RSVP/RHIC accelerator operation

RHIC performance and upgrade plans

RSVP requirements

RHIC/RSVP operation

AGS High Intensity Performance

AGS modifications for RSVP

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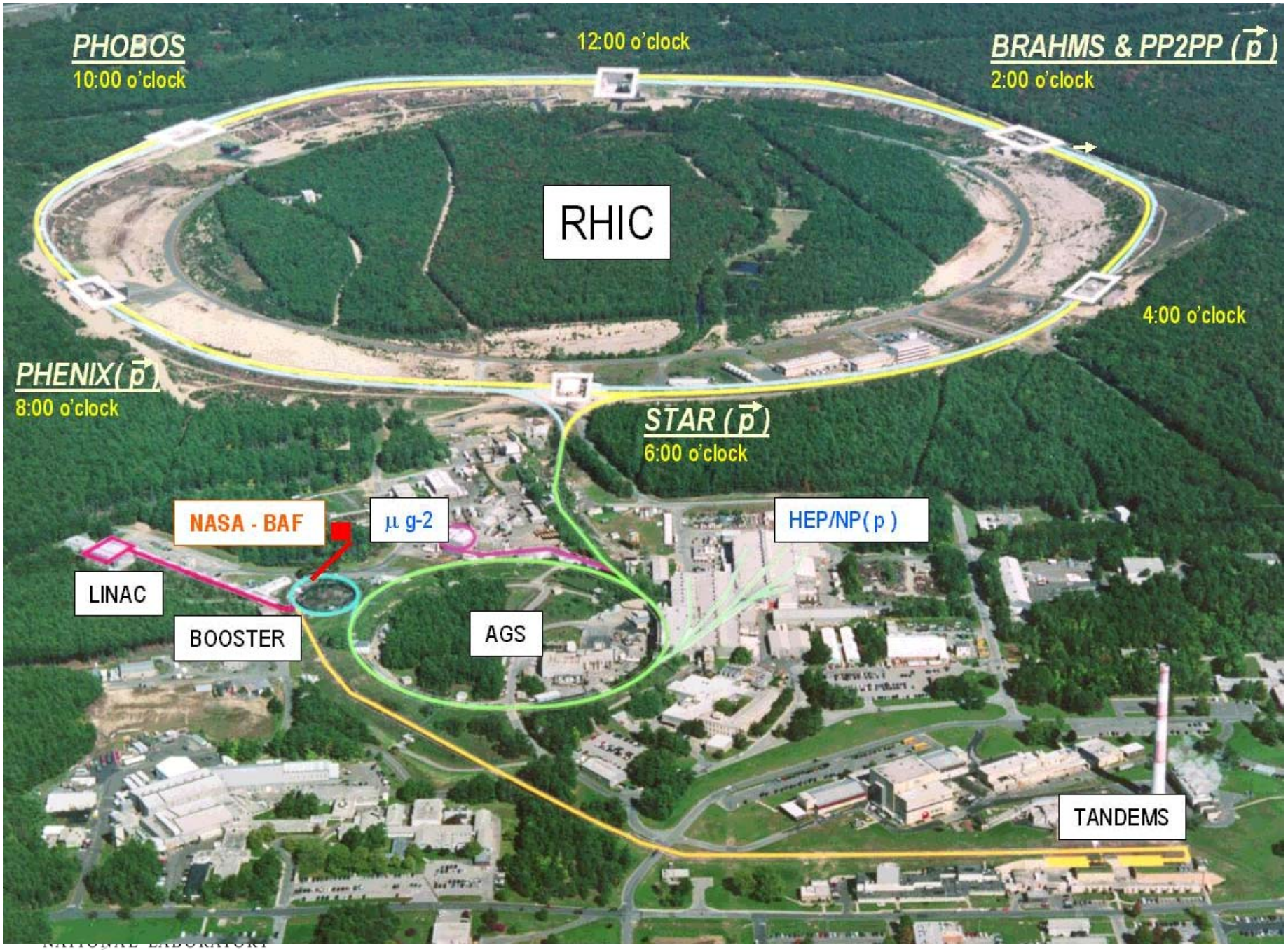
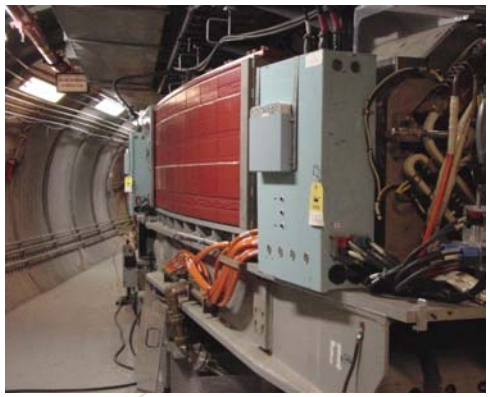
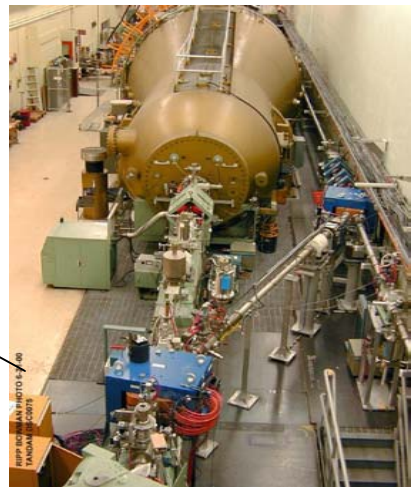
Thomas Roser
DOE RSVP/RHIC Review
January 27 - 28, 2004


PHOBOS
10:00 o'clock
12:00 o'clock
BRAHMS & PP2PP ($\vec{p}$)
2:00 o'clock
RHIC
4:00 o'clock
PHENIX($\vec{p}$)
8:00 o'clock
STAR ($\vec{p}$)
6:00 o'clock
NASA - BAF
μ g-2
HEP/NP(p)
LINAC
BOOSTER
AGS
TANDEMS

Gold Ion Collisions in RHIC





Beam Energy = 100 GeV/u

L_{ave} per IR = 2×10^{26} cm^{-2} sec^{-1}

RHIC

9 GeV/u
Q = +79

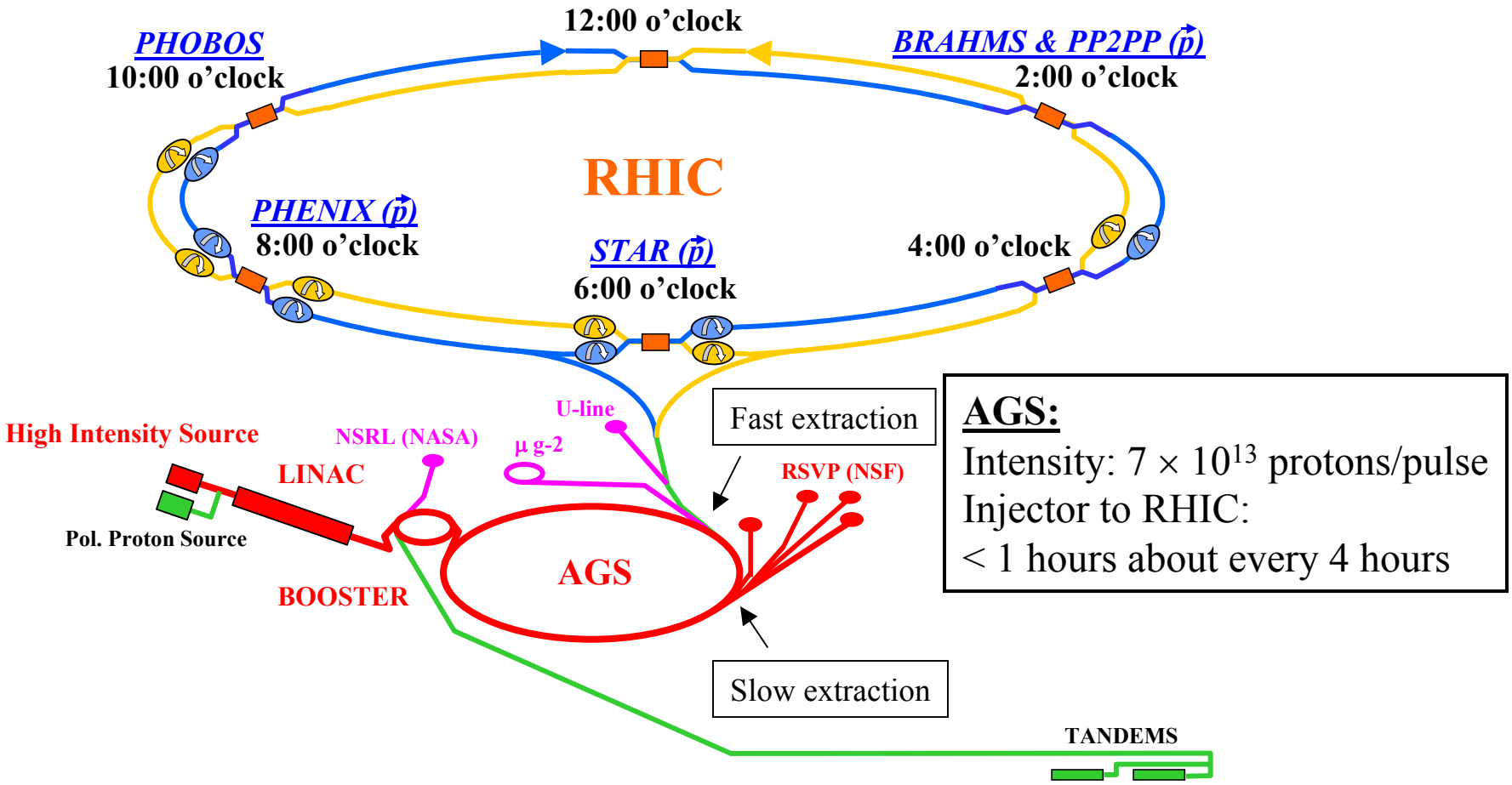
BOOSTER

AGS

TANDEMS

1 MeV/u
Q = +32

AGS/RHIC Accelerator Complex



AGS:

Intensity: 7×10^{13} protons/pulse

Injector to RHIC:

< 1 hours about every 4 hours

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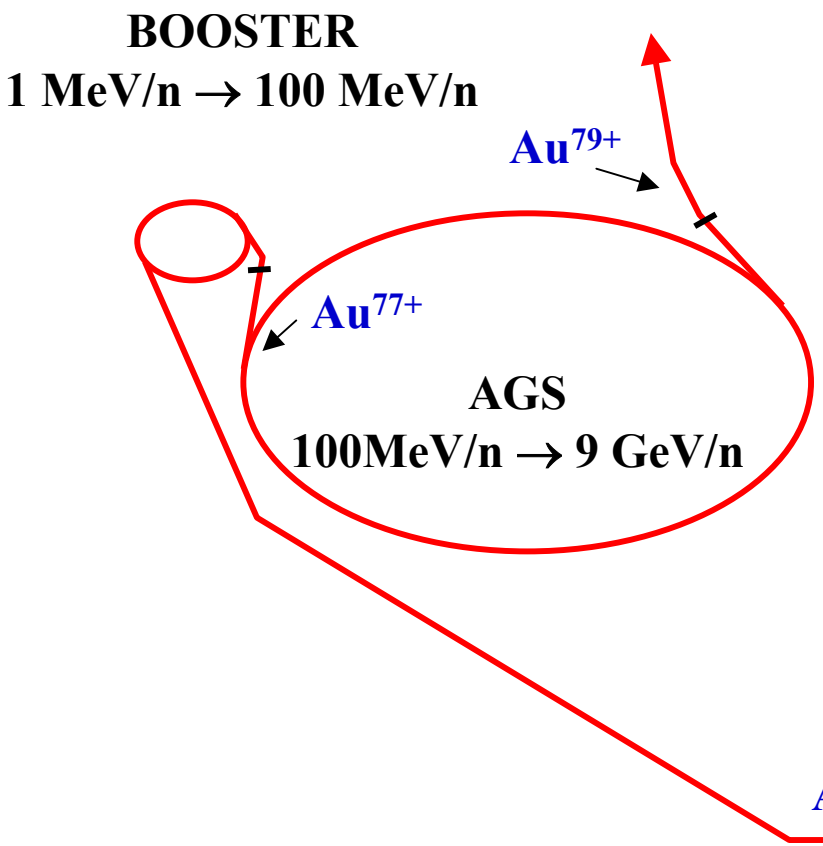
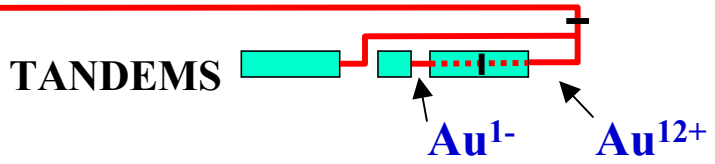
Au Injector Performance



	Intensity/RHIC bunch	Efficiency[%]
Tandem	5.4×10^9	
Booster Inj.	2.9×10^9	54
Booster Extr.	2.4×10^9	83
AGS Inj.	1.2×10^9	50
AGS Extr.	1.1×10^9	92
Total		20

Emittances: 10 π μm, 0.3-0.4 eVs/n
Limit: Beam induced gas desorption at Booster injection.

Au^{32+} : 1.4 part. μA, 530 μs (40 Booster turns)

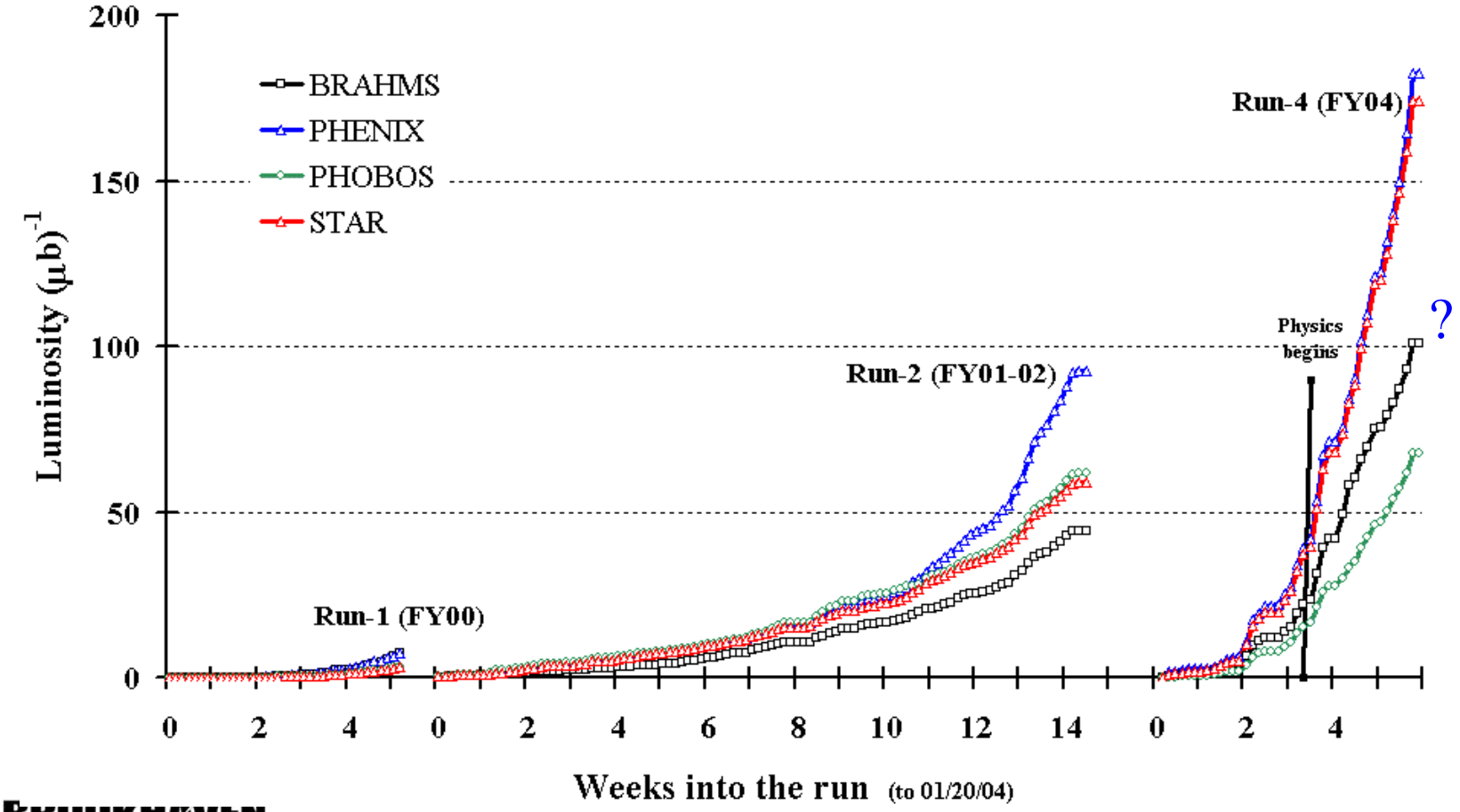


Au-Au integrated luminosity evolution as of 01/20/04

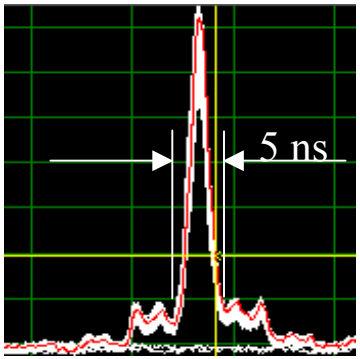
Delivered 182.5 $(\mu b)^{-1}$ to Phenix

72.7 $(\mu b)^{-1}$ last week

Target 330 $(\mu b)^{-1}$



Performance summary



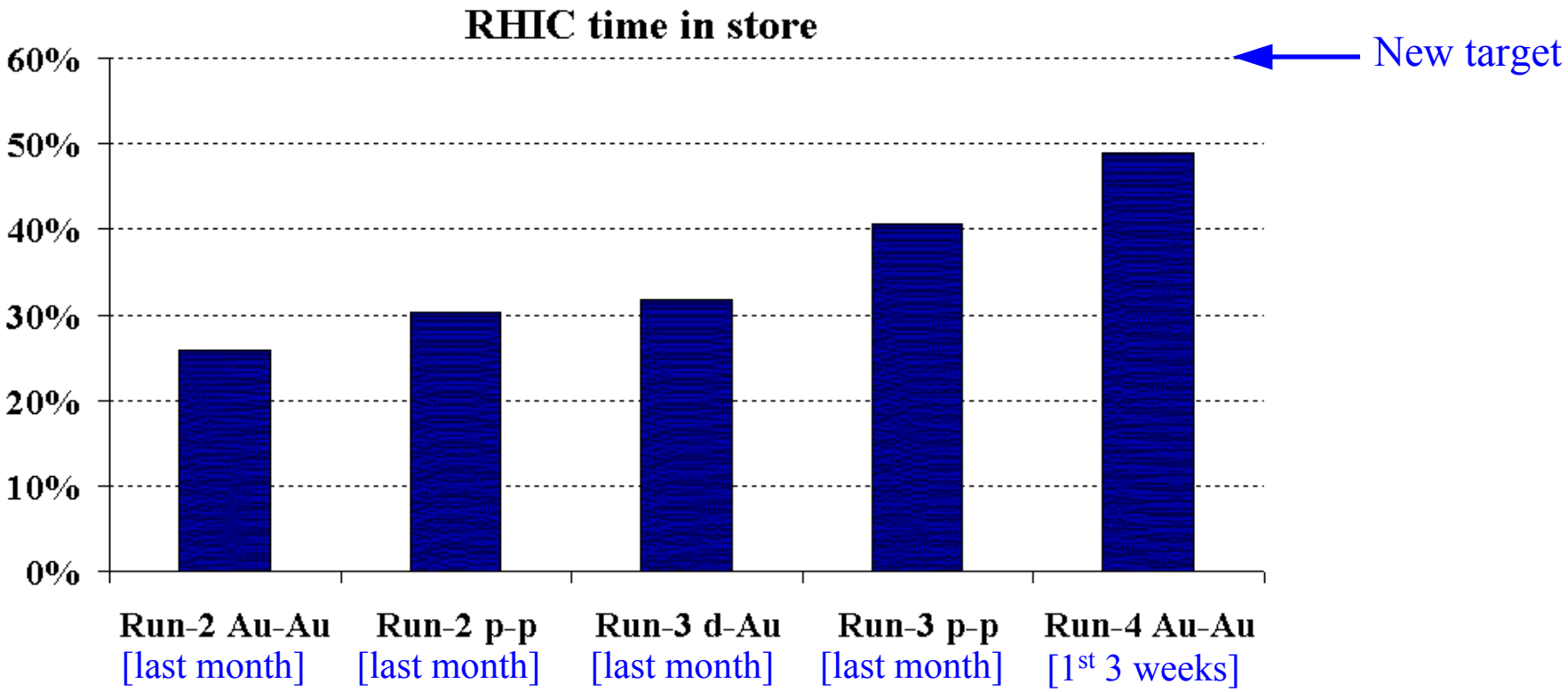
RHIC bunch profile

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

Mode	# bunches	Ions/bunch [10^9]	β^* [m]	Emittance [$\pi\mu$m]	L_{peak} [$cm^{-2}s^{-1}$]	L_{ave}(store) [$cm^{-2}s^{-1}$]	L_{ave} (week) [$week^{-1}$]
Au-Au (*) [Run-4]	61	1.0(b)/0.7(y)	1	15 - 40	8×10^{26}	3×10^{26}	73 $(\mu b)^{-1}$
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 $(pb)^{-1}$
Au-Au (max. goal)	56	0.9	1	15 - 40	12×10^{26}	3×10^{26}	70 $(\mu b)^{-1}$
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]

RHIC time in store



Comments:

- Not all store time used by experiments (initial background, detector turn-on, etc.)
- Usable store time differs from experiment to experiment

RHIC Collider Operation

- Each running period: 2 weeks cool-down and 1 week warm-up
- For each running 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

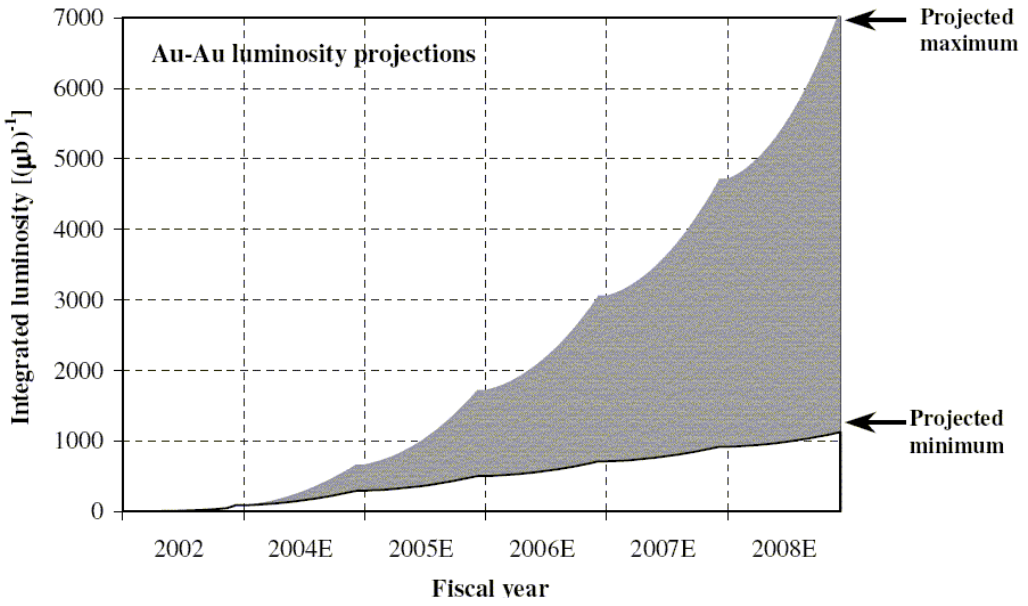
Machine goal for next 5-years

- **Enhanced RHIC luminosity (112 bunches, $\beta^* = 1$m):**
- **Au – Au: 8×10^{26} cm^{-2} s^{-1} (100 GeV/nucleon)**
- **For protons also 2×10^{11} protons/bunch (no IBS):**
- **p↑ – p↑: 6×10^{31} cm^{-2} s^{-1}; 70 % polarization (100 GeV)**
  1.5×10^{32} cm^{-2} s^{-1}; 70 % polarization (250 GeV)
  (luminosity averaged over store delivered to 2 IRs)

Additional assumptions for 5-year luminosity projections:

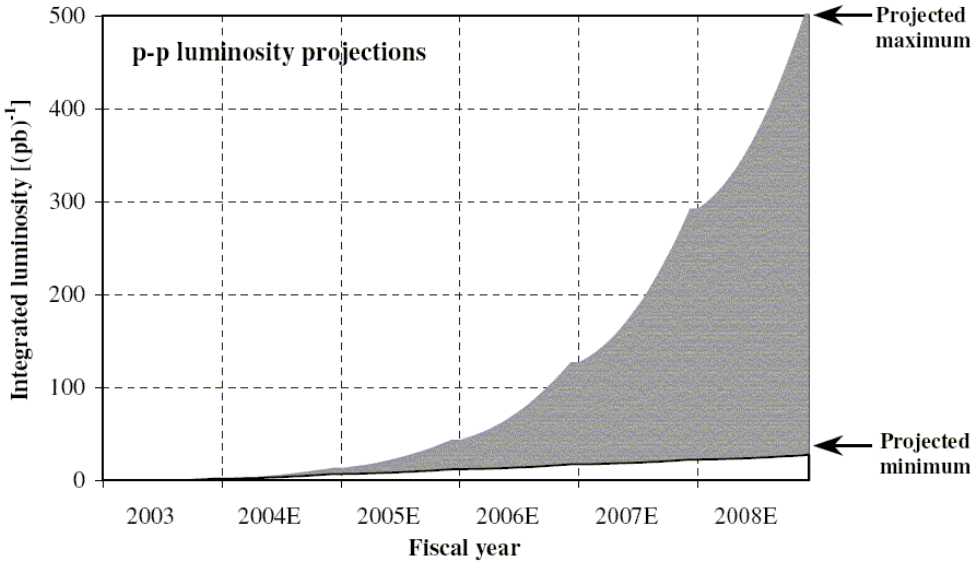
- At least 5+14 weeks of operation of each mode for luminosity development per year
- Upgrade projects need to be completed

Projected 5-year Au-Au luminosity evolution



Fiscal year		achieved 2002A	projected maximum 2008E
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



		achieved	projected maximum
Fiscal year		2003A	2008E
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

RSVP/RHIC operation

AGS operation for RSVP when RHIC is at store

RHIC at store: presently ~ 70 hrs/week (40%), goal: ~ 100 hrs/week (60%)

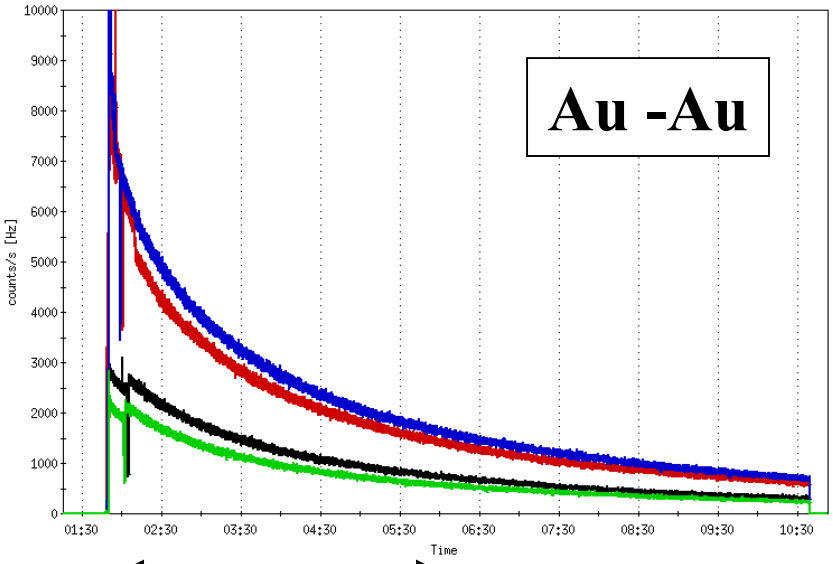
Au – Au:

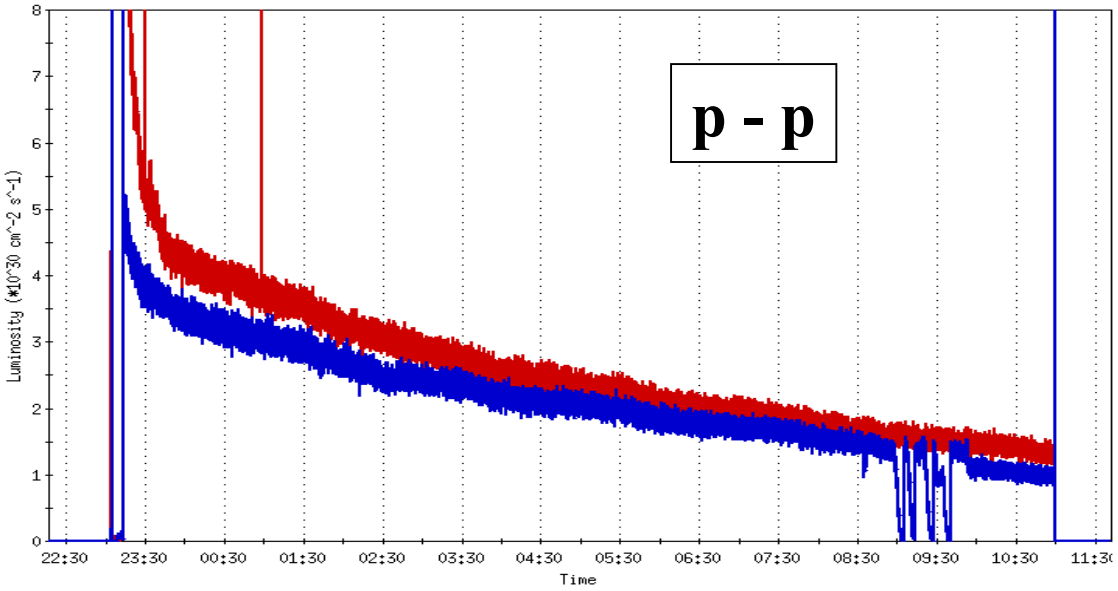
- Typical 4-hour store length determined by Intra-Beam-Scattering (IBS)
- With future luminosity upgrade (RHIC II) 4-hour store length determined by "burn-off"
- Minimum refilling time is 5 – 10 minutes, typically takes < 1 hour
- Fast injector switching between RSVP and RHIC mode beneficial

p – p:

- Typical store length: 8 – 10 hours
- Slower injector switching possible and necessary to ramp super-conducting AGS Siberian snake

Typical RHIC stores





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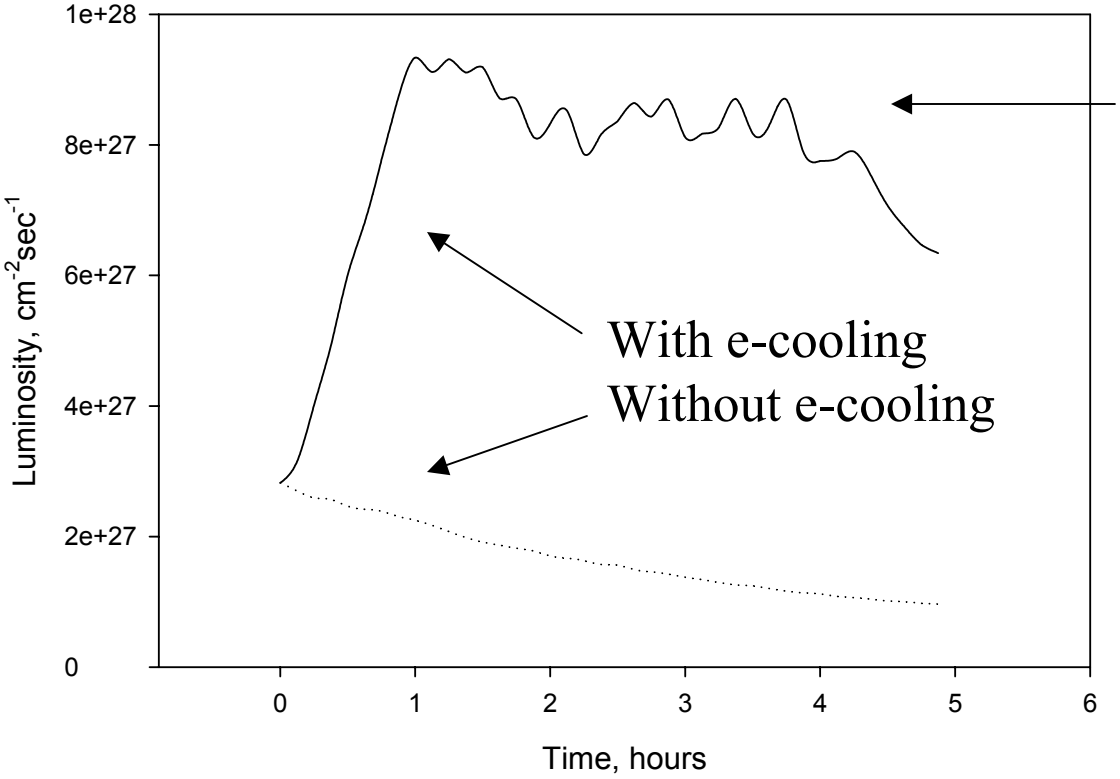
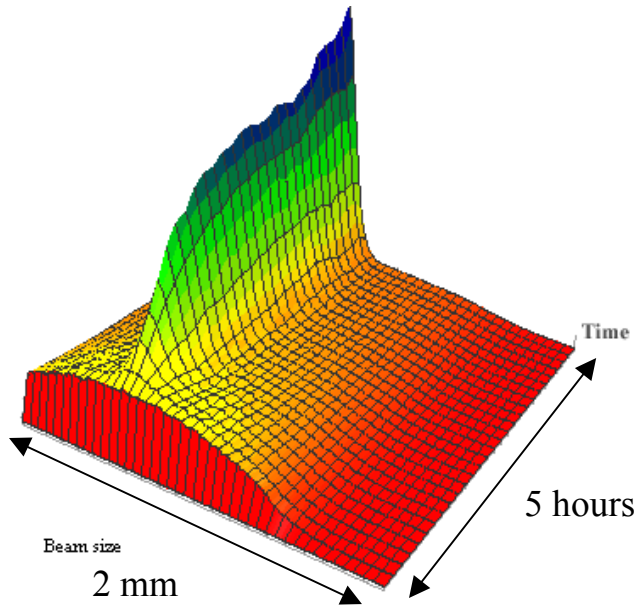
RHIC Luminosity with Electron Cooling (RHIC II)



Luminosity leveling through continuous cooling and beta squeeze
Store length limited by "burn-off"

Transverse beam profile during store



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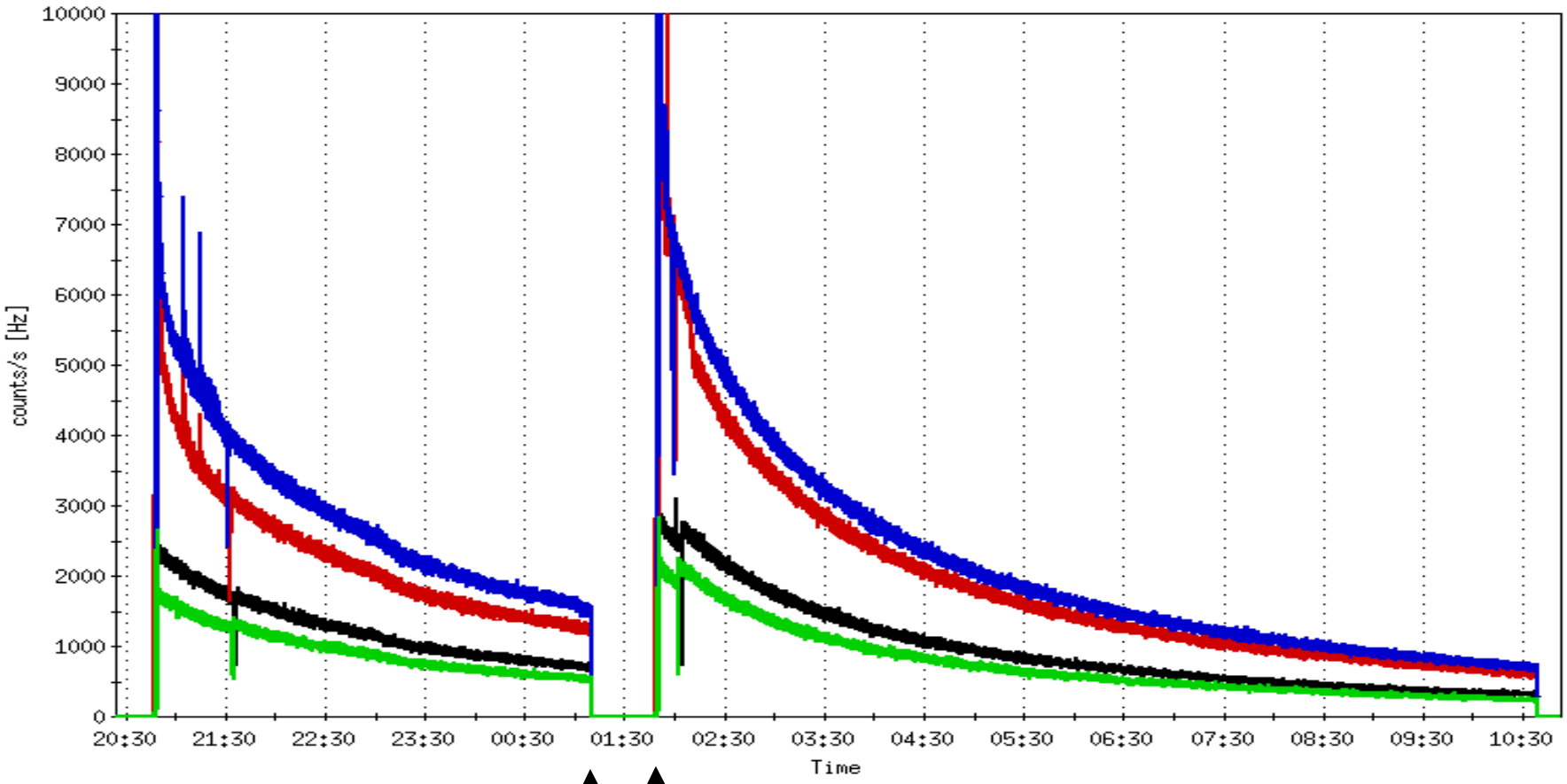
Refill of RHIC



End of store

40 min.

Start of store

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RSVP requirements

KOPIO:

100 $\times 10^{12}$ ppp; 5 s cycle; extraction @ 24 GeV [20 $\times 10^{12}$ p/s]

- Proton throughput achieved
- AGS injection energy upgrade to 2 GeV to reach 100 $\times 10^{12}$ ppp (R&D)

Slow extraction with micro-bunching (200ps (σ) every 40 ns)

- Extraction with high frequency cavity (25 MHz, 100 MHz) (R&D)
  < 250 ps every 10 ns demonstrated; no change in losses
- Extinction of 10^{-3} (R&D)

MECO:

40 $\times 10^{12}$ ppp; 1 s cycle; extraction @ 8 GeV [40 $\times 10^{12}$ p/s]

- No transition losses and reduced AGS injection losses (R&D)

Slow extraction of 2 bunches with 10^{-9} extinction during 1.35 μs gap.

- h=2 Booster operation; achieved 22$\times 10^{12}$ protons per Booster cycle
- Two Booster cycles per AGS cycle
- Bunch merging to 2 bunches or develop h=1 Booster ops. (R&D)
- Gap cleaning with resonant transverse kicker plus rf kicker in beam line (R&D)

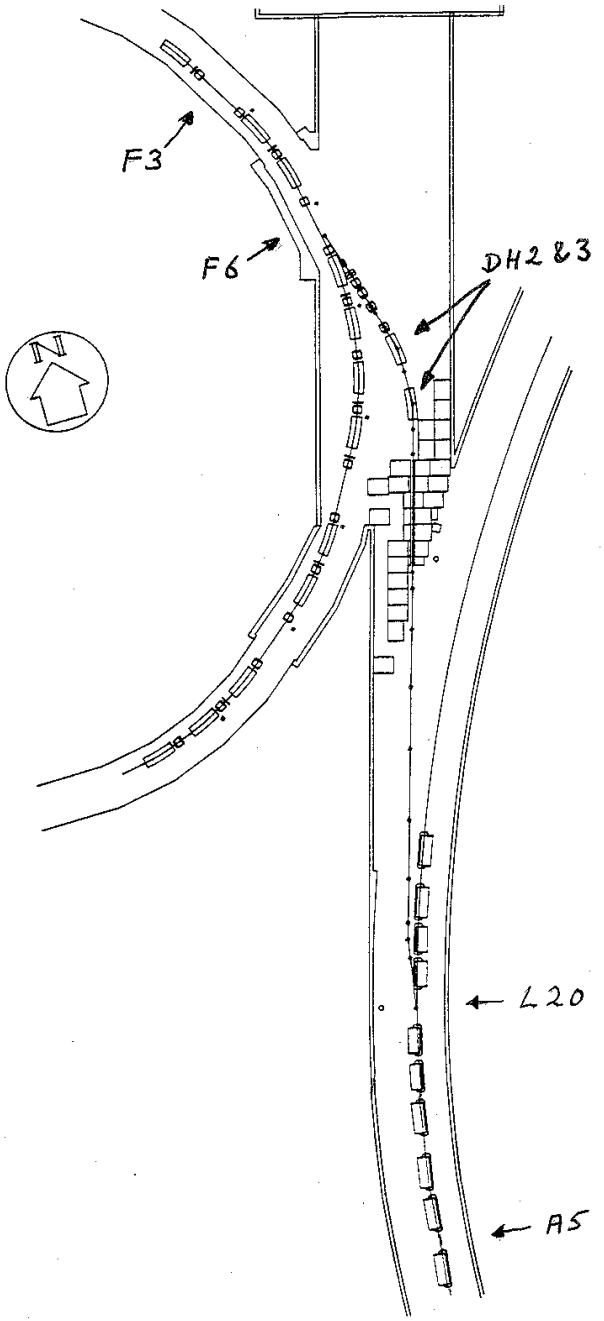
BTA Upgrade to 2 GeV (CFI funded)

Upgrade BTA + AGS injection from
1.9 GeV with large mismatch to
2.0 GeV without mismatch

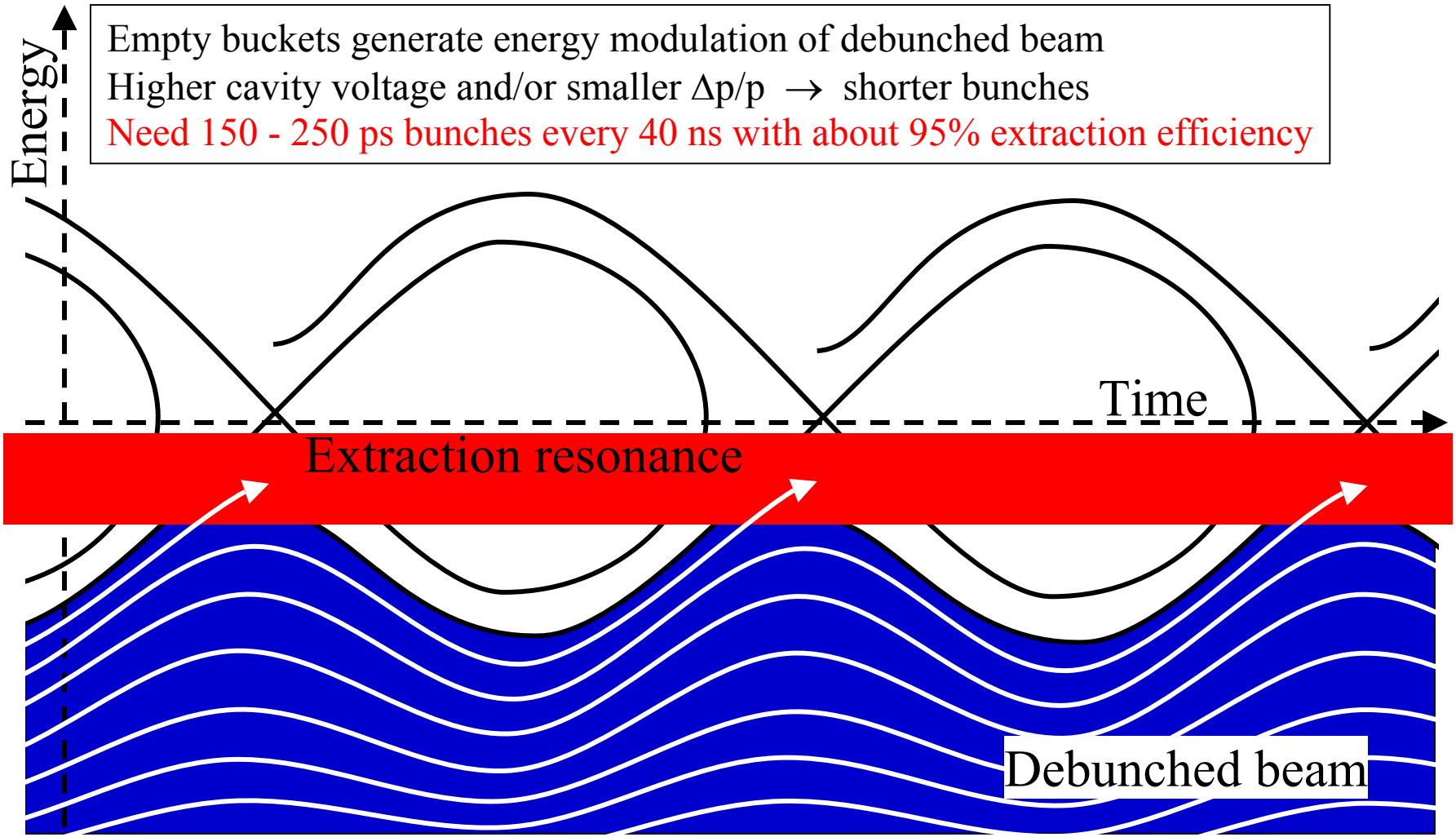
→ improved space charge limit and no halo formation (“1 ms loss”)

All elements except kickers are OK

AGS injection kicker: add kicker modules
Booster extraction kicker: modify PFN



Micro-bunched slow extraction

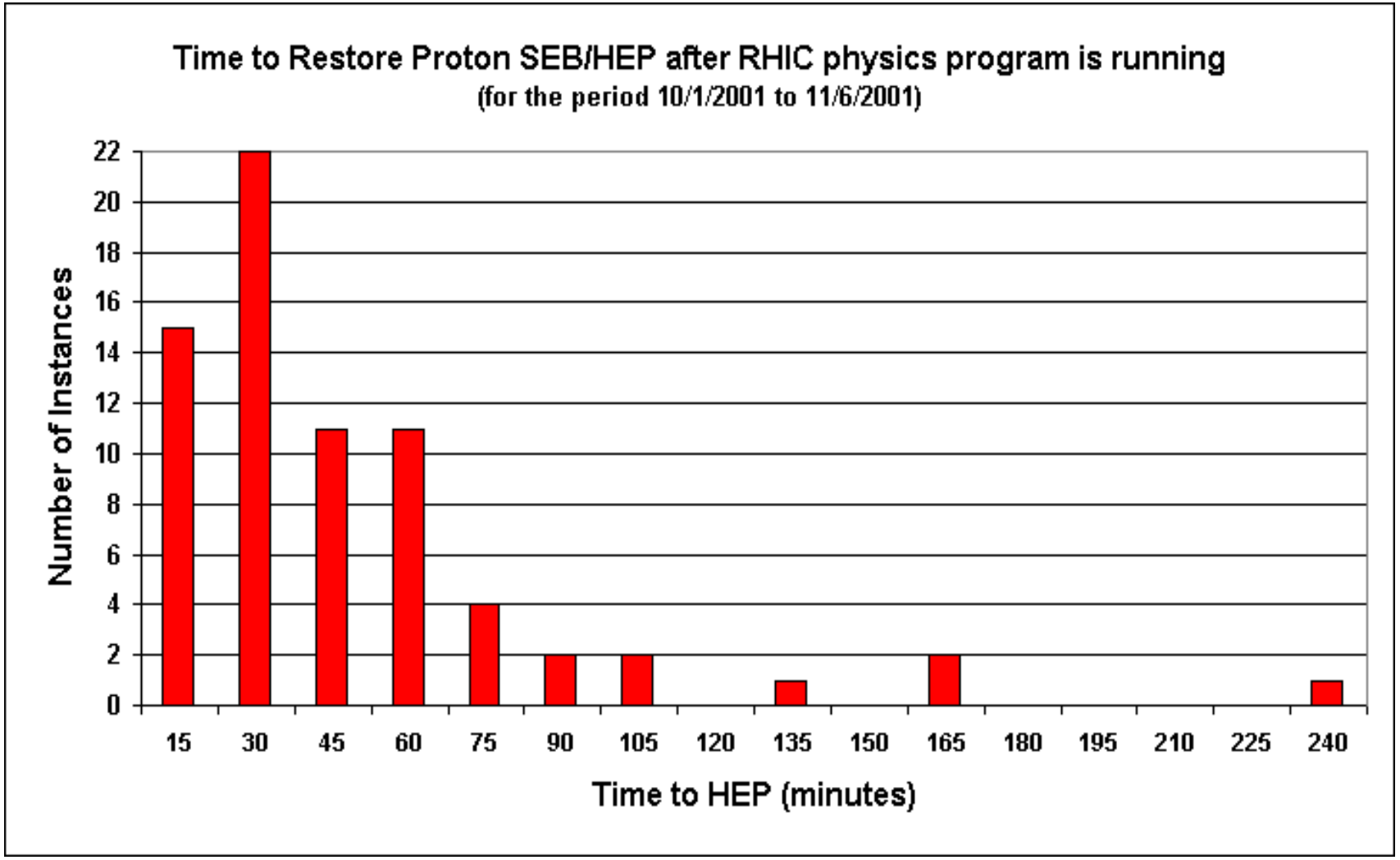


Injector operation

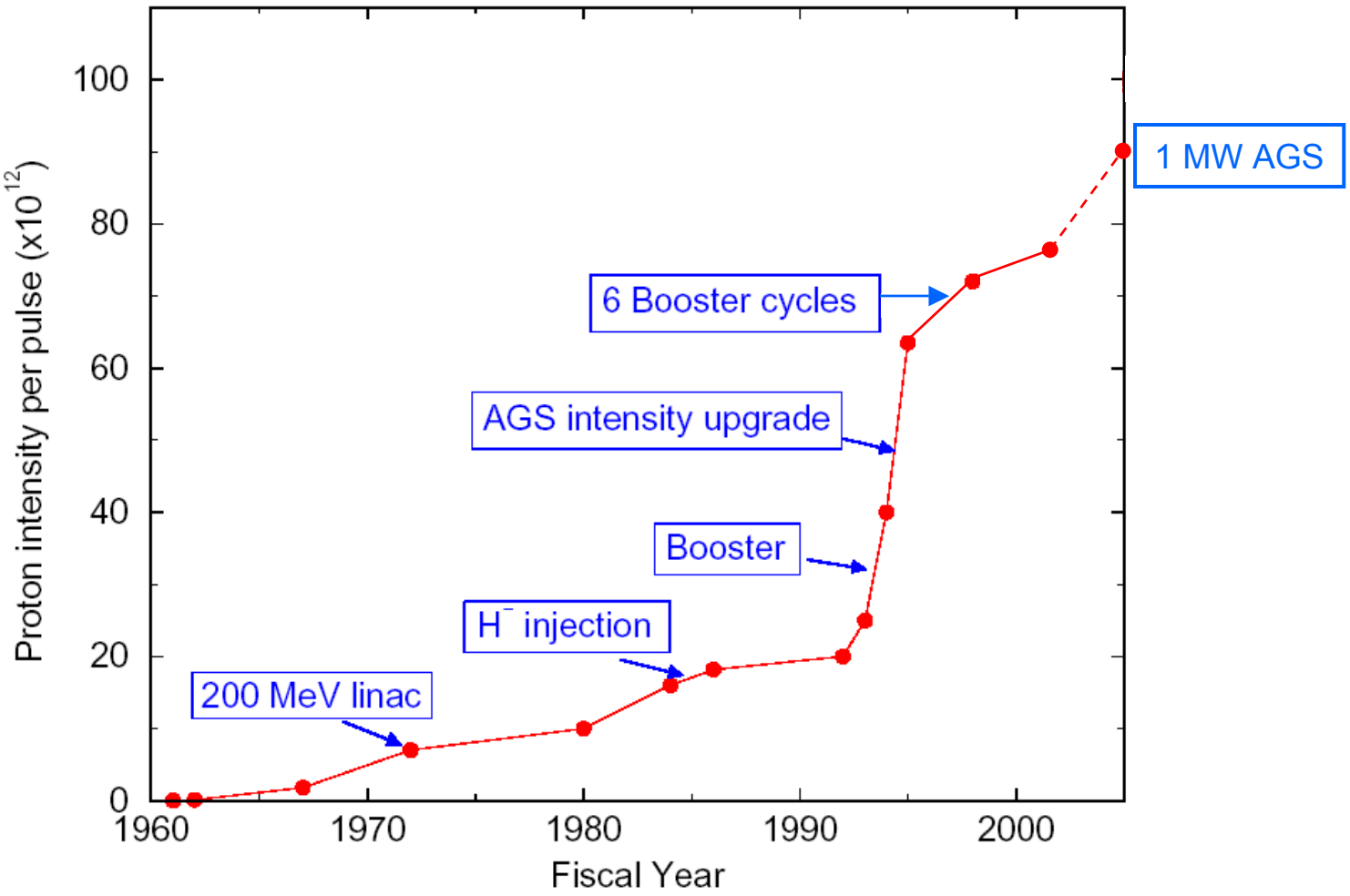
Injector accelerators (Linac, Booster, AGS) can run for multiple users:

- Fast and accurate switching of all control points between 4 different modes of operation
- Pulse-to-pulse modulation (PPM): switching in between two pulses (cycles)
  - Each mode tuned to maximum performance
  - Synchronous (repetitive) operation (mostly Linac and Booster)
  - Asynchronous (on demand) operation (mostly AGS) [“context switching”]
  - Used for: early RHIC commissioning during AGS HI SEB
    g-2 FEB commissioning during AGS SEB
    NSRL operation during AGS set-up for RHIC ops.
    Routinely used for study cycles
- “Mode switching”: includes slower device (stripping foils, …)
  - Used for: High intensity AGS SEB (E949) during RHIC ops.
    AGS pol. Proton commissioning during RHIC HI ops.
  - Presently planned for RSVP ops during RHIC ops.
- Possible upgrade of RSVP/RHIC switching to PPM
  - Better availability of AGS for RSVP with short RHIC stores

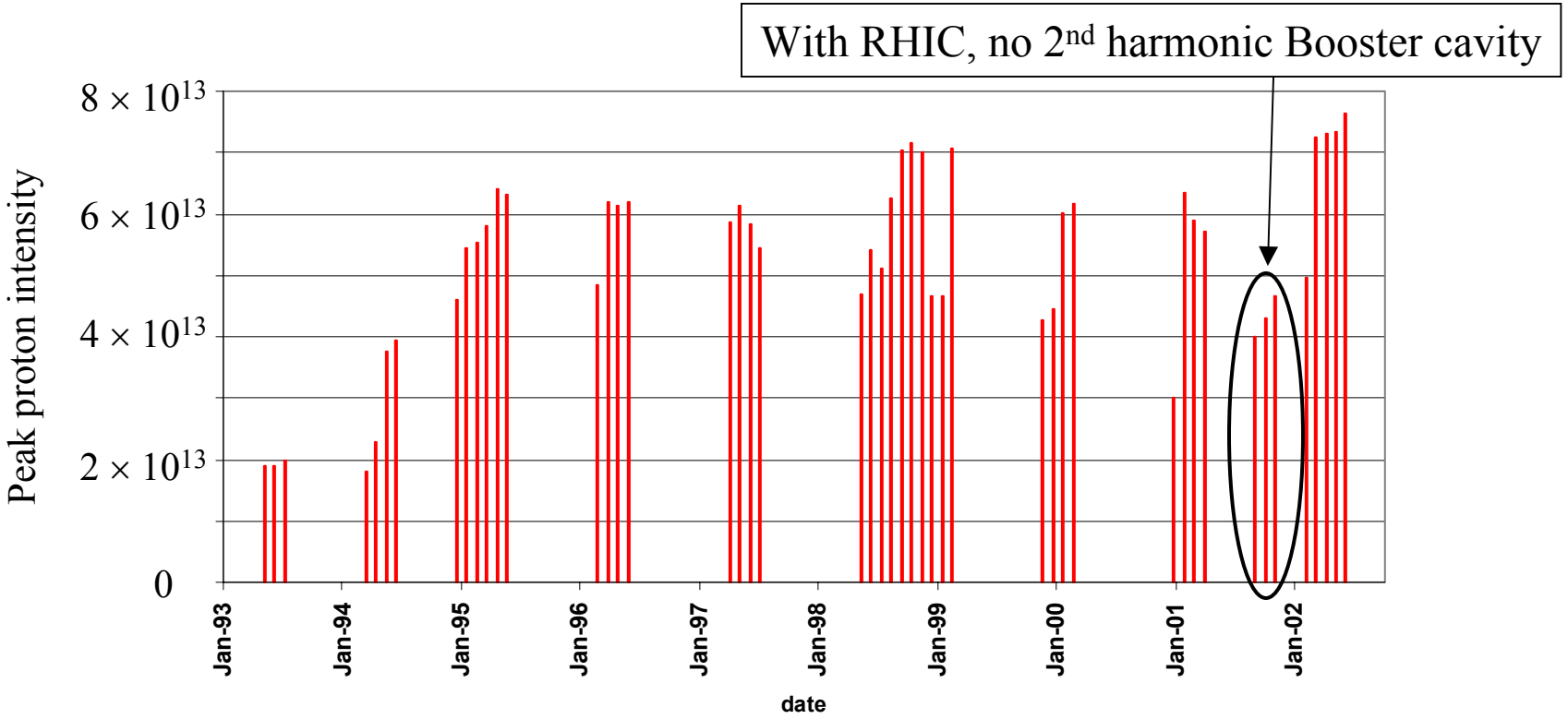
Transition Time to Restore HEP



AGS Intensity History

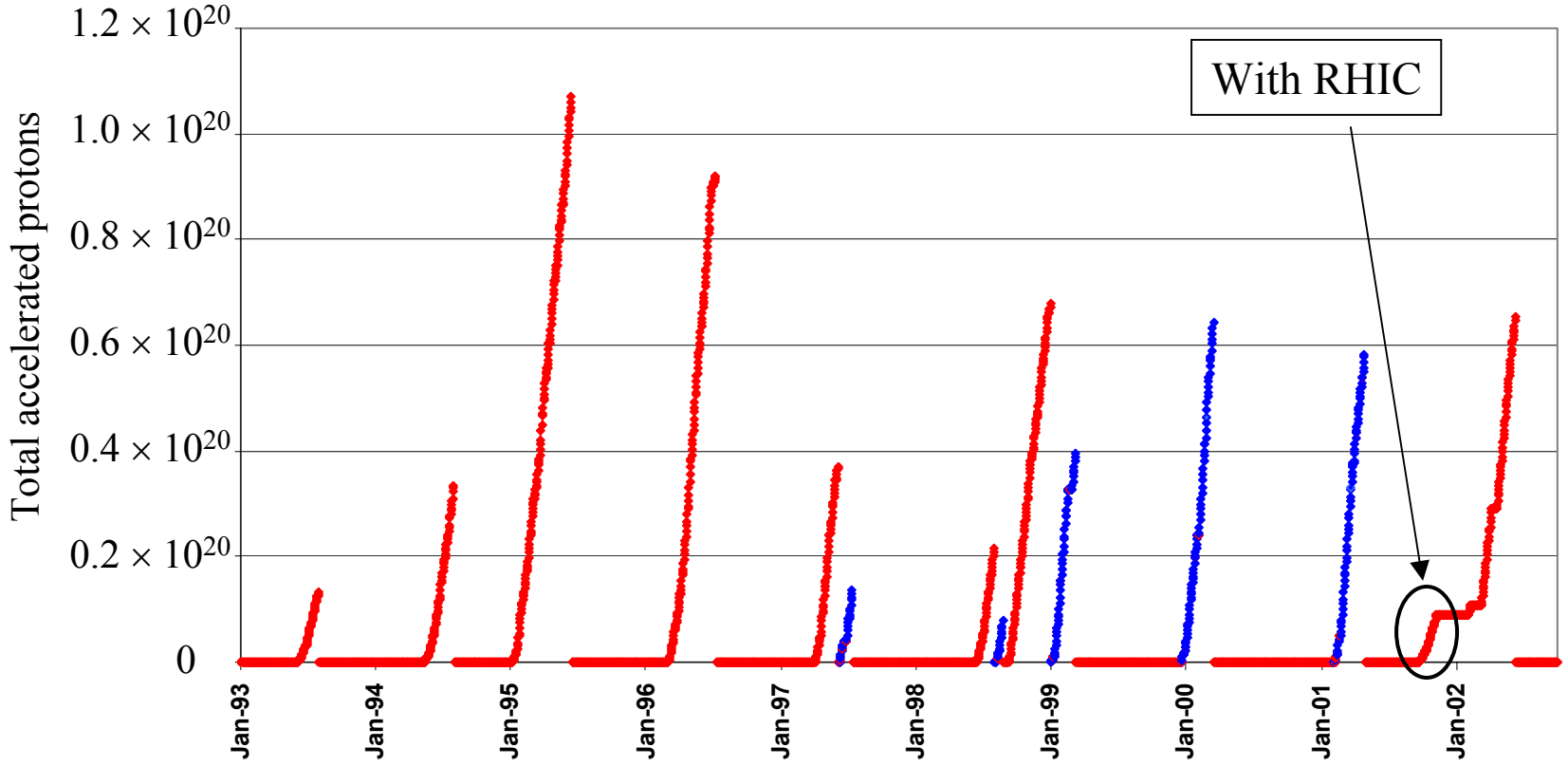


AGS Peak Proton Intensities



World record proton synchrotron intensity!

Total Accelerated Protons at the AGS



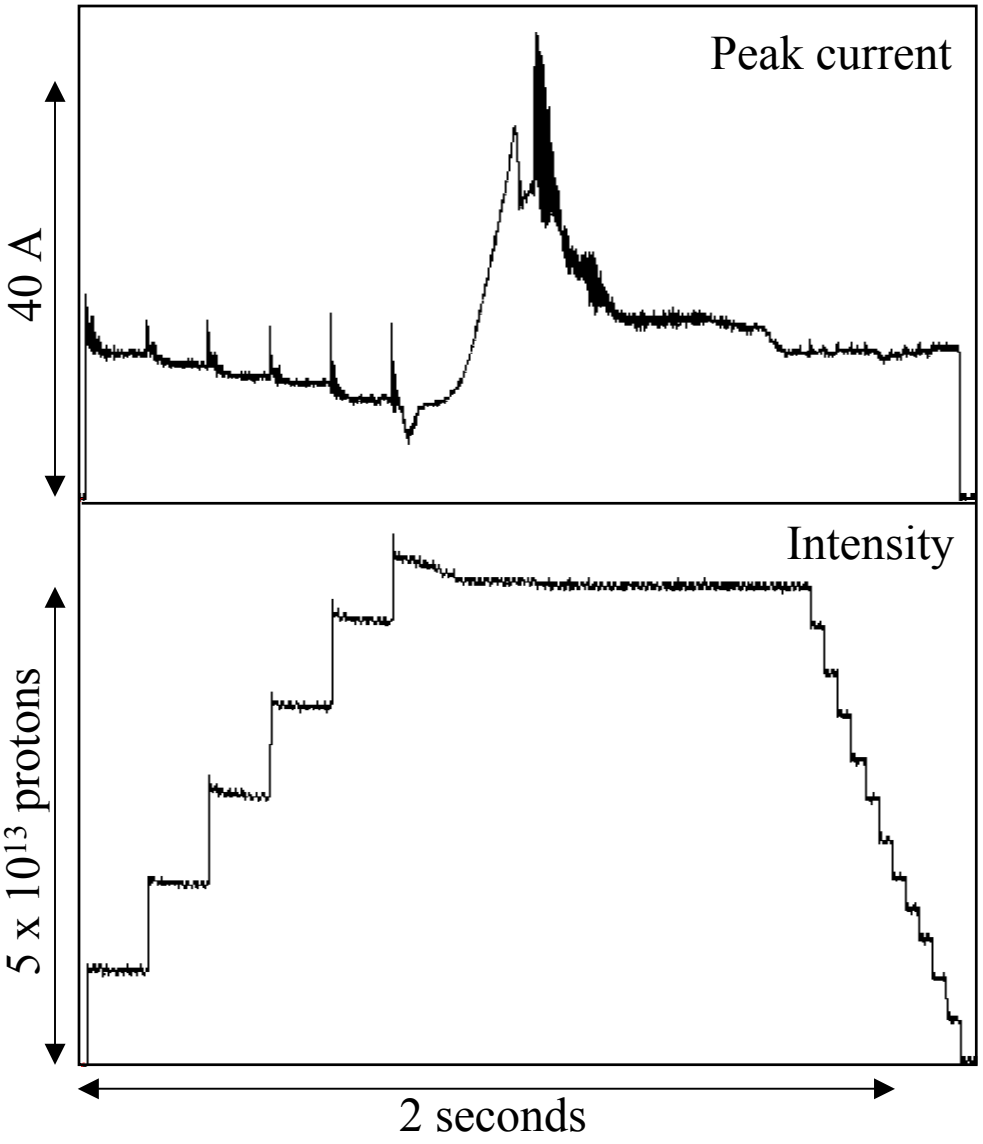
Slow extracted beam (Kaon decay)

Fast extracted beam (g-2)

Note: Lower total accelerated protons in later years due to much shorter running time

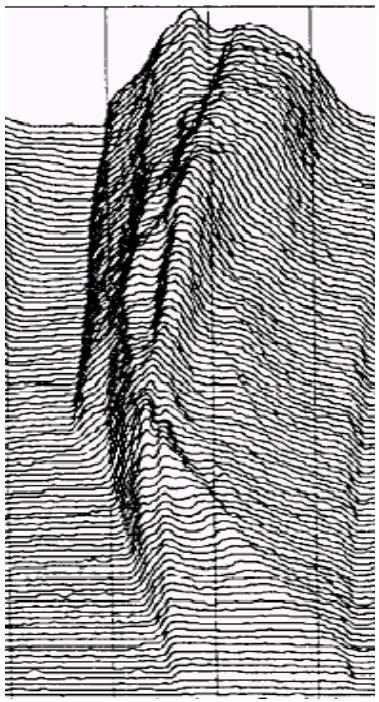
AGS performance for fast extraction

- 6 single bunch transfers from Booster
- Peak intensity reached: 72×10^{12} ppp (20×10^{12} p/s for 3.6 s cycle)
- Bunch area: 3 eVs at injection
  10 eVs at extraction
- Intensity for g-2 ops: 60×10^{12} ppp (24×10^{12} p/s for 2.5 s cycle)
- Strong space charge effects during accumulation in AGS
- 2nd order transition energy jump limits available momentum aperture.
- Chromatic mismatch at transition causes emittance dilution
- Dilution needed for beam stability

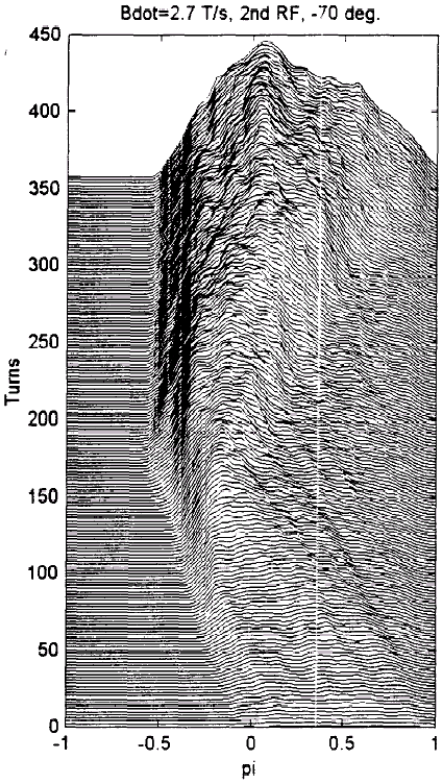


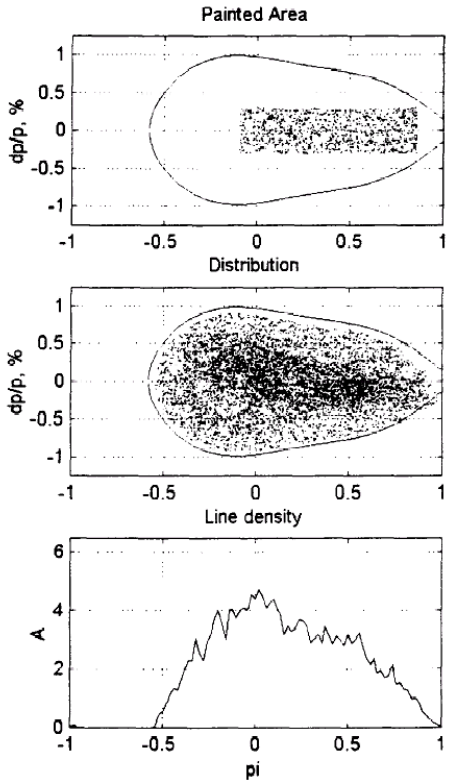
H^- injection into the Booster

Measurement



Simulation





Injected:
23×10^{12} ppb
1.3 eVs
18×10^{12} /eVs

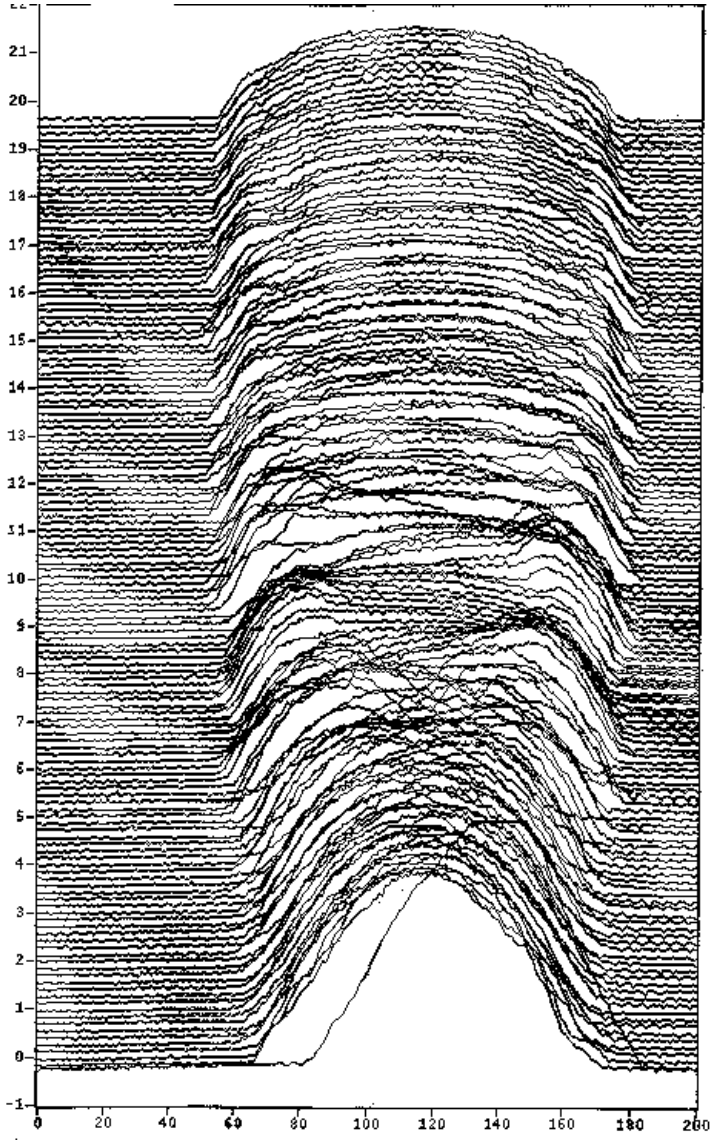
Circulating:
17×10^{12} ppb
3.0 eVs
5×10^{12} /eVs

High B dot gives effective long. phase space painting.
Injection period is approx. equal to synchrotron period.

Controlled dilution at AGS injection

Longitudinal emittance dilution at AGS injection through mismatch followed by smoothing with high frequency (93 MHz) cavity.

Needed to avoid excessive space charge tune spread and coupled bunch instabilities.



Typical efficiencies and lost beam power

1999 AGS SEB operation, 3.6 s AGS cycle time, 4 Booster cycles:

Linac Beam 156×10^{12}

Booster:				
Early	102×10^{12}	Injection and Capt.	65 %	0.5 kW
Late	88×10^{12}	Acceleration	86 %	0.2 kW
AGS:				
Early	71×10^{12}	Transfer/Injection	81 %	1.1 kW
Late	67×10^{12}	Late Acceleration	94 %	0.9 kW

Imposed limits to lost beam power to maintain hands-on maintenance.

Component activation during RSVP operations

Same limits to lost beam power will be applied during RSVP operations

- Accelerators remain maintainable “by hand”
- RSVP proton throughput (20 – 40 Tp/s) is similar to previously achieved levels
- “Cool-off” period of a few hours required to access activated areas for emergency repairs -> possible impact on RHIC. Partially offset by early detection of failed components.
- Preventive replacement of strongly exposed components:
  - Replace one or two Booster magnets every year as indicated by “High Pot” tests
  - Replace extraction elements once during RSVP experiment

AGS modifications

- Additional section for the AGS injection kicker
- Upgraded pulse forming network for Booster extraction kicker
- 25/100 MHz micro-bunching cavities
- Upgraded AGS AC dipole
- New power supply for transverse damper kicker

- Space in AGS lattice has been identified for all items. No interference with present and future RHIC needs
- All installations can be accomplished during the typical three-months RHIC shutdown periods

Conclusion

RSVP operation possible with minimal impact on RHIC running

Machine activation managed by controlling lost beam power and preventive component replacement

AGS modifications can be installed during RHIC shut-down periods.