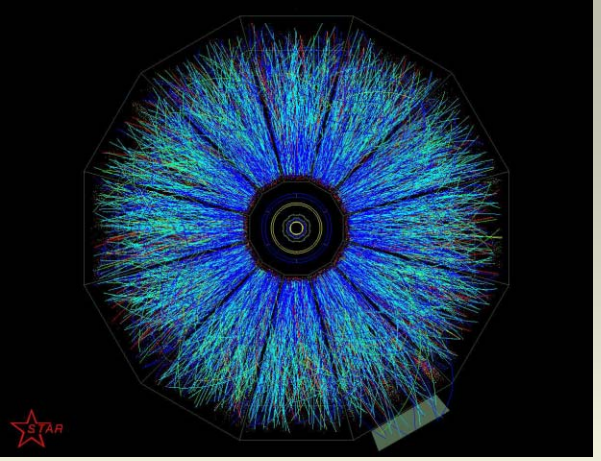
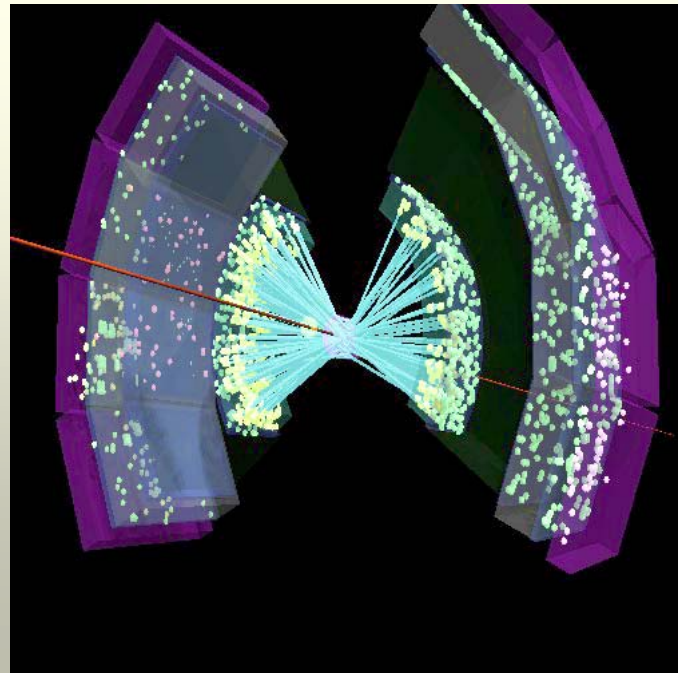
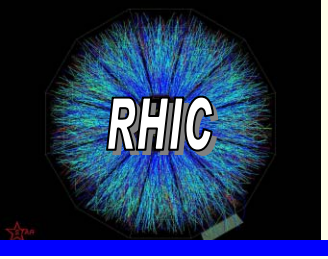


RHIC Status and Plans

Fulvia Pilat

EPAC 2002





Outline

- **Introduction, RHIC run organization**
- **Gold run 2001** [D.Trbojevic at al. MOPLE062, MOPLE061]

  performance – developments – challenges & limitations
- **Polarized proton run 2001** [T.Roser et.al. THAGB003]

  performance – developments – challenges & limitations
- **Beam experiments 2001**
- **Plans for run 2003**
- **A vision for RHIC future and upgrades**
- **Summary**

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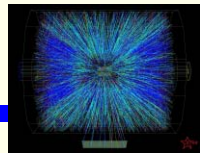

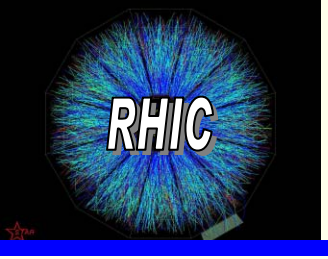

Run 2001 organization

Overall Coordinator	T. Roser
Gold Run Coordinator	D. Trbojevic
PP Run Coordinator	W. MacKay
Beam Experiments	F. Pilat
Scheduling Physicists	T. Satogata, A. Drees
MCR Shift Leaders	Ahrens, Bai, Drees, Huang,Montag, Pilat, Ptitsyn, Satogata, Trbojevic
System Groups	M. Brennan (RF), P.Cameron (Instr.)
System Commissioners	
Operation group	

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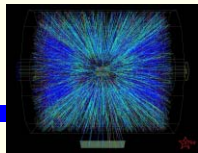
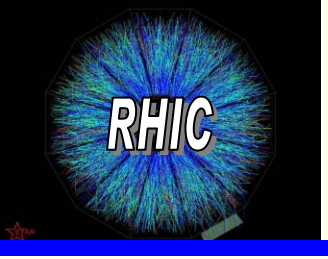
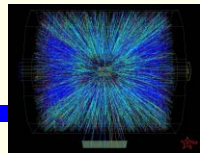




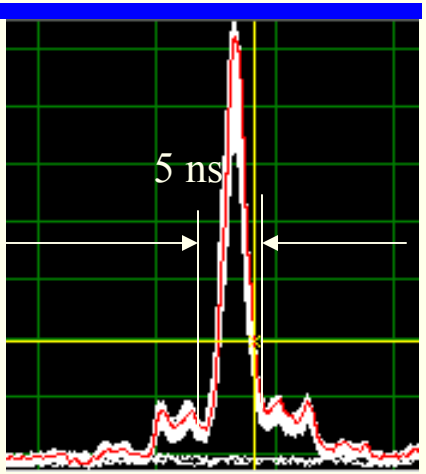
Au 2001 - Parameters

- **55 - 56 bunches** per ring ✓ (110 bunches tested - intensity limited)
- **7.5×10^8 Au/bunch @ storage energy)**
- **1×10^9 Au/bunch achieved @ injection** ✓
- **Longitudinal emittance**: **0.5 eVs**/nucleon/bunch ✓
- **Transverse emittance** at storage: **15 π μm** (norm, 95%) ✓
- **Storage energy: 100 GeV/ amu ($\gamma = 107.4$)** ✓
- **Lattice with β^* squeeze during acceleration ramp:**
  - $\beta^* =$ 3 m and 10m @ all IP at injection ✓
  - $\beta^* =$ 1 m @ 8 and 2 m @ 2, 6 and 10 o'clock at storage ✓
- **Peak Luminosity: 5×10^{26} cm^{-2} s^{-1}** ($2.5 \times$ design average) ✓
- **Bunch length: 5ns** (200 Mhz operational) ✓

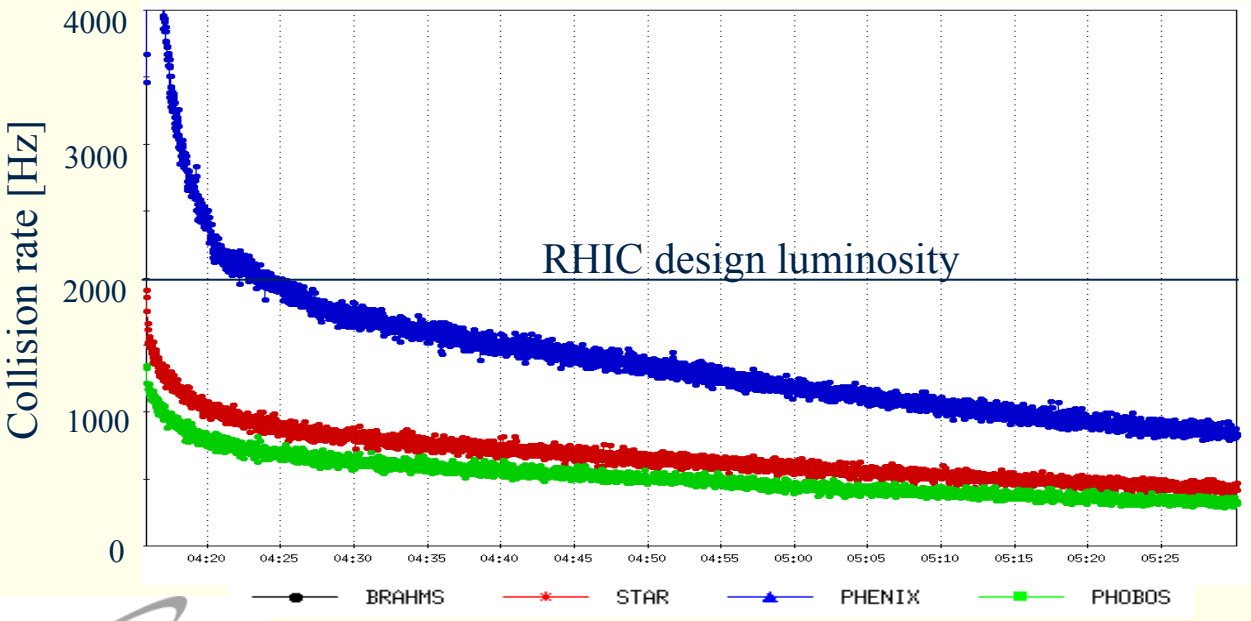


2001 Au - Performance

- Collisions at RHIC design beam energy **(100 GeV/nucl)**
- 200 MHz rf system operational
  - **5 ns bunch length** and an interaction region with $\sigma \sim 25$ cm
- Luminosity exceeding RHIC design luminosity of **2×10^{26} cm^{-2} s^{-1}**
- 40% availability is limiting total integrated luminosity



RHIC bunch profile



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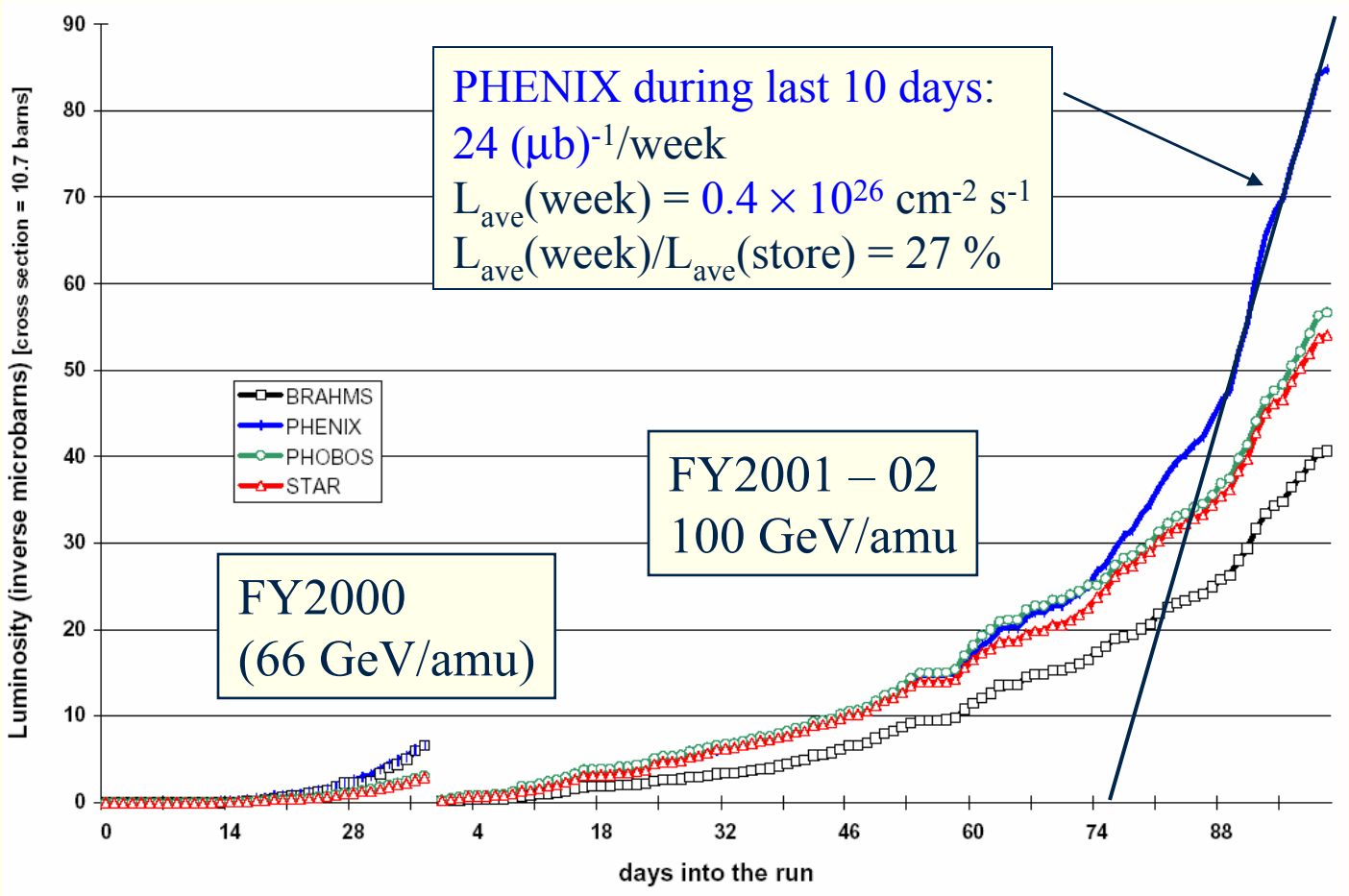
Integrated Au-Au luminosity



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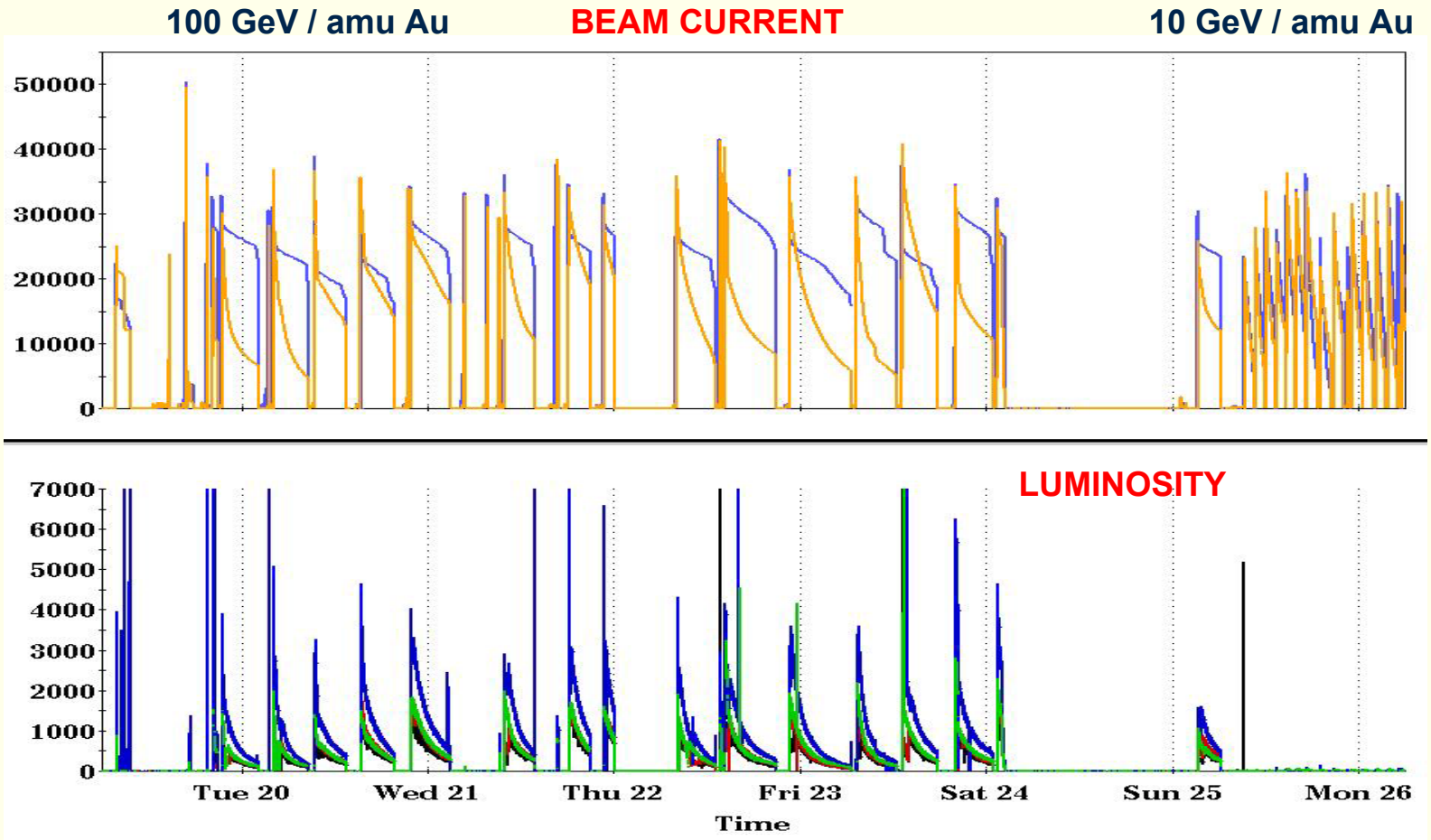
2001 Au - Performance



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2001 Au developments

- **Systems commissioned**:

gammaT jump quadrupole system → ramp transmission [J.Kewisch, C.Montag]

200 MHz storage RF system → bunch length [M.Brennan et.al.]

- **System upgrades**:

Beam **abort** [L.Ahrens et.al. MOPLE069], **BPM** [T.Satogata et.al.THPRI102]

BLM [M.Bai et al.THPRI084], **collimators** [A.Drees et al. TUPDO035] **, …**

- **Improvement of operational procedures**

Orbit correction [V.Ptitsyn et al. MOPLE073], **decoupling**[F.Pilat et al.WEPLE041]

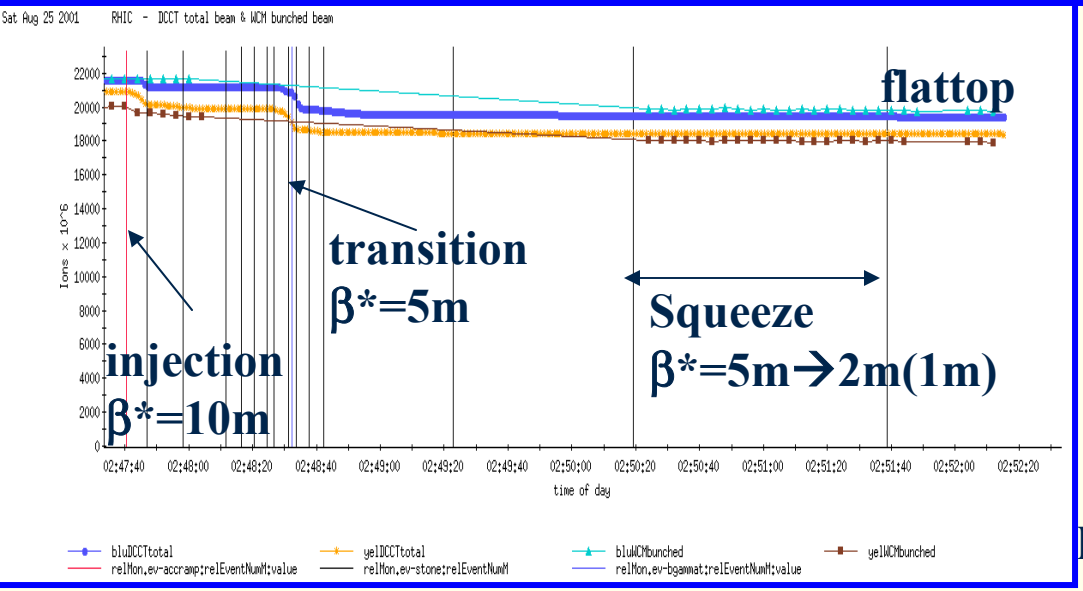
chromaticity [S.Tepikian et al.THPRI075] , **gap cleaning** [A.Drees, THPRI073]

Ramp Control [J.vanZeijts, MOPLE059], **Electronic Logbook**[T.Satogata,MOPDO009]

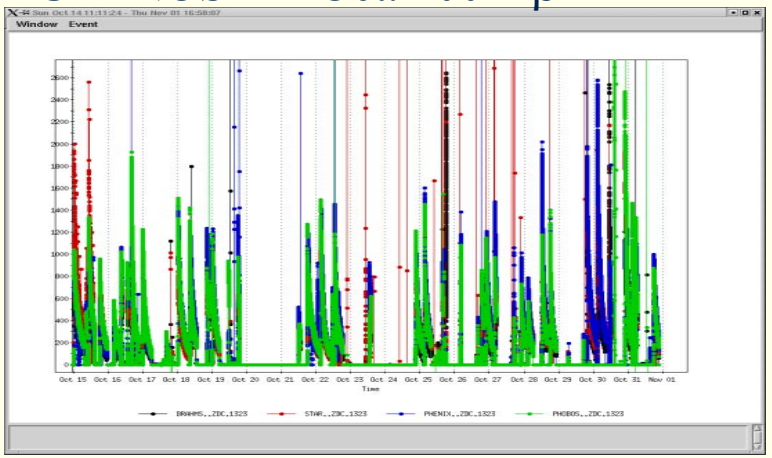
- **Developments**

β* squeeze on the ramp, phase lock loop **(PLL), crystal channeling**

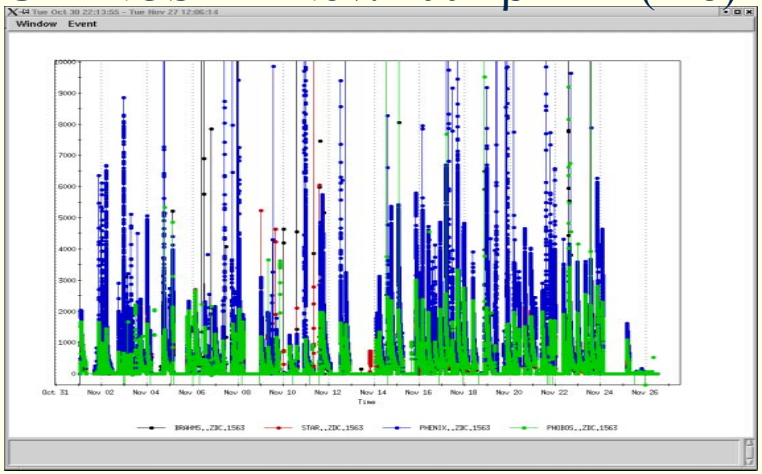
2001 Developments – β^* squeeze



LUMINOSITY Oct. 2001 β*=2m



LUMINOSITY Nov. 2001 β*=1m(IP8)



- β* squeeze on the ramp worked well
- Few commissioning ramps needed
- Big payoff in luminosity with β*=1m, but:
  - **lifetime** problem in yellow
  - up to 50% **beta beating**
  - up to 1m **vertical dispersion**

[T.Satogata et al. WEPLE049]

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2001 developments - PLL

PLL [P.Cameron et al. THPRI072]

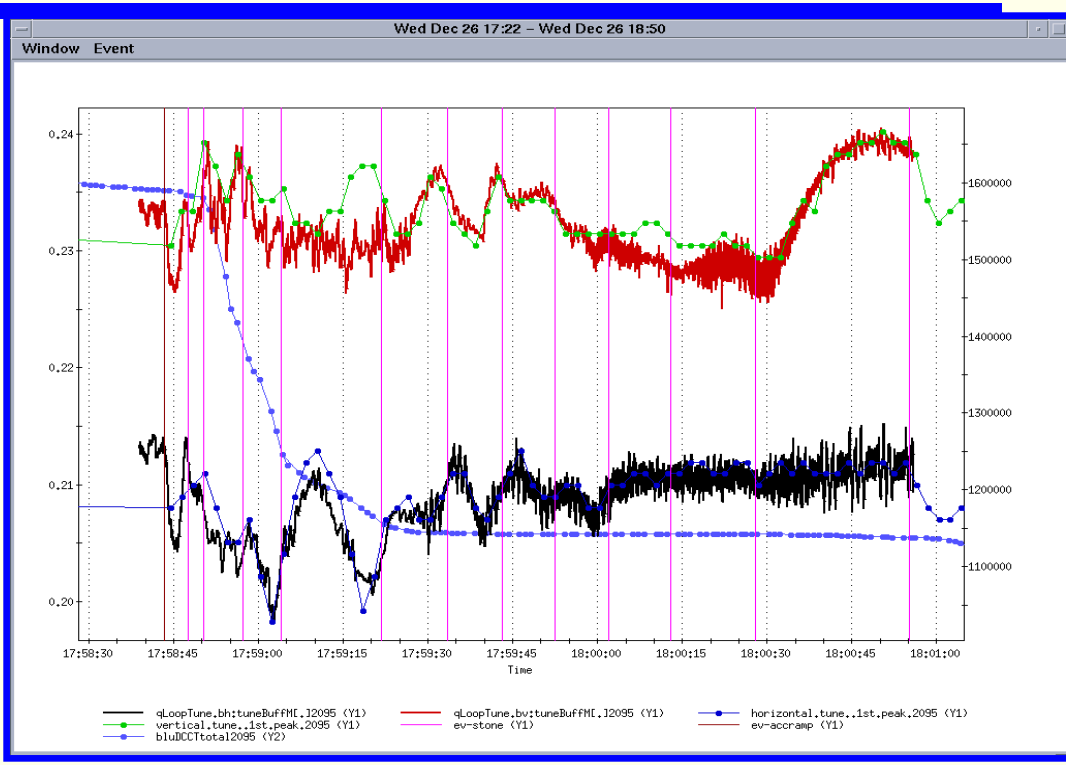
- accuracy ($<10^{-5}$)
- resolution (a few 10^{-6})
- Auto-lock
- chromaticity control essential
- coupling control desirable

Run 2001

- **system commissioning**
- **Q measurement on the ramp**
- **beam experiments**
- **tune feedback (pp run)**

Run 2003

- **System improvements**
- **Q feedback from "day one"**



PLL measurement on the ramp
Good agreement PLL – Tune Meter

Radial modulation 0.2mm for chromaticity measurement [S.Tepikian et al.THPRI075]

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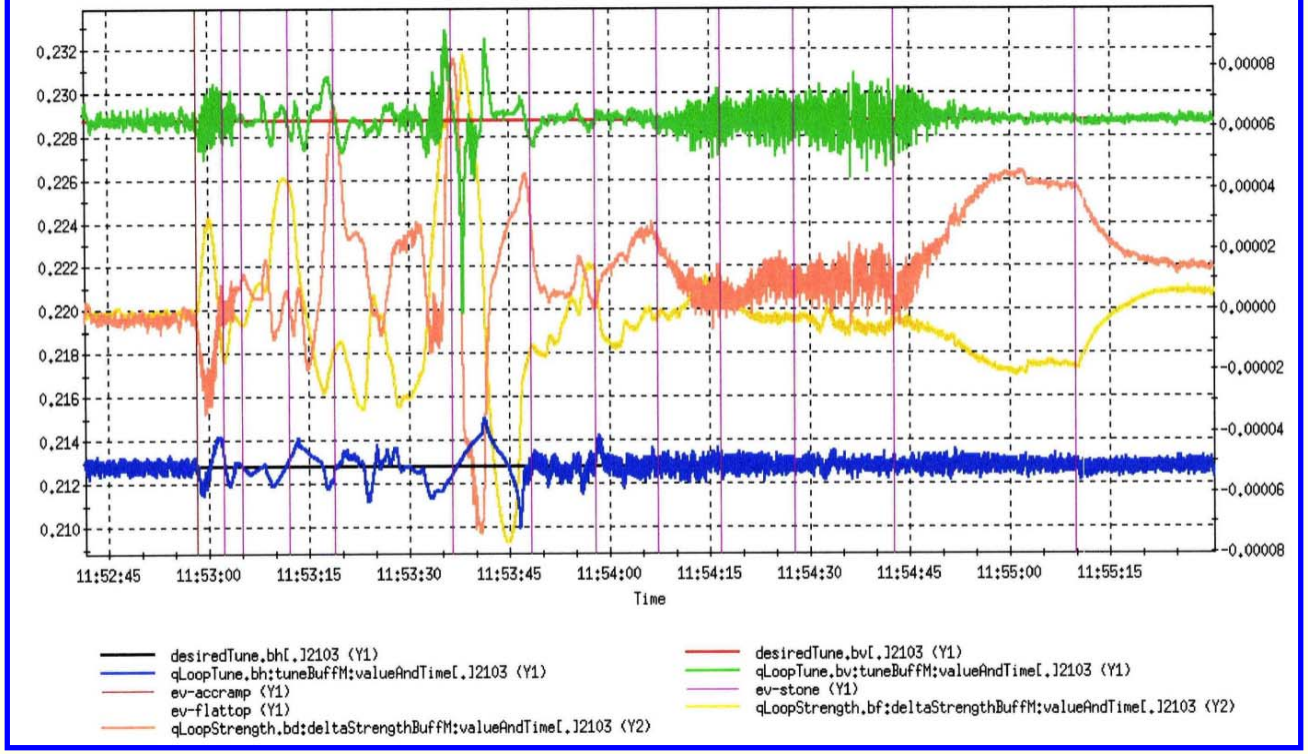
2001 developments – tune feedback

Q_V →

Q-loop strengths →

Q_H →



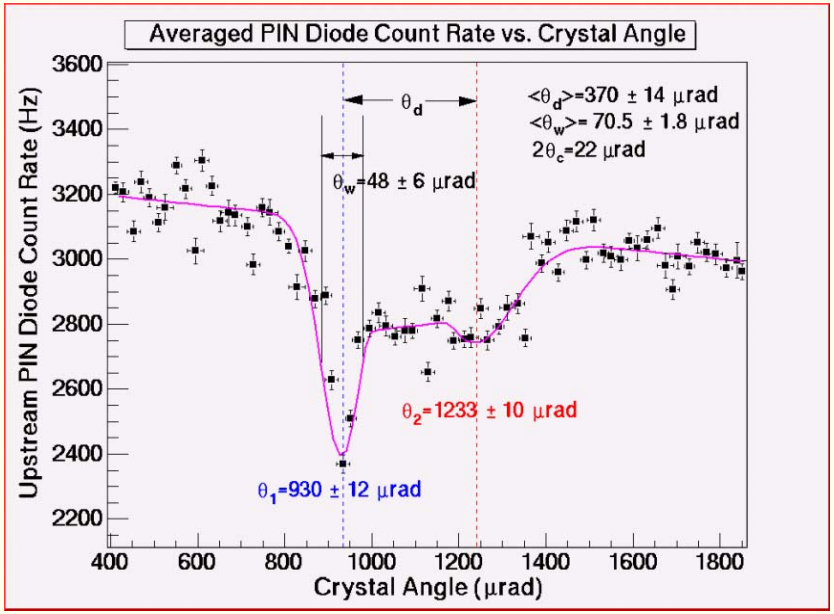
First ramp with tune feedback (PP)

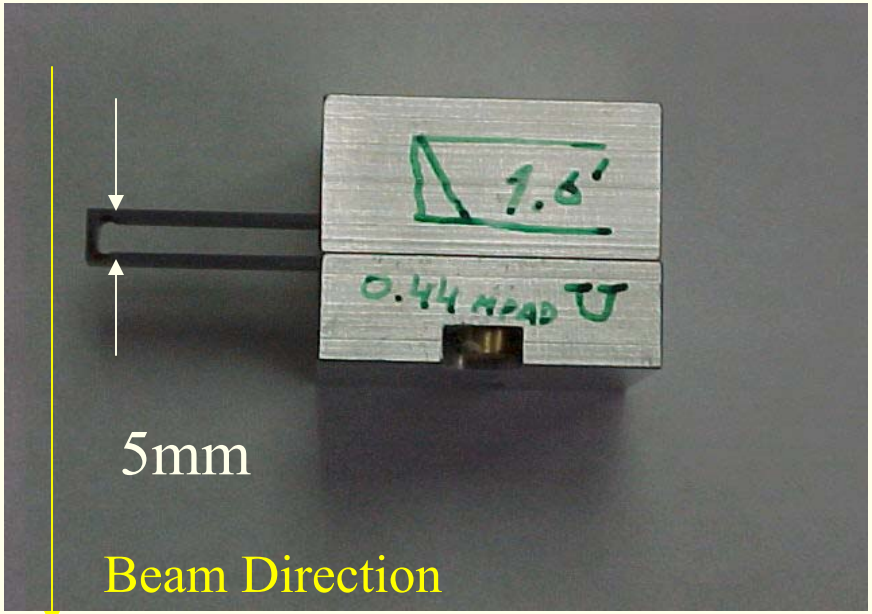
Controlled tunes to **0.002** Corrected for up to **0.02**

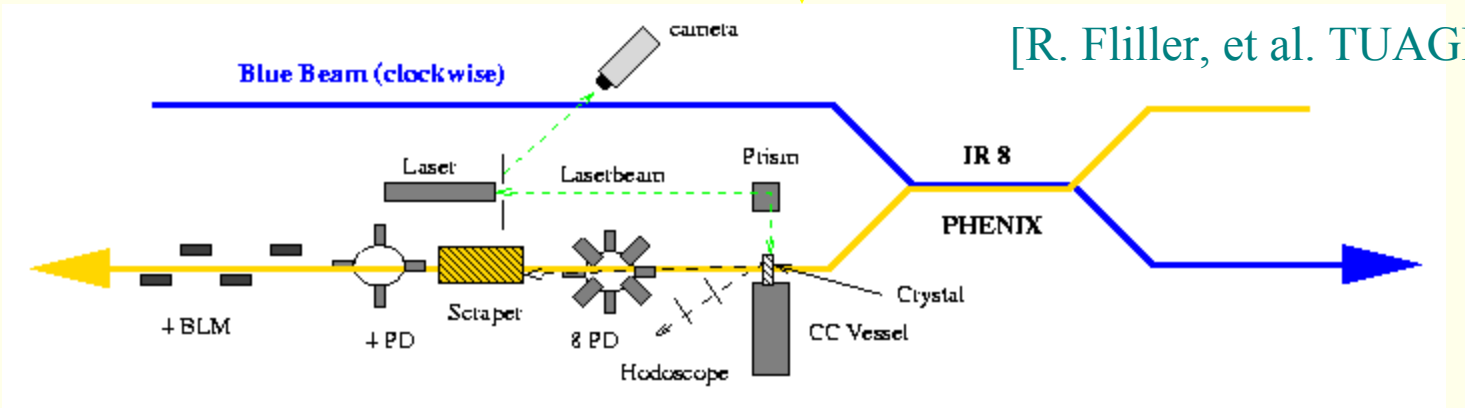
PLL signal→ **feedback** to main Q bus (blue ring feedback successful)

Q-loop integrated into **sequencer** [C.Schultheiss et al.THPRI041]

2001 Au developments - Crystal







[R. Fliller, et al. TUAGB002]

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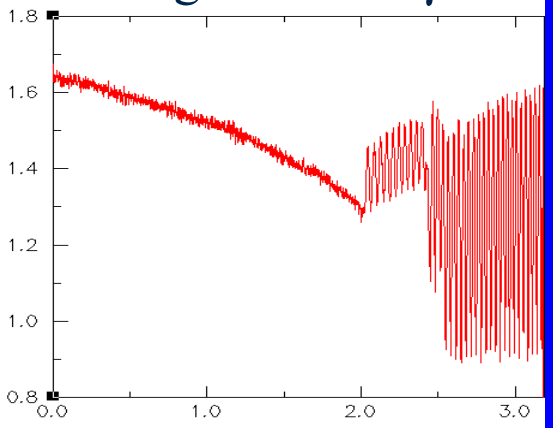
2001 Au - limitations

- **Machine reliability** (availability **40%**)
- Single- and multi-bunch **instabilities**
- **Intensity limitation** due to vacuum break-down
  - Limited to about 40×10^9 Au/ring
- **Intra-Beam Scattering** (IBS) [W.Fischer et al.WEBGB002]
  - Transverse and longitudinal **emittance growth**
  - Eventually will need **electron cooling**
- **Beam-beam** tune shift and spread
- **Lifetime** deterioration in **Yellow** with β^***=1m**

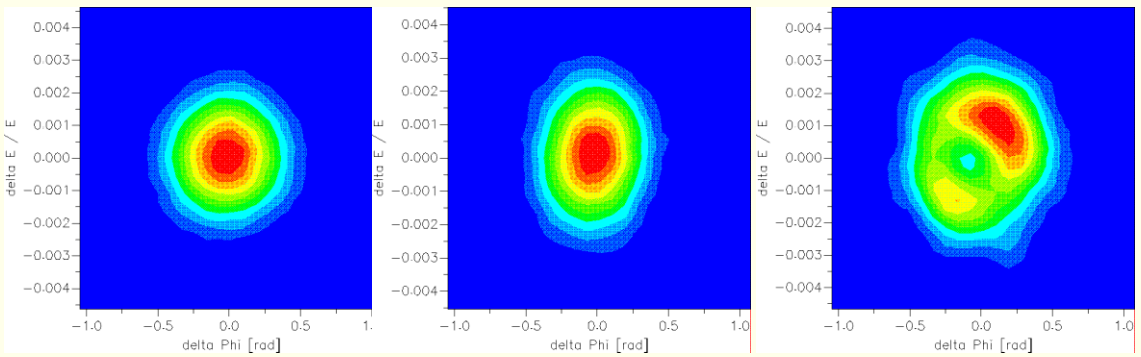
Instability around γ^T

Fast instability causing beam loss controlled by **chromaticity** everywhere but around transition **($\zeta \rightarrow 0$)**
Tune spread (around transition) :
Beam-beam (collisions) → **octupoles** (2 families in arcs)

Bunch length around γ^T

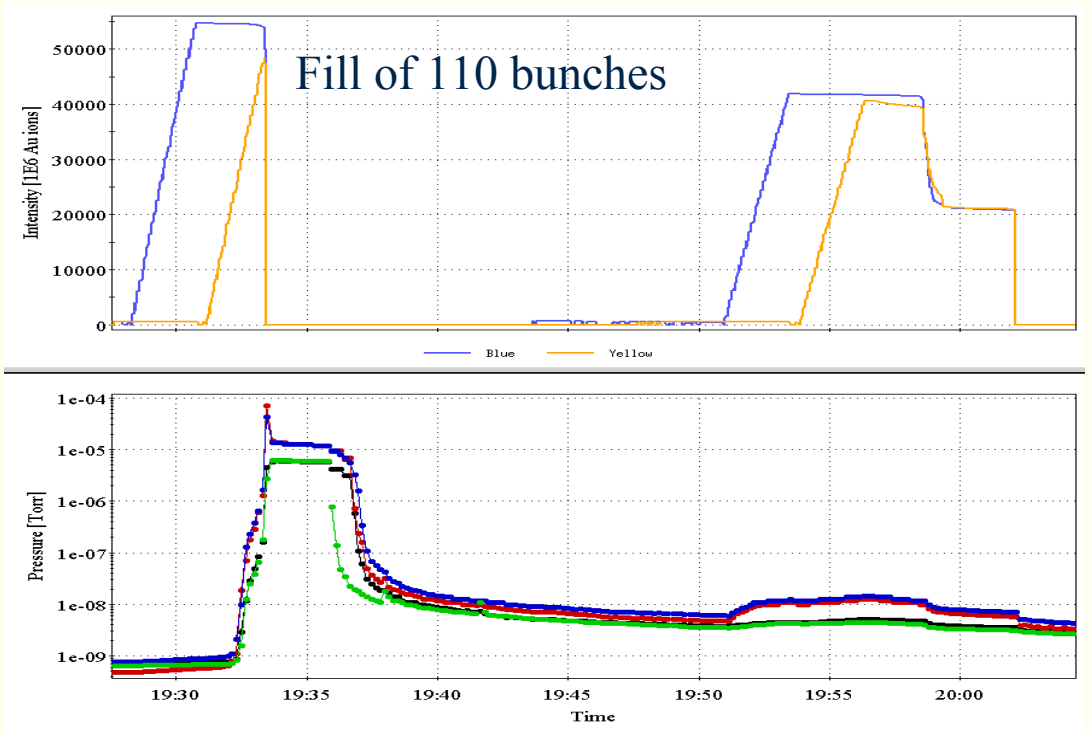


Projection of longitudinal phase space from tomographic reconstruction, before, at and after transition (instability growth ~10 msec) [C. Montag, THPRI074]



Pressure rise – (intensity)

A **vacuum breakdown** in the RHIC **warm sections** limited the overall Au beam intensity to ~40x10^9 ions/ring
beam data → dependence on **intensity**, **bunch spacing**, **species**



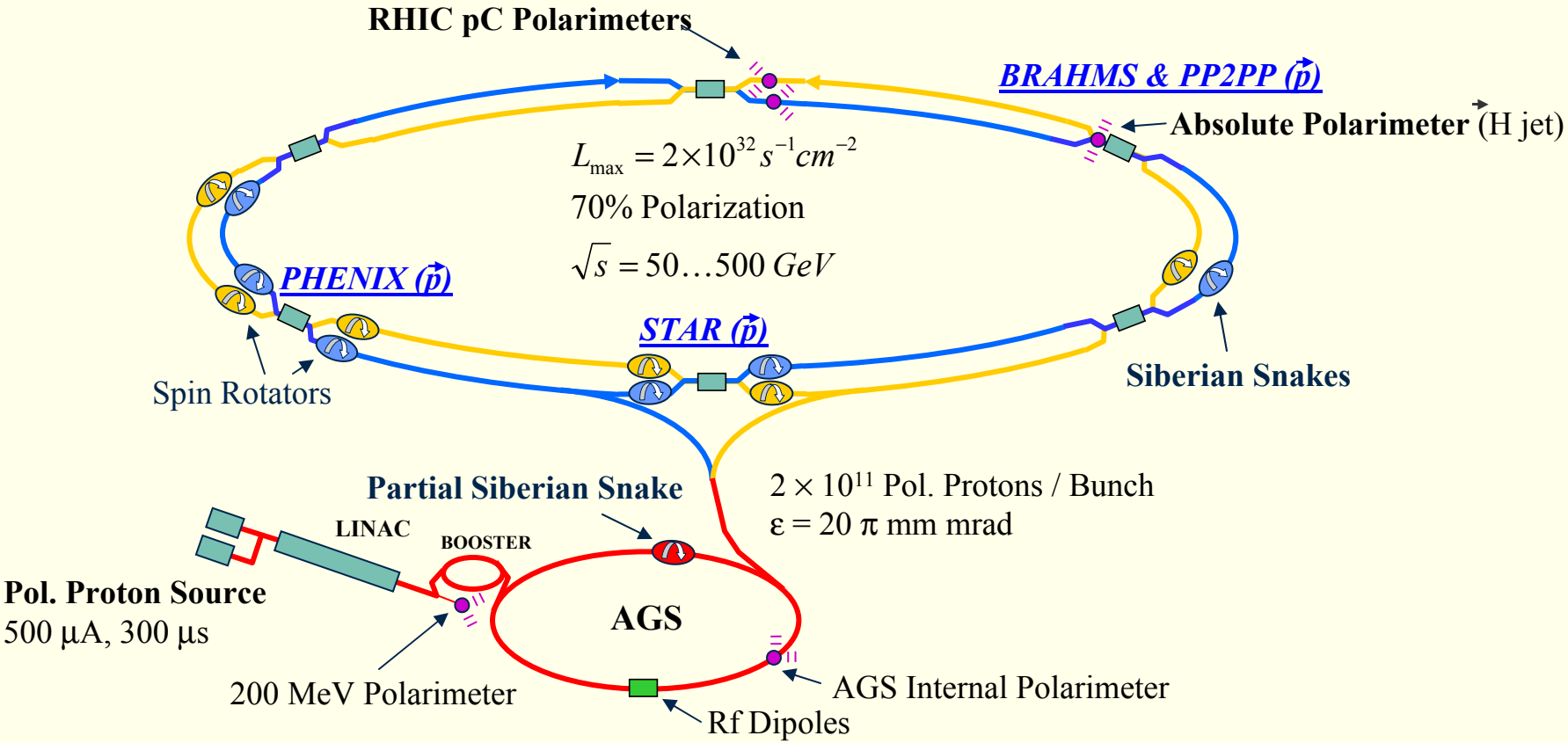
Effect under investigation (2001 data analysis)

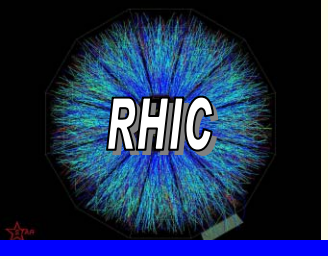
Likely causes:
- Ion induced desorption
- Beam loss induced desorption
- Electron desorption – e-cloud?

For run 2003:
- vacuum baking
- electron detectors, solenoids?

[W.Fischer et al.WEPRI034]
[H.Hseuh et al. WEPLE052]

PP run 2001: Layout





2001 PP performance

- **55 bunches** per ring with **0.8 x 10^{11} p↑/bunch**
- **Peak luminosity** at beginning of store: **1.5×10^{30}** cm^{-2} s^{-1}
- **Energy/beam**: **100 GeV**
- Beam **polarization ~ 25 % (→AGS)**
- **RHIC polarimeters work reliably**
- Little if any depolarization in RHIC during acceleration and store **(Siberian Snakes work)**
- Keep **β*=3m constant** throughout the ramp
- **Orbit** and **tune** control on the ramp

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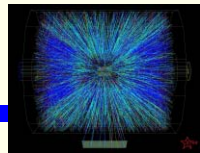


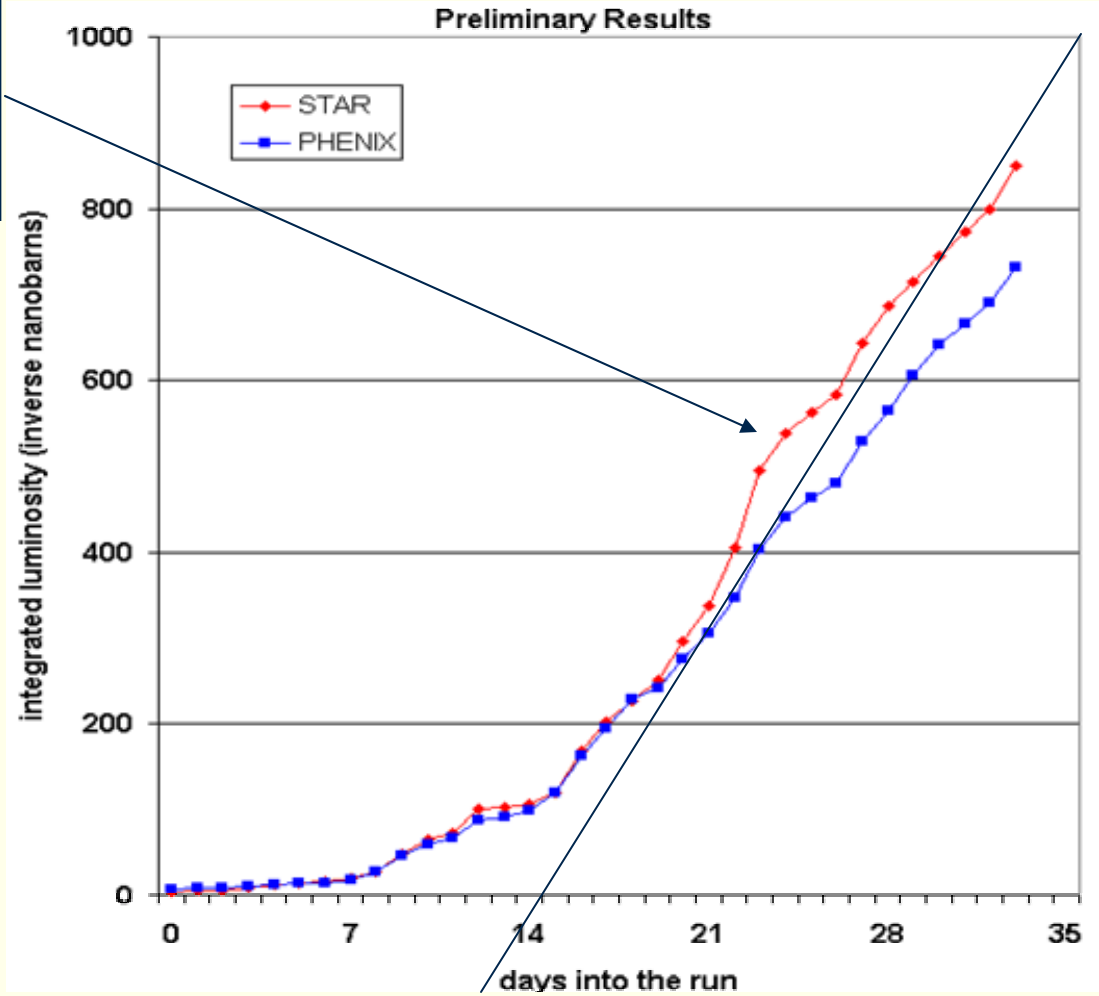
Integrated p - p luminosity

STAR during last 20 days:

290 (nb)$^{-1}$/week

L_{ave}(week) = 0.5 × 10^{30} cm^{-2} s^{-1}

L_{ave}(week)/L_{ave}(store) = 42 %



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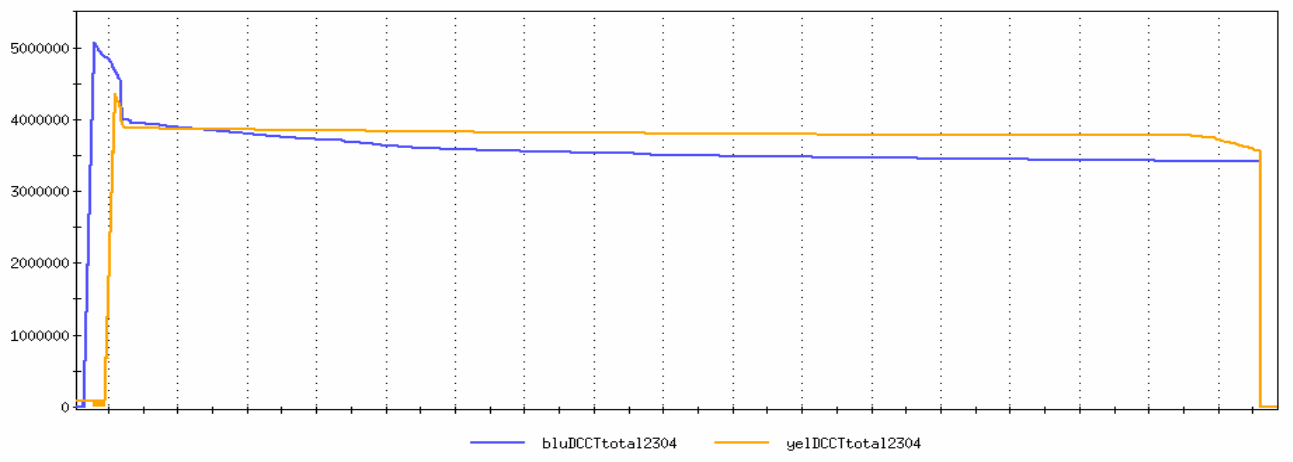
2001 PP: Typical store

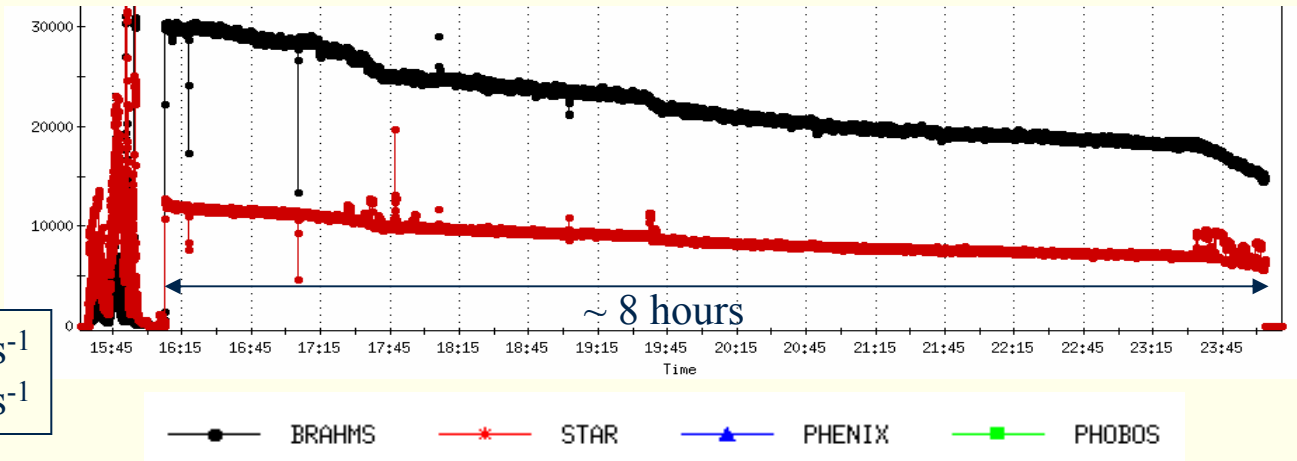
Beam currents [$\times 10^6$ ions]



Blue Beam Current Yellow Beam Current

Collision rate [Hz]

Vernier scans:
STAR: $10^4 \rightarrow 0.6 \times 10^{30}$ cm^{-2} s^{-1}
PHENIX: $10^4 \rightarrow 1.6 \times 10^{30}$ cm^{-2} s^{-1}



STAR: $L_{peak} = 1.8 \times 10^{30}$ cm^{-2} s^{-1}
$L_{ave} = 1.2 \times 10^{30}$ cm^{-2} s^{-1}

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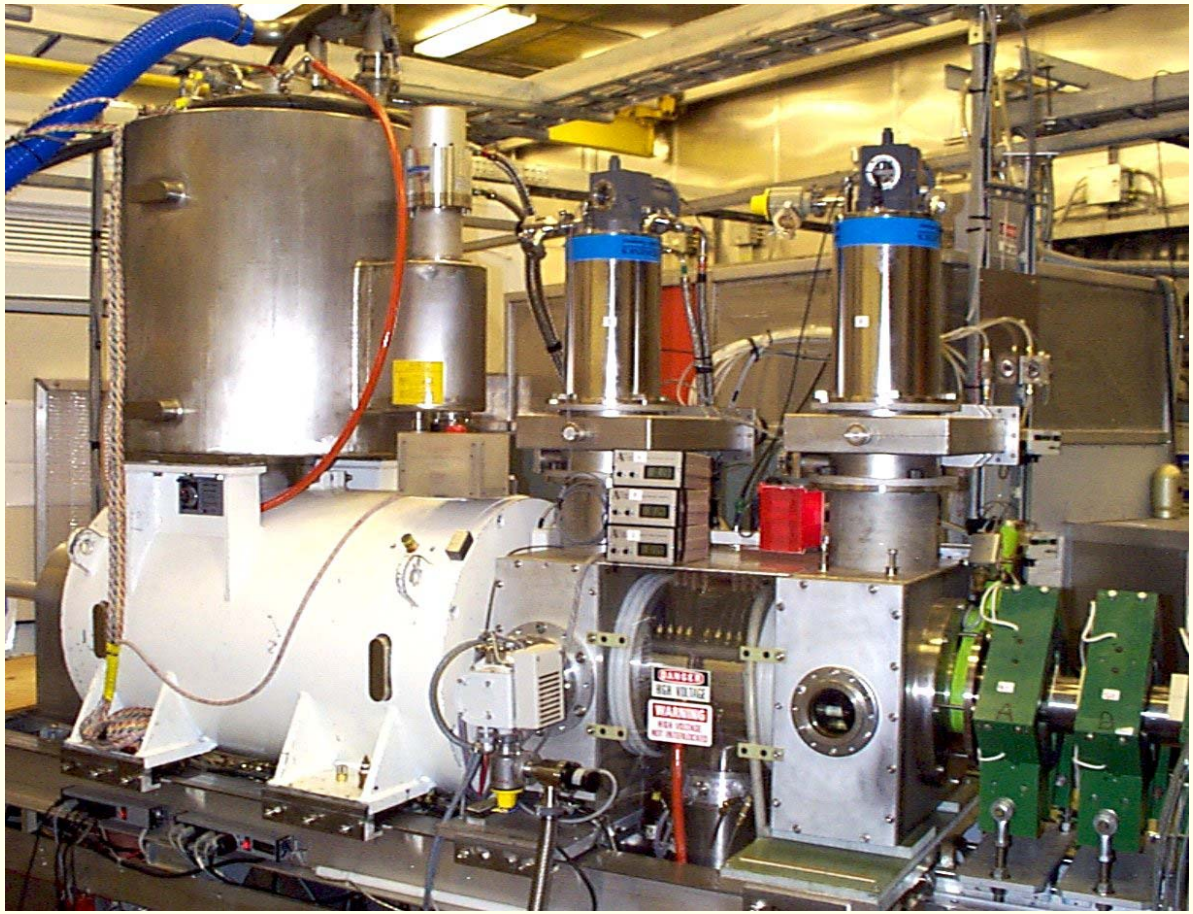
PP developments: PP source



KEK OPPIS
upgraded at TRIUMF

70 - 80 % Polarization

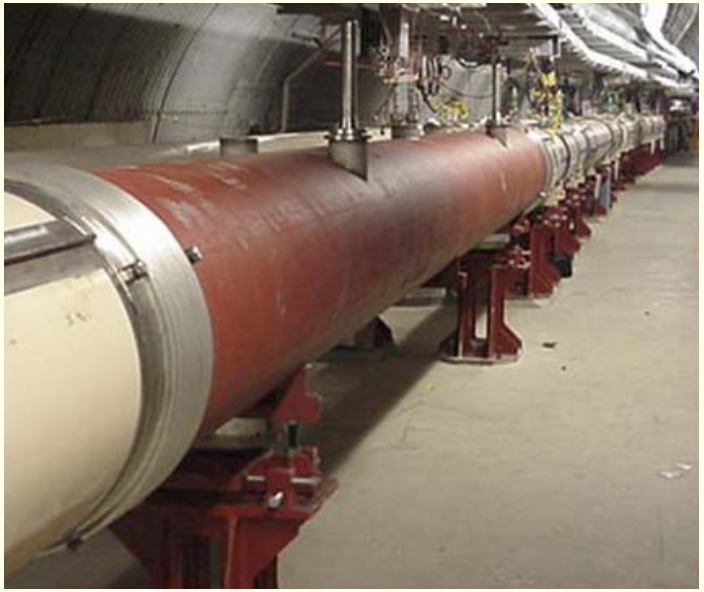
15×10^{11} protons/pulse
at source

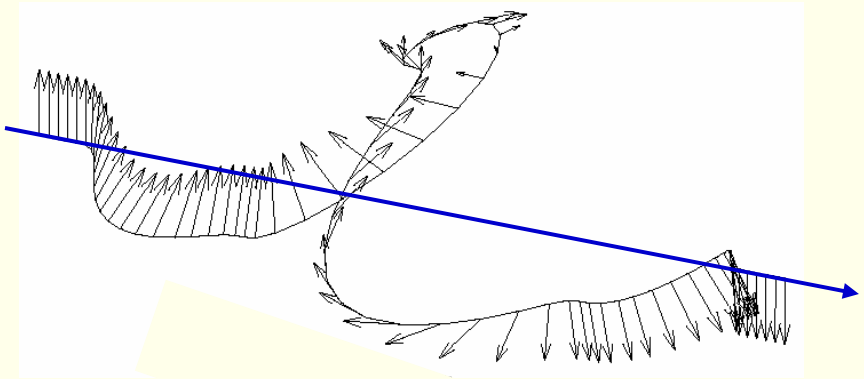
6×10^{11} protons/pulse
at end of LINAC

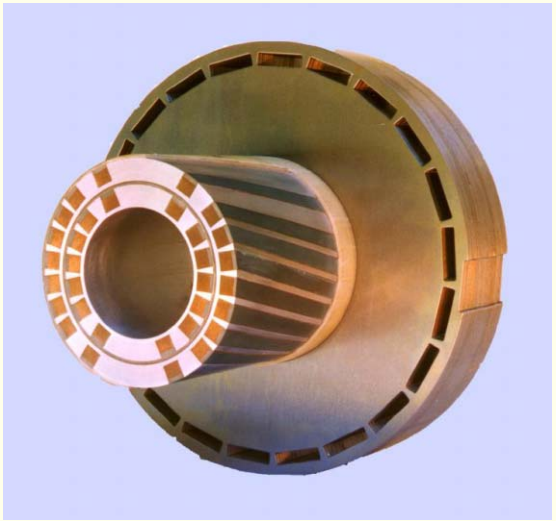
[A.Zelenski]

PP developments: Siberian Snakes

Siberian Snake: 4 superconducting **helical dipoles**, **4Tesla**, 2.4 m long with full 360° twist







Funded by RIKEN, Japan
Designed and constructed at BNL

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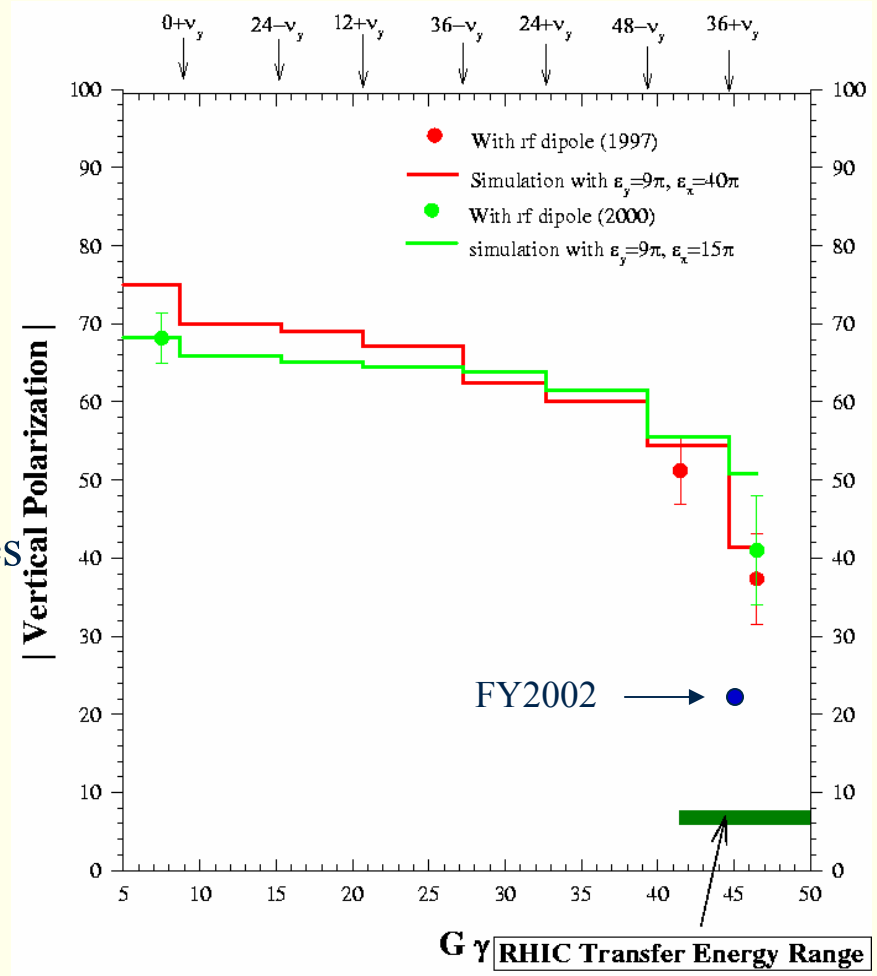
PP run 2001: Limitations

- **60% polarization loss** in AGS – lower ramp rate from **Westingshouse MPS**
- Full spin flip at all **imperfections** using **partial snake**
- Full spin flip at **strong intrinsic** resonances using **RF dipole**
- Remaining polarization loss from **coupling** and **weak intrinsic** resonances
- Strong **siberian snake in AGS** (~30% of full snake could avoid all depolarization in the AGS (>2003)

[H.Huang et al. MOPLE054]
[T. Roser et al. THAGB003]
[V.Ranjibar et al. MOPLE050]



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2001 Beam Experiments

Beam studies program in parallel to Operations and Machine development for

- **Testing new techniques** (→operations)
- **Collaborative beam experiments** (CERN, FNAL,…)

70 h (gold run) and **20 h** (PP run)

Main activities/results:

- **IR measurements/corrections** [F.Pilat WEPLE042][J.Cardona MOPLE060]
- **Beam-beam** studies [W.Fischer]
- **Longitudinal** [W.Fischer et al. WEPRI033] and **transverse** [S.Y.Zhang et al. MOPLE066] **impedance**
- **Resonance** compensation [V. Ptitsyn et al. MOPLE072]
- **Spin** manipulations [M. Bai et al. MOPLE056 WEPLE040]
- **Pressure rise** investigations / 110 bunches
- Testing of new **decoupling techniques** [M.Bai, F. Schmidt]
- **Beam dynamics** studies [R.Filler, MOPLE067]

IR corrections: linear, nonlinear

2 methods: **IR bumps** and **action-phase jump**

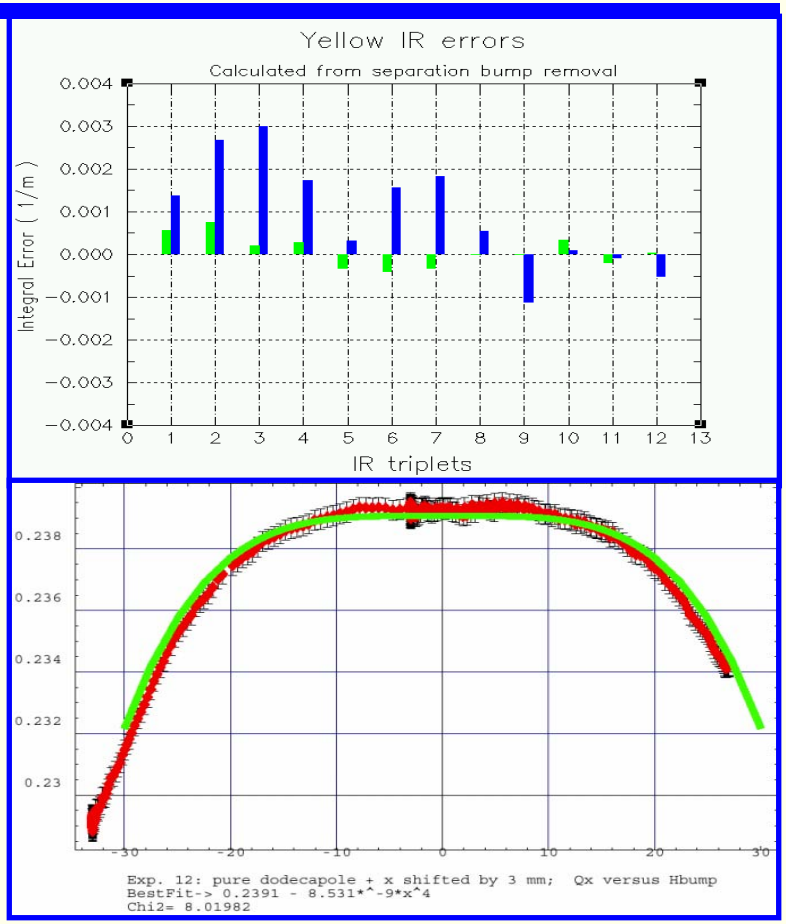
LINEAR

- Measurement and correction of IR **coupling**(roll in IR triplets) → operations
- Good agreement with cold mass **alignment**
- Measurement of triplet **gradient errors**

NONLINEAR

- Measurement of bump amplitude dependent **tune shifts** in IP8 IP2
- Mathematica analysis to derive **multipoles**
- **Correction of tune shift in IR8** (octupole and sextupole)

[Pilat, Koutchouk, Ptitsyn, Cardona]



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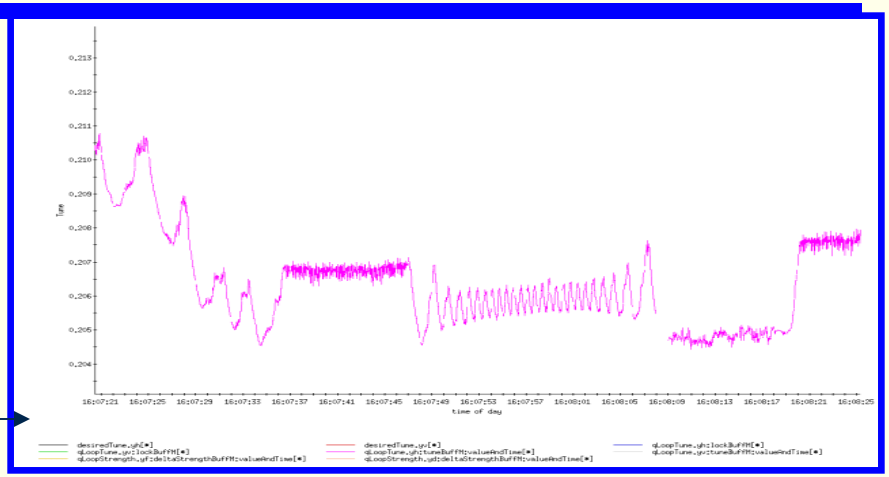
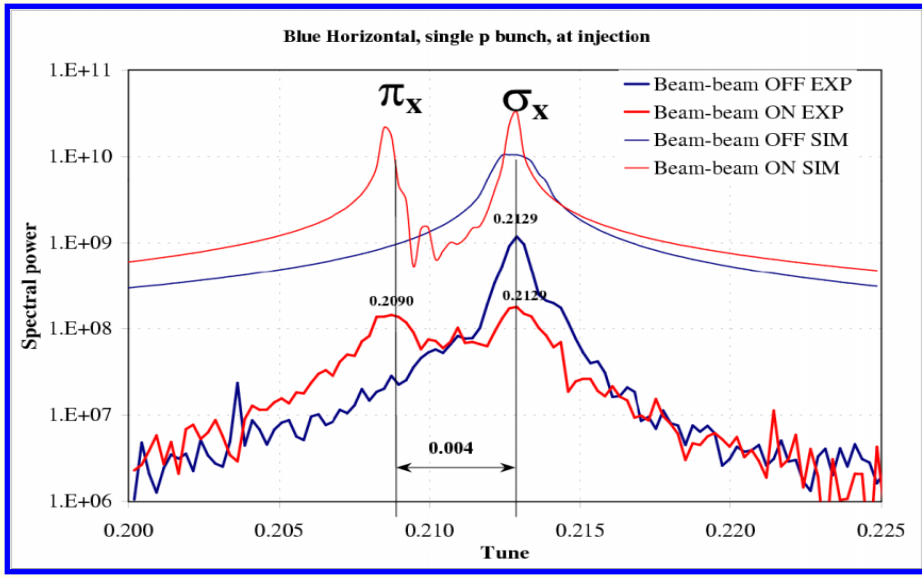
Beam-beam studies

RHIC operates in a strong-strong beam-beam regime

- Measure **beam-beam tune shift** with PLL (cogged, uncogged, cogged again)
  [W.Fischer, P. Cameron]



- Experimental evidence of **coherent beam-beam modes** in a hadron collider (dedicated experiment)
  [Fischer, Pilat, Sen, Syphers, Vogt]



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Plans 2003 – RHIC retreat

RHIC Retreat March 2002. http://www.c-ad.bnl.gov/RHIC/retreat2002

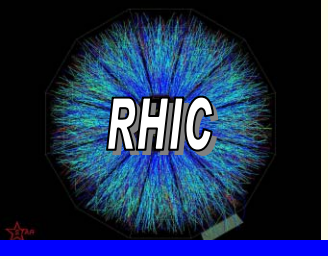
Goals:

- Set **realistic goals** for machine and experiments in 2003
- Set **priorities for shutdown 2002**
- Review **run 2001 experience**

Outcome:

- **Performance goals for 2003**
- Set of **guidelines** for operations in 2002, for example:

  truly **weekly planning** of activities
  polarization development time for **AGS**
  start operations with **tune feedback**
  flattop configurations (experiments magnets)



2003: Performance Goals

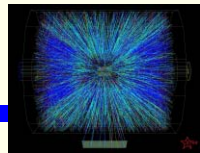
Performance goals

T.Roser

Mode	# bunches	Ions/bunch [$\times 10^9$]	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	56	1	1	15-40	14×10^{26}	3×10^{26}	70 $(\mu b)^{-1}$
(p↑-p↑)*	112	100	1	25	16×10^{30}	10×10^{30}	2.8$(pb)^{-1}$
d-Au	56	100(d), 1(Au)	2	20	5×10^{28}	2×10^{28}	5 $(nb)^{-1}$
Si-Si	56	7	1	20	5×10^{28}	2×10^{28}	5 $(nb)^{-1}$

Minimum and maximum expected performance

Mode	L_{ave} (week) [$week^{-1}$]	Int. Lumi. 2 modes	Int. Lumi. 3 modes	L_{ave} (week) [$week^{-1}$]	Int. Lumi. 2 modes	Int. Lumi. 3 modes
Au-Au	24$(\mu b)^{-1}$	168$(\mu b)^{-1}$	72$(\mu b)^{-1}$	70 $(\mu b)^{-1}$	490$(\mu b)^{-1}$	210$(\mu b)^{-1}$
(p↑-p↑)*	0.3$(pb)^{-1}$	2.1$(pb)^{-1}$	0.9$(pb)^{-1}$	2.8$(pb)^{-1}$	19.6$(pb)^{-1}$	8.4$(pb)^{-1}$
d-Au	?	?	?	5 $(nb)^{-1}$	35 $(nb)^{-1}$	15 $(nb)^{-1}$
Si-Si	?	?	?	5 $(nb)^{-1}$	35 $(nb)^{-1}$	15 $(nb)^{-1}$



2003 – running scenarios

Estimate for integrated luminosity for **29 week FY2003 run**:

- 4 weeks cool down, 1 week warm-up, 2 weeks setup (for each mode), 3 weeks ramp up (for each mode): →

29 weeks of cryo ops.: **2 modes: 7 weeks at "final" luminosity / mode**
3 modes: 3 weeks at "final" luminosity / mode
4 modes: 1 week at "final" luminosity / mode

Running modes considered for 2003:

- **d-Au** at 100 GeV/u
- **Polarized pp** at 100 GeV
- **Au-Au** at 100 GeV/u
- **Au-d** at 100 GeV/u
- **Polarized pp** at 250 GeV
- **Au-Au** at different energies

Possible:

- **D-Au at 100 GeV**
- **Polarized pp at 100 GeV**

Decision in summer 2002
(RBUP's, PAC…)

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Heavy Ion Luminosity Upgrades

	RDM	RDM+	RHIC II
Initial emittance(95%) πμm	15	15	15
Final emittance (95%) πμm	40	40 →	3
Beta function at IR [m]	2.0 →	1.0	1.0 → 0.5
Number of bunches	56 →	112	112
Bunch population [10^9]	1	1	1
Beam-beam parameter per IR	0.0016	0.0016 →	0.004
Angular size at IR [μrad]	108	153	95
RMS beam size at IR [μm]	216	150	95
Peak luminosity [10^{26} cm^{-2} s^{-1}]	**8**	**32**	**83**
Average luminosity [10^{26} cm^{-2} s^{-1}]	**2**	**8**	**70**

RHIC II includes **electron beam cooling** and assumes 5 hr stores since burn-off is high

RDM and RDM+ assume 10 hr stores

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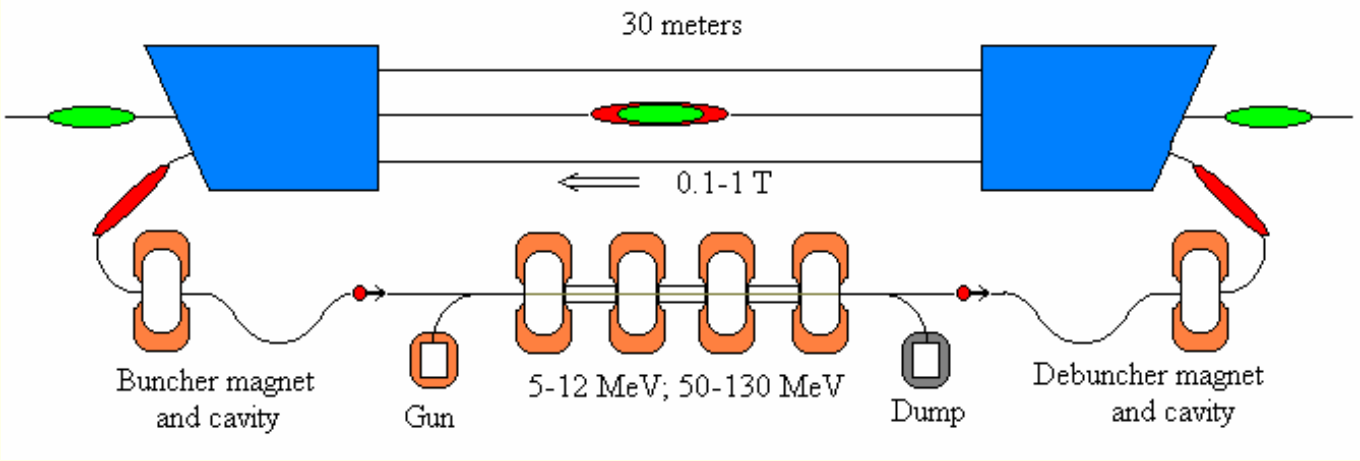
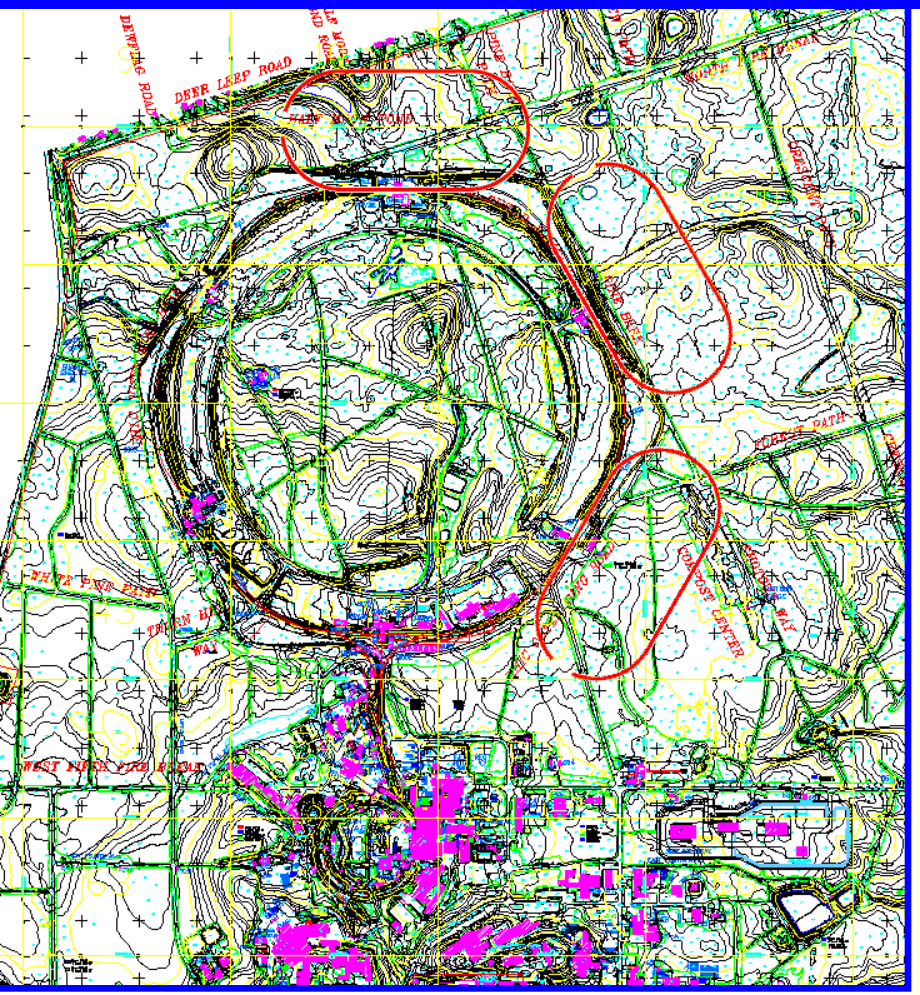
The RHIC Electron Cooling Project



- Bunched **electron beam requirements** for **100 GeV/u** gold beams:
  E = 54 MeV, **<I> ≤ 100 mA**, electron beam power: **≤ 5 MW**!
- Requires **high brightness**, high **power**, **energy recovering superconducting linac**, almost identical to IR FEL at TJNAF
- Has several applications at BNL: **PERL**, **eRHIC** (EIC)
- Timeline: 3Y **test facility** operative 5Y installed in RHIC

[I.Ben-Zvi et al. "e-cooling for RHIC" PAC2001"]

eRHIC – electron ion collisions



10 GeV e- 100 GeV/u ions

Electron cooling – polarized e-

3 options being studied:

- e-ring + ion ring
  0.5 A polarized e- beam
- ERL e- linac + ion ring
  E e- beam 10GW (halo)
- ERL e-linac +recycling ring+ ion ring
  (1000 turns)→10 MW linac

1-2 IR's with electrons-ion collisions keep Au experiments running in the other IR's

http://www.c-ad.bnl.gov/eicaw

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Proton Luminosity Upgrades

	RHIC Spin	RHIC II	Future Upgrade
Emittance(95%) πμm	20	12	12
Beta function at IR [m]	1	1	0.3
Number of bunches	112	112	336
Bunch population [10^{11}]	2	2	2
Beam-beam parameter per IR	0.007	0.012	0.012
Angular size at IR [μrad]	112	86	157
RMS beam size at IR [μm]	112	86	47
Luminosity [10^{32} cm^{-2} s^{-1}]	**2.4**	**4.0**	**40.0**

RHIC II : Beam-beam tune shift limited for 2 interaction regions

Future Upgrade: Mini-beta quads and more bunches

Will also require major detector upgrades

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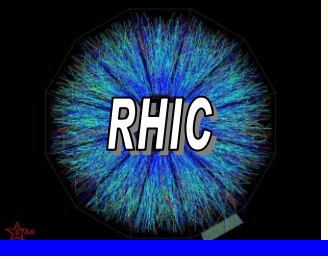

Conclusions

- **Successful 2001 operations** for RHIC

  design energy and **luminosity** for Au-Au collisions

  PP collision at 100 GeV – 25% polarization

- **Run 2003** starts in November 2002

- **Luminosity upgrade scenarios** are planned for **heavy-ion** and **polarized proton** operations

  (RHIC electron cooling project R&D underway)

- RHIC is well positioned to play a major role in research **in this and into the next decade**

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