Hadron Polarimetry Simulation

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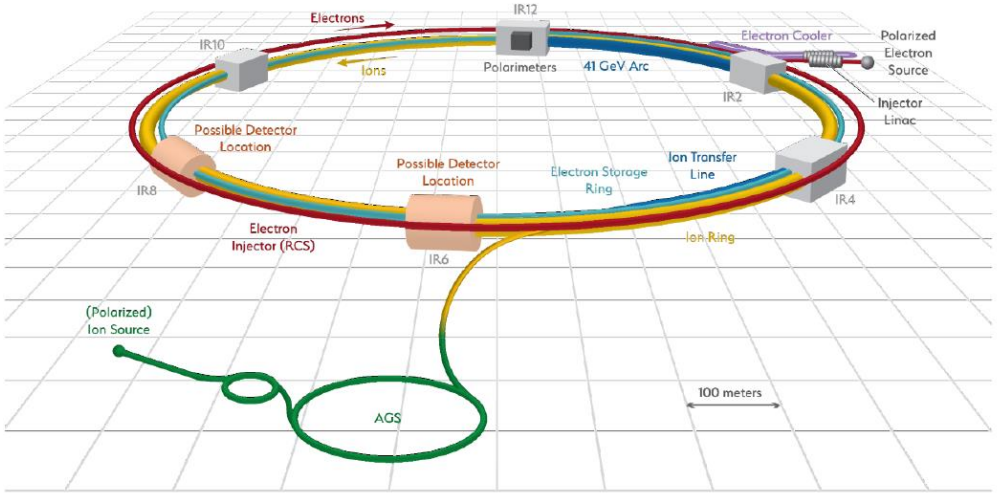
Requirements for an Electron-Ion Collider

- Physics observables
  - High beam polarizations: electrons & protons
- High EIC Luminosity → small systematics ≈ 1%
- Flexible bunch polarization orientation
- Polarimeter ⟺ polarization in collision
  - Bunch polarization profile in x, y, z
  - Polarization lifetime
  - Polarization per bunch

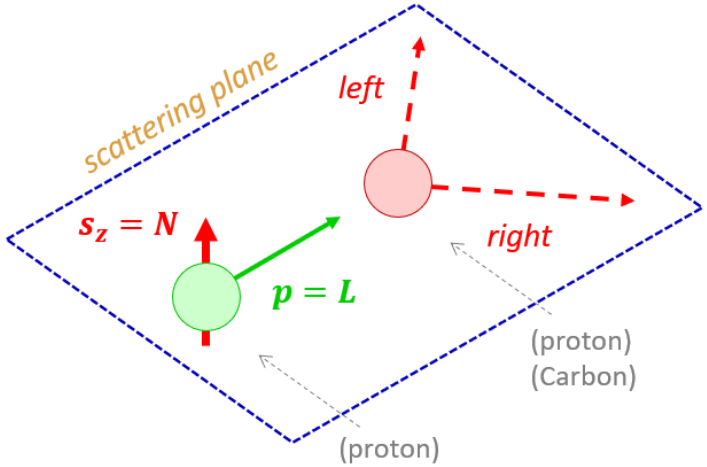


- Absolute beam polarization
- Polarization decay in store
- Transverse polarization profile
- Longitudinal polarization profile
- Polarization vector in experiment

Proton Polarimetry at RHIC

Recoil from elastic scattering:

$$\sigma_P = \sigma_0(1 + A_N P_y \cos\phi)$$



$$A_N = \frac{d\sigma_{left} - d\sigma_{right}}{d\sigma_{left} + d\sigma_{right}}$$

$$\varepsilon = A_N \cdot P = \frac{N_L - N_R}{N_L + N_R}$$

$$P_{Beam} = -\frac{\varepsilon_{Beam}}{\varepsilon_{Target}} P_{Target}$$

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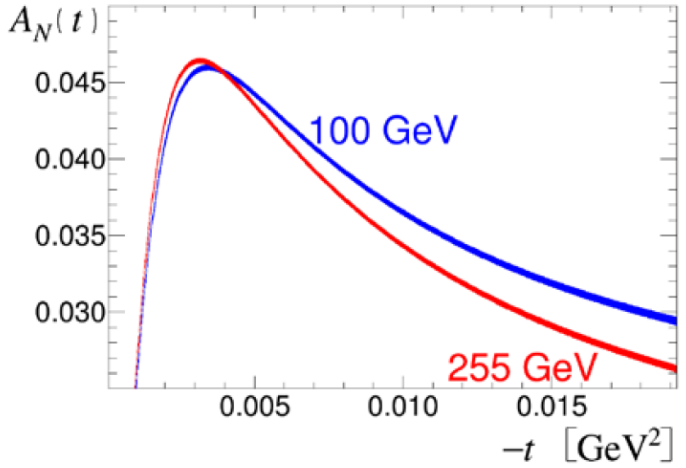
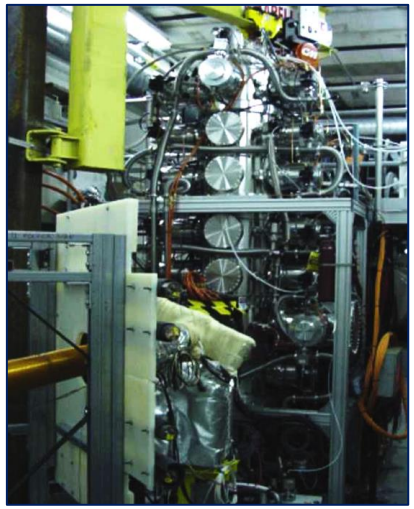
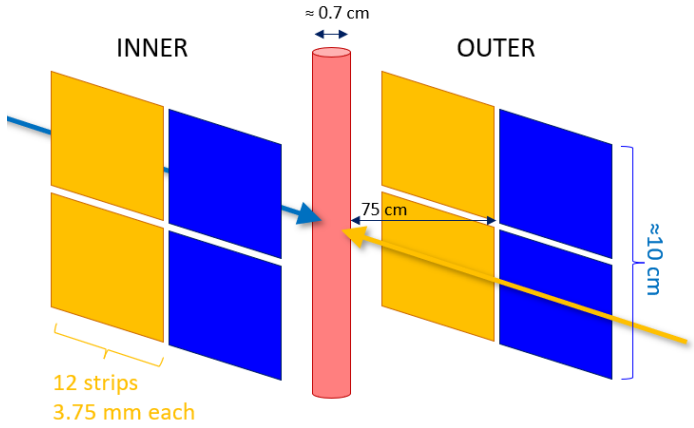


Proton Polarimetry at RHIC

HJET: Polarized atomic hydrogen jet target





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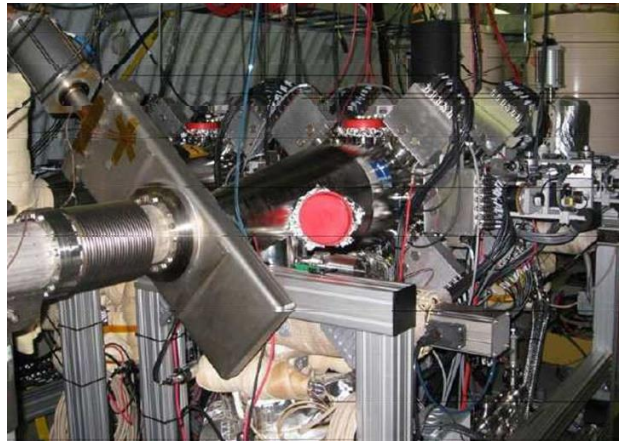
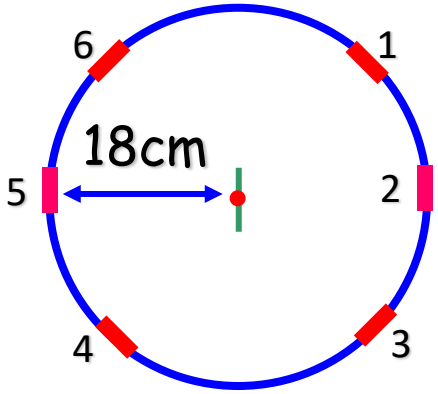
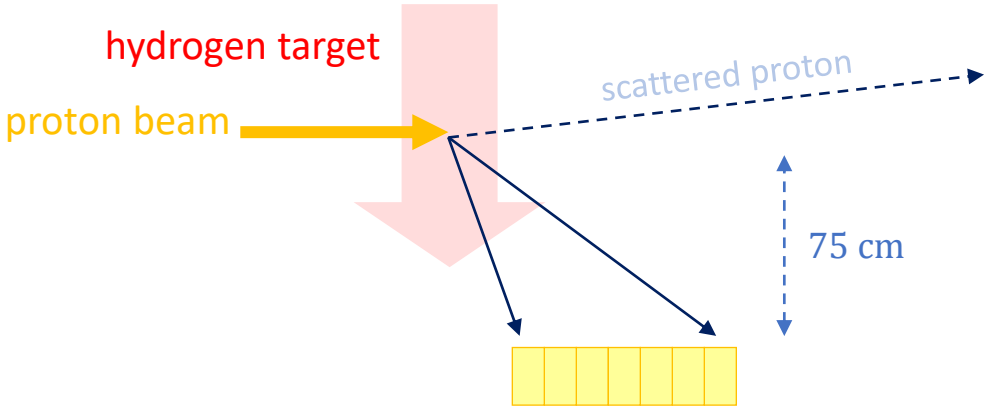
pC: ultra-thin Carbon fiber (ribbon) targets

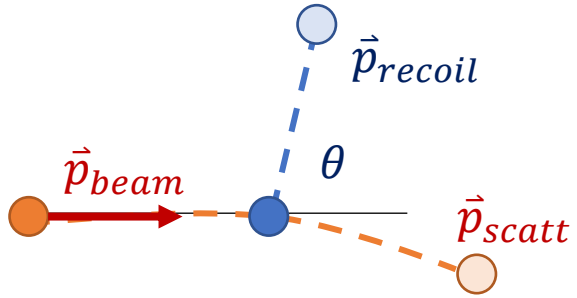


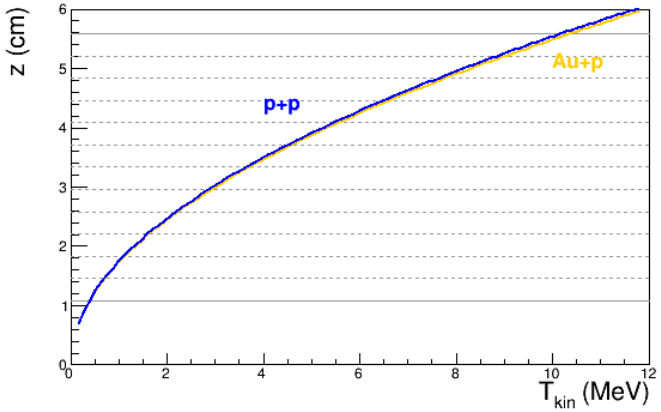


- pC detectors can measure a polarization tilt (P_x, P_y)
- HJET only measures vertical component P_y

Measurement of the Elastic Recoil

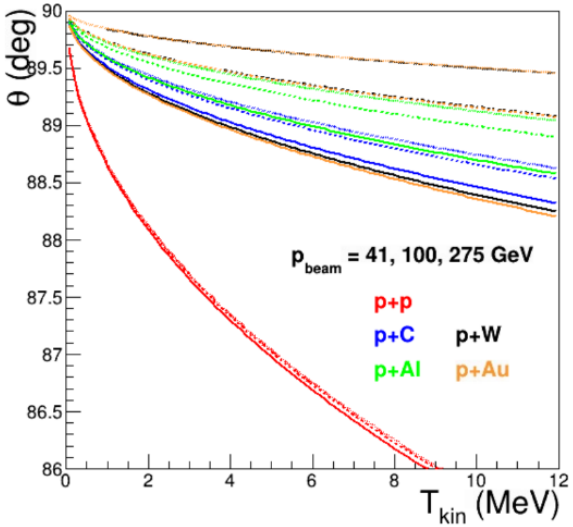


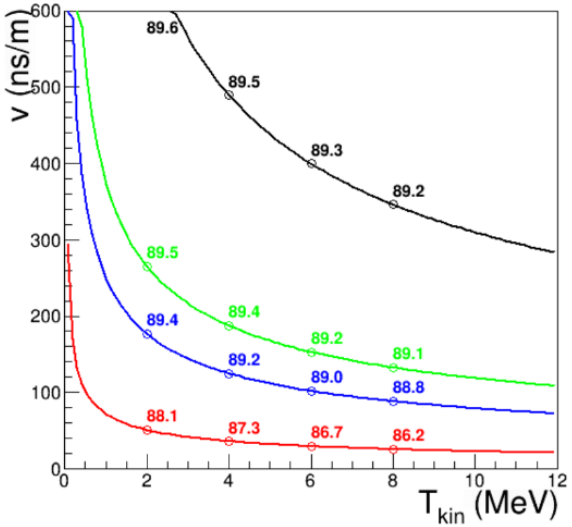




Independent of (high) beam energy

EIC: possibly different target material

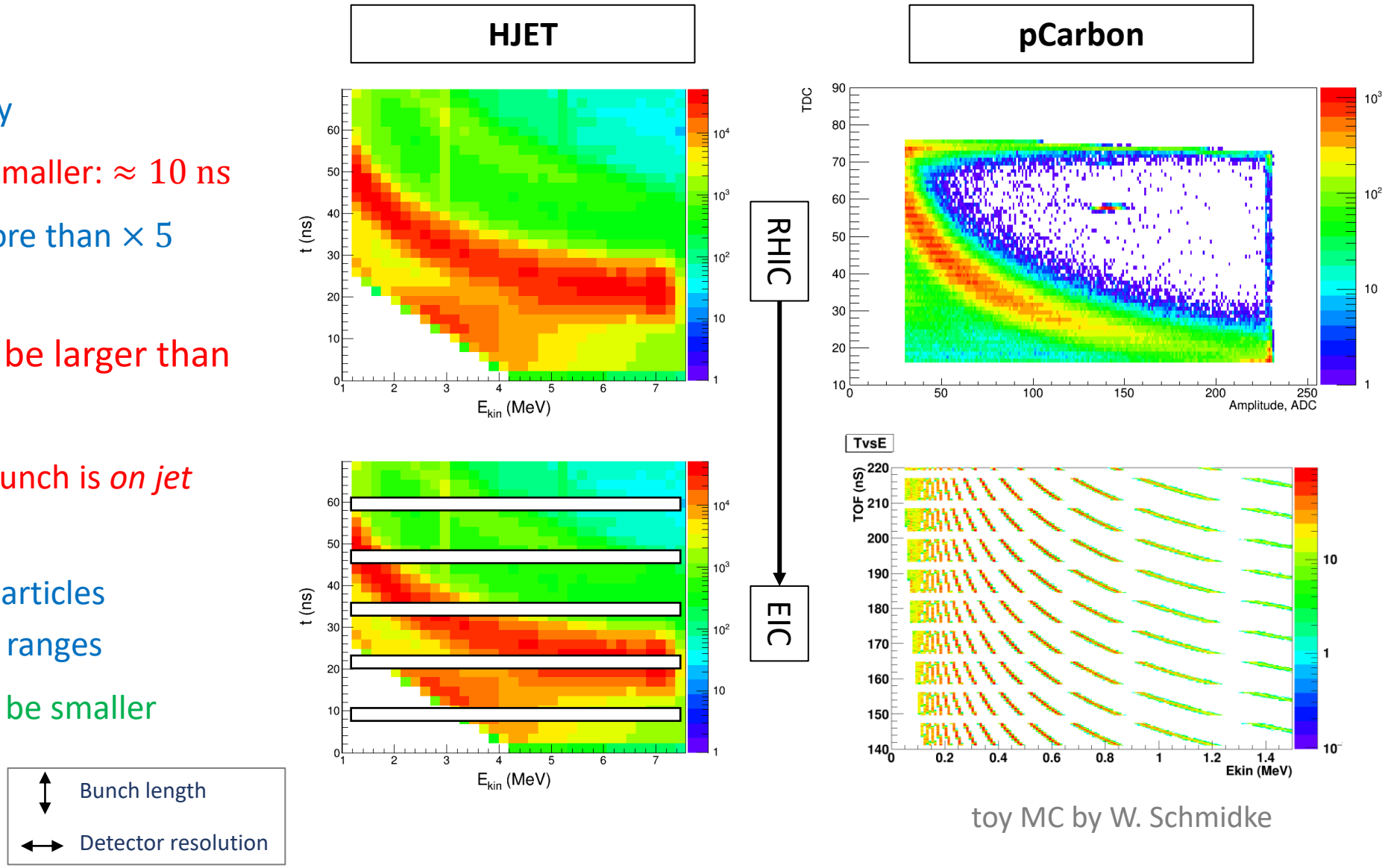




- Detector location (75 cm) is based on strip pitch and recoil energy
  - possible to reduce blocked time with smaller detectors

Particle ID

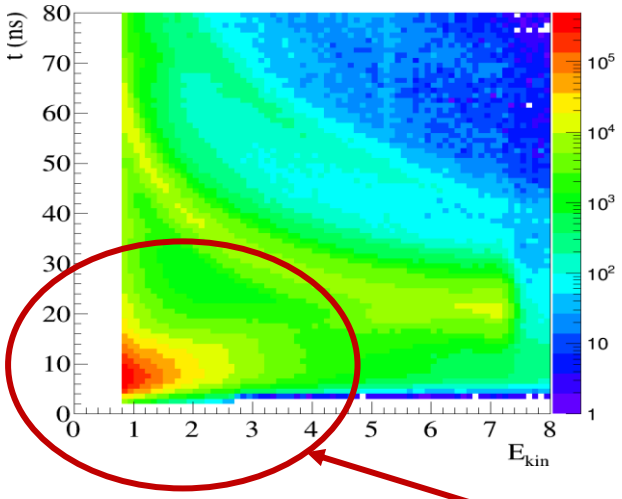
- Electron-Ion Collider
  - Similar bunch intensity
  - Bunch spacing much smaller: ≈ 10 ns
  - Rates increased by more than $\times 5$ (single beam)
- Recoil time-of-flight will be larger than bunch spacing
  - Block readout when bunch is *on jet target*
  - Veto punch-through particles
    Loss of certain energy ranges
  - Bunch length will also be smaller



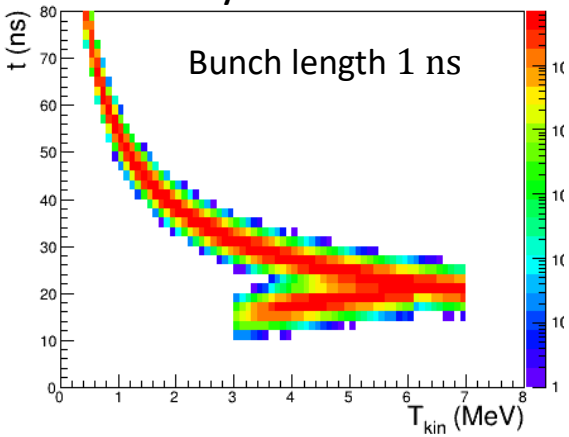
toy MC by W. Schmidke

Elastic Recoil and Background

Data

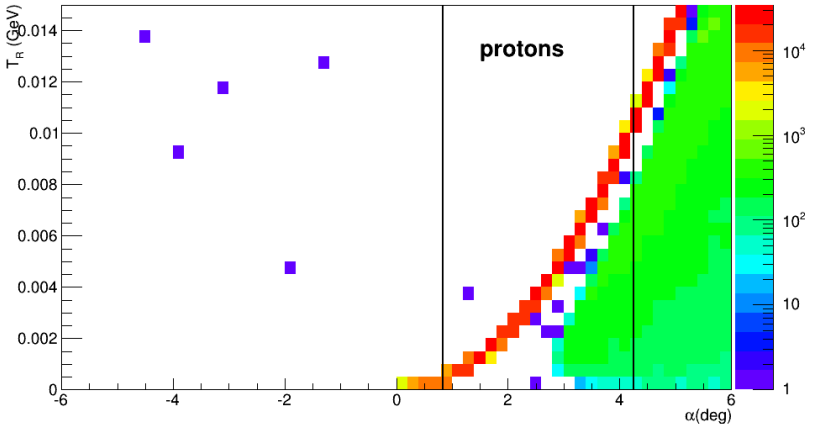


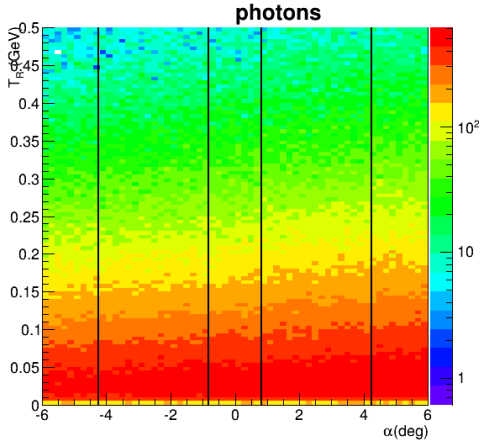
Toy simulation

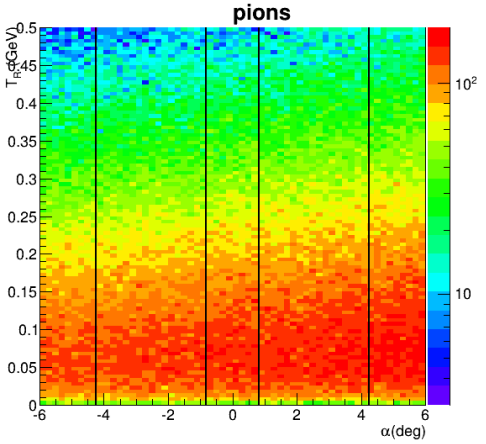


- $p+p$ at $\sqrt{s} = 21.6$ GeV
- PYTHIA 6.4.28, Tune 320
  - QCD $2 \rightarrow 2$
  - Elastic
  - Diffractive
- Prompt/fast background
  - pions / photons up to a few GeV
  - Kinematic correlation lost

Punch-through protons and pions are problematic background, especially when from different beam bunches!





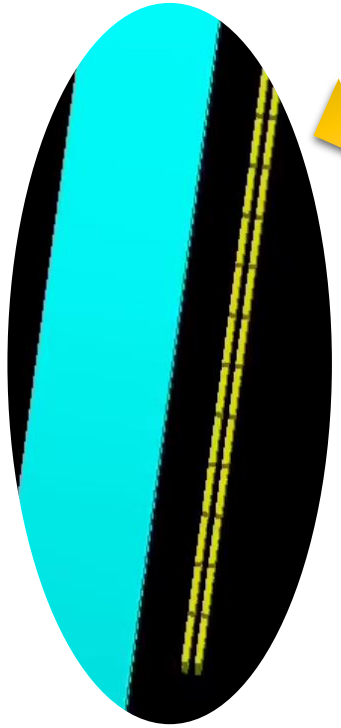


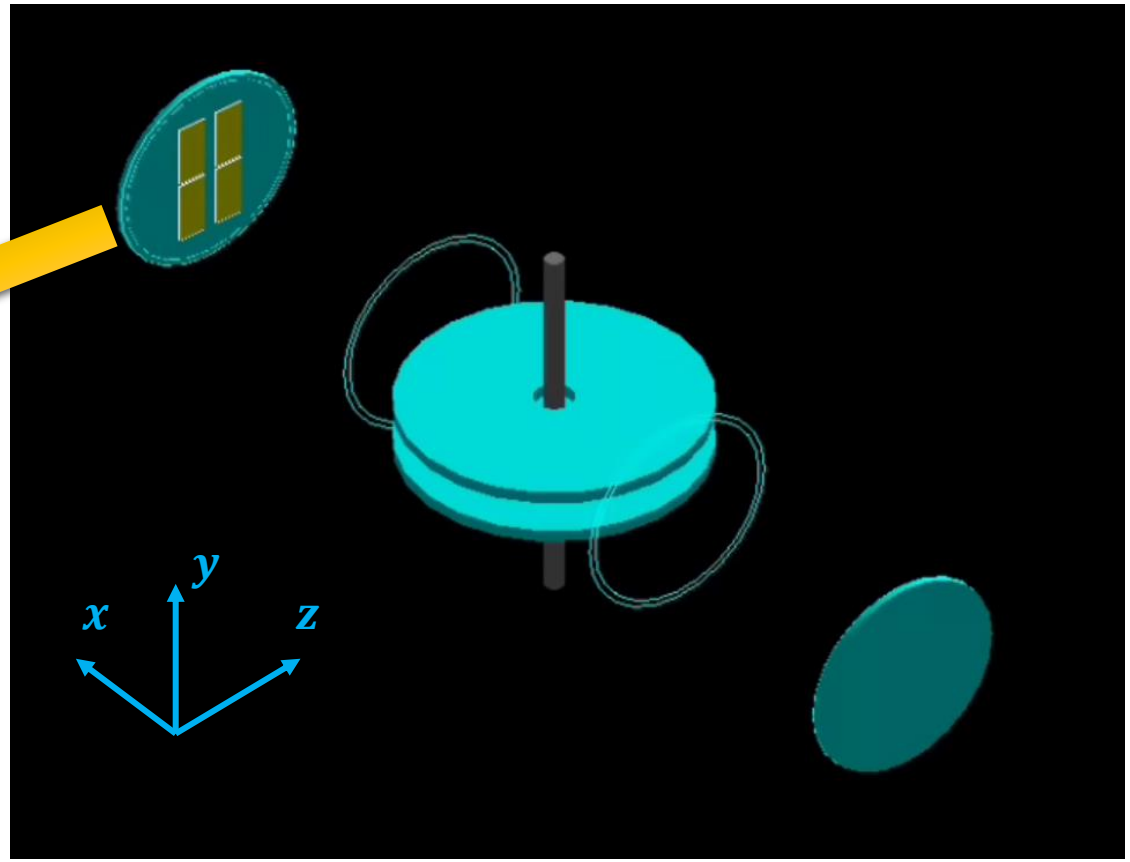
upstream detector

downstream detector

Polarimeter Simulation

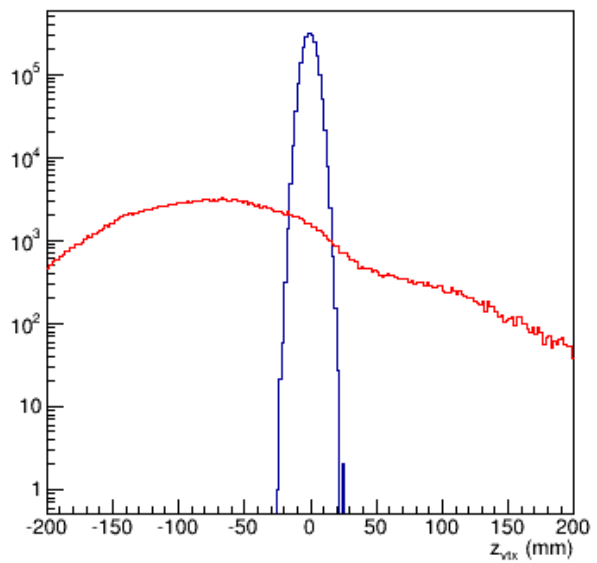
- Full detector in GEANT4
  - Double layer of strips
  - $470\ \mu\mathrm{m}$ Silicon, $8\ \mu\mathrm{m}$ dead layer
- Detector chamber and flanges
- Atomic hydrogen jet target
  - $\rho \approx 0.4 \cdot 10^{-11}\ \mathrm{g/cm^3}$
- Parameterized magnetic holding field: B_y
- Beam bunch length (3 ns)
- Vertex distribution
  - Polarized jet H target: 6 mm FWHM
  - Molecular ^{2}H component: 10 cm
- PYTHIA input
  - Single beam

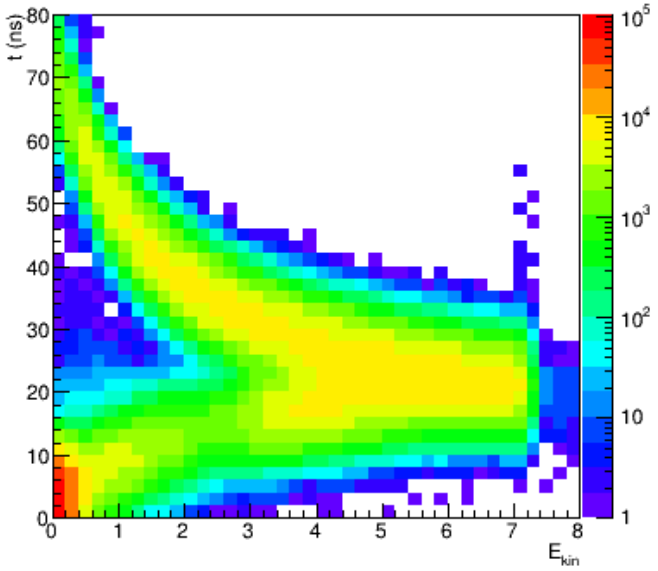


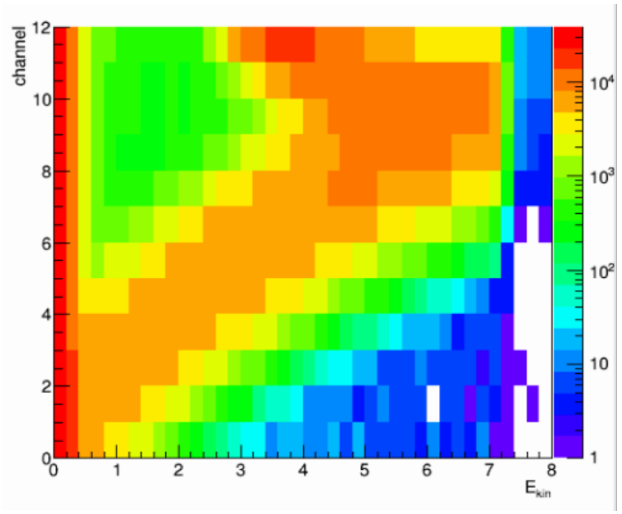


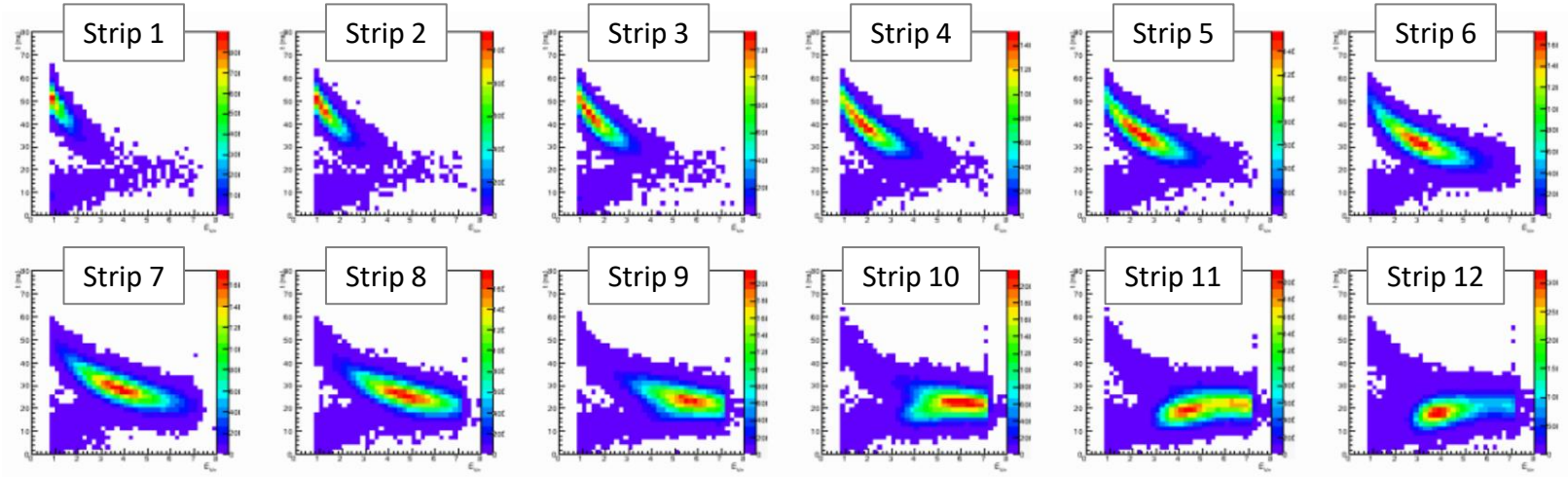
Simulation Results

- 100M + 10M filtered PYTHIA events
  - Tracks within 30^o of detector center
  - About 2M + 250k hits
  - Rarely more than one track per event
- Simulation reproduces the basic features
  - Signal and background (particle id)
  - Kinematic correlation (elastic scattering)



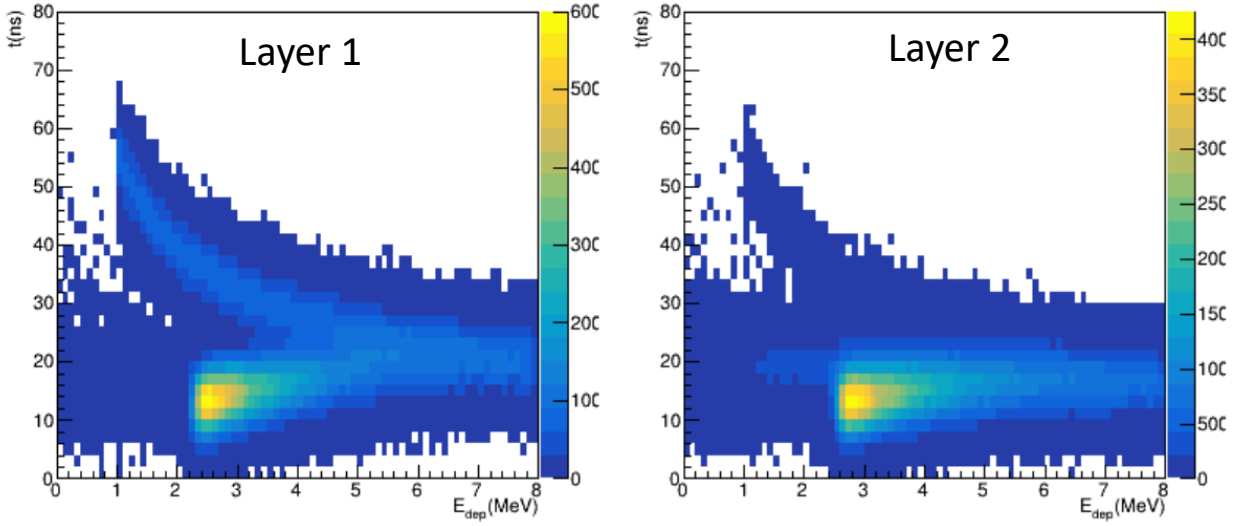


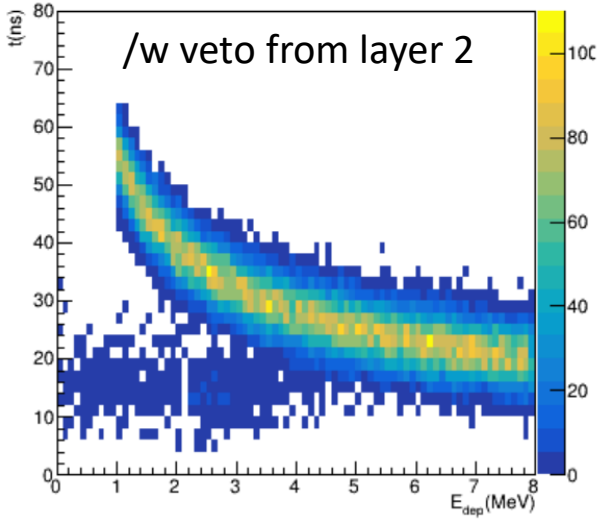


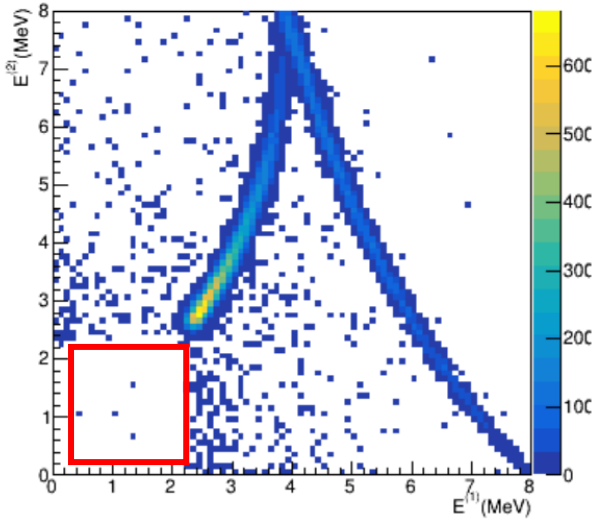


Background Rejection

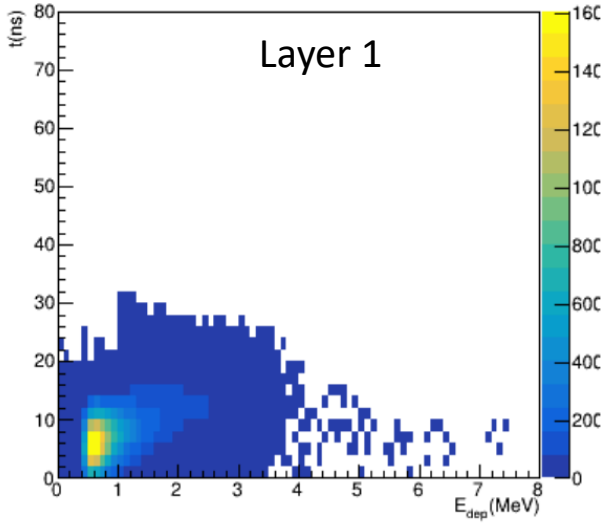
PROTONS (single particle)

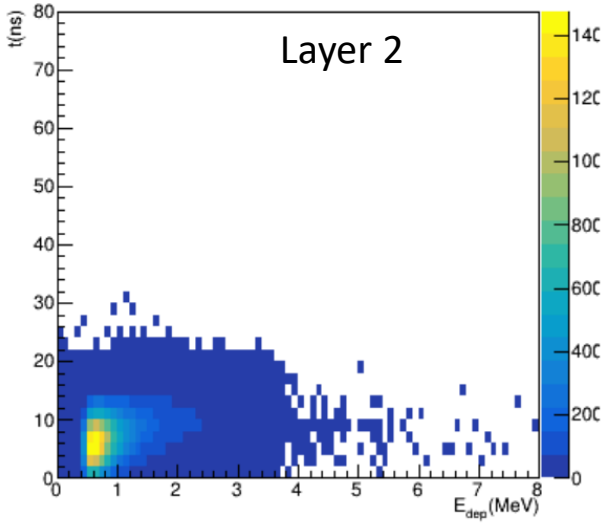


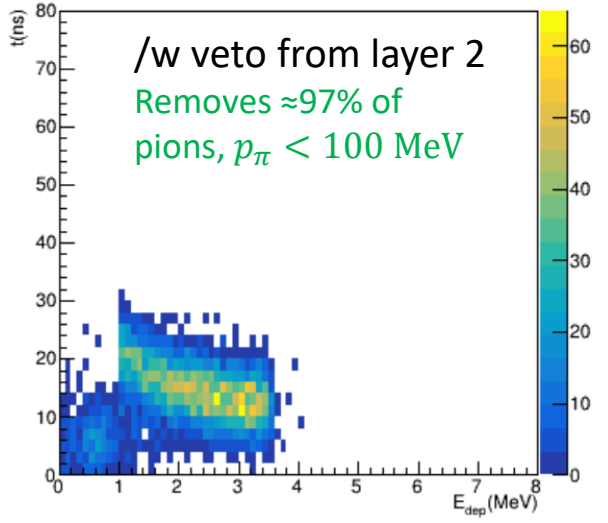


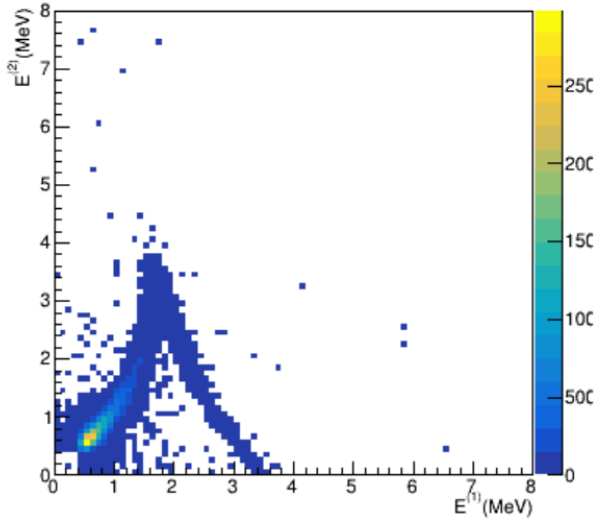


PIONS (single particle)







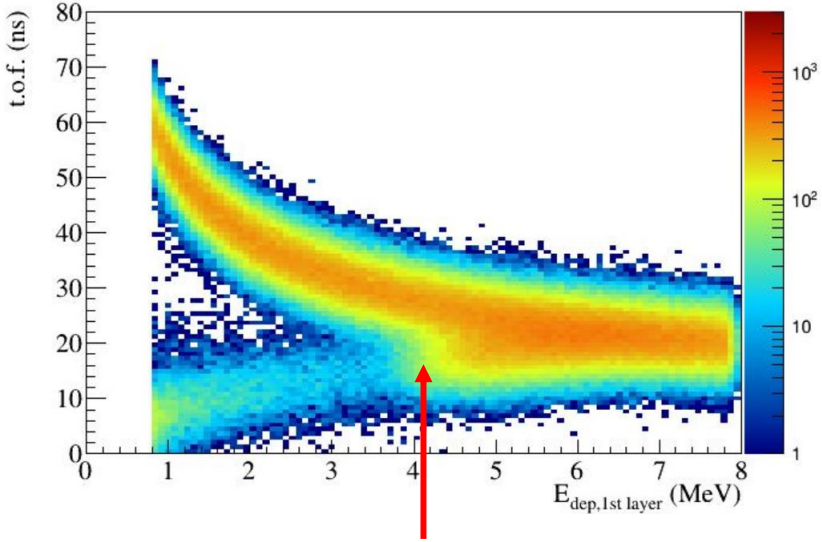


PYTHIA + GEANT4

- Simulation of second layer shows good rejection of punch-through particles
  - RHIC parameters: bunch length 3 ns, bunch spacing 106 ns
  - Protons with higher energies (from wide vertex contribution)
  - Pions (independent of elastic correlation)

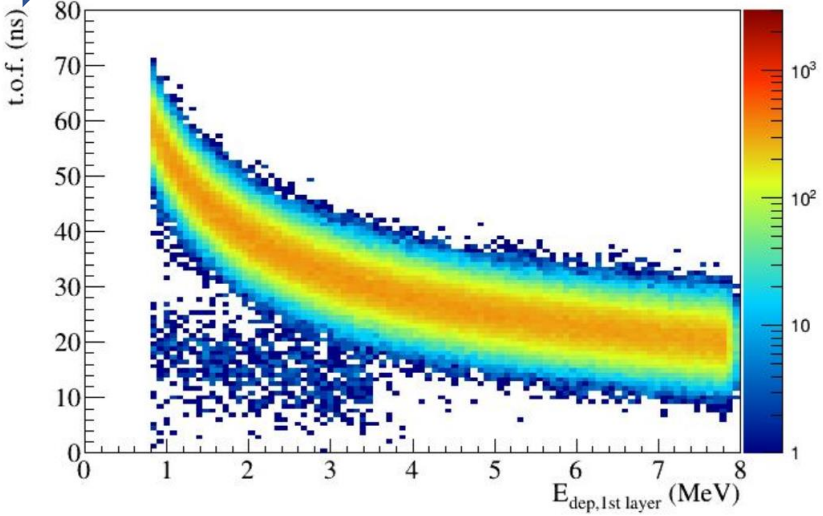
initial study by A. Nunes

Layer 1

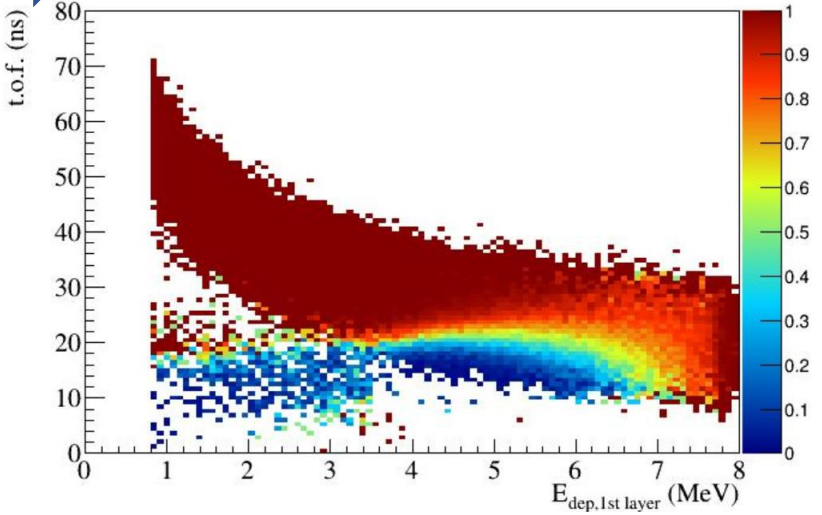


detector acceptance
for elastic protons

/w veto from layer 2



effiency = 1 / rejection

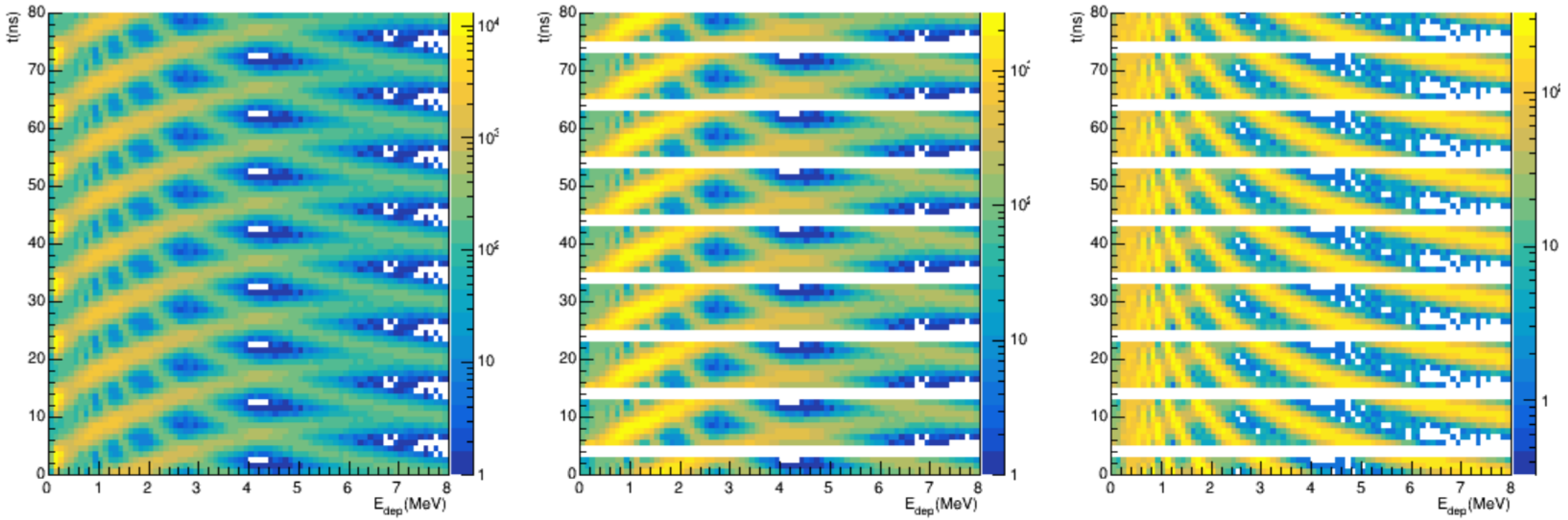


- Efficiency can be improved by modified veto on energy in layer 2 (depends on slope of A_N)

PYTHIA + GEANT4

- Simulation of second layer shows good rejection of punch-through particles
  - EIC parameters: bunch length 1 ns, bunch spacing 10 ns
  - Currently no digitization included (time & energy resolution)
  - Remnants of pion punch-through (detector edge effects → fiducial cuts or limited energy range)

raw data → **b/o EM pulse** → **veto layer 2**

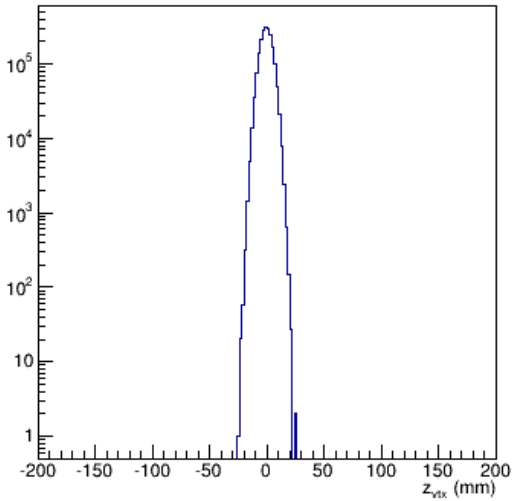


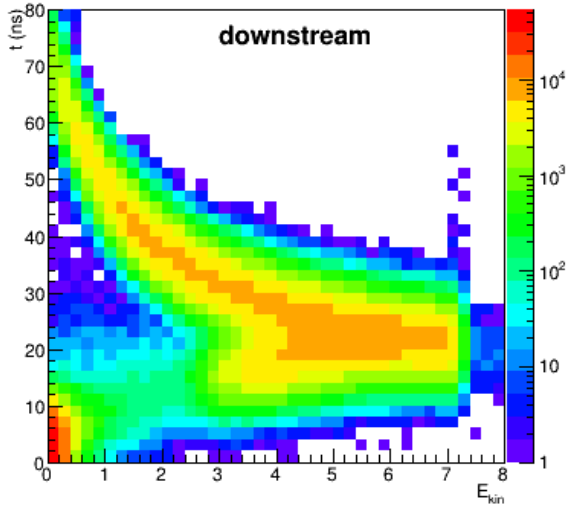
Summary / Outlook

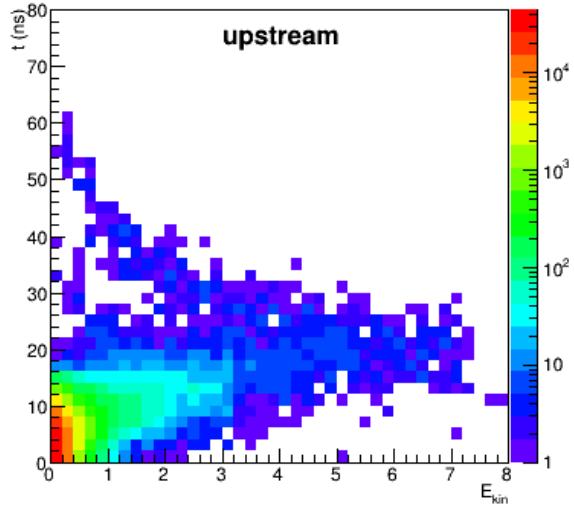
- Hadron polarimetry at RHIC
  - 20+ years experience
  - Data driven background rejection/correction: $\frac{\Delta P}{P} < 1.4\%$ (2017)
  - Qualitative agreement with event generator and full detector simulation
- High luminosity at EIC
  - Short bunch spacing requires improvements in detector performance and read-out
  - More quantitative understanding of background is necessary
    - Polarized bunch pattern & rejection of background
    - Initial studies show good results
    - Test in RHIC Run 22 possible (next talk)
  - Beam heating of ultra-thin targets may be problematic

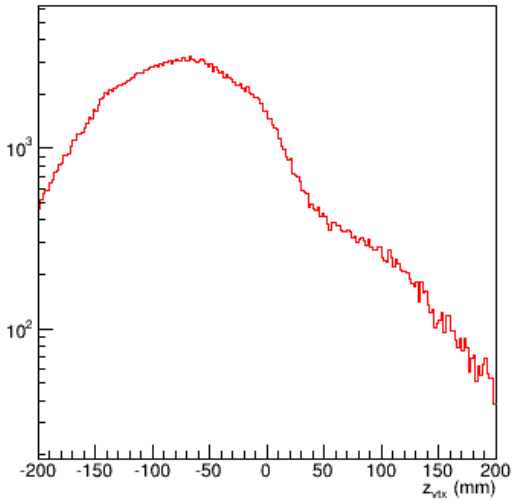
Simulation Results

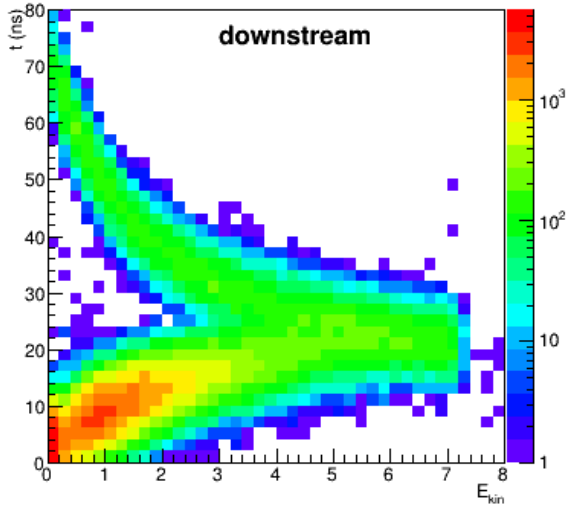
- Punch-through particles
  - Fast, little energy deposit
- Very few recoil protons in upstream detector
  - Compare target width with detector length
- Contribution from widely distributed molecular hydrogen
  - Wide range of punch-through particles
  - Skewed vertex distribution due to detector acceptance
- Test measurements in RHIC Run 2022

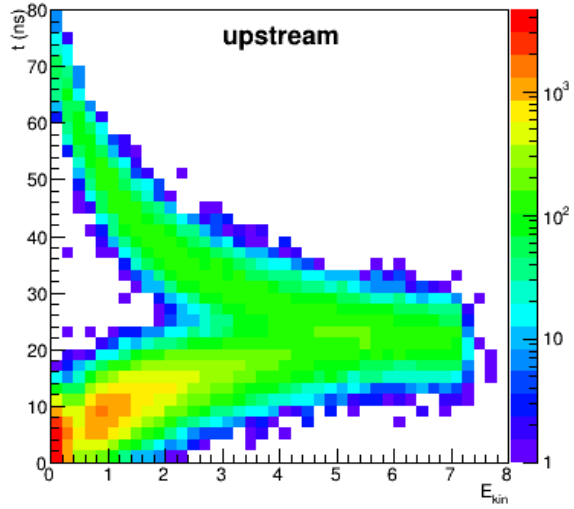












Waveform Analysis

- Waveform digitizer
  - 1.2 ns per TDC count
  - TDC_0 is determined from the rise of the waveform
  - Linear extrapolation from half-rise point to 0
- Waveform is much longer than bunch spacing
  - Multiples per single bunch crossing is still small
  - Signals from different bunches may overlap
  - Better time resolution (TDC)
  - FPGA analysis of waveforms → streaming DAQ
- High bunch frequency will induce base line shift
  - Track over μs or longer (streaming DAQ)