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Needed Improvements to the H-Jet for an EIC

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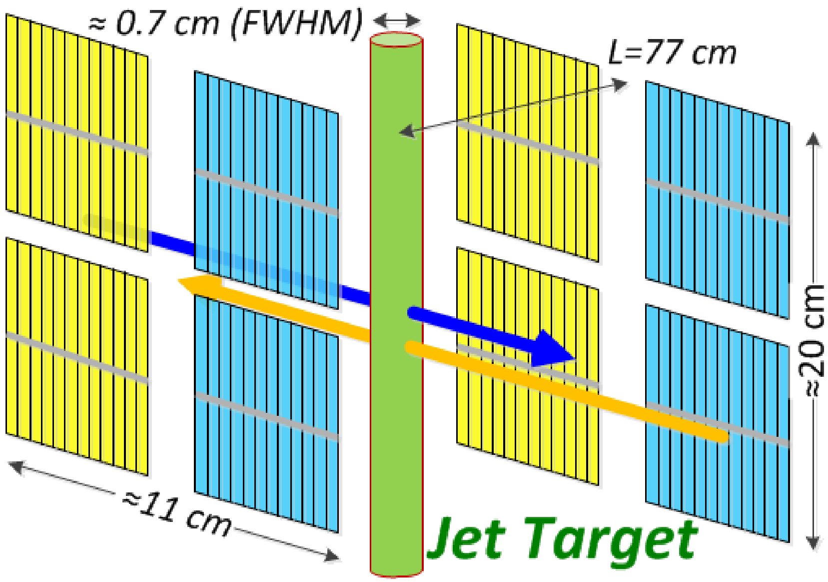
HJET detector configuration



- HJET consist of 8 Silicon detecors, 12 strips. each. 4 detectors per RHIC beam.
- Full waveform is recorded for every event.
- For elastic scattering, the detected recoil proton kinetic energy T_R range is defined by HJET geometry

$$0.5 < T_R < 11\ \mathrm{MeV}$$

- The momentum transfer is proportional to T_R

$$t = (p_R - p_t)^2 = -2m_pT_R$$

- Both RHIC beams (**Blue** and **Yellow**) are measured simultaneously.
- The waveform shape analysis was employed to separate stopped and punched-trough ($T_R > 7.8$ MeV)recoil protons.
- The detectors granulation (vertical strips) allowed us to accurately identify backgrounds and subtract them separately for
  - *every detector*
  - *every* $\sqrt{T_R}$ *bin*
  - *every combination of beam/jet spins*

Essential kinematics

For elastic pp scattering:

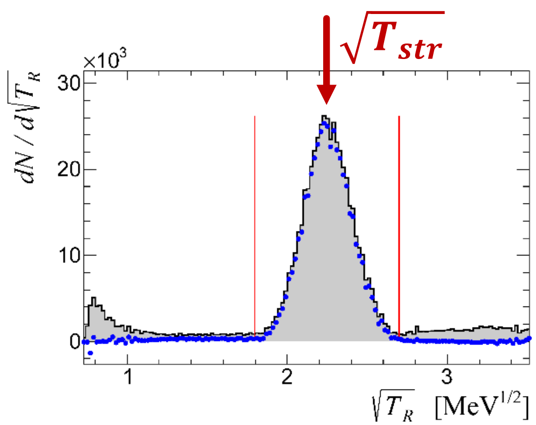
$$\tan\theta_R = \frac{z_{det} - z_{jet}}{L} = \frac{\kappa\sqrt{T_R}}{L} \qquad \kappa = \sqrt{\frac{T_R}{2m_p}\frac{E_{beam}+m_p}{E_{beam}-m_p+\cancel{T_R}}} \approx 18\,\frac{\mathrm{mm}}{\mathrm{MeV}^{1/2}}$$

In a Si strip

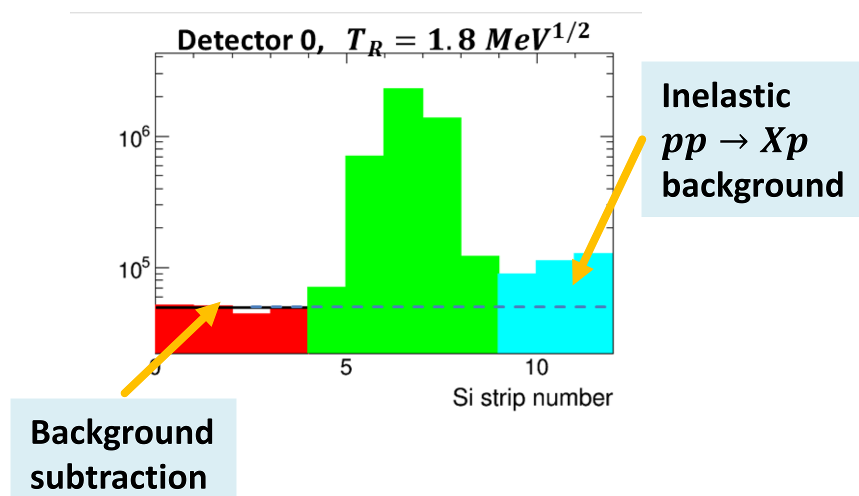
$$\left(\frac{d\sigma}{dt}\sqrt{T_R}\right)^{-1}\frac{dN}{d\sqrt{T_R}} = f\left(\kappa\sqrt{T_R} - \kappa\sqrt{T_{\mathrm{strip}}}\right)$$

$f(z)$ is jet density profile and
T_{strip} is kinetic energy corresponding to the strip position.

$dN/d\sqrt{T_R}$ distribution in a Si strip.



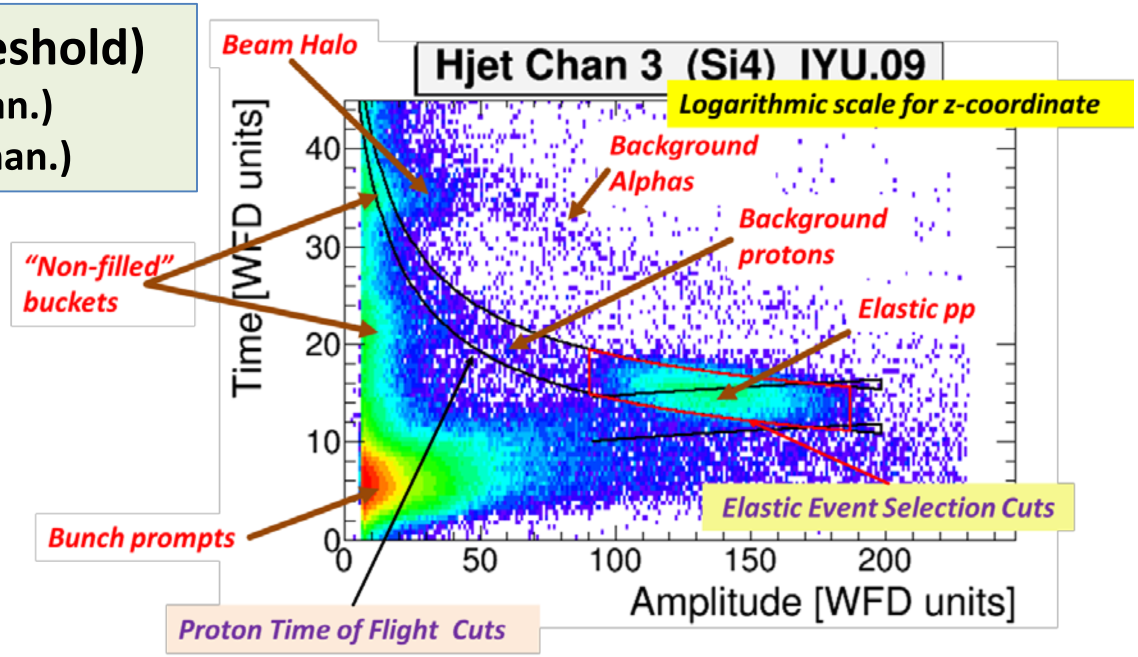
Event rate in the Si strips for fixed $\sqrt{T_R}$.



Background overview

Event rate (for the 0.5 MeV threshold)

- **Total: ~ 5 kHz (~ 50 Hz per chan.)**
- **Elastic pp: ~150 Hz (~ 1.5 Hz per chan.)**



The "prompts" strongly dominate in the event rate but do not affect the elastic pp data.

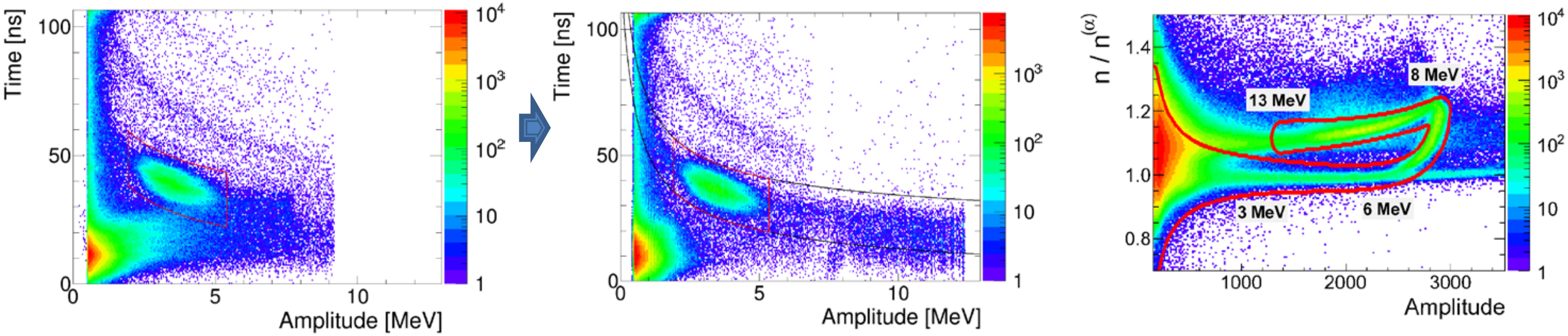
Background related the systematic uncertainties:

- **pA inelastic scattering - the dominant background $\sim 3\%$, can be subtracted**
- **"Molecular hydrogen" - $\lesssim 1\%$, effectively dilute the Jet polarization, can be subtracted**
- **Inelastic $pp \to Xp$ - Essential for 255 GeV, can be eliminated by the event selection cuts**

The elastic pp events can be reliably isolated

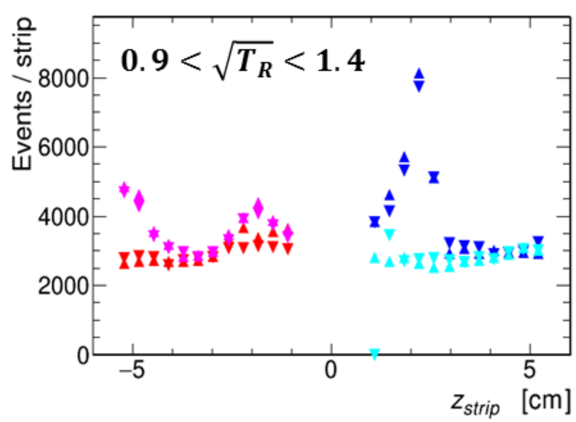
Possible improvements

To reconstruct kinetic energy of the punch through proton a simulation of the waveform dependence on the proton's energy is used. Some improvements are desired.



The background suppression is based on assumption that background has the same energy distribution in all Si strips. This does not work well for the molecular hydrogen background due to recoil proton tracking in the magnetic field. The corrections were simulated. Some improvements are are desired.

Empty Target (no Jet) Run dAu 9.8 GeV The event rate was expected to be the same in all Si strips.

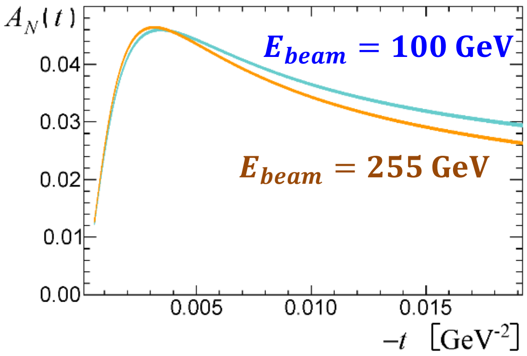


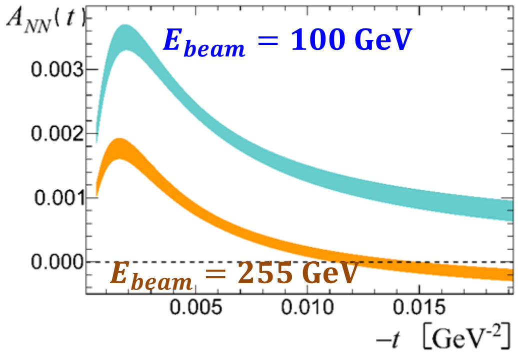
For EIC with only one proton beam, the effect can be strongly suppressed.

HJET performance at RHIC

- Systematic uncertainties of the proton beam polarization measurements are well controlled and are as low as $(\sigma_P/P)_{syst} \lesssim 0.5\%$
- A typical result for a 8-hour store: $\langle P_{\rm beam}\rangle = (\sim 56 \pm 2.0_{stat} \pm 0.3_{syst})\%$
- For elastic pp scattering, single and double spin-flip analyzing powers were determined with a high precision.

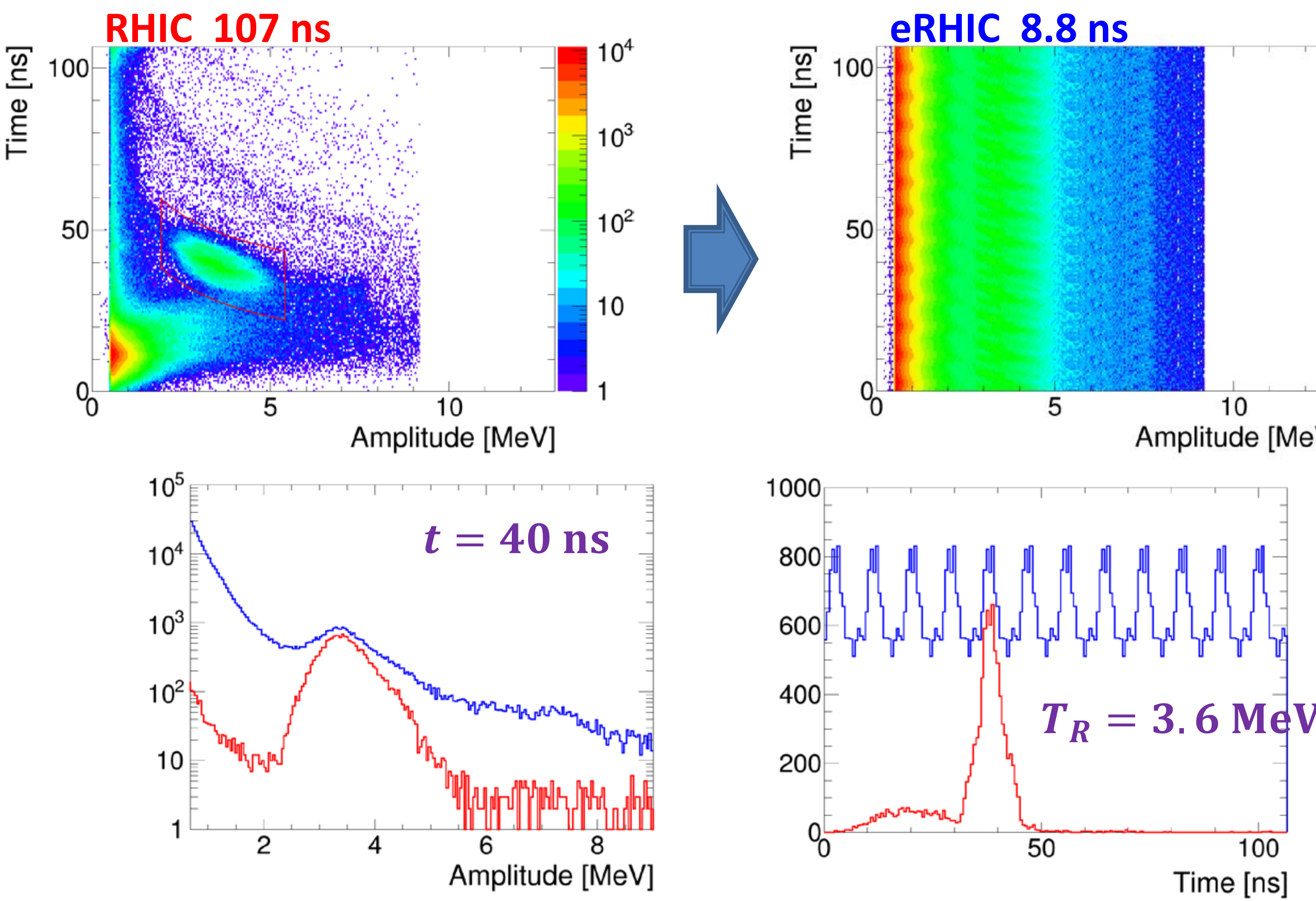
The $A_N(t)$ was measured with relative accuracy better than 1%.





The HJET, as is, satisfies the EIC requirements for an absolute proton polarimeter if the bunch frequency is ~ 100 ns.

From 120 bunches (107 ns) to 1320 bunches (8.8 ns)

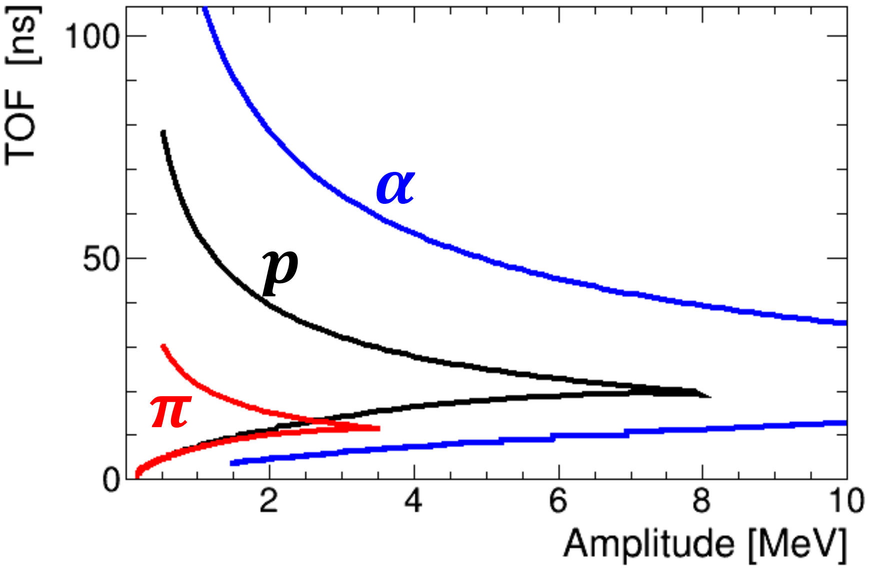


The background is about factor 3 larger than elastic signal (in the peak) !

What are the prompts ?

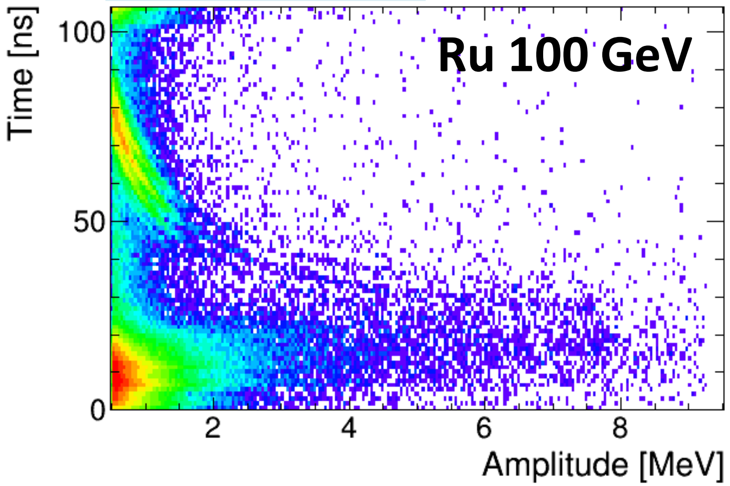
Simulation of Time amplitude distributions:

- **The prompts position is consistent with fast particles: $\pi, p, \alpha, \ldots$**
- **Detection of fast protons and alphas from the *pp* scattering is kinematically forbidden in HJET**
- **pA scattering is expected to be important for the prompts.**

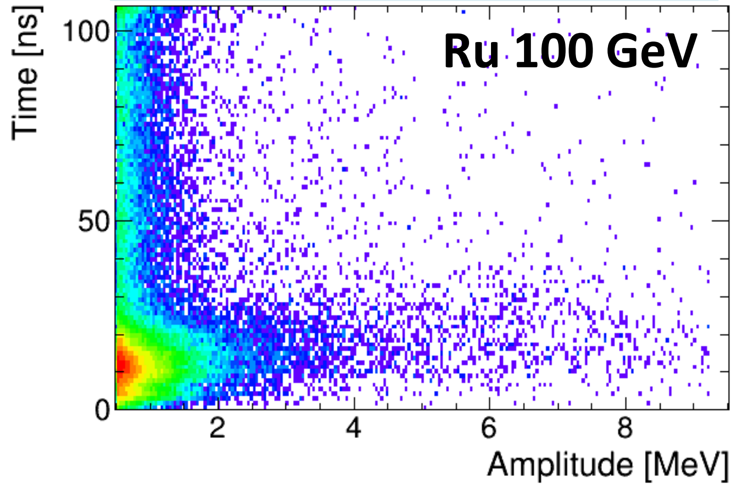


Prompt Correlation with Jet

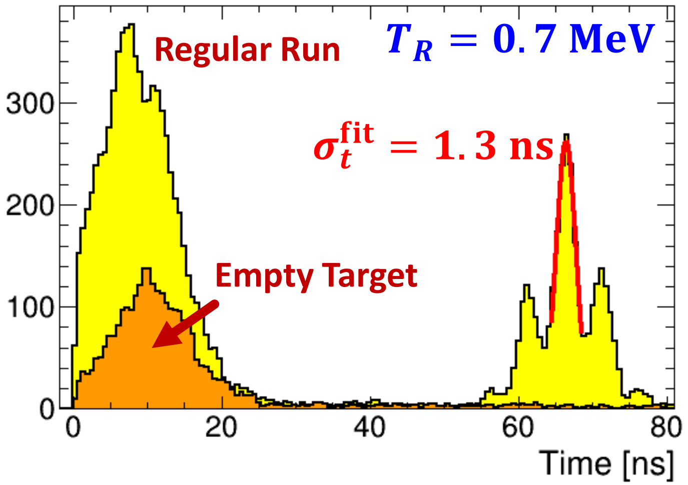
Regular run



Empty target run (Jet Off)



Integral beam intensity was approximately the same in these data samples.



$$\sigma_t^{\rm fit} = \sigma_t \oplus {\rm TOF}\,\frac{\sigma_E}{2T_R} \oplus \sigma_t^{\rm bunch}$$

About 70% of prompts are due to the beam scattering on the Jet.
The possible candidates for remaining 30% are

- **the beam scattering on the beam gas (too large ?)**
- **The beam halo scattering on the HJET frame**

Since $\sigma_E \sim 20$ keV

- $\sigma_t^{\rm eff}(0.7\ {\rm MeV}) = 1.2 \pm 0.1$ ns
- $\sigma_t\ \ (0.7\ {\rm MeV}) < 0.7$ ns

Reducing the distance to the detectors

The time distribution of detected signals is defined by the TOF, i.e. by the distance $L = 77\ \mathrm{cm}$ to the detectors. If $L \to \frac{L}{12} = 6.4\ \mathrm{cm}$ the bunches in EIC will be separated in the same way as currently in RHIC.

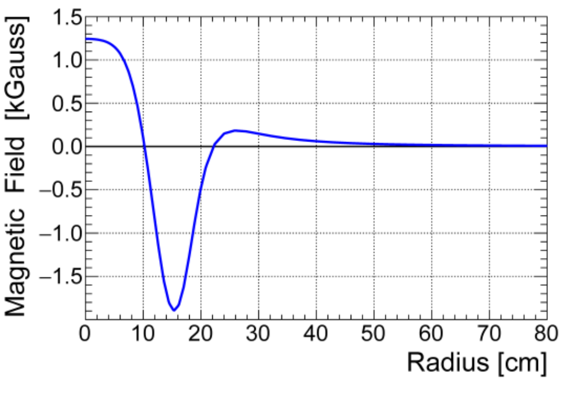
Advantages:

- with time resolution $\sigma_t < 0.7\ \mathrm{ns}$ the signals seem to be well separated from the prompts.
- Effectively, Si strips solid angle will be increased by the factor 144 which allow us to use smaller detectors (improving electronic noise and consequently time and energy resolution) and/or increasing the statistics.

Expected problems:

- The Jet effective size (in $\sqrt{T_R}$ units) will be enlarged by the factor 12. An important control for backgrounds will be lost.
- The detectors will be located inside the magnet. Many problems with the construction, performance and data analysis.
- The detector will be very close to the beam. Possible problems with beam halo rate and beam induced charge in detectors.

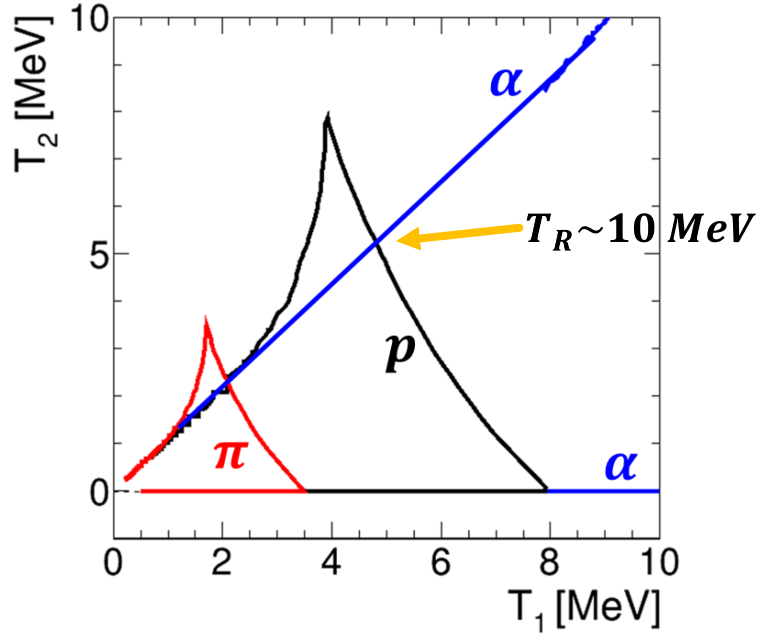
I do not think that this way is promising. However some optimization of the detectors location may be helpful.



Two-layers Si detectors

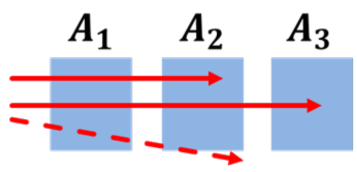
- Recoil protons with kinetic energies 1-10 MeV may be separated from the prompts background by comparison deposited energy in 2 Si layers.
- The background caused by low energy pions and alphas stopped in the first layer is expected to be small and may be suppressed using the standard background subtraction procedure.

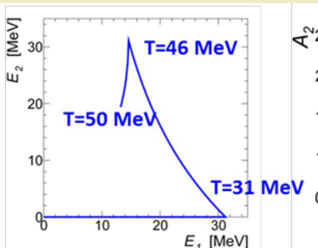
Correlation of the deposited energies in two Si layers

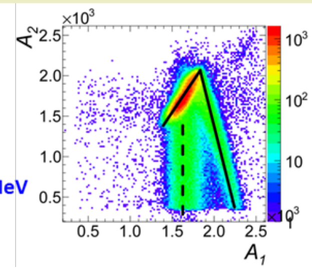


- **From the data analysis point of view, I am optimistic about this method.**
- **It might be convenient to test prototype during Gold Run at RHIC.**

We already used similar configuration in the telescope of scintillator counters at 200 MeV pCarbon polarimeter (Linac)







Unpolarized HJET

At RHIC, HJET provides determination of the absolute average beam polarization. However, the experiments need more information:

Polarization decay time

Polarization profile $R = \sigma_I^2/\sigma_P^2$ **=>** $\frac{\langle P\rangle_{exp}}{\langle P\rangle_{jet}} \approx 1 + (R_x + R_y)/4$

The p-Carbon polarimeters were used for these purpose. However, it will be very difficult to use p-Carbon with EIC bunch frequency.

Can the "unpolarized H-Jet" substitute p-Carbon ?

- **The jet density 100 times polarized jet (Anatoli Zelenski). If so, yhe statistical accuracy is better than 2% per hour.**
- **Continuoues measurement during the whole Run.**
- **The analyzing power is already well determined (from RHIC)**
- **However, no profile measurement.**

The model dependent correlation between average beam polarization and the "zero emittance polarization" $P_0 = P_{source}$

$$\langle P\rangle_{jet} = \frac{P_0}{(1+R_x)(1+R_y)} \quad \Rightarrow \quad \langle P\rangle_{\mathrm{exp}}(3\langle P\rangle_{\mathrm{jet}} + P_0)/4$$

The model is not considered as proved yet.

Can the study (using already available data) of the $\langle P\rangle_{jet}$ **dependence on the beam emittance** $\epsilon_{x,y}$ **help?**

HJET at JLEIC

- **Above, a possible performance of the H-JET polarimeter at eRHIC was considered.**
- **The discussion is also relevant for JLEIC.**
- **However, JLEIC bunch frequency $\sim 2\ \mathbf{ns}$ requires better time resolution. The electronic noise should be much better than at RHIC ($\sim 20\ \mathbf{keV}$). However this requirement may be not strict, if we take into account the bunch trains.**

Summary

- HJET shows a very good performance at RHIC
- Some improvements may need for
  - Separation of stopped and punch through protons
  - Better control for tracking in the magnetic field in the background subtraction procedure.
- HJET can not be used "as is" due to the much higher bunch frequency.
- Two layer's Si detectors may help to resolve the problem.
  - The detector prototype could be tested with RHIC Heavy Ion beam.
- More study is needed for "unpolarized HJET"

Backup

Systematic correction and uncertainties

Detailed study of systematic errors for the polarization measurements at **255 GeV** is given in PSTP 2017 Proceedings.

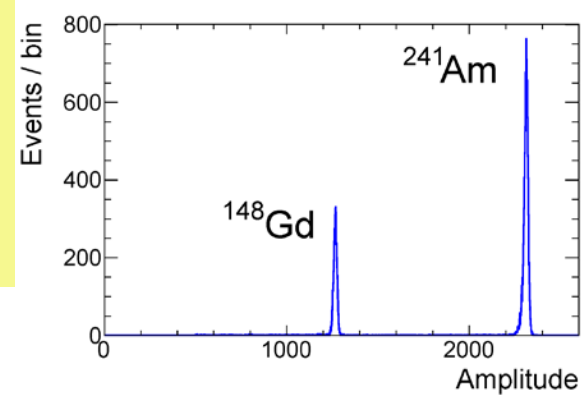
The inelastic scattering $pp \to Xp$ uncertainty is irrelevant for **100 GeV**

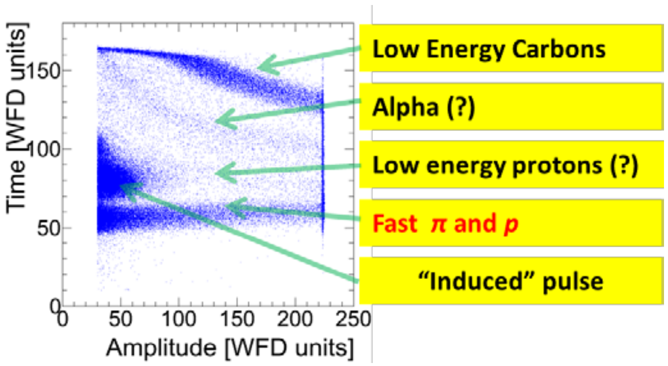
For analyzing power measurements we should also consider systematic corrections/uncertainties which are effectively canceled in the beam polarization measurements.

Source	$\delta P/P$ (%)	σ_P/P (%)
Long term stability		$\mathbf{0.1}$
Jet Polarization		$\mathbf{0.1}$
Jet H_2		$\mathbf{0.06}$
Flat H_2	$\mathbf{+0.06}$	$\lesssim \mathbf{0.1}$
pA scattering		$\lesssim \mathbf{0.2}$
p+p→X+p	$\mathbf{+0.15}$	$\mathbf{0.1}$
Jet spin correlated noise		$\lesssim \mathbf{0.2}$
Total	$\mathbf{+0.21}$	$\lesssim \mathbf{0.37}$

- Corrections to the background subtraction due to the recoil proton tracking in the Holding Field Magnet were simulated
- Corrections due to vertical size of the detectors $\boldsymbol{P_{jet}^{\mathrm{eff}} = P_{jet}\langle \sin\varphi \rangle = 0.997\, P_{jet}}$
- The energy calibration (gains and dead-layers) was done using α-sources. It was not verified for recoil protons. Using indirect methods we established an upper limit for the calibration uncertainty as

$$\boldsymbol{\delta T = (\pm 15\ \mathrm{keV}) \oplus (\pm 0.01\, T)}\ .$$




Time [WFD units]
150
100
50
0
0
50
100
150
200
250
Amplitude [WFD units]
Low Energy Carbons
Alpha (?)
Low energy protons (?)
Fast π and p
"Induced" pulse