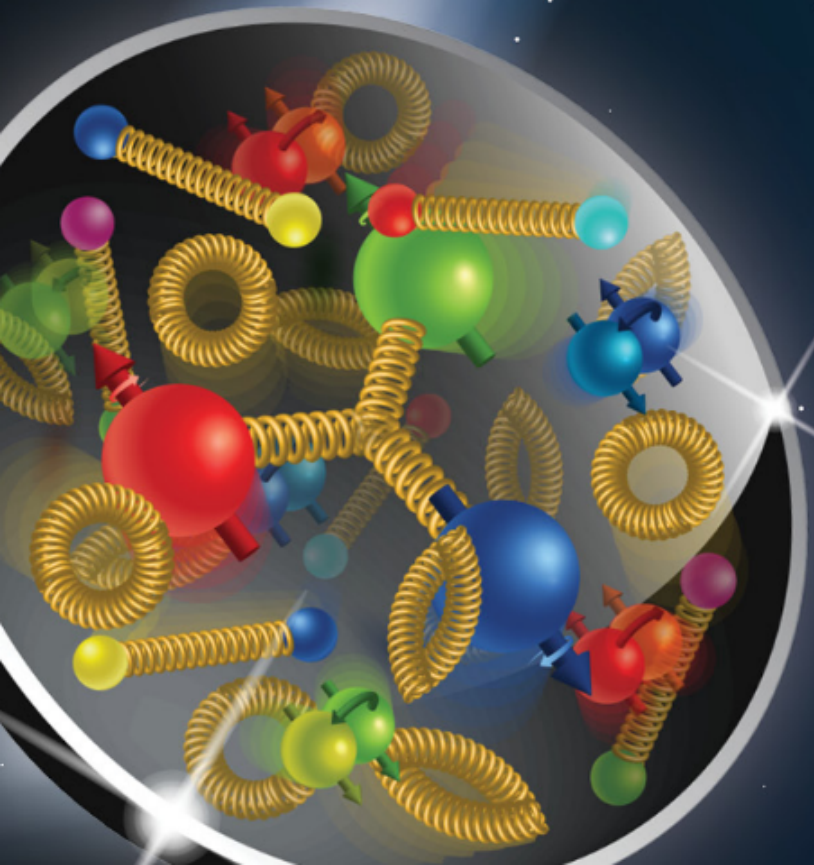
POLARIMETRY FOR IONS AT THE EIC



Ana S. Nunes

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Argonne National Laboratory
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BROOKHAVEN NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

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Physics Motivation

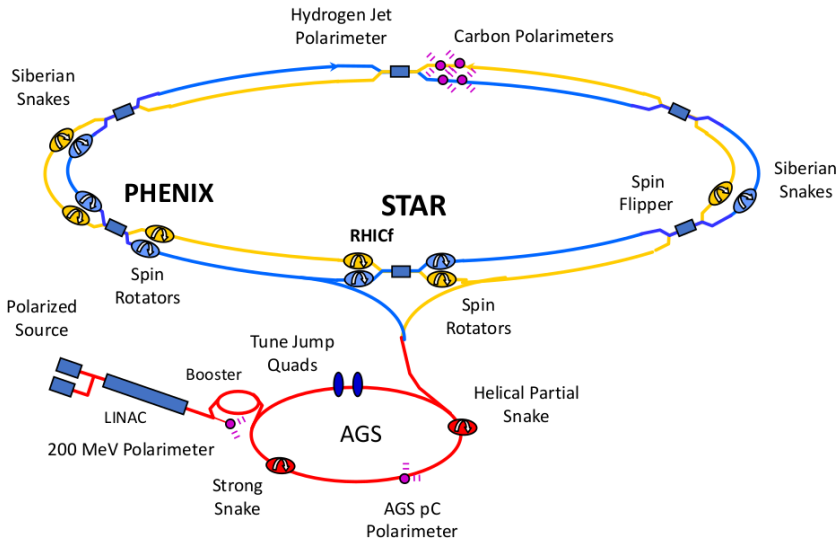
- The EIC will be the **first collider with polarized lepton and polarized hadron beams** in the world, and it will explore the structure of **nucleons and nuclei** in yet unexplored conditions
- The EIC has a rich spin physics program, using polarized electrons, protons and ions, that will lead to a much increased knowledge of the proton, by the extraction of **polarized PDFs**, **GPDs** and **TMDs**, and ultimately the **Wigner function**, and includes the quest for **saturation** at low x
- Beams of polarized light ions, namely ^{3}**He and D**, provide **polarized neutrons**, and polarized D is also interesting for the study of nuclear binding
- Measurements with neutrons combined with measurements with protons allow for **flavor separation of u and d quarks** in the valence region

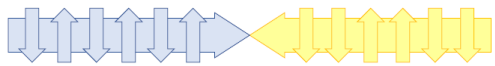
Outline

Polarimetry at RHIC

- In contrast to lepton polarimetry, **hadron polarimetry doesn't use a physical process that can be calculated from first principles**
- Requirements: **precision** measurements, **polarization profile** and **lifetime** to know **polarization in collisions** in experiments
- A **two-tier measurement** is needed: one for the **absolute polarization** (with low statistical power), and one for **relative polarization** (with high statistical power)

- At RHIC, the absolute polarization is measured with the **H-Jet polarimeter**, and the relative polarization is measured by 4 **proton-carbon polarimeters**
- There are also **local polarimeters** at the experimental interaction regions, to define the spin direction and the degree of rotation in the experimental area





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

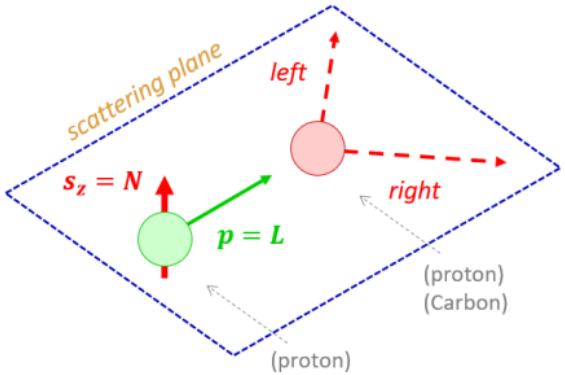
Outline

Absolute Polarimeter: the H-Jet

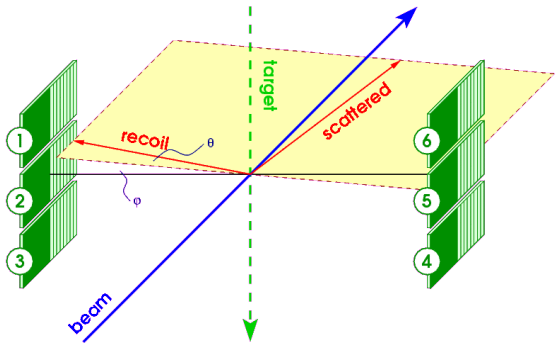
- A **polarized proton jet, with known polarization** (measured with a Breit-Rabi polarimeter) is used as target for **elastic scattering in CNI region** by beam $\overrightarrow{p}$. Asymmetry: $\varepsilon = A_N P$.
- The analyzing power A_N doesn't have to be known and allows the **self-calibration** of the polarimeter
- **Left-right asymmetries** ε are extracted
- Beam polarization given by

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

- Silicon strips detect the recoil particles
- Pros: provides absolute values of polarization
- Cons: low statistics (because of diffuse target) limits the precision, doesn't allow online monitoring, nor measuring the polarization transverse and longitudinal profile, nor measuring the polarization lifetime, only per fill measurements



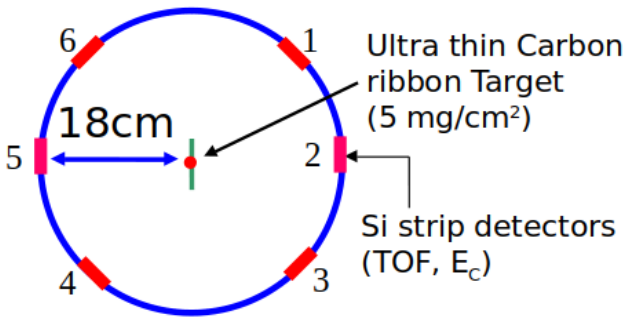
$$\varepsilon = \frac{N_L - N_R}{N_L + N_R}$$

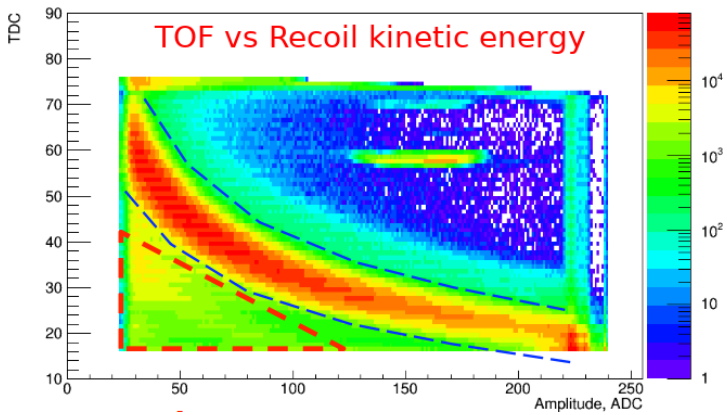


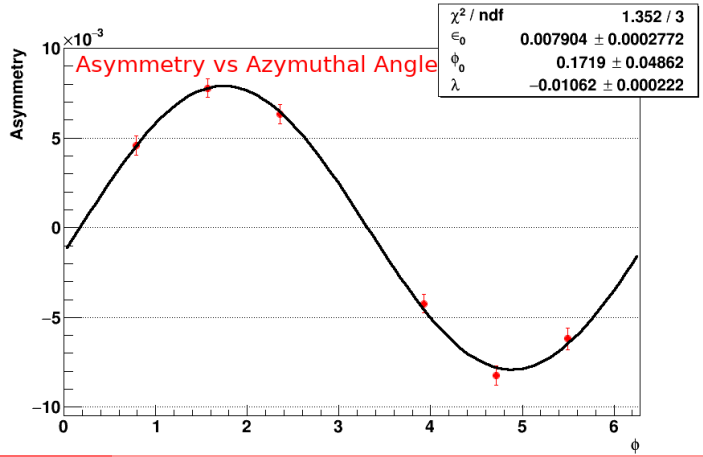
Outline

Fast and Precise Polarimeter: the pC Polarimeter

- **Non-polarized, ultra-thin carbon ribbon** ($w = 10\ \mu$m), 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 particles, measurements of 20-30 s in target scan mode
- Pros: the high statistics allows precise measurements (**statistical precision 2-3%**), online monitoring, measurement of the **polarization transverse and longitudinal profile**, **polarization lifetime**, and fill by fill polarization
- Cons: stability of targets, calibration of Si detectors every year







Outline

EIC Hadron Polarimetry

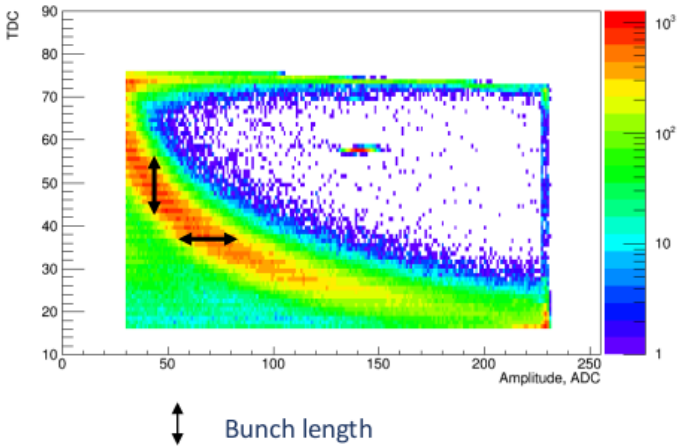
Requirements:

- 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)

Challenges:

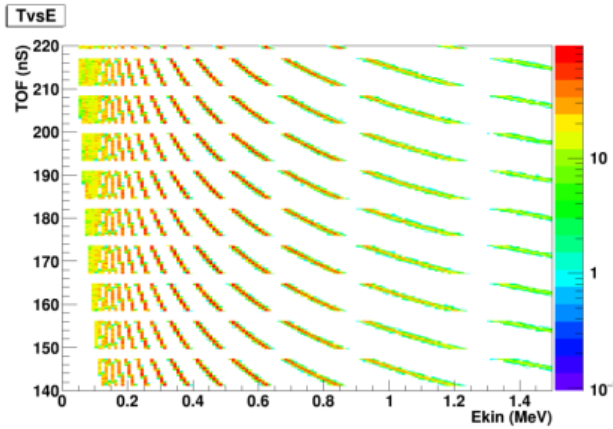
- Short spacing between bunches
- Background to the signal events may contaminate preceeding bunch
- Luminosity measurement may depend on the polarization:
  $\sigma_{\mathrm{Brems.}} = \sigma_0(1 + aP_eP_h)$
- **Pioneering light ion beam polarization measurements at high energies**

RHIC data:



120 bunches → 1320 bunches
106 ns → 8.9 ns

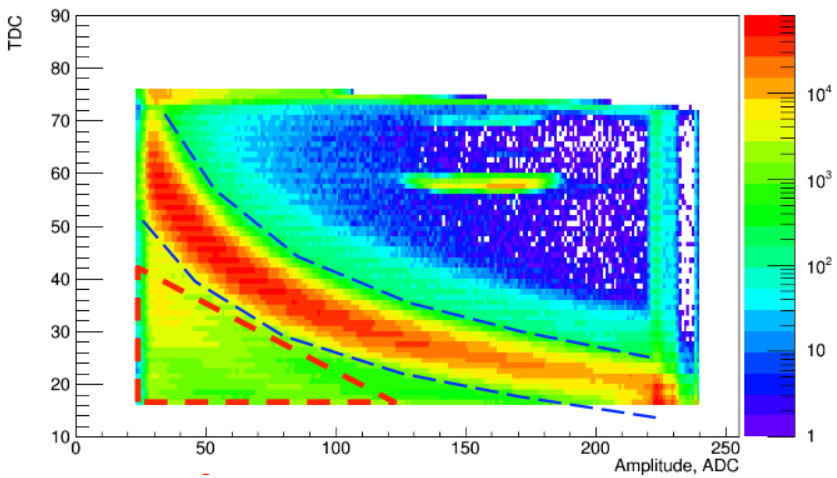
EIC (simulation):



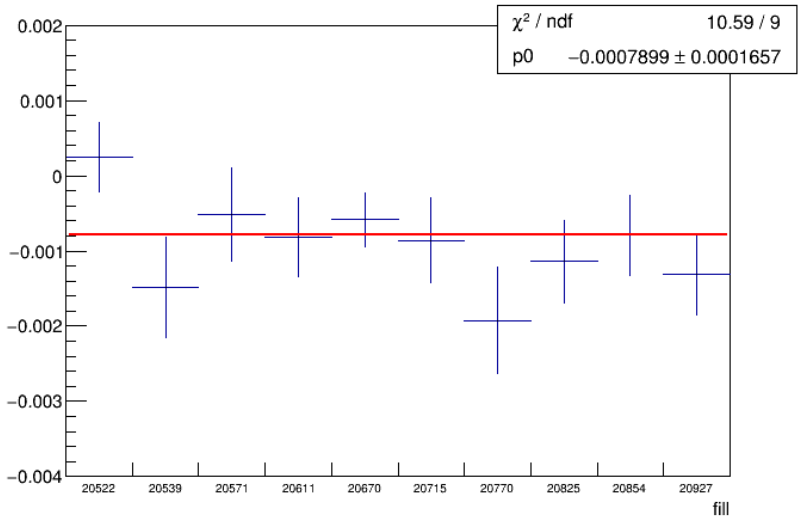
Outline

Polarized Proton Beams

- Problems: **background** to the elastic scattering events "banana" from triangular region in plot, **"prompts"** from the following bunch
- Ideas for improvements: second layer of silicon detectors can be installed in the polarimeters to **veto prompts** (to be tested in 2021 in pC and H-Jet polarimeters)
- **Other materials** could be used for more stable nuclear targets
- Silicon detectors and associated electronics (now: wave form digitizers) polarimeters can be upgraded to get **better timing resolution**



Background asymmetry, 10 measurements of RHIC pC polarimeters in 2017:

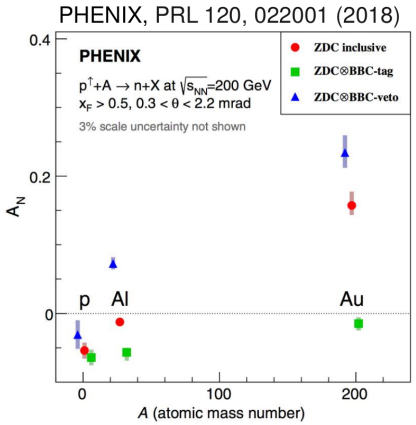


Outline

Alternative Approach

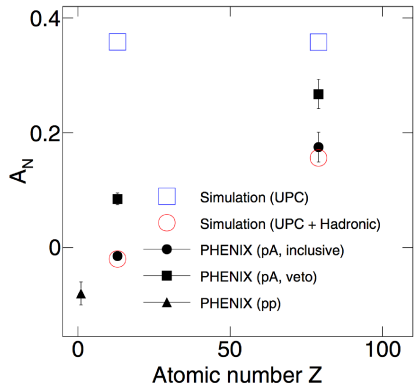
- A **large asymmetry** was measured by PHENIX in **forward neutrons from $\vec{p}$ on nuclei** (Al and Au)
- γ from high Z nucleus scatters on $\vec{p}$ target; parameterizations of $\gamma + \vec{p} \rightarrow n + \pi^+$ (MAID**) and photon flux (STARlight*) describe PHENIX results:

Data:

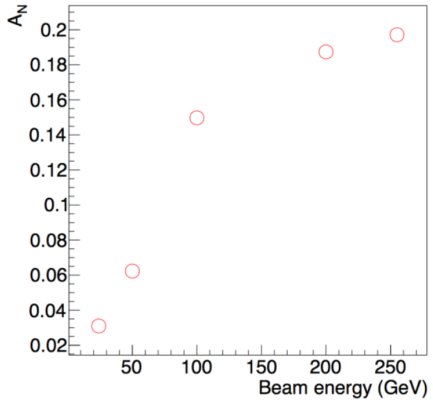


Model vs data

[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

Outline

Polarized Light Ion Beams

- Kinematics of elastic scattering in the CNI region for light ions is similar to that of pp
- **Breakup of light ions** has to be taken into account: **inelastic events must be vetoed**
- Simplest model (no spin flip, Coulomb phase nor ρ):

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

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

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

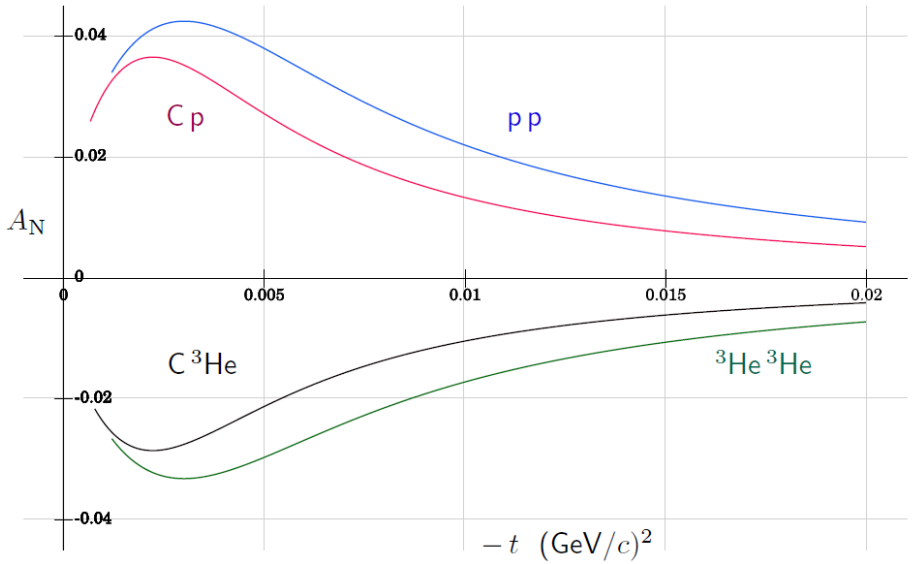


Figure 1: Analyzing power A_N versus invariant momentum transfer (-t) in (GeV/c)^2 for (1) p p and p h scattering, (2) C p scattering, (3) C h scattering, (4) h h and p h scattering

[N. Buttimore]

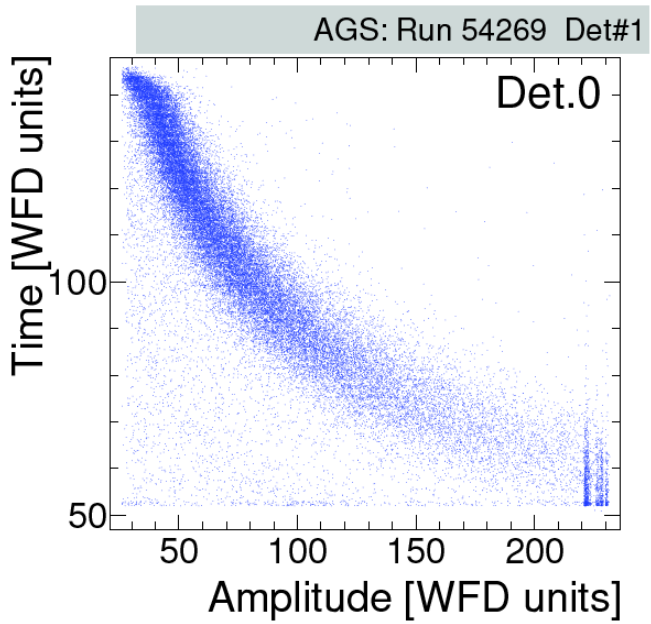
- The measurement of the polarization using the left-right asymmetry in D-D or D-C elastic scattering is very difficult
- A **test with a jet of polarized deuterons with known polarization** can be done in the next few years **at the H-Jet**, to measure the analyzing power for D-$\vec{D}$ deuterons at the EIC and check viability of deuteron polarimetry at the EIC

Outline

Polarized Helium-3 Beams

- Gas of **polarized helium-3** nuclei (helion) was used as **fixed target** at HERMES [Phys. Lett. B 404 (1997) 383], JLab and Jülich
- A helium-3 beam was **tested sucessfully at the AGS C polarimeters** (beam energy: 24 GeV)

Helion-carbon scattering at C polarimeters of the AGS:



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

- Now that a source of polarized ^{3}He is available, a **test with a polarized ^{3}He beam in C polarimeters of the AGS** can be envisioned in the next few years

Outline

Conclusions

Summary:

- The EIC physics programme requires precision measurements, and thus **hadron polarimetry with small uncertainties**
- The methods for **proton polarimetry** measurements are **mature** and **the experience of RHIC is essential for the EIC**
- **Small D magnetic moment** makes **D polarimetry very difficult**
- **Polarized He-3** is the best candidate as source of **polarized neutrons** at the EIC
- Elastic scattering of beam ^{3}**He** ions by **C** observed at the **AGS** (24 GeV)

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Outlook:

- A test on the RHIC polarimeters, using a **second layer of silicon strips**, will take place in 2021, to understand the feasibility of **vetoing prompts**
- Tests of **D-D at the RHIC H-Jet** and of **polarized ^{3}He on the AGS carbon polarimeters** are envisaged in the next years to measure the corresponding A_N values and to **evaluate the viability of D polarimetry** at the EIC
- Usage of **other technologies, including better timing resolution**, considered

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Thank you for your attention!