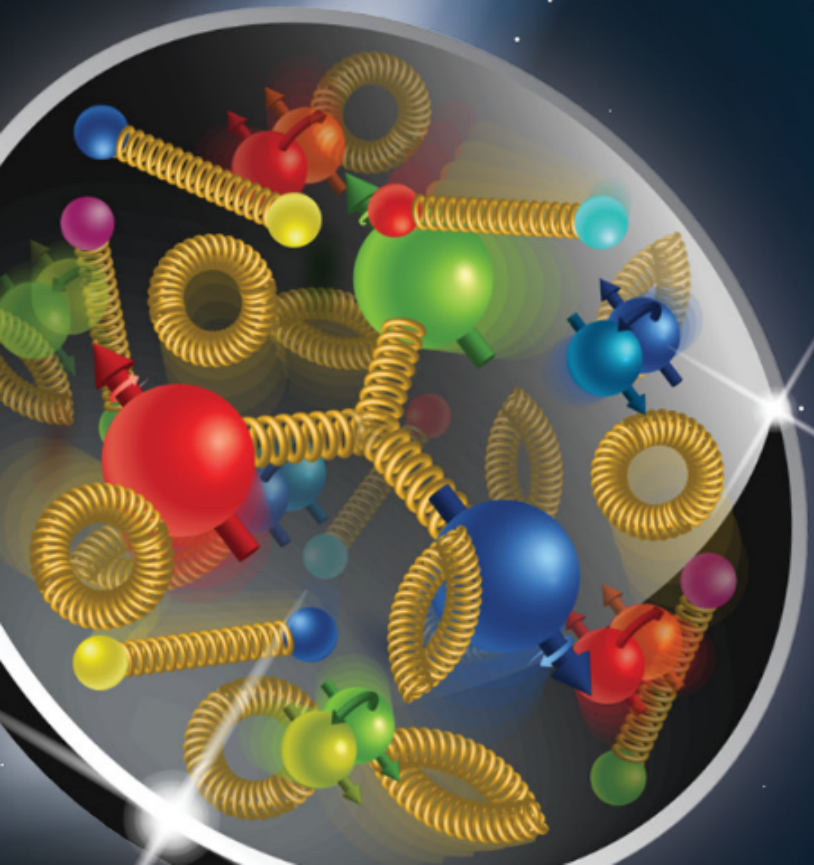
POLARIMETRY FOR IONS AT THE EIC

Ana S. Nunes

for the RHIC Spin Group



Early Career Research Symposium 2019
Brookhaven National Laboratory
November 14, 2019

BROOKHAVEN NATIONAL LABORATORY

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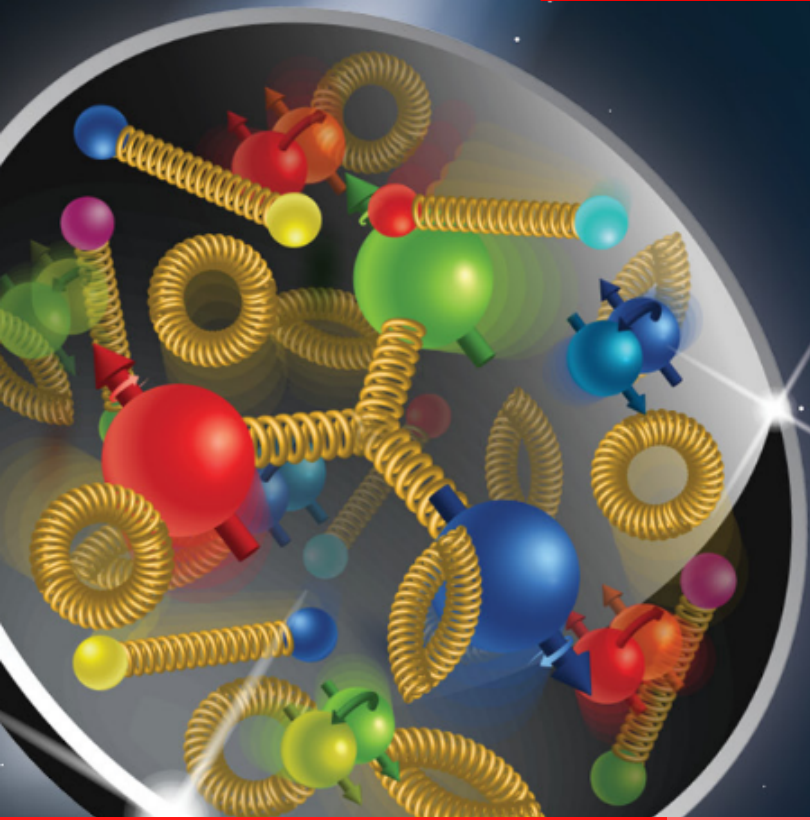
PHYSICS MOTIVATION



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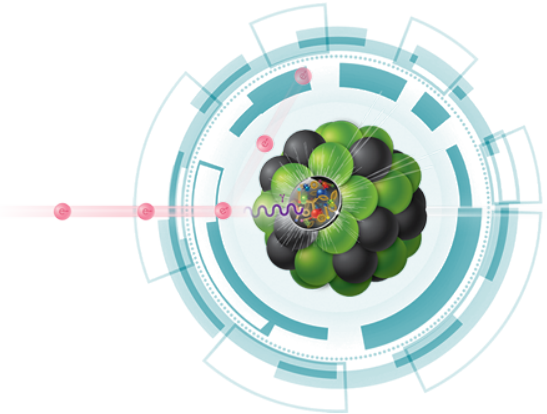
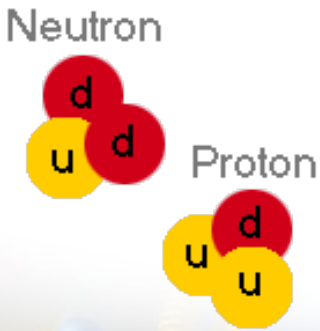
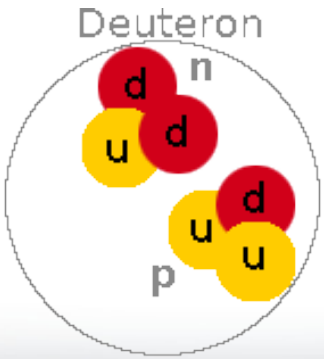
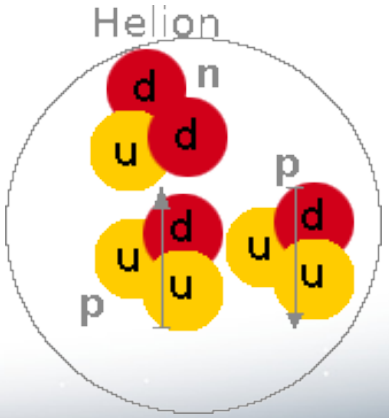
Why Ion Polarimetry at the Electron Ion Collider?

- EIC: **first collider with polarized lepton and polarized hadron beams**, to study structure of **nucleons and nuclei**
- **EIC rich spin physics program**, requiring **precision measurements**
- Polarized light ions, e.g. **D and ^{3}He**, provide **polarized neutrons**; neutrons and protons allow **flavor separation of u and d quarks**; D to study nuclear binding







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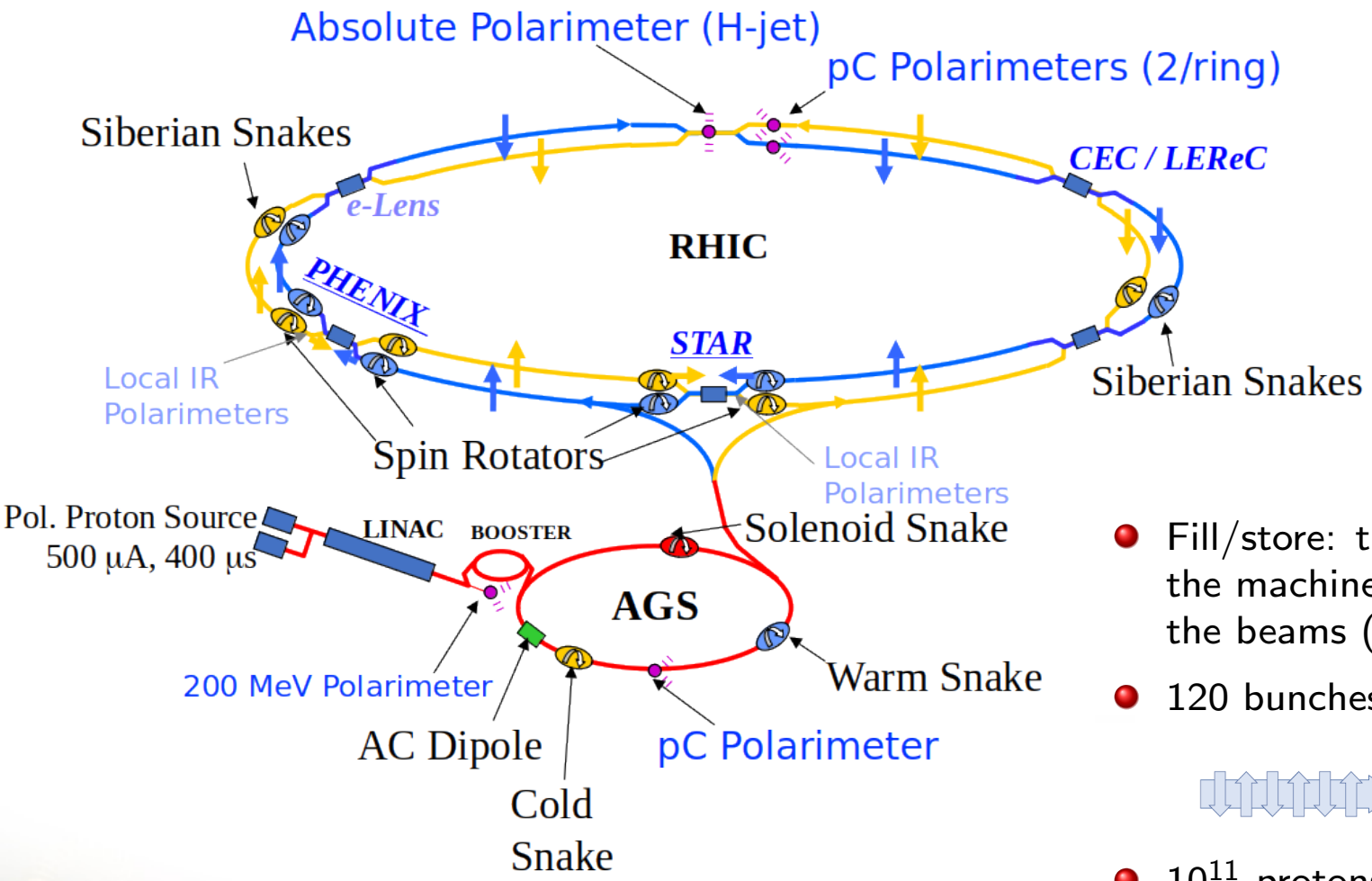
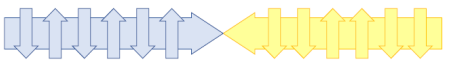
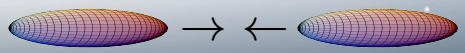
Relativistic Heavy Ion Collider



- Fill/store: time unit over which the machine is filled and collides the beams ($\sim$ 8 hours)
- 120 bunches (106 ns spacing)

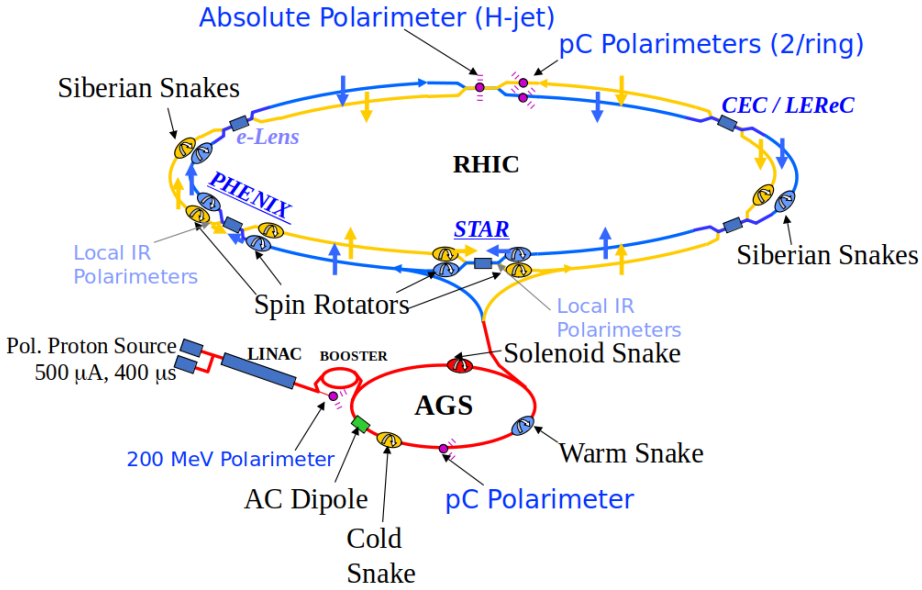


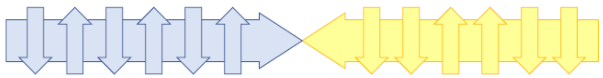
- 10^{11} protons per bunch
- Bunches have extension in x, y, s



Proton Polarimetry at RHIC

- **There is no physical process that can be calculated from first principles that can be used in ion polarimetry**
- Requirements: **precision**, **polarization profile** and **lifetime** to know **polarization in collisions**
- **Two-tier measurement**:
  - one for the **absolute polarization** (with low statistical power)
  - one for **relative polarization** (with high statistical power)

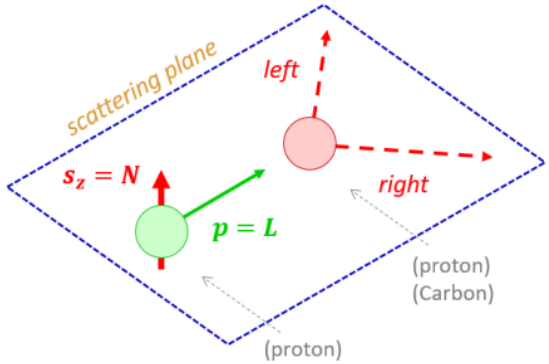




120 bunches (106 ns spacing)
10^{11} protons per bunch
Store $\sim$ 8 hours

Absolute Polarimeter: H-Jet Polarimeter

- A **polarized proton jet, with known polarization** used as target for **elastic scattering in Coulomb-nuclear interference (CNI) region** by beam $\vec{p}$. Asymmetry: $\varepsilon = A_N P$.



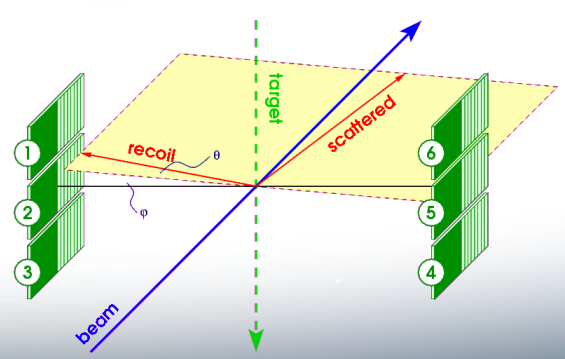
- The analyzing power A_N doesn't have to be known and allows the **self-calibration** of the polarimeter

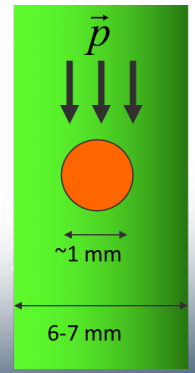
- Beam polarization given by

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

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

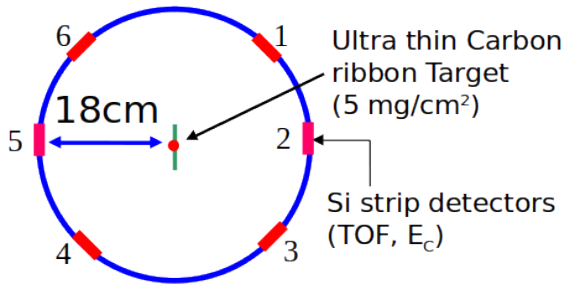
- Silicon strips detect the recoil protons



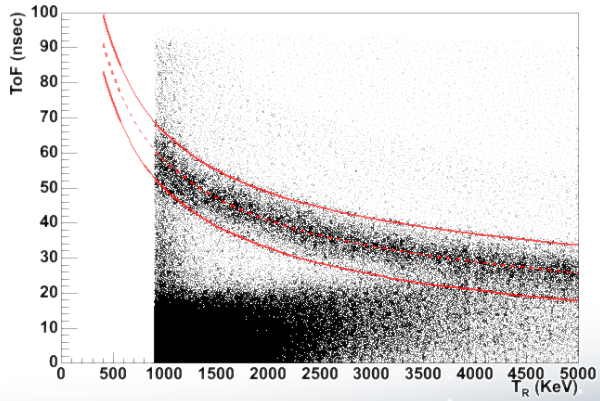


Fast and Precise Polarimeter: pC Polarimeter

- **Non-polarized, ultra-thin carbon ribbon** ($w = 10$ μm), used as target for **elastic scattering in the CNI region** by beam $\vec{p}$
- Azimuthal asymmetries $\varepsilon(\phi)$ measured
- A_N from normalization to the H-Jet; dependence with energy agrees well with models
- Beam polarization: $P_b = \dfrac{\varepsilon(\phi)}{A_N \cdot \sin(\phi)}$
- Silicon strips detect the recoil carbon nuclei, measurements of 20-30 s in target scan mode



Time of flight vs kinetic energy



Bunch Transverse Profile

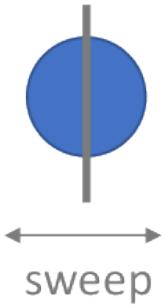
Experiments

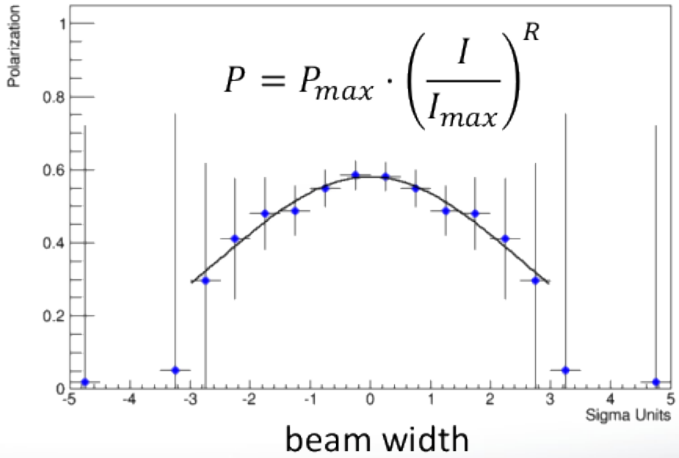
$$P = \frac{\int P(x,y,t) \cdot I_B(x,y,t) \cdot I_Y(x,y,t) dxdydt}{\int I_B(x,y,t) \cdot I_Y(x,y,t) dxdydt}$$

HJET Polarimeter

$$P = \frac{\int P(x,y,t) \cdot I(x,y,t) dxdydt}{\int I(x,y,t) dxdydt}$$

Carbon Polarimeter

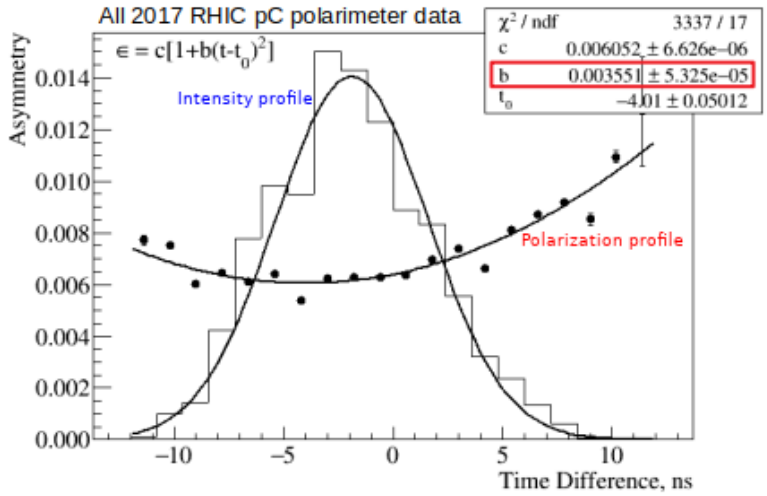


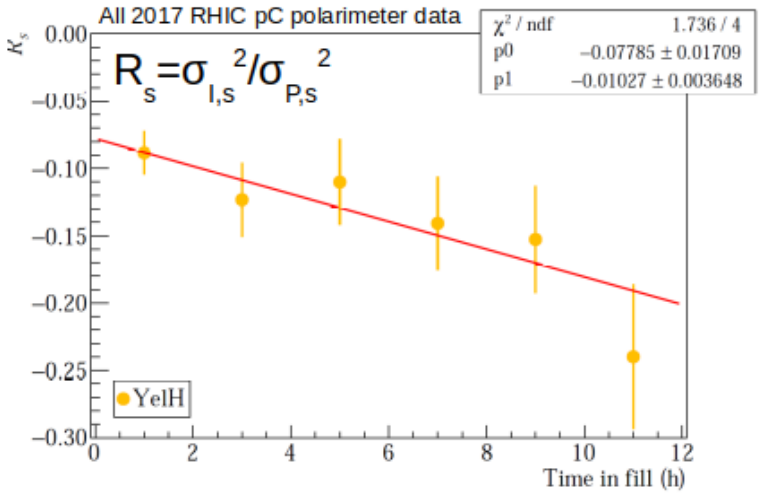


beam width

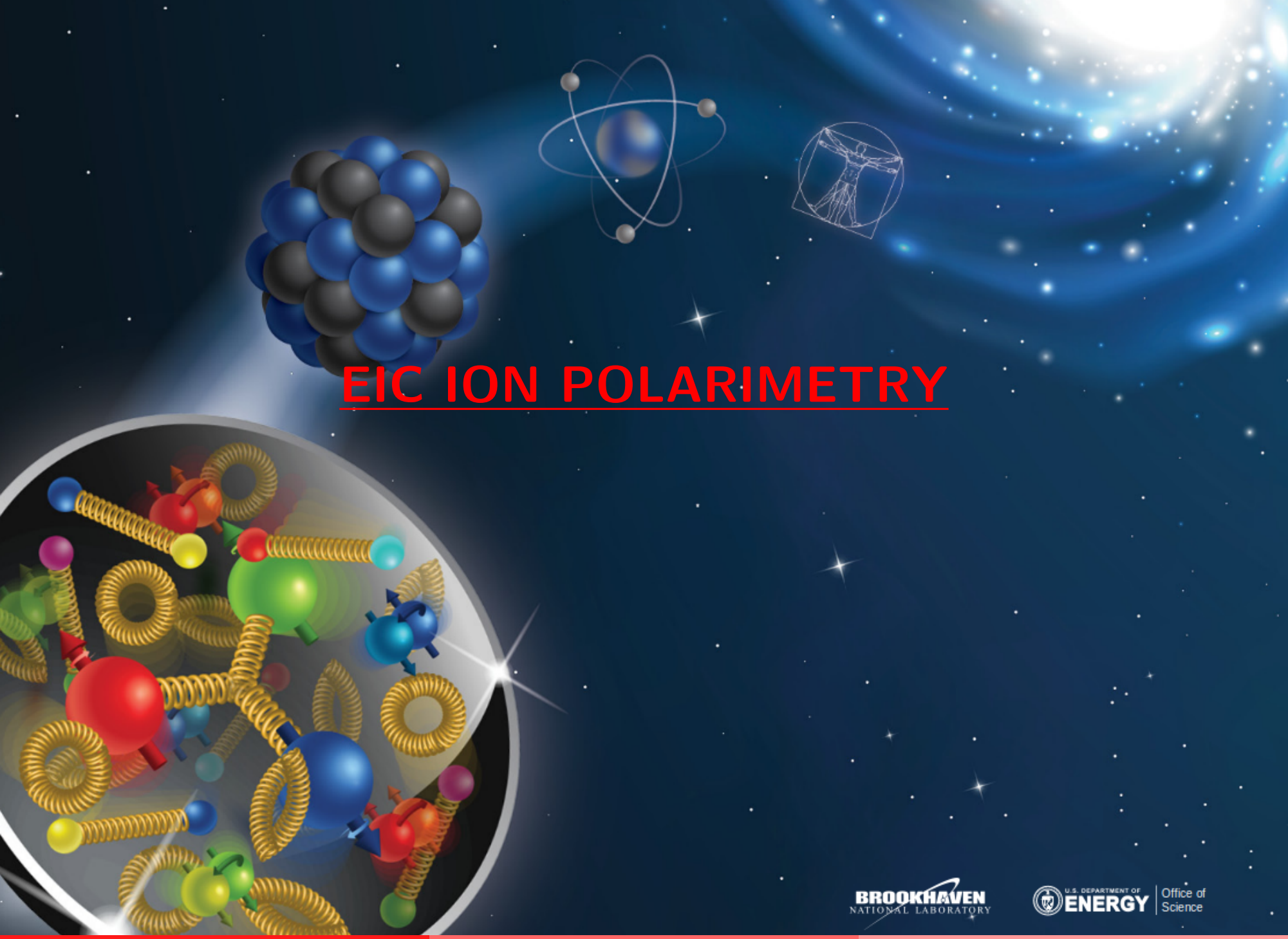
B: blue beam; Y: yellow beam

Bunch Longitudinal Profile





- **Top opening parabola shape** (implying corrections to the polarization)
- Effect increases (in absolute value) along the fill
- May be more important in the EIC case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EIC Ion Polarimetry

Requirements:

- Large polarization, long. and transv., flexible bunch polarization orientation
- Small uncertainty in polarization measurement: $\sim$1%
- Bunch polarization profile in x, y and z, polarization lifetime
- **Polarization per bunch** (2 detectors, not all bunches collide at a given IP)

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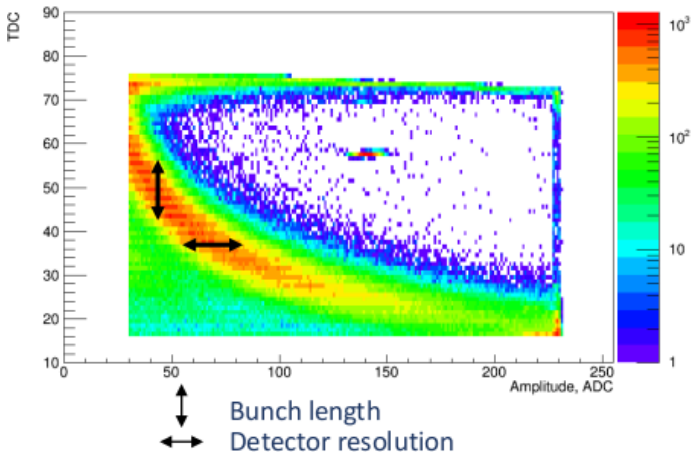
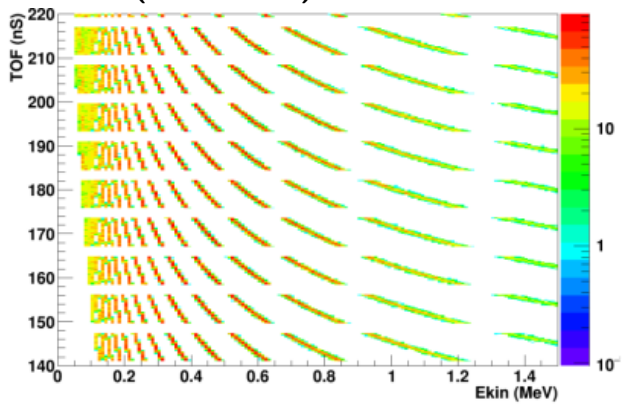
RHIC data:



120 bunches → 1320 bunches
106 ns → 8.9 ns

EIC (simulation):



Challenges:

- Short spacing between bunches (for high luminosity)
- Background to the signal events may contaminate preceeding bunch
- Luminosity measurement may depend on polarization: $\sigma_{\mathrm{Brems.}} = \sigma_0(1 + aP_eP_h)$
- **Pioneering light ion beam polarization measurements at high energies**

Polarized Light Ion Beams

- **Similar kinematics** of light ions and pp
- **Breakup of light ions** has to be taken into account
- Simplest model:

$$A_N = \frac{\sqrt{x}}{x^2+3} \cdot A_N^{\text{opt}} = \frac{\sqrt{x}}{x^2+3} \cdot \frac{k}{4m_p}\sqrt{-3t_e}$$

with $x = \frac{t}{t_e}$, $t_e = -\frac{\sqrt{3}ZZ'}{\sigma_{\text{tot}}}$

$k_p = 1.793,\ k_{^3He} = -1.398,\ k_D = -0.143$

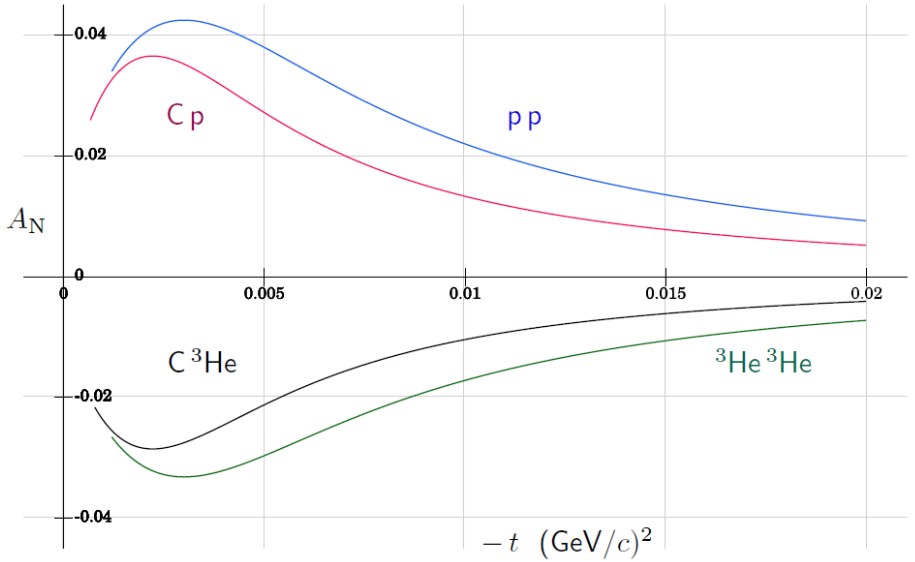


Figure 1: Analyzing power A_N versus invariant momentum transfer (-t) in (GeV/c)^2 for (1) p p and p h scattering, (2) C p scattering, (3) C h scattering, (4) h h and p h scattering

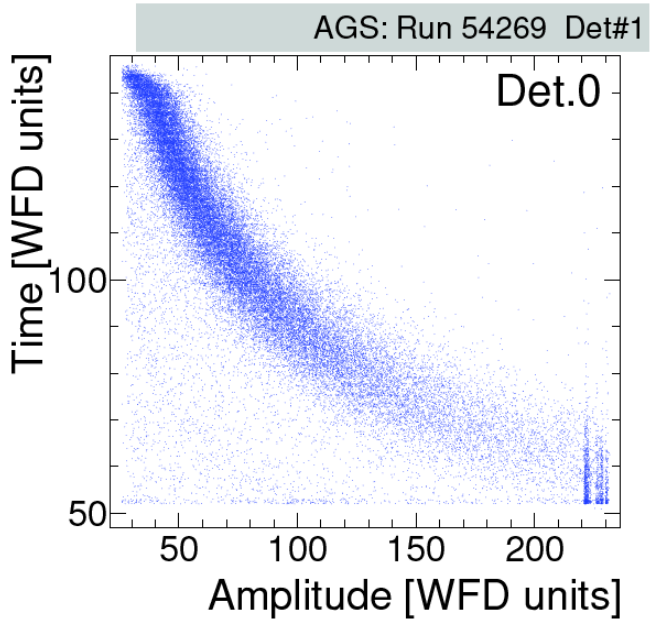
[N. Buttimore]

- Polarimetry using elastic scattering in the CNI region in D-D or D-C **very difficult**
- A **test with a jet of polarized deuterons with known polarization** can be done in the next few years **at the H-Jet**

Polarized Helium-3 Beams

- Gas of **polarized helium-3** nuclei (helion) was used as **fixed target** at HERMES [Nucl. Instr. & Methods A367 1995 9699], JLab and Jülich
- A helium-3 beam was **tested sucessfully at the AGS C polarimeters**

Helion-carbon scattering at C polarimeters of the AGS:



[H. Huang *et. al.*, Proceedings of IPAC2014, Dresden, Germany, doi:10.18429/JACoW-IPAC2014-WEPRO071]

- Source of polarized ^{3}He is available; a **test with polarized ^{3}He in C polarimeters of the AGS** can be envisioned

Conclusions

Summary:

- **Hadron polarimetry** requires **small uncertainties**
- **Proton polarimetry mature** and **experience of RHIC essential for EIC**
- **D polarimetry very difficult**
- **Polarized helions** best source of **polarized neutrons**
- Elastic scattering of ^{3}**He** ions by **C** tested at the **AGS**

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Outlook:

- Tests of **D-D at the RHIC H-Jet** and of **polarized ^{3}He on the AGS carbon polarimeters** envisaged
- Usage of **other technologies, including better timing resolution**, considered

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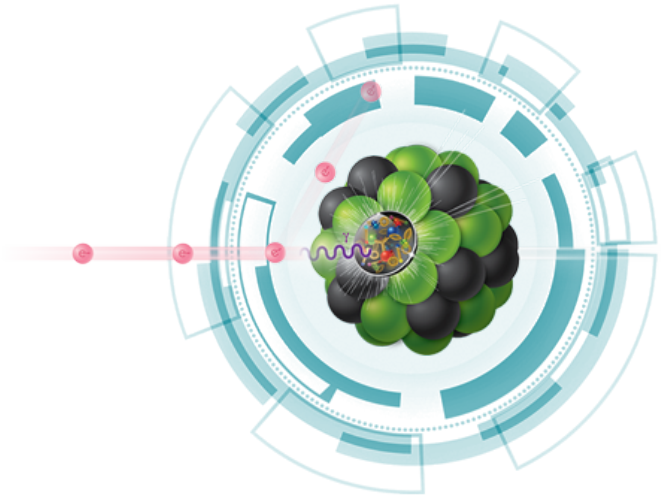
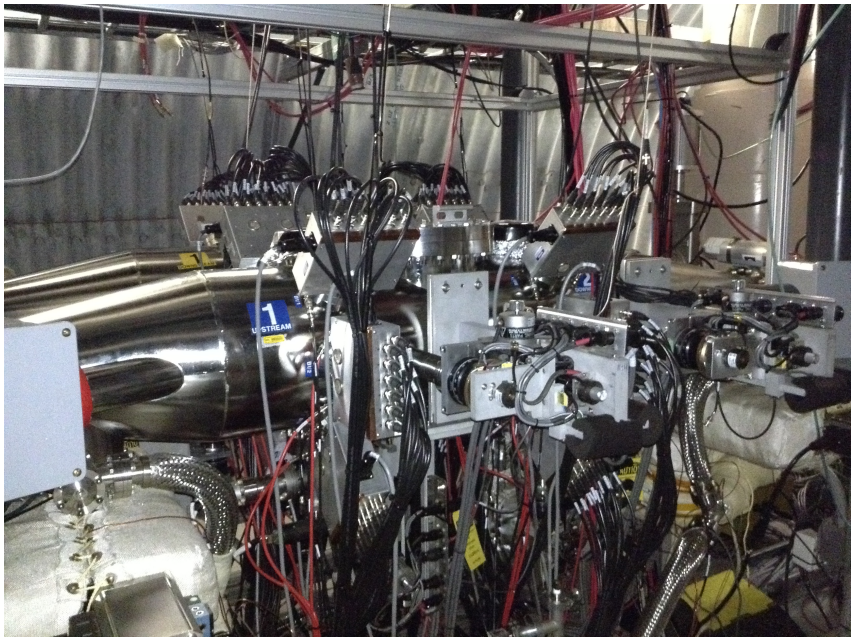
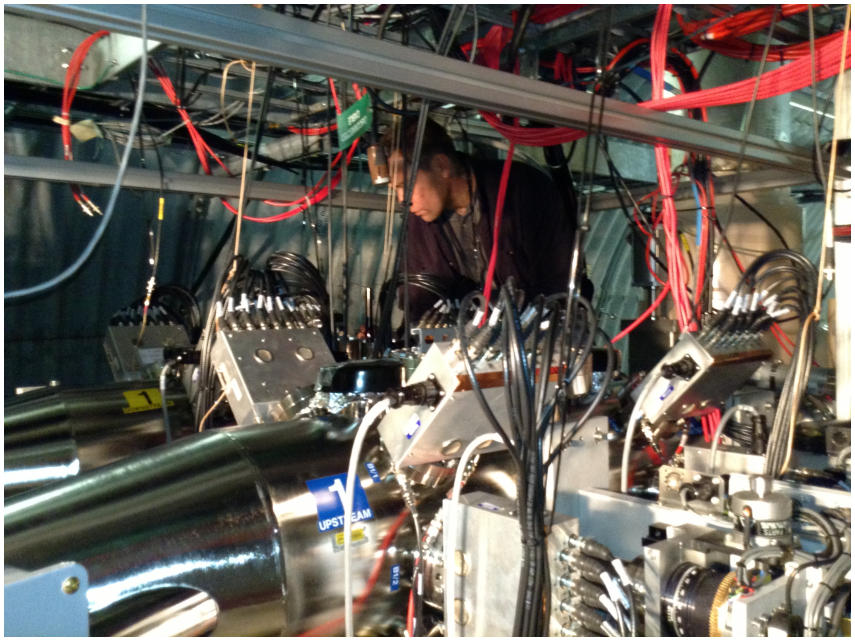
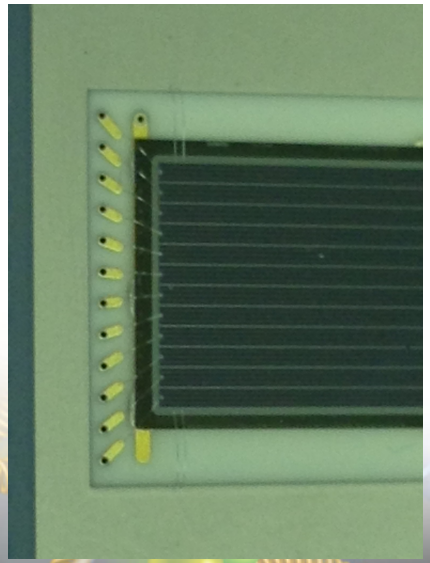
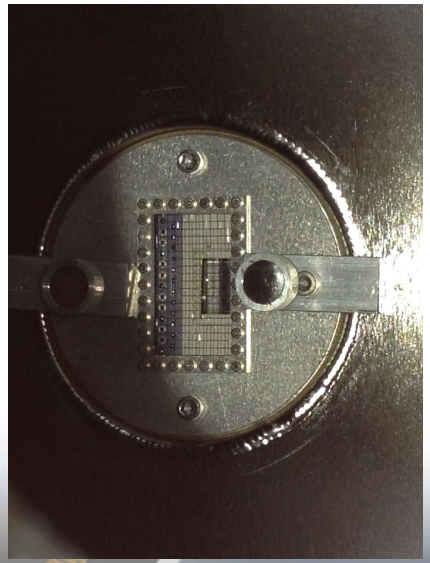
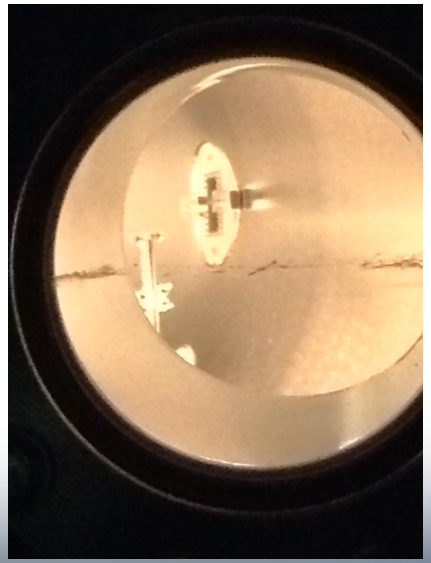
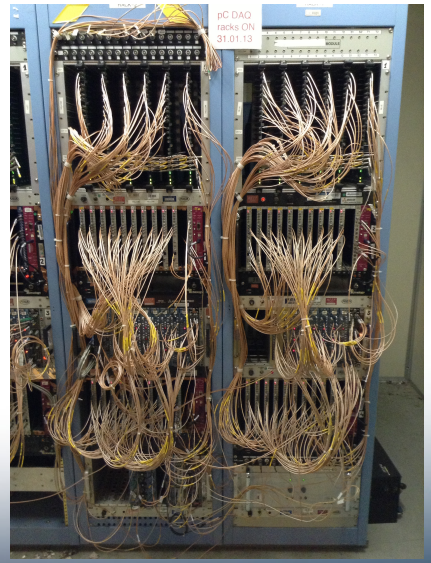


Thank you for your attention!

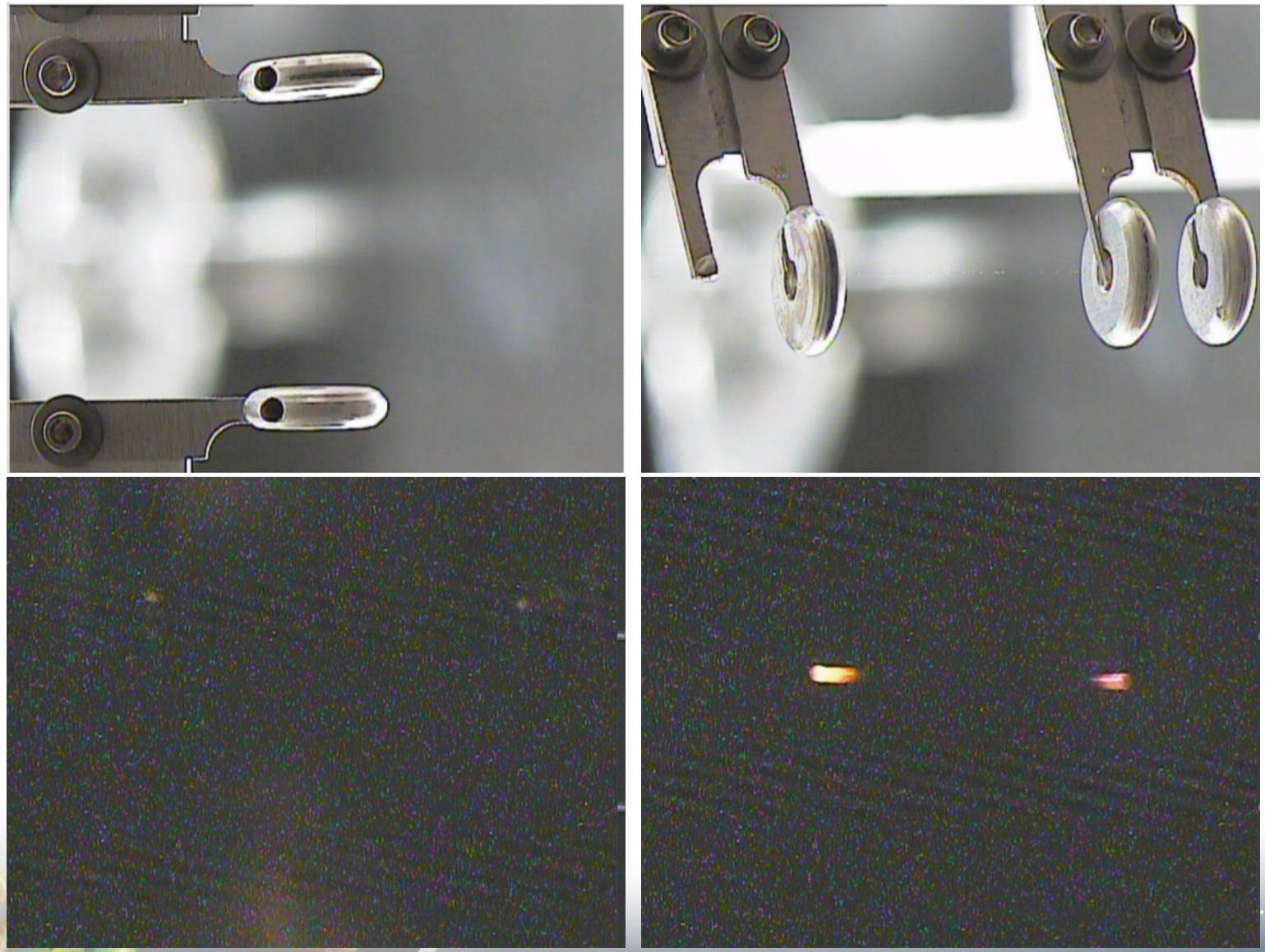
BACKUP


2013-03-10 20:59:24

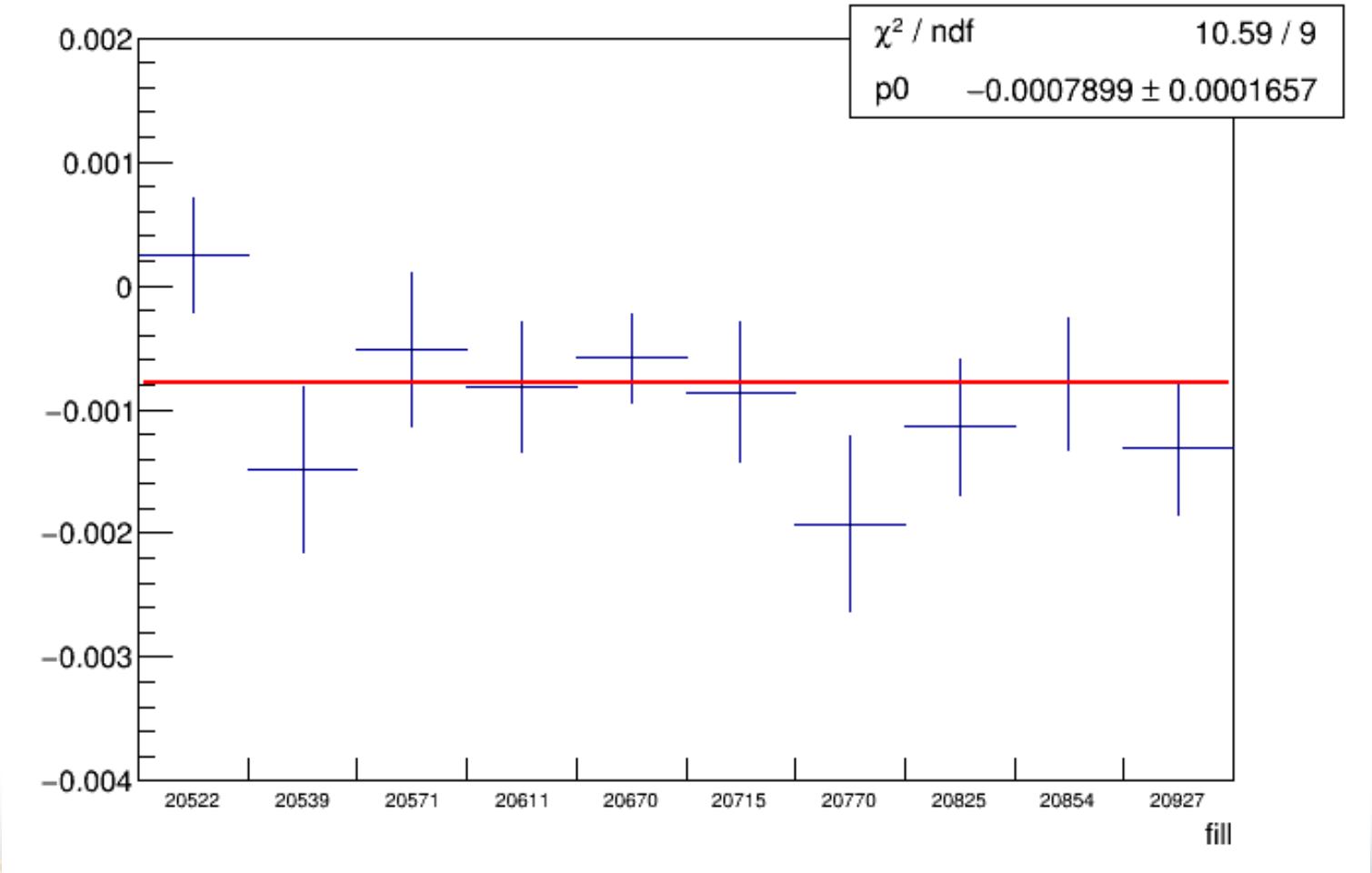
RHIC Proton-Carbon Polarimeters

RHIC Proton-Carbon Polarimeters



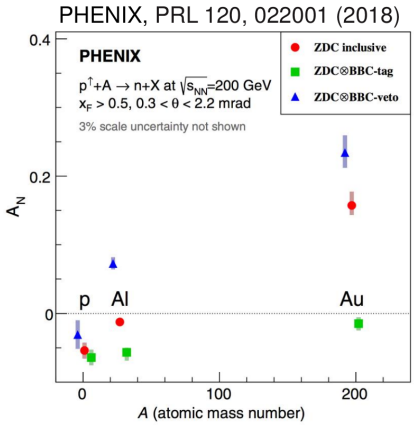
Background asymmetry in 2017 pC polarimeter data



Alternative Approach for Ion Polarimetry in EIC

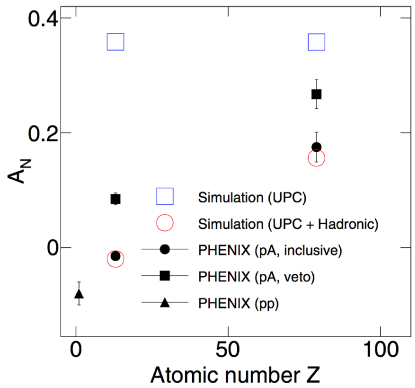
- A **large asymmetry** was measured by PHENIX in **forward neutrons from $\vec{p}$ on nuclei** (Al and Au)
- γ from high Z nucleus scatters on $\vec{p}$ target; parameterizations of $\gamma + \vec{p} \rightarrow n + \pi^+$ (MAID**) and photon flux (STARlight*) describe PHENIX results:

Data:

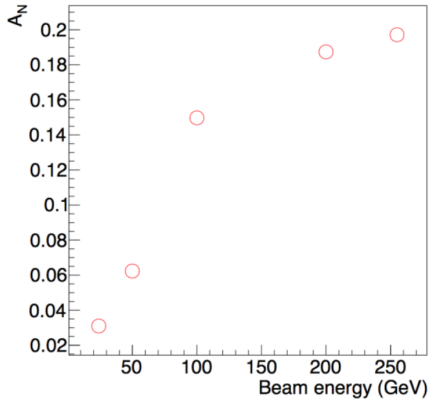


Model vs data

[G. Mitsuka, PRC 95, 044908 (2017)]



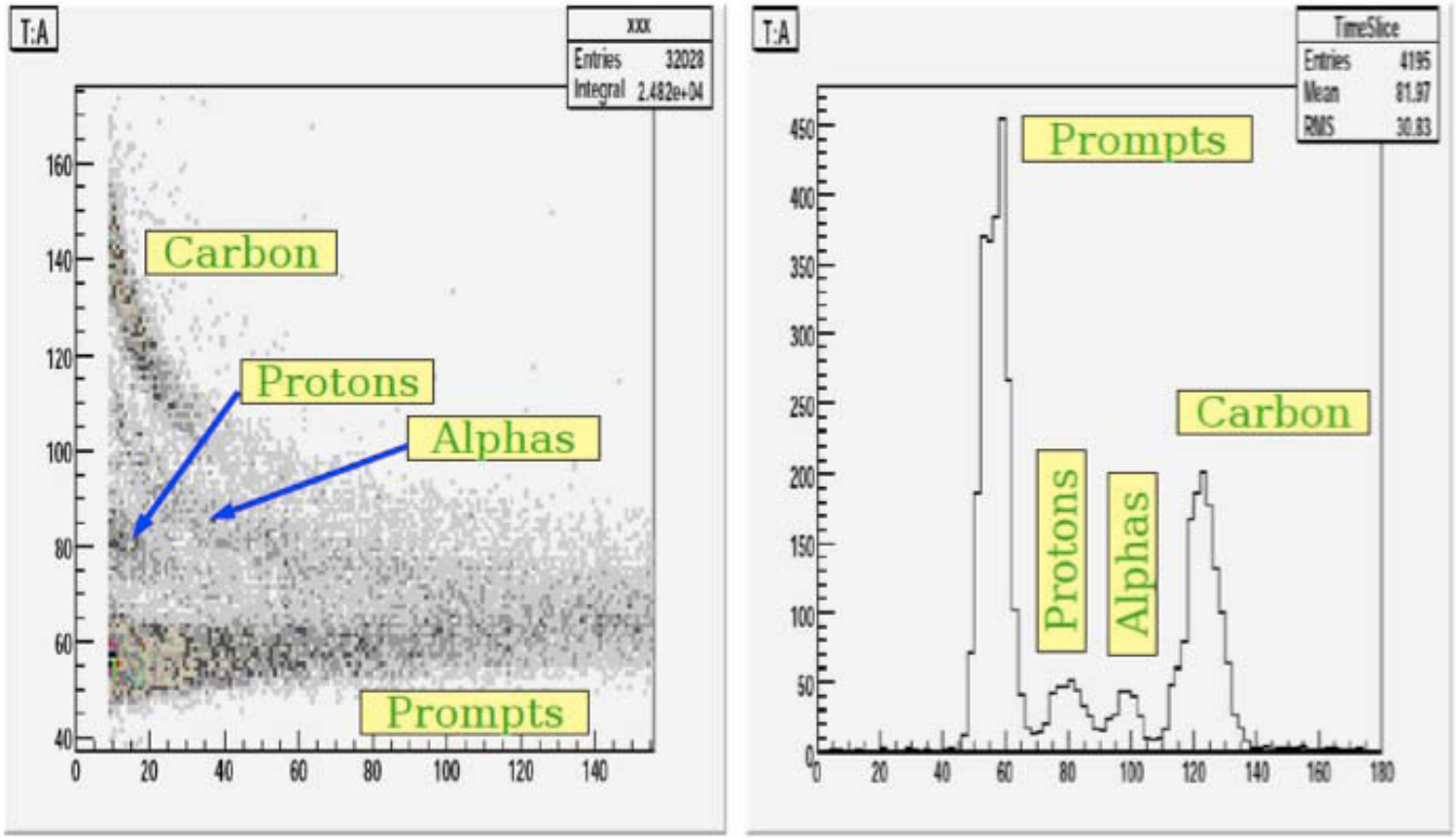
Simulation (pAu):



- **Polarimeter: high Z target (*e.g.* Xe gas jet) in $\vec{p}$ beam**
- Would require a calorimeter to detect neutrons at low angles
- Open questions: can a thin jet ($\sim 100\ \mu$m) of Xe gas be produced and allow enough statistics for lifetime of P and profile measurements?

(*) Klein et al., Comput. Phys. Comm. 212 (2017) 258 (**) Drechsel et al., Eur. Phys. J. A 34 (2007) 69

RHIC pC polarimeter data without cuts



Y. Makdisi et al. 2011 J. Phys.: Conf. Ser. 295 012130

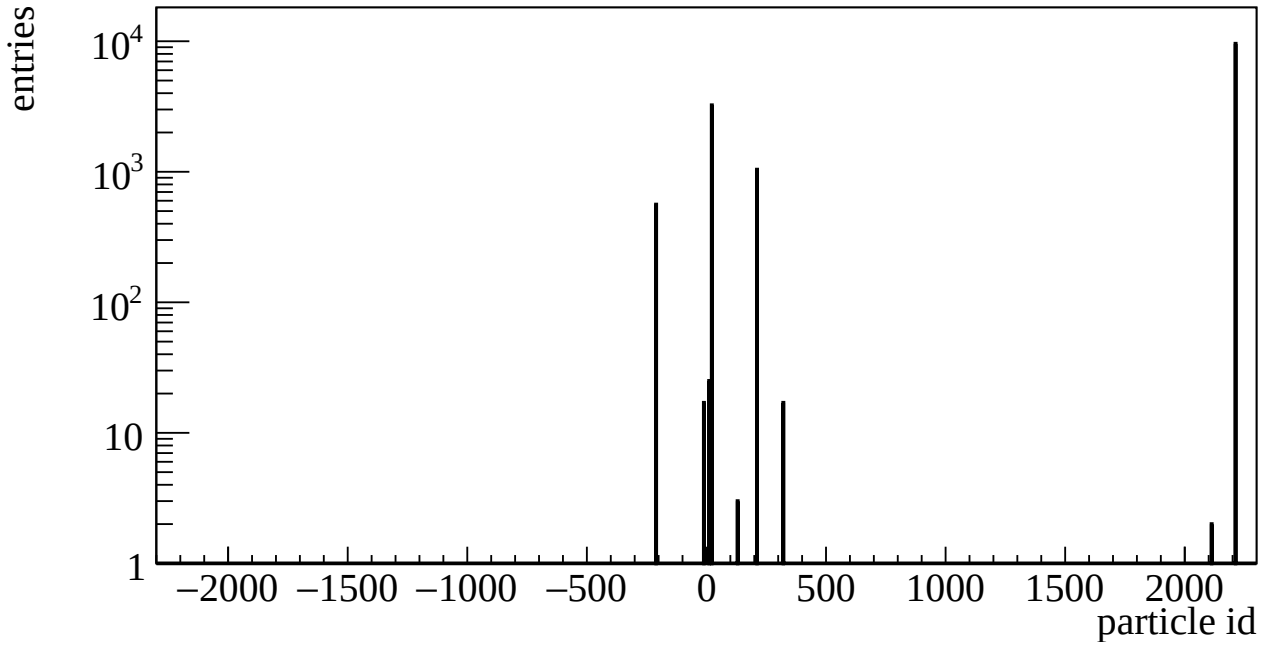
Tests foreseen

Tests at BNL for hadron polarimetry of EIC

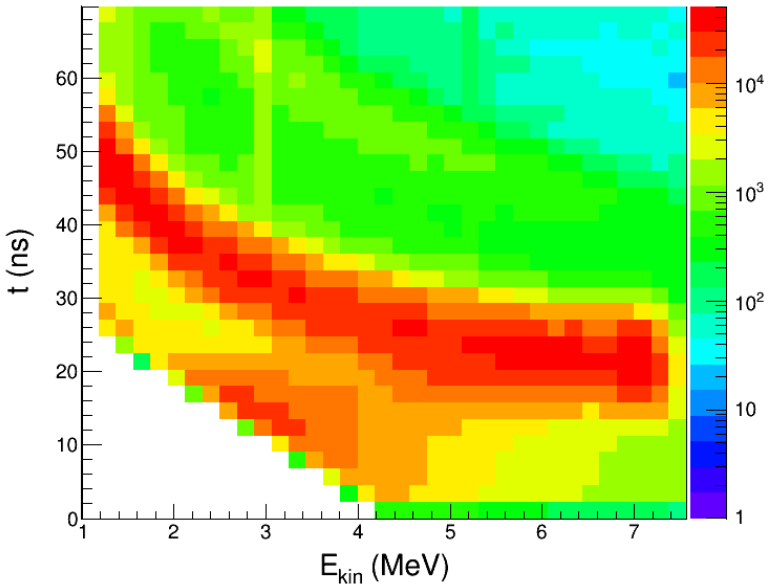
Beam	Target	Ring/ Polarimeter	Energy/ nucleon	Comments
He-3	C	AGS/C	24 GeV	Was already done, useful to know rates (including background)
Polarized He-3	C	AGS/C	24 GeV	Useful to get the scaling factor of the A_N
He-3	He-3	RHIC/X	166 GeV	Useful to know rates (including background)
He-3	Polarized He-3	RHIC/X	166 GeV	Useful to get the scaling factor of the A_N
Polarized He-3	Polarized He-3	RHIC/X	166 GeV	Useful to get the A_N
He-3	C	RHIC/C	166 GeV	Useful to know rates (including background)
D	C	AGS/C	24 GeV	Useful to know rates (including background)
D	D	RHIC/Jet	100 GeV	Useful to know rates (including background)
D	Polarized D	RHIC/Jet	100 GeV	Useful to get the scaling factor of the A_N
D	C	RHIC/C	100 GeV	Useful to know rates (including background)

Maximum energies provide the smallest analysing powers, hence are better suited for tests.
X – dedicated setup attached to bottle with gas

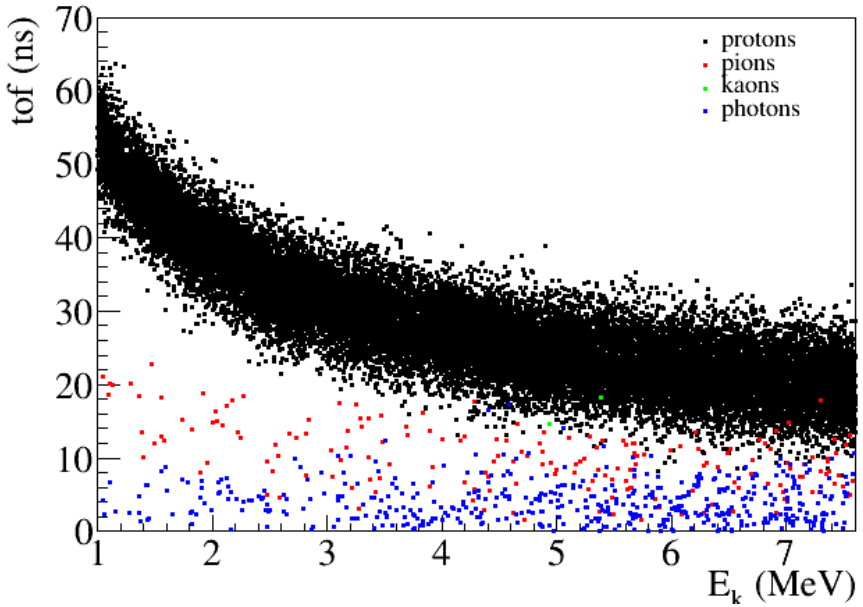
Pythia simulations of the present RHIC H-Jet polarimeter



- phythiaRHIC (Phythia6), $E_1 = 255$ GeV, $E2 = 0.00001$ GeV; 5×10^6 events, acceptance of the H-Jet silicon detectors
- MSEL=0
  MSUB(91)=1 ! Elastic
  MSUB(92)=1 ! Singly diffractive (XB)
  MSUB(93)=1 ! Singly diffractive (AX)
  MSUB(94)=1 ! Double diffractive
  MSUB(95)=1 ! Low-pT scattering
  MSUB(96)=1 ! Semihard QCD $2 \rightarrow 2$
- Most common particles in the final state: protons, pions, photons, kaons

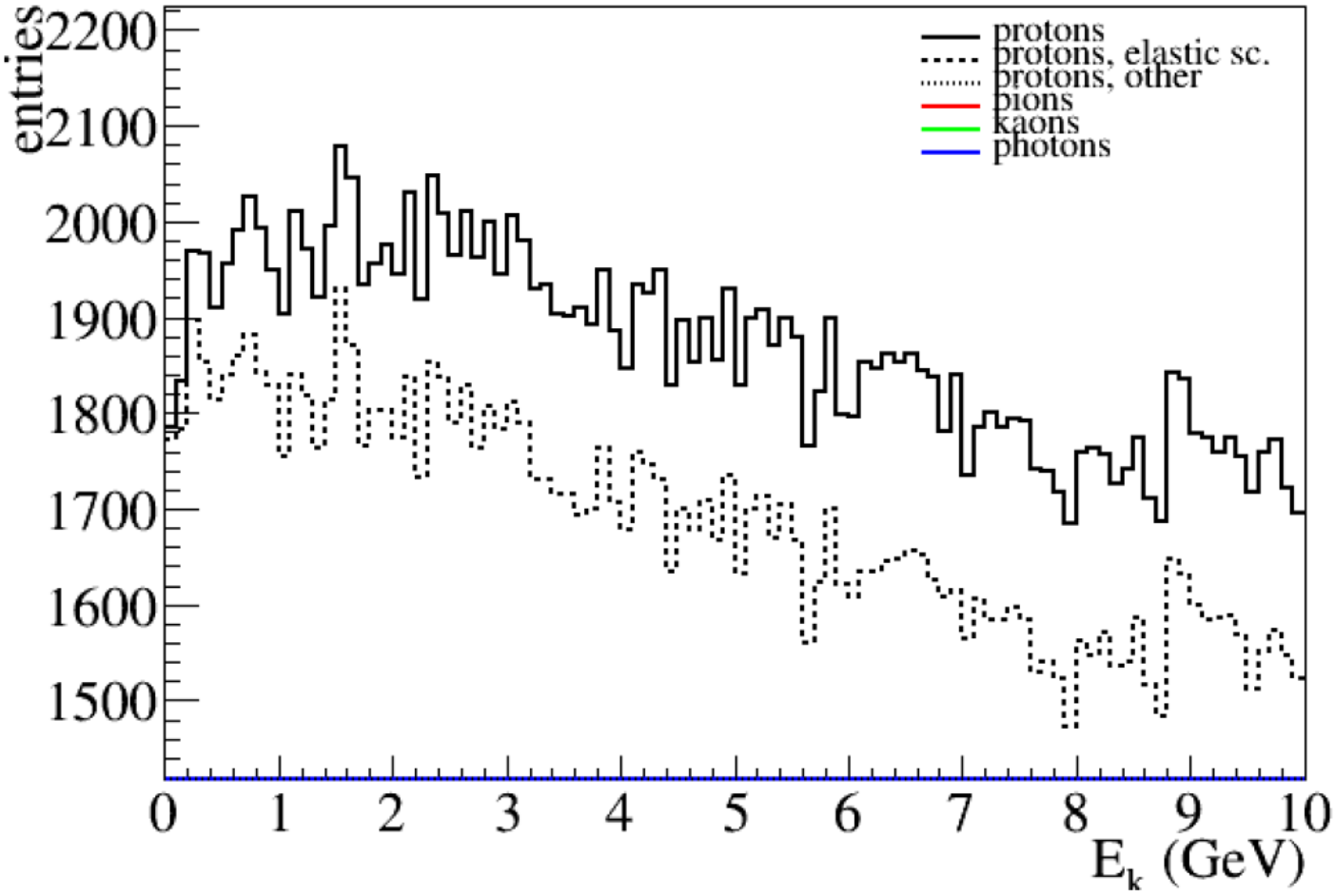


2017 H-Jet data

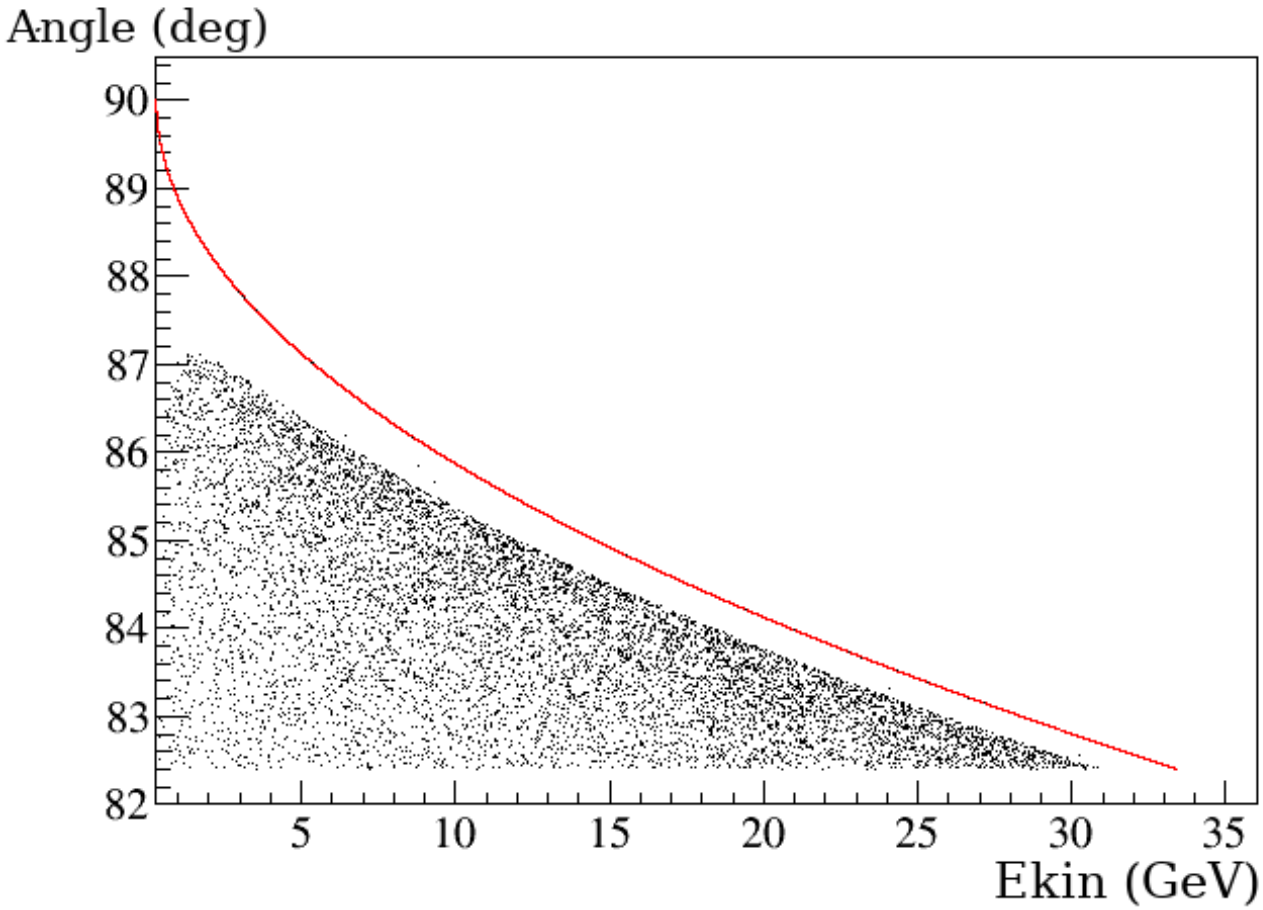


Pythia pp simulations

- Bunch length of 3.7 s used to produce the smearing
- "Banana" plot is reproduced



- High energy produced particles are protons



- It is possible to separate elastic and inelastic scattering protons based on angle and kinetic energy