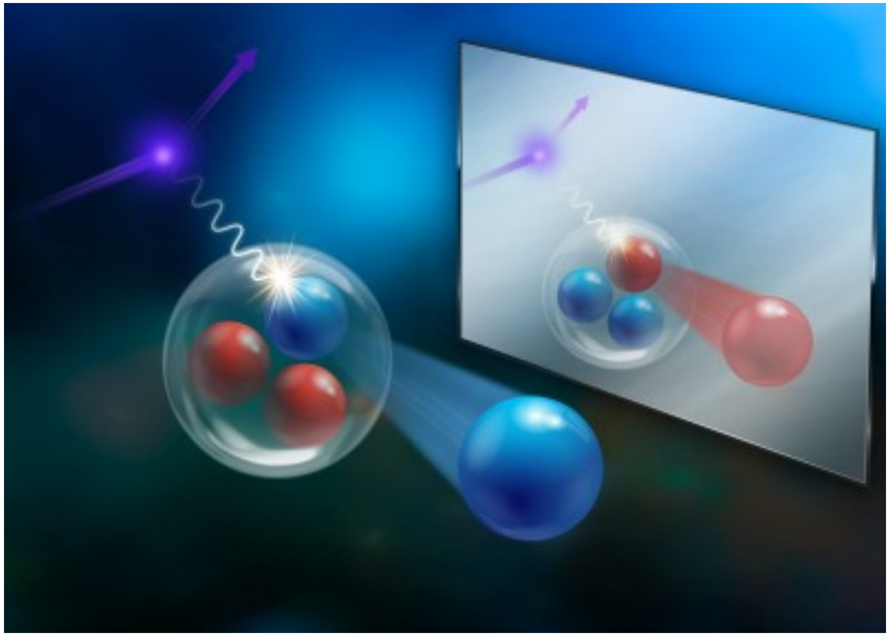
Precision measurements of A = 3 nuclei in Hall B

Proposal PR12-20-005



Spokespersons:

O. Hen, D. Nguyen (MIT),

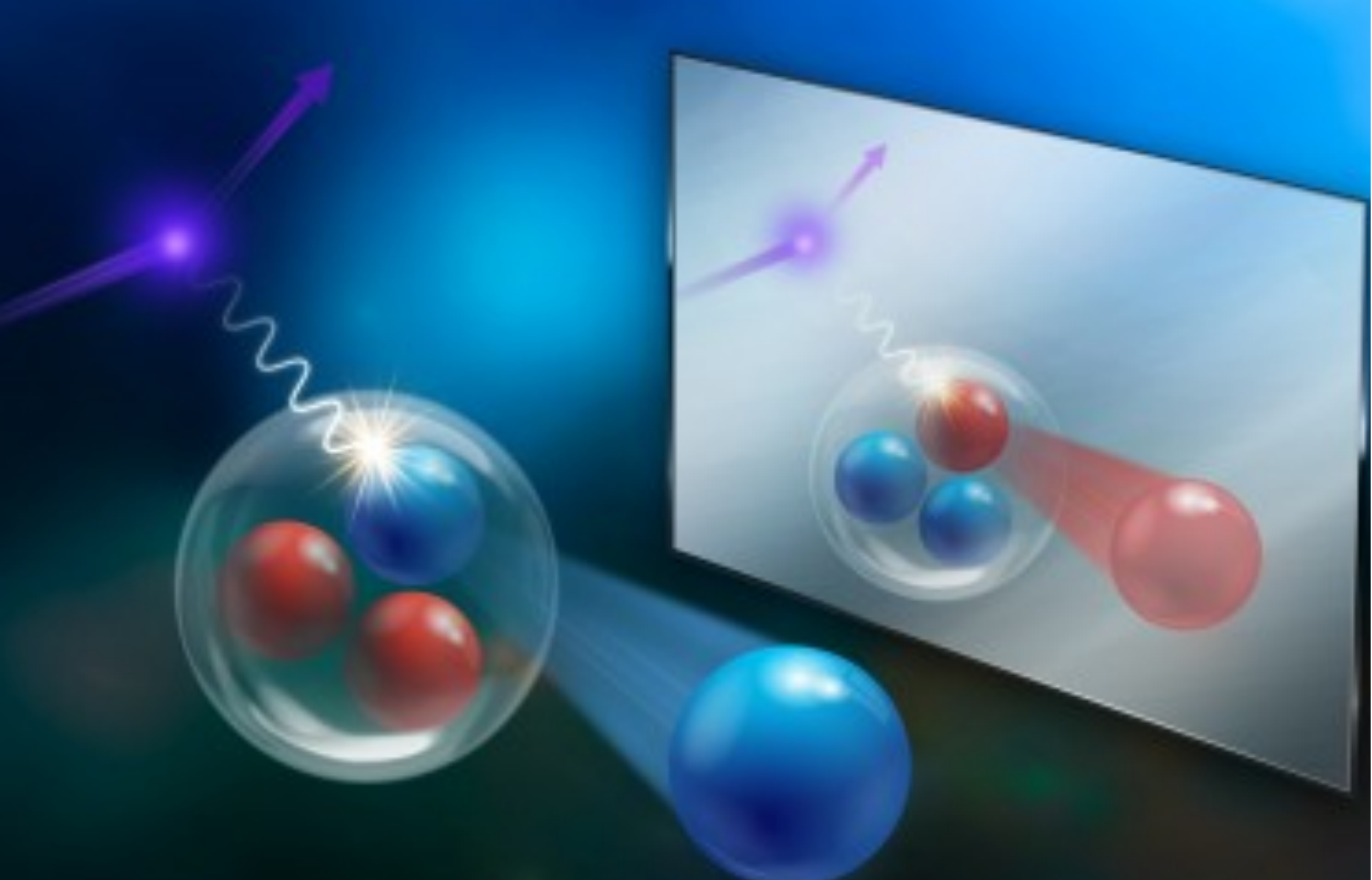
A. Schmidt (GWU),

L. B. Weinstein (ODU),

E. Piasetzky (TAU),

H. Szumila-Vance, D. Meekins (JLab)

To be presented to Jefferson Lab PAC-48, August 10–14, 2020



Looking through the isospin mirror…

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

Precision measurements of A = 3 nuclei in Hall B

- Advantages of the A=3 System
  - Isospin Mirror System
  - Light and calculable
  - Highly asymmetric
- We propose:
  - 60-day measurement, using 3He, 3H (and d) targets
  - Measure QE (e,e'p) and (e,e'pN) cross sections
- Vastly exceed aims and scope of Hall A program
  - Use high-acceptance to overcome limited luminosity
  - Cover wider and better kinematics, with more impact.

In this talk:

- The Impact of the A=3 System
  - Hall A program showed just a glimpse of what we can learn.
- Putting Tritium in Hall B
  - We have a safe and feasible plan.
- The Proposed Measurement
  - In 60 days, we can tackle important questions.

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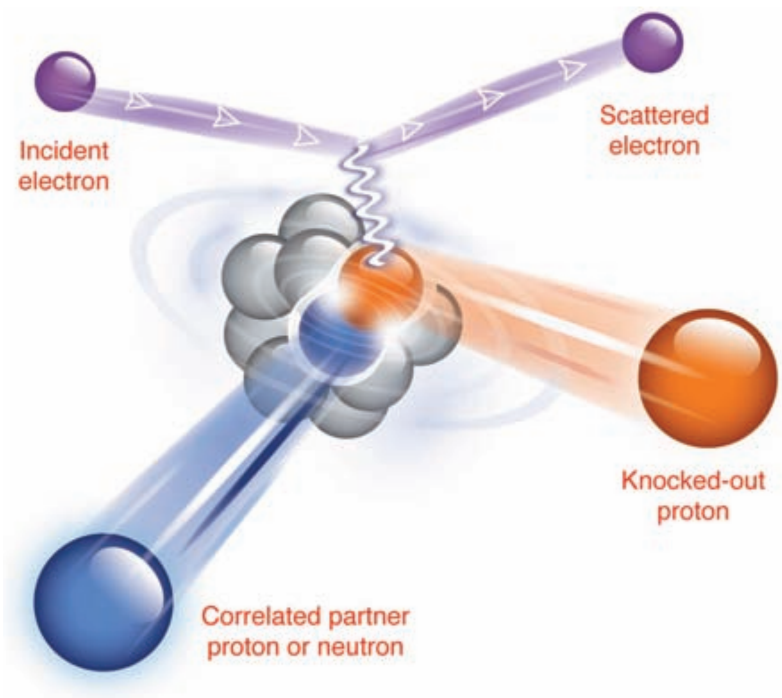
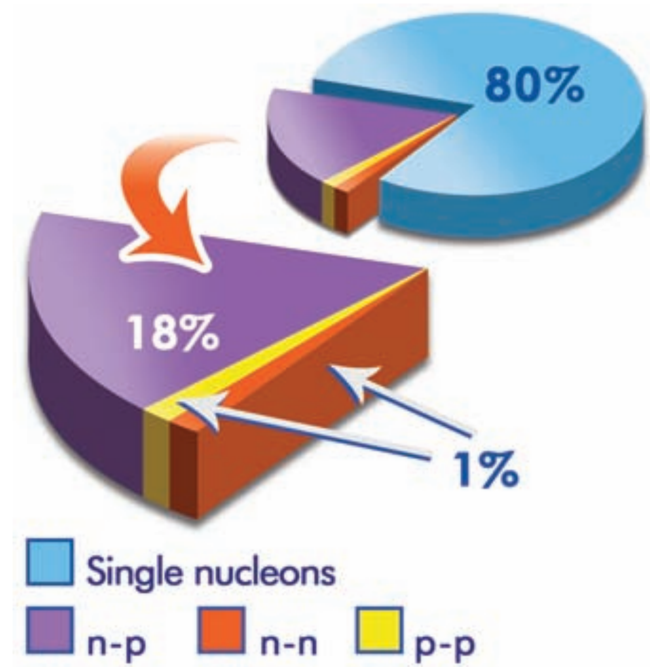
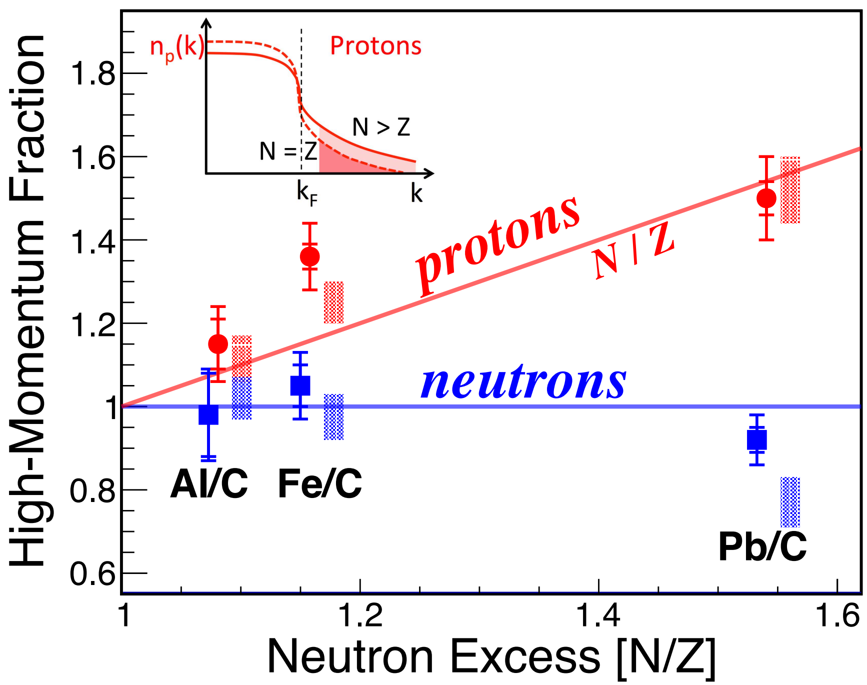
Short-range correlations tell us about the isospin-structure of the NN force.



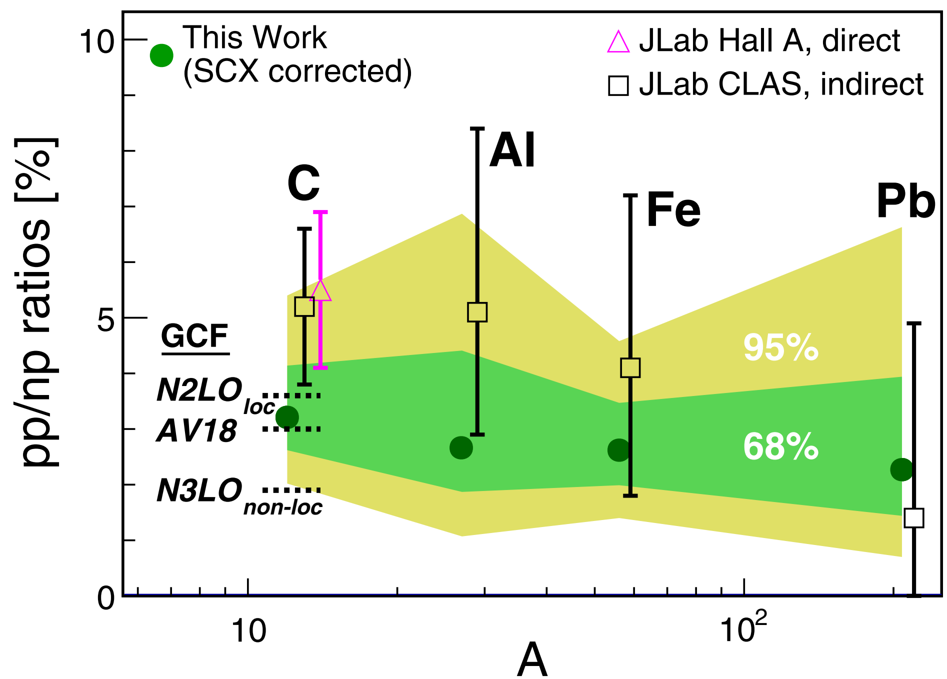


Subedi et al., Science 320, p. 1476 (2008)

Even in neutron-rich nuclei, np-pairs predominate.

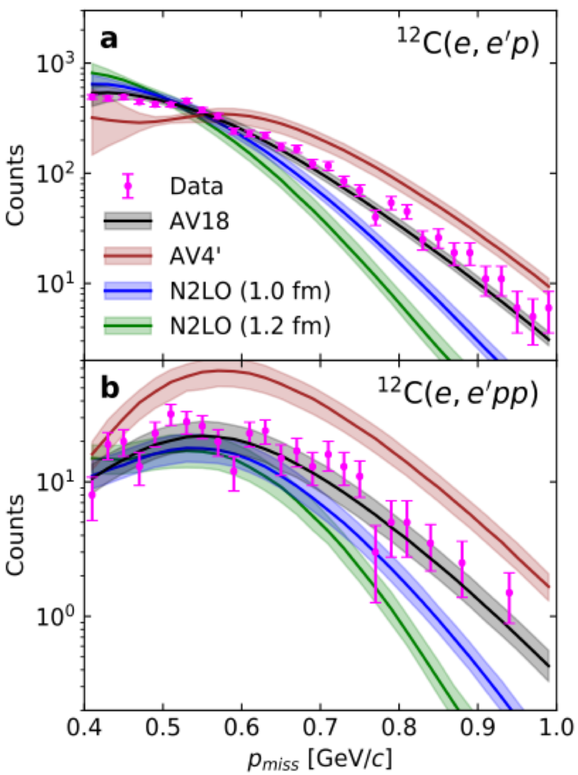


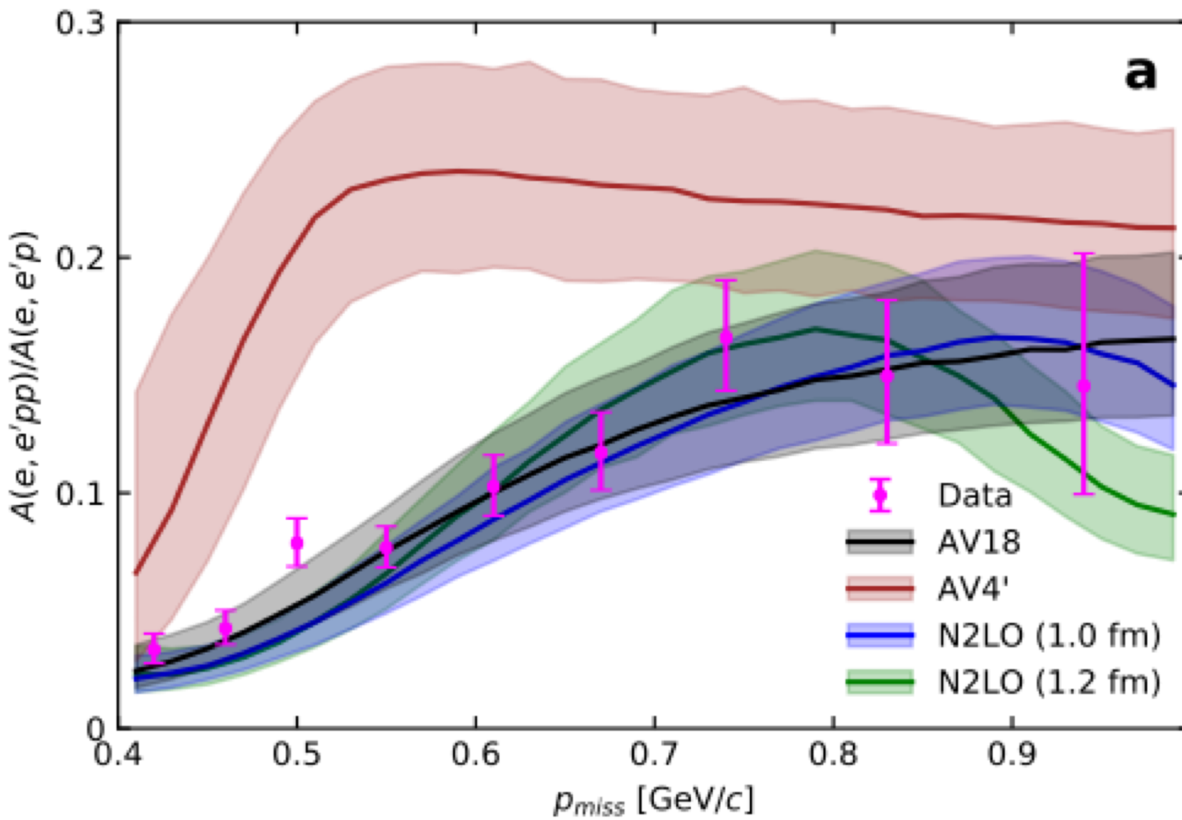
M. Duer et al., Nature 560, p. 617 (2018)



M. Duer et al., PRL122, 172502 (2019)

This gives way at very high momentum. Evidence of a scalar repulsive core!





A. Schmidt et al., Nature 578 p. 540 (2020)

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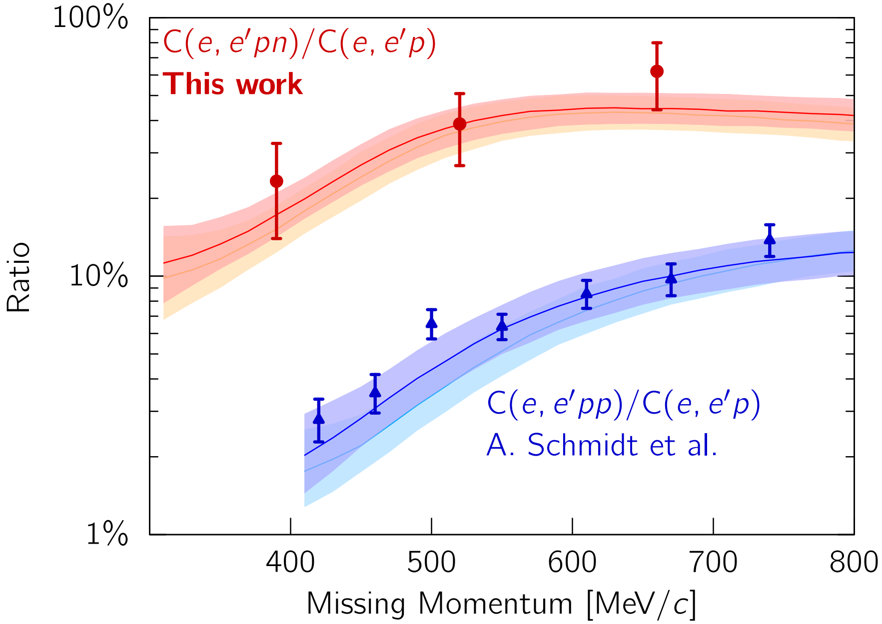
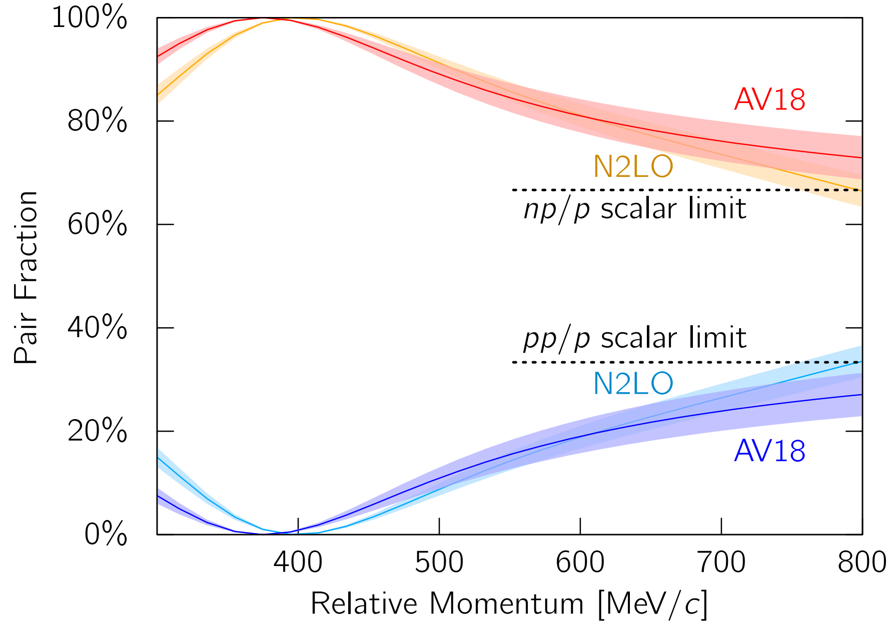
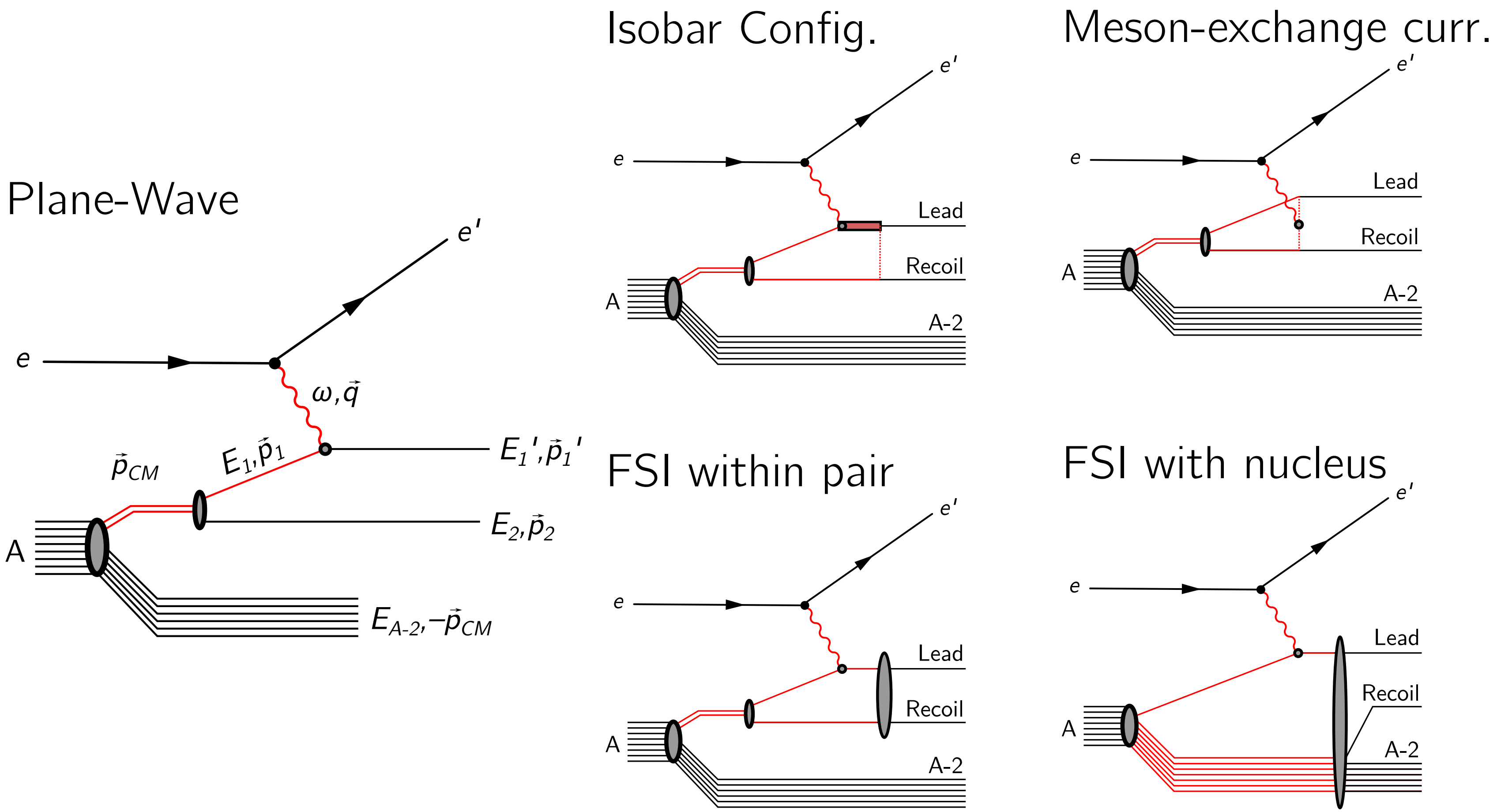




I. Korover et al., Submitted to PRL (2020)

Interpretation is complicated by competing reactions.



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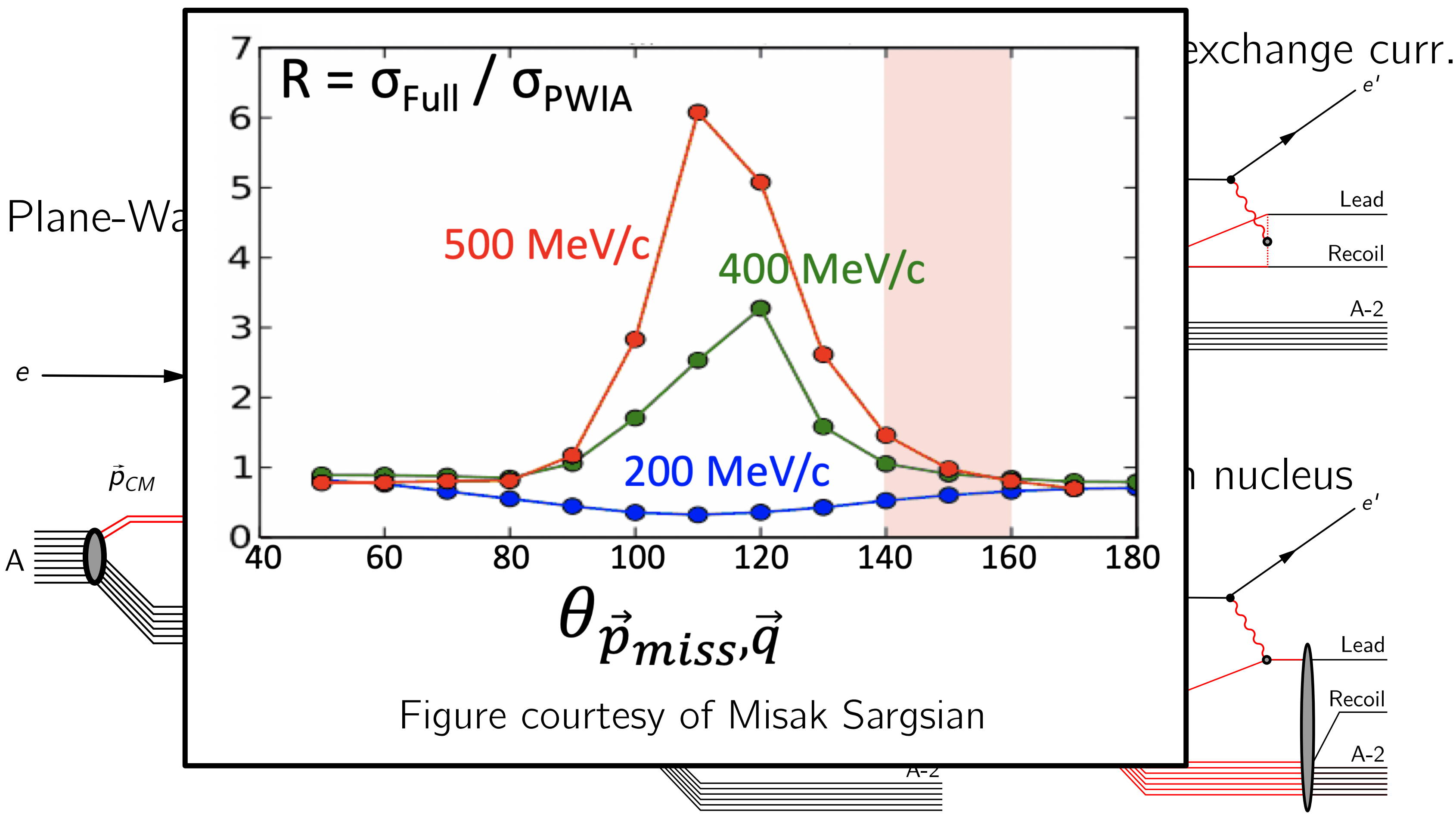
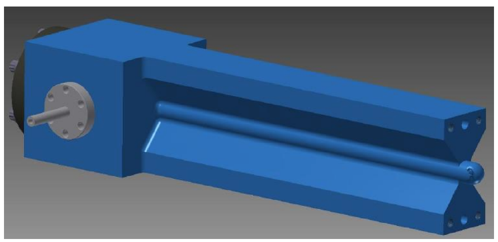
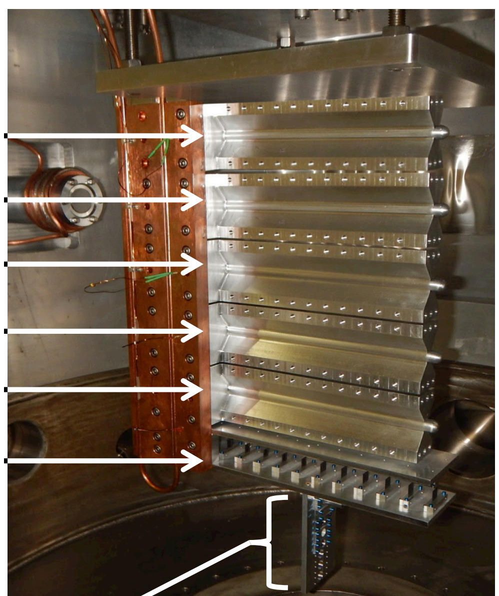


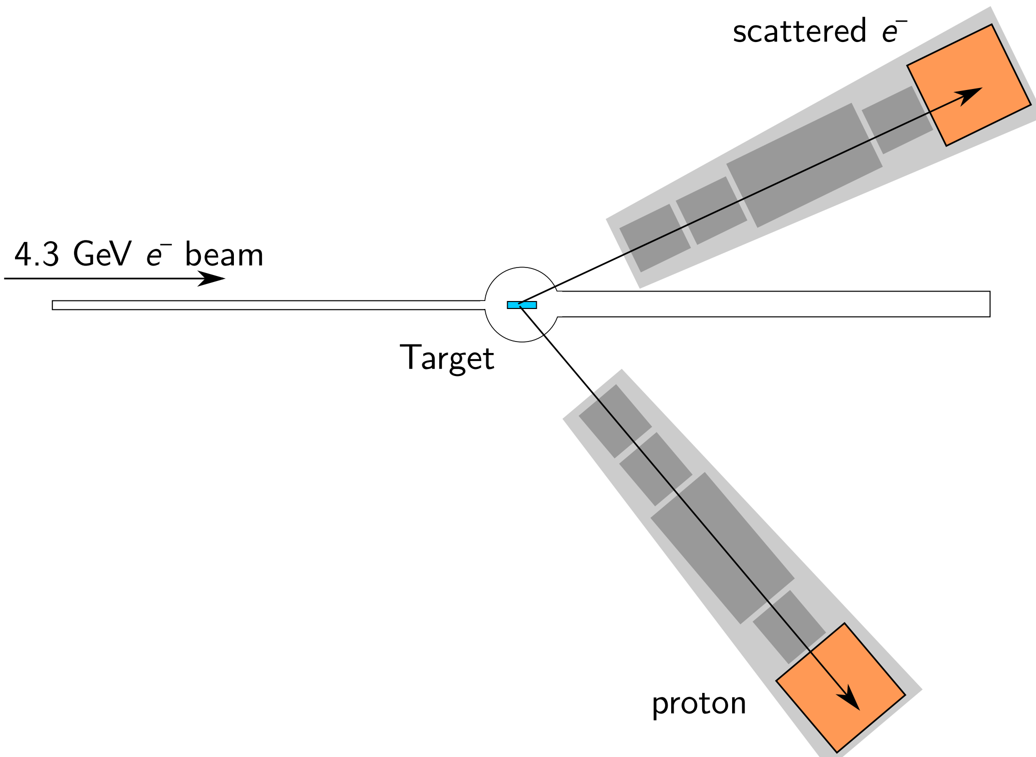
Figure courtesy of Misak Sargsian

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

- One of 5 experiments in Hall A Tritium Program.







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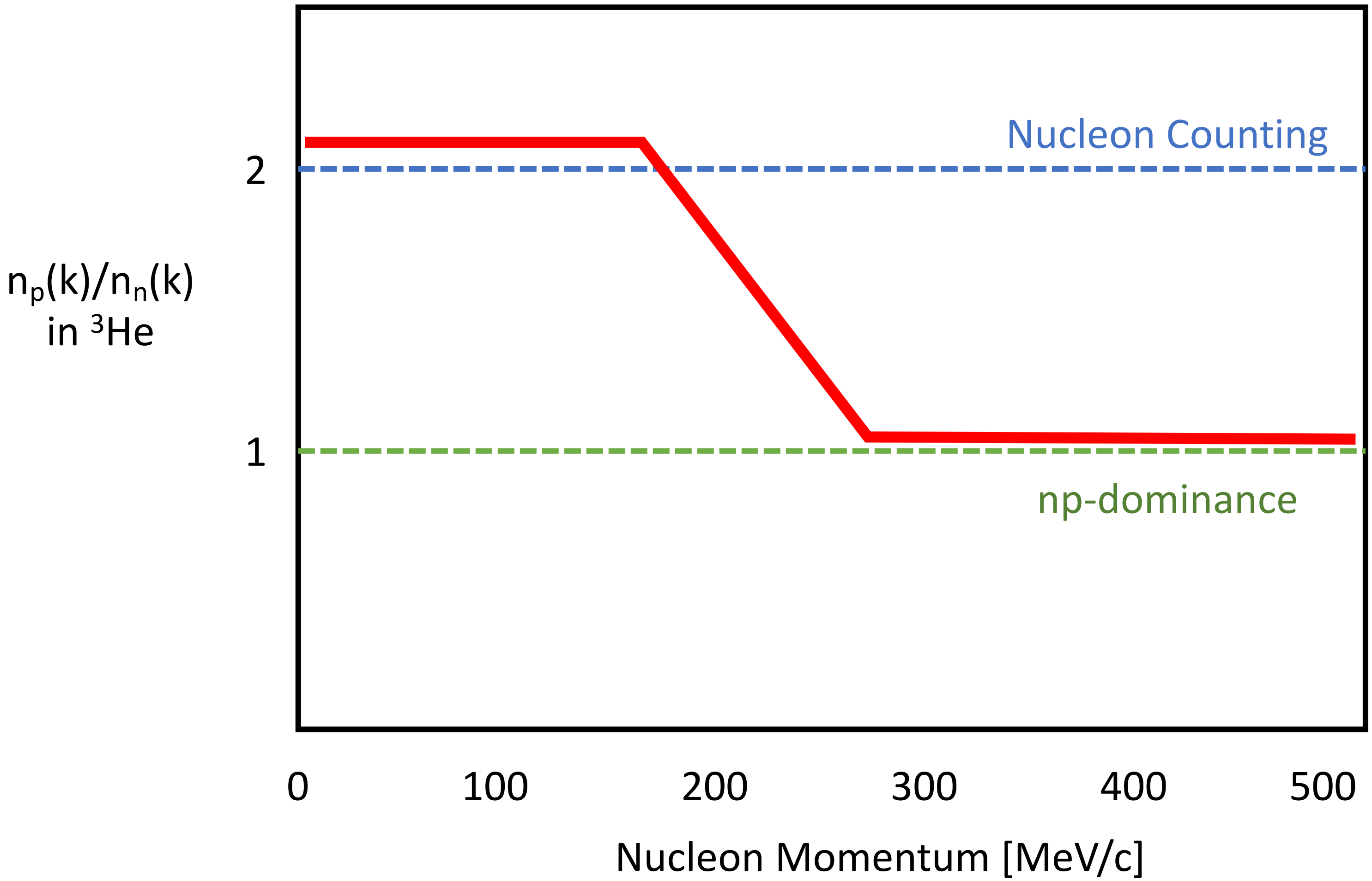
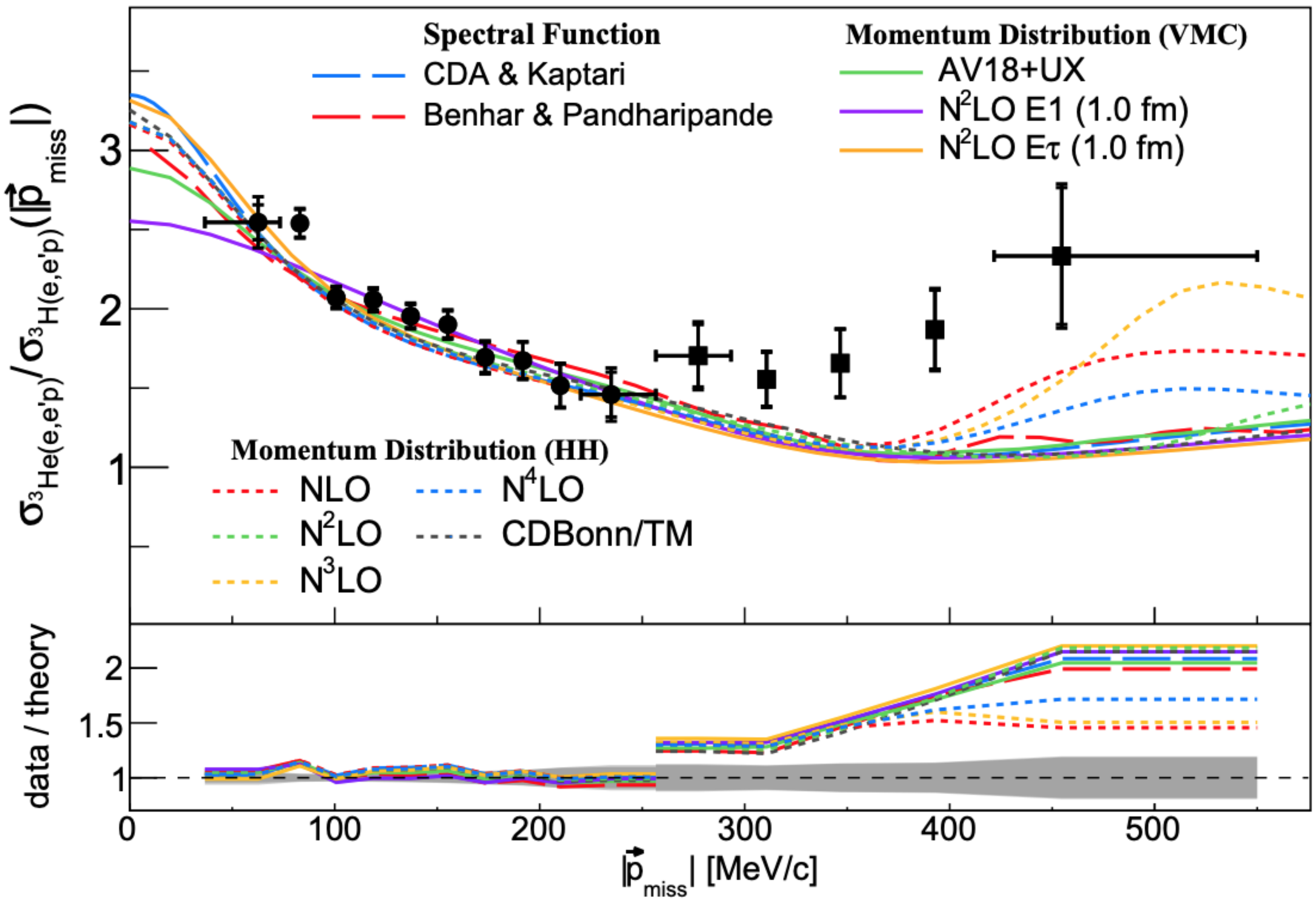
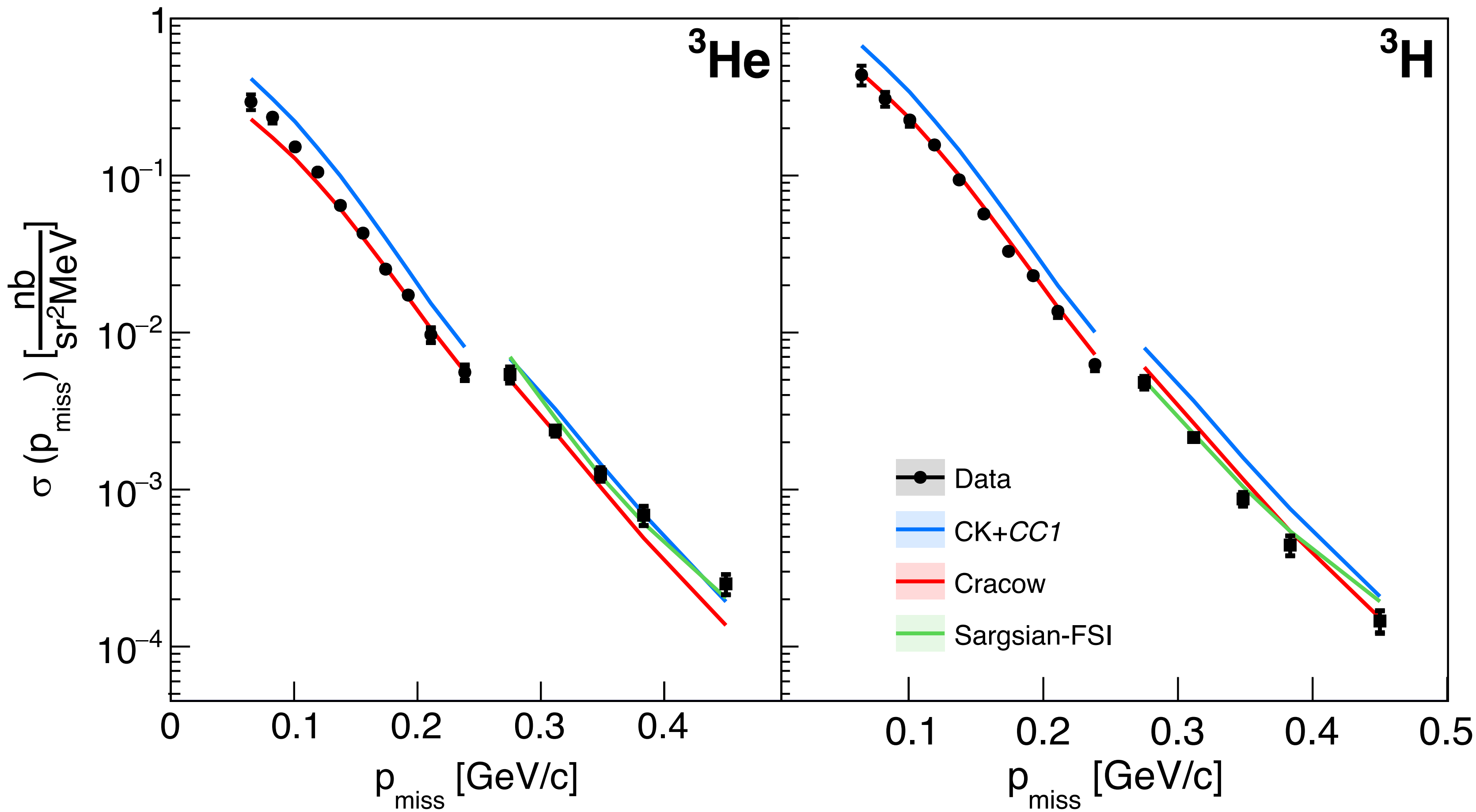


3He/3H ratio was more interesting than expected.



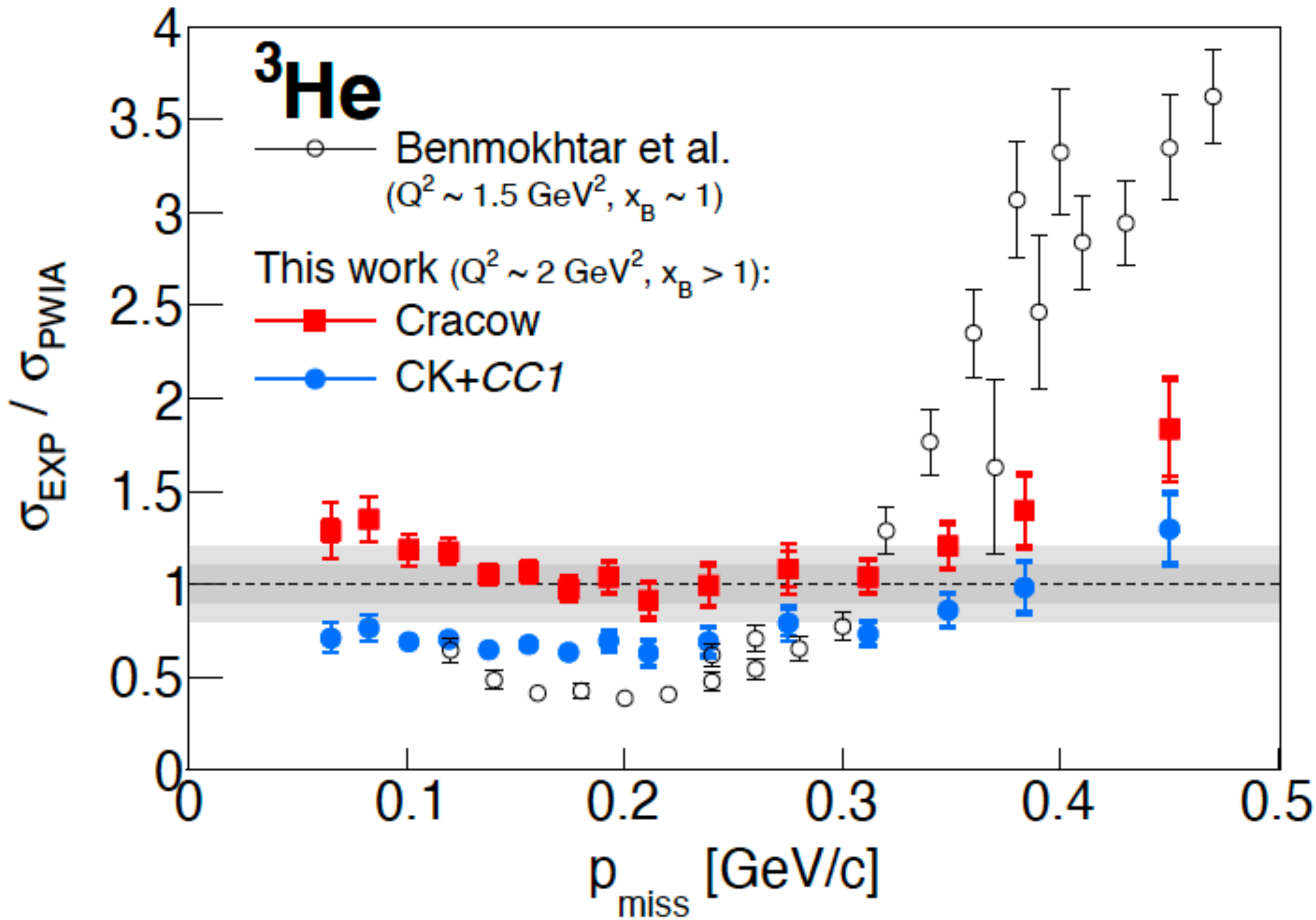
R. Cruz-Torres et al., PLB 797 134890 (2019)

We extracted absolute cross sections.



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

Absolute Cross Section Results



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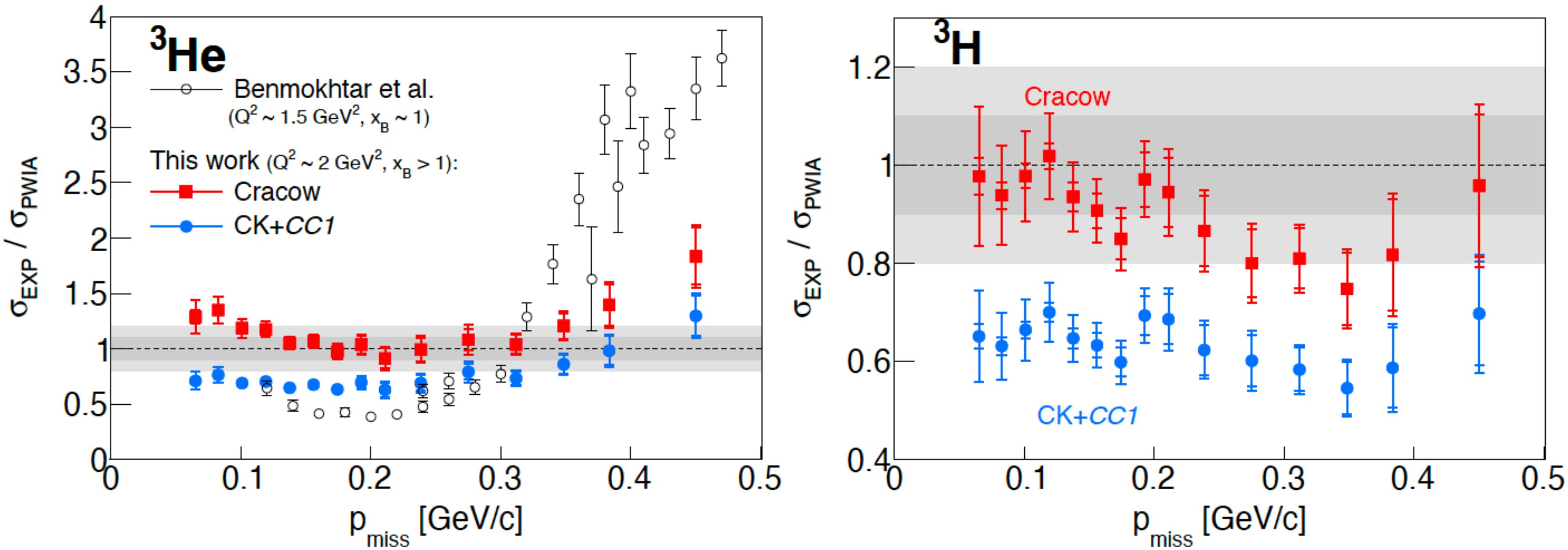
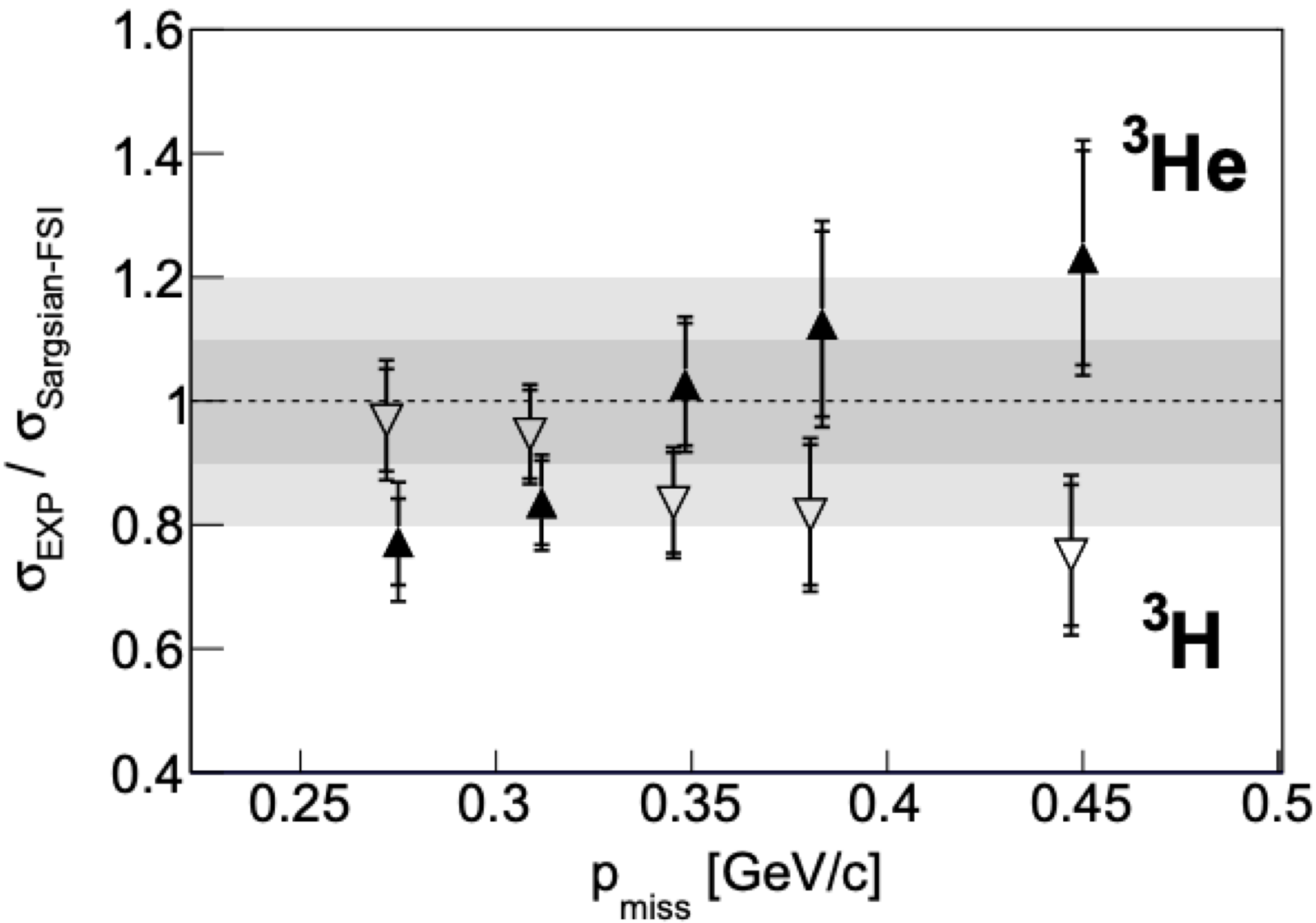


Anti-parallel kinematics are a huge improvement!

Absolute Cross Section Results



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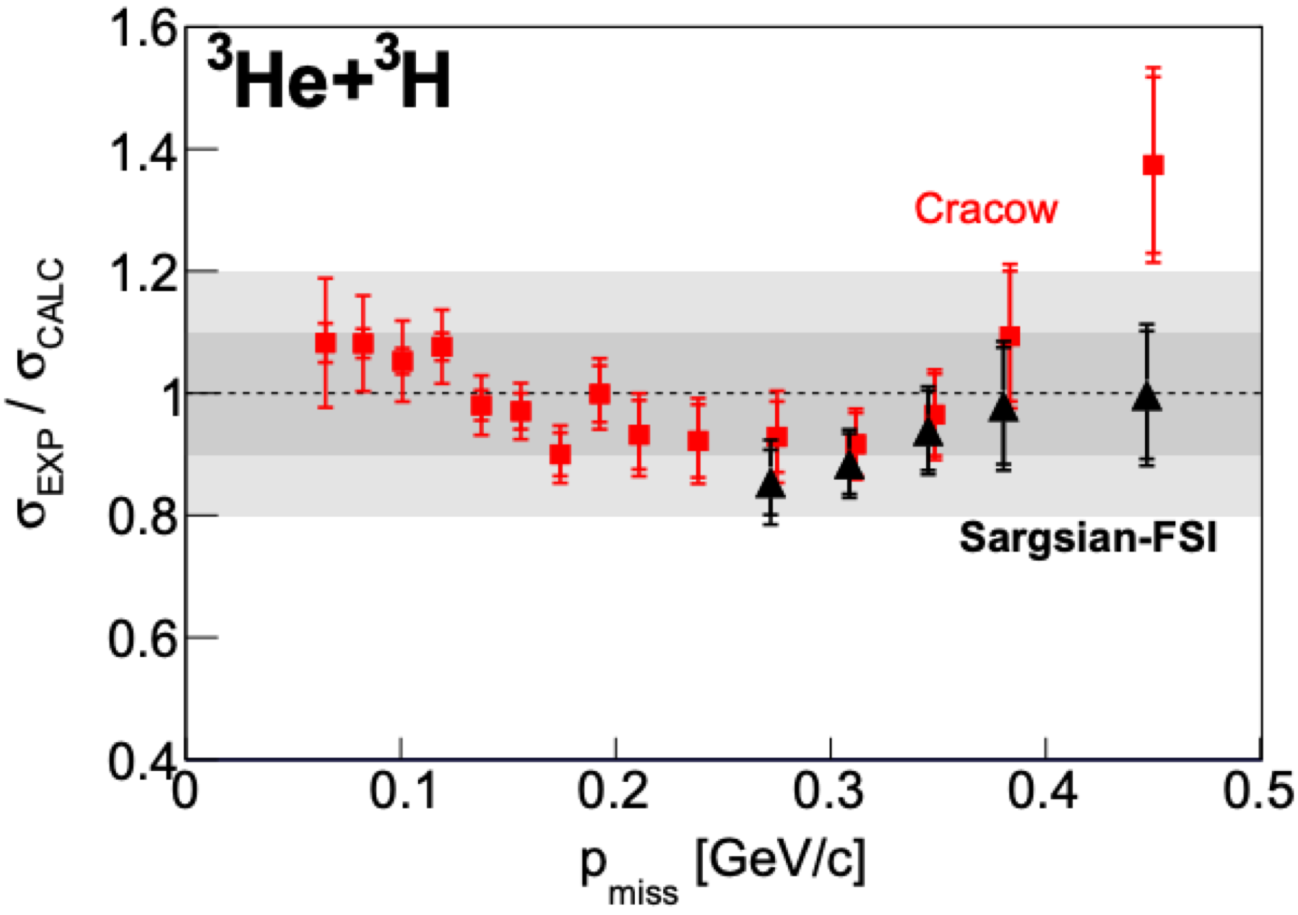

Isoscalar sum is robust to asymmetric final-state effects!

Lessons from Hall A Measurement

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

- To explore:
  - Push p_{miss} to 1 GeV/c
  - Cover broad range of kinematics

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  - Hall A program showed just a glimpse of what we can learn.

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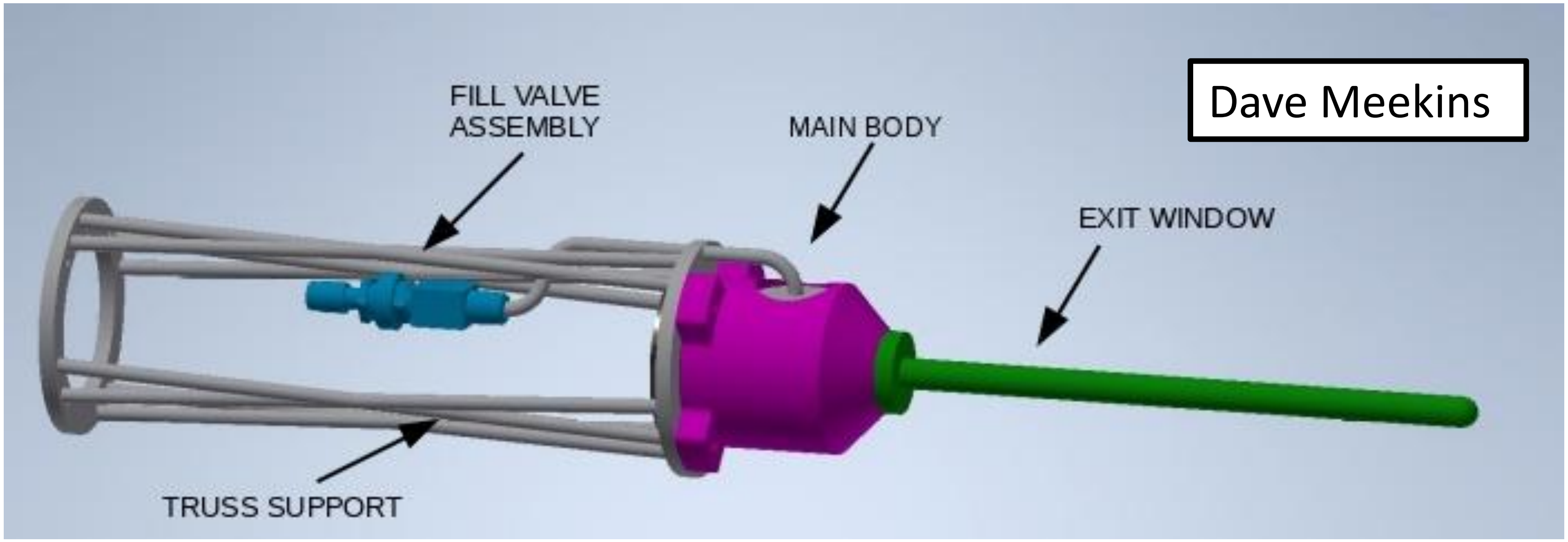
  - **We have a safe and feasible plan.**

- The Proposed Measurement
  - In 60 days, we can tackle important questions.

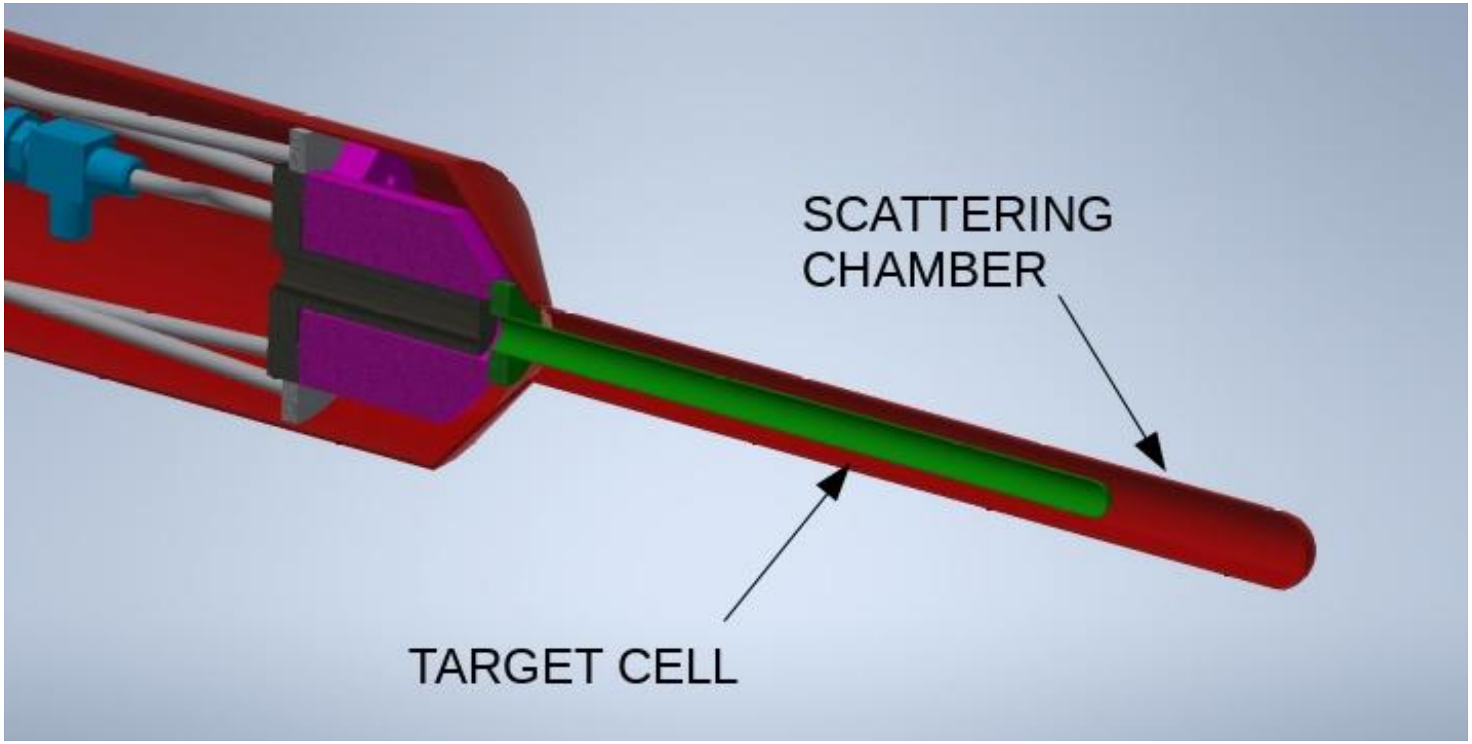
Target Design for Tritium @ CLAS12



- Sealed-cell design
- Separate cells for ^{3}H, ^{3}He, d
- 25 cm total length
- 1.2 kCi of tritium

- Full Azimuthal Acceptance
- Full Acceptance to 120˚
- Easier to fabricate than Hall A cell

Target Design for Tritium @ CLAS12



Material	Tritium	Al Windows	Be Window	Total
Length(g/cm^2)	0.085	0.21	0.037	0.33
Luminosity	3.54×10^{34}	8.42×10^{34}	1.54×10^{34}	1.35×10^{35}

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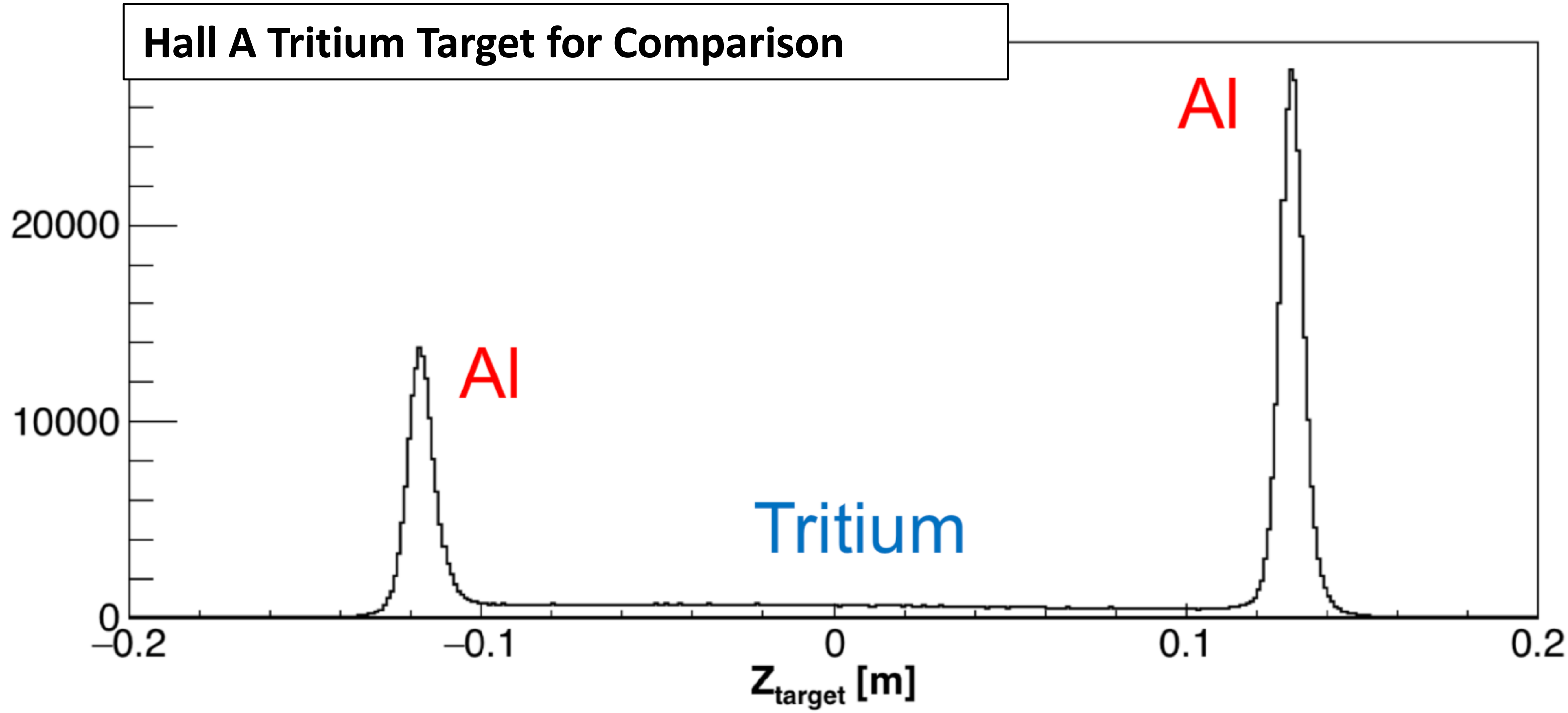

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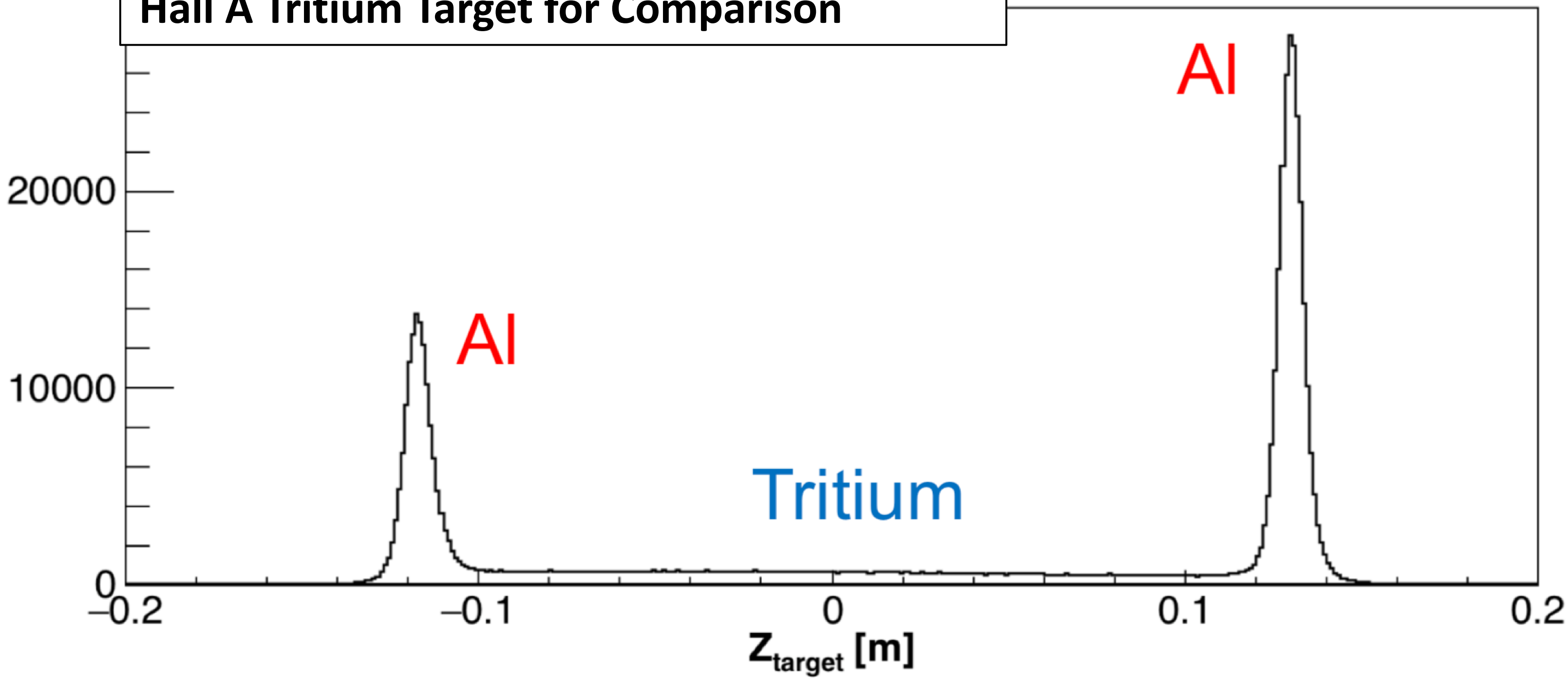
Target Design for Tritium @ CLAS12

Hall A Tritium Target for Comparison



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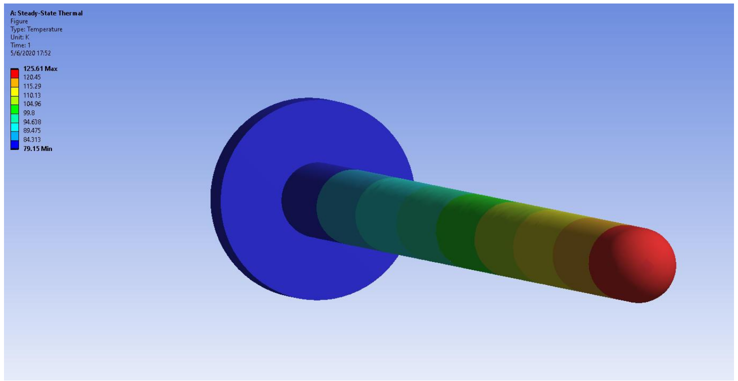
Assume 15 cm of useable target ---> 2E34 of useable luminosity!

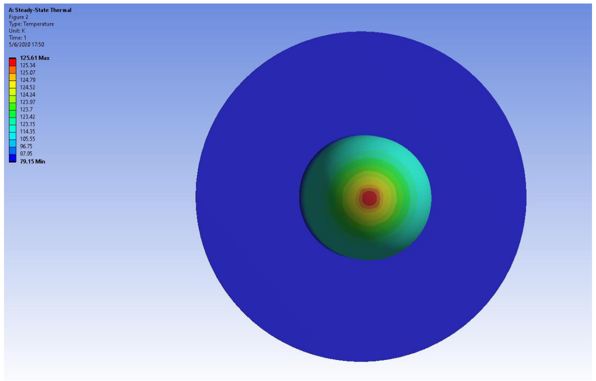
A tritium target needs a multi-layer confinement system.

Stage	Layer 1	Layer 2	Layer 3
Installation	Cell	Handling Hut	Hall B
Storage	Cell	Inner Containment Vessel	Outer Containment Vessel
Beam	Cell	Scattering Chamber	Hall B

Target Design continued…

- Operating Temp ≈ 50 K at 100 nA
- Heat load < 1W, mostly on windows





- Separate sealed gas cells for each
  - H_2 density is 0.00275 g/cc (68.75 mg/cm2)
  - D_2 density is 0.00500 g/cc (125 mg/cm2)
  - T_2 density is 0.00330 g/cc (82.5mg/cm2)
  - ^3He density is 0.00410 g/cc (102.5 mg/cm2)

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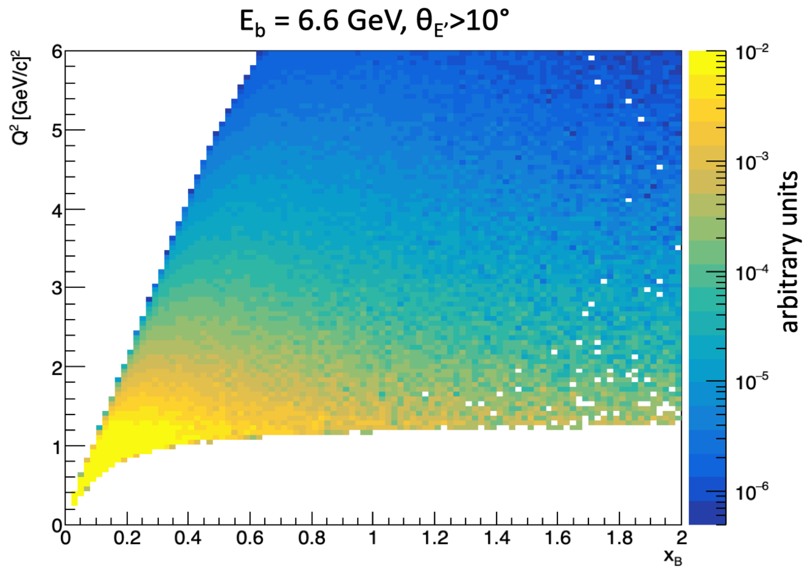
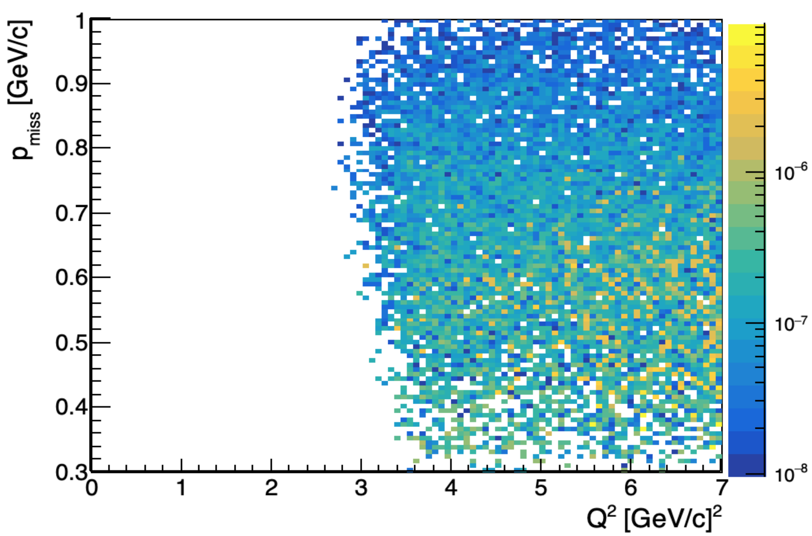
  - **In 60 days, we can tackle important questions.**

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

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



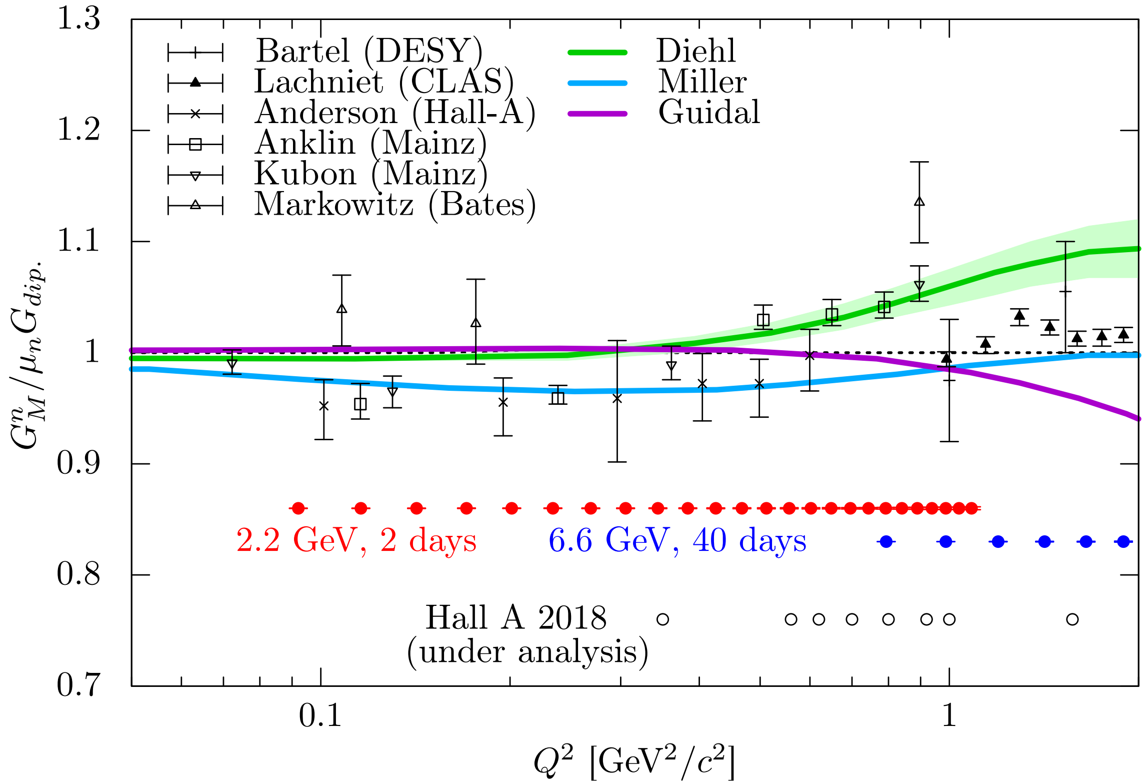


A=3: Helium-3 + Tritium @ CLAS12

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

(e,e'): Neutron Form Factor

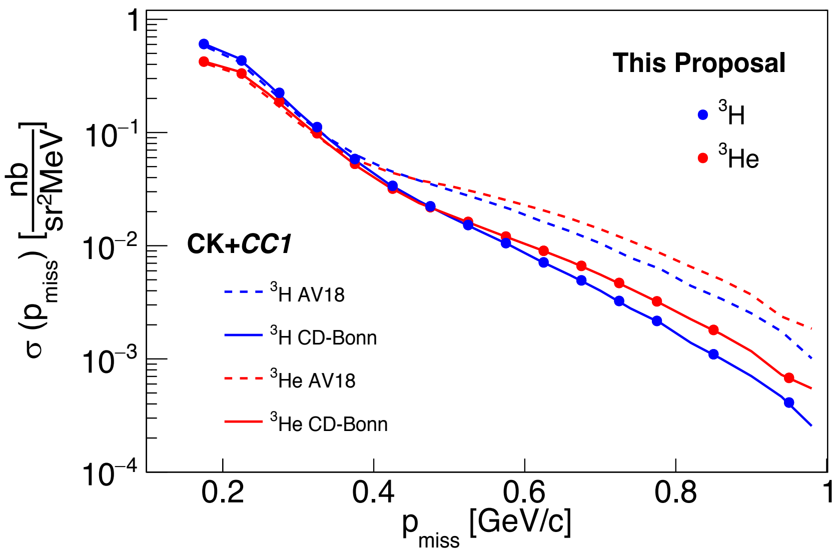
- **^{3}He(e,e') / ^{3}H(e,e') @ x_B = 1 sensitive to σ_n / σ_p**
- Measured @ Hall A \w limited Q^2 coverage
- CLAS12 reaches down to Q^2 = 0.1
- Can probe exactly where theory and data show interesting differences



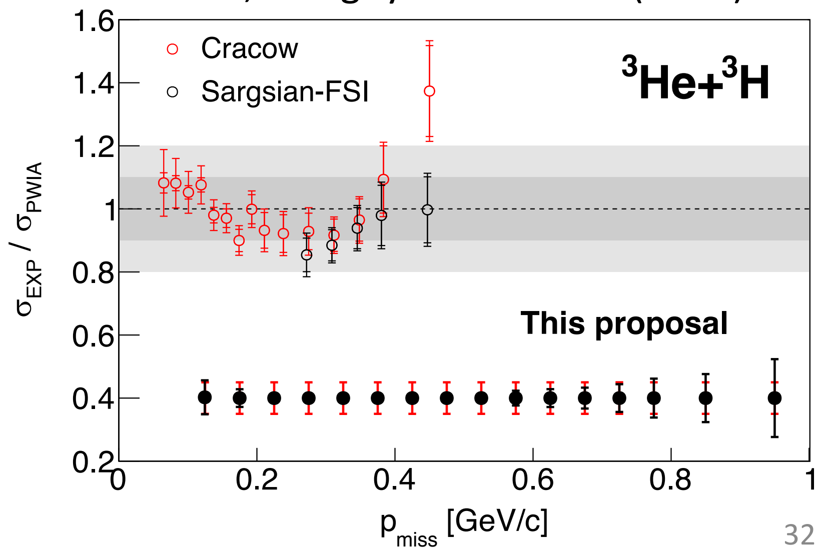
Adapted from A. Lachniet et al. PRL (2009)

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

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



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



- CLAS12:

  x0.1 luminosity

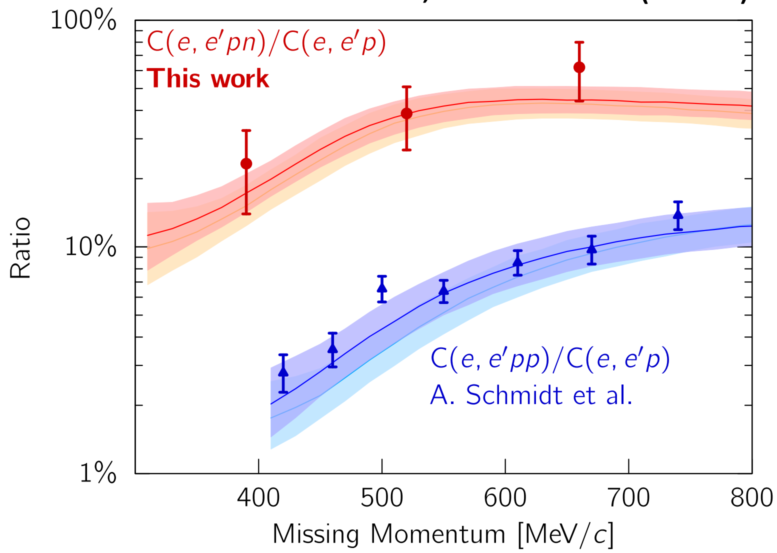
  x100 acceptance

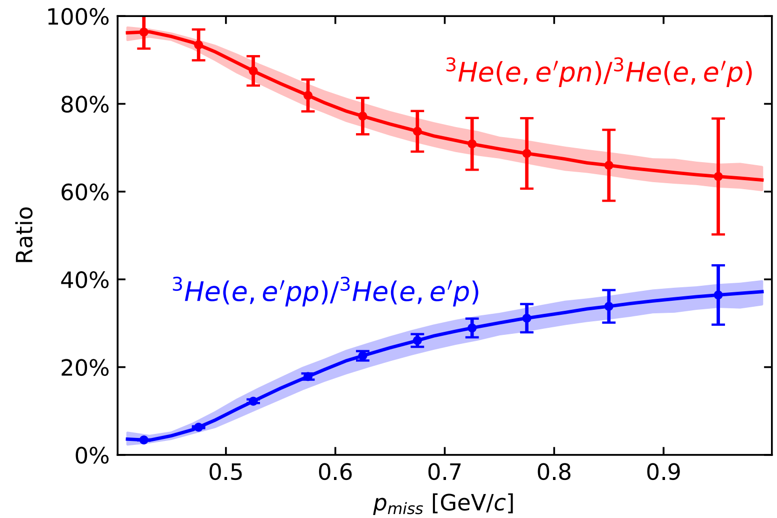
  => x10 statistics + larger kinematical coverage!

(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

I. Korover et al., Submitted (2020)





Beam time requirement

Target:	^{1}H	d	^{3}He	^{3}H	Total
Measurement Days (6.6 GeV)	1	10	20	20	**51**
Calibration (inbending field)					**1**
Target Changes					**2**
Total at 6.6 GeV:					**54**
Measurement Days (2.2 GeV)	0.5	0	1	1	**2.5**
Calibration (outbending field)					**1**
Target Changes					**2**
Total at 2.2 GeV:					**5.5**
Total beam time requested:					**59.5**

0.5 PAC day is required for target change

Total number of events:

Reaction	$(e, e'pp)$	$(e, e'pn)$
# events (6.6 GeV)	8k	6k

Systematic uncertainty for A=3 measurements

(e,e'p): Few-Body nuclear Structure

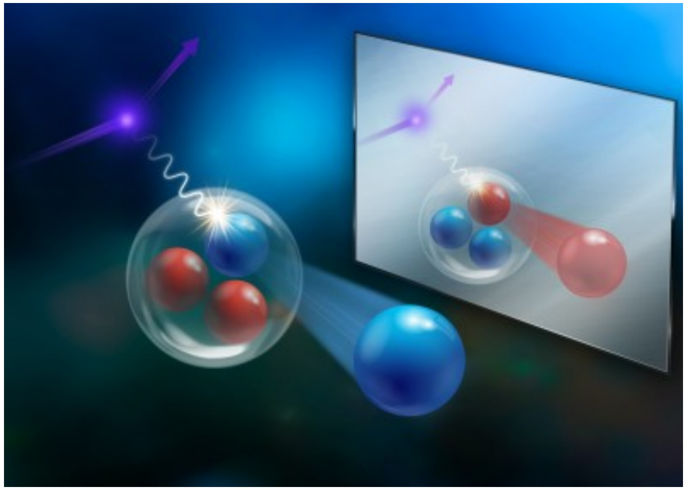
- Absolute cross-section: 5% point-to-point systematic uncertainty
- Cross-section ratio Exp/pwia: 5% point-to-point systematic uncertainty
- Isobar sum Exp/pwis: 5% point-to-point systematic uncertainty

(e,e'pN): NN interaction study

- 5% point-to-point systematic uncertainty

Summary

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



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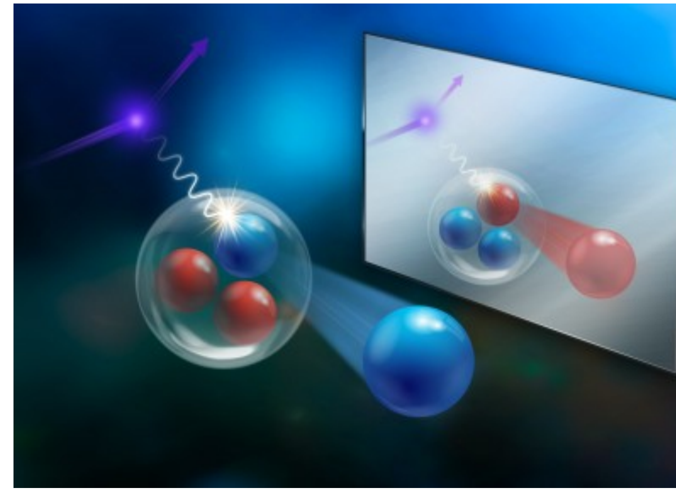
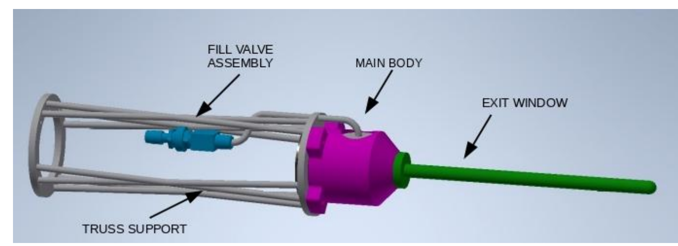
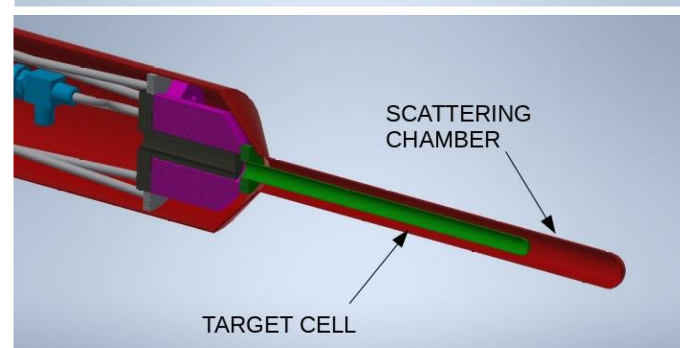
  - **Need both ^{3}He and ^{3}H!**

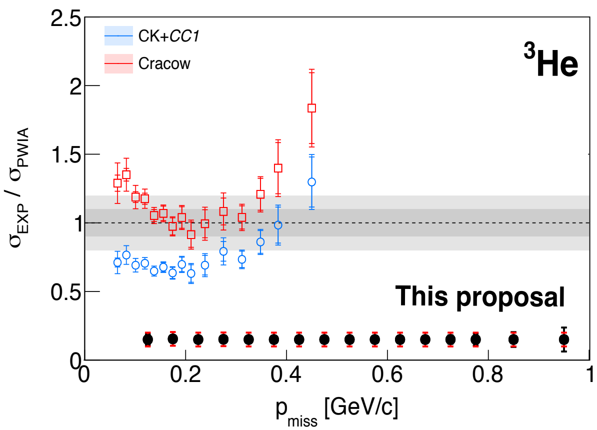
- Proposed experiment
  - CLAS-12 in standard configuration
  - Open e– trigger
  - 60 days on ^{3}He, ^{3}H, d at 6.6 and 2.2 GeV.
  - **New target system!**

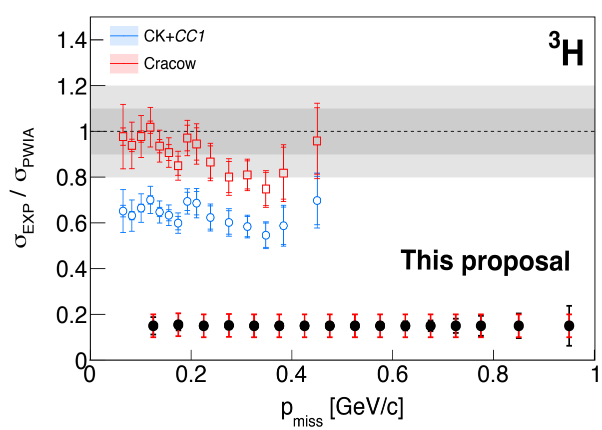


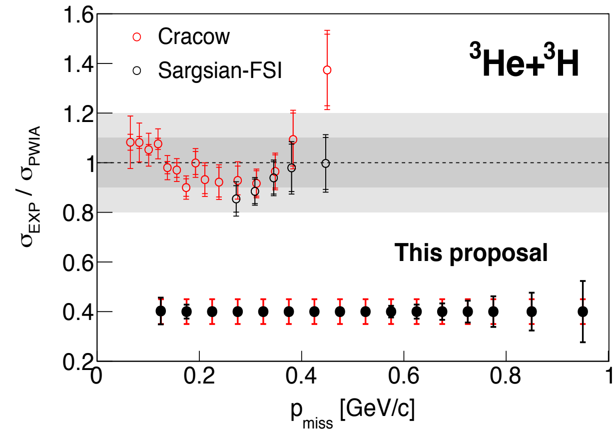


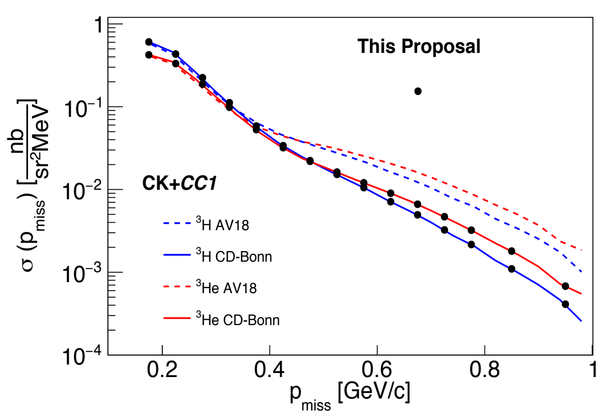


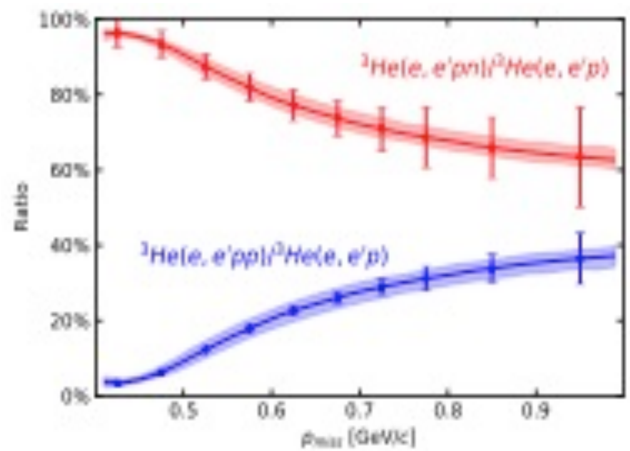
Everything we learn from A=3 will help us interpret data on heavier nuclei!

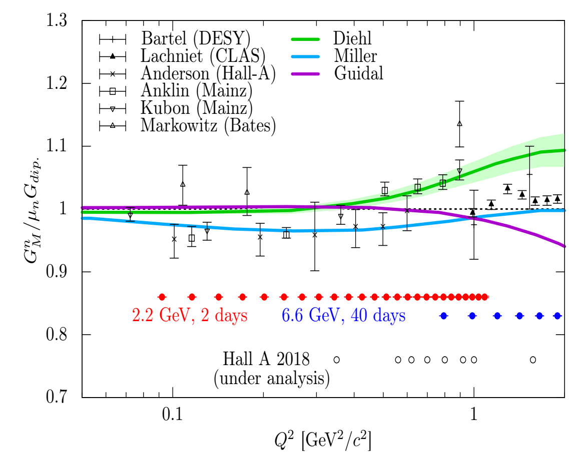








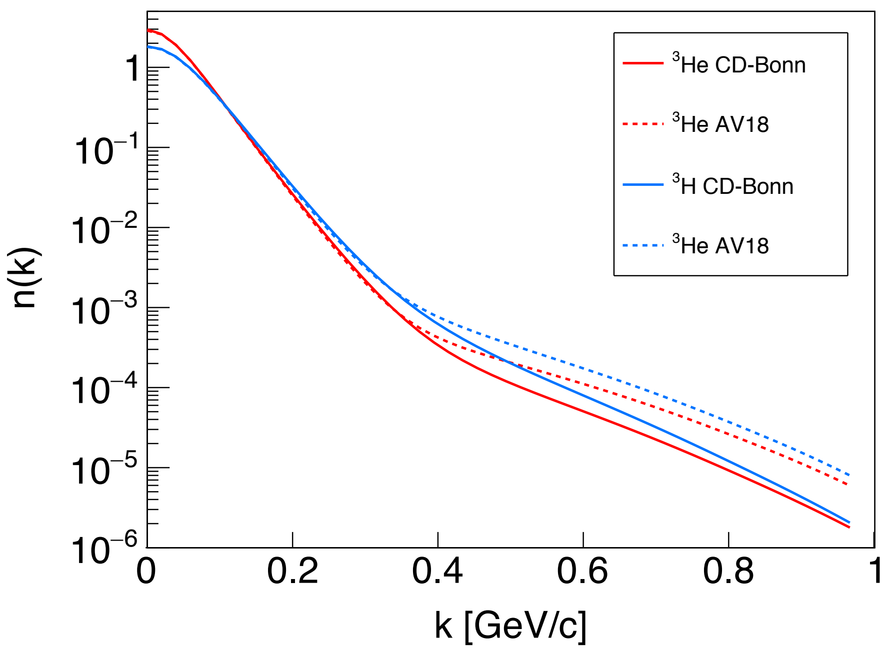


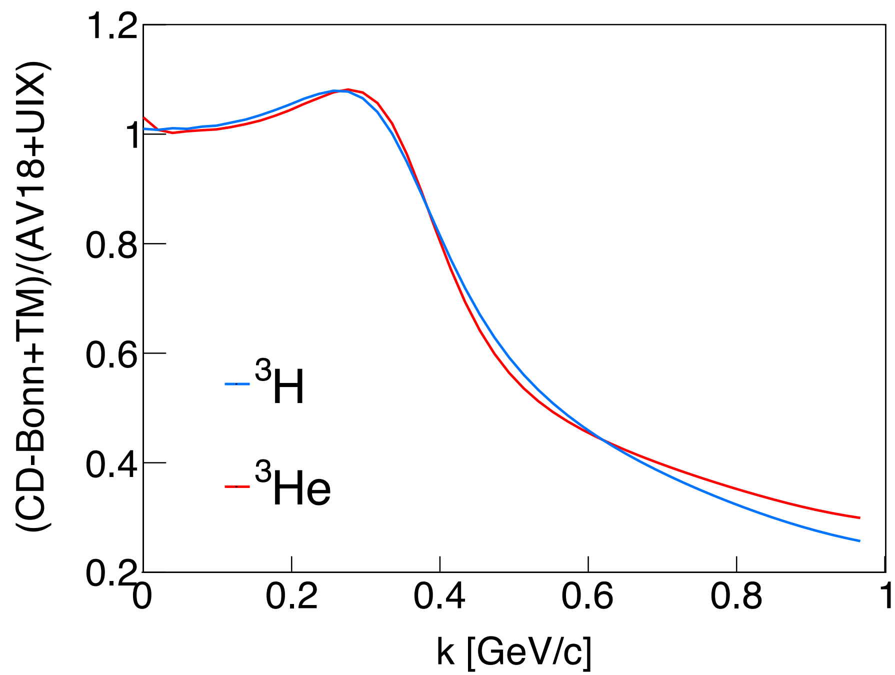


Back-Up Slides

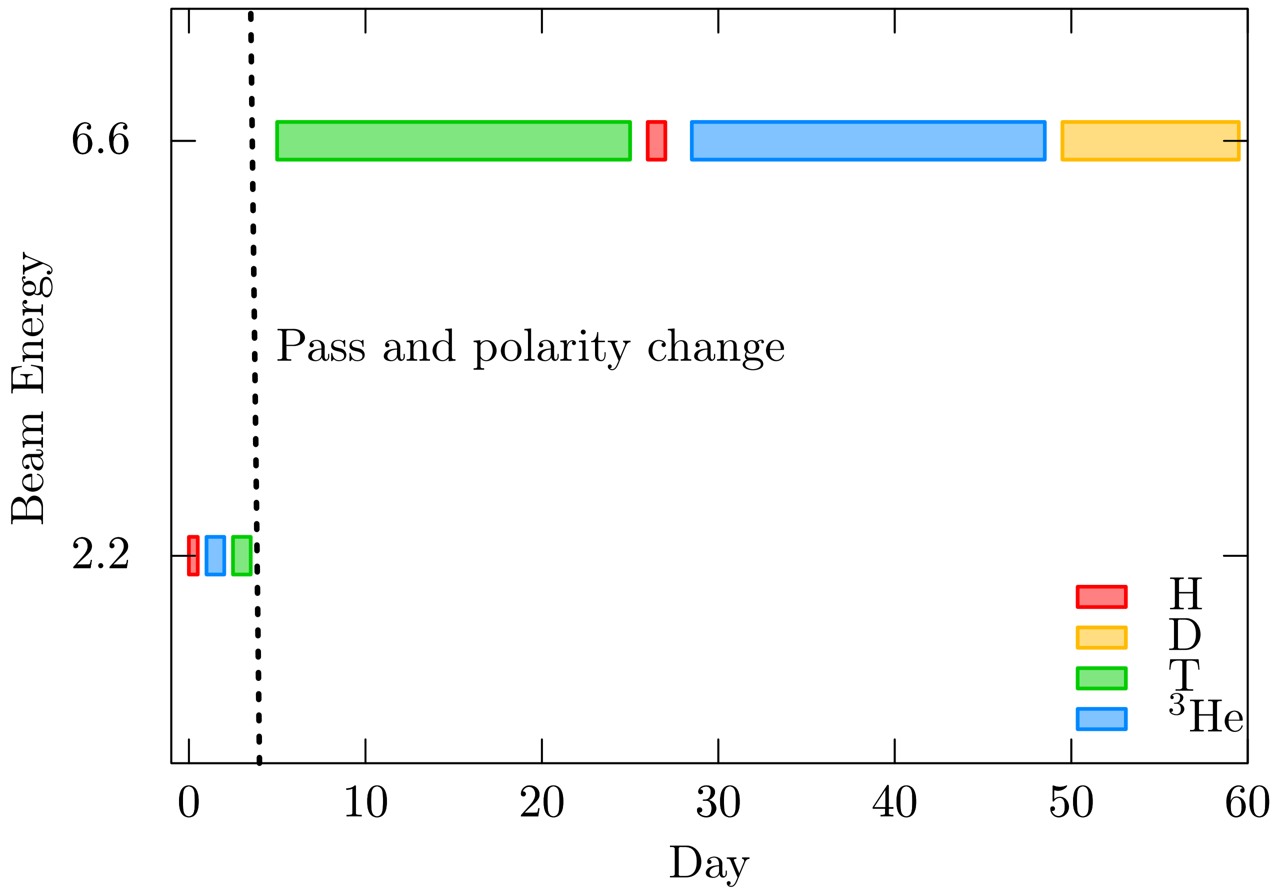
Momentum distributions

- AV18+UIX
- CD-Bonn+TM





Run plan:



Minimize target changes
Only one tritium install
Beam-checkout on a non-tritium cell!

Geant4 Study of the Target

- 1.35E35 Total Luminosity
  - Only 2E34 usable tritium luminosity

- Geant4 study to assess how new target design affects DC rates
  - LH_2 used as target material
    - Geant4 can't reliably simulated A=2,3
    - Main source of background is other material, not the gas.

  - Rates are slightly higher
    - Similar rates in SVT
    - Slightly higher occupancy in DC region 1

1E35 on empty 5cm nominal target			
		damage rate	
particles:	krad/yr	rate (MHz)	1 MeV neutron damage rate
electrons	1.4	1.6	0.1
pions		0.7	0.5
neutrons	5	0.013	0.014
protons	11.4	1	5.7
gamma	0.2		
pi-	2.5		
pi+	1.5		
e+	0.3		
Total:	**19**	**3.3**	**6.3**

1E35 on empty tritium target			
		damage rate	
particles:	krad/yr	rate (MHz)	1 MeV neutron damage rate
electrons	6.5	7.6	0.2
pions		1.1	0.7
neutrons	0	0.025	0.021
protons	27	2.5	14.5
gamma	0.5		
pi-	2.6		
pi+	2.8		
e+	1.5		
Total:	**44.8**	**11.2**	**15.4**

1E35 on LH2 5cm nominal target			
		damage rate	
particles:	krad/yr	rate (MHz)	1 MeV neutron damage rate
electrons	6	11	0.1
pions		1.3	0.9
neutrons	0	0.019	0.021
protons	19.5	2	13.4
gamma	1.4		
pi-	4.2		
pi+	7.2		
e+	1.9		
Total:	**41.5**	**14.3**	**14.4**

1E35 on H gas tritium target			
		damage rate	
particles:	krad/yr	rate (MHz)	1 MeV neutron damage rate
electrons	6.6	9.1	0.1
pions		0.9	0.6
neutrons	0	0.032	0.031
protons	24	2.3	13.7
gamma	1		
pi-	2.4		
pi+	4.6		
e+	1.2		
Total:	**42.5**	**12.4**	**14.5**