Technical Requirements for Hadron Polarimeters

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1st Yellow Report Workshop

Polarimetry, Luminosity & Ancillary Detector WG

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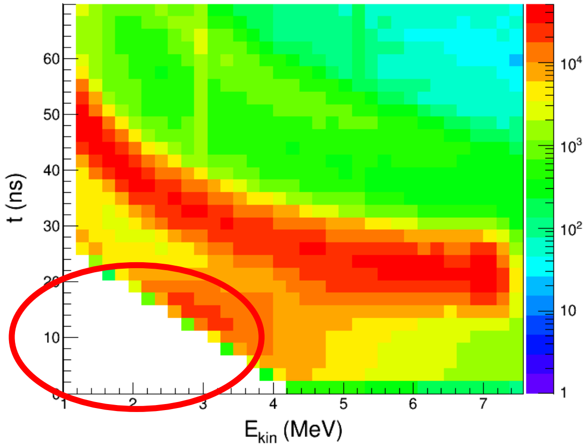
Requirements for an Electron-Ion Collider

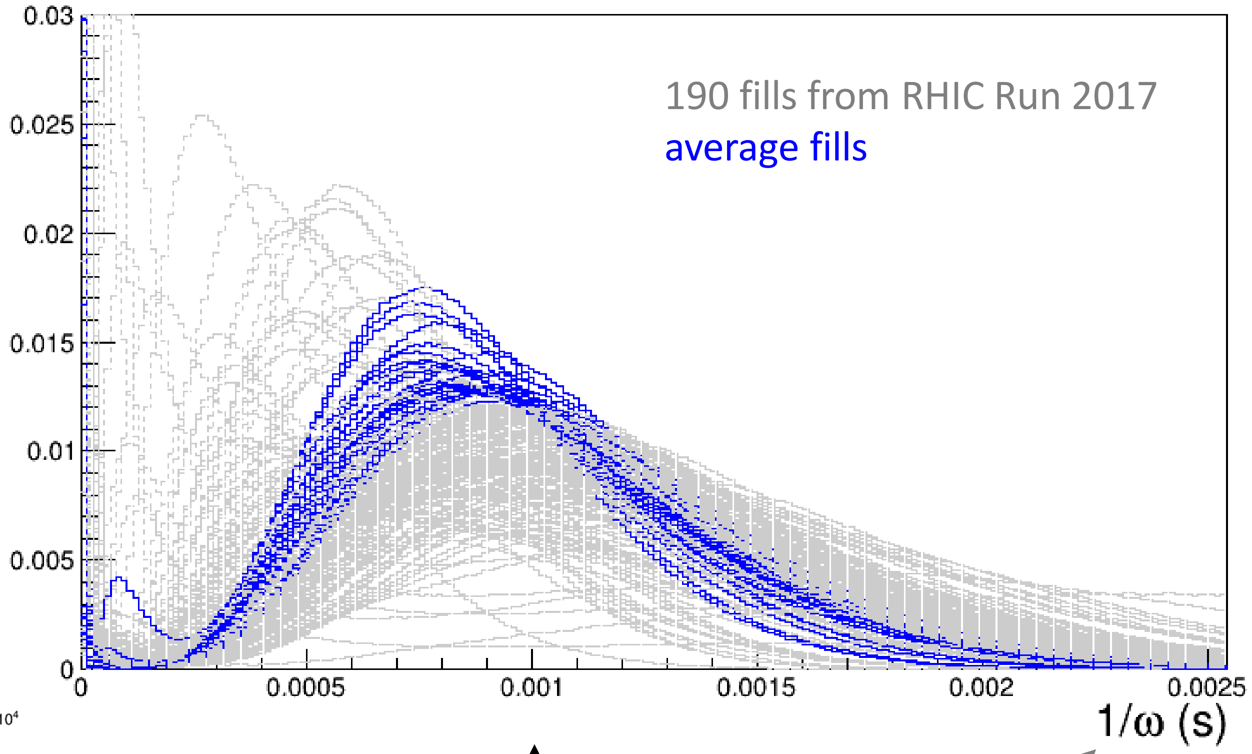
- Physics observables
  - High beam polarizations: electrons & protons
- High EIC Luminosity $\rightarrow$ small systematics $\approx 1\%$
- Flexible bunch polarization orientation
- Polarimeter $\Longleftrightarrow$ polarization in collision
  - Bunch polarization profile in x, y, z
  - Polarization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

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

Rates from Hydrogen Jet Target

- 2017 RHIC data
  - $255\ \mathrm{GeV}/c$ proton beams
  - Luminosity leveled
  - $2.2 \cdot 10^{11}$ protons per bunch at injection
  - Bunch spacing: $106\ \mathrm{ns}$
- Includes all events
  - Elastic recoil protons
  - Background (prompt particles etc.)
  - about 2/3 are prompts



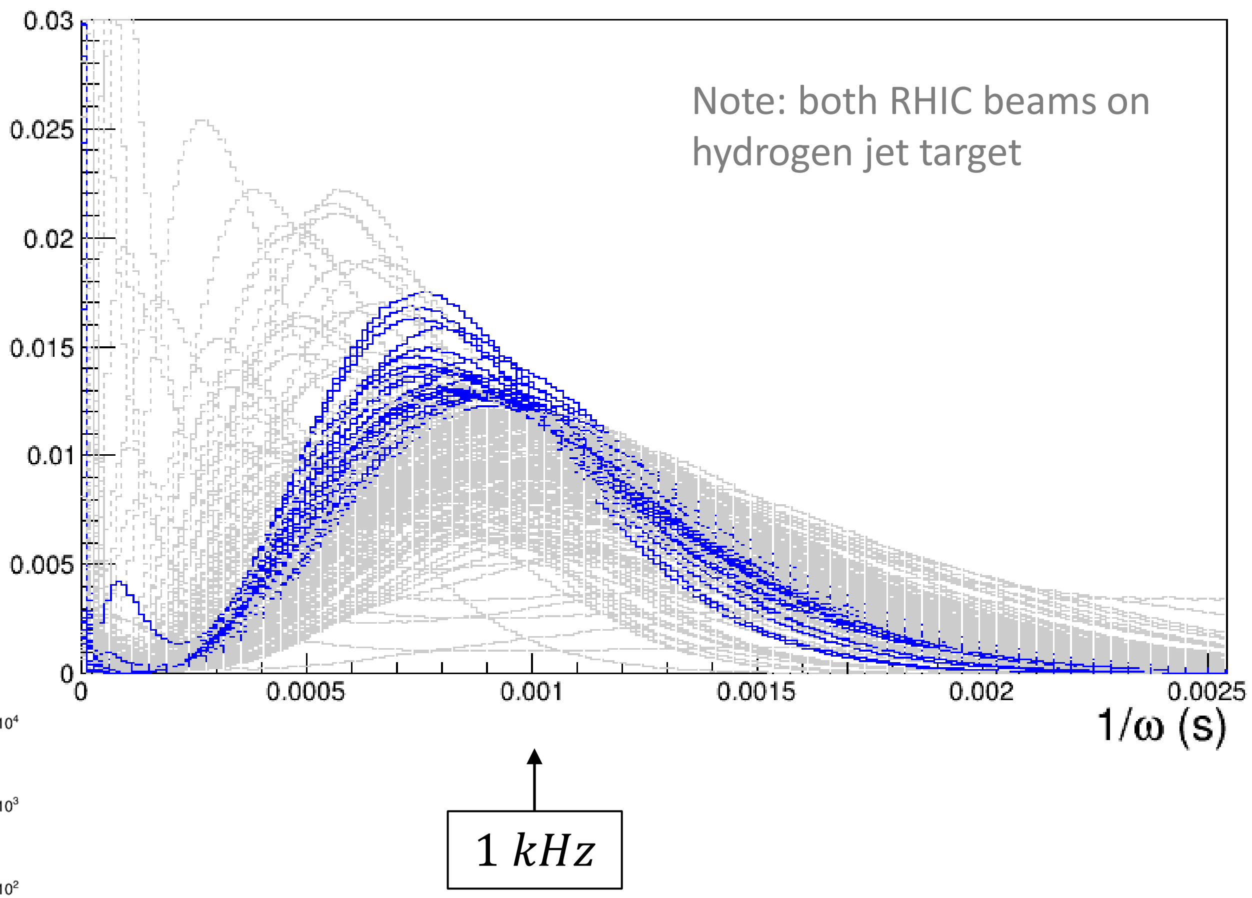


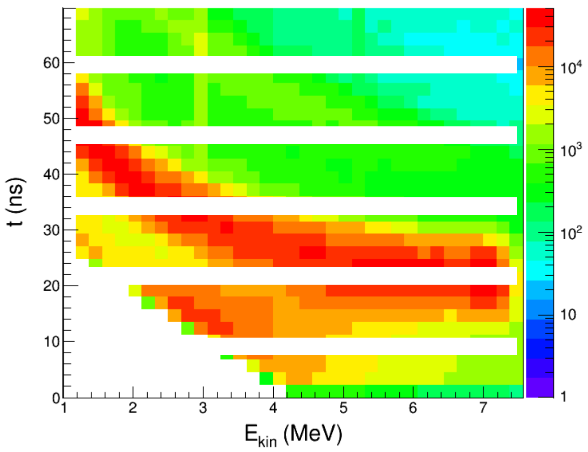
$1\ kHz$

Time between two recorded events

Rates from Hydrogen Jet Target

- 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





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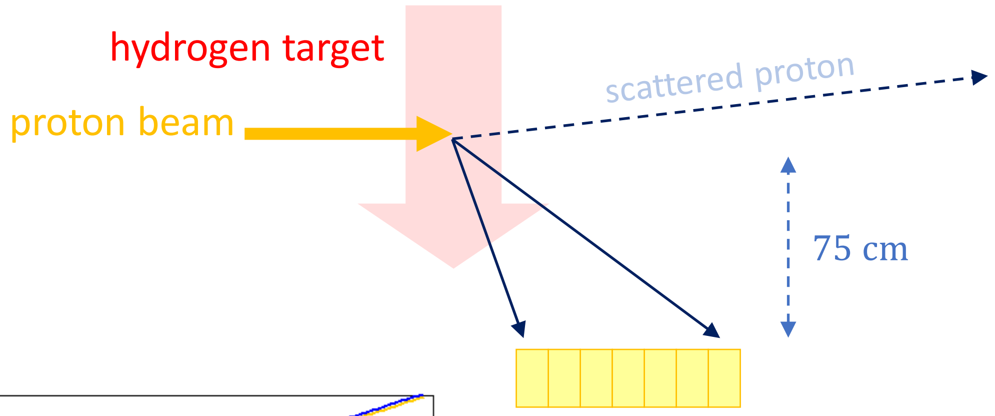
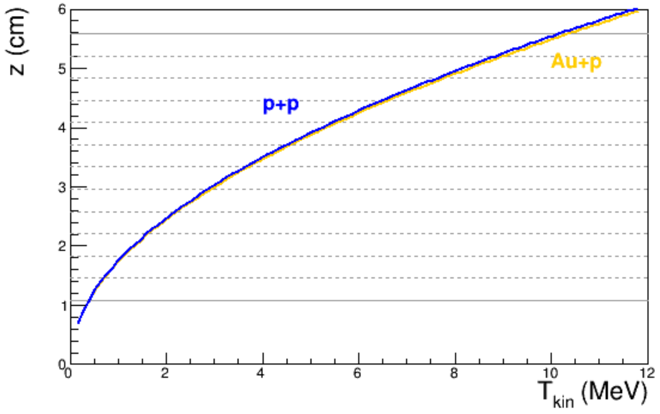
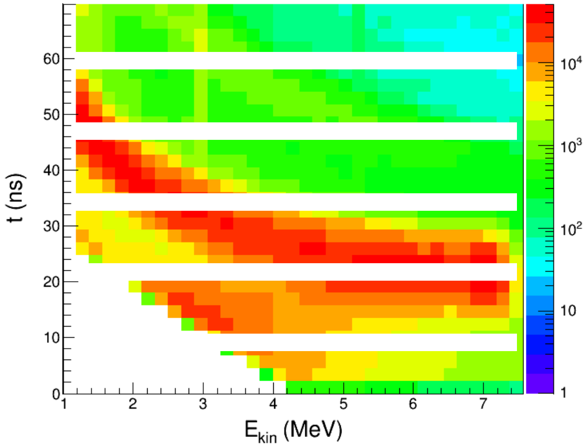




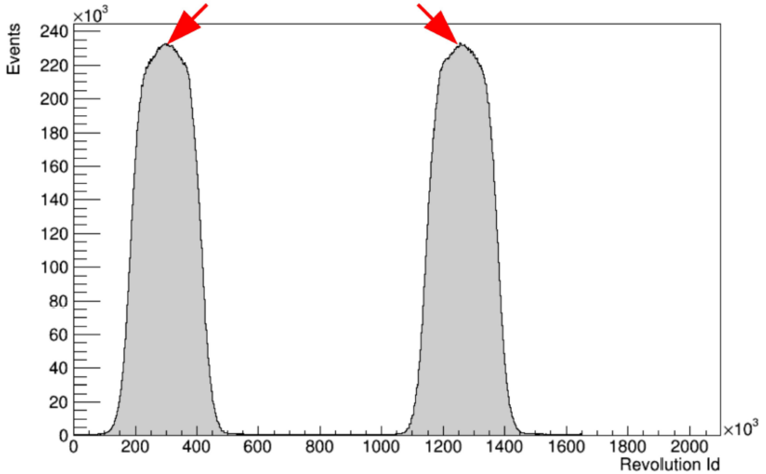
Independent of (high) beam energy

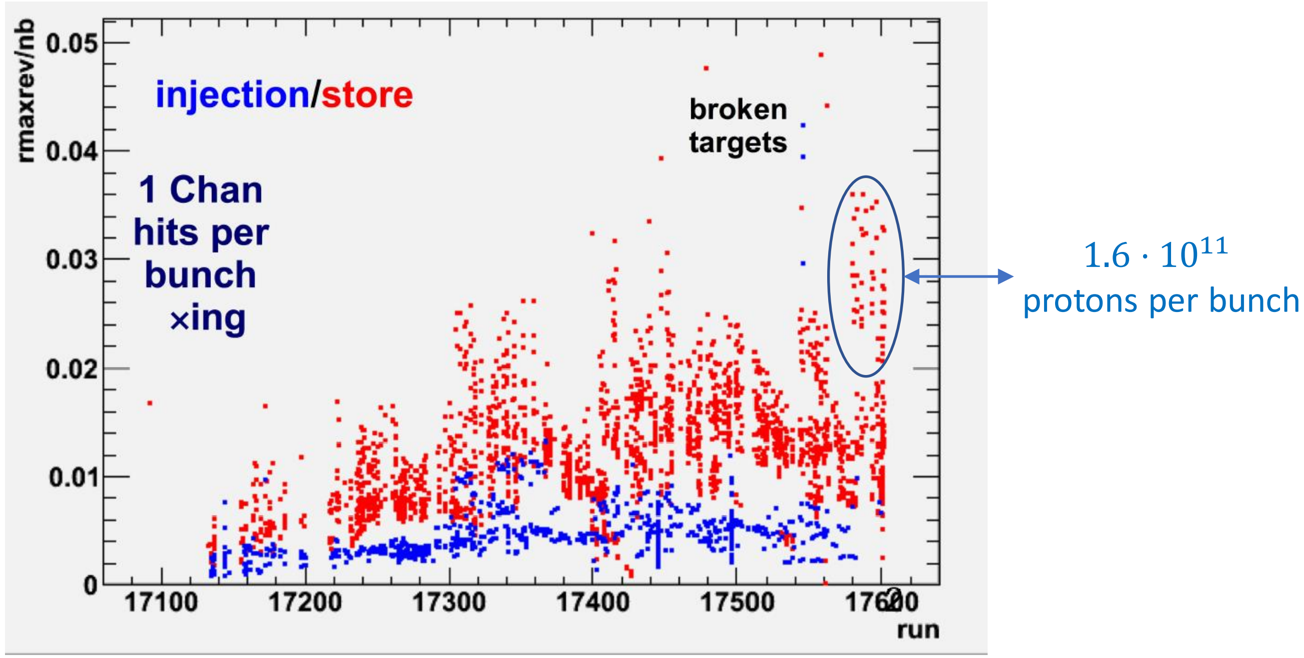


- Detector location (75 cm) is based on strip pitch and recoil energy
  - possible to reduce blocked time with smaller detectors

Rates from Carbon Targets

- RHIC data
  - Ultra-thin Carbon ribbon targets
  - Rate depends on transverse beam size
  - 2-3% per bunch ($1.6 \cdot 10^{11}$ protons per bunch)
  - $\sigma_{xy} \approx 0.2$ mm
- Electron-Ion Collider
  - Rate scales with bunch number and inverse transverse beam size
  - Multiples probability scales with inverse transverse beam size
  - FPGA waveform analysis (next slide)





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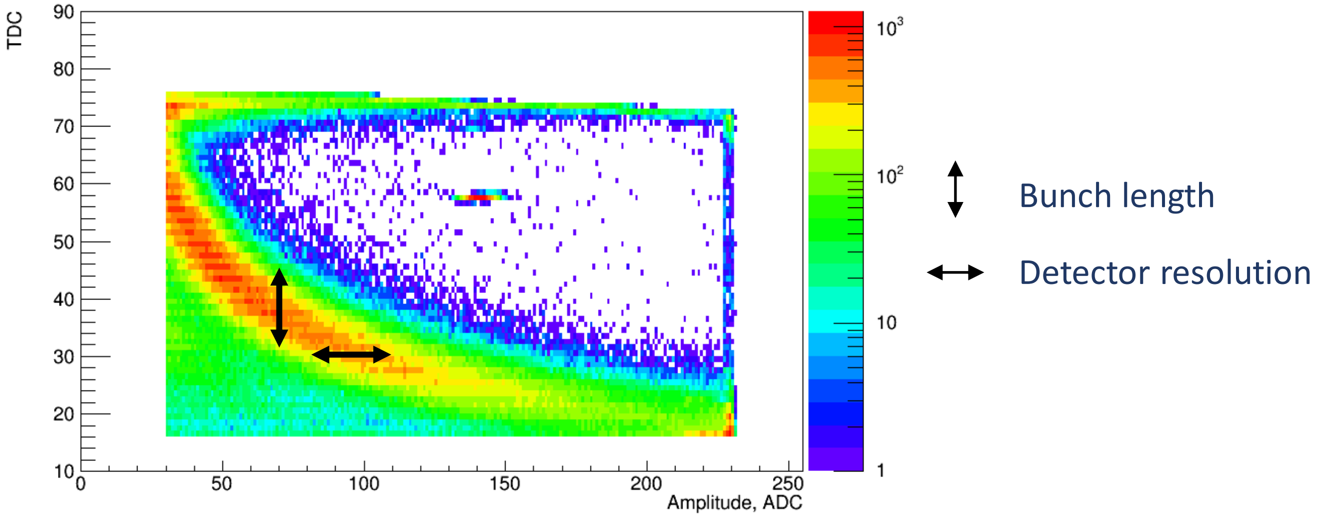
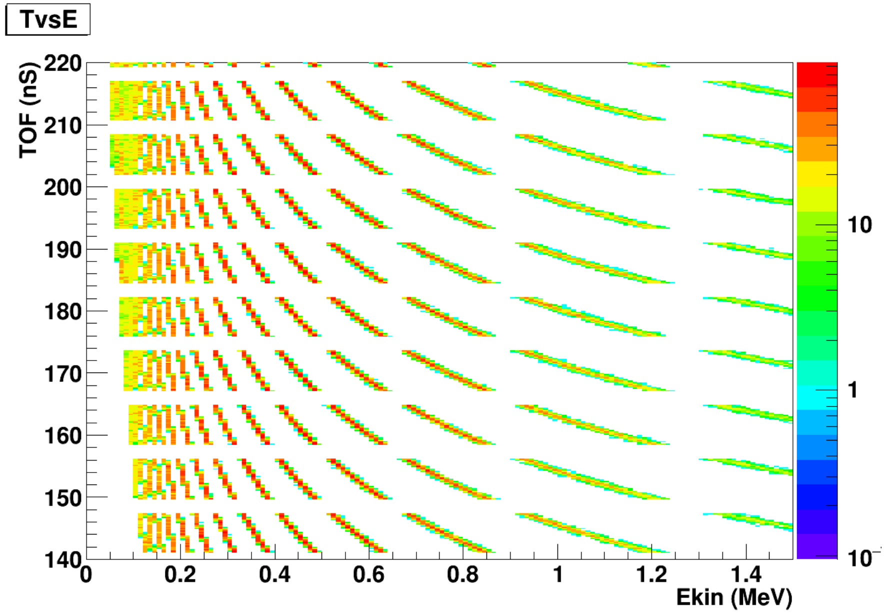
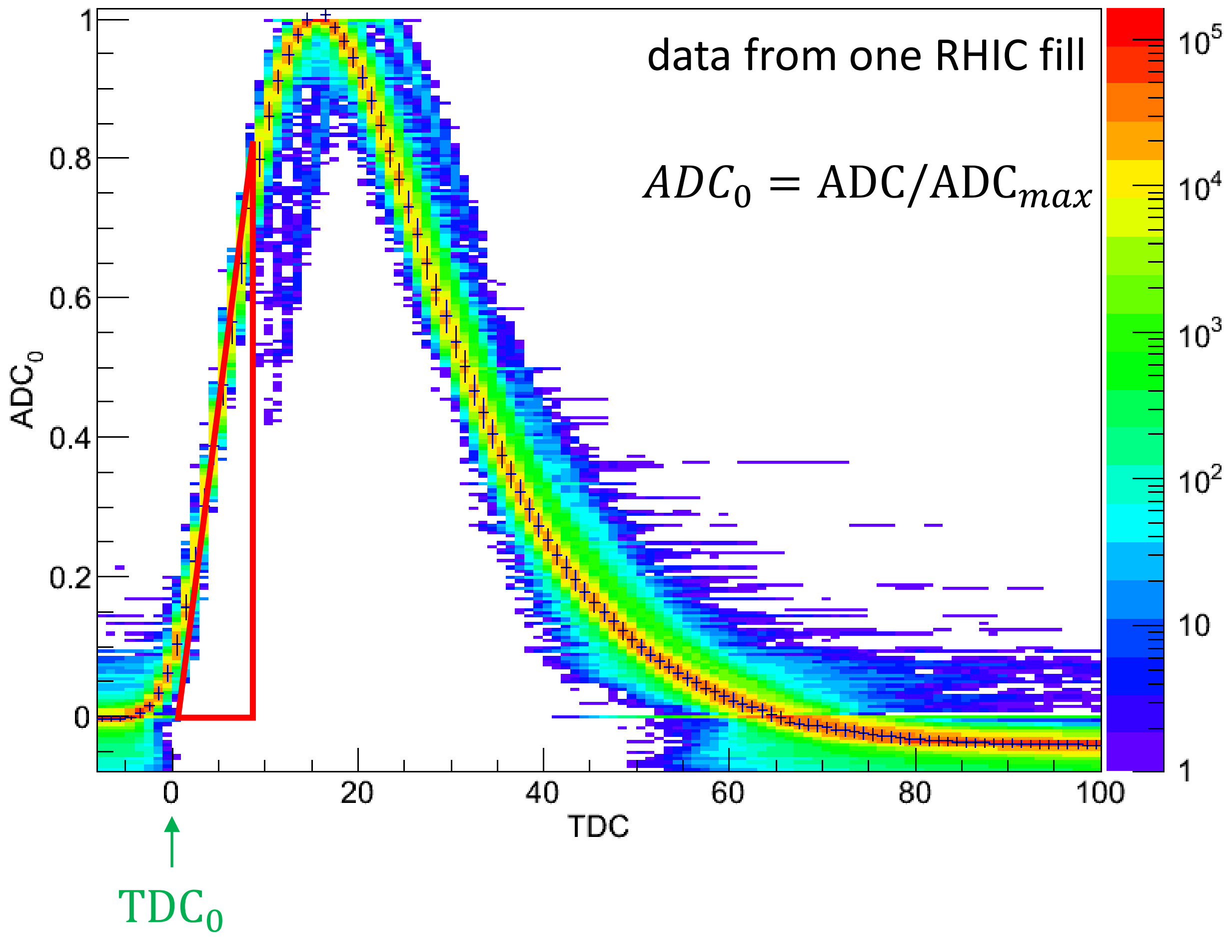




Waveform Analysis

- 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)



Polarization Determination

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

$$P = \frac{\epsilon}{A_{N,C}}$$

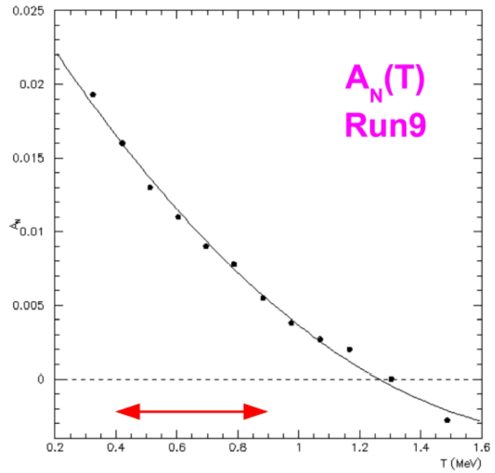
$$P_{Beam} = -\frac{\varepsilon_{Beam}}{\varepsilon_{Target}} P_{Target}\Big|_{jet}$$

measure $A_{N,C}$
for future use

calibrate $< A_{N,C} >$
for specific setup

$$P_{Beam} = -\frac{\varepsilon_C}{< A_{N,C} >_{jet}}$$

$C + p \to C + X$



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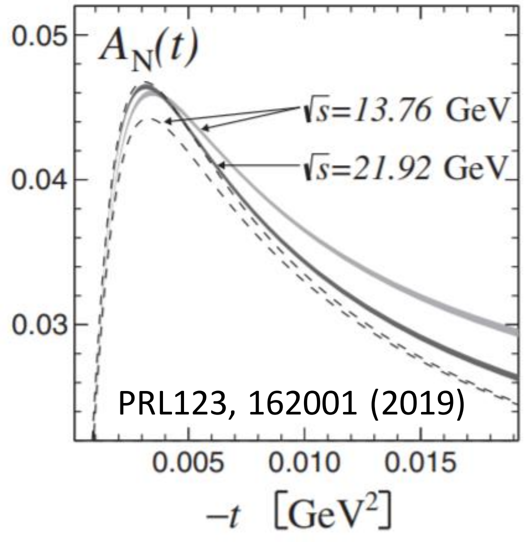
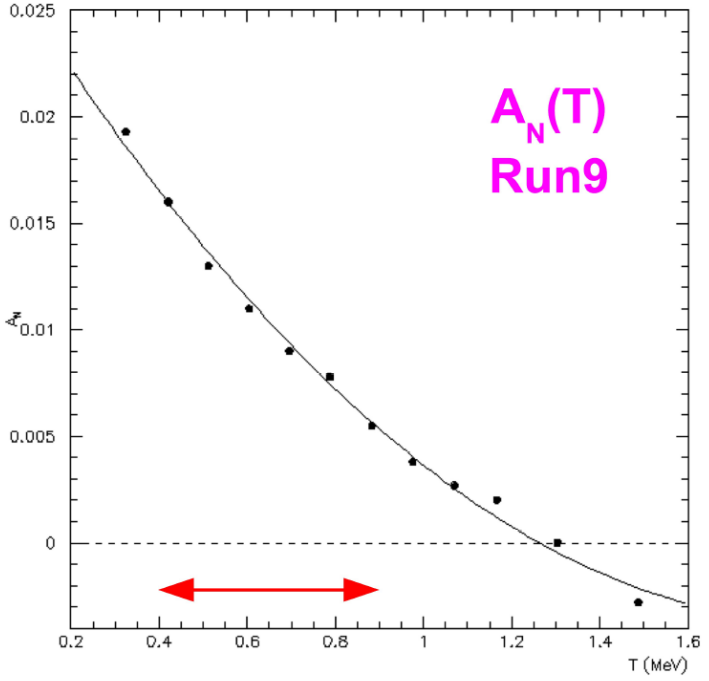


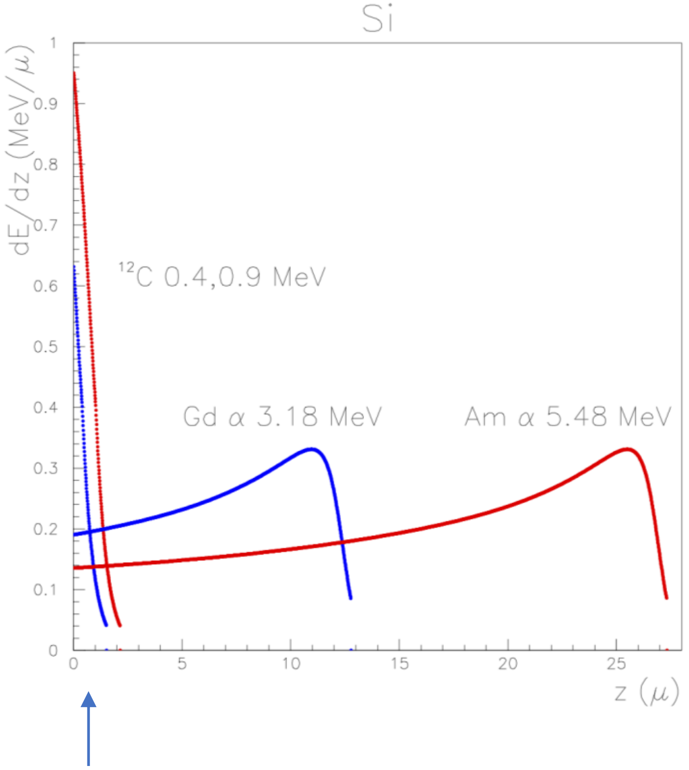
PRL123, 162001 (2019)

Carbon Polarimeter

- $A_{N,C}(T)$ is very steep
  - $\Delta T = 25\ keV\ \ -> \delta A_N/A_N \approx 5\%$
- Energy calibration with α-particles
  - Thickness of dead layer in front of Si detectors
  - $60\ \mu g/cm^2 \rightarrow 200\ keV \pm 10\%$
- Energy loss in target
  - Path length depends on ribbon orientation
  - Multiple scattering in target
  - Sway of ribbon in proton beam
- Target lifetime
  - Material, beam current and RF pickup



Measured energy



Dead layer
$z \approx 0.25 - 0.5\ \mu m$

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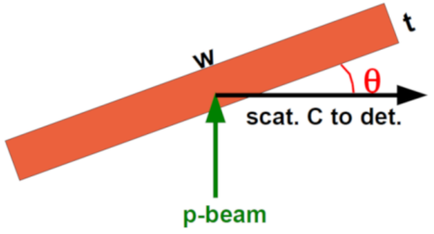

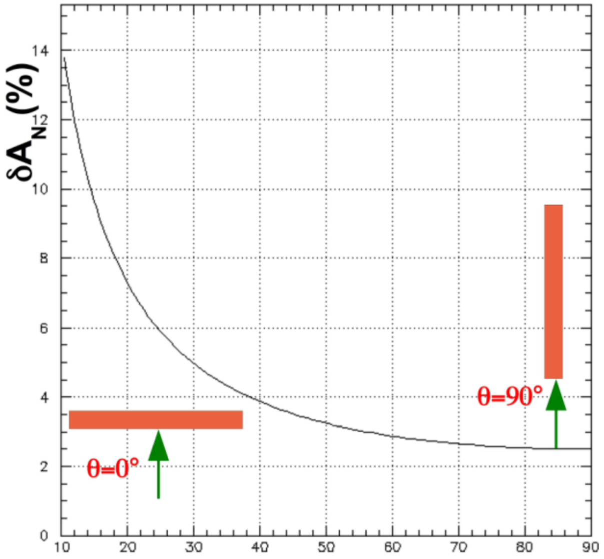

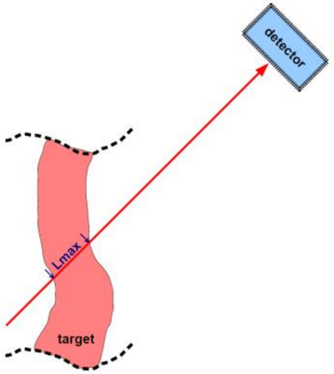

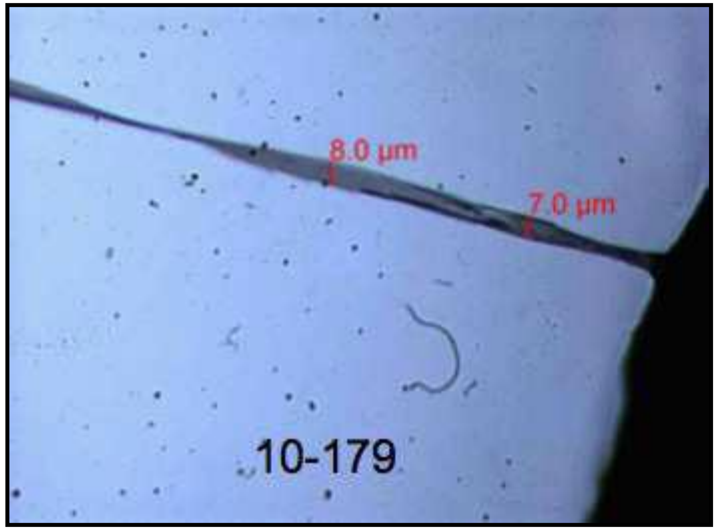

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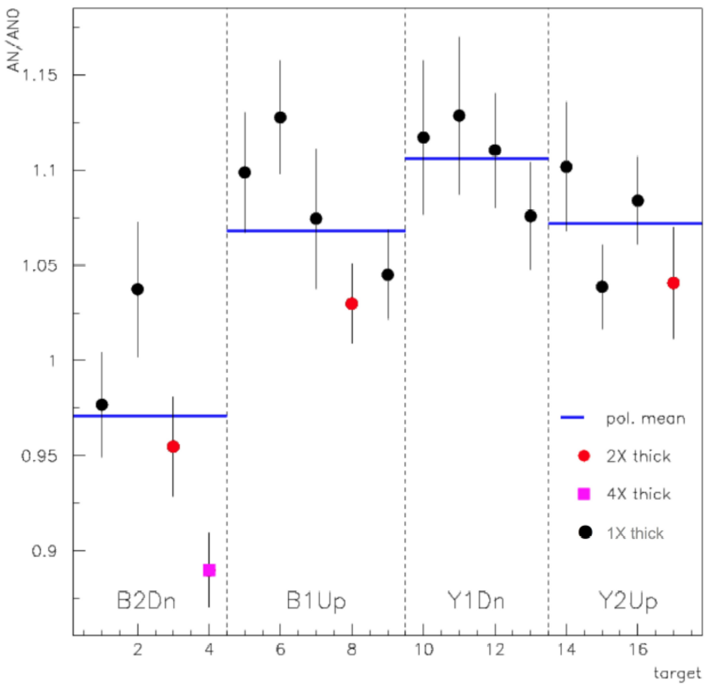

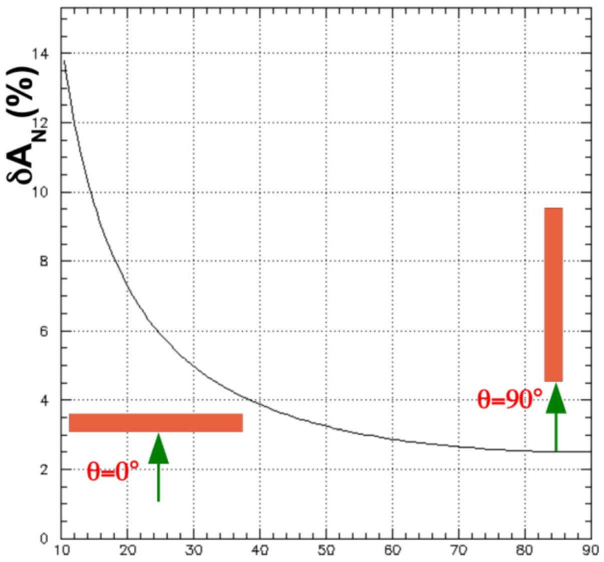

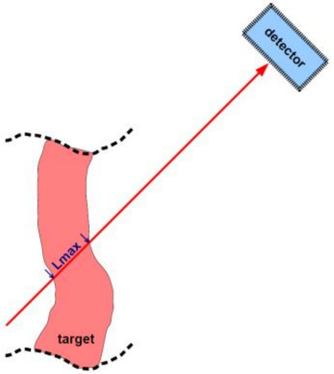

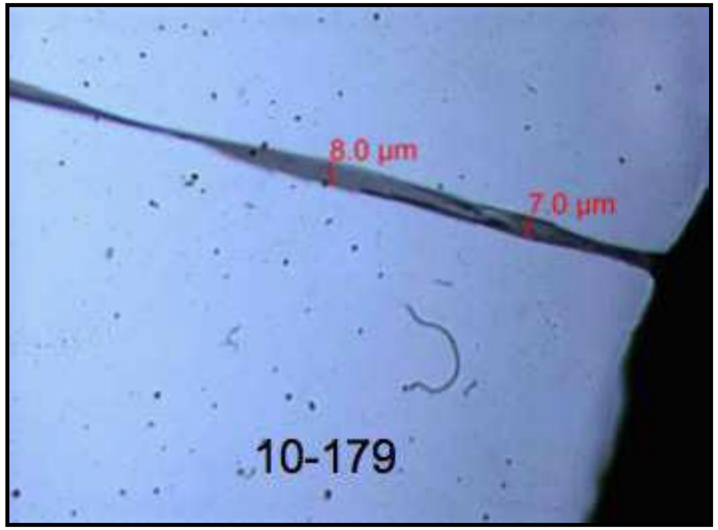

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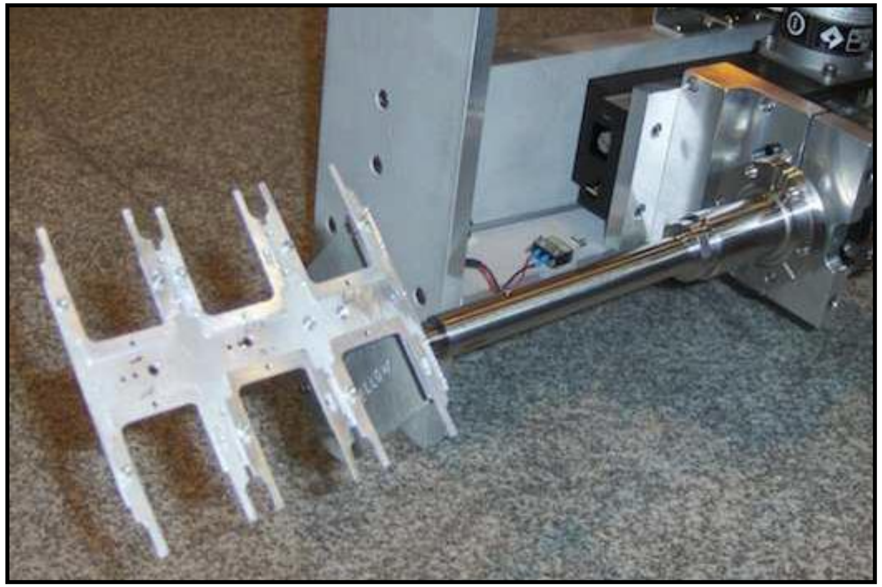


Requirements

	Polarized HJET	Unpolarized HJET	Carbon polarimeter	Forward neutrons
Absolute beam polarization	+	[+]	×	[×]
Polarization decay	×	×	+	+
Transverse profile	×	×	+	[×]
Longitudinal profile	+	+	+	×
Polarization vector	[×]	+	+	+
Bunch polarization	×	×	+	×

(*) Increased systematics

(*) A_N can be calculated, but needs to be confirmed

(*) depends on the target

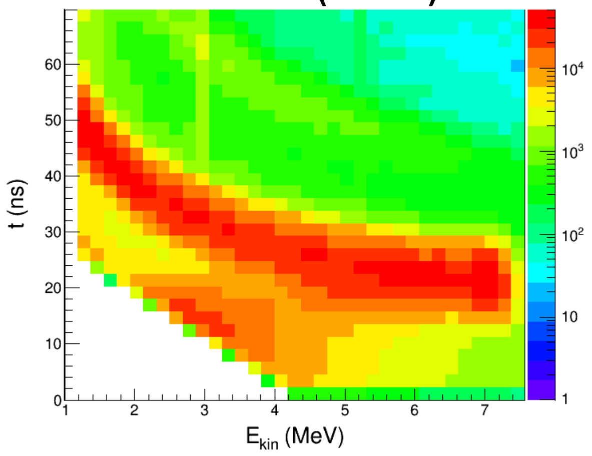
(*) limited space for detectors

Summary

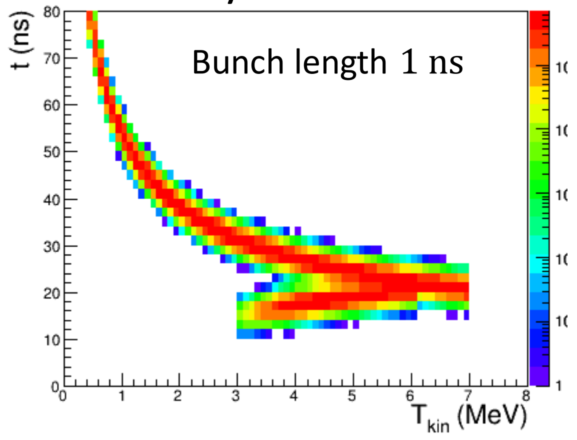
- Combination of absolute normalization with fast measurements
  - Time dependent polarization decay
  - Transverse and longitudinal bunch profiles
  - Bunch by bunch polarization
- High luminosity (short bunch spacing)
  - Improvements in detector performance and read-out needed
  - Veto for prompt particles
  - Time resolution of digitization
  - Streaming DAQ
  - Ribbon target material
- Light ion polarimetry
  - Recoil kinematics not much different from protons
  - Asymmetries potentially too small
  - Break-up and background under investigation (simulation)

Elastic Recoil and Background

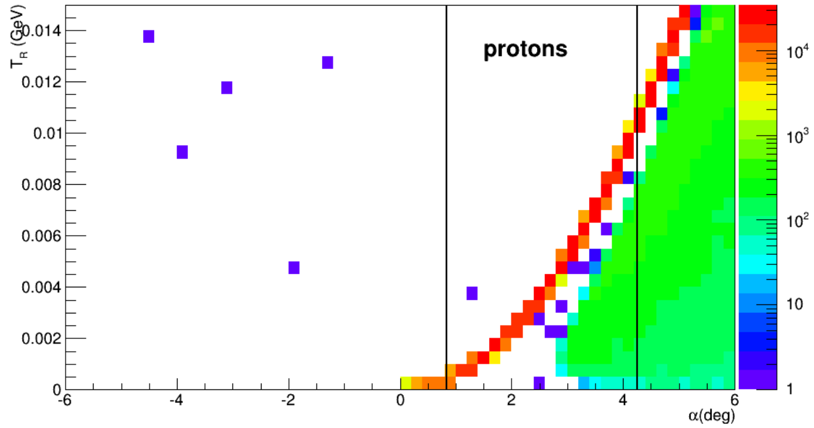
Data (2017)

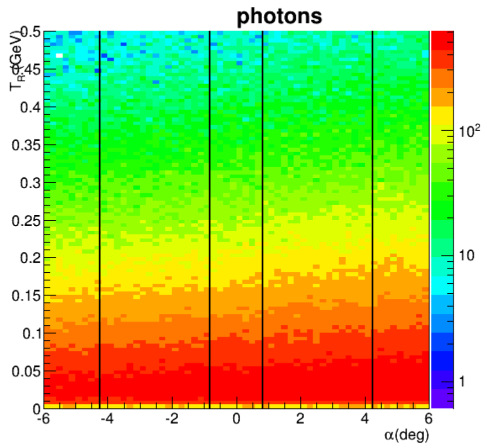


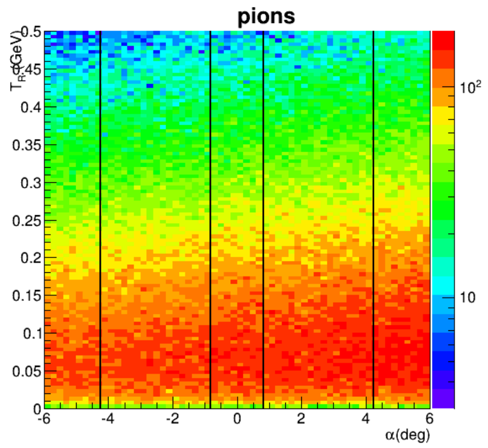
Toy simulation



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

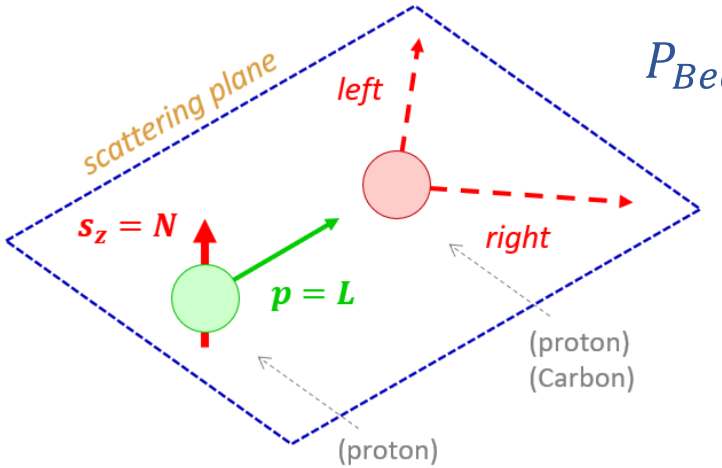




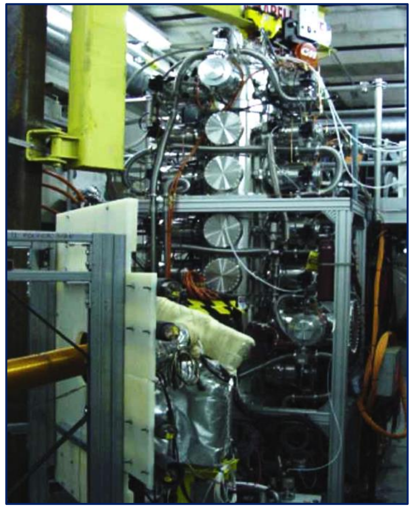


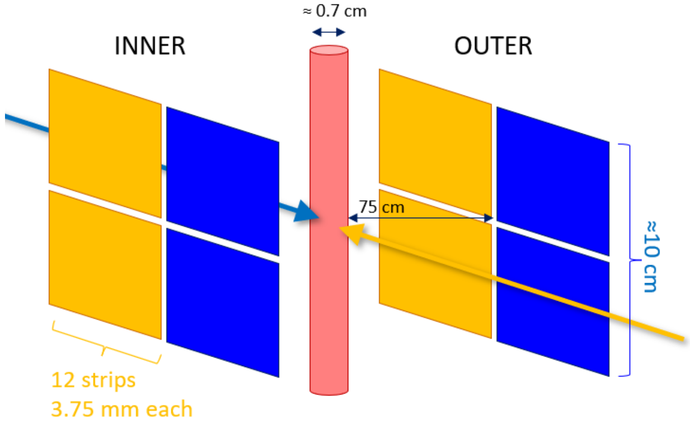
- Planned test with veto detector for charged pions
- Significant background also at low energies
- Problematic for much reduced bunch spacing

Proton Polarimetry at RHIC



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





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

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

(*) perpendicular to polarization vector

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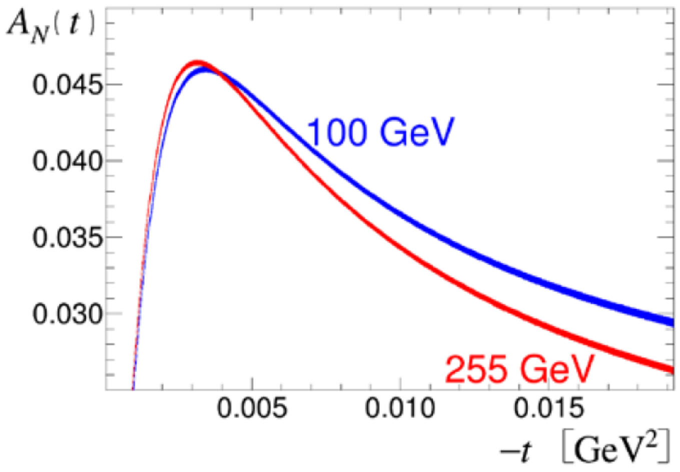
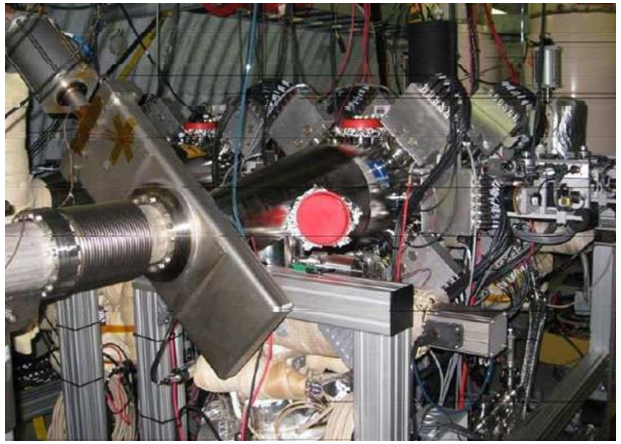
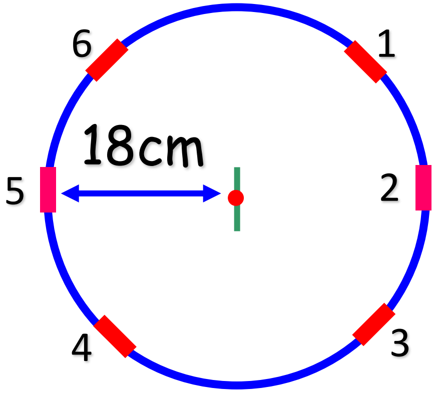






Acceleration of Polarized Hadron Beams

Magnetic moment precession in magnetic fields:

- Thomas-BMT equation
- Lorentz force

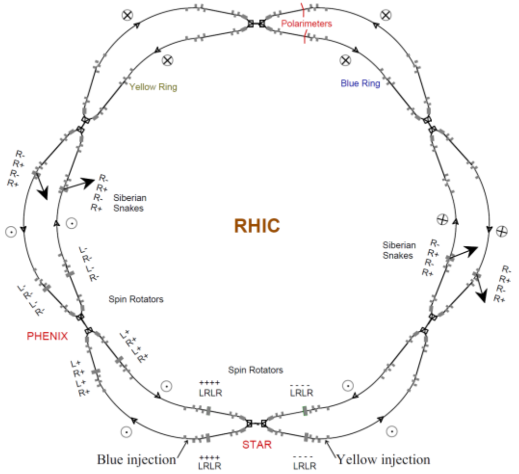
$$\frac{d\vec{P}}{dt} = -\left(\frac{e}{\gamma m}\right)\left[G\gamma\vec{B}_{\perp} + (1+G)\vec{B}_{\parallel}\right] \times \vec{P}$$

$$\frac{d\vec{v}}{dt} = -\left(\frac{e}{\gamma m}\right)\vec{B} \times \vec{v}$$

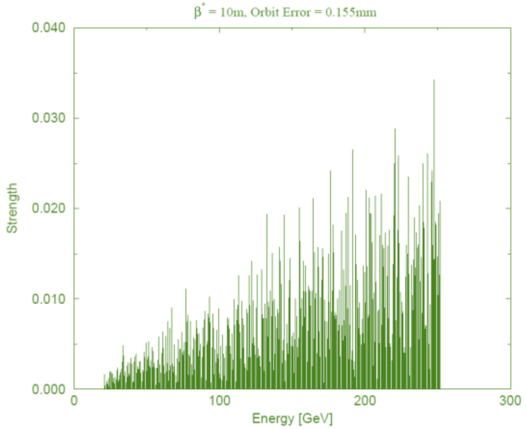
$$G = 1.7928$$

$$\gamma = E/m$$

$$\nu_{spin} \equiv G\gamma$$



- Imperfection resonances
  - $\nu_{spin} = n$
  - integer n



- Intrinsic resonances
  - $\nu_{spin} = kP + \nu_y$
  - integer k
  - superdiodicity P
  - vertical betatron tune ν_y