Hadron Polarimetry: Kinematics, Background & Simulation

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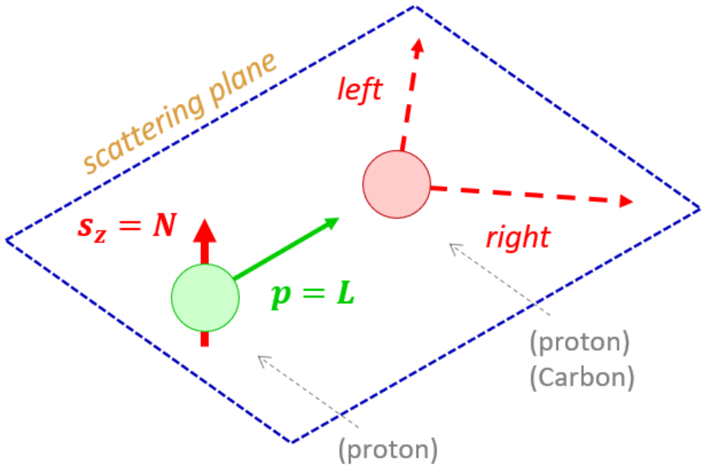
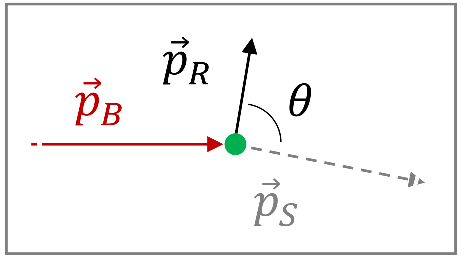
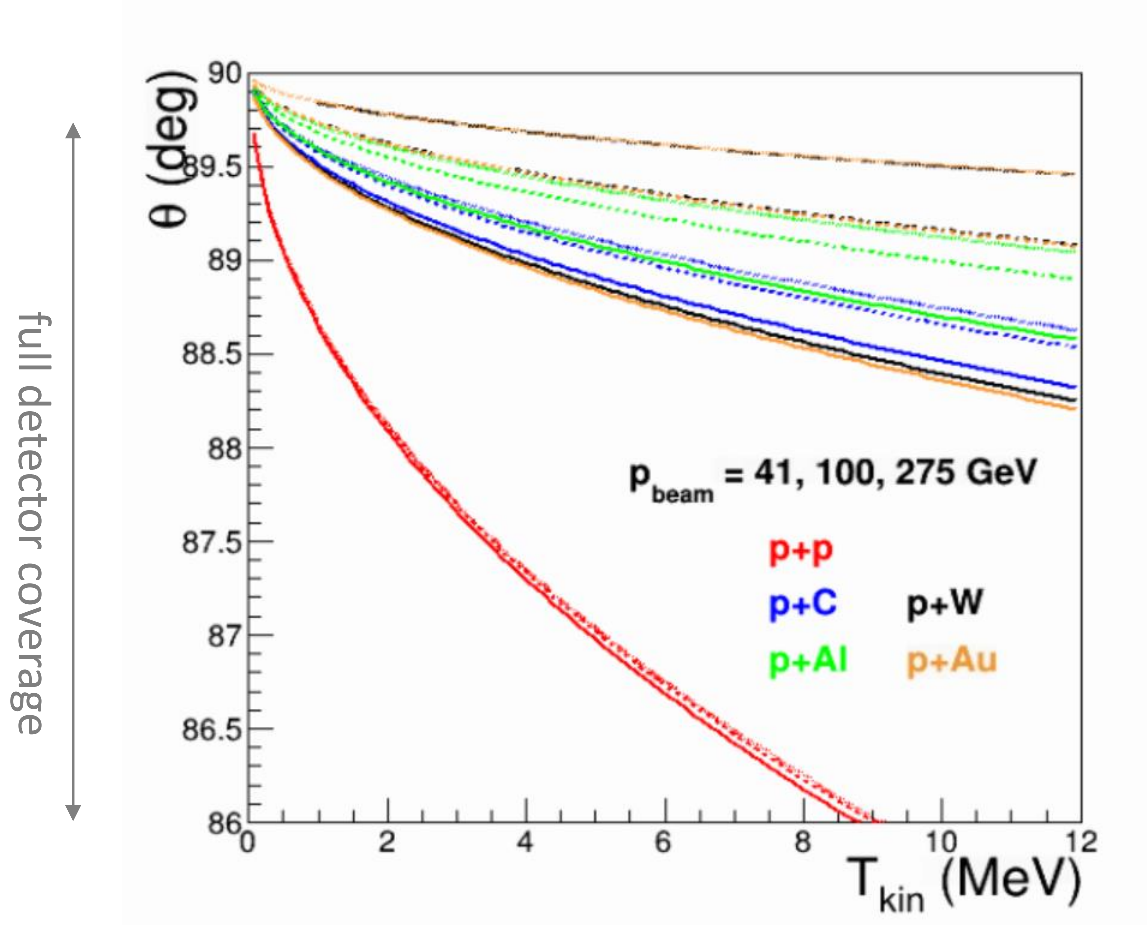
August 18, 2020

1) Ultra-thin Carbon ribbon targets will not survive EIC conditions
2) Bunch repetition rate can be problematic if background is not under control

Elastic Recoil Kinematics



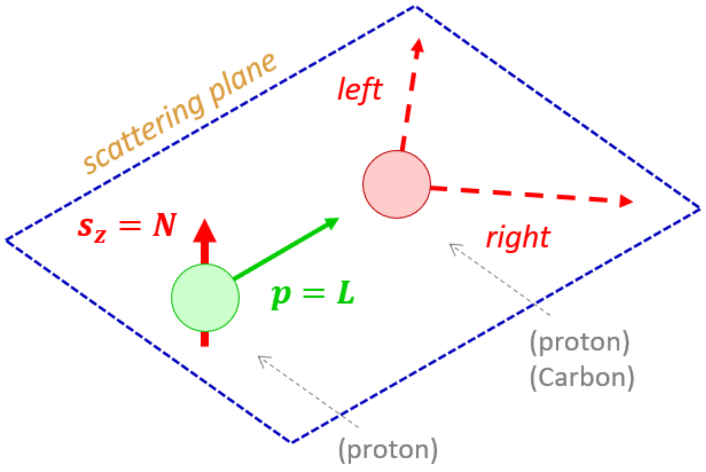


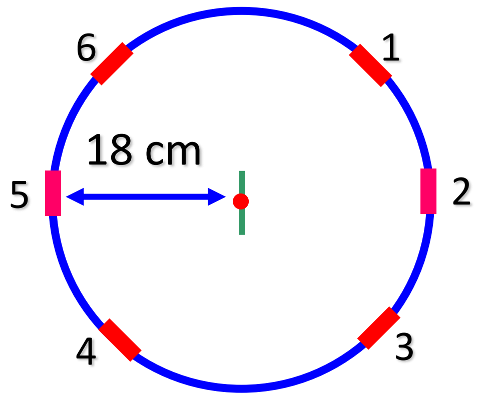


$$P_4^2 = \begin{pmatrix} E_B + m_T \\ \vec{p}_B \end{pmatrix}^2 = \begin{pmatrix} E_S + E_R \\ \vec{p}_S + \vec{p}_R \end{pmatrix}^2$$

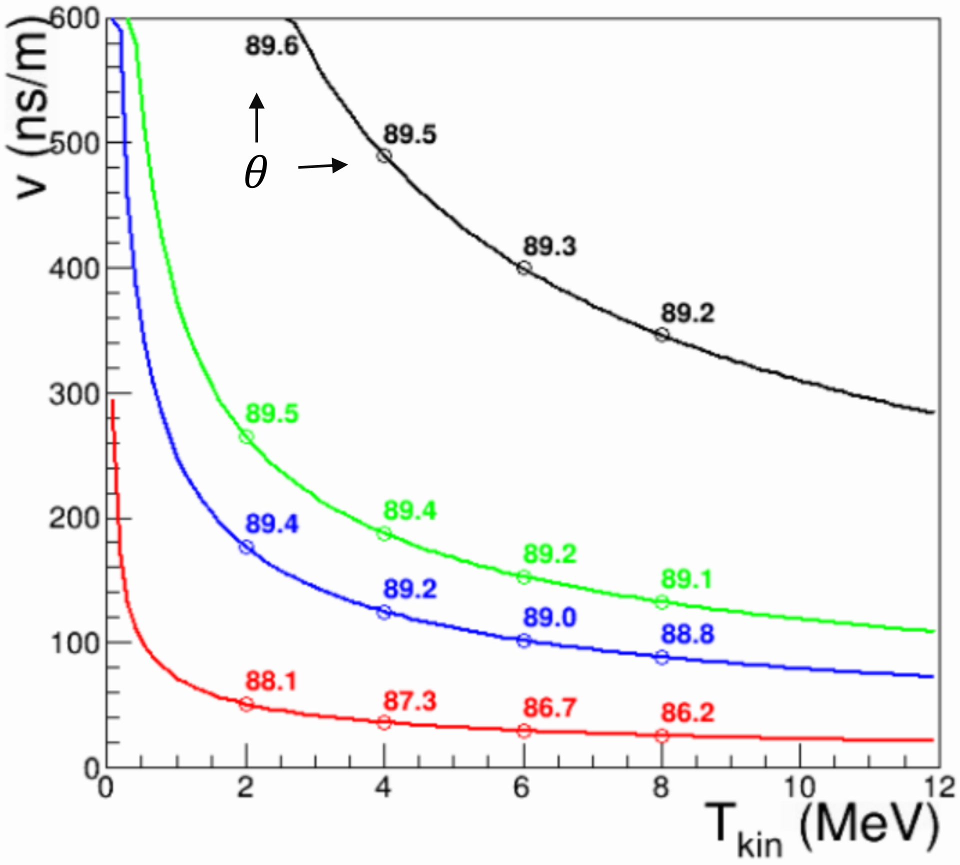
- Discussion with BNL-CFN about different targets for fast polarization measurement
- Calculations by P. Thieberger show extreme heating at EIC

Elastic Recoil Kinematics



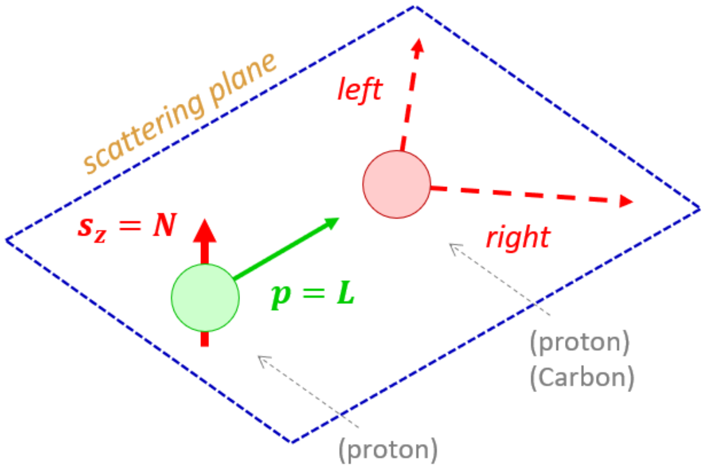


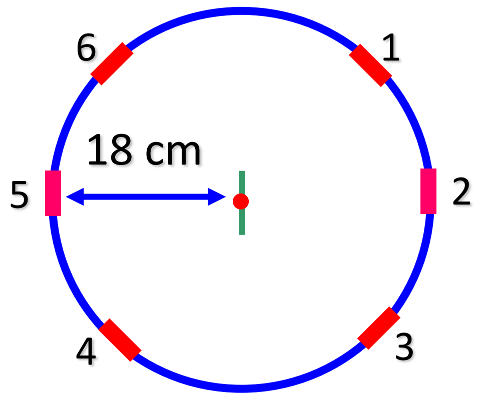
divide by ≈ 5 for current detector →

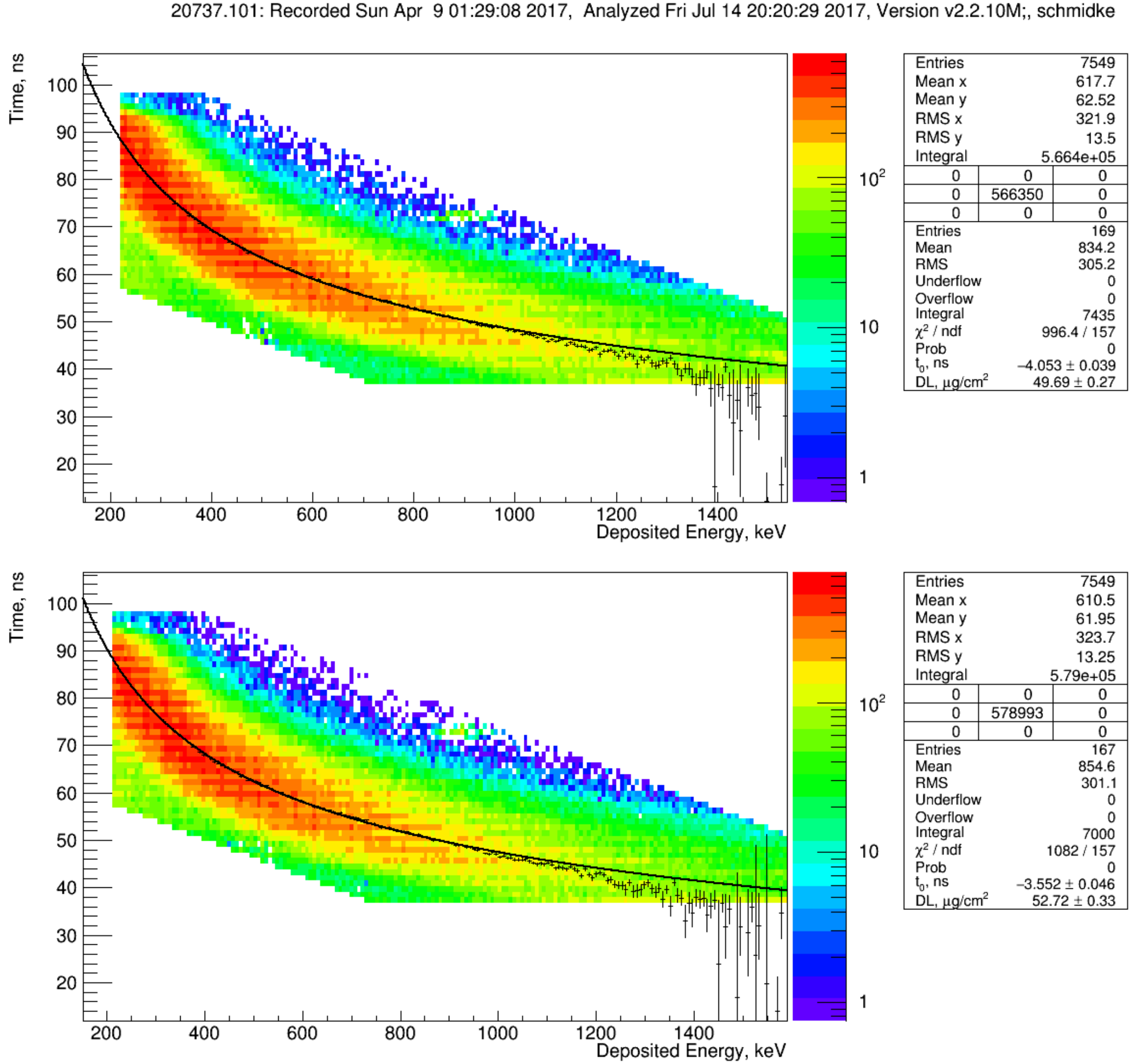


- Potential for internal cross checks with different materials
- BUT: small angle scattering is an issue

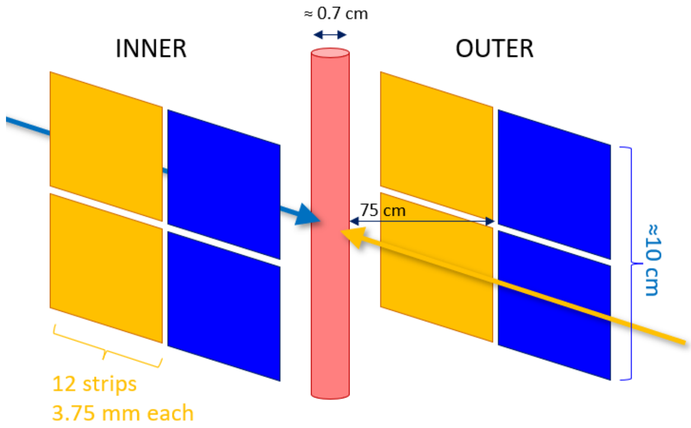
RHIC Measurements



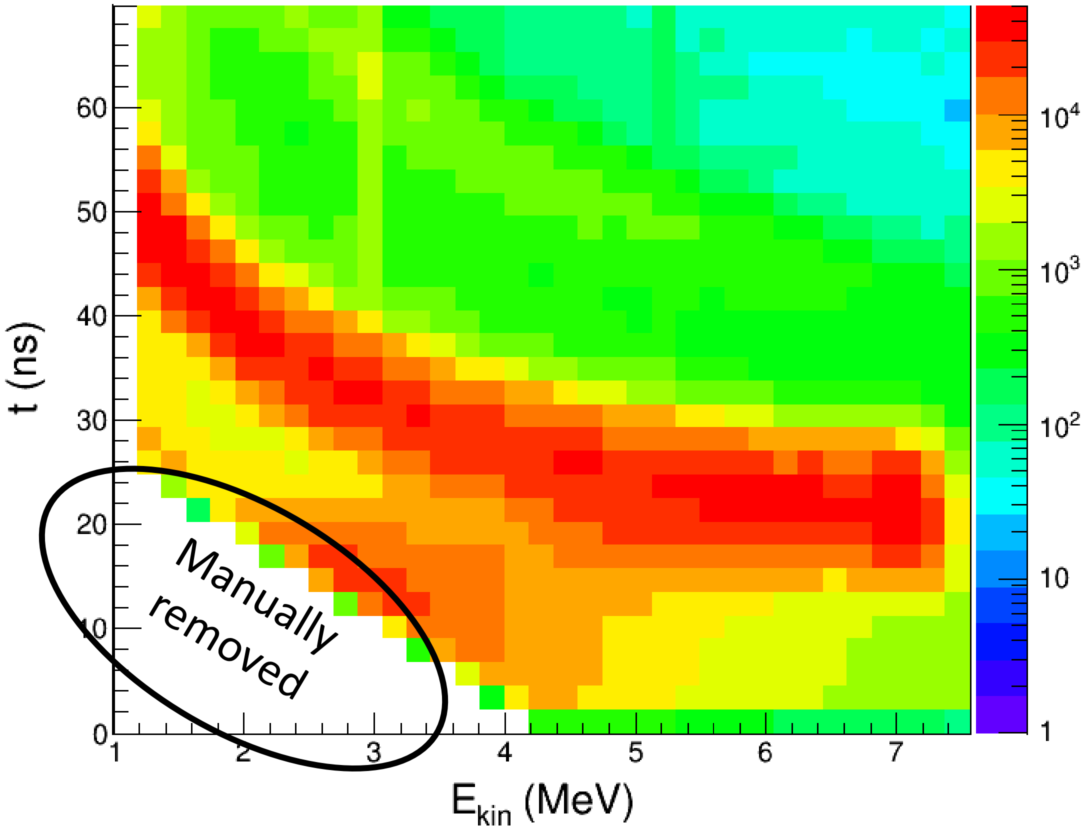




HJET Signal & Background

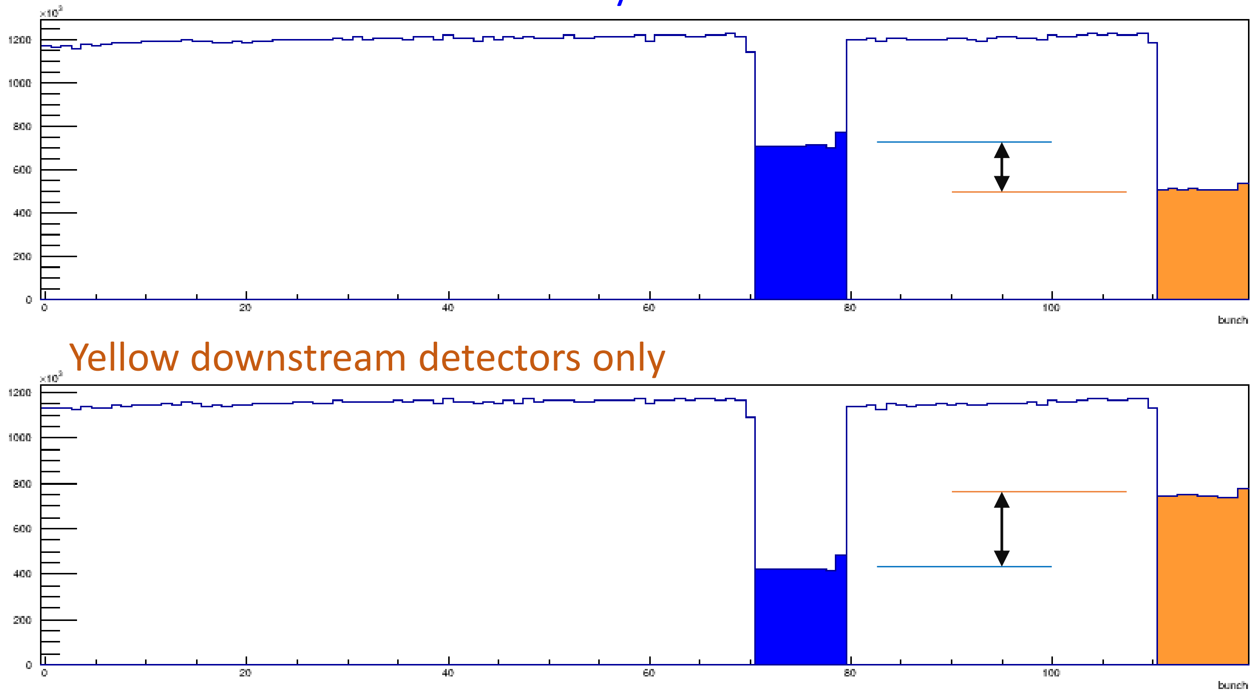


Typical presentation of elastic recoil protons



Blue downstream detectors only

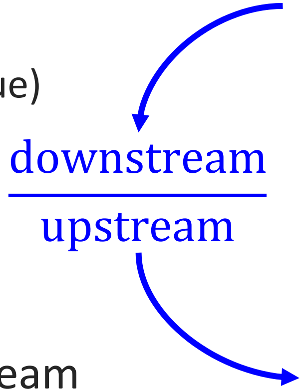
Yellow downstream detectors only

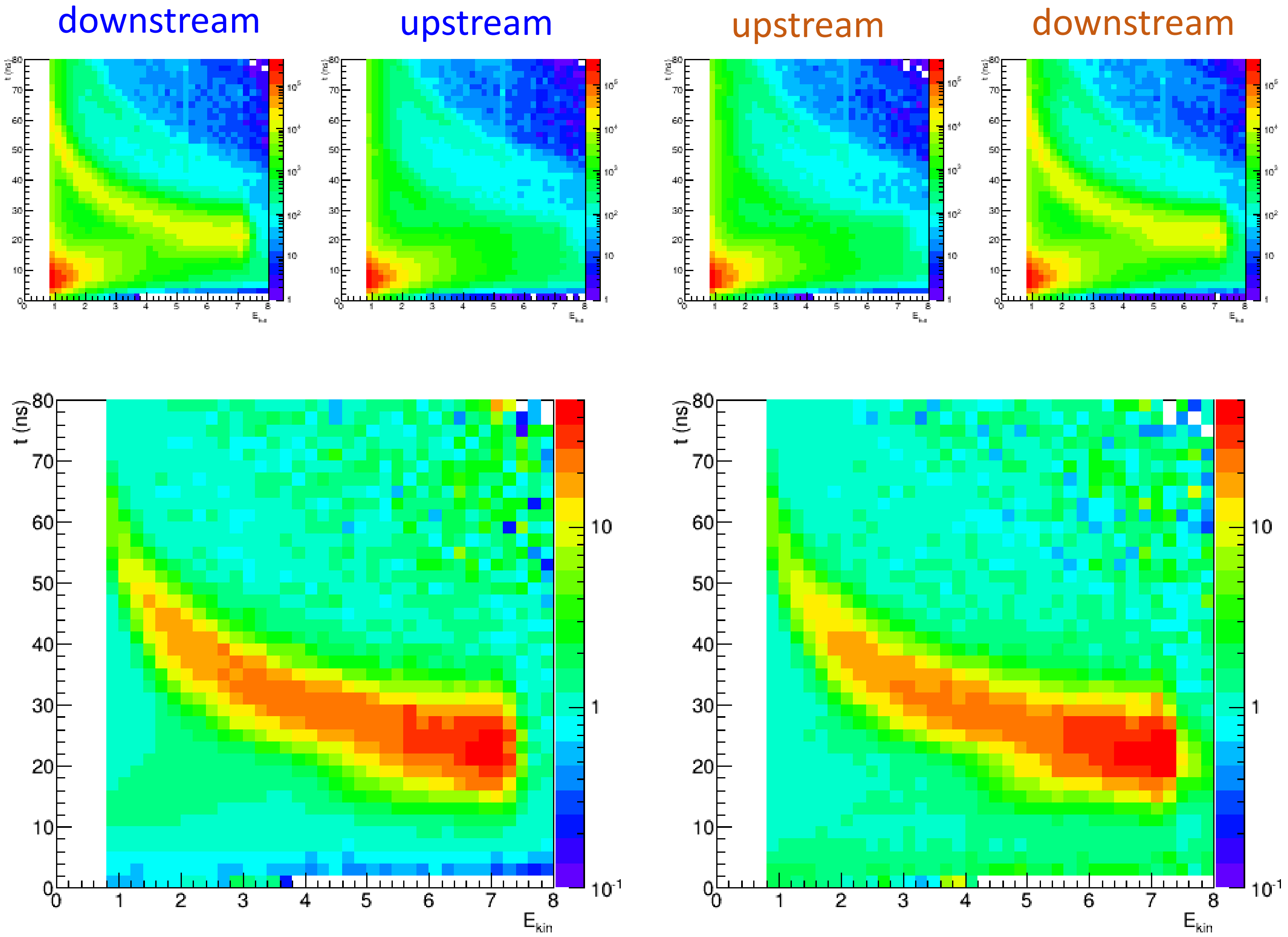


RHIC bunch crossing number

HJET Signal & Background

- Six RHIC fills from 2017
  - Typical RHIC fill is 8 hours long
- Single beam only
  - Abort gaps (yellow, blue)
- Elastic recoil will only reach the downstream detectors
- Ratio downstream/upstream
  - Same z-scale (0.1 – 50)
  - Background is evenly distributed over whole kinematic range





HJET Polarimeter Setup

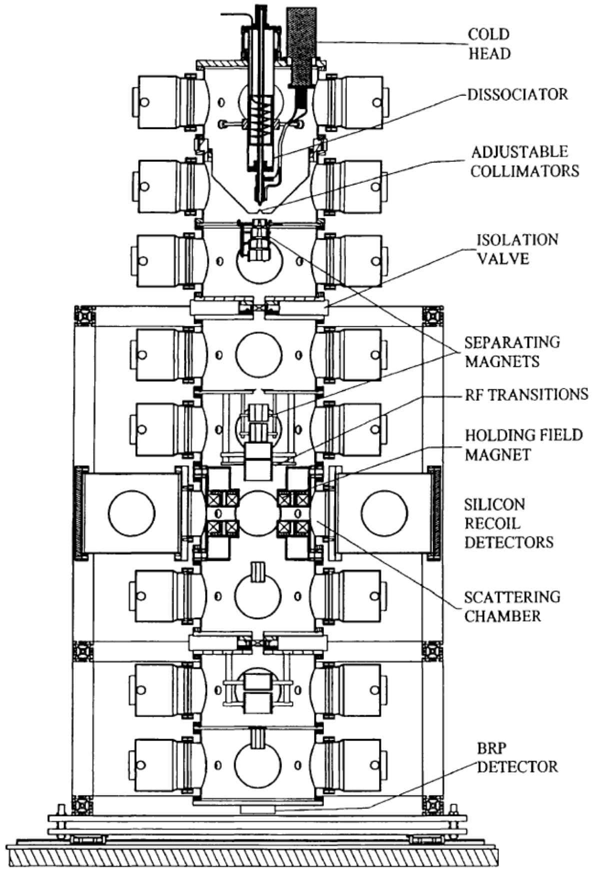
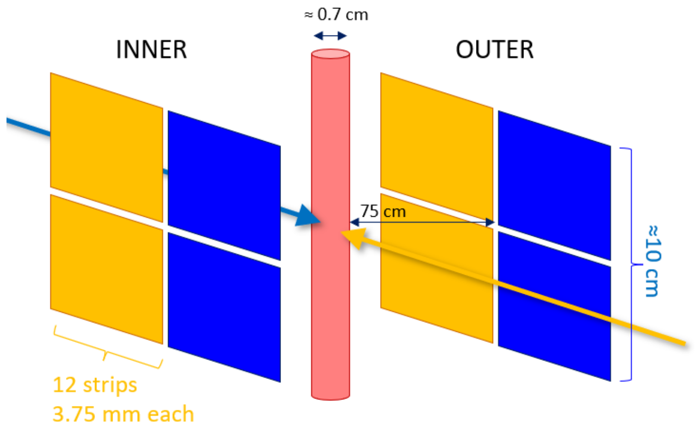


Fig. 1. H-jet polarimeter general layout.



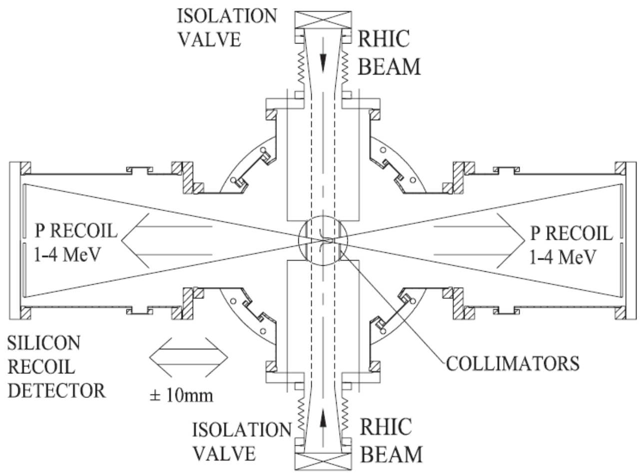


Fig. 4. Scattering chamber. The distance from collision point to silicon detector is 80 cm.

- NIM A 536 (2005) 248-254
- PRD 79 (2009) 094014
- Additional information from G. Atoian

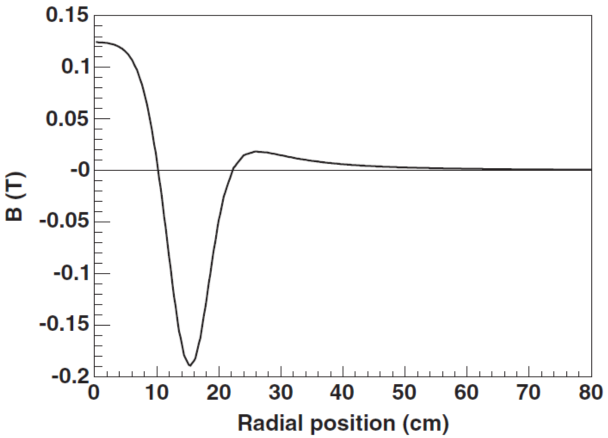


FIG. 3. The H-jet target holding magnetic field calculated by the OPERA program with the experimental setting: inner coil 349 A (N = 56); outer coil 275 A (N = 40). The recoil proton detectors sit at ~78 cm from the H-jet target center.

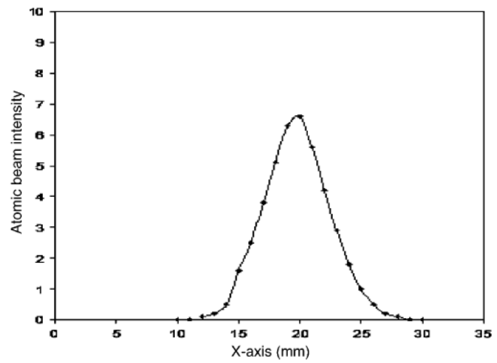
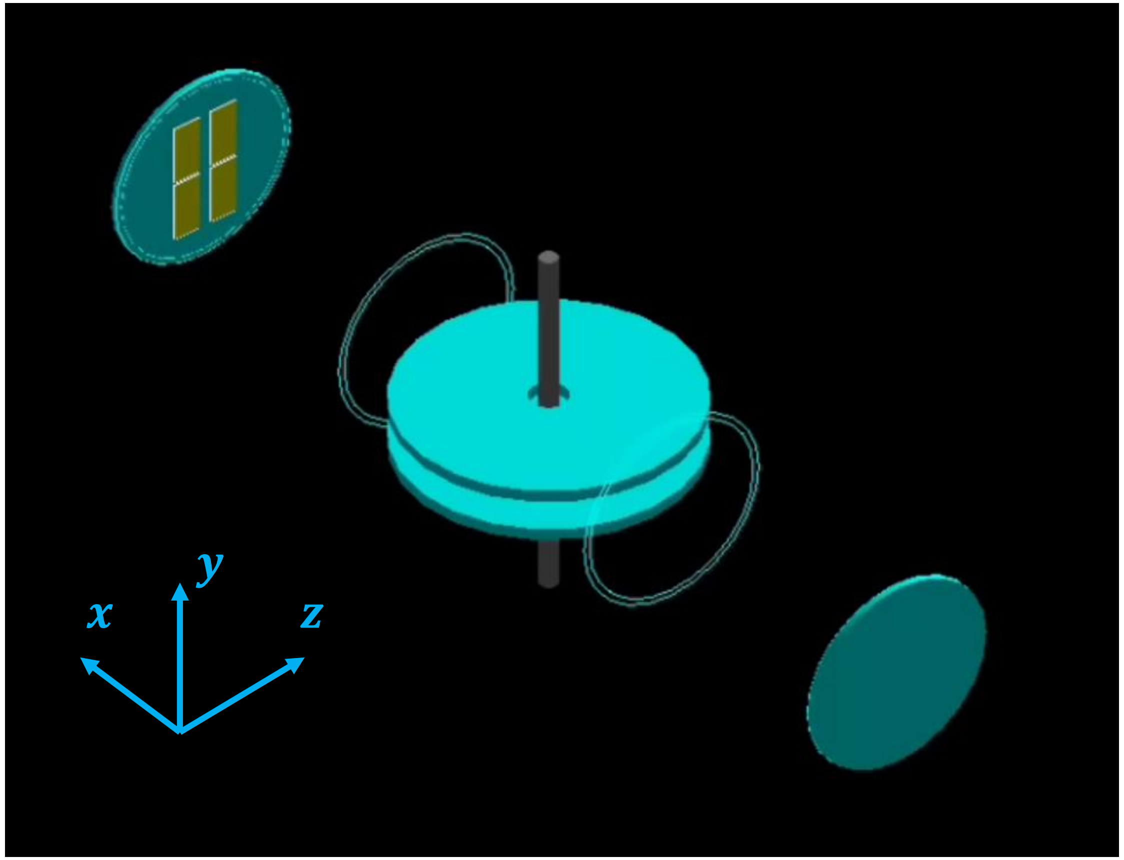


Fig. 5. The measured atomic beam profile at the collision point. The FWHM, corrected for the finite size of the compression tube aperture, is 5.5 mm).

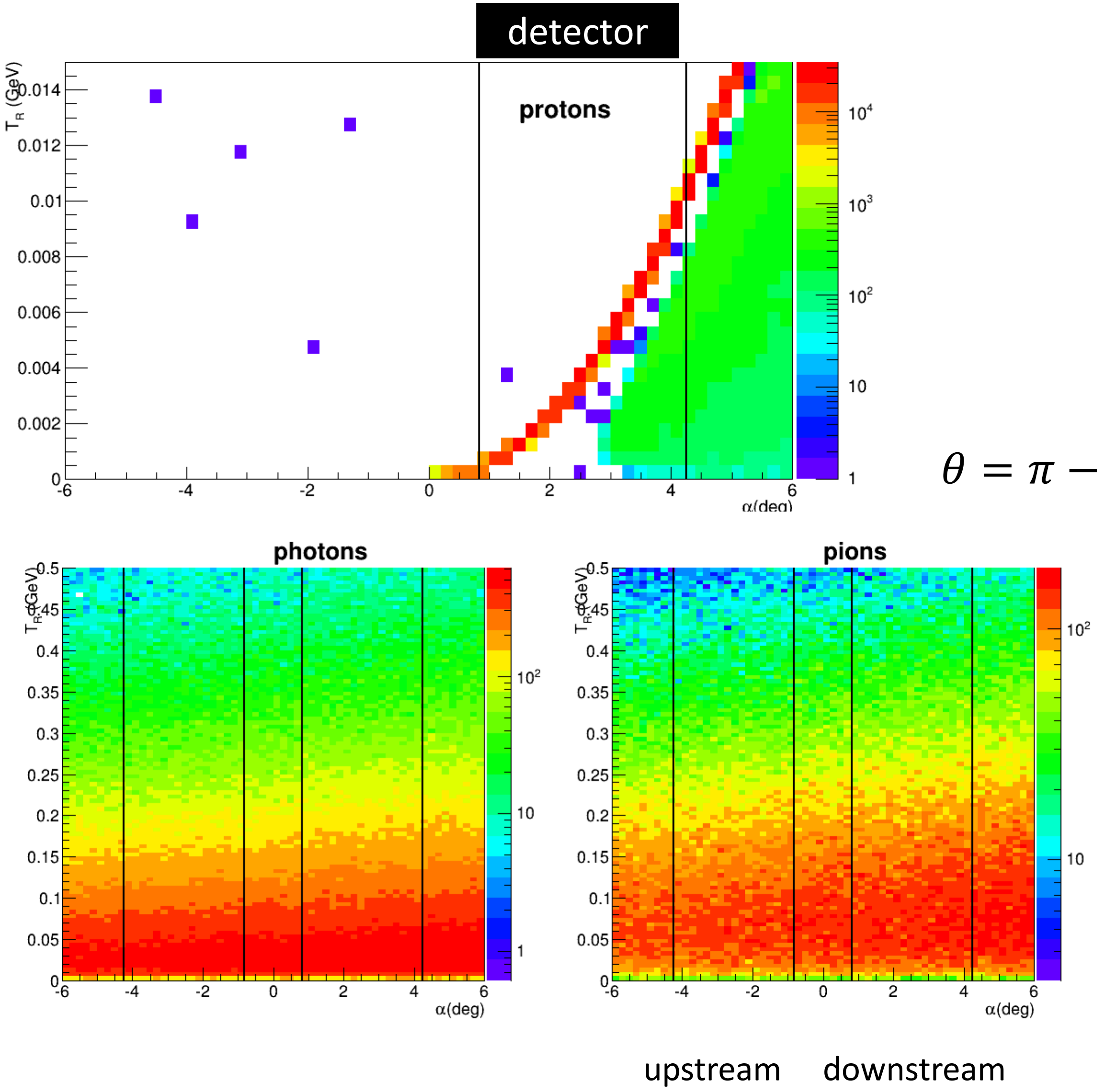
GEANT4 Setup

- 8 detectors
  - $400\ \mu\text{m}$ Silicon, $8\ \mu\text{m}$ dead layer
  - No strip segmentation (no pile-up seen in data)
- Detector chamber and flanges
- Atomic hydrogen jet target
  - $\rho \approx 0.4 \cdot 10^{-11}\ \text{g/cm}^3$
- Parameterized magnetic holding field
- Beam bunch length (3.5 ns)
- Vertex distribution (5 mm, 10 cm)
- PYTHIA input
  - Single beam



PYTHIA Input

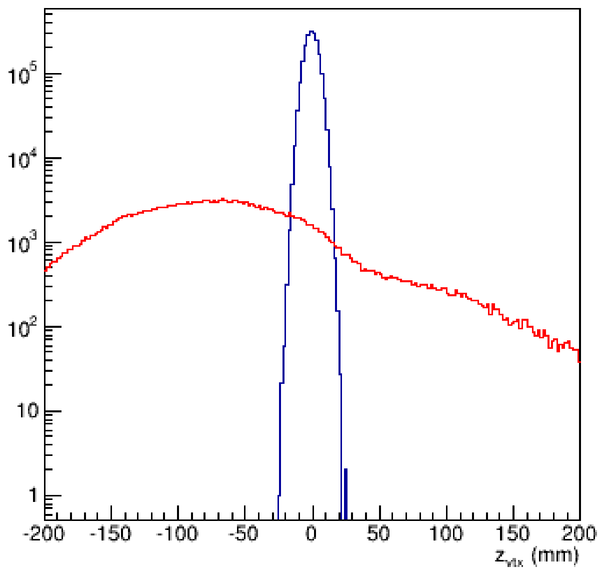
- p+p at $\sqrt{s} = 21.6$ GeV with boost
  - Equivalent to 250 GeV beam on fixed target
- PYTHIA 6.4.28, Tune 320
  - QCD 2 → 2
  - Elastic
  - Diffractive
- Fast background
  - pions, (*photons*) up to a few GeV
  - Kinematic correlation lost

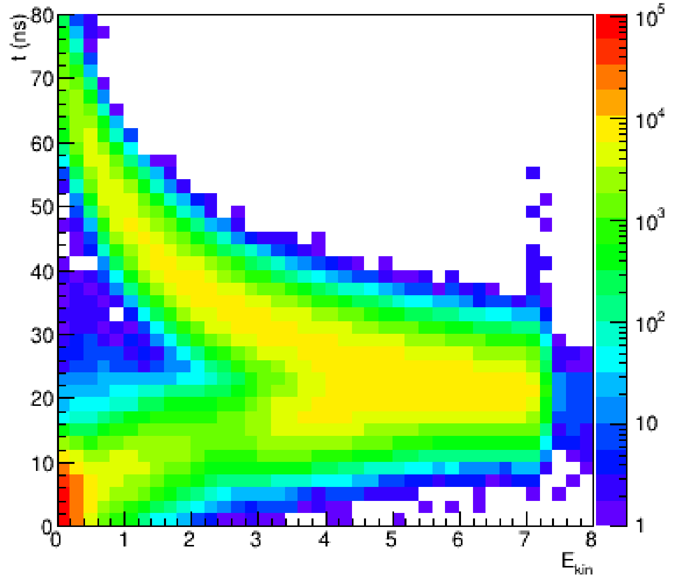


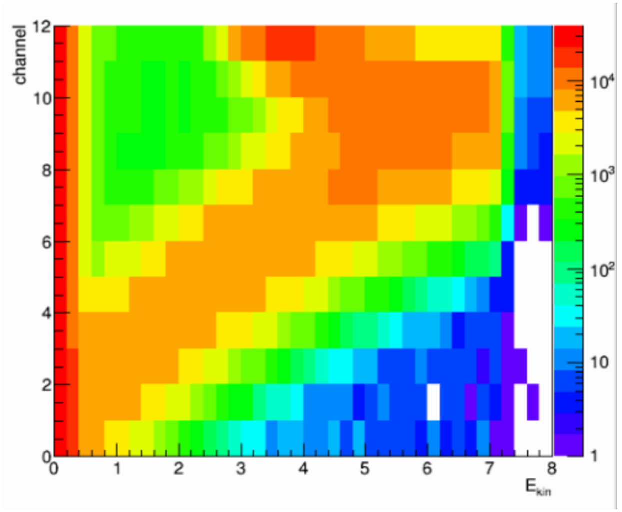
$\theta = \pi - \alpha$

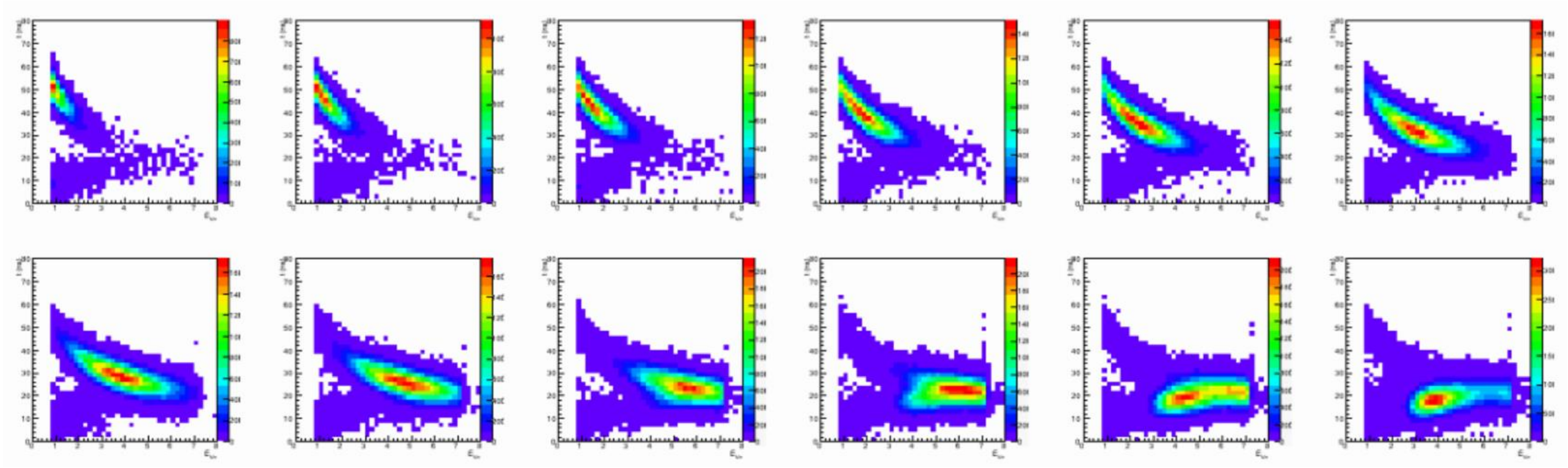
Simulation Results

- 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
  - Kinematic correlation
  - Signal and background
- Skewed vertex distribution due to detector acceptance



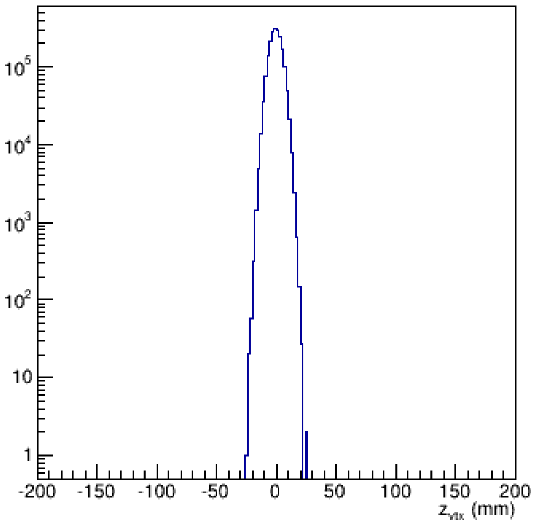


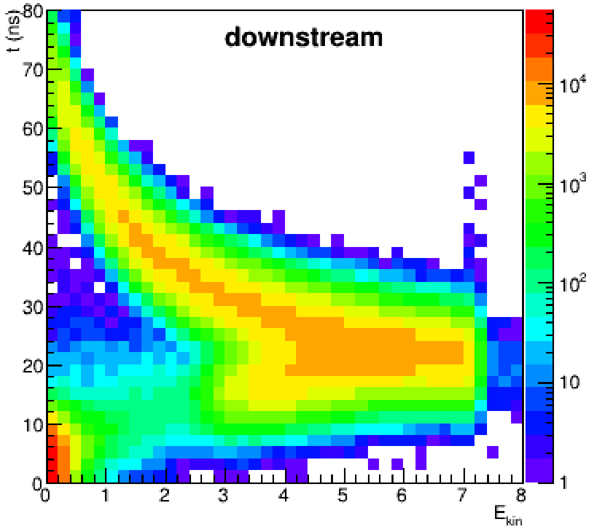


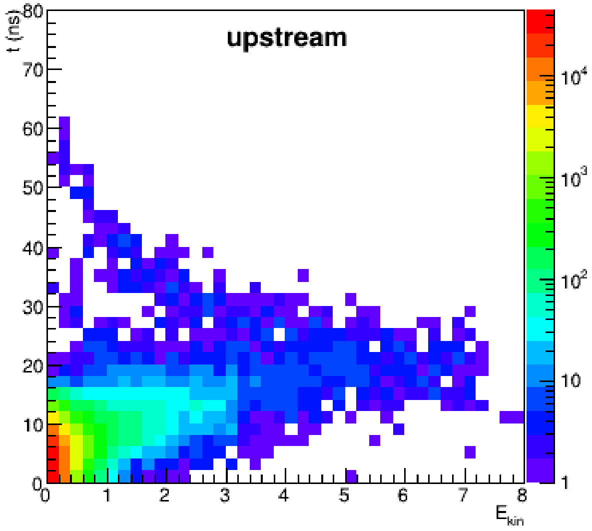


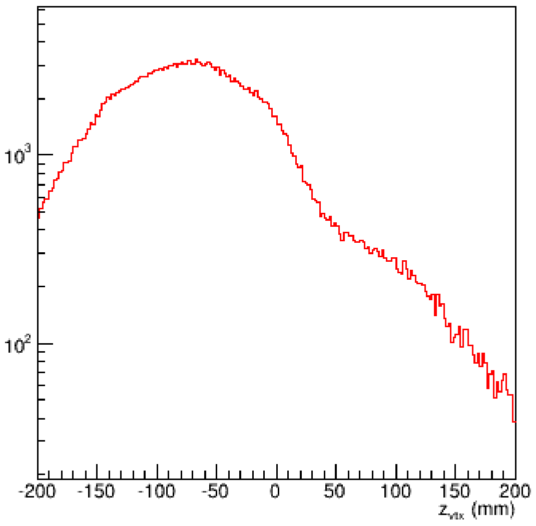
Simulation Results

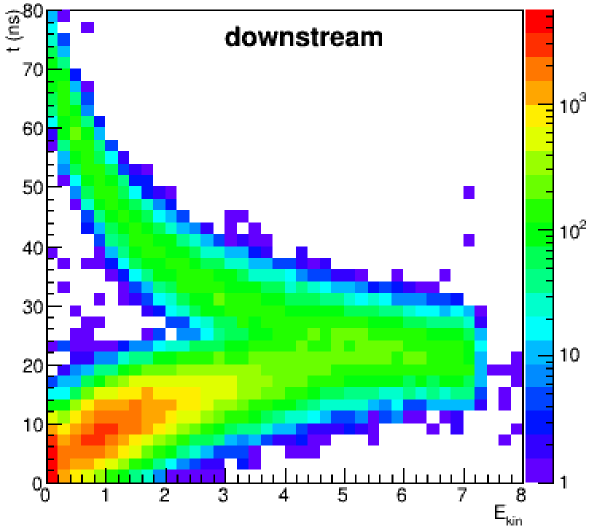
- Punch-through particles
  - Fast, little energy deposit
- Very few recoil protons in upstream detector
  - Compare target width with detector length
- Contribution from widely distributed molecular hydrogen
  - Wide range of punch-through particles
  - Skewed vertex distribution due to detector acceptance

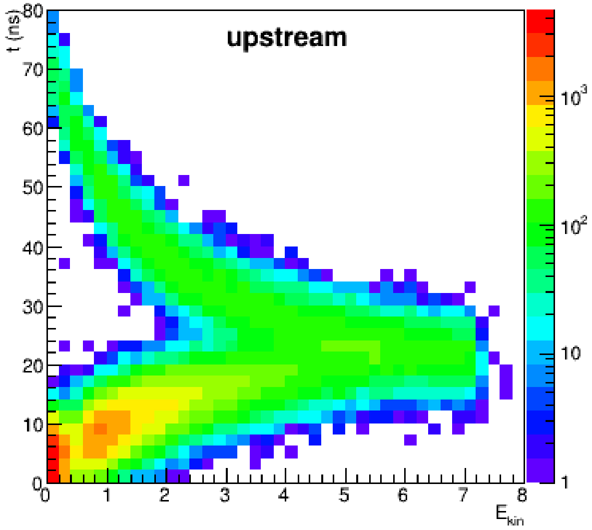






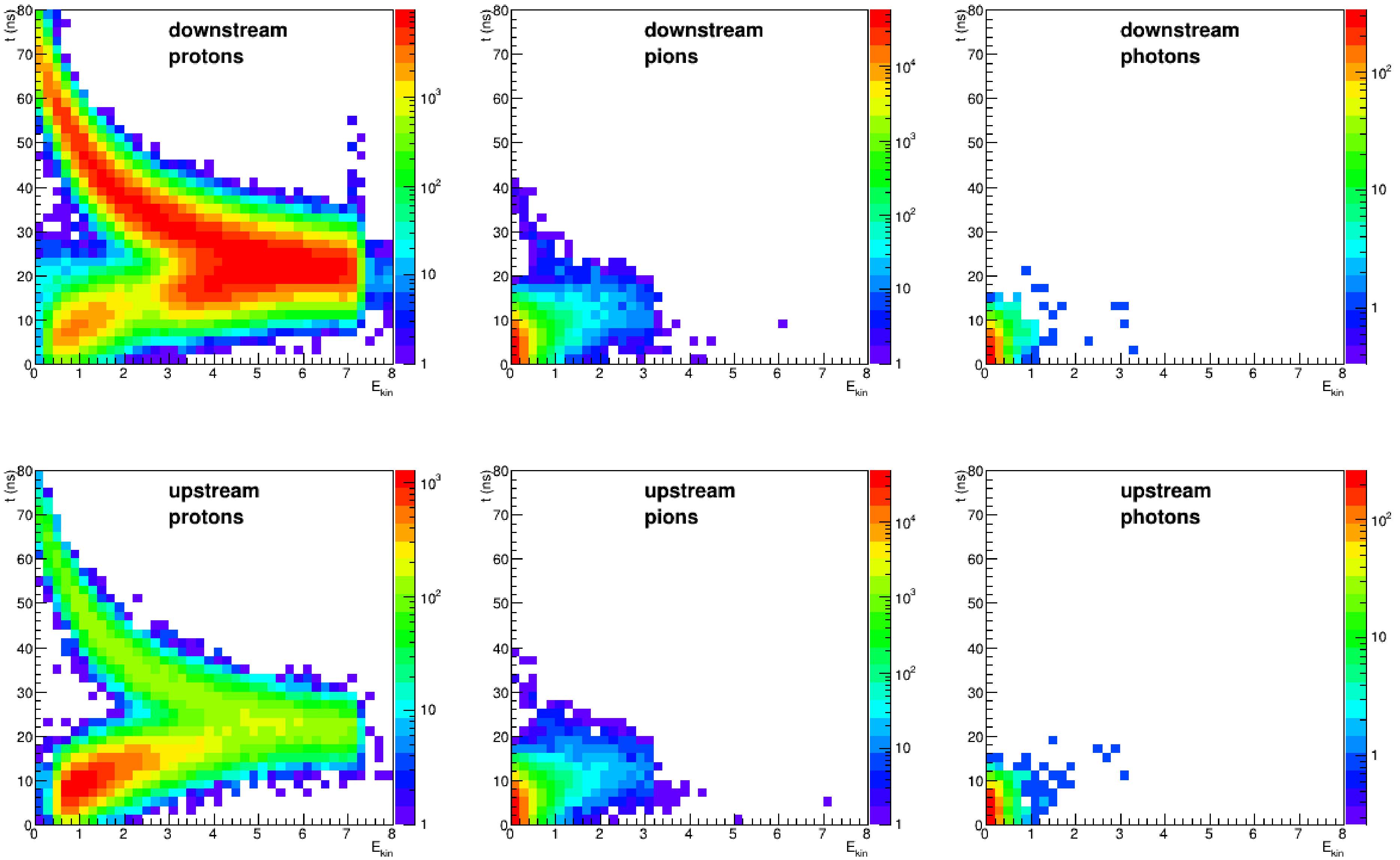






Simulation Results

- Very little background from photons
- Dominant pion background at low energy and short times
- Punch-through protons from far upstream scattering (mostly molecular hydrogen)

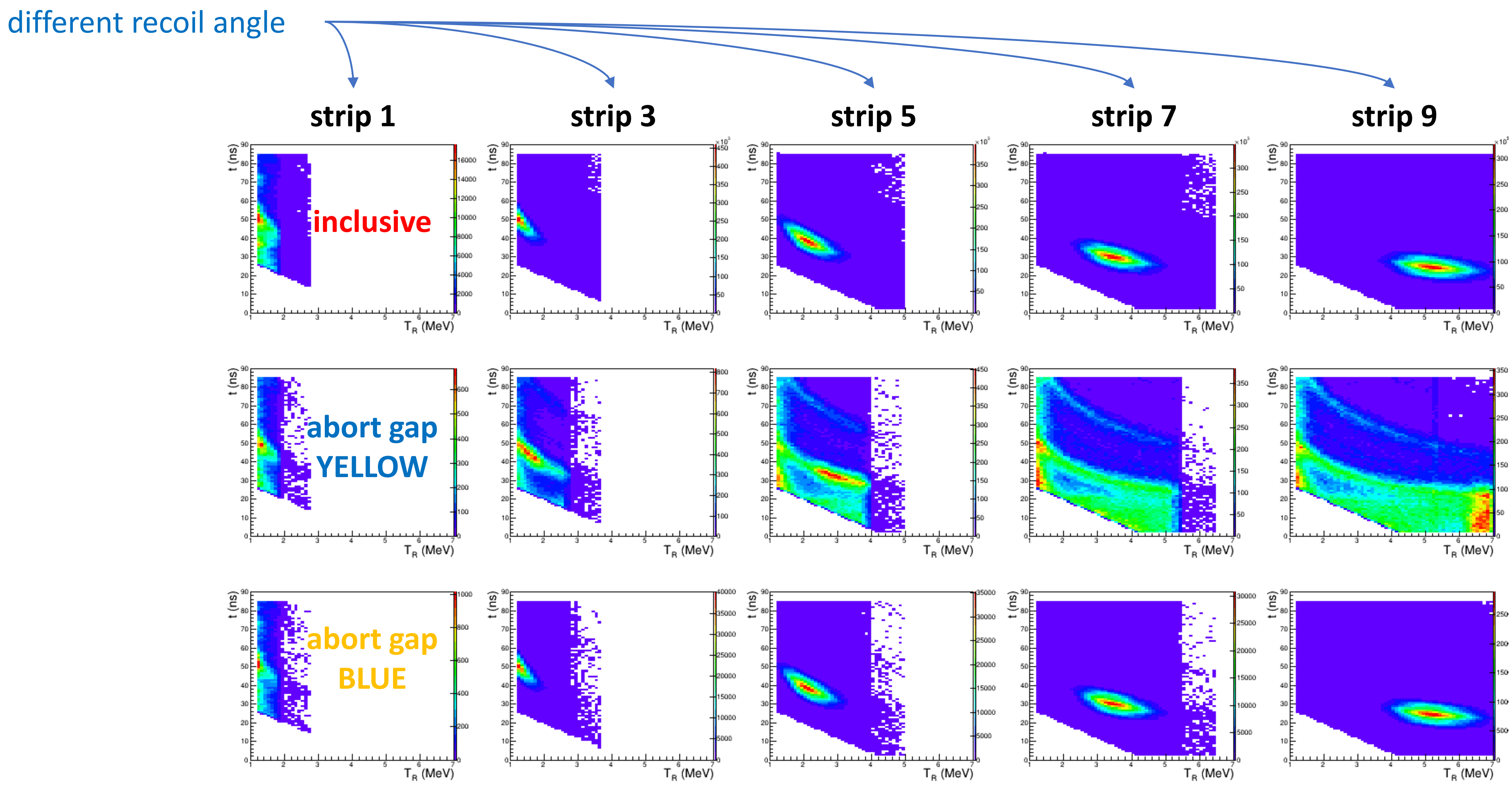


Conclusions & Summary

- Carbon target lifetime is an issue
  - Beam on target produces too much heat
  - Alternative target materials are being discussed
  - Composite materials potentially problematic for short bunch spacing
  - Material will affect detector location

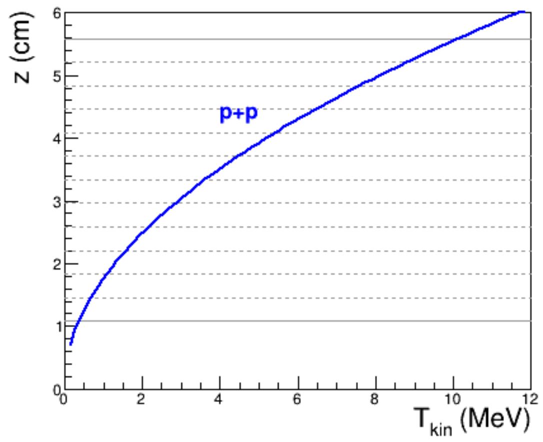
- Simulation studies for HJET background
  - Background is dominantly from pions
    - Probably not spin-dependent
  - Wide distribution of molecular hydrogen allows protons with higher energy into detector acceptance
    - Different spin dependence for beam/target
    - Problematic for normalization of beam polarization
  - Collimator will reduce proton background
  - Second Silicon layer can remove punch-through particles

Kinematics of the Recoil Proton

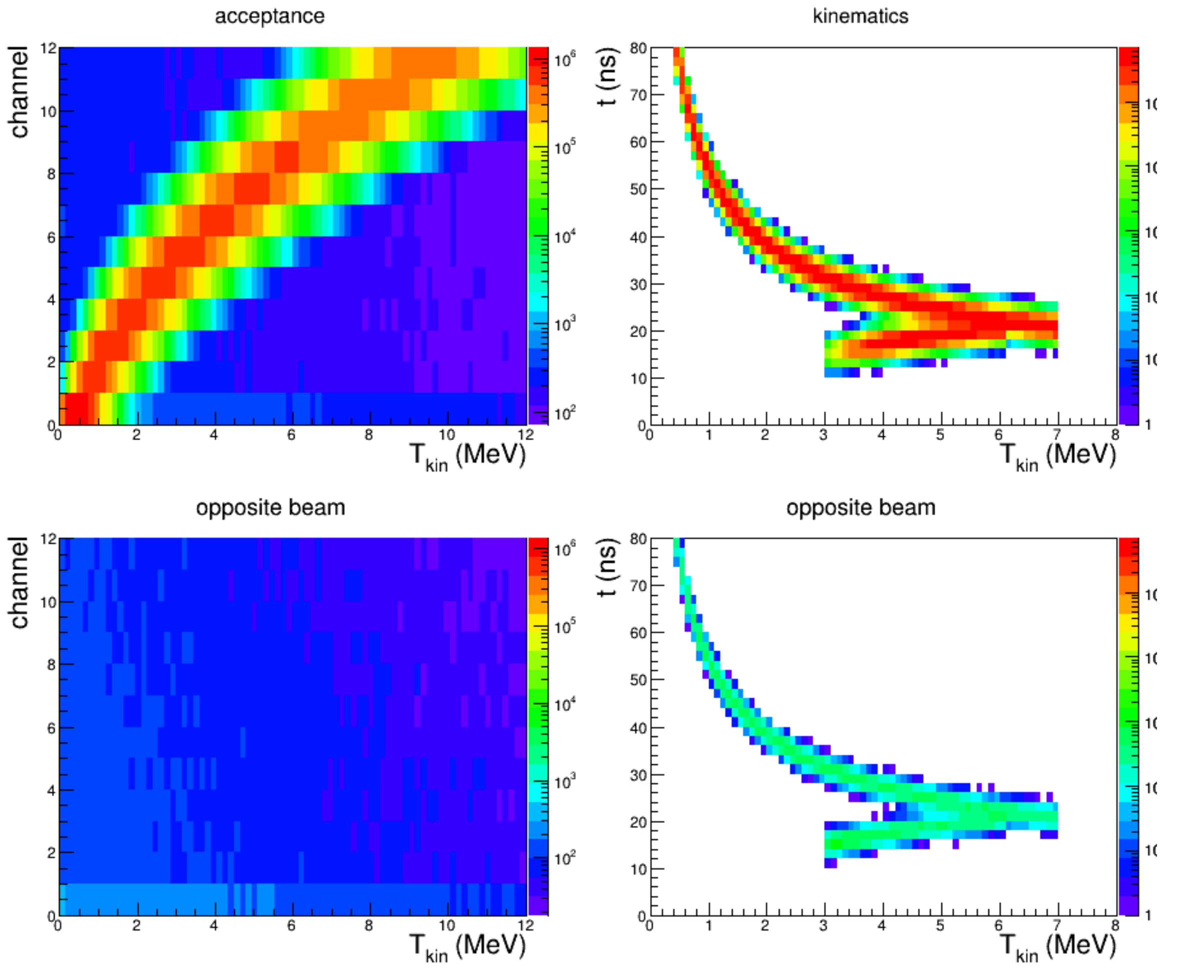


Toy Simulation

- Recoil angle calculated from kinetic energy
- Assume slow exponential cross section as function of energy
- Deposited energy from punch through particles calculated with empirical model (NIST)
- Size of atomic beam target and molecular component
- Effect of opposite beam (upstream contribution from molecular target)



bunch length σ_B = 1.0 ns
target width σ_T = 0.3 cm
molecular width σ_M = 9.0 cm
molecular fraction r = 1%



Main uncertainties:
- Bunch length
- Target thickness (z)
- Molecular background (z)

Other uncertainties:
- Energy resolution
- Strip pitch