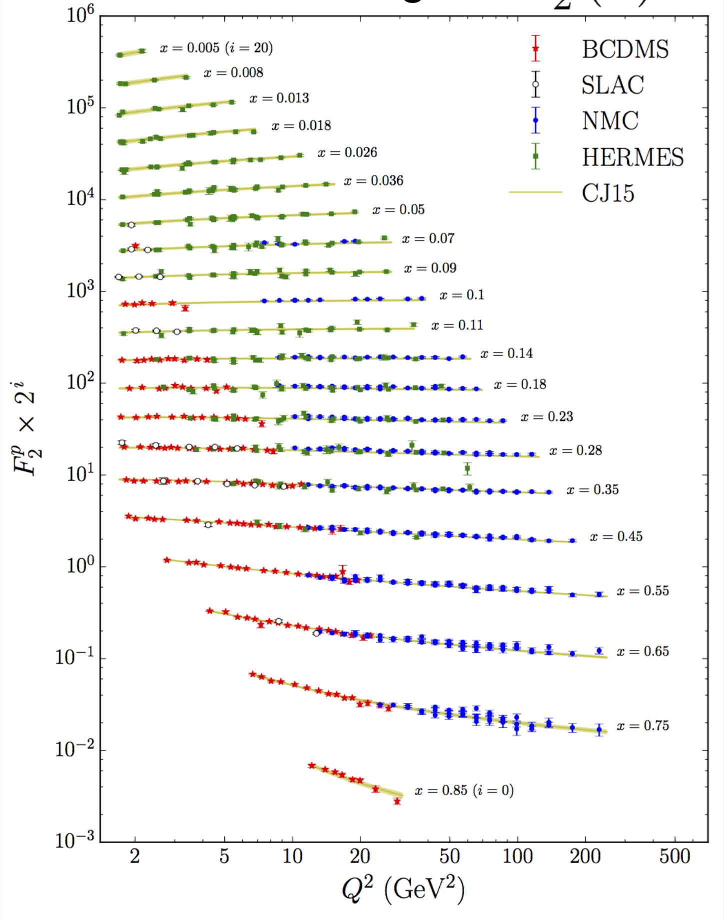
The neutron structure function F_2 at high-x with BONuS at CLAS

C. Ayerbe Gayoso

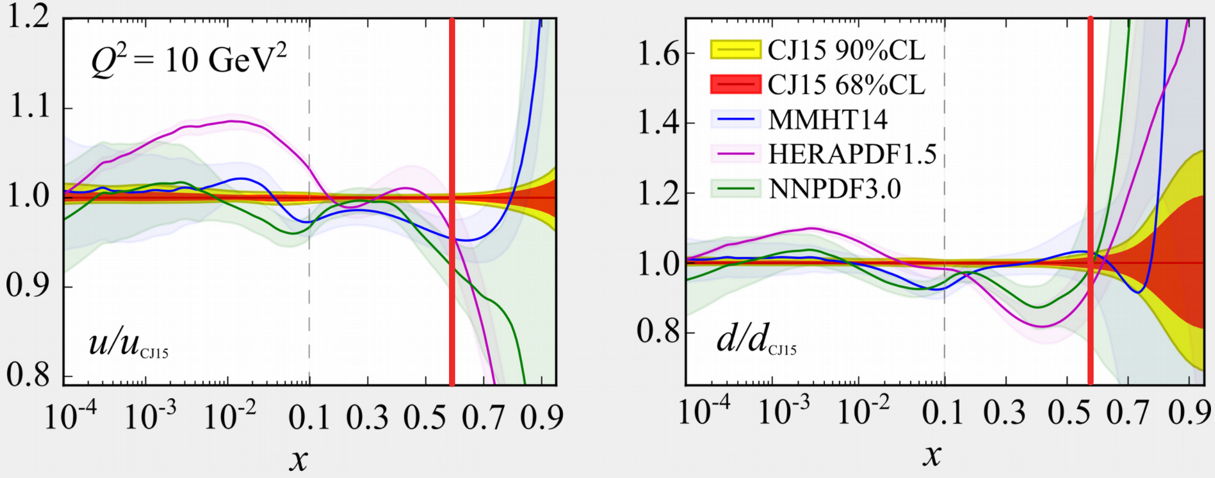
The College of William and Mary
on behalf of the BONuS collaboration

Motivation I

Vast knowledge of $F_2^p(x)$



PDF models normalized to CJ15



A. Accardi, L. T. Brady, W. Melnitchouk, J. F. Owens and N. Sato, Phys. Rev. D 93, 114017 (2016)

LO and $s(x) \approx 0$

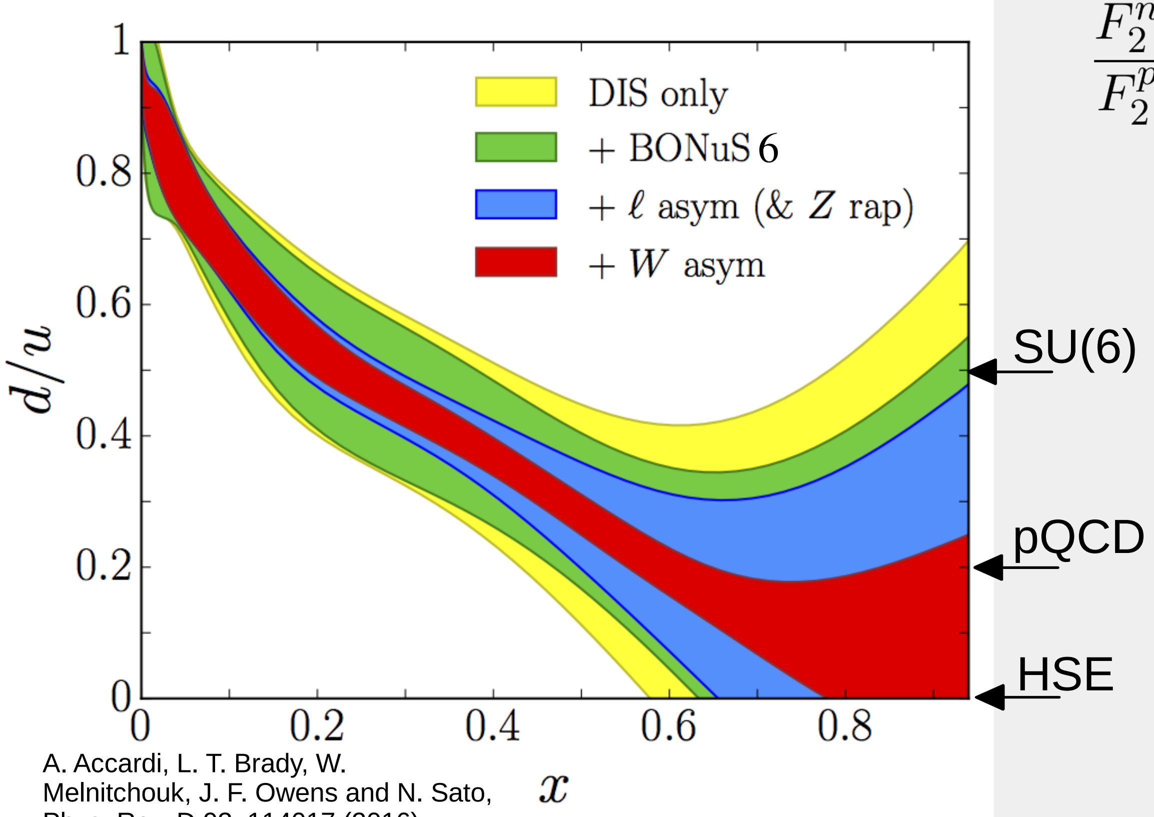
$$\frac{F_2^p(x)}{x} = \left[\frac{4}{9}u(x) + \frac{1}{9}d(x)\right]$$

u(x) is dominant → well determined from proton data

$$\frac{F_2^n(x)}{x} = \left[\frac{4}{9}d(x) + \frac{1}{9}u(x)\right]$$

Lack of free neutron data → *d(x)* larger uncertainties

Motivation II



A. Accardi, L. T. Brady, W. Melnitchouk, J. F. Owens and N. Sato, Phys. Rev. D 93, 114017 (2016)

$$\frac{F_2^n(x)}{F_2^p(x)} \approx \frac{1+4d/u}{4+d/u} \Rightarrow \frac{d}{u} \approx \frac{4F_2^n/F_2^p - 1}{4 - F_2^n/F_2^p}$$

Data from neutron F_2 comes primarily from inclusive scattering off deuterium → theoretical uncertainties led to ambiguities

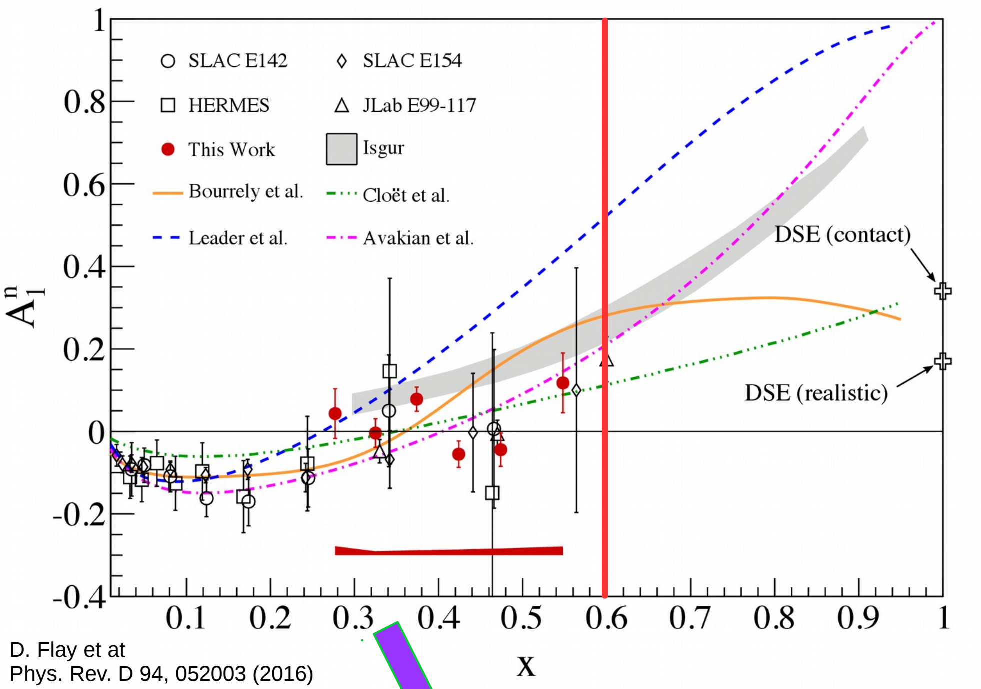
Representative predictions of d/u at $x \rightarrow 1$:

- SU(6): 1/2
- pQCD: 1/5
- Hyperfine Structure Effect: 0

Motivation III

- the d/u ratio as $x \to 1$ is crucial to interpret $A1n$ and $A1p$ measurements for information on SU(6) symmetry breaking:

	A_1^p	A_1^n	$\Delta u/u$	$\Delta d/d$
SU(6)	5/9	0	2/3	-1/3
HFSE	1	1	1	-1/3
pQCD	1	1	1	1



D. Flay et at
Phys. Rev. D 94, 052003 (2016)

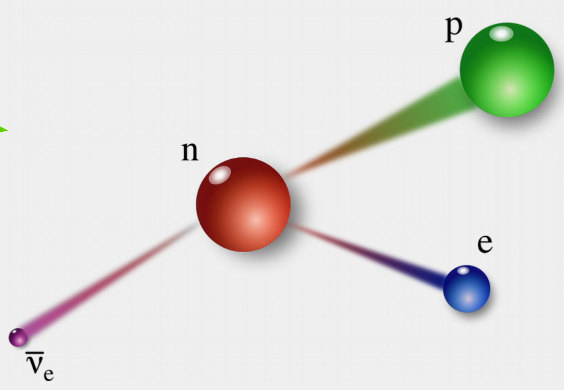
- Neutron F_2 is needed in general to extract neutron spin structure functions from measured asymmetries on nuclei like D and ^{3}He

$$F_2(x) = 2xF_1(x) \quad \rightarrow \quad A_1^n \approx g_1^n / F_1^n$$

unpolarized

Neutron sources

- Free neutrons decay in 15 minutes

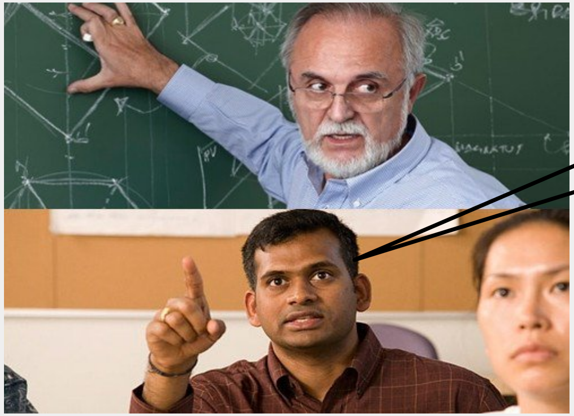


- Difficulty to make a dense target

S.Materne, NIMA 611, 2-3 (2009)

  - ✗ Magnetic bottle ~10^6 n/cm^2(PENeLOPE TU München)
  - ✔ Typical proton target ~10^{23} p/cm^2 (10 cm LH)

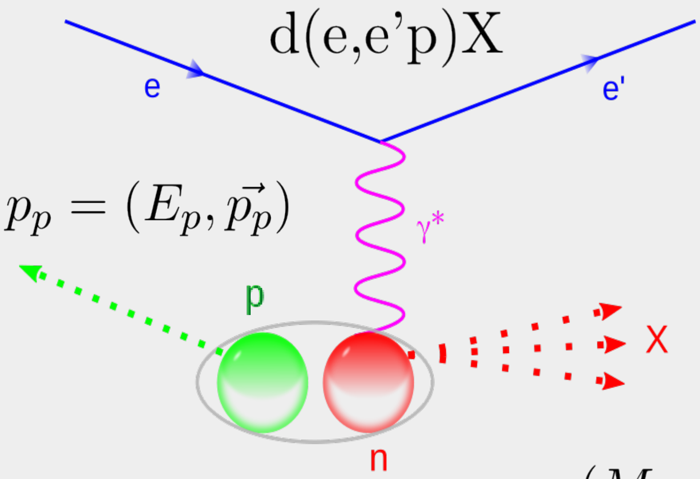
- Neutron sources solution: Deuterons and ^{3}He
  - But... Nuclear model dependence:
    - Fermi motion
    - Off-shell effects
    - EMC effect
    - Final State interactions
    - ...



Is there any way to reduce uncertainties?

YES

Spectator Tagging I



$$p_p = (E_p, \vec{p_p})$$

Plane-wave impulse approximation (PWIA)

Measuring the proton (spectator) we can infer the motion of the struck neutron

$$W^{*2} = (p_n + q)^2 = p_n^2 - Q^2 + 2((M_d - E_p)\nu - \vec{p}_n\vec{q}$$

$$\approx M^{*2} - Q^2 + 2M_p\nu(2 - \alpha_p)$$

$$\alpha_p = \frac{E_p - \vec{p}_p\hat{q}}{M_p}$$

deuteron light cone momentum fraction carried by spectator proton

$$p_n = (M_d - E_p, -\vec{p_p})$$

$$M_d = E_n + E_p$$

$$E_n = M_d - \sqrt{M_p^2 + p_p^2}$$

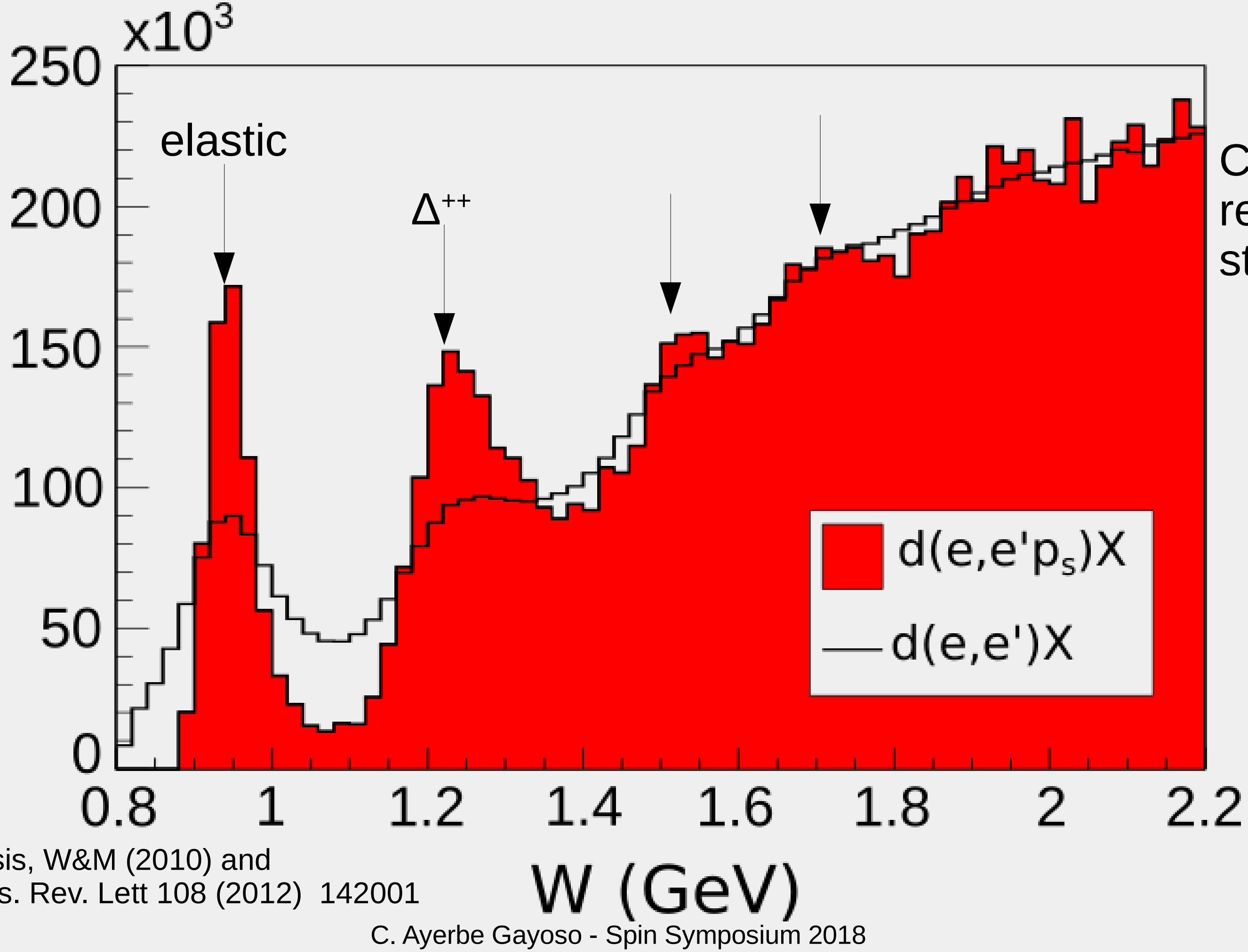
$$M^{*2} = (M_d - E_p)^2 - \vec{p_p}^{\,2}$$

invariant mass squared of the off-shell nucleon

$$x^* = \frac{Q^2}{2p_n\, q} \approx \frac{Q^2}{2M_p\nu(2 - \alpha_p)} = \frac{x}{2 - \alpha_p}$$

Spectator Tagging II

Elastic and Δ peaks better resolved



Corrections make resonances to stand out

N. Baillie PhD Thesis, W&M (2010) and
N. Baillie et al, Phys. Rev. Lett 108 (2012) 142001

The BONuS experiment

- The **B**arely **O**ff-shell **Nu**cleon **S**tructure experiment* BONuS12 (E12-06-113) at CLAS is the dedicated experiment to measure the neutron structure function making use of the tagged functions technique
  .
  - It is the successor of the successful experiment with the same name (E03-012) which ran in 2005.

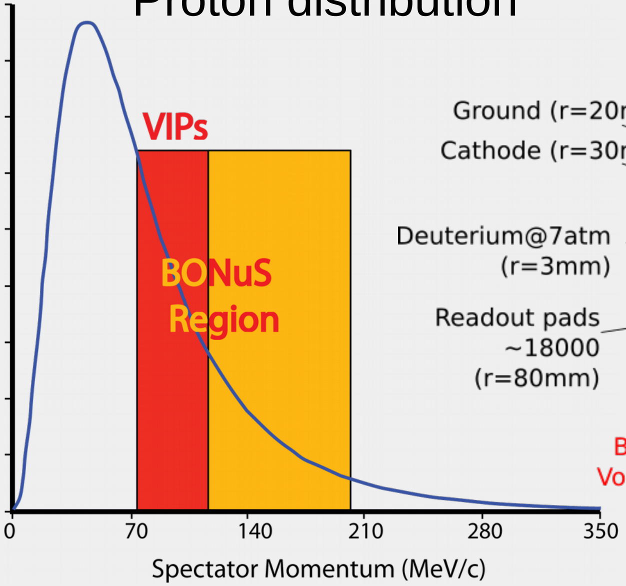
- BONuS12 kinematics:
  - $0.1 < x < 0.8$
  - over a Q^2 range of $1\text{-}14 \mathrm{GeV}^2/\mathrm{c}^2$
  - W up to 4.5 GeV
  - Luminosity up to $2 \cdot 10^{34}$ cm^{-2} s^{-1}
  - 35 days on D_2 and 5 days on H_2 with an energy beam of 11 GeV

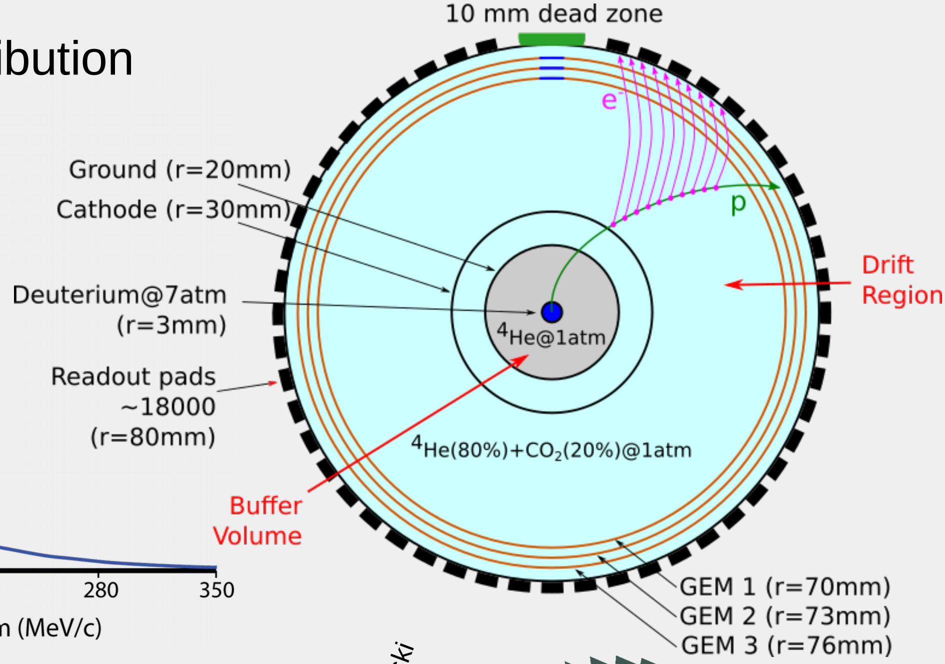
- The heart of the experiment is a 3rd generation state-of-the-art **R**adial **T**ime **P**rojection **C**hamber (RTPC).

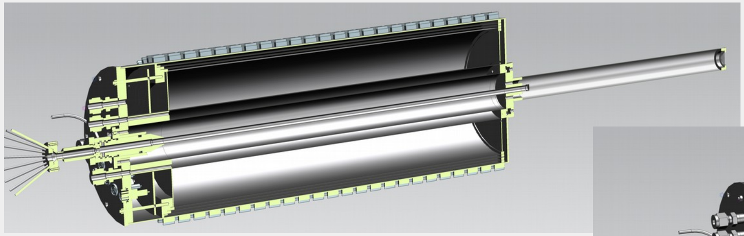
*aka **Bo**und **Nu**cleon **S**tructure

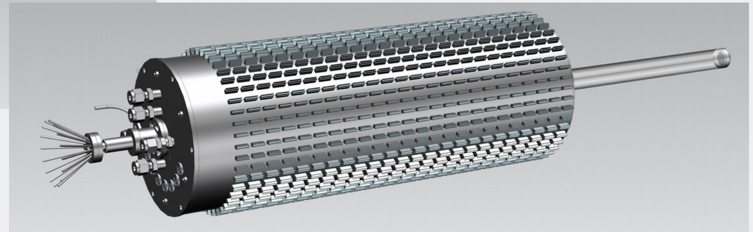
BONuS12 RTPC

- Active length: 40 cm
- Radial drift distance: 4 cm
- uniform |E| = 500 V/cm, |B| = 5 T
- Drift gas He/CO2 (80/20)
- 3 GEM amplification layers
  → 16 HV sectors per GEM
- Pad readout: 2.8 mm x 4 mm
  → ~18k channels

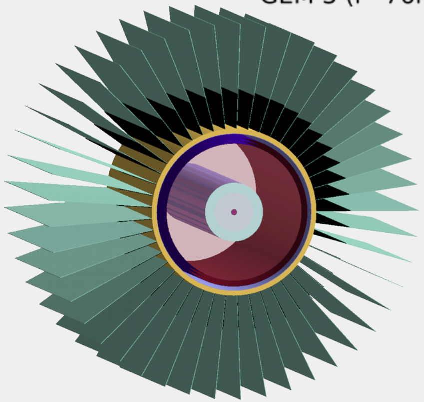








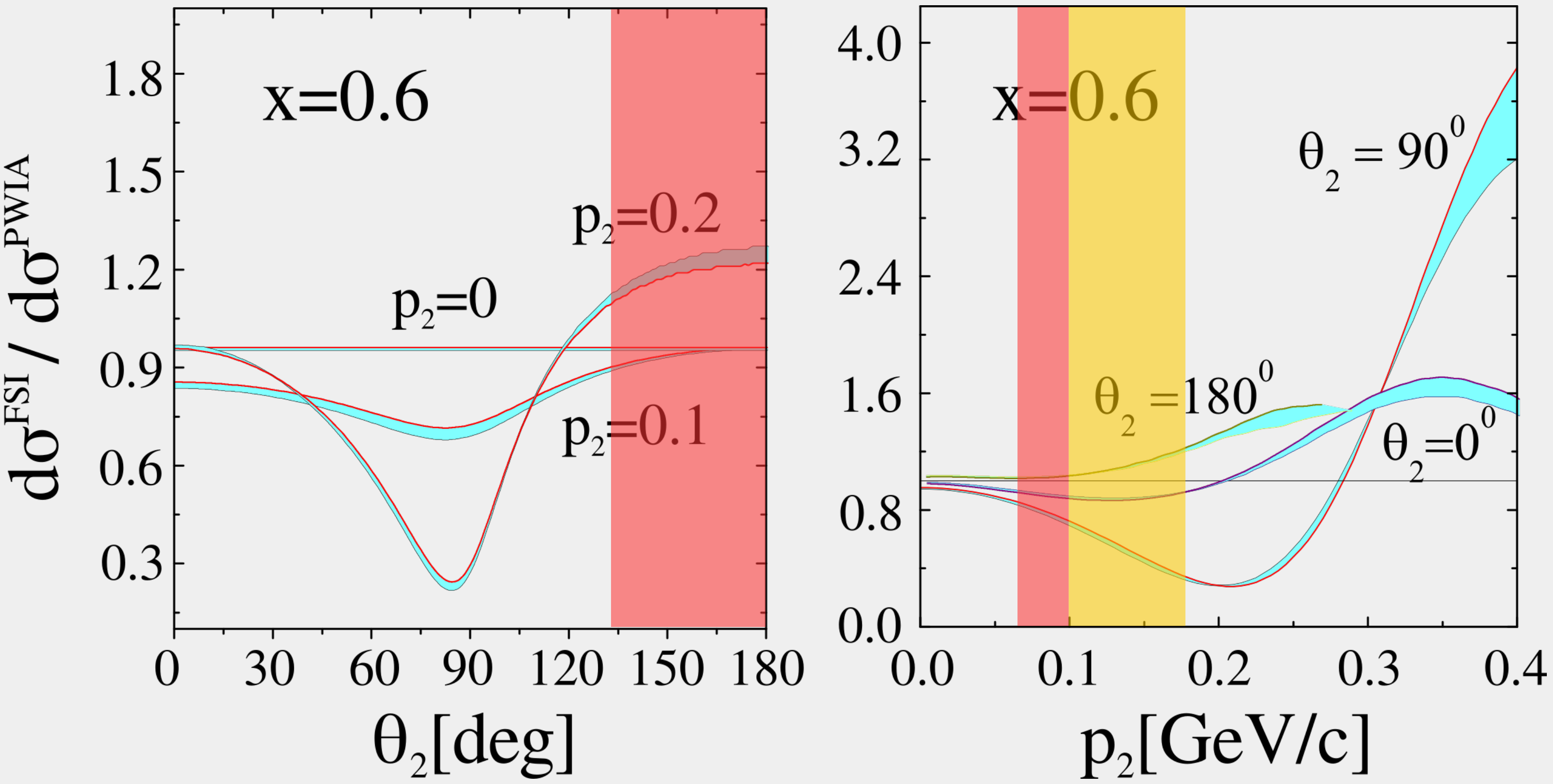
JLab Designer M. Zarecky



Simulation by Nathan Dzbenski <ndzbe001@odu.edu>

Final State Interactions

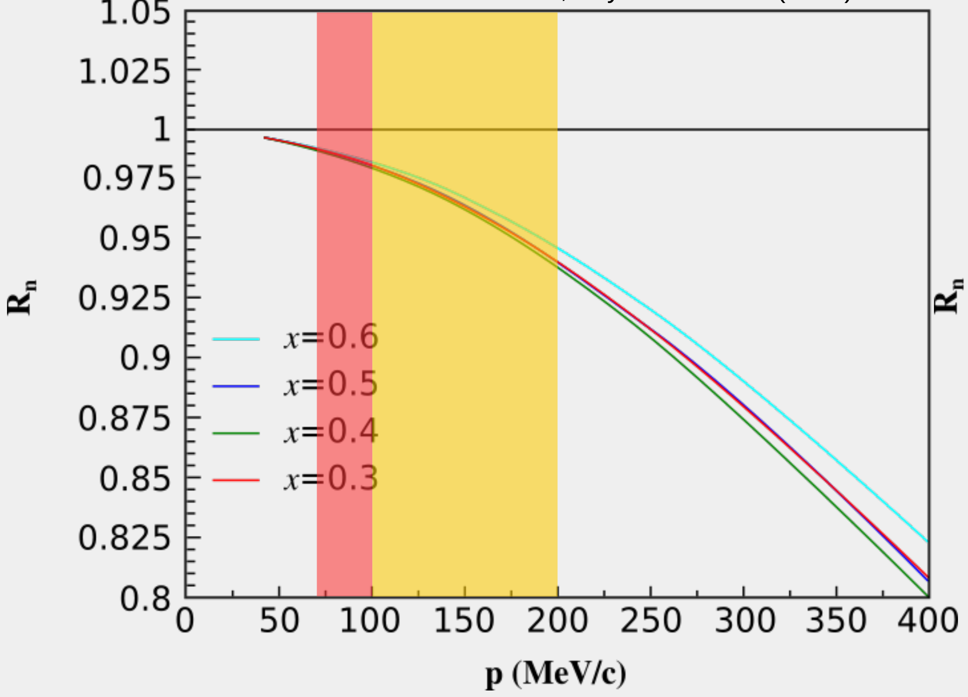
V. Palli et al, Phys. Rev. C 80(2009) 054610



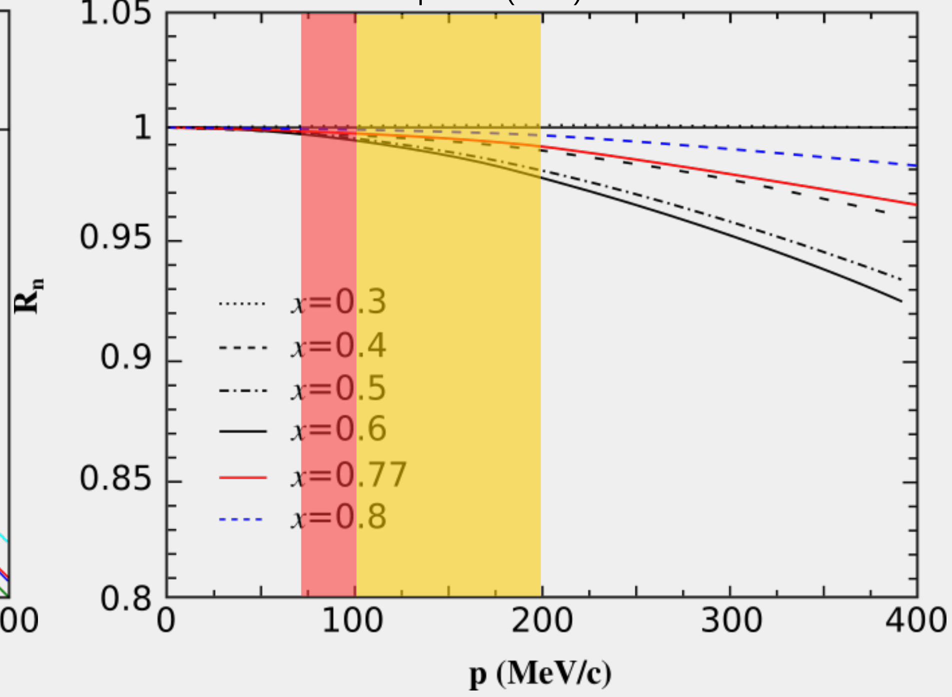
Off-Shell Effects

$$R_n \equiv F_2^{n(\mathrm{eff})} / F_2^n$$

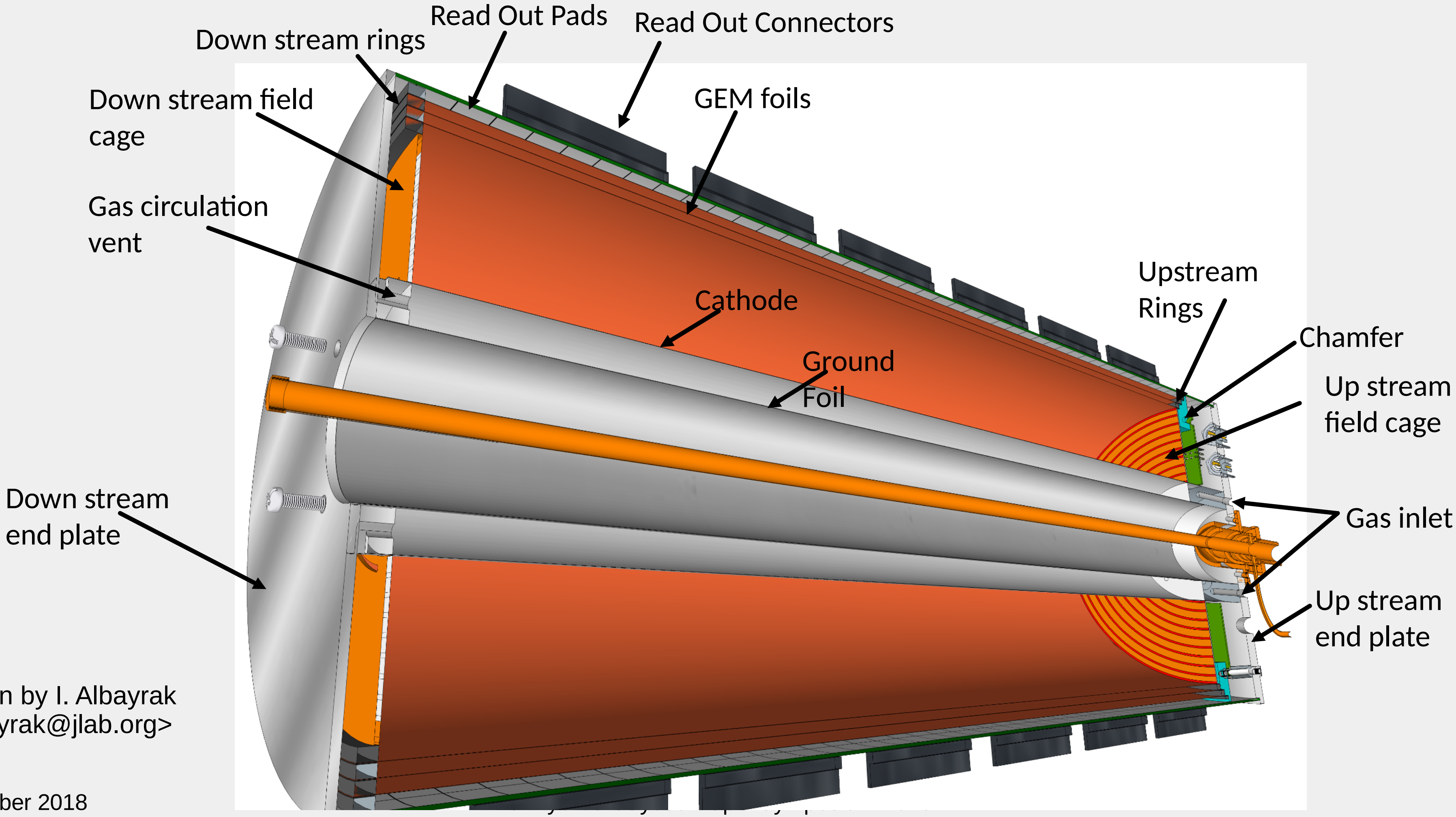
S. Liuti et al, Phys. Lett. B 356(1995) 157



W. Melnitchouk et al, Phys. Lett. B 335(1994) 11 updated (2010)



RTPC design

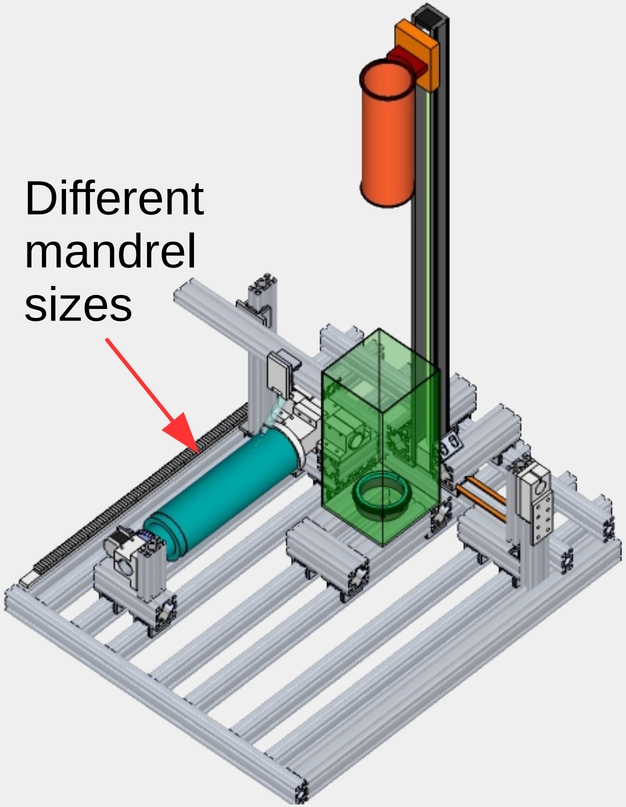


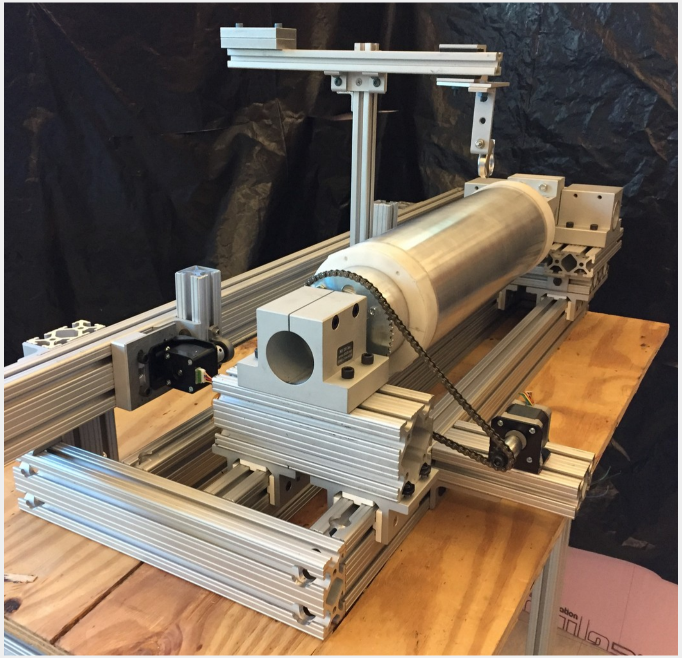
Design by I. Albayrak
<albayrak@jlab.org>

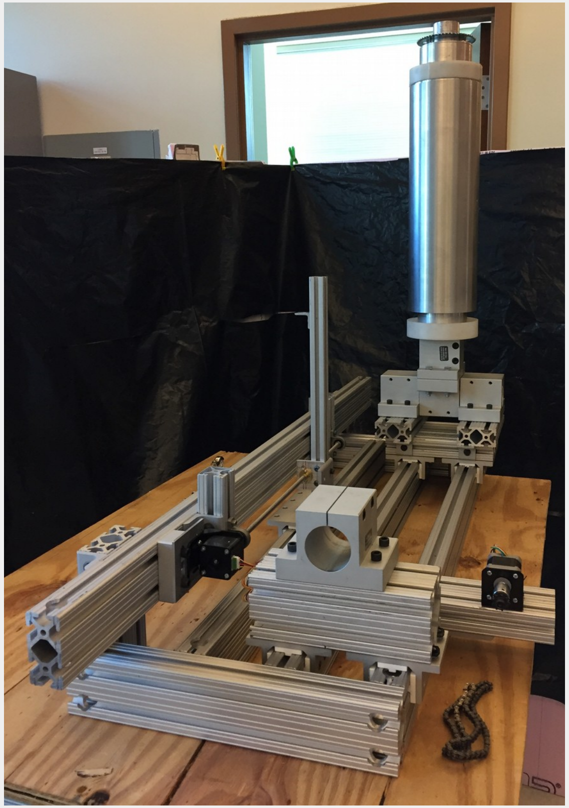
RTPC assembly

Assembly station built in Hampton University

Different mandrel sizes





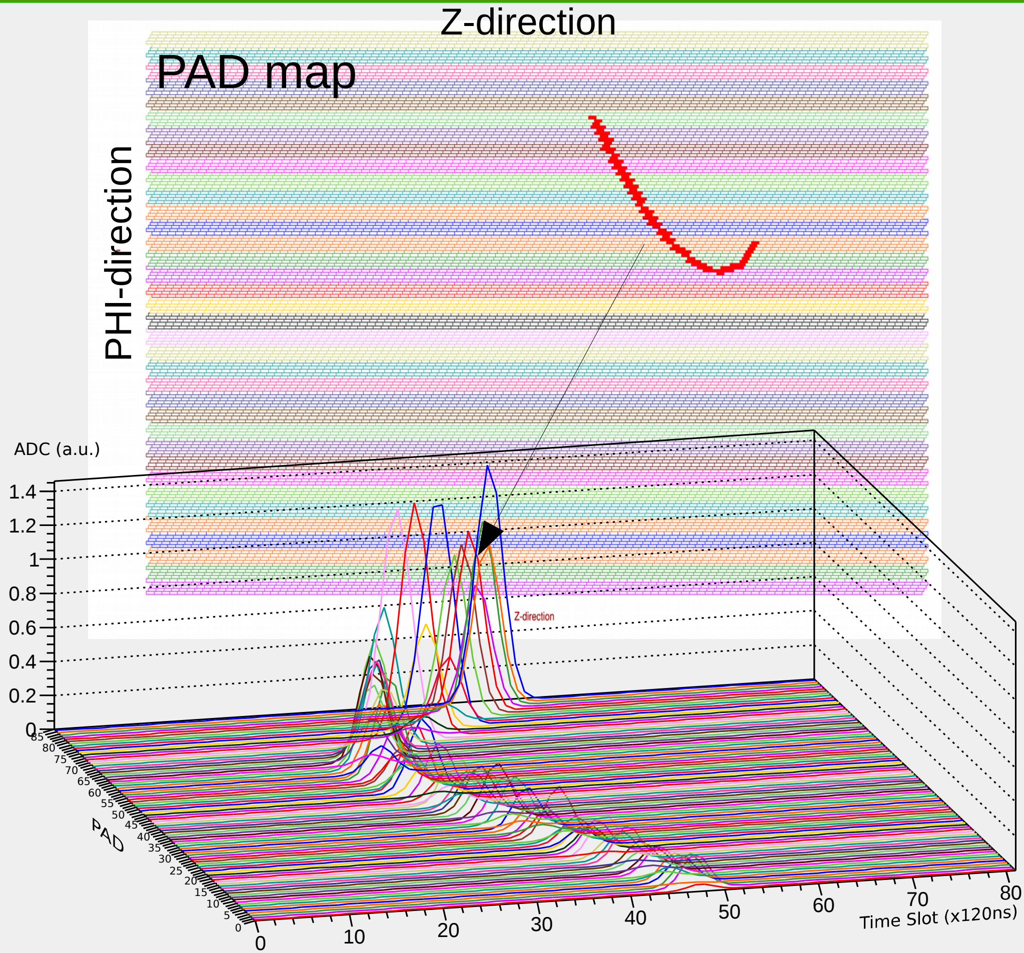


Pictures courtesy of:
I. Albayrak <albayrak@jlab.org>
A. Nadeeshani <arunin@jlab.org>
E. Christy <christy@jlab.org>

RTPC read out

- Maximum drift time: 5 μs
- Read out time: 10 μs
- Integration every 40 ns
- Each pad read every 120 ns
- Each track will hit 40 to 50 pads
- Read out by Micromegas DREAM electronics

- Trigger determined by CLAS
- Max BONuS trigger rate ~2kHz

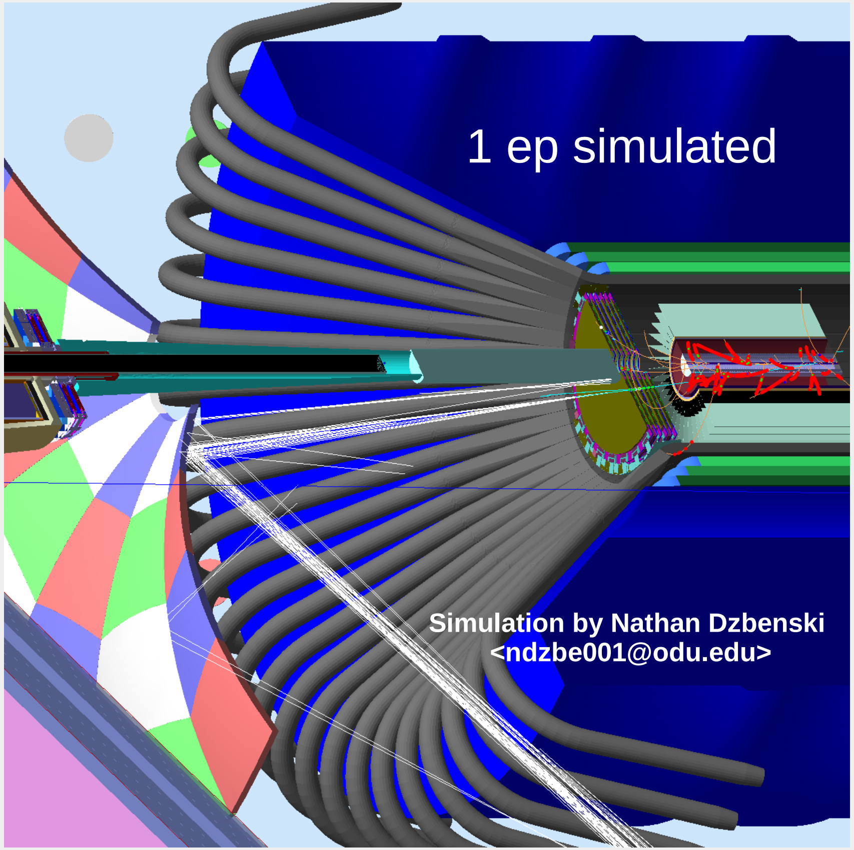


BONuS12 Simulation

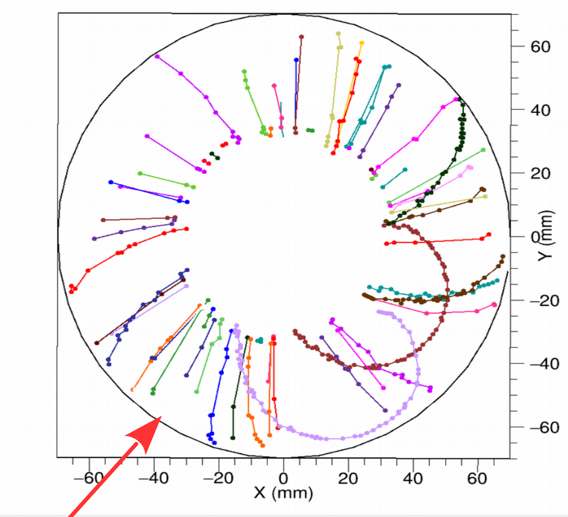
BONuS12 makes use of GEMC*, Coatjava** as well as two BONuS12 specific codes: the Track finder (TF) and the Kalman Filter (KF).

*GEant4 MonteCarlo

**CLAS Offline Analysis Tools Java

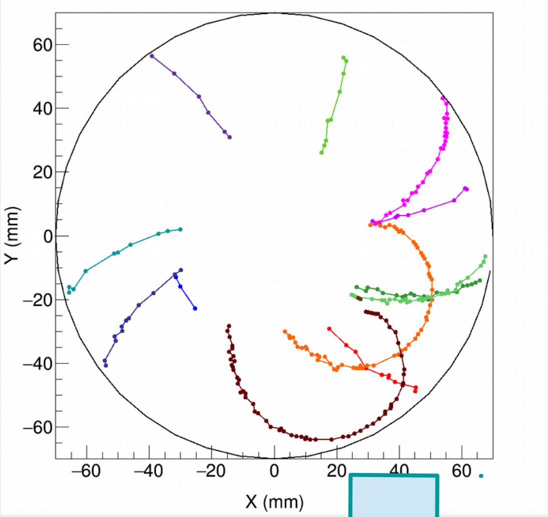


1 EVENT → many particles



Color and lines just for visual help

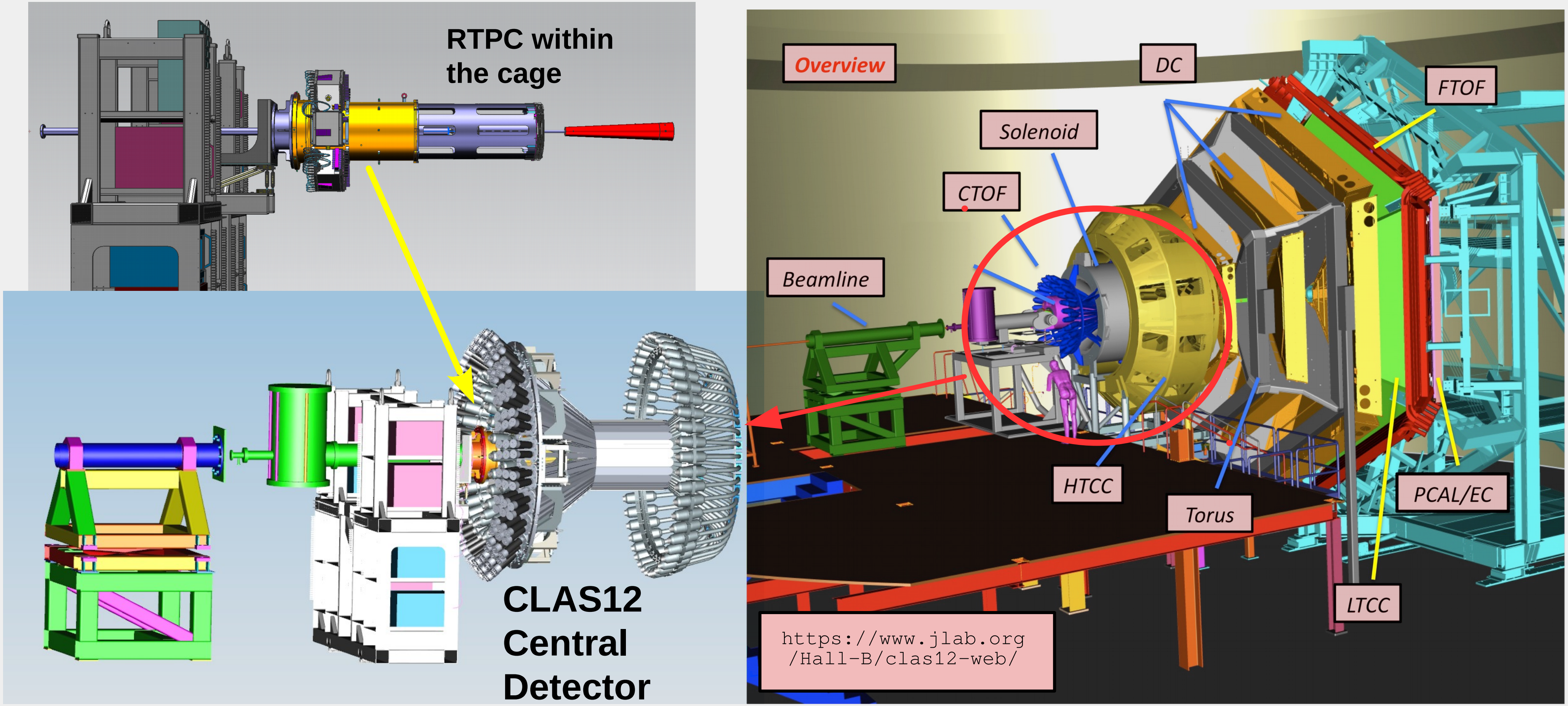
Each color → one track



KALMAN FILTER
Will extract vertex and momentum

New track finder under development by David Payette <dpaye001@odu.edu>

BONuS RTPC at CLAS



Expected Results

Dark Symbols:

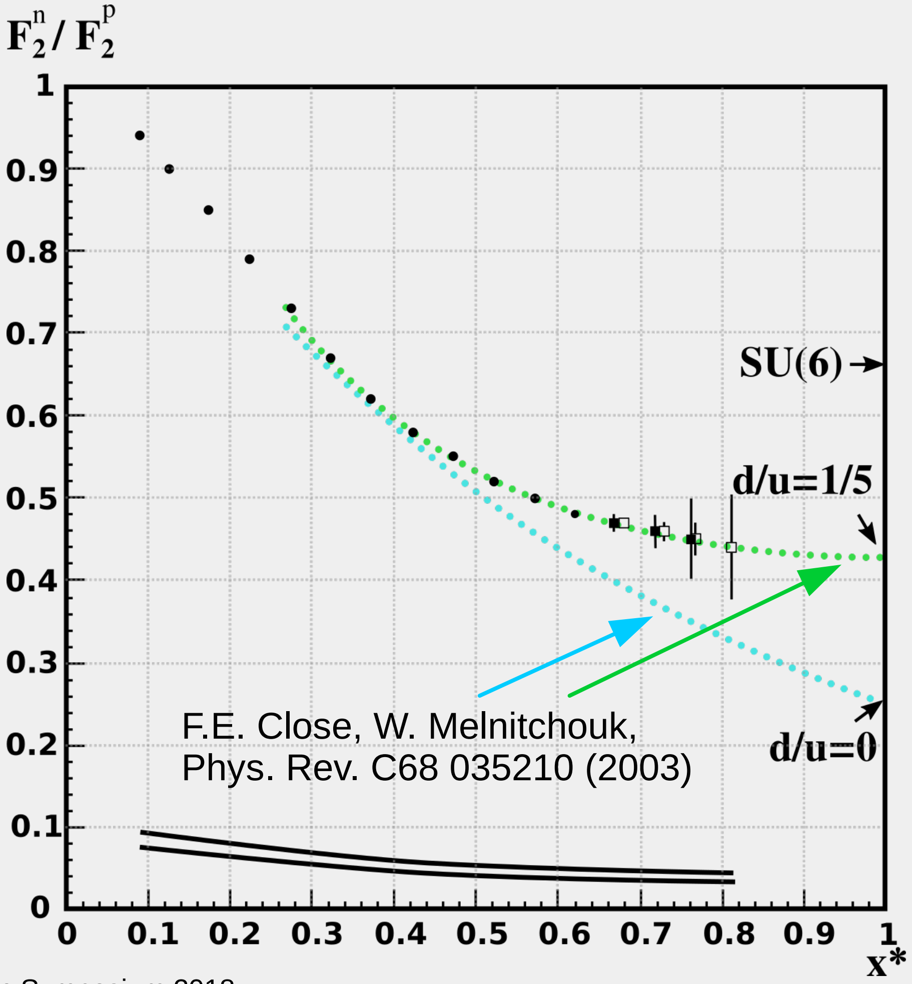
W* > 2 GeV

(x* up to 0.8, bin centered x* = 0.76)

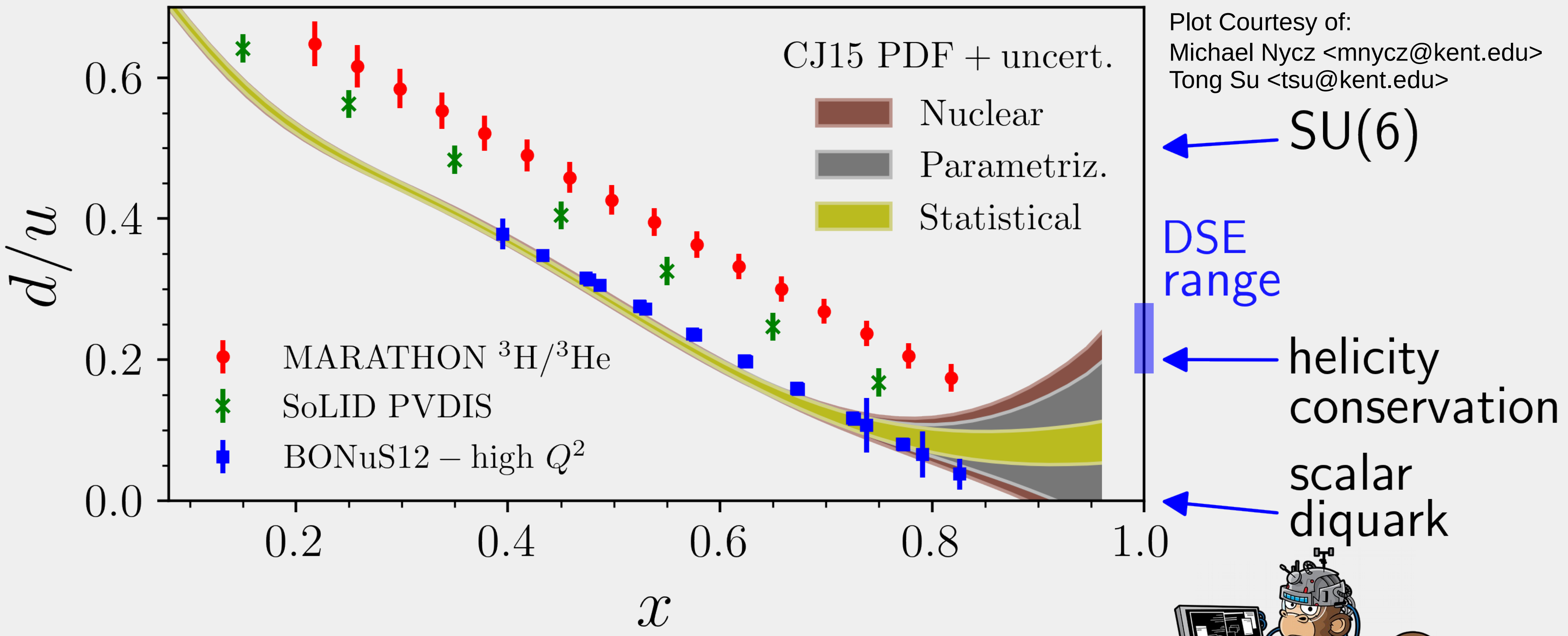
Open Symbols:

“Relaxed cut” W* > 1.8 GeV

(x* up to 0.83)



Bonus (but not BONuS)



Plot Courtesy of:
Michael Nycz <mnycz@kent.edu>
Tong Su <tsu@kent.edu>

Marathon ran past Winter/Spring 2018 and it's under analysis

SoLID under development

Collaboration summary

- **Simulation,Tracking and Analysis Group**
  S. Kuhn, J. Zhang, C. Ayerbe, G. Charles,N. Dzbenski, D. Payette, G. Dodge, M. Hattawy.
- **Prototyping, Target, HV, DAQ and testing group**
  S. Kuhn, S. Bültmann, J. Poudel, G. Dodge, N. Dzbenski, D. Payette, G. Charles, M. Hattawy, P. Pandey, I. Neththikumara.
- **Detector Design group**
  E. Christy, A. Nadeeshani, I. Albayrak, K. Griffioen, S. Bültmann, M. Hattawy, S. Kuhn, N. Kalantarians, H. Fenker, C. Wiggins, B. Miller, D. Kashy, C. Cuevas, M. Taylor, N. Liyanage, K. Gnanvo, S. Covrig
- **Gas and slow controls group**
  C. Ayerbe, N. Kalantarians, K. Griffioen, N. Dzbenski, S. Bültmann, I. Niculescu, Y. Prok, W. Moore
- **CLAS12 Integration group**
  S. Kuhn, S. Bültmann, M. Hattawy, R. Miller, C. Wiggins, S. Stepanyan, C. Cuevas

Summary/Outlook

- ✔ The neutron longitudinal structure information is not rich as the proton.
  - ✔ Information of $d(x)$ distribution less known than $u(x)$
- ✔ The tagging spectator technique has shown to be a powerful tool in order to extract information from bound neutrons.
- ✔ BONuS 12 will measure the Structure Function F_2 at x up to 0.85 at CLAS.
- ✔ The recoil proton will be detected with a state-of-the-art Radial Time Projection Chamber (under construction).

  - The first BONuS 12 RTPC will be ready by Sep/Oct 2018.
  - A second BONuS 12 RTPC will be delivered by March/April 2019.
  - The installation of the detector in Hall B is expected by Nov 2019.
  - The experiment will be taking data by the spring of 2020.

BACKUP SLIDES

Ratio Method to extract F_2

$$R_{\text{exp}} = \frac{N_{\text{tagged}}(\Delta Q^2,\ \Delta W^*, \Delta p_s^{(\text{VIP})})}{N_{\text{inc}}(\Delta Q^2,\ \Delta W)} \times \frac{A_e(Q^2, W)}{A_e(Q^2, W^*)}$$

Experimental ratio (tagged/untagged) corrected by CLAS acceptance

$$R_{\text{exp}} = \frac{F_2^n(Q^2, W^*)}{F_2^d(Q^2, W)} \times I_{\text{VIP}}$$

Spectator approximation

$$I_{\text{VIP}} = \int_{\text{VIP}} d\alpha_s dp_s^{\perp} A_p(\alpha_s, p_s^{\perp}) S(\alpha_s, p_s^{\perp})$$

Spectral function

Proton acceptance of the RTPC

$$\left(\frac{F_2^n}{F_2^d}\right)_{\text{exp}} = \frac{R_{\text{exp}}}{I_{\text{VIP}}}$$

Well-measured values parametrized by:

$$\frac{F_2^n}{F_2^p} = \left(\frac{F_2^n}{F_2^d}\right)_{\text{exp}} \left(\frac{F_2^d}{F_2^p}\right)_{\text{model}} \quad \Rightarrow \quad \frac{F_2^n}{F_2^p} = \frac{R_{\text{exp}}}{I_{\text{VIP}}} \left(\frac{F_2^d}{F_2^p}\right)_{\text{model}}$$

P. E. Bosted and M. E. Christy, Phys. Rev. C 77, 065206 (2008)
M. E. Christy and P. E. Bosted, Phys. Rev. C 81, 055213 (2010).

To obtain F2n, just multiply the final expression by the values of F2p from the parametrization from Bosted/Christy

Polarized quark distributions

The EMC Effect and The Quest to High x Quark Distributions

Patricia Solvignon

Argonne National Laboratory

Hall C seminar

Jefferson Lab

April 9 2009

In the parton model:

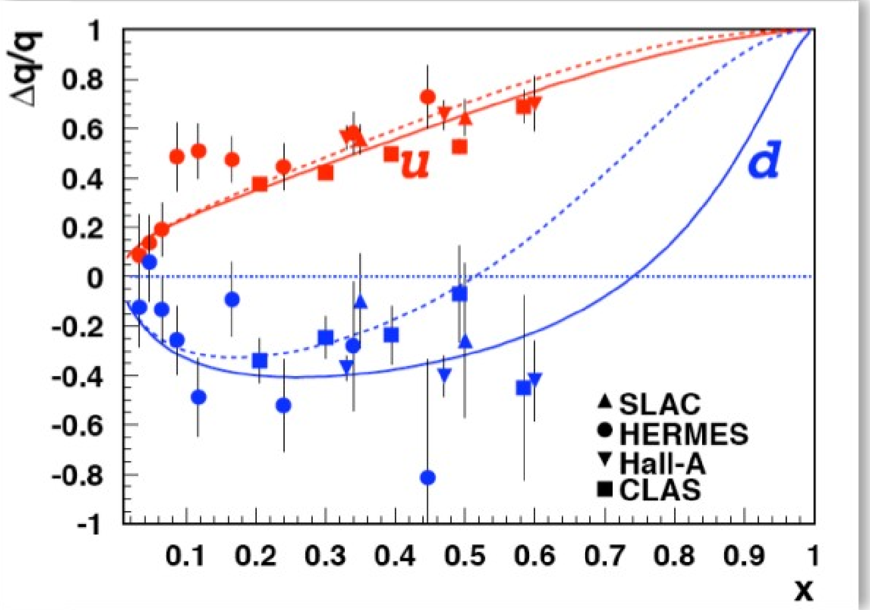
$$F_1(x) = \frac{1}{2}\Sigma_i e_i^2 [q_i(x)]$$

$$g_1(x) = \frac{1}{2}\Sigma_i e_i^2 [\Delta q_i(x)]$$

At high Q^2, $A_1 = g_1/F_1$ and:

$$\frac{g_1^n}{F_1^n} = \frac{\Delta u + 4\Delta d}{u + 4d}$$

$$\frac{g_1^p}{F_1^p} = \frac{4\Delta u + \Delta d}{4u + d}$$

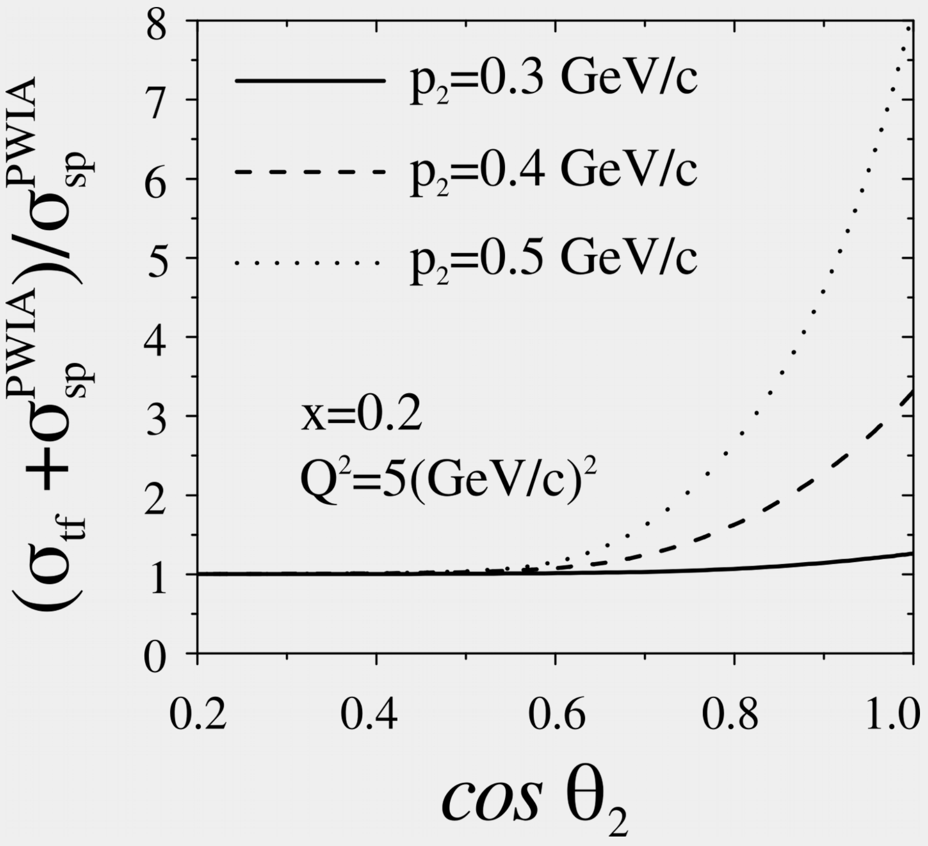


$$\frac{\Delta u}{u} = \frac{4}{15}\frac{g_1^p}{F_1^p}\left(4+\frac{d}{u}\right) - \frac{1}{15}\frac{g_1^n}{F_1^n}\left(1+4\frac{d}{u}\right)$$

$$\frac{\Delta d}{d} = \frac{4}{15}\frac{g_1^n}{F_1^n}\left(4+1/\frac{d}{u}\right) - \frac{1}{15}\frac{g_1^p}{F_1^p}\left(1+4/\frac{d}{u}\right)$$

Target Fragmentation

V. Palli et al, Phys. Rev. C 80(2009) 054610



RTPC construction (now!)