Hadron polarimetry for the EIC

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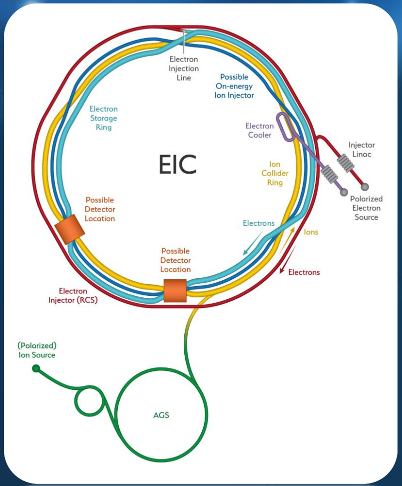
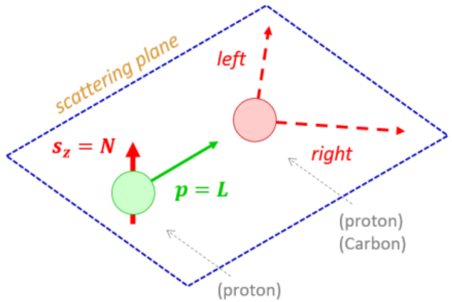


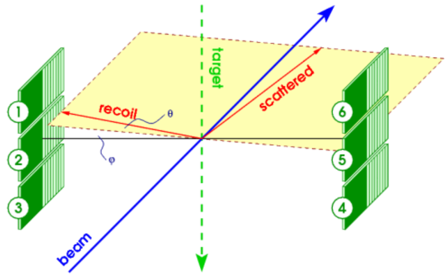
Outline:
1. Introduction
2. Experimental measurements
3. Simulations
4. Scenarios for tests in early 2020's
5. Summary and outlook

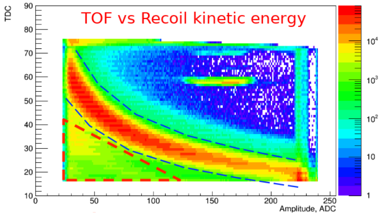
Hadron polarimetry: RHIC vs EIC

RHIC	What?	EIC
First collider of polarized protons	Pioneers	First collider of polarized electrons and polarized light hadrons (protons, deuterons and helions)
120 bunches separated by 106 ns, $1.4 \cdot 10^{11}$ protons/bunch	Beam characteristics	1160 bunches separated by 8.9 ns, $6.9 \cdot 10^{10}$ protons/bunch (less for light ions)
High values of polarization, transverse and longitudinal, controlled bunch by bunch	Hadron polarization requirements	High values of polarization, transverse and longitudinal, controlled bunch by bunch
Non-destructive, with minimal impact on the beam lifetime; systematic uncertainty ~2%, transverse profile of polarization, polarization lifetime; rapid, quasi-online analysis for accelerator setup	Hadron polarimetry requirements	Non-destructive, with minimal impact on the beam lifetime; systematic uncertainty ~1%, transverse profile of polarization, polarization lifetime, bunch by bunch measurement of polarization; rapid, quasi-online analysis for accelerator setup; polarization required for luminosity measurement: $\sigma_{\text{Brems.}} = \sigma_0(1 + aP_eP_h)$
Elastic scattering in Coulomb-nuclear interference (CNI) region, with recoil target particles emitted at close to 90^o with respect to the beam direction	Physical process used for hadron polarimetry	Elastic scattering in Coulomb-nuclear interference (CNI) region (and neutron production asymmetry in polarized proton-nucleus interactions, as measured by PHENIX?)
For monitoring: pC polarimeters and local polarimeters. For physics analysis: HJet and pC polarimeters	Polarimeter types	For monitoring: local polarimeters and other new type of polarimeters? For physics analysis: HJet (and other new type of polarimeters?)
HJet polarimeter has low statistical power; pC polarimeter does not provide absolute polarization; carbon targets wiggle and break; background to elastic events	Polarimeter limitations	HJet polarimeter with polarized protons has low statistical power; carbon targets at EIC would immediately break, background to elastic events from preceding bunches; for deuterons, the measured asymmetries may be too small

Elastic scattering at the CNI region







Data from pC polarimeters at RHIC

Measured left-right asymmetry of recoil particles:

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

Asymmetry and polarization are related by an analyzing power:

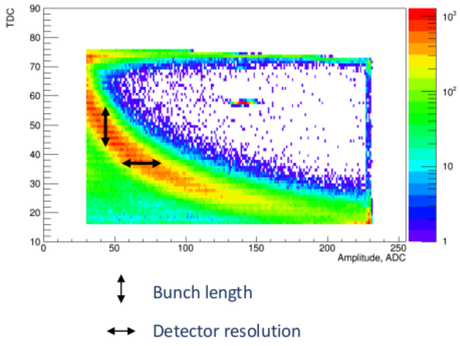
$$\epsilon = A_N P$$

When one can polarize the target and measure its polarization in an alternative way (as in the HJet):

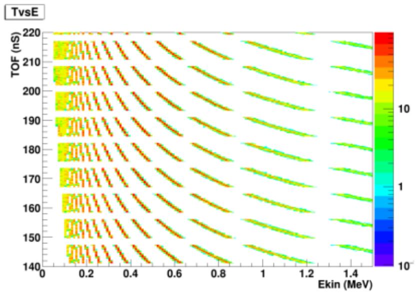
$$P_{\text{beam}} = \frac{\epsilon_{\text{beam}}}{A_N} = \frac{\epsilon_{\text{beam}}}{\epsilon_{target}} P_{\text{target}}$$

But, for the EIC:

- For deuterons, the analyzing powers are thought to be much smaller (factor 10), because of its smaller magnetic moment
- As distance between bunches will be 8.9 ns, the elastic signals of different bunches will almost overlap

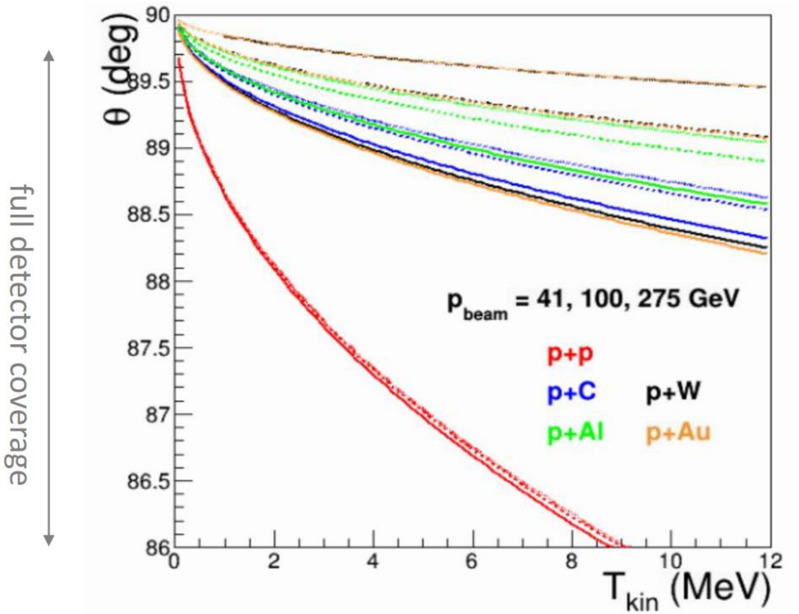


120 bunches → 1320 bunches
106 ns → 8.9 ns



Kinematics of elastic scattering at the EIC

Protons



(Oleg Eyser)

Light ions

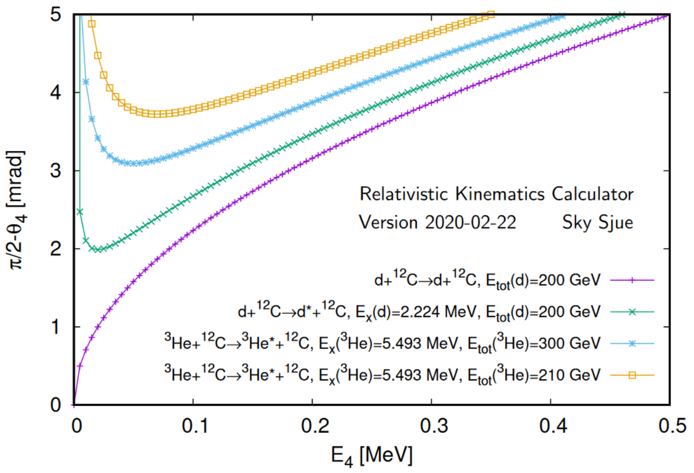


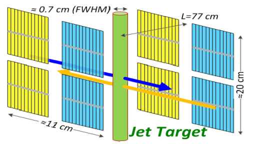
Figure 1: Complementary recoil angle versus recoil kinetic energy $T_R = E_4$ for, from top, (below legend), (1) h–C → [p+d]–C at 70 GeV/n, (2) h–C → [p+d]–C at 100 GeV/n, (3) d–C → [p+n]–C at 100 GeV/n, (4) d–C and h–C elastic (≈ same) at 100 GeV/n.

(Nigel Buttimore)

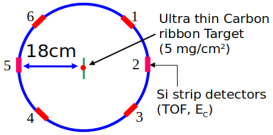
- The recoil angles of protons and light ions at the EIC, and for different target materials, is not very different from that a t RHIC

Hadron polarimetry simulations

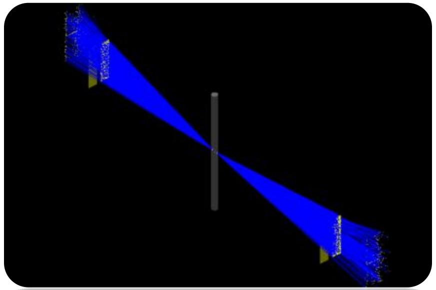
- **Pythia6** (for proton-proton) and **DPMJET-III** (for all nucleus-nucleus interactions) event generators
- Interaction with matter in HJet using HjetSim (developed by Oleg Eyser), based on **Geant4**, including:
  - Silicon sensors: 400 μm, 8 μm dead layer
  - Longitudinal dimension of bunches (3.5 ns)
  - Material around interactions (chamber and flanges)
  - Atomic hydrogen jet target ($\rho \approx 0.4 \cdot 10^{-11}$ g/cm^3)
  - Two components of vertex distributions: σ_1 = 5 mm, σ_2 = 10 cm



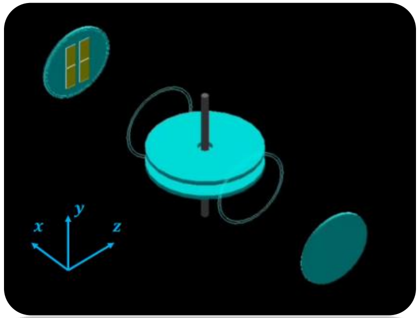
HJet polarimeter @ RHIC



pC polarimeter @ RHIC



Final state particles of Pythia6 in pp@ HJet @ RHIC, 255 GeV beam, filtered to silicon detector acceptance, in HjetSim



HJet silicon sensors, chamber and flanges in HjetSim

Possible scenarios:

Current polarimeters:
1. pp @ HJet @ RHIC, 255 GeV beam
2. pC @ Carbon polarimeters @ RHIC, 255 GeV beam
3. pC @ Carbon polarimeters @ AGS, 24 GeV beam

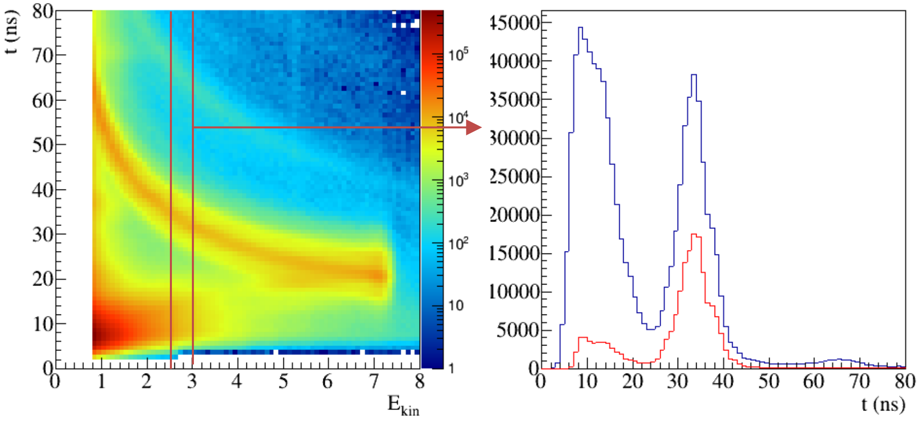
Polarimetry tests in the early 2020's at RHIC: and AGS
1. dd @ HJet @ RHIC, 100 GeV/n beam
2. hh @ HJet @ RHIC, 100 GeV/n beam
3. dp @ HJet @ RHIC, 100 GeV/n beam
4. hp @ HJet @ RHIC, 100 GeV/n beam
5. pC @ HJet @ RHIC, 255 GeV beam
6. dC @ HJet @ RHIC, 100 GeV/n beam
7. hC @ HJet @ RHIC, 100 GeV/n beam
8. pC @ Carbon polarimeters @ AGS, 24 GeV beam
9. dC @ Carbon polarimeters @ AGS, 24 GeV/n beam
10. hC @ Carbon polarimeters @ AGS, 24 GeV/n beam
11. pW @ 'Carbon' polarimeters @ RHIC, 255 GeV beam

EIC polarimeters (?):
1. pp @ HJet @ EIC, 255 GeV beam
2. dd @ HJet @ EIC, 100 GeV/n beam
3. hh @ HJet @ EIC, 166 GeV/n beam
4. pC @ HJet @ EIC, 255 GeV beam
5. dC @ HJet @ EIC, 100 GeV/n beam
6. hC @ HJet @ EIC, 166 GeV/n beam
7. pC @ Carbon polarimeters @ AGS, 24 GeV beam
8. dC @ Carbon polarimeters @ AGS, 24 GeV/n beam
9. hC @ Carbon polarimeters @ AGS, 24 GeV/n beam

pp @ HJet @ RHIC, 255 GeV beam

2017 HJet Data

Run
#20592

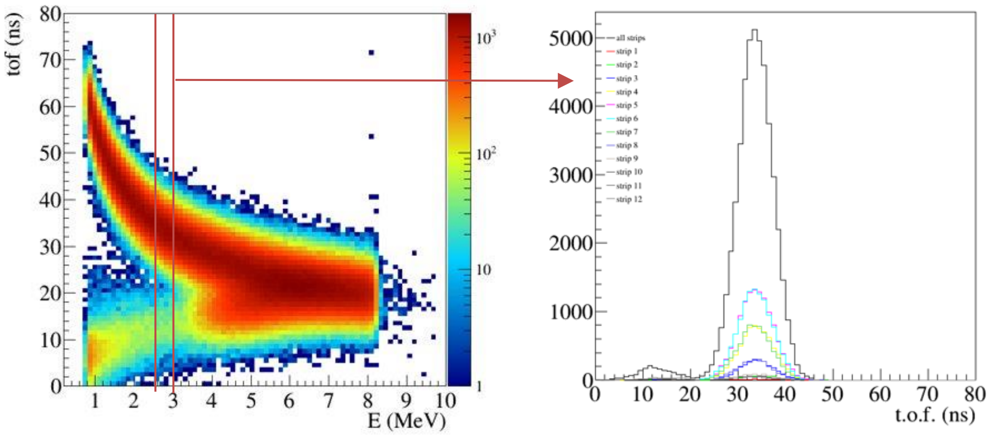


Excluding blue beam abort gap data (bunch<=110), downstream (w.r.t. blue beam) silicon strips

Excluding blue beam abort gap data (bunch<=110), downstream (w.r.t. blue beam) silicon strips; 2.5<E<3.0 MeV all strips(blue) & strip #5 only (red)

Pythia6+Geant4 simulation

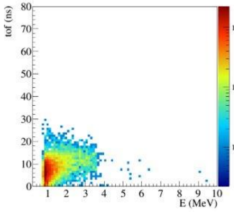
100M events in detector acceptance. Includes: sigma=3.5 ns long bunches, material around interaction, H2 beam pipe gas (HJetSim)



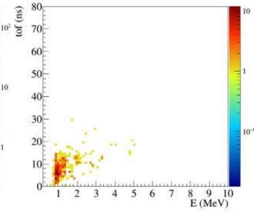
T.o.f., 2.5<E<3.0 MeV, by silicon strip

- Main data features are reproduced by the simulation
- The low energy, low time of flight background results from charged pions, charged kaons, and a few photons and electron-positron pairs
- Protons and other particles punch-through the silicon detectors => motivation for their detection with a second layer of silicon sensors
- There is still room for improvement in the background description

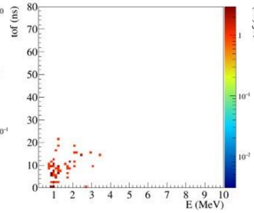
Charged pions



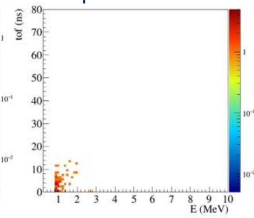
Charged kaons



Photons



Electrons and positrons

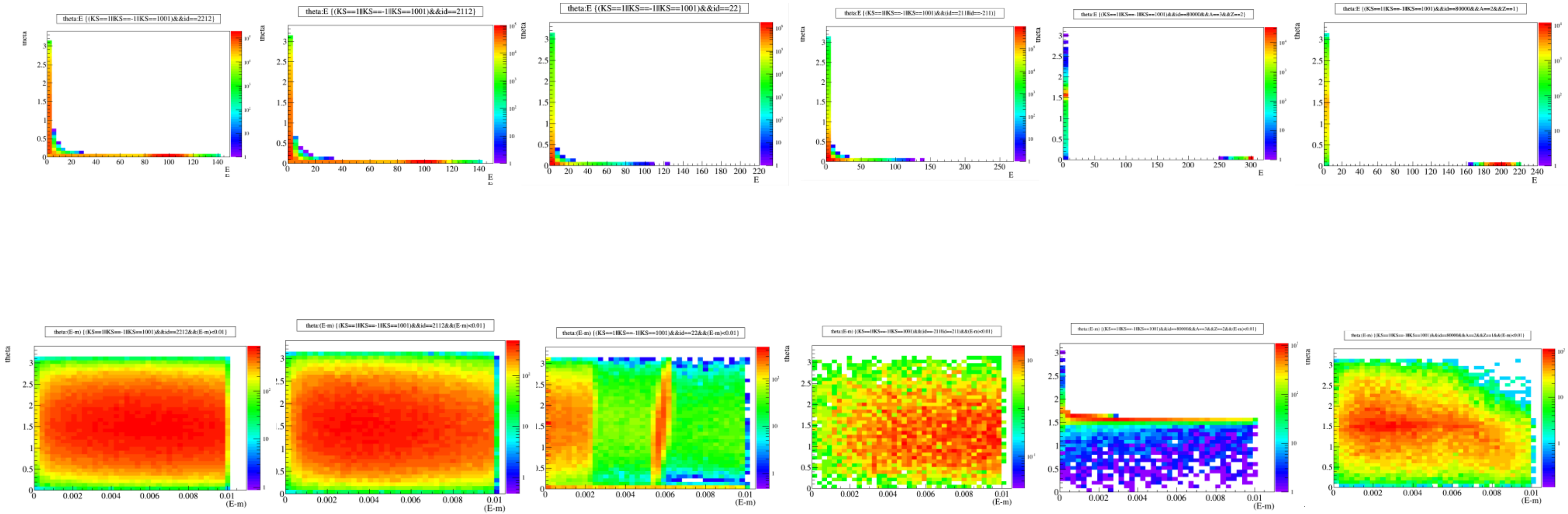


hh @ HJet @ RHIC, 100 GeV/n beam

Protons | Neutrons | Photons | pi+/- | He-3 | Deuterons

All energies:

(E-m) < 0.01 GeV

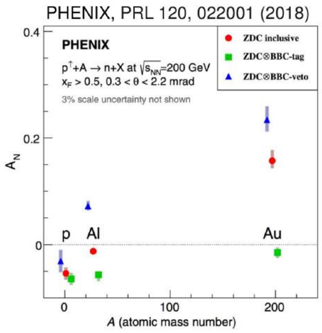


- At generator level (DPMJET-III), one can see particles up to the beam energy going forward, and of low energies emitted at all angles
- The elastic signal from recoil helions is potentially diluted by protons, deuterons, photons, pions => this background can potentially be reduced by a Zero Degree Calorimeter that tags spectator neutrons from the breakup of helions

An alternative physics process

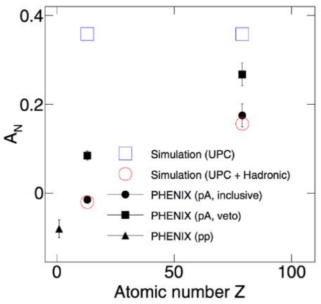
- A large asymmetry was measured by PHENIX in forward neutrons from interactions of polarized protons on nuclei (Al and Au)
- A photon from a high Z nucleus scatters on a polarized proton target; parameterizations by MAID(*) of the process $\gamma + \vec{p} \rightarrow n + \pi^+$ and by the photon flux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

Data:

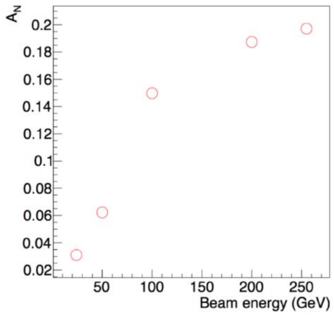


Model vs data

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



Simulation (pAu):



- Opportunity for a polarimeter: high Z target (e.g. Xe gas jet) in polarized proton beam
- Would require a calorimeter to detect neutrons at low angles
- Open questions: can a thin jet (~100 mm) of a Xe gas be produced and allow enough statistics for the measurements of the beam polarization lifetime and profile, and bunch by bunch?

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

Scenarios for tests in early 2020's

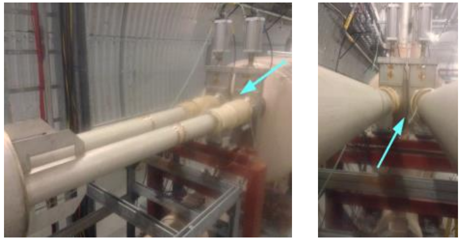
AGS: studies can be done in parallel w/ RHIC physics stores
RHIC: need dedicated beam time – APEX

With unpolarized particles: background studies
With one polarized particle: measure single spin asymmetries
Better with nominal energies at EIC, poor-man solution with lower energies
Better with nominal beam intensity…

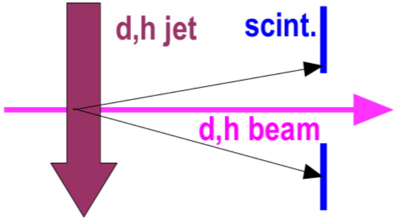
<u>Beams</u>
d in AGS
d in RHIC
h in AGS
h in RHIC
h↑ in AGS: 2022
h↑ in RHIC: 2022

<u>Jet targets</u>
d
d↑
h
h↑

Possible additions in hardware:



Easy (noninvasive) polarimeter upgrades (outside vacuum):
- ZDC (spare PHENIX) @ 18m from Hjet
    - tag n spectators from d, h breakup



Harder (invasive) polarimeter upgrades (inside vacuum):
- Scintillators inside beampipe, downstream of jet target
    - tag target, beam breakup

Summary and outlook

- **The EIC will be the first collider using polarized light ion beams: protons, helions and eventually deuterons**

- The kinematics of protons and light ions at EIC conditions, and with different target materials is not very different from the current conditions at RHIC => the current polarimeters could be used with minimal adaptations

- **Challenges for EIC**:
  - 1% systematic uncertainty
  - expected smaller spin asymmetries for deuterons
  - the beam bunches will be closer in time
  - the background cannot be totally avoided
  - temperature becomes too high for carbon targets

- **Tests can be done at RHIC in the next few years**, to evaluate cross section rates between beam species, rates of elastic scattering and backgrounds, and analyzing powers in case of polarized particles, impact of second layer of silicon sensor, impact of a ZDC to tag spectator neutrons, different target materials, etc. Some examples:
  - Unpolarized and polarized h at the carbon polarimeters at the AGS (24 GeV/n)
  - Polarized h at injection energy (24 GeV/n) and more (100 GeV/n) at RHIC
  - Unpolarized deuteron beam at full energy at RHIC (~100 GeV/n)
  - Possibly deuteron and helion targets (unpolarized and polarized) at the Jet polarimeter

- Simulations using Pythia6, DPMJET-III and Geant4 underway

- Request of test beam at AGS and RHIC is being prepared