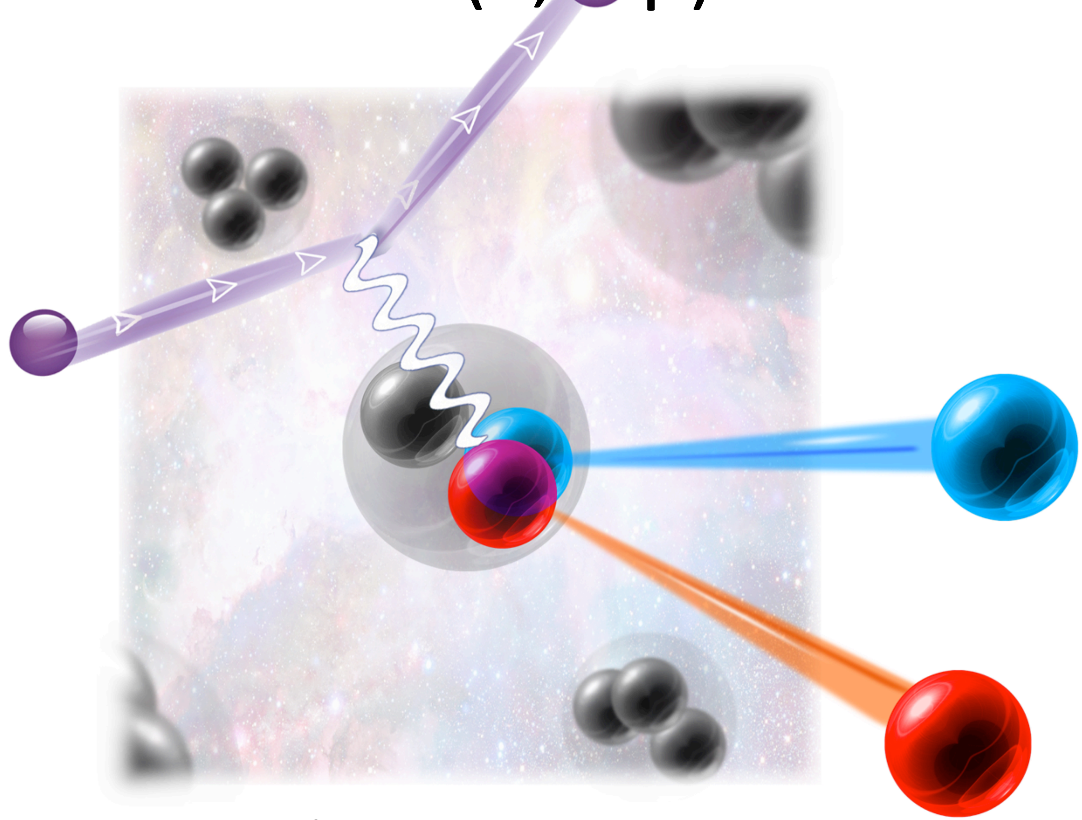
Comparing proton momentum distributions in A=3 nuclei via ^{3}He and ^{3}H(e, e′p) measurements



Reynier Cruz Torres

2nd Workshop on Quantitative Challenges in SRC and EMC Research

March 20th, 2019

Hen Lab

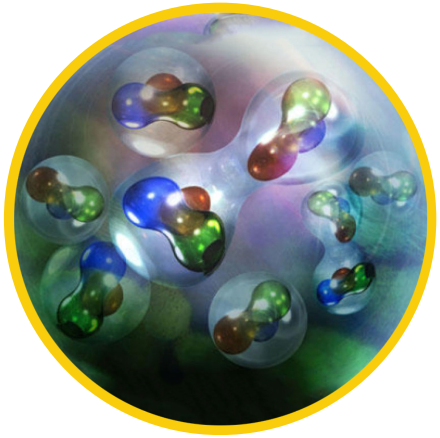
Laboratory for Nuclear Science @ MIT

Jefferson Lab

Nucleon-nucleon interaction

Crucial for:
- Ab-Initio nuclear structure calculations
- understanding dense astrophysical objects such as neutron stars

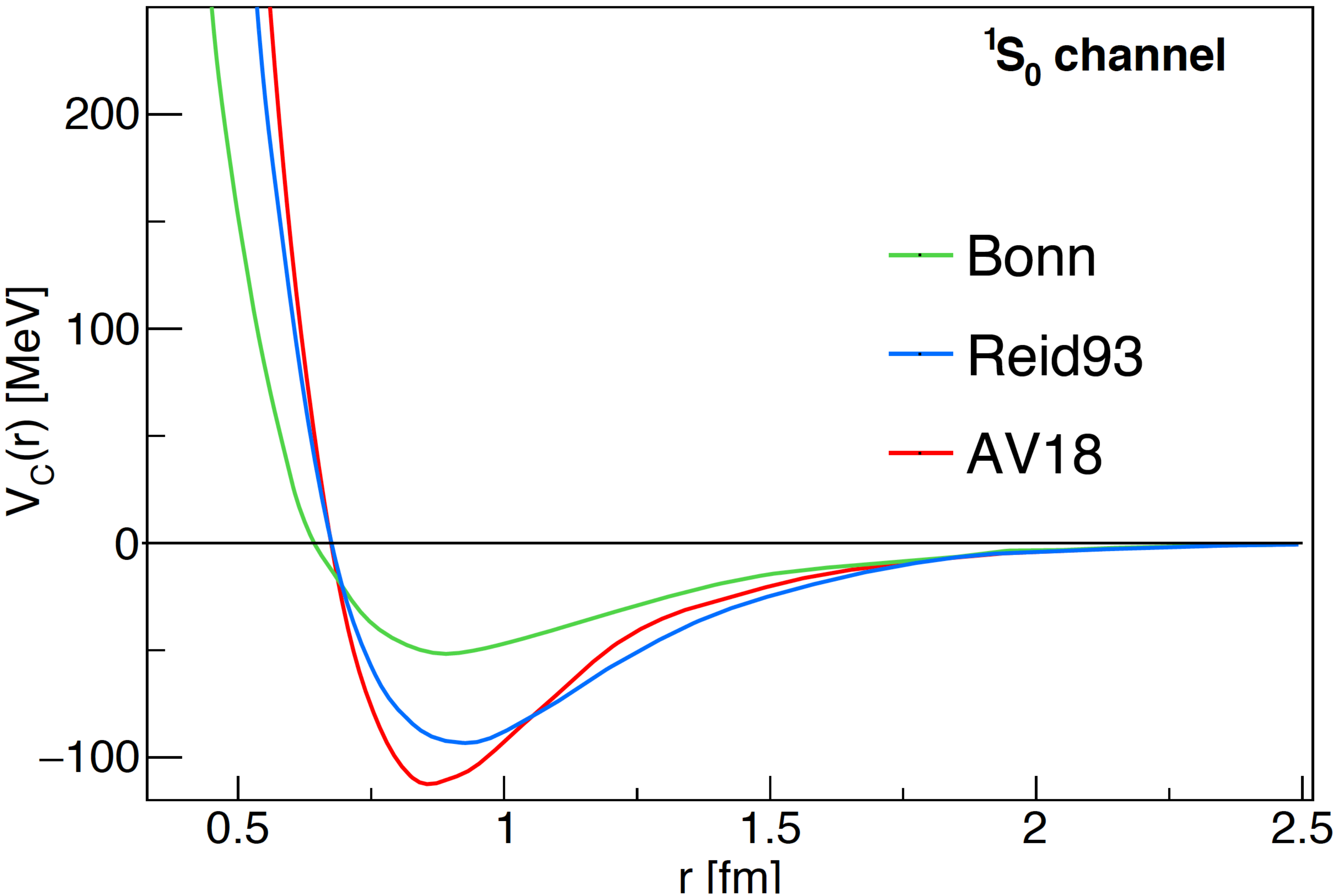
Strong nuclear force, Coulomb force, spins, magnetic moments ...



There are many NN potential models…

- Hamada-Johnston Potential
- Yale-Group Potential
- Reid68 Potential
- Reid-Day Potential
- Partovi-Lomon Potential
- Paris-Group Potentials
- Stony-Brook Potential
- dTRS Super-Soft-Core Potentials
- Funabashi Potentials
- Urbana-Group Potentials
- Argonne-Group Potentials
  - Argonne V14
  - Argonne V28
  - Argonne V18
- Bonn-Group Potentials
  - Full-Bonn Potential
  - CD-Bonn Potential
- Padua-Group Potential
- Nijmegen-Group Potentials
  - Nijm78 Potential
  - Partial-Wave-Analysis
  - Nijm93
  - NijmI
  - NijmII
  - Reid93 Potential
  - Extended Soft-Core
  - Nijmegen Optical Potentials
- Hamburg-Group Potentials
- Moscow-Group Potentials
- Budapest(IS)-Group Potential
- MIK-Group Potential
- Imaginary Potentials
- QCD-Inspired Potentials
- The Oxford Potential
- The First CHPT NN Potentials
- Sao Paulo-Group CHPT Potentials
- Munich-Group CHPT Potentials
- Idaho-Group CHPT Potentials
- Bochum-Julich-Group CHPT Potentials
  - LO Potentials
  - NLO Potentials
  - NNLO Potentials
  - NNNLO Potentials
- **and more!**

…still, short-range behavior in unconstrained



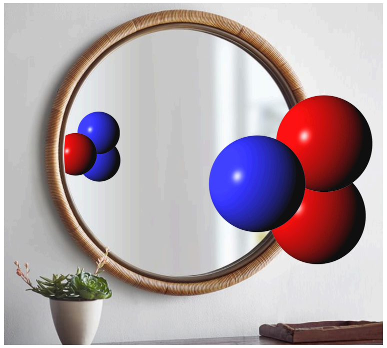
Why light nuclei?

- can be exactly calculated for a given two- and three-nucleon interaction model.

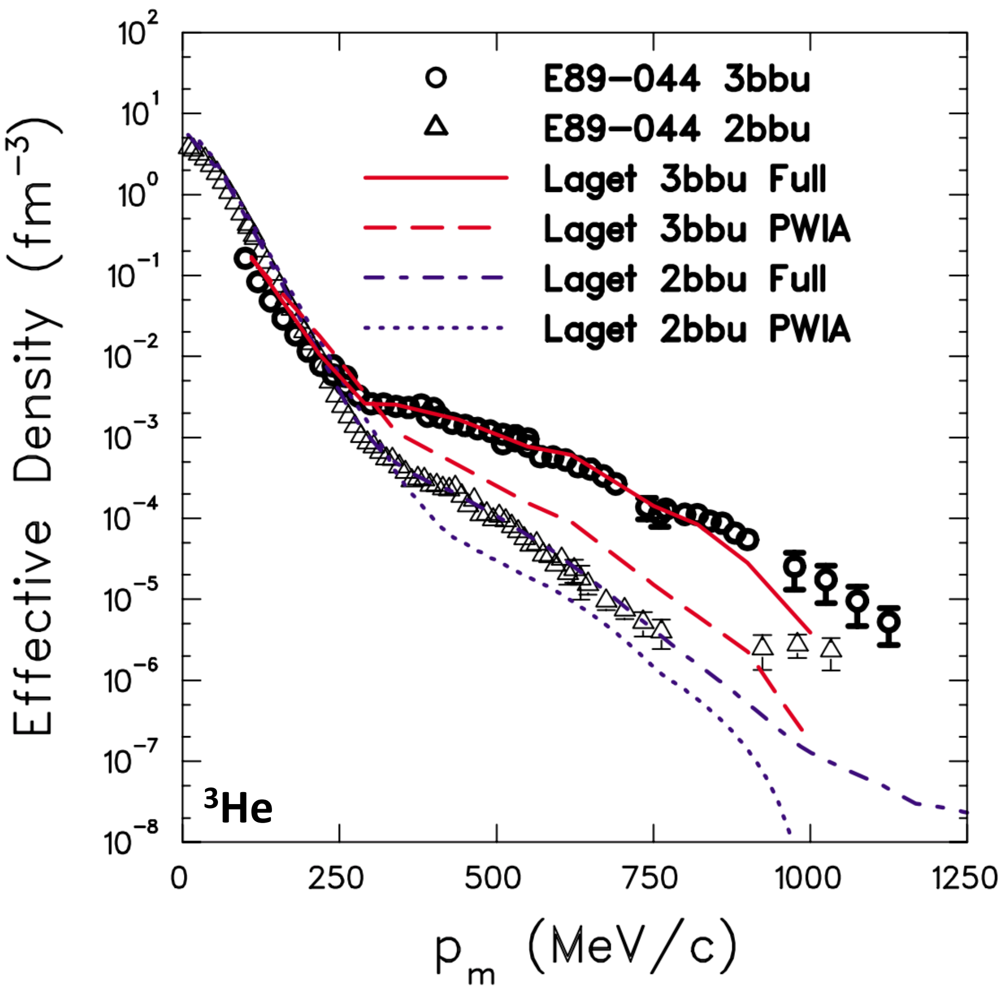
Why Tritium?

- Isospin doublet:
  - ^{3}He is stable mirror nucleus

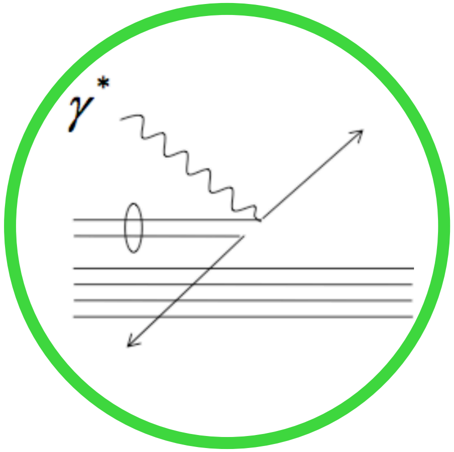
$$\frac{^{3}\text{He}\ (\mathbf{p})}{^{3}\text{H}\ (\mathbf{p})} \cong \frac{^{3}\text{He}\ (\mathbf{p})}{^{3}\text{He}\ (\mathbf{n})}$$

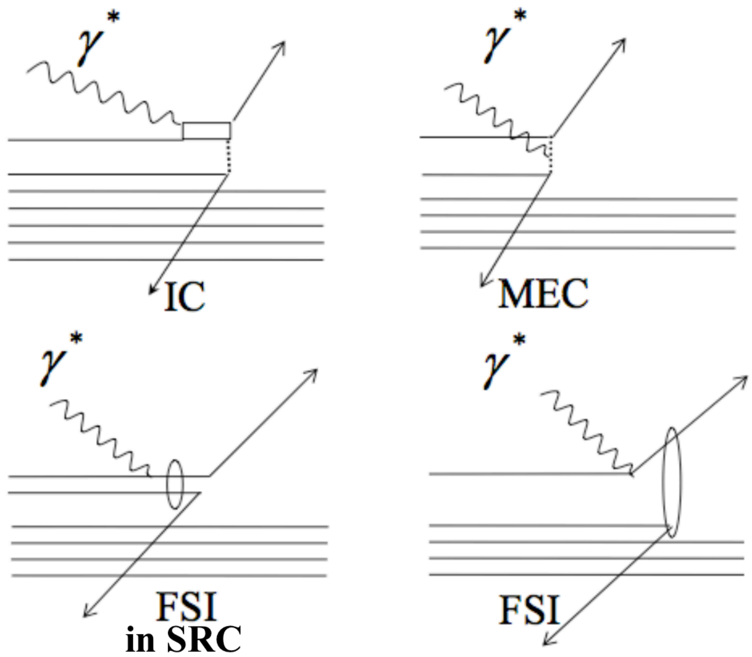


Previous studies and non-QE mechanisms



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

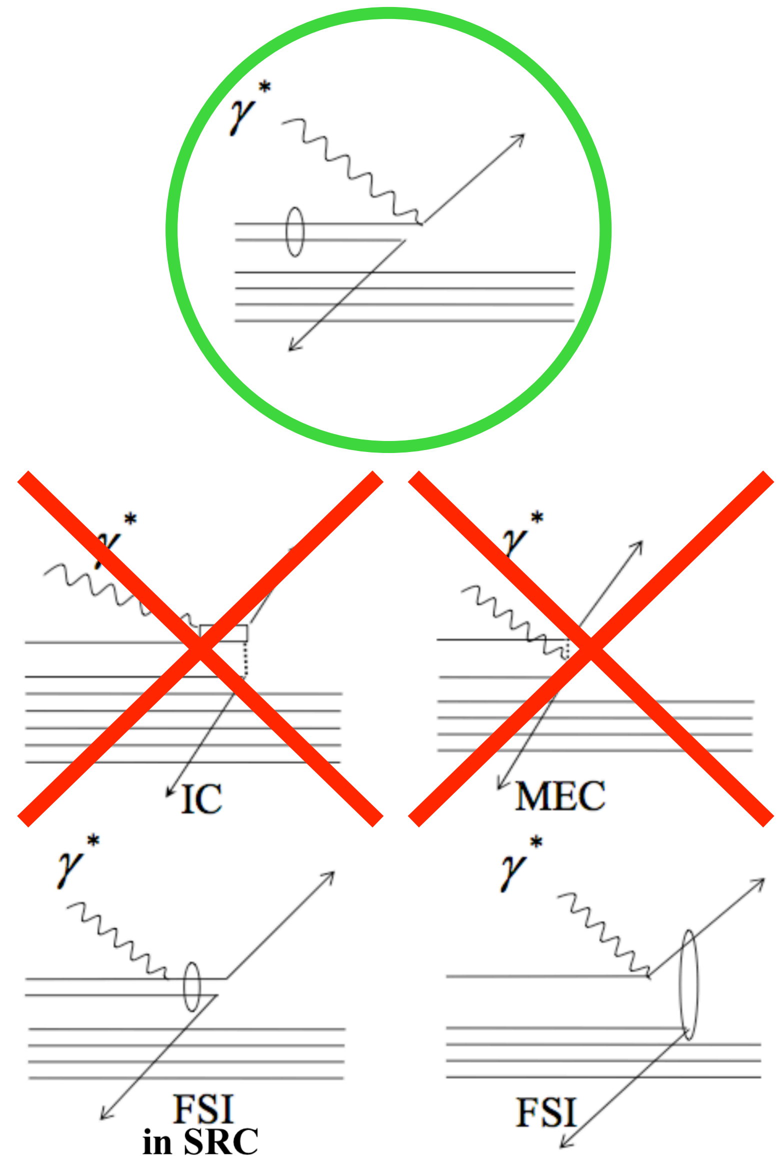




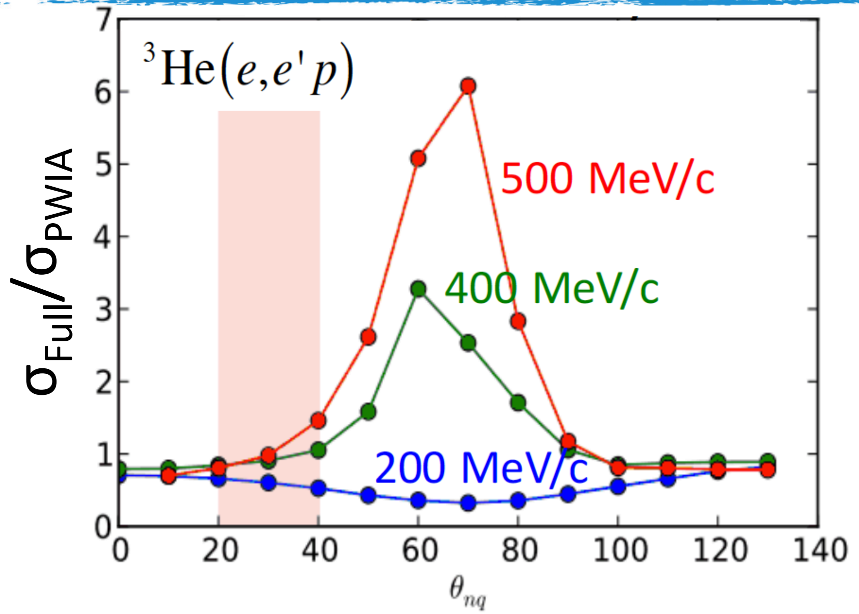
Minimizing non-QE mechanisms

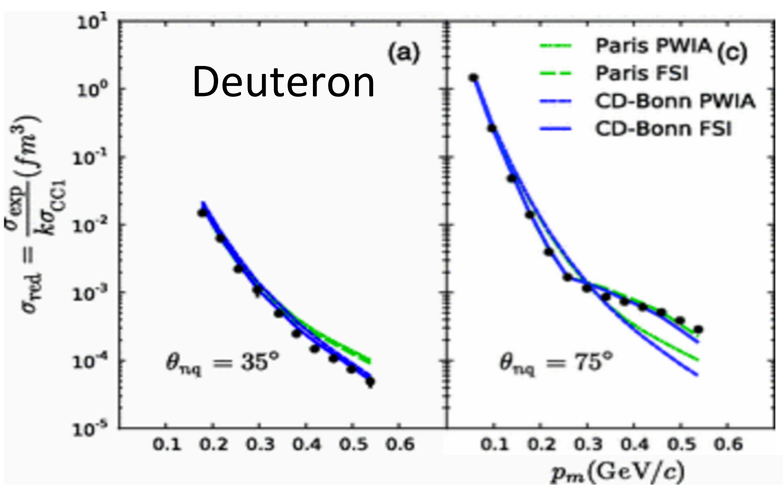
$Q^2 > 2$ GeV^2

$x_B > 1$

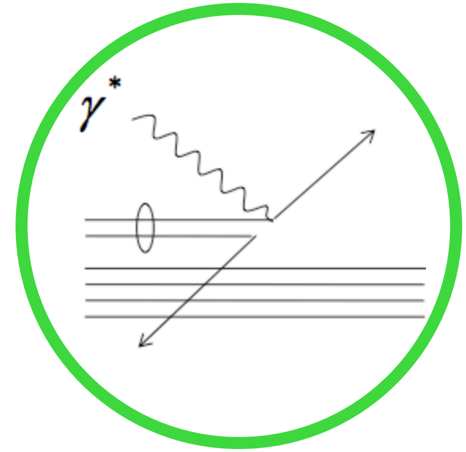


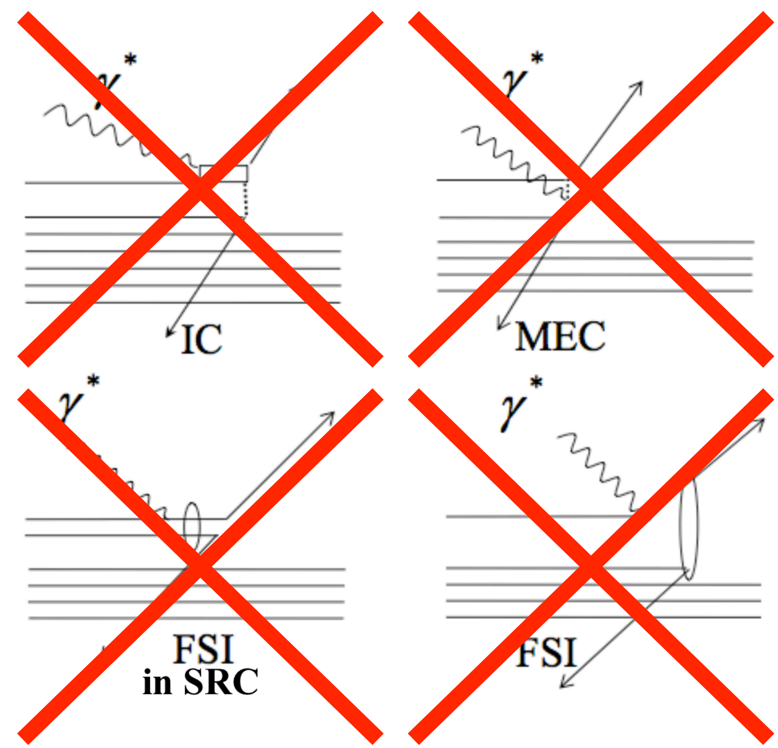
Minimizing non-QE mechanisms





Boeglin et al., PRL 107 (2011) 262501





High Q^2: factorized approximation

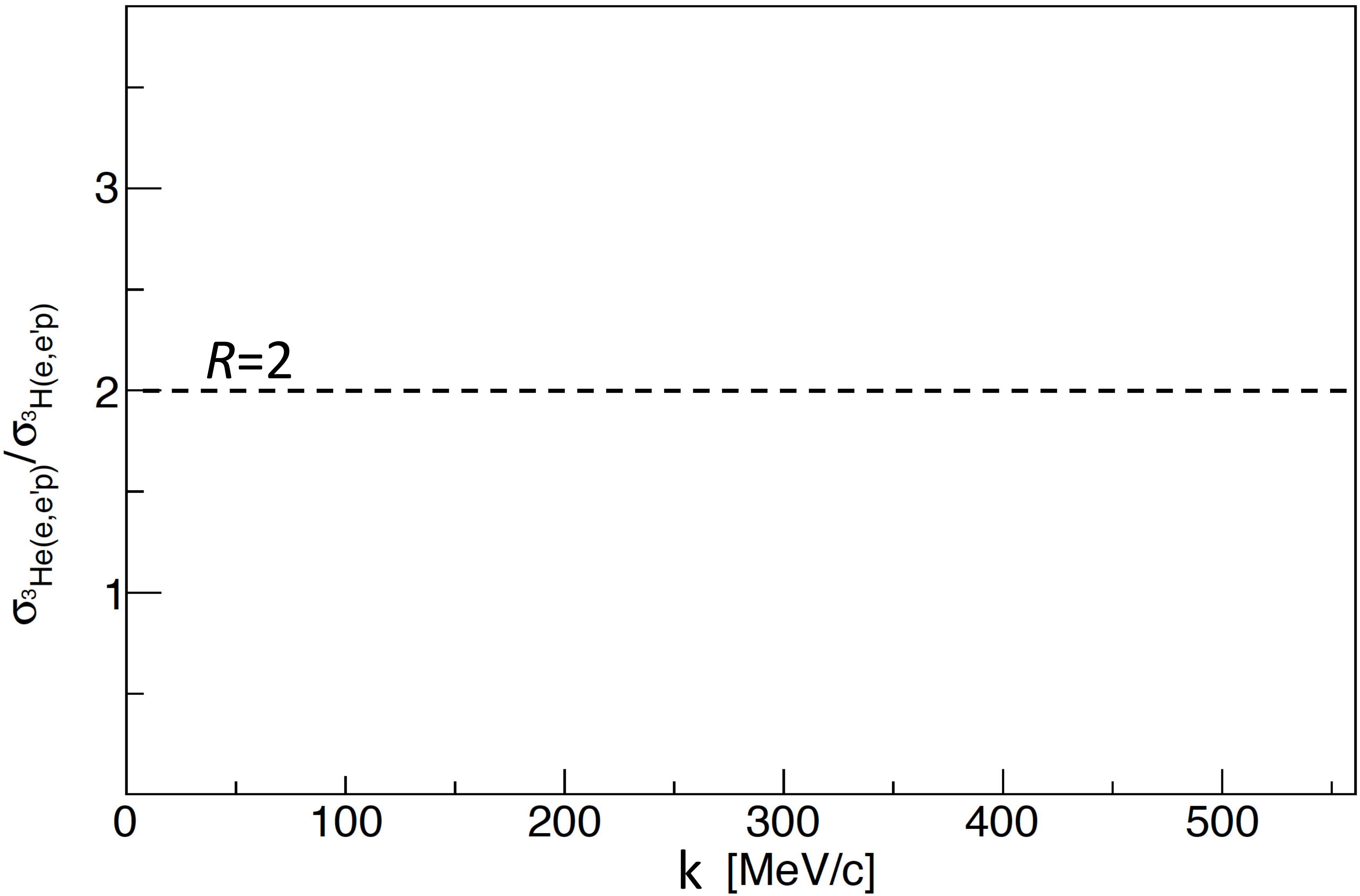
In PWIA:

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

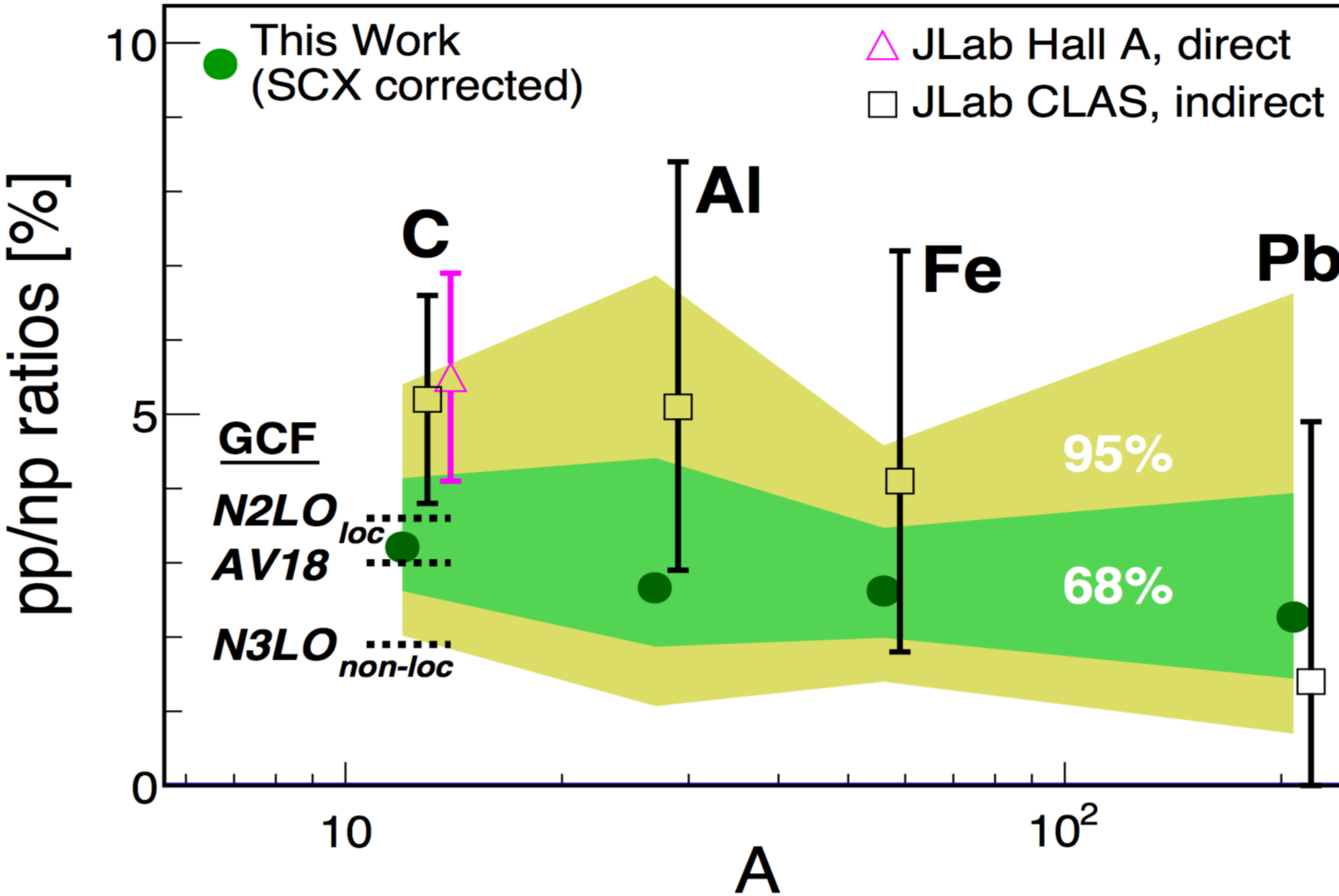
thus:

$$\frac{\sigma_{3He(e,e'p)}}{\sigma_{3H(e,e'p)}} \cong \frac{S_{3He}(|\mathbf{p}_i|,E_i)}{S_{3H}(|\mathbf{p}_i|,E_i)}$$

Phenomenological expectations

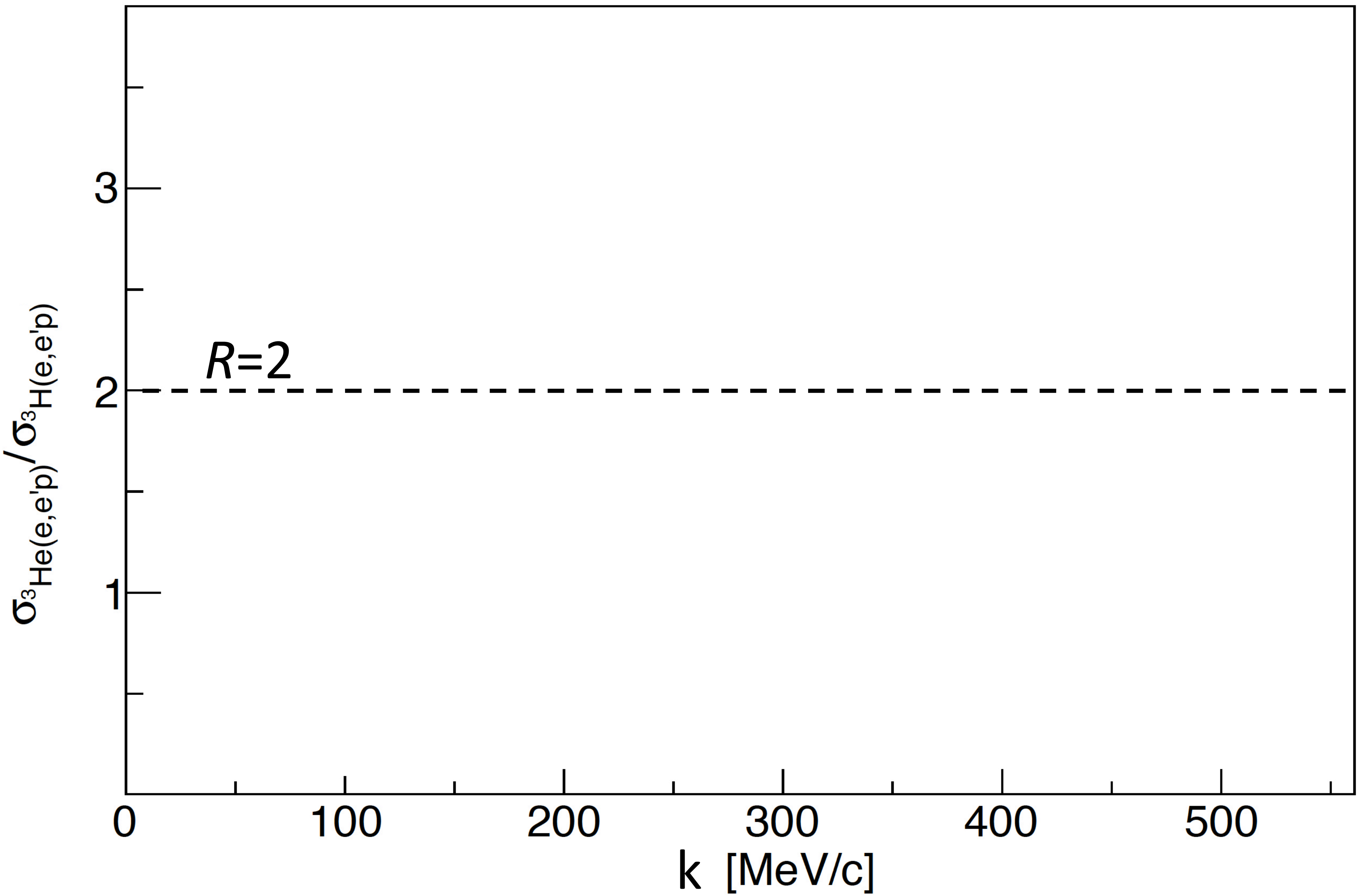


np-dominance

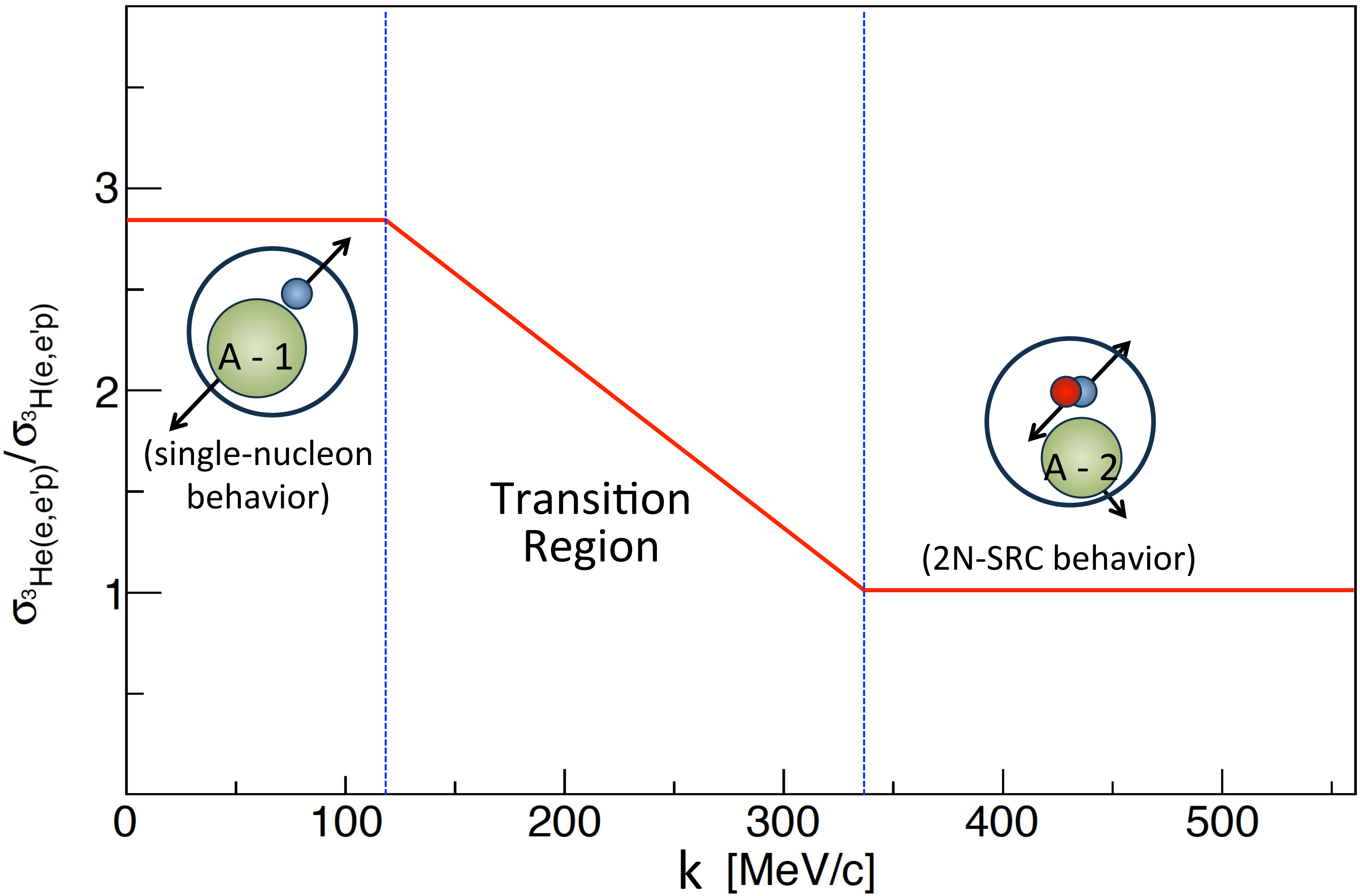


M. Duer et al., (Jefferson Lab CLAS Collaboration)
arXiv:1810.05343 (2018)

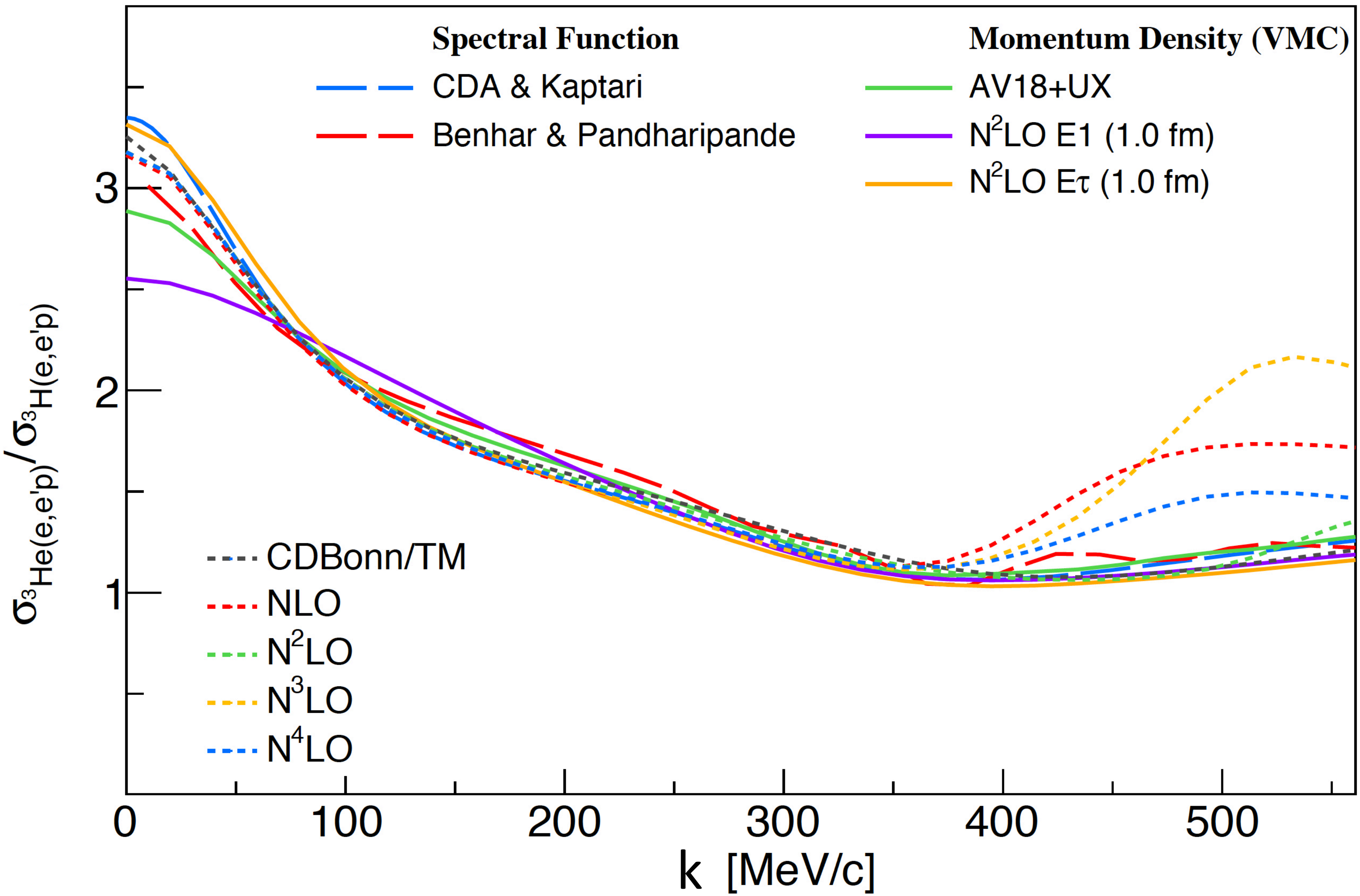
Phenomenological expectations



Phenomenological expectations

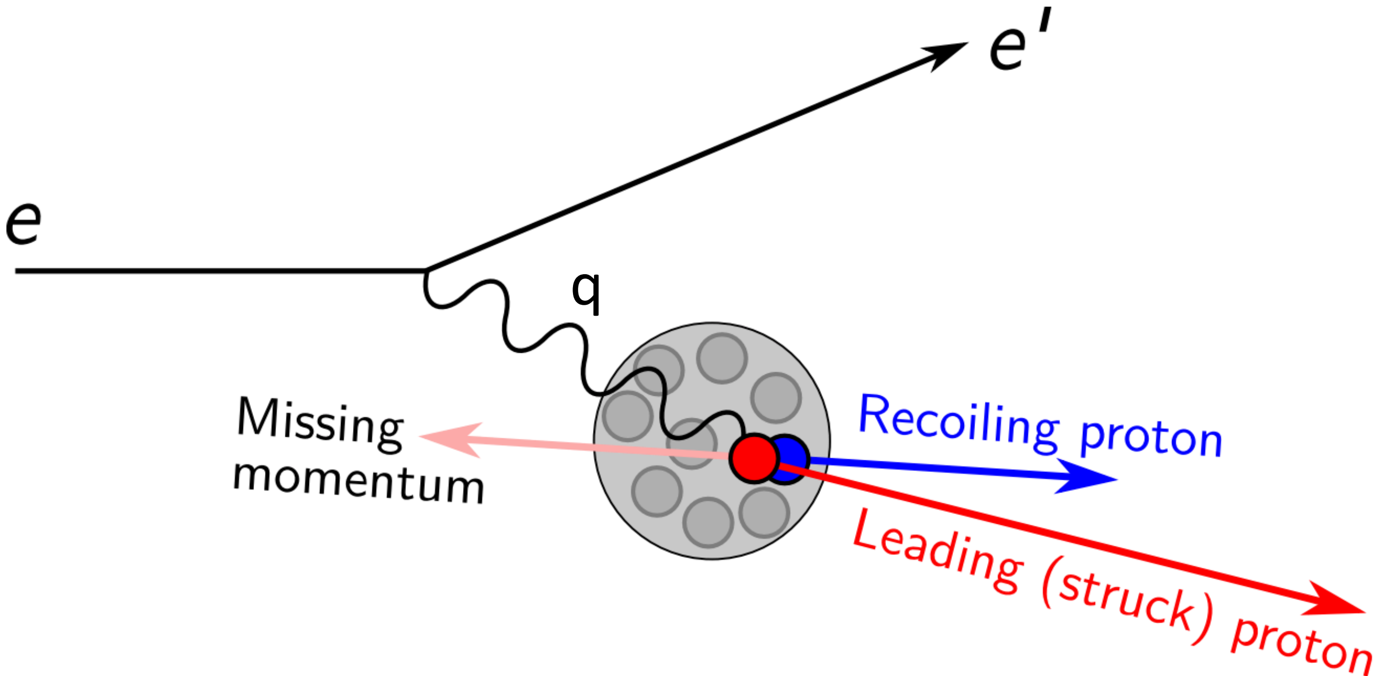


Theory predictions



Missing momentum

$$\vec{p}_{miss} = \vec{p}_p - \vec{q}$$

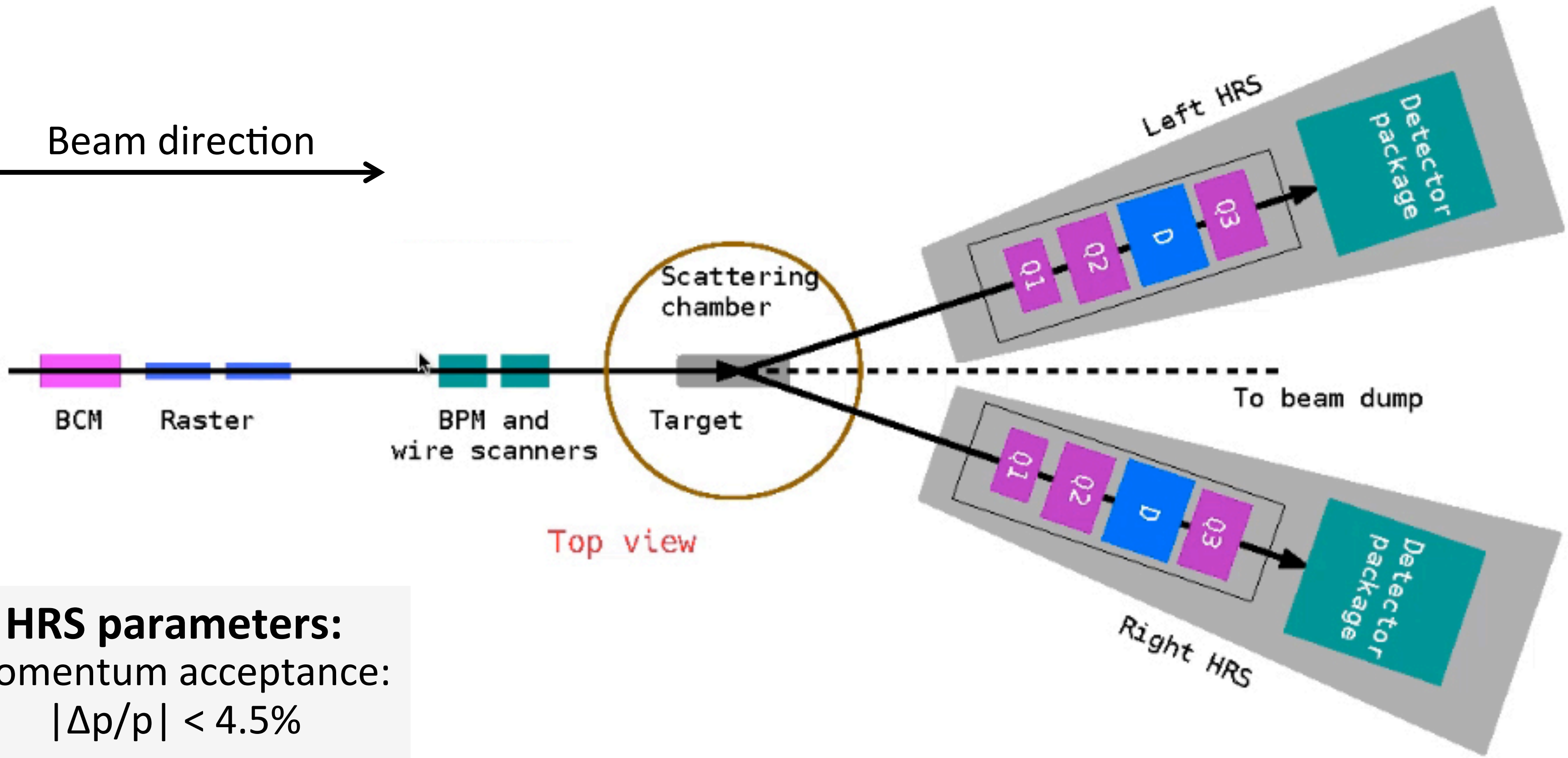


a proxi for the nucleon momentum before the interaction took place

Hall-A spectrometers (top view)

More information here: http://hallaweb.jlab.org/equipment/HRS.html

Beam direction



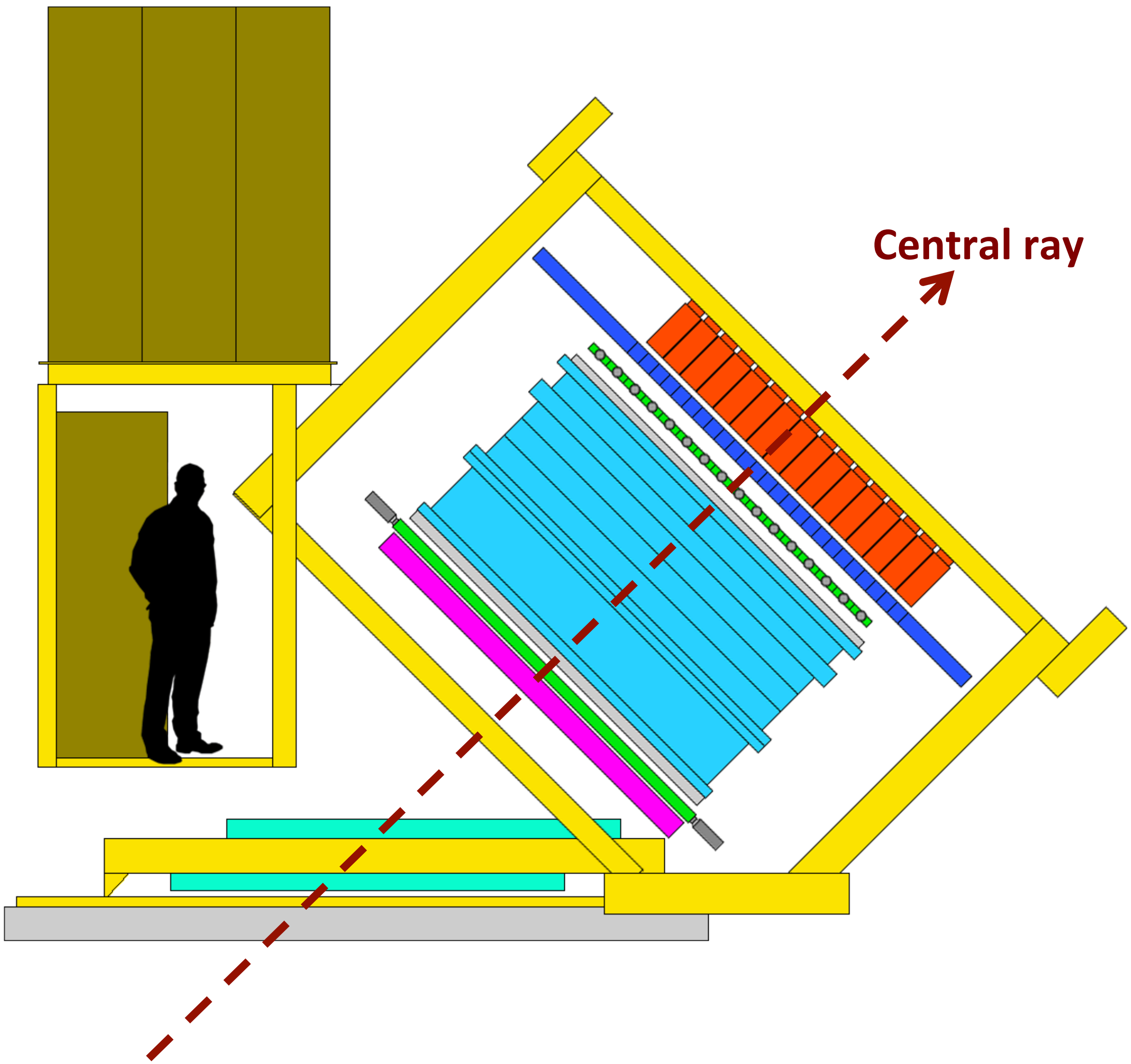
HRS parameters:

Momentum acceptance: $|\Delta p/p| < 4.5\%$

Angular acceptance:

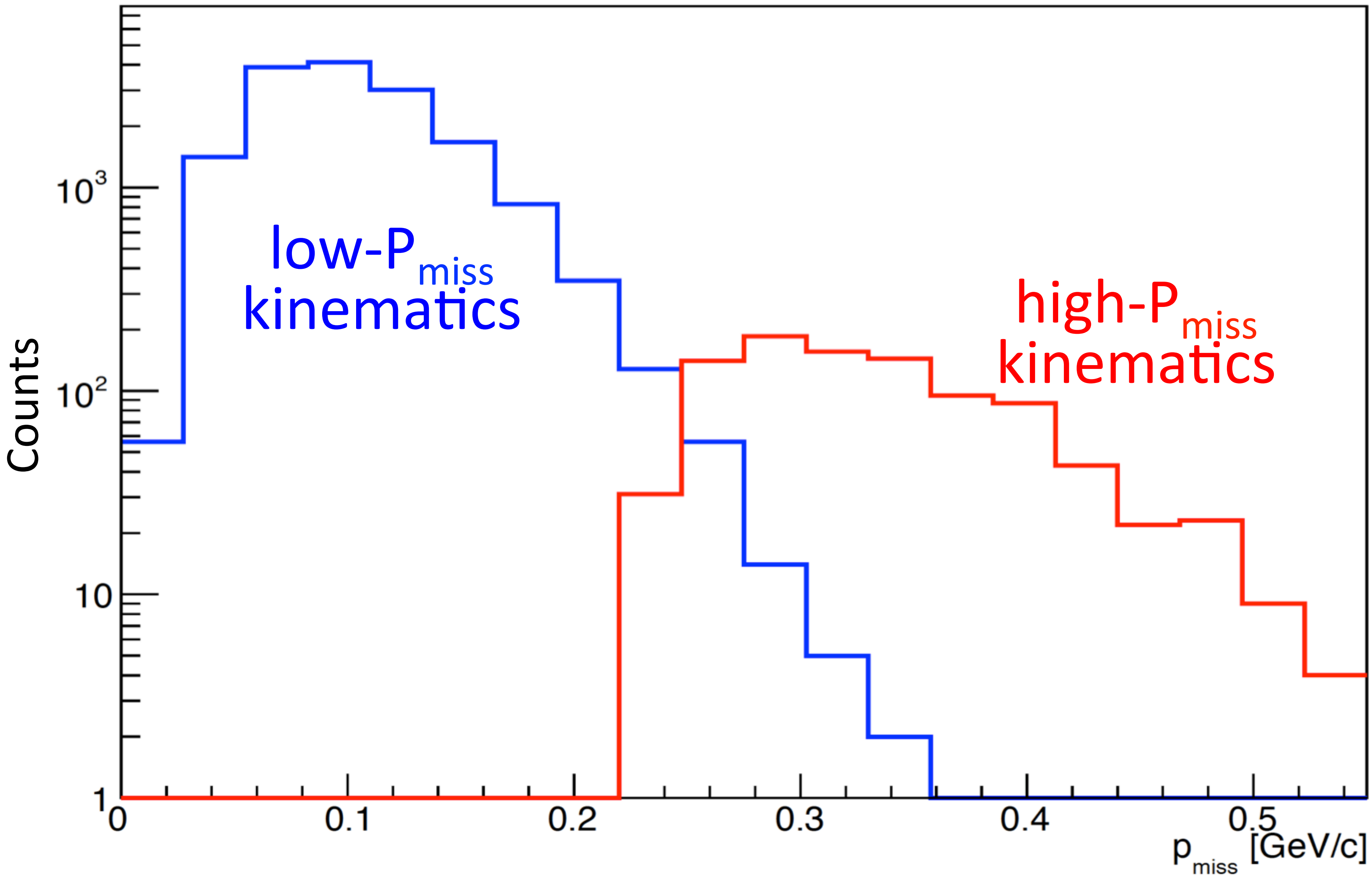
- Horizontal: 28 mrad
- Vertical: 60 mrad

HRS detector package

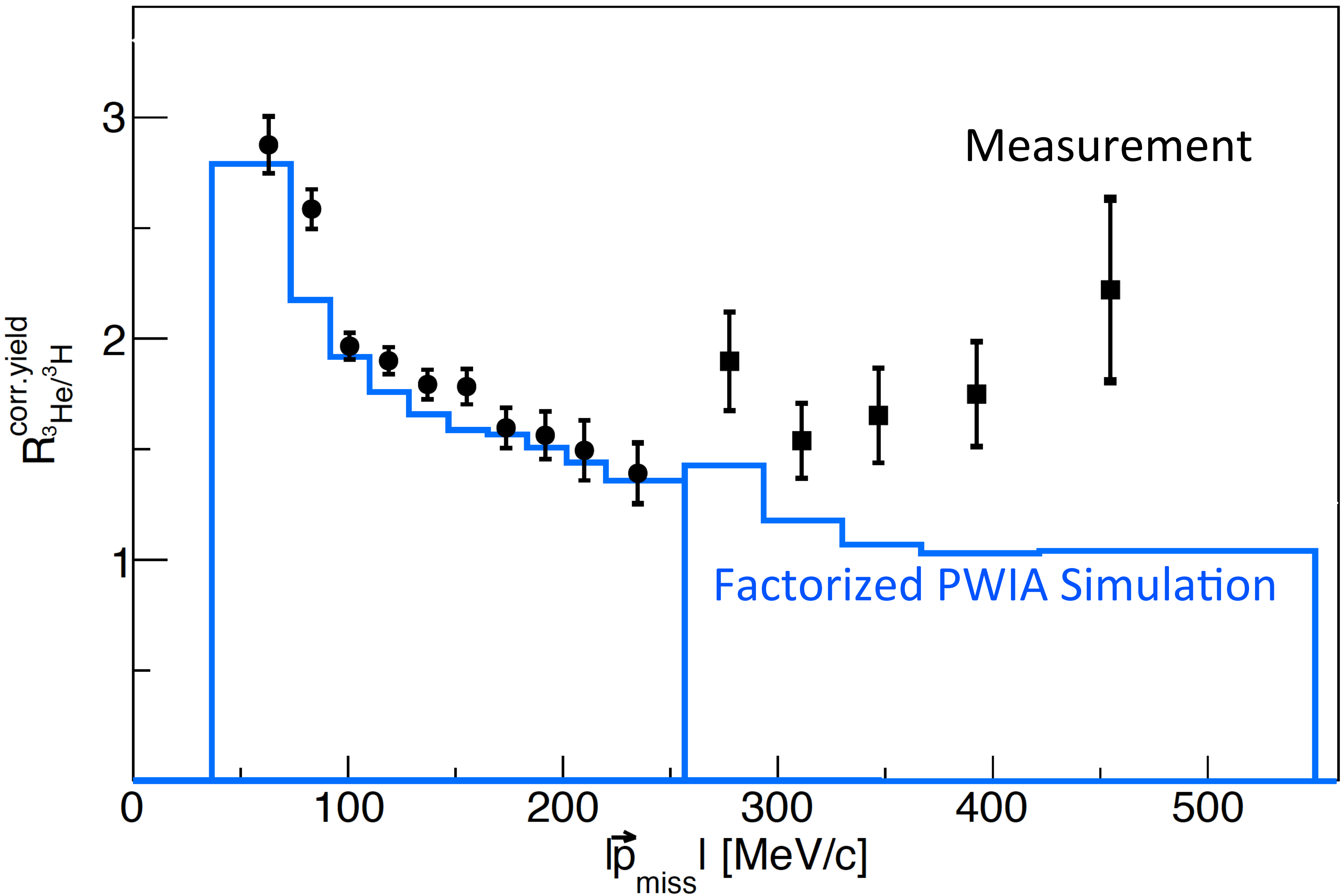


Allow for excellent momentum reconstruction and particle identification

Kinematical settings



Measured $^3He/^3H$ ratio

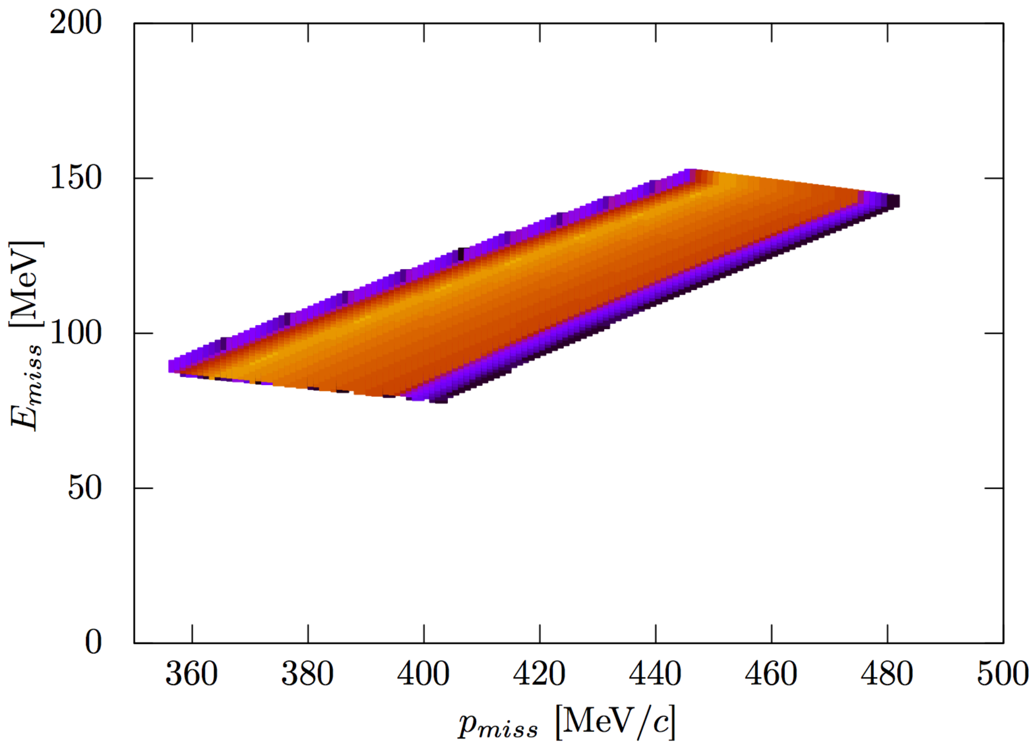


arXiv:1902.06358 (2019)

Corrections

$$R_{n(p)}^{\mathrm{meas.}}(p_{miss}) \neq R_{^3\mathrm{He}/^3\mathrm{H}}^{corr.yield}(p_{miss})$$

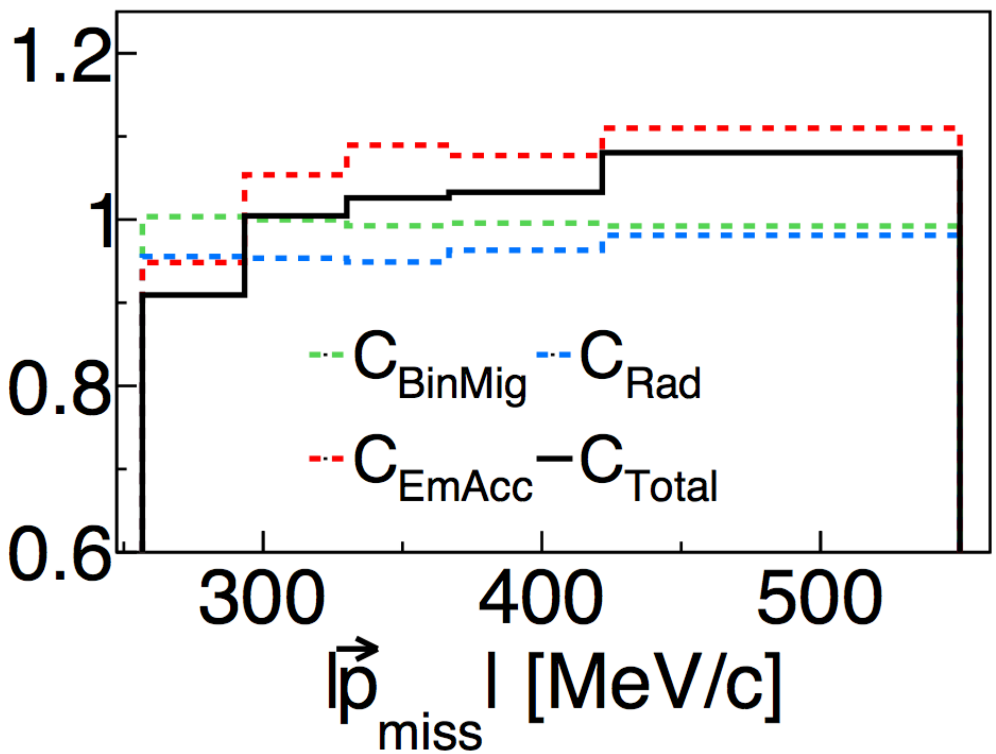
High missing momentum setting
(toy model by A. Schmidt)



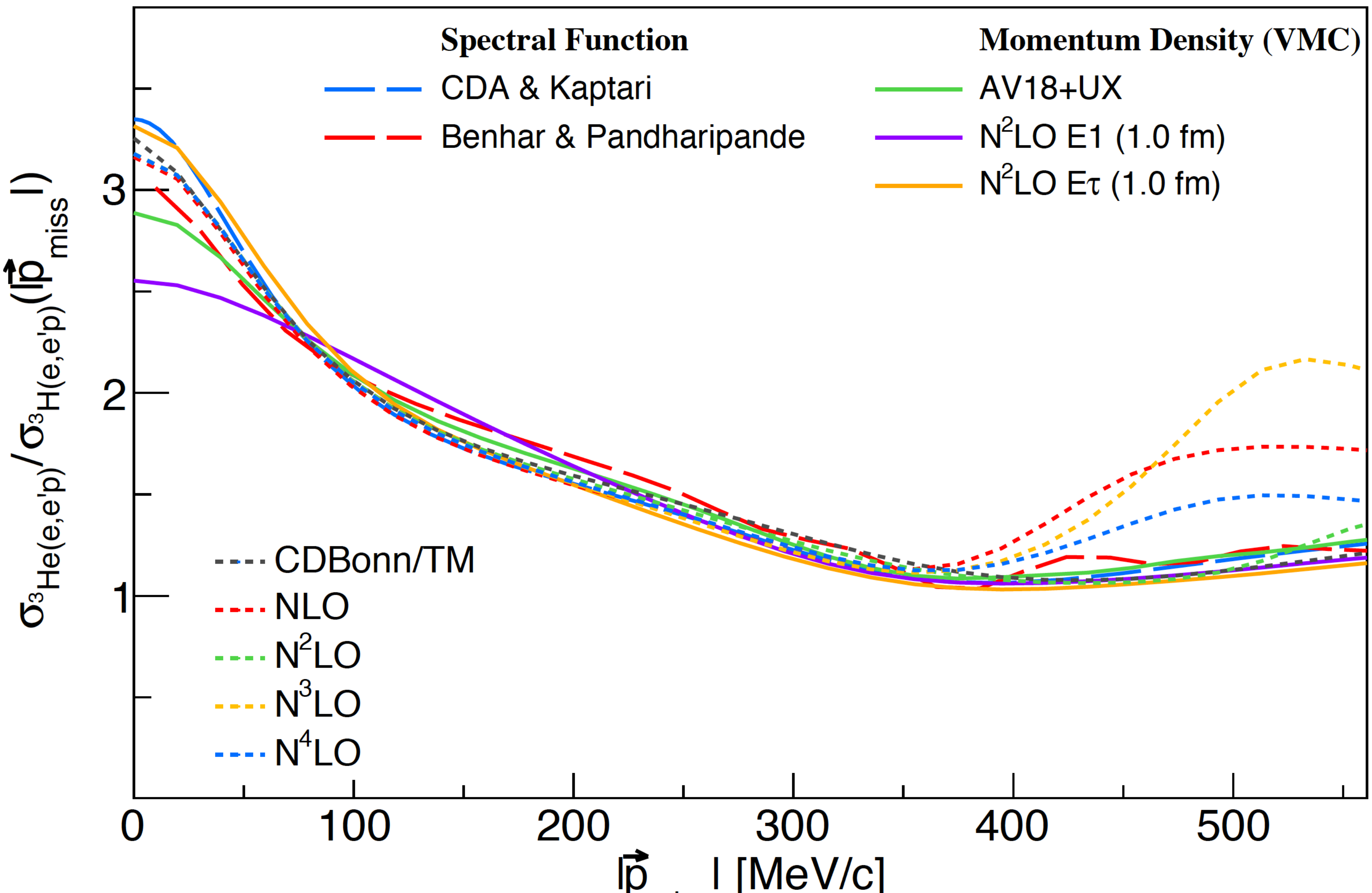
Corrections

$$R^{\mathrm{meas.}}_{n(p)}(p_{miss}) = R^{corr.yield}_{^3\mathrm{He}/^3\mathrm{H}}(p_{miss}) \times C_{\mathrm{BinMig}} \times C_{\mathrm{Rad}} \times C_{E_m\mathrm{Acc}}$$

High missing momentum setting

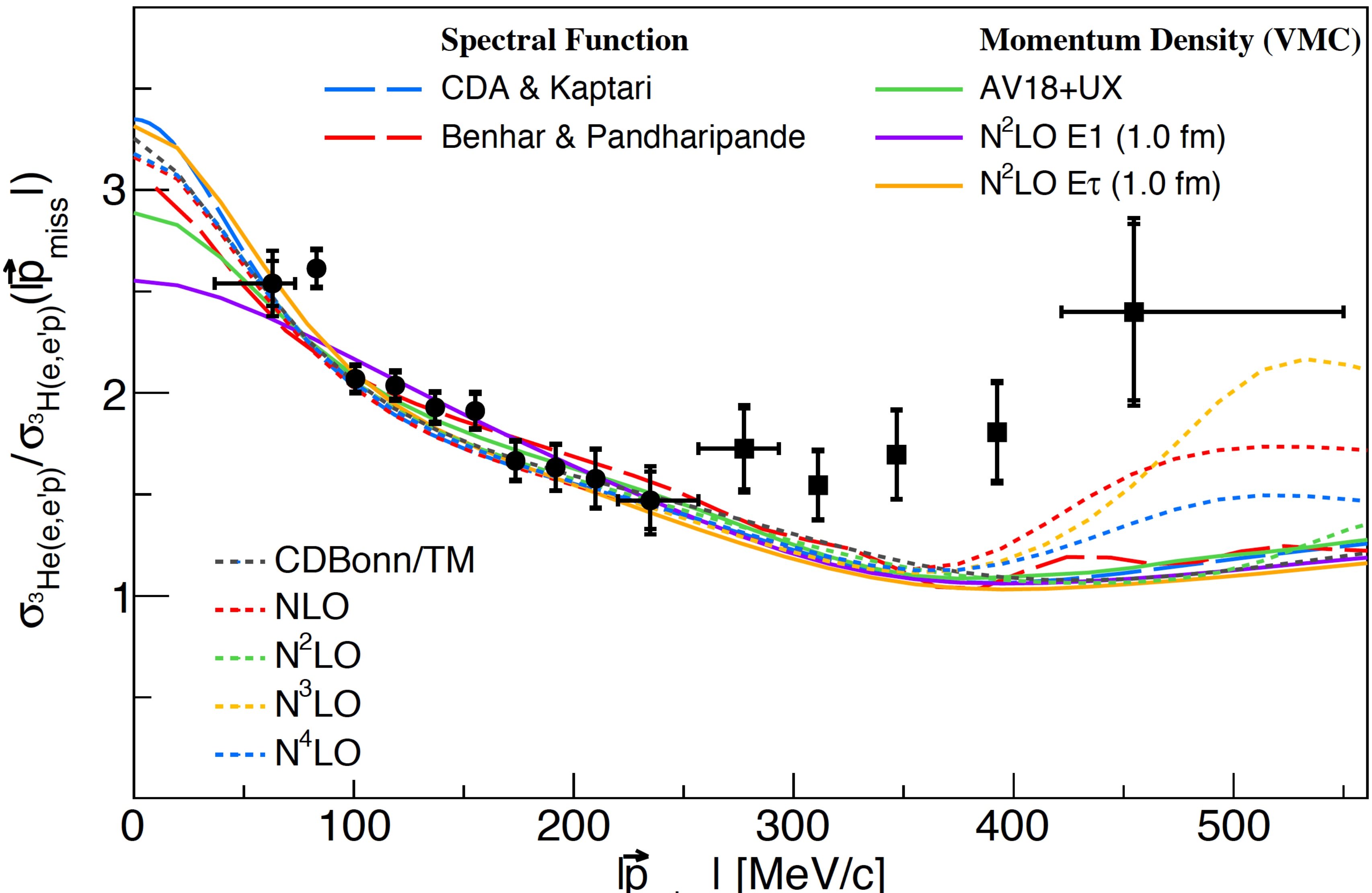


Final results



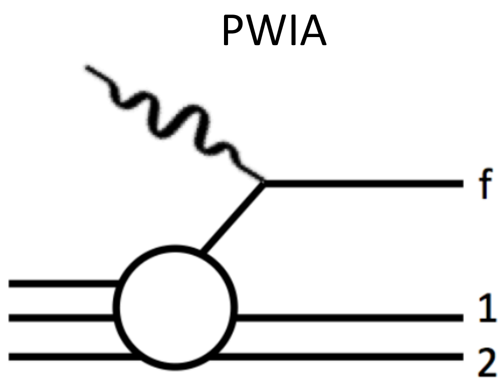
arXiv:1902.06358 (2019)

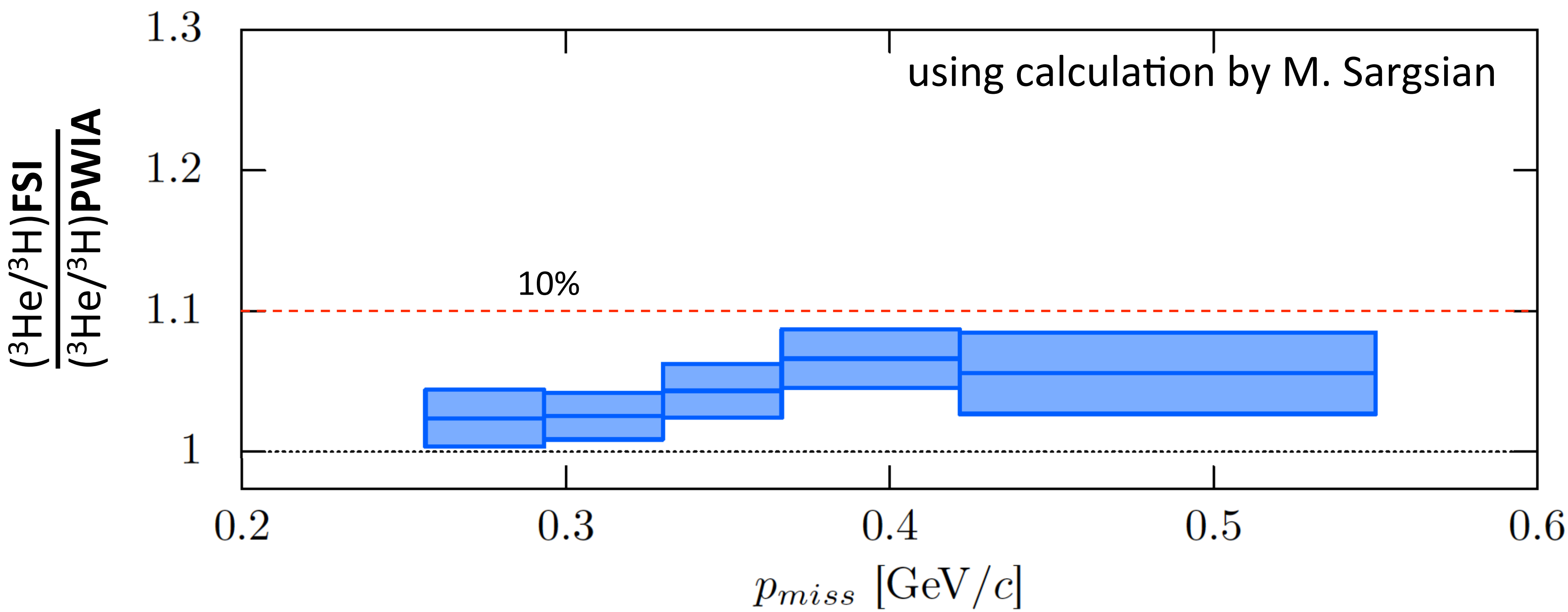
Final results



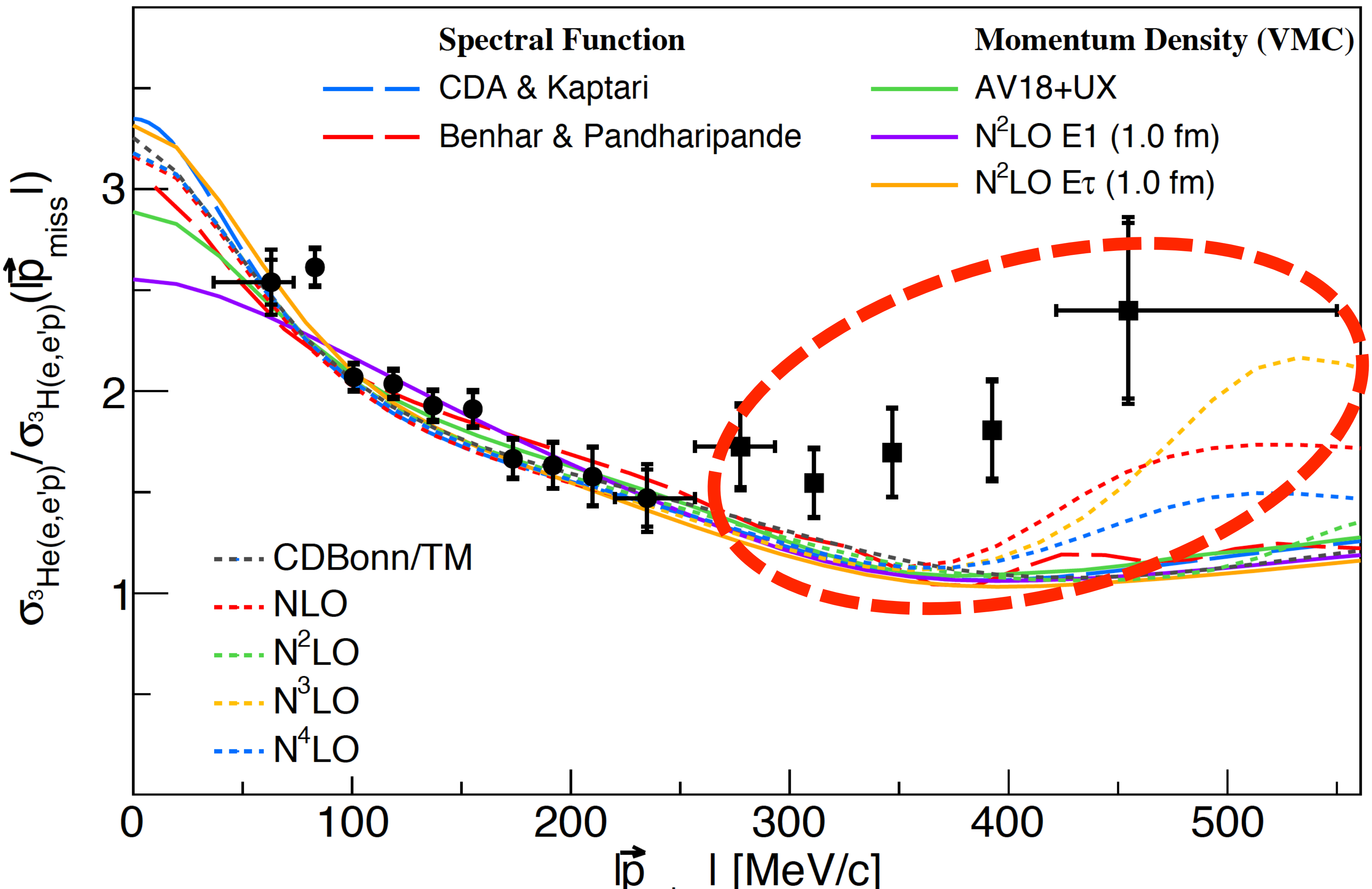
arXiv:1902.06358 (2019)

Effect of Final-State Interactions





Where do we go from here?



arXiv:1902.06358 (2019)

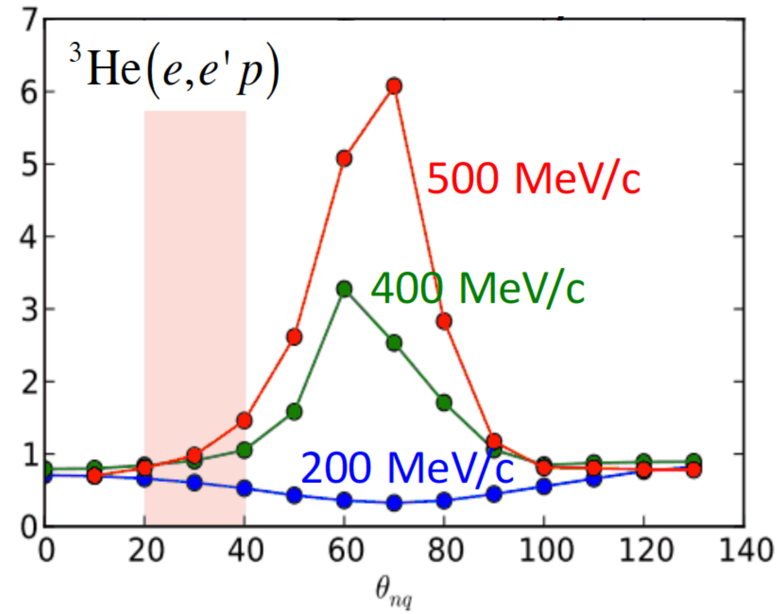
Backup slides

Event selection cuts

electron-PID: $E_{cal}/|\mathbf{p}| > 0.5$
proton in coincidence: $\Delta t_{e\text{-}p} < 3\sigma$
target wall cut: $|vz| < 9.5$ cm
$\Delta vz_{e\text{-}p} < 1.2$ cm ($< 3\sigma$)

Acceptance:
$\delta < 4\%$
ϕ (horizontal) < 25.5 mrad
θ (vertical) < 55.0 mrad

FSI: $\theta_{rq} <$ 37.5 deg



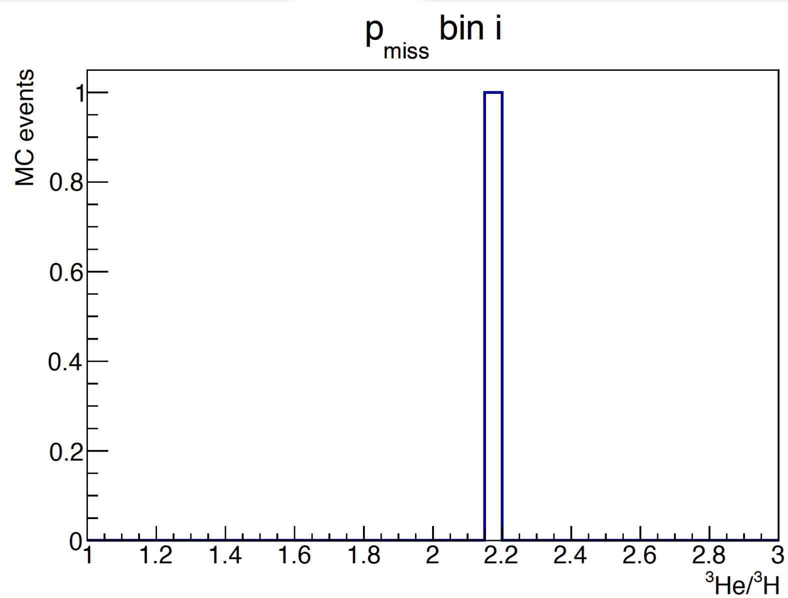
non-QE events: xB > 1.3
(high-Pmiss kinematics)

Systematic Uncertainties

From event selection

Determined as follows: for a given p_{miss} bin:

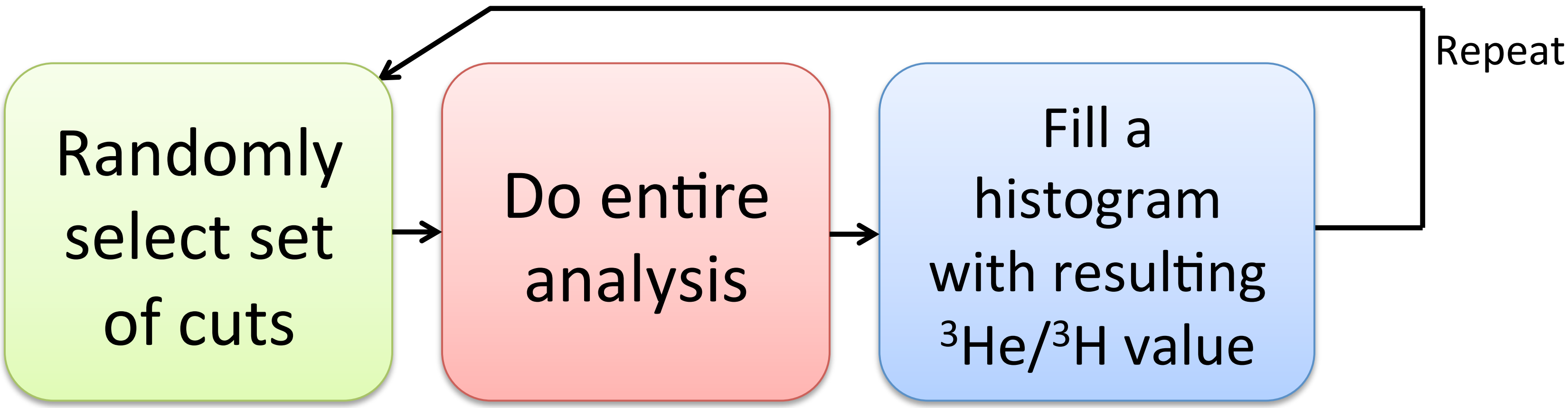
Randomly select set of cuts → Do entire analysis → Fill a histogram with resulting $^3He/^3H$ value

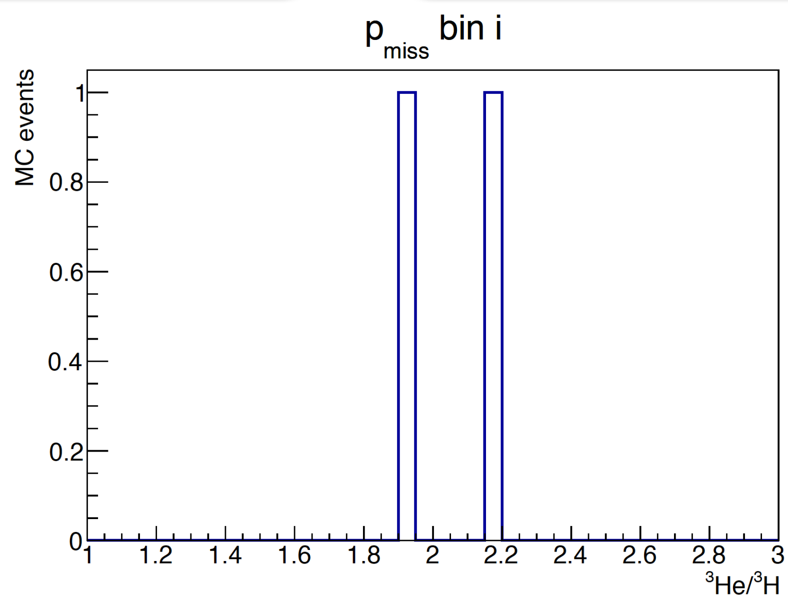


Systematic Uncertainties

From event selection

Determined as follows: for a given p_{miss} bin:

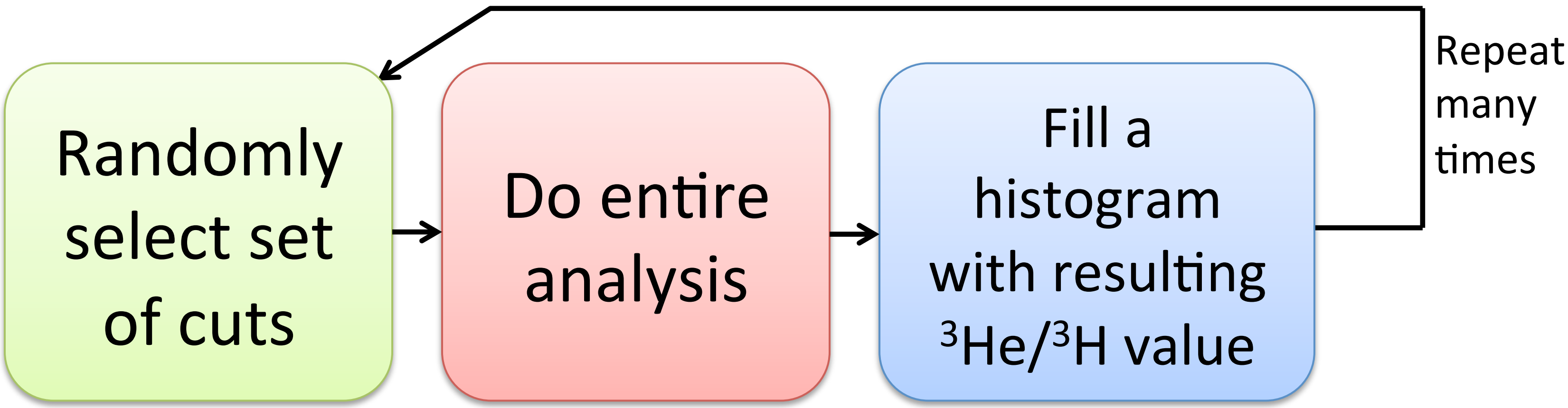


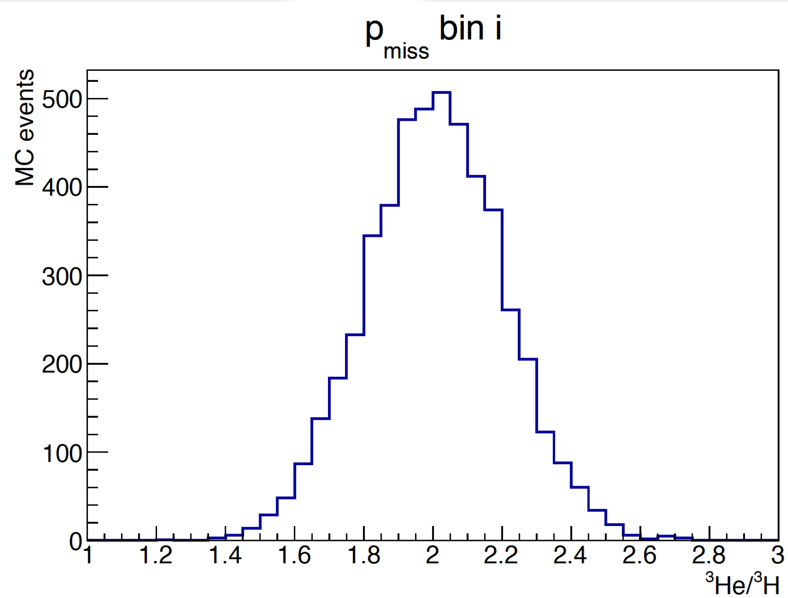


Systematic Uncertainties

From event selection

Determined as follows: for a given p_{miss} bin:



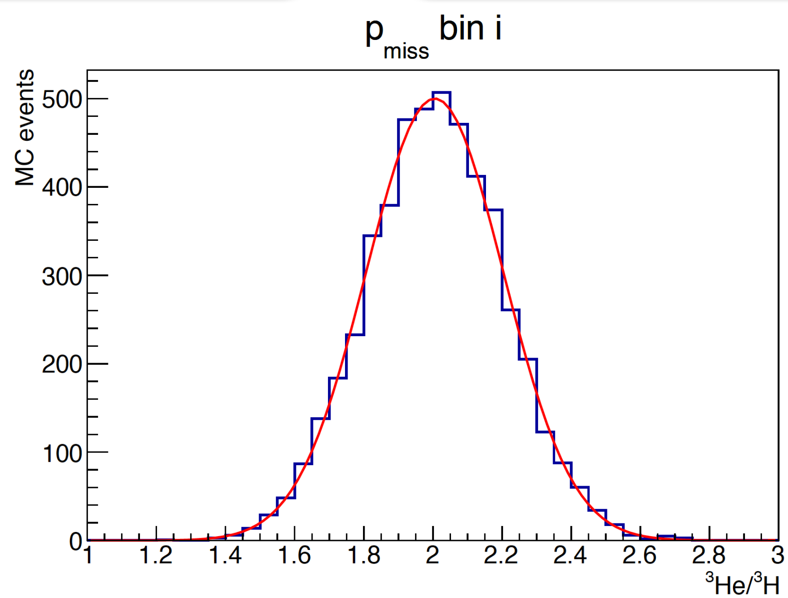


Systematic Uncertainties

From event selection

Determined as follows: for a given p_{miss} bin:

Randomly select set of cuts → Do entire analysis → Fill a histogram with resulting $^3He/^3H$ value → Fit histogram with Gaussian and take σ as systematic uncertainty



Systematic Uncertainties

From event selection

Determined as follows: for a given p_{miss} bin:

Randomly select set of cuts → Do entire analysis → Fill a histogram with resulting $^3He/^3H$ value → Fit histogram with Gaussian and take σ as systematic uncertainty

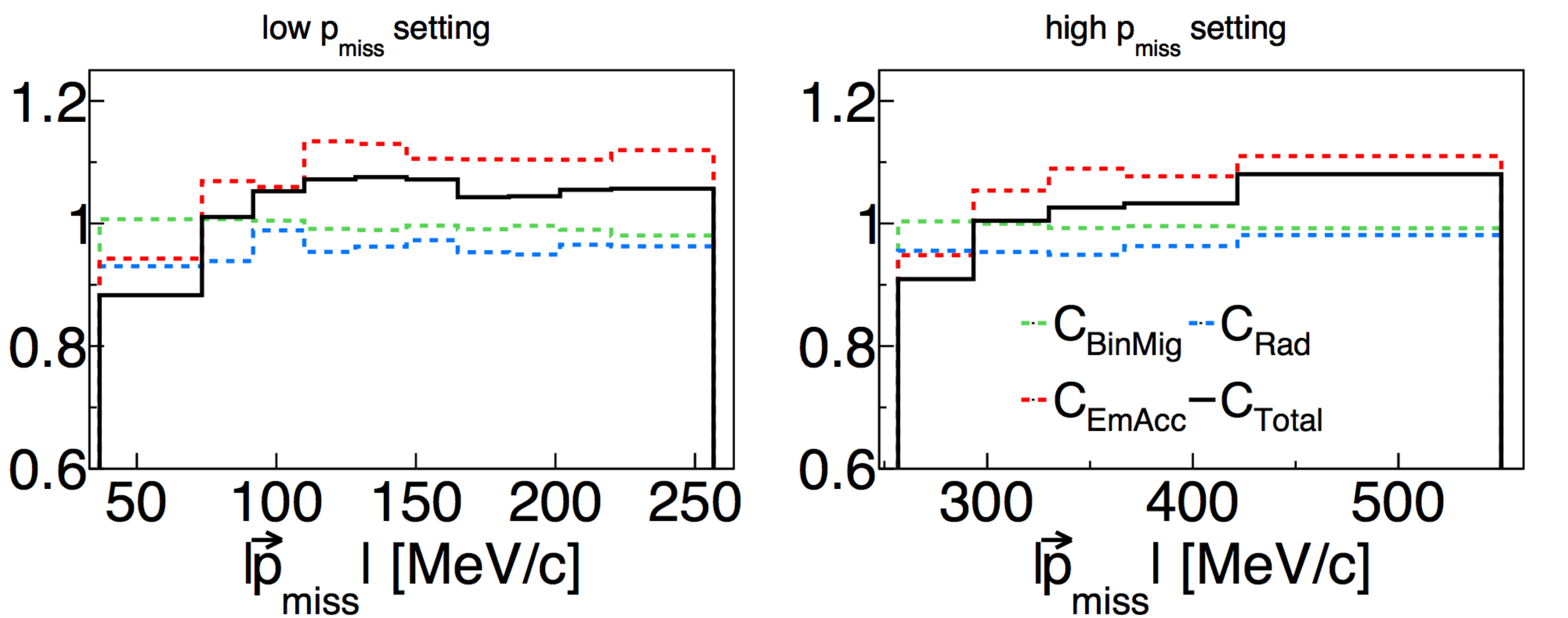
Others:

	Overall	Point-to-point
Target Walls	$\ll 1\%$	
Target Density	1.5%	
Beam-Charge and Stability	1%	
Tritium Decay	0.18%	
spectral function isospin symmetry	3%	
Cut sensitivity		1% - 8%
Simulation Corrections (bin-migration, radiation, E_m acceptance)		1% - 2%

Corrections

$$R^{\mathrm{meas.}}_{n(p)}(p_{miss}) = R^{corr.yield}_{^3\mathrm{He}/^3\mathrm{H}}(p_{miss}) \times C_{\mathrm{BinMig}} \times C_{\mathrm{Rad}} \times C_{E_m\mathrm{Acc}}$$

$$\begin{aligned} C_{\mathrm{BinMig}} &= R^{\sigma_{\mathrm{Rad}}}_{\mathrm{Sim}}(p^{\mathrm{gen}}_{miss}) \;/\; R^{\sigma_{\mathrm{Rad}}}_{\mathrm{Sim}}(p^{\mathrm{rec}}_{miss}), \\ C_{\mathrm{Rad}} &= R^{\sigma_{\mathrm{Born}}}_{\mathrm{Sim}}(p^{\mathrm{gen}}_{miss}) \;/\; R^{\sigma_{\mathrm{Rad}}}_{\mathrm{Sim}}(p^{\mathrm{gen}}_{miss}), \\ C_{E_m\mathrm{Acc}} &= n_{^3\mathrm{He}/^3\mathrm{H}}(p^{\mathrm{gen}}_{miss}) \;/\; R^{\sigma_{\mathrm{Born}}}_{\mathrm{Sim}}(p^{\mathrm{gen}}_{miss}) \end{aligned}$$



Ratios of AV18/N²LO momentum distributions

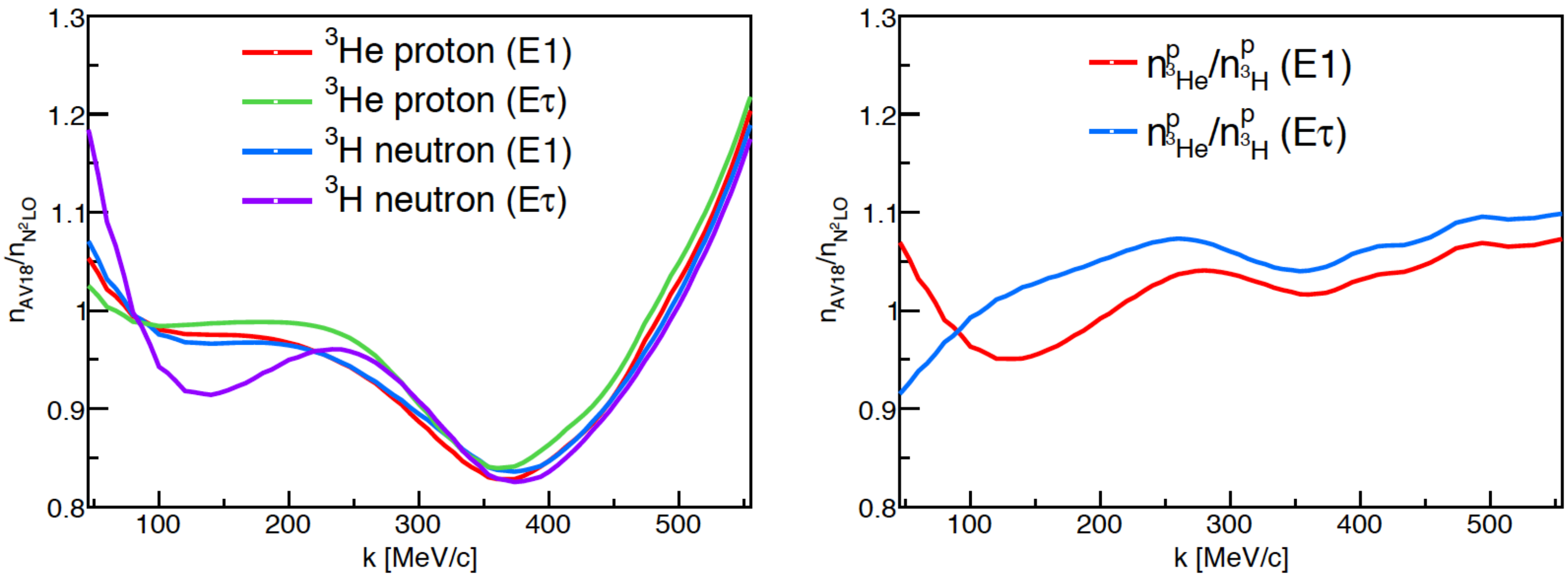
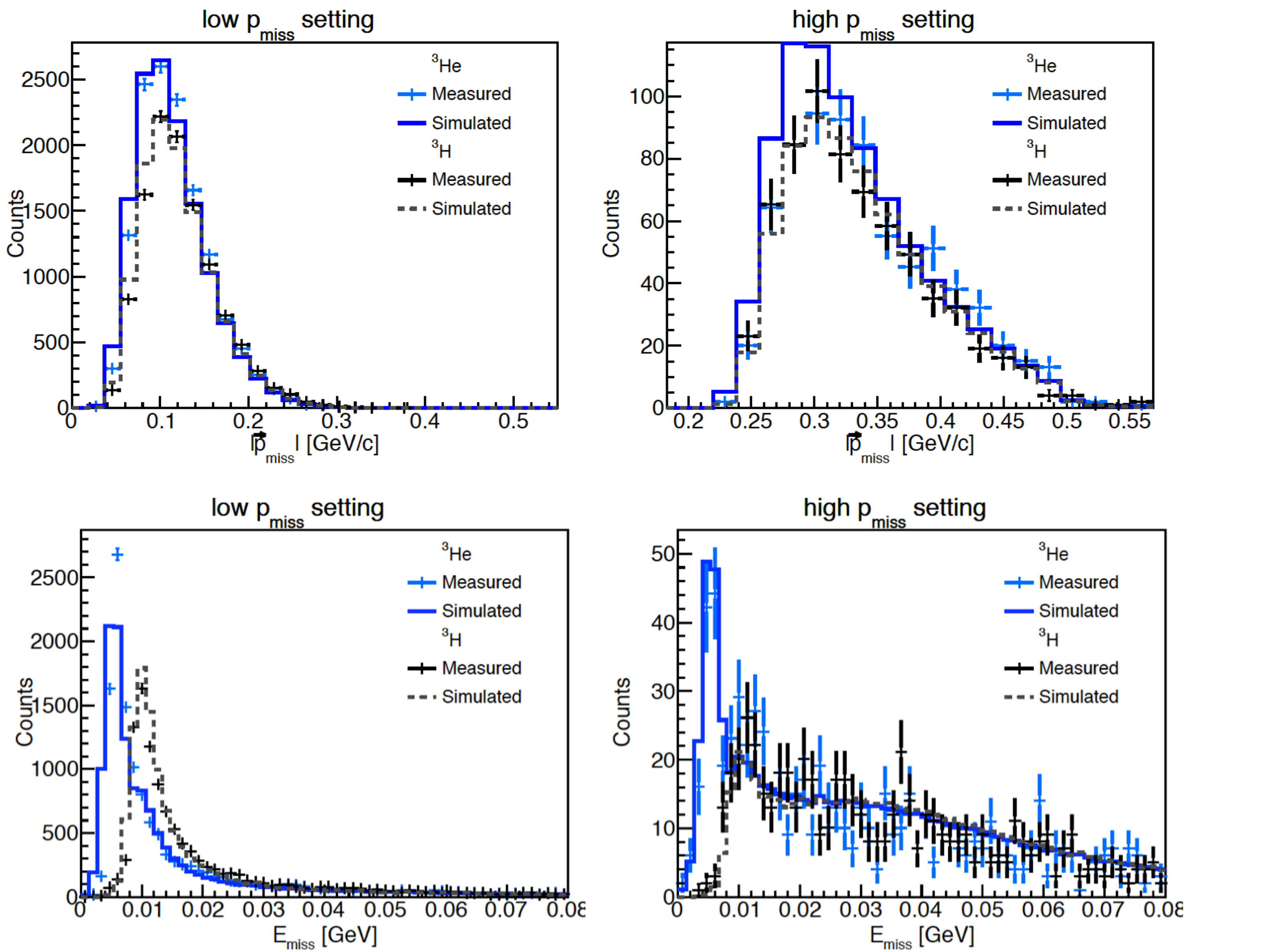
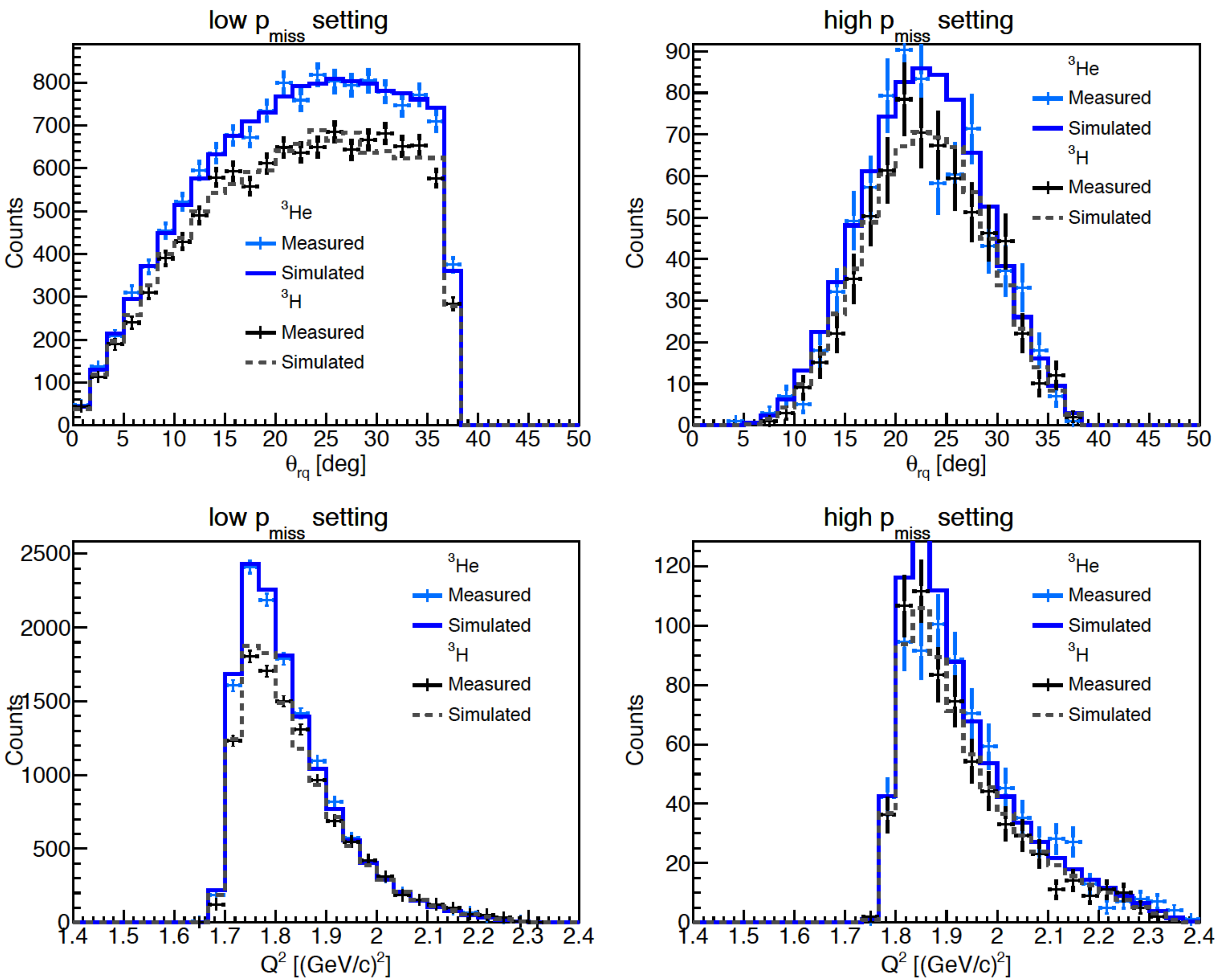


FIG. 2: Ratio of different distributions obtained using the AV18 and N^{2}LO potentials. The left figure shows the $(n_{A=3})_{AV18}/(n_{A=3})_{N^2LO}$, where $n_{A=3}$ refers to the ^{3}He proton and ^{3}H neutron momentum distributions. The right figure shows the double ratio $(n^p_{^3He}/n^p_{^3H})_{AV18}/(n^p_{^3He}/n^p_{^3H})_{N^2LO}$.

Measurement-simulation comparison



Measurement-simulation comparison



2- and 3-body breakups in ^3He