

# RHIC Enhanced Luminosity Program

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Wolfram Fischer



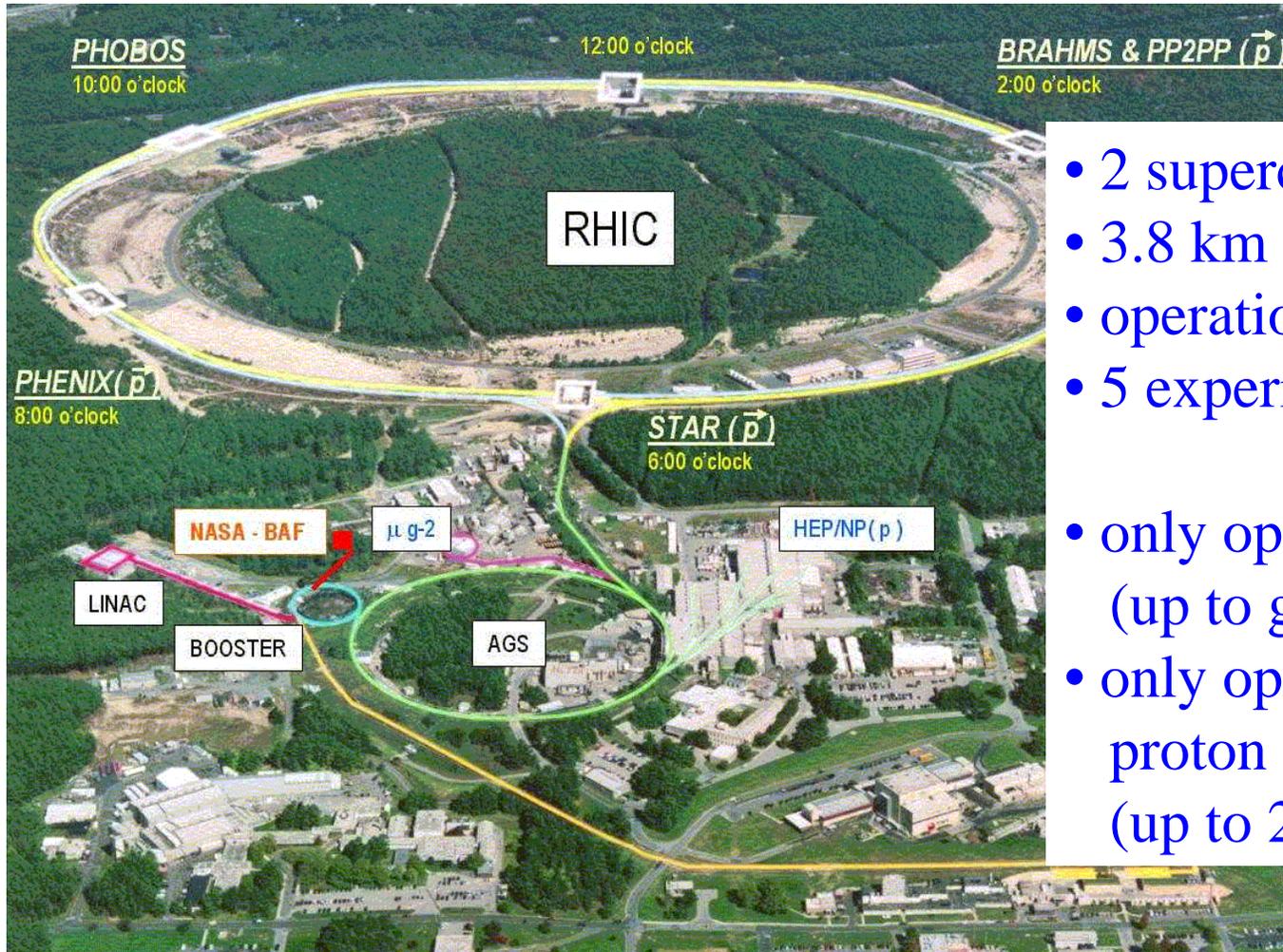
Science and Technology Review  
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# Content

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1. Achieved performance
2. Enhanced RHIC goals  
**Luminosity, Polarization, Time in store**
3. Ion luminosity
4. Polarized proton luminosity  
**Polarization covered in T. Roser's presentation**
5. Time in store

# Relativistic Heavy Ion Collider



- 2 superconducting rings
- 3.8 km length
- operation since 2000
- 5 experiments so far
- only operating ion collider (up to gold 100 GeV/n)
- only operating polarized proton collider (up to 250 GeV)

# RHIC running modes

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Au–Au 10, 28, 31, 65, 100 GeV/n

d–Au 100 GeV/n

**Important control  
experiment  
in physics program**

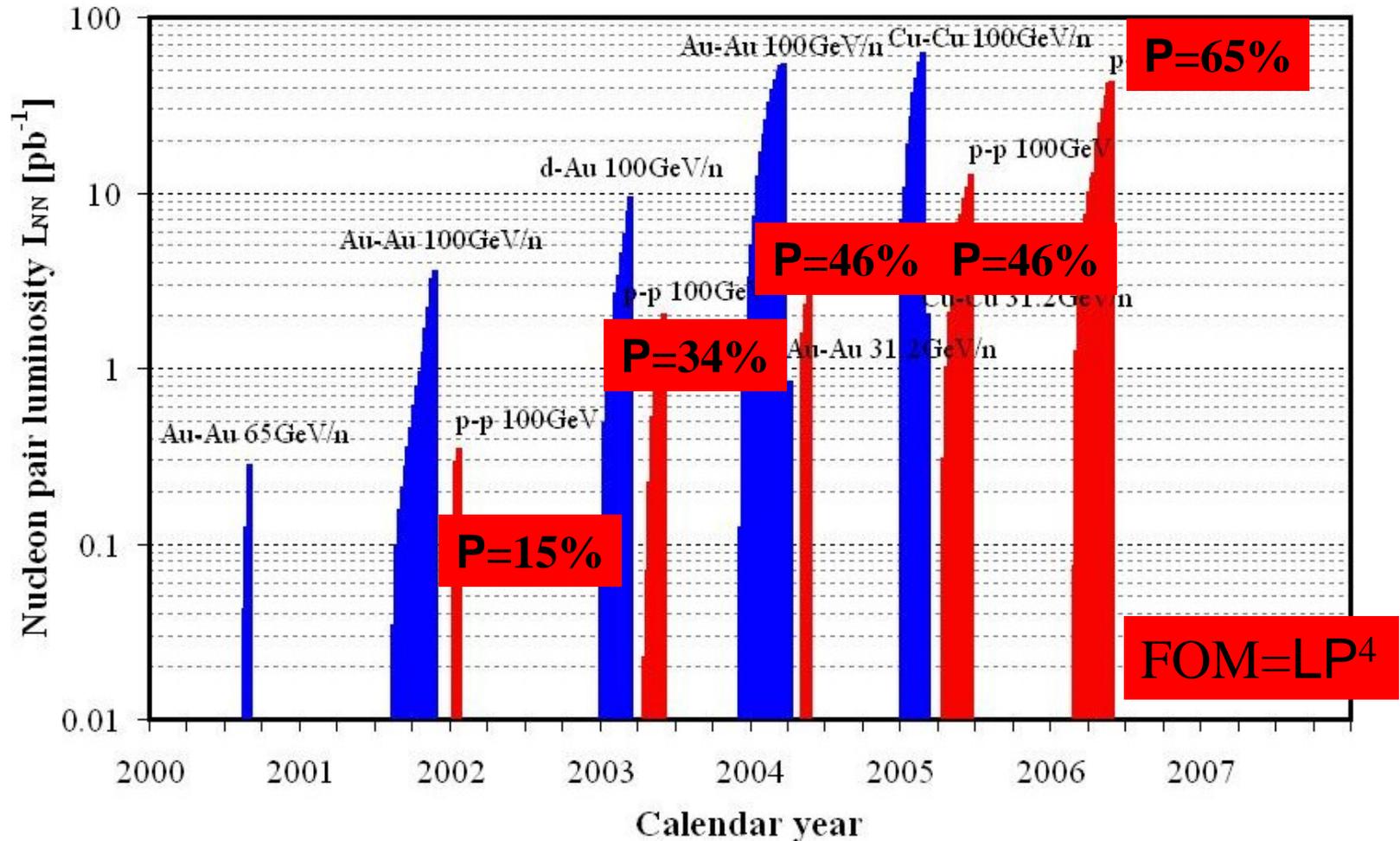
Cu–Cu 11, 31, 100 GeV/n

polarized p–p 11, 31, 100, 205, 250 GeV

**Some modes only for days – fast machine setup essential.**

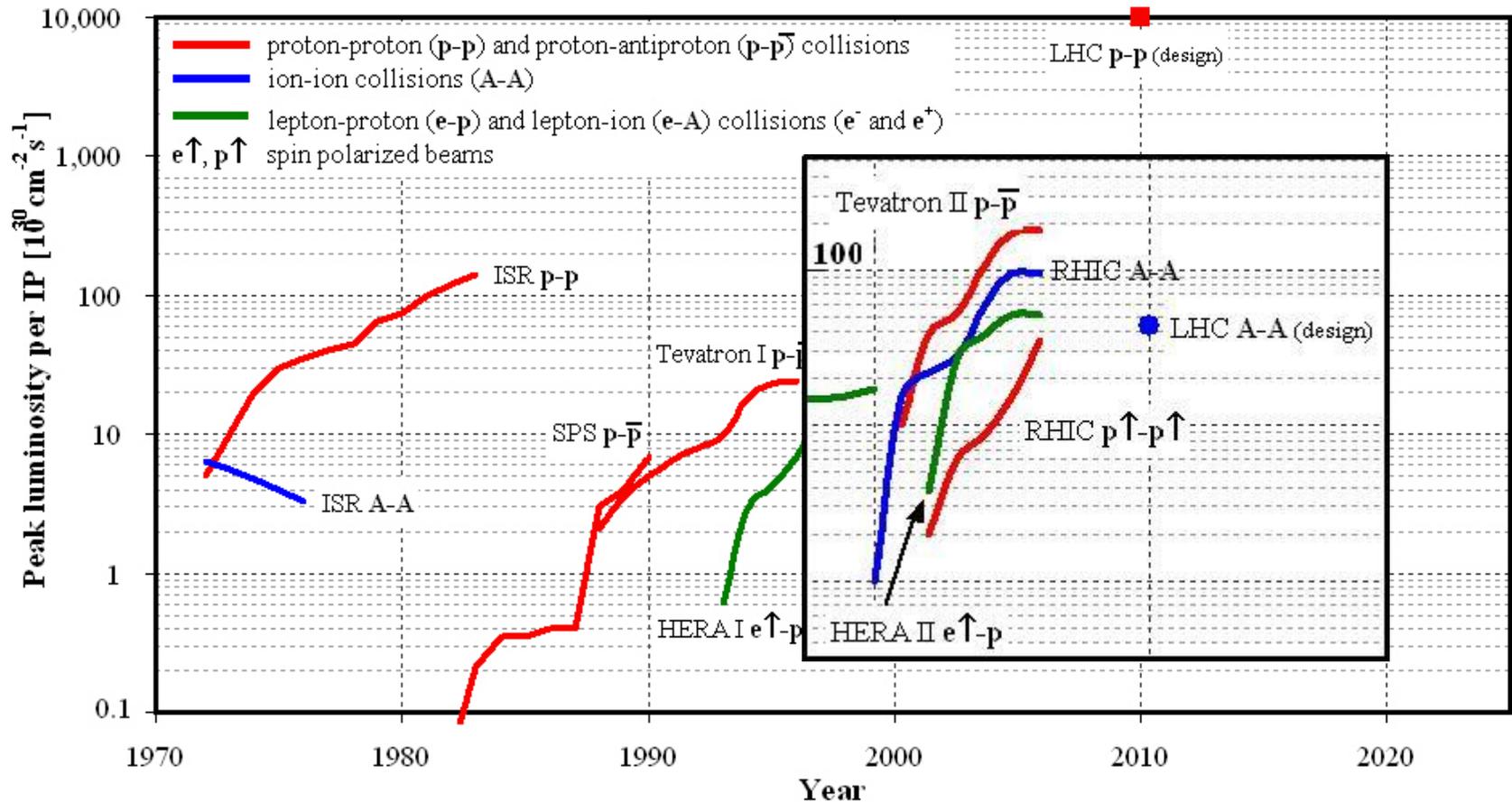
# RHIC delivered luminosity

Delivered luminosity increased by 2 orders of magnitude in 5 years.



Delivered to PHENIX, one of RHIC's high-luminosity experiments.

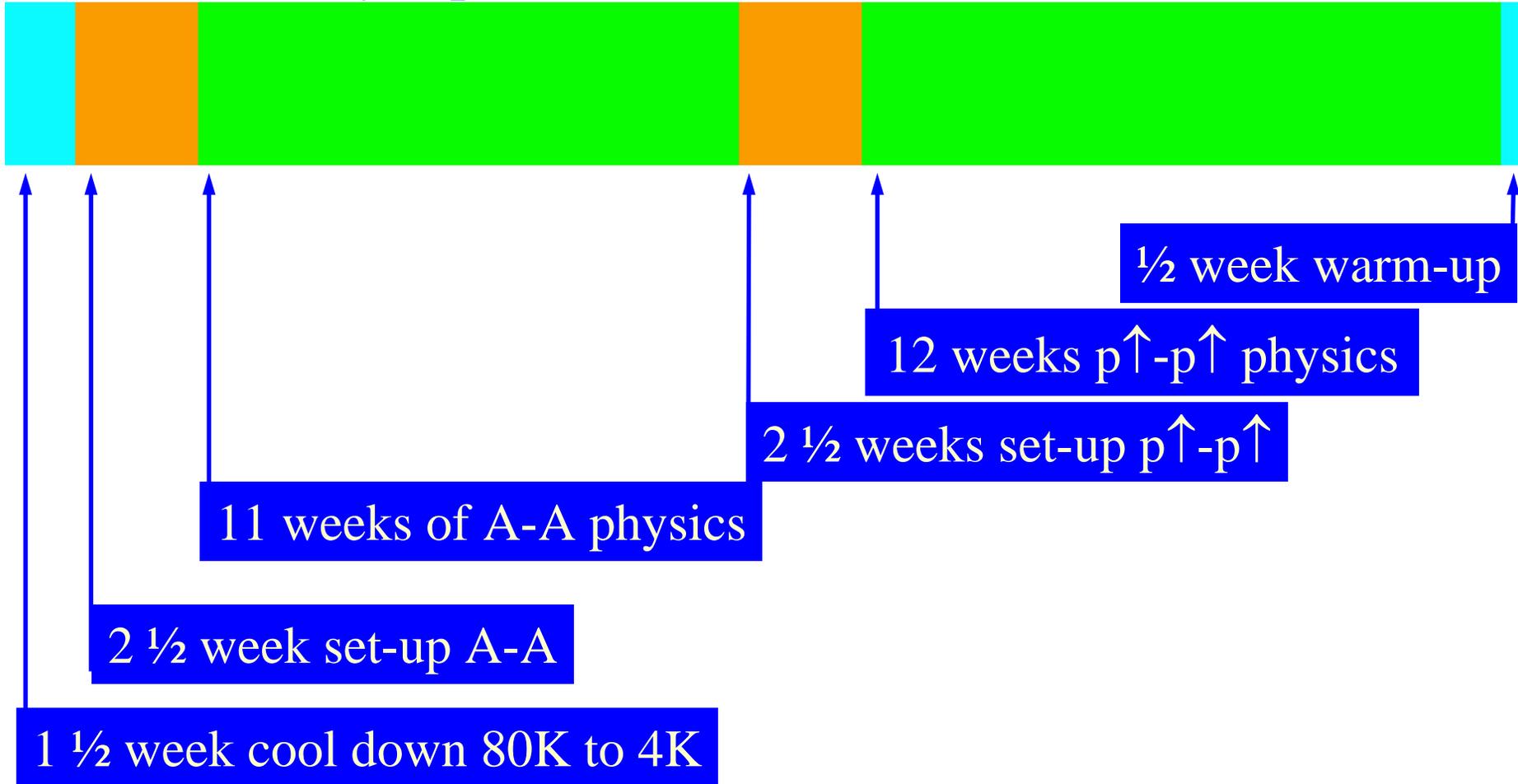
# Hadron collider luminosities



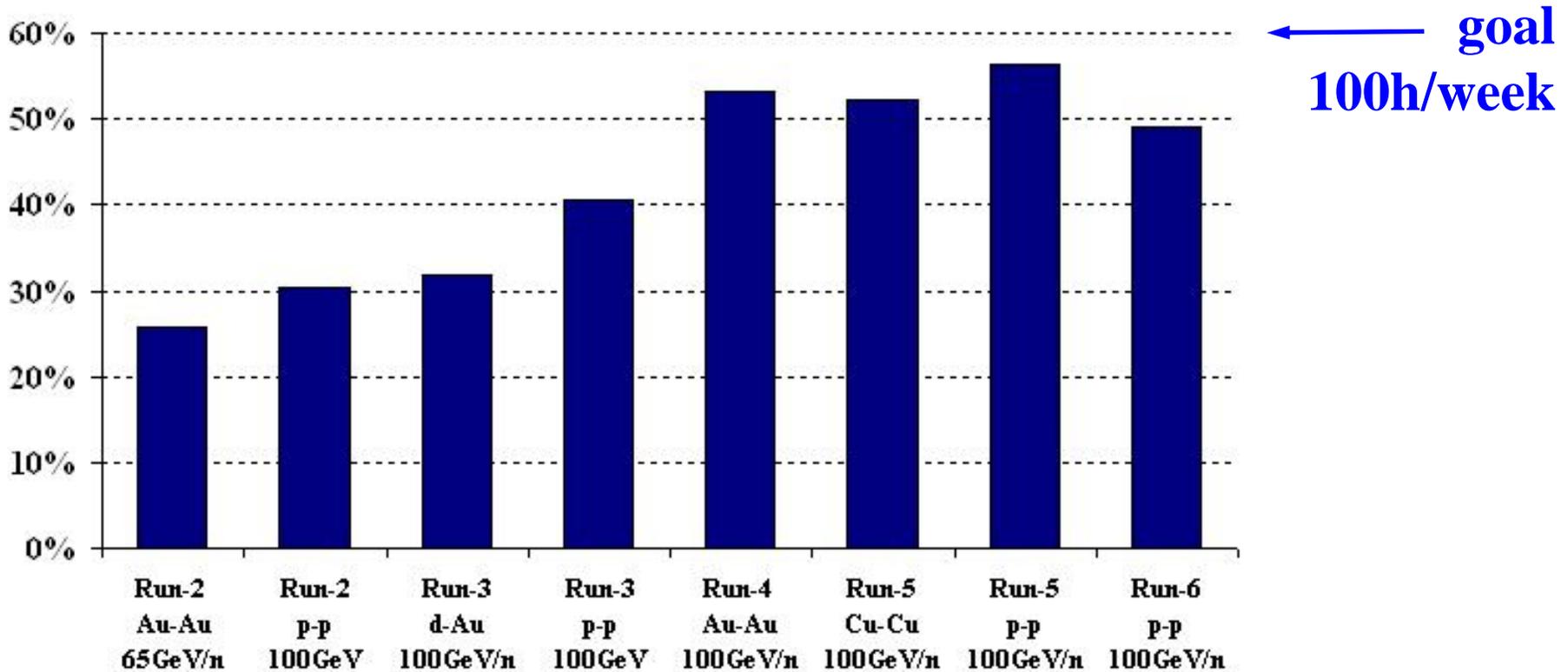
Show nucleon-pair luminosity for ions:  $L_{NN}(t) = A_1 A_2 L(t)$   
 (can compare different ion species, including protons)

# Typical year (Run)

~30 weeks of cryo operation



# Calendar time in store after setup



## Rest of the time:

~20% machine tuning/ramping

~15% failures

~10% machine development and accelerator physics experiments

~ 5% maintenance and access

# Enhanced Design Parameters

1. **Au-Au**  $\mathcal{L}_{\text{store avg}} = 8 \times 10^{26} \text{ cm}^{-2} \text{ s}^{-1}$  at 100 GeV/n
2. **p↑-p↑**  $\mathcal{L}_{\text{store avg}} = 150 \times 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$  at 250 GeV
3.  $\mathcal{P}_{\text{store avg}} = 70\%$
4. **60% of calendar time in store = 100h/week**

# Enhanced Design Parameters (~2008\*)

Parameter	unit	Achieved	Enhanced design	
<b><u>Au-Au operation</u></b>				
Energy	GeV/n	100	100	
No of bunches	...	45	111	
Bunch intensity	$10^9$	1.1	1.0	
<b>Average L</b>	$10^{26}\text{cm}^{-2}\text{s}^{-1}$	<b>5</b>	<b>8</b>	← <b>1.6×</b>
<b><u>p↑-p↑ operation</u></b>				
Energy	GeV	100	250	
No of bunches	...	111	111	
Bunch intensity	$10^{11}$	1.4	2.0	
<b>Average L</b>	$10^{30}\text{cm}^{-2}\text{s}^{-1}$	<b>20</b>	<b>150</b>	← <b>7.5×</b>
<b>Polarization P</b>	%	<b>65</b>	<b>70</b>	← <b>+5%</b>

\* First 250 GeV p↑-p↑ physics run currently scheduled for 2009.

# Enhanced RHIC Task Force

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- Department supports a number of other activities (including the long-term RHIC upgrades)
- Task force is a group dedicated to the short-term RHIC improvements

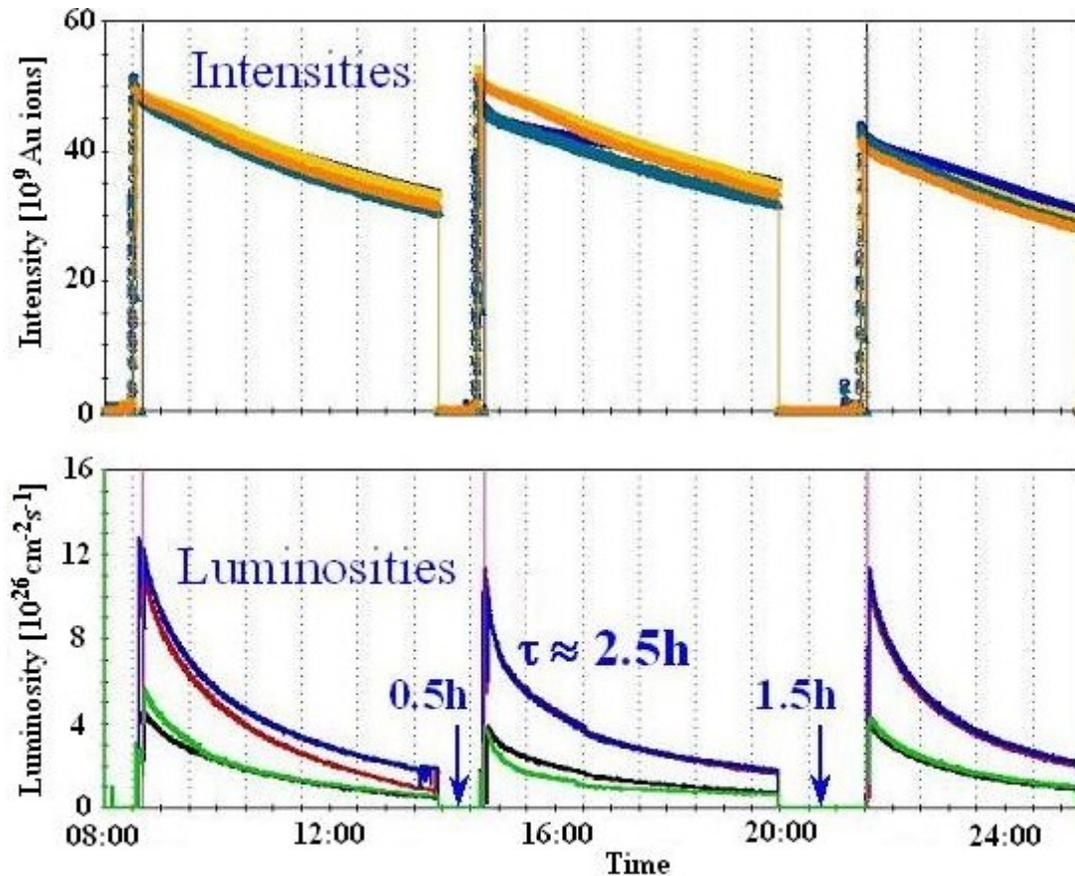


# Enhanced RHIC goal 1: Au-Au luminosity

Beam and luminosity lifetime for Au – Au dominated by IBS

$$\tau^{-1} \propto \frac{Z^4}{A^2} N_b$$

[Factor 10 between Au and p]



- Debunching requires continuous abort gap cleaning
- Luminosity lifetime requires frequent refills
- Ultimately need cooling at full energy

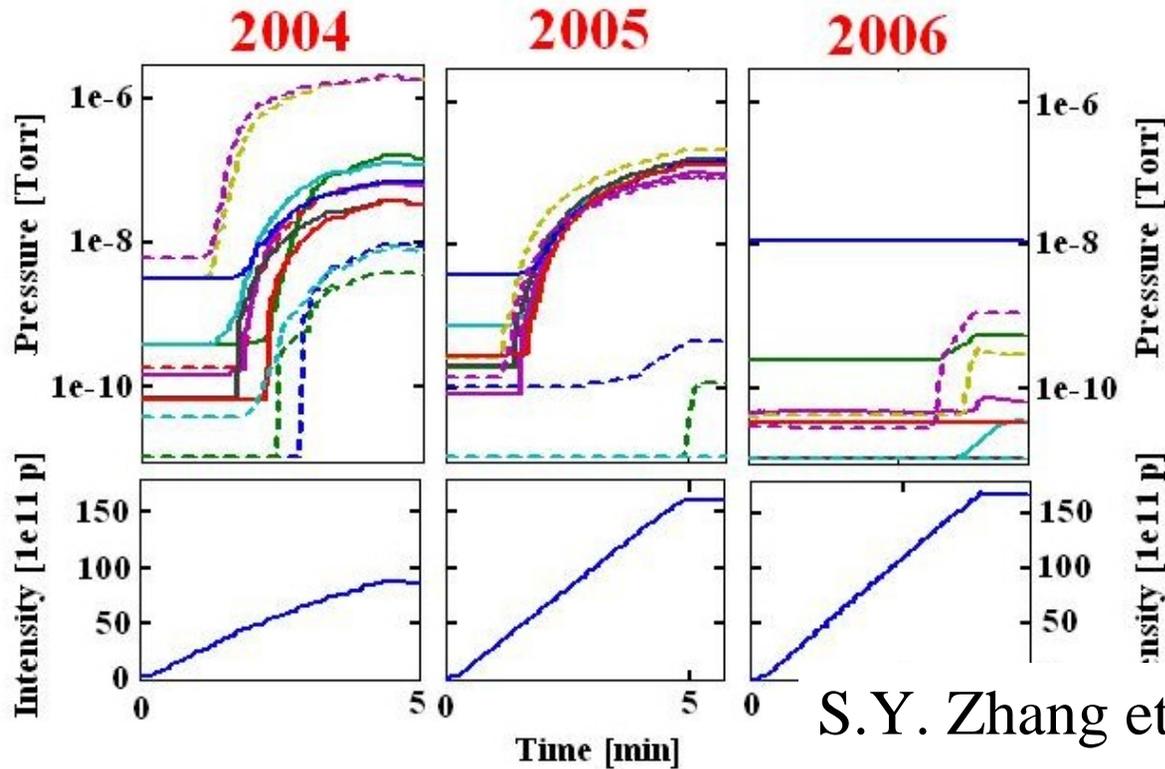
# Enhanced RHIC goal 1: Au-Au luminosity

Parameter	unit	Achieved	Enhanced design
<b><u>Au-Au operation</u></b>			
Energy	GeV/n	100	100
No of bunches	...	45	111
Bunch intensity	$10^9$	1.1	1.0
<b>Average L</b>	<b><math>10^{26}\text{cm}^{-2}\text{s}^{-1}</math></b>	<b>5</b>	<b>8</b> ← <b>1.6×</b>

**Number of bunches in Run-4 (last Au-Au operation, 2004) was limited by dynamic pressure in PHOBOS experiment, caused by electron clouds.**

PHOBOS (and BRAHMS) experiments finished data taking,  
PHOBOS beam pipe (Be) replaced with NEG coated stainless steel

# Enhanced RHIC goal 1: Au-Au luminosity



S.Y. Zhang et al., EPAC06

- Dynamic pressure rise caused by electron clouds
- Upgraded warm and cold vacuum system:
  - installed 430m of NEG pipes (~700m warm sections)
  - reduced pressure in cold section to 1e-7 Torr before cool-down
- Dynamic pressure was not a concern in 2006 proton operation
- Need only 1/2 the charge/bunch for Au, but bunches are <1/2 length

# Enhanced RHIC goal 1: Au-Au luminosity

Crossing transition with slowly ramping sc. Magnets  
(all ions except protons)

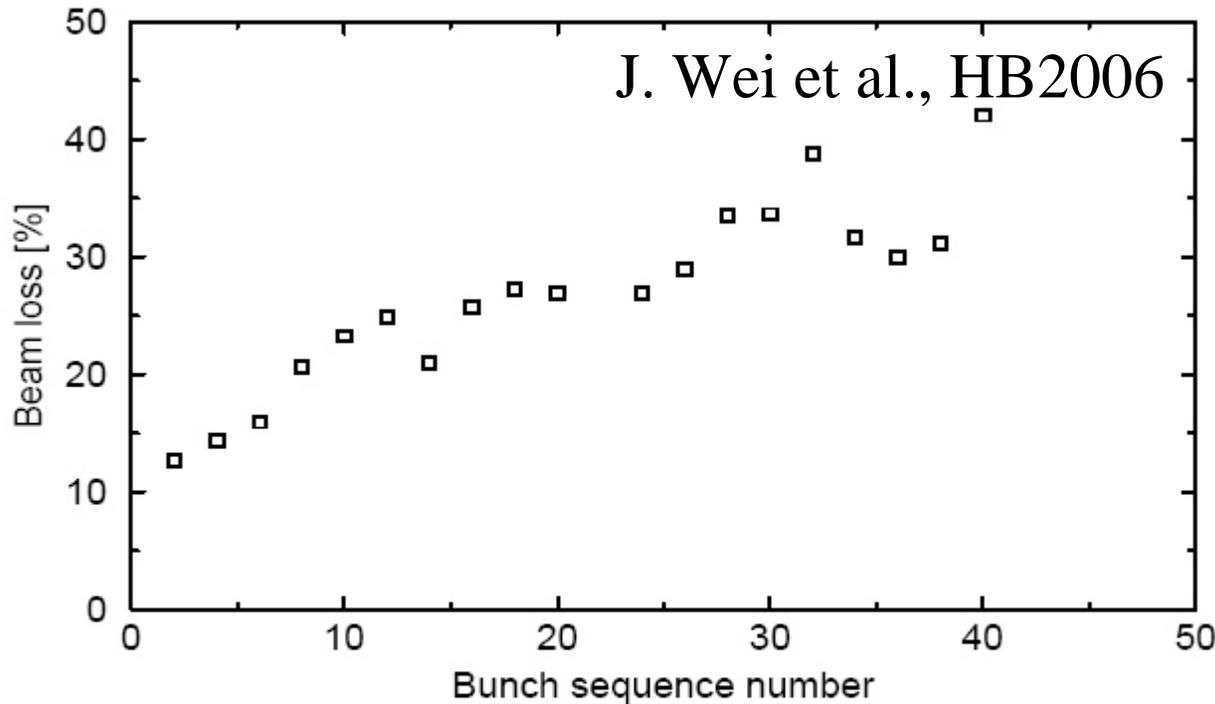
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(need  
bunch)



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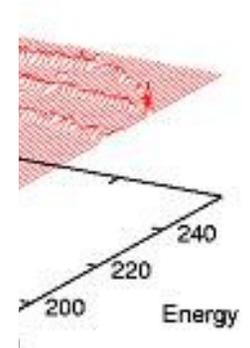


Figure 6: Beam loss at transition as a function of bunch sequence number with  $V_{rf}=200$  kV and  $b_{oct} = -3$  unit.

→ Elec... will gain more operational experience in next ion run

# Enhanced RHIC goal 1: Au-Au luminosity

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## Pipeline for more Au-Au luminosity:

- Reduction in  $\beta^*$  from 1.0m to 0.9m  
(used  $\beta^*=1.0\text{m}$  in last Cu-Cu run)
- Longitudinal stochastic cooling  
(expect to stop Au debunching, 20-50% more luminosity, see presentation by M. Brennan)
- Booster bunch merge  
(potential doubling of bunch intensity)
- Lattice with higher phase advance  
(lower IBS growth rates, lattice not yet analyzed – need stronger arc sextupole which have 18-pole errors)

Further out (beyond 2008):

- Electron cooling (RHIC II)
- Possibly transverse stochastic cooling

# Enhanced RHIC goal 2: p↑-p↑ luminosity

Parameter	unit	Achieved	Enhanced design	Luminosity increase
<b><u>p↑-p↑ operation</u></b>				
Energy	GeV	100	250	← 2.5×
No of bunches	...	111	111	
Bunch intensity	10 <sup>11</sup>	1.35	2.0	← 2.2×
Emittance $\epsilon_n$ (95%)	mm mrad	18	20	
$\beta^*$	m	1.0	0.9	← 1.1×
Hour glass factor	...	0.75	0.9	← 1.2×
Peak L	10 <sup>30</sup> cm <sup>-2</sup> s <sup>-1</sup>	35	225	
<b>Average L</b>	<b>10<sup>30</sup>cm<sup>-2</sup>s<sup>-1</sup></b>	<b>20</b>	<b>150</b>	<b>← 7.5×</b>
<b>Polarization P</b>	<b>%</b>	<b>65</b>	<b>70</b>	

**Need 10 weeks of running time every year to continue progress.**

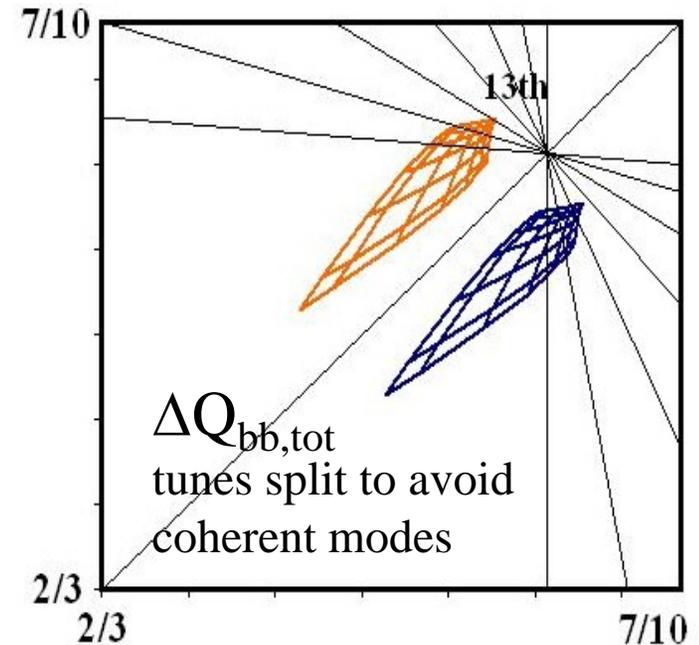
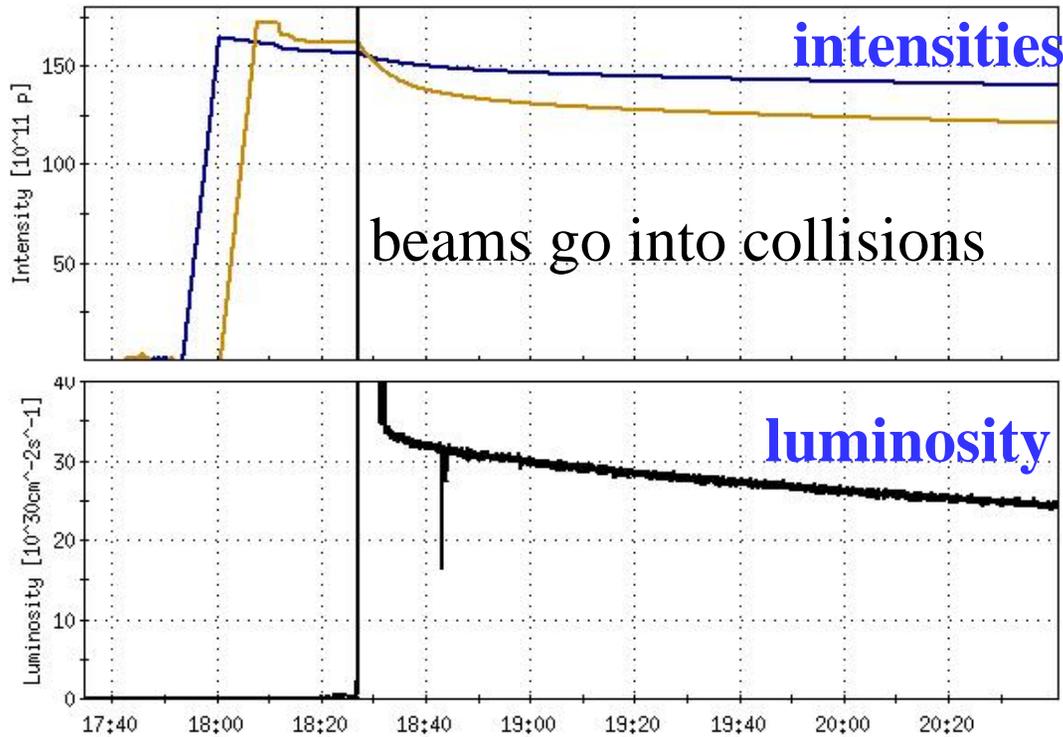
## Enhanced RHIC goal 2: $p\uparrow$ - $p\uparrow$ luminosity

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Increase in bunch intensity from  $1.35$  to  $2.0 \times 10^{11}$

- Increases beam-beam  $\xi$ /IP by 50% (to 0.009)
- Accommodation of larger beam-beam  $\Delta Q$  through
  - Nonlinear chromaticity correction ( $\Delta Q$  of approx. 0.003)
  - $Q_x=2/3$  resonance correction or new working point
- Nonlinear chromaticity correction implemented for next run (4 arc families instead of 2)
- $Q_x=2/3$  resonance correction tried empirically (beam lifetime vs. sextupole settings) – not successful in operation, needs systematic study/simulation

# Performance limit: beam-beam for $p\uparrow - p\uparrow$



- Total beam-beam induced tune spread reached  $\Delta Q_{bb,tot} = 0.012$
- Other sources of tune spread:  $\Delta Q \approx 0.005$ 
  - nonlinear chromaticity (correction planned for next year)
  - triplet errors (locally corrected)

# Enhanced RHIC goal 2: $p\uparrow$ - $p\uparrow$ luminosity

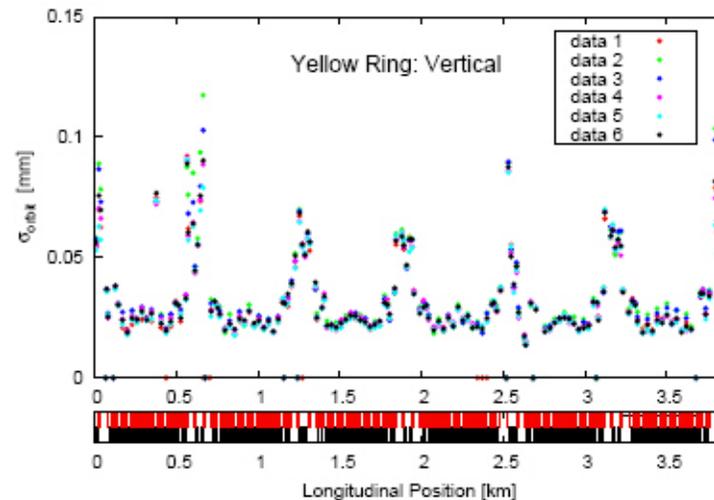
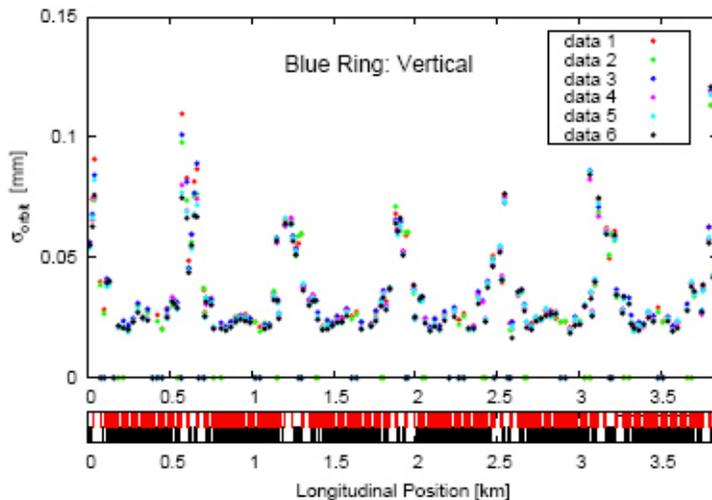
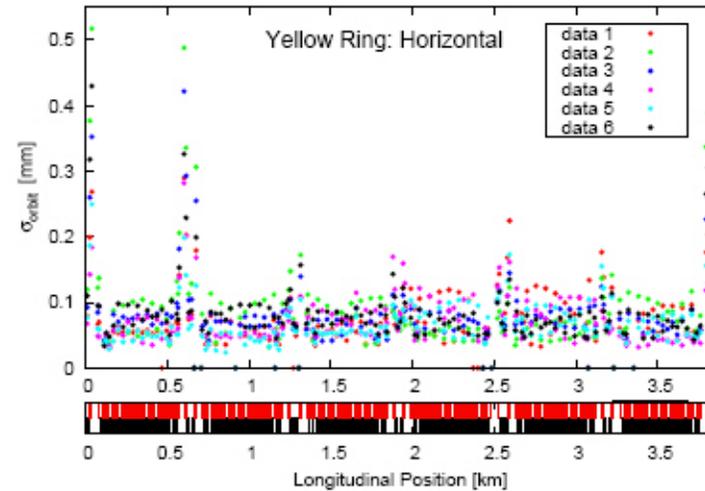
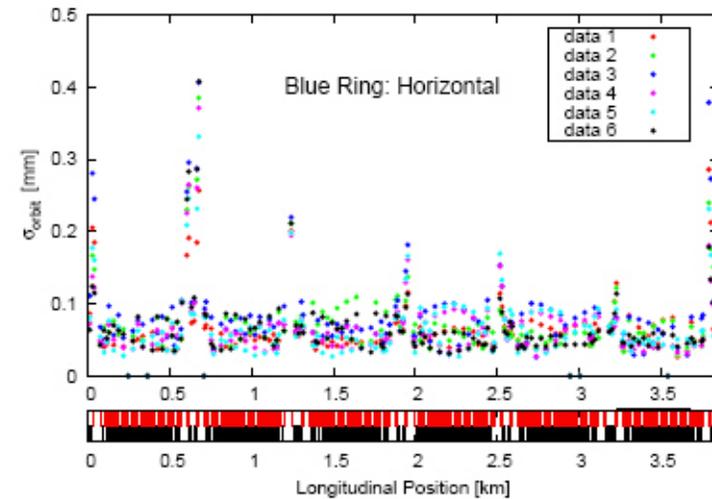
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## Parameter modulations (affect L lifetime):

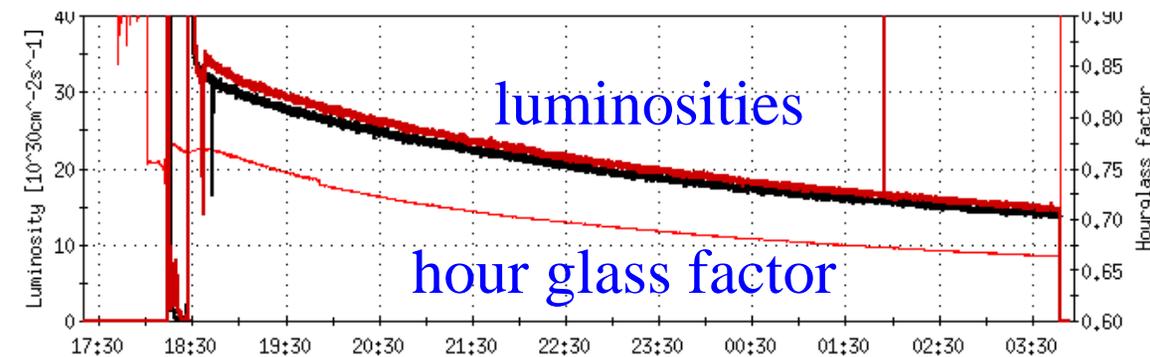
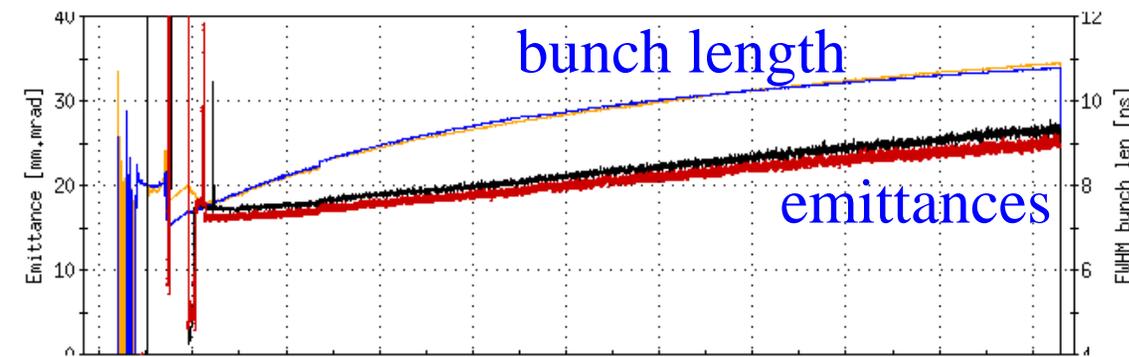
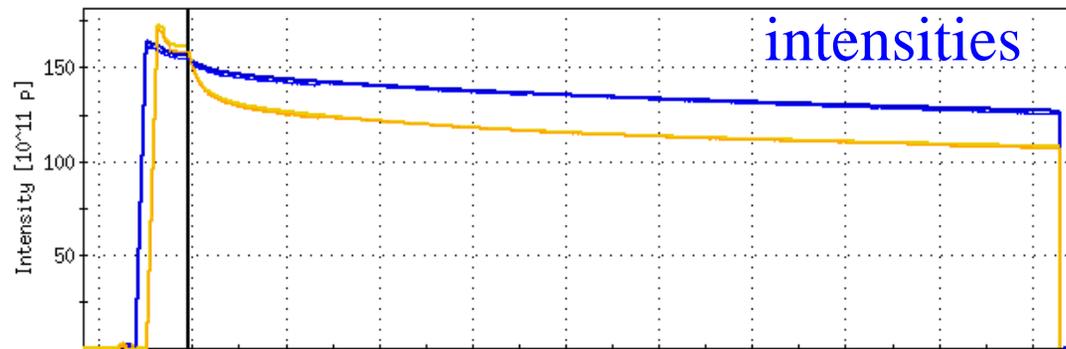
- 10 Hz horizontal orbit oscillations
  - excited mechanical eigenfrequencies of triplets
  - built orbit feedback to stabilize beam-beam offset ( $\sim 0.1\sigma$ )
  - shown not to do any harm – not yet used in operation
  - probably need to modify triplets
- 24h vertical orbit changes
  - one IR4 triplet identified as source
  - cause for triplet movement not identified  
(disconnected cryo pipes from roof last shut-down – no effect)
  - implemented orbit correction at beginning of every store  
(uncorrected orbit varies by  $\sim 1$ cm in high- $\beta$  triplets)
- Tune ripple from other sources being assessed

# Enhanced RHIC goal 2: $p\uparrow$ - $p\uparrow$ luminosity

10Hz oscillations: measured orbit rms (R. Calaga)



# Enhanced RHIC goal 2: $p\uparrow$ - $p\uparrow$ luminosity



Hour-glass factor increase from 0.75 to 0.9

- 4× bunch area increase at RHIC injection (close to  $\gamma_{tr}$ )
- short bunches also enhance e-cloud (signs of  $\epsilon$ -growth)
- currently acceleration with  $h=360$
- new  $h=120$  cavity (**M. Brennan**) common to both rings, would allow:
  - longitudinal matching
  - ring-to-ring lock
  - acceleration of long bunches (e-cloud less harmful at store)
  - turn on  $h=360$  system at store

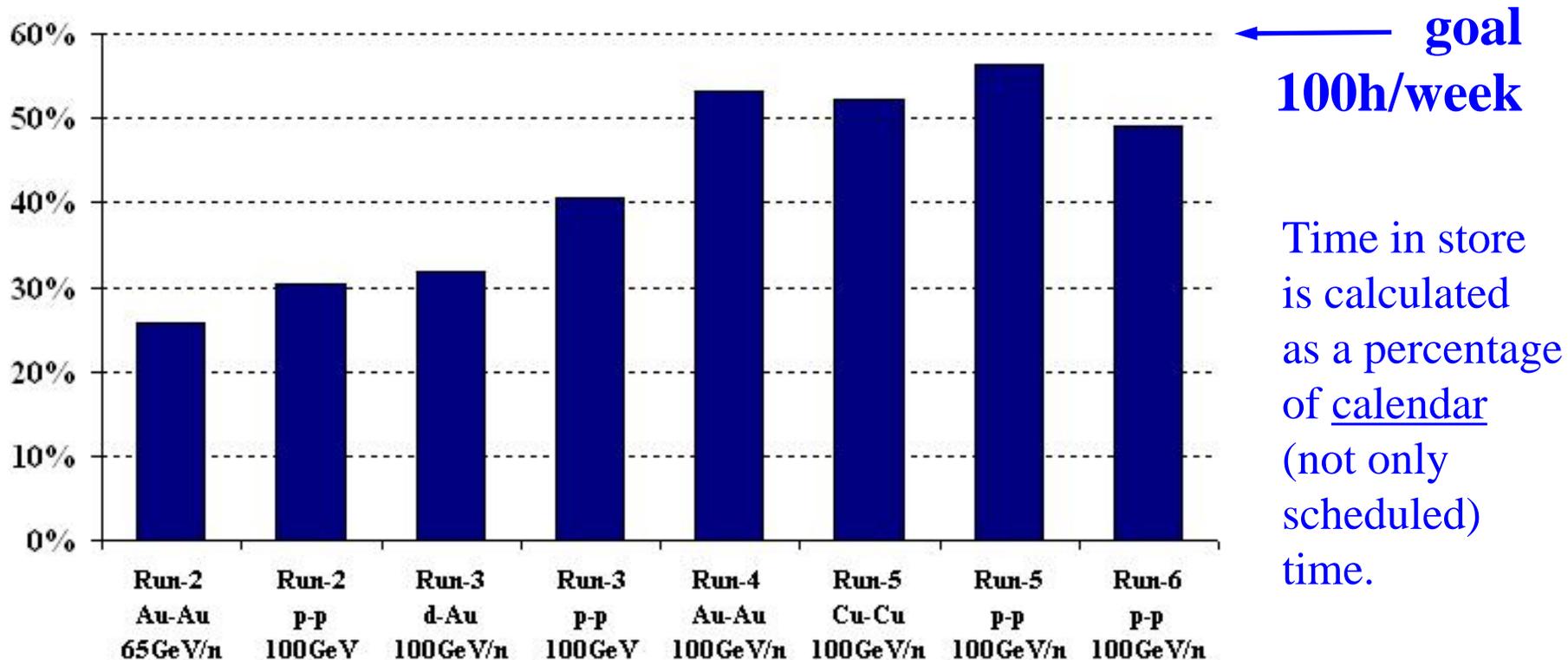
# Enhanced RHIC goal 3: $p\uparrow$ polarization

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Details covered in T. Roser's presentation

- Goal:  
70% store average at 250 GeV
- Run-5 (2005):  
reached 65% store average at 100 GeV
- Run-5 (2205):  
accelerated beam to 250 GeV  
(new energy record for polarized proton beam)  
>45% polarization

# Enhanced RHIC goal 4: Time in store



## Rest of the time:

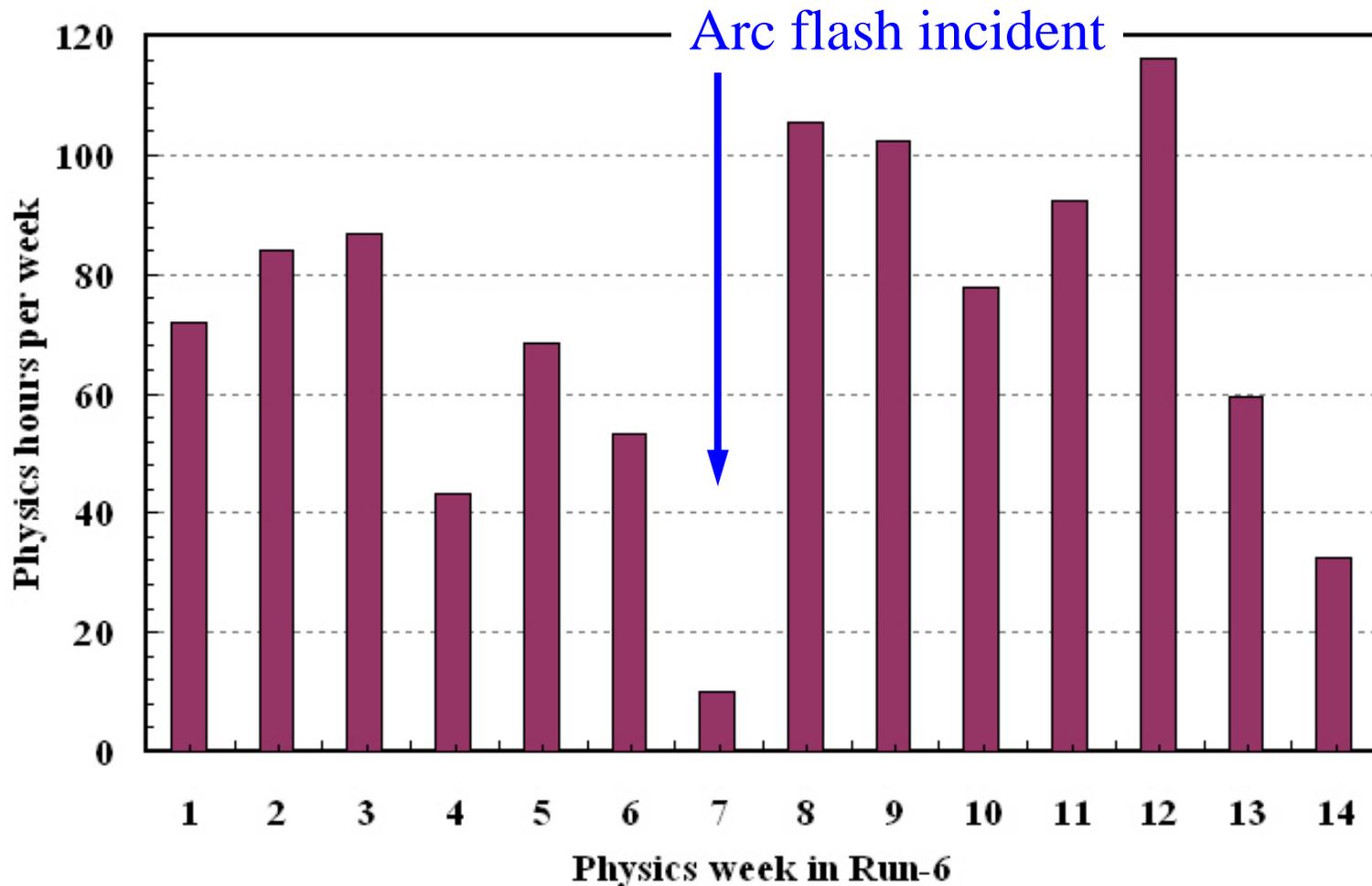
~20% machine tuning/ramping

~15% failures

~10% machine development and accelerator physics experiments

~ 5% maintenance and access

# Enhanced RHIC goal 4: Time in store



Problem with weekly consistency of operation

# Enhanced RHIC goal 4: Time in store

## Time distribution in physics operation.

	FY2004	FY2005		FY2006
	Au-Au	Cu-Cu	p <sup>↑</sup> p <sup>↑</sup>	p <sup>↑</sup> p <sup>↑</sup>
	[%]	[%]	[%]	[%]
physics	46	46	42	39
machine development	4	8	12	8
accelerator physics studies	6	4	5	5
machine setup	22	20	21	18
experimenter setup	1	2	2	3
failure	16	15	12	16
maintenance	4	5	3	6
scheduled shutdown			2	0
unscheduled shutdown				4
<b>availability (DOE definition)</b>	<b>83</b>	<b>84</b>	<b>87</b>	<b>82</b>
<b>time in store</b>	<b>53</b>	<b>52</b>	<b>56</b>	<b>46</b>

can be reduced after luminosity goals are met

may be able to reduce with more automation

need to remain vigilant just to maintain

[Comment: In p<sup>↑</sup>-p<sup>↑</sup> operation greater emphasis on performance improvements than for A-A.]

# Summary

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Enhanced RHIC goals require:

- 1.6× increase in heavy ion luminosity  
→ very likely achievable
- 7.5× increase polarized proton luminosity  
(2.5× increase from energy)  
→ challenging
- 5% increase in store polarization (65% to 70%)  
→ likely achievable
- Increase of time in store by 12h/week (to 100h/week)  
→ achievable after luminosity goals have been reached

[Also look forward to commission EBIS in 2009.]

# Backup: DOE availability

	ALL04	AuAu	p^p^	ALL05	CuCu	p^p^	ALL06	p^p^
fiscal year	FY04	FY04	FY04	FY05	FY05	FY05	FY06	FY06
RHICRefrigerator hours	4368	3336	1031	5328	3024	2280	3576	3576
physics	1124	1046	77	1564	787	776	1069	1069
machine development	487	92	394	718	325	393	851	851
beam studies	136	128	8	158	70	88	129	129
machine setup	1285	1061	225	1278	757	521	655	655
experimenter setup	153	83	71	144	86	58	120	120
failure	791	616	176	696	395	301	699	699
maintenance	287	207	80	702	575	128	227	227
Scheduled Shutdown	0	0	0	101	65	36	157	157
Unscheduled Shutdown	0	0		14	12	2	119	119
Total hours	4264	3233	1031	5313	3012	2301	4025	4025
availability =	80.1%	79.6%	81.5%	84.7%	83.7%	85.9%	80.2%	80.2%