RHIC Operations

d-Au and pp operations during Run-3 (FY2003)

Projections for Run-4 (FY2004)

5-year projections

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Office of Science
U.S. DEPARTMENT OF ENERGY

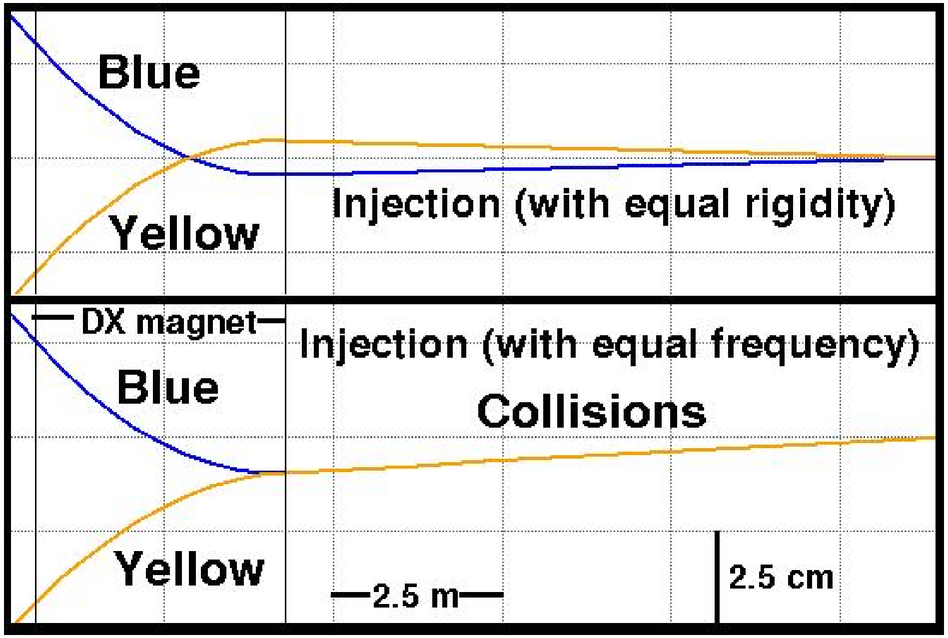
Thomas Roser
Program Advisory Committee Meeting
September 29-30, 2003

Run-3 Achievements

- First asymmetric d-Au collisions with equal-energy injection and acceleration
- Additional bunch merge for deuteron: two Tandem pulses per RHIC bunch
- β^* = 1 meter at both PHEINX and STAR for proton-proton collisions
- Commissioning of eight new spin rotators to give longitudinal polarization at PHENIX and STAR
- 50 % polarization at AGS extraction; 35 % polarization at 100 GeV
- Commissioning of new AGS polarimeter and first polarization measurements during the AGS and RHIC acceleration ramps

Deuteron-Gold Collisions in RHIC (RUN-3)

- Important comparison measurement: will not produce quark-gluon plasma
- Collisions at 100 GeV/nucleon requires 20% different rigidities
- Use two Tandems; add. bunch merging in Booster:
  1.1×10^{11} d/bunch, $\varepsilon[95\%] = 12\ \pi\ \mu m$; 0.7×10^{9} Au/bunch, $\varepsilon[95\%] = 10\ \pi\ \mu m$
- Initial injection with equal rigidity failed because of beam loss from modulated beam-beam interactions during acceleration ramp
- Injection and acceleration with same energy was successful.



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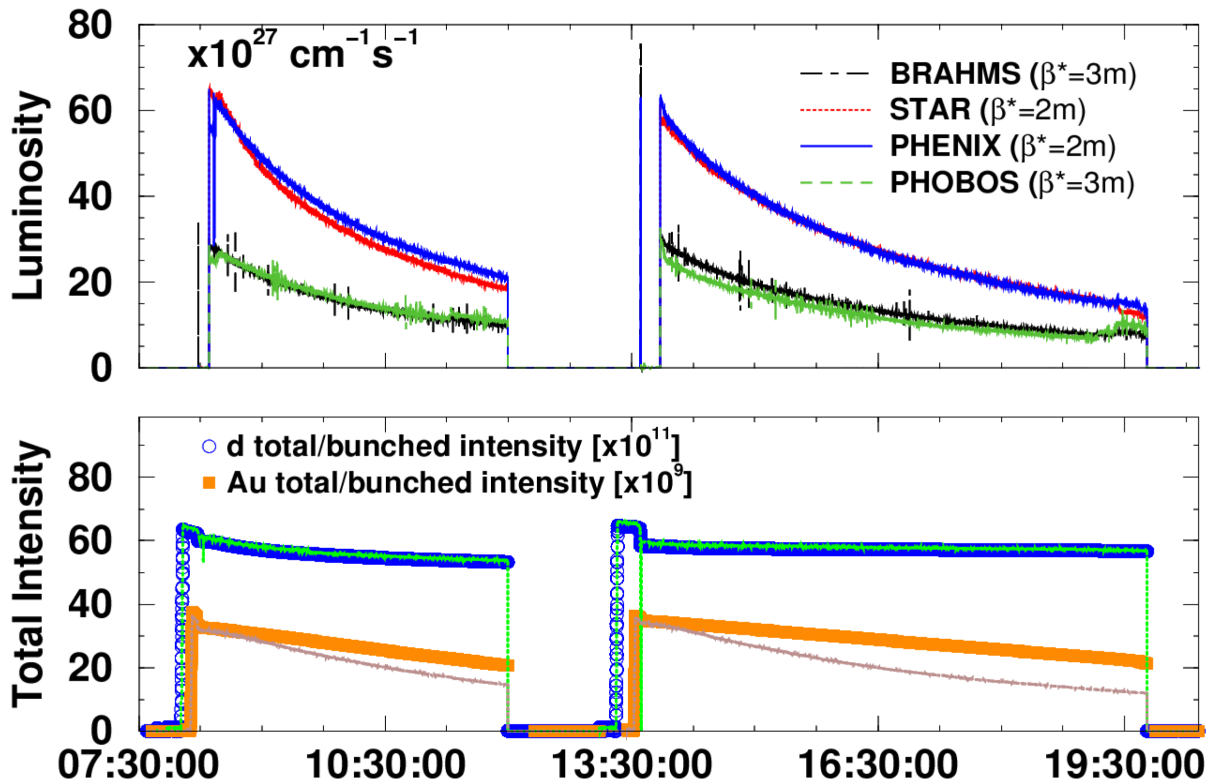
“Typical” Deuteron-Gold Stores

- Vacuum pressure rise limits total charge (both beams) to 10^{13} (~ 56 bunches)
- Transverse instability cured by crossing zero-chromaticity before transition
- Need Landau cavities to avoid coherent longitudinal oscillation during acceleration.
- Fixed noise in 200 MHz system to give good deuteron lifetime
- Intra-beam scattering affects gold beam



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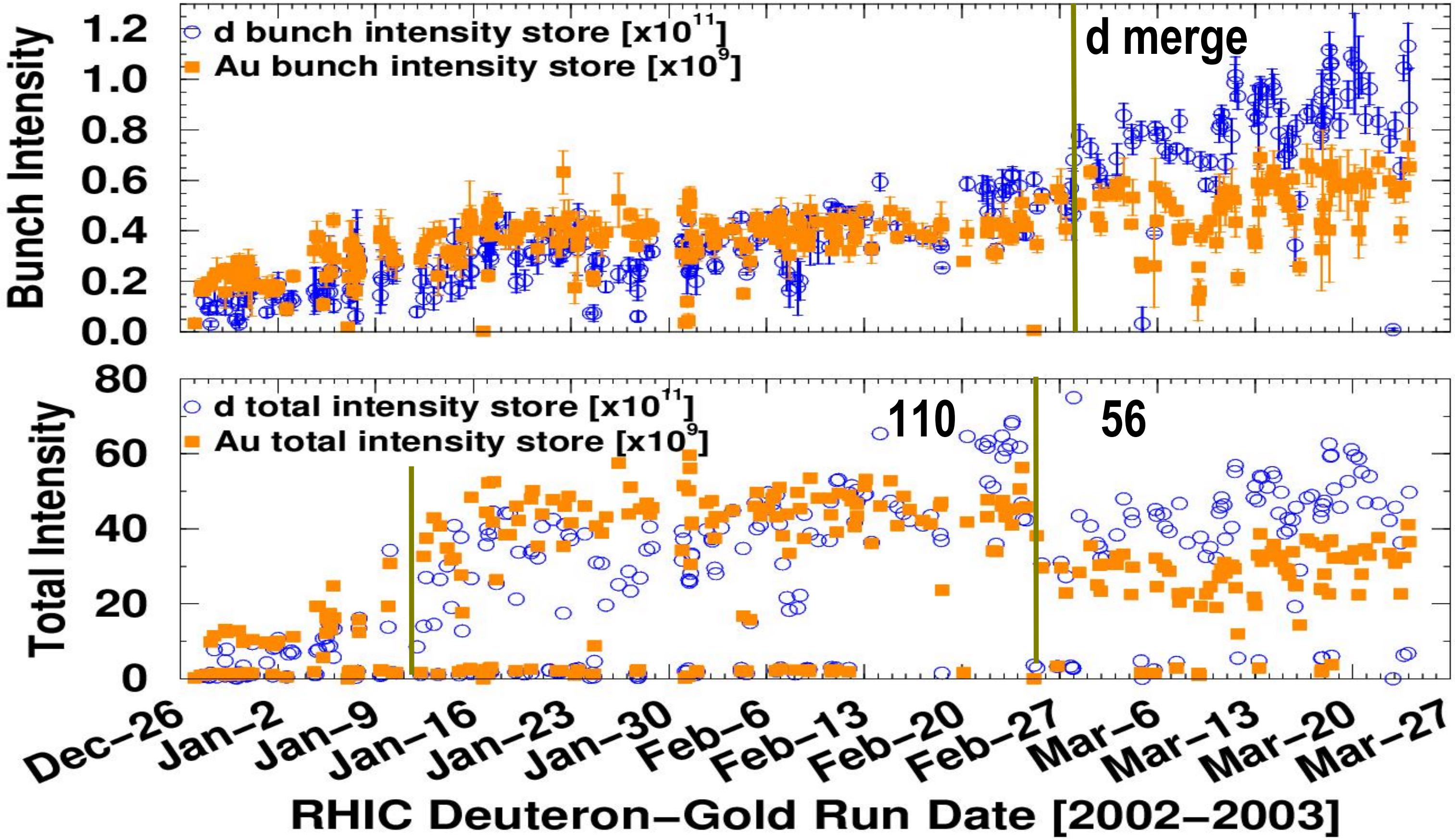
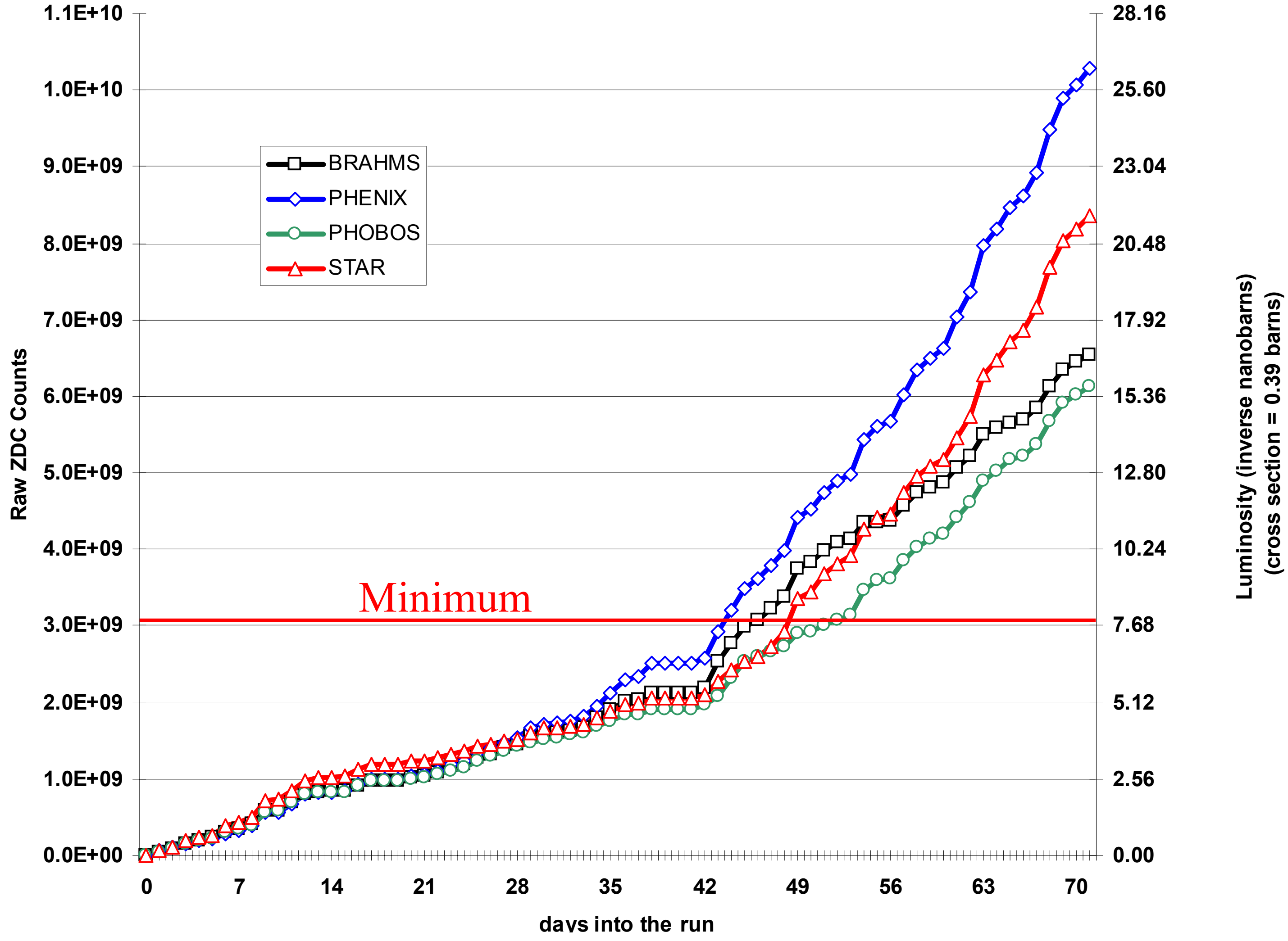
RHIC Deuteron-Gold Intensity Performance



- Injector dAu "mode switch" time usually 3-5 minutes, below goal
- About an even division between 110 and 56 bunch ramping

Integrated d-Au Luminosity



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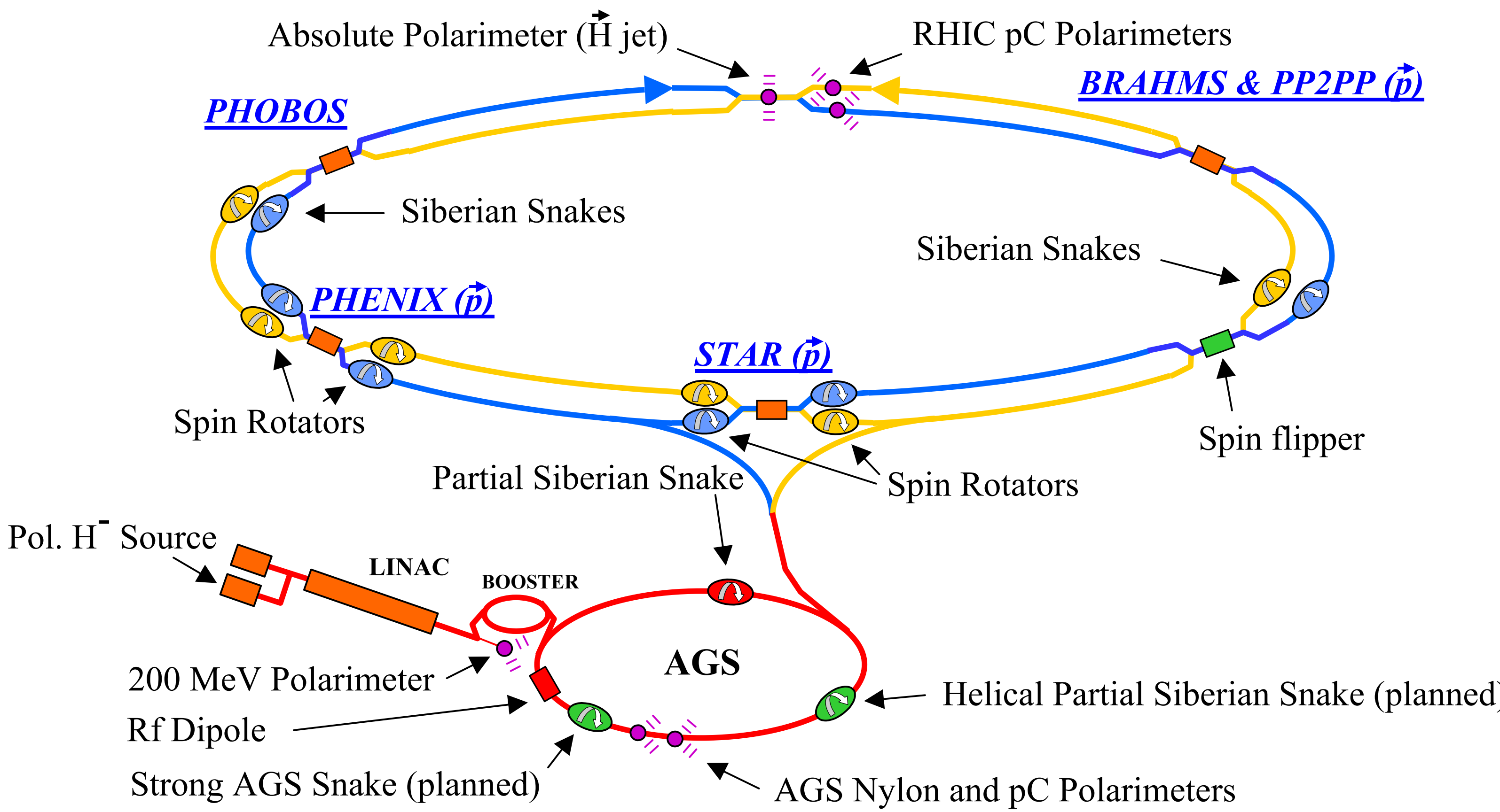
Polarized Proton Collisions in RHIC



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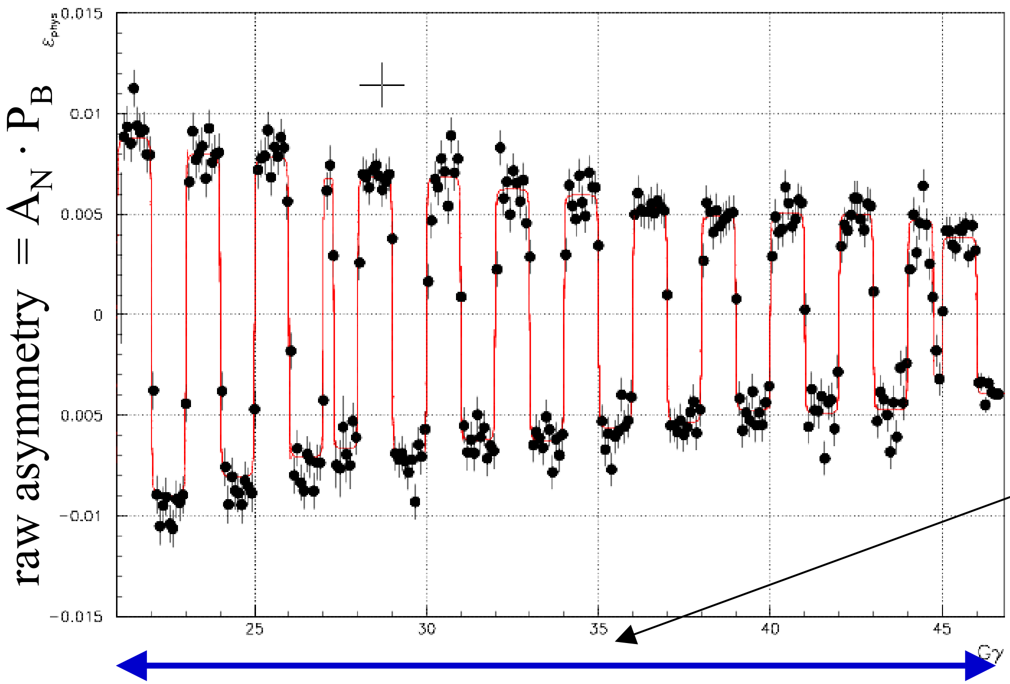
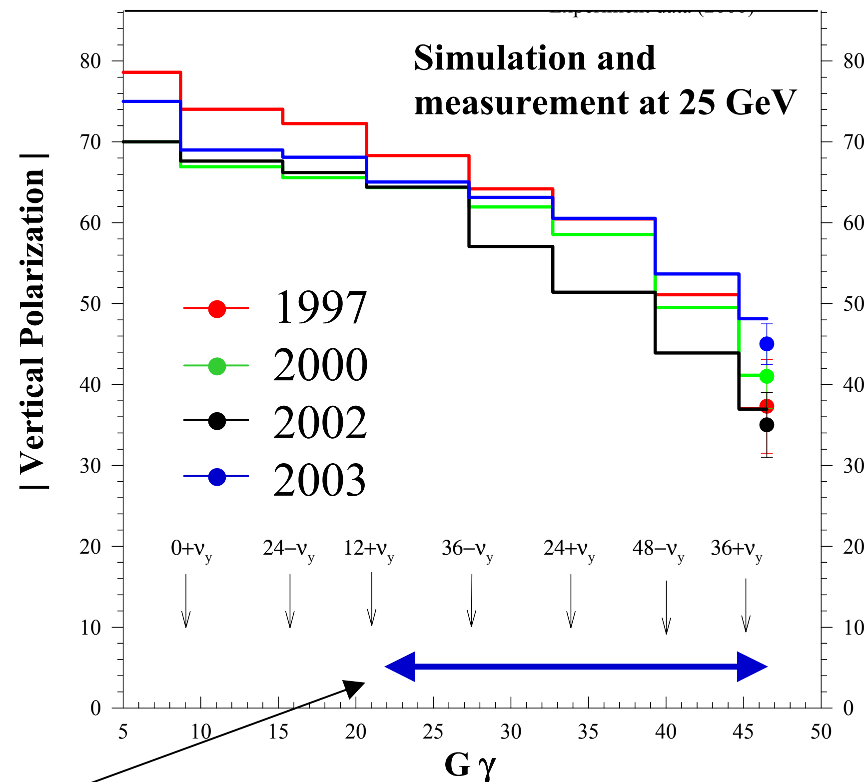
Proton polarization at the AGS

- Full spin flip at all imperfection and strong intrinsic resonances using partial Siberian snake and rf dipole
- Ramp measurement with new AGS pC CNI polarimeter:





- Remaining polarization loss from coupling and weak intrinsic resonances
- New helical partial snake (RIKEN funded) will eliminate coupling res.
- To avoid all depolarization in AGS build strong AGS helical Siberian snake! (Installation: late 2004)

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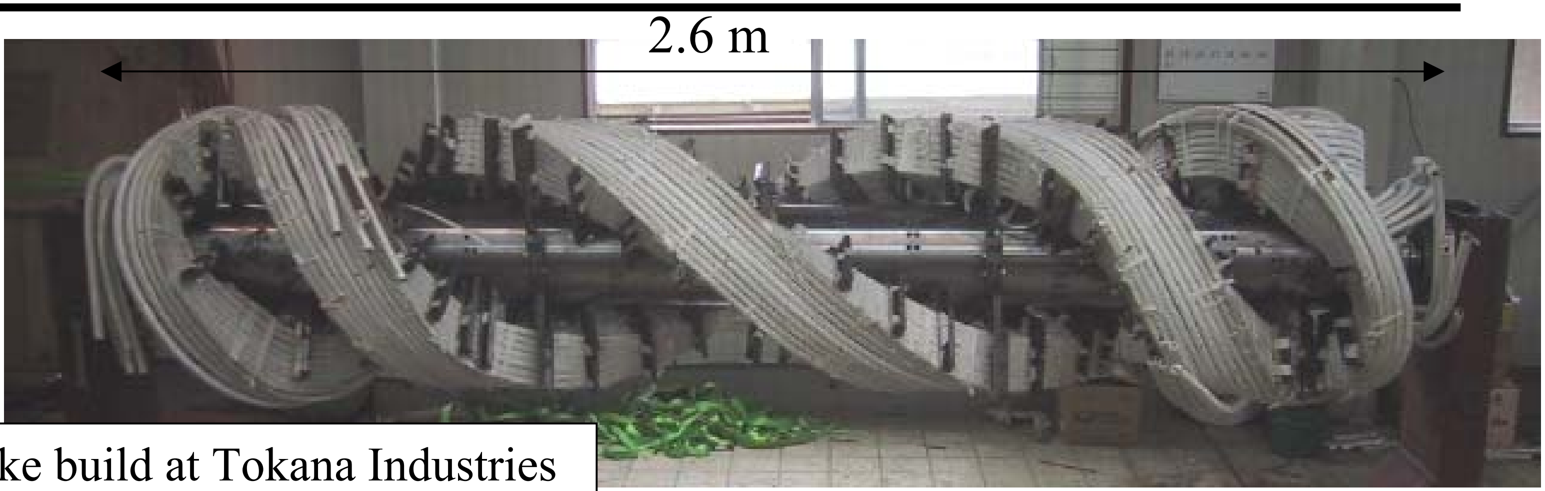
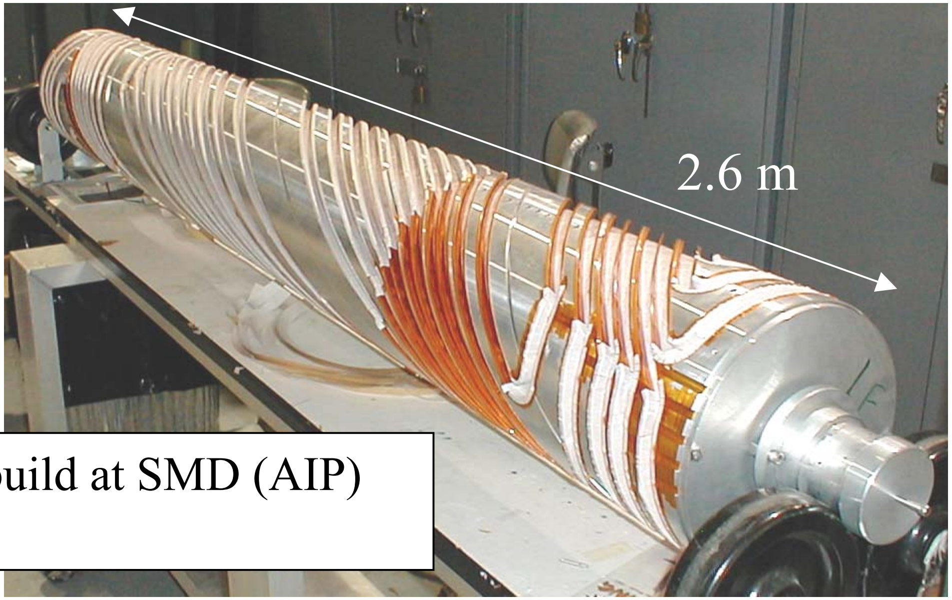
New AGS helical snakes



5 % helical snake build at Tokana Industries funded by RIKEN. Installation: Jan. 2004.

- Cold strong snake eliminates all depolarizing resonances in AGS.
- Warm snake avoids polarization mismatch at AGS injection and extraction.



30% s.c. helical snake build at SMD (AIP) Installation: Sep. 2005

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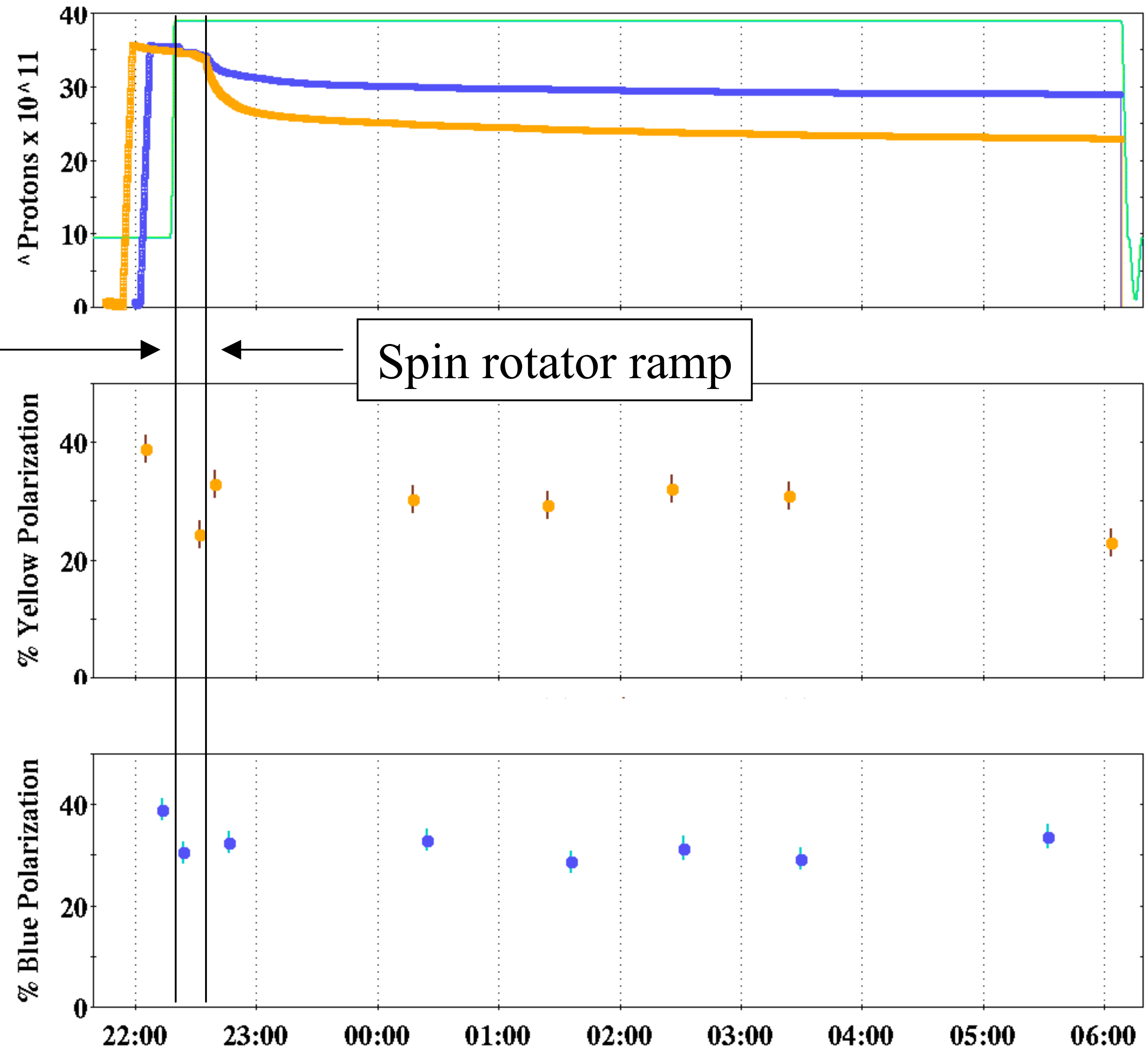
Polarization survival in RHIC (store # 3713)

Acceleration and squeeze ramp

Spin rotator ramp



Some loss during accel/squeeze ramp (Tune too close to ¼)

No loss during spin rotator ramp and during store

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Achievements during 9-week p-p run

- Source polarization ~70-75%
- AGS provided 50% peak and 40% average polarization.
- Spin rotators commissioned successfully. Longitudinal polarization for the first time at IR 6 and 8.
- One helix in 9 o'clock Yellow snake failed. Remaining helices allowed for 88% snake, which was sufficient to maintain polarization.
- Set up six different lattices (!): β^* = 2m for all IRs; β^* = 1m at IR 6 and 8 and 3m for IR 2 and 10; with 88% Yellow snake; with PHEINX spin rotators; with PHENIX and STAR spin rotators; β^* =10m for pp2pp.
- 55 bunches per ring with 0.65 x 10^{11} p↑/bunch, emittance ~15 π, Beam polarization at store: 35% peak, 30% average
- Peak luminosity at beginning of store: $\sim 6 \times 10^{30}$ cm^{-2} s^{-1} at 100GeV
- Beam life-time affected by beam-beam effect. Needed to reduce number of collisions from 4 to 2. Also working point has to be accurate at 0.001 level.

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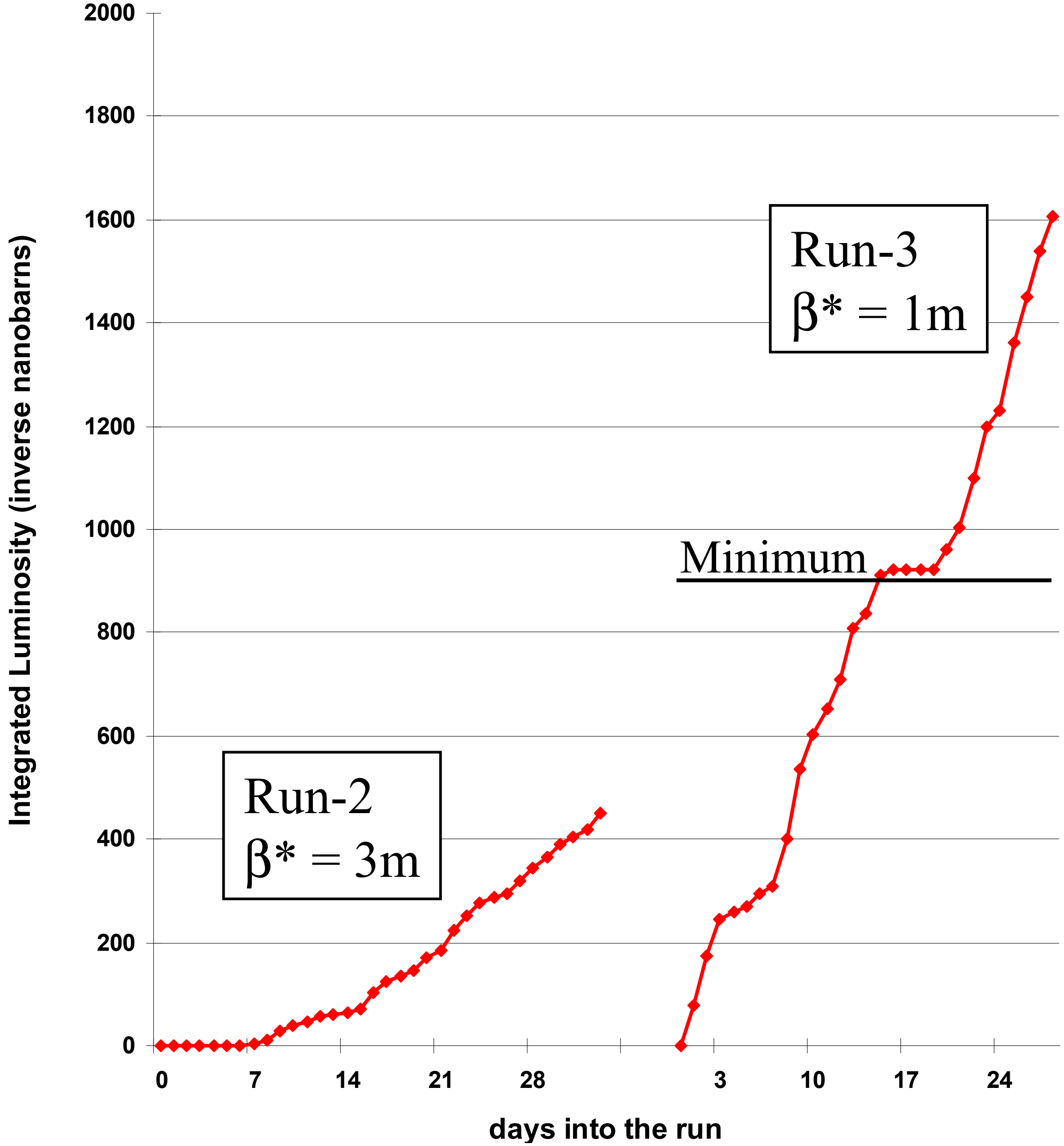
Delivered integrated p-p Luminosity

- Luminosity determined from Zero Degree Calorimeters (ZDC) that were calibrated with Vernier scans.
- Luminosities are similar for STAR and PHENIX with β* = 3m in Run-2 and 1m in Run-3
- Days shown are from start of physics data taking.



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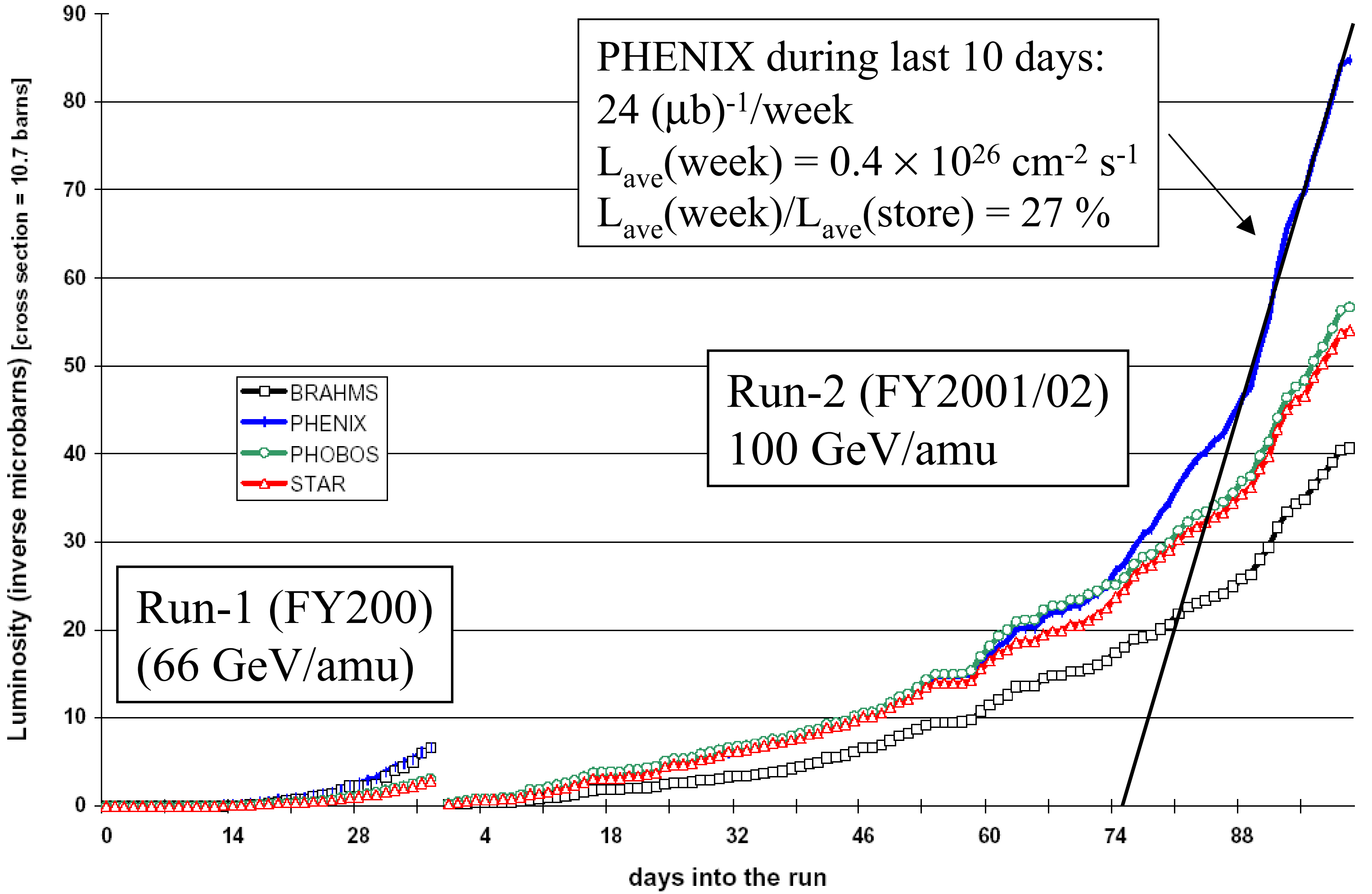
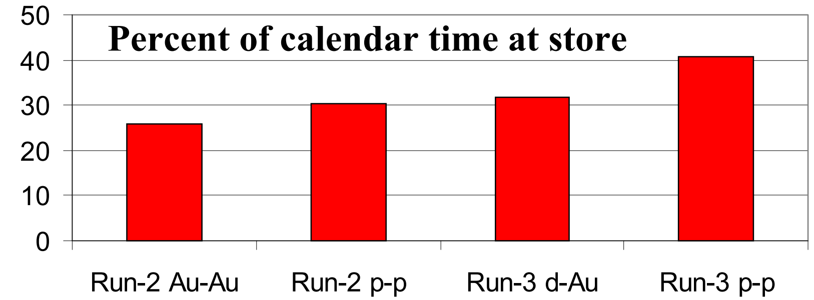
Integrated Au-Au luminosity



Performance summary

- Energy/beam: 100 GeV/nucl.
- Diamond length: σ = 20 cm

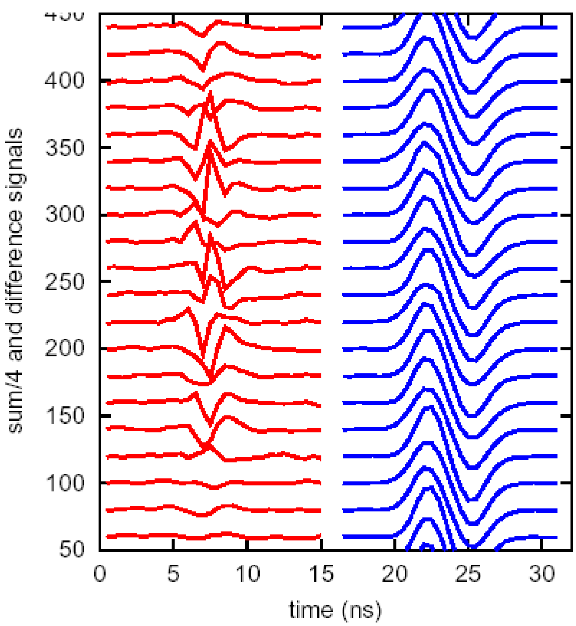


Mode	# bunches	Ions/bunch [10^9]	β* [m]	Emittance [πμm]	L_{peak} [$cm^{-2}s^{-1}$]	L_{ave}(store) [$cm^{-2}s^{-1}$]	L_{ave} (week) [$week^{-1}$]
Au-Au (*) [Run-2]	55	0.7	1	15 - 40	5×10^{26}	1.5×10^{26}	24 $(\mu b)^{-1}$
d-Au (*) [Run-3]	55	110(d), 0.7(Au)	2	15	7×10^{28}	2.0×10^{28}	4.5 $(nb)^{-1}$
p↑-p↑ (*) [Run-3]	55	70	1	20 - 30	6×10^{30}	3×10^{30}	0.6 $(pb)^{-1}$
d-Au (max. goal)	56	80(d), 1(Au)	2	20	4×10^{28}	1.6×10^{28}	4 $(nb)^{-1}$
p↑-p↑ (max. goal)	112	100	1	25	16×10^{30}	10×10^{30}	2.8$(pb)^{-1}$
Au-Au RHIC design	56	1	2	15 - 40	9×10^{26}	2×10^{26}	50 $(\mu b)^{-1}$
p-p RHIC design	56	100	2	20	5×10^{30}	4×10^{30}	1.2 $(pb)^{-1}$
p↑-p↑ RHIC spin	112	200	1	20	80×10^{30}	65×10^{30}	20$(pb)^{-1}$

[(*) Best store or last week]

Luminosity Limitations (1)

- Injector performance (routine):
  - Au 0.7 × 10^9 /bunch 10 π µm 0.3 eVs
    - additional bunch merge
  - p 0.8 × 10^{11} /bunch 10 π µm 0.3 eVs 40%
  - p 2.0 × 10^{11} /bunch 20 π µm 0.5 eVs 20% (?)
    - strong AGS partial snake, thinner H^- stripping foil
- Single bunch instabilities around transition:
  - Effect of vacuum chamber impedance, electron cloud (?)
  - Au: < 0.8 × 10^9 ions/bunch
    - cross zero-chromaticity before transition (why?)
- Vacuum break-down due to ion desorption (?)
  - Au: < 40 × 10^9 ions/ring
    - More baking, scrubbing, NEG coating
- Vacuum problem due to halo scrapping around transition (?)
  - Total accelerated charge in both rings < 10^{13} e
    - More baking, scrubbing, NEG coating



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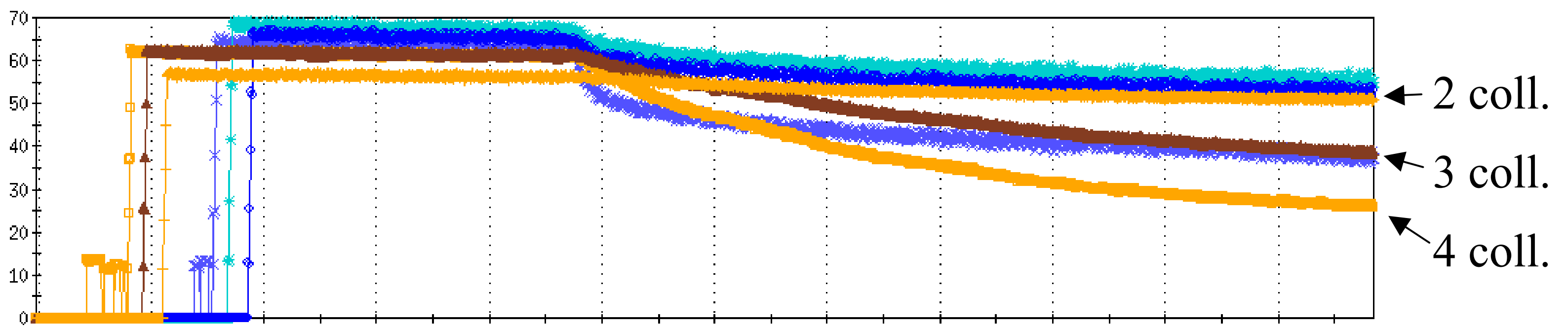
Luminosity Limitations (2)

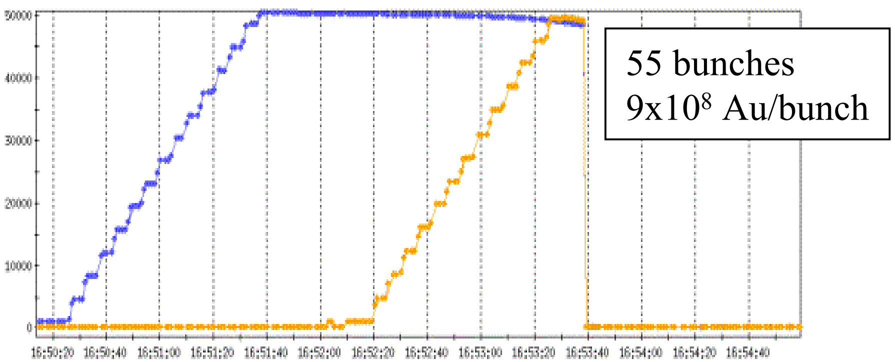
- Electron multi-pacting (electron cloud)
  - Total charge per ring less than ~ 10^{13} e, worse for 110 bunches
    - Solenoids, scrubbing, NEG coating
- Beam-beam tune shift and spread
  - First strong-strong hadron collider (after ISR)
  - Limits high luminosity pp operation to two IRs
    - Non-linear corrections, better working point

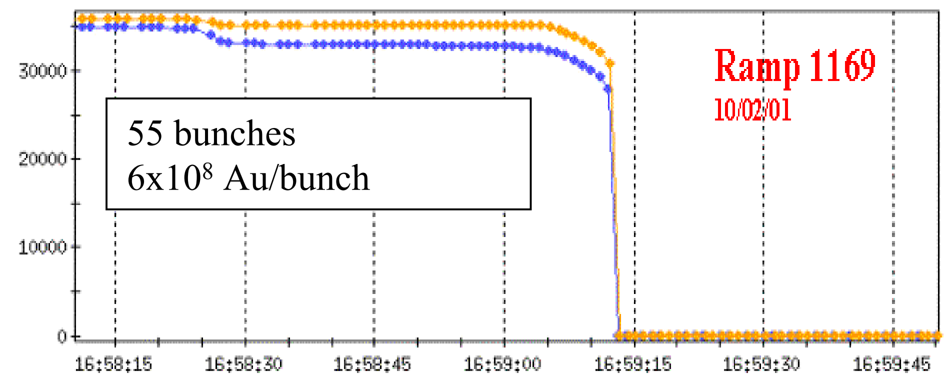


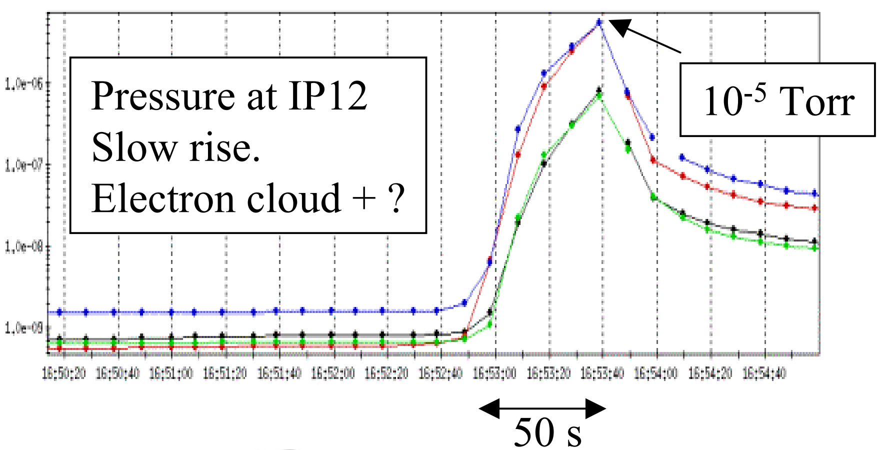
- Intra-Beam Scattering (IBS)
  - Transverse and longitudinal emittance growth
  - Eventually will need electron cooling (see below)

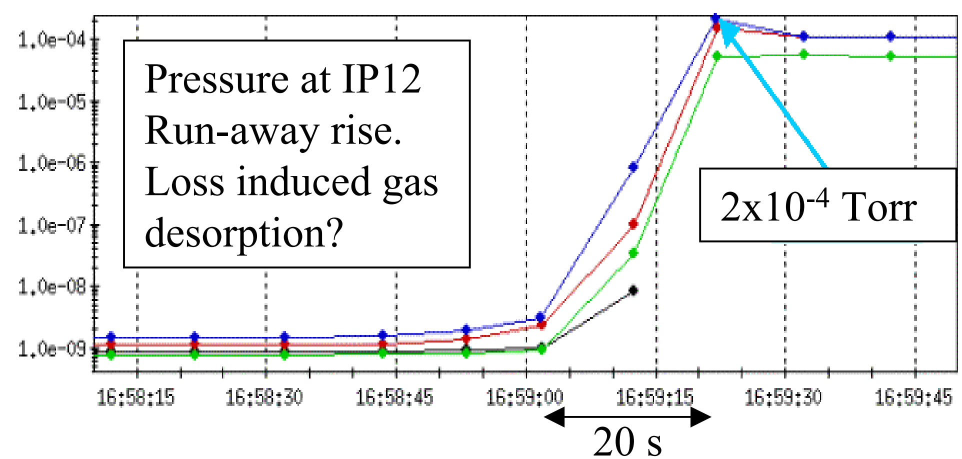
Vacuum break-down

- Mainly in warm sections that didn't have bake-out; worse with 110 bunches/ring
- Ion desorption, electron desorption, electron multi-pacting, electron cloud
- Installed electron detectors in IP12 and IP2 and solenoids for electron suppression in IP12.
- "scrubbing" with beam, NEG coated vacuum chambers









NEG coating

- NEG strips first used in TTB(BNL) and LEP(CERN)
- Non-Evaporable Getter coating: $Ti_{30}\ Zr_{30}\ V_{40}$ sputtered ~ 1 μm thick onto walls
- Developed at CERN for LHC warm sections
- Ultimate pressure < 10^{-12} Torr
- Activation: 1 h @ 250º C, 5 h @ 200º C, 24 h @ 180º C
- Secondary Electron Yield (SEY): 1.1 after activation of 2 h @ 200º C
  Strong suppression of multi-pacting (tested at SPS)
- Electron stimulated gas desorption: ~ 100 times lower than baked SS
- Ion stimulated gas desorption: ~ 10 times lower than SS (tested with 4.2 MeV/n Pb)
- **Test at RHIC: install 60 m of coated pipe, test ion desorption at Tandem**

- ICFA Mini-Workshop at BNL:
  Beam Induced Pressure Rise in Rings
  December 9-12, 2003

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Assumptions for RHIC Collider Projections

- For each mode: 2 weeks set-up and 3 weeks ramp-up
- Collisions available for trigger set-up during owl shifts of ramp-up period
- Luminosity development to continue for about an additional 14 weeks during day shifts from Monday to Friday

5-year luminosity projections:

- At least 5+14 weeks of operation of each mode for luminosity development per year
- Collisions at only two interaction regions for pp operation
- Upgrade projects need to be completed

Projected Run-4 Luminosities

Achieved:

Mode	# bunches	Ions/bunch $[10^9]$	β* [m]	Emittance [μm]	L_{peak} $[cm^{-2}s^{-1}]$	$L_{store\ ave}$ $[cm^{-2}s^{-1}]$	L_{week}
Au-Au	55	0.6	1	15-40	3.7×10^{26}	1.5×10^{26}	24 $(\mu b)^{-1}$
(p↑-p↑)	55	70	1	20	6.0×10^{30}	3.0×10^{30}	0.6 $(pb)^{-1}$

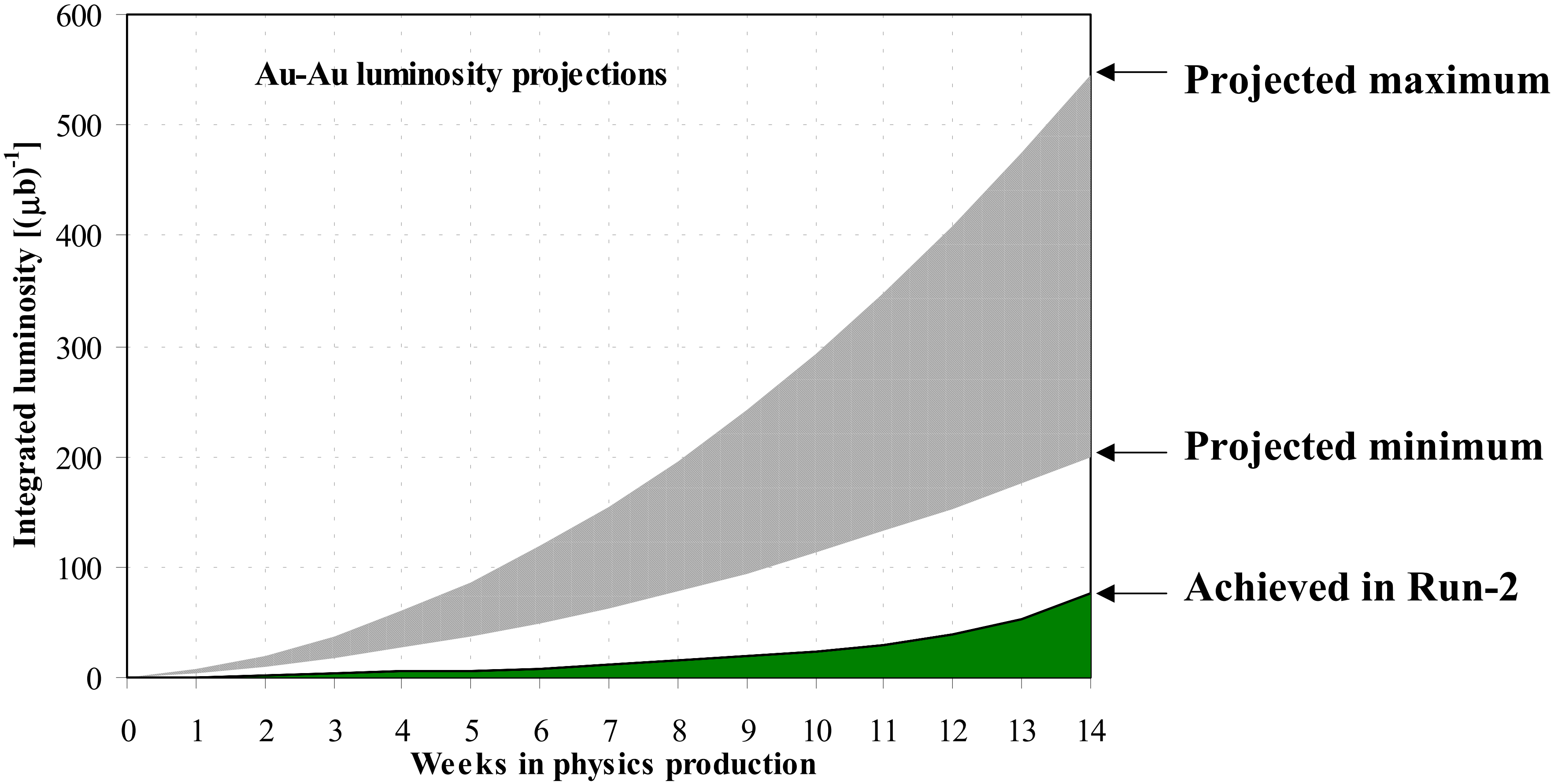
Maximum expectations:

Mode	# bunches	Ions/bunch $[10^9]$	β* [m]	Emittance [μm]	L_{peak} $[cm^{-2}s^{-1}]$	$L_{store\ ave}$ $[cm^{-2}s^{-1}]$	L_{week}
Au-Au	56	0.9	1	15-40	12×10^{26}	3×10^{26}	70 $(\mu b)^{-1}$
(p↑-p↑)	56	100	1	20	11×10^{30}	6×10^{30}	1.4 $(pb)^{-1}$
Si-Si	56	7	1	20	5×10^{28}	2×10^{28}	5 $(nb)^{-1}$

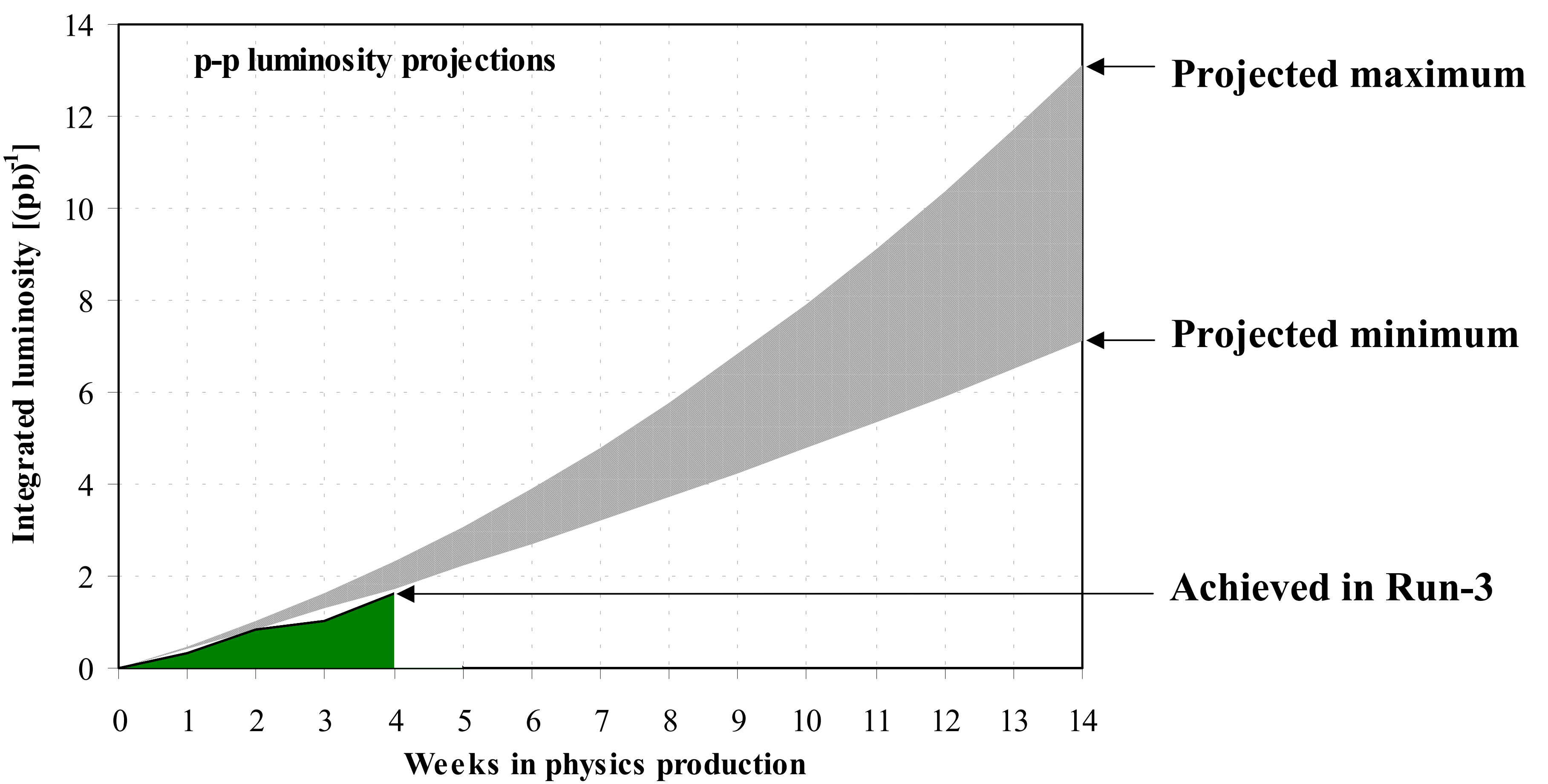
Integrated luminosity for 1 or 2 modes:

Mode	Integrated luminosity per mode			
	1 Mode (19 weeks)		2 Modes (7 weeks/mode)	
	Minimum	Maximum	Minimum	Maximum
Au-Au	320 $(\mu b)^{-1}$	895 $(\mu b)^{-1}$	63 $(\mu b)^{-1}$	155 $(\mu b)^{-1}$
(p↑-p↑)	10 $(pb)^{-1}$	20 $(pb)^{-1}$	3.2 $(pb)^{-1}$	4.8 $(pb)^{-1}$
Si-Si	?	65 $(nb)^{-1}$	?	12 $(nb)^{-1}$

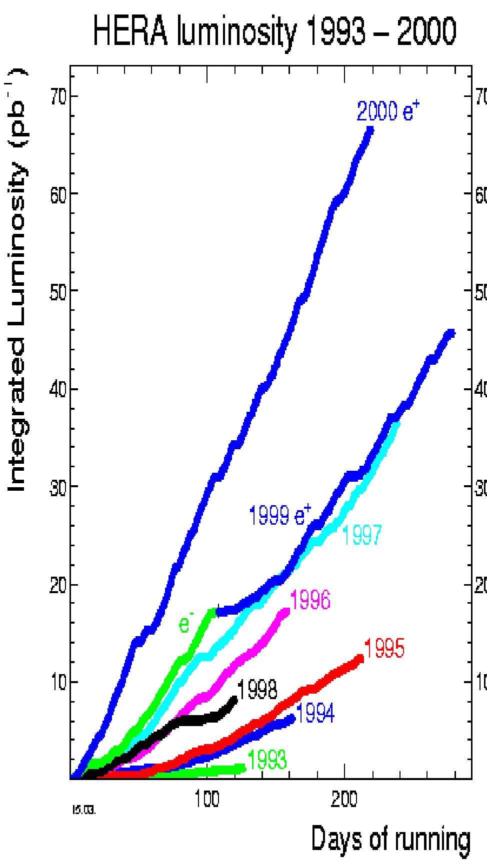
Projected Run-4 Au-Au Luminosity Evolution

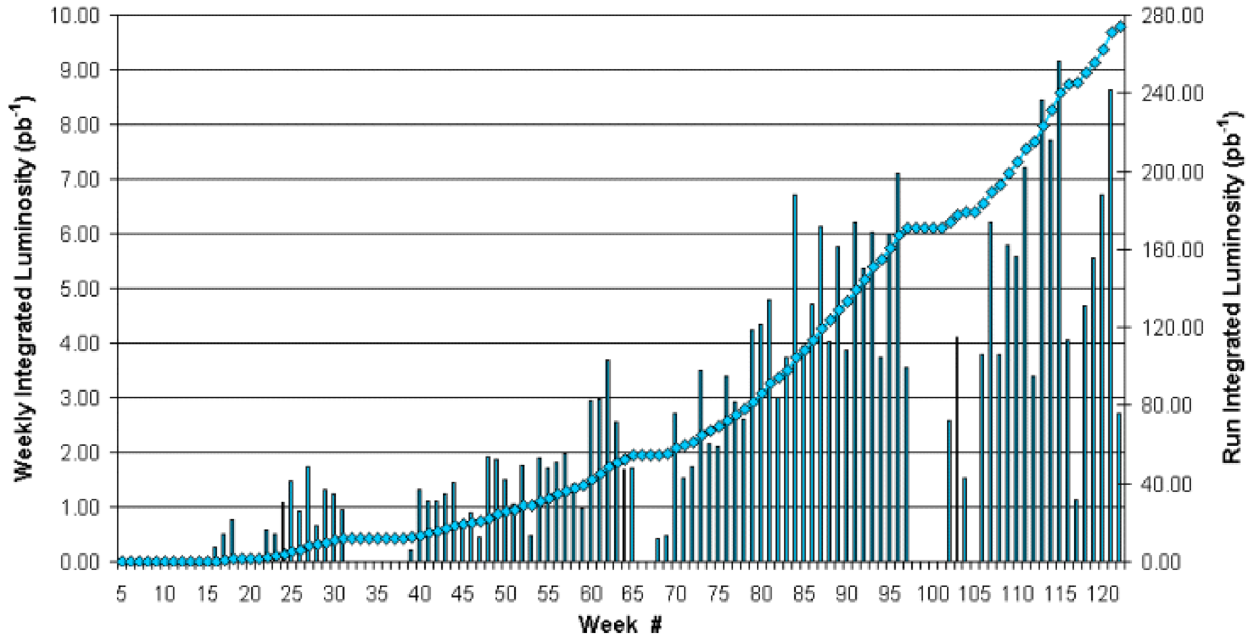


Projected Run-4 p - p Luminosity Evolution



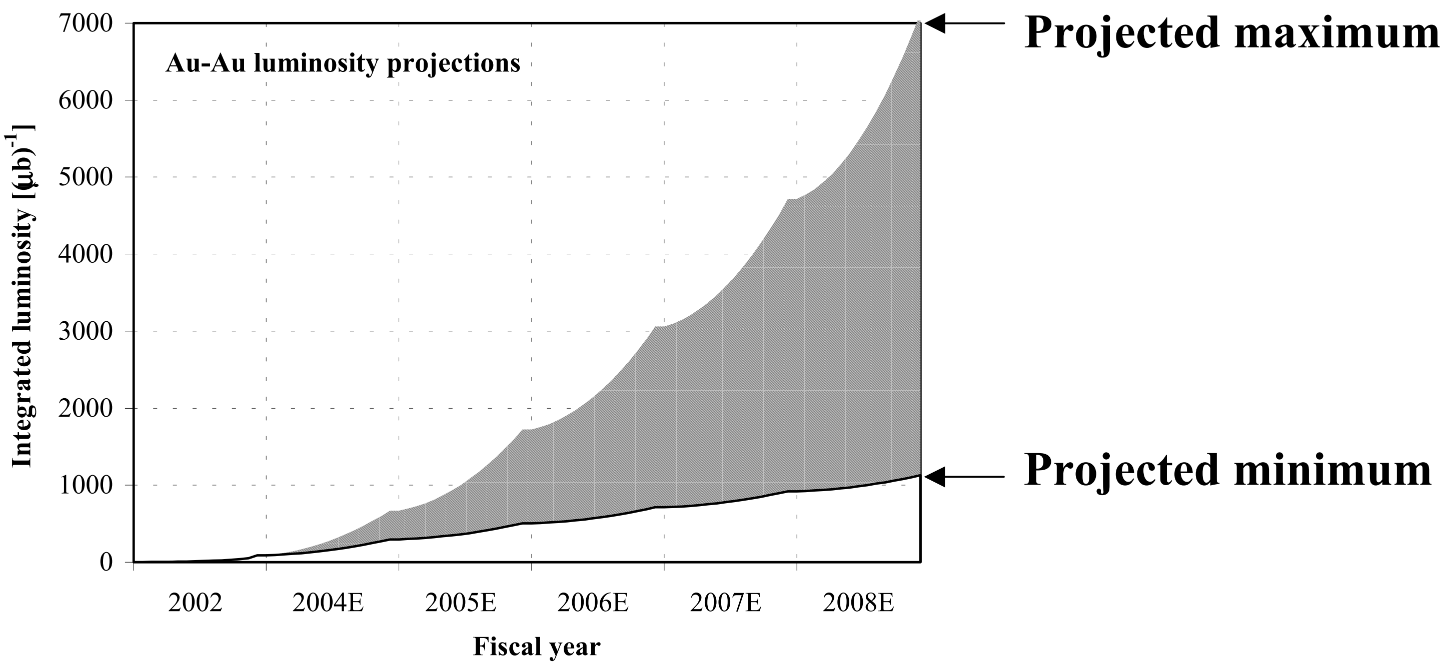
HERA and Tevatron luminosity evolutions





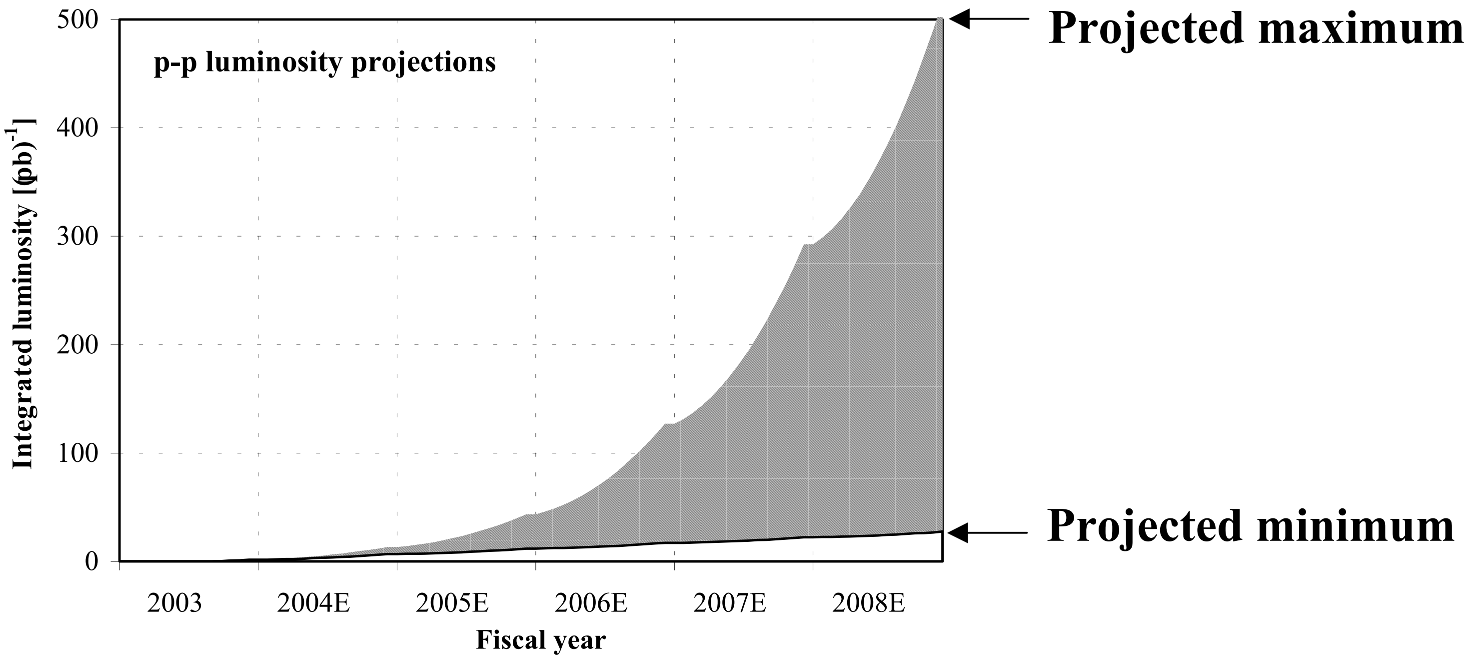
14 weeks

Projected 5-year Au-Au Luminosity Evolution



Fiscal year		2002A	2004E	2005E	2006E	2007E	2008E
No of bunches	…	55	56	70	80	90	112
Ions/bunch, initial	10^9	0.7	0.9	1.0	1.0	1.0	1.0
Average beam current/ring	mA	38	49	69	79	89	114
β*	m	1	1	1	1	1	1
Peak luminosity	10^{26} cm^{-2}s^{-1}	5	12	19	21	24	32
Average store luminosity	10^{26} cm^{-2}s^{-1}	1.5	2.9	4.7	5.3	6.0	8.0
Time in store	%	25	40	45	50	55	60
Maximum luminosity/week	(μb)$^{-1}$	25	70	127	161	199	290
Minimum luminosity/week	(μb)$^{-1}$		25	25	25	25	25
Maximum integrated luminosity	(μb)$^{-1}$	89	580	1050	1340	1660	2410
Minimum integrated luminosity	(μb)$^{-1}$		210	210	210	210	210

Projected 5-year p - p Luminosity Evolution



Fiscal year		2002A	2003A	2004E	2005E	2006E	2007E	2008E
No of bunches	…	55	55	56	56	56	90	112
Ions/bunch, initial	10^{11}	0.7	0.7	1.0	1.4	2.0	2.0	2.0
Average beam current/ring	mA	48	48	70	98	140	225	280
β*	m	3	1	1	1	1	1	1
Peak luminosity	10^{30} cm^{-2}s^{-1}	2	6	11	22	45	72	89
Average store luminosity	10^{30} cm^{-2}s^{-1}	1.5	3	6	13	32	57	72
Time in store	…	30	41	40	45	50	55	60
Maximum luminosity/week	(pb)$^{-1}$	0.2	0.6	1.4	3.5	10	19	26
Minimum luminosity/week	(pb)$^{-1}$			0.6	0.6	0.6	0.6	0.6
Maximum integrated luminosity	(pb)$^{-1}$	0.5	1.6	12	30	84	165	224
Minimum integrated luminosity	(pb)$^{-1}$			5	5	5	5	5
AGS polarization at extraction	%	35	45	55	65	75	80	80
RHIC store polarization, peak	%	25	35	45	60	70	75	75
RHIC store polarization, average	%	15	30	40	55	65	70	70

Major RHIC Improvements

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				

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5-year projections for 27 weeks

Fiscal Year	2003	2004	2005	2006	2007	2008
PHENIX	d+Au 200 GeV 16 weeks, 2.7 nb-1 p+p 200 GeV 10 weeks, 0.35 pb-1 27%	Au+Au 200 GeV 5+14 weeks, 123 ub-1 p+p 200 GeV 5+0 weeks beam development	Si+Si 200 GeV 5+9 weeks, 2.2 nb-1 p+p 200 GeV 5+5 weeks, 1.2 pb-1 50%	Au+Au 62.4 GeV 5+19 weeks, 45 ub-1	p+p 200 GeV 5+19 weeks, 62 pb-1 60%	Au+Au 200 GeV 5+19 weeks, 840 ub-1
STAR	d + Au 38.2M 5+11 weeks ; pp 10 weeks : T 0.39 pb^{-1} L 0.37 pb^{-1}	AuAu 5+14 pp 200 GeV 5 wk	Au or Fe 5+9 Energy scan pp 200 GeV 5+5 wk	d + Au 5+9 pp 200 GeV 5+5 wk	AuAu 5+5 pp 200 GeV 5+9wk	AuAu 5+10 pp 500 GeV 5+5wk
PHOBOS		AuAu@200 5+10(18) FeFe@200 5+4(6)	pp@200 5+7(12) AuAu@63 5+7(12)	pp@500 8+4 Add. Species Add. Energy	Possible additional running to make up shortfalls	-------------
BRAHMS		Au-Au 200 5+19	Fe-Fe 200 5+5 pp 200 5+4	Au-Au 63 2+6 Au-Au 200 2+5 pp 200 5+4	-----------	-------------

Comments on 5-year BUPs (1)

- Currently C-AD sees its main effort in developing luminosity. If frequent mode changes are essential for the physics program, efforts could be redirected towards shortening the setup time. With frequent mode changes luminosities will be greatly reduced.
- The RHIC Run Projections assume that only 2 experiments run in p-p mode. To serve 4 experiments with p-p collisions, the requested p-p time needs to be doubled. This is not taken into account in the Beam Use Proposals. Alternatively, 4 experiments can be run simultaneously with luminosities reduced by at least a factor 2.
- All experiments request at some point short p-p runs of about 4-5 weeks. Although there may be good reasons for these runs, it should be understood that it is difficult to develop the luminosity under these conditions. With the total time requested until 2008 it is not possible to accumulate an integrated luminosity of a few 100 $(pb)^{-1}$.
- Three or more different modes during one run stretch the current C-AD resources beyond acceptable limits. The setup of a new mode requires a considerable effort of a number of people.
- The set-up time for collisions at injection is considerably shorter than at any other energy. The time in store is significantly increased due to the increased quench resistance and the reduced overhead from ramping. The luminosity, however, is reduced by close to 2 orders of magnitude compared to collisions at top energy.

Comments on 5-year BUPs (2)

BRAHMS

- Currently β* at Brahms is limited to 3m. Brahms could be operated at a β* smaller than 3m if additional interaction region correctors were powered. So far, no funds were made available to buy and install the needed power supplies.

PHENIX

- Generally long runs with few mode changes are requested. This will yield the highest possible integrated luminosities.
- The integrated luminosity for Au-Au operation at 31.2 GeV beam energy in Run-6 is on the optimistic side.

PHOBOS

- The PHOBOS experiment currently sets the loss thresholds leading to an abort on the ramp, and additional radiation limits during store. In the last run, those limits have affected the number of successful ramps, and the time in store. A careful review of these thresholds is requested. (done)

STAR

- In Star's BUP there is no table with the expected integrated luminosities. For p-p collisions, up to 30 $(pb)^{-1}$/week are mentioned in the text, beyond even the most optimistic projections in FY2008. Note that 30 $(pb)^{-1}$/week is 50 times more than the demonstrated weekly luminosity. This cannot be achieved with the short running times for p-p in this proposal.
- In Run-5 Au-Au operation at 20 GeV/u is requested. This is close to the transition energy and may require extra care.

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5-year projections for 27 weeks

Fiscal Year	2003	2004	2005	2006	2007	2008
PHENIX						
Ops Costs	$6.0M (24K/wk)	6.3M (27K/wk)	6.6M (42K/wk)	6.8M (42K/wk)	7.1M (42K/wk)	7.4M (42K/wk)
R&D	$0.12M	1.15M	0.95M	0.6M	---	---
Ops Equip.	$0.5M	0.5M	0.5M	0.5M	0.5M	0.5M
Res. Equ.			2.85M VTXb, HBD, DAQ	2.95M VTXb, HBD, DAQ	4.2M VTXb/e, TPC, DAQ	4.5M VTXe, TPC
STAR						
Ops Costs	$5.9M (38K/wk)	6.4M (40K/wd)	6.7M (41K/wk)	7.0M (43K/wk)	7.3M (45K/wk)	7.6M (47K/wl)
R&D	$0.12M	1.14M	1.73M	1.28M	0.3M	---
Ops Equip.	$0.49M	0.6M	0.45M	0.45M	0.25M	0.25M
Res. Equ.	$3.0M BEMC [$1.5M EEMC]	2.7M BEMC, EEMC	2.0M TOF	5.0M TOF, MVTX, FTU	8.5M MVTX, DAQ, FEE, FTU	4.5M MVTX, DAQ, FEE, TPC
PHOBOS						
Ops Costs	$0.75M (10K/wk)	0.89M (10K/wk)	0.92M (10K/wk)	0.96M (11K/wk)	1.0M (11K/wk)	-------------
Ops Equ.		0.1M	0.1M	0.1M	----	
BRAHMS						
Ops Costs	$0.78M (10K/wk)	0.8M (10K/wk)	0.8M (10K/wk)	0.8M (10K/wk)	-----------	-------------
Ops Equ.		0.11M	0.1M	0.075M		
RCF						
Ops Costs	$5.18M	5.78M	6.45M	6.71M	6.98M	7.26M
Ops Equ.	$2.0M	2.0M	3.4M	2.0M	2.0M	2.0M
C-AD						
Ops Costs	$89.7M (580K/w)	90.3 (600K/wk)	93.6M (620K/wk)	101.1M (800K/w)	104.6M (820K)	105.9M (850K)
R&D	$0.9M	2.0M	3.0M	2.0M	2.1M	2.2M
Ops Equip.	$4.4M	4.5M	4.9M	5.1M	5.4M	5.6M
Res. Equ.	---	---	2.5M EBIS	2.6M EBIS	2.7M EBIS	---
ALD/Users	$0.86M	0.90M	0.93M	0.97M	1.00M	1.05M
Totals						
Ops costs	$109.2M (662K)	$111.4M (687K)	$116.0M (723K)	$124.3M (906K)	$128.0M (920K)	$129.2M (939K)
R&D	$1.1M	$4.3M	$5.7M	$3.9M	$2.4M	$2.2M
Ops Equip.	$7.4M	$7.8M	$9.45M	$8.2M	$8.15M	$8.35M
Ops Total	**$117.7M**	**$123.5M**	**$131.2M**	**$136.4M**	**$138.5M**	**$139.8M**
	Actual: $118.0M	Pres: $121.1M				
Res. Equ.	$3.0M	$2.7M	$7.35M	$10.55M	$15.4M	$9.0M