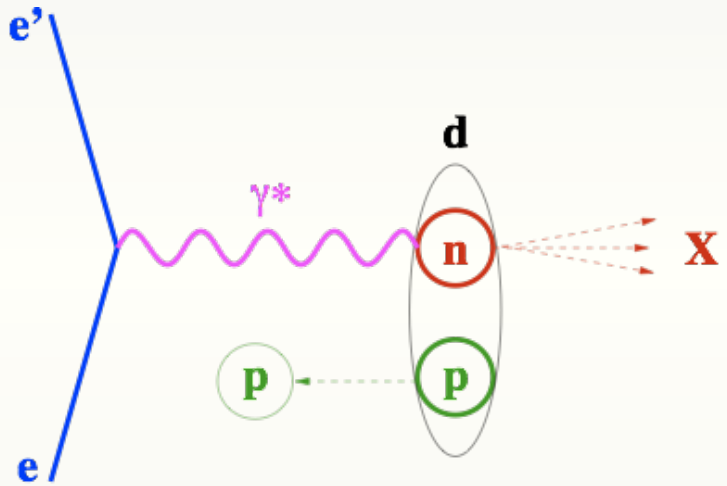
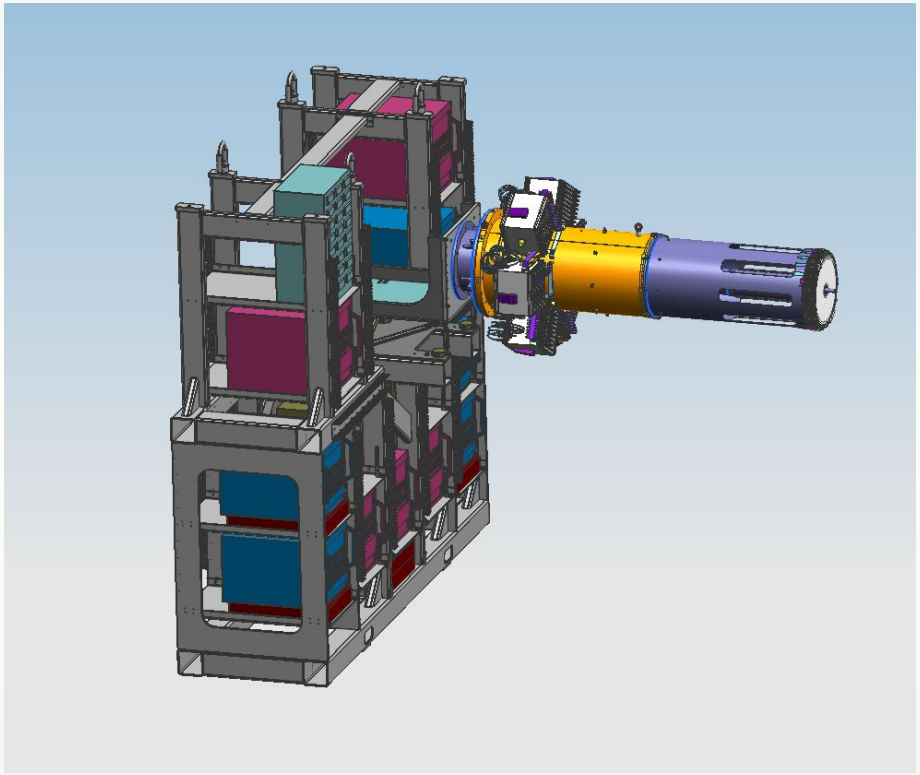
Status Report

BONuS12 (E12-06-113, CLAS12 Run Group F)

Oct 5, 2017



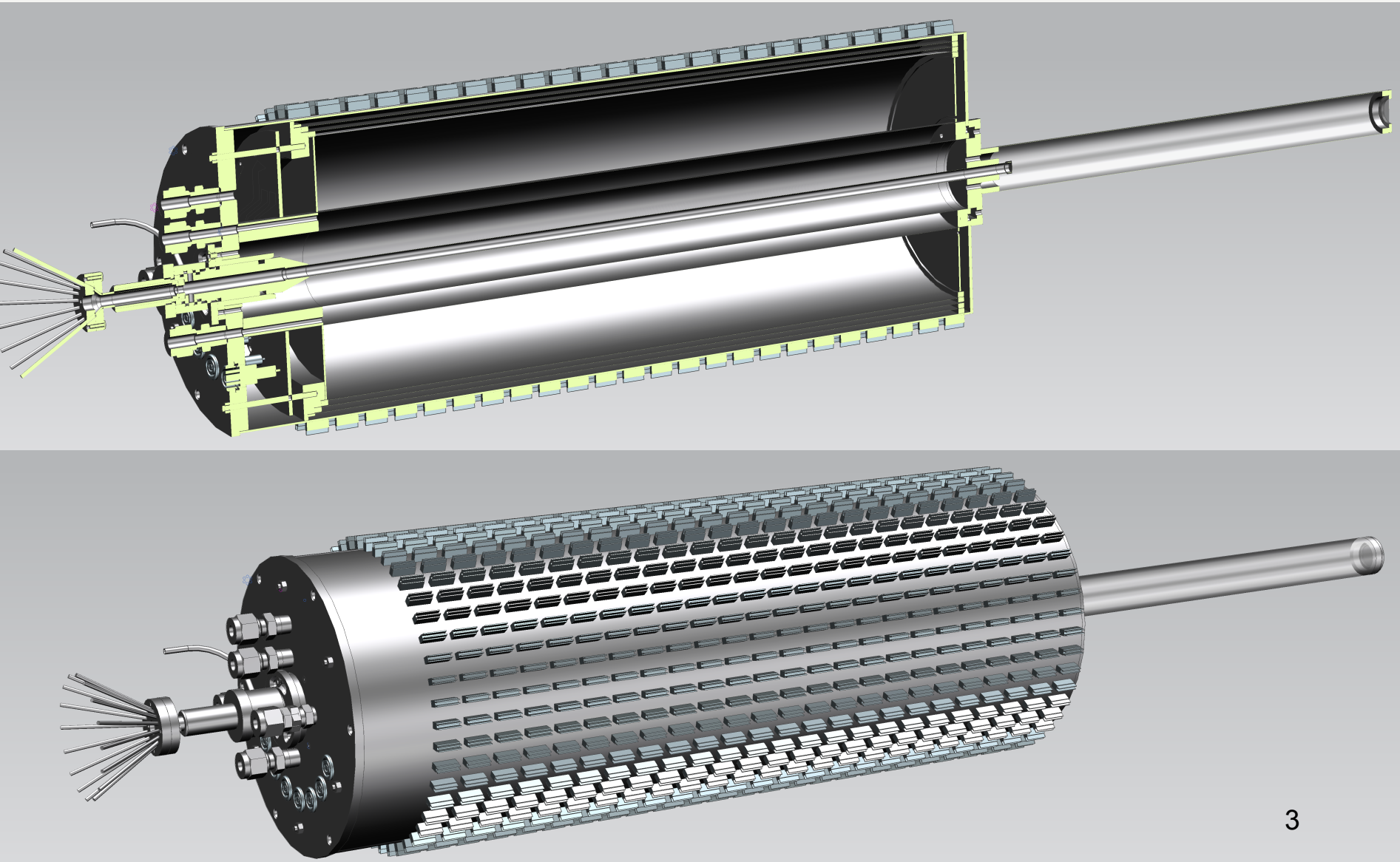


Sebastian Kuhn, *Old Dominion University*

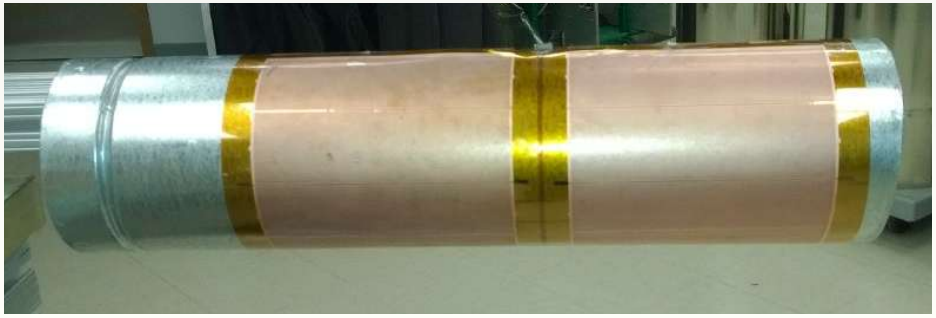
Project Status

- All detector parts designed
  - Design choices verified by extensive simulations, prototyping and tests
  - 7.5 atm deuterium target straws in hand and tested
  - Pressure system reviewed
  - Gas system designed
  - All electrical systems and circuit boards preliminary designs completed
  - DAQ system evaluated, DREAM Electronics tested
  - Slow Controls under development
- Integration into CLAS12 central detector and beamline under design
- GEM foils on hand, about to be tested
- Preliminary detector simulations in GEANT4 and GEMC done; Full Physics simulation chain (GEMC -> Coatjava -> HLA) underway
- Pattern recognition and track fitting (Kalman) algorithms developed
- Operations, commissioning & calibration and safety documentation exists

RTPC w/ target

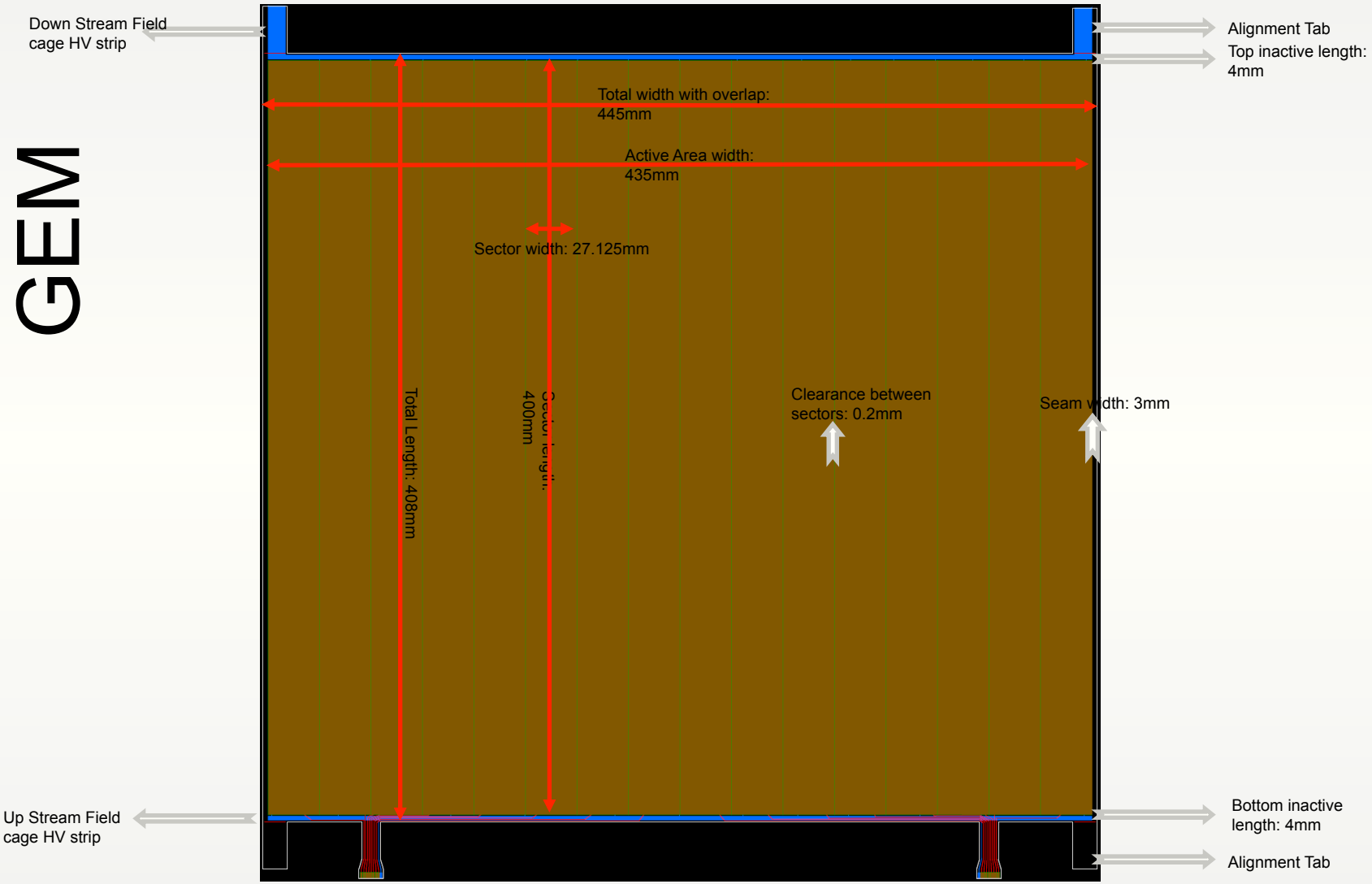


Mechanical Design/Prototyping



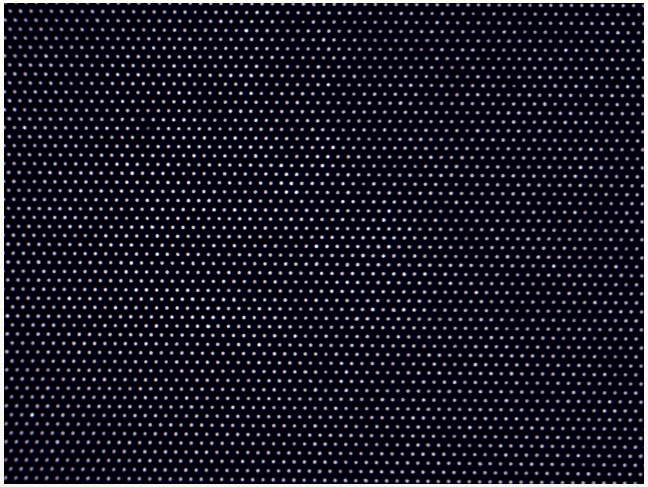
GEMs

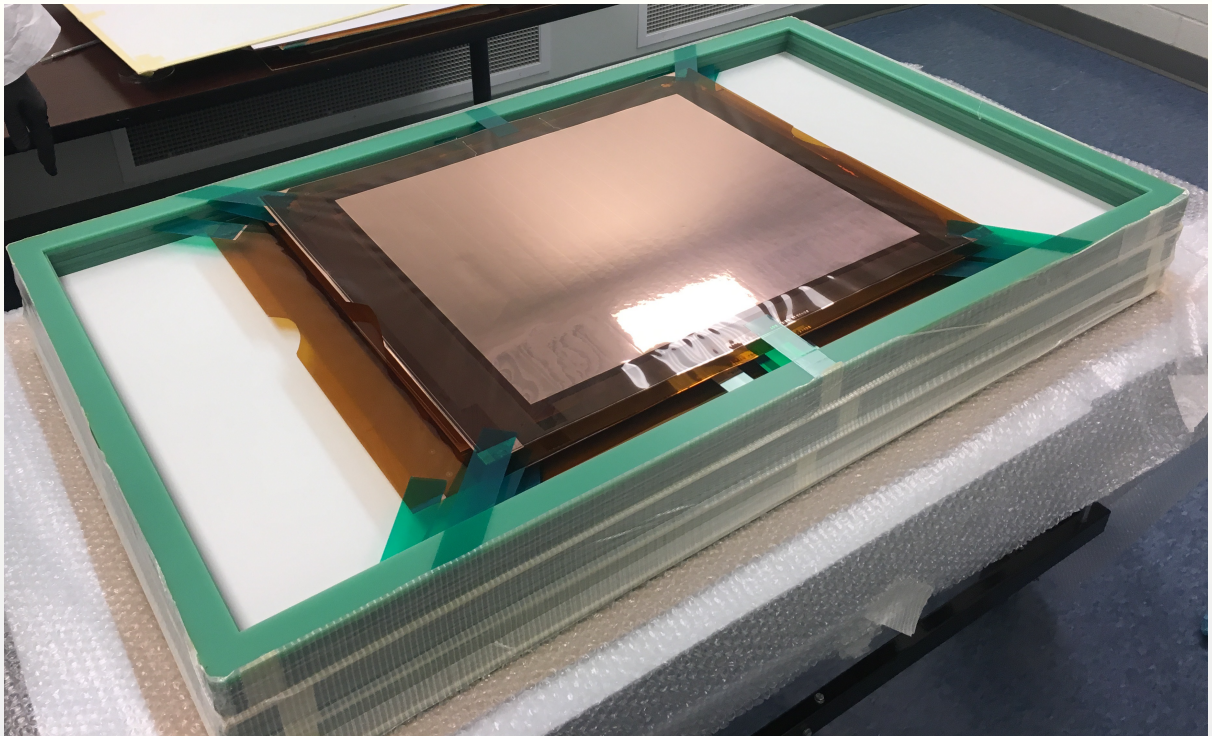
Inner GEM



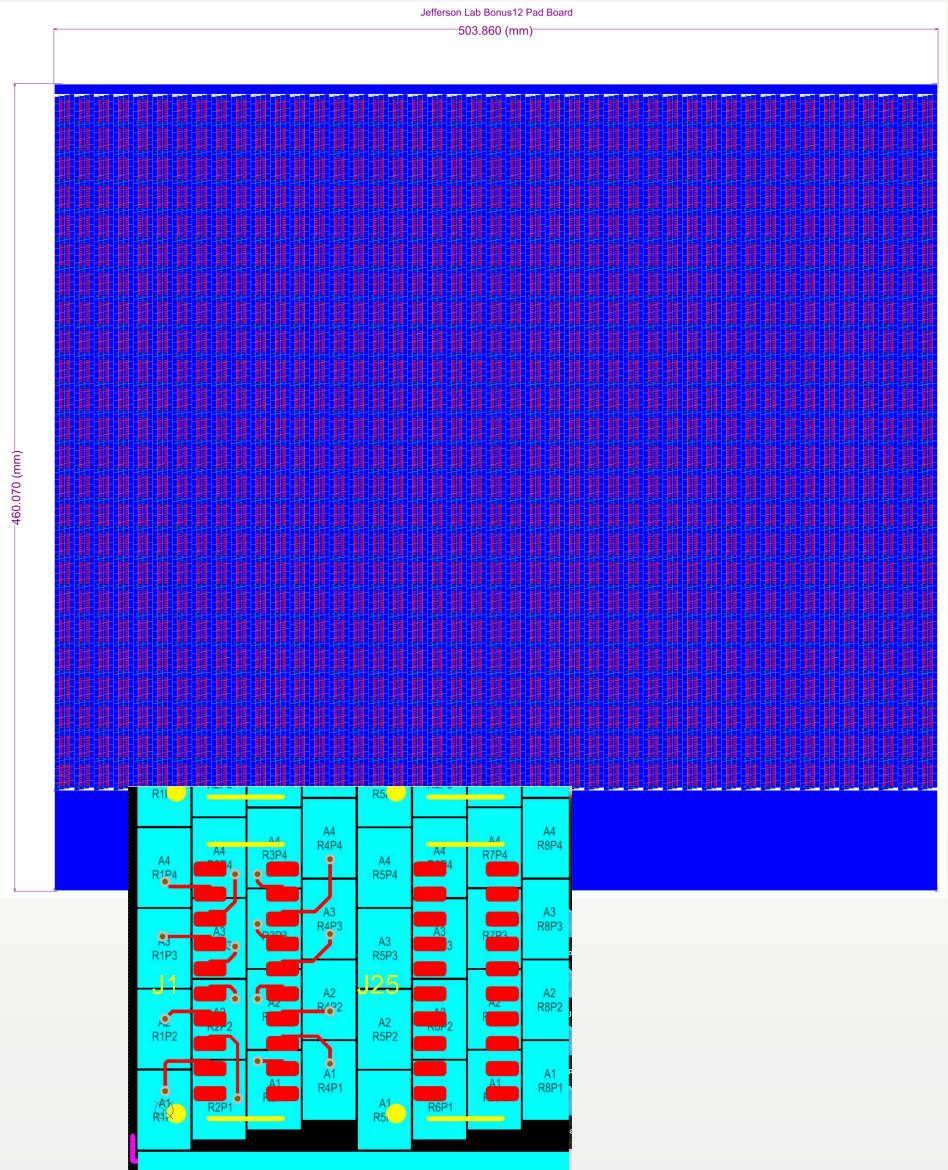
GEMs

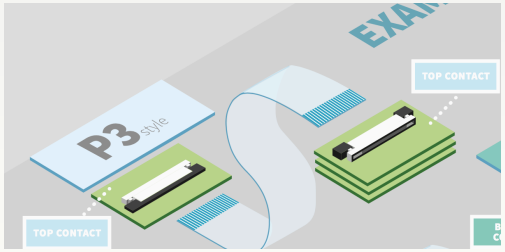
- We have 27 (3x9) GEMs in hand (produced by CERN)
- Developing testing procedures, storage and assembly

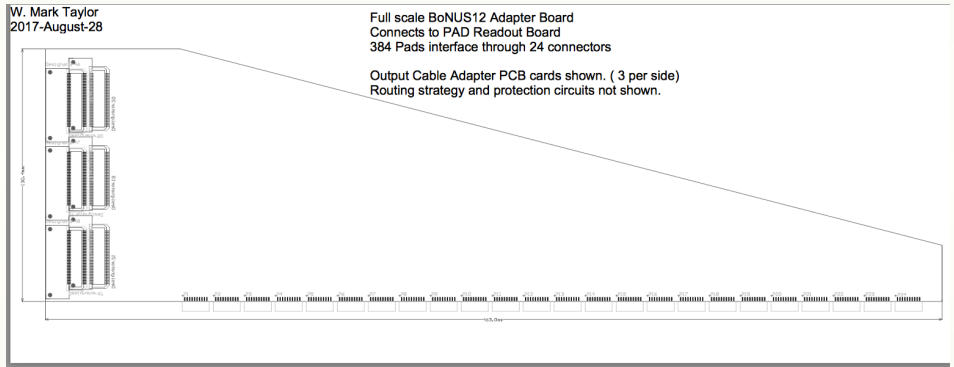


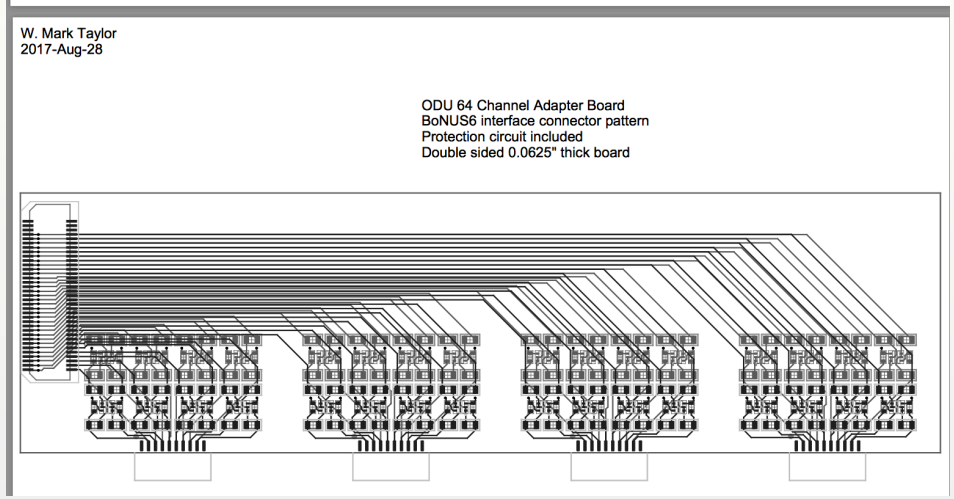


Readout Board Design



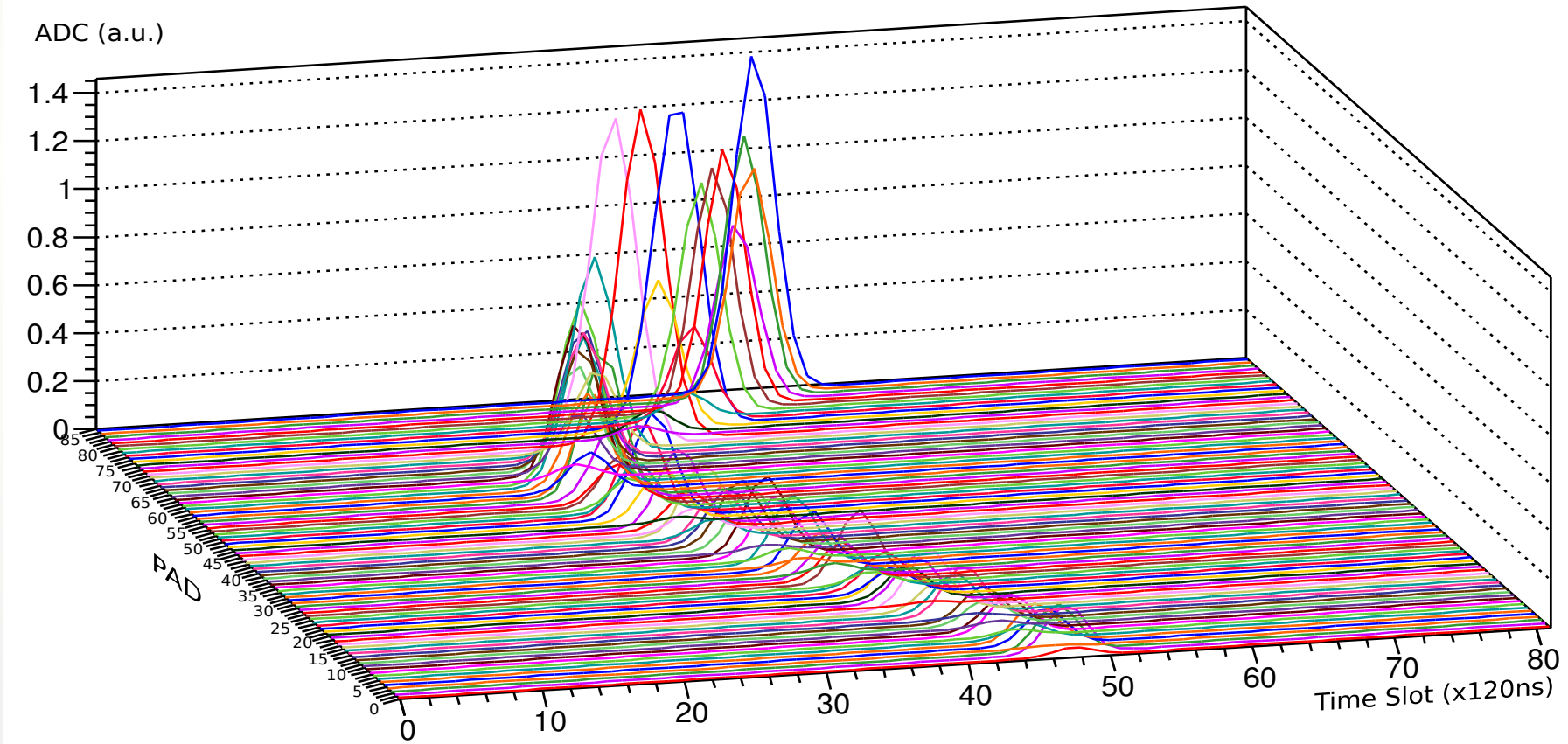




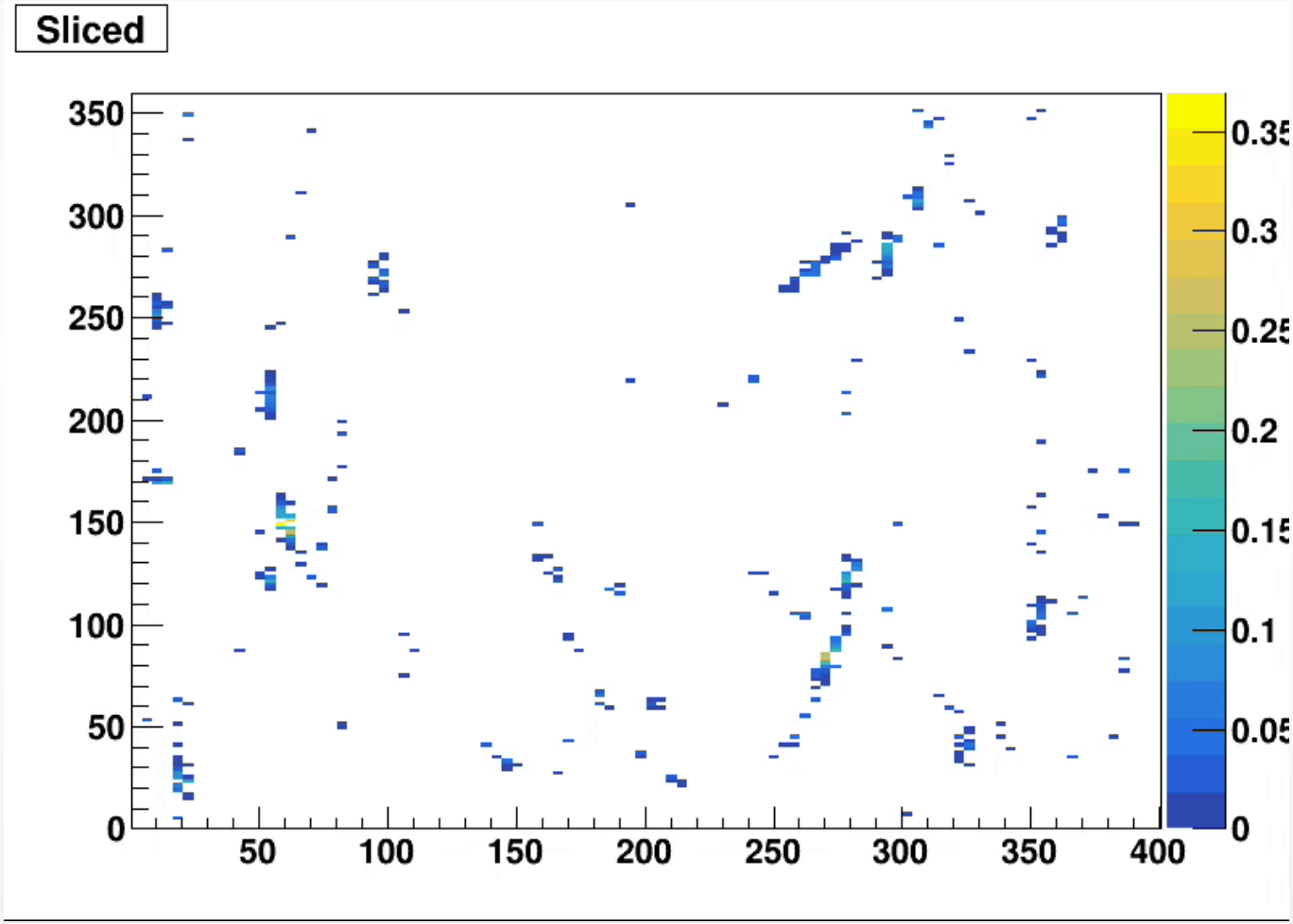


Software/Simulation

- Full simulation with signal shape in DREAM
- GEMC, Coatjava, track finder, Kalman filter,…



Software/Simulation



Manpower

*) Co-spokesperson

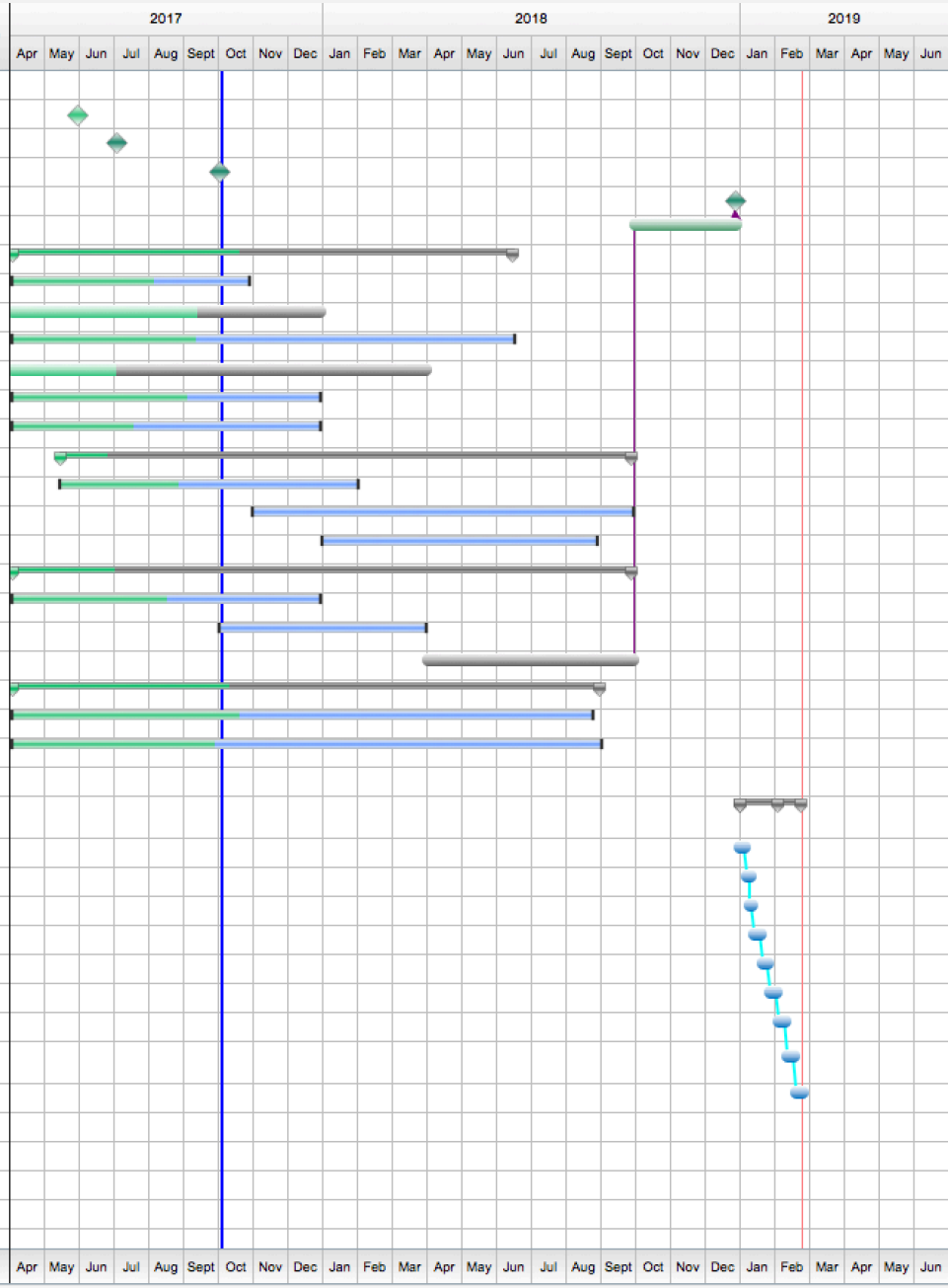
- Old Dominion University
  - Faculty: S. Bültmann *) (contact), S. Kuhn *), G. Dodge
  - Postdoc: G. Charles (100% FTE) [+ technician T. Hartlove (25% FTE)]
  - Students: **N. Dzbenski, D. Payette, J. Poudel**, (M. Ehrhart) + 3 UG students
- Hampton University
  - Faculty: M.E. Christy *)
  - Postdoc: I. Albayrak
  - Student: **A. Nadeeshani**
- William and Mary
  - Faculty: K. Griffioen *)
  - Postdoc: C. Ayerbe (Ph.D. Student, TBD)
- Jefferson Lab
  - Senior Physics Staff: H. Fenker *), C. Keppel *), W. Melnitchouk *), S. Stepanyan (Physics Liaison)
  - Electronics/DAQ: C. Cuevas, S. Boiarinov
  - Engineering/Design: R. Miller, M. Zarecky
  - Gas flow simulation: S. Covrig, S. Gopinath
  - Simulation and Analysis software: M. Ungaro, V. Ziegler, N. Harrison, V. Gyurjyan, G. Gavalian
  - Acc/Ops: M. Tiefenback, B. Cade
- Other institutions
  - Virginia Union University: N. Kalantarians (Slow Controls) + UG students
  - Virginia Commonwealth University: Y. Prok (Slow Controls) + UG students
  - University of Virginia: J. Zhang (tracking, simulation); N. Lianage, K. Gnanvo (GEM design)
  - James Madison University: I. Niculescu
  - Mississippi State University: K. Adhikari, L. El Fassi, A. Kabir (Tracking)
  - Ohio University: Paul King (DAQ)
  - Saclay: M. Defurne, S. Aune, F. Sabatié, I. Mandjavidze (DREAM electronics, Integration)
  - CERN: Rui De Oliveira (GEM production)

Analysis Plans

- Have already 4 Ph.D. students and 3 FTE postdocs
  - being trained on CLAS12 operations, DAQ (including DREAM) and calibration/analysis (RG A)
- Plan to add more in near future
- Working on tools for DAQ, simulation and analysis
- Together with CLAS collaboration, developing standard calibration, data reduction and higher-level analysis tools
  (CALCOM, ACE committees)
- Plan: Have full simulation, analysis software in place at start of experiment

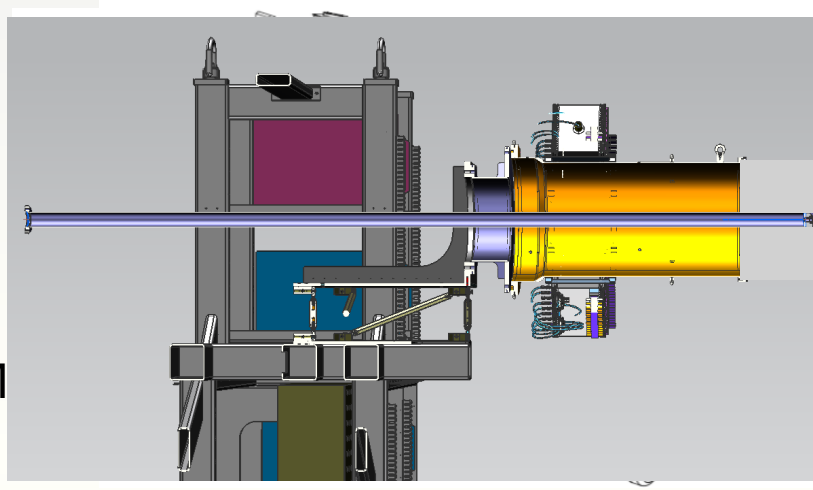
Overall Schedule

Activity Name	Resources Assigned	Duration (Weeks)	Start Date	% Done	Finish Date
Milestones					
Readiness Review		0.0	5/31/17	100%	5/31/17
Schedule Request		0.0	7/3/17	0%	7/3/17
Schedule Released by JLab		0.0	10/2/17	0%	10/2/17
All BONuS Equipment Ready to Install		0.0	12/28/18	0%	12/28/18
Float		13.0	10/1/18	0%	12/28/18
Detailed Design		**63.0**	**4/3/17**	**45%**	**6/15/18**
RTPC...		**30.0**	**4/3/17**	**60%**	**10/27/17**
Target	M. Zarekcy, ODU, R. Miller	39.0	4/3/17	60%	12/29/17
Ancillary Systems...		**63.0**	**4/3/17**	**37%**	**6/15/18**
Slow Controls	VCU, VUU, W. Moore	52.0	4/3/17	25%	3/30/18
Electronics...		**39.0**	**4/3/17**	**57%**	**12/29/17**
Integration...		**39.0**	**4/3/17**	**39%**	**12/29/17**
Construction		**72.0**	**5/15/17**	**8%**	**9/28/18**
GEM Assembly...		**37.6**	**5/15/17**	**40%**	**1/31/18**
Rest of RTPC...		**47.6**	**11/1/17**	**0%**	**9/28/18**
Target...		**34.3**	**1/1/18**	**0%**	**8/28/18**
Data Acquisition		**78.0**	**4/3/17**	**17%**	**9/28/18**
Front End Units...		**39.0**	**4/3/17**	**50%**	**12/29/17**
Back End Units...		**26.0**	**10/2/17**	**0%**	**3/30/18**
Online Monitoring Tools	CLAS CALCOM, ODU	26.0	4/2/18	0%	9/28/18
Data Analysis Software		**74.0**	**4/3/17**	**37%**	**8/31/18**
Data Processing...		**73.0**	**4/3/17**	**39%**	**8/24/18**
Simulation...		**74.0**	**4/3/17**	**34%**	**8/31/18**
Installation in Hall (Arbitrary start point; after end of previous experiment and Hall ready)		**7.8** 5.0	**1/1/19** 1/1/19	**0%** 0%	**2/22/19** 2/4/19
Remove MVT/SVT cart and bring to EEL		0.8	1/1/19	0%	1/4/19
Separate MVT from SVT, store SVT		0.6	1/7/19	0%	1/9/19
Disconnect all MVT cables from FEUs, secure		0.4	1/10/19	0%	1/11/19
Remove FMVT, remove BMVT and store		1.0	1/14/19	0%	1/18/19
Mechanically install all RTPC components and FMVT		1.0	1/21/19	0%	1/25/19
Install and test all cables, HV, gas lines		1.0	1/28/19	0%	2/1/19
Transport to Hall B, fiducialize, insert and align		1.0	2/4/19	0%	2/8/19
Integrate into CLAS12 DAQ, ancillary systems, beam line		1.0	2/11/19	0%	2/15/19
Cosmic tests		1.0	2/18/19	0%	2/22/19



Backup Slides

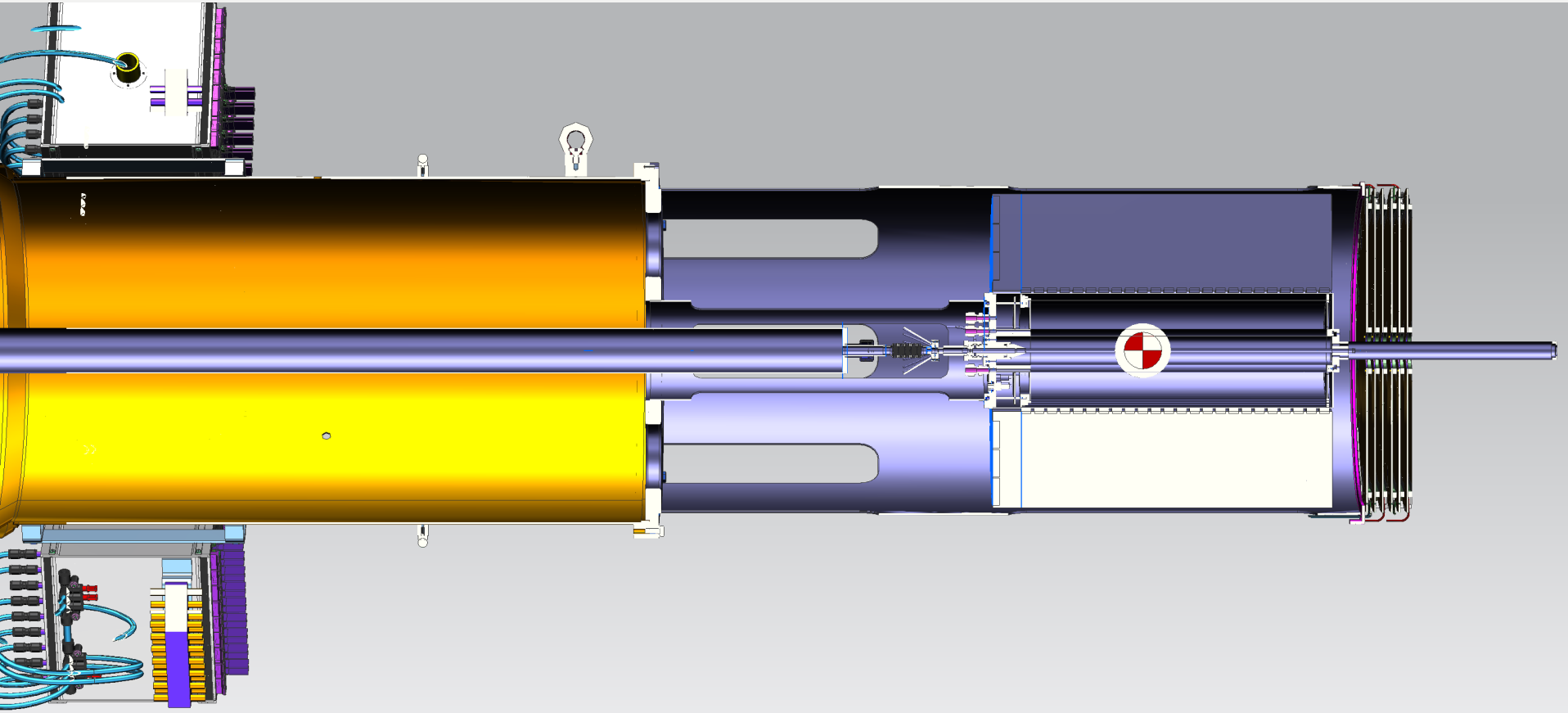
Installation



- Remove upstream beamline
- Retract MVT/SiVT cart
- Separate MM assembly from SiVT
- Store SiVT
- Disconnect all MM-DREAM cables at MM
- Remove MM, store Barrel MM safely
- Install upstream MM electronics barrel, RTPC holder and beam pipe on cart
- Install RTPC + target, attach all plumbing, readout boards, electrical connections, cables to DREAM FEUs
- Fiducialize RTPC position relative to alignment targets
- Install outer shell/Forward MM Vtx holder
- Install and cable up Forward MM Vtx counters
- Insert cart back into CLAS12 CD and align
- Replace beam line, align and pump down.

Estimate: 4 weeks

Installation



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Commissioning

- Commissioning without beam
  - Test run with ^{90}Sr source
  - Cosmic test run on bench (before installation)
  - Cosmic test run with CTOF (no solenoid field)
    - Check operation, alignment, acceptance/efficiency
  - Cosmic test run with CTOF (solenoid on)
    - Check track reconstruction, efficiency, resolution
- Commissioning with beam (2.2 GeV)
  - Low current (20 nA), 1 atm target (“empty)
    - Check backgrounds, noise
  - Low current, full (7.5 atm H) target
    - Check occupancies, data rates, dead channels
  - Full current (200 nA), 7.5 atm H target (1 PAC day)
    - p(e,e’p) and p(e,e’p $\pi^+\pi^-$) reactions to calibrate alignment, tracking parameters, resolution and gain/efficiency of RTPC
  - 7.5 atm D target (1 PAC day)
    - d(e,e’pπ^- p_S) to further calibrate RTPC and determine acceptance, efficiency, track reconstruction, and particle ID

Run Plan

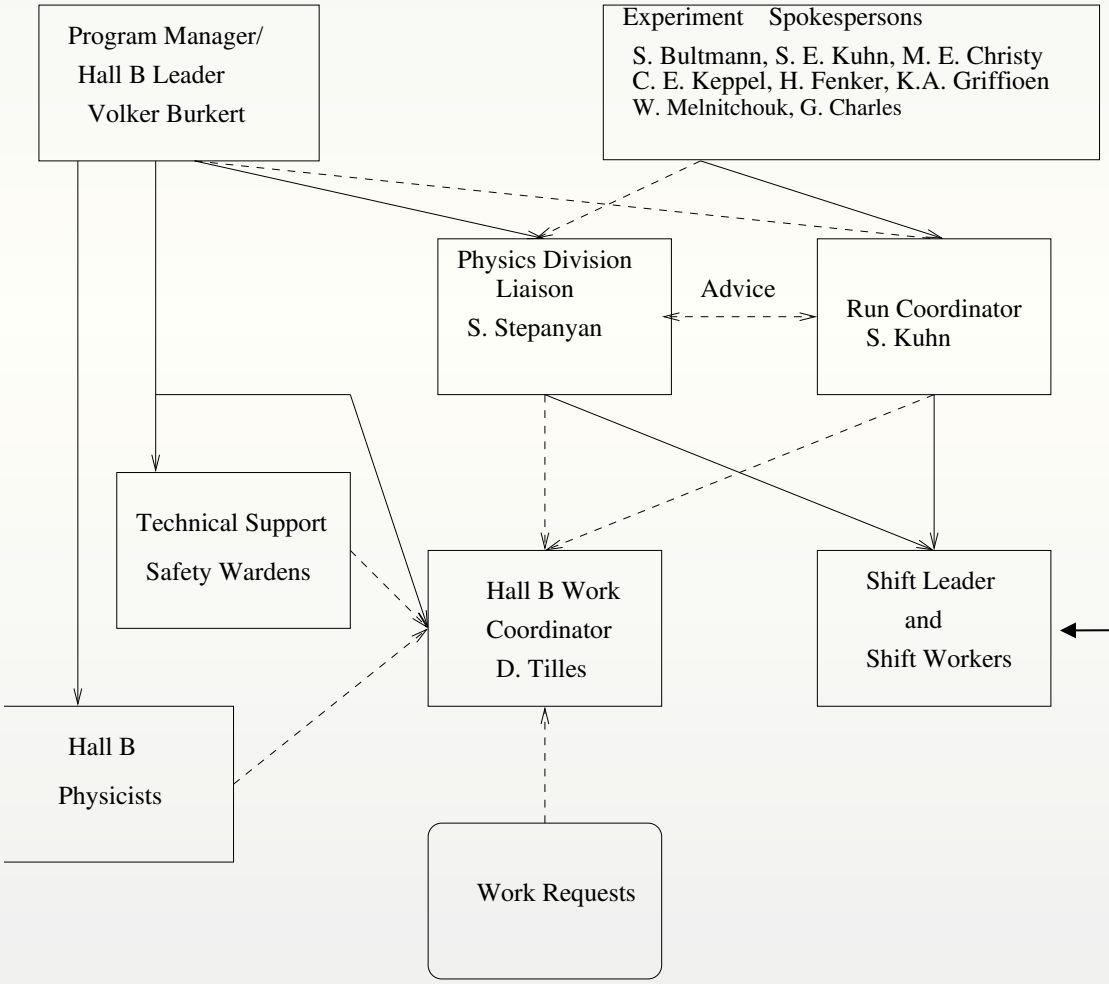
- Commissioning Run (2.2 GeV, 2 PAC days)
- Standard Data Taking (11 GeV, 40 PAC days)
  Assume 3-4 PAC days per week -> 10-13 weeks of running. Each week:
  - About 1 calendar day of H_2 for cross normalization and calibration check (use p(e,e'p $\pi^+\pi^-$) reaction)
  - About 5-6 calendar days of running with D_2;
  - Interspersed with short (2 hour) "empty" (1 atm H) target runs and occasional ^{4}He target runs (to check for contamination of target and improve PID)

Deinstallation

- Final cosmic ray run
- Open beam pipe, retract cart
- Disconnect all detector cables
- Remove forward MM Vtx trackers
- Deinstall RTPC, beam line and all ancillary devices
- Reinstall full MM complement, combine with SiVT
- Align, cable up
- Reinsert into CD; establish beam line

Estimate: 4 weeks

Organization



CLAS collaboration:
Responsible for manning all beam shifts

BONuS group:
Responsible for RTPC expert shifts / expert on call

The Structure of the Free Neutron at Large x-Bjorken

A 12 GeV Research Proposal to Jefferson Lab (PAC 36)

Resubmission of Conditionally Approved Experiment E12-06-113

M. Amarian, S. Bültmann (co-spokesperson)*, G. E. Dodge, C. E. Hyde,
S. E. Kuhn (co-spokesperson), L. B. Weinstein
Old Dominion University, Norfolk, Virginia, USA

J. Arrington, R. Dupré, A. El Alaoui, K. Hafidi, X. Zhan
Argonne National Laboratory, Argonne, Illinois, USA

M. Battaglieri, R. De Vita
INFN Genova, Genova, Italy

N. Baillie, M. E. Christy (co-spokesperson), C. E. Keppel (co-spokesperson)
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University of Illinois at Urbana-Champaign, Urbana-Champaign, Illinois, USA

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V. Burkert, A. Deur, R. Ent, H. Fenker (co-spokesperson),
W. Melnitchouk (co-spokesperson), S. Stepanyan, J. Zhang
Thomas Jefferson National Accelerator Facility, Newport News, Virginia, USA

N. Kalantarians
University of Virginia, Charlottesville, Virginia, USA

K. A. Griffioen (co-spokesperson)
The College of William and Mary, Williamsburg, Virginia, USA

and The CLAS Collaboration

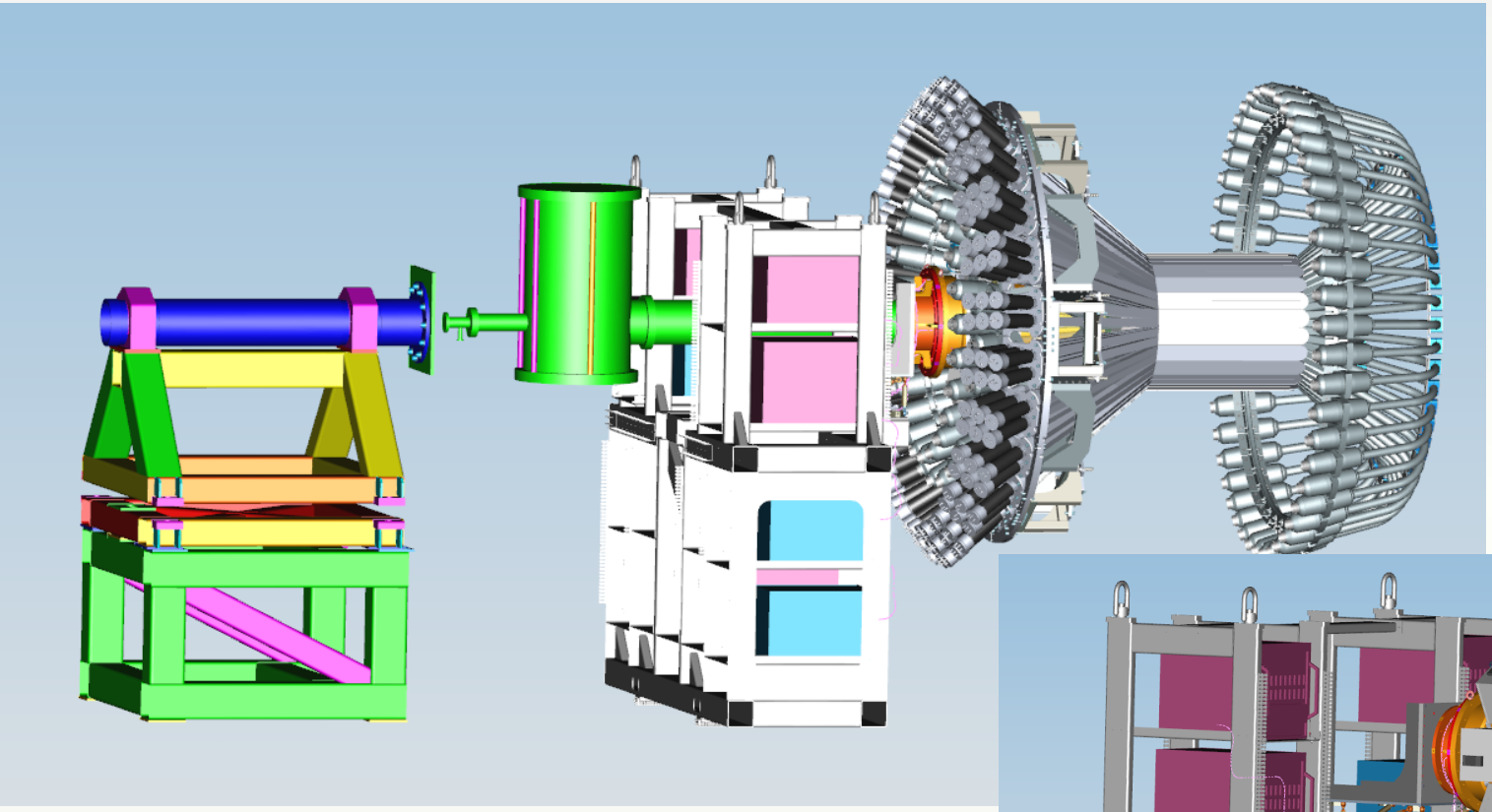
* Contact: Stephen Bueltmann, Department of Physics, Old Dominion University, Norfolk, VA 23529. Email: sbueltma@odu.edu

Estimated Cost to Completion

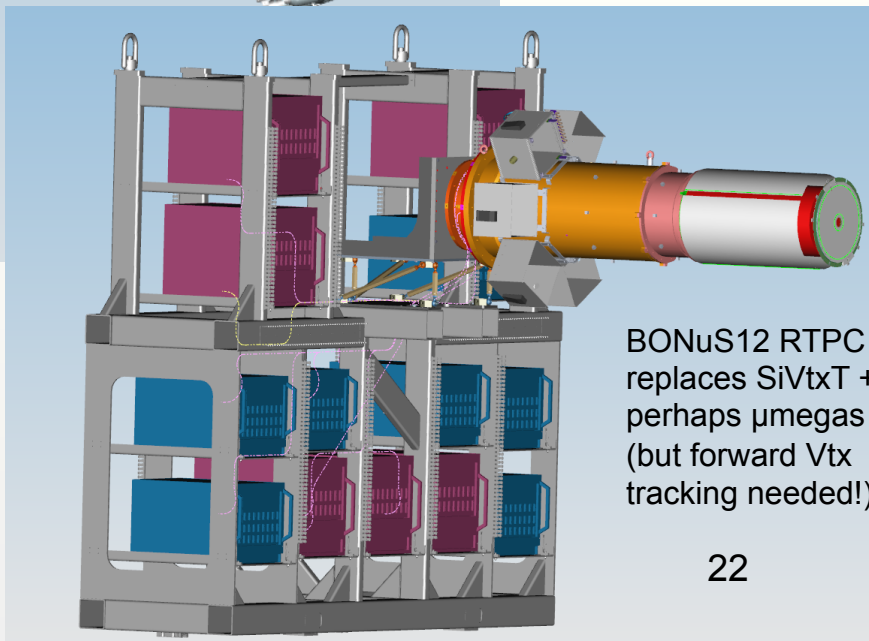
- Parts (Note: Most parts for RTPC and target gas system already exist)
  - GEM foils: $30,000 contract with CERN, to be paid for by ODU through VA ETF
  - DAQ test stand with 4 DREAM FEU: $13,249, paid by ODU DOE grant
  - HV supplies: $7,000, to be paid by ODU DOE grant

  - 2 Readout pad boards: $15,000
  - Adapter circuit boards: $25,000
  - Samtec MicroBNC cables: $45,000
  - Small structural items for RTPC (ULTEM, Al): $1,000 (material)
  - Mandrels for GEM and cathode/ground foil assembly: $5,000 (material)
  - Assorted cables, tubing, sensors etc. $20,000
- Construction
  - Machine shop detector parts $5,000 (JLab)
  - Machine shop mandrels + assembly fixture, tooling $20,000 (JLab)
- Manpower
  - All principal members of the collaboration are funded by DOE and NSF grants – several specifically for BONuS-related expenses (ODU, UVa, HU, VUU, W&M)
  - Jefferson Lab Hall B staff, electronics group, designer, engineer, design authority
- Total: Still to spend $146,000

BONuS12 RTPC Design

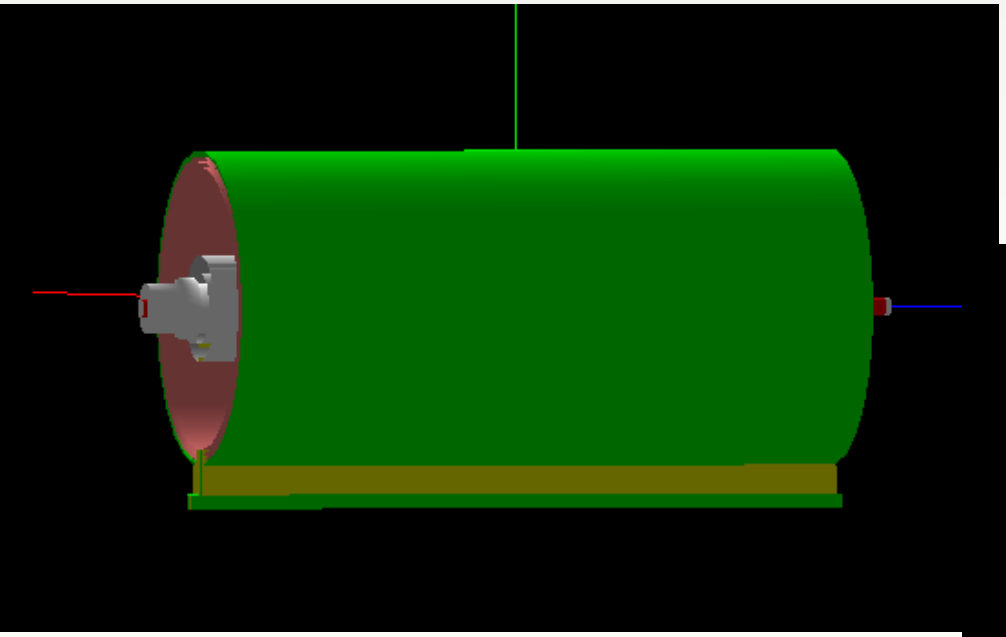


CLAS12 Central Detector

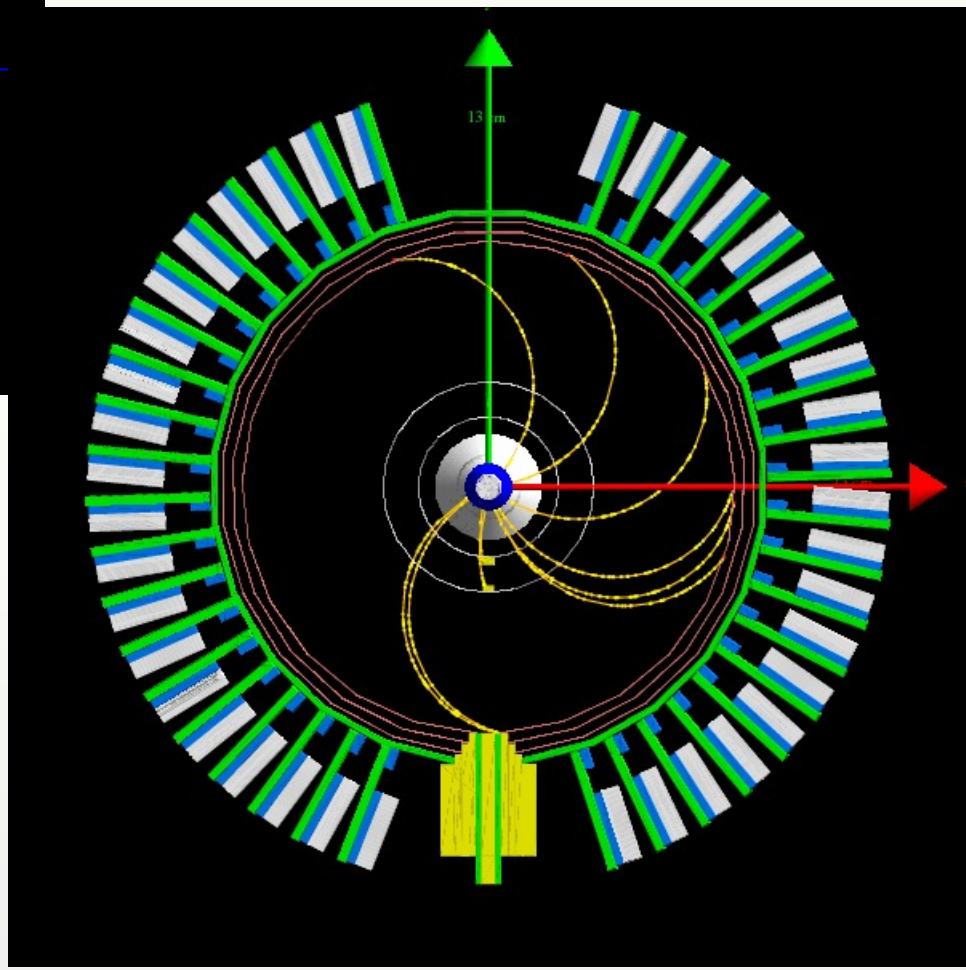


BONuS12 RTPC replaces SiVtxT + perhaps μmegas (but forward Vtx tracking needed!)

GEANT4 Studies (Jixie Zhang)



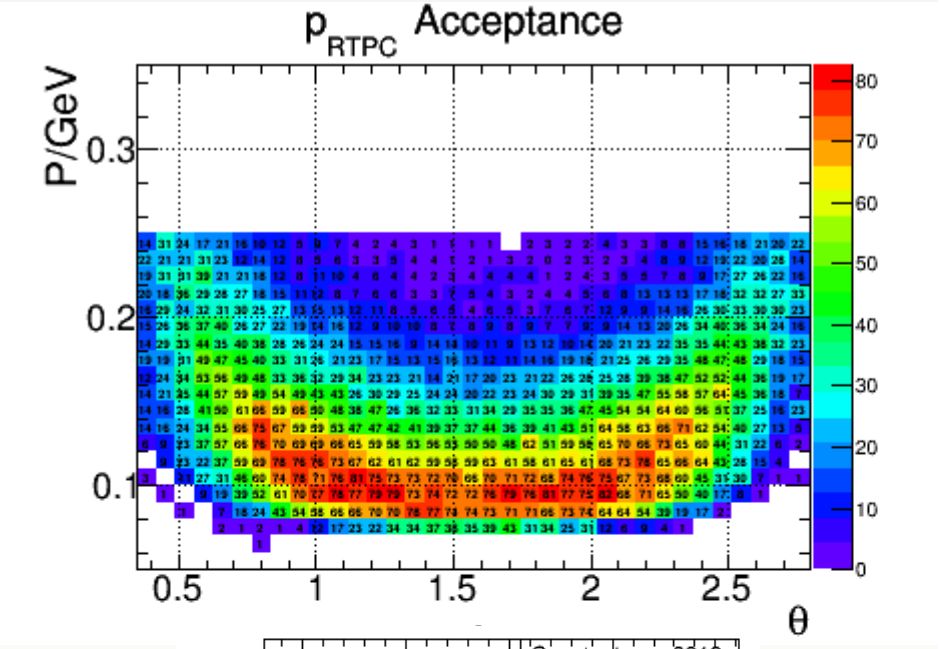
70 MeV/c protons

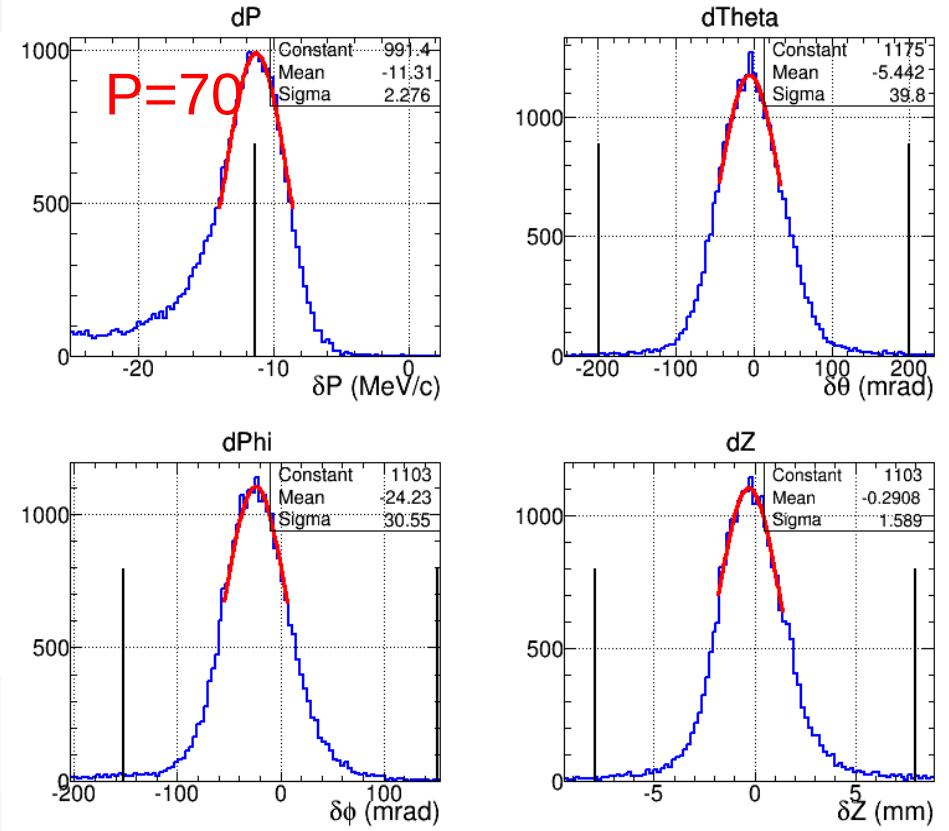


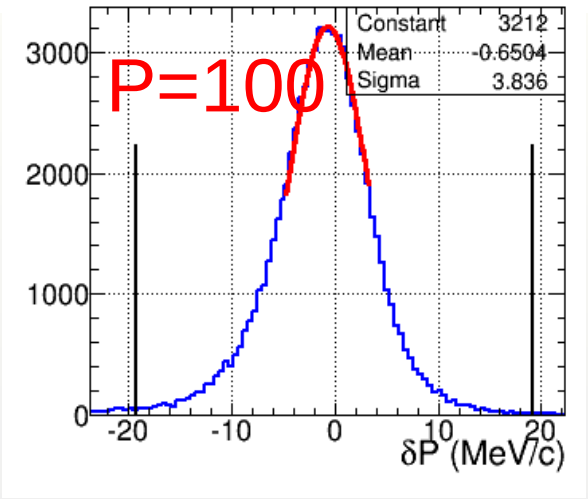
Target: D_2 gas, 293k,
7.0 atm, 3(5?) mm radius, 40 cm long
Target Wall: 28 μm Kapton
Drift Region: 3<R<7 cm
Drift Gas: 293k, 1 ATM, He/DME (90/10)

Use CLAS12 Solenoid with 5T field pointing upstream

GEANT4 Studies

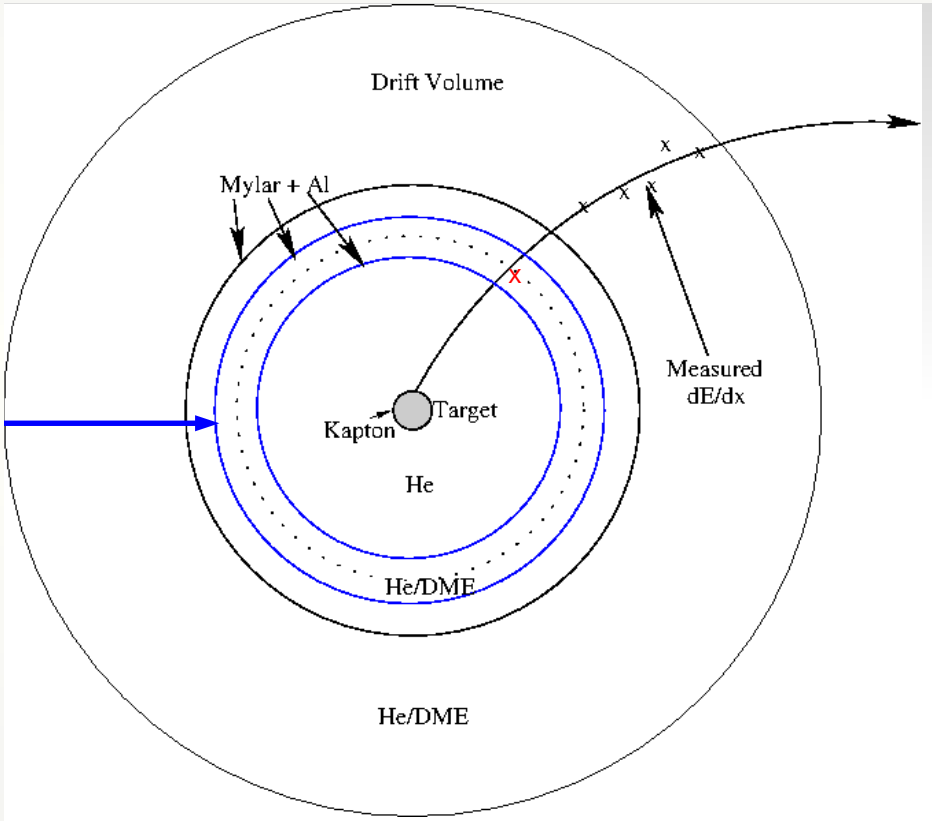


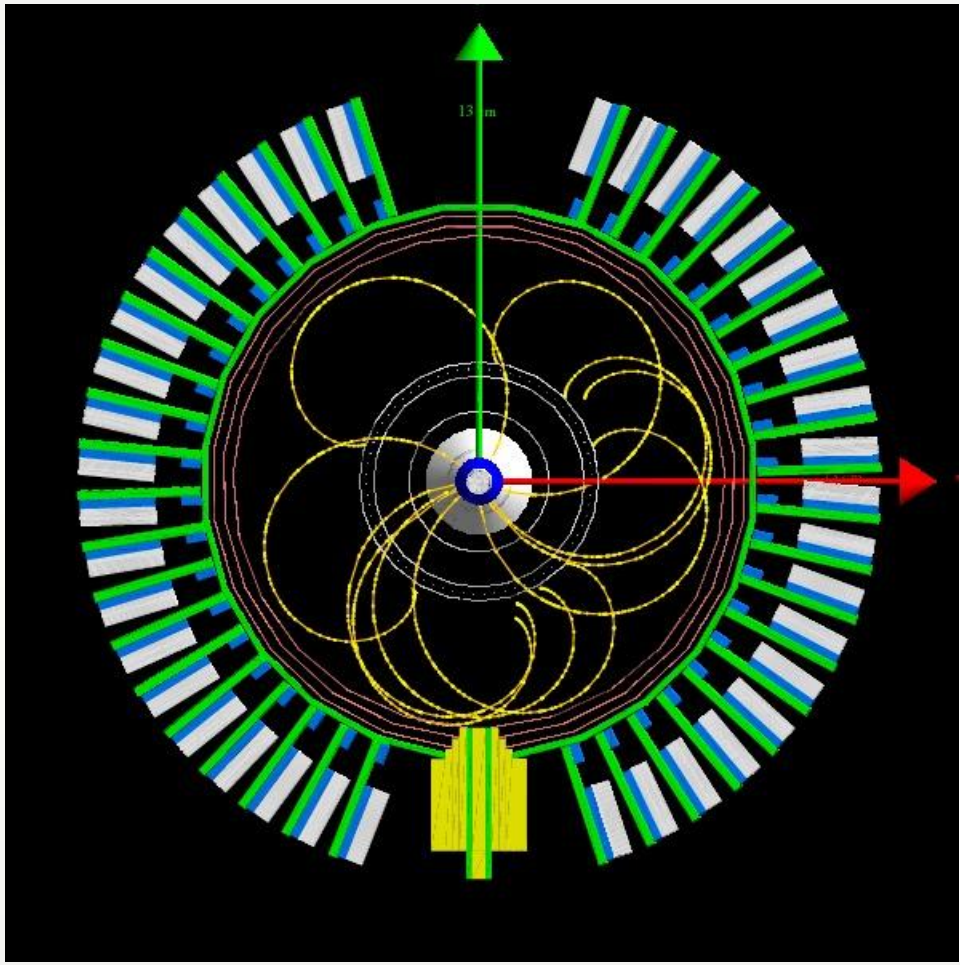




GEANT4 Studies – Hybrid Design

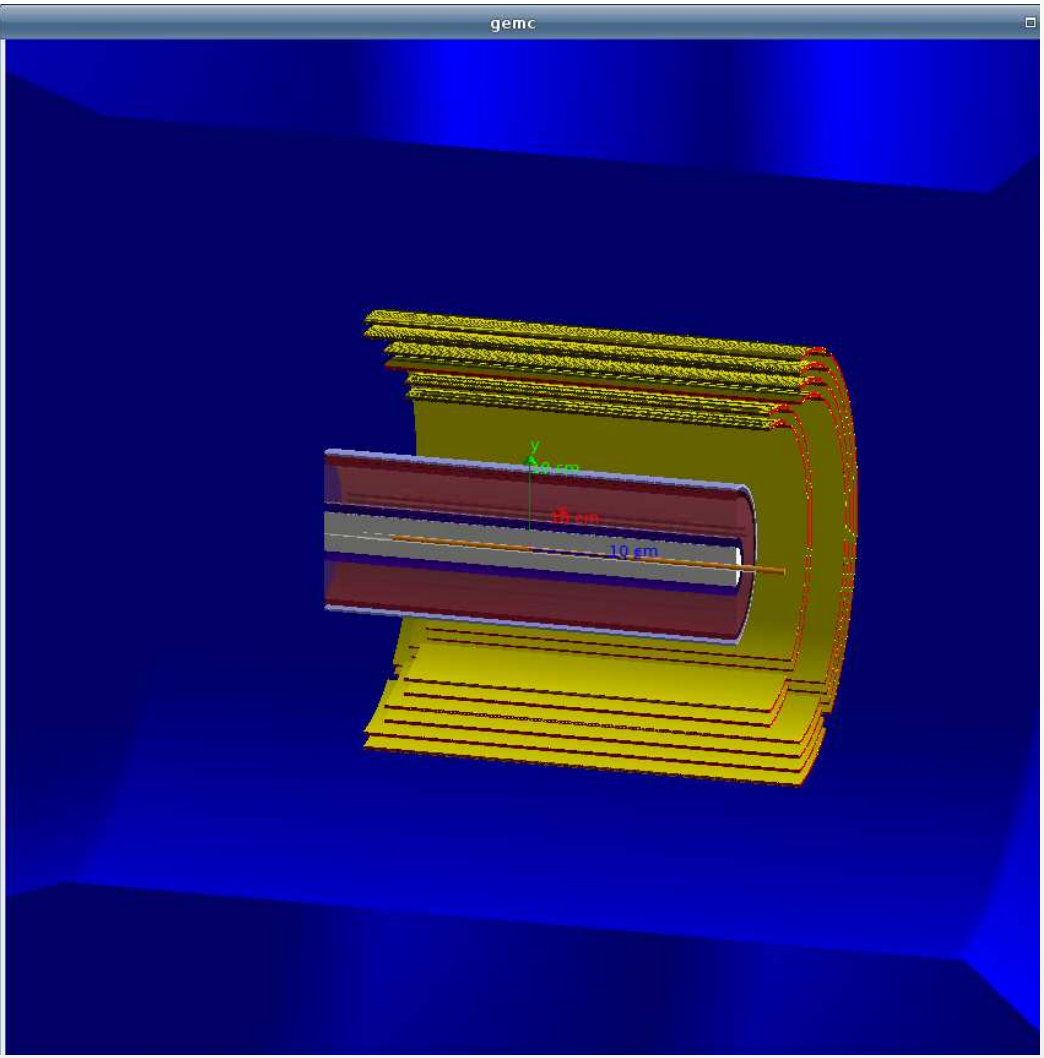
(E. Christy, H. Fenker, J. Zhang)

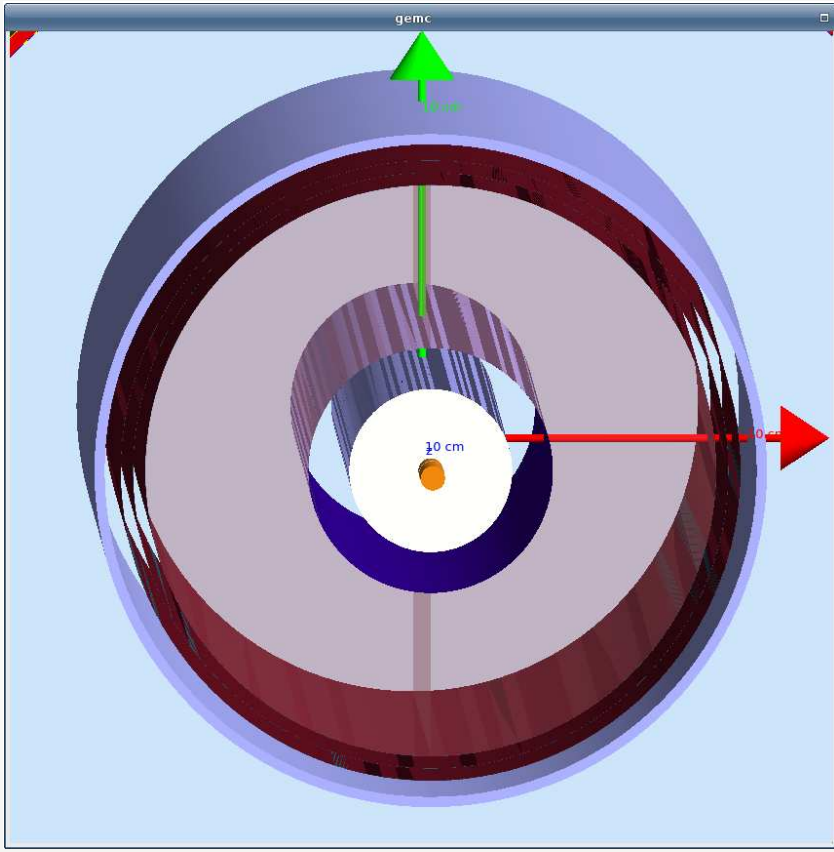




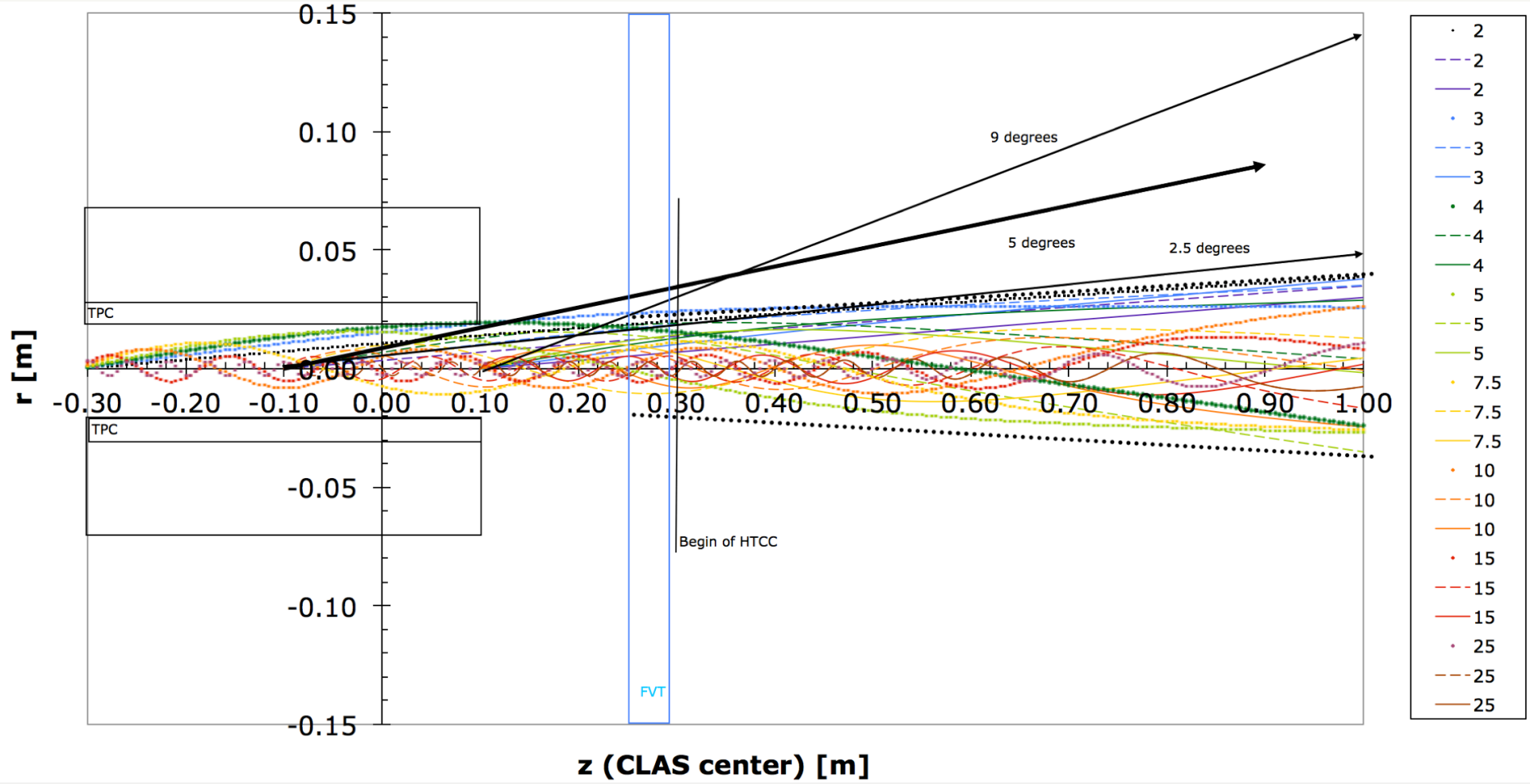
69 MeV/c p – may be recoverable!

GEMC Studies
(K. Park, N. Dzbenski)

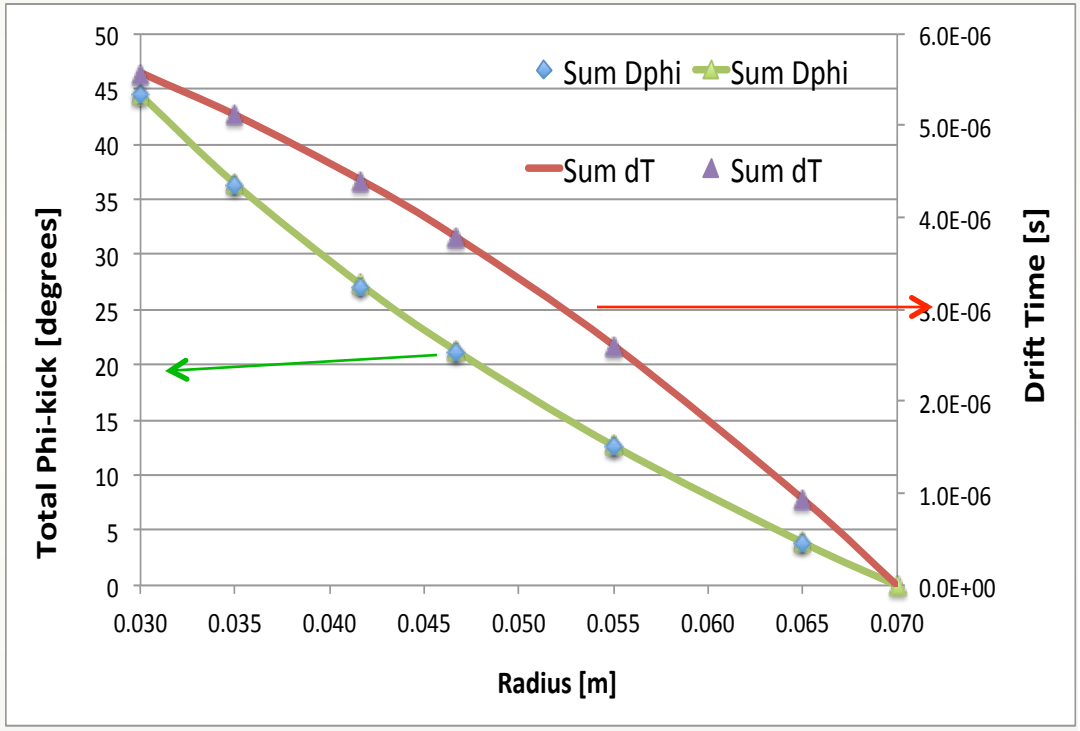




Møller Bckgnd:

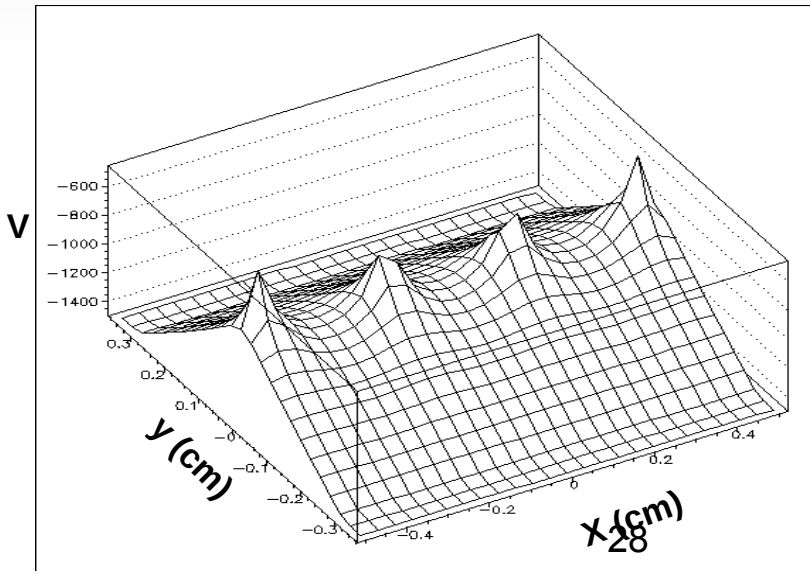


Magboltz/Garfield calculations



Drift time and Lorentz angle in the RTPC active region

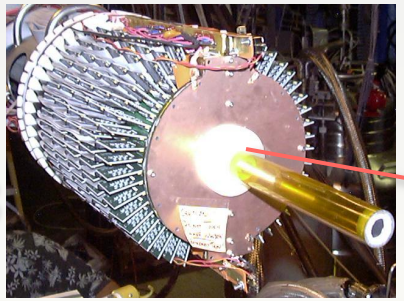
Potential for hybrid design

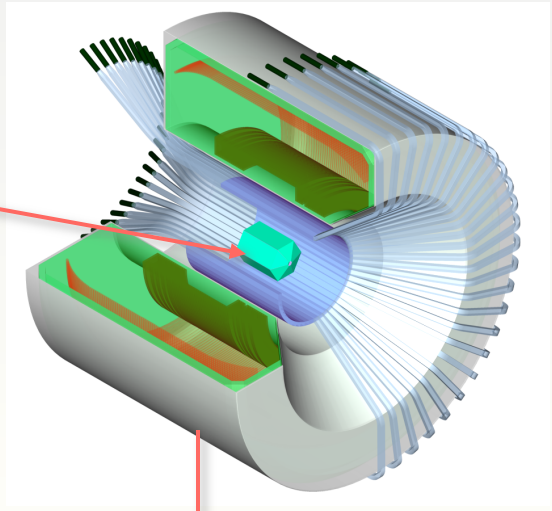


Plans for 12 (really: 11) GeV

BoNuS12

E12-06-113

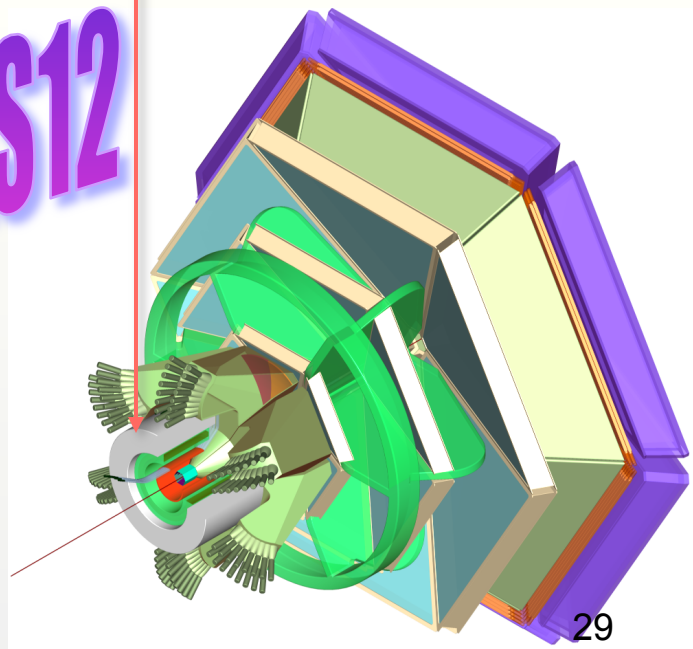




Central Detector

- Data taking of 35 days on D_2 and 5 days on H_2 with $\mathcal{L} = 2 \cdot 10^{34}$ cm^{-2} sec^{-1}
- **Planned** BoNuS detector DAQ and trigger **upgrade**
- DIS region with
  - $Q^2 > 1$ GeV$^2/c^2$
  - $W^* > 2$ GeV
  - $p_s > 70$ MeV/c
  - $10° < \theta_{pq} < 170°$
- Extend to higher momenta using central detector alone

CLAS12



Simple (Constituent) Quark Model

Flavor	Isospin I	I_3	Strangeness S	Charge Q	Baryon Number B
U	$1/2$	$+1/2$	0	$+2/3$	$1/3$
D	$1/2$	$-1/2$	0	$-1/3$	$1/3$
S	0	0	-1	$-1/3$	$1/3$

$$|\Delta^{++}\uparrow\rangle = |U\uparrow U\uparrow U\uparrow\rangle$$

$$|\Delta^{+}\uparrow\rangle = 1/\sqrt{3}\,(|U\uparrow U\uparrow D\uparrow\rangle + |U\uparrow D\uparrow U\uparrow\rangle + |D\uparrow U\uparrow U\uparrow\rangle)$$

The case of the proton is a bit more complicated, since the wave function cannot be symmetric in spin and flavor separately. The most intuitive way to derive the proton wave function is by observing that 2 of the 3 quarks are equal (U), and therefore their relative spin wave function should be symmetric also. This leads to the conclusion that the two U–quarks couple their spins to a total spin of one. Let's denote the case where this spin has a z-projection of $+1$ as $(UU\Uparrow) := |U\uparrow U\uparrow\rangle$, while the projection with $S_z = 0$ will be indicated by $(UU\Rightarrow) := 1/\sqrt{2}\,(|U\uparrow U\downarrow\rangle + |U\downarrow U\uparrow\rangle)$. We can now combine the spin $1/2$ of the remaining D quark with the spin 1 of the UU pair in two ways to get total spin and projection $1/2$; the proper way follows simply from insertion of the correct Clebsch-Gordon coefficients:

$$|P\uparrow\rangle = 1/\sqrt{3}\left(\sqrt{2}|(UU\Uparrow)D\downarrow\rangle - |(UU\Rightarrow)D\uparrow\rangle\right). \qquad (2)$$

Quark Model:

- SU(6)-symmetric wave function of the proton in the quark model:

$$|p\uparrow\rangle = \frac{1}{\sqrt{18}}\left(3u\uparrow[ud]_{S=0} + u\uparrow[ud]_{S=1} - \sqrt{2}u\downarrow[ud]_{S=1} - \sqrt{2}d\uparrow[uu]_{S=1} - 2d\downarrow[uu]_{S=1}\right)$$

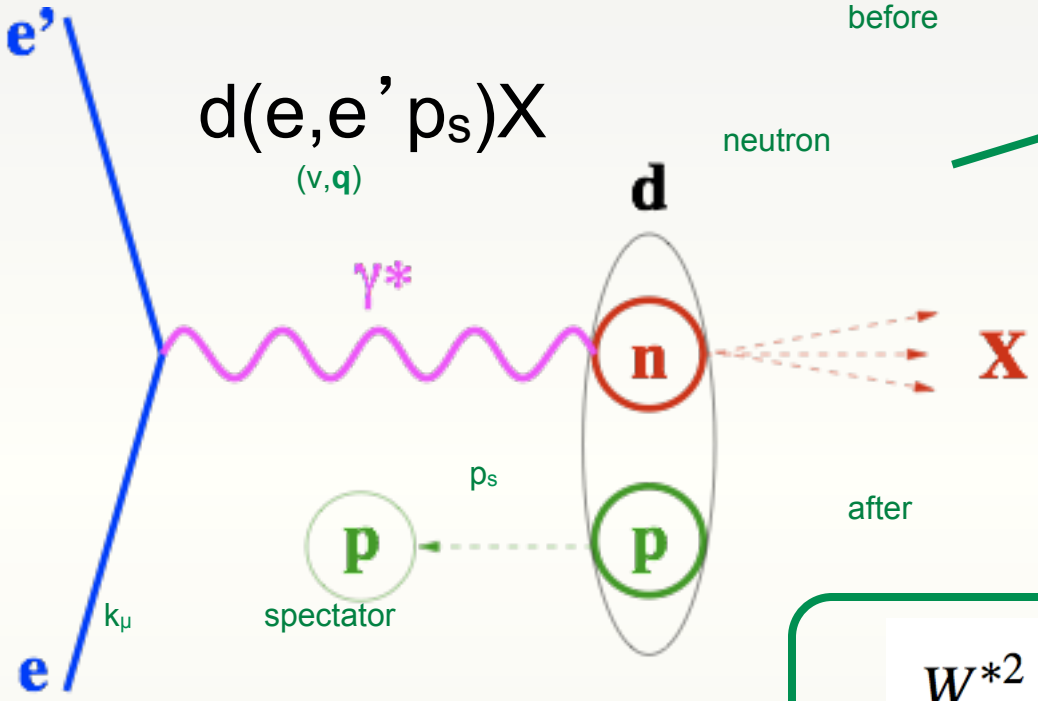
- In this model: d/u = 1/2, Δu/u = 2/3, Δd/d = -1/3 for all *x*
  => A_{1p} = 5/9, A_{1n} = 0, A_{1D} = 1/3 *)

- Hyperfine structure effect: S=1 suppressed => d/u = 0, Δu/u = 1, Δd/d = -1/3
  for *x* -> 1 => A_{1p} = 1, A_{1n} = 1, A_{1D} = 1

- pQCD: helicity conservation (q$\uparrow\uparrow$p) => d/u =2/(9+1) = 1/5, Δu/u = 1, Δd/d = 1
  for *x* -> 1

- Wave function of the neutron via isospin rotation:
  replace u -> d and d -> u => using experiments with protons and neutrons one can extract information on u, d, Δu and Δd in the valence quark region.

*) $$A_{1p} = \frac{4/9\cdot u\cdot\Delta u/u + 1/9\cdot d\cdot\Delta d/d}{4/9\cdot u + 1/9\cdot d} = \frac{4\cdot\Delta u/u + (d/u)\cdot\Delta d/d}{4 + (d/u)}$$



$$p_N^\mu = (M_d - E_s, -\vec{p}_s)$$

$$E_p + E_n = M_d$$

$$E^* = M_d - \sqrt{M_s^2 + p_s^2}$$

$$M^{*2} = (M_d - E_s)^2 - \vec{p}_s^{\,2}$$

$$W^{*2} \approx M^{*2} - Q^2 + 2M\nu\,(2 - \alpha_s)$$

$$\alpha_s = \frac{E_s - p_{s_{||}}}{M_s}$$

$$x^* = \frac{Q^2}{2p_N^\mu q^\mu} \approx \frac{Q^2}{2M\nu(2-\alpha_s)} = \frac{x}{2-\alpha_s}$$

- plane-wave impulse approximation
- backward-emitted p is spectator
- struck neutron is off-shell
- momenta are equal and opposite
- Lorentz invariants are corrected for initial neutron 4-momentum

PWIA Spectator Formalism

Cross Section

$$\frac{d\sigma}{dx^* dQ^2} = \frac{4\pi\alpha_{\rm EM}^2}{x^* Q^4}\left[\frac{y^{*2}}{2(1+R)} + (1-y^*) + \frac{M^{*2}x^{*2}y^{*2}}{Q^2}\frac{1-R}{1+R}\right] F_2(x^*, \alpha_s, p_T, Q^2) \times S(\alpha_s, p_T)\frac{d\alpha_s}{\alpha_s} d^2p_T,$$

Off-Shell F_2

$R=\sigma_L/\sigma_T$

Light Cone

Spectral Function

Nonrelativistic w.f.

$$P(\vec{p}_s) = J|\psi_{\rm NR}(p_s)|^2$$

$$J = 1 + \frac{p_{s_{||}}}{E_n^*} = \frac{(2-\alpha_s)M_d}{2(M_d - E_s)}$$

$$S(\alpha_s, p_T)\frac{d\alpha_s}{\alpha_s} d^2p_T = P(\vec{p}_s) d^3p_s$$

$$S^{\rm LC}(\alpha_s, p_T)\frac{d\alpha_s}{\alpha_s} d^2p_T = |\psi_{\rm NR}(|\vec{k}|^2)|^2 d^3k$$

$$|\vec{k}| = \sqrt{\frac{M^2 + p_T^2}{\alpha_s(2-\alpha_s)} - M^2}$$

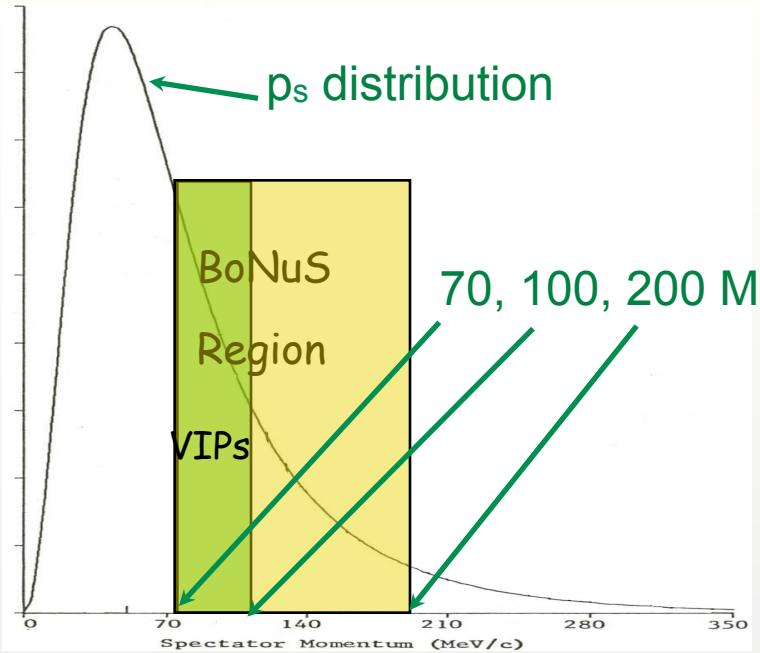
$$\alpha_s = 1 - \frac{k_{||}}{\sqrt{M^2 + \vec{k}^2}}$$

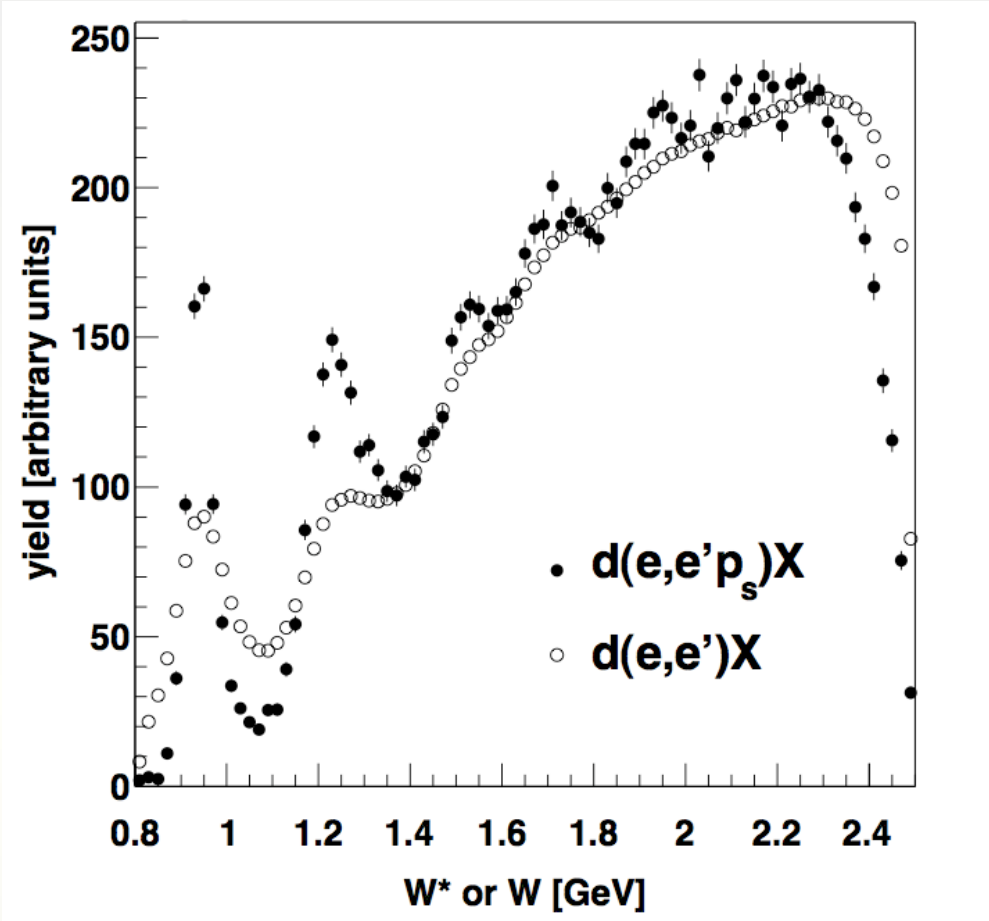
$$k_0 = \sqrt{M^2 + \vec{k}^2}$$

$$\vec{p}_T = \vec{k}_T$$

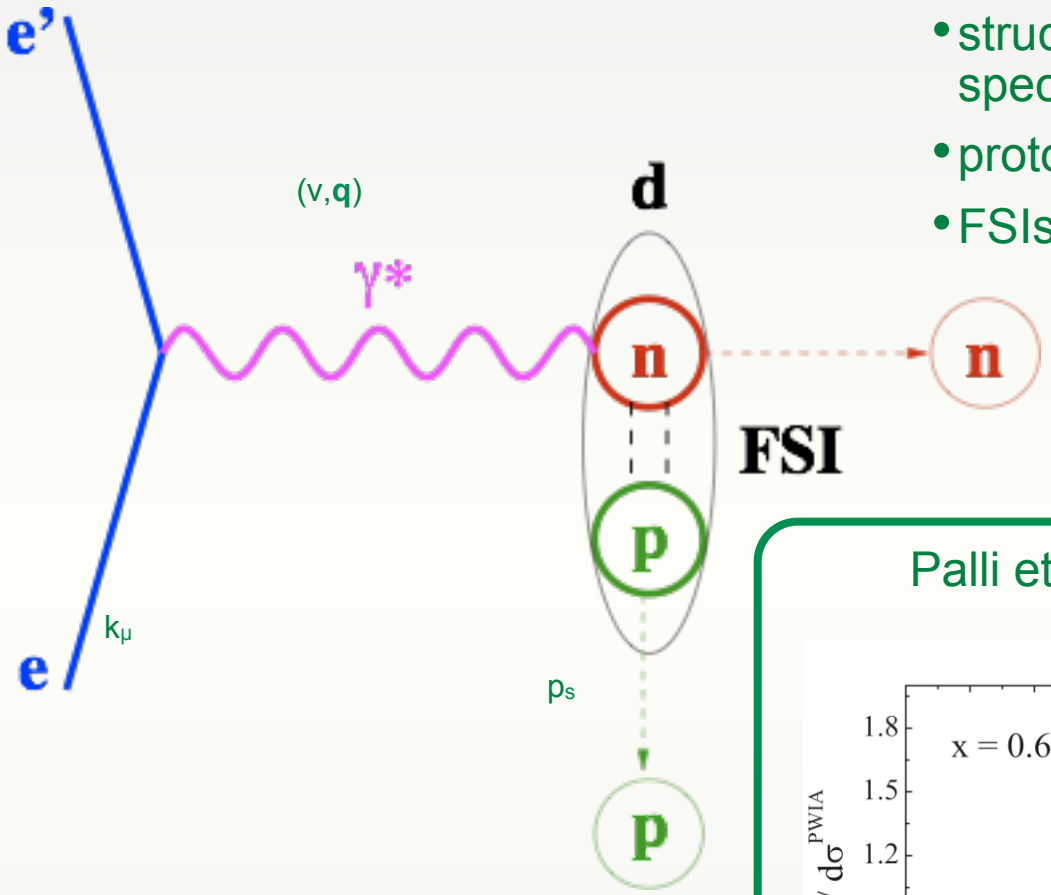
$$\int\int\int S^{\rm LC}(\alpha_s, p_T)\frac{d\alpha_s}{\alpha_s} d^2p_T = 1$$

- Very Important Protons $70<p_s<100$ MeV/c
- Corrections make resonances stand out
- F_2^n/F_2^p can be measured at high x*





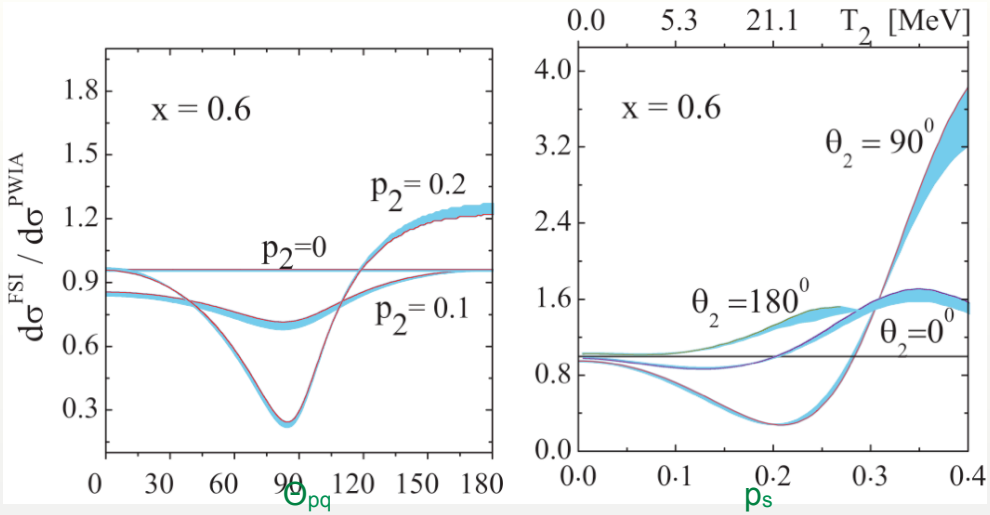
Final State Interactions



- struck neutron can interact with the spectator proton
- proton momentum is enhanced
- FSIs are small at low p_s and large Θ_{pq}

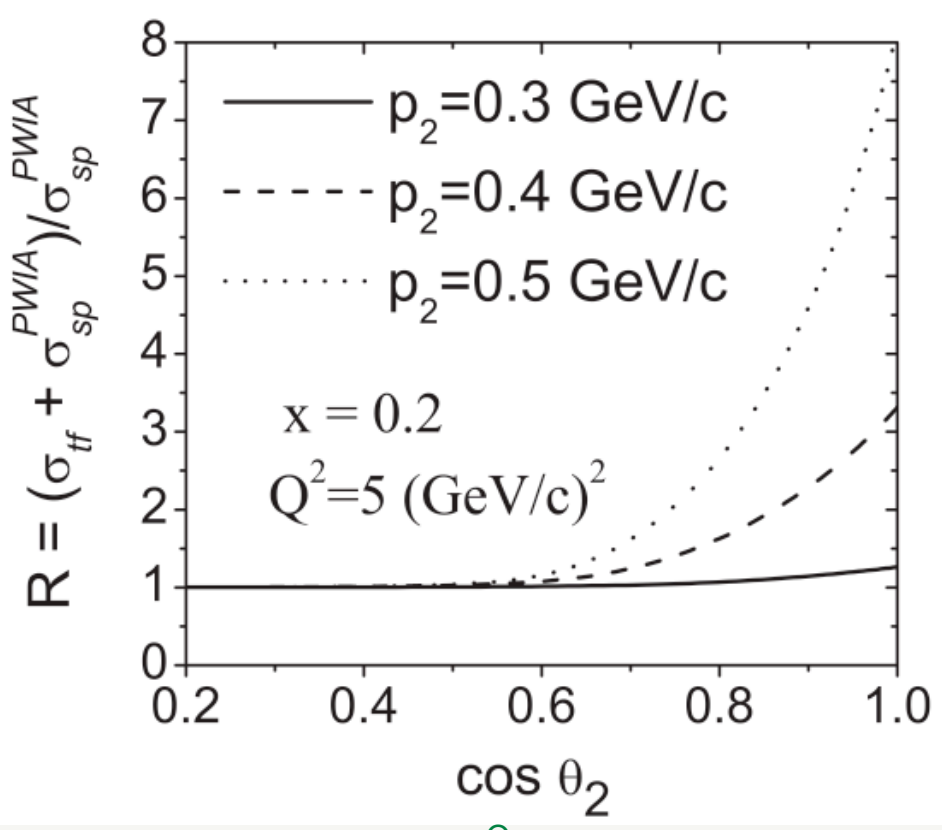
- several groups have calculated FSIs
- $\Theta_{pq} > 110^o$ minimizes FSIs

Palli et al, PRC80(09)054610



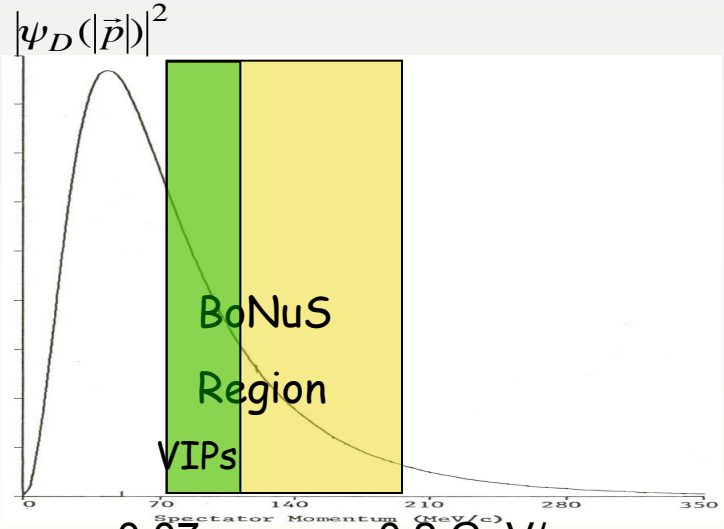
Target Fragmentation

Palli et al, PRC80(09)054610



- target fragmentation enhances the proton yield only at forward angles (cos Θ_{pq} >0.6)
- this can be ignored

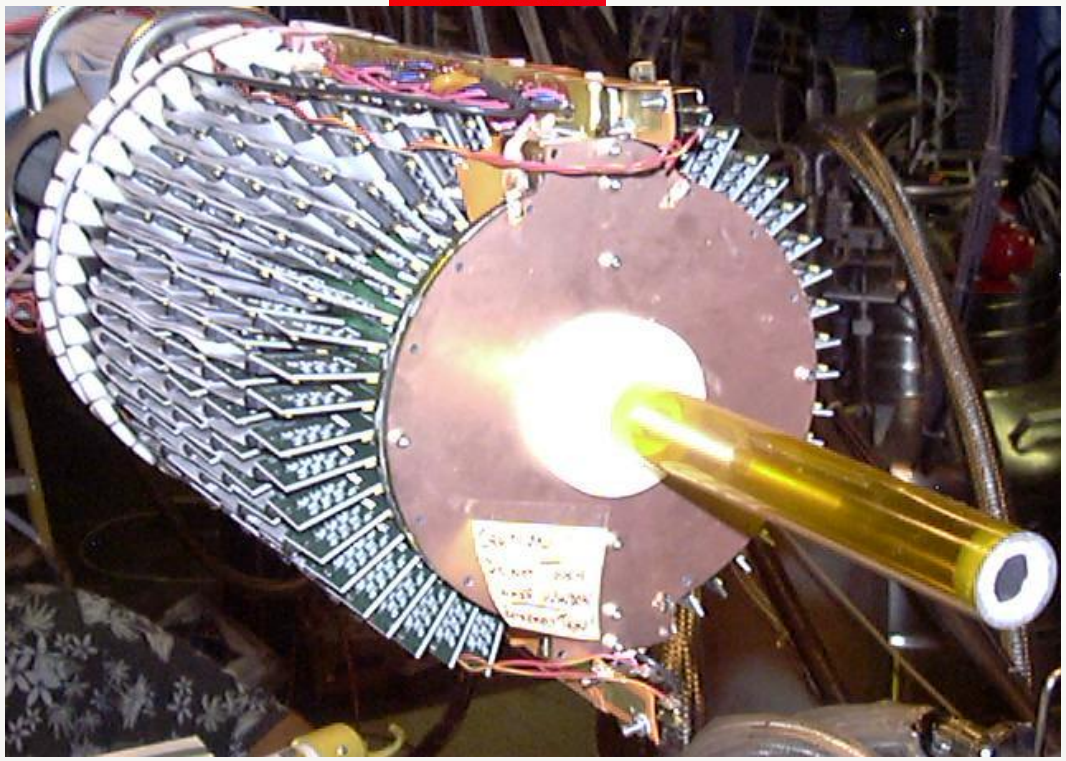
Low Spectator Momenta - Nearly Free Neutrons ?



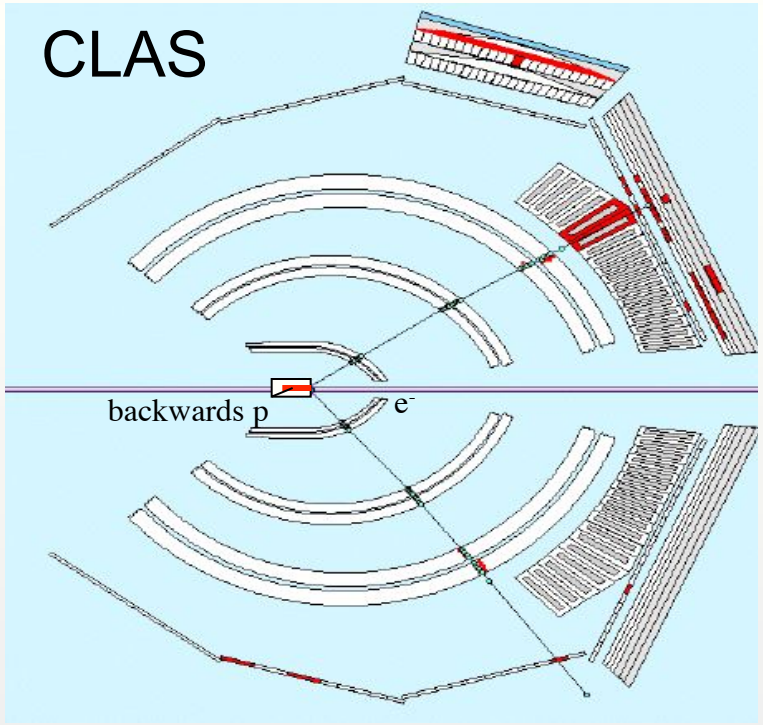
0.07 0.2 GeV/c

The 

Experiment

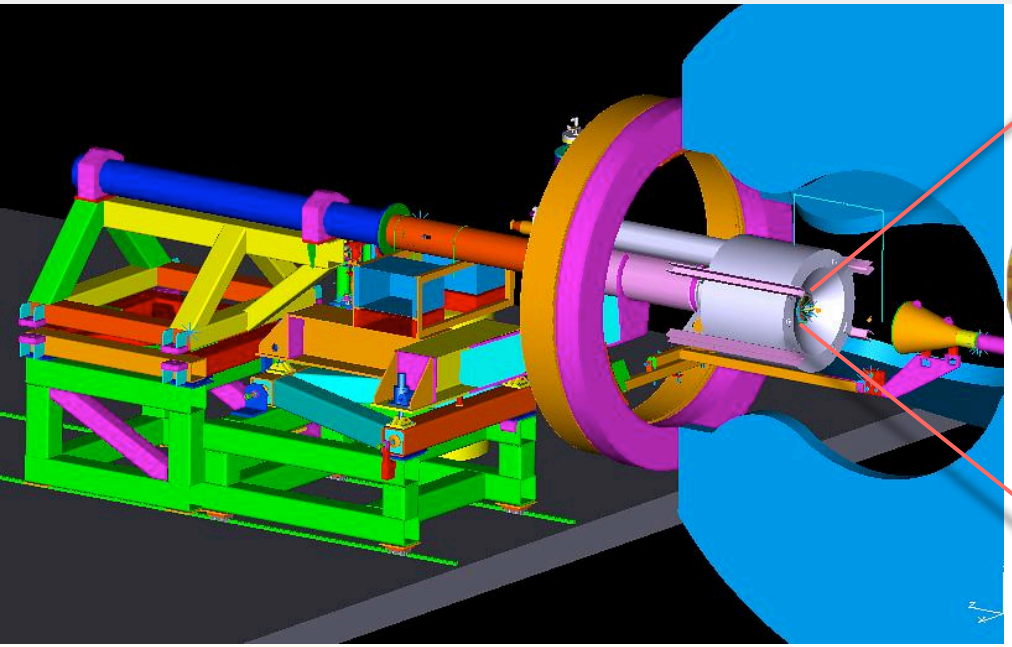


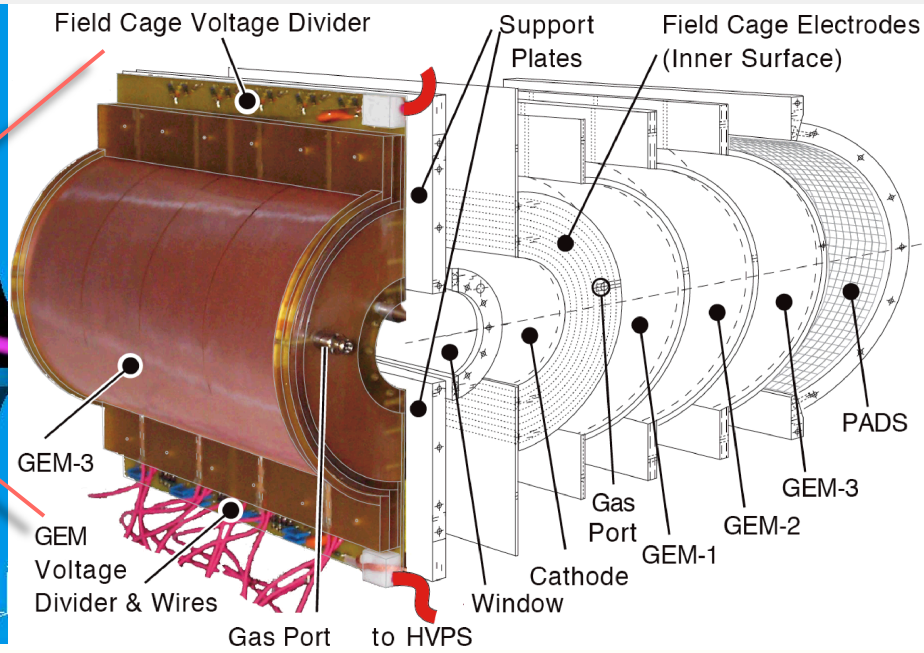
Radial TPC (view from downstream)

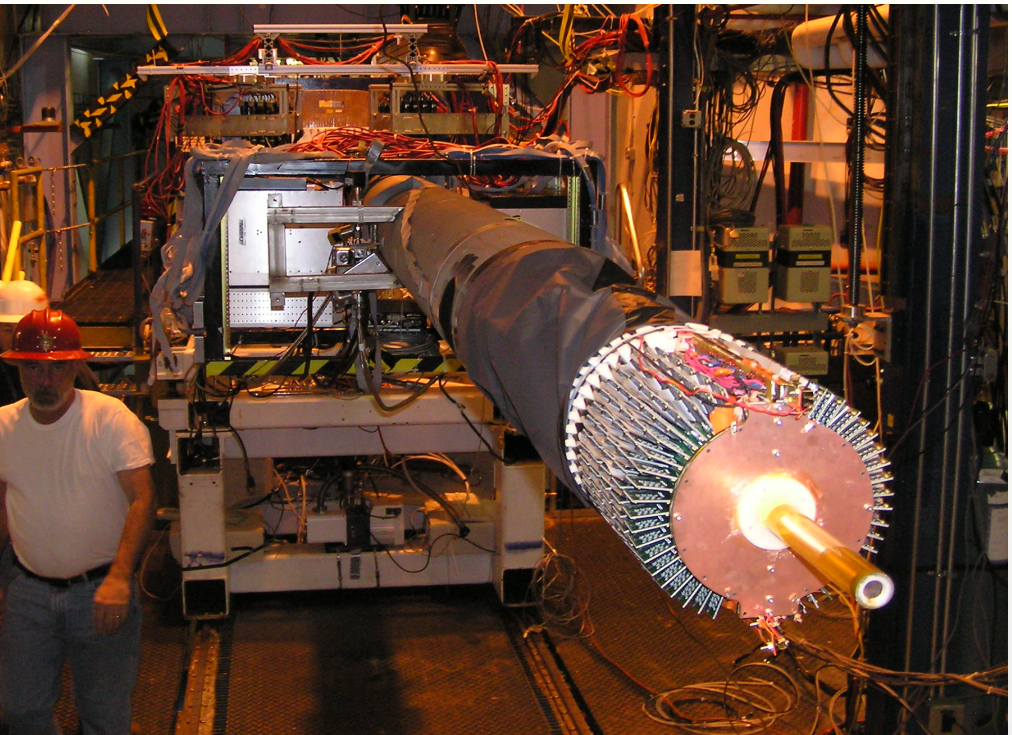


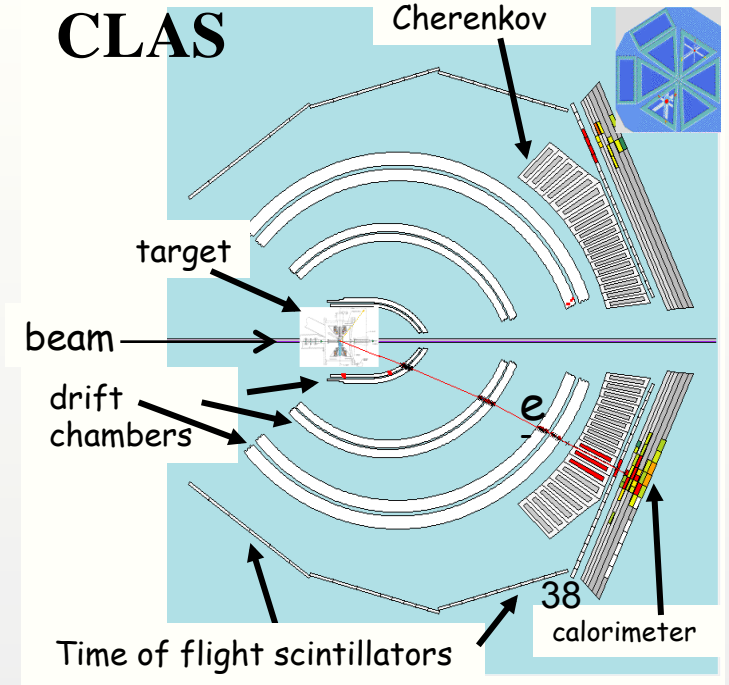
*BoNuS = **B**arely **o**ff-shell **Nu**cleon **S**cattering

**RTPC = Radial Time Projection Chamber

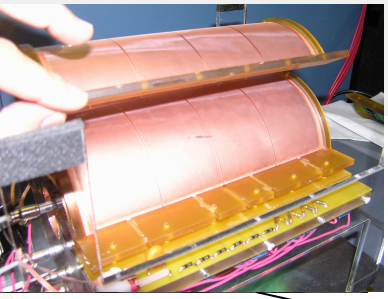



Field Cage Voltage Divider
Support Plates
Field Cage Electrodes (Inner Surface)
PADS
GEM-3
GEM-3
Gas Port
GEM-2
GEM-1
GEM Voltage Divider & Wires
Cathode
Window
Gas Port
to HVPS

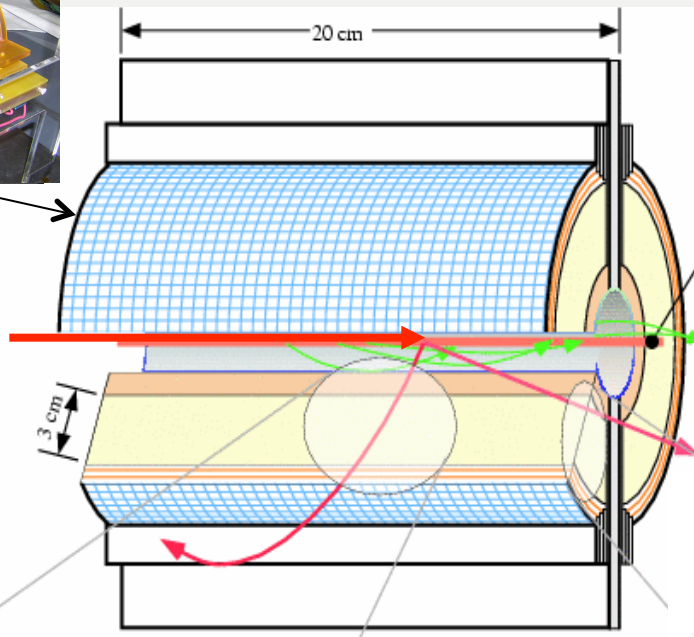



CLAS
Cherenkov
target
beam
drift chambers
e-
38
calorimeter
Time of flight scintillators

BoNuS RTPC



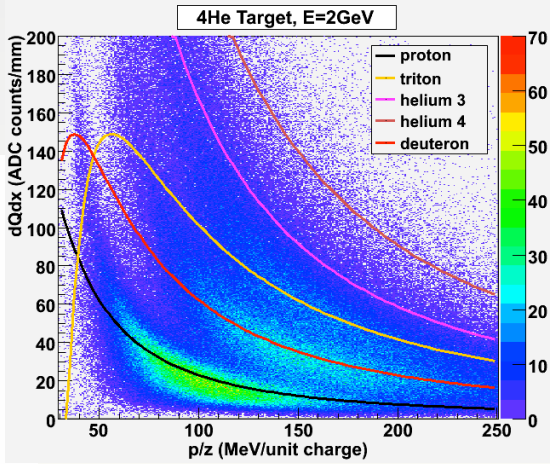
Gas
Electron
Multiplier



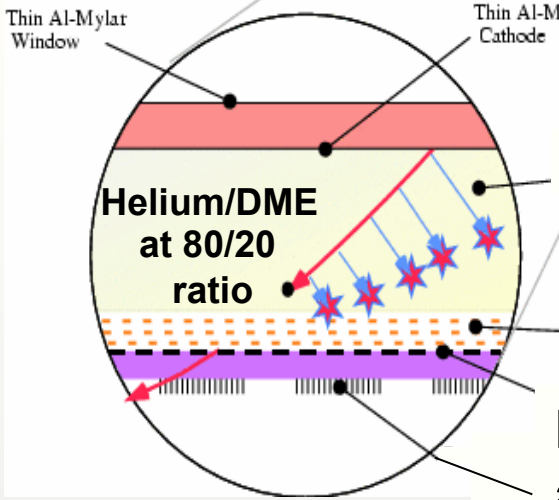
7 atm D_2 gas

Møller el.

e^- (to CLAS)



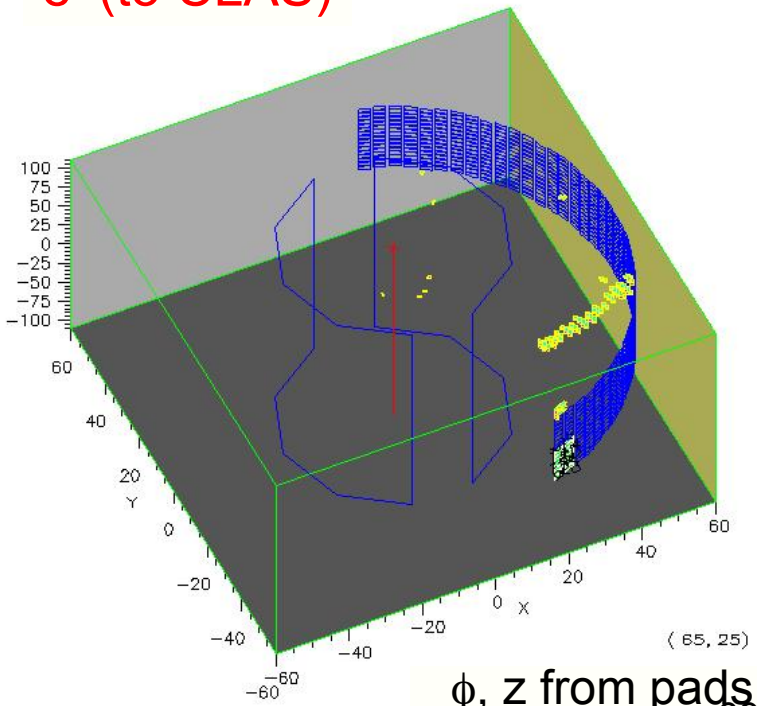
dE/dx from charge
along track (particle ID)



Drift
Region

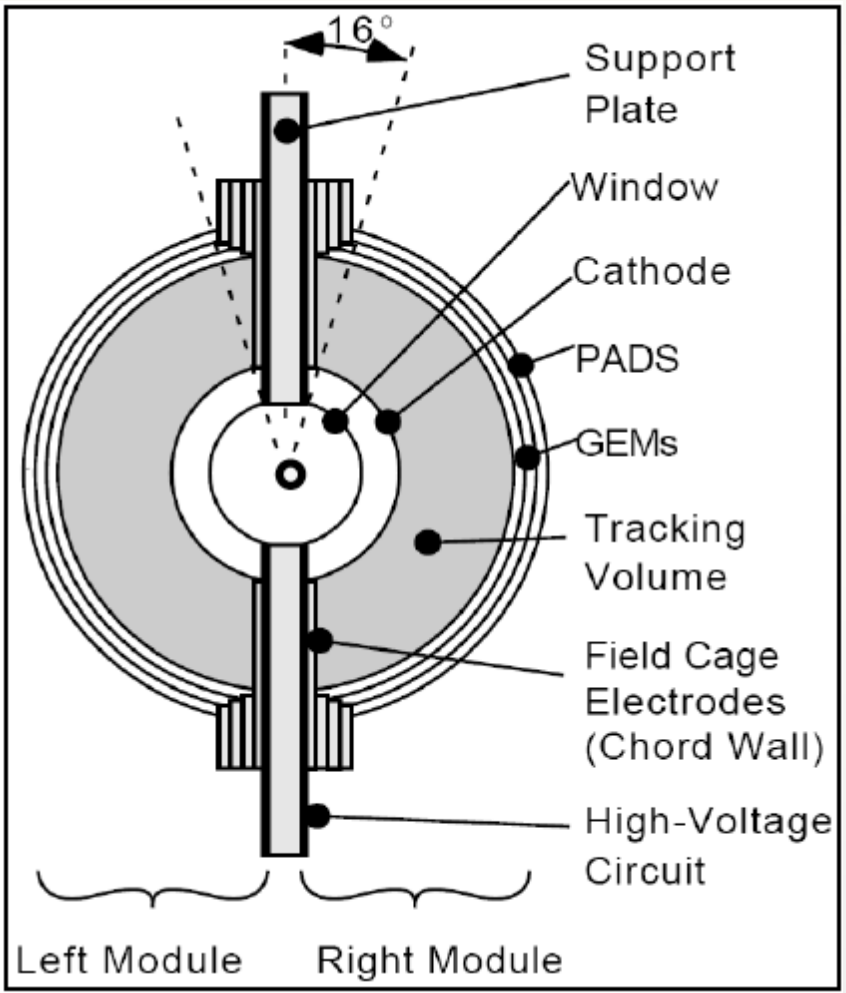
3 GEMs

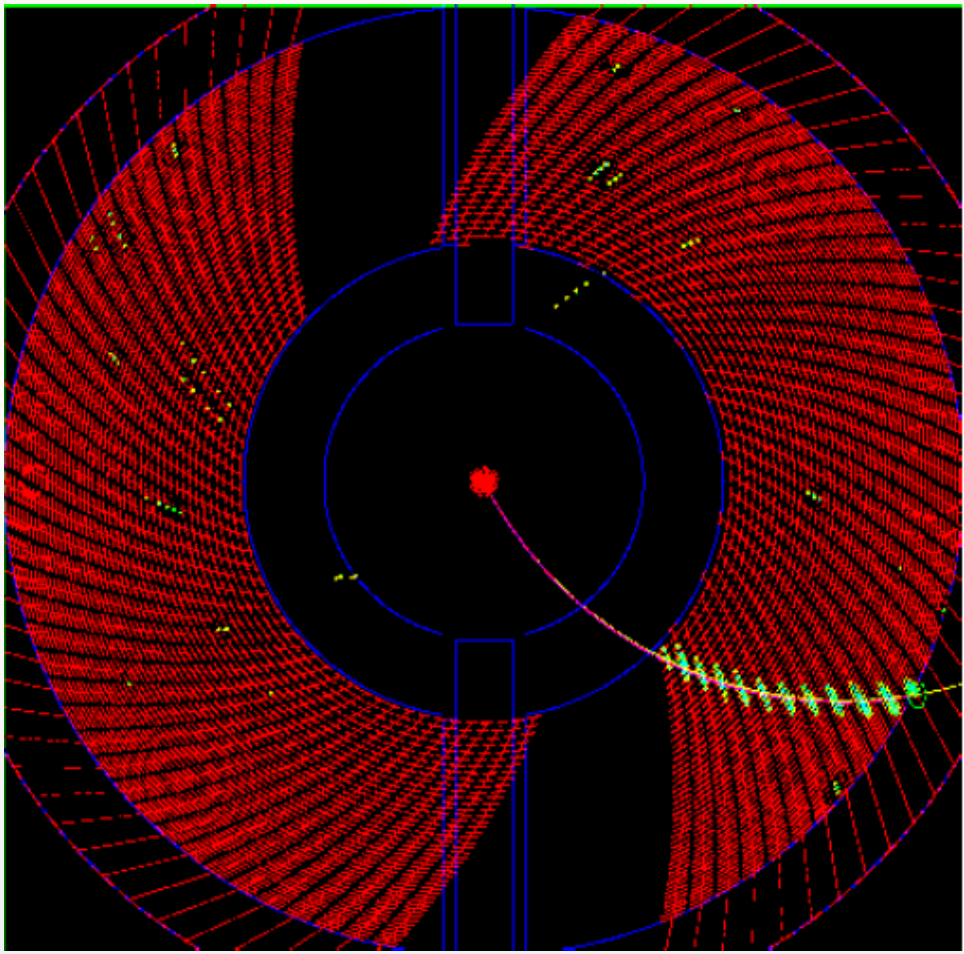
Readout pads
and electronics



ϕ, z from pads
r from time

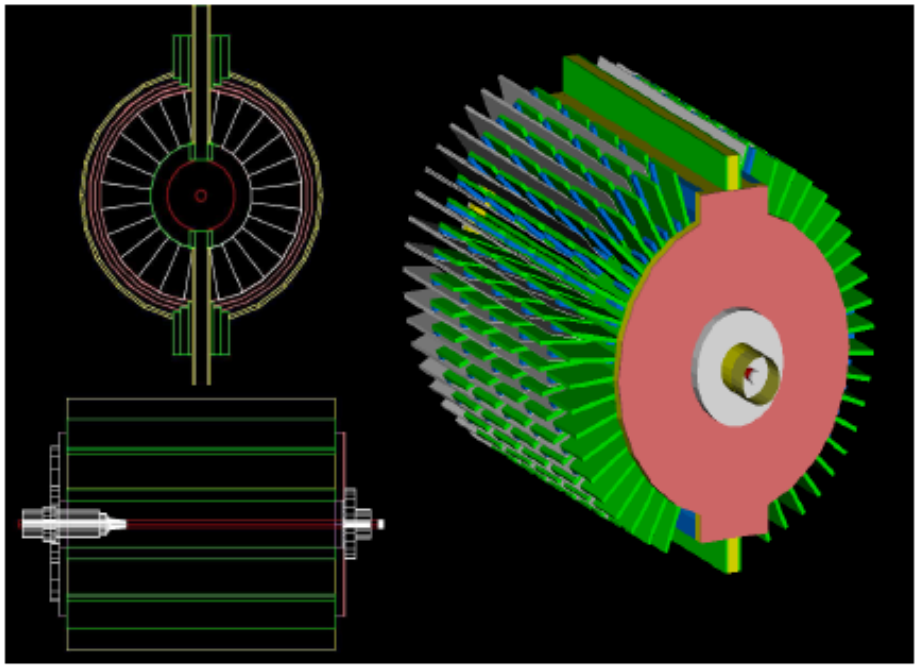
RTPC Cross Section



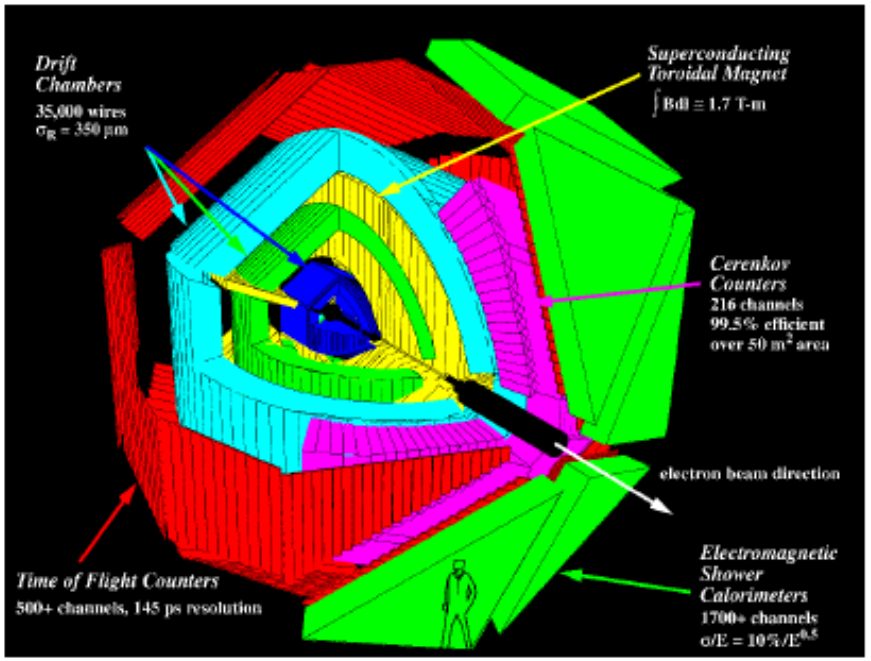


Simulation Overview

Evgen (fsgen or other event generators) → RTPC (BONUS)
CLAS(gsim) → Gsim Post Processing (gpp) → Reconstruction (user_ana) → Skim → Higher Level Simulation Ntuple



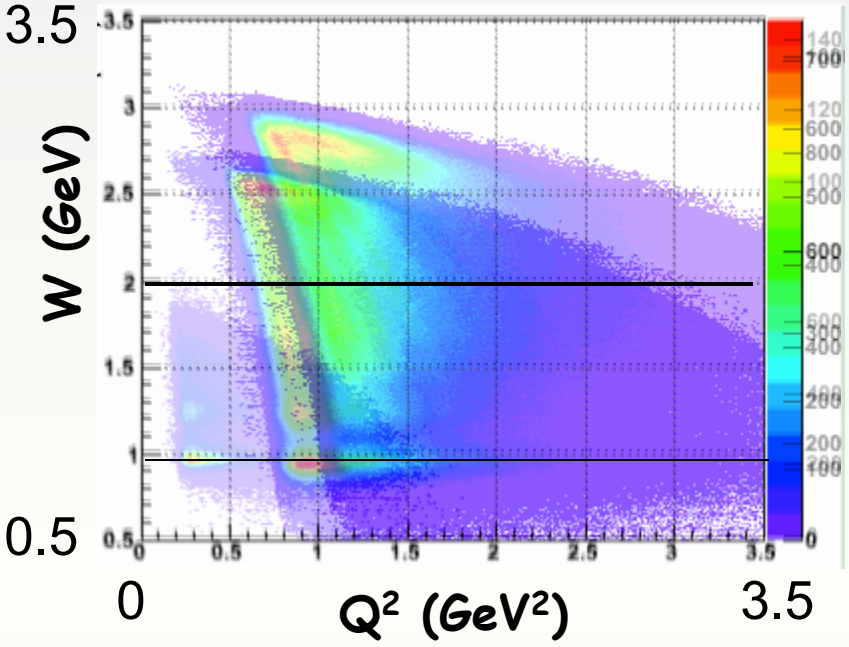
+

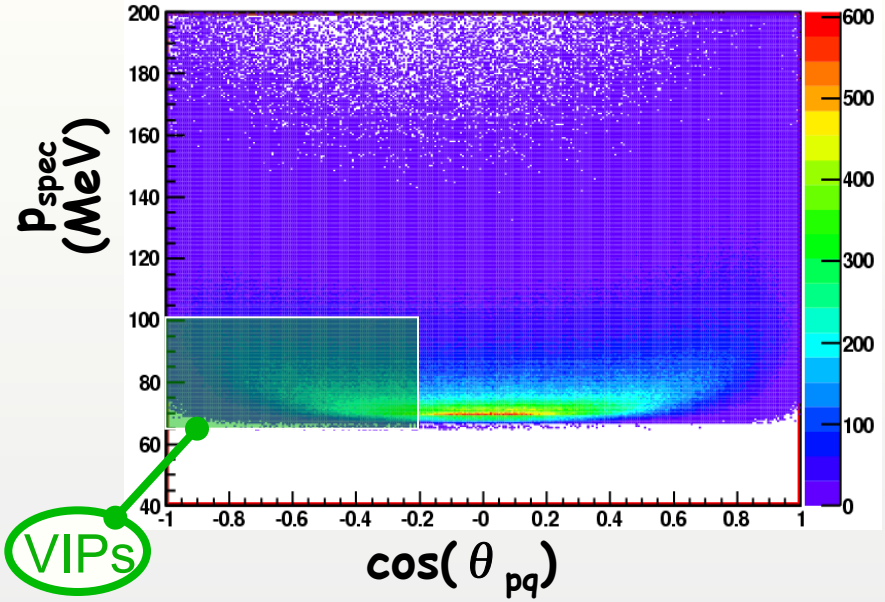


What can be done with simulation?

- Help to design the detector and choose the best configurations of HV and Drift Gas
- Debug/optimize reconstruction code of RTPC
- Generate energy loss correction tables, radiation length tables
- Detector's acceptance and efficiency study

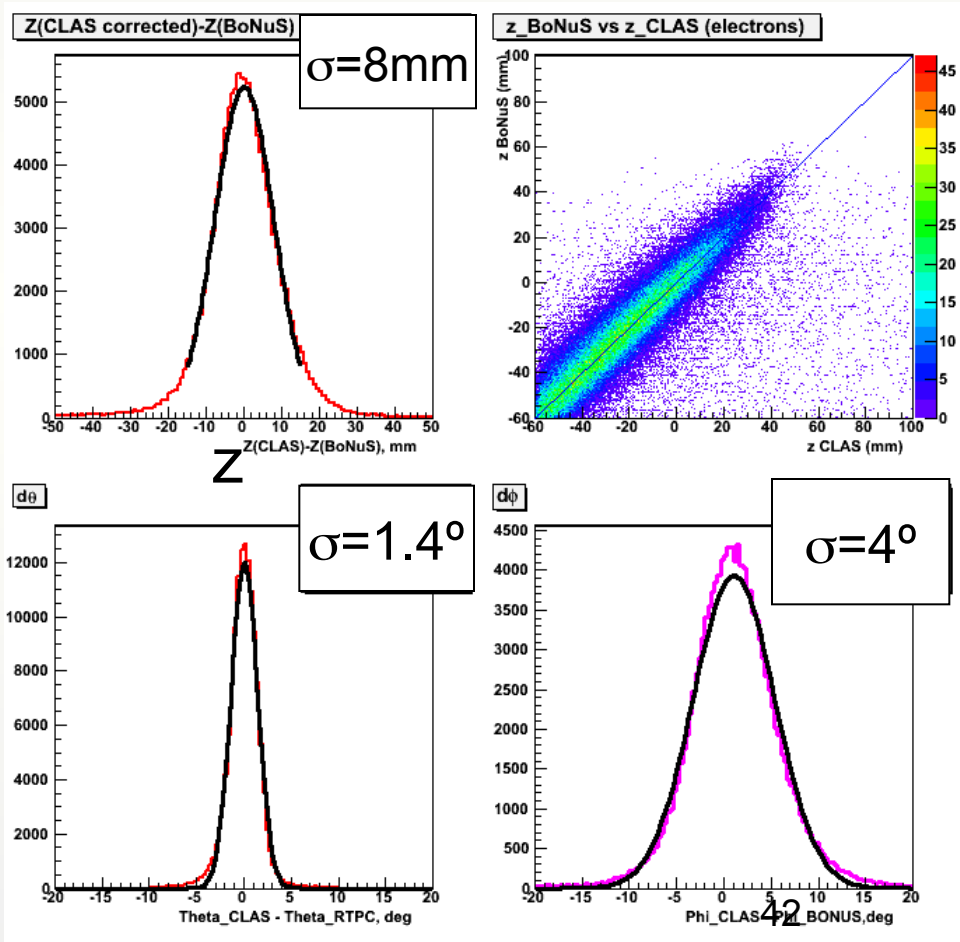
Kinematic Coverage - 2.1, 4.2 & 5.3 GeV



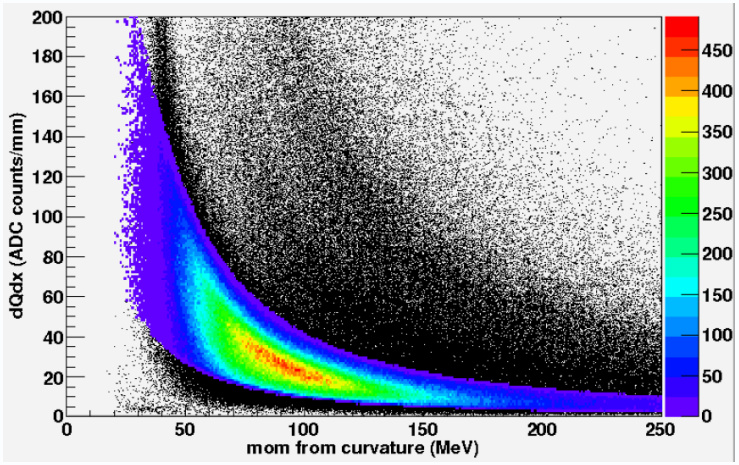


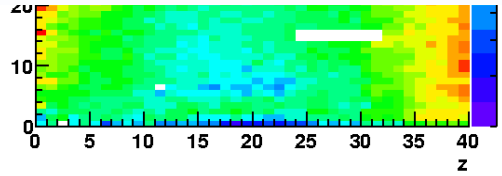
RTPC Performance

e⁻ reconstructed in CLAS & RTPC



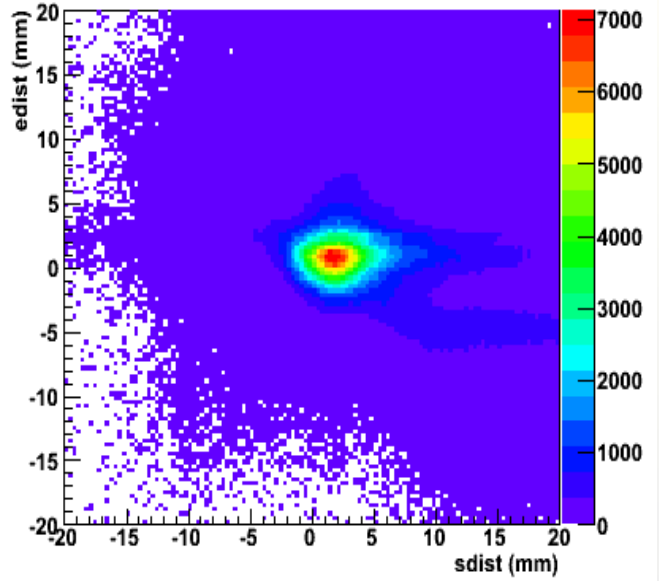
Particle ID (after gain calibration of each channel)



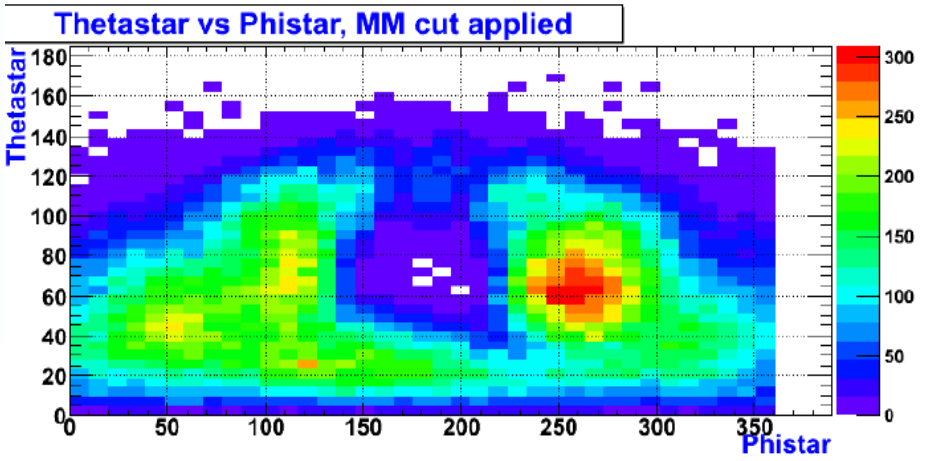


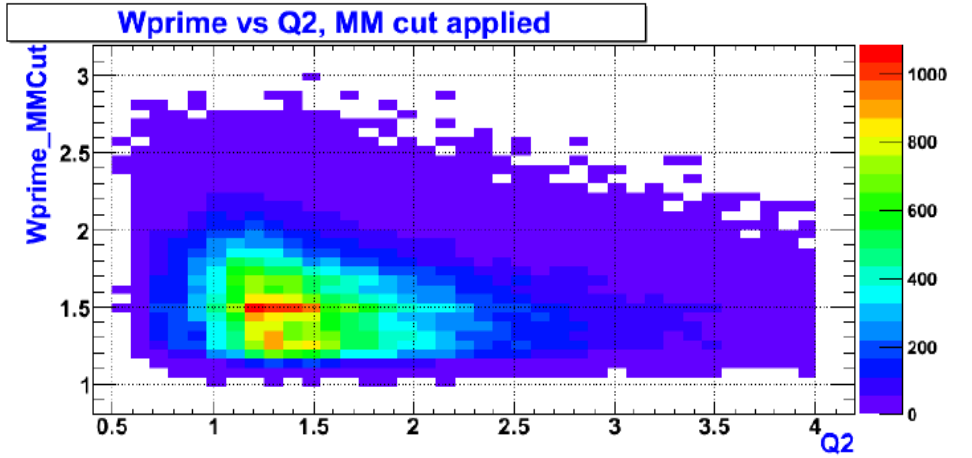
hotter (colder)
than average pads

Out-of-time track suppression



inematics coverage, D(e,e′π⁻p)p , E = 5.3 GeV

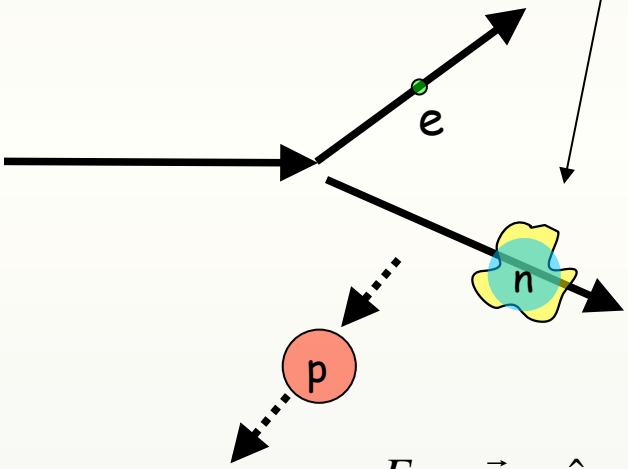


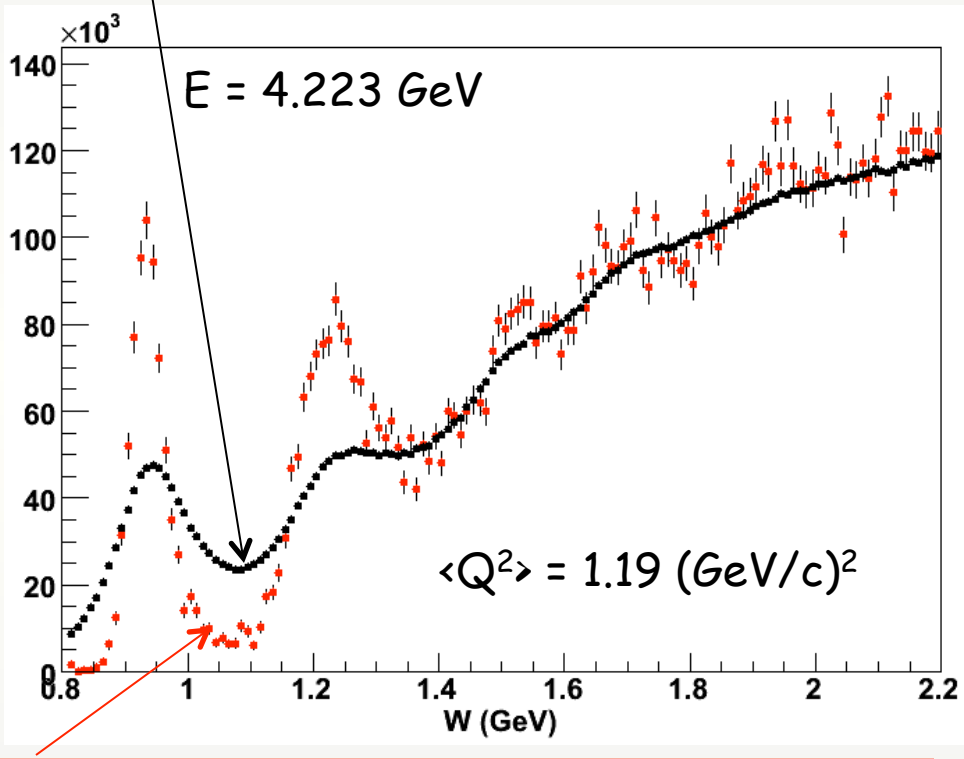


Minimizing Nuclear Uncertainties: "Spectator Tagging"

$$W^2 = M^2 + 2M\nu - Q^2$$

$$p_n = \left(M_D - E_S, -\vec{p}_S\right);$$
$$\alpha_n = 2 - \alpha_S$$



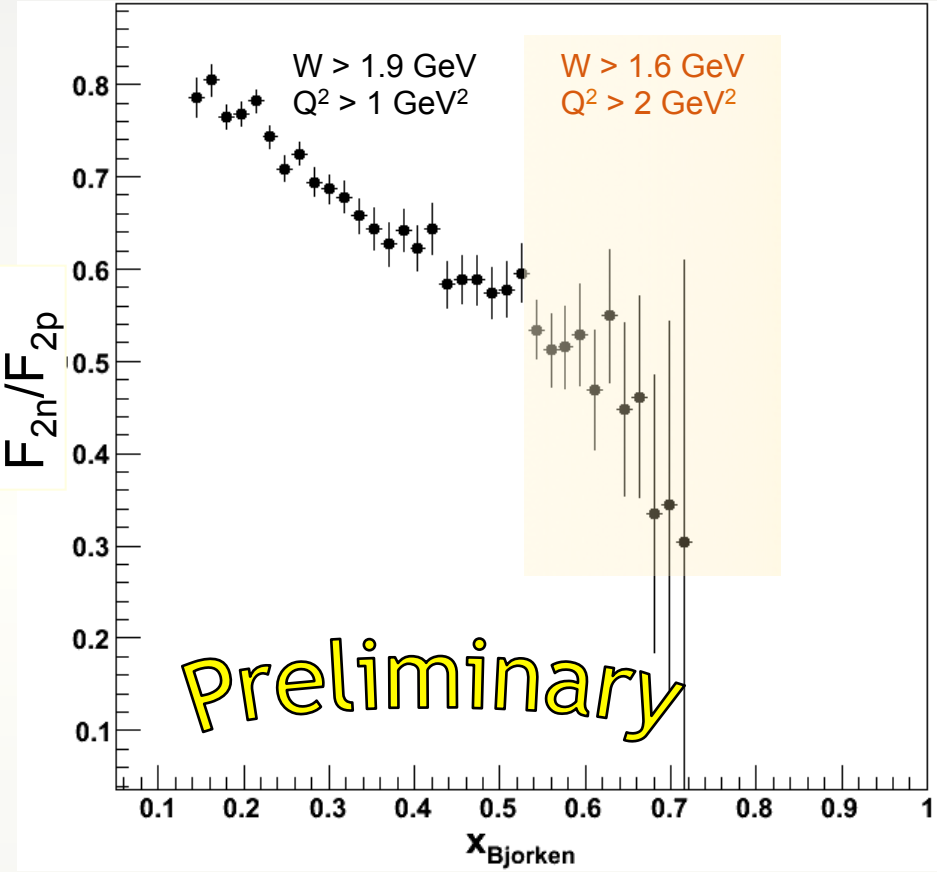


$$p_S = \left(E_S, \vec{p}_S\right); \quad \alpha_S = \frac{E_S - \vec{p}_S \cdot \hat{q}}{M_D/2}$$

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

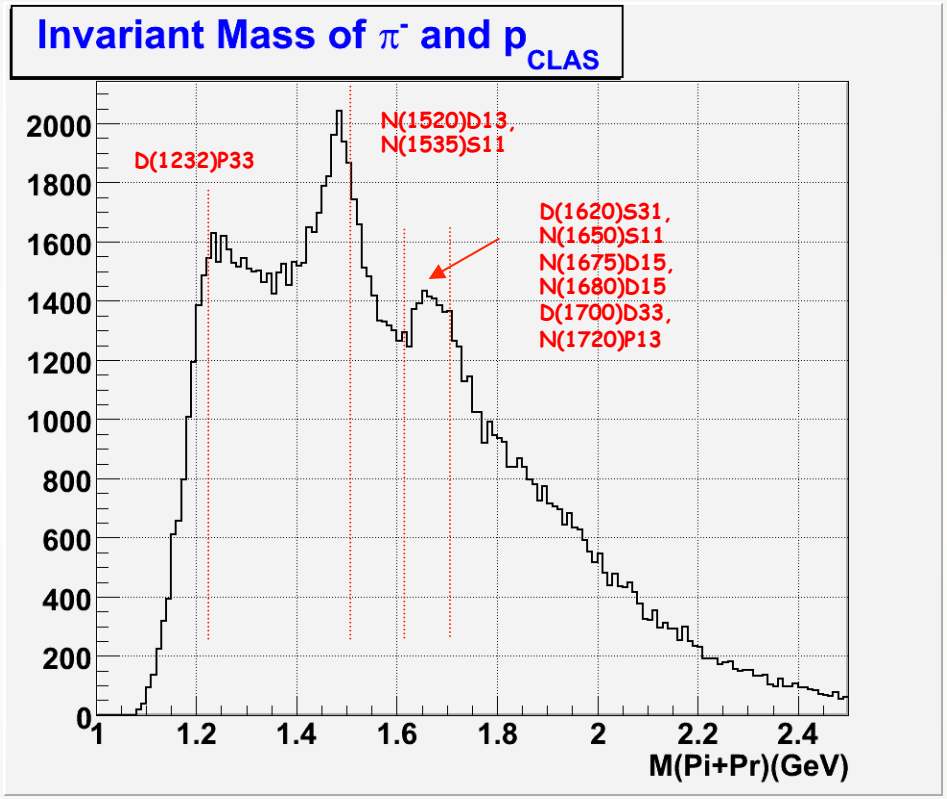
$$x^* = \frac{Q^2}{2p_n{}^{\mu} q_{\mu}} \approx \frac{Q^2}{2M\nu(2-\alpha_S)}$$

Preliminary Results from BoNuS



Baryonic Resonances, D(e,e′π-p)p

E = 5.26 GeV, Accepance and momentum not corrected yet

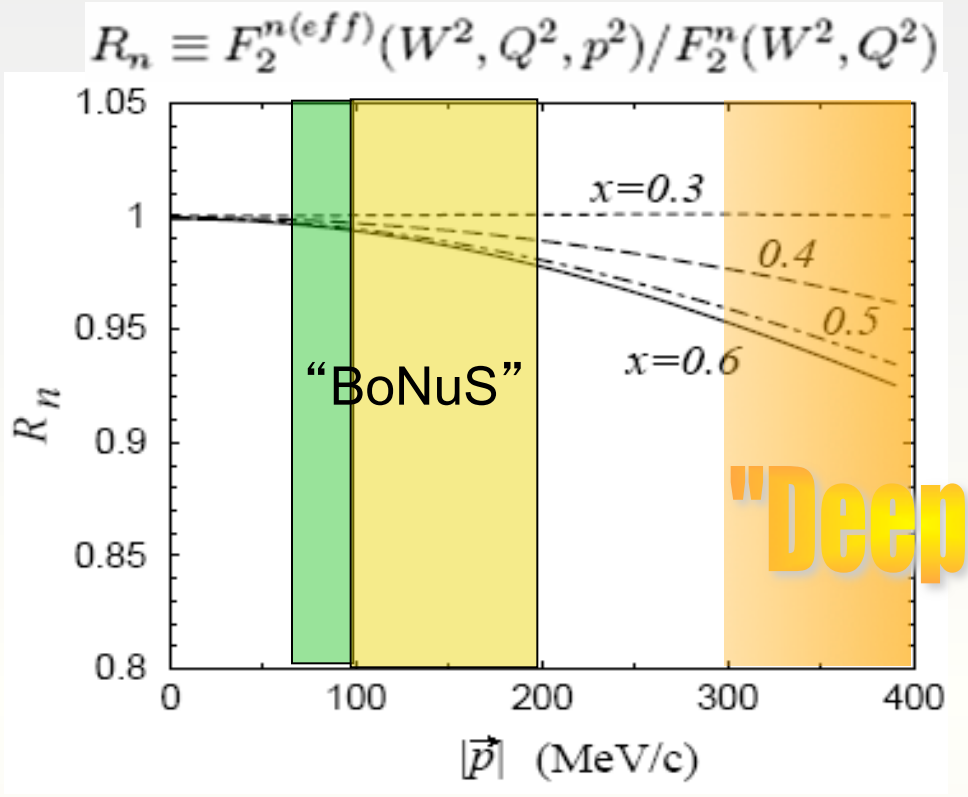


- Measured tagged n / inclusive d
- Multiplied with F_{2d}/F_{2p}
- Normalized at small *x*
- Acceptance corrections underway

$D(e, e' \pi^- p_{CLAS})p_s$ +

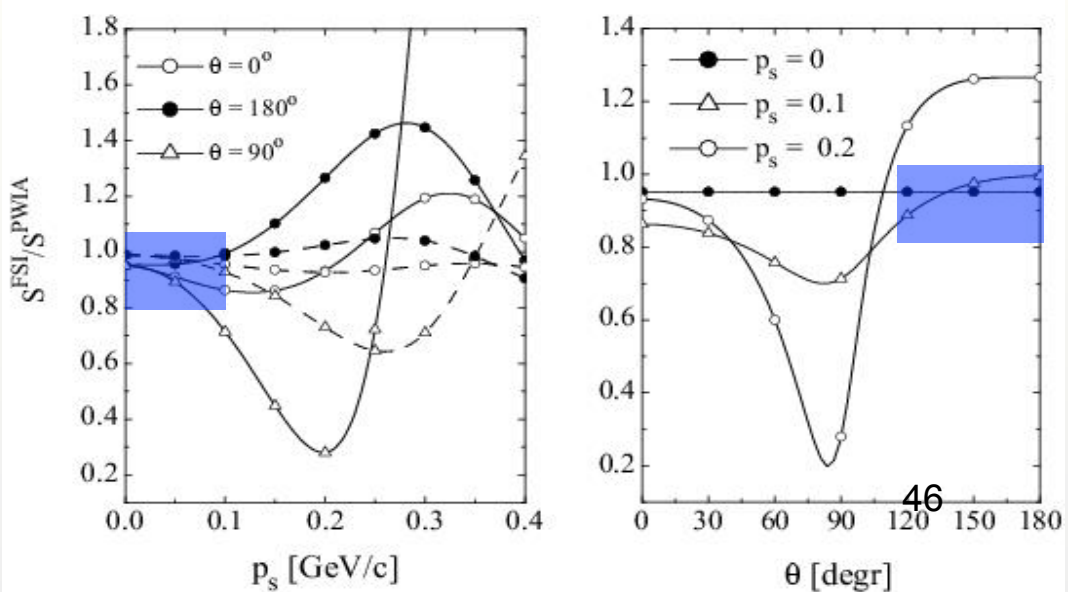
$D(e, e' \pi^- p_{RTPC})p_{decay}$

Modifications to Simple Spectator Picture



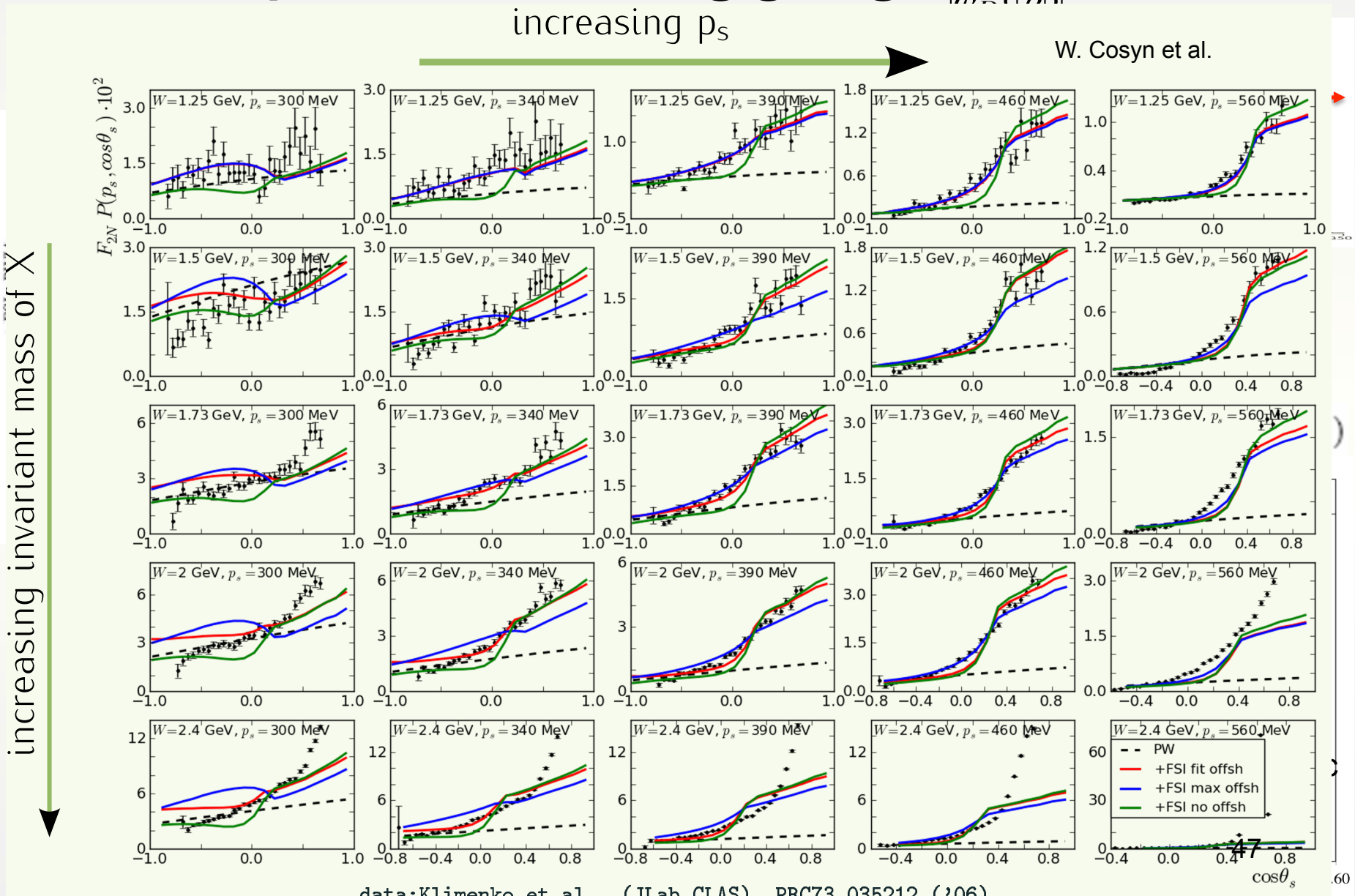
Final State Interactions ↓

Binding Effects ↑



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

Spectator Tagging



data:Klimenko et al. (JLab CLAS), PRC73 035212 ('06)

Deviations from free structure function:
Off-shell Effects [should depend on α (p_s), x, Q^2]

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

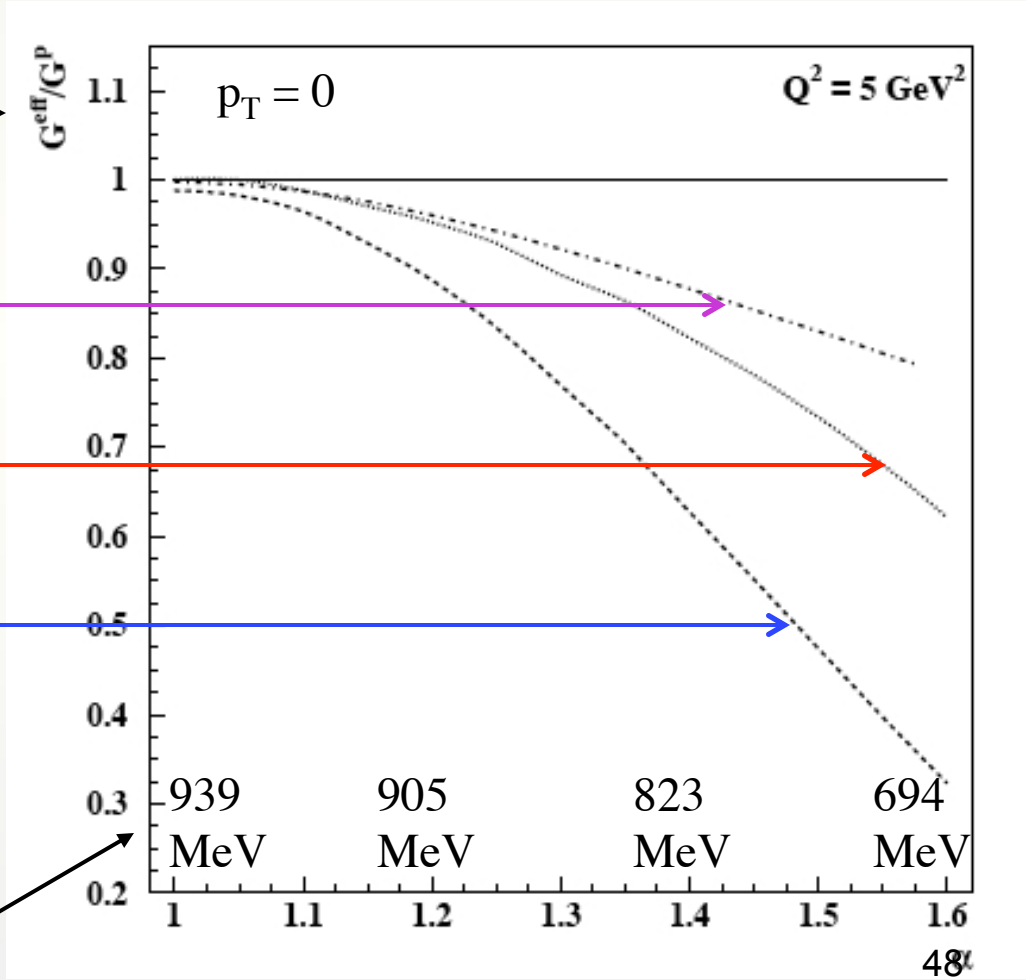
Modification of the off-shell scattering amplitude (Thomas, Melnitchouk et al.)

Color delocalization Close et al.

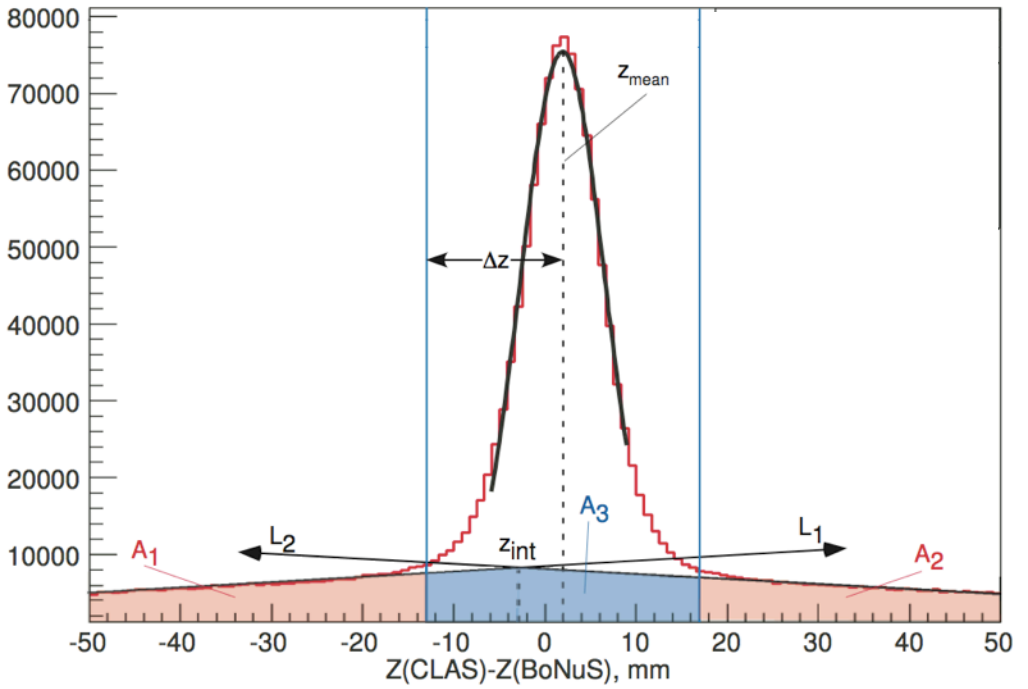
Suppression of "point-like configurations" Frankfurt, Strikman et al.

… plus 6-quark bags, ΔΔ, MEC…

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

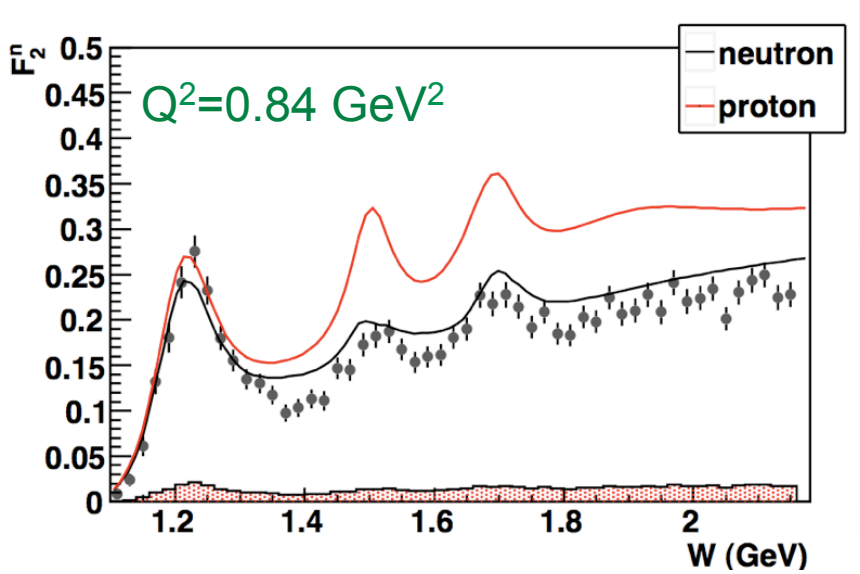


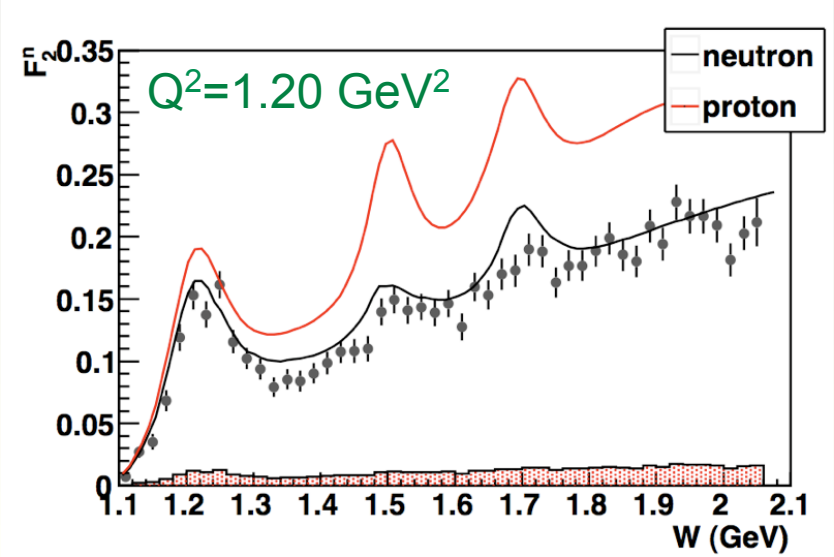
- The Ratio Method
  - measure tagged counts divided by inclusive counts
  - correct this ratio for backgrounds
  - one scale factor gives F_2^n/F_2^d
- The Monte Carlo Method
  - measure tagged counts
  - divide by spectator model Monte Carlo results
  - multiply by F_2^n used in the model
- The two methods have different systematic errors, but give very similar results.

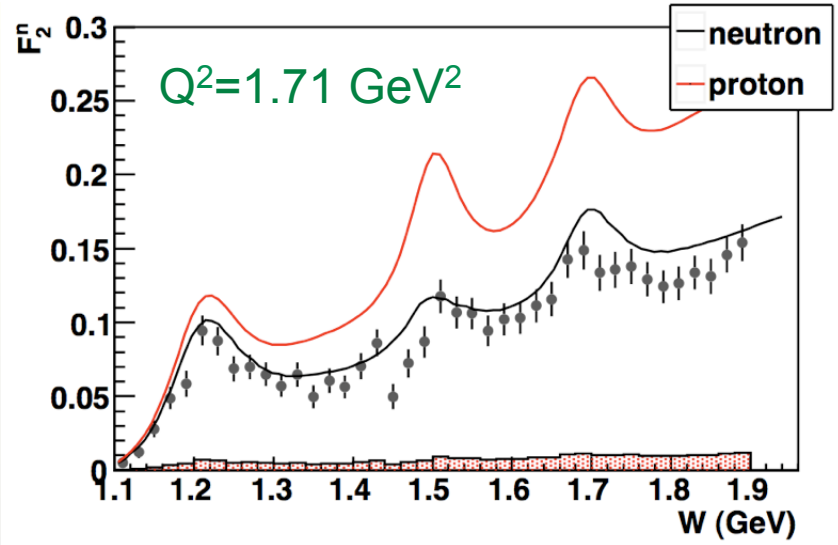


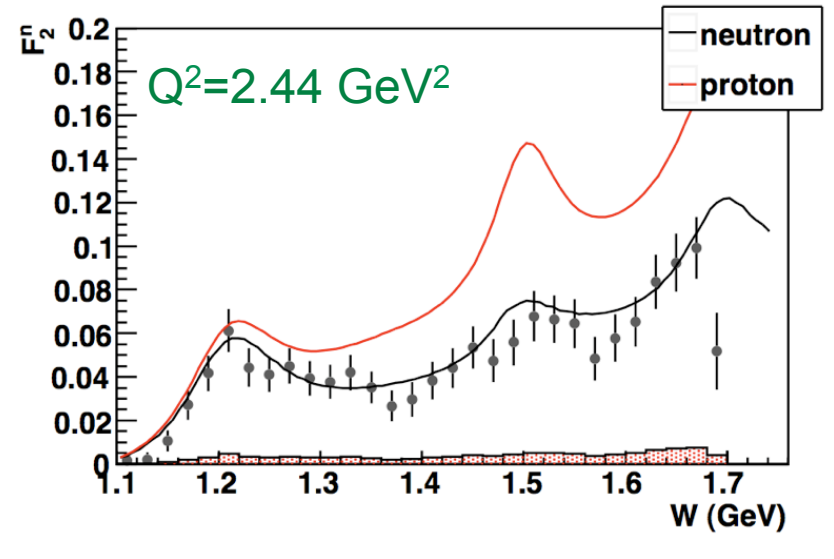
- Z is the position along the beam direction
- Tracking of the electron gives Z(CLAS)
- Tracking of the spectator proton gives Z(BoNuS)
- ΔZ=Z(CLAS)-Z(BoNuS) shows a coincidence peak and a triangular background
- Fits to the triangular background allows us to measure backgrounds underneath the peak
- Blue area = R_{bg} x Pink area
- R_{bg} is independent of kinematics

BoNuS F_2^n



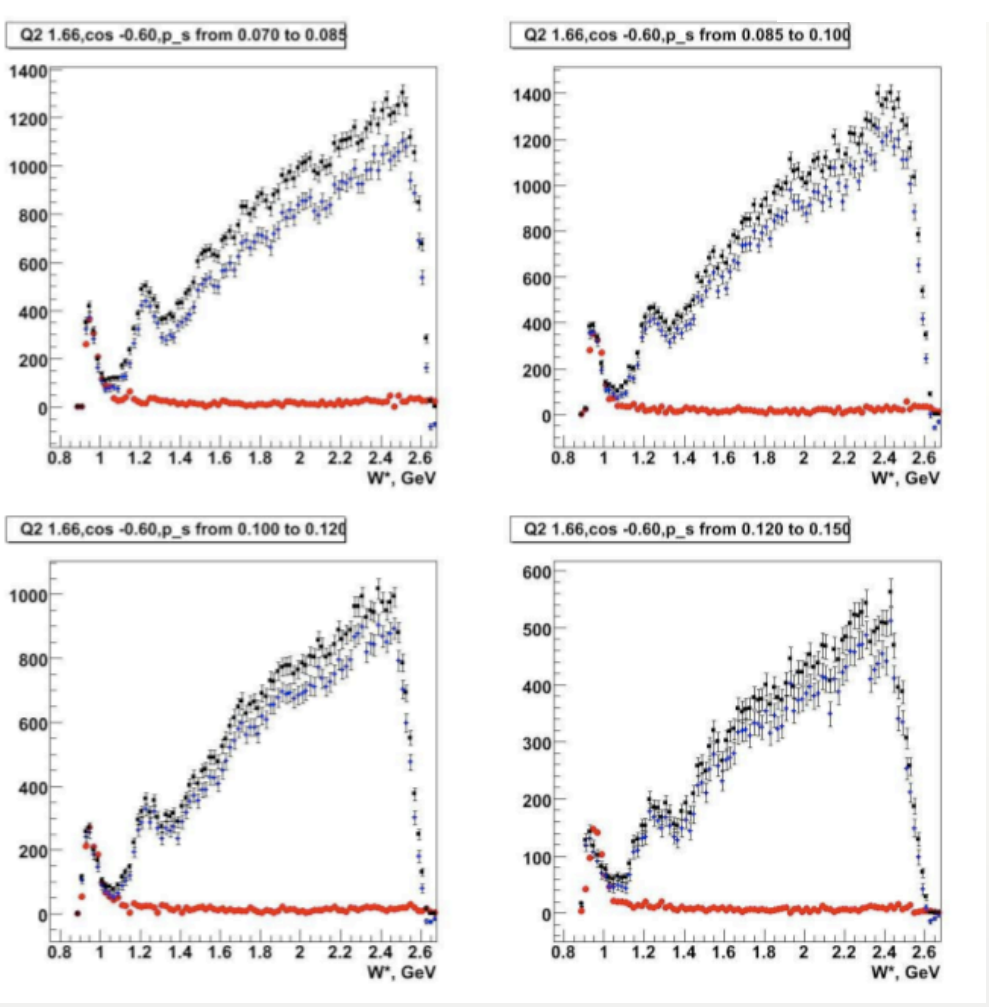






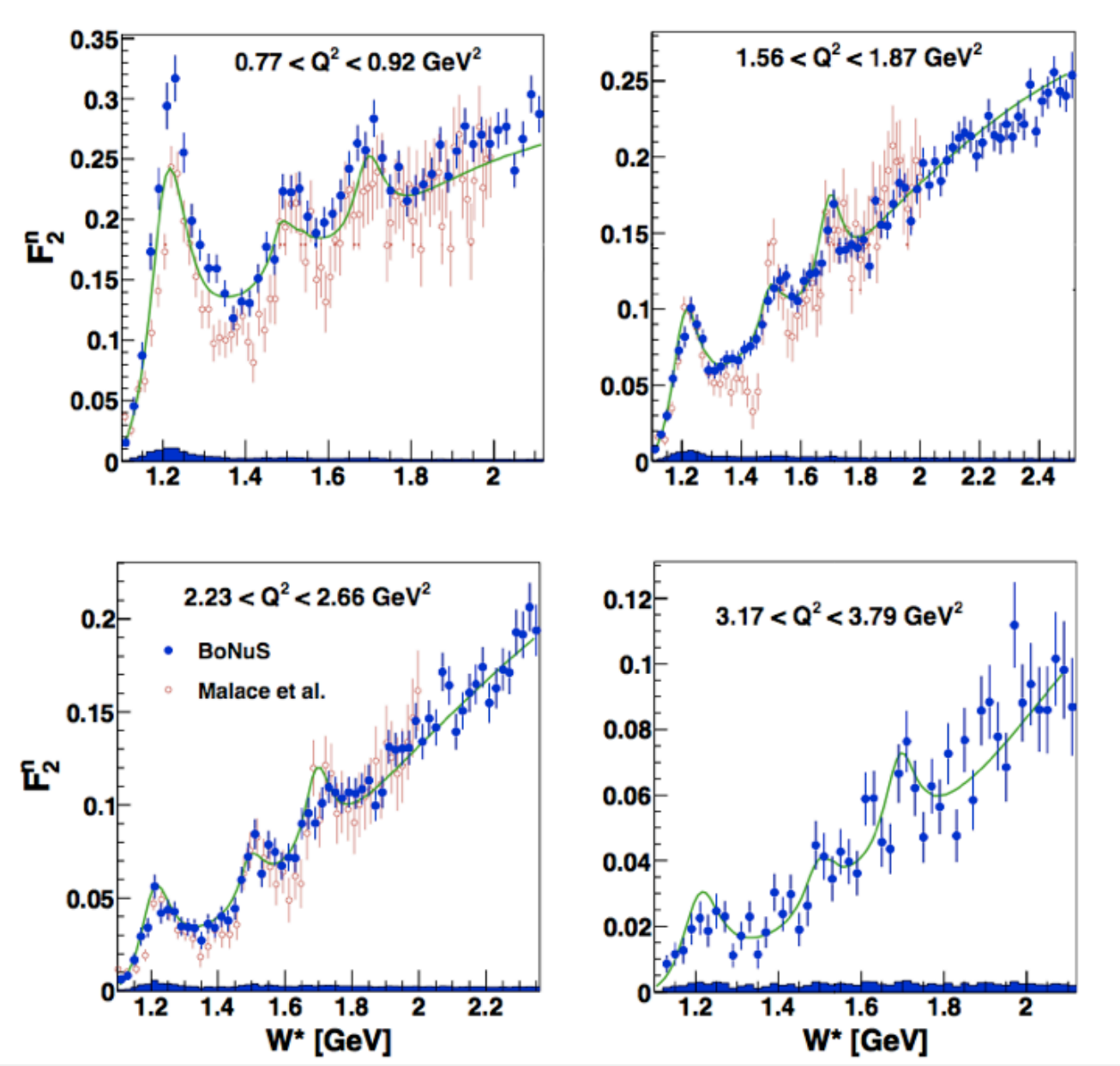
4 of 16 spectra: $0.8 < Q^2 < 4.5$; E_{beam} = 4.2 & 5.3 GeV; Bosted/Christy world fits

$$R(data/MC) = \frac{F_{2n}^{eff}(W^*, Q^2, \vec{p_s})}{F_{2n}^{model}(W, Q^2)}$$



Left: Black=raw tagged data; blue=accidental subtracted data; red=elastic and radiative tail

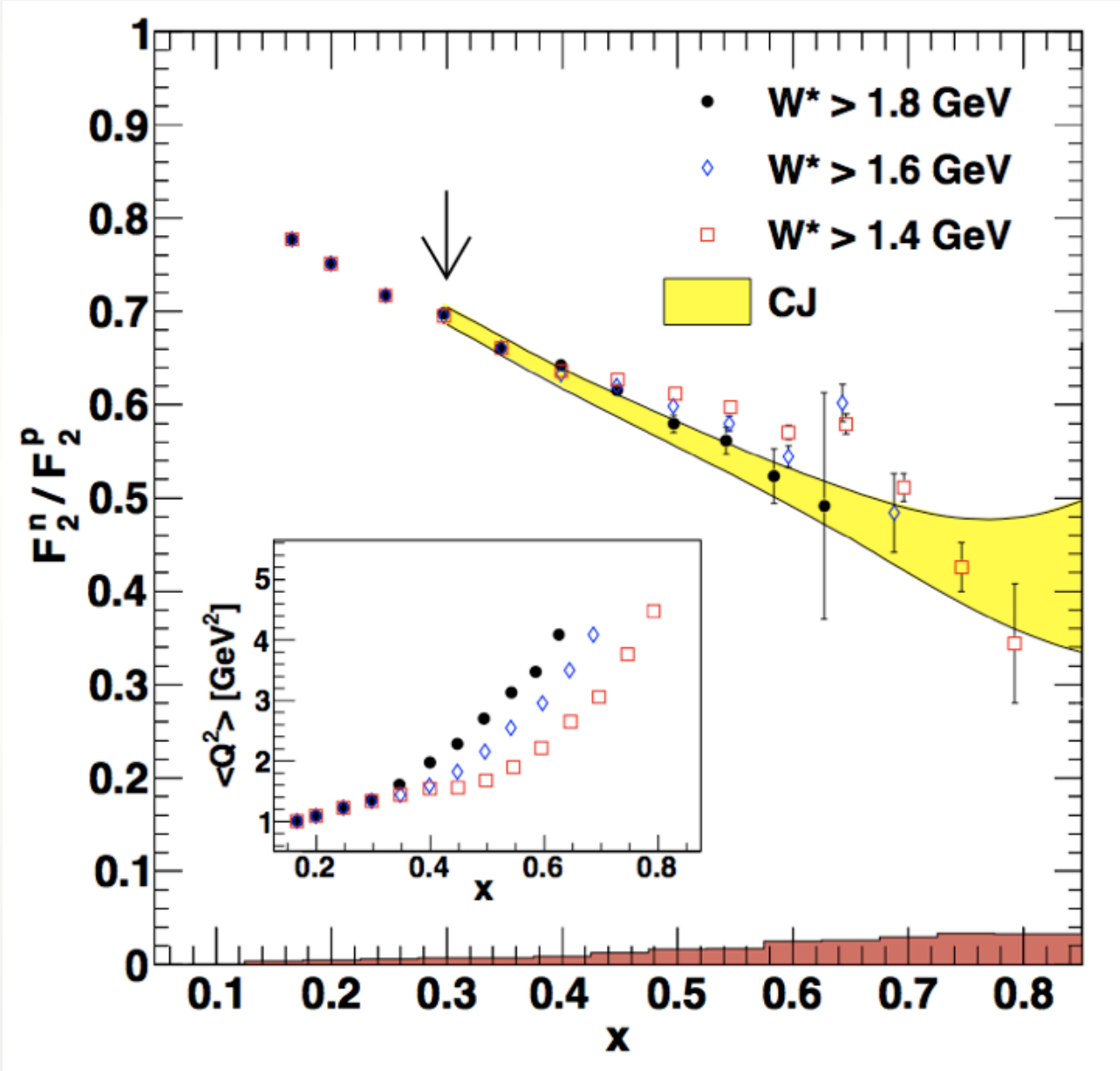
Final 4 GeV Data F_{2n}



BoNuS data compared to a state of the art nuclear physics extraction of neutron structure functions from deuterium (red points, Malace, et al.)

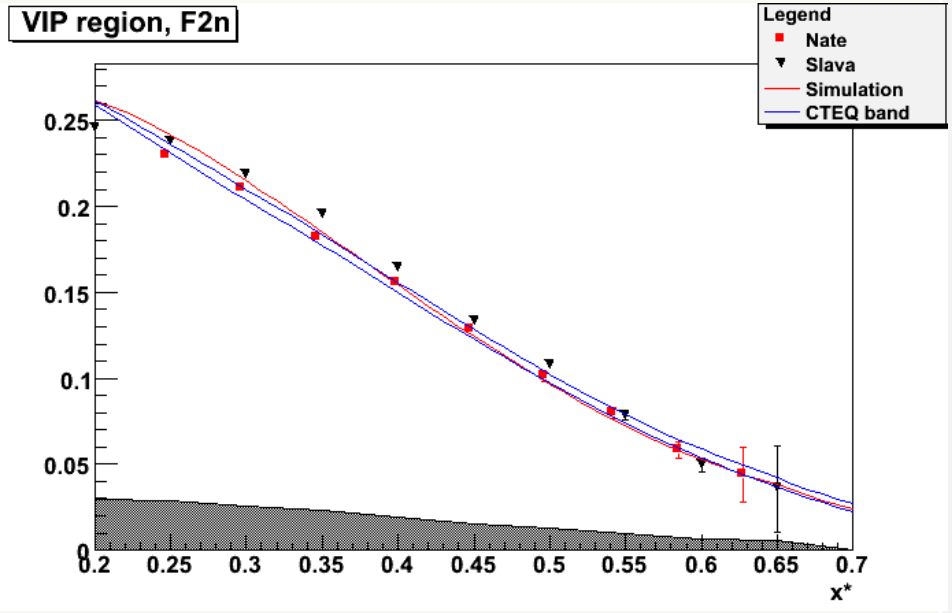
and a model (green line by Christy et al.)

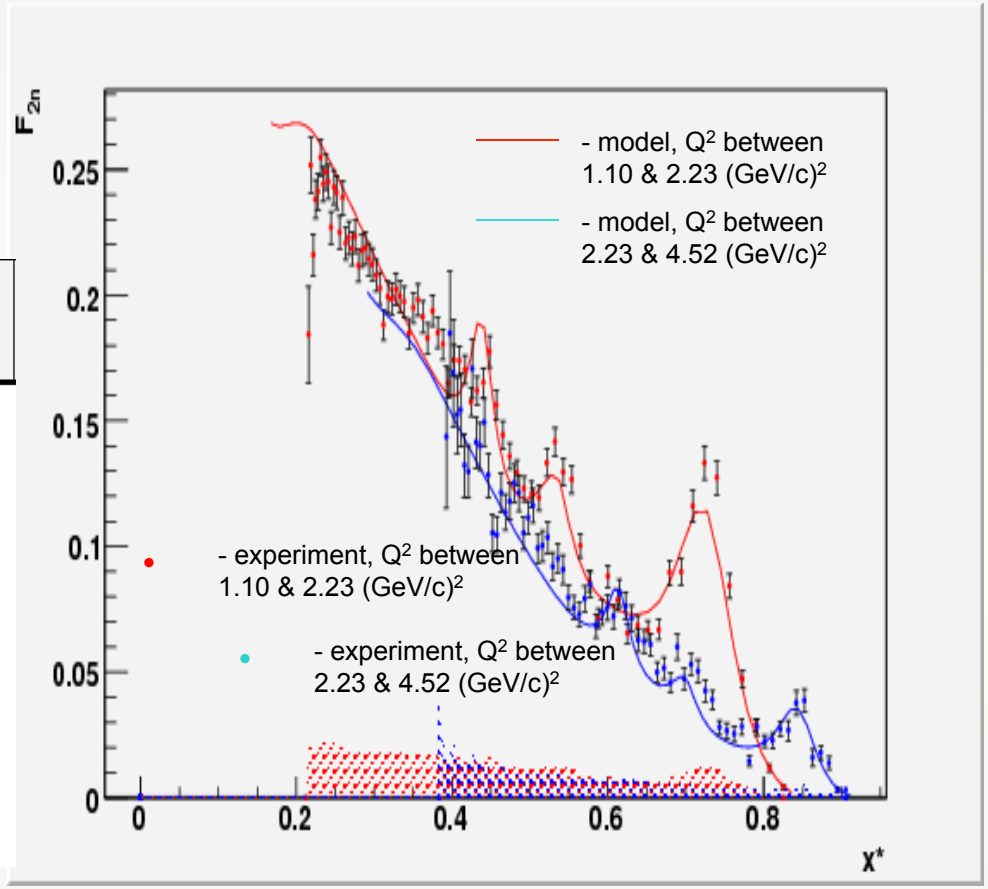
BoNuS F_2^n/F_2^p



- F_2^n/F_2^n vs. x
- Curves are CETQ error bands
- CETQ cuts off at low x because Q^2 is too low
- Lower cuts in W* imply higher x but the inclusion of resonance contributions.
- Results are consistent with CETQ trends at high x.

Results from BoNuS (iii)

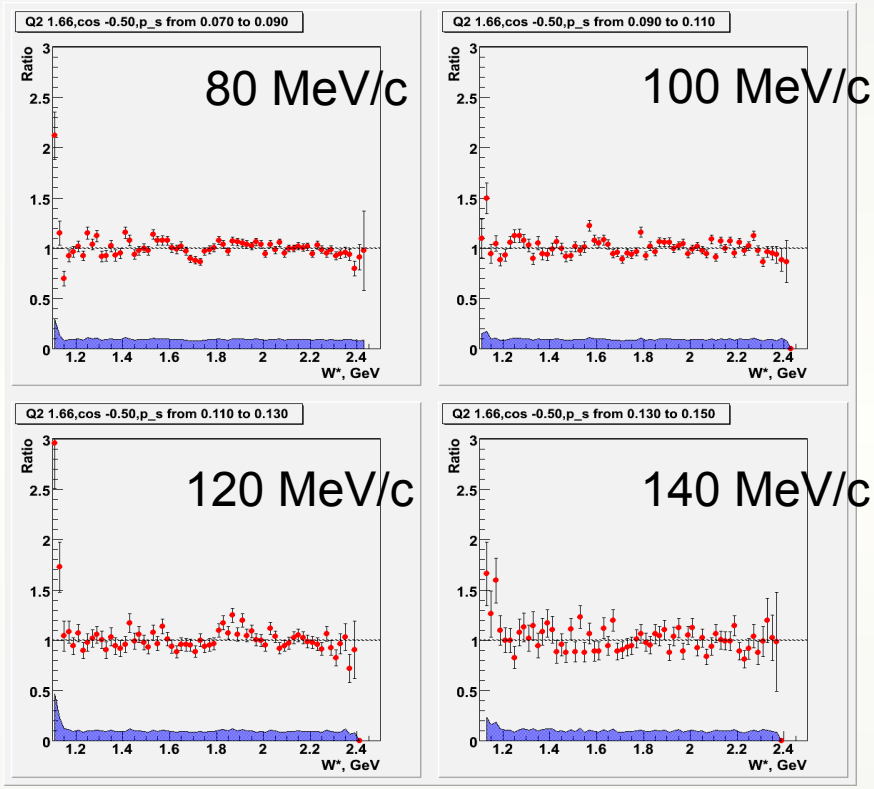




5 GeV Data

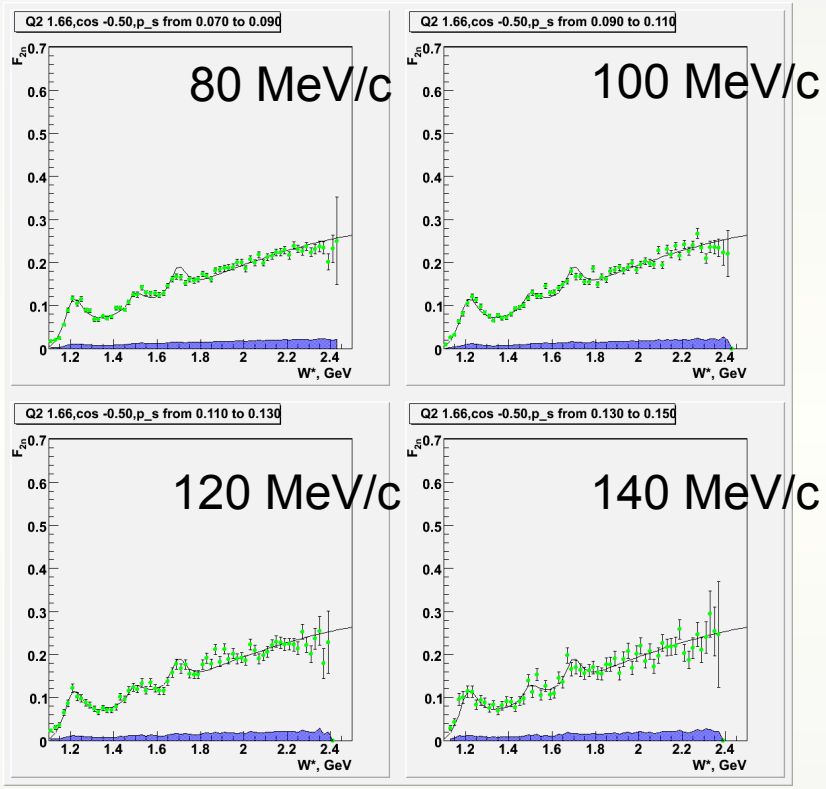
Results from BoNuS (iv)

Testing the Spectator Assumption - dependence on p_s



W* [GeV]

Ratio Data/Model

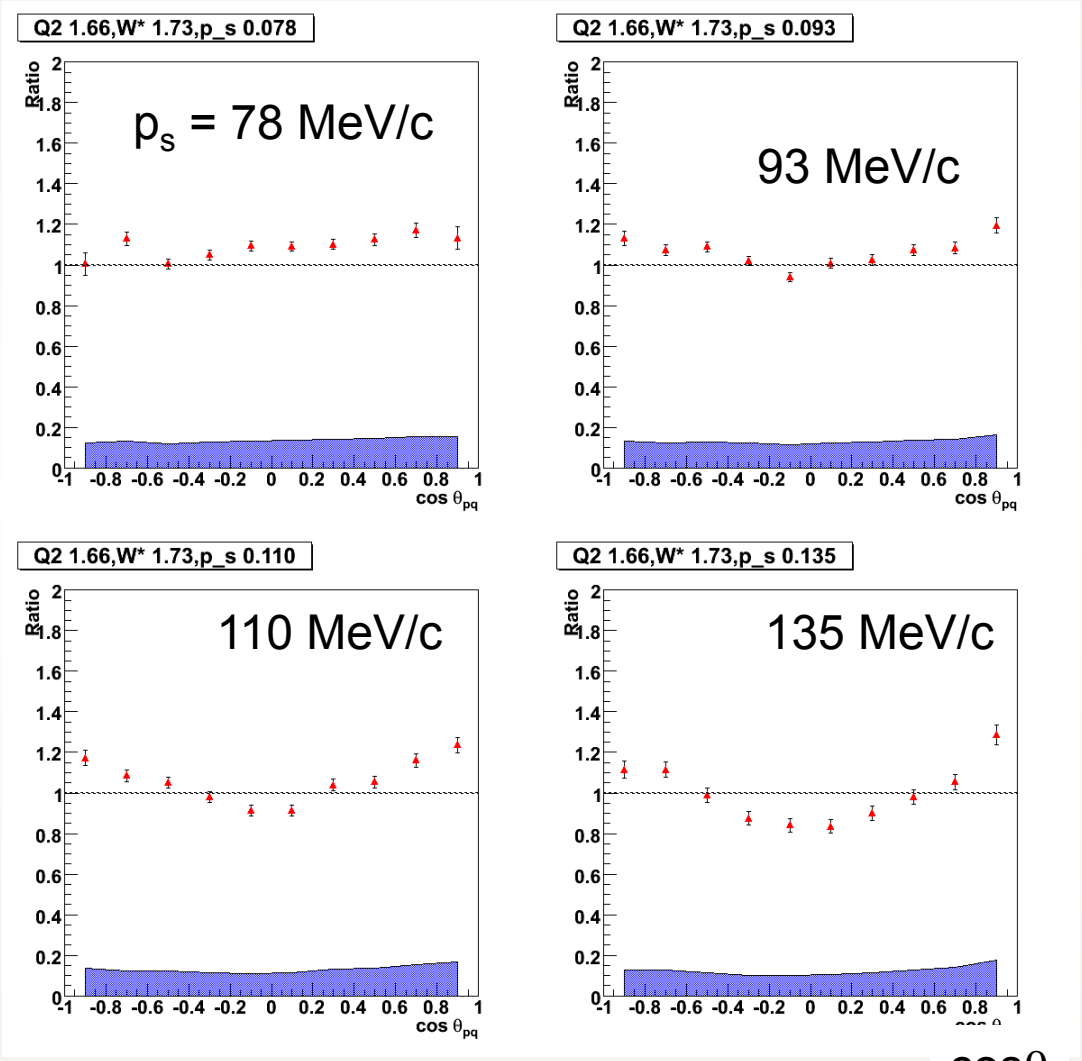


W* [GeV]

Extracted "effective structure function" F_{2n}

- Data have radiative elastic tail subtracted
- Simulation uses simple spectator model, radiative effects, full model of RTPC and CLAS

Results from BoNuS (v)

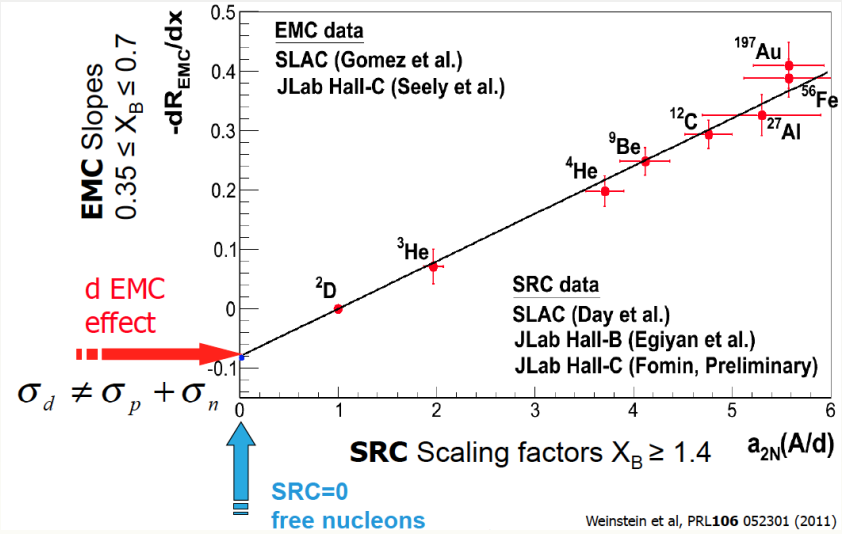


W* = 1.73 GeV
Q^2 = 1.66 $(GeV/c)^2$

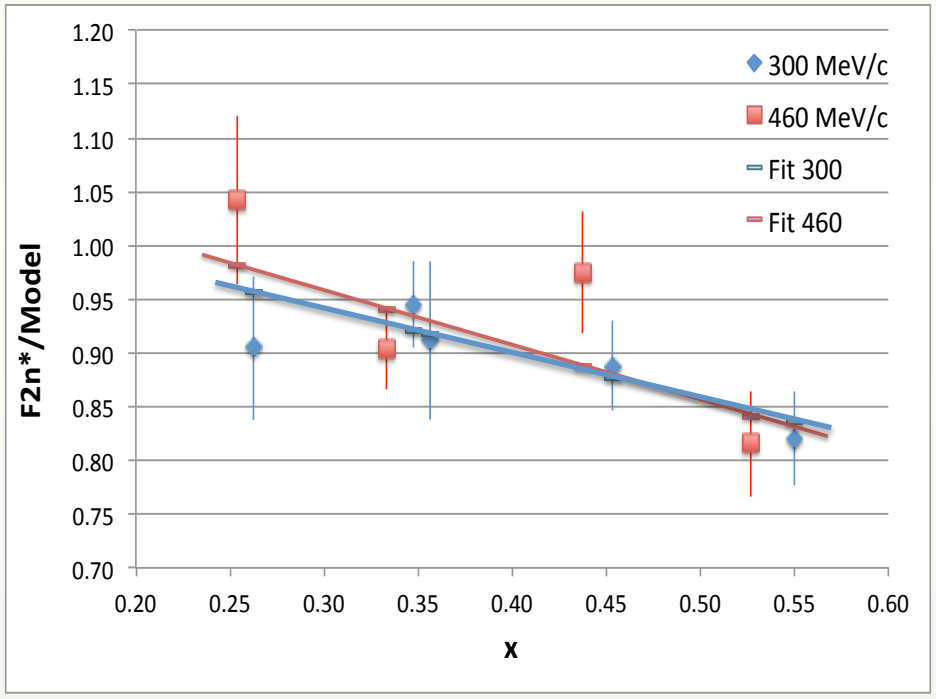
Testing the Spectator Assumption - dependence on θ_{pq}

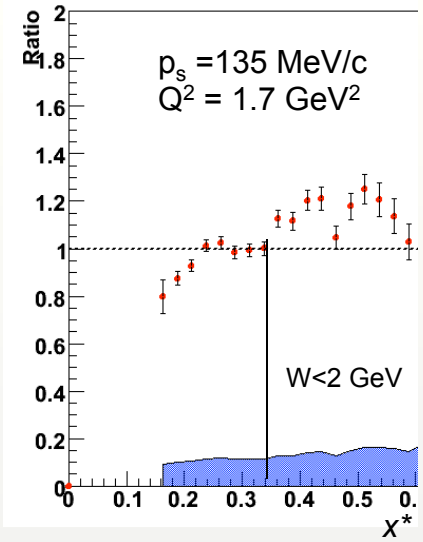
- So far, no strong deviations from naïve PWIA spectator picture at lower spectator momenta
- Possible indication of θ-dependence at higher p_s
- Have systematics for a wide range in Q^2, W* and beam energies

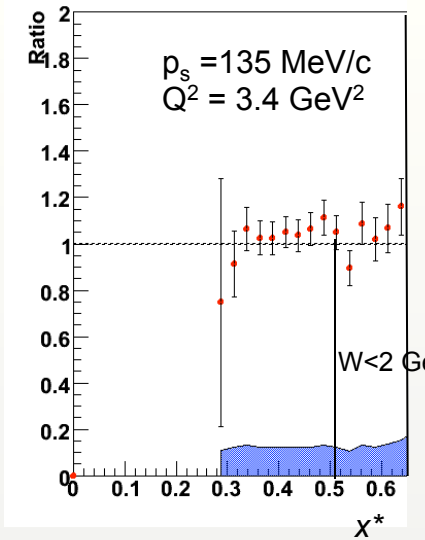
What can we say about the EMC effect in Deuterium?



Slope for most tightly bound nuclei (20% SRC) about -0.4!







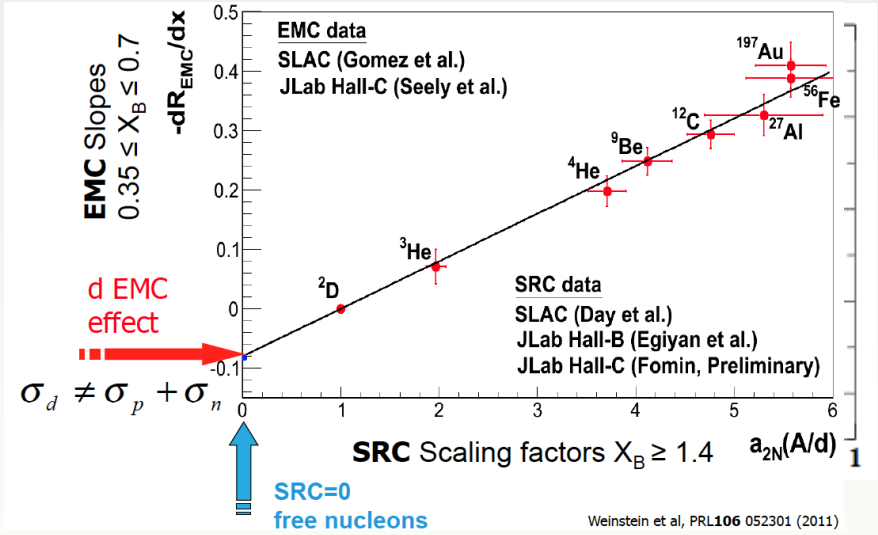
Deeps backward angles > 110°
Slope approx. -0.4 – -0.5 nearly independent of p_s

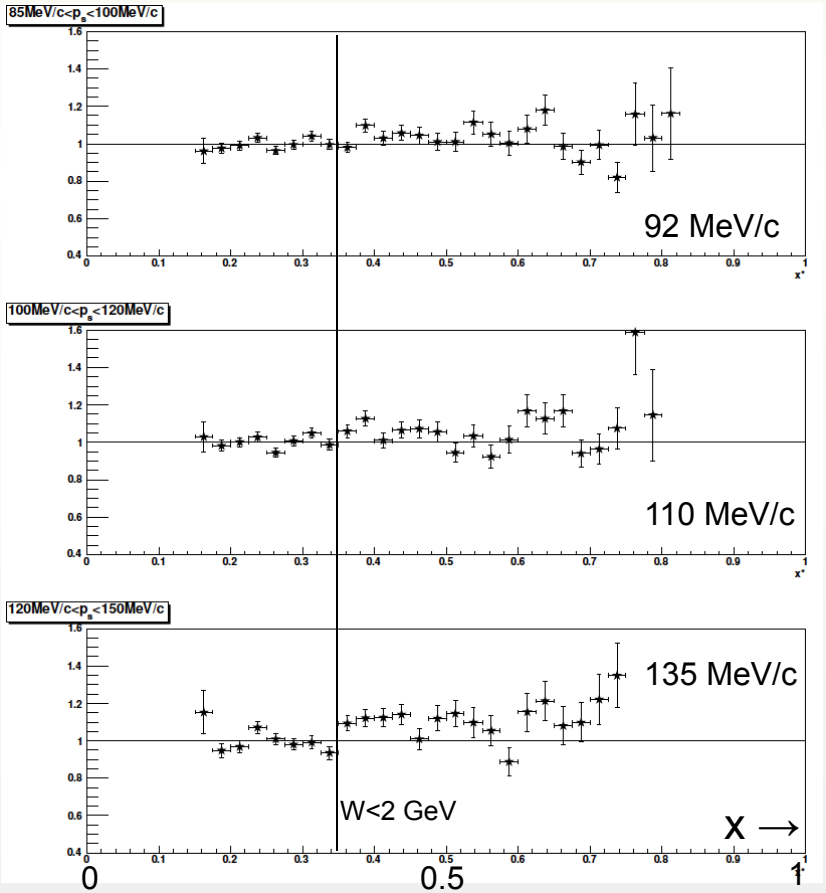
BoNuS results for low p_s indicate little dependence on x^*

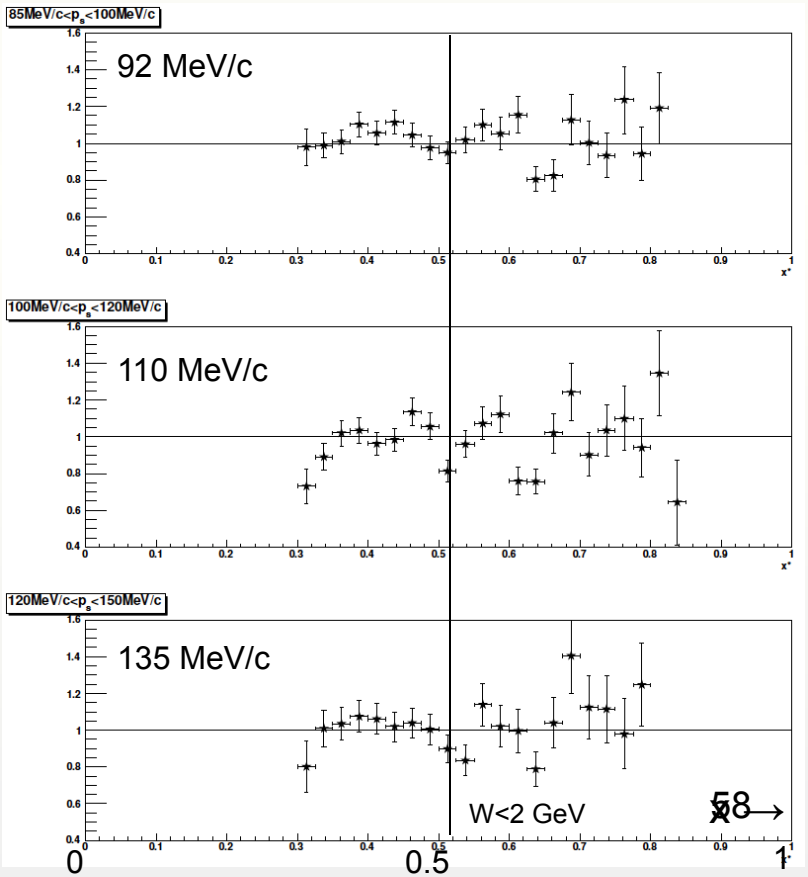
What can we say about the EMC effect in Deuterium?

see talk by L. Weinstein

Ratio $F_{2n}(x, p_s)/F_{2n}(x,p_s=78\ \text{MeV/c})$
as function of spectator momentum p_s



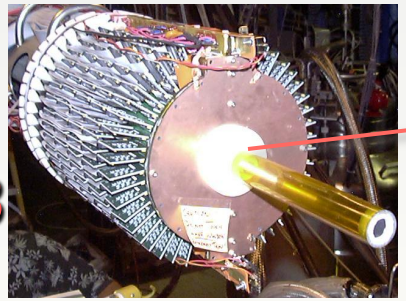


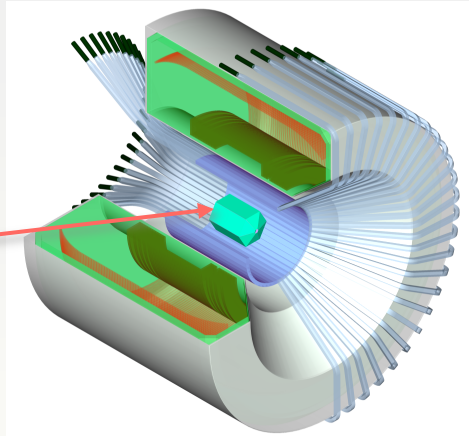


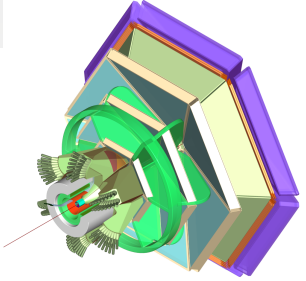
Plans for 12 GeV

BoNuS

E12-06-113

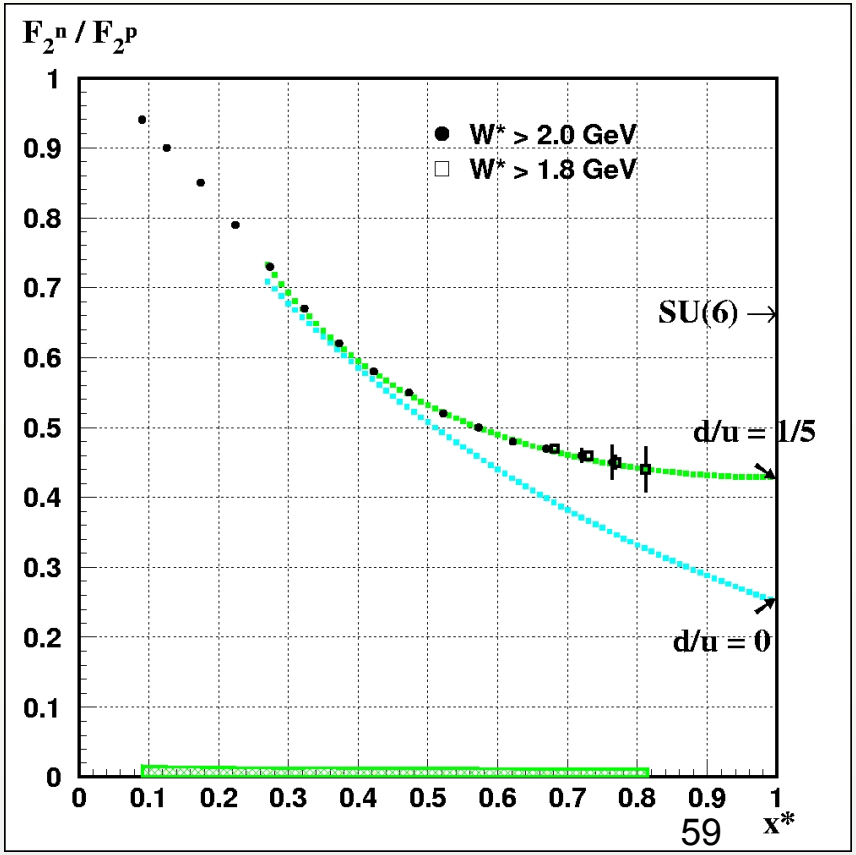






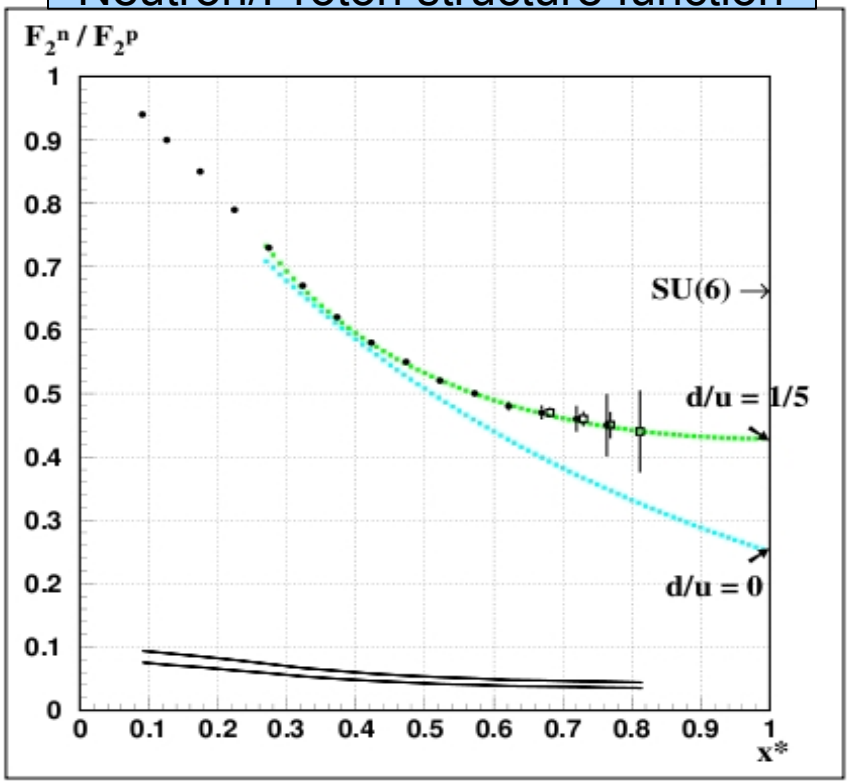
CLAS12 Central Detector

- Data taking of 35 days on D_2 and 5 days on H_2 with $\mathcal{L} = 2 \cdot 10^{34}$ cm^{-2} sec^{-1}
- **Planned** BoNuS detector DAQ and trigger **upgrade**
- DIS region with
  - $Q^2 > 1$ GeV$^2/c^2$
  - $W^* > 2$ GeV
  - $p_s > 70$ MeV/c
  - $10° < \theta_{pq} < 170°$
- Largest value for $x^* = 0.80$ (bin centered $x^* = 0.76$)
- Extend to higher momenta using central detector alone

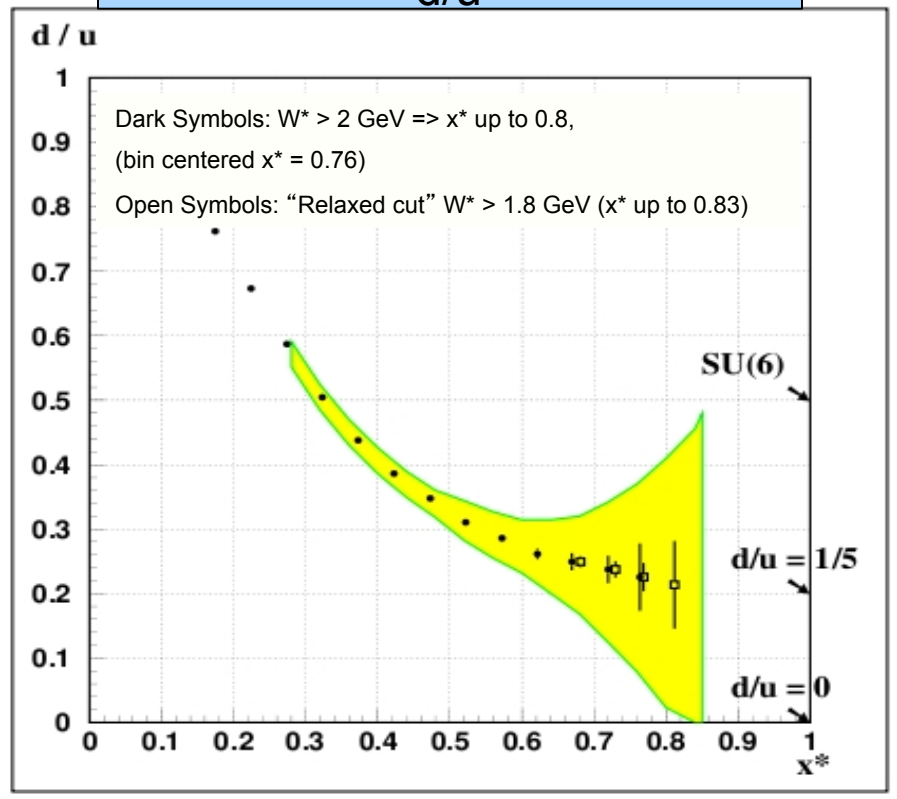


Expected Results - BoNuS12 E12-06-113

Neutron/Proton structure function



d/u



Data taking of 35 days on D_2 and 5 days on H_2 with $\mathcal{L} = 2 \cdot 10^{34}$ cm^{-2} sec^{-1}

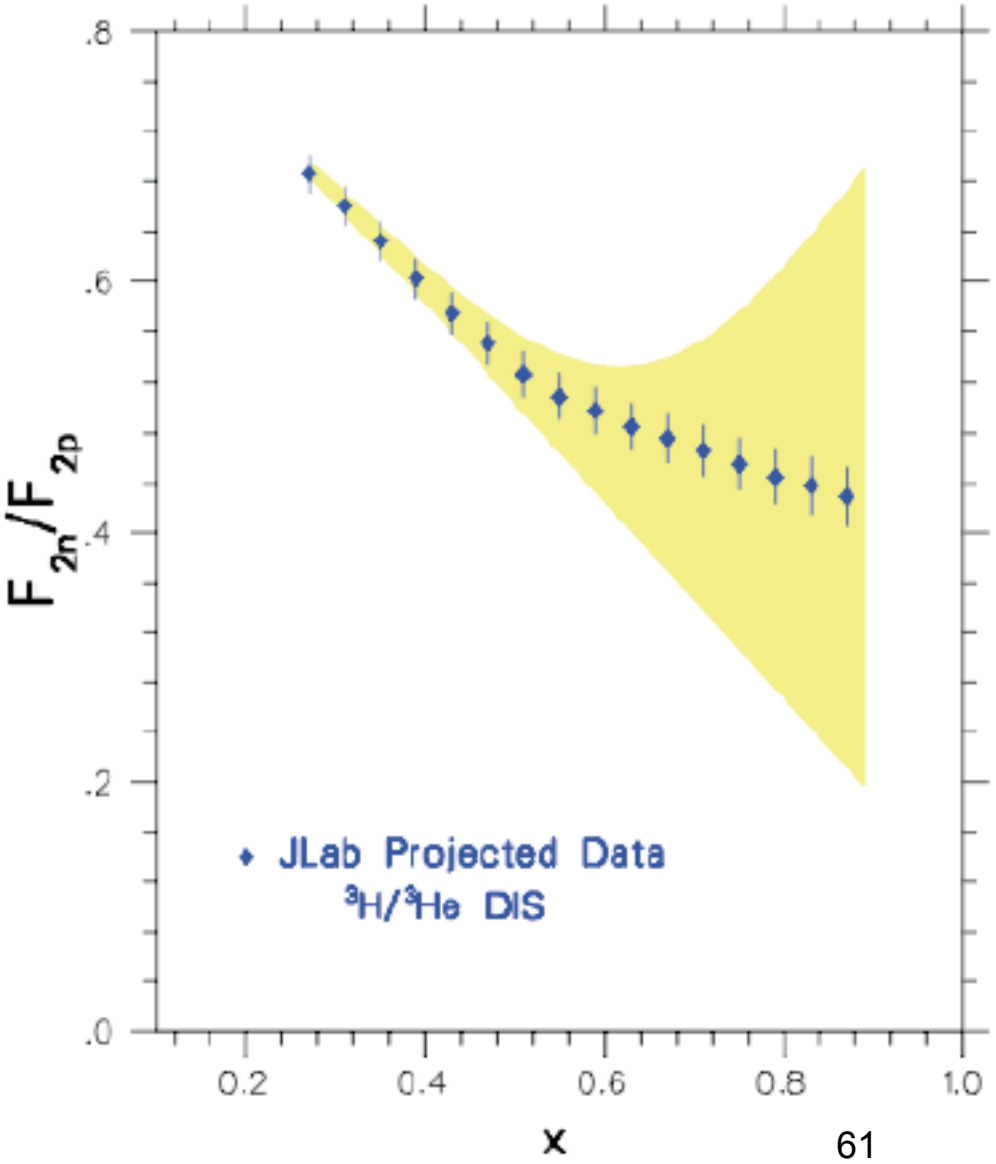
- DIS region with
  - $Q^2 > 1$ GeV$^2/c^2$
  - $W^* > 2$ GeV
  - $p_s > 70$ MeV/c
  - $-10° < \theta_{pq} < 170°$

New methods – DIS from A=3 ("MARATHON")

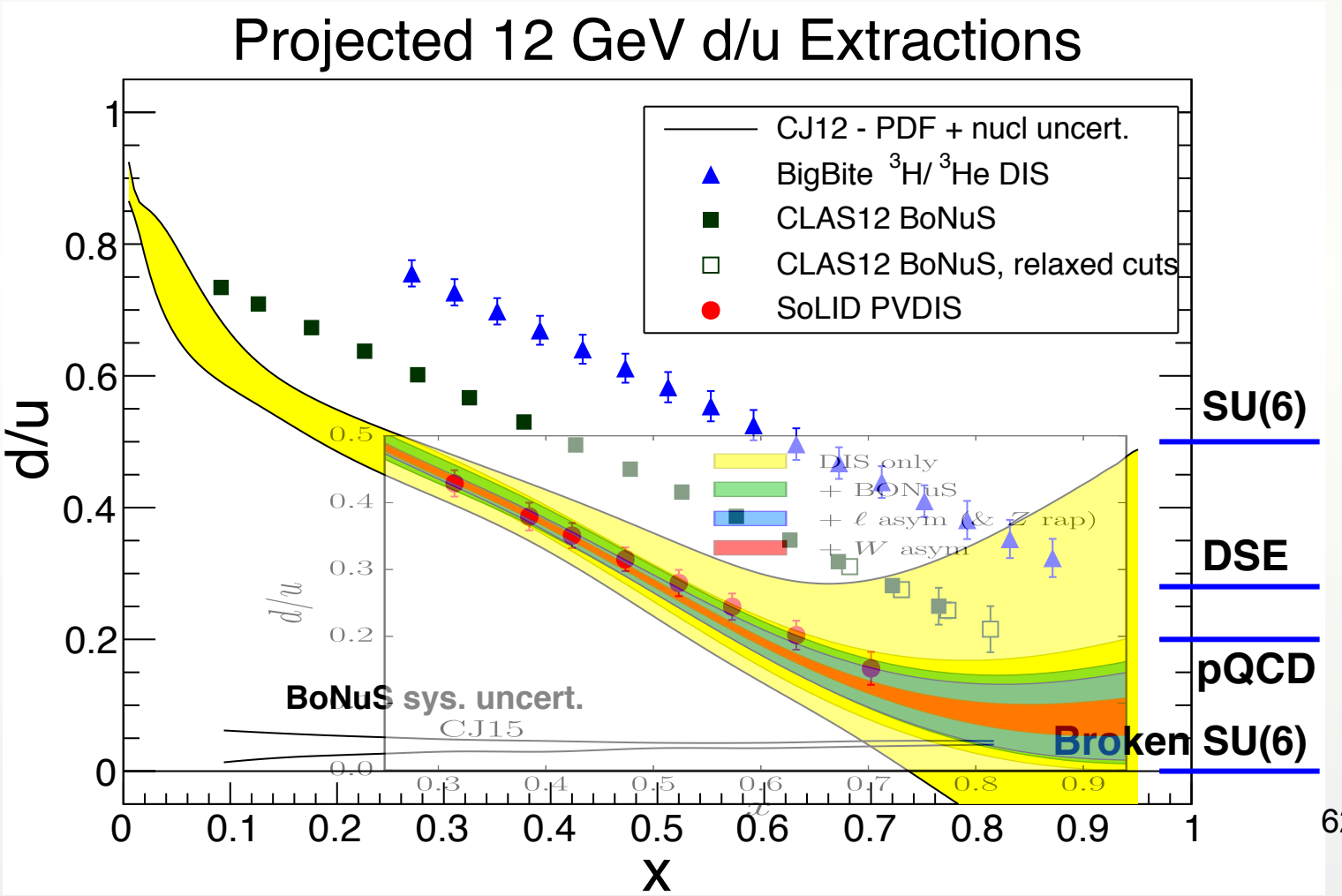
- extract n/p ratio from ratio of A=3 structure functions

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

→ ratio of ^{3}He to ^{3}H EMC ratios cancels to ~1% for $x < 0.85$



d/u: JLab at 11 GeV



Conclusion

- Few-body nuclei (D and ^{3}He) continue to be "neutron targets of choice"
- Interpretation of results complicated by off-shell effects, possible structure modifications and final state interaction…
- …but we can also learn a lot about NN interaction and few-body nuclear structure by studying these effects
- New, more precise theoretical calculations are becoming available and can be tested experimentally
- New experimental techniques allow us to minimize binding effects or study them in detail
- Started new initiative to "mine" CLAS data for more insight into the interplay between Nuclear and Quark d.o.f.
- Lots more data at 12 GeV!

Conclusion - Status of Spectator Experiments

- Lots of data with coincident spectator detection already exist, many have been (partially) analyzed
  - FSI seems very important in perpendicular and forward kinematics
  - simple spectator picture with LC wave functions seems to work reasonably in some kinematic regions
  - Possible modifications of internal nucleon structure (dependent on spectator momentum) still an open question
- New data from EG6 will extend this study to ^{4}He target
- Data mining initiative will unlock much more information from all nuclear data taken with CLAS
- Lots more exciting experiments after JLab energy upgrade!
- Requires theory-experiment interaction: Agree on definition of "reduced cross section"; need predictions of this cross section including FSI over large kinematic range (not only for p_T = 0 ;-)
- ULTIMATE GOAL: EIC - can smoothly map out $p_{spect.}$ from 0 to 1 GeV/c