Polarization Technology Meeting
August 28, 2024

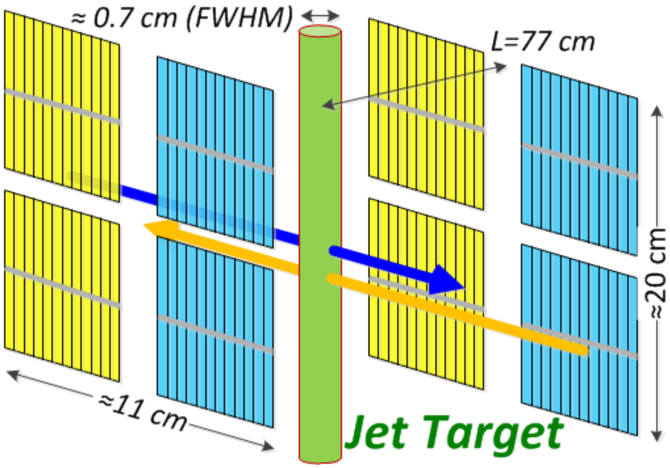
Tagging He3 breakup in HJET. 100 GeV beam.

A.A. Poblaguev

Brookhaven National Laboratory

Brookhaven National Laboratory

The RHIC proton beam polarization measurement at HJET



Asymmetry of the recoil proton detection is measured for the beam and target (the jet) spins simultaneously and in the same Si detectors:

$$a_{\text{beam}}(T_R) = \frac{N_R^{\uparrow} - N_R^{\downarrow}}{N_R^{\uparrow} + N_R^{\downarrow}} = A_N(t) P_{\text{beam}}$$

$$a_{\text{jet}}(T_R) = \frac{N_R^{+} - N_R^{-}}{N_R^{+} + N_R^{-}} = A_N(t) P_{\text{jet}}$$

For elastic events, $\boldsymbol{P_{\text{beam}} = \frac{\langle a_{\text{beam}}(T_R)\rangle}{\langle a_{\text{jet}}(T_R)\rangle} P_{\text{jet}}}$ $\quad \left(P_{\text{jet}} = 0.957 \pm 0.001\right)$

At HJET the proton beam polarization is measured with low systematic uncertainty

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

Excellent performance of the HJET at RHIC suggests using this method for the He3 polarimetry the EIC

Two possibilities for the He3 polarimeter at the EIC

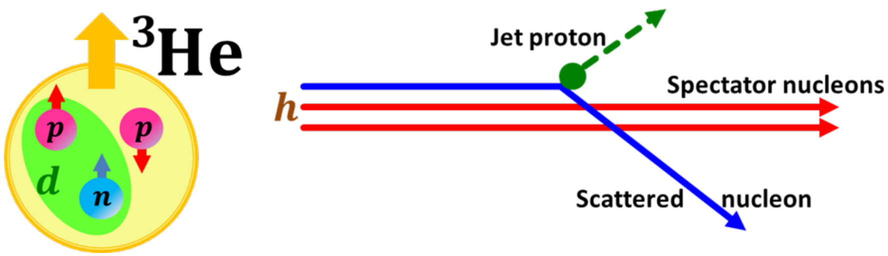
1. **Polarized He3 Target:**

$$P_{\mathrm{beam}} = \frac{a_{\mathrm{beam}}}{a_{\mathrm{target}}} P_{\mathrm{target}}$$

2. **Polarized Hydrogen Target (HJET):**

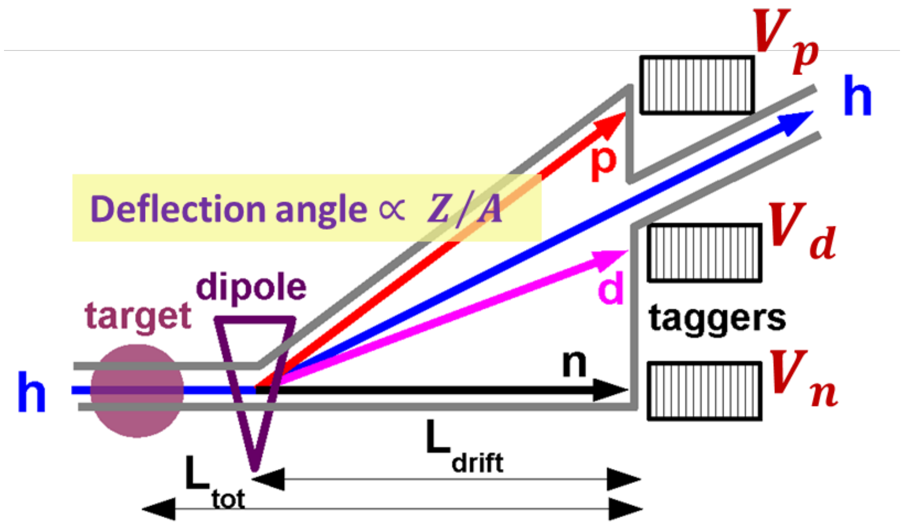
$$P_{\mathrm{beam}} = \frac{a_{\mathrm{beam}}}{a_{\mathrm{jet}}} P_{\mathrm{jet}} \times \left(\frac{\mu_h/2 - 1/3}{\mu_p - 1} + \mathrm{corr} \right)$$

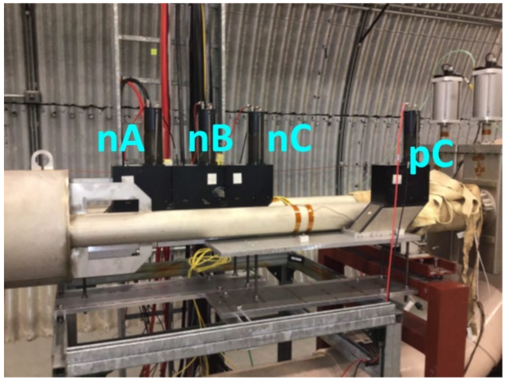
The correction due to the hadronic spin-flip amplitude is small, ~1%, and can be evaluated with sufficient accuracy.



Potentially, the He3 beam breakup in the scattering may affect results of the beam polarization measurements.

Detecting of the spectator nucleons with Tagger



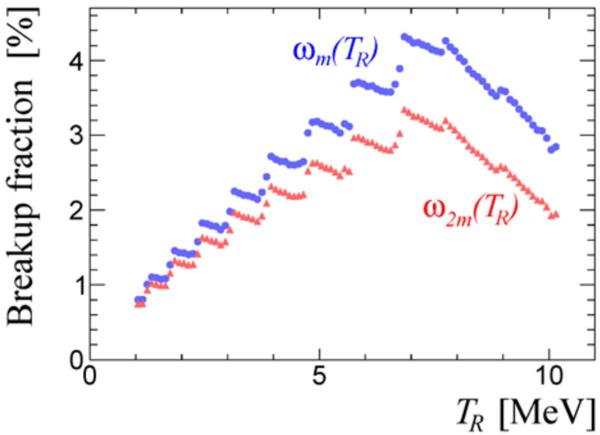


$V_p = \{pC\}$
$V_d = \{\text{not available}\}$
$V_n = \{nA, nB, nC\}$

Based on the study of the deuteron beam breakup in HJET (Run 2016), the 100 GeV He3 beam breakup fraction has been estimated.
The calculations should be interpreted as an upper limit.

An incoherent scattering of proton from $^3\mathrm{He}$ 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:

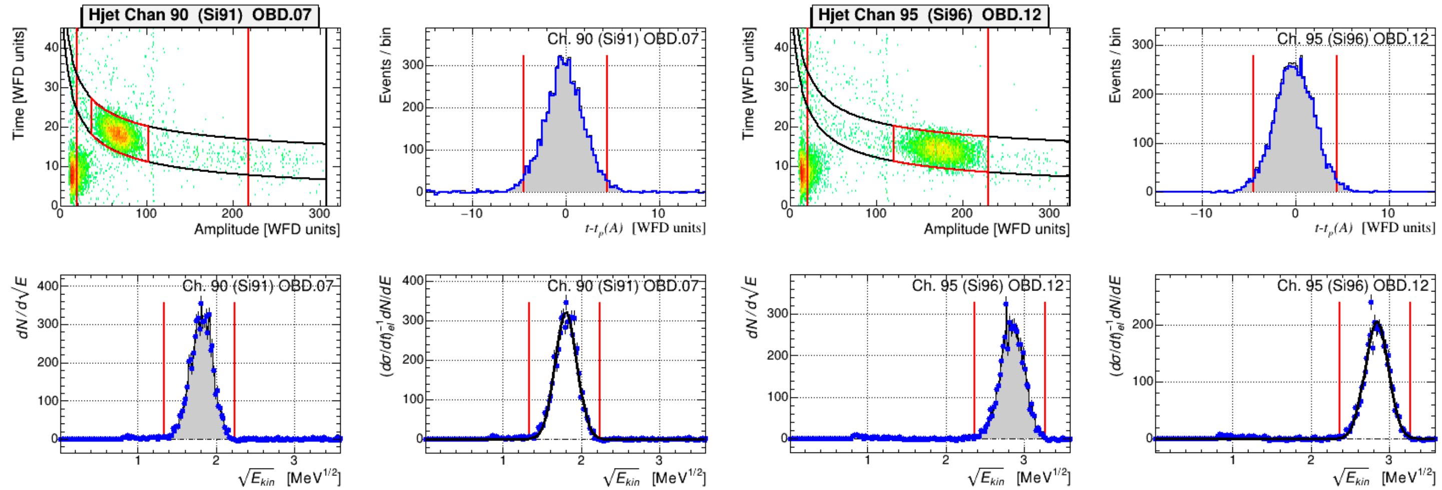
$$\omega_{2m}(T_R) \le \omega_{\text{int}}(T_R) \le \omega_m(T_R)$$



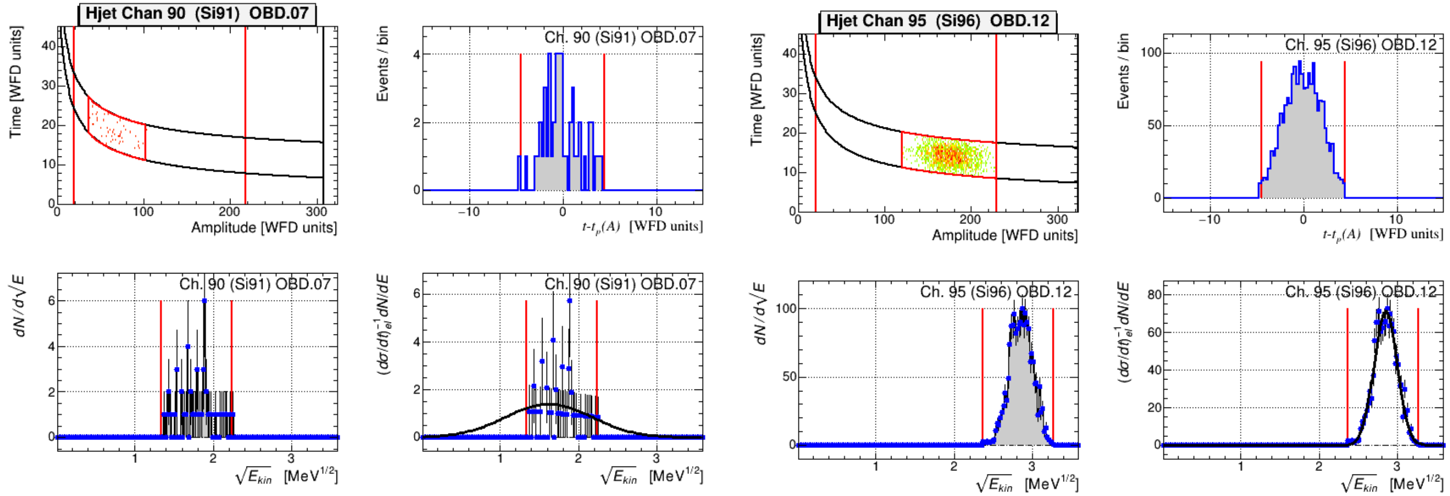
Elastic Events distribution for Injection (16.2 GeV)

- **For Ch. 90, fraction of tagged event is reasonable, <1%.**
- **For Ch. 95, fraction of tagged event is too large ~30%.**
- **The result is inconsistent with expectations.**

Total statistics



Tagged event



Statistics per channel for injecton

Total statistics

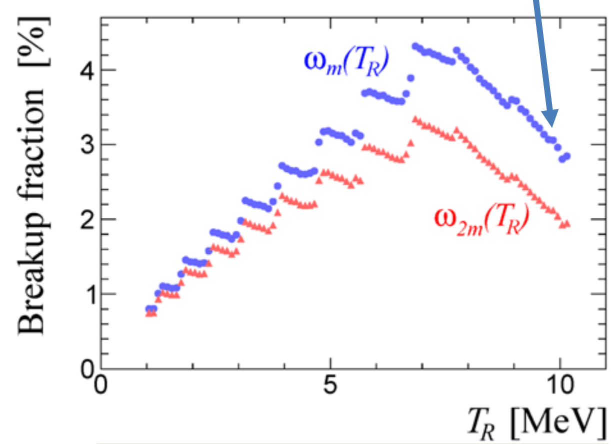
LeftDown	0	102	1569	4312	5298	5423	5389	5649	5787	5586	5748	5459
LeftUp	0	71	1508	4221	5117	5286	5343	5543	5710	5613	5669	5237
RightUp	13	288	2318	4214	4770	4921	5103	5168	5017	5198	5194	4709
RightDown	0	457	2646	4770	5183	5337	5530	5677	5690	5836	5650	5072

Tagged events

LeftDown	0	0	0	1	27	35	56	51	71	89	140	208
LeftUp	0	0	2	17	32	30	38	53	78	108	121	211
RightUp	0	0	1	11	23	34	39	72	236	812	1382	1491
RightDown	0	3	9	13	23	42	44	80	287	850	1517	1694

Ch. 95

- **The tagged events in Ch. 95 cannot be attributed to the He3 breakup in the scattering off the jet.**
- **Most likely, those are elastic events (with large momentum transfer) which are re-scattered (and breakup) outside the jet.**
- **Such an effect should be suppressed for 100 GeV beam.**



For injection (16 GeV), the detectable breakup rate should be order of magnitude lower due to the effectively reduced acceptance of the tagger detectors.

Simple Calculations for Elastic Scattering at 16 GeV

For the forward elastic scattering of He3 off a jet proton:

$$p_T^2 \;\approx\; -t \;=\; 2m_p T_R$$

For the recoil proton detected in Channel 95,

$$T_R \approx 9.5\ \mathrm{MeV},$$

the He3 scattering angle is approximately

$$\theta \approx 8\ \mathrm{mrad}$$

The deflection of He3 from the beam axis at the tagger location is:

$$\Delta x \approx 16\ \mathrm{cm}$$

- Therefore, for a 16 GeV beam, elastically scattered He3 can strike both the neutron and proton taggers.
- However, for a 100 GeV He3 beam, the scattering angle is reduced by a factor of 6, making it impossible for elastically scattered He3 to be detected by the tagger.

Statistics per channel for 100 GeV

Total statistics

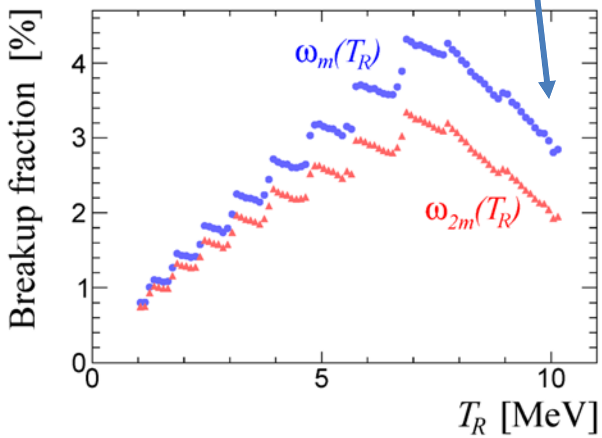
LeftDown	0	0	0	27	373	1067	1359	1400	1416	1456	1457	1322
LeftUp	0	0	0	46	354	1055	1430	1384	1365	1496	1394	1336
RightUp	0	0	7	96	669	1286	1448	1415	1403	1468	1471	1244
RightDown	0	0	11	108	696	1239	1403	1463	1411	1471	1371	1232

Tagged events

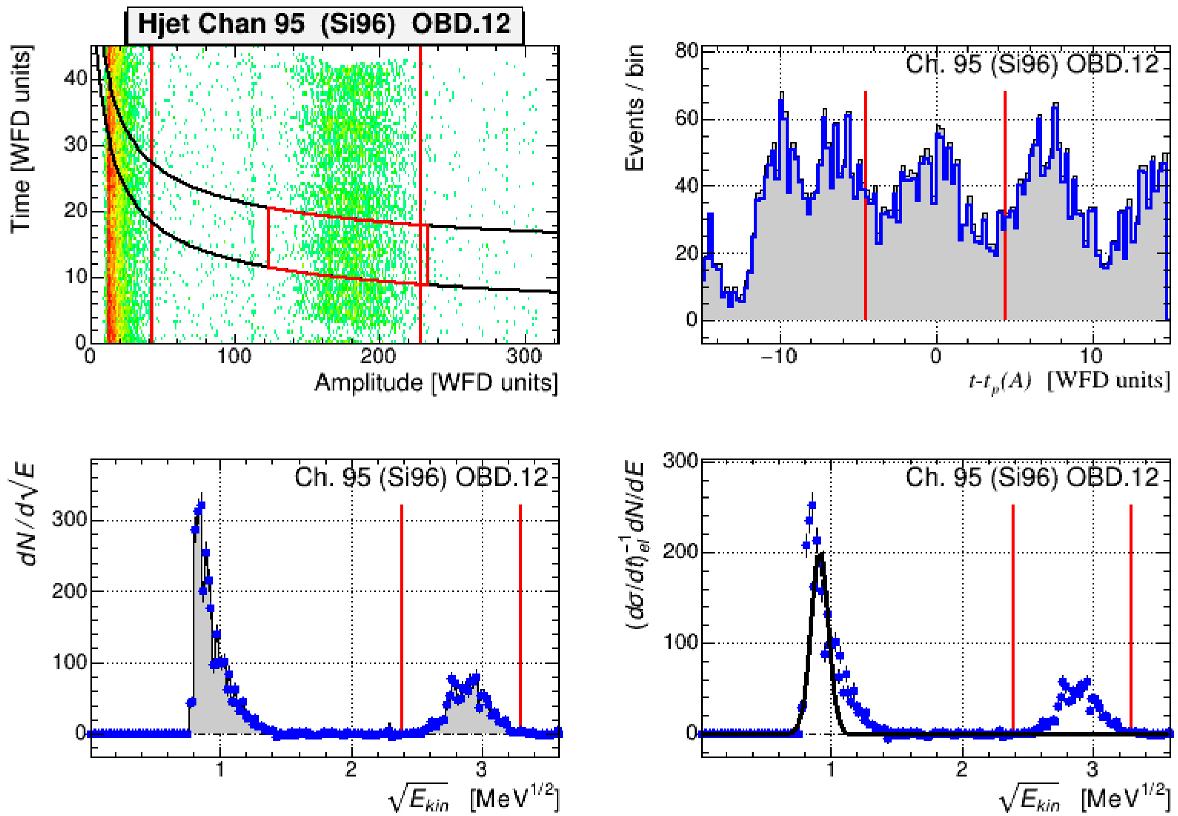
LeftDown	0	0	0	8	8	7	12	15	18	24	25	25
LeftUp	0	0	0	8	20	8	27	14	19	20	26	21
RightUp	0	0	1	6	19	13	20	15	18	26	25	22
RightDown	0	0	3	4	9	17	20	27	21	23	25	29

Ch. 95

- The experimentally evaluated breakup event fraction does not exceed 2.5%.
- The obtained results align well with the expected upper limit.



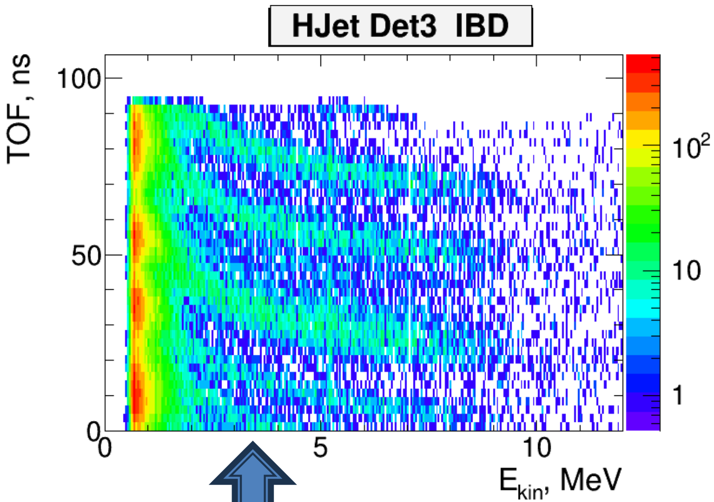
An issue with the HJET time alignment to bunch zero



320 min. run

- Such a time alignment instability has never been observed before or since.
- The elastic statistics are significantly diluted in the standard processed data.
- I expect that the availability of all data can be restored through a simple, though time-consuming, analysis.
- I see no reason to believe that the time alignment instability would distort the estimate of the breakup rate.

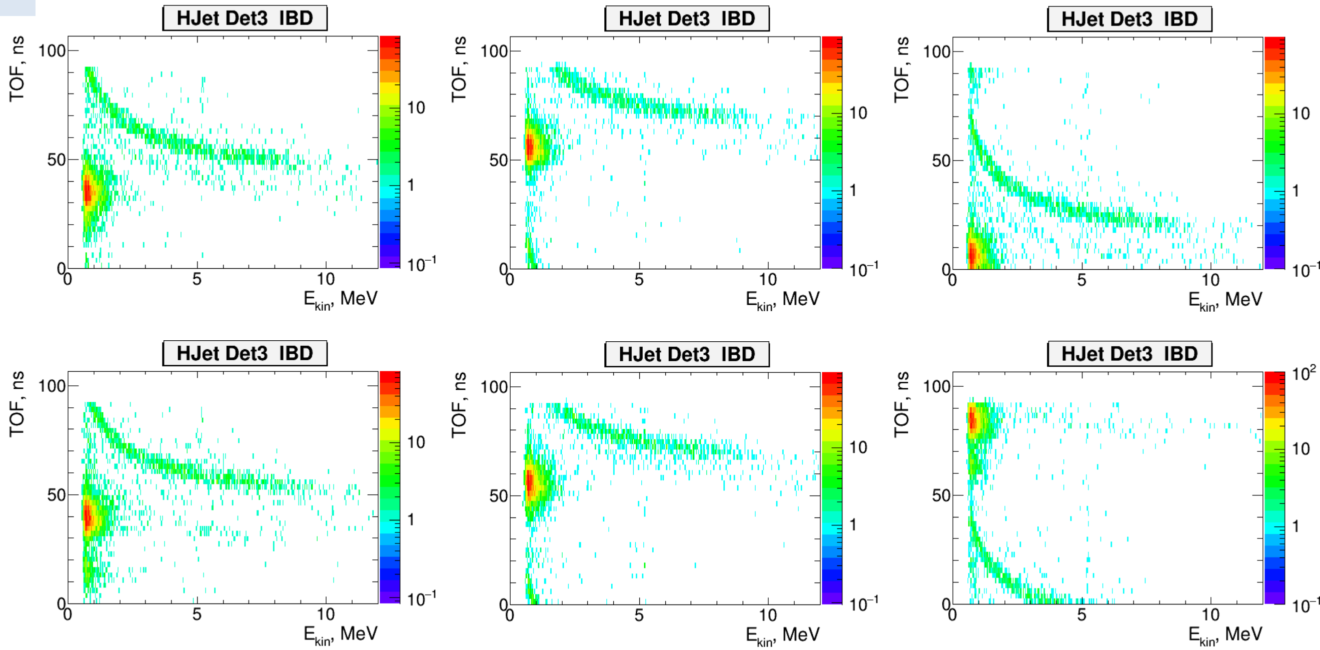
Time-amplitude distribution in a HJET Si detector



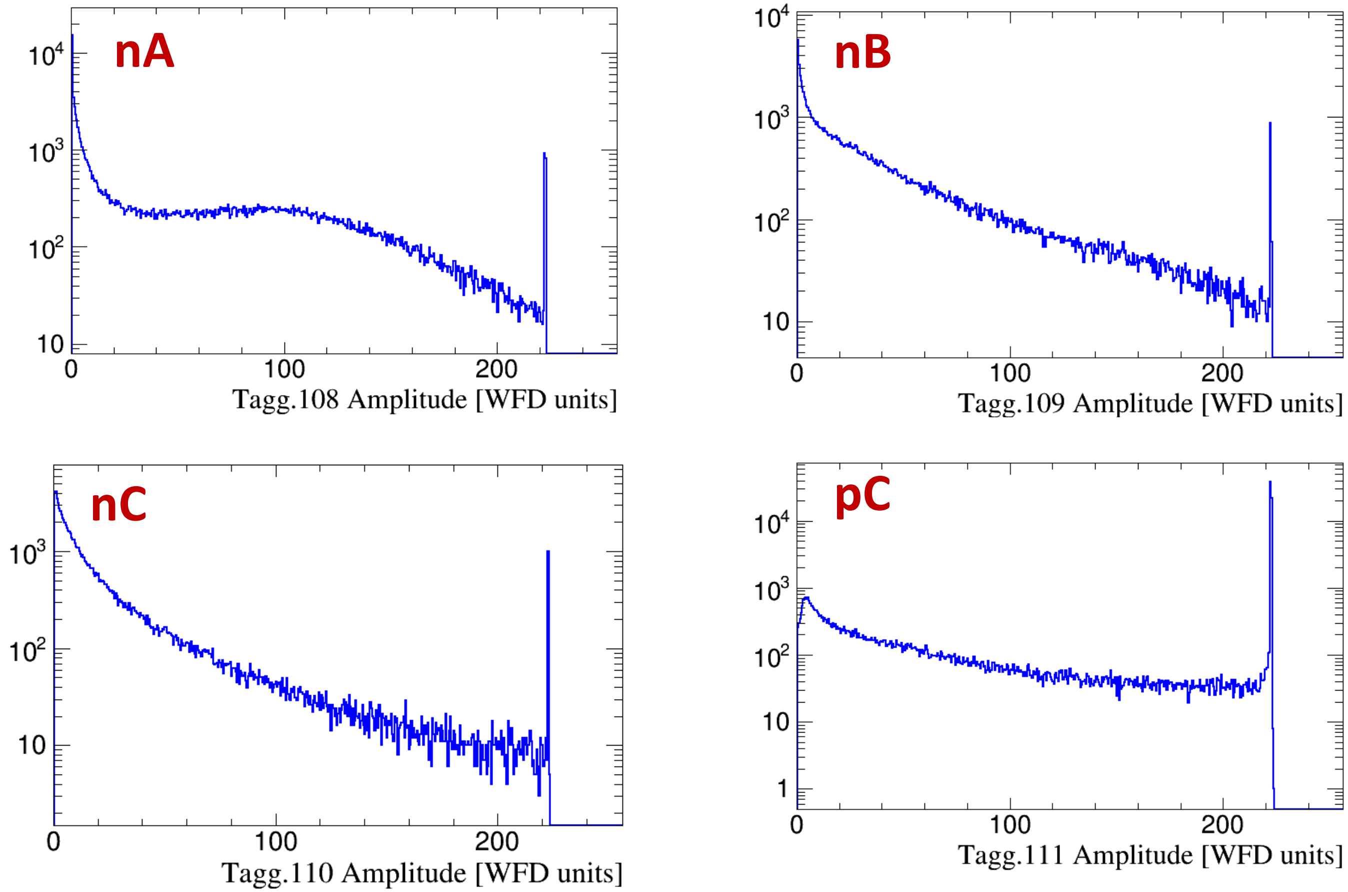
Run 34922.004. Total statistics.

- The problem is with the HJET clocks alignment to the Bunch 0.
- Such an alignment is done every HJET cycle (changing RF state)
- Never see such an effect before or after this He3 100 GeV beam.

Six consecutive HJET cycles

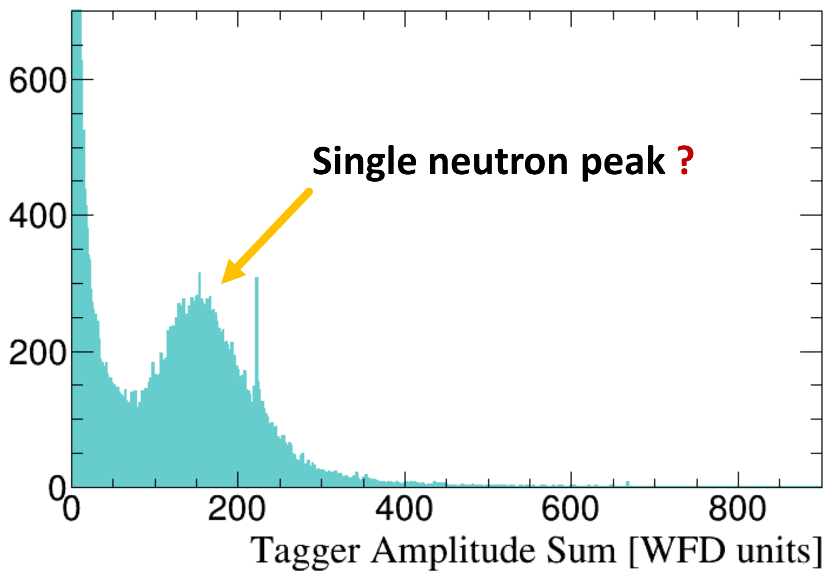


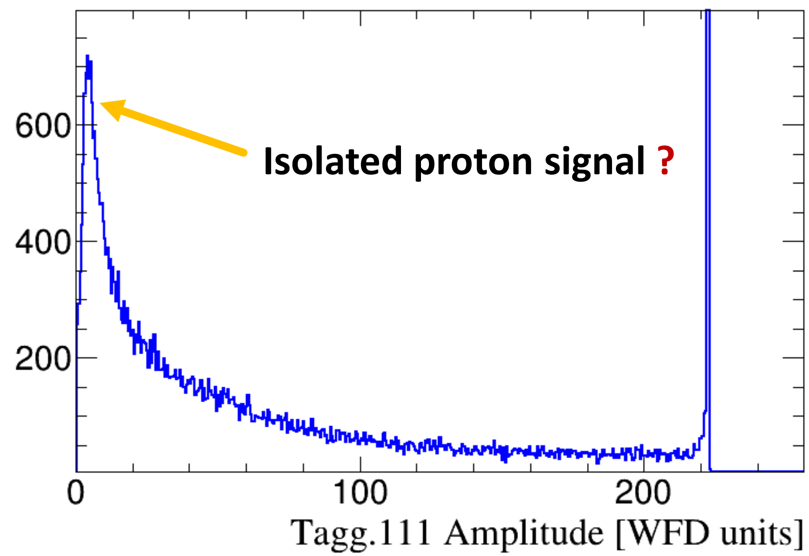
Amplitude distributions in Taggers (all events)



- Only a very small part of the displayed events is interesting for the He3 beam polarimetry (i.e. for "breakup tagging" of the recoil protons detected in the Si detectors after He3 scattering off the jet proton).
- In particular, the rate of neutron signals (nA+nB+nC) should be order of magnitude lower than the proton (pC) rate.

Identification of the neutrons and protons





- Perhaps, we do see neutrons (associated with prompts in HJET) in the ZDC and protons in the pC tagger.
- In this test a tungsten/fiber ZDC module was used as the proton tagger pC.
  For better performance, it should be replaced by a scintillator telescope.

Summary

- A complete analysis of the Tagger test data will be conducted after the time alignment is performed separately for each HJET cycle.
- Preliminary results indicate that the breakup fraction in the elastic data is approximately 3%, which is in reasonable agreement with expectations.
- Consequently, these breakup corrections should be largely canceled out in the He3 beam polarization measurements with HJET.
- However, using taggers to veto breakup events at the EIC could be important for ensuring redundancy and monitoring corresponding systematic errors.

<u>The referenced calculations can be found in:</u>

AP, Phys. Rev. C **106**, 065202 (2022),
AP, Phys. Rev. C **106**, 065203 (2022),
AP, Phys. Rev. C **108**, 025202 (2023),
AP, Universe **10**, 32 (2024).

Time-amplitude distribution in a HJET Si detector