Measurement of the Proton Beam Polarization with Ultra Thin Carbon Targets at RHIC

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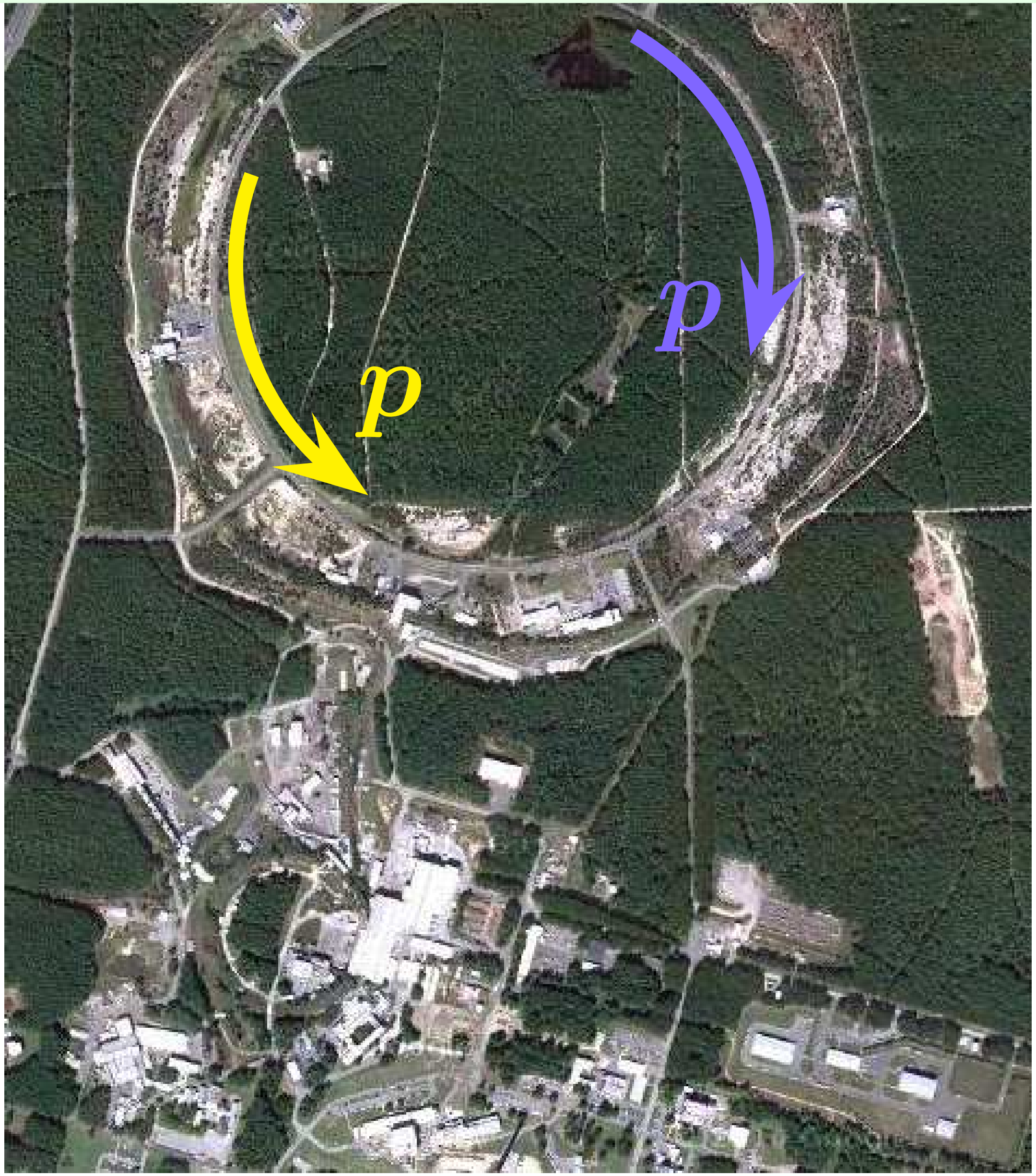
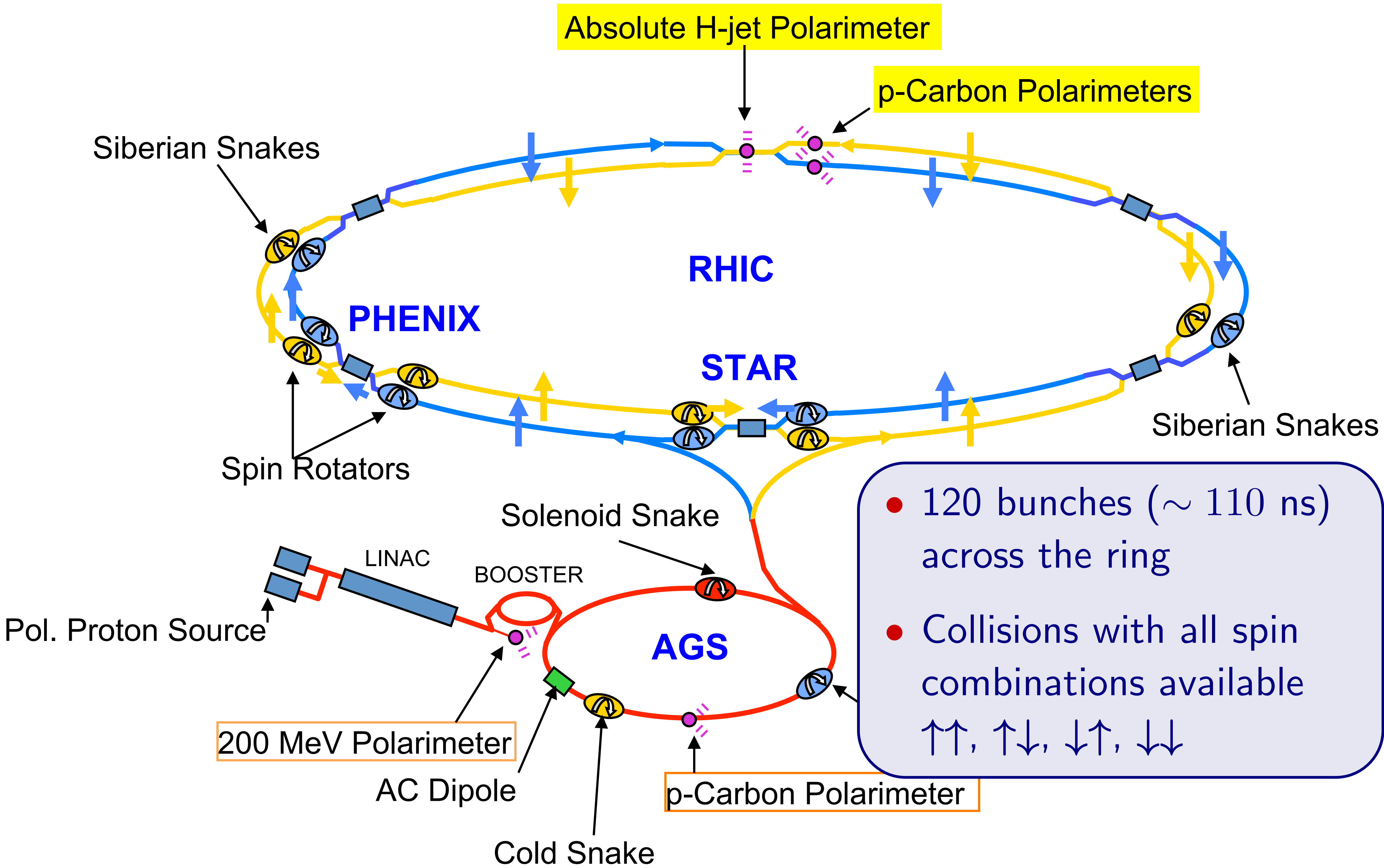
Relativistic Heavy Ion Collider
world's only polarized proton collider



Outline

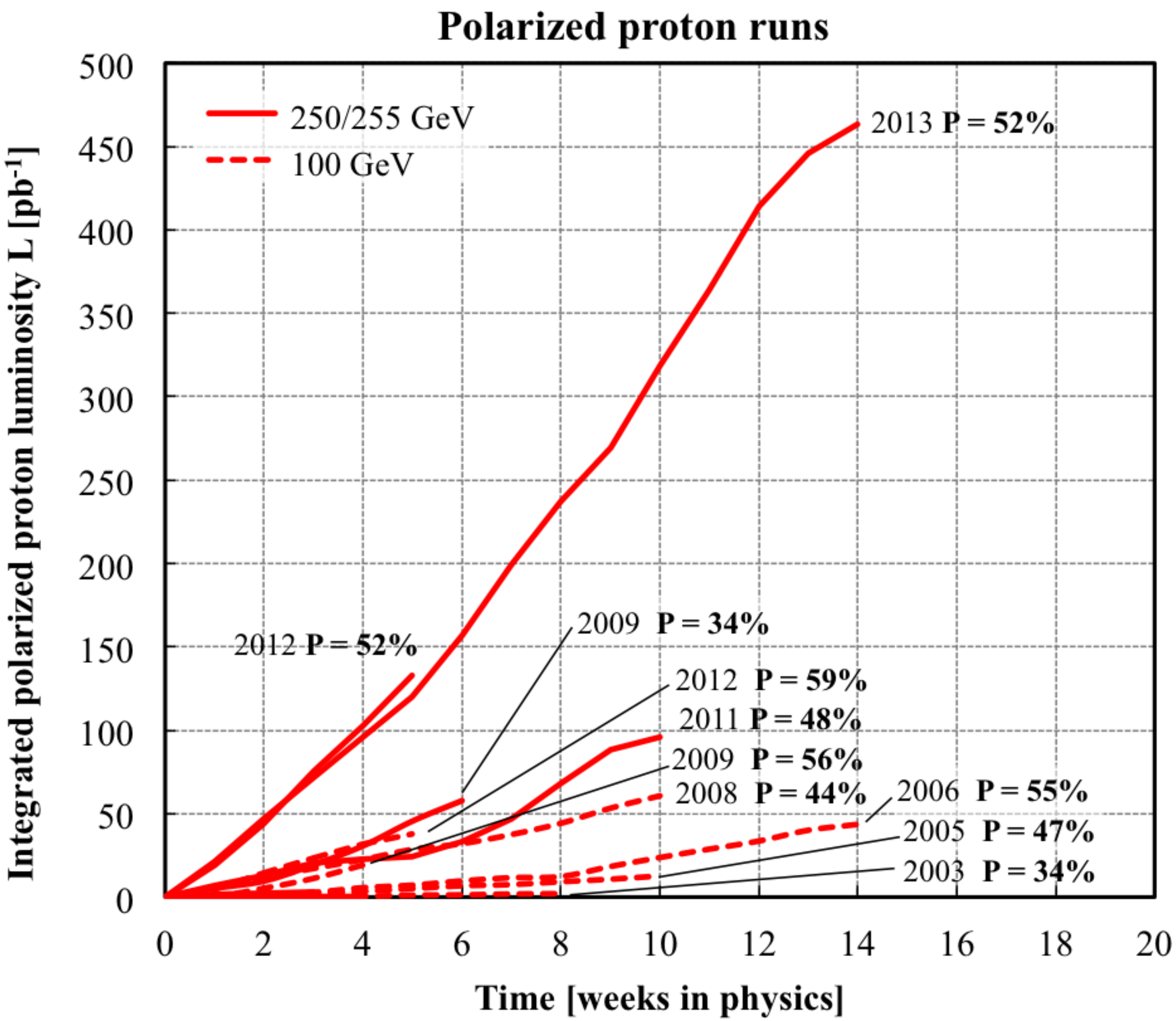
- Polarization measurement principles at RHIC
- Overview of RHIC polarimeters
- Polarimeter operations in 2013 run
- Beam polarization profile
- Carbon target challenge
- Systematic Errors and Summary

Accelerator Complex and Polarimeters



- 120 bunches ($\sim$ 110 ns) across the ring
- Collisions with all spin combinations available $\uparrow\uparrow$, $\uparrow\downarrow$, $\downarrow\uparrow$, $\downarrow\downarrow$

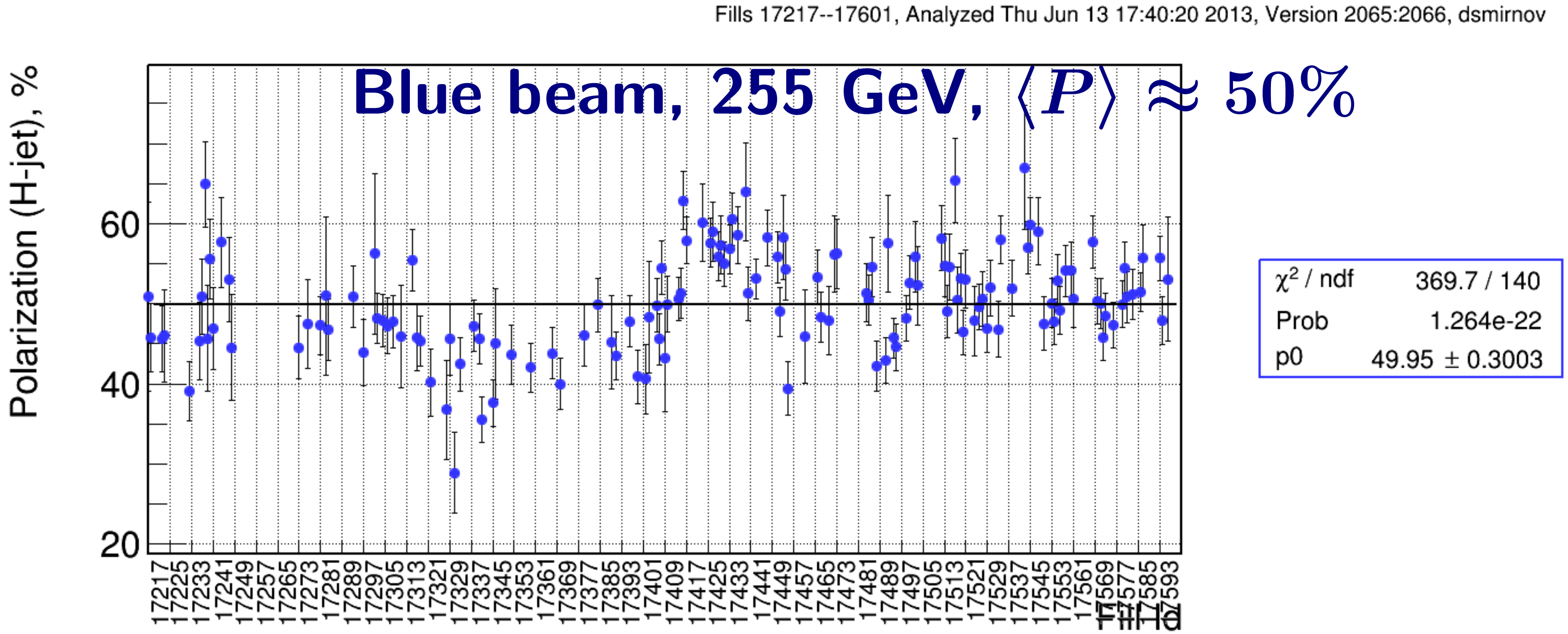
Recent RHIC Performance

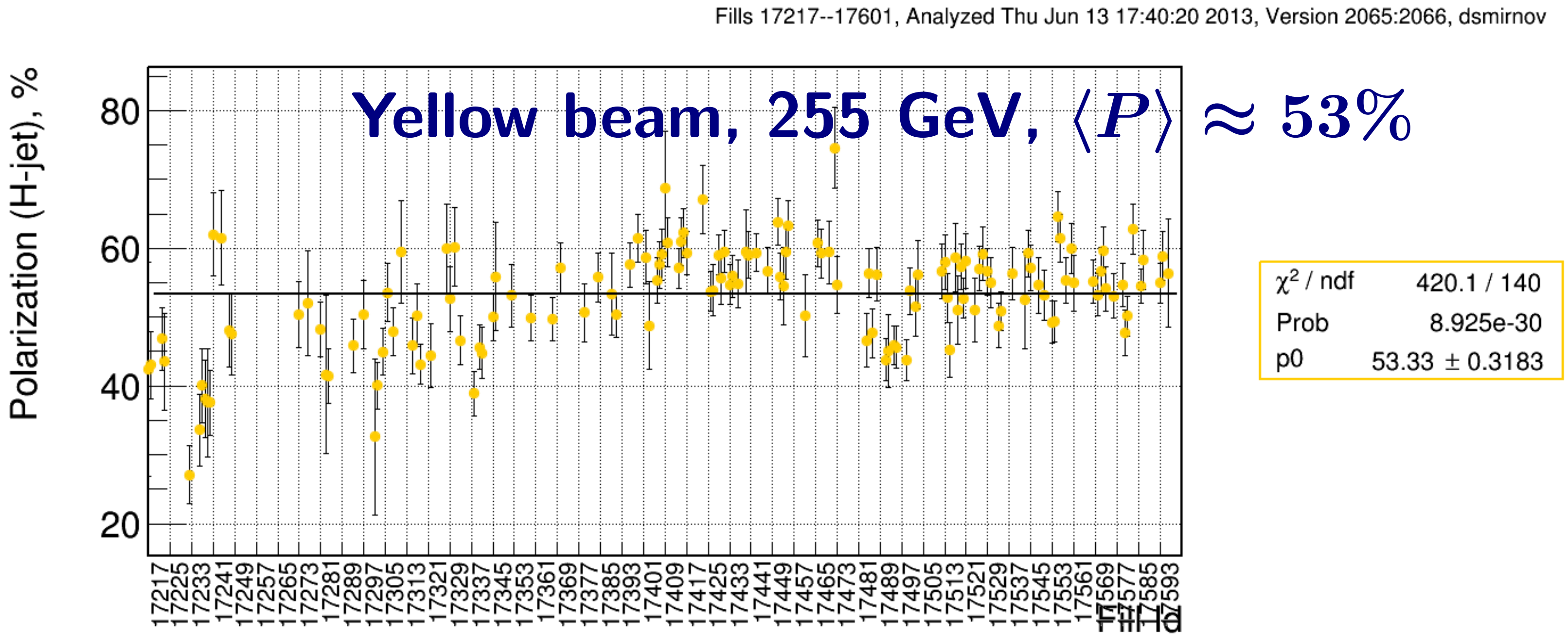


- **2014**: No polarized protons run
- **2015**: Expect 100 GeV polarized beams

- **Excellent RHIC performance**
  - Each year RHIC sets new record peak, average, or integrated luminosities
  - Improves average polarization
- **2009**
  - $P = 56\%$ at $\sqrt{s} = 100$ GeV
  - $P = 34\%$ at $\sqrt{s} = 250$ GeV
- **2011**
  - $P = 48\%$ at $\sqrt{s} = 250$ GeV
- **2012**
  - $P = 59\%$ at $\sqrt{s} = 100$ GeV
  - $P = 52\%$ at $\sqrt{s} = 255$ GeV
- **2013**
  - $P = 52\%$ at $\sqrt{s} = 255$ GeV

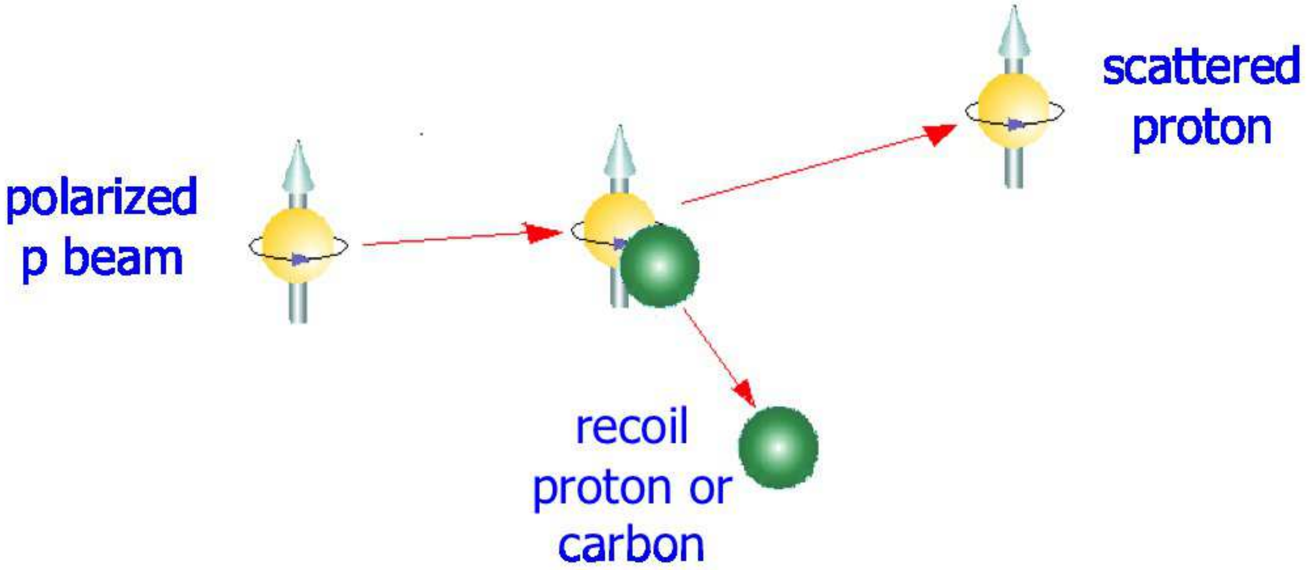
Average Polarization in 2013 at $E_{\text{beam}} = 255$ GeV



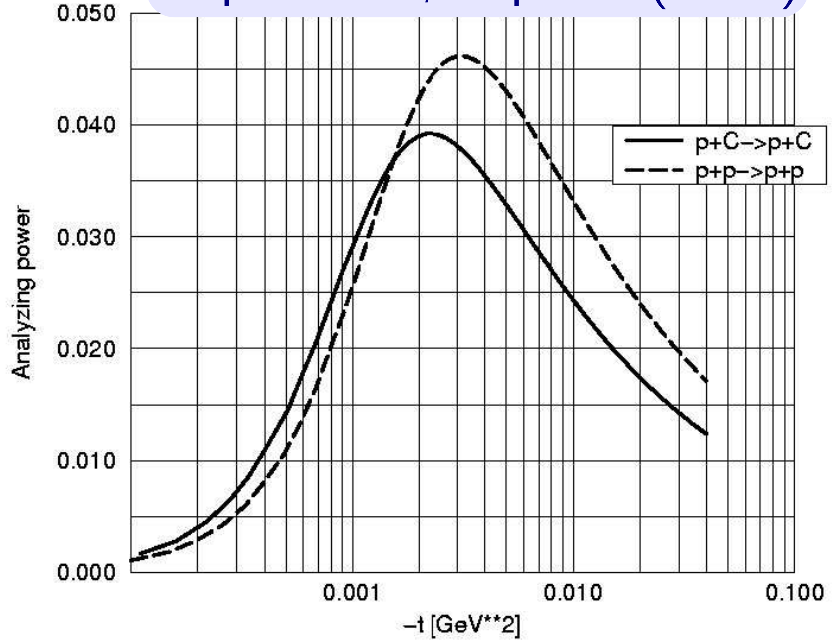


CNI Polarimetry at RHIC

- In elastic scattering maximum asymmetry A_N is expected in the region of **Coulomb-Nuclear Interference** where EM and strong amplitudes are comparable in strength



Kopeliovich, Lapidus (1974)



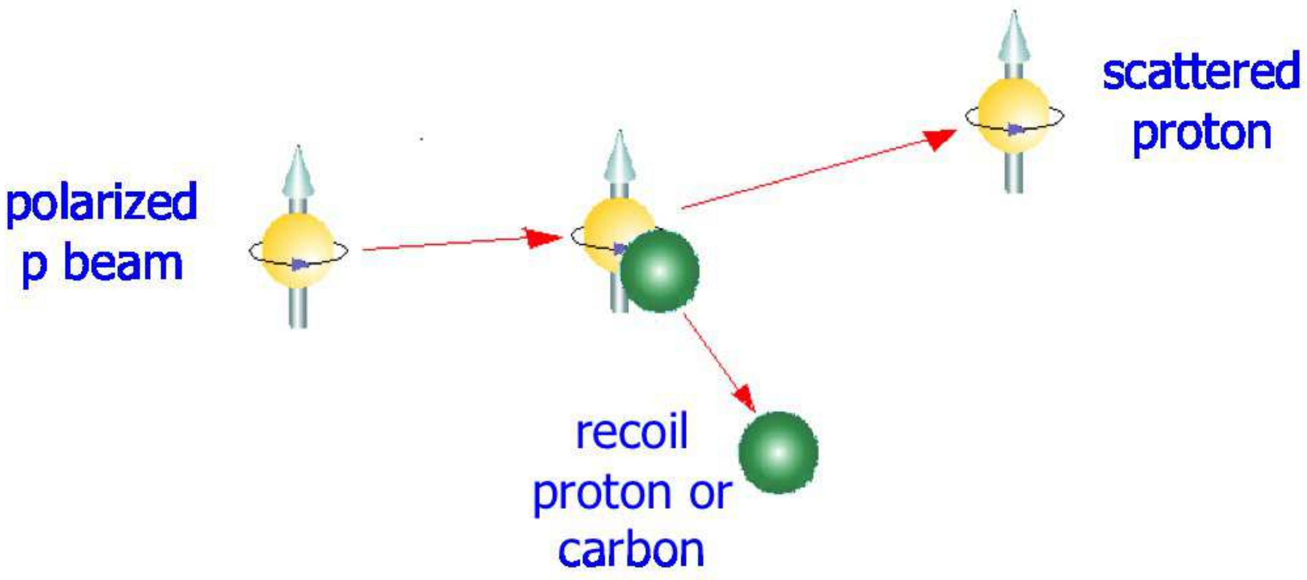
In absence of hadronic spin-flip amplitude analyzing power A_N can be calculated exactly

- **Measured polarization** $\boldsymbol{P = \frac{1}{A_N} \times \varepsilon}$
- In general, knowledge of A_N is required

CNI Polarimetry at RHIC

- In elastic scattering maximum asymmetry A_N is expected in the region of **Coulomb-Nuclear Interference** where EM and strong amplitudes are comparable in strength

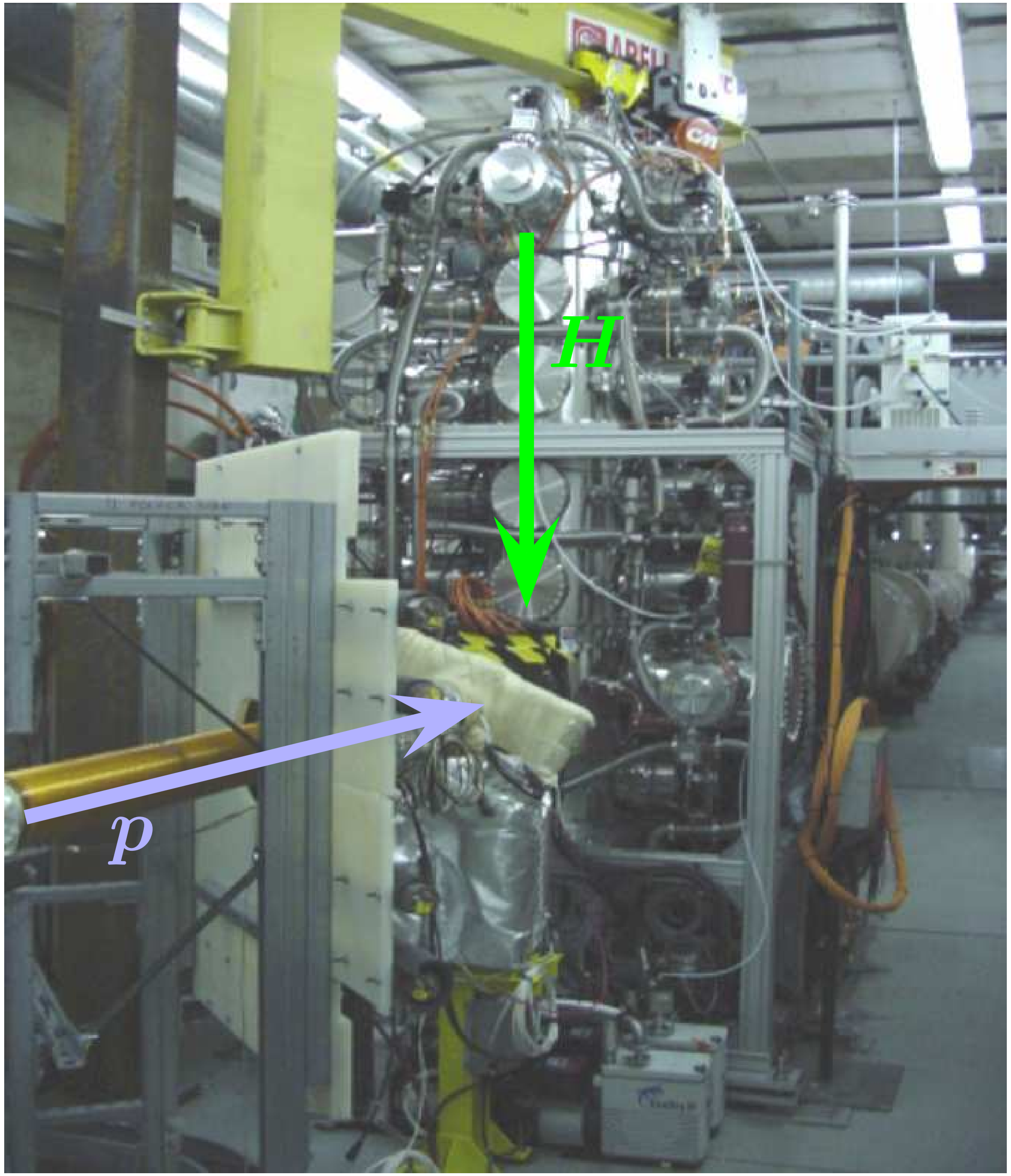
$$\varepsilon = \frac{N_L - N_R}{N_L + N_R}$$



$$\varepsilon = \frac{\sqrt{N_L^{\uparrow} N_R^{\downarrow}} - \sqrt{N_L^{\downarrow} N_R^{\uparrow}}}{\sqrt{N_L^{\uparrow} N_R^{\downarrow}} + \sqrt{N_L^{\downarrow} N_R^{\uparrow}}}$$

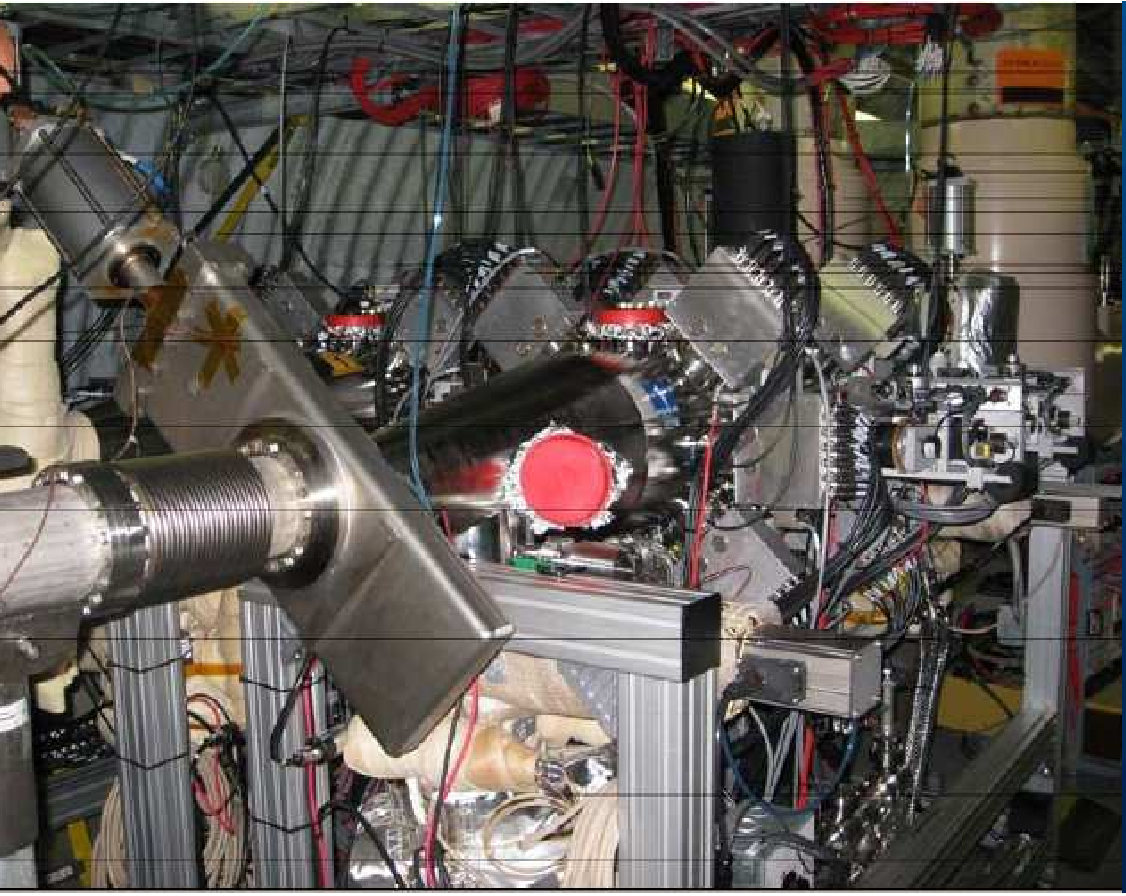
- **Measured polarization** $P = \frac{1}{A_N} \times \varepsilon$
- In general, knowledge of A_N is required

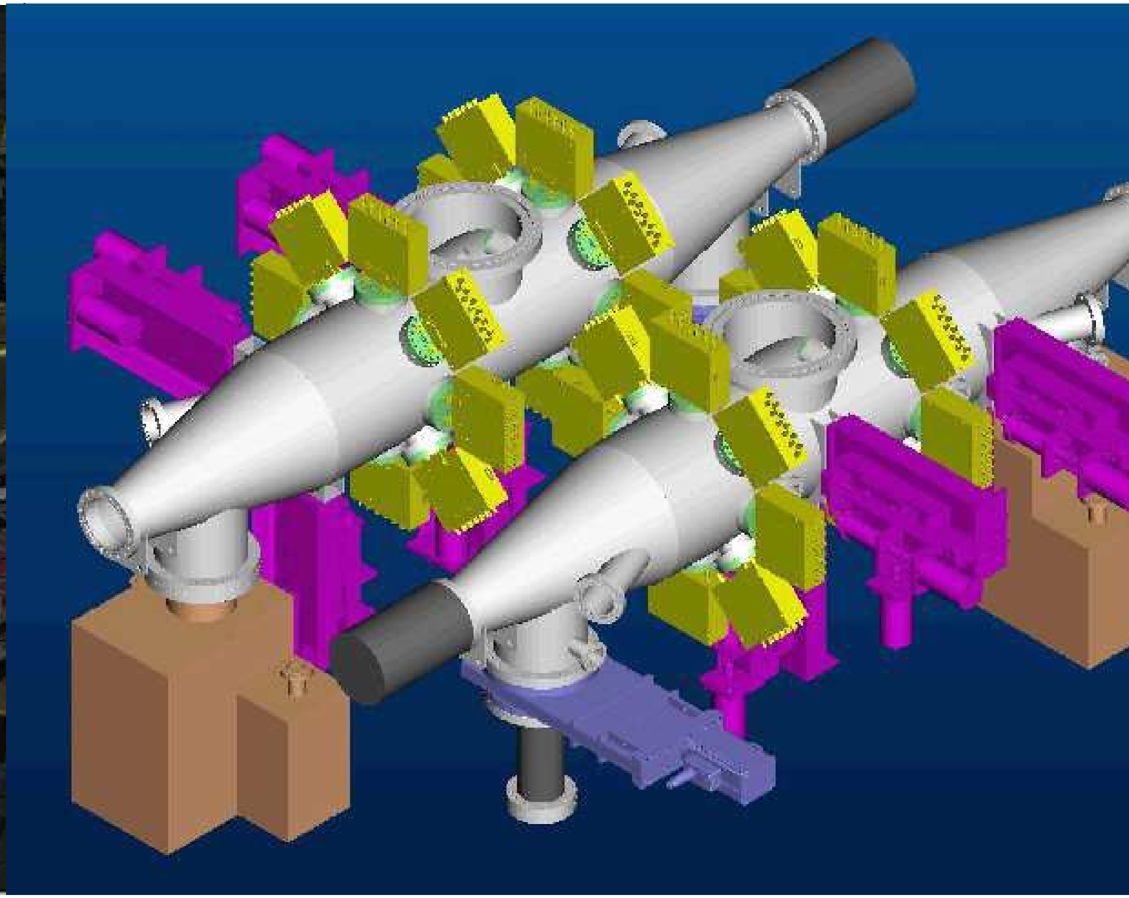
RHIC Polarimeters: Hydrogen-Jet (H-Jet) Polarimeter



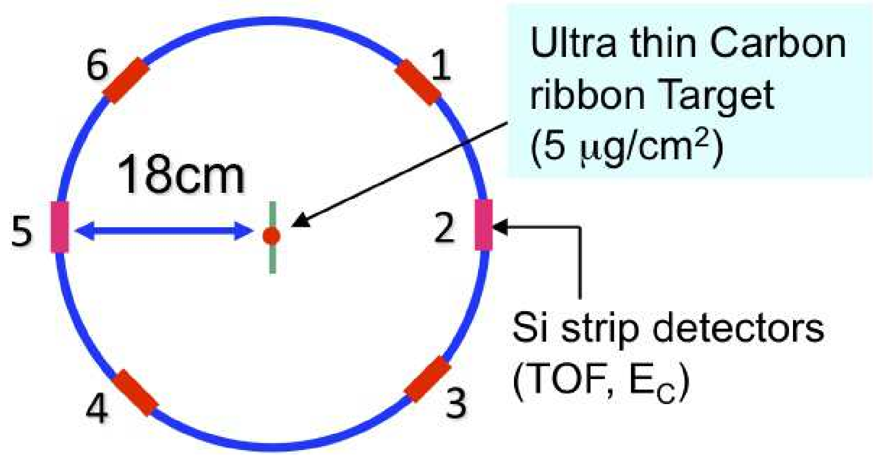
- Provides **average absolute polarization** over a fill ($\sim 8-10$ hours)
- The jet target is polarized $\Rightarrow A_N$ is not required
  - Target polarization cycles through $\uparrow /0/ \downarrow$ spin states
- More details in next talk **"The polarized hydrogen jet target measurements at RHIC"** by **Andrei Poblaguev**

RHIC Polarimeters: p-Carbon Polarimeters

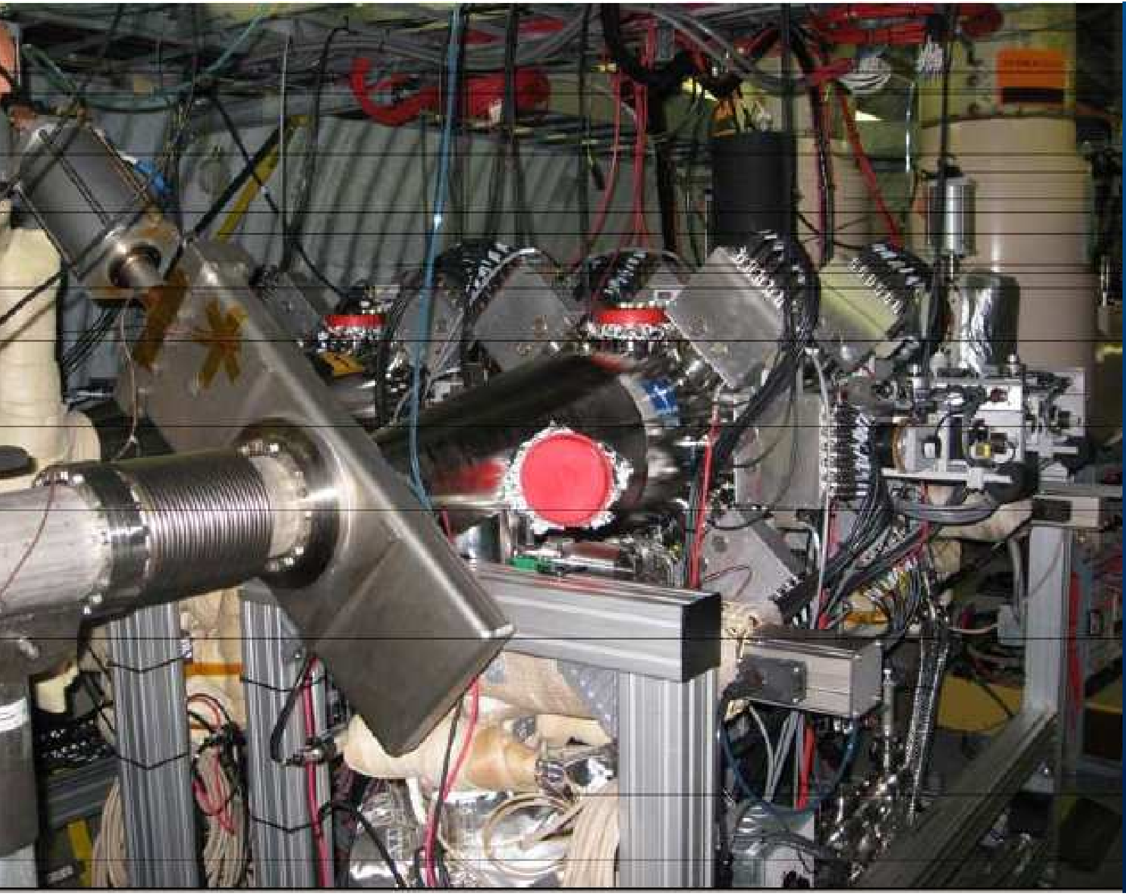


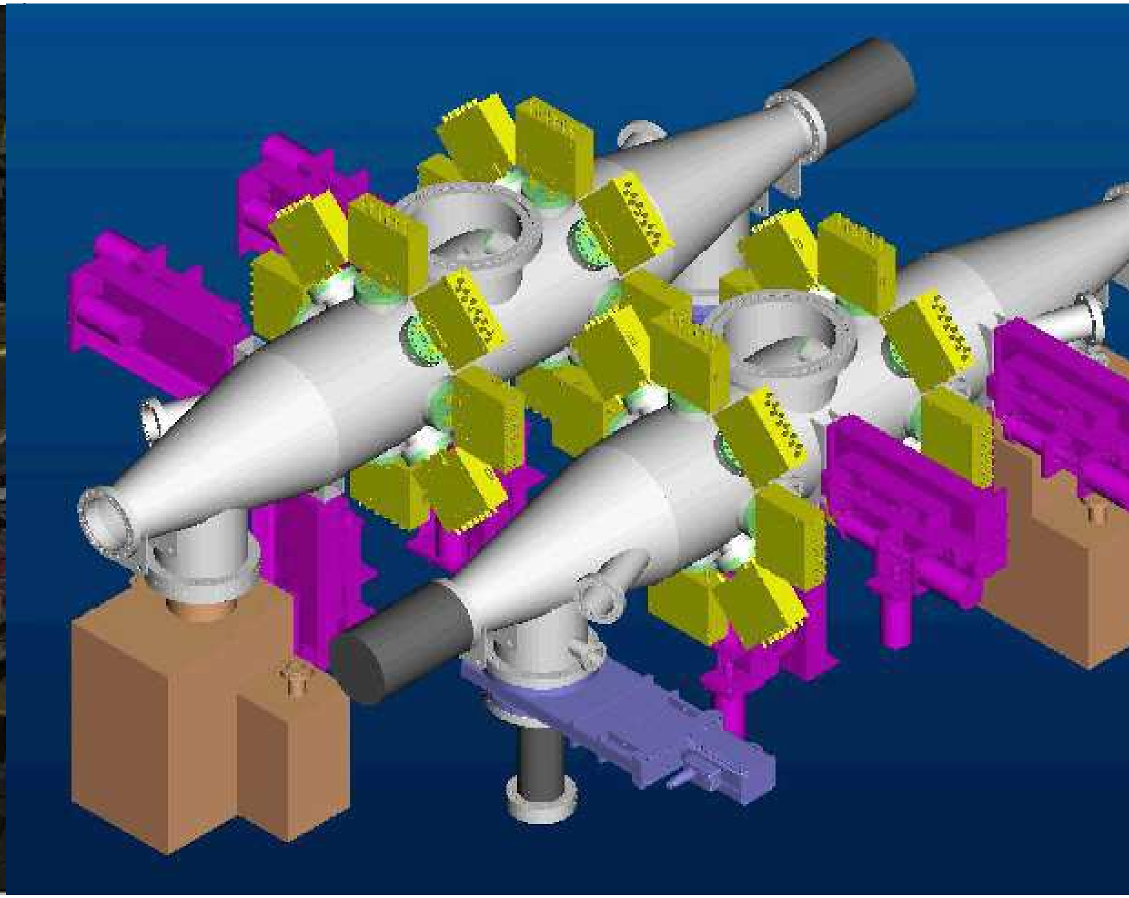


- Two polarimeters in each ring
- **$\sim 3-4$% relative stat. uncert. per measurement**
- About four 2-minute measurements per fill
- Bunch-by-bunch polarization

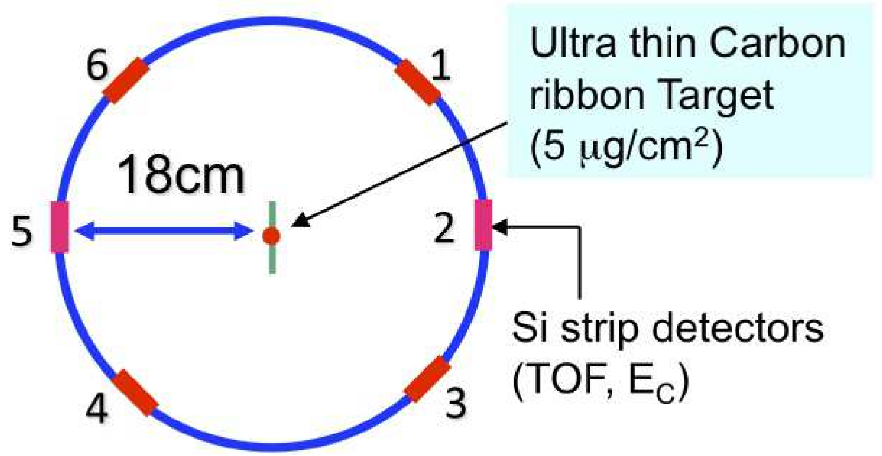


RHIC Polarimeters: p-Carbon Polarimeters

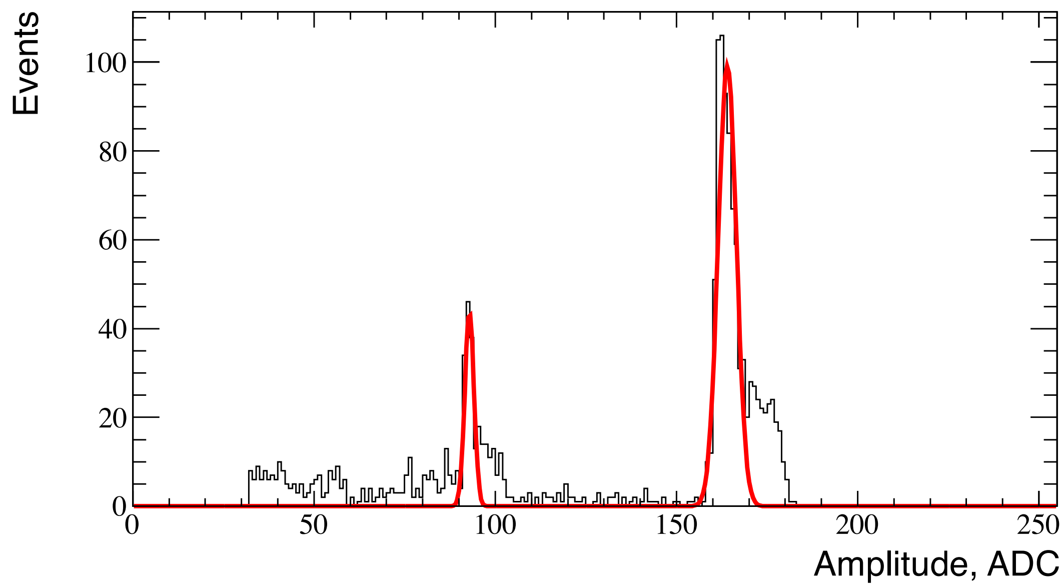


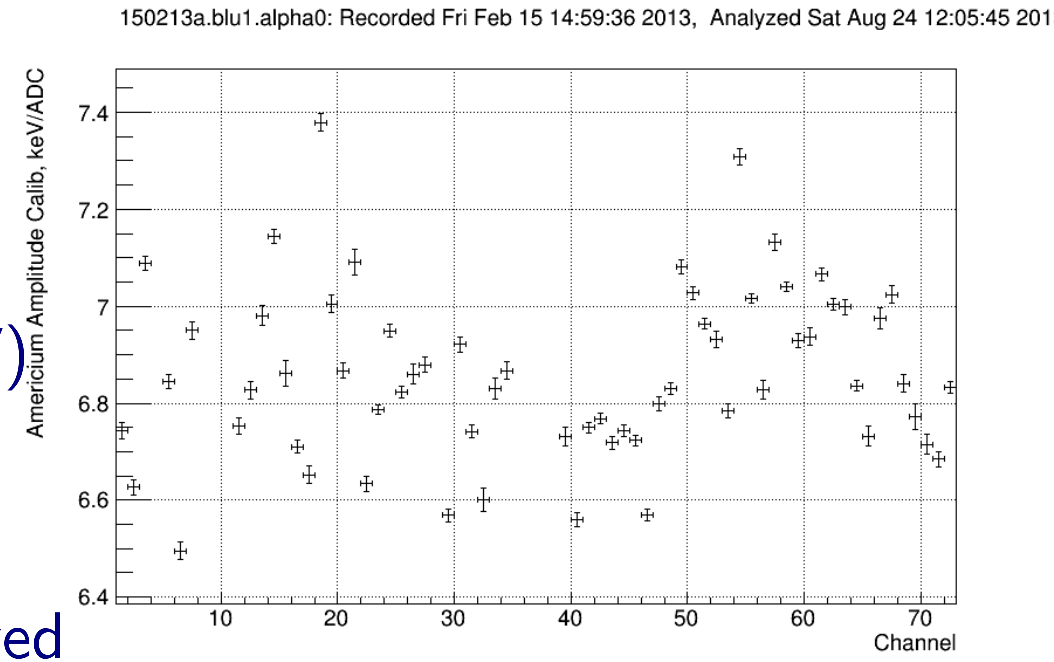


- Vertical and horizontal beam **polarization profiles**
- **Polarization decay** in a fill
- Each polarimeter employs six vertical and six horizontal ultra thin carbon targets



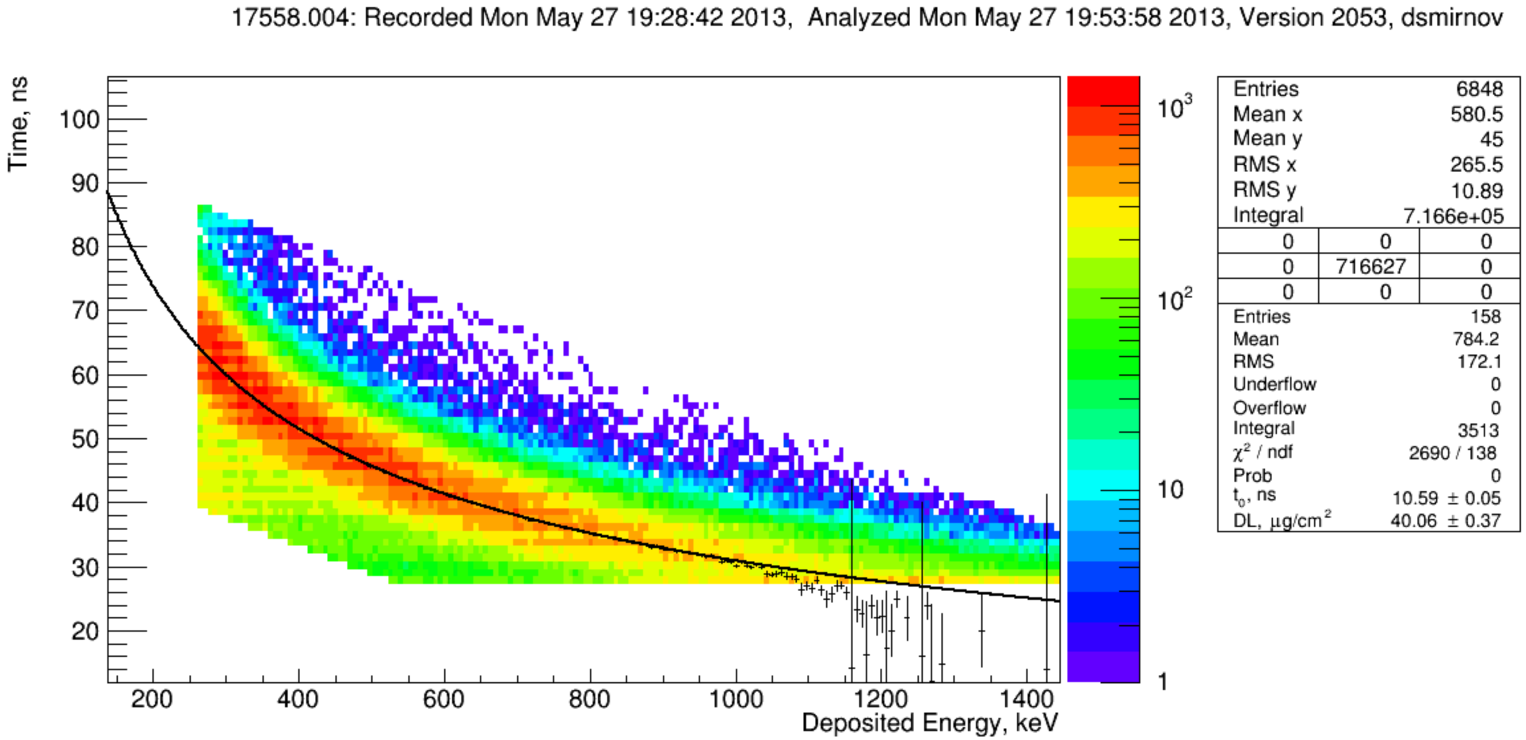
p-Carbon Polarimeters: Silicon Strip Detectors





- Detectors energy-calibrated with α sources ^{241}Am (5.5 MeV) and ^{148}Gd (3.3 MeV)
- Detectors are in the vacuum ≈ 20 cm from the beam
- No significant radiation damage observed

p-Carbon Polarimeters: Signal Event Selection

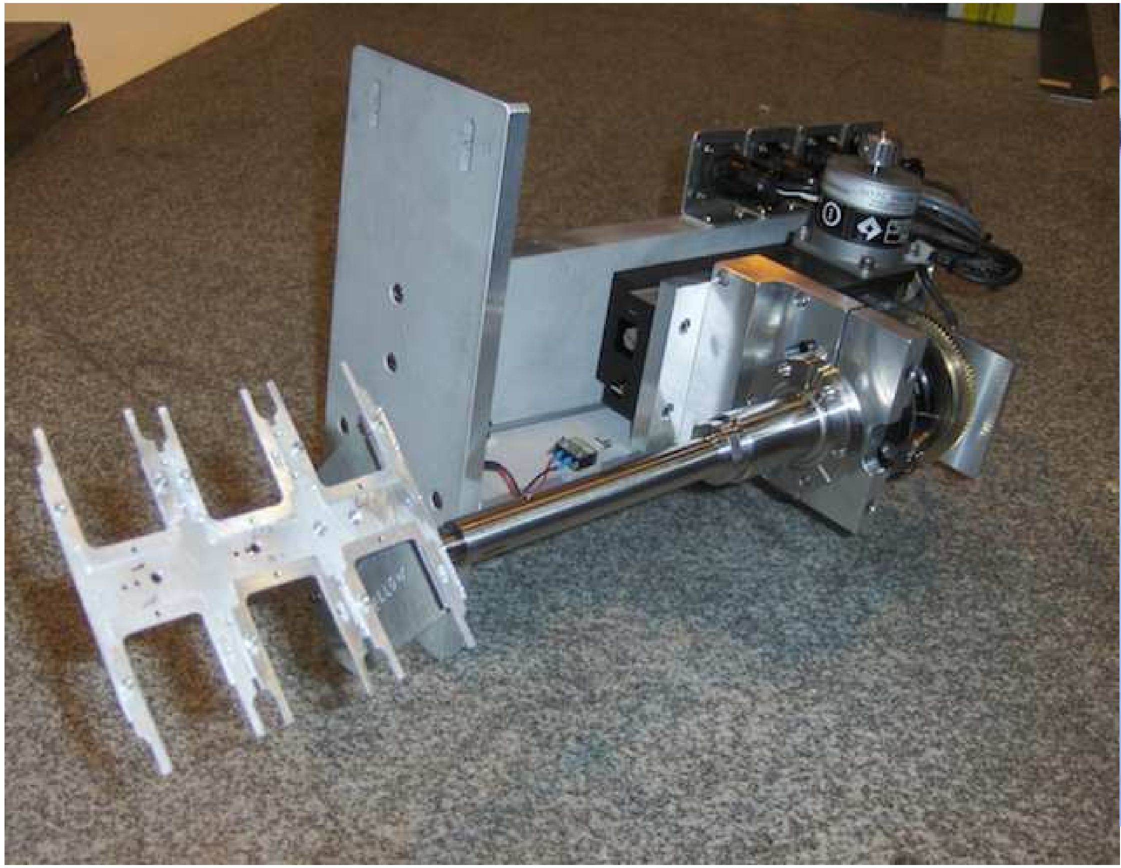


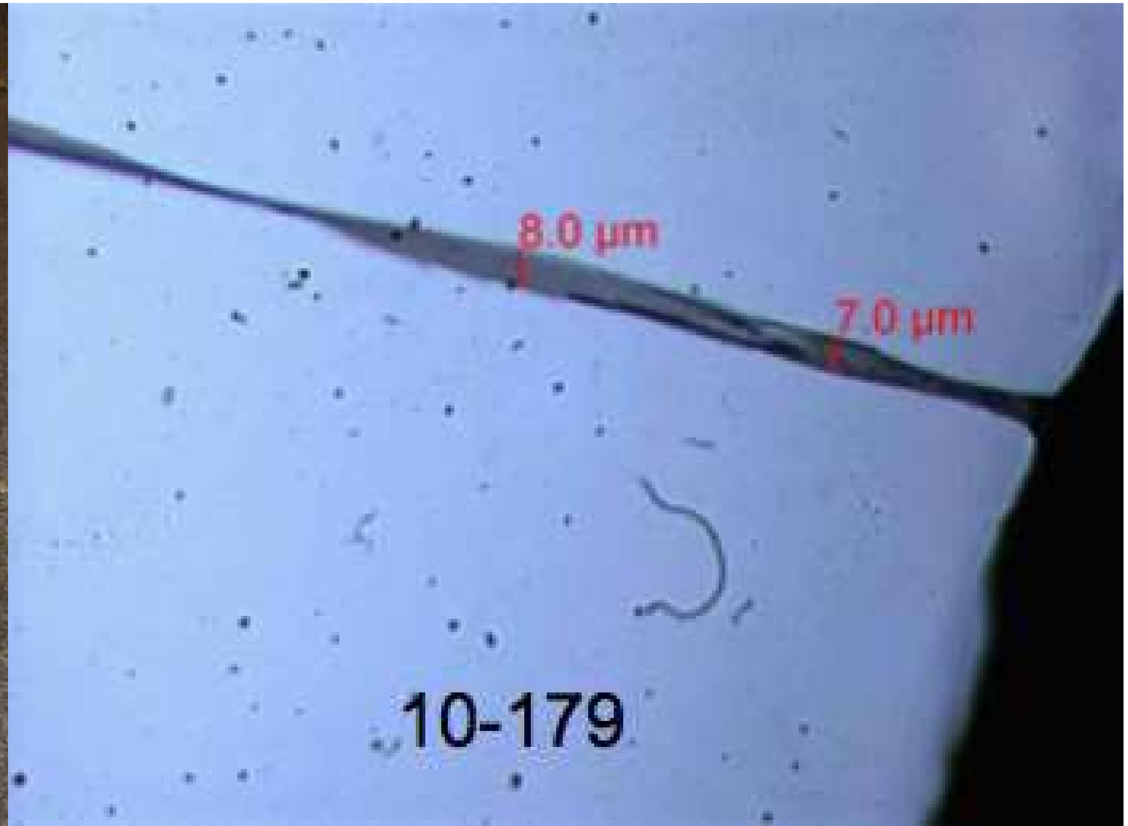
- Calibration parameters **time offset** t_0 and **effective energy losses** E_{loss} extracted from non-relativistic equation:

$$E_{\text{meas}} + E_{\text{loss}} = \frac{M_C}{2} \times \frac{L^2}{(t_{\text{meas}} + t_0)^2}$$

- Carbon events selected within a certain Time-Energy window optimized for minimum background

p-Carbon Polarimeters: Ultra-Thin Carbon Targets



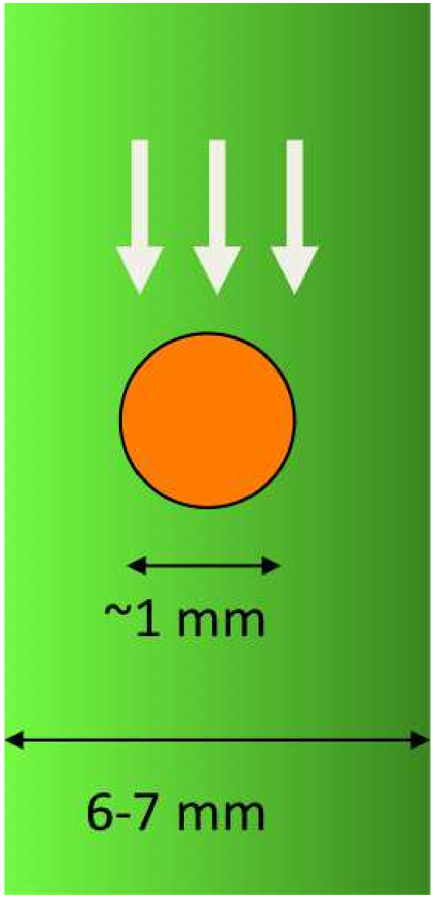


- Typical target size is 2.5 cm $\times$ 10 μm $\times$ 25 nm
- Targets are made by vacuum evaporation-condensation onto glass substrate
- Two stepping motors are used to move the ladder and to rotate the targets into the beam

Beam Polarization Profile

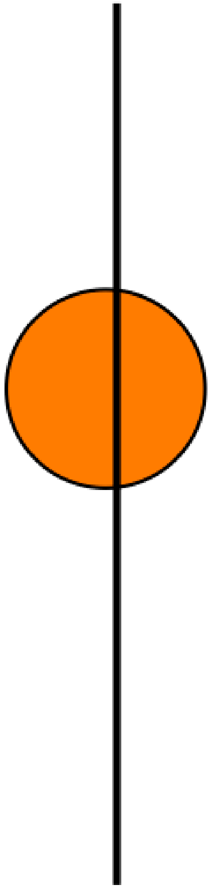
- If polarization varies across the beam the average polarization seen by polarimeters and experiments is different

H-Jet



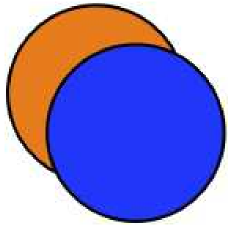
$$P = \frac{\int P(x,y)I(x,y)dxdy}{\int I(x,y)dxdy}$$

p-Carbon



$$P_{\text{sweep}} = P$$

Beam collisions



$$P_{\text{coll}} = \frac{\int P(x,y)I_1(x,y)I_2(x,y)dxdy}{\int I_1(x,y)I_2(x,y)dxdy}$$

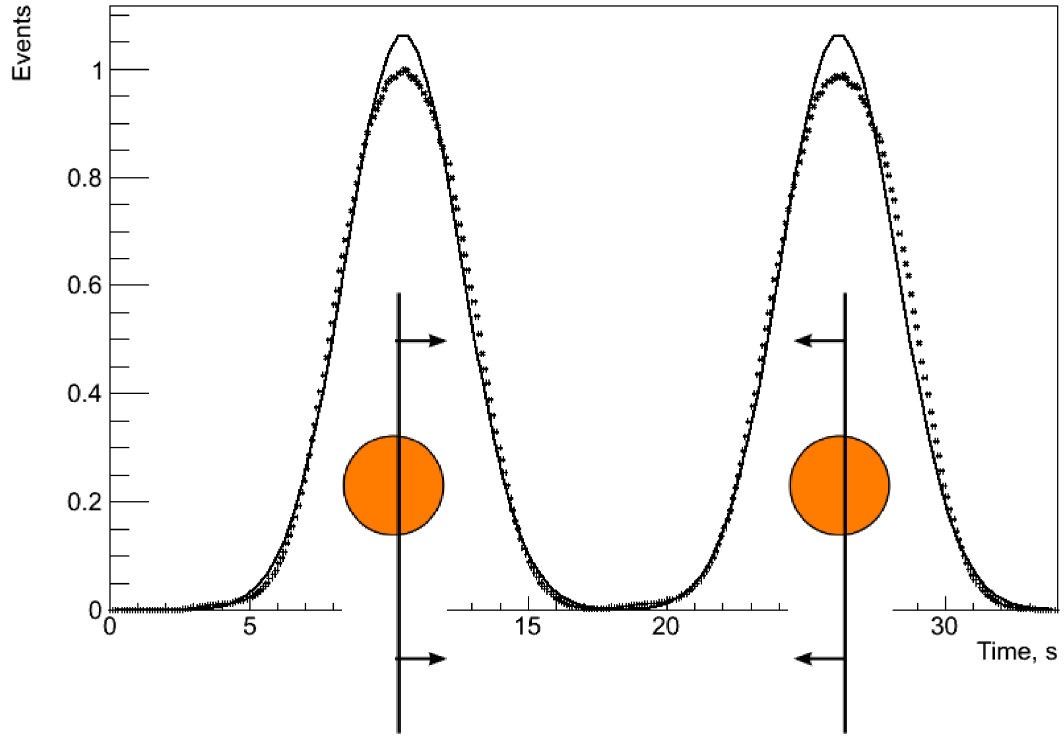
Measuring Beam Polarization Profile

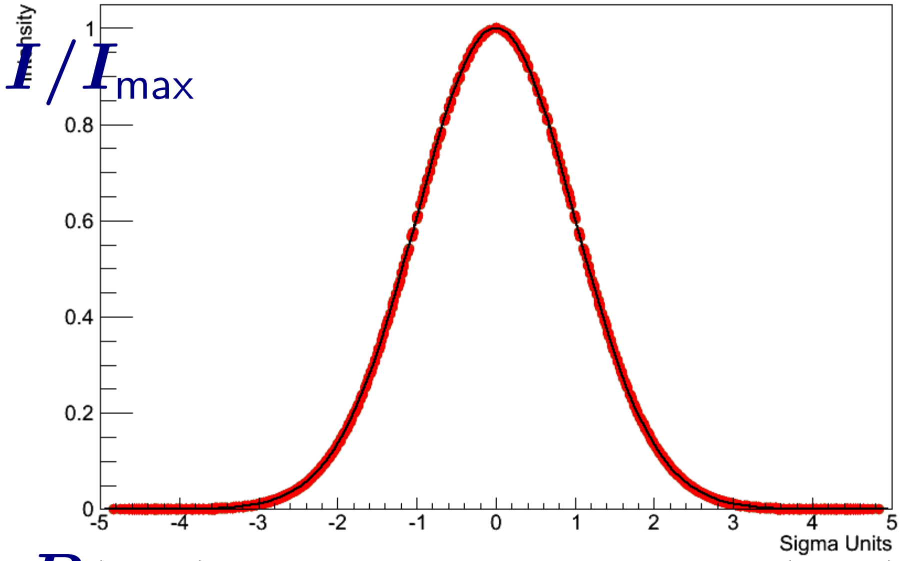
- Polarization and intensity profile can be described with gaussian distributions:

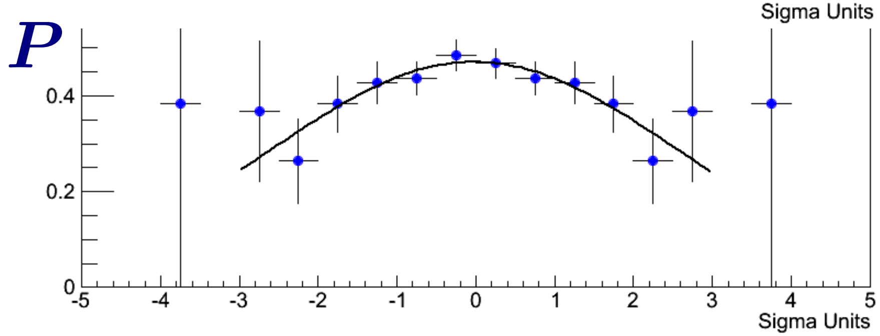
$$P = P_{\mathsf{max}} e^{-\frac{\vec{x}^2}{\sigma_P^2}}, \qquad I = I_{\mathsf{max}} e^{-\frac{\vec{x}^2}{\sigma_I^2}}$$

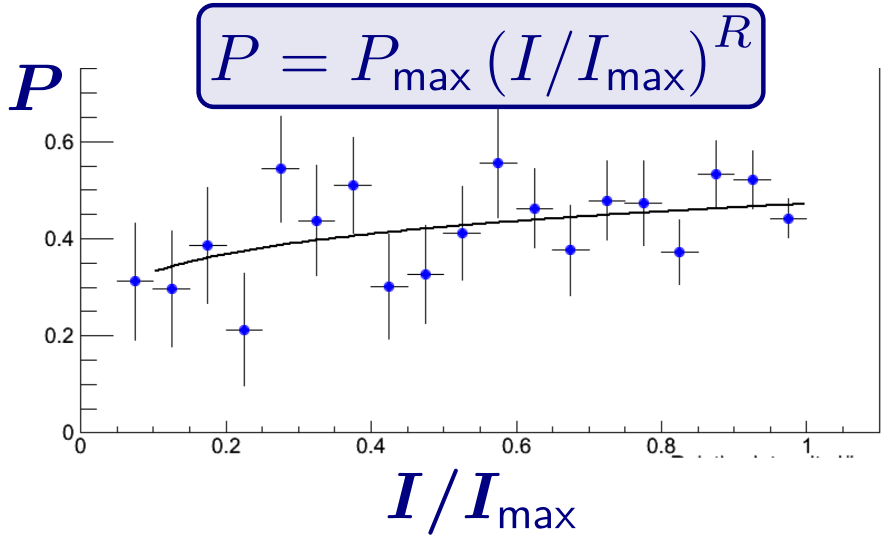
Measuring Beam Polarization Profile

- Assume gaussian profiles:
  $P = P_{\text{max}} \exp(-\frac{\vec{x}^2}{\sigma_P^2})$, $I = I_{\text{max}} \exp(-\frac{\vec{x}^2}{\sigma_I^2})$
- Polarization profile can be described by
  - Center value P_{max}
  - Profile parameter $R = \frac{\sigma_I^2}{\sigma_P^2}$
  - $R = 0$ if $\sigma_P = \infty$ *i.e.* no Pol. profile









Ultra-Thin Carbon Targets: Survival Rate

- 2009 (10 weeks) and 2011 (10 weeks) RHIC Runs
  - Carried through the runs on a single batch of targets
  - Some targets survived 300–400 measurements during 2–3 months
- In 2012 (10 weeks) and 2013 (14 weeks) RHIC Runs
  - Used three batches of 48 targets each

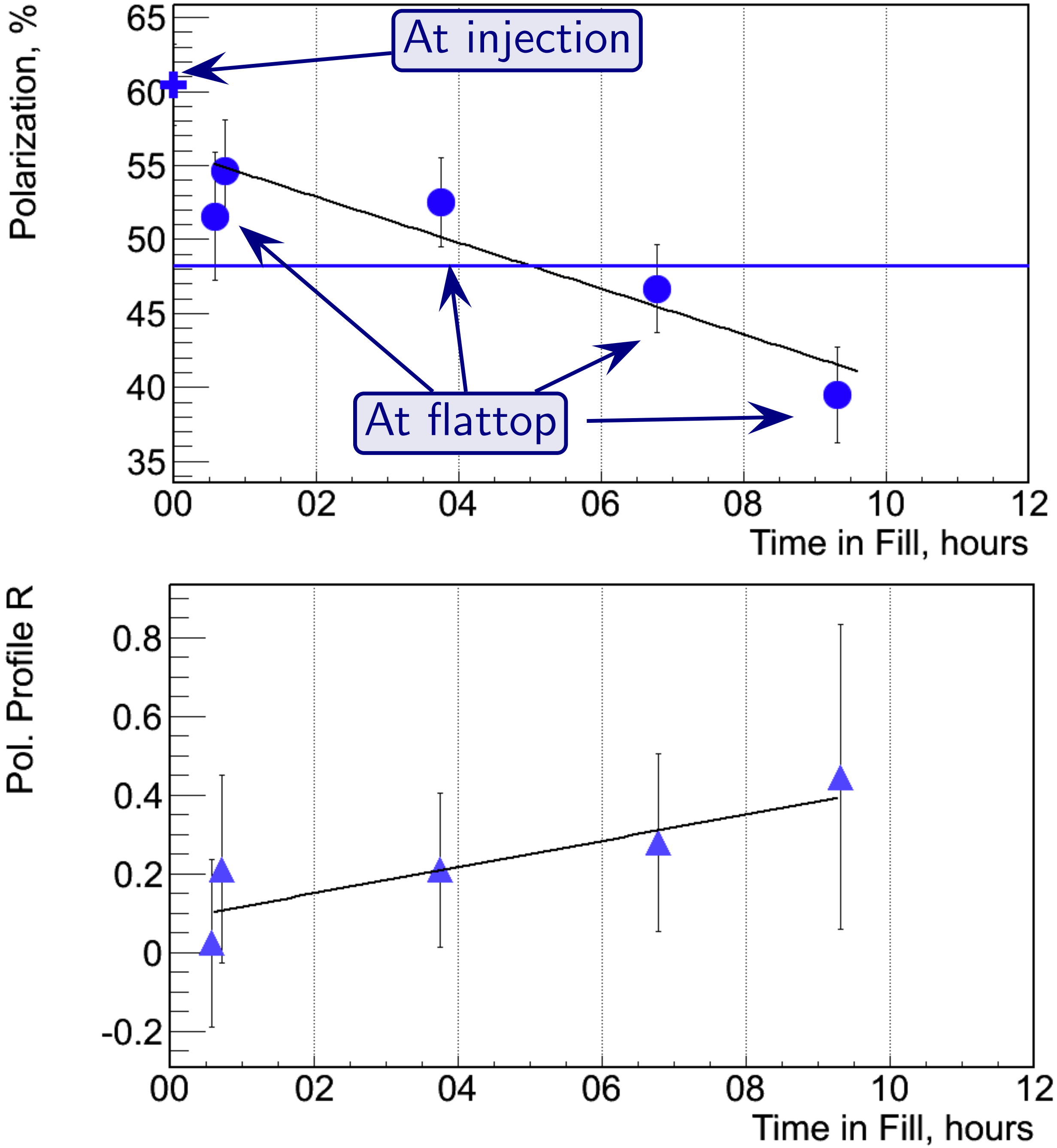
Carbon Target Crossing Beam

- The targets is attracted electrostatically to the beam
- No direct control of the amount of target material in the beam

Ultra-Thin Carbon Targets: The Challenge

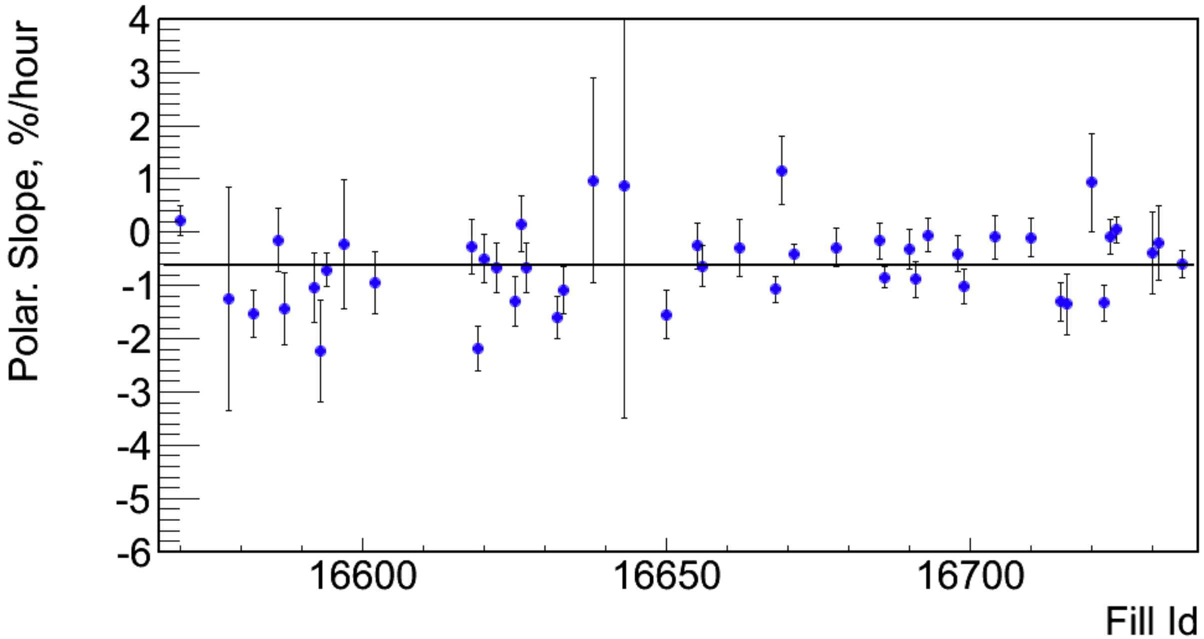
- Observations (naturally statistically limited)
  - **Confirmed:** The targets graphitize after exposure with the beam
  - **An indication:** Thicker targets can survive longer
  - **A hint:** Targets may survive longer if first exposed to low intensity beams
- Solutions to mitigate target losses
  - Tried to graphitize the targets on the bench test (not very successful)
  - Move targets farther from the beam while not in use
  - Use thicker targets
  - Conserved targets by reducing the number of measurements
- Future tests:
  - New target ladder geometry with fins to reduce the electric field from induced charge

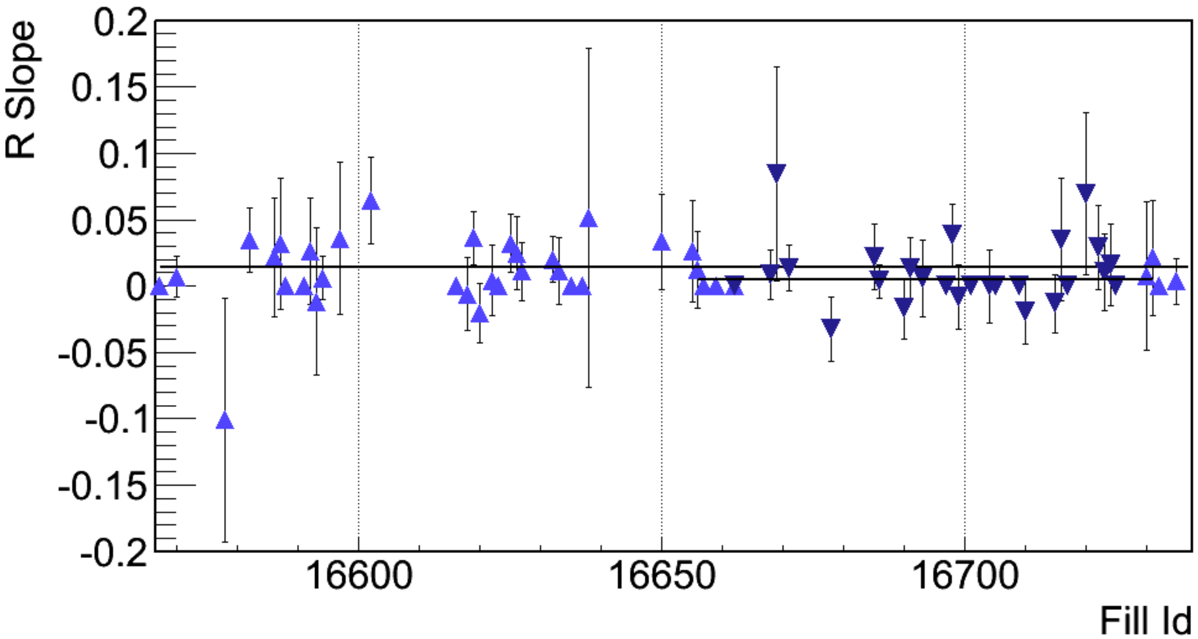
Polarization Losses in a Fill



- Polarization is lost during beam accelleration
- Polarization decreases during the fill while R increases
  - Losses consistent with beam profile broadening
  - $R_v \sim R_h \approx 0.20$ for accelerated beam
- With $\frac{dP}{dt}$ RHIC experiments can reweight individual fills according to their recorded luminosity

Change in Proton Beam Polarization during a Fill





- Linear approximation for beam polarization P and profile R in a fill:

$$P = P_0 + \frac{dP}{dt}t$$
$$R = R_0 + \frac{dR}{dt}t$$

- Average change in P and R is:

$$\frac{1}{P}\frac{dP}{dt} \sim -1\% \quad \text{per hour}$$
$$\frac{1}{R}\frac{dR}{dt} \sim +5\% \quad \text{per hour}$$

Systematic Uncertainties on Polarization (In collisions)

- **Overall scale uncertatinty** $\boldsymbol{\frac{\sigma(P)}{P} \approx 3\%}$
  - Due to normalization to the H-jet measurements
  - Includes:
    $\sim 3\%$ on H-jet target polarization,
    $\sim 1\%$ due to background dilution, and
    $\lesssim 2\%$ reflects uncertainty in average difference between H-jet and pC
- **Fill-to-fill uncorrelated uncertatinty** $\boldsymbol{\frac{\sigma(P)}{P} \approx 5 - 8\%}$
  - Scales down as $1/\sqrt{N}$ when fills combined
  - Statistically dominated
  - Includes:
    $\sim 2.2\%$ due to possible profile miss-measurement. Determined as:

$$\langle P \rangle = \frac{P_{\text{max}}}{\sqrt{1+R}} \quad \text{vs.} \quad \langle P \rangle_{\text{sweep}}$$

Summary

- **p-Carbon polarimeters at RHIC performed well in 2011, 2012, and 2013**
- Minimal changes in the setup allowed for year-to-year systematic studies
- p-Carbon polarimeters work well for
  - Measurements of beam polarization profile
  - Statistically significant measurements of polarization losses during a RHIC store
- Ongoing efforts and improvements:
  - Target lifetime with higher beam intensities
  - More control over the amount of material in the beam
  - Absolute detector calibration will benefit in another "absolute" polarimeter
  - Potential to precisely measure pC A_N at very high beam energies