Jefferson Lab
Thomas Jefferson National Accelerator Facility

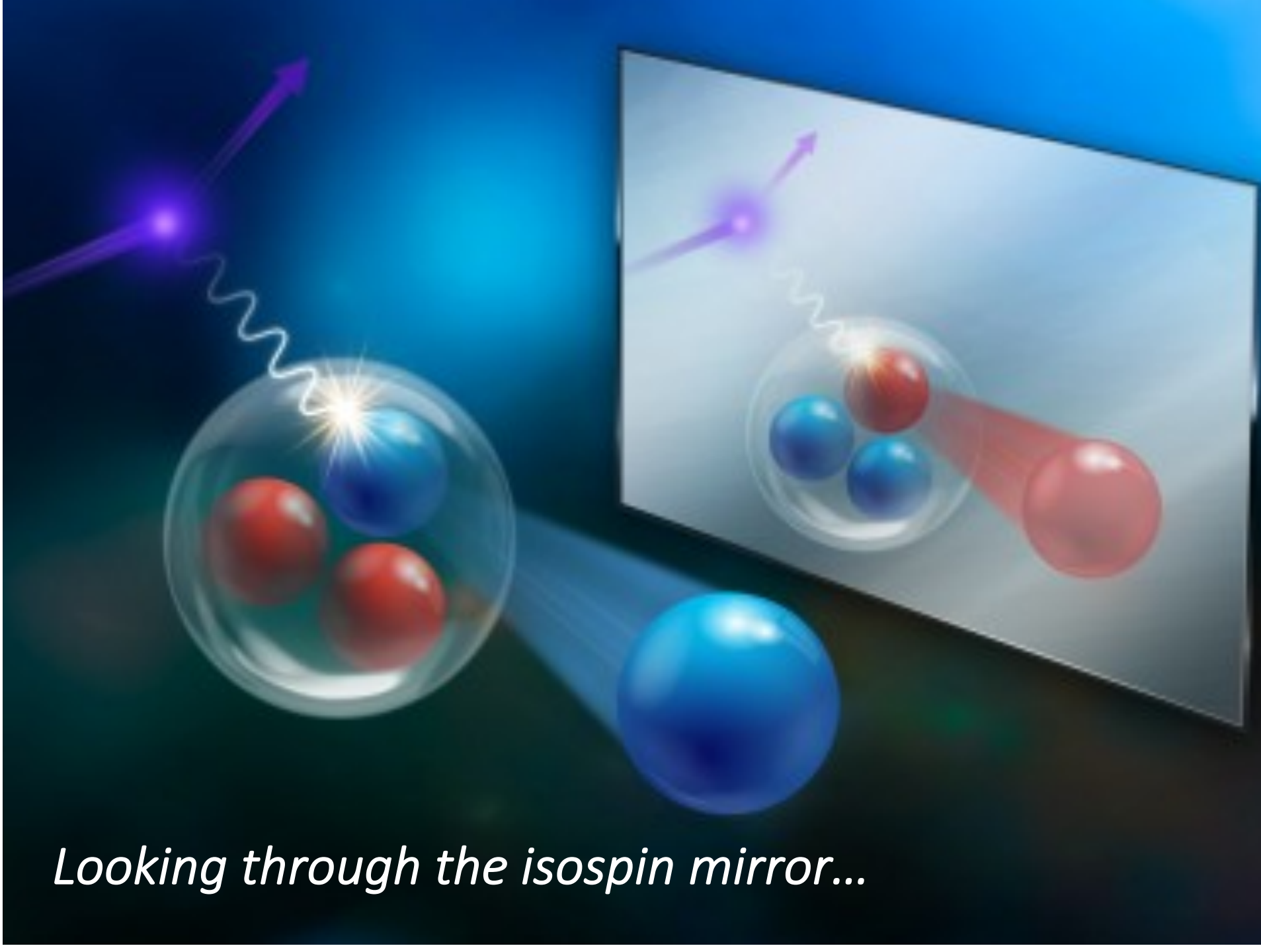
JSA

Precision measurements of A = 3 nuclei in Hall B to study NN interaction and SRC

Proposal PR12-20-005

Dien Nguyen
(Nathan Isgur Fellow at JLab)

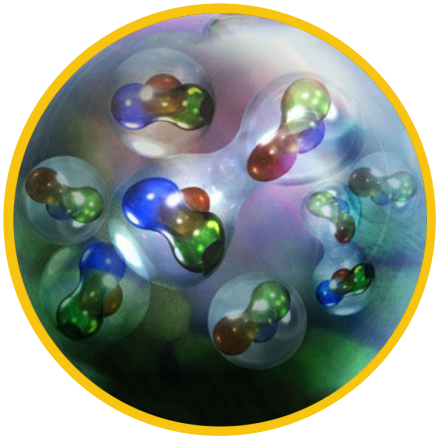
ECT* Workshop
Short-Distance Nuclear Structure and PDFs


Looking through the isospin mirror…

Nucleon-nucleon interaction

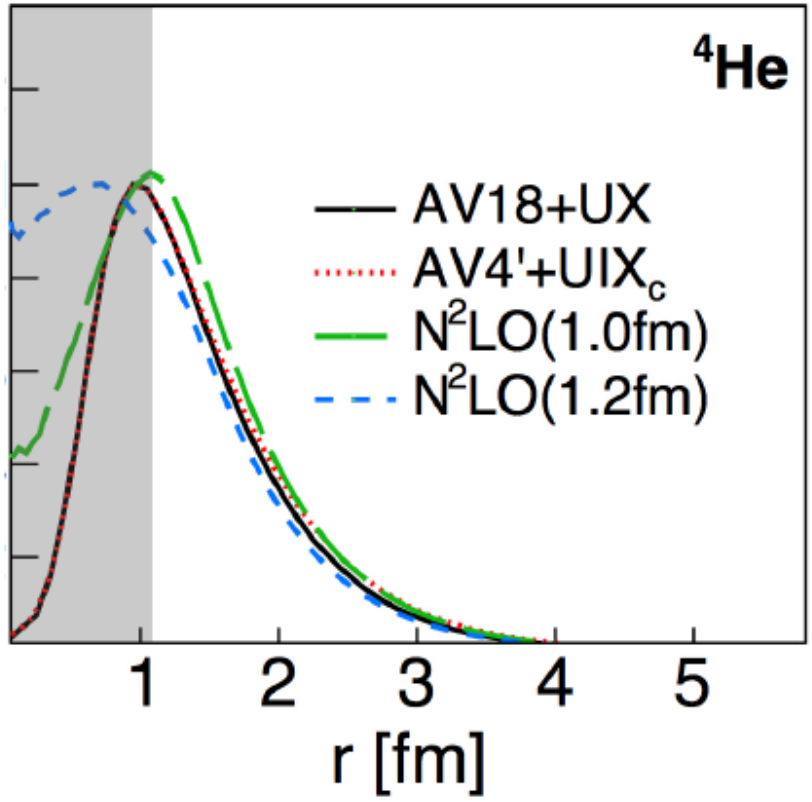
Crucial for:

- Ab-Initio structure & reaction calculations
- Dense astrophysical objects, e.g. neutron stars

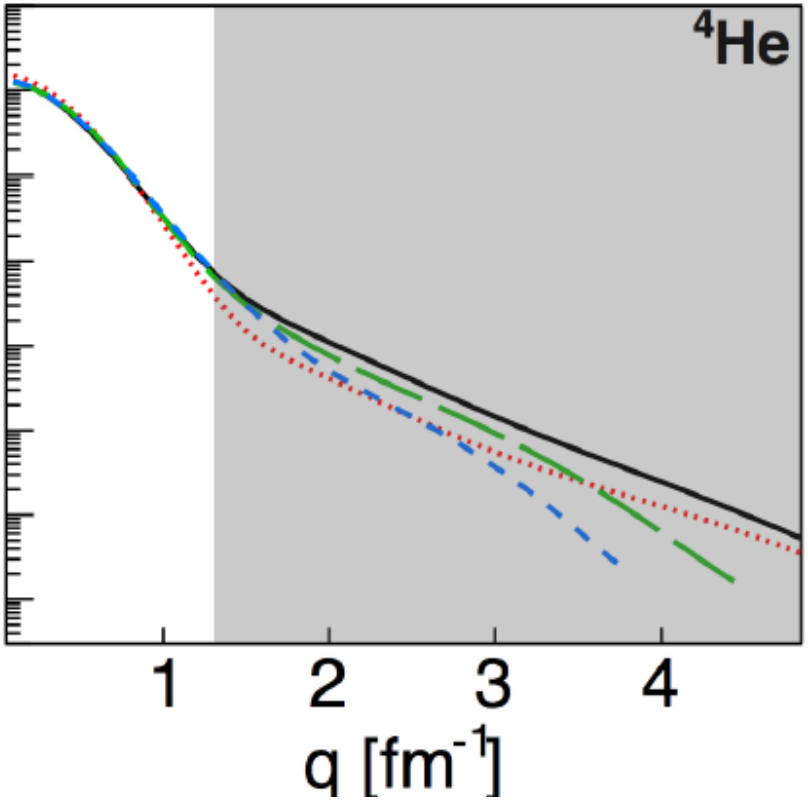


Nucleon-nucleon interaction

Probability to find two nucleons with relative distance r



Probability to find two nucleons with relative momentum q.



Need to put these models to test

Testing NN models and Reaction-Mechanism

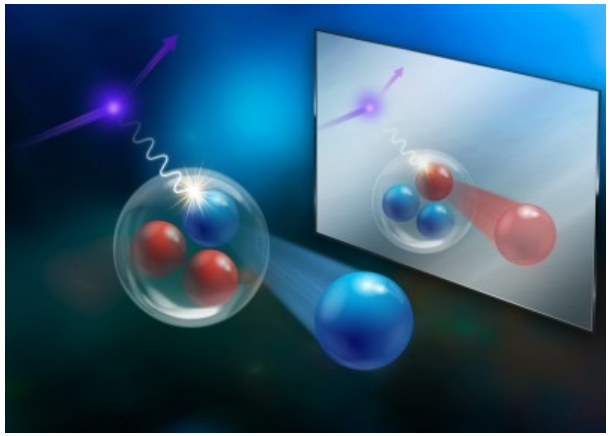
- Measure nucleon-knockout QE cross-section (e,e'p)
- Compare to calculation using different NN models and reaction-mechanism

Why A=3?

3-Body system:

- Exactly calculatable
- Nuclear environment effects
- Ideal for Test & benchmark theory

Why Tritium?



- Proton in ^{3}He = Neutron in ^{3}H
- Better constraints on reaction mechanism and ground-state wave function

Tritium Program (2018) at Hall A JLab

Tritium experiments and publications

- E12-11-103: Marathon F2n/p, EMC : DIS(e,e')
  - PRL 128 (2022)
- E12-11-112: Isospin Dependent of SRC QE(e,e') *See S. Li's talk*
  - Nature 609 (2022)
- E12-17-003: nnL hypernuclei
  - PRC 105 (2022)
- E12-14-011: High momentum nucleon distribution QE(e,e'p)
  - PLB 797 (2019)
  - PRL 124 (2021)
  - PLB 831 (2022)

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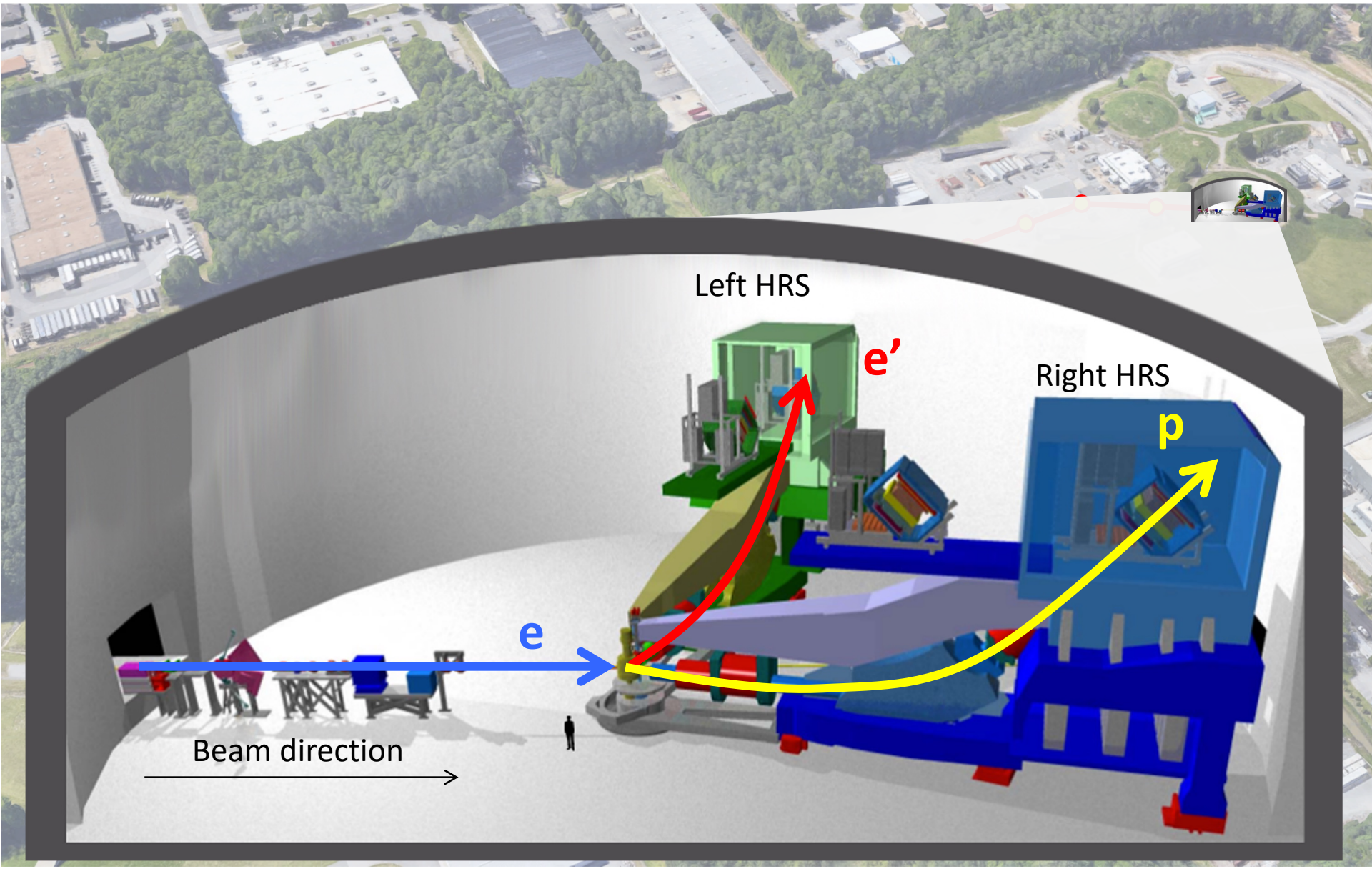
In this talk:

- Impact of A=3 (e,e’p) results in hall A

- New Tritium Program in Hall B

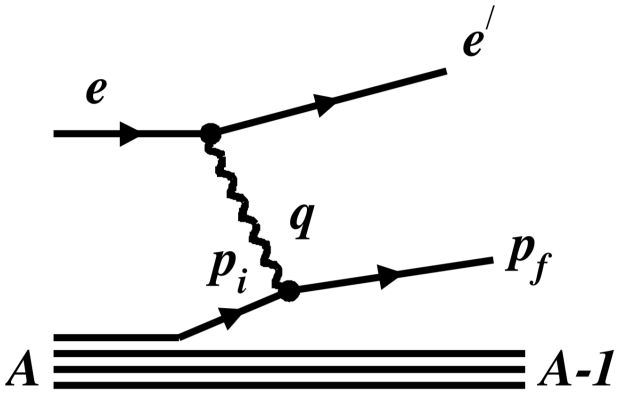
2018 Hall-A Tritium (e,e'p) Experiment



High Q^2: PWIA factorized approximation

$$\frac{d^6\sigma}{d\omega dE_p d\Omega_e d\Omega_p} = K\,\sigma_{ep}\,S(|\overrightarrow{P_i}|, E_i)$$

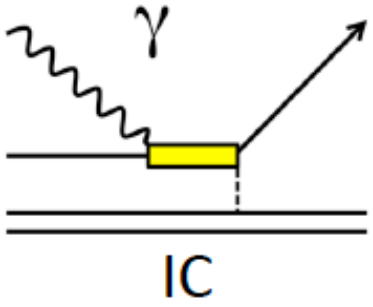
PWIA approximation:

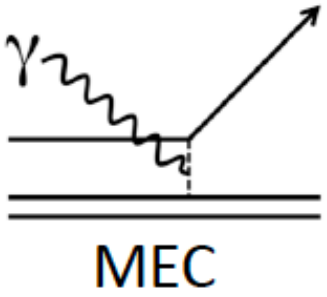


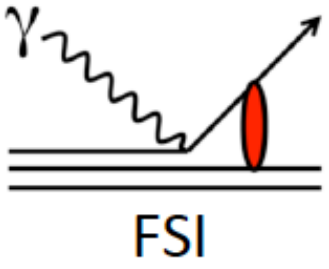
$$\boldsymbol{p_i \sim p_{miss} = p_f - q}$$

$$\frac{\sigma_{^3He(e,e'p)}}{\sigma_{^3H(e,e'p)}} \approx \frac{S_{^3He}(|\overrightarrow{P_i}|,E_i)}{S_{^3H}(|\overrightarrow{P_i}|,E_i)}$$

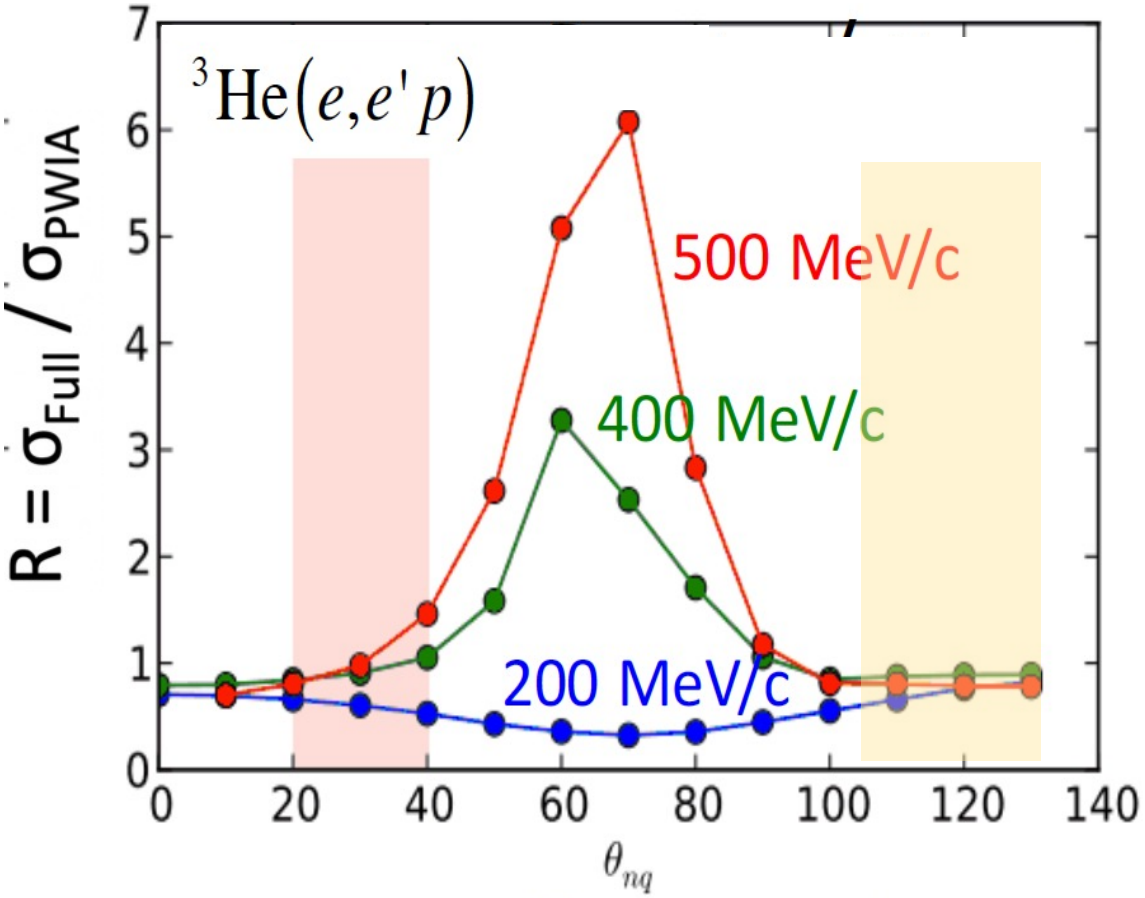
Complications:







Choosing Kinematic: Minimizing non-QE mechanisms



$$x_B = \frac{Q^2}{2m_p\omega} > 1 \qquad Q^2 > 2\ \mathrm{GeV}^2$$

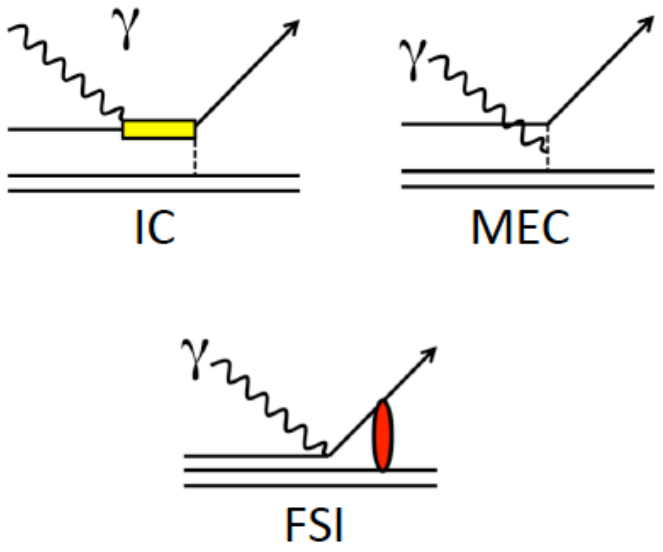
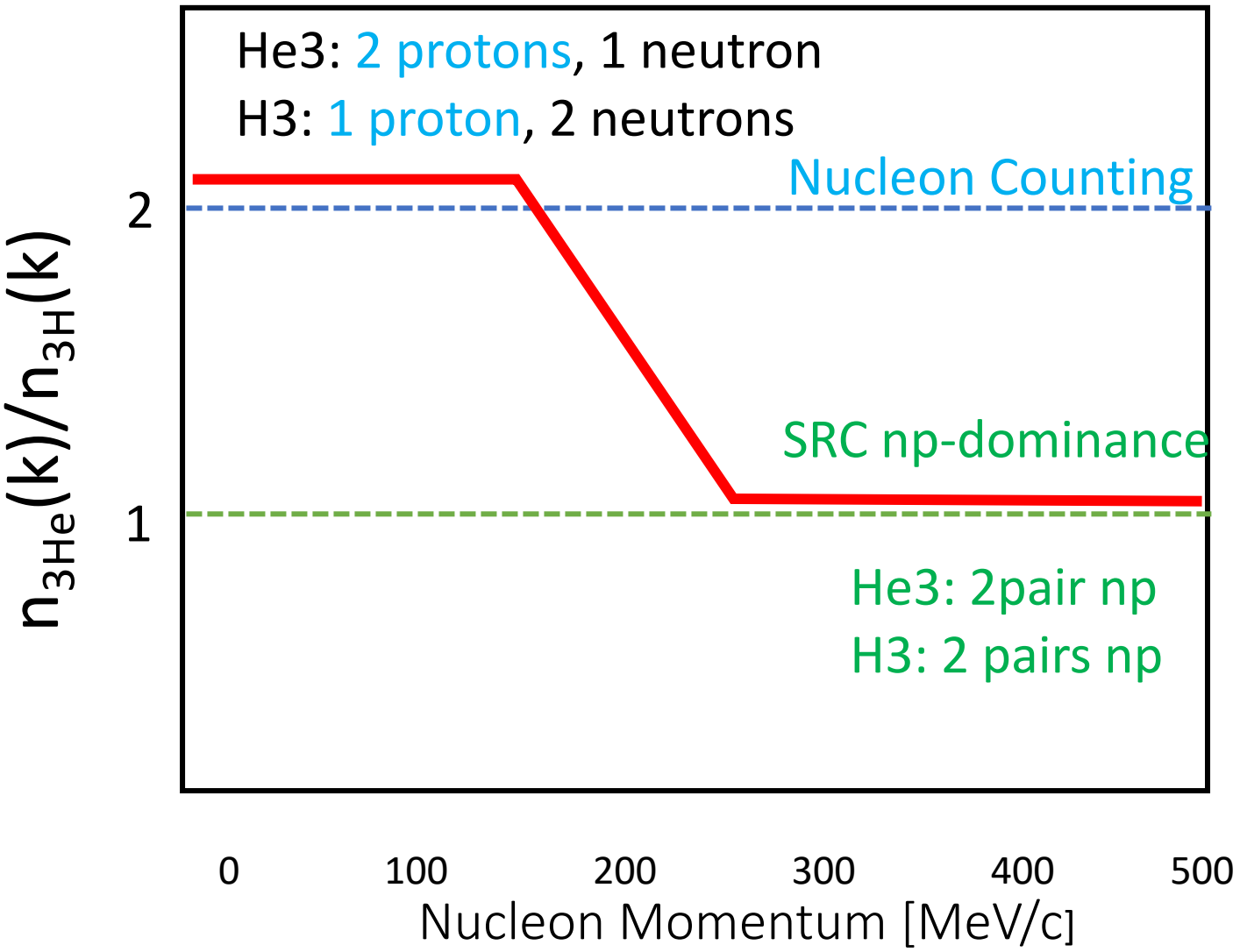


Figure courtesy of Misak Sargsian

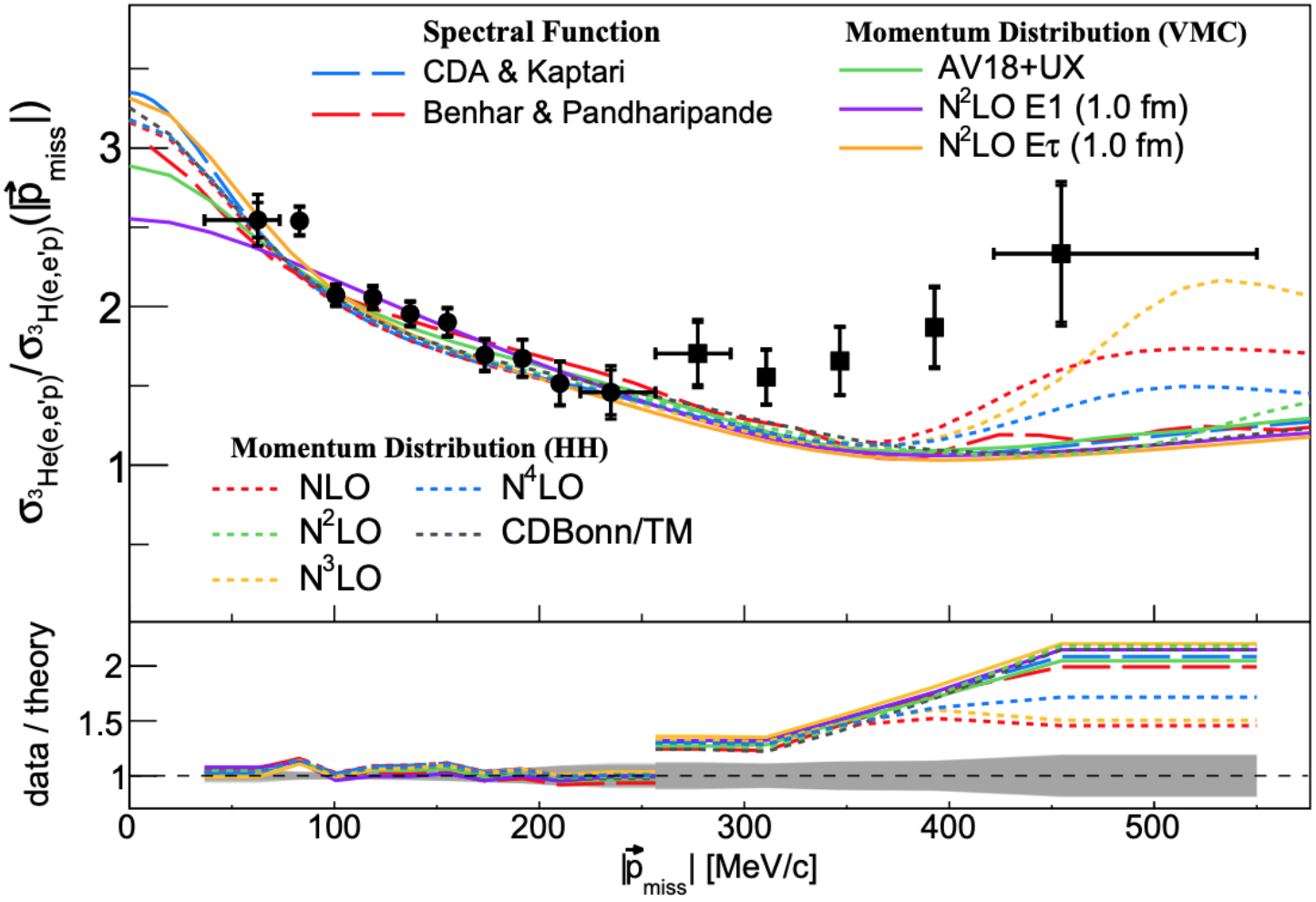
See Carlos Yero and Misak Sargsian's talks

2018 Hall A Tritium (e,e'p) Expt.



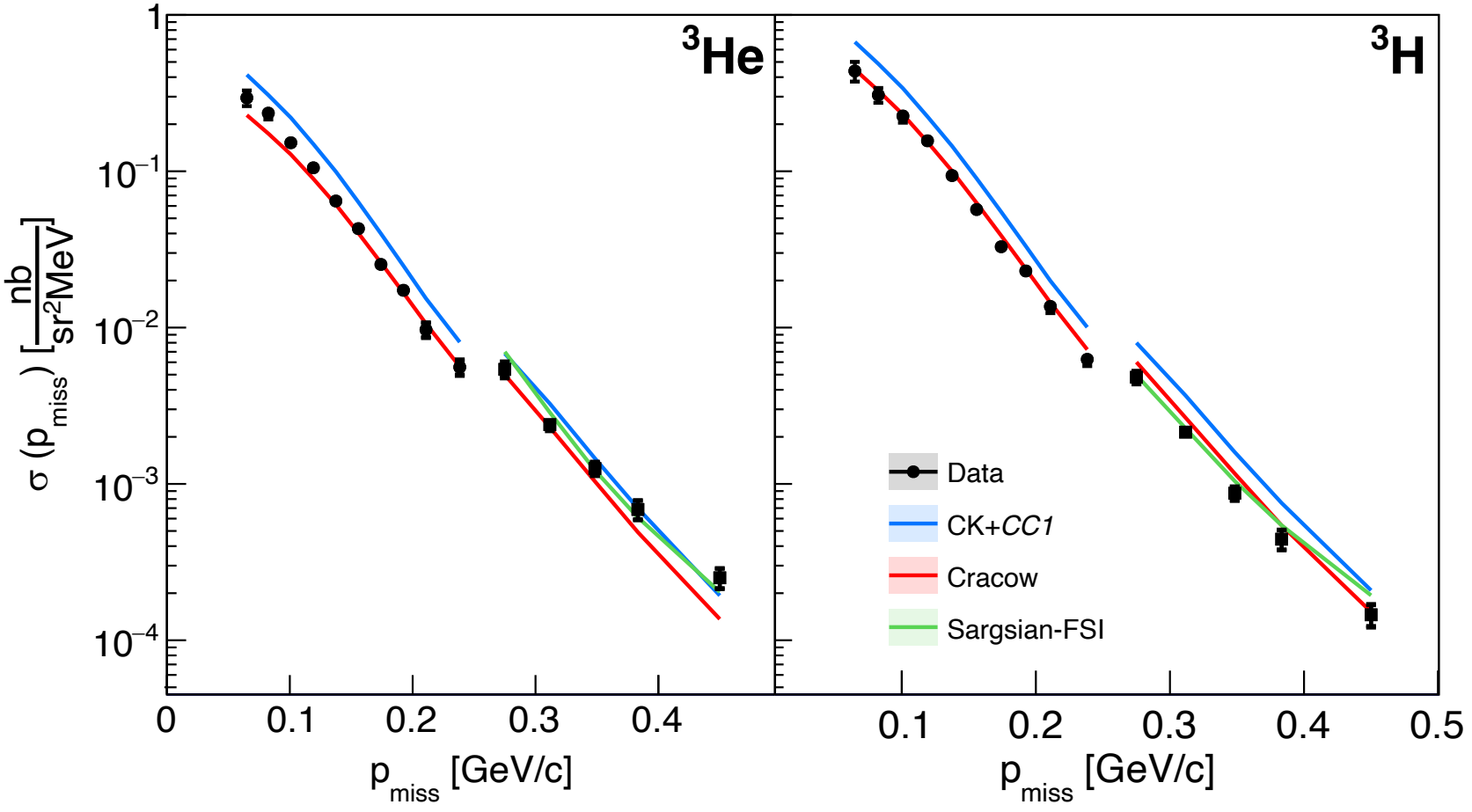
See the talk from Nadia, Shujie, Florian, Justin for SRC part

3He/3H ratio was more interesting than expected.



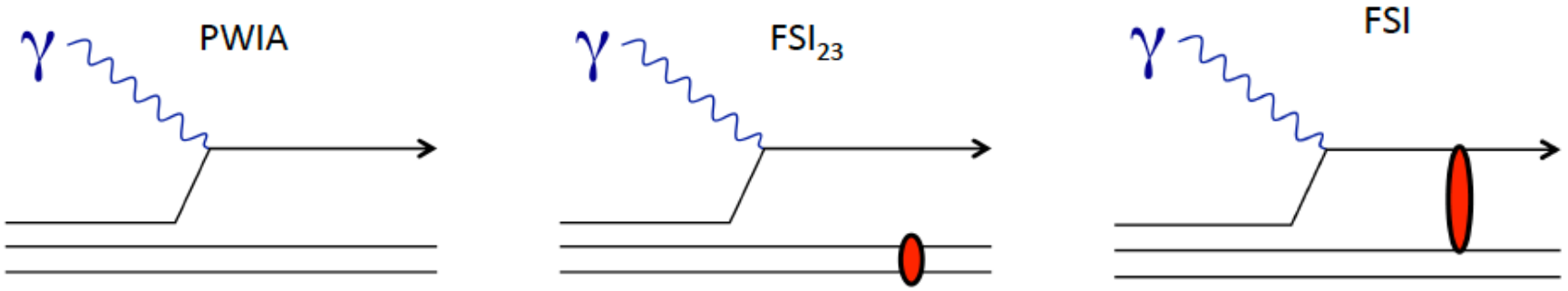
R. Cruz-Torres et al., PLB 797 134890 (2019)

We extracted absolute cross-sections.



R. Cruz-Torres, D. Nguyen PRL 124 212501 (2020)

Compare to different theory calculation



Cracow:

- Faddeev-formulation-based calculations
- Continuum interaction between two spectator nucleons (FSI_{23})

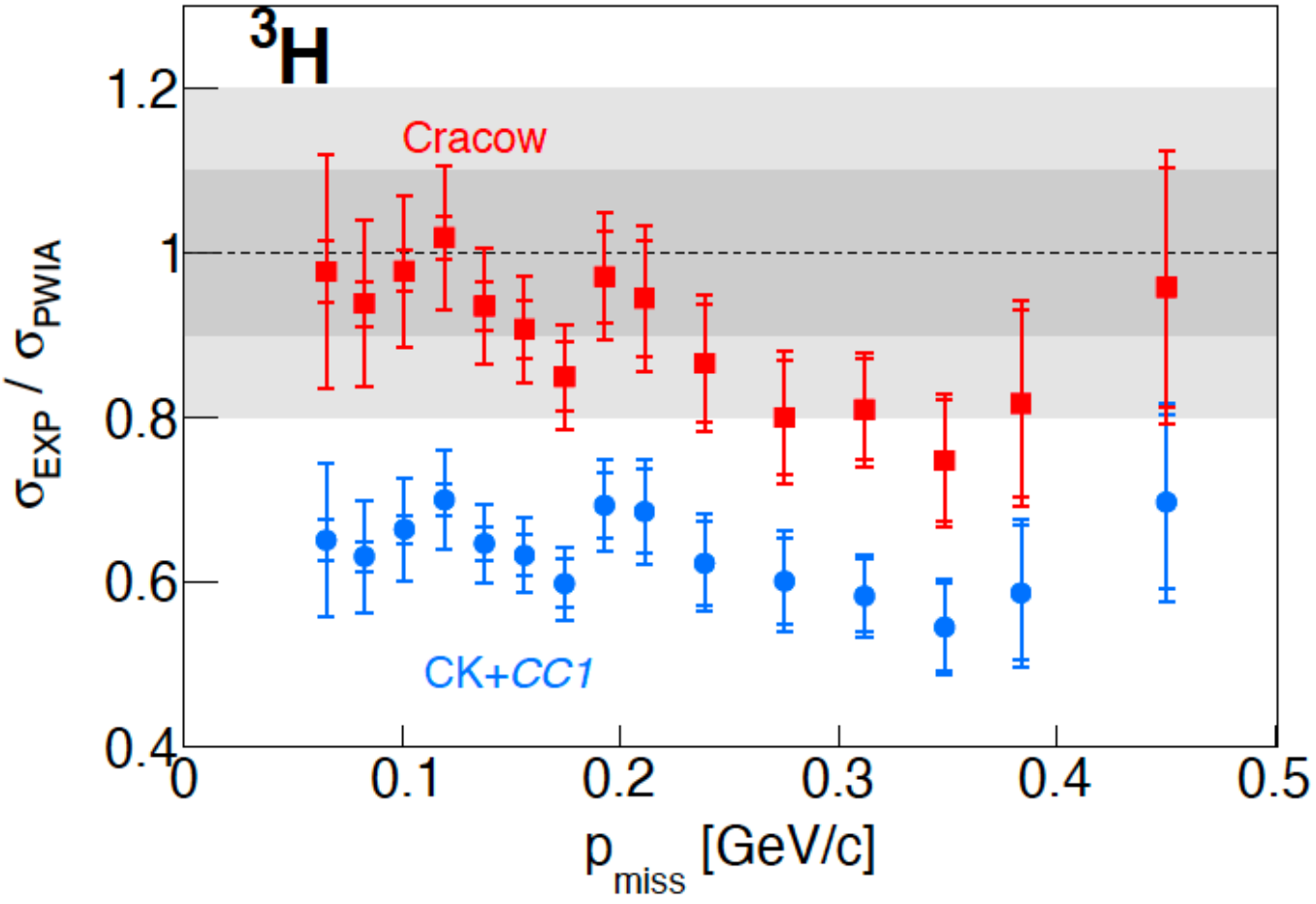
CK + *CC1*:

- ^{3}He spectral function of C. Cio degli Atti and L. P. Kaptari and electron off-shell nucleon cross-section
- Including FSI_{23}

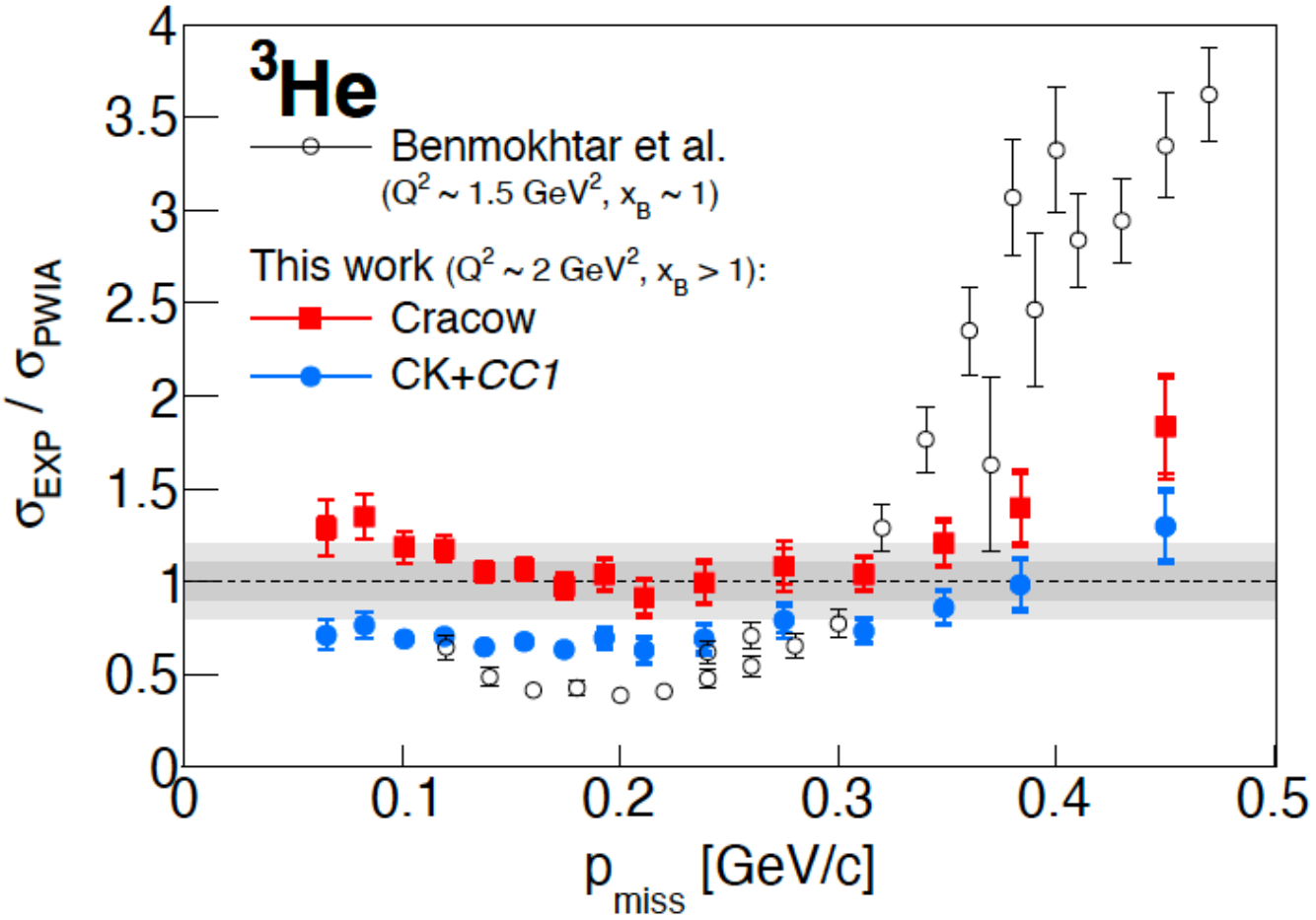
M. Sargian (FSI):

- FSI calculation based on generalized Eikonal approximation
- Does not include FSI23, FSI od struck nucleon

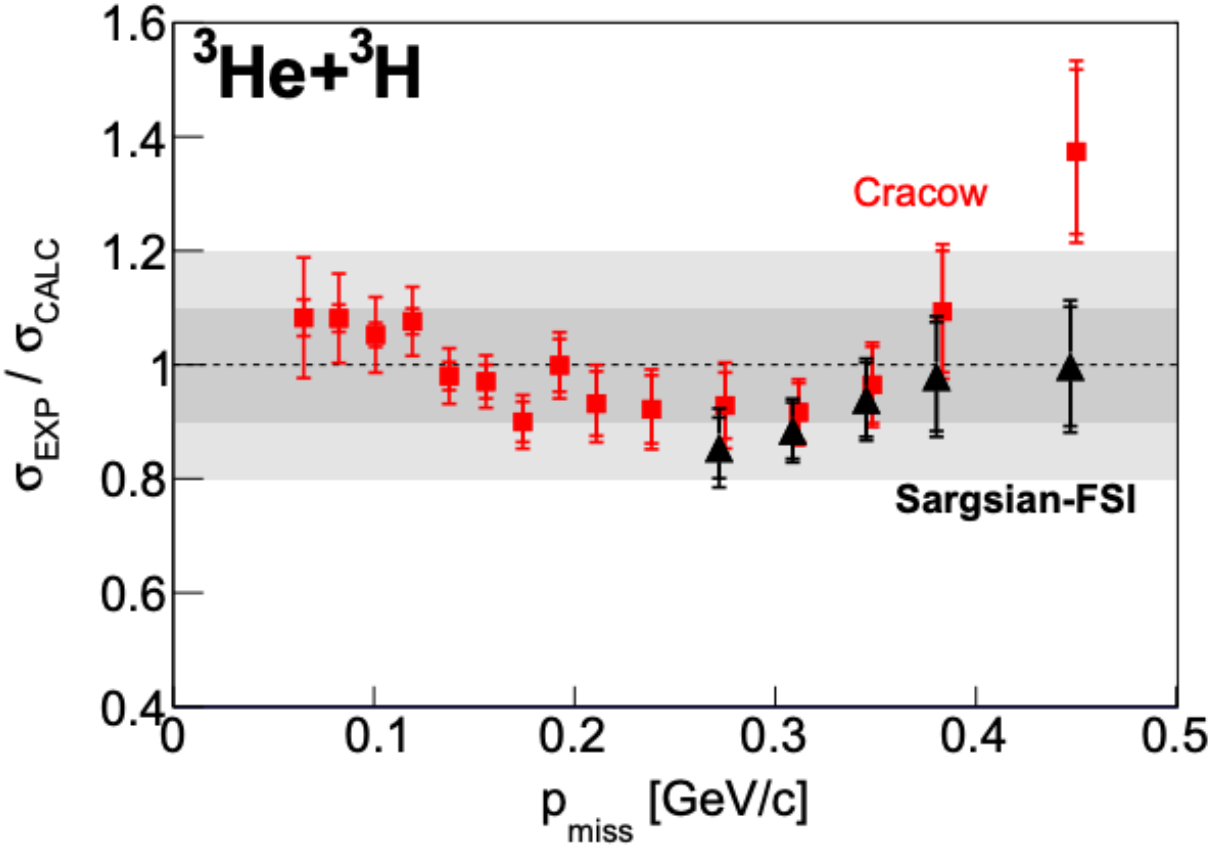
Absolute Cross Section Results



Absolute Cross Section Results



Absolute Cross Section Results



This result validates current models of the ground state of the three-nucleon system up to very high initial nucleon momenta of 500 MeV/c

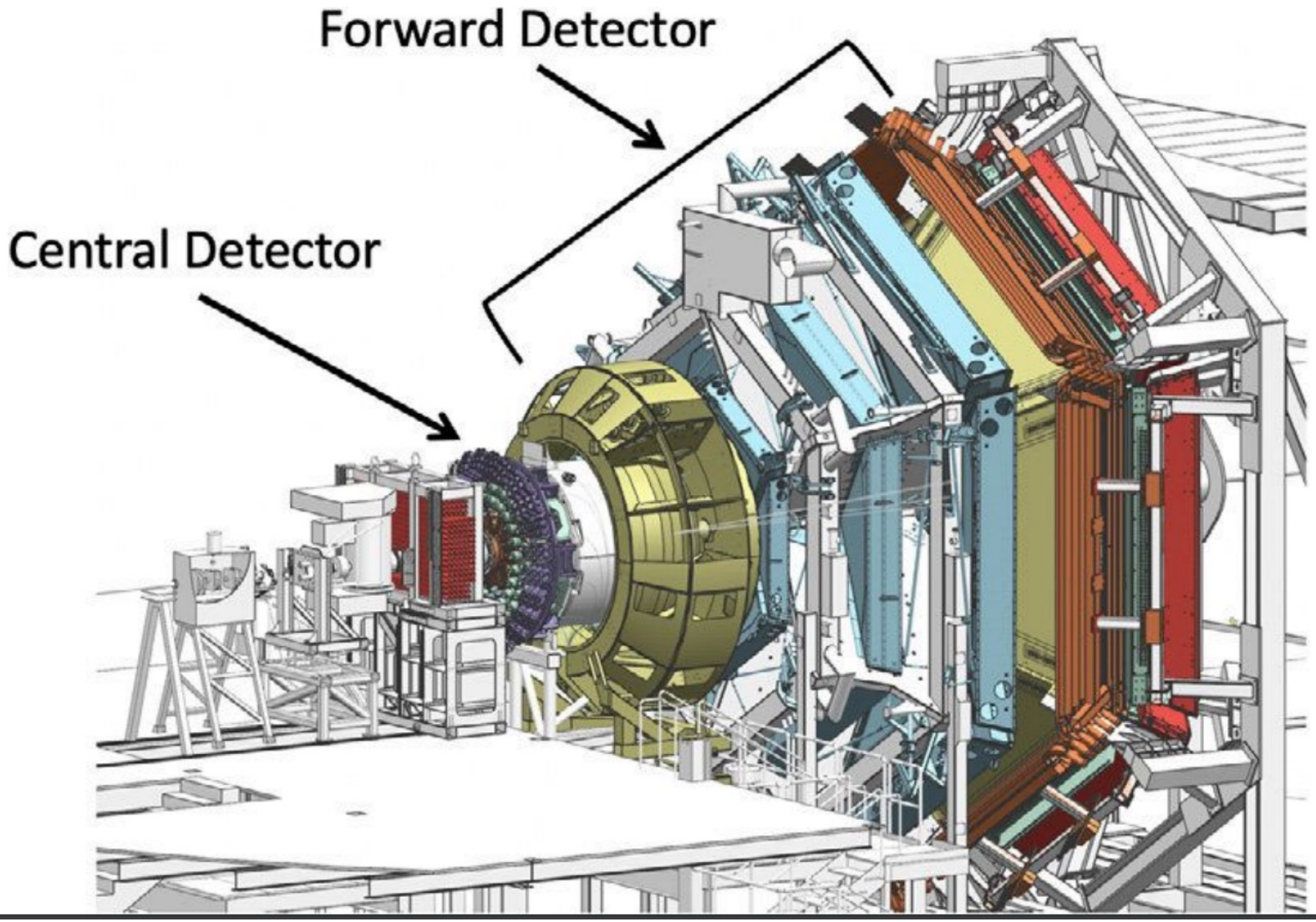
Lessons from Hall A Measurement

- Anti-parallel kinematics reduce the effects of FSIs.
- Need absolute cross-sections!
- Need both 3He and 3H (and deuterium too!)
  - Isoscalar sum

Bring Tritium target to Hall B to explore

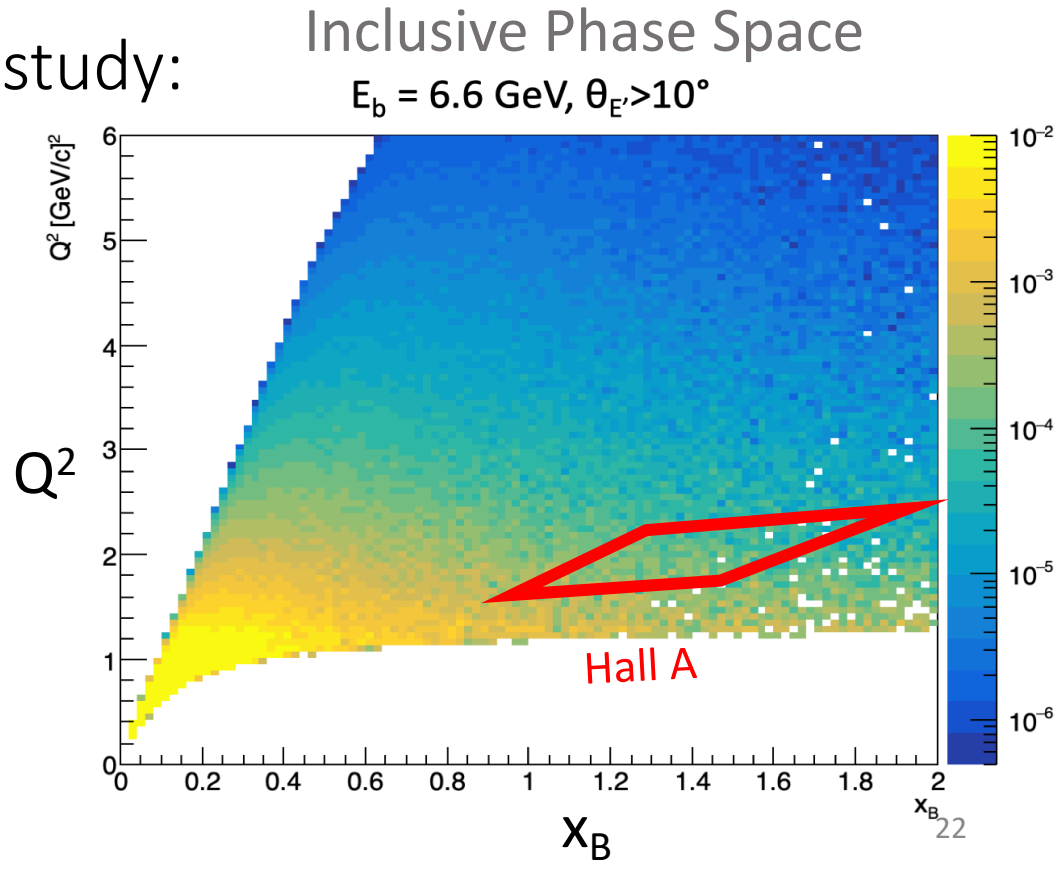
- Push Pmiss to 1000 MeV
- Cover a broad range of kinematics

CLAS12 Detector: Large acceptance Spectrometer



CLAS-12 lets us vastly exceed reach of Hall A measurement.

- Acceptance takes advantage of limited target luminosity.
- Kinematic coverage to study:
  - Q^2-dependence
  - x_B-dependence
  - θ_{pq}-dependence
  - Higher p_{miss}
  - Wider E_{miss}



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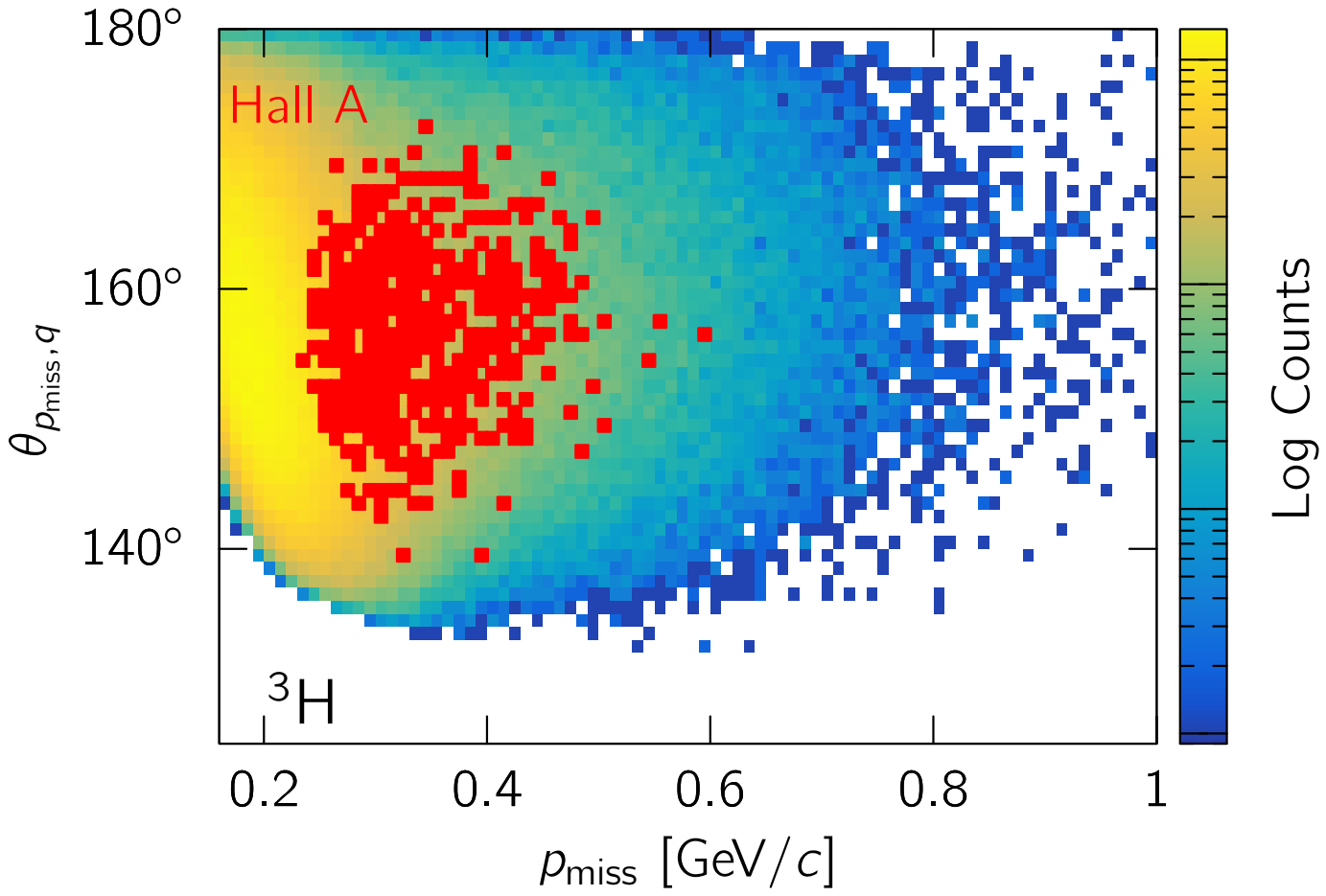

Cuts: Fiducial Acceptance, $x_B > 1.4$, $P_{miss} > 0.15$

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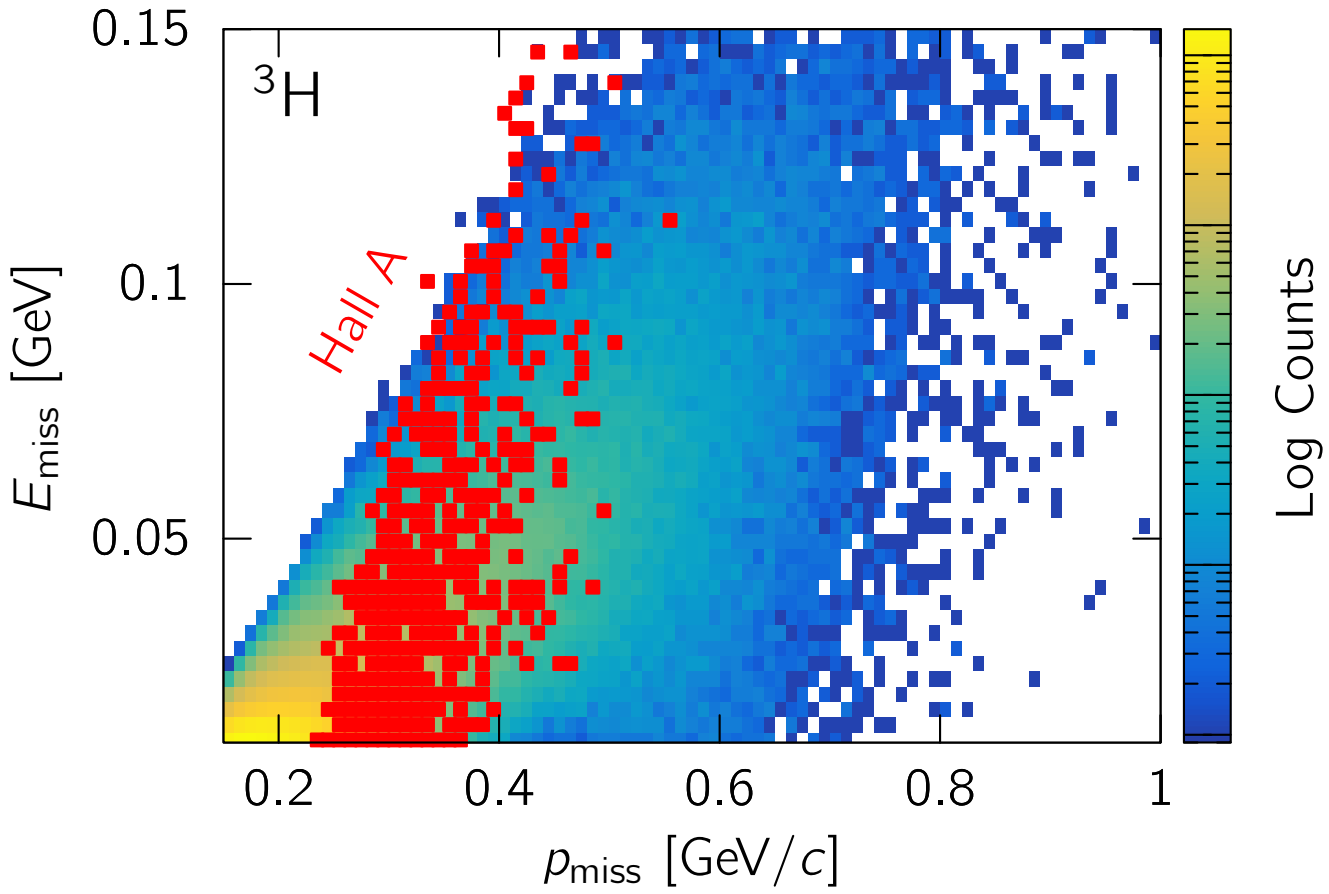

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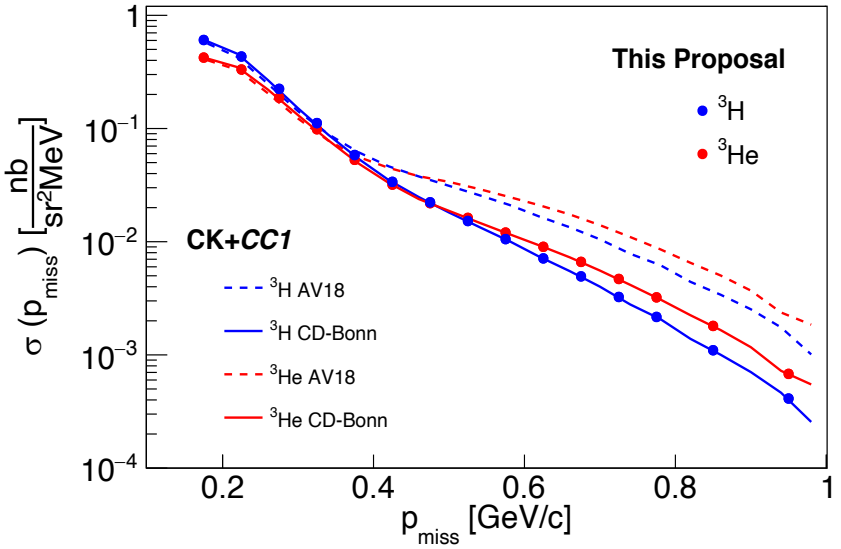
A=3: Helium-3 + Tritium @ CLAS12

- Quasielastic on A = 3
  - (e,e'p): Few-Body nuclear Structure
  - (e,e'pN): SRCs
  - (e,e'): Neutron form factor

(e,e'p): Few-body nuclear structure

- Unique test of:
  - few-body nuclear structures.
  - Short-range NN interaction
  - Reaction mechanisms
  - Final-state effects!



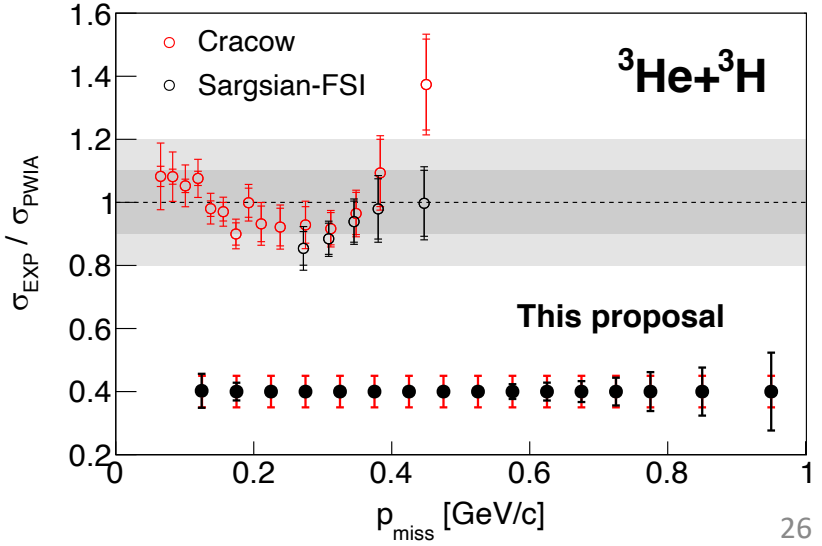
- CLAS12:

  x0.1 luminosity

  x100 acceptance

  => x10 statistics + larger kinematical coverage!

R. Cruz, D. Nguyen et al. PRL (2020)



(e,e'p): Few-body nuclear structure

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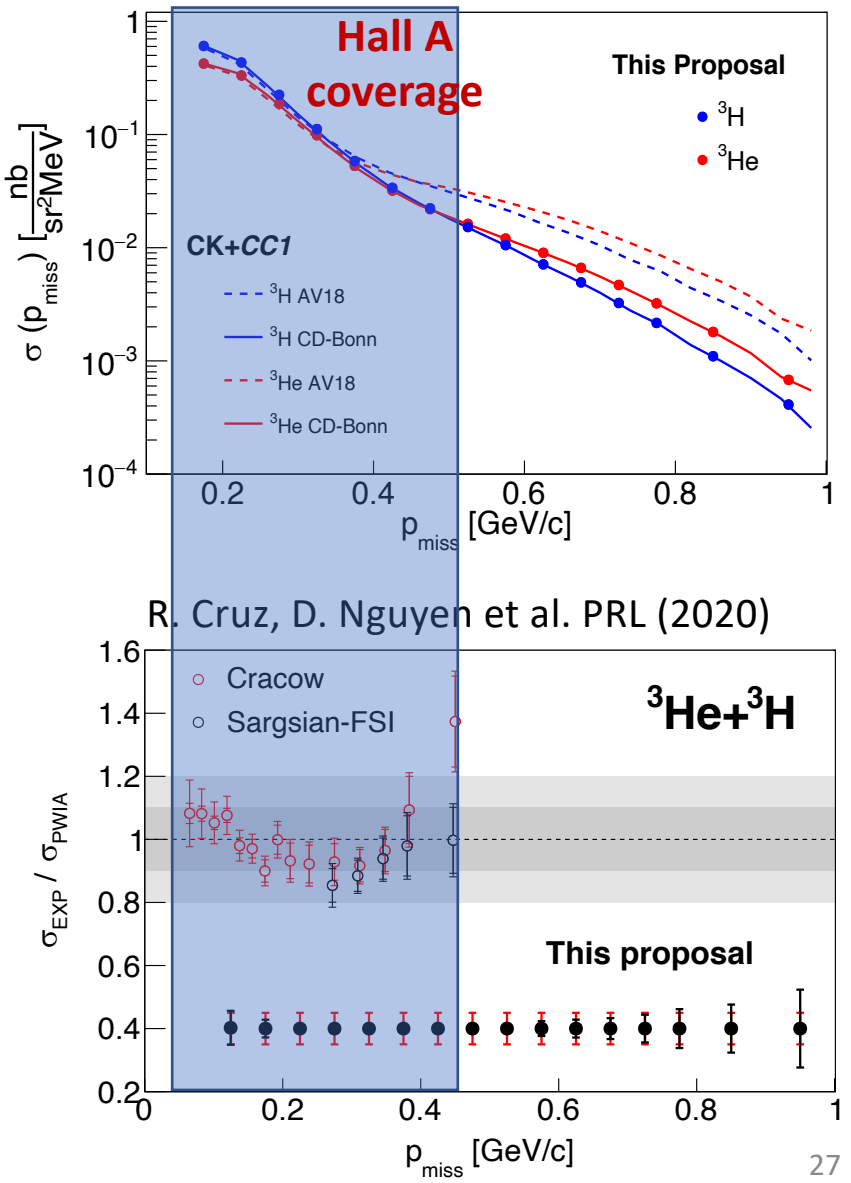
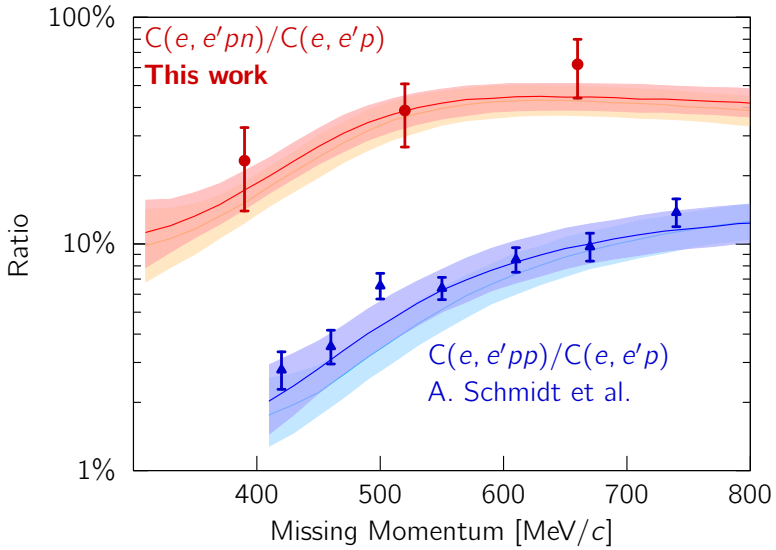
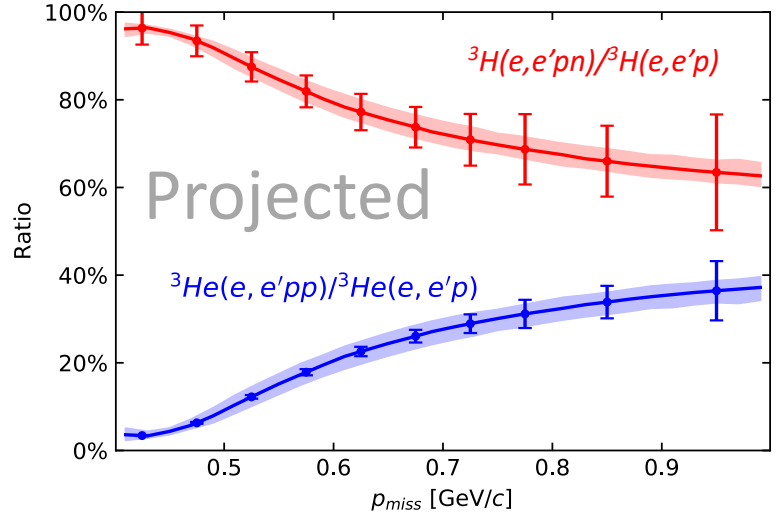


(e,e'pN): SRCs

- CLAS acceptance will allow multi-nucleon detection!
- Further suppression of final-state effects!
- Detailed map of isospin structure of short-range NN interaction

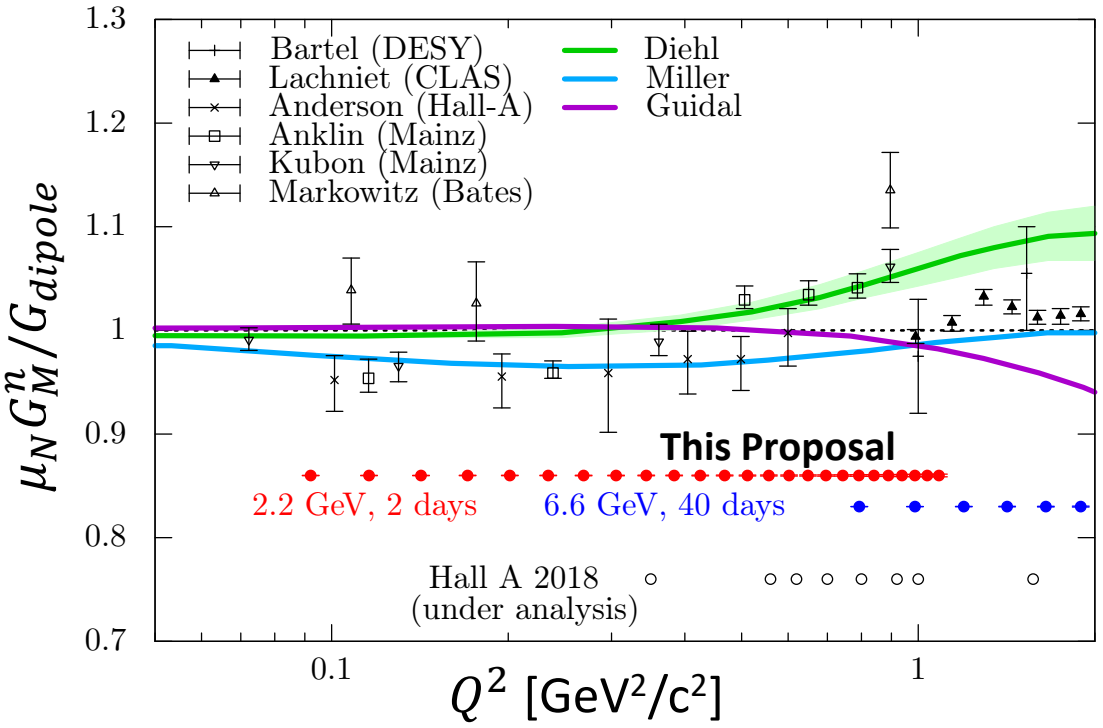
A. Schmidt et al., Nature (2020)
I. Korover et al., Submitted (2020)





(e,e'): Neutron Form Factor

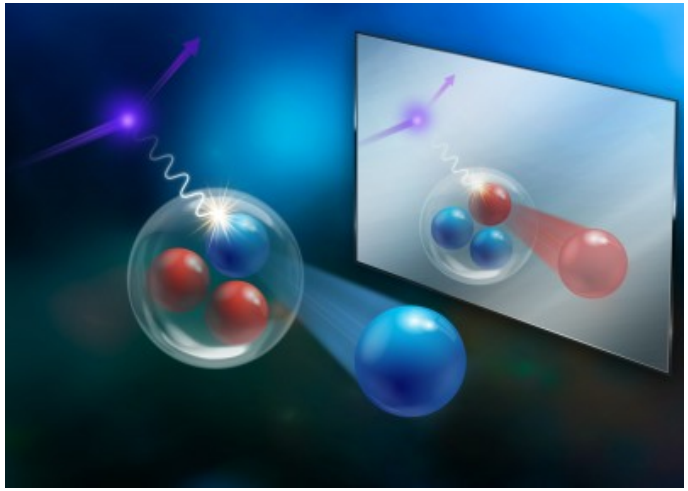
- ^{3}He(e,e') / ^{3}H(e,e') @ $x_B = 1$ sensitive to σ_n / σ_p
  - Measured @ Hall A \w limited Q^2 coverage
- CLAS12 reaches down to $Q^2 = 0.1$
- Probe region of data/theory discrepancies
- Systematic errors orthogonal to those from other techniques
- Only need 2 days at 2.2 GeV!



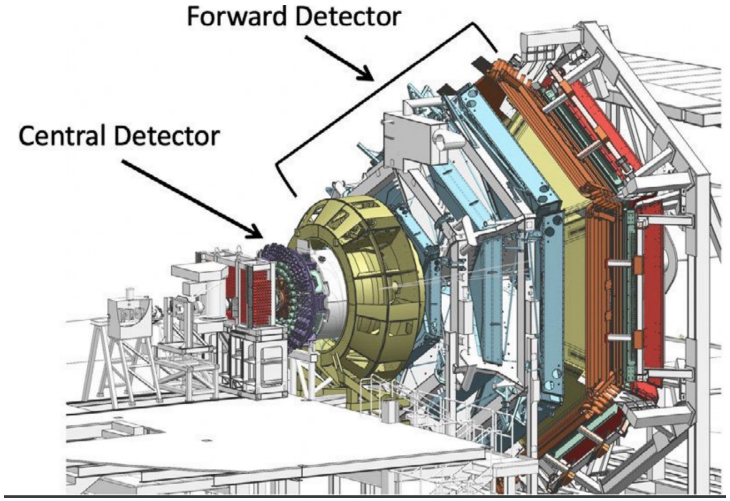
Adapted from J. Lachniet et al. PRL (2009)

Summary

- A=3 is a vital system!
  - Test nuclear calculations in few-body regime
    - Calculable nuclei
    - Extreme p/n asymmetry
    - Constrain reaction effects
  - Probe short-range NN interaction
  - Pin down G_M^n
  - Need both ^{3}He and ^{3}H!



- Proposed experiment
  - CLAS-12 in standard configuration
  - Open e– trigger
  - 60 days on ^{3}He, ^{3}H, d at 6.6 and 2.2 GeV.
  - New target system!



Proposal PR12-20-005 is Fully approved

This measurement will produce many high-impact results!