BNL EIC Polarimetry Monthly Meeting
December 2, 2020 (online)
https://indico.bnl.gov/event/10147/

^{3}He *breakup in the helion beam polarization measurements at EIC*

A.A. Poblaguev

Brookhaven National Laboratory

BROOKHAVEN NATIONAL LABORATORY

$^{3}\mathrm{He}$ *Polarimetry at EIC*

The EIC requirement for the $^{3}\mathrm{He}$ beam polarization measurement: $\sigma_P/P \lesssim 1\%$

Several polarimetry methods can be considered:

- **Polarized $^{3}\mathrm{He}$ jet target**
  (we have no experience with such a polarimeter)
- **Polarized hydrogen jet target (HJET)**
  ($p^{\uparrow}h$ and $h^{\uparrow}p$ hadronic spin-flip must be predetermined elsewhere.)
- **"Zero emittance polarization P_0"**
  (the conservation of P_0 is not proved yet. New methods of beam control may be required)

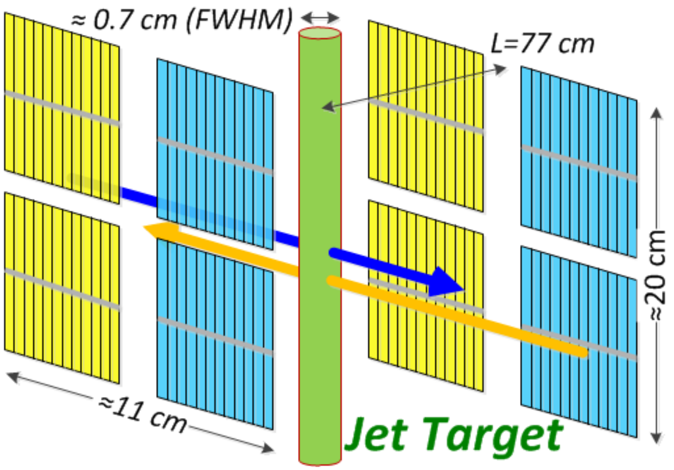
All methods should be developed to confidently measure the $^{3}\mathrm{He}$ beam polarization at EIC.

There is a concern about the beam $^{3}\mathrm{He}$ breakup in the gas jet measurements (both for $^{1}\mathrm{H}$ and $^{3}\mathrm{He}$ jets)

The main goal of this study: an evaluation of the breakup effects in the polarization measurements

Conclusion: the breakup corrections are strongly canceled in the beam/jet asymmetry ratio measurements.

The HJET recoil spectrometer



The recoil proton kinematics: $t = -2m_p T_R$

$$\tan\theta_R = \frac{z_{\text{det}} - z_{\text{jet}}}{L} = \frac{\kappa\sqrt{T_R}}{L} \qquad \kappa \approx 18\,\frac{\text{mm}}{\text{MeV}^{1/2}}$$

The energy range, $0.5 < T_R < 10\ \text{MeV}$, is defined by the detector geometry.

The measured single spin asymmetries:

$$a_{\text{beam}} = \langle A_{\text{N}} \rangle P_{\text{beam}} \Rightarrow \frac{\sqrt{N_R^{\uparrow} N_L^{\downarrow}} - \sqrt{N_R^{\downarrow} N_L^{\uparrow}}}{\sqrt{N_R^{\uparrow} N_L^{\downarrow}} + \sqrt{N_R^{\downarrow} N_L^{\uparrow}}}$$

$\langle A_{\text{N}} \rangle \sim 0.037$

The rate and acceptance systematic errors are strongly suppressed

Since the jet protons are polarized, the beam polarization can be determined with no knowledge of $\langle A_{\text{N}} \rangle$.

$$P_{\text{beam}} = \frac{a_{\text{beam}}}{a_{\text{jet}}} P_{\text{jet}} \qquad P_{\text{jet}} \approx 0.96 \pm 0.001$$

Proton Runs 15 (100 GeV) & 17 (255 GeV)

A.A. Poblaguev *et al.*, Phys. Rev. Lett. **123**, 162001 (2019)
A.A. Poblaguev *et al.*, Nucl. Instr. Meth. A **976**, 164261 (2020)

Proton Beam Polarization:

$$P_{\text{beam}} = \frac{a_{\text{beam}}}{a_{\text{jet}}} P_{\text{jet}} \qquad P_{\text{jet}} = 0.957$$

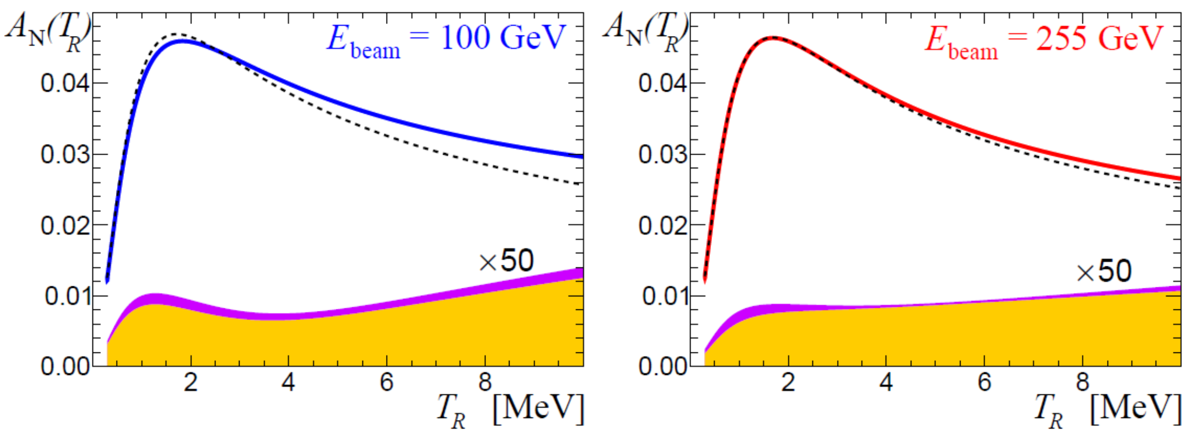
Typically, for 8 hour stores (Run 17, 255 GeV):

$$P_{\text{beam}} \approx (56 \pm 2.0_{\text{stat}} \pm 0.3_{\text{syst}})\%$$

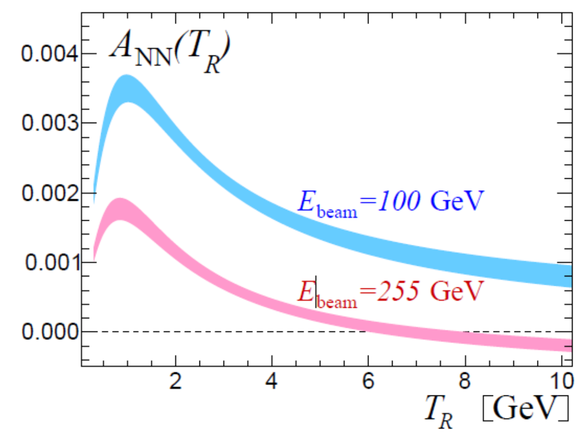
$$\sigma_P^{\text{syst}} / P_{\text{beam}} \lesssim 0.5\%$$

Elastic *pp* analyzing powers:

Single Spin



Double Spin



- **The displayed analyzing powers are model independent**
- **The analyzing powers can be extrapolated to other beam energies**

$h^{\uparrow}p$ scattering in an unpolarized hydrogen jet

For elastic scattering in the CNI region, the analyzing power is defined by the interference of the *spin-flip* $\phi_5(s,t)$ and *non-flip* $\phi_+(s,t)$ amplitudes

$$A_N(s,t) = -2\,\mathrm{Im}(\phi_5^*\phi_+)/|\phi_+|^2$$

$\phi = \phi^{\mathrm{had}} + \phi^{\mathrm{em}} e^{i\delta_C}$ (hadronic and electromagnetic components)

$T_R = -t/2m_p$ (recoil proton kinetic energy, $T_R < 10\ \mathrm{MeV}$)

$\phi_5^{\mathrm{em}}\,\mathrm{Im}\,\phi_+^{had}$ $\phi_+^{\mathrm{em}}\,\mathrm{Im}\,\phi_5^{had}$ $\mathrm{Re}\,\phi_5^{\mathrm{had}}\,\mathrm{Im}\,\phi_+^{had}$

$$A_{\mathrm{N}}(T_R) = A_{\mathrm{N}}^{\mathrm{nf}}(T_R) \times \left(\kappa_h - 2I_5^{hp} - 2R_5^{hp}\,T_R/T_c\right)$$

$$A_{\mathrm{N}}^{\mathrm{nf}}(T) = \sqrt{\frac{2T_R}{m_p}} \times \frac{T_c/T_R}{(T_c/T_R)^2 - 2\tilde{\rho}\,T_c/T_R + 1}$$

$\left|\phi_+^{had}\right|^2 \propto d\sigma/dt$

$\kappa_h = \mu_h/Z_h - m_p/m_h = -1.398$

$T_c = 4\pi\alpha/m_p\sigma_{\mathrm{tot}}^{hp} \approx 0.7\ \mathrm{MeV}$

$\tilde{\rho} = \rho + \delta_C \approx -0.05$

$|r_5| = |R_5 + iI_5| = \mathcal{O}(1\%)$

- Some small corrections are omitted here
- Since helion spin is mostly carried by the constituent neutron, the $h^{\uparrow}p$ value of r_5 can be related to the $p^{\uparrow}p$ one, measured at HJET

Analyzing power in elastic $h^{\uparrow}p$ and $p^{\uparrow}h$ scattering

- **Dominant component, an anomalous magnetic moment κ, of the spin-flip part of A_{N} is well determined in QED. The hadronic spin-flip amplitudes are assumed to be related, with a sufficient accuracy, to the experimentally measured proton-proton one $r_5 \approx -0.016 - i\,0.005$ (100 GeV).**
  - **For polarized helion:**
    $$\kappa_h = \mu_h/2 - m_p/m_h - m_h/E_{\mathrm{beam}} = -1.428$$
    $$r_5^{hp} = 0.27 r_5 \pm 0.001 \pm i\,0.001$$
  - **For polarized proton**
    $$\kappa_p = \mu_p - 1 - m_p^2/m_h E_{\mathrm{beam}} = 1.790$$
    $$r_5^{ph} = r_5 \pm 0.001 \pm i\,0.001$$
- **The non-flip part of A_{N}, defined by an elastic cross section $d\sigma/dt\,(\sigma_{\mathrm{tot}}, \rho, B)$, is common for $h^{\uparrow}p$ *and* $p^{\uparrow}h$ analyzing power. Precision experimental determination of the cross section parametrization is not available. *This may be an issue.***

Here, we will assume that the elastic analyzing power is well known, i.e. we will only evaluate the $^3\mathrm{He}$ breakup correction to A_{N}.

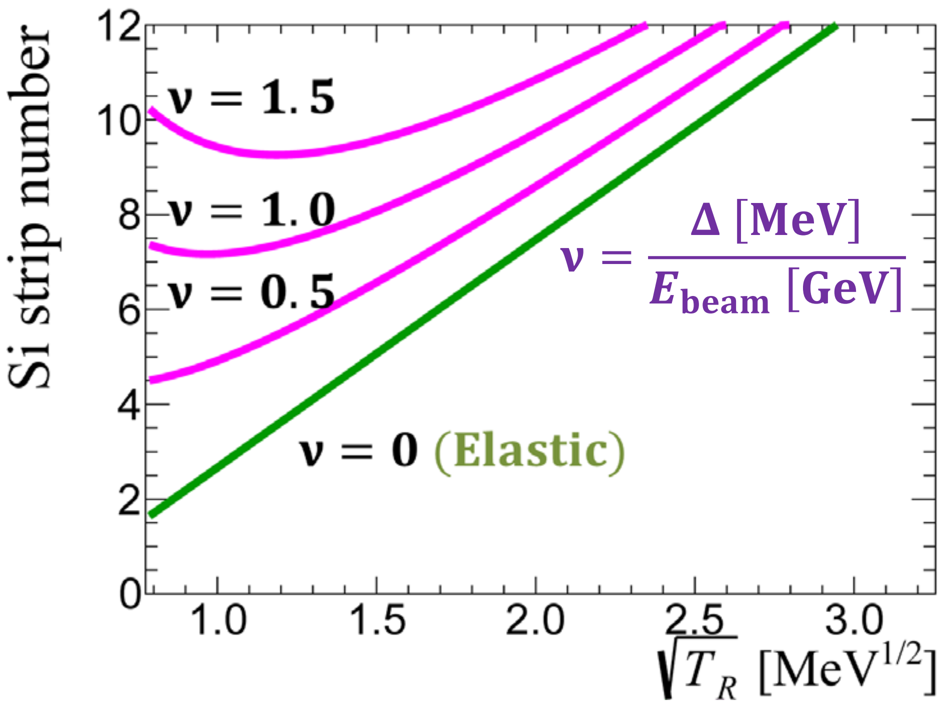
Inelastic scattering

At the HJET, the elastic and inelastic events can be separated by studying recoil proton energy and angle (i.e. the Si strip location). For $A + p \to X + p$ scattering:

$$\tan\theta_R = \frac{z_{\mathrm{str}} - z_{\mathrm{jet}}}{L} = \sqrt{\frac{T_R}{2m_p}} \times \left[1 + \frac{m_p^2}{m_A E_{\mathrm{beam}}} + \frac{m_p \Delta}{T_R E_{\mathrm{beam}}}\right]$$

$$\Delta = M_X - m_p$$

At HJET, $\tan\theta_R$ is discriminated by the Si strip number.



For given T_R, the background rate, excluding inelastic scattering, is expected to be the same in all Si strips.

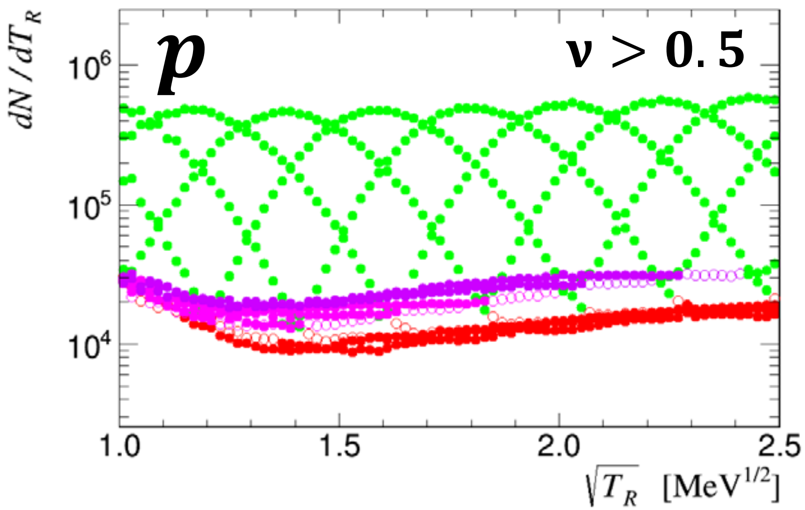
The inelastic events can be identified by comparing the background with large and small values of z_{str}

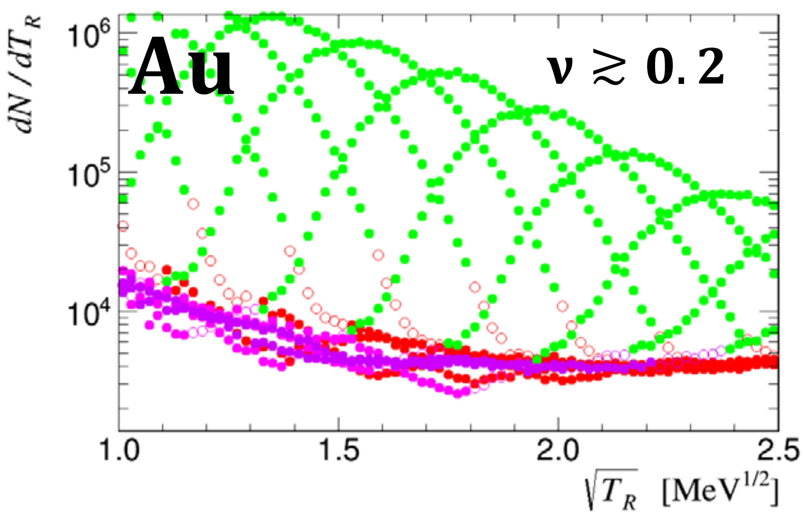
However, the result may be affected by

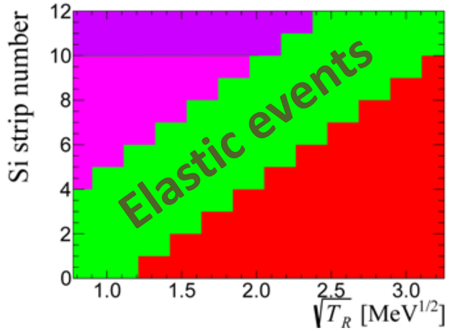
- the recoil proton tracking in magnetic field (especially for $T_R < 2.5$ MeV)
- partial shadowing of the detector

Inelastic scattering for the HJET measurements

Superposition of $dN/d\sqrt{T_R}$ in all strips of a Si Detector







color legend

Pion production: $p + p \rightarrow (\pi + X) + p$

$E_{\mathrm{beam}} = 255\ \mathrm{GeV},\ \Delta > 135\ \mathrm{MeV}$

- The inelastic events are well isolated
- We know how to handle this data in proton beam measurements.
- The method can be straightforwardly applied to the helion beam

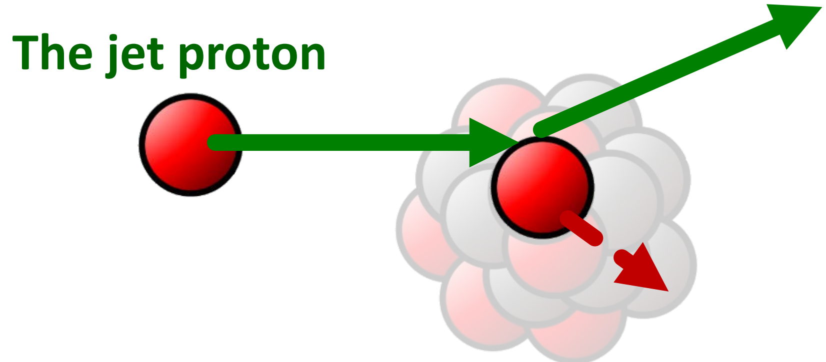
Au breakup: $\mathrm{Au} + p \rightarrow X + p$

$E_{beam} = 27.2\ GeV/\mathrm{n},\ \Delta \gtrsim 6\ MeV$

No evidence of breakup is observed in the Gold beam (3.85-31.2 GeV) measurements $\lesssim \mathrm{few} \times 10^{-3}$

Why is Au *breakup not observed at HJET ?*

For incoherent proton-nucleus scattering:



Simple kinematical consideration gives:

$$\Delta = \left(1 - \frac{m_p}{M_A}\right) T_R + p_x^* \sqrt{\frac{2T_R}{m_p}}$$

where T_R is the jet recoil proton energy and p_x^* is the target nucleon transverse momentum in the nucleus. For HJET $T_R < 10\ \mathrm{MeV}$ and assuming $p_x^* < 250\ \mathrm{MeV}/c$, one finds $\Delta < 50\ \mathrm{MeV} \ll M_A$ **(breakup is strongly suppressed by phase space).**

If $f(p_x, \sigma)dp_x$ is the nucleon momentum distribution in a nucleus then, in HJET measurements,

$$dN(T_R, \Delta)/d\Delta \propto F(T_R, \Delta) \times \Phi(\Delta)$$

$$F(T_R, \Delta) = \mathrm{f}(\Delta - \Delta_0, \sigma_\Delta), \quad \Delta_0 = (1 - m_p/M_A)T_R, \quad \sigma_\Delta = \sigma\sqrt{2T_R/m_p}$$

For the $h + p \rightarrow (p + d)_h + p$ breakup, the phase space factor is equal to

$$\Phi(\Delta) = \frac{\sqrt{2m_p m_d}}{4\pi m_h} \times \sqrt{\frac{\Delta - \Delta_{\mathrm{thr}}^h}{m_h}}, \qquad \Delta_{\mathrm{thr}}^h = m_p + m_d - m_h = 5.5\ \mathrm{MeV}$$

The effective amplitude

$$\phi(t) \to \phi(t) + \int d\Delta\ \tilde{\phi}(t,\Delta)$$

($\phi(t)$ and $\tilde{\phi}(t,\Delta)$ do not interfere)

The effective breakup amplitude

$\tilde{\phi}(t,\Delta) = \phi(t) \times k(t,\Delta)$

$k(t,\Delta)$ is "the decay" amplitude

$$\left|\phi_+^{\mathrm{had}}\right|^2 \to \left|\phi_+^{\mathrm{had}}\right|^2 \times [1 + \omega(t)]$$

$$\omega(t) = \int d\Delta\ |k(t,\Delta)|^2 F(t,\Delta)\Phi(\Delta)$$

$$= \langle |k(t,\Delta)|^2 \rangle \omega_\Phi(t)$$

$$\mathrm{Im}\ \phi_5^{\mathrm{em}} \phi_+^{\mathrm{had}} \to \kappa \times [1 + \tilde{\omega}(t)]$$

$$\tilde{\omega}(t) = \int d\Delta\ \mathrm{Re}[\tilde{\kappa}/\kappa \times k(t,\Delta)]\ F(t,\Delta)\Phi(\Delta)$$

$$|\tilde{\omega}(t)| \le \sqrt{\omega(t)\omega_\Phi(t)}$$

The breakup corrections to A_N are the same for $p^\uparrow h$ and $h^\uparrow p$, if neglect r_5 !

(the uncorrelated corrections are of about $\sim r_5\tilde{\omega}$)

For the $A \to A_1 + A_2$ breakup,

$$\Phi(\Delta) = \frac{\sqrt{2m_1 m_2}}{4\pi m_A} \times \sqrt{\frac{\Delta - \Delta_{\mathrm{thr}}^A}{m_A}} \propto m_A^{-1} \qquad \text{(or } \propto m_A^{-1/2} \text{ if } m_1 \approx m_2\text{)}$$

A model to describe helion and/or deuteron breakup

$$\left.\frac{dN(T_R,\Delta)}{d\Delta}\right|_{\text{breakup}} = \left.\frac{dN(T_R,\Delta)}{d\Delta}\right|_{\text{elastic}} \times \left|k\left((T_R,\Delta)\right)\right|^2 F(T_R,\Delta)\,\Phi(\Delta)$$

$k(T_R,\Delta)$ is the ratio of the breakup and elastic amplitudes

The model used is based on the following approach:

- $k(T_R,\Delta) = \text{const}$
- $F(T_R,\Delta)$ **is derived from one of the momentum distribution functions:** $f_{\mathrm{G}}(p_x,\sigma),\ f_{\mathrm{BW}}(p_x,\sigma),\ f_{\mathrm{H}}(p_x,\sigma)$, **considering σ as an adjustable parameter.**

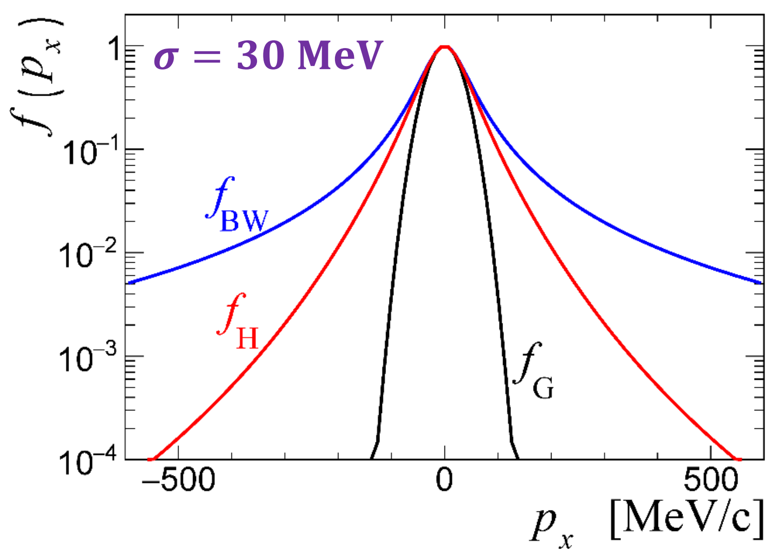
$$f_{\mathrm{G}}(p_x,\sigma) \propto \exp(-p_x^2/2\sigma^2)/\sqrt{2\pi}\sigma$$

$$f_{\mathrm{BW}}(p_x,\sigma) \propto \pi^{-1}\sqrt{2}\sigma/(p_x^2+2\sigma^2)$$

$f_{\mathrm{H}}(p_x,\sigma = 30\ \mathrm{MeV})$ is expected to be a nucleon momentum distribution function for the deuteron.

All three functions have the same behavior around $p_x = 0$:

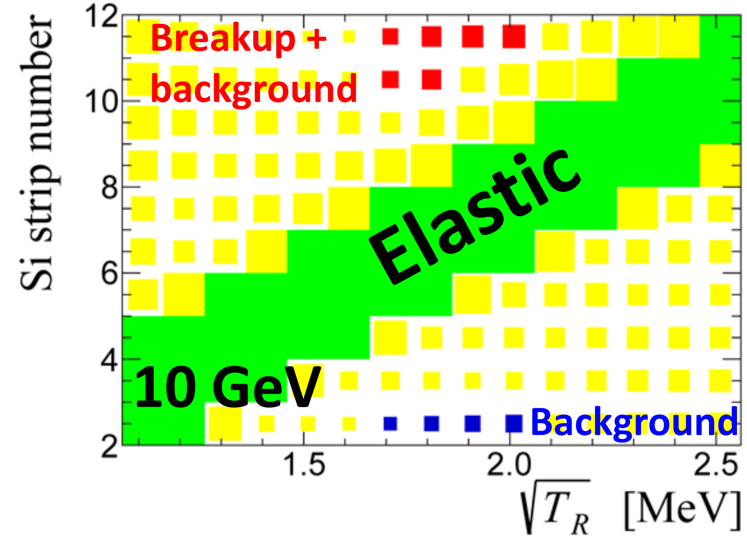
$$f(p_x,\sigma) = f(p_x,\sigma)\times[1-p_x^2/2\sigma^2]$$



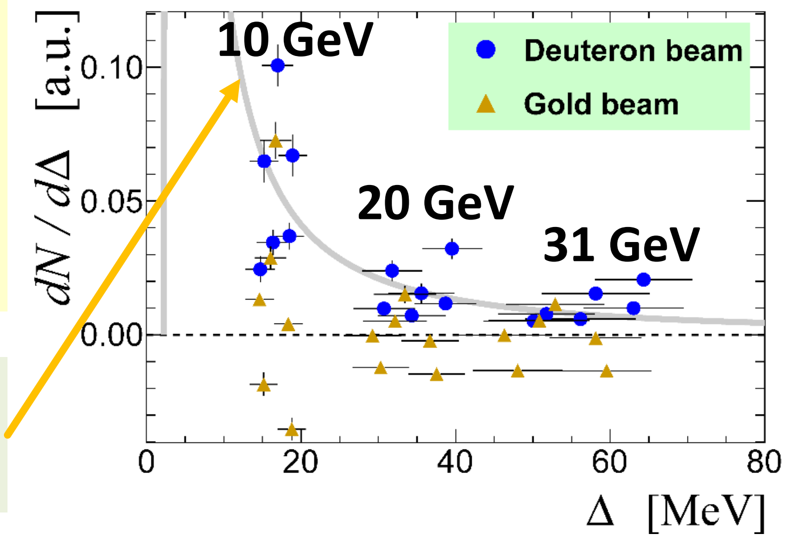
The breakup events in the deuteron beam measurements

- In RHIC Run 16, energy scan of deuteron-gold scattering had been made.
- HJET operation in this Run allowed us to experimentally evaluate the **deuteron** $\left(\Delta^{d}_{\mathrm{thr}}=2.2\ \mathrm{MeV}\right)$ breakup rate from the 10, 20, and 31 GeV/n beam data.
- The suggested breakup model was ***qualitatively*** confirmed in the data analysis.
- For the deuteron beam, the breakup events can be clearly identified.
- However, the numerical estimate of the breakup rate is not accurately normalized due to
  - effects of the recoil proton tracking in the holding field magnet and partial shadowing of the detectors by the HJET collimators
  - theoretical uncertainties in the model and extrapolation of the measurements to low Δ.

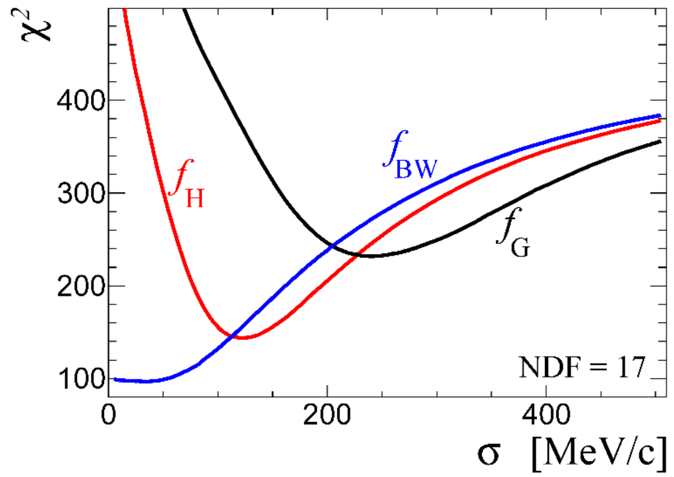
The peak elastic rate is $\sim 75\ k/\mathrm{bin}$
The histogram maximum is $5\ k/\mathrm{bin}$



For comparison, the distribution, based on $f_{BW}(p_x, \sigma = 35\ \mathrm{MeV})$ and calculated for $T_R = 3.5\ \mathrm{MeV}$, is shown. The distribution has a maximum of 1 at $\Delta \approx 3\ \mathrm{MeV}$.



The results of a fit to deuteron data



Four functions $f(p_x, \sigma)$ were used in the fit:
$f_H(\sigma = 30\text{ MeV})$ - compatible with Dubna measurements,
f_H, f_G, and f_{BW} with σ minimizing χ^2

The breakup events are clearly identified for the deuteron beam, but no evidence of such events appeared for gold (in the same measurement)

n_d and n_{Au} are normalization factors for the simulation
f_d is the evaluated fraction of the breakup events for the 100 GeV deuteron beam
f_h is the projected fraction for the helion beam

			Deuteron Beam			Gold Beam
$f(p_x, \sigma)$	σ [MeV/c]	χ^2	n_d	f_d [%] (2.8–4.2 MeV)	f_h [%] (1–10 MeV)	n_{Au}
f_H	30	403.1	0.923 ± 0.198	11.1 ± 2.4	4.0 ± 0.9	0.135 ± 0.189
f_H	122	143.6	0.180 ± 0.019	3.3 ± 0.3	1.9 ± 0.2	-0.010 ± 0.029
f_G	240	231.9	0.132 ± 0.019	2.6 ± 0.4	1.6 ± 0.2	-0.007 ± 0.022
f_{BW}	35	96.6	0.400 ± 0.033	5.7 ± 0.5	2.7 ± 0.2	-0.022 ± 0.065
$1/\chi^2$ weighted average				5.0 ± 1.4	2.4 ± 0.4	0.000 ± 0.027

Expectations for the helion beam measurements

$f(p_x,\sigma)$	σ [MeV/c]	χ^2	ω_0 [%]	$\omega_1 T_c$ [%]	$\tilde{\omega}_0$ [%]	$\tilde{\omega}_1 T_c$ [%]
f_{H}	30	403.1	−0.92	0.76	−0.10	0.08
f_{H}	122	143.6	0.74	0.20	0.21	0.05
f_{G}	240	231.9	0.74	0.15	0.24	0.05
f_{BW}	35	96.6	0.37	0.38	0.10	0.07
	$1/\chi^2$ weighted average		0.41 ± 0.28	0.33 ± 0.10	0.13 ± 0.06	0.06 ± 0.01

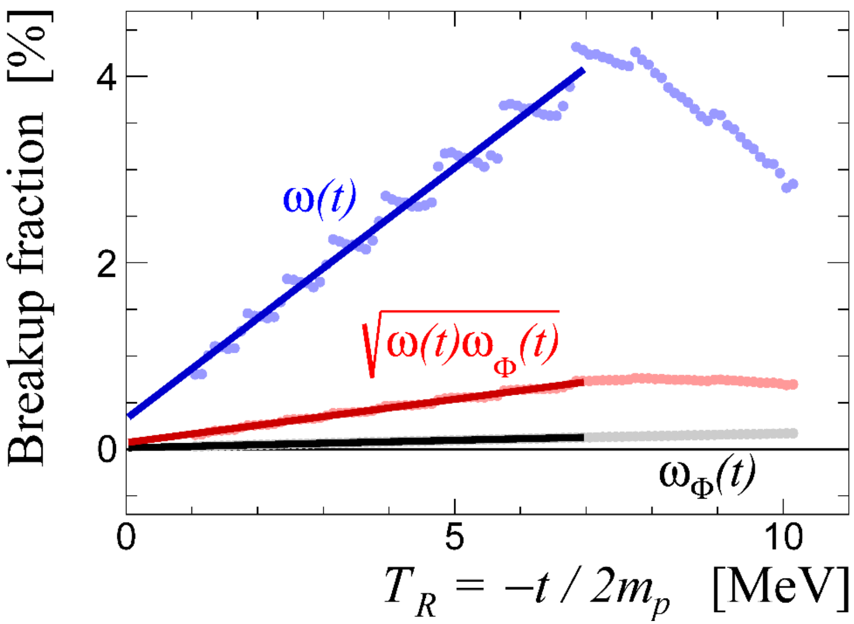
$$\omega(T_R) = \omega_0 + \omega_1\, T_R/T_c$$

$$\sim 0.4\% + 0.4\%\, T_R/\mathrm{MeV}$$

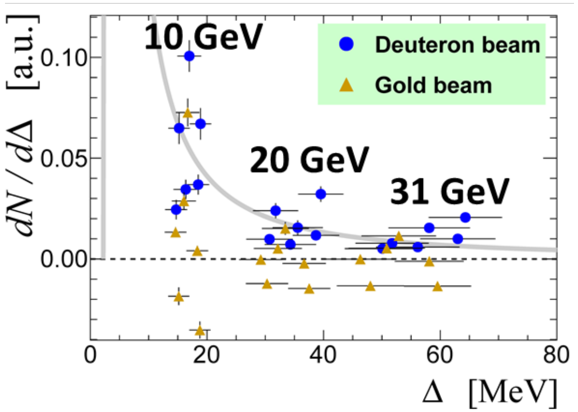
$$\tilde{\omega}\,(T_R) = \sqrt{\omega\omega_\Phi} = \tilde{\omega}_0 + \tilde{\omega}_1\, T_R/T_c$$

$$\sim 0.13\% + 0.08\%\, T_R/\mathrm{MeV}$$

The evaluation includes the effects of the event selection cuts and of detector acceptance.



How reliable is the evaluation of breakup rates ?



- The Run 16 deuteron data used was affected by many experimental uncertainties of order of the searched effect.
- The experimental evaluation was done for $\Delta > 15$ MeV, i.e. most of the breakup data remained under control.
- The theoretical model for $dN/d\Delta$ is not well justified
- Application to the helion beam case is model dependent.

A verification of the evaluated breakup rate is needed !

Improving the evaluation of the breakup rate could result from short (~ 1 day) measurements with an unpolarized ^{3}He beam at RHIC:

- Beam energies of 10.6 GeV (RHIC injection energy for helion), 5 GeV, 20 GeV.
- Single beam
- The holding field magnet OFF.

In the proposed measurements, ^{3}He breakup events can be isolated with reduced experimental uncertainties for low $\Delta \gtrsim 5.5$ MeV and in wide range of T_R.

Breakup rate in a ^{6}Li measurement

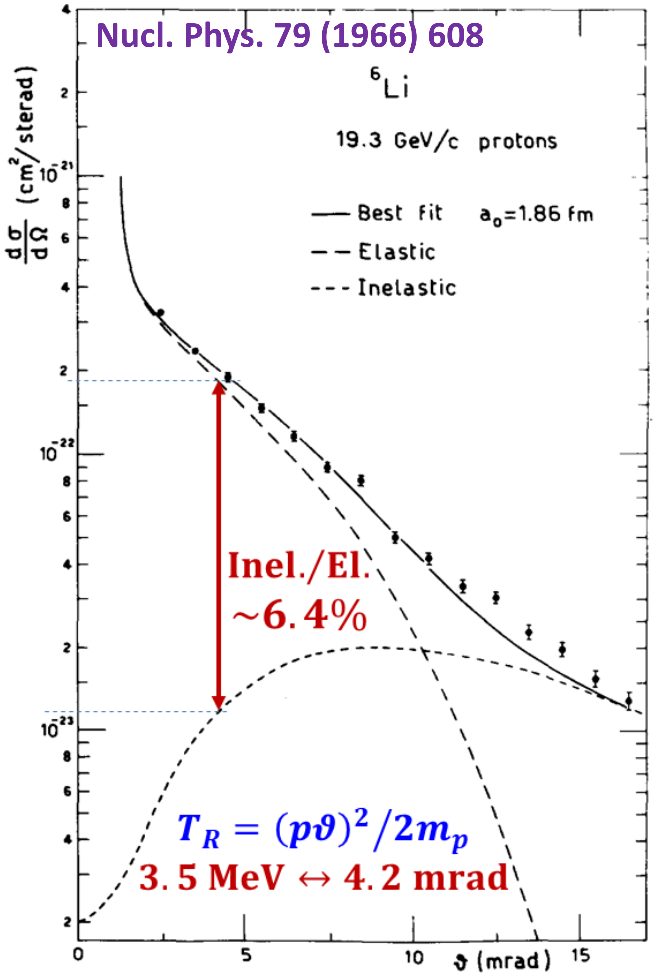


Fig. 1. The experimental data of ref. [4] on the scattering of 19.3 GeV/*c* protons by ^{6}Li are shown together with the result of the best fit. Elastic and inelastic contributions are shown separately.

Experimental results on elastic+breakup $d\sigma/dt$ for a 19.3 GeV/c proton beam scattering on ^{6}Li were fit by R.J Glauber and Matthiae, Nucl. Phys. B21 (1970) 135

For equivalent $T_R = 3.5$ MeV ($\vartheta = 4.2$ mrad):

$$\left.\frac{d\sigma}{dt}\right|_{\text{breakup}} \Big/ \left.\frac{d\sigma}{dt}\right|_{\text{elastic}} = 6.4\%\ (\,^{6}\text{Li})$$

Assuming the following breakup channels,

- $^{6}_{3}\text{Li} + 6.1\ \text{MeV} \to {}^{5}_{3}\text{Li} + n,$
- $^{6}_{3}\text{Li} + 4.8\ \text{MeV} \to {}^{5}_{2}\text{He} + p,$
- $^{6}_{3}\text{Li} + 1.6\ \text{MeV} \to \alpha + d,$
- $^{6}_{3}\text{Li} + 17\ \text{MeV} \to h + t,$

An application (phase space correction only) to ^{3}He, based on the model used at HJET, gives:

$$\left.\frac{d\sigma}{dt}\right|_{\text{breakup}} \Big/ \left.\frac{d\sigma}{dt}\right|_{\text{elastic}} = 2.2\%\ (\,^{3}\text{He})$$

This comparison with ^{6}Li significantly improves confidence in the ^{3}He breakup rate, $2.0 \pm 0.4\%$, evaluated using the analysis of the HJET deuteron beam data.

Upper limit for $^{3}\mathrm{He}$ breakup rate

The inclusive (elastic + breakup) cross section

$$\left.\frac{d\sigma}{dt}\right|_{\mathrm{incl}} = \left.\frac{d\sigma}{dt}\right|_{\mathrm{el}} \times [1 + \omega(t)]$$

$$d\sigma_{\mathrm{el}}/dt = \sigma_{tot}^2 e^{Bt}/16\pi$$

$$R = \sigma_{\mathrm{el}}/\sigma_{\mathrm{tot}} \propto \sigma_{\mathrm{tot}}/B$$

For $t \to 0$:

$$\omega(t) \to 0, \quad d\sigma/dt|_{incl} = C \times \exp B_{\mathrm{incl}} t, \quad d\sigma/dt|_{\mathrm{el}} = C \times \exp B_{hp} t$$

$B_{pp} = 11.2 \pm 0.2\ \mathrm{GeV}^{-2}$ is elastic pp "slope" (100 GeV)

$B_{hp} = B_{pp} + a^2/2 \approx 38\ \mathrm{GeV}^{-2}$ (harmonic oscillator model)

$$\omega(t) \approx \left(B_{\mathrm{incl}} - B_{hp}\right)t$$

N.H. Buttimore et al., Phys. Rev. D **64**, 094021 (2001)

Since $R_{hp}^{\mathrm{incl}} \leq R_{pp}$ ⇨ $B_{incl} > B_{pp}\, \sigma_{\mathrm{tot}}^{hp}/\sigma_{\mathrm{tot}}^{pp} = f A_h B_{pp}$

$$A_h = 3$$

$$f = \sigma_{\mathrm{tot}}^{hp}/A_h\sigma_{\mathrm{tot}}^{pp} \approx 0.9$$

$$\omega(t) < \omega^{\max}(t) = 2m_p T_R \times \left(B_{hp} - f A_h B_{pp}\right) = 1.6\%\ T_R/\mathrm{MeV}$$

The upper limit $\omega^{\max}(t)$ is only about a factor 2.6 larger than the rate $\omega^{(d)}(t)$ evaluated from the deuteron beam analysis

The breakup rates used to evaluate corrections to elastic A_{N}

The $^3\mathrm{He}$ breakup rate evaluated in the HJET deuteron beam data analysis is reasonably consistent with

- **the evaluation of the breakup rate in $p\,^6\mathrm{Li}$ scattering**
- **the estimate of the upper limit for $p\,^3\mathrm{He}$ scattering**

Therefore:

$$\omega(T_R) = \omega_0 + \omega_1\, T_R/T_c = (0.41 \pm 0.28)\% + (0.33 \pm 0.10)\%\, T_R/T_c$$

$$\widetilde{\omega}\,(T_R) = \widetilde{\omega}_0 + \widetilde{\omega}_1\, T_R/T_c = (0.11 \pm 0.06)\% + (0.06 \pm 0.01)\%\, T_R/T_c$$

$$|\widetilde{\omega}\,(T_R)| < 0.8\%$$

Generally, due to event selection cuts, $\omega_0 \neq 0$ and $\widetilde{\omega}_0 \neq 0$.
To evaluate the upper limit, we will use

$$\omega^{\max}(T_R) = 3 \times \omega(T_R), \qquad \widetilde{\omega}^{\max}(T_R) = 2 \times \widetilde{\omega}(T_R), \qquad |\widetilde{\omega}^{\max}(T_R)| < 1.5\%$$

Breakup corrections $(\omega, \tilde{\omega})$ to the analyzing power

$$A_\mathrm{N}(T_R) = A_\mathrm{N}^\mathrm{nf}(T_R) \times \left[\kappa_h + \kappa_h\tilde{\omega}_0 - 2I_5^{hp} + \left(\kappa_h\tilde{\omega}_1 - 2R_5^{hp}\right)T_R/T_c\right]$$

$$A_\mathrm{N}^\mathrm{nf}(T) = \sqrt{\frac{2T_R}{m_p}} \times \frac{T_c/T_R}{(T_c/T_R)^2 - 2\tilde{\rho}\,T_c/T_R + 1 + \omega_0 + \omega_1 T_R/T_c}$$

- **The measured beam polarization:**

$$P_\mathrm{meas}(T_R) = P_\mathrm{beam} \times (1 + \eta_0 + \eta_1 T_R/T_c)$$

- **The evaluated systematic errors (based on the HJET proton beam measurements):**

$$\eta_0 = \quad 1.0\,\delta\tilde{\rho} + 0.2\,\delta\sigma_\mathrm{tot}/\sigma_\mathrm{tot} + 1.4\,\delta I_5^{hp} + 0.6\,\omega_0 - 0.8\,\omega_1 - \tilde{\omega}_0$$

$$\eta_1 = -0.1\,\delta\tilde{\rho} + 0.1\,\delta\sigma_\mathrm{tot}/\sigma_\mathrm{tot} + 1.4\,\delta R_5^{hp} - 0.0\,\omega_0 - 1.2\,\omega_1 - \tilde{\omega}_1$$

Unpolarized hydrogen gas jet target

The breakup correction, $\widetilde{\omega}\,(T_R)$, to the spin-flip term in A_N is small:

$$\delta_{\text{syst}}^{(\text{sf})}P/P \sim \pm\,\widetilde{\omega}_0 \;\sim 0.1\% \qquad [< 0.2\% \text{ (upper limit)}]$$

About the same uncertainties are expected due to the hadronic spin-flip amplitude

- The breakup corrections to the spin-flip part of A_N gives only a negligible contribution to the beam polarization systematic error

The breakup corrections to the hp cross section,

$$\frac{d\sigma}{dt} = \frac{\sigma_{\text{tot}}^2\, e^{Bt}}{16\pi} \times \left[\left(\frac{t_c}{t}\right)^2 - 2\widetilde{\rho}\,\frac{t_c}{t} + 1 + \omega_0 + \omega_1\,\frac{t}{t_c},\right]$$

result in the following uncertainties in the polarization measured:

$$\delta_{\text{syst}}^{(\text{nf})}P/P \sim \pm\,(0.6\,\omega_0 - 0.8\,\omega_1) \;\sim 0.3\% \qquad [\lesssim 1\% \text{ (upper limit)}]$$

- The breakup corrections to the non-flip part of A_N are about to satisfy the EIC requirement $\delta P/P \lesssim 1\%$. However
  - More accurate evaluation of the breakup rate, including breakup corrections to the electromagnetic amplitudes, are needed.
  - The uncertainties due to the elastic cross section parameters $\sigma_{\text{tot}}, \rho, B$ were not considered here.

Polarized hydrogen gas jet target

The $d\sigma/dt$ parametrization problem can be eliminated by using a polarized hydrogen jet target:

$$P_{\text{beam}} = P_{\text{jet}}\,\frac{a_N^{\text{beam}}}{a_N^{\text{jet}}} \times \frac{\kappa_p \times [1+\widetilde{\omega}(T_R)] - 2I_5^{ph} - 2R_5^{ph}\,T_R/T_c}{\kappa_h \times [1+\widetilde{\omega}(T_R)] - 2I_5^{hp} - 2R_5^{hp}\,T_R/T_c}$$

Since $|r_5| = |R_5 + iI_5| {\sim} 0.02$ and $|\widetilde{\omega}^{max}(T_R)| < 1.5\%$, the breakup corrections **are canceled** in this ratio**.**

$$\boxed{P_{\text{beam}} = P_{\text{jet}}\,\frac{a_N^{\text{beam}}}{a_N^{\text{jet}}} \times \frac{\kappa_p - 2I_5^{ph} - 2R_5^{ph}\,T_R/T_c}{\kappa_h - 2I_5^{hp} - 2R_5^{hp}\,T_R/T_c}}$$

$$\boxed{\sigma_P^{\text{breakup}}/P \lesssim 1.6|r_5|\,\widetilde{\omega}^{max} \sim 0.05\%}$$

Polarized $^{3}\mathrm{He}$ *gas jet target*

A polarized $^{3}\mathrm{He}$ gas jet target allows one to eliminate both theoretical (r_5) and breakup $\left(\widetilde{\omega}\,(T_R)\right)$ systematic errors:

$$P_{\mathrm{beam}} = P_{\mathrm{jet}}\,\frac{a_{\mathrm{N}}^{\mathrm{beam}}}{a_{\mathrm{N}}^{\mathrm{jet}}}$$

However, systematic errors achieved at HJET should not be straightforwardly applied to the $^{3}\mathrm{He}$ jet polarimeter:

- The proton and helion recoil kinematics are different
- Possible breakup of the target helion
- Possible uncertainty in the helion jet polarization

The HERMES polarized $^{3}\mathrm{He}$ internal gas target:
$P{\sim}54\%$ $\quad \sigma_P/P = 3.4\%$

Tagging the breakup of a helion beam seems unnecessary for the $^{3}\mathrm{He}$ jet polarimeter. However, would there be a possibility to detect coincidence between scattered and recoil particles, such a method could be used to suppress *ALL backgrounds* including prompts. This method, if feasible, is applicable to both hydrogen and He-3 jet targets.

Summary

- Using Run 16 deuteron beam data (10, 20, and 31 GeV/n), contamination of the elastic data by deuteron breakup events at 100 GeV was evaluated to be ~5%. The projected result for the case of the 100 GeV/n $^{3}\mathrm{He}$ beam is 2-3%.
- The evaluated breakup rate, was found to be in reasonable agreement with a $p\,^{6}\mathrm{Li}$ scattering data and with an estimate of the upper limit for for a $p\,^{3}\mathrm{He}$ scattering
- It was found that the breakup corrections cancel in the measured beam/jet asymmetry ratio $a_{\mathrm{beam}}^{(h)}/a_{\mathrm{jet}}^{(p)}$
- The expected uncertainties in the EIC 100 GeV $^{3}\mathrm{He}$ beam absolute polarization measurements by HJET are

$$\sigma_P/P = \left(0.6_{\mathrm{syst}} \oplus 0.5_{r5} \oplus 0.2_{\mathrm{method}}\right)\%,$$

- where "r5" denotes experimental uncertainties in the proton-proton value of r_5 and "method" denotes the additional uncertainties due to evaluation of the proton-helion r_5 and breakup corrections using the method outlined.
- "The $^{3}\mathrm{He}$ breakup tagging" ***should*** be designed primarily to suppress prompts (at HJET to begin with).

Backup

Kinematics dependence on the Beam + Target

$\mathbf{p+p}$: $$z_R - z_{\text{jet}} \approx L\sqrt{\frac{T_R}{2m_p}} \times \left[1 + \frac{m_p}{E_p} + \frac{m_p\Delta^*}{E_pT_R}\right]$$

$\mathbf{A+p}$: $$z_R - z_{\text{jet}} \approx L\sqrt{\frac{T_R}{2m_p}} \times \left[1 + \frac{m_p^2/M_A}{E_p} + \frac{m_p\Delta^*}{E_pT_R}\right]$$

$\mathbf{p+A}$: $$z_R - z_{\text{jet}} \approx L\sqrt{\frac{T_R}{2M_A}} \times \left[1 + \frac{M_A}{E_p} + \frac{m_p\Delta^*}{E_pT_R}\right]$$

$\mathbf{A+A}$: $$z_R - z_{\text{jet}} \approx L\sqrt{\frac{T_R}{2M_A}} \times \left[1 + \frac{m_p}{E_p} + \frac{m_p\Delta^*}{E_pT_R}\right]$$

$$E_p = E_{\text{beam}} \times \frac{Am_p}{M_A} \approx E_{\text{beam}}$$
$$\Delta^* = \Delta \times (1 + \Delta/2m_{\text{beam}})$$

$\mathbf{E}_{\text{beam}}$ is given in GeV/nucleon units
E_p is the jet proton energy in the beam frame

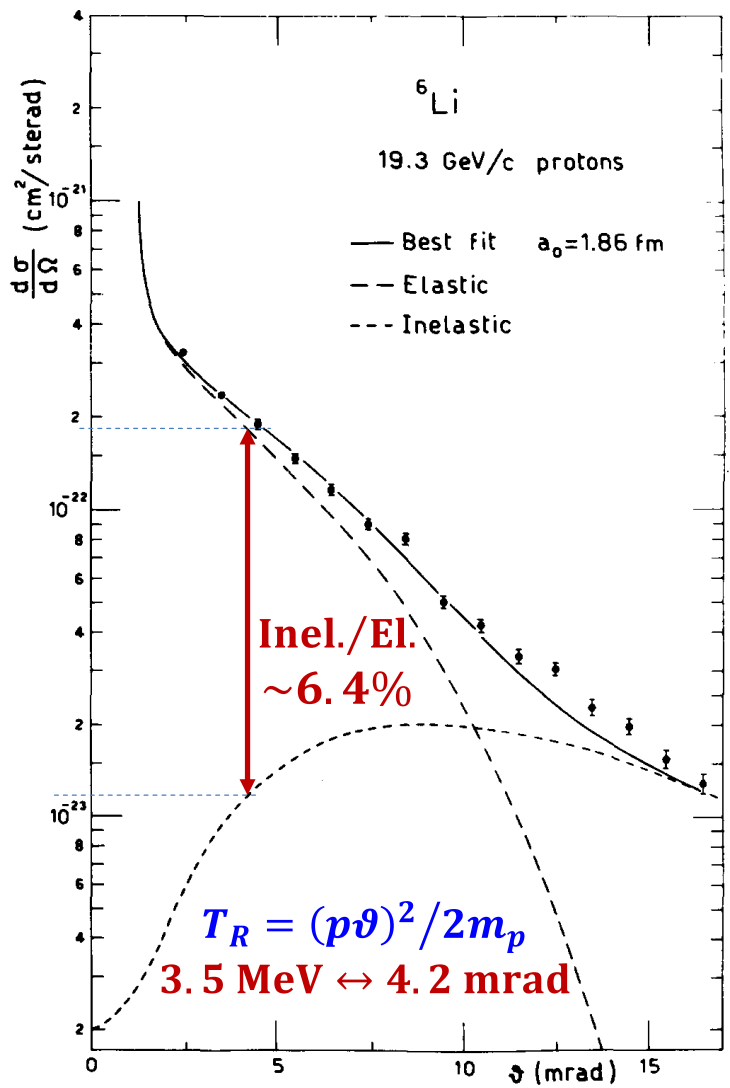


Fig. 1. The experimental data of ref. [4] on the scattering of 19.3 GeV/c protons by ^{6}Li are shown together with the result of the best fit. Elastic and inelastic contributions are shown separately.