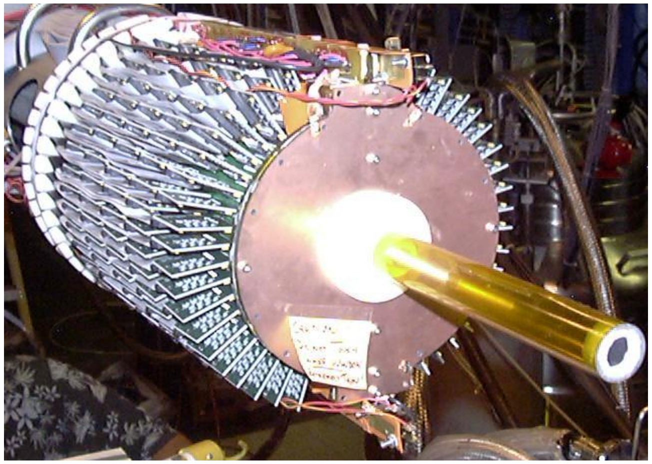
~~IDEA~~ for a measurement of the Pion Structure Function using SBS, LAC, BONUS-like rTPC, BigBite, in Hall A

Jefferson Lab



Small working group formed….(thanks!!)

J. Annand, A. Camsonne, E. Christy, D. Dutta, P. King, J. LeRose, R. Lindgren, J-C Peng, P. Reimer, J. Roche, B. Wojtsekhowski, J. Zhang *– feel free to join!*

- Have had two working meetings
  - Talks available on SBS web page
  - Basics – luminosity (target), rates, backgrounds, simulation
  - Physics generator and simulation development
- Seeking theory guidance
  - Idea presents multiple opportunities, a program
  - Informal local meeting in ~couple weeks
  - January 16-18 workshop

Motivation in a Nutshell - a reminder
(see also See also http://www.ectstar.eu/node/95 ECT workshop July 2013, "Flavor Structure of the Nucleon Sea"

- A.W. Thomas, Phys. Lett. 126B (1983) 97-100: "... it is rather disturbing that no one has yet provided direct experimental evidence of a pionic component in the nucleon."

  "A Limit on the Pionic Component of the Nucleon through SU(3) Flavor Breaking in the Sea"
- Pion is the simplest hadron with only two valence quarks.
  - multiple theory predictions, QCD testing ground
- Knowledge of the pion structure function is *<u>very limited</u>* due to the lack of stable pion target.
  - some Drell-Yan data at moderate x and HERA data at low x
  - compare to 5+ orders of magnitude in x, Q^2 measurements of nucleon structure function at DESY, SLAC, NMC, BCDMS, JLab,….
- 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 pion exchange (Sullivan) process can be used to measure the pion structure function.
- This experiment can, more generally, measure the "mesonic" contribution to DIS (~50% according to Kopeliovich…..)

Educated guess

$$\mathbf{R_{\pi/p}(x, Q^2) = F_2^\pi(x, Q^2)/F_2^p(x, Q^2) = \, ?}$$

The small q-qbar dipole, $\gamma^* \to \bar{q}q$, is a good counter of valence quarks, so one could (naively) expect $\mathbf{R_{\pi/p}(x, Q^2) = 2/3}$

However, the proton has a considerable pion component: $\mathbf{p \to N\pi}$

It can be evaluated relying on the observed deviation from the Gottfried sum rule:

$$\mathbf{R_{\pi/p} = \frac{2}{3 + 2\langle n_\pi \rangle}}$$

DY E866: $\langle \mathbf{n}_\pi \rangle = \mathbf{0.36}$

NMC: $\langle \mathbf{n}_\pi \rangle = \mathbf{0.44}$

HERMES $\langle \mathbf{n}_\pi \rangle = \mathbf{0.48}$

G. Garvey & J.-Ch. Peng, Prog.Part.Nucl.Phys. 47(2001)203

Adding the poorly known contribution of the iso-scalar mesons, our guess is

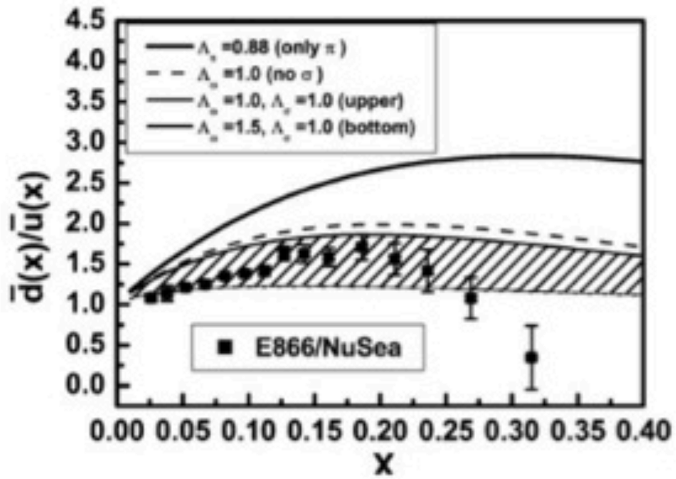
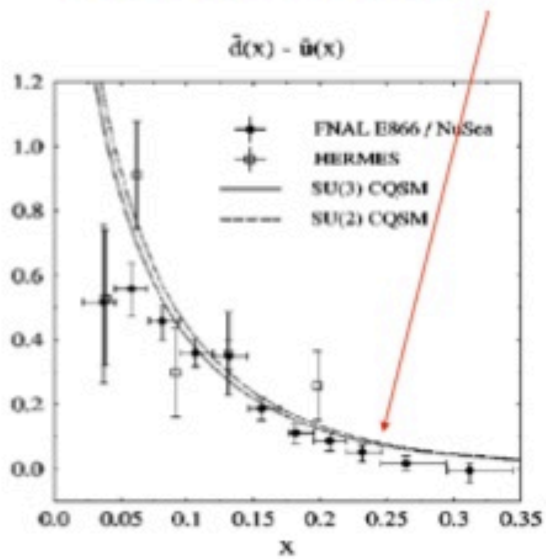
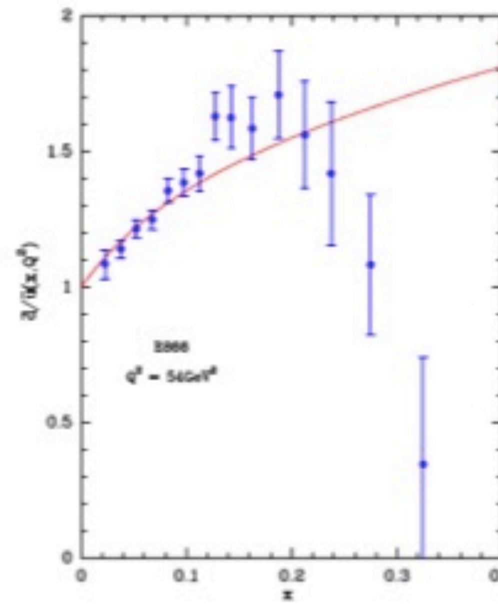
$$\mathbf{R_{\pi/p} = \frac{1}{2}}$$

This is our trial value for further calculations

Sign change of $\bar{d}(x)-\bar{u}(x)$ at $x \sim 0.25$?

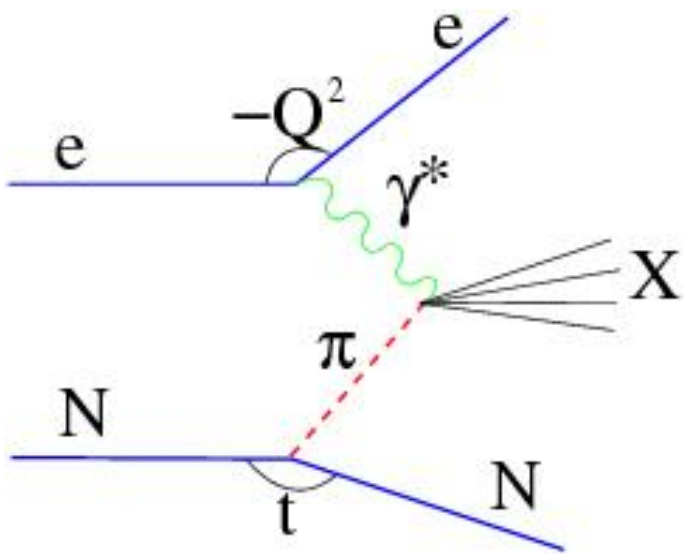
(or $\bar{d}(x)/\bar{u}(x)<1$ at $x \sim 0.25$?)

Why is it interesting? (no models can explain it yet!)

Meson cloud model	Chiral-quark soliton model	Statistical model
		
From Alberg's talk	From Wakamatsu's talk	From Soffer's talk

J-C Peng, Trento 2013 workshop

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



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

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

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

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

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

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, ρ^0 production.
- 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

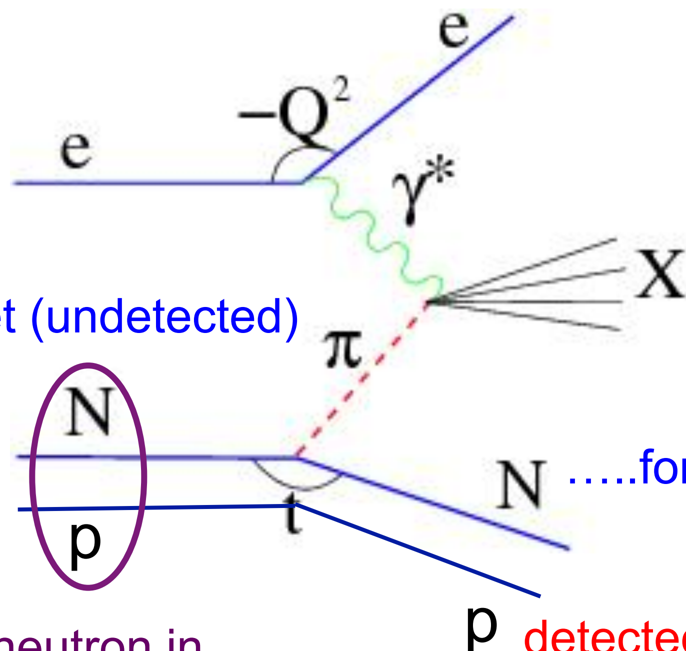
So, what to measure…?... Inclusive DIS from a *pion* target

detect scattered electron

DIS event – reconstruct missing mass W of undetected recoiling hadronic system

want *charged* pion target (undetected)

need fluctuating nucleon to be a neutron…….



…..for detected nucleon to be a proton

neutron in deuteron target

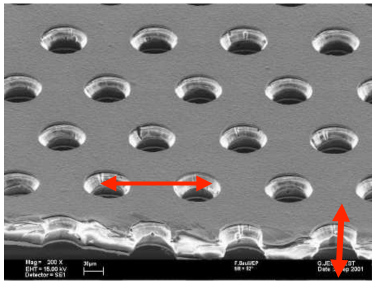
detected spectator proton tags neutron target (BONUS experiment technique)

detecting two protons with common vertex in coincidence tags pion target!

First, what kind of luminosity is possible?

- Small cross sections, need to do better than CLAS12/BONUS
- Detectors near target, Moller background
- SBS and BigBite (not limiting factors)

BONUS Radial TPC (and target) Design

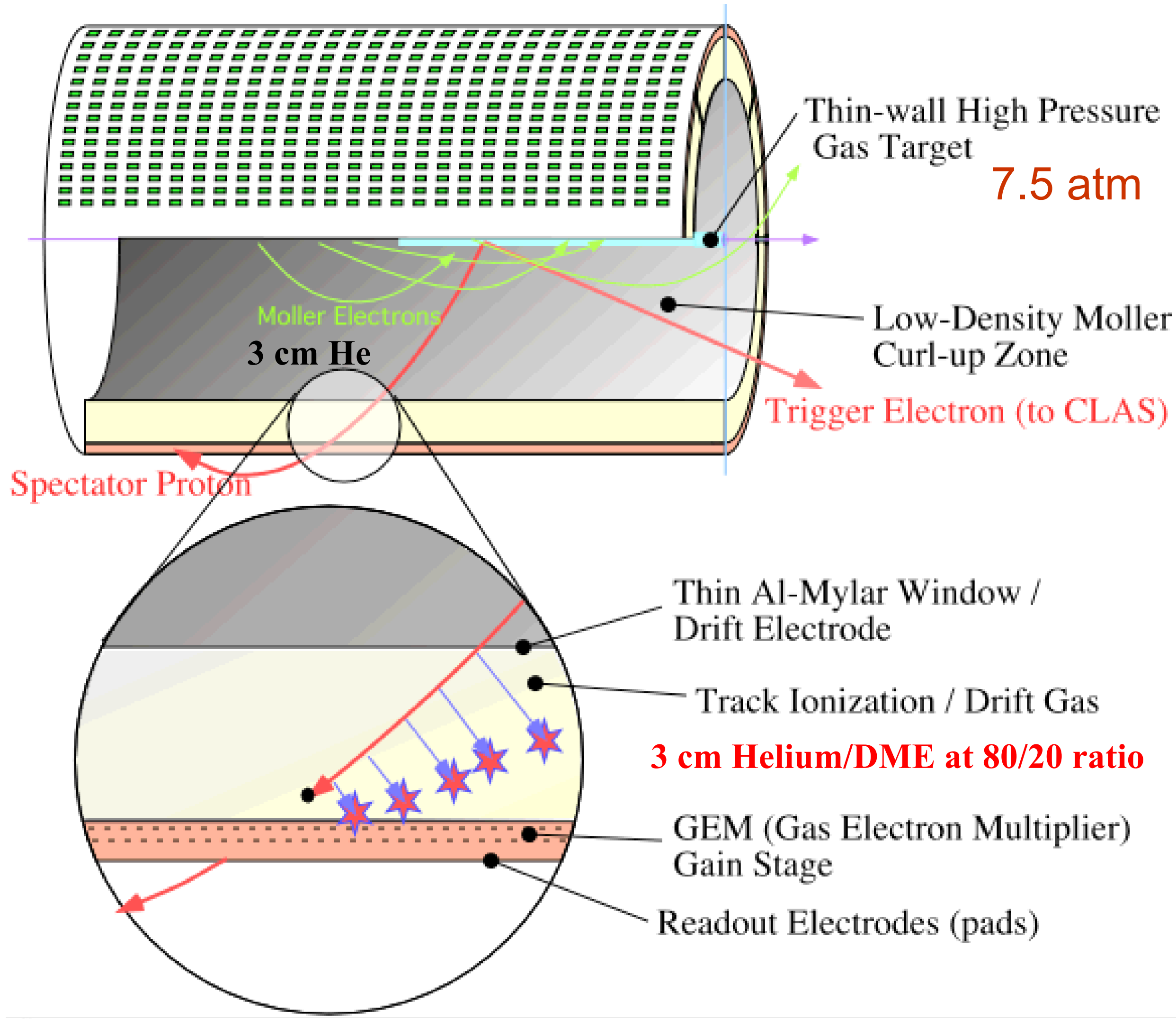


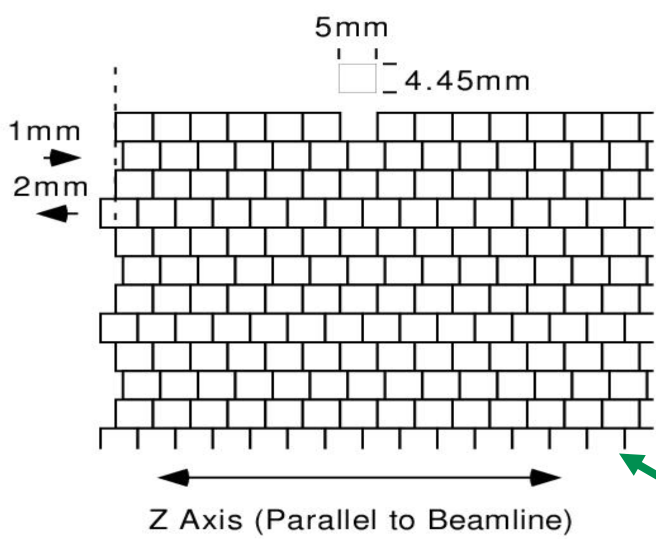
140 μm

~50 μm

φ, z from pads, r from time

dE/dx from charge along track (particle ID)





Stagger pads in z to improve theta angle reconstruction

Target cell

- The luminosity of 1 x 10^{37} nucleon/cm^2 is the goal
- Assuming beam intensity of 50 μA => 3.1 x 10^{14} e/s

The cell diameter? 10 mm in Tritium 25 cm long cell: use 10 mm

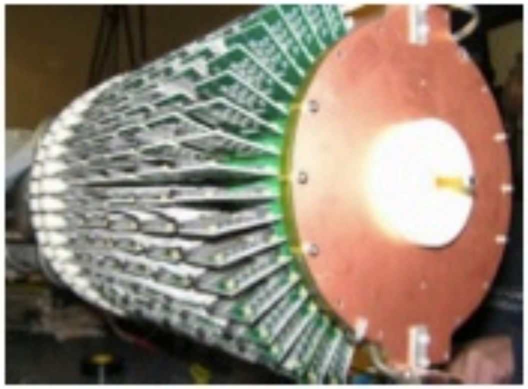
- Use a kapton film, which contributes 2/3 of the total mass: 15 micron corresponds to 2 mg/cm^2
- Kapton strength 22100 psi => 1500 atm Such 15 micron tube can hold the pressure of

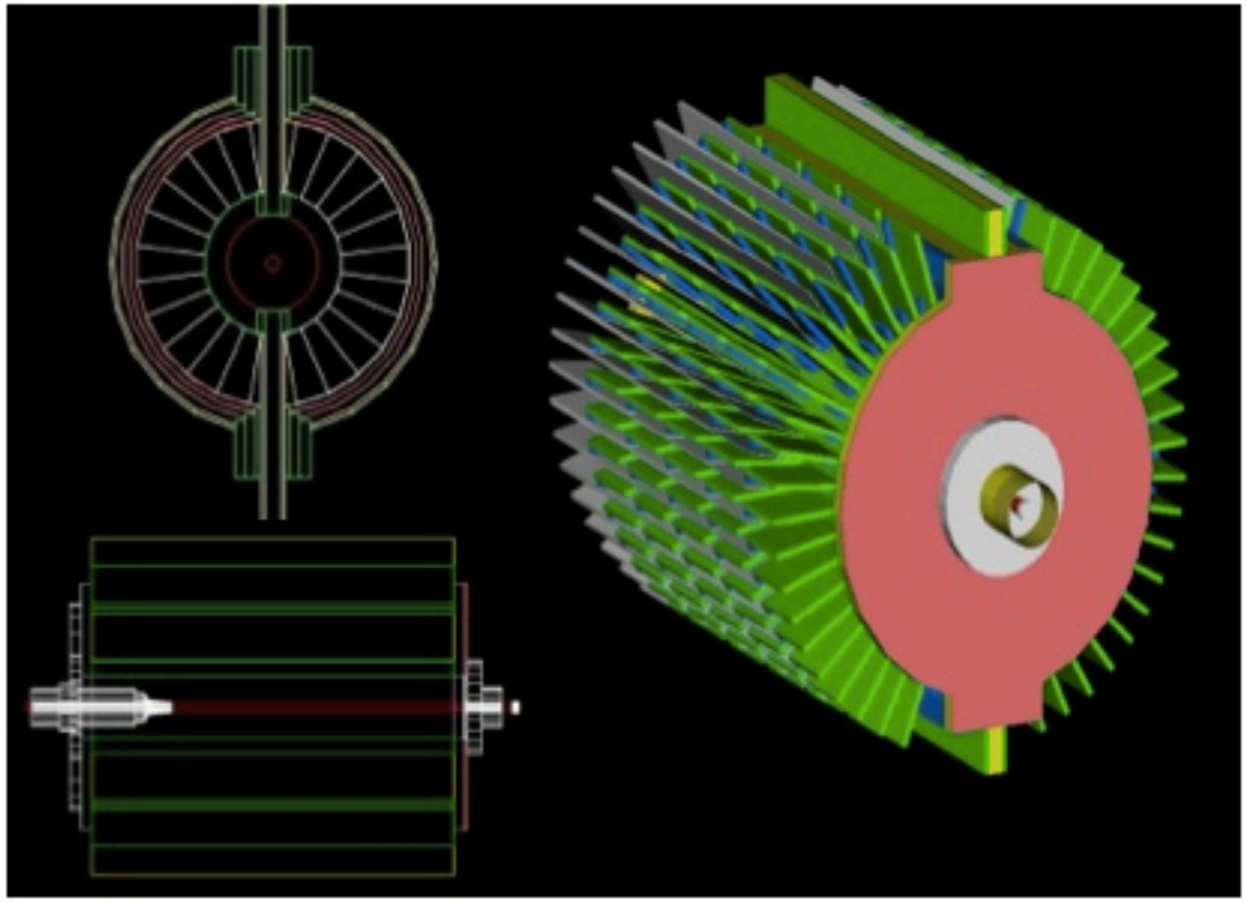
t/r x s = 15/5000 x 1500= 4.5 atm

Mass: 5 / 250 (radius/length) for 1/50 x 3 x 10^{22} = 1 mg/cm^2

Such a density (2 mg/cm^3 ~ 1/36 of LH2) => 25 K, p= 2 atm

The RTPC in Geant4 Simulation





Using the exist RTPC Geant4 simulation program, geometry was built exactly for BoNuS experiment.

Optimize Threshold

Set #	Target P. (ATM)	Target Temp. (K)	Target D. (mm)	Target Wall (um)	He4 P. (ATM)	Threshold, Smax<35 theta=90°	Threshold, Smax>55 theta=90°	Threshold, Smax<35 theta=30°
1	7.5	300	6	50	1	66	70	80.5
5	7.5	300	6	30	1	59.4	64.8	74
6	7.5	300	6	20	1	55.7	61.3	72
11	7.5	80	6	20	1	59.3	64.6	75
12	4.5	80	6	20	1	57.9	63	72
13	7.5	80	5	20	1	59.3	64.6	74.8
14	7.5	80	4	20	1	59.2	63.8	73.6
15*	7.5	80	6	20	No both mylars	55.6	61.0	70
16	7.5	80	6	20	No 1st mylar	57.5	63.0	71.8
17*	7.5	80	6	20	Drift Region 25-60	59.3	64.6	75

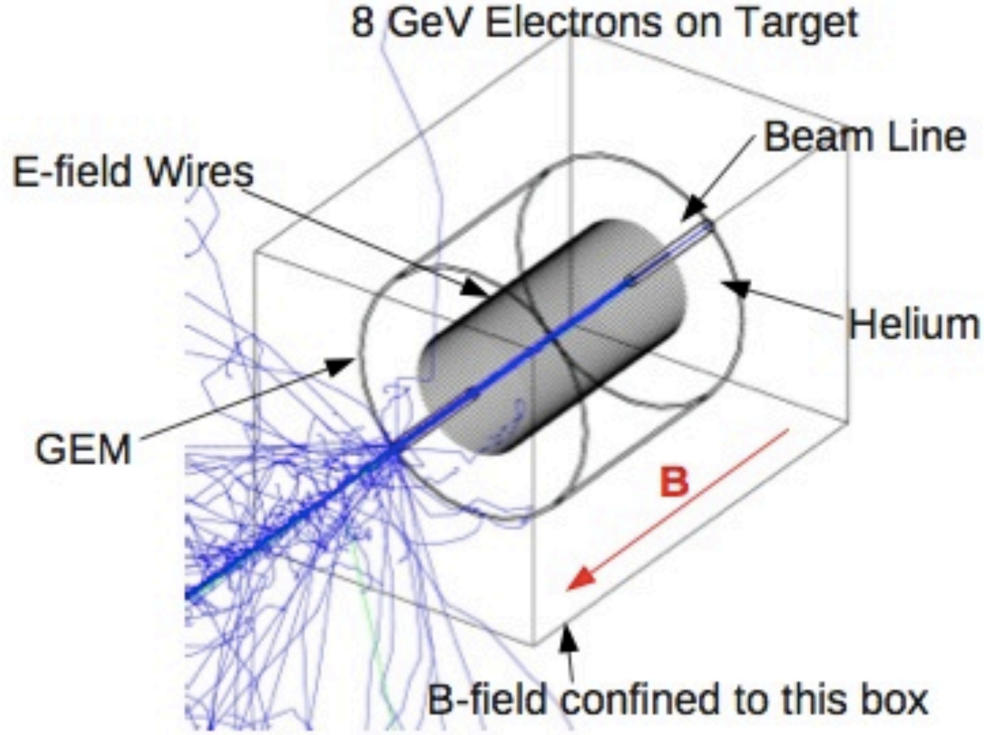
To change the cathode layer from 30 mm to 25 mm, one needs to study moller background ...

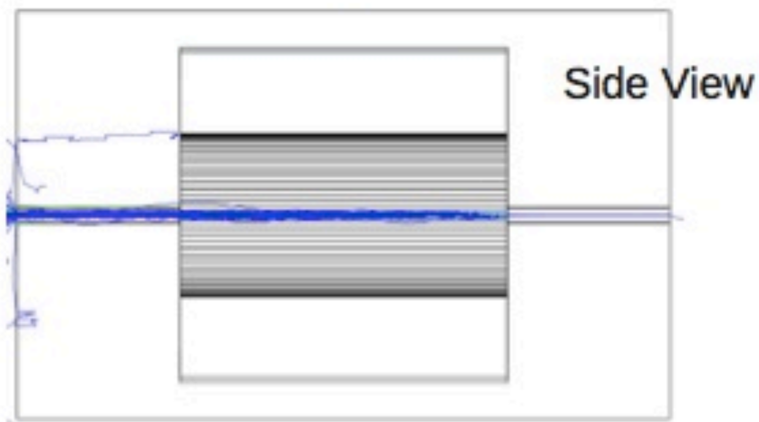
Recoil Proton Spectrometer: Radial-Field TPC

Gas H_2/D_2 Target, 25° K, 2 atm
Container 15 μm Kapton
400mm long × 20mm Ø
I_e = 50 μA, $L_N \sim 10^{37}$

He gas 25° K, 0.1 atm
Ring of 100 12.7 μm W wires
Divides He volume in 2
r = 5 - 100mm, r = 100 - 200mm

Outer cylindrical GEM
No detail coded yet

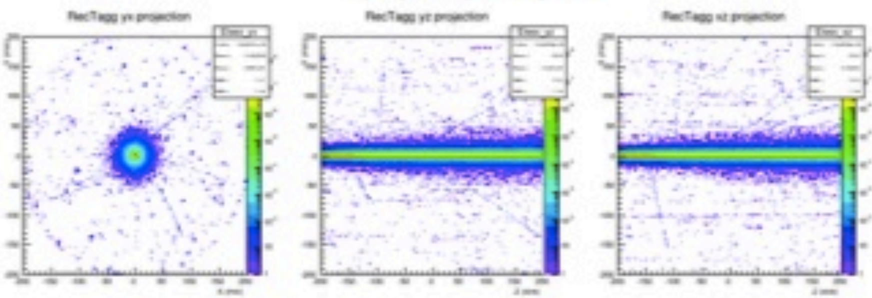




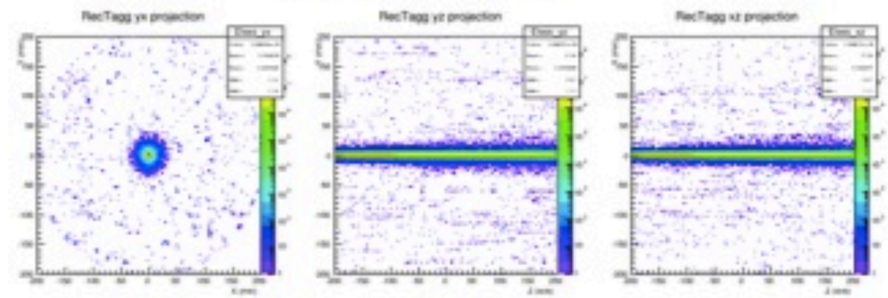
- 2 T longitudinal magnetic field assumed uniform
- Or TOSCA generated field map (B. Wojtsekkowski)

Energy Deposit Profile Comparison

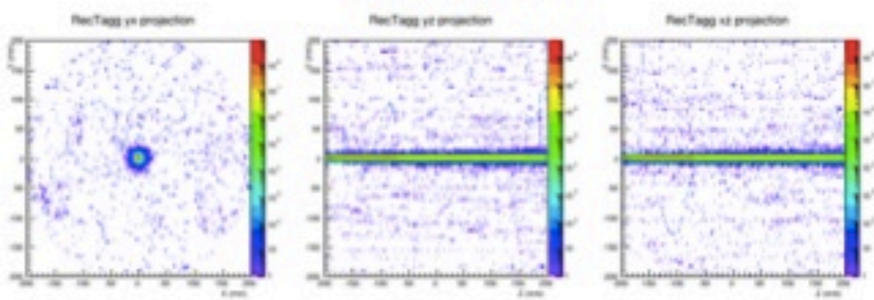
0.5T Uniform



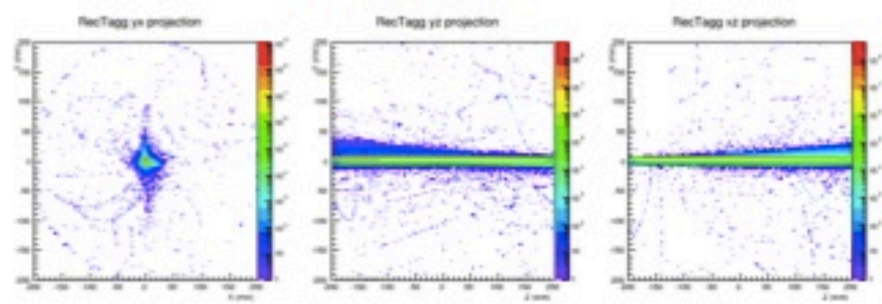
0.95T Uniform



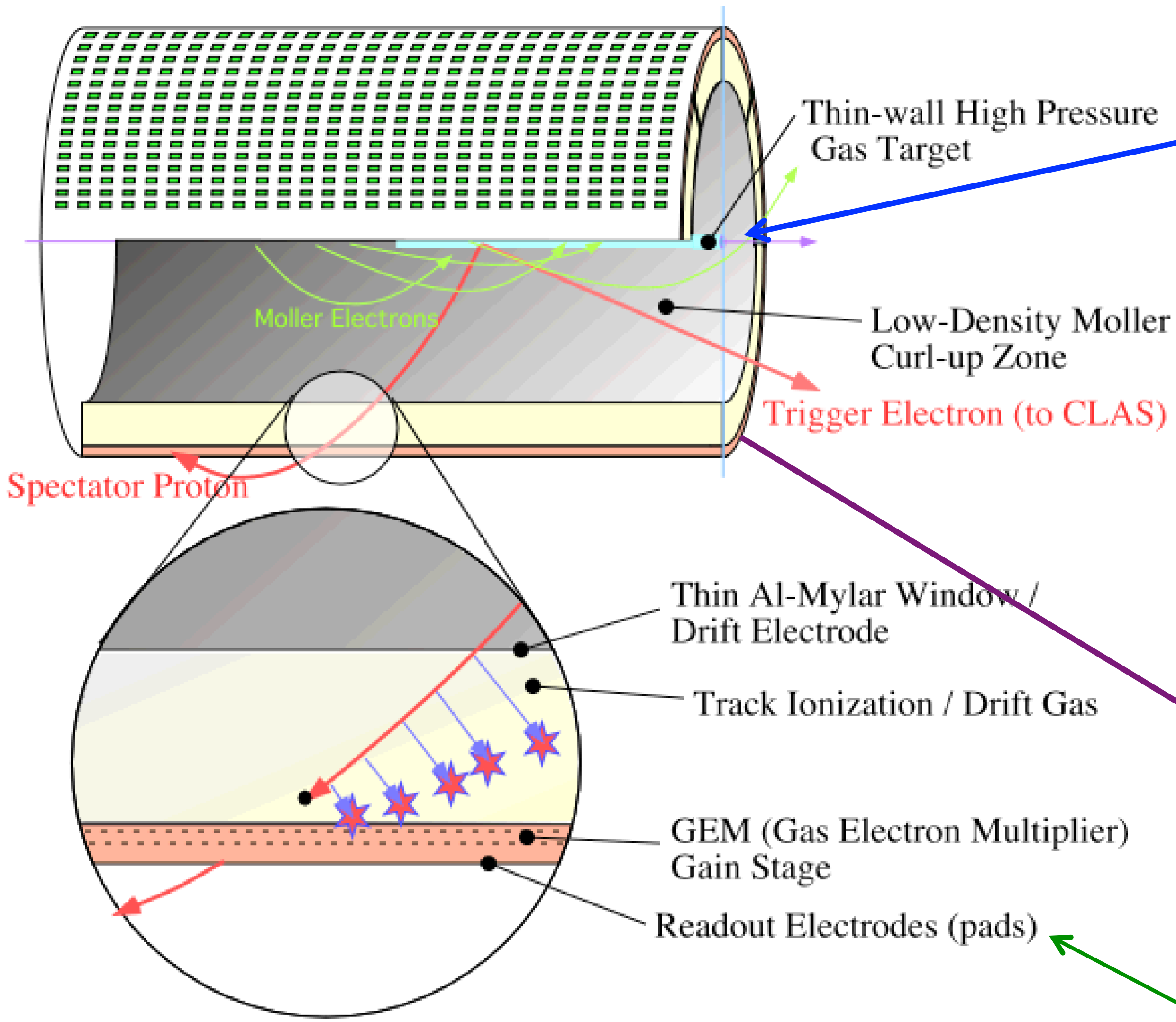
2.0T Uniform



B7 TOSCA



- Uniform magnetic field varied from 0.5 to 2.0T
- Close to the beam axis the region of significant energy deposition definitely shrinks
- Further from the beam axis the background does not reduce
- Still to quantify how serious this backgroud is and its source



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

Perhaps increase drift region for improved momentum resolution – or improved GEM readout may accomplish this already?

Thinner-walled straw target also possible

Need to detect "single arm" high E electrons (so as to get to high W, Q^2 DIS kinematics)…

Super Bigbite

Solid angle

$\theta_{central}$, degree	Ω, msr	D, meter	Hor. range, degree	Vert. range, degree
3.5	5	9.5	$\pm$ 1.3	$\pm$3.3
5.0	12	5.8	$\pm$ 1.9	$\pm$4.9
7.5	30	3.2	$\pm$ 3	$\pm$8
15	72	1.6	$\pm$ 4.8	$\pm$12.2
30	76	1.5	$\pm$ 4.9	$\pm$12.5

Resolution:

Momentum =>

$$\frac{\sigma_p}{P} = 0.0029 + 0.0003 \times p[\mathrm{GeV}]$$

Angular =>

$$\sigma_\theta = 0.14 + 1.3/p \ [\mathrm{GeV}], \mathrm{mrad}$$

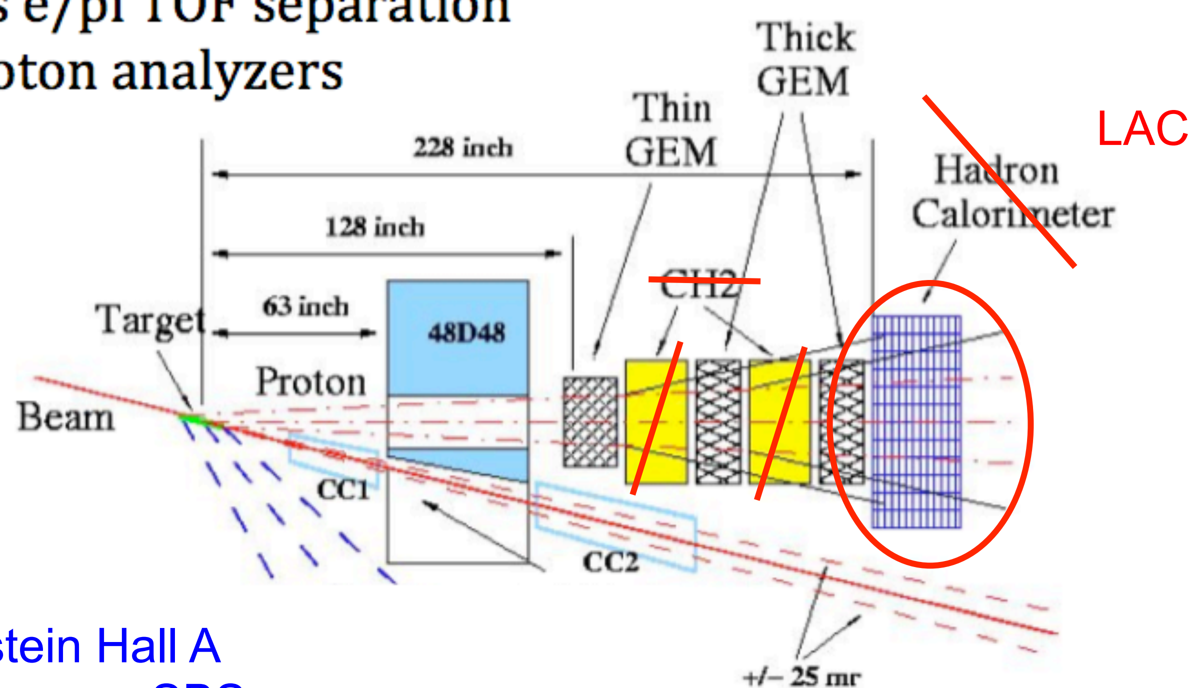
Momentum acceptance =>

P range from $2 - 10$, GeV/c

SBS + LAC

Using the SBS for electron detection:

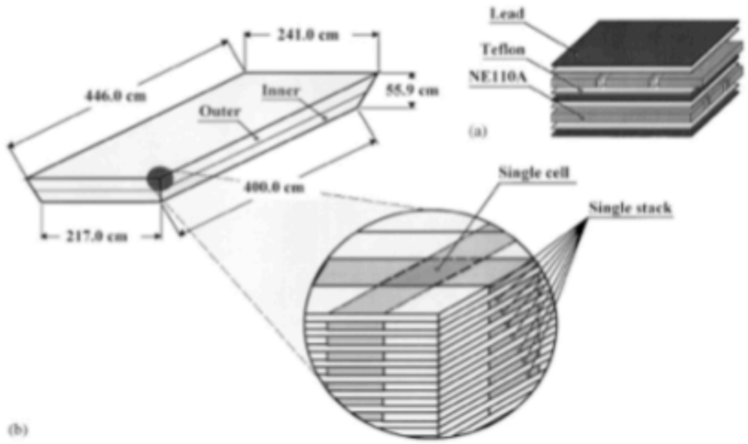
- Replace Hadron Calorimeter with LAC
  - Similar sizes (5.5 m^2 vs 8.7 m^2)
  - Place the LAC as far back as possible to match the solid angle.
    - Improves angular resolution
    - Improves e/pi TOF separation
- Remove CH2 proton analyzers



Slide from L. Weinstein Hall A Collaboration talk, more on SBS from Bogdan

The Large Angle Calorimeter (LAC)

We recovered this detector from CLAS6 – stored under cover

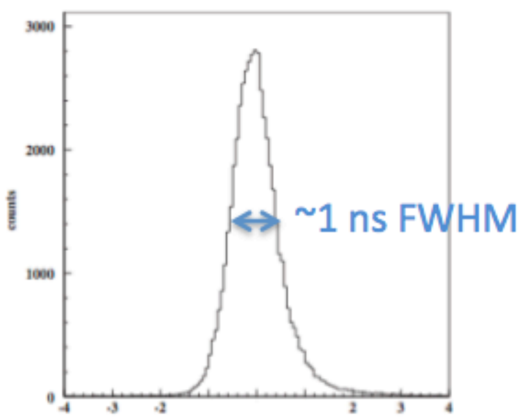


Active area: 2.2 m by 4 m
33 layers
- 0.20 cm Pb foil
- 1.50 cm NE110A scintillator

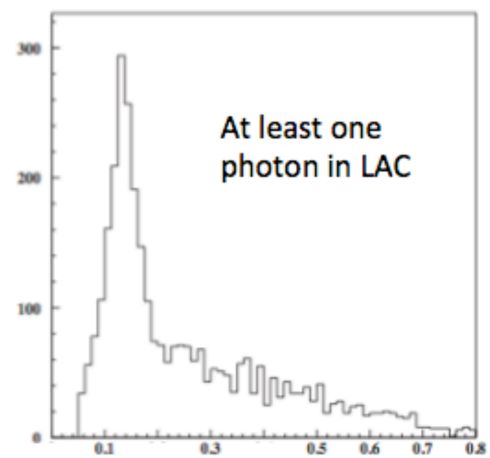
Readout segmentation:
- 40 strips in X (each ~ 10 cm)
- 24 strips in Y (each ~ 10 cm)
- "Inner" (17 layer) vs "outer"

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

Coupling of scintillators to PMTs



t(X-strips) – t(Y-strips) [ns]

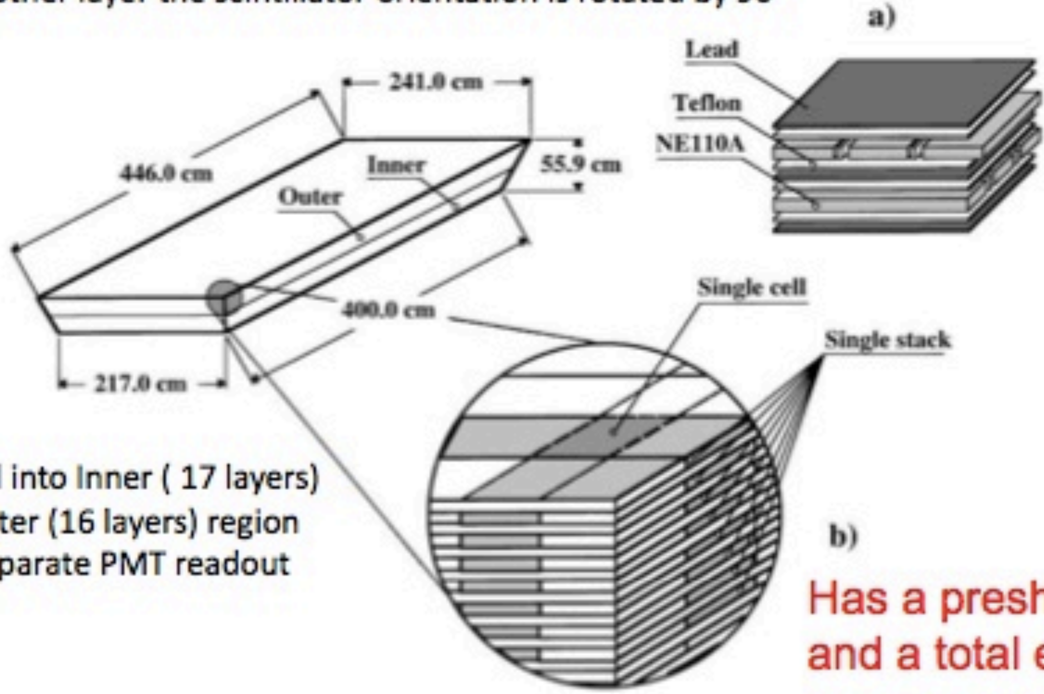


Mγγ (GeV)

Super Bigbite PID

LAC details

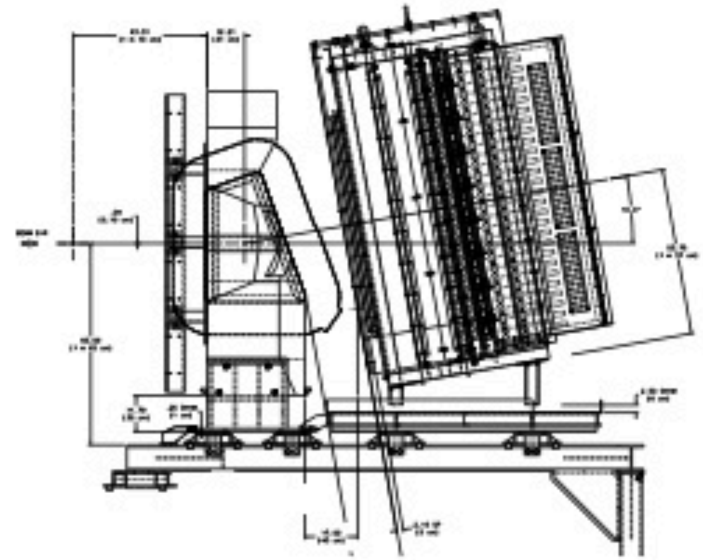
- Each detector has 33 layers of material. 12.9 Radiation lengths
- 0.20 cm lead , 0.02 cm Teflon , 1.5 cm thick scintillator with 10cm width
- every other layer the scintillator orientation is rotated by 90°



Divided into Inner (17 layers) and Outer (16 layers) region with separate PMT readout

Has a preshower section and a total energy section

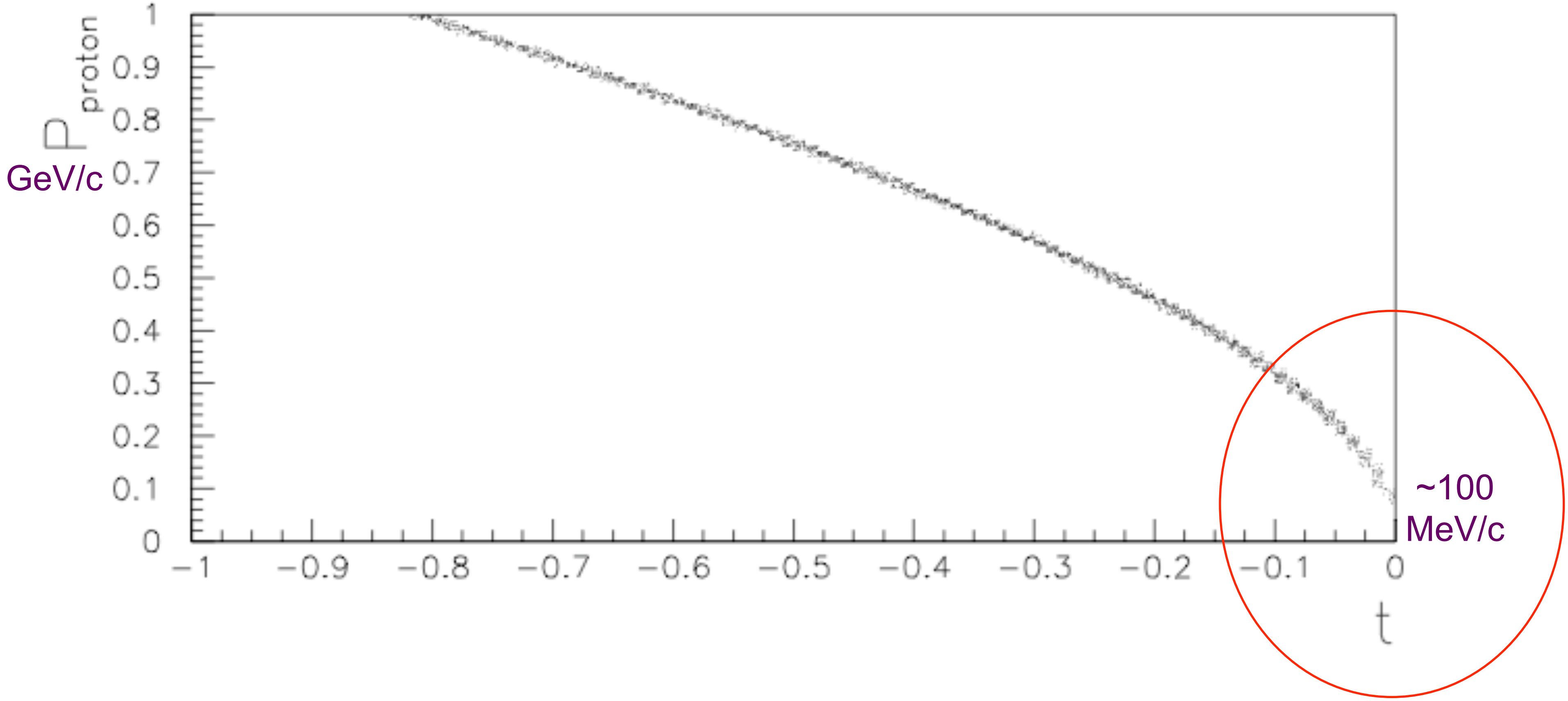
BigBite as an electron arm, E02-013



- Magnet: BB - 25 cm gap, 1 Tesla·m
- Solid angle is 96 msr at angle > 45 deg.
- MWDC chambers with 150 μm resolution
- Momentum resolution is 0.5% for 1.5 GeV/c
  ~ 1/p => 2% at 6 GeV/c
- Angular resolution is 1 mrad

Next, how to detect protons? (a reminder)

How to identify fluctuating nucleon?



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

Plot from E. Christy

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

-Suggest use this approach!

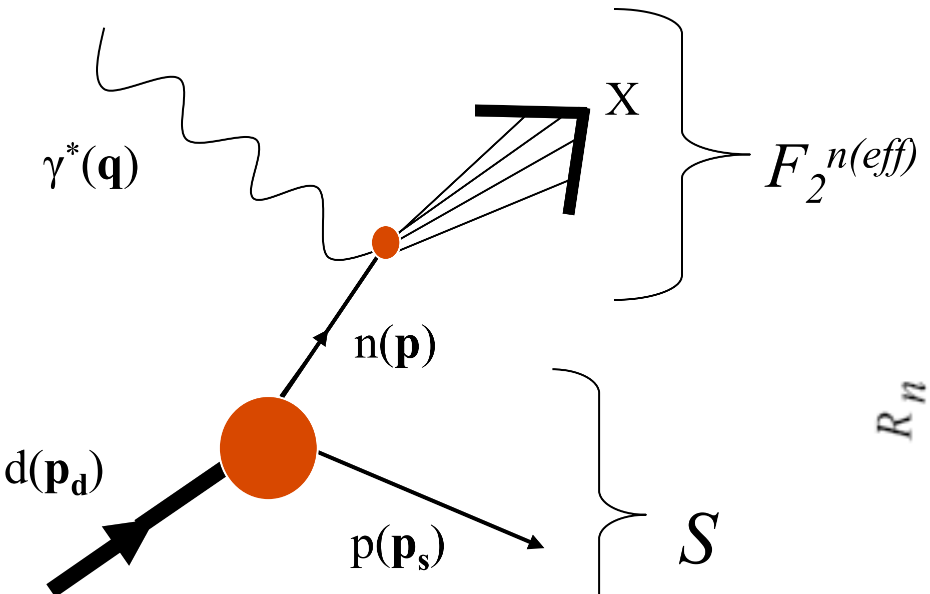
Spectator Proton Detector Features

- *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

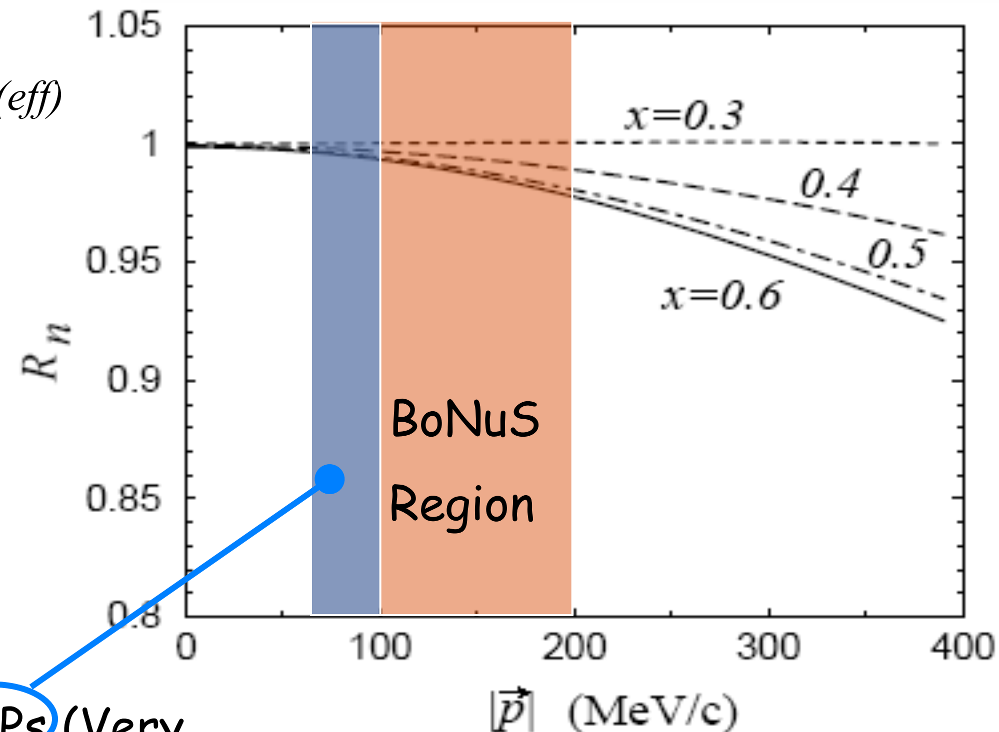
The BONUS approach to create neutron target

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 $\mathbf{p_s} = -\mathbf{p}$

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



$$R_n \equiv F_2^{n(eff)}(W^2, Q^2, p^2) / F_2^n(W^2, Q^2)$$



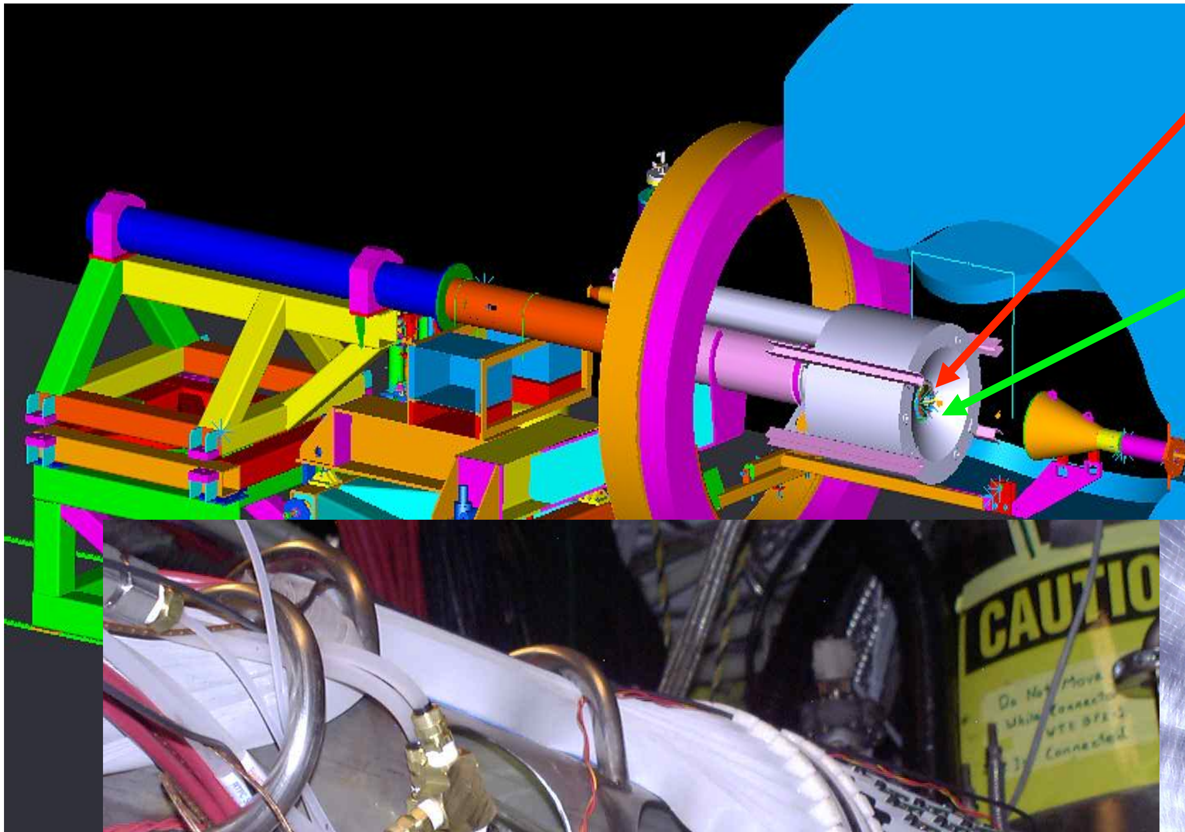
$\nu = E - E'$

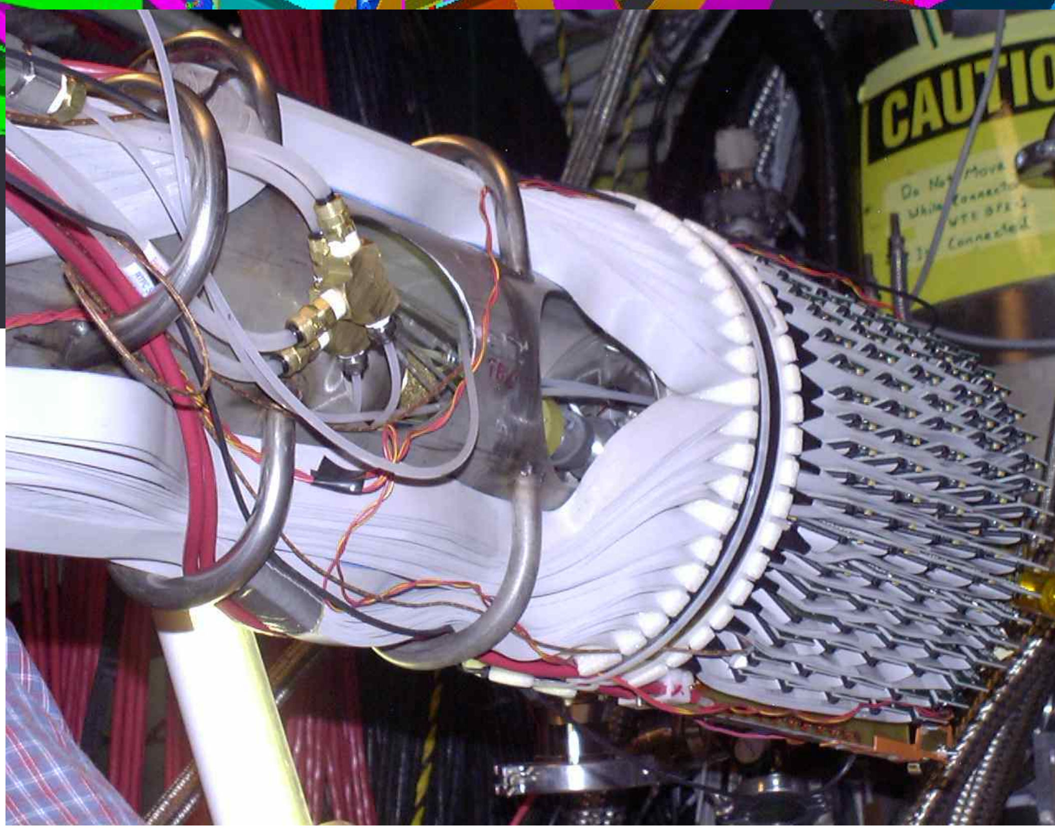
$\alpha = (E_s - p_s^z)/M$

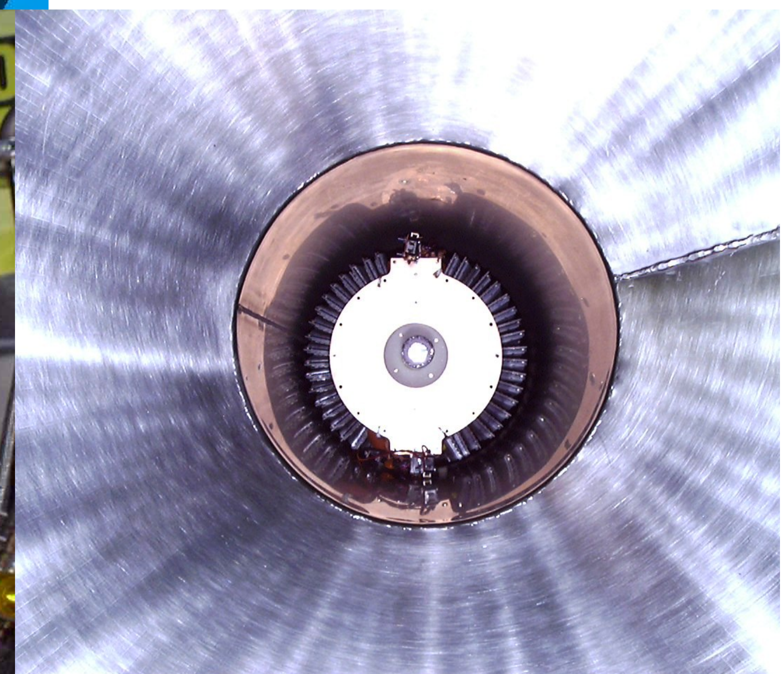
$Q^2 = 4EE' \sin^2 \frac{\theta}{2}$

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

BONUS in CLAS

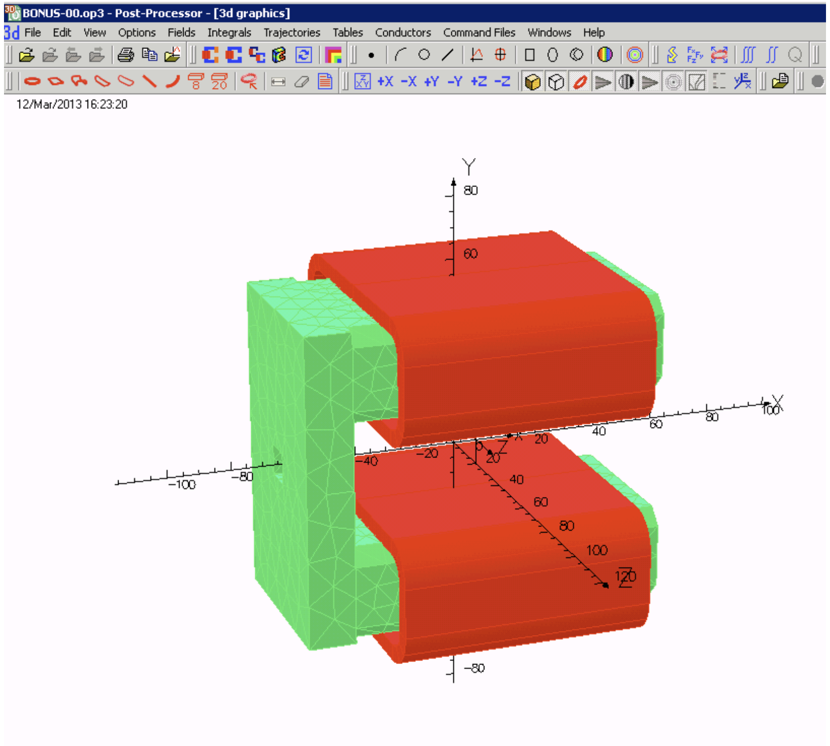






Unlike BONUS, though….

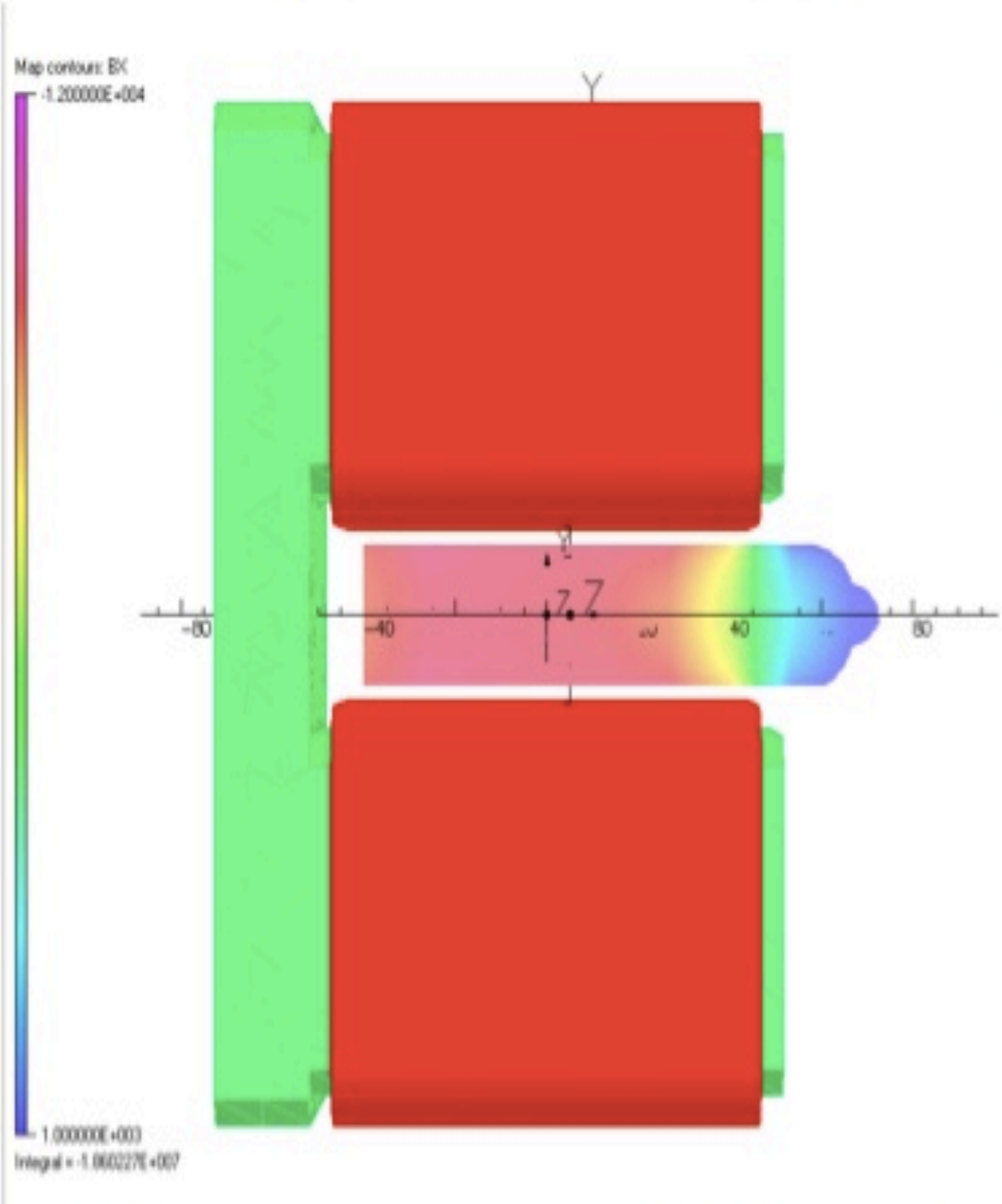
- Need range of electron angles solenoid in the way



New magnet or magnet design (Bogdan)?

- Also…may need *forward* angle, low p proton detection

Longitudinal Field (5): Push it Max



B_target = 9.5 kG

Do we have enough rate for a good experiment?....

Process used in the model

- Generate a real proton, virtual neutron pair from an at-rest deuteron
- Generate a real proton, virtual pion pair from the neutron with the proton carrying momentum fraction, z, and transverse momentum, p_T
- Calculate the en→e'p'X cross-section using

$$\frac{d\sigma(en\rightarrow e'p'X)}{dx_{Bj}\,dQ^2\,dz\,dp_T^2}=f_{p\pi/n}(z,p_T^2)\,\sigma_\pi(x_{Bj}/(1-z),Q^2)$$

Paul King

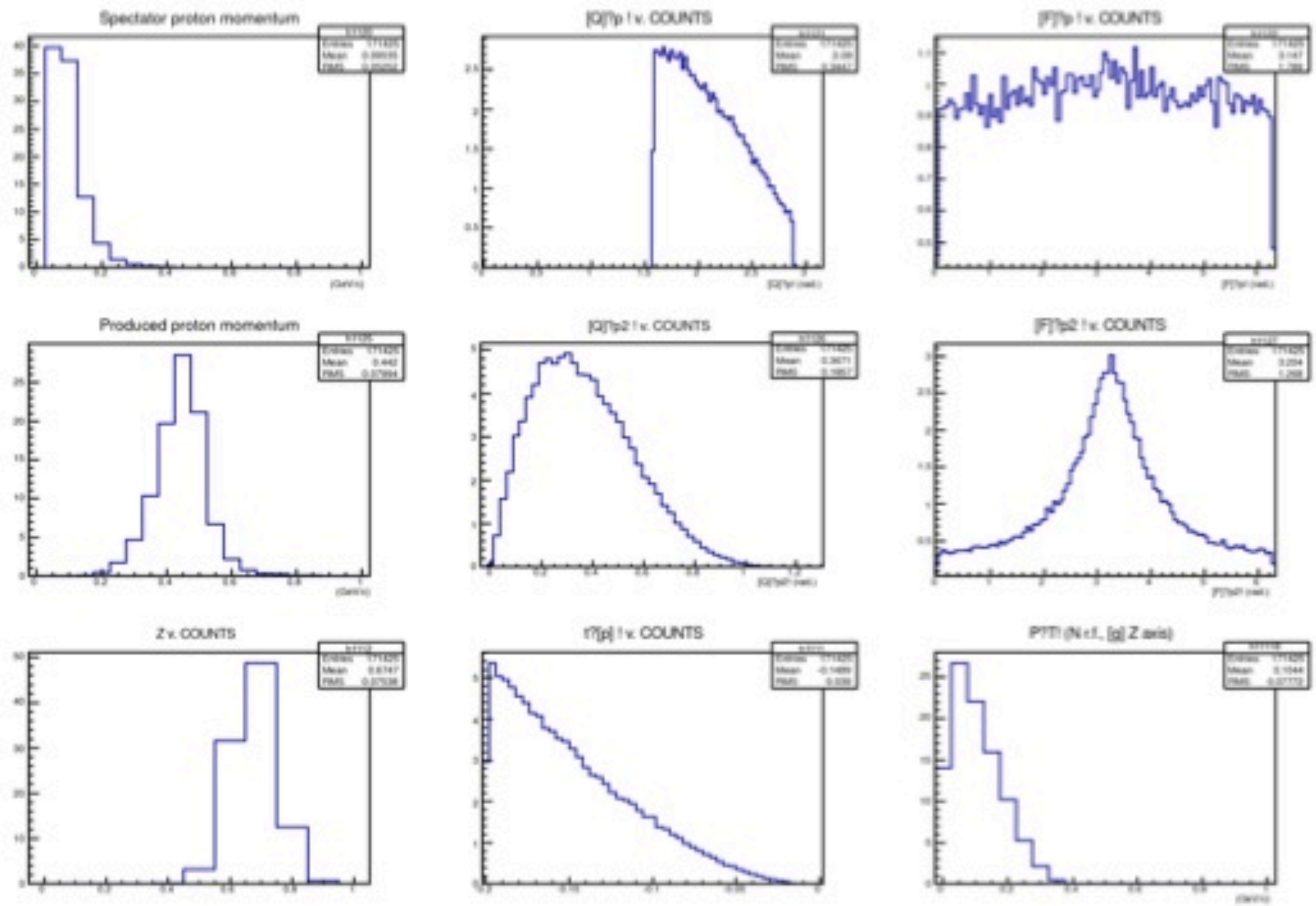
Assumptions and ranges

- Use a luminosity of 1.0e37 cm-2s-1 --> (1.0e10 mbarn-1s-1)
- Parameter ranges
  - Q2, 1.0 - 5.0
  - X_A, 0.001 - 0.5
  - P_T, 0.0 - 1.0
  - Z, 0.0 – 1.0
- Cuts
  - 0.05 < P_p1 < 0.50
  - 90deg < Th_p1 < 165deg
  - E_e > 0.25
  - 5deg < Theta_e < 30deg
  - |t_pi| < 0.2
  - x_pi < 1.0
- Rate:

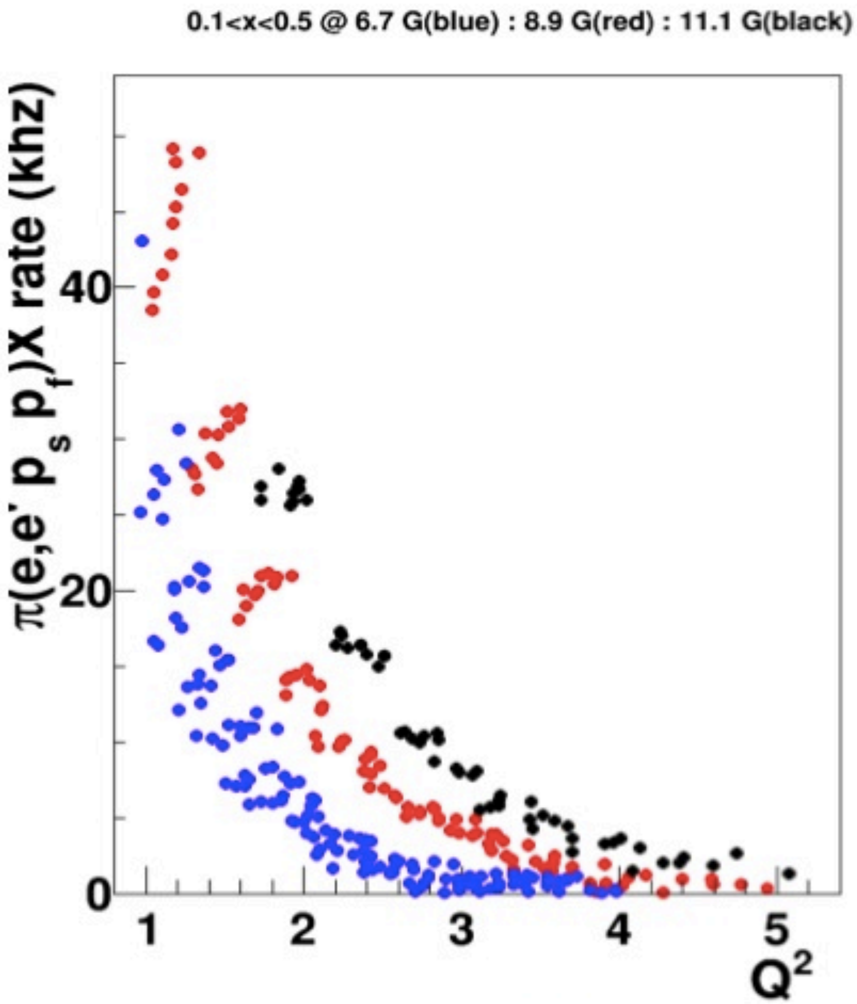
  Sum(sigma)*(Parameter _ranges)*L/N_gen ~ 100 Hz

Paul King

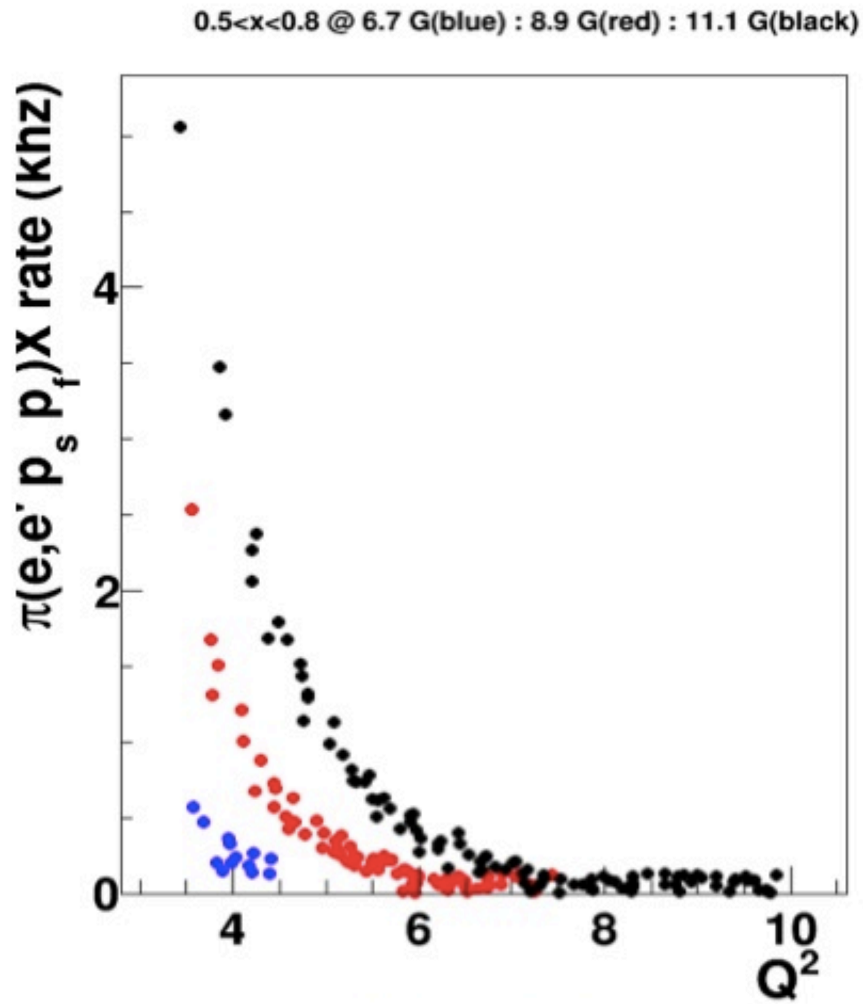
Proton parameters vs rate



Rates vs Q2 at Various x Bins



0.1 < x < 0.5

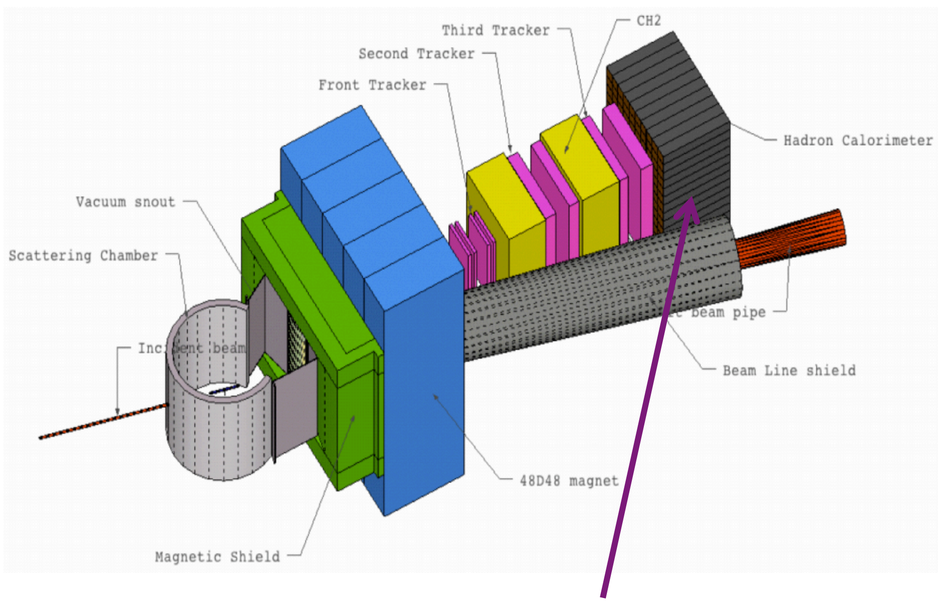


0.5 < x < 0.8

Pion on-shell model (Jixie Zhang) – agrees with Paul's physics generator!

Reminder 1: one potential major plus using SBS++ as compared to CLAS12....
(besides running a lot earlier)...

Move Hadron Calorimeter to different angle – use for rTPC *calibration*, facilitate real cross section measurement



HCAL on separate, moveable stand – here replaced in SBS by LAC – move and use for elastic neutron detection!

- 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
- Neutron form factor for free

Other (potential) pluses of this program

- 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
- Can vary target density – check lower p, also raise to get more rate….complementary data, requires planning

Other physics - this could be an exciting program for SBS:

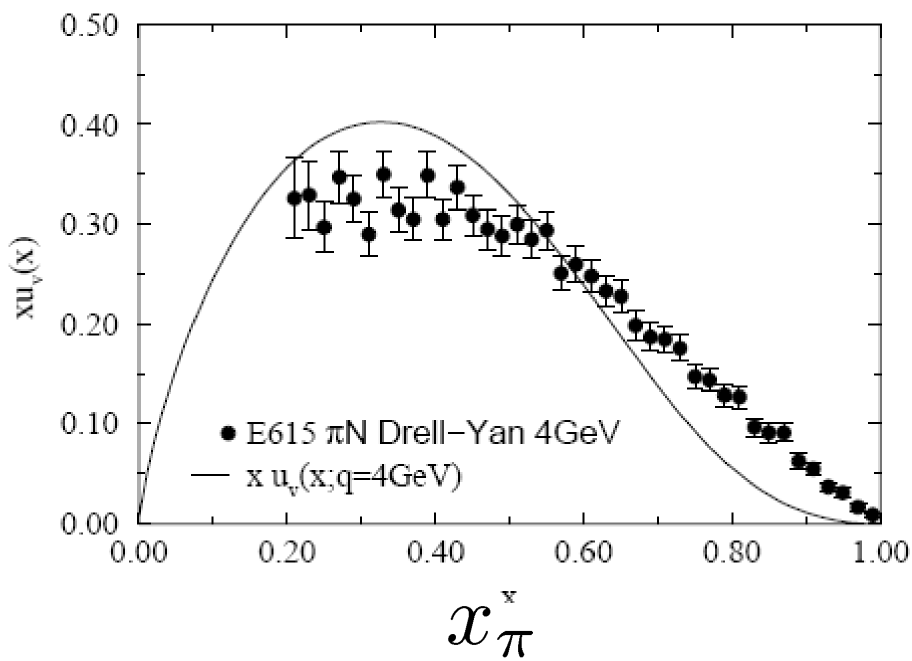
- Deuteron target pi- structure function
- Proton target pi^0 structure function
- Possibility of low momentum neutrons for pi+ too (R. Lindgren), stay tuned!
- Deuteron target F_2^n
- Detect also pion to measure pion form factor at pole (excellent complement to Hall C L/T)
- DVCS (detecting proton in coincidence should remove ~15% background from (e,e'Δ)γ, (e,e'π)γ,...) – neutron, pion DVCS!
- Helium target SRC experiments?
- Look for Lambda -> p pi- decay to measure p -> K+ Lambda kaon cloud of the nucleon??

Conclusion: Still lots of work to do, but looking increasingly like a doable and promising program for SBS:

- Most equipment exists, needs only modifications
- Can get $\mathcal{L}$ to ~2 x 10^{37}
- Can reduce $p_{spectator}$ to ~ <60 MeV/c
- Rates ~100Hz

Other Useful Slides

Pion Structure Function



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

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

Pion structure function is not well measured, although pion is the simplest hadron with only two valence quarks....would like, for instance range in x, Q^2

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

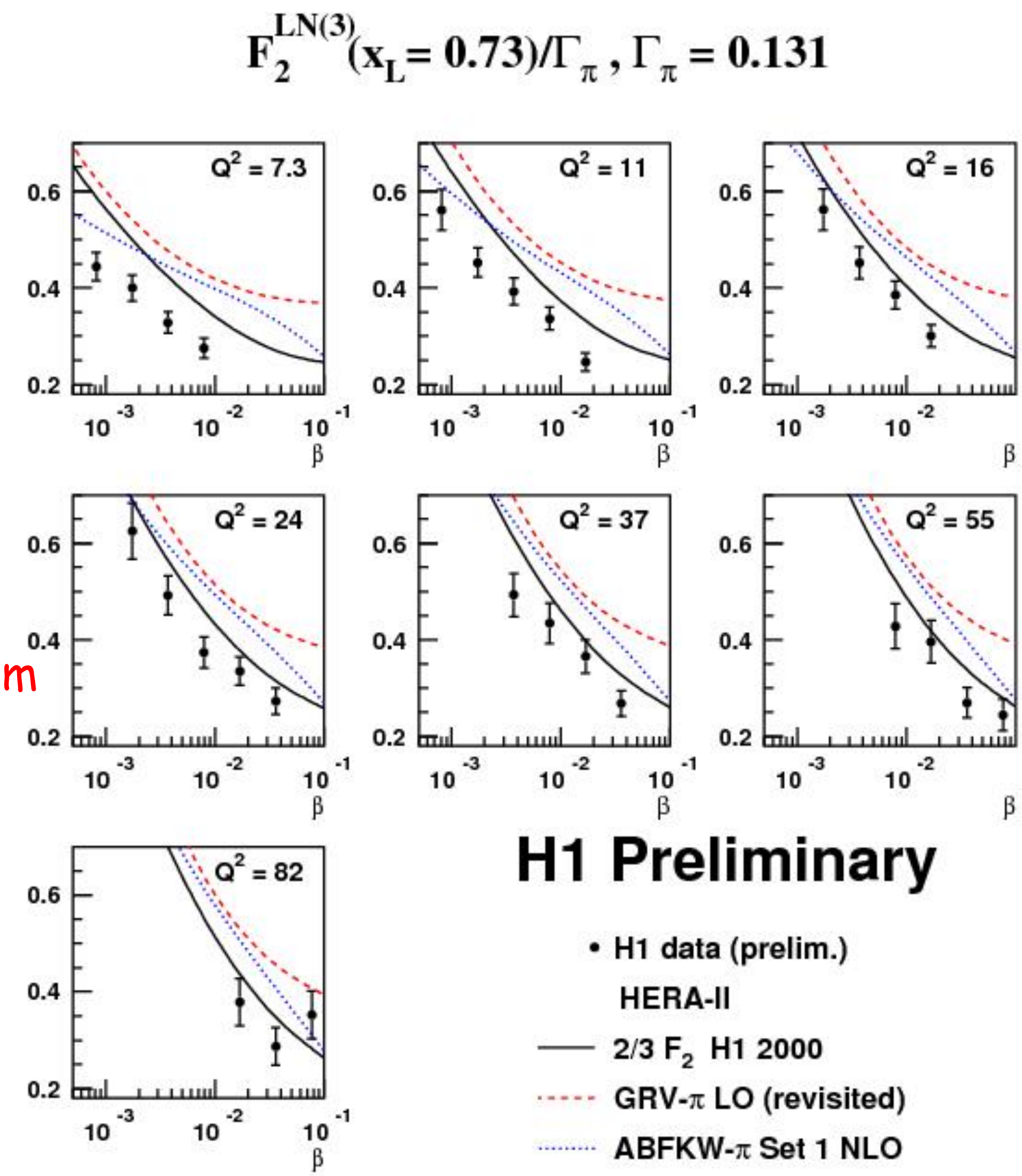
Pion Structure Measurement at HERA

$$ep \rightarrow e'nX$$

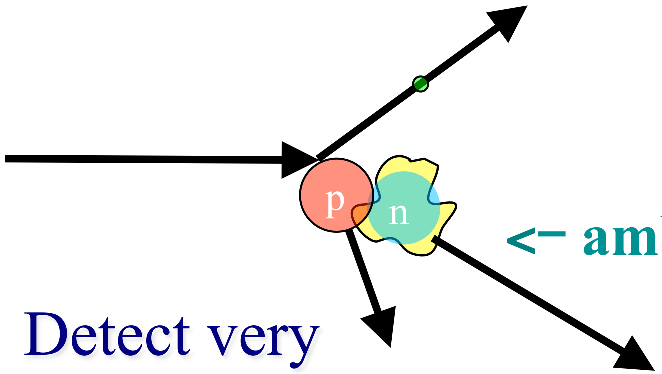
$$\beta \equiv x_\pi$$

Similar results from ZEUS

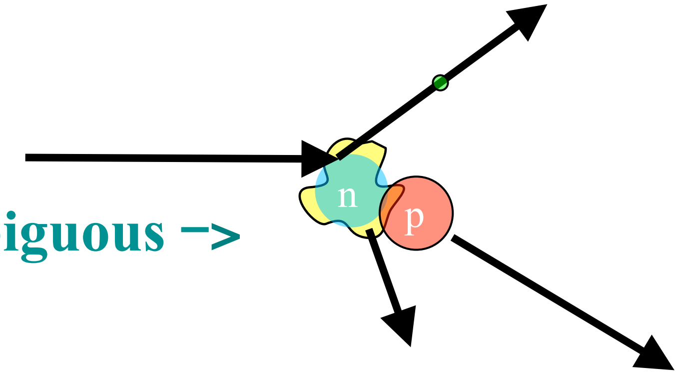
Very small x_π



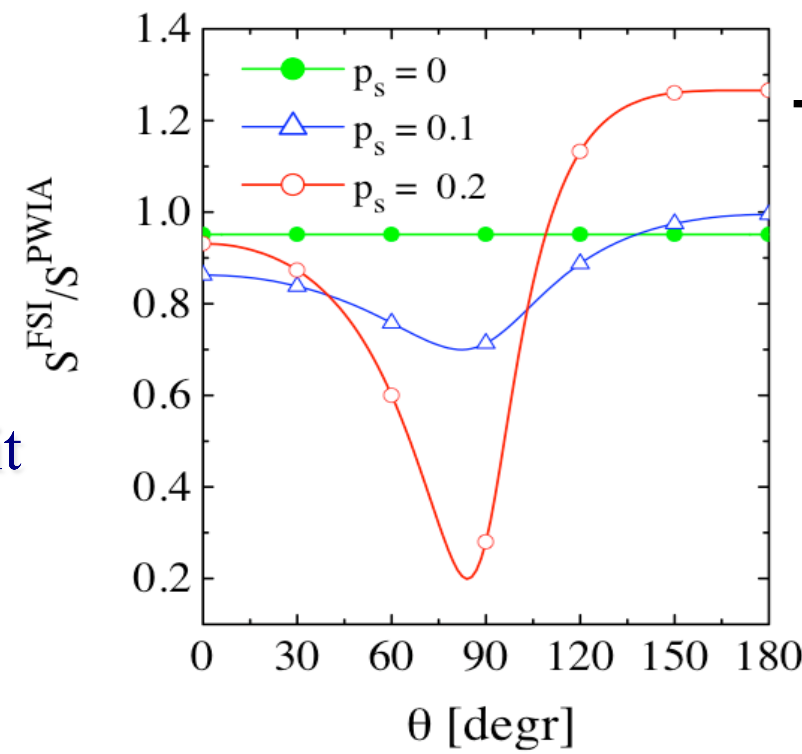
Need Low Momentum AND Large Angle for Spectator

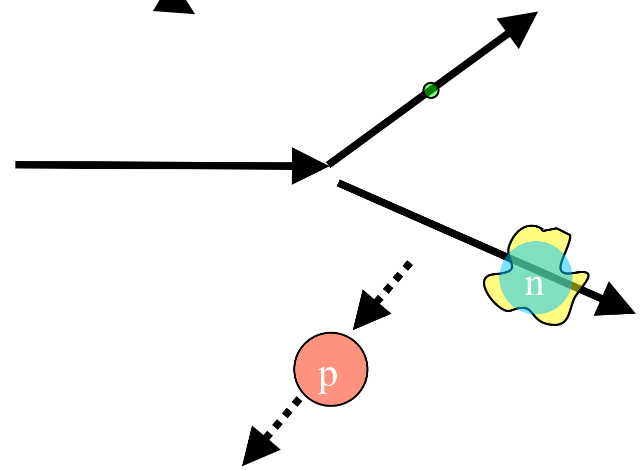


<− ambiguous −>



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**