20 Years of RHIC Machine

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

Beam Energy = 100 GeV/u

9 GeV/u
Q = +79

1 MeV/u
Q = +32
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

First STAR event at 21:00
Blue Current: $3.25 \times 10^3$ ions
Yellow Current: $3.07 \times 10^3$ ions
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.
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

![Graph showing RHIC energies, species combinations, and luminosities (Run-1 to 19)]

![Graph showing integrated nucleon-pair luminosity L_{NN}[pb^{-1}]]
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.
  - $\sim$ 2-3 % absolute accuracy possible

![Diagram showing polarization measurement setup](image)
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
Total integrated luminosity of polarized proton collisions at $\sqrt{s} = 500\text{ GeV}$ 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.