Update on the Jefferson Lab Hall A Tritium Experiments

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May 30, 2018

The spring run used a tritium target.

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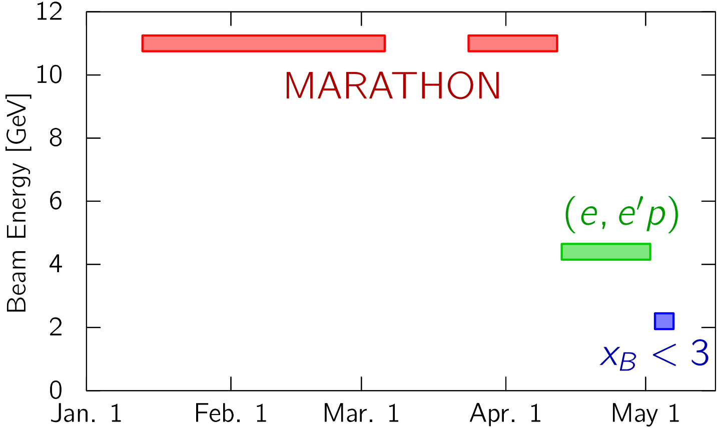
Tritium in real life is even cooler than in Spiderman 2.

- Small
  - It's well in range of *ab initio* approaches.
- Isospin doublet
  - ^{3}He is stable mirror nucleus.
- Wicked asymmetric
  - $A/2Z = 1.5$, compare to Pb, ≈ 1.27

Tritium targets are once-in-a-generation.

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

Hall A 2018 Spring Tritium Run



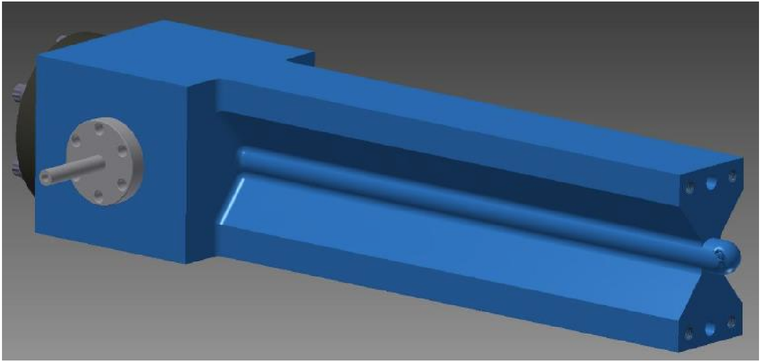
Hall A 2018 Spring Tritium Run

1. MARATHON
   - Inclusive deep-inelastic scattering: d/u ratio
2. $(e, e'p)$ Experiment
   - Coincident quasielastic proton knock-out
3. $x_B < 3$ Experiment
   - Inclusive scattering in the $1 < x_B < 3$ range

In my talk today:

1. Hall A target and equipment
   - A quick refresher of what we had to work with
2. Spring experiments
   - $(e, e'p)$
   - $x_B < 3$
   - MARATHON
3. Looking ahead
   - Tritium running this fall

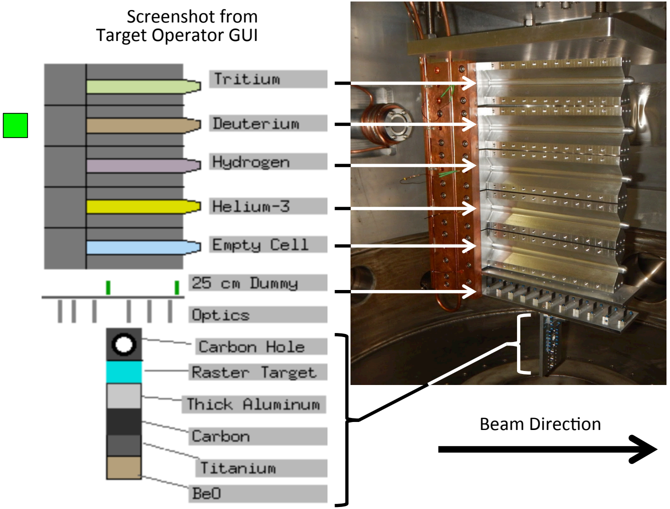
The Jefferson Lab target is sealed-cell gas design.



The JLab target is designed to maximize luminosity per unit activity.

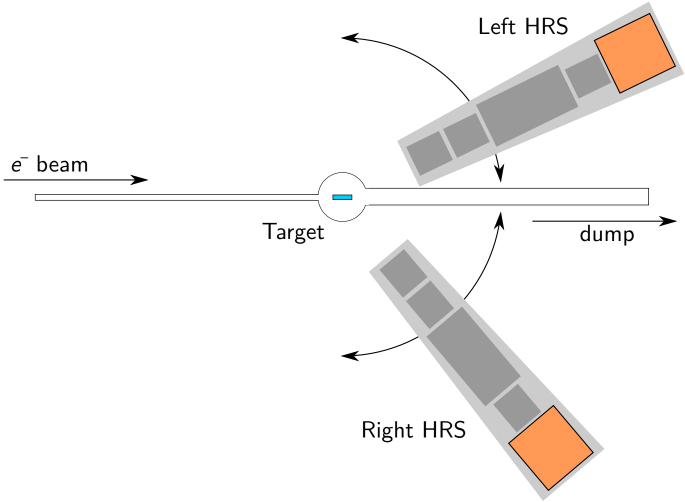
Target	Thickness [mg/cm^2]	Current [μA]	Activity [kCi]	FoM
SLAC	800	1	25	32
Bates	300	20	180	33
Saclay	1200	10	10	1200
JLab	**80**	**22.5**	**1**	**1800**

The target ladder had identical cells for ^{1}H, ^{2}H, ^{3}H, ^{3}He.



Hall A has two high-resolution spectrometers.

- Angular acceptance: 6.7 msr
- Momentum acceptance: $\pm 4.5\%$



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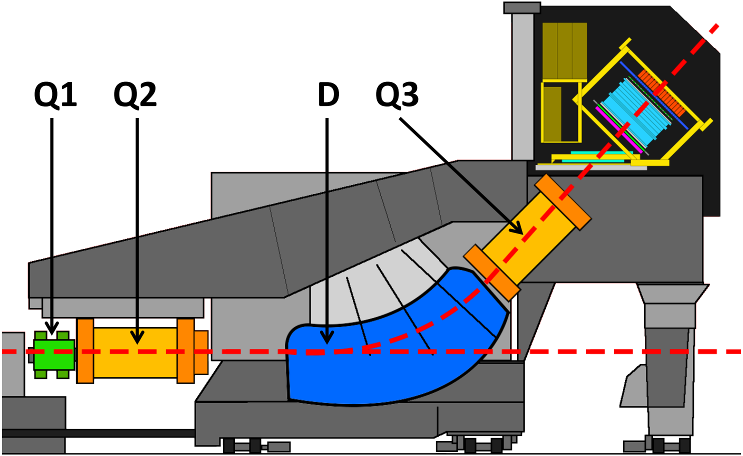

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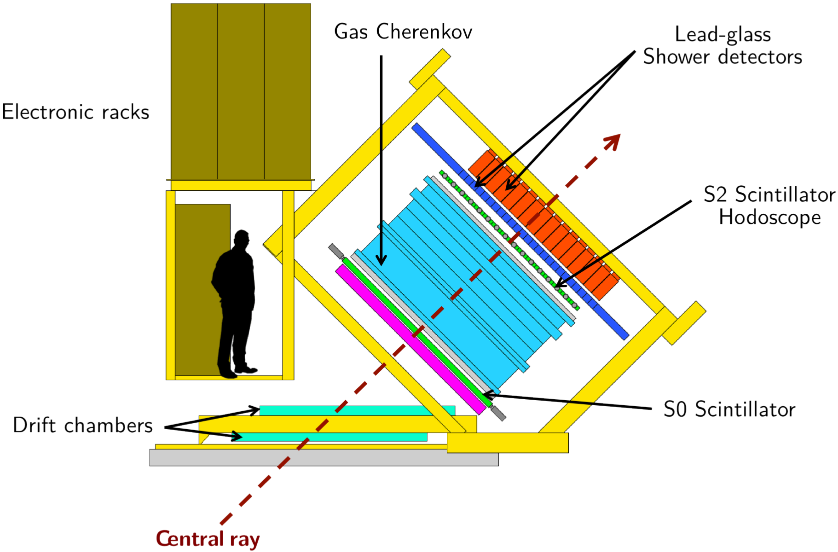
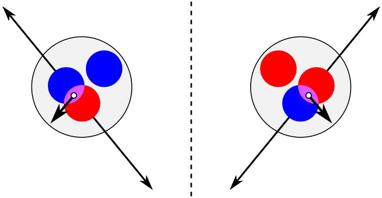
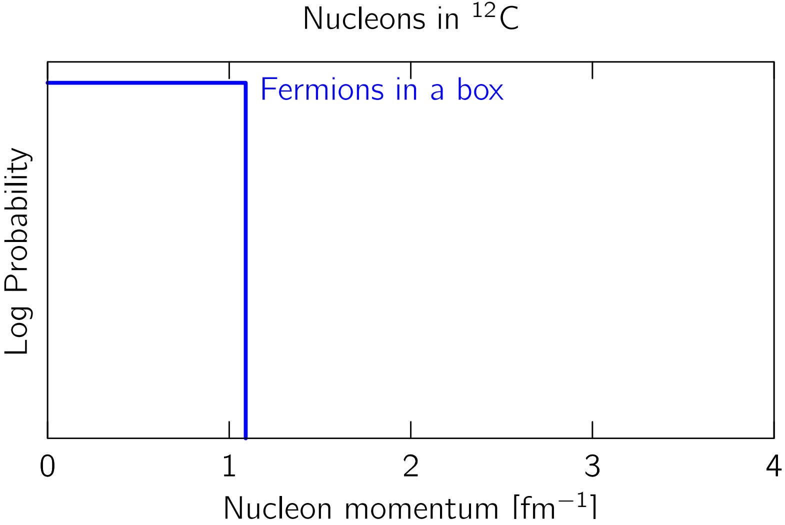


The $(e, e'p)$ experiment used protons in tritium to learn about neutrons in helium-3.



- E12-14-001
- What is the isospin dependence of short range correlations in extremely asymmetric nuclei?

Short-range correlations produce high-momentum tails.



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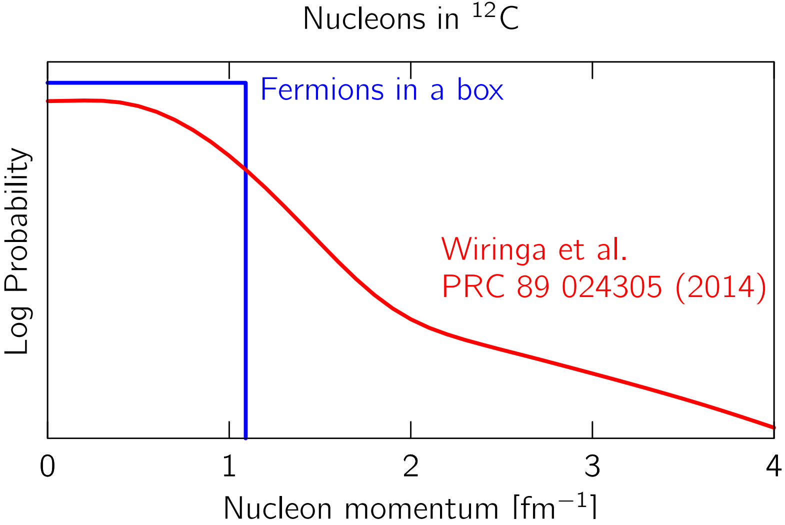

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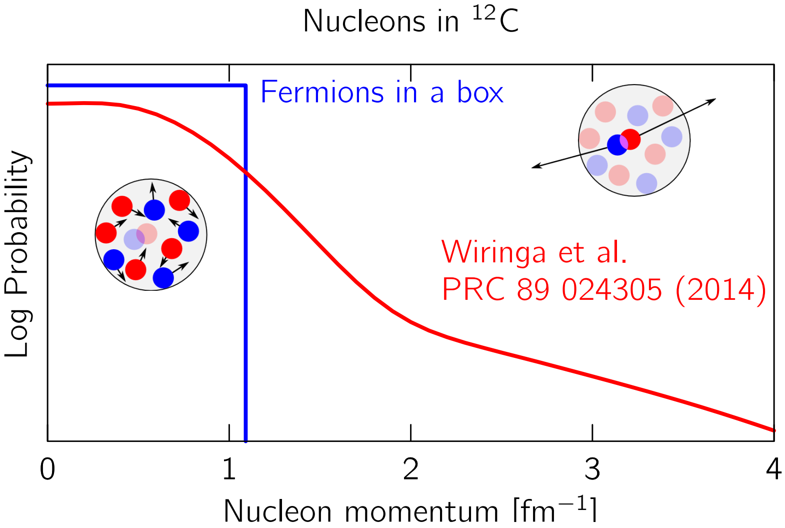
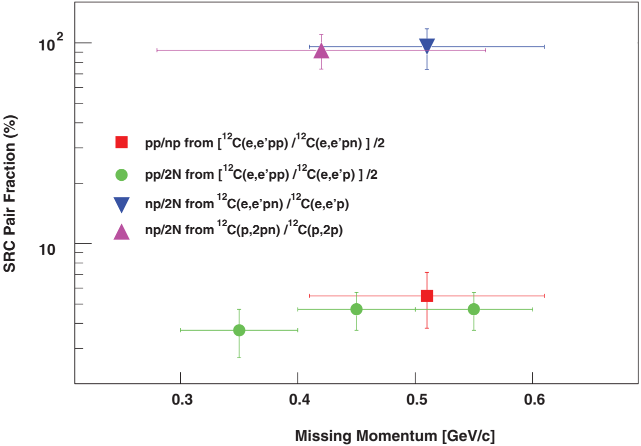
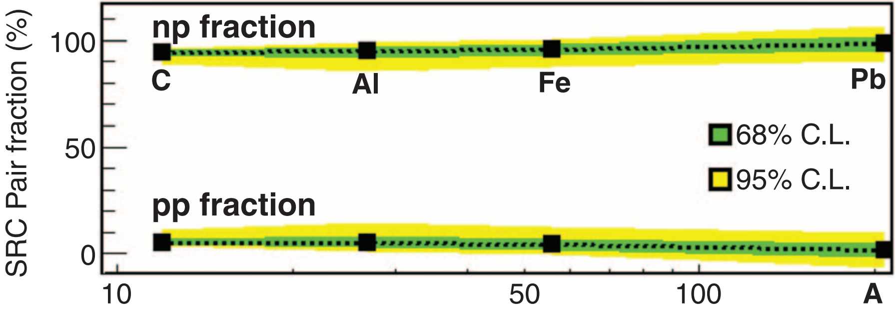


Between 300–600 MeV, *np* pairs predominate.



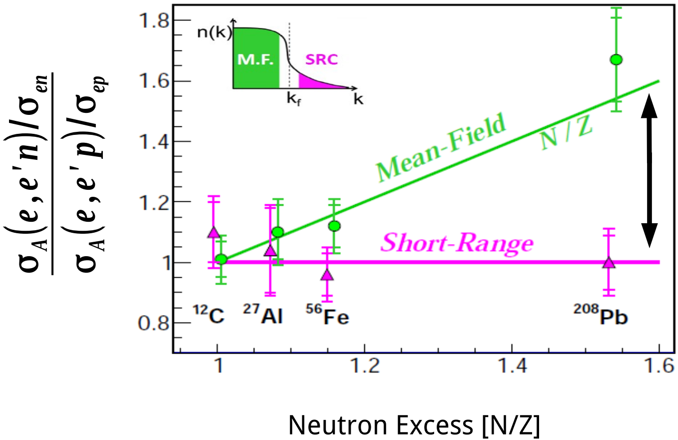
E. Piasetzky et al., PRL 97 162504 (2006)
R. Shneor et al., PRL. 99, 072501 (2007)
R. Subedi et al., Science 320, 1476 (2008)

np-dominance was indirectly observed from carbon to lead.



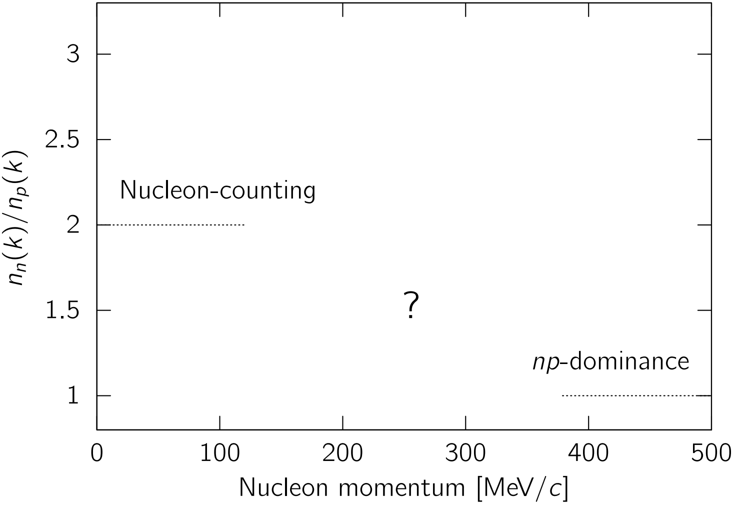
O. Hen et al, Science 346, 614 (2014)

. . . and has now been directly confirmed by detecting neutrons in CLAS.



To appear in Nature. See talk tomorrow by Or Hen

np-dominance implies a transition in the n/p ratio.



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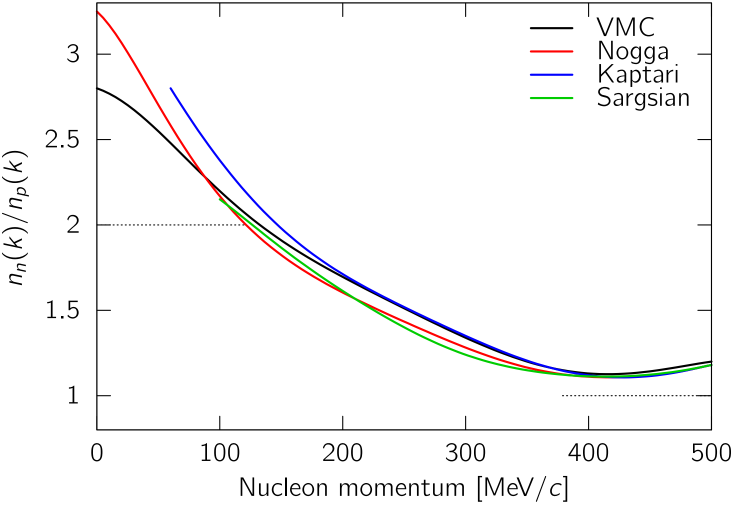
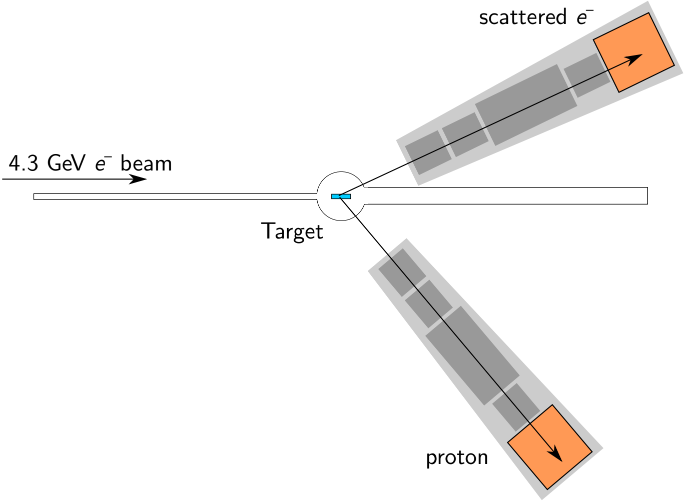


Proton momentum can be determined from coincident detection.



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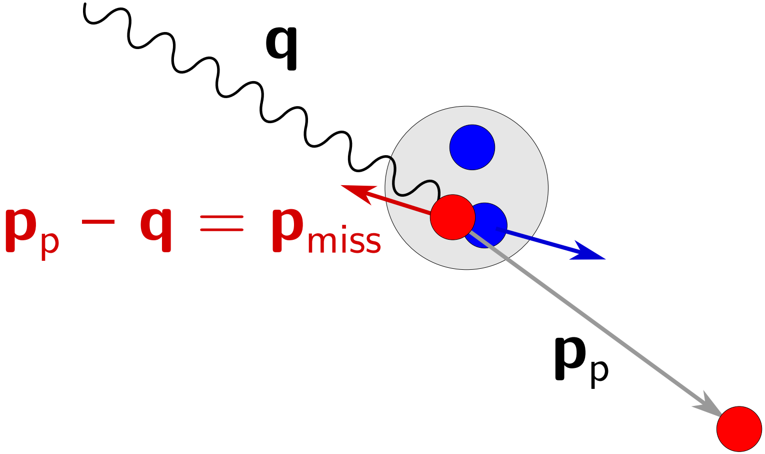
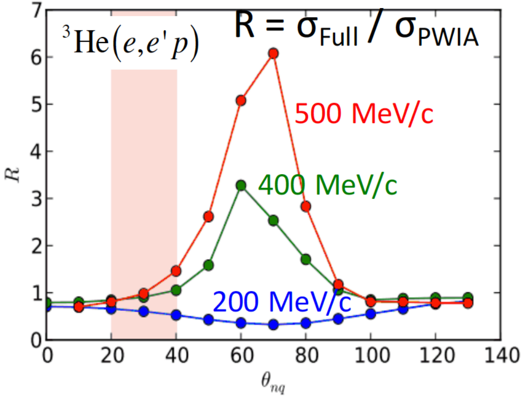
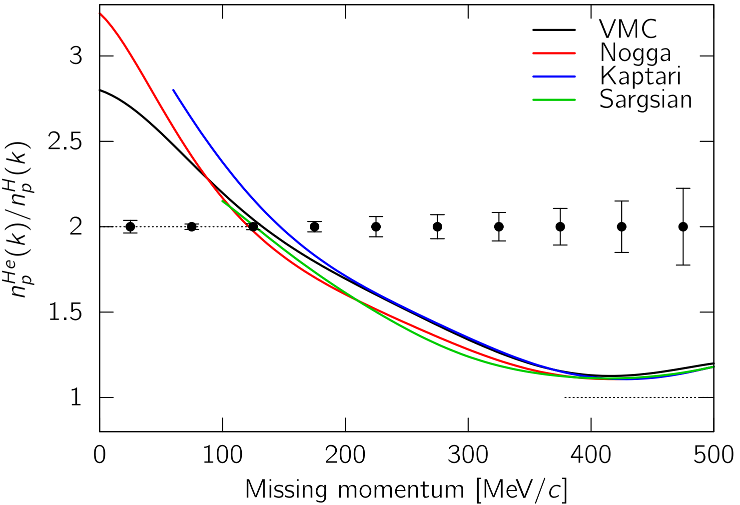


Care must be taken to avoid final state interactions.

- High $Q^2 \longrightarrow$ reduce meson-exchange currents
- $x > 1 \longrightarrow$ reduce resonance production
- $\vec{p}_{\text{miss}}$ anti-parallel to $\vec{q} \longrightarrow$ reduce rescattering



The $(e, e'p)$ experiment will be able to map out this transition.



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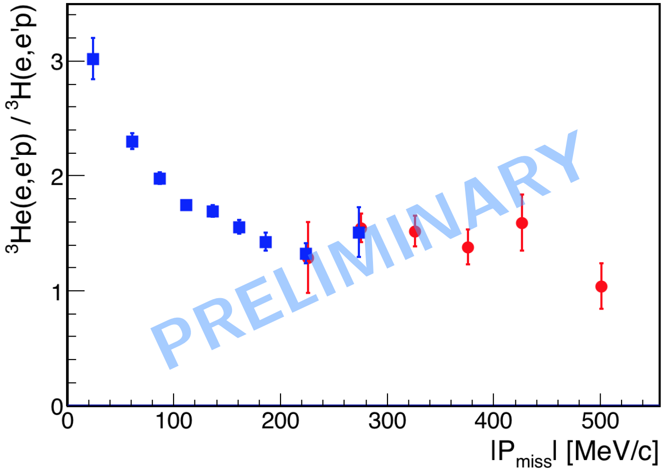
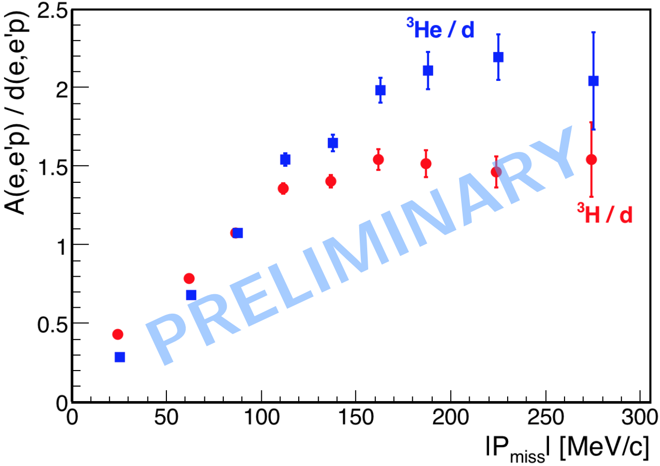
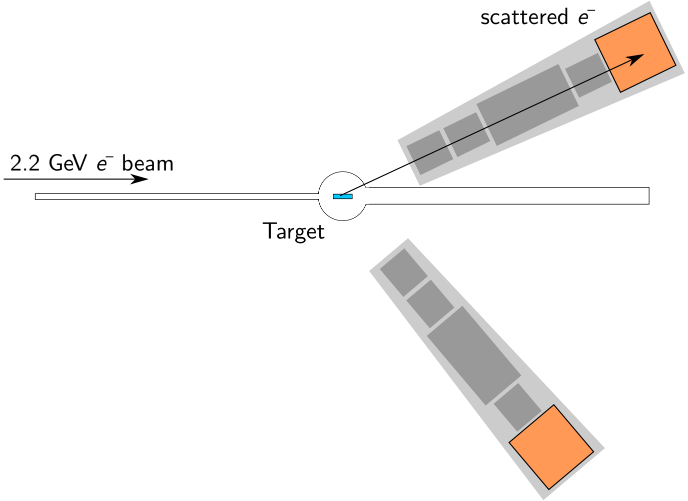


We can also make comparisons to deuterium.



The $x_B < 3$ experiment used two spectrometers to maximize inclusive acceptance.



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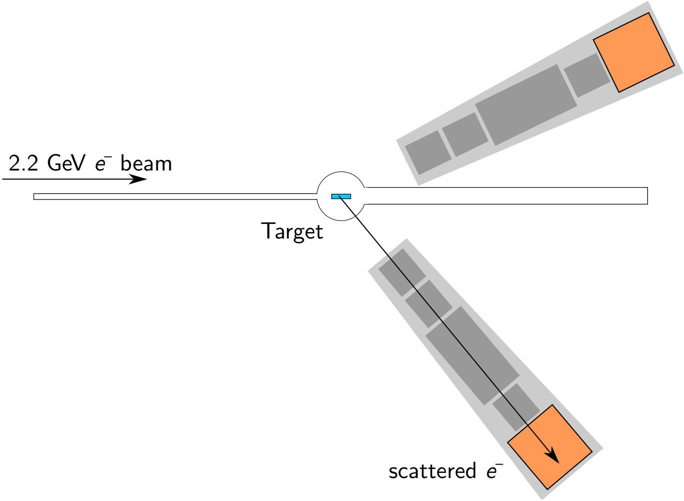
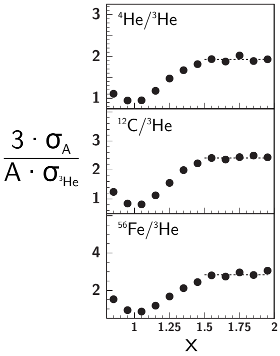
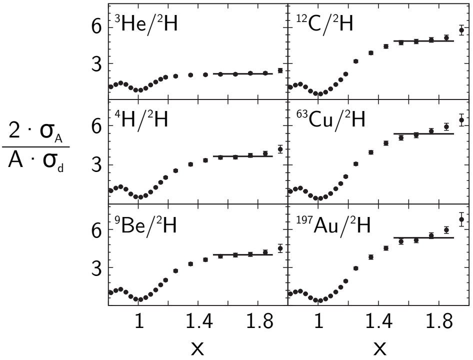


Inclusive electron scattering can already tell us about short range interactions.

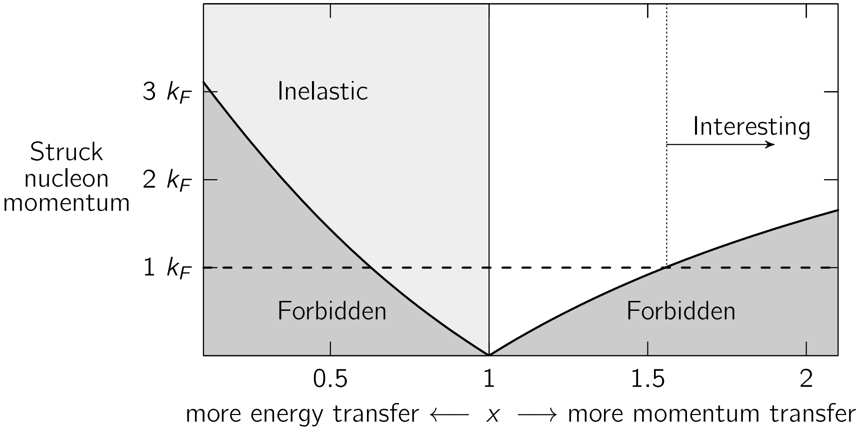


K.S. Egiyan et al. PRL 96, 082501(2006)

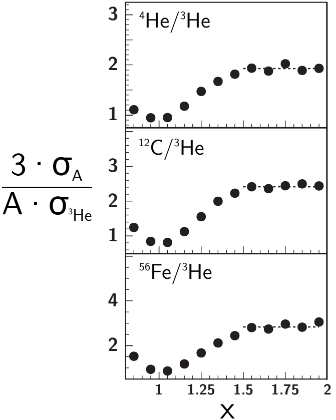


Fomin et al., PRL 108, 092502 (2012)

At high x, quasielastic scattering can only proceed from a high-momentum nucleon.



a_2 plateaus tell us that high-momentum tails are universal.



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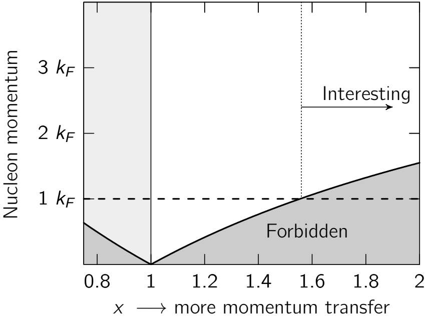


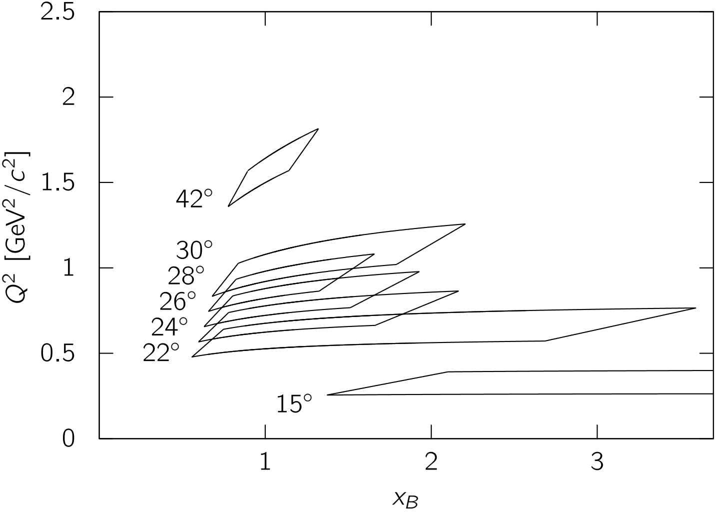
Scaling constant a_2:

$$\sigma_A = \mathbf{a}_2 \times \frac{A}{2}\sigma_d$$

Isospin-dependence between $1 < x_B < 3$

- a_2 scaling in ^3H and ^3He
- 3N correlations: $x_B > 2$
- Elastic neutron form factors

The $x_B < 3$ experiment covered a wide range of Q^2 and x_B settings.



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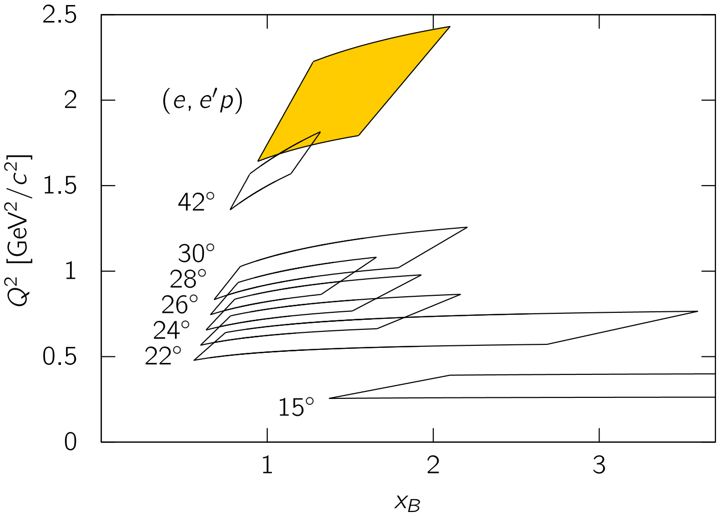

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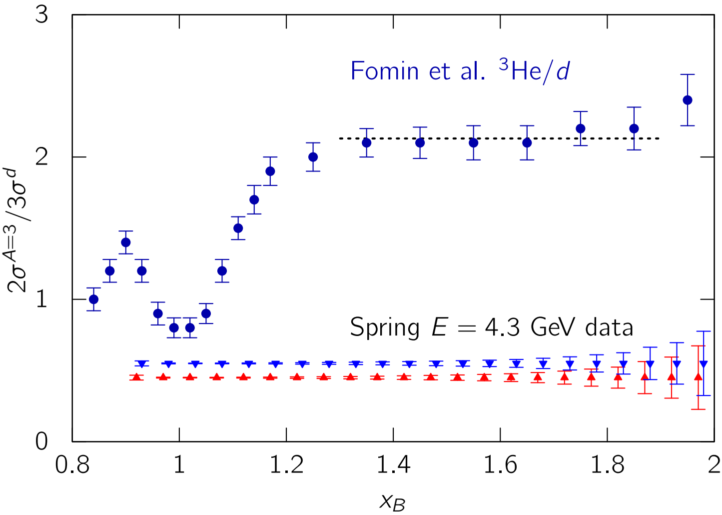

How can u and d quark distributions be extracted from DIS?

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

In the infinite-momentum frame:

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

$$F_2 = x\sum_i e_i^2 q_i(x)$$

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In the infinite-momentum frame:

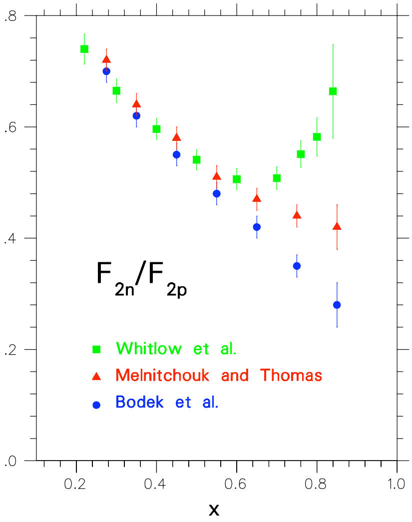
$$F_2 = x\left[\left(\frac{2}{3}\right)^2 (u(x)+\bar{u}(x)) + \left(-\frac{1}{3}\right)^2 (d(x)+\bar{d}(x)) + \left(-\frac{1}{3}\right)^2 (s(x)+\bar{s}(x))\right]$$

How can u and d quark distributions be extracted from DIS?

1. Semi-inclusive DIS
   - Smaller cross section
   - Messy extraction of u/d from $\pi^+/\pi^- \ldots$

2. Exploit isospin symmetry: F_2^p/F_2^n
   - No free neutron target

Deuterium has a neutron but also binding, fermi-motion!



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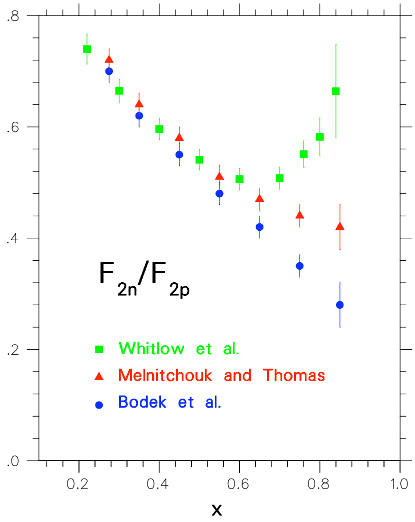
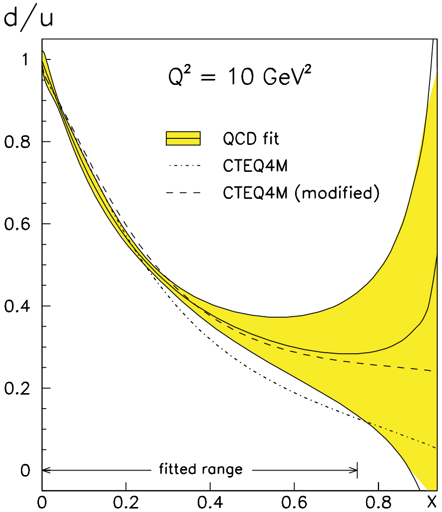




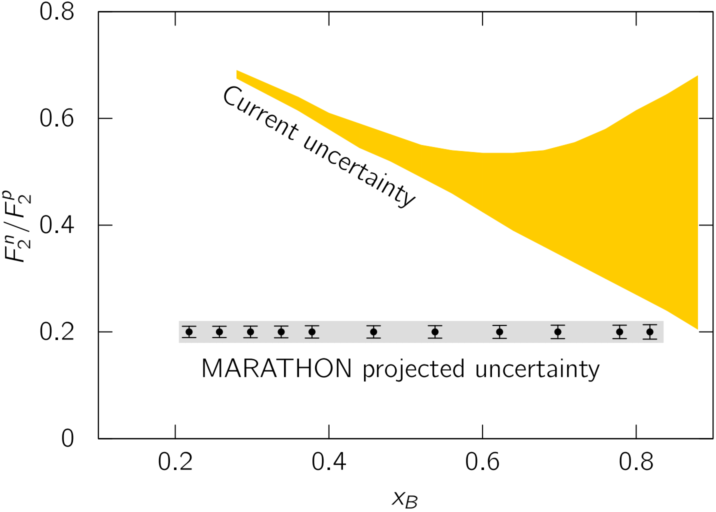
Tritium/Helium-3: a better way to get F_2^p/F_2^n!

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

Depends on the *ratio* of EMC effects!

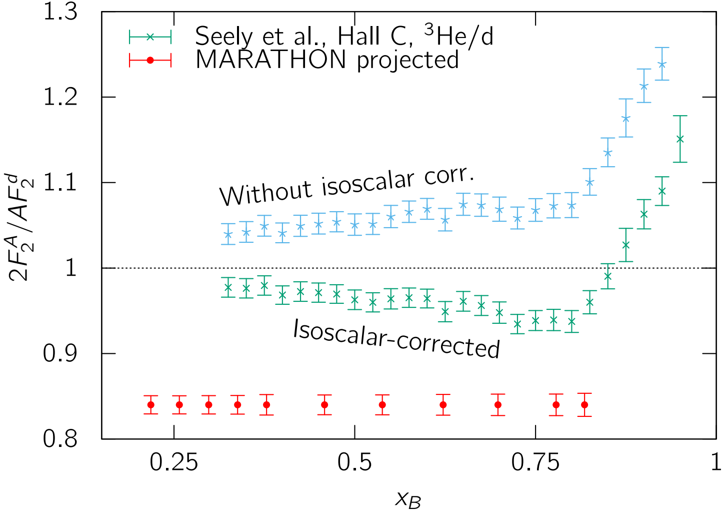
$$\mathcal{R} \equiv \frac{F_2^{^3\mathrm{He}}}{2F_2^p + F_2^n} \times \frac{2F_2^n + F_2^p}{F_2^{^3\mathrm{He}}}$$

MARATHON can make huge improvements on current uncertainties.



What is the EMC effect in $A = 3$?

So far, only data on Helium-3

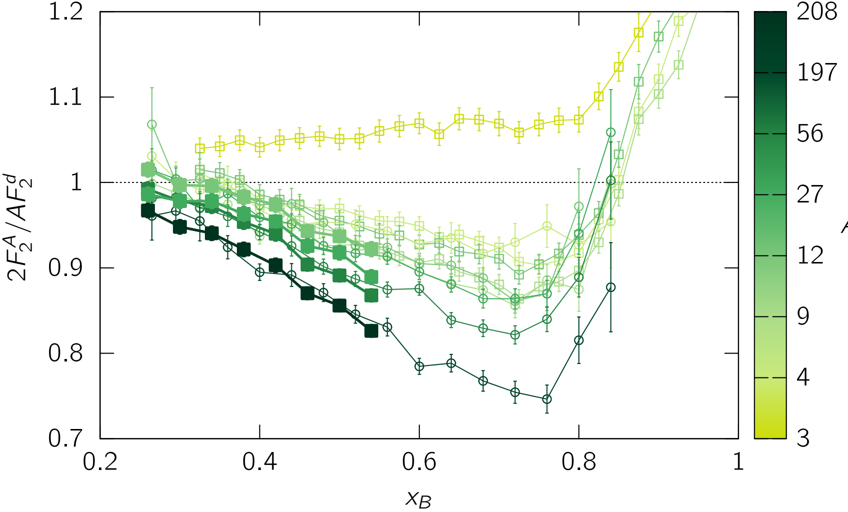


We tried to model the modification of a single *np*-SRC pair.

See Barak Schmookler's talk tomorrow!

$$F_2^A = ZF_2^p + NF_2^n + n_{\text{SRC}}^A(\Delta F_2^p + \Delta F_2^n)$$

We extracted the “modification” of a single SRC pair.



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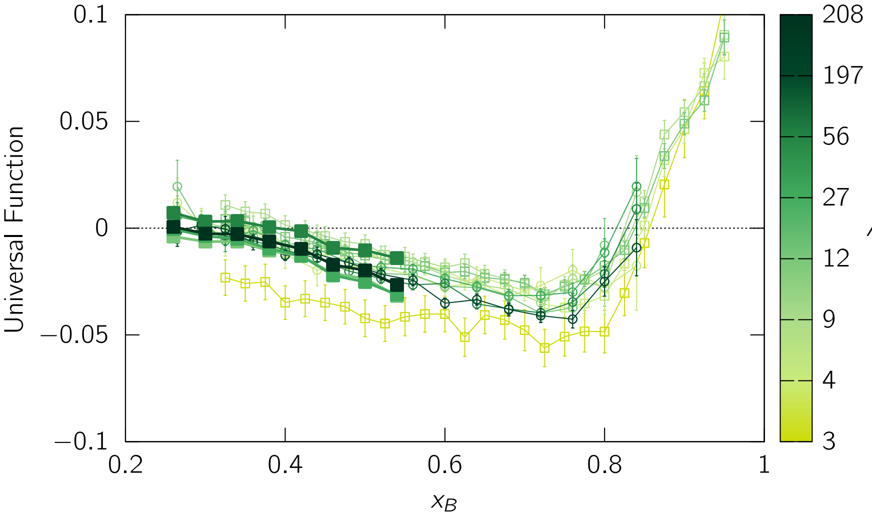
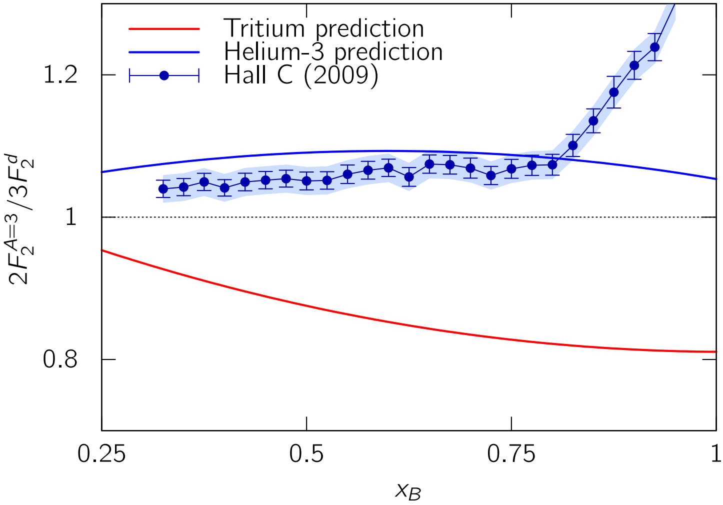


We can make predictions for $A = 3$.



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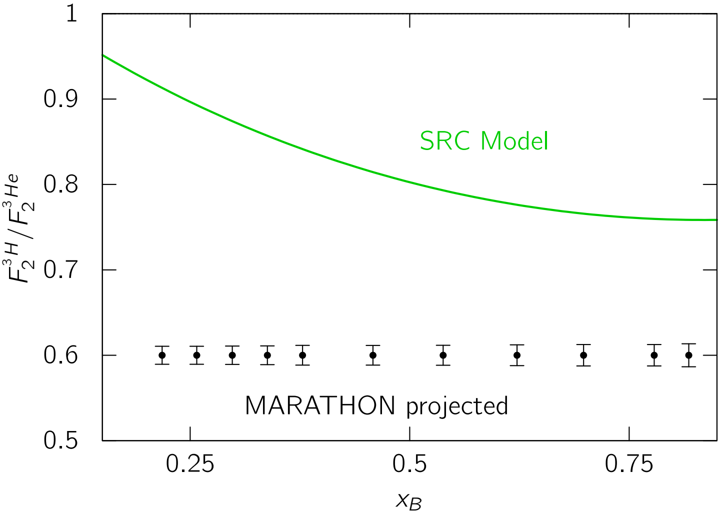
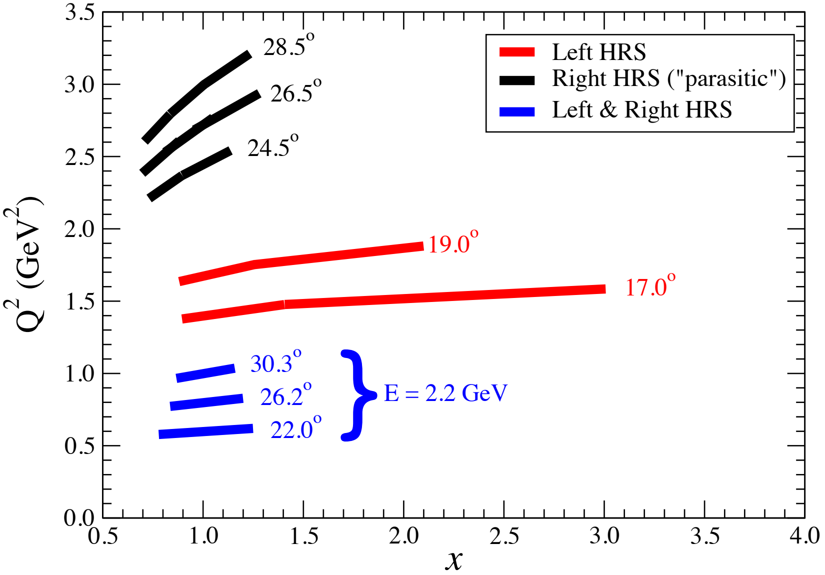


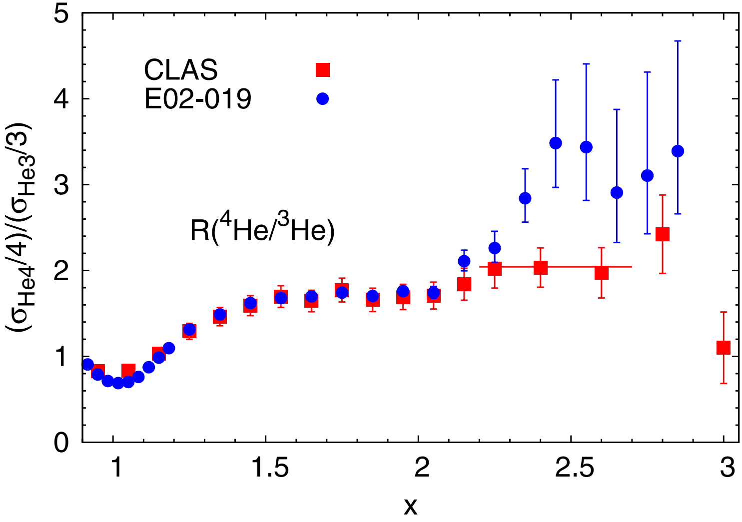
There will be more tritium running in the fall.

1. $x_B < 3$ continued ...
   - Investigation of $x > 1$ and $x > 2$ regions
2. $x_B = 3$ Experiment
   - Elastic form factors of the triton.
3. Hypernucleus Experiment
   - Λn interaction via ^{3}H$(e, e'K^+)$

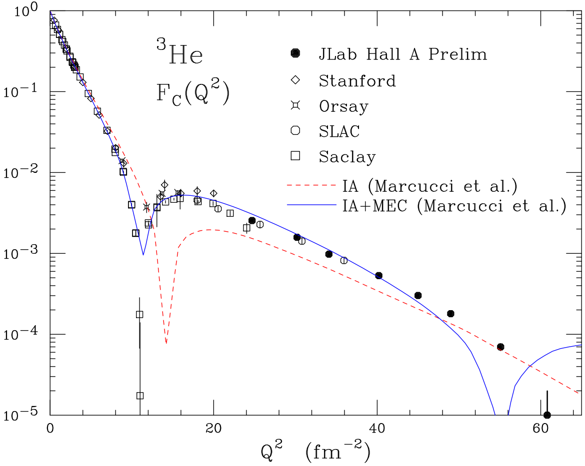
$x_B < 3$ will take data at higher Q^2.



The $x_B > 2$ region will tell us about $3N$-correlations.



Previous tritium experiments have poor coverage of the diffraction minima.



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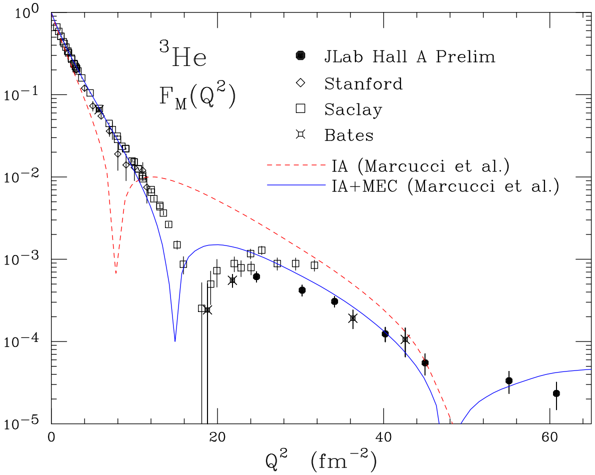

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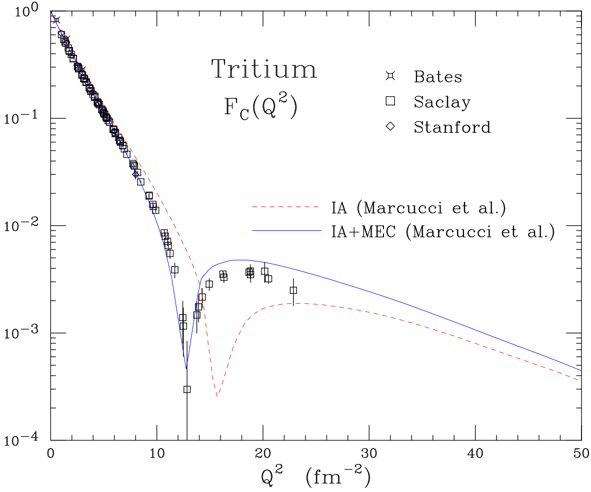

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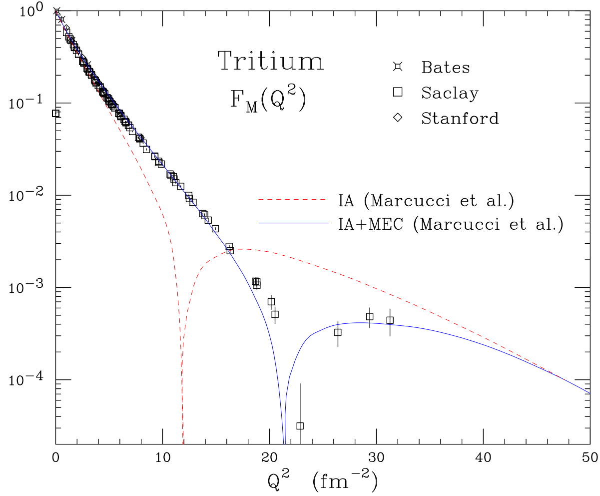
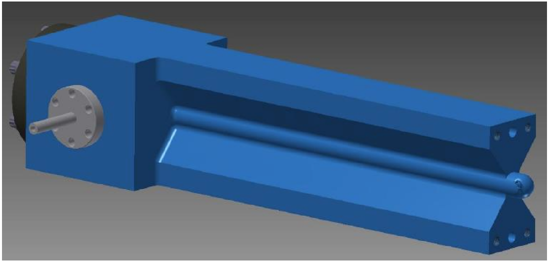


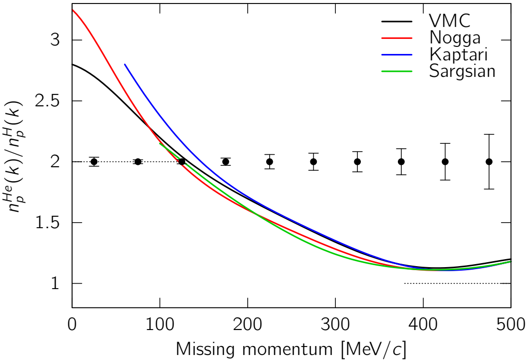
To recap:

- Tritium target in Hall A



To recap:

- Tritium target in Hall A
- $(e, e'p)$ Experiment



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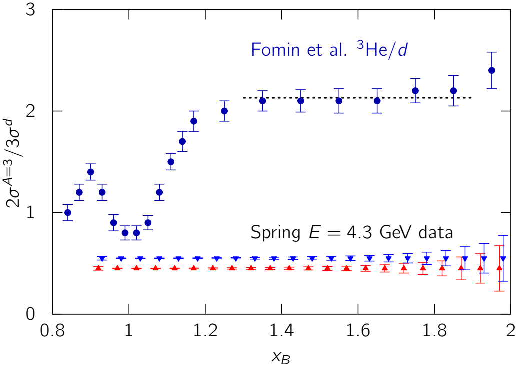
- $(e, e'p)$ Experiment
- $x_B < 3$ Experiment



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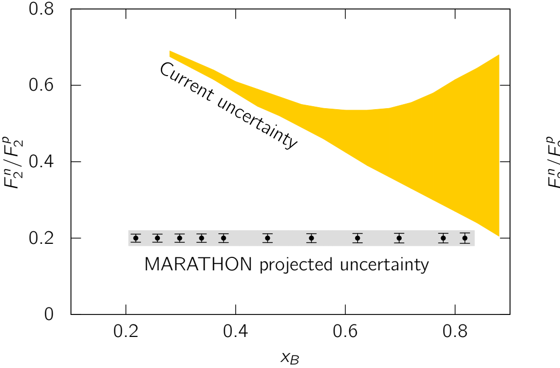
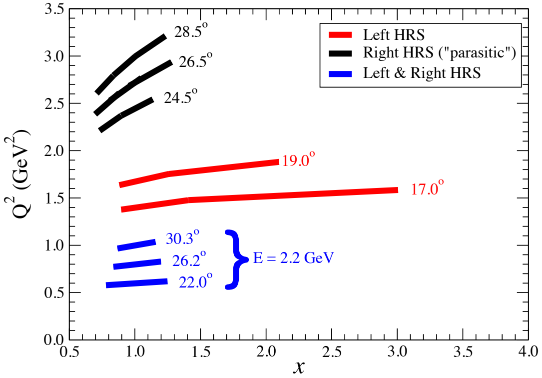
- $(e, e'p)$ Experiment
- $x_B < 3$ Experiment
- MARATHON Experiment



To recap:

- Tritium target in Hall A
- $(e, e'p)$ Experiment
- $x_B < 3$ Experiment
- MARATHON Experiment
- More tritium running coming up this fall.



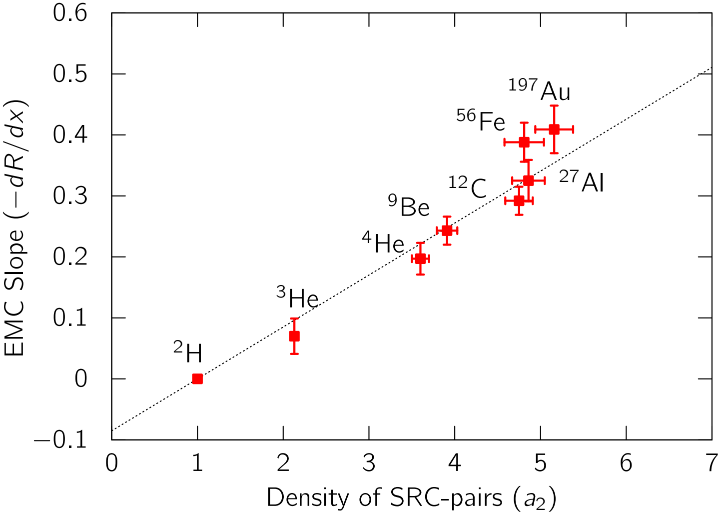
Conclusions

- Lots of new results are on the way!

- See additional talks about the SRC-EMC connections!
  - Or Hen, tomorrow afternoon
  - Barak Schmookler, tomorrow afternoon

BACK-UP SLIDES

EMC-effect correlates with SRC pair density.



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See Barak Schmookler's talk tomorrow!

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We tried to model the modification of a single *np*-SRC pair.

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$$F_2^d = F_2^p + F_2^n + n_{\text{SRC}}^d (\Delta F_2^p + \Delta F_2^n)$$

We tried to model the modification of a single *np*-SRC pair.

$$\frac{n^d_{\text{SRC}}}{F^d_2}(\Delta F^p_2 + \Delta F^n_2) = \frac{\frac{F^A_2}{F^d_2} - (Z - N)\frac{F^p_2}{F^d_2} - N}{\frac{n^A_{\text{SRC}}}{n^d_{\text{SRC}}} - N}$$

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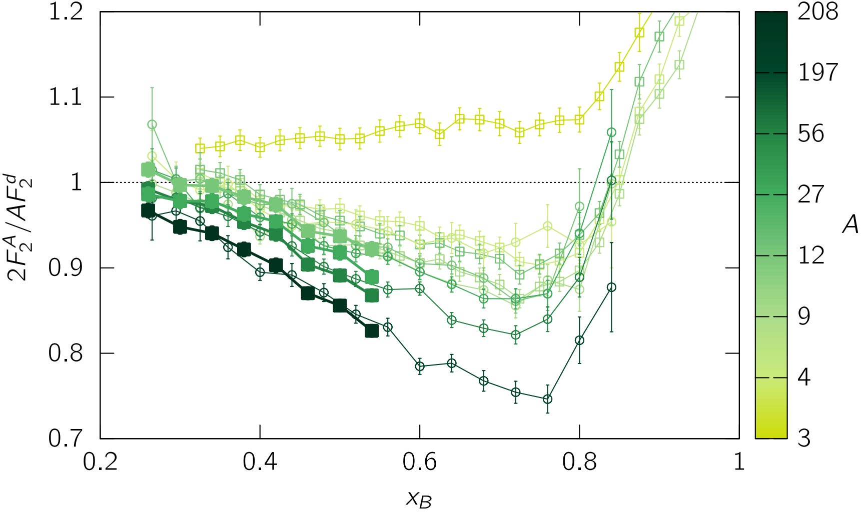
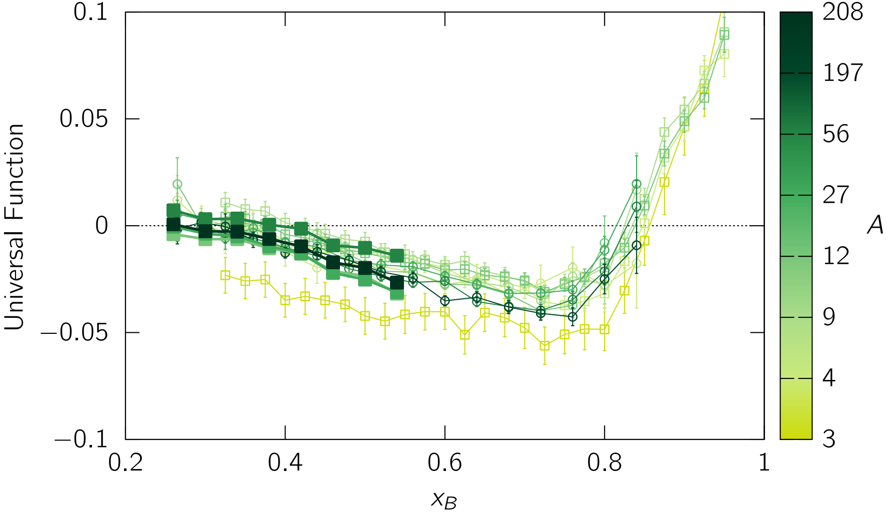
Universal function　　　Nucleus-dependent

EMC data vary significantly by nucleus.



Submitted for publication

The SRC-modification function seems universal.



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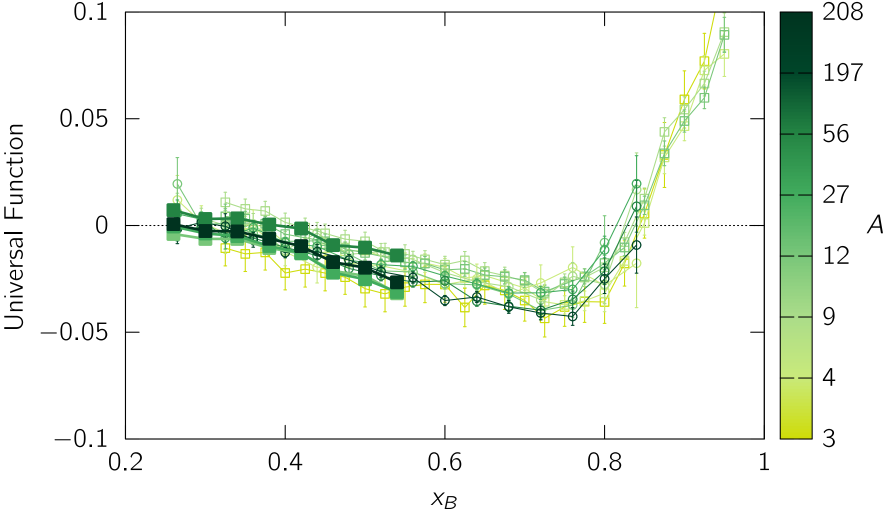

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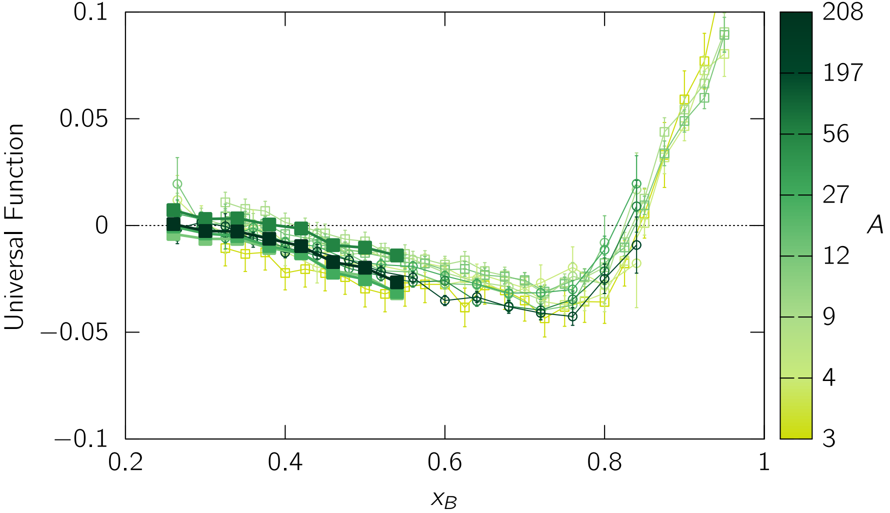
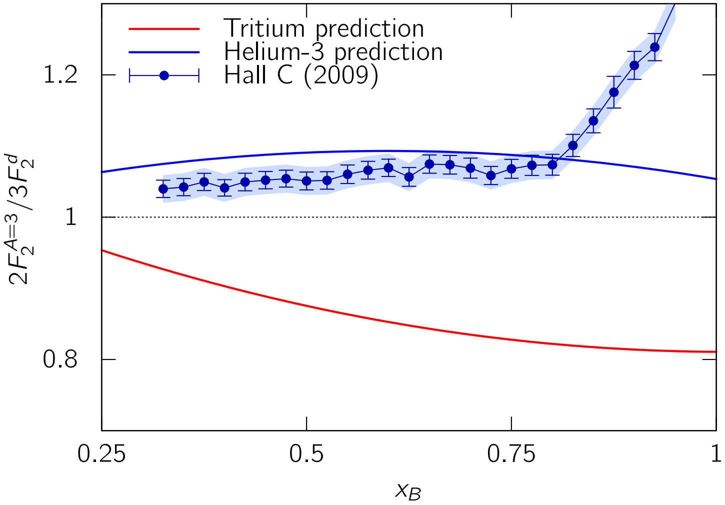


See Kulagin and Petti, PRC 82 054614 (2010)

MARATHON Prediction



MARATHON Prediction