Radial polarization

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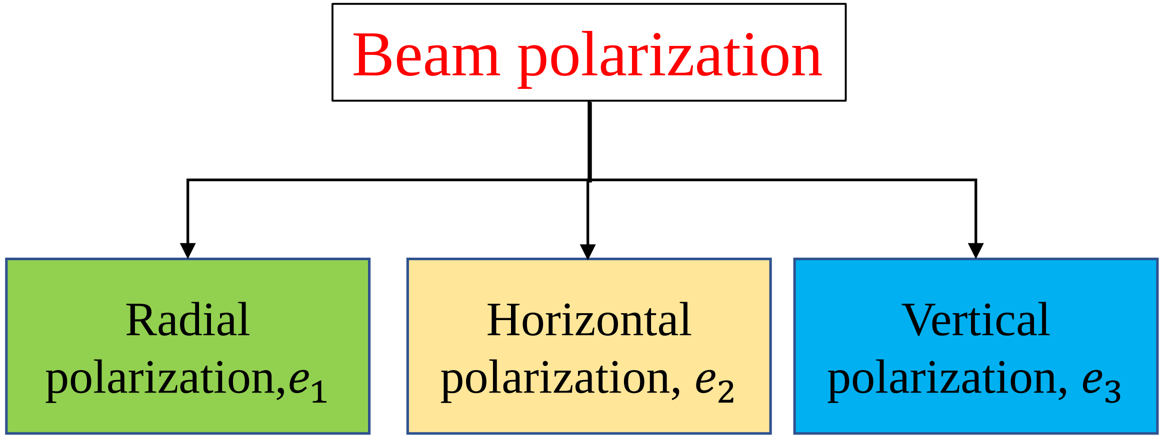
Outline

- Introduction of radial polarization
- RHIC polarimeter

Beam Polarization

➢ Definition of the polarization



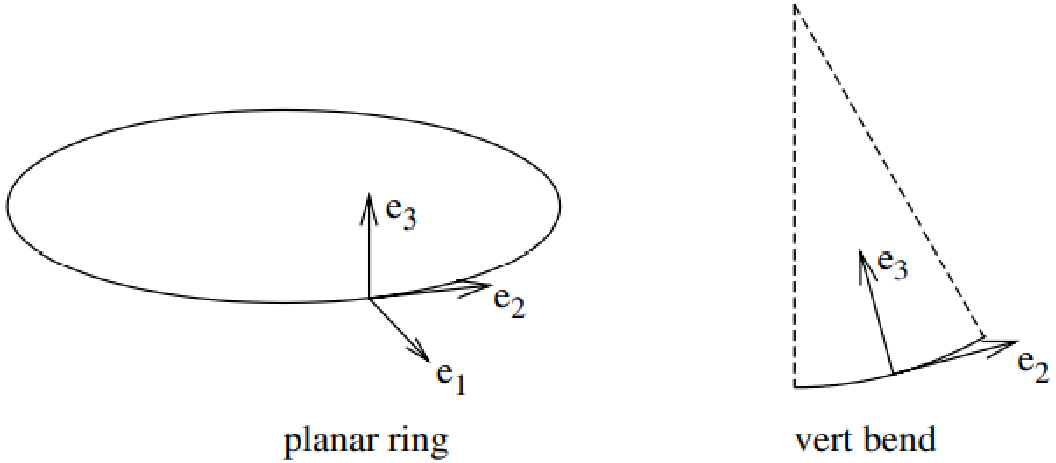


Figure 23. Sketch of the coordinate basis for a planar ring and a vertical bend.

Ref: Mane_2005_Rep._Prog._Phys._68_1997

Spin rotators

- Sokolov-Ternov effect produces vertical polarization in the arcs of an electron storage ring.
- Experiments require longitudinal polarization, two spin rotators are required at each interaction region that rotate the spin into the longitudinal direction and back to the vertical direction behind the IP.

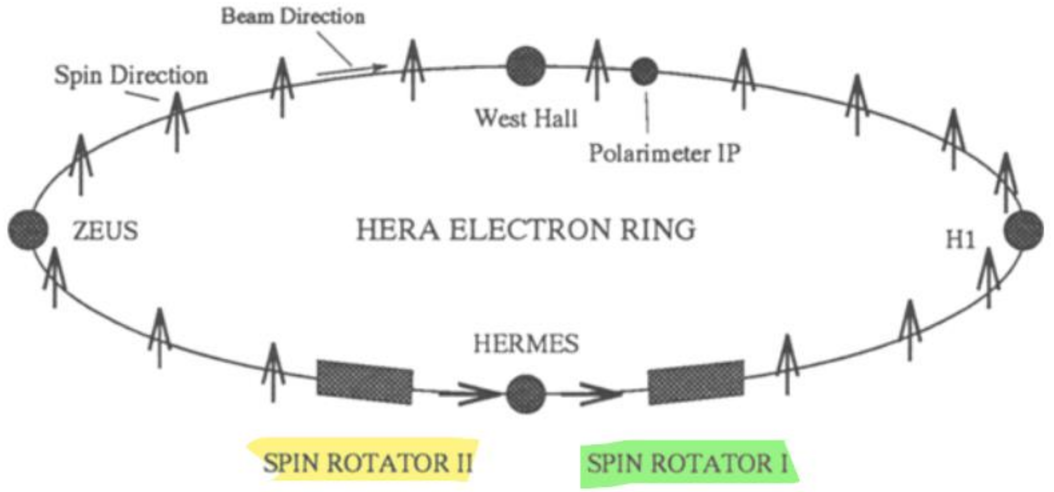


Figure 2: A sketch of the HERA electron ring showing the positions of the spin rotators.

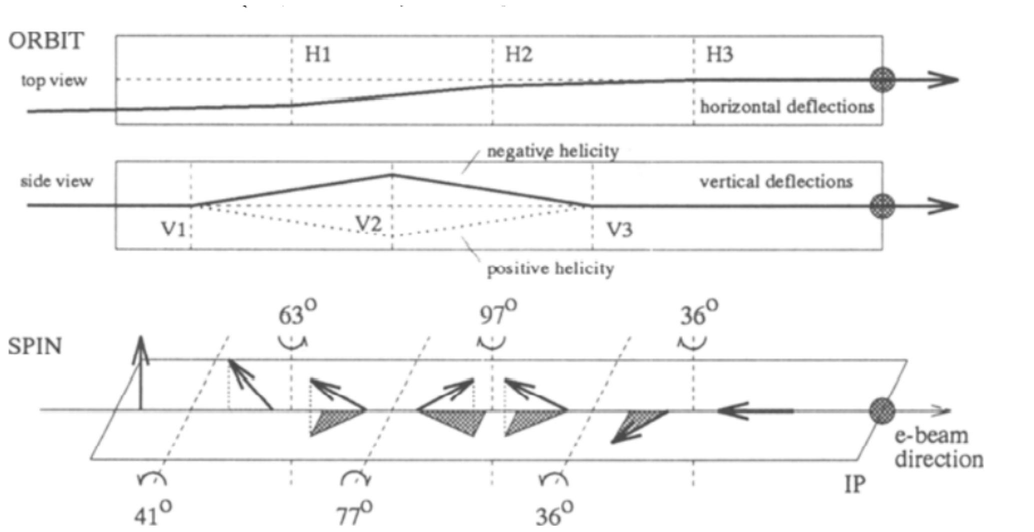
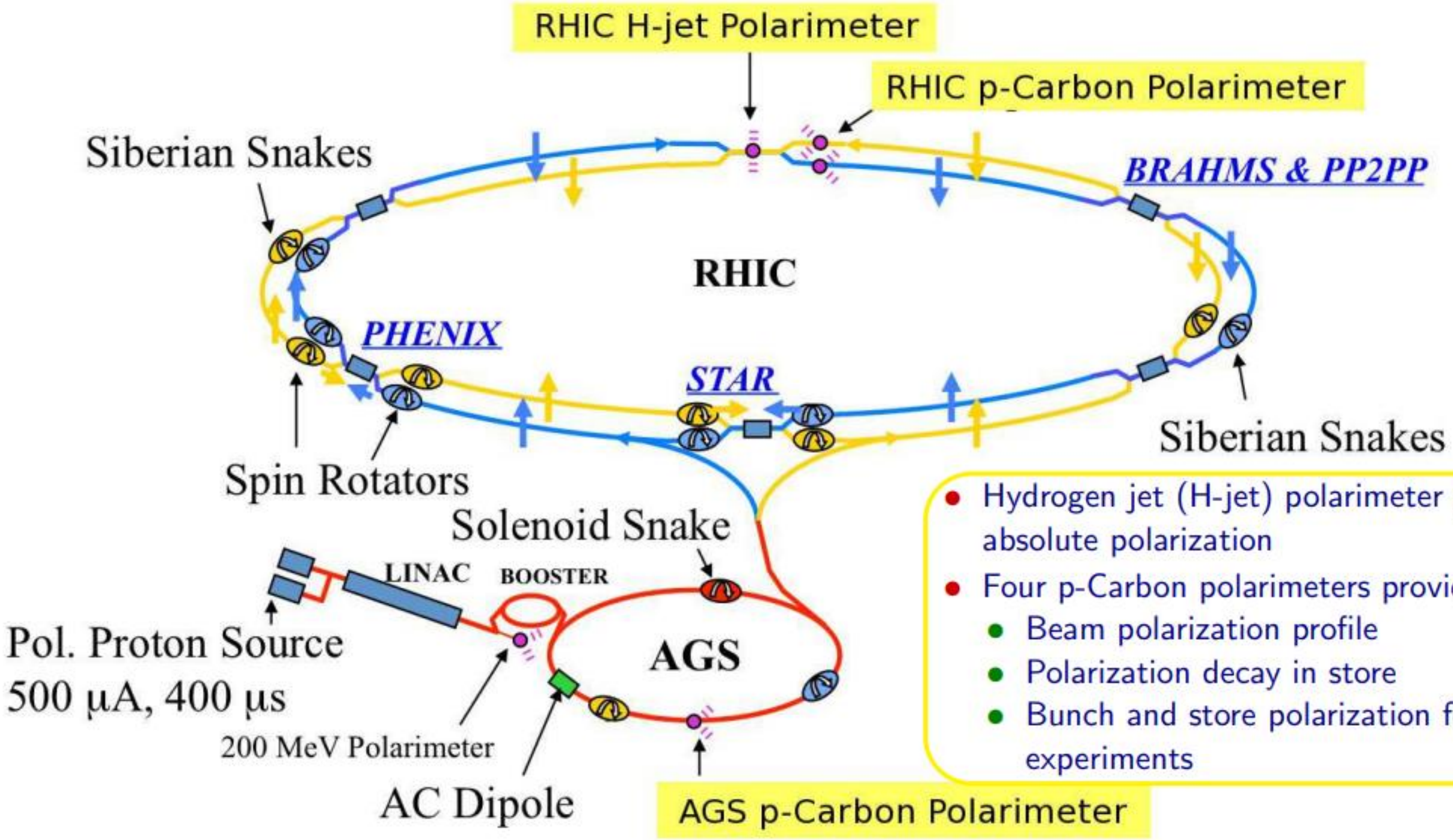


Figure 4: A functional diagram of the Mini-Rotator showing the horizontal and vertical deflections of the orbit and the corresponding spin precession angles.

Ref: Michael Düren, "Transverse and longitudinal electron polarization at HERA", 1980

RHIC layout

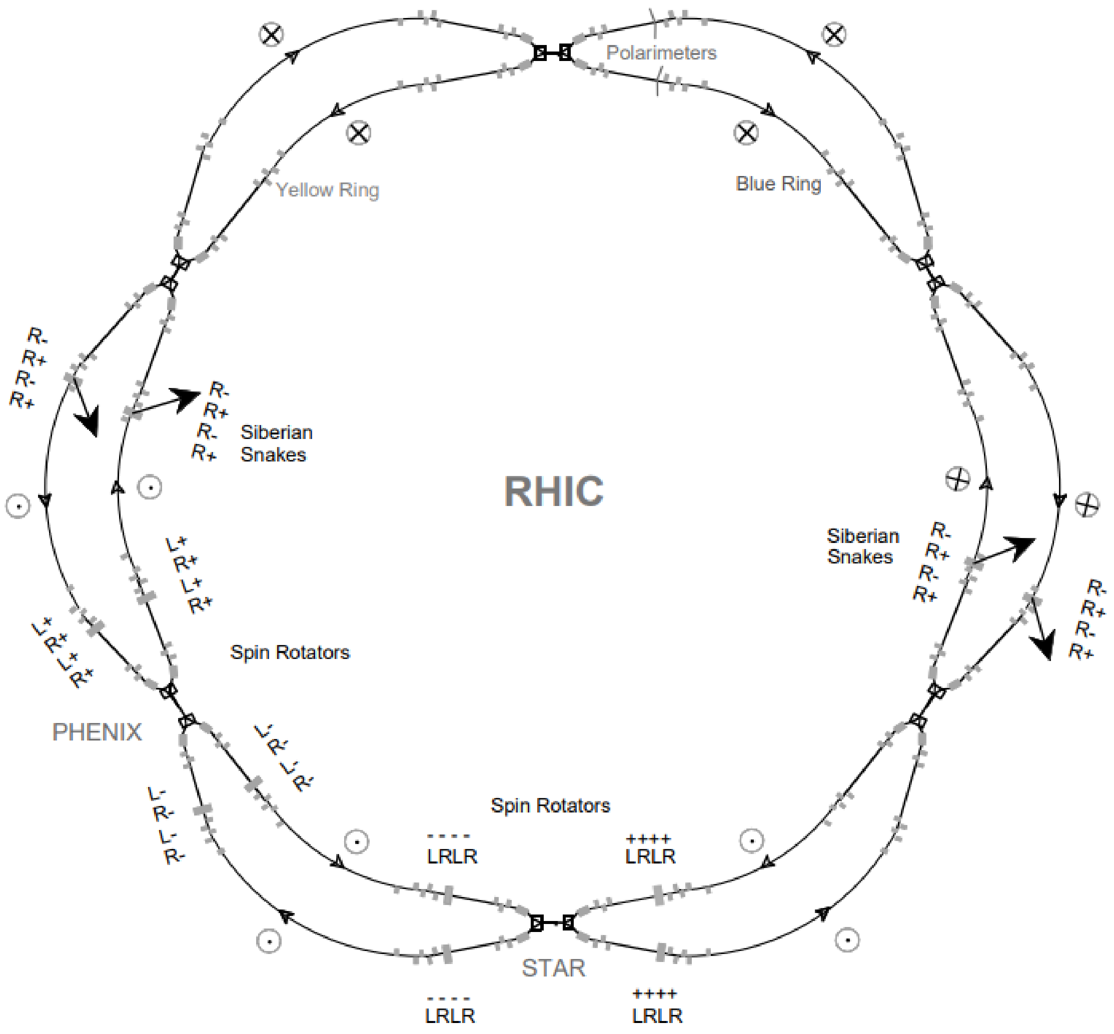


- Hydrogen jet (H-jet) polarimeter provides absolute polarization
- Four p-Carbon polarimeters provide:
  - Beam polarization profile
  - Polarization decay in store
  - Bunch and store polarization for the experiments

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

Ref: Dmitri Smirnov," Measuring Polarization of Proton Beams at RHIC" 2011

RHIC

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Rotators = Hor field (at ends), + = radially out, - = radially in
Snakes   = Ver field (at ends), + = u ,             - = down
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Fig. 7. View of RHIC overemphasizing the interaction regions to show the location of the Siberian Snakes and the spin rotators placed around the collider experiments STAR and PHENIX. Also shown are the polarization directions around the rings and around the detectors for collisions with longitudinal polarization.

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

Carbon is simpler and cheaper than a hydrogen jet, and can be installed in the individual rings. In addition, the carbon target is easier to handle in the vacuum

Ref: Dmitri Smirnov," Measuring Polarization of Proton Beams at RHIC" 2011

RHIC polarimeters

- Method: Proton-Carbon elastic scattering in the Coulomb-Nuclear Interference (CNI) region
- Aim： 探测反冲的C核
- It will be impossible to measure the forward-scattered proton at RHIC without drastically reducing the beam divergence at the target, which would severely reduce the scattering rate and cause unacceptable beam emittance growth.

✓ In the experiment, we measure the asymmetry ε

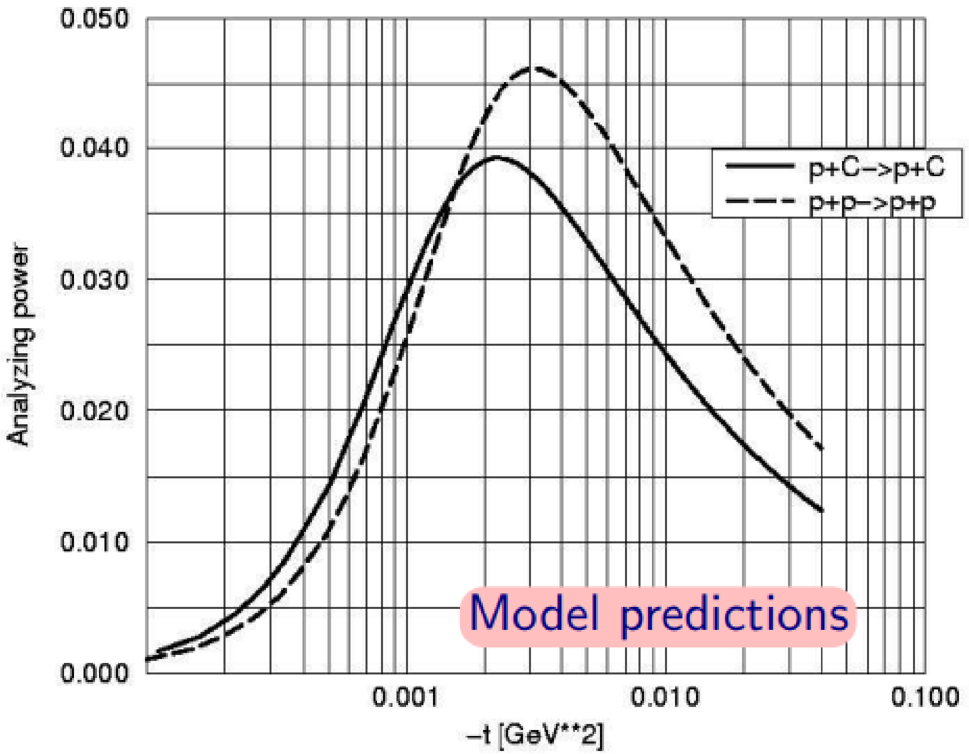
$$\varepsilon = \frac{N_L - N_R}{N_L + N_R}$$

✓ Measured polarization $P = \varepsilon / A_N(t)$, where A is the analyzing power (physical asymmetry).

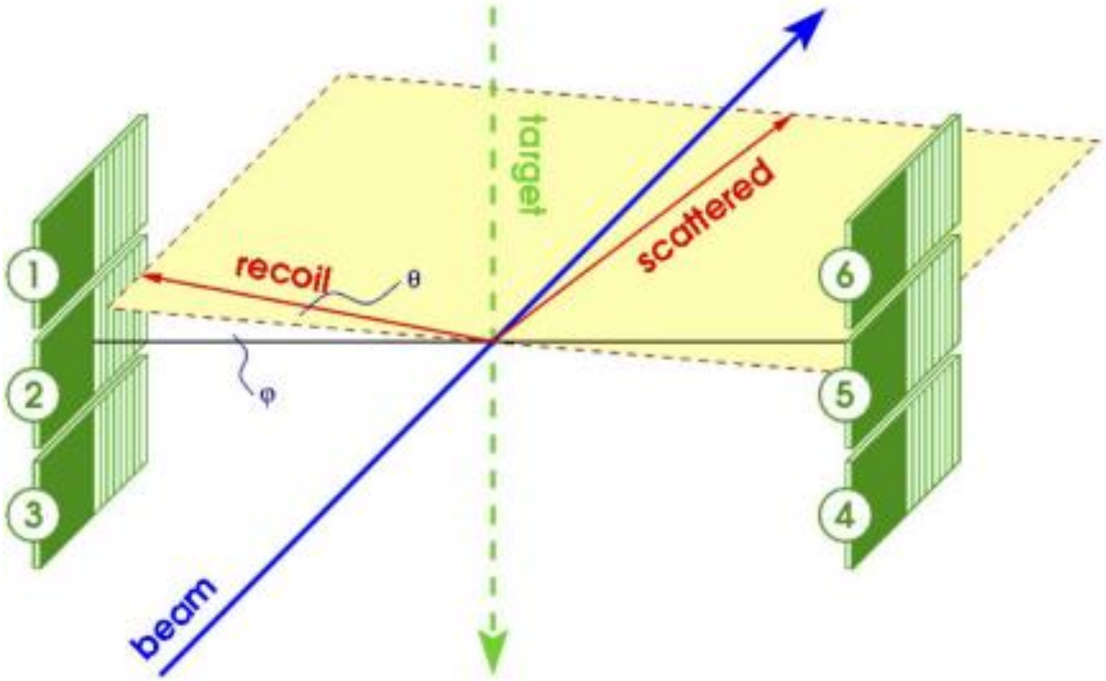
$$A_N(t) = \frac{G t_0 t \sqrt{t}}{m_p (t^2 + t_0^2)}$$

G is anomalous magnetic moment of the proton;
m_p is the proton mass
$t_0 = 8\pi\alpha Z / \sigma_{tot}$ (for carbon target $Z = 6$, for Hydrogen target $Z = 1$)

Figure Analyzing power of pC and pp



Experimental setup



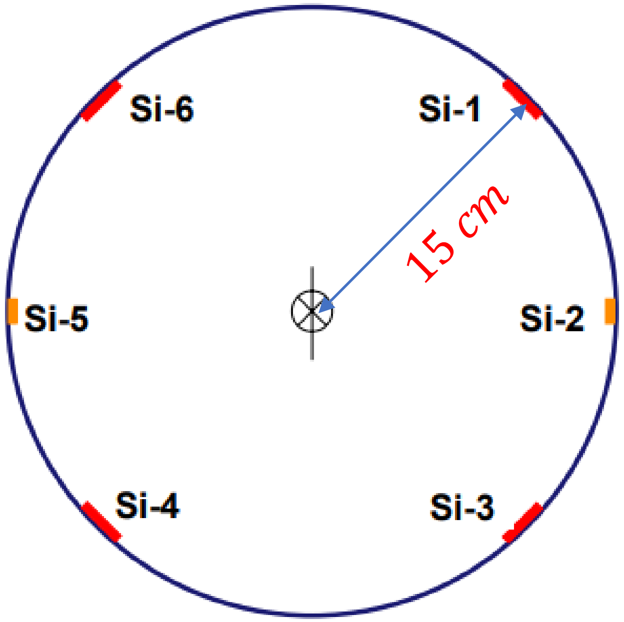
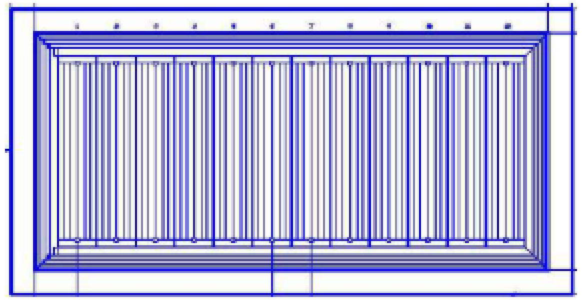


Figure. The schematic geometry layout of the silicon detectors inside the 15cm radius RHIC beam vacuum pipe. The polarized proton beam direction is into the paper, and the carbon target is represented by the vertical line at the center of the vacuum pipe.

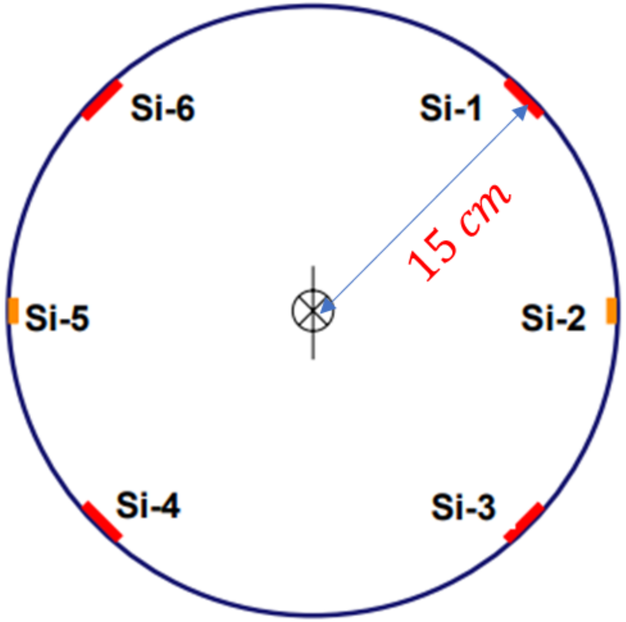
- Require ultra-thin target: target size is $2.5cm \times 5\mu m \times 30nm$
  - the recoil carbon carries only hundreds of keV kinetic energy.
  - The target would survive heating from the RHIC beam, provide sufficient luminosity for a quick precision polarization measurement,
  - and be sufficiently thin to avoid pile-up of events in the detector at the same time.

Ref: O.Jinnouchi," RHIC pC CNI Polarimeter: Status and Performance from the first collider run" 2003

Experimental setup



12 strips 2×10 mm



- The six detectors are mounted inside of the vacuum chamber with readout preamplifier boards directly attached to the chamber detector ports through vacuum feedthrough connectors.
- the 90^0 detectors are sensitive to vertical polarization, and the 45^0 detectors can be used to measure vertical polarization (left-right asymmetry, $\sin\varphi$ dependence) and radial polarization (up-down asymmetry, $\cos\varphi$ dependence).

Ref: [1] O.Jinnouchi," RHIC pC CNI Polarimeter: Status and Performance from the first collider run" 2003
[2]I.Alekseev, "Polarized proton collider at RHIC", 2003

Experimental results (1)

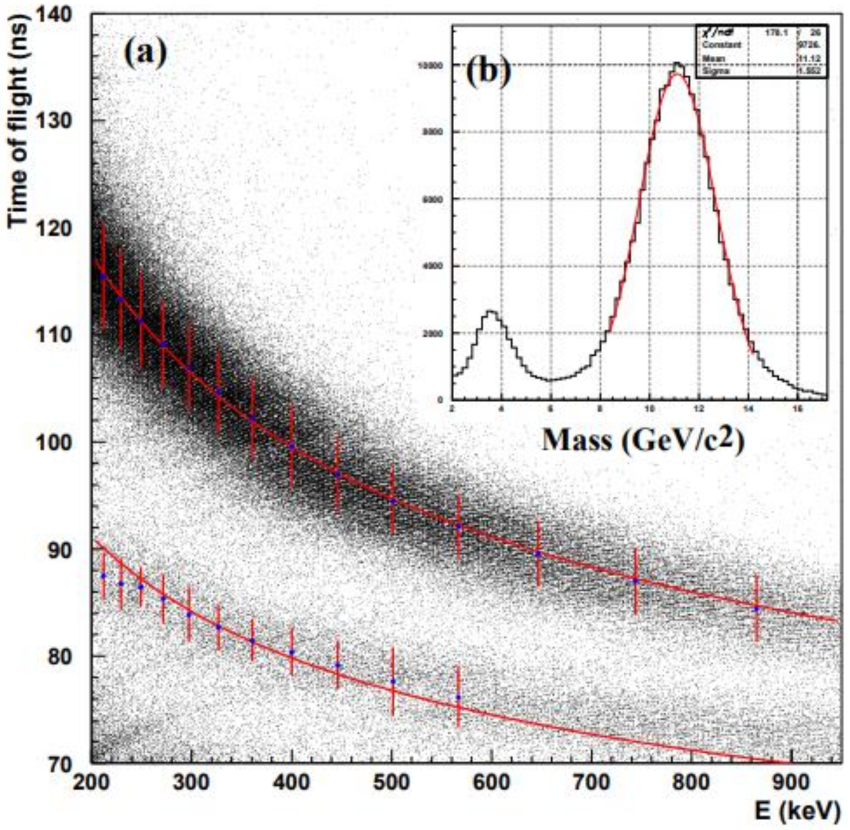
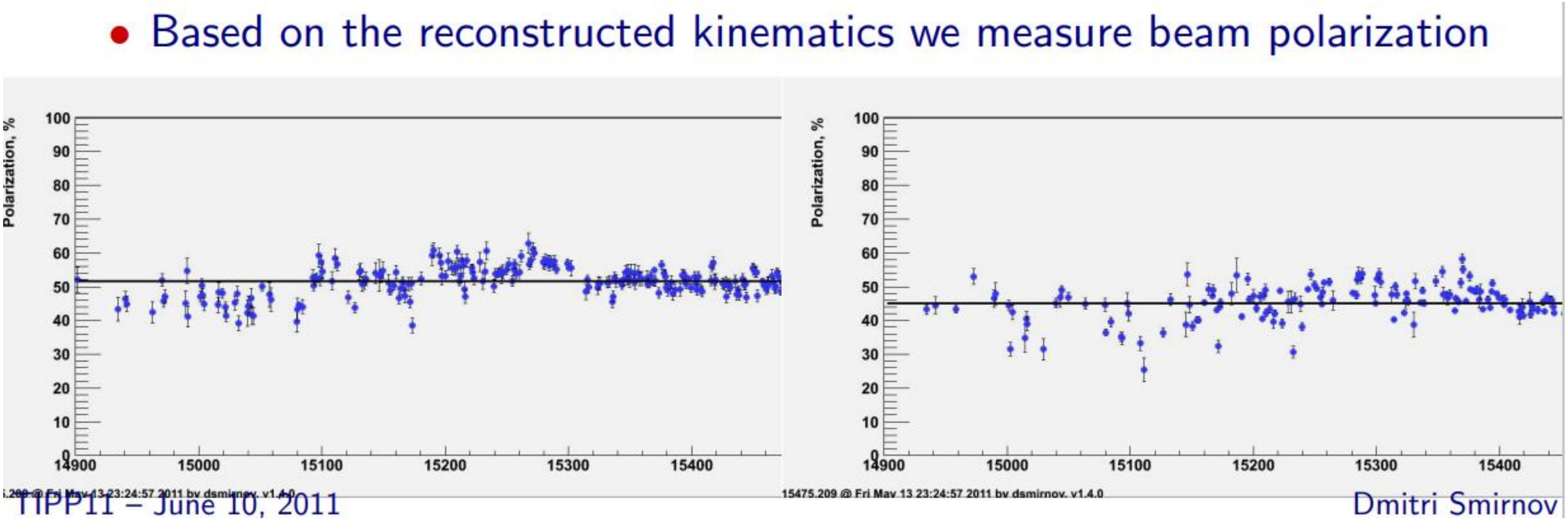


FIGURE 2. (a) The time of flight is plotted as a function of kinematic energy of the detected particle. (b) Sub-figure shows the projected mass distribution. A Carbon mass peak (11.18 GeV/c ^{2}) is clearly separated from an alpha mass peak (3.7 GeV/c ^{2}).

Ref: [1] O.Jinnouchi,” RHIC pC CNI Polarimeter: Status and Performance from the first collider run” 2003

Experimental results (2)



- a fast and reliable polarimeter is required that produces a polarization measurement with a 10% relative error within a few minutes.

Ref: Dmitri Smirnov," Measuring Polarization of Proton Beams at RHIC" 2011

backup

Radial Polarization

测极化的原理： Measuring the scattering asymmetry

- 束流极化同一方向时，由于探测器效率、 polarimeter 错位、 束流电流波动等会导致一些系统上的偏差
- 可通过改变极化方向，消除大部分的系统偏差： alternating the source polarization or flipping the polarization direction of a stored beam
- for instance, a proton scattered to the left, with the beam polarization up, is equivalent to a proton scattered to the right, with the beam polarization down.

The vertical polarization P_V is calculated as

$$P_V = \frac{1}{\bar{A}} \frac{\sqrt{N_{L\uparrow}N_{R\downarrow}} - \sqrt{N_{L\downarrow}N_{R\uparrow}}}{\sqrt{N_{L\uparrow}N_{R\downarrow}} + \sqrt{N_{L\downarrow}N_{R\uparrow}}}, \tag{3}$$

where $\bar{A}$ is the angle-weighted average analyzing power and $N_{L(R)\uparrow(\downarrow)}$ is the total number of events scattered into the left (right) quadrant with the beam polarization up (down). Similarly, the radial beam polarization P_R is calculated using

$$P_R = \frac{1}{\bar{A}} \frac{\sqrt{N_{U\uparrow}N_{D\downarrow}} - \sqrt{N_{U\downarrow}N_{D\uparrow}}}{\sqrt{N_{U\uparrow}N_{D\downarrow}} + \sqrt{N_{U\downarrow}N_{D\uparrow}}}, \tag{4}$$

where $N_{U(D)\uparrow(\downarrow)}$ is the total number of events scattered into the up (down) quadrant with the source polarization up (down). Using this method of determining the polarization

Ref: Yaroslav S. Derbenev ,"Siberian Snakes, Figure-8 and Spin Transparency Techniques for High Precision Experiments with Polarized Hadron Beams in Colliders"