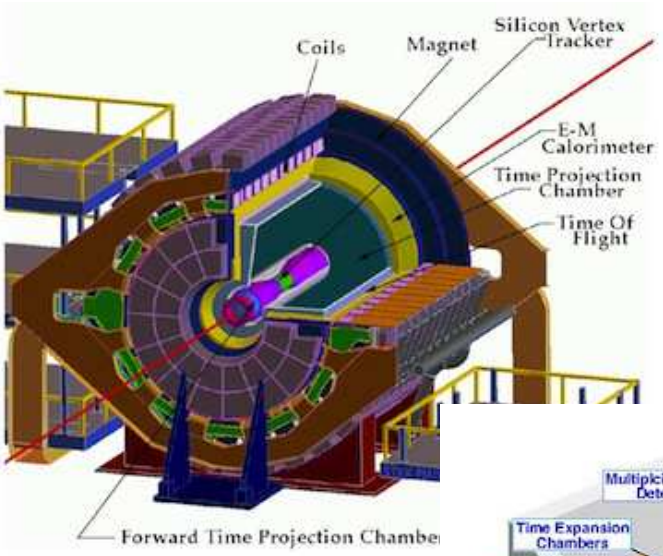
Measuring Polarization of Proton Beams at RHIC

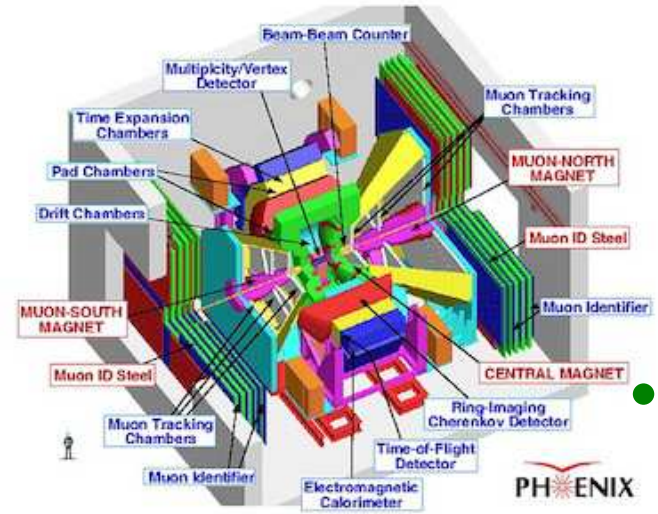
Dmitri Smirnov
Brookhaven National Laboratory

for the RHIC Spin Group

June 10, 2011

Physics Objectives and Facilities





- Two operational detectors STAR and PHENIX
  - **Measure transverse and longitudinal spin asymmetries**
  - **Understand gluon polarization in the proton spin structure**

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_z + \Delta g$$

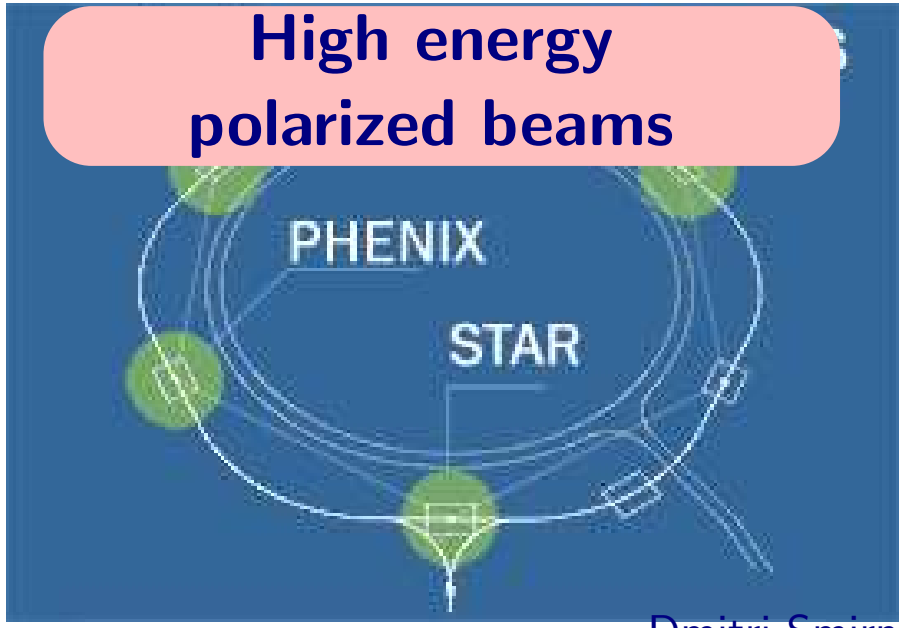
$\Delta\Sigma \sim 15\%$ – quark contribution

$\Delta g =?$ – gluon contribution

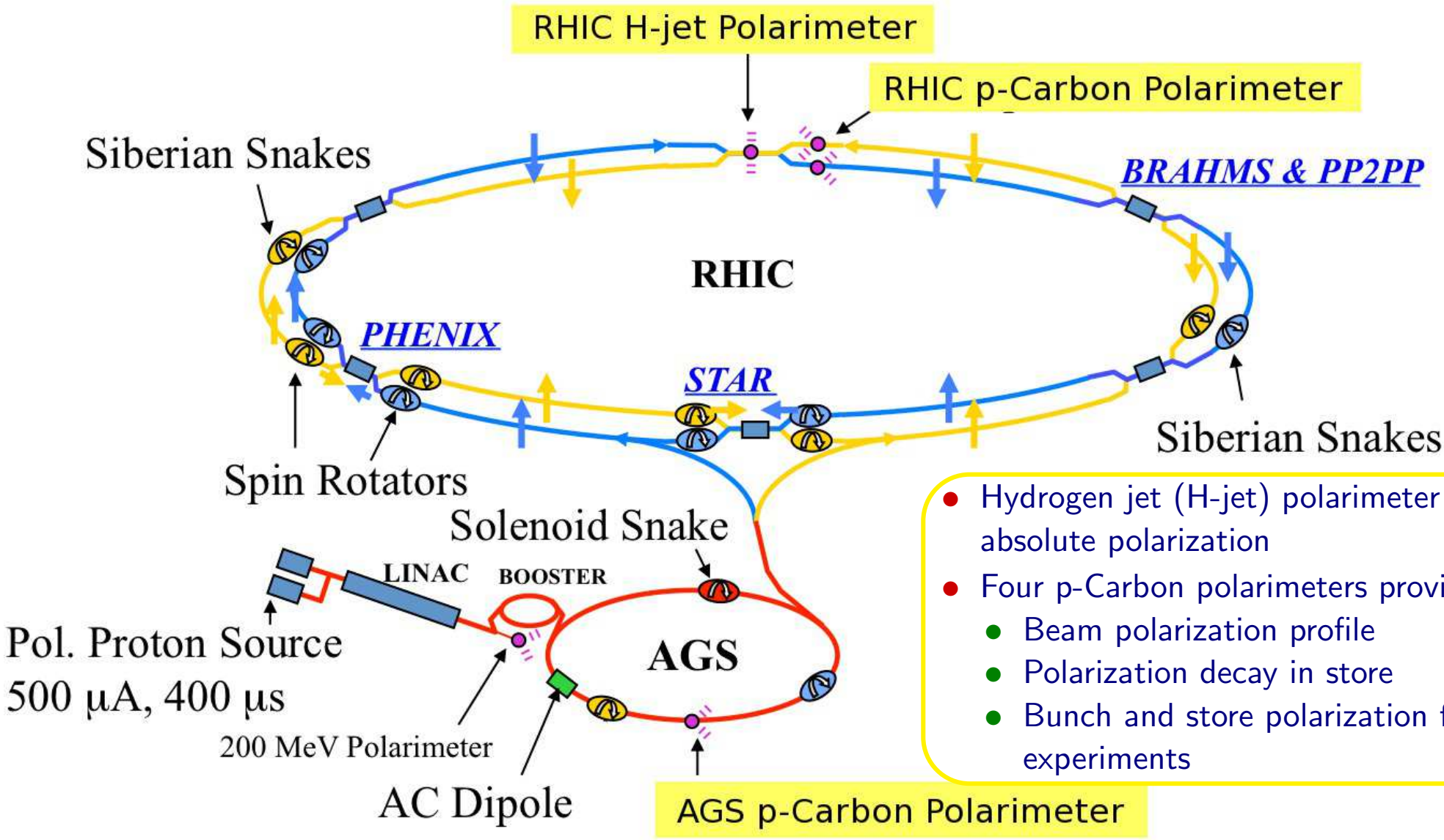
$L_z =?$ – orbital motion

- Study quark-gluon plasma

- Relativistic Heavy Ion Collider (RHIC) operational since 2000
  - **Provides polarized proton beams**
  - **Wide range of energies 24 GeV to 250 GeV**
  - Also unpolarized heavy ion beams
    Au-Au, d-Au, Cu-Cu



RHIC and AGS Polarimeters

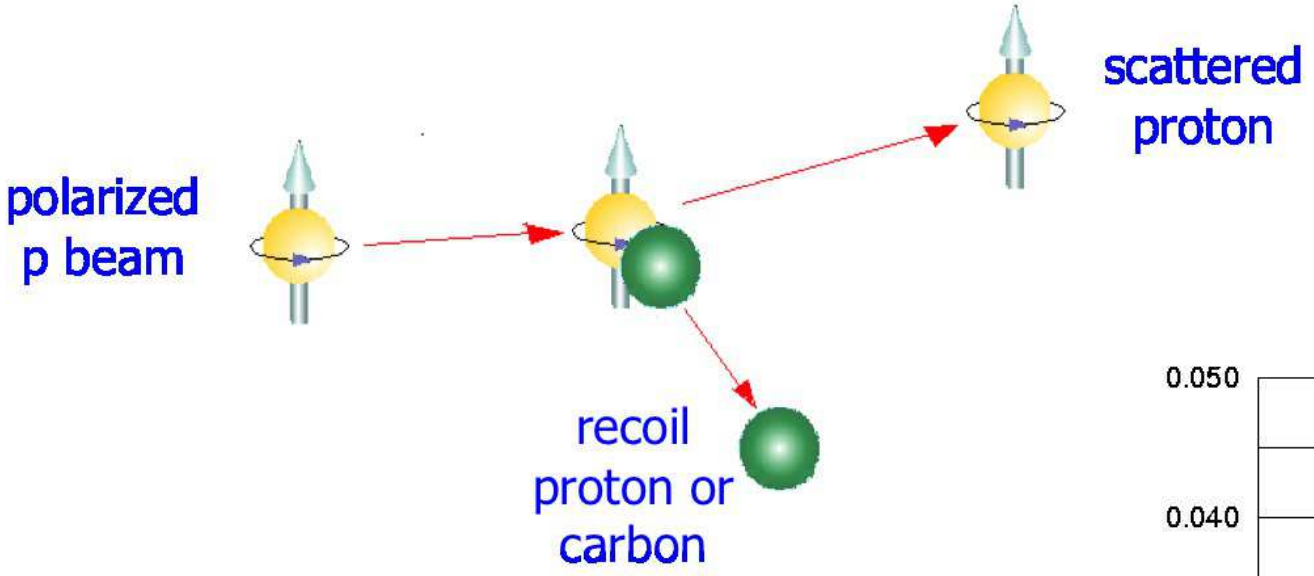


- Hydrogen jet (H-jet) polarimeter provides absolute polarization
- Four p-Carbon polarimeters provide:
  - Beam polarization profile
  - Polarization decay in store
  - Bunch and store polarization for the experiments

- Polarimeter at Alternatig Gradient Synchrotron (AGS) is similar to RHIC p-Carbon polarimeter
- PHENIX and STAR local polarimeters monitor spin direction at collision points

Measuring Beam Polarization

- The kinematics of elastic scattering is fully defined by the recoil products
- The momentum transfer $t = (p_{\text{in}} - p_{\text{out}})^2 = -2ME_{\text{kin}}$

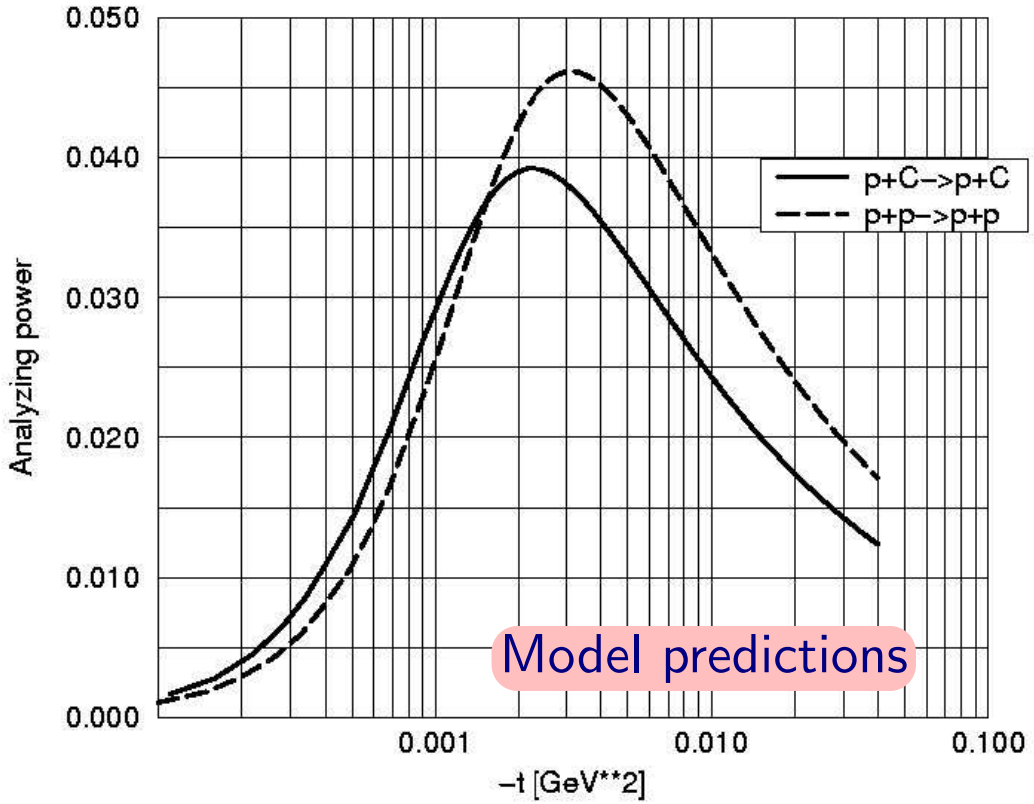


Analyzing power A_N is defined by the interference between the electromagnetic and strong amplitudes

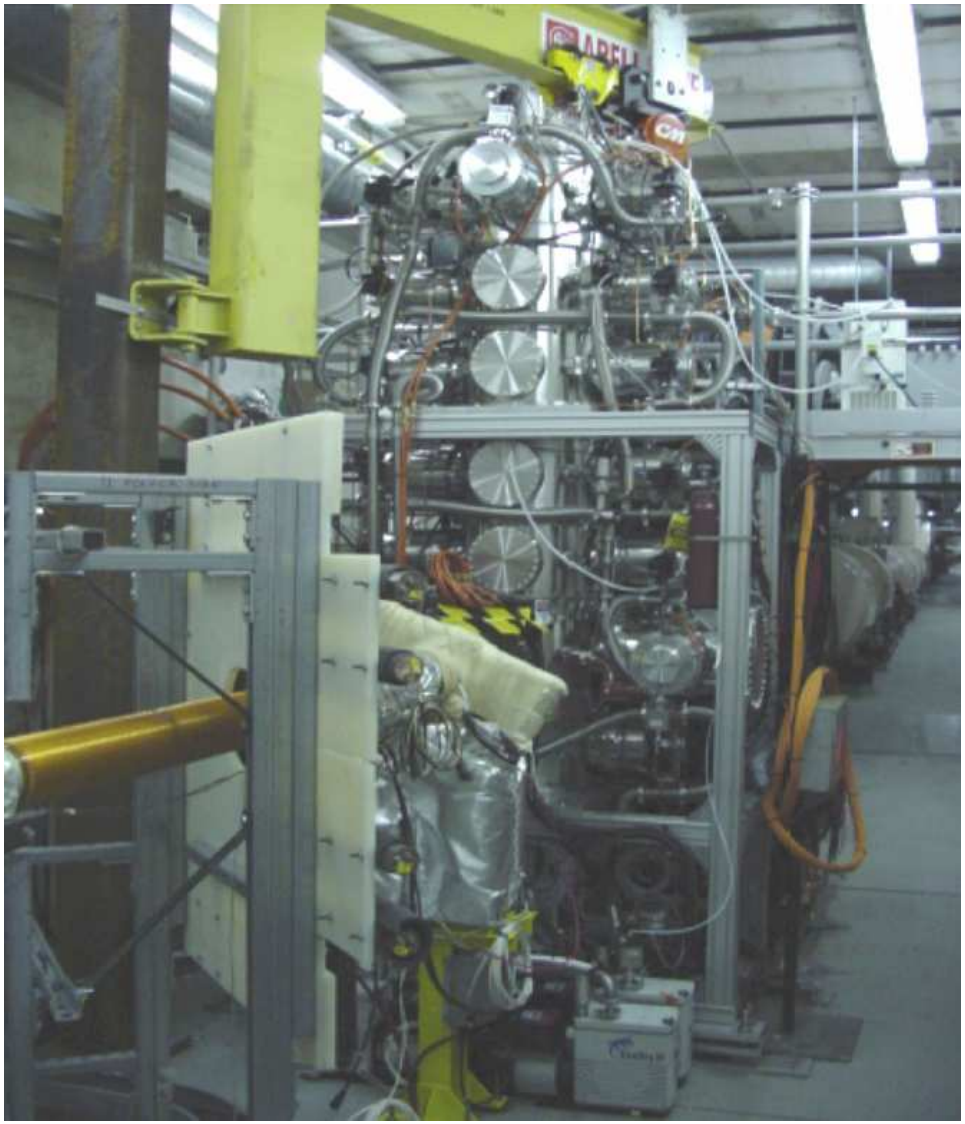
- In the experiment we measure asymmetry ε

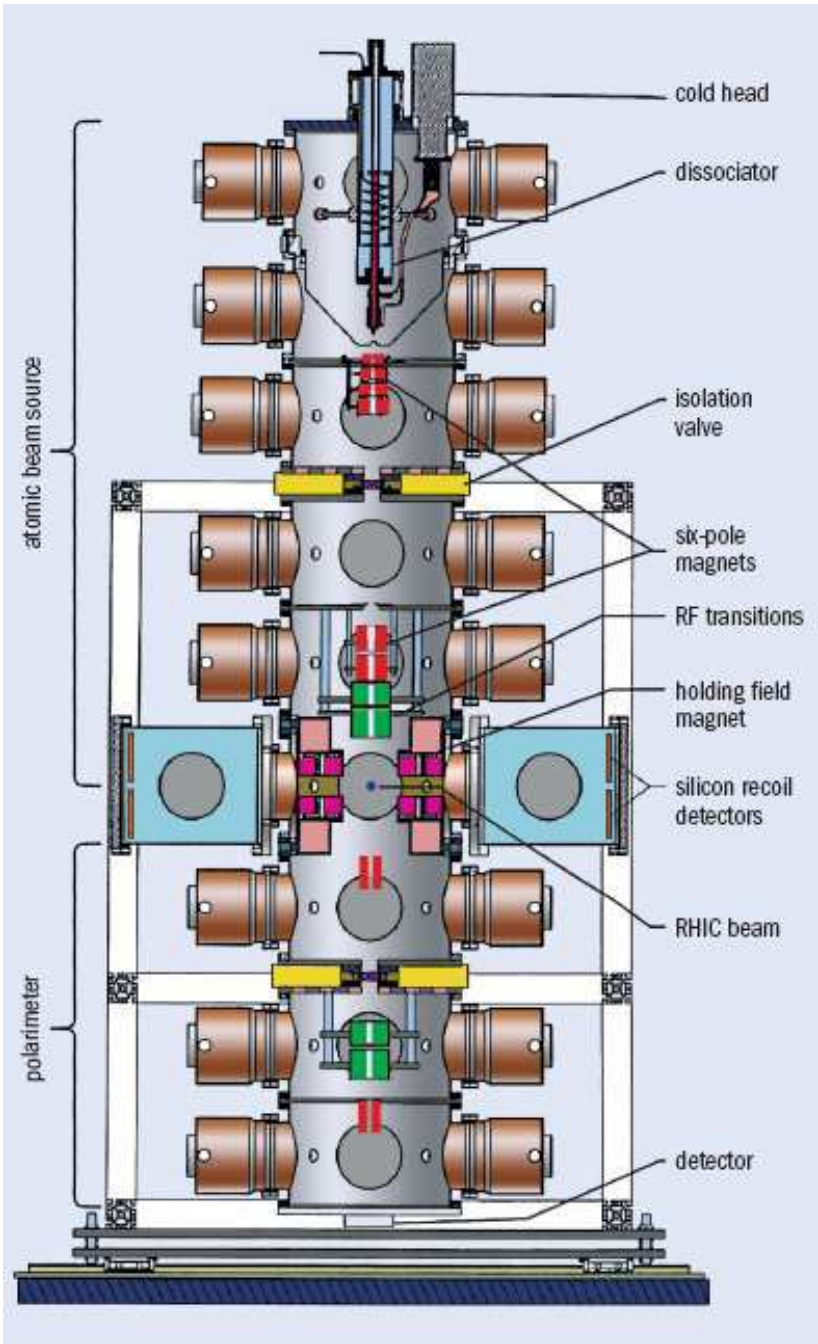
$$\varepsilon = \frac{N_L - N_R}{N_L + N_R}, \qquad \varepsilon = \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$$

- Measured polarization $P = \varepsilon / A_N(t)$, where $A_N(t)$ is the **analyzing power**



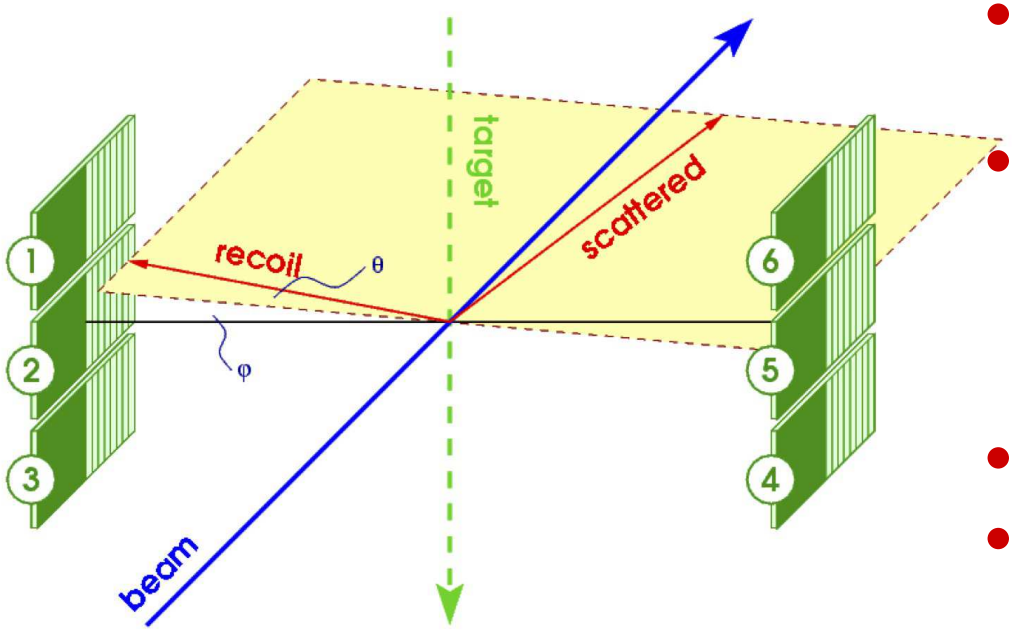
Hydrogen Jet Polarimeter





- The polarized jet target is vertical
- Target polarization cycles $\uparrow / - / \downarrow$ every 500/50/500 seconds

Hydrogen Jet Polarimeter: Kinematics



- Both beams separated by ~ 4 mm intersect the hydrogen jet target
- The beam and the target are both protons:

$$P_{\text{beam}} = -\frac{\varepsilon_{\text{beam}}}{\varepsilon_{\text{target}}} \times P_{\text{target}}$$

- P_{target} is measured by a Breit-Rabi polarimeter
- After correction for molecular contamination in the jet

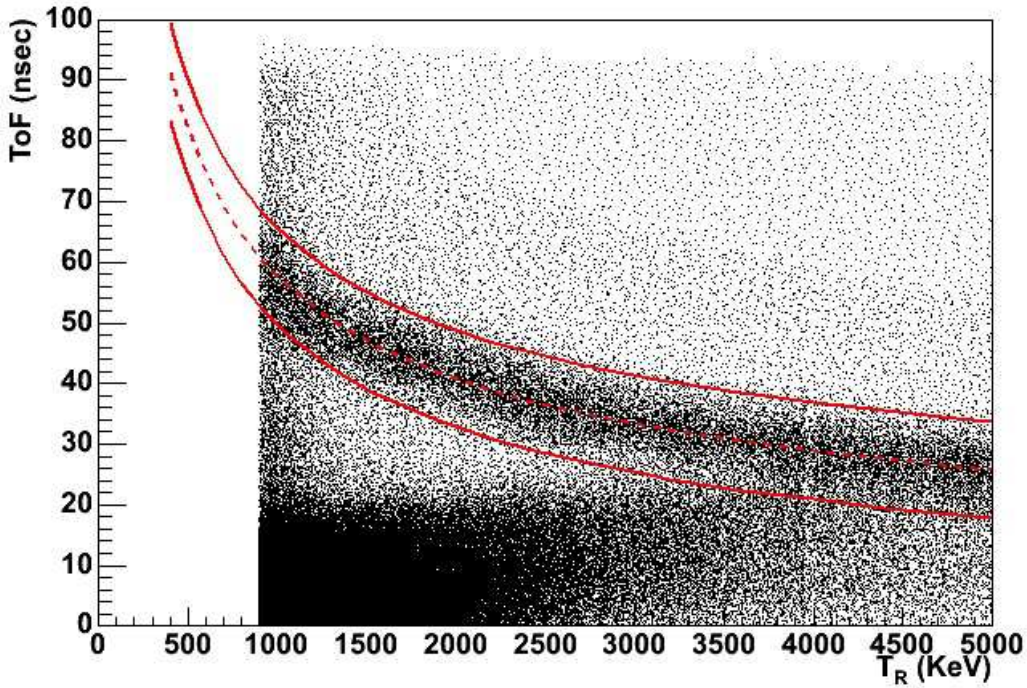
$$P_{\text{target}} \approx 92 \pm 2\%$$

- Elastic events are easily identified from non-relativistic equation

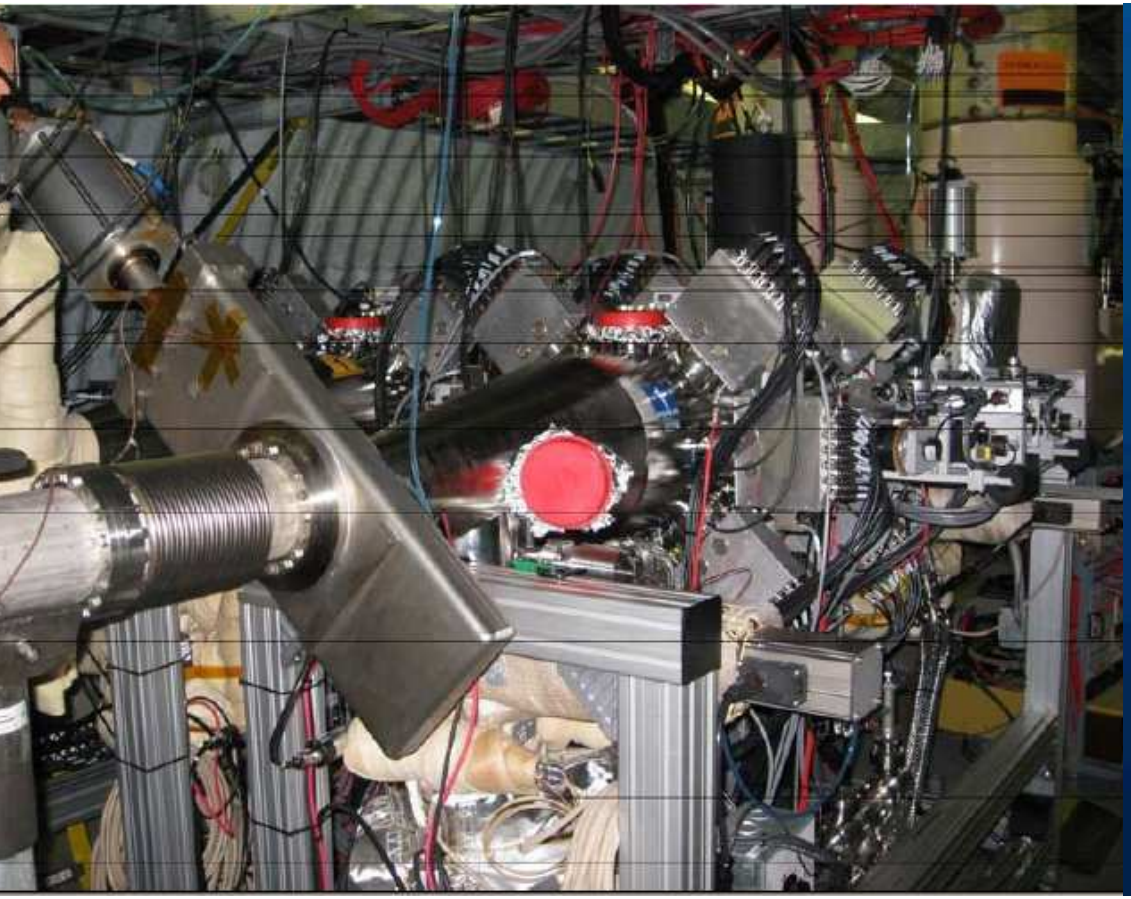
$$t_{\text{TOF}} = L\sqrt{\frac{m_p}{2E_{\text{kin}}}}$$

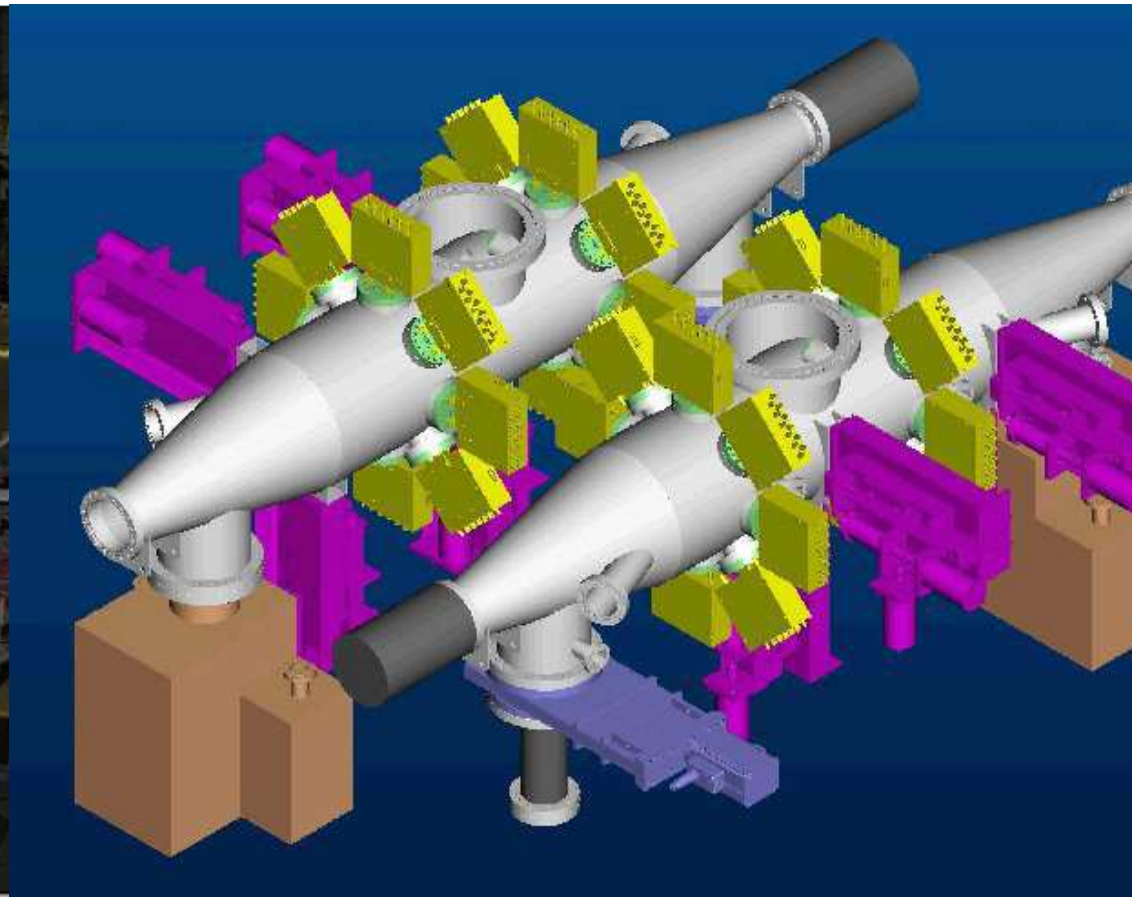
and recoil angle Θ

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

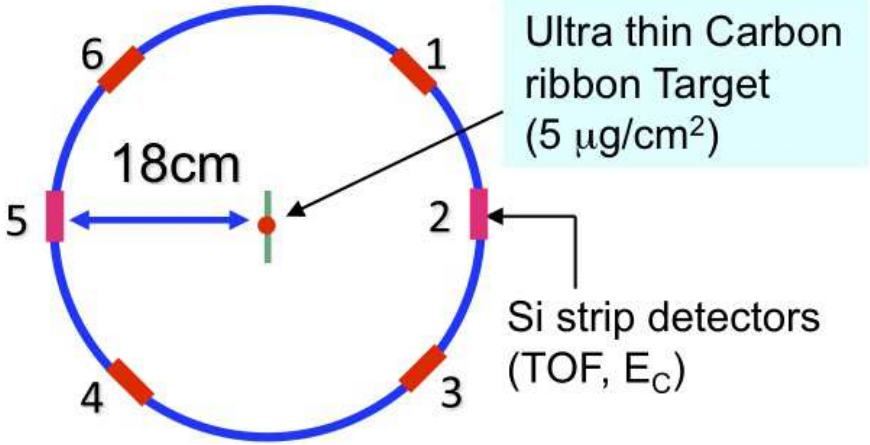


p-Carbon Polarimeters

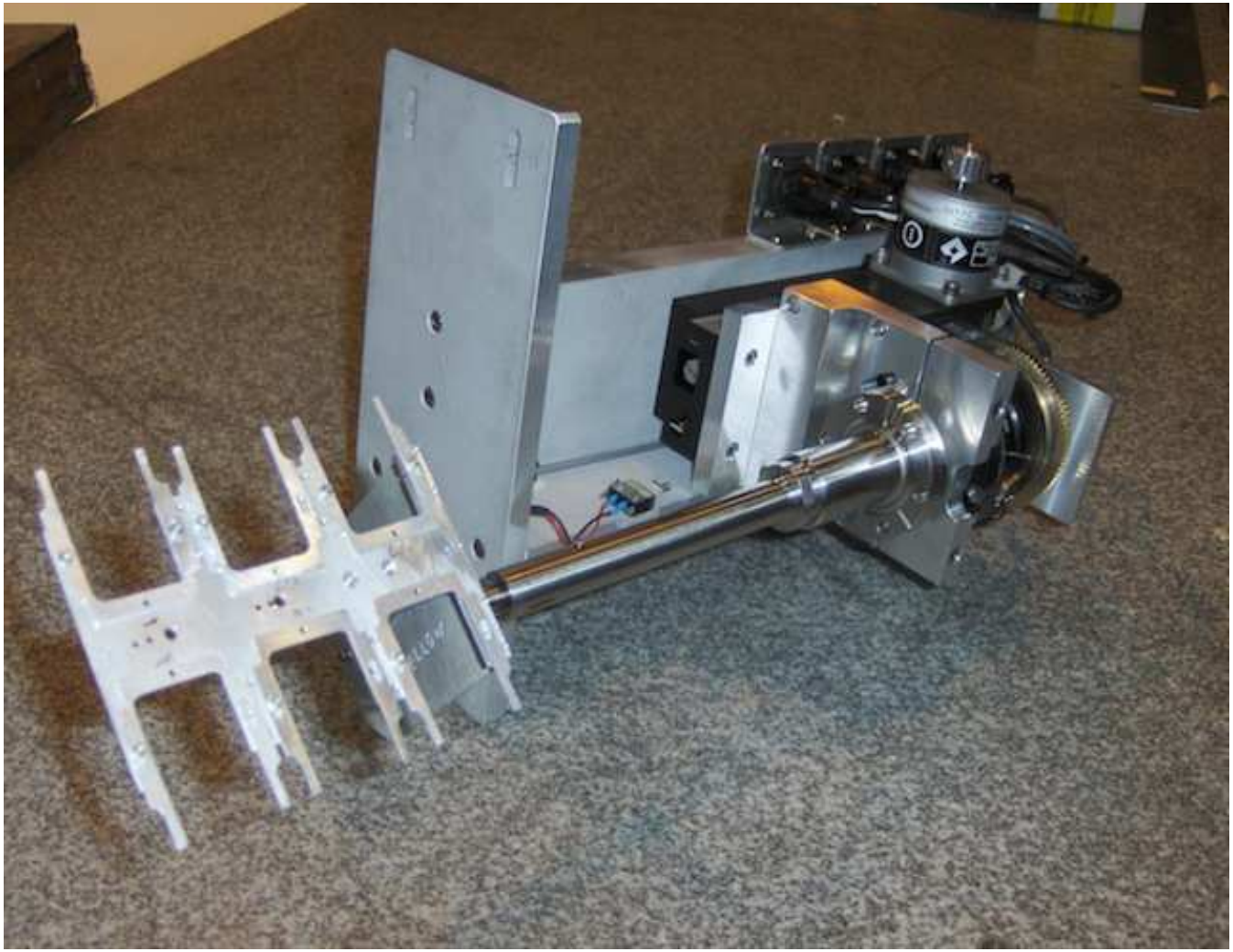




- Two polarimeters in each ring
- The readout system is multiplexed between the two pairs
- Each polarimeter employs six vertical and six horizontal ultra thin carbon targets

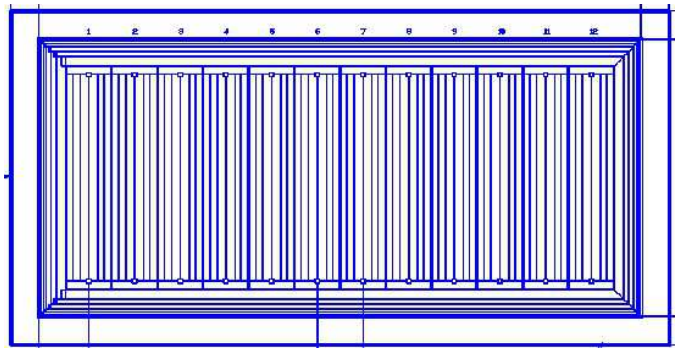


p-Carbon Polarimeters: Targets



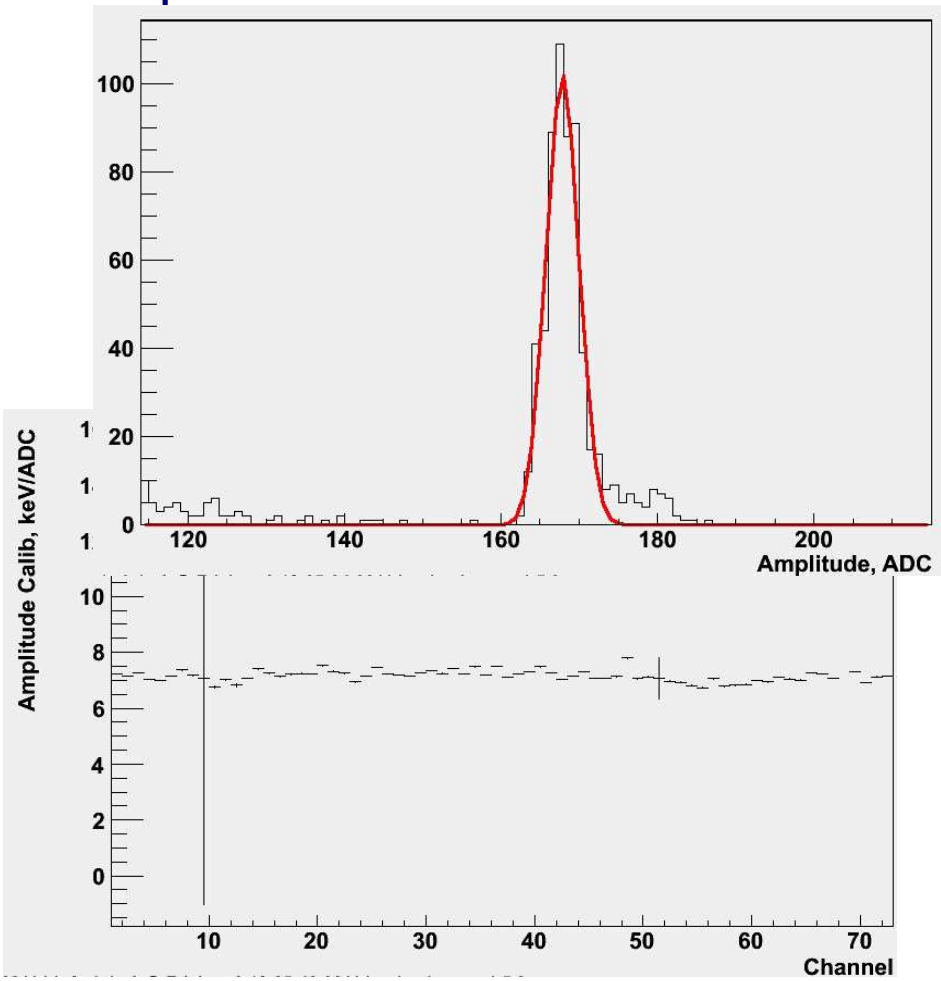
- Typical target size is $2.5\text{cm} \times 5\mu\text{m} \times 30\text{nm}$
- Targets are made by vacuum evaporation-condensation onto glass substrate
- Two stepping motors are used to move the assembly and to rotate the targets into the beam

p-Carbon Polarimeters: Detector Calibration

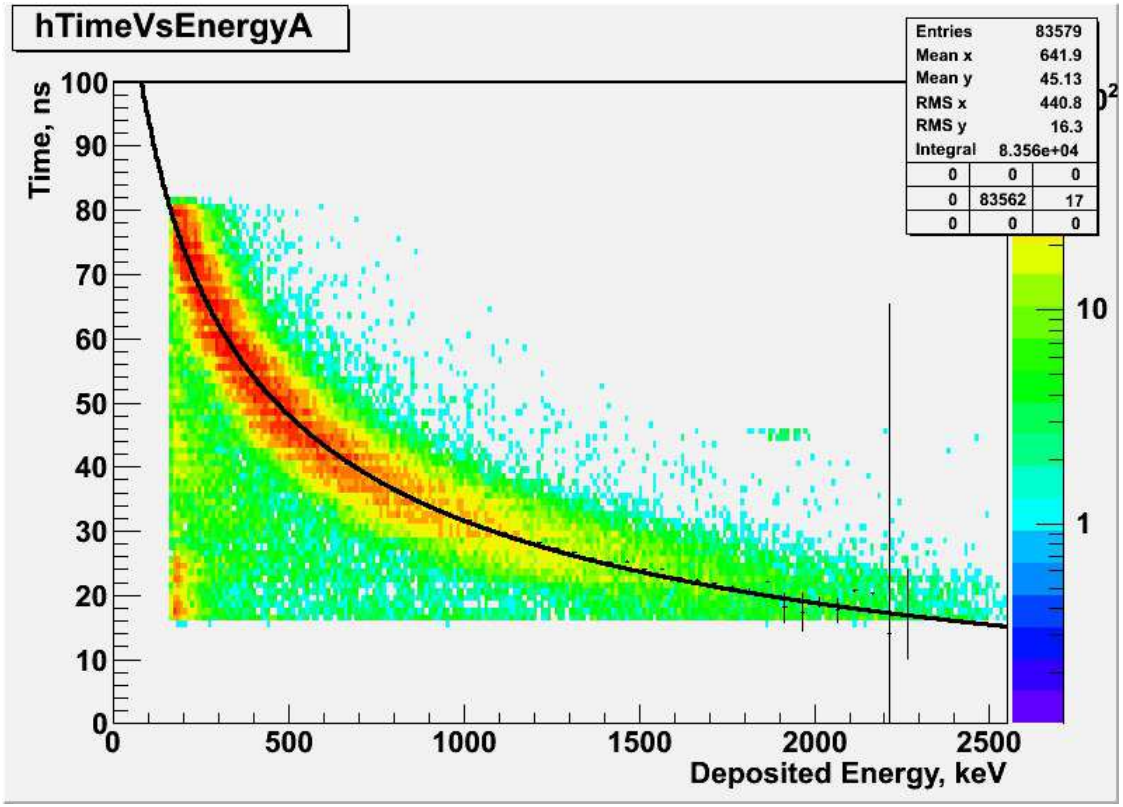


12 strips 2×10 mm

- Detectors calibrated with α source (^{241}Am, 5.5 MeV)
- The α signal is attenuated by 5 to fit the carbon dynamic range
- The α's do not probe the surface of the detector where the carbon ions stop
  Unaccounted energy losses $\Rightarrow$
  "effective dead-layer"



p-Carbon Polarimeters: Kinematics



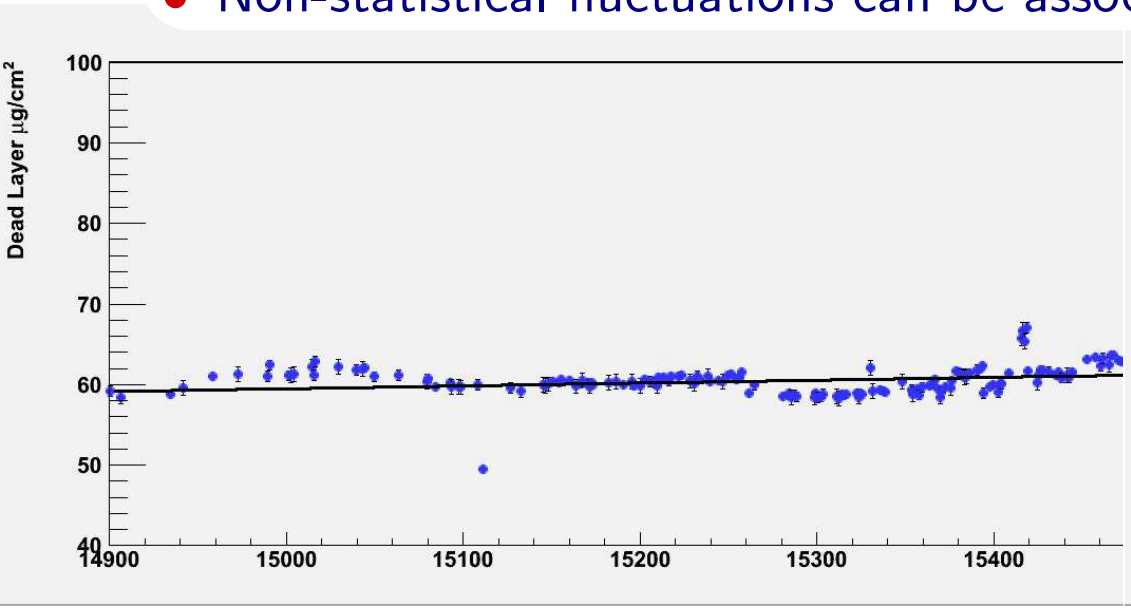
- Calibration parameters the **time offset** t_0 and the **effective dead layer thickness** x_{DL} extracted from the non-relativistic equation:

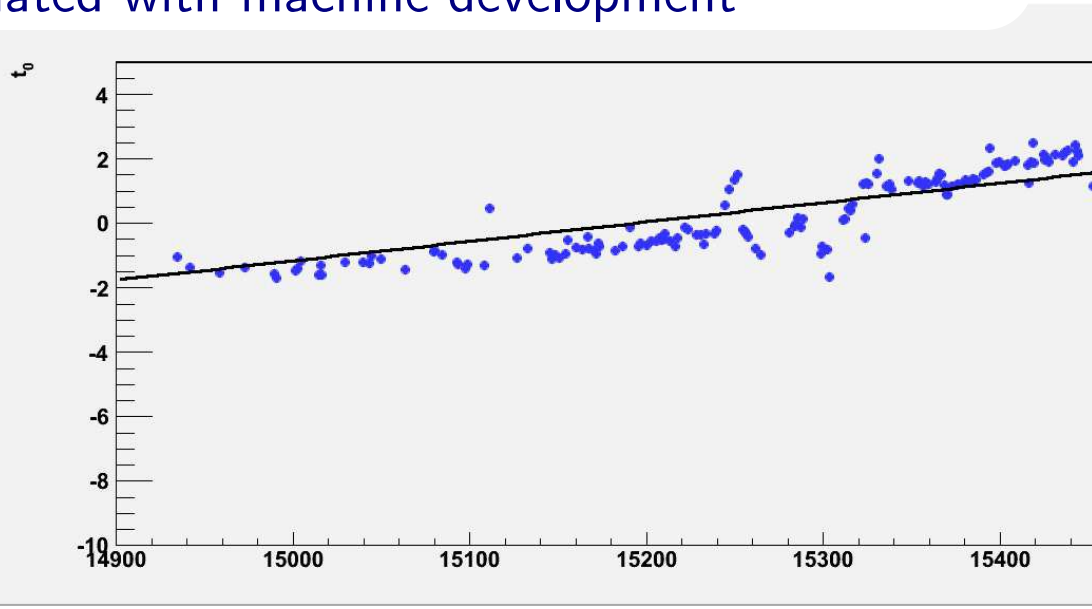
$$E_{\mathrm{meas}} + E_{\mathrm{loss}} = \frac{M_C}{2} \times \frac{L^2}{(t_{\mathrm{meas}} + t_0)^2},$$

where $E_{\mathrm{loss}} = E_{\mathrm{loss}}(E_{\mathrm{meas}}, x_{\mathrm{DL}})$ is an energy loss parameterization for carbon

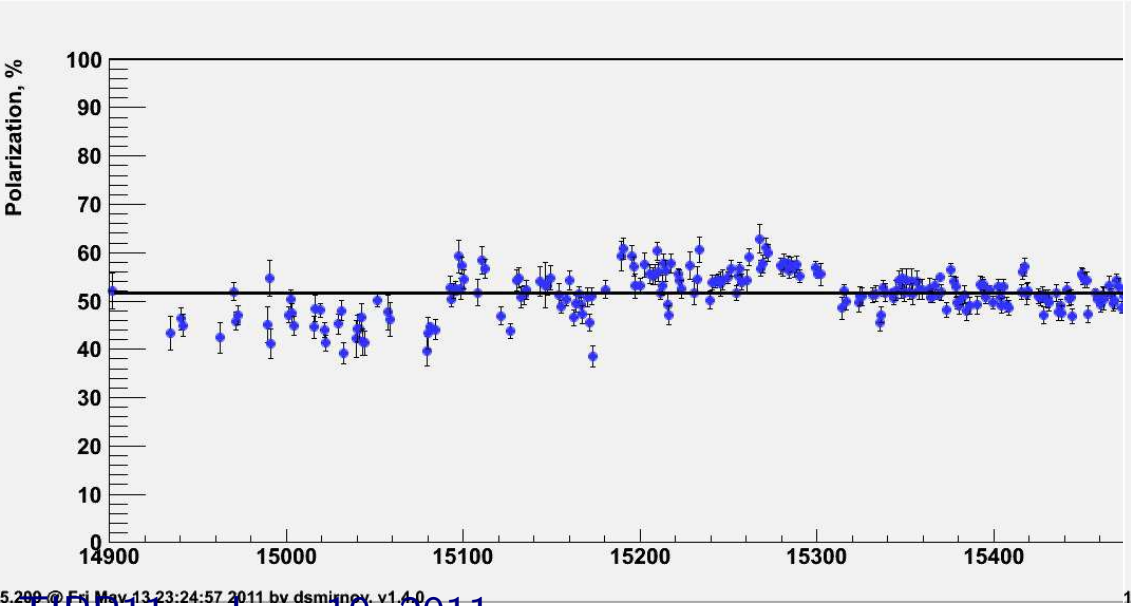
p-Carbon Polarimeters: Monitoring Stability

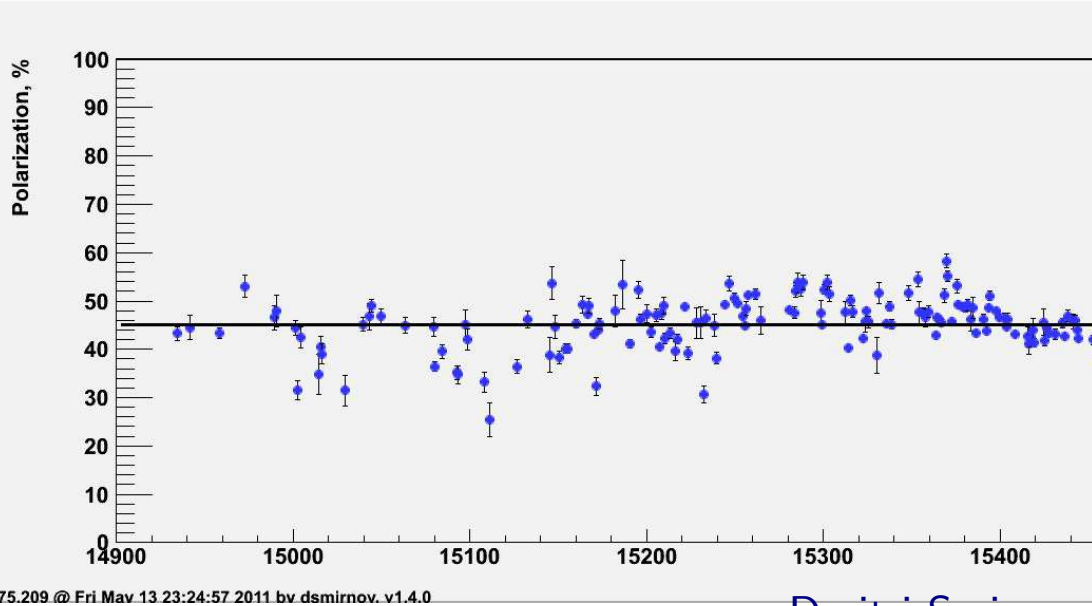
- Detector stability is monitored by looking at how parameters evolve in time
- Non-statistical fluctuations can be associated with machine development



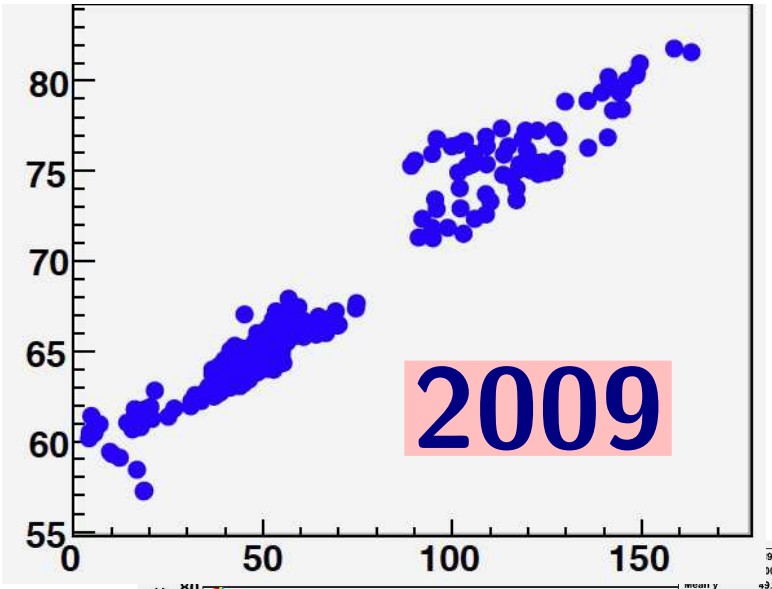


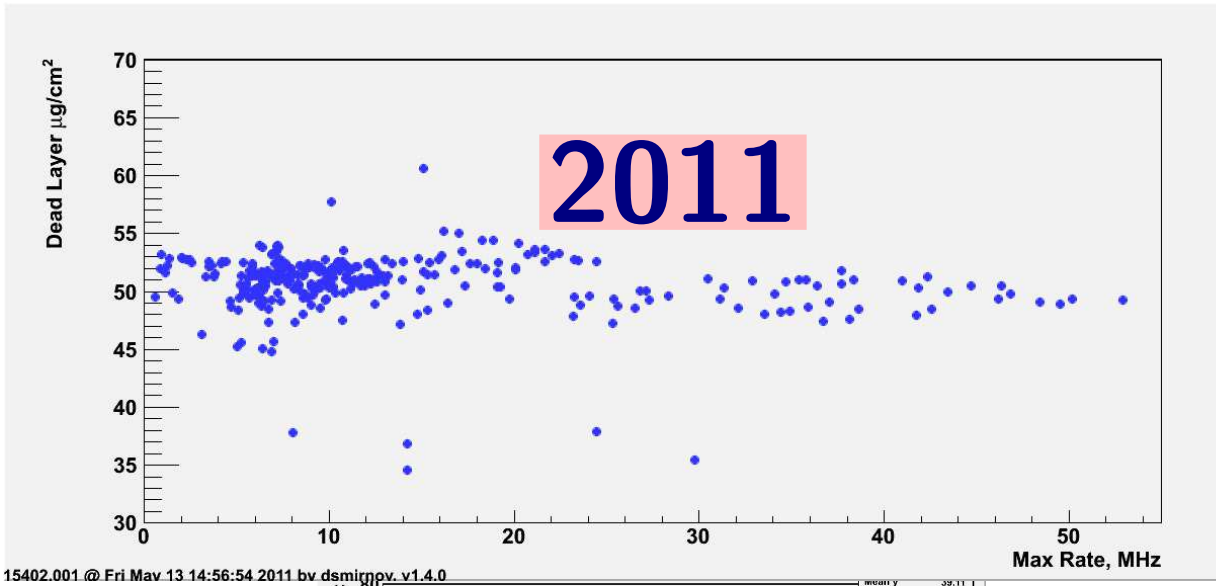
- Based on the reconstructed kinematics we measure beam polarization





Solving Problems: Event Pile-up

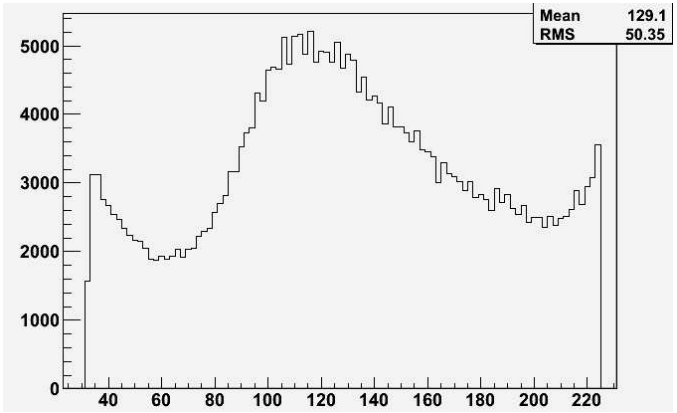


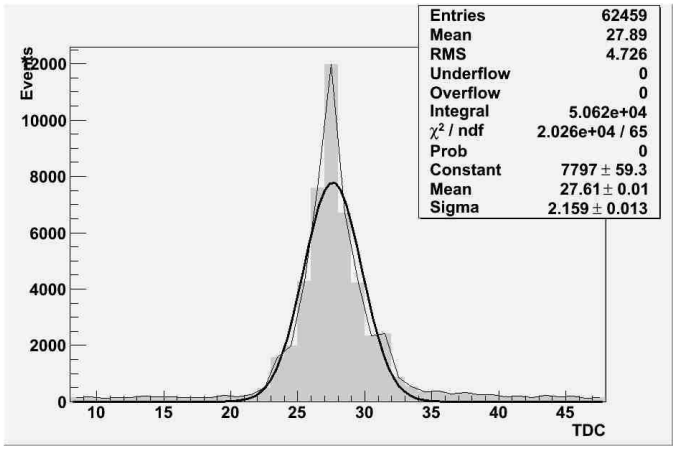


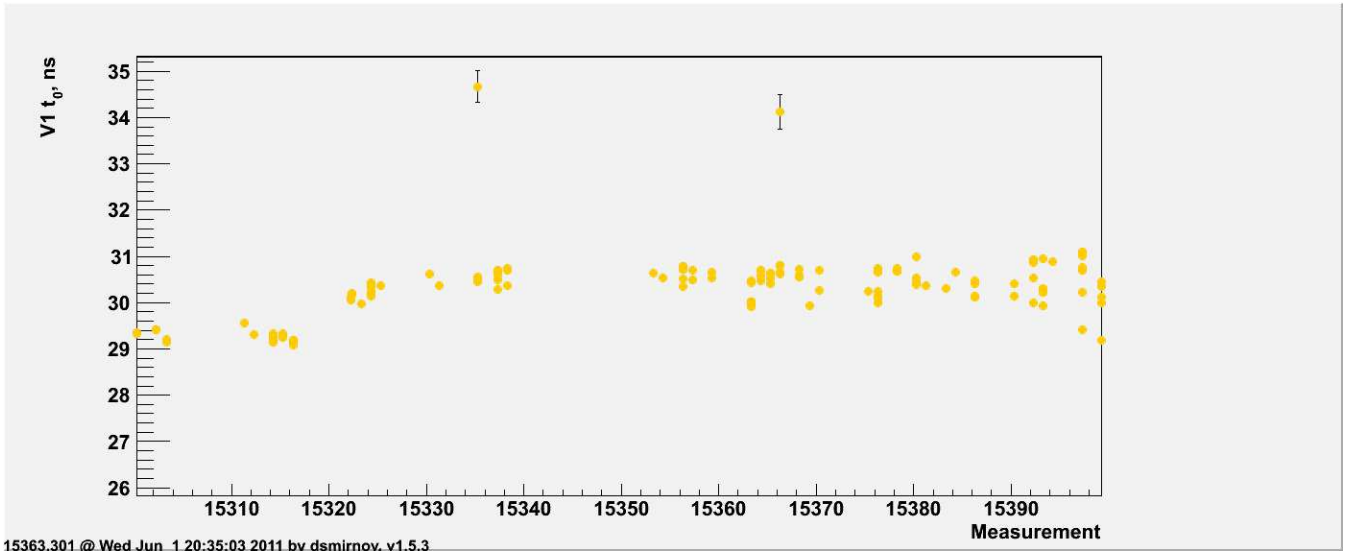
- In 2010 the system was upgraded to address the rate problems
  - Faster current sensitive preamplifiers replaced charge sensitive ones
  - The effective signal width decreased from few 10's ns to ~ 10 ns

Solving Problems: t_0 Time Offset

- To monitor the time offset t_0 additional scintillators were installed
- The PMT gain is adjusted to match prompt MIPs

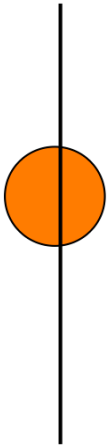


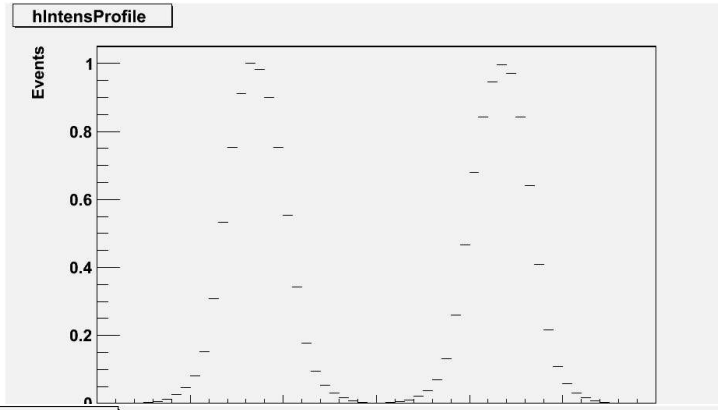


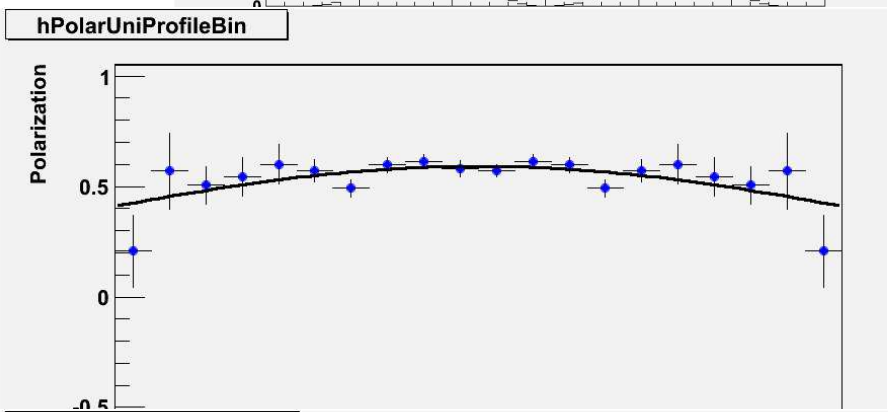


- Final conclusion is to be made on the benefits for the future use

Beam Polarization Profile







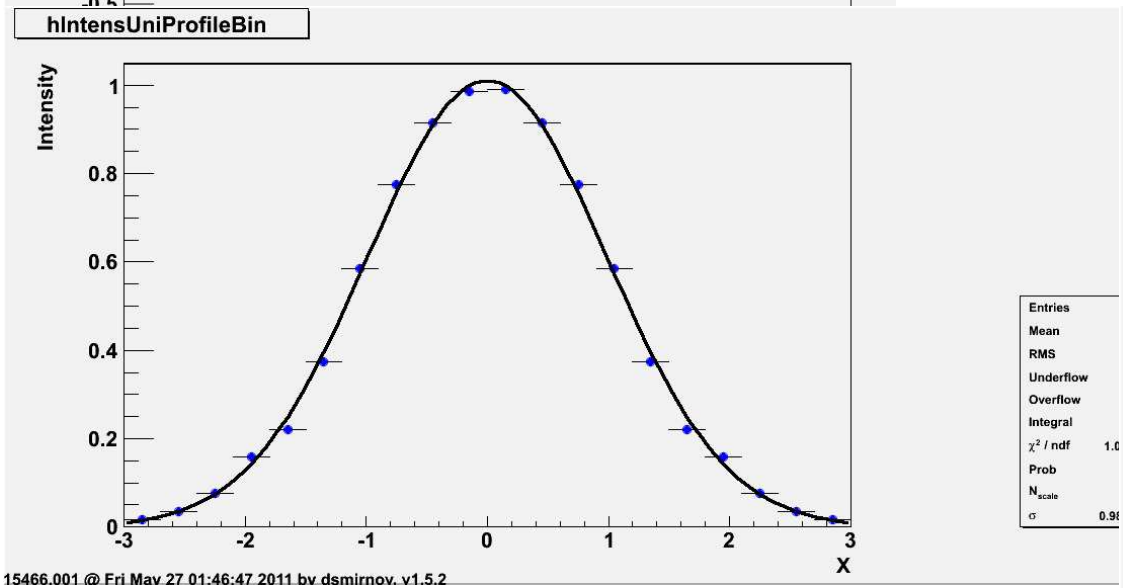
- Precise target position is not necessary if the beam is assumed to have a gaussian profile

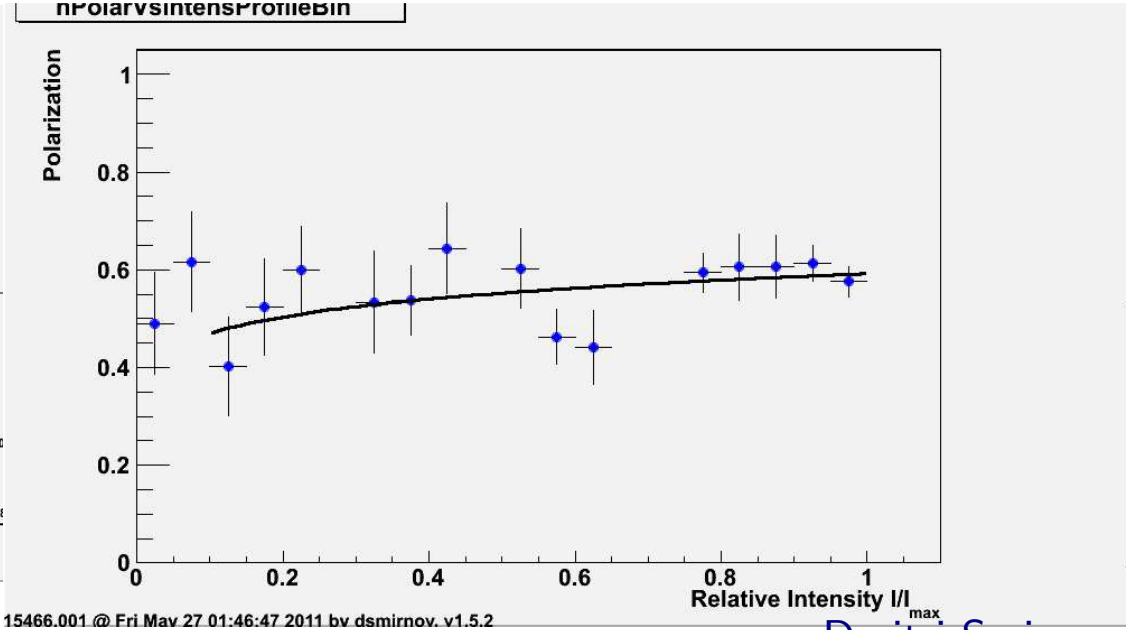
$$I(x) = I_{\max} e^{-\frac{x^2}{2\sigma_I^2}}, \qquad P(x) = P_{\max} e^{-\frac{x^2}{2\sigma_P^2}}$$

x can be either time or distance

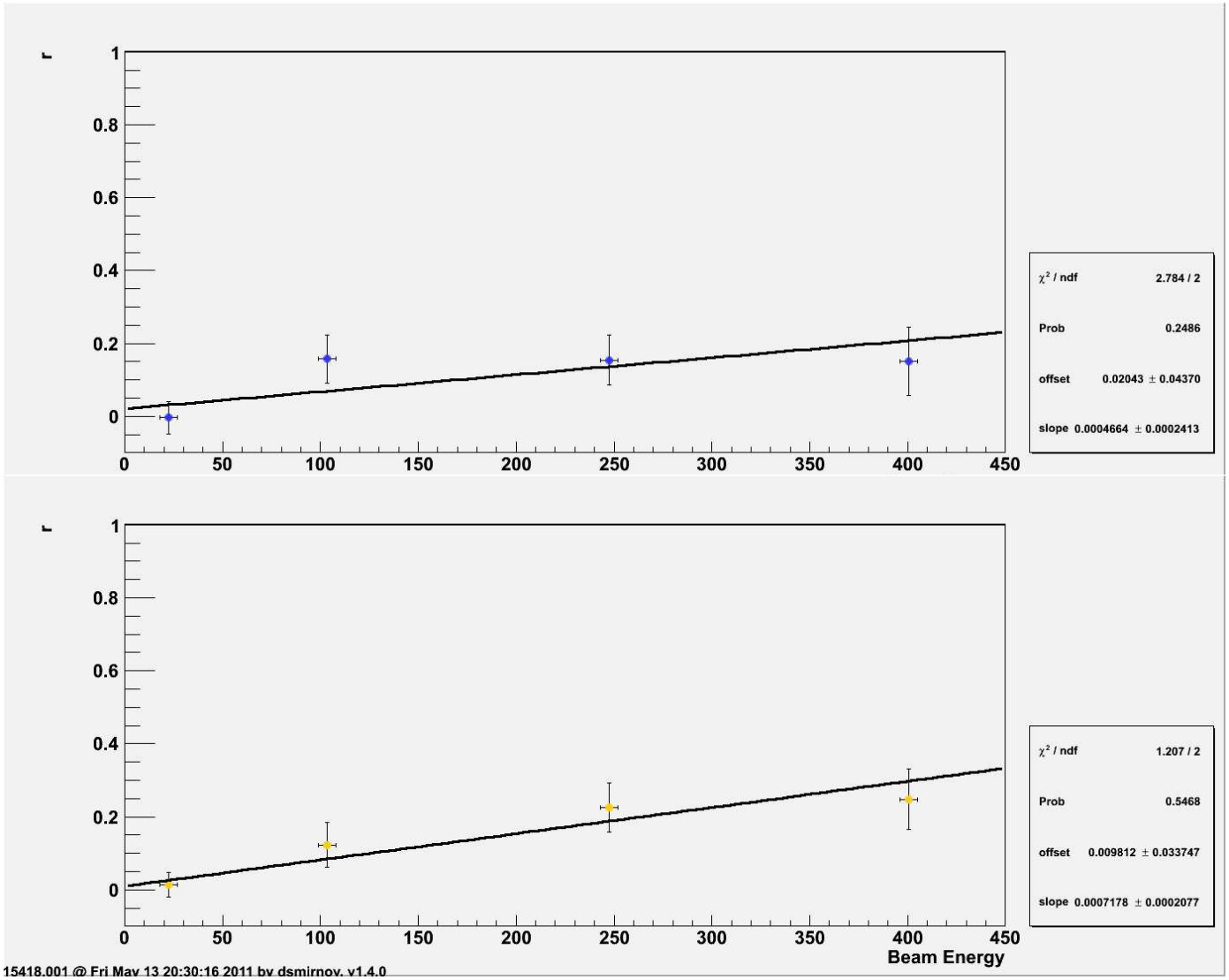
- The intensity and polarization can be related as

$$\frac{P}{P_{\max}} = \left(\frac{I}{I_{\max}}\right)^r \quad \text{with} \quad r = \frac{\sigma_I^2}{\sigma_P^2}$$





Beam Polarization Profile



- Special ramp-up/ramp-down study confirmed the widening of the polarization profile
  - Note: The "400 GeV" point corresponds to actuall energy of 100 GeV after a ramp-down from 250 GeV

Overview of RHIC Polarimeters

	H-jet Polarimeter	p-Carbon Polarimeters
Target	Polarized atomic hydrogen gas jet target	Ultra thin carbon ribbon
Calibration	Self-calibrating due to known target polarization	Normalized to H-jet due to lack of direct energy scale calibration
Event Rate	~ 20 Hz Stat. uncertainty $\sim 8\%$ in 6–8 hour fill	~ 2 MHz Stat. uncertainty $\sim 2\%$ per measurement
Operation	Continuous throughout a store	Few minutes every few hours
Role	• Average beam polarization • Calibration for other polarimeters	• Fast online feedback • Beam profile • Bunch by bunch polarization • Store by store polarization for the experiments

Summary

- **pp elastic scattering in CNI region is well suit for polarimetry in wide beam energy range**
- RHIC polarimeters are non-destructive, unique, and compliment each other
- Upgrade for Run 2011 eliminated some problems
  - The benefit from the promt monitors is under investigation
- **Polarimeters provide feedback for the accelerator team:**
  - Beam emittance
  - Horizontal and vertical beam polarization profiles
  - Polarization loss in transfer
  - Beam polarization decay
- Currently all polarization measurements rely on the H-jet polarimeter
  - **Desired redundancy in polarization measurement can be achieved if p-Carbon polarimeters are calibrated by other means**
- An ongoing effort aims to better understand the systematic effects in polarization measurements

RHIC Spin Group (Polarimetry) in 2010/2011

Igor Alekseev
Elke Aschenauer
Grigor Atoian
Sasha Bazilevsky
Alan Dion
Haixin Huang
Yousef Makdisi
Andrei Poblaguev
Bill Schmidke
Dmitri Smirnov
Dima Svirida
Anatoli Zelenski

RHIC Spin Group web page