40 Years at BNL in ~15 Minutes

Derek I. Lowenstein

Thank you to the committee for selecting me for this honor and inviting me to IPAC'16.

Special thanks go to my BNL colleagues, Thomas Roser and Bill Weng, and my long term friend Shin-ichi Kurokawa.

Without the support and hard work of very many (>1000) individuals, the successes at BNL would have not been possible.

A bittersweet moment for the inaugural ACFA/IPAC'16 Xie Jialin award. The passing of Prof. Xia Jialin marks a milestone in the history of accelerator physics and the relationship of PRC accelerator physicists with the rest of the world. Today we celebrate the inaugural Xia Jialin prize, as a recognition of his significant contributions. Unfortunately, he did not live to be with us today.

A brief summary of some physics and <u>accelerator</u> impacts.

Physics:

AGS

- 2 neutrinos
- CP violation
- **J**/Ψ
- μ g-2
- Rare kaon decays

RHIC

- Quark Gluon Plasma
- Gluon spin component of the proton

BNL and Xie Jialin

1979: T.D.Lee, Sam Ting and R.R.Rau worked to establish the joint cooperative agreement between the PRC and the US.

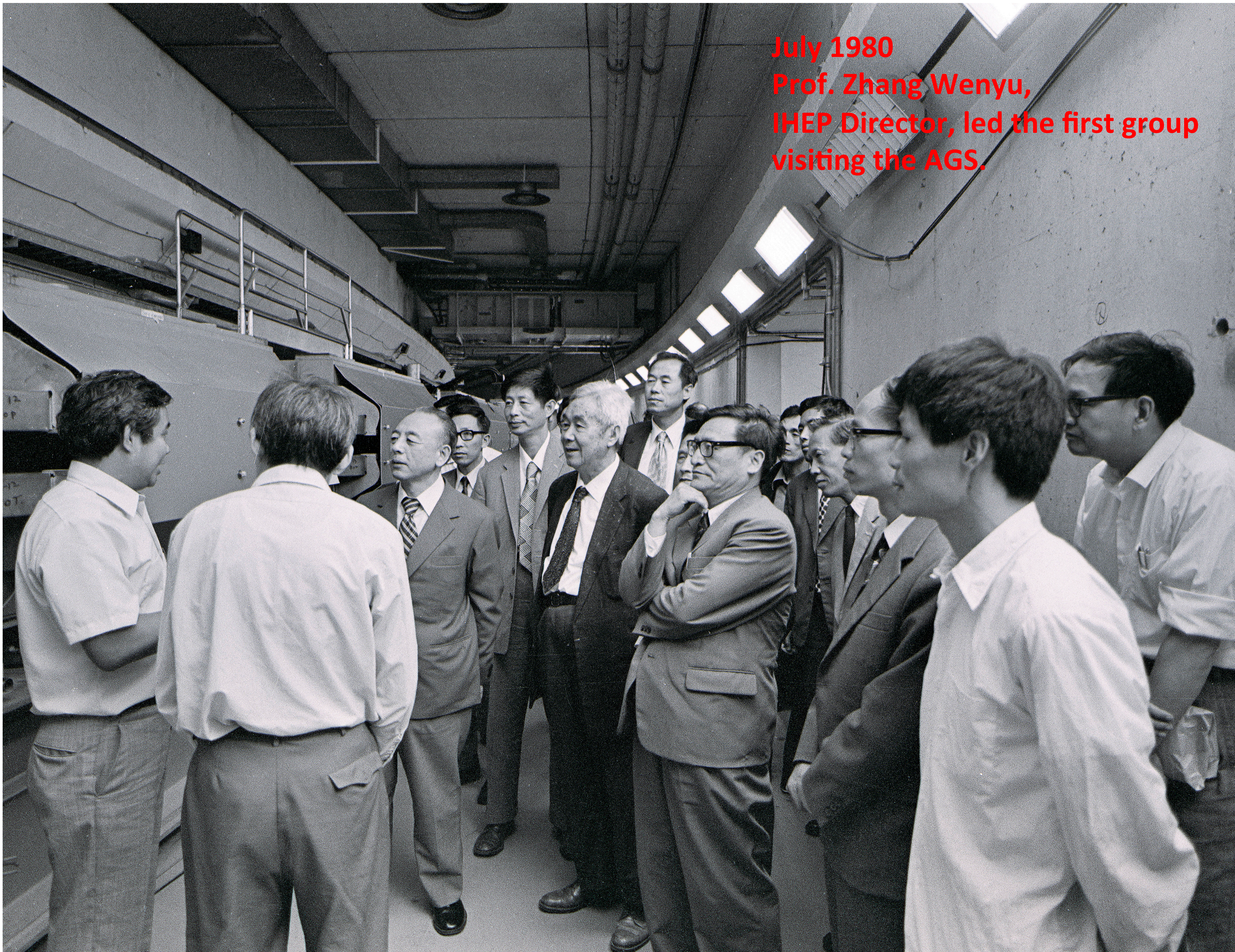
1980: Xie Jialin, Ye Minghan and many other scientists spent a year or more at the AGS to study the design and construction of proton synchrotrons.

Ultimately the PRC priority changed and protons gave way to the construction of a lepton collider, BEPC.

In subsequent years the US/PRC collaboration expanded to include:

AGS: Heavy ions

RHIC: STAR detector



July 1980
Prof. Zhang Wenyu,
IHEP Director, led the first group
visiting the AGS.

Quick tour of some accelerator highlights at BNL

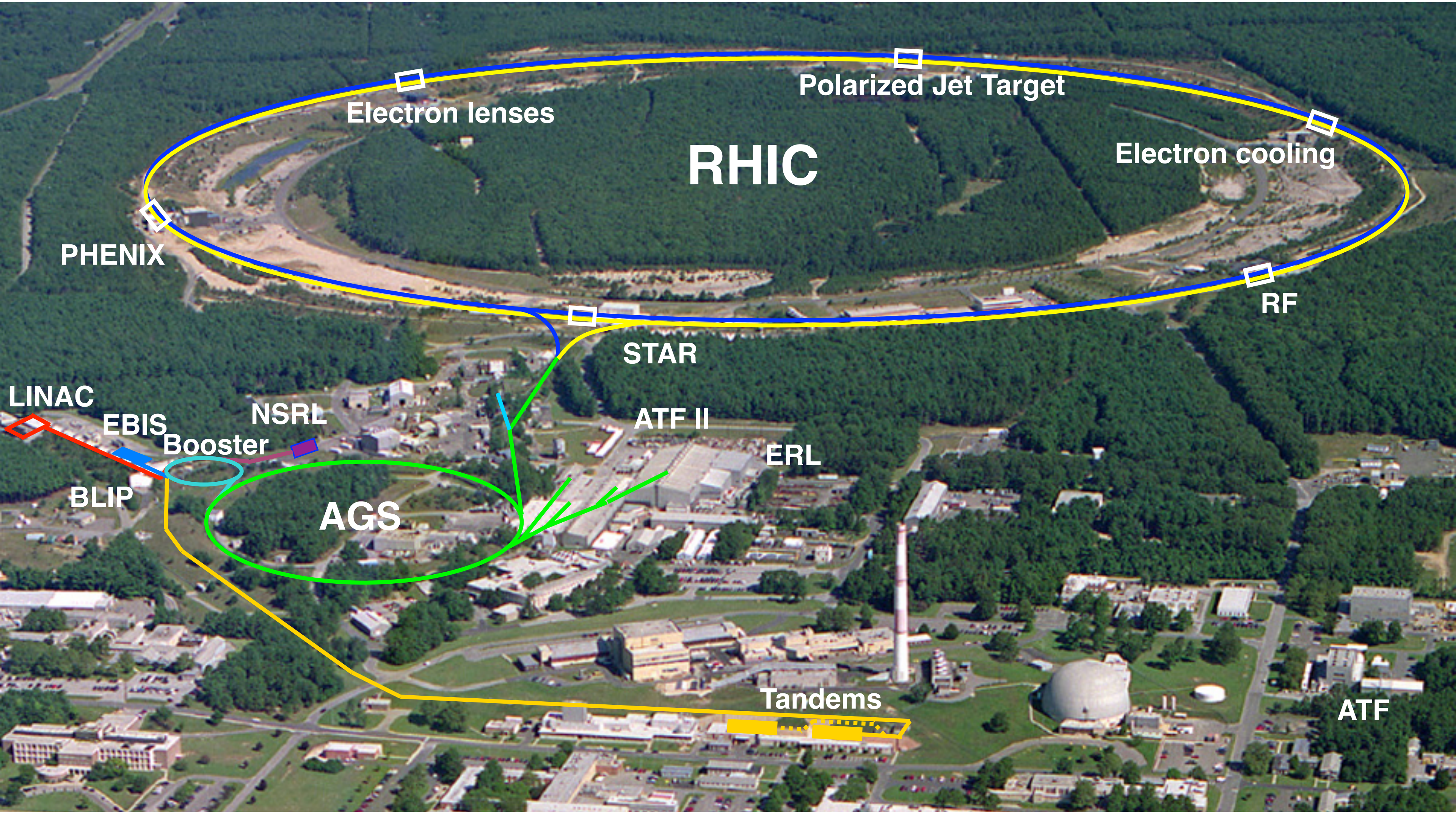
AGS

RHIC

NSRL

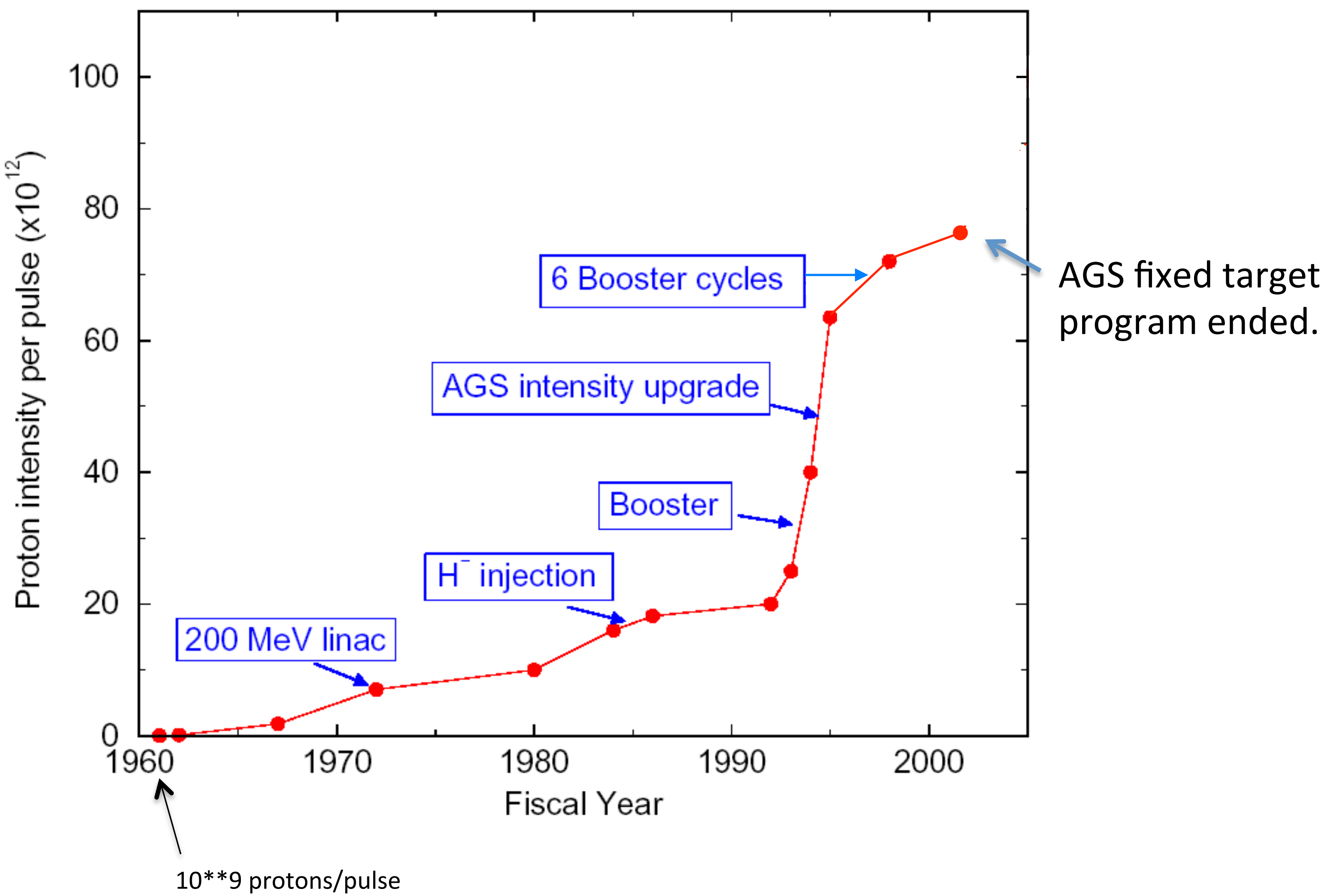
Future (eRHIC)

The RHIC/AGS/NSRL Accelerator Complex Today

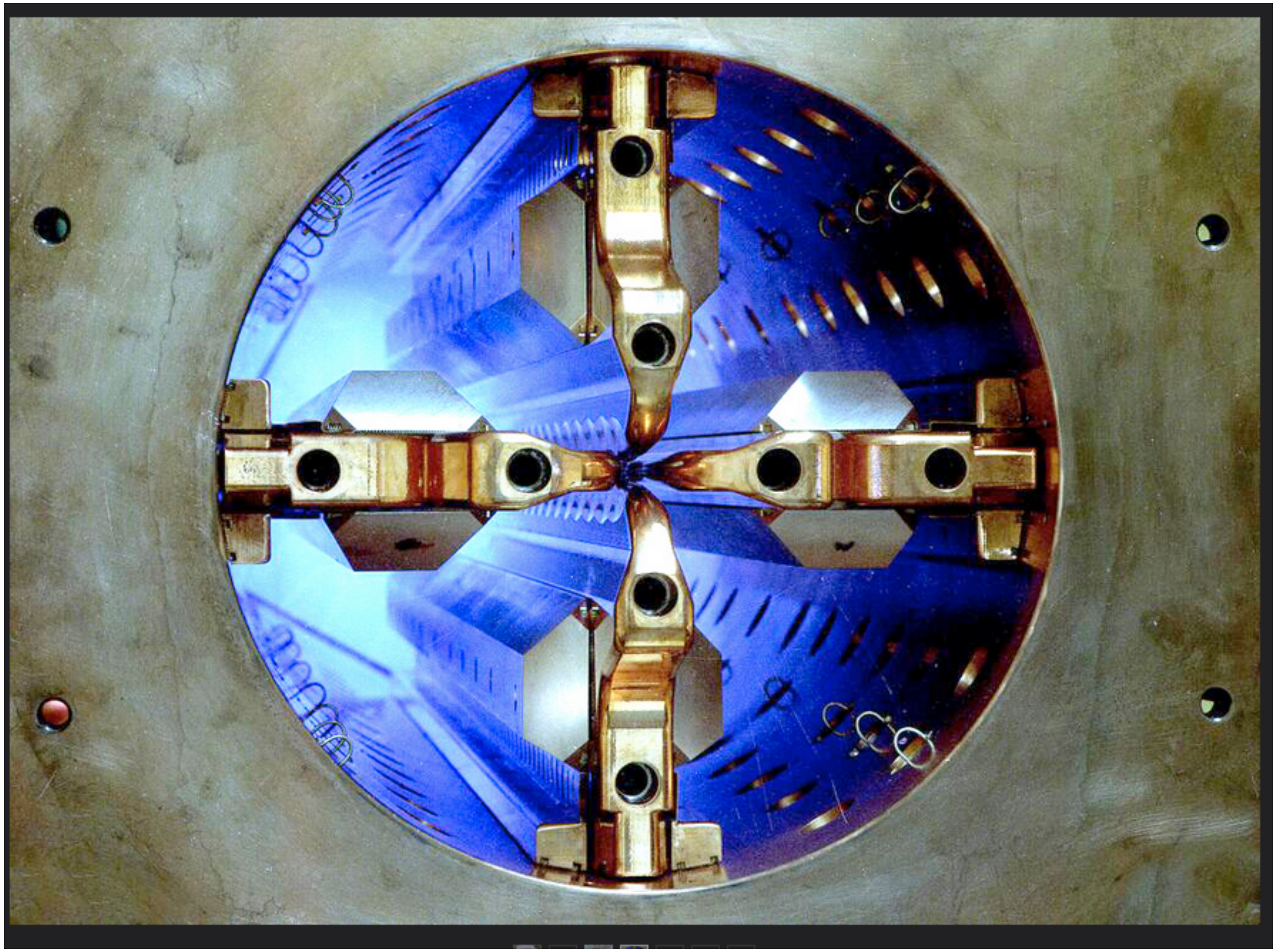


- Highly flexible and only US Collider
- Injectors also provide beams for unique applications

AGS Proton Intensity History



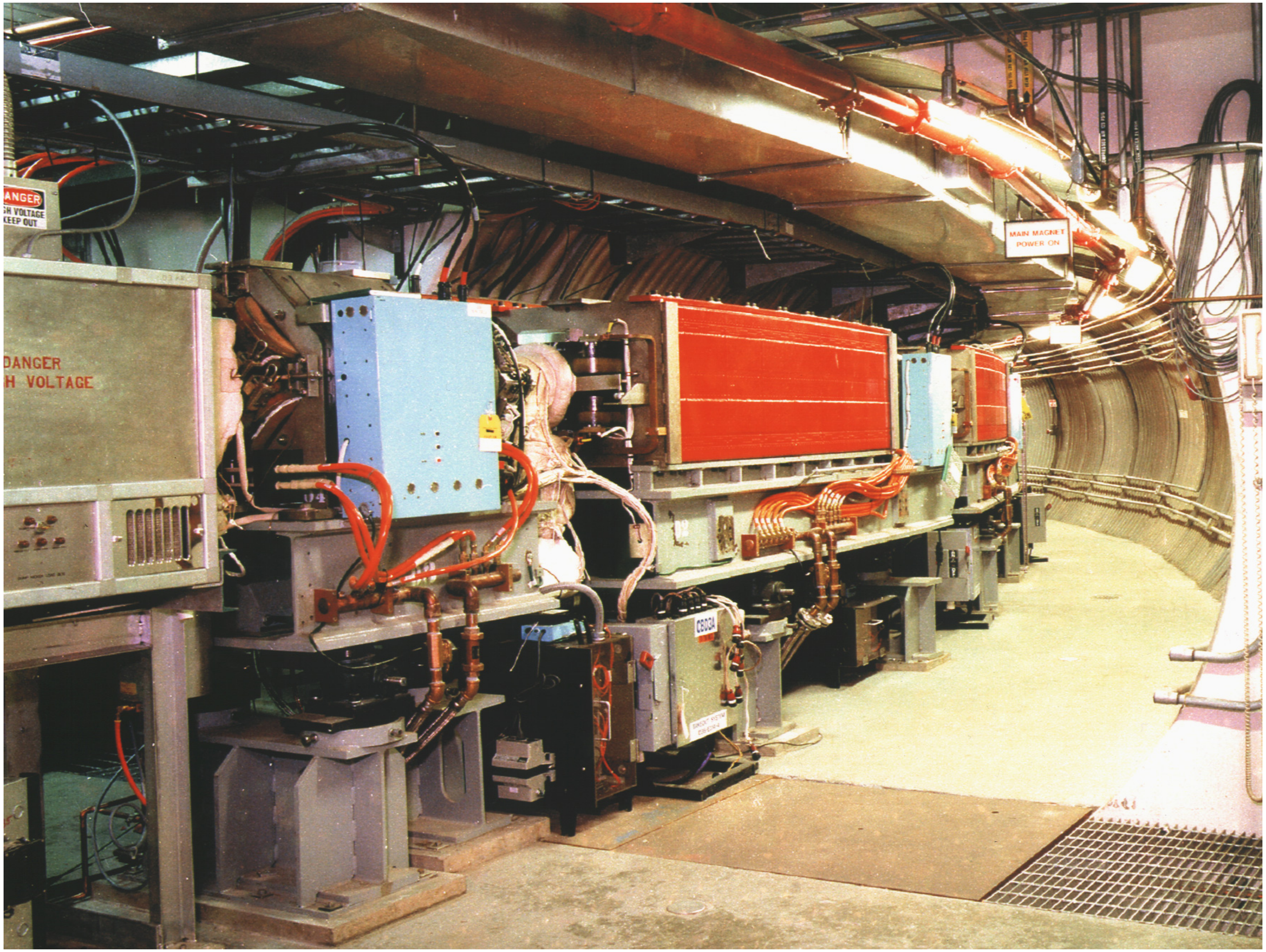
RFQ linac (circa 1983)



First RFQ used for particle physics operations.

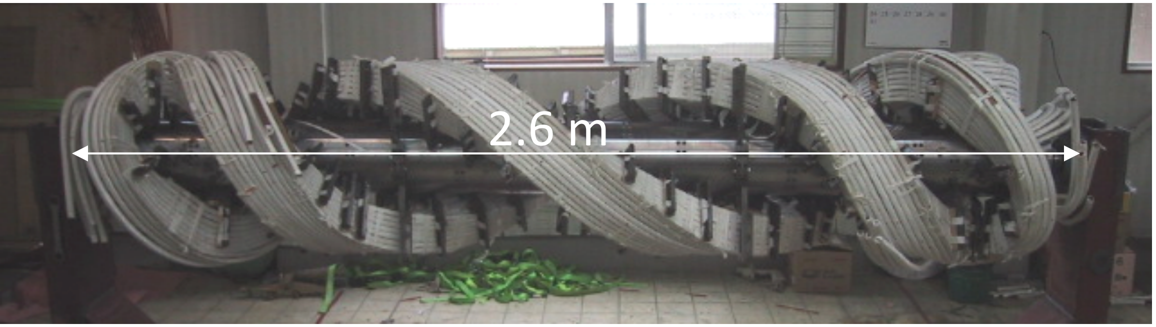
Increased proton intensity & injection of ion species up to U.

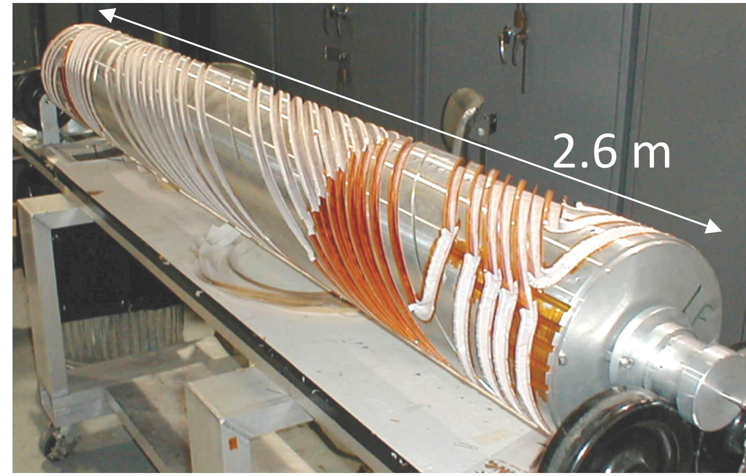
Booster Synchrotron (1993)

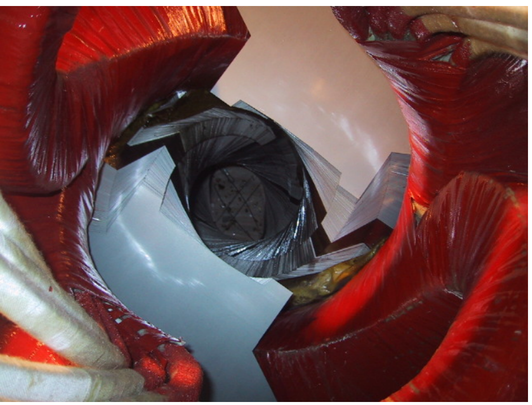


Siberian Snakes (AGS & RHIC)

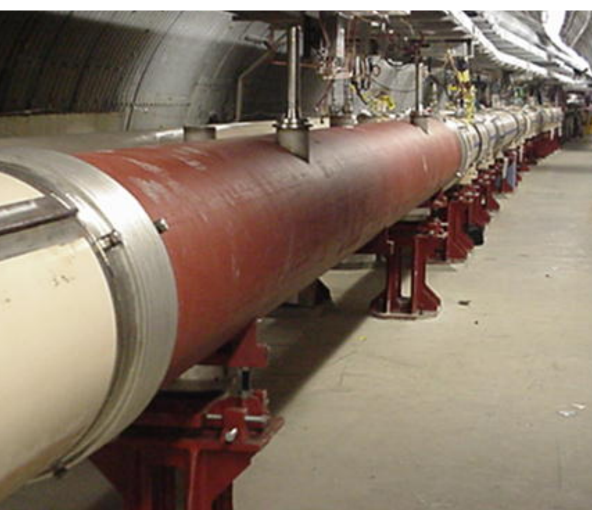
Provided polarized proton acceleration to 100 GeV/n

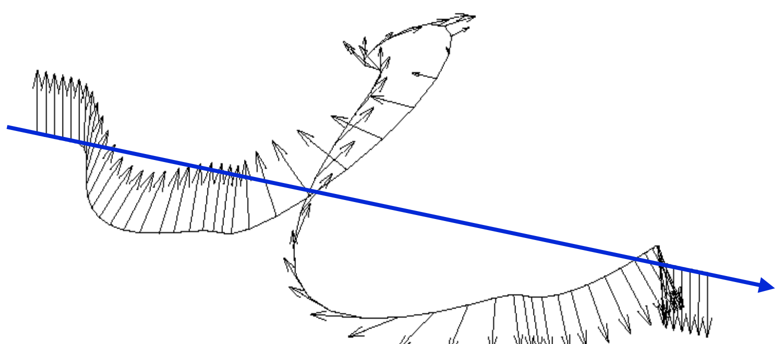


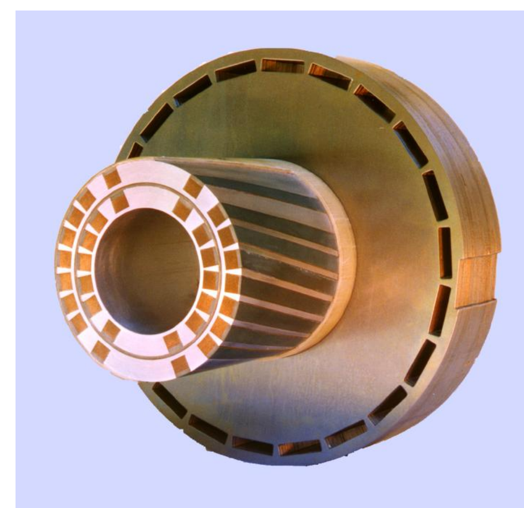




- AGS Siberian Snakes: variable twist helical dipoles, 1.5 T (RT) and 3 T (SC), 2.6 m long
- RHIC Siberian Snakes: 4 SC helical dipoles, 4 T, each 2.4 m long and full 360° twist

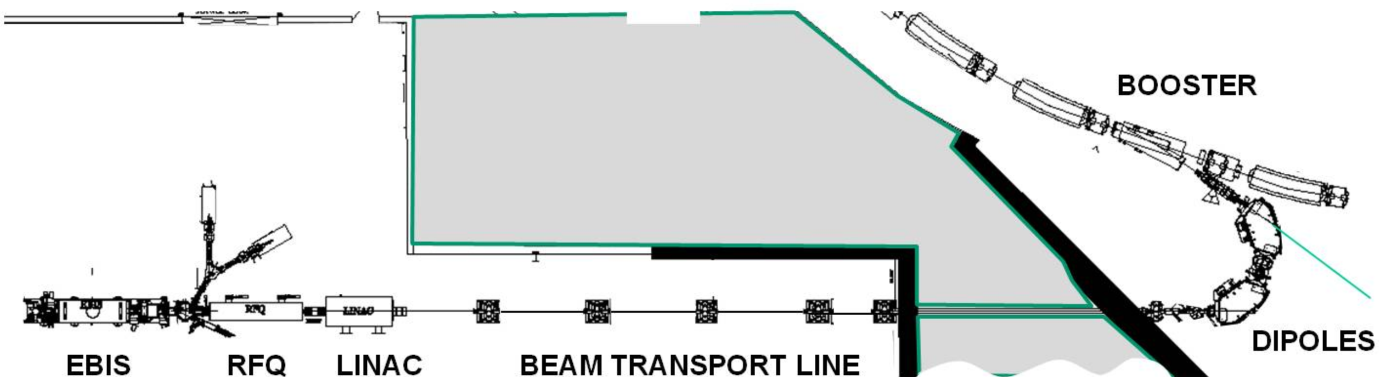


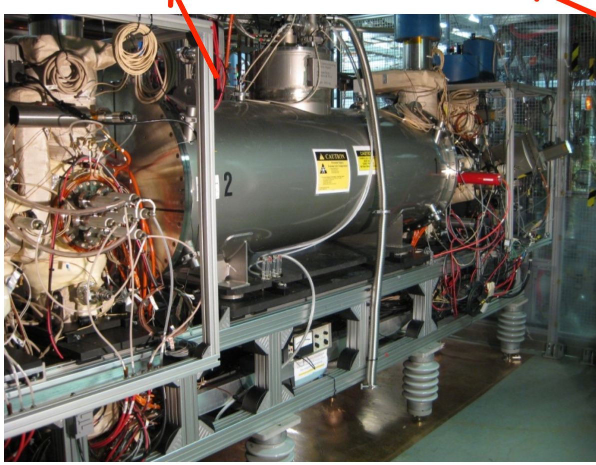


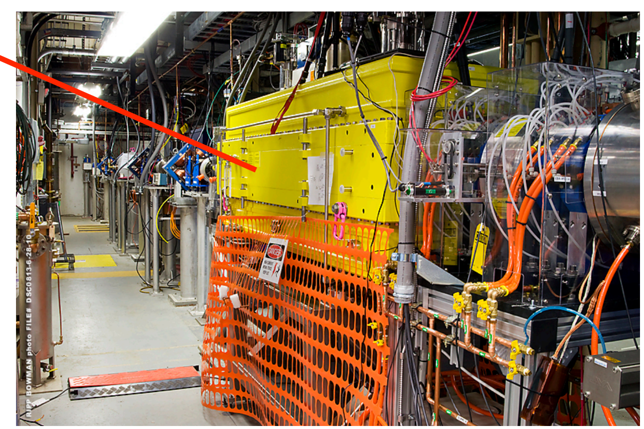


Electron Beam Ion Source (EBIS) (2010)

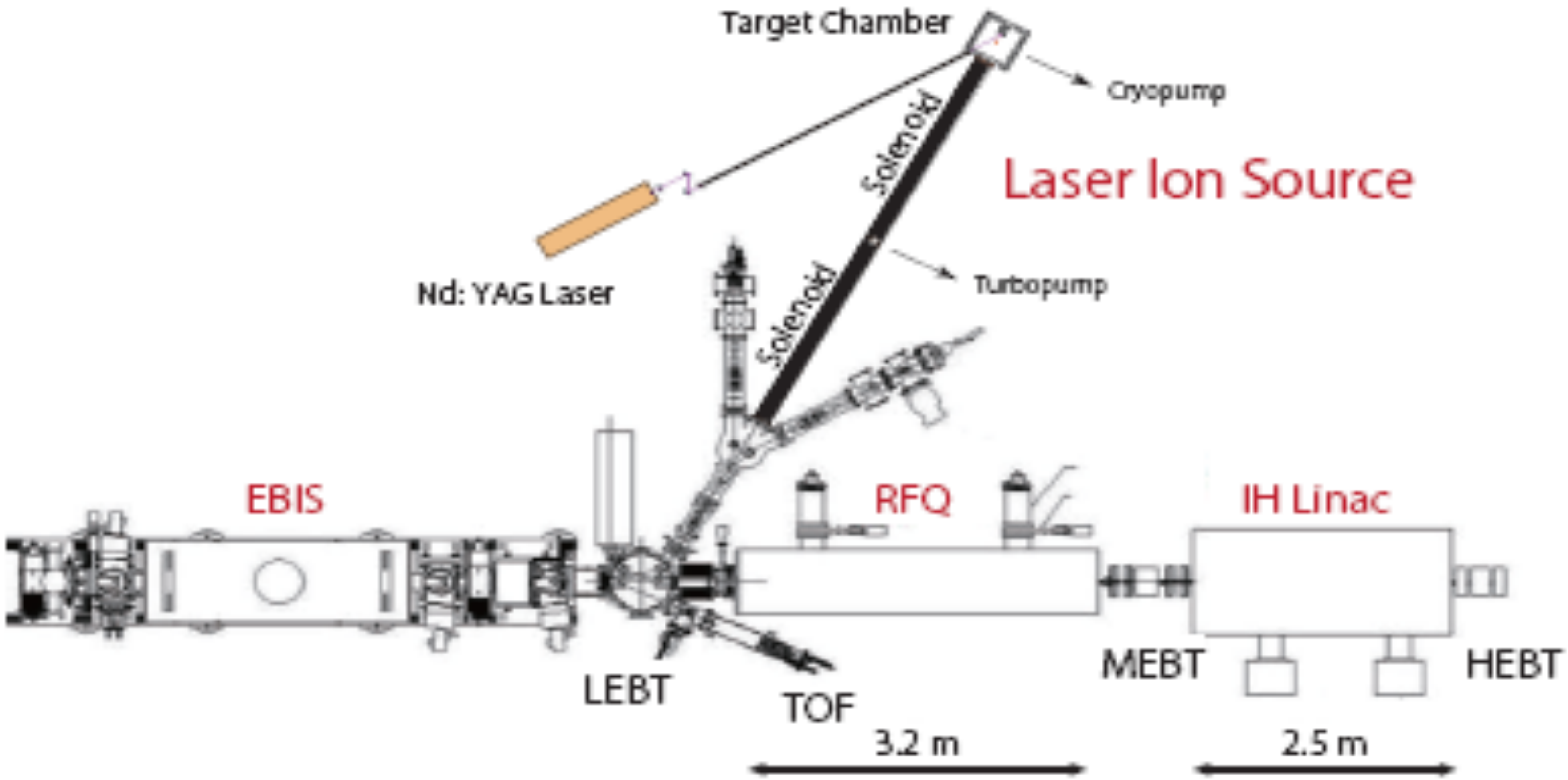
- Can produce *any* ion species for RHIC and NSRL
- Fast switching between species (pulse-to-pulse)
- No stripping needed before the Booster, resulting in more stable beams
- Simple, modern, low maintenance, lower operating cost







Laser Ion Source (LIS) - allows fast pulse to pulse switching between a large number of ion species (2011)

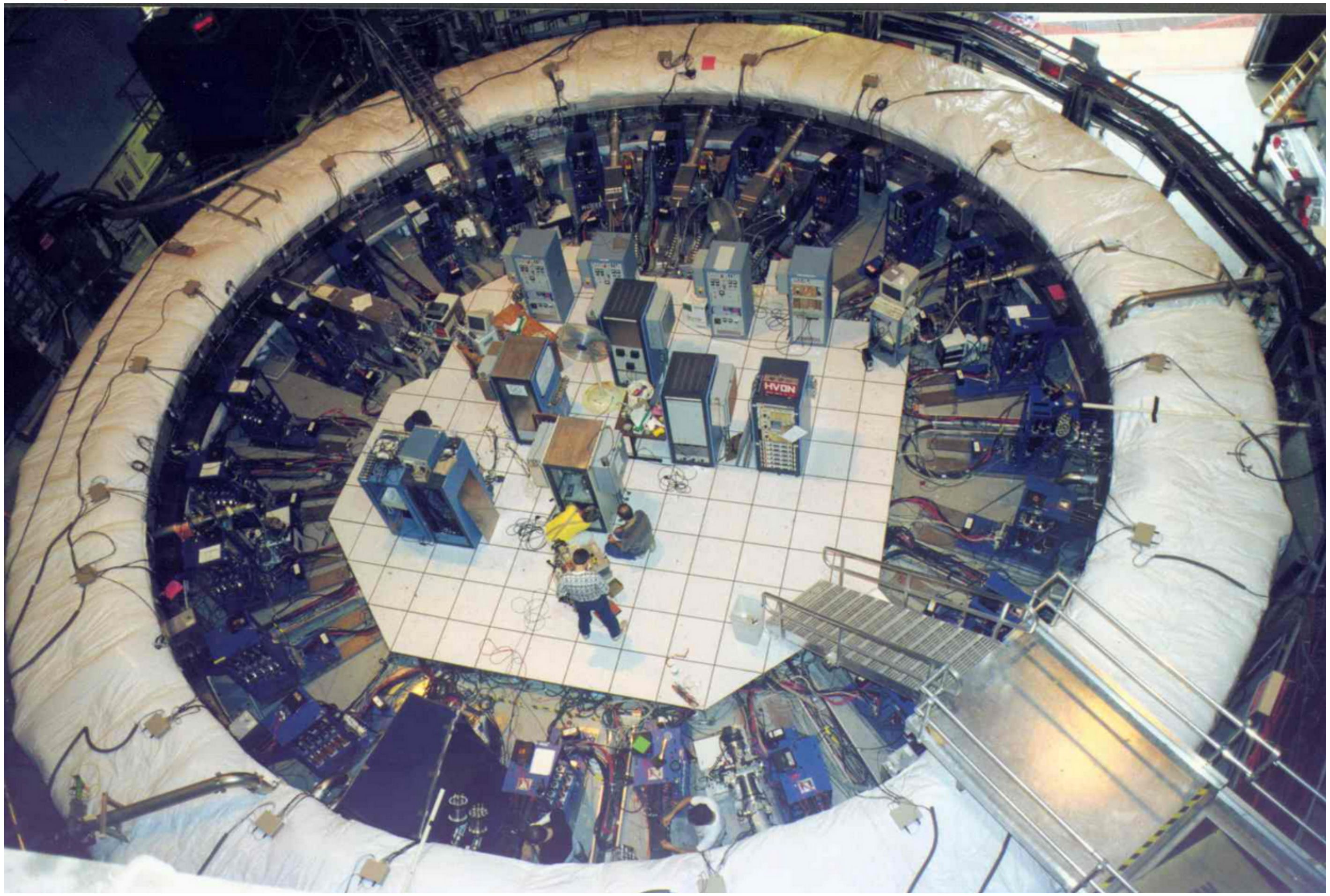


E821 Muon g-2 Storage Ring

(now at Fermilab)

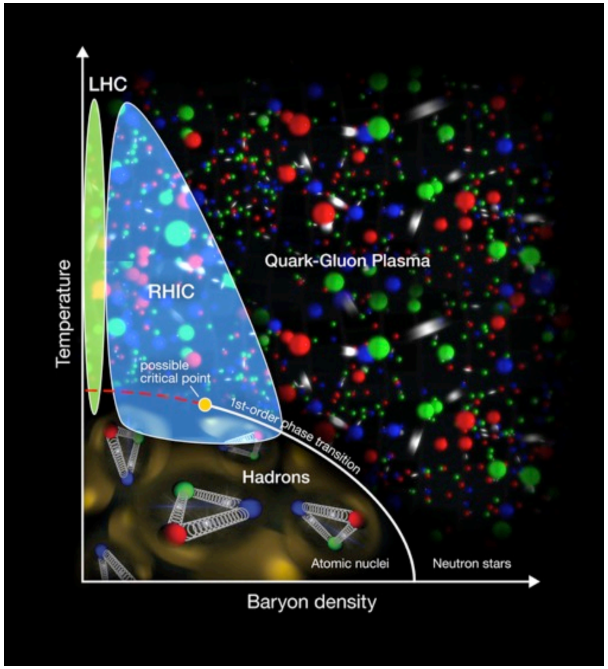
Best μ g-2 measurement to date. $a_\mu = 116\ 592\ 089\ (63) \times 10^{-11}$ – a precision of 0.54 ppm. 3-4 σ

1.45 T dipole field , 44.7 m circumference

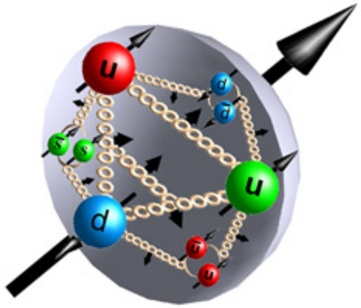


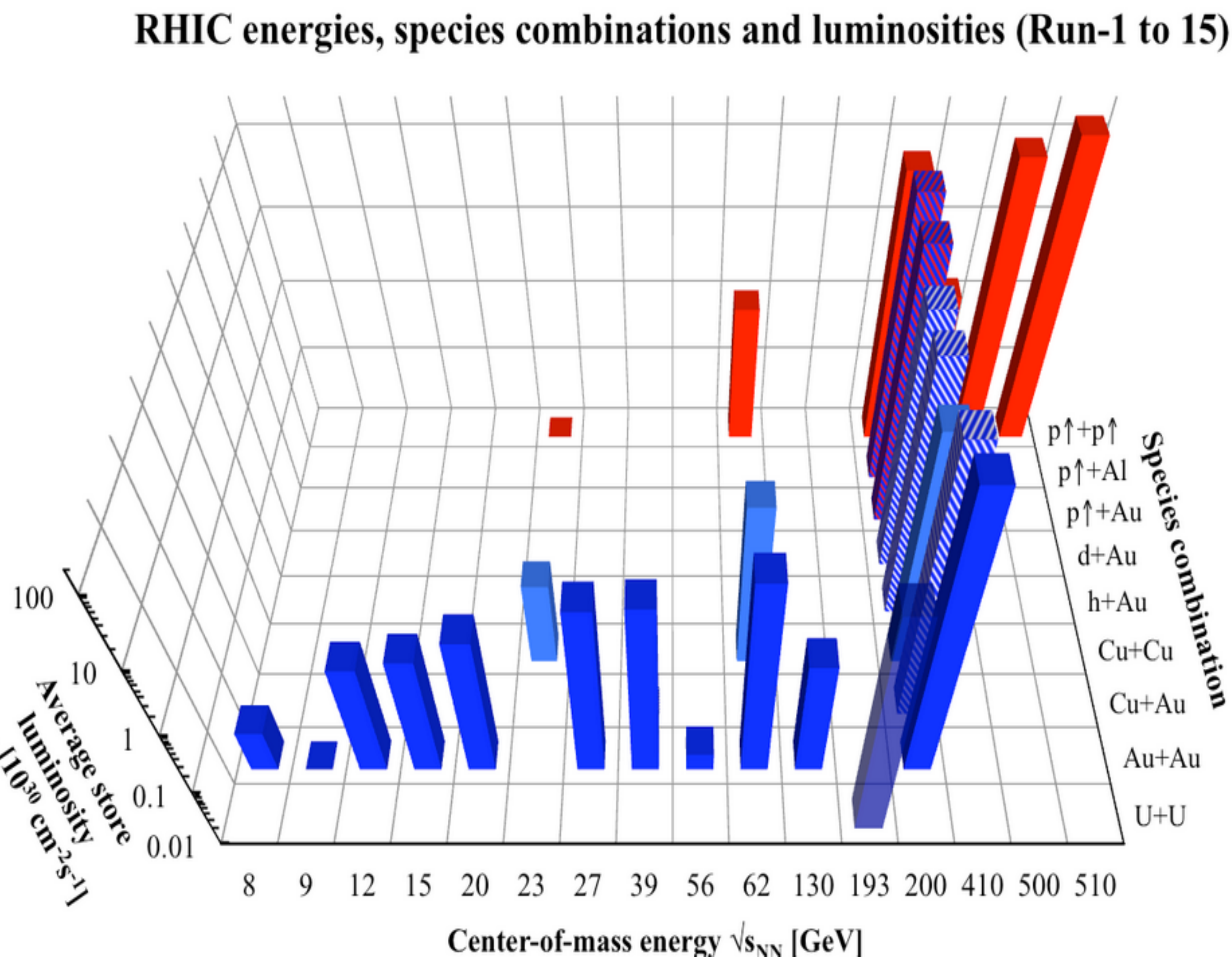
RHIC – a Unique Research Tool

Discovered the quark-gluon plasma state of matter.
Measuring the gluon spin component of the proton.



- Heavy ion program
  - Energy range ($\sqrt{s_{NN}}$ = 7 – 200 GeV) spans transition energy to Quark Gluon Plasma
  - Highest luminosities (collision rates)
  - Unparalleled flexibility:
    9 species (p↑+p↑, p↑+Au, p↑+Al, d+Au, Cu+Cu, Cu+Au, Au+Au, U+U, ^{3}He+Au),
    ~ 15 different c.o.m. energies to date
- Polarized proton program
  - Only collider of spin polarized protons, P ~ 60%




RHIC energies, species combinations and luminosities (Run-1 to 15)
Average store luminosity L_{NN} [10^{30} cm^{-2}s^{-1}]
100
10
1
0.1
0.01
8
9
12
15
20
23
27
39
56
62
130
193
200
410
500
510
Center-of-mass energy $\sqrt{s_{NN}}$ [GeV]
Species combination
p↑+p↑
p↑+Al
p↑+Au
d+Au
h+Au
Cu+Cu
Cu+Au
Au+Au
U+U

Major RHIC Luminosity Upgrades

- Electron Beam Ion Source
(higher Au intensity, U, ^{3}He↑)

- 3-D stochastic cooling
(~ 4 x Au-Au luminosity)

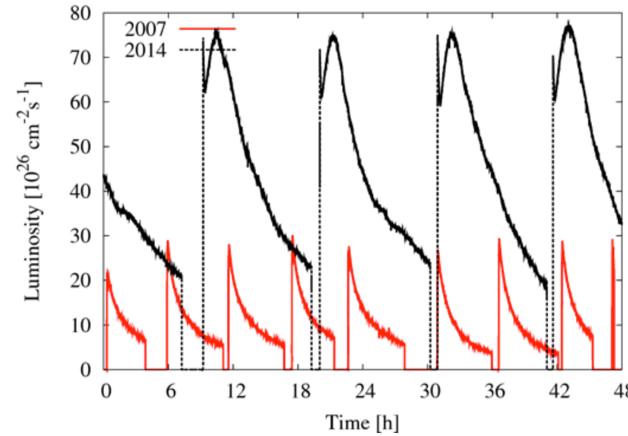
- High-intensity polarized proton source
(~10 x p↑ intensity)

- 56 MHz SRF cavity for short luminous region
(~ 1.5 x Au-Au luminosity)

- Beam-beam compensation with electron lenses.
(~ 2 x p↑ - p↑ luminosity)

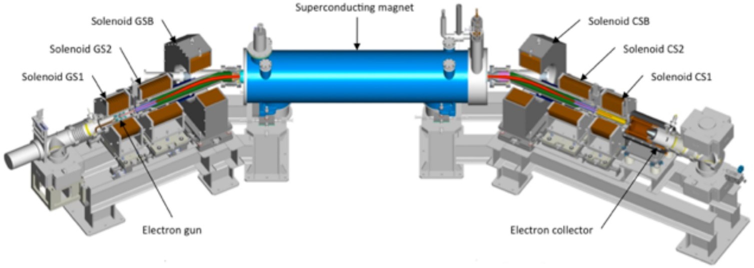
- Low Energy RHIC electron Cooling (LEReC)
(4 – 10 x Au-Au luminosity for
√s < 20 GeV/n-pair)

Au-Au luminosity with 3-D cooling



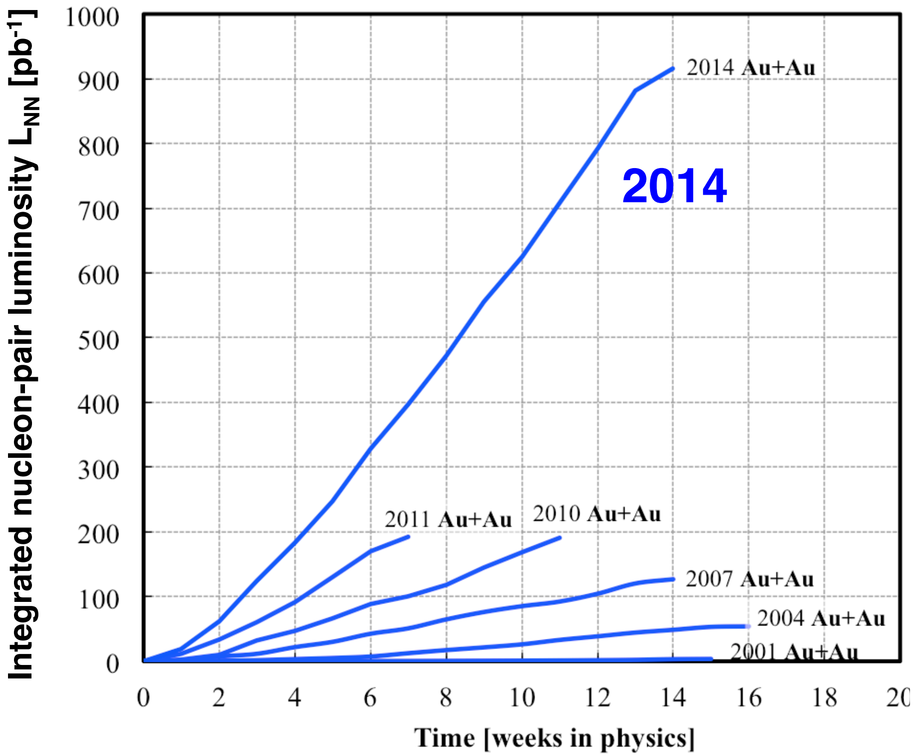
56 MHz quarter wave SRF cavity

Electron lens

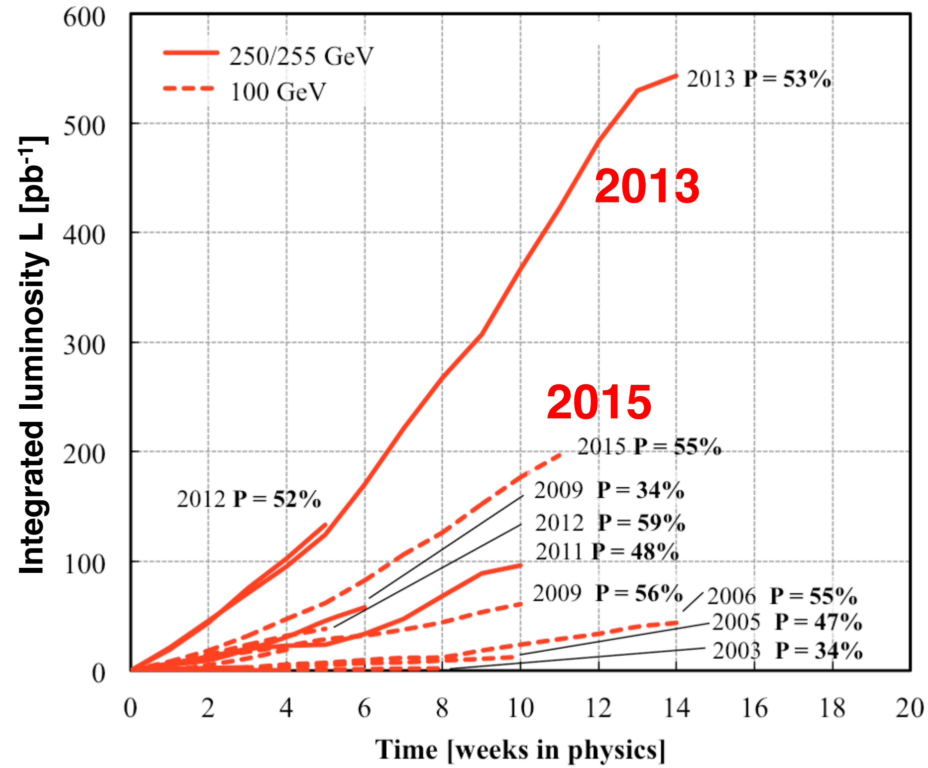


RHIC Integrated Luminosity and Polarization

Au + Au runs

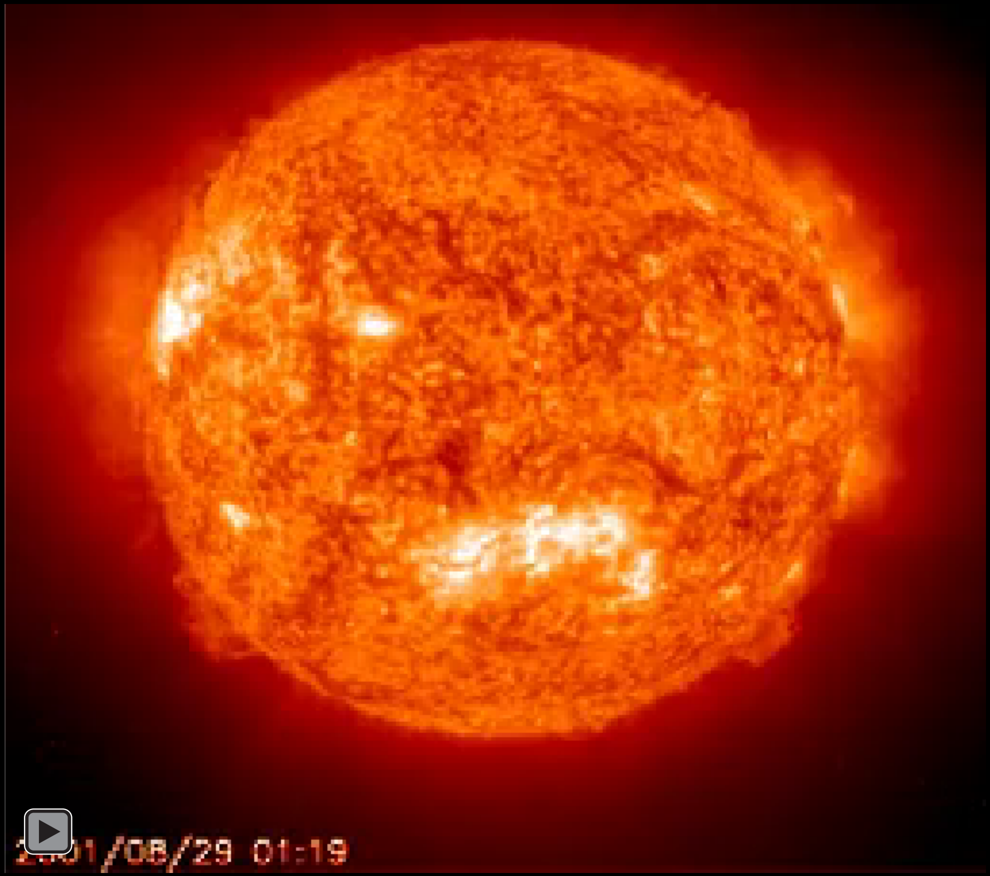


Polarized proton runs



- Dramatic increase of RHIC performance as a result of R&D, capital projects, Accelerator Improvement Projects, and replacement of obsolete technology
- Consistently high facility availability (FY12: 85%; FY13: 84%; FY14: 87%; FY15: 88%) and calendar time-in-store (physics) of over 60% (~100 hours per week)

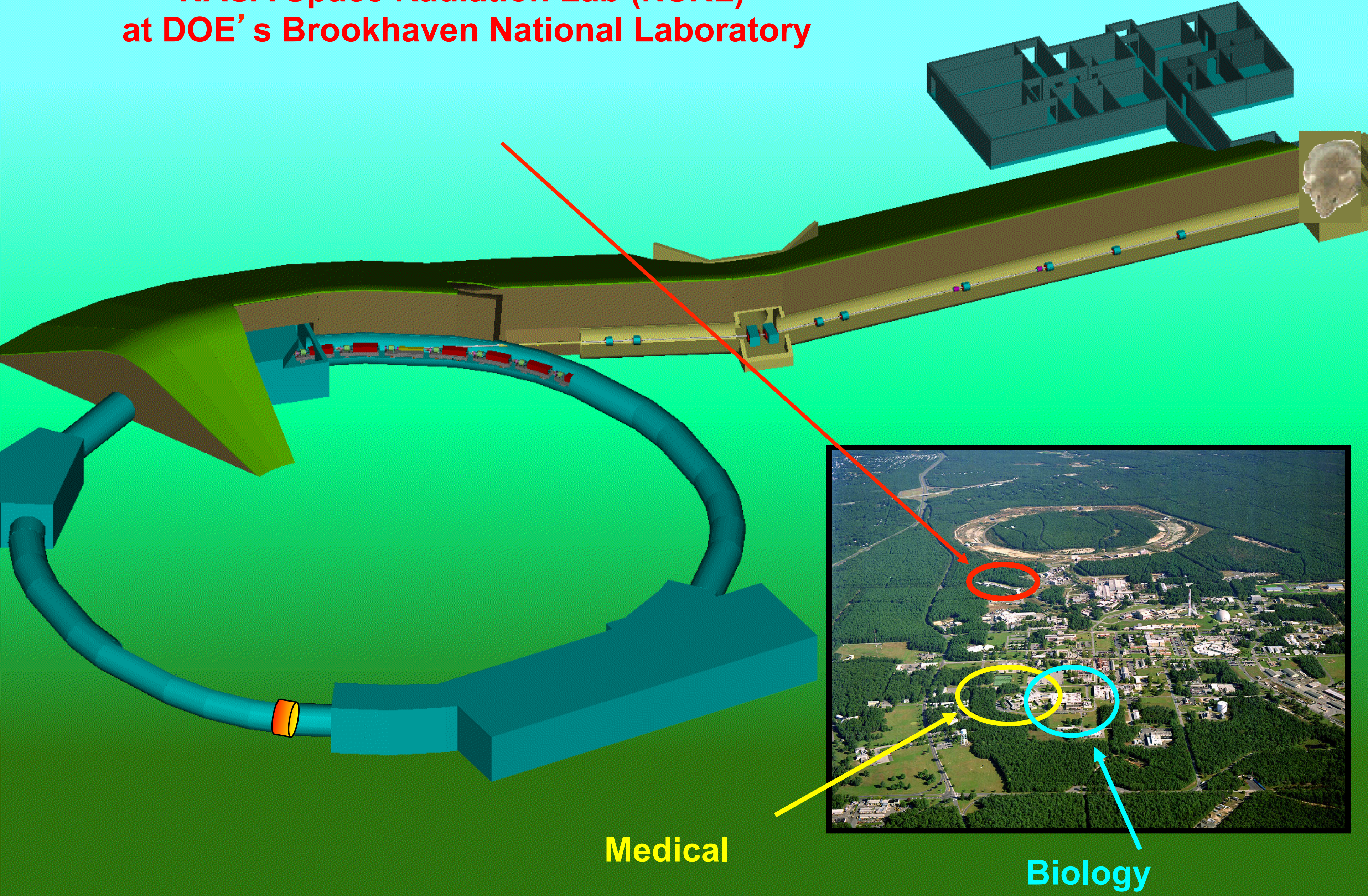
THE SPACE RADIATION ENVIRONMENT SIMULATED AT THE NASA SPACE RADIATION LABORATORY



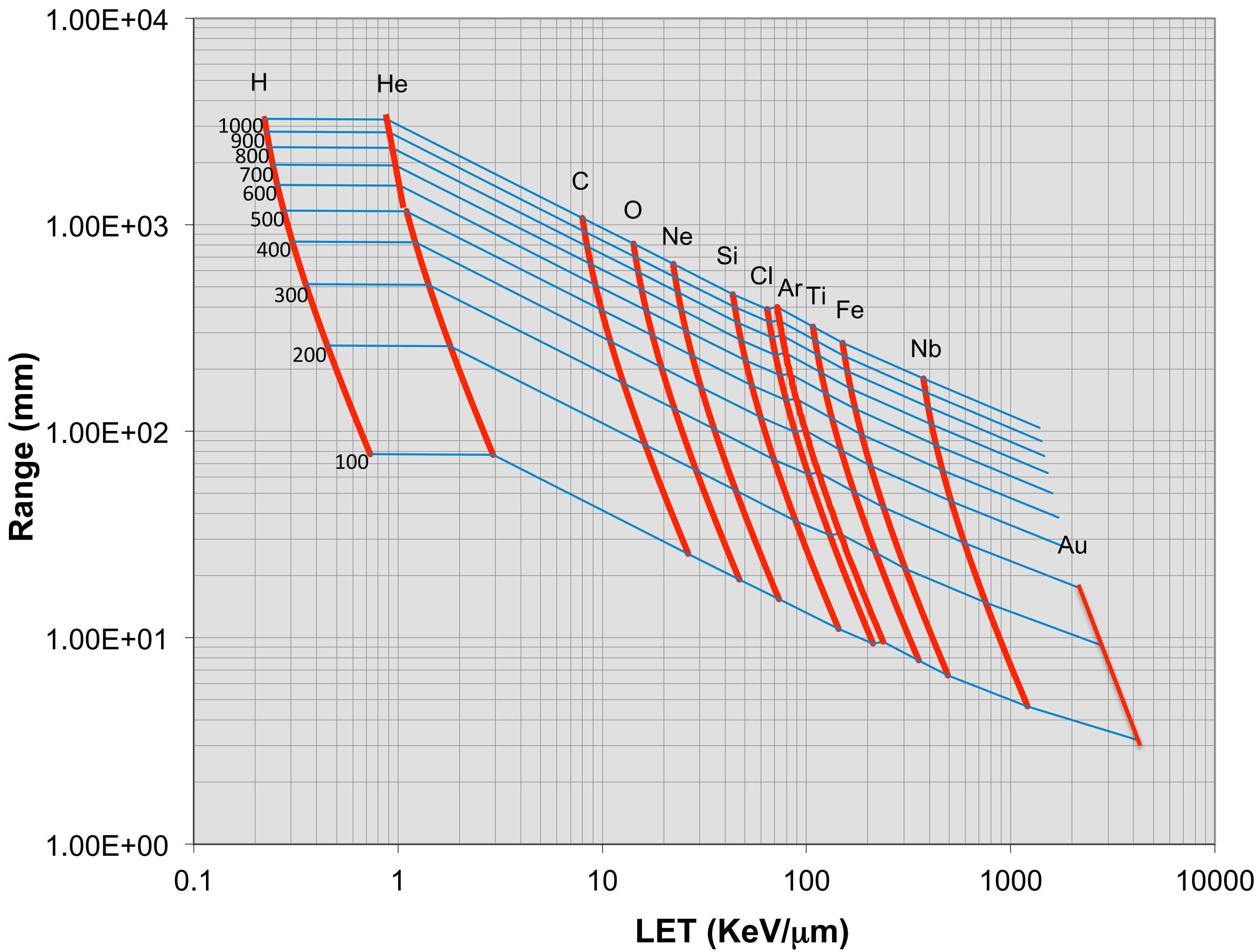
Why does NASA support an accelerator facility?

- There are two major questions that require study.
  - What are the radiation risks for extended space travel?
  - Can the risks be mitigated?

NASA Space Radiation Lab (NSRL) at DOE's Brookhaven National Laboratory



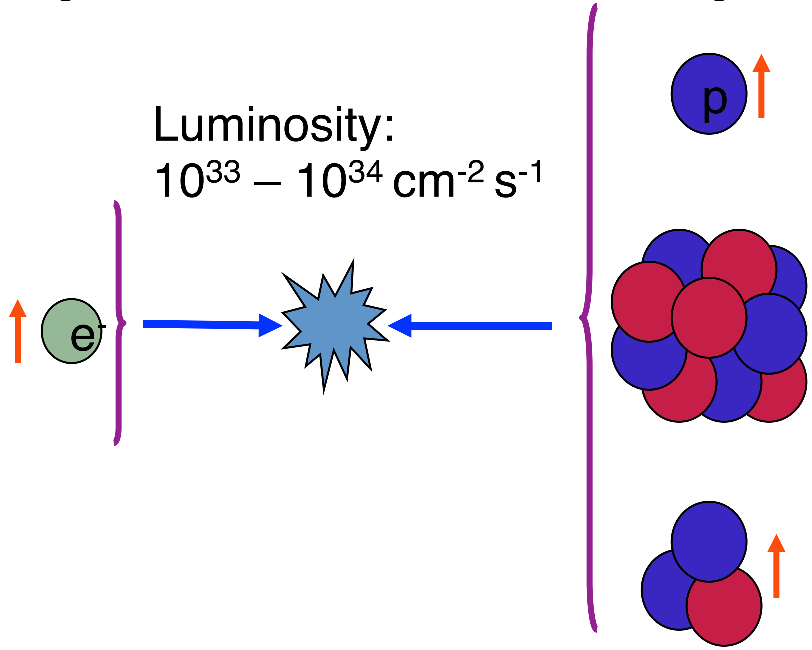
Range vs. LET for Kinetic Energy



eRHIC: Electron Ion Collider at BNL

Add an electron accelerator to the existing $2.5B RHIC
including existing RHIC tunnel, detector buildings and cryo facility

80% polarized electrons:
1.3 – 21.2 GeV

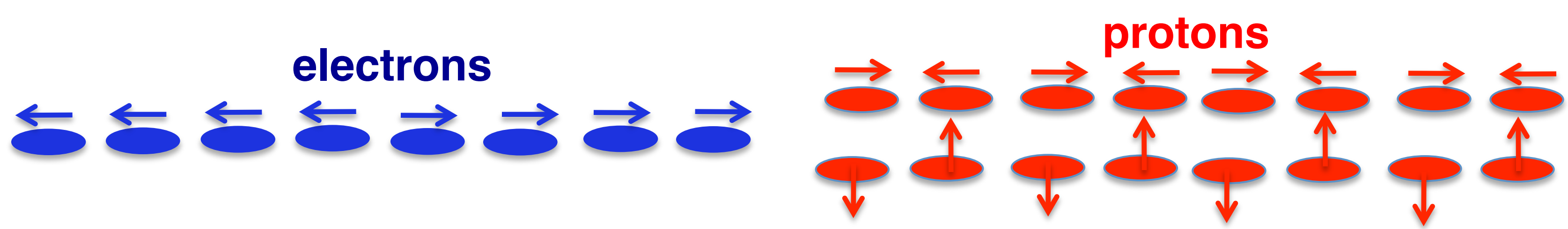


70% polarized protons
25 - 250 (275*) GeV

Light ions (d, Si, Cu)
Heavy ions (Au, U)
10 - 100 (110*) GeV/u

Pol. light ions (He-3)
17 - 167 (184*) GeV/u

- Center-of-mass energy range: 20 – 145 GeV
- Full electron polarization at all energies
  Full proton and He-3 polarization with six Siberian snakes
- Any polarization direction in electron-hadron collisions:



* It is possible to increase RHIC ring energy by 10%

THANK YOU