D(e,e'p_s)X with "Spectator Tagging"

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Overview

- Bound Neutron Structure Functions
- Spectator Tagging
- Final State Interactions
- Results from “Deeps”
- Preliminary Results from BoNuS
- Plans for 12 GeV

Bound Neutron Structure Functions - 2 Questions:

1) How can we explore the structure of the neutron if all we have are neutrons bound in nuclei?
   - In many cases, a neutron bound in deuterium can be considered “nearly free”.
   - BUT: For certain kinematics (large $x > 0.5$, resonance region $W < 2$) the high-momentum (short-distance tail) of the deuteron wave function plays a large role and might distort the result.

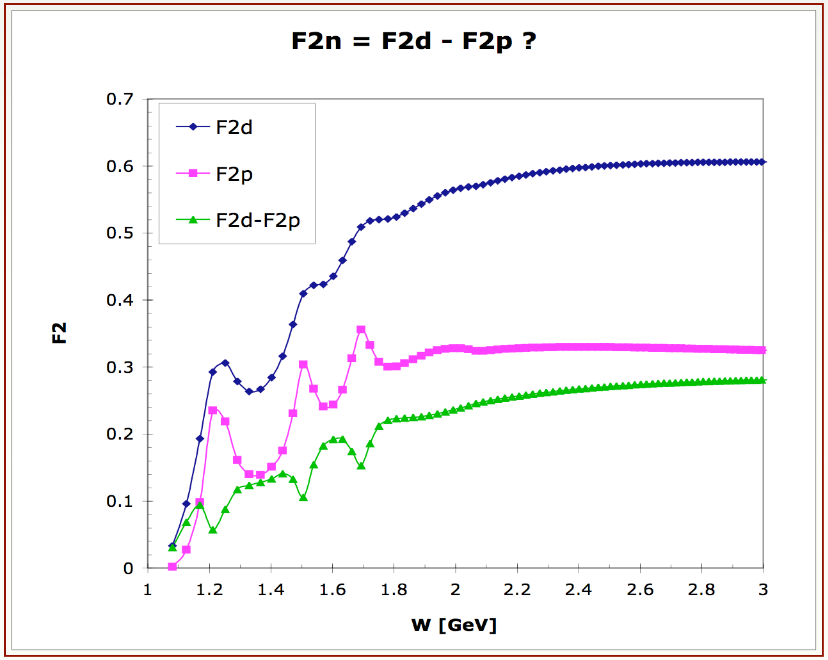
2) Can we learn something about what happens to a nucleon if it is part of a short-distance pair?
   - Many ideas: Off-shell modifications of on-shell structure functions, color delocalization, suppression of point-like components, $\Delta\Delta$ components, extra mesons or 6-quark bags
   - Fundamental question about QCD in bound hadron systems that we haven’t understood yet. Relevant for QCD phase diagram (high baryon density, neutron stars, color superconductivity?)

Bound Neutron Structure Functions

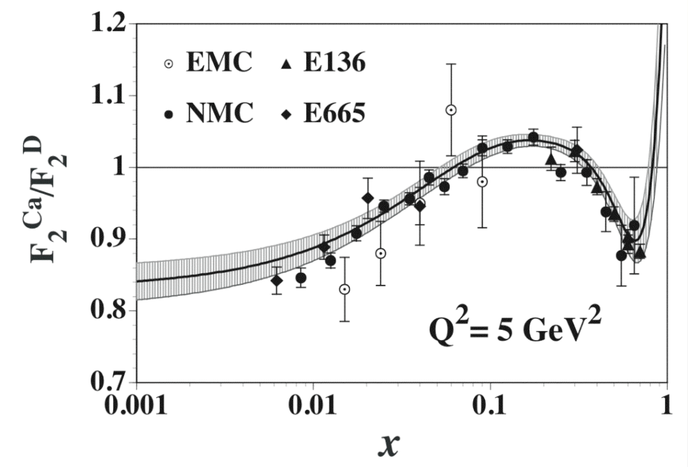
- Simple subtraction (deuteron-proton) yields nonsense
- Kinematic shift of the effective Bjorken variable x or of W

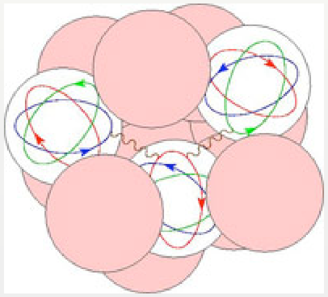
$$x_{\text{measured}} = \frac{Q^2}{2M\nu} \qquad \langle x_{\text{relevant}} \rangle = \left\langle \frac{Q^2}{2(E_n\nu - \vec{p}_n \cdot \vec{q})} \right\rangle$$

0.70	0.69
0.80	0.78
0.90	0.85
1.00	0.90



+ Binding (off-shell) effects, coherent scattering, final state interactions, non-nucleonic degrees of freedom in the ground state, nucleon structure modification ("EMC"-effect)

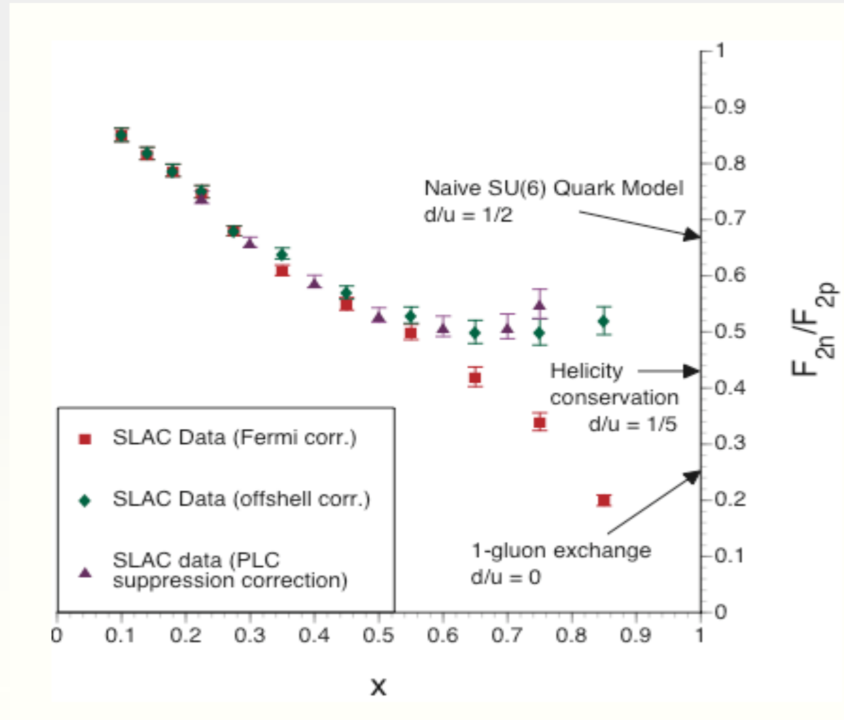




Free n structure function

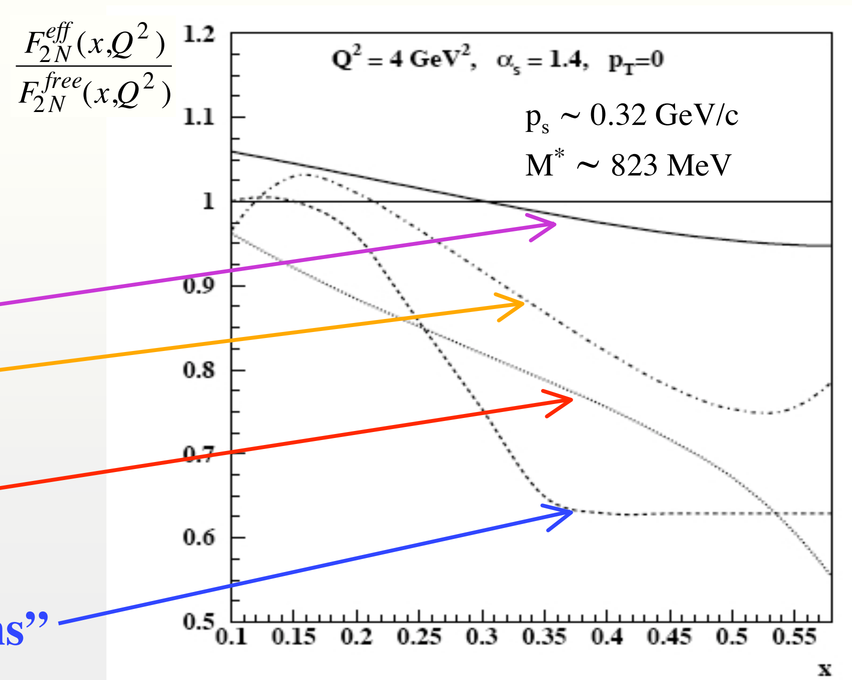
- Needed to study duality in the neutron and to pin down d/u(x -> 1)

$$\frac{F_{2n}}{F_{2p}} \approx \frac{1+4d/u}{4+d/u}$$



Bound n structure function

- Constrain models of the EMC effect, hadrons “in medium”



Off-shell modifications

6-quark bags

Color delocalization

Suppression of “point-like configurations”

Deviations from free structure function:

Off-shell Effects [should depend on α (p_s), x, Q^2]

$$\frac{F_{2N}^{eff}(x=0.6, Q^2, \alpha)}{F_{2N}^{eff}(x=0.2, Q^2, \alpha)}$$

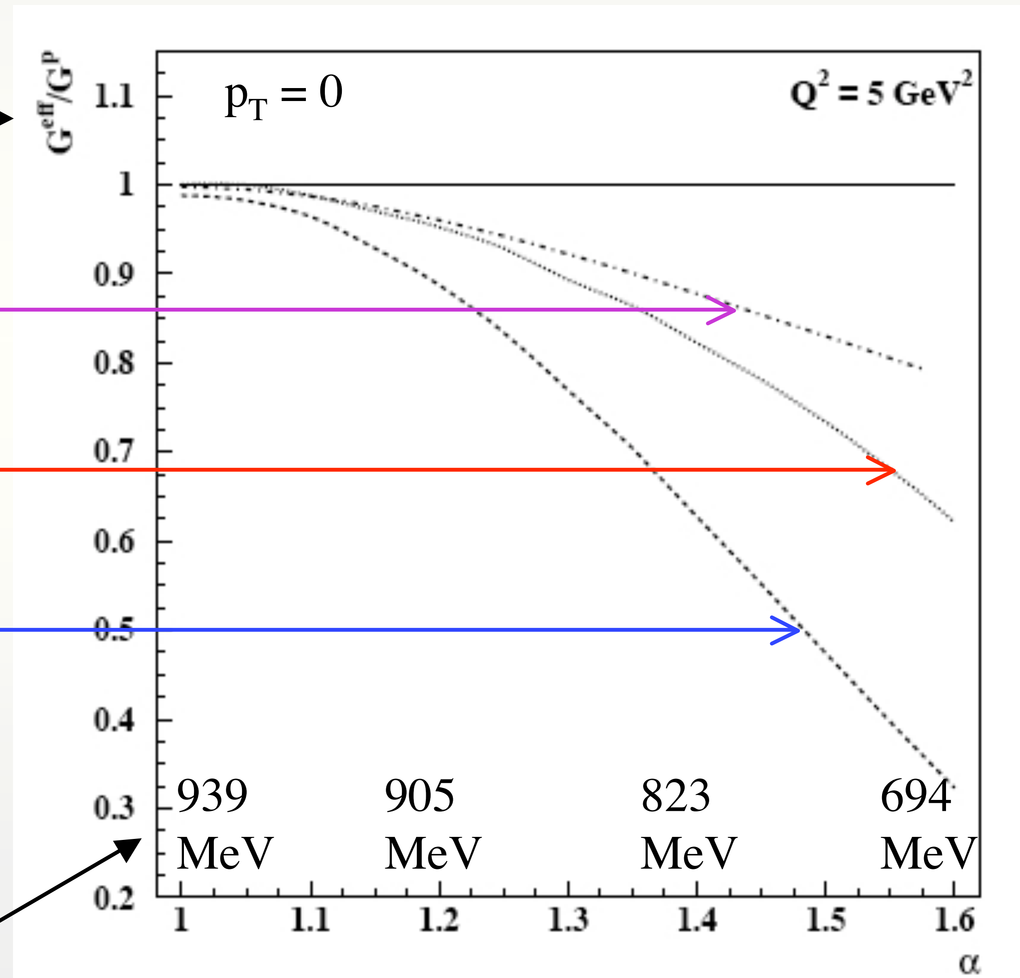
Modification of the off-shell scattering amplitude (Thomas, Melnitchouk et al.)

Color delocalization Close et al.

Suppression of "point-like configurations" Frankfurt, Strikman et al.

… plus 6-quark bags, ΔΔ, MEC…

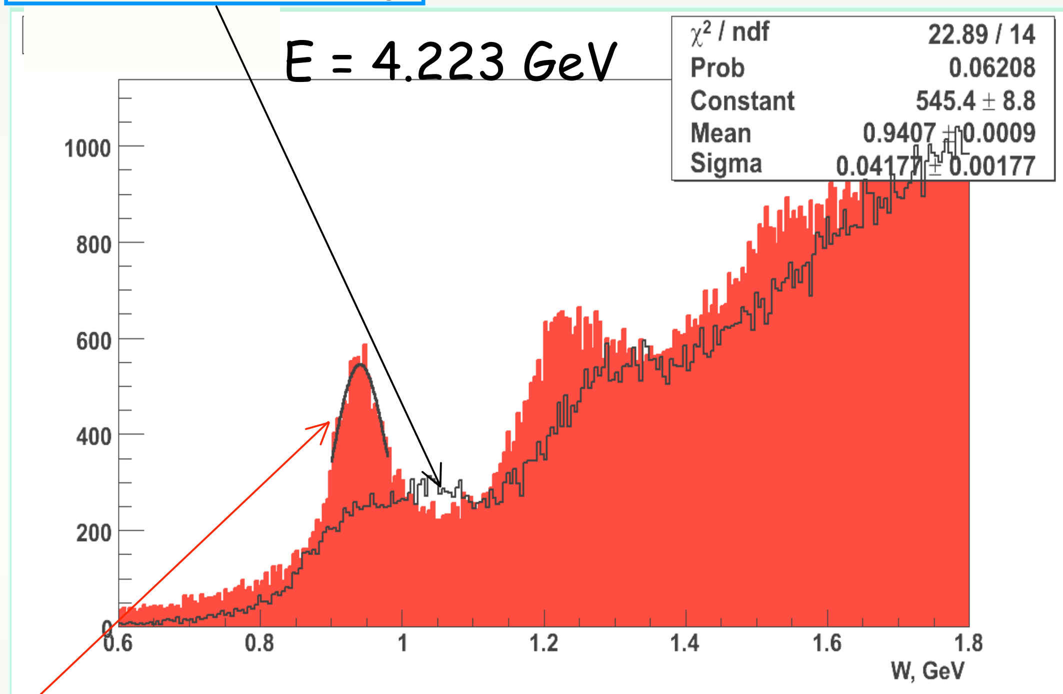
"Off-shell" mass of the nucleon M^*



P_s = 0 0.09 0.17 0.25 0.32 0.39 GeV/c

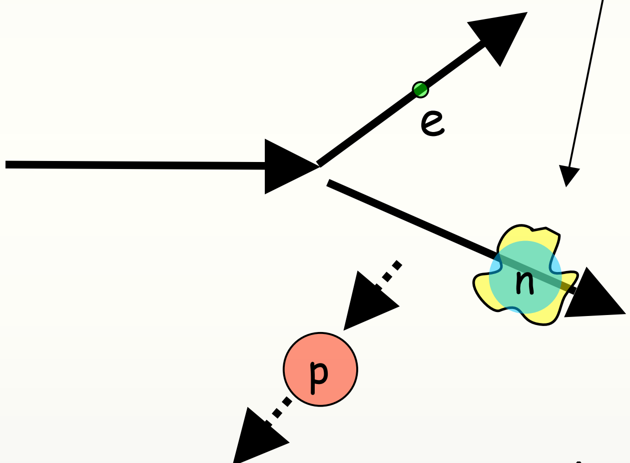
Spectator Tagging

$$\boxed{W^2 = M^2 + 2M\nu - Q^2}$$



$$p_n = \left(M_D - E_S, -\vec{p}_S\right);$$

$$\alpha_n = 2 - \alpha_S$$



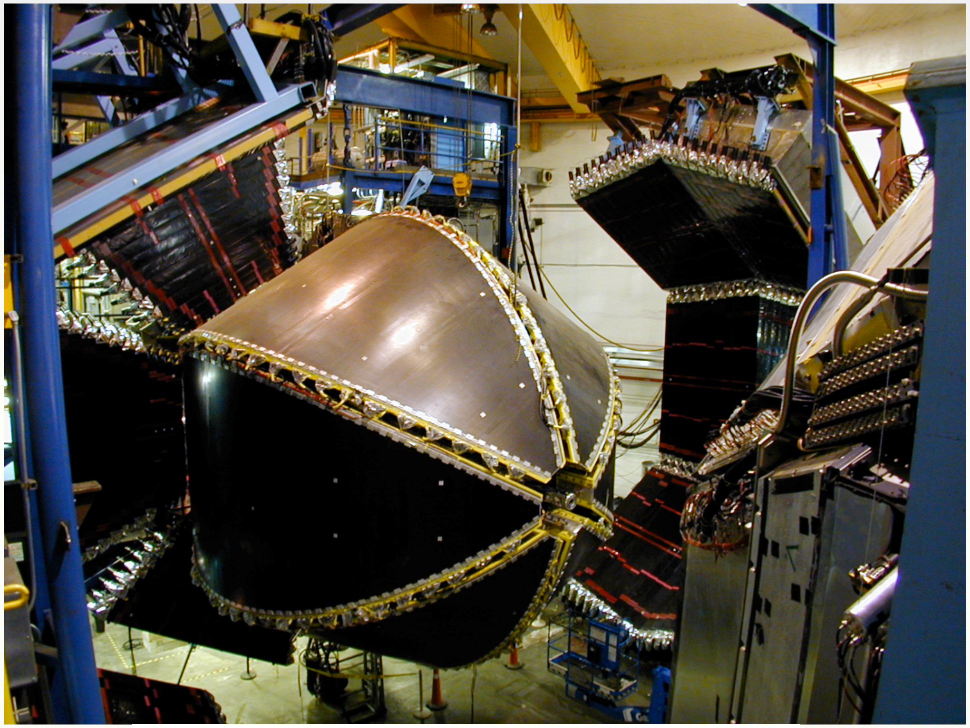
$$p_S = \left(E_S, \vec{p}_S\right); \quad \alpha_S = \frac{E_S - \vec{p}_S \cdot \hat{q}}{M_D/2}$$

$$W^{*2} = \left(p_n + q\right)^2 = p_n^{\mu} p_{n\mu} + 2\left(\left(M_D - E_s\right)\nu - \vec{p}_n \cdot \vec{q}\right) - Q^2$$

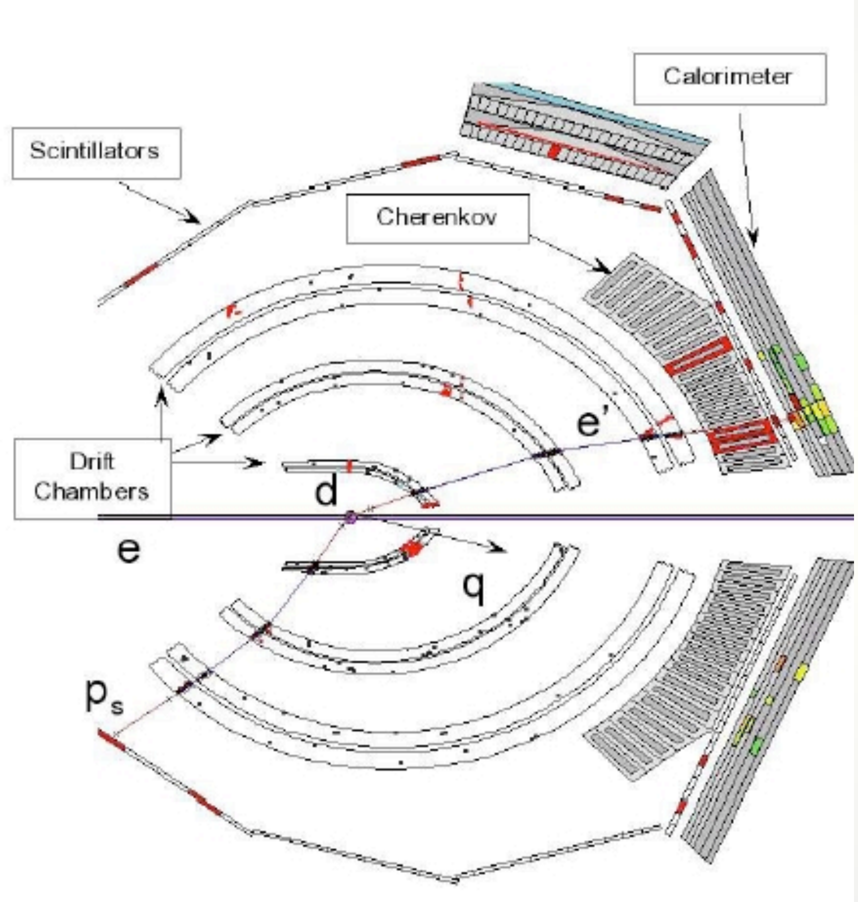
$$\approx M^{*2} + 2M\nu\left(2 - \alpha_S\right) - Q^2$$

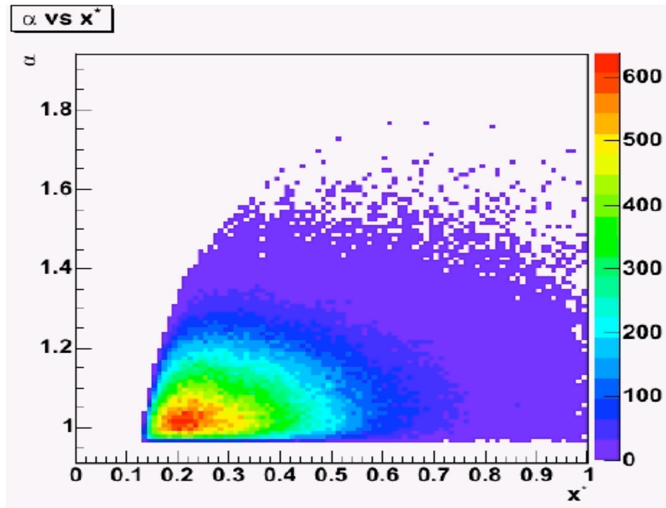
$$x^* = \frac{Q^2}{2 p_n^{\mu} q_{\mu}} \approx \frac{Q^2}{2M\nu\left(2 - \alpha_S\right)}$$

High spectator momenta (> 0.2 - 0.3 GeV/c): "Deeps"

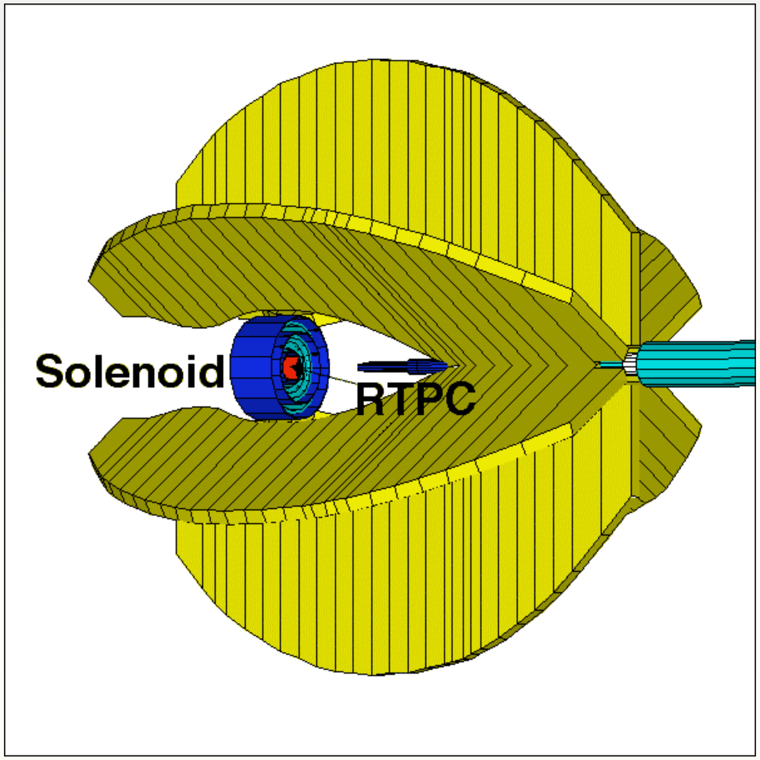


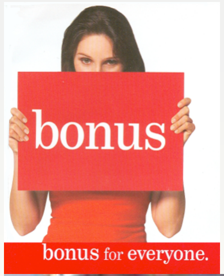
CLAS

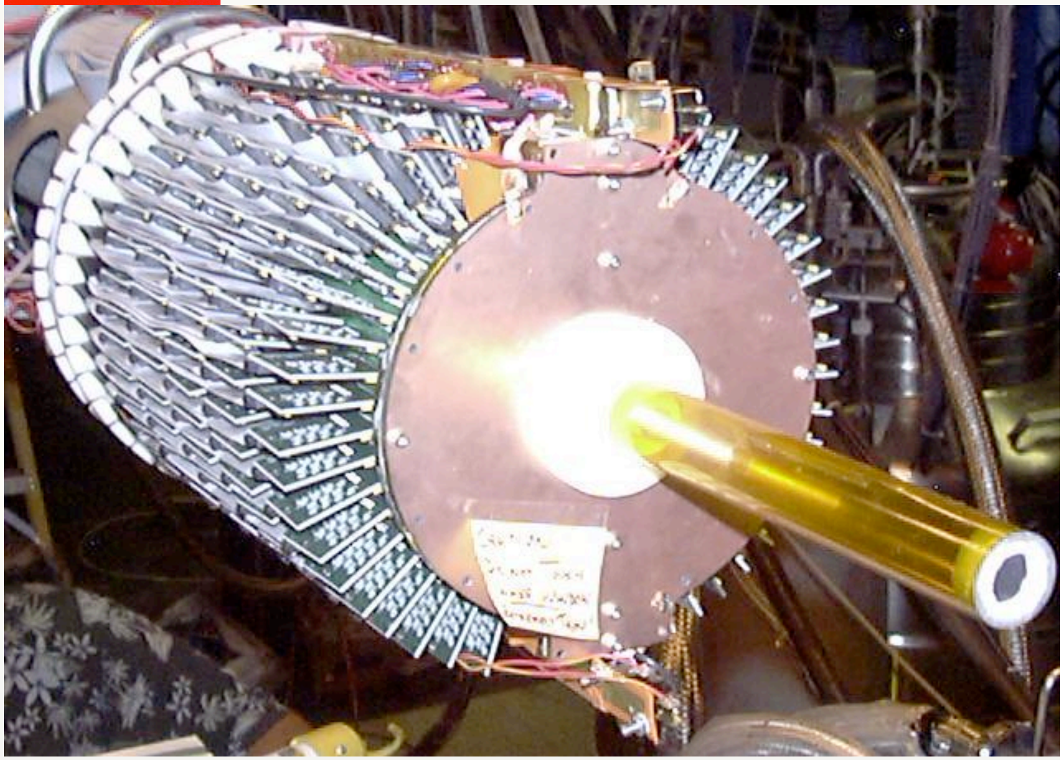




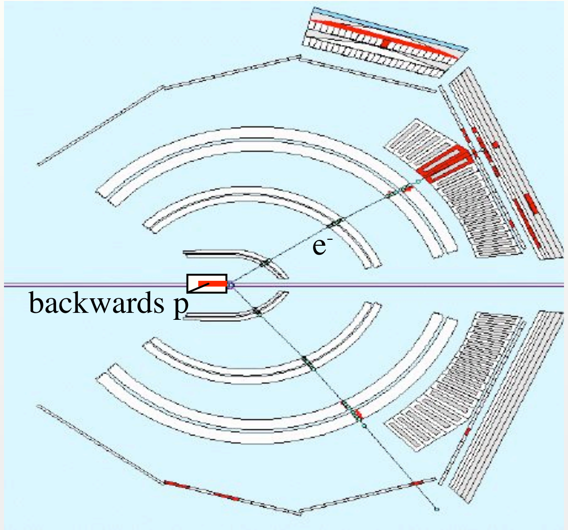
Low spectator momenta (0.07…0.2 GeV/c):







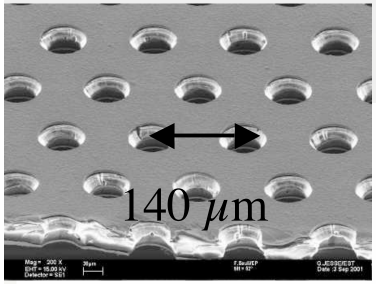
Radial TPC (view from downstream)



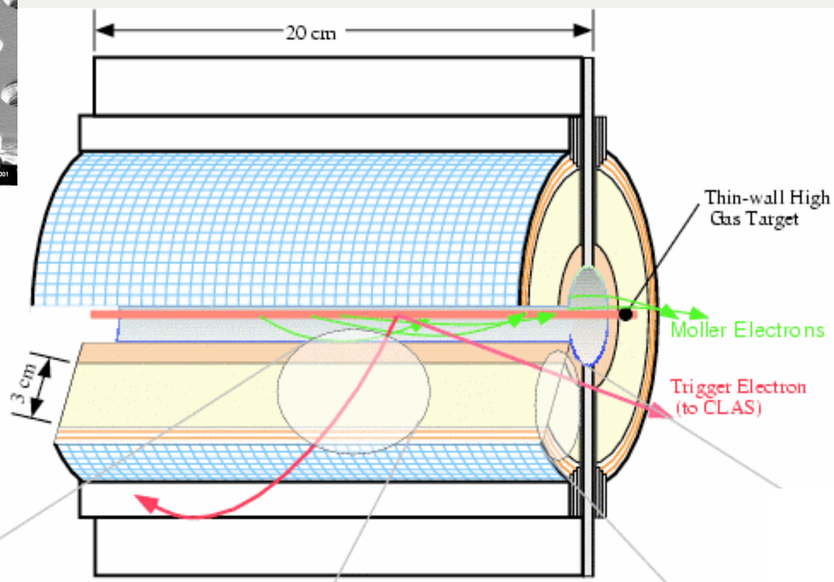
*BoNuS = **B**arely **o**ff-shell **Nu**cleon **S**cattering

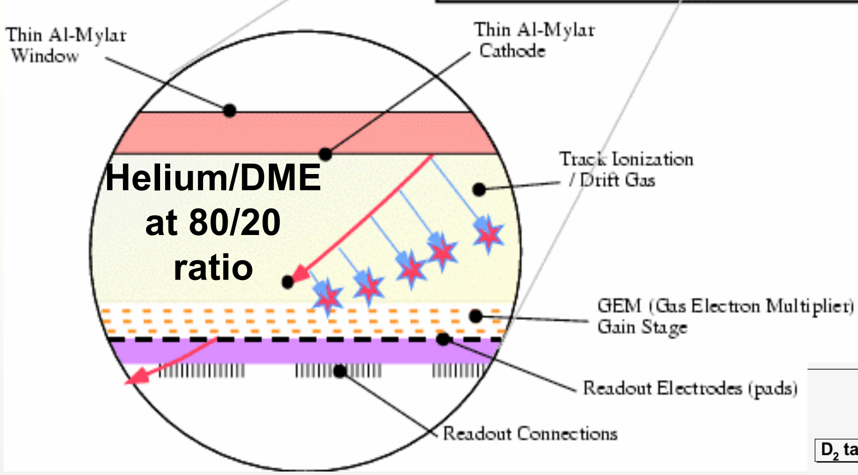
**RTPC = Radial Time Projection Chamber

BONUS RTPC Design



Gas
Electron
Multiplier

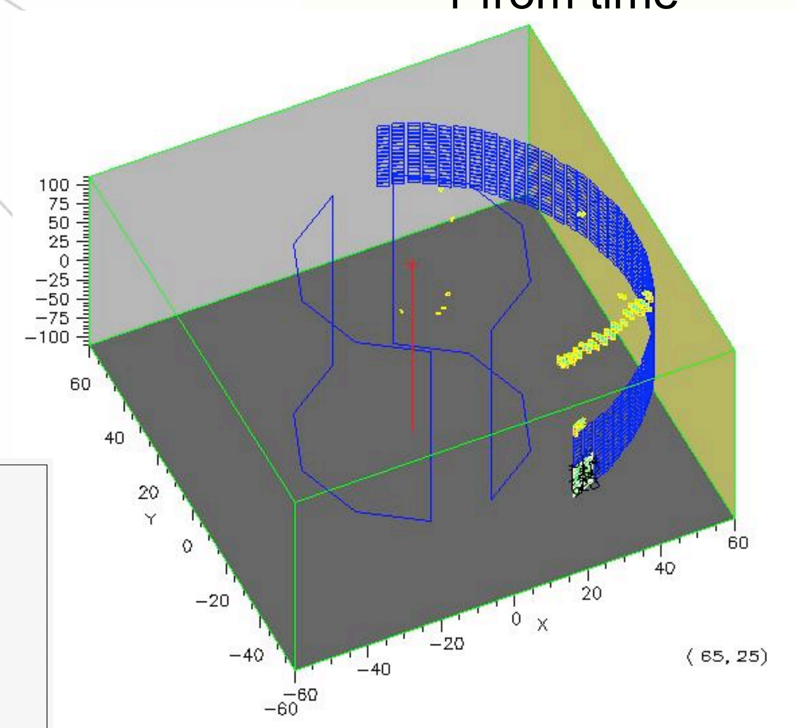




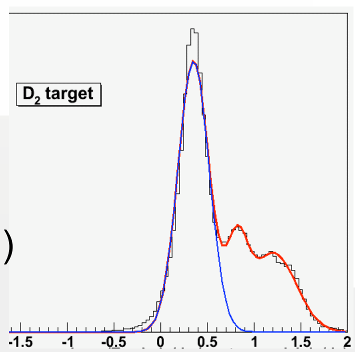
beam

φ, z from pads

r from time

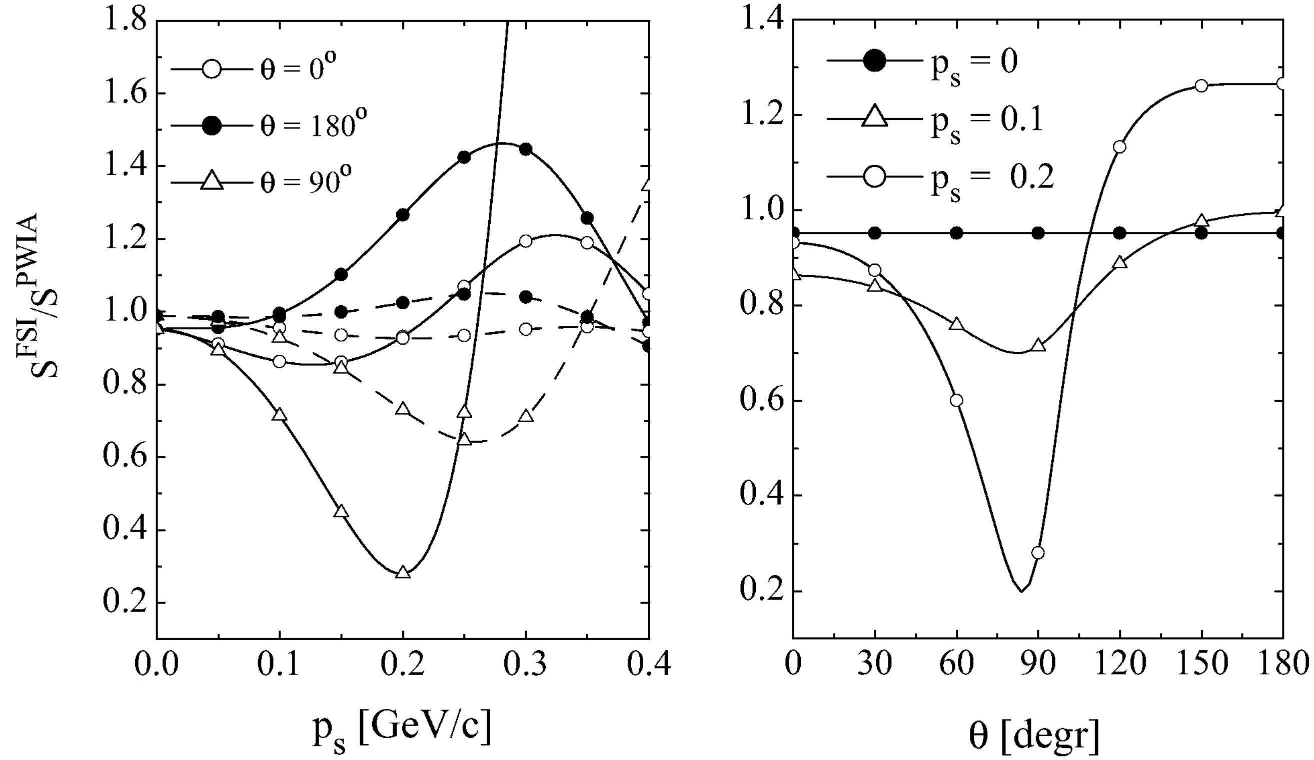


dE/dx from charge
along track (particle ID)



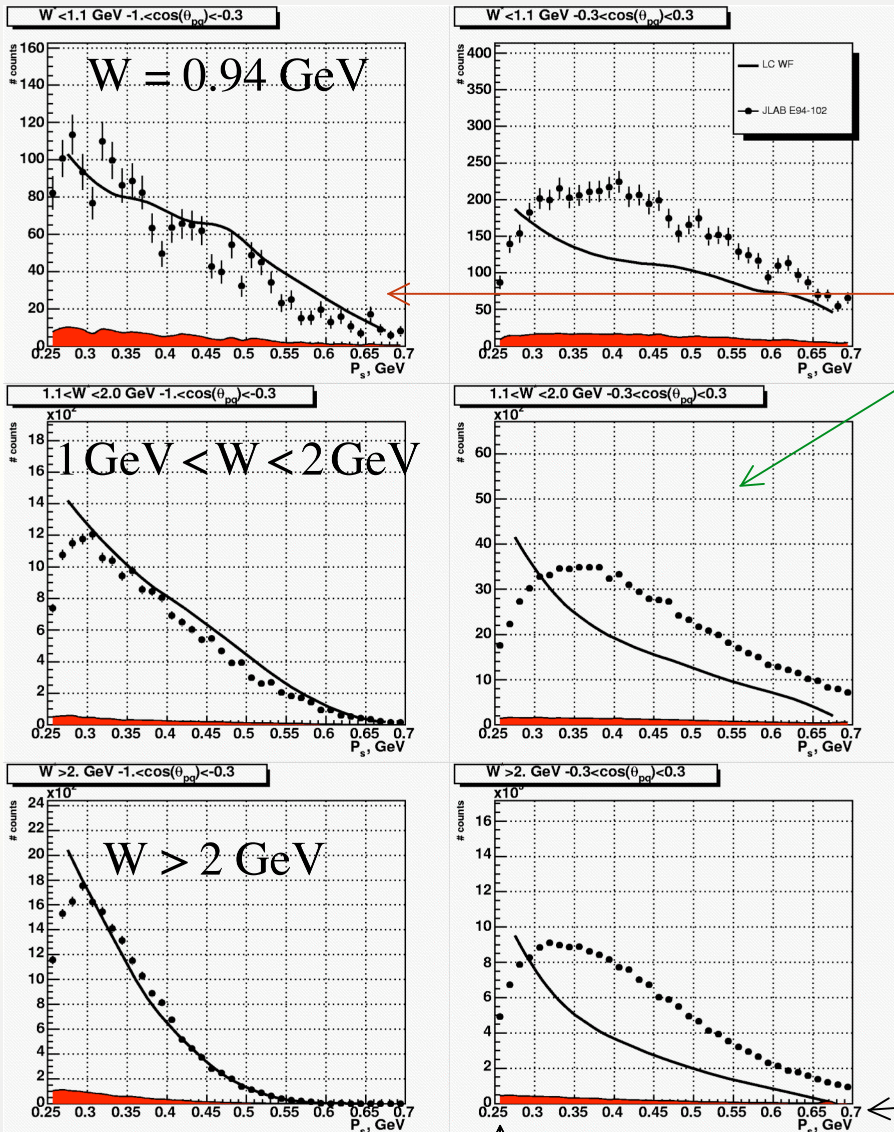
Final State Interactions

Most pronounced for high spectator momenta and around 90° (θ_{qp}) -> need to understand!



Ciofi degli Atti and Kopeliovich, Eur. Phys. J. A17(2003)133

Results from “Deeps”: Momentum Distribution



P_s

Vertical axis: Number of events

Horizontal axis: Proton momenta from 250 to 700 MeV/c

Left: Angular range > 107.5^O

Right: Angular range 72.5^O - 107.5^O

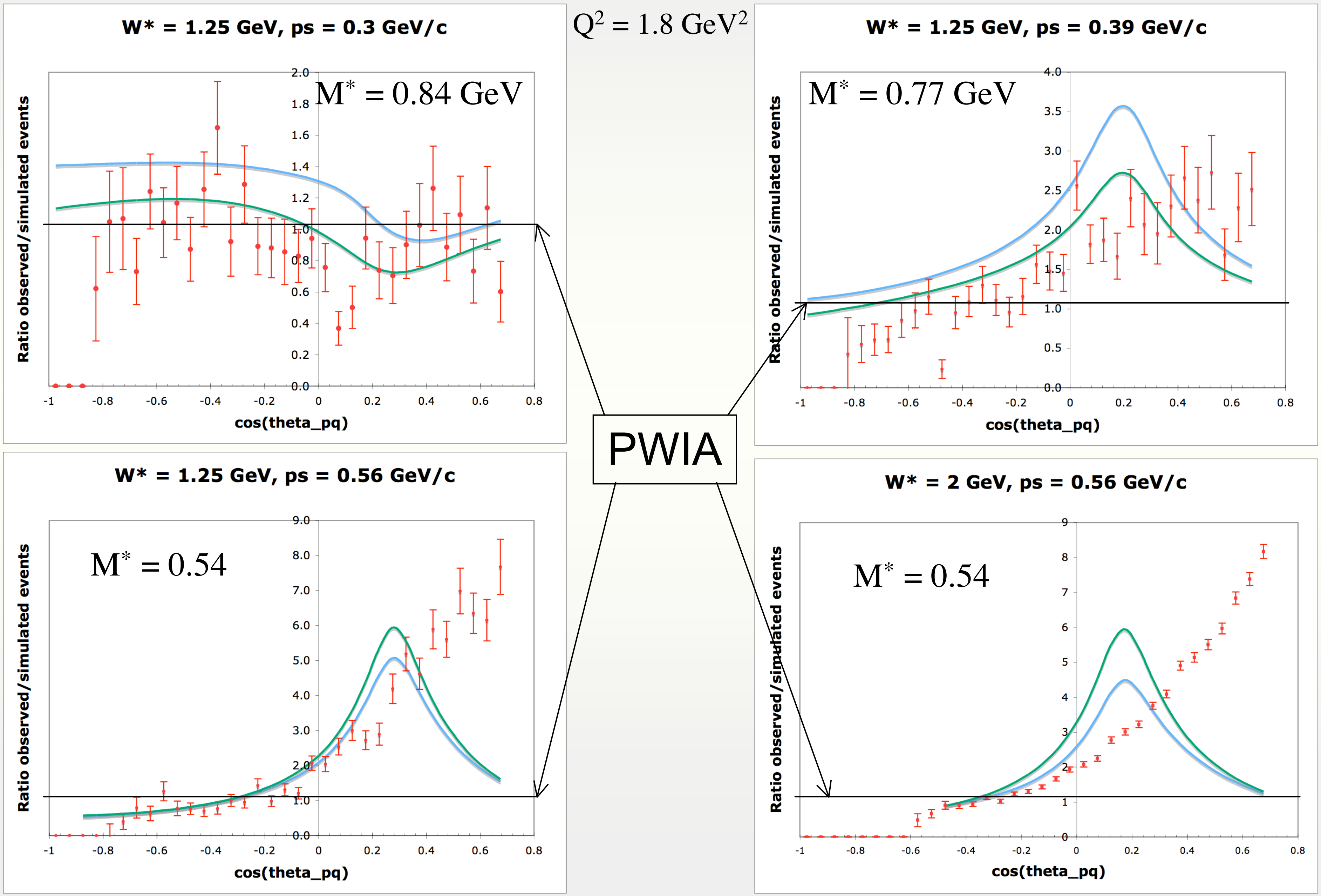
3 different ranges in the final state mass W of the unobserved struck neutrons

PWIA model with “light cone”-wave function for deuterium

700 MeV/c

250 MeV/c

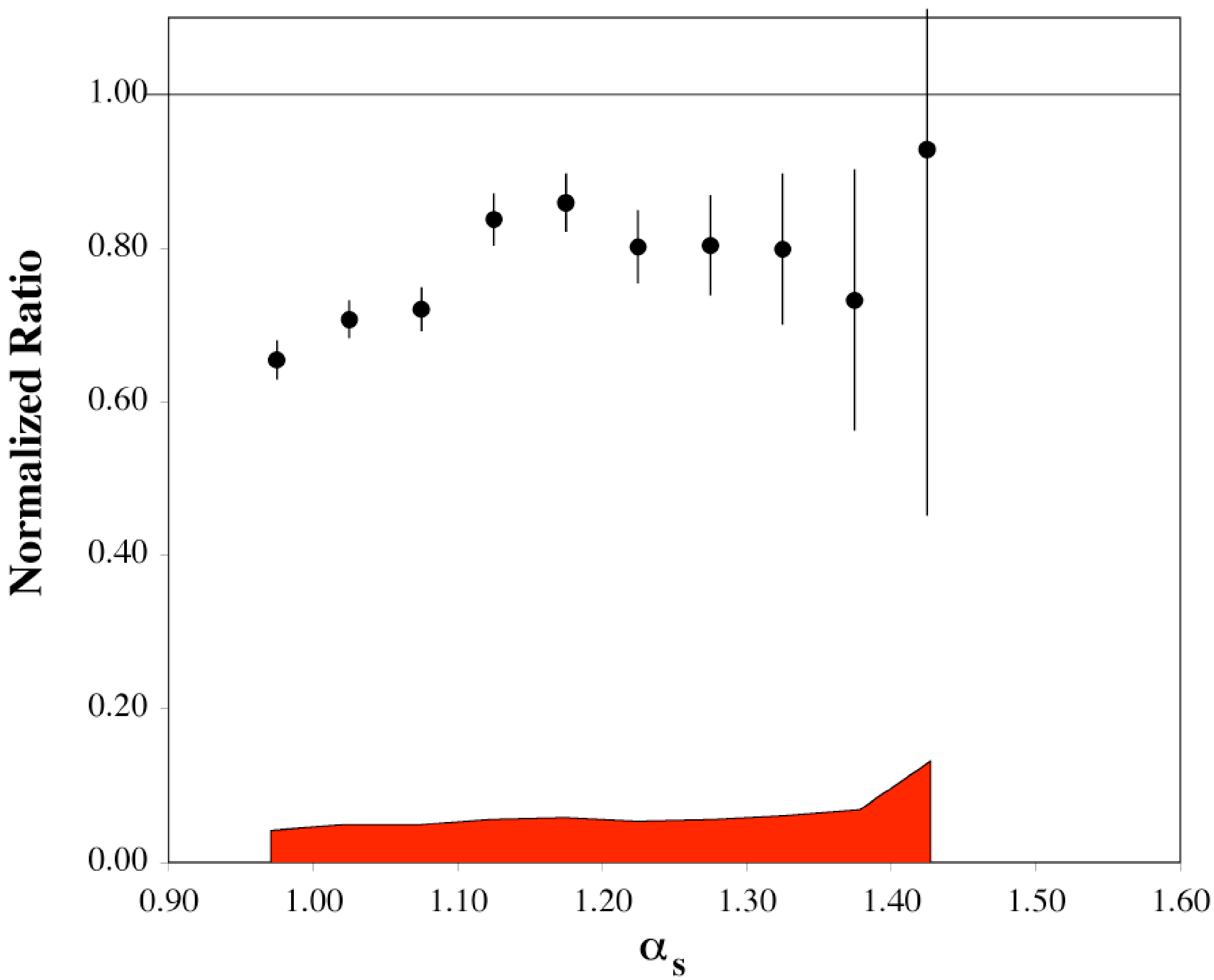
Results from “Deeps”: Comparison w/ FSI model (CdA et al.)



Results from "Deeps": Ratio Method

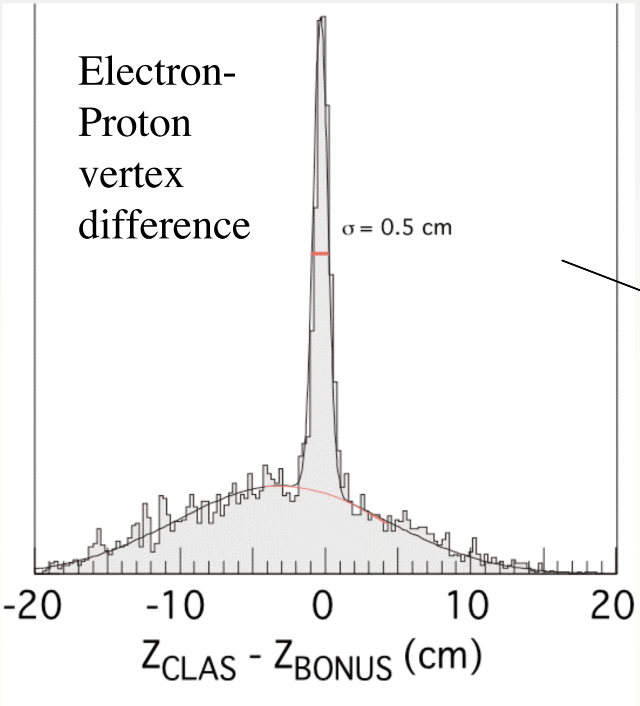
Ratio =

$$\frac{\dfrac{\sigma(x^* = 0.55, \alpha_s)}{\sigma(x^* = 0.25, \alpha_s)}(\text{bound n})}{\dfrac{\sigma(x = 0.55)}{\sigma(x = 0.25)}(\text{free n})}$$

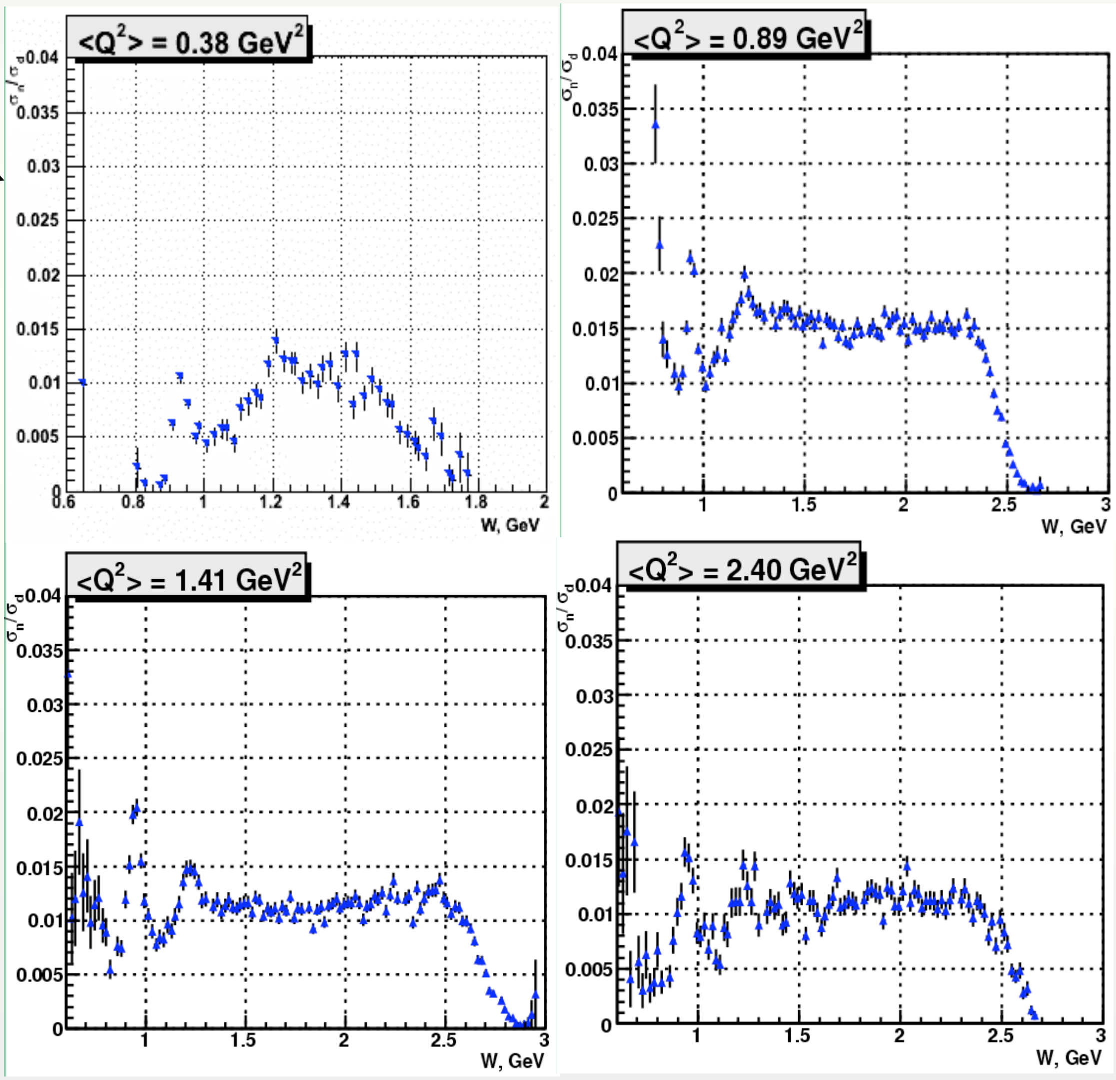


- Independent of deuteron WF, acceptance, kinematic factors
- Should be sensitive to off-shell effects at large x, but also influenced by FSI and target fragmentation
- Fixed p_T = 0.3 GeV/c - TOO LARGE!

Preliminary Results from BoNuS



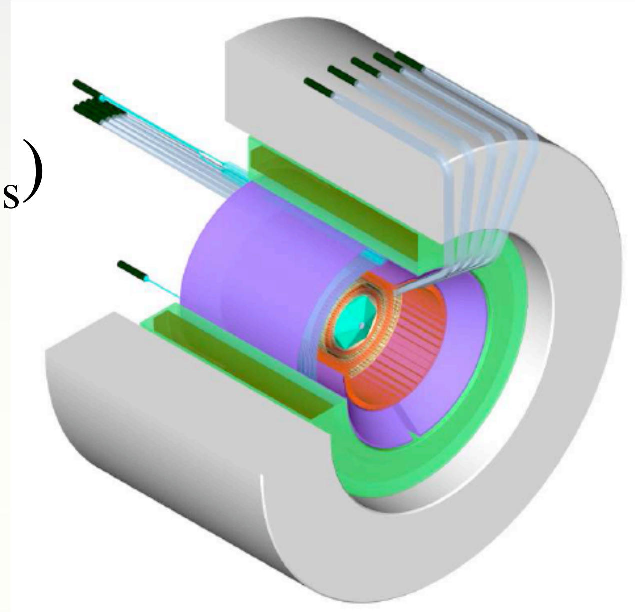
σ_n/σ_D as a function of invariant mass (not corrected for tagging efficiency)

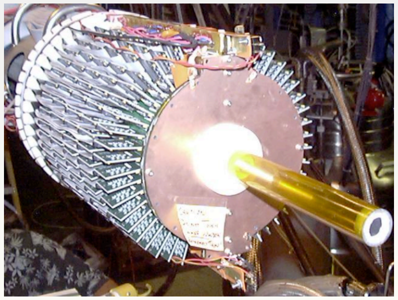


Plans for 12 GeV

$D(e,e'p_s)$

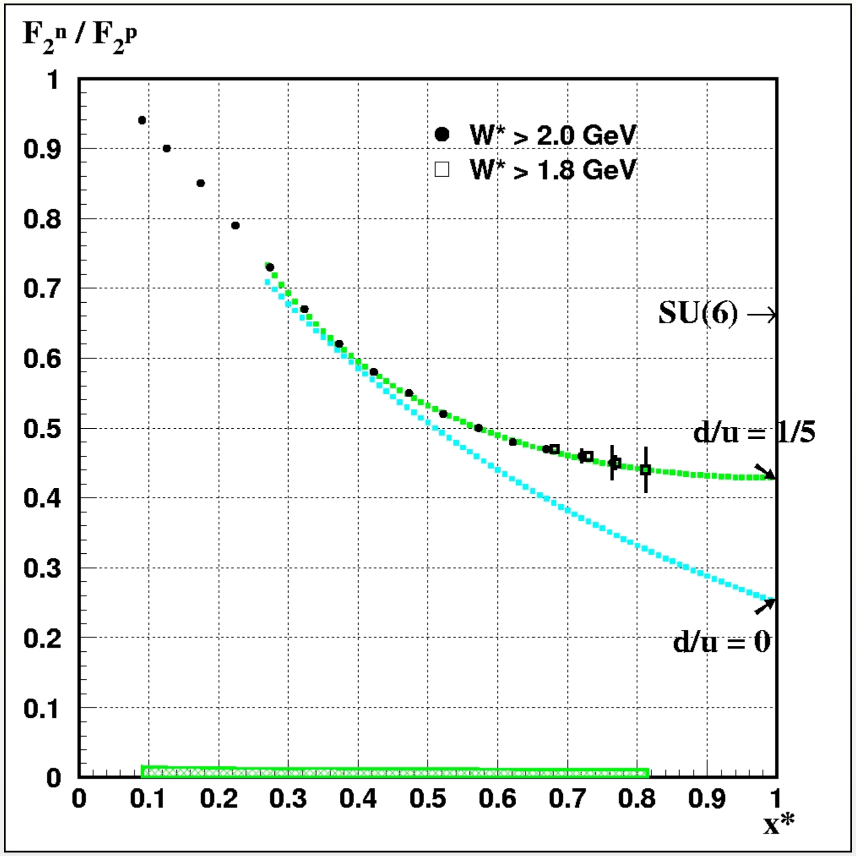
LOI
12-07-102

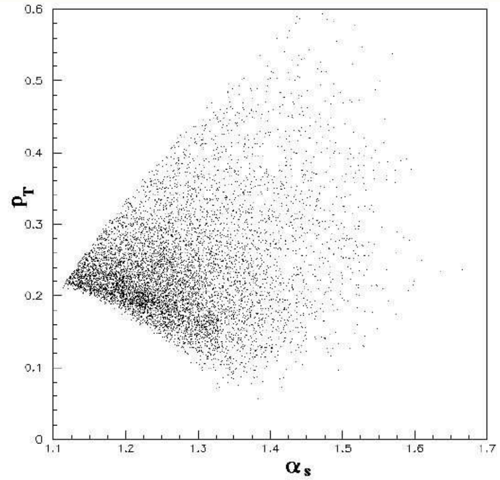




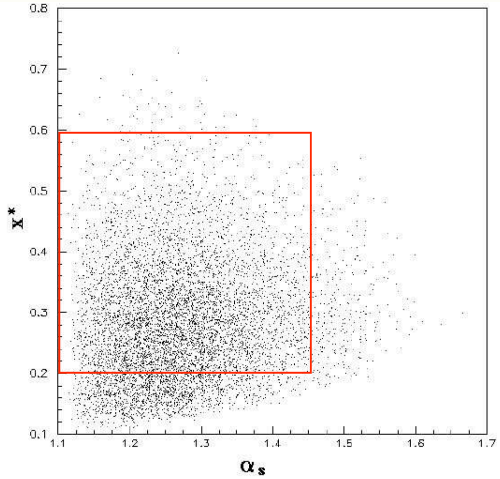
BoNuS

E12-06-113





$\theta_{pq} > 110^o$



Q^2>1.5, W>2