Storage Rings for Science with: Electron-Positron Collisions Hadron Collisions and Synchrotron Light

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SIXTY YEARS
OF DISCOVERY
1947-2007

BROOKHAVEN
NATIONAL LABORATORY

Office of Science
U.S. DEPARTMENT OF ENERGY

Citation:
"For his outstanding contribution to the design and construction of accelerators that has led to the realization of major machines for fundamental science on two continents, and. his promotion of international collaboration"

Contents of Talk

- Construction of TRISTAN e^+e^- Collider: E_B = 30 GeV
  at KEK, Tsukuba, Japan [1981 – 1987]
- Construction of RHIC: E_B = 100 GeV/u for Au, 250 GeV for proton
  at BNL, Upton, NY [1989 – 1999]
- Conceptual Design of NSLS–II: E_B = 3 GeV
  [2005 – 2007]
- Some Lessons Learned

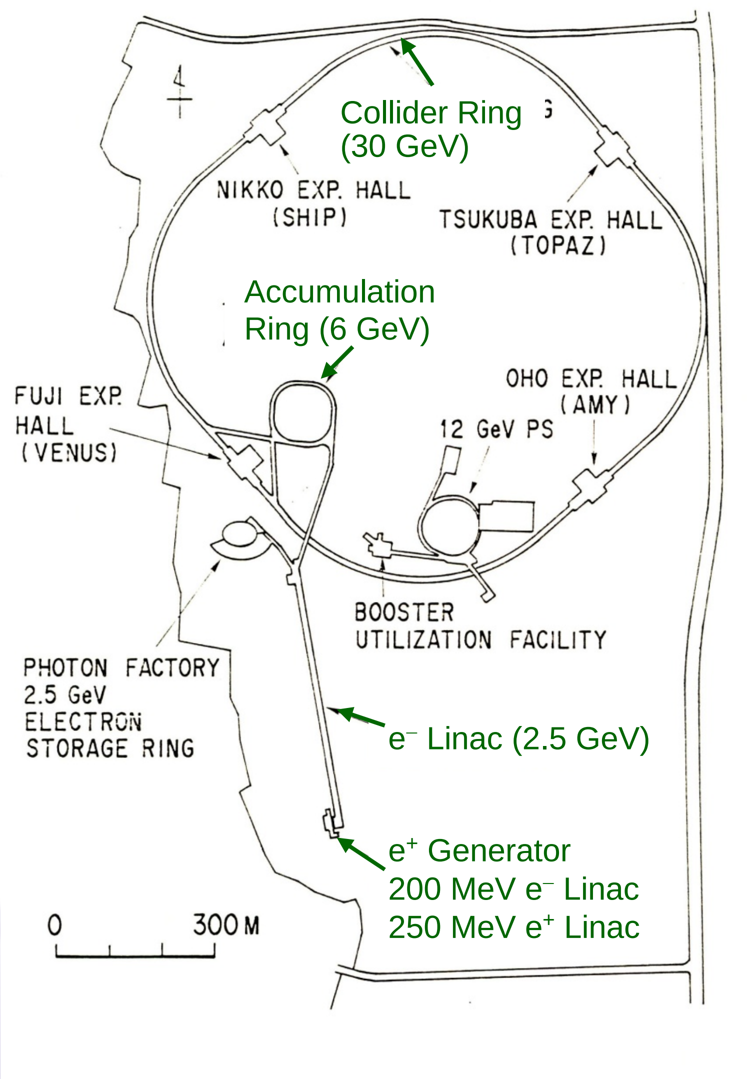
Aerial View of KEK

During the TRISTAN Construction (~1984)

KEK Site: ~1km×1.5km

KEK after TRISTAN Completion

TRISTAN e^+e^- Collider Layout

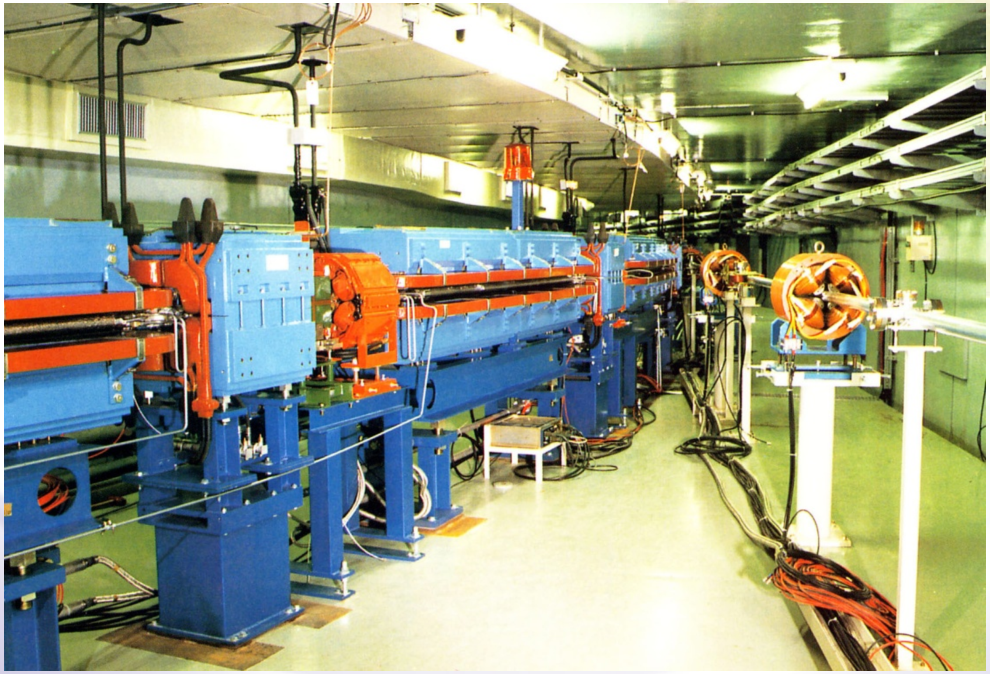


- How to build ~30 GeV e-storage ring in a site with 1 km width
- Build 4 linacs connected by 4 arcs
- Ring Circumference: 3018.1 m
  - Straight Sections: 4 × 194.4 m
  - Curved Sections: 4 × 560.2 m
- RF Acceleration Sections
  - Radiation Loss/turn: 290 MeV@30 GeV
  - Peak RF Voltage (I=0, τ_q~10hr): 379 MV
  - Total Linac Length: 413 m
    - Room Temp: 316 m
    - Superconducting: 97 m
  - RF Frequency: 508 MHz
  - Number of 1 MW CW klystrons: 34
- Total Project Cost ~900 (~$450M)

Magnet Rings in Tunnel

Main Ring Tunnel is Now used for KEK B-Factory

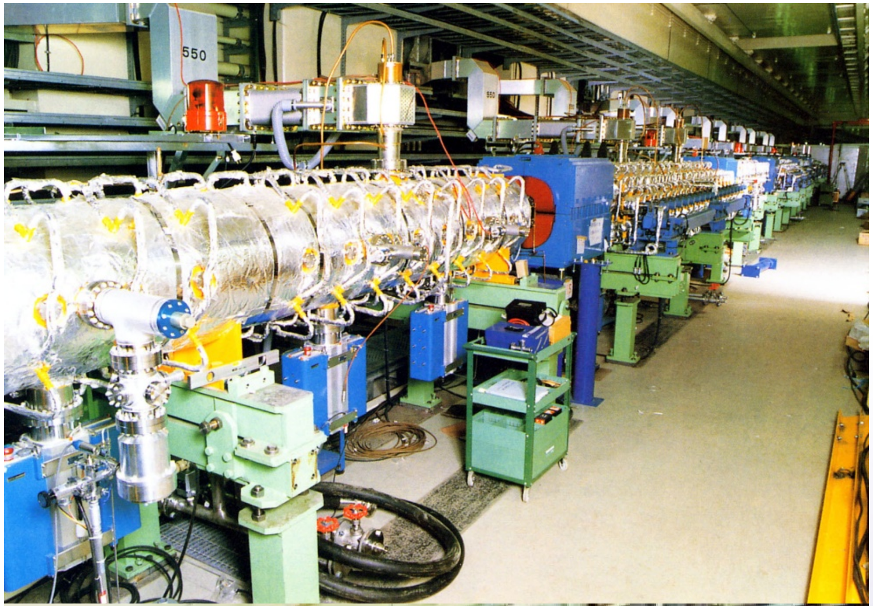
- Collider Ring

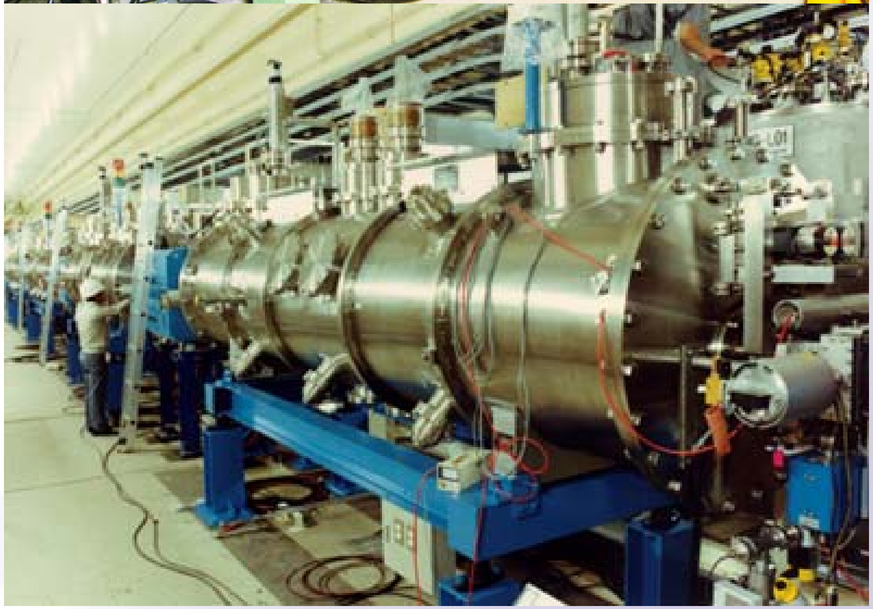


Accumulation Ring

RF Sections (500 MHz)

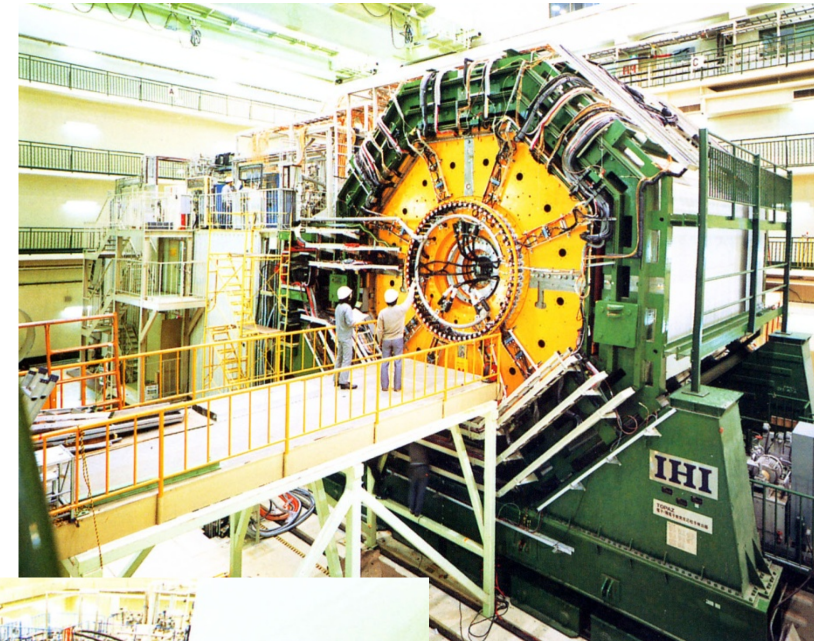
- RF Cavities:
  - Twin 9 Cell NC : 316 m
  - Twin 5 Cell SC: 97 m
- 1 MW CW Klystrons





Detectors

AMY
International
Collaboration
led by a US
team



TOPAZ
with TPC

VENUS with
Cylindrical
Drift
Chamber

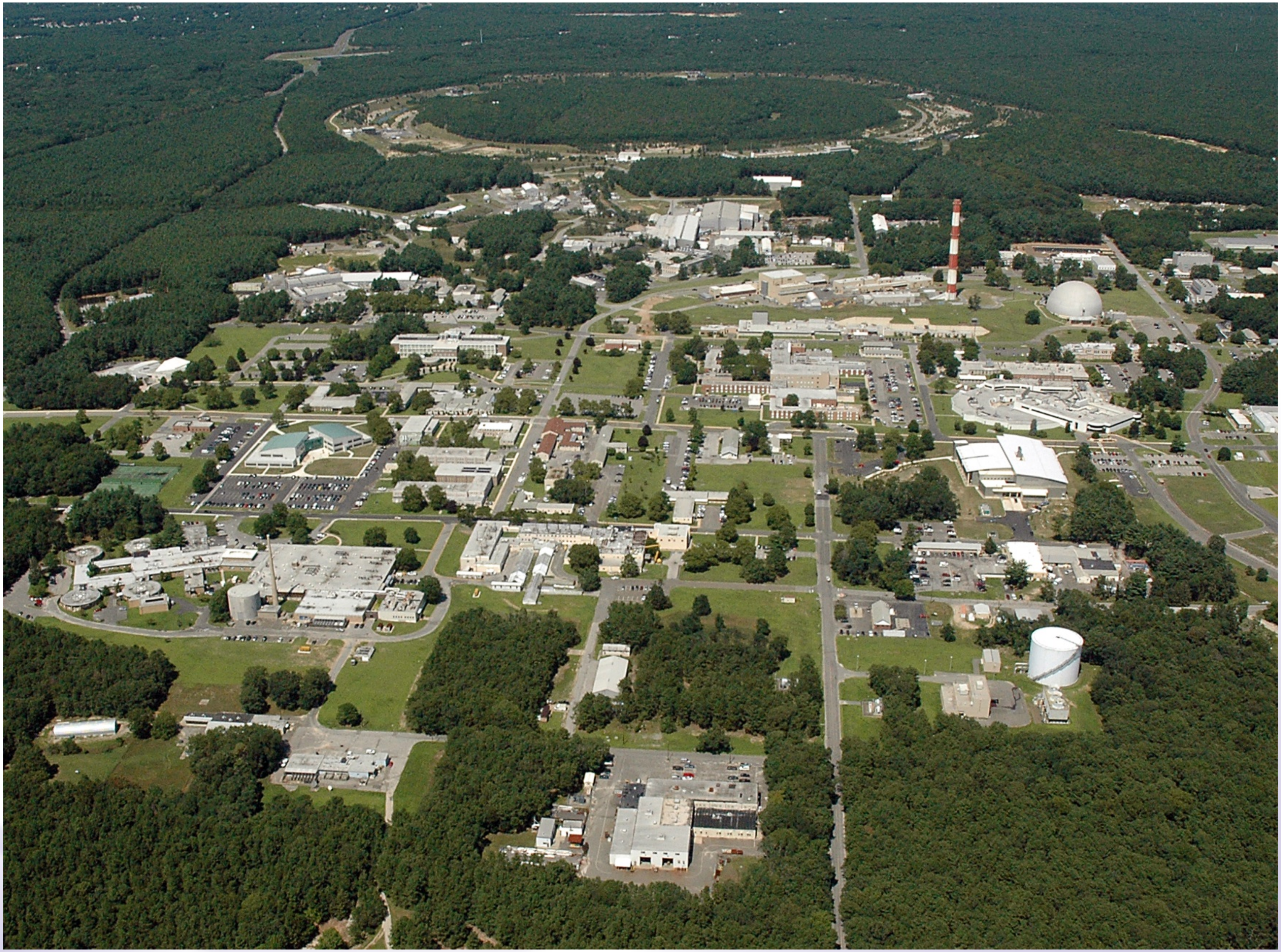
Notes on the TRISTAN Project

- TRISTAN, then the highest energy e^+e^- collider, was built using accelerator capability in Japan, both at laboratories and industry, which was nurtured through construction of small scale accelerators over years, starting with Dr. Nishina's cyclotron at RIKEN in 1937 and the latest one before TRISTAN being KEK 12 GeV PS in 1976 and Photon Factory in 1983.
- Detector design and construction was supported by many physicists who were trained in overseas labs, such as under the US-Japan Collaboration in High Energy Physics.
- The AMY experiment was the forerunner of a large scale international collaboration in a Japanese Laboratory, and helped open the door of Japan to foreign researchers.
- The most important achievement of this Project was establishing the modern accelerator physics and technology base that opened the way for Japan to compete and collaborate in an international accelerator arena.

Lessons Learned from TRISTAN

- The Japanese Industry was very eager to engage in the technological development for the Project, but their success rate was much better where the Laboratory had scientific and engineering capability.
- We made a lot of mileage by treating the industry as partners in the Project and not as a vendor with adverse relationships.
- The overall design of accelerator system for a user facility must be conservative, relying on the proven technology, but a small number of new ideas can be introduced after thorough R&D to prove that they can be adopted as critical components of the system.
- Maintaining the schedule is the way to control the project cost and people's moral.

Aerial View of BNL and RHIC



The RHIC Project

RHIC is

- The Flagship of the US-DOE Nuclear Physics Research Facility
- A Two-Ring, High Energy Collider for Heavy Ion Collisions
- Uses Existing AGS Complex as the Injector
- World's Only Polarized Proton Collider

(Made possible by RIKEN-BNL Collaboration funded by Japanese STA)

Total Project Cost (including R&D and Pre-Operations) =$ 616.5M

Completed on Schedule and within Budget

RHIC Project History:

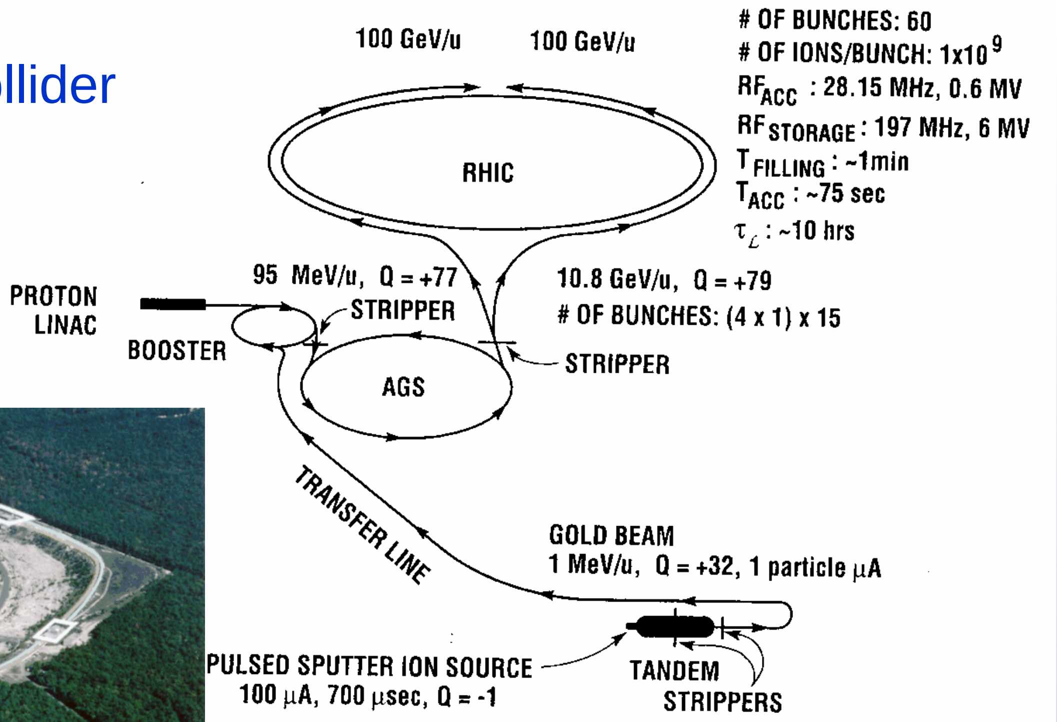
1983: The Project Conceived as Part of US NSAC Long Range Plan
1989: CDR Updated and Detector R&D Initiated
1991: Construction Began
1999: Construction Completed and Functionality Verified
2000: Relativistic Heavy Ion Collision Physics Program Began

17 Years after the Idea was Conceived

RHIC Collider System

Two Ring Superconducting Collider

3.8 km in Circumference
Maximum Beam Energy
100 GeV/u for Au
250 GeV for proton

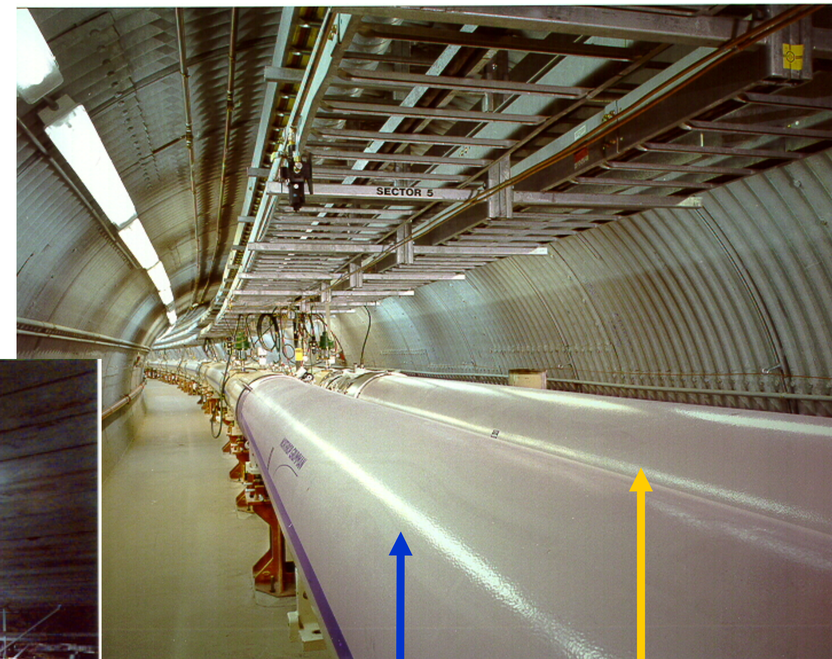


RHIC Configuration and
Au-Au Beam Collision Scenario

1740 Superconducting Magnets
- 360 Arc Dipoles: 3.46T, 9.5m
- 420 ARC CQS: 71T/m, 1.1m
- 36 IR Dipoles
- 96 FF Quads,

Arc and Interaction Region

Arc Sector

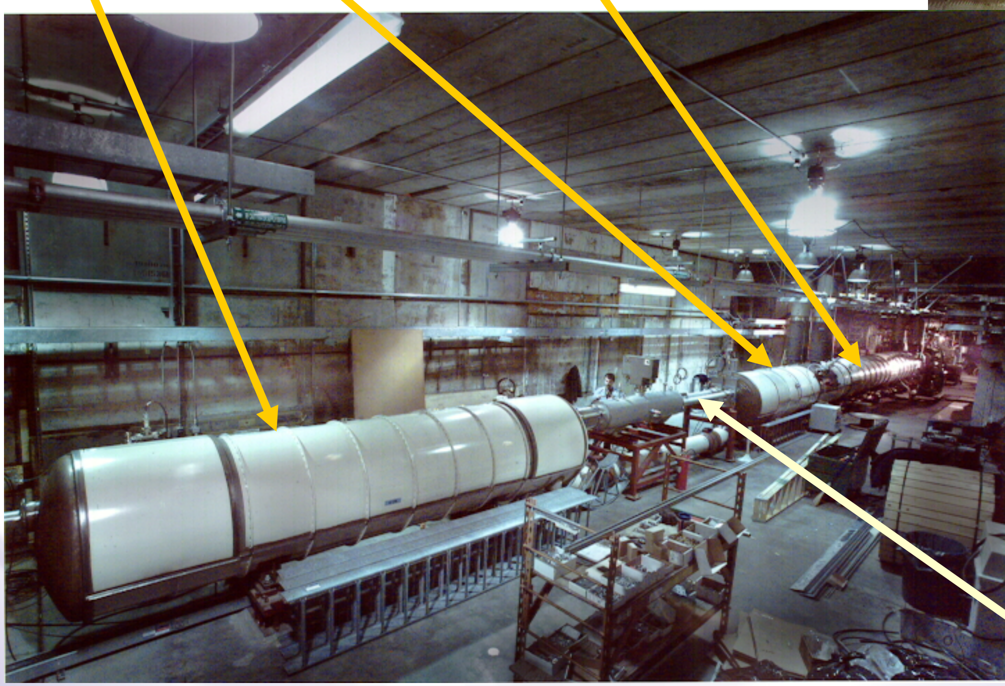


Blue Ring (Clockwise)

Yellow Ring (Counter-Clockwise)

Interaction Region

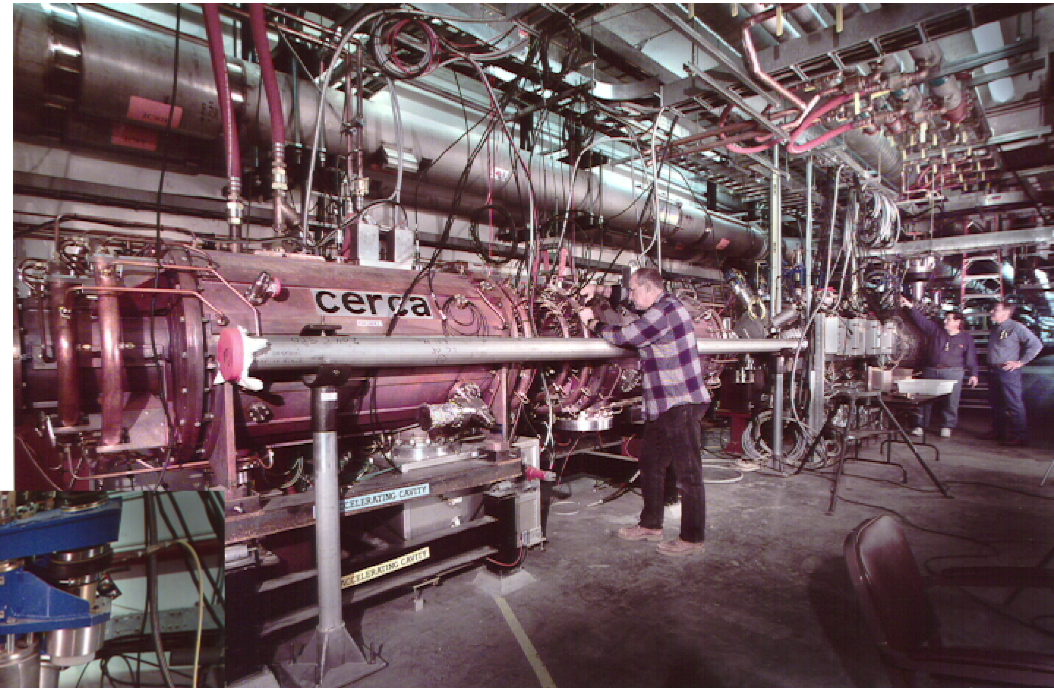
DX D0 FF Triplet

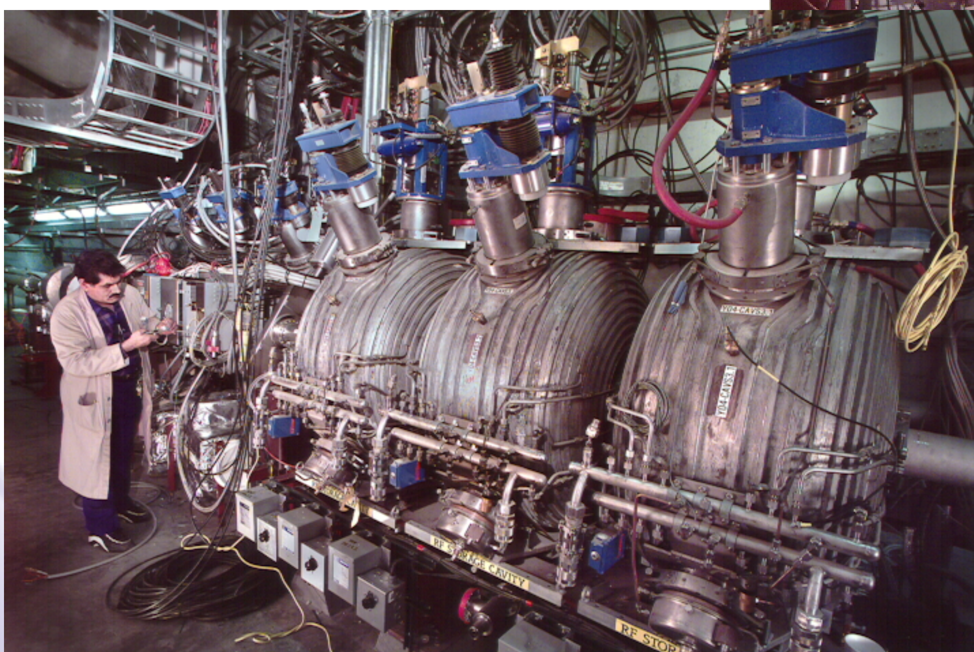


Zero Degree Calorimeter

Acceleration and Storage RF

28 MHz RF for Capture and Acceleration
600KV/Beam
Bunch Rotation
Transfer to the 197 MHz RF

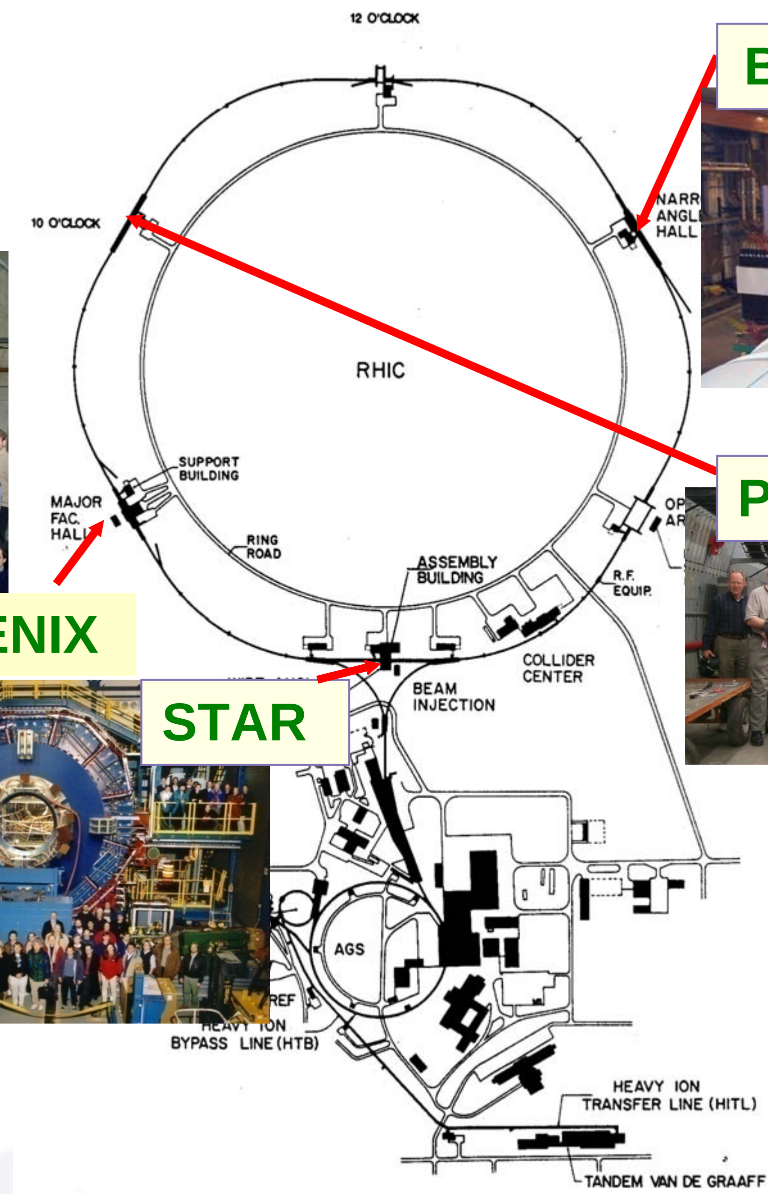




197 MHz RF for Storage
3/Ring (3MV) + 4 Common (4MV)

Maintain Short Bunches
On-going Upgrade by Stochastic Cooling of HI Beams

RHIC Detectors



2 Large Detectors
- STAR
- PHENIX

2 “Small” Detectors
- PHOBOS
- BRAHMS

International Participants in RHIC Research

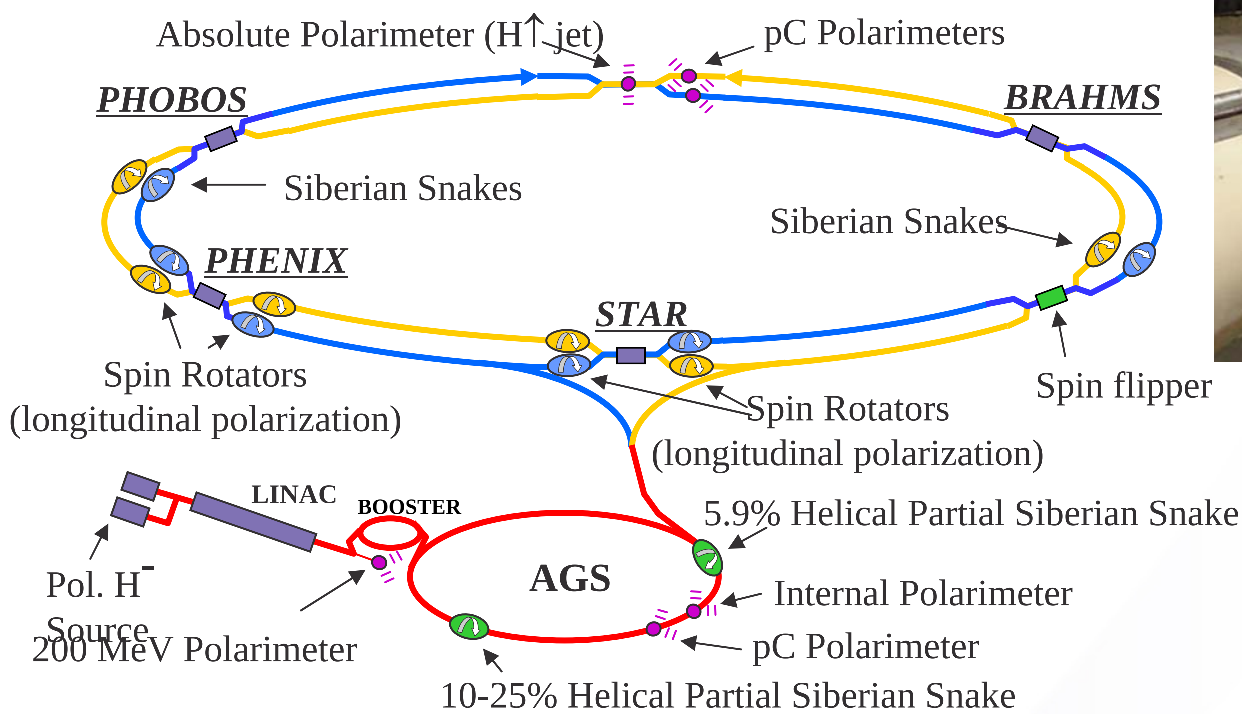
~1000 people from ~100 Institutions - Worldwide

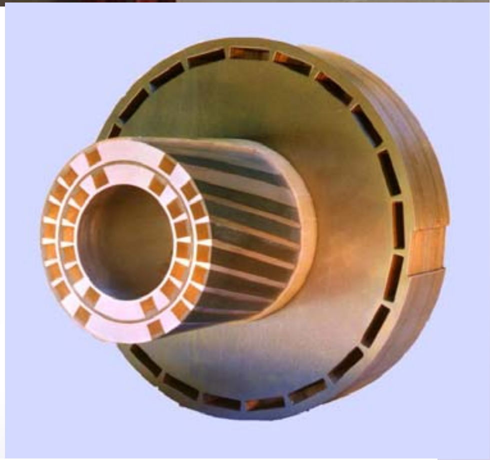
Brazil, Canada, China, Croatia, Denmark, France, Germany, India, Israel, Japan, Korea, Norway, Poland, Russia, Sweden, Taiwan, UK, US

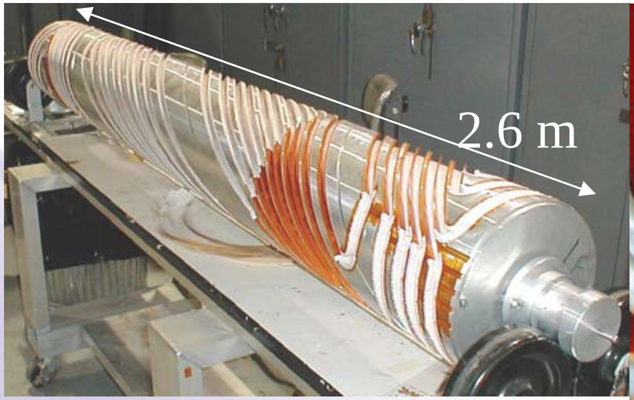
+ Significant Contributions from US NSF and Foreign Governments

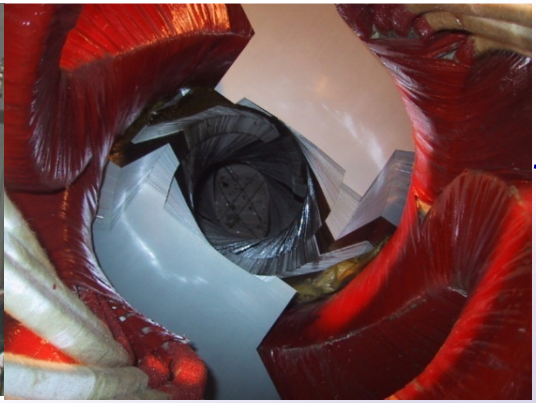
RHIC – First Polarized Hadron Collider

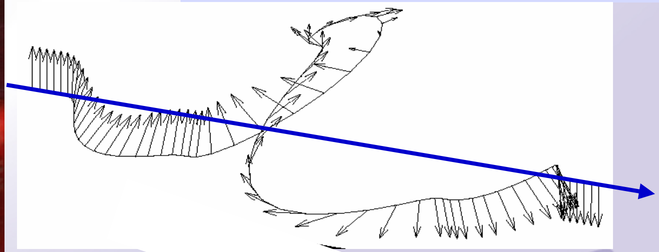
With Siberian Snake Magnets for Spin Control











Notes on the RHIC Project

- RHIC was built for experiments with relativistic heavy ion collisions
- It was thought that such collisions might create a microcosm of hot and dense matter that might have existed shortly after the Big Bang
- RHIC experiments indeed found that Au-Au collisions at top energy create hot and dense state of matter that behaves like perfect fluid, contrary to behaving like "plasma"

  Strongly Interacting Quark Gluon Plasma (SQGP)?

- There has been a puzzle as to where the nucleon spin comes from. Since the observation that quark contribution is very small, the hope was to find the gluon to the contributor.
- The RHIC experiments with 200 GeV polarized proton collisions preliminary observed the gluon contribution also is negligible

Issues with the RHIC Collider System

- The need for the successive election stripping to fully stripped heavy ions for storage. Therefore, an ion source of heavy ion beams requires a cascade of accelerators and stripping stations, and is costly.
- Changeable charge states (or e/m) during storage from electron capture in beam-gas collisions, leading to the need for ultra high vacuum to prevent beam loss
- Rapid growth of beam emittance due to enhanced intra-beam scattering caused by the high charge of heavy ions, leading to a relatively short luminosity life-time
- Instability at the transition crossing during slow acceleration in the superconducting collider like RHIC
- Steering of beams from two separate rings to co-linear collisions and maximize the luminosity
- The need for Siberian Snakes to overcome depolarizing resonances and to rotate spin orientation from vertical to longitudinal

Lessons Learned from RHIC

- The existence of technical knowledge and capability at BNL and within the project teams really helped us in achieving our goal
- This included expertise on the superconducting magnet science and engineering that had been built up at BNL since early 1980's
- The idea of partnership with industry, in particular with the contractor of superconducting magnet manufacturing helped smooth out the accelerator component procurement process
- A change in the funding profile, even relatively small, after the major contract was signed made the management of the project very difficult, resulting in the stretch out of baseline schedule and cost.

NSLS-II at BNL:

A New Third Generation Light Source to replace 25 yr old NSLS

The basic mission requirements:

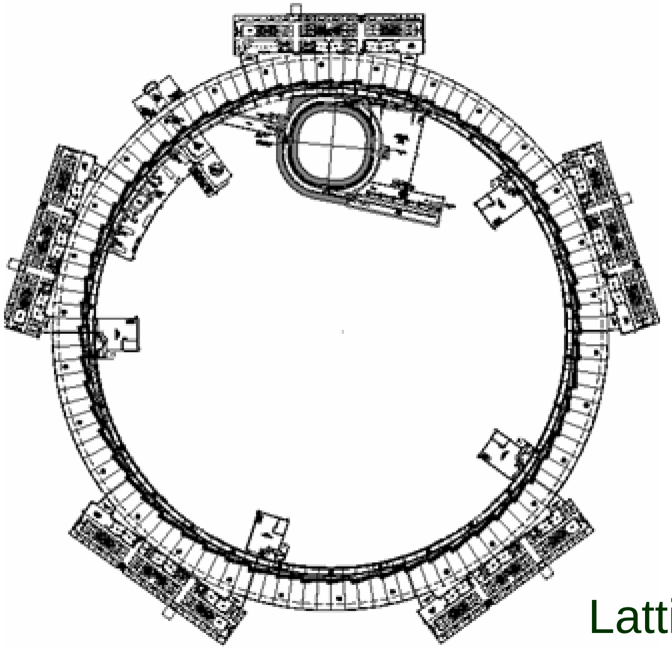
the achievement of x-ray sources providing
1 nm spatial resolution and
0.1 meV energy resolution with
single atom sensitivity.

These requirements lead to:

- A high performance storage ring source with ultra-high brightness and stability.
- 3 GeV storage ring
- Ultra-small emittance
  - Horizontal: $\varepsilon x<1.0$nm (achromatic)
  - Vertical: diffraction limited @12 keV
- Beam stability $\leq$10% of beam size (~30nm)
- Stored current > 500 mA $\pm$1% with Top-off injection,

NSLS-II Storage Ring Concept

- A 3 GeV electron storage ring: with 30 Double Bend Achromatic Cells
- Emittance control by Damping Wigglers and large bend radius dipoles
- Large Circumference (791.5 m), H = 1320 with Dipole Bend Radius (25 m)
  - Sam Krinsky: Monday this conference



- Superconducting RF (500 MHz): 1/4 $\rightarrow$1 MW
- 15 long and 15 short straights with Hi-Lo β
  (11 of long straights for machine services)
- Damping Wigglers (21m) (full built-out: 56 m)
- Provision for IR Source
  (3 pairs of Wide Gap Dipoles)
- Three-pole wiggler x-ray sources

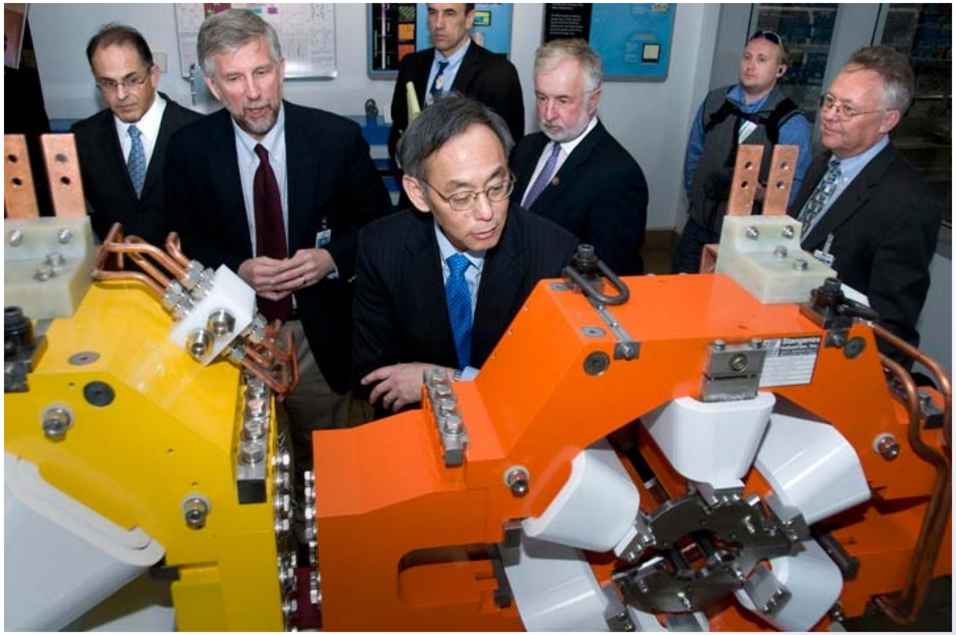
Technical Challenges

Lattice design: dynamic aperture, energy acceptance
Source stability: vibrations, thermal issues, fast feedback
Impedance budget: IR vacuum chambers, small gap (5 mm) ID tapers, etc
Insertion Device: DW, IVUs, EPUs, SCUs(?) and their impact to dynamics of beam

Note on the NSLS-2 Project

Construction Milestones

- Aug 2005: (**CD-0**) Approval
  DOE Mission Need
- Dec 2006: Conceptual Design
  Completed
- Jul 2007: (**CD-1**) Approval
  Alternative Selection
  and Cost Range
- Jan 2008: (**CD-2)** Approval
  Performance Baseline
- Jan 2009: (**CD-3)** Approval
  Start of Construction



  - Feb 2009 Contract Award for Ring Building
  - Feb 2012 Beneficial Occupancy of Ring Building
  - Oct 2013 Start Accelerator Commissioning
  - Jun 2014 Early Project Completion; Ring Available to Beamlines
- Jun 2015 (**CD-4**) Approval to Start of Operations

Acknowledgement

- I sincerely thank APS and its DPB for awarding me this prestigious Wilson Prize with recognition of what I have done for the Science Community and
- I appreciate having been given this opportunity to speak on the history of these projects I was involved in on two continents,
- Thanks to the Directors of KEK and BNL and their funding agencies for their trust in me and giving me the opportunity to lead the construction of their laboratories' major and critical research facilities for their science program
- What I discussed were achievements of team work. I would like to take this opportunity to thanks my colleagues and teams at respective Laboratories and the user communities whose hard work brought these projects to their success and outstanding scientific results
- Thank my wife, Yoko, for her steady support throughout these trying periods