20 Years of RHIC Machine

- The first heavy ion collider
- The first polarized proton collider

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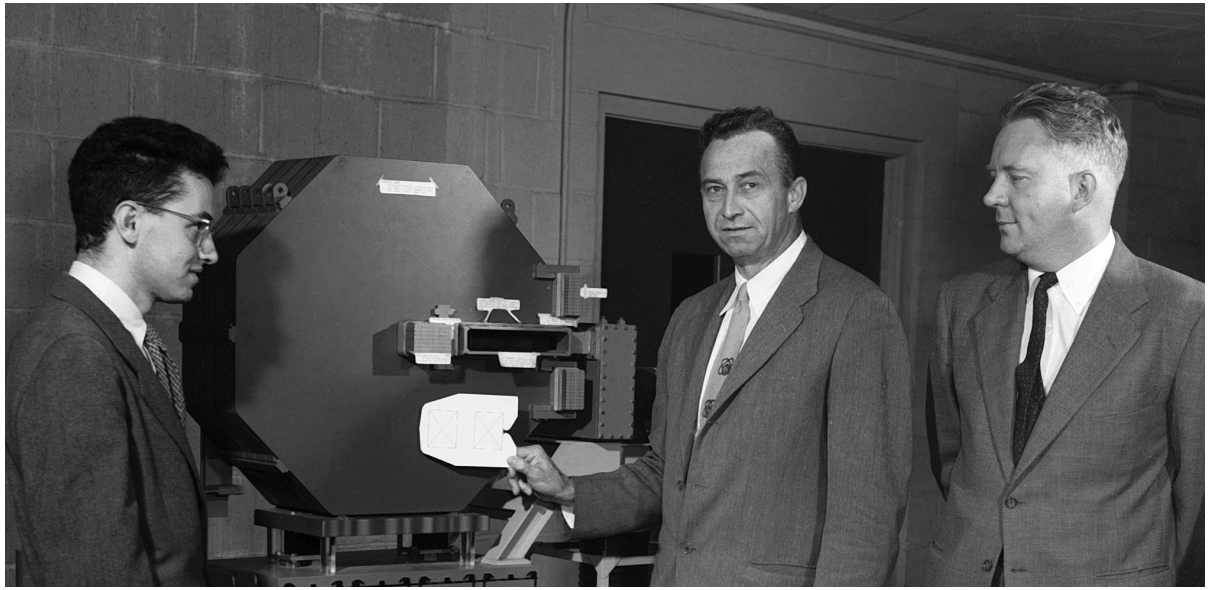
U.S. DEPARTMENT OF ENERGY

In Memory

Ernest D. Courant

1920 - 2020

- 1948 Courant joined the BNL team that was building the Cosmotron
- He co-invented and developed the strong focusing principle, the basis of most modern accelerators including RHIC
- “Little did I know when I joined Brookhaven back in 1948 that accelerator physics would be my whole career,” Courant said at the 2010 RHIC/AGS Users’ Meeting.
- Courant also coined the name “Siberian snake” and first proposed the use of helical dipoles for Siberian snakes



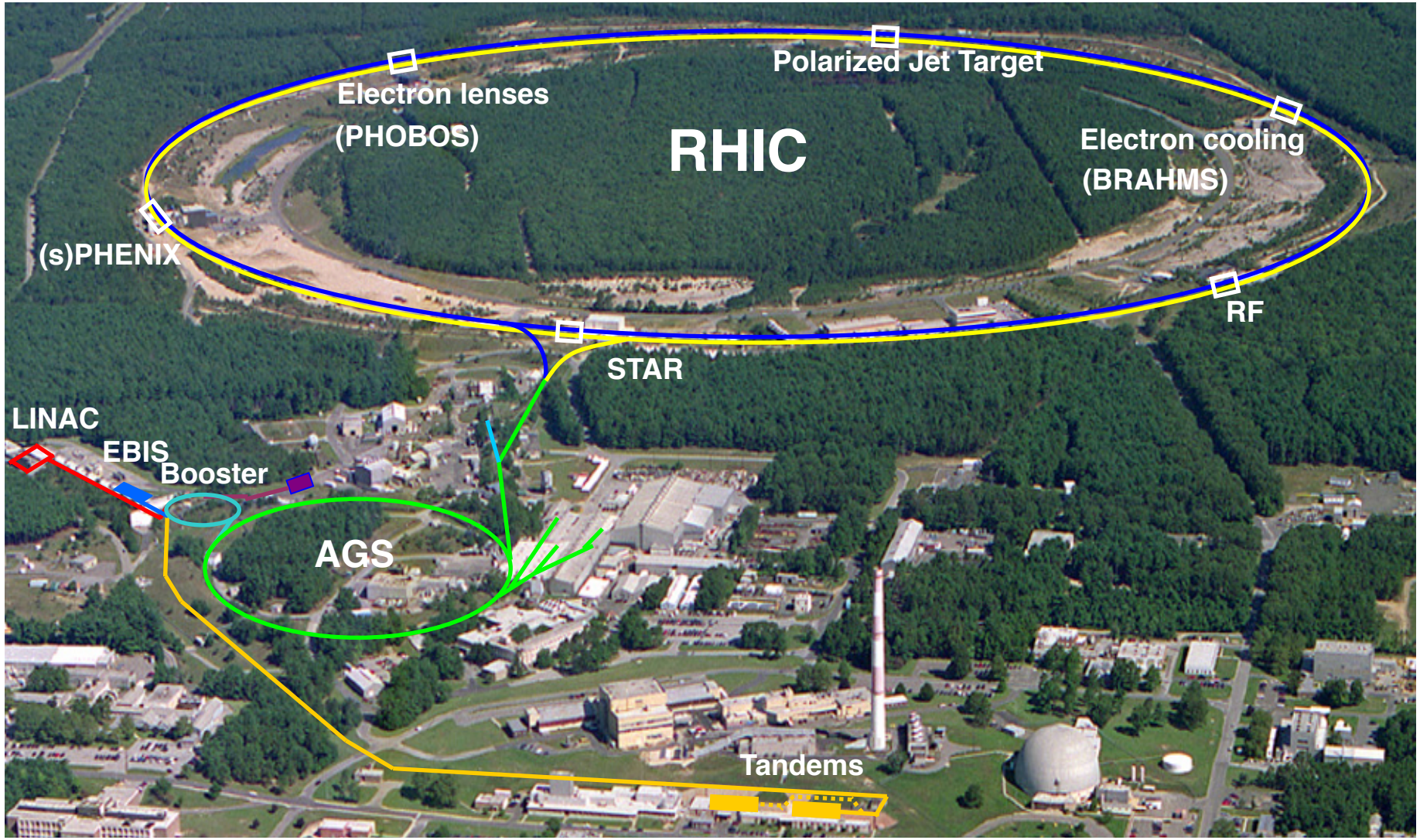
Timeline of RHIC

- The 1983 NSAC Nuclear Physics Long Range Plan included a relativistic heavy ion collider as the highest priority new facility
- It would use the tunnel and a 25-kW helium refrigerator from the ISABELLE/CBA project (it's good to have a tunnel!)
- First idea of a polarized proton collider was discussed at the 1990 Polarized Collider Workshop at Penn State
- RHIC construction started in 1991
- First beam in RHIC tunnel (sextant test) in 1998
- RHIC commissioning started in 1999
- First gold-gold collisions on June 12, 2000
- Reached RHIC gold-gold design luminosity in 2001
- First polarized proton collisions in RHIC in 2001
- RHIC running time is shared between heavy ion collisions and polarized proton collisions

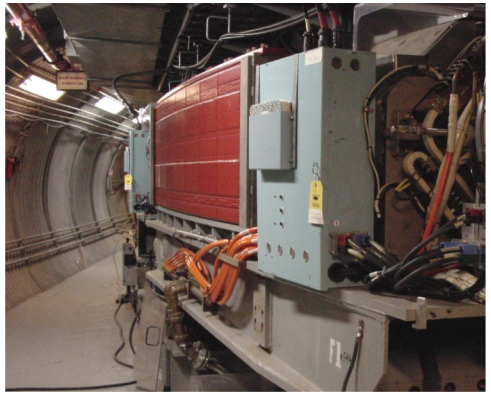
The RHIC Accelerator Complex

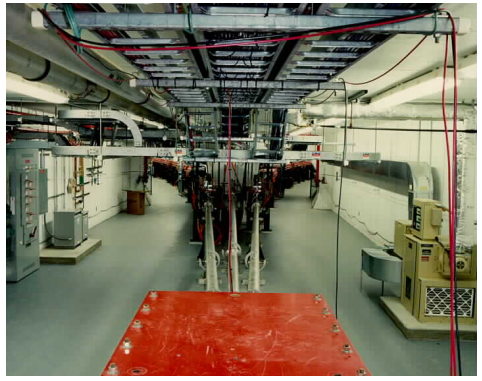
- Collider with two independently powered 3.8 km superconducting rings that allows gold-gold, proton-gold, and proton-proton collisions at equal energies up to 100 GeV. Proton-proton collisions up to 250 GeV.

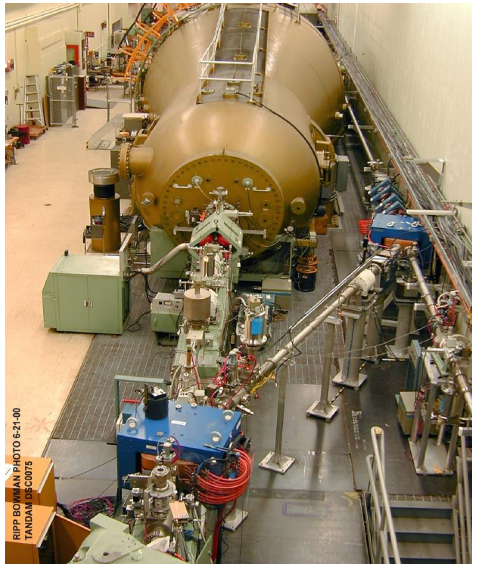
- Six interaction regions and initially instrumented with four detectors: STAR, PHENIX, PHOBOS, BRAHMS.



Gold Ion Collisions in RHIC



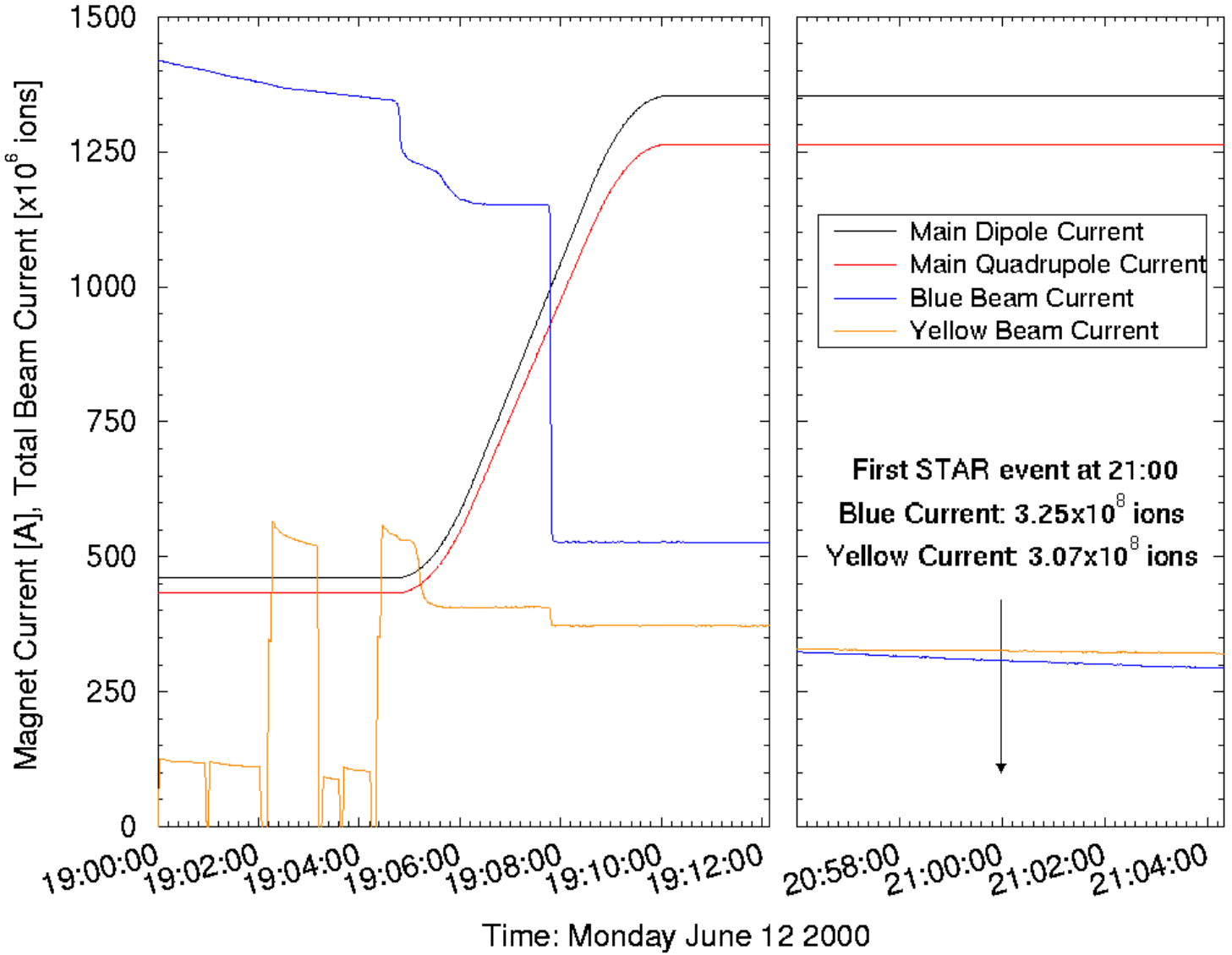


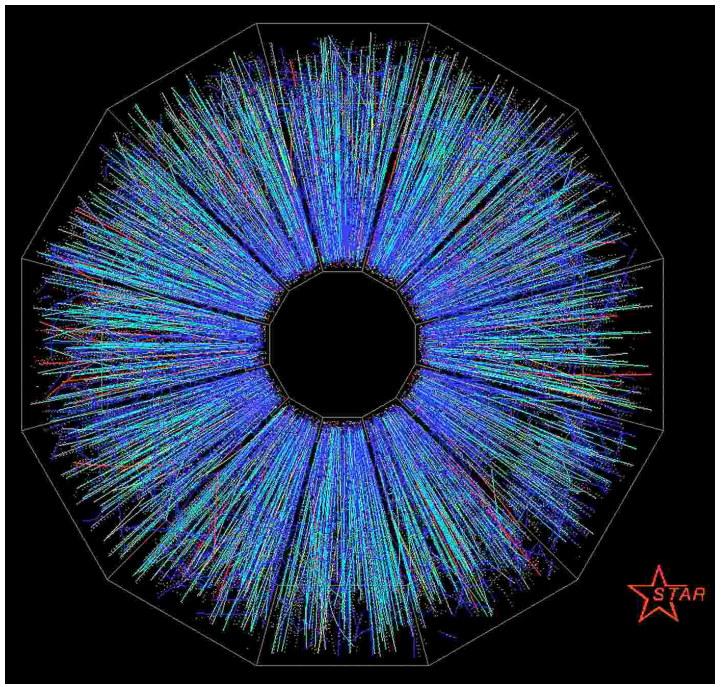


Timeline of RHIC Commissioning in 2000

- February 5 — RHIC cool-down starts
- April 2 — First gold beam circulating in blue ring
- May 7 — First gold beam circulating in yellow ring
- May 17 — Beam accelerated through transition in blue ring
- May 21 — Beam accelerated to 56 GeV in blue ring
- June 2 — Beam accelerated to 60 GeV in yellow ring
- June 5 — Beams synchronized to collide in IRs
- **June 12** — **Beams accelerated to 28 GeV and first collisions**
- June 24 — Collisions at all four detectors at 66 GeV

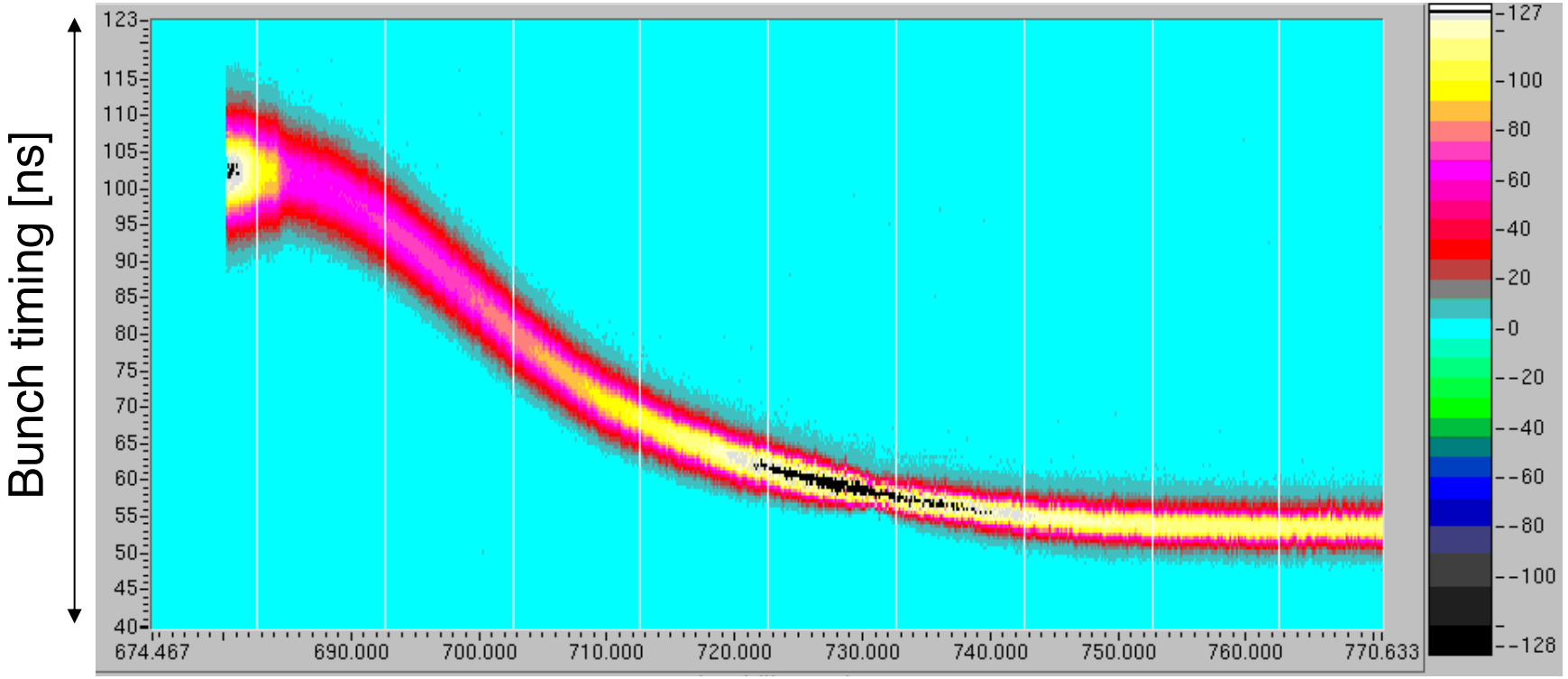
Ramp to First Collisions in RHIC





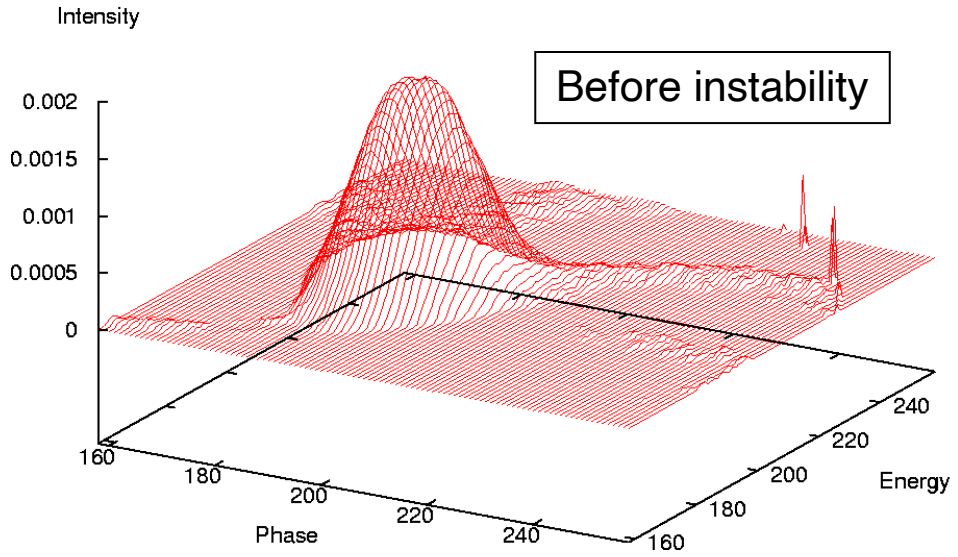
Accelerating a gold bunch in RHIC

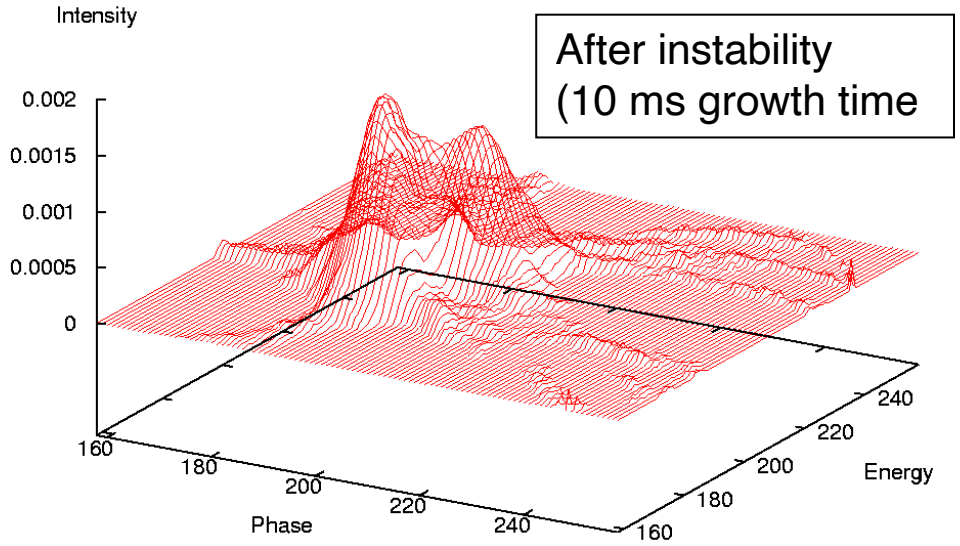
- First superconducting accelerator to cross transition energy
- With the low acceleration rate beam spends a long time close to transition
- Design includes a linear “transition jump”: fast lattice change that moves the transition energy quickly through the beam energy



Electron Clouds in RHIC

- RHIC beam intensity was limited by rapid dynamic pressure rise in beam pipes.
- Also, large losses were observed at transition crossing with increased number of bunches
- Identified a fast transverse instability with growth time shorter than the synchrotron period
- Both issues were caused by electron clouds in the room temperature sections of RHIC, an emerging realization at many accelerators at the time.
- NEG coating and scrubbing resolved this issue over the next ~ 5 years

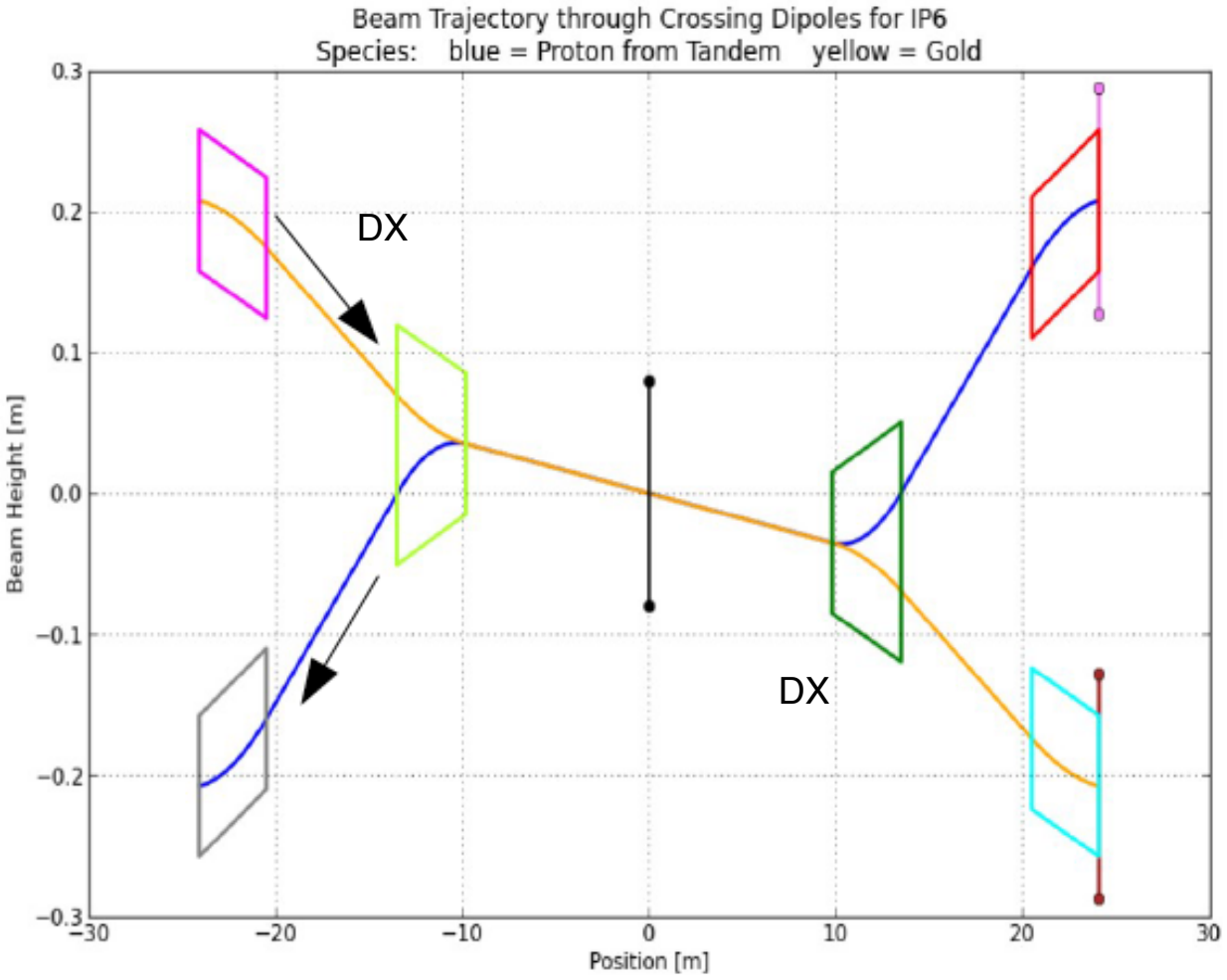




Unique Feature of RHIC: Asymmetric Collisions

- The two independent RHIC rings allow for colliding protons on gold ions with equal beam energy and therefore different rigidity.

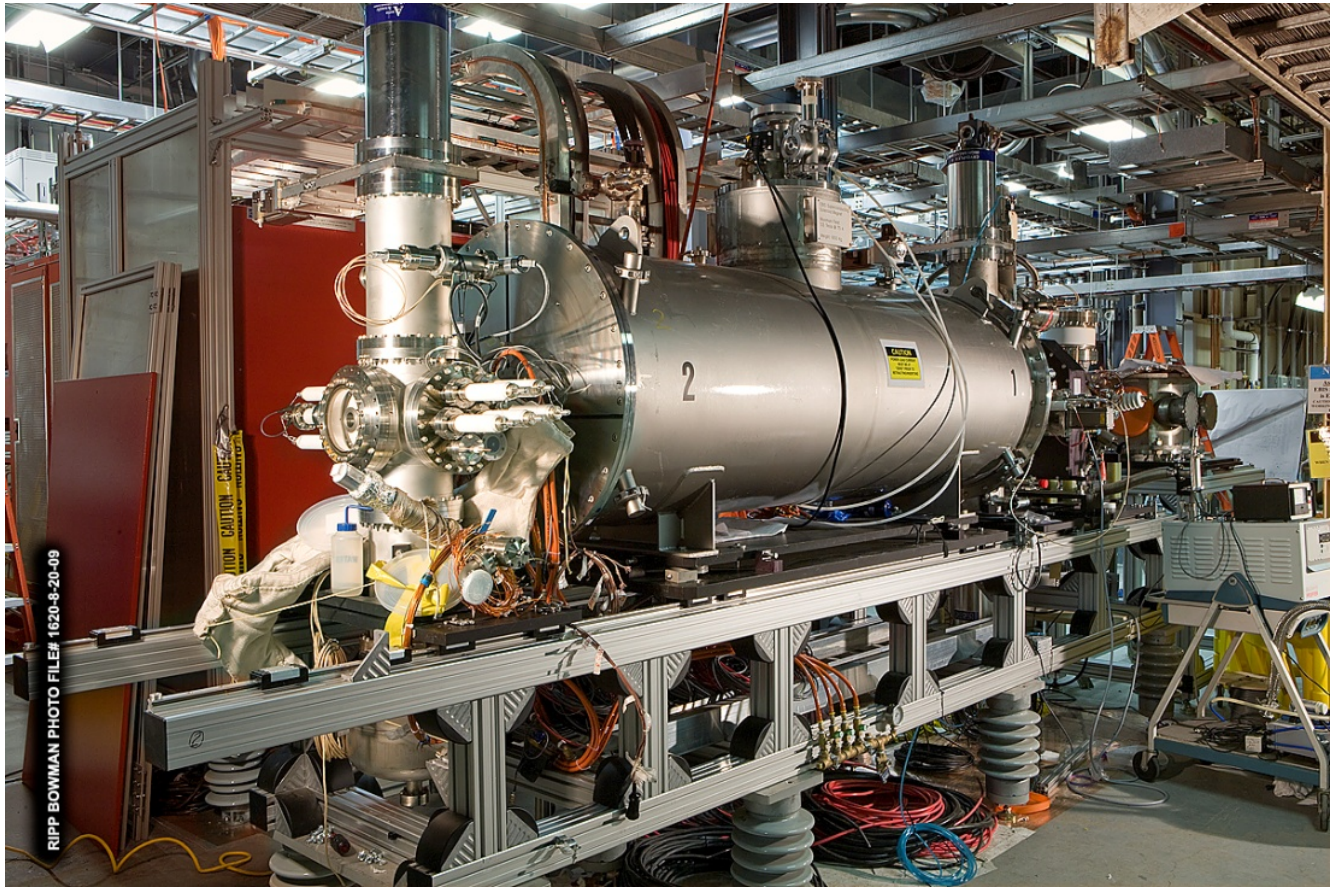
- The common magnet (“DX”) has to be moved by 2 cm for this mode. This feature of the original RHIC design was finally used in 2015!



RHIC upgrade: EBIS

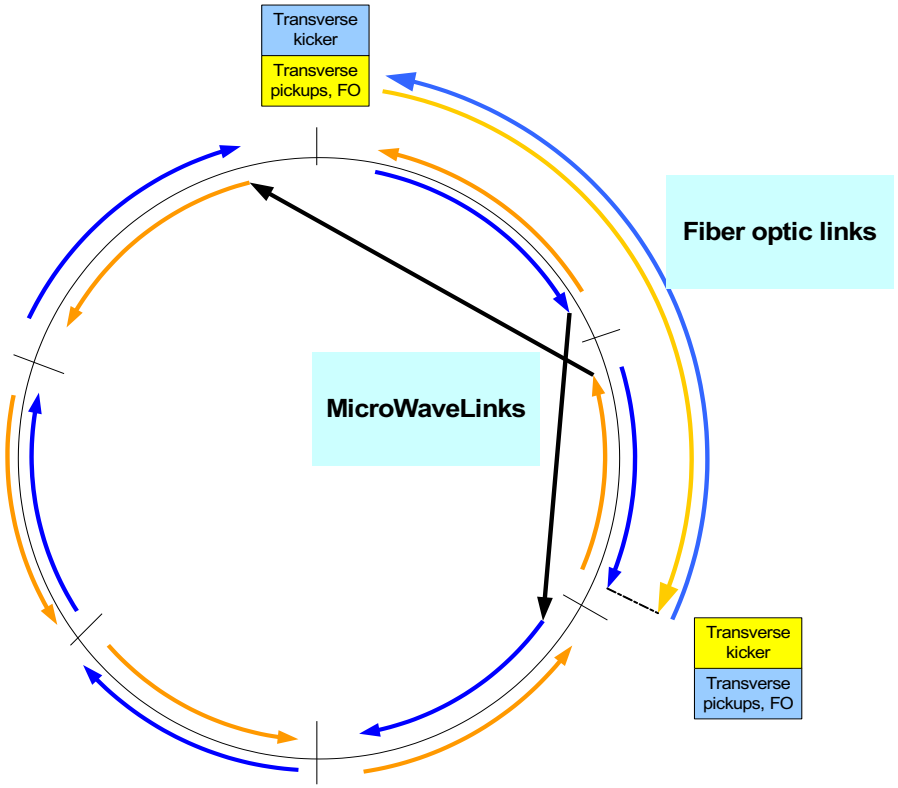
- Highest intensity Electron Beam Ion Source

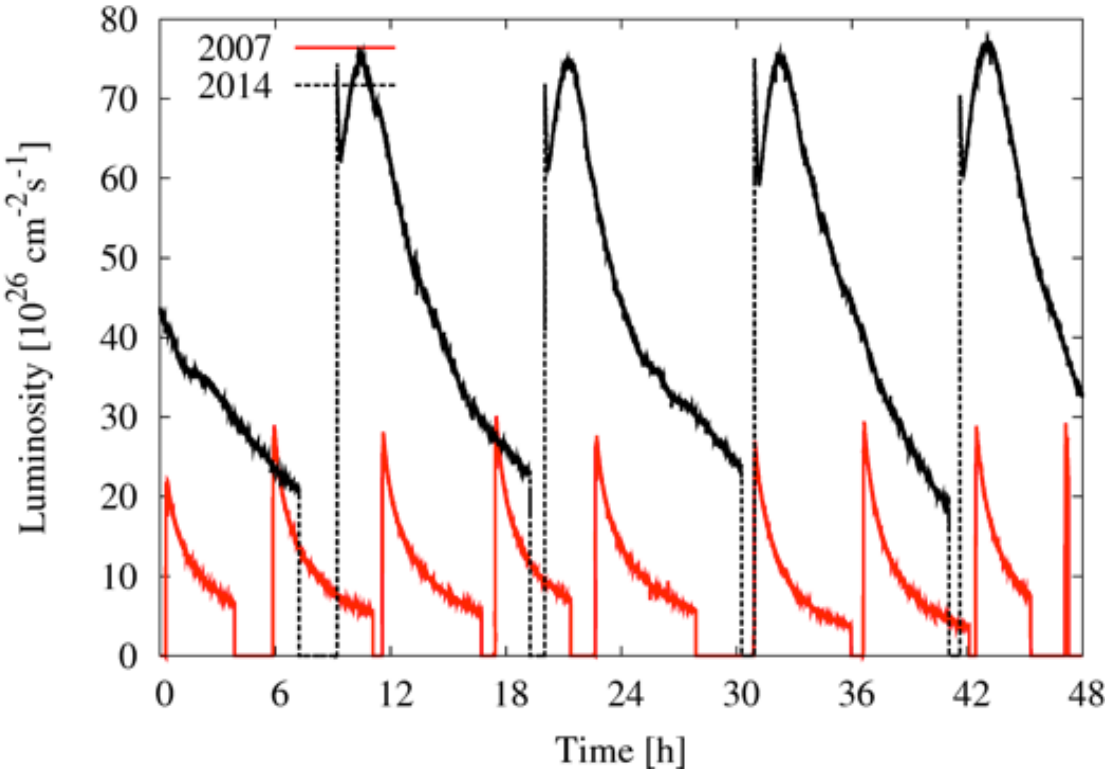
- Can provide higher Au intensity, Uranium and, potentially, polarized He-3 beams

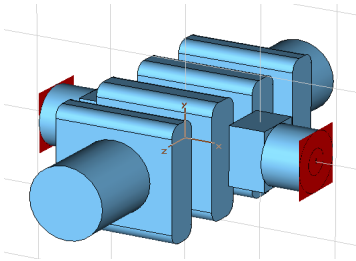


RHIC upgrade: 3-D Stochastic Cooling in RHIC

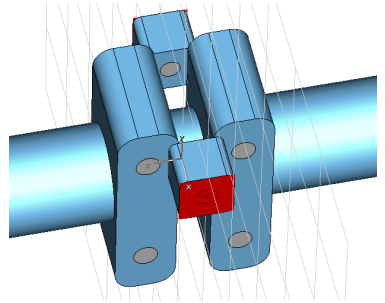
- First high energy, bunched beam longitudinal and transverse stochastic cooling (3-D) in both rings to counteract Intra-Beam scattering.
- Bunch structure of RHIC beams allowed for powerful high-Q cavity kickers







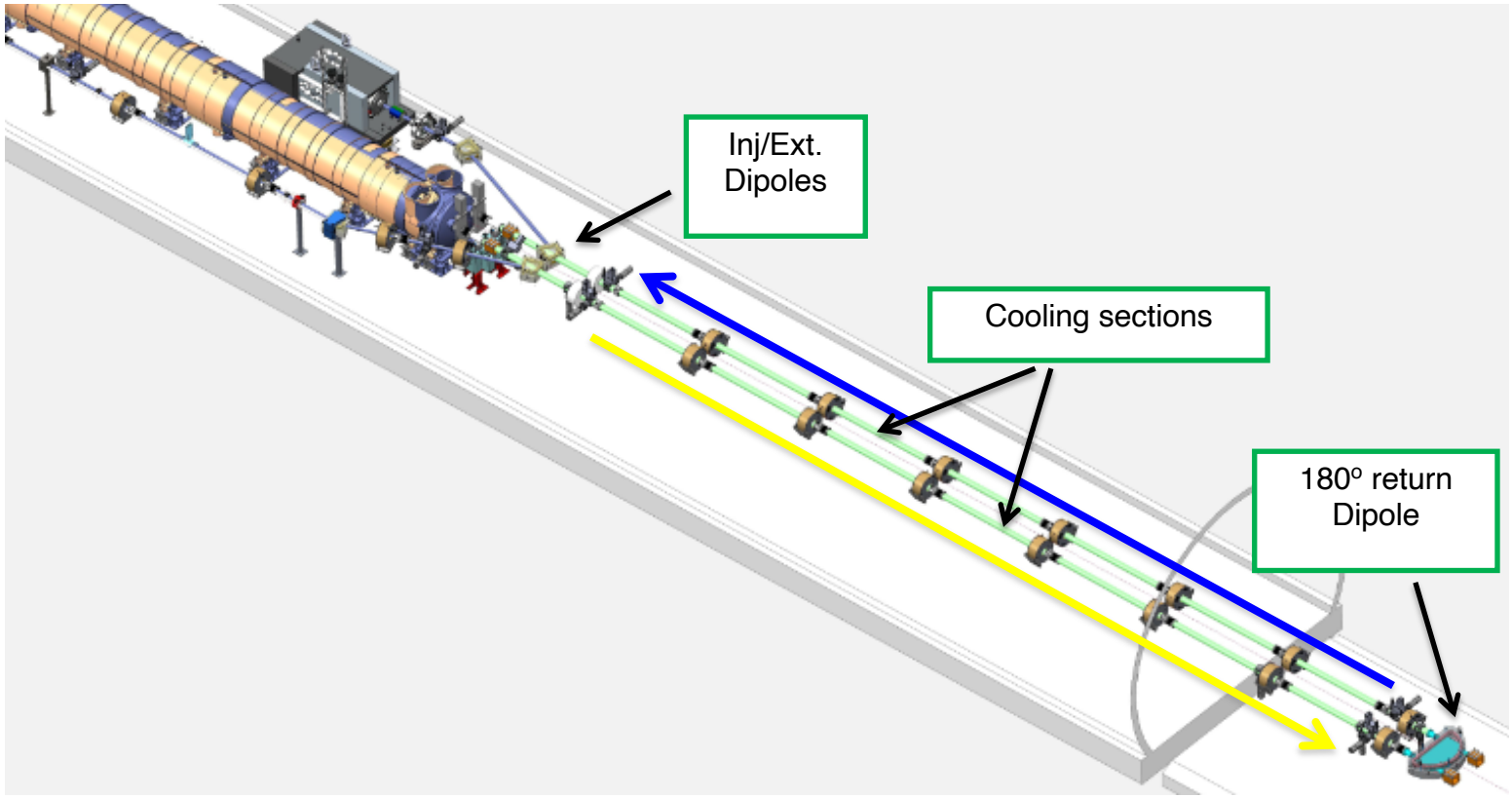
Longitudinal kickers

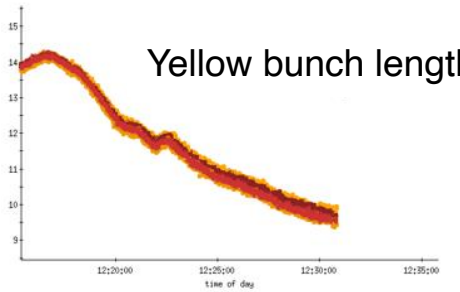


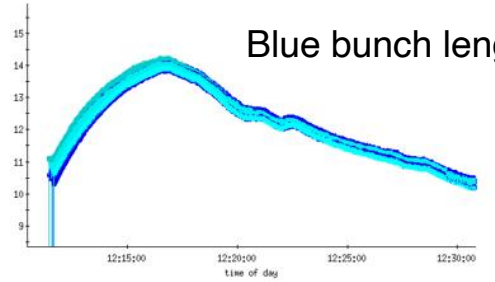
Transverse kickers

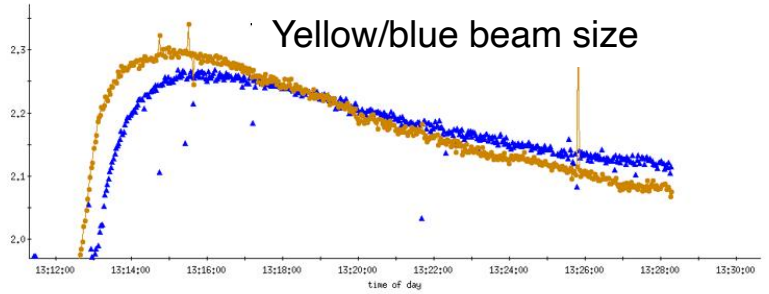
RHIC upgrade: Low Energy RHIC electron Cooling

- First bunched electron beam, non-magnetized electron cooling
- Successfully cooled 4.6 GeV gold beams in both rings simultaneously
- Longitudinal and transverse cooling demonstrated



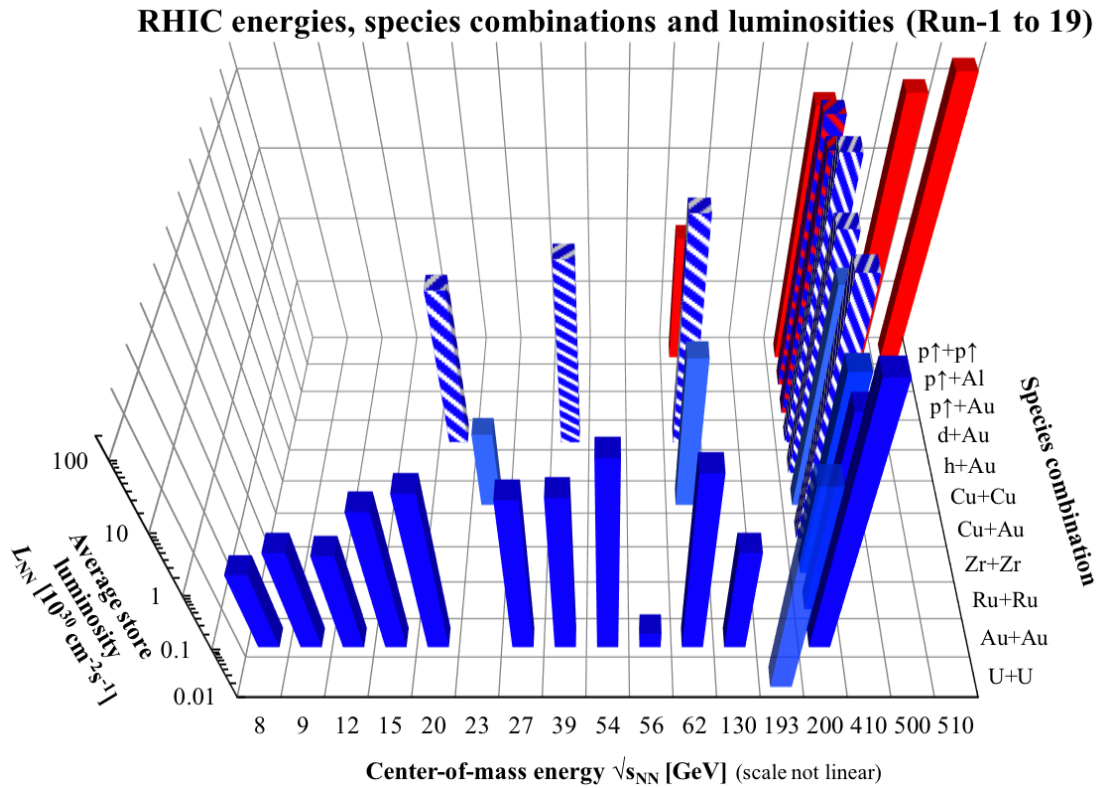


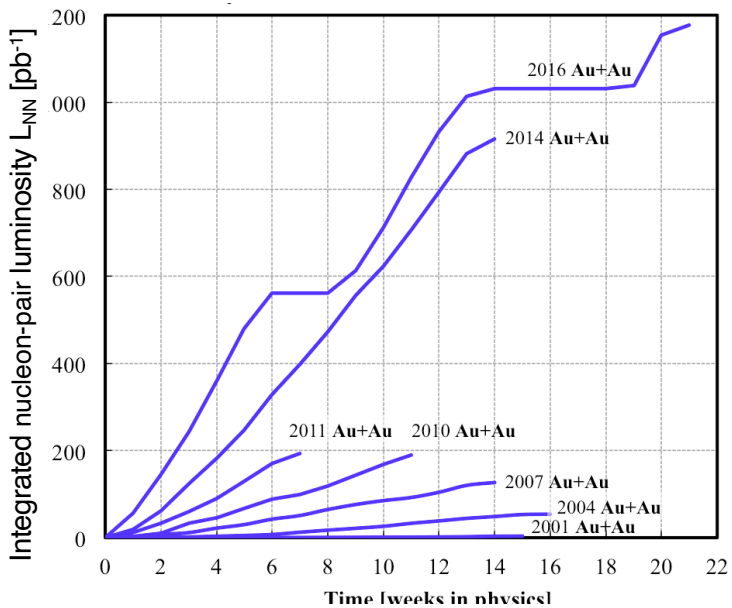


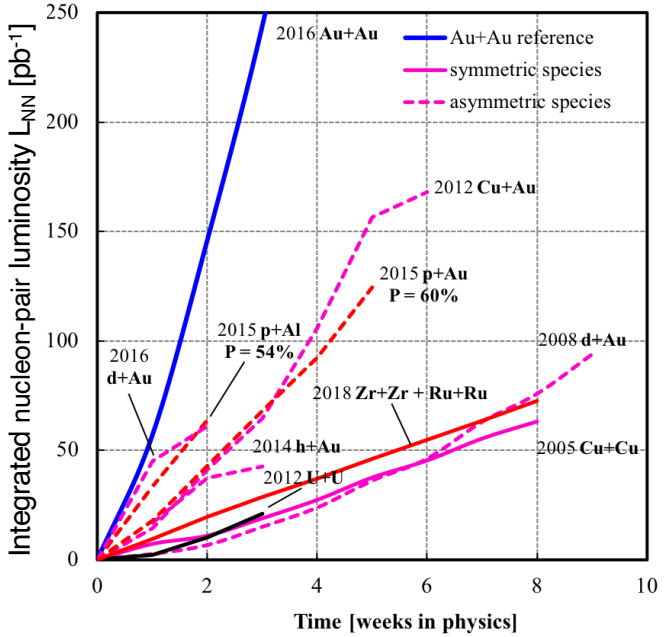


RHIC Integrated Luminosity

- Dramatic increase of RHIC performance as a result of ongoing accelerator R&D, accelerator improvements, and replacement of obsolete technology
- Consistently high facility availability

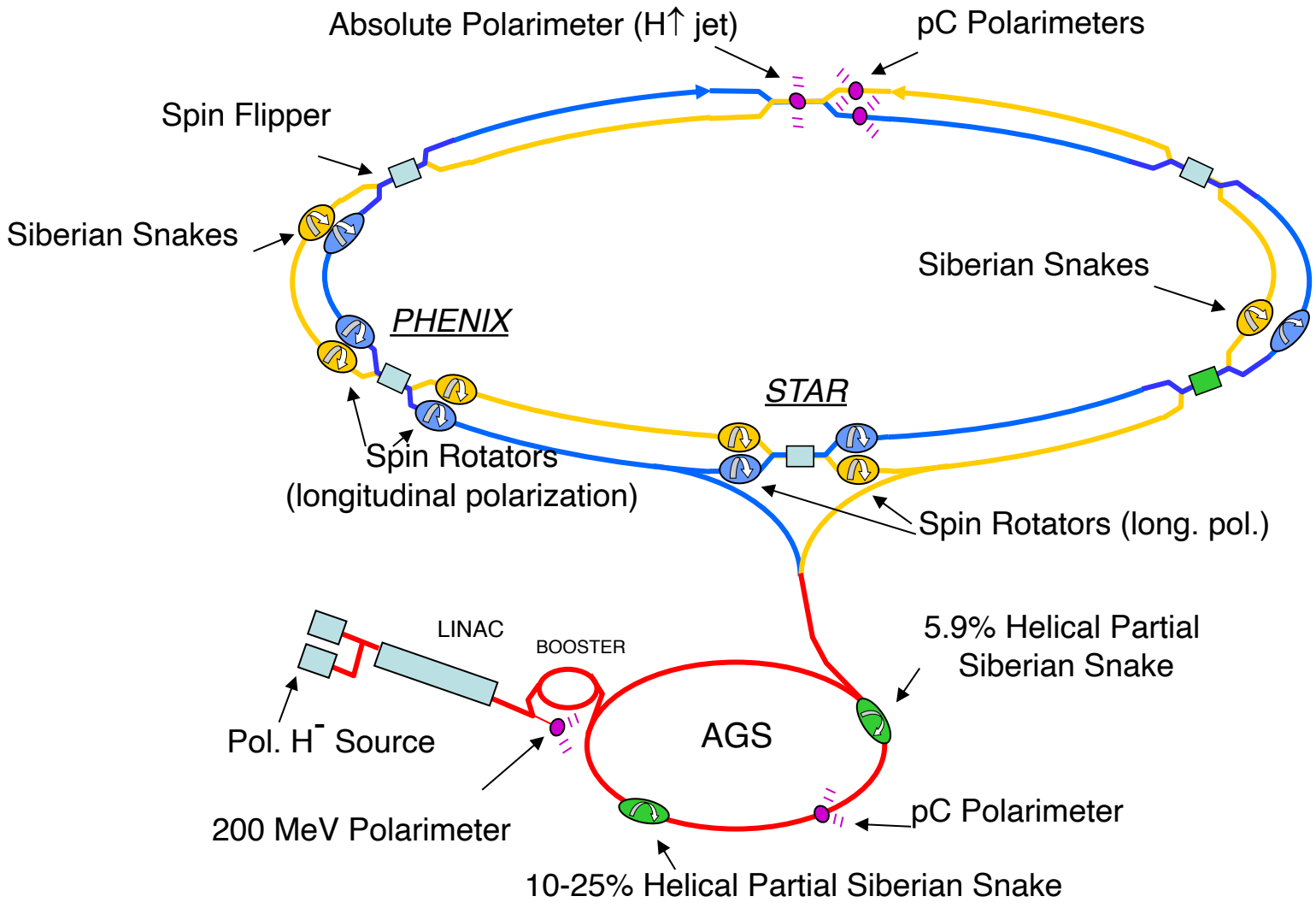






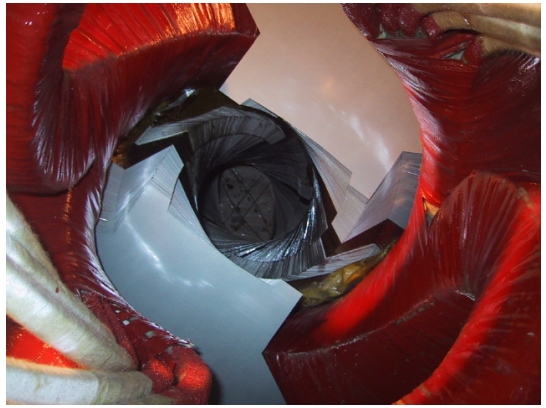
RHIC – First Polarized Proton Collider

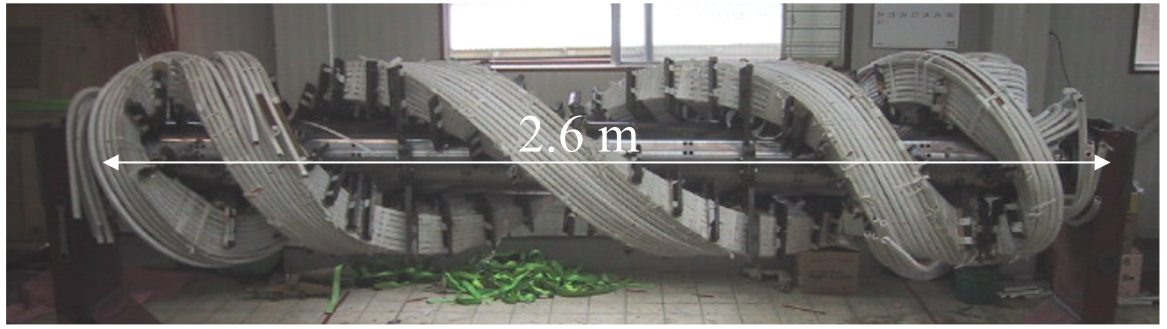
- Two full Siberian snakes per ring preserve proton polarization to 255 GeV
- Spin direction control at detectors with spin rotators
- Minimally invasive polarimeters; also measure polarization profiles
- Absolute polarimeter using an intense polarized H jet

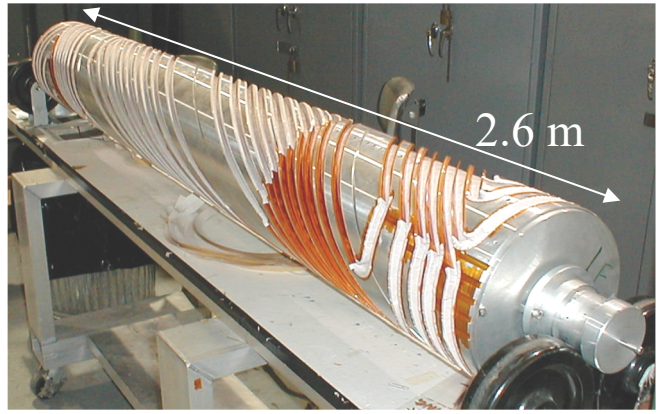


Siberian Snakes in AGS and RHIC

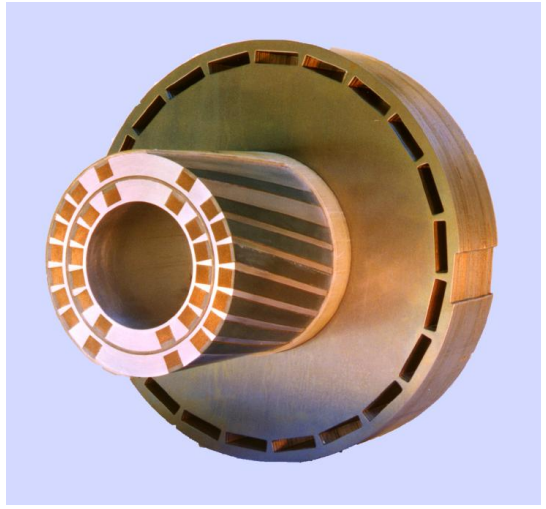
- AGS Siberian Snakes: variable twist helical dipoles, 1.5 T (RT) and 3 T (SC), 2.6 m long

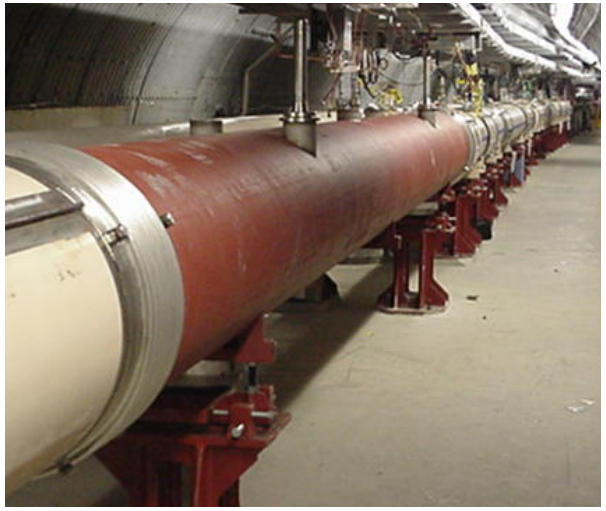






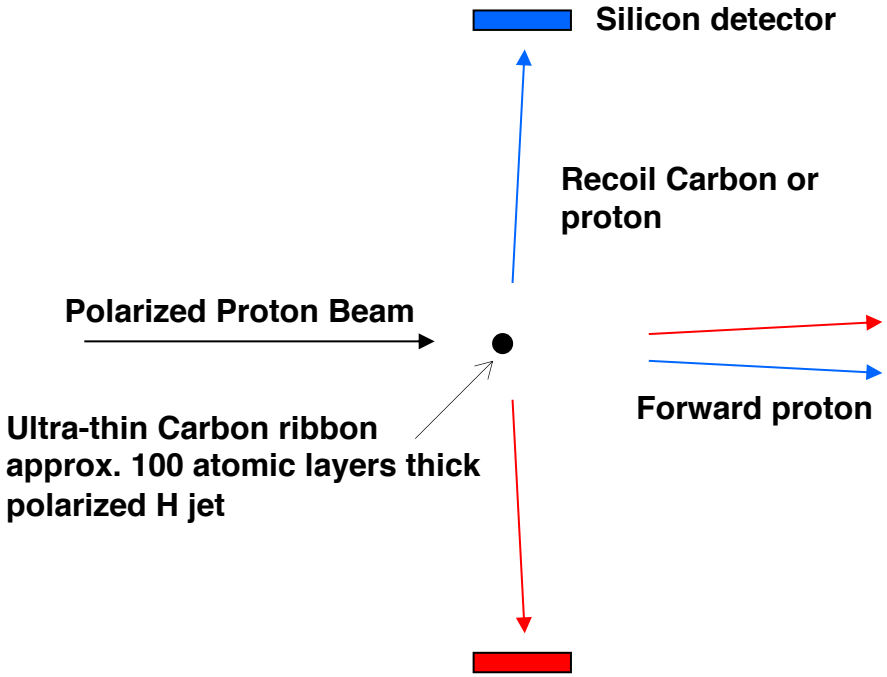
- RHIC Siberian Snakes: 4 SC 4 Tesla helical dipoles, each 2.4 m long with full 360-degree twist



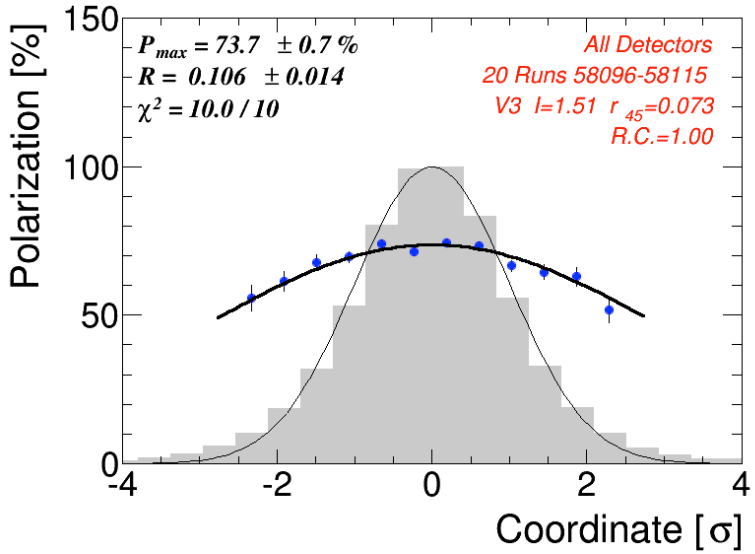


Polarimeters for High Energy Polarized Beams

- Non-invasive relative polarization measurements
  - Very small-angle elastic scattering in the Coulomb-Nuclear Interference (CNI) region from ultra thin Carbon fiber causes little beam emittance growth
  - 2-3% energy independent analyzing power originates from anomalous magnetic moment of proton
  - Fiber target allows for polarization profile measurement



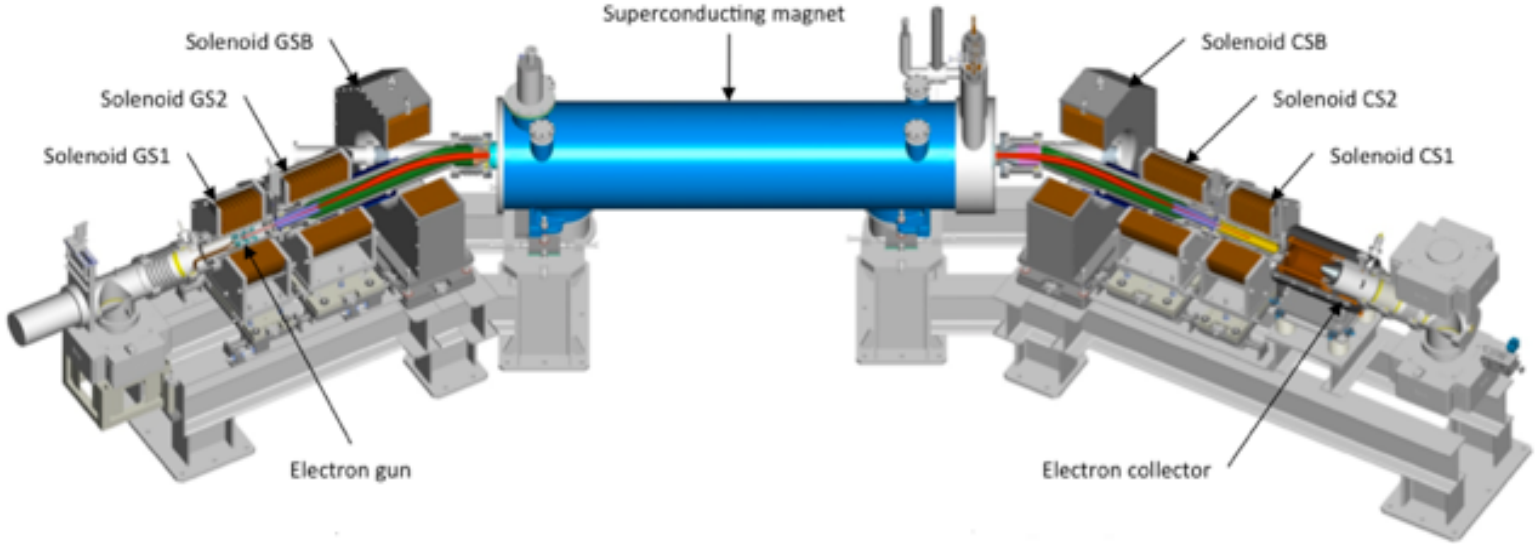
- Non-invasive absolute polarization measurement
  - No calibrated analyzing powers available for high energy protons
  - Use polarization sensitive CNI on polarized H jet to compare beam polarization to measurable H jet polarization.
  - ~ 2-3 % absolute accuracy possible



RHIC Polarized Proton Luminosity Upgrades

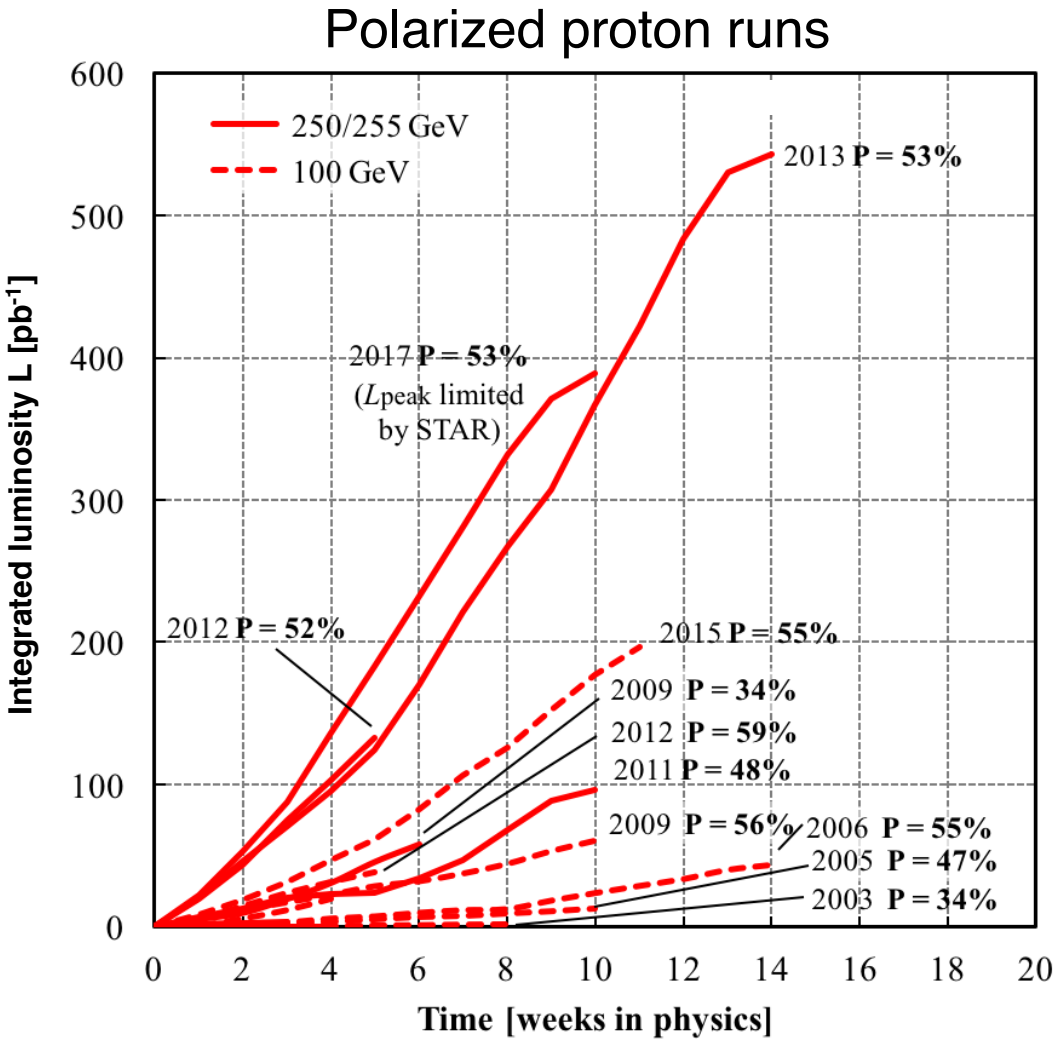
- High Intensity Optically Pumped Polarized Ion Source (OPPIS)
  - Polarized electrons from optically pumped Rubidium are used to generate polarized H- ions
  - Highest intensity (1 mA) polarized (83%) H- source

- Beam-beam compensation with electron lenses.
  - Proton-proton collisions in RHIC are limited by beam-beam tune spread
  - First successful head-on beam-beam compensation by colliding with electron beam



RHIC Integrated Luminosity and Polarization

- Total integrated luminosity of polarized proton collisions at √s = 500 GeV was more than 1 inv-fb
- Polarization averaged over both rings and over full store length was more than 50%;
- Peak polarization at beginning of stores was above 60%.
- Remaining polarization losses are about 10% in AGS and RHIC, respectively.



Summary

- RHIC is the first heavy collider and reached record luminosities over a wide energy range with advanced beam cooling techniques
- RHIC is also the first polarized proton collider establishing the feasibility of accelerating polarized proton beams to high energy using Siberian snakes and demonstrating head-on beam-beam compensation
- Over the last 20 years RHIC has been operated with unparalleled flexibility in collision energy from 7 to 510 GeV and ion species from protons to Uranium.
- Record performance will also be required during the final 5 years of RHIC operation.
- The fantastic achievements of RHIC form the basis for the polarized Electron Ion Collider.