cloud: 0.001-0.02

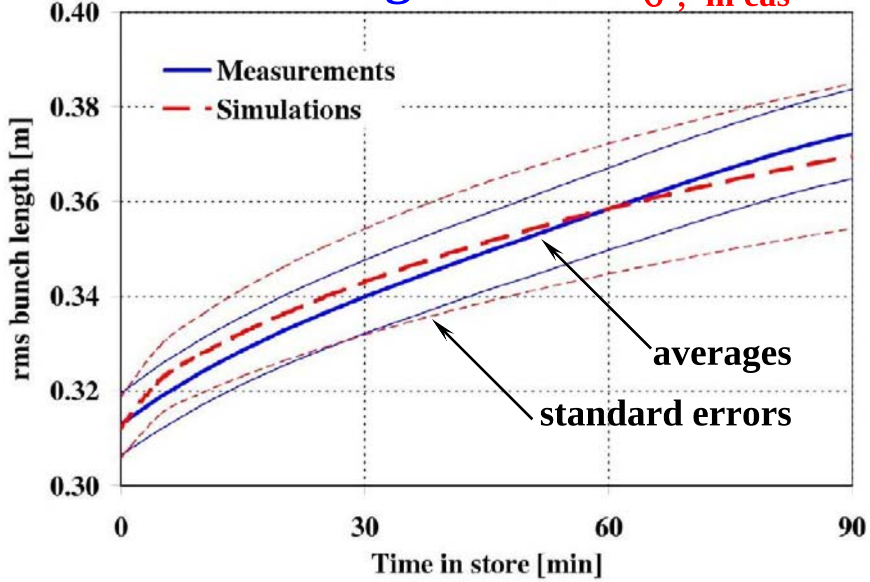
(large error from multiple sources)

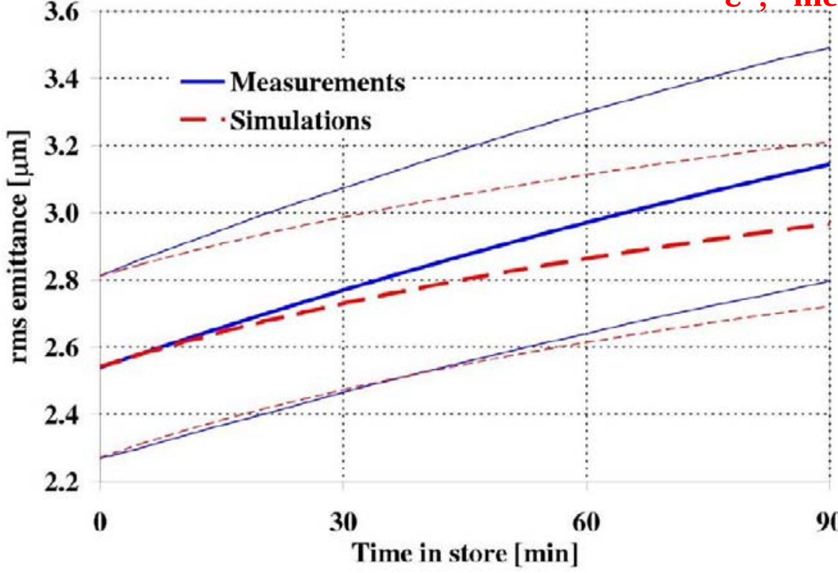
[U. Iriso-Ariz et al. "Electron cloud observations at RHIC during FY2003", in preparation.]

- In-situ baking (>95% of 700m/ring warm pipes baked)
  → Occasionally installation schedules too tight
- Solenoids (only against e-clouds)
  → Tested last year, installed near Yellow limit
- NEG coated pipes
  → Installed last shut-down for test purposes
  → Few hundred meters next shut-down, experiments
- Bunch patterns (only against e-clouds)
  → Tested last year
  → Implemented flexible bunch patterns for operation
- Scrubbing
  → Tested last year
  (concerns due to electronics in ring – BPMs, experiments)

[Run-2 data]

Bunch length σ $\tau_{\sigma,\ meas} \approx$ 8h **Transverse emittance ε** $\tau_{\varepsilon,\ meas} \approx$



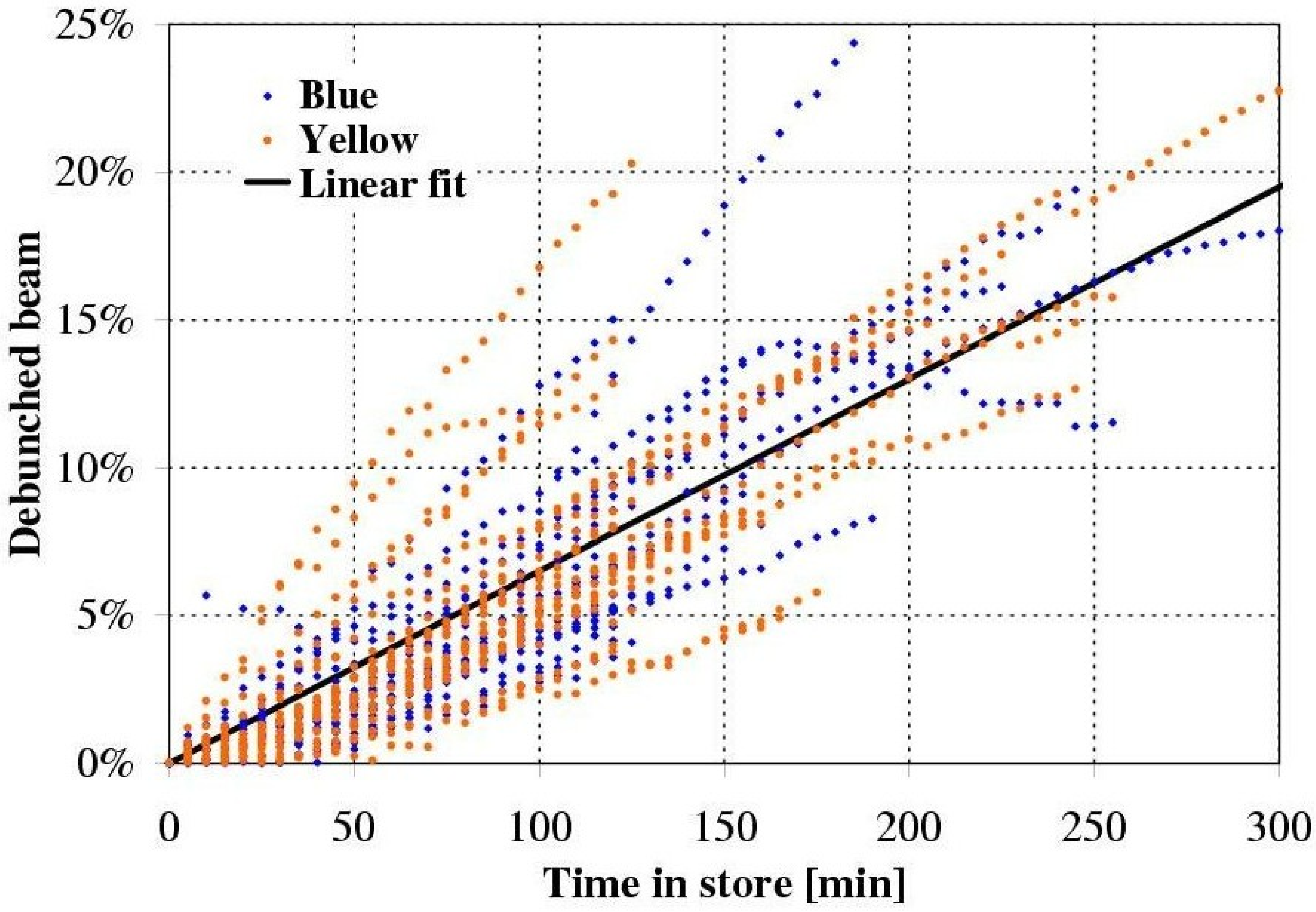


After 90 min	Δσ/σ	Δε/ε
Measured Au	20%	24%
Computed Au	18%	17%
Measured p		5%

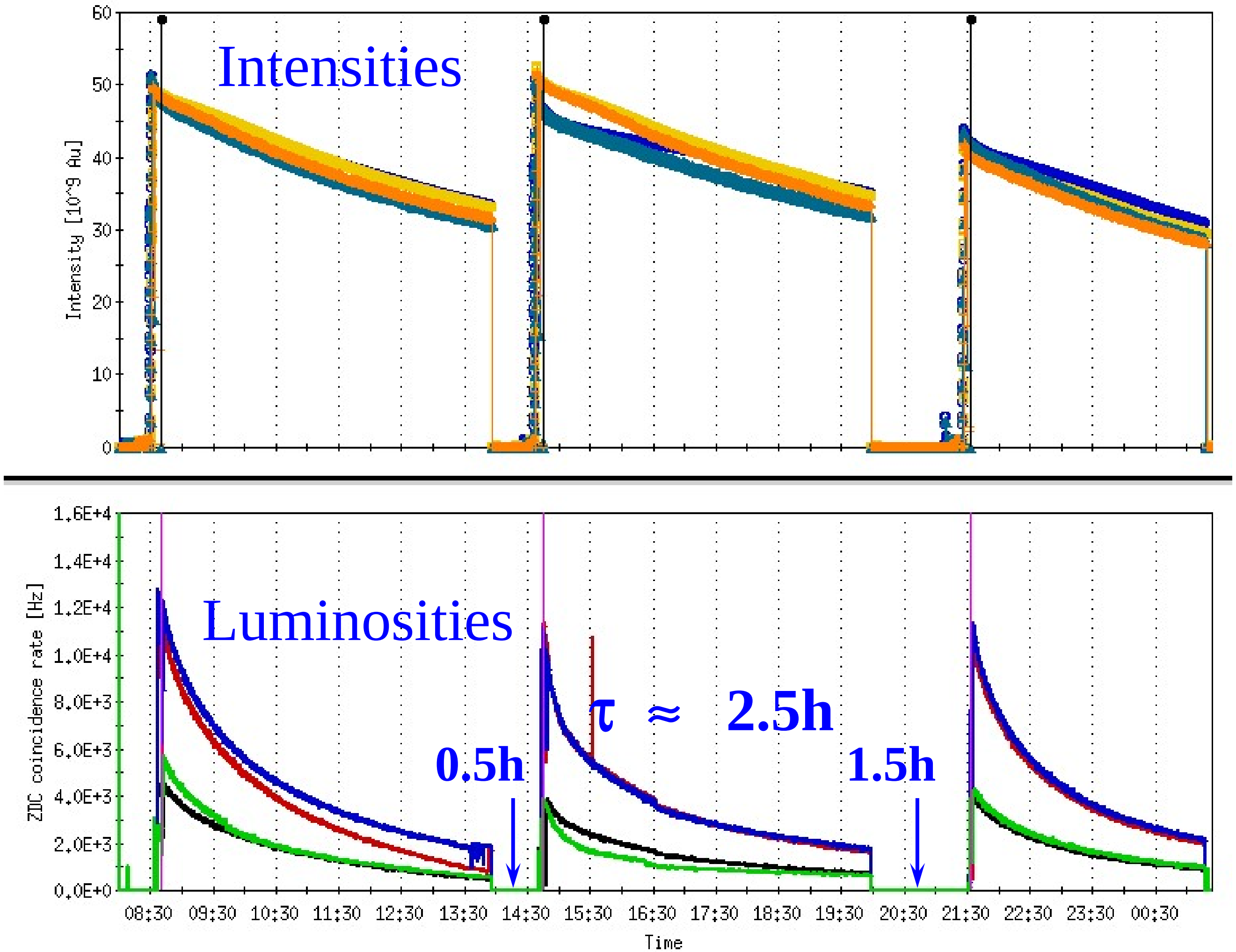
- IBS growth rates smaller by factor 10
- Beam-beam stronger by factor 2

[Run-2 data]

Au^{79+} stores, β^*=5m, N_b=0.25…0.4 · 10^9/bunch, storage rf system



20% of beam debunched after 5 hours



- Debunching requires continuous gap cleaning (tune meter)
- Luminosity lifetime requires frequent refills
- Ultimately need cooling at full energy (later presentations)

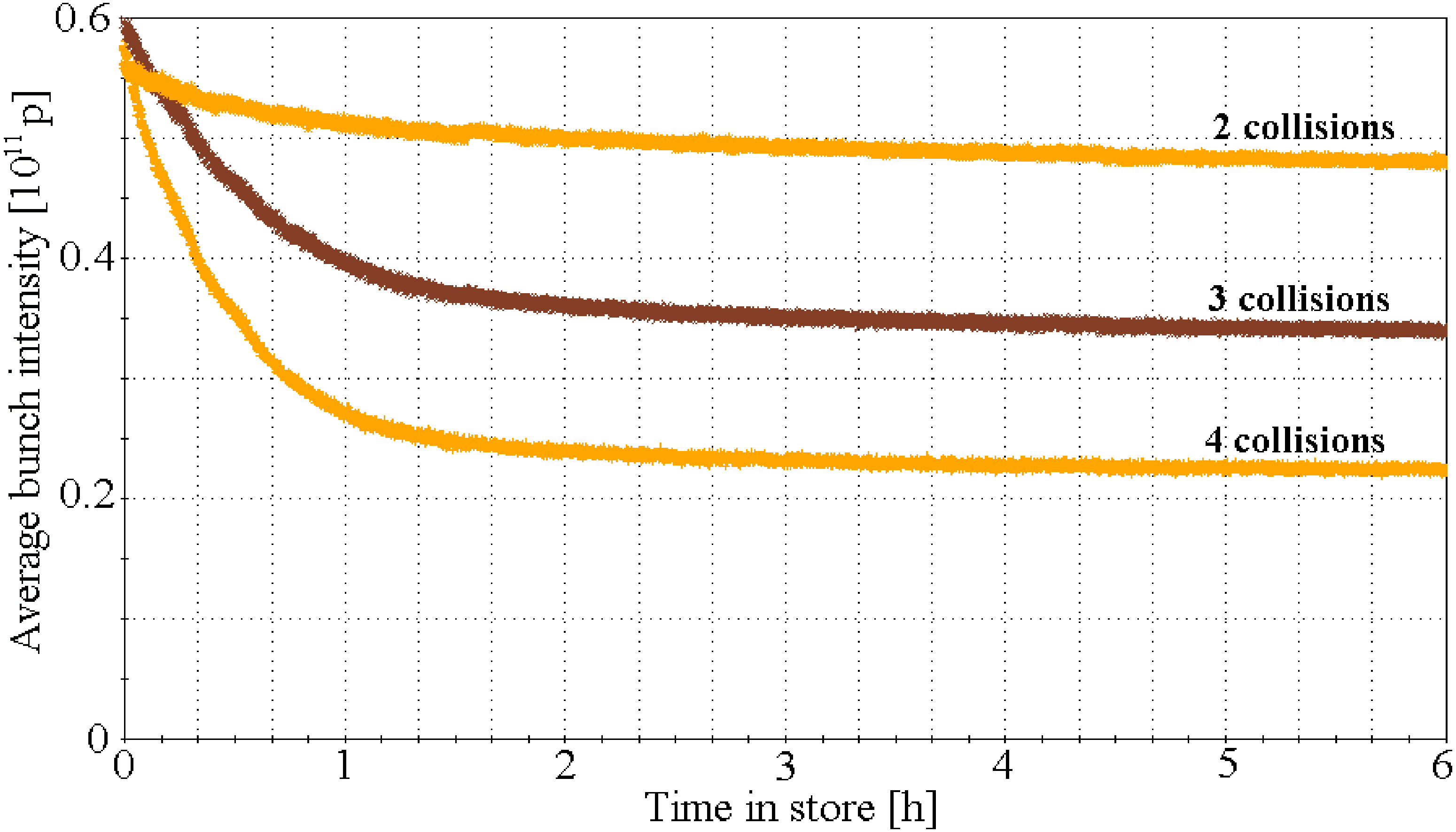
	ISR	SPS	Tevatron Run I	HERAp	RHIC* pp 2003	RHIC pp goal	LHC
Bunches per beam	coasting	3	6	174	55	111	2808
Experiments	6	2	2	2	4	2	4
Parasitic interactions		4	10	—	—	—	120
beam-beam ξ / IP	0.001	0.009	0.008	0.0007	0.004	0.007	0.003
Total bb tune spread, max	0.008	0.028	0.024	0.0014	0.015	0.015	0.010

* Numbers for ε_N=15μm and N_b=0.7 10^{11}

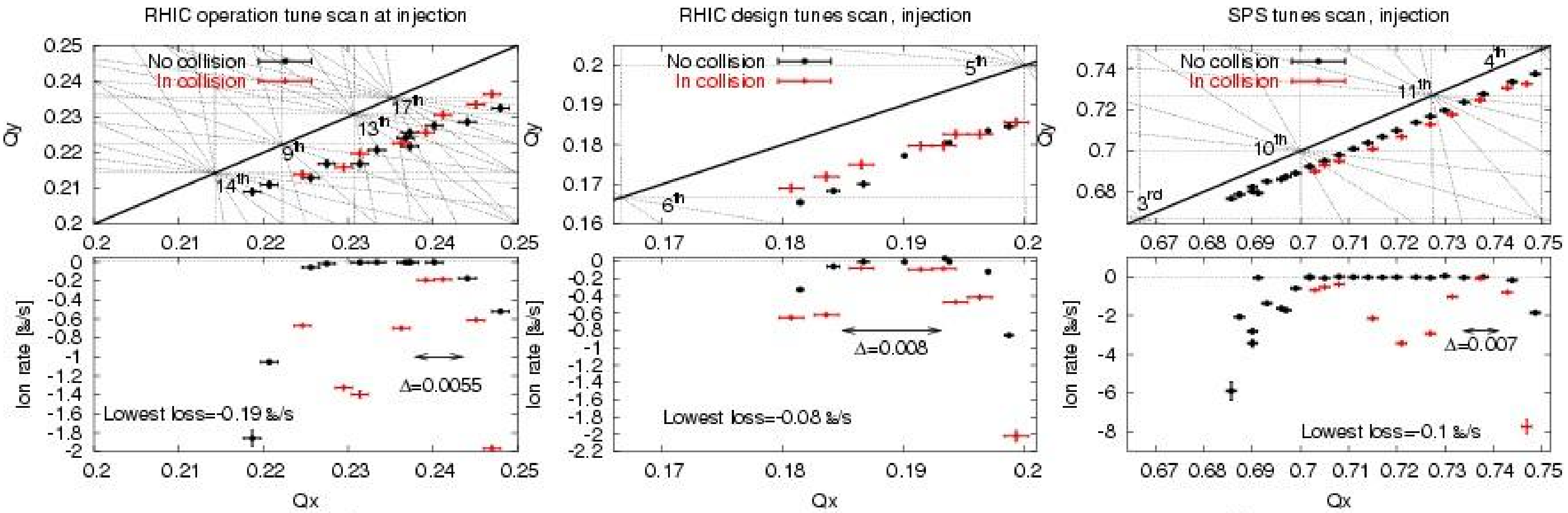
Sources: W. Schnell PAC75, W. Herr, V. Shiltsev, C. Montag

- Total tune spread from beam-beam in proton operation with ε_N=20μm (95%) and N_b=2·10^{11} will be as large as the maximum achieved in any past hadron collider
- Unlike past hadron colliders (weak-strong except ISR), RHIC operates in a strong-strong regime (no operational limit so far)

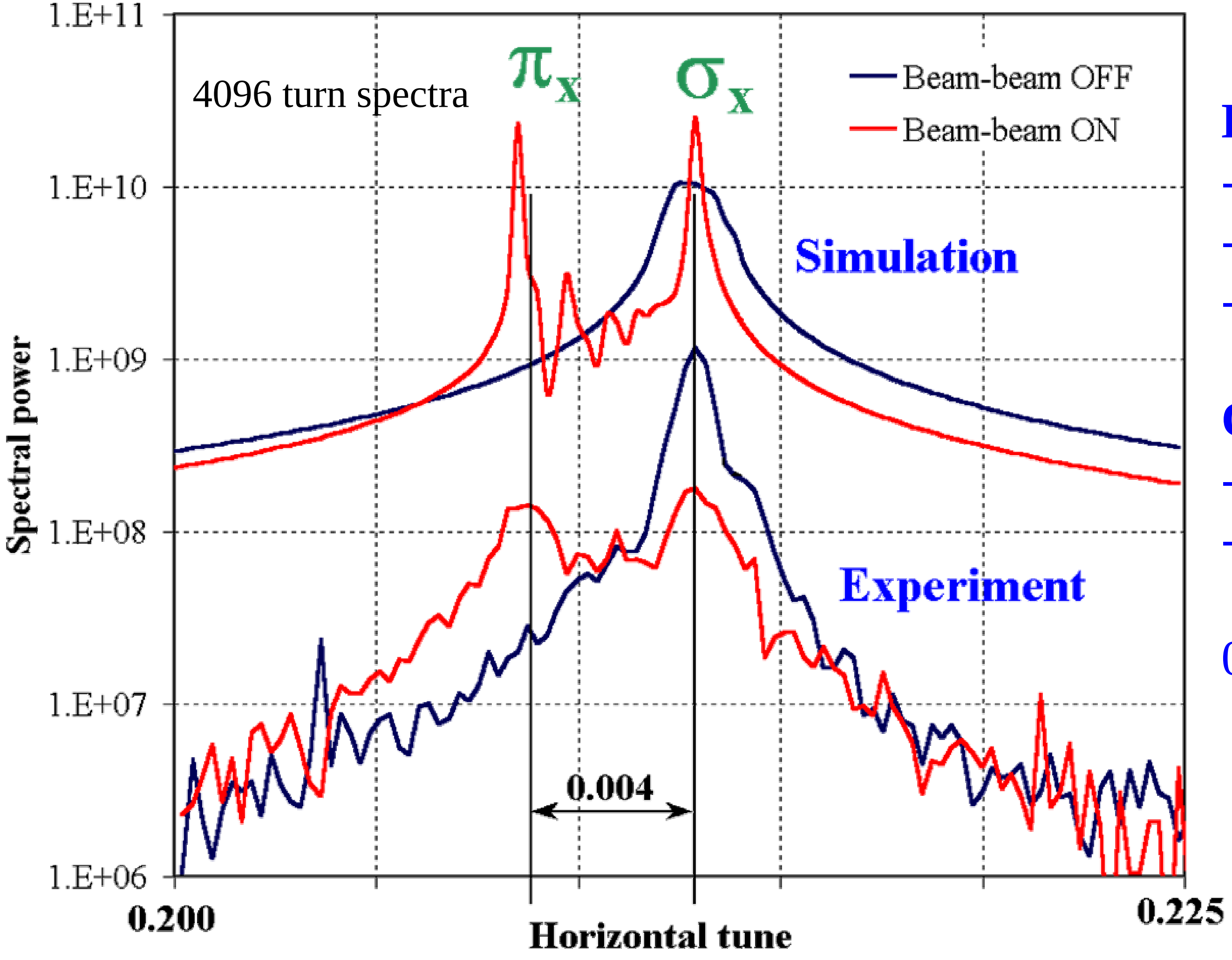
Beam lifetime with different number of collisions, ξ =0.003/IP
(due to abort gaps some bunches see only 2 or 3 collisions per turn)



Quest for a new working point in RHIC



- RHIC design tunes show the least beam-beam effect but are hard during the ramp
- Single particle simulations with beam-beam (Au) at store still show similar performances for the candidates.
- More single and multi-particle simulations are being performed.



Experiment:
- single p bunch/ring
- ξ **= 0.003**
- $|Q_{x,B}-Q_{x,Y}| < 0.001$

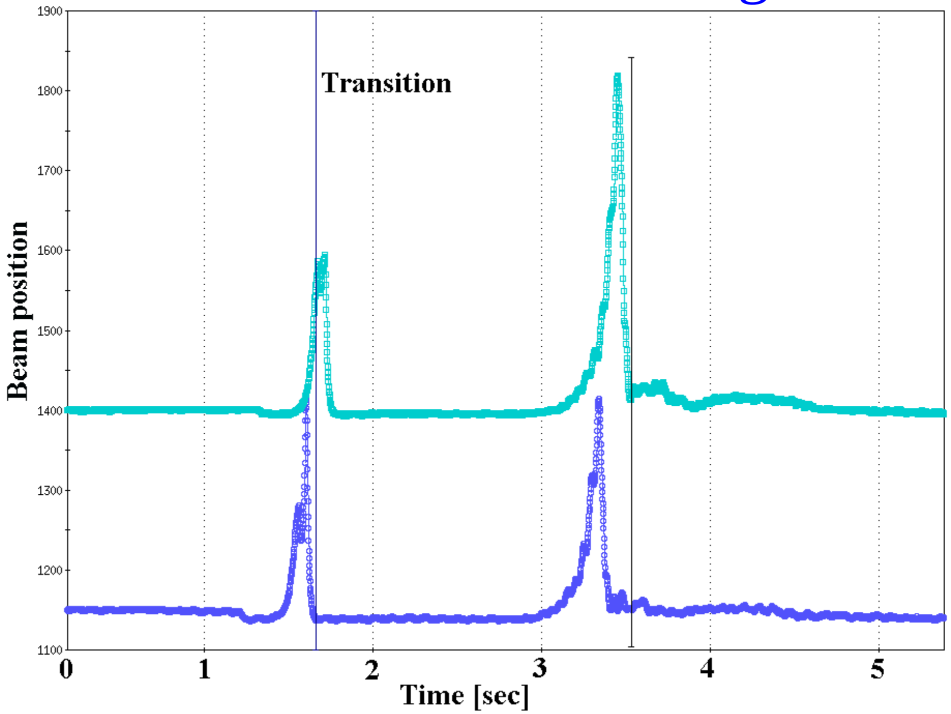
Observation:
- π_x-mode shift: 0.004
- expectation: $1.21 \cdot \xi = 0.0036$

[Yokoya, Meller, Siemann]

Coherent beam-beam modes observable, no operational problem so far

[Simulation: M. Vogt et al., DESY, "Simulations of coherent beam-beam modes at RHIC", EPAC02]

Coherence monitor signal



Use of coherence monitor [R. Michnoff]
lead to 10-15% higher integrated luminosity.

Coherent beam motion observable near transition (and other places)

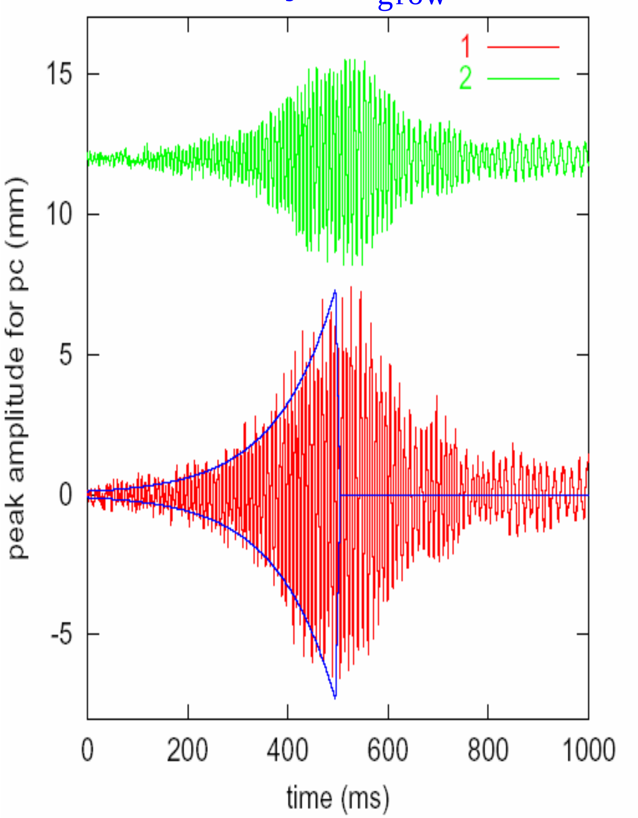
→ Leads to emittance growth and luminosity reduction

→ Requires feedback (not yet) or tune spread (earlier beam-beam, now octupoles)

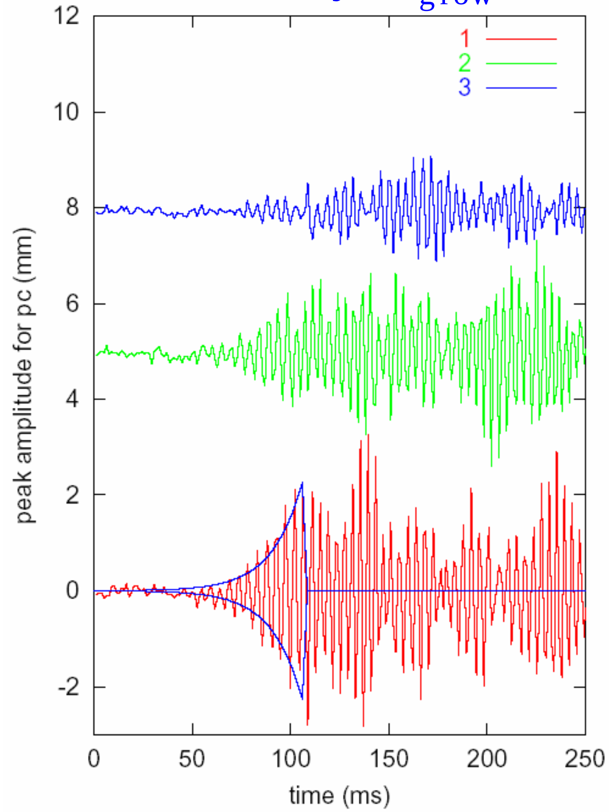
→ Large tune spread requires good tune control (tune feedback)

→ Tune feedback requires decoupling on ramp

Slow instability: $\tau_{grow} \sim 100$ ms



Fast instability: $\tau_{grow} \sim 15$ ms



Head-tail: only γ and no ξ jump leads to wrong chromaticity at some point.

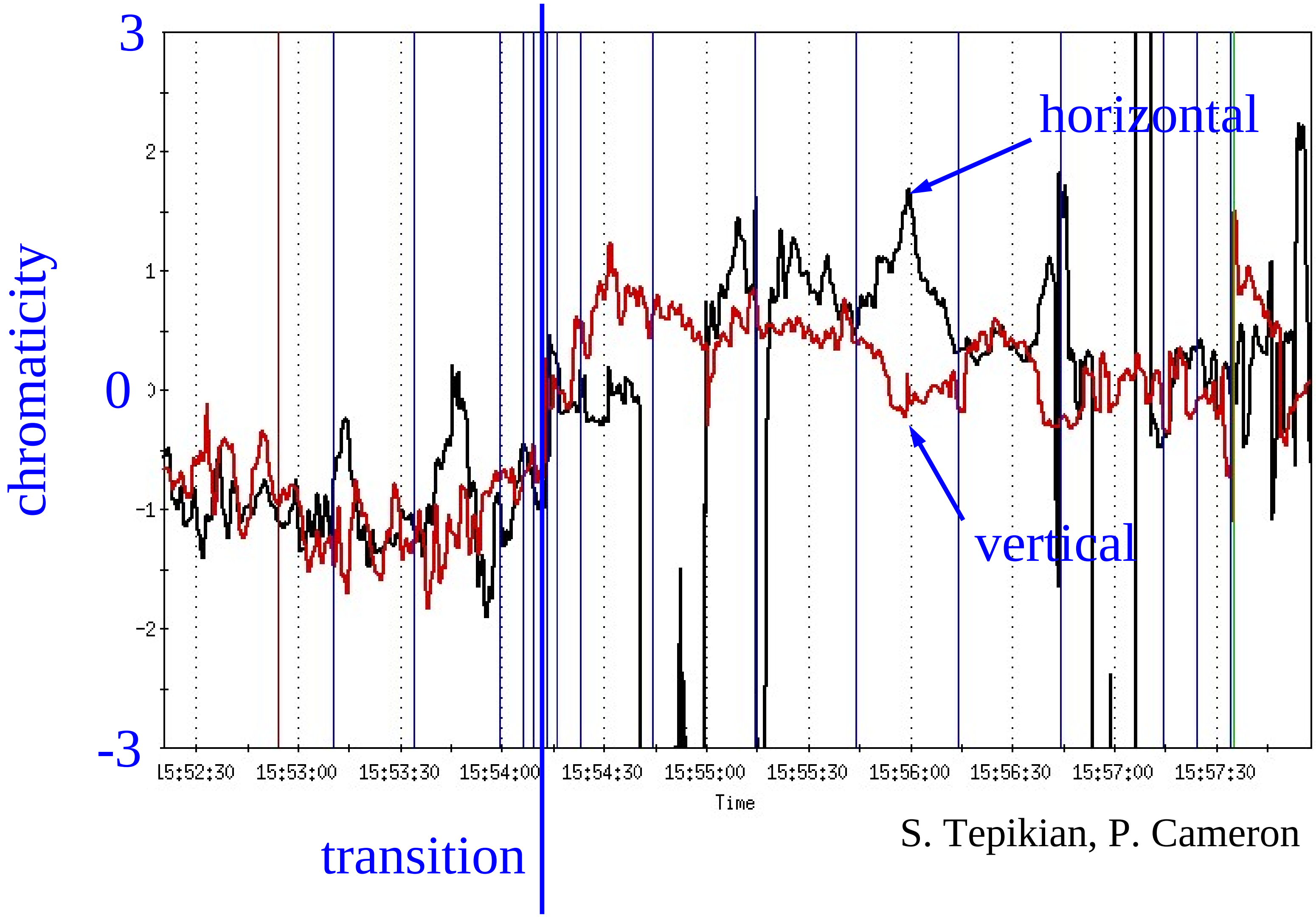
Not well understood.

No instabilities found when sign of ξ changed shortly before γ -jump.

M. Blaskiewicz, PAC03

Chromaticity measurement along the ramp

[PLL tune measurement with radius modulation]



S. Tepikian, P. Cameron

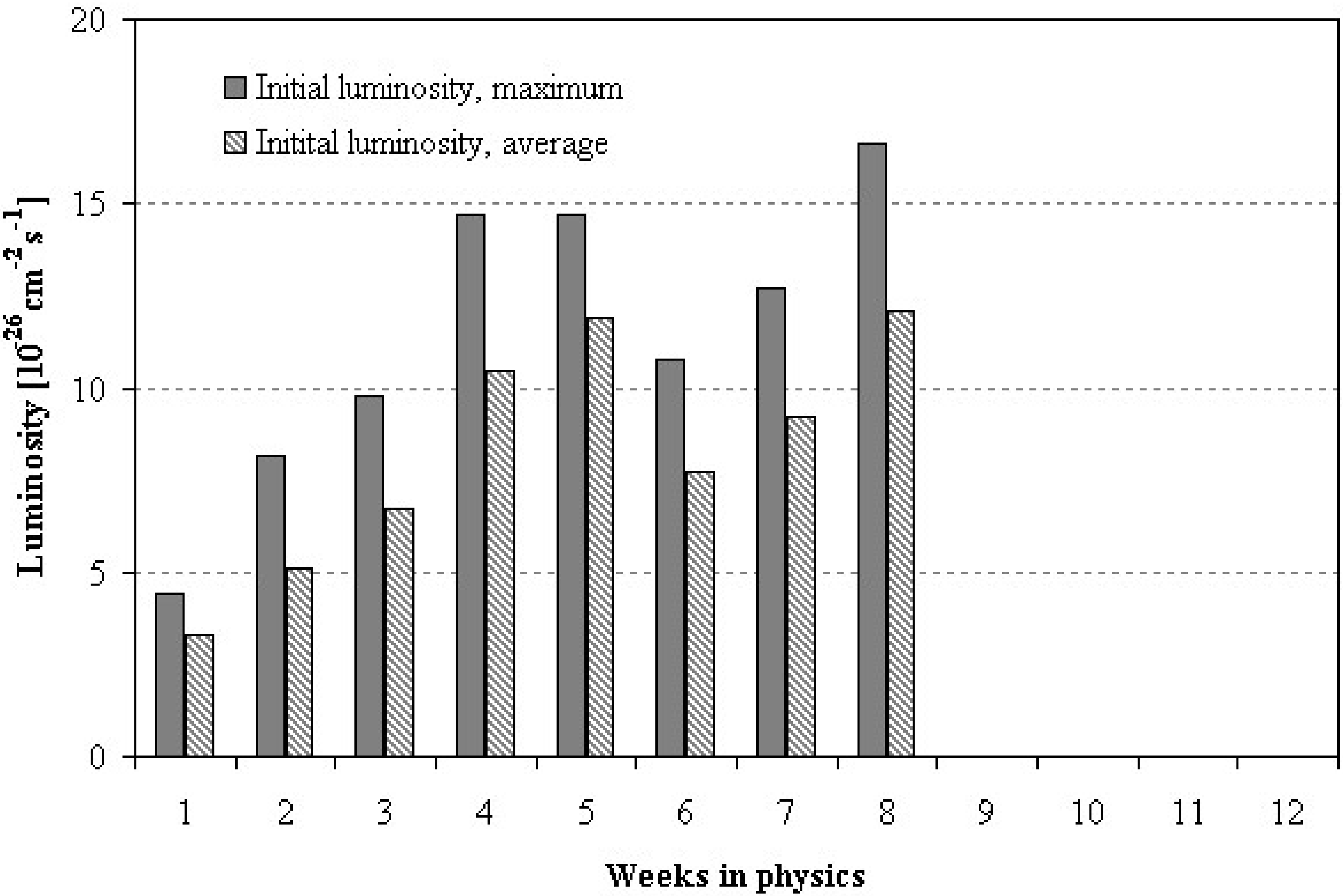
- **Enhanced Luminosity Goals** (before e-cooling)
  - For Au-Au, average per store
    $L = 8 \cdot 10^{26} cm^{-2}s^{-1}$ at 100GeV/u

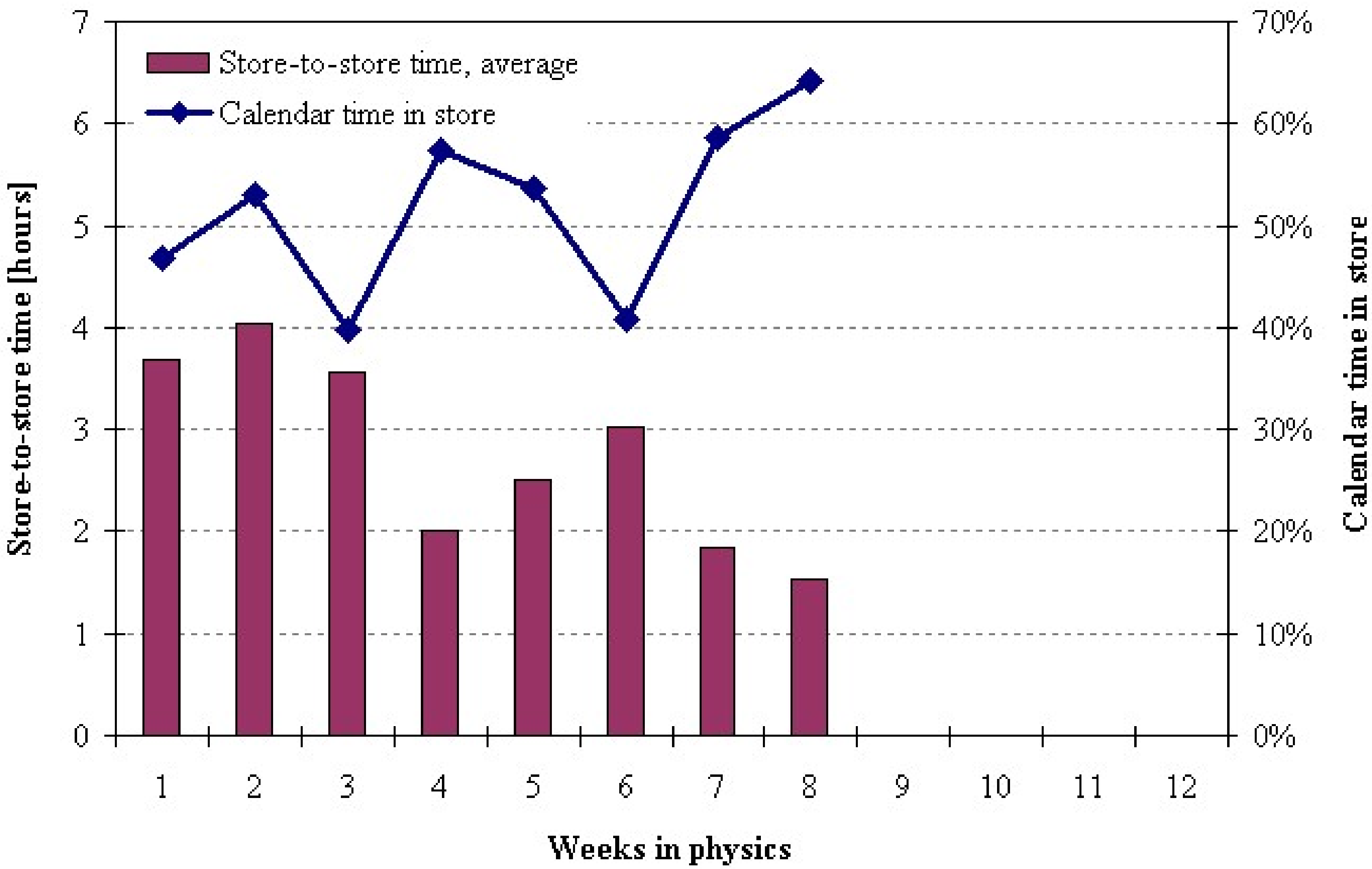
    4× design
    2× achieved
  - For p↑ -p↑ average per store, 2 IRs
    $L = 6 \cdot 10^{31} cm^{-2}s^{-1}$ at 100GeV
    $L = 1.5 \cdot 10^{32} cm^{-2}s^{-1}$ at 250GeV
    with **70% polarization**

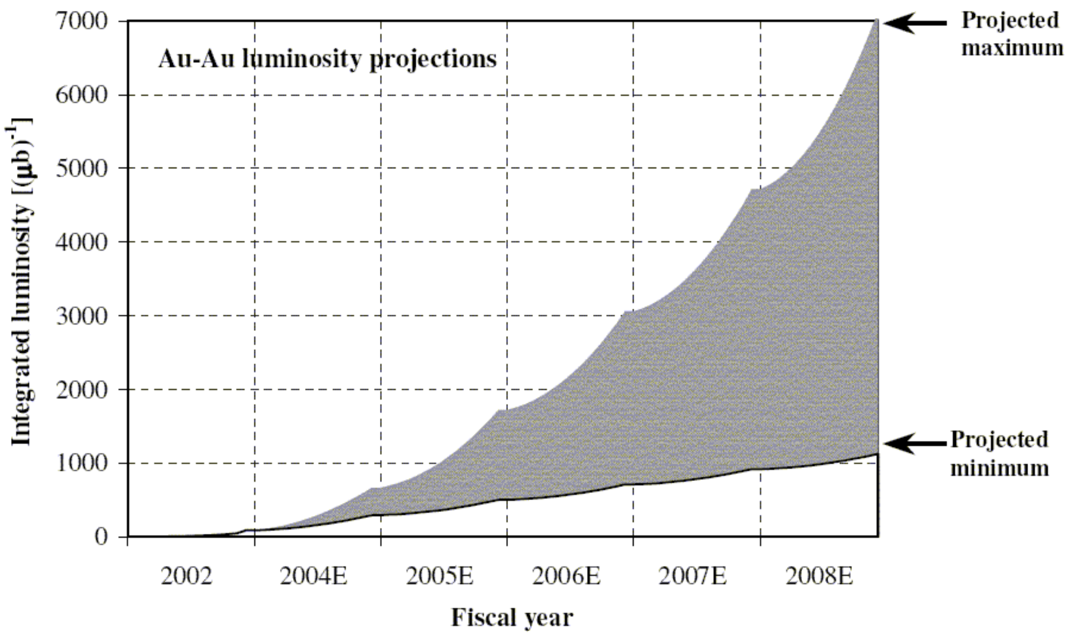
    16× design
    10× achieved

- **Work on luminosity limits**
  - Vacuum →NEG coated warm beam pipes
  - Intrabeam scattering →fast refills (later cooling)
  - Beam-beam →possibly new working point
  - Instabilities → chromaticity control, octupoles, damper

RHIC Run-4 – weekly statistics (1)



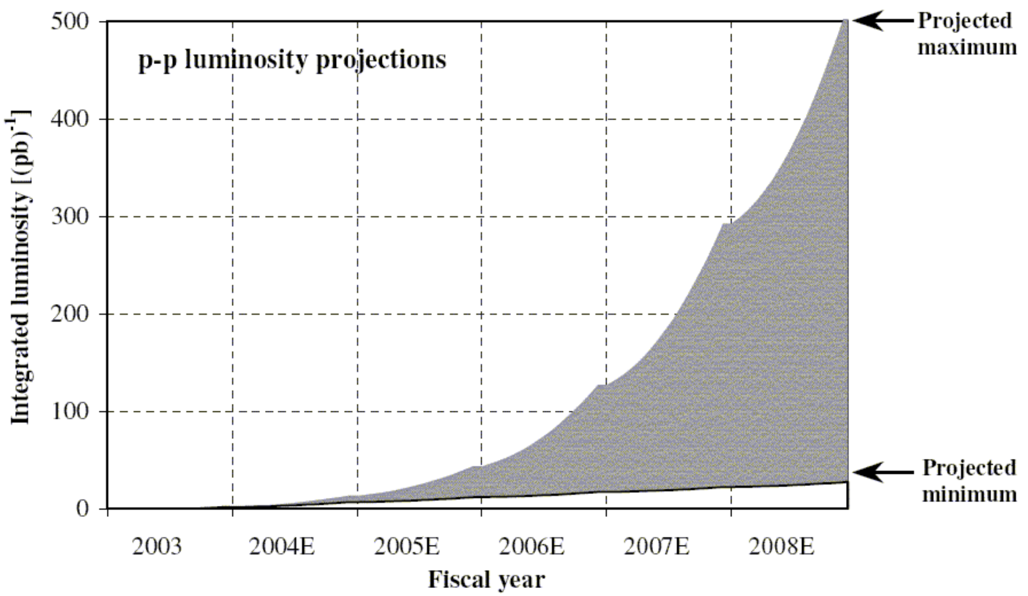

Store-to-store time, average
Calendar time in store
Store-to-store time [hours]
Calendar time in store
Weeks in physics
0
1
2
3
4
5
6
7
0%
10%
20%
30%
40%
50%
60%
70%
1
2
3
4
5
6
7
8
9
10
11
12



Assume
- **14 weeks production in every year**
- **linear luminosity increase during run**
- **4 experiments**
- **completion of improvements**

Fiscal year		2002A (achieved)	2008E (projected maximum)
No of bunches	…	55	112
Ions/bunch, initial	10^9	0.7	1.0
Average store luminosity	10^{26} cm^{-2}s^{-1}	1.5	8.0
Time in store	%	25	60
Maximum luminosity/week	$(\mu b)^{-1}$	25	290

Projected 5-year p-p luminosity evolution



Assume
- **14 weeks production in <u>every</u> year**
- **linear luminosity increase during run**
- **only 2 experiments**
- **completion of improvements**

Fiscal year		2003A (achieved)	2008E (projected maximum)
No of bunches	…	55	112
Ions/bunch, initial	10^{11}	0.7	2.0
Average store luminosity	10^{30} cm^{-2}s^{-1}	3	72
Time in store	…	41	60
Maximum luminosity/week	(pb)$^{-1}$	0.6	26
RHIC store polarization, average	%	30	70

For FY2004	For FY2005	For FY2006	For FY2007	For FY2008
RHIC injectors				
Booster low level rf upgrade			New OPPIS solenoid	EBIS test
AGS warm helical snake	AGS cold helical snake		2nd AGS cold helical snake?	
RHIC luminosity and background				
Collimation system, 1st half	Collimation system, 2nd half			
Shielding PHENIX	Shielding STAR			
Shielding BRAHMS	Shielding PHOBOS			
NEG pipe test (60 m)	NEG pipes (300 m)	NEG pipes (400 m)		
	Solenoids?	Solenoids?		
Dedicated Landau cavities	Transverse damper system			
½ of BPM electronics to alcoves	All BPM electronics to alcoves			
	1 alcove outside ring	2 alcoves outside ring	2 alcoves outside ring	2 alcoves outside ring
Stochastic cooling 1st test	Stochastic cooling 2nd test	Stochastic cooling		
RHIC time in store				
Orbit feed forward (ramp)	Orbit feed forward (ramp)			
Decoupling (ramp and store)	Decoupling (ramp and store)			
Gradient error correction	Gradient error correction			
AtR cooling	Tune feedback (ramp)			
Current lead ice balls elimination	Chromaticity feedback (ramp)			
Corrector PS reliability	Injection set-up			
Gap cleaning				
Abort kicker pre-fires				
Faster down-ramps				

Injectors

Luminosity and background

Time in store

New things to be filled in as we understand the machine better

[T. Roser, W. Fischer, "RHIC Collider Projections (FY2004-FY2008)"]