Scattering on Tritium: From EMC to SRC

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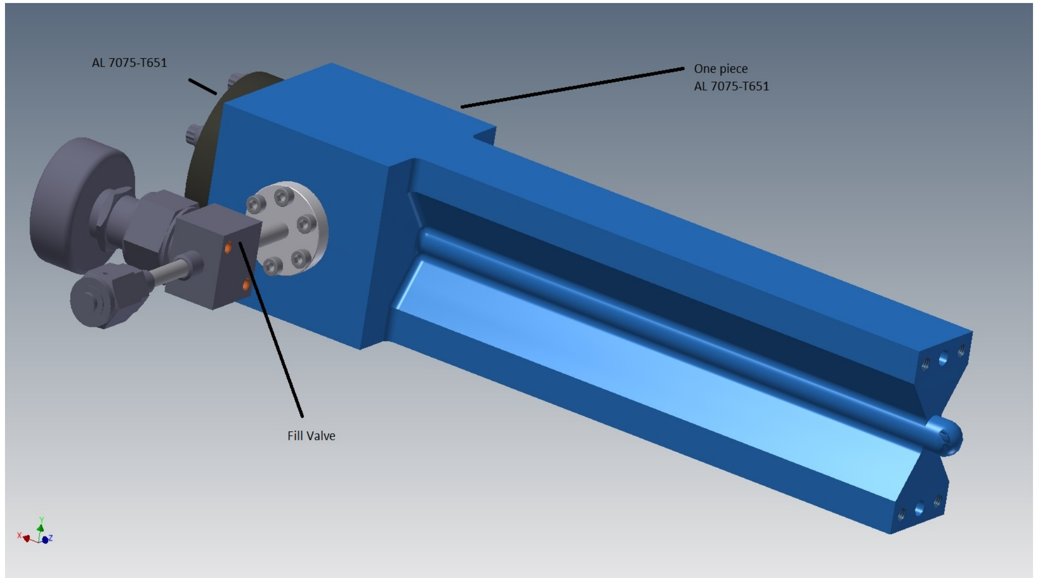
User Group Meeting, JLab, 20.06.18

OLD DOMINION UNIVERSITY

Tritium Target: Once per Generation

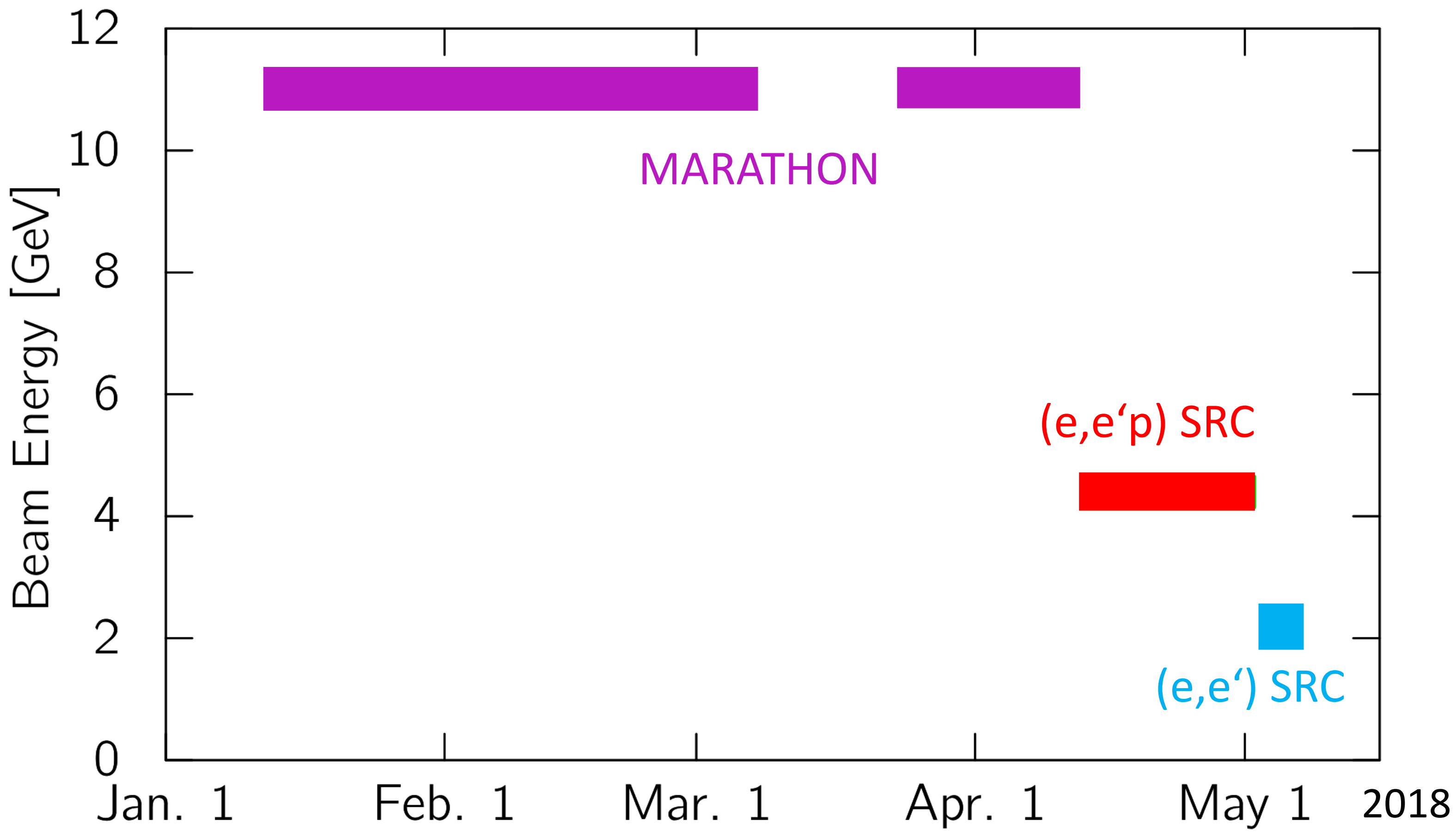
- Isospin doublet and mirror nucleus with ^{3}He
- High asymmetry A/2Z = 1.5 (larger than Pb ≈ 1.27)
- Calculable by *ab-initio* methods

Lab	Year
SLAC	1963
Bates	1984
Saclay	1985/1992
JLab	**2018**

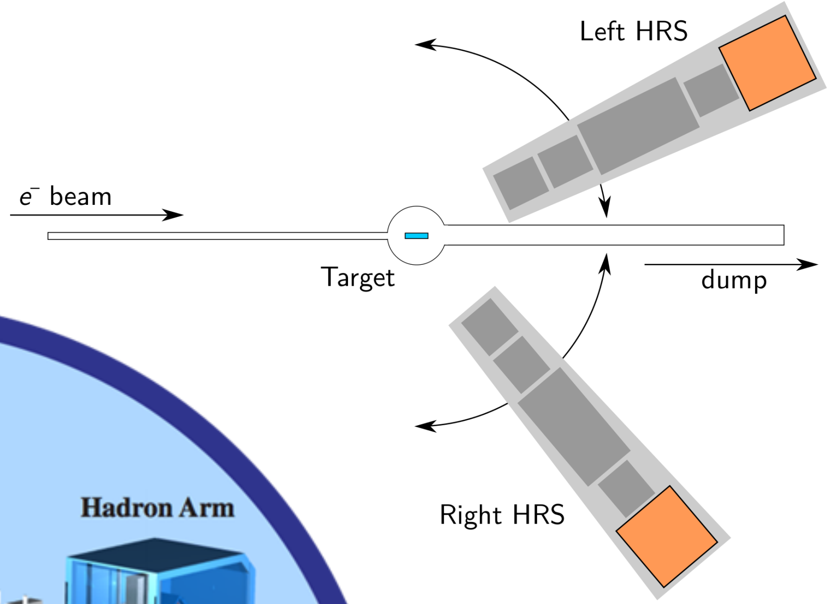


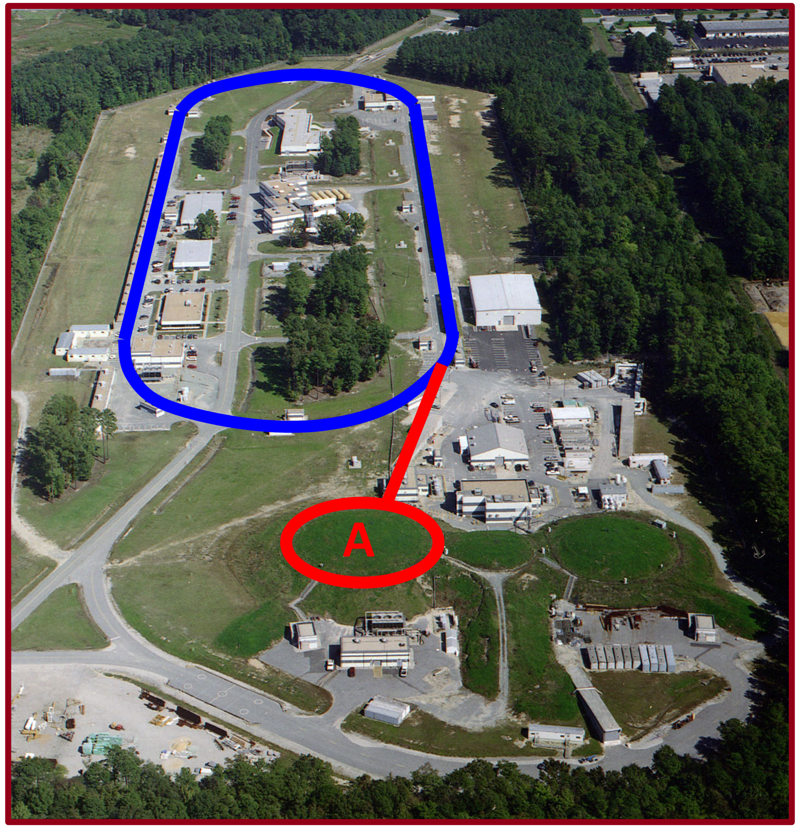
Tritium@Jlab thanks to Dave Meekins

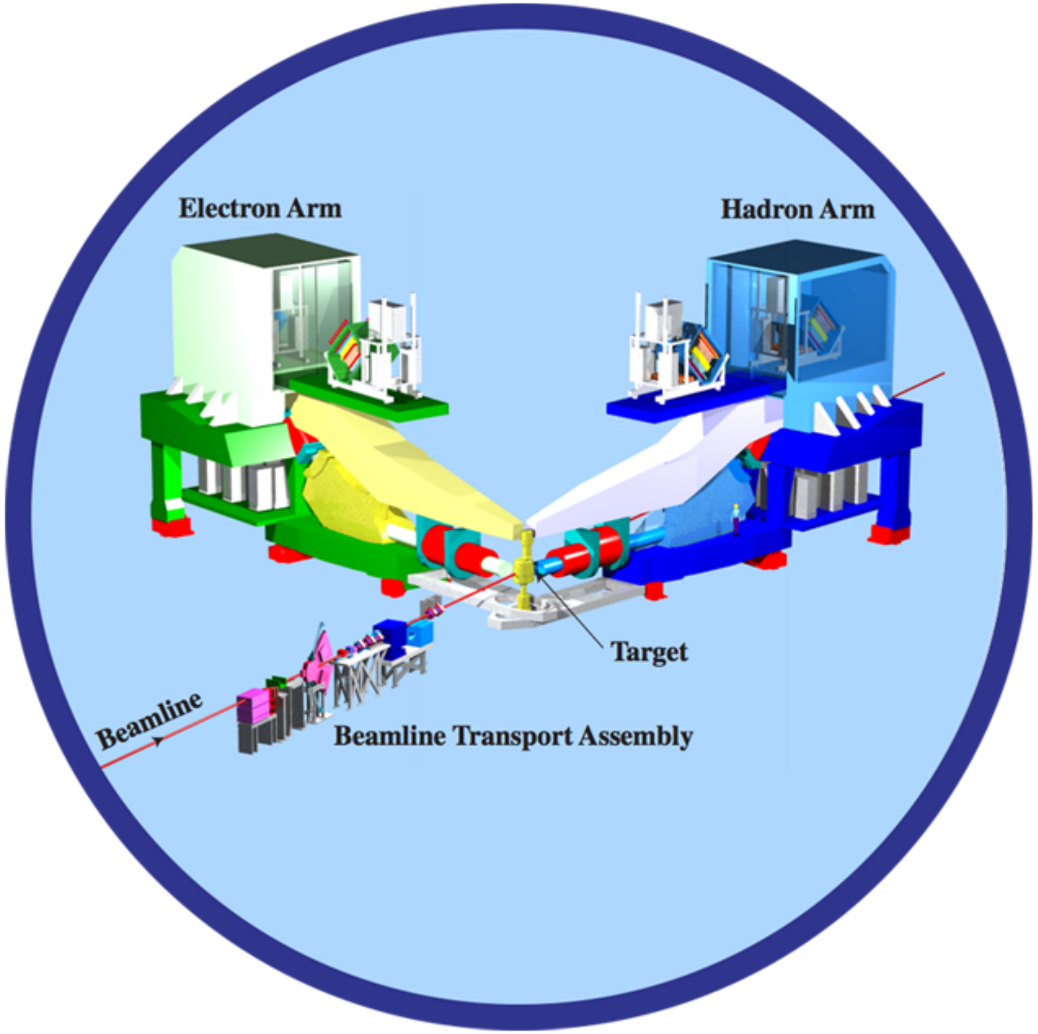
Tritium Spring Run Period



Experimental Setup – Hall A







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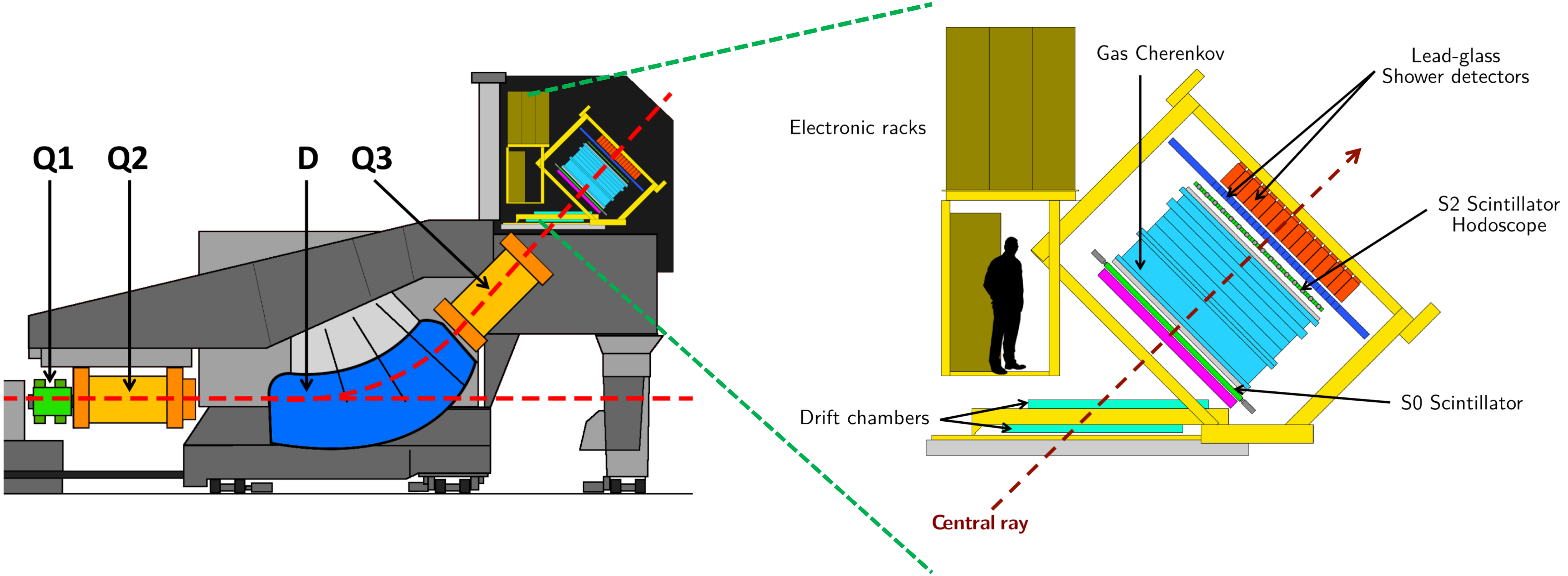
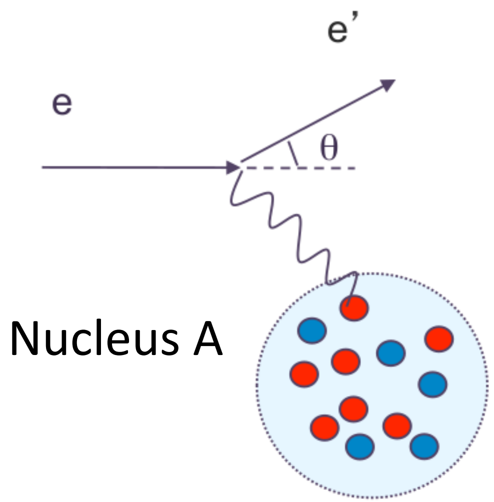
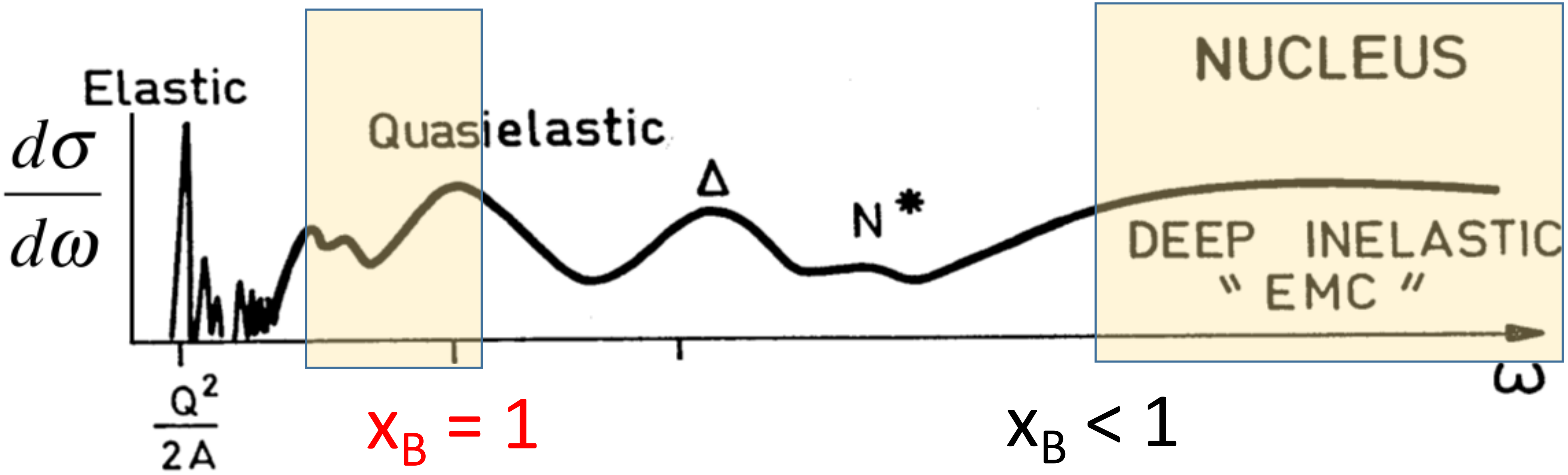


Electron Nucleus Scattering



$$x_B = \frac{Q^2}{2m\omega}$$

$$Q^2 = 4E_0E\sin^2(\frac{\theta}{2})$$



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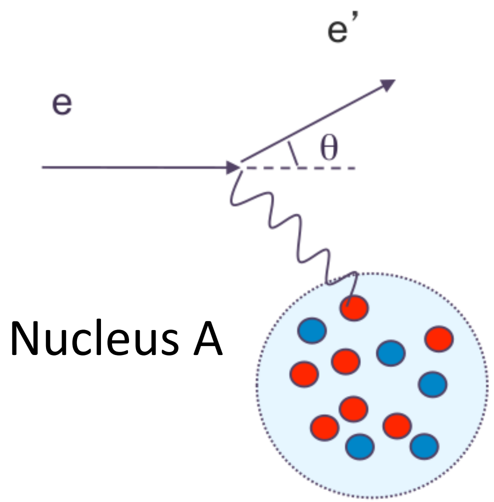

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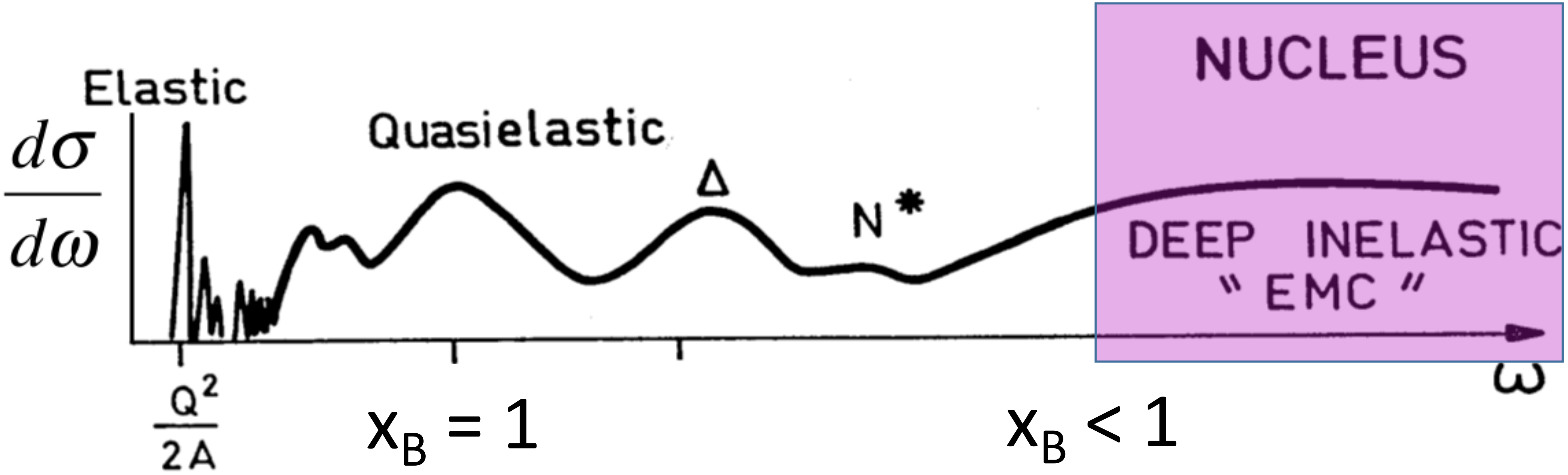
E12-10-103: MARATHON



Deep Inelastic Scattering (DIS)

$$\frac{d\sigma}{d\Omega dE'} = \left(\frac{2\alpha E'}{Q^2}\right)^2 \times \left(\frac{1}{\nu}F_2 + \frac{2}{m}F_1 \tan^2\frac{\theta}{2}\right)$$

In infinite momentum frame

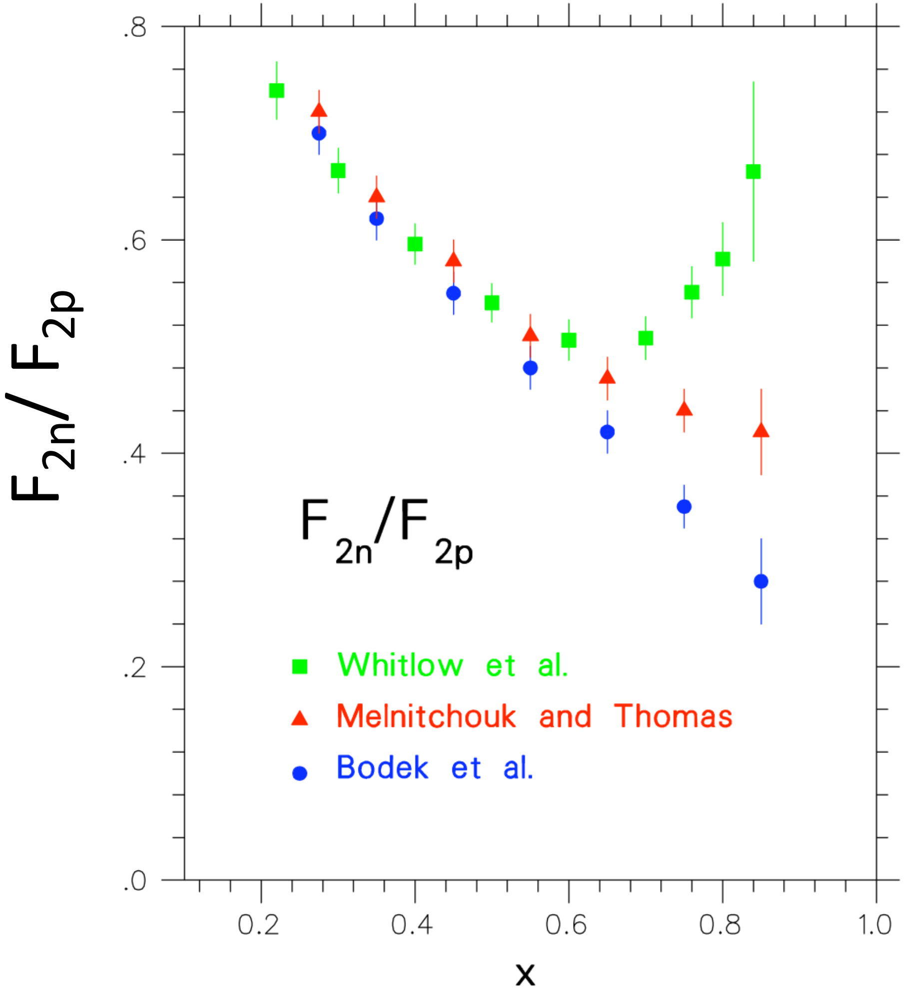
$$F_1 = \frac{1}{2}\sum_i e_i^2 q_i(x) \qquad F_2 = x\sum_i e_i^2 q_i(x)$$

$$F_2^p = x\left[\left(\frac{2}{3}\right)^2 (u(x) + \bar{u}(x)) + \left(-\frac{1}{3}\right)^2 \left(d(x) + \bar{d}(x)\right) + \left(-\frac{1}{3}\right)^2 (s(x) + \bar{s}(x))\right]$$

$$F_2^n = x\left[\left(-\frac{1}{3}\right)^2 (u(x) + \bar{u}(x)) + \left(\frac{2}{3}\right)^2 \left(d(x) + \bar{d}(x)\right) + \left(-\frac{1}{3}\right)^2 (s(x) + \bar{s}(x))\right]$$

-> Access to *u*/*d* quark distributions via F_2^p/F_2^n ratio

F_2 - Ratio



- From DIS measurements on proton and deuterium as neutron target
- Fermi-Motion and binding energy in deuterium
- Extraction of ratio depends on model

Tritium / ^{3}He –Another Way for F_2 Ratio

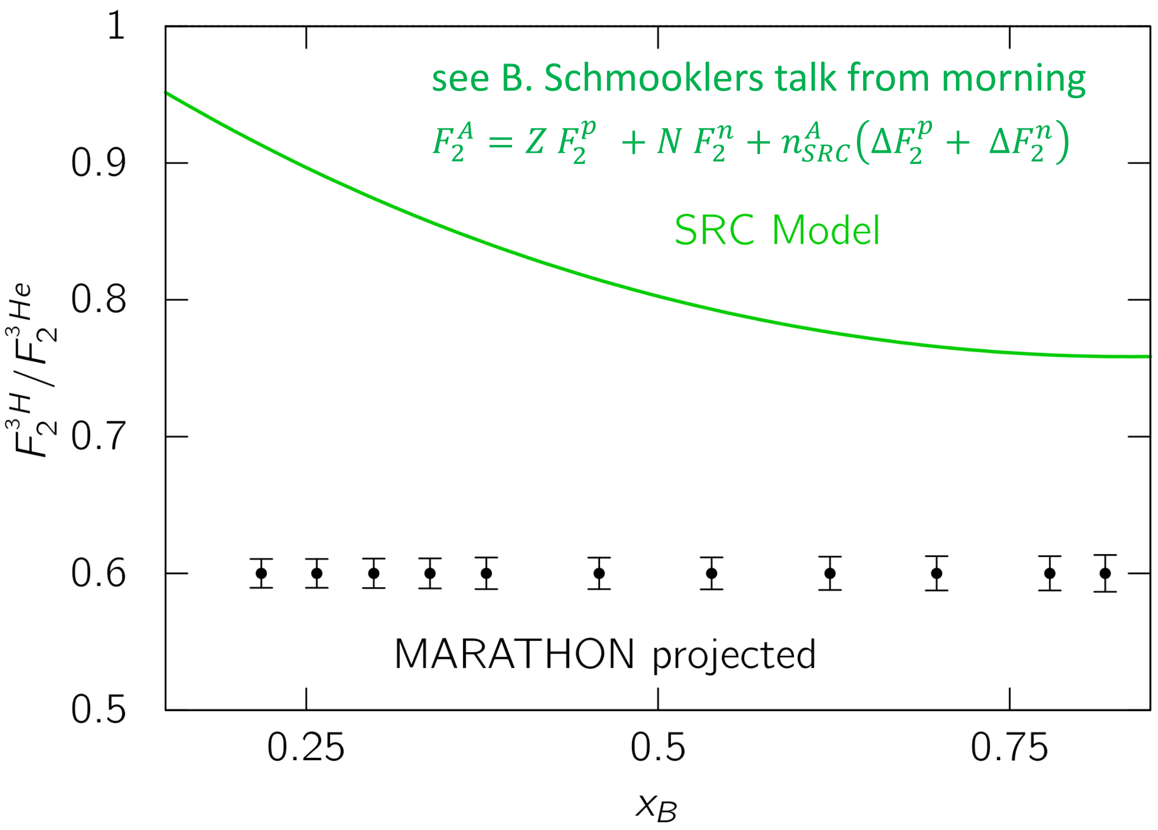
$$\frac{F_2^p}{F_2^n} = \frac{2R - \frac{F_2^{3He}}{F_2^{3H}}}{\frac{2\,F_2^{3He}}{F_2^{3H}} - R}$$

measured

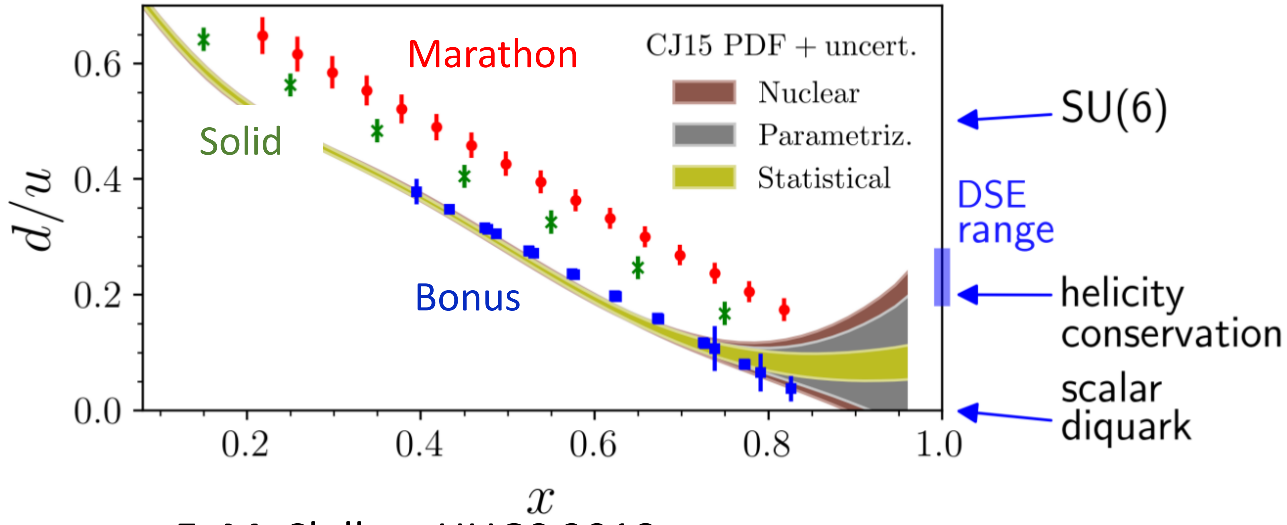
Ratio of EMC effect in tritium and ^{3}He $\quad R \equiv \frac{F_2^{3He}}{2F_2^p + F_2^n} \times \frac{2F_2^n + F_2^p}{F_2^{3H}}$

- A = 3 system well understood theoretically
- *R* and F_2 ratio will be calculated in an iterative procedure

Marathon – Projected Results



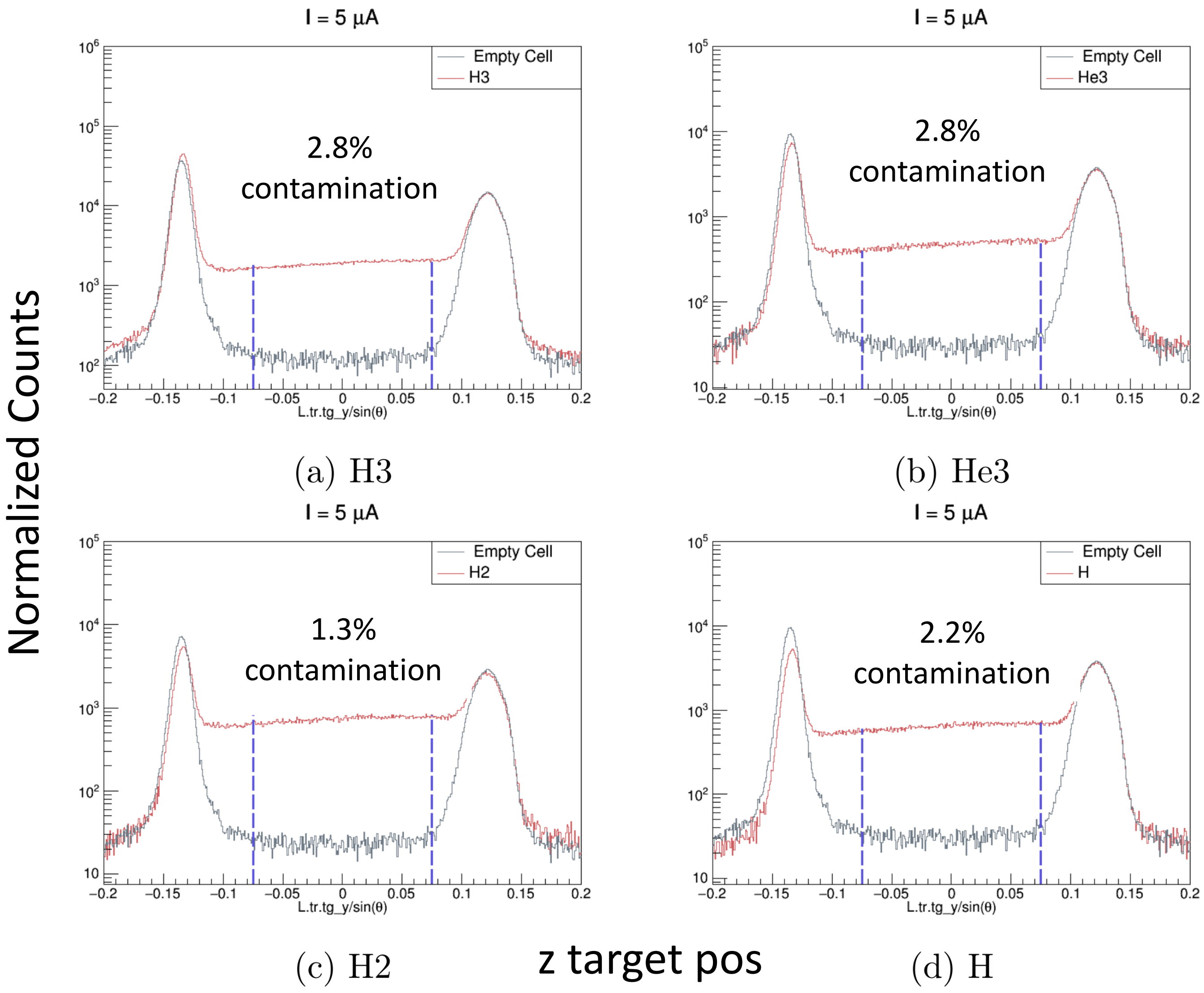
A. Schmidt, CIPANP2018



E. McClellan, HUGS 2018

- Analysis ongoing
- Total 6 PhD theses
- F_2 ratio and EMC data

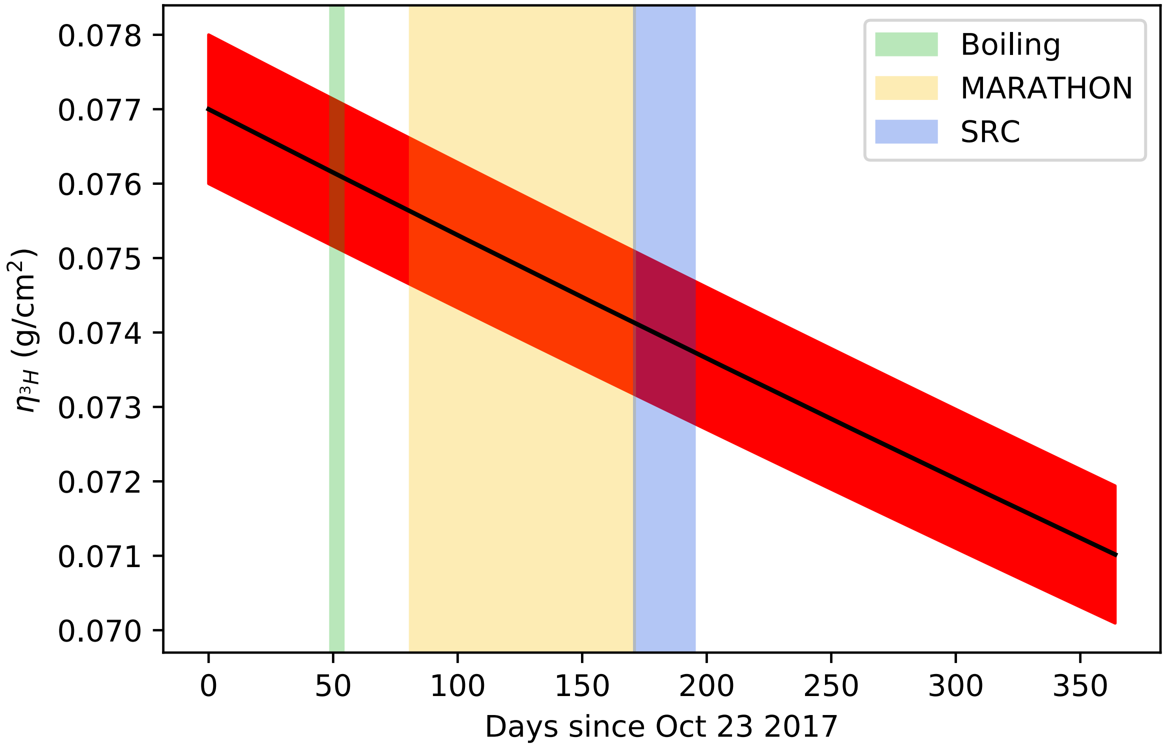
Ongoing Analysis: Target Background

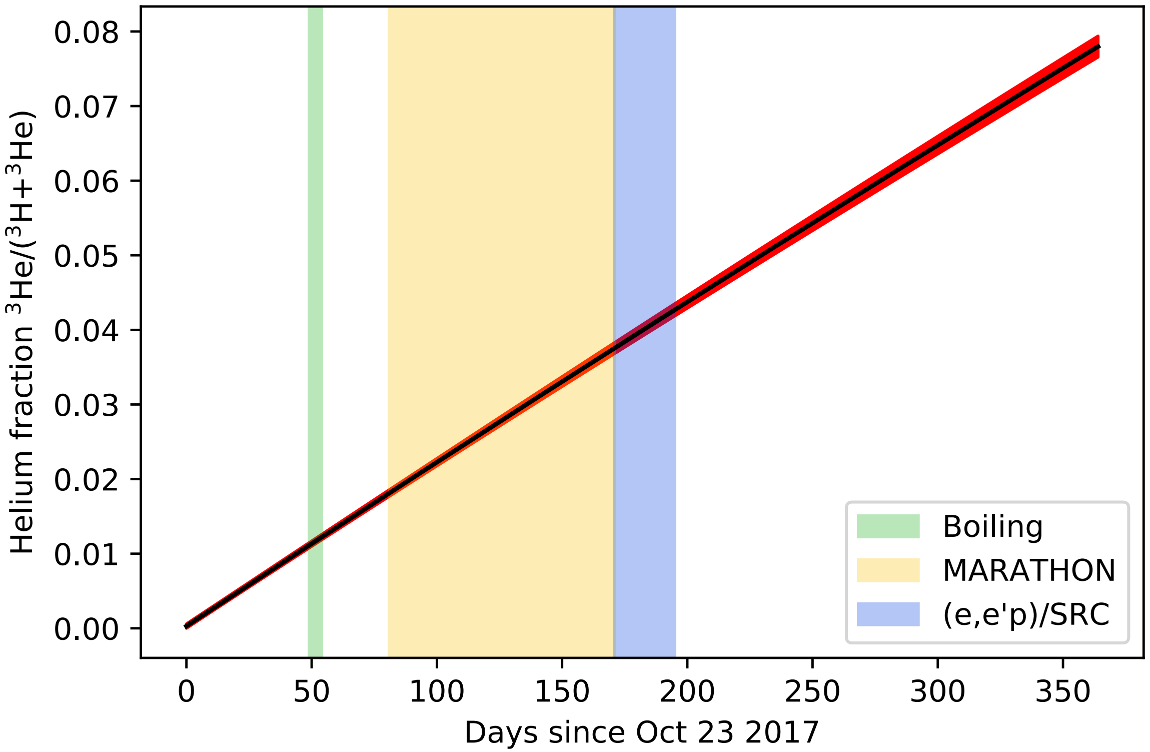


Courtesy of S. Alsalmi

- Endcap background 1-3%

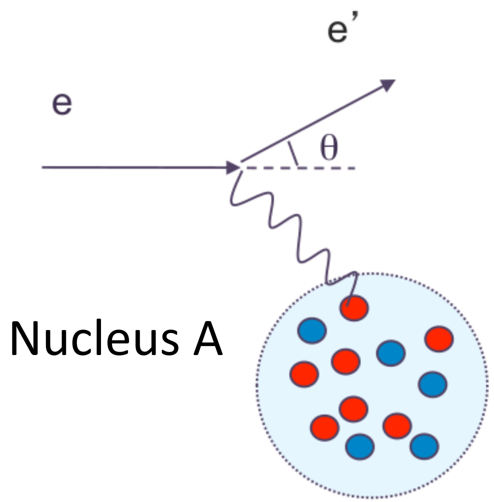
Ongoing Analysis: Tritium Contamination from Decay





Courtesy of T. Kutz

Electron Nucleus Scattering



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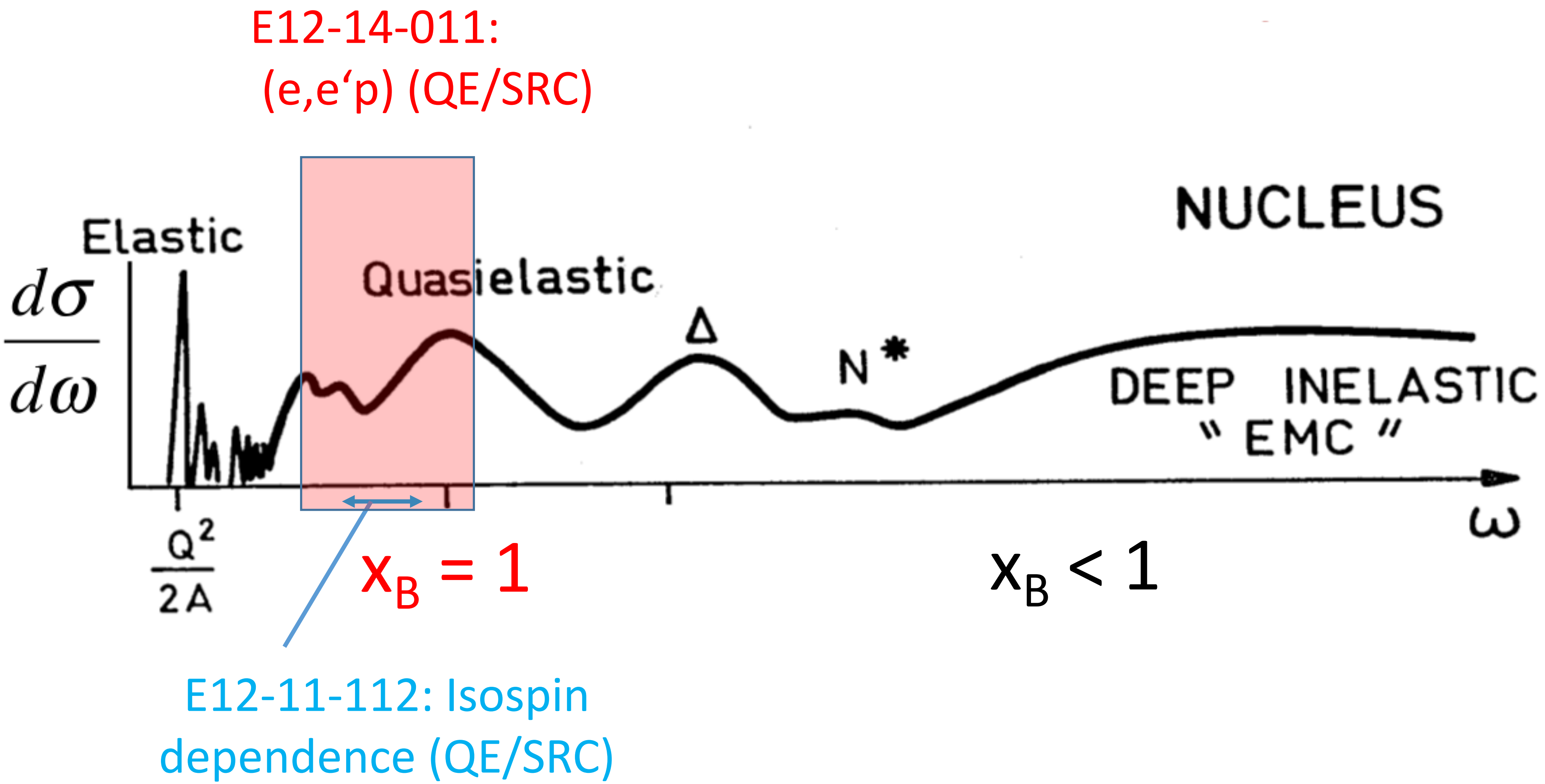
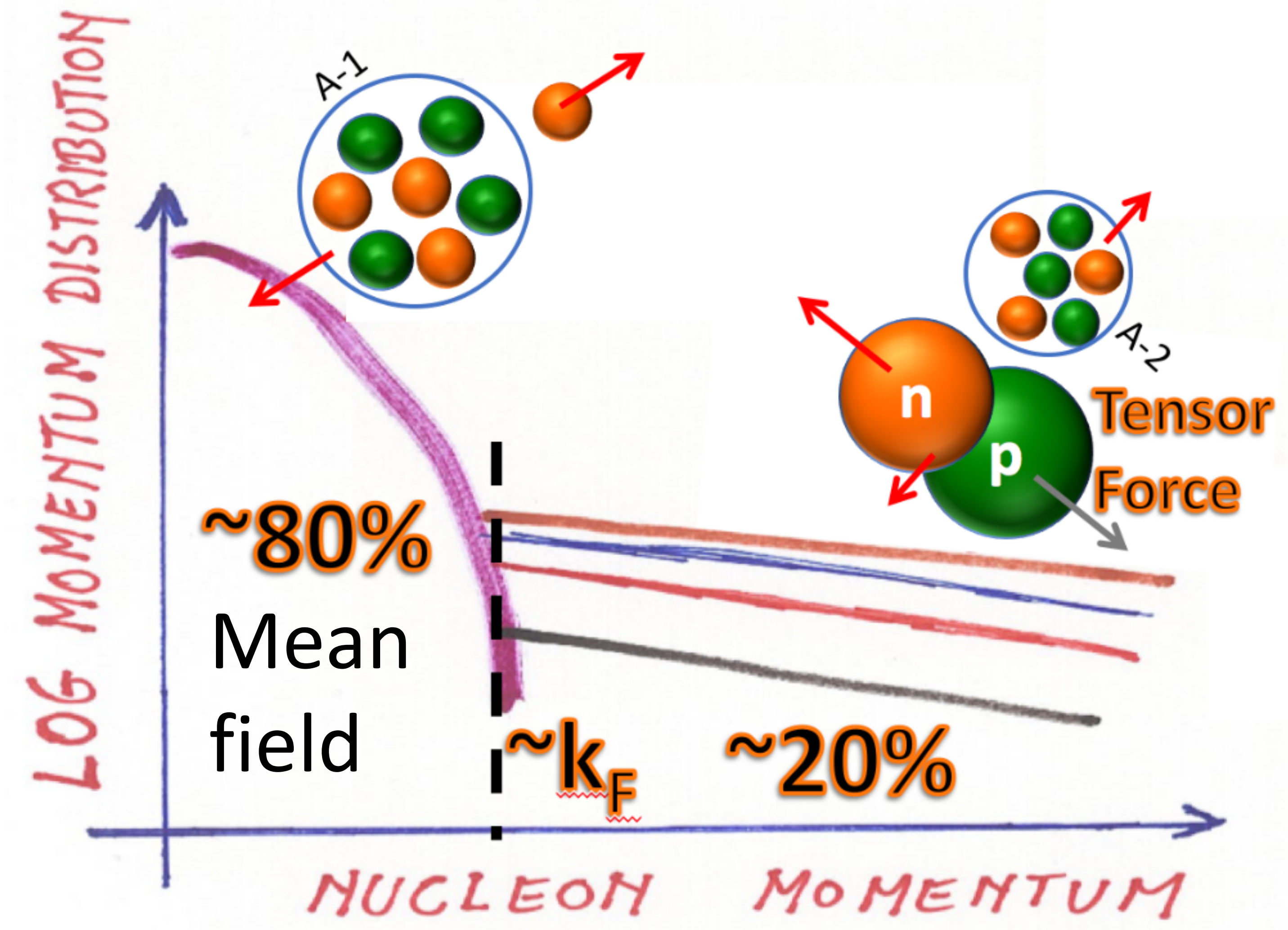
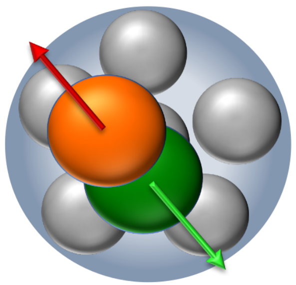


Momentum Distribution



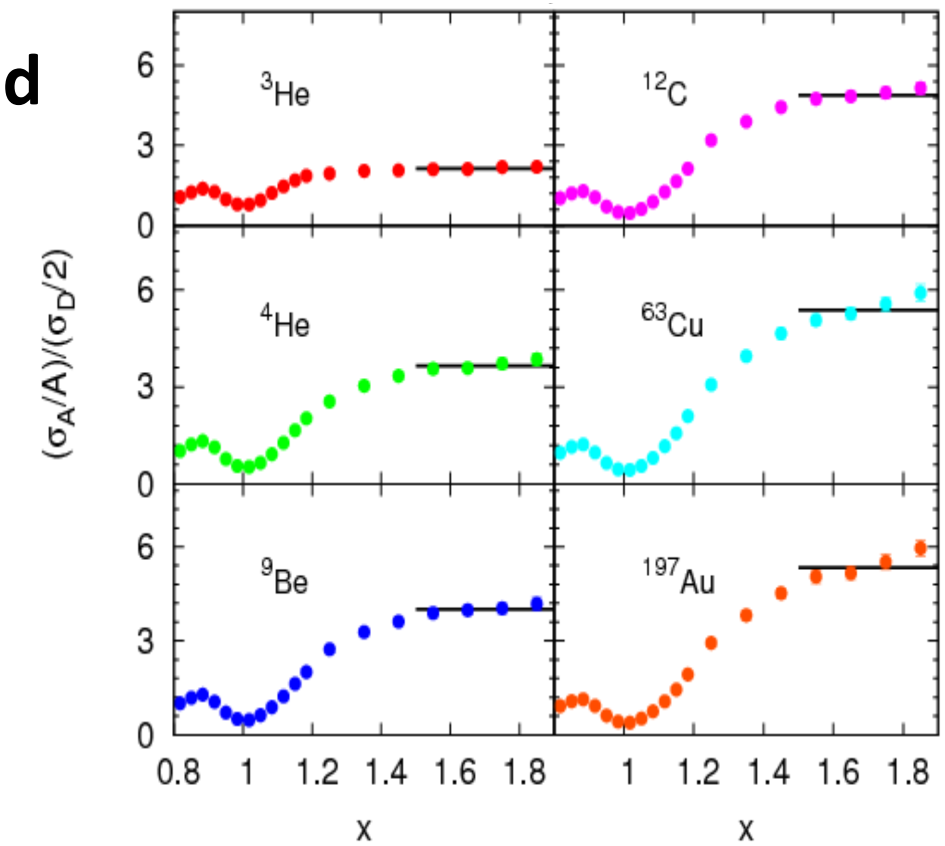
Short Range Correlations (SRC)



Short Range Correlations (SRC)

1. NN pair with **large relative momentum and small c.m. momentum**
2. Internucleon distance < size of nucleon

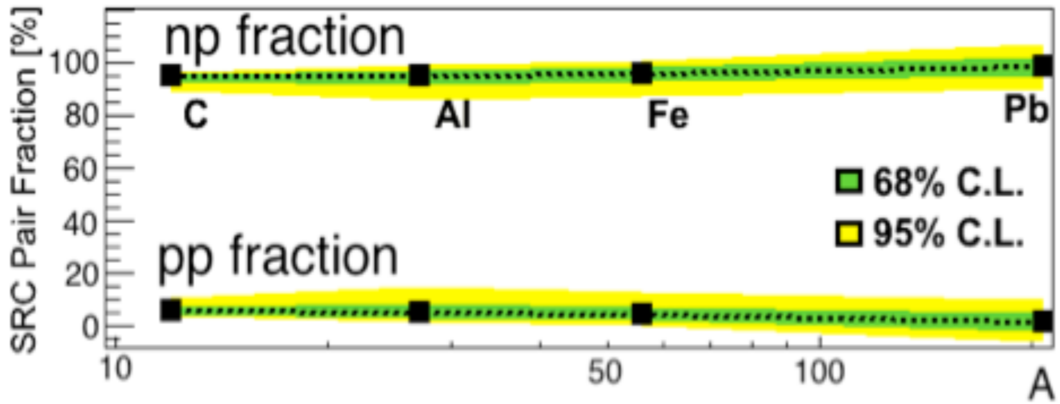
- Account for ~ 20% of nucleons in nuclei
- SRC dominates the nucleon momentum distribution for $k_F \geq 300$ MeV/c



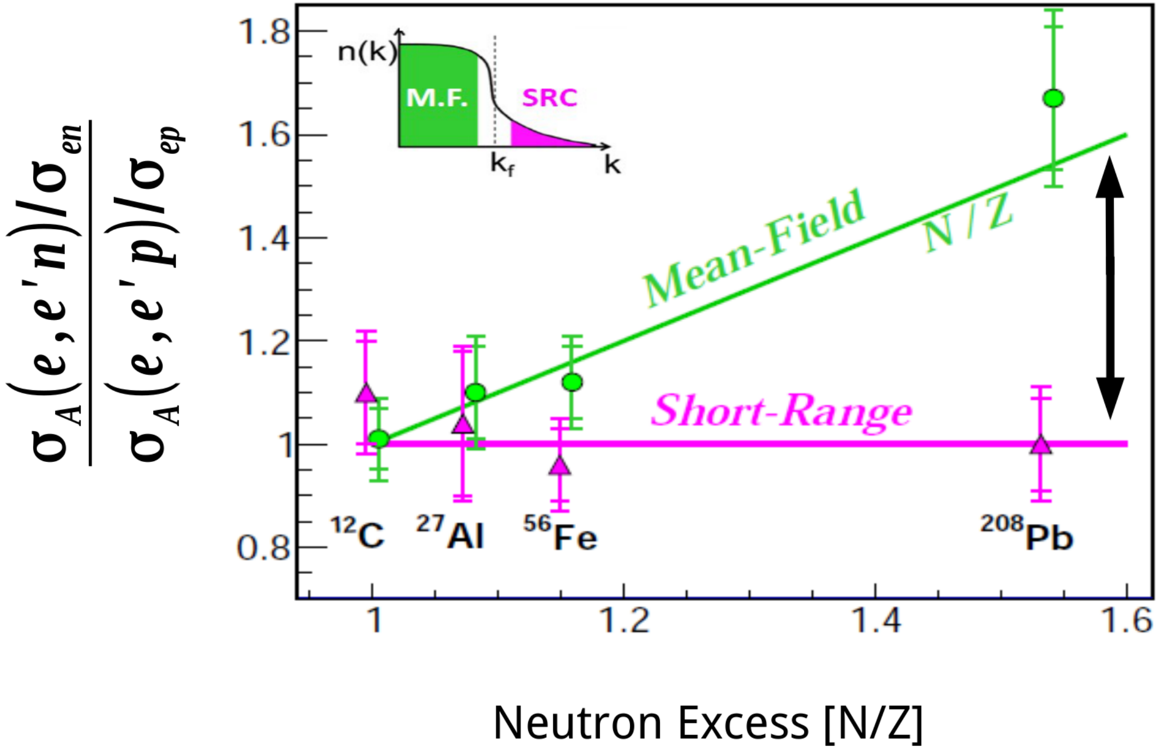
N. Fomin et al., Phys. Rev. Lett. 108, 092502 (2012)

SRC – np Dominance

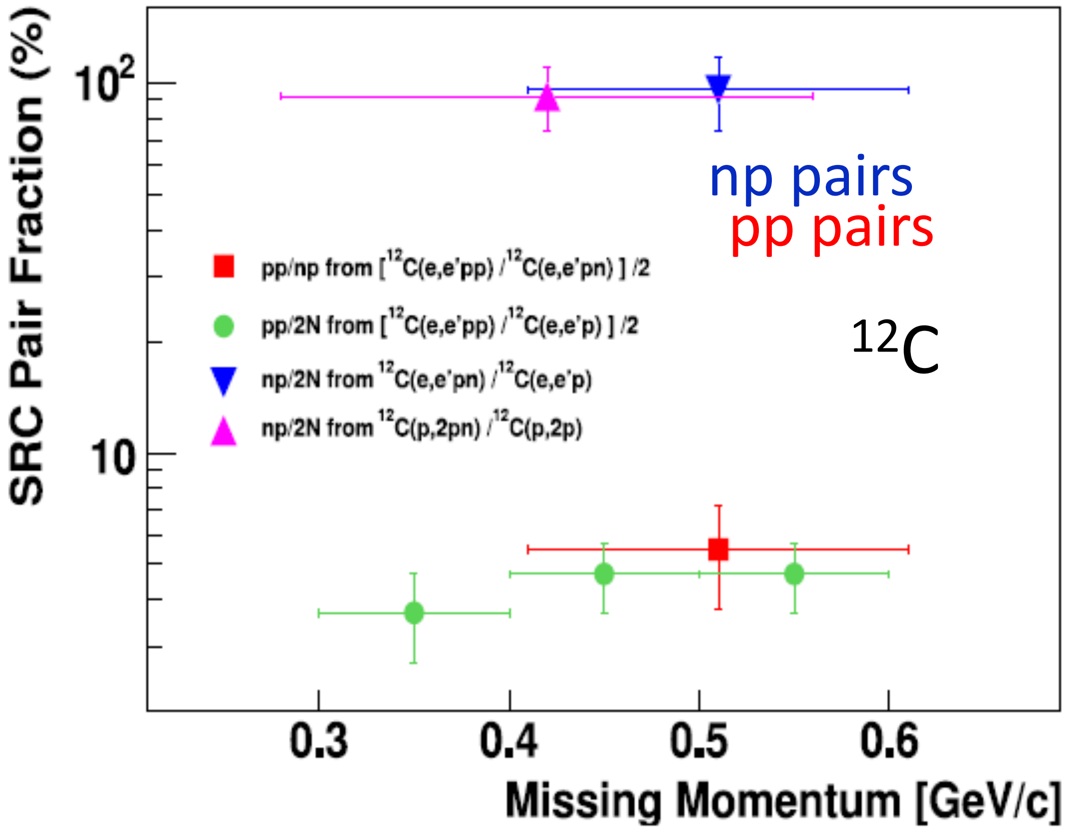
- Probability for np-SRC ~18 times larger than pp-SRC.



Or Hen et al., Science 346, 614 (2014)

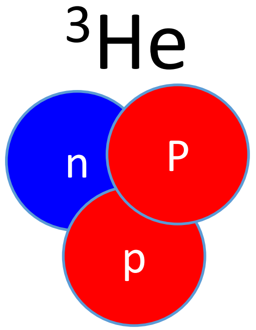


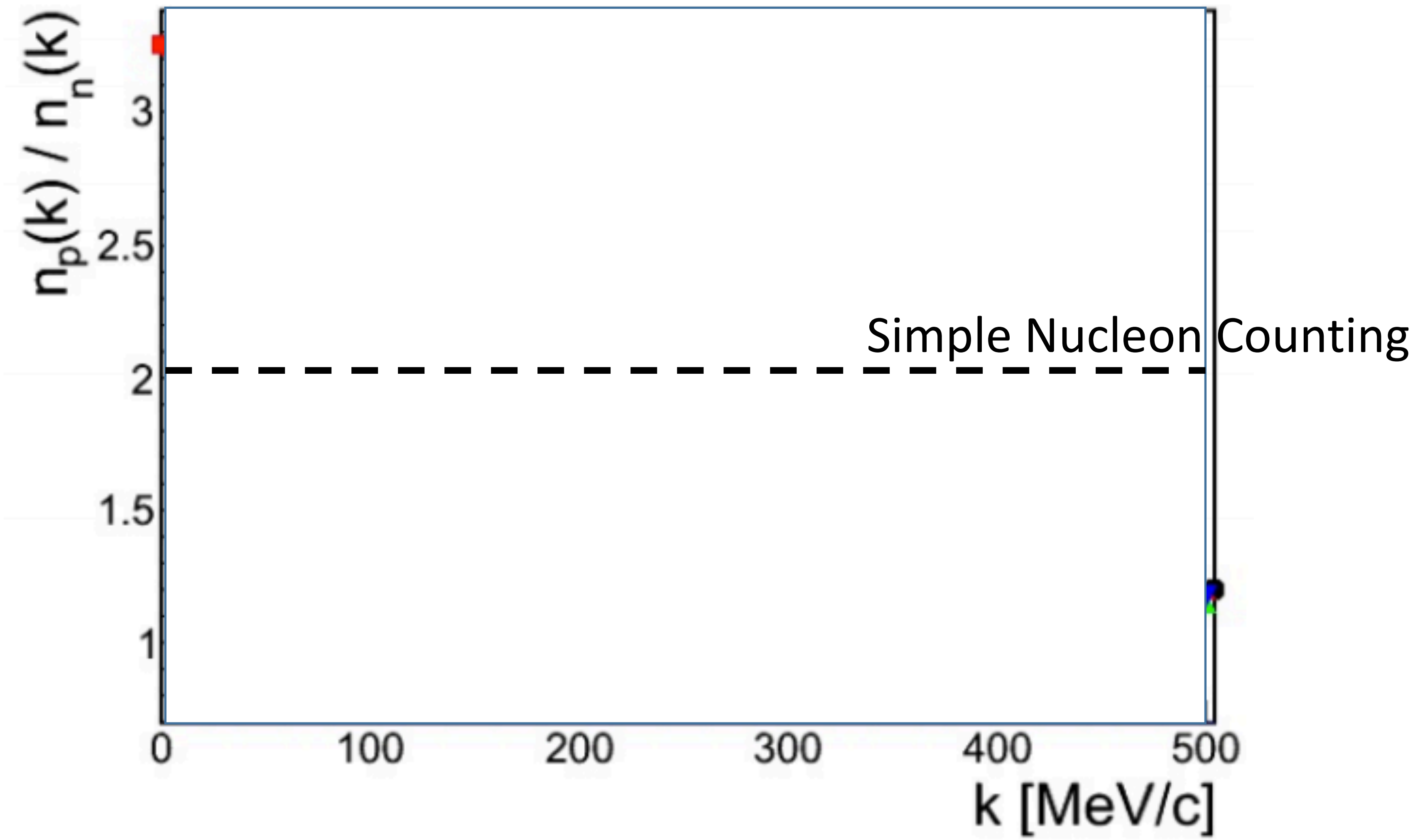
M. Duer et al., Nature in press (2018)



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

Nucleon Momentum Ratio





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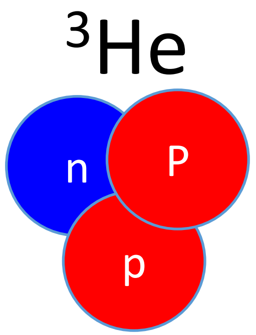

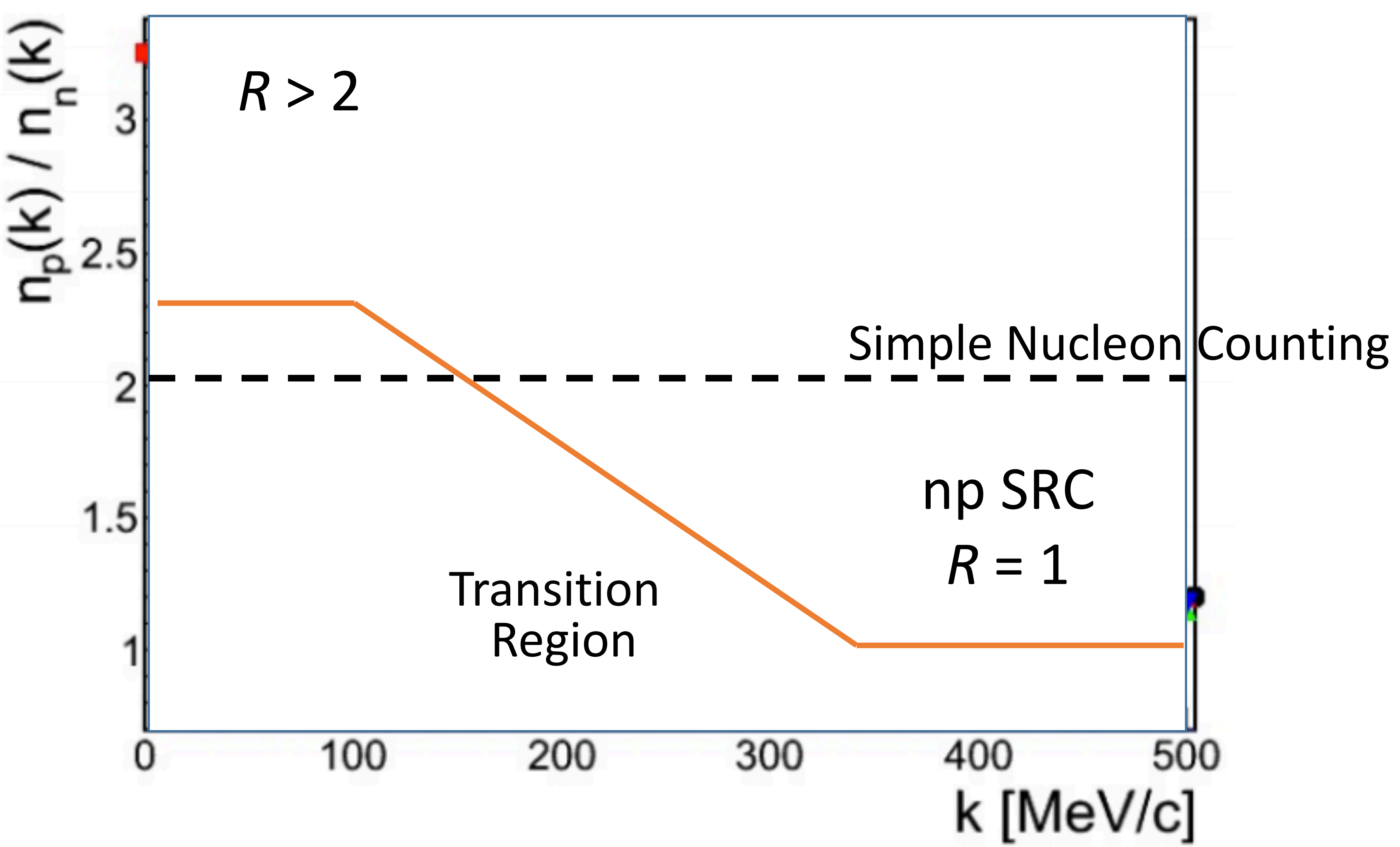

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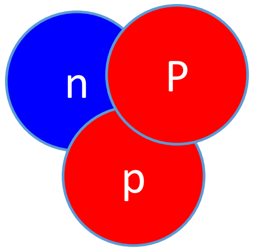
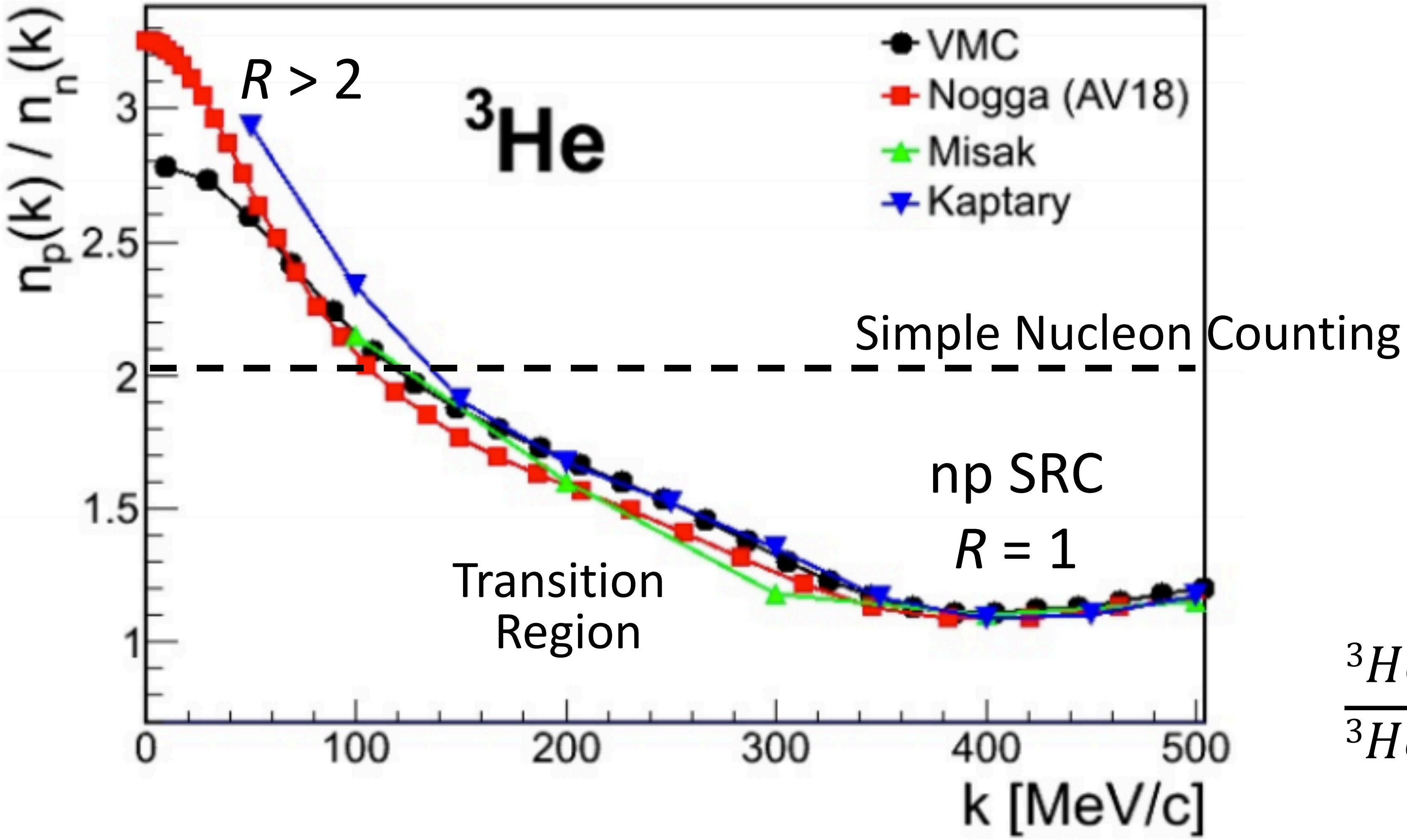




Measurement of ratio via mirror nuclei ^3H

$$\frac{^3He(e,e'p)}{^3He(e,e'n)} \approx \frac{^3He(e,e'p)}{^3H(e,e'p)}$$

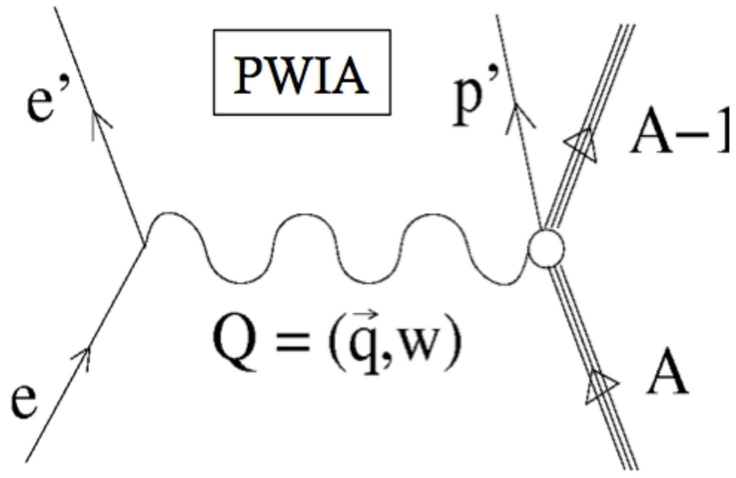
The A(e,e‘)p Reaction

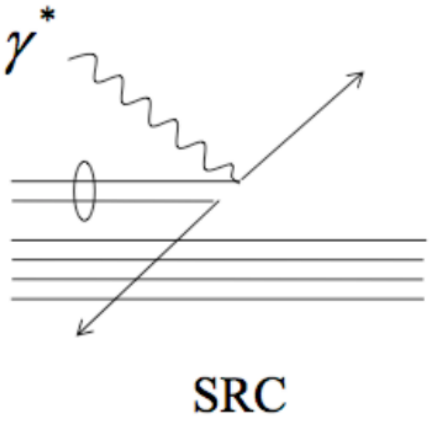
What we want:

$$\sigma_{\mathrm{PWIA}} = k \cdot \sigma_{ep} \cdot S_p\left(E_{\mathrm{miss}}, p_{\mathrm{miss}}\right)$$

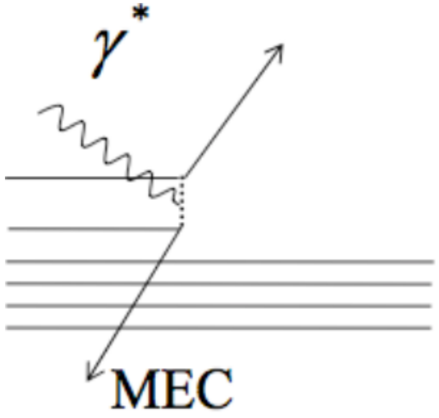
$$E_{\mathrm{miss}} = \omega - T_p - T_{A-1}$$

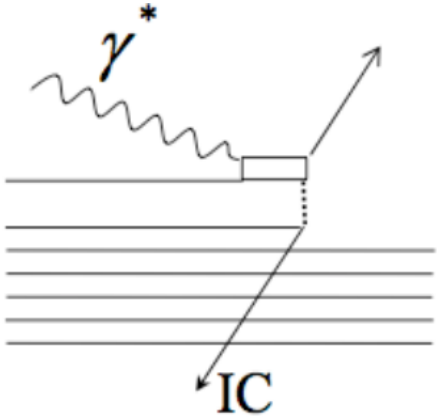
$$\vec{p}_{miss} = \vec{q} - \vec{p}\,' = -\vec{p}_{init}$$

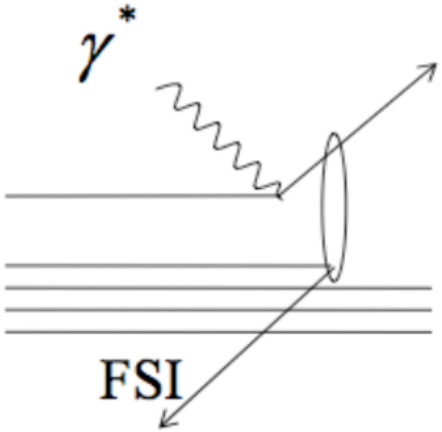


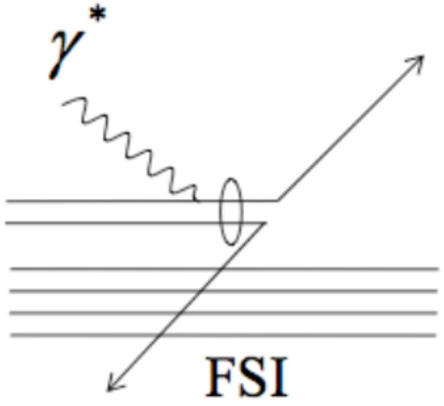


What we might get:









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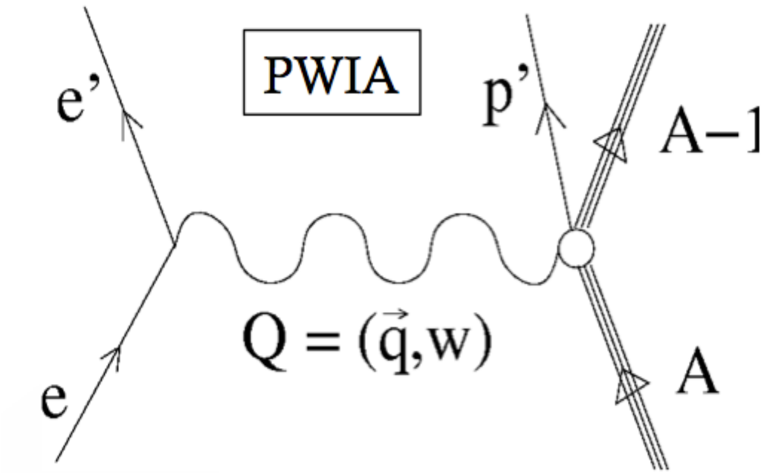

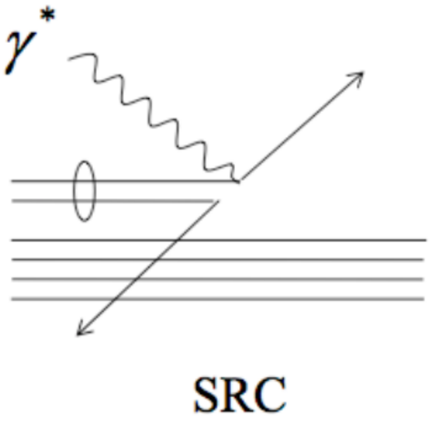

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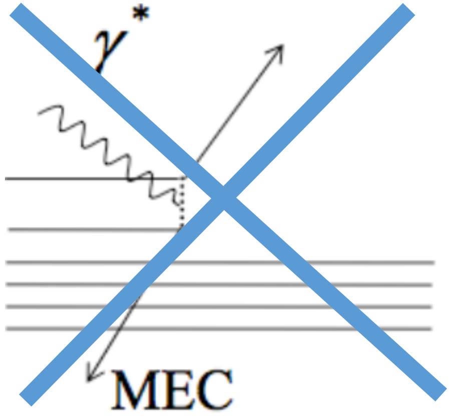
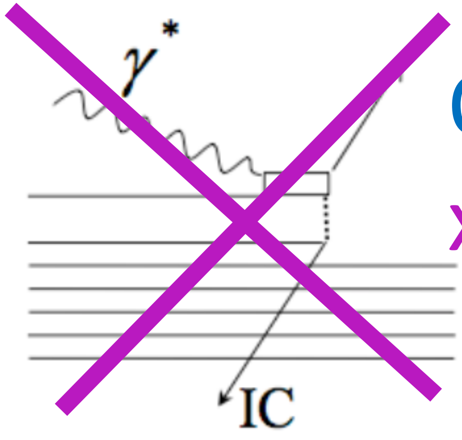
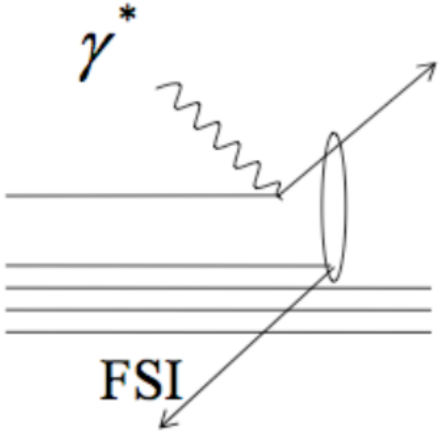
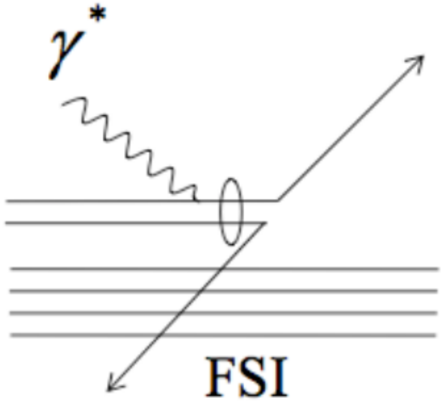




$Q^2 > 1.8\ \mathrm{GeV}^2$

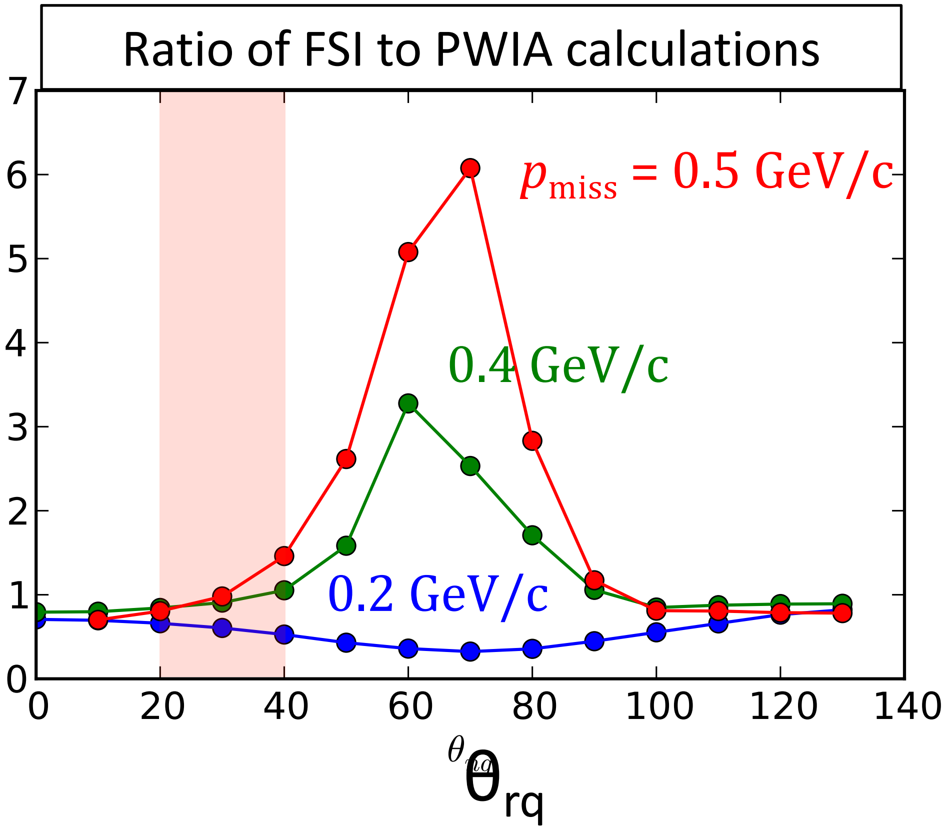
$x > 1$

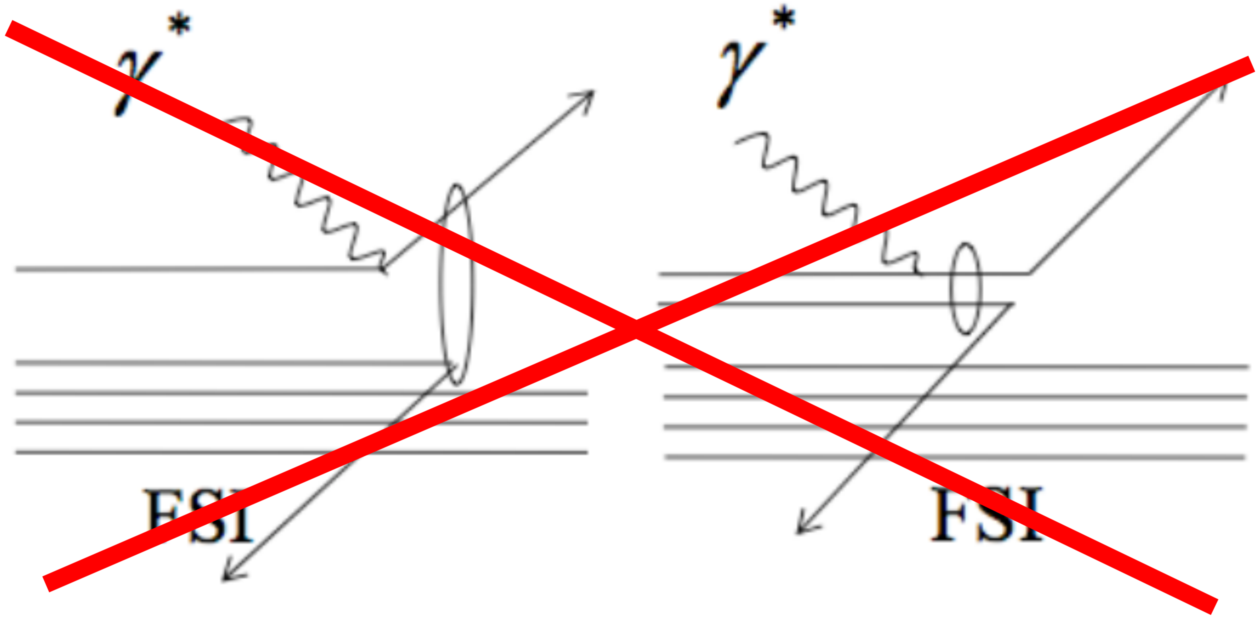




Minimizing FSI Effects

^{3}He(e,e'p)np





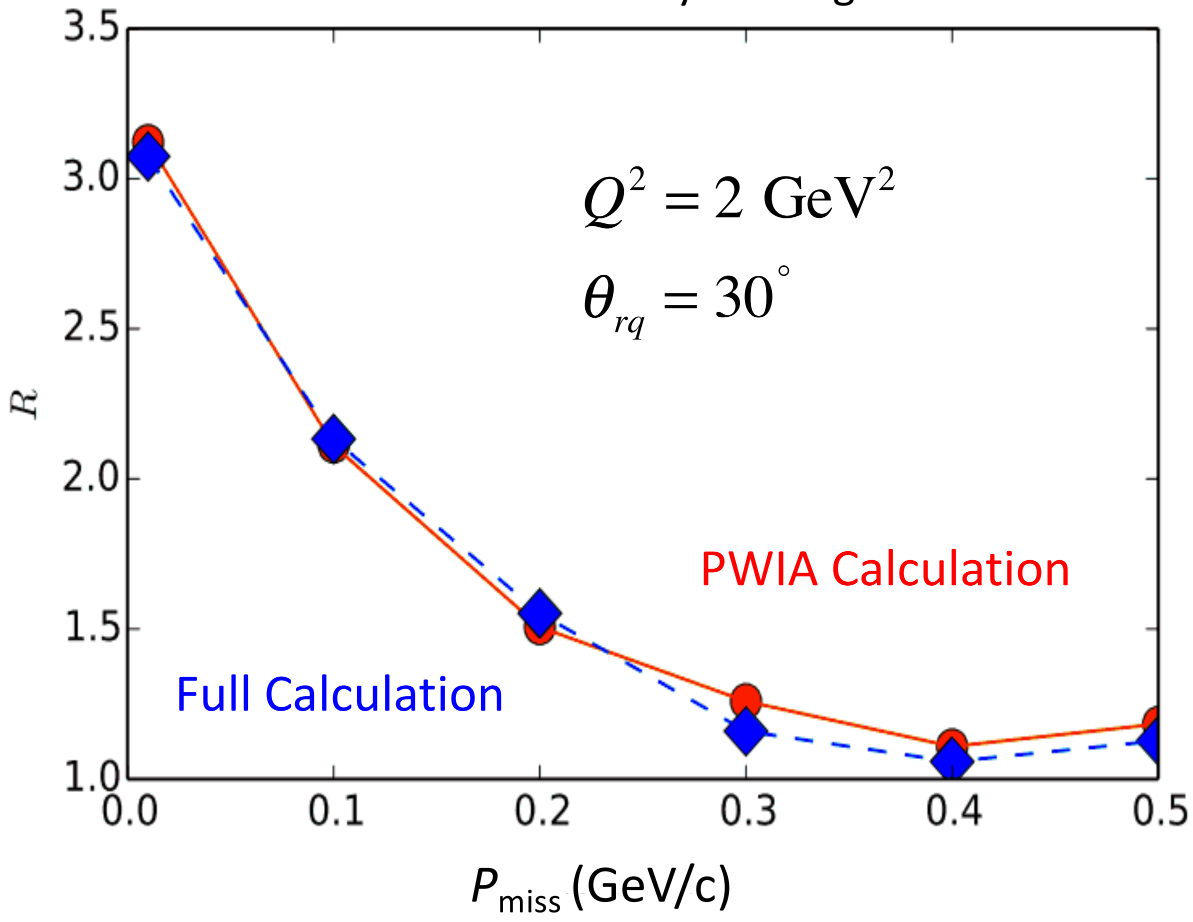
➔ Choose $\theta_{rq} < 40^o$

P_{miss} antiparallel to q

Minimizing FSI Effects

$$\frac{\sigma({}^3\mathrm{He}(e,e'p))}{\sigma({}^3\mathrm{H}(e,e'p))}$$

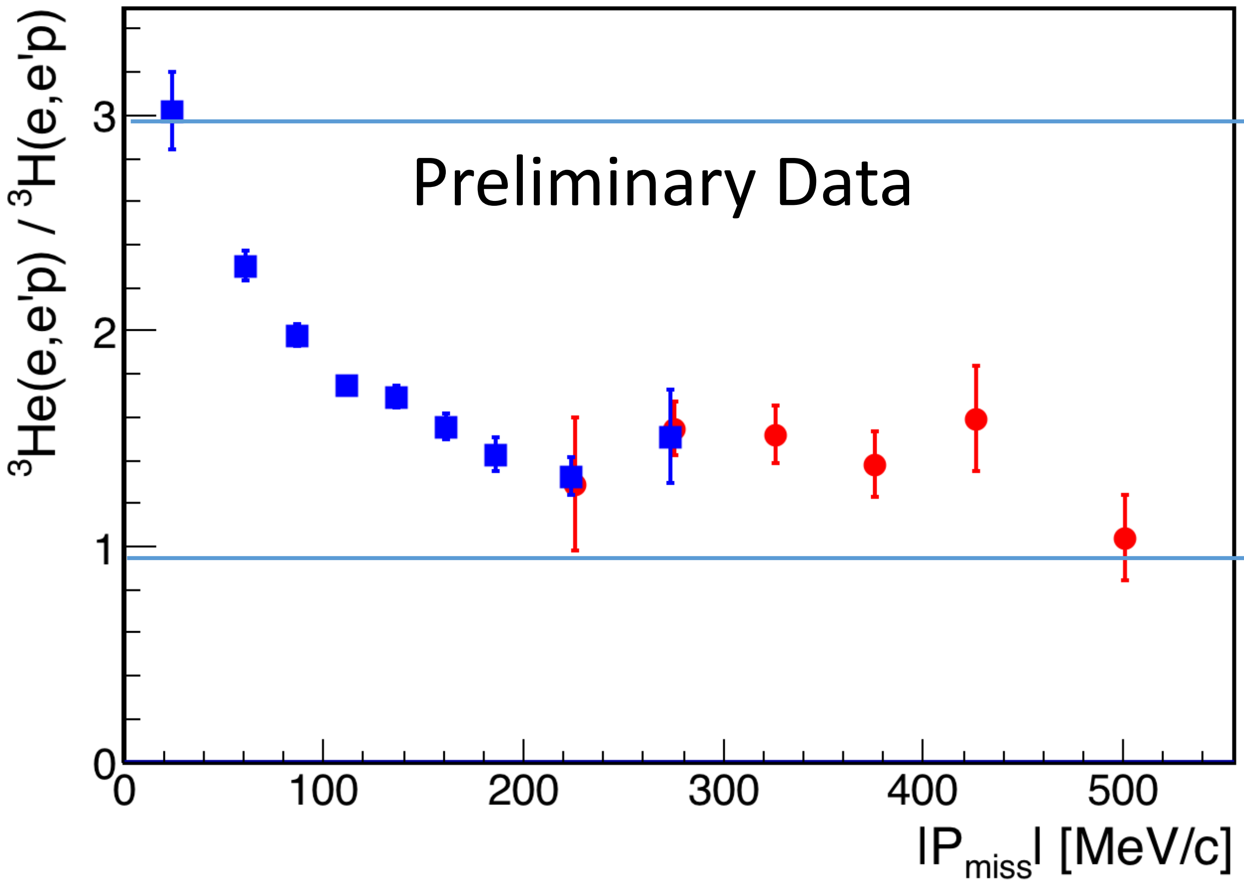
Calculations by M. Sargsian

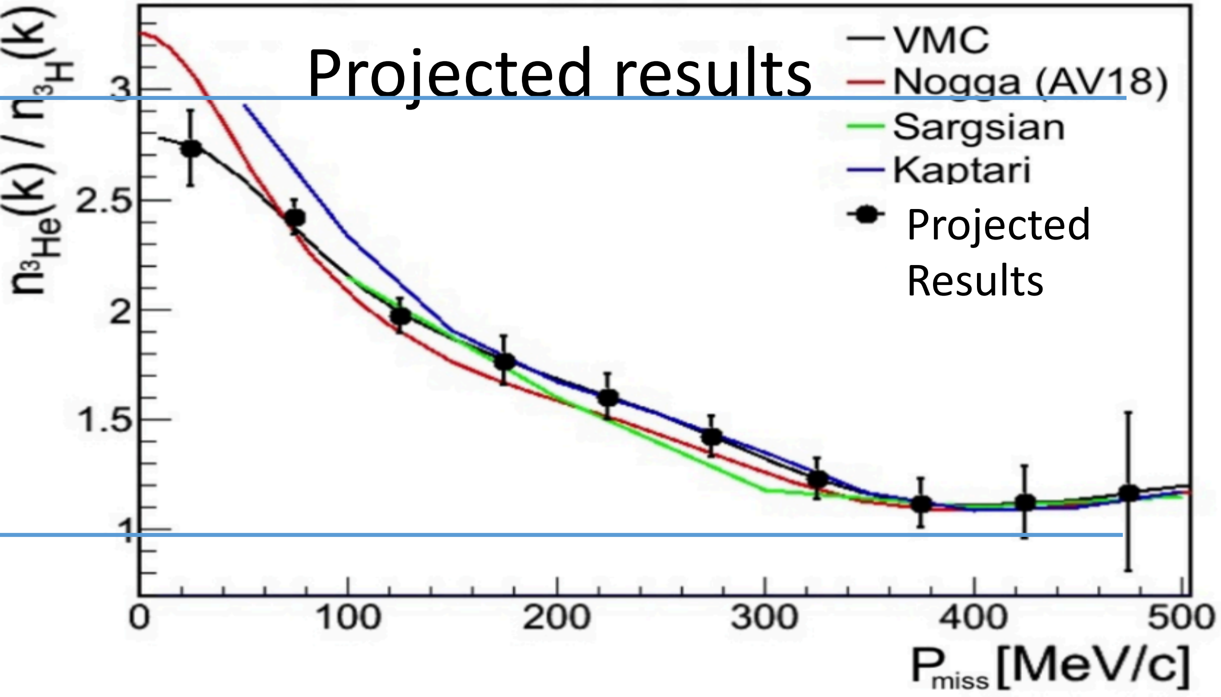


- Choose $\theta_{rq} < 40^{o}$
- Take ratios to cancel residual FSI

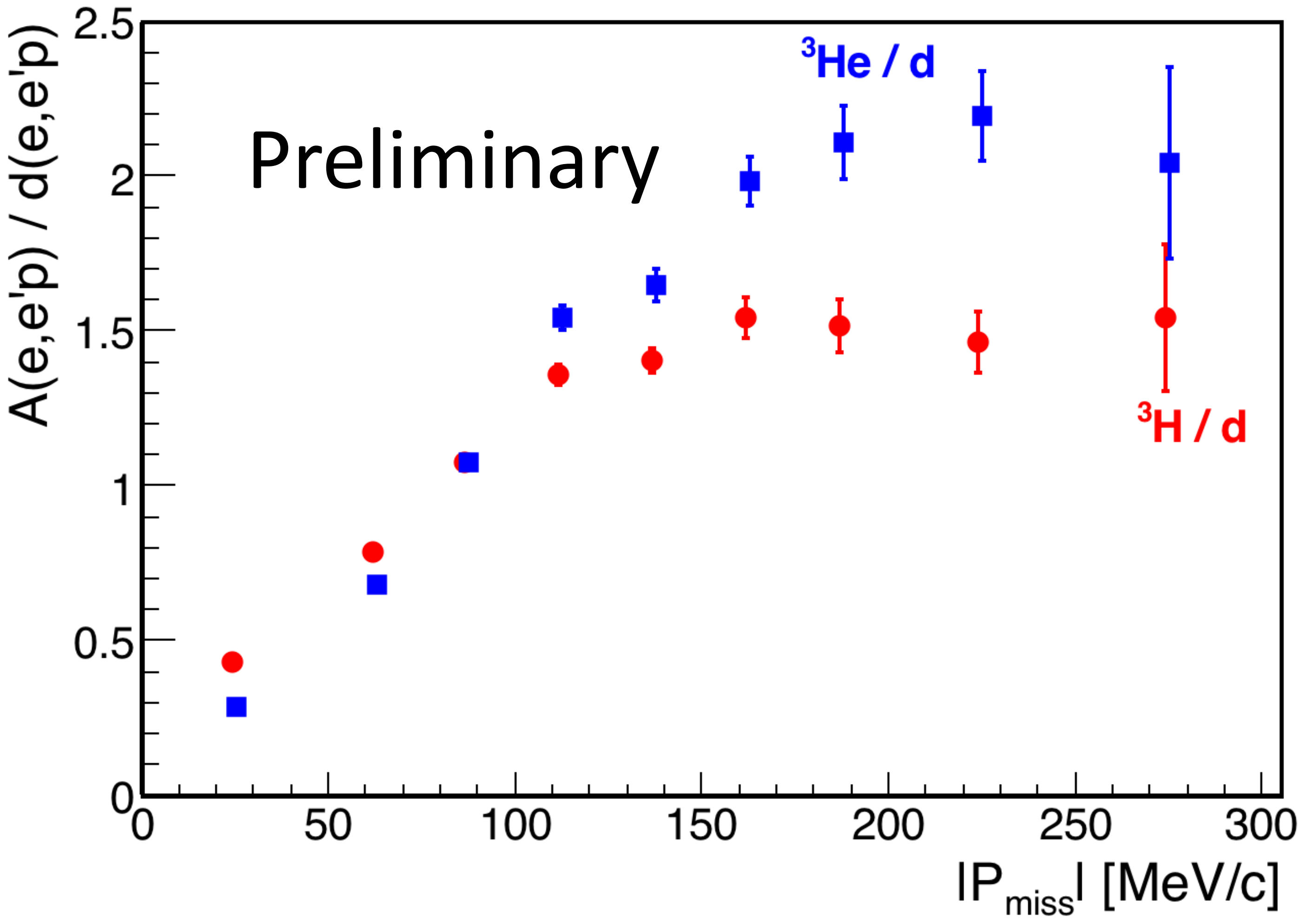
$$\frac{\sigma({}^3\mathrm{He}(e,e'p))}{\sigma({}^3\mathrm{H}(e,e'p))} \approx \frac{S_{3\mathrm{He}}(E_m, p_m)}{S_{3\mathrm{H}}(E_m, p_m)}$$

Preliminary Results





Preliminary Results (2)

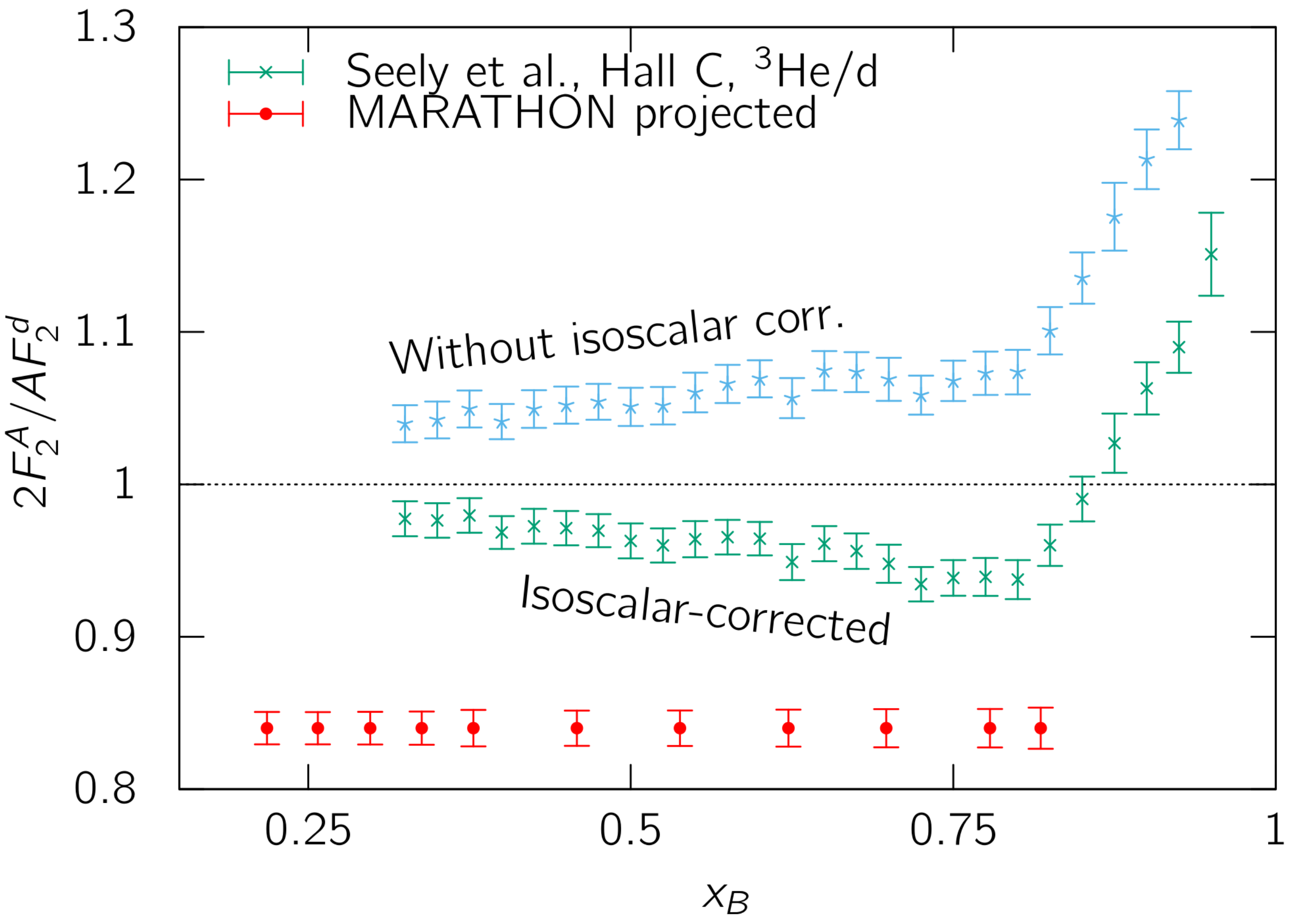


Summary

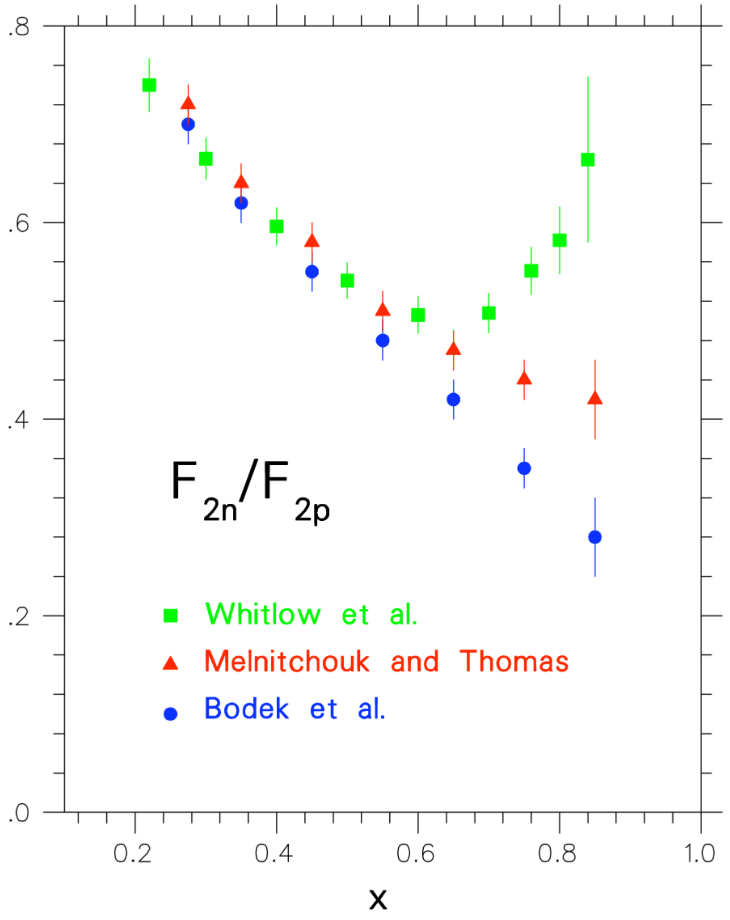
- Once in a generation tritium target at HallA at JLab
- Successful spring operation of tritium experiments
- MARATHON will impact uncertainties in high-x F_2 ratio
  - Analysis ongoing
  - Results by next year
- SRC (e,e'p) experiment
  - Preliminary results agree with np dominance for high momentum nucleons
  - Expected final results by the end of the year
- Tritium running will continue in fall with SRC inclusive and (e,e'K) experiment

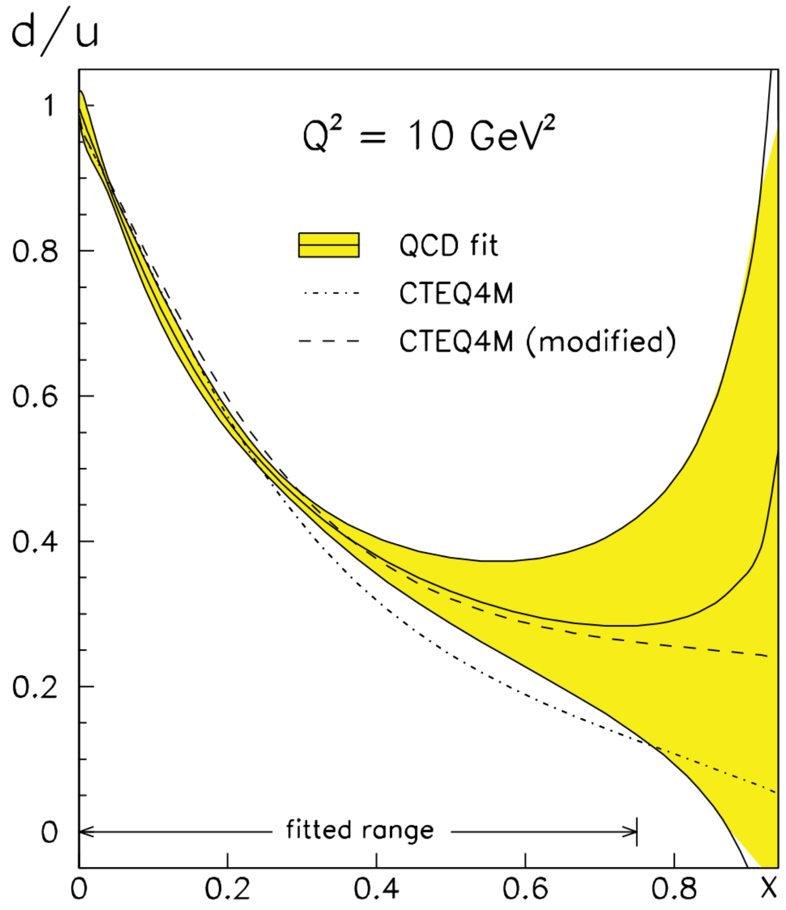
Backup Slides

Marathon EMC Measurements

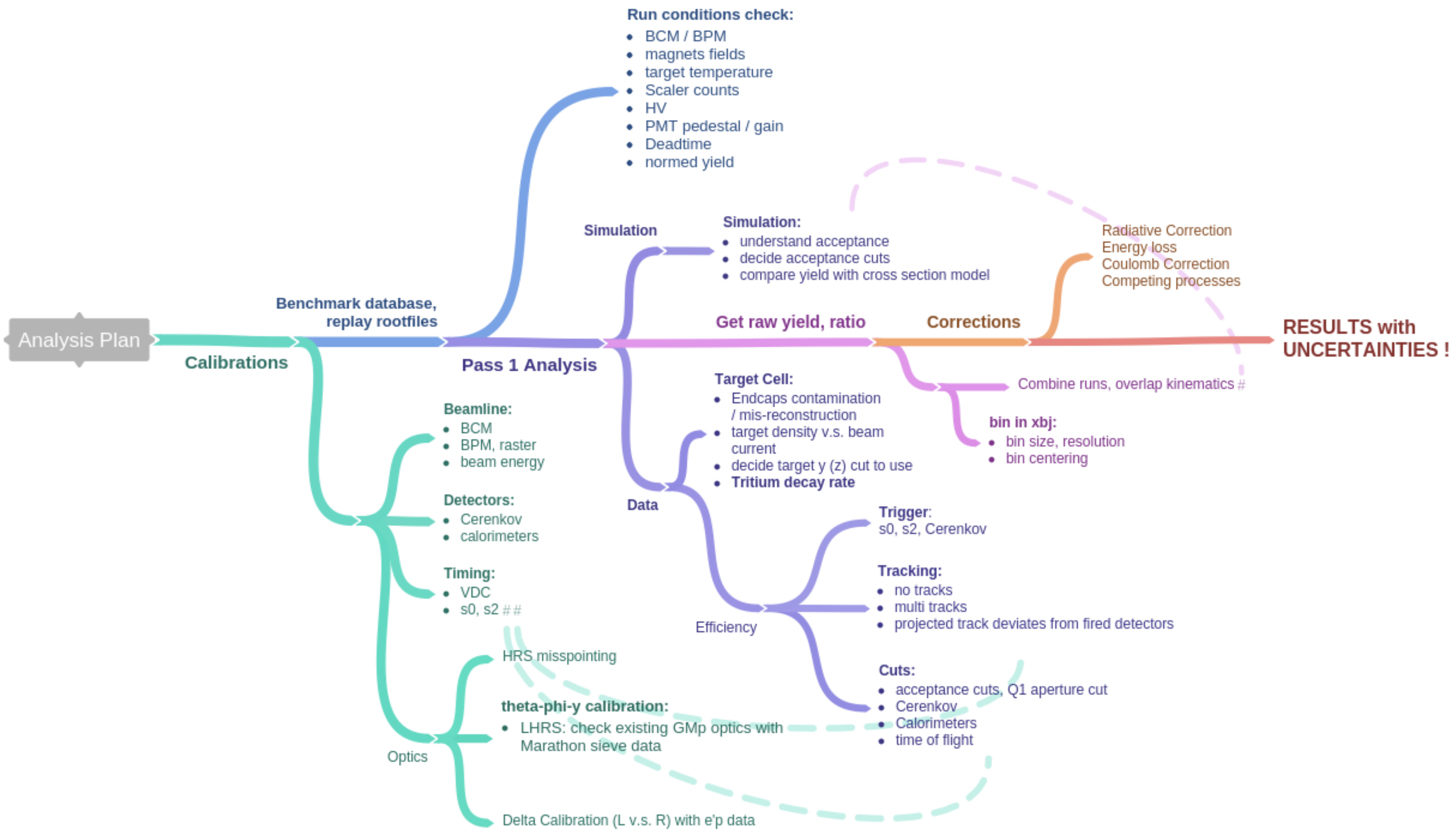


F_2 and u/d Ratio



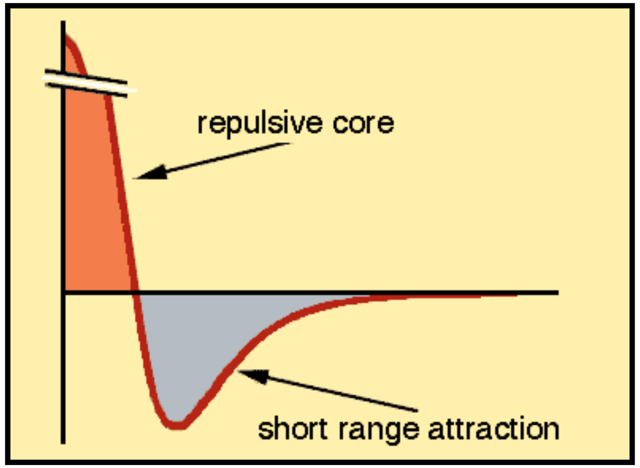


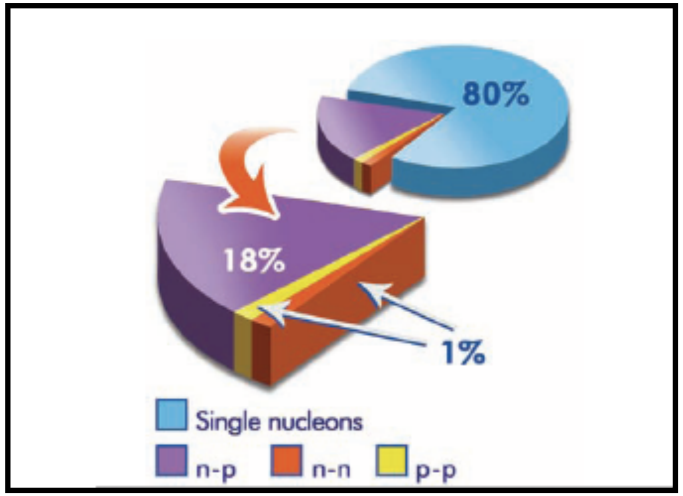
Ongoing Analysis

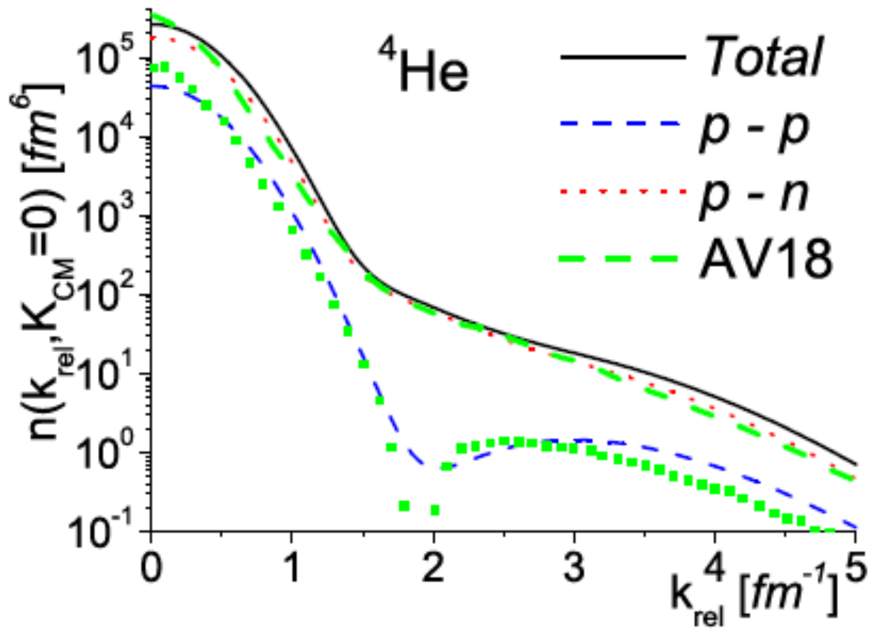


Plot by S. Li

SRC - NN Tensor Force







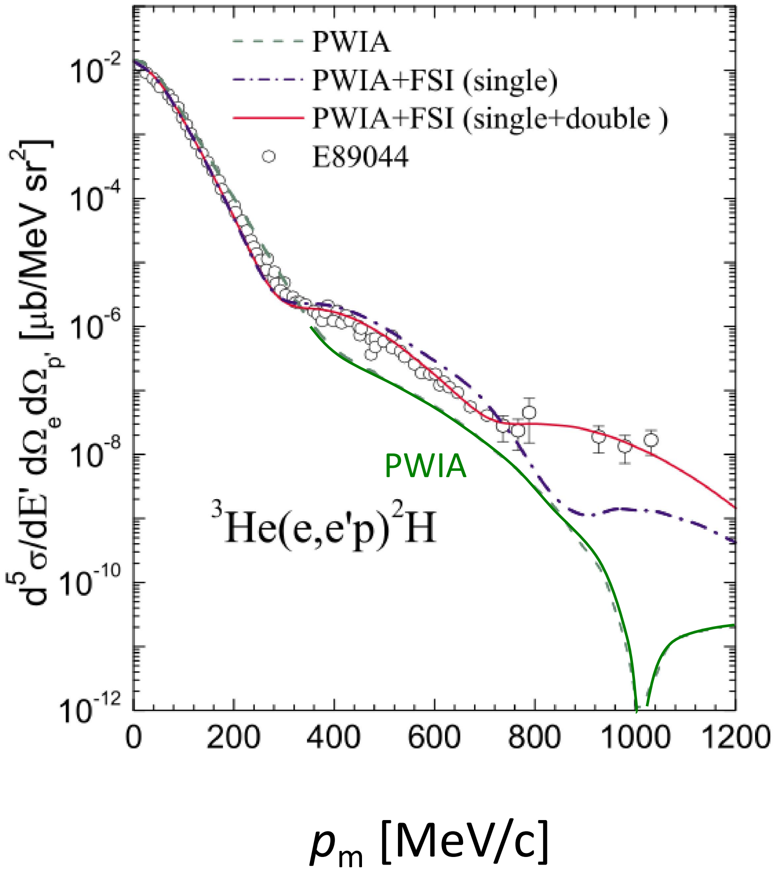
M. Alvioli et al., PRL 100, 162502 (2008)

- Dominant NN force in the 2N-SRC is tensor force

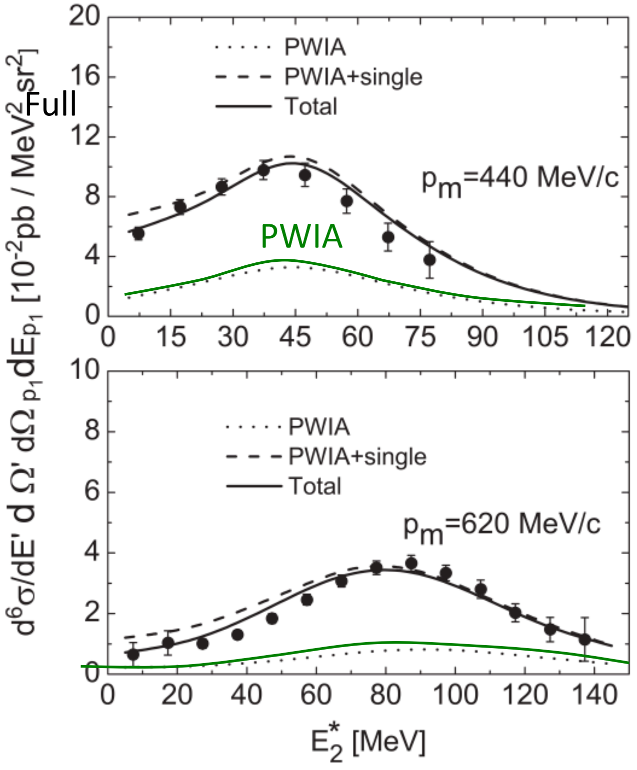
- The high momentum tail is dominated by L = 0,2   S= 1 np-SRC pairs

Previous Hall-A ^{3}He (e,e'p)X measurements

^{3}He(*e,e'p*)*d*



^{3}He(*e,e'p*)*np*



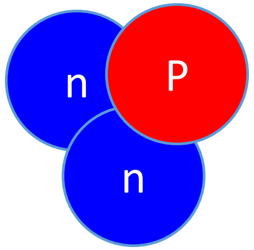
- Dominated by FSI at large momentum
- Well described by theory

Data: Rvachev *et al*., PRL94 192302 (2005); Benmokhtar *et al*., PRL94 082305 (2005)
Theory: Ciofi degli Atti and Kaptari, PRL95 052502 (2005) ; Alvioli *et al*., PRC81 021001 (2010)

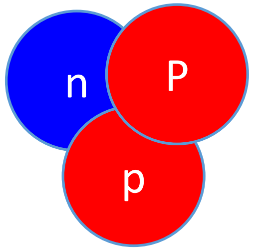
The A = 3 System

- ^{3}He and ^{3}H are mirror nuclei
  - Neutron in ^{3}He = Proton in ^{3}H
- Two-ways to study the proton-to-neutron momentum distribution ratio in ^{3}He:
  - Measure the ^{3}He(e,e'p) / ^{3}He(e,e'n) ratio
    (Low accuracy due to the neutron measurement)
  - **Measure the ^{3}He(e,e'p) / ^{3}H(e,e'p) ratio.**
    (Tritium Target necessary, available at Jefferson Lab Hall-A (MARATHON))

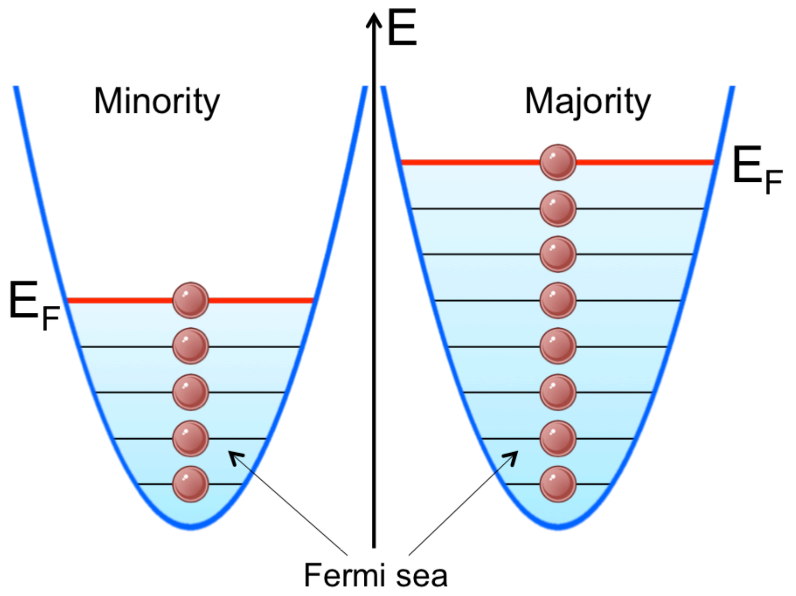
^{3}H

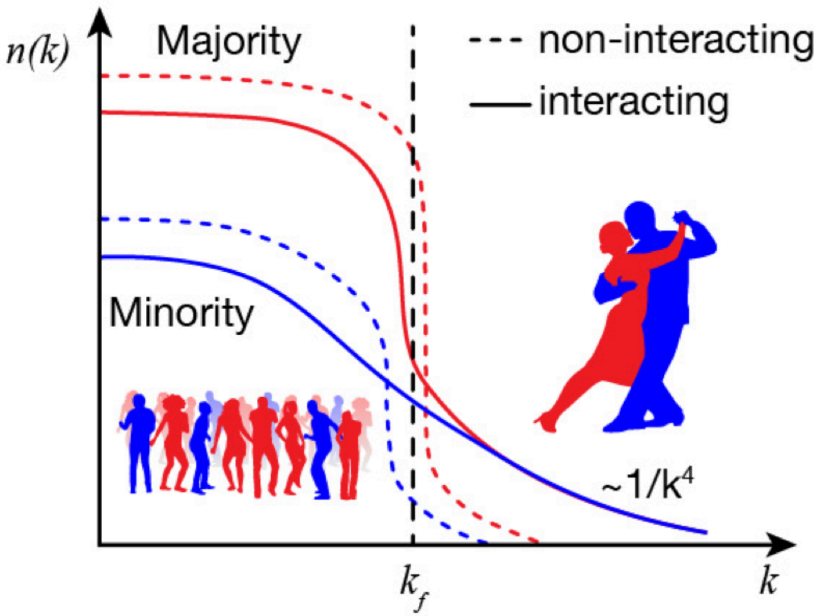


^{3}He



SRC and Kinetic Energy Sharing





Pauli-Principle:

<T>(Majority) **>** <T> (Minority)

SRC np pairs

<T>(Majority) **<** <T> (Minority)

VMC Prediction for <T>

<T> (Minority)

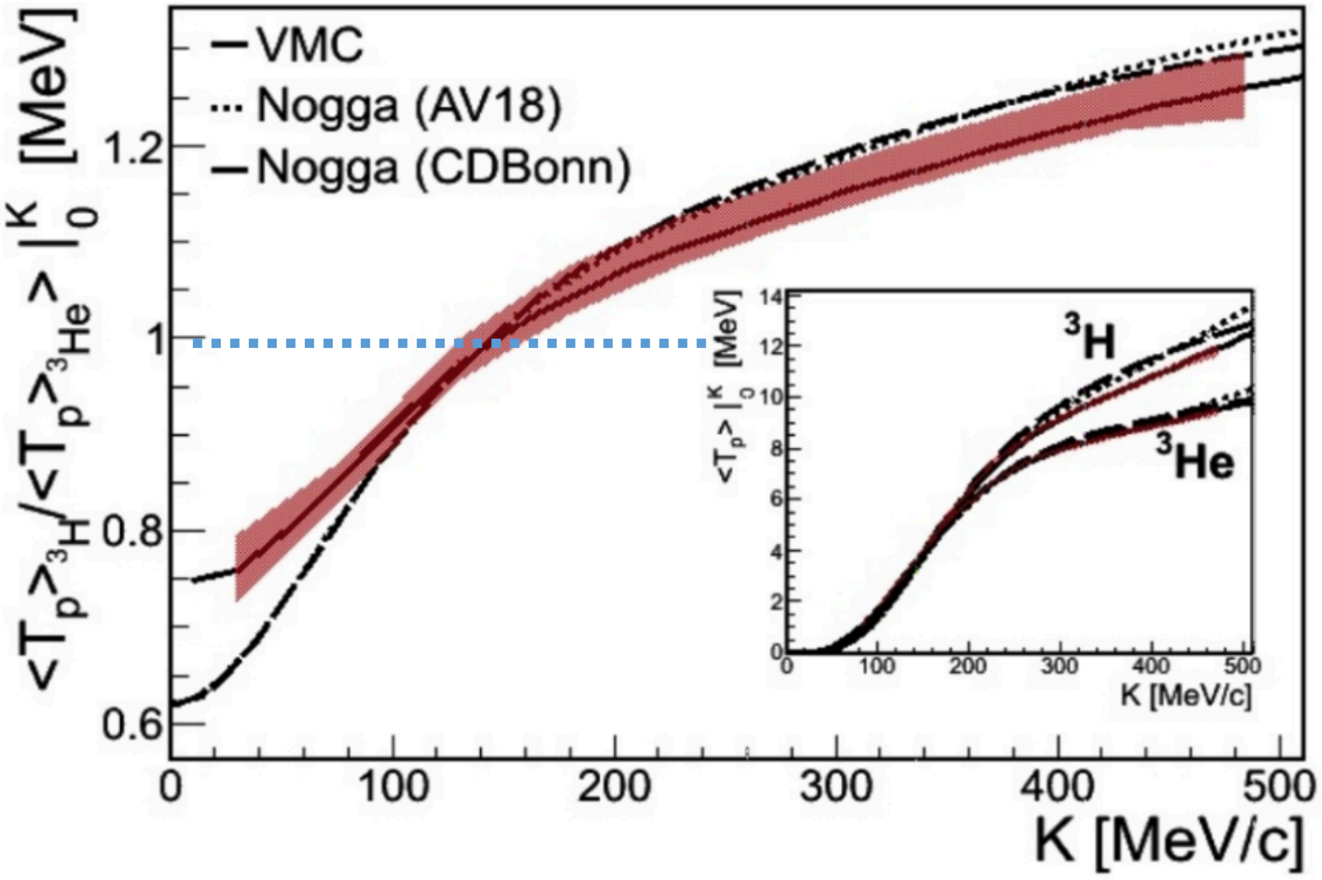
v

<T>(Majority)

	$\frac{\lvert N-Z \rvert}{A}$	$<T_p>$	$<T_n>$	$<T_p> - <T_n>$
^{8}He	0.50	30.13	18.60	11.53
^{6}He	0.33	27.66	19.06	8.60
^{9}Li	0.33	31.39	24.91	6.48
^{3}He	0.33	14.71	19.35	-4.64
^{3}H	0.33	19.61	14.96	4.65
^{8}Li	0.25	28.95	23.98	4.97
^{10}Be	0.2	30.20	25.95	4.25
^{7}Li	0.14	26.88	24.54	2.34
^{9}Be	0.11	29.82	27.09	2.73
^{11}B	0.09	33.40	31.75	1.65

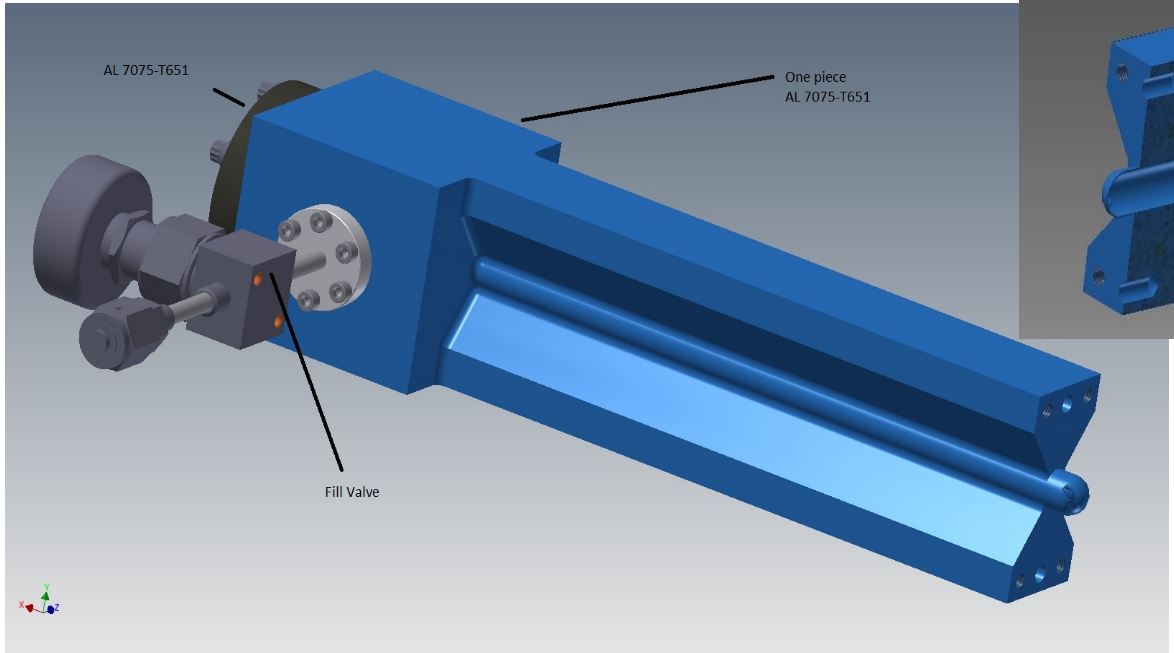
R. Wiringa et al. (Phys. Rev. C **89**, 024305 (2014))

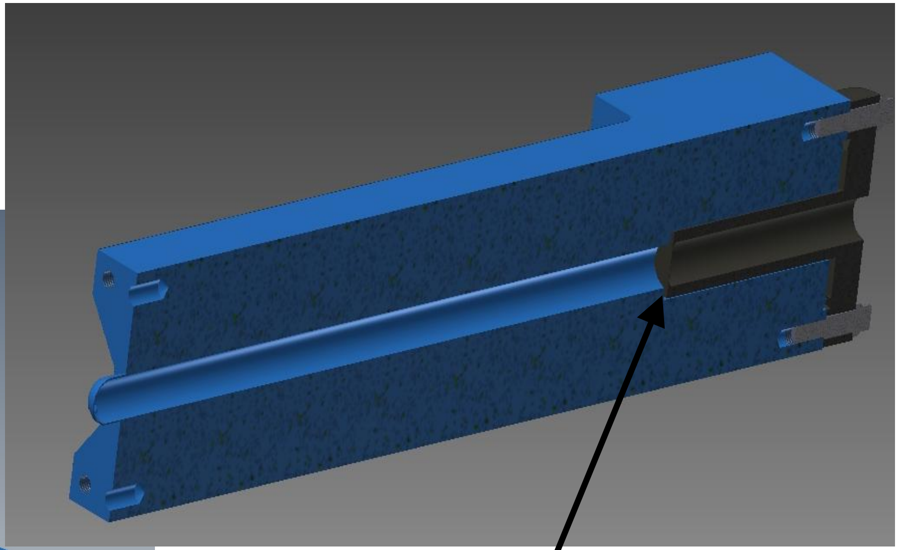
Kinetic Energy Sharing - Estimated Results



Mapping of Inversion

Marathon Target





- Open cell design allows a wide range of scattering angles
- Wall thickness 0.018” Al (120 mg/cm^2)
- Entrance and exit windows: 0.010” Al (65 mg/cm^2)
- The proton HRS will not see the cell windows

Adopted from David Meekins