Light ion polarimetry at the EIC

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Outline:
1. Introduction
2. Theoretical insights
3. Experimental measurements
4. Simulations
5. Summary and outlook

Introduction

- Polarized light ions D and ^{3}He are effective **polarized neutrons targets**; neutrons and protons allow for **flavor separation of u and d quarks**; D useful to study nuclear binding

- A simulation program was started to reproduce the current RHIC polarimeter data (including background) and predict rates for the tests' conditions envisaged at the AGS and RHIC in the next few years and the EIC polarimeter conditions
  - Generators:
    - For pp in Hjet: Pythia6 (or Dpmjet3)
    - For dd and hh in Hjet, and pC in the pC polarimeters: Dpmjet3
  - Interaction with matter: Geant4

Theoretical insights

- Simplest model:

$$A_n = \frac{\sqrt{x}}{x^2+3} \cdot A_N^{\rm opt} = \frac{\sqrt{x}}{x^2+3} \cdot \frac{k}{4m_p}\sqrt{-3t_e}, \quad \text{with } x = \frac{t}{t_e}, \quad t_e = \frac{\sqrt{3}ZZ'}{\sigma_{\rm tot}}$$

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

- **Asymmetries** for dd, He3-He3, dC, He3-C **unknown** and expected to be smaller than for p (compared to p: 78% for He3, **8% for d**)

- In a more complete model, there are unknown free parameters, that allow even for sign changes of the analyzing power => **experimental measurements required**

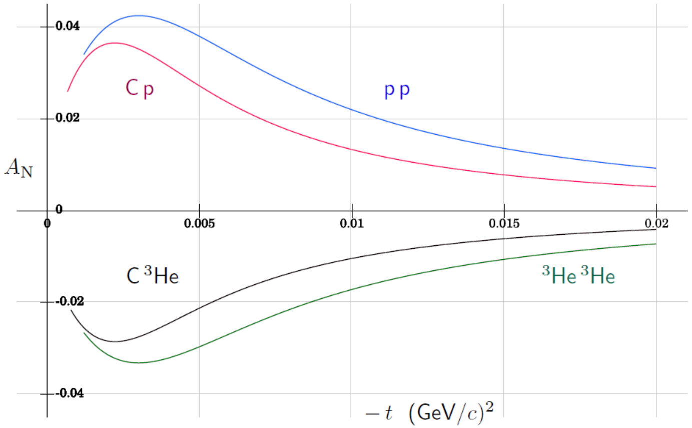


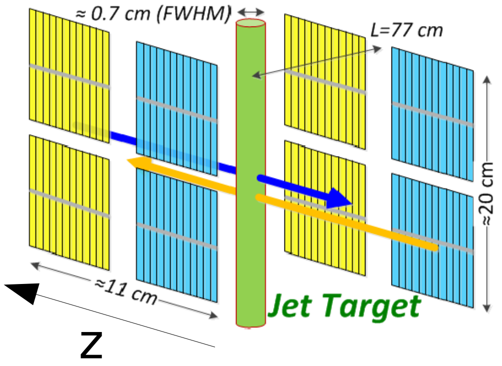
Figure 1: Analyzing power A_N versus invariant momentum transfer (-t) in (GeV/c)^2 for (1) p p and p h scattering, (2) C p scattering, (3) C h scattering, (4) h h and p h scattering

LHCspin 2019-07-16 LHCspin and Polarimetry University of Ferrara 12

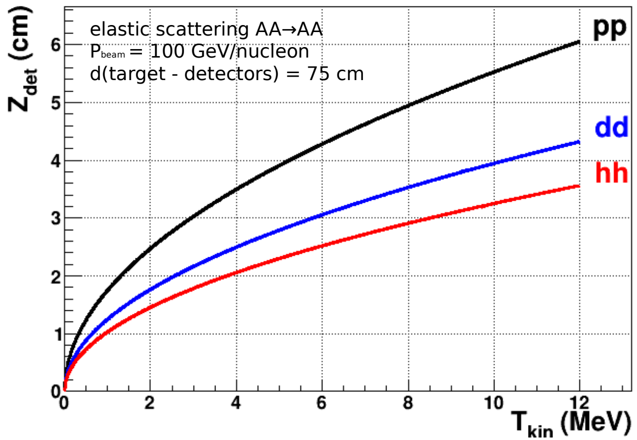
N. Buttimore

Kinematics

- Polarimetry at RHIC is based on **elastic scattering** in the Coulomb-nuclear interference (CNI) region
- The recoil particle from the target is detected at nearly right angles to the beam
- **Similar kinematics** of light ions and pp allow the use of polarimeters similar to those used at RHIC
  - Hjet: 1 MeV < E_{kin} < 7.6 MeV
  - RHIC pC polarimeters: 300 < E_{kin} <900 KeV
- **Breakup of light ions** may occur, eventually resonances may distort the kinematics

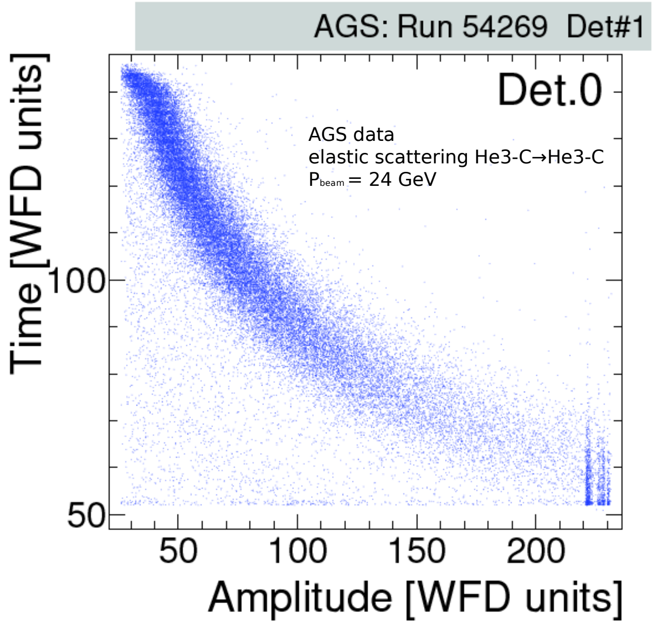


W. Schmidke



Experimental measurements

- Event rates expected to be larger than for p (2x for hC measured at AGS)
- **Tests in RHIC lifetime** with beams of **d (unpolarized)** and **h (unpolarized and polarized)** and **d and h jets (unpolarized and polarized)** are envisaged; forward detectors can be used to detect breakup fragments



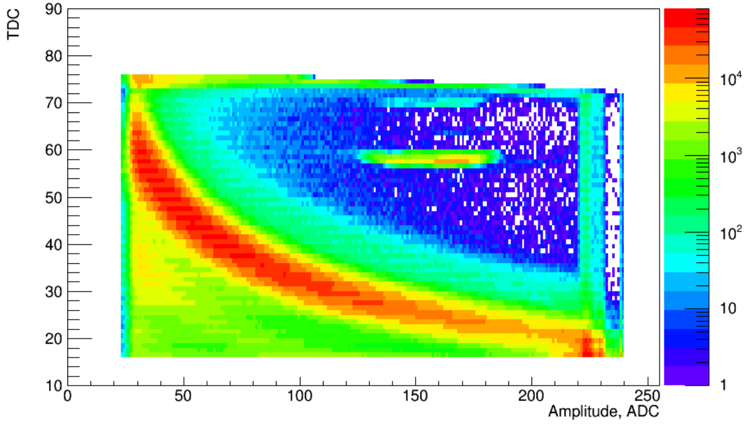
H. Huang et al., IPAC2014

Studies in early 2020's for d, h

pC polarimeters:

unpolarized beam:

- check TOF vs. E_{kin} (carbon bananas):



polarized beam:

- beam asymmetry

Jet target:

unpolarized beam:

- check TOF vs E_{kin} (different p,d,h 'bananas'); check scat. angle vs. E_{kin} (different for pp, dd, hh)

polarized target:

- target asymmetry

polarized beam:

- beam asymmetry

polarized beam & target:

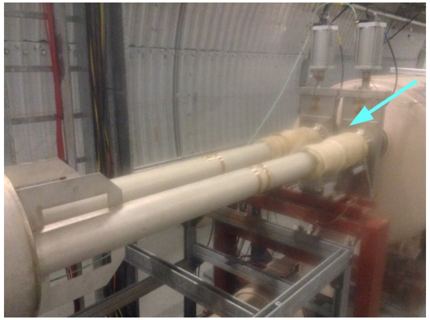
- P_{beam}/P_{target}

Additions in early 2020's for d, h

Easy (noninvasive) polarimeter upgrades (outside vacuum):

- ZDC (spare PHENIX) 18m from Hjet

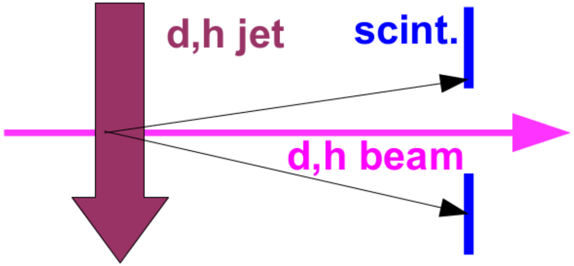
    tag n spectators from d, h breakup



Harder (invasive) polarimeter upgrades (inside vacuum):

- Scintillators inside beampipe, downstream of jet target

    tag target, beam breakup



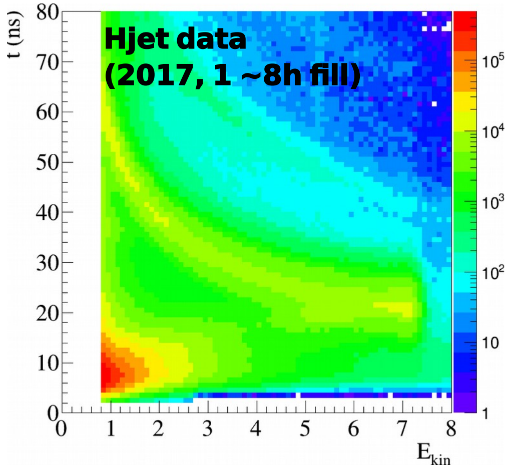
Scenarios for tests

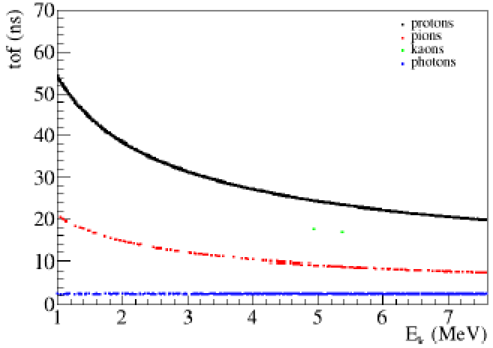
AGS: studies can be done behind RHIC physics stores
RHIC: need dedicated beam time - APEX

Availability timelines?

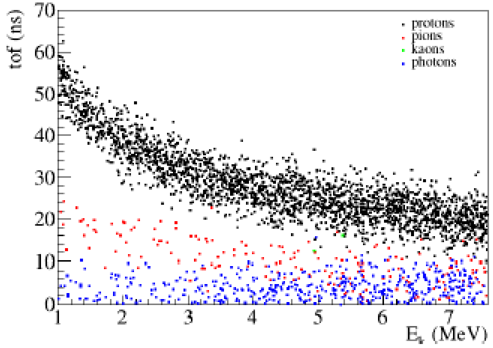
Beams	Jet targets
d in AGS:	d:
d in RHIC:	d↑:
h in AGS:	h:
h in RHIC:	h↑:
h↑ in AGS: 2022	
h↑ in RHIC: 2022	

Simulations: pp @ current HJet





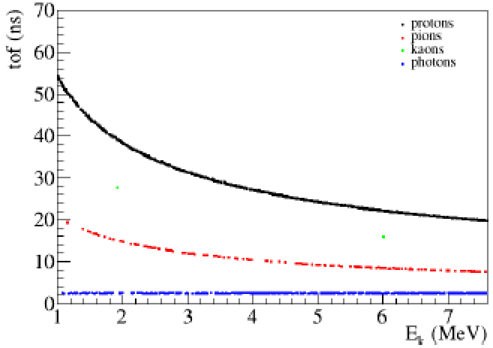
Pythia6 pp simulation
non elastic events, $\sigma_t = 0$



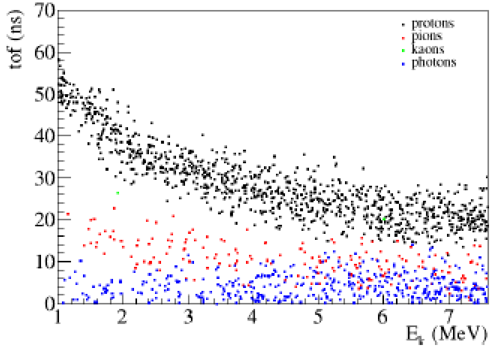
Pythia6 pp simulation
non elastic events, $\sigma_t = 3.7$ ns

- 1M events generated, cut on detector acceptance, energy loss in detector not yet taken into account

- Pythia6 and Dpmjet3 results are compatible



Dpmjet3 pp simulation
non elastic events, $\sigma_t = 0$



Dpmjet3 pp simulation
non elastic events, $\sigma_t = 3.7$ ns

Pythia6, pp @RHIC Hjet

Generated events: 1M, $E_{\mathrm{beam}} = 255$ GeV, w/ detector acceptance cut

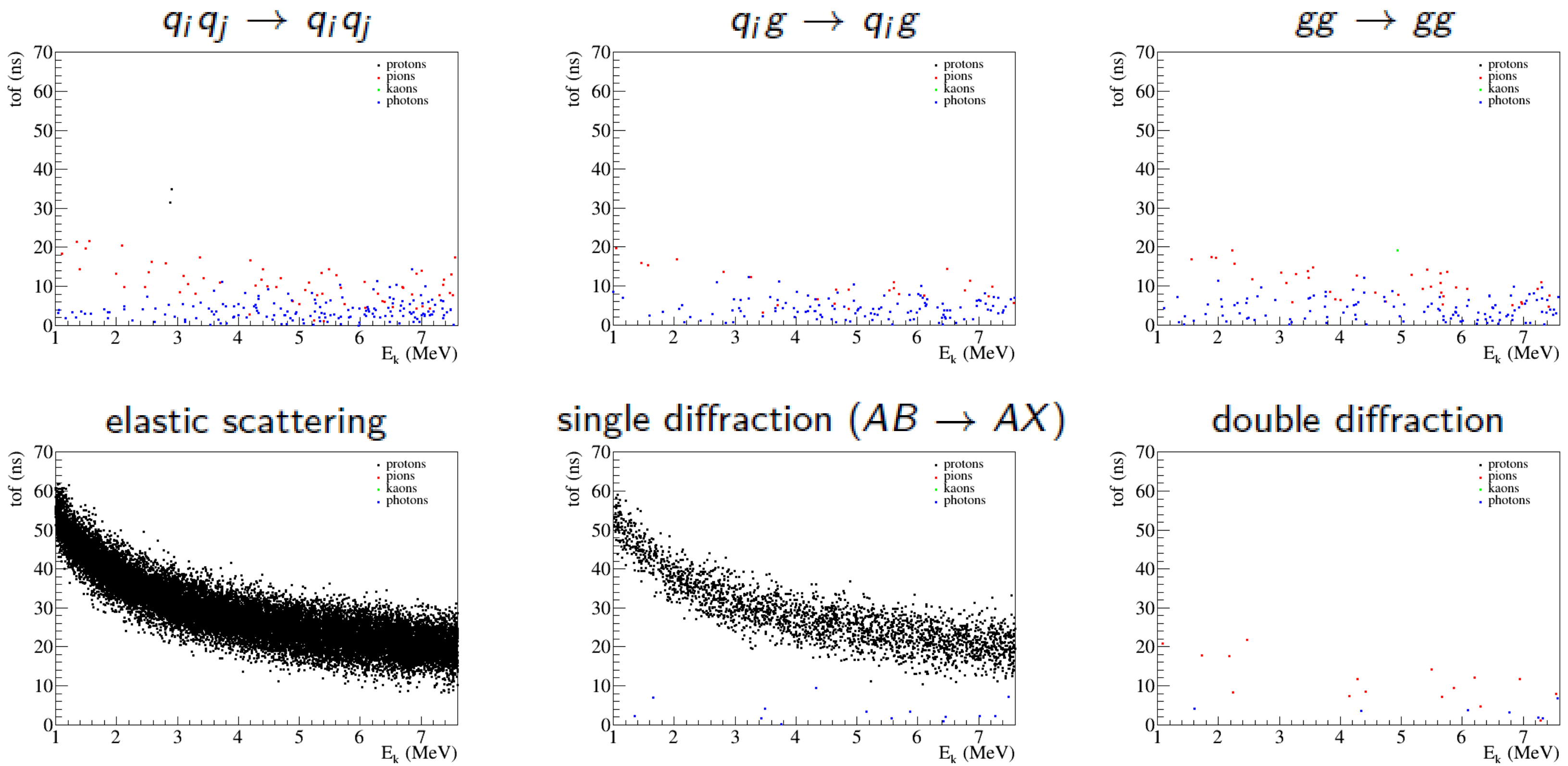
PID	Particle	Entries
-321	K^-	6
-211	π^-	5697
-12	$\bar{\nu}_e$	2
-11	e^-	182
11	e^+	199
12	ν_e	1
13	μ^-	1
22	γ	32197
130	K_L^0	31
211	π^+	10339
321	K^+	129
2112	n	21
2212	p	97255

ProcessID	Process	Entries
1	$f_i\bar{f}_j \to \gamma^*/Z^0 \to F_K\bar{F}_k$	0
2	$f_i\bar{f}_j \to W^+ \to F_k\bar{F}_l$	0
10	$f_i f_j \to f_k f_l$	0
11	$q_i q_j \to q_i q_j$	15769
12	$q_i\bar{q}_i \to q_k\bar{q}_k$	14
13	$q_i\bar{q}_i \to gg$	31
14	$q_i\bar{q}_i \to g\gamma$	1
28	$q_i g \to q_i g$	8949
29	$q_i g \to q_i\gamma$	0
53	$gg \to q_k\bar{q}_k$	141
68	$gg \to gg$	8950
82	$gg \to Q_k\bar{Q}_k$	0
91	elastic scattering	88859
92	single diffraction ($AB \to XB$)	9791
93	single diffraction ($AB \to AX$)	8580
94	double diffraction	4974
95	low-p_T production	0
96	semihard QCD $2 \to 2$	0
114	$gg \to \gamma\gamma$	0
115	$gg \to g\gamma$	0

- Pythia generates: **elastic**, **single and double diffractive** and all the **hard scattering** processes in pp

Pythia6, TOF vs E_{kin} w/ PID

- 1M Generated events, E_{beam} = 255 GeV, w/ detector acceptance cut



Dpmjet3, pp @RHIC HJet

Generated events: 1M, $E_{\mathrm{beam}} = 255$ GeV, w/ detector acceptance cut

PID	Particle	Entries
-321	K^-	16
-211	π^-	6198
-11	e^-	12
11	e^+	9
22	γ	2247
111	π^0	10161
130	K_L^0	53
211	π^+	10379
310	K_S^0	44
321	K^+	113
2112	n	4
2212	p	89392

ProcessID	Entries
1	25466
2	85801
3	0
4	0
5	2917
6	3419
7	1025
8	0

DPMJET subprocesses in ep/eA

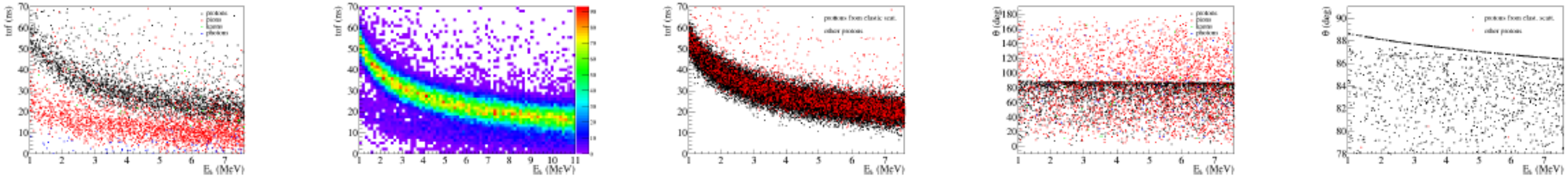
process1	Description
1	non-diffractive inelastic scattering
2	purely elastic scattering
3	quasi-elastic scattering
4	central diffraction (double-pomeron scattering)
5	single diffractive dissociation of particle 1
6	single diffractive dissociation of particle 2
7	double diffractive dissociattion
8	hard direct interactions

Dpmjet3, pp @RHIC HJet

Generated events: 1M, $E_{\rm beam} = 255$ GeV, w/ and w/o detector acceptance cut

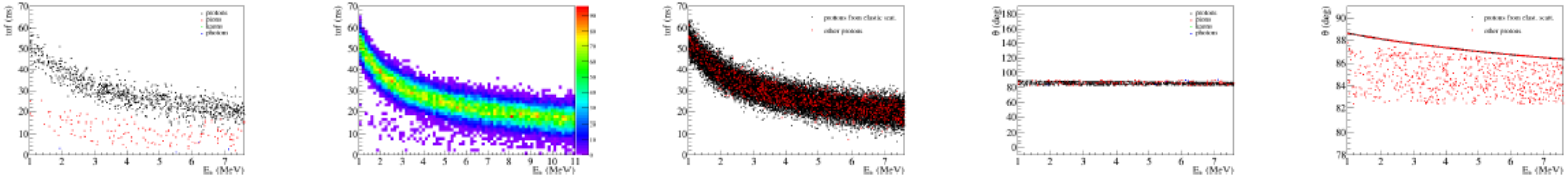
WITHOUT acceptance cut

TOF vs $E_{\rm kin}$ Non elast., w/ PID	TOF vs $E_{\rm kin}$ Non elast.	TOF vs $E_{\rm kin}$ Protons	θ vs $E_{\rm kin}$ w/ PID	θ vs $E_{\rm kin}$ Protons



WITH acceptance cut

TOF vs $E_{\rm kin}$ Non elast., w/ PID	TOF vs $E_{\rm kin}$ Non elast.	TOF vs $E_{\rm kin}$ Protons	θ vs $E_{\rm kin}$ w/ PID	θ vs $E_{\rm kin}$ Protons



Summary and Outlook

- Polarized light ion beams, like D and He-3, provide unique opportunities for spin physics measurements
- The kinematics of interactions with deuterons or helions is similar to the proton case => **the current polarimeters can in principle be used with minimal adaptations**
- Challenges for EIC: 1% systematic uncertainty requirement, expected small spin asymmetries for D, bunches closer in time, background not yet totally understood, temperature of pC polarimeter targets
- **Tests can be done at RHIC in the next few years**, to evaluate rates of elastic scattering and backgrounds, and analysing powers when possible:
  - Polarized Helium-3 at injection energy (24 GeV/n) at RHIC
  - Unpolarized deuteron target at full energy at RHIC (~255 GeV/n) at RHIC
  - Possibly deuteron and helion (unpolarized and polarized) at the Jet polarimeter at RHIC
- **Simulation program initiated** using Pythia6, Dpmjet3 and Geant4
  - Ongoing: describe energy loss of particles in silicon detectors

Backup

From Haixin

- On d beams:

- “The biggest problem is the source. If we have a polarized deuteron source, then it is not a problem. There is no polarization loss expected in the AGS and Booster. So whatever asymmetry you measured should be the full polarization. I will check with JLab about if they have polarized deuteron source. Last month, I was told by Wolfram not to work on polarized deuteron related work. We published a paper on feasibility of polarized deuteron in EIC in Feb. His comment is to remind me that should be it. But this can change if there is new demand to work on polarized deuteron.”
- “I just got reply from JLab. They don’t have polarized deuteron source or any ion source. So if want to do it, we need to develop it on our own. COSY in Germany has deuteron source, and some labs in Russia also use it.”
- “For deuteron, yes it can only be unpolarized.”

- On h beams:

- “The polarized He3 source supposed to be ready next year. The additional solenoid was planned to be ready by the end of this year for higher gold intensity. Then the polarized He3 beam test can follow next year. In 2022, we should be able to work on polarized He3 beam.”
- “For He3, it is possible to be polarized at flattop but lower polarization. We don’t expect that polarization to be completely lost in RHIC with two snakes. The other option is to stop before the strongest resonance at a lower energy.

From Anatoli

- On jet polarimeter target beams:

"we plan to further upgrade polarized H-jet polarimeter for operation at EIC.

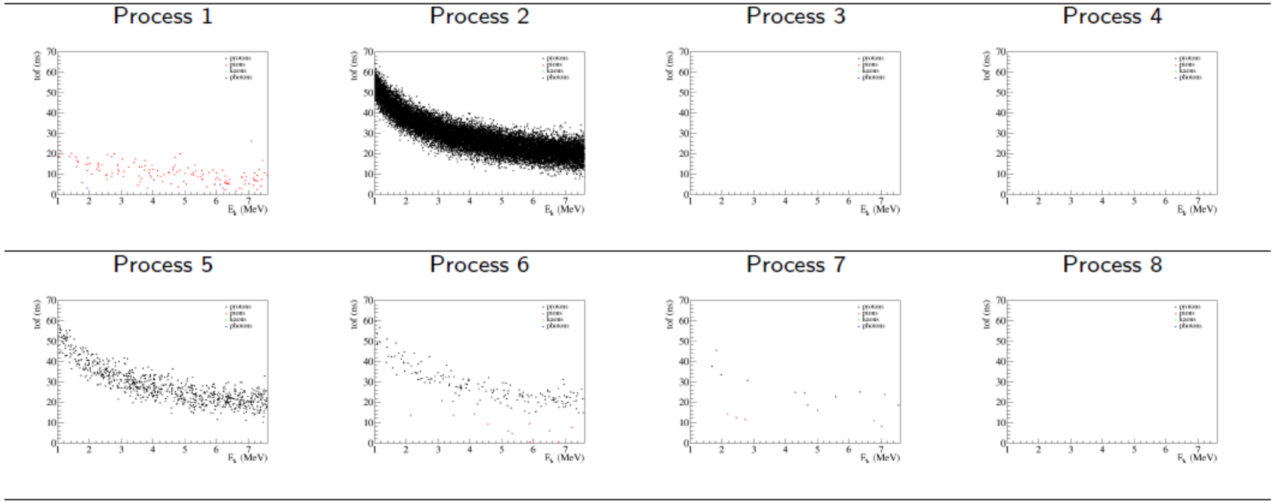
We also consider building un-polarized H-jet cluster target with thickness 10^14 atoms/cm^2.

Polarized deuteron target can be produced by H-jet.

Polarized He-3 target, polarized by metastability exchange technique is also under consideration."

Dpmjet3, TOF vs E_{kin} w/PID

Generated events: 1M, $E_{\mathrm{beam}} = 255$ GeV, w/ detector acceptance cut



DPMJET subprocesses in ep/eA

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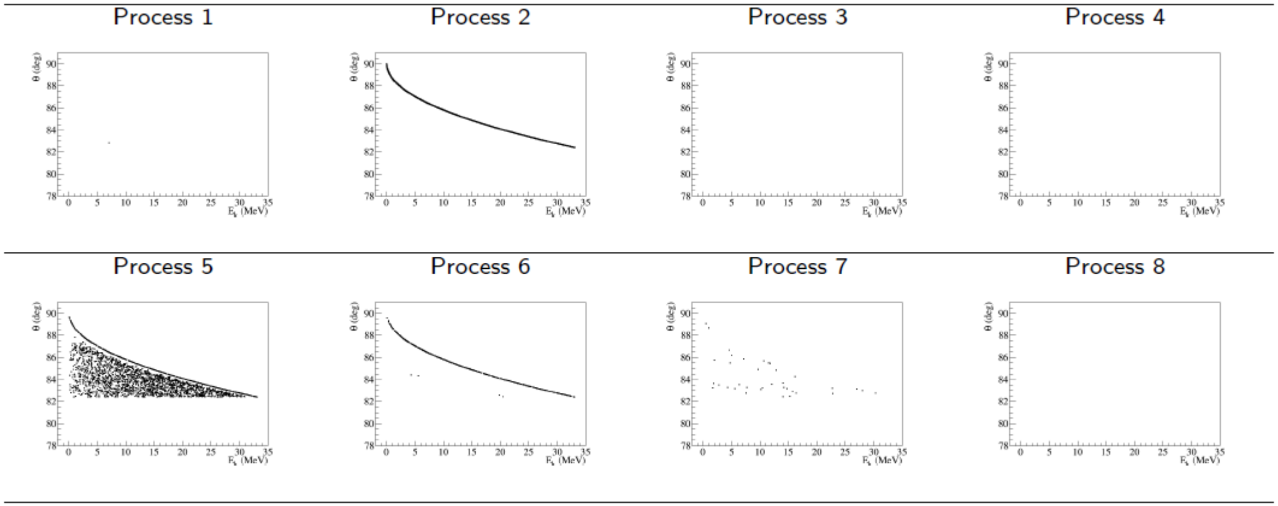
Dpmjet3, Theta vs E_{kin}

Generated events: 1M, $E_{\text{beam}} = 255$ GeV, w/ detector acceptance cut



DPMJET subprocesses in ep/eA

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Generated events: 1M, E_{beam} = 255 GeV, w/o detector acceptance cut