d/u Ratio at High x with BoNuS

(Barely Off-Shell Nucleon Structure)

K. Griffioen

JLab Users Meeting

20 June 2005

for the BONUS Collaboration

[Jlab, ODU, Hampton, JMU, W&M, & CLAS collaboration]

(with special thanks to S. Kuhn, S. Bueltmann, H. Fenker and C. Keppel)

Neutron Targets are Hard to Come By

- Free neutrons decay in 15 minutes.

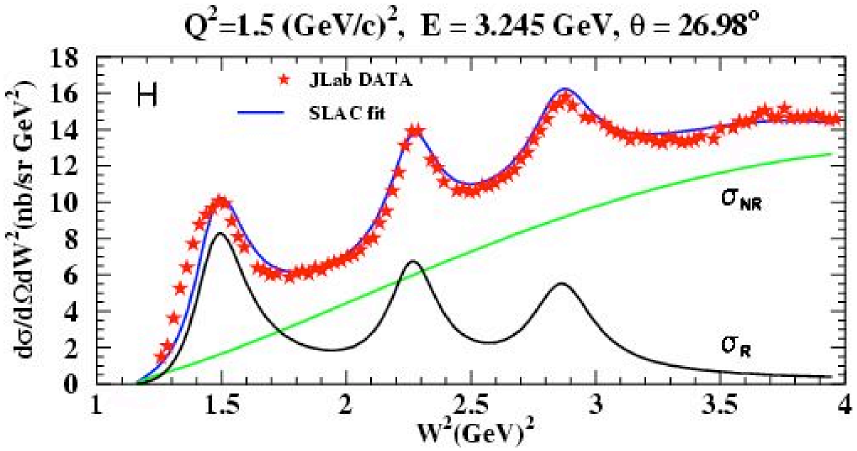
- It's difficult to create a dense target of neutral particles:
  Typical proton target: $4 \cdot 10^{23}$ p/cm^2 [10 cm LH]
  Magnetic bottle: 10^3 - 10^4 n/cm^2 [TU München]

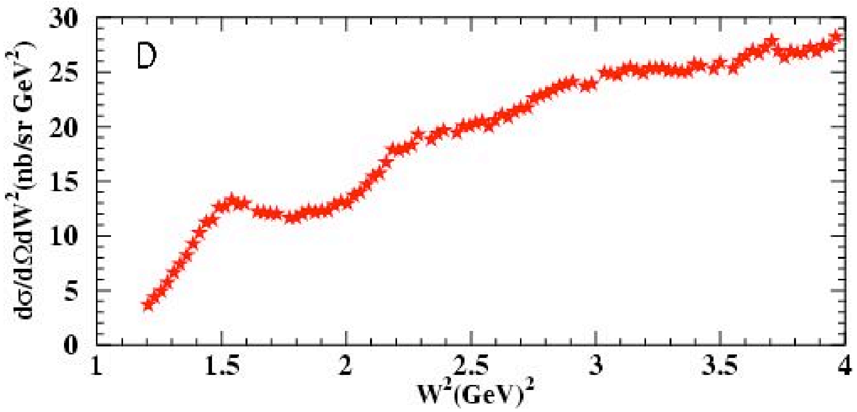
- Traditional solutions (deuterons and ^{3}He) have potentially large (and not completely known) nuclear corrections: kinematic smearing, binding and off-shell effects, the EMC effect, final state interactions, coherent processes, non-nucleonic components of the wave function, etc.

Cross Section in the Resonance Region

- Data on the Proton: Clear resonant structure, separation from the non-resonant background is possible

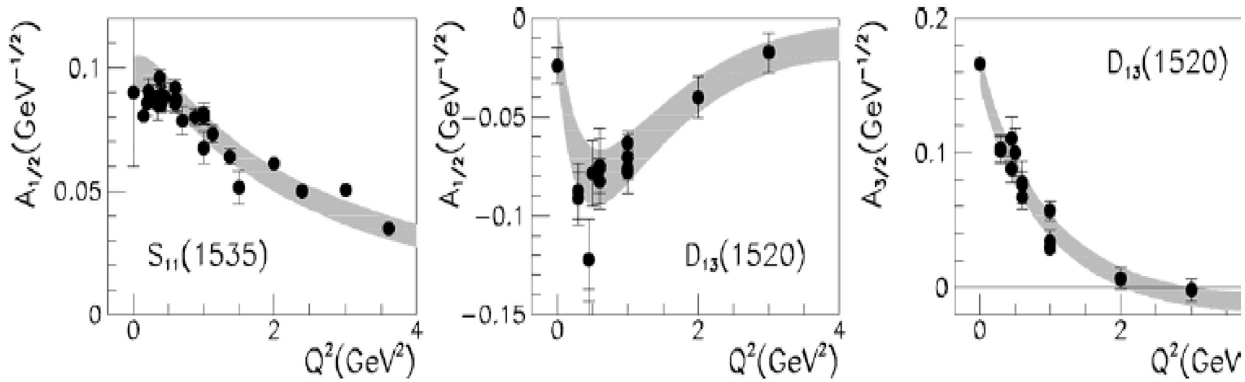
- Data on the deuteron: Kinematically smeared - even with perfect knowledge of the wave function information is lost



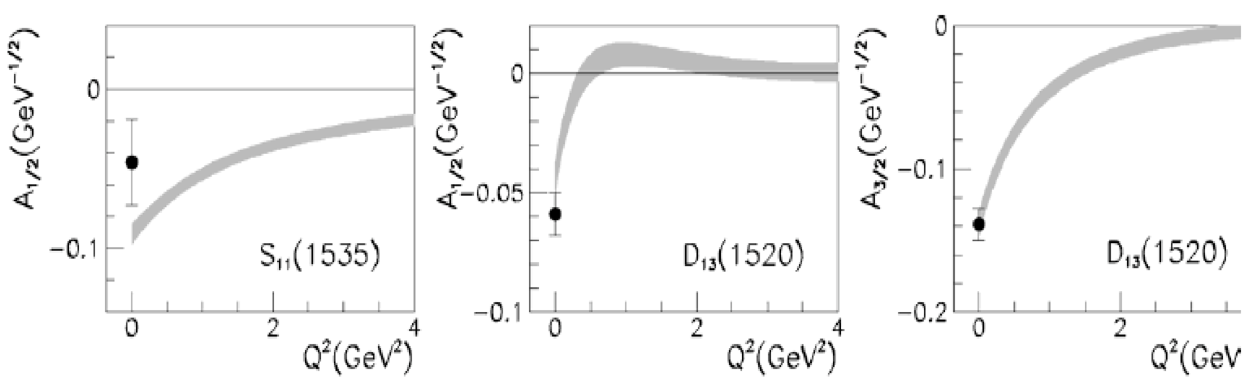


Resonance Transition Amplitudes
(in comparison with a quark model)

- Proton



- Neutron

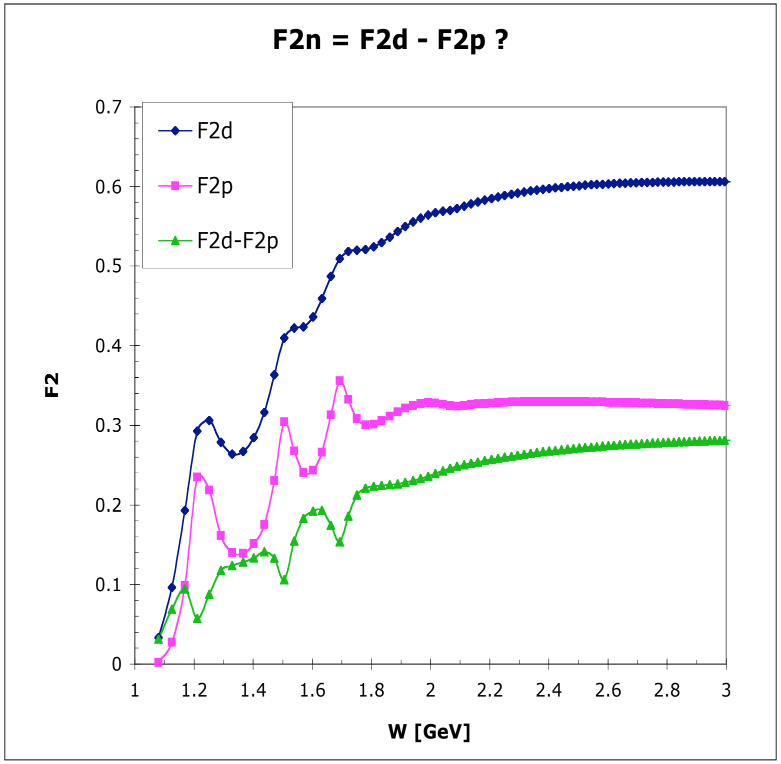


Structure Functions of the Neutron

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

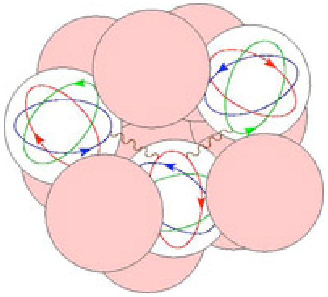
$$x_{\text{measured}} = \frac{Q^2}{2M\nu} \qquad x_{\text{relevant}} = \frac{Q^2}{2(E_n\nu - \vec{p}_n \cdot \vec{q})}$$

0.70	0.69
0.80	0.78
0.90	0.85
1.00	0.90



+ Binding effects, coherent scattering, final state interactions, non-nucleonic degrees of freedom in the ground state

("EMC"-effect)



A Neutron Target?

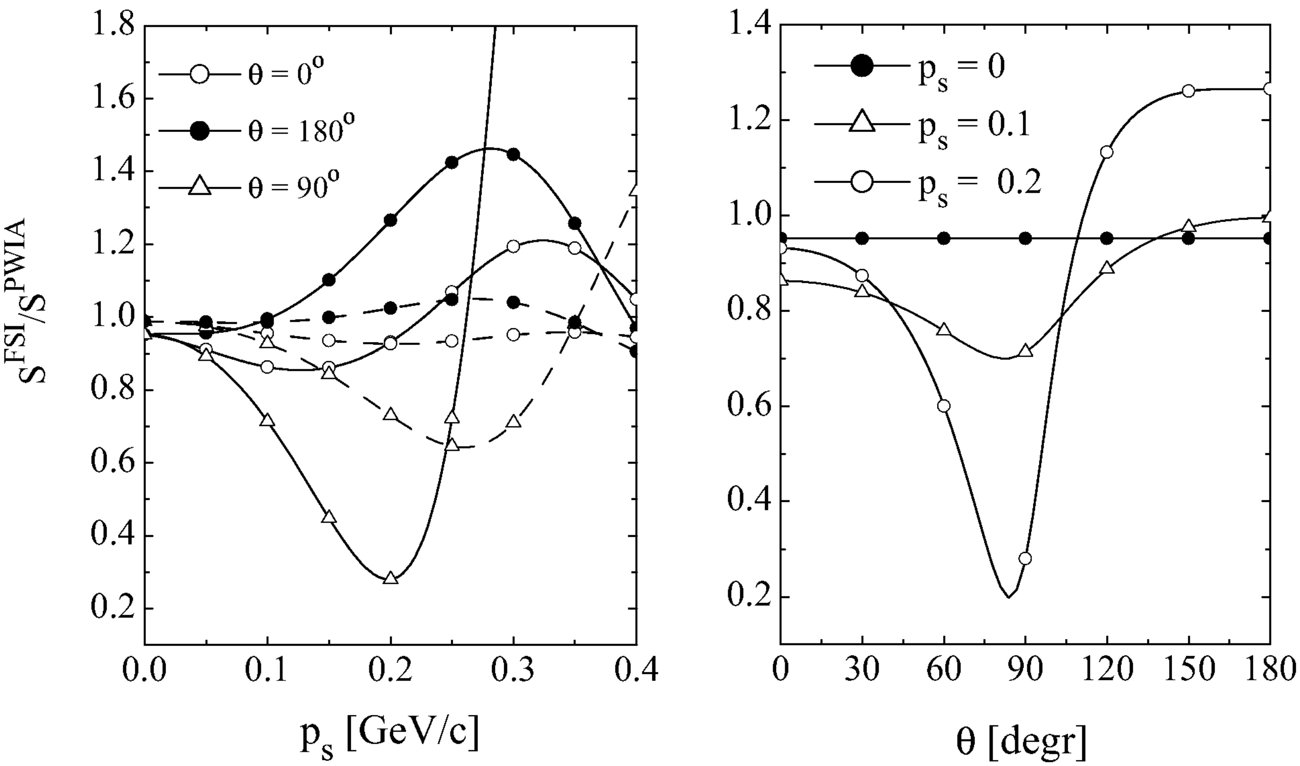
Ya say ya want a revolution[ary neutron target]
Well, you know
We all wanna to change the world.

Ya tell me that it's evolution
Well, you know
We all wanna change the world.
- John Lennon

What can we do?

Use the best possible approximation for a free neutron target: a neutron that is "barely" off-shell. Measure d(e, e'p) for low-momentum recoiling protons.

Deviations from the simple “spectator”picture:
1. Final State Interaction

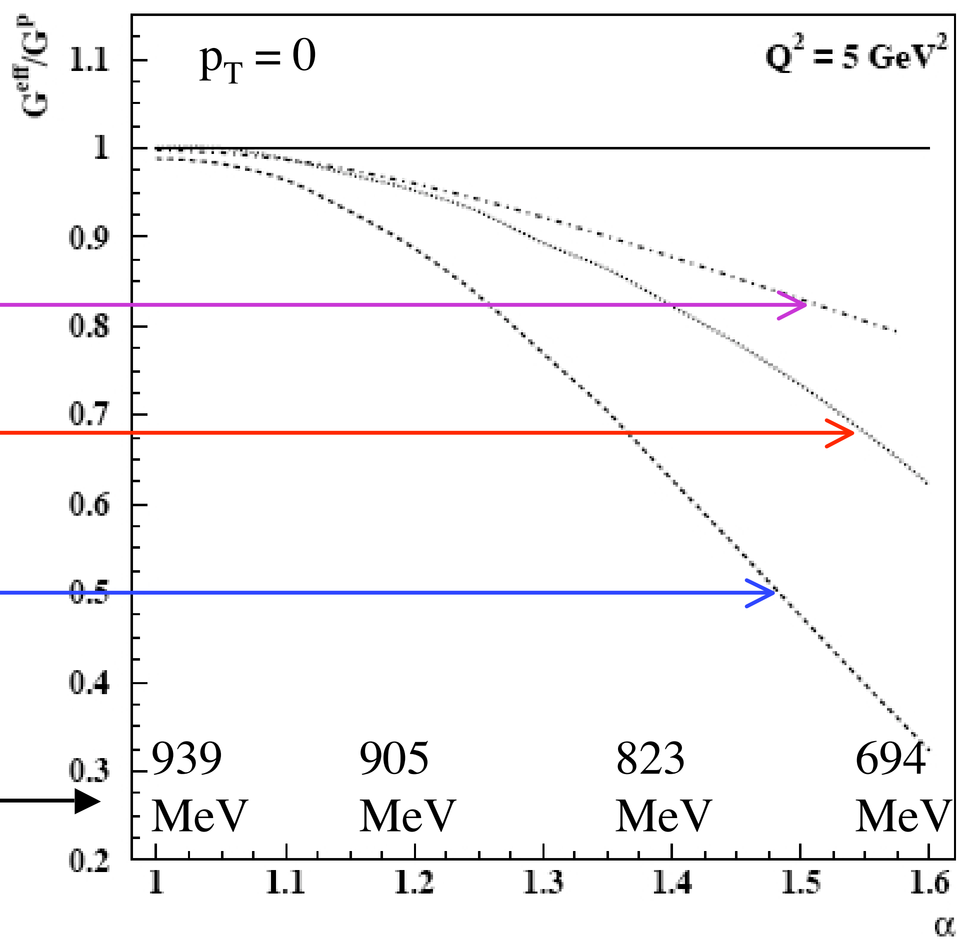


Ciofi degli Atti and Kopeliovich, Eur. Phys. J. A17(2003)133

Deviations from the simple “spectator” picture:

2. Off-shell Effects

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



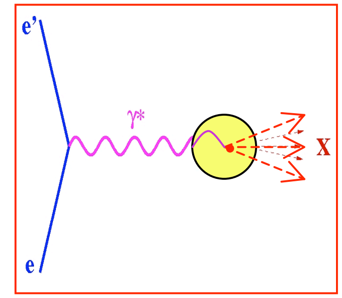
Modification of the off-shell scattering amplitude (Thomas, Melnitchouk et al.)

Color delocalization Close et al.

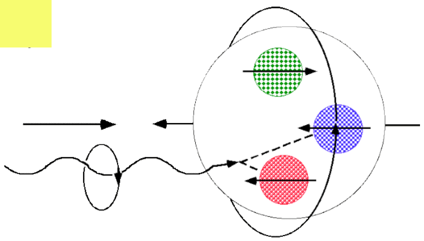
Suppression of “point-like configurations” Frankfurt, Strikman et al.

“Off-shell” mass of the nucleon M^* →

Deep Inelastic Structure Functions



How fast do the quarks move inside the nucleon?
(□ Bjorken x)



Which way do they spin? (helicity q↑ - q↓ = Δq)

- 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
- Hyperfine structure effect: S=1 suppressed => d/u = 0, Δu/u = 1, Δd/d = -1/3 for x -> 1
- pQCD: helicity conservation (q↑↑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.

d/u (x □ 1)

Quark momentum / Nucleon momentum

(Momentum transfer)^2

$$x = \frac{Q^2}{2m□}$$

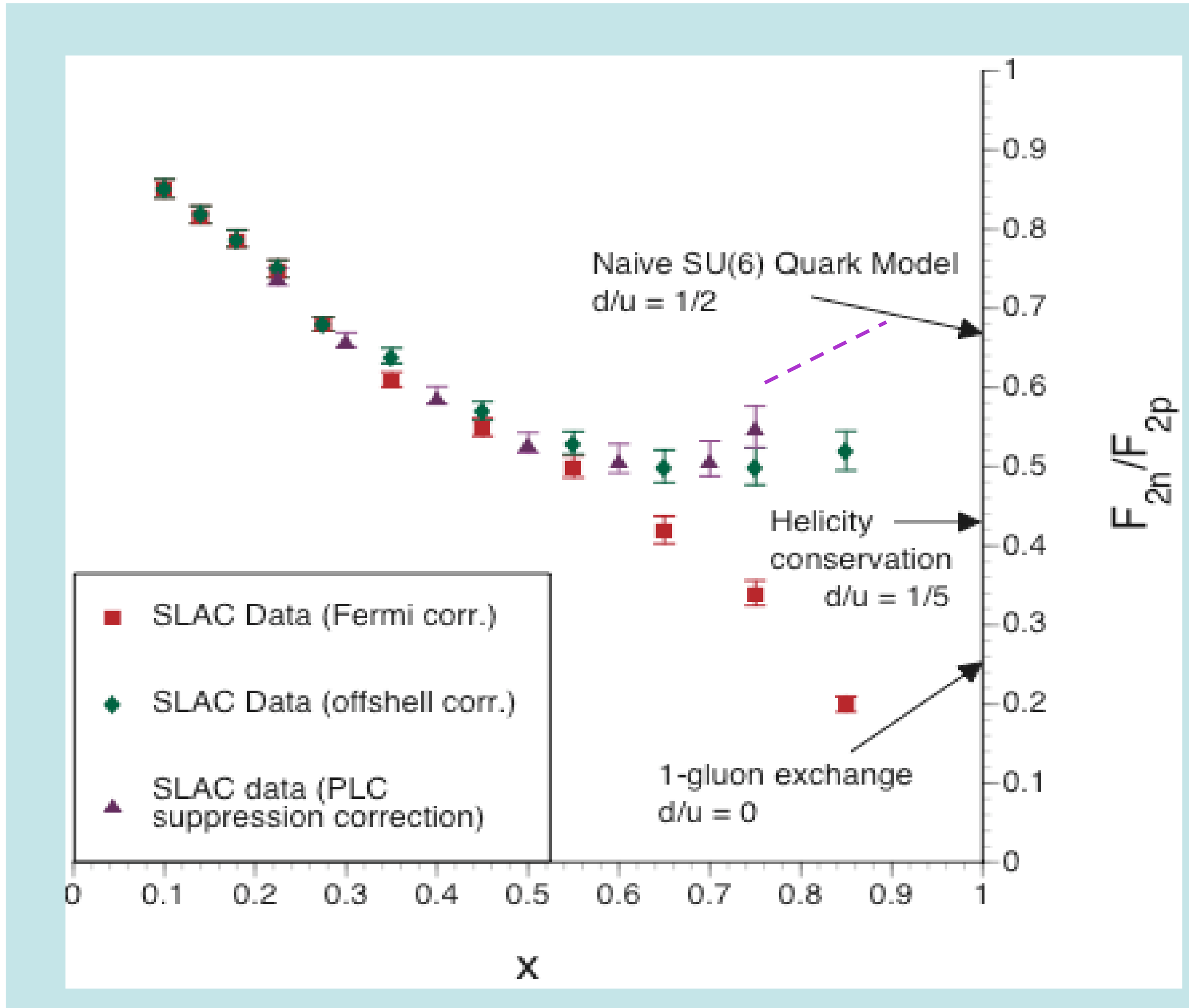
Nucleon mass   Energy transfer

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

$$\frac{d}{u} □ \frac{4\,F_{2n}/F_{2p} □ 1}{4 □ F_{2n}/F_{2p}}$$

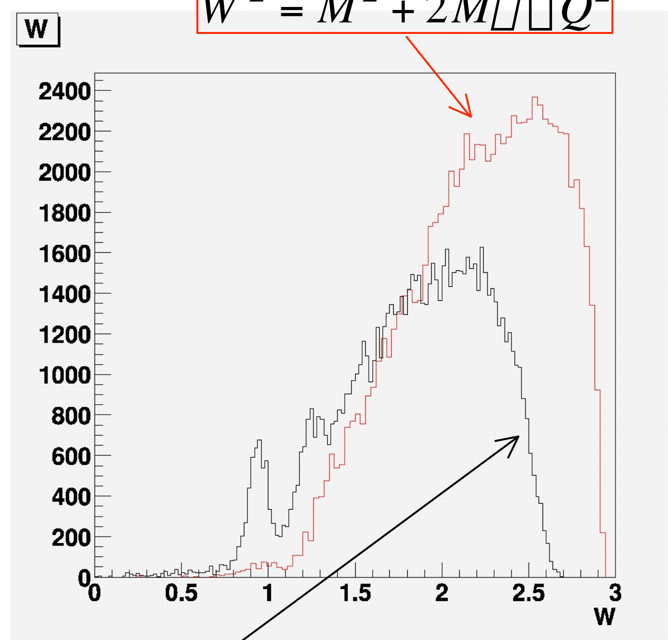
$F_{2n}/F_{2p} = F_{2d}/F_{2p} - 1$

???

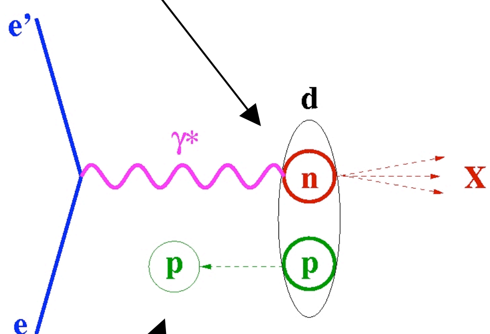


"Spectator Tagging"

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



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



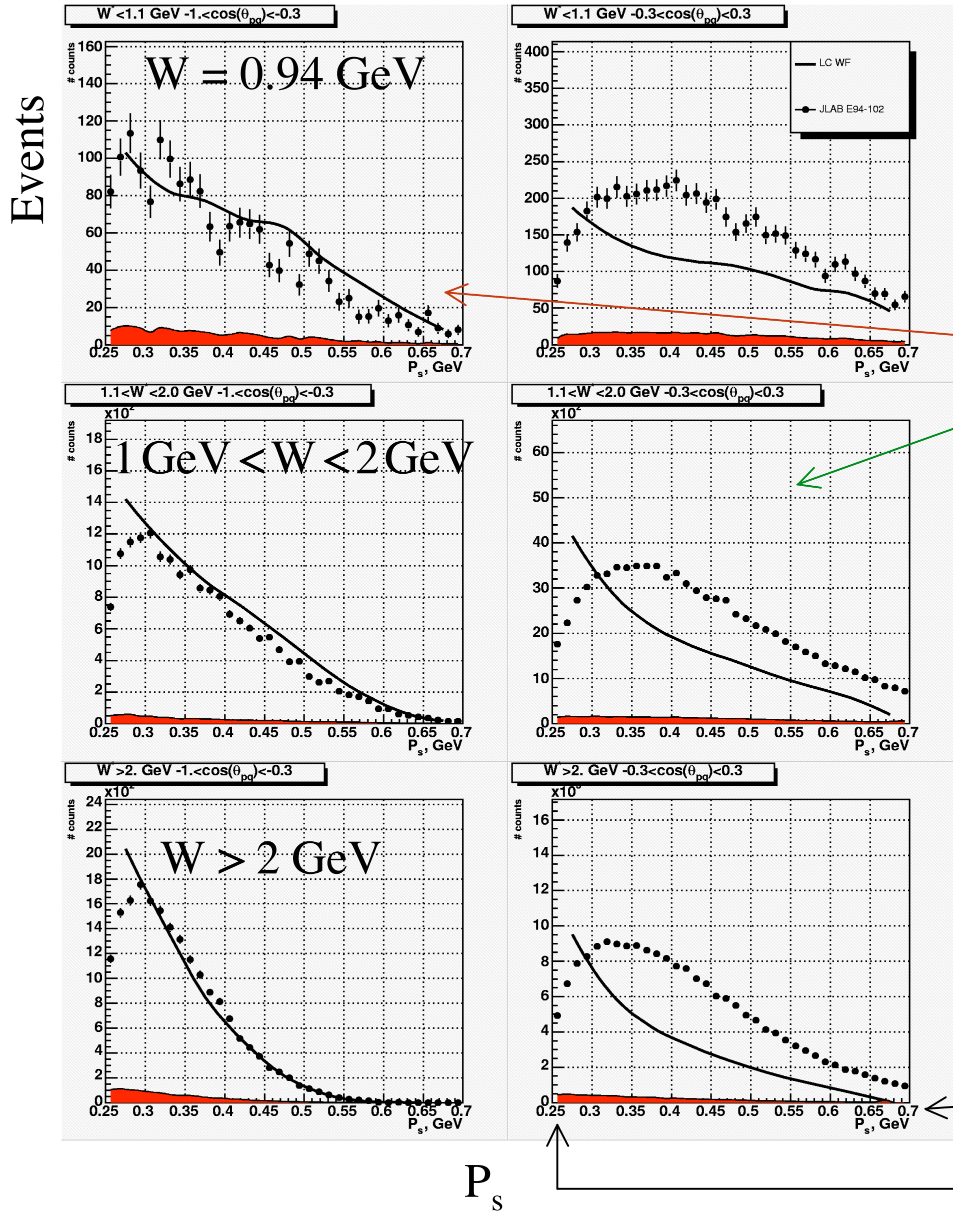
$p_S = (E_S, \vec{p}_S); \quad \alpha_S = \frac{E_S - \vec{p}_S \cdot \hat{q}}{M_D/2}$

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

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

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

Results: Momentum Distribution



Vertical axis: Number of events

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

Left: Angular range > 107.5°

Right: Angular range 72.5° - 107.5°

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

PWIA model with "light cone"-wave function for deuterium

700 MeV/c

250 MeV/c

A Neutron Target?

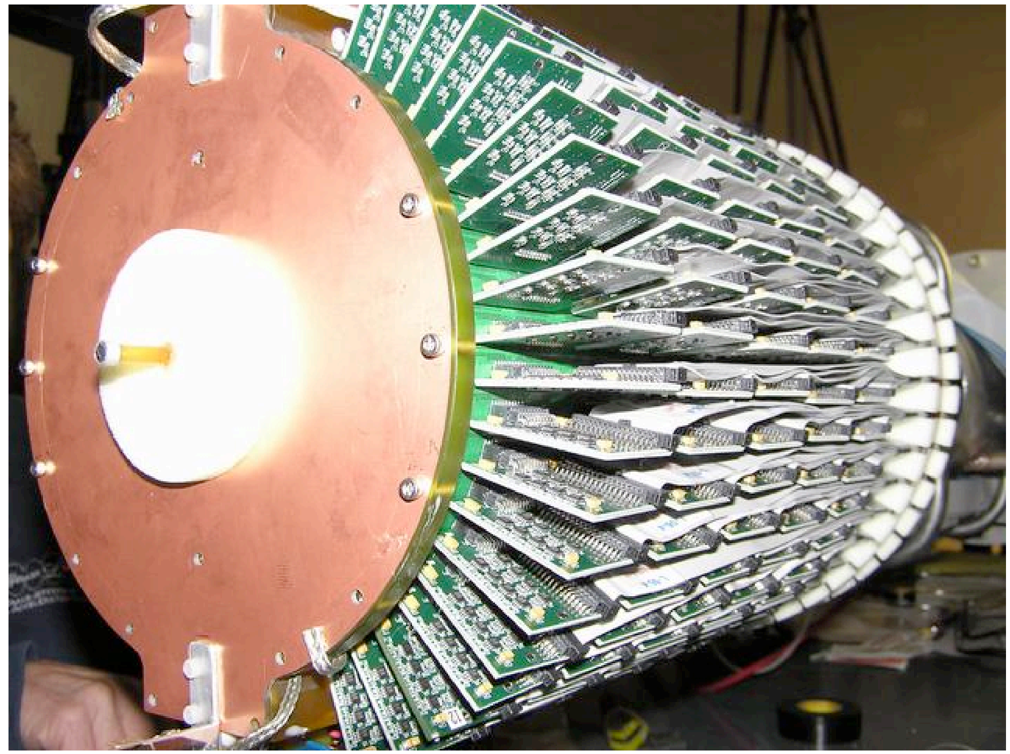
Say ya got a real solution
Well, you know
We'd all love to see the plan.

Ask me for a contribution
Well, you know
We all doin' what we can.

- John Lennon

Inclusive Scattering off a "free" Neutron - the BoNuS* Experiment

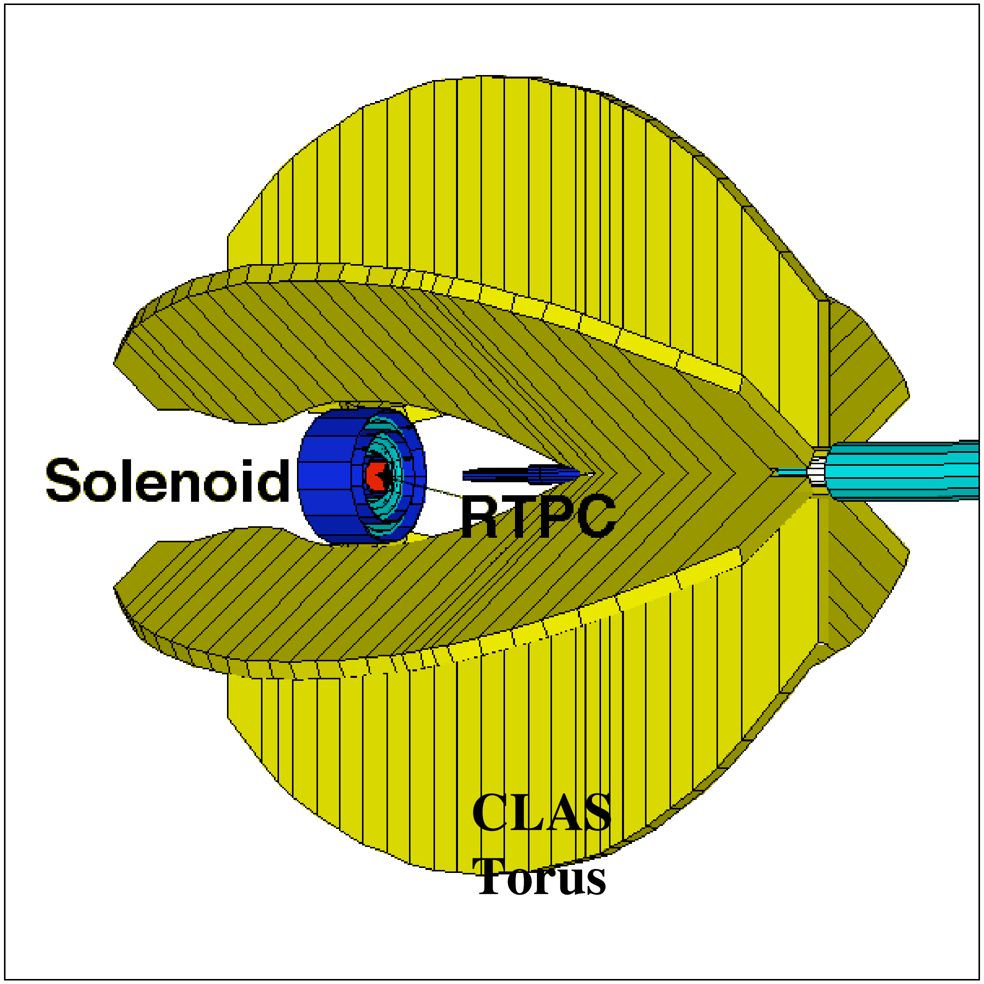
- Experiment 03-012 at Jefferson Lab in Hall B (CLAS)
- 4 and 6 GeV / 200 nA electrons impinging on a 10 cm long D_2 gas target (7 atm) => $L = 0.4 \cdot 10^{34}/cm^2 s$
- PAC-approved for 2 calendar months of running (2005/6)
- Old Domininon Univ., Jefferson Lab, Hampton Univ., William & Mary, James Madison Univ., and the CLAS collaboration

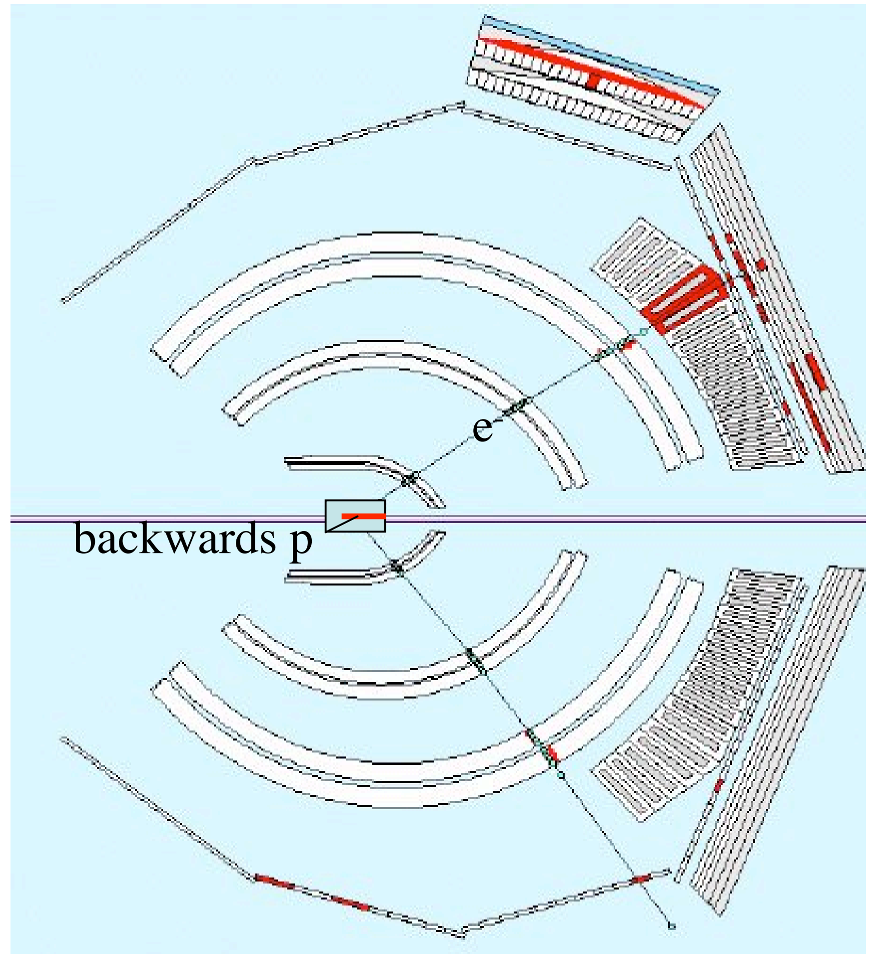


The full BoNuS detector

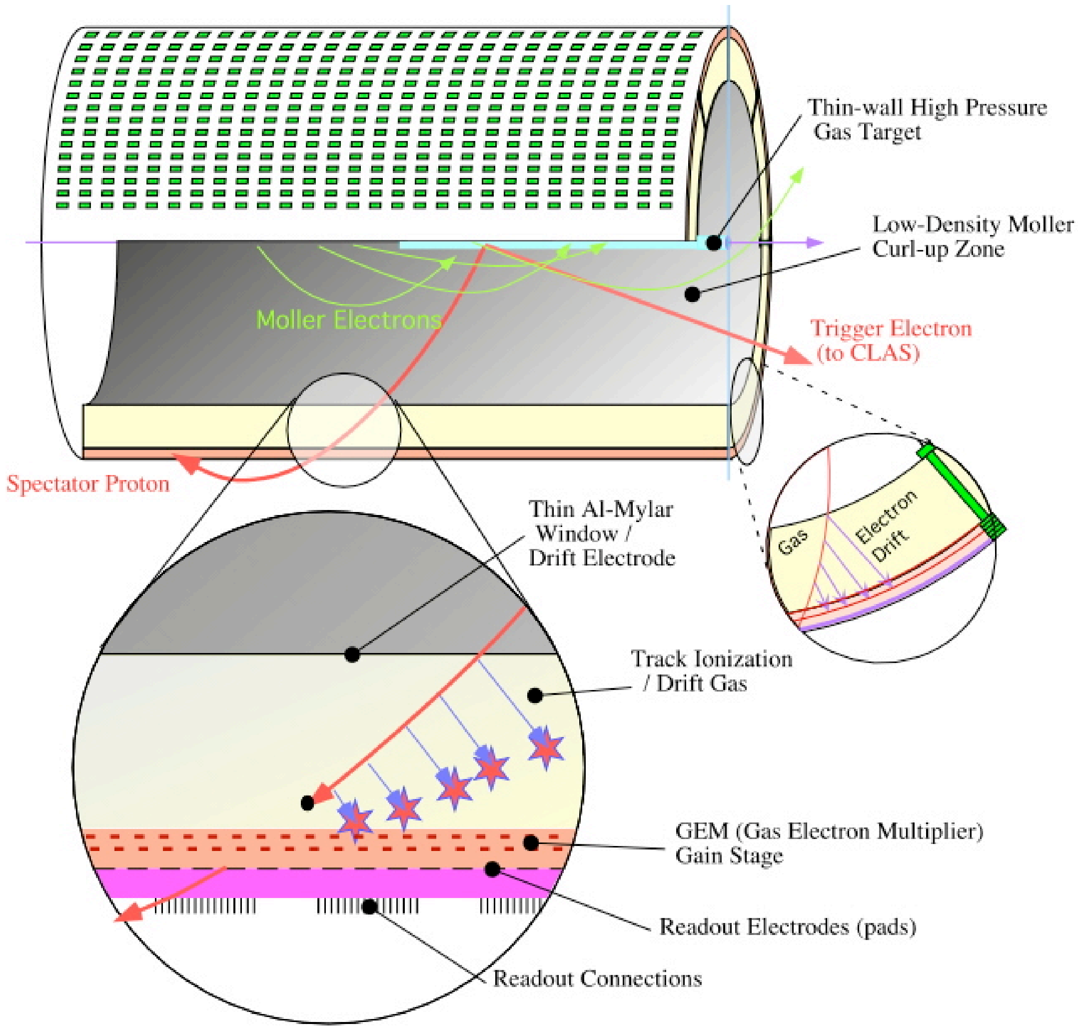
* BoNuS = **B**arely **o**ff-shell **Nu**cleon **S**cattering

BoNuS - Experimental Setup





Target-detector system for slow protons

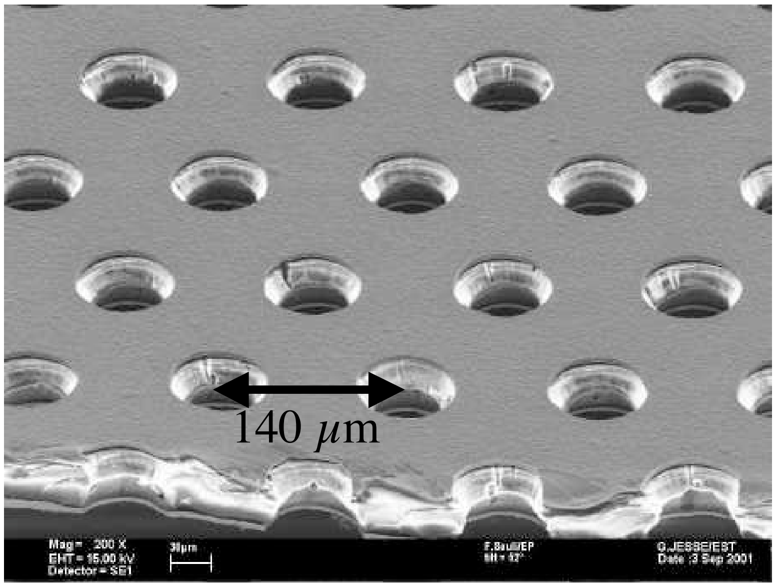


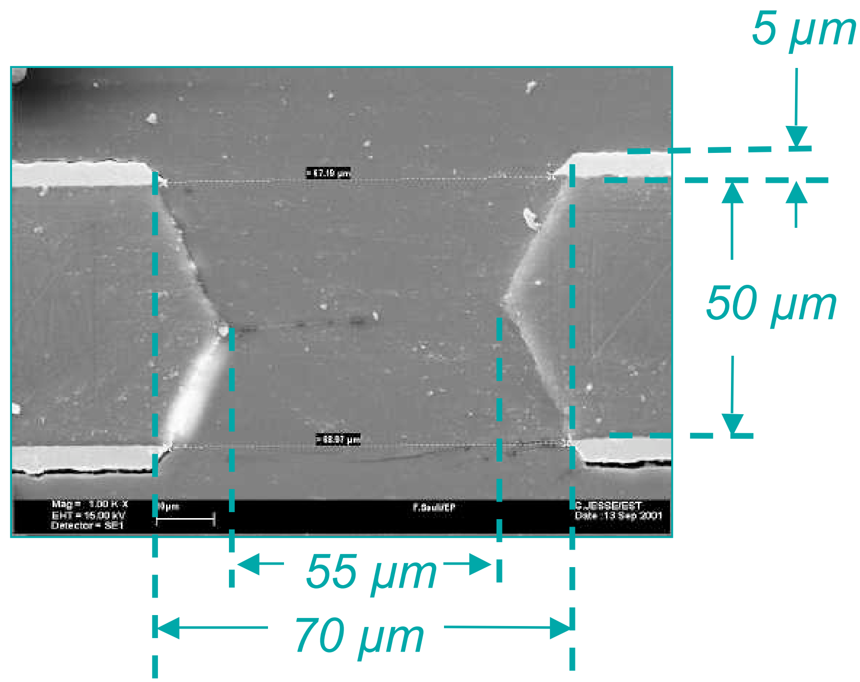
- Thin-walled gas target (7 atm., room temperature)
- **R**adial **T**ime **P**rojection **C**hamber (RTPC) with **G**aseous **E**lectron **M**ultipliers (GEMs)
- 2 Tesla longitudinal magnetic field (to suppress Möller electrons and to measure momentum)
- 3-dimensional readout of position and energy loss (“pads”)

Detector Parameters

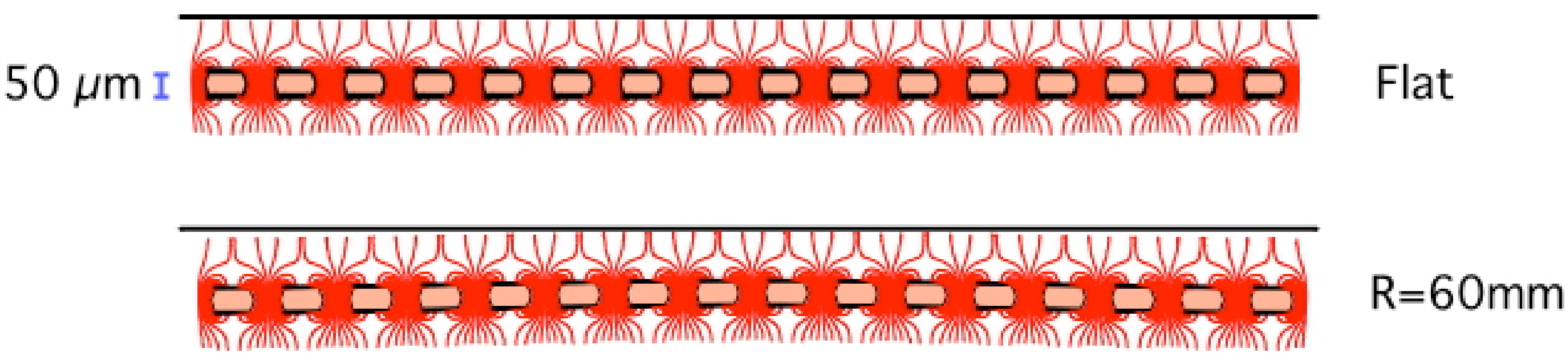
- Geometric Acceptance
  - Sensitive over 148x2 deg. in phi, 20 cm in Z.
- Momentum Acceptance
  - Protons from ~70 to 250 MeV/c
- 3200 readout pads
- Proton Identification from dE/dx
- Vertex Z resolution <~ 10 mm
- Proton Momentum from track curvature
- Track E information from dE/dx

RTPC - GEMs



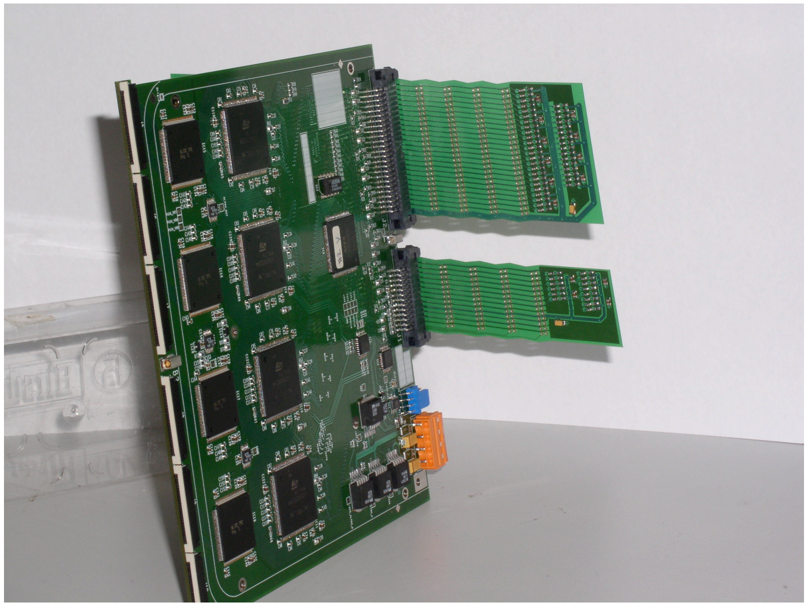


300-500 V, Gain 100-200



RTPC - Data Acquisition

- Alice TPC electronics (CERN) with Altro Chip
- 16 channels, 10 bit ADC with up to 25 MHz data rate
- 3-dimensional track reconstruction (using drift time information and 2 -dimensional location of readout pads)



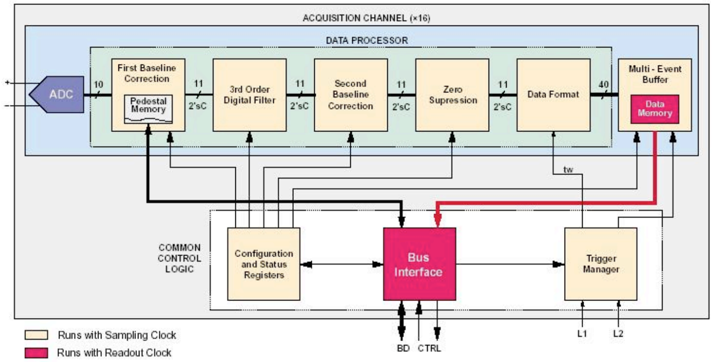
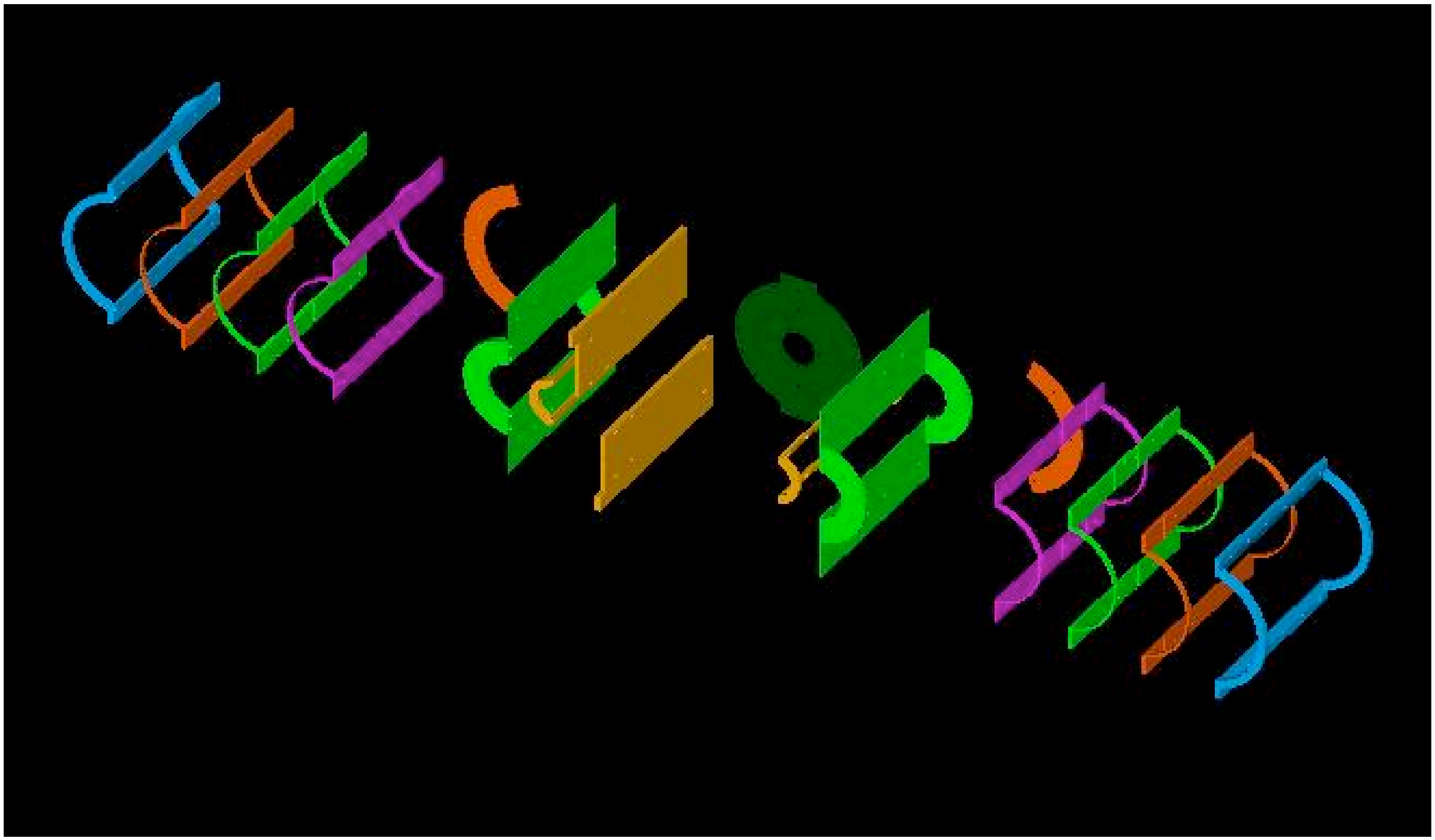
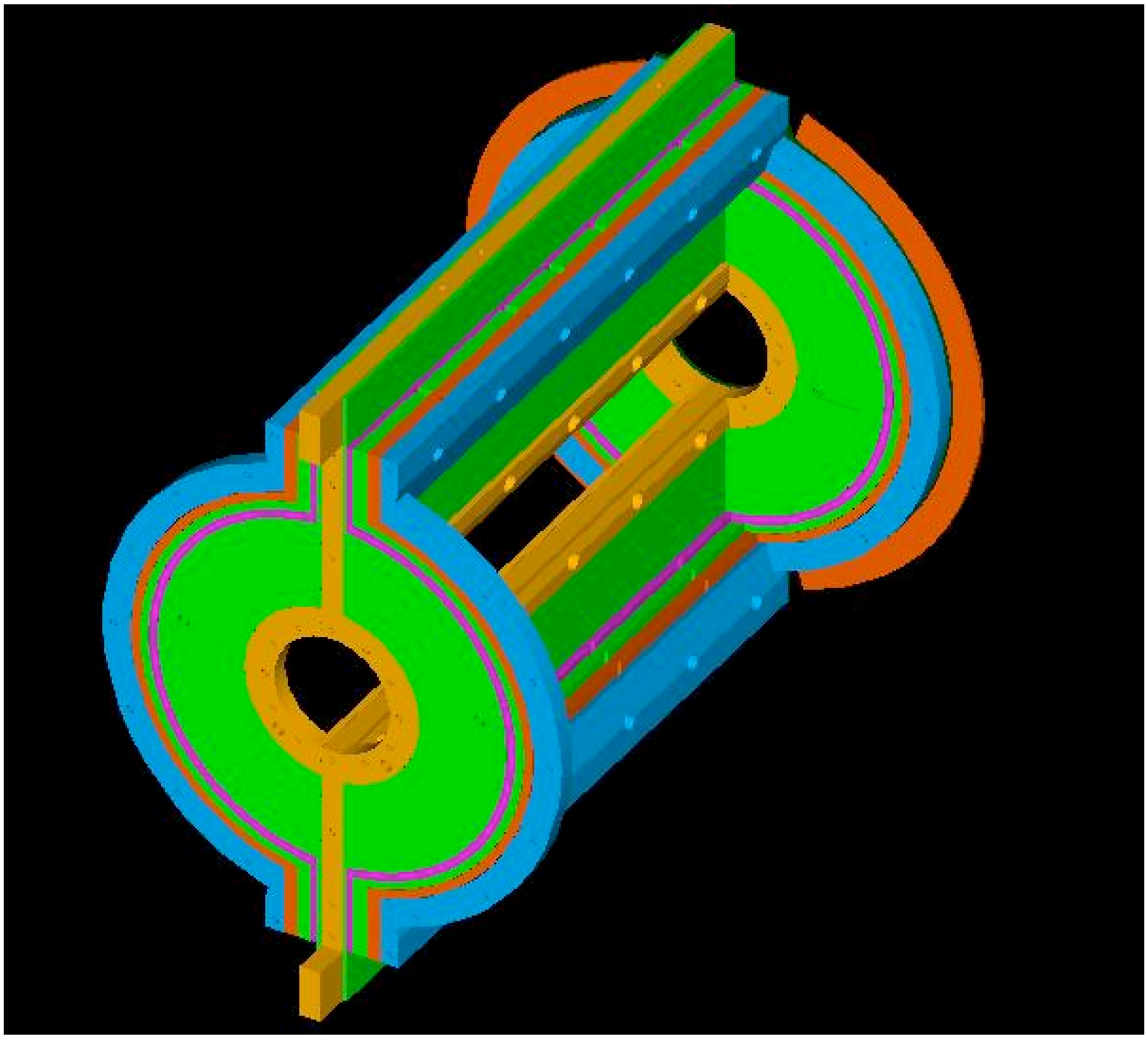


Figure 1.1. ALTRO Processing Chain

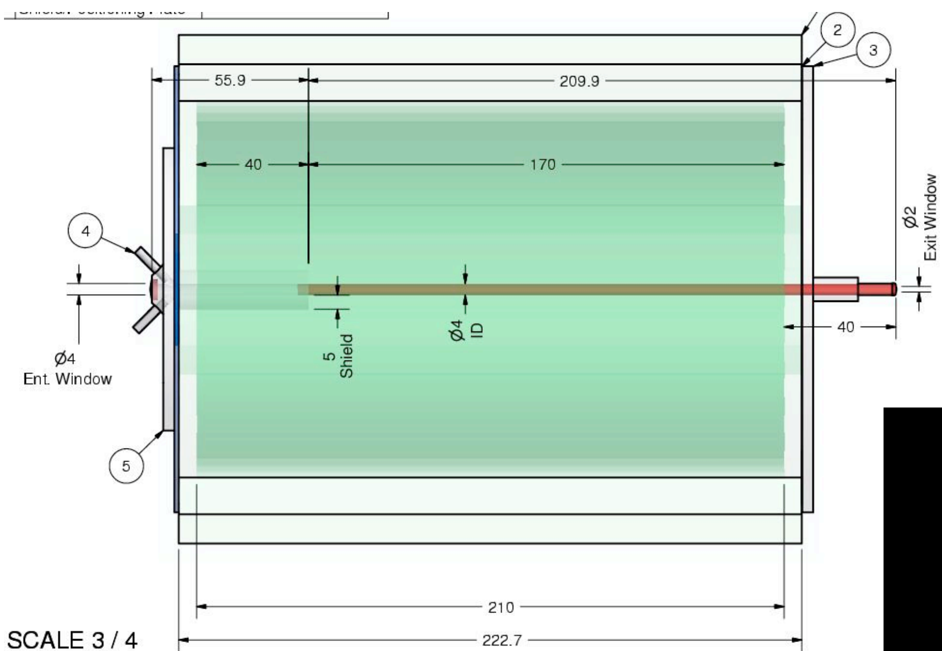
Production Model: Exploded View

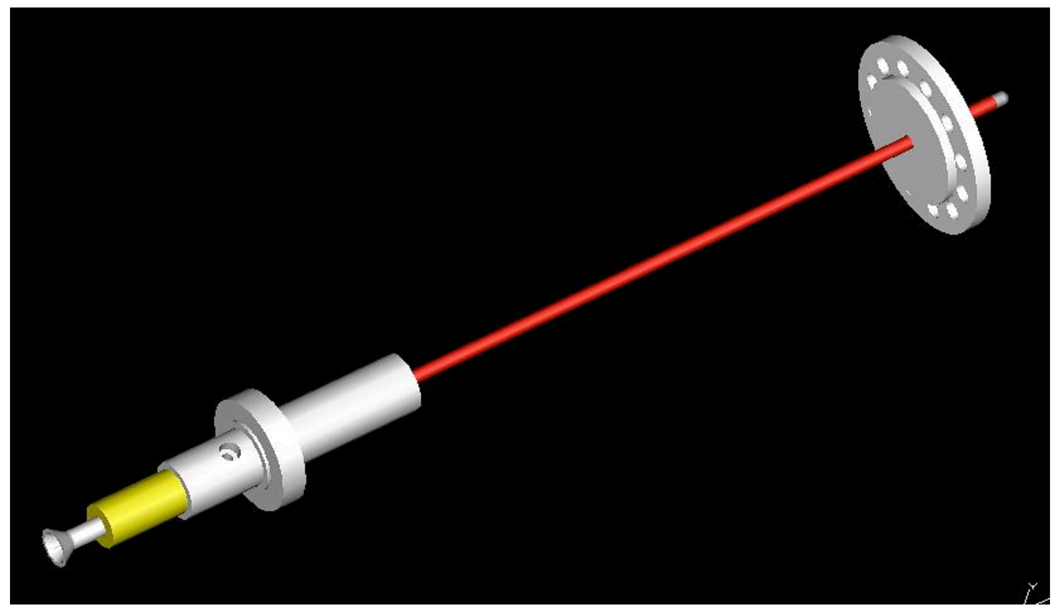


Production Model

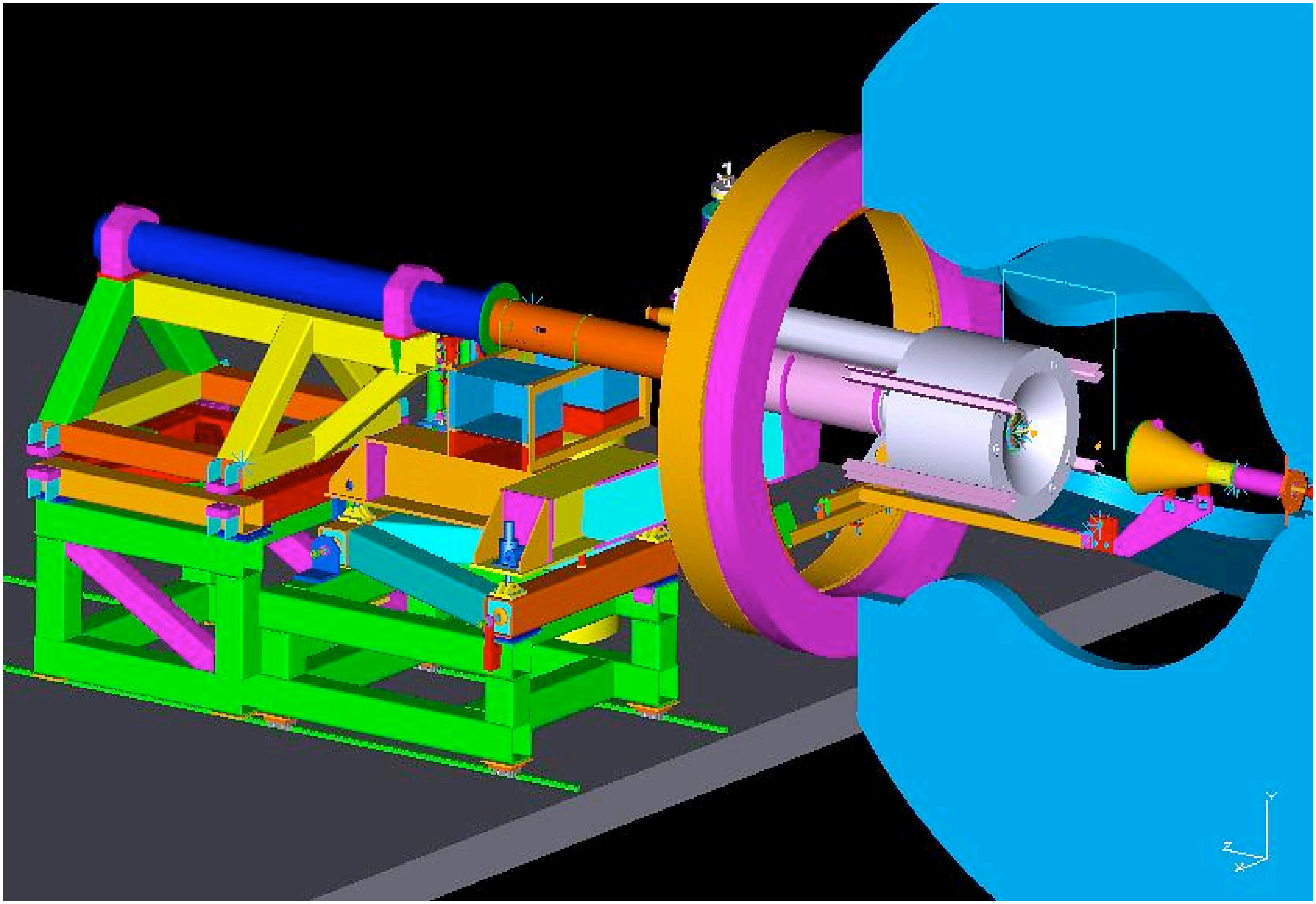


BoNuS Target

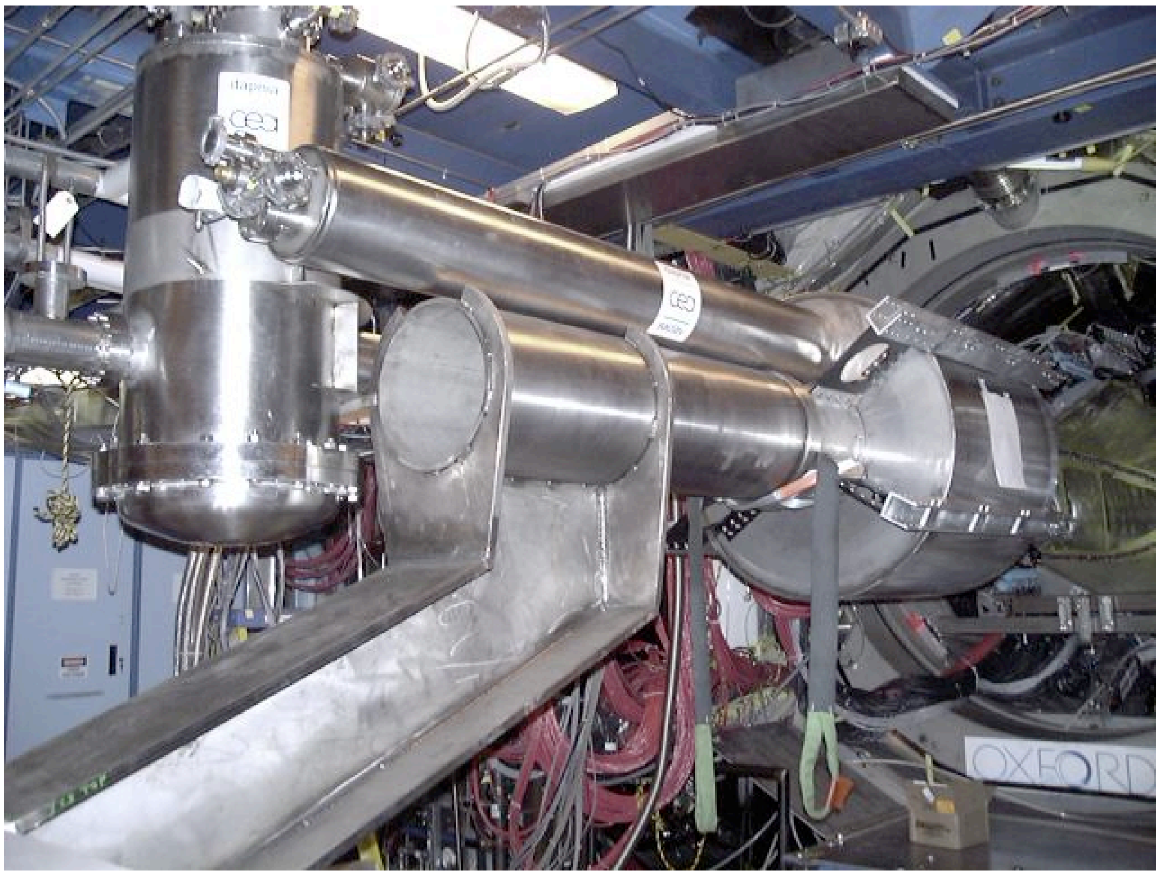




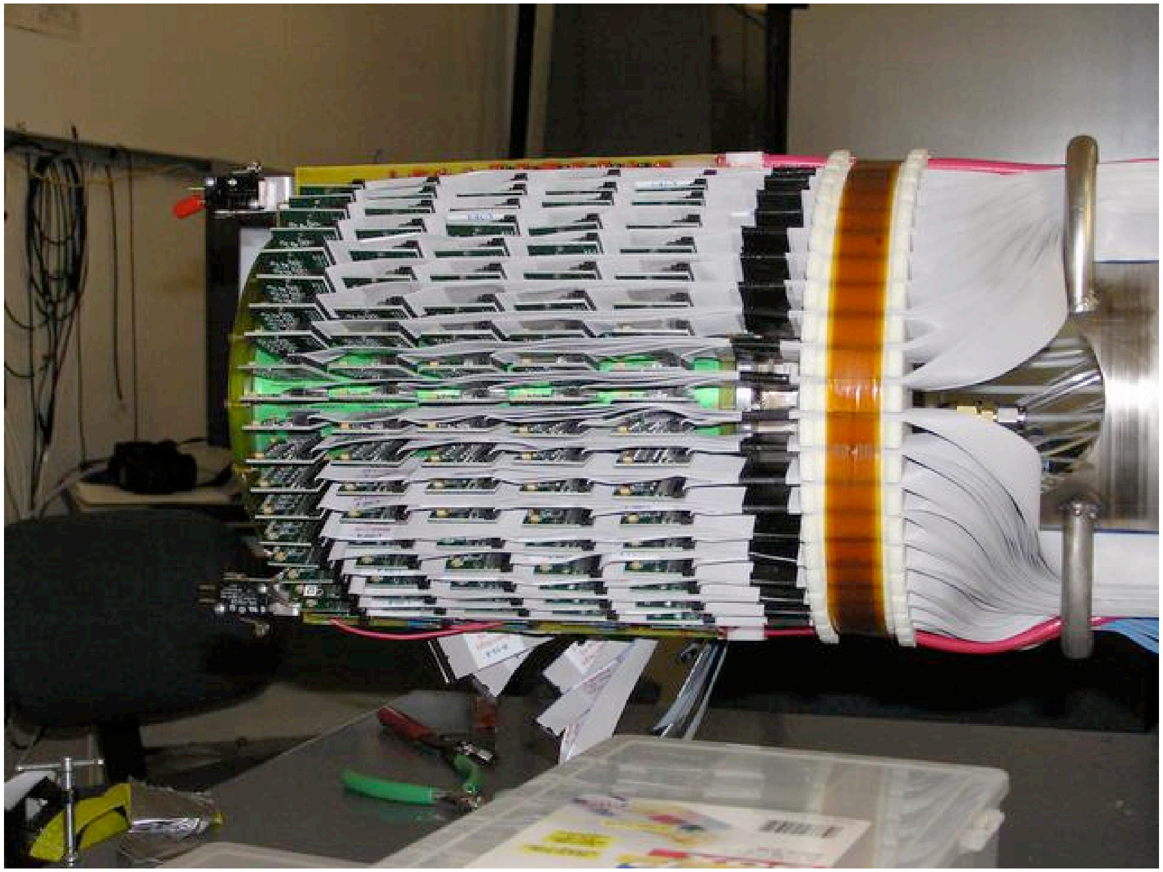
BoNuS Beamline



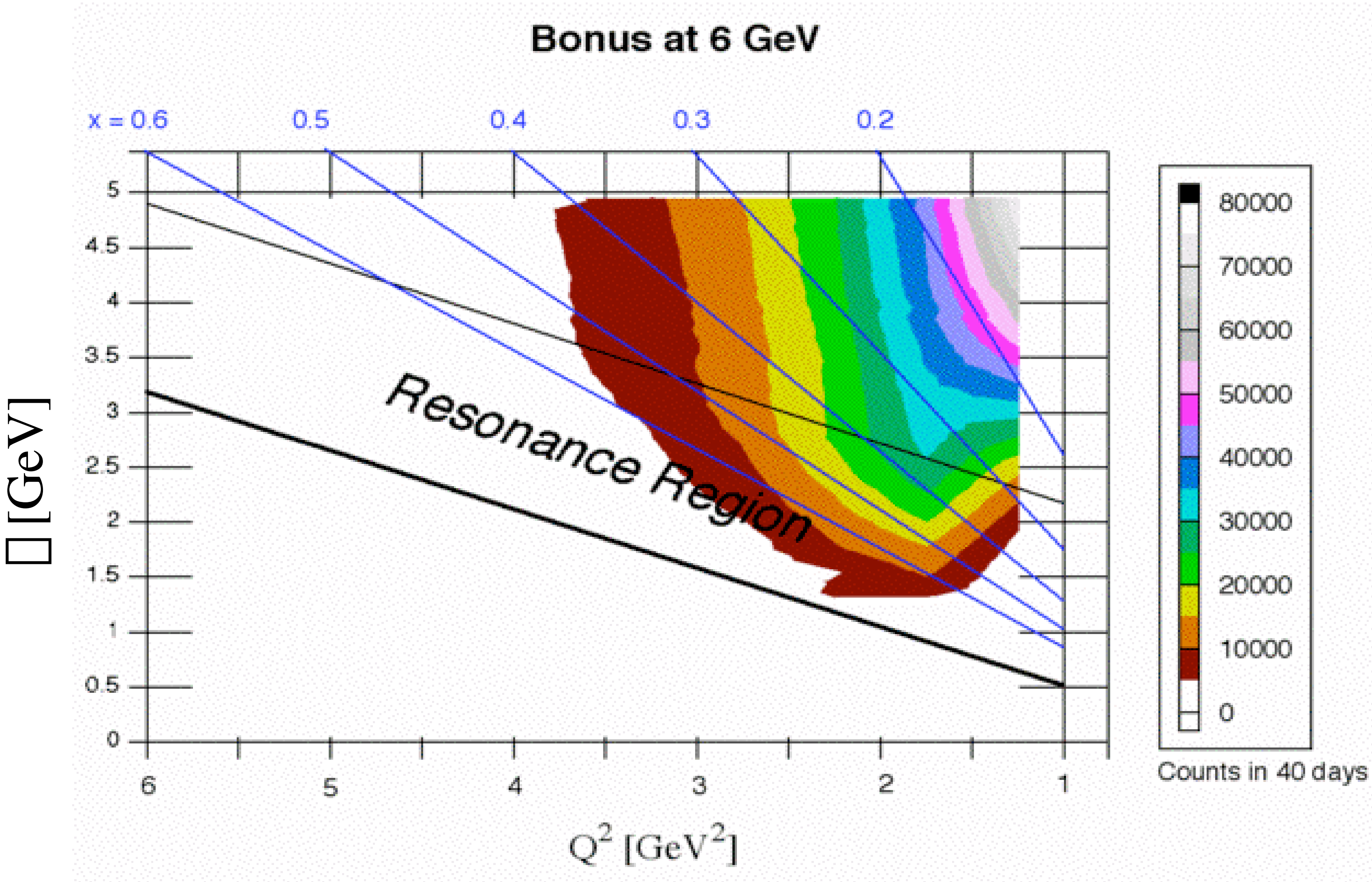
DVCS Superconducting Solenoid



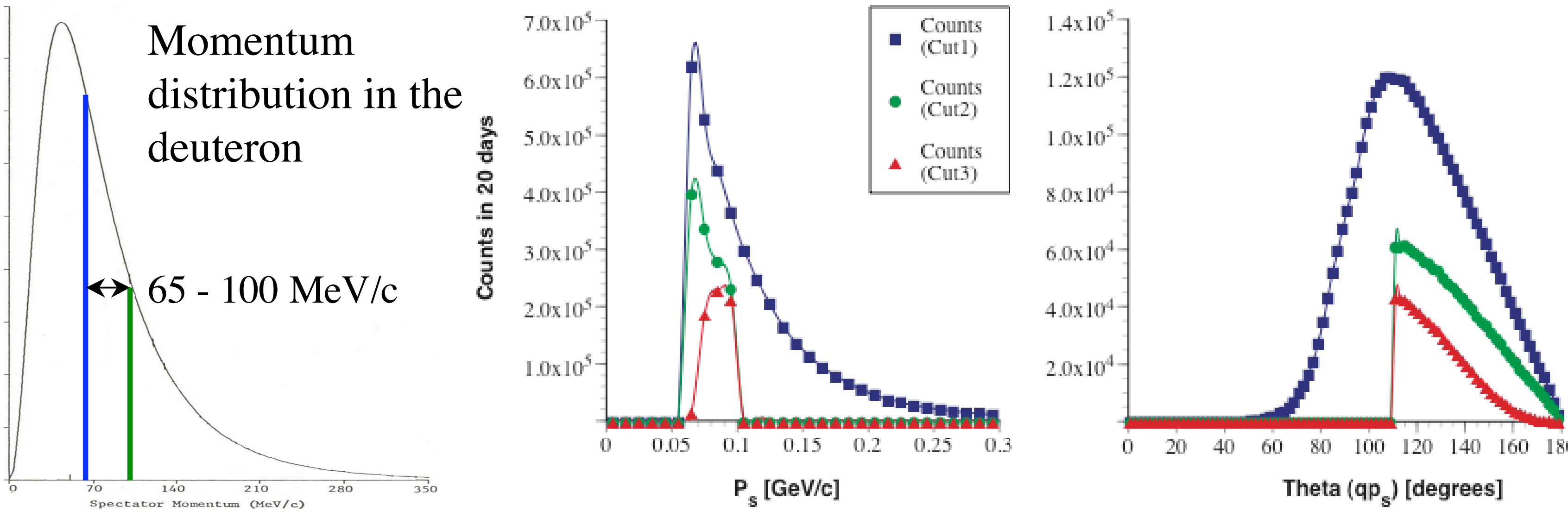
Fully Instrumented Detector



BoNuS 6 GeV Kinematics



Acceptance for Protons



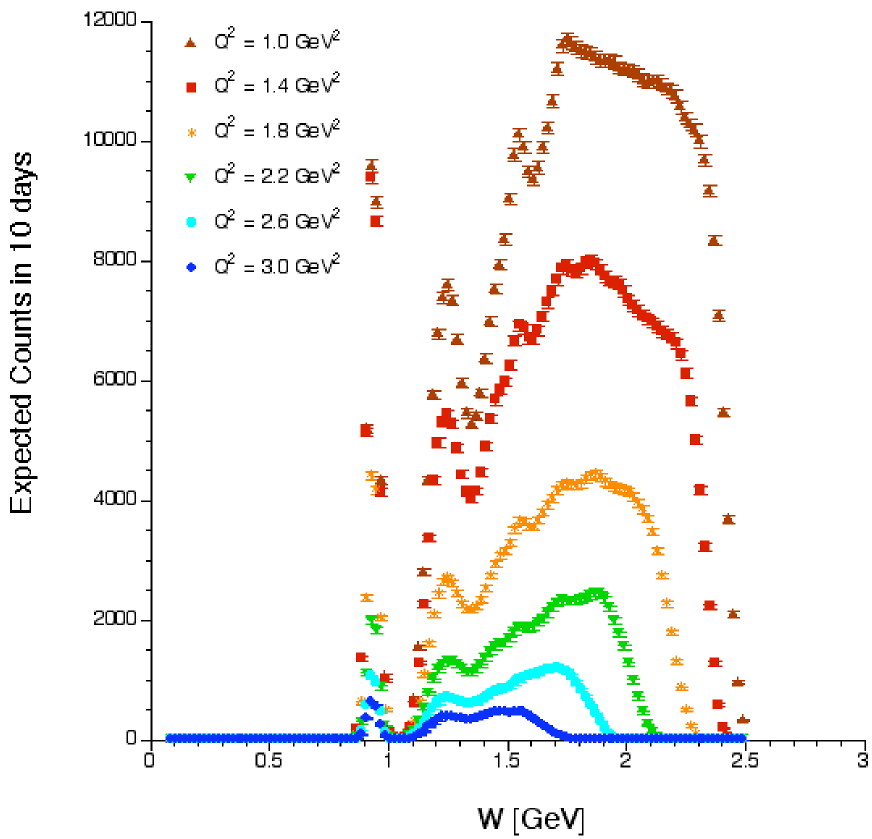
6 GeV electron beam, 20 “ideal” days -> registered “events”

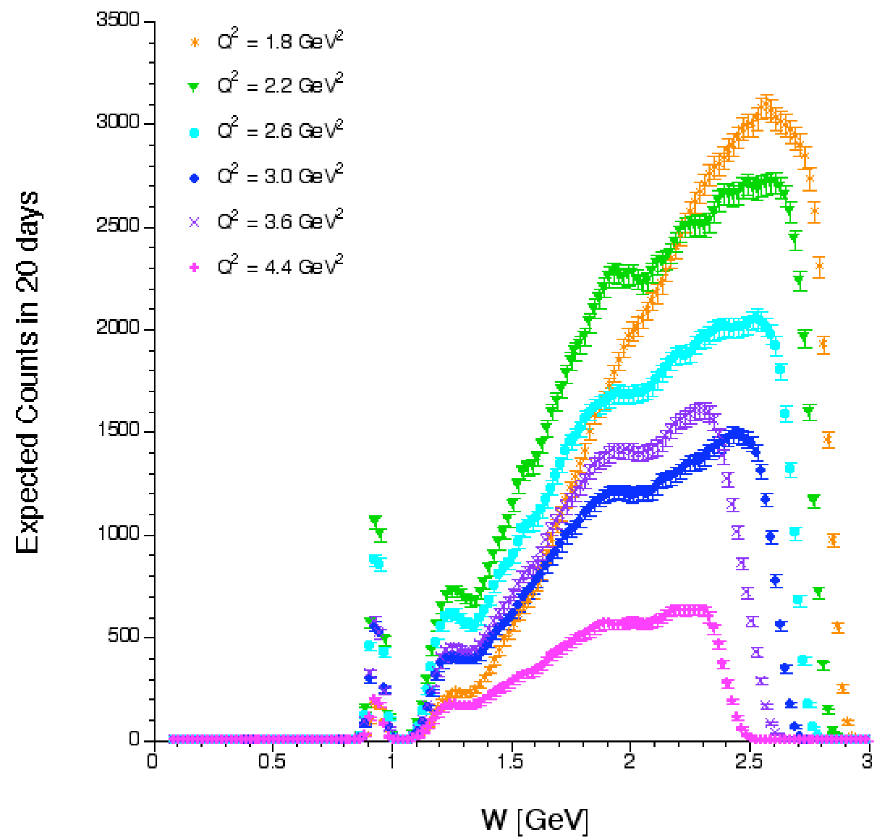
Scattered electron within CLAS fiducial cuts, proton above 60 MeV/c and 90^o

“VIPs”: p(proton) < 100 MeV/c, $\theta_{pq} > 110^o$

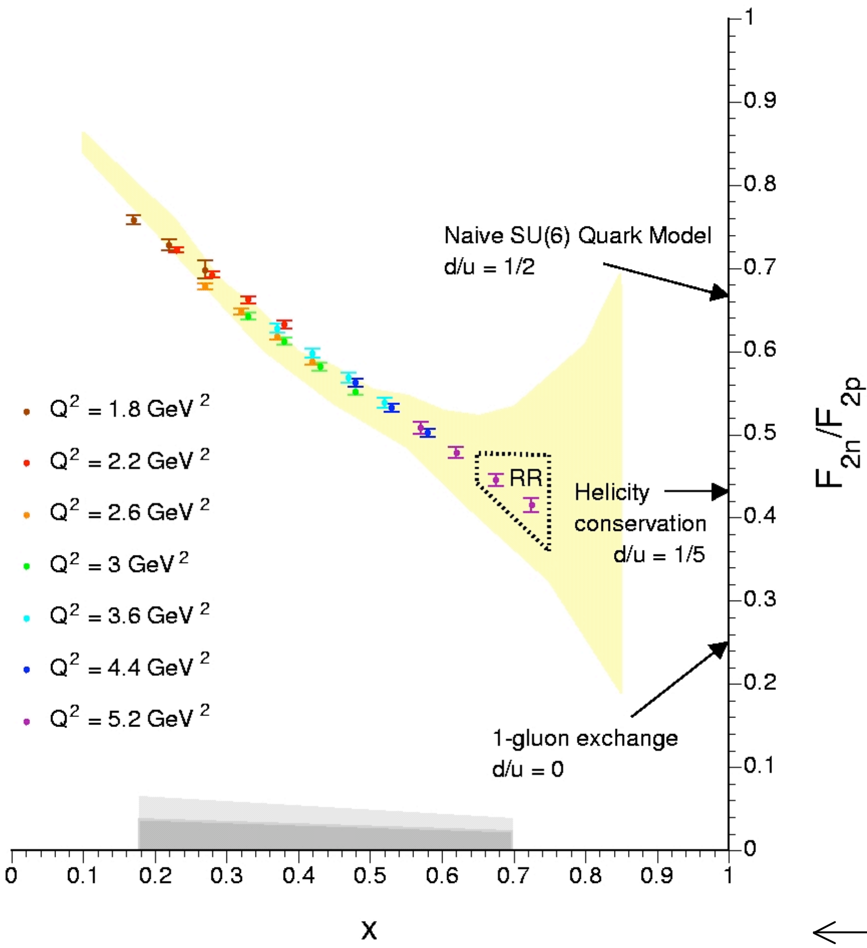
Proton reconstructed by the RTPC

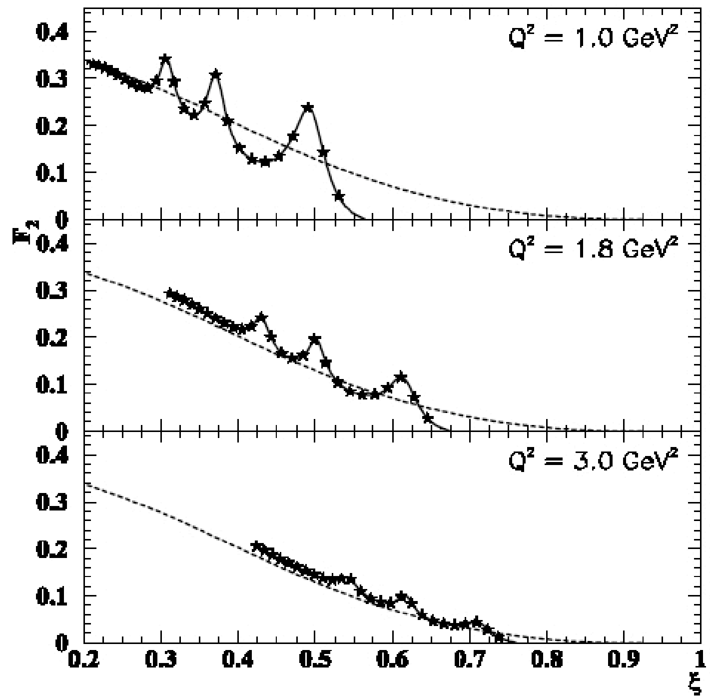
Expected W Distributions at 4 and 6 GeV





Expected Data



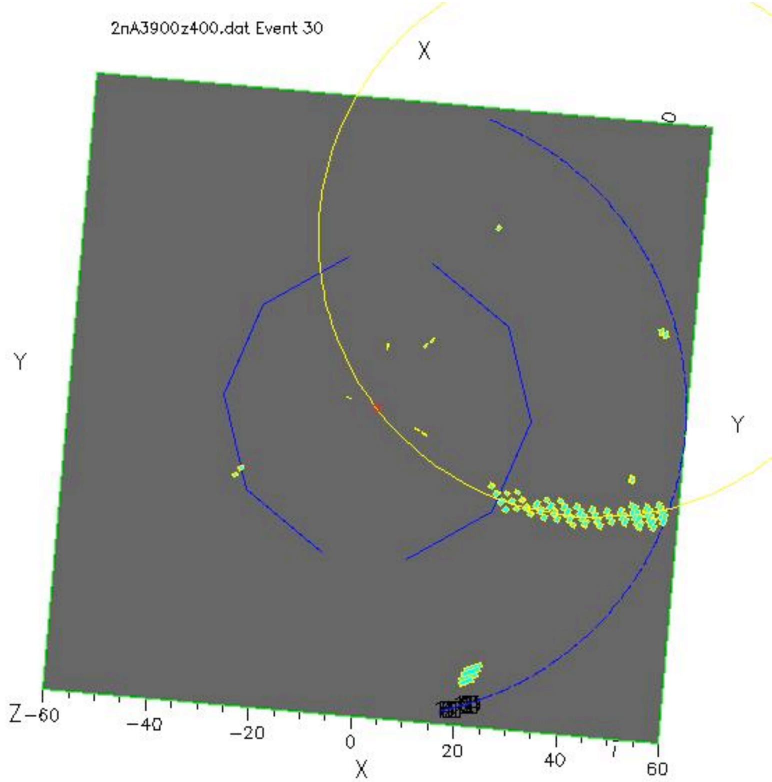


Systematics ~5%

← d/u

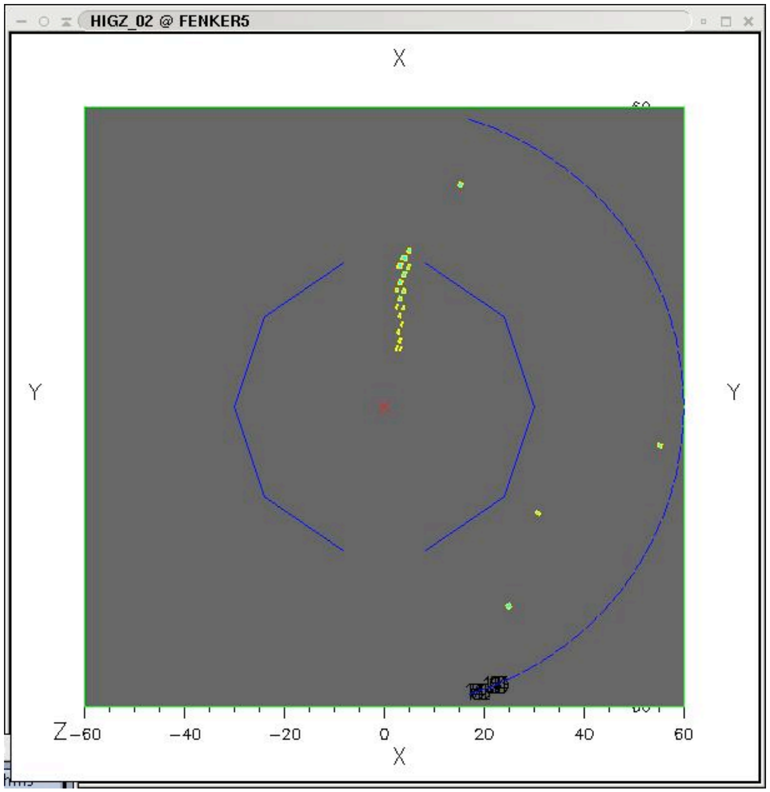
↑ Duality

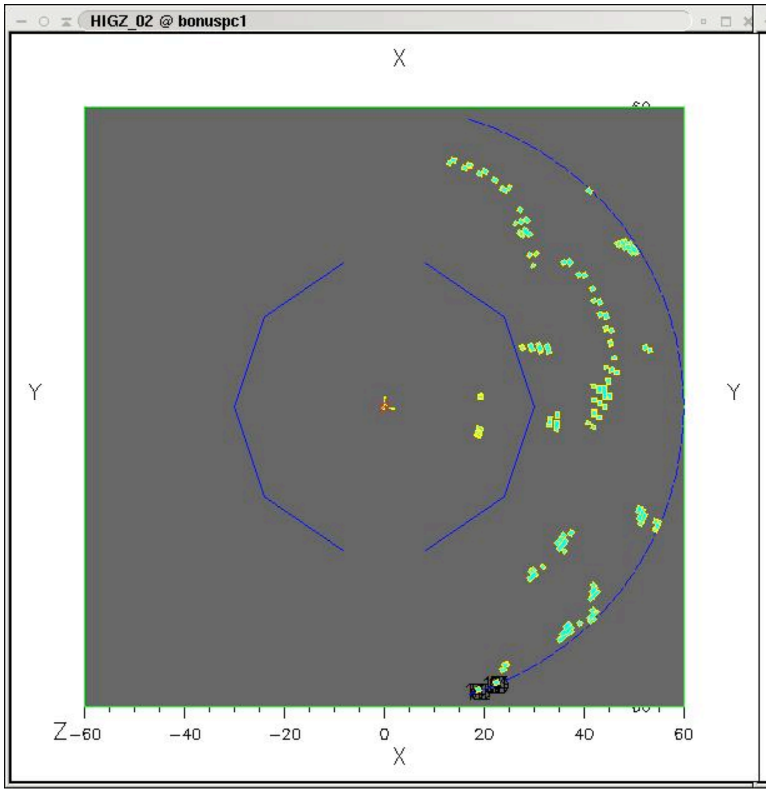
Fitted Proton Track
BoNuS Engineering Run
(3-13 June 2005)



- Active region of the BONUS detector lies between the two blue arcs.
- Projection: along the beam direction.
- Curved proton track.

Other Events

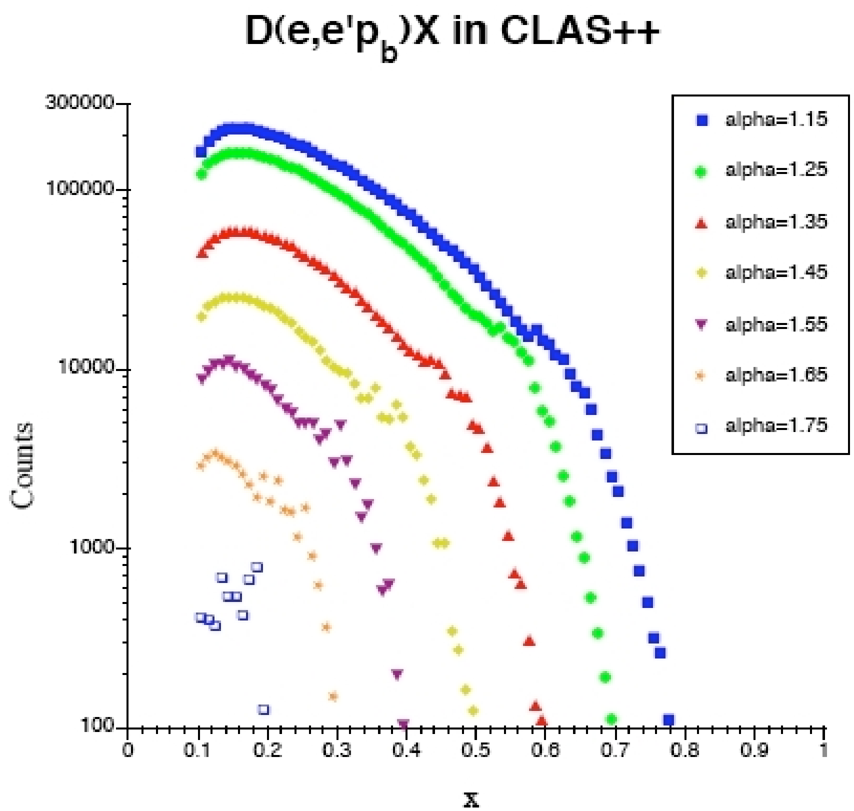




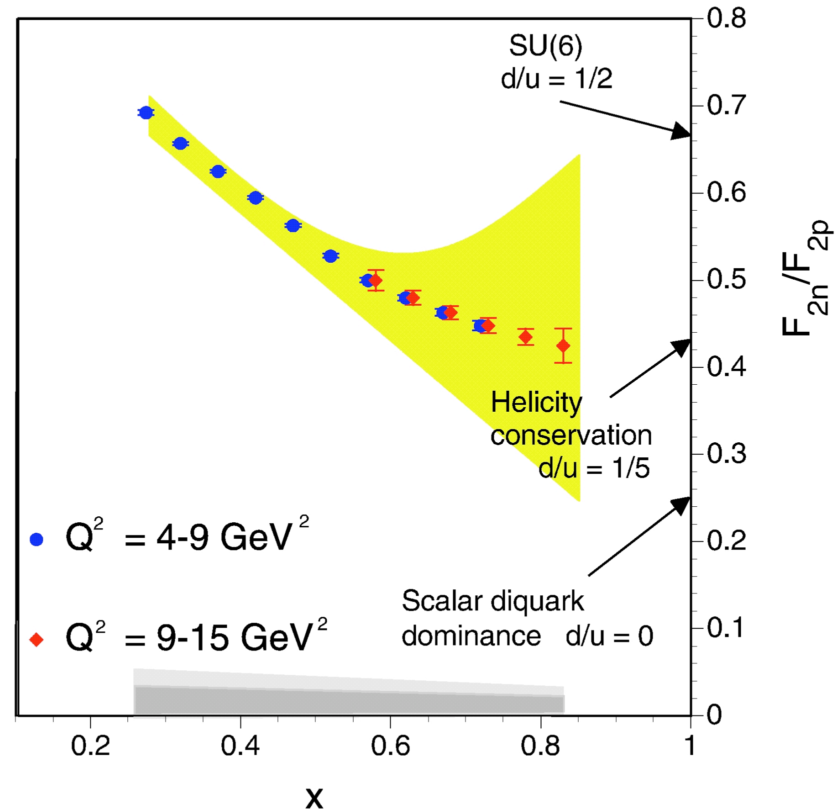
- Left: Out-of-time proton
- Right: Minimum-ionizing tracks at high gain

The Future - 11 GeV

$D(e,e'p_s)$



BoNuS



The MINER□A Experiment

Main INjector ExpeRiment □□□

MINER□□ is a compact, fully active neutrino detector designed to study neutrino-nucleus interactions with unprecedented detail.

The detector will be placed in the NuMI beam line, in front (upstream) of the MINOS near detector.

The MINER□A Collaboration

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* Co-Spokespersons
\# Members of the MINERvA Executive Committee

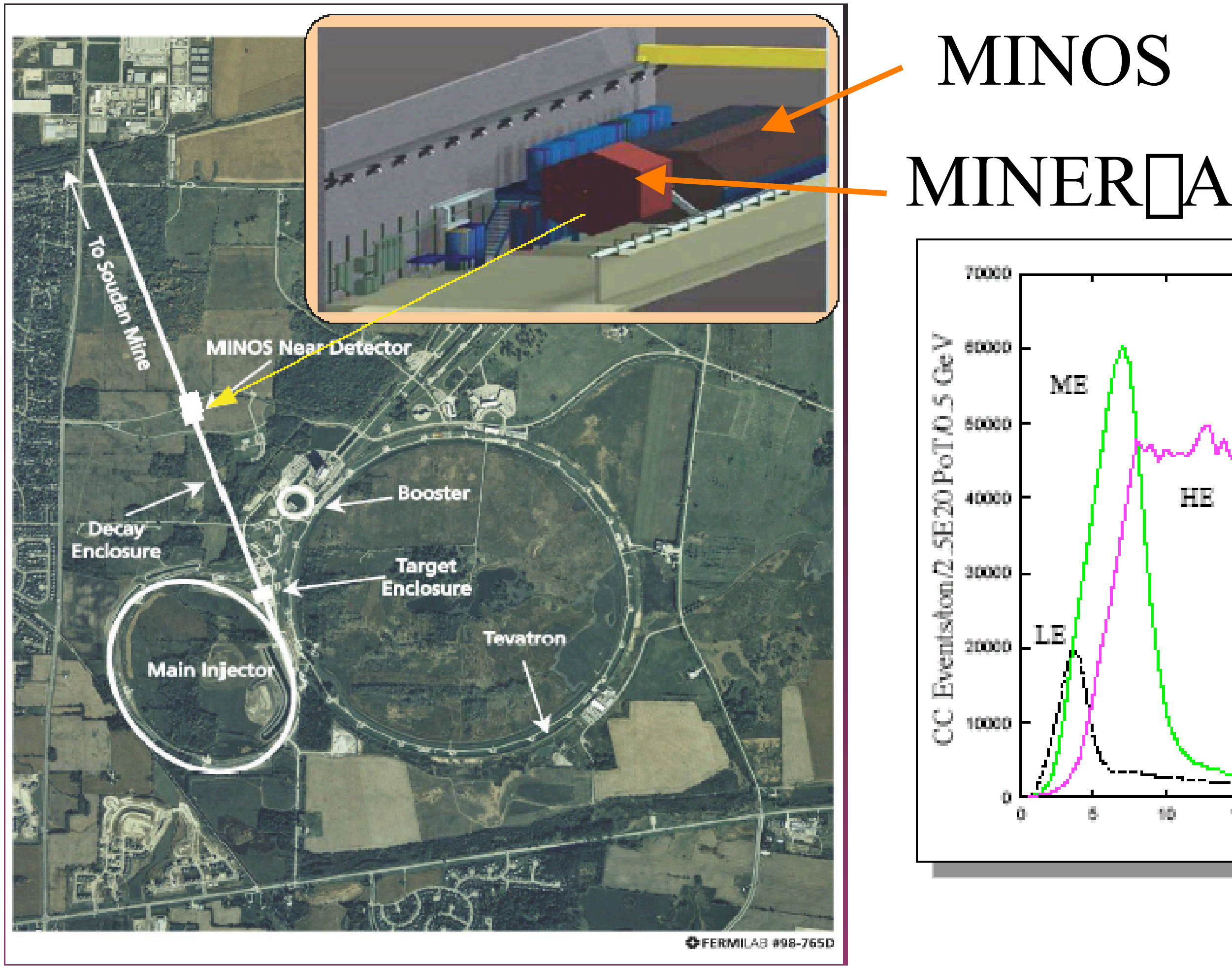
Collaboration of Particle, Nuclear, and Theoretical physicists

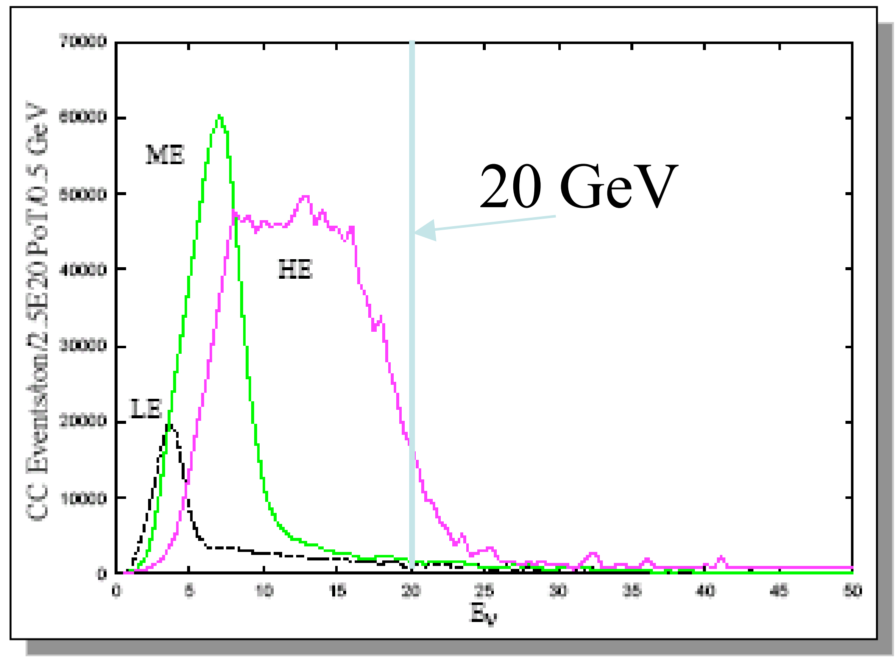
Objectives of MINER□A

Physics Goals

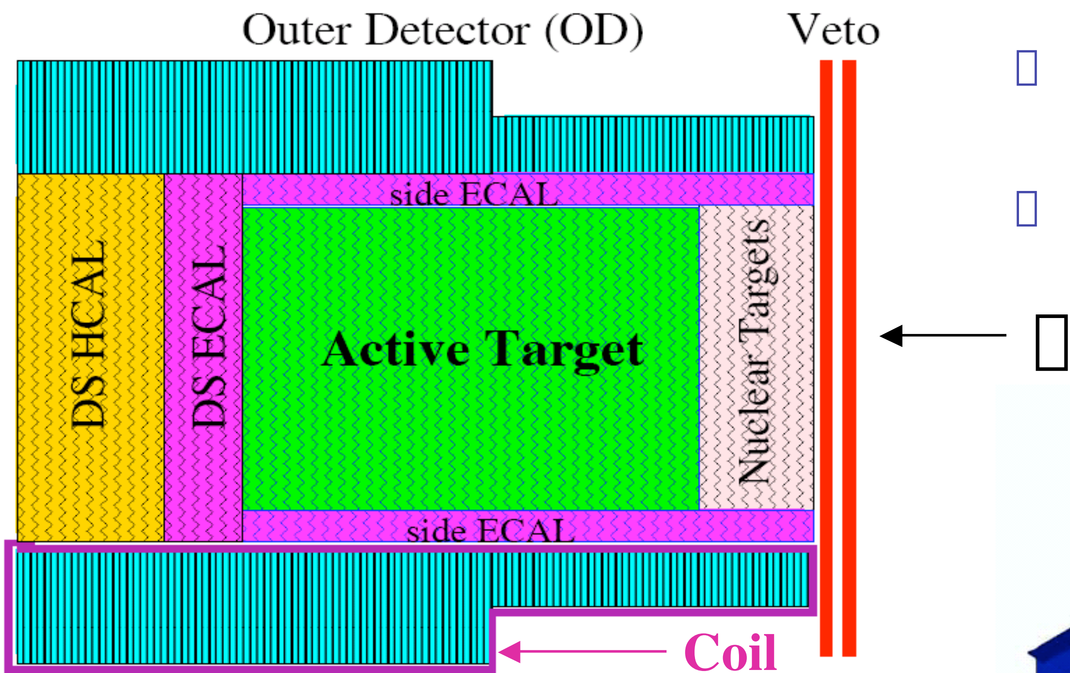
- Reduce uncertainties in new generation of neutrino oscillation experiments
  - Require precise knowledge of cross sections for Monte Carlo input
- Axial form factor of the nucleon
  - Yet to be accurately measured over a wide Q^2 range.
- Resonance production in both NC and CC neutrino interactions
  - No statistically significant measurements with 1-5 GeV neutrinos.
  - Study of quark-hadron duality with neutrinos.
- Coherent pion production
  - No statistically significant measurements of □ or A-dependence.
- Nuclear effects
  - Expect significant differences for □-A vs e/□-A nuclear effects.
- Strange Particle Production
  - Important backgrounds for proton decay.
- Parton distribution Functions
- Measurement of high-x behavior of quarks.
- Generalized parton distributions

Lots of Neutrinos-NuMI Beam Line at Fermilab

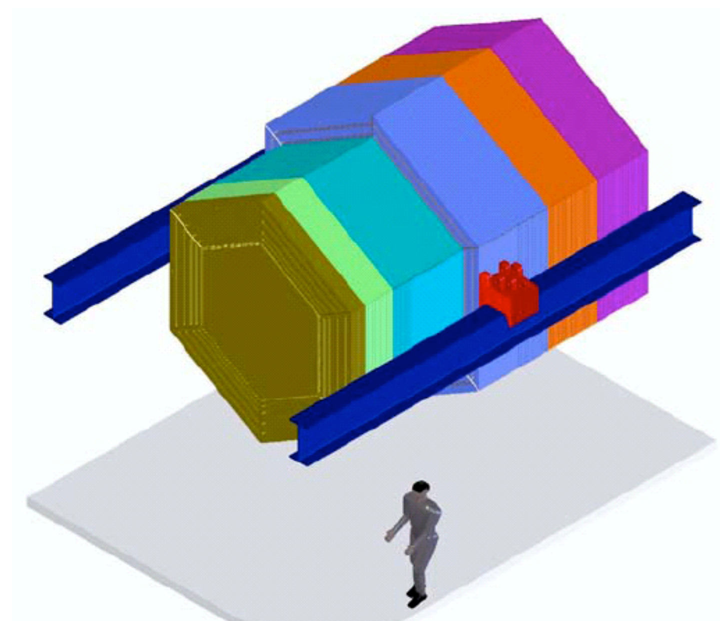




The MINERνA Detector

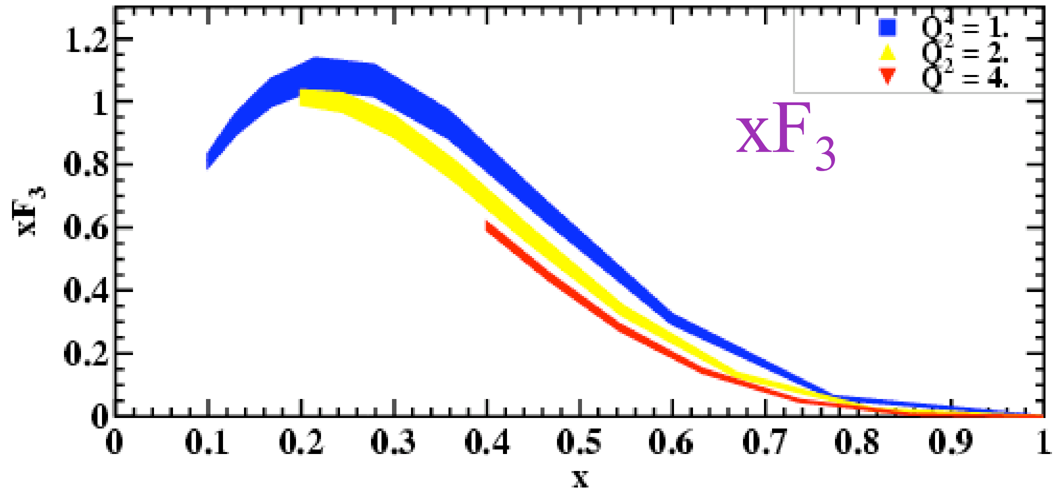


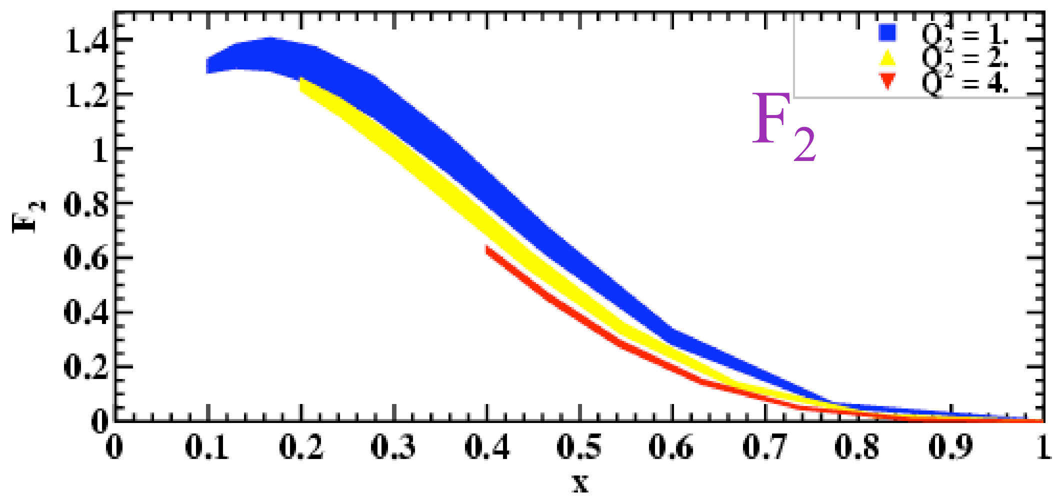
- Active segmented scint. detector 5.87 tons.
- ~1 ton each of nuclear target planes (C, Fe, Pb) upstream.



MINOS used for higher energy forward muon detection.

Large x Structure Functions





- xF_3 and F_2 structure function predictions and error bands
- Will cover wide range in x, Q^2, overlapping and complementary to Jefferson Lab 12 GeV regime

Current Status of MINER□A

- Received Stage I approval in April 2004.
- Successful summer 2004 R&D program concentrating on front-end electronics and scintillator extrusions.
- Detailed costing and schedule module exists.
- Underwent first FNAL Director's (Temple) Review in January 2005.
- MINER□A is a project in PPD with project directorate approved by Fermilab and project management plan currently under discussion.
- Developing prototypes of many components.
- Current scheduling model indicates construction starting in Oct. 2006 and installation-finishing/commissioning-starting in early Fall 2008.

Conclusions

- Data from neutron targets is important for understanding the nucleon.
- BoNuS provides the first almost free nucleon target.
- BoNuS had a successful engineering run in June 2005. The full experiment is scheduled for October-November 2005.
- BoNuS and MINERvA will determine d/u at high x.