Status of the Neutron's Electromagnetic Form Factor Ratio Measurement up to $9.8 GeV^2$

Jacob Koenemann

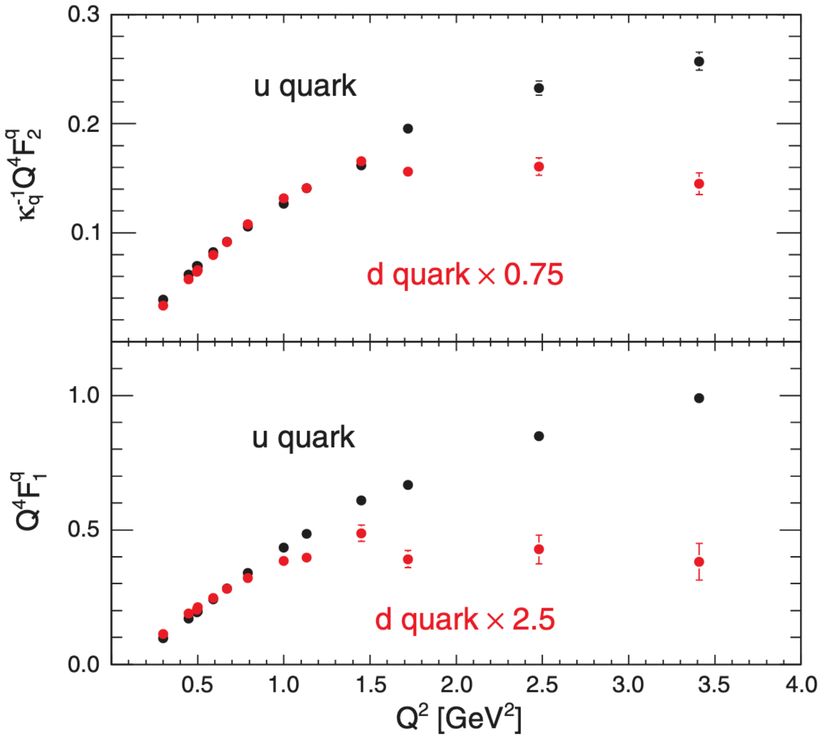






Nucleon Form Factors and Diquarks

- In Summary:
  - The connection between nucleon form factors and to the quark form factors was established by Cates et al. (2011).
  - The Q^2 dependence of $F_{1,2}^{u,d}$ as observed in the data has it's connections with diquarks.
  - What was needed next from this was to have data at higher Q^2.



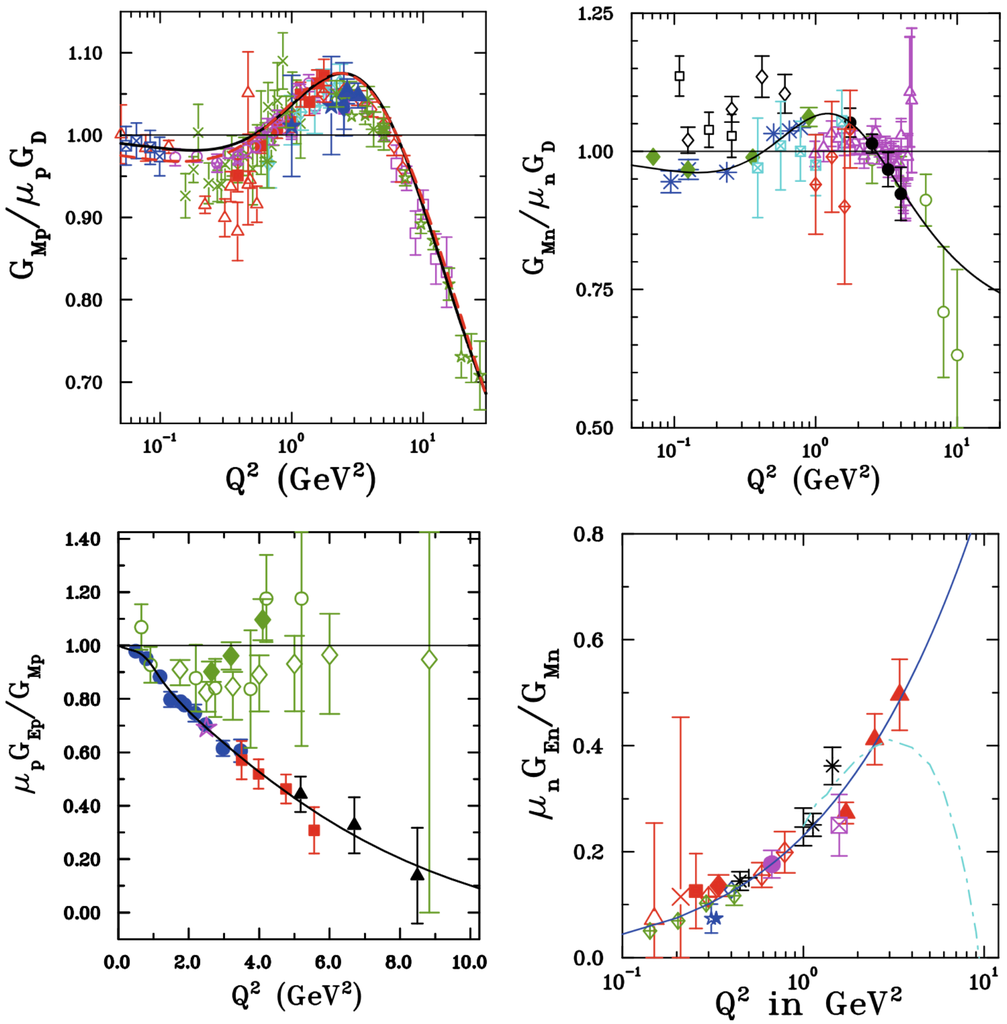
Cates et al., PRL 106, 252003 (2011)

$$F_{1,2}^{d} = 2F_{1,2}^{n} + F_{1,2}^{p}$$

$$F_{1,2}^{u} = 2F_{1,2}^{p} + F_{1,2}^{n}$$

What Data is Needed?

- As shown, there is a $Q^2 < 3.5$ limitation in the flavor separation extraction.
- This limitation purely comes from the limitation in Q^2 of G_E^n/G_M^n.
- This means in order to understand their higher Q^2 dependence, one needs to measure G_E^n/G_M^n.

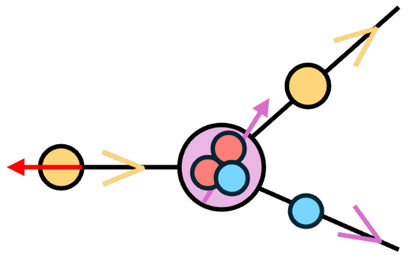


V. Punjabi et al., Eur. Phys. J. A (2015) 51: 79

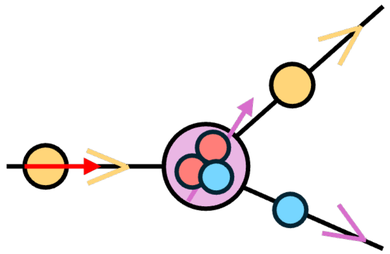
Measuring G_E^n/G_M^n at high Q^2 (GEn-II)

- The GEn-II experiment, as part of the Super Bigbite Spectrometer (SBS) program at Jefferson Lab, has measured G_E^n/G_M^n up $9.8GeV^2$.
- This was achieved by using the double polarization method with a fixed polarized 3He target and positive and negative helicity electron beam.
  - The physical asymmetry between positive and negative helicity electron scattering is dependent on G_E^n/G_M^n

$$\frac{d\sigma^{\Rightarrow,\rightarrow}}{d\Omega} =$$



$$\frac{d\sigma^{\Rightarrow,\leftarrow}}{d\Omega} =$$

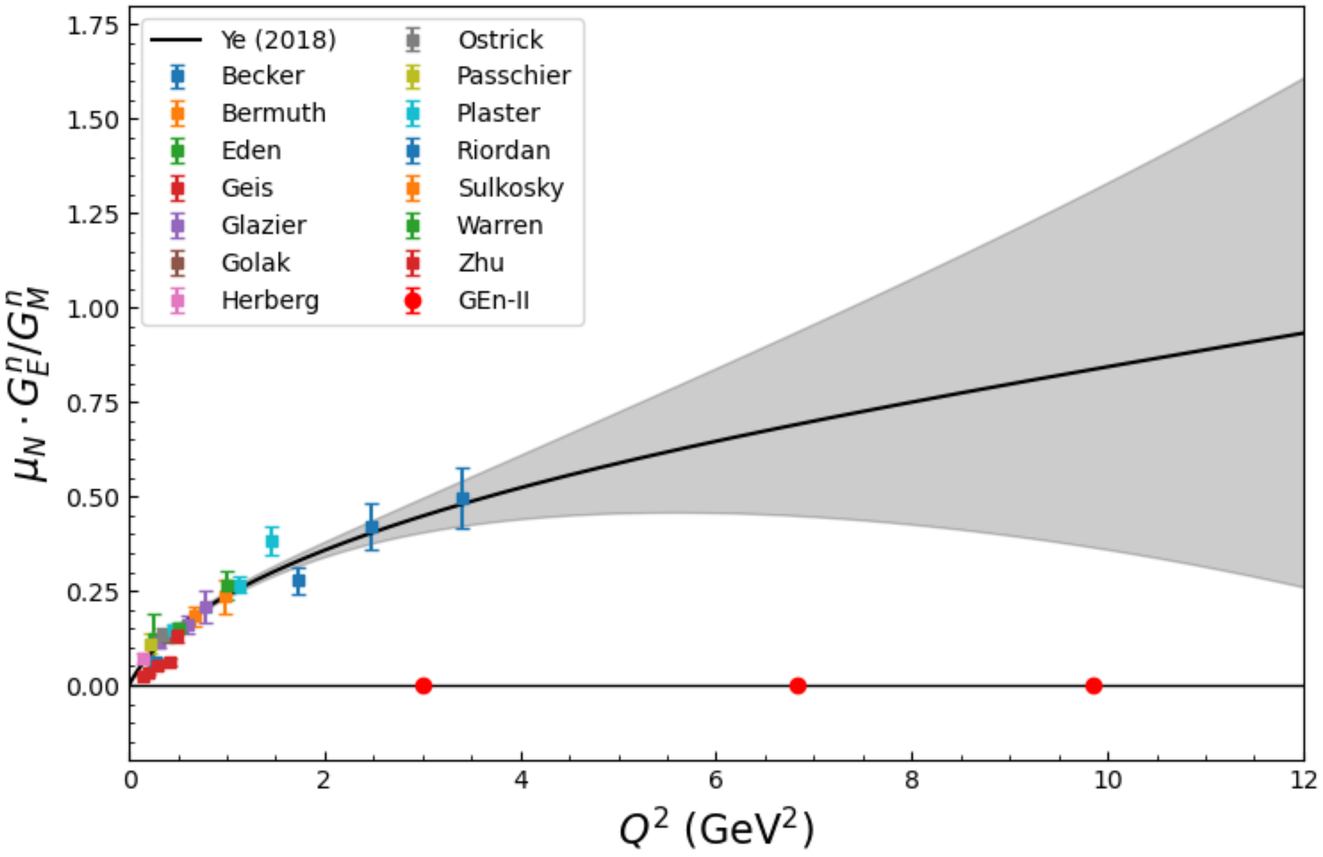


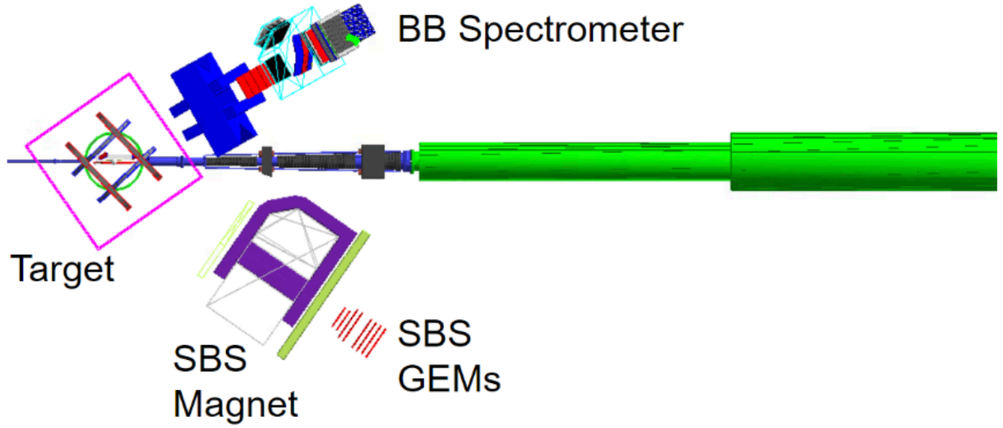
$$A_{phys} = \frac{1}{1+(\epsilon/\tau)\Lambda^2}\left[\Lambda\sqrt{2\epsilon(1-\epsilon)/\tau}P_x + \sqrt{1-\epsilon^2}P_z\right]$$

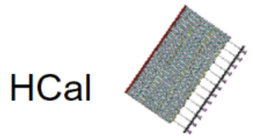
$$\Lambda = G_E^n/G_M^n$$

$\epsilon = (1+2(1+\tau)\tan^2(\theta/2))^{-1}$
$\tau = Q^2/4M_N$
P_x – target spin $\perp$ to $\vec{q}$
P_z – target spin $\parallel$ to $\vec{q}$

Measuring G_E^n/G_M^n at high Q^2 (GEn-II) cont.



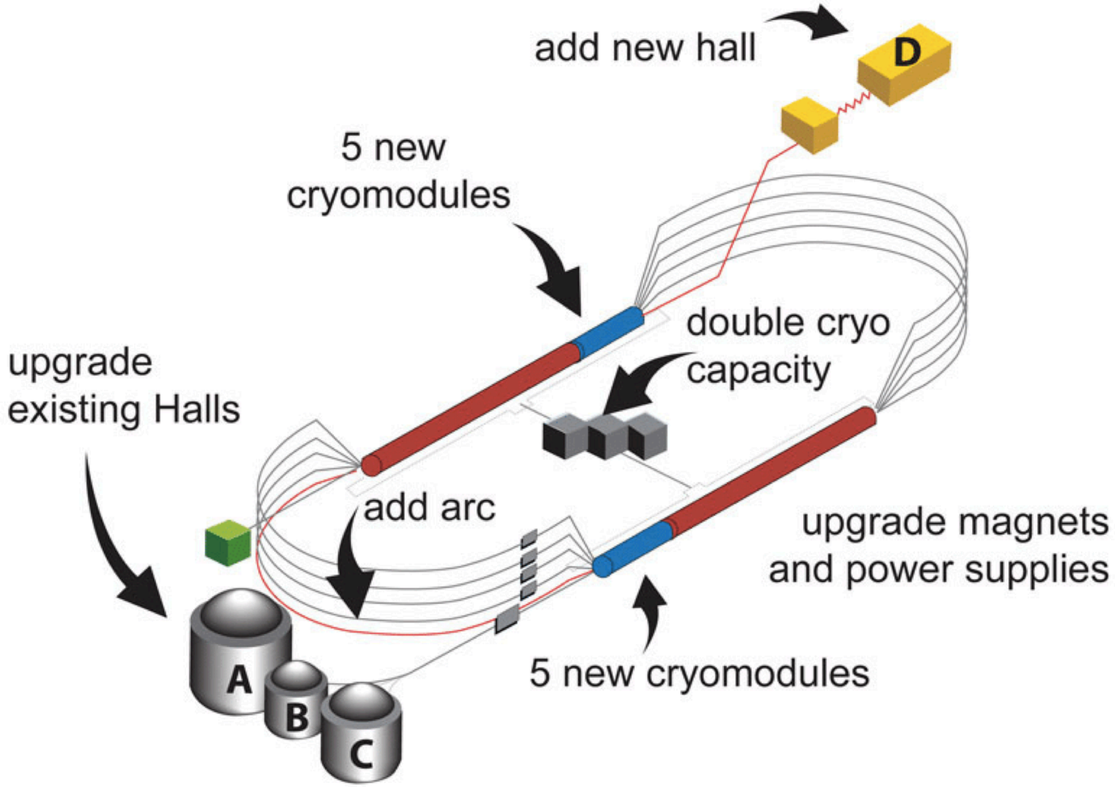




Kinematic	Q2
GEN2	3.00
GEN3	6.83
GEN4	9.85

CEBAF – Polarized Electron Source

- The Continuous Electron Beam Accelerator Facility (CEBAF) provides the, up to 12 GeV, polarized electron beam
  - In experimental Hall A, a Møller polarimeter is used to measure beam polarization



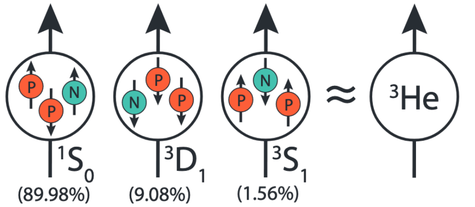
Polarimetry Results for GEn-II

Beam Energy (GeV)	<P>_beam (%)
4.2	84.1 ± 0.181
6.3	86.5 ± 0.080
8.4	86.2 ± 0.163
8.4	82.3 ± 0.070
8.4	80.8 ± 0.097

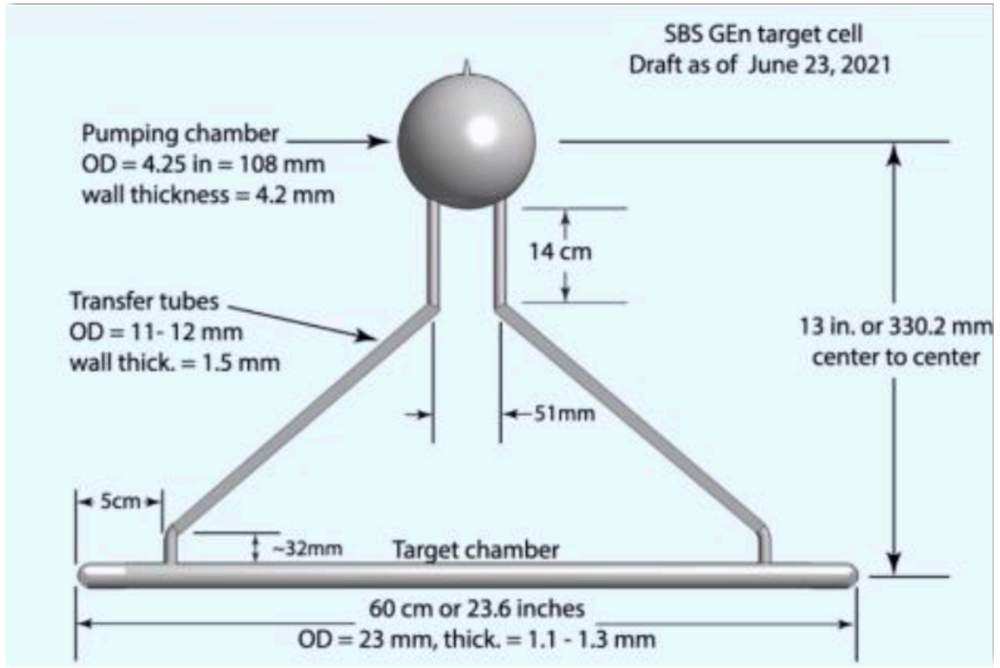
Error bars are at most 0.2%

Analysis done by Faraz Chahili

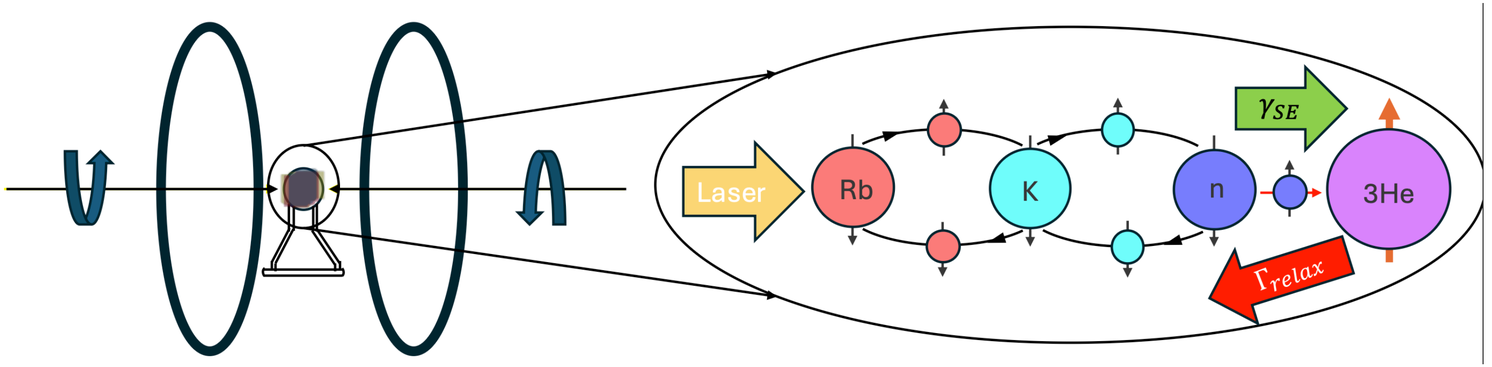
Polarized ^3He Target



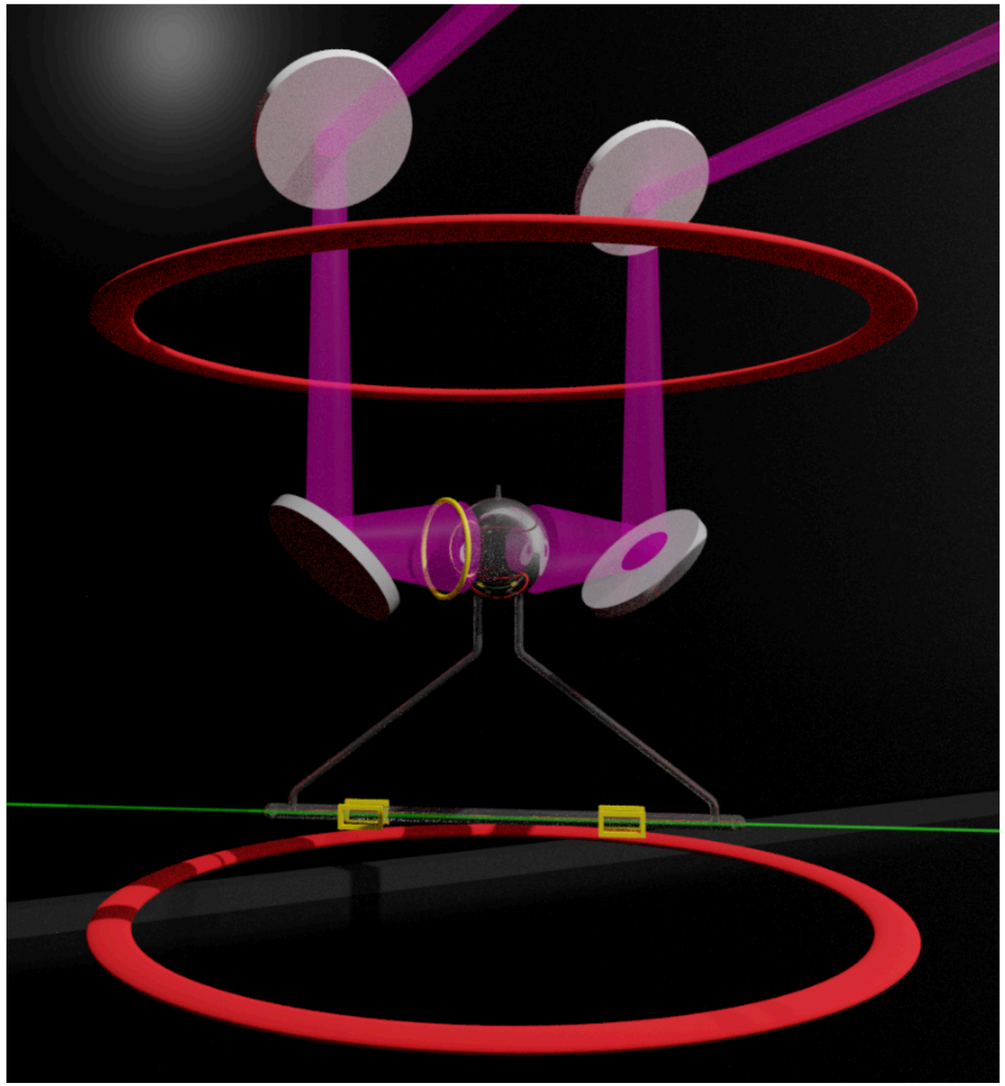
- Polarize the ^3He nucleus via alkali-hybrid Spin-Exchange Optical Pumping (SEOP).
  - Neutron predominantly carries the nucleus spin.
- Temperature differential on the transfer tube drives convection of the polarized ^3He gas.



Kinematic Setting	$\langle P \rangle$ (%)	Uncertainty ΔP (%)
Kin2	34.91	± 1.73
Kin3	41.76	± 1.09
Kin4a	53.18	± 1.92
Kin4b	36.52	± 2.19

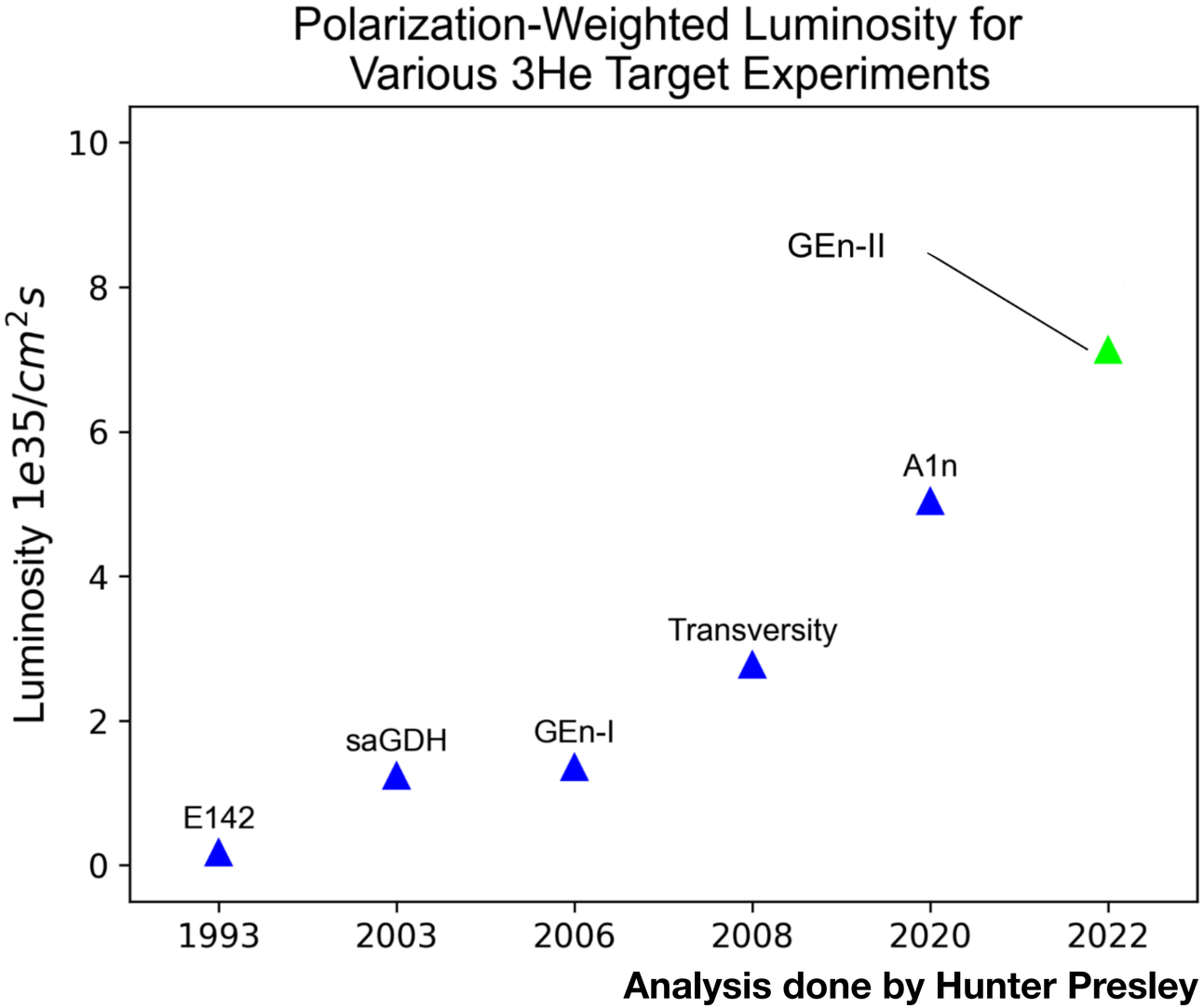


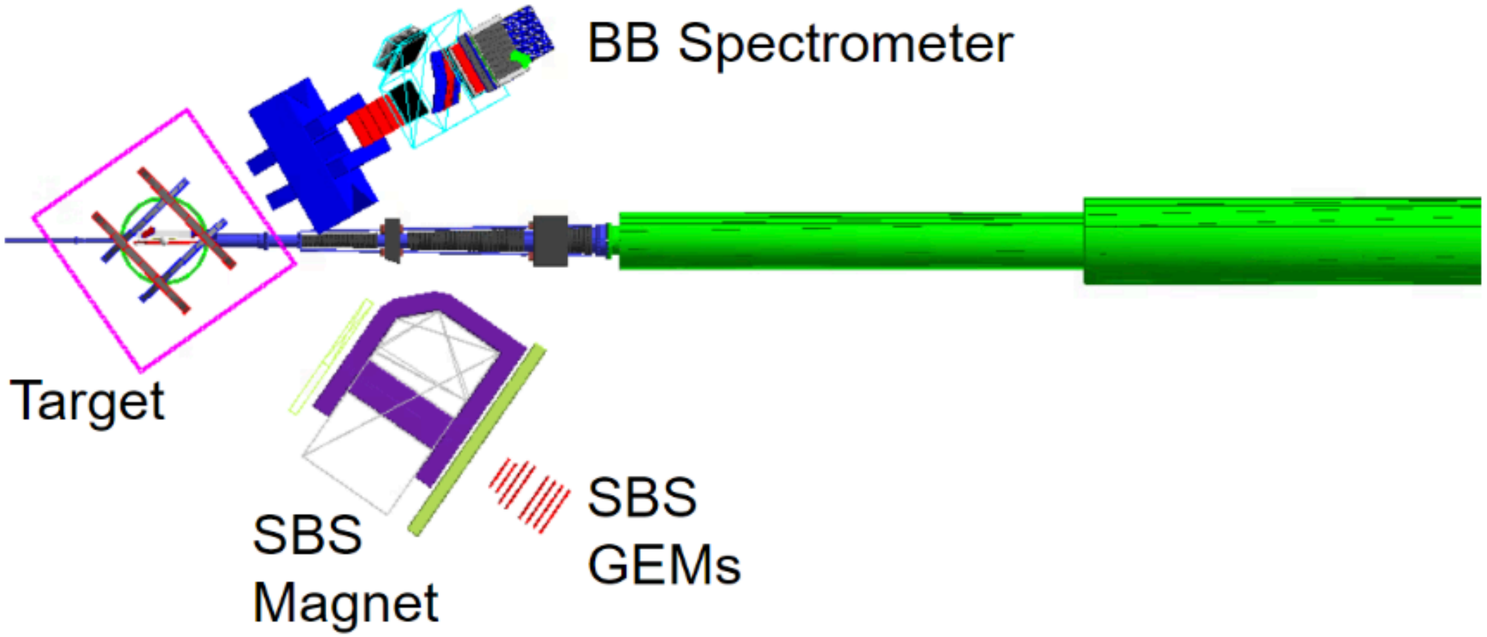
Polarized ^3He Target

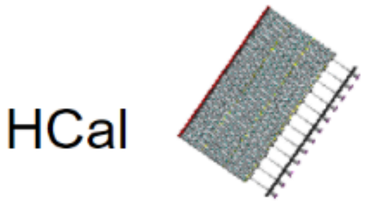


Polarized ^3He Target cont.

- The new “Coat hanger” target cell design set a new polarization weighted luminosity record with polarized 3He.




BB Spectrometer
Target
SBS
Magnet
SBS
GEMs

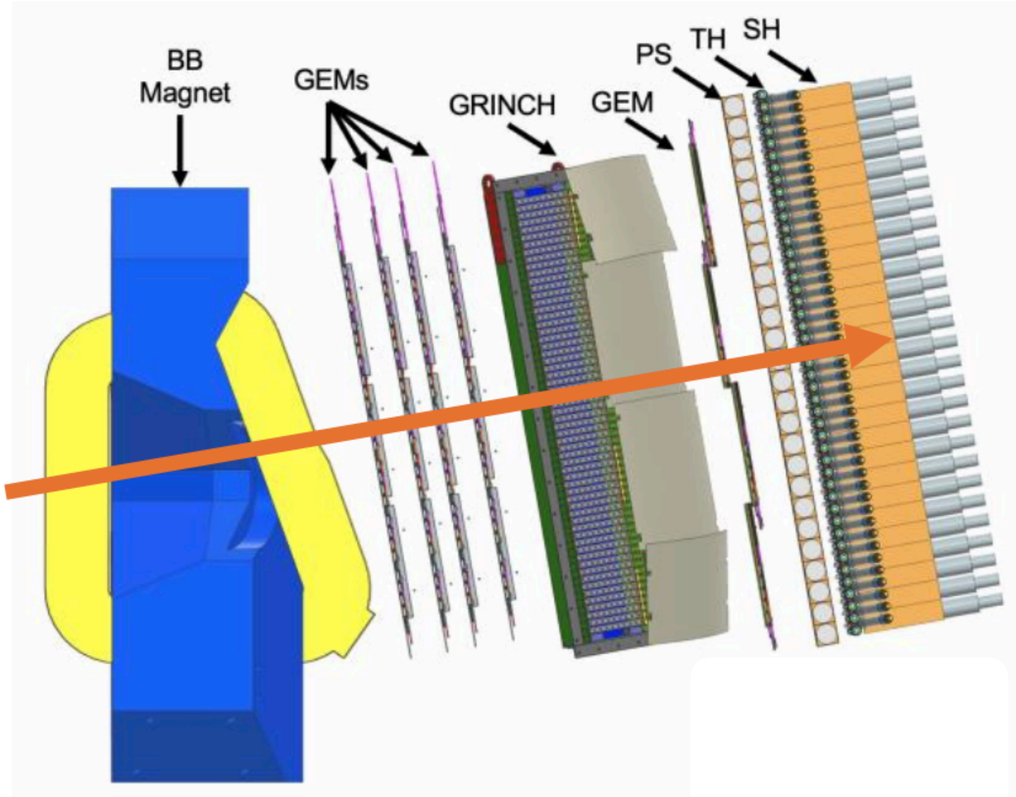

HCal

Electron Arm

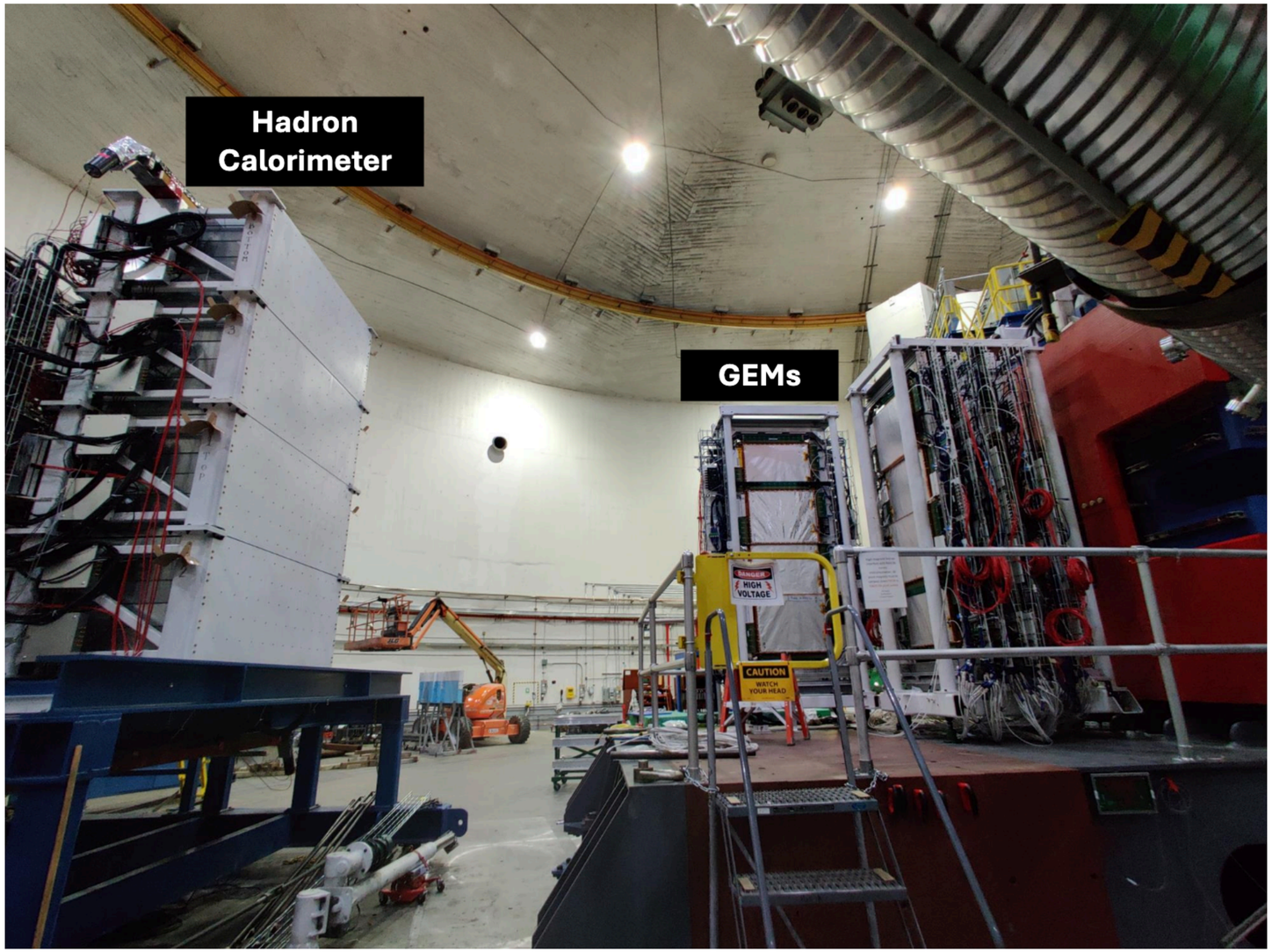


Electron Arm

- Instrument purposes:
  - BB Magnet: Momentum and charge selection.
  - GEMs: Tracking of charged particles ($\delta \approx 0.1mm$). Total of 5 layers.
  - GRINCH: Particle identification (PID). Distinguishes electrons and pions through Cherenkov radiation.
  - Timing hodoscope: High resolution timing detector. All detectors are time aligned to it.
  - BBCAL: PS spectrum is used for further PID. The PS + SH capture the total energy of the electron. SH's position reconstruction allows for constraints on track reconstruction. SH and PS timing for electron selection and coincidence time with the hadron arm.

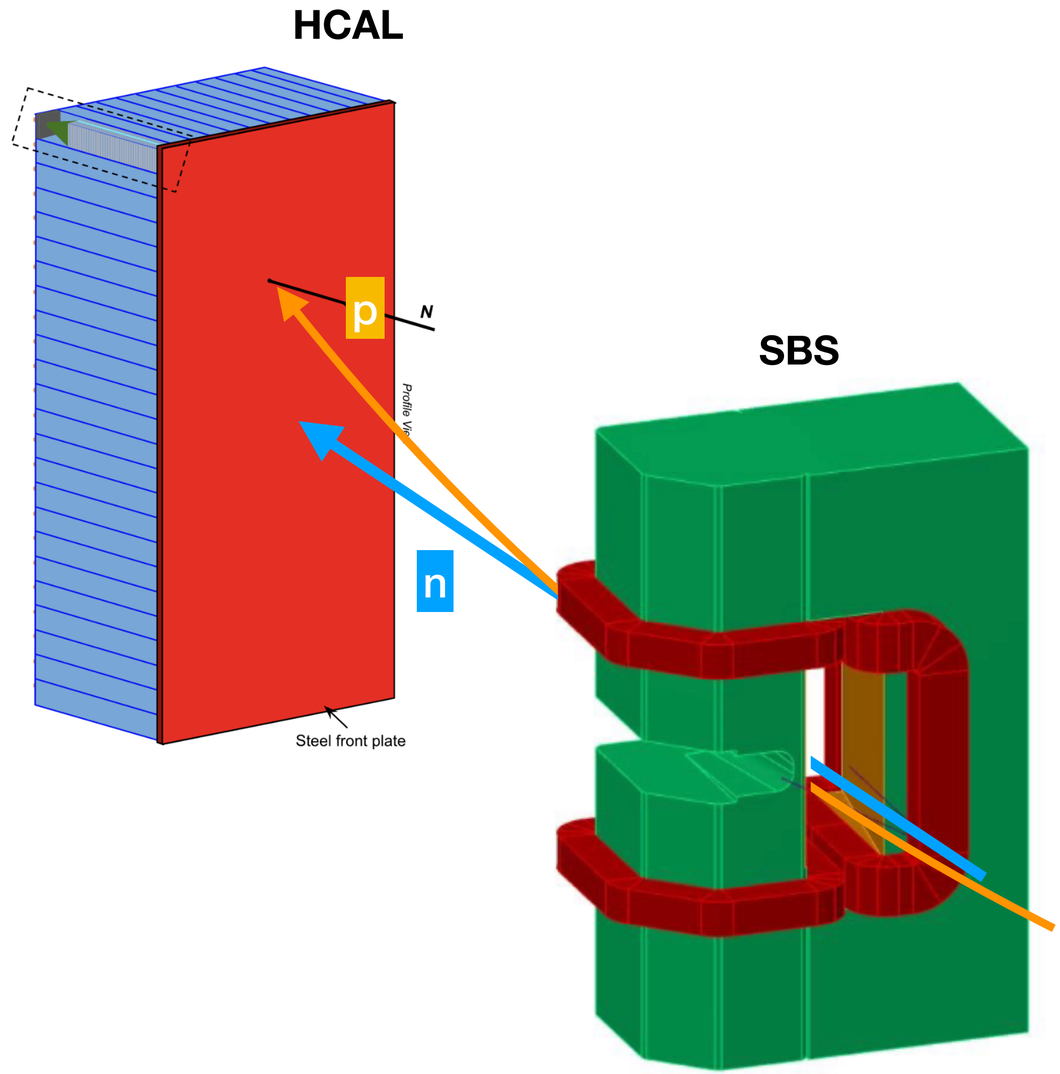


Hadron Arm

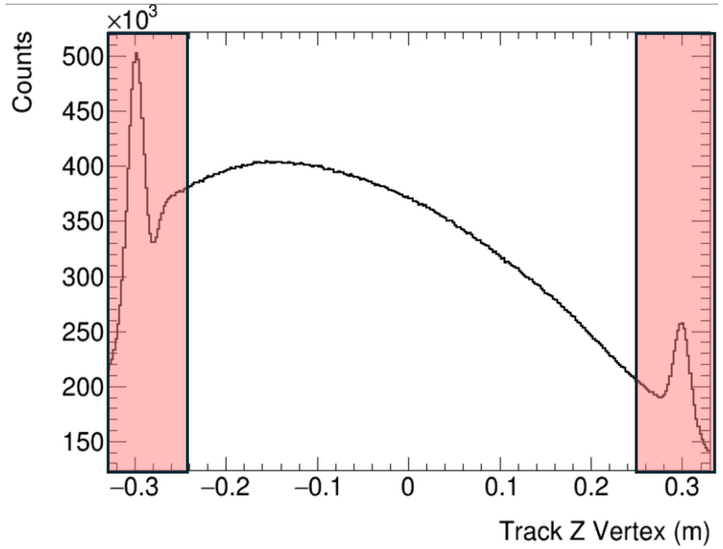

Hadron
Calorimeter
GEMs
DANGER
HIGH
VOLTAGE
CAUTION
WATCH
YOUR HEAD

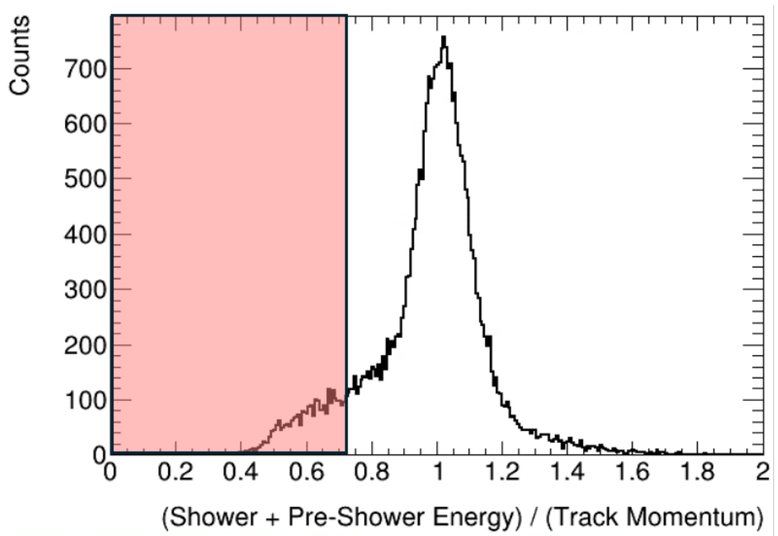
Hadron Arm

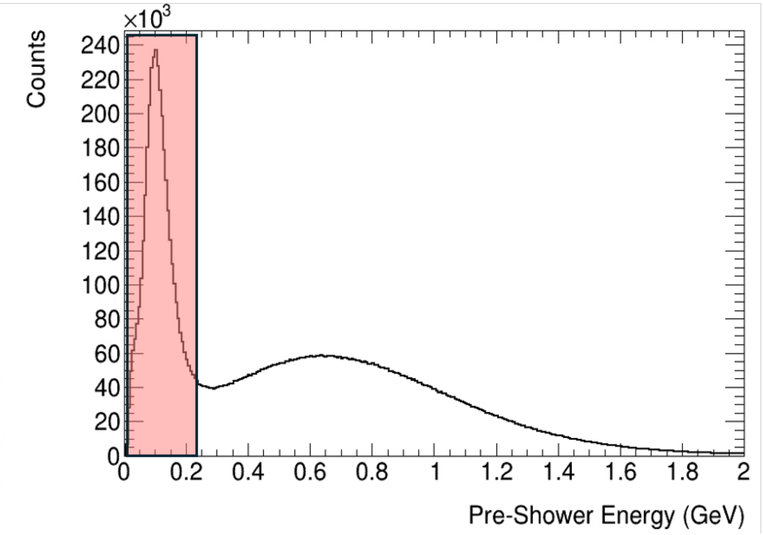
- SBS: Charge and momentum selection. Separates QE neutrons form protons.
- SBS GEMs (shown on previous slide): Just like the BB GEMs, provide track construction for charged particles.
- HCAL: Provides position, timing information, and samples a fraction of the nucleon kinetic energy (15-10%).

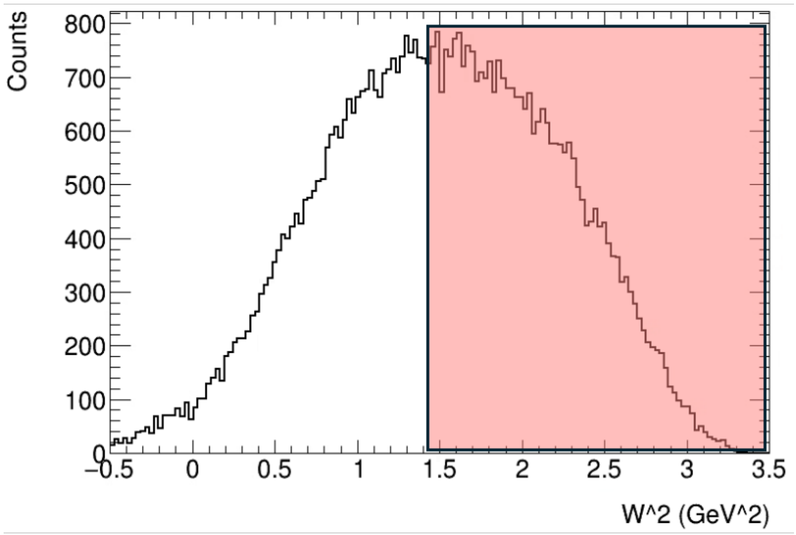


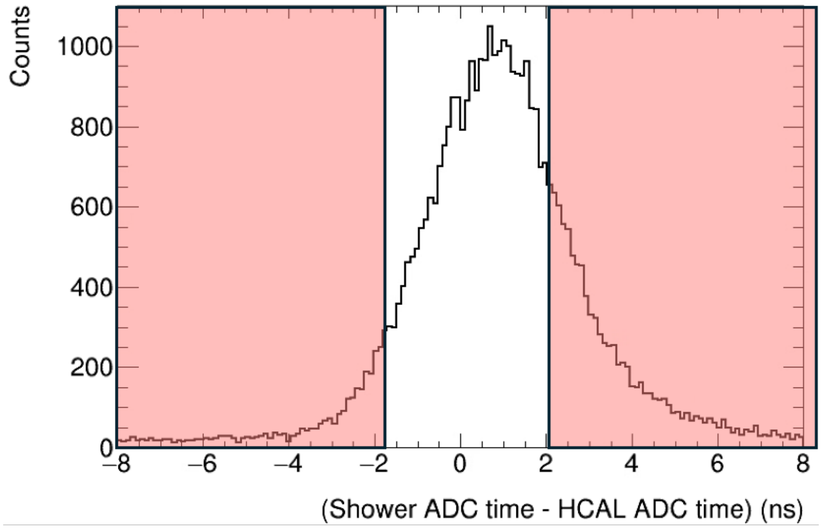
Extracting QE Events



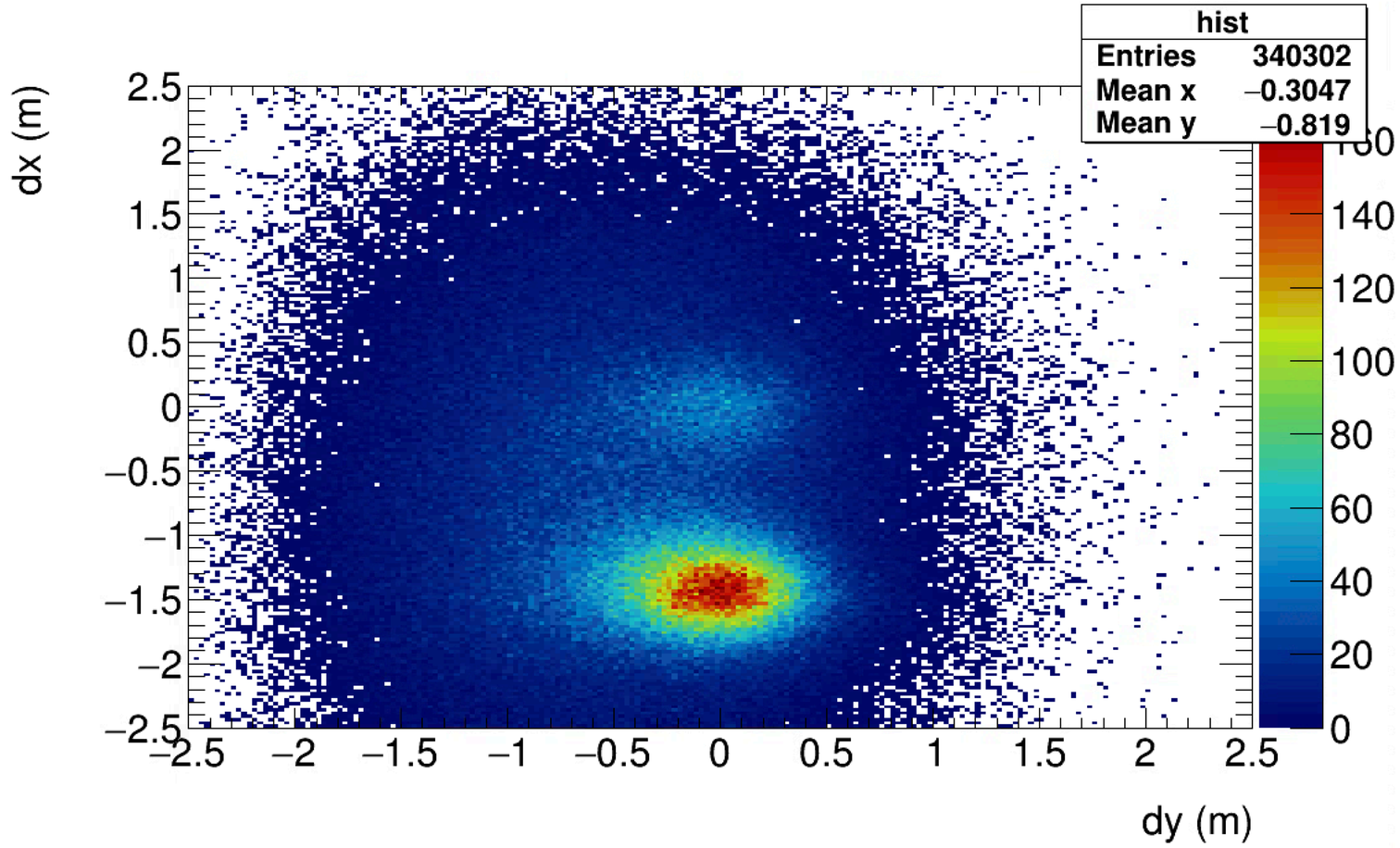


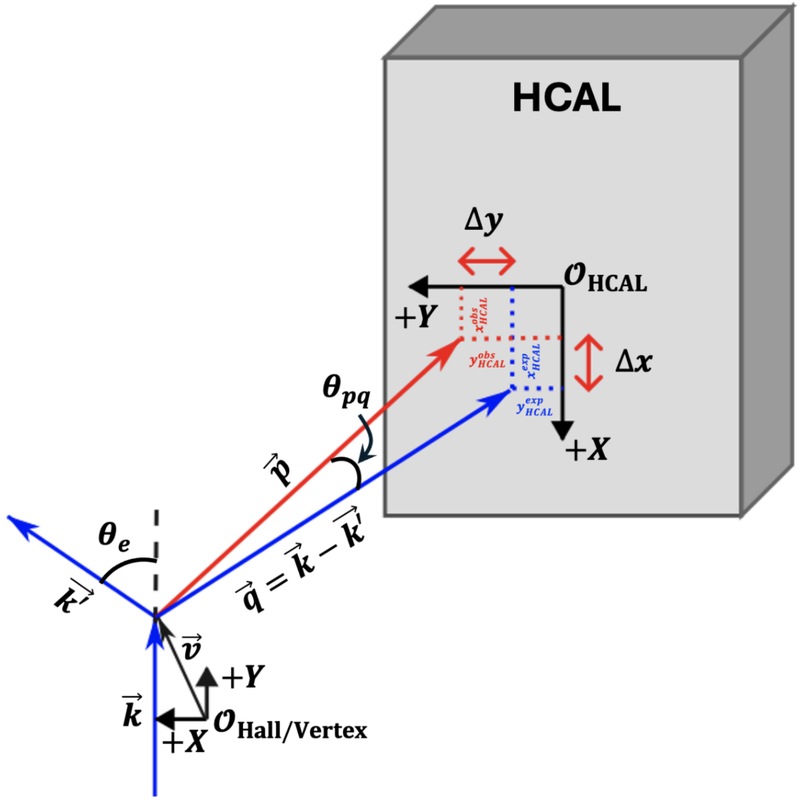






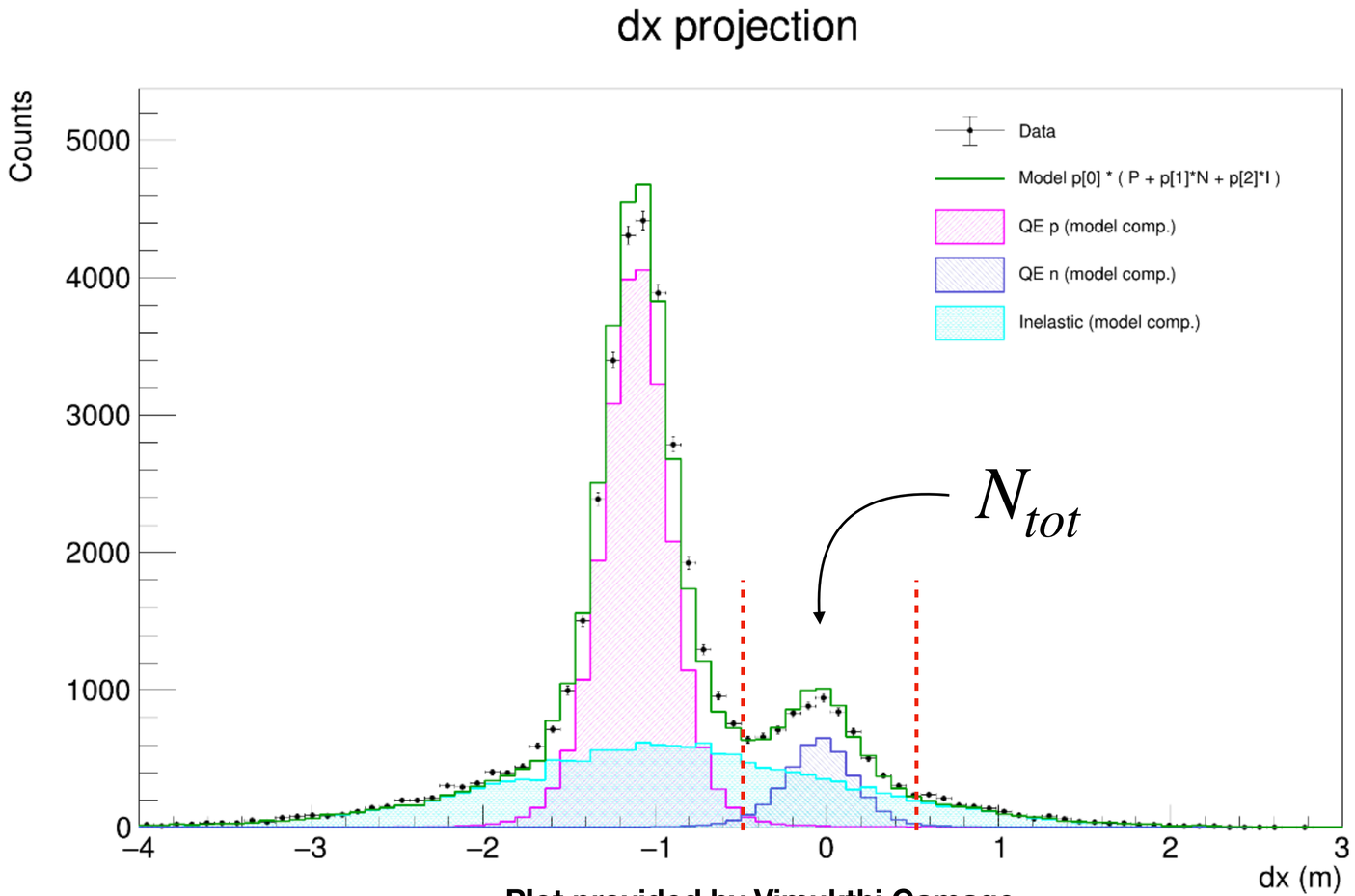
Extracting QE Neutrons





Extracting QE Neutrons cont.

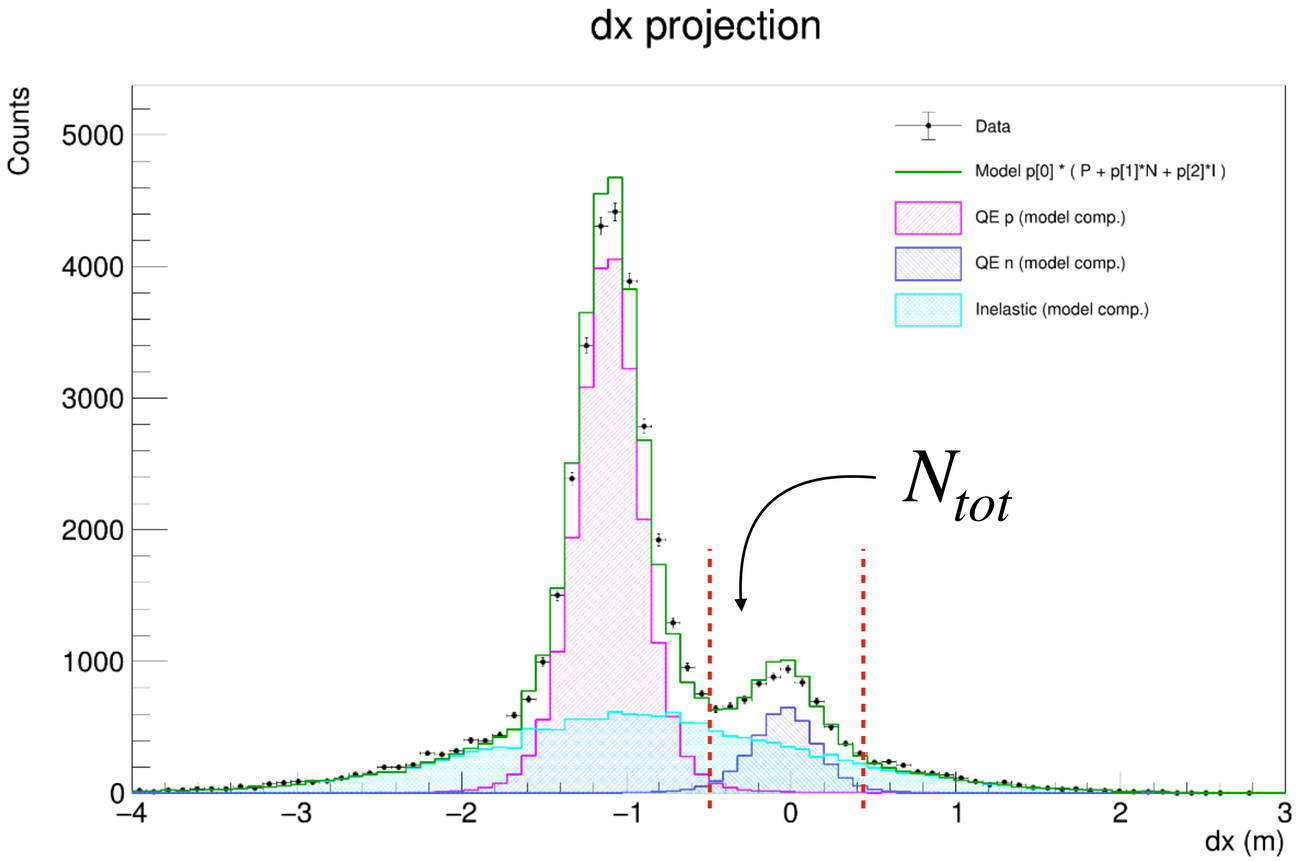
- Fit Monte-Carlo simulation data to final QE event selection and extract:
  - Neutron event yield and neutron spot cut window.



Plot provided by Vimukthi Gamage

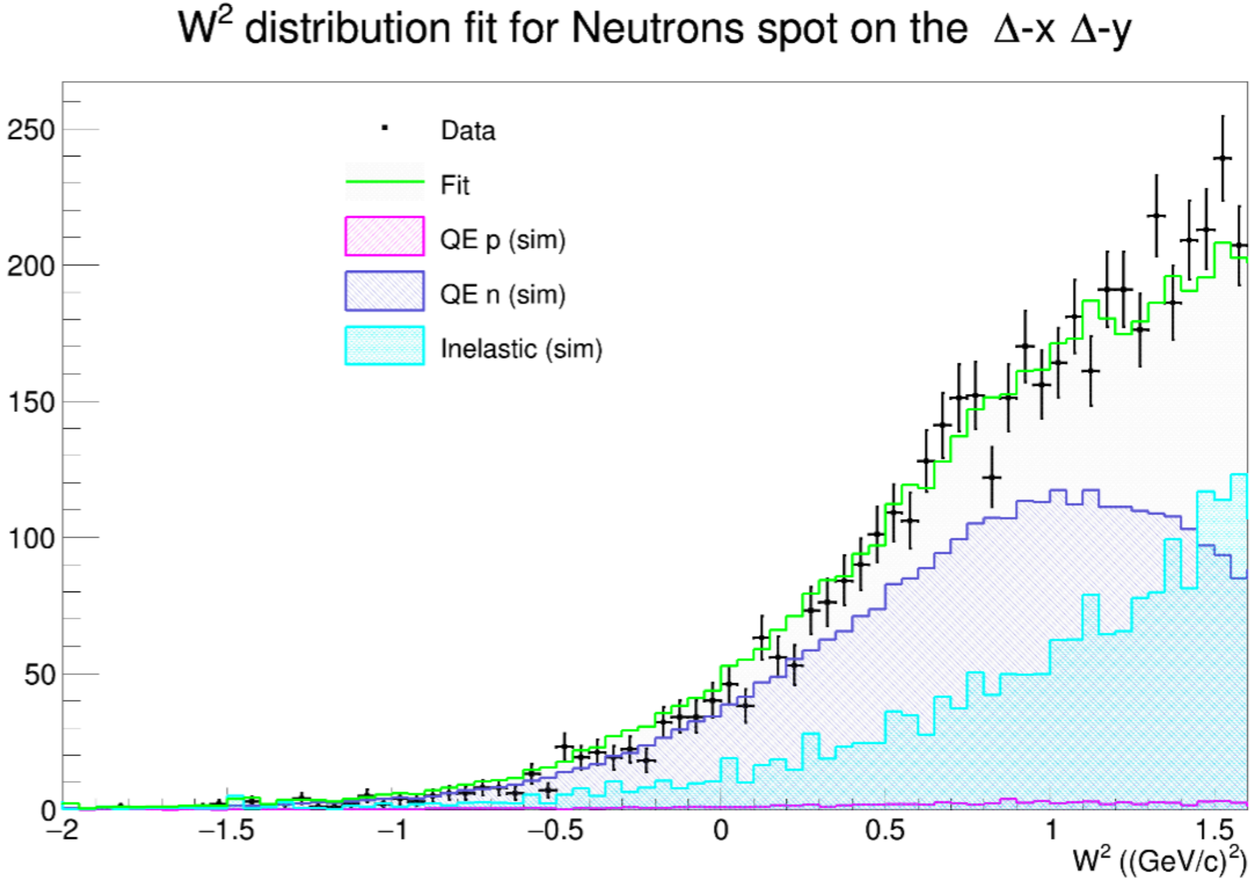
Calculating the A_{phys}

- From $N_{tot} = N_{tot}^{+} + N_{tot}^{-}$, we can compute
  $A_{raw} = (N_{tot}^{+} - N_{tot}^{-})/(N_{tot})$
- But, N_{tot} is not just neutron events.



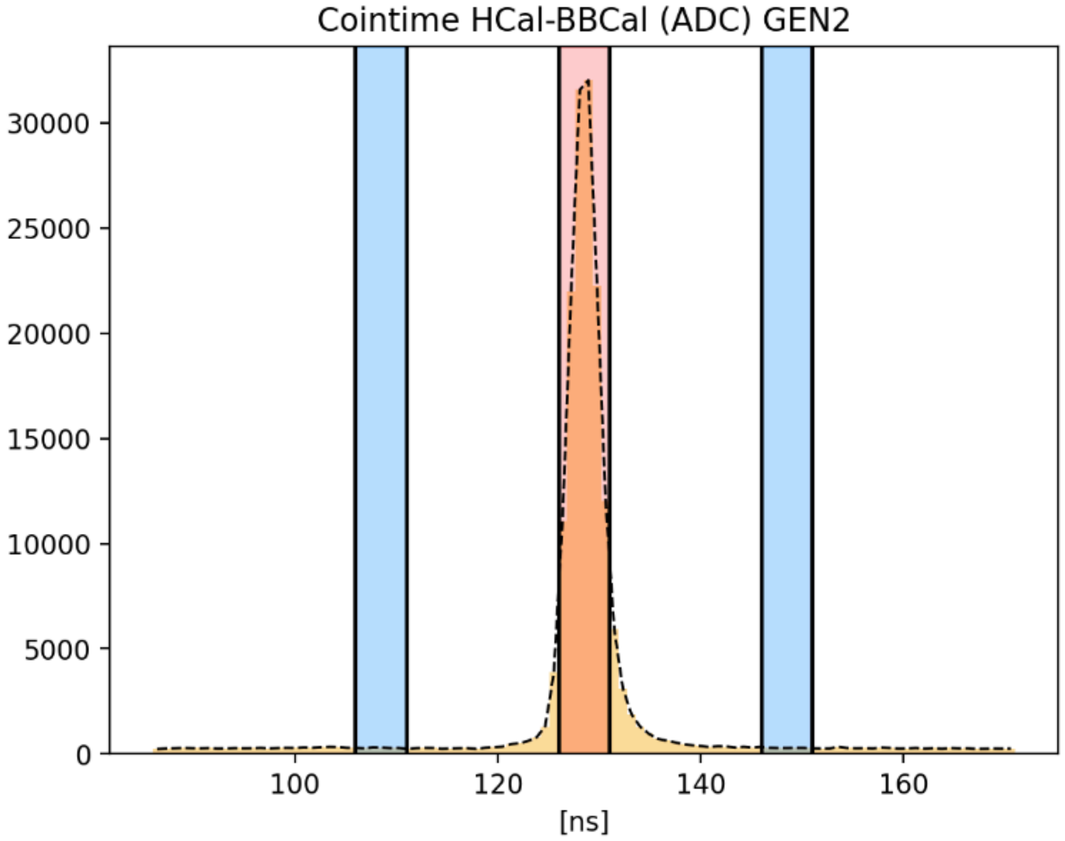
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- But, N_{tot} is not just neutron events.
  - Inelastic



Calculating the A_{phys}

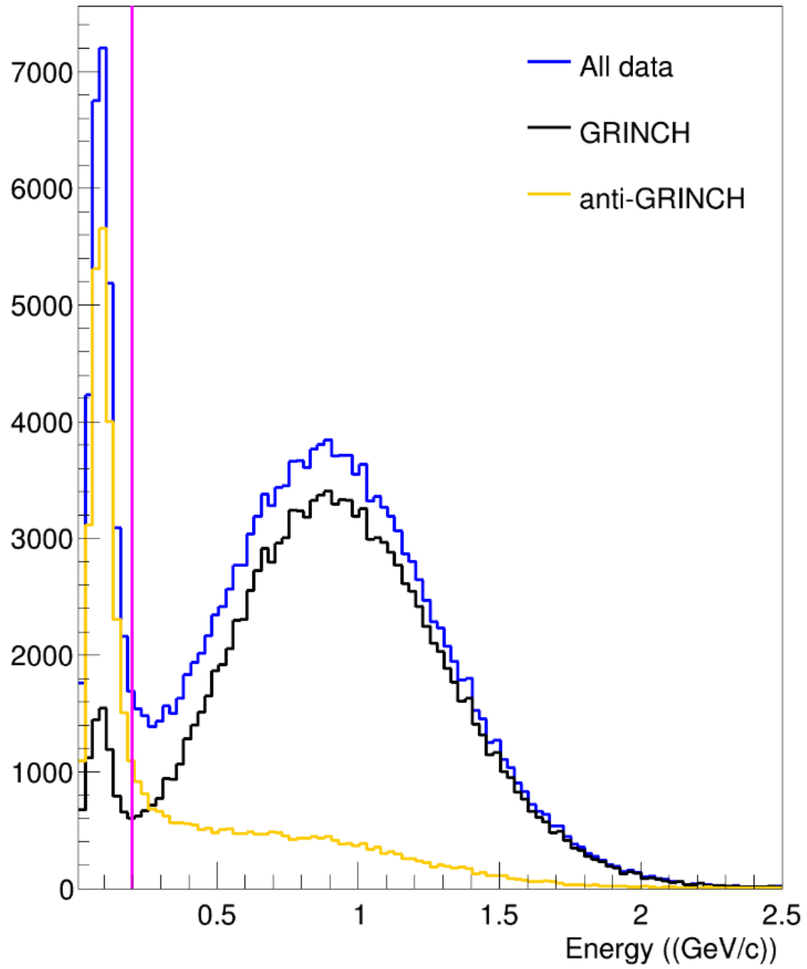
- From $N_{tot} = N^{+}_{tot} + N^{-}_{tot}$, we can compute
  $A_{raw} = (N^{+}_{tot} - N^{-}_{tot})/(N_{tot})$
- But, N_{tot} is not just neutron events.
  - Inelastic
  - Accidentals



Calculating the A_{phys}

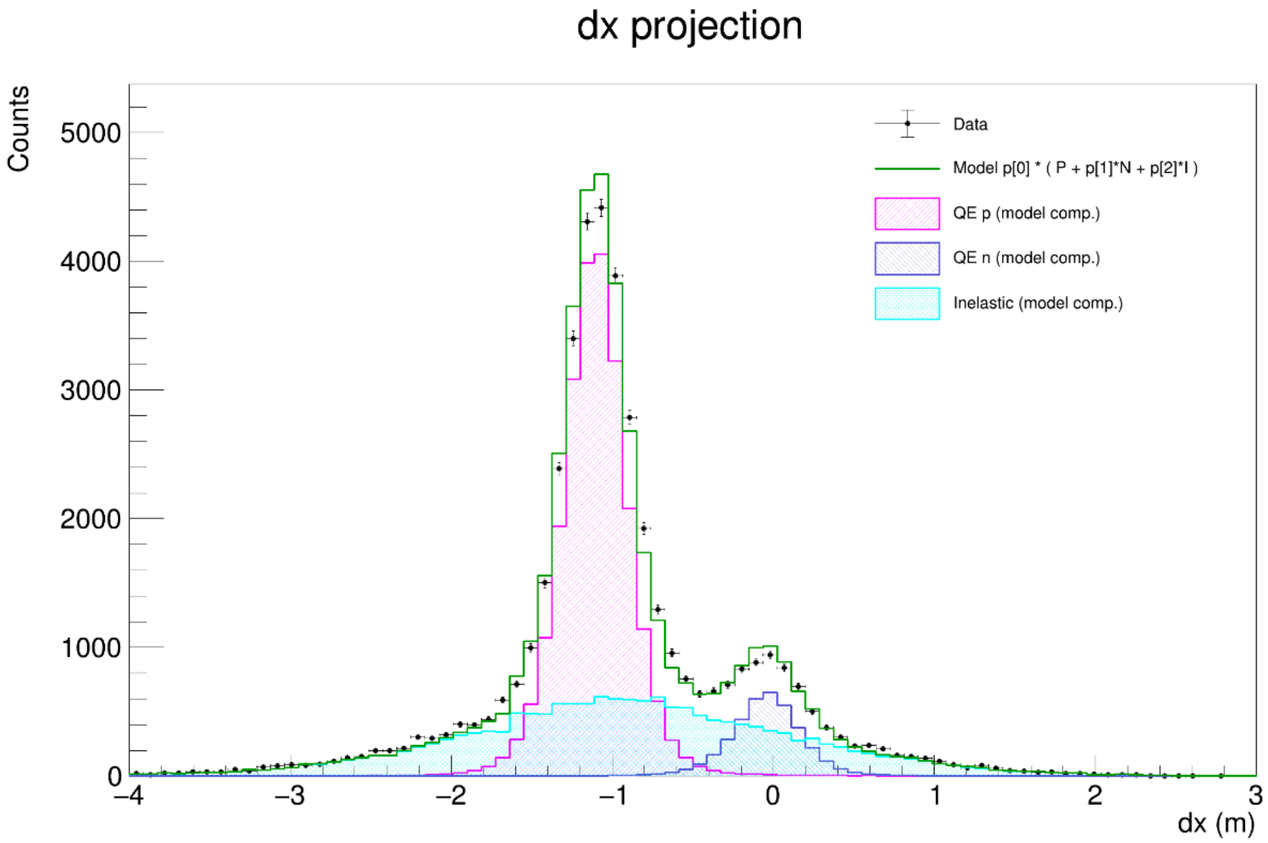
- From $N_{tot} = N_{tot}^{+} + N_{tot}^{-}$, we can compute
  $A_{raw} = (N_{tot}^{+} - N_{tot}^{-})/(N_{tot})$

- But, N_{tot} is not just neutron events.
  - Inelastic
  - Accidentals
  - Pions



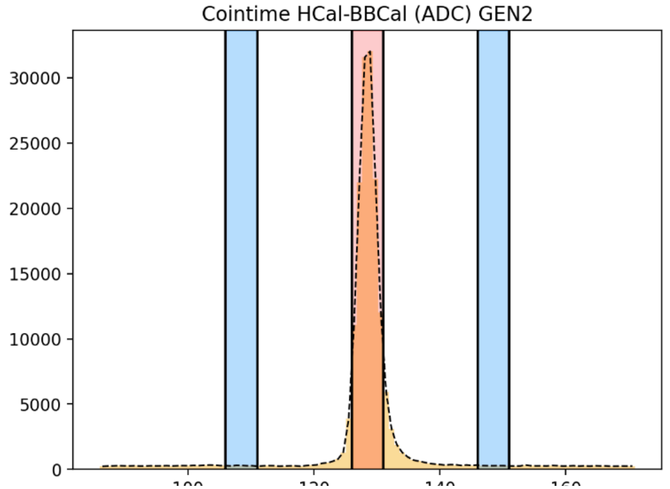
Calculating the A_{phys}

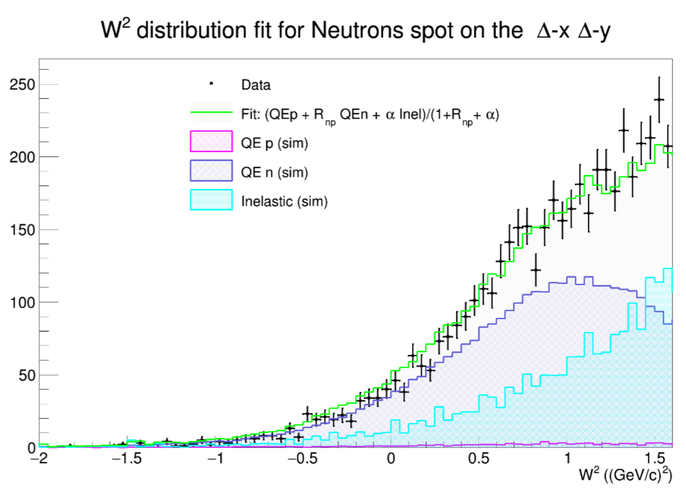
- From $N_{tot} = N_{tot}^{+} + N_{tot}^{-}$, we can compute$A_{raw} = (N_{tot}^{+} - N_{tot}^{-})/(N_{tot})$
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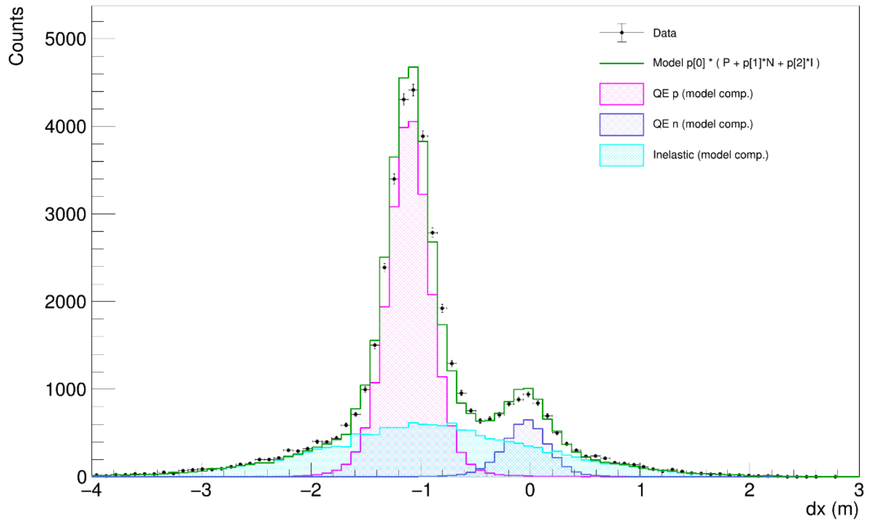


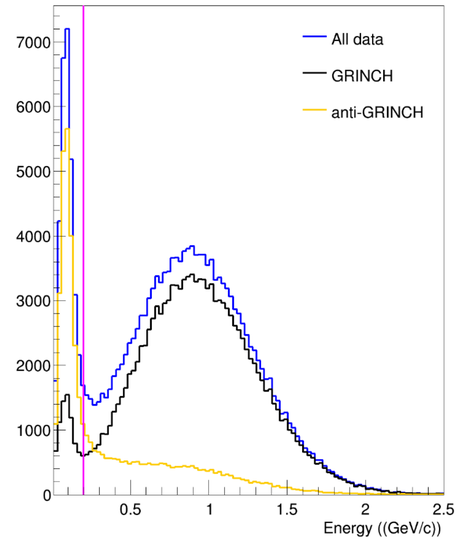
Calculating the A_{phys}

- From $N_{tot} = N_{tot}^{+} + N_{tot}^{-}$, we can compute $A_{raw} = (N_{tot}^{+} - N_{tot}^{-})/(N_{tot})$
- But, N_{tot} is not just neutron events.
  - Inelastic
  - Accidentals
  - Pions
  - Protons
  - Nitrogen (simulation)
  - Final state interactions (simulation)









Calculating the A_{phys}

- From $N_{tot} = N^{+}_{tot} + N^{-}_{tot}$, we can compute $A_{raw} = (N^{+}_{tot} - N^{-}_{tot})/(N_{tot})$
- But, N_{tot} is not just neutron events.
  - Inelastic
  - Accidentals
  - Pions
  - Protons
  - Nitrogen (simulation)
  - Final state interactions (simulation)
- Correcting A_{raw} by subtracting out these fractional contributions to the asymmetry and the imperfect beam and target polarizations, we can extract A_{phys}

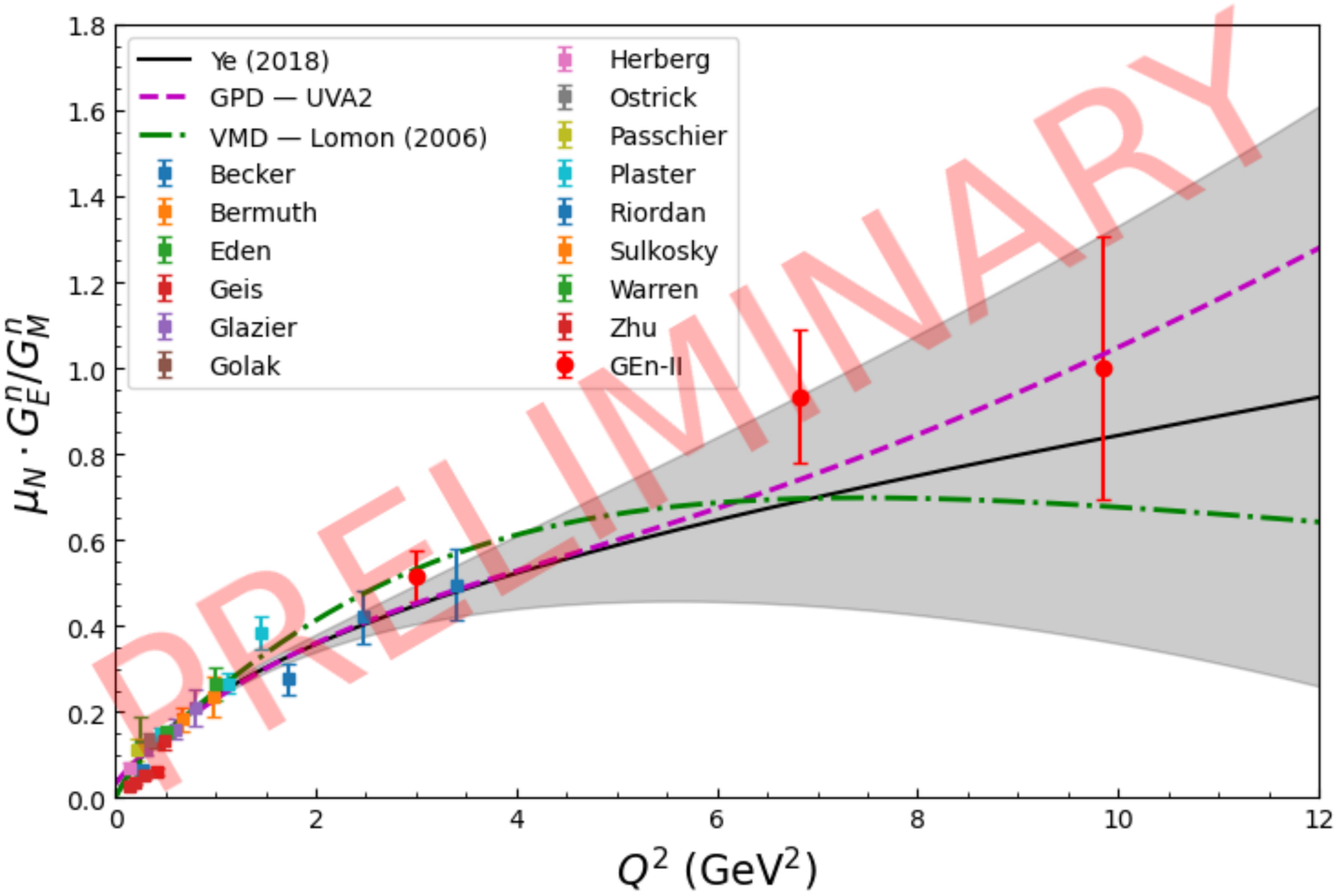
$$A_{phys} = \frac{A_{raw} - \Sigma_i f_i A_i}{P_{beam} P_{3He} P_n (1 - \Sigma_i f_i)}$$

$$A_{phys} = \frac{1}{1 + (\epsilon/\tau)\Lambda^2} \left[\Lambda \sqrt{2\epsilon(1-\epsilon)/\tau} P_x + \sqrt{1-\epsilon^2} P_z \right]$$

Preliminary Results for G_E^n/G_M^n

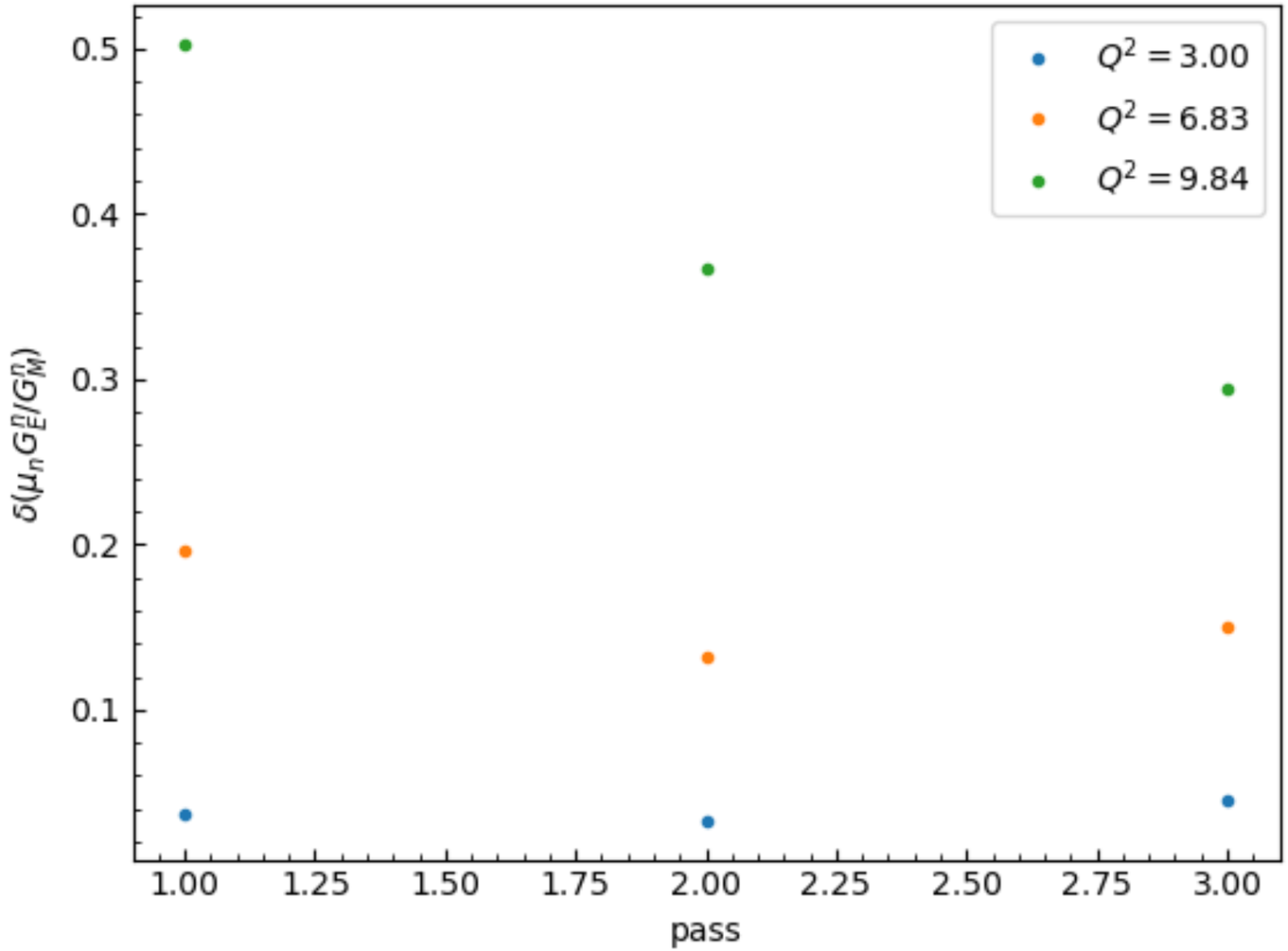
Preliminary GEn-II Error Bars

Q2	Systematic	Statistical
3.00	0.0380	0.0547
6.83	0.0403	0.1506
9.85	0.0858	0.2945

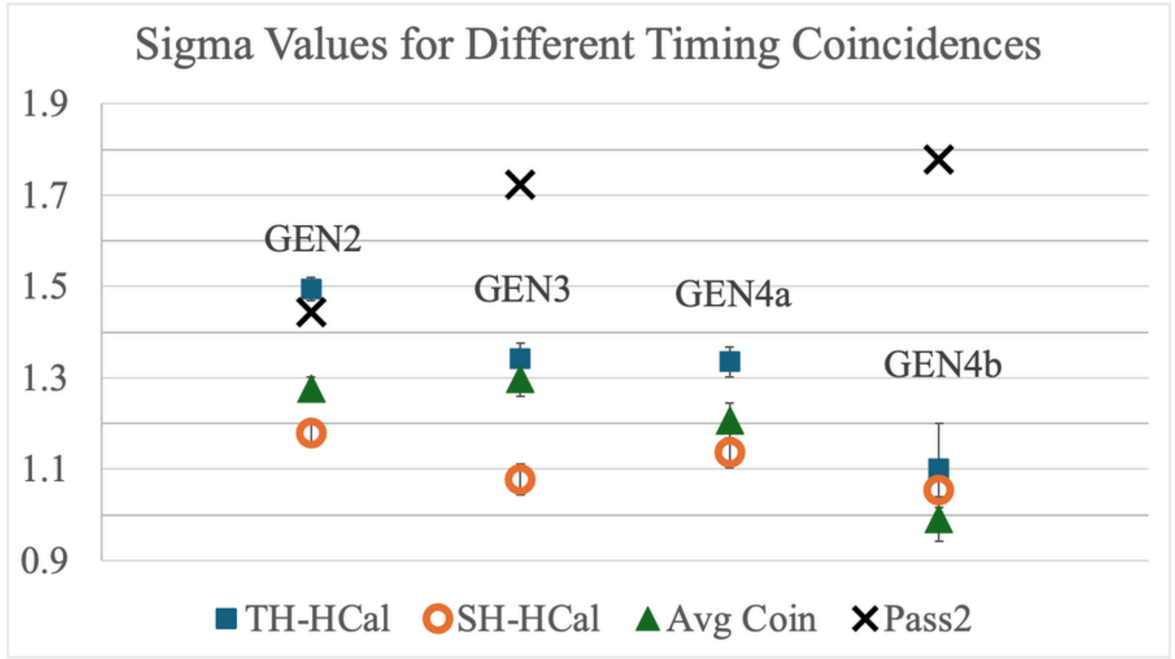


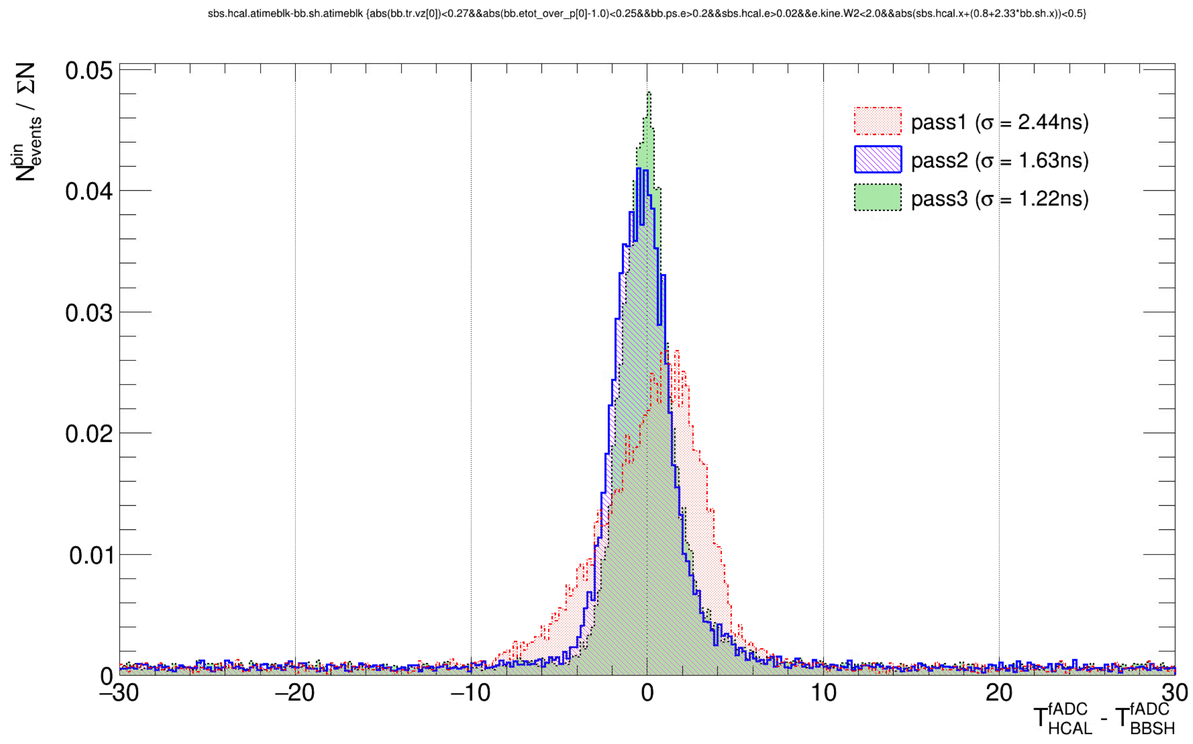
Results provided by Vimukthi Gamage

Highlighting Progress cont.



Highlighting Progress



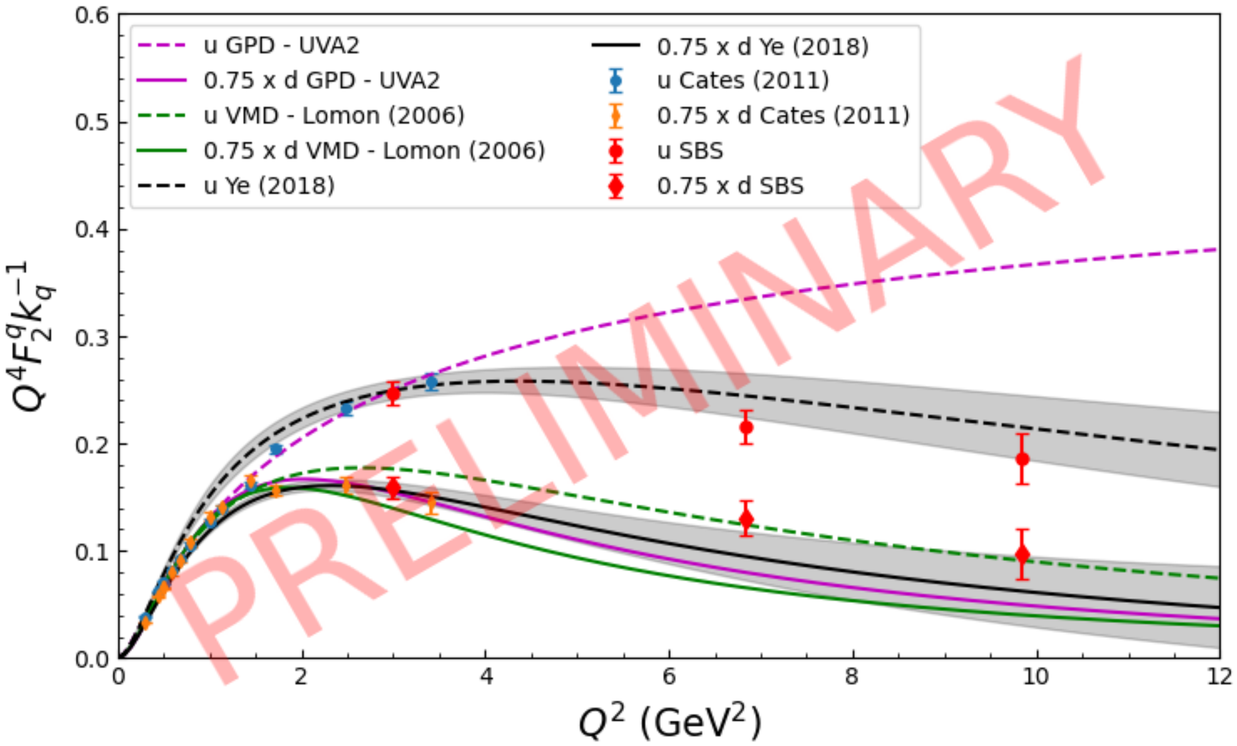


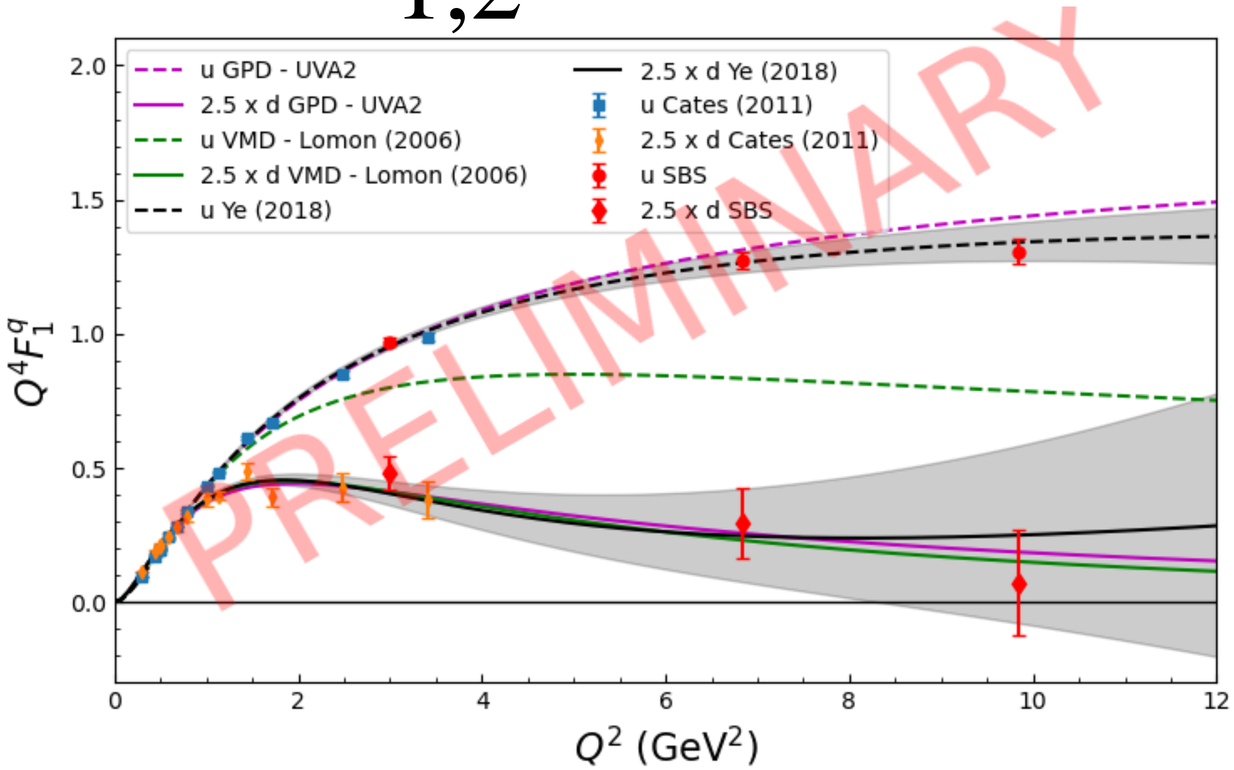
Preliminary Extraction of $F_{1,2}^{u,d}$ – Method

- To extract G_E^n, preliminary results from the SBS G_M^n experiment were used with this analysis's G_E^n/G_M^n results.
- The Ye (2018) fit to proton's G_E^p and G_M^p was used for proton's contribution to the flavor separation extraction.
- Both data error bars (for the neutron) and Ye (2018) model error bars (for the proton) were propagated to the final error bars of the flavor separated form factors.

$$F_{1,2}^d = 2F_{1,2}^n + F_{1,2}^p \quad F_2^{p,n} = (G_M^{p,n} - G_E^{p,n})/(1+\tau)$$
$$F_{1,2}^u = 2F_{1,2}^p + F_{1,2}^n \quad F_1^{p,n} = (G_E^{p,n} + \tau G_M^{p,n})/(1+\tau)$$

Preliminary Extraction of $F_{1,2}^{u,d}$ – Results





Please don't use these results until our analysis is complete :)

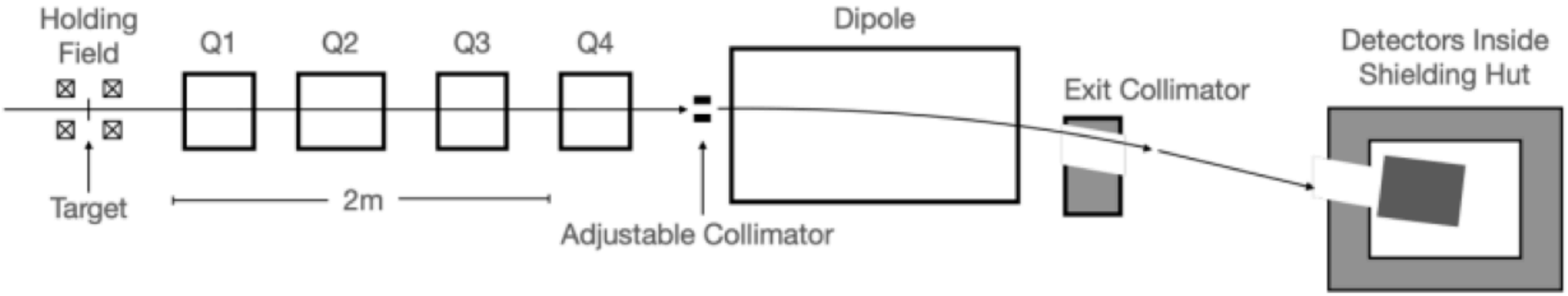
Concluding Remarks

- There is still more to be done with the analysis. Just to name a few:
  - Detailed studies on HCAL ADC waveforms and cluster selection are on going.
    - Allow for better selection and construction of QE proton and neutron clusters.
  - Adding radiative corrections to QE Monte-Carlo simulation for more accurate understanding of expected event yield and fits to proton and neutron peaks.
- We are still hopeful that we can can continue the trend in reducing the error bar for the highest Q^2 measurement.

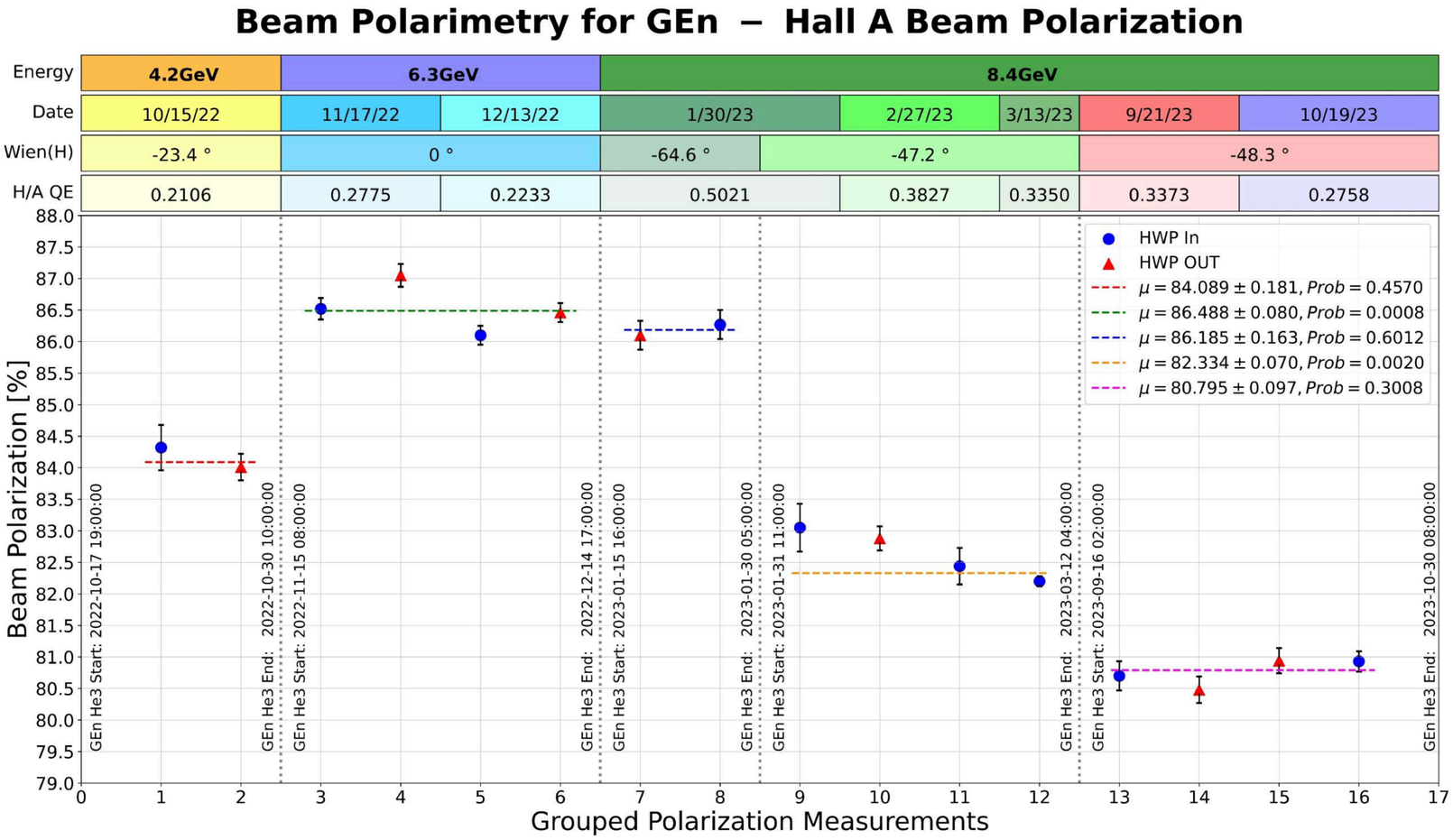
Questions?

Back up

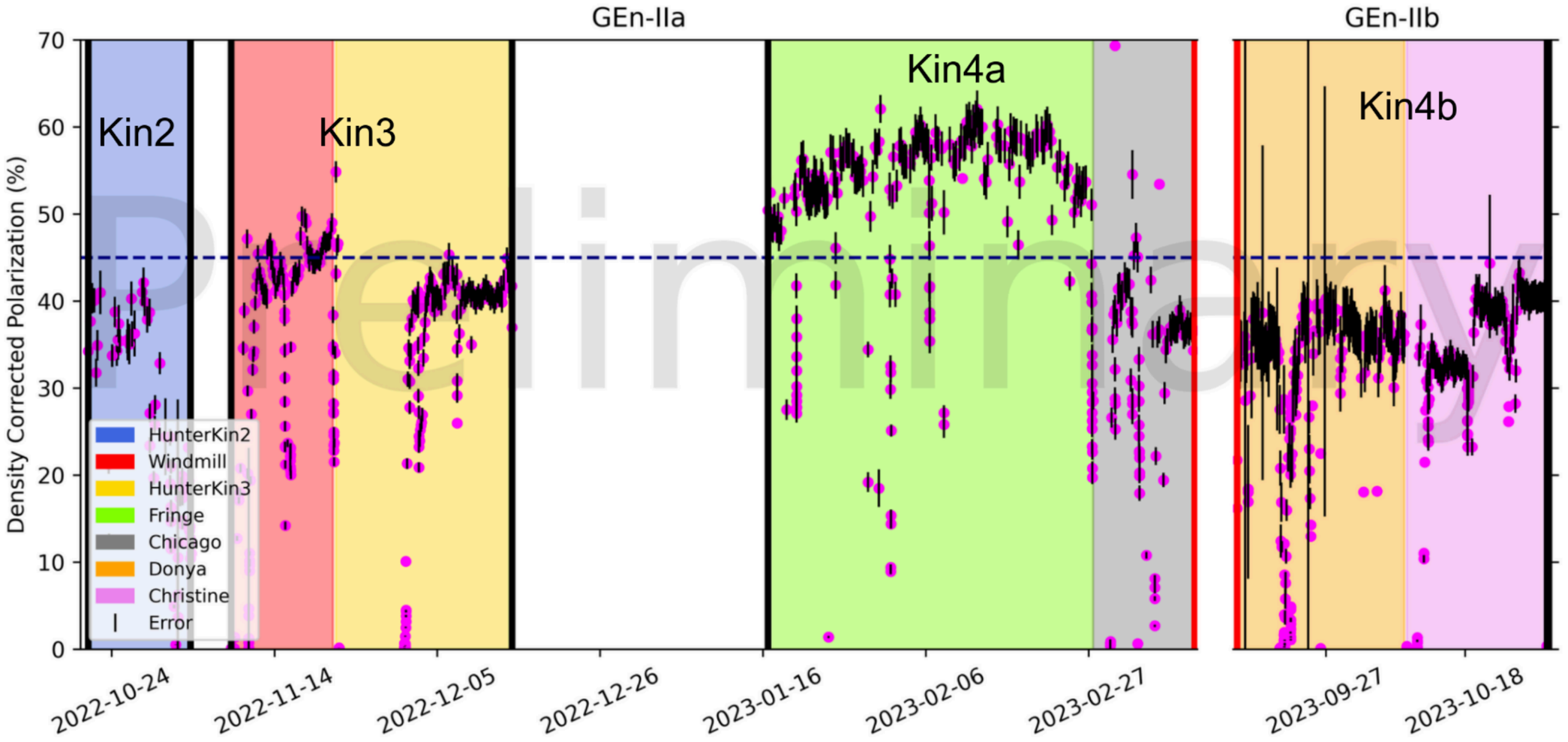
Møller Polarimeter



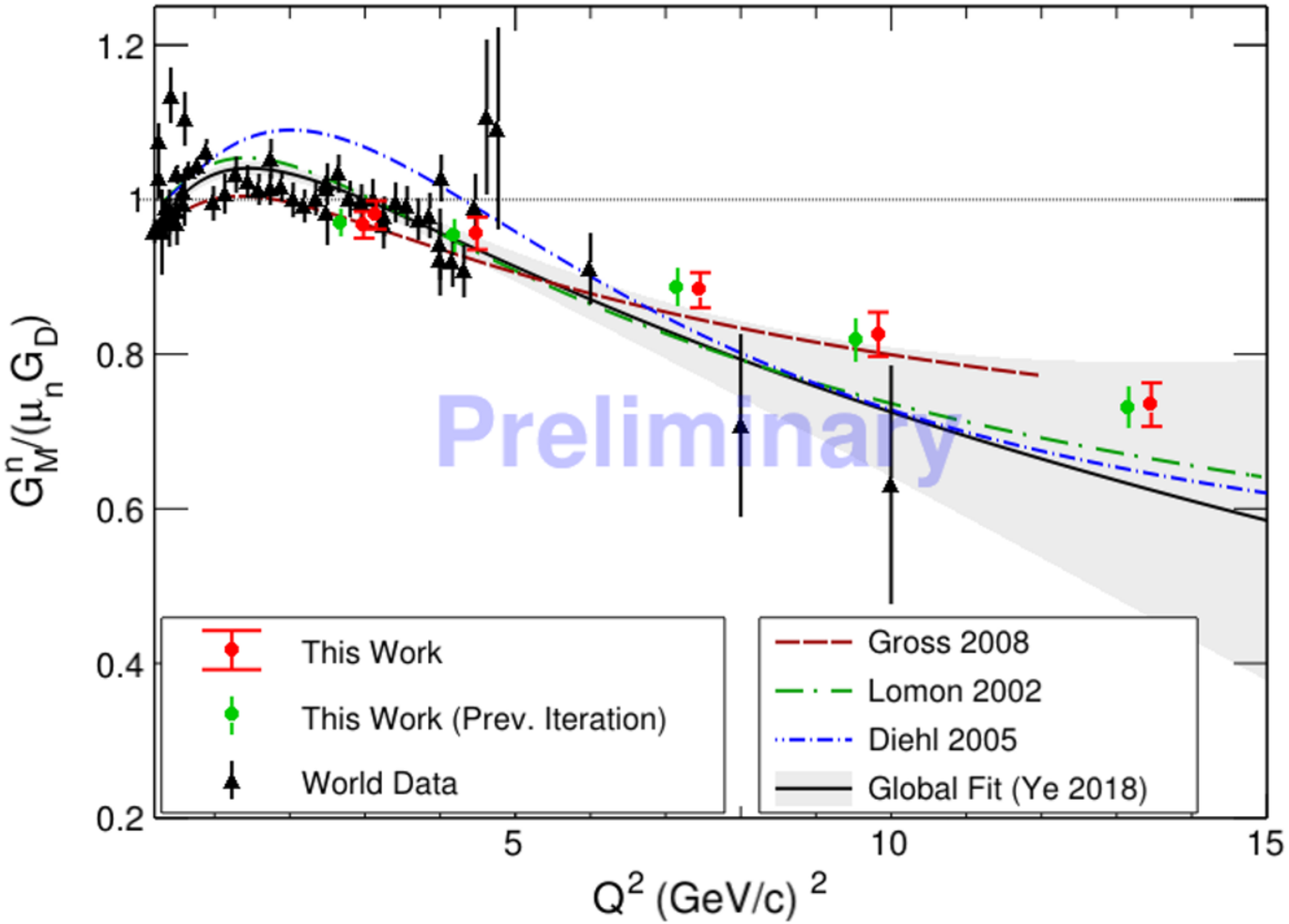
Møller Polarimetry Results



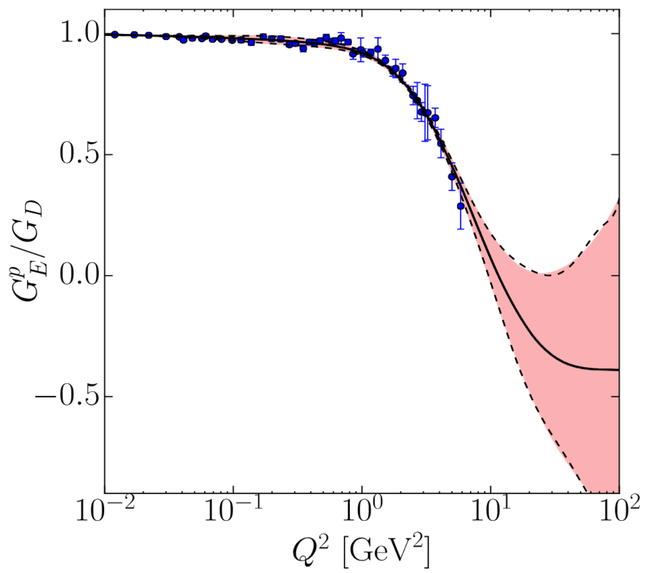
^3He Polarimetry Results

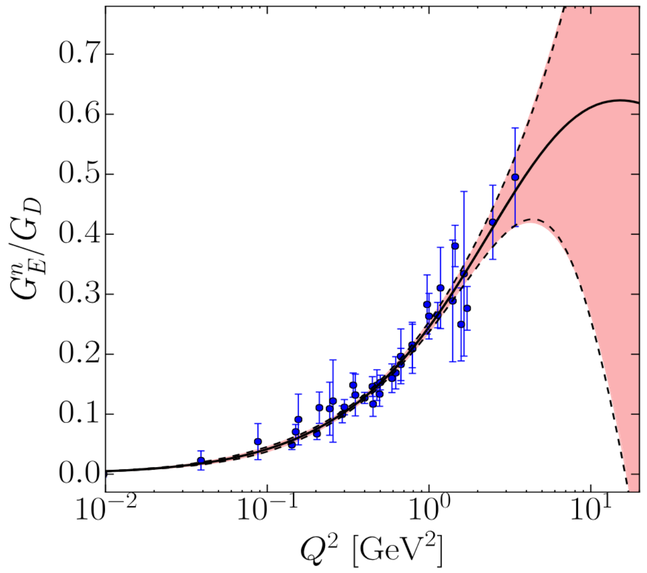


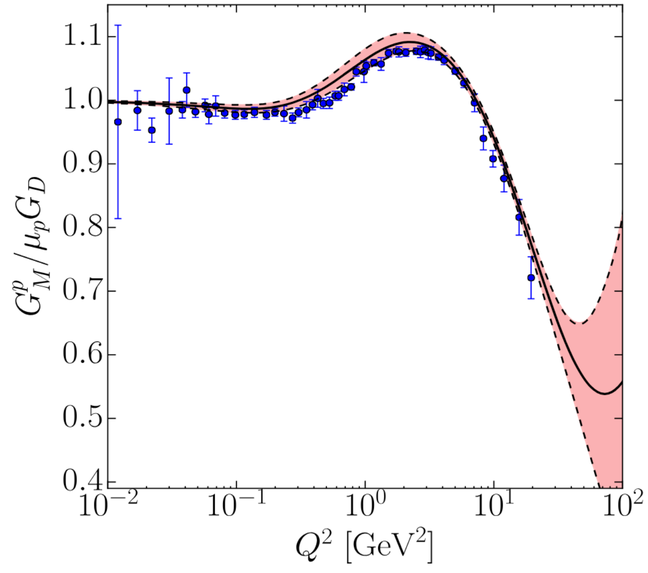
GMn Preliminary Results

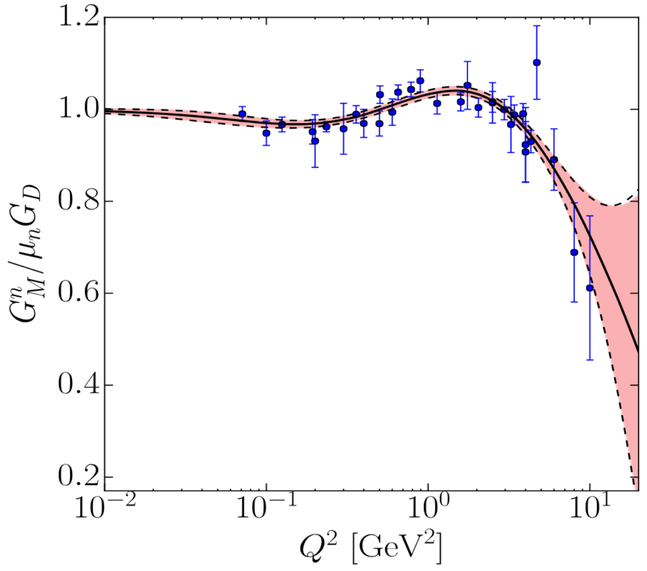


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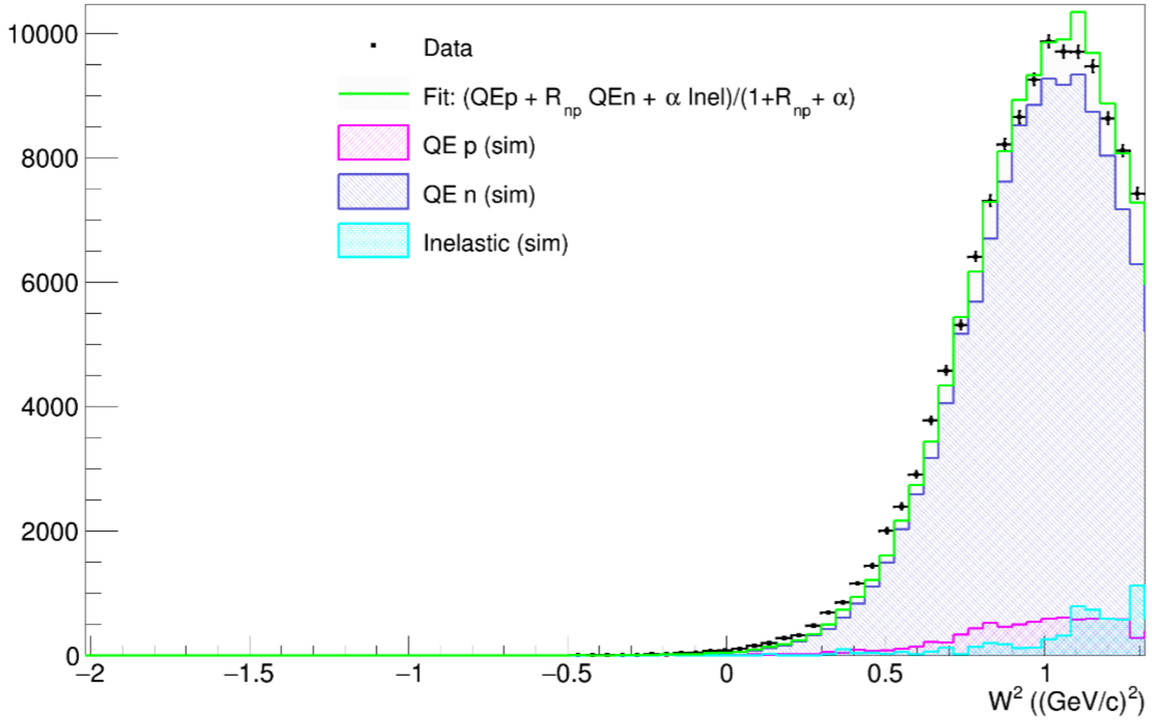


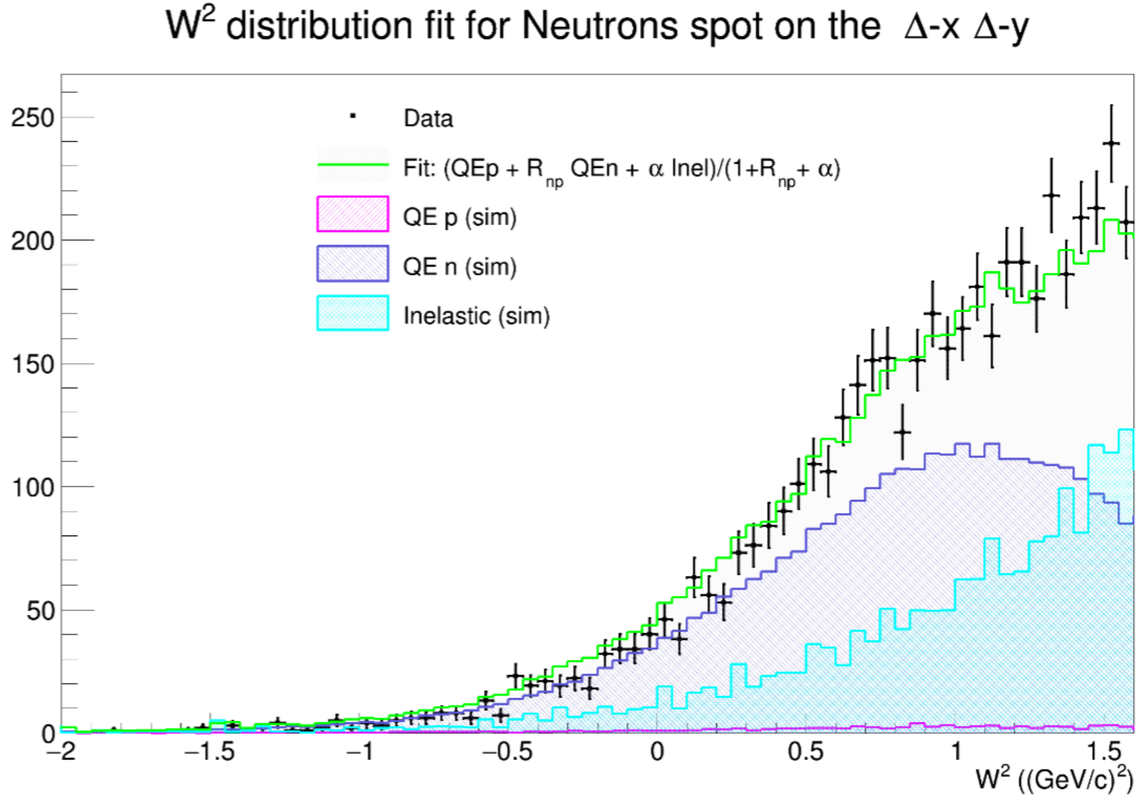




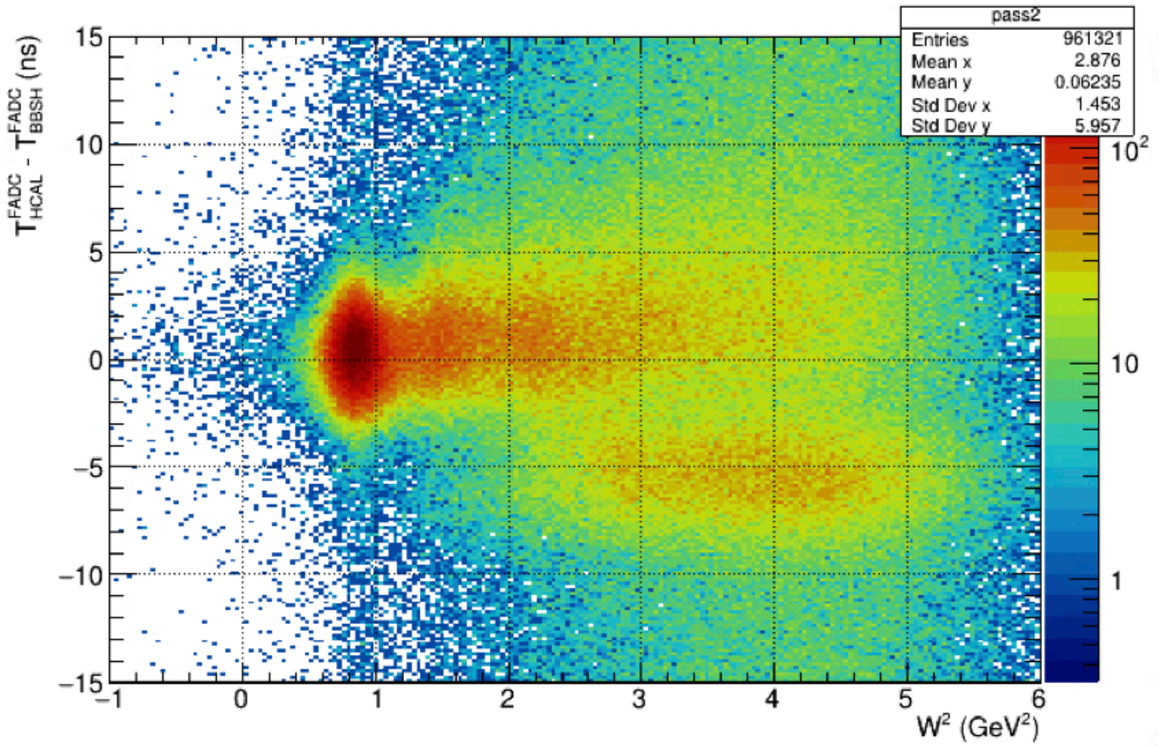


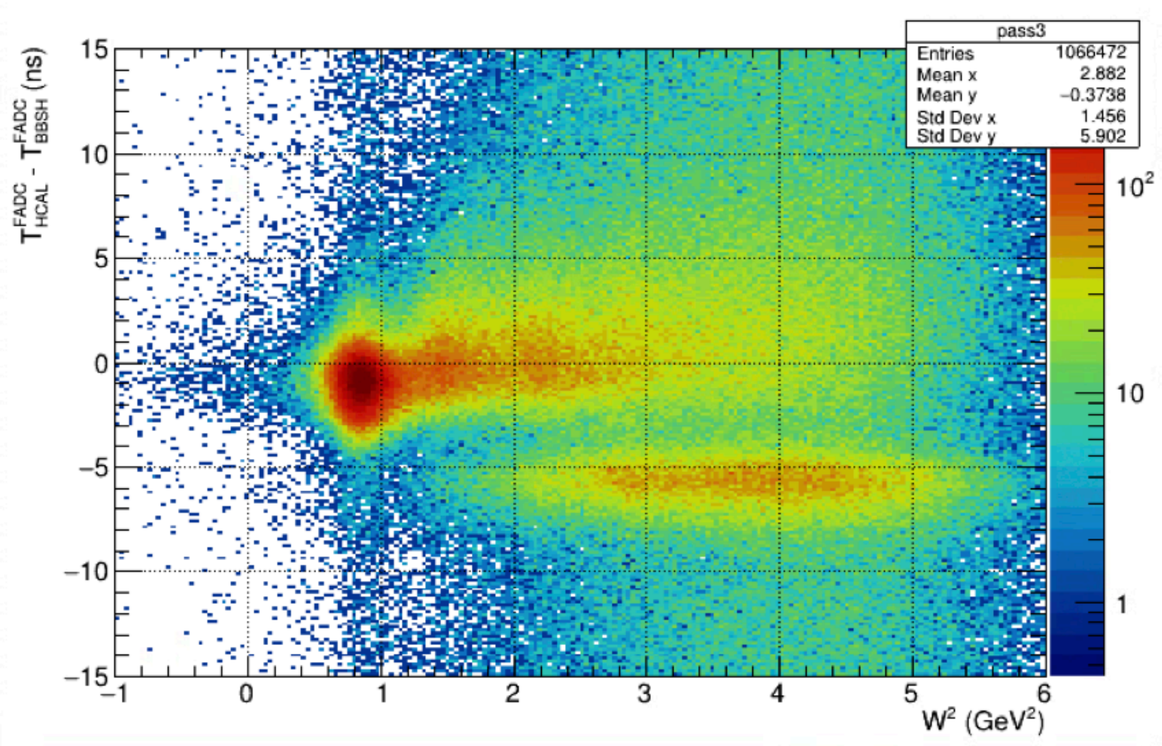
Final W2 distributions





Timing vs W2


pass2
Entries 961321
Mean x 2.876
Mean y 0.06235
Std Dev x 1.453
Std Dev y 5.957
$T^{FADC}_{HCAL} - T^{FADC}_{BBSH}$ (ns)
W^2 (GeV^2)


pass3
Entries 1066472
Mean x 2.882
Mean y −0.3738
Std Dev x 1.456
Std Dev y 5.902
$T^{FADC}_{HCAL} - T^{FADC}_{BBSH}$ (ns)
W^2 (GeV^2)