**EIC Polarimeter Monthly Meeting**
June 7, 2023

# *Simple estimates for the* $^{3}\mathrm{He}$ *breakup test*

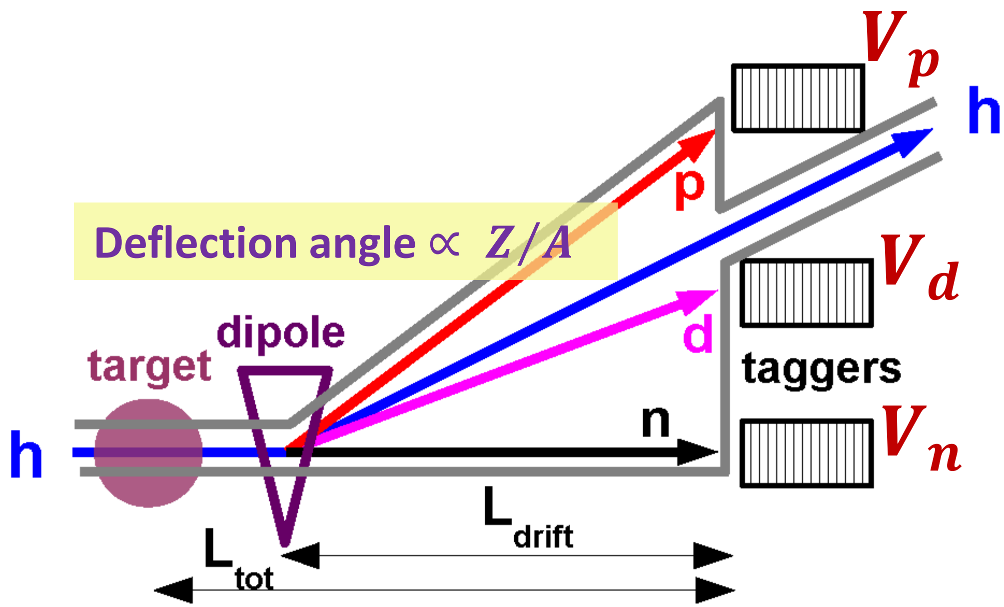
**A.A. Poblaguev**

*Brookhaven National Laboratory*

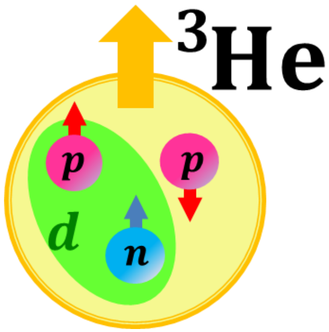
Brookhaven National Laboratory

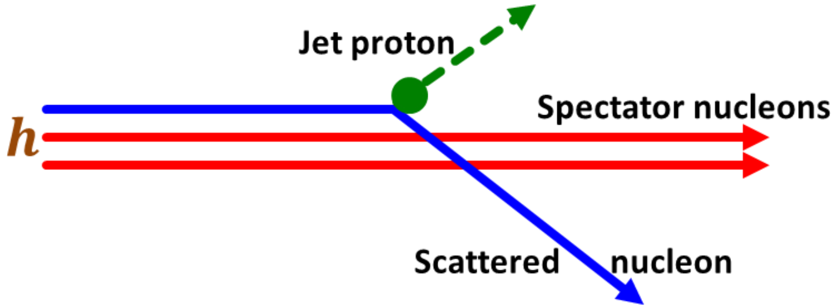
# *The* $^3$He *breakup test*

- At RHIC, the proton beam polarimetry, based on detecting of recoil protons from the forward elastic beam scattering off the polarized proton target, was successfully used.
- The same (similar) method is being considered for the hadronic polarimetry at RHIC.
- However, for the $^3\mathbf{He}$ beam, there is a concern that the helion breakup can significantly affect result of the polarization measurement.
- To tag and veto the breakup events, a system consisting of scintillator counters $V_p$ and $V_d$, and ZDC $V_n$ to detect the breakup protons, deuterons, and neutrons, respectively, is considering.
- In Run 23, the veto system is planned to be tested in the APEX sessions.

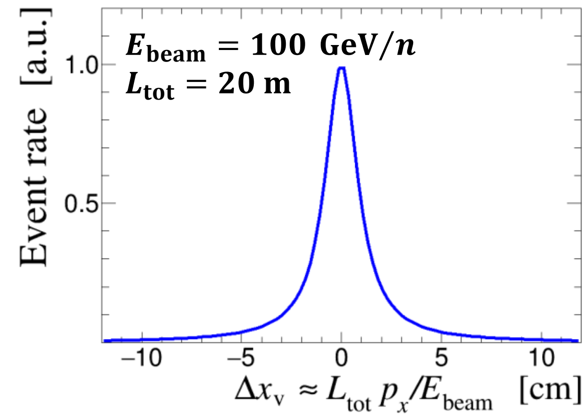


# Schematic explanation of the breakup detection




Displacement of the spectator nucleons in the veto detectors.



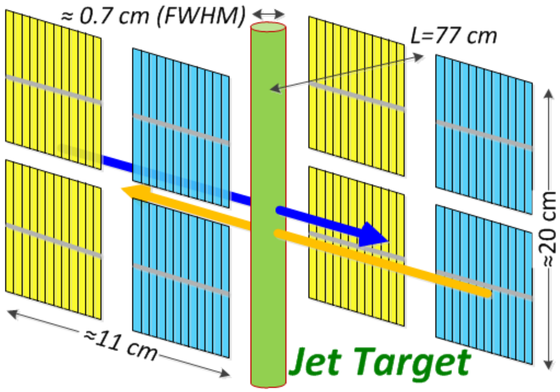

- ***Schematically*** high energy helion can be approximated as a flux of weakly bounded constituent nucleons.
- If one of the nucleons is kicked out in the scattering, the spectator ones continue to move forward as a deuteron or two unbounded nucleons
- The opening angle $\sim p_x/E_{beam}$ is defined by the internal motion transverse momentum $p_x$.
- The veto events, i.e., those which trigger $V_p, V_d, V_n$, may include meson production scatterings of the beam helion.

$dN/dp_x$ distribution used was evaluated at HJET for the 10 GeV/n deuteron beam.

| Scattered nucleon | Spectators | Detectors |
|---|---|---|
| $n^\uparrow$ | $p^\uparrow p^\downarrow$ | $\boldsymbol{V_p}$ $(\times 2)$ |
| $p^\uparrow$ | $n^\uparrow p^\downarrow$ | $\boldsymbol{V_n, V_p}$ |
| $p^\downarrow$ | $d^\uparrow$ | $\boldsymbol{V_d}$ |

# *The breakup events in HJET*

- At the HJET, only low momentum transfer, $-t < 0.02\ \mathrm{GeV}^2$ events can be detected.
- For the $^3$He beam, only following processes can be detected in HJET
  - $h + p_j \to h + p_j$ (elastic)
  - $h + p_j \to p + d + p_j$
  - $h + p_j \to p + p + n + p_j$
- For 100 GeV/n helion beam, the elastic and breakup events cannot be separated in the recoil proton measurements only
- If the recoil proton from the breakup scattering is detected at HJET, then, due to low $t$, all breakup particles can be efficiently detected in the Veto detectors.
- Geometrical acceptance of the HJET detectors is about $\boldsymbol{f_{\mathrm{acc}} \approx 7.4\%}$.

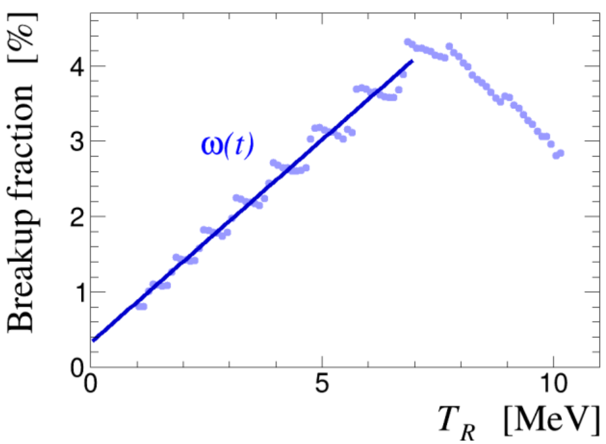



**The main goal of the $^3$He *breakup test* should be evaluation of the breakup fraction in the HJET elastic data**

$$\boldsymbol{\omega(T_R = -t/2m_p) = dN_{\mathrm{breakup}}(T_R)/dN_{\mathrm{elastic}}(T_R)}$$

AP, Phys. Rev. C, 106, 065202 (2022)
AP, Phys. Rev. C, 106, 065203 (2022)
AP, arXiv 2305.13099

An estimate (upper limit) of the breakup ($h \to pd$) fraction in the elastic $h^{\uparrow}p$ data used to measure $^3$He beam polarization with HJET. The result is based on the study of the 10-31 GeV/n deuteron beam scattering in HJET,

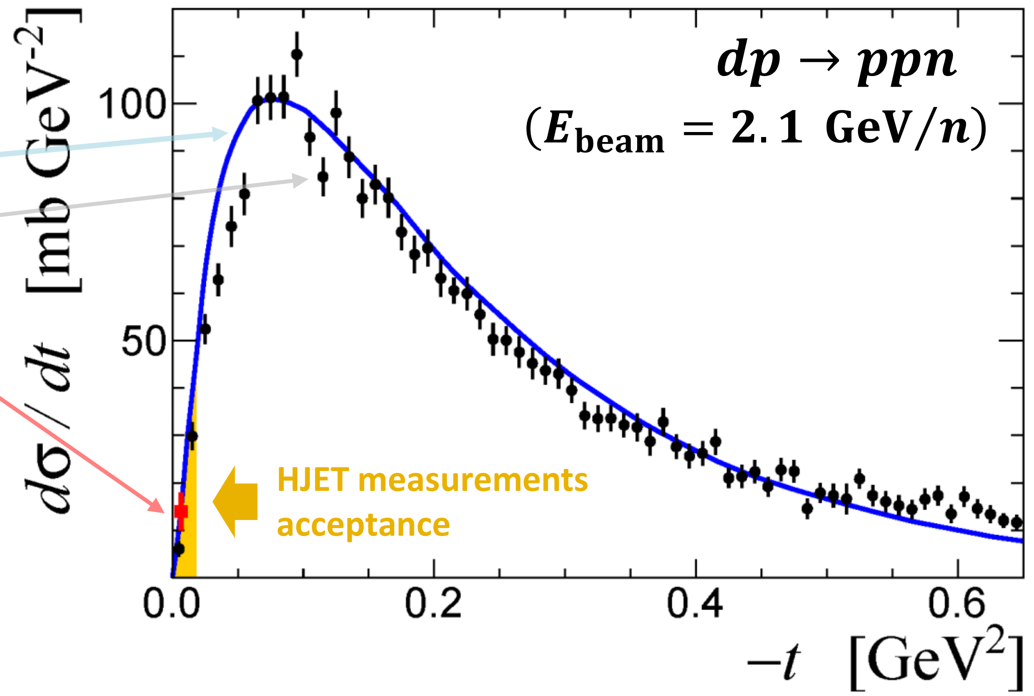


# $d \to pn$ breakup in the hydrogen bubble chamber

B. S. Aladashvili *et al.*, J. Phys. G **3**, 1225 (1977).

$d\sigma/dt$ @ $-t = 0.0066\ \mathrm{GeV}^2$
($T_R = 3.5$ MeV)

| | | |
|---|---|---|
| $15 \pm ?$ | $\mathrm{mb/GeV}^2$ | Theory |
| $8 \pm 2$ | $\mathrm{mb/GeV}^2$ | Experiment |
| $14 \pm 4$ | $\mathrm{mb/GeV}^2$ | From the HJET deuteron beam measurements |




- The HJET measurement of the deuteron beam breakup is in reasonable agreement with the bubble chamber measurements
- The model used satisfactory describes the HJET measurements (within the experimental accuracy.
- Only a small fraction, $\sim 1.5\%$, of $d \to pn$ breakups can be detected at HJET.

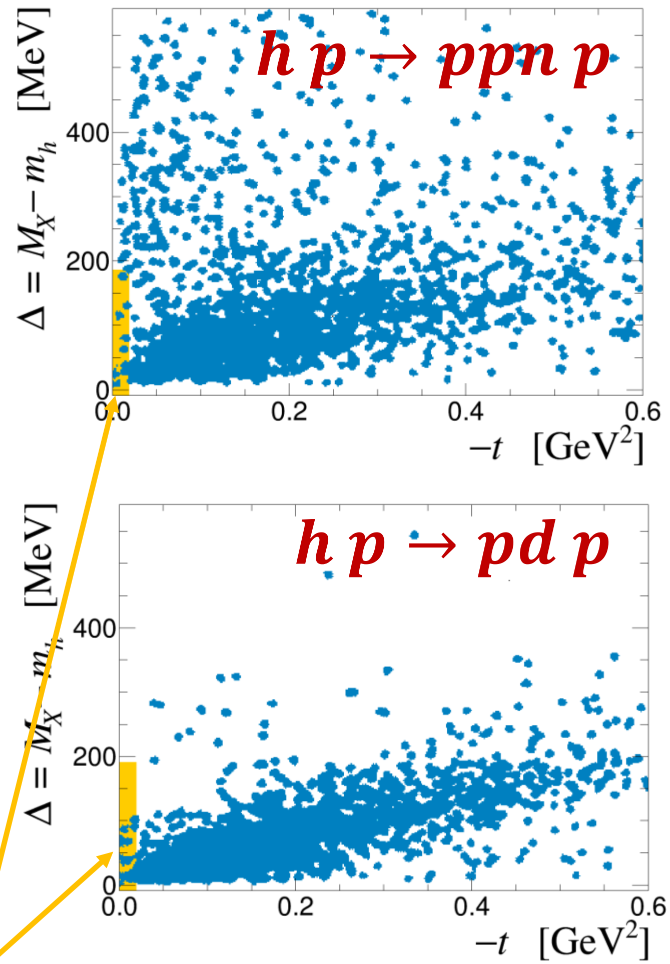
# $^3$He *breakup measurements in the hydrogen bubble chamber*

V.V. Glagolev et al., C **60**, 421 (1993)

$$\sigma_{tot} = 118.0 \pm 1.2\ \text{mb}$$
$$\sigma_{tagger} = 80 - 90\ \text{mb}$$
$$\sigma_{el} = 24.2 \pm 1.0\ \text{mb}$$
$$\sigma_{h\to pd} = 7.29 \pm 0.14\ \text{mb}$$
$$\sigma_{h\to ppn} = 6.90 \pm 0.14\ \text{mb}$$

J. Stepaniak , Acta Phys. Polon. B **27**, 2971 (1996)

$E_{beam} = 4.6\ \text{GeV/n}$




**The effective cross sections in HJET measurements:**

| | |
|---|---|
| $\sigma^{HJET}_{elastic} \approx 11\ \text{mb}$ | |
| $\sigma^{HJET}_{h\to ppn} < 0.02\ \text{mb}$ | (bubble chamber) |
| $\sigma^{HJET}_{h\to pd} \sim 0.15\ \text{mb}$ | (bubble chamber) |
| $\sigma^{HJET}_{h\to pd} \approx 0.25\ \text{mb}$ | (*deuteron beam in HJET*) |

**Only a very small fraction of the $^3$He breakup events can be seen in HJET.**

# Proton-$^3$He elastic scattering at intermediate energies

A. Watanabe et al., Phys. Rev. C **103**, 044001 (2021)

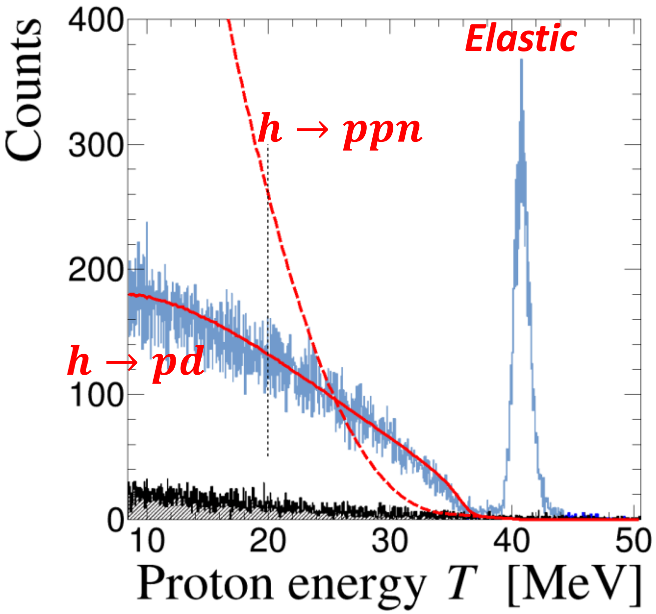
- 65 MeV proton beam scattering off the $^3$He target was studied.
- The scattered protons were detected by the NaI(Tl) scintillator at $\theta_{\mathrm{lab.}} = 75°$.
- **The breakup spectrum is consistent with $h \rightarrow pd$ and inconsistent with $h \rightarrow ppn$.**

**The phase space factor in the breakup event rate:**

- $h \rightarrow pd$ $\quad dN/d\Delta \propto (\Delta - 5.5\ \mathrm{MeV})^{1/2}$
- $h \rightarrow ppn$ $\quad dN/d\Delta \propto (\Delta - 7.7\ \mathrm{MeV})^{2}$

$$\Delta = M_X - M_h$$

**For low momentum transfer, the 3-body breakup $h \rightarrow ppn$ fraction is strongly suppressed.**



# *Rate estimates*

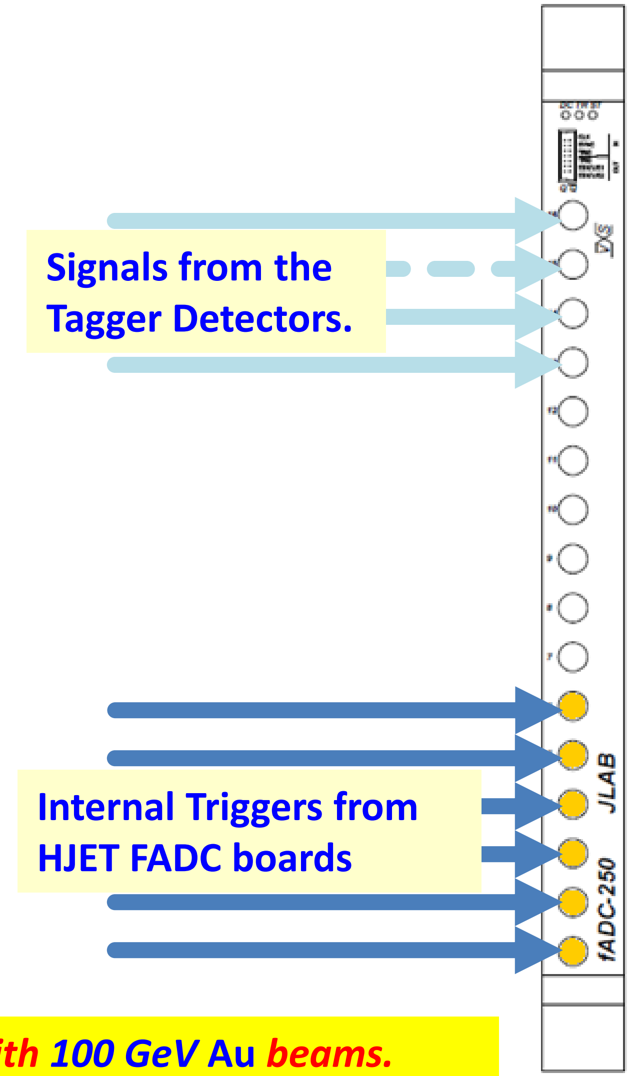
(For $1.2 \times 10^{11}\ \mathrm{cm}^{-2}$ jet density, $10^{11}\ \mathrm{bunch}^{-1}$ beam intensity, and $100\ \mathrm{ns}$ bunch spacing)

| | | $\mathrm{bunch}^{-1}$ | $\mathrm{Hz}$ |
|---|---|---|---|
| **Taggers** | $V_p \vert V_d \vert V_n$ | $10^{-3}$ | $10000$ |
| | $V_d$ | $3 \times 10^{-4}$ | $3300$ |
| | $V_p$ | $7 \times 10^{-4}$ | $6700$ |
| | $V_n$ | $3 \times 10^{-4}$ | $3300$ |
| **HJET** | **prompts** | $10^{-3}$ | $10000$ |
| | $h + p_j \to h + p_j$ | $10^{-5}$ | $100$ |
| | $h + p_j \to p + d + p_j$ | $\lesssim 3 \times 10^{-7}$ | $\lesssim 3$ |
| | $h + p_j \to p + p + n + p_j$ | $< 3 \times 10^{-8}$ | $< 0.3$ |
| **Taggers triggered by HJET "elastic"** | $V_p \vert V_d \vert V_n$ | $\lesssim 3 \times 10^{-7}$ | $\lesssim 3$ |
| | $V_d$ | $\lesssim 3 \times 10^{-7}$ | $\lesssim 3$ |
| | $V_p$ | $\lesssim 3 \times 10^{-7}$ | $\lesssim 3$ |
| | $V_n$ | $< 3 \times 10^{-8}$ | $< 0.3$ |

- Estimates by order of magnitude only.
- **Accidental background was not considered.**

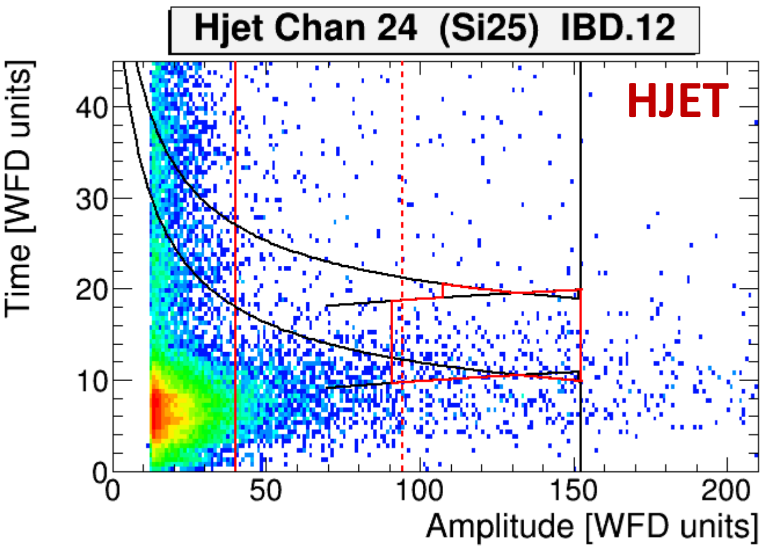
# The $^3$He breakup test DAQ

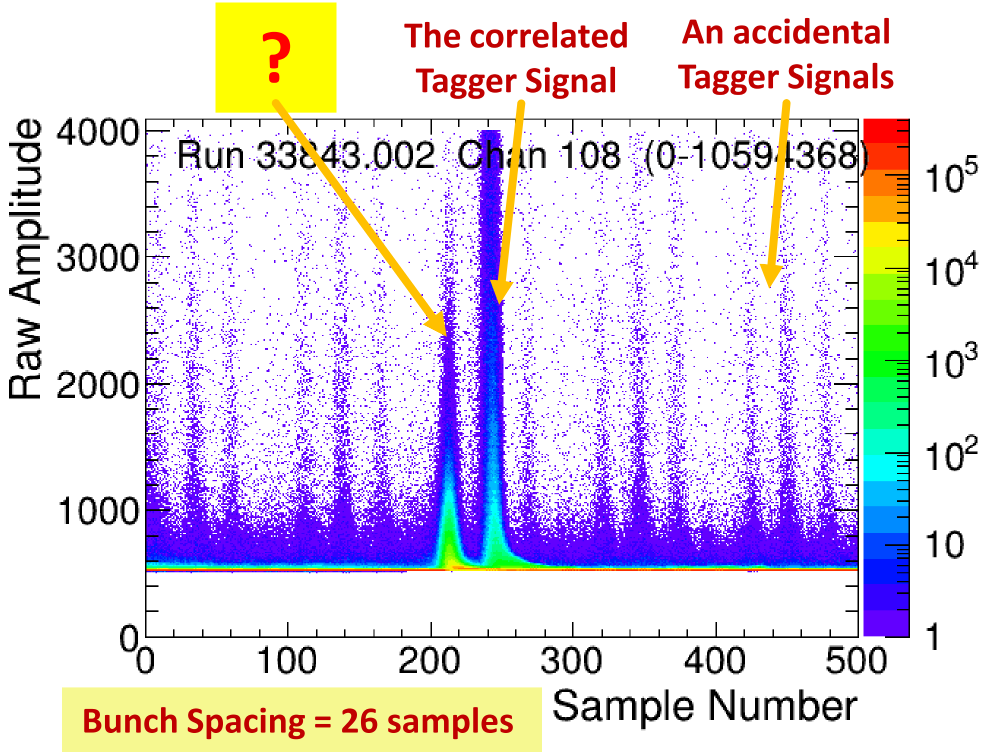
- The breakup test DAQ is incorporated to the HJET DAQ.
- The dedicated FADC board is used for the Tagger Signals.
- The readout trigger is generated by internal logical OR of the internal triggers in 6 HJET FADC boards.
- **The DAQ is ready for operation:**
  - ✓ The readout Veto signals are recorded to the disk in standard HJET format.
  - ✓ The tagger signals are synchronized with the triggers.
  - ✓ Simplified analysis of the data (amplitude, time distributions) is provided.
  - ✓ The signals waveform can be viewed.
- **However,**
  - ✓ The offline analysis (including matching HJET and Tagger signals) is not developed yet.

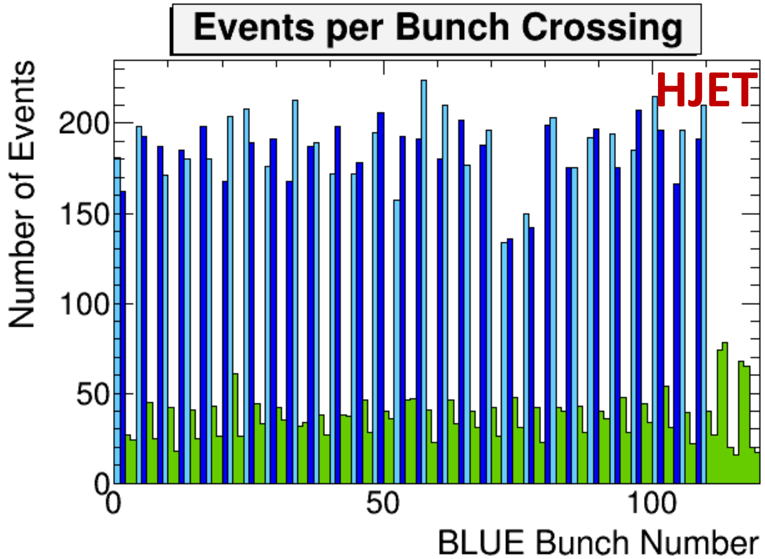



- ***The commissioning of the Taggers can be done with 100 GeV Au beams.***

# *The DAQ Tests with 100 GeV* Au *Beams*

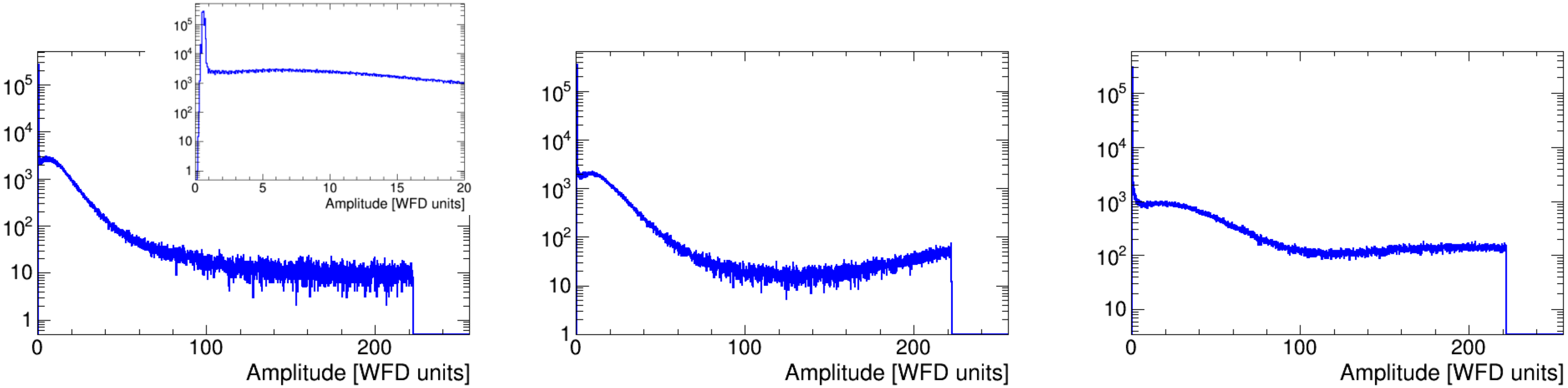



- **The Jet is OFF**
- **Prompts in JET are used as triggers**
- **The beam bunch structure is 56x56**
- **The tagger signals are well correlated with the trigger (the prompts production in the scattering also cause the Au breakup)**

# *Amplitude distributions in Tagger counters (ZDC ?)*




- **HJET Trigger (prompt signals)**
- **No threshold readout for Taggers**
- **Correlation between taggers amplitudes >95%.**

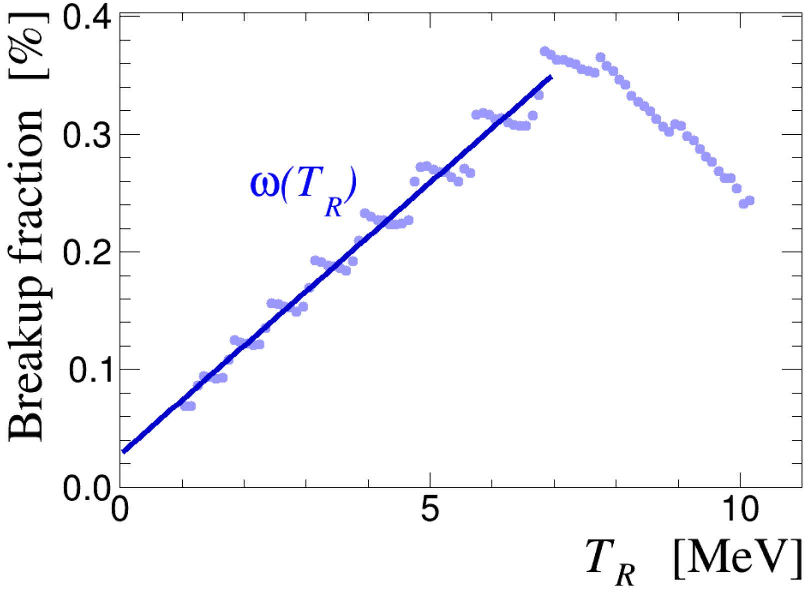
# Summary

- Only a very small fraction $\lesssim \mathbf{10^{-3}}$ of all Tagger hits is relevant to the $^3$He beam polarization measurement with HJET
- The $h \to pd$ breakup fraction in the elastic data used to measure the beam polarization is $\lesssim \mathbf{3\%}$. This events are not detected by ZDC.
- The $h \to pp$n breakup fraction is very small $\lesssim \mathbf{0.3\%}$.
- Proton and deuteron taggers are much more important for the $^3$He breakup tests than ZDC.
- DAQ is ready for the tests.
- Online data analysis is ready.
- Offline analysis (including matching of HJET and Tagger signals) should be prepared.

# Backup

# Measurements without scintillators $V_d$ and $V_p$

- ZDC ($V_n$) is not sensitive to the dominant breakup mode $h + p_j \to p + d + p_j$.
- So, only the low intensity breakup component $\sigma^{\mathrm{HJET}}_{h\to ppn}/\sigma^{\mathrm{HJET}}_{h\to h} < 0.3\%$ can be evaluated.
- In one hour running about 1000 inelastic events (if $\sigma^{\mathrm{HJET}}_{h\to ppn} = 0.3\ \mathrm{mb}$) can be detected.
- This is sufficient to check if our understanding of $h \to ppn$ breakup rate is correct (unless the accidental rate is too high)
- **However, such measurements cannot provide evaluation of the total breakup fraction in the HJET elastic data.**



# $13.5\ \mathrm{GeV}/c\ {}^{3}\mathrm{He}$ *scattering in the hydrogen bubble chamber*

V.V. Glagolev et al., C **60**, 421 (1993)

$E_{\mathrm{beam}} = 4.6\ \mathrm{GeV}/n$

**Table 3.** Topological cross sections for the $^3$He-$p$ interactions

| Number of prongs | $\sigma$ (mb) |
|---|---|
| 2 | 27.1 $\pm$0.9 |
| 3 | 62.5 $\pm$1.0 |
| 4 | 0.82 $\pm$0.06 |
| 5 | 25.6 $\pm$0.5 |
| 6 | 0.07 $\pm$0.02 |
| 7 | 1.86 $\pm$0.09 |
| $\geqq$8 | 0.0023$\pm$0.008 |

$\sigma_{\mathrm{tot}} = 118.0 \pm 1.2$ mb

$\sigma_{\mathrm{el}} = 24.2 \pm 1.0$ mb, $B = 33.2 \pm 1.3\ \mathrm{GeV}^{-2}$

$\sigma_{h\to pd} = 7.29 \pm 0.14$ mb

$\sigma_{h\to ppn} = 6.90 \pm 0.14$ mb

From Table 5, one can evaluate the cross section seen by the Veto detectors:

$\sigma_{\mathrm{Veto}} \sim 80$ mb

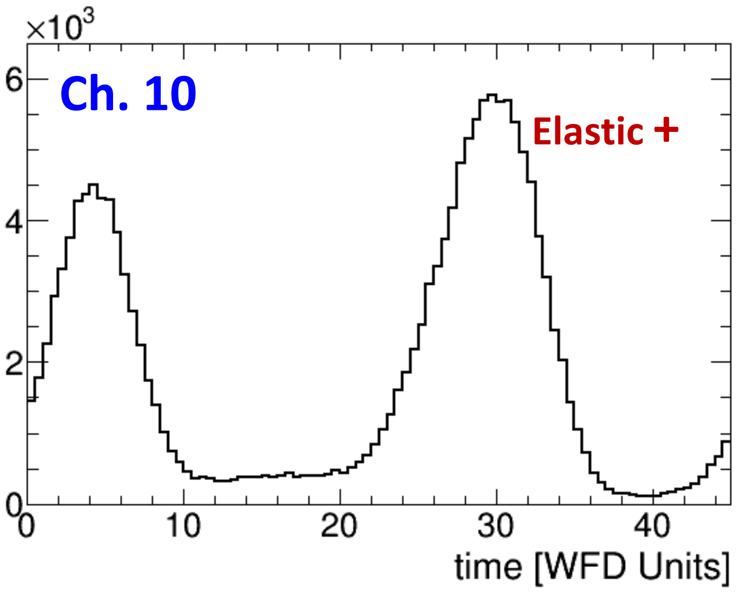
**Table 5.** Cross sections of the $^3$He-$p$ reaction channels at 13.5 GeV/c

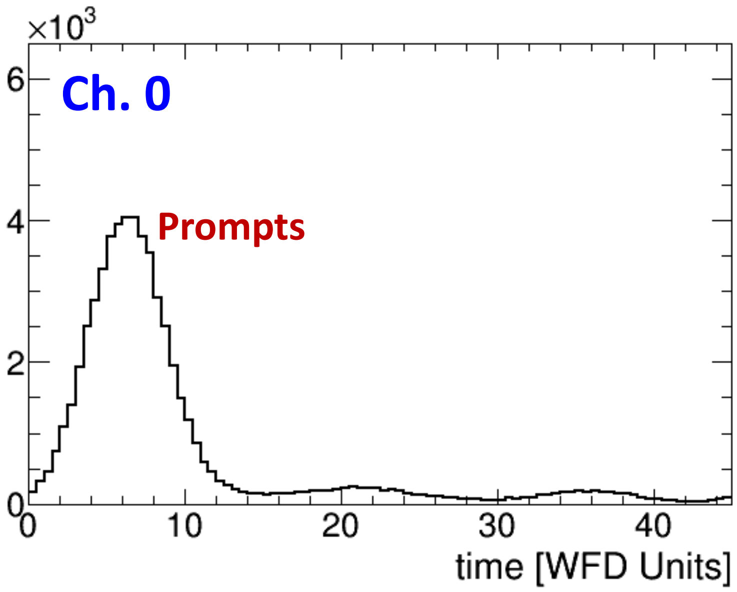
| Two prongs | | Four prongs | |
|---|---|---|---|
| Channel | $\sigma$ (mb) | Channel | $\sigma$ (mb) |
| $^3\mathrm{He}p\pi^0$ | 0.83$\pm$0.05 | $^3\mathrm{He}p\pi^+\pi^-$ | 0.61$\pm$0.05 |
| $^3\mathrm{He}p\pi^+n$ | 0.25$\pm$0.03 | $^3\mathrm{He}p\pi^+\pi^-\pi^0$ | 0.04$\pm$0.01 |
| $^4\mathrm{He}p\pi^+\pi^0$ | 0.35$\pm$0.04 | $^3\mathrm{He}\pi^+\pi^+\pi^-n$ | 0.01$\pm$0.01 |
| Charged + $X$ | 1.46$\pm$0.07 | $^4\mathrm{He}\pi^+\pi^+\pi^-\pi^0$ | 0.03$\pm$0.01 |
| | | Charged + $X$ | 0.13$\pm$0.02 |

| Three prongs | | Five prongs | |
|---|---|---|---|
| Channel | $\sigma$ (mb) | Channel | $\sigma$ (mb) |
| $dpp$ | 7.29$\pm$0.14 | $pppp\pi^-$ | 1.10 $\pm$0.05 |
| $tp\pi^+$ | 0.94$\pm$0.05 | $dpp\pi^+\pi^-$ | 2.23 $\pm$0.08 |
| $dd\pi^+$ | 0.05$\pm$0.01 | $tp\pi^+\pi^+\pi^-$ | 0.55$\pm$ 0.04 |
| $dpp\pi^0$ | 2.51$\pm$0.08 | $dd\pi^+\pi^+\pi^-$ | 0.19$\pm$ 0.02 |
| $tp\pi^+\pi^0$ | 0.09$\pm$0.02 | $pppp\pi^-\pi^0$ | 0.97$\pm$ 0.05 |
| $dd\pi^+\pi^0$ | 0.43$\pm$0.03 | $dpp\pi^+\pi^-\pi^0$ | 1.24$\pm$ 0.06 |
| $pppn$ | 6.90$\pm$0.14 | $tp\pi^+\pi^+\pi^-\pi^0$ | 0.003$\pm$0.003 |
| $dp\pi^+n$ | 4.69$\pm$0.11 | $dd\pi^+\pi^+\pi^-\pi^0$ | 0.12 $\pm$0.02 |
| $t\pi^+\pi^+n$ | 0.01$\pm$0.01 | $ppp\pi^+\pi^-n$ | 5.32 $\pm$1.21 |
| $dppX$ | 3.68$\pm$0.10 | $dp\pi^+\pi^+\pi^-n$ | 1.37 $\pm$0.06 |
| $pppX$ | 8.18$\pm$0.15 | $t\pi^+\pi^+\pi^-n$ | 0.003$\pm$0.003 |
| $dp\pi^+X$ | 6.89$\pm$0.14 | $ppp\pi^+\pi^-X$ | 3.75 $\pm$0.10 |
| $pp\pi^+X$ | 14.15$\pm$0.19 | $dp\pi^+\pi^+\pi^-X$ | 1.01 $\pm$0.05 |
| $d\pi^+\pi^+X$ | 2.32$\pm$0.08 | $pp\pi^+\pi^+\pi^-X$ | 4.31 $\pm$0.11 |
| $p\pi^+\pi^+X$ | 2.98$\pm$0.09 | $p\pi^+\pi^+\pi^+\pi^-X$ | 1.05 $\pm$0.05 |
| Charged + $X$ (the rest) | 1.36$\pm$0.06 | Charged + $X$ (the rest) | 2.35 $\pm$0.08 |

$X$ – means two or more neutral particles

# *HJET Time distribution for Yellow 19.7 GeV Au beam*




- The elastic rate is pre-defined by $d\sigma/dt$, i.e., by the Si strip angle.
- The tagger signals will have fixed time relative to the bunch.
- It may be interesting to search for correlations between prompts and tagger signals.

# Run 23 Timeline

**RHIC Run**

| Weeks | Designation |
| --- | --- |
| 0.5 | Cool Down from 50 K to 4 K **May, 8 ?** |
| 2.0 | Set-up mode 1 (Au+Au at 200 GeV) |
| 0.5 | Ramp-up mode 1 (8 h/night for experiments) |
| 11.5 | sPHENIX Initial Commission Time |
| 9.0 (13.0) | Au+Au Data taking (Physics) |
| 0.5 | Controlled refrigeration turn-off |
| 24.0 (28.0) | Total cryo-weeks |

**sPHENIX Commissioning:**

| Weeks | Details |
| --- | --- |
| 2.0 | low rate, 6-28 bunches |
| 2.0 | low rate, 111 bunches, timing |
| 1.0 | low rate, crossing angle checks |
| 1.0 | low rate, calorimeter timing |
| 4.0 | medium rate, TPC timing, optimization |
| 2.0 | full rate, system test, DAQ throughput |
| 12.0 | **total** |