Measuring Proton Beam Polarization at Relativistic Heavy Ion Collider (RHIC)

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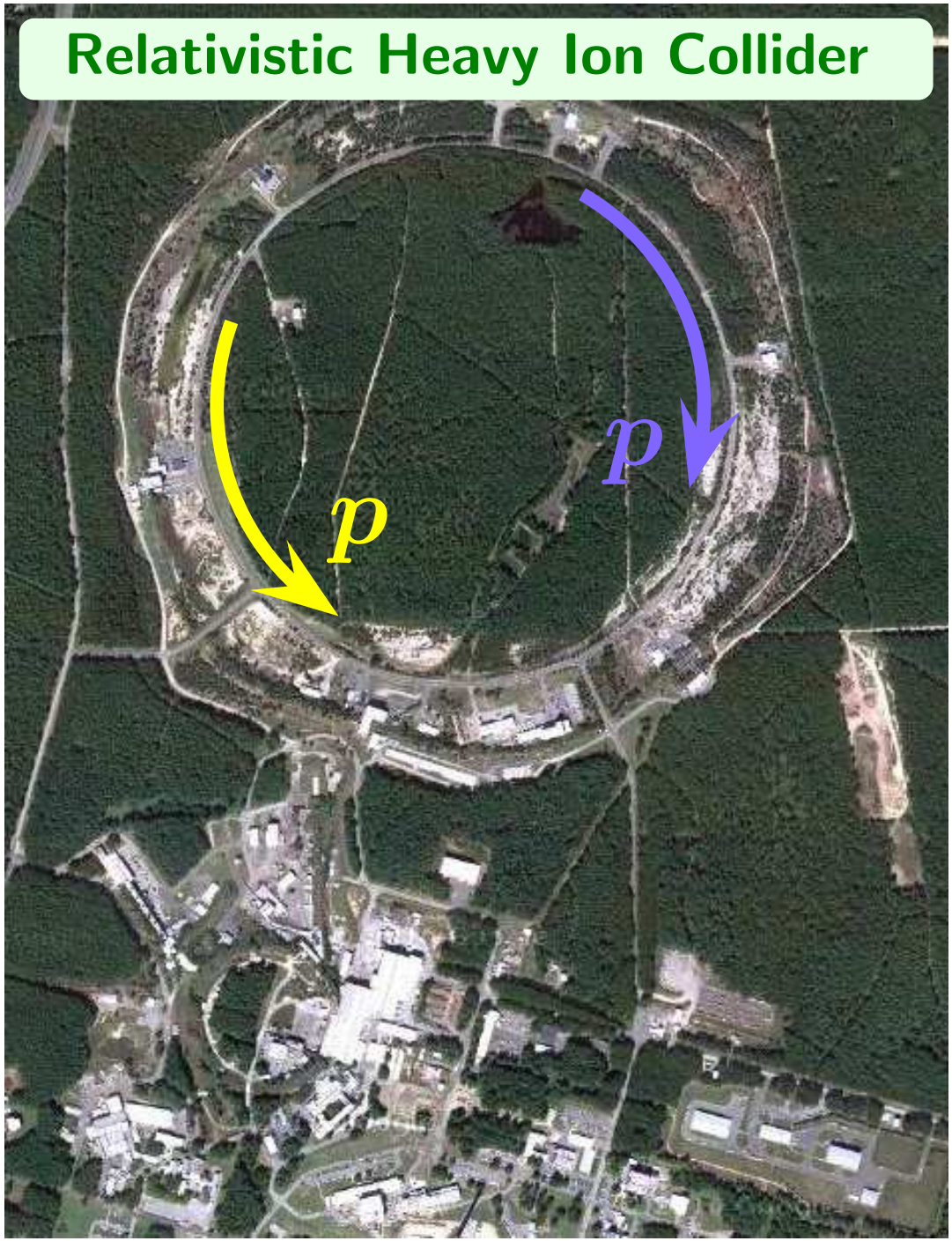
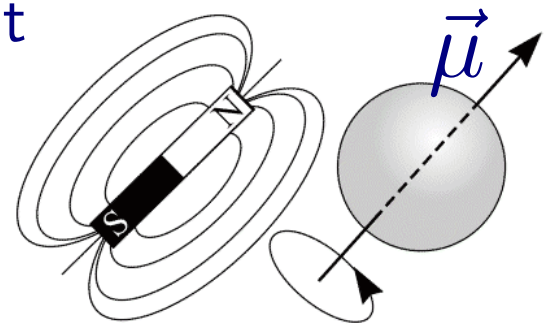
What Is RHIC?



- **RHIC is the largest scientific tool at BNL**
  - Ring diameter is ≈ 0.75 miles
  - Accelerates subatomic particles **protons, deuterons, Si, Cu, Au, U** to nearly the speed of light
  - Collides particles head-on at two interaction points
- **RHIC is the first and only world's polarized collider**
  - In operation since 2000
  - Improving performance from year to year

Polarized Protons

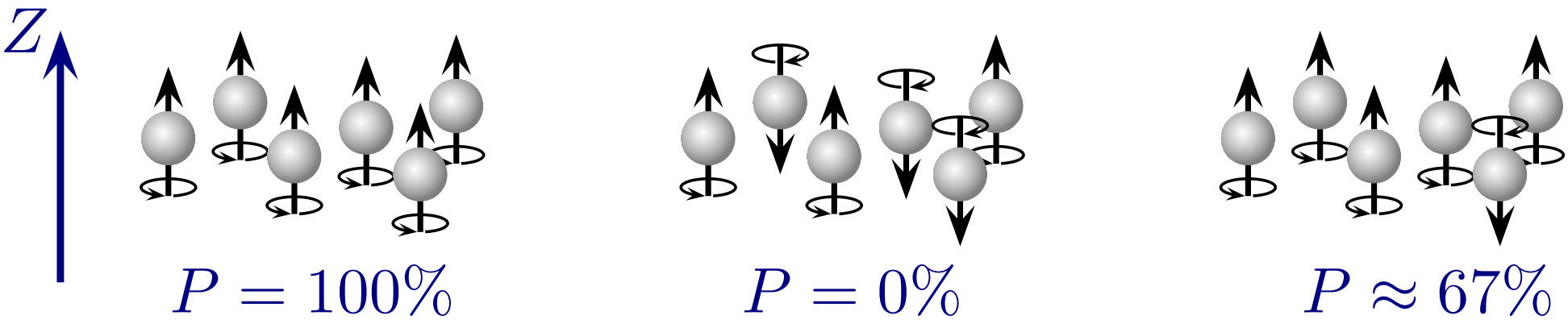
- Electrically charged particles possess a magnetic moment



$$\vec{\mu} \propto \frac{q}{m}\vec{s}$$

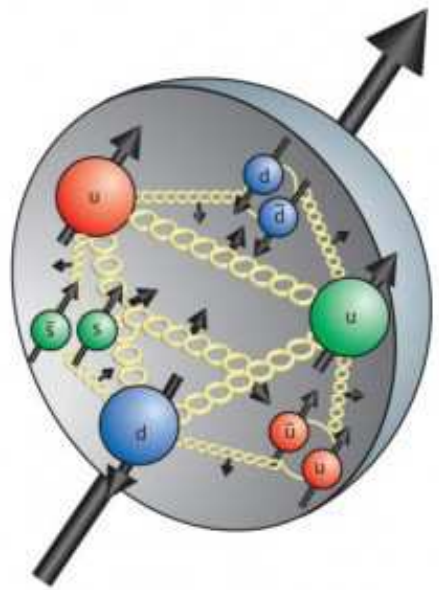
  - In classical mechanics particle simply spins around its center of mass
  - In quantum mechanics **spin is a truly intrinsic property of particle**
- Spin can have only two orientations in space: "up" and "down" along Z
- Polarization P is a fraction of particles contributing to total momentum

$$P = \frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\downarrow}$$



What Do We Study with Polarized Protons at RHIC?

- Proton is a composite particle made of **quarks and gluons**
  - At low interaction energies proton is a point-like particle
  - At high RHIC energies we see the internal structure of the protons

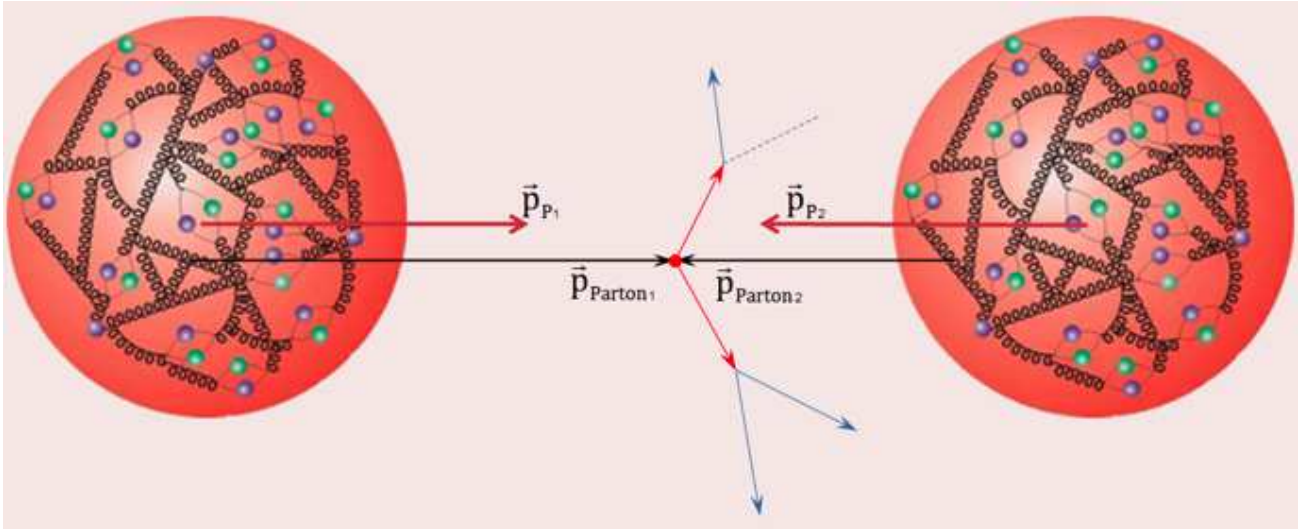


- Total proton spin is the sum of the spins and orbital angular momenta of the constituents: **quarks and gluons**

$$\underbrace{S_p = \frac{1}{2}}_{\text{proton spin}} = \underbrace{\langle S_q \rangle}_{\substack{\text{quark spin} \\ \sim 30\%}} + \underbrace{\langle S_g \rangle}_{\substack{\text{gluon spin} \\ \sim 20\%}} + \underbrace{\langle L_{q,g} \rangle}_{\substack{\text{orbital momentum} \\ ?}}$$

Extracting Knowledge from Asymmetry Measurement

- Due to spin the product of proton collisions can have spacial asymmetry w.r.t. the spin direction

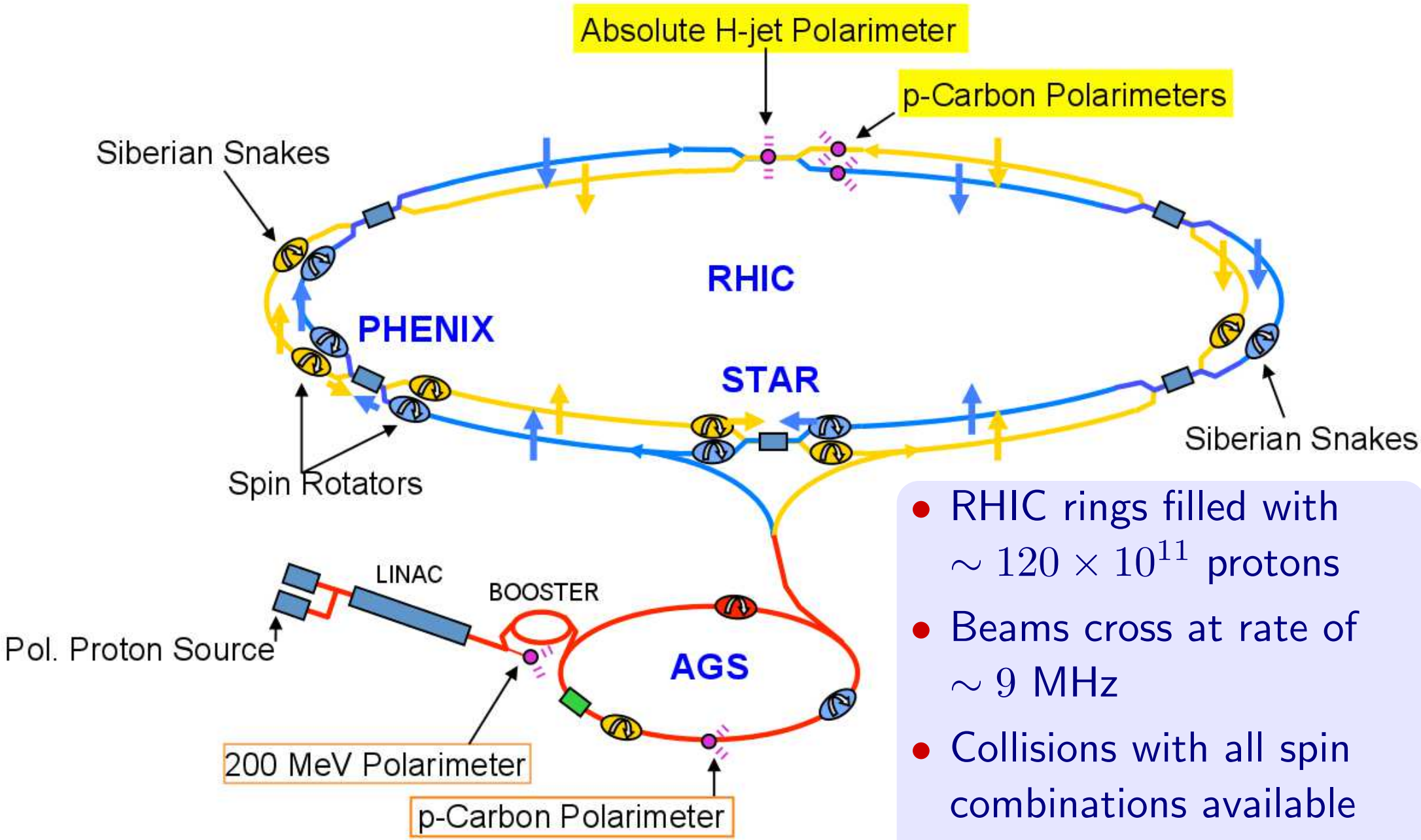


- The knowledge about the internal proton structure is extracted from the measured asymmetry:

$$\underbrace{A = \frac{1}{P} \times \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}}_{\text{single spin asymmetry}} \qquad \underbrace{\mathbb{A} = \frac{1}{P^2} \times \frac{N^{\uparrow\uparrow} - N^{\uparrow\downarrow}}{N^{\uparrow\uparrow} + N^{\uparrow\downarrow}}}_{\text{double spin asymmetry}}$$

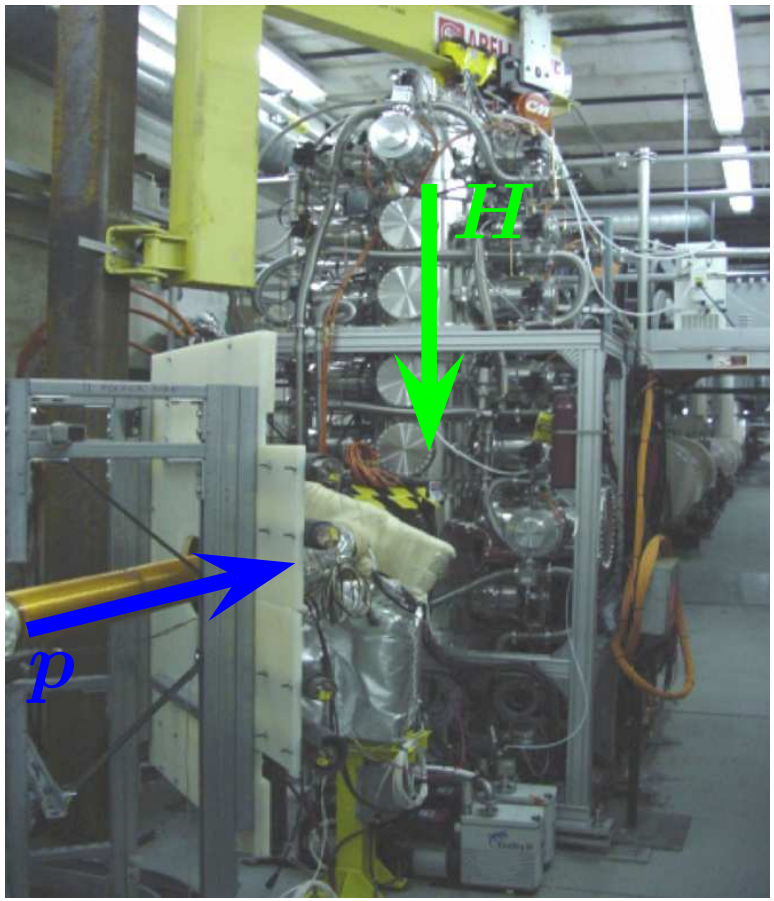
- We must know the spin direction of colliding protons (only at RHIC!)
- **Precise knowledge of polarization $P \pm \Delta P$ is essential for all spin analyses at RHIC**

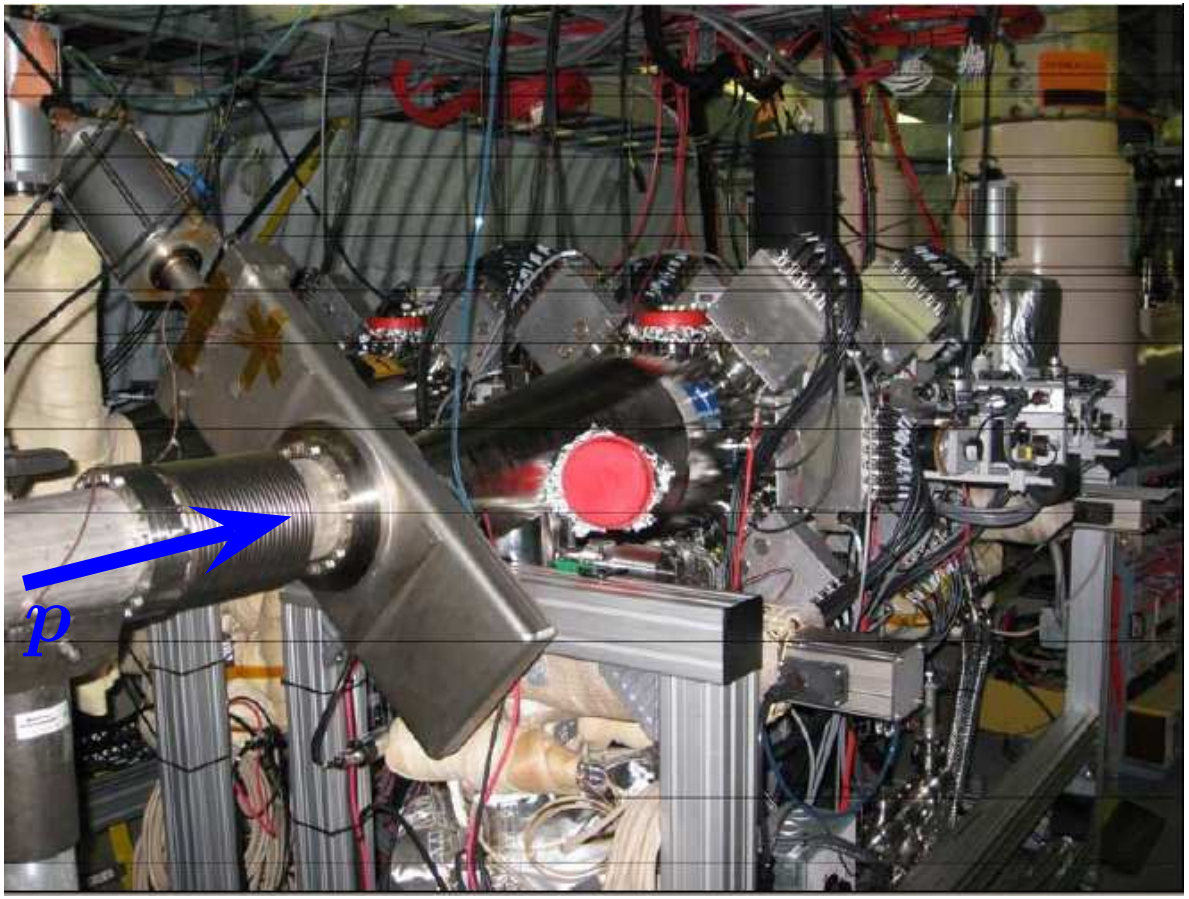
Accelerator Complex and Polarimeters



- RHIC rings filled with $\sim 120 \times 10^{11}$ protons
- Beams cross at rate of ~ 9 MHz
- Collisions with all spin combinations available $\uparrow\uparrow, \uparrow\downarrow, \downarrow\uparrow, \downarrow\downarrow$

RHIC Polarimeters



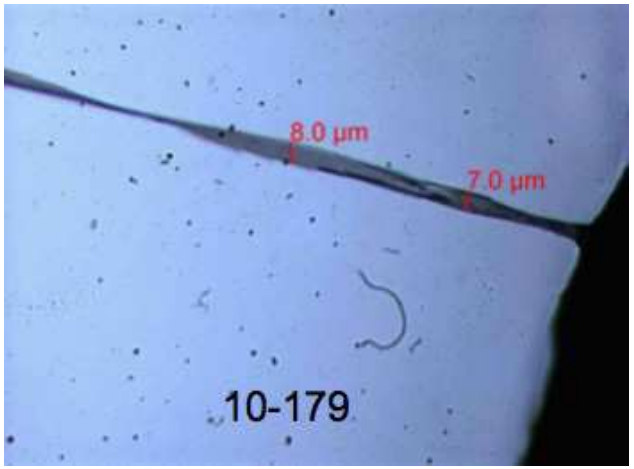


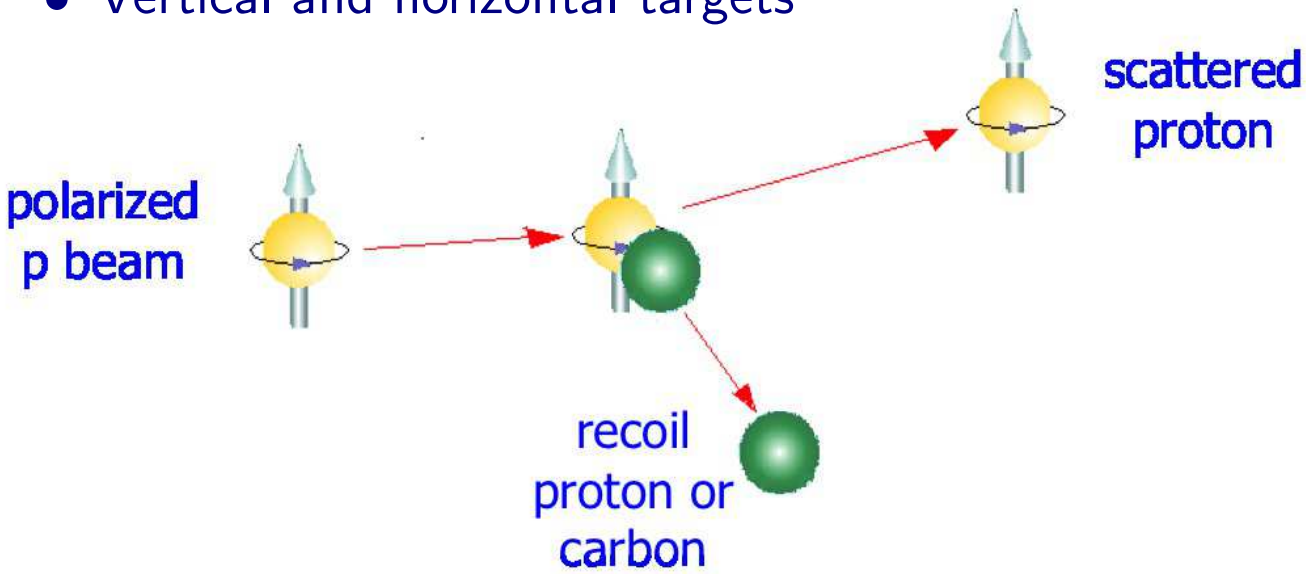
- **Hydrogen Jet Polarimeter**
  - **Jet is polarized!**
  - Continuous operation throughout the fill ($\sim 8 - 10$ hours)
  - Provides **absolute average** polarization over the fill
  - Lower statistical power

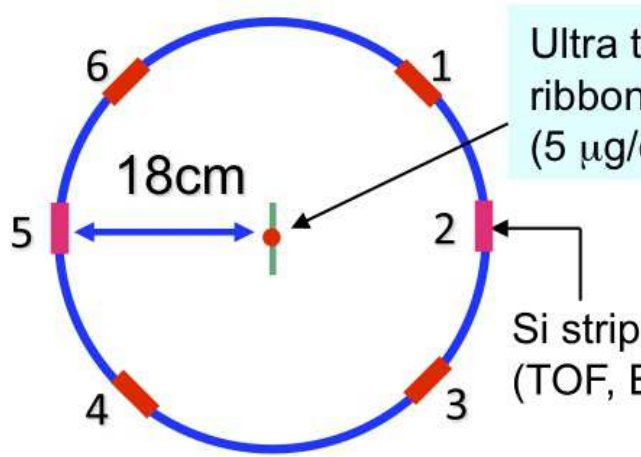
- **p-Carbon Polarimeters (two in each ring)**
  - About four 3-minute measurements per fill
  - Polarization decay in fill
  - Beam polarization profiles
  - Higher statistical power

Principles of RHIC Polarimetry

- Fixed targets are used to measure proton beam polarization
  - **H-jet polarimeter**
    - Vertical hydrogen jet target $\sim 6 - 7$ mm in diameter
  - **p-Carbon polarimeters**
    - Ultra thin carbon ribbon 2.5 cm $\times$ 10 μm $\times$ 25 nm
    - Vertical and horizontal targets

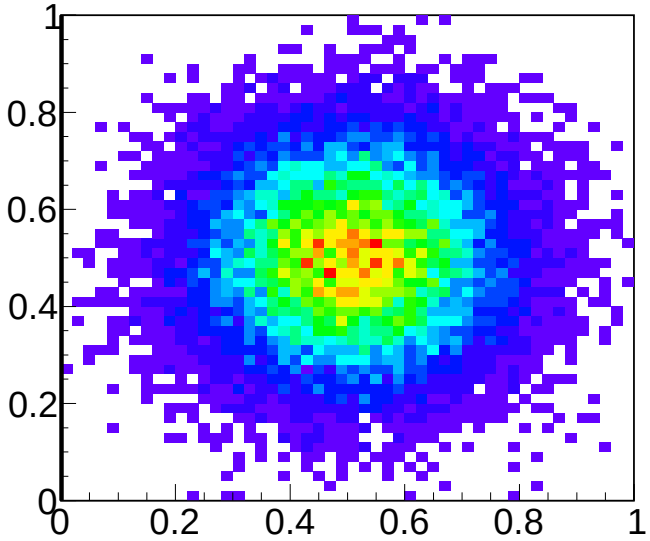






- **Measured polarization is:** $\boxed{P = \frac{1}{A_N} \times \frac{N_L - N_R}{N_L + N_R}}$, where A_N is small ~ 3 %
- No need to know A_N with Hydrogen Jet polarimeter

Measuring Beam Profile



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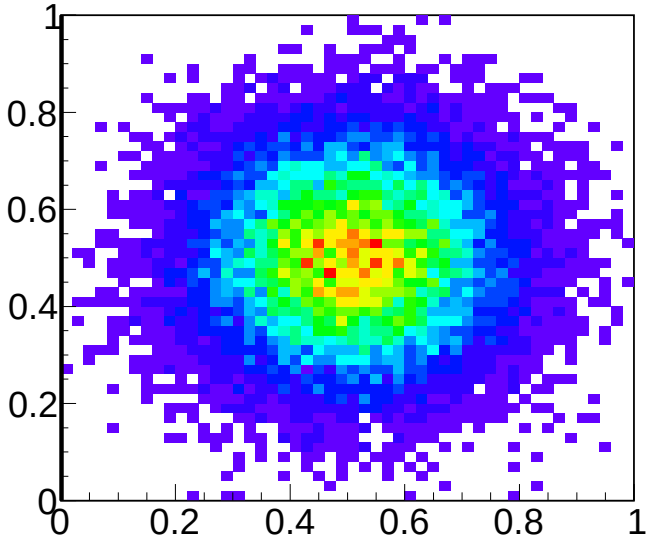

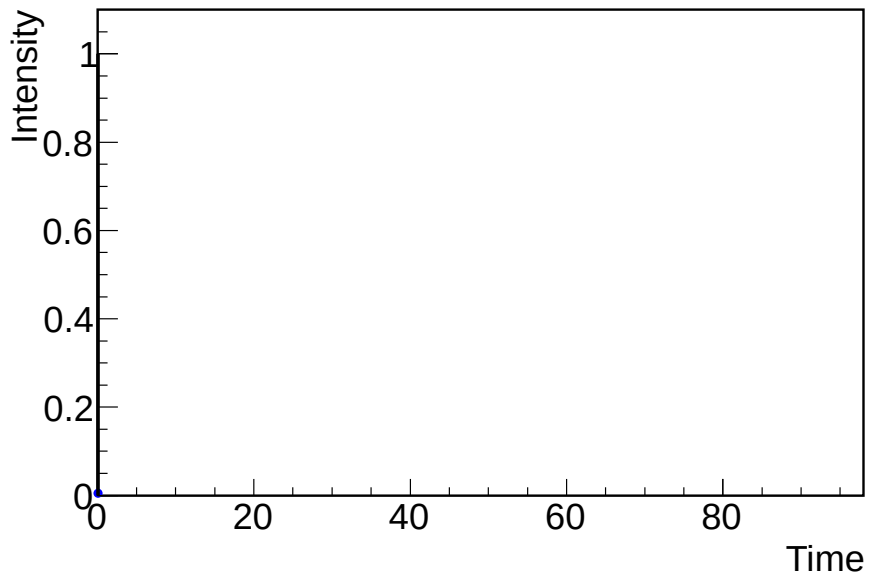

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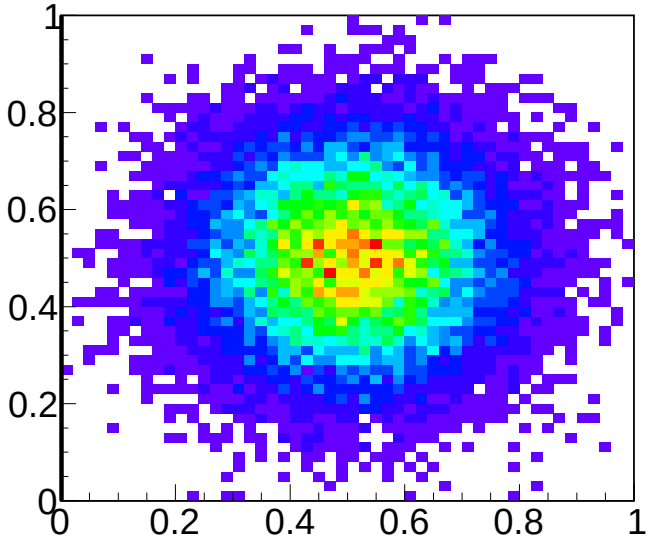
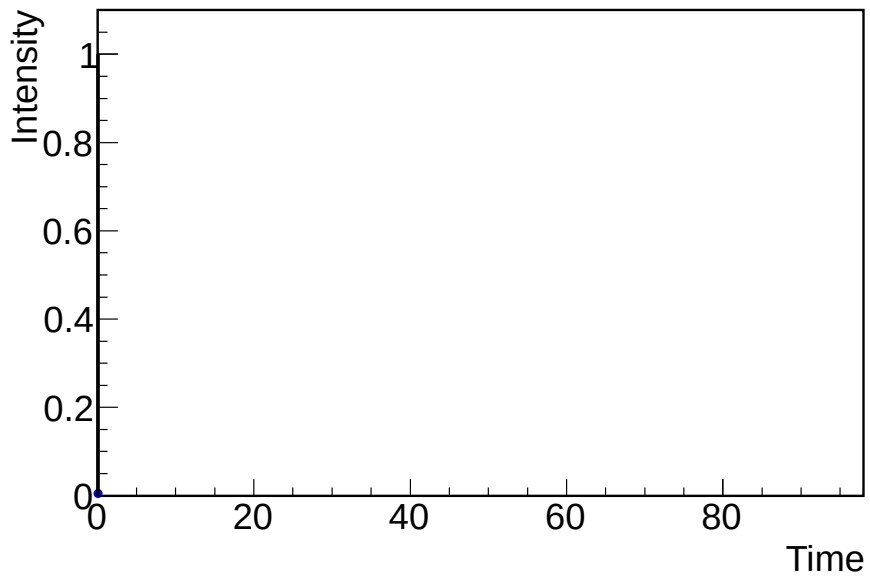
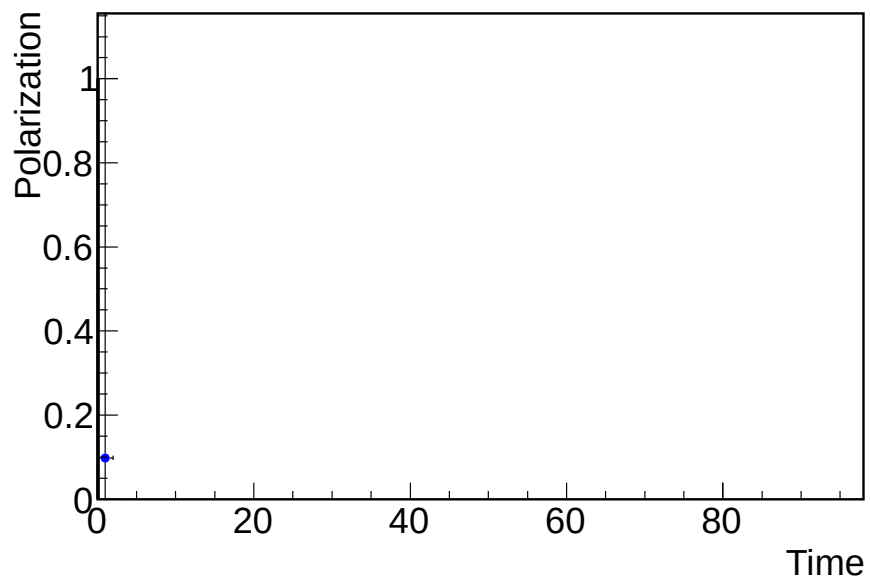




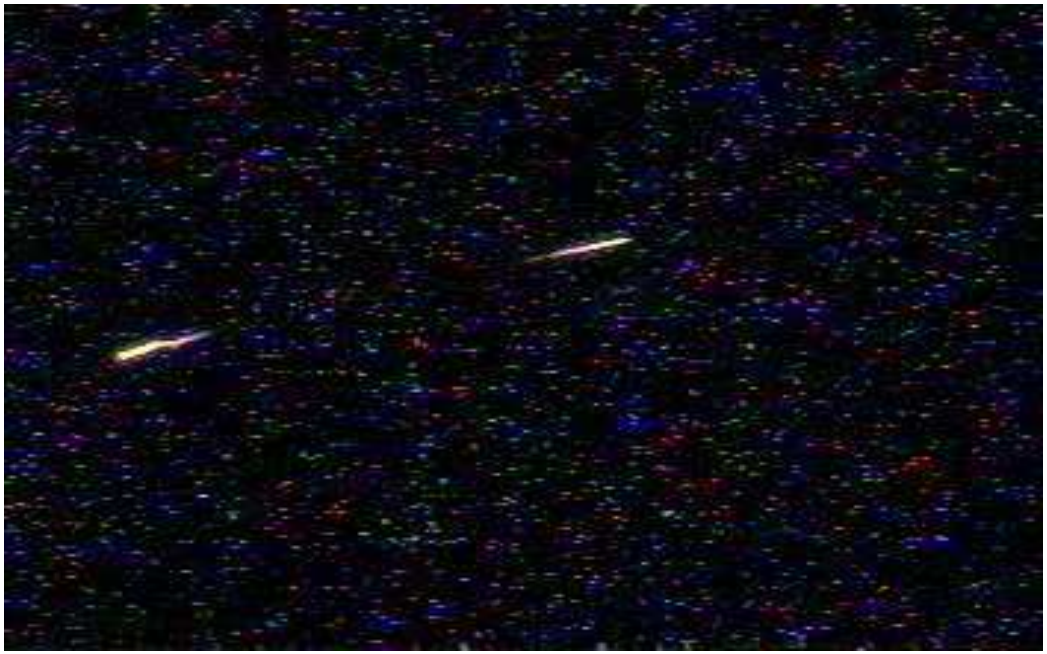
- Polarization and intensity profile can be described with gaussian distributions:

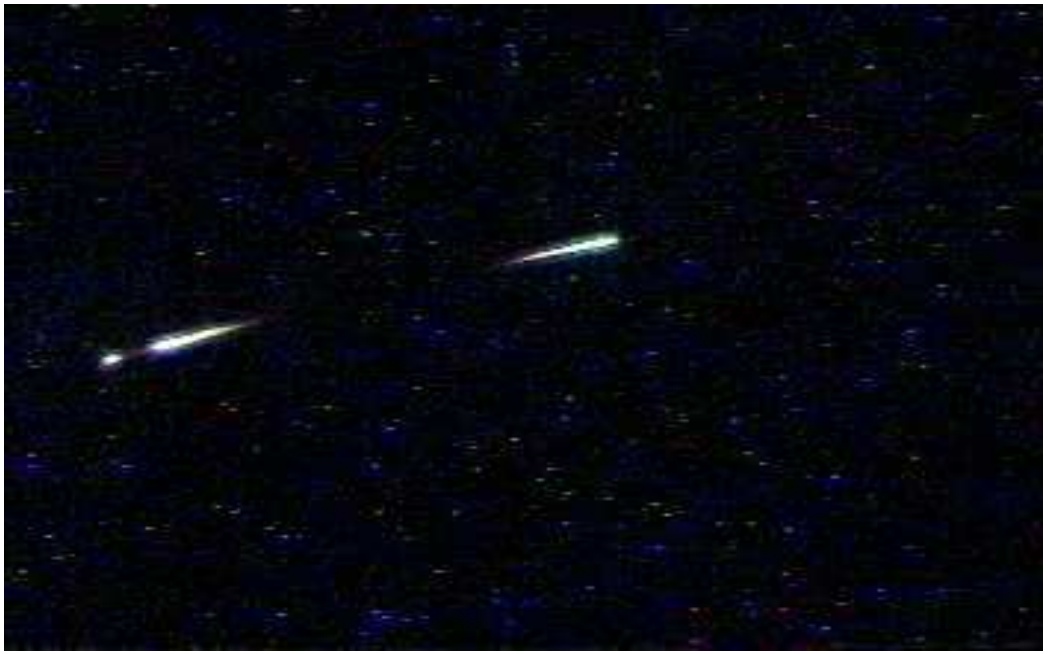
$$P = P_{\text{max}} e^{-\frac{\vec{x}^2}{\sigma_P^2}}, \qquad I = I_{\text{max}} e^{-\frac{\vec{x}^2}{\sigma_I^2}}$$

- Profile parameter $\boxed{R = \frac{\sigma_I^2}{\sigma_P^2}}$



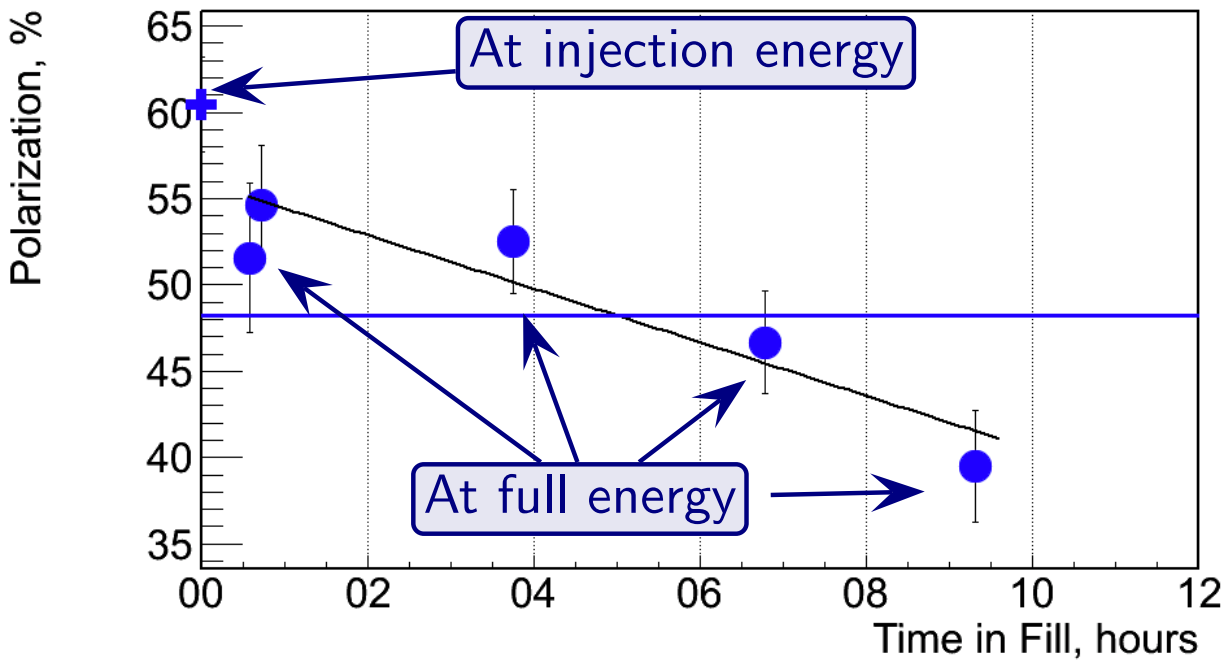
Carbon Target Crossing Beam

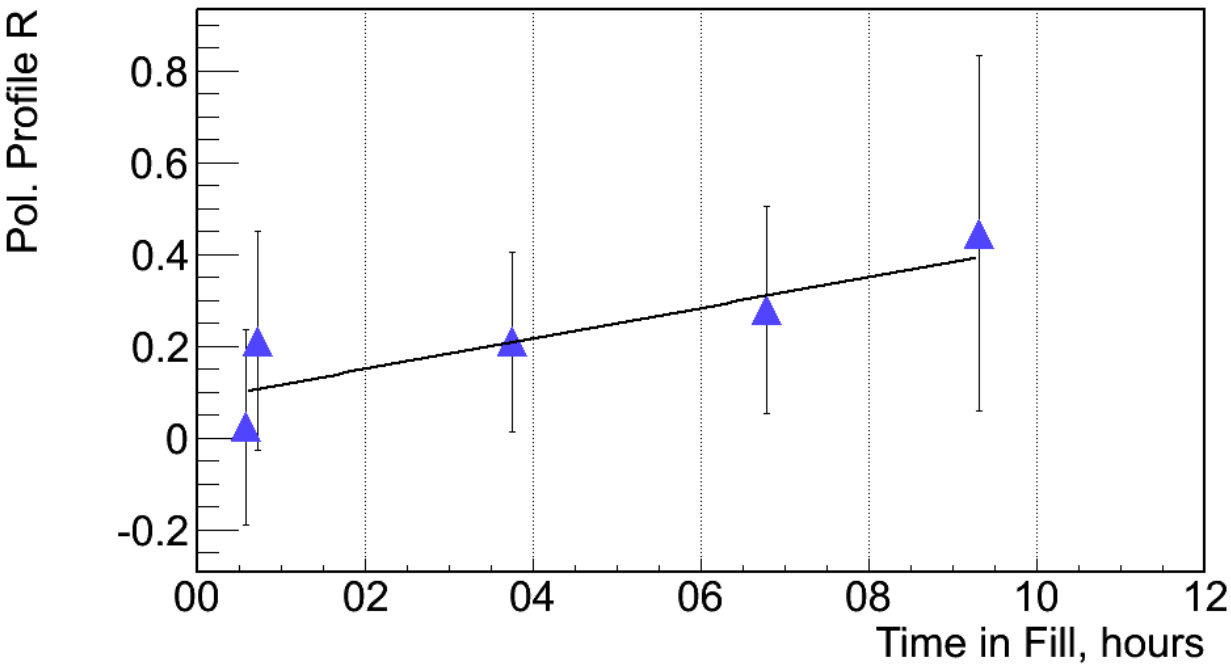




- Inserting something in a high energy beam is fun ☺
- Main instability in polarization measurements is believed to be due to uncertainty in target position while moving through the beam

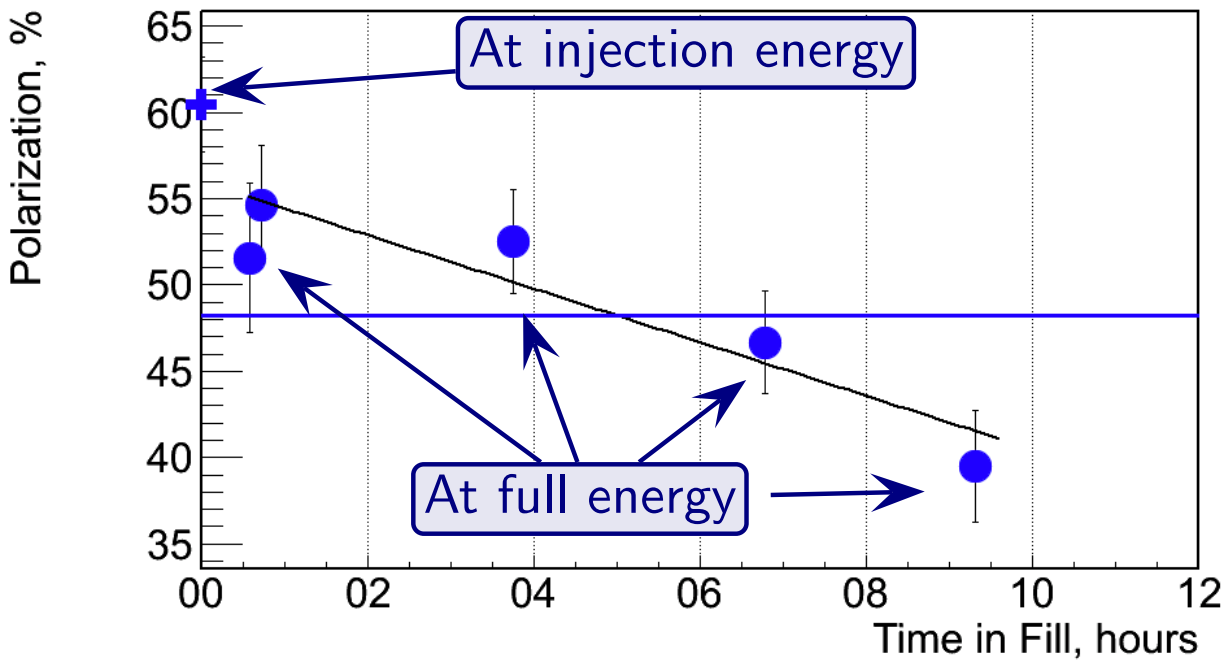
Polarization Losses in a Fill

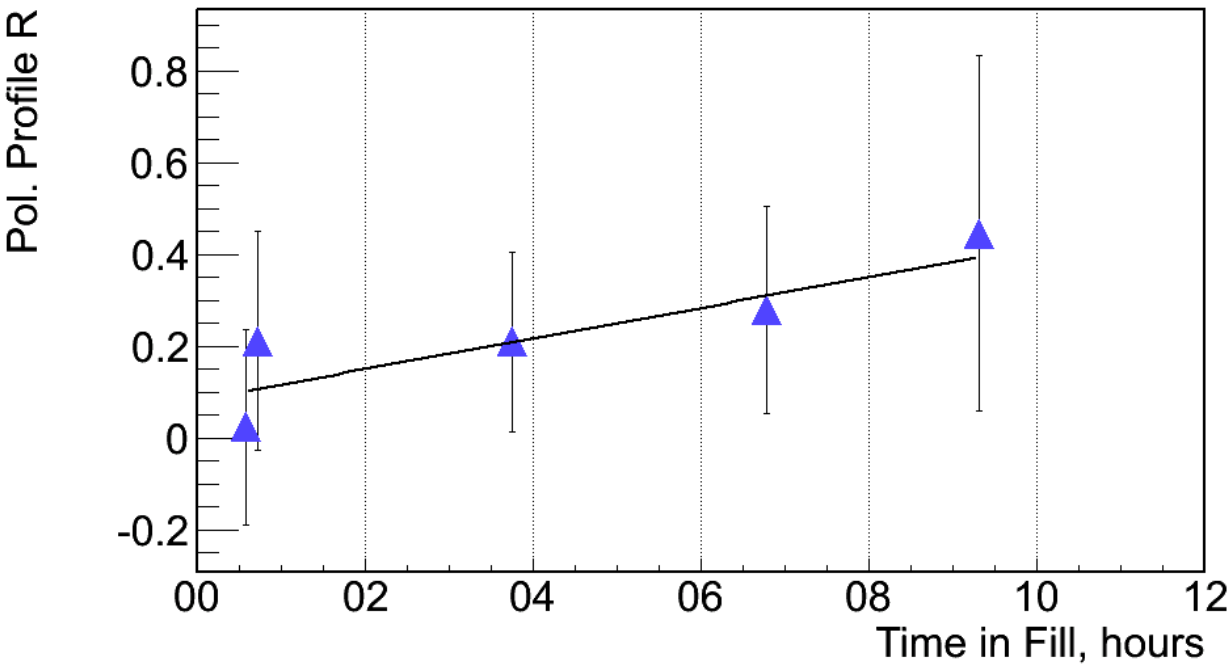




- Polarization is lost during beam accelleration
- Polarization decreases during the fill while R increases
  - Our measurement confirms de-polarizing mechanism due to widening of polarization profile

Some Numbers to Remember

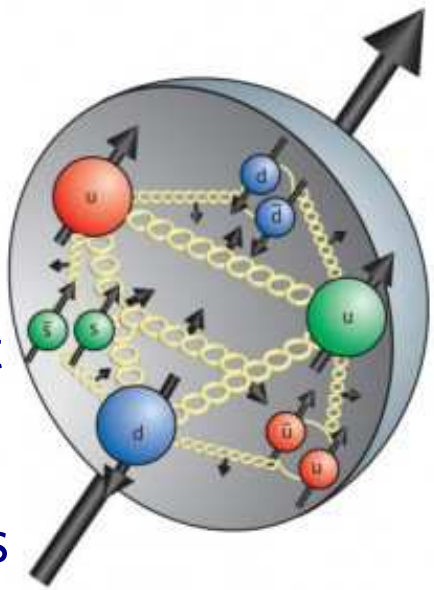


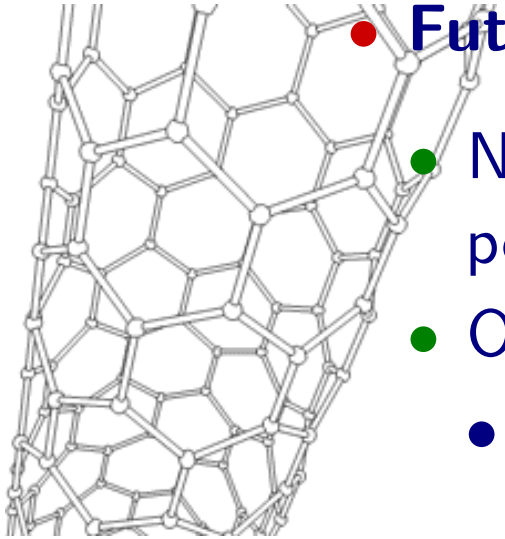


- **Initial** beam polarization at the source is $\sim \mathbf{80}\ \%$
- In RHIC **average** beam polarization was $\mathbf{52}\ \%$ and $\mathbf{58}\ \%$ for two periods in 2012
- Polarization **losses** are $\frac{dP}{dt} \sim -0.5\%$ per hour during a fill
- Relative measurement **uncertainty** per fill is $\frac{\Delta P}{P} \sim 5\%$

Summary and Outlook

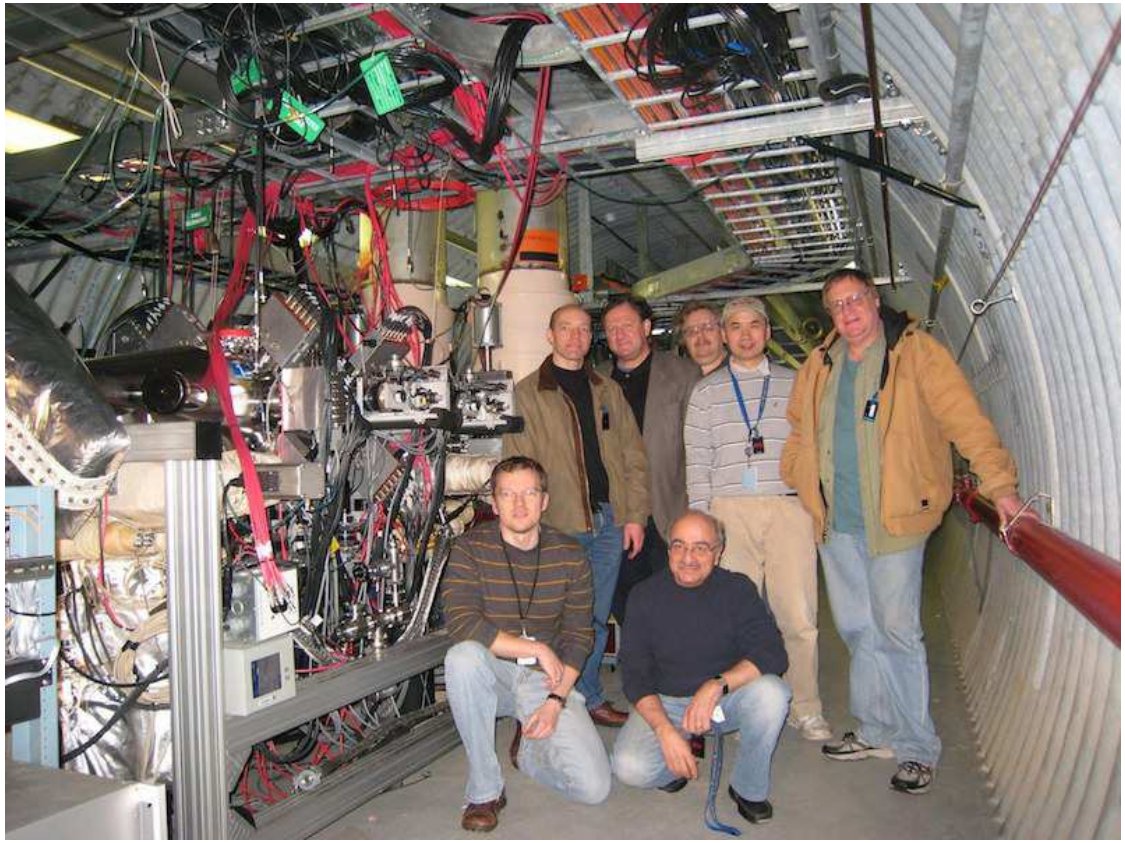
- **RHIC polarimeters are unique scientific tools at BNL**
  - Perform undestructive measurement of proton beam polarization
  - Provide polarization measurements for all spin analyses at RHIC
  - Provide valuable feedback to the RHIC machine operators





- **Future plans:**
  - Next RHIC Run in 2013 we expect more data and $\sim +5\%$ in polarization
  - Ongoing studies aim to improve systematic uncertainties
    - Different geometry and production techniques for carbon targets
    - Cleaner signal selection in recoil samples

RHIC Polarimetry Group



- I would like to thank the **Instrumentation Division** and **Collider Accelerator Department** at BNL for their work on the silicon detectors, electronics, and the RHIC polarized proton beam

- I am thankful for discussions with the members of the **RHIC Spin Collaboration**, in particular

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http://www.phy.bnl.gov/cnipol/