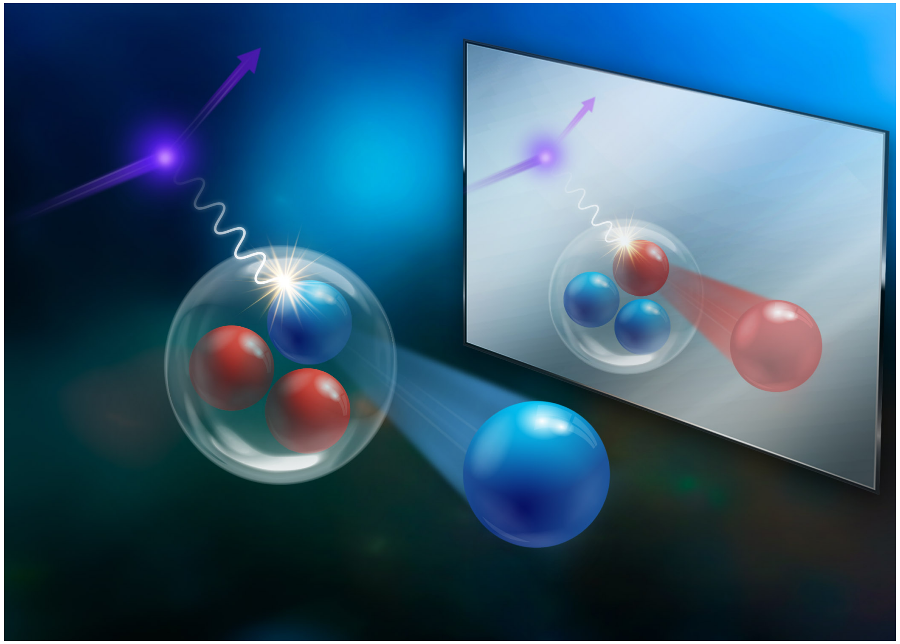
Precision measurements of A = 3 nuclei in Hall B

Proposal PR12-20-005



Spokespersons:

O. Hen, D. Nguyen (MIT),

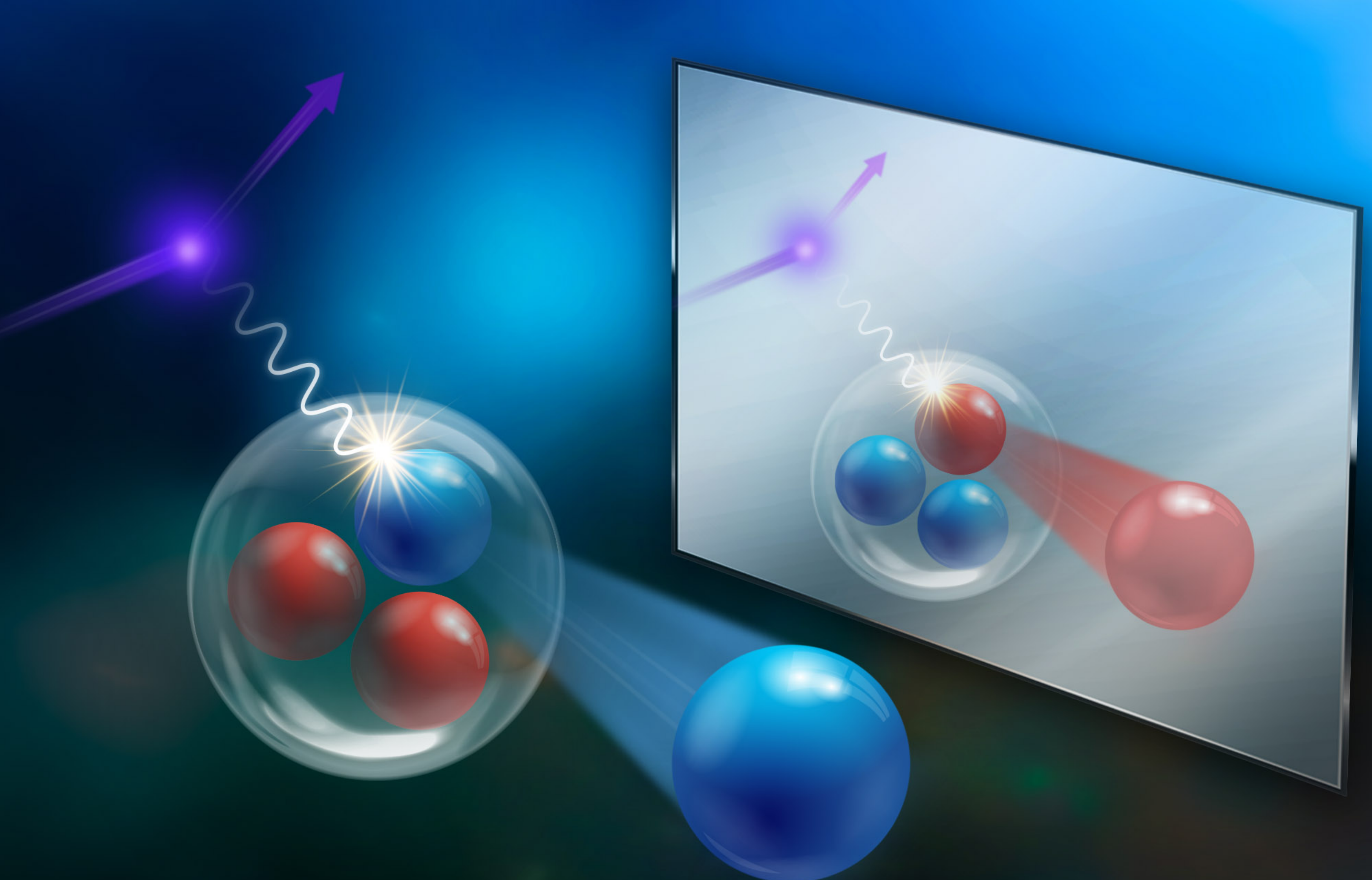
A. Schmidt (GWU),

L. B. Weinstein (ODU),

E. Piasetzky (TAU),

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

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

Executive Summary

- 60-day experiment with **tritium**, helium-3, d, H targets
- CLAS-12 in standard configuration, e^- trigger
- Quasi-elastic cross sections over wide phase space
  - Benchmark few-body nuclear structure calculations
  - Probe short-distance NN-interaction
  - Study reaction mechanisms
  - Measure neutron magnetic form factor

- 2nd generation experiment, dramatically extending scope of the 2018 Hall A program.

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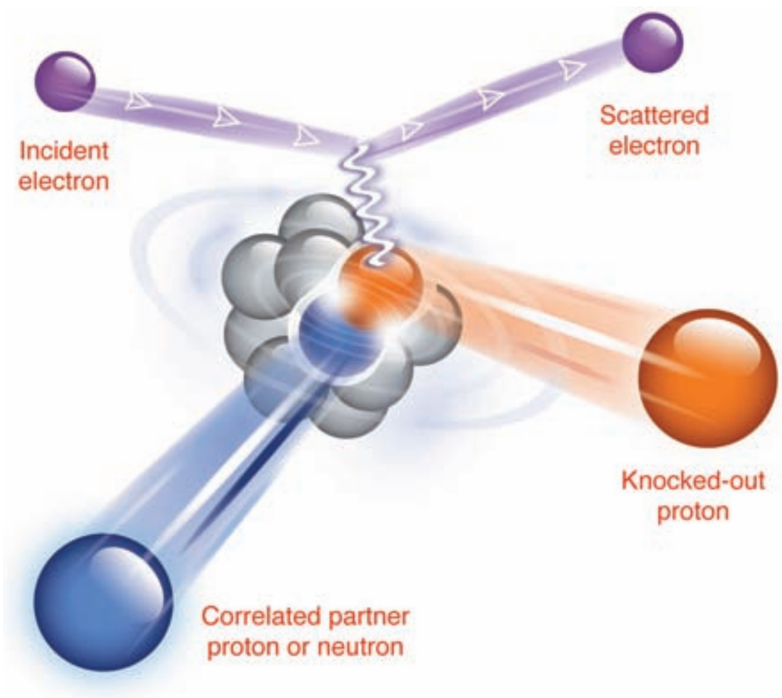
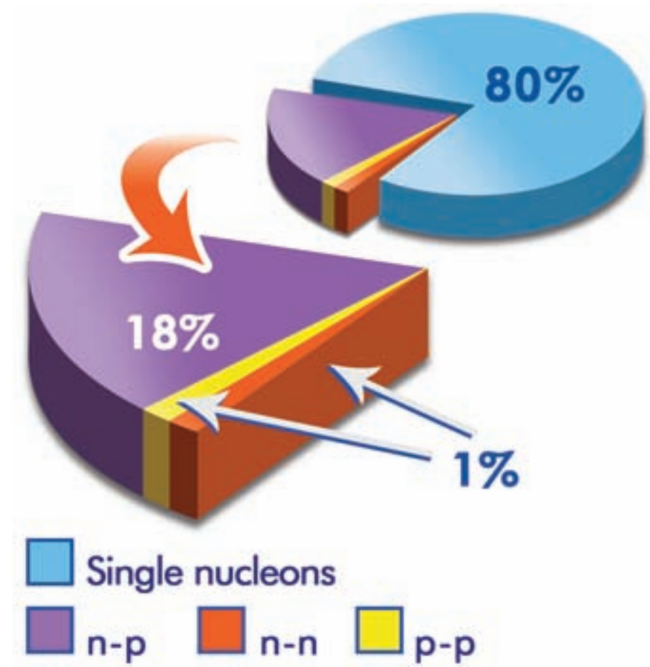
Short-range correlations tell us about the isospin-structure of the NN force.

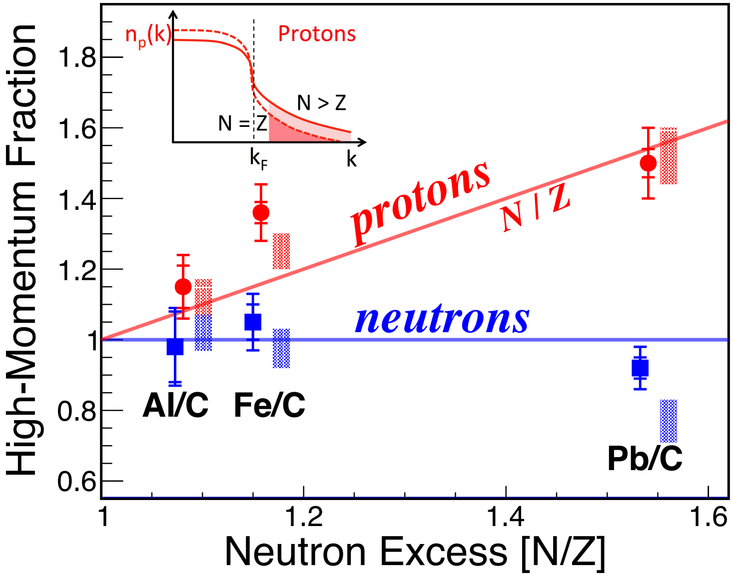




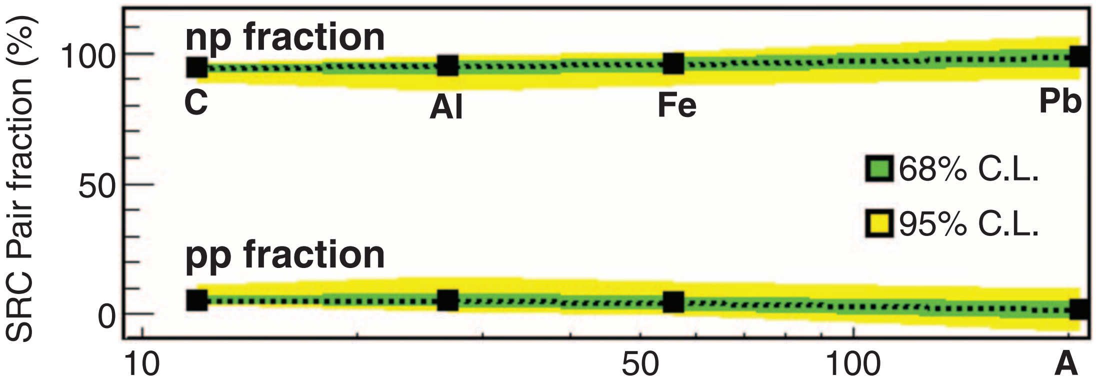
Subedi et al., Science 320, p. 1476 (2008)

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

For nucleons with ≈300–600 MeV/c



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



O. Hen et al., Science 346 p. 614 (2014)
M. Duer et al., PRL122, 172502 (2019)

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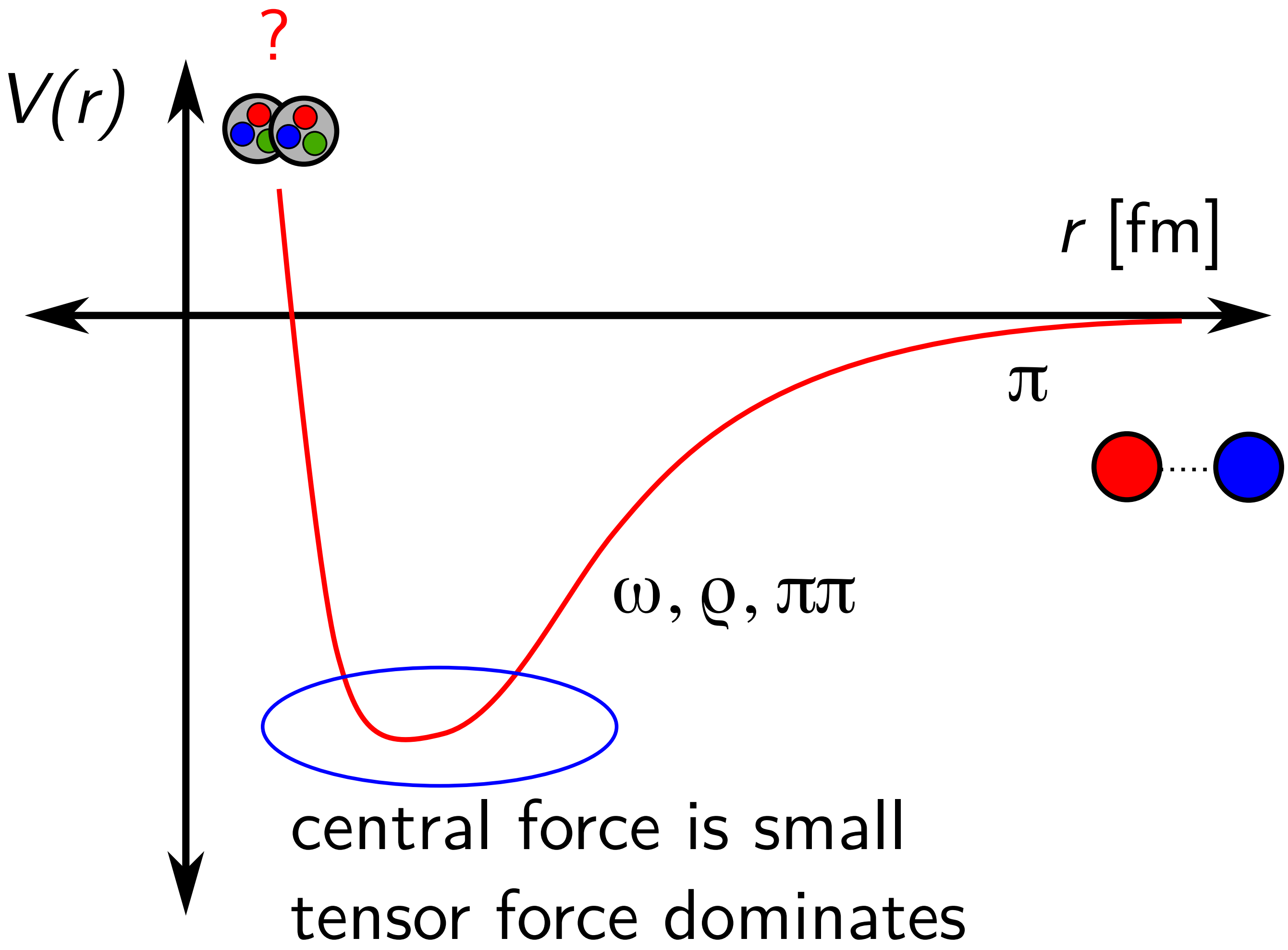
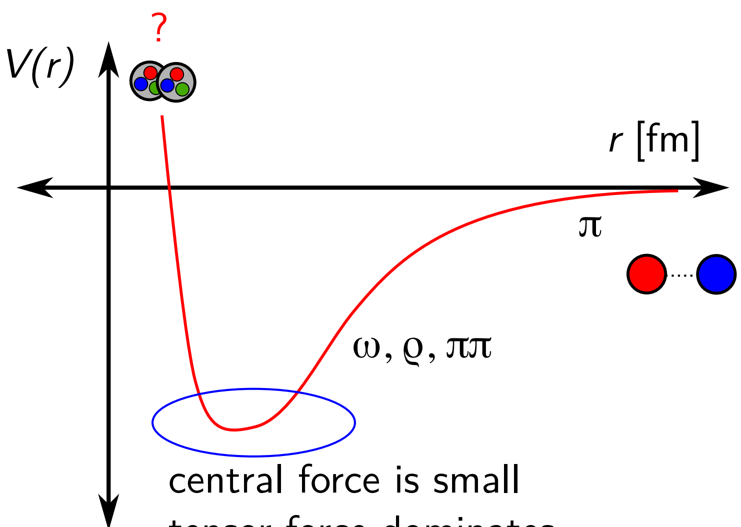
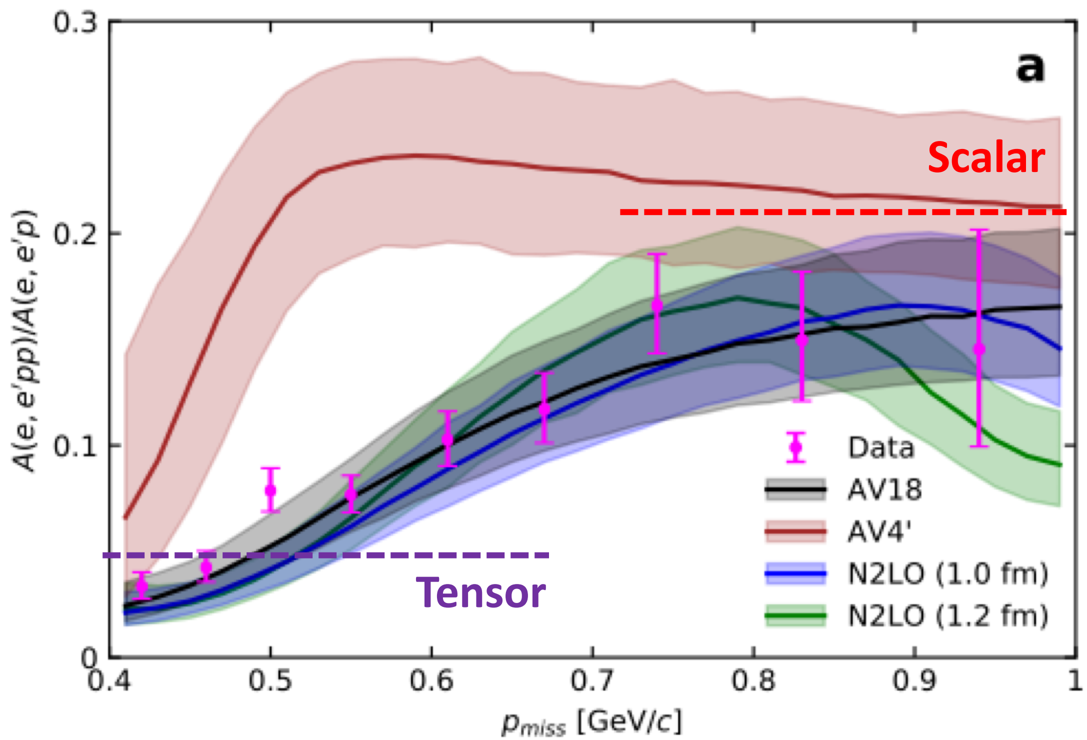


This gives way at very high momentum. Evidence of a scalar repulsive core!





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

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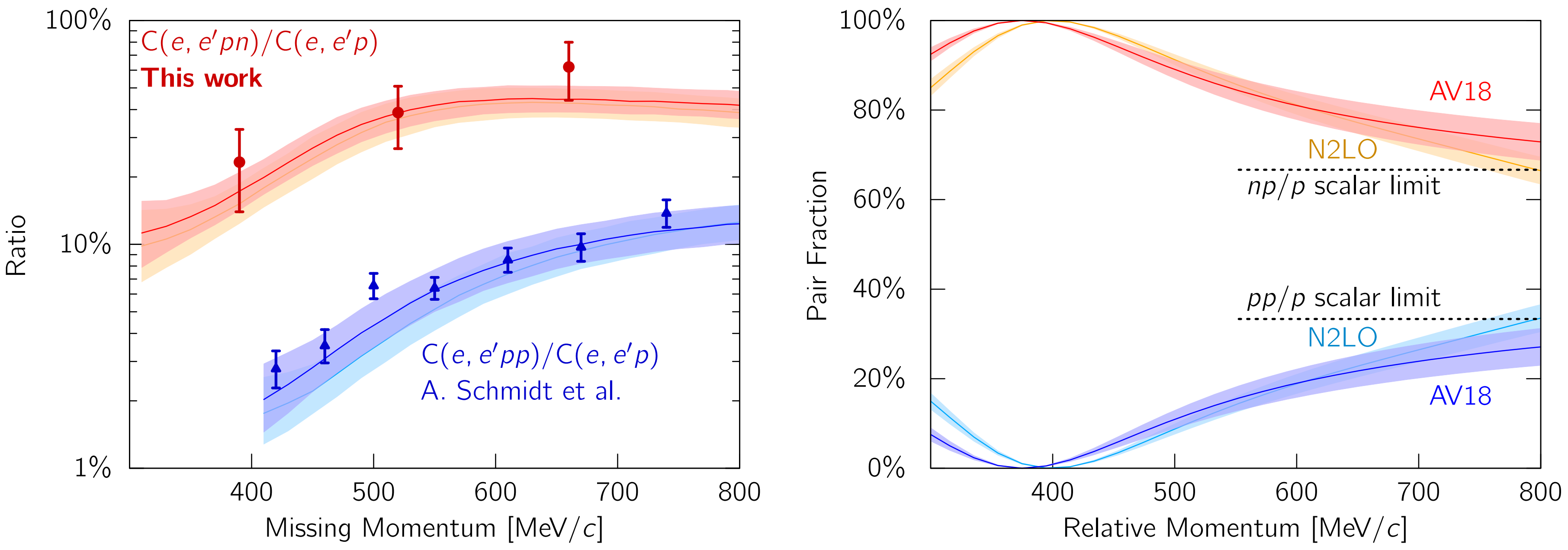
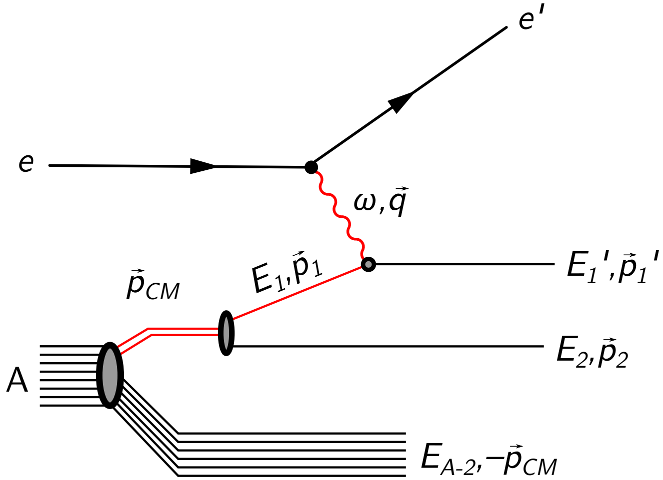


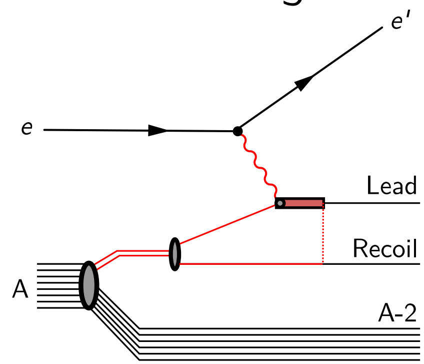
I. Korover et al., Submitted to PRL (2020)

Interpretation is complicated by competing reactions.

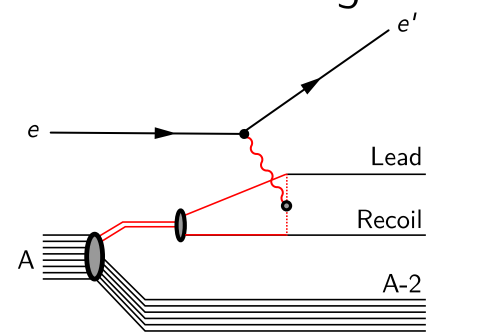
Plane-Wave



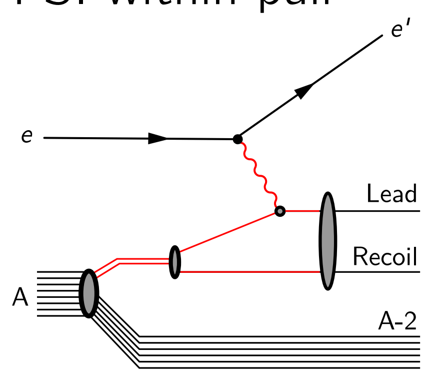
Isobar Config.



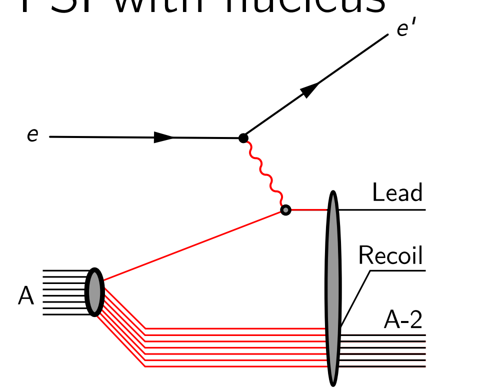
Meson-exchange curr.



FSI within pair



FSI with nucleus



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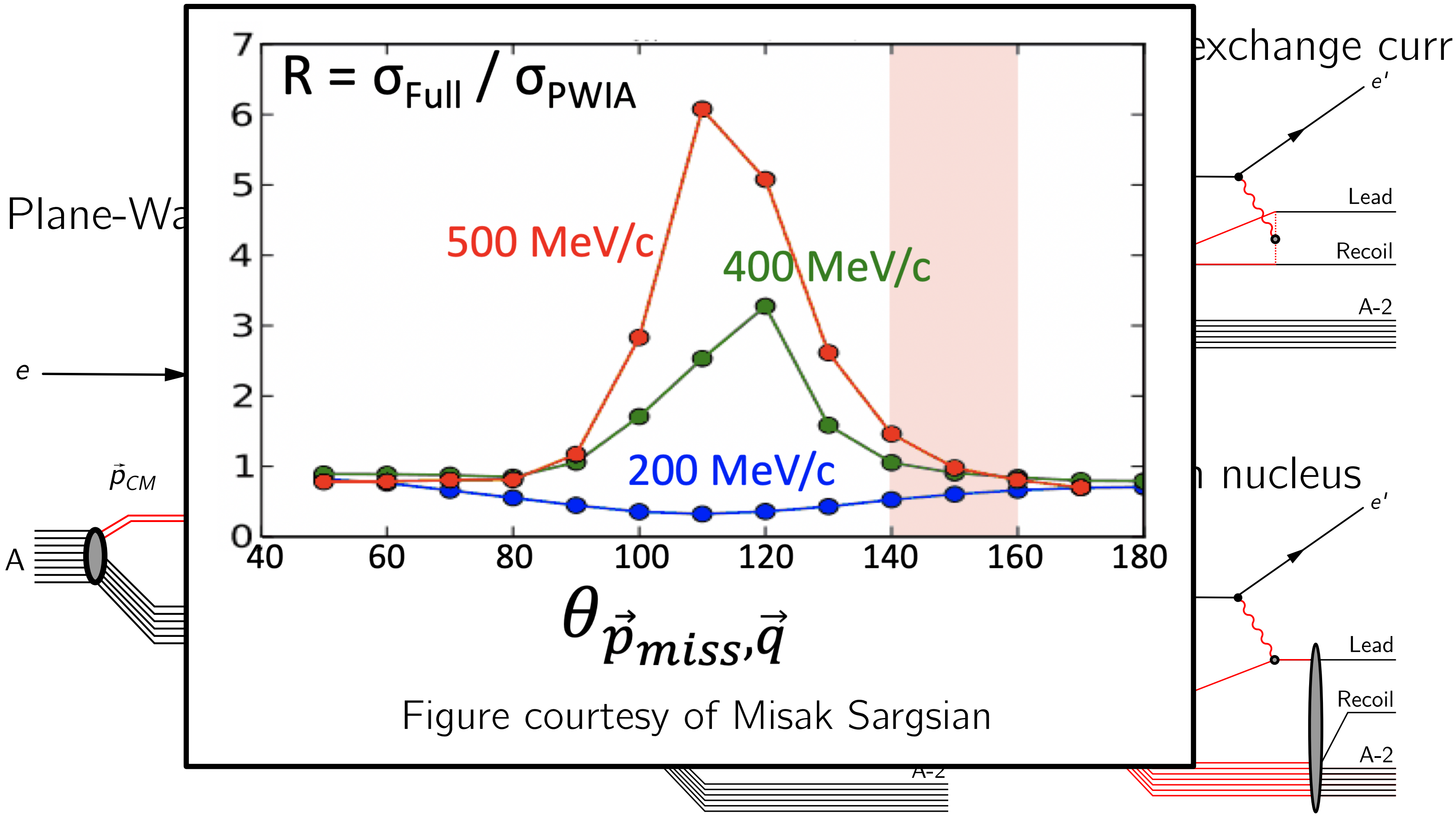
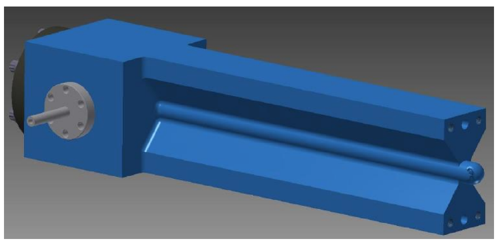
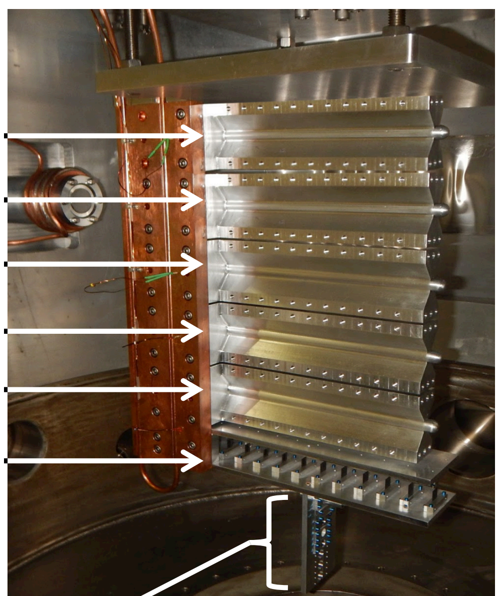


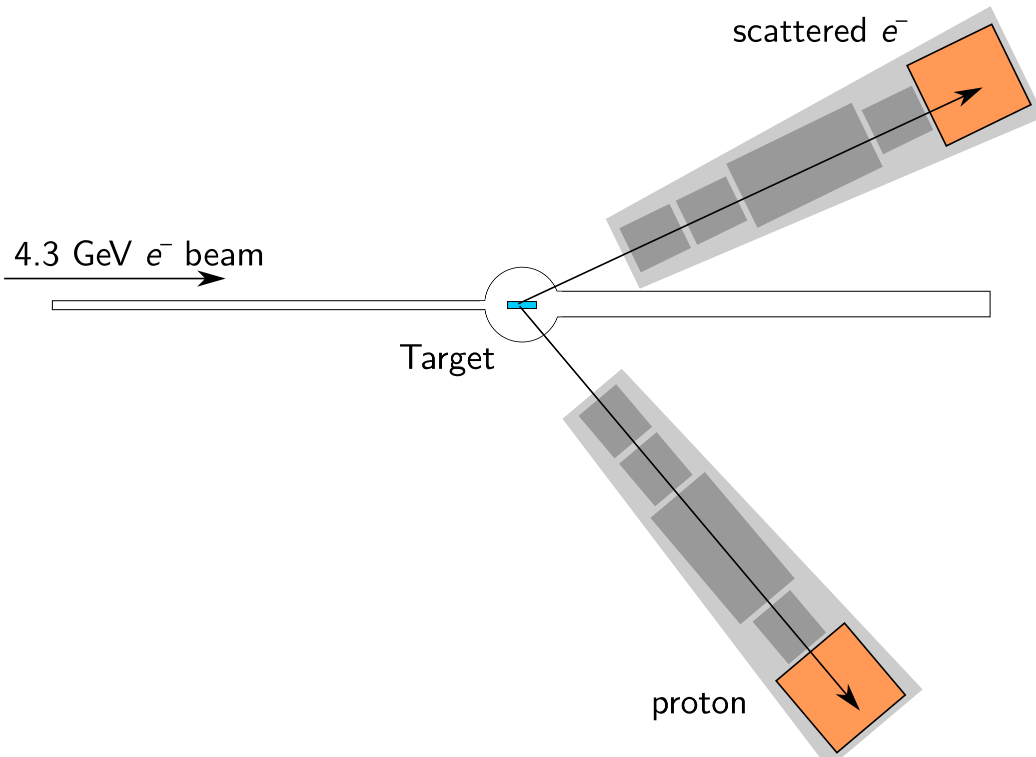
Figure courtesy of Misak Sargsian

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

- One of 5 experiments in Hall A Tritium Program.







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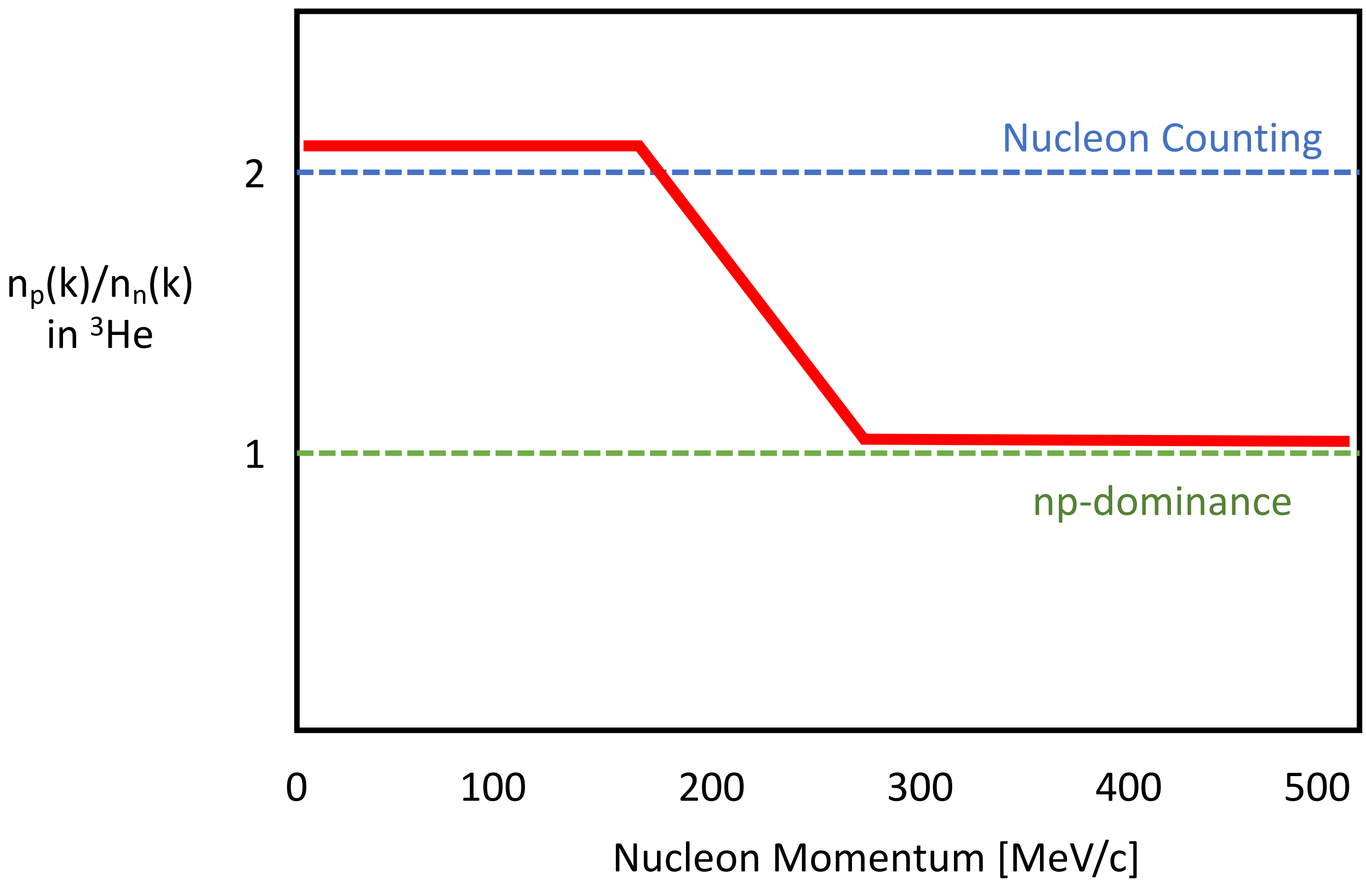
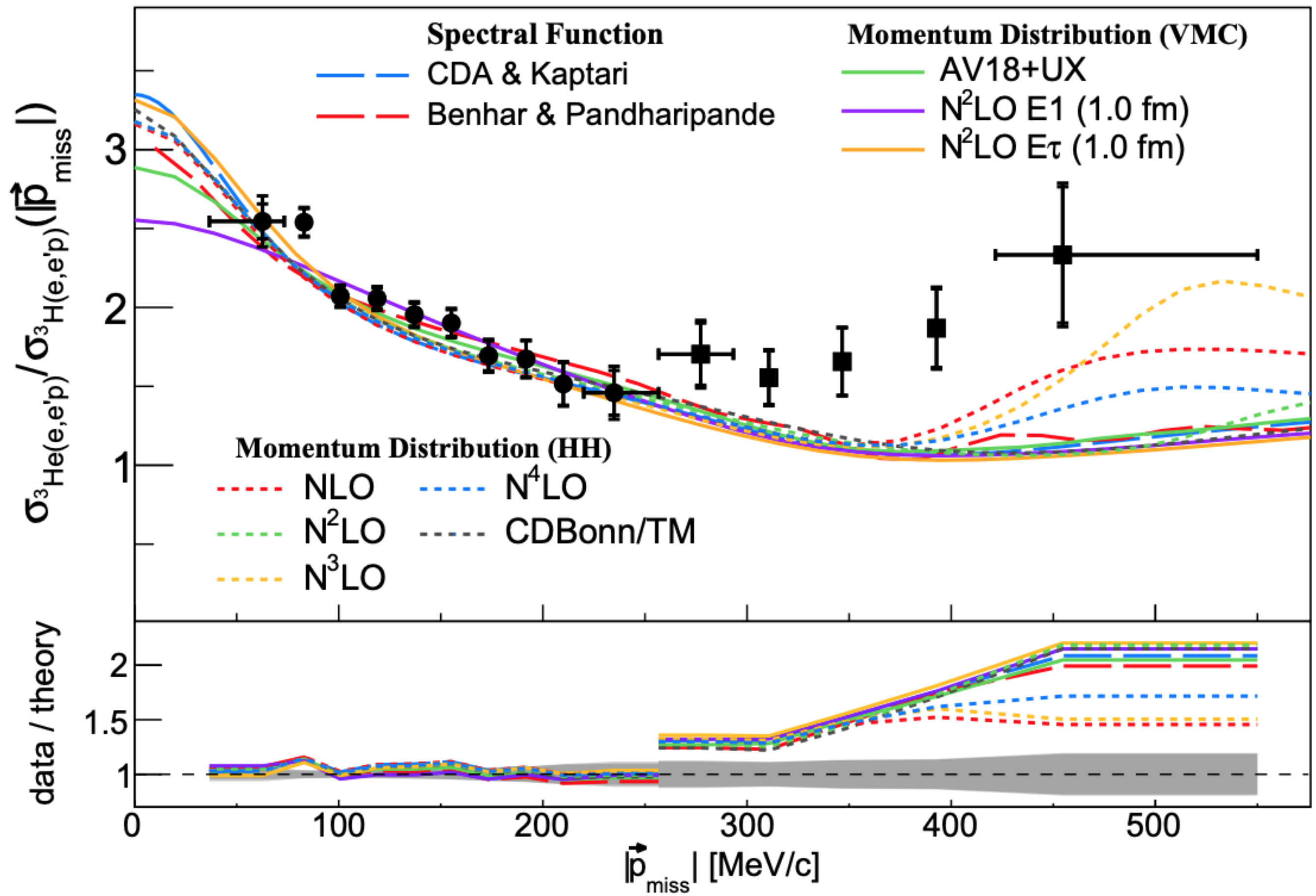
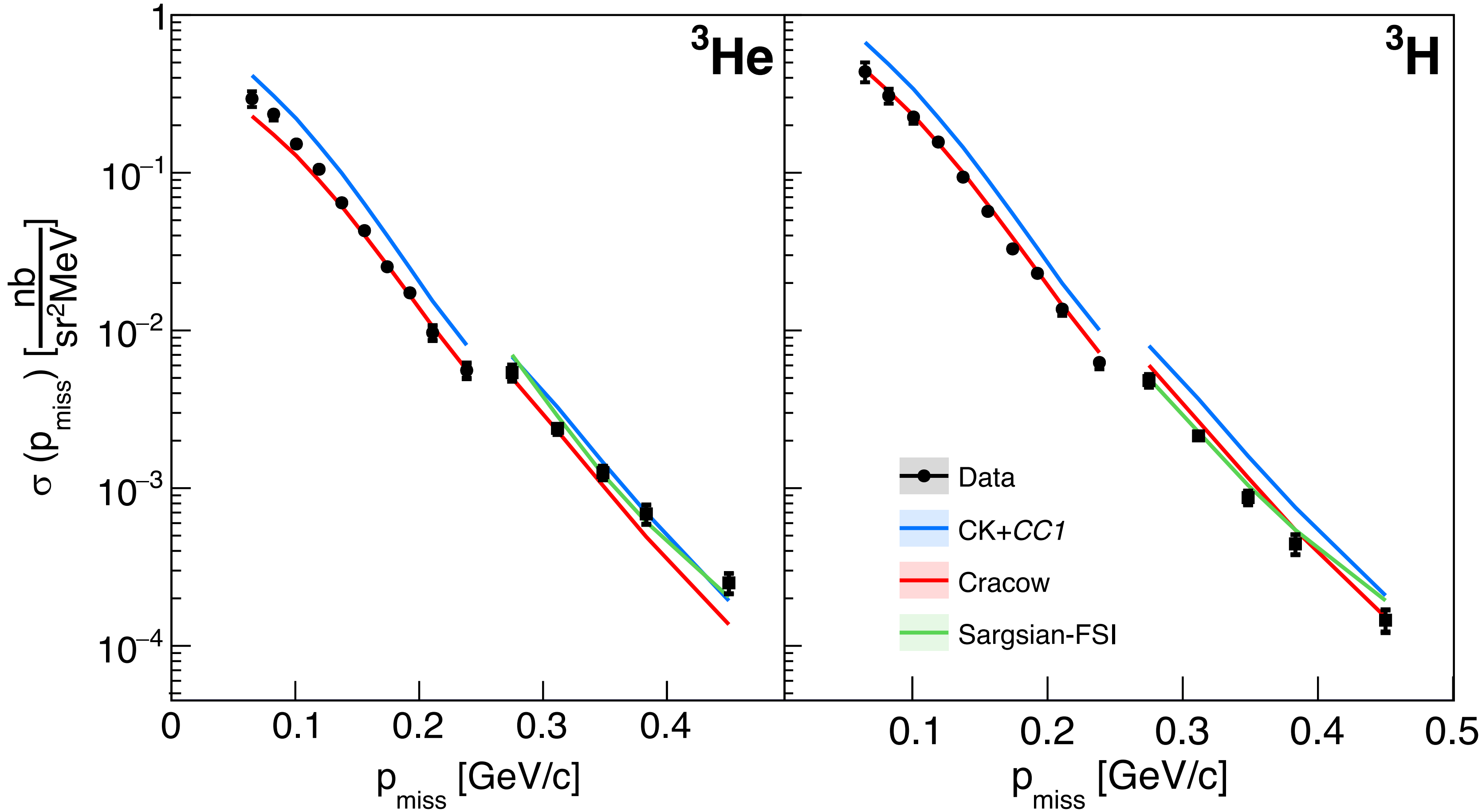


3He/3H ratio was more interesting than expected.



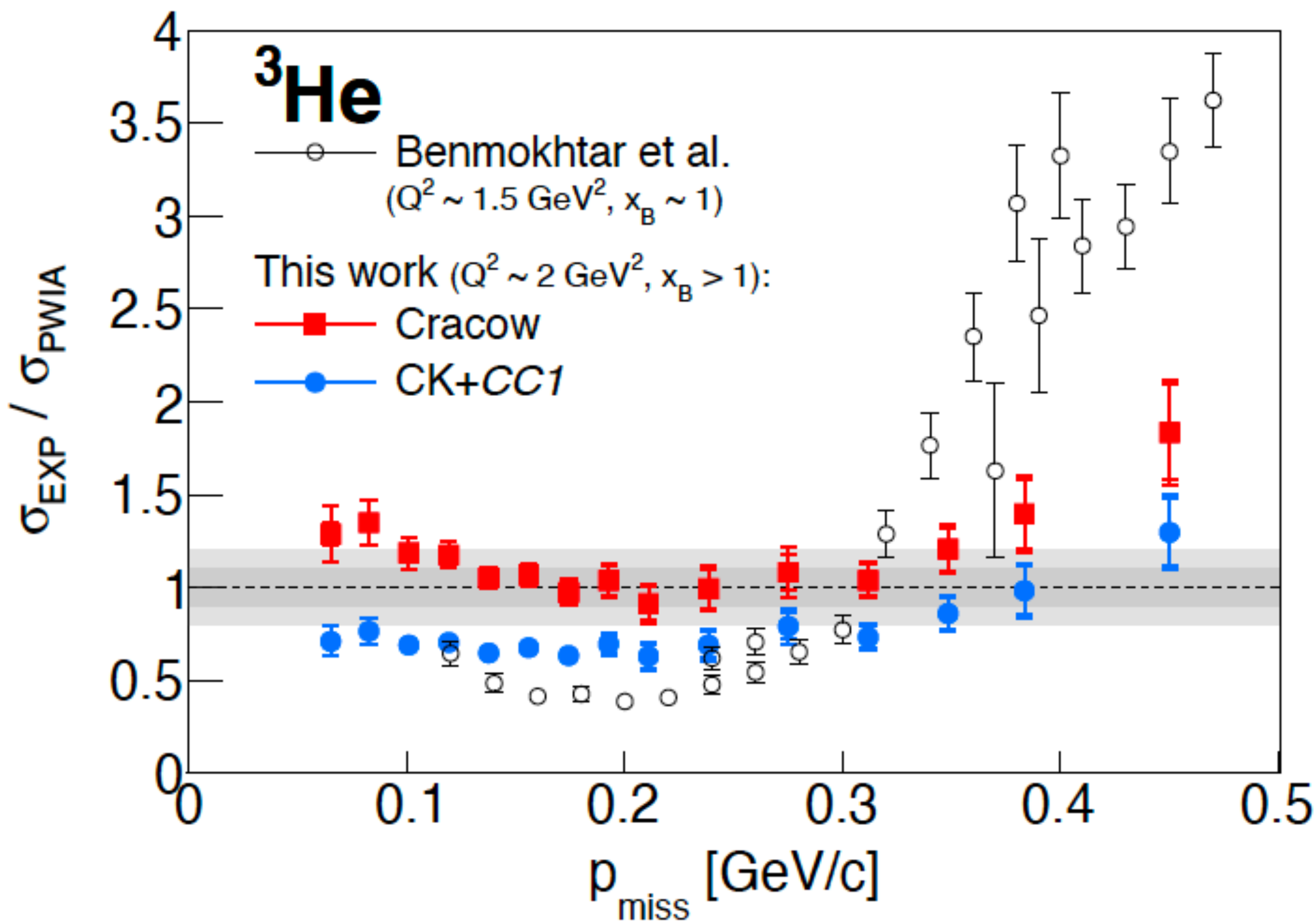
R. Cruz-Torres et al., PLB 797 134890 (2019)

We extracted absolute cross sections.



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

Absolute Cross Section Results



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

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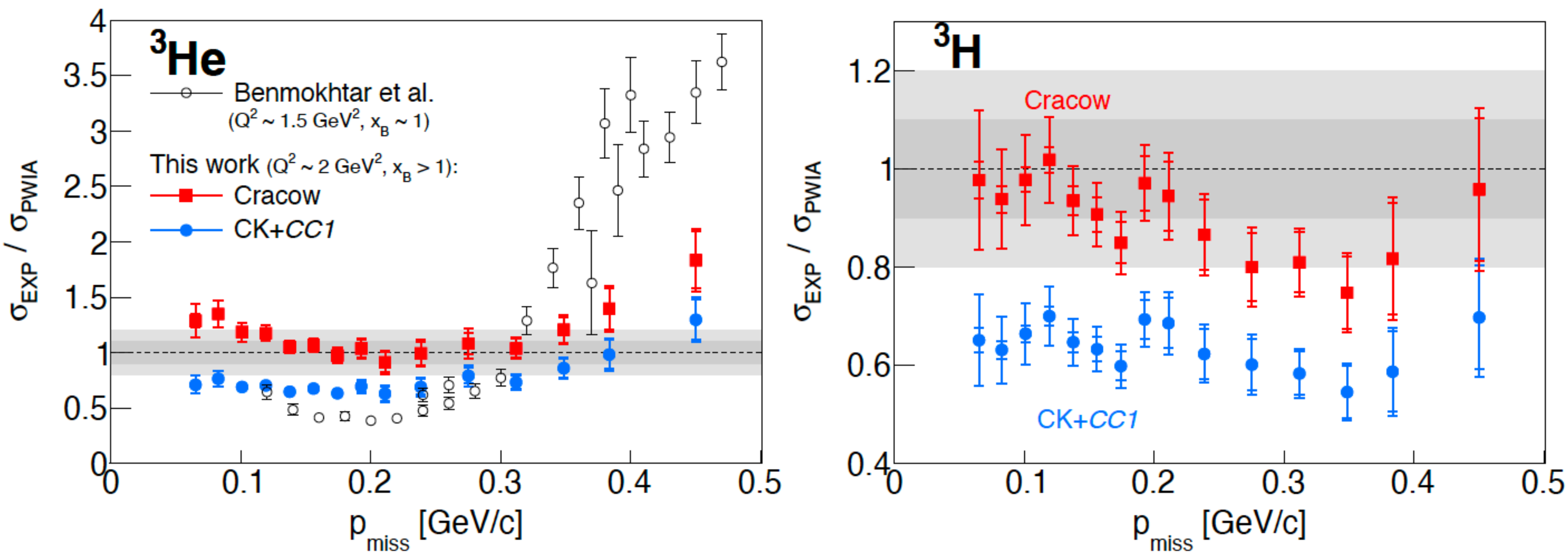
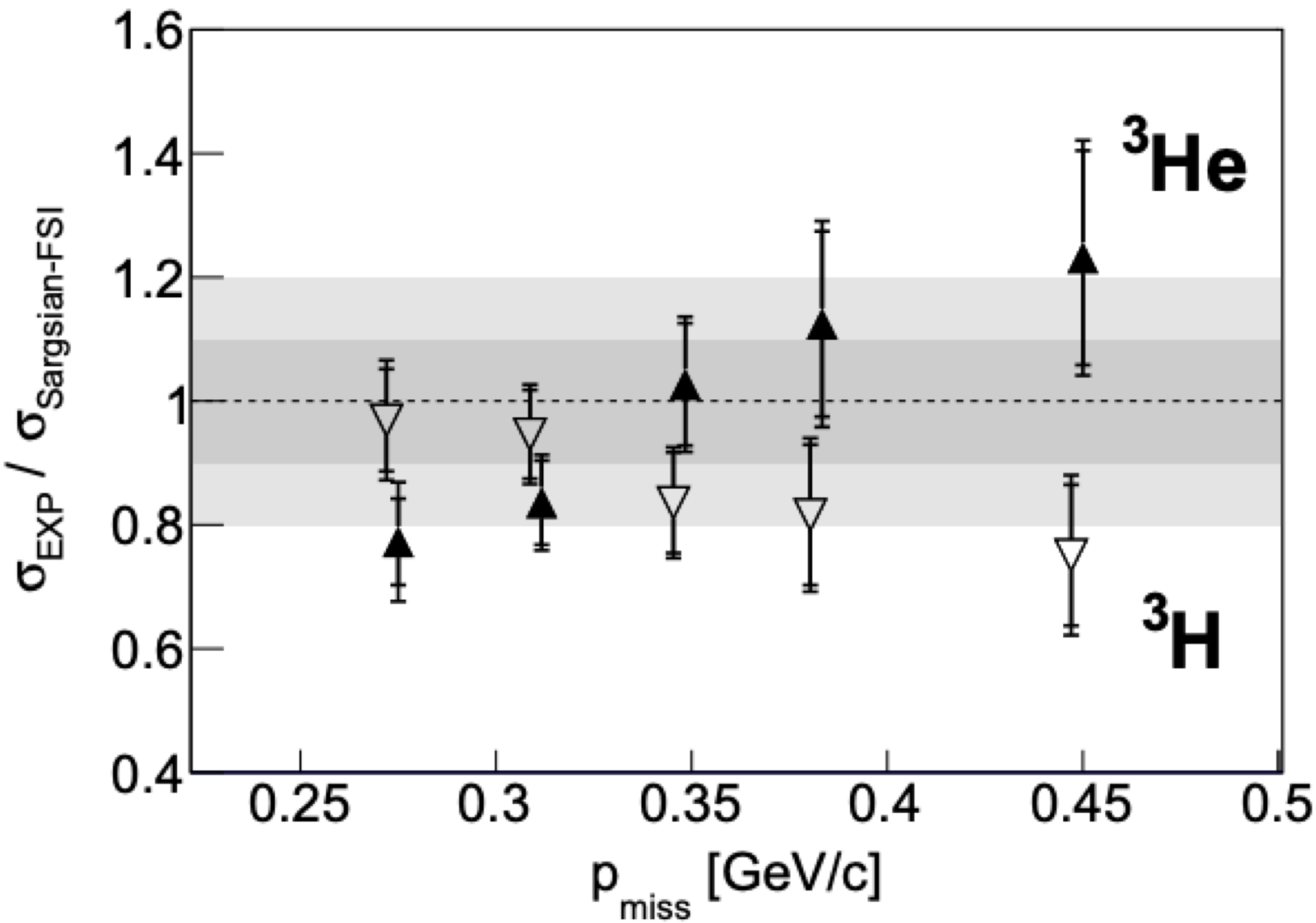


Anti-parallel kinematics are a huge improvement!

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

Absolute Cross Section Results



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

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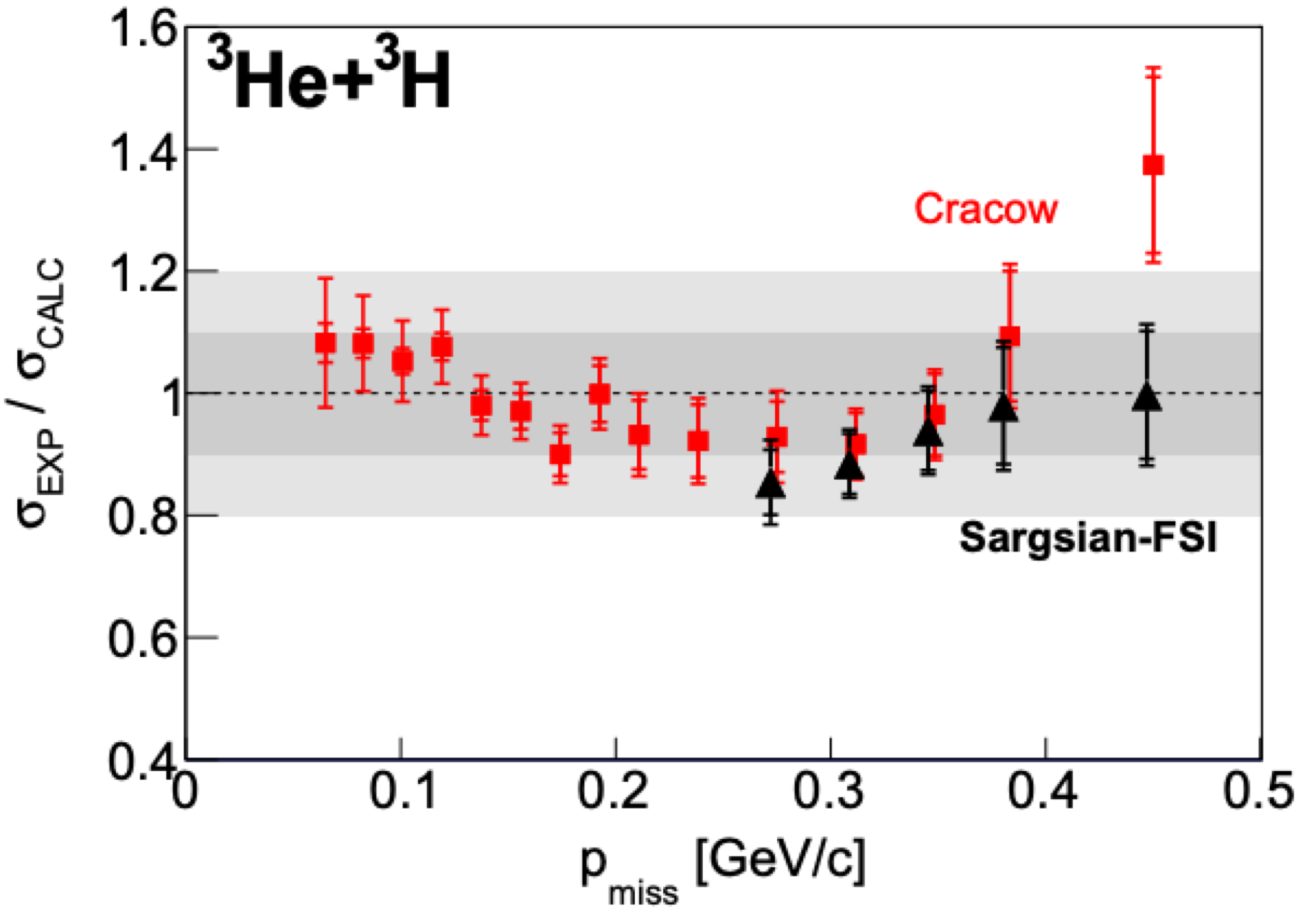


Isoscalar sum is robust to asymmetric final-state effects!

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

Lessons from Hall A Measurement

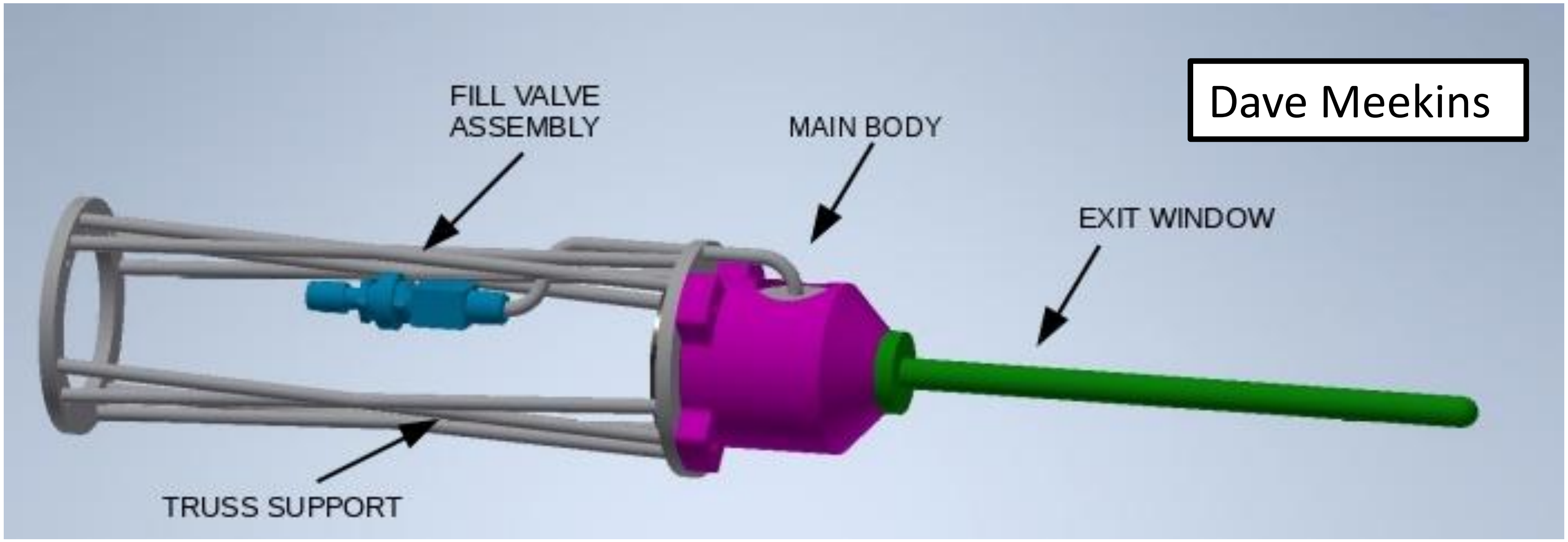
- Anti-parallel kinematics reduce effects of FSIs.
- Need absolute cross sections!
- Need both ^3He and ^3H (and deuterium too!)
  - Isoscalar sum

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

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.

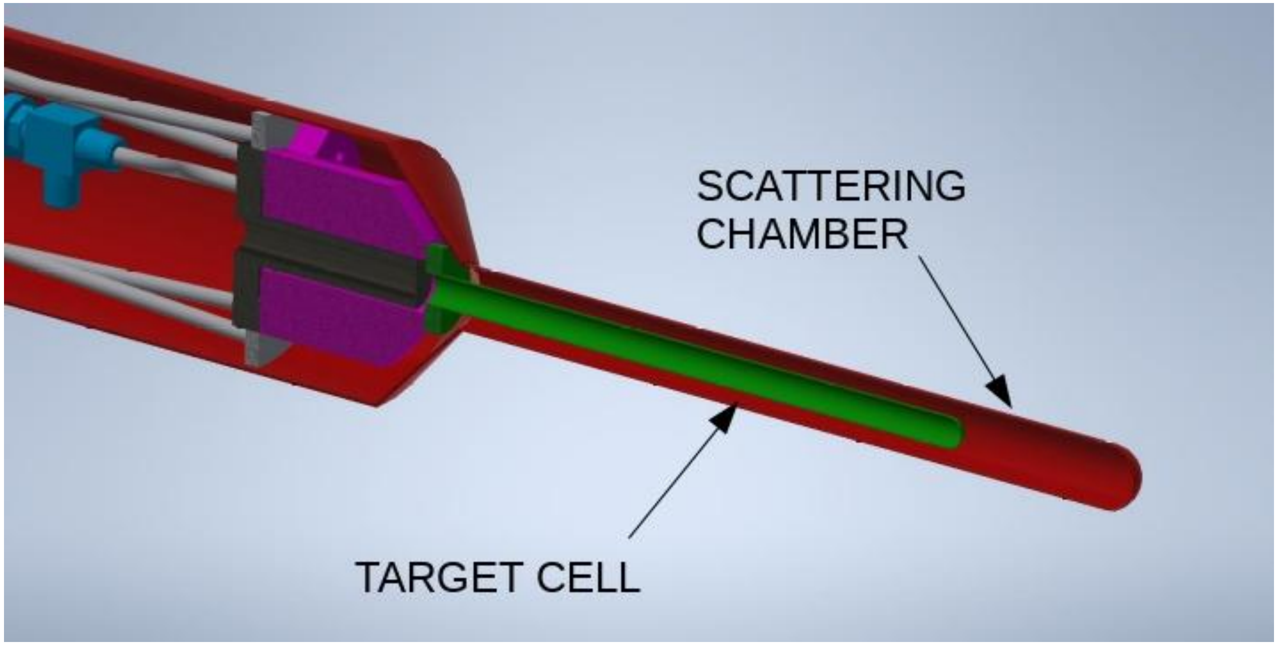
Target Design for Tritium @ CLAS12



- Sealed-cell for ^{3}H
  - 1.2 kCi
- Simple refillable cell for
  H, d, ^{3}He, empty
- 0.5 PAC days to change cells

- 25 cm total length
- Full azimuthal acceptance
- Full acceptance to 120˚
- Easier to fabricate than Hall A cell

Target Design for Tritium @ CLAS12



	Tritium	Al Windows	Be Window	Total
Thickness (mg/cm^2)	85	210	37	332
Luminosity ($10^{34} cm^{-2} s^{-1}$)	3.5	8.4	1.5	13.4

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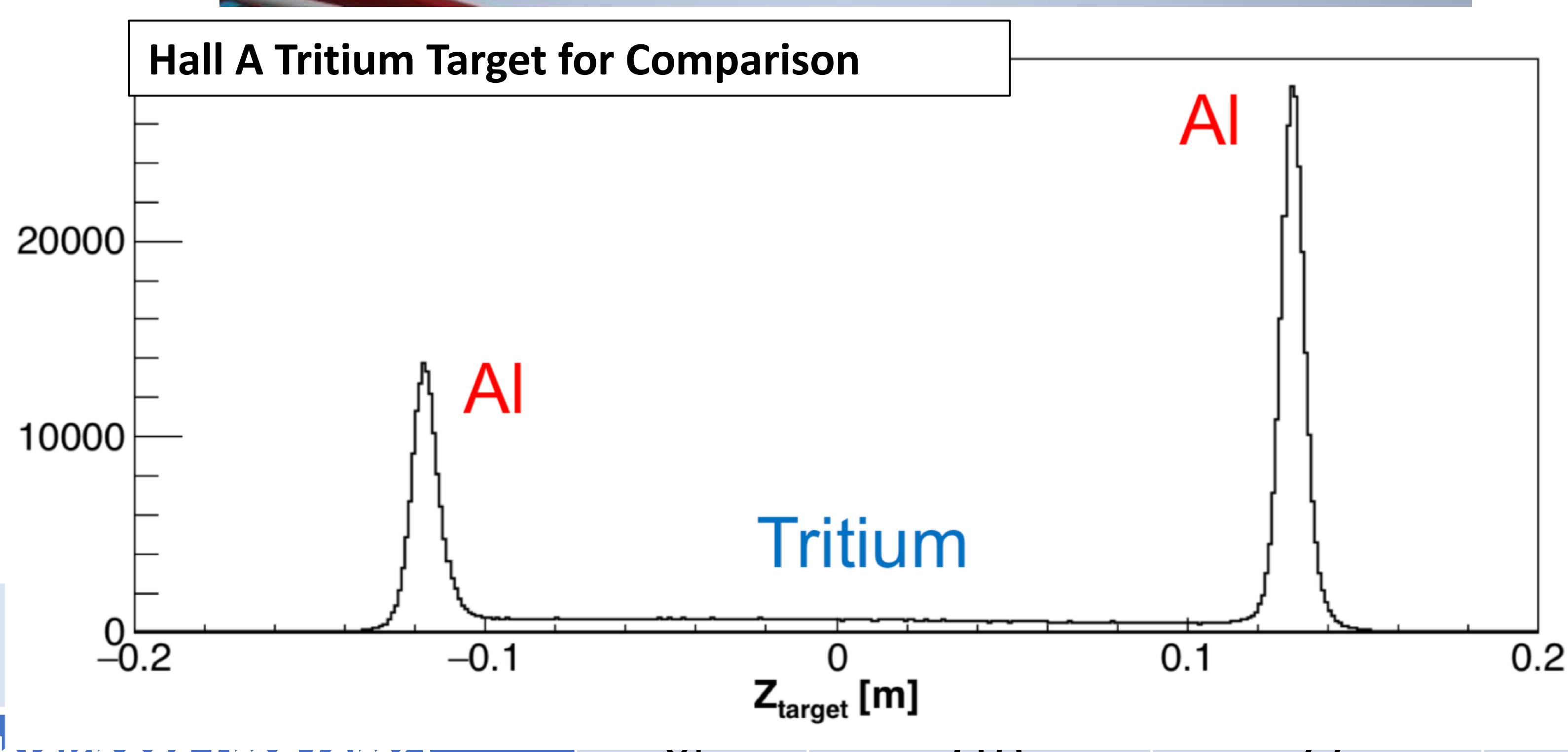

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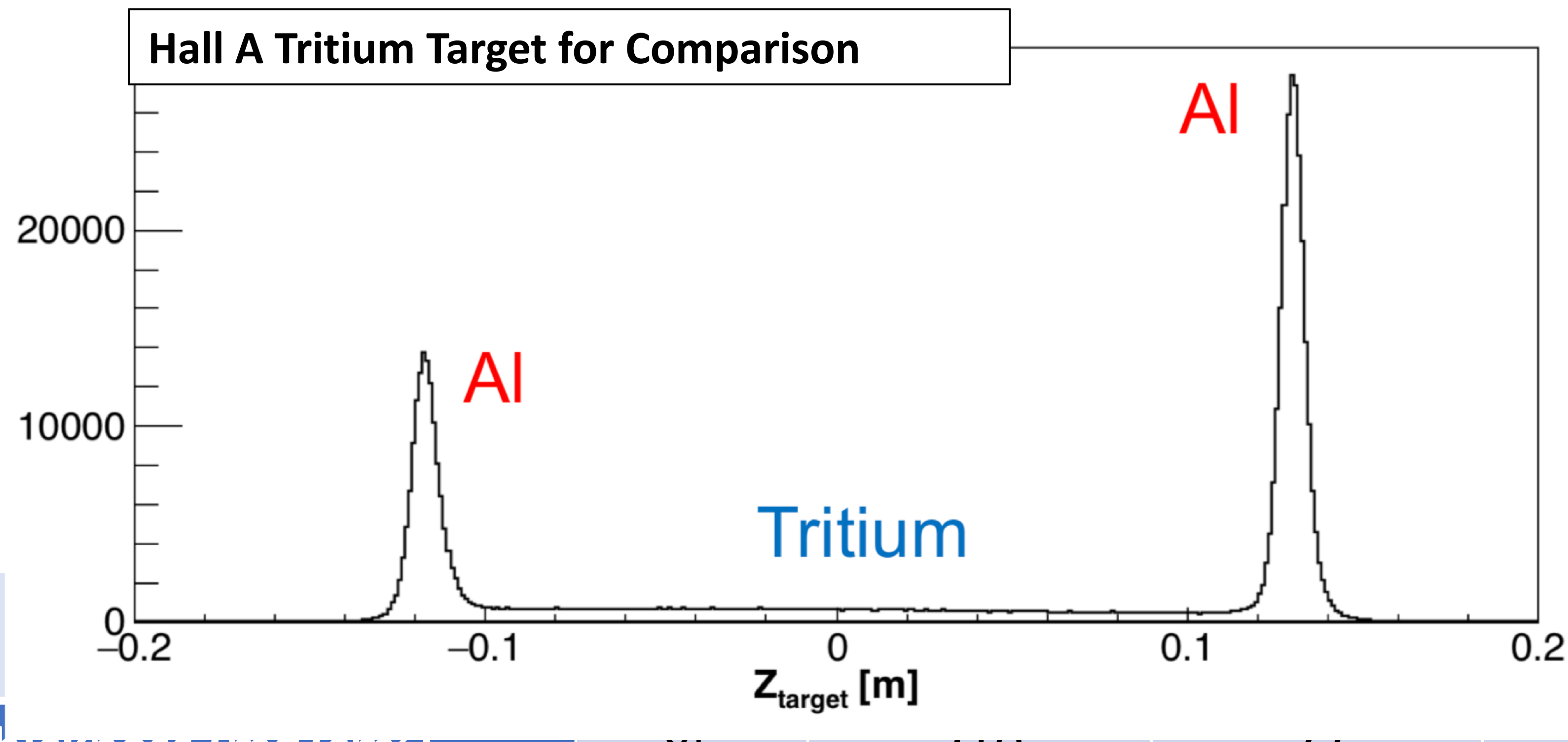

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Luminosity (10^{34}cm^{-2}s^{-1})	3.54	8.42	1.54	13.5

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

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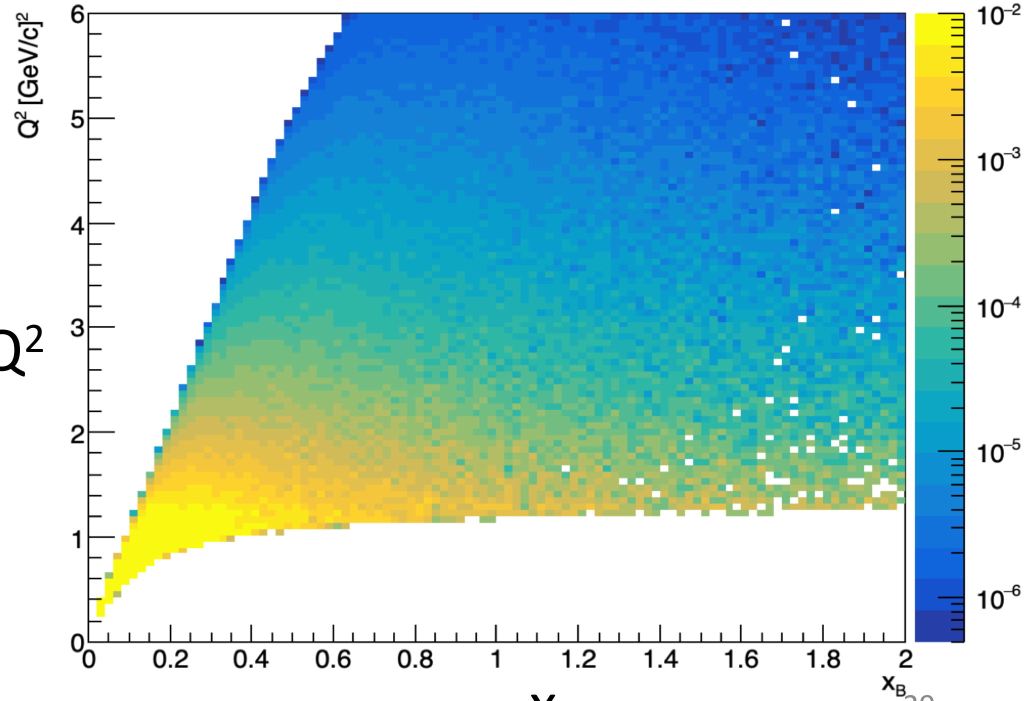
  - **In 60 days, we can tackle important questions.**

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

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

Inclusive Phase Space

E_b = 6.6 GeV, $\theta_{E'}$>10°



x_B

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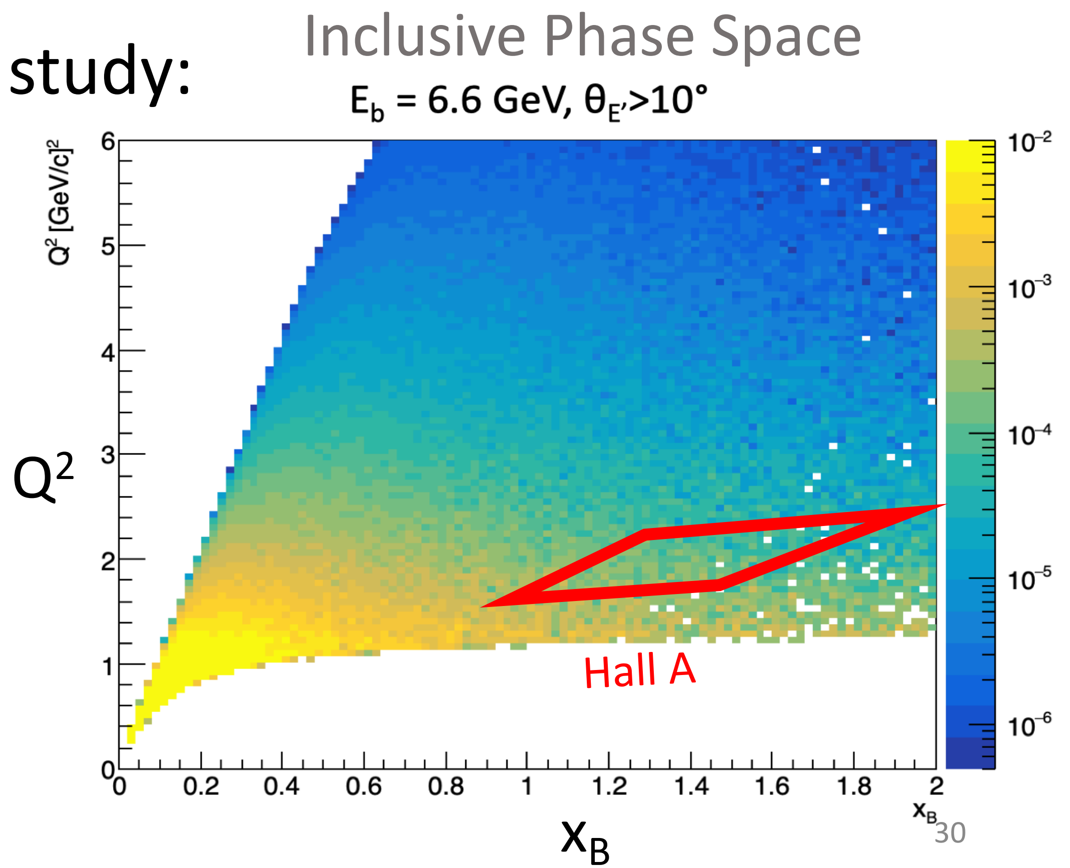

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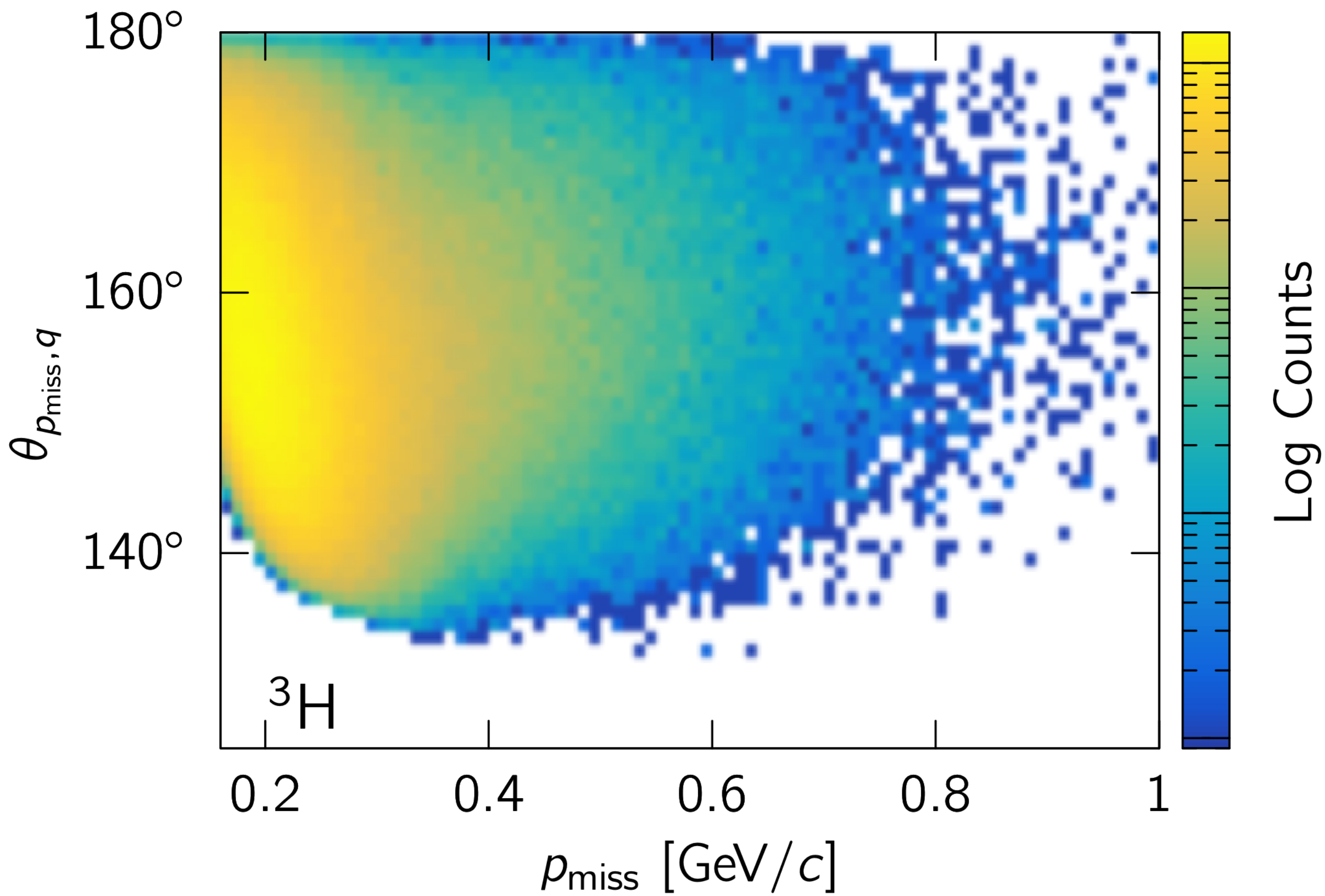

Cuts: Fiducial Acceptance, $x_B > 1.4$, $P_{miss} > 0.15$

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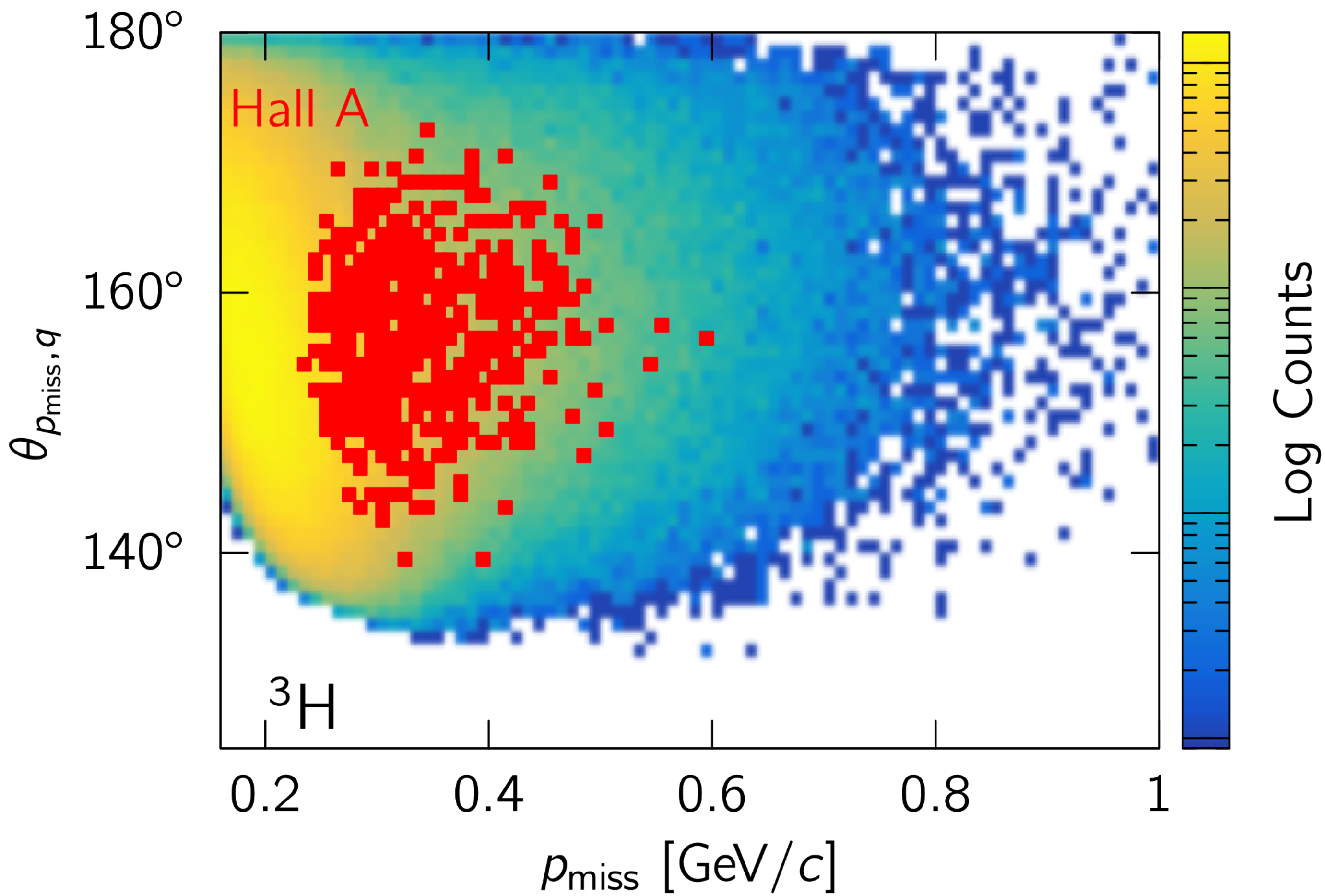

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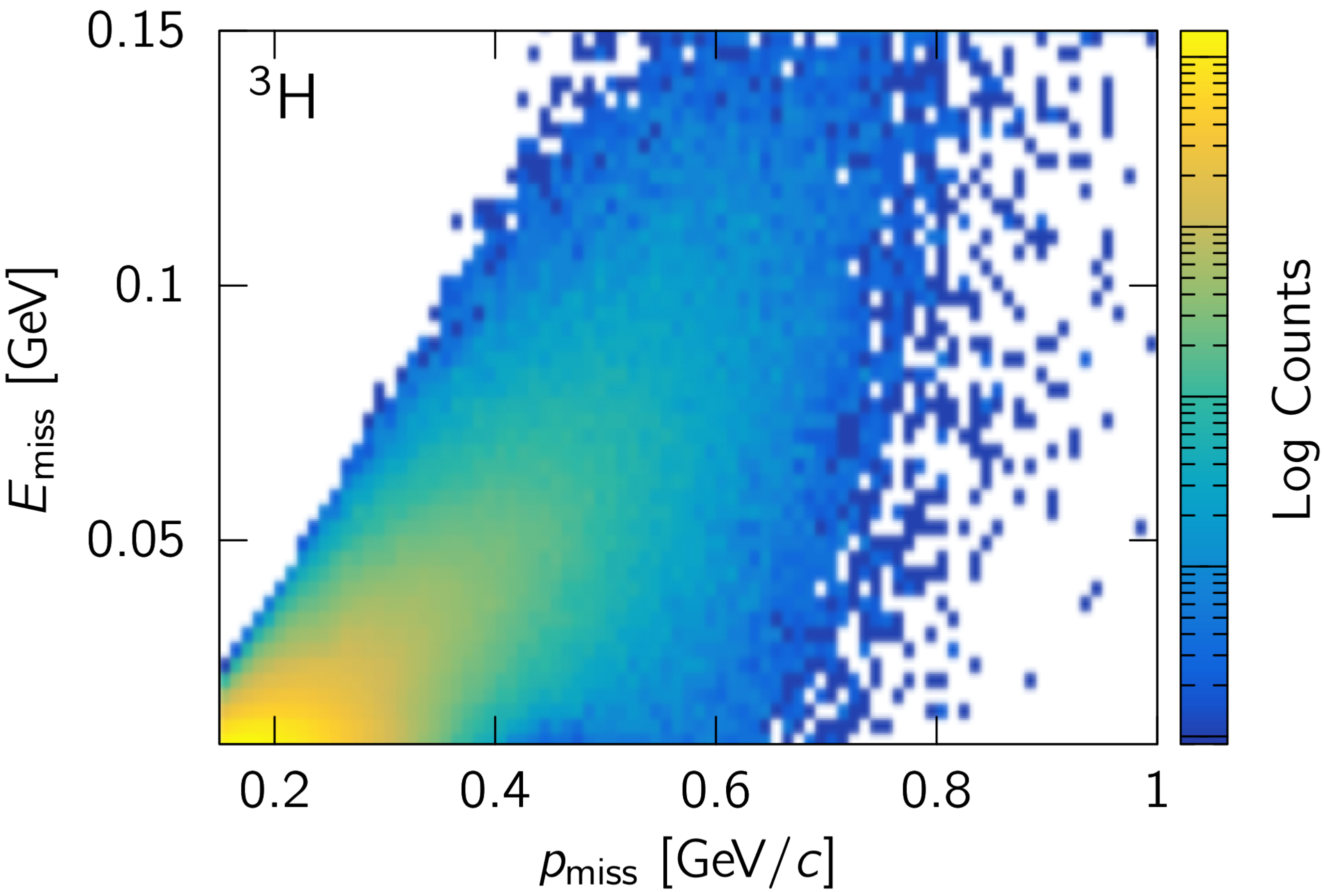

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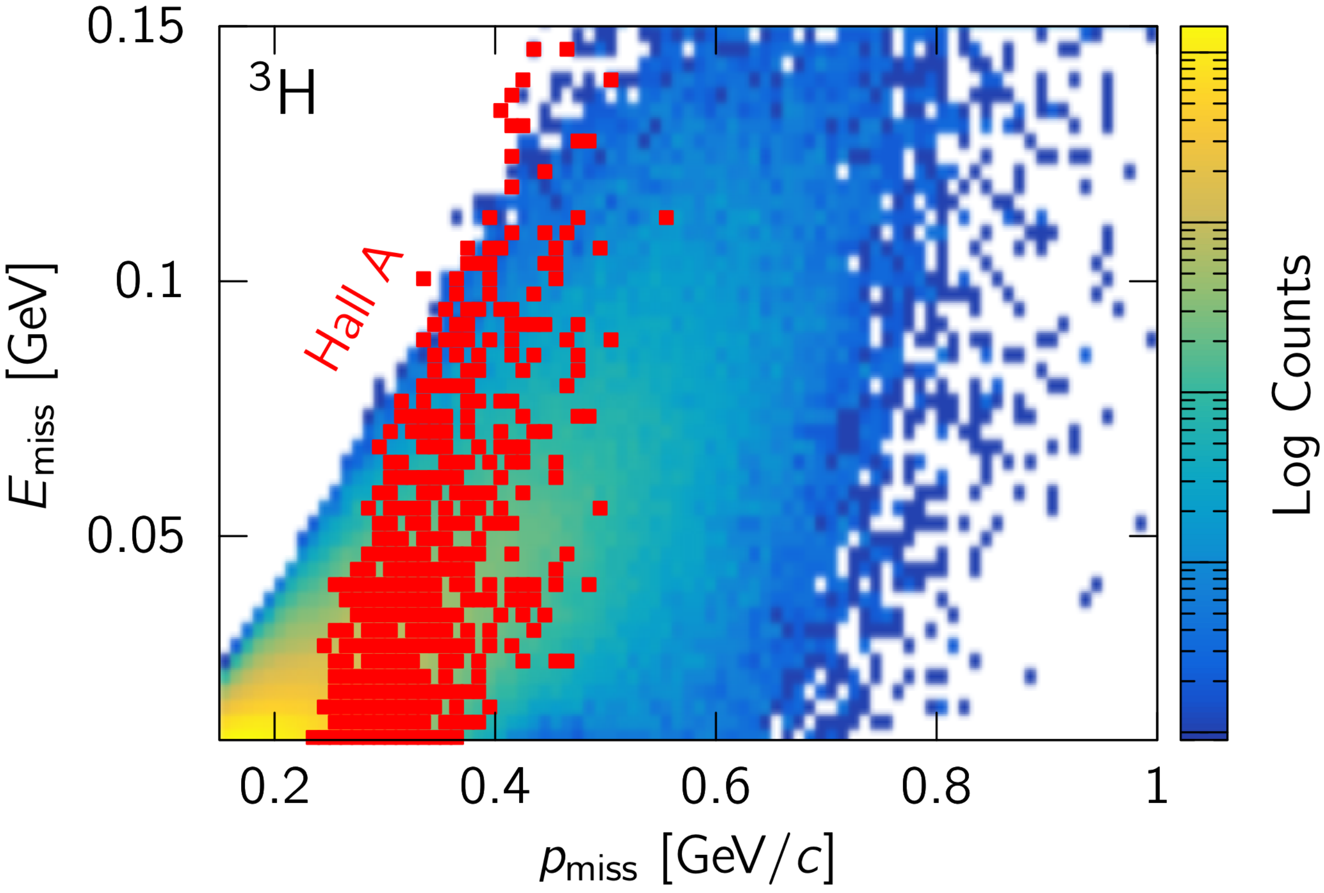


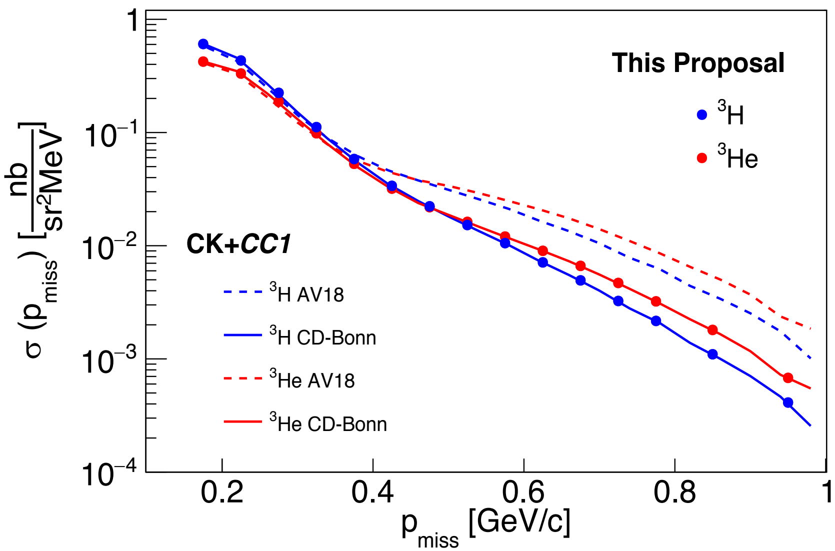
Cuts: Fiducial Acceptance, $x_B > 1.4$, $P_{miss} > 0.15$

A=3: Helium-3 + Tritium @ CLAS12

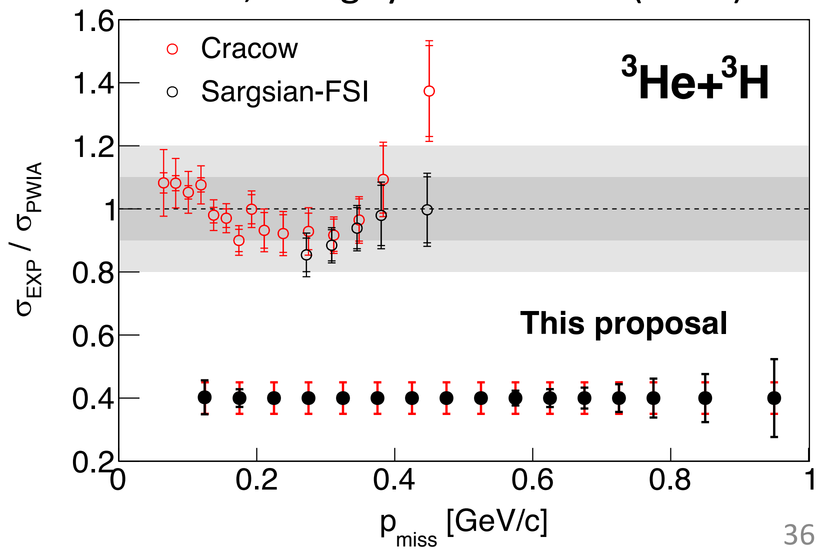
- **<u>Quasielastic on A = 3</u>**
  - (e,e'p): Few-Body nuclear Structure
  - (e,e'pN): SRCs
  - (e,e'): Neutron form factor

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

- ❑ Unique test of:
  - ❑ few-body nuclear structure.
  - ❑ 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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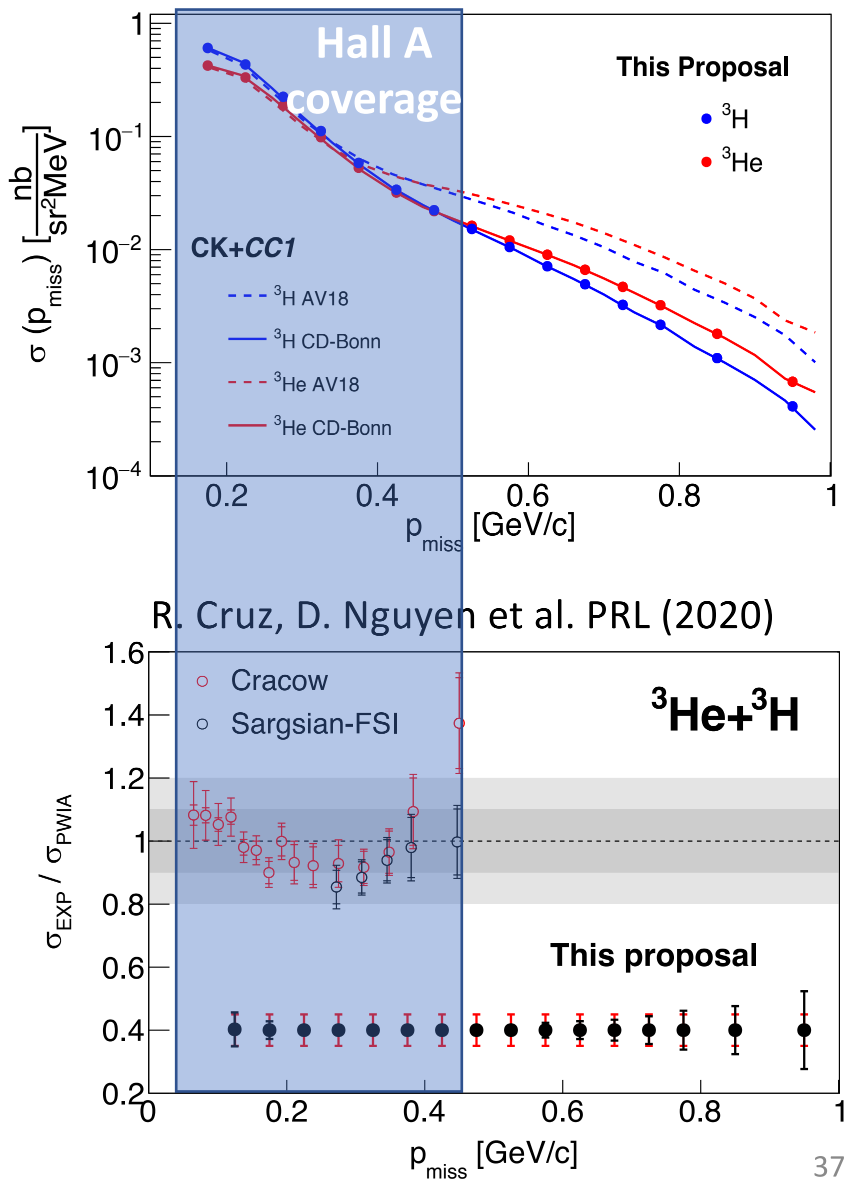


- ❑ CLAS12:
  - x0.1 luminosity
  - x100 acceptance
  - => x10 statistics + larger kinematical coverage!

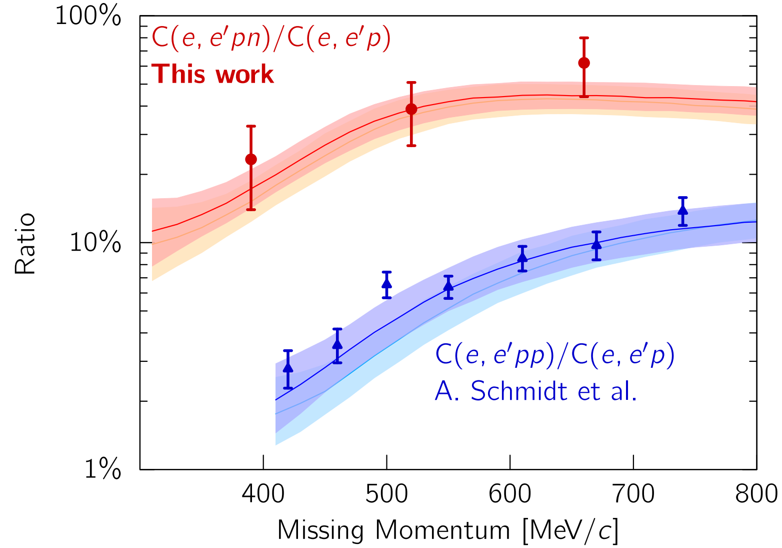
(e,e'pN): SRCs

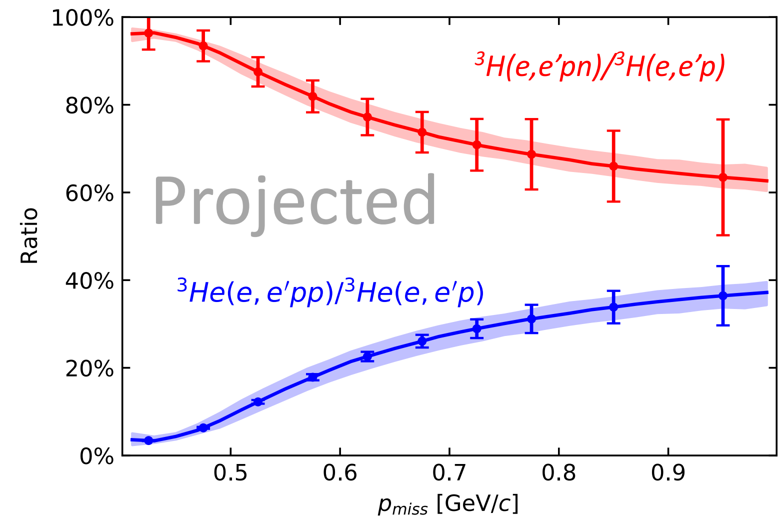
- ❑CLAS acceptance will allow multi-nucleon detection!

- ❑ Further suppression of final-state effects!

- ❑ Detailed map of isospin structure of short-range NN interaction

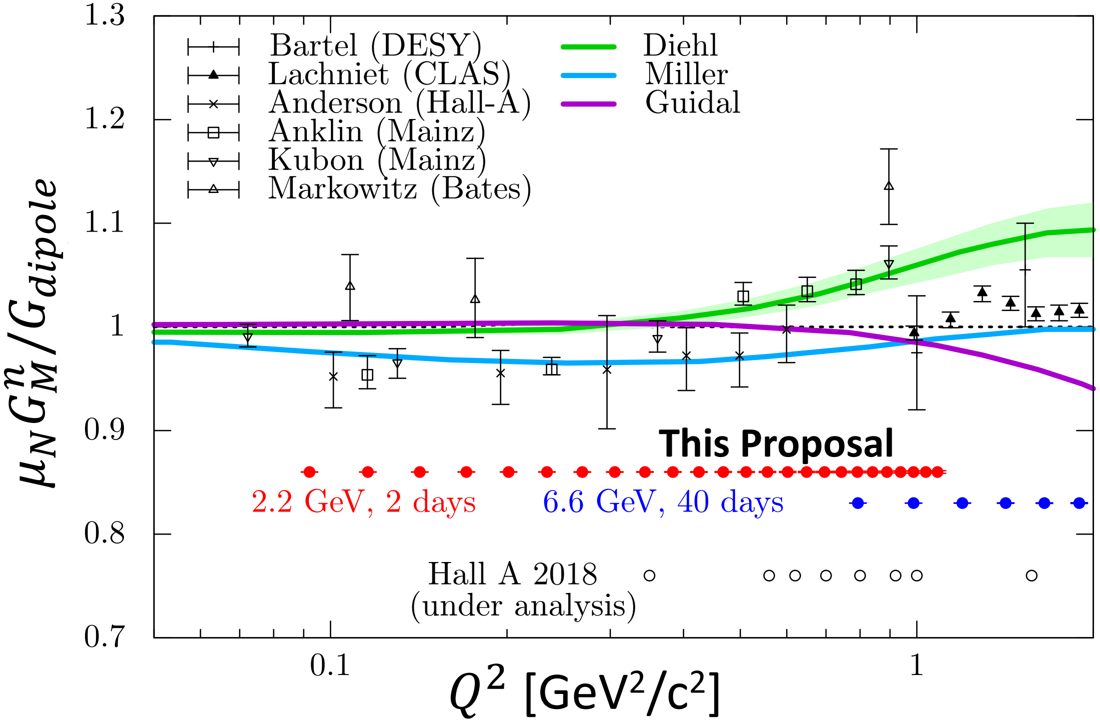
A. Schmidt et al., Nature (2020)
I. Korover et al., Submitted (2020)





(e,e'): Neutron Form Factor

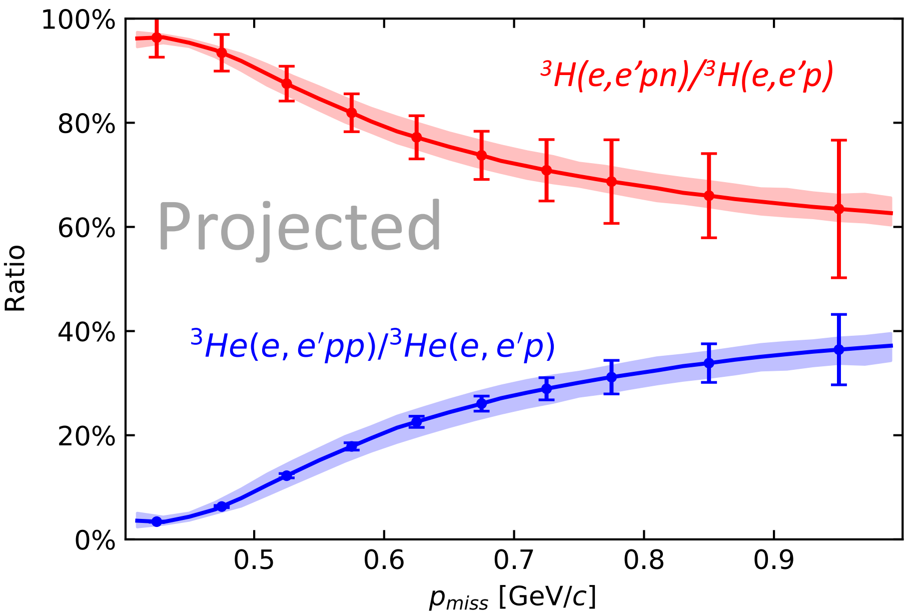
- **^{3}He(e,e') / ^{3}H(e,e') @ x_B = 1 sensitive to σ_n / σ_p**
  - Measured @ Hall A \w limited Q^2 coverage
- CLAS12 reaches down to Q^2 = 0.1
- Probe region of data/theory discrepancies
- Systematic errors orthogonal to those from other techniques
- Only need 2 days at 2.2 GeV!

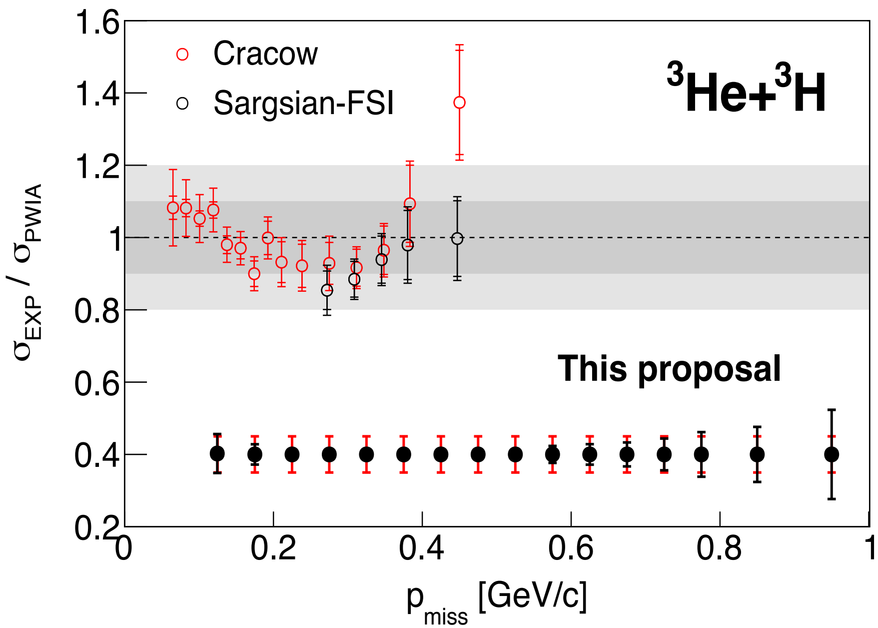


Adapted from J. Lachniet et al. PRL (2009)

Beam time requirement

Energy	H	d	^{3}He	^{3}H	Measurement	Calibr.	Target changes	Total
6.6 GeV	1	10	20	20	**51 days**	1	2	**54 days**
2.2 GeV	0.5	0	1	1	**2.5 days**	1	2	**5.5 days**
Total time requested								59.5 days

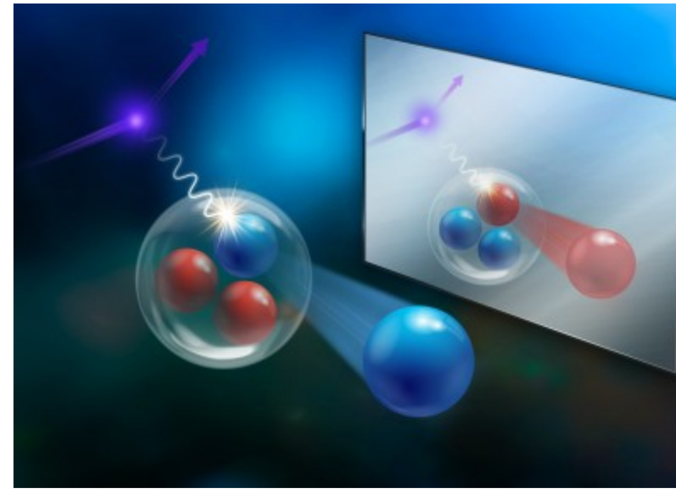


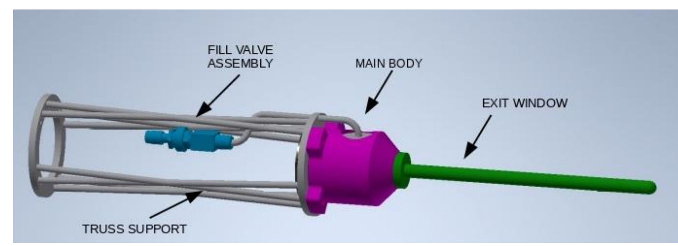


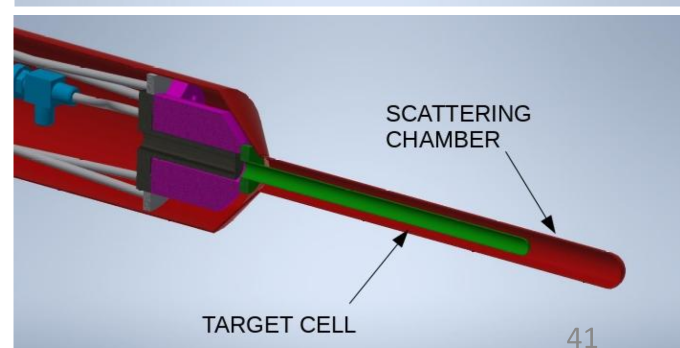
Summary

- 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!**

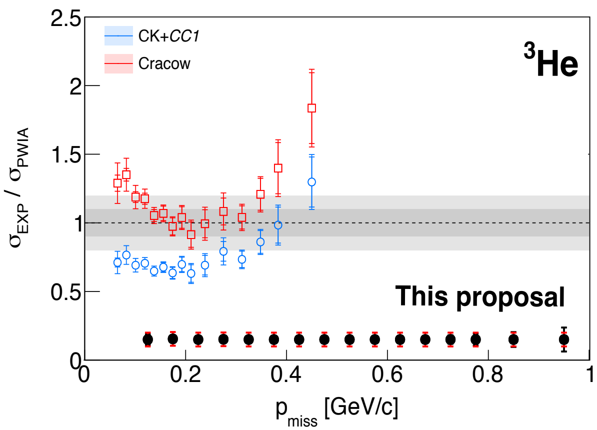
- Proposed experiment
  - CLAS-12 in standard configuration
  - Open e– trigger
  - 60 days on ^{3}He, ^{3}H, d at 6.6 and 2.2 GeV.
  - **New target system!**

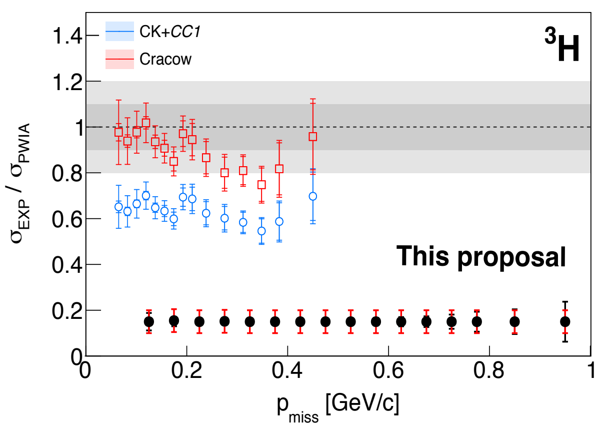


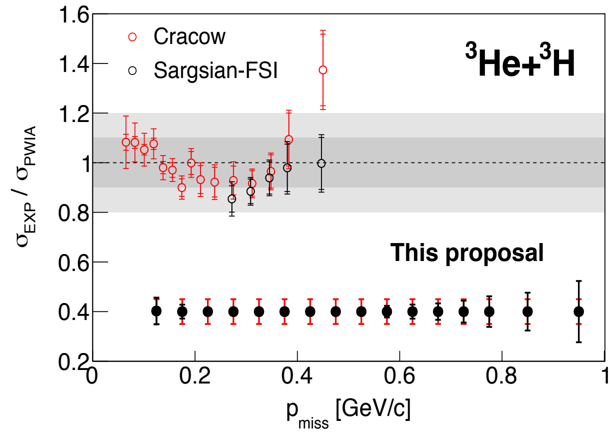


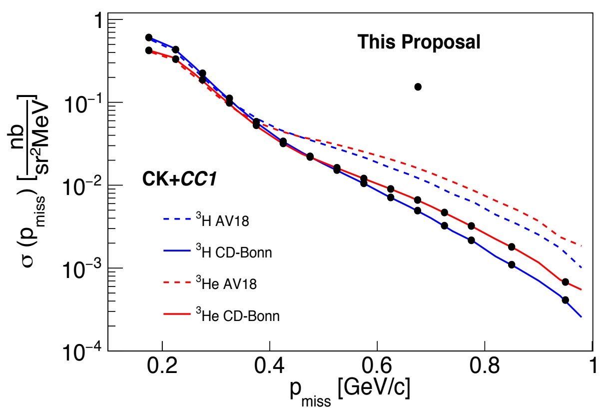


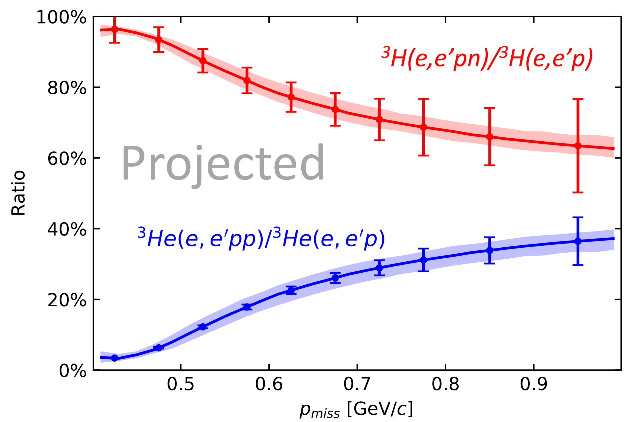
This measurement will produce many high-impact results!

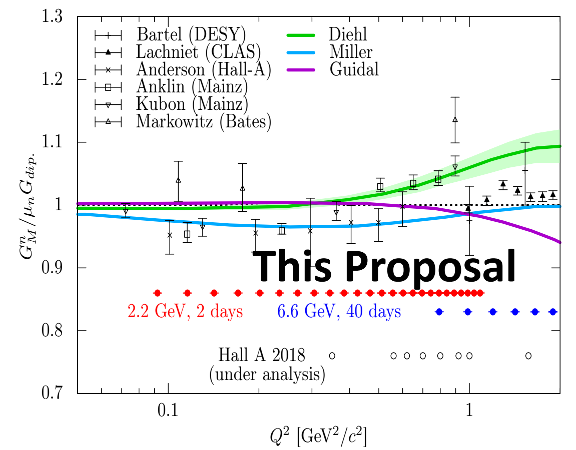












Back-Up Slides

Path Forward

- Unfortunately it is difficult to provide a timeline with any reasonable accuracy;
- We will work through the JLAB Experimental Readiness Review (ERR) process and a similar process at Savannah River Site to ensure both safety and compliance with applicable Codes and Standards.
- This process is expected to have the following steps:
    - Review of basic conceptual design which is the first step in the ERR process. (Expect 6 months to prepare)
    - Review of the final design of the target system. This includes all subsystems including the target cell, chamber, exhaust system, safety systems, etc. (1 year to prepare).
    - Acquire approvals from DOE OS, DOE NNSA, JLAB, SRS, DOT. Some of these approvals have already been realized but many will have to be repeated recognizing the unique features of the Hall B system. Some of these steps may also be completed while the final design is under development. (Expect 3-9 months).
    - Review/inspection of final installation with full checks of all systems for operability. (1 month)
    - We expect ~2 to 2.5 years total to complete the process which is in line with the Hall A experience.

Applicable Codes, Standards, Polices etc.

- To give some appreciation for the design, fabrication, and approval processes, a selected subset of the Codes, laws, regulatory agencies, and policies which need to be addressed is given below:
  - Code of Federal Regulations:
    - 10 CFR 851, 71, 20
    - 49 CFR 172 and 173 (DOT HAZMAT)
    - NEPA National Environmental Policy Act
  - DOE Orders: 460.1, 441.1, 458.1
  - DOE NNSA Packaging, Shipping, Filling, Handling, Security
  - DHS/DOE NMCA
  - SRS safety basis
  - JLAB pressure safety and Radiation Control
  - JLAB ERRs
  - Codes:
    - ASME BPVC VIII D1 and D2 and IX, B31.3, STC-1
    - AWS D1.1 and 1.6

Tritium To JLAB

Shipping Is not Easy

Tritium is

HAZMAT

Radio Active Material

Nuclear Material (NNSA)

Pressurized Gas

Regulators:

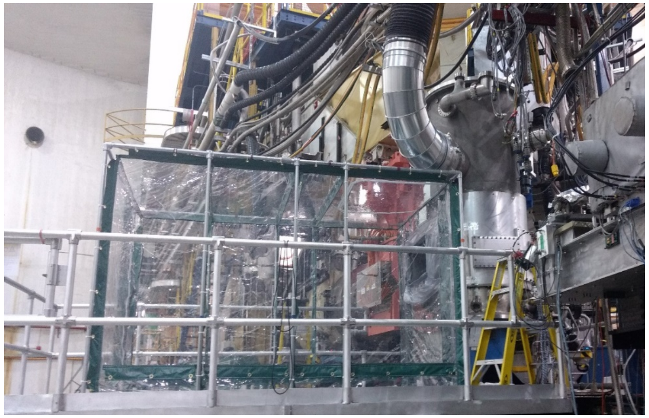
- USDOE OS
- USDOE NNSA
- NRC
- DOT

BTSP
Was almost ready for our config

Exhaust System/Confinement

Target Exhaust System and Stack

Transfer Hut



Exhaust System/Confinement

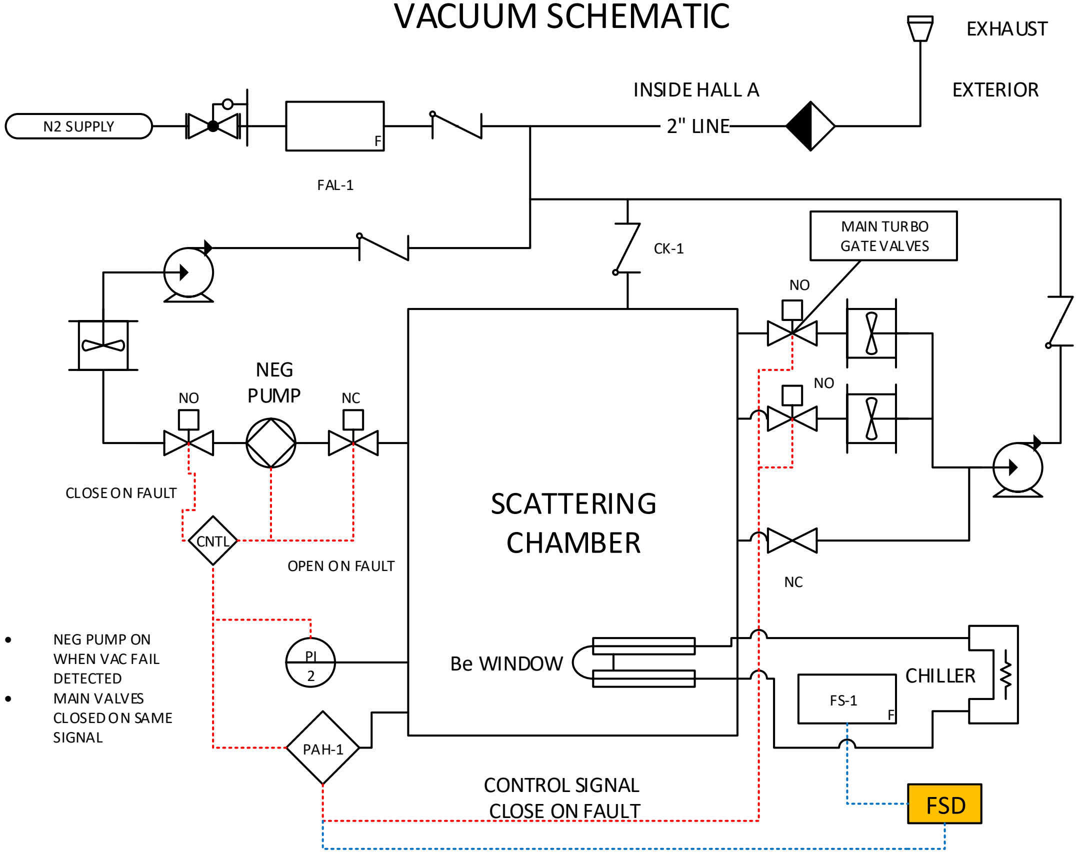
Target Exhaust System and Stack

Transfer Hut

Vacuum System

- Scattering chamber (standard Hall A)
  - 1900 liters
  - Thin sections for recoil particles (0.014” aluminum)
- Two 800 l/s turbos backed by Leybold D60 Mech pump
- NEG Pump with backing turbo and mech pumps
- Vacuum exhaust part of Tritium Exhaust System and is continuously purged with N2 (1 cfm)
- Isolated from upstream beamline vacuum (Be window)
- Remote RGA may help diagnose leaks. Serve as leak detector.

VACUUM SCHEMATIC

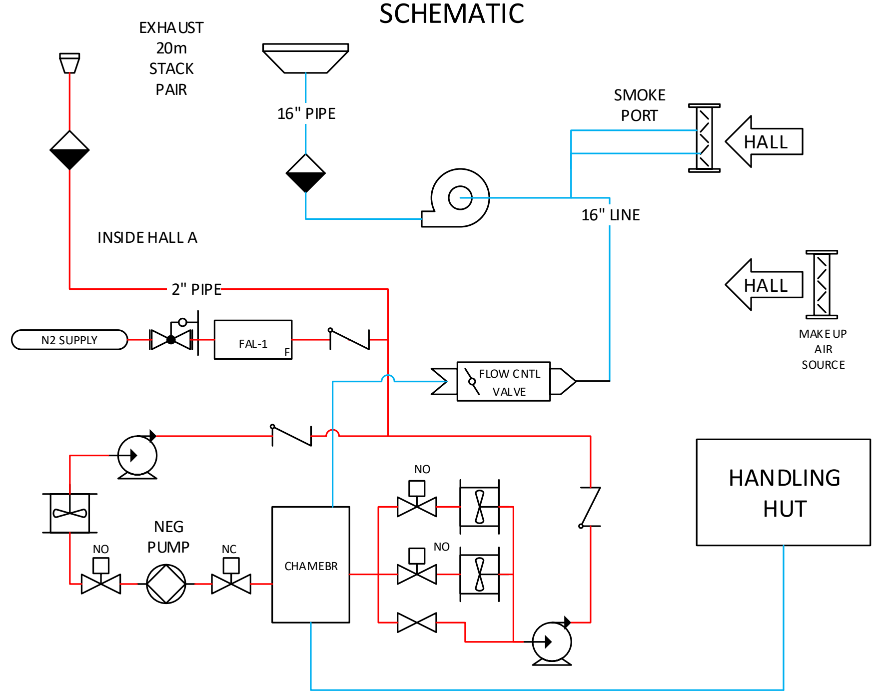


- NEG PUMP ON WHEN VAC FAIL DETECTED
- MAIN VALVES CLOSED ON SAME SIGNAL

Exhaust System

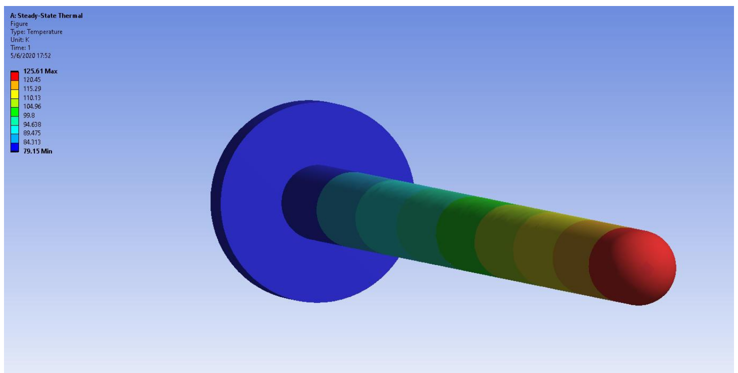
- 24” OD 20m tall Stack
- 12000 cfm blower multispeed
- 2” pump exhaust
    - Run parallel to stack
- Stack must also serve as smoke removal
- Provides controlled release of secondary and tertiary containment
- Pump exhaust is continuous
- Blower activated:
    - Manual
    - Interlocks

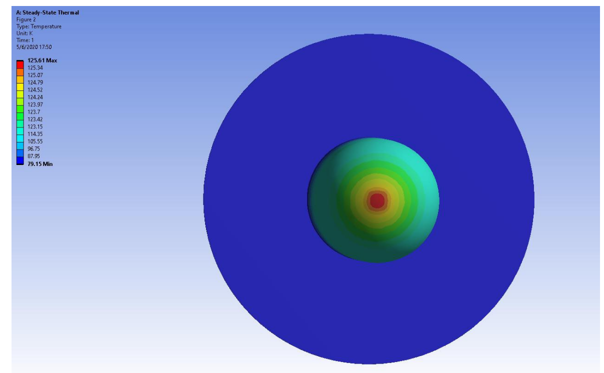
TRITIUM EXHAUST SYSTEM SCHEMATIC



Target Design continued…

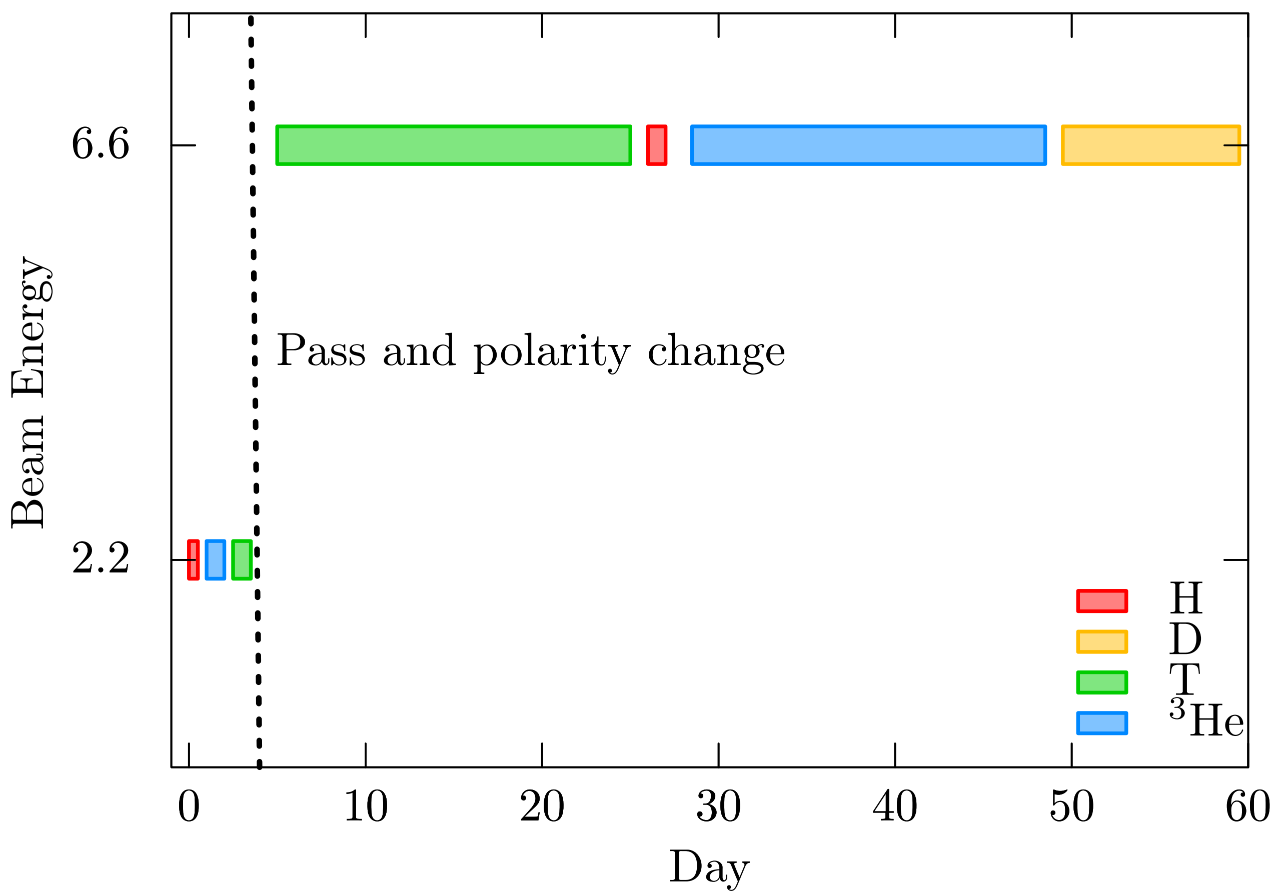
- Operating Temp ≈ 50 K at 100 nA
- Heat load < 1W, mostly on windows





- Slightly different density for each gas
  - H_2: 2.75 mg/cc 68.75 mg/cm^2
  - D_2: 5.00 mg/cc 125.0 mg/cm^2
  - T_2: 3.30 mg/cc 82.5 mg/cm^2
  - ^{3}He: 4.10 mg/cc 102.5 mg/cm^2

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**

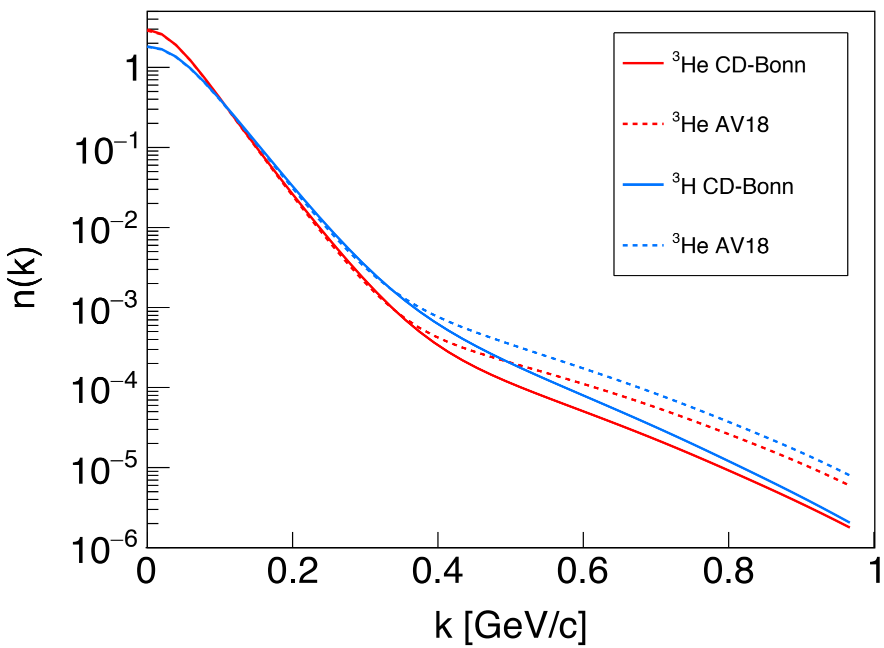
1E35 on empty tritium target			
		damage rate	
particles:	**krad/yr**	**rate (MHz)**	**1 MeV neutron damage rate**
electrons	6.5	7.6	0.2
pions		1.1	0.7
neutrons	0	0.025	0.021
protons	27	2.5	14.5
gamma	0.5		
pi-	2.6		
pi+	2.8		
e+	1.5		
Total:	**44.8**	**11.2**	**15.4**

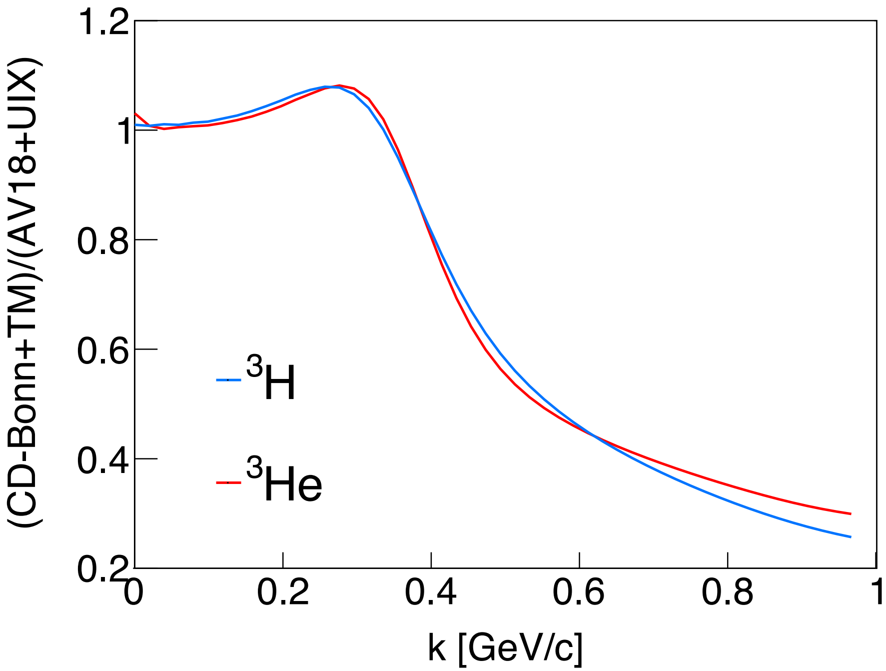
1E35 on LH2 5cm nominal target			
		damage rate	
particles:	**krad/yr**	**rate (MHz)**	**1 MeV neutron damage rate**
electrons	6	11	0.1
pions		1.3	0.9
neutrons	0	0.019	0.021
protons	19.5	2	13.4
gamma	1.4		
pi-	4.2		
pi+	7.2		
e+	1.9		
Total:	**41.5**	**14.3**	**14.4**

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**

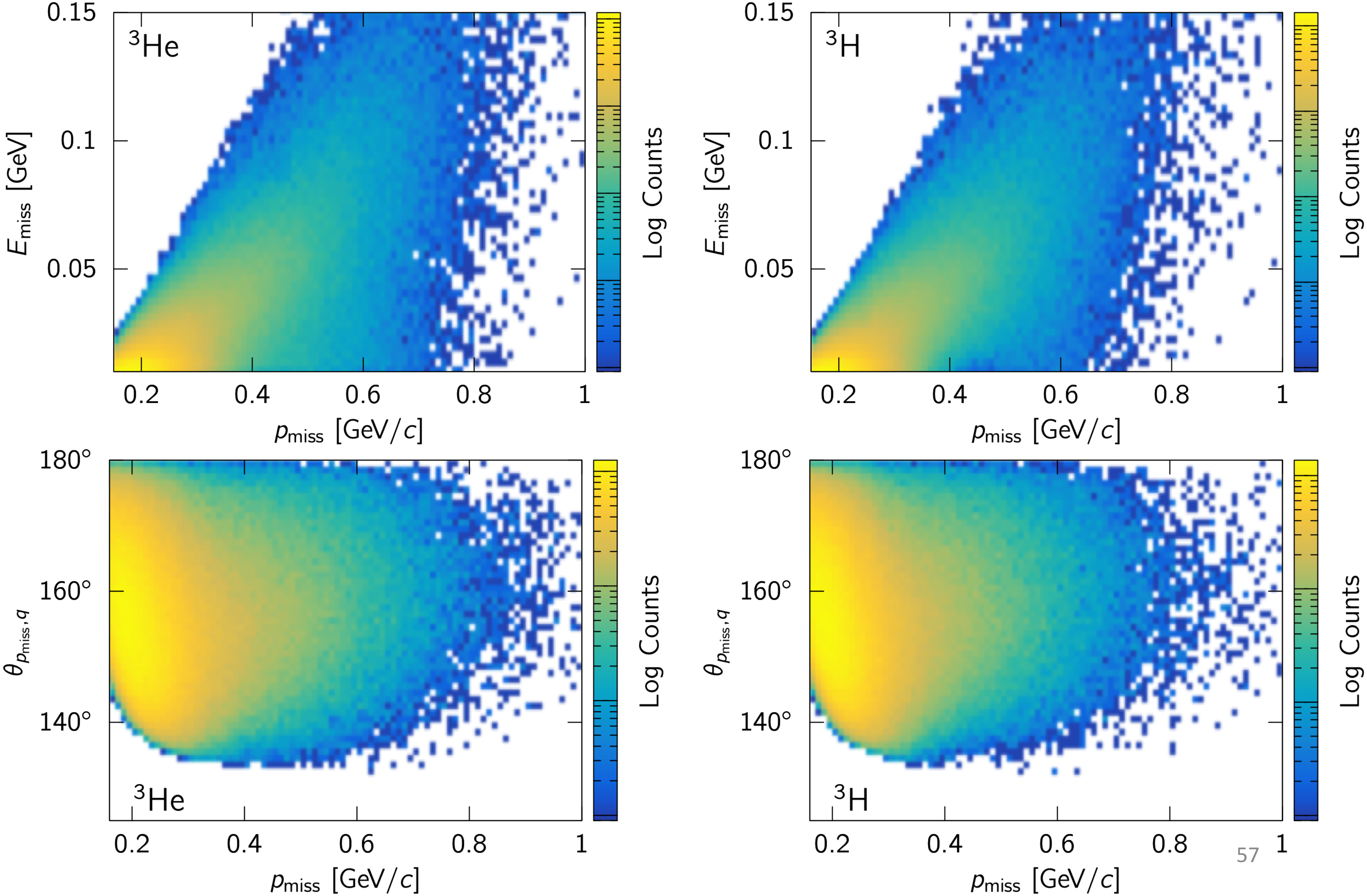
Momentum distributions

- AV18+UIX
- CD-Bonn+TM

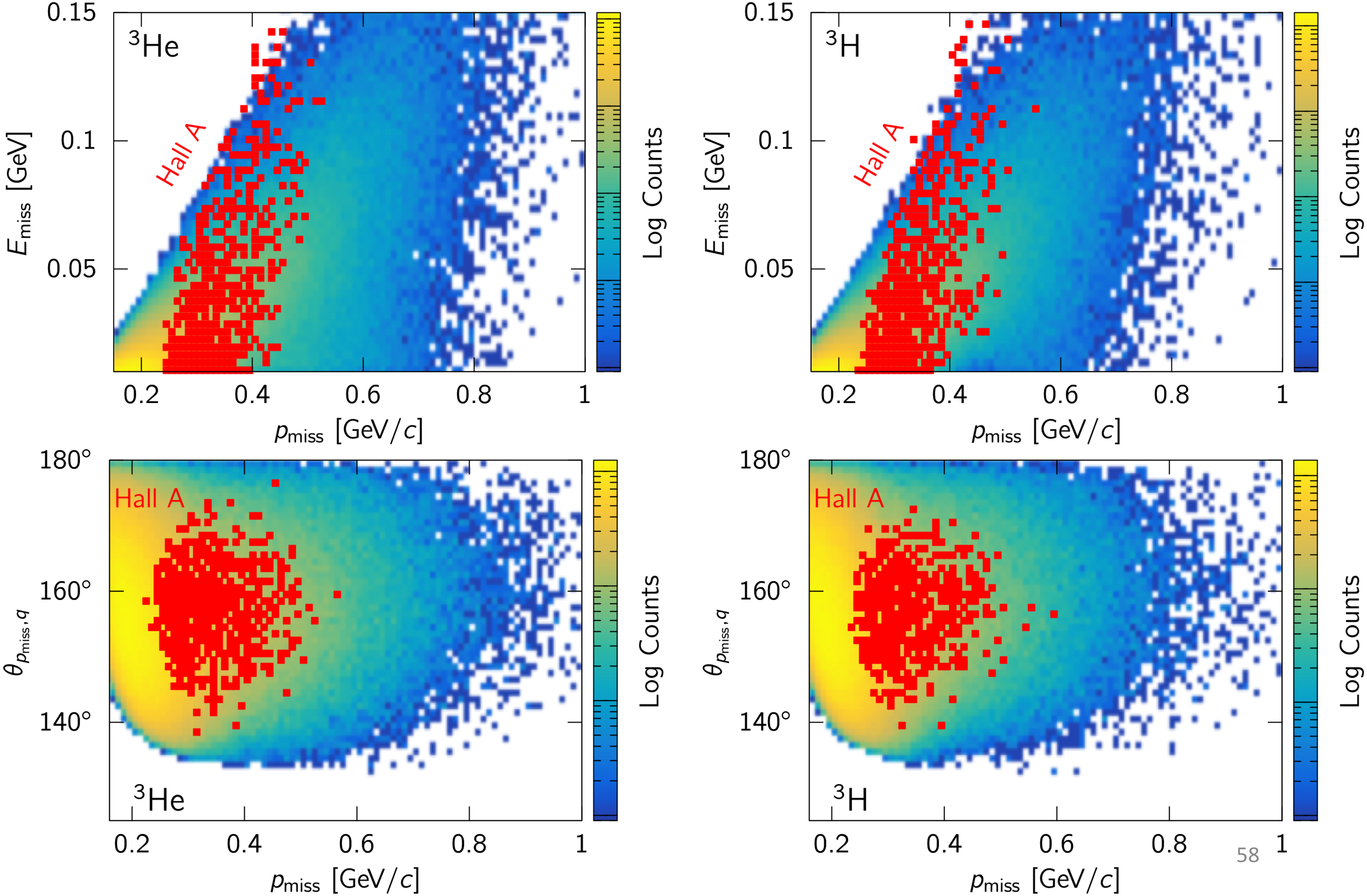




Similar Kinematic Distributions for He-3 and H-3

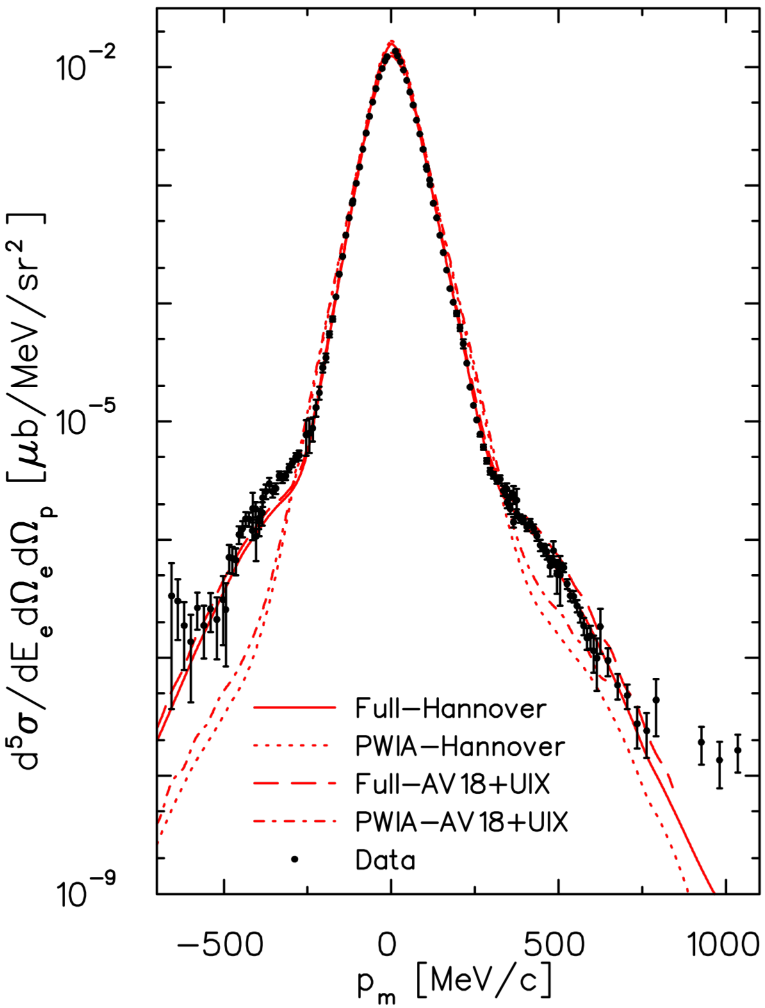


Similar Kinematic Distributions for He-3 and H-3



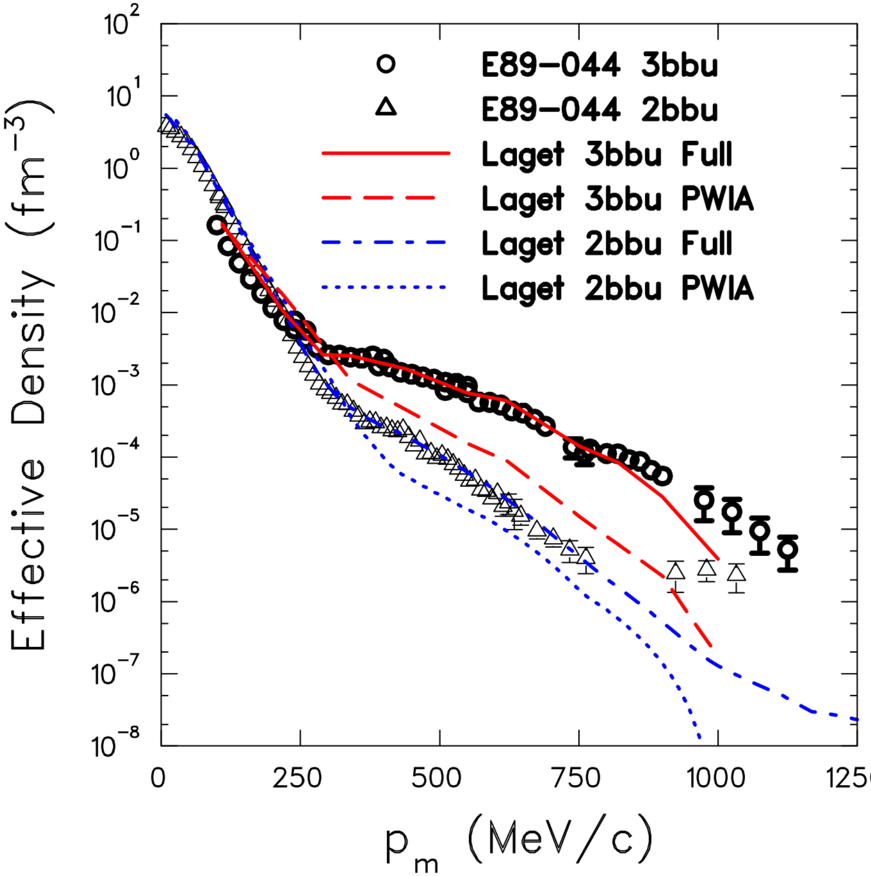
Results on $^{3}He(e,e'p)$ from Hall A, near x_B=1

2-body break-up



M. M. Rvachev et al., PRL 94, 192302 (2005)

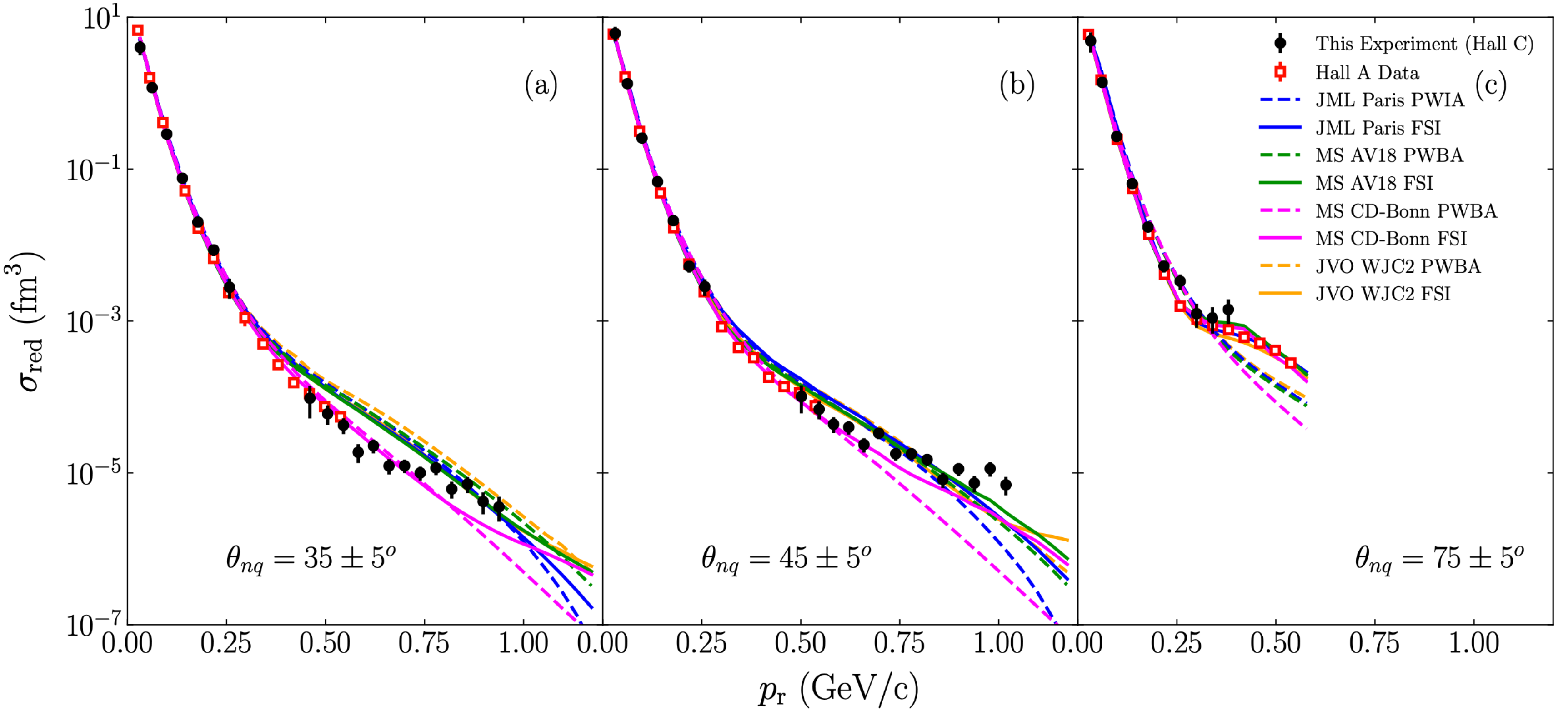
3-body break-up



F. Benmokhtar et al., PRL 94, 082305 (2005)

Preliminary results on d(e,e’p) from Hall C

(C. Yero, W. Boeglin, M. Jones et al., in preparation)



Preliminary results on d(e,e'p) from Hall C

(C. Yero, W. Boeglin, M. Jones et al., in preparation)