He3 breakup test
August 5, 2024

Preliminary results for injection, 16.2 GeV

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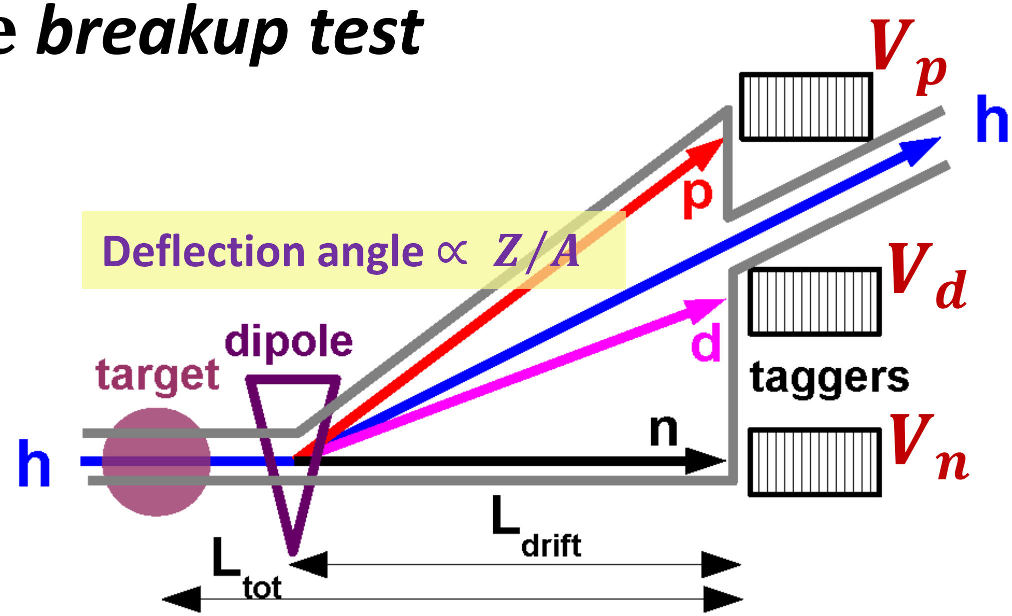
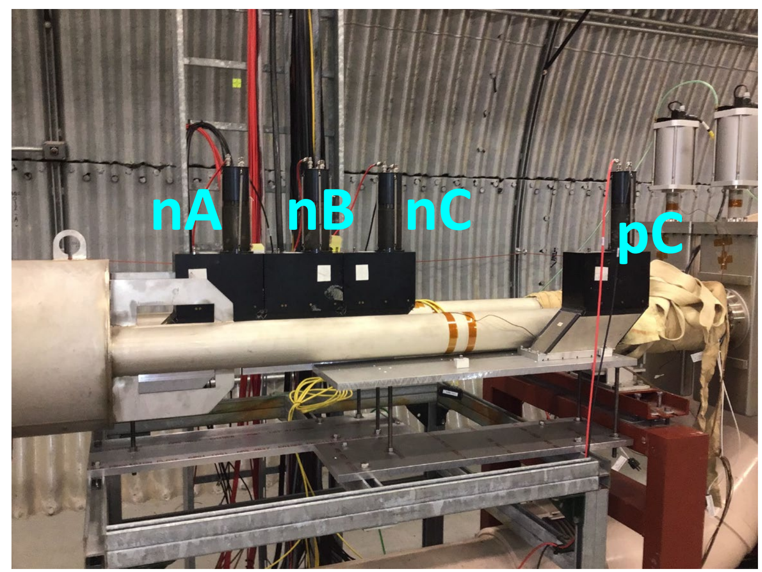
The ^{3}He *breakup test*

$V_p = \{pC\}$
$V_d = \{\text{not available}\}$
$V_n = \{nA, nB, nC\}$

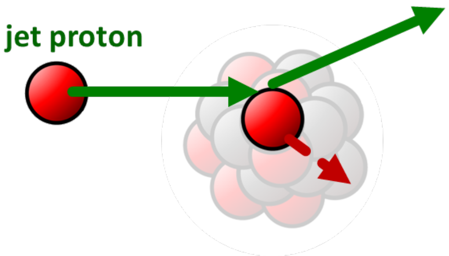


- The taggers readout is triggered by HJET (any signals, prompts or recoils)
- Main goal of the study is to find correlation between elastic-like recoil protons in HJET and hits in the taggers.



The recoil proton kinematics for the breakup events

$$\frac{z_R - z_{\text{jet}}}{L} = \sqrt{\frac{T_R}{2m_p}} \times \left[1 + \frac{m_p}{E_{\text{beam}}} + \frac{m_p \Delta}{T_R E_{\text{beam}}}\right]$$



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

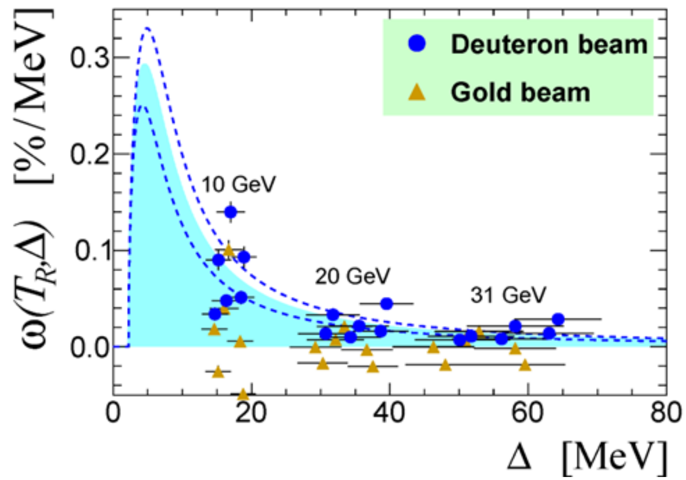
$$\left.\frac{d\sigma}{dt}(t)\right|_{\text{breakup}} \to 0 \text{ if } t \to 0$$

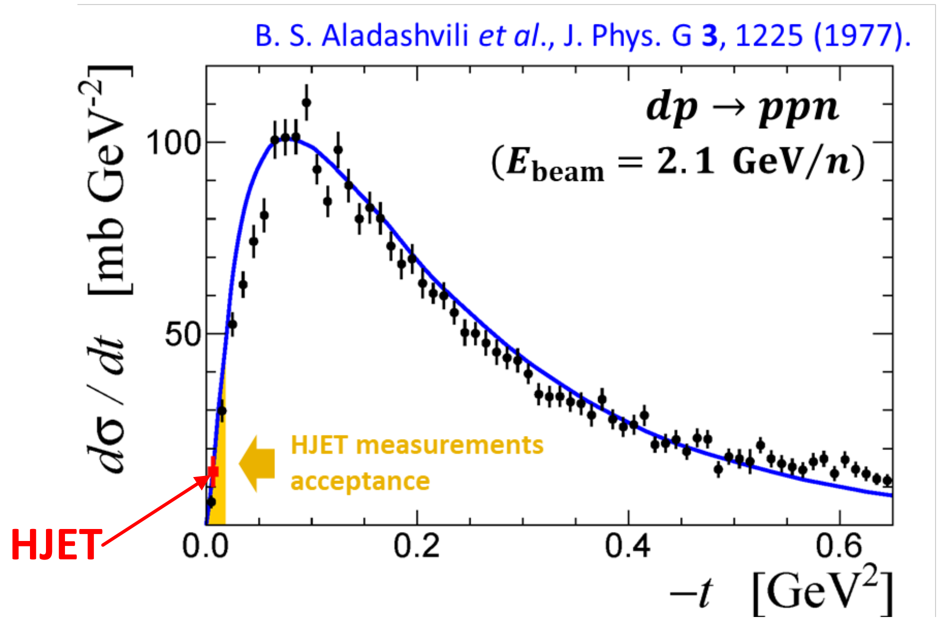
$$\left.\frac{d\sigma}{dt}(t)\right|_{\text{breakup}} \propto t = -2m_p T_R$$

Since $|t| < 0.02\ \text{GeV}^2$ in the HJET measurements, the breakup fraction should be strongly suppressed.

Deuteron breakups at HJET

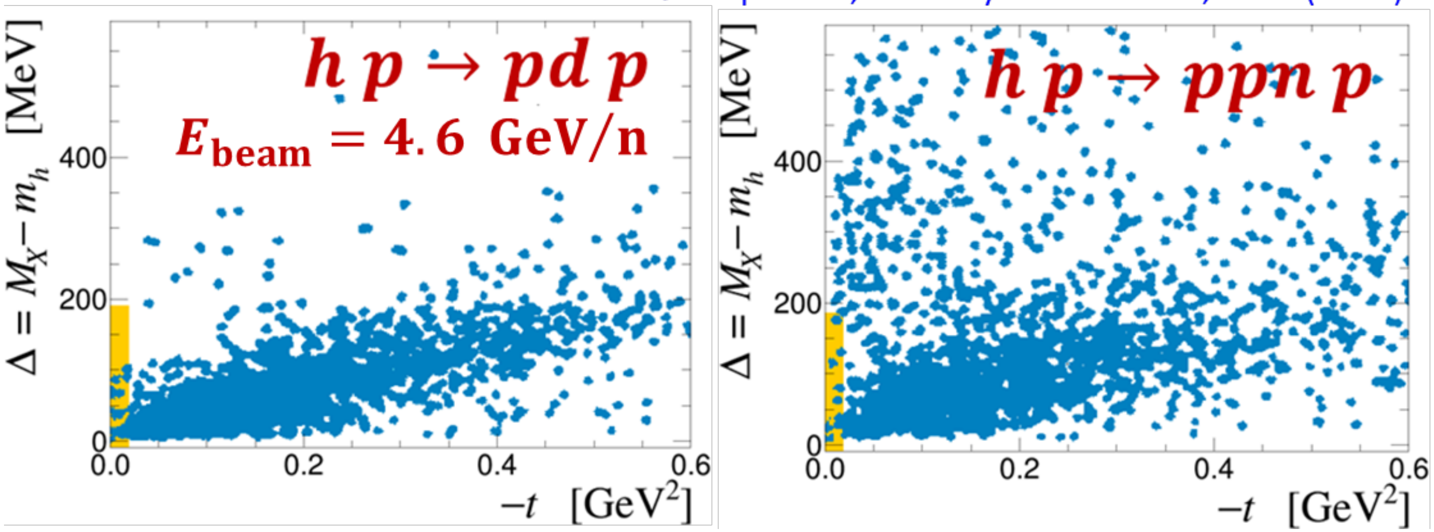
- In Run 16, the deuteron-gold collisions were studied at RHIC for 4 beam energies, 10, 20, 31, and 100 GeV.
- The deuteron breakup events were isolated in the HJET data.
- The evaluated breakup rate is in good agreement with the buble chamber measurements in Dubna.



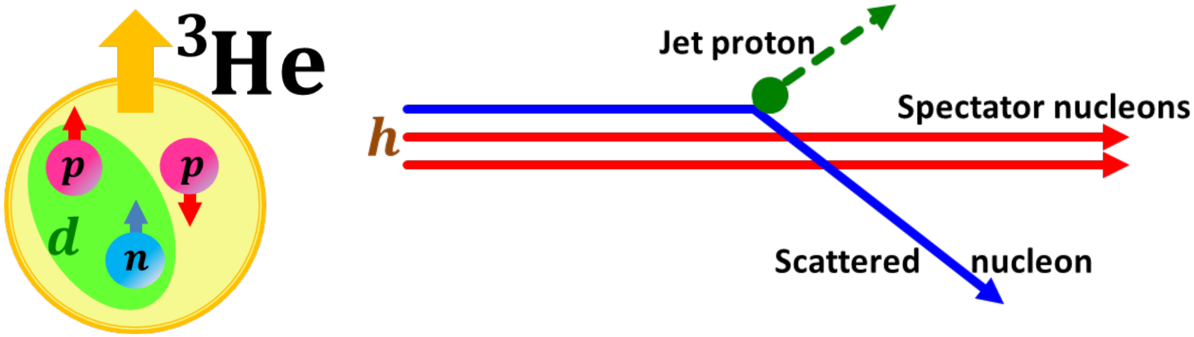


The bubble chamber results for He3

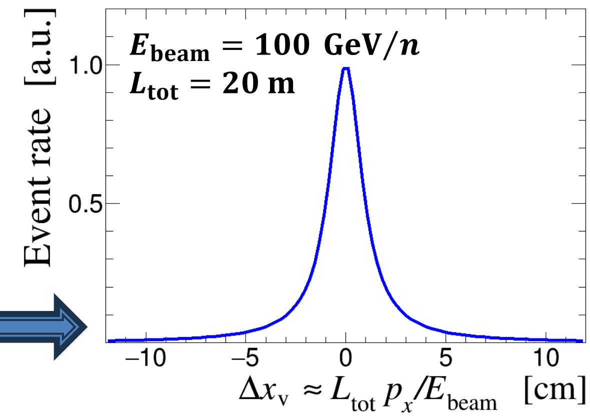
J. Stepaniak , Acta Phys. Polon. B **27**, 2971 (1996)



Schematic explanation of the breakup detection



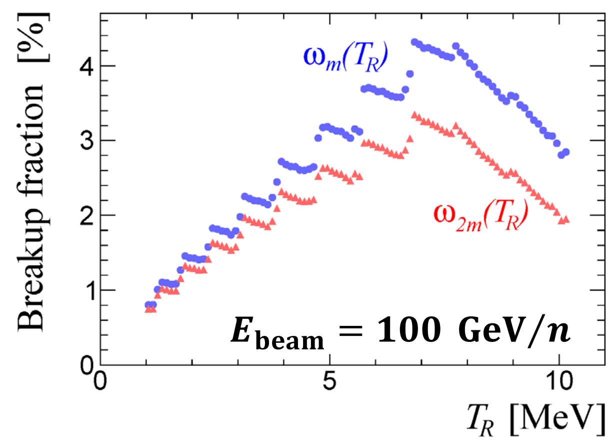
Displacement of the spectator nucleons in the veto detectors.



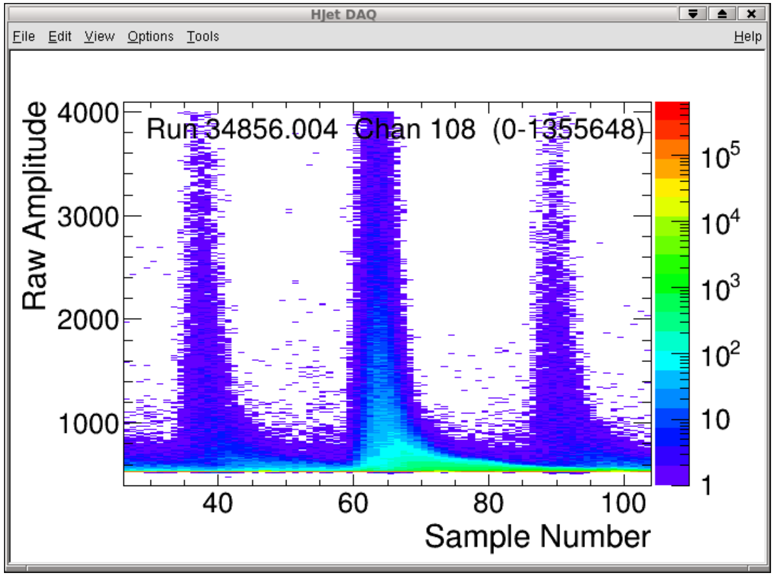
dN/dp_x distribution used was evaluated at HJET for the 100 GeV/n deuteron beam. For 16 GeV (injection beam) it should be a factor 6 wider. For the breakup detection, the efficiency quadratically depends on the width.

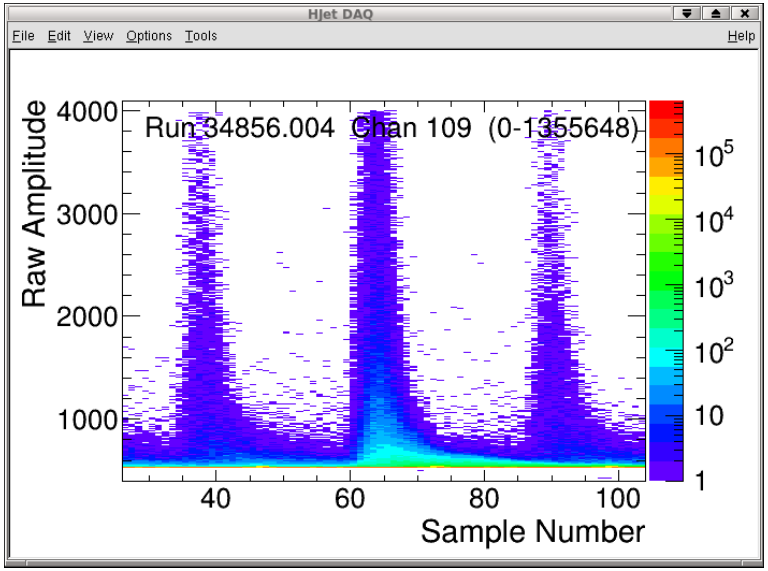
An incoherent scattering of proton from ^{3}He can be approximated by scattering off a nucleon $(m^* = m_p)$ or di-nucleon $(m^* = 2m_p)$. Thus, the breakup corrections (to the interference terms) are limited by:

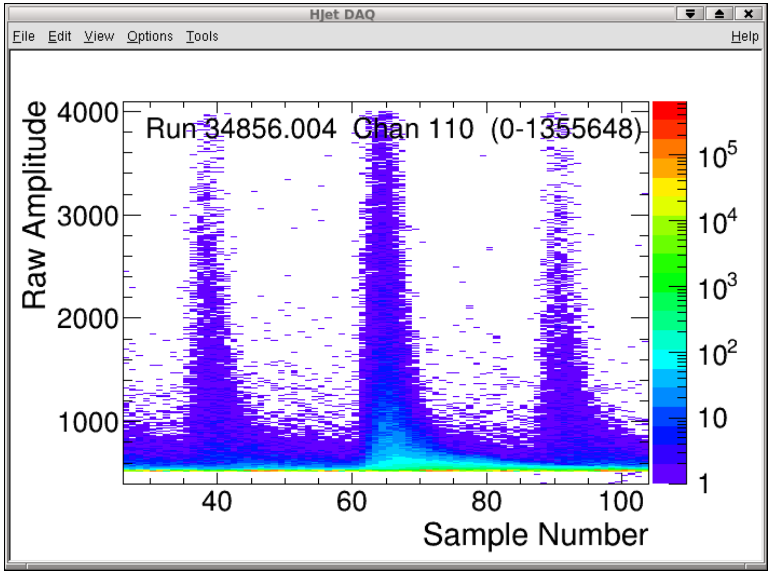
$$\omega_{2m}(T_R) \leq \omega_{\text{int}}(T_R) \leq \omega_m(T_R)$$

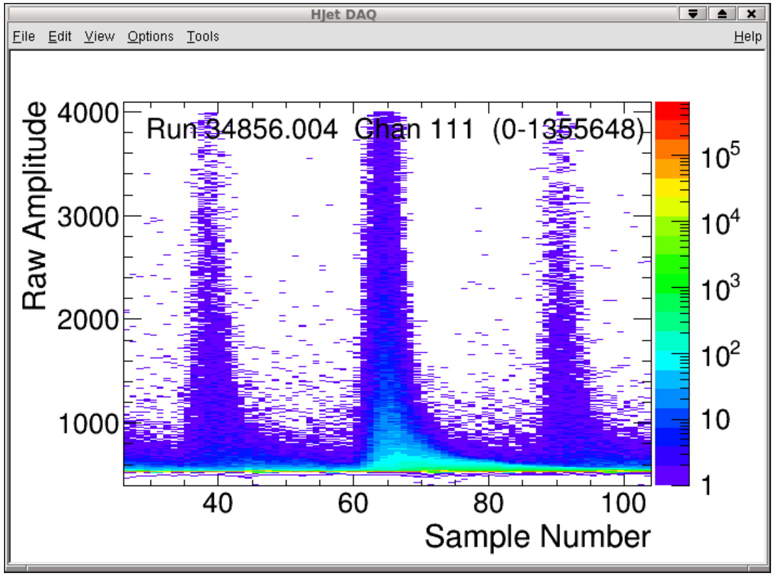


Tagger waveforms

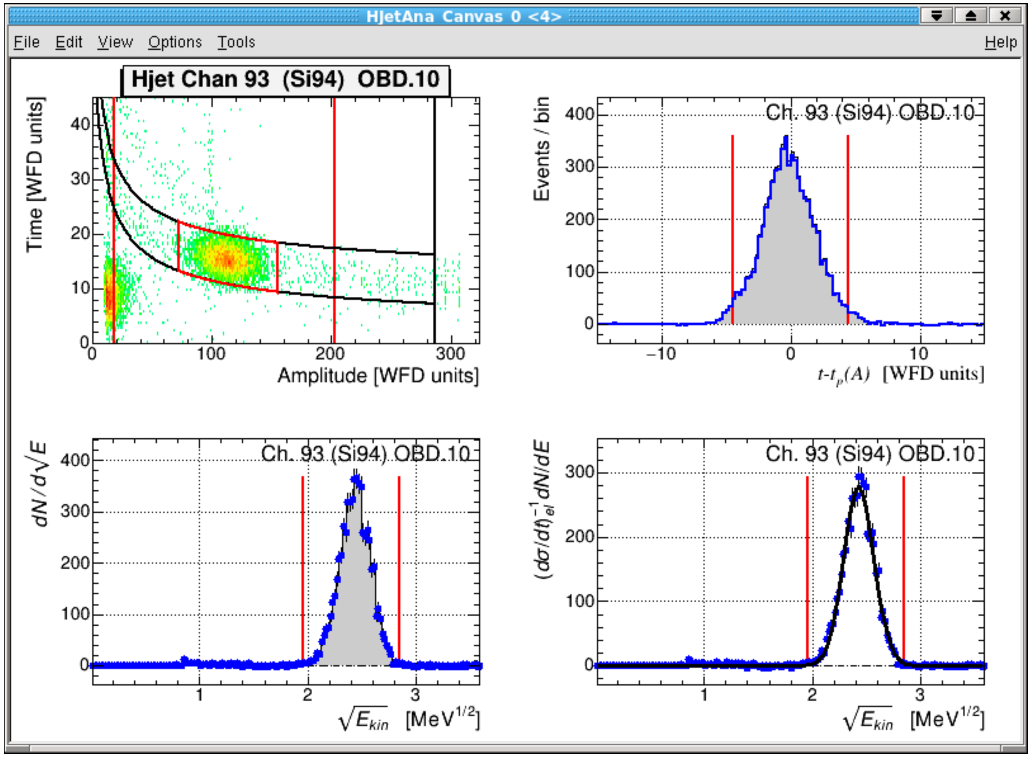


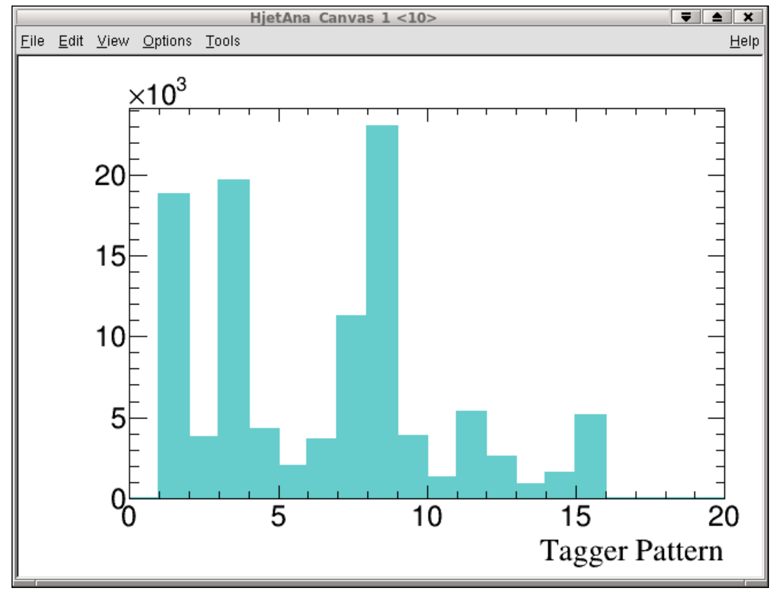






Event distributions (no correlation cuts)

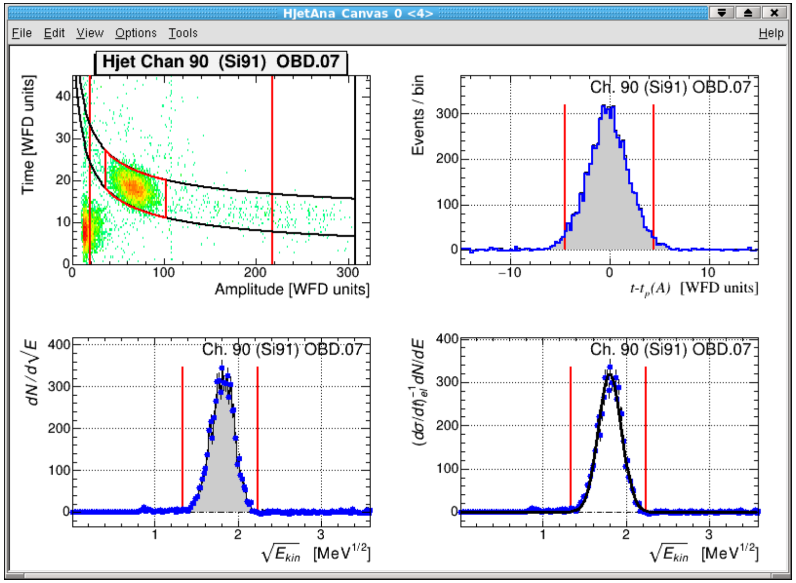




$$\textbf{Pattern} = w_{\mathrm{nA}} \times 1 + w_{\mathrm{nB}} \times 2 + w_{\mathrm{nC}} \times 4 + w_{\mathrm{pC}} \times 8$$

$$w_i = 0 \text{ or } 1$$

The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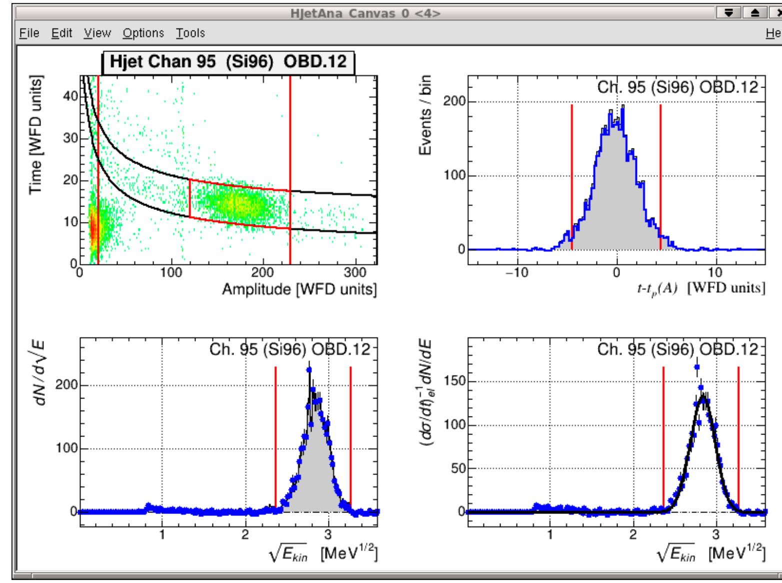
File Edit View Options Tools Help
Hjet Chan 90 (Si91) OBD.07
Time [WFD units]
Amplitude [WFD units]
Ch. 90 (Si91) OBD.07
Events / bin
t-t_p(A) [WFD units]
dN/d√E
(dσ/dt)_el^-1 dN/dE
√E_kin [MeV^1/2]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Hjet Chan 95 (Si96) OBD.12
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Events / bin
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dN/d√E
(dσ/dt)_el^-1 dN/dE
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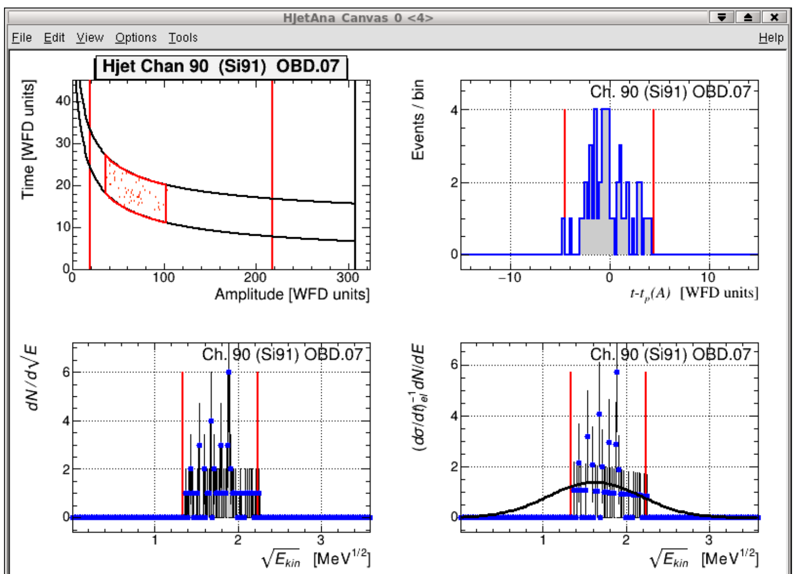
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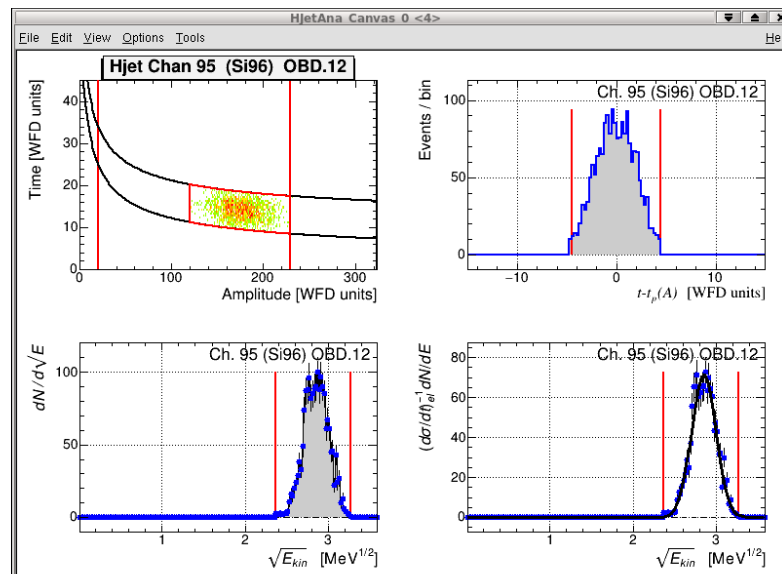
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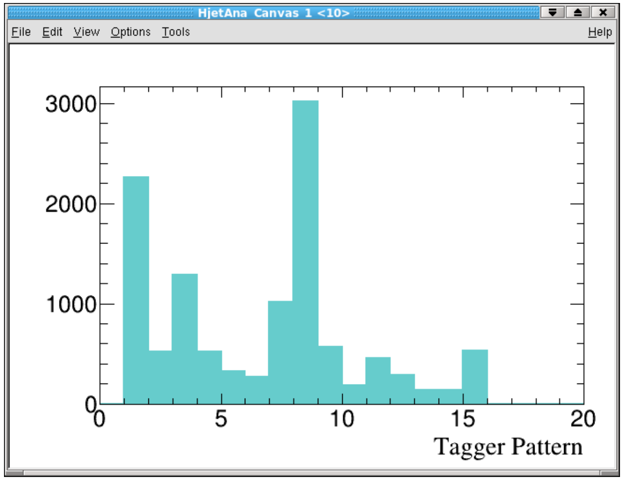
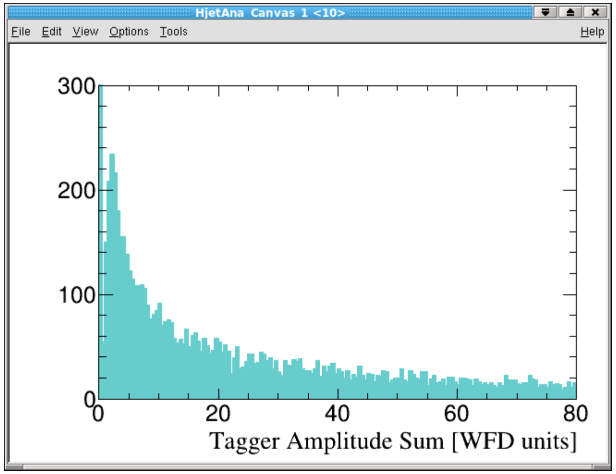
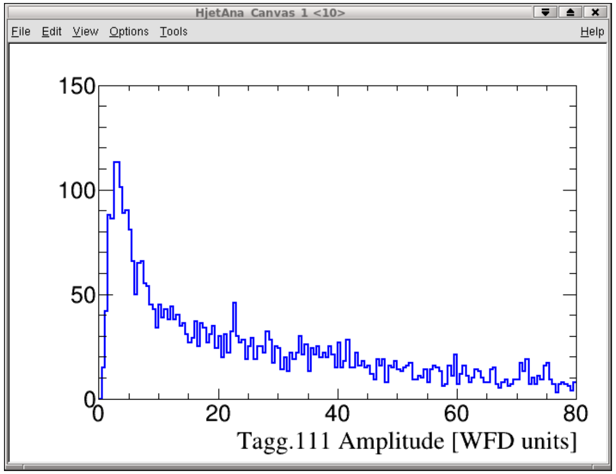
Tagger distributions





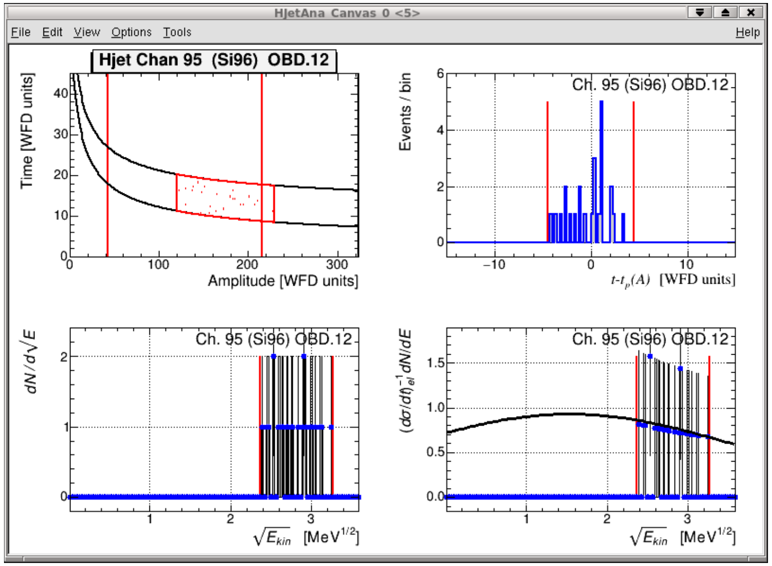


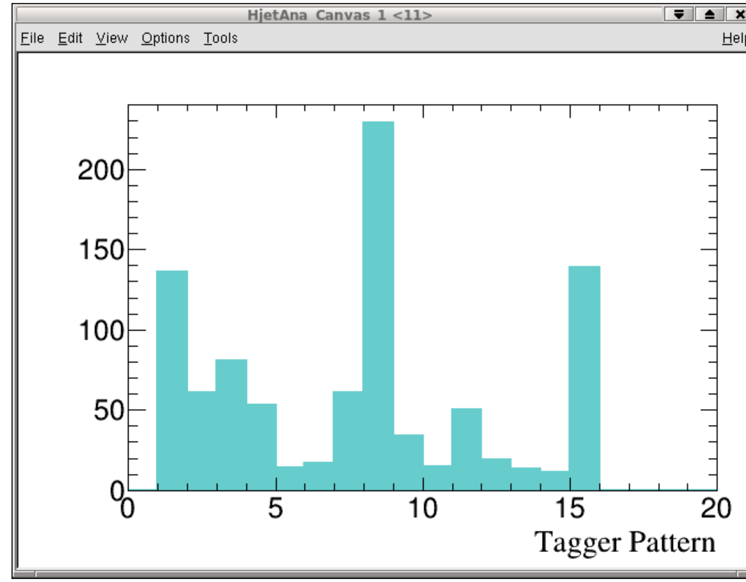
Statistics per channel

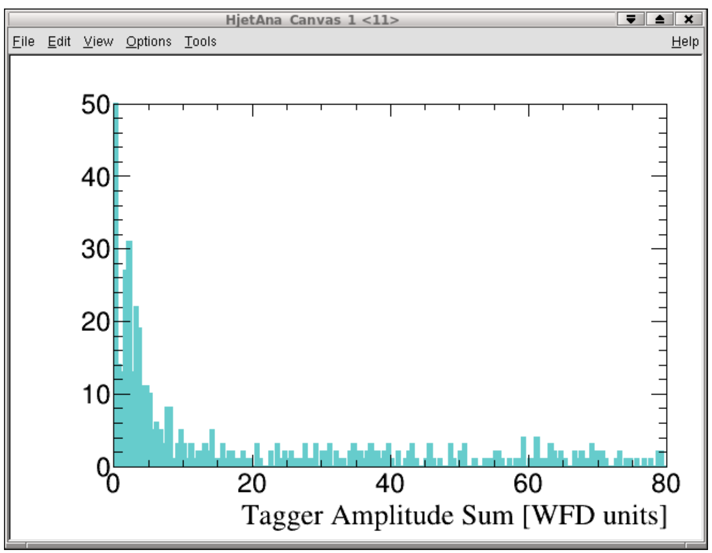
15	18	14	19	18	14	11	11	6	2	0	0
0	4	5	6	9	20	18	15	21	12	12	19
208	140	89	71	51	56	35	27	1	0	0	0
0	0	2	17	32	30	38	53	78	108	121	211
13	14	20	8	15	15	14	8	2	2	0	0
0	0	3	10	12	12	11	19	5	16	14	21
1491	1382	812	236	72	39	34	23	11	1	0	0
0	3	9	13	23	42	44	80	287	850	1517	1694

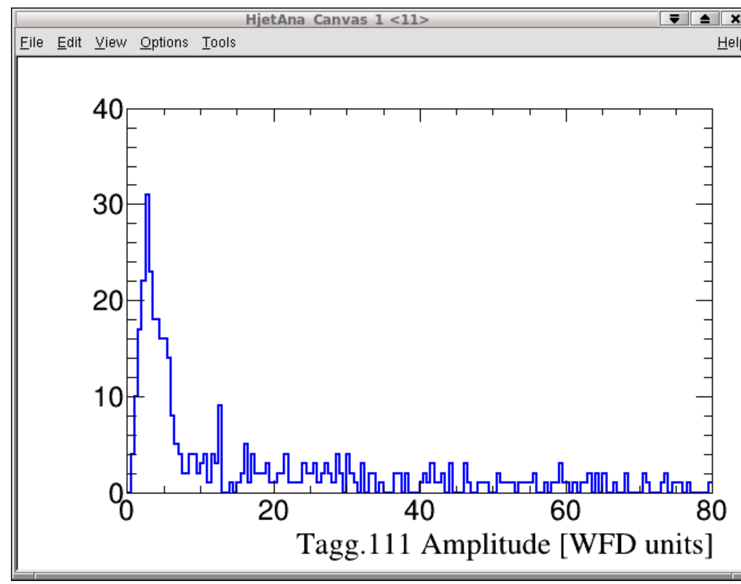
68	128	102	94	77	72	83	85	76	44	31	13
10	34	58	92	90	75	79	73	79	96	103	64
5253	5605	5497	5714	5597	5336	5389	5268	4306	1570	105	0
0	71	1495	4200	5087	5257	5307	5489	5629	5505	5547	5027
67	78	68	66	54	64	111	144	197	187	53	0
0	73	159	194	115	76	67	68	74	57	67	44
3217	3815	4385	4779	5101	5064	4886	4745	4208	2325	288	11
0	451	2623	4766	5164	5293	5489	5596	5403	4984	4134	3377

Accidental Coincidense









Statistics per channel (accidental events)

3	5	1	2	1	1	5	1	1	0	0	0
0	0	0	1	1	0	1	4	2	1	2	2
28	19	25	26	24	18	24	6	1	0	0	0
0	0	0	0	5	14	19	15	34	17	30	24
3	1	2	1	4	5	3	3	1	0	0	0
0	0	0	0	4	2	0	5	1	1	1	3
20	24	33	24	16	24	17	5	7	0	0	0
0	0	1	0	8	10	35	27	24	36	27	21

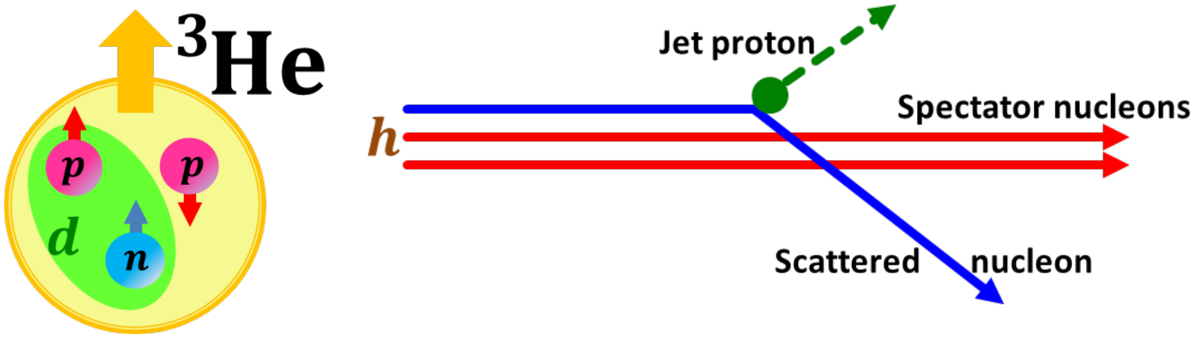
Summary

- **Too many coincidence events (~50%) in Chan. 95.**
- **Reasonable number (~0.3%) of such events in Chan 90.**
- **The best explanation I have, we observe hadronic showers after secondary interaction of the elastically scattered He3 in some walls. (No proofs, no reasonable explanations)**
- **If so, situation for 100 GeV must be much better.**

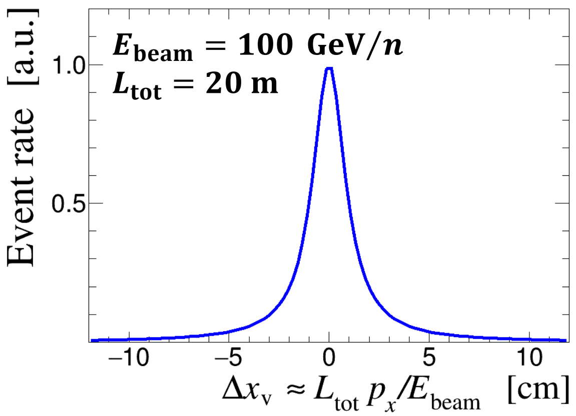
The

The

Schematic explanation of the breakup detection



Displacement of the spectator nucleons in the veto detectors.

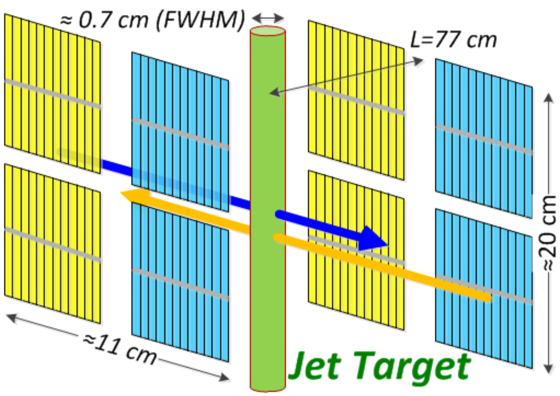


dN/dp_x distribution used was evaluated at HJET for the 10 GeV/n deuteron beam.

- 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 $\sim p_x/E_{\text{beam}}$ 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.

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 $^3\mathrm{He}$ 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 $f_{\mathrm{acc}} \approx 7.4\%$.

My personal opinion (arXiv: 2207.09420, 2207.06999) is that the EIC helion beam polarization can be precisely measured by the HJET

$$P_{\mathrm{beam}} = P_{\mathrm{jet}} \frac{a_{\mathrm{beam}}}{a_{\mathrm{jet}}} \times \frac{\mu_p - 1 - 2\mathrm{Im}\, r_5^{ph} + \ldots}{\mu_h/2 - 1/3 - 2\mathrm{Im}\, r_5^{hp} + \ldots}$$

It is assumed that

- Proton-helion hadronic spin-flip amplidudes $r_5^{ph} \approx r_5^{pp}$ and $r_5^{hp} \approx r_5^{pp}/3$ can be derived from the proton-proton one (measured at the HJET)
- The breakup correction are small and cancel in the analyzing power ratio

AP, Phys. Rev. C, 106, 065202 (2022)
AP, Phys. Rev. C, 106, 065203 (2022)
AP, arXiv 2303.10409

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

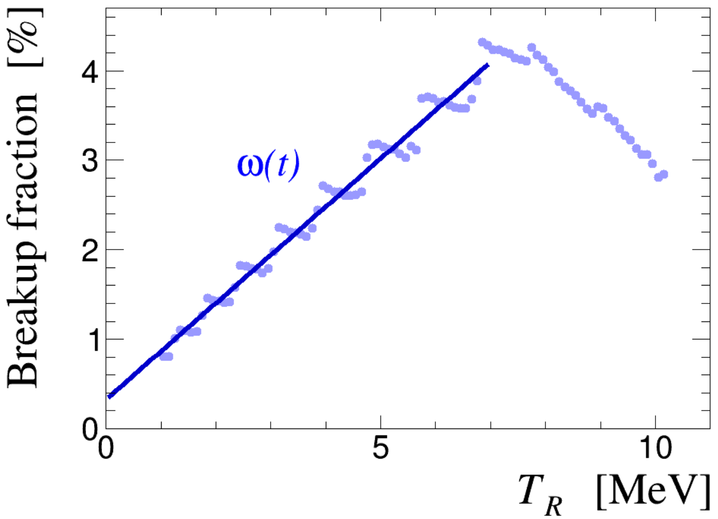
$$\omega(T_R = -t/2m_p) = dN_{\mathrm{breakup}}(T_R)/dN_{\mathrm{elastic}}(T_R)$$

What should be measured?

- It is considered that Veto Tagger signals will be recorded in the HJET FADC250 (in a dedicated 7th board).
- To trigger DAQ, HJET "OR" will be used.
- The Veto signal coincidence with the elastic-like, $hp \to (h, pd, ppn)_h p$, events in HJET will be studied.
- The primary goal should be experimental evaluation of the breakup fraction in the elastic data

$$\boldsymbol{\omega(T_R) = dN_{\text{Veto}}(T_R)/dN_{\text{elastic}}(T_R)}$$

- An estimate of $\omega(T_R)$ for the 100 GeV/n ^3He beam, based on the deuteron beam measurements at HJET (Run 16).
- It is likely that actual $\omega(T_R)$ will be about factor lower.
- The main contribution to the $\omega(T_R)$ is given by $h \to pd$.
- The **accidental coincidence** rate should be flat (T_R independent) and thus can be separated from the elastic one (unless the accidental rate is too high)



- The Run 23 regular gold beam can be used to test and adjust the DAQ.
- For the preliminary study, "Bunch zero" trigger can be very helpful.
- The gold beam $\omega(T_R)$ is also of great interest for us.

$13.5\ \mathrm{GeV}/c$ ^{3}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	σ (mb)
2	27.1 ± 0.9
3	62.5 ± 1.0
4	0.82 ± 0.06
5	25.6 ± 0.5
6	0.07 ± 0.02
7	1.86 ± 0.09
≧8	0.0023 ± 0.008

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

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

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

X – means two or more neutral particles

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

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

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

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

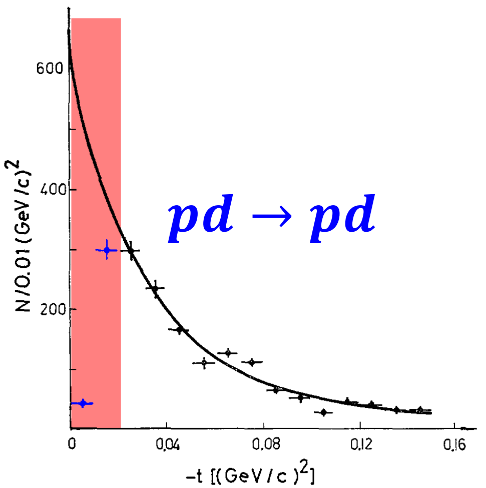
From Table 5, one can evaluate the cross section seen by the Veto detectors:

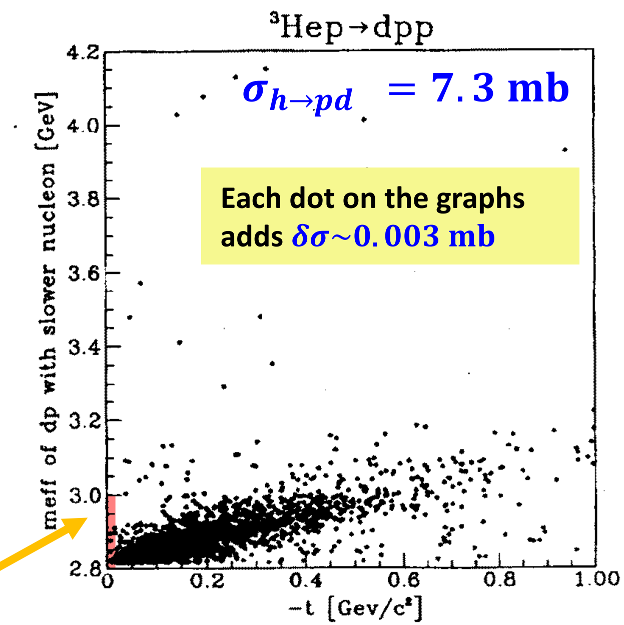
$\sigma_{\mathrm{Veto}} \sim 80\ \mathrm{mb}$

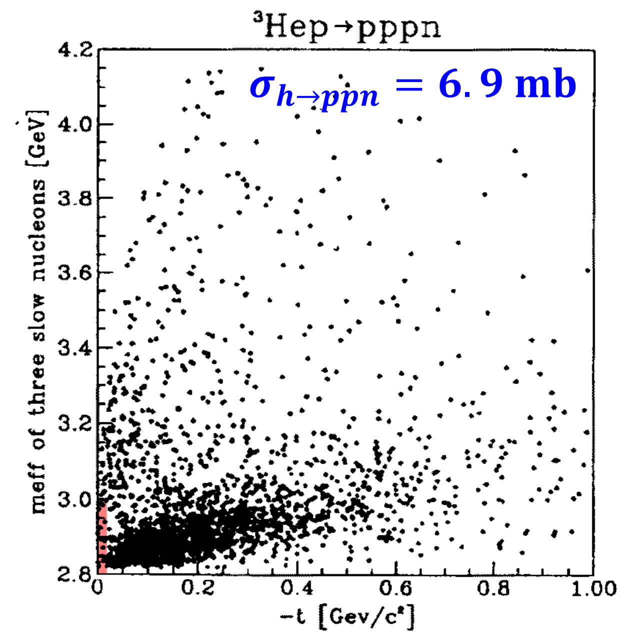
$^3\mathrm{He} \to dp$ and $^3\mathrm{He} \to ppn$ *breakups at* $4.6\ \mathrm{GeV}/n$

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

Hydrogen bubble chamber, $E_{\mathrm{beam}} = 4.6\ \mathrm{GeV}/n$







The HJET acceptance (for 100 GeV/n)

A superficial (but considering efficiency of the recoil proton detection) analysis gives the following estimate for $|t| < 0.018\ \mathrm{GeV}^2$(**HJET**):

$\sigma^{\mathrm{HJET}}_{h\to ppn} < 0.03\ \mathrm{mb} \ll \sigma^{\mathrm{HJET}}_{h\to pd} < 0.35 \pm 0.10\ \mathrm{mb}$

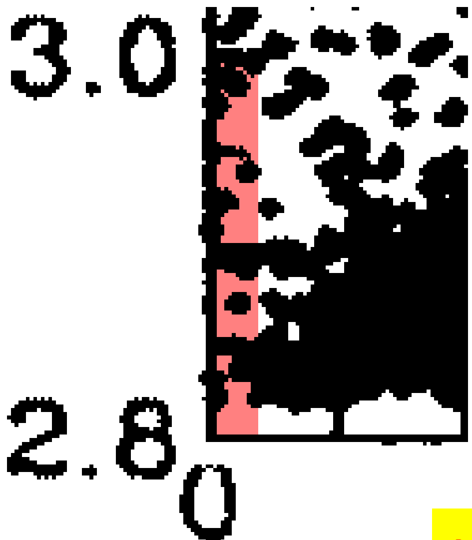
(for elastic scattering, $\sigma^{\mathrm{HJET}}_{h\to h} \sim 11\ \mathrm{mb}$)

If $\left(\sigma_{h\to pd} + \sigma_{h\to ppn}\right)^{\mathrm{HJET}} < 1\ \mathrm{mb}$, then the breakup corrections are negligible in the $^3\mathrm{He}$ beam polarization measurement by HJET.

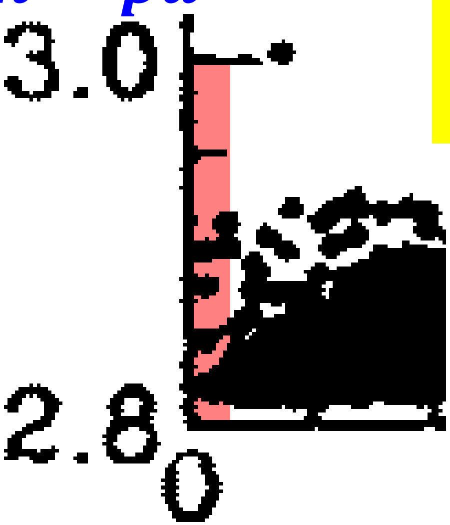
An estimate based on the deuteron beam measurements at HJET

The estimates details

$hp \to pppn$



$h \to pd$



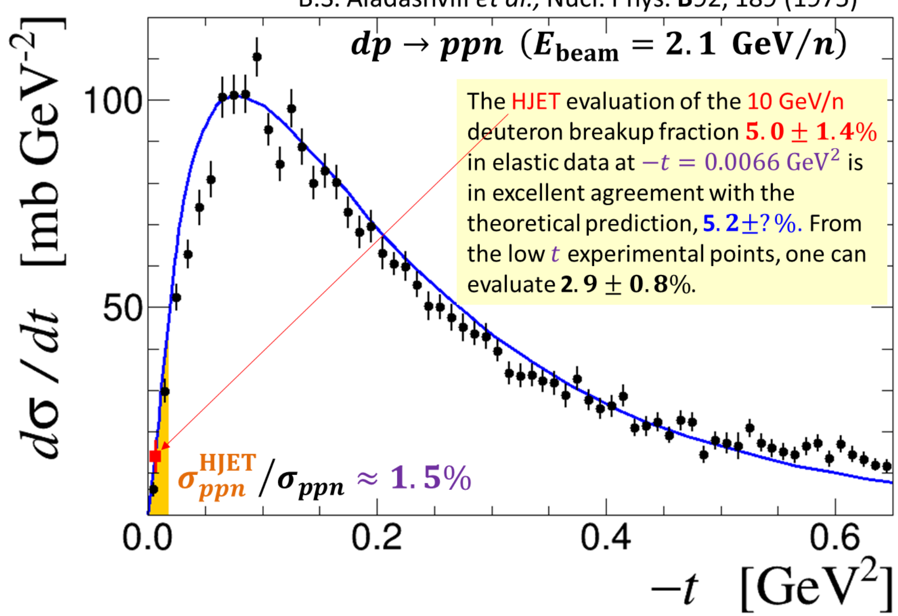
$h \to ppn$ In the HJET area, only isolated point (which can be associated with a background) are seen. Only an upper limit, $\sigma_{pppn}^{HJET} < \mathbf{0.02\ mb}$ can be set (before the efficiency corrections).

$h \to pd$ A continuous distribution is seen in the HJET area. Number of events cannot be counted. A conservative estimate gives $\sigma_{dpp}^{\mathrm{HJET}} \sim 0.04\sigma_{dpp} = \mathbf{0.28\ mb} \Rightarrow \sim\mathbf{0.15\ mb}$

- It might be interesting to simulate the considered distributions. (Only an event generator is needed)

Most of the ^{3}He beam breakup events **are not seen** in the HJET

B.S. Aladashvili *et al.*, Nucl. Phys. **B**92, 189 (1975)



Proton-^{3}He elastic scattering at intermediate energies

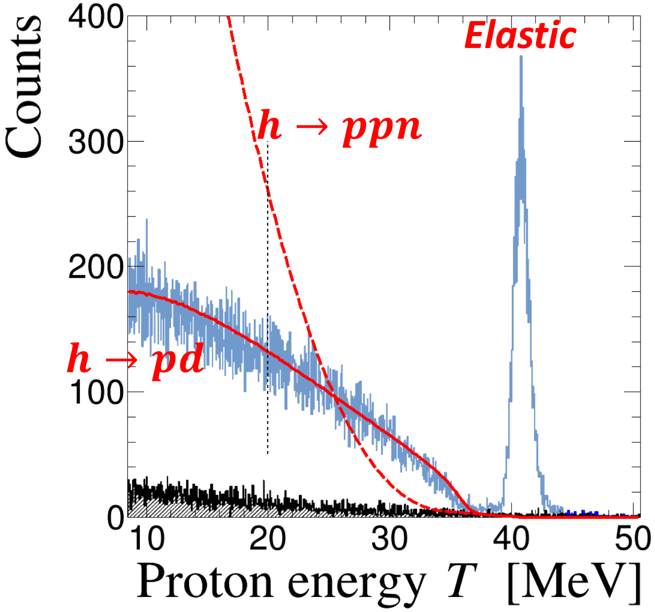
A. Watanabe et al., Phys. Rev. C **103**, 044001 (2021)

- 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 $h \to pd$ and inconsistent with $h \to ppn$.**

The phase space factor in the breakup event rate:

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

$$\Delta = M_X - M_h$$



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

Rate estimates

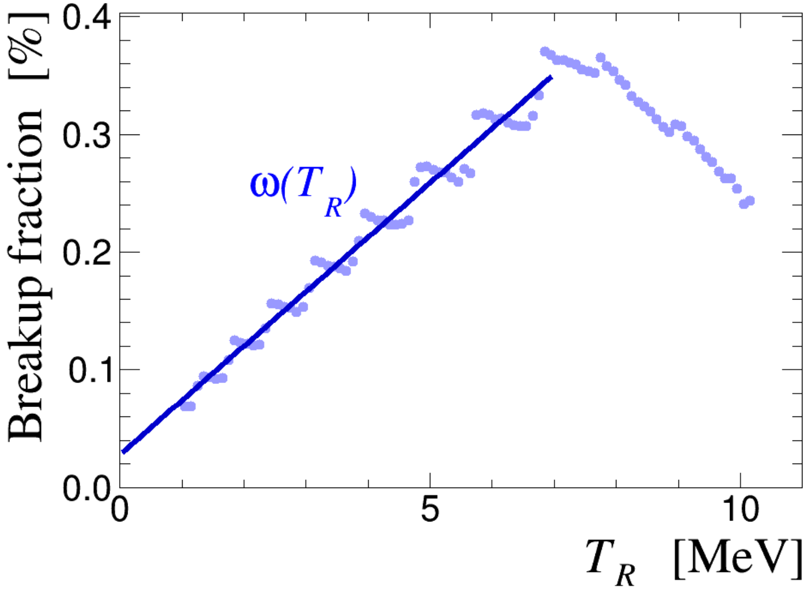
(For $\mathbf{1.2 \times 10^{11}\ cm^{-2}}$ jet density, $\mathbf{10^{11}\ bunch^{-1}}$ beam intensity, and $\mathbf{100\ ns}$ bunch spacing)

		$\mathbf{bunch^{-1}}$	$\mathbf{Hz}$
Veto	$V_p \mid V_d \mid V_n$	10^{-3}	10000
	V_d	3×10^{-4}	3300
	V_p	7×10^{-4}	6700
	V_n	3×10^{-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
Veto triggered by HJET elastic	$V_p \mid V_d \mid V_n$	$\lesssim 3 \times 10^{-7}$	$\lesssim 3$
	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.**

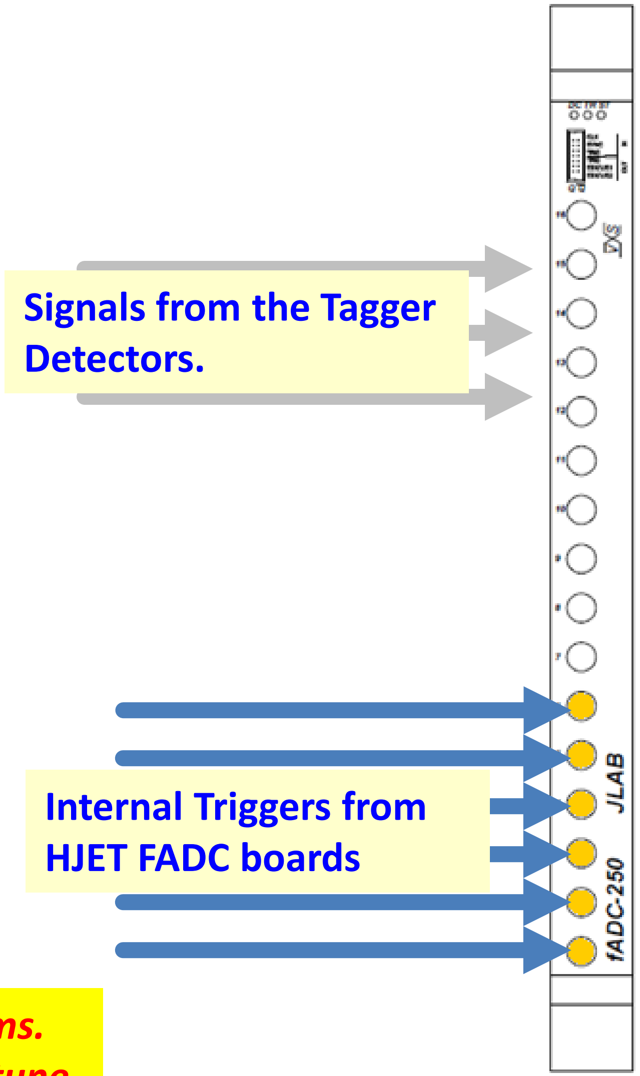
Measurements without scintillators V_d and V_p

- ZDC ($\boldsymbol{V_n}$) is not sensitive to the dominant breakup mode $h + p_j \to p + d + p_j$.
- So, only the low intensity breakup component $\boldsymbol{\sigma^{\text{HJET}}_{h\to ppn}/\sigma^{\text{HJET}}_{h\to h} < 0.3\%}$ can be evaluated.
- In one hour running about 1000 inelastic events (if $\sigma^{\text{HJET}}_{h\to ppn} = 0.3\ \text{mb}$) 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.**



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.
  - ✓ Simplified analysis of the data (amplitude, time distributions) is provided.
  - ✓ The signals waveform can be viewed.
- However,
  - ✓ The signals must be synchronized with the triggers.
  - ✓ The thresholds and waveform length should be optimized.
  - ✓ The offline analysis (including finding coincidence between HJET and Tagger signals) is not developed yet.



- ***The commissioning of the Taggers can be done with Au beams.***
- ***2 weeks of low intensity stores with 6-28 bunches for initial tune up of timing and trigger at sPHENIX is convenient time for that.***

Run 23 Timeline

RHIC Run

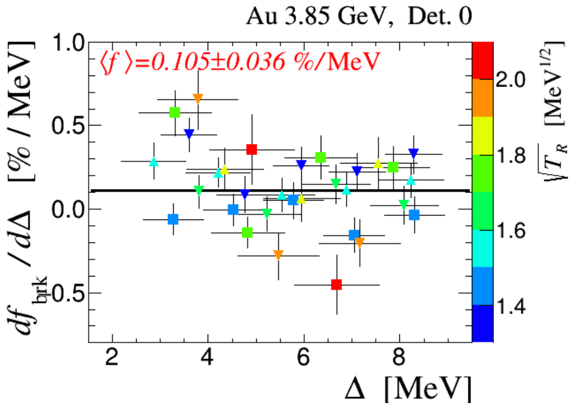
Weeks	Designation
0.5	Cool Down from 50 K to 4 K **May, 8 ?**
2.0	Set-up mode 1 (Au+Au at 200 GeV)
0.5	Ramp-up mode 1 (8 h/night for experiments)
11.5	sPHENIX Initial Commission Time
9.0 (13.0)	Au+Au Data taking (Physics)
0.5	Controlled refrigeration turn-off
24.0 (28.0)	Total cryo-weeks

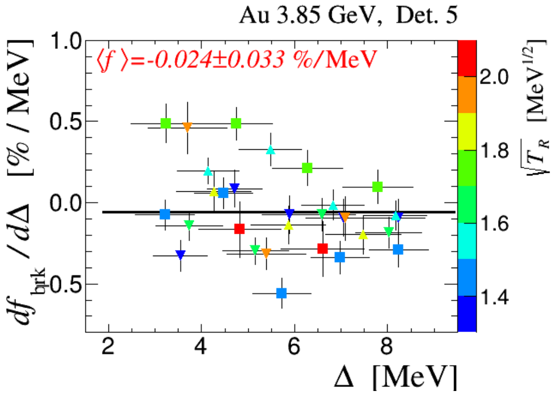
sPHENIX Commissioning:

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**

An alternative way to evaluate the ^{3}He beam breakup rate

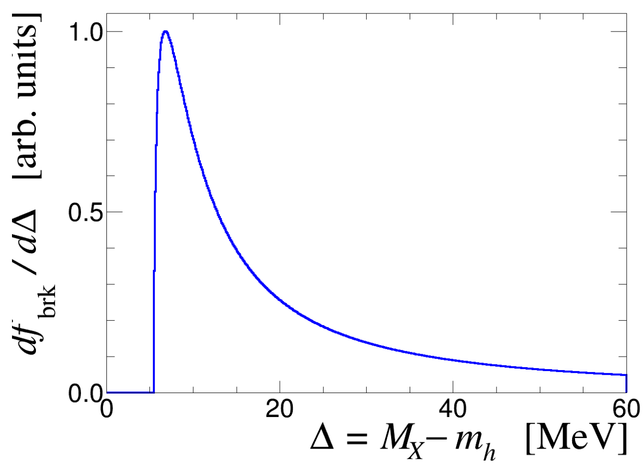
$df_{brk}(\sqrt{T_R}, \Delta)/d\Delta = dN_{\mathrm{brk}}(\sqrt{T_R}, \Delta)/dN_{\mathrm{el}}(\sqrt{T_R})$, $\Delta = M_{\mathrm{brk}} - M_{\mathrm{Au}}$





For $\mathbf{1.3 < \sqrt{T_R} < 2.1\ MeV^{1/2}}$ $(0.003 < -t < 0.009\ \mathrm{GeV}^2)$, the measured averaged breakup fraction was experimentally evaluated to be

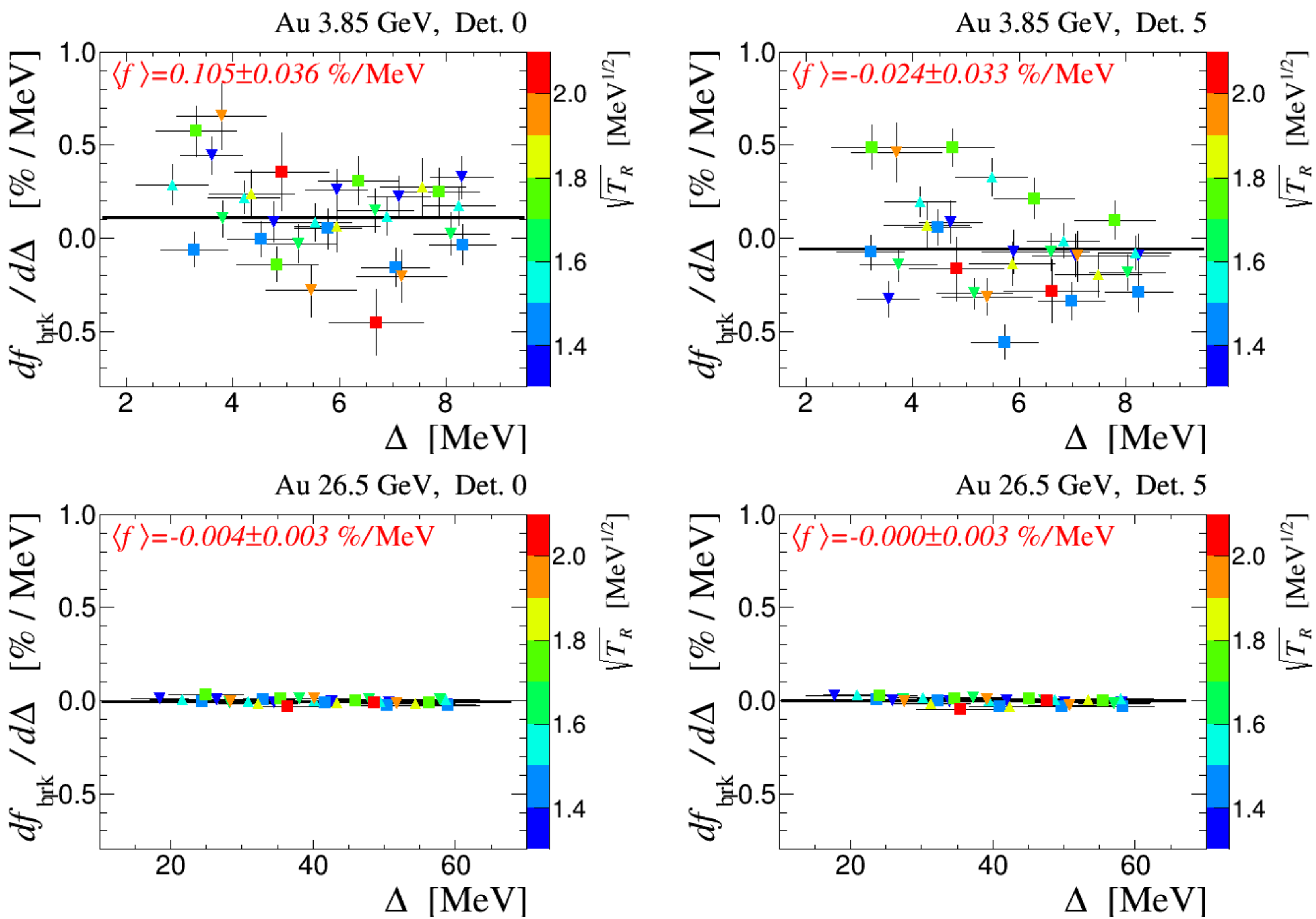
- $\langle f_{\mathrm{brk}} \rangle = \mathbf{0.20 \pm 0.12\ \%}$ for 3.6 < Δ < 8.5 MeV (3.85 GeV)
- $\langle f_{\mathrm{brk}} \rangle = \mathbf{-0.08 \pm 0.06\ \%}$ for 20 < Δ < 60 MeV (26.5 GeV)



Evaluation of the $f_{\mathbf{brk}}(\sqrt{T_R}, \Delta)$

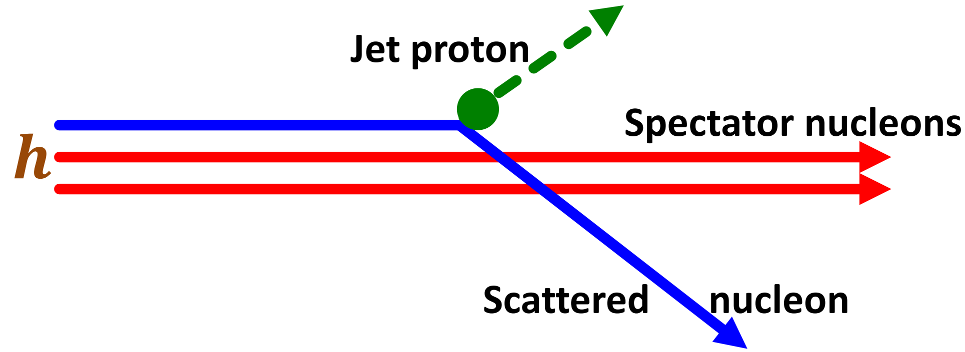
Left side detector #0

Right side detector #5



The $^{3}\mathrm{He}$ *breakup test*

Schematic explanation of the breakup detection



B.S. Aladashvily *et al.,* Nucl. Phys. **B**92, 189 (1975)

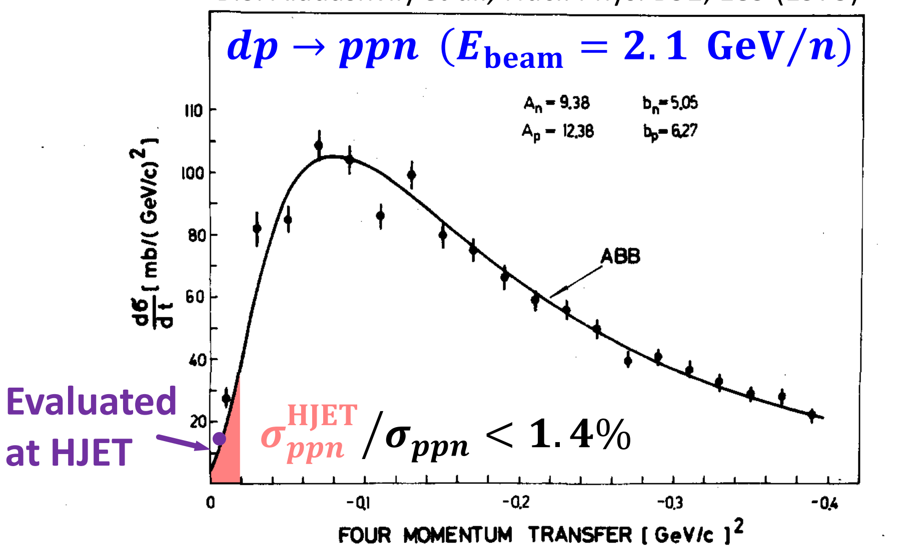
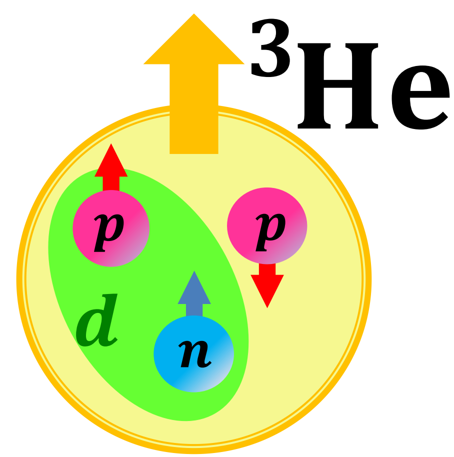
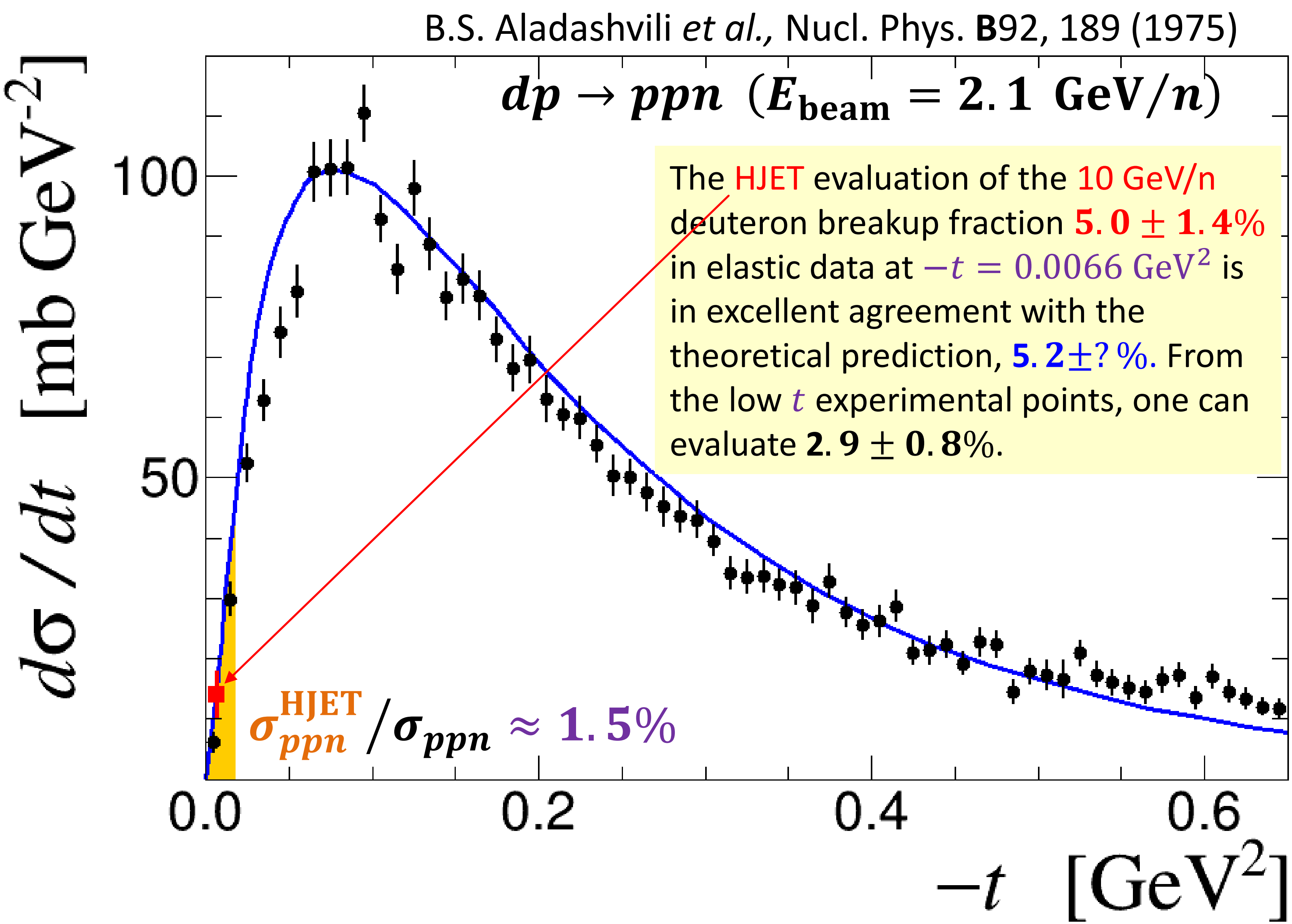


Fig. 3. The result of the fit of the Glauber model dσ/dt distribution with the Bressel-Kerman form factor to the experimental differential cross section.





B.S. Aladashvili et al., Nucl. Phys. B92, 189 (1975)
$dp \to ppn$ ($E_{\mathrm{beam}} = 2.1$ GeV/n)
The HJET evaluation of the 10 GeV/n deuteron breakup fraction $5.0 \pm 1.4\%$ in elastic data at $-t = 0.0066\ \mathrm{GeV}^2$ is in excellent agreement with the theoretical prediction, $5.2 \pm ?\%$. From the low t experimental points, one can evaluate $2.9 \pm 0.8\%$.
$\sigma_{ppn}^{\mathrm{HJET}} / \sigma_{ppn} \approx 1.5\%$
$d\sigma / dt$ [mb GeV^{-2}]
100
50
0.0
0.2
0.4
0.6
$-t$ [GeV^2]