RHIC Heavy Ion Operations

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DOE RHIC Program Science and Technology Review
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- FY05 Cu-Cu Run Summary
- Achieved Parameters and Status
- Operations Efficiency
- Luminosity Improvements

BROOKHAVEN
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FY05 Cu-Cu Run Results

- All experiments had a successful $\sqrt{s}$=200 GeV/n Cu-Cu run
- Delivered 15 nb^{-1} with 200 GeV/n top energy collisions
  - More than twice the large-experiment goal of 7 nb^{-1}
  - Exceeded maximum luminosity projections
- Setup and ramp-up time with beam was 2.5 weeks
  - Significantly shorter than planned 4 weeks

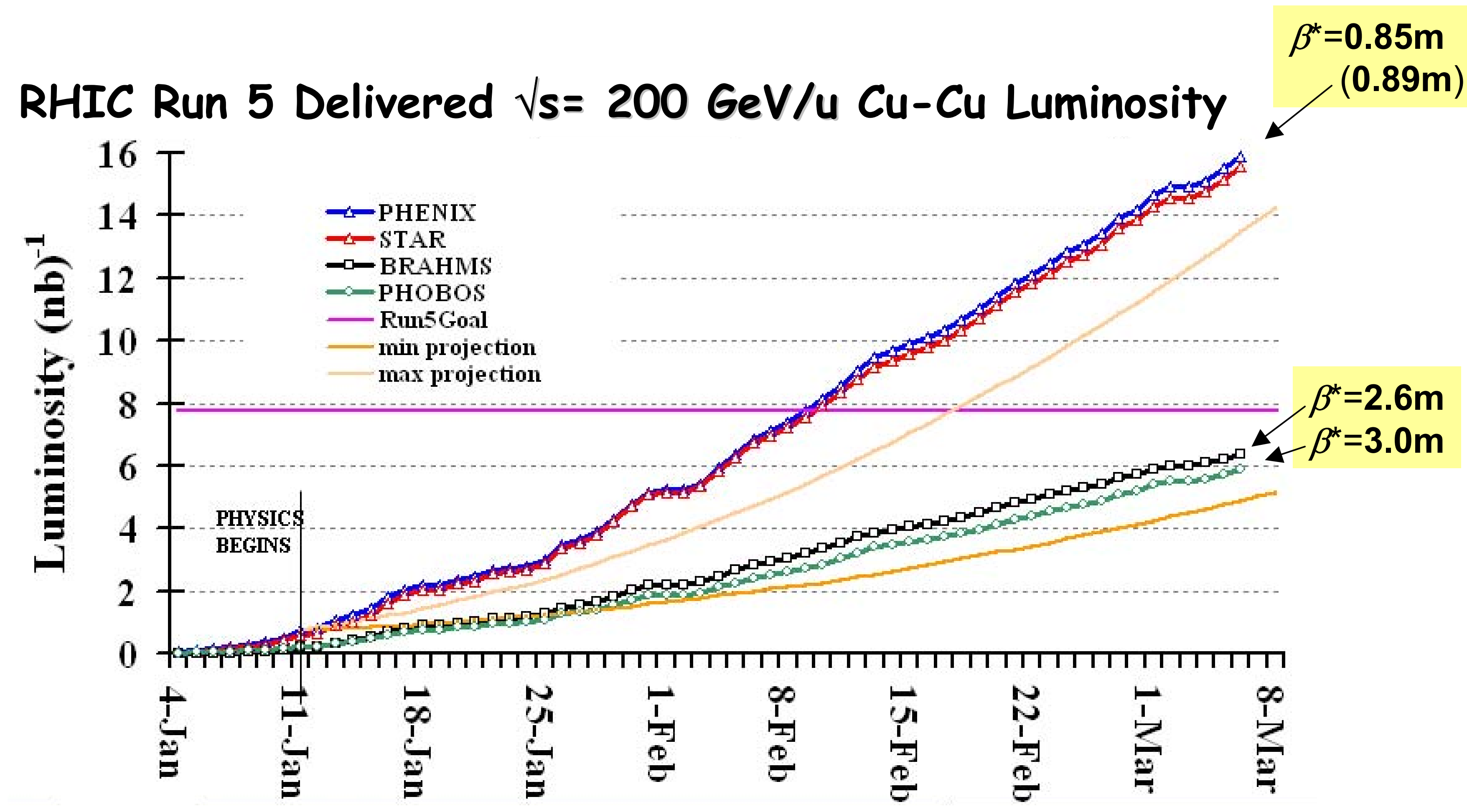
- Multiple successful lower-energy runs with Cu-Cu
  - Successful 2 week run at $\sqrt{s}$= 62.4 GeV/n medium energy
    - Setup in only 2 days
  - Successful 1 day run at $\sqrt{s}$= 22 GeV/n injection energy

Run-5 Heavy Ion Chronology

Aug 16	Choice of ion
Sep 7	Start cool-down to 80K
Nov 15	Start injector setup for Cu
Nov 18	Start cool-down to 4K
Nov 22	Beam circulating in injection in blue (54 min)
Dec 1	Bus shorts discovered in yellow ring
Dec 4-21	Warm-up, repair, cool-down
Dec 23-25	Restart beam ops, blue ramps 95% trans
Dec 28	Setup-starts, both beams – yellow obstruction
Dec 31	Both rings at store
Jan 4	Ramp-up starts, overnight collisions
Jan 11	$\sqrt{s}$= 200 GeV/n physics starts
Mar 7-22	$\sqrt{s}$= 62 GeV/n setup (2.5 days) and physics run
Mar 23	$\sqrt{s}$= 22 GeV/n injection energy run

2 weeks

Run-5 Cu-Cu Integrated Luminosity



(calendar) time at store: 53%

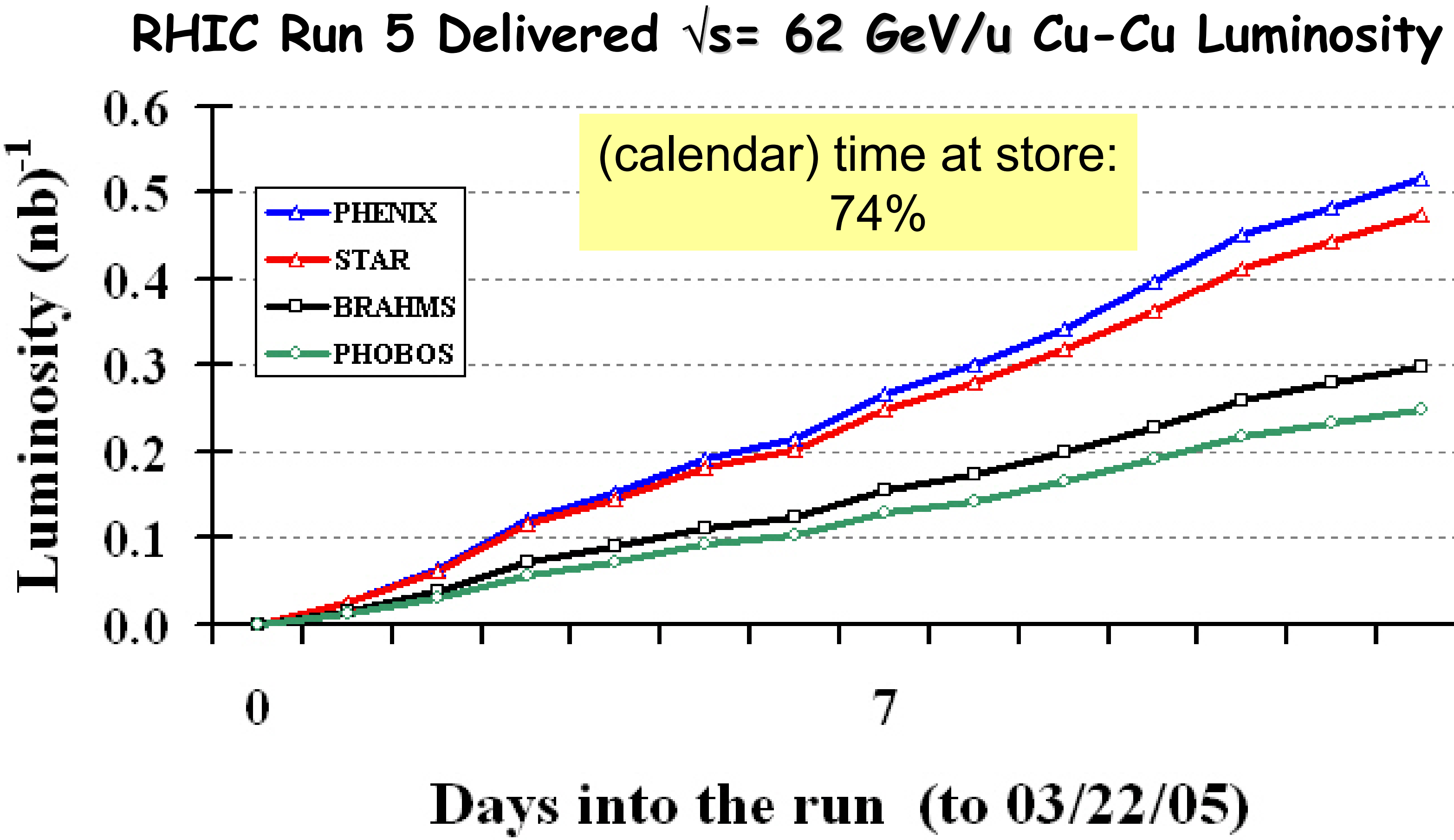
Cu-cu ZDC cross section measured at 2.6 barn

Cu-Cu Projections vs Performance

- Factors for exceeding performance
  - Average luminosity prediction (8×10^{27} cm^{-2} s^{-1}) and slope were quite accurate
  - Beta squeeze from 1m to 0.85 m (measured 1.1 m to 0.89 m)
  - In-run optimization of intensity and number of bunches
  - Luminosity ramp-up faster than projection model
    - Achieved peak luminosity about 2 weeks into run

- Luminosity dents
  - January snowstorm
  - Access + winter power dip
  - Access + series of equipment failures
    - Reviewing access and maintenance schedules with experiments to minimize program impact

Run-5 Cu-Cu Integrated Luminosity



High Energy vs Low Energy Cu Runs

- All experiments had successful Cu-Cu low-energy runs
  - Low energy (LE) 62.4 GeV/n and injection energy 22 GeV/n

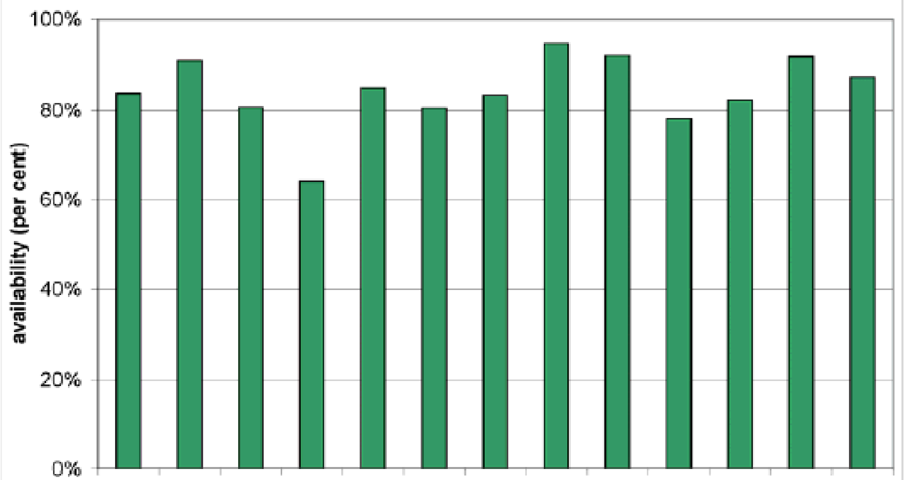
- Observables

Time at store	HE: 53%	LE: 74%
Luminosity lifetime	HE: 3.5 hours	LE: 6 hours
Time between stores	HE: 75 minutes	LE: 30 minutes

- Variables: Machine Parameters

Number of bunches	37-41 (limited by pressure rise)	
Transmission	85-95%	
Bunch Intensity	HE: $41 \times 4.5 \times 10^9$	LE: $37 \times 3.8 \times 10^9$
β^*	HE: 0.85m	LE: 3m
Energy ($\sqrt{s}$)	HE: 200 GeV/n	LE: 62.4 GeV/n

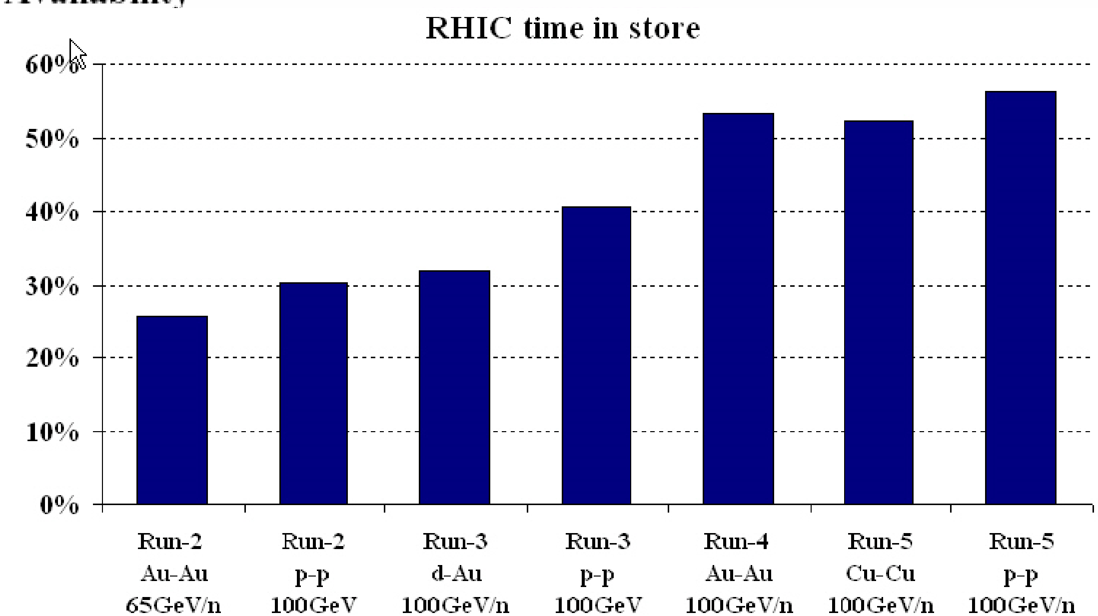
RHIC Availability and Time in Store



FY05Q2 Weekly Availability

Excellent availability (82%) despite very complex operational modes.

Machine setup time reduced to 2.5 weeks.

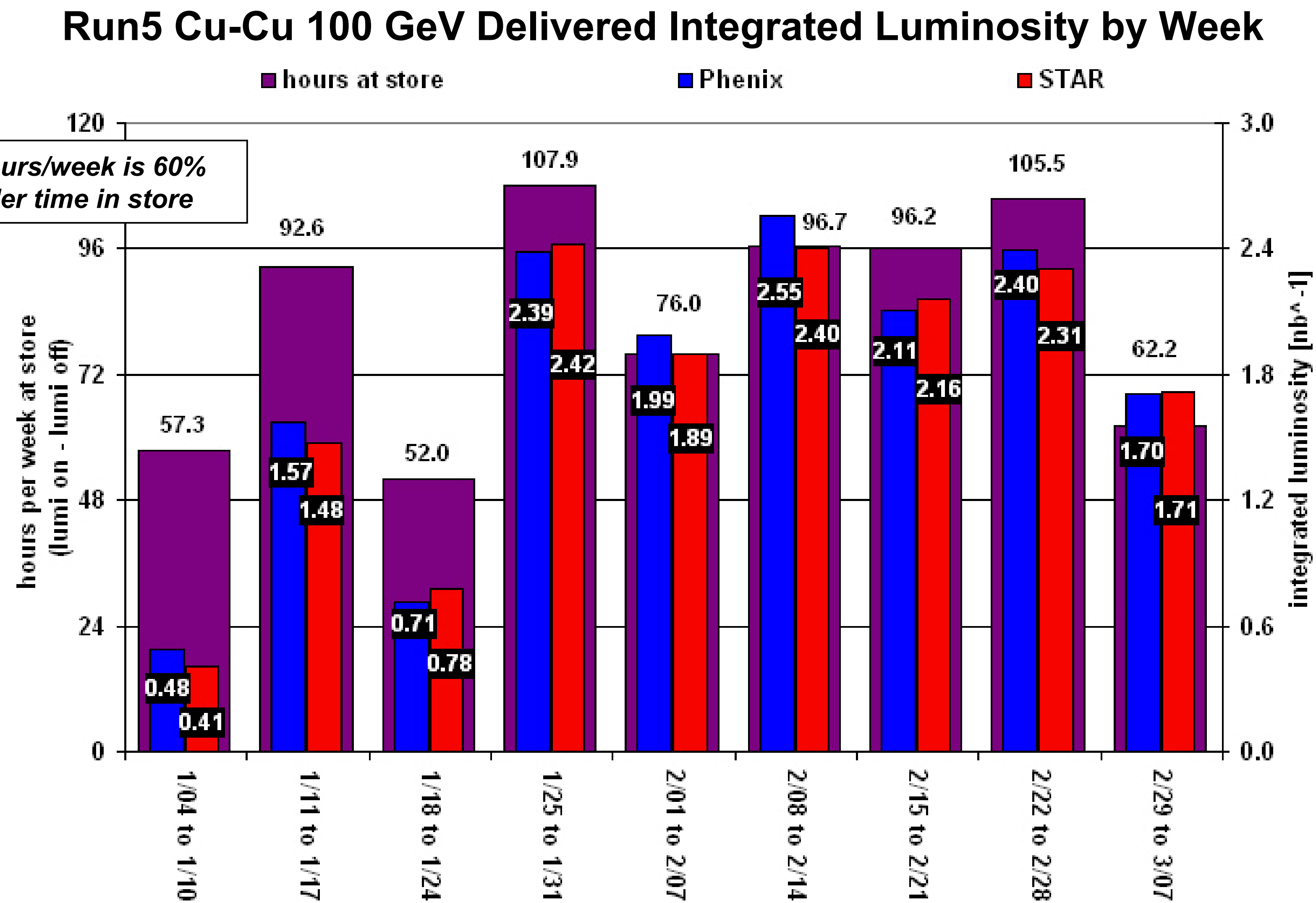


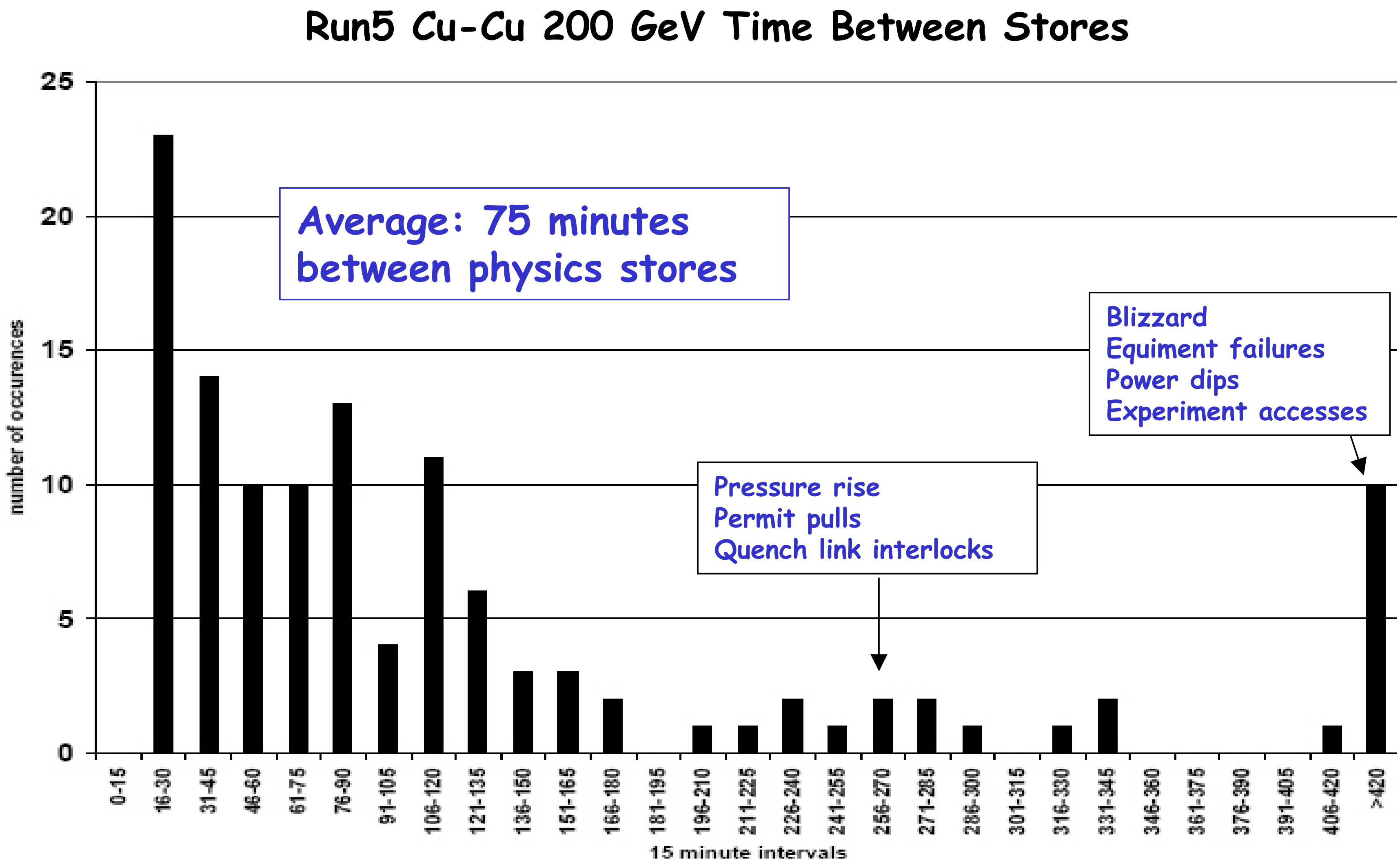
Time in store (53%) comparable to successful Au-Au Run-4 run

Goal is 60% time in store

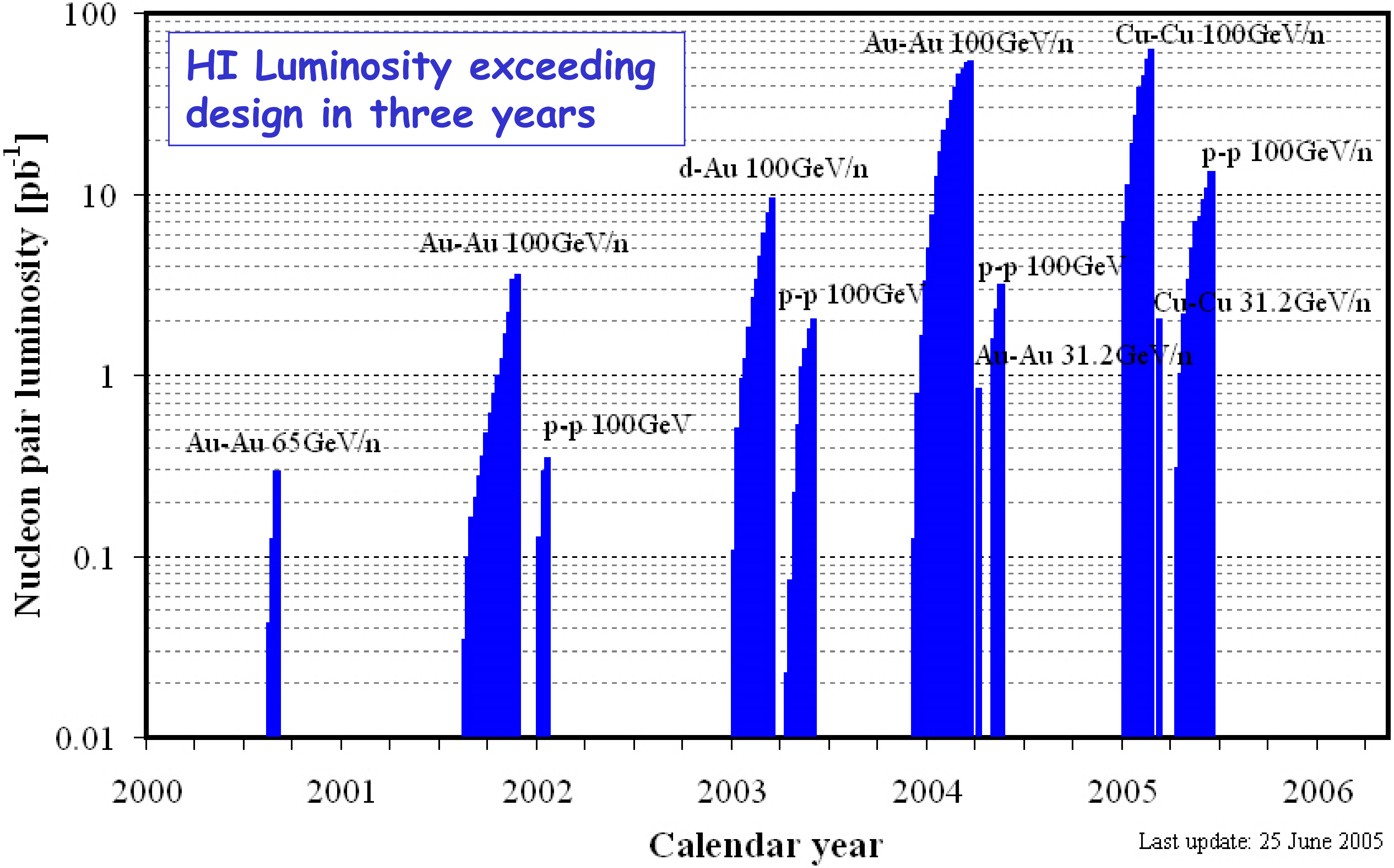
Weekly Cu-Cu Luminosity and Physics Time

101 hours/week is 60%
calender time in store




Run5 Cu-Cu 200 GeV Time Between Stores
number of occurences
15 minute intervals
0
5
10
15
20
25
0-15
16-30
31-45
46-60
61-75
76-90
91-105
106-120
121-135
136-150
151-165
166-180
181-195
196-210
211-225
226-240
241-255
256-270
271-285
286-300
301-315
316-330
331-345
346-360
361-375
376-390
391-405
406-420
>420
Average: 75 minutes between physics stores
Pressure rise
Permit pulls
Quench link interlocks
Blizzard
Equiment failures
Power dips
Experiment accesses

Nucleon-pair luminosity A_1A_2L delivered to PHENIX



RHIC HI Achieved and Planned Parameters

Mode	No of bunches	Ions/bunch $[10^9]$	β^* [m]	$L_{store\ ave}$ $[cm^{-2}s^{-1}]$	$A_1A_2L_{store\ ave}$ $[cm^{-2}s^{-1}]$	$A_1A_2L_{store\ peak}$ $[cm^{-2}s^{-1}]$
Au-Au design	56	1.0	2	2×10^{26}	8×10^{30}	31×10^{30}
d-Au [Run-3]	55 (110)	120d/0.7Au	2	3×10^{28}	6×10^{30}	24×10^{30}
Au-Au [Run-4]	45	1.1	1	4×10^{26}	16×10^{30}	58×10^{30}
Cu-Cu [Run-5]	36	4.5	0.85	80×10^{26}	32×10^{30}	79×10^{30}
Au-Au enhanced	112	1.0	1	8×10^{26}	32×10^{30}	124×10^{30}

For $\sqrt{s}$=200 GeV/n Au-Au, the enhanced luminosity goal (c. 2008, before electron cooling) is

$$L_{store\ ave} = 8\times10^{26}\ cm^{-2}\ s^{-1}$$

4x design

2x achieved

Luminosity Limitations for RHIC HI

- Beam-Beam (maximize bunch intensity)
  - Excellent Cu injector intensity performance (5×10^9 ions/bunch)
    - Cu-Cu FY05 operated near beam-beam limit
- Electron cloud pressure rise (maximize bunch number)
  - Pressure rise in IR10 after rebucketing ⇨ 43x43 bunches
  - Transition pressure rise at IR4 ⇨ 45x45 bunches
- Intrabeam scattering (IBS)
  - Longitudinal cooling, debunching ⇨ stochastic cooling
  - Transverse cooling, luminosity lifetime ⇨ electron cooling
- Experiment backgrounds
  - Improve shielding, collimation efficiencies
- Operational efficiency
  - Expect only small improvements from time in store
    - About 55% of calendar time in Au-Au, Cu-Cu, pp
  - Expect to reach peak performance 2-4 weeks into run

Electron Cloud Pressure Rise

- All operationally relevant dynamic pressure rise effects in RHIC can be explained with electron clouds
  - Abnormally large beam losses also lead to desorption and unacceptable vacuum pressure rise
  - Particularly problematic with short bunch lengths (transition, rebucketing)
- Electron cloud driven pressure rises have been observed
  - With all species (Au, d, p, Cu)
  - In warm and cold regions
  - At injection, transition, and store
- Countermeasures include
  - Warm areas: NEG pipe installation, baking
  - Cold areas: Pre-pumping before cooldown

NEG Beam Pipe Installation

NEG pipes clearly benefit RHIC operations (pumping, low SEY)

57 m installed in 2003

195 m installed in 2004 (shown)

- 15 warm sections, mostly Q3-Q4

All NEG tubes are

- baked at 100C for > 40 hours
- activated at 250 C for 1 hour

Another ~150 m planned in 2005

- 21 warm sections

IR10, BO3, YI3, BI4, YO4, YI11, YO12

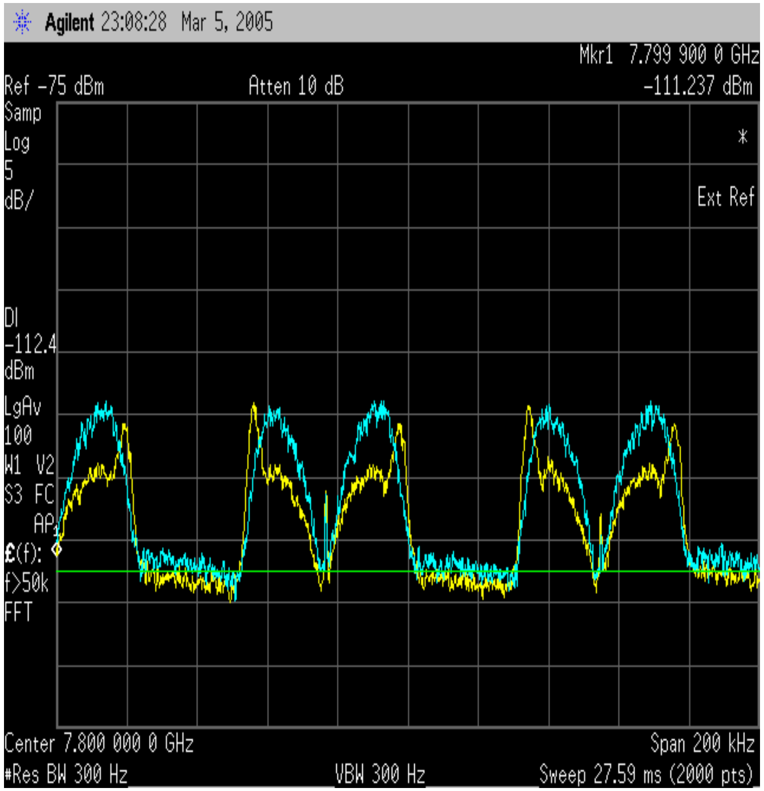
All NEG-coated beam tubes for 2005 shutdown installation are in hand

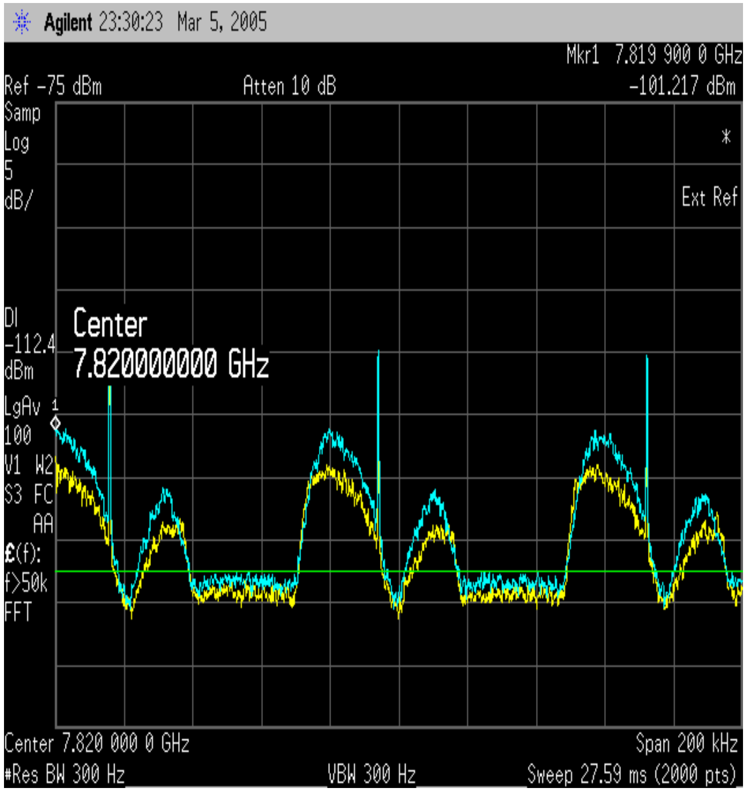
NEG Beam tube Locations for Run 2005

Sect #	L(m)	S(m)	Sect #	L(m)	S(m)
YO1	3.95	48 - 52	BO7	5.2	39 - 44
	1.7	57 - 59		3.1	44 - 47
	5.2	60 - 65		5.2	49 - 54
	4.05	66 - 70		5.2	54 - 59
YI2	1.23	39 - 40	YO8	5.2	39 - 44
	1.61	41 - 43		3.1	44 - 47
	5.2	44 - 49		5.2	49 - 54
	1.45	49 - 51		5.2	54 - 59
	4.93	56 - 61	BI8	1.24	39 - 40
	5.2	61 - 66		5.2	42 - 47
	1.9	70 - 72		1.78	48 - 50
BO2	3.95	48 - 52		4.17	52 - 56
	1.7	57 - 59	BI9	10.4	40 - 50
	5.2	61 - 66		5.2	50 - 55
YO4	5.2	62 - 67		5.2	56 - 61
	1.94	67 - 70		5.2	61 - 66
BI5	5.2	39 - 44		5.2	66 - 71
	3.1	44 - 47	BO10	3.41	59 - 62
	5.2	49 - 54	YI10	20.8	45 - 66
	5.2	54 - 59		5.2	40 - 45
YI6	4.14	39 - 43		5.2	66 - 71
	2.77	45 - 48	BO11	5.2	40 - 45
	5.2	49 - 54		5.2	45 - 50
	5.2	54 - 59		5.2	50 - 55
IP6	2.79	4 - 7		5.2	56 - 61
	2.79	4 - 7		5.2	61 - 66
IP12	5.2	2 - 7		5.2	66 - 71
	3.7	2 - 5			

NEG beam tubes for Run 2004

Cu Stochastic Cooling

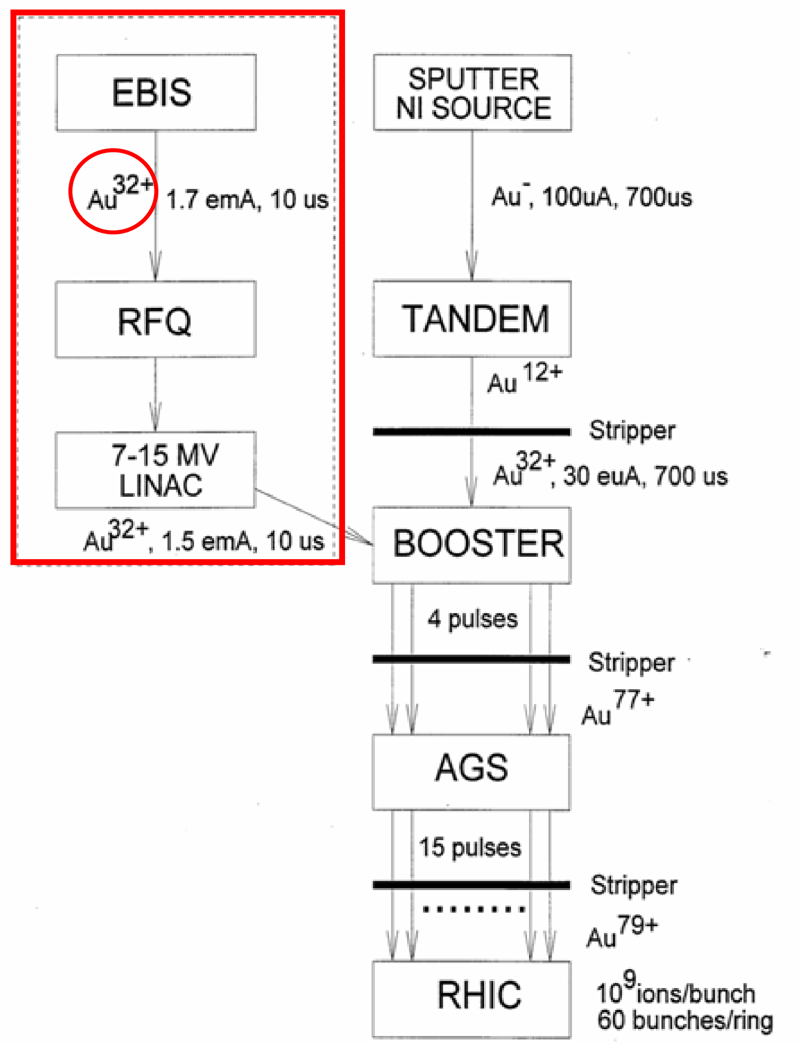




- Signal suppresion extends well beyond the 10 MHz cavity bandwidth
- Cooling loop is closed, kicker voltage sufficient for 100 GeV/n beams
- Plan to build an operational 16-cavity system for yellow for FY06

Advantages of EBIS for RHIC HI

- Simple, modern, low-maintenance
- Lower operating cost
- Produce any ion species
- Fast switching between species
- Higher Au injection energy into Booster
- Short Booster transfer line (30m)
- No stripping needed before Booster
- Few-turn injection
- Higher intensities with future improvements



Summary

- FY05 Cu-Cu run delivered 15 nb^{-1} at $\sqrt{s}$= 200 GeV/n
  - Exceeded maximum luminosity projections of 13.5 nb^{-1}
- Setup and ramp-up time with beam only 2.5 weeks
  - Significantly shorter than planned 4 weeks
- Multiple successful lower-energy runs with Cu-Cu
  - Successful 2 week run at $\sqrt{s}$= 62.4 GeV/u medium energy
  - Successful 1 day run at $\sqrt{s}$= 22 GeV/u injection energy

- Luminosity limitations and plans
  - Pressure rise in interaction regions, potentially cold bore
    - Cold-bore pumping upgrade, 150m additional NEG pipe
  - Emittance growth from IBS
    - Stochastic cooling, electron cooling
  - EBIS improves the flexibility of RHIC HI program

NEG and Anti-Grazing Ridge Study

Vadim Ptitsyn, Haixin Huang, SY Zhang, Peg Harvey, Dick Hseuh

BO11 & BI9 have NEG coating

ΔP only at BO11 pw3.3 and BI9 pw3.1 (difficult to estimate η w/ NEG due to large pumping speed provided by NEG)

No observable pressure rise at BI5 (NEG + ridges)

η w/o NEG coating is higher especially at large Θ and at yo12 polarimeter (high P_o)