P-Carbon Polarimetry at EIC

Haixin Huang
For the EIC Polarimetry Team

Mar 11th, 2025
Workshop on Polarized Ion Sources and Beams at EIC
Stony Brook University

@BrookhavenLab

Outline

- RHIC p-Carbon Polarimeter
- EIC Polarimeter Development
- Summary

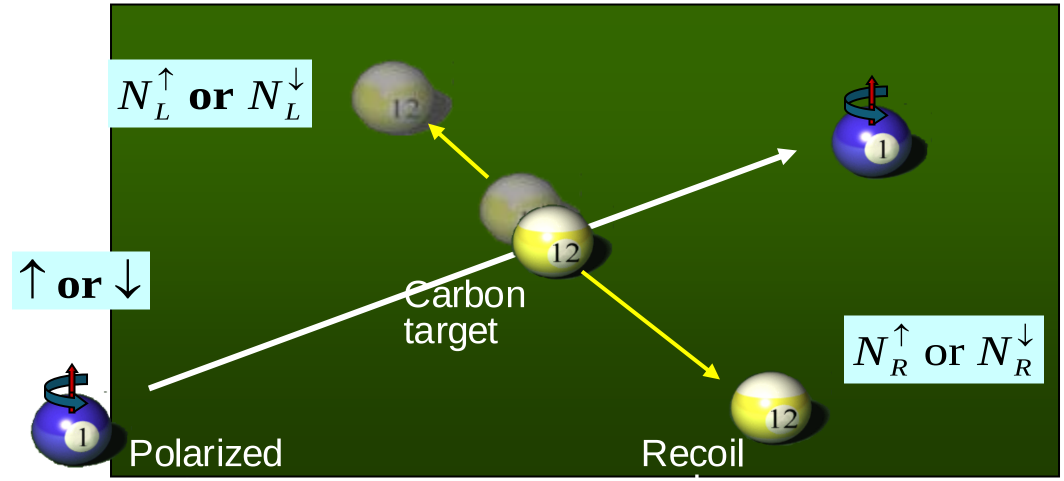
The RHIC p-Carbon CNI Polarimeter

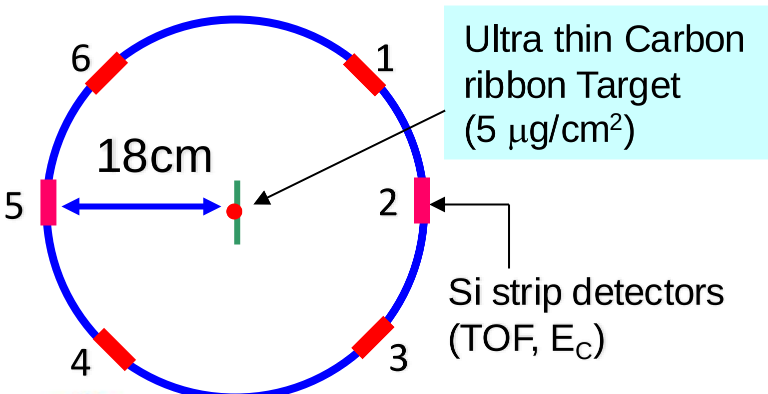
Elastic scattering: interference between electromagnetic and hadronic amplitudes in the Coulomb-Nuclear Interference (CNI) region.

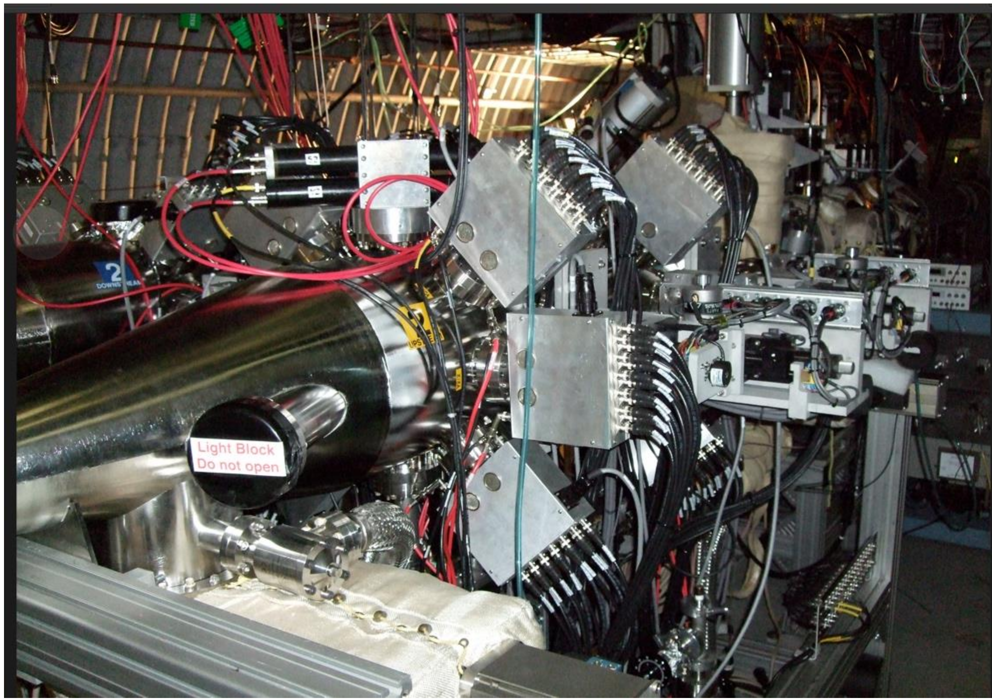
$$P_{beam} = -\frac{\varepsilon_N}{A_N^{pC}}$$

$A_N(pC) \sim 1\%$

$$\varepsilon_N = \frac{N_L - N_R}{N_L + N_R}$$

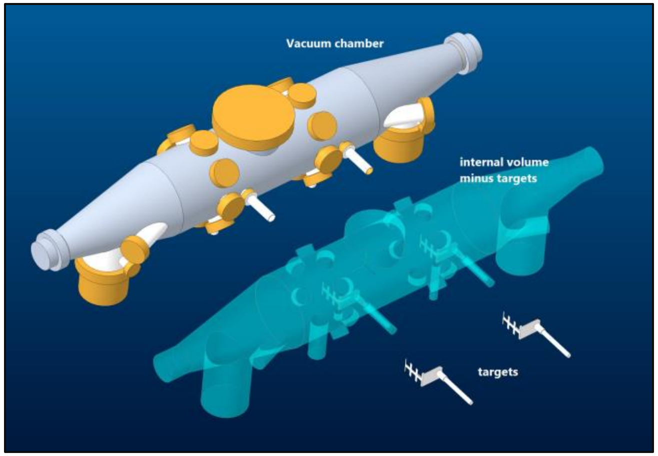


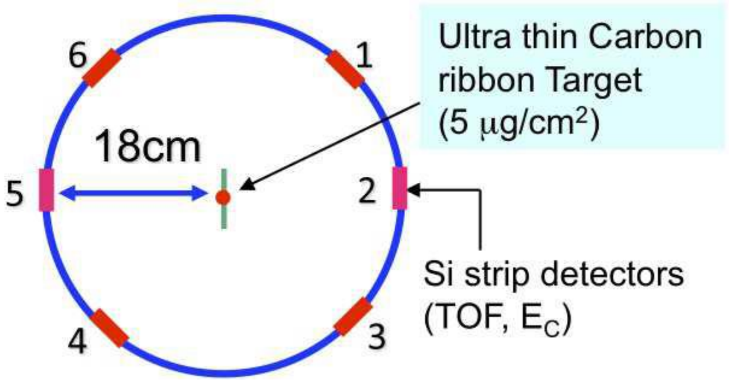


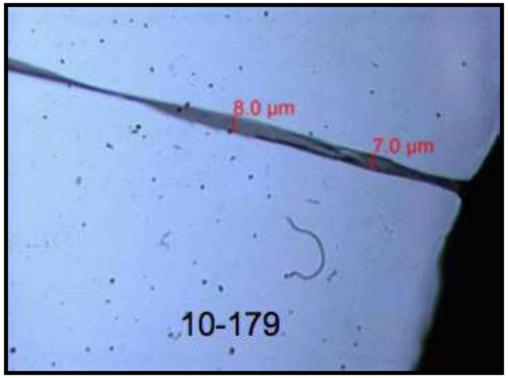


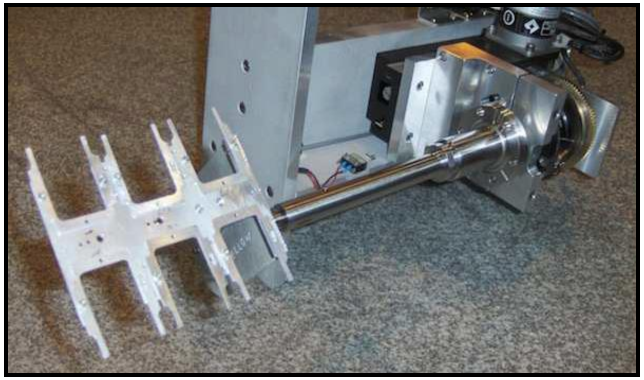
Brookhaven National Laboratory

Components of Polarimeters





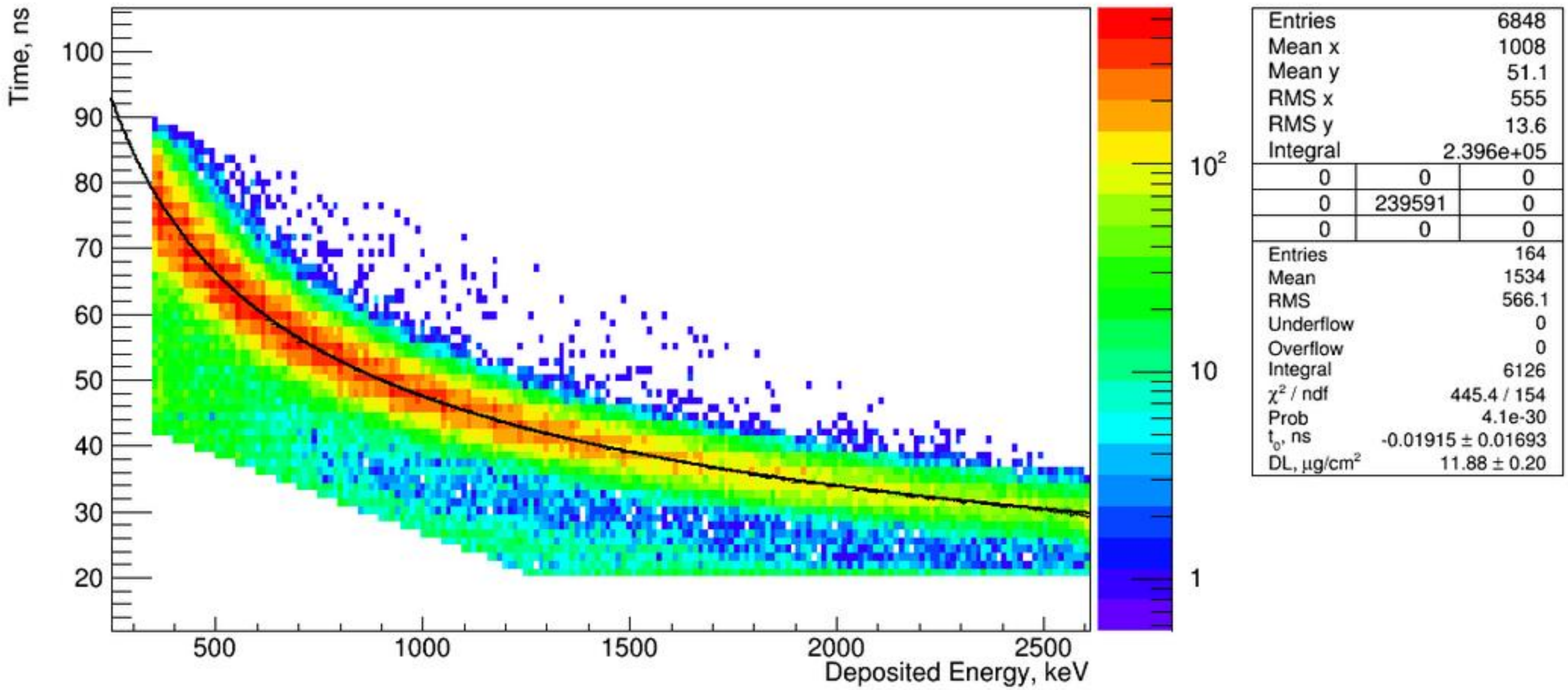




- Ultra-thin ribbon targets:

  $\approx 10\ \mu\text{m} \times 50\ \text{nm}$
- Target holder inside beam pipe

Carbon Event Selection



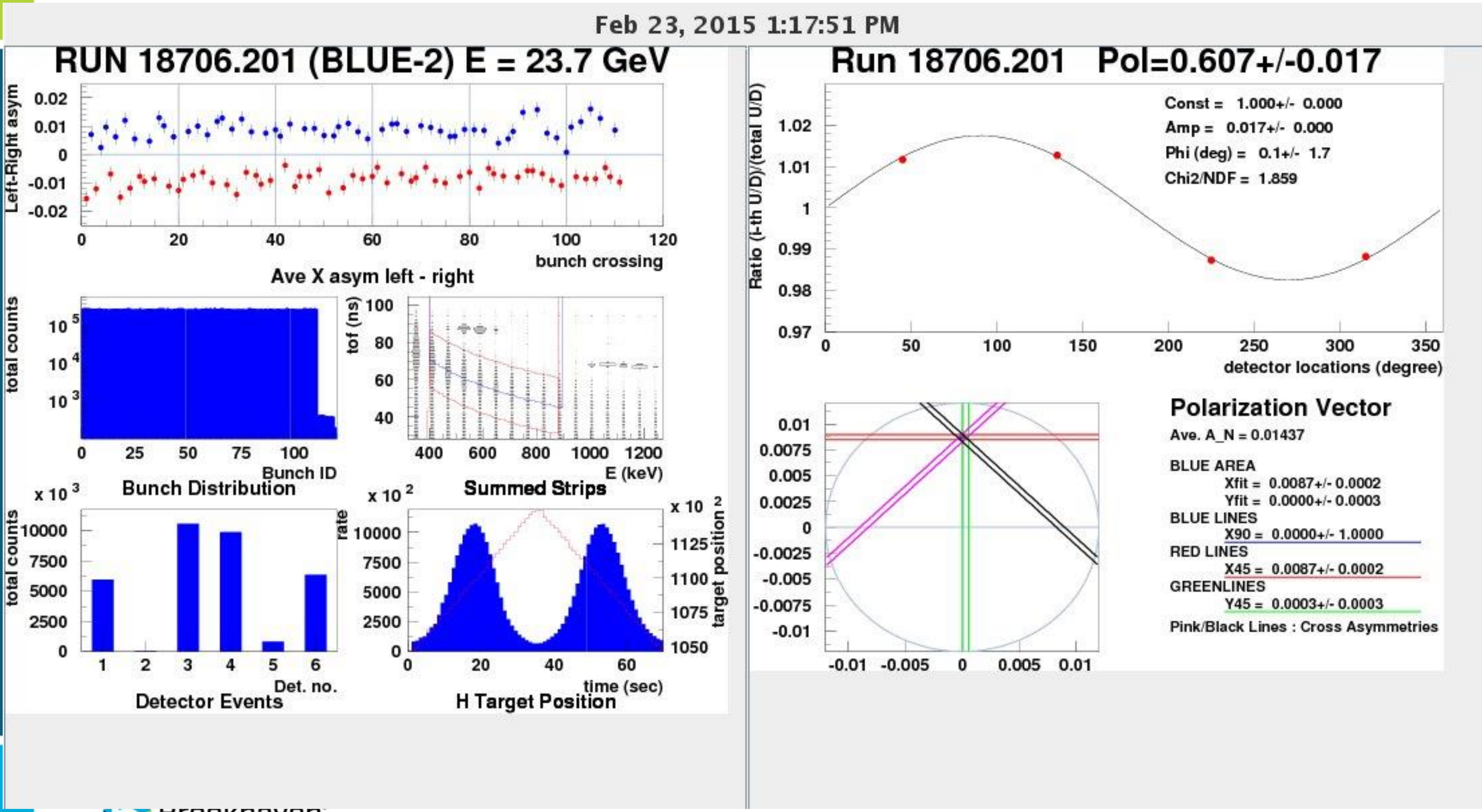
- The effective energy losses E_{loss} and time offset t_0 are determined from the kinematical fit to the banana-like band

$$E_{kin} = E_{meas} + E_{loss} = \frac{1}{2} M \times \frac{L^2}{\left(t_{meas} + t_0\right)^2}$$

- Carbon Events are selected within a Time-Energy window, 400 < T < 900 keV, optimized for minimal background

Brookhaven National Laboratory

Bunch by Bunch Polarization



Brookhaven National Laboratory

Depolarization and Polarization profiles

Polarization loss from intrinsic resonances: polarization lost at edge of beam → polarization profile

- Impact of polarization profile on beam polarization at collisions $P_{coll.}$:

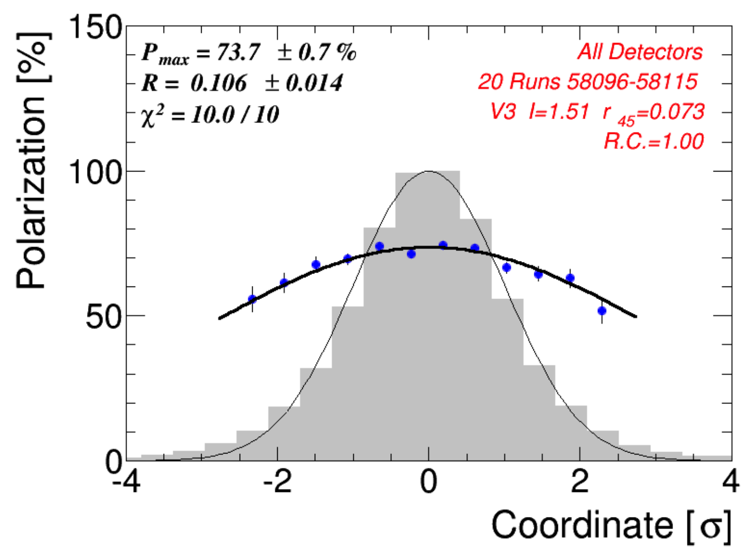
$$P(x,x',y,y') = P_0 e^{-\frac{x^2+x'^2}{2s^2_{x,P}}} e^{-\frac{y^2+y'^2}{2s^2_{y,P}}}; \quad I(x,x',y,y') = I_0 e^{-\frac{x^2+x'^2}{2s^2_{x,I}}} e^{-\frac{y^2+y'^2}{2s^2_{y,I}}}; \quad R_H = \frac{s^2_{x,I}}{s^2_{x,P}}; \quad R_V = \frac{s^2_{y,I}}{s^2_{y,P}}$$

$$\langle P \rangle = P_0 \frac{1}{(1+R_H)(1+R_V)}; \quad P_{coll.} = P_0 \frac{1}{\sqrt{1+\frac{1}{2}R_H}\sqrt{1+R_H}\sqrt{1+\frac{1}{2}R_V}\sqrt{1+R_V}} = \langle P \rangle \frac{\sqrt{1+R_H}\sqrt{1+R_V}}{\sqrt{1+\frac{1}{2}R_H}\sqrt{1+\frac{1}{2}R_V}}$$

- For $R_H \approx R_V \approx R$ and small: $P_0 = \langle P \rangle (1+R)^2$; $P_{coll.} \approx \langle P \rangle (1+½R)$
- <P> measured with H jet polarimeter; R measured with pC polarimeter
- Typical best values at RHIC 255 GeV: P_0= 80%; <P>=57%, R=0.18, $P_{coll.}$=62%

Note that P_0, the polarization of the core particle, should be equal to the maximum achievable polarization.

Loss of average polarization is compatible with development of polarization profiles → all remaining polarization loss in AGS and RHIC is due to intrinsic resonances. (no coherent polarization loss)



Brookhaven National Laboratory

Operation of p-Carbon Polarimeter

- Due to the target orientation and thickness variation, the calibration of p–Carbon polarimeter with polarized jet can not be once-and-done.
- The polarized hydrogen jet needs to be running in parallel.
- The jet can give polarization error of ±3% for an 8-hour store.
- In sweep mode, a polarization of ±2% measurement can be done by p-Carbon polarimeter in about 30sec.
- Normally, four sets of polarization measurements are done at store: 0, 3, 6, and 8 hours into a store. Each set consists of two polarization measurements done with horizontal and vertical targets, respectively. Besides polarization information, polarization profile information is also obtained. Several polarization measurements over a store provide possible polarization decay over time.

Outline

- RHIC p-Carbon Polarimeter
- EIC Polarimeter Development
- Summary

Beam Parameter Differences between RHIC and EIC

Parameters	RHIC	HSR
No. of Bunches	110	290
Energy (GeV)	255	275
Bunch spacing (ns)	106	10
Bunch Intensity [10^{11}]	2	2.76
RMS normalized emittance, h/v [um]	2.5	5/0.5

- More intensity will generally cause more energy deposit in the target. Can Carbon target survive?
- The impedance of the polarimeter chamber and target holder may also be problematic.
- Less bunch spacing, means the separation of events from different bunches is not possible with current Si detector configuration.

EIC Proton Polarization Requirements

- 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

EIC Proton Polarization Options

	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

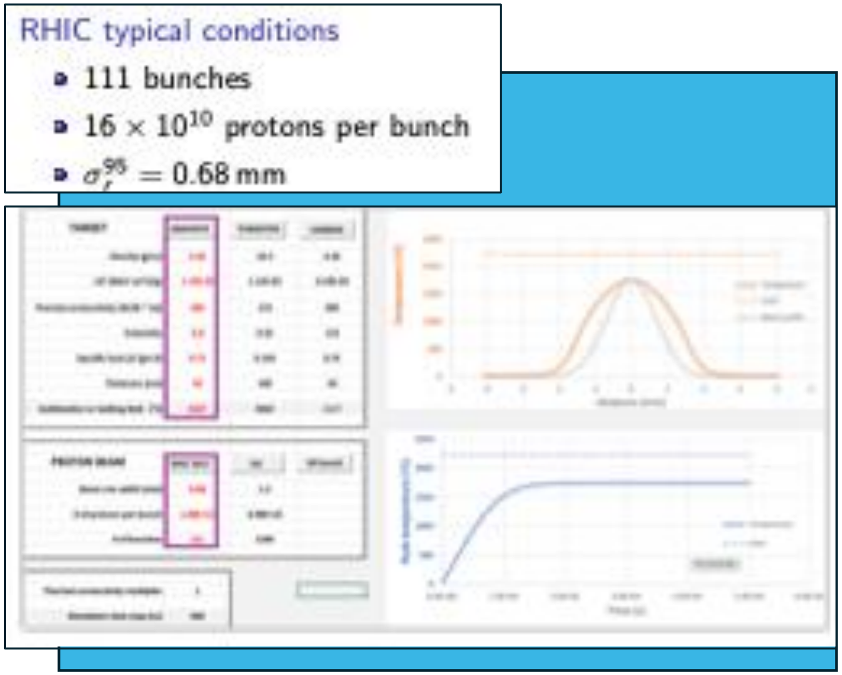
pC only measures P_x and P_y

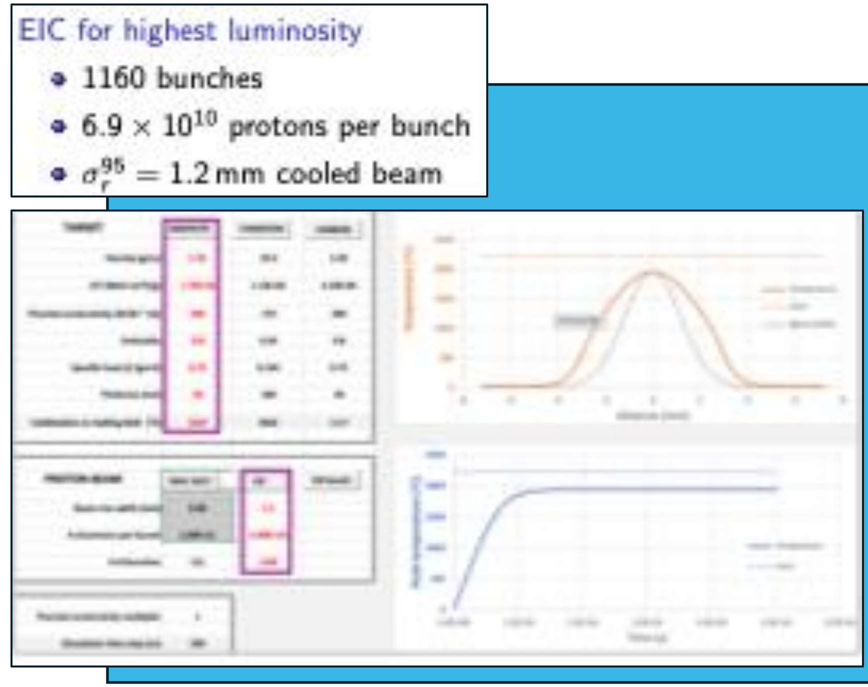
Brookhaven National Laboratory

Carbon fiber targets at EIC

Target heating (code by Peter Thieberger)

- **With realistic beam sizes, target heating about the same at RHIC and EIC**



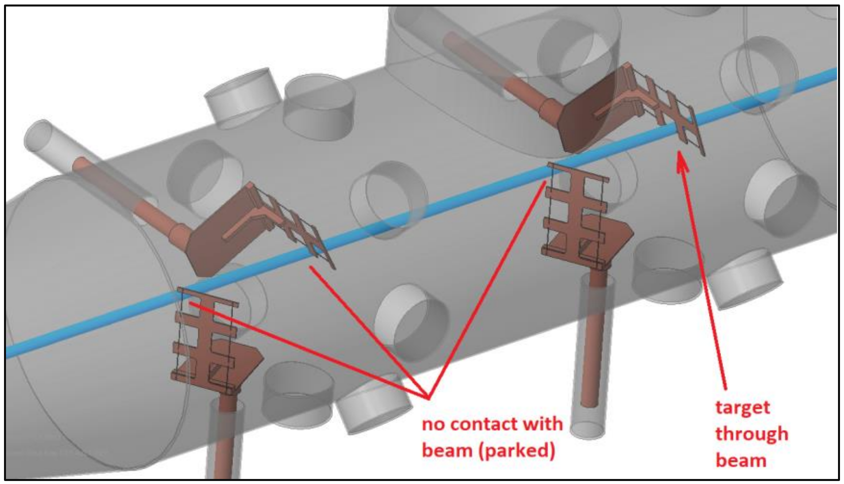


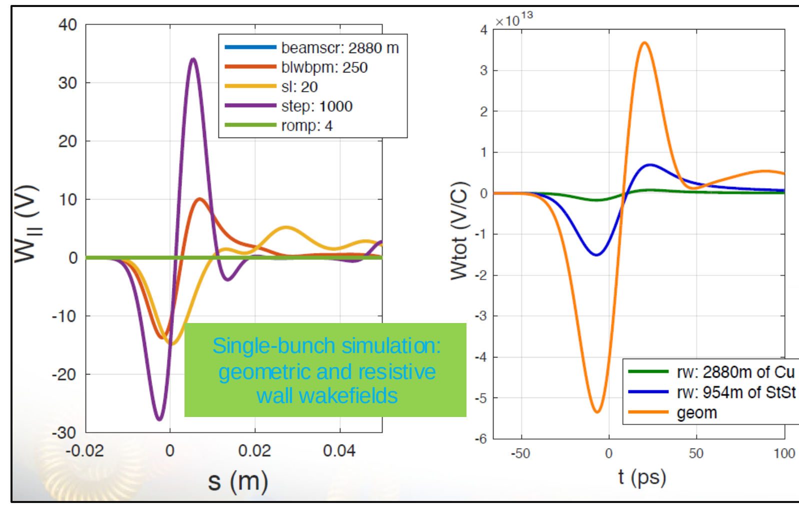
- By increasing the beta function at the polarimeter location (30m-> 240m), the beam size can be significantly increased. The target heating can be managed at the similar level in RHIC with higher total intensity and smaller emittance.
- This also implies a longer target and different target chamber design.

Impedance Calculations

Short bunch spacing at EIC(10 ns)

- Fiber target chambers ok for single-bunches
- Higher order modes → pumping ports → RF shielding





- **RF simulations of C targets**
    - RF heating more severe at EIC → target holders need to be RF-optimized

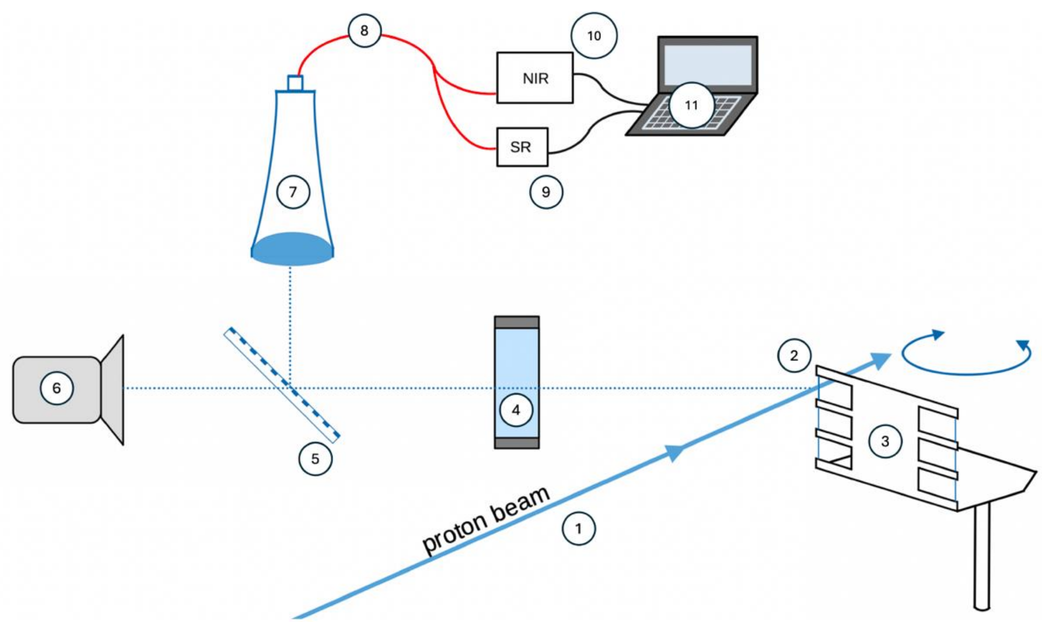
Wakefield and Impedance Simulation in Progress

- Performed CST simulations of wakefield, impedance, and the beam induced resistive wall (RW) loss for the HSR polarimeter with both RHIC and EIC parameters.
- Only one target holder is incorporated in the simulations.
- The beam induced loss seems comparable for both target holders with the RHIC beam.
- For the EIC proton beam, the aluminum target holder introduces large wakefield oscillations and resonances in the impedance plot.
- The amplitude of the wakefield and impedances reduces significantly while using the alumina (dielectric target).
- Simulations done so far is with $2*10^{11}$/bunch. It will be carried out for higher intensity $2.8*10^{11}$/bunch.

Brookhaven National Laboratory

Direct Measurement of the C Target Temperatures

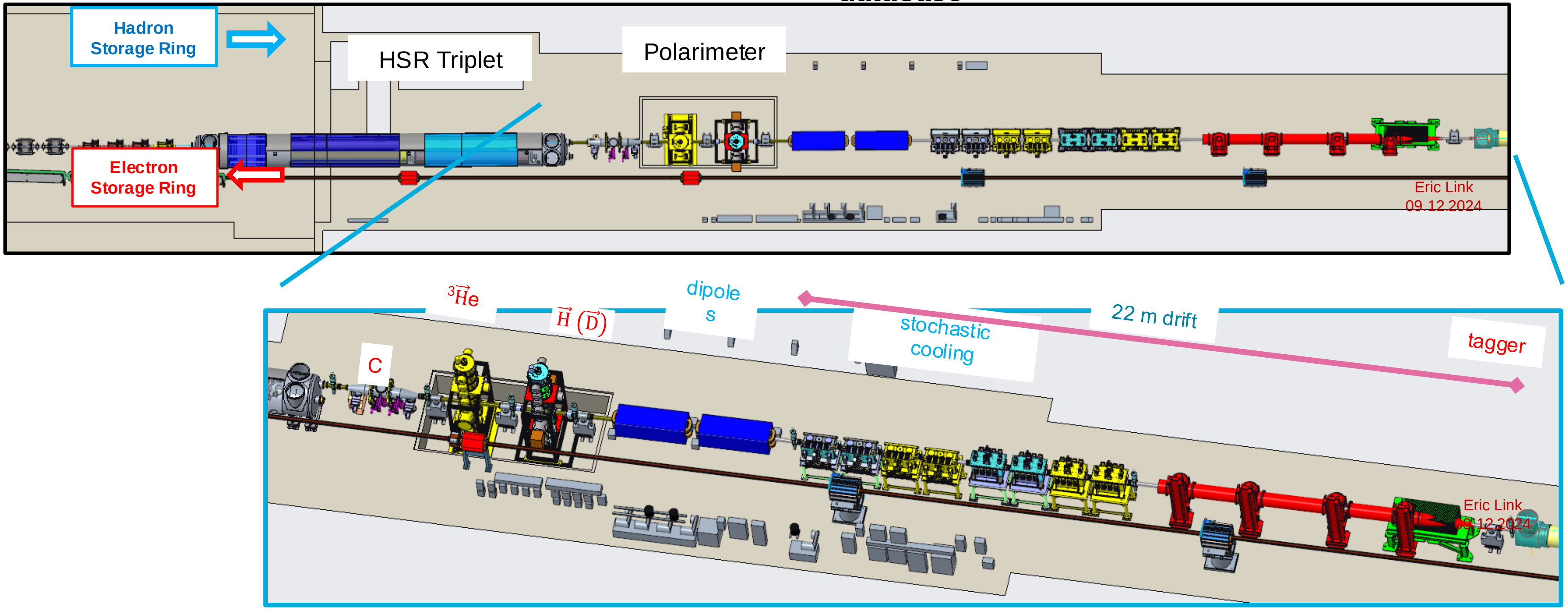
- Up to now, the temperatures of the polarimeter carbon targets during interaction with proton beam cannot be directly measured.
- A dedicated optical light collection system was implemented in IP12 to capture and analyze emitted light across the visible and near-infrared spectrum.
- This study investigates the feasibility of using light emission as a diagnostic tool to determine the target temperatures.
- A dedicated experiment with proton beam is planned in run 25.
- This work is critical for assessing the applicability of carbon fiber targets in the EIC under increased beam intensity.



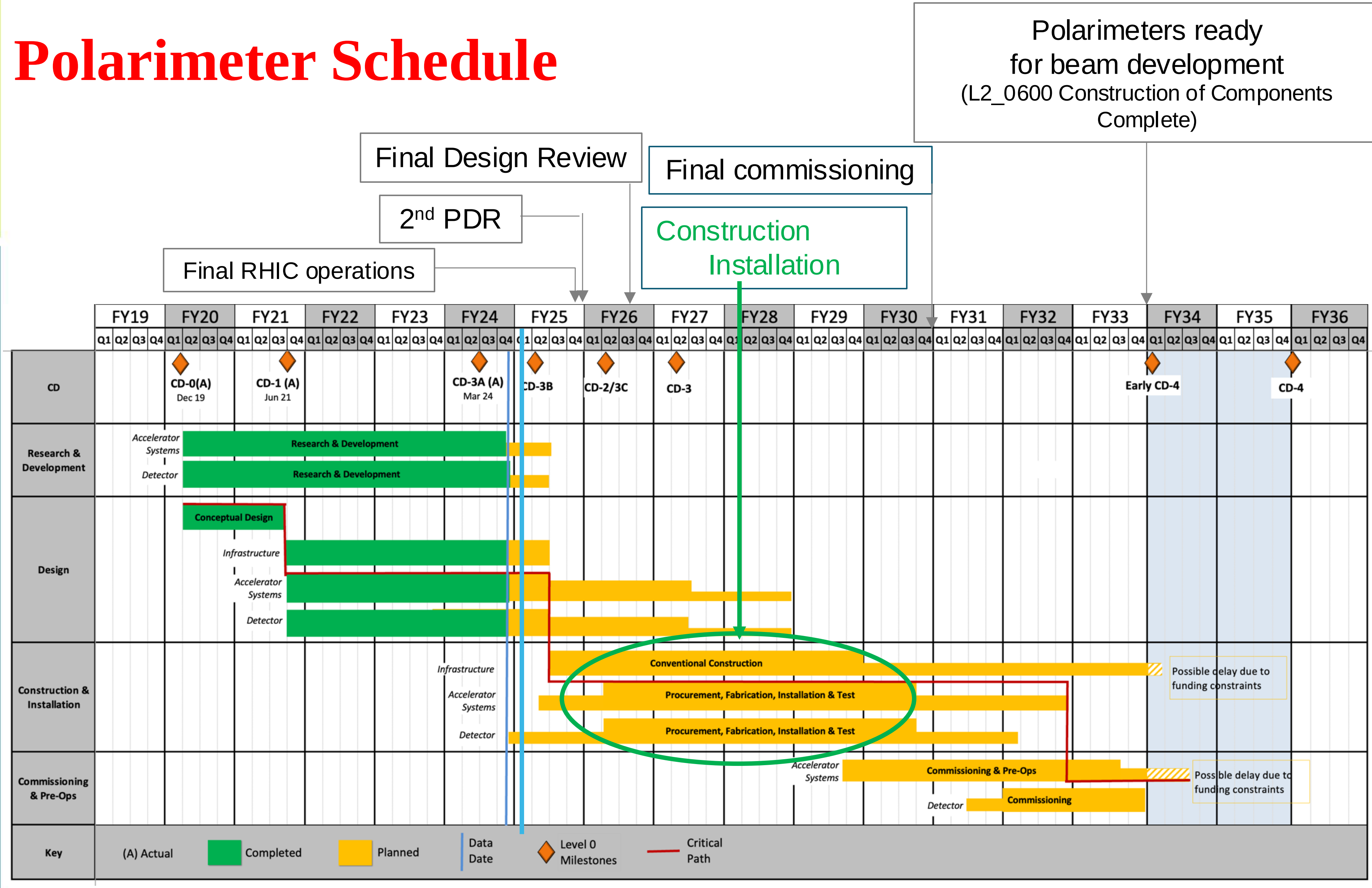
New layout of hadron polarimetry at IP4

- Choice of location driven by size of HJET/drift space
  - C, polarized H and ^{3}He targets in one place to minimize spin rotation between them

- HJET setup in 510 for refurbishment/modifications (Q4/25)
  - Double layer silicon detectors
  - Breit-Rabi upgrade with QMA (H_2 content)
  - Target chamber/magnetic field
  - Upgrade slow control system, plus EPICS database



Polarimeter Schedule



Summary

- Basic polarimetry methods established
  - New chamber with additional lock chamber to hold extra targets will be needed.
  - RF shielding is needed for pump ports and view ports etc.
  - Longer C targets are needed, and the aluminum target holder will need to be replaced with alumina.
  - Readout/detector choice for C targets are still needed
- Design progressing towards CD-2 in FY25 and CD-3 in FY26
- Demands at EIC significantly higher than at previous facilities
  - designs are in progress to meet demands
- Future modifications beyond EIC baseline not precluded with current designs
- All polarimeters shall be ready for operation at start of polarized beam commissioning

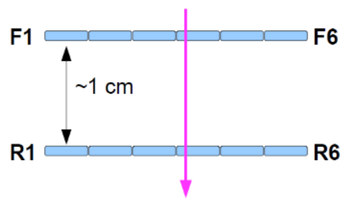
Backup Slides

Hadron Polarimeter R&D

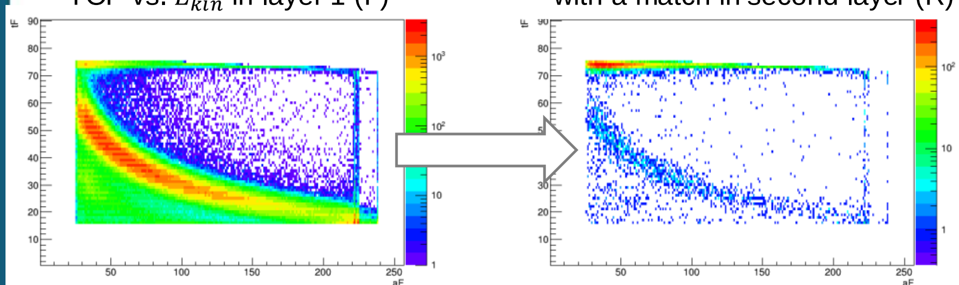
Second detector layer installed in pC polarimeter

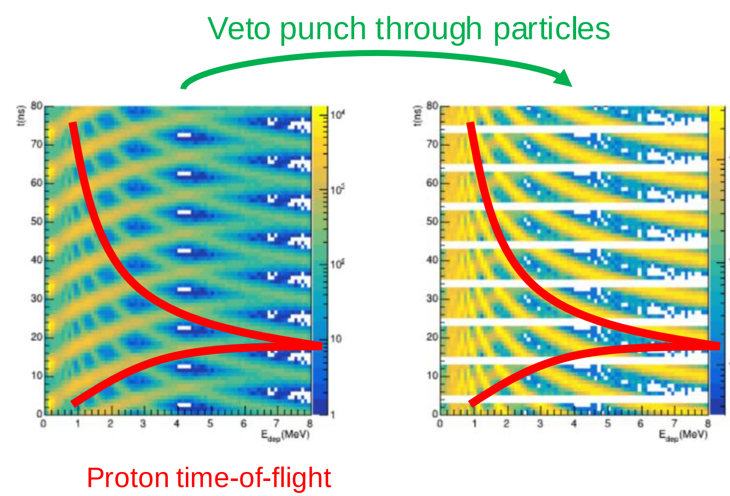
- Included in DAQ since start of Run22 operations
- Data from RHIC Run 22

- Hybrid simulation
  - PYTHIA & GEANT
  - Repeated with 10 ns bunch spacing



TOF vs. E_{kin} in layer 1 (F)   with a match in second layer (R)





21