Probing the ^3H and ^3He in the QuasiElastic regime

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On behalf of the E12-11-112 collaboration

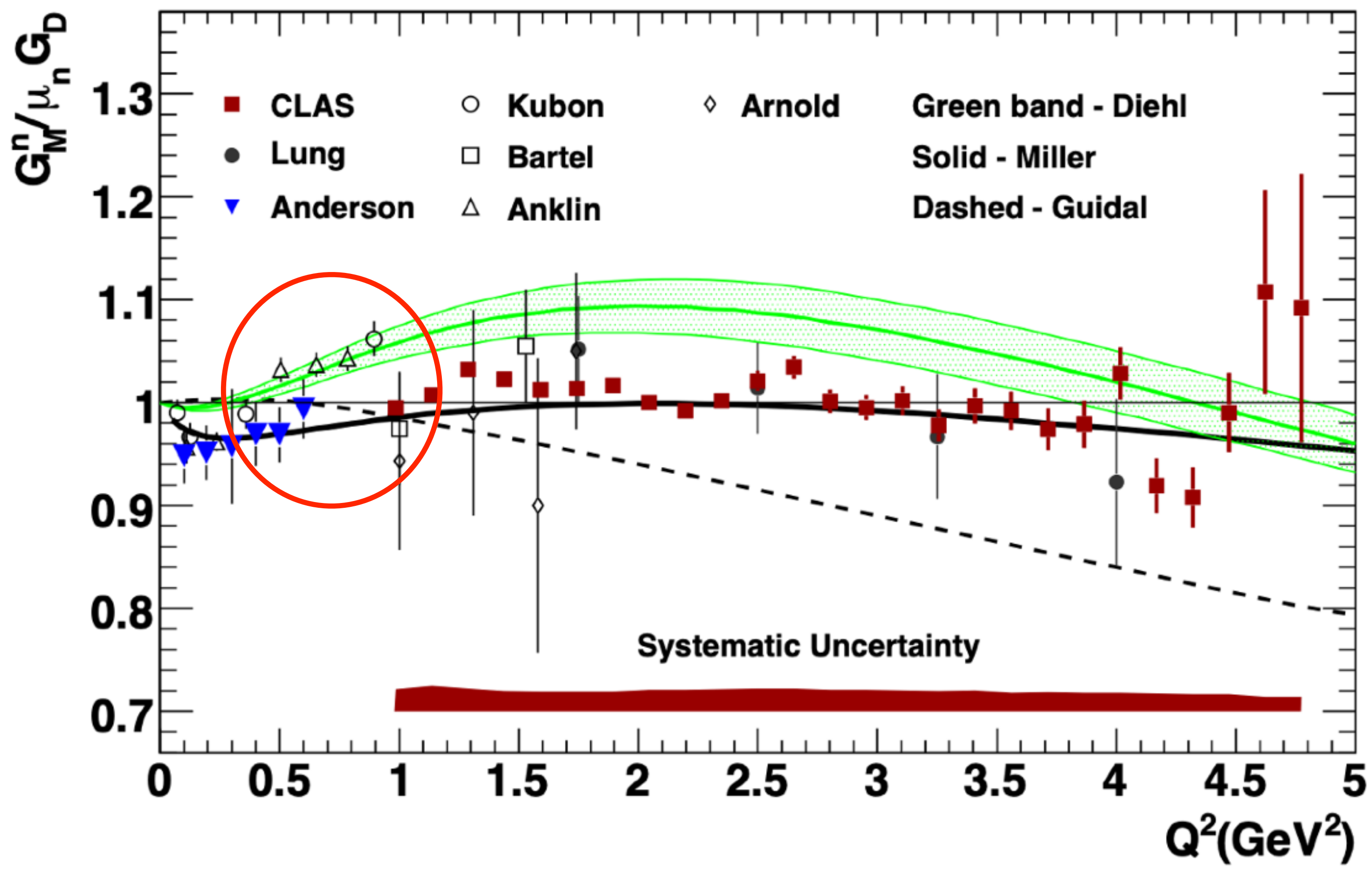
University of New Hampshire

Hall A Winter Collaboration Meeting
January 22, 2021

Jefferson Lab
Thomas Jefferson National Accelerator Facility

E12-11-112 motivation

P. Solvignon, J.Arrington, D.B.Day, D. Higinbotham, Z. Ye (Spokepeople)
On behalf of the E12-11-112 Collaboration



CLAS Collaboration. Phys.Rev.Lett. **102** (2009)

Data from:

- Mainz [G. Kubon, et al., Phys. Lett. B **524**, 26 (2002); H. Anklin et al., Phys. Lett. B **428**, 248 (1998)]
- Jefferson Lab [B. Anderson et al. Phys. Lett. C **75**, 034003 (2007); J. Lachniet, et al., Phys. Rev. Lett. **102**, (2009).

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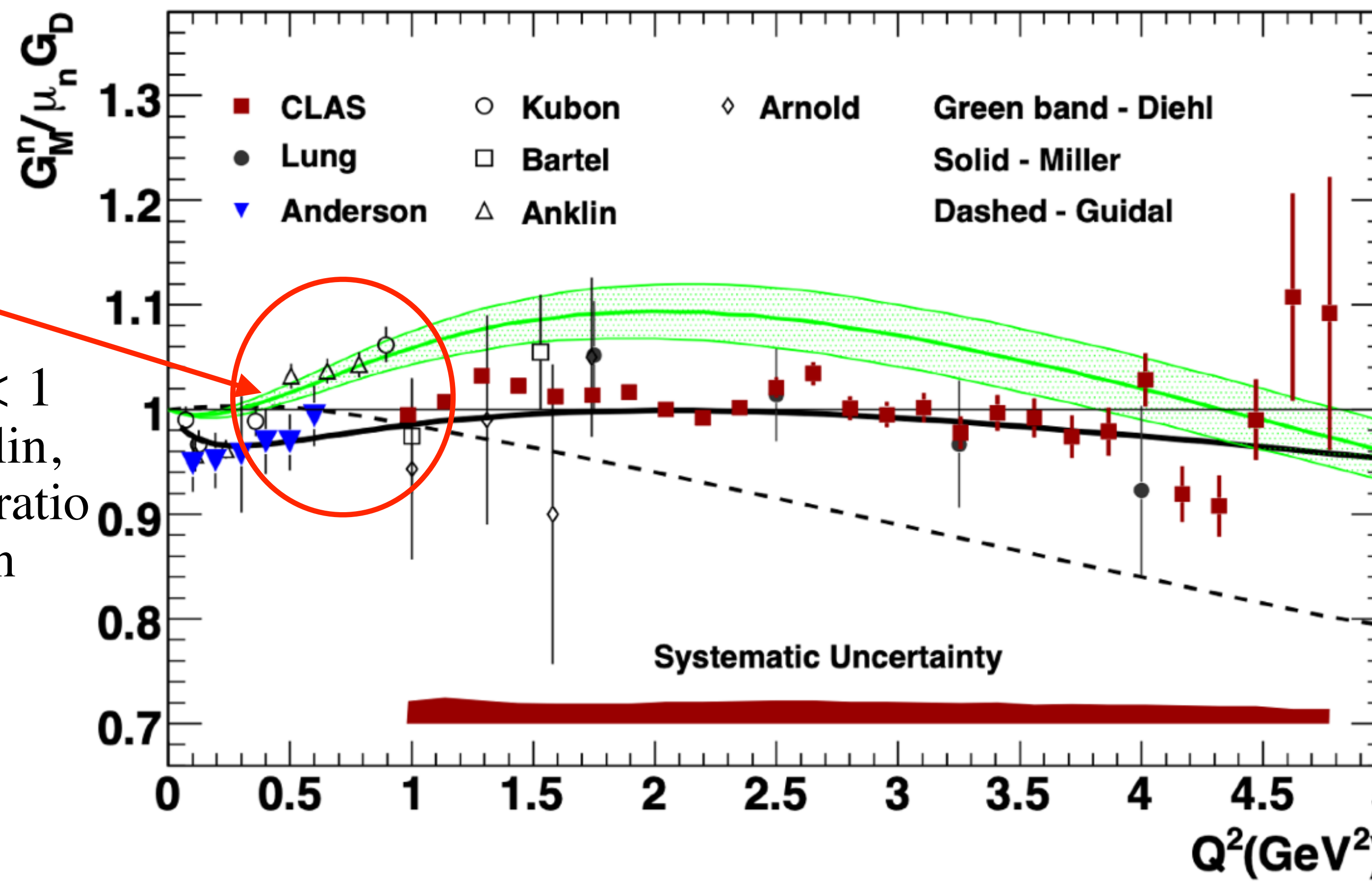
Discrepancy in the data

High precision measurements in the $0.5 < Q^2 < 1$ region have ~8% discrepancy between the Anklin, Kubon data and the CLAS $D(e,e'n)/D(e,e'p)$ ratio method, and the Hall A polarized ^{3}He extraction (Anderson).



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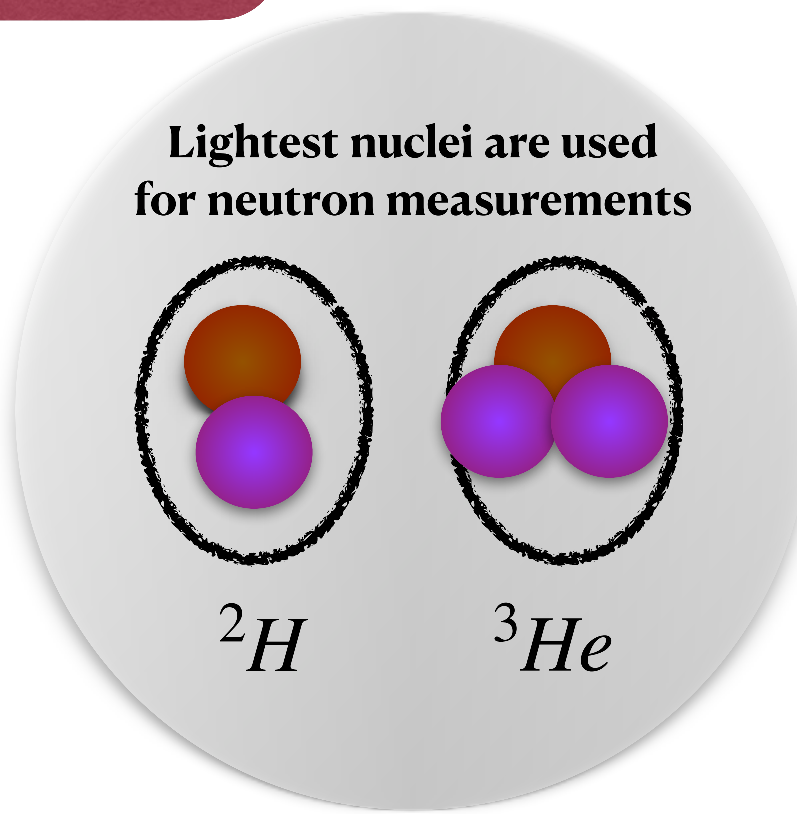
Neutron case: no free neutron target

If measuring neutrons (no charge):
- Energy information from time of flight
- Requires precise measurement of neutron detection efficiencies

Measurement Corrections:
- Reaction mechanisms FSI and MEC
- Nuclear structure



Neutron measurements include:

$^3\overrightarrow{He}(\overrightarrow{e}, e')$ QE polarization experiments

$\dfrac{^2H(e,e'p)}{^2H(e,e'n)}$ QE ratio

$^2\overrightarrow{H}(\overrightarrow{e}, e')$ QE Vector-polarized deuterium

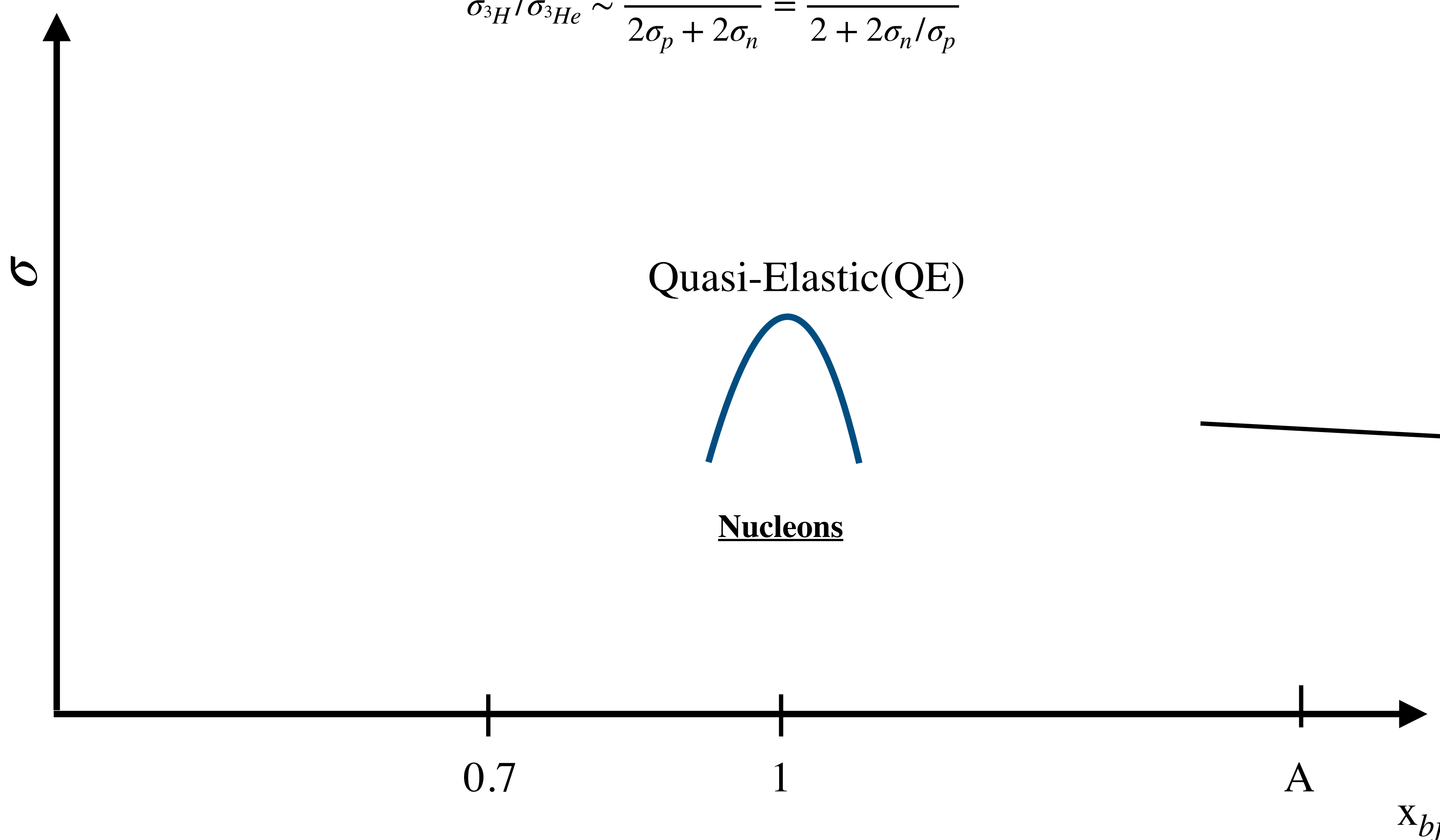
$^2H(e,e') - p(e,e')$
$^2H(e,e'p)$, $^2H(e,e'n)$

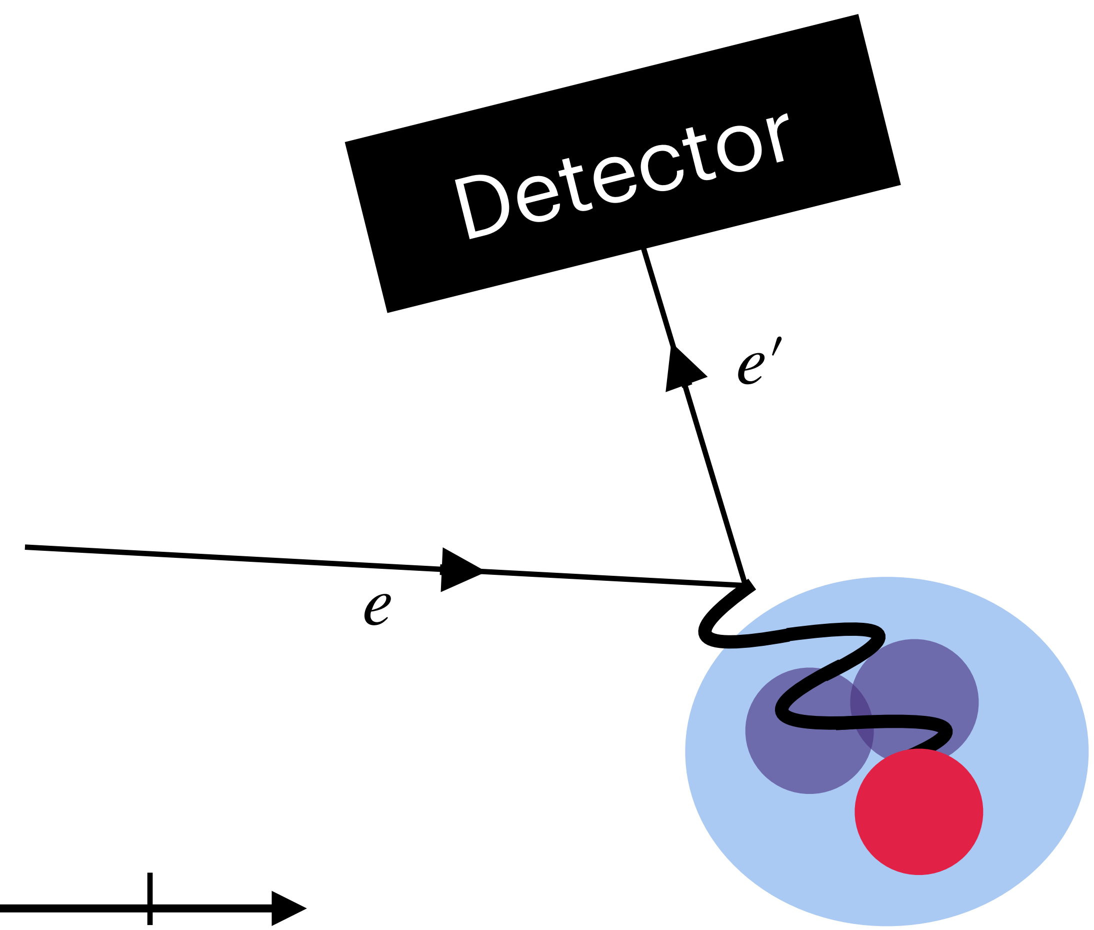
Probing nucleons with electron scattering

Access nucleons in QE scattering of ^{3}H and ^{3}He

Measuring: $\dfrac{d^2\sigma}{d\Omega dE'}$

$$\sigma_{^3H}/\sigma_{^3He} \sim \frac{\sigma_p + 2\sigma_n}{2\sigma_p + 2\sigma_n} = \frac{1 + 2\sigma_n/\sigma_p}{2 + 2\sigma_n/\sigma_p}$$





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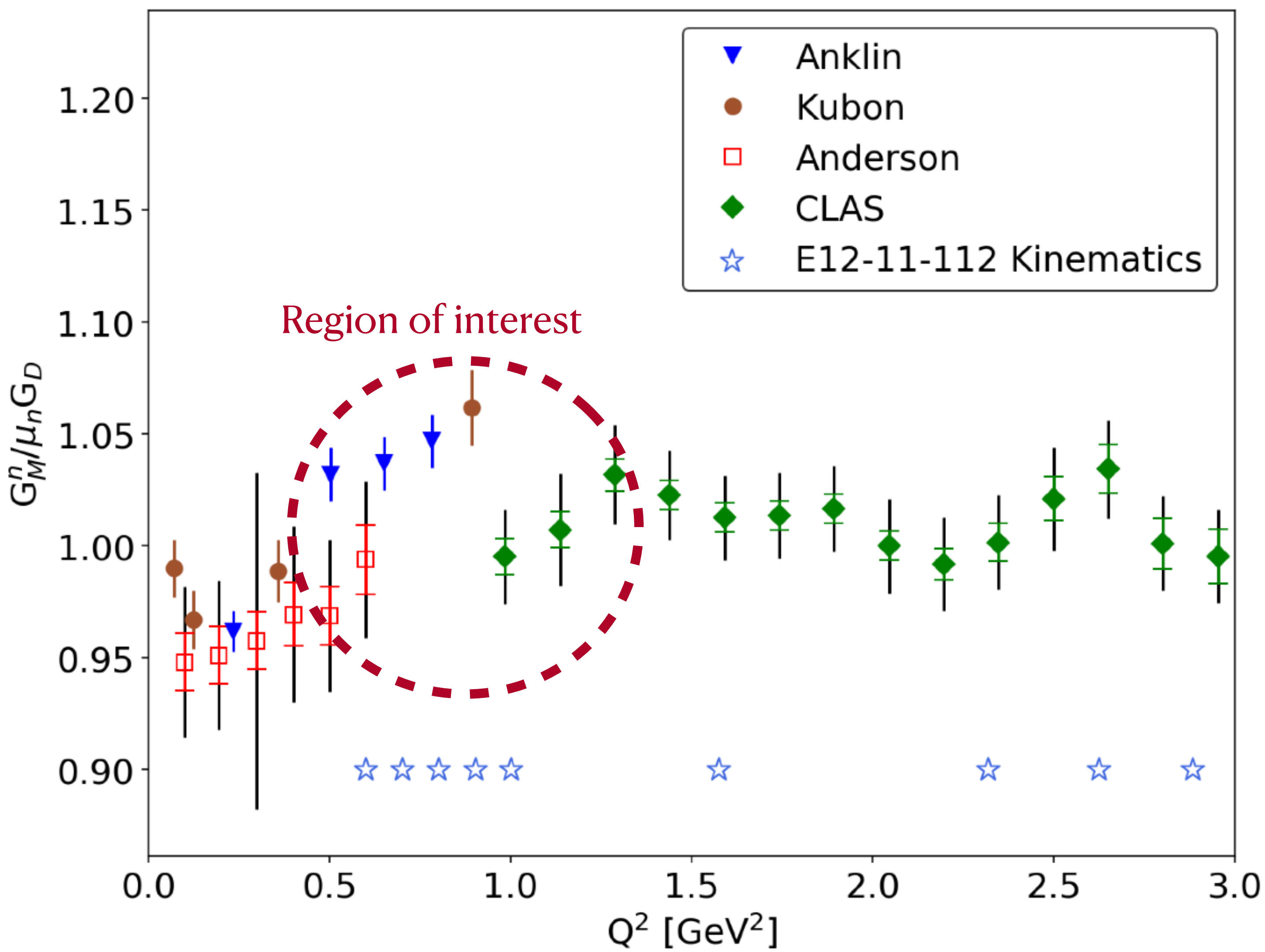
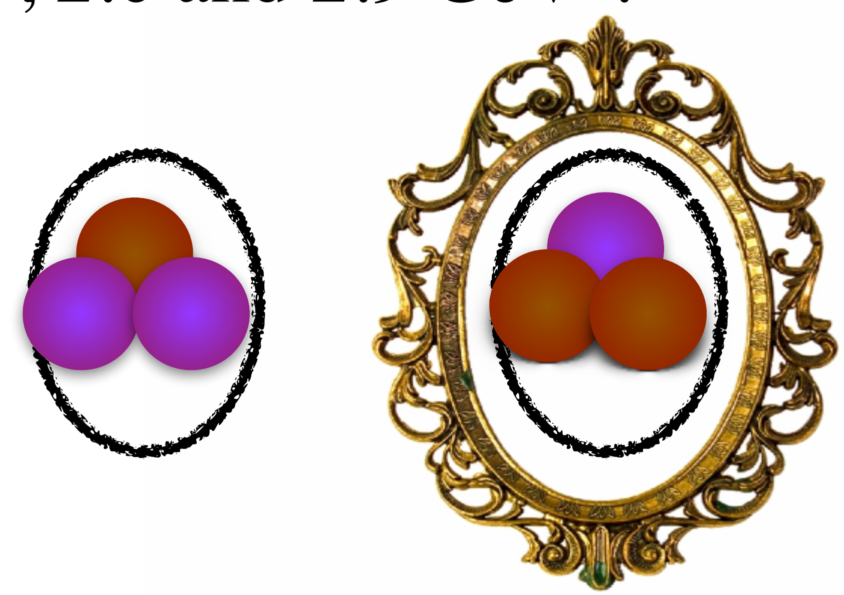


This experiment:
$Q^2 = 0.6, 0.7, 0.8, 0.9, 1, 1.5, 2.3, 2.6$ and 2.9 GeV^2.



Measure the neutron magnetic form factor using the $^3H/^3He$ cross-section ratios

Kinematics Coverage

P. Solvignon, J.Arrington, D.B.Day, D. Higinbotham, Z. Ye (Spokepeople)
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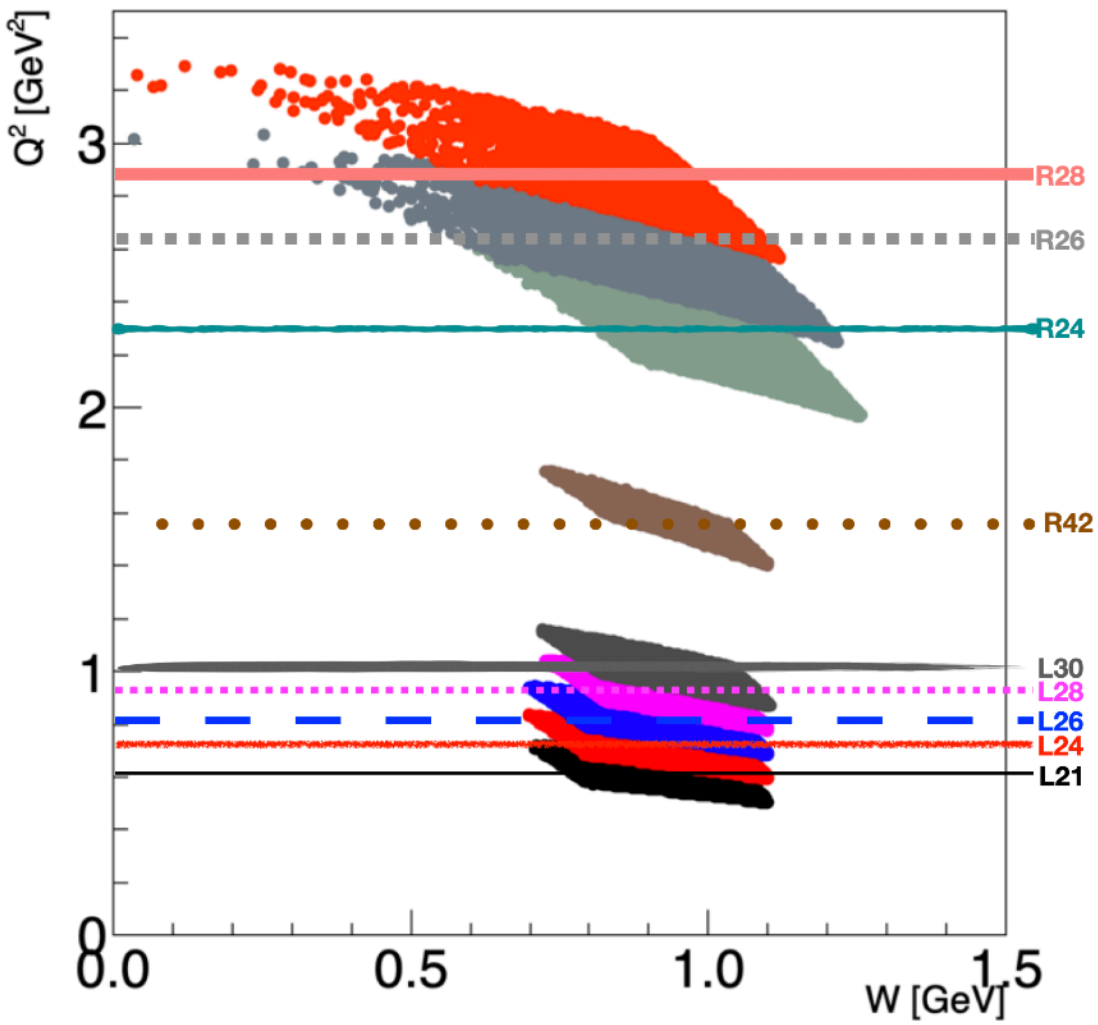
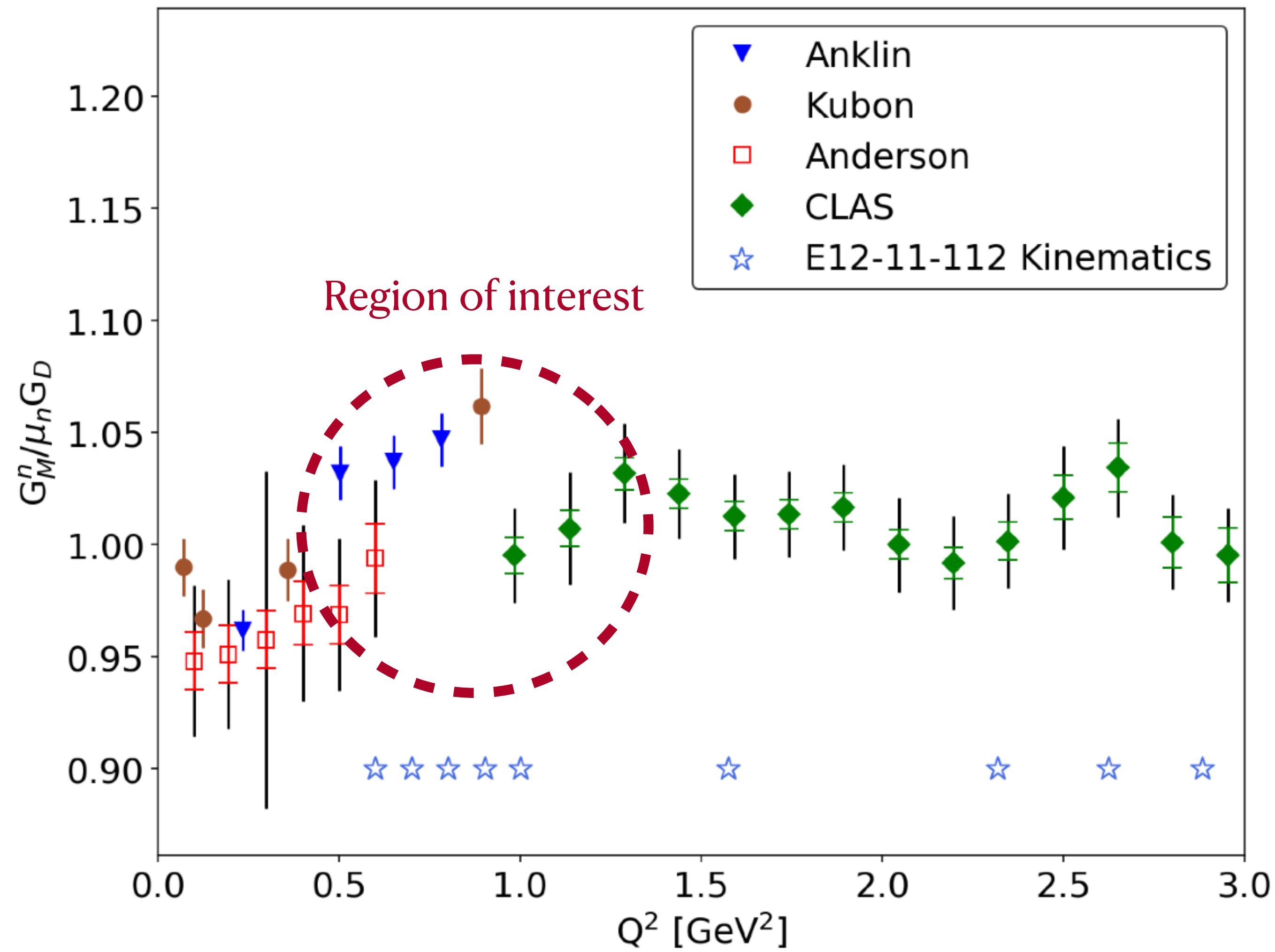
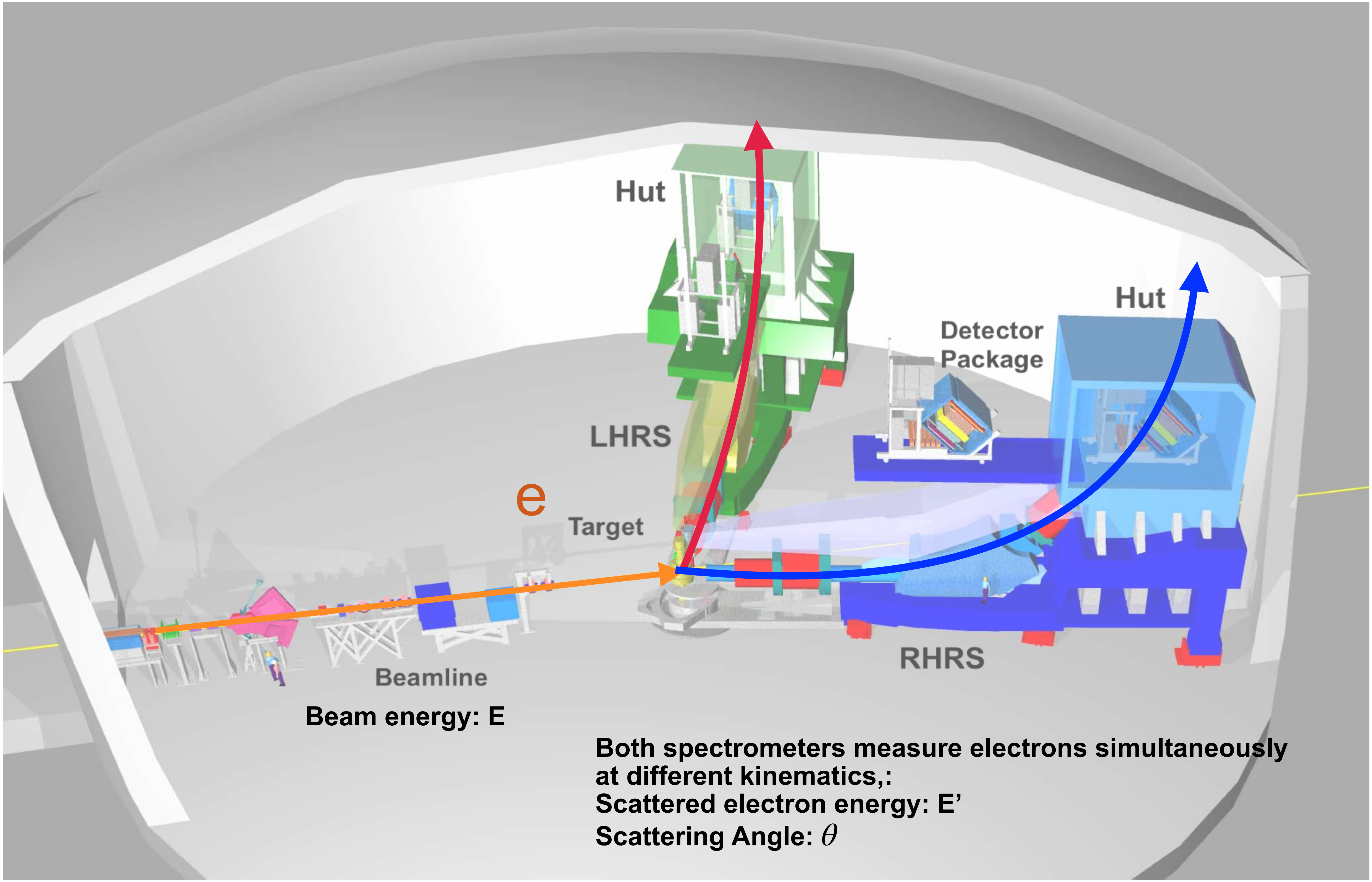




The experiment was performed in 2018.
In the plot, L(R) is the spectrometer used in Hall A Left(Right), and the number is related with the scattered angle of the electron.

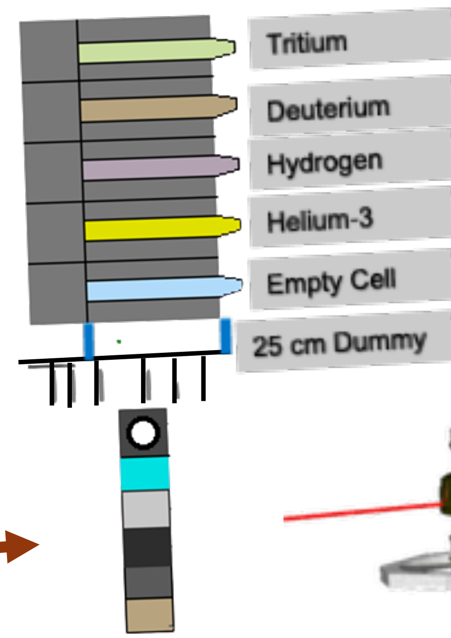
Hall A Configuration



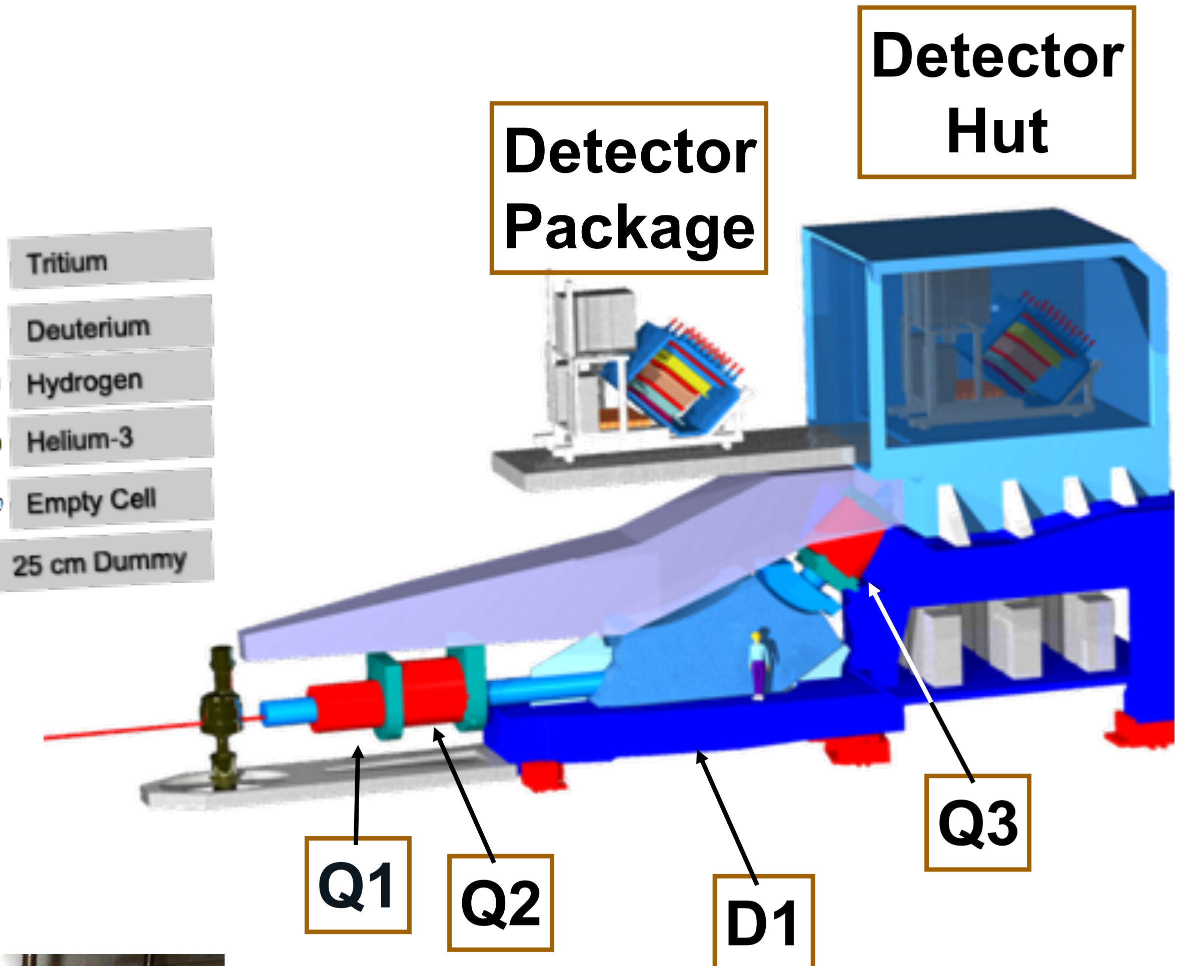
Experimental setup

Hall A

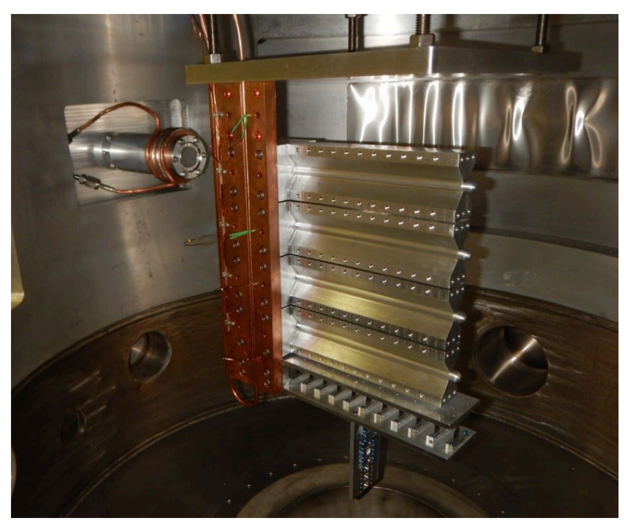
E = 2.2 Gev
E = 4.3 Gev



Electron Beam



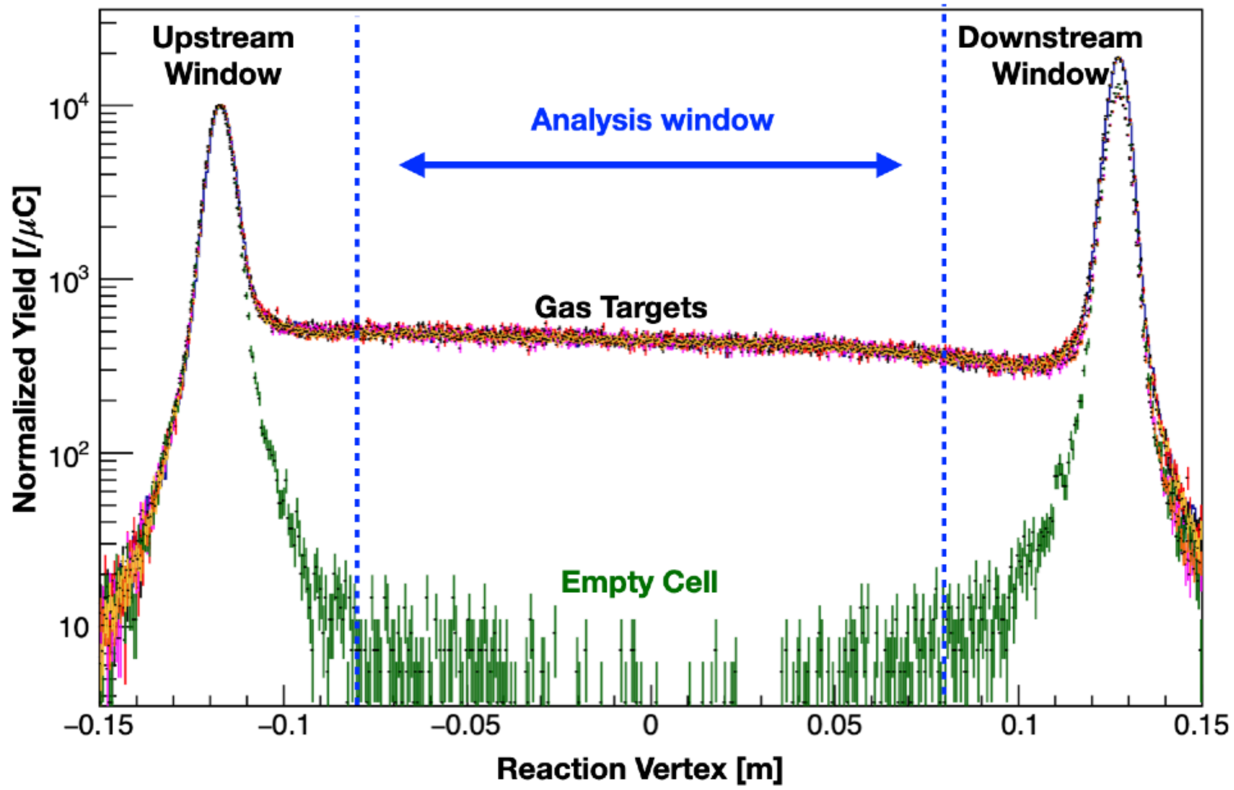
LHRS and RHRS
*10 different Q^2 Points
*2-3 Kinematics Settings per Q^2 point.
*3 run periods.
*2 Tritium Cells



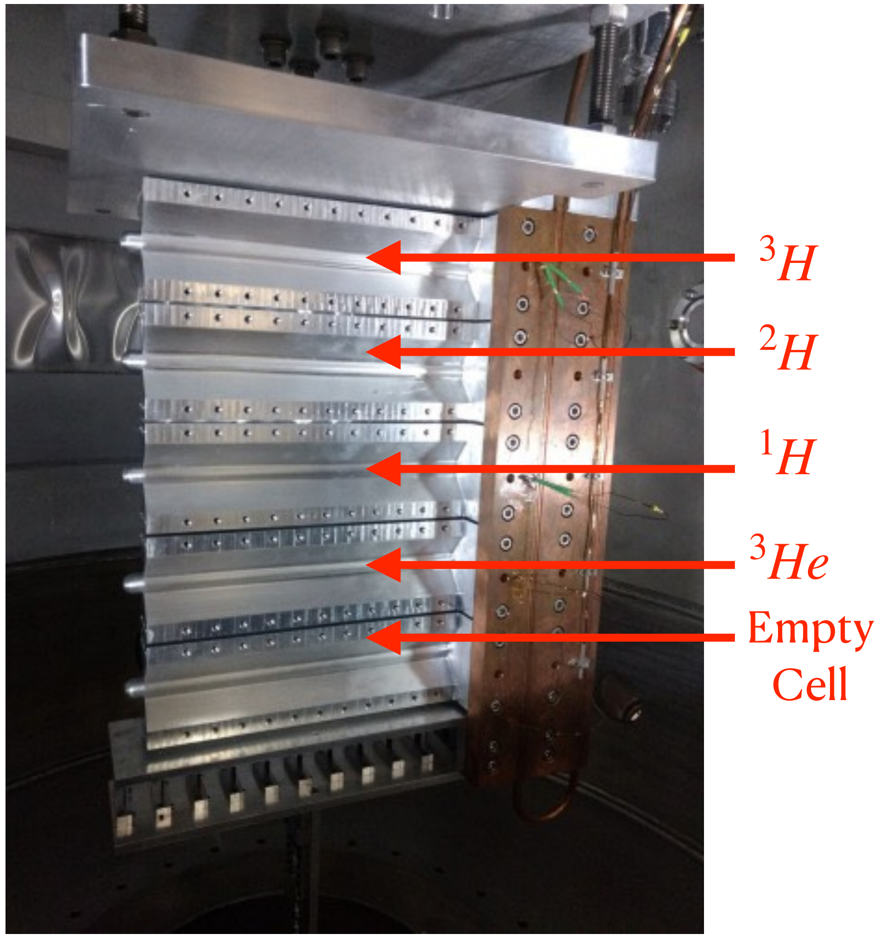
Target System

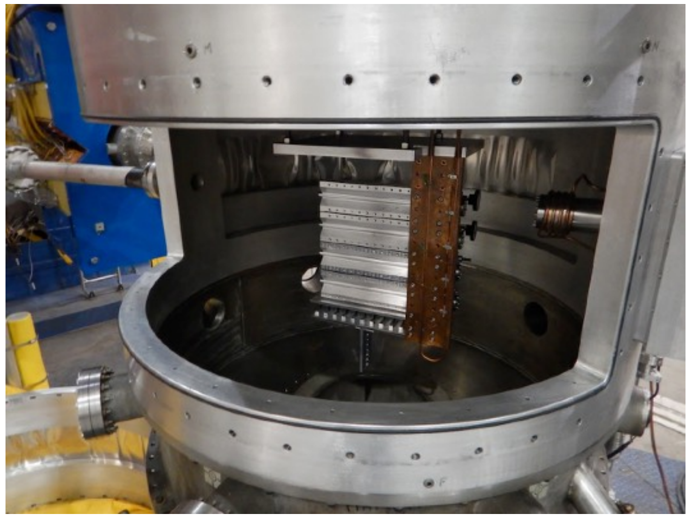
Target System

Normalized Yield: Number of events measured per unit of charge



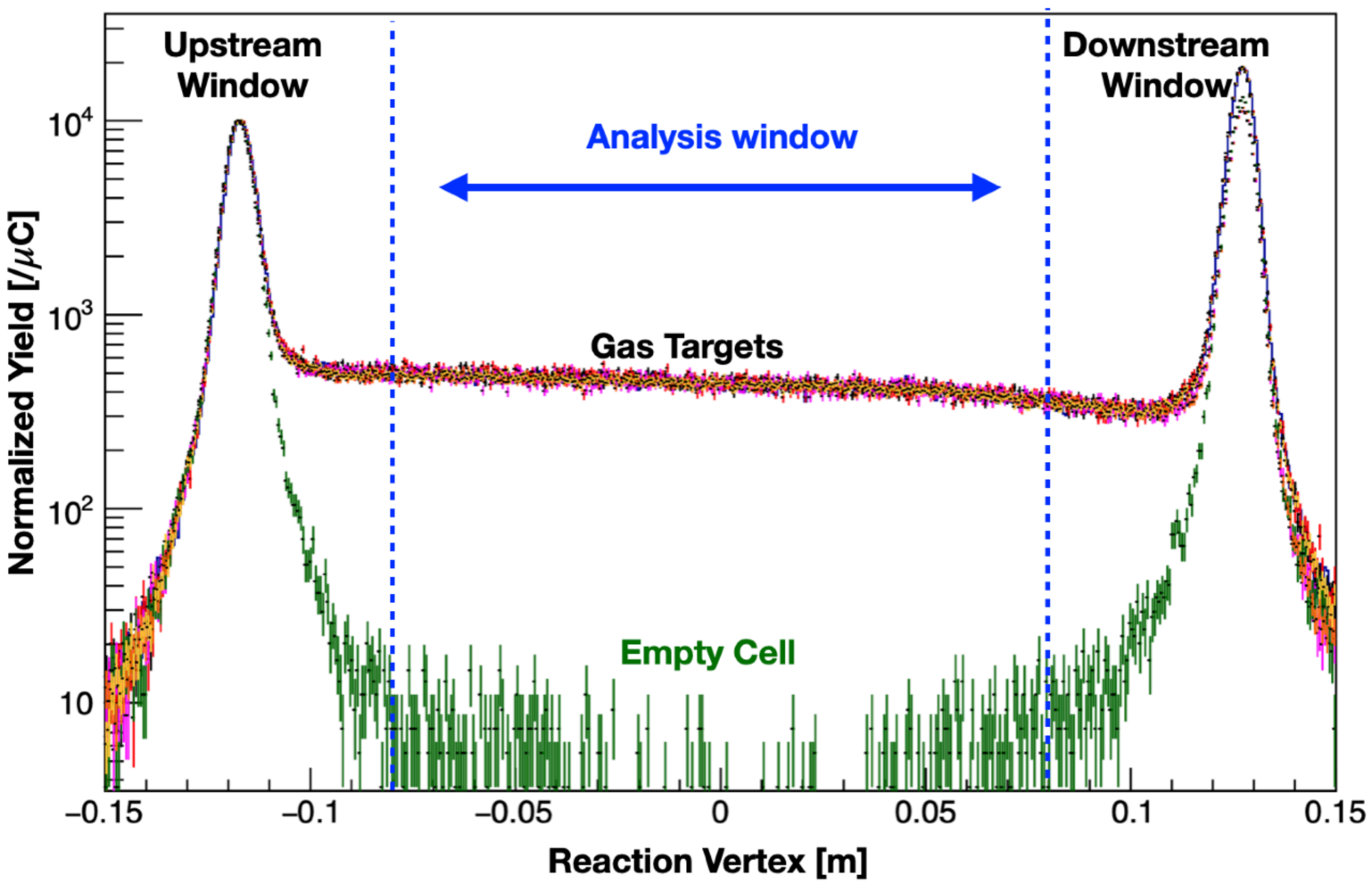
First Tritium experiment in Jefferson Lab





- Tritium cell was filled at Savanah River Site (SRS).
- The scattering chamber is vacuum with a pumping system directed to an exhaust stack, provided a layer of tritium confinement.
- Cells were machined from a single piece of aluminum. Due to machining tolerances, the wall thickness of each cell varies slightly over its length.
- Maximum current allowed on target was 22.5 μA.

Endcap contamination

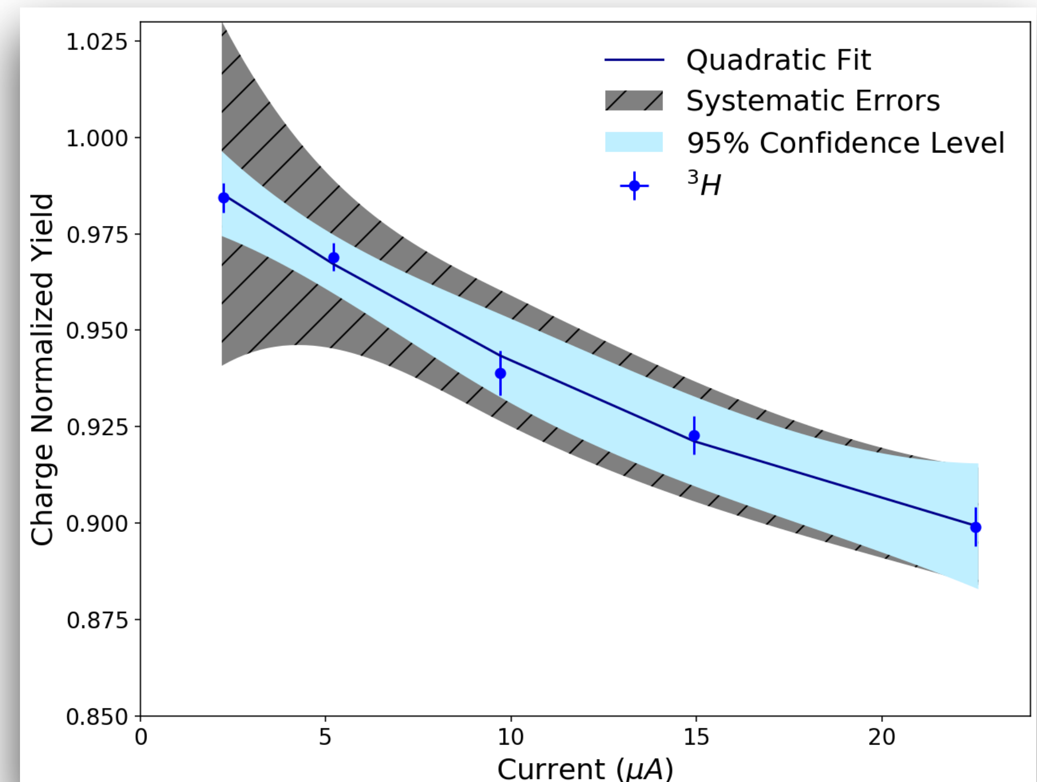


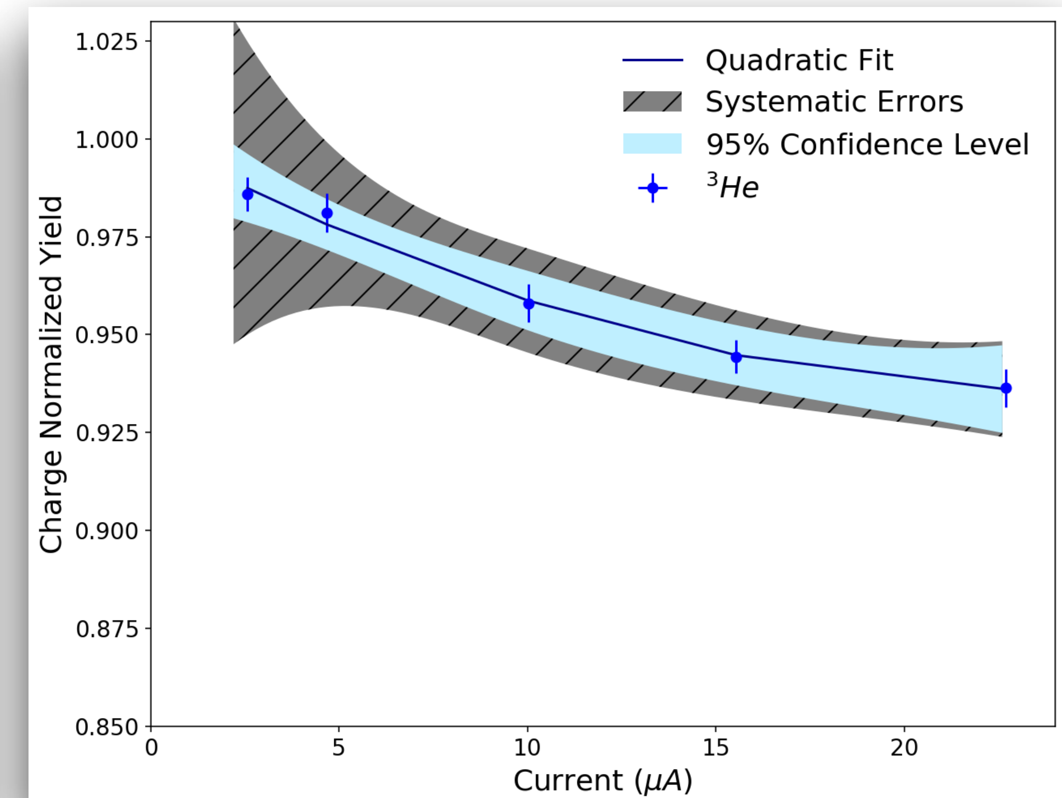
Endcaps background is addressed by:

- Cutting the end windows in the target cell data.
- Subtract the remaining background events from the electron sample using the empty cell runs.
- The contamination varied between 0.5 - 2 % in the analysis window depending on the kinematics.

Density study of the gas targets

The density of the gas targets decreases due to heating effects from the electron beam.
Goal of the study: Find a functional form to measure the density reduction for any given current.





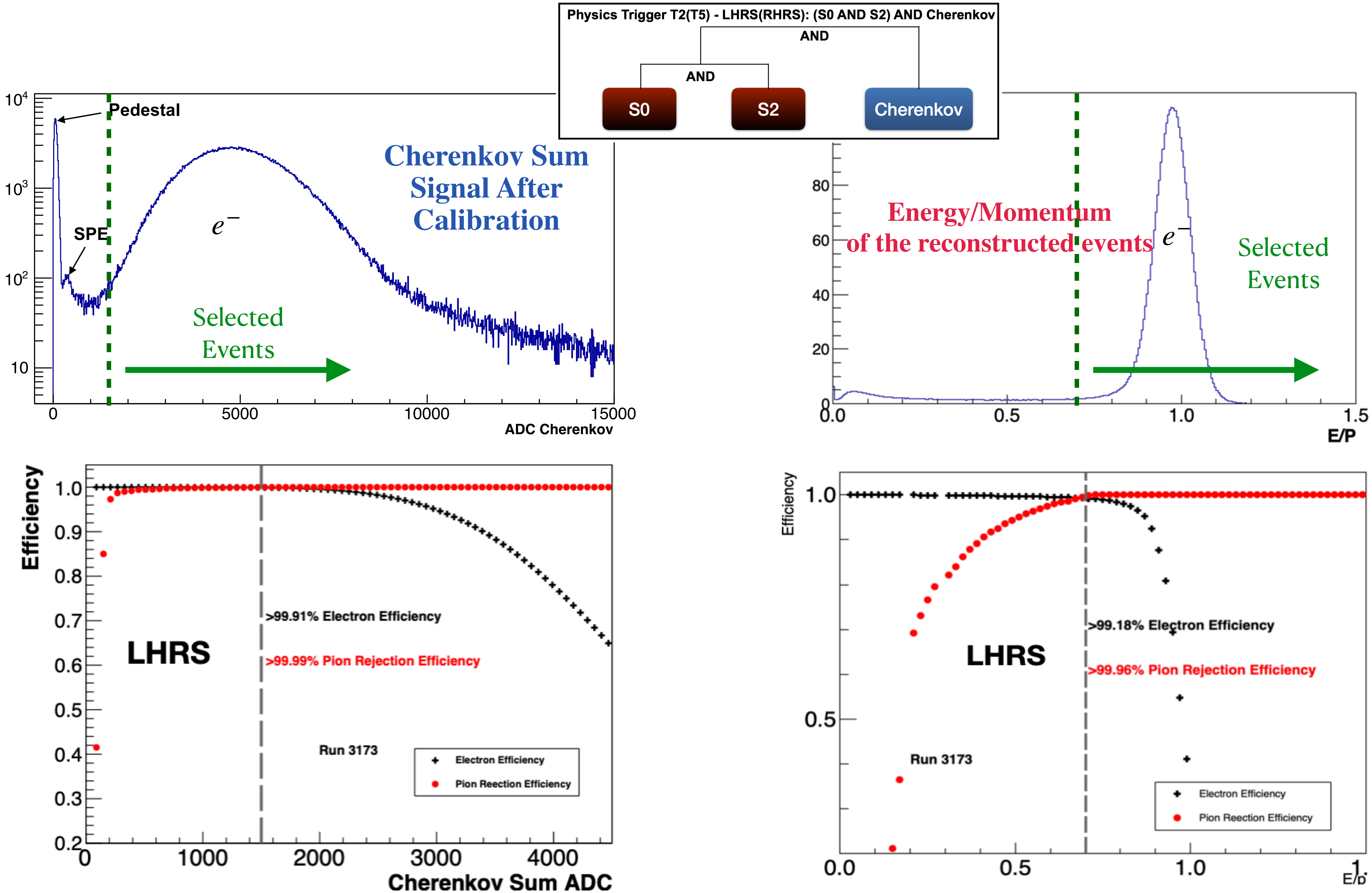
Charge Normalized Yield: Number of events measured per unit of charge.

Santiesteban S. N. *et al*. Nucl. Instrum. Meth. A940 (2019) 351-358

Density Reduction at the production current $22\mu A$:

^3H~ 10 %　　　　^3He~ 6%

Particle Identification (PID)



Tritium considerations: ^3H decay

Cell	Filling Date	E12-11-112 Running time	Purity (%)
Cell 1	10/23/2017	12/15/2017	98.83
Cell 1	10/23/2017	05/03/2018-05/06/2018	95.82-95.73
Cell 2	08/24/2018	09/26/2018-10/29/2018	99.27-98.55

^{3}H in the cell at any time t:

$$n_{^3H}(t) = n_0 e^{-t/\tau}$$

^{3}He in the cell at any time t:

$$n_{^3He}(t) = n_0(1 - e^{-t/\tau})$$

$\tau = 4500 \pm 8$ days

Lifetime

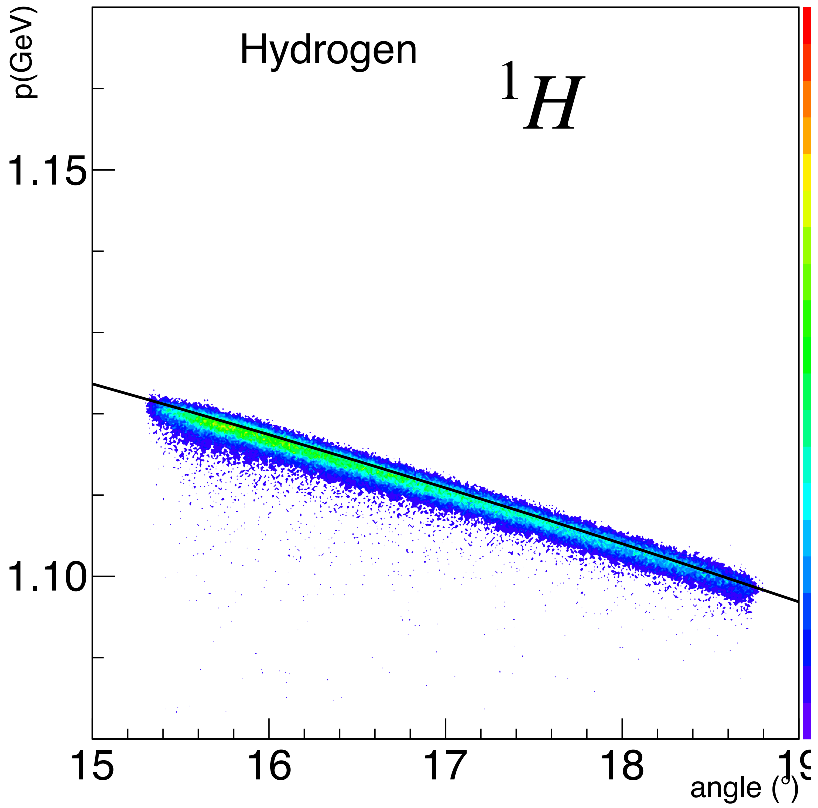
Measured cross section:

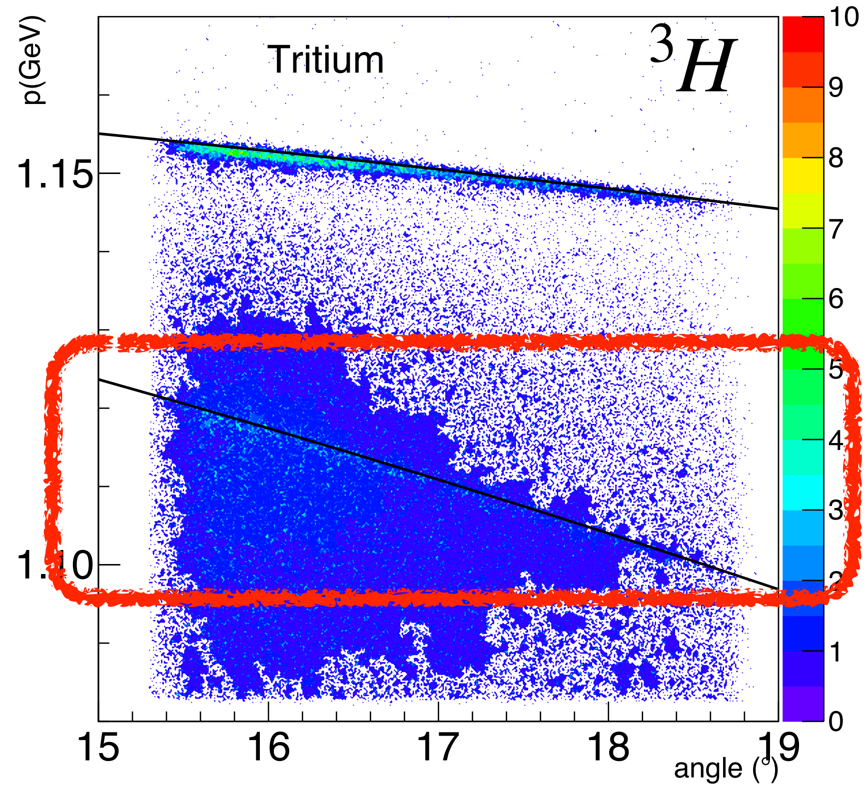
$$\sigma^{measured} = \sigma^{^3H} e^{-t/\tau} + \sigma^{^3He}(1 - e^{-t/\tau})$$

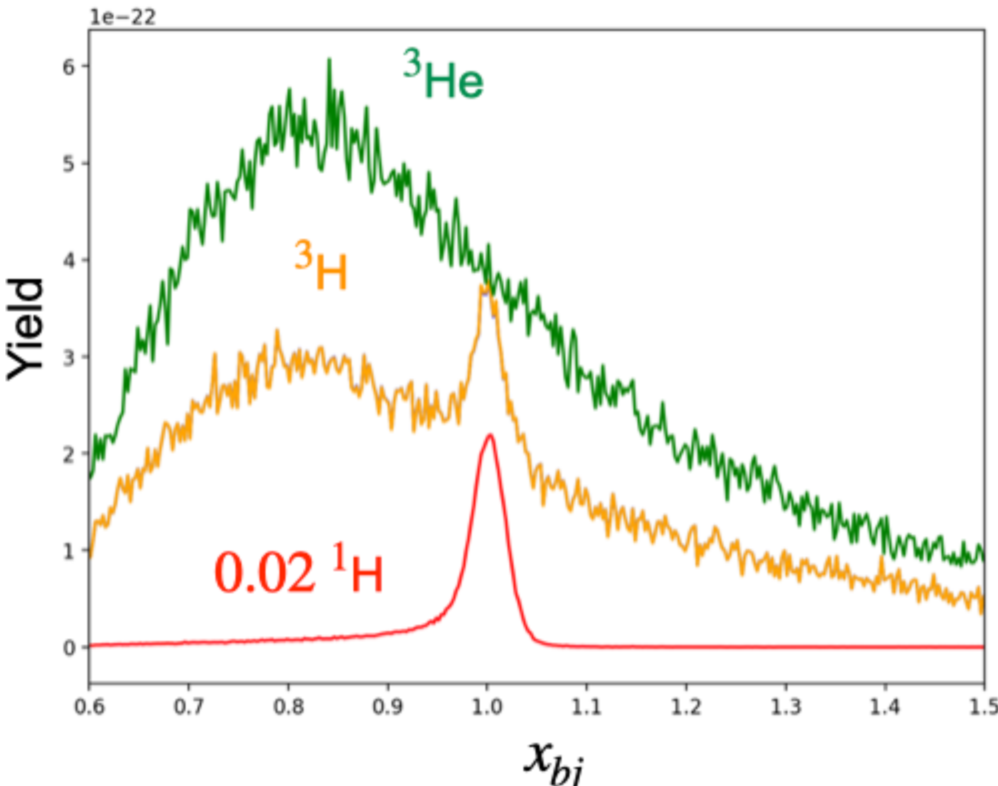
^{3}He contamination has to be removed from the ^{3}H events:

- The correction is applied depending on the running time.
- ^{3}He data is used to account for the contamination

Tritium considerations: ^{1}H contamination in the second ^{3}H cell







$$H_2O + T_2 \rightarrow HTO + HT$$

Liquid stick to the wall at low temperature

Maximum 4.12% Hydrogen Contamination in the Second Tritium Cell, affecting the $Q^2 > 2$ GeV^2 kinematics.

Proper estimation of the hydrogen contamination is expected after the mass spectrometer analysis is done at Savanah River Site (SRS)

From Data to cross sections

The experimental cross section is defined by:

$$\frac{d\sigma^{\text{target}}(E',\theta)}{d\Omega dE} = \frac{\overbrace{Y^{\text{target}}(E',\theta)}^{\text{Yield}}\,\overbrace{\text{RC}^{\text{target}}}^{\text{Radiative Corrections}}}{\underbrace{\text{A}^{\text{target}}(E',\theta)}_{\text{Acceptance}}}$$

If we have a model cross section using a MonteCarlo (MC) generator:

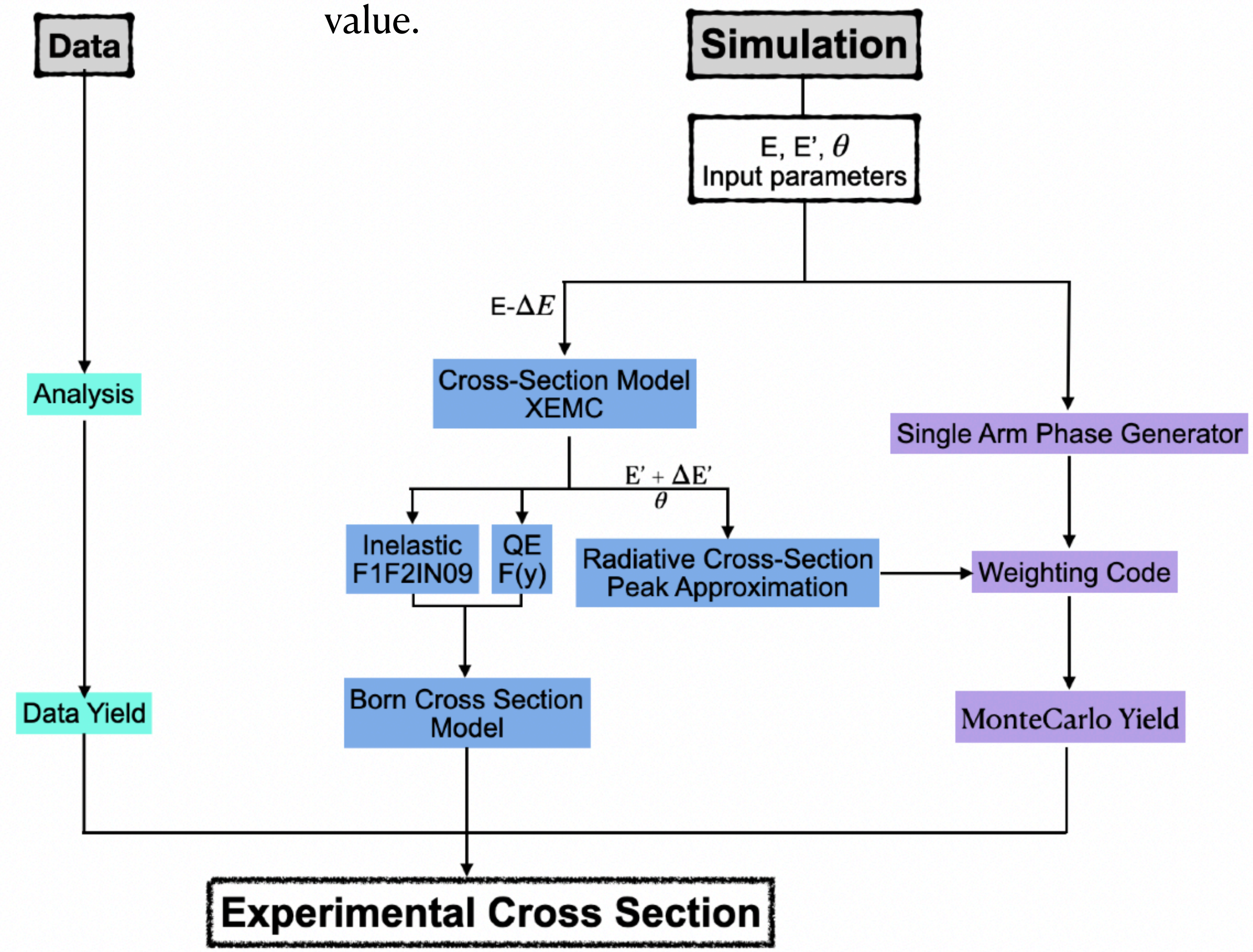
$$\frac{d\sigma^{\text{Model}}(E',\theta)}{d\Omega dE} = \frac{Y^{\text{MC}}(E',\theta)\text{RC}^{\text{MC}}}{\text{A}^{\text{MC}}(E',\theta)}$$

If the MC reproduces the data and the acceptance properly:

$$\frac{d\sigma^{target}(E',\theta)}{d\Omega dE} = \frac{d\sigma^{Model}(E',\theta)}{d\Omega dE}\cdot\frac{Y^{target}(E',\theta)}{Y^{MC}(E',\theta)}$$

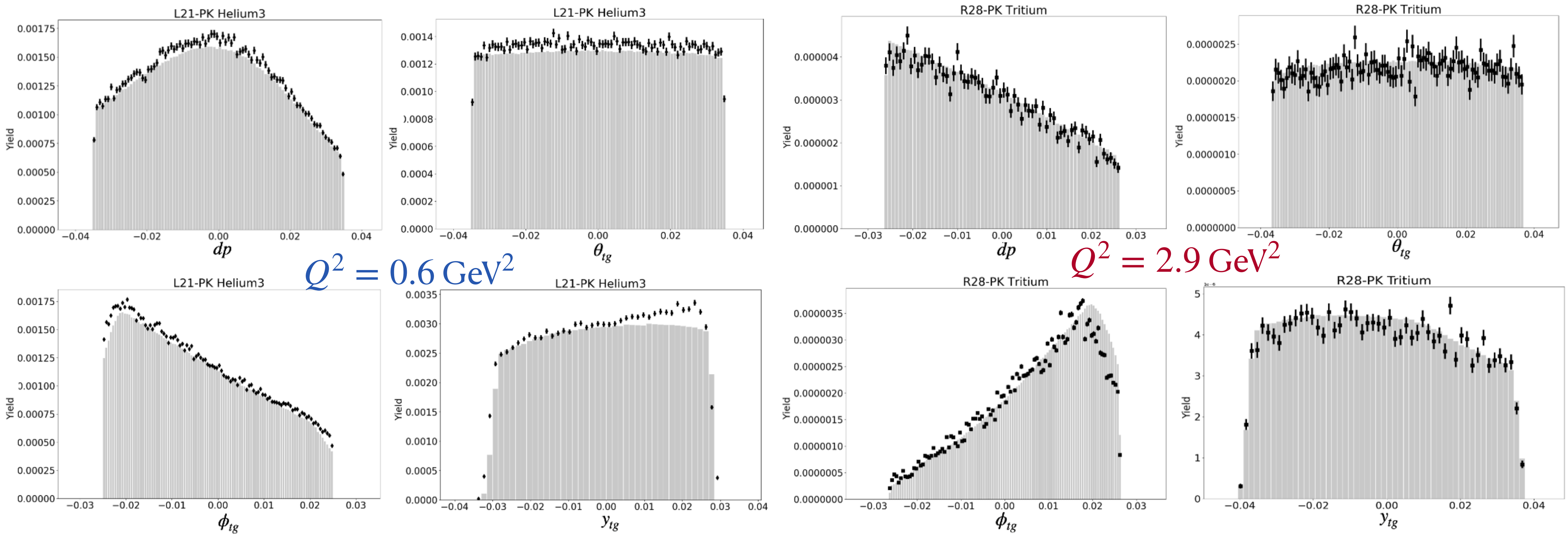
The MC is composed of:

- Single phase generator: Generates events with the acceptance of the spectrometer.
- XEMC: Generates the Born and the radiative cross sections for any given event.
- Weighting package: Assigns the physics value to each event generated using the appropriate cross section value.



Data/MC comparison for the target variables

Sample



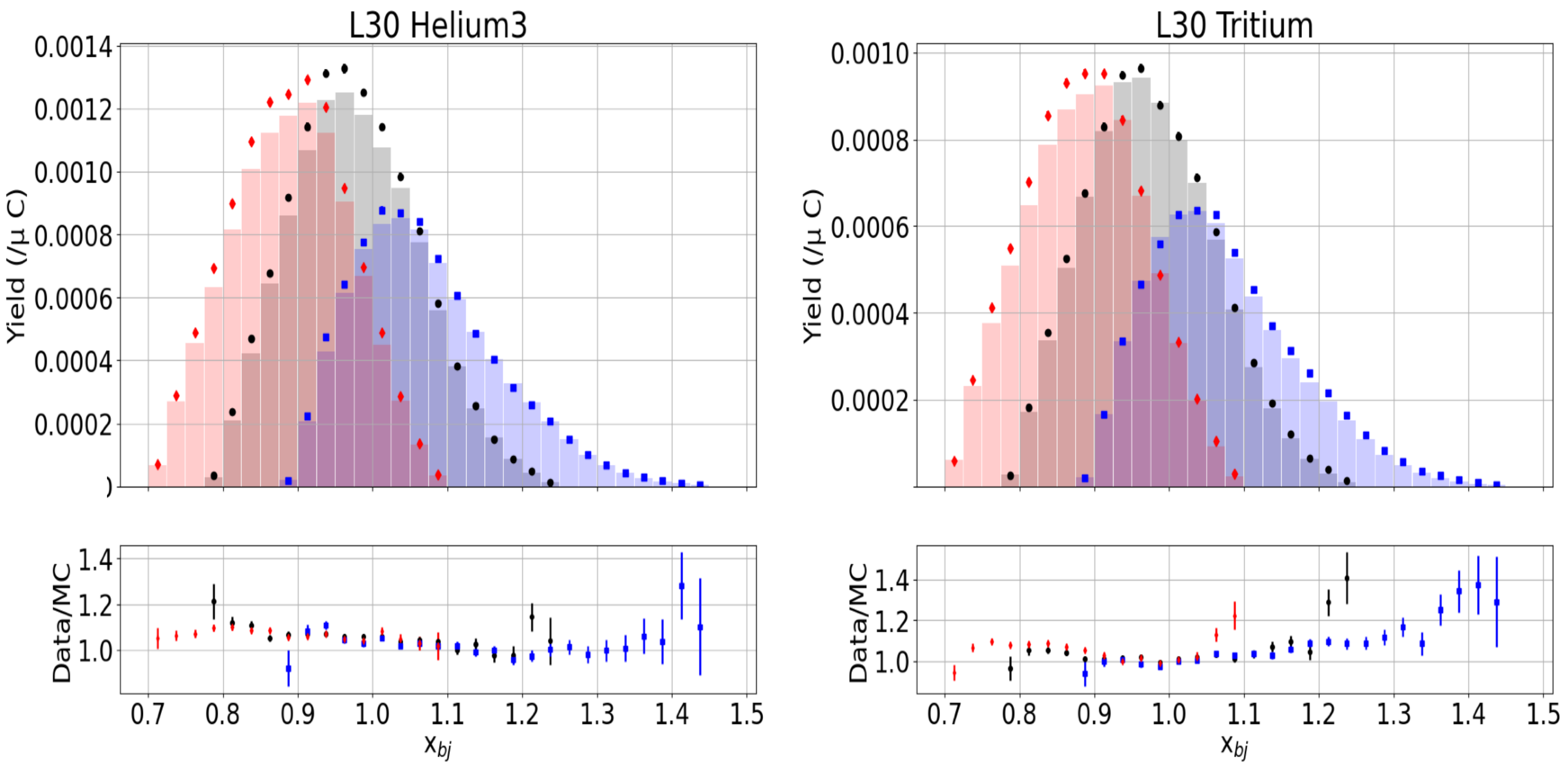
LHRS Kinematics

RHRS Kinematics

✦ Experimental data

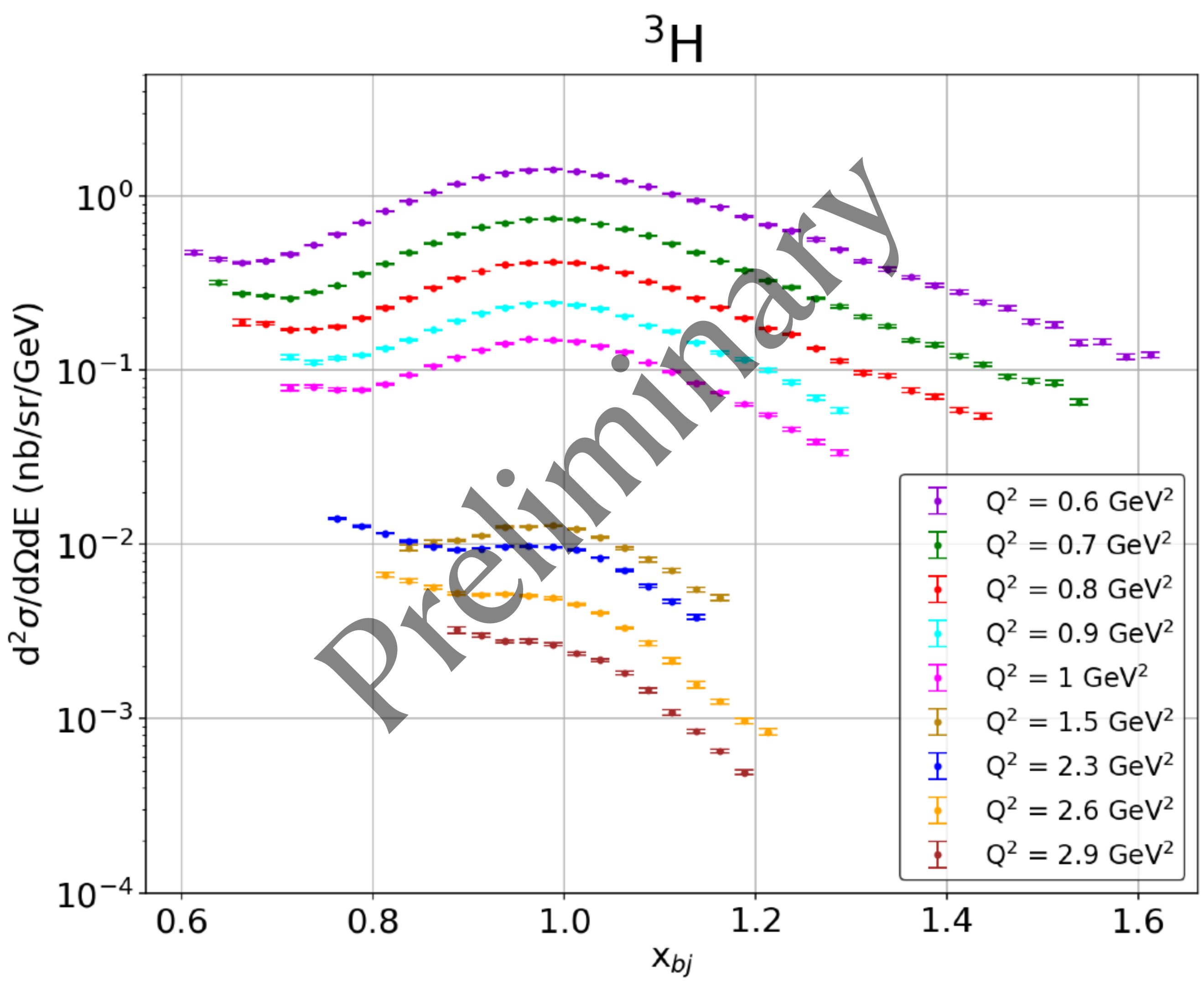
MC

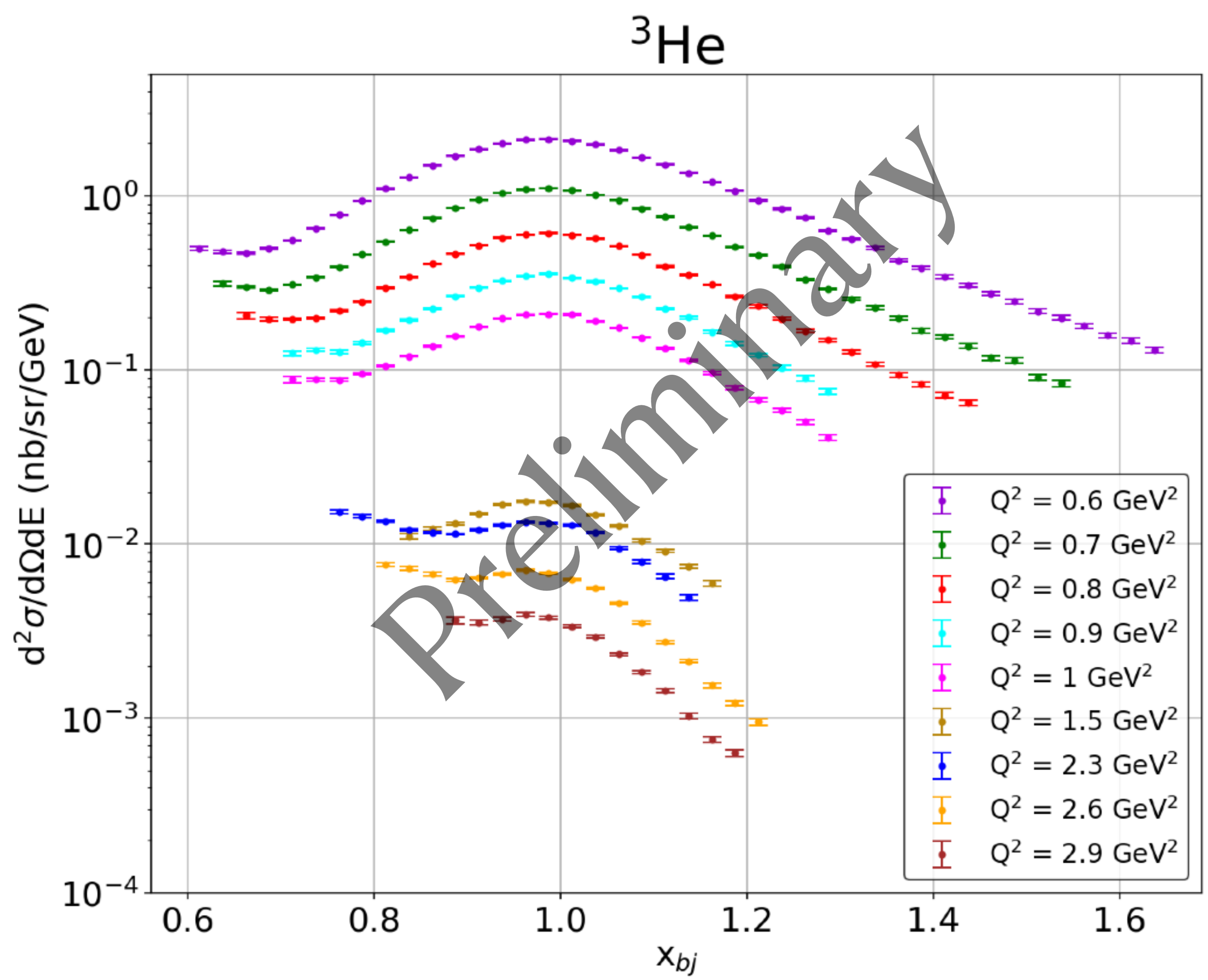
Data/MC comparison for x_{bj}



LS: Low Side of the QE peak
PK: Centered at the QE peak
HS: High side of the QE peak

Cross section results





Systematic Uncertainties

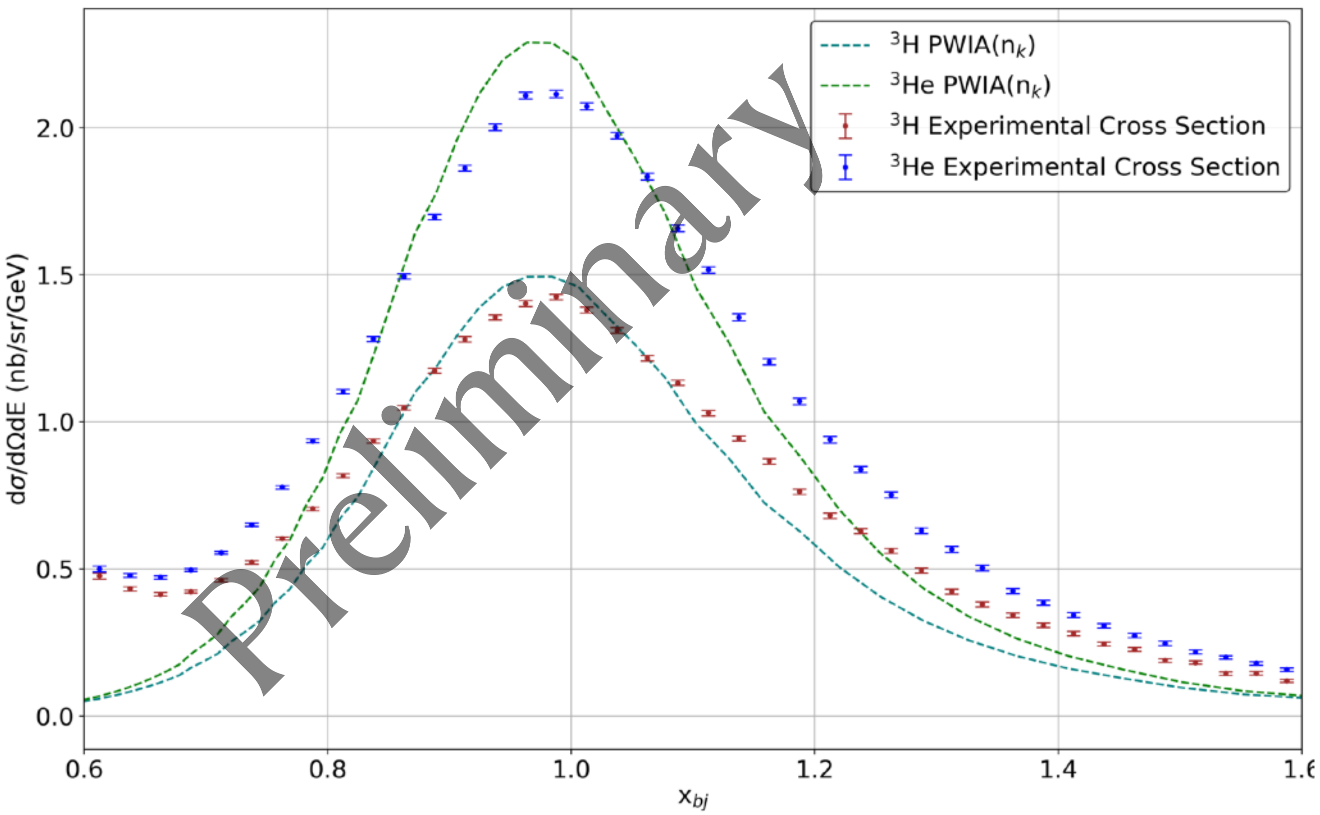
	Cross Section		Cross Section Ratios	
Source	Normalization [%]	Point-to-Point [%]	Normalization [%]	Point-to-Point [%]
Beam Energy	---	0.5-2	---	---
E'	---	2-3	---	---
Scattering Angle	0.6	0.2	---	---
Background Contamination	0.07	0.1-0.4	0.1	0.15-0.4
Target Thickness	0.3-1	---	1	---
Target length cut	0.4	---	---	---
Boiling	0.3-0.4	---	0.5	---
Charge	0.5	---	0.1	---
Efficiencies and live-time	0.01-0.1	---	---	---
Tracking	0.2	0.1	---	---
Coulomb correction	---	0.001	---	0.01
Bin Centering	---	---	---	---
3He contamination	----	0.03-1.75	---	0.03-1.75
Hydrogen contamination	2	----	2	----
Model Dependence	0.2	---	---	----
Acceptance corrections	1.5	---	---	---
Radiative corrections	1	1	0.3	0.4

Preliminary

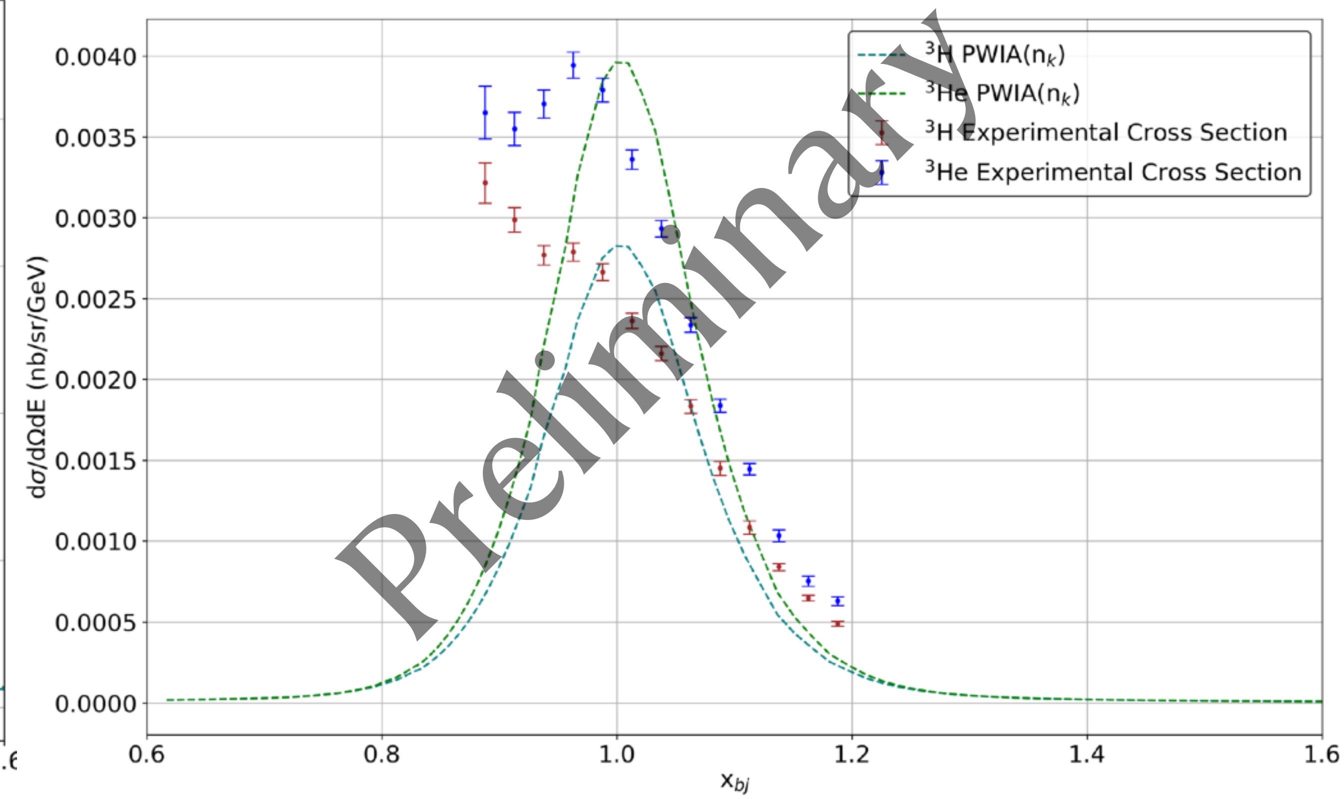
Estimating nuclear effects

Goal: Estimate the medium effects from a theory model

$Q^2 = 0.6$ Gev^2



$Q^2 = 2.9$ Gev^2



The error bars in the data correspond to the statistical and point-to-point uncertainties.
The normalization uncertainty in the data is 3.1% for all cross sections except for the ^{3}H data at 2.9 GeV^2, which is 3.7% because of the hydrogen contamination.

- PWIA Calculations from Rocco and Lovatto (QE only)
- Comparisons above are a sanity check.
- FSI calculations being performed, expected to be negligible in ratio
- Calculations used to look at difference between naive “Stationary approximation: sum of nucleon" approach and full QE ratio.

Stationary approximation: From cross sections to G_M^n

Assuming no-nucleon interactions or medium effects:

$$\sigma_{3H} \sim 2\sigma_n + \sigma_p$$
$$\sigma_{3He} \sim \sigma_n + 2\sigma_p$$

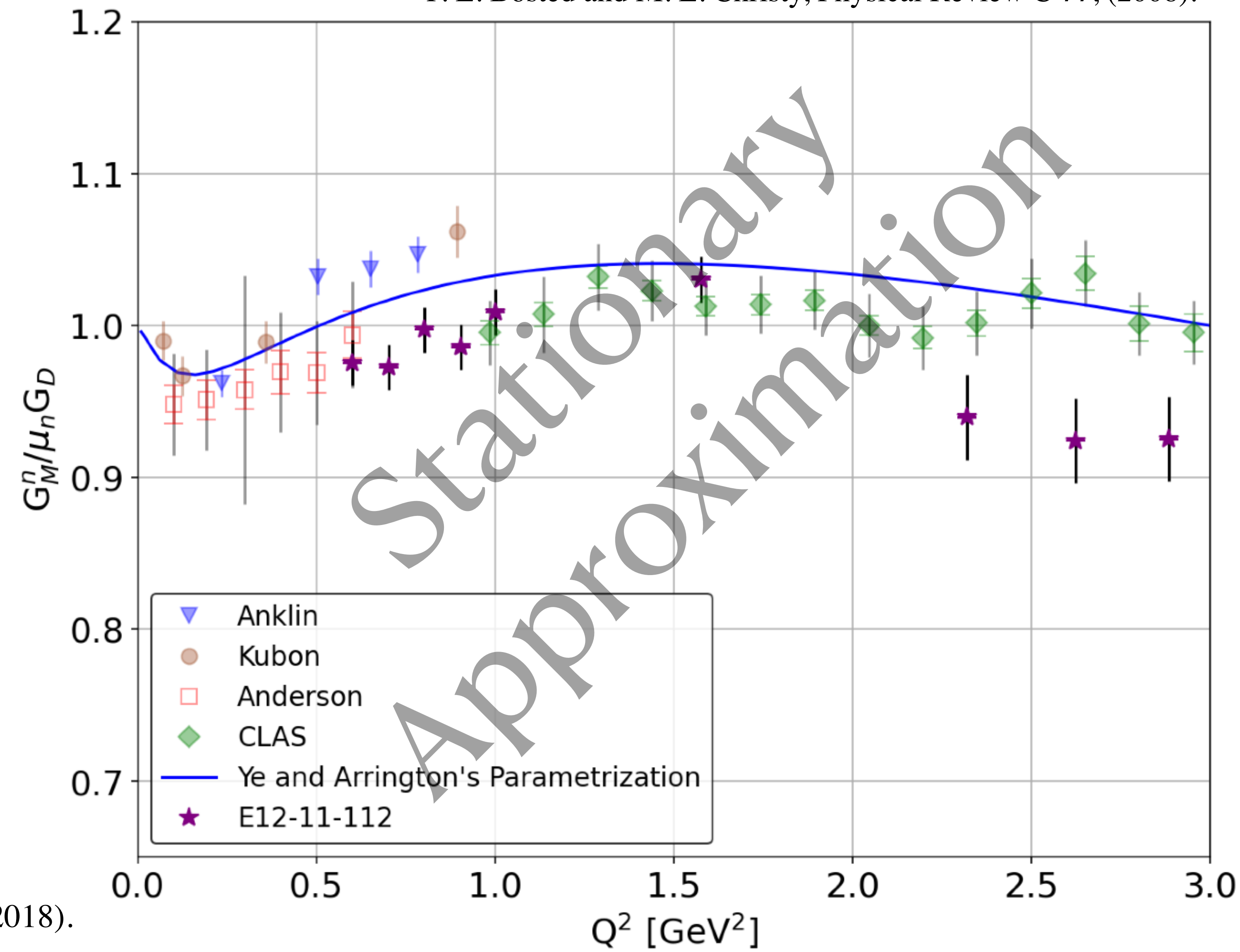
$$R = \frac{\sigma_{3H}}{\sigma_{3He}} \sim \frac{2\sigma_n + \sigma_p}{\sigma_n + 2\sigma_p}$$

$$\sigma_n \sim \frac{1-2R}{R-2}\sigma_p$$

$$(G_M^n)^2 \sim \frac{\epsilon}{\tau}\left[\frac{1-2R}{R-2}\sigma_p \frac{1+\tau}{\sigma_{mott}} - (G_E^n)^2\right]$$

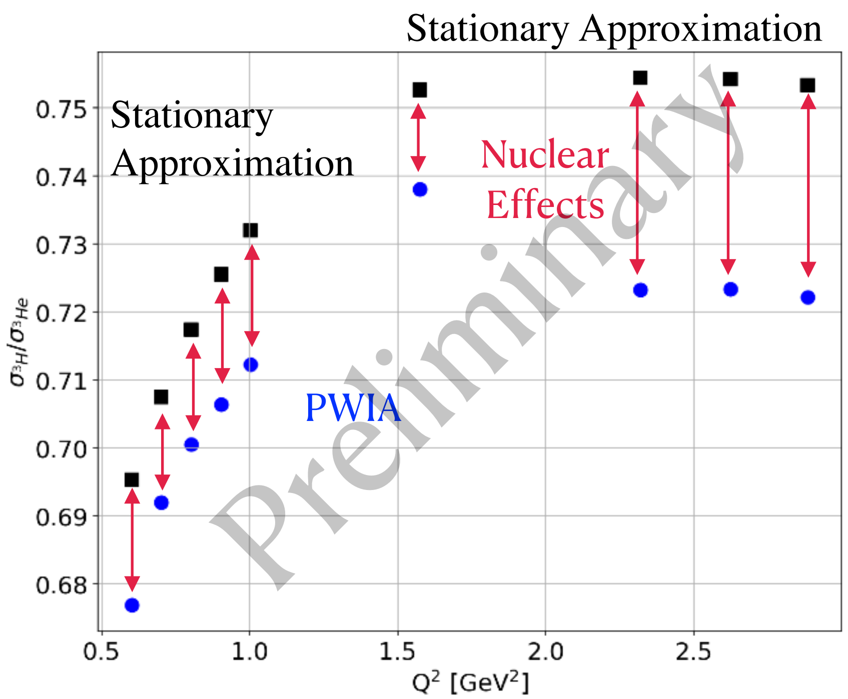
G_M^p, G_E^p and G_E^n form factors were taken from:
Z. Ye, J. Arrington, R. J. Hill, and G. Lee, Phys. Lett. B **777**, 8 (2018).

$^3H/^3He$ Ratio: Integrals from Peak to 2 sigma from the peak .
Inelastic contribution to the integrals subtracted by using the Bosted and Christy Model.
P. E. Bosted and M. E. Christy, Physical Review C **77**, (2008).



Neglecting the nuclear effects in the A=3 targets: G_M^n up to 8% away from the real value. However, these results still reflect the expected experimental uncertainty (for the preliminary values used at the moment).

Cross section ratio $^3H/^3He$ Comparison



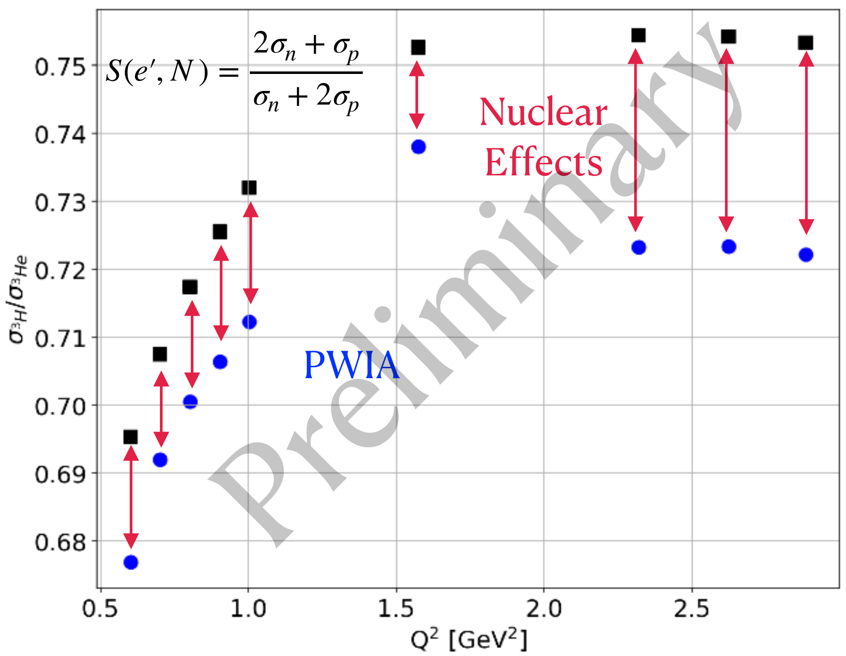
$^3H/^3He$ Ratio: Integrals from Peak to 2 sigma from the peak for PWIA .

G_M^p, G_E^p and G_E^n form factors were taken from:
Z. Ye, J. Arrington, R. J. Hill, and G. Lee, Phys. Lett. B **777**, 8 (2018).

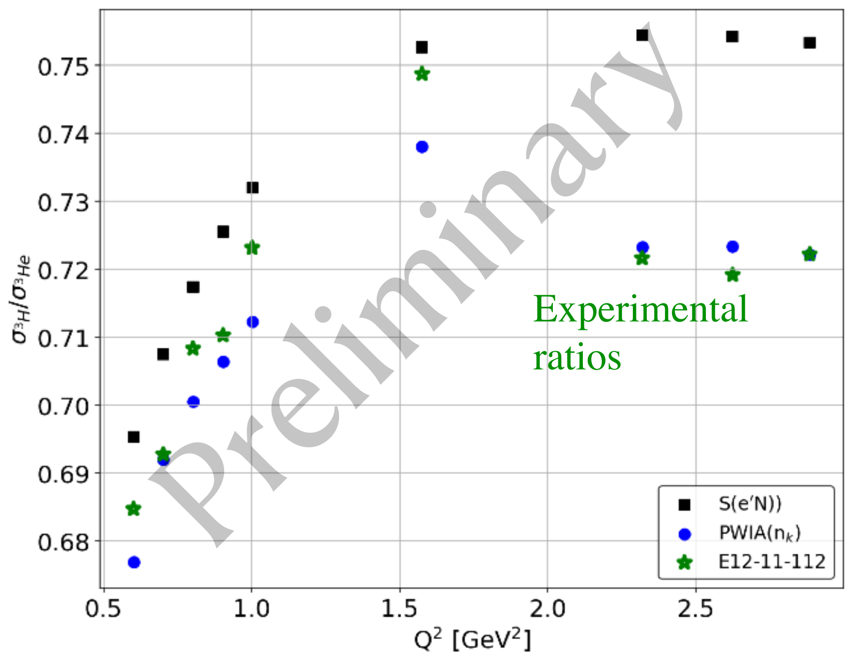
- Theory model input for the nucleon interactions and medium effects from Rocco and Lovatto.
- **Goal**: Find a suitable input model that describes the nuclear effects, where the **only** correction to match the data is the magnetic form factor.

Cross section ratio $^3H/^3He$ Comparison

Stationary cross sections ratio vs PWIA



Adding E12-11-112 ratios



^{3}H/^{3}He Ratio: Integrals from Peak to 2 sigma from the peak for PWIA .
^{3}H/^{3}He Ratio: Integrals from Peak to 2 sigma from the peak same than PWIA. Inelastic contribution to the integrals subtracted by using the Bosted and Christy Model.

G_M^p, G_E^p and G_E^n form factors were taken from:
Z. Ye, J. Arrington, R. J. Hill, and G. Lee, Phys. Lett. B **777**, 8 (2018).

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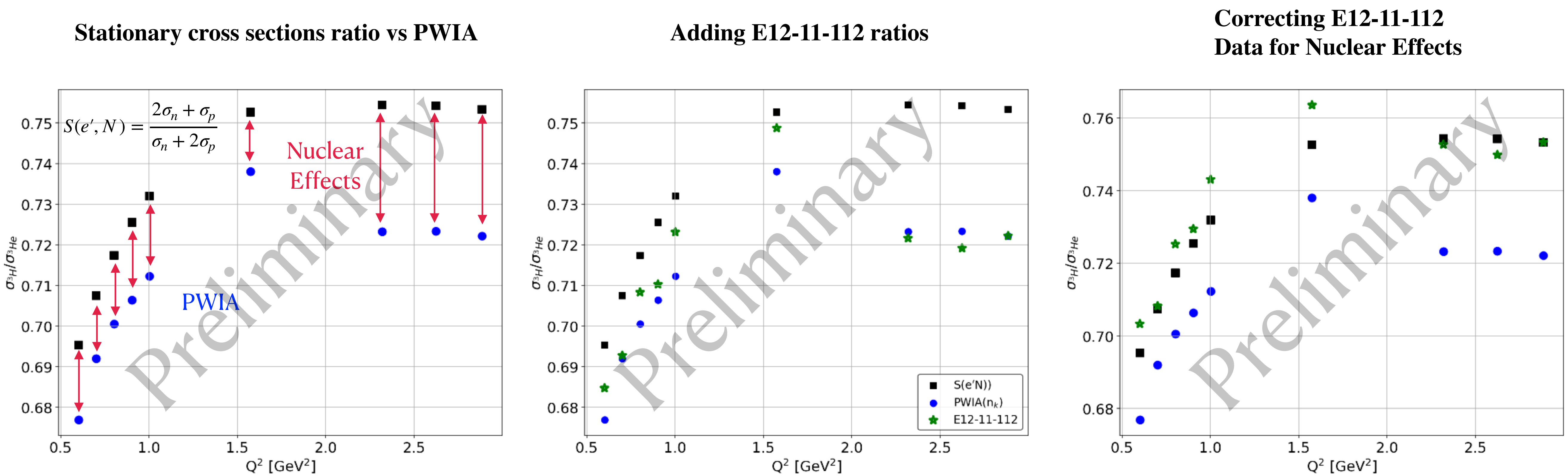

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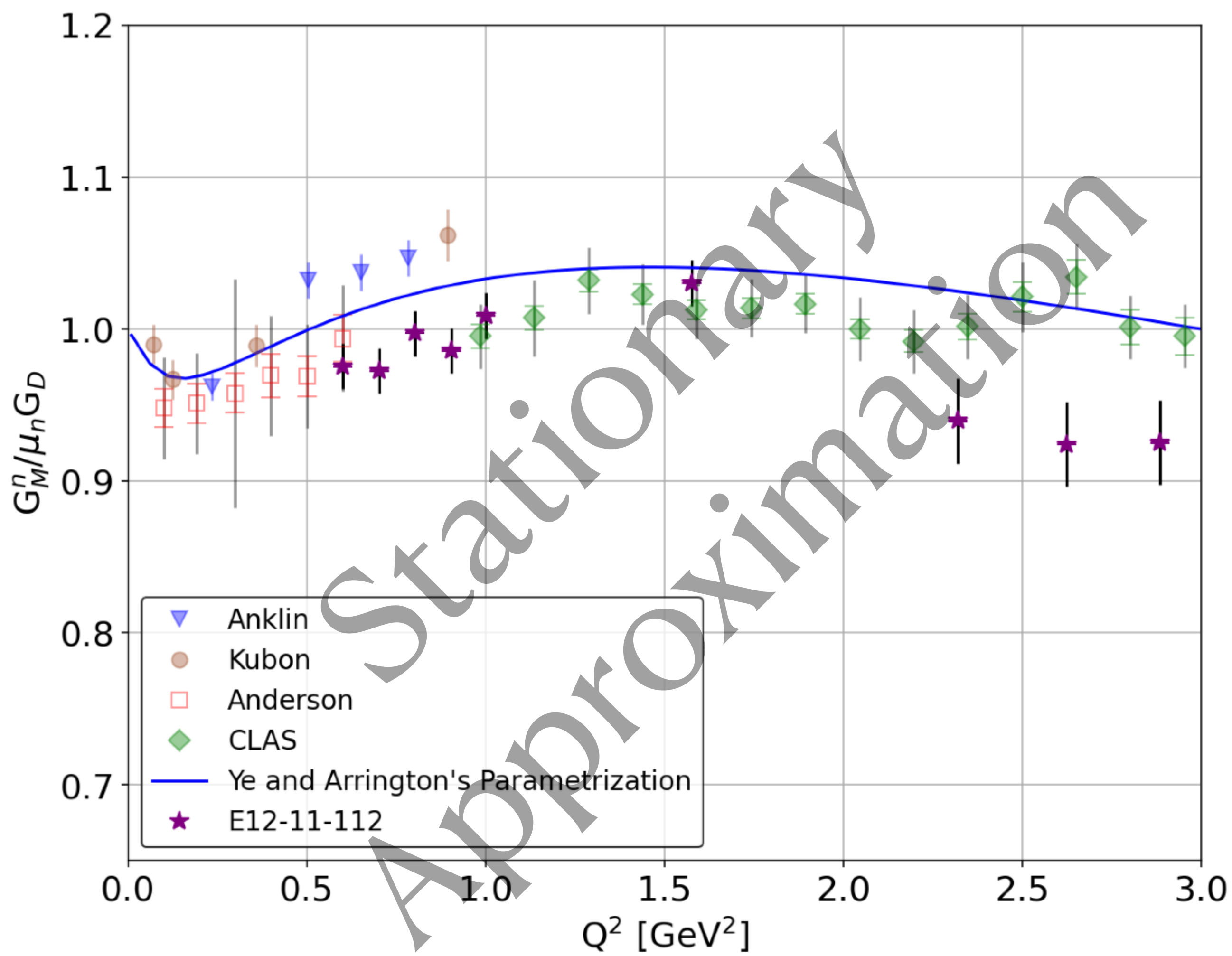
Implications of the E12-11-112 preliminary results

- Preliminary E12-11-112 show a high impact for the medium effects, and currently the contribution to the form factor is under study.
- The uncertainty of the higher Q^2 points will decrease once the mass spectrometer analysis from the tritium cell are received.
- The final uncertainty has a maximum 1.5% in the region of interest, which will be enough to claim a precise measurement.



Future Work

- We are in the process of cross checking the cross section results with other group member (Shujie Li).
- More systematic studies are being done to reduce the uncertainties.
- Check with other theory models, specially in the region of interest. We are contacting other theory physicists to help understanding the medium effects.
- Publish the results.

Thank you !

Do you have any questions?