Recent RHIC Performance and Upgrade Plans

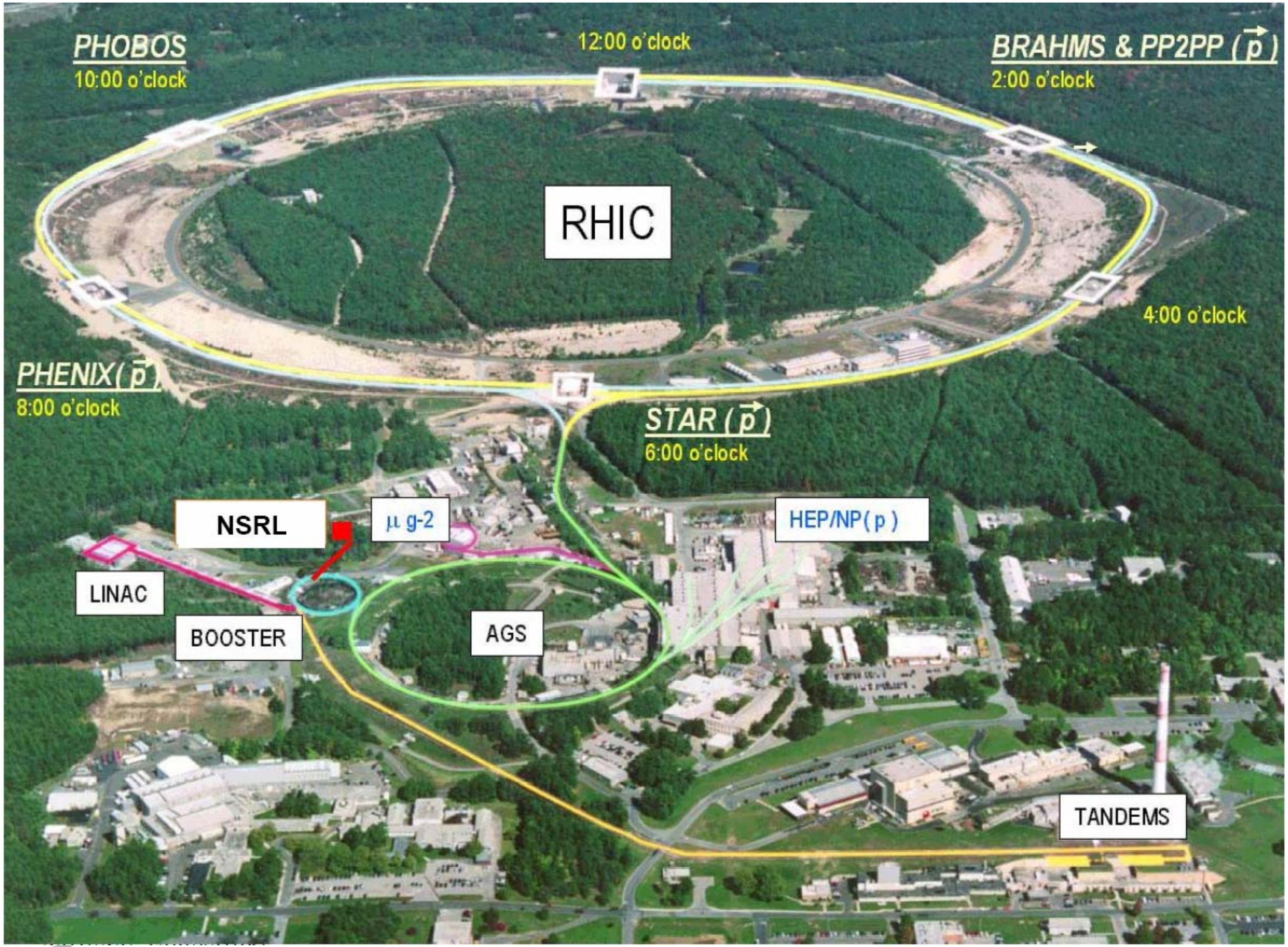
Todd Satogata
For the RHIC Operations and Upgrade Teams

EPAC 2004 July 6 2004

- RHIC Run-4 Performance: Au-Au and p↑+p↑
- RHIC Performance Limitations and Near-Term Plans
- RHIC Beam Cooling and eRHIC

BROOKHAVEN NATIONAL LABORATORY

RHIC Layout



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
NSRL
μ g-2
HEP/NP(p)
LINAC
BOOSTER
AGS
TANDEMS

Machine Challenges at RHIC

- More flexibility than at other hadron colliders
  - Variation in particle species, including asymmetric operations
    - So far Au+Au, d+Au, p+p, p↑+p↑ (light ions planned in 2005)
  - Variation in energy, energy scans
    - Au+Au at 10, 31, 65, 100 GeV/u
    - p↑+p↑ at 100 GeV (250 GeV planned in 2006)
  - Variation in lattice
    - Low β^* in most cases (1-3 m)
    - Large β^* for small angle scattering experiment ($\geq$10 m)
    - Polarity change in experimental magnets ~ every 2 weeks
- Short runs (~30 weeks/year), with multiple modes
  - Significant amount of set-up time required
- Four experiments (2 large, 2 small)
  - Work to avoid single-experiment bottlenecks
- Short luminosity lifetime with heavy ions (IBS, ~ few hours)
  - Fast refills essential

RHIC Achieved and Planned Parameters

Mode	No of bunches	Ions/bunch $[10^9]$	β^* [m]	Emittance $[\pi\ \mu m]$	L_{peak} $[cm^{-2}s^{-1}]$	$L_{store\ ave}$ $[cm^{-2}s^{-1}]$	L_{week}	Time in Store
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}	
Au-Au [Run-2]	55	0.7	1	15-40	6×10^{26}	1×10^{26}	15 μb^{-1}	26%
d-Au [Run-3]	55 (110)	110d/0.7Au	1	15	12×10^{28}	3×10^{28}	4.5 nb^{-1}	31%
Au-Au [Run-4]	45	1.1	1	15-40	15×10^{26}	5×10^{26}	160 μb^{-1}	53%
p↑-p↑ [Run-4] *	28	170	1	20	15×10^{30}	10×10^{30}	0.9 pb^{-1}	n/a
Au-Au enhanced	112	1.1	1	15-40	36×10^{26}	9×10^{26}	350 μb^{-1}	60%
p↑-p↑ enhanced *	112	200	1	20	80×10^{30}	65×10^{30}	25 pb^{-1}	60%

[best store or week]

[incl. beam studies and maintenance]

* Achieved polarization performance in p↑-p↑ Run-4 was 40-45% in store
* Planned polarization performance by p↑-p↑ enhanced is 70% in store

RHIC Run-4 Au-Au Accomplishments

W. Fischer et al, MOPLT165

- Start-up/ramp-up in 4 weeks
  - 1 week less than planned
- Consistent high bunch intensity from injector
  - $\geq$ design of 10^9 Au/bunch, not yet single-bunch limited
- Time in store increased to 53%
  - 65% in low-energy 9-day 31.2 GeV/u run
- Reliable, near-complete rebucketing into 196 MHz storage RF

J.M Brennan et al, MOPLT159

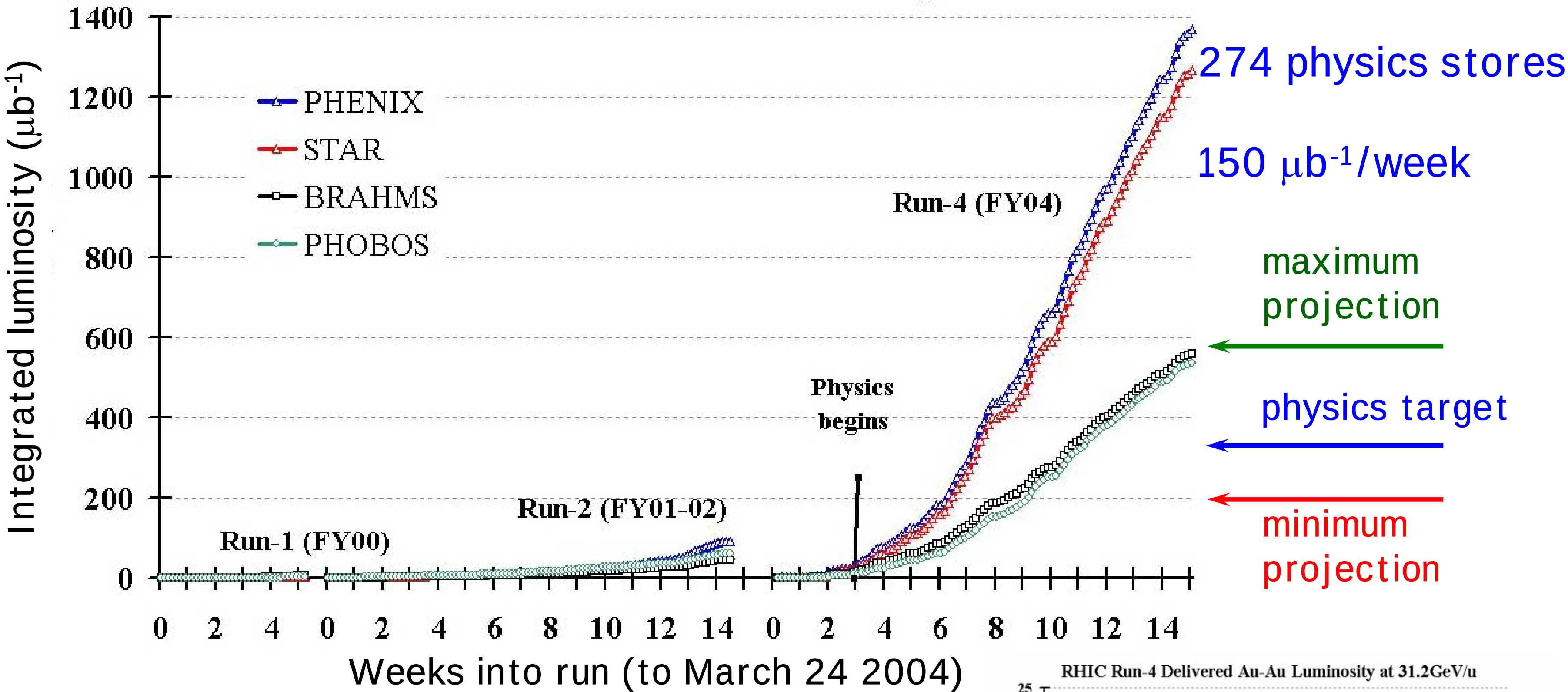
- Steering/collimation reduced to 10 min

A. Drees et al, MOPLT163

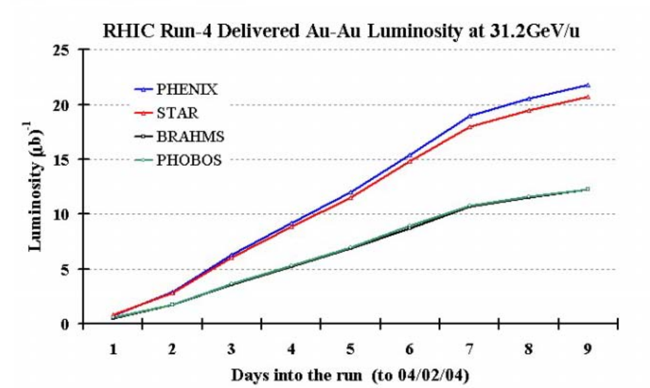
- Best 7 days delivered 179 μb^{-1} to PHENIX
  - Nearly 2x all of Run-2 delivered luminosity
- Set-up for 31.2 GeV/u run in less than 2 days
  - Optics/model predictability improvements

J. van Zeijts, TUPLT191

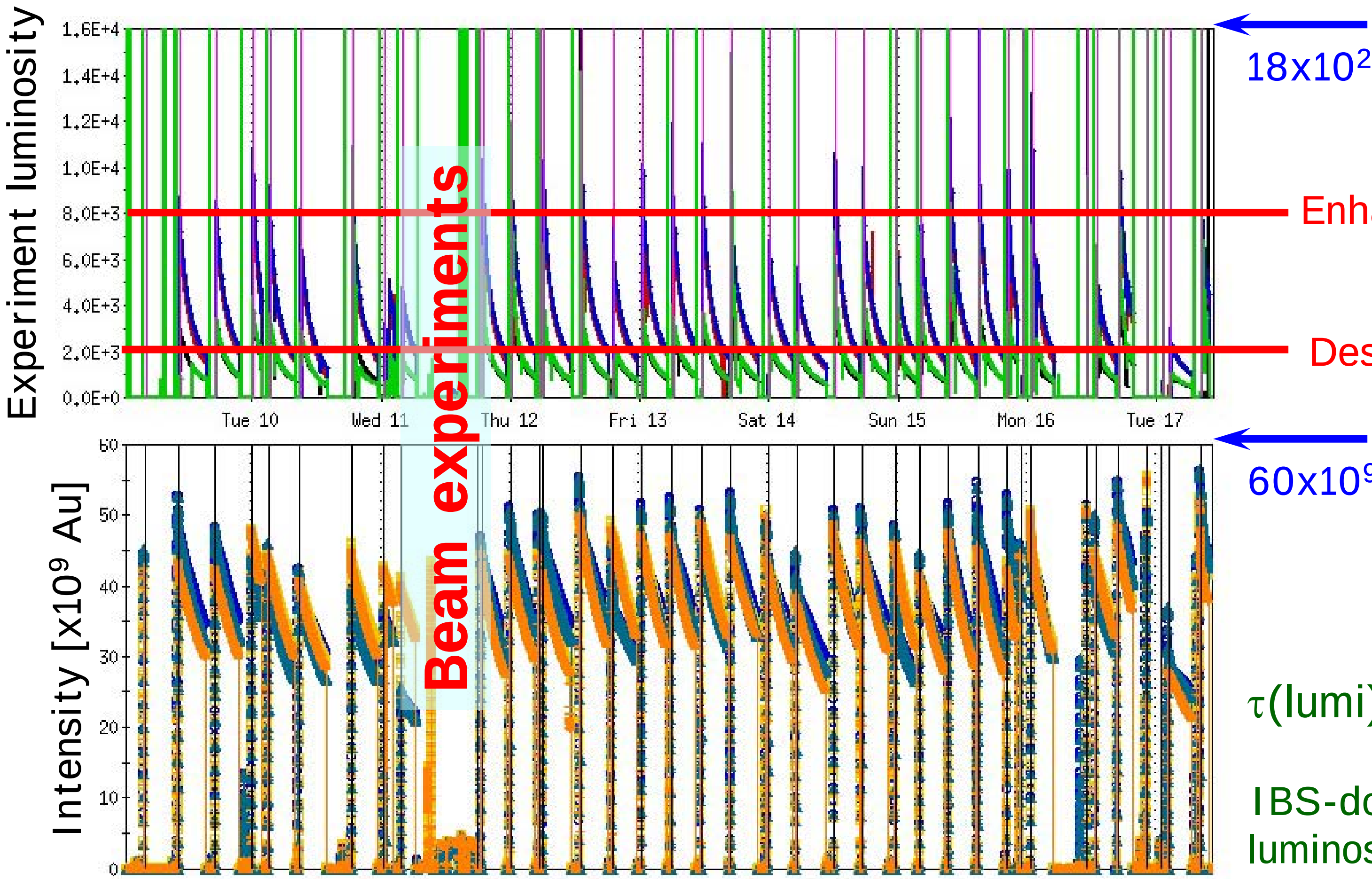
RHIC Run-4 Au-Au Luminosity Evolution



	100GeV/u	Relative to Run-3	31.2GeV/u $(\mu b)^{-1}$
PHENIX	**1370**	**15x**	**21.8**
STAR	**1270**	**21x**	**20.7**
BRAHMS	**560**	**13x**	**12.2**
PHOBOS	**540**	**7x**	**12.3**



RHIC Run-4: One Week of Au-Au Physics



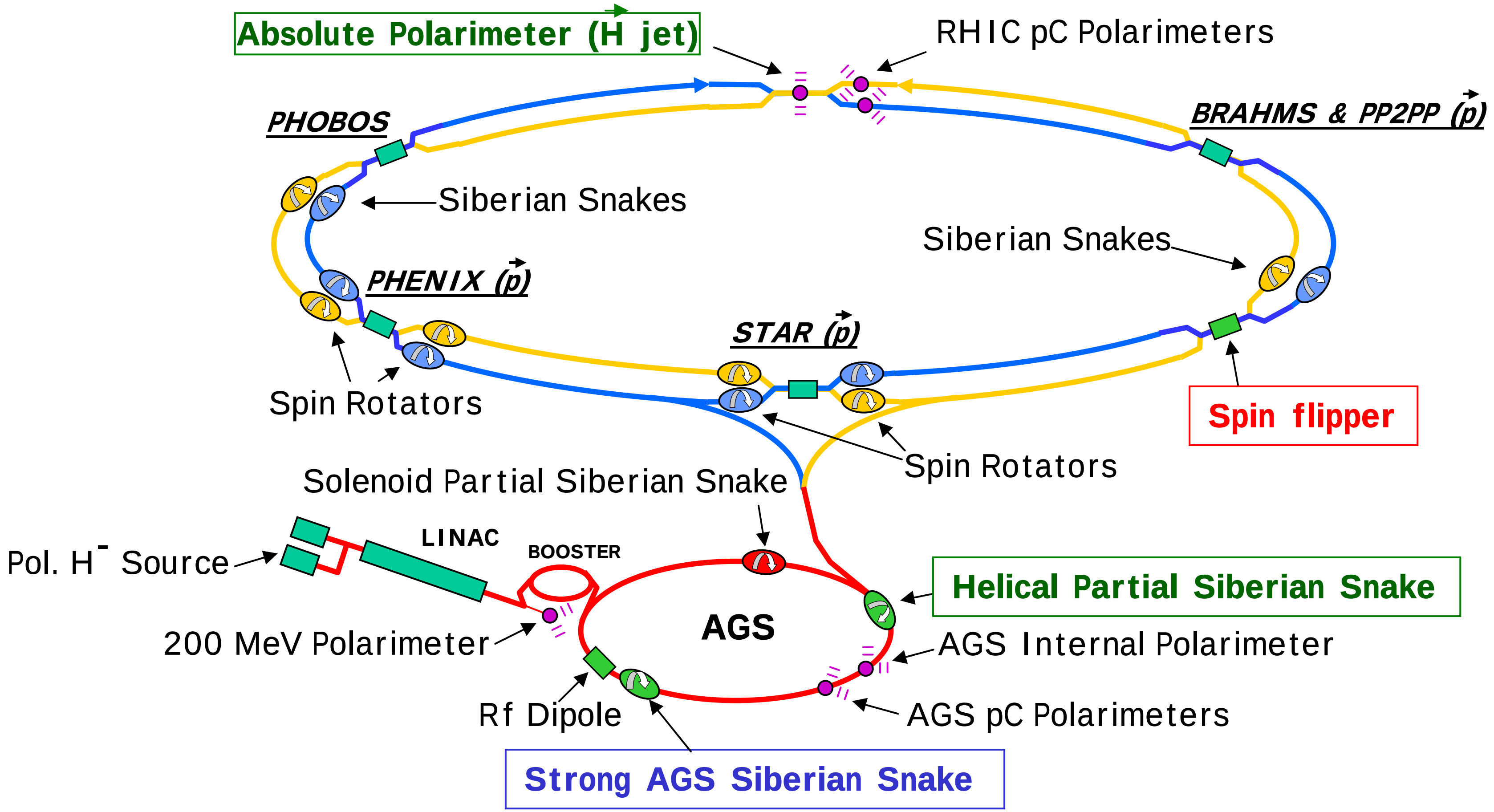
Week 9 Feb to 17 Feb [66% of calendar time in store]

τ(lumi) = 2.5 hours

IBS-dominated beam and luminosity lifetimes

Vacuum-dominated beam intensities

RHIC Polarized Proton Layout



- RHIC Jet polarimeter/AGS warm snake: Installed and commissioned during Run-4
- Spin flipper: Plan to be commissioned during Run-5 M. Bai, WEXLH01
- Strong AGS cold snake: Plan to be installed and commissioned during Run-5

RHIC Run-4 Polarized Protons Accomplishments

- Commissioned the AGS warm 5% partial helical snake
  - AGS extraction polarization improved to 50%
- Developed ramps to a new working point to optimize
  - Polarization
  - Beam-beam limit
- Commissioned absolute polarimeter using Hydrogen jet target
  - Obtained calibration of analyzing power for CNI polarimeters at RHIC injection, store energies

- Explore the total beam intensity limit with protons
  - Electron cloud formation and pressure rise

AGS Helical Warm Snake

- Successfully commissioned the warm helical 5% partial snake provided by RIKEN (Japan)

- Replaces the AGS solenoidal 5% partial snake
  - improves linear coupling, polarization transfer efficiency

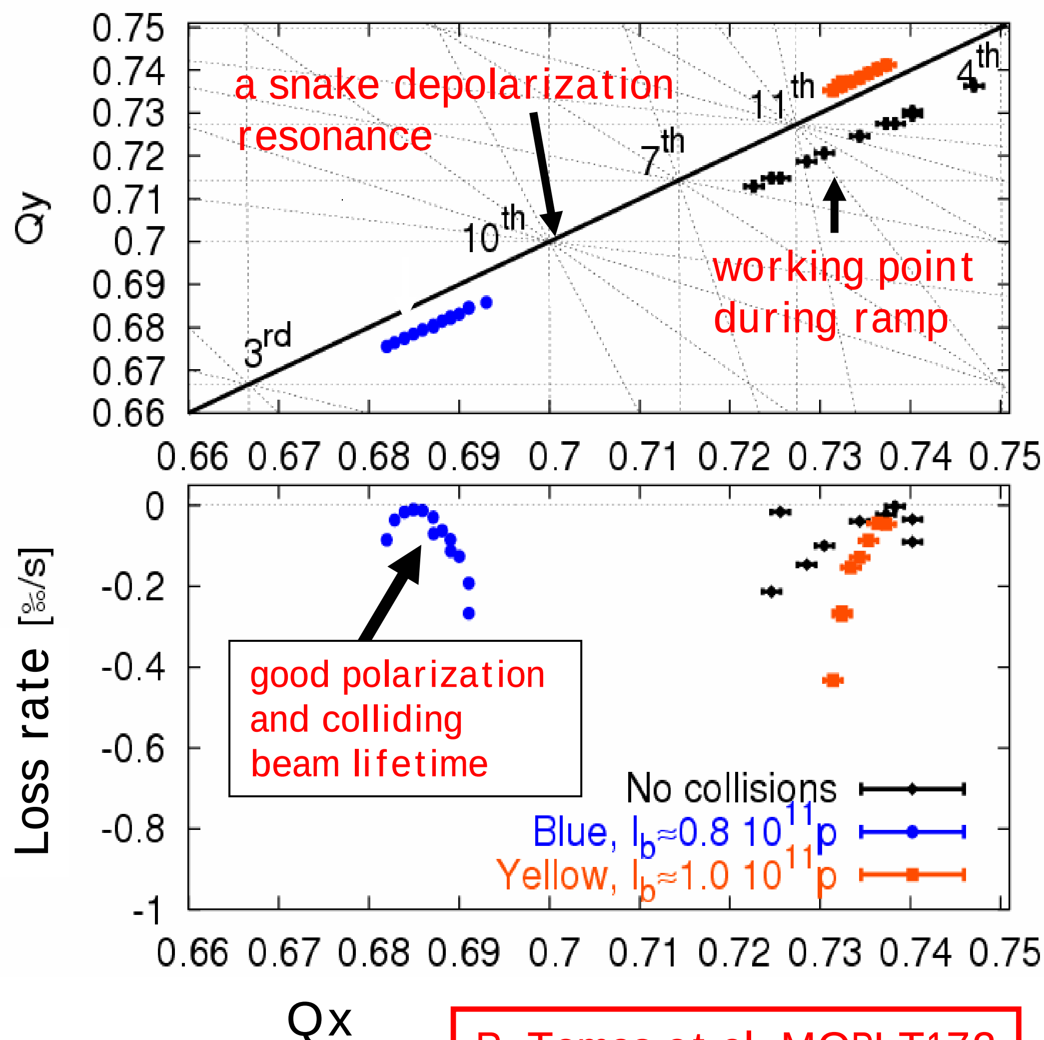
- AGS performance after warm helical snake commissioning:
  - 0.7×10^{11} protons per bunch with 45% - 50% polarization
  - 1.1×10^{11} protons per bunch with 45% polarization (at run end)

RHIC Working Point

- Previous RHIC working area (0.22-0.23) constrained polarized operations

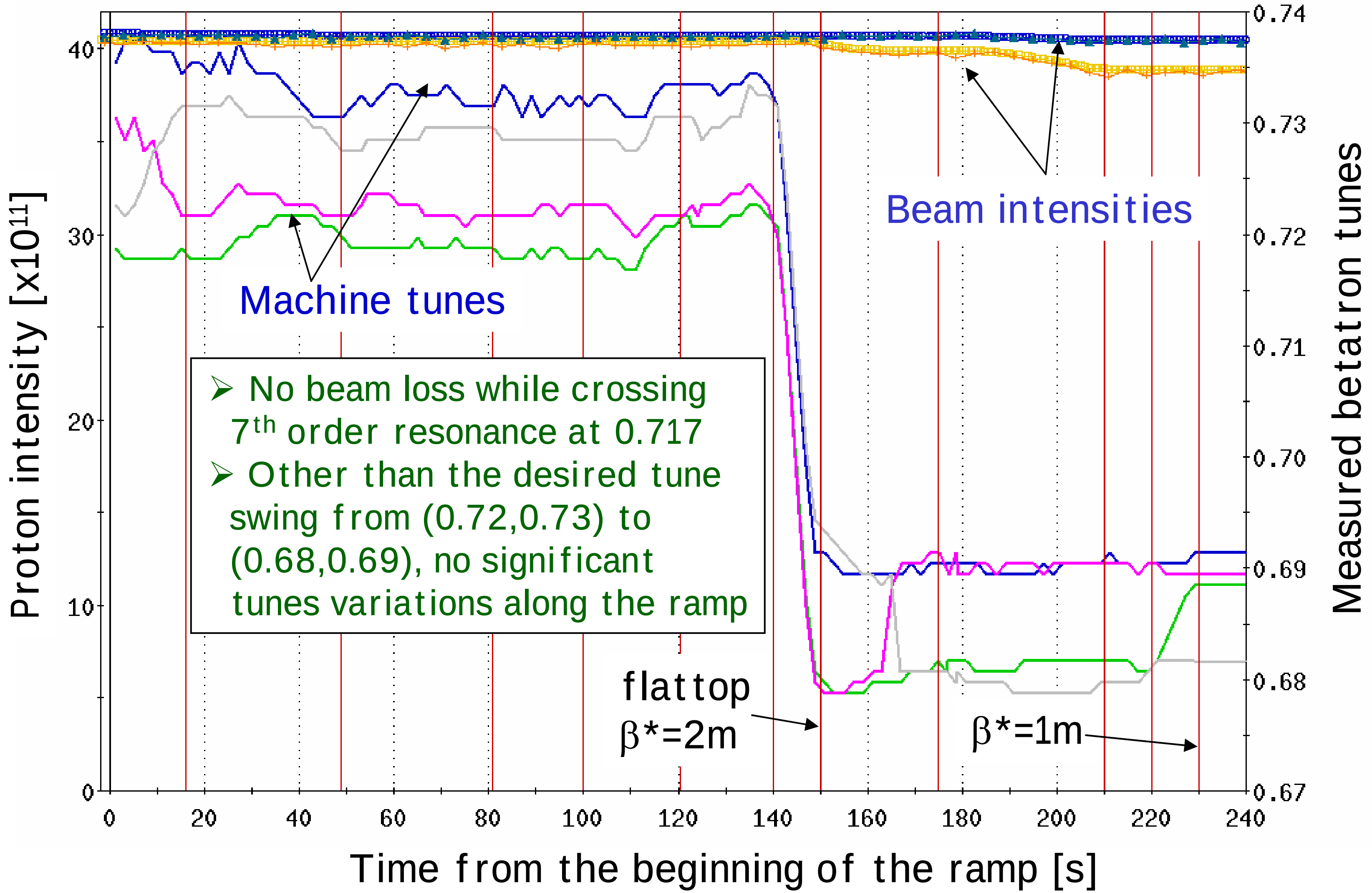
- New working point
  - Improves polarization transmission/lifetime to effectively 100%
  - Improves collision lifetime
  - Beam-beam tune spread 0.016 with 2 collisions

- Injection infeasible at store tunes due to strong 2/3 resonance
  - Move tunes along ramp



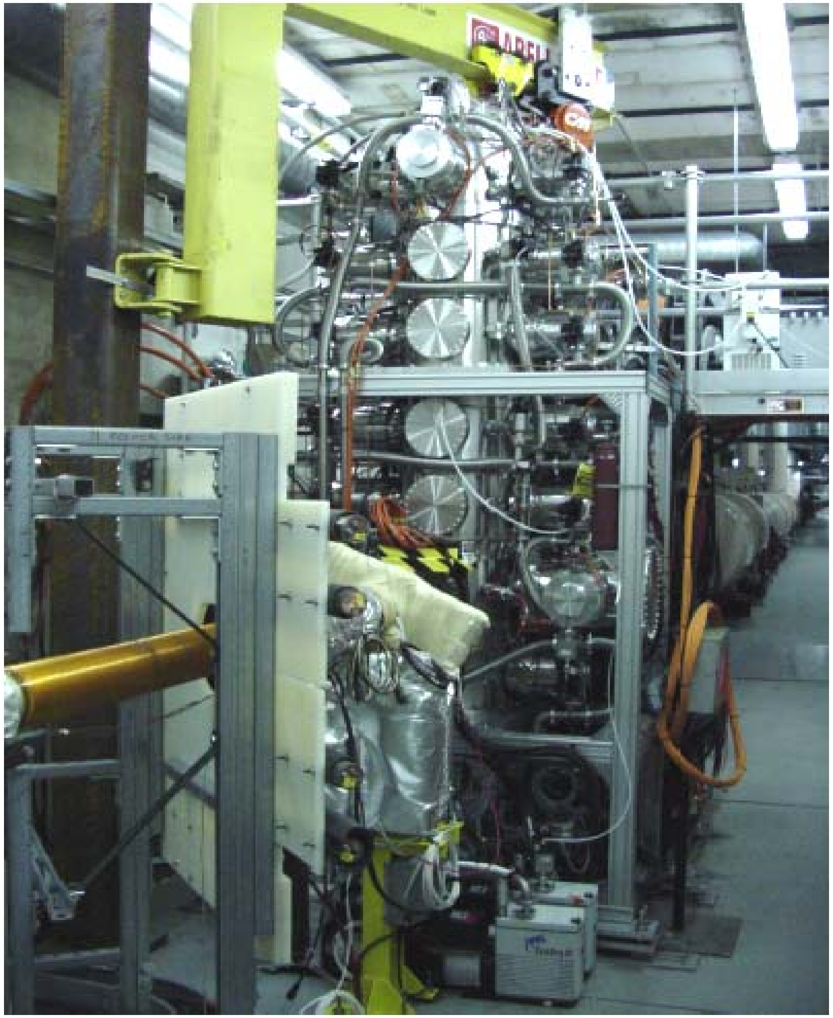
R. Tomas et al, MOPLT172

Polarized Proton Ramp Tunes

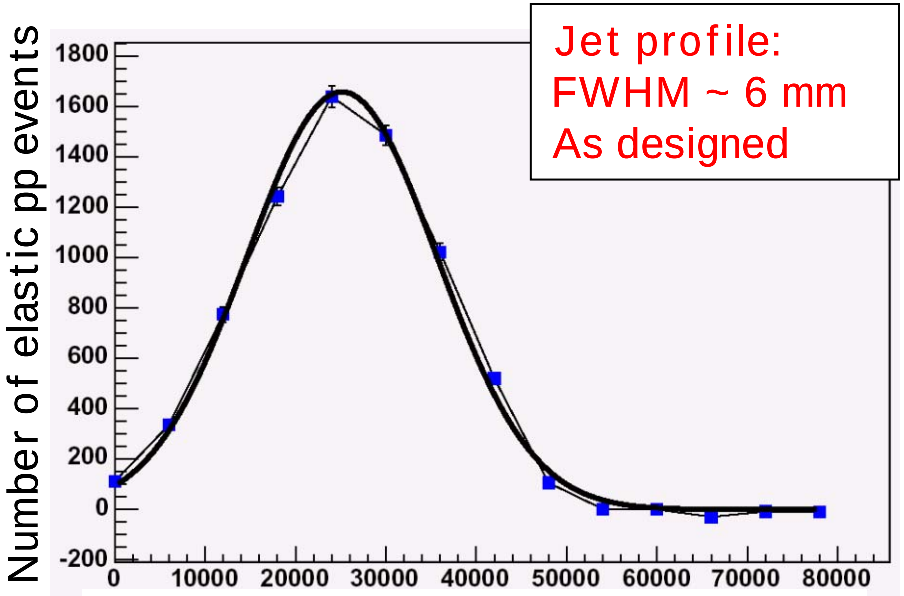


Polarized H Jet Gas Target Polarimeter

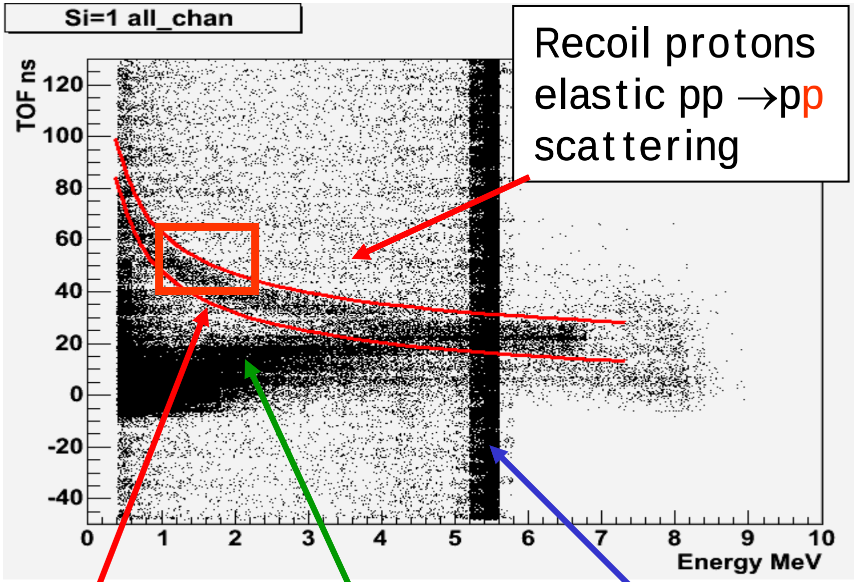
- Jet polarization very good
  - 95.9% / 95.7% in both states
- Jet thickness ~ 10^{12} atoms/cm^2
  - no discernable effect on beam
- Jet vacuum rise by factor 5
  - Jet off: 4×10^{-9} Torr
  - Jet on: 2×10^{-8} Torr
  - Beamline vacuum at 6×10^{-9} Torr 1 m from jet
- No observed depolarization from beam wake fields at 56 bunches



Polarized H Jet p-p Elastic Data



Hor. pos. of Jet 10000 cts. = 2.5 mm



CNI peak A_N
$1 < E_{REC} < 2$ MeV

prompt events and beam gas

α source calibration

- 100 GeV: ~ 700,000 events at peak of analyzing power (~ 3 x 10^6 total useful pp elastic events)

CNI calibration to <10%

- 24 GeV: ~ 120,000 events at peak of analyzing power (~ 5 x 10^5 total useful pp elastic events)

CNI calibration to <20%

Goal: CNI calibration to 5%

RHIC Polarization and Luminosity Limitations

- Beam-Beam (pp, lighter ions)
  - Limits number of experiments to 2 (out of 4)
  - ⇨ New working point
- Instabilities
  - Vulnerable near transition (short bunches, no chrom-jump)
  - ⇨ Chromaticity, octupoles for transition crossing (transverse)
    Landau cavities (longitudinal)

- Polarization
  - ⇨ Strong AGS snake, eliminate polarization losses
- Vacuum (electron clouds, desorption from beam loss)
  - Vacuum instabilities; large experiment backgrounds
  - ⇨ Use optimized bunch patterns
  - ⇨ Installation of NEG coated pipes in warm regions

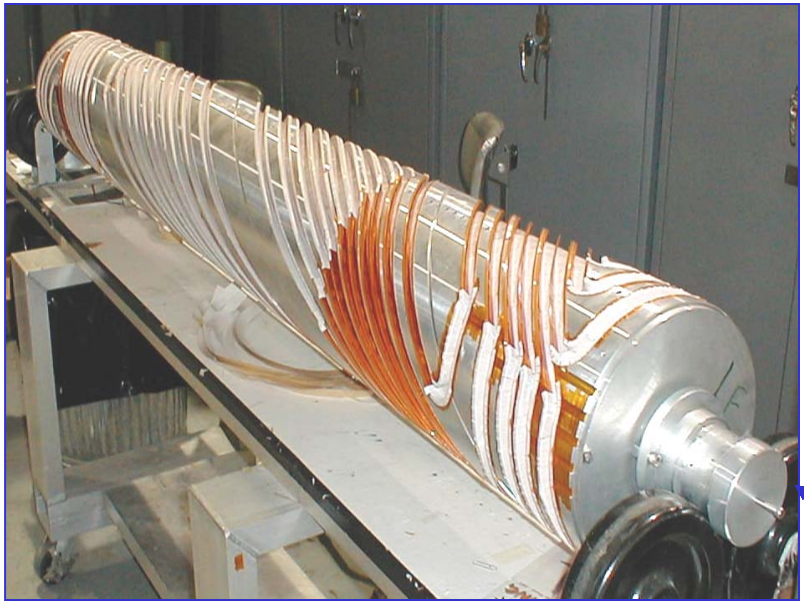
Fischer/Iriso, MOPLT164

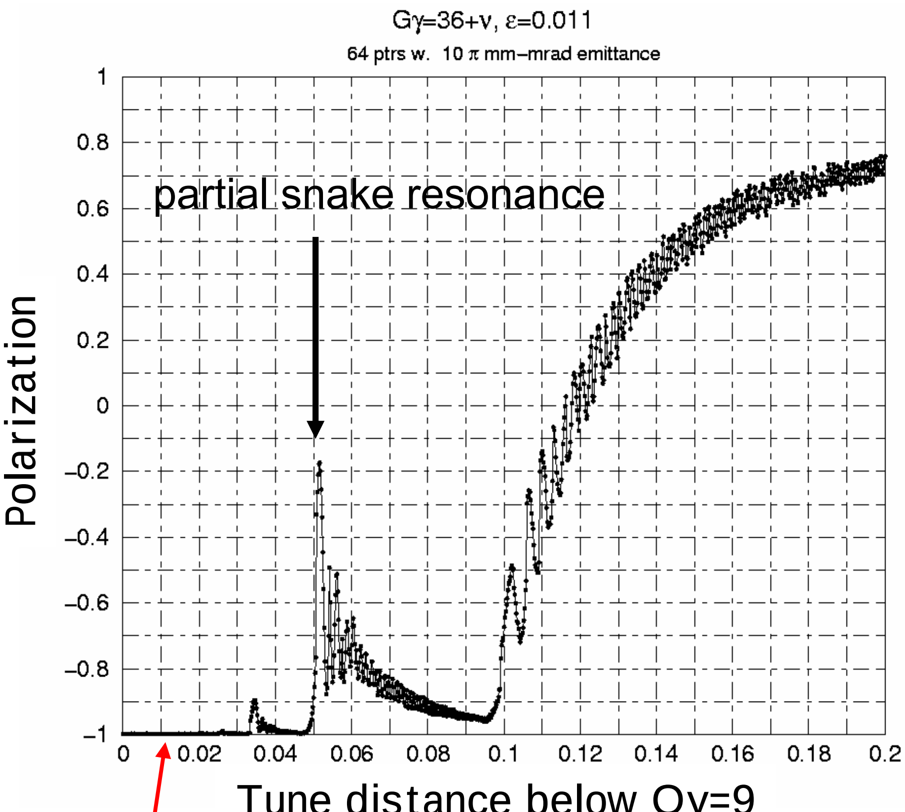
- Intrabeam scattering (Au)
  - Leads to luminosity lifetime of a few hours
  - ⇨ Ultimately need cooling at full energy (stochastic, electron)

Polarization Upgrade: AGS Cold Snake

Superconducting 20-30% partial snake

- Should give 100% polarization transmission through AGS ramp
- Increase AGS extraction polarization to OPPIS source value (70-75%)



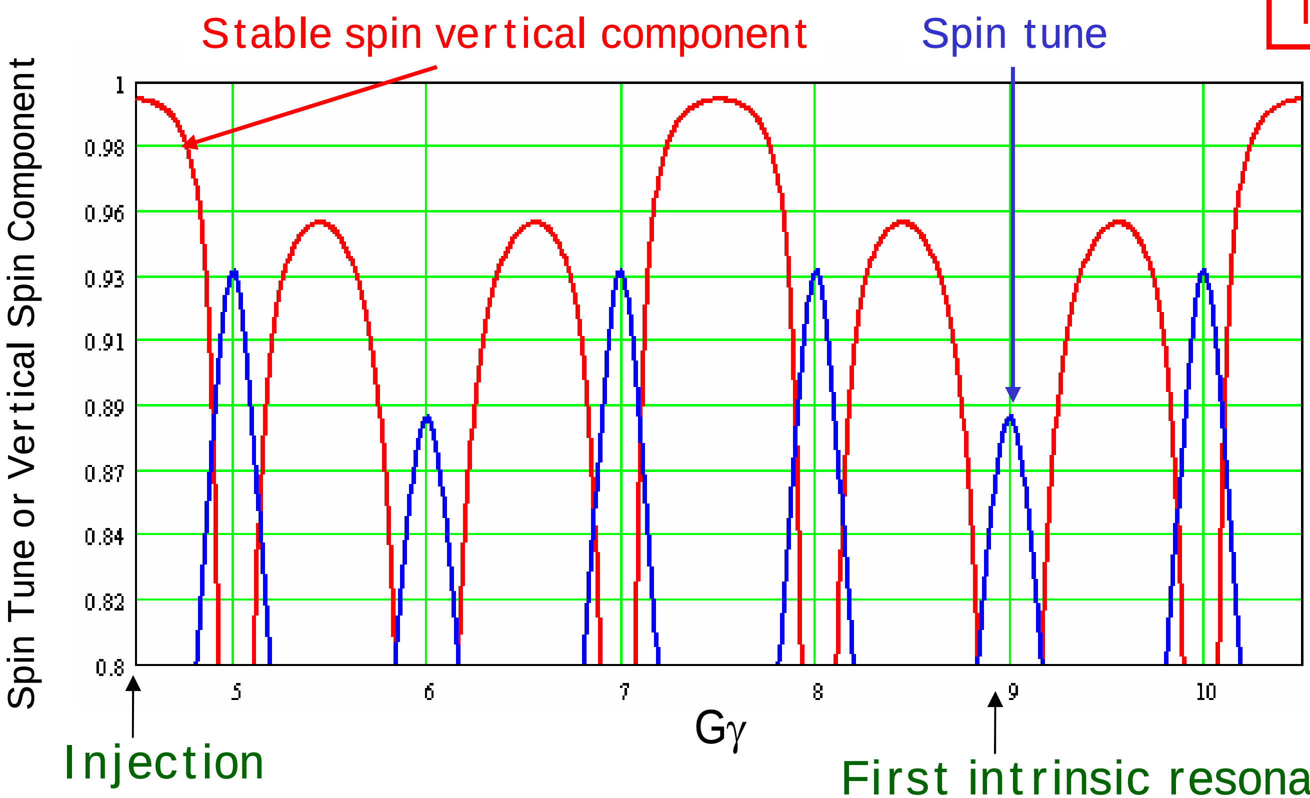


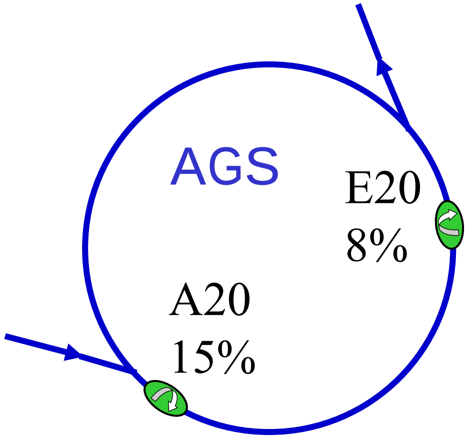
desired vertical betatron tune to avoid depolarization

20-30% superconducting helical snake
Installation: Dec. 2004

AGS Spin Matching with Two Snakes

T. Roser et al, TUPLT190

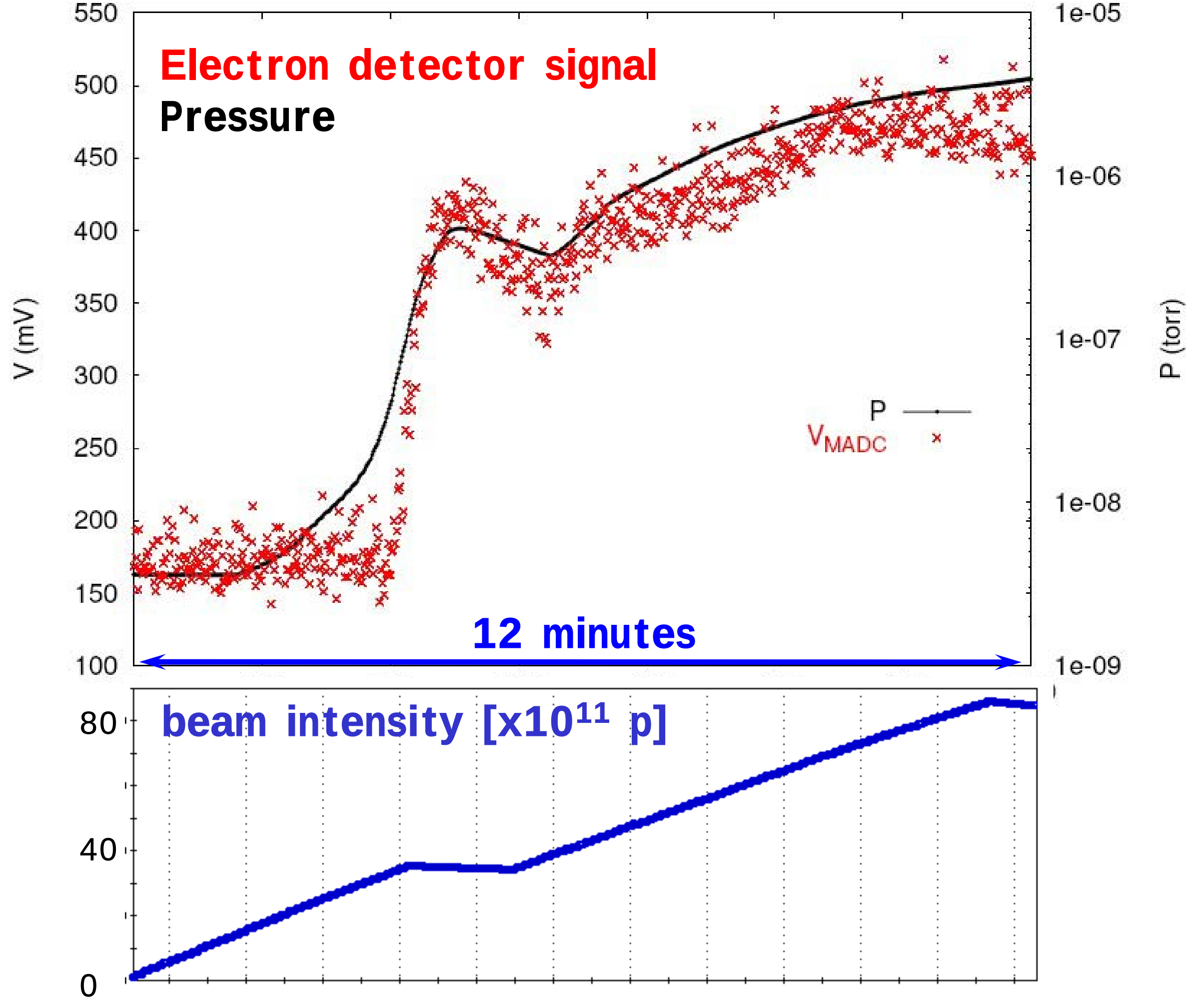




- Stable spin direction is vertical at injection/extraction
- Maximum vertical tuning area at intrinsic resonances

RHIC Electron Cloud Limitations

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



Clear connection between e-cloud and pressure at injection

Strongly dependent on bunch pattern

Fischer/Iriso, MOPLT164

Estimate for η_e assuming pressure caused by e-cloud:

0.001-0.02

(large error from multiple sources)

Iriso et al, WEPLT177

Intensity Upgrade: NEG Coating

Low Temperature (~200ºC) $Zr_{30}Ti_{30}V_{40}$ alloy developed at CERN

To reduce SEY and ESD, and provide linear pumping

- Q3-Q4 Regions (12cm Φ)

  Installed 11 x 5m in Summer 2003 shutdown

  Installing 50 x 5m NEG coated pipes during Summer 2004 shutdown

- IR Regions (7cm & 12cm Φ)

  BRAHMS: Coated SS sections of 3m x 2, coated Al sleeves in Be-Al pipe

  PHENIX: Summer 2005

  PHOBOS: Summer 2005 (3 x 4m Be pipes)

  STAR: Coated SS sections of 1.5m x 2. NEG Activation an issue!

- Developing NEG coating at BNL for IR beam pipes

  Horizontal cathode with internal permanent magnets

  Vs. vertical twisted wires and external solenoid at ESRF, SAES, CERN

  due to cost of solenoids, building, mounting, schedule, safety…

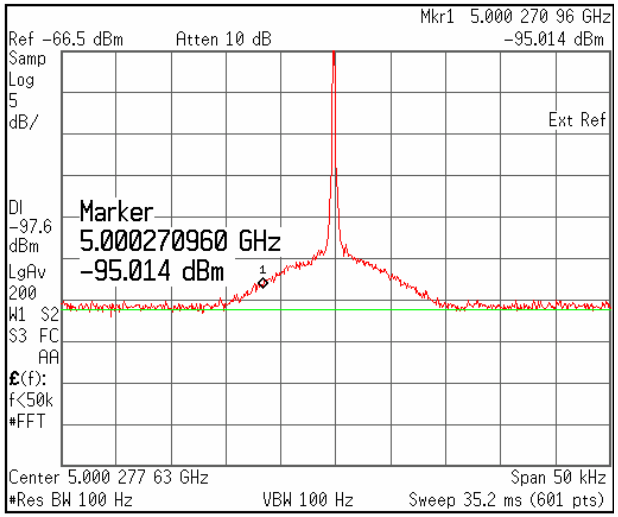
  Cathode: Zr and V ribbons wrapped around Ti tube

  1m long SS pipe was coated, activated and reached low 10^{-11} Torr

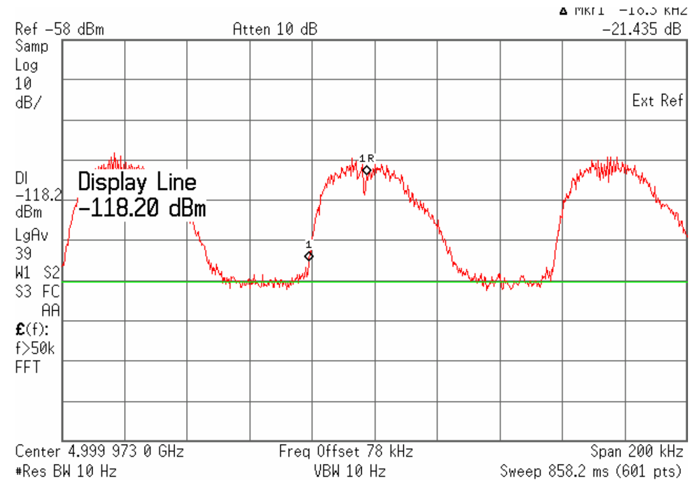
  Assembly of 6m horizontal cathode for 4m pipes and Al sleeves

Stochastic Bunched Beam Cooling at RHIC

Longitudinal bunched-beam HF Schottky spectra during store:



Protons: persistent coherence (solitons) interferes with cooling



Gold: no persistent coherence due to IBS; debunched beam visible

Microwave stochastic cooling (4-8 GHz) should work for longitudinal cooling and avoid beam debunching due to IBS during store

M. Blaskiewicz et al, THPLT171

Optical stochastic cooling (~ 30 THz) has great potential for the long term.

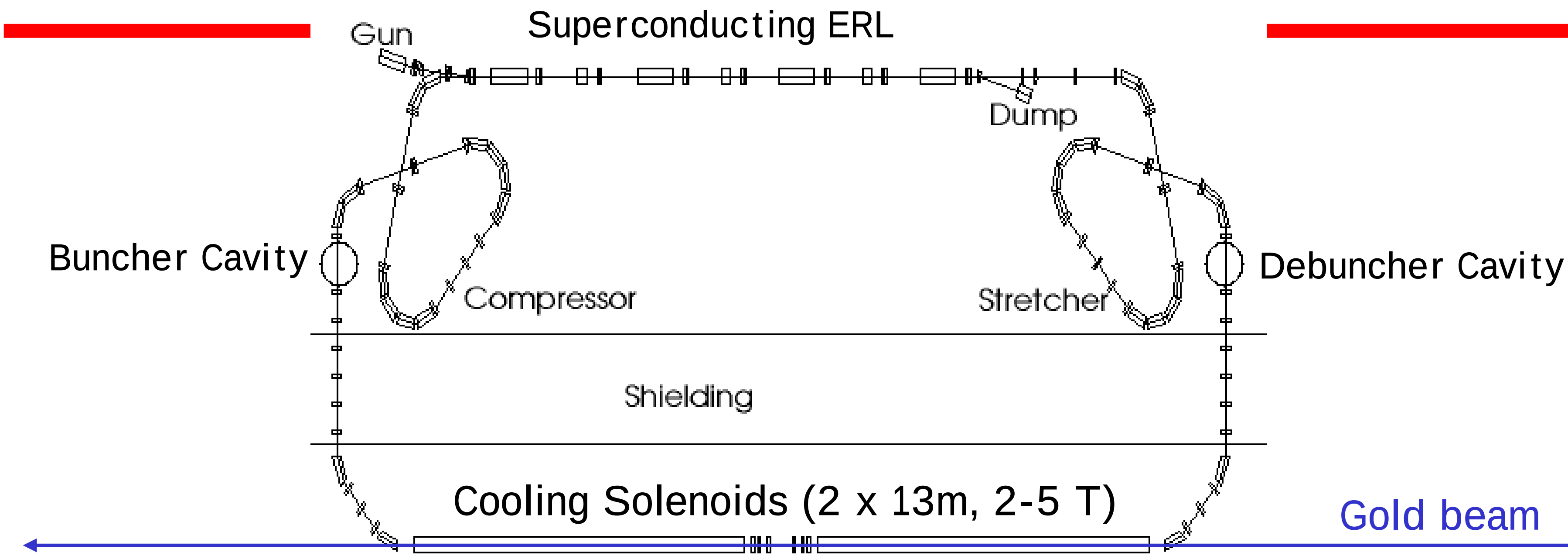
V. Yakimenko et al, WEPLT185

RHIC Electron Cooling

- Au ion energy 100 GeV/u, x100 higher than typical cooler
  - Relativistic factors slow cooling by factor of γ^2
  - Cooling power a factor of γ^2 higher than typical
- Bunched electron beam requirements:
  - E = 54 MeV, <I>=100-200 mA
  - electron beam power: ~ 5-10 MW!
- Requires high-brightness, high-power, energy recovering superconducting linac
  - Similar to ERL demonstrated by JLab for IR FEL (88 MeV, 9 mA)

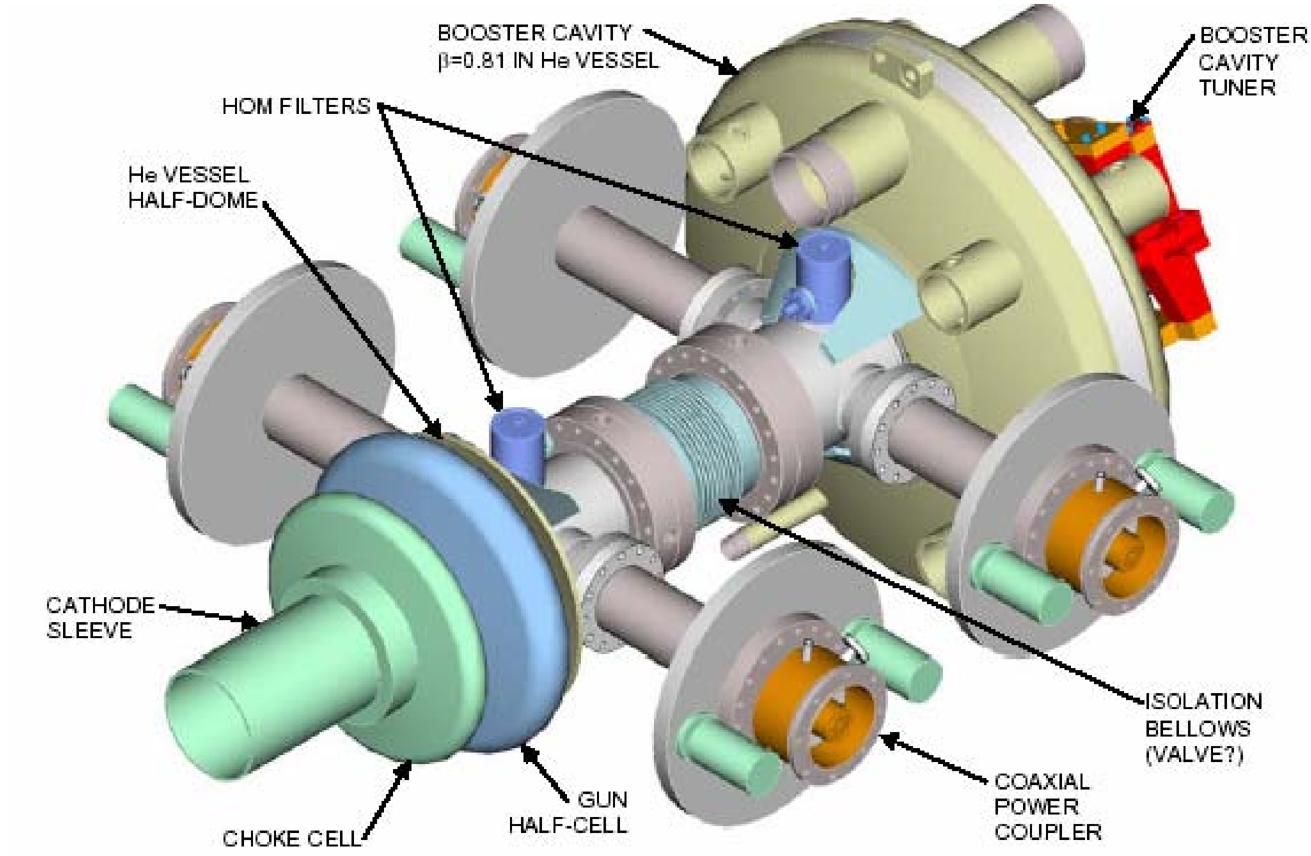
    L. Merminga, MOYCH02
  - First linac-based, bunched electron beam cooling system used at a collider

RHIC Electron Cooler R&D



- Simulation and experimental benchmarking of cooling force for RHIC energies
  - SIMCOOL, BETACOOL, direct numerical calculations [Vorpal, Tech-X, Colorado], e-coolers at GSI, COSY, CELSIUS, collaboration with INTAS
- Demonstrate high precision (<10 ppm) solenoid (5 T design started)
- Demonstrate 20 nC, 100-200 mA 703.8 MHz CW SCRF photocathode electron gun
- Develop 703.8 MHz CW superconducting cavity for high intensity beams
- Build R&D Energy Recovering Linac (ERL)

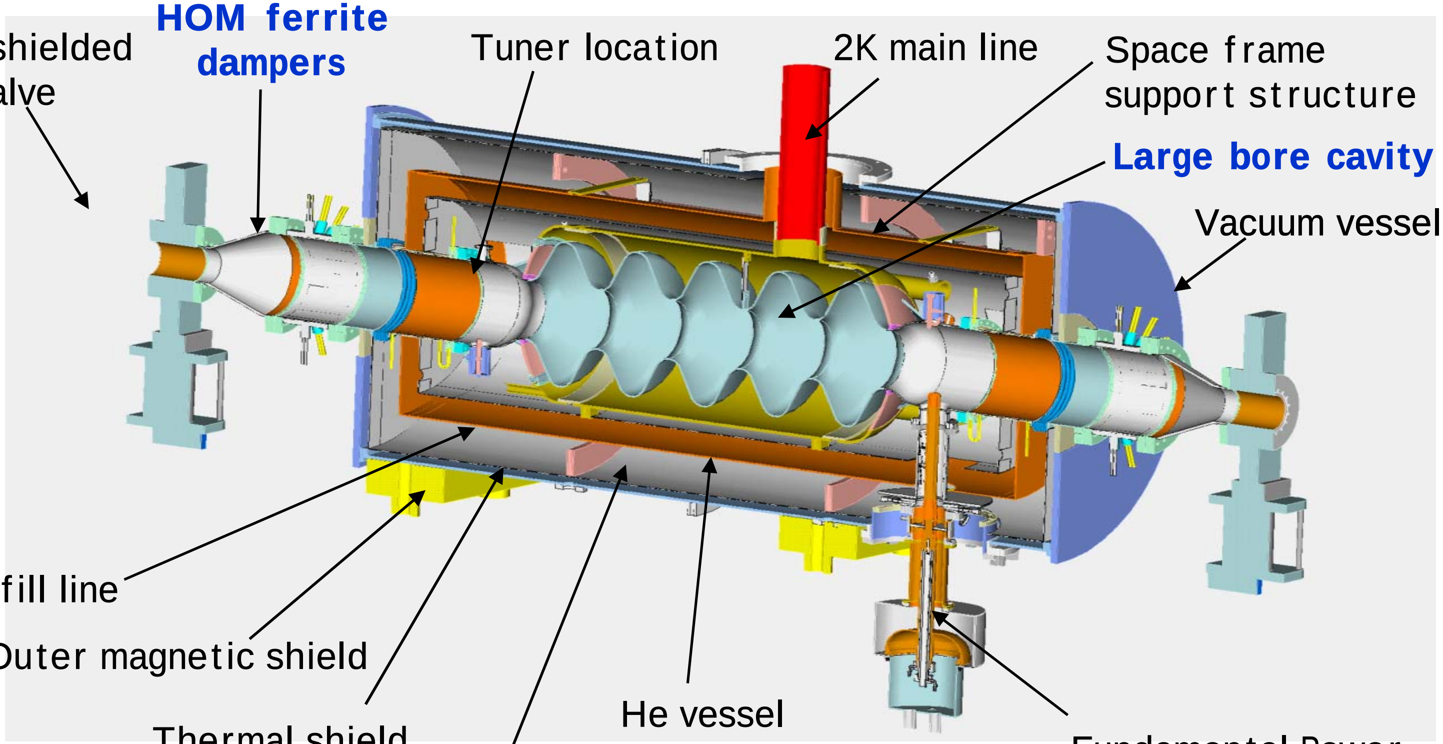
CW Photo-Cathode/Superconducting RF Gun R&D



H. Bluem (AES) et al, MOPLT156

Initial conceptual design for 703.75 MHz photocathode superconducting gun.
Prototype fabrication in 2005. (AES, BNL, Navy)

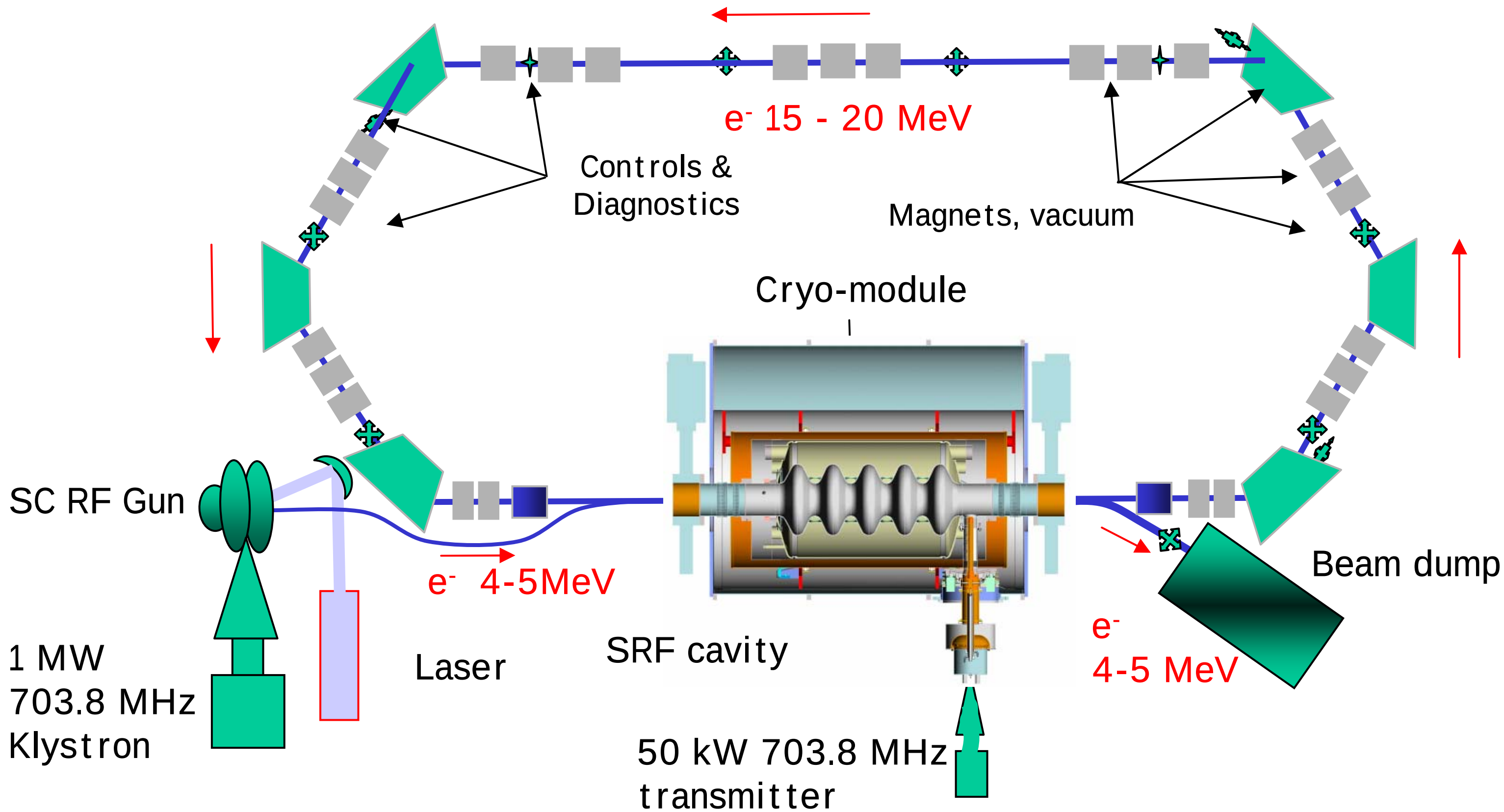
703.8 MHz CW Superconducting Cavity



Niobium prototype delivery next year
Cold Cu model testing Aug 2004
(AES, Navy, JLab, BNL)
Predicted BBU threshold > 1 A!

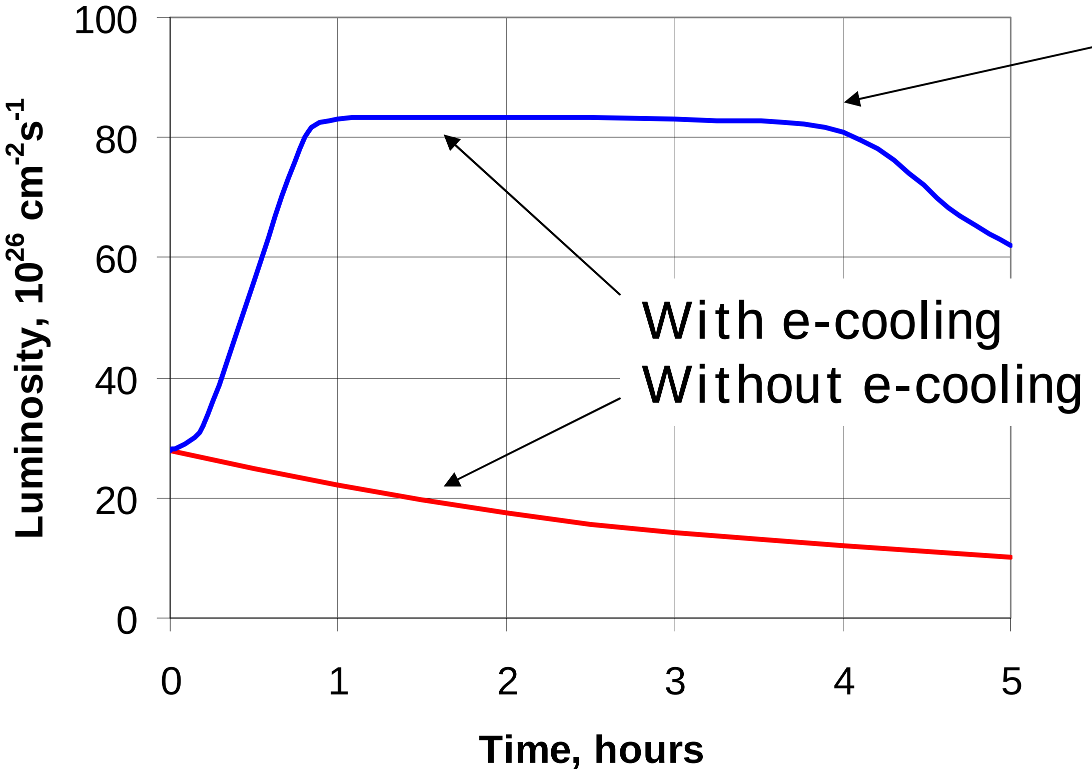
R. Calaga et al, TUPKF078

R&D Energy Recovery Linac



- ➢ Integrated testing of major RHIC electron cooling components
- ➢ Expected to be operational in 2006

RHIC Luminosity With Electron Cooling



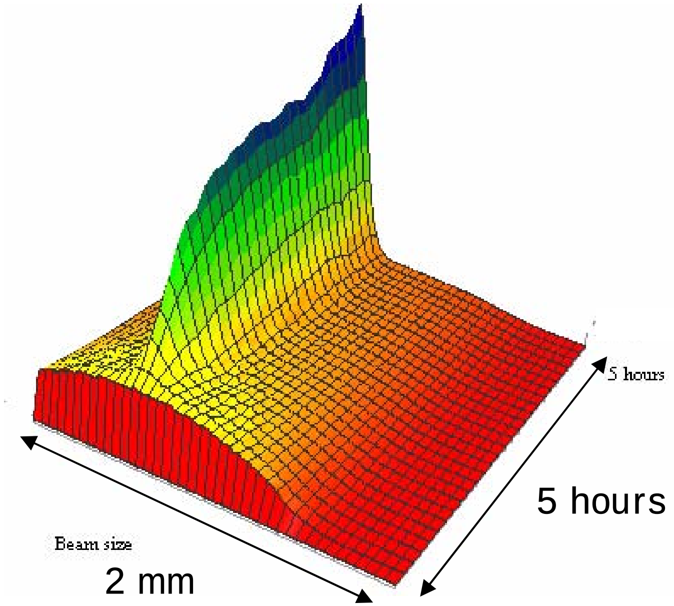
Luminosity leveling through continuously adjusted cooling

Store length limited to 4 hours by "burn-off"

Four IRs with two at high luminosity

Transverse beam profile during store

Also may be able to pre-cool polarized protons at injection energy



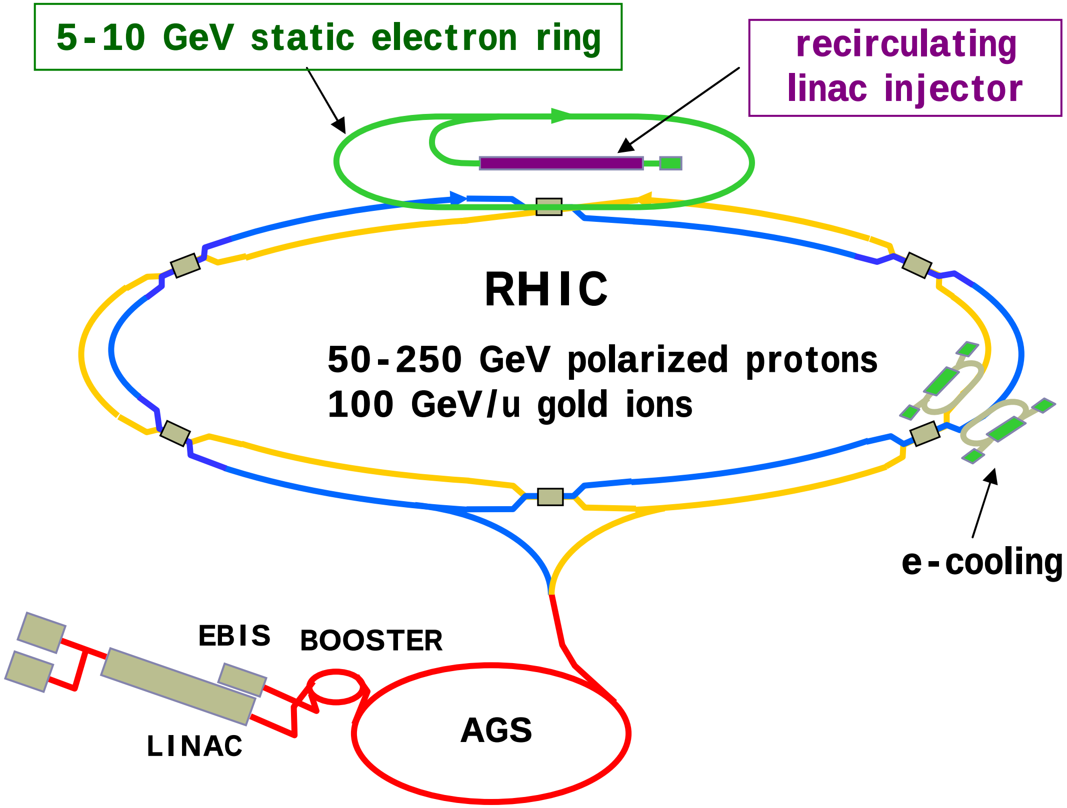
Electron-Ion Collider at RHIC: eRHIC

- 10 GeV, 0.5 A e-ring with 1/3 of RHIC circumference
  - similar to PEP II HER
  - $s^{1/2}$ = 63 GeV/u for e-Au; $s^{1/2}$ = 100 GeV for e↑-p↑
- Luminosity: up to 10^{33} cm^{-2} s^{-1}
- ZDR completed
  - http://www.agsrhichome.bnl.gov/eRHIC/eRHIC_ZDR.htm

- Electron cooling is a prerequisite for design luminosity
- Design development
  - ring-ring and linac-ring options (with MIT Bates)
- High-intensity polarized He3 source development
- High-current polarized electron source development (with Jlab and MIT Bates, mainly for linac-ring option)

V. Ptitsyn et al, MOPLT170

eRHIC: Ring-Ring Design Option



Design development in collaboration between BNL, MIT-Bates, BINP and DESY

- The electron ring of 1/3 of the RHIC ion ring circumference

F. Wang et al, MOPLT148

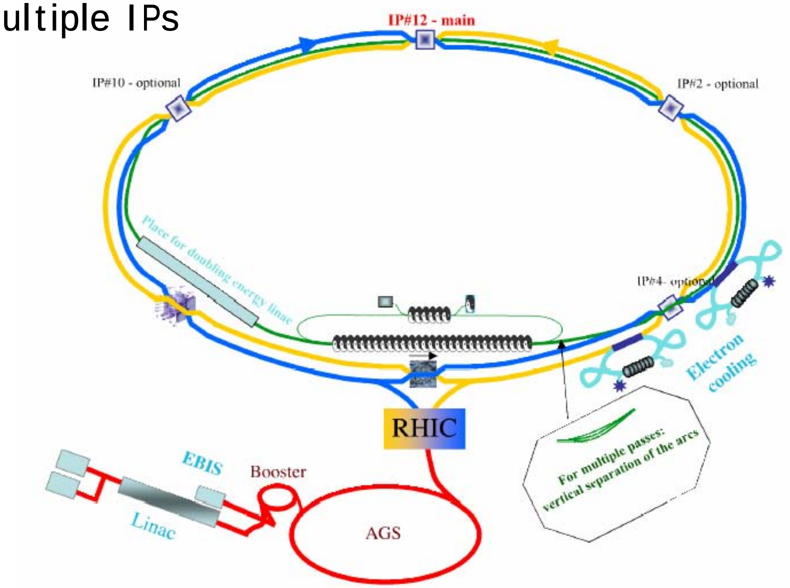
- Full energy injection using polarized electron source and 10 GeV energy linac.
- e-ion collisions in one interaction point.

  Ion-ion collisions in two other IPs at the same time.
- Longitudinal polarization produced by local spin rotators in interaction regions.

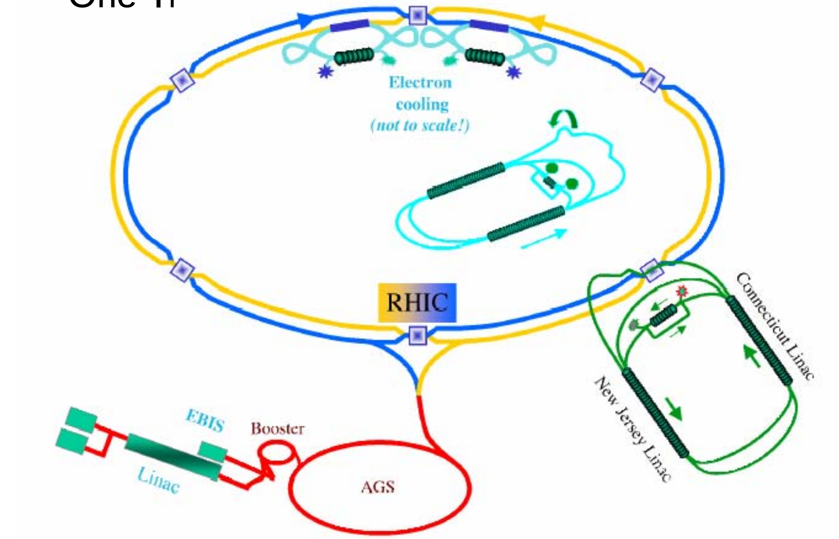
eRHIC: Linac-Ring Design Option

- Two alternative designs are presented in the ZDR Appendix A (V. Litvinenko, I. Ben-Zvi, et al).
- Electron beam is transported to collision point(s) directly from superconducting ERL
- 450mA electron current; 10 GeV energy (extendable).

Electron arcs in the RHIC tunnel
Multiple IPs



Local racetrack linac
One IP



Summary

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- RHIC Run-4 (Au-Au, p↑-p↑) was a great success
  - All program goals achieved or exceeded
  - Exceeded Run-3 Au-Au integrated luminosity by 15-20x !!
  - Polarized development: jet, AGS warm snake, working point successes
- Run-5 will likely be split between light ions and polarized protons
- Near-term limitations and required upgrades
  - Polarization: AGS cold partial snake (15-20% improvement)
  - Vacuum → NEG coated warm beam pipes
  - Intrabeam scattering → stochastic cooling, fast refills
- Active R&D on beam cooling, design development on eRHIC

Acknowledgements

Many thanks to…

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…and of course all RHIC Operations and Upgrade teams