Jefferson Lab

Brookhaven National Laboratory

Hadron Polarimetry

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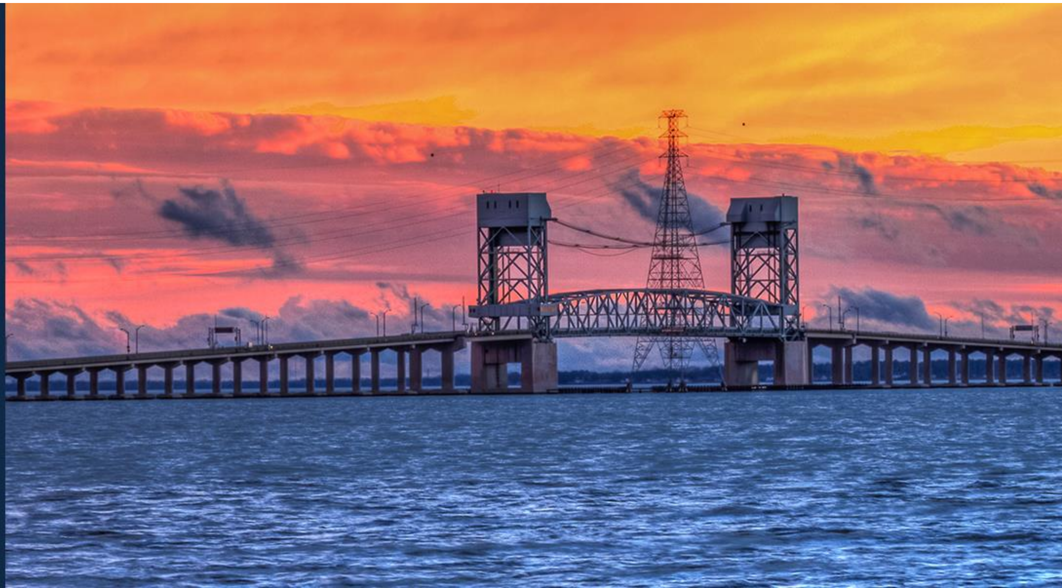
20TH INTERNATIONAL WORKSHOP ON POLARIZED SOURCES, TARGETS, AND POLARIMETRY

SEPT. 22-27 | JEFFERSON LAB, NEWPORT NEWS, VA



Polarization and Figure of Merit

$$\delta f(x) \propto \delta\sigma = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$

Physics observable of interest $\delta f(x)$

$$N = \int \frac{d\sigma}{d\Omega} \mathcal{L} d\Omega dt$$

$$\epsilon_0 = \frac{N^+ - N^-}{N^+ + N^-}$$

If the measurement is fully polarized

$$\epsilon = P\frac{N^+ - N^-}{N^+ + N^-}$$

With polarization $P = \frac{n^+ - n^-}{n^+ + n^-}$

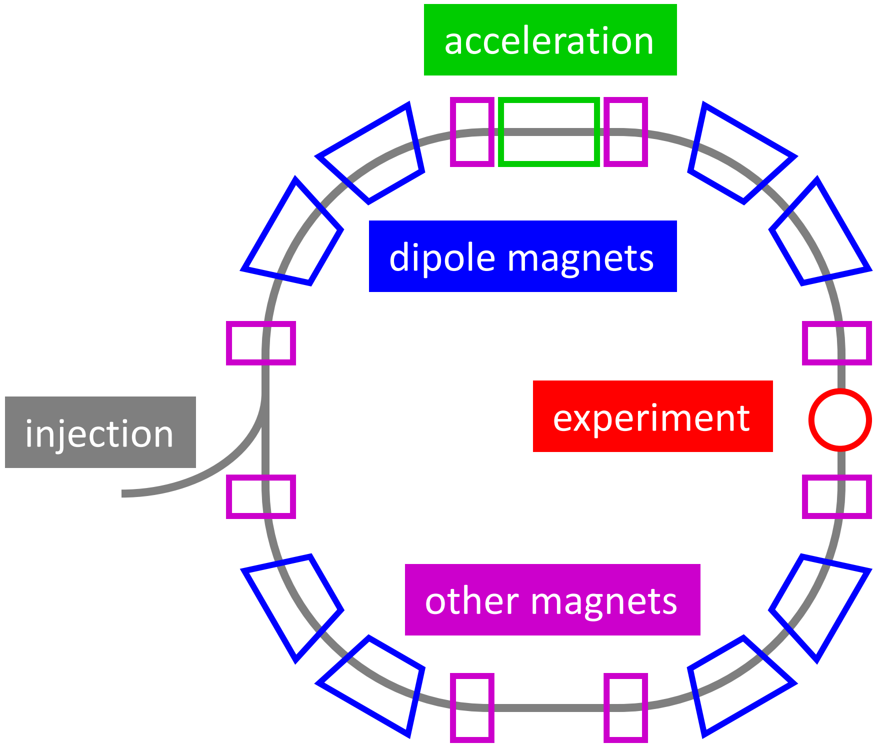
(note the assumption: $P^+ = P^-$)

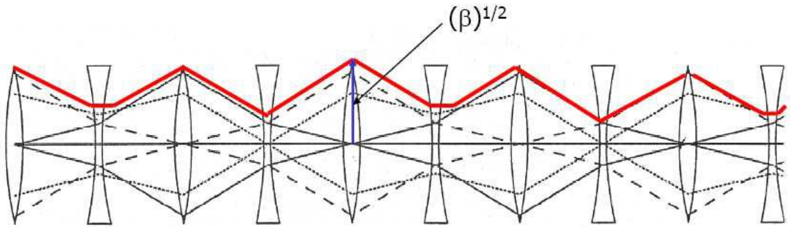
Uncertainty of physics observable $\Delta_f = \Delta_{\epsilon,0} P$

Statistical uncertainty of measurement $\Delta_{\epsilon,0} = \sqrt{N}$

Figure of merit: $FOM = NP^2$

Particle Beam Optics





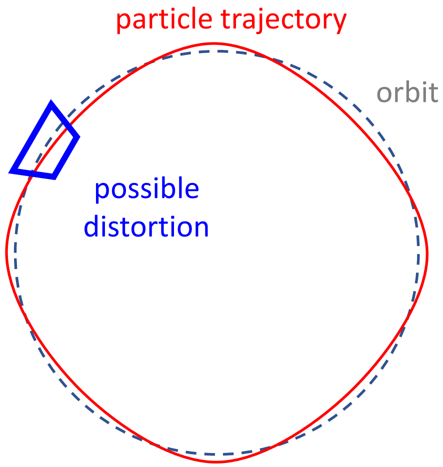
F0D0 lattice and orbit envelope

- We need to keep the particles on a circle.
- There is a closed orbit.
- Beam has a size and momentum spread.
- Particles oscillate around the closed orbit (betatron oscillation).
- Periodicity can lead to resonances and beam instability

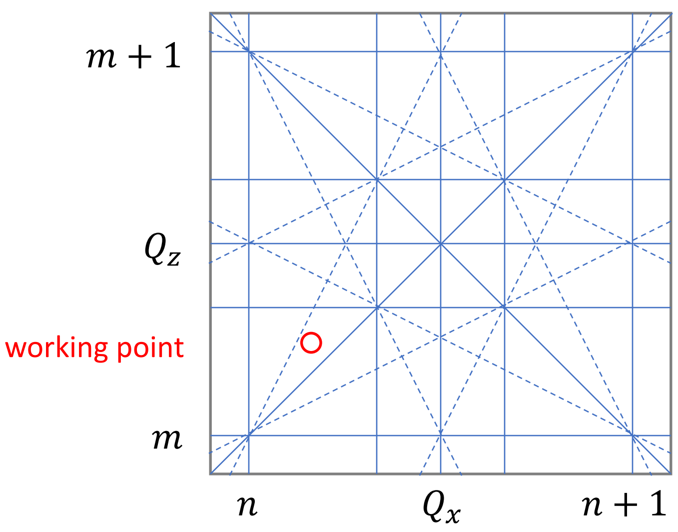
$$mQ_x + nQ_z = p \text{ with } (m, n, p) \text{ integer numbers}$$

Lorentz Force:

$$\vec{F} = e(\vec{E} + \vec{v} \times \vec{B})$$



Optical resonances up to 3rd order



- The magnetic moment of particles precesses in magnetic fields.

Depolarizing Resonances

Thomas-BMT equation:

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

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

$$G = 1.7928$$
$$\gamma = E/m$$

L.H. Thomas "The kinematics of an electron with an axis." *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science* 3.13 (1927)

V. Bargmann, L. Michel, and V.L. Telegdi "Precession of the polarization of particles moving in a homogeneous electromagnetic field." *Physical Review Letters* 2.10 (1959)

- The spin tune Q_s is the number of precessions per revolution.
- There are two types of depolarizing resonances
  - Intrinsic resonances

    $$\gamma G = kP \pm (\nu_y - 2)$$

  - Imperfection resonances

    $$\gamma G = k$$

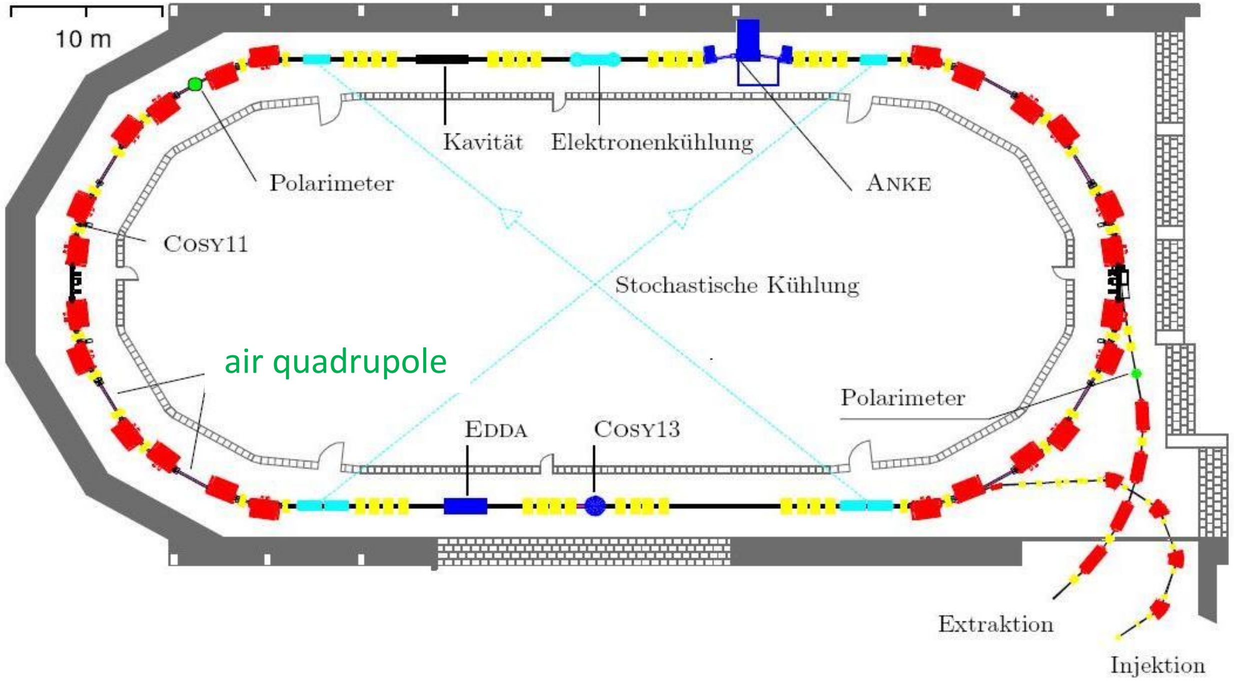
- The resonance strength depends on the local orbit distortion, magnetic field, and crossing speed.
- The number of resonances grows linearly with the top energy.

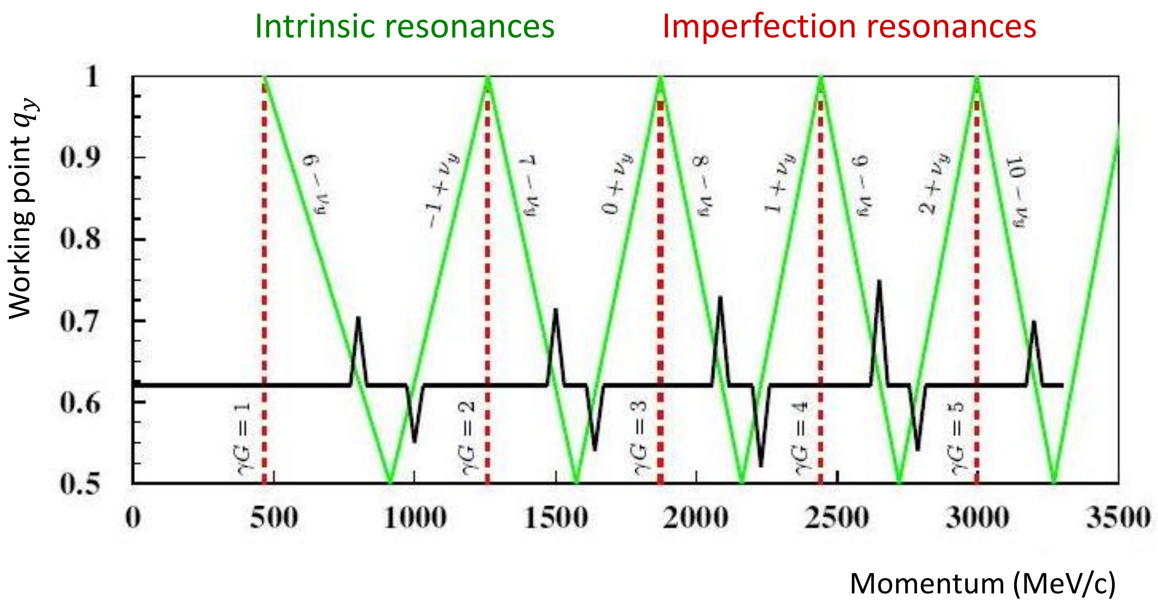
Example: COSY

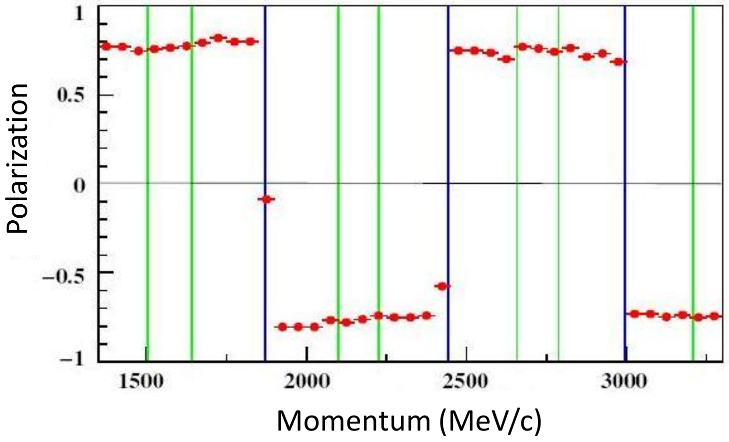
Cooler Synchrotron at FZ Jülich, Germany

Proton accelerator / storage ring

$p_{max} = 3.3$ GeV/c







The Relativistic Heavy Ion Collider

"Configuration Manual Polarized Proton Collider at RHIC." I. Alekseev et al. (2004)

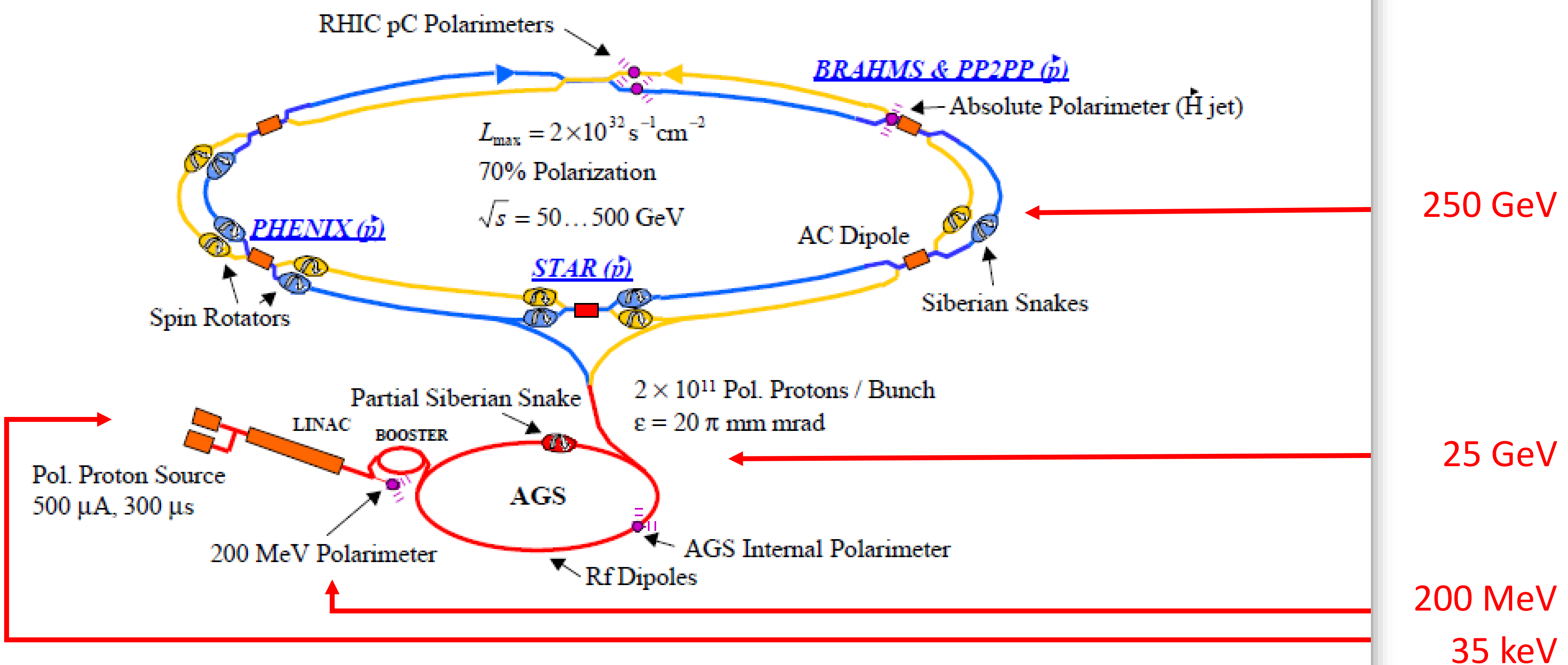
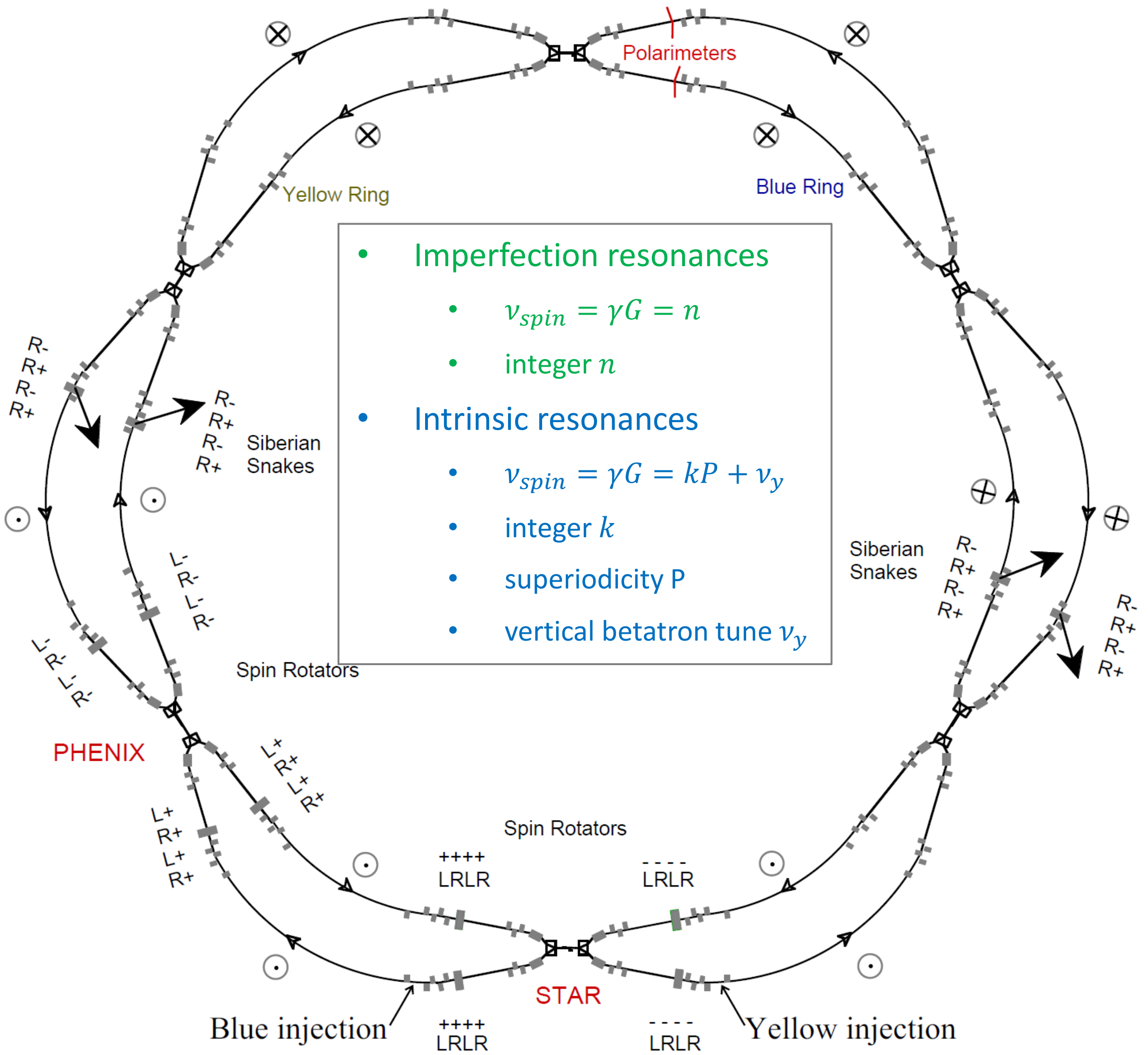
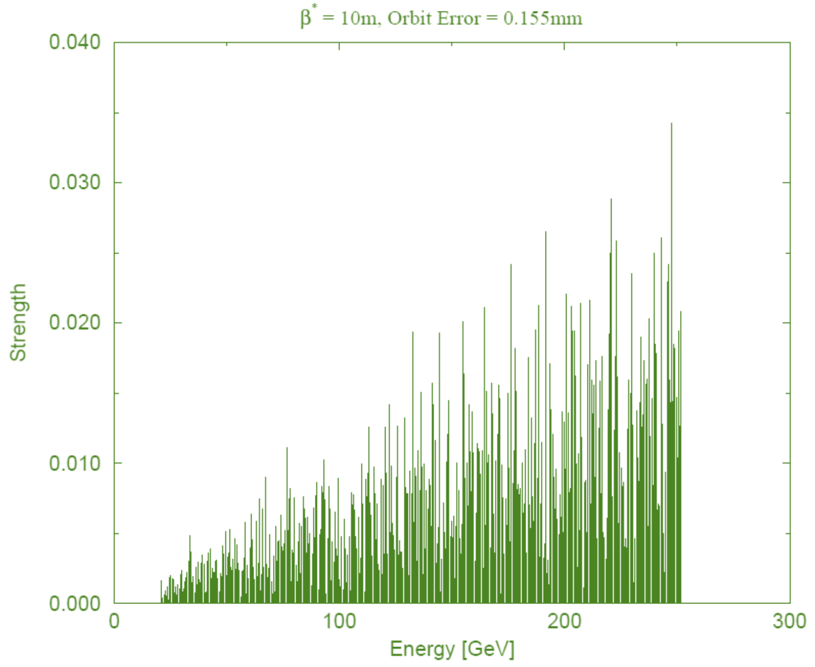


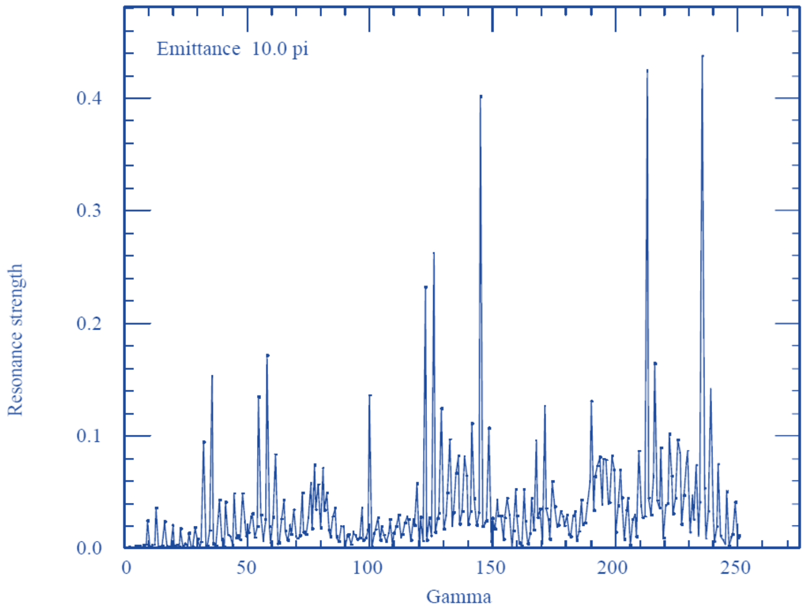
Figure 1.1: The Brookhaven hadron facility complex, which includes the AGS Booster, the AGS, and RHIC. The RHIC spin project will install two snakes per ring with four spin rotators per detector for achieving helicity-spin experiments.

Spin Resonances in RHIC

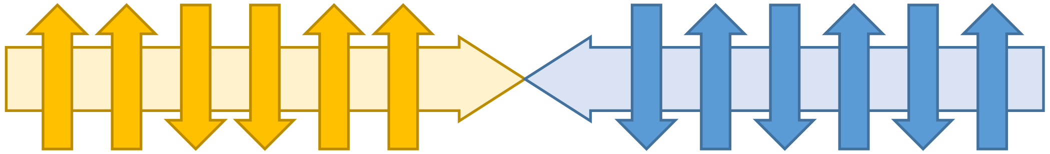


- Imperfection resonances
  - $\nu_{spin} = \gamma G = n$
  - integer n
- Intrinsic resonances
  - $\nu_{spin} = \gamma G = kP + \nu_y$
  - integer k
  - superiodicity P
  - vertical betatron tune ν_y

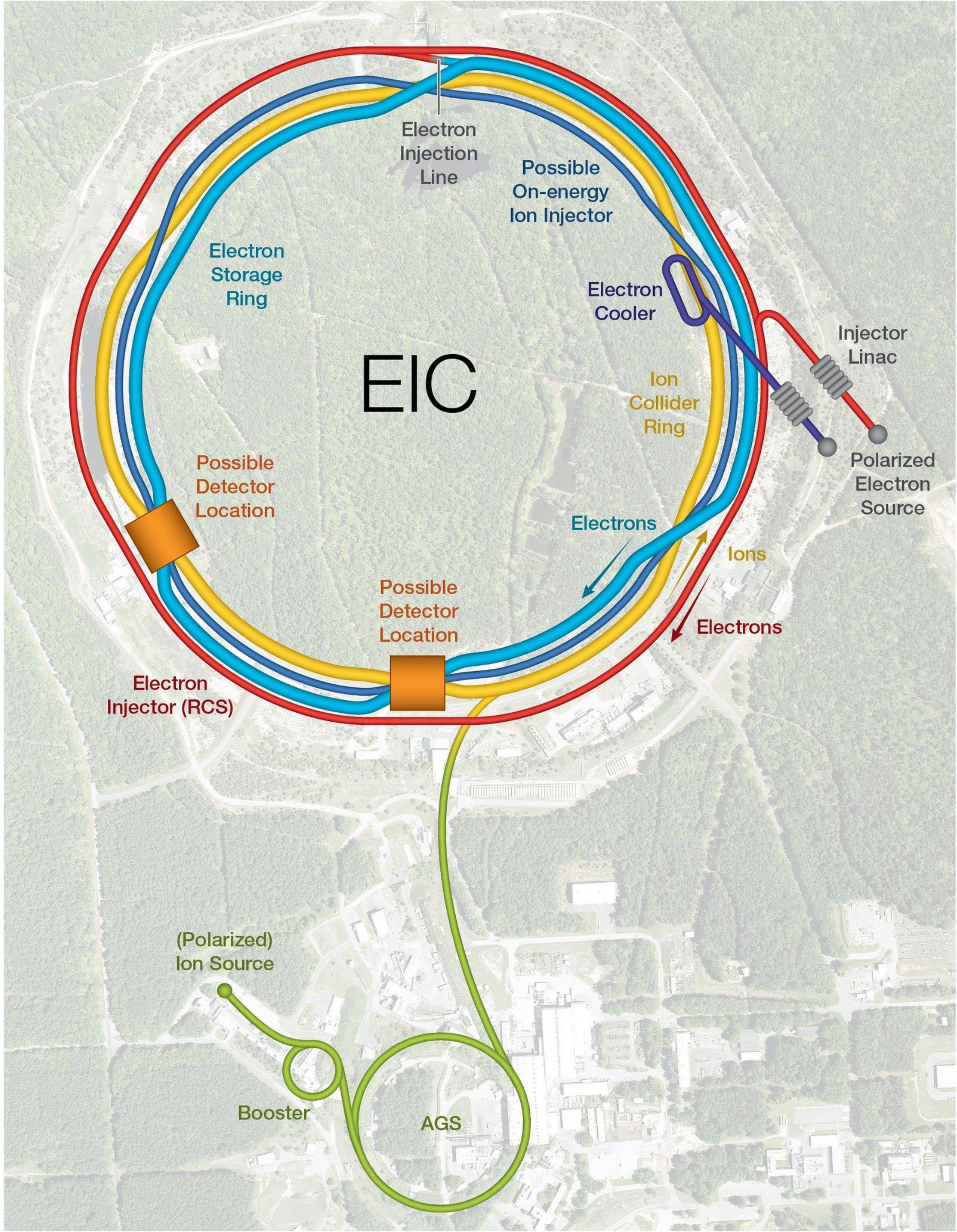




Polarized Beams at EIC



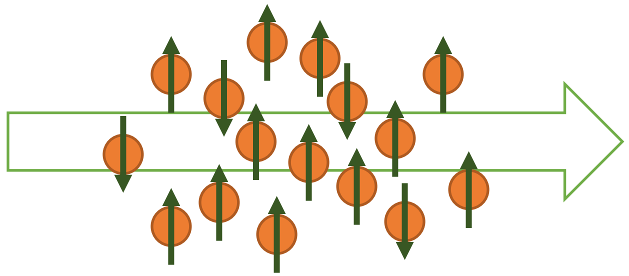
- **Proton beam polarization has to be measured up to 275 GeV.**
- Electron beam polarization has to be measured up to 18 GeV.
- The beams are bunched and will have alternating polarization states to reduce time-dependent systematic uncertainties.
  - Bunch spacing is around 10 ns
- Required:
  - Absolute beam polarization $\Delta P/P \approx 1\%$
  - Time-dependence (polarization decay)
  - Bunch-by-bunch polarization
  - Polarization profile of bunches
  - Polarization vector at experiment

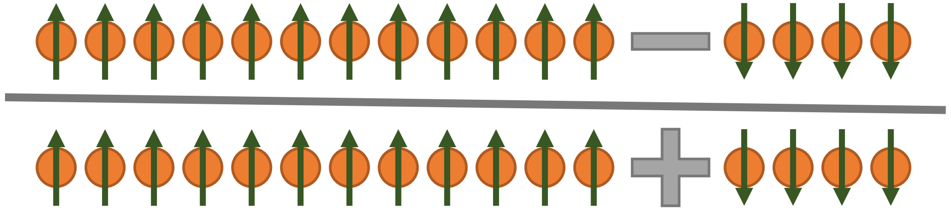


Polarization of Particle Bunches

A bunch of particles in vacuum travelling at almost the speed of light

Goes in circles, will be back in about 13 μs (78 kHz).





- For the determination of the polarization we will have to devise an experiment which is spin-dependent.
- We need a representative sample of scattered particles to make conclusive statements about the polarization.
- Only a fraction of the scattering probability will depend on the spin: $\sigma^{\uparrow\downarrow} = \sigma_0 \pm \sigma_s = \sigma_0(1 \pm a_s)$
- It is convenient to introduce an asymmetry: $\epsilon = (\sigma^{\uparrow} - \sigma^{\downarrow})/(\sigma^{\uparrow} + \sigma^{\downarrow}) = a_s$

The Right Frame

- The momentum and spin direction define a coordinate system.

  Longitudinal $\boldsymbol{L}$

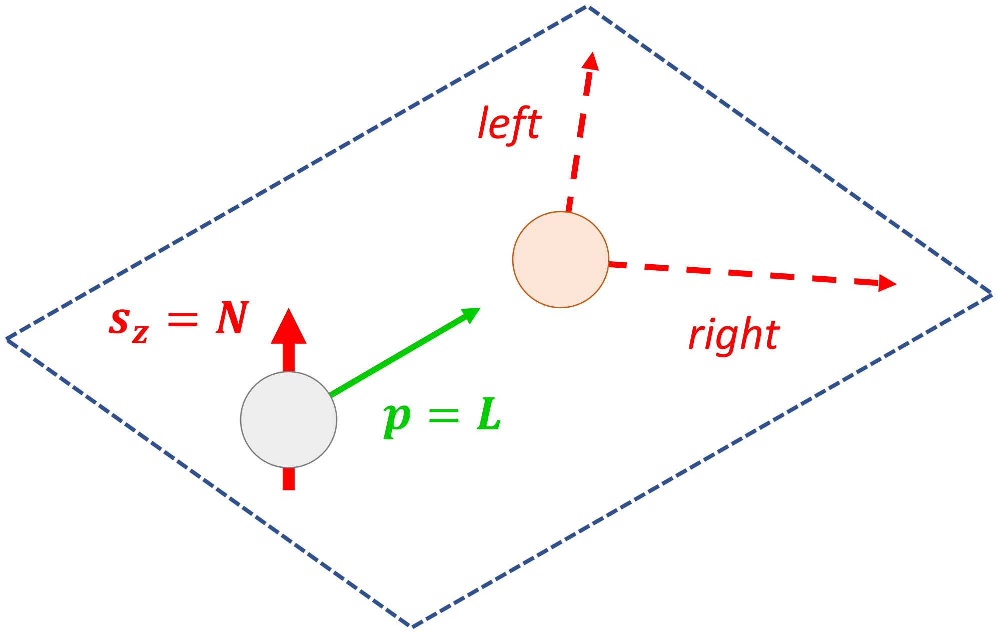
  Normal $\boldsymbol{N}$

  Sideways $\boldsymbol{S}$

$$\boldsymbol{S} = \boldsymbol{N} \times \boldsymbol{L}$$

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

refers to the projectile



Analyzing power A_N

Polarization $P = \frac{n^{\uparrow} - n^{\downarrow}}{n^{\uparrow} + n^{\downarrow}}$

The Full Picture

- Elastic scattering obeys parity conservation and time invariance.
- The collision is symmetric (in the center-of-mass frame), recoil and ejectile are indistinguishable.

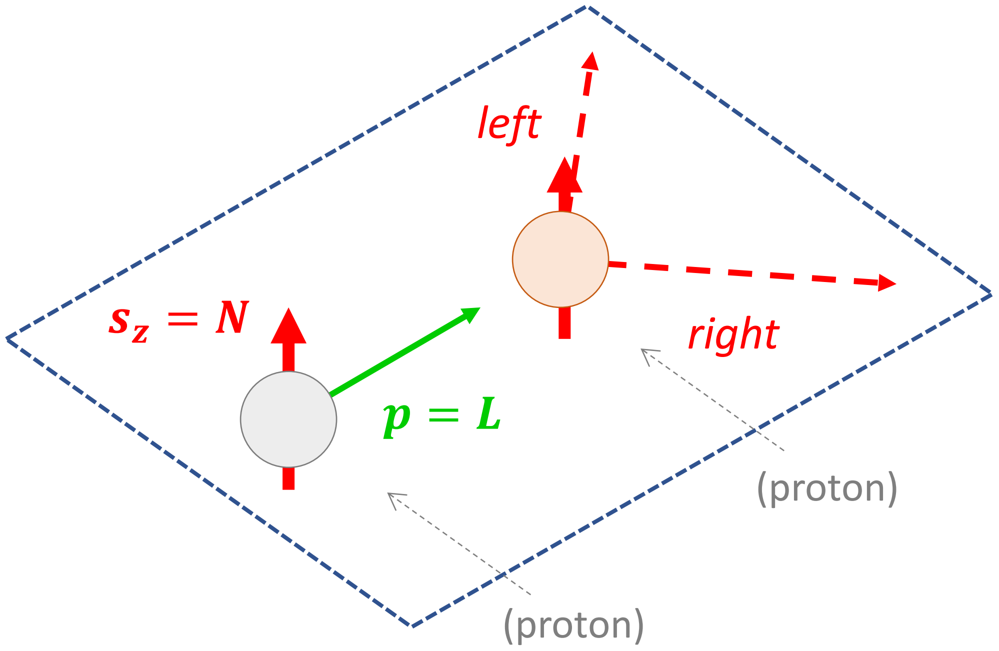
$$\rho_f = \boldsymbol{M}\rho_i\boldsymbol{M}^* \qquad \rho = \sum_n p_n \,|n\rangle\langle n| \qquad \boldsymbol{M} = \sum_{i,f} a_{f,i}\sigma_i \otimes \sigma_f$$

$$\rho_i = \rho_{beam} \otimes \rho_{target}$$

$$\frac{d\sigma}{d\Omega} = Tr(\rho_f) = \sum_n p_n \,|\langle n|\boldsymbol{M}|n\rangle|^2$$

$$\frac{d\sigma}{\mathrm{d}\Omega} = a_{0000} + \sum_n P_n a_{00n0} + \sum_m Q_m a_{000m} + \sum_{m,n} P_n Q_m a_{00nm} + \cdots$$

$$\frac{d\sigma}{\mathrm{d}\Omega} = \frac{d\sigma}{d\Omega_0}\left(1 + \sum_n P_n A_{00n0} + \sum_m Q_m A_{000m} + \sum_{m,n} P_n Q_m A_{00nm} + \cdots\right)$$



→ 4^4=256 possible Observables (25 independent parameters)

Transverse Single-Spin Asymmetries

- Elastic scattering obeys parity conservation and time invariance.
- The collision is symmetric (in the center-of-mass frame), recoil and ejectile are indistinguishable.

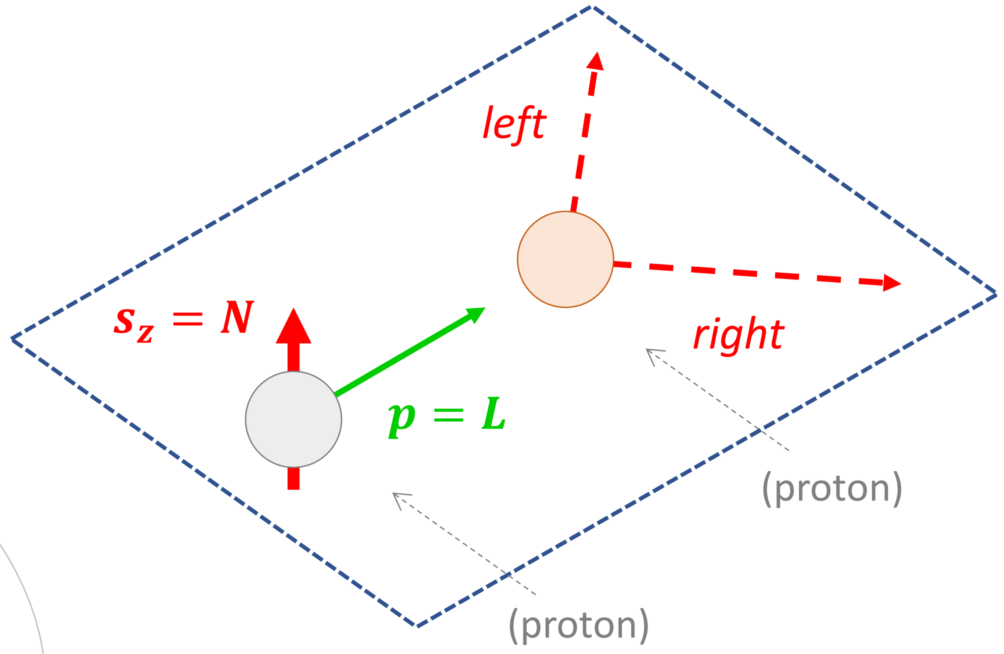
$$\frac{d\sigma}{\mathrm{d}\Omega} = \frac{d\sigma}{d\Omega_0}\left(1 + P_{beam}A_{00N0} + P_{target}A_{000N}\right)$$

ejectile, recoil, projectile, target

- For elastic scattering:

$$A_{00N0} = A_{000N}$$

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

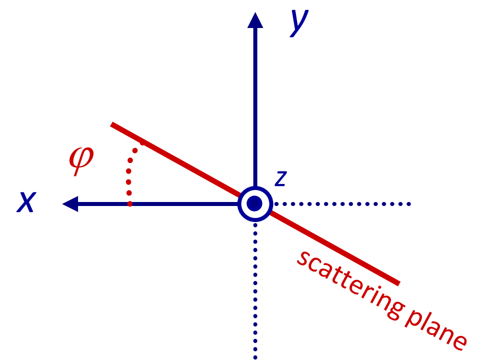


Remember, we just call this A_N

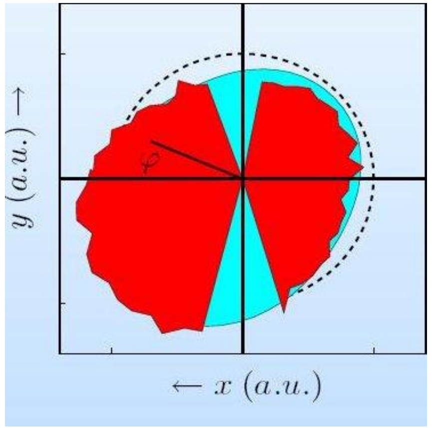
Transverse Single-Spin Asymmetries

- Transformation of $\boldsymbol{S} = \boldsymbol{N} \times \boldsymbol{L}$ into the laboratory frame

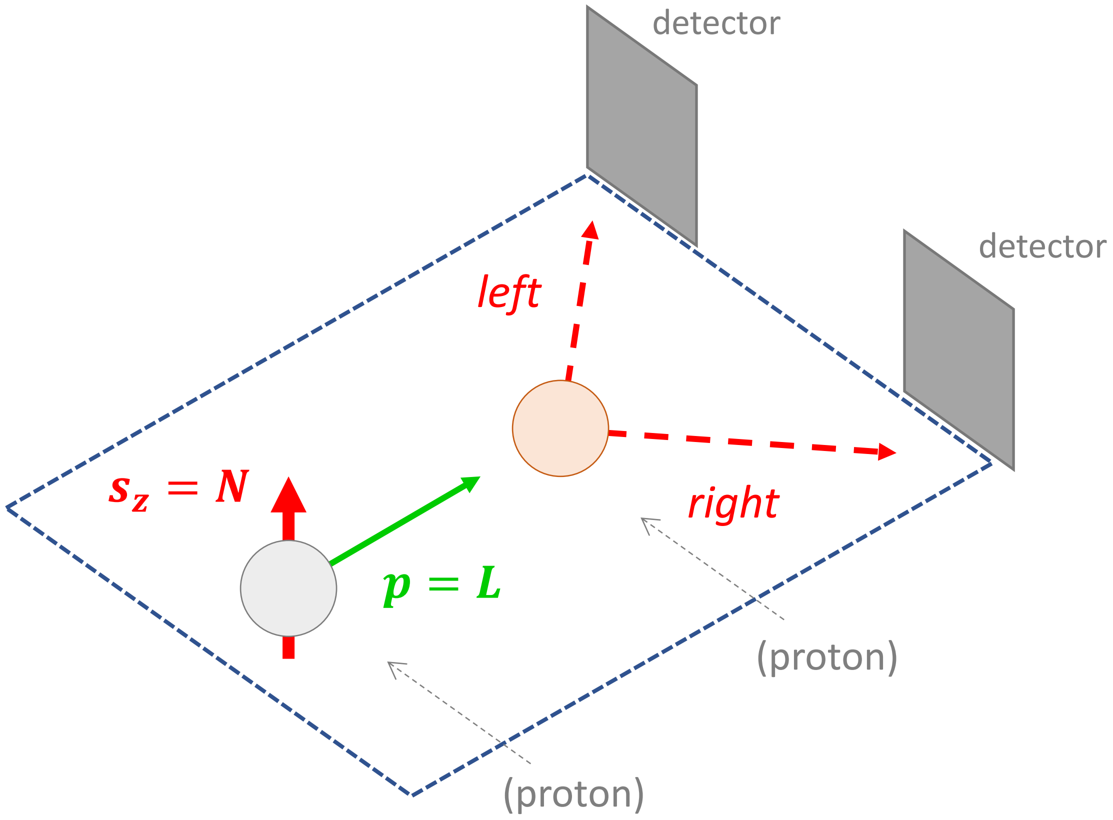
$$\frac{d\sigma}{\mathrm{d}\Omega} = \frac{d\sigma}{d\Omega_0}\,(1 + P \cdot A_N \cdot \cos\varphi)$$



$$P_N = -P_x \sin\varphi + P_y \cos\varphi$$
$$P_S = P_x \cos\varphi + P_y \sin\varphi$$
$$P_L = P_z$$

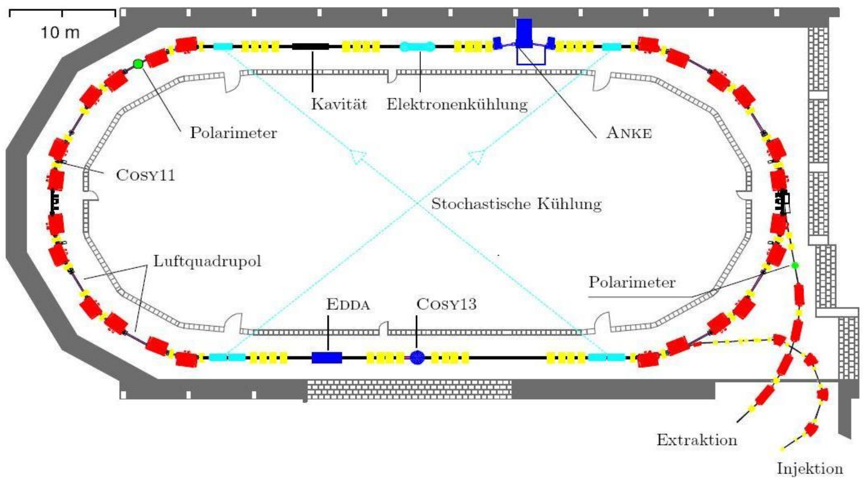


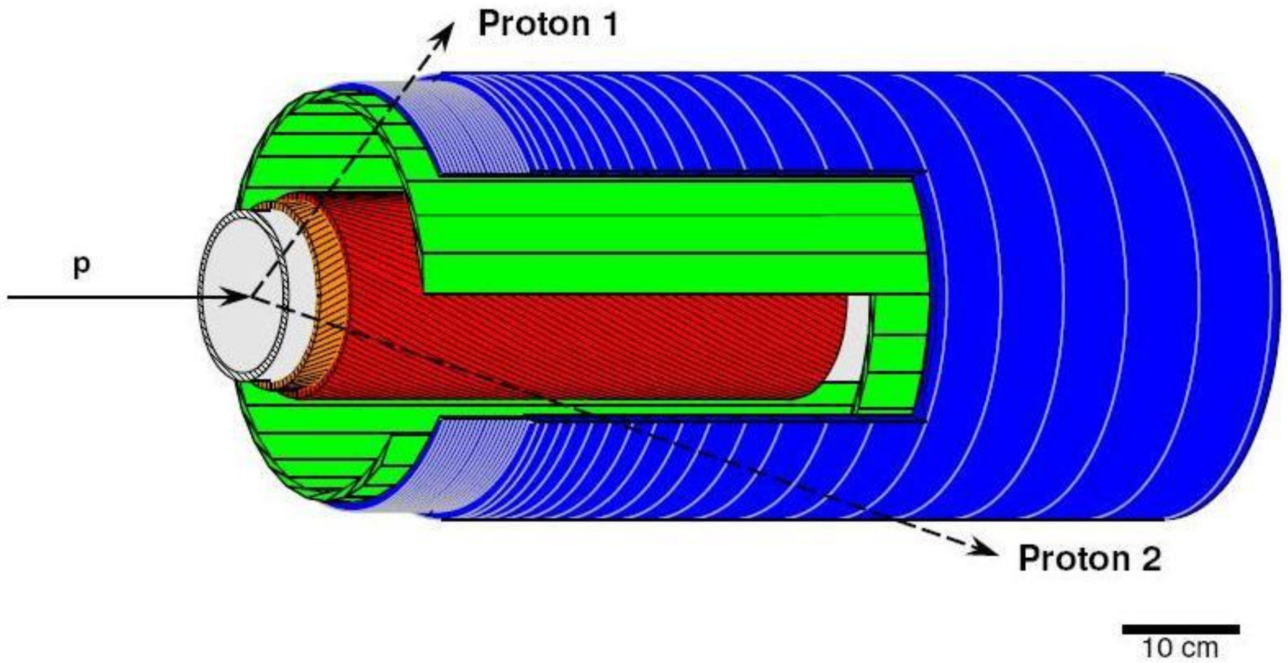
$$N = \int \frac{d\sigma}{d\Omega} \mathcal{L}_P(t) e(d\Omega, t) d\Omega dt$$



Elastic $p + p$ Scattering

- Example: EDDA @ COSY





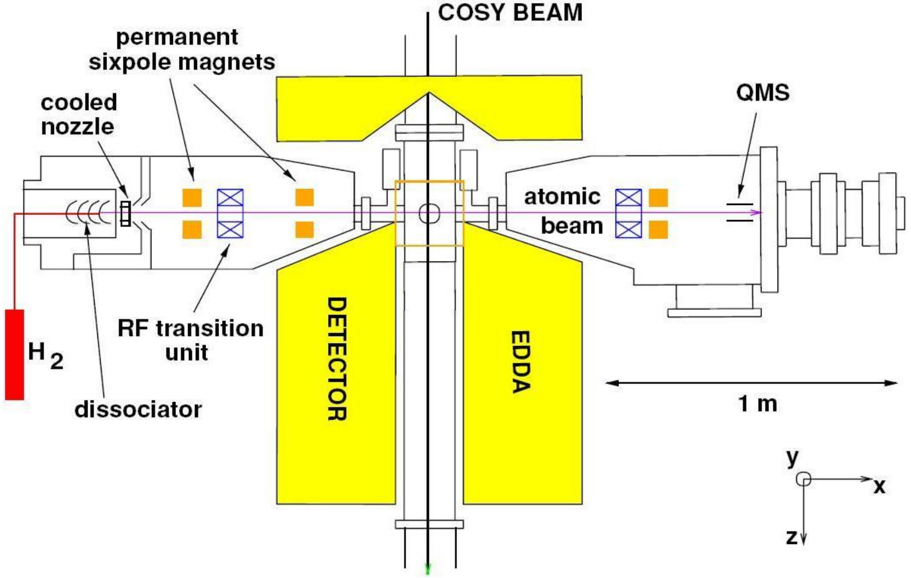
- Kinematic correlation in elastic scattering

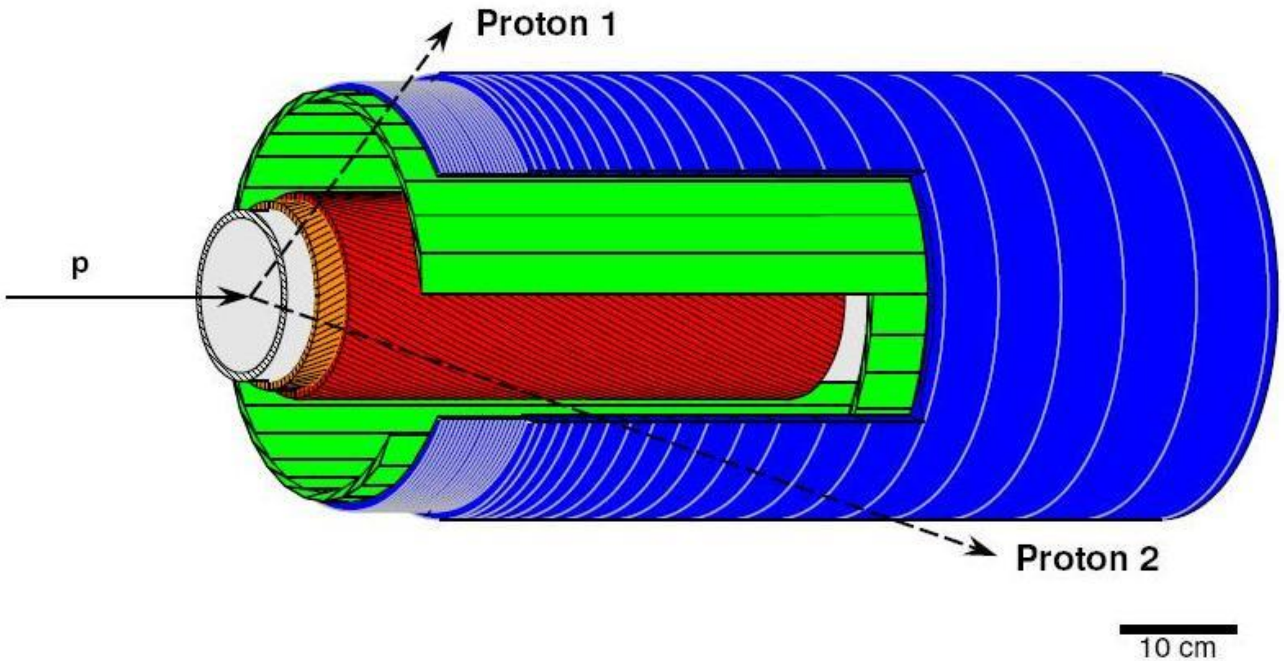
$$\varphi_1 - \varphi_2 = \pi$$
$$\tan\vartheta_1 \cdot \tan\vartheta_2 = 1/\gamma_{cm}^2$$

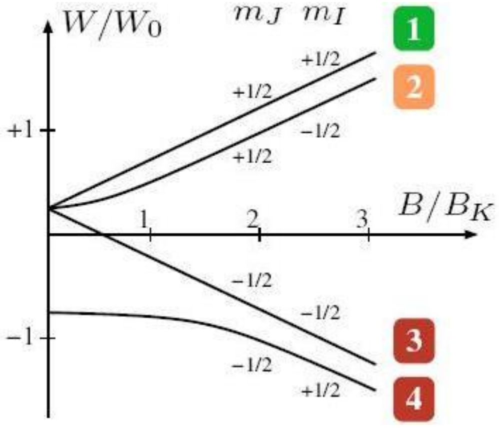
- EDDA detector
  - Scintillator hodoscope specifically designed for elastic $p + p$ scattering

Elastic $p + p$ Scattering

- Example: EDDA @ COSY







- Atomic hydrogen target
  - Selection of hyperfine state 1 (of 4)
  - Magnetic holding field $\mathrm{B_{x,y,z}} \approx 10\ \mathrm{G}$
  - Rabi unit for polarization measurement
  - Target polarization $Q \approx 70\%$

Elastic Scattering at RHIC energies

- The beam momentum is $100 - 250\ \mathrm{GeV}$.
- A significant analyzing power exists in the Coulomb-Nuclear Interference region.

$$\varphi(s,t) = \langle \lambda_C \lambda_D | \varphi | \lambda_A \lambda_B \rangle$$

$$\varphi_1(s,t) = \left\langle +\frac{1}{2} + \frac{1}{2} \middle| \varphi \middle| + \frac{1}{2} + \frac{1}{2} \right\rangle$$

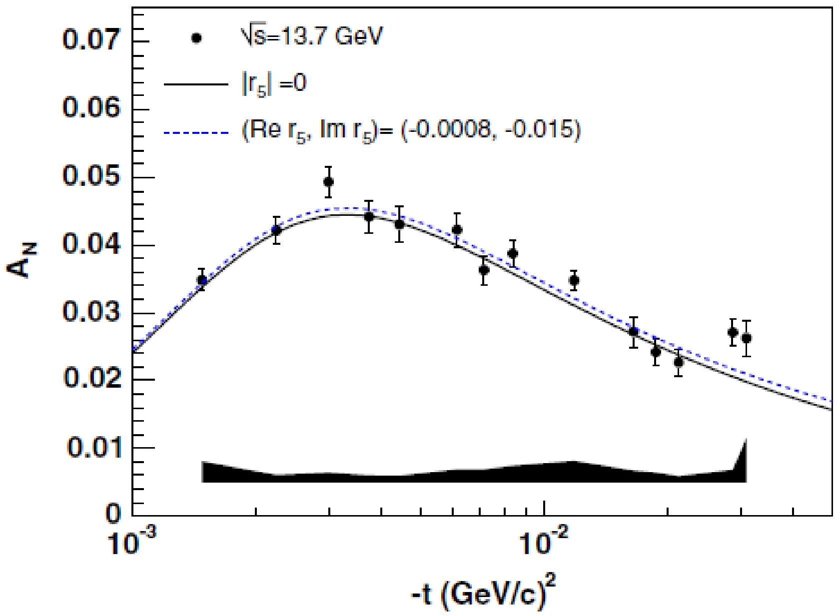
$$\varphi_2(s,t) = \left\langle +\frac{1}{2} + \frac{1}{2} \middle| \varphi \middle| - \frac{1}{2} - \frac{1}{2} \right\rangle$$

$$\varphi_3(s,t) = \left\langle +\frac{1}{2} - \frac{1}{2} \middle| \varphi \middle| + \frac{1}{2} - \frac{1}{2} \right\rangle$$

$$\varphi_4(s,t) = \left\langle +\frac{1}{2} - \frac{1}{2} \middle| \varphi \middle| - \frac{1}{2} + \frac{1}{2} \right\rangle$$

$$\varphi_5(s,t) = \left\langle +\frac{1}{2} + \frac{1}{2} \middle| \varphi \middle| + \frac{1}{2} - \frac{1}{2} \right\rangle$$

Phys. Lett. B638 (2006) 450

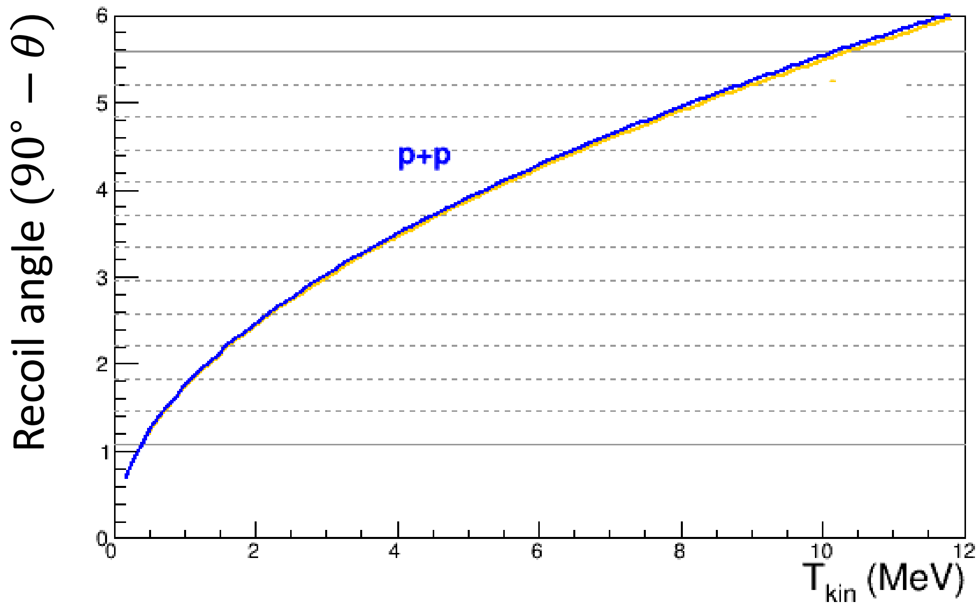


$$A_N \frac{ds}{dt} = -\frac{4\pi}{s^2} \mathrm{Im}\left[\varphi_5^{em*}(s,t)\varphi_+^{had}(s,t) + \varphi_5^{had*}(s,t)\varphi_+^{em}(s,t)\right]$$

no-flip amplitude: $\varphi_+(s,t) = \frac{1}{2}[\varphi_1(s,t) + \varphi_3(s,t)]$

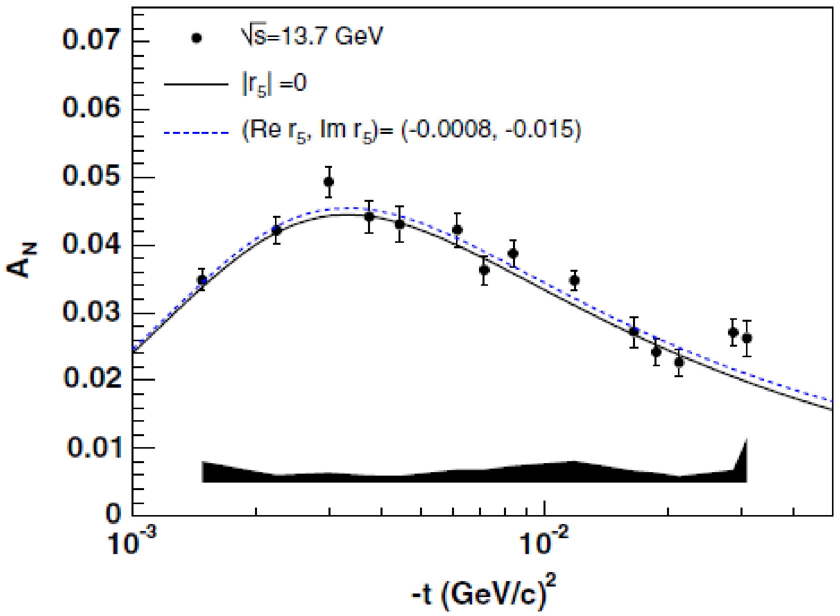
Elastic Scattering at RHIC energies

- The beam momentum is $100 - 250\ \mathrm{GeV}$.
- A significant analyzing power exists in the Coulomb-Nuclear Interference region.
- Recoil comes out almost perpendicular to the beam direction.

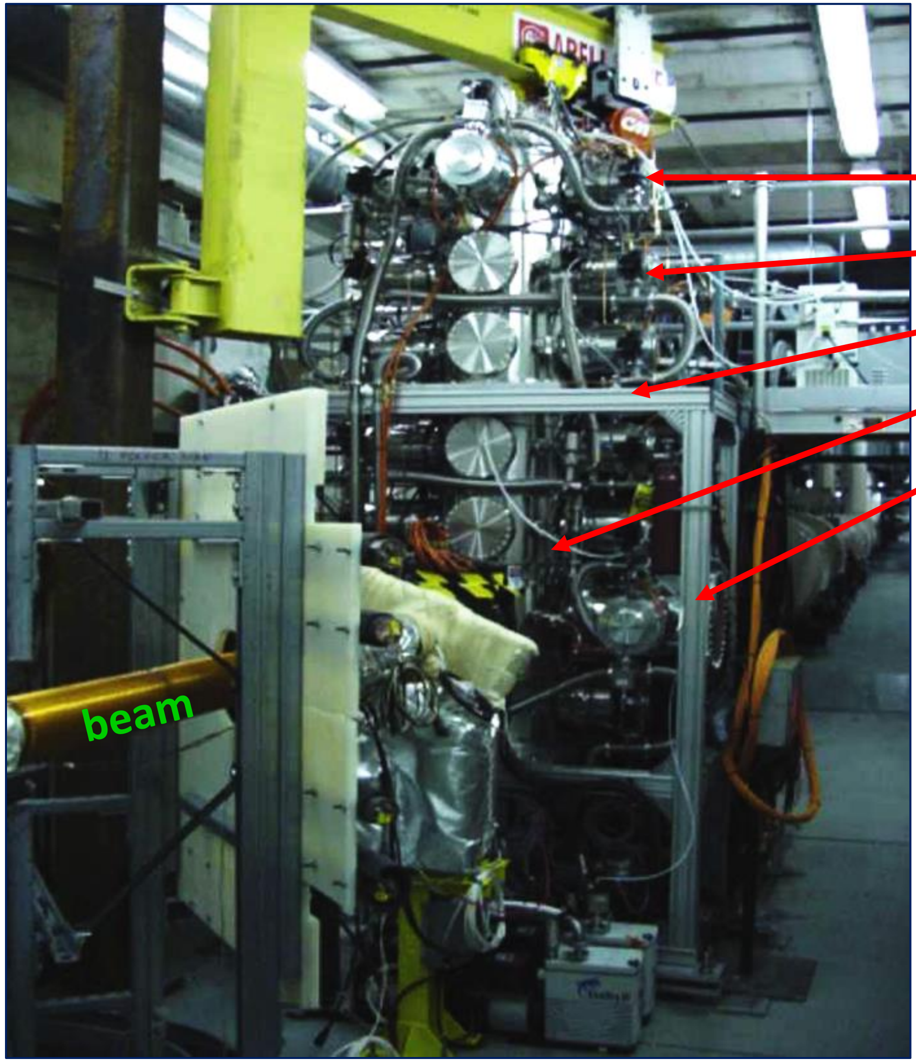


Kinetic energy of the recoil proton

A. Poblaguev et al., Phys. Rev. D 79, 094014 (2009)

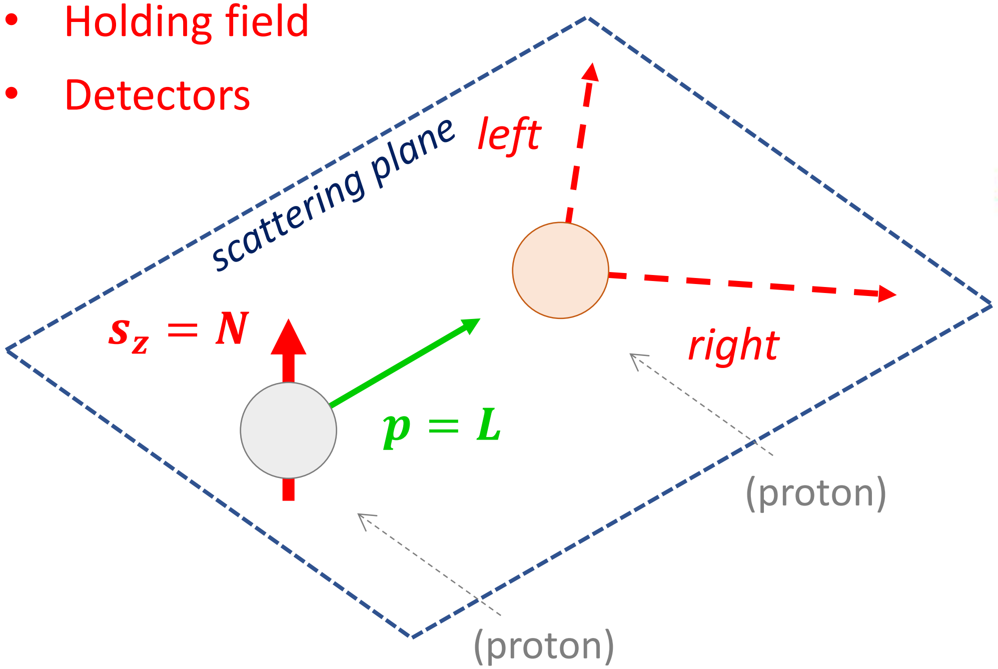


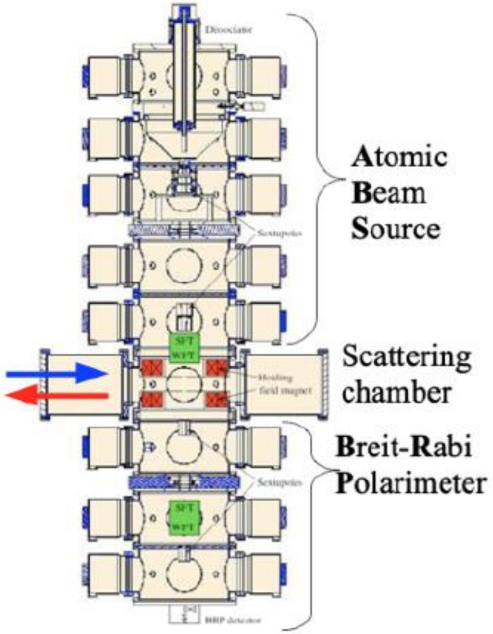
An Absolute Polarimeter at RHIC / EIC



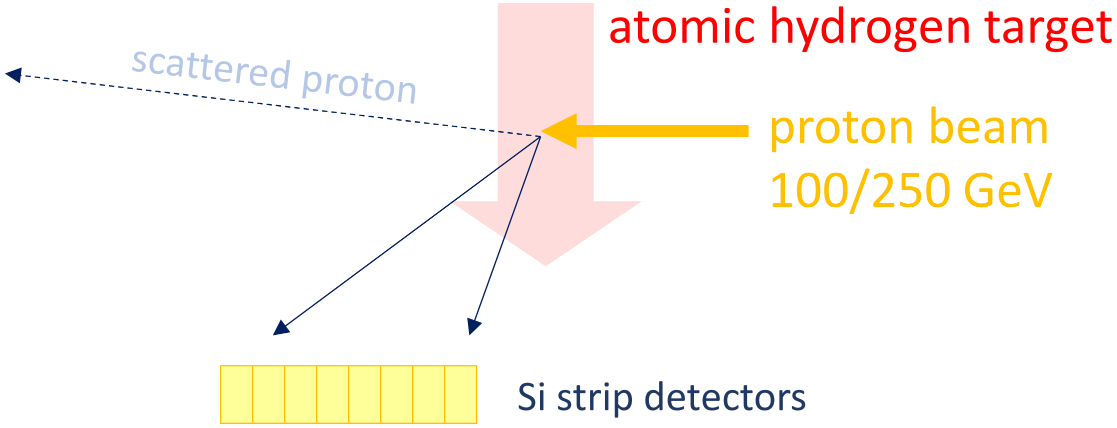
- Polarized atomic hydrogen jet target (HJET)

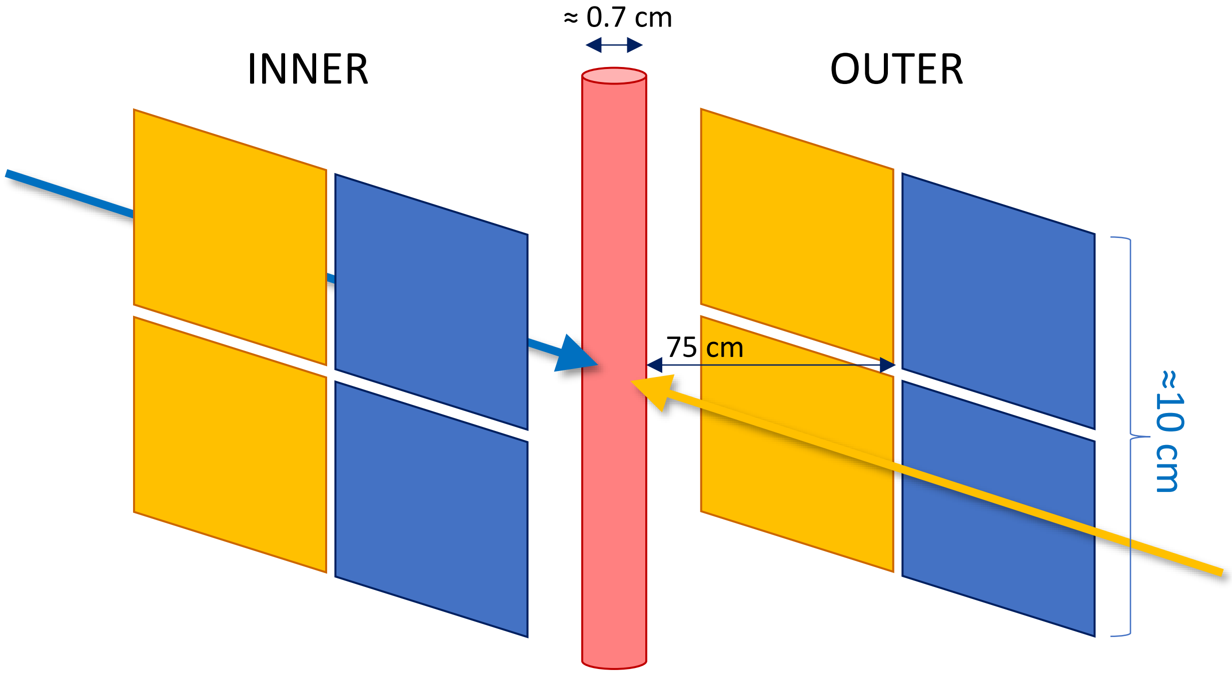
- H_2 source
- Dissociator
- RF unit
- Holding field
- Detectors



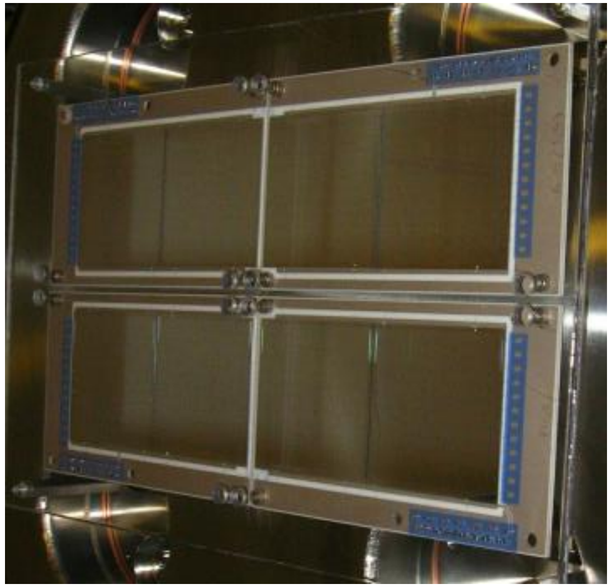


HJET Setup for RHIC / EIC

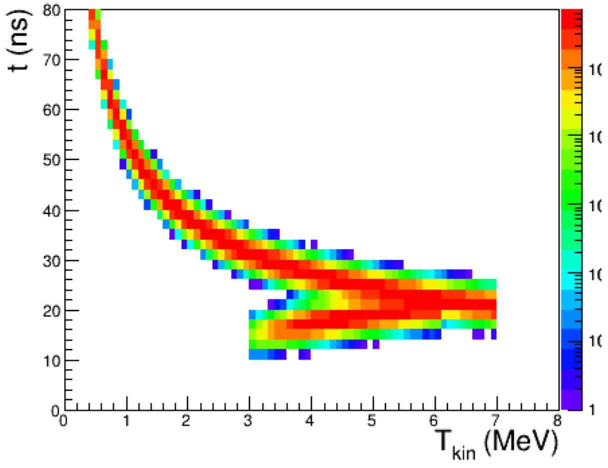




- Polarized atomic hydrogen jet target
- Set of eight Hamamatsu Si strip detectors
- 12 vertical strips
  - 3.75 mm pitch
  - 500 μm thick
- Uniform dead layer ≈ 1.5 μm



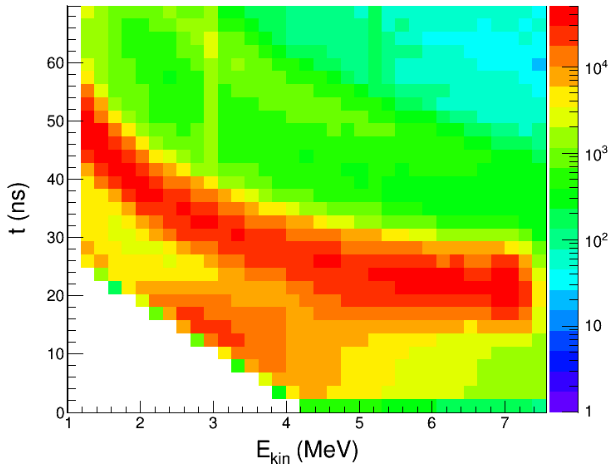
Proton Recoil Measurement



Expected elastic signal

Simple toy simulation with bunch length 3 ns

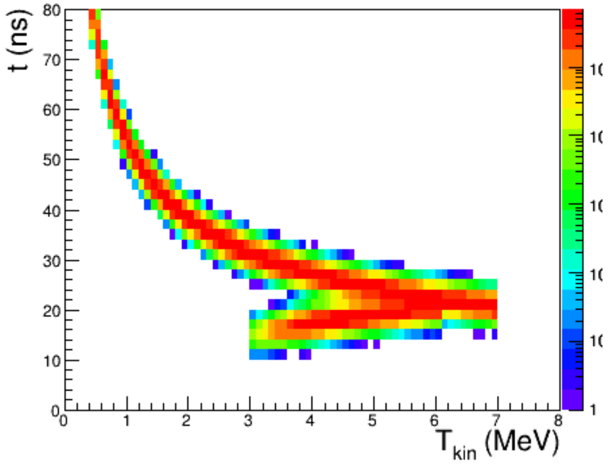
Non-relativistic: $T_{kin} = \frac{1}{2}mv^2$ → Time of flight is used for particle identification

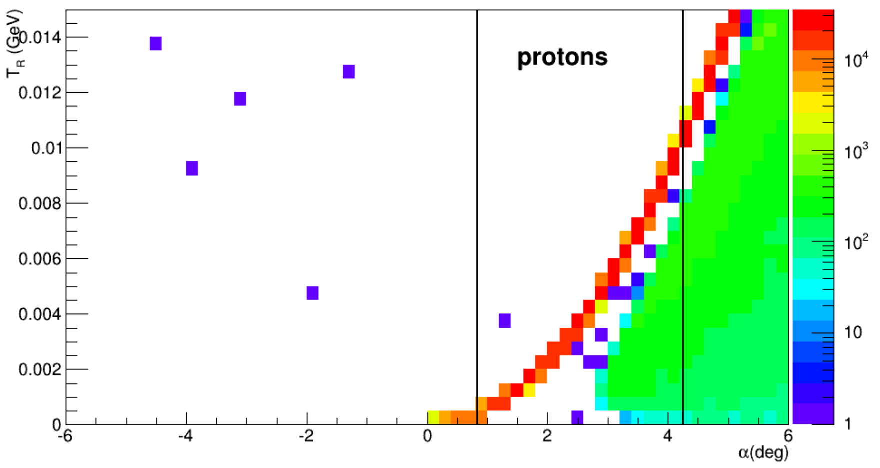


Real measurement

Already includes some basic cuts (low E, low t)

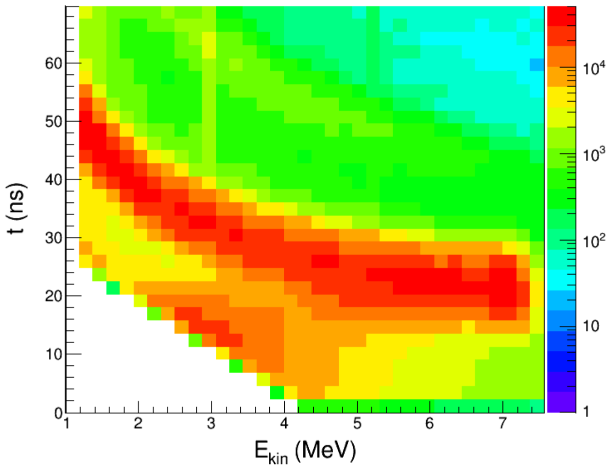
Proton Recoil Measurement

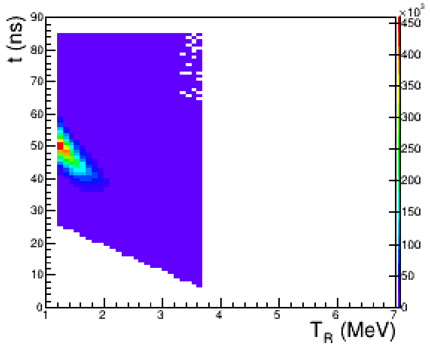


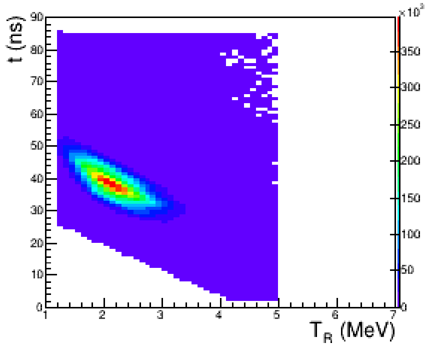


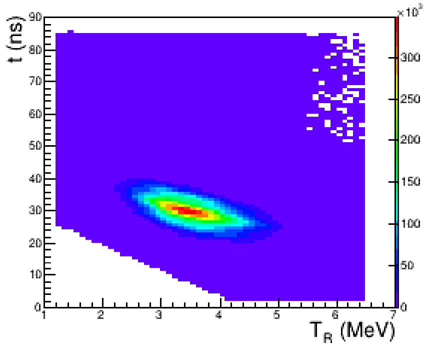
Time of flight is used for particle identification

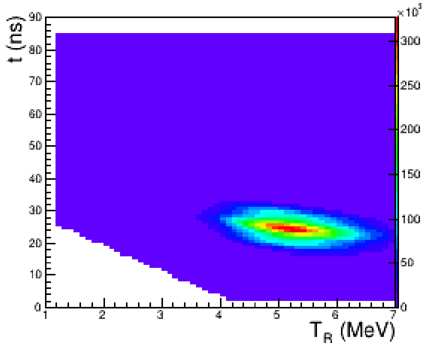
Recoil angle is used for kinematic correlation in elastic scattering











Absolute Beam Polarization

$$\varepsilon = A_N \cdot P$$

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

1

Polarization independent background

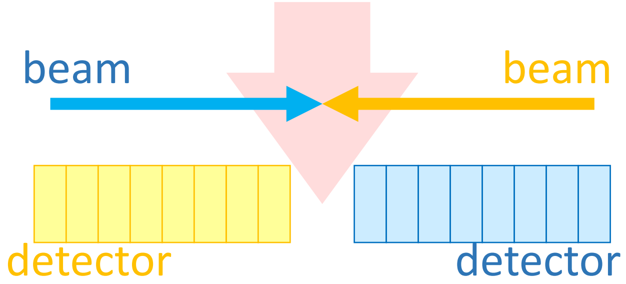
$$\varepsilon = \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow} + 2 \cdot N_{bg}} \Rightarrow \frac{\varepsilon_B}{\varepsilon_T} = \frac{N_B^{\uparrow} - N_B^{\downarrow}}{N_T^{\uparrow} - N_T^{\downarrow}}$$

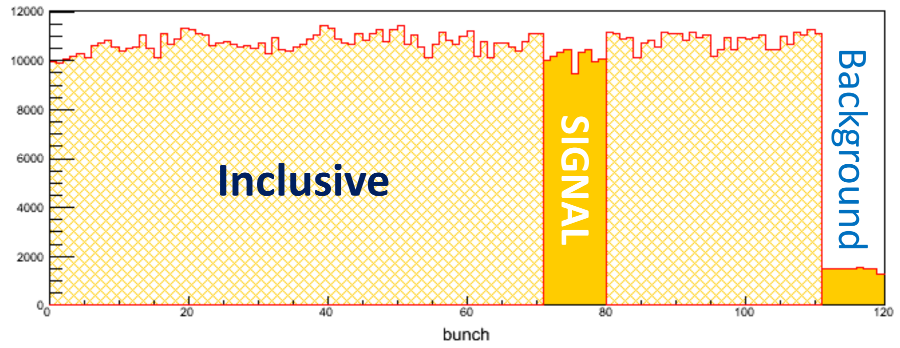
2

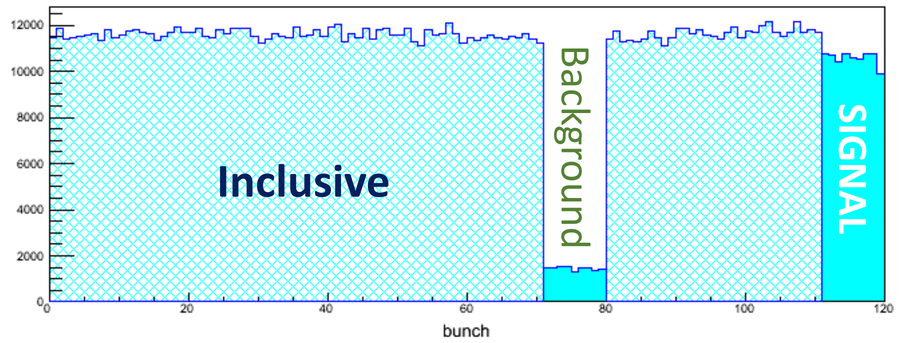
Polarization dependent background

$$\varepsilon = \frac{\varepsilon_{inc} - r \cdot \varepsilon_{bg}}{1 - r}$$

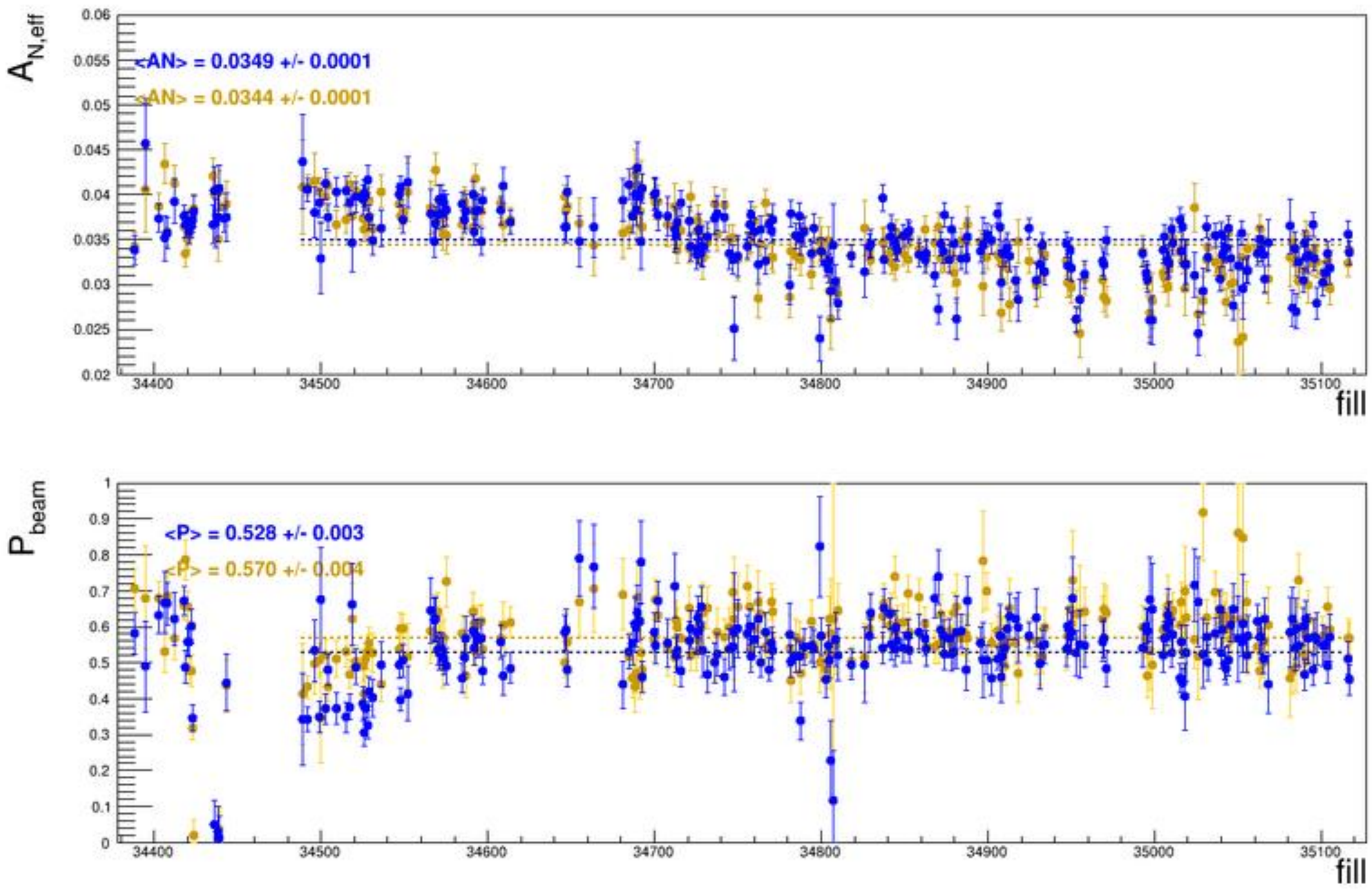
background fraction $r = N_{bg}/N$



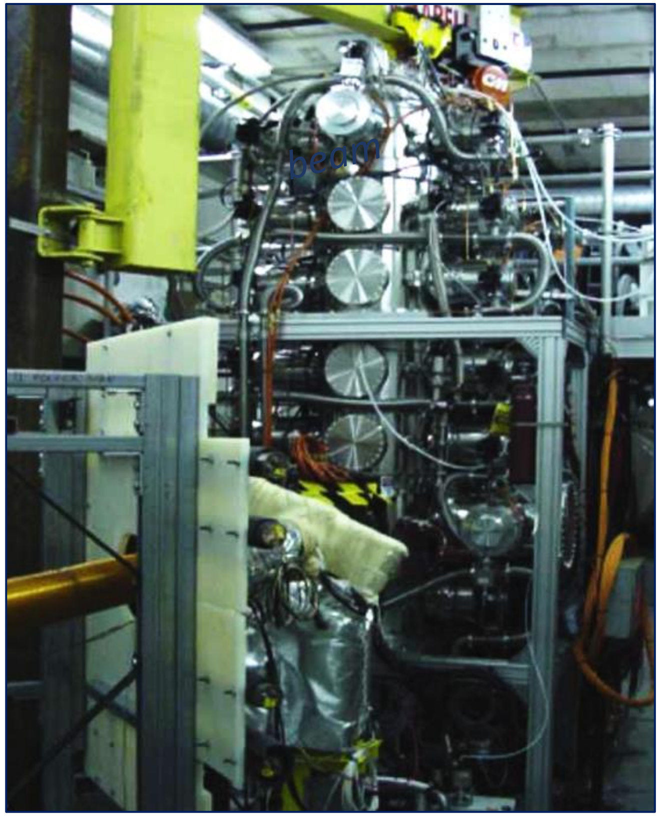




Measured Beam Polarizations



Additional Fast Polarimeters



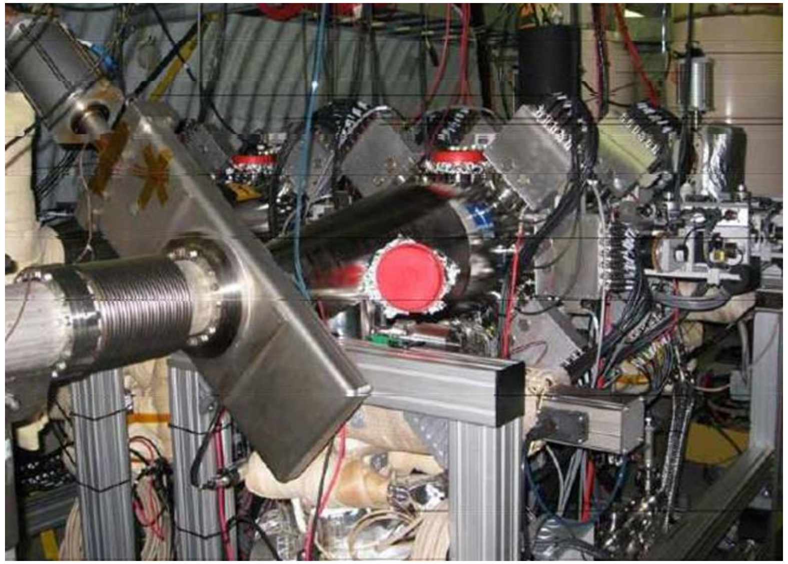
From our list of requirements:

Time-dependence (polarization decay)

Bunch-by-bunch polarization

Transverse polarization profile of bunches

Also has to be non-destructive!



Hydrogen jet polarimeter

Polarized target

Continuous operation

$\delta P/P \approx 5-6\%$ per 8 hours of operation

normalization →

Carbon polarimeters

Fast measurement

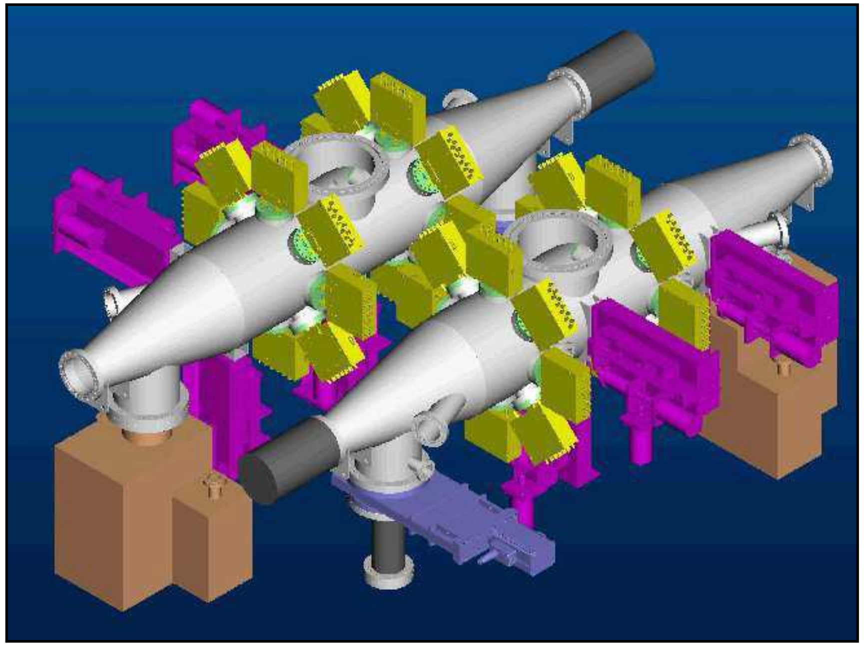
$\delta P/P \approx 4\%$

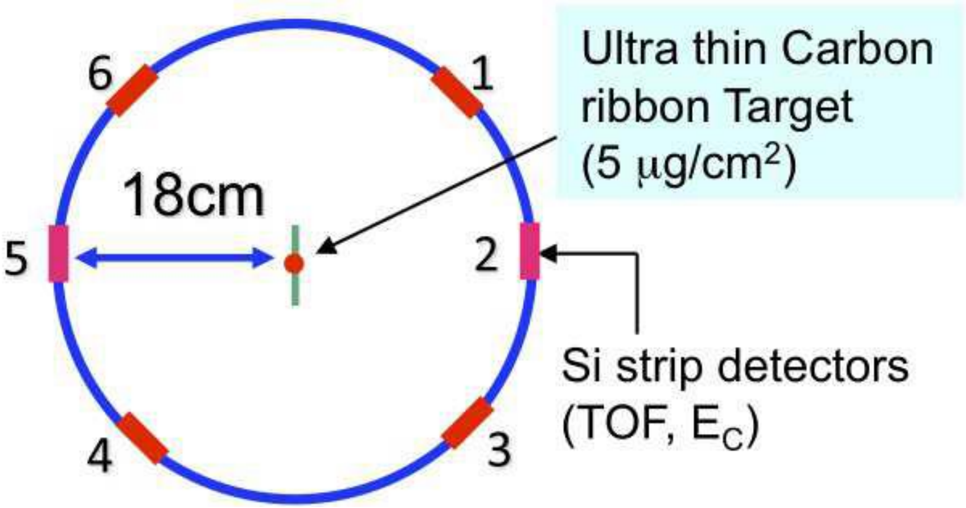
Beam polarization profile

Bunch-by-bunch

Polarization decay (time dependence)

Fiber Target Polarimeters

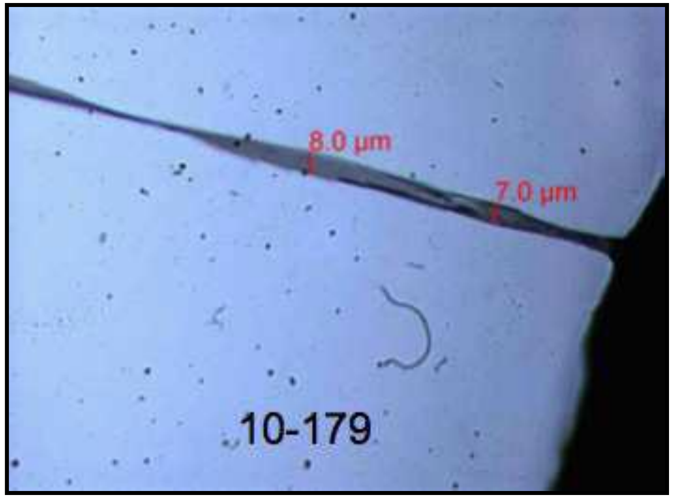


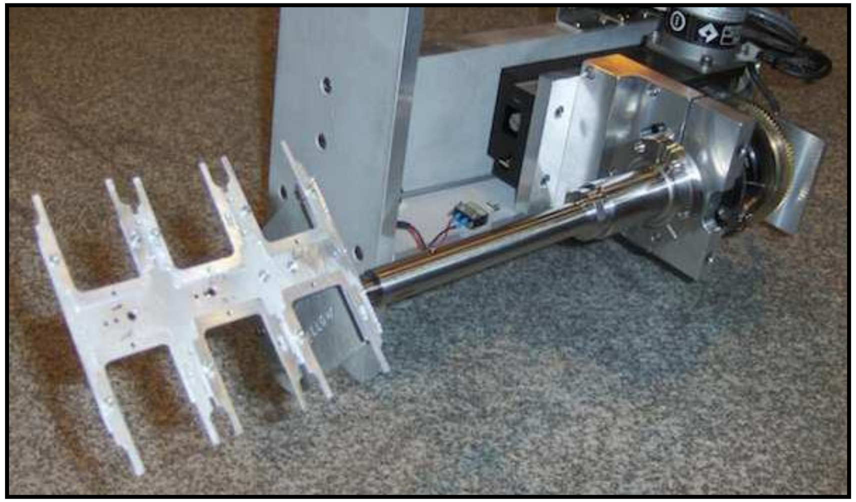


- Ultra-thin ribbon targets:

  $$\approx 10\ \mu m\ x\ 100\ \mathrm{nm}$$

- Target holder inside the beam pipe





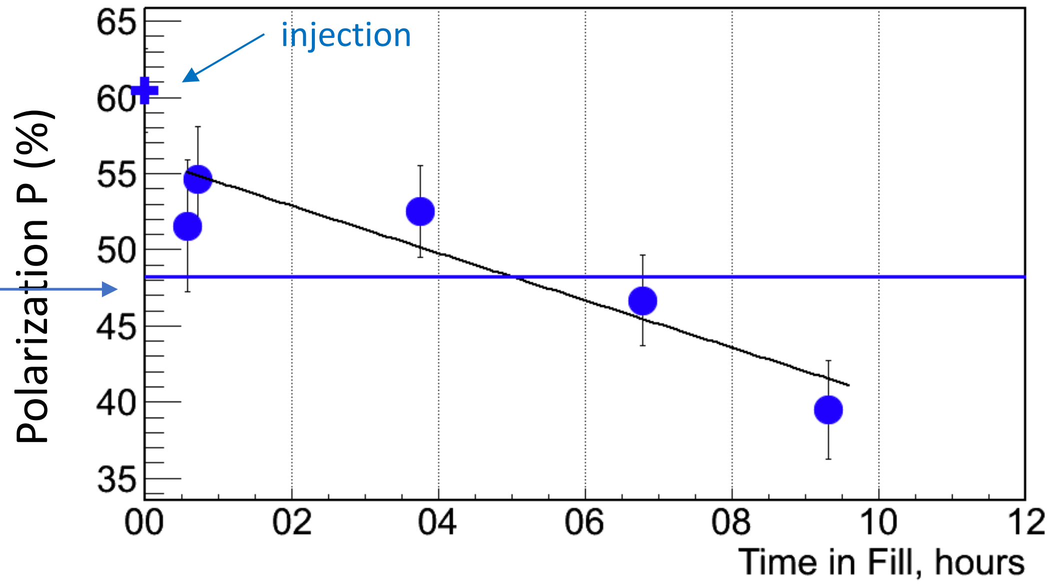
Polarization Decay

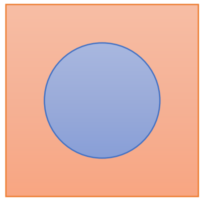
Polarization losses during the store are correlated to

- acceleration
- emittance
- profile

$$P = P_0 + \frac{dP}{dt} t$$

normalization with HJET





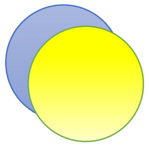
$$P_{jet} = \frac{\int dxdyP(t)I_B(t)}{\int dxdyI_B(t)}$$

Polarization Decay

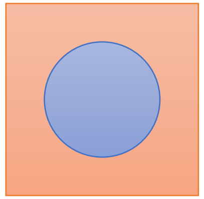
Polarization losses during the store are correlated to

- acceleration
- emittance
- profile

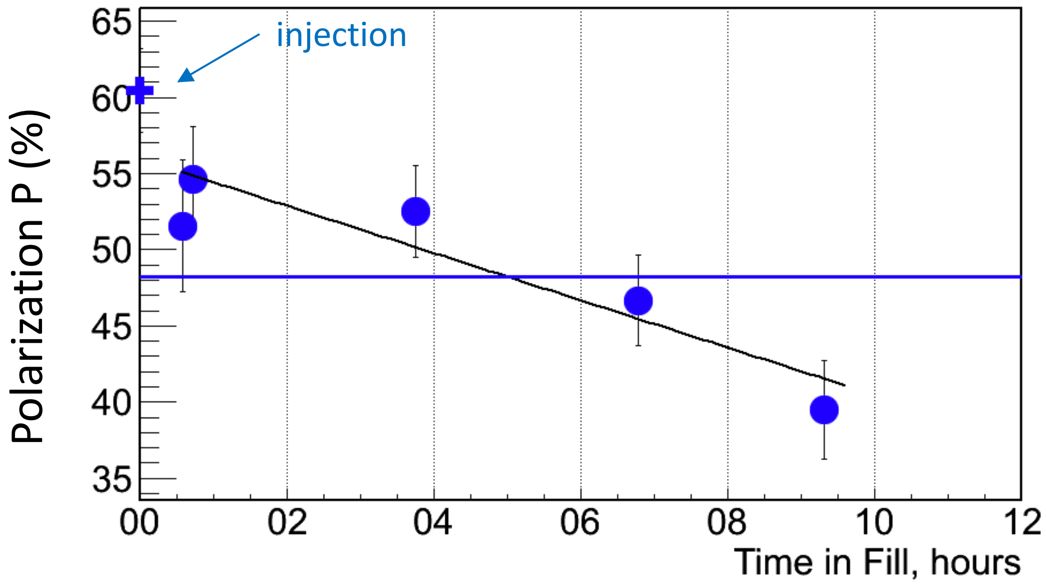
$$P = P_0 + \frac{dP}{dt}t$$



$$P_{coll} = \frac{\int dxdyP(t)I_B(t)I_Y(t)}{\int dxdyI_B(t)I_Y(t)}$$



$$P_{jet} = \frac{\int dxdyP(t)I_B(t)}{\int dxdyI_B(t)}$$



Important for experiments:

Luminosity changes throughout each store

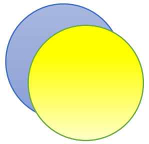
Polarization Profile

Polarization losses during the store are correlated to

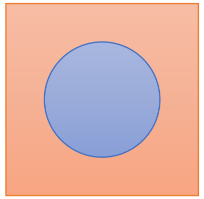
- acceleration
- emittance
- profile

$$P = P_0 + \frac{dP}{dt}t$$

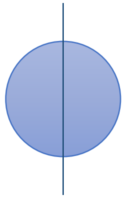
$$\mathrm{R} = R_0 + \frac{dR}{dt}t$$



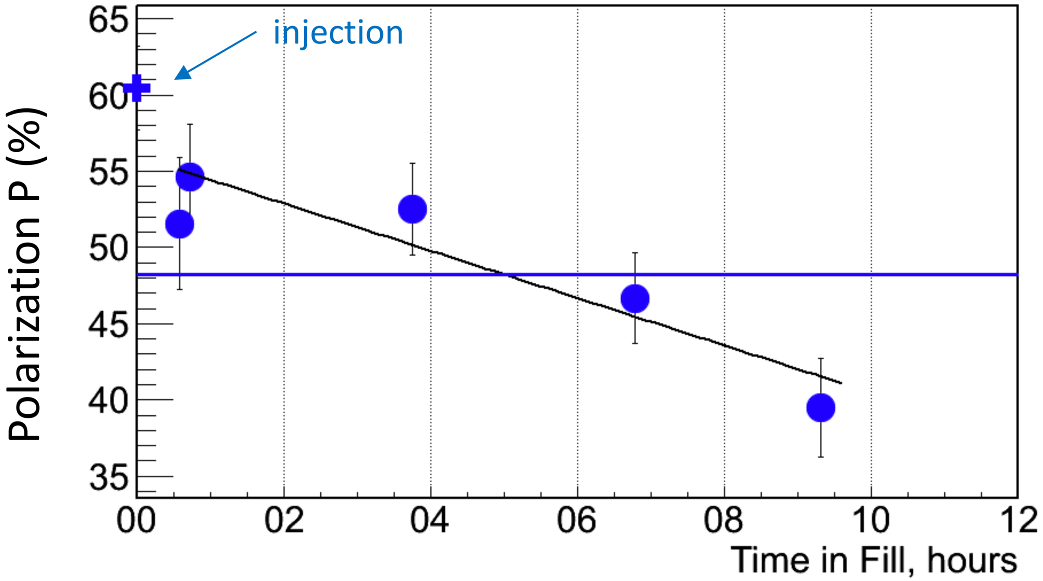
$$P_{coll} = \frac{\int dxdyP(x,y)I_B(x,y)I_Y(x,y)}{\int dxdyI_B(x,y)I_Y(x,y)}$$

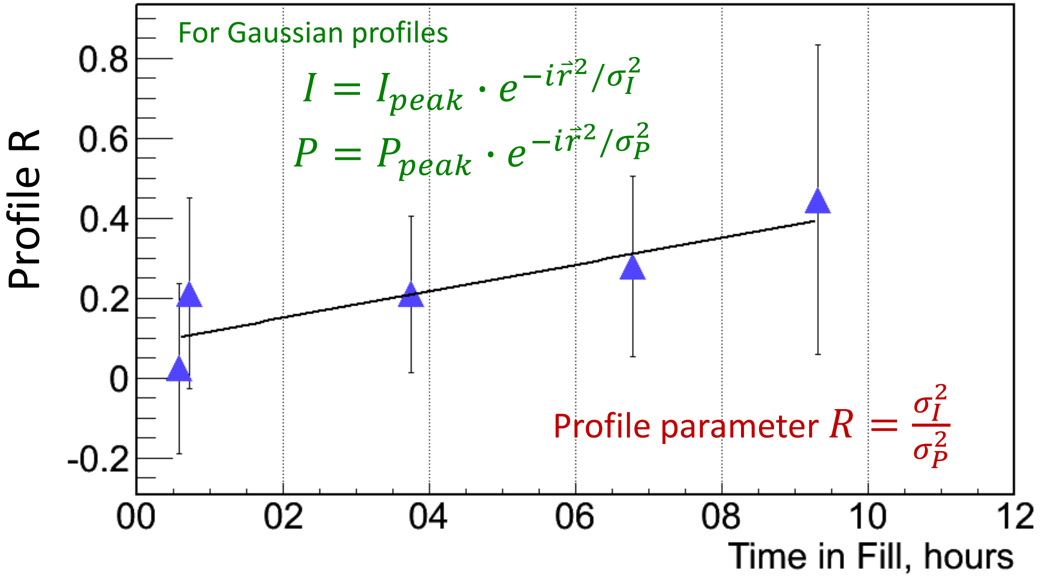


$$P_{jet} = \frac{\int dxdyP(x,y)I_B(x,y)}{\int dxdyI_B(x,y)}$$



$$P_{sweep} = \frac{\int dyP(y)I_B(y)}{\int dyI_B(y)}$$





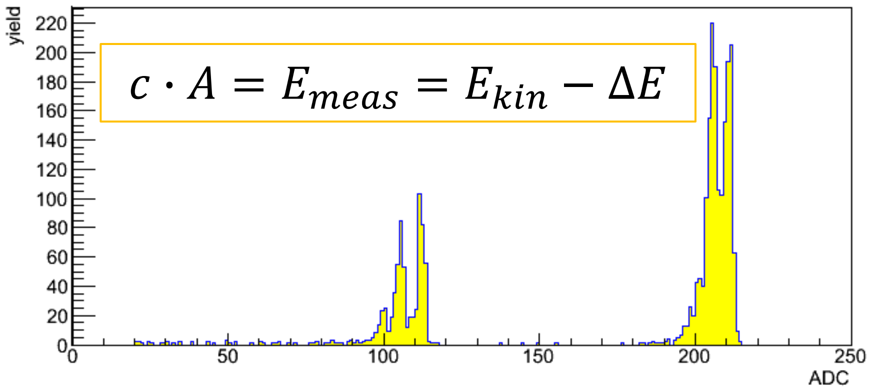
Limitations of the Measurement

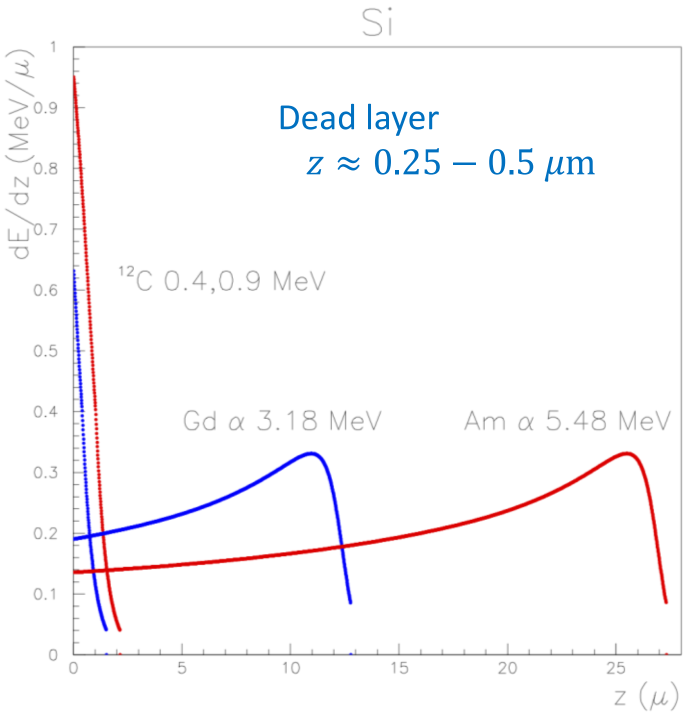
- Recoil particles have very low energy.
  - significant impact of the inactive detector parts (dead layer ΔE), especially for the Carbon measurement
  - Calibration with α-sources

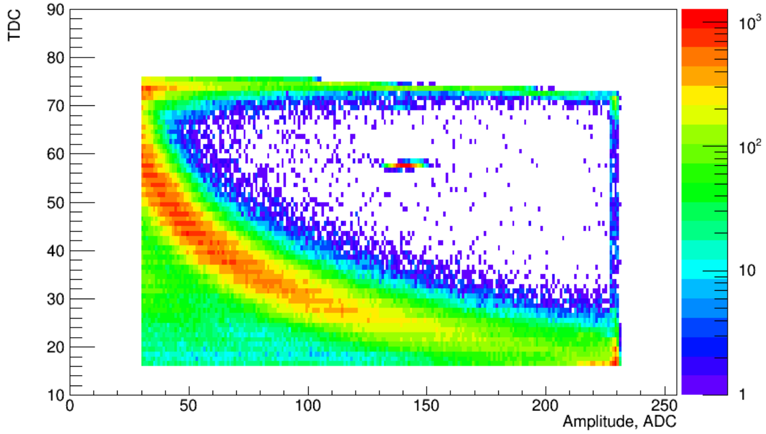
$$^{148}Gd(E_\alpha = 3.183 \text{ MeV})$$

$$^{243}Am(E_\alpha = 5.486 \text{ MeV})$$

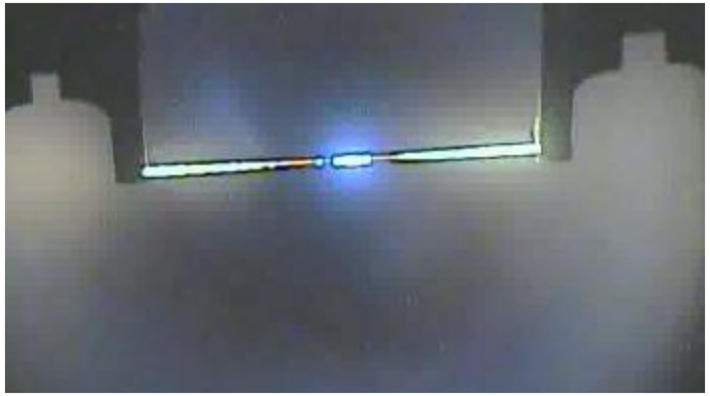
- Small angle scattering of recoil inside the target dilutes the kinematic correlation for elastic scattering.
  - Background dilutes the measured asymmetry (increases statistical uncertainty), but normalized with HJET
  - A_N drops above 1 MeV

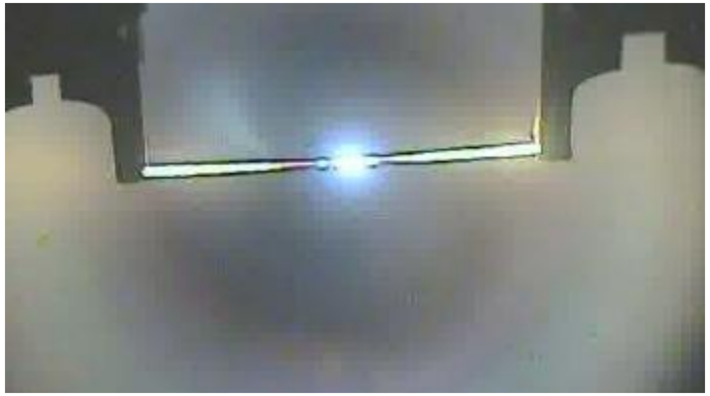


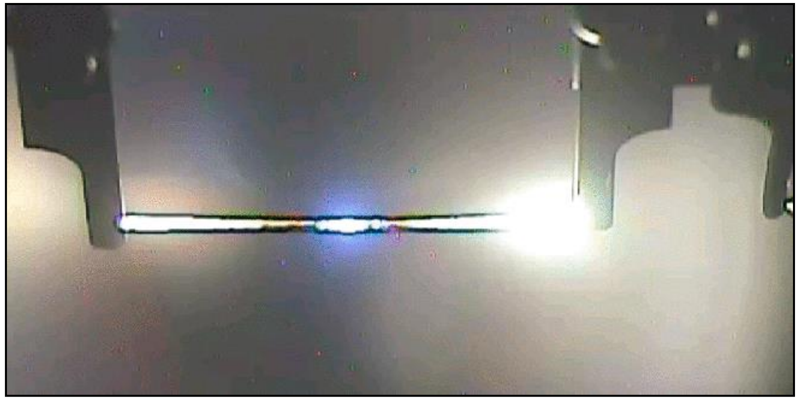




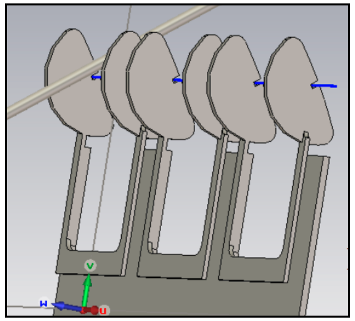
Target Lifetime

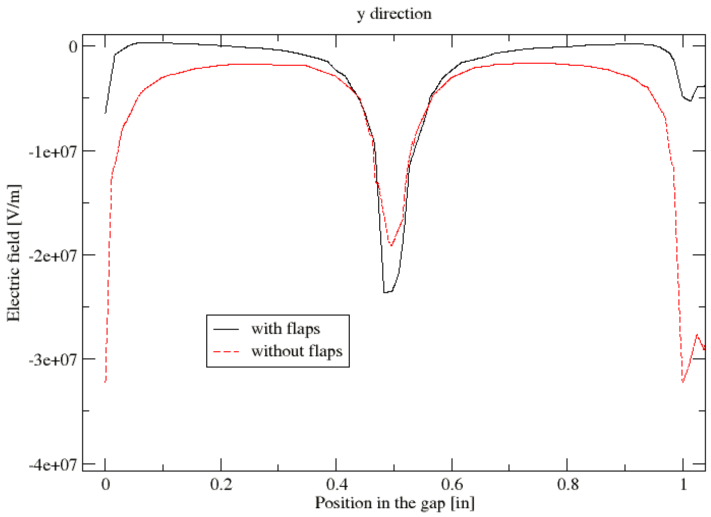






- High energy, high intensity proton beams provide an extreme environment
  - Energy loss of beam in the target
- Target is electrostatically attracted to the beam
  - Mechanical stress on target
  - Material in beam is hard to control
- Induced charge from wake field on target ends
  - Change to insulated ladder construction
- Targets have a limited lifetime

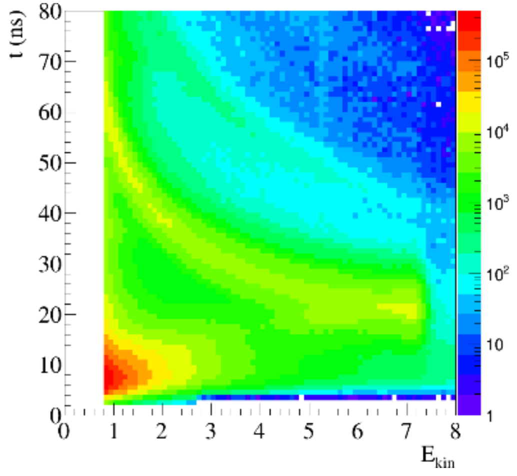




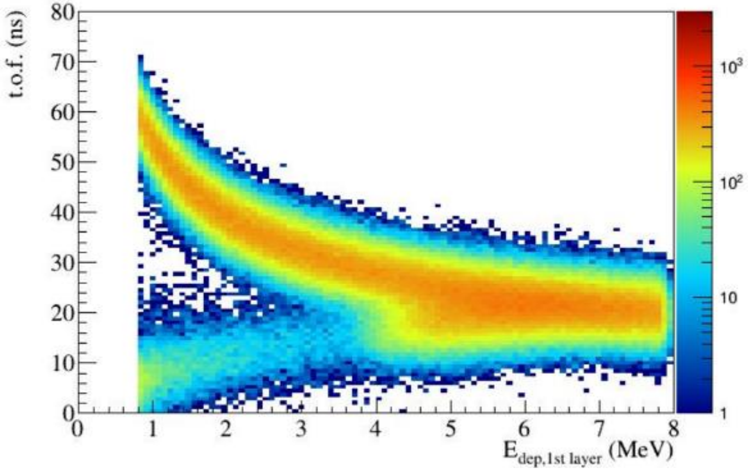
Simulation by J. Kewisch, BNL

From RHIC…

RHIC Data



Simulation (PYTHIA+GEANT4)



- Reasonable description in simulation
- More background in real data
- Punch-through particles only leave fraction of their energy in detector

↕ Bunch length

↔ Detector resolution

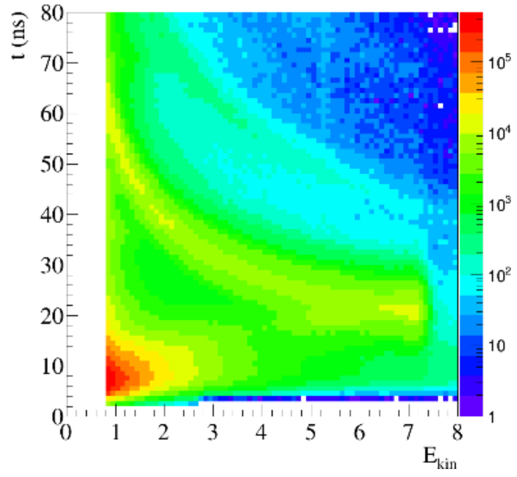
120 bunches

Bunch spacing 106 ns

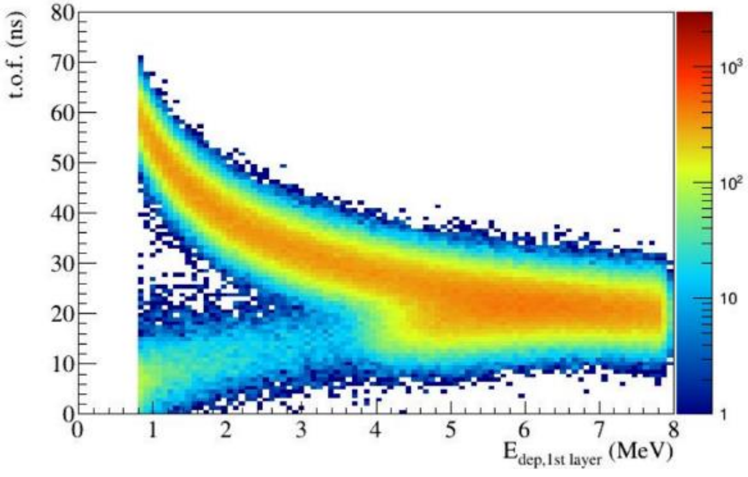
Bunch length 3.5 ns

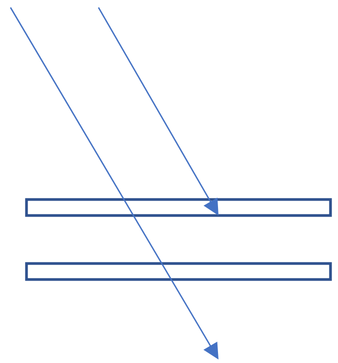
From RHIC to EIC

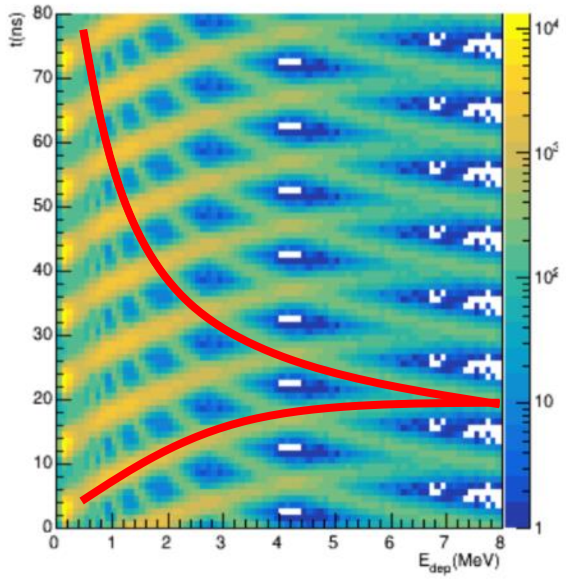
RHIC Data

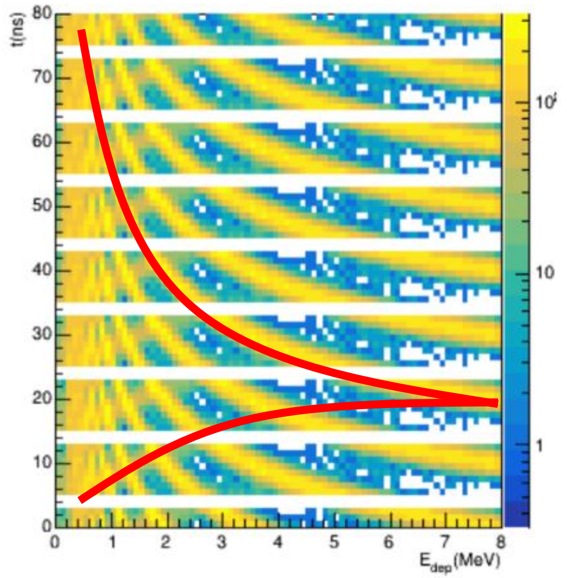


Simulation (PYTHIA+GEANT4)









Bunch length

Detector resolution

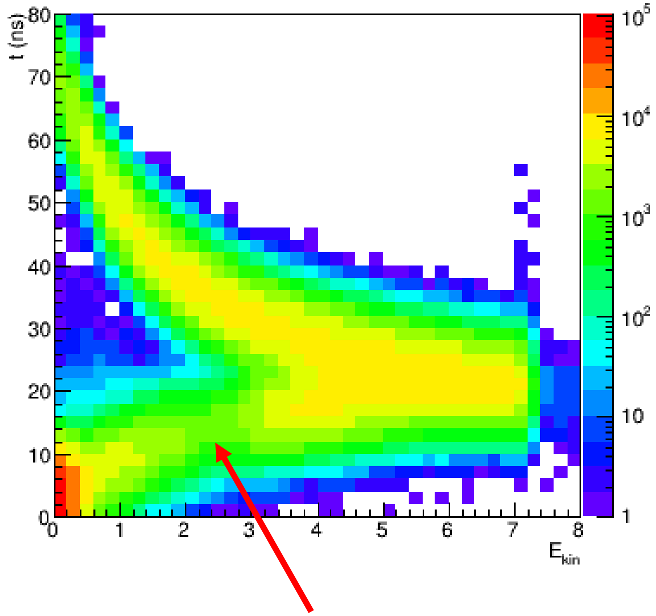
120 bunches → 1320 bunches

Bunch spacing 106 ns → 9.6 ns

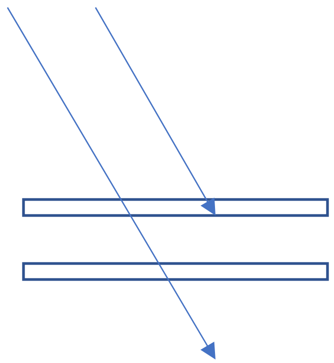
Bunch length 3.5 ns → 0.2 ns

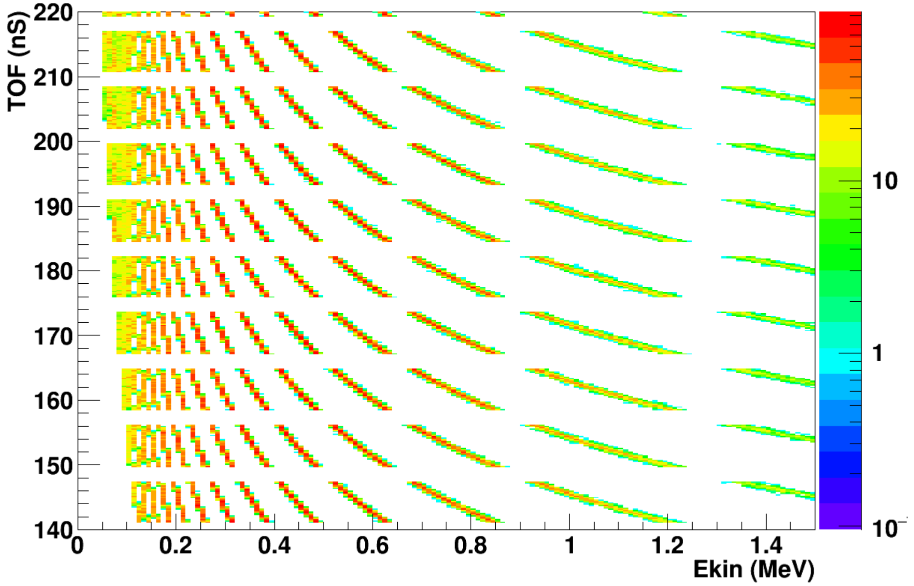
From RHIC to EIC

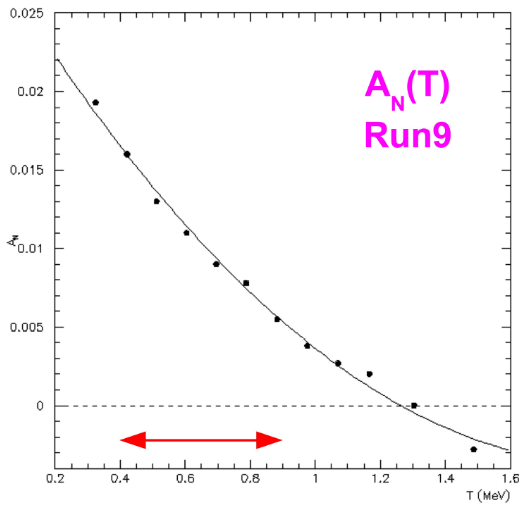
- Loss of increased asymmetry at lower energies, $A_N(-t)$
- Reduced bunch spacing requires much better understanding of background
  - Polarized or unpolarized
  - Better: reject/suppress background
  - Second detector layer to veto high energy particles



Punch through region

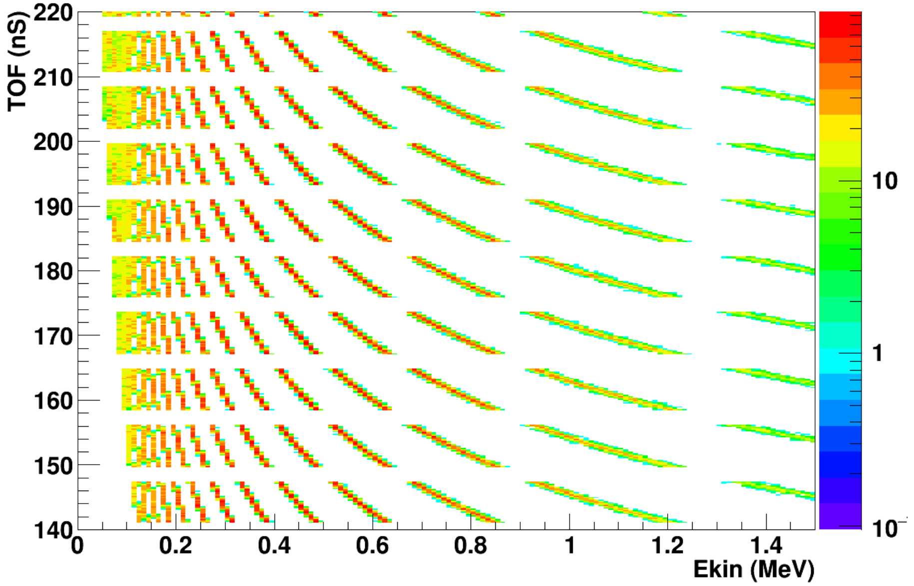


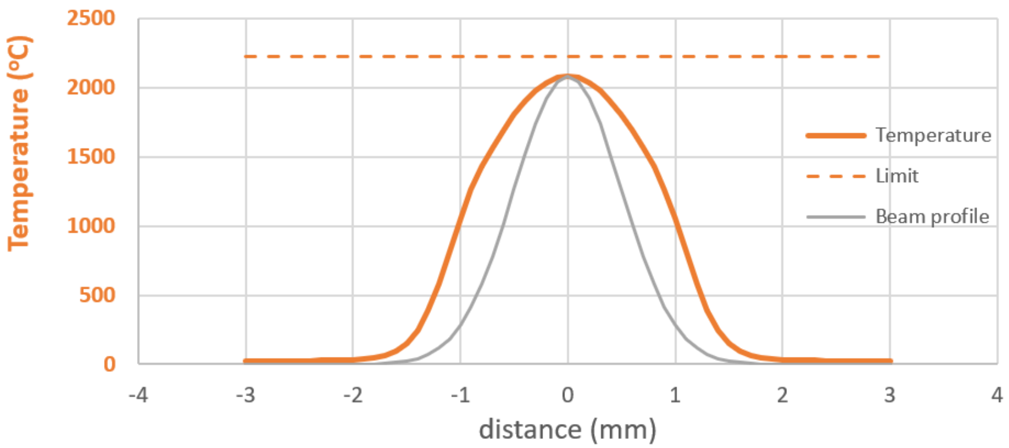




From RHIC to EIC

- Loss of increased asymmetry at lower energies, $A_N(-t)$
- Reduced bunch spacing requires much better understanding of background
  - Polarized or unpolarized
  - Better: reject/suppress background
- Increased beam current is problematic for the fiber target
  - Very limited cooling (radiation, thermal conductivity)
  - Sublimation temperature $T_{Carbon} \approx 2200° C$
  - Temperature saturates in a few ms





Can we find a target material that withstands higher temperatures?

Calculation by P. Thieberger, BNL

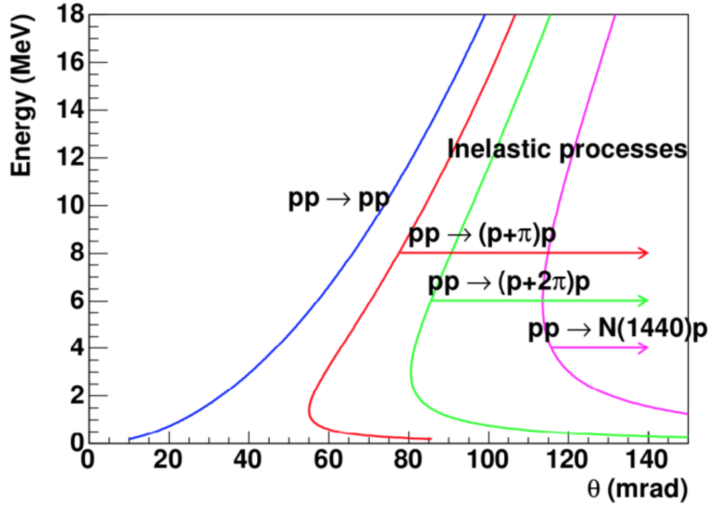
Polarized Light Ion Beams

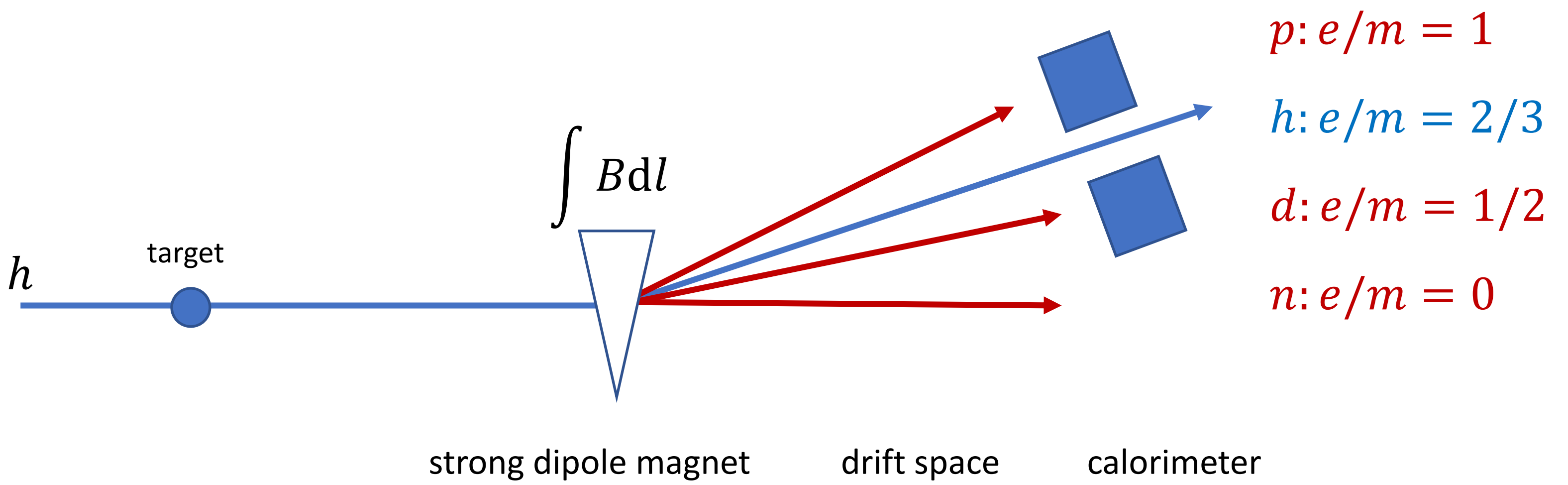
- Polarized d and ^3He beams are not part of the EIC baseline design.
- Absolute polarization will (likely) require a polarized ^3He target.
  - Elastic scattering is necessary for the sign-flip of the analyzing power

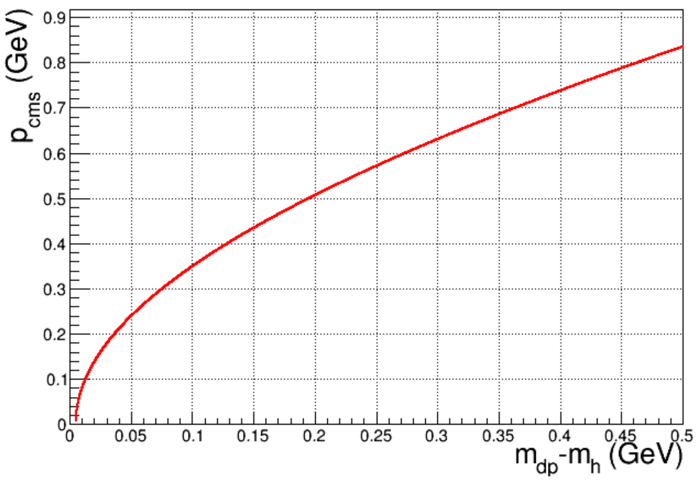
$$A_{00N0} = -A_{000N}$$

  - Breakup energy is only 5.5 MeV: problematic if beam breaks up $h \to pd$
  - Tag/veto breakup products downstream of the polarimeter

threshold for $pp \to pp\pi$



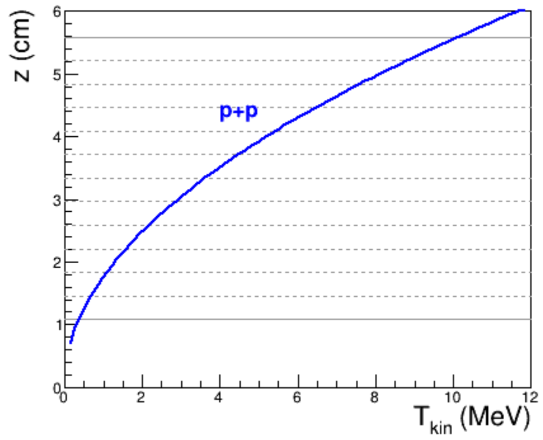




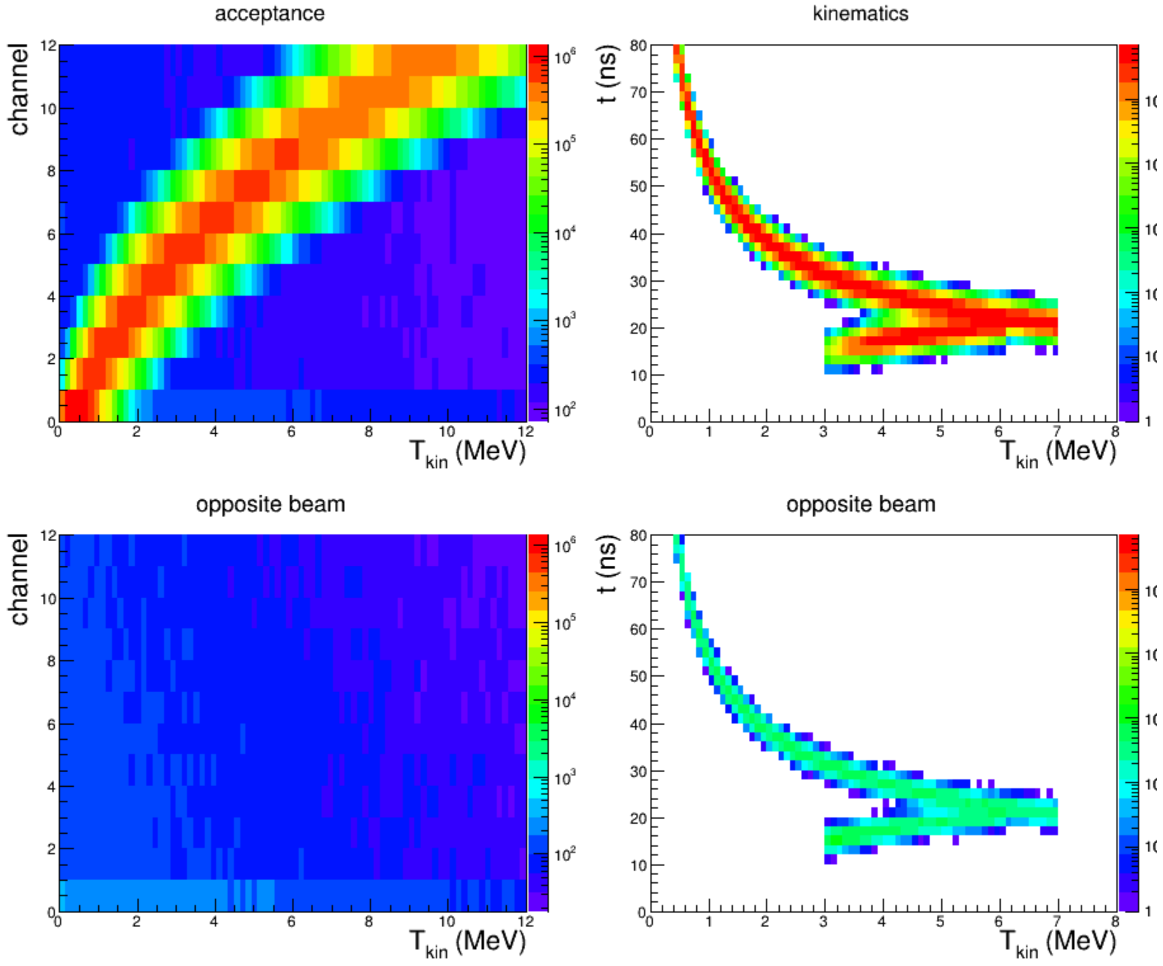
Backup

Toy Simulation

- Recoil angle calculated from kinetic energy
- Assume fairly 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%

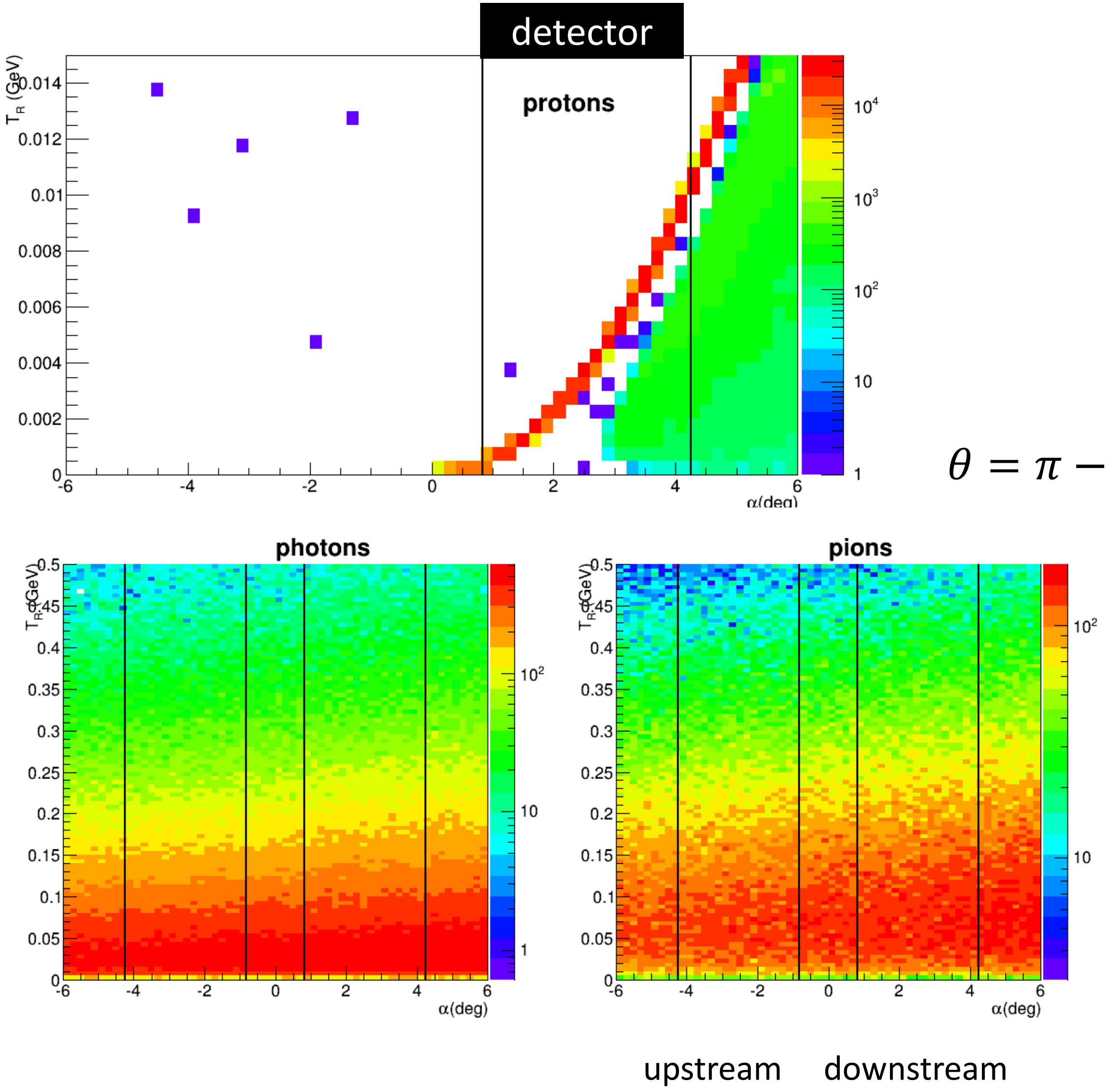


Main uncertainties:
- Bunch length
- Target thickness (z)
- Molecular background (z)

Other uncertainties:
- Energy resolution
- Strip pitch

PYTHIA Studies

- 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
- For this study, the vertical size of the detector is not relevant (no asymmetry measurement, keep full azimuthal range φ)

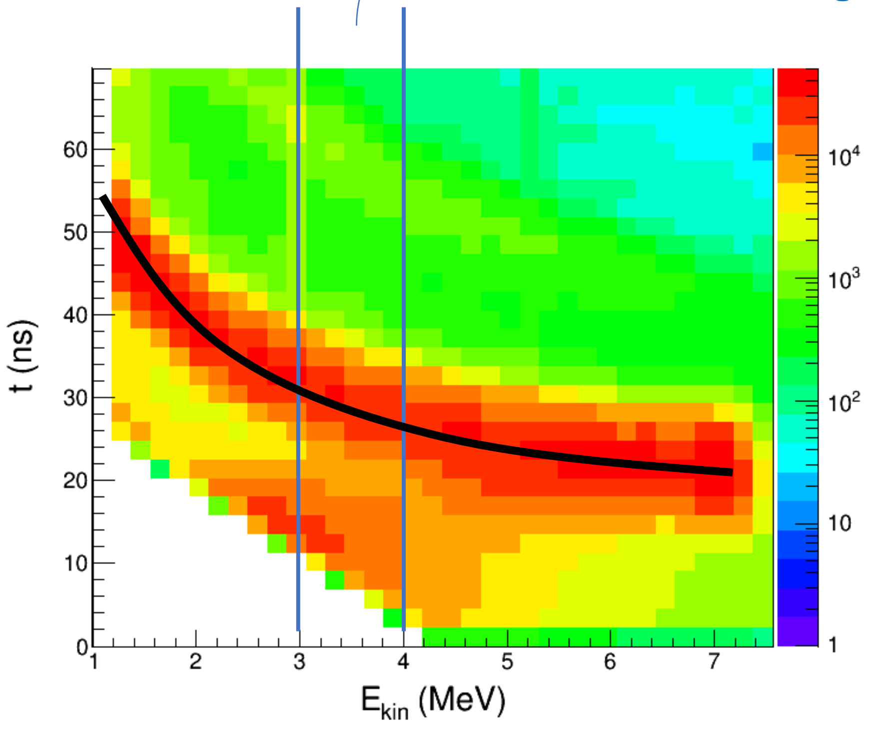


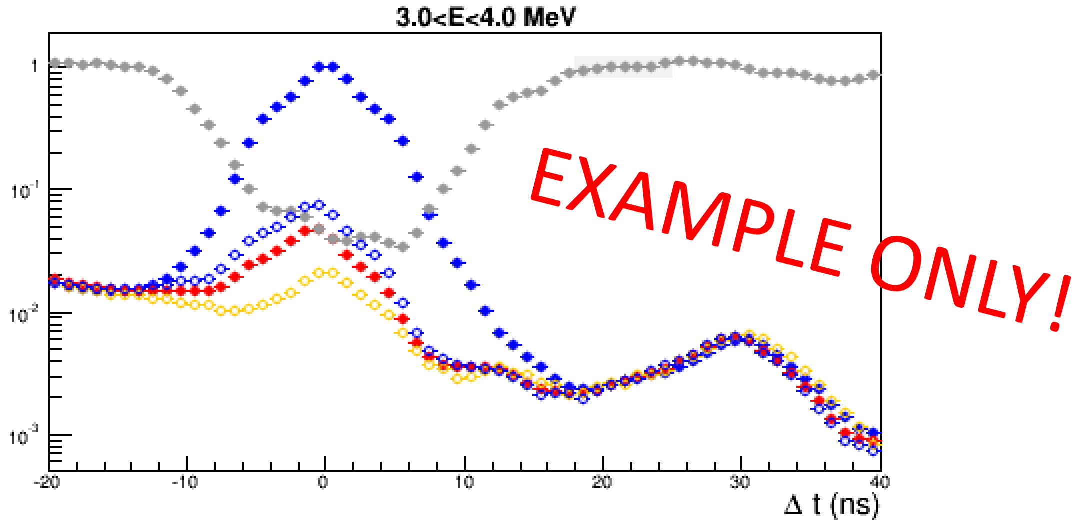
$\theta = \pi - \alpha$

Combine signal and background into time-of-flight vs. deposited energy

How to quantify the background

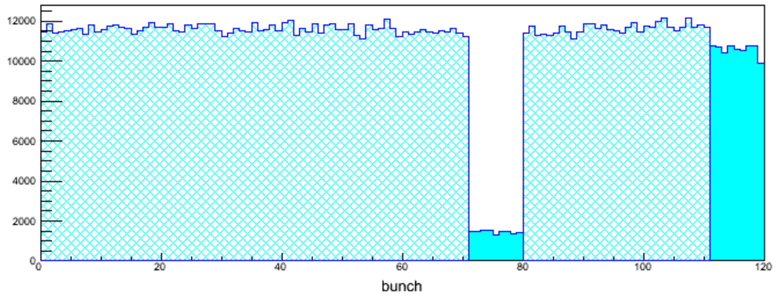
- Slice in kinetic energy
- Compare
  - signal
  - punch through
  - background





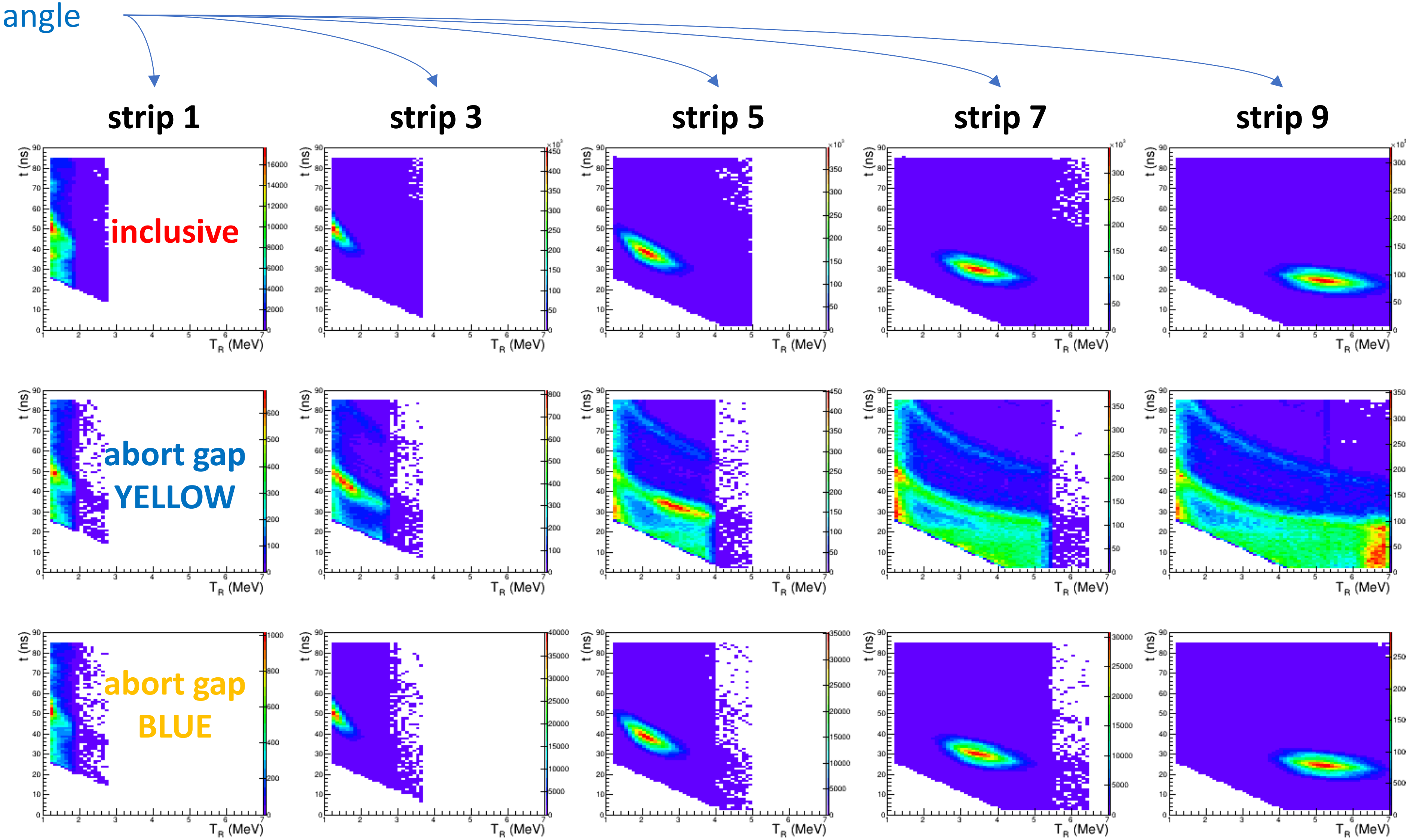
$$\Delta t = t_{meas} - t_{calc}$$

	$m_{miss} \approx m_p$	$m_{miss} \neq m_p$
Inclusive	●	○
Abort gap	○	
Signal		●



Kinematics of the Recoil Proton

different recoil angle



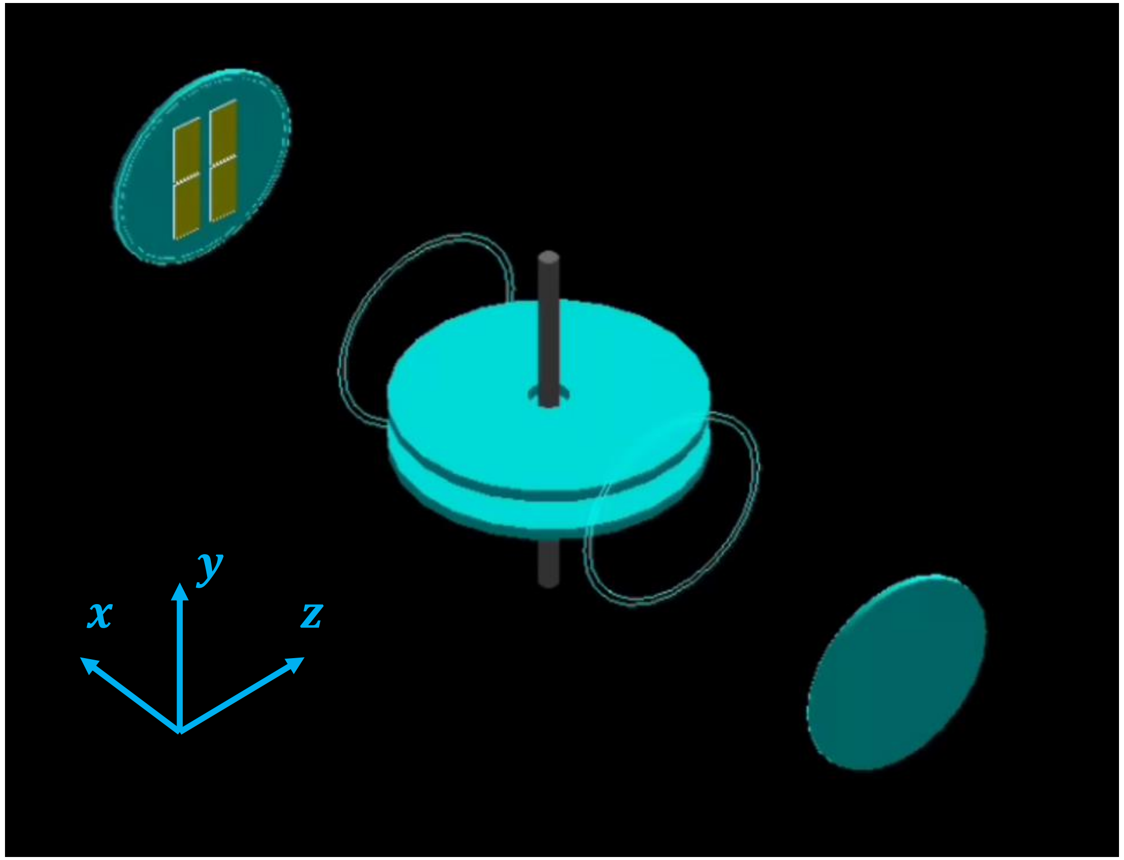
DST files are available with jetTree:

- tof
- ekin
- strip (α)

Will need to rerun a few fills without the manual tof/ekin cut

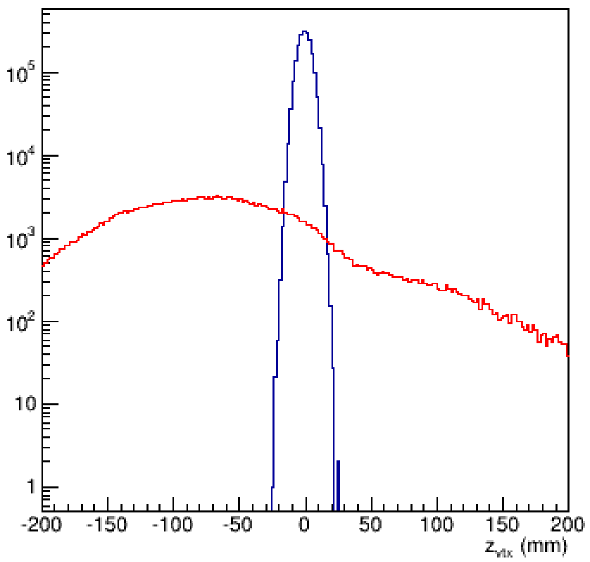
Polarimeter Simulation

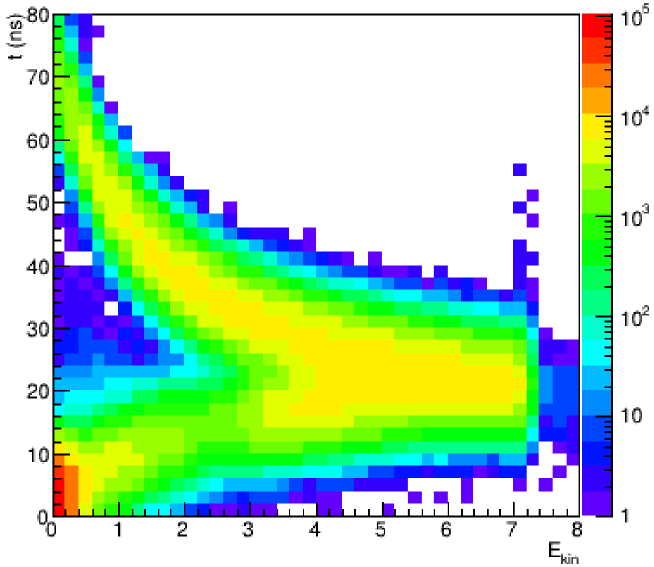
- Full detector in GEANT4
  - $400\ \mu\text{m}$ Silicon, $8\ \mu\text{m}$ dead layer
  - No strip segmentation (no pile-up seen in data)
- Detector chamber and flanges
- Atomic hydrogen jet target
  - $\rho \approx 0.4 \cdot 10^{-11}\ \text{g/cm}^3$
- Parameterized magnetic holding field
- Beam bunch length $(3.5\ \text{ns})$
- Vertex distribution $(5\ \text{mm},\ 10\ \text{cm})$
- PYTHIA input
  - Single beam

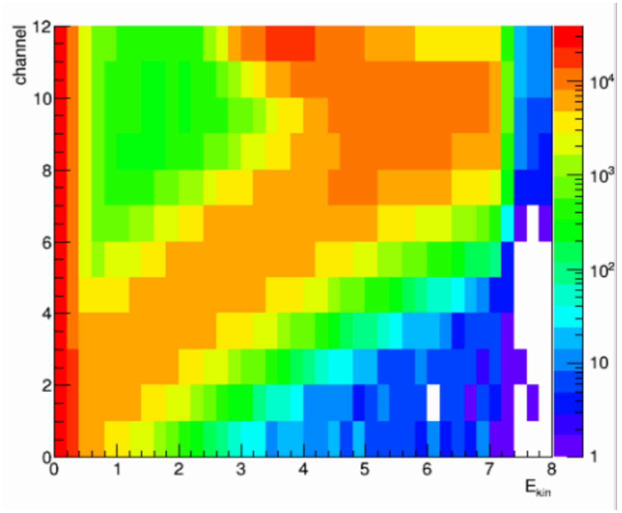


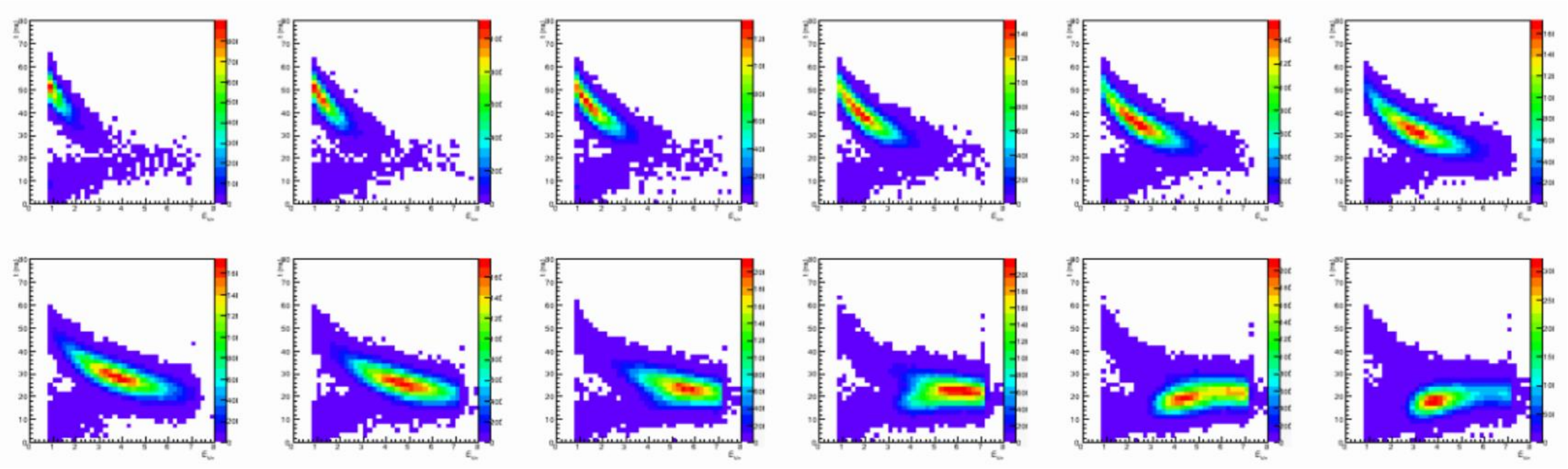
Simulation Results

- 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
  - Kinematic correlation (elastic scattering)
  - Signal and background (particle id)



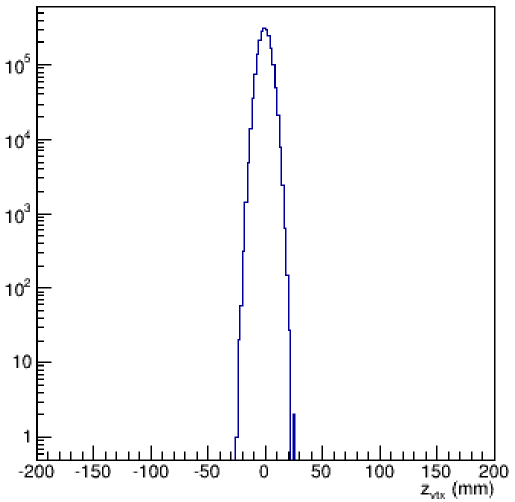


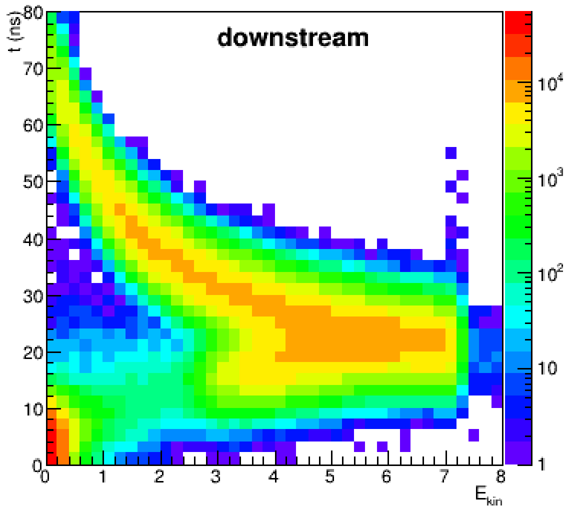


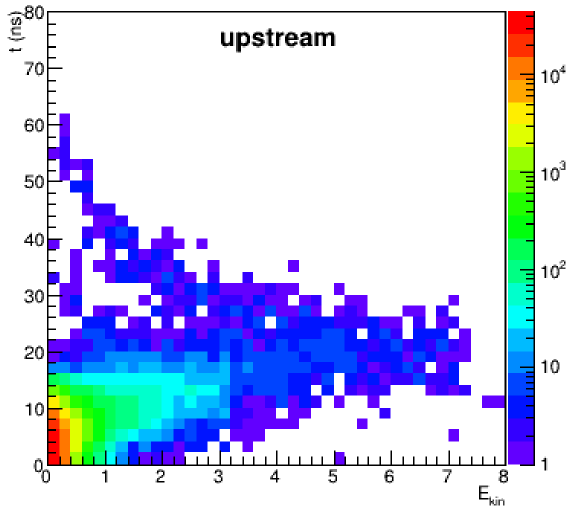


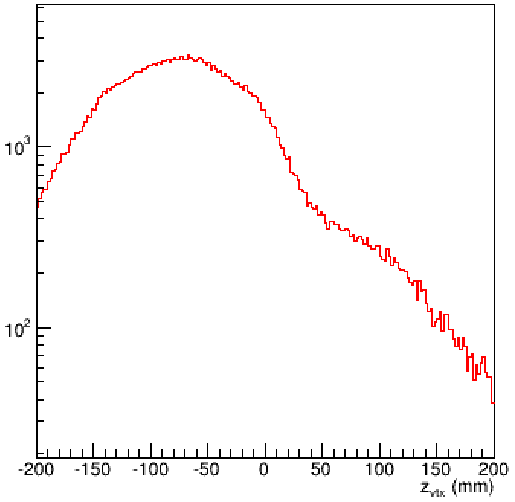
Simulation Results

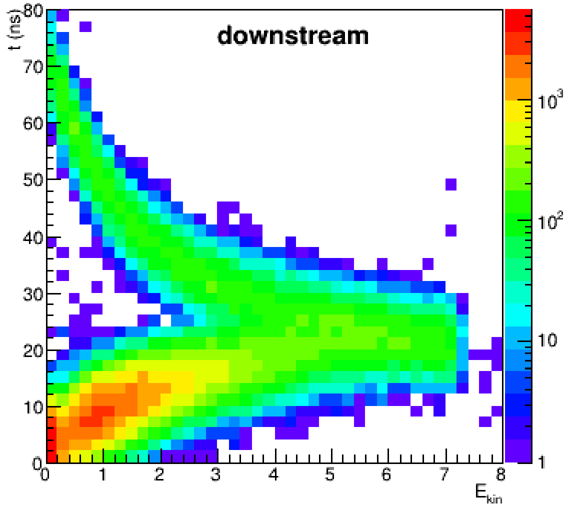
- Punch-through particles
  - Fast, little energy deposit
- Very few recoil protons in upstream detector
  - Compare target width with detector length
- Contribution from widely distributed molecular hydrogen
  - Wide range of punch-through particles
  - Skewed vertex distribution due to detector acceptance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

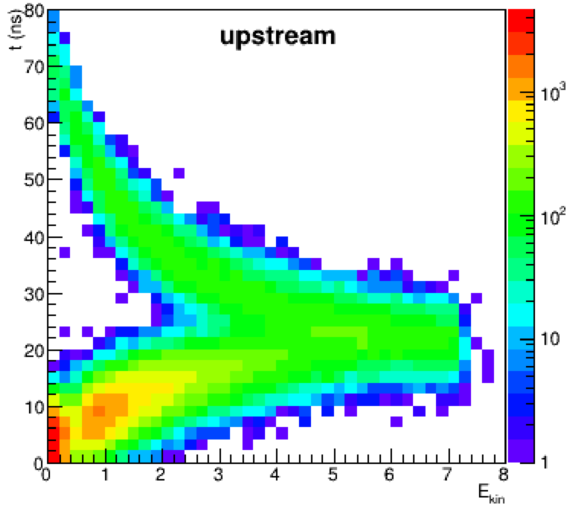






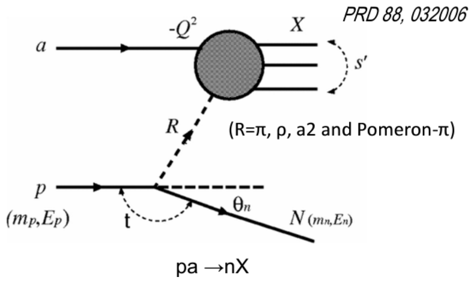


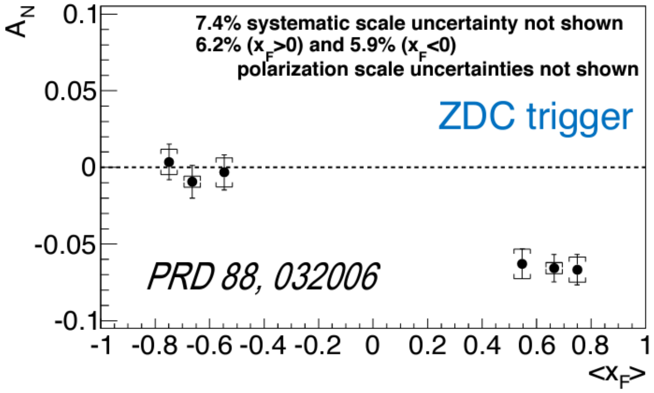




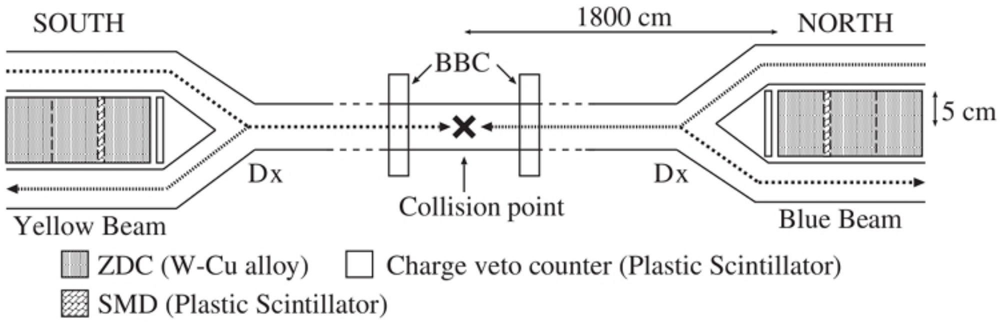
Local Polarimetry at RHIC

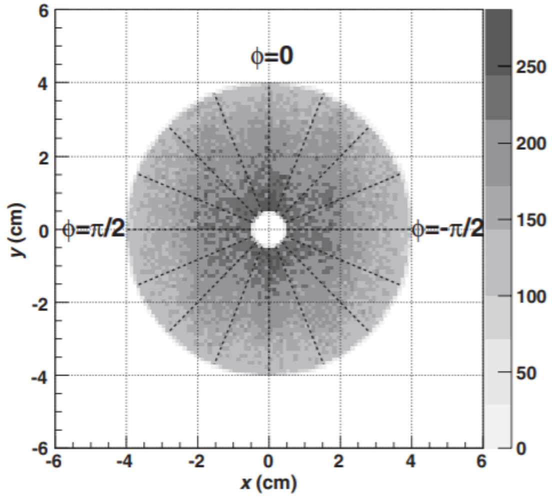
- Local polarimetry is primarily for confirming the direction of the polarization vector at the experiment.
  - Observe suppression of asymmetry or change of direction
  - Very forward going production of neutrons in $p + p$ collisions
  - First established at RHIC-IP12, standard method for RHIC experiments

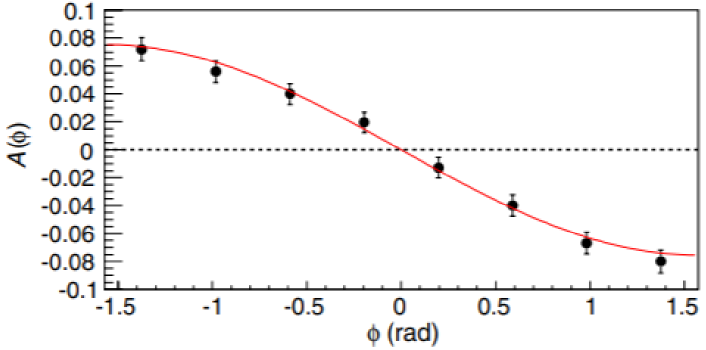




$$x_F = 2p_z/\sqrt{s}$$







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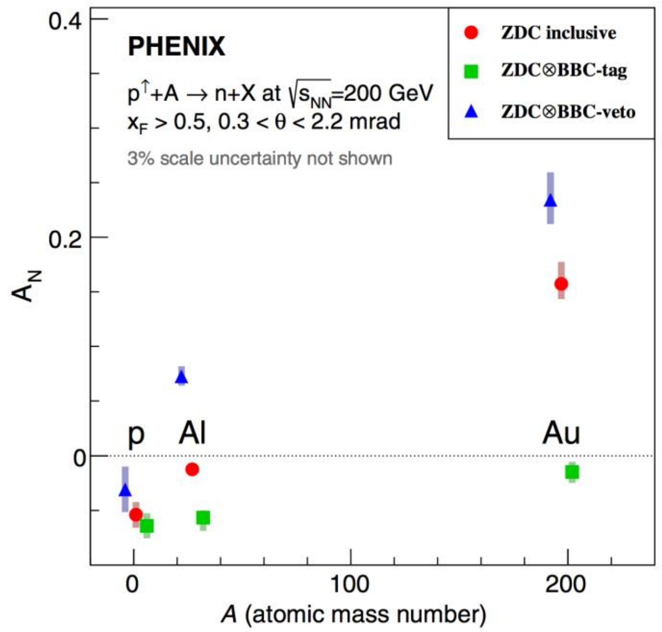
Potential for Future Applications

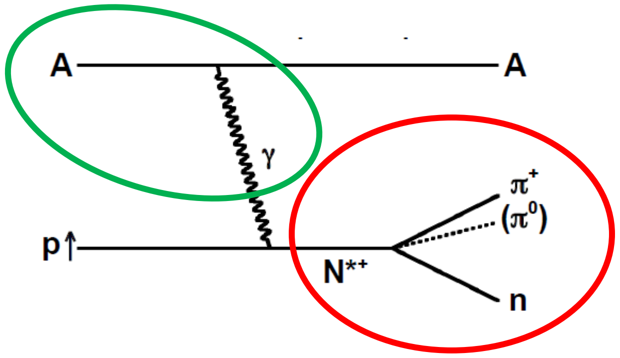
- Nuclear dependence of very forward going neutrons
  - Very large asymmetry (with opposite sign)
  - Select low multiplicity with beam-beam counters
  - Ultra-peripheral collision extension to π/a_1 model
  - Photon flux from STARlight
    Klein et al., Comput. Phys. Comm. 212 (2017) 258
  - $\gamma + p^{\uparrow} \rightarrow n + \pi^{+}$ from MAID
    Drechsel et al., Eur. Phys. J. A 34 (2007) 69

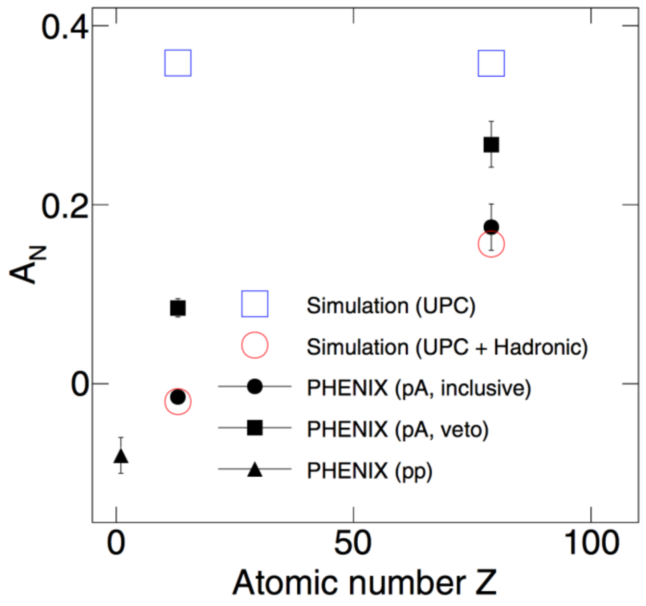
$p^{\uparrow} + p$

$p^{\uparrow} + Al$

$p^{\uparrow} + Au$







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The Electron-Ion Collider

- Variable center-of-mass energy:

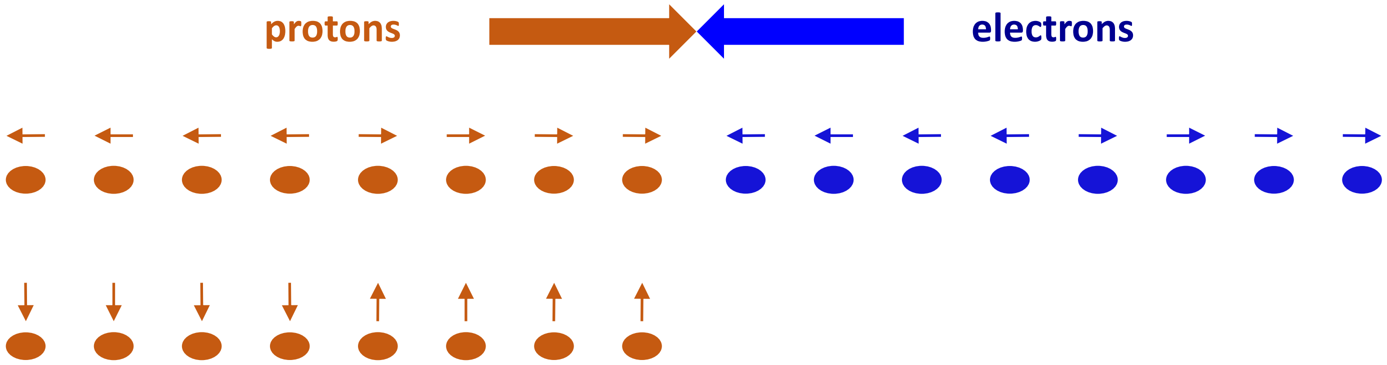
$$\sqrt{s} = 20 - 140\ \mathrm{GeV}$$

- Ion beams: protons, $^{3}\mathrm{He}$, Au, Pb, U
- High luminosity:

$$L = 10^{33} - 10^{34}\ \mathrm{cm}^{-1}\mathrm{s}^{-1}$$

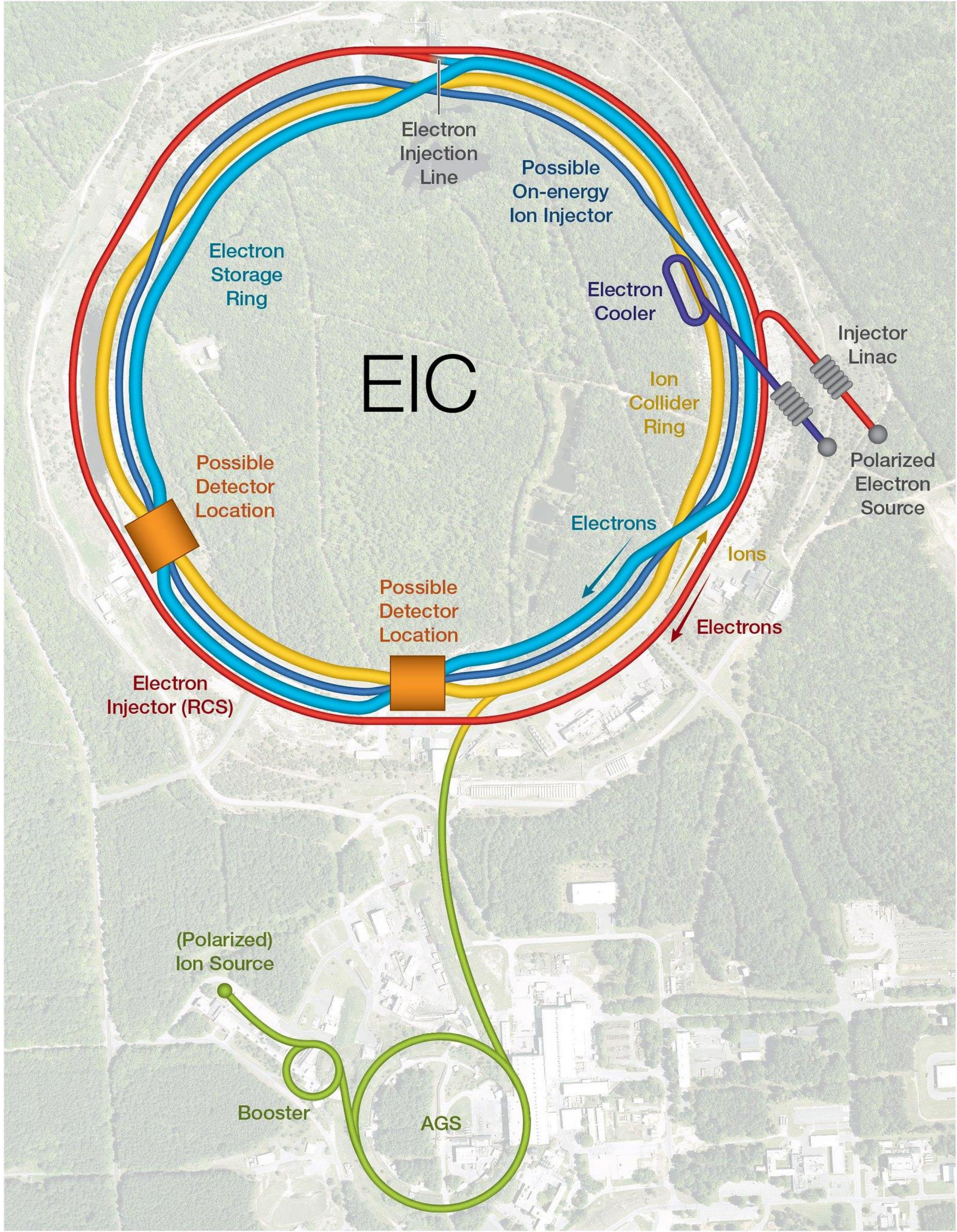
- **Polarized electron and proton beams:**

$$\boldsymbol{P \approx 70\%}$$



Electrons: $5 - 18\ \mathrm{GeV}$

Protons: $50 - 275\ \mathrm{GeV}$



Requirements and Delivery

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

(*) Increased systematics

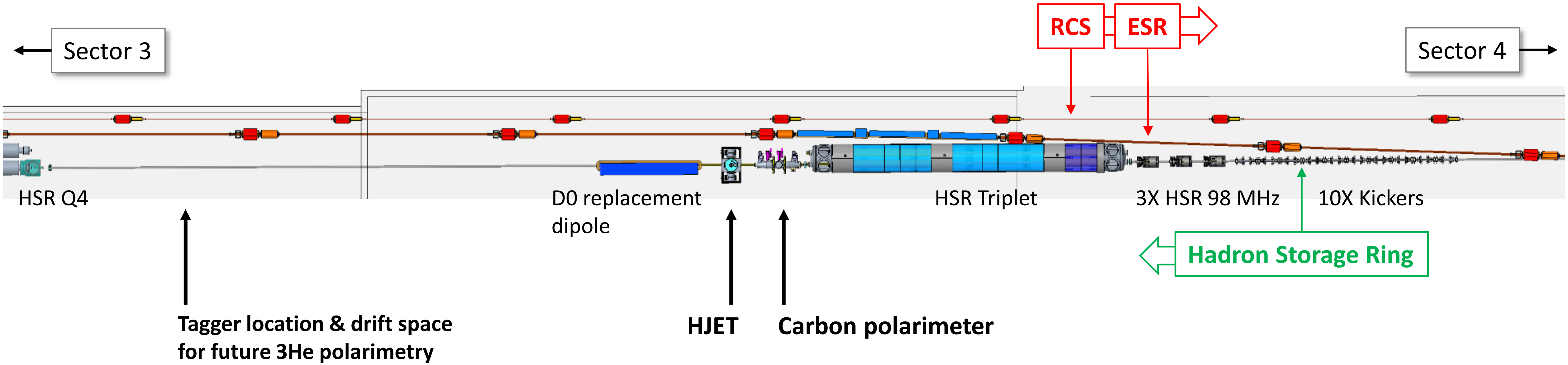
(*) A_N can be calculated, but needs to be confirmed; full background subtraction

(*) less accurate than pC

(*) depends on the target

(*) limited space for detectors with current magnet configuration

Polarimeters are an integral part of the EIC



Local Polarimeter for EPIC

- Spin rotators for longitudinal polarization
- Crab cavities for increased luminosity in collision
- Limited space in hall / straight section
- Polarimeter in incoming hadron beam