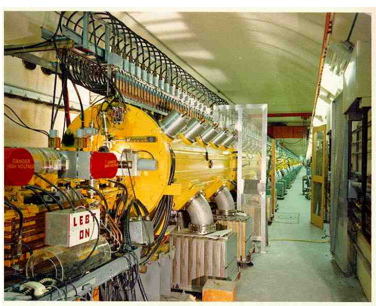
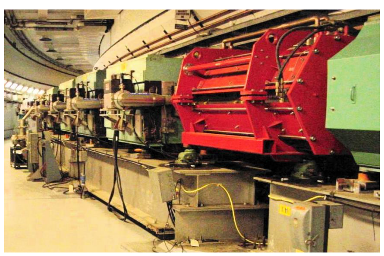
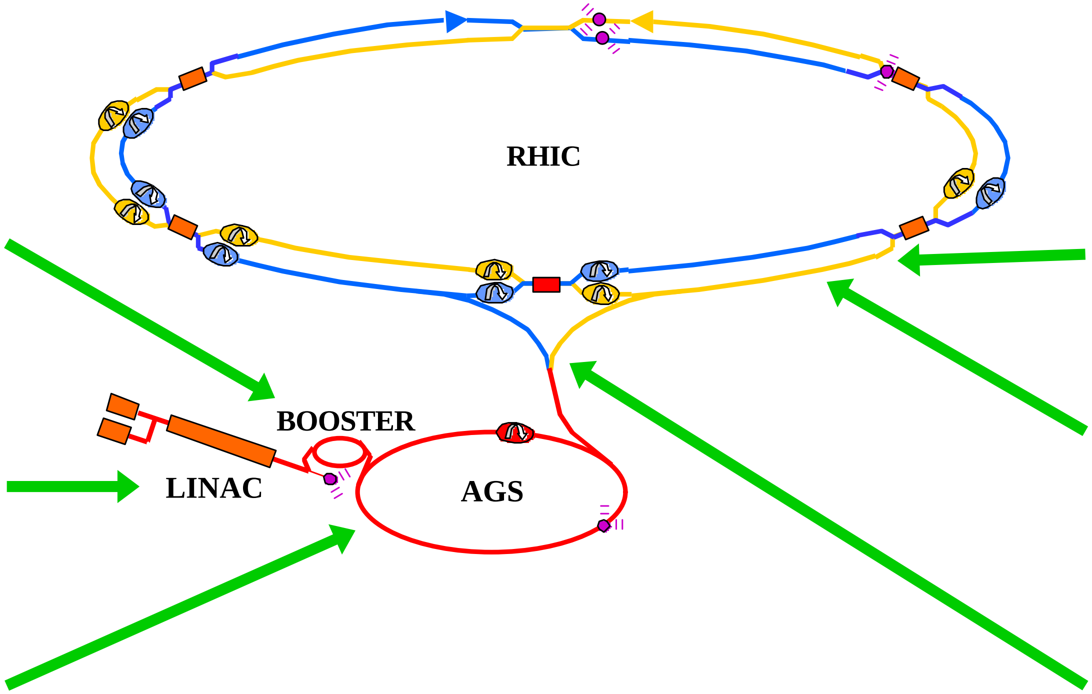
Polarized Protons in RHIC

- Layout of the RHIC and injectors.
- RIKEN contributions to RHIC Spin program.
- Intro to accelerator physics.
  - Spin dynamics.
  - Depolarizing resonances.
- Hardware: Siberian snakes and rotators.
- 1^{st} polarized proton run.
- Future plans.
- Summary: successes of RIKEN/BNL Collaboration.

Accelerator Complex







LINAC: Linear Accelerator
AGS: Alternating Gradient Synchrotron
RHIC: Relativistic Heavy Ion Collider

RIKEN Contributions to RHIC Spin

- Superconducting Helical Siberian Snakes
- Superconducting Helical Spin Rotators (PHENIX and STAR)

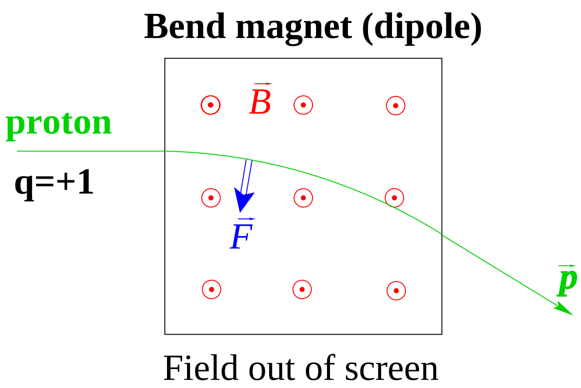
Total of 48 helical dipoles

- Special probe for magnetic measurements of helical dipoles
- Power supplies and quench circuits for Snakes and Rotators
- Polarimeters (Subject of following talk by Dr. K. Kurita)

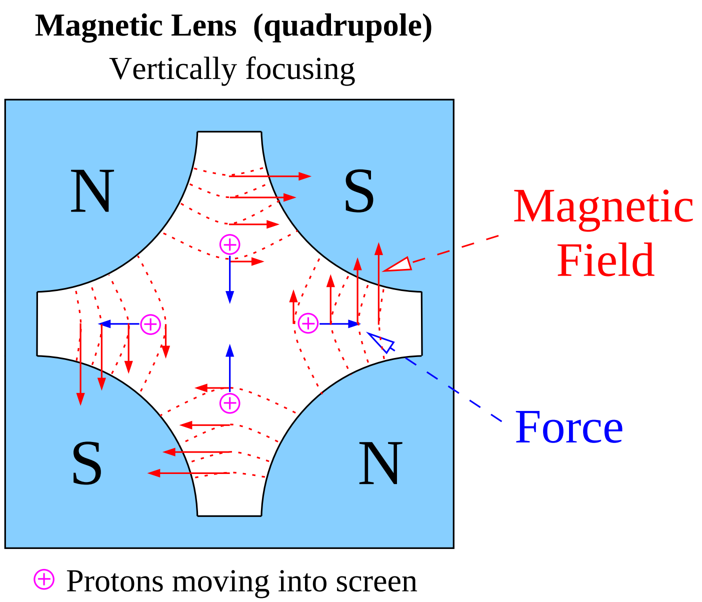
Domo Arigato Gazaimashita.

Particle Trajectories in Magnetic Fields

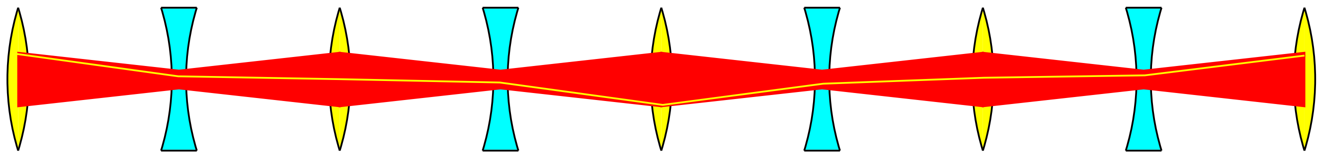
Dipole magnets bend the beam around the ring.



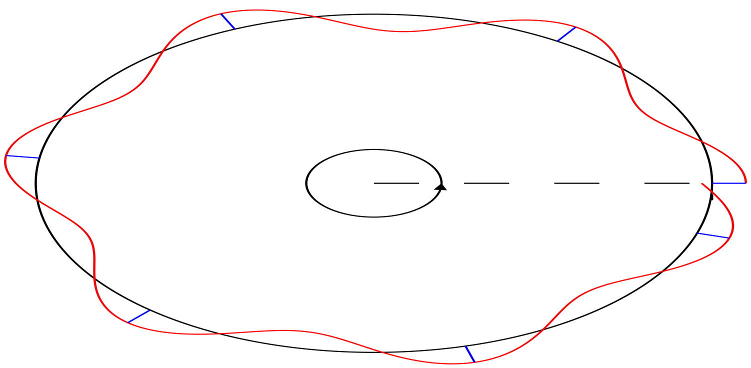
Quadrupole magnets focus the beam for stability.



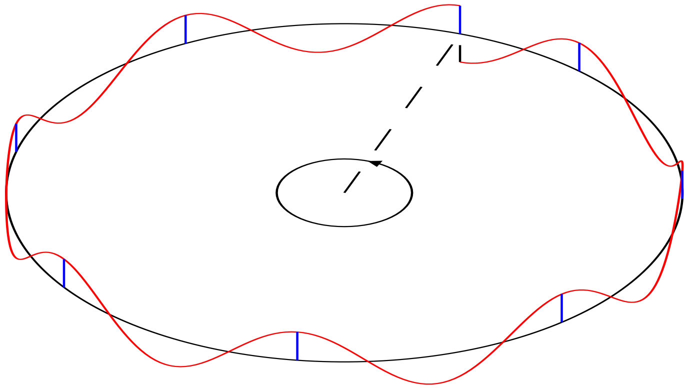
Transport and Betatron Oscillations



Alternate focusing and defocusing lenses for stability.



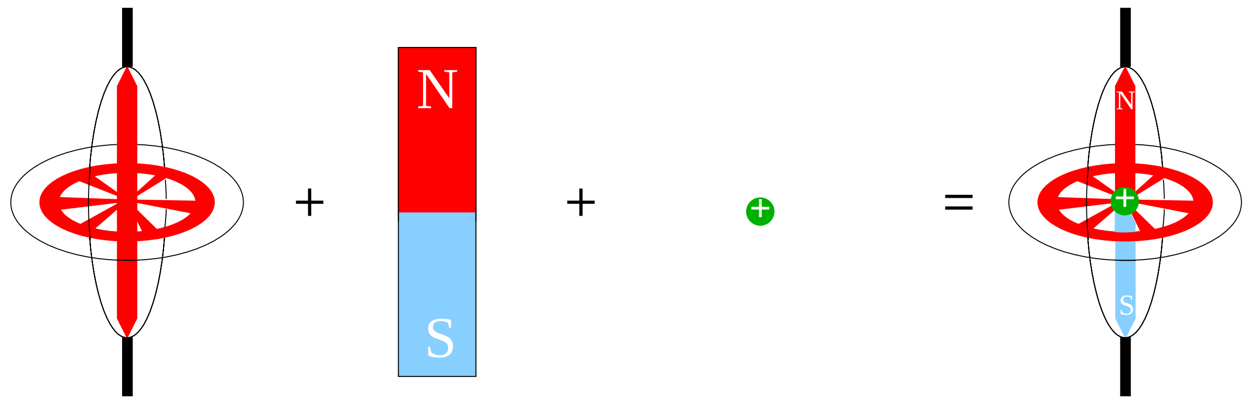
Horizontal Betatron Oscillation
with tune: $\nu_h = 6.3$,
i.e., 6.3 oscillations per turn.



Vertical Betatron Oscillation
with tune: $\nu_y = 7.5$,
i.e., 7.5 oscillations per turn.

BROOKHAVEN NATIONAL LABORATORY

Simple Model of Proton



Gyroscope + Bar magnet + Charge = "proton"

Spin

Magnetic
Dipole
Moment

Polarization: Average spin of the ensemble of protons.

Thomas—Frenkel (BMT) Equation

In the local rest frame of the proton, the spin precession of the proton obeys the Thomas-Frenkel equation:

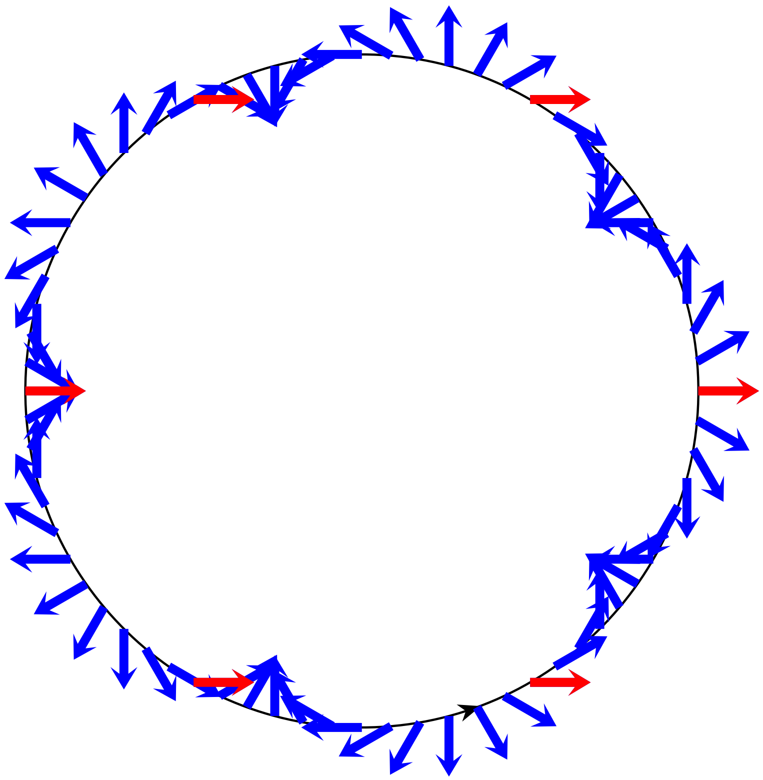
$$\text{Torque}: \quad \frac{d\vec{S}^*}{dt} = \frac{q}{\gamma m}\vec{S}^* \times \left[(1+G\gamma)\vec{B}_\perp + (1+G)\vec{B}_\parallel\right] \qquad \text{TF}$$

$$\text{Force}: \quad \frac{d\vec{p}}{dt} = \frac{q}{\gamma m}\vec{p} \times \vec{B}_\perp \qquad \text{Lorentz}$$

(This is a mixed description: t, and $\vec{B}$ in the lab frame, but spin $\vec{S}^*$ in local rest frame of the proton.)

$$G = \frac{g-2}{2} = 1.7928, \qquad \gamma = \frac{\text{Energy}}{mc^2}.$$

Spin Precession in a Ring



Example with 6 precessions of spin in one turn:

$$G\gamma + 1 = 6.$$

Spin tune: number of precessions per turn relative to beam's direction.
So we subtract one:

$$\nu_{\rm spin} = G\gamma \quad \propto \quad \text{energy},$$

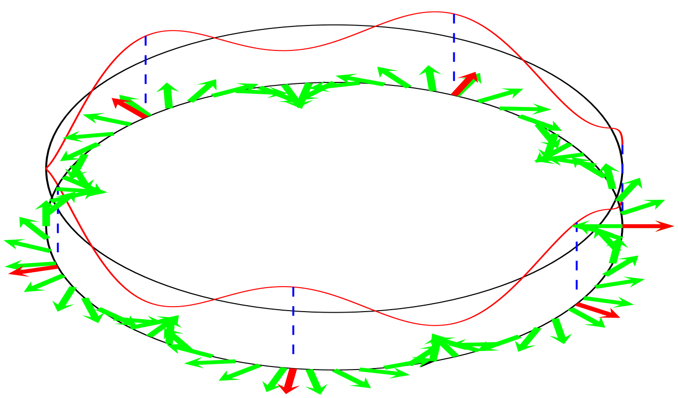
i.e., 5 in this example.

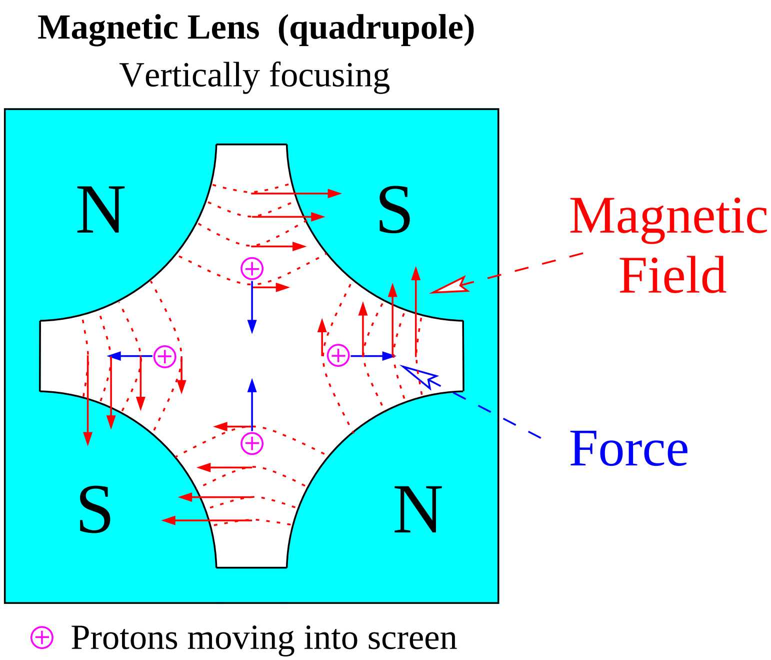
Depolarizing Resonances

Resonance Condition:

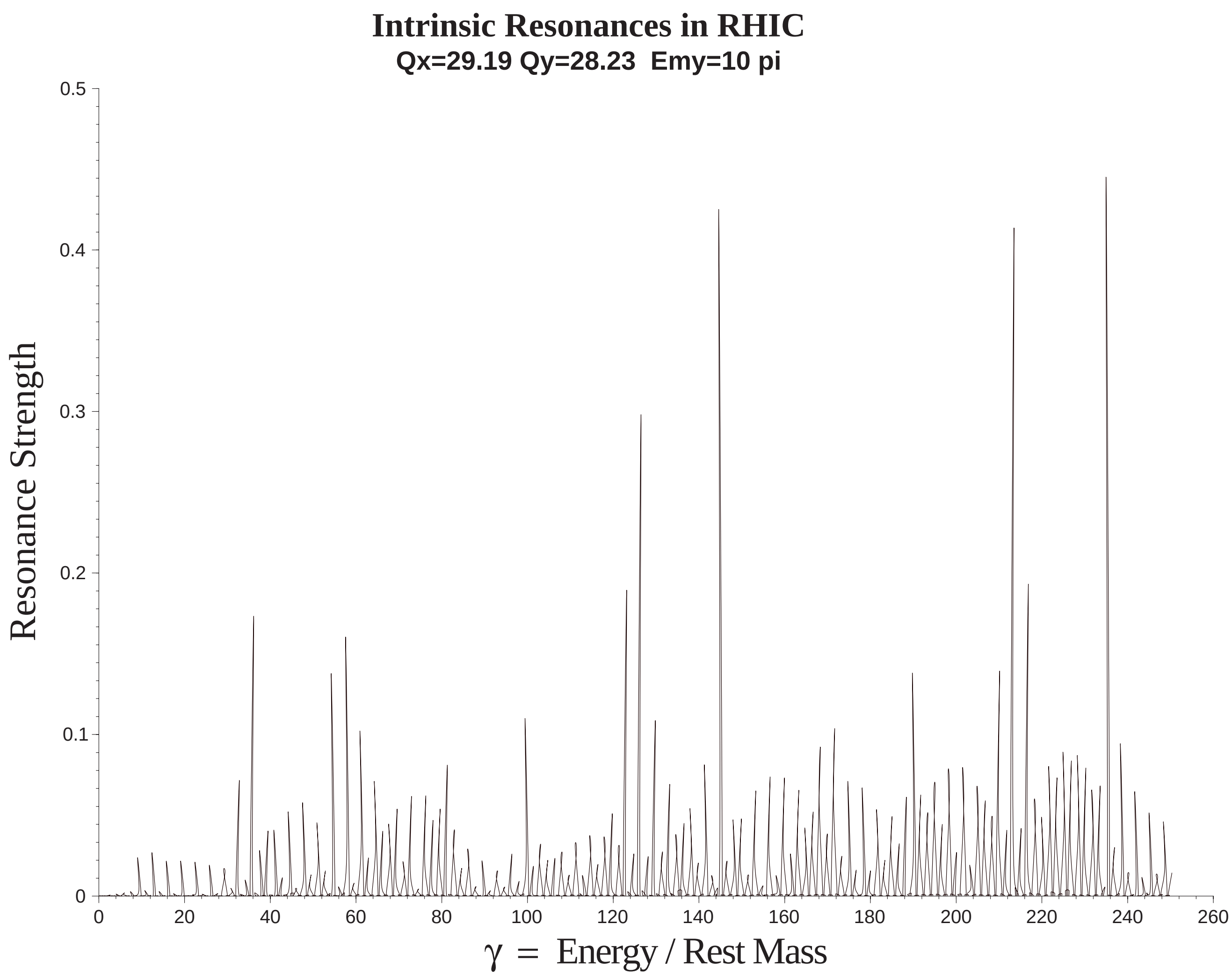
$$\nu_{\rm spin} = N + N_{\rm v}\nu_{\rm v},$$

where N and $N_{\rm v}$ are integers.





Depolarizing Resonances

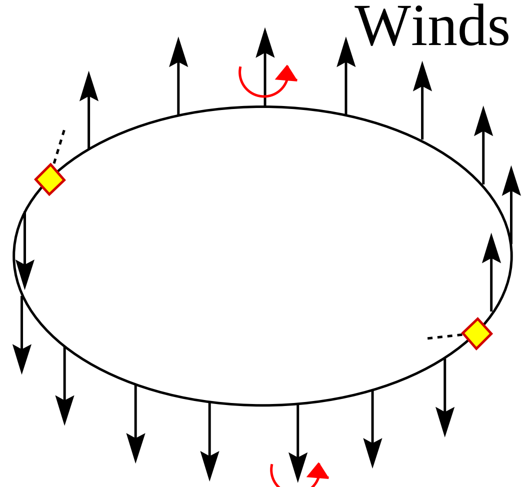


Will depolarize beam during acceleration.

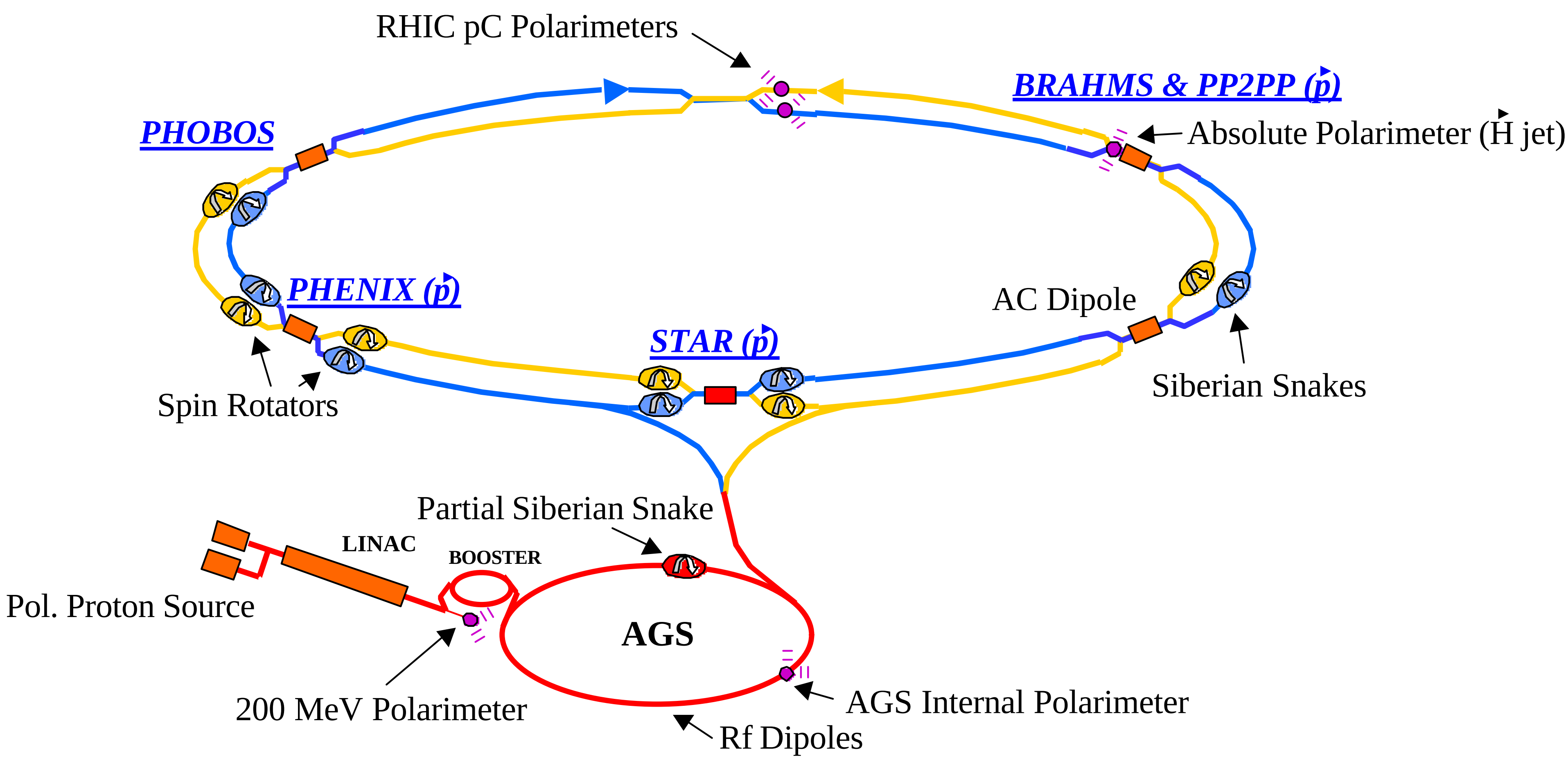
Solution: Snakes

Snake Charming

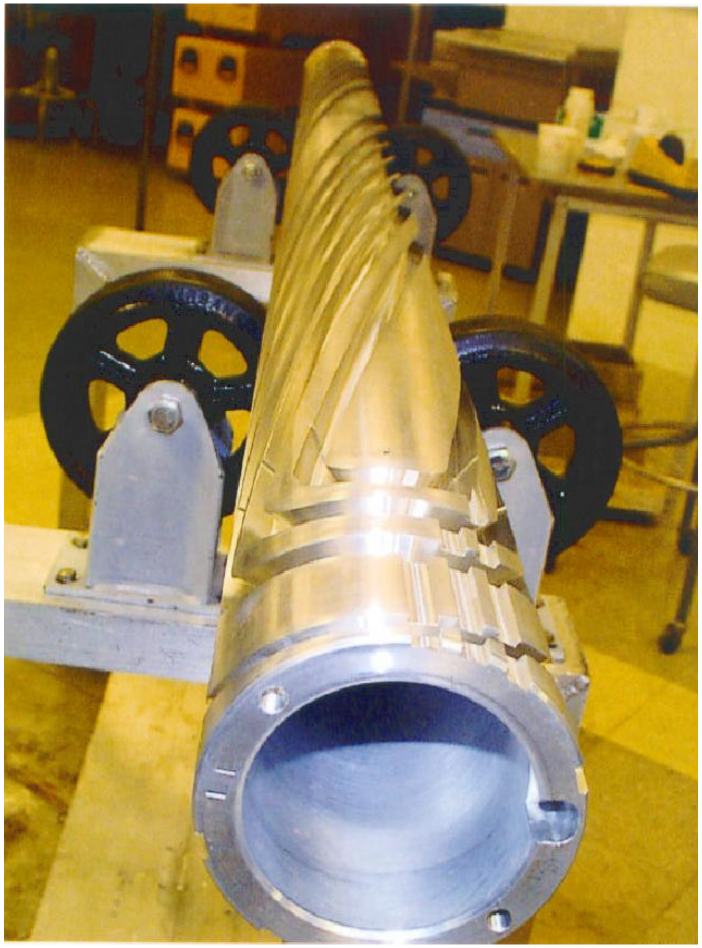
- 2 snakes: spin is up in one half of the ring, and down in the other half.
- Spin tune: $\nu_{\text{spin}} = \frac{1}{2}$
  (It's energy independent.)
- "The unwanted precession which happens to the spin in one half of the ring is unwound in the other half."

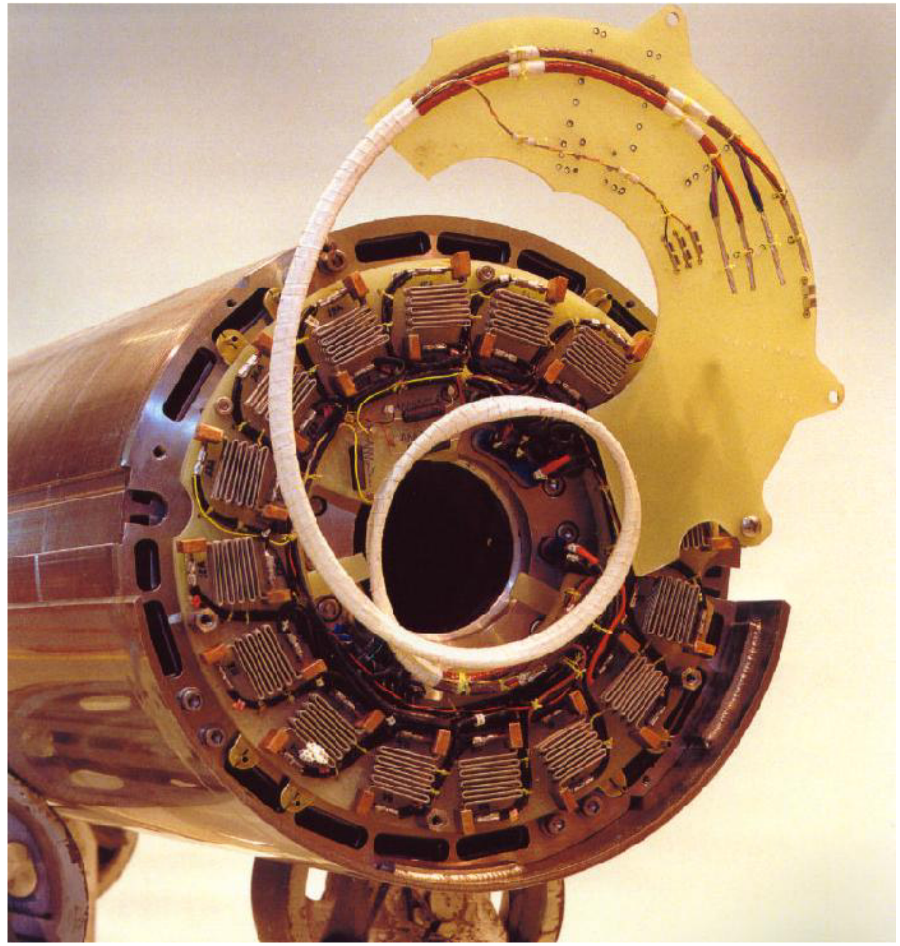


Accelerator Complex for Protons

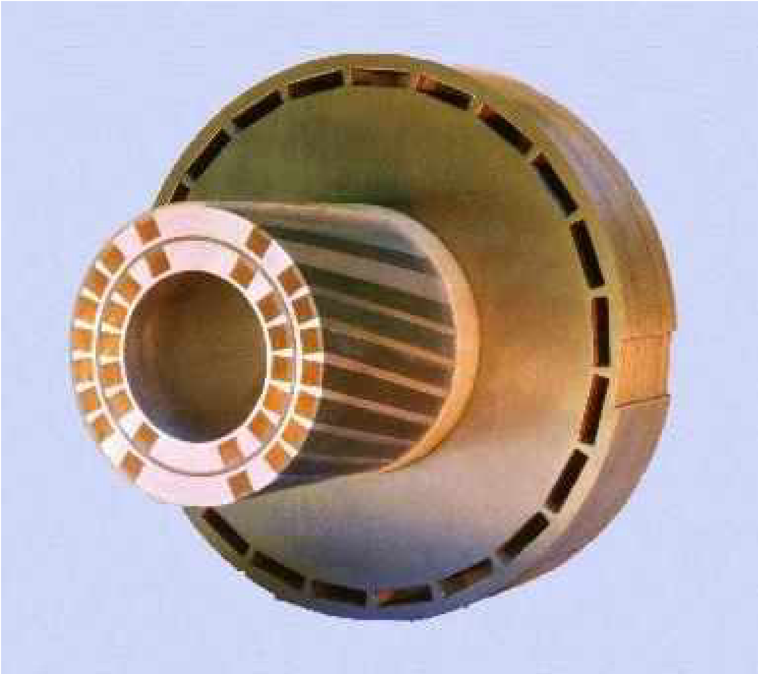


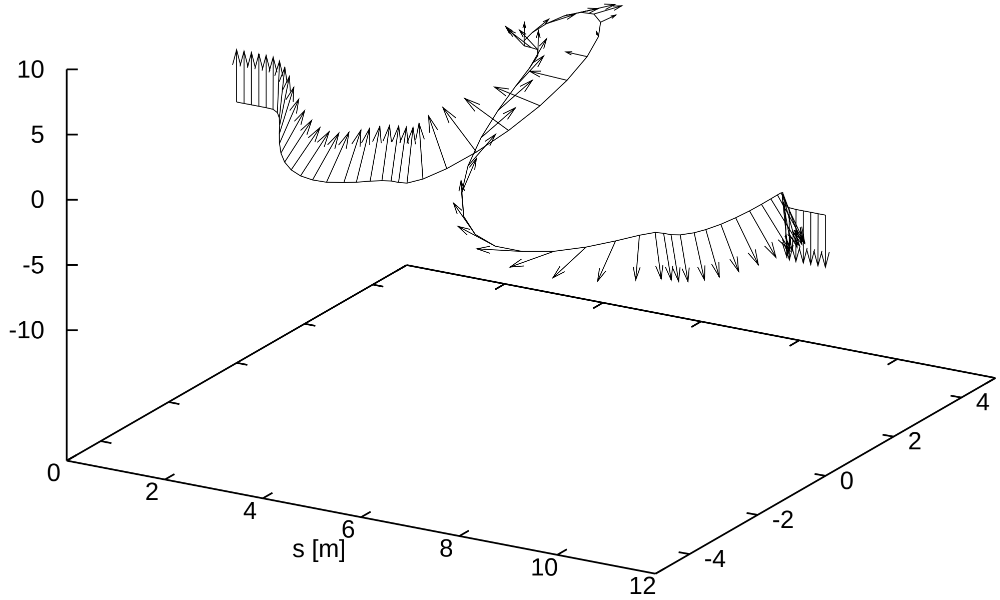
Helical Dipoles





Trajectory and Spin through Snakes

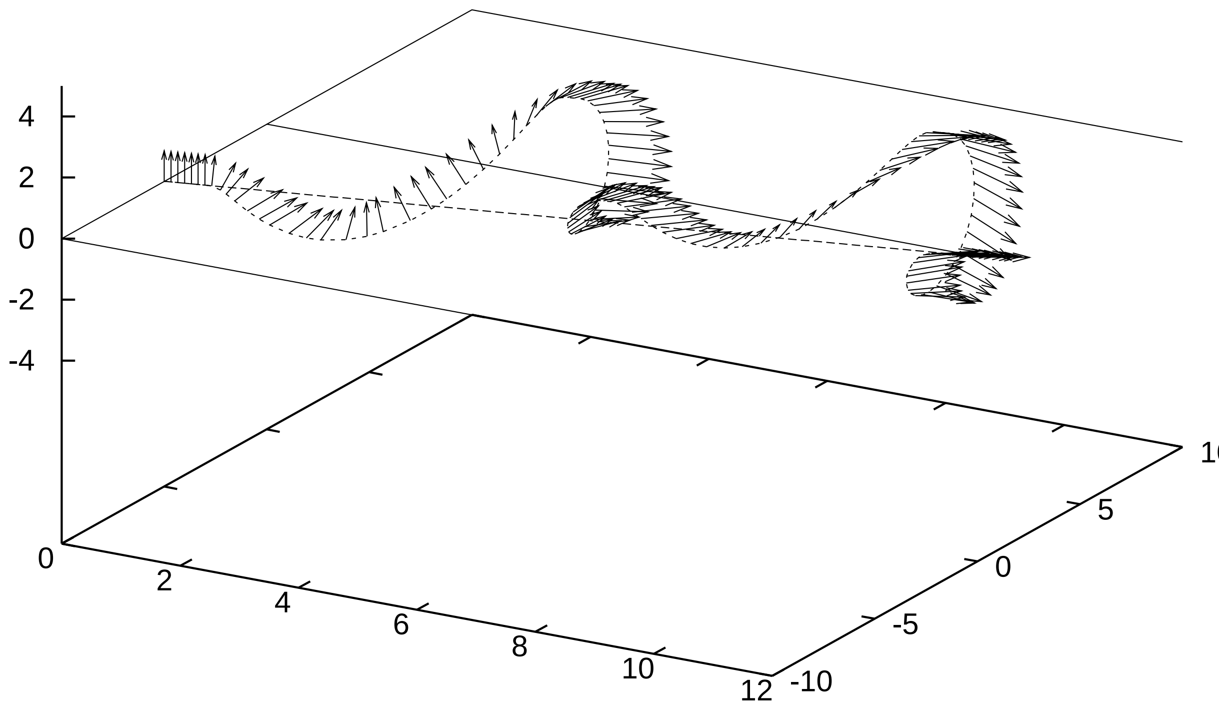


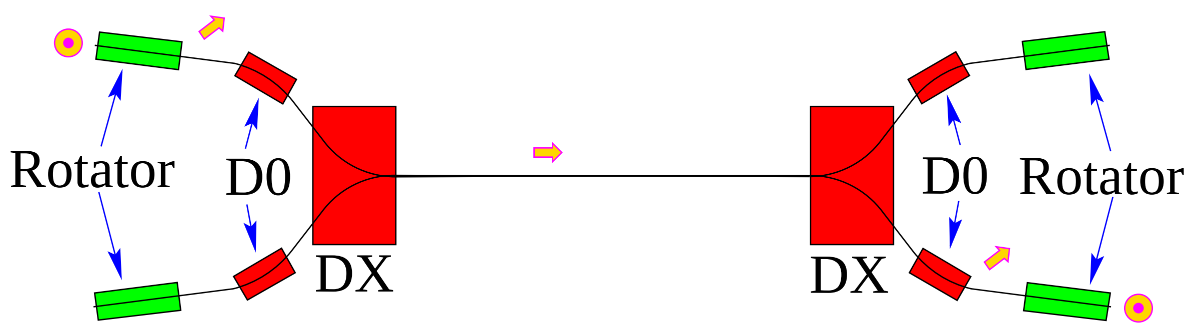


Construction of Cold Masses

Installation of Rotators

Helical Spin Rotators





Performance of 1st Run

Parameter	Design	1st Run
C.M. Energy [GeV]	500	200
L_{peak} $[\times 10^{30}\,\text{cm}^{-2}\text{s}^{-1}]$	200	1.5
Polarization	70%	25%
Polarization direction	Vert. & Long.†	Vert.
Protons/bunch $[\times 10^{11}]$	2	0.8
bunches/ring	112	55
β^* [m]	1†	3
Emittance $\pi\epsilon^N_{95\%}$ $[\pi\ \mu\text{m}]$	20	25

† STAR and PHENIX only.

High Intensity Polarized H^- Source

KEK OPPIS*
upgraded at TRIUMF

$70 \rightarrow 80\%$ Polarization

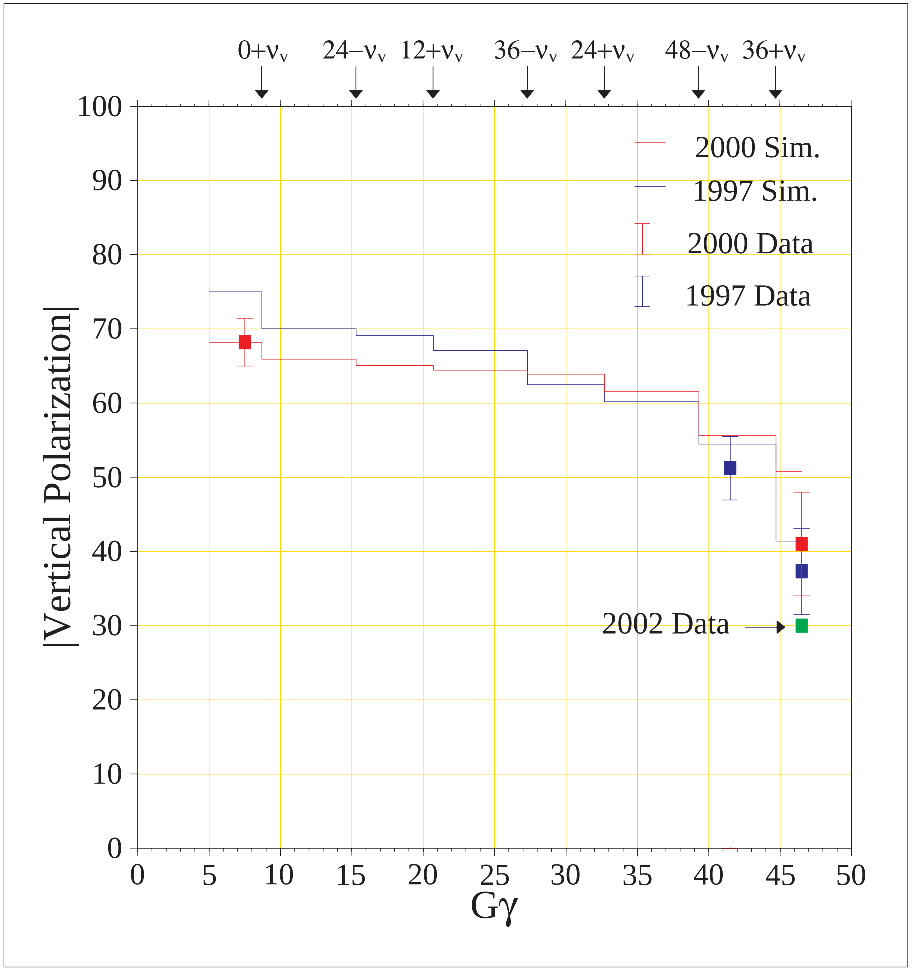
15×10^{11} protons/pulse at source

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

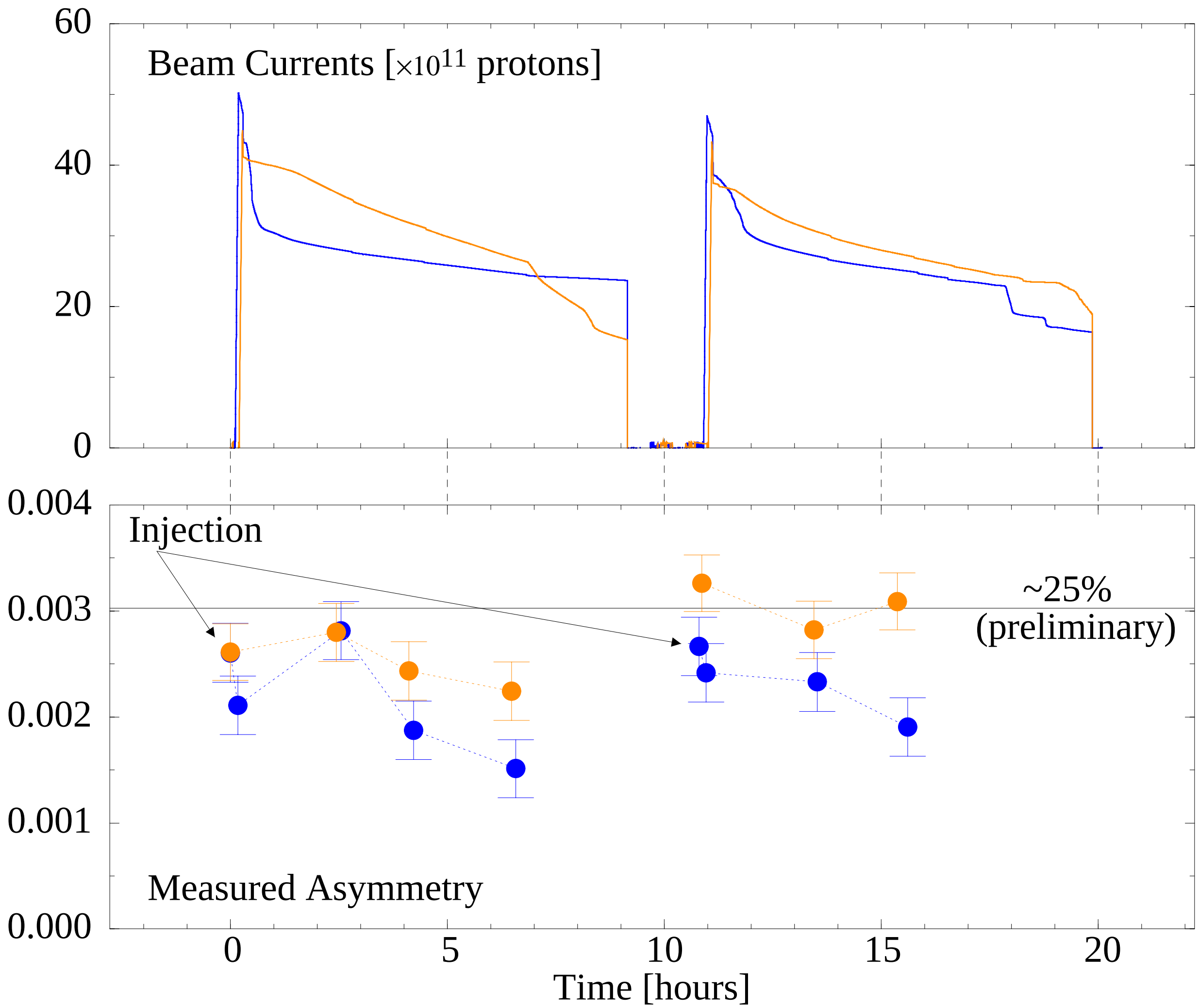
*Optically Pumped Polarized Ion Source

Comments on Injector Performance

- Source: Worked beautifully.
- Booster: No depolarization.
- AGS: Polarization loss larger in FY02 due to lower ramp rate and higher bunch intensity
  - Failed main magnet power supply. (Repair by Fall'02.)
- AGS: New partial superconducting helical snake should give polariation $\sim 70\%$.



RHIC Beam Polarization



Future Plans

Preparations for Next Run

- Next time: spin rotators at STAR and PHENIX
  for longintudinal polarization.
- New CNI† polarimeter in AGS
  to improve tuning AGS for higher polarization.

Beyond Next Run

- Polarimeter using Polarized Hydrogen Jet target
  for absolute calibration of CNI polarimeters in RHIC.
- New Superconducting Helical Partial Snake in AGS
  to improve polarization transmission.

†CNI: Coulomb Nuclear Interference.

Summary

Successes from RIKEN/BNL Collaboration

- First superconducting helical snakes. (Work very well!)
- Polarized protons accelerated to highest energy.
- First collider with polarized protons! $\sqrt{s} = 200$ GeV
- CNI polarimeters work beautifully. (See next talk by Dr. Kurita.)