

# Measurement of Complete Final States in DIS from Light Nuclei

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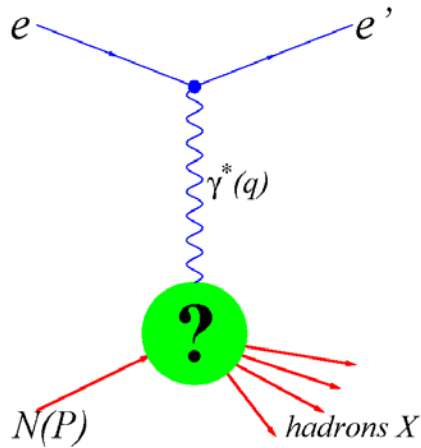
Latifa Elouadrhirs, Rolf Ent, Stepan Stepanyan  
Jefferson Lab

# Outline

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- Physics Motivation
- Proposed Experimental Program with CLAS12
- Simulations
- Summary

# Deep Inelastic Scattering (DIS)



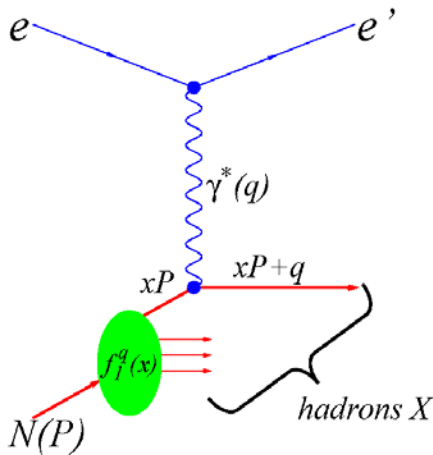
$$\frac{d^2\sigma}{dx dQ^2} = \frac{4\pi\alpha_{em}^2}{xQ^4} [(1-y)F_2(x, Q^2) + y^2x F_1(x, Q^2)]$$

Unpolarized structure functions

$$\left. \begin{array}{l} q^2 = -Q^2 \\ W^2 = (p+q)^2 \end{array} \right\} \text{large} \quad \left. \begin{array}{l} x_B = \frac{Q^2}{2p \cdot q} \\ \text{fixed} \end{array} \right\} \text{Bjorken kinematic limit}$$

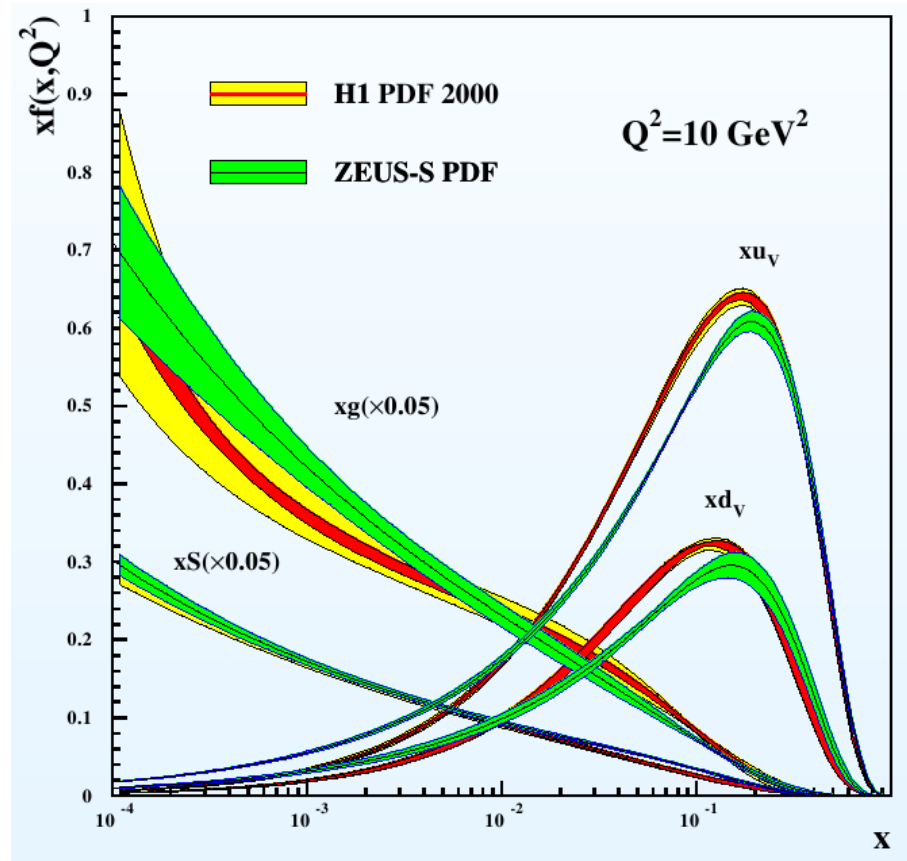
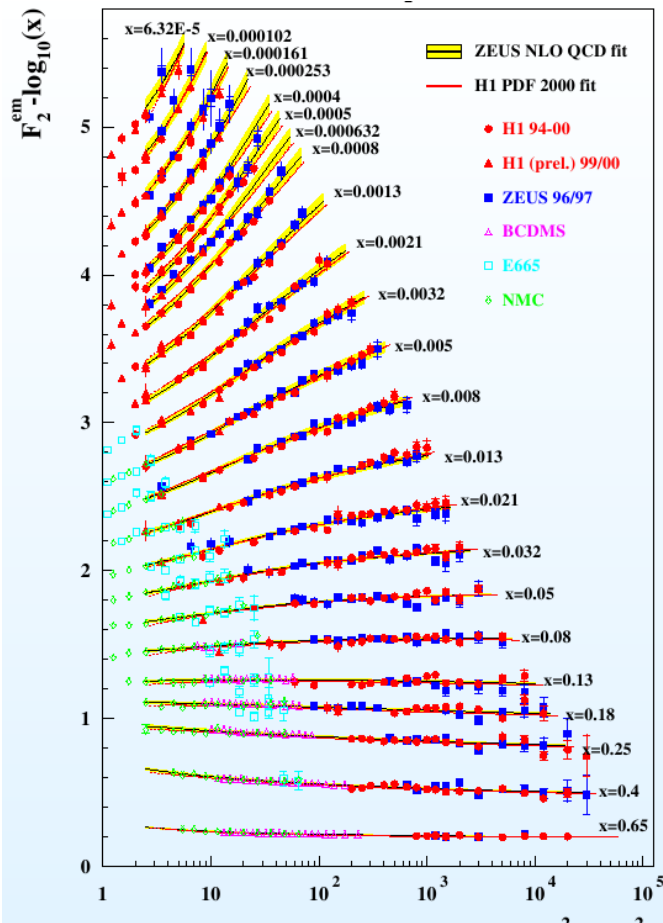
$$= \sum_q e_q^2 \underbrace{\left( \text{probability to find a "free" } q \text{ with momentum } xP \text{ in } N \right)}_{f_1^q(x)} \times d\sigma^{eq \rightarrow e'q'}$$

$f_1^q(x) \equiv$  parton distribution function (PDFs)



# Deep Inelastic Scattering (DIS)

A huge amount of data on DIS off nucleons and nuclei have been collected and analyzed in terms of PDFs:



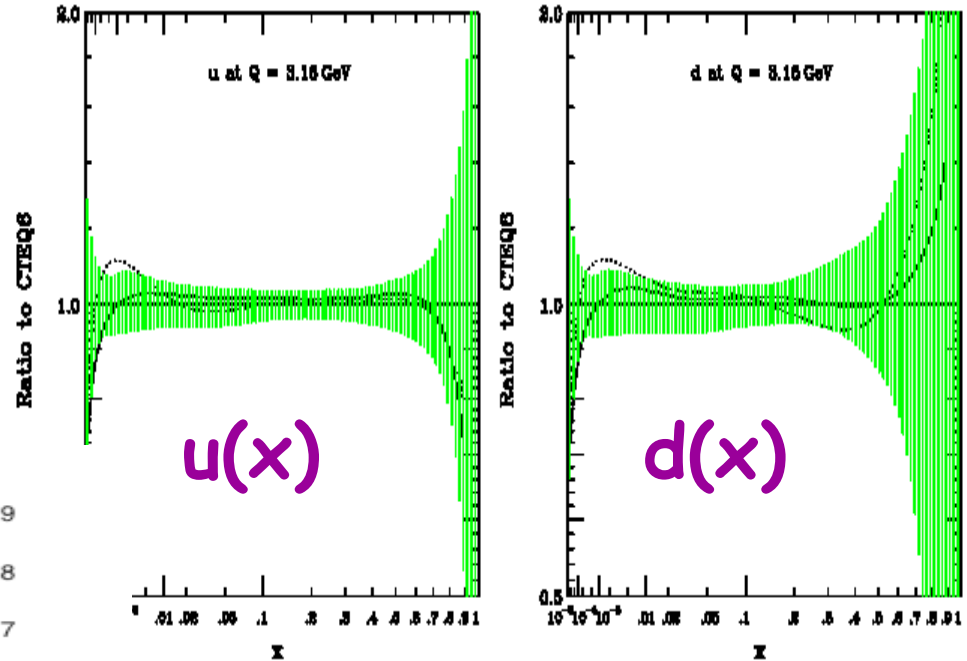
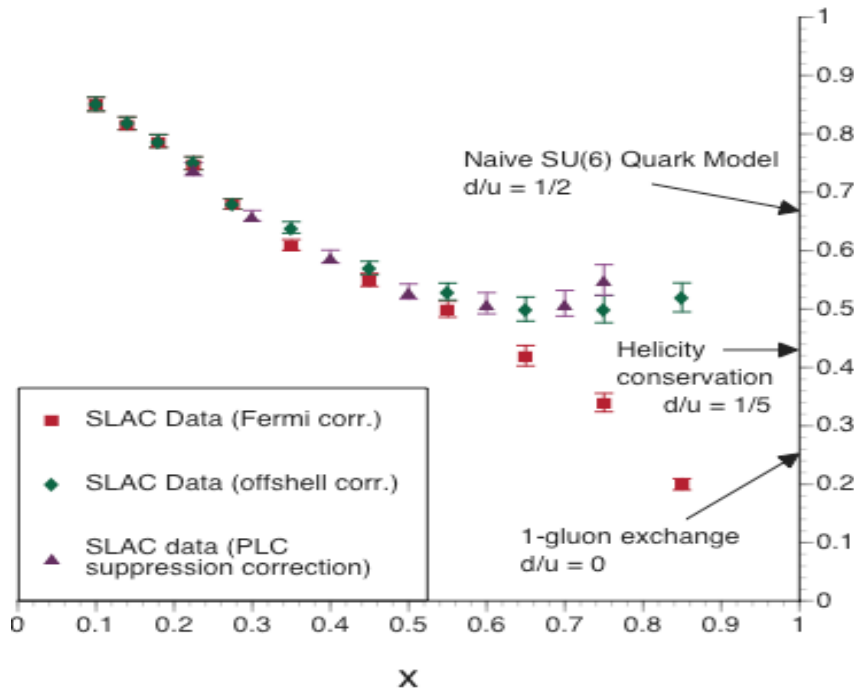
# Nucleon vs. Nucleus

We know that DIS off nucleon is not the same as DIS off nucleus.

→ The momentum distribution of quarks in a nucleus differs in a non-trivial way from the momentum distribution of quarks in the nucleon.

# PDFs Uncertainties

proton + neutron data provides way to separate valence quark.



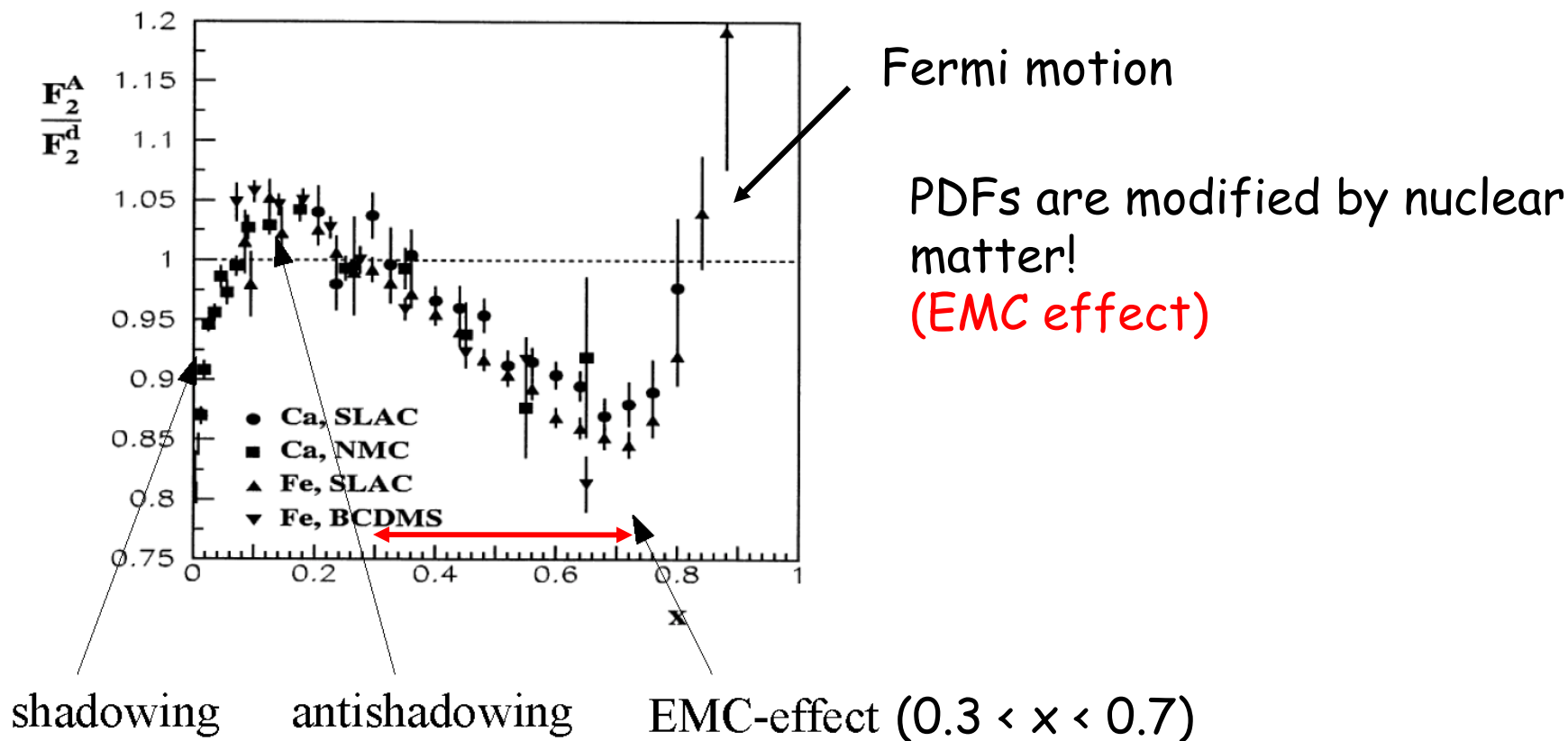
$F_2/F_{2n}$

Deuteron + proton data does *not* allow clean determination of neutron for  $x \rightarrow 1$  due to nuclear corrections

Deuteron is a nucleus!

# DIS off nuclei

Ratio of the nuclear to deuteron inclusive structure functions



# EMC Effect

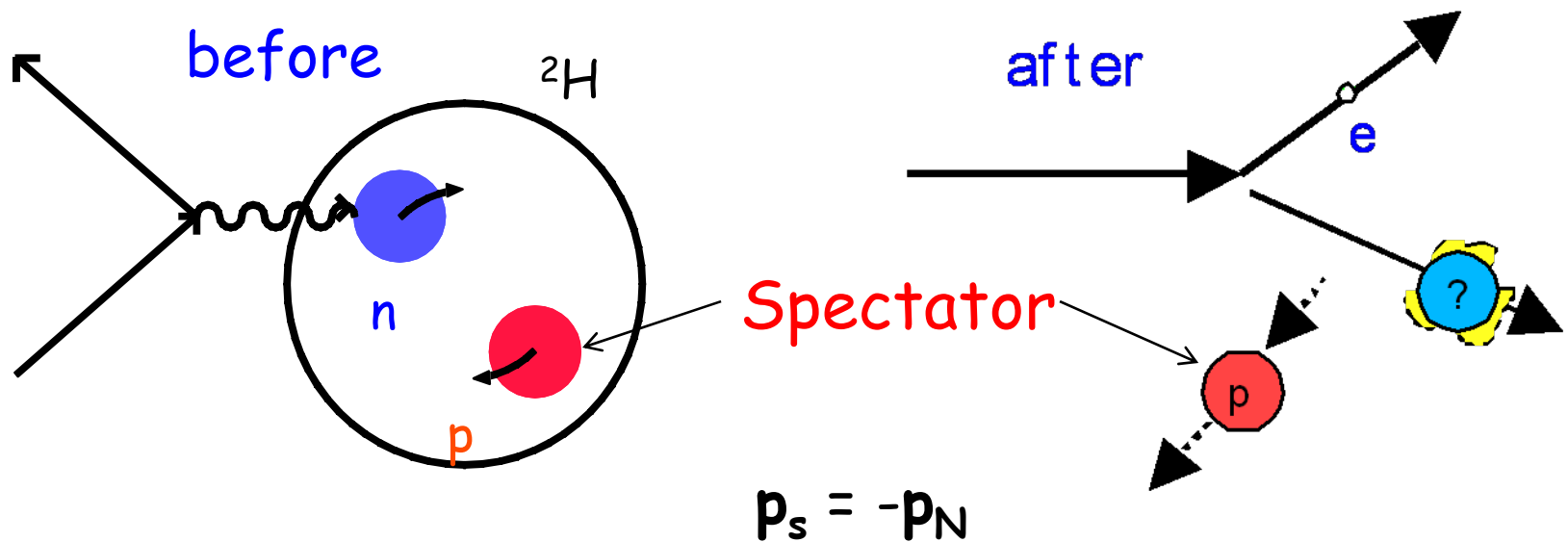
- Observation that structure functions are altered in nuclei **stunned** much of the HE/NP community more than 25 years ago.
- Two category models:
  - ✓ Quark Effects: Multi-cluster, Rescaling model ...
  - ✓ Traditional Nuclear Model: Nuclear binding model ...
- ~1000 papers on the topic; the best models explain the curve by change of nucleon structure, **BUT** no fully accepted explanations!
- More data are needed to uniquely identify the origin.



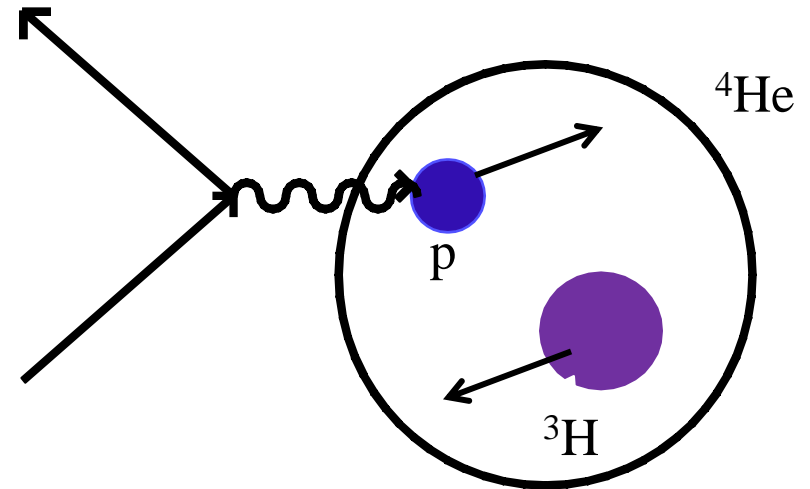
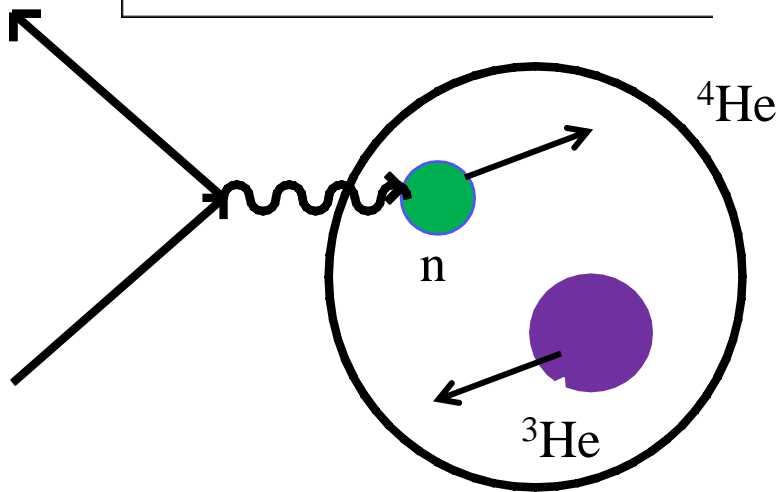
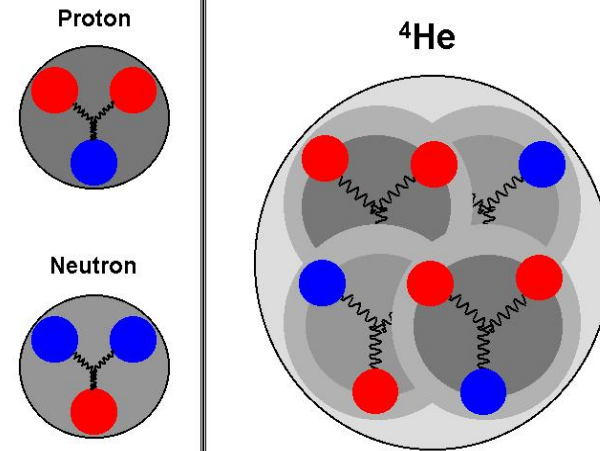
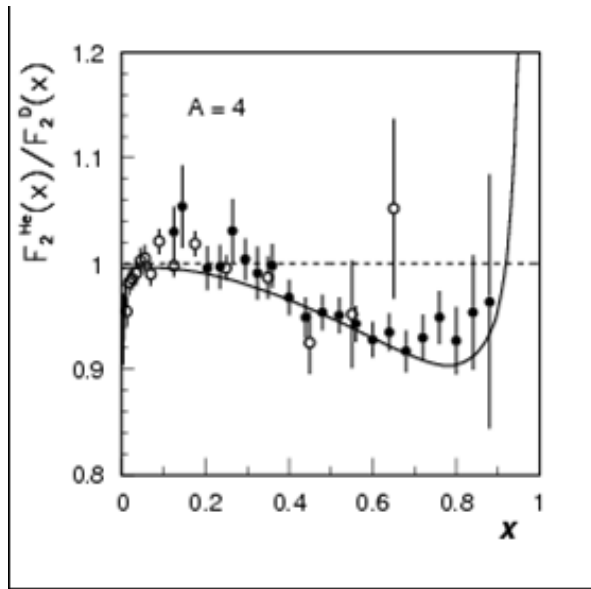
# Method of Spectator Tagging

## Barely Off-shell Nucleon Structure (BoNuS)

- Detect slow protons (BONUS Experiment at Hall B)
  - Identify spectator protons from deuteron scattering to ensure that the struck nucleon is a neutron.
  - Measurement of recoil proton momentum tells the initial state of the neutron.



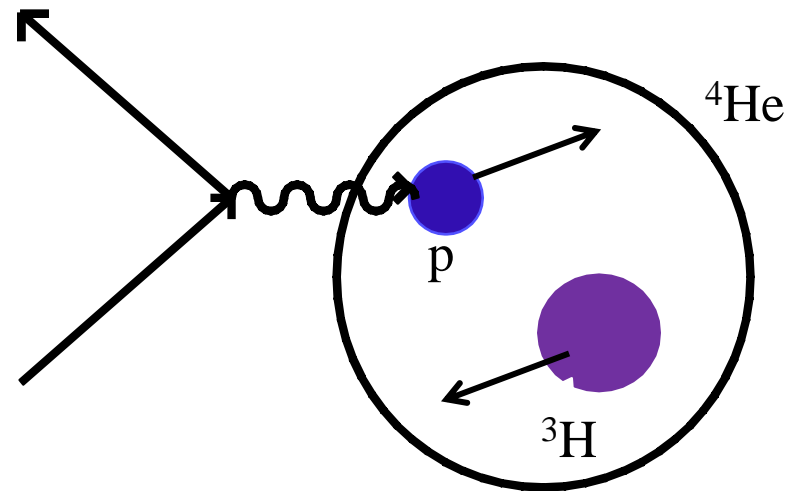
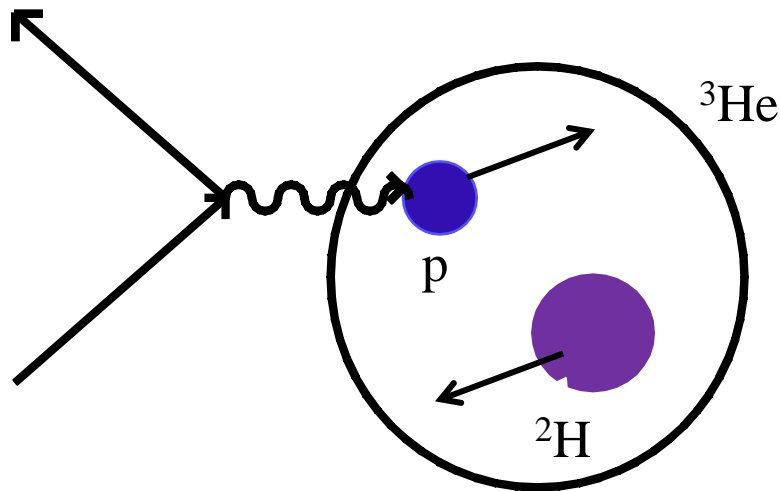
# EMC effect significant in light nuclei



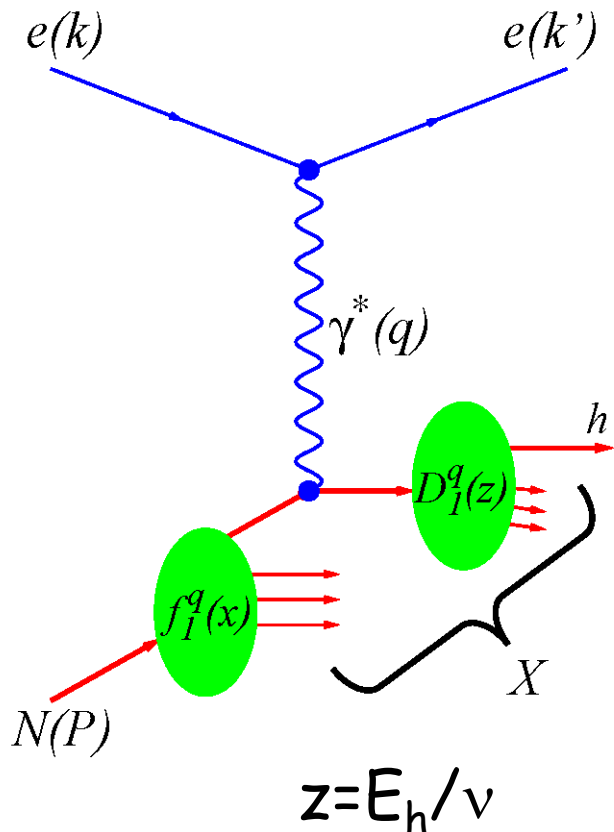
# EMC Effect in $^3\text{He}$ and $^4\text{He}$

EMC effect has been extensively measured in  $A > 8$  nuclei, but current data do not differentiate between models with either an  $A$ -dependence or a  $\rho$ -dependence.

→ Test models of the EMC effect in exact few-body calculations



# Semi-Inclusive Deep Inelastic Scattering (SIDIS)



final state: hadron +  $X$

cross section factorizes

→ fragmentation function  $D_1^q(z)$  (FFs)

→  $P_{h\perp}$ : transverse momentum dependent PDF (TMD)

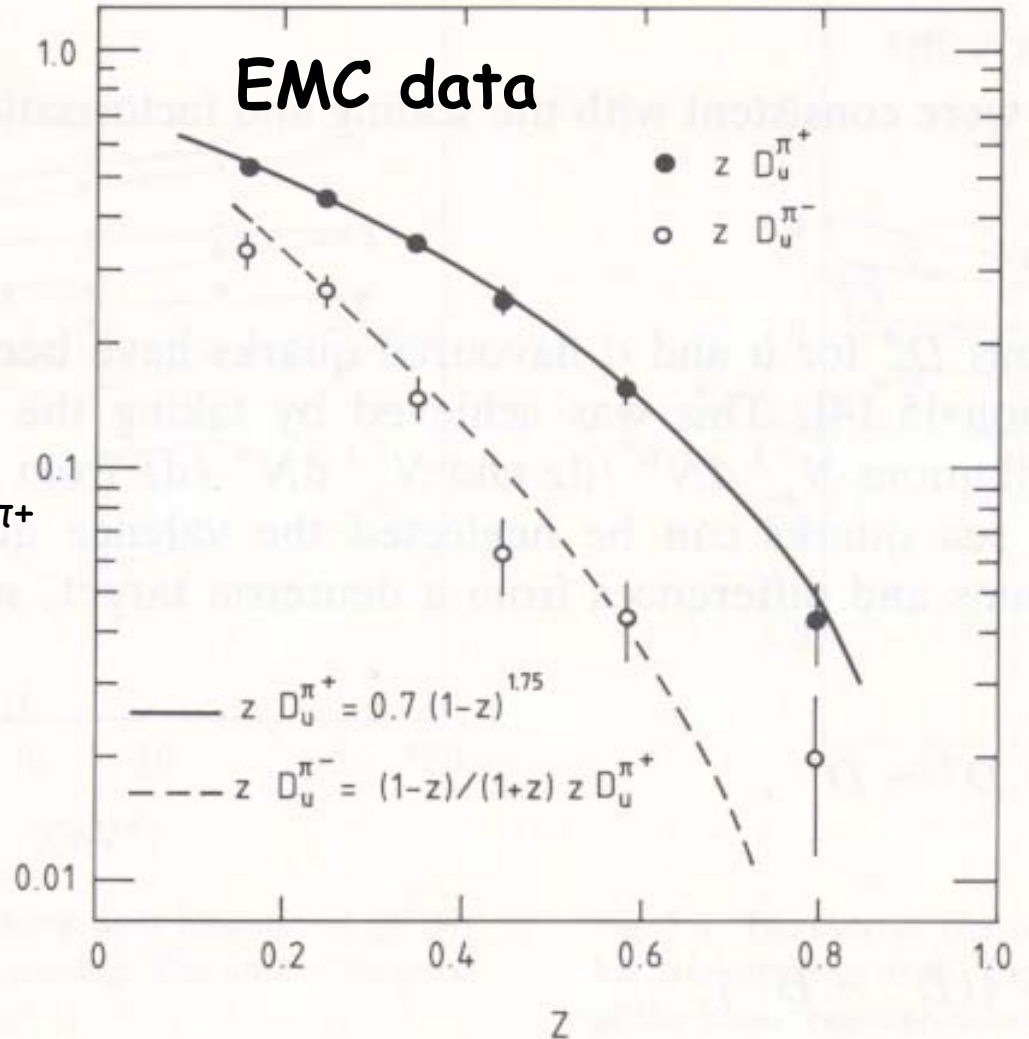
# Fragmentation Functions

Favored FF:

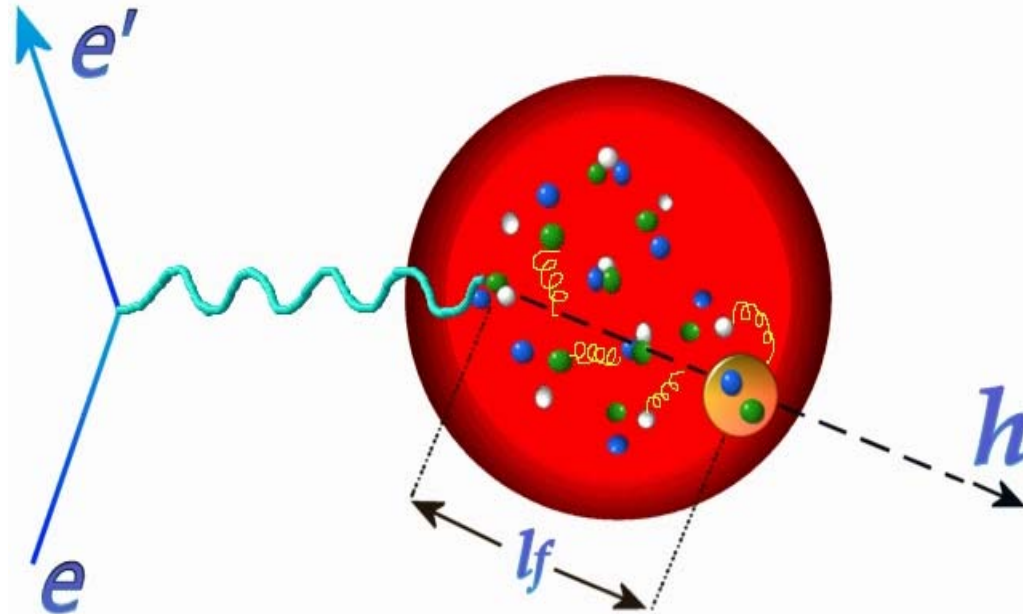
$$zD_u^{\pi^+} = 0.7 (1-z)^{0.75}$$

Unfavored FF:

$$zD_u^{\pi^-} = (1-z)/(1+z) zD_u^{\pi^+}$$

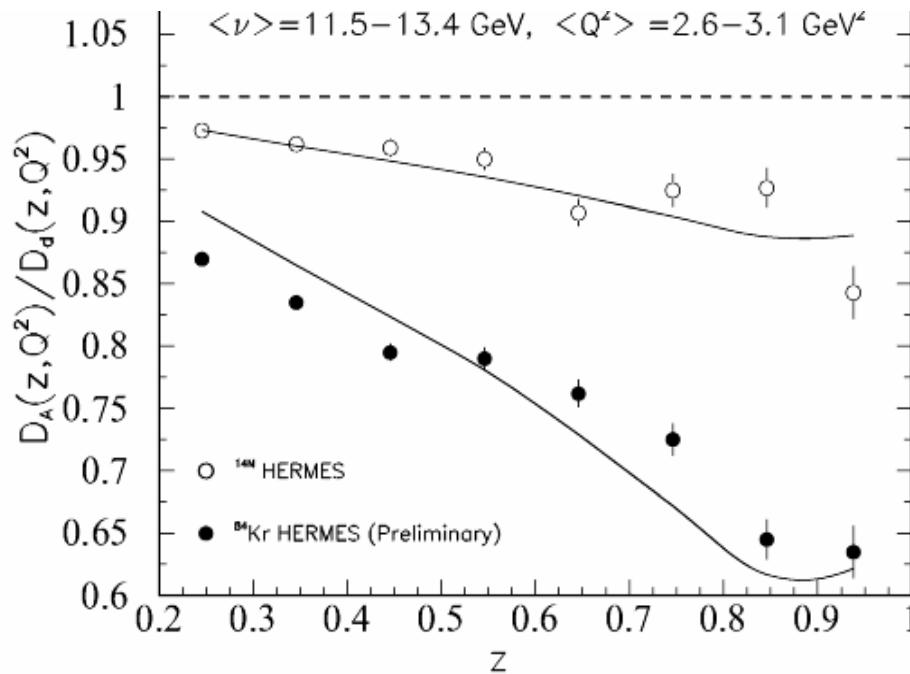


# SIDIS off Nuclei



Production and Formation Times + FF modifications are crucial for the understanding of the space-time evolution of the hadron formation process

# Fragmentation Function (FF) Modification



X.N.Wang et al.,  
 NPA696(2001)788  
 PRL89(2002)162301

Multiple parton scattering and induced parton energy loss  
 (without hadron rescattering).  
 pQCD approach  $\rightarrow A^{2/3}$  dependence.

# Proposed Program with CLAS12

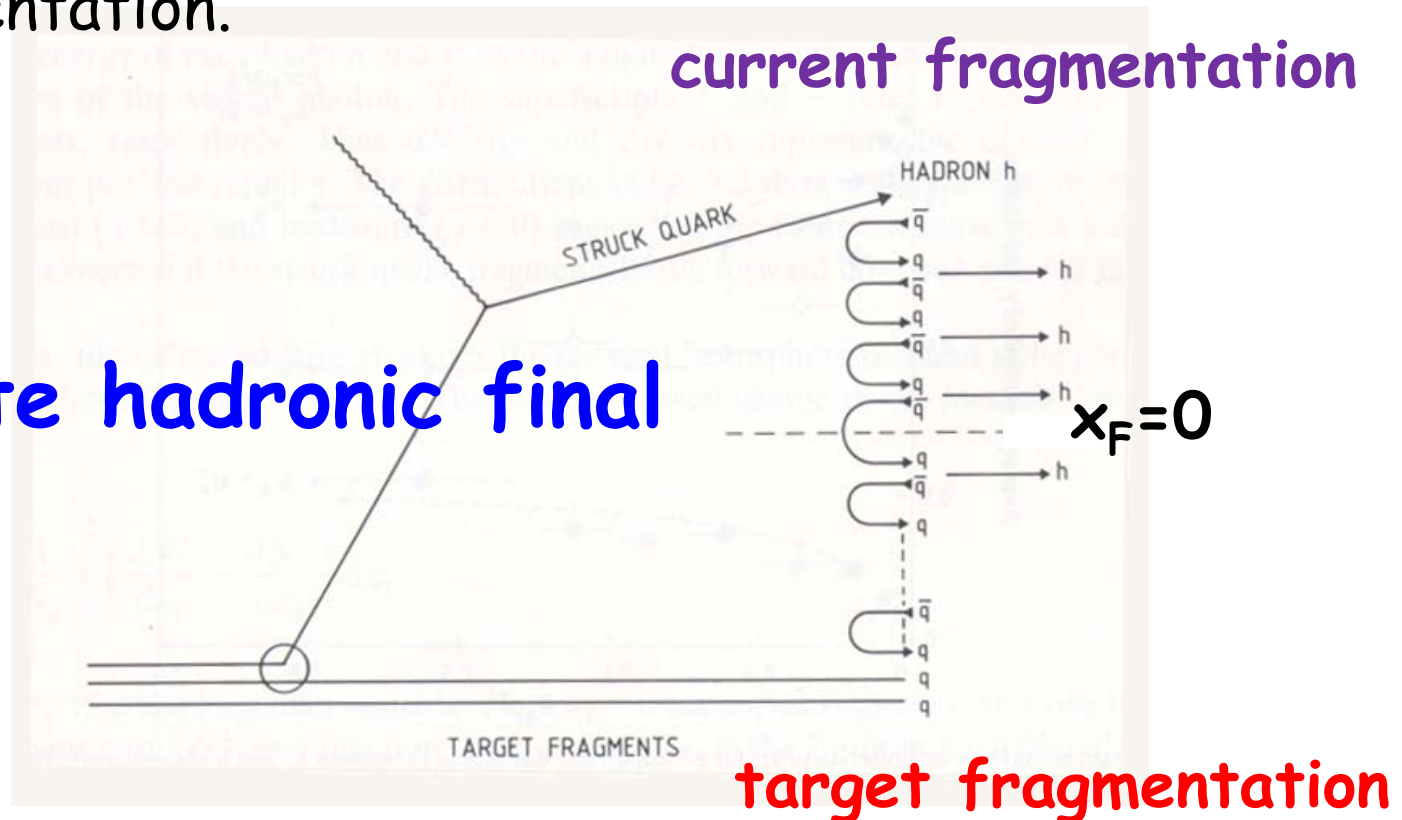
1. Measure DIS off light nuclei controlling “binding configurations”:
  - (a)  ${}^4\text{He}(e,e')X$  by tagging on  ${}^3\text{He}$ , and  ${}^4\text{He}(e,e')X$  by tagging on  ${}^3\text{H}$ .
    - >  $F_2^n/F_2^p$  for nucleons bound in the  ${}^4\text{He}$  nucleus.
  - (b)  ${}^3\text{He}(e,e')X$  by tagging on  ${}^2\text{H}$ , and  ${}^2\text{H}(e,e')X$  by tagging on proton.
- Presumably, the recoil  $A-1$  momentum measurement will provide the momentum of the initial struck nucleon.
  - > Study “Local EMC effect” by mapping out the initial nucleon momentum.
- We will examine how far up in  $A$  we can push this technique.



# Proposed Program with CLAS12

2. Measure SIDIS off light nuclei by detecting current pions and kaons tagging on low energy fragment or by detecting low energy pions and kaons from target fragmentation.

**Complete hadronic final states**



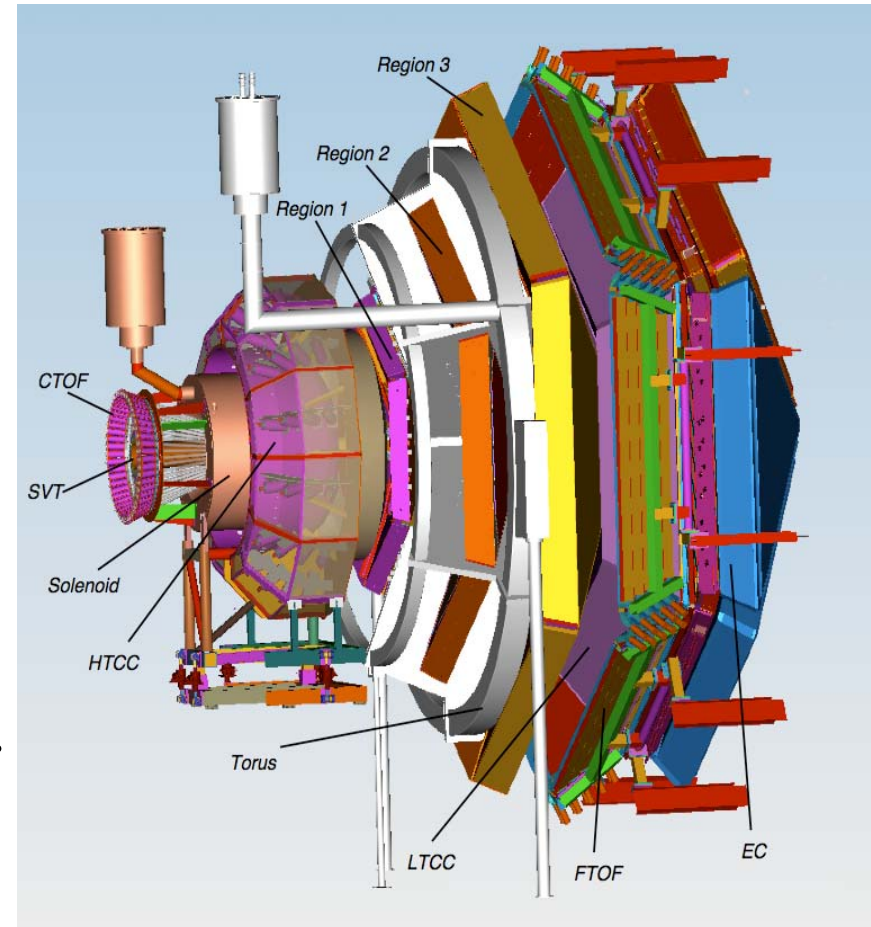
# Monte-Carlo Simulations

## Event Generators:

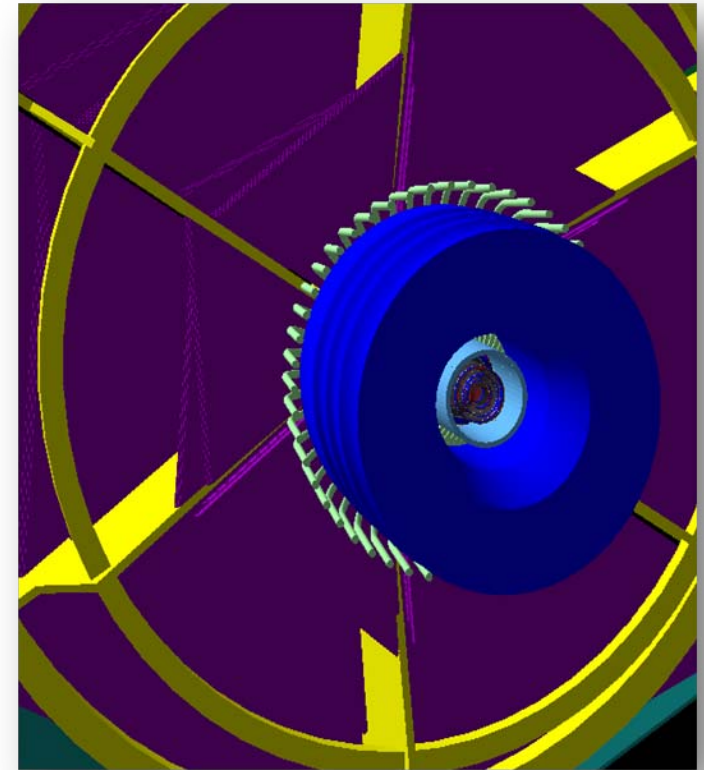
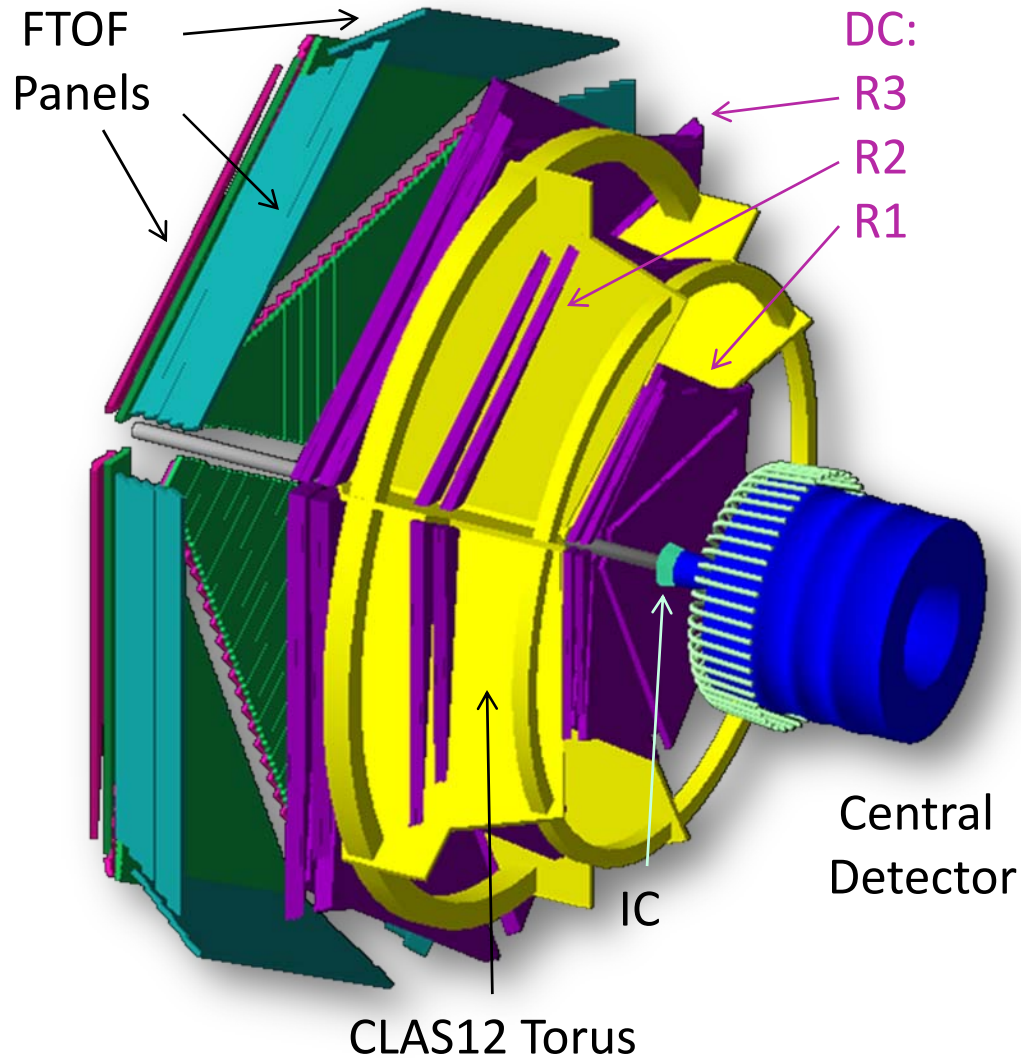
- VENUS
- FSGEN

## CLAS12:

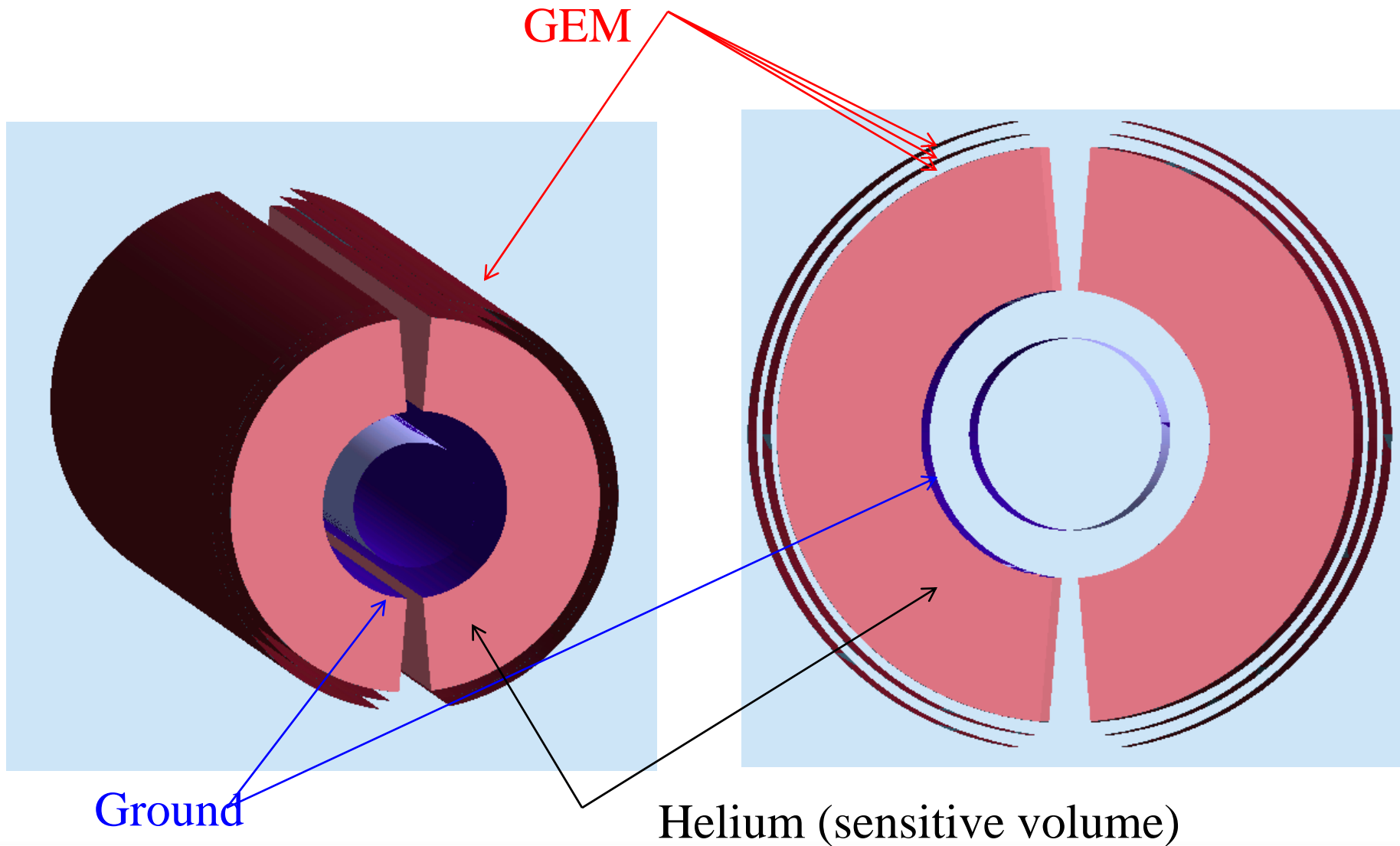
- GEMC: Geant4 based MC simulation program.
- FASTMC: Parameterization of realistic geometric acceptances and resolutions.



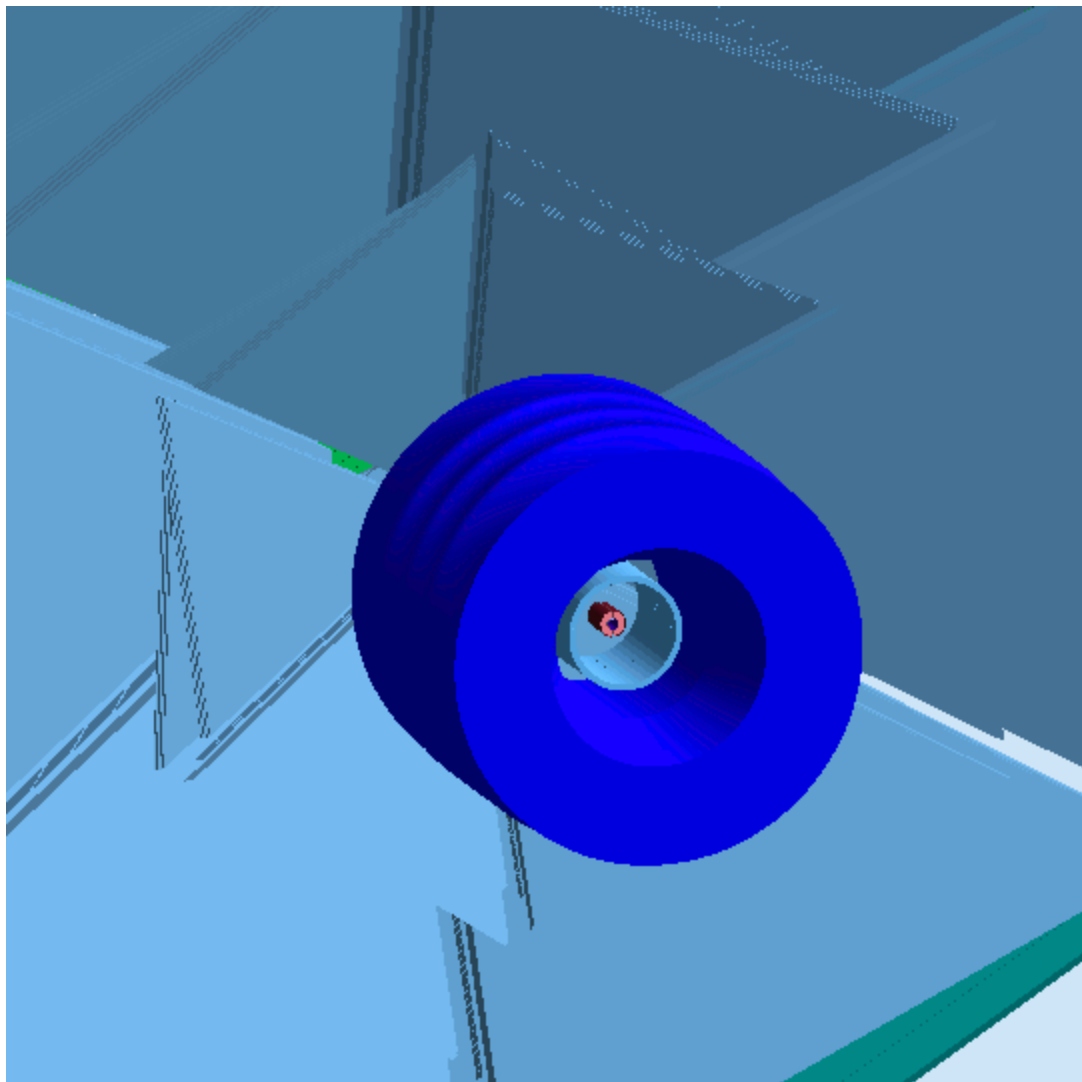
# CLAS12 Geometry



# BoNuS Implementation

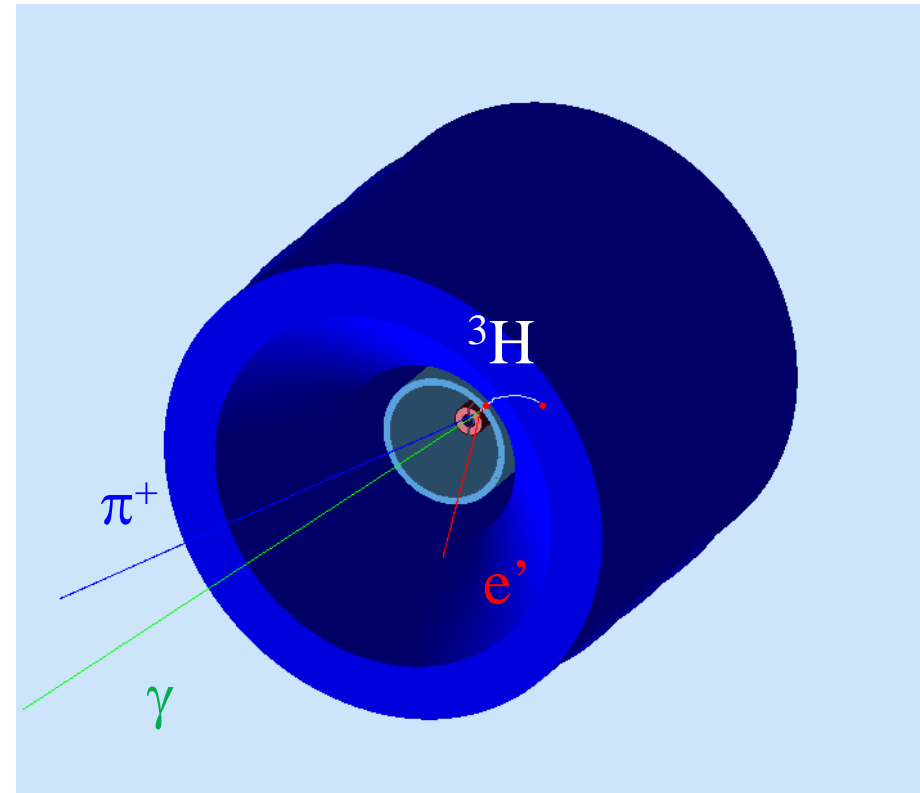
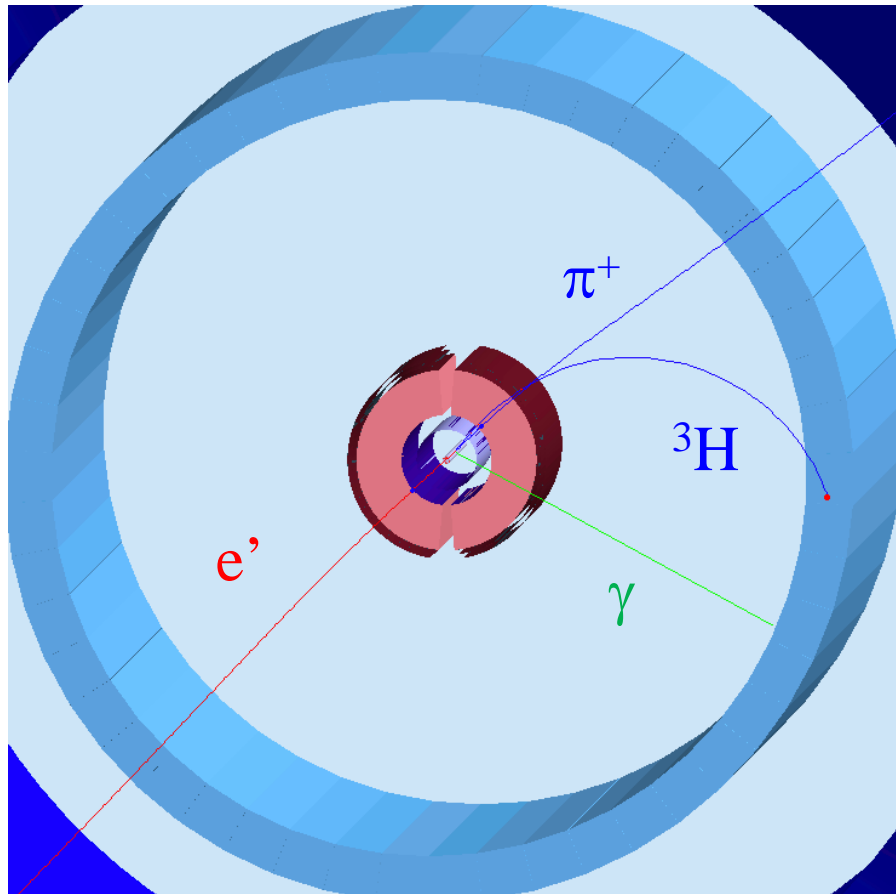


# BoNuS Implementation



- BoNuS
- CTOF
- DC
- OTOF
- Torus Fields
- Solenoid Fields

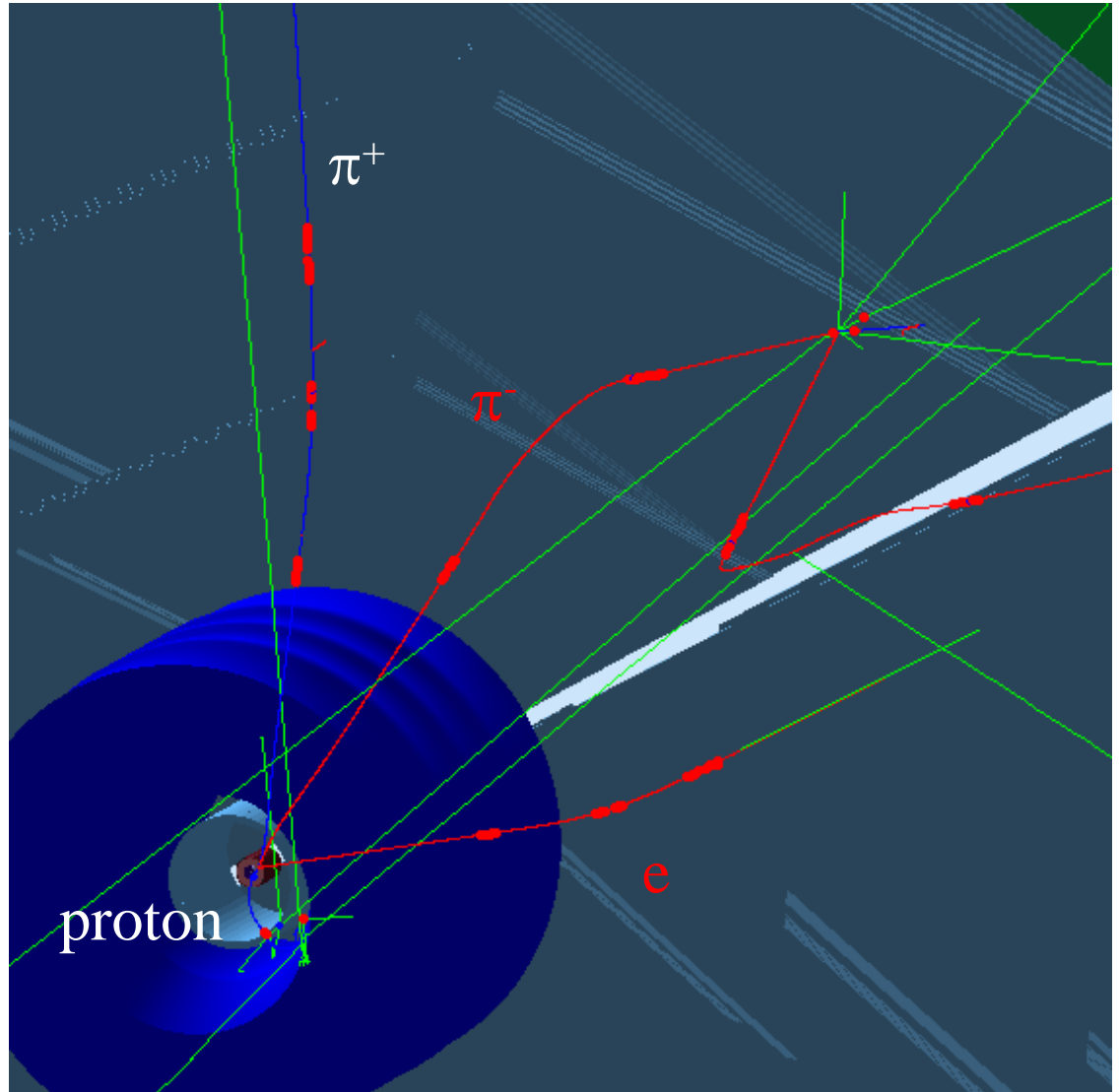
# Event Display in GEMC



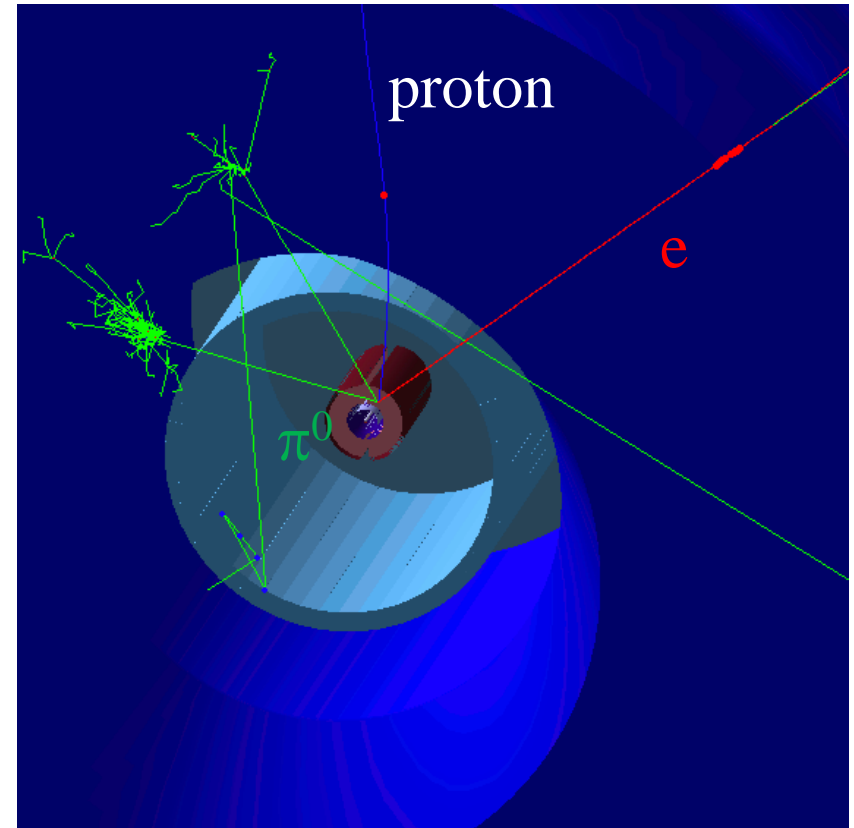
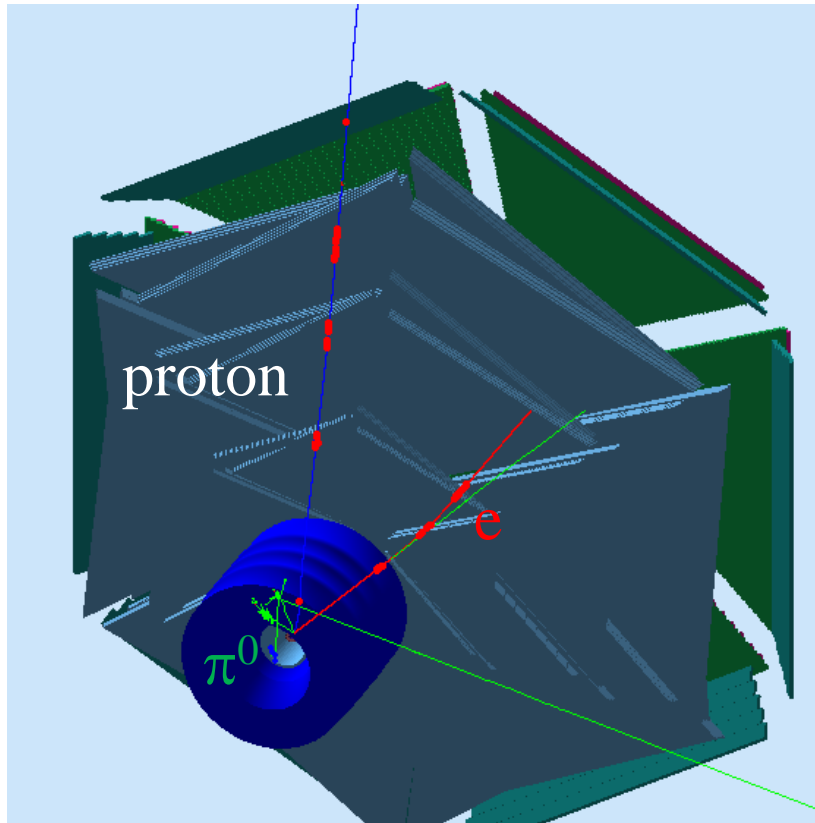
from  ${}^4\text{He}(e, e' \pi^+)X$  tagging on  ${}^3\text{H}$

# Event Display in GEMC

from  ${}^2\text{He}(e, e' \pi^+ \pi^-)X$   
tagging on proton



# Event Display in GEMC



from  ${}^2\text{He}(e,e' p\pi^0)X$



# "Reconstruction"

In the Forward Detector: DC

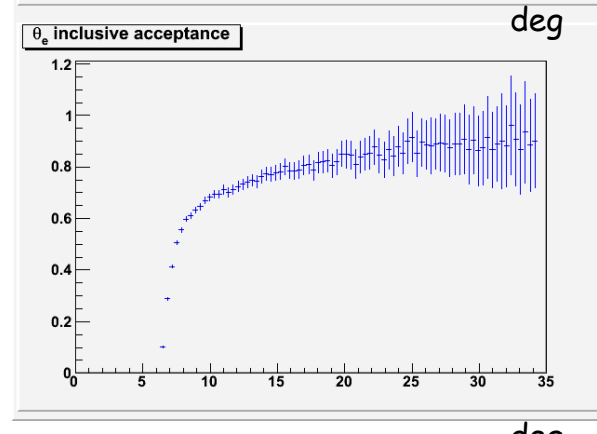
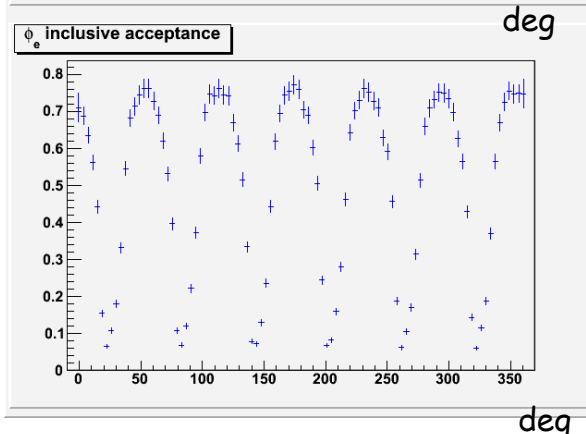
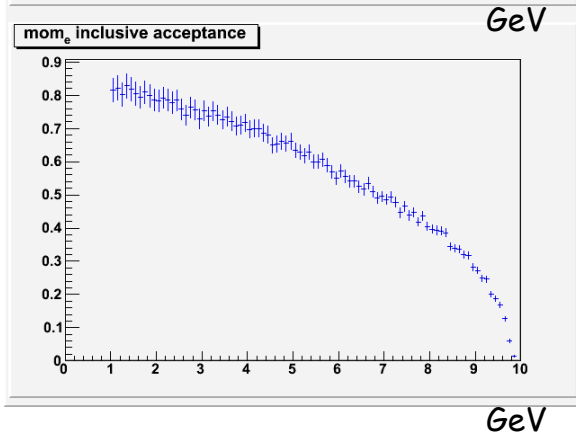
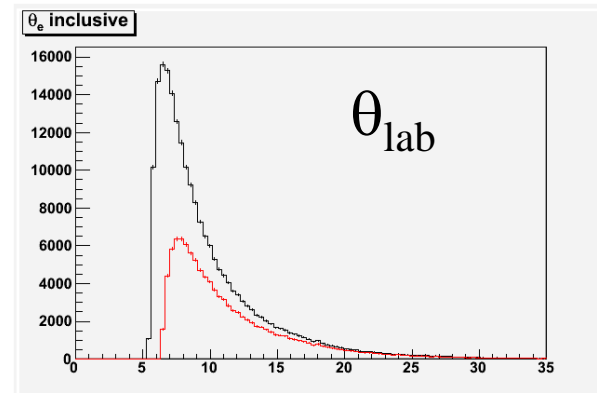
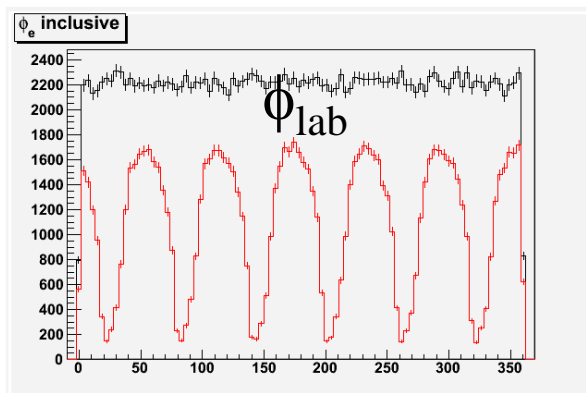
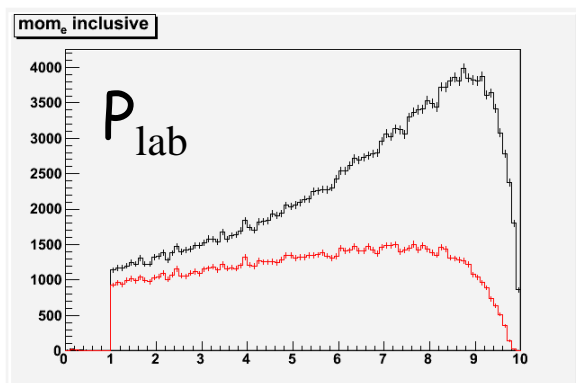
At least 5 out of 6 layers in one SuperLayer  
At least 5 out of 6 SuperLayers

In Bonus:

Hit, release at least 100 eV

# Electron Acceptance at 11 GeV

————— generated  
————— Reconstructed (GEMC)  
————— Acceptance

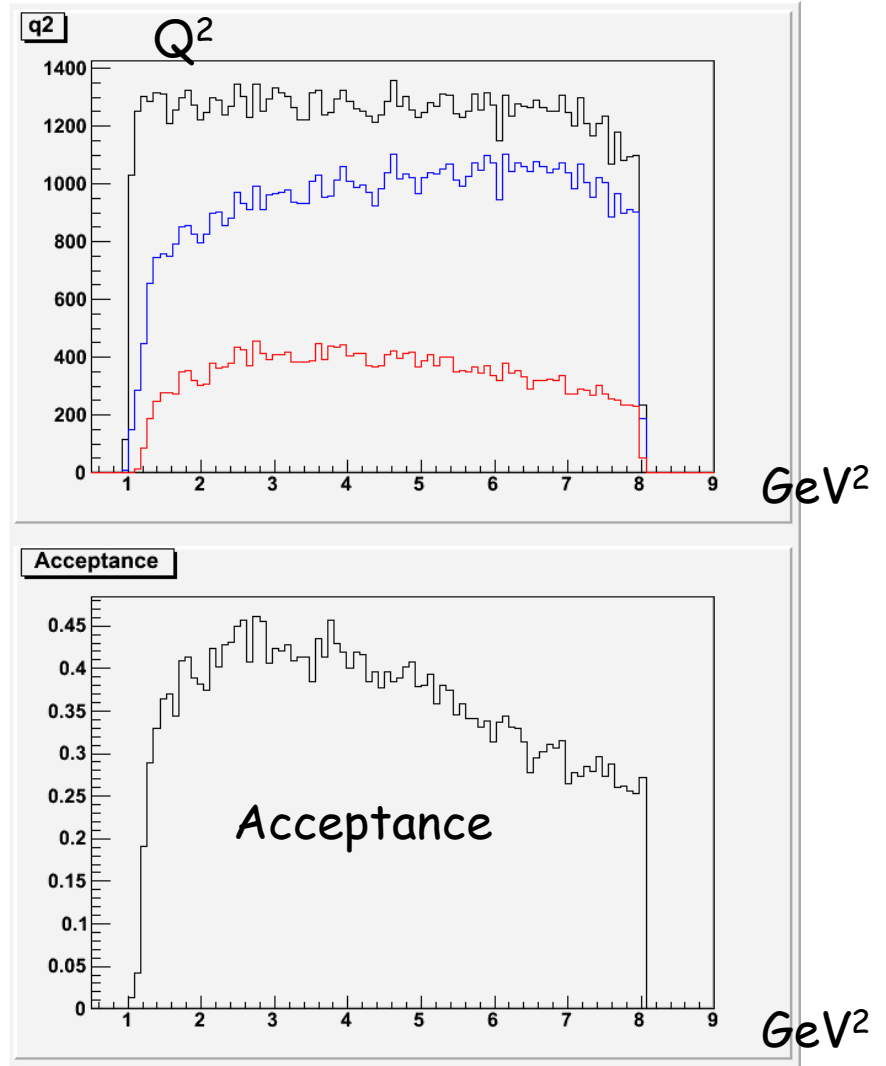
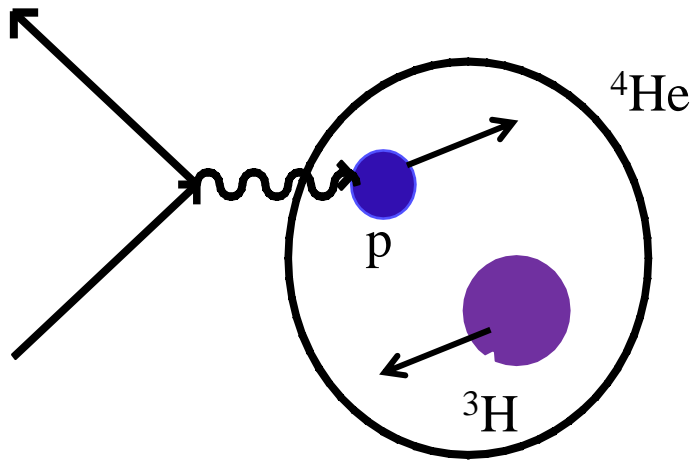


# $^4\text{He}(e,e')$ tagging on $^3\text{H}$

Generated (FSGEN)

Reconstructed (GEMC)  
Without tagging

Reconstructed (GEMC)  
With tagging  $^3\text{H}$

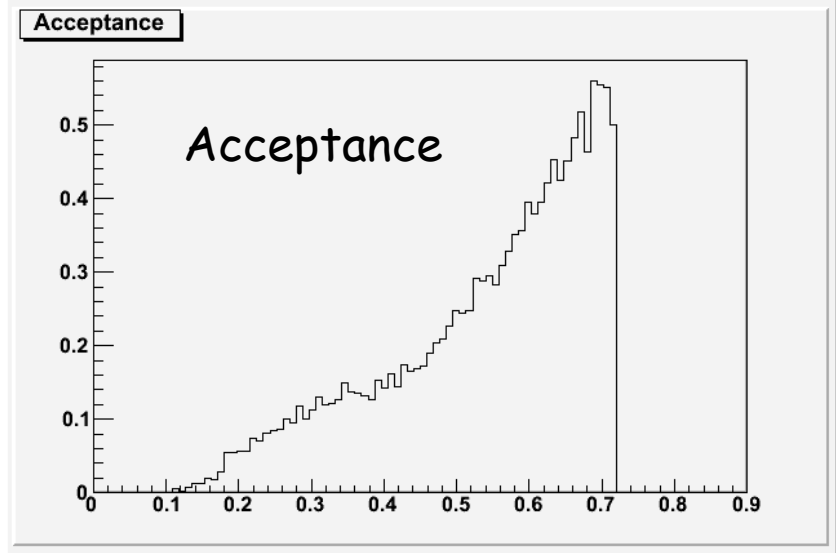
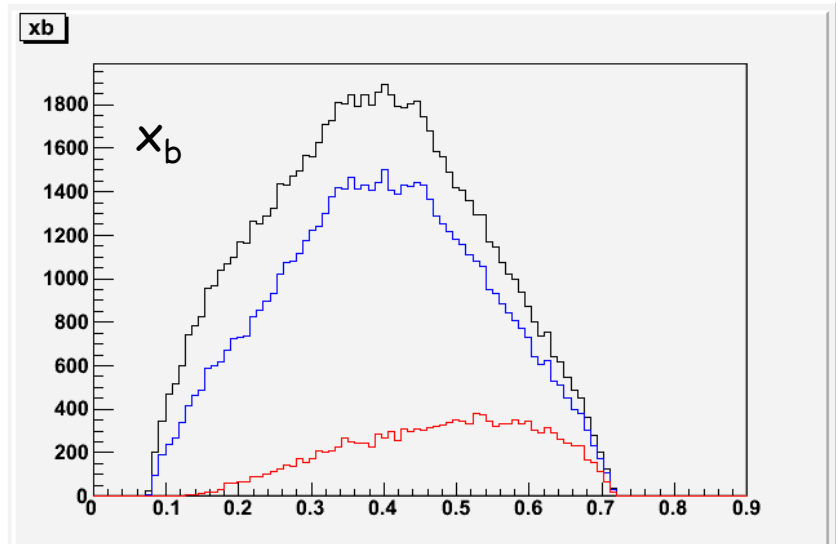
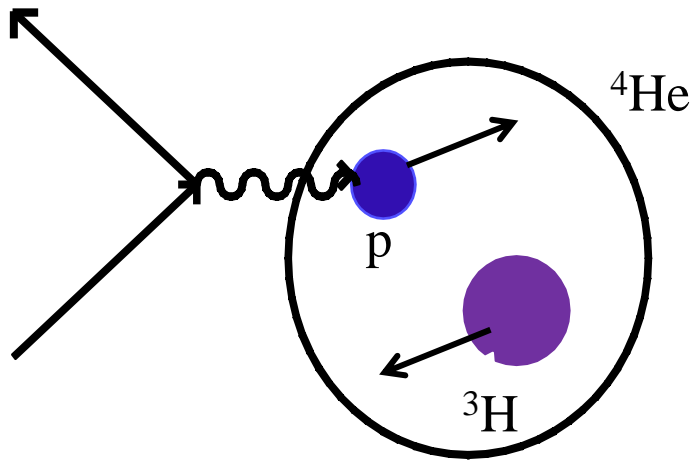


# $^4\text{He}(e,e')$ tagging on $^3\text{H}$

Generated (FSGEN)

Reconstructed (GEMC)  
Without tagging (GEMC)

Reconstructed (GEMC)  
With tagging  $^3\text{H}$

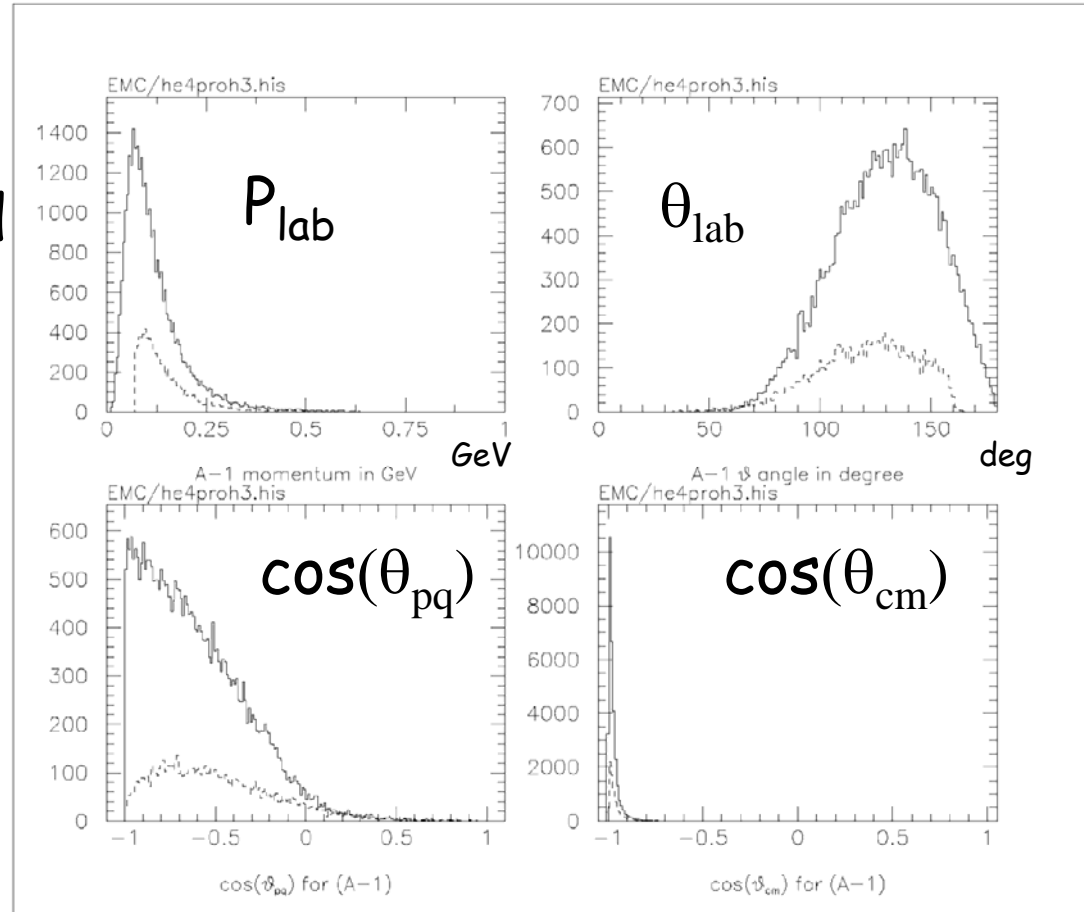
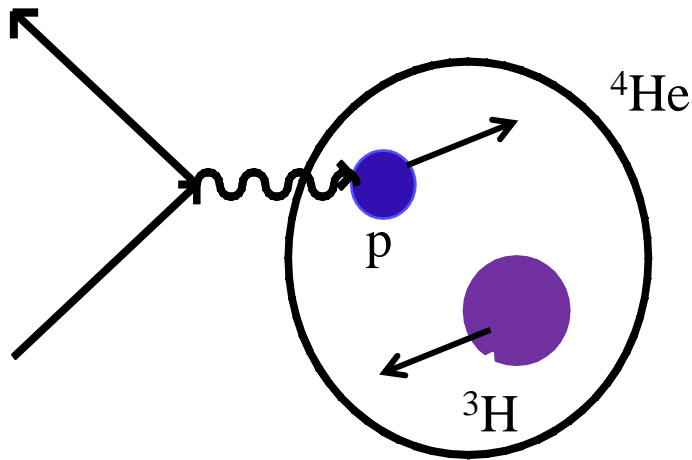


# $^4\text{He}(e,e')$ tagging on $^3\text{H}$

## Tagged $^3\text{H}$ kinematics

Generated  
(FSGEN)

Reconstructed  
(FASTMC)

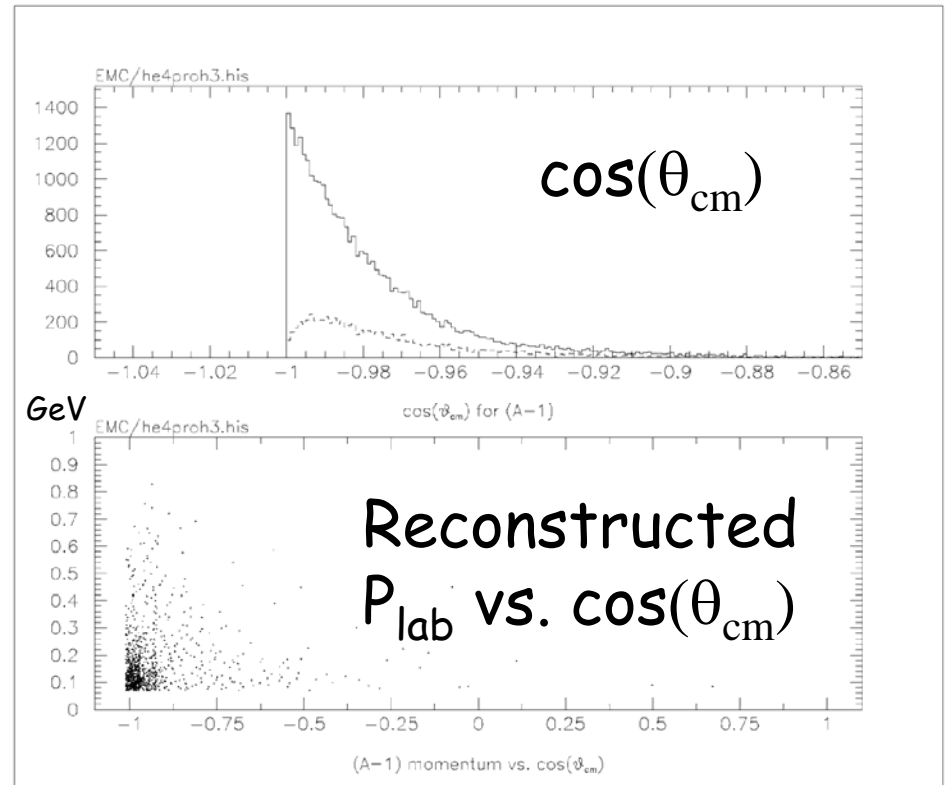
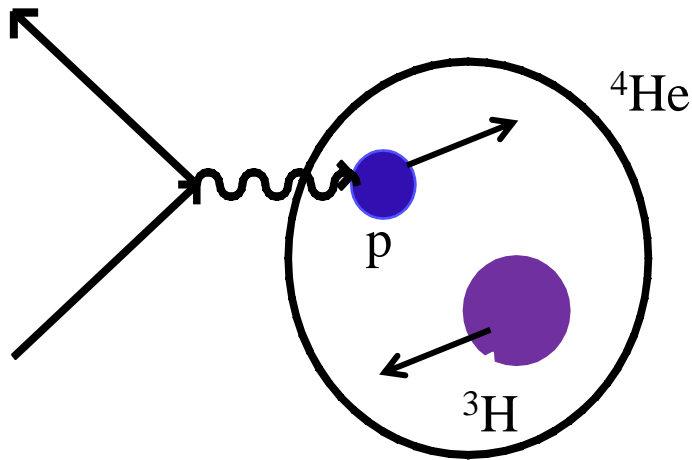


# $^4\text{He}(e,e')$ tagging on $^3\text{H}$

## Tagged $^3\text{H}$ kinematics

Generated  
(FSGEN)

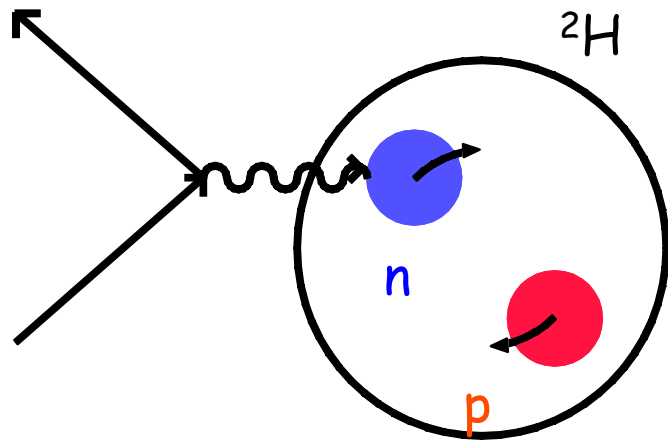
Reconstructed  
(FASTMC)



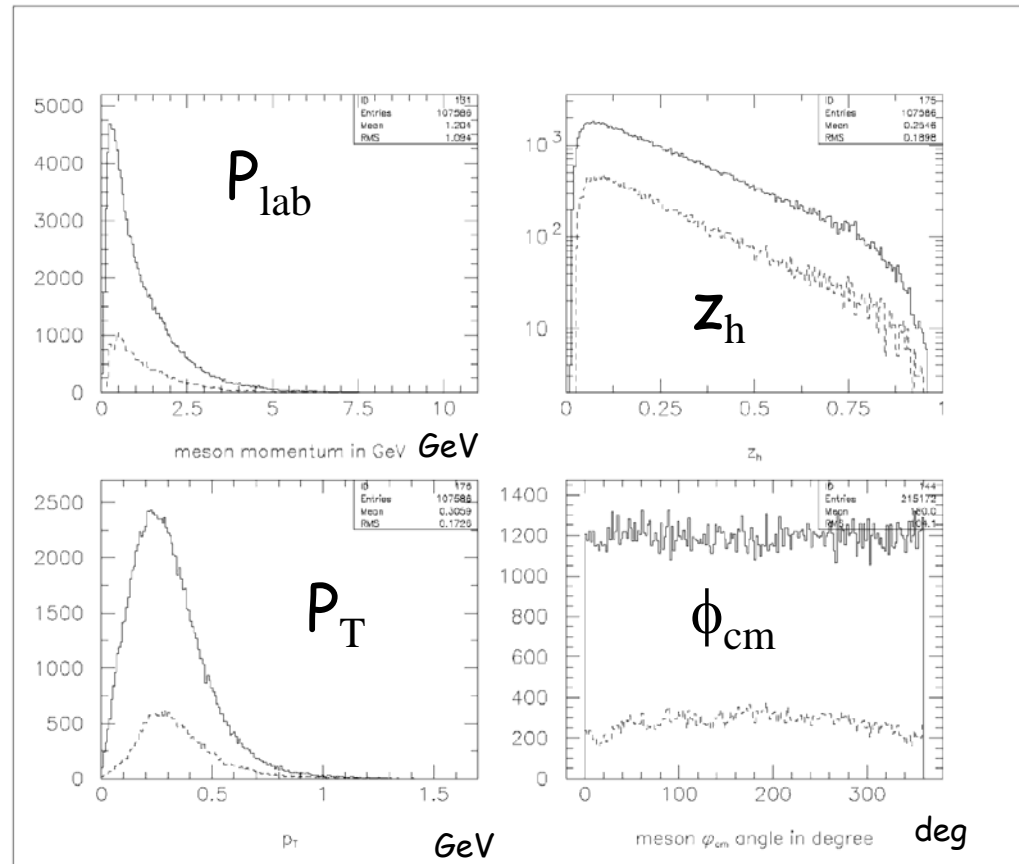
# SIDIS ${}^2\text{H}(e, e'\pi^+)X$ tagging on proton

Generated  
(VENUS)

Reconstructed  
(FASTMC)



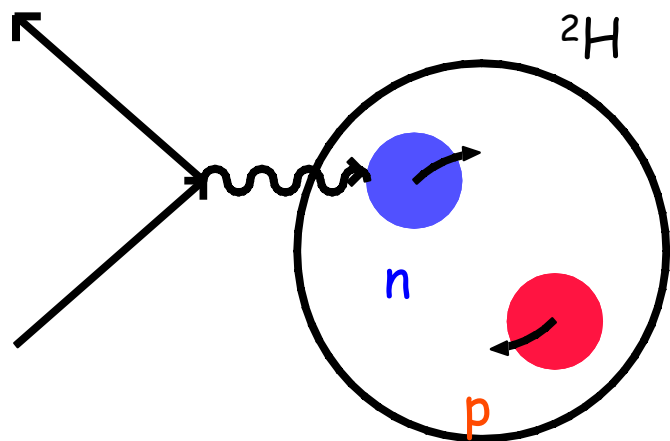
${}^2\text{H}(e, e'\pi^+)X$



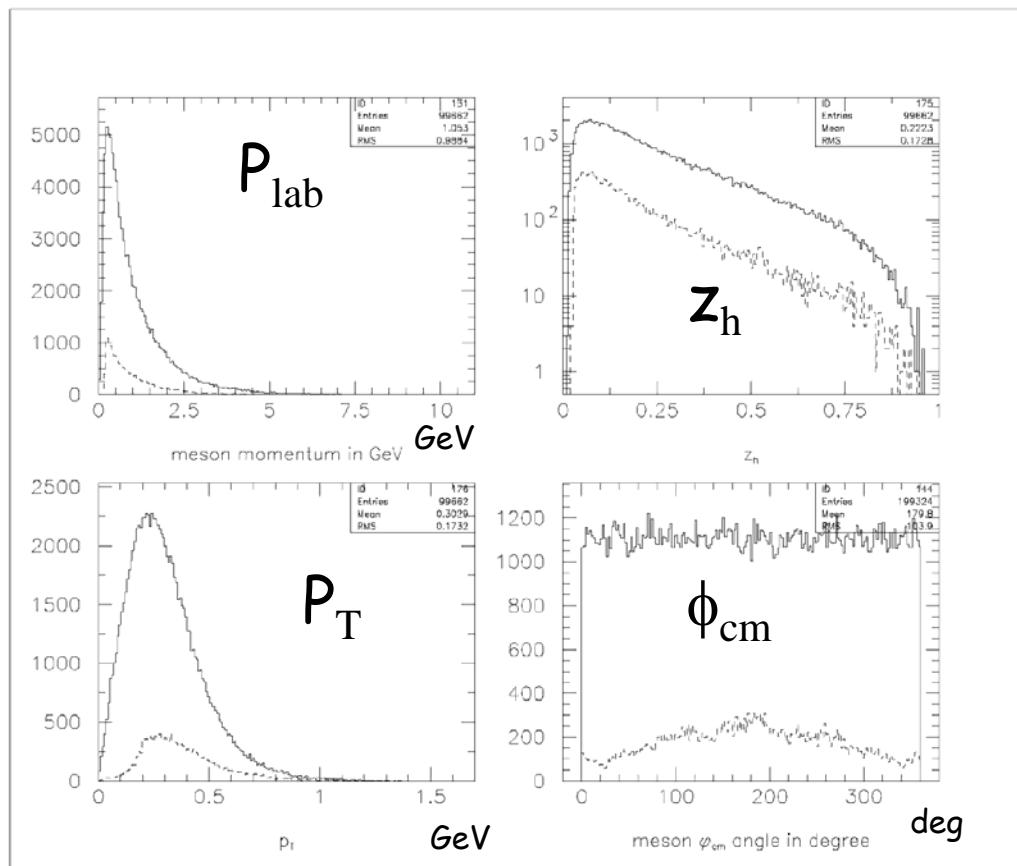
# SIDIS ${}^2\text{H}(e, e'\pi^-)X$ tagging on proton

Generated  
(VENUS)

Reconstructed  
(FASTMC)



${}^2\text{H}(e, e'\pi^-)X$

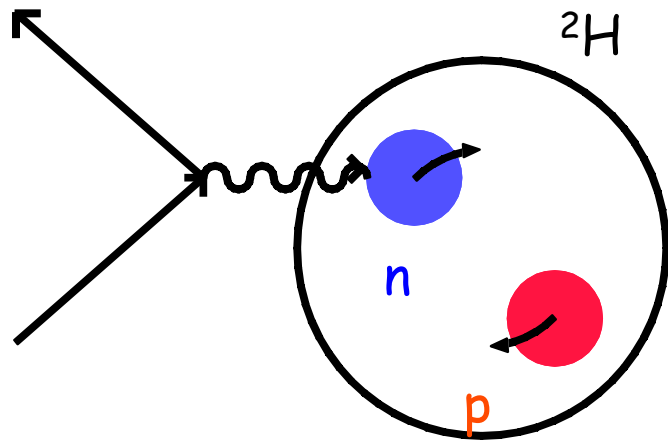




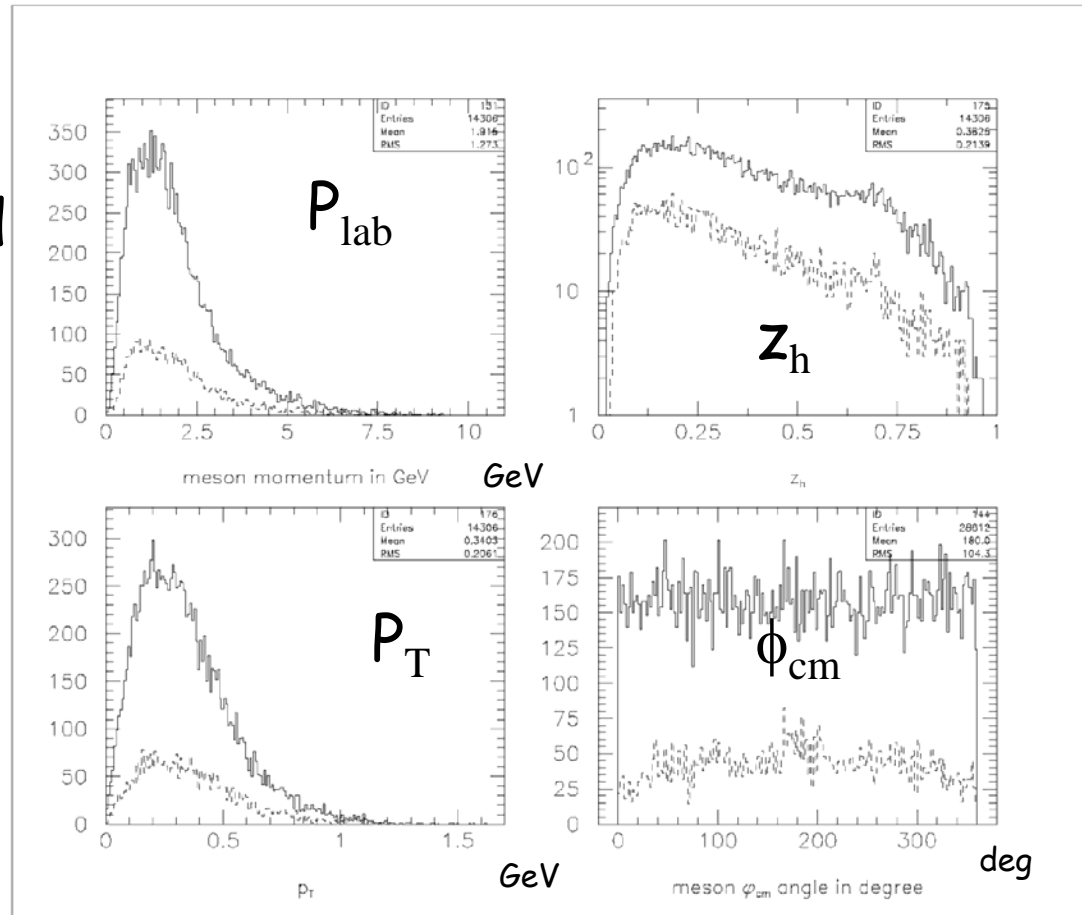
# SIDIS ${}^2\text{H}(e,e'K^+)X$ tagging on proton

Generated  
(VENUS)

Reconstructed  
(FASTMC)



${}^2\text{H}(e,e'K^+)X$



# Summary

- Develop experimental programs in DIS and SIDIS to understand why the momentum of the quarks in the nucleus is different from that in the free nucleon using **a spectator tagging method**.
- Much more work in simulations is needed to optimize detector components such as an upgraded BoNuS, SVT and neutron detector etc. as well as to study acceptances, resolutions and count rate estimations.
- Richard Milner of MIT is looking into a new technology to detect low energy neutrons ( $\sim 2.5$  MeV).
- Plan to submit proposals to the next JLab PAC in January, 2010.