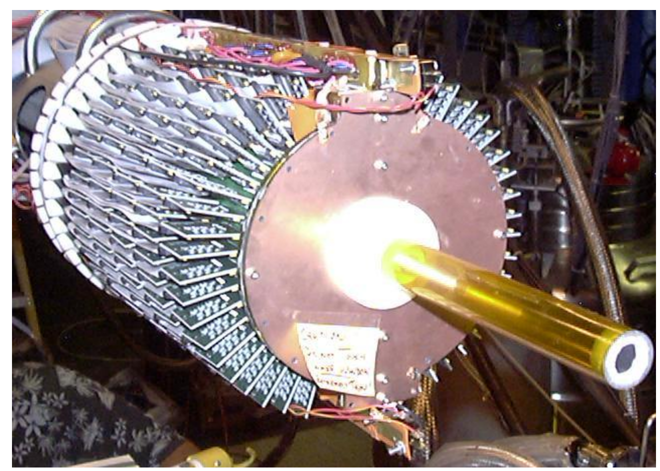
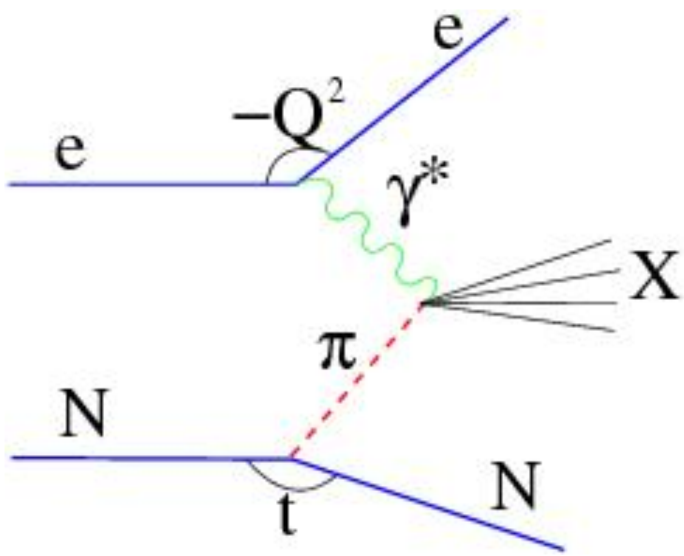
IDEA (very beginning!!) for a measurement of the Pion Structure Function using BONUS rTPC, SBS, BigBite in Hall A

- Needs lots of work still! -



Jefferson Lab

Pion Exchange (Sullivan) Process - DIS from the pion cloud of the nucleon



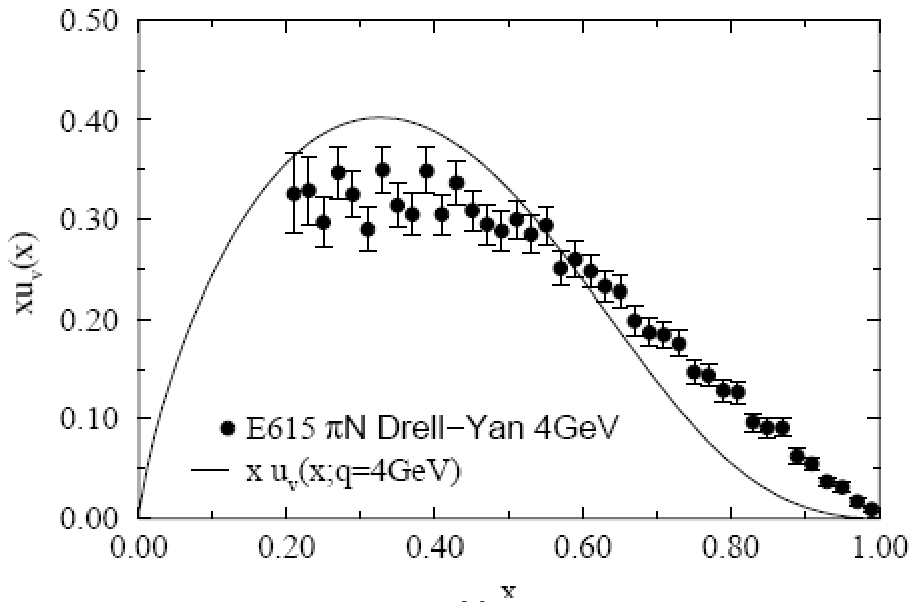
$$N(e,e'N')X$$

$$x_\pi \equiv \frac{Q^2}{2p_\pi \cdot q} = \frac{x_B}{1-x_L} \qquad x_L \equiv \frac{p_{N'} \cdot q}{p_N \cdot q} = 1 - \frac{x_B}{x_\pi}$$

$$t = (p_{N'} - p_N)^2 = m_N^2 + m_{N'}^2 - 2m_N E_{N'}$$

|t| has to be small to enhance contribution from Sullivan process.

Pion Structure Function



x_π

$$\pi^- W \rightarrow \mu^+ \mu^- X$$

$$\sigma \propto \bar{u}(x_{\pi^-}) u(x_N)$$

Pion structure function is not well measured, although pion is the simplest hadron with only two valence quarks.

The x_p->1 behavior of $(1-x_p)$ in Drell-Yan data differs from pQCD prediction of $(1-x_p)^2$.

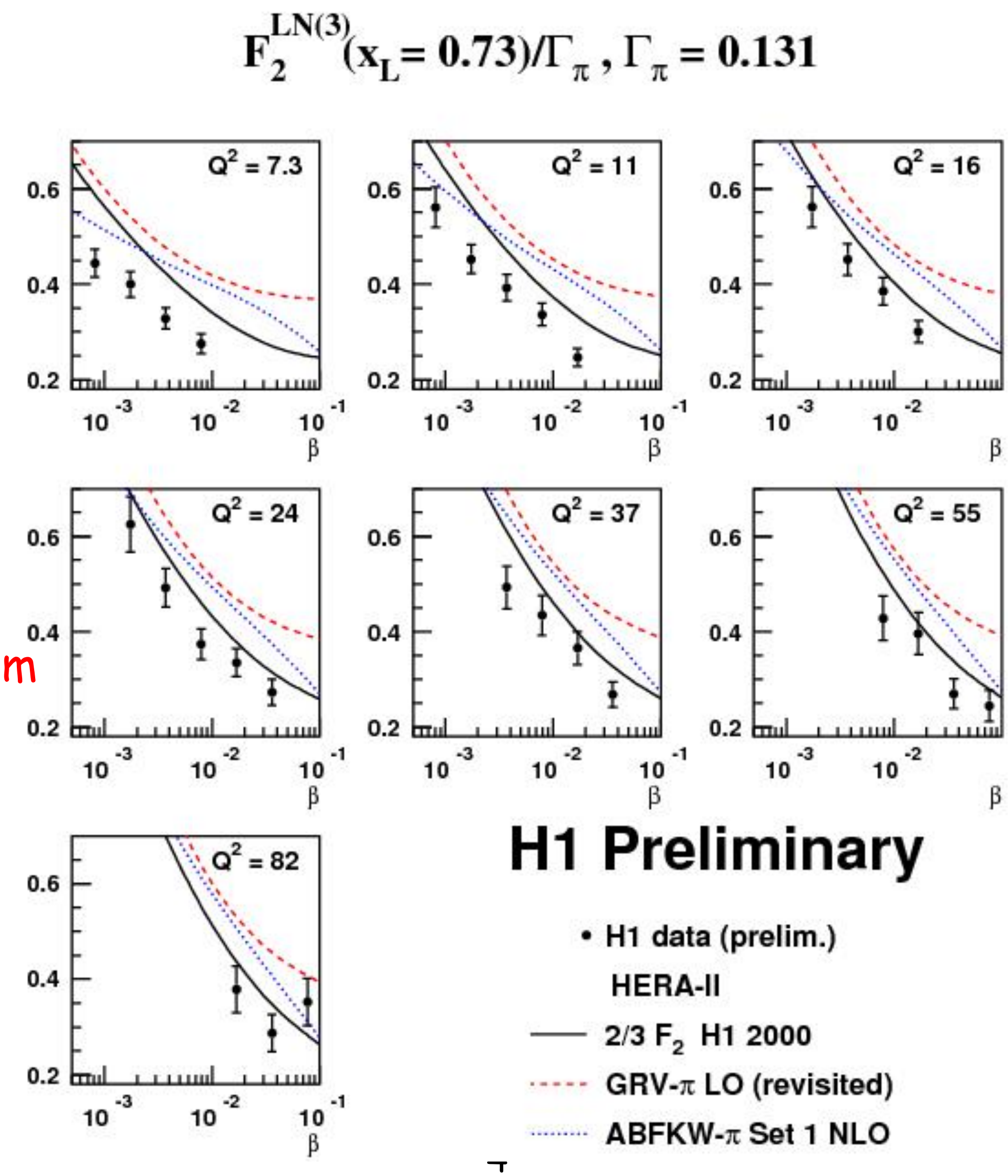
Pion Structure Measurement at HERA

$$ep \rightarrow e'nX$$

$$\beta \equiv x_\pi$$

Similar results from ZEUS

Very small x_π



- Knowledge of the pion structure function is very limited due to the lack of stable pion target.
- The pion exchange (Sullivan) process can be used to measure the pion structure function.
- Many questions, for instance what is the origin of the d(bar) – u(bar) flavor asymmetry…asymmetry in anti-quarks generated from pion valence distribution?
- The JLab 12 GeV upgrade allows phase space for $|t|<0.2$, $Q^2>1$ and $M_x>1.0$ and enables us to measure the pion structure function in the intermediate x_p region.

Think about both hydrogen and deuterium

p(e,e' p)X   n(e,e' p)X

- Charged pion exchange has less background from Pomeron and Reggeon processes.
- The π^+N cloud doubles π^0N cloud in the proton.

$$
\begin{aligned}
|p> \quad &\rightarrow \quad \sqrt{1-a-b}|p_0> \\
&+ \quad \sqrt{a}\left(-\sqrt{\frac{1}{3}}|p_0\pi^0> + \sqrt{\frac{2}{3}}|n_0\pi^+>\right) \\
&+ \quad \sqrt{b}\left(-\sqrt{\frac{1}{2}}|\Delta_0^{++}\pi^-> - \sqrt{\frac{1}{3}}|\Delta_0^{+}\pi^0> + \sqrt{\frac{1}{6}}|\Delta_0^{0}\pi^+>\right)
\end{aligned}
$$

Regge approach: a=0.105, b=0.015
Nikolaev et al.,PRD60(1999)014004

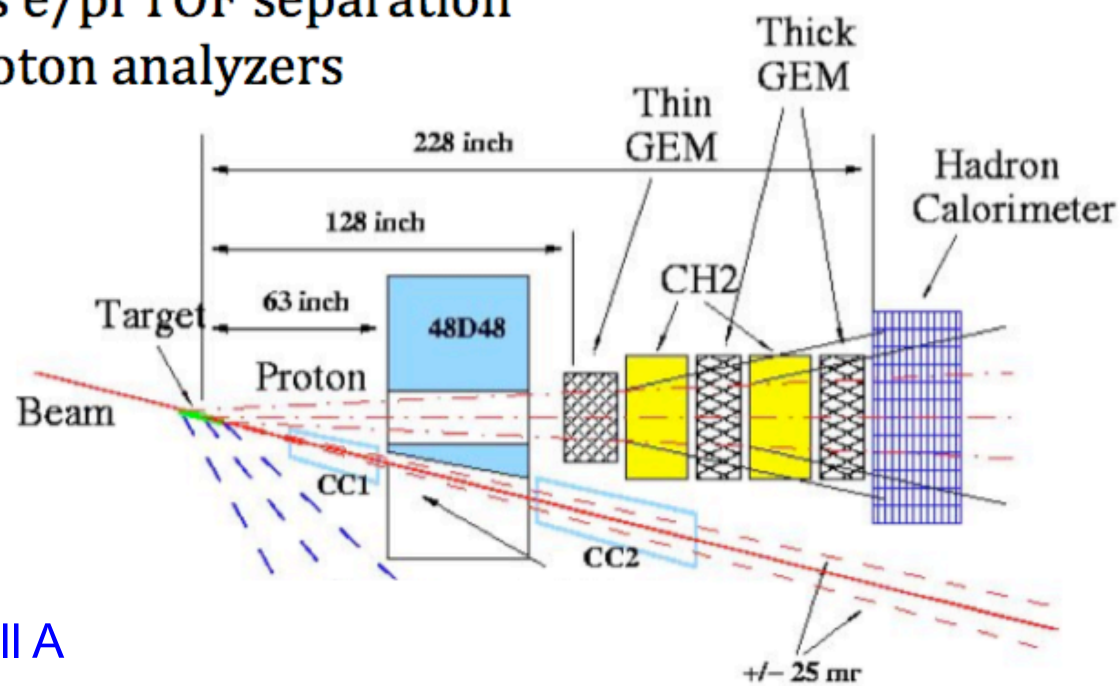
Chiral approach: a=0.24,b=0.12
Thomas, Melnitchouk & Steffens,PRL85(2000)2892

First, how to detect high E electrons (so as to get to high W, Q^2 DIS kinematics)?

SBS + LAC

Using the SBS for electron detection:

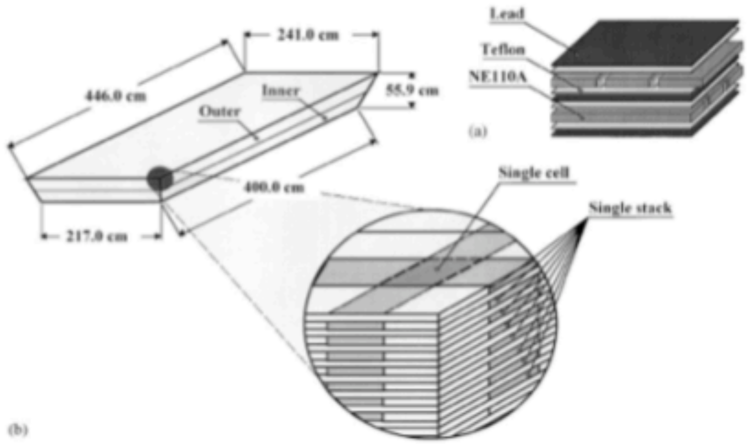
- Replace Hadron Calorimeter with LAC
  - Similar sizes (5.5 m^2 vs 8.7 m^2)
  - Place the LAC as far back as possible to match the solid angle.
    - Improves angular resolution
    - Improves e/pi TOF separation
- Remove CH2 proton analyzers



from L. Weinstein Hall A Collaboration talk

The Large Angle Calorimeter (LAC)

We now have this detector, recovered from CLAS6

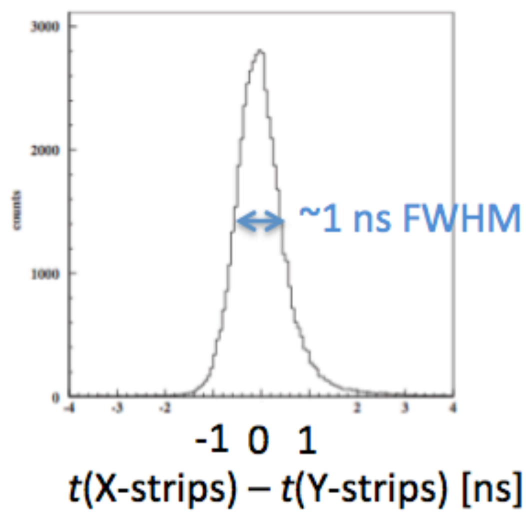


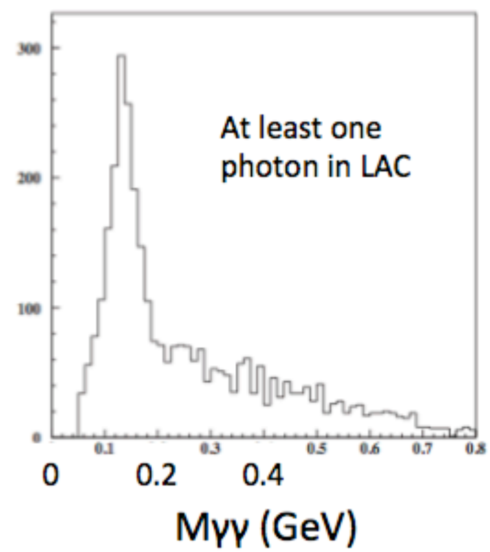
Active area: 2.2 m by 4 m
33 layers
- 0.20 cm Pb foil
- 1.50 cm NE110A scintillator

Readout segmentation:
- 40 strips in X (each ~ 10 cm)
- 24 strips in Y (each ~ 10 cm)
- "Inner" (17 layer) vs "outer"

Intrinsic resolution (from MC) of $6\%/\sqrt{E}$

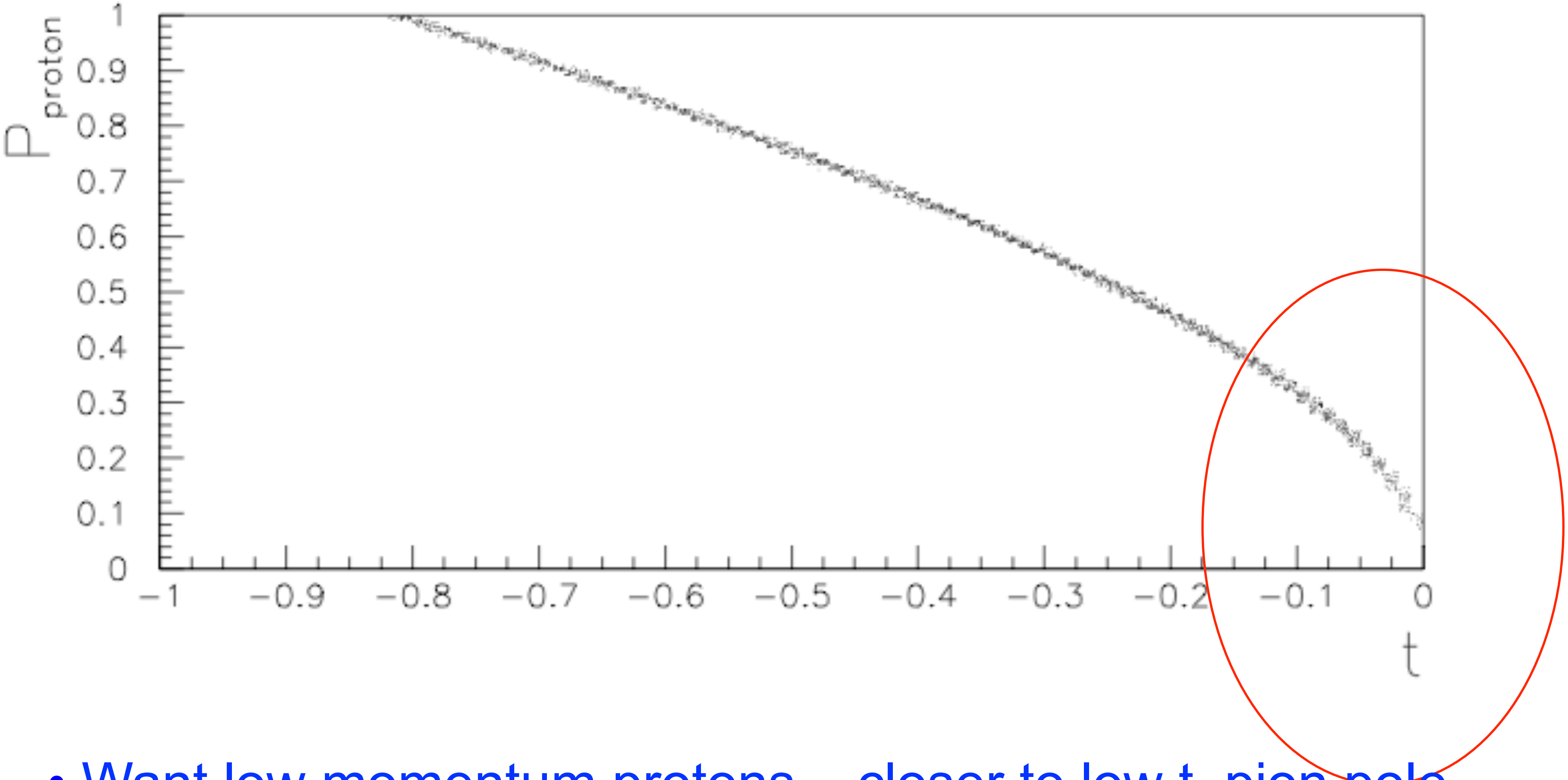
Coupling of scintillators to PMTs





Can also use BigBite for additional electron detection

Next, how to detect protons?

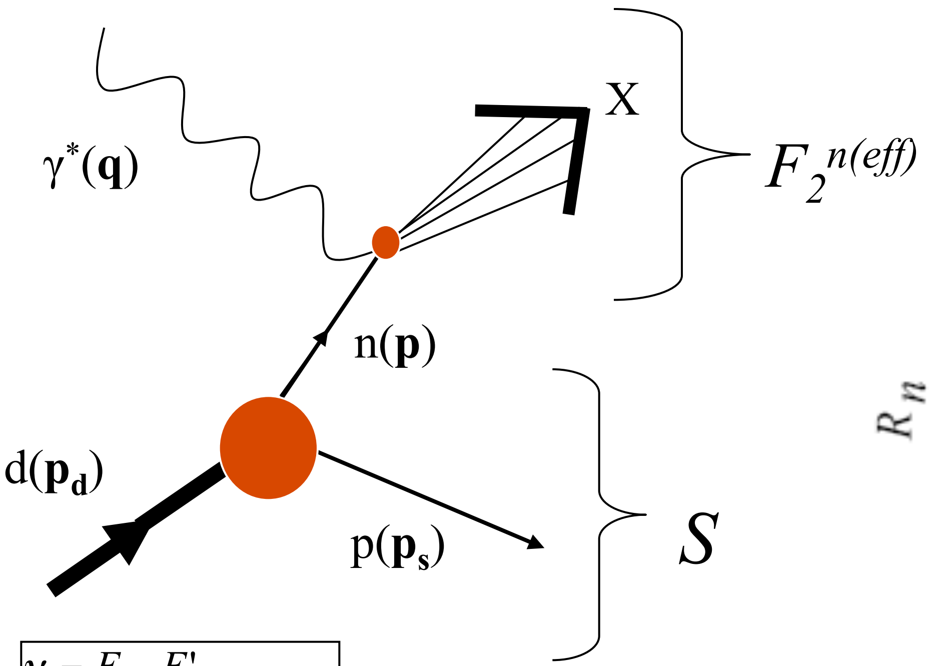


- Want low momentum protons – closer to low t, pion pole
- Difficult to detect!
- Range in momentum to extrapolate possibly?
- Best to measure at low momentum

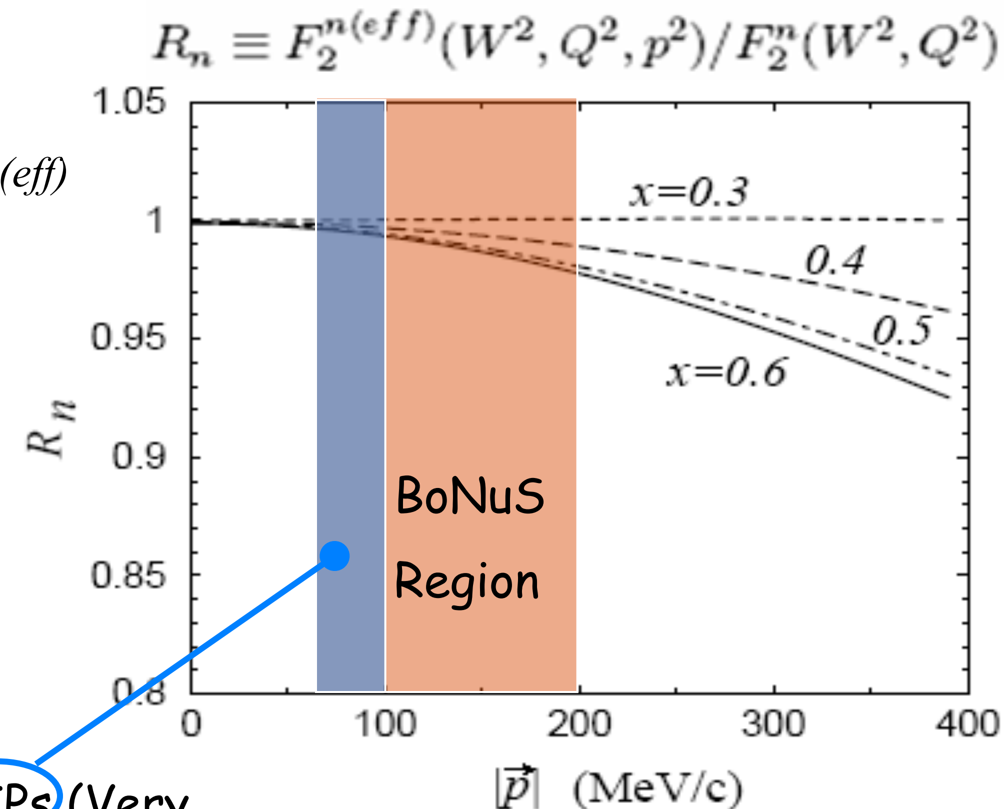
The BONUS approach to measure F_2^n

Within the nuclear impulse approximation. The virtual photon interacts with the neutron on a short enough time scale that the proton doesn't know what happened. The spectator continues on unperturbed w/ momentum $\mathbf{p_s} = -\mathbf{p}$

$$\frac{d\sigma}{dx\,dW^2\,d\alpha\,d^2p_T} \approx \frac{2\alpha_{em}^2(1-\nu/E)}{Q^4}\;\alpha\;\mathcal{S}(\alpha,p_T)\;F_2^{n(eff)}(W^2,p^2,Q^2)$$

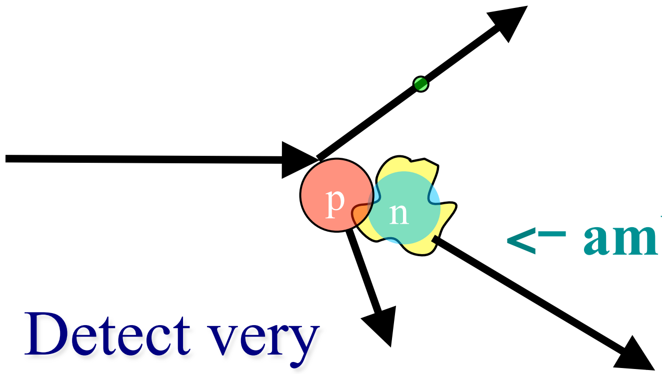


$$\nu = E - E'$$
$$\alpha = (E_s - p_s^z)/M$$
$$Q^2 = 4EE'\sin^2\frac{\theta}{2}$$

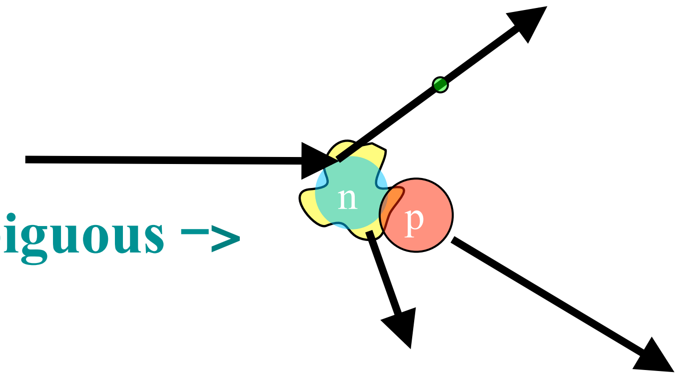


We focus on VIPs (Very Important Protons) where R_n > 99%

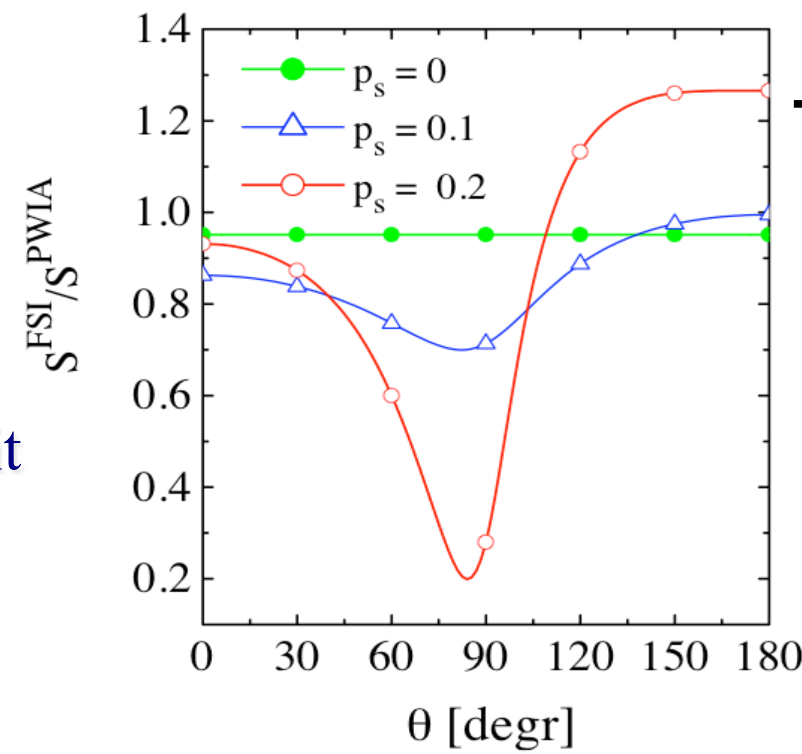
Need Low Momentum AND Large Angle

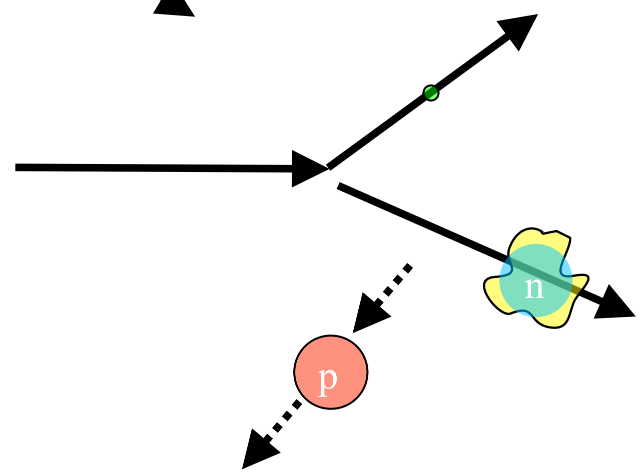


<- ambiguous ->



Detect very important low momentum protons. If the proton is also going *backwards* in the lab frame it is almost guaranteed to be only a spectator.





Backward angle

Spectator **proton =**

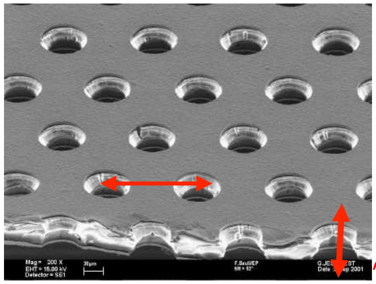
Neutron **target**

BONUS is a Standard Inclusive Fixed Deuterium Target Electron Scattering Experiment, with a Tagged Spectator Proton to Ensure the Electron Scattered from the Neutron

Spectator Proton Detector Features

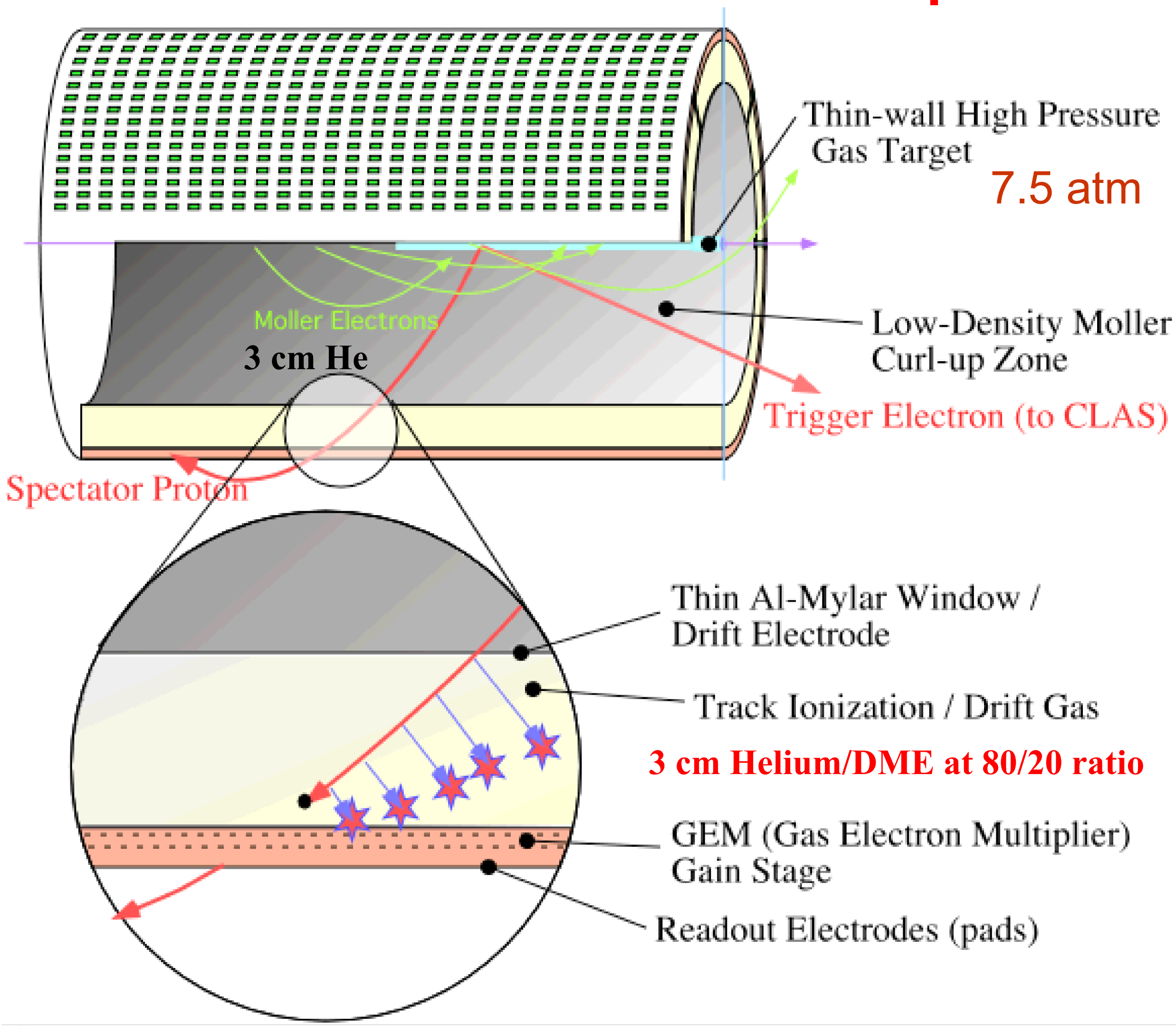
- *Low momentum* spectator must escape target
  - Thin deuterium target
  - Low density detector media
  - Minimal insensitive material
- Large acceptance
  - Backward angles important
  - Symmetric about the target
- Detector sensitive to spectators, insensitive to background

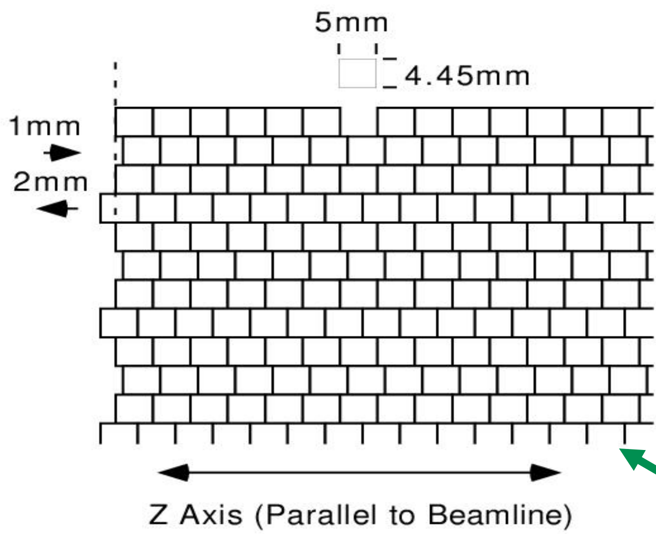
BONUS Radial TPC Design using Cylindrical Gas Electron Multipliers



φ, z from pads, r from time

dE/dx from charge along track (particle ID)



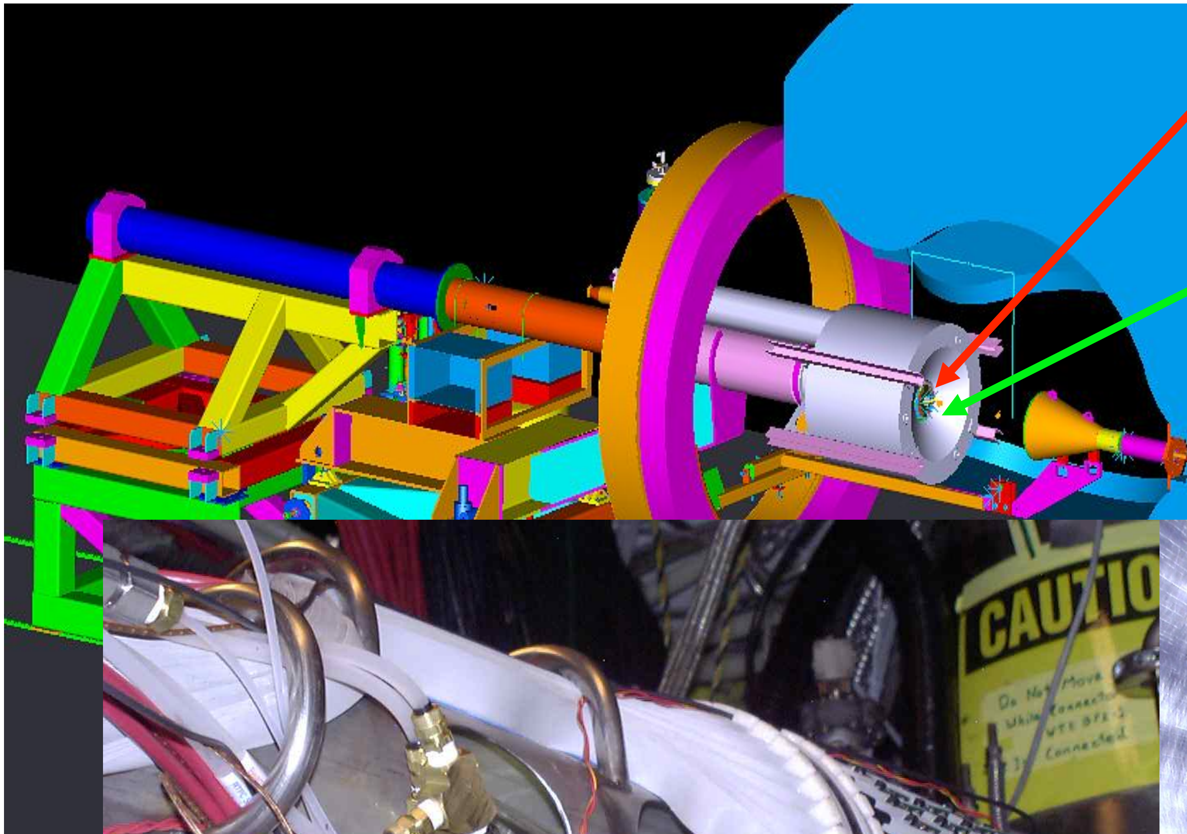


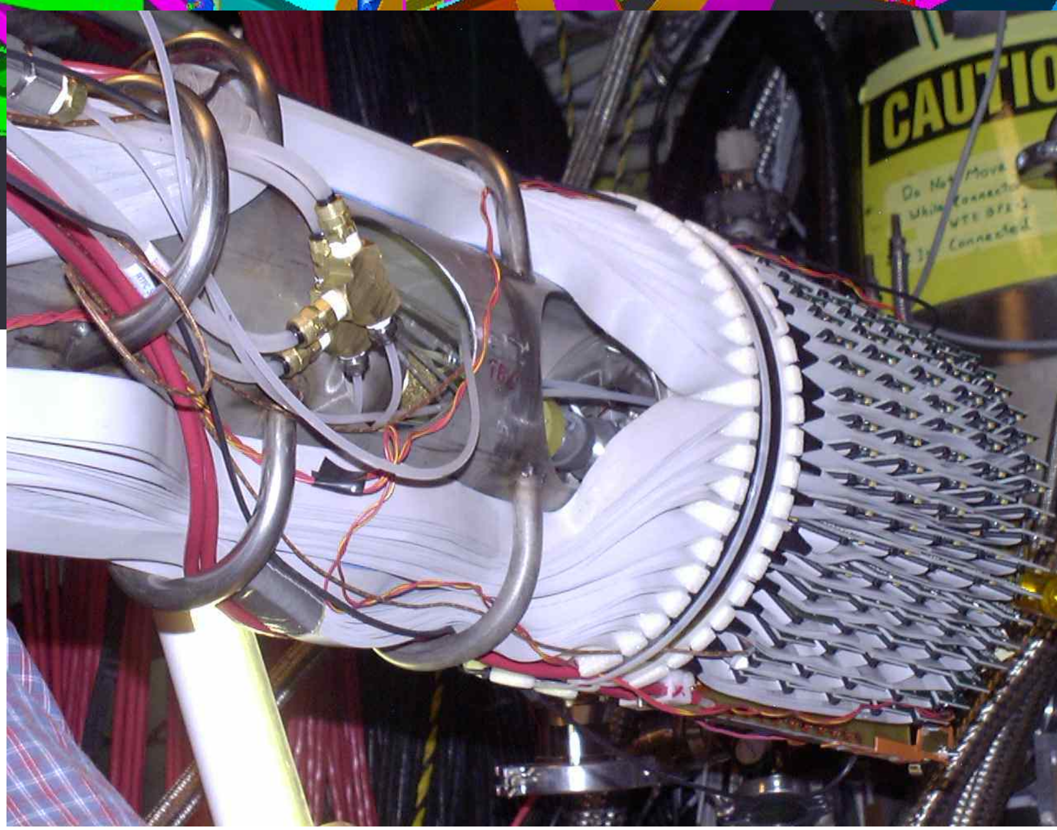
Stagger pads in z to improve theta angle reconstruction

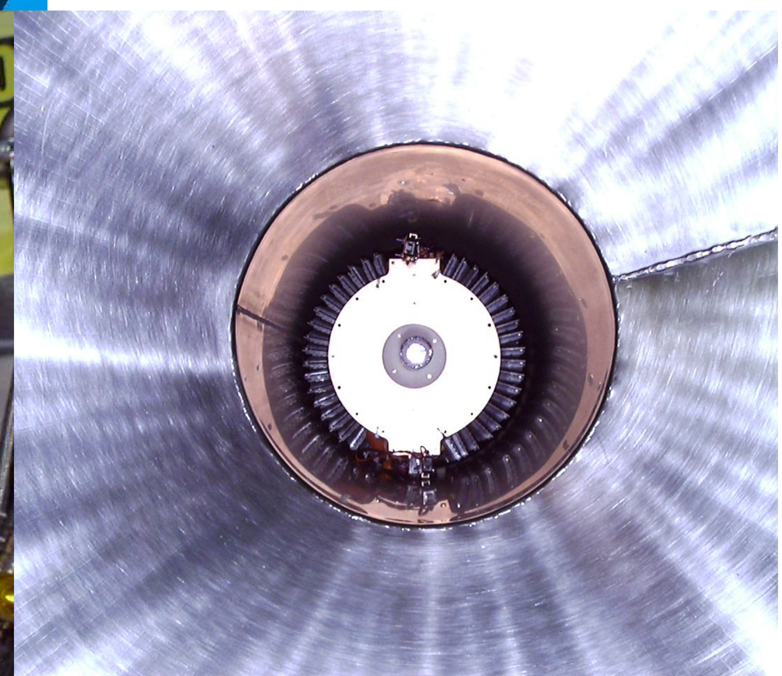
BONUS in CLAS

BoNuS

Solenoid Magnet

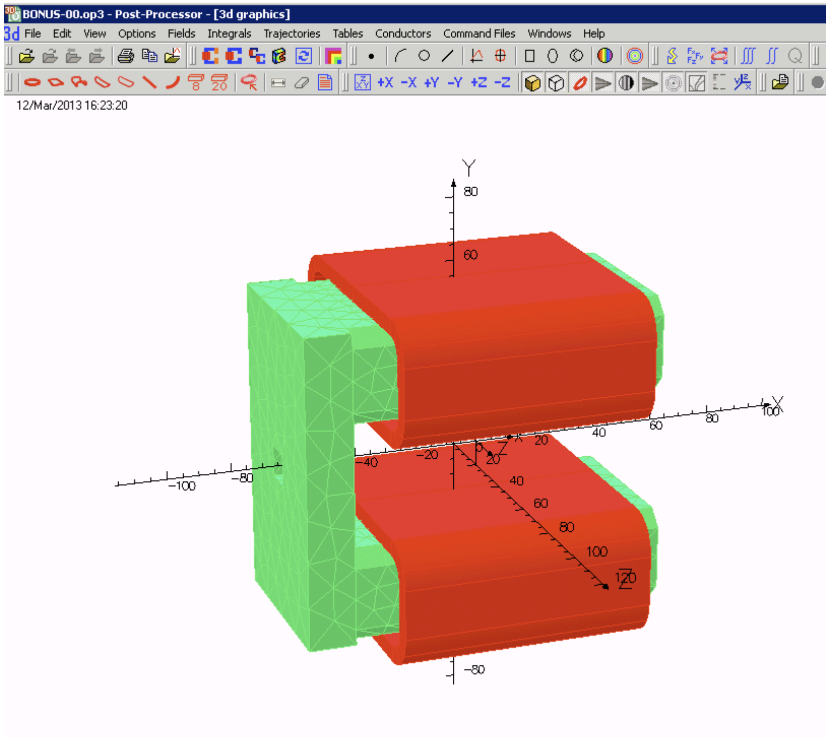






Unlike BONUS, though....

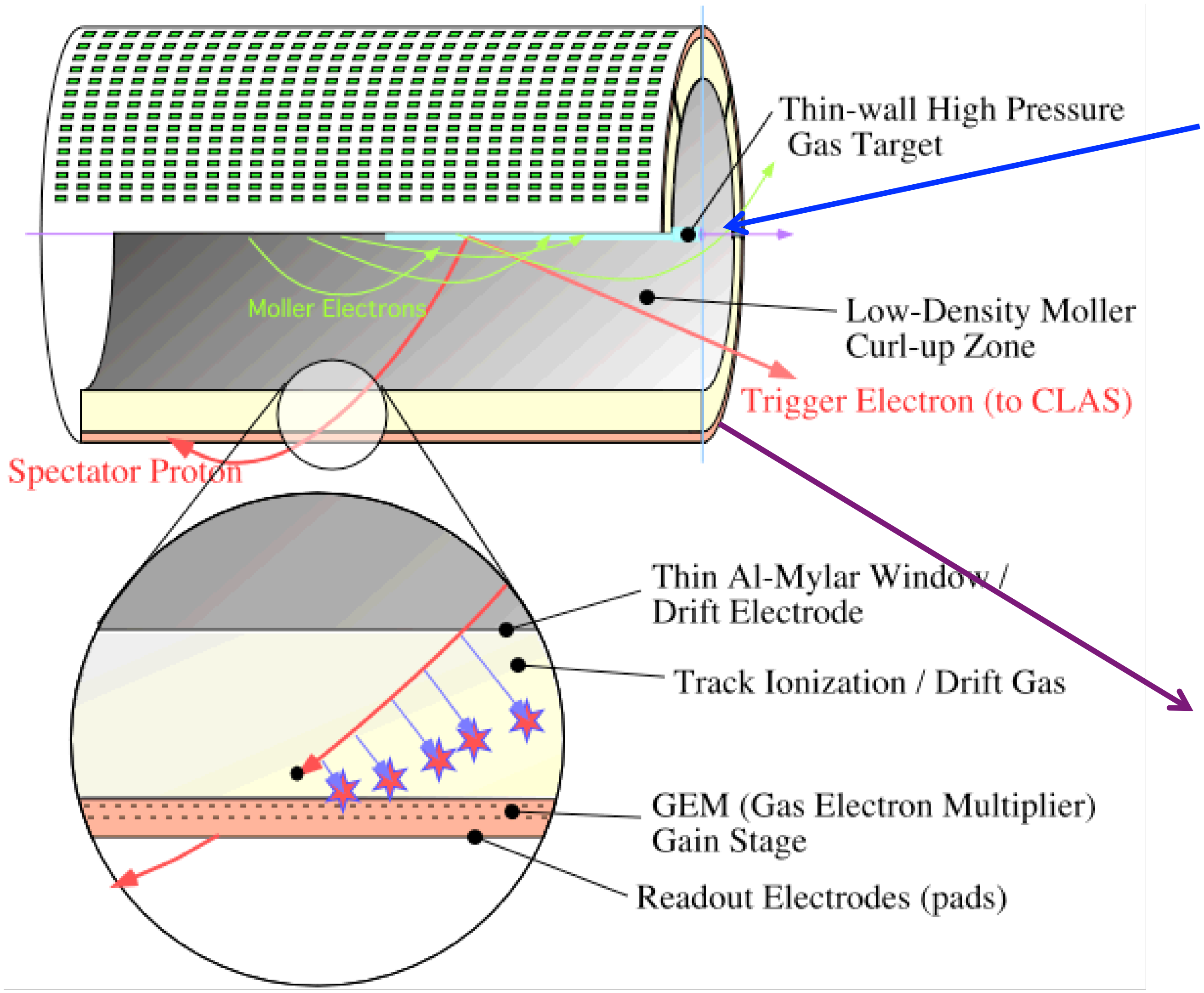
- Need range of electron angles solenoid in the way



Bogdan to the rescue!! ☺

20 cm bore, 4.7 kG field along the beam.

- Need _*forward*_ angle, low p proton detection

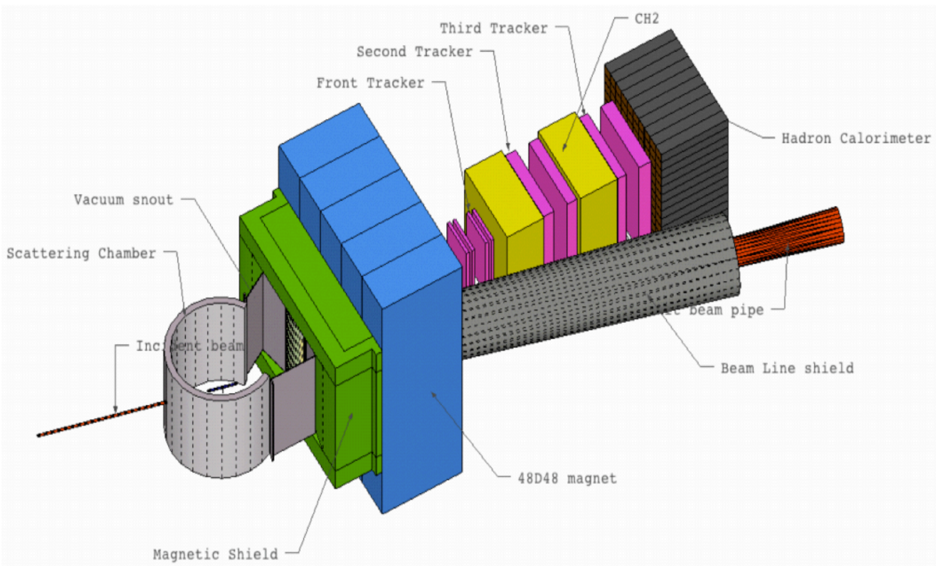


Move target upstream for forward proton detection, or make full rTPC length target

Perhaps increase drift region for improved momentum resolution

And, a major plus!! (as compared to original Hall B thoughts.....)

Move Hadron Calorimeter to different angle - use for rTPC calibration

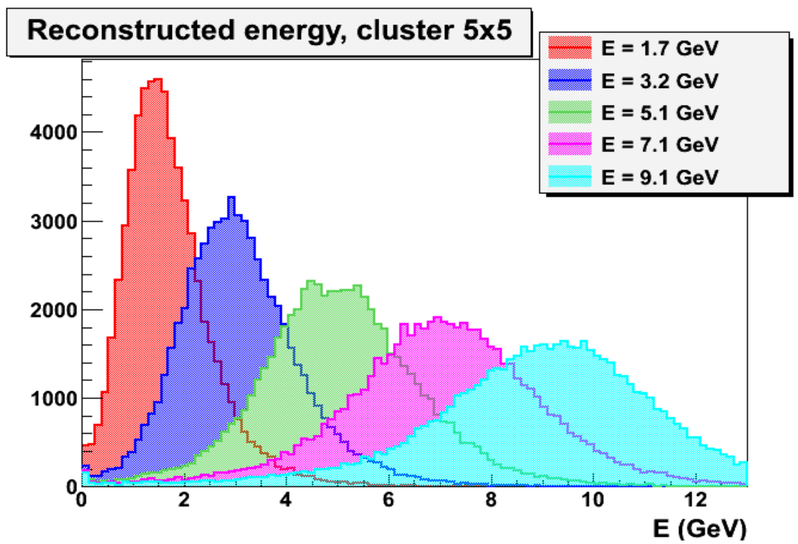


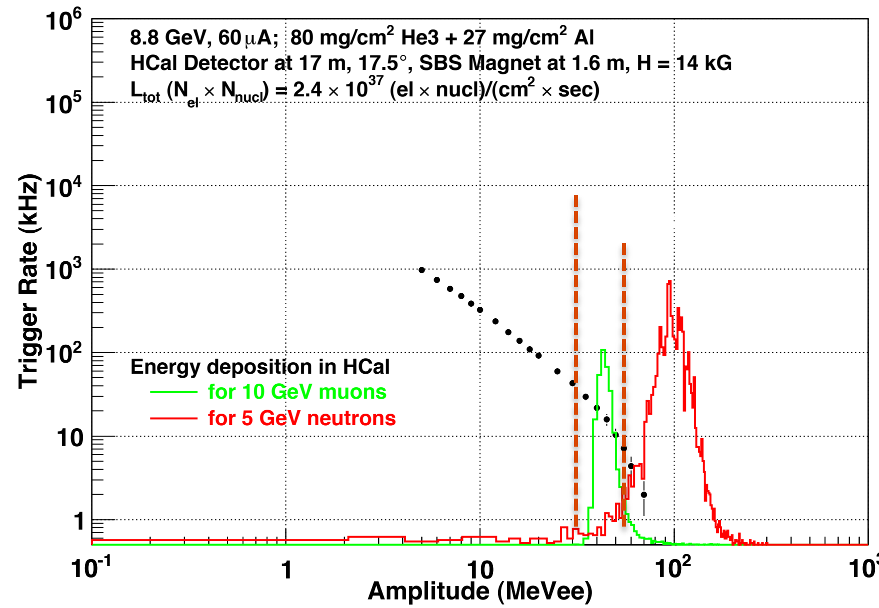
HCAL on separate, moveable stand

- Deuterium target in rTPC
- Electron-neutron *elastic scattering*
- Electron detected in SBS or BigBite
- Neutron detected in HCAL
- There MUST be a spectator proton! So……
- Measure rTPC (spatial) efficiency
- Maybe also momentum calibration

Geant4 Energy Resolution Studies

from G. Franklin SBS Collaboration talk





Energy	2.5 GeV	5.0 GeV	7.5 GeV	10.0 GeV
Resolution: ¾/E	48%	31%	27%	22%
Efficiency at ¼ mean signal: Neutrons	97.3%	99.2%	99.1%	99.1%
Efficiency at ¼ mean signal: Protons	98.8%	99.6%	99.4%	99.0%

Other (potential) pluses

- Raising current may mean don't need 7.5 atm target -> would push down minimum momentum measureable in rTPC, get closer to pole!
- Actually get F_2^n/F_2^p for free if make full length target for deuterium run
  - Pion structure function requires one forward angle + one backward angle proton
  - F_2^n requires just one backward angle proton
  - Maps Sullivan contribution to F_2^n

Conclusion: Lots of work to do, but this could be an exciting program for SBS:

- Proton target pi^0 structure function
- Deuteron target pi- structure function
- Deuteron target F_2^n
- Helium target SRC experiments?
- Look for Lambda -> p pi- decay to measure p -> K+ Lambda kaon cloud of the nucleon??