Neutron Structure Functions and a Radial Time Projection Chamber

Stephen Bültmann

Old Dominion University

for the BoNuS Collaboration

The Structure of the Neutron

The BoNuS Experiment at CLAS

A New Proton Recoil Detector for CLAS

2nd EIC Workshop at Jefferson Lab, March 15 - 17, 2004

Neutron Structure Function F_2^n

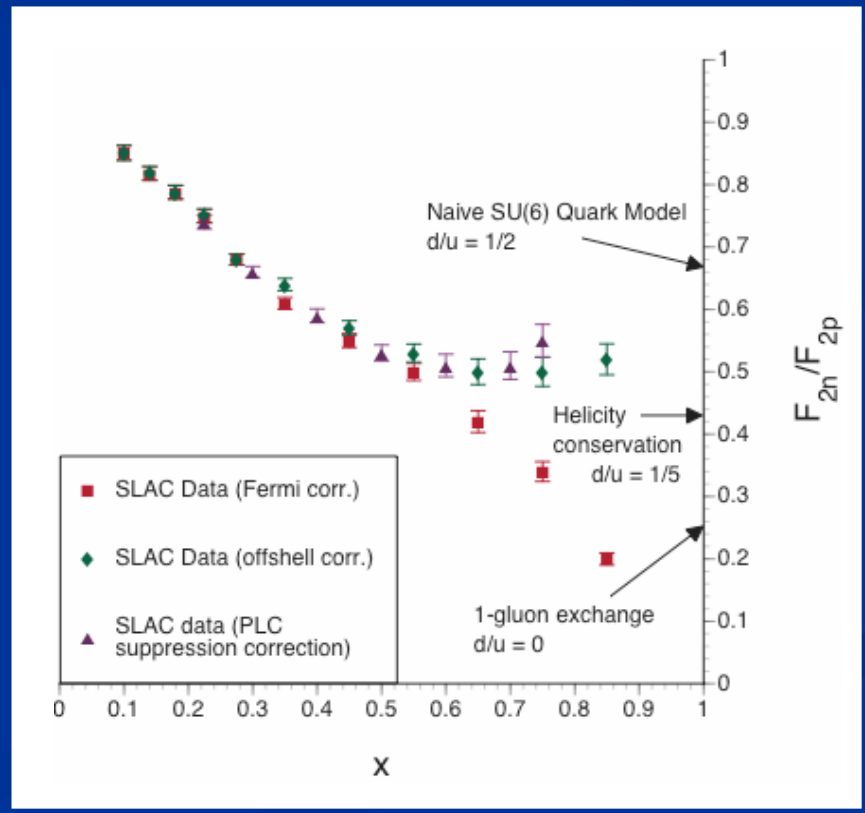
Proton structure function F_2^p measured very accurately

Neutron structure function F_2^n is obtained from measurements on bound neutrons, e.g. using deuterium targets

Extraction of F_2^n at large x_{Bj} introduces theoretical model dependence on nuclear corrections (Fermi motion, nucleon offshell corrections, FSI, …)

$$\frac{F_2^n}{F_2^p} \approx \frac{1 + 4\ d/u}{4 + \ d/u}$$

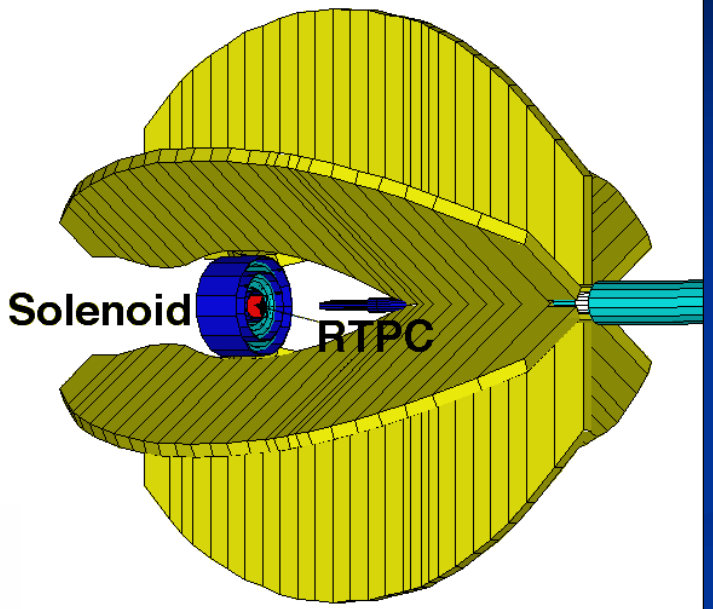
at leading order and for $x_{Bj} > 0.4$



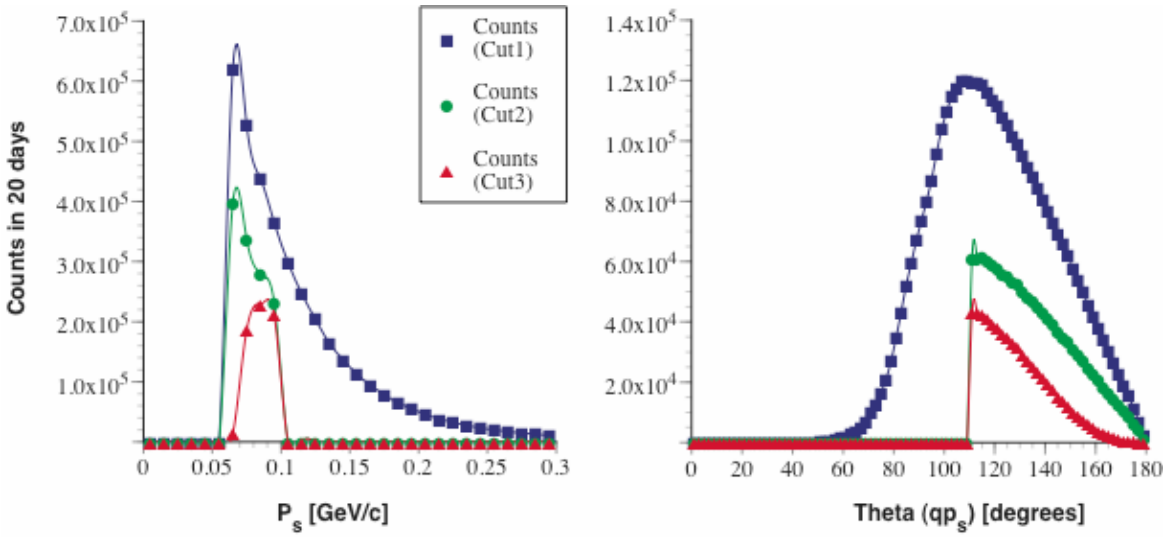
BoNuS in a Nutshell (CLAS)

Measurement of the structure function F_2^n on nearly free neutrons in the reaction $e^- d \rightarrow e^- p X$ by measuring the slowly backward moving recoil proton with momentum below 100 MeV/*c*

(suppress FSI and uncertainties from on-shell extrapolation)



Simulated event count for 20 days of data taking at 6 GeV



Cut1: p_s > 60 MeV/c

Cut2: p_s < 100 MeV/c && θ_{qp} > 110°

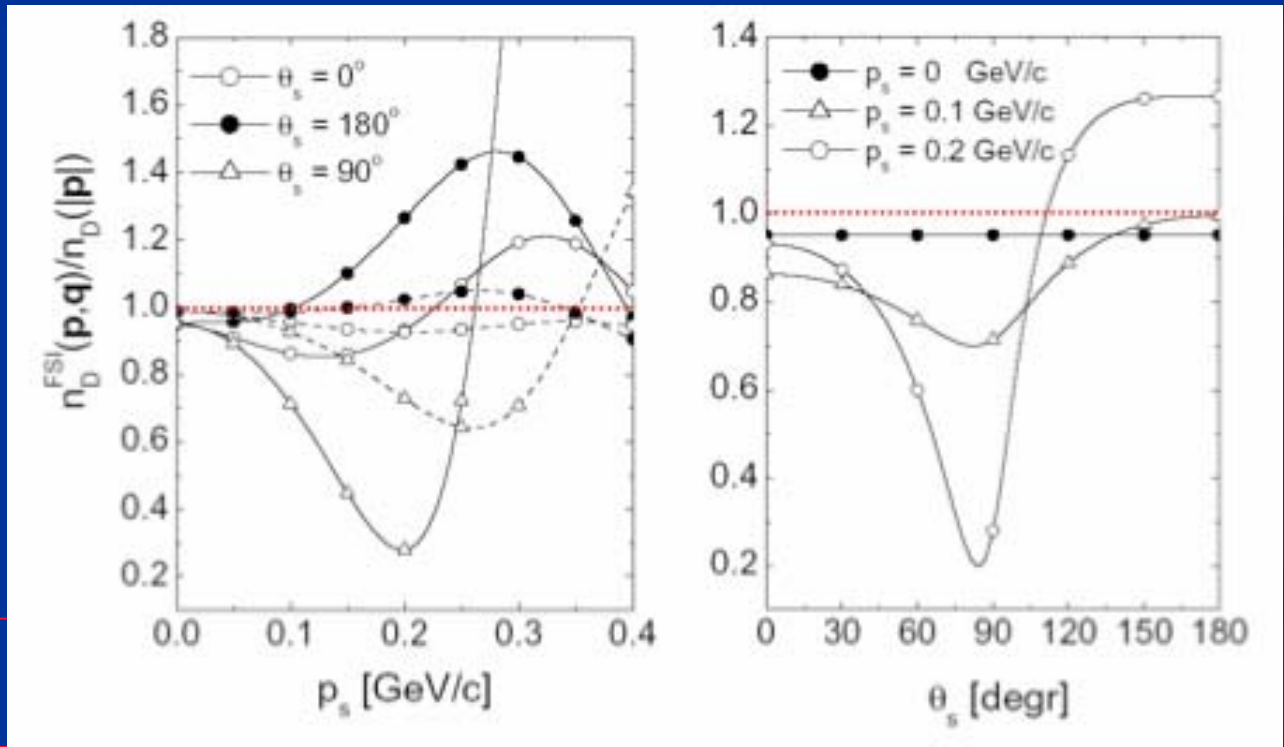
Cut3: recoil detector acceptance

Final State Interactions

DIS ratio of neutron momentum distributions including FSI to PWIA

Calculation at $Q^2 = 5$ (GeV/c)^2 and $x_{Bj} = 0.2$

Small effect for spectator momenta below 100 MeV/c and backward scattering angles

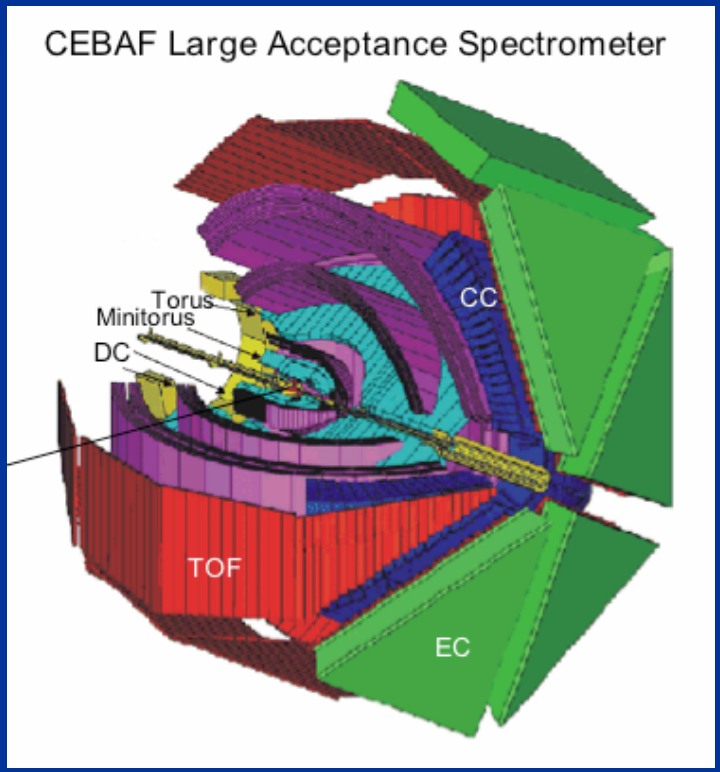


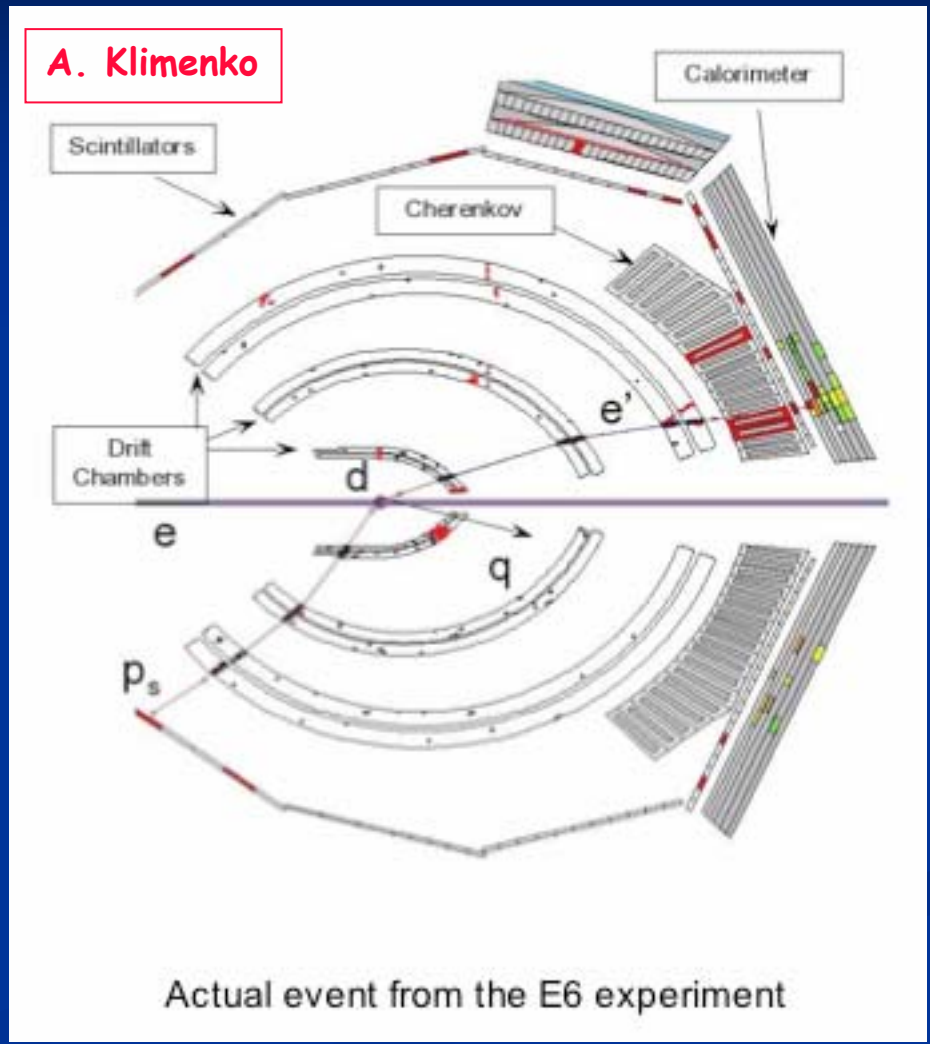
C. Ciofi degli Atti, L.P. Kaptari, B.Z. Kopeliovich, Eur. Phys. J. A19, 145 (2004)

Experiment E6 in CLAS

CLAS presently limited to spectator proton momenta > 280 MeV/c

Scattering angle $10° < \theta < 140°$

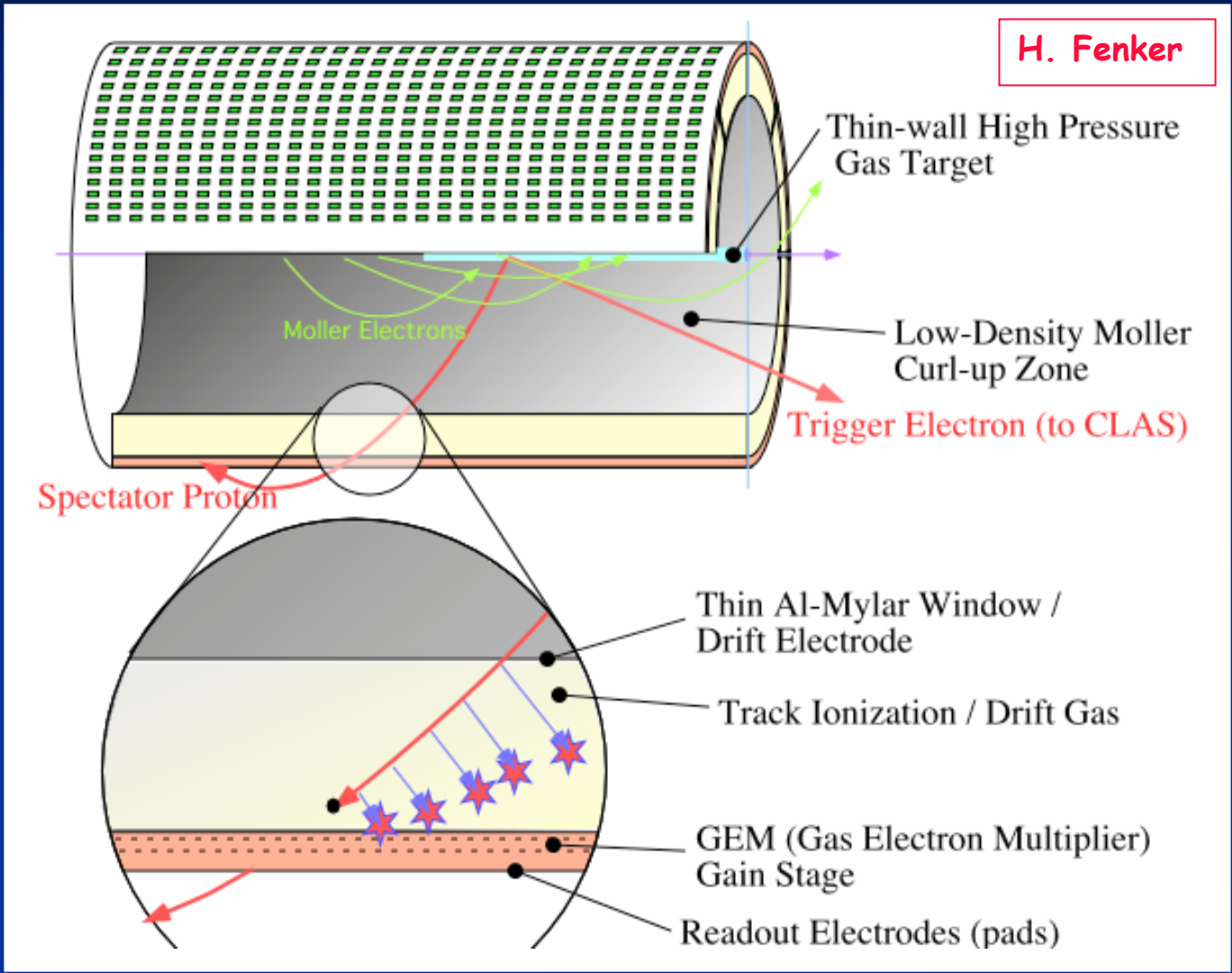




The BoNuS Experiment

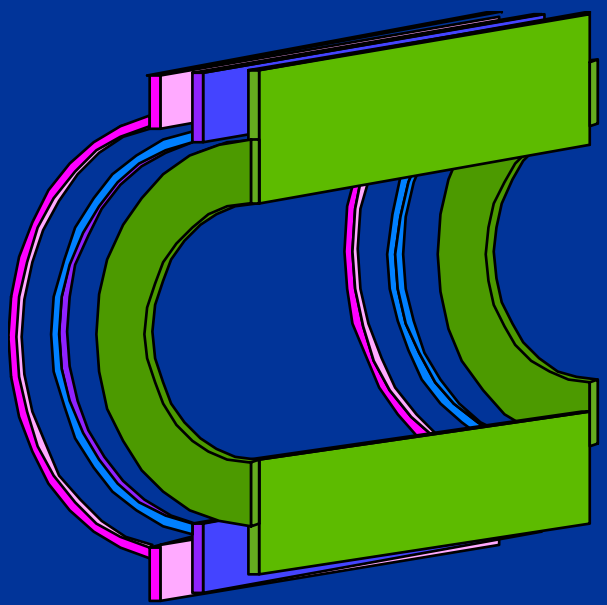
- Long deuterium gas target
  (spectator protons have to leave target)
- Large acceptance coverage including backward angles
- Measure momentum by tracking in solenoidal magnetic field around target region (spectator momenta to around 70 MeV/*c)*
- Measure energy deposit for particle identification
  (spectator protons are 20 to 50 times minimum ionizing)
- Detector needs to measure high rates
- Main background from Møller electrons
  (new solenoid will curl up electrons up to 20 MeV, the higher momentum electron will miss the detector)
- Measurement at 4 and 6 GeV electron beam energy
- Expected trigger rate below 1 kHz

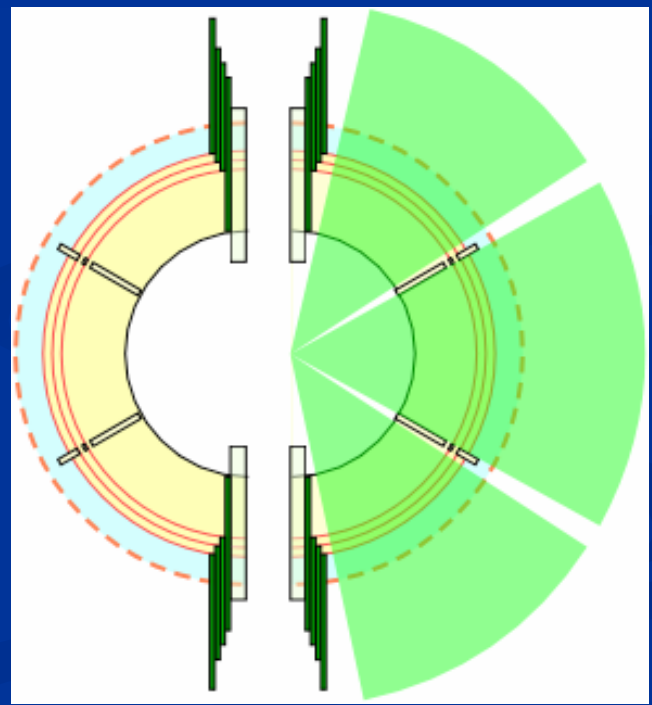
Conceptual Design of BoNuS RTPC



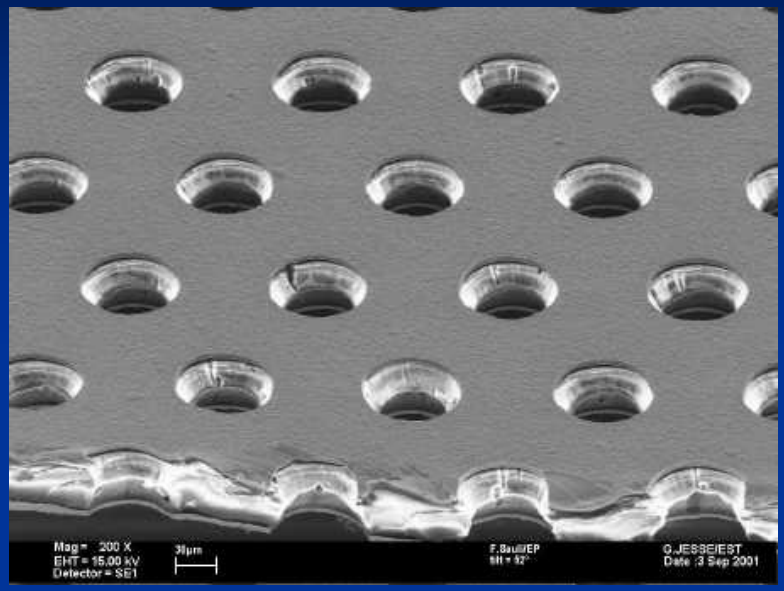
The BoNuS Recoil Detector

- Radial Time Projection Chamber (RTPC)
- Covering target region
- Gas Electron Multipliers (GEM's) instead of wires allows new curved geometry
- Drift time over 2 cm drift region about 2 μsec
- Strip or pad readout





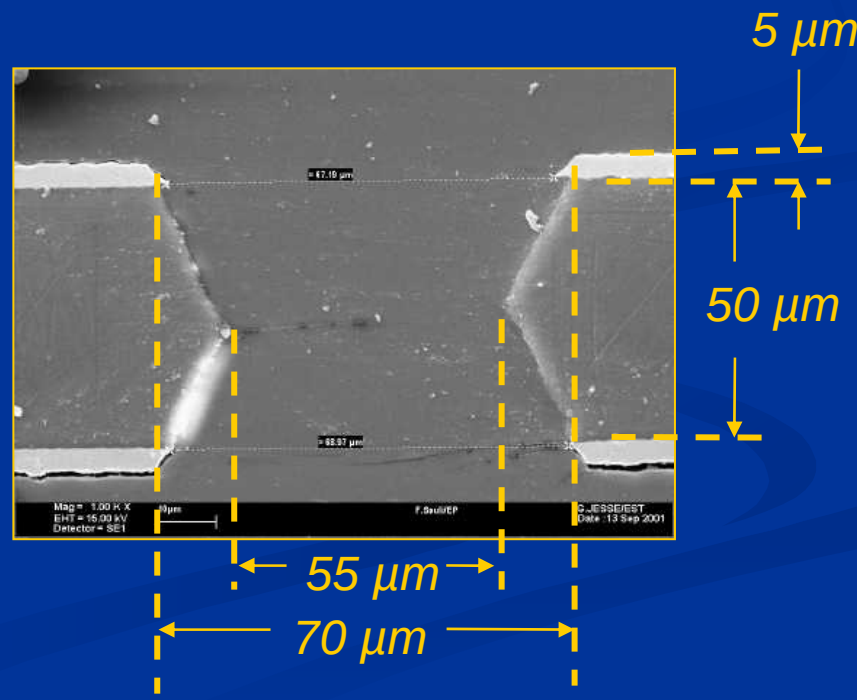
Gas Electron Multiplier (GEM)



F. Sauli, NIM A386, 531 (1997)

Thin polymer foil (Kapton, APICAL) covered on both sides with conductive (copper) layer

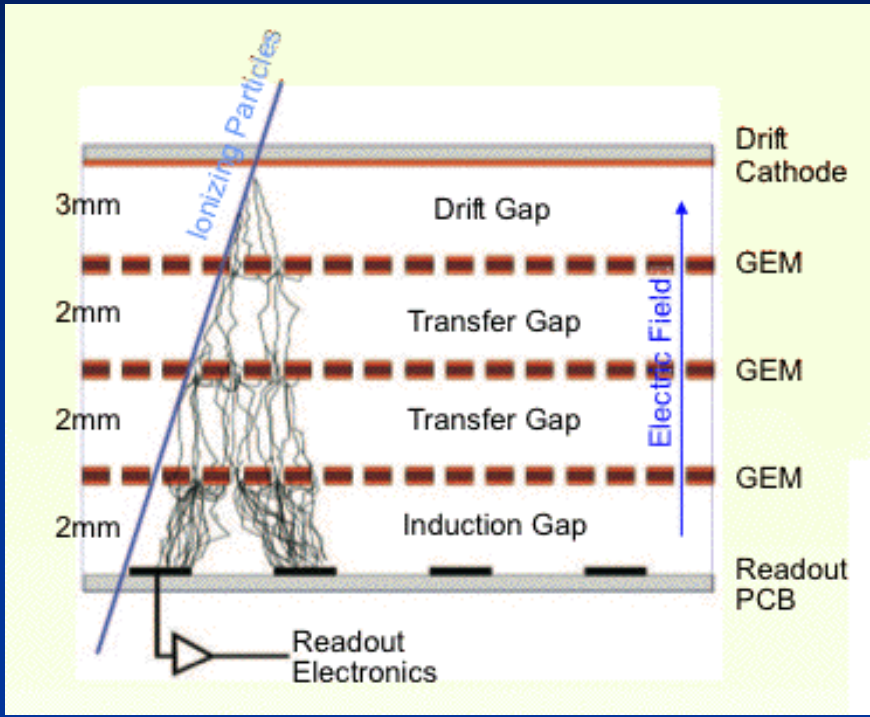
Double-conical holes by lithography and chemical etching



High electric field (kV/cm) through hole when applying 300 - 500 V potential difference between the two copper layers

Gain >100 per GEM

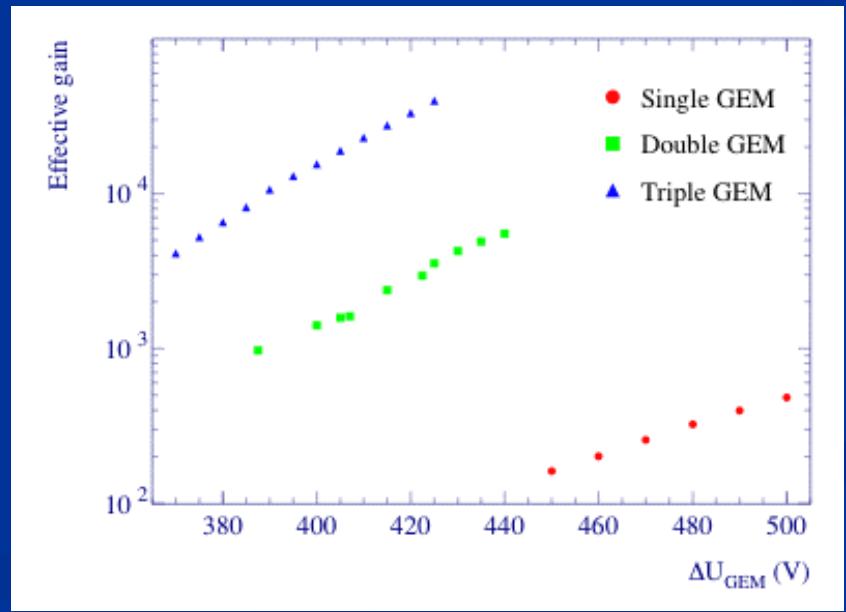
Amplification with Multi-GEM's



B. Ketzer, VIC 2004

Cascading GEM foils

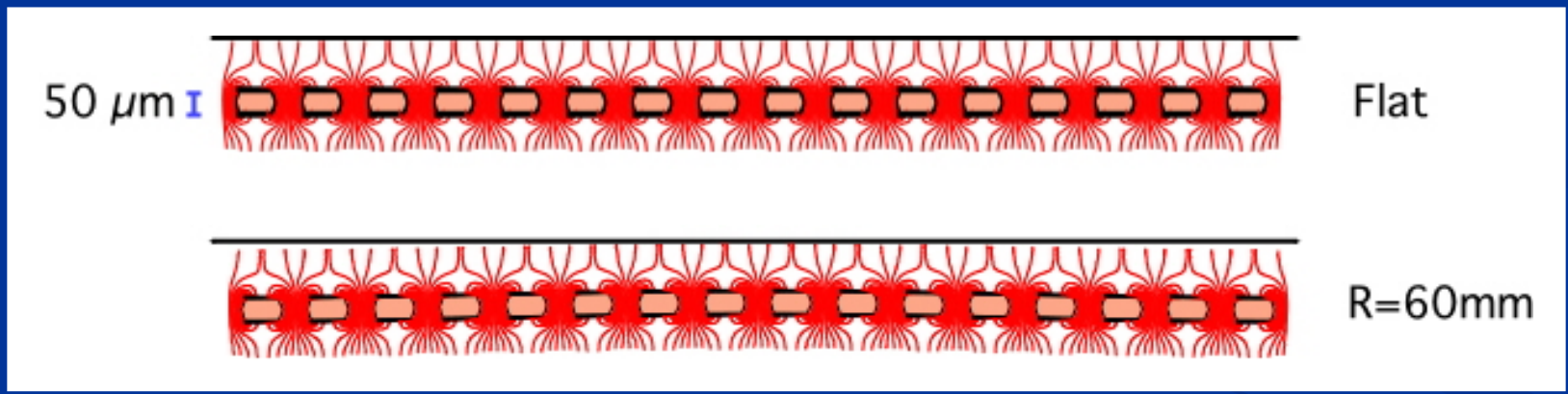
- Suppress ion feedback
- Increase gain up to 10^7 with three GEM's
- Operate GEM's at lower differential voltage



Field Calculation for Curved GEM's

Radius 60 mm

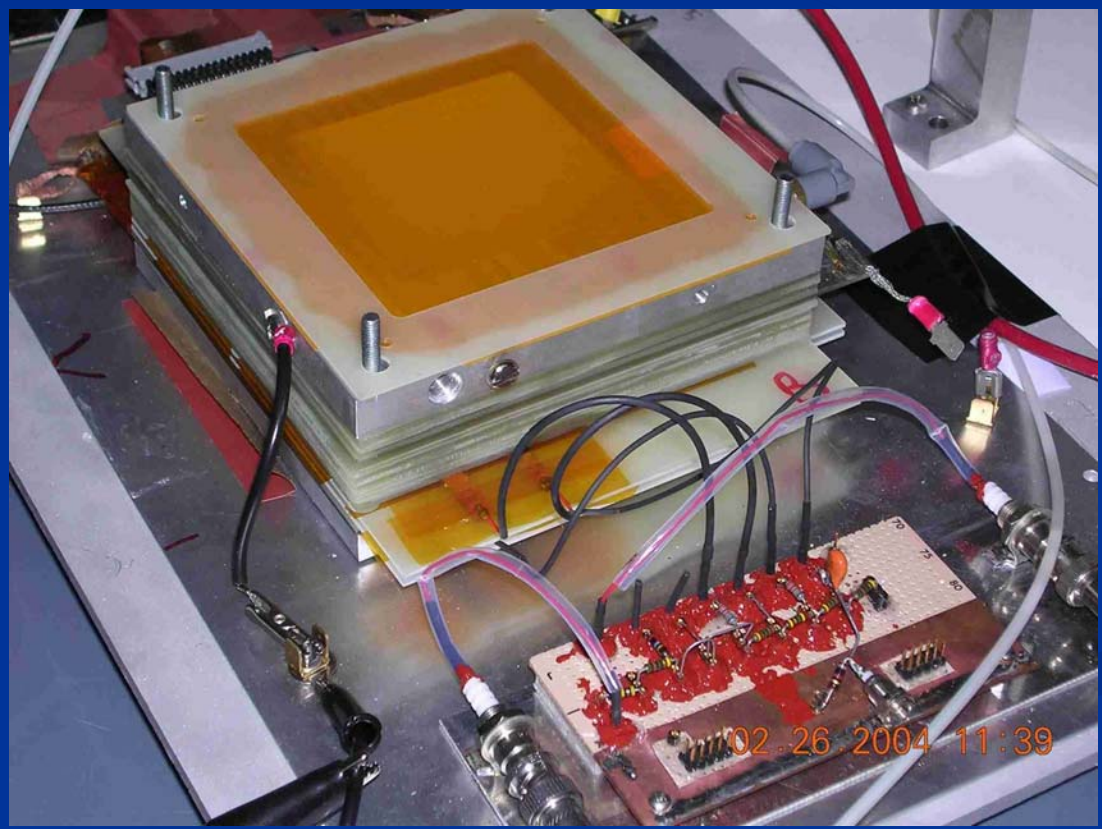
Electric field does not change significantly



Planar Prototype TPC

Using initially three standard 10 x 10 cm^2 GEM foils from 3M Corp. with gain ~30

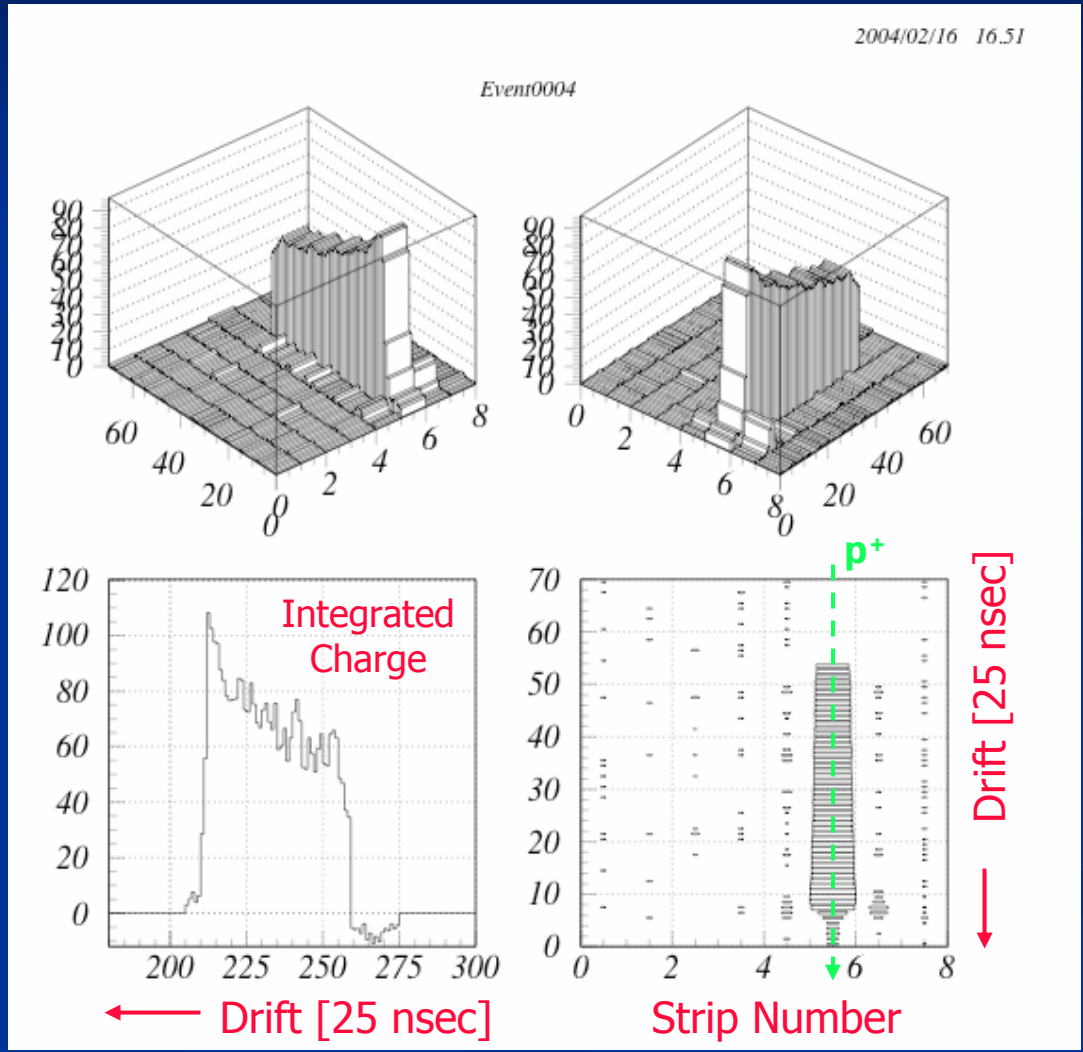
- Tests with cosmic rays, x-ray sources, and ~100 MeV/*c* protons at TUNL
- Readout plane with eight strips
- Ar (80) / CO_2(20) drift gas



The planar prototype TPC with two new GEM foils of gain >100 at JLab

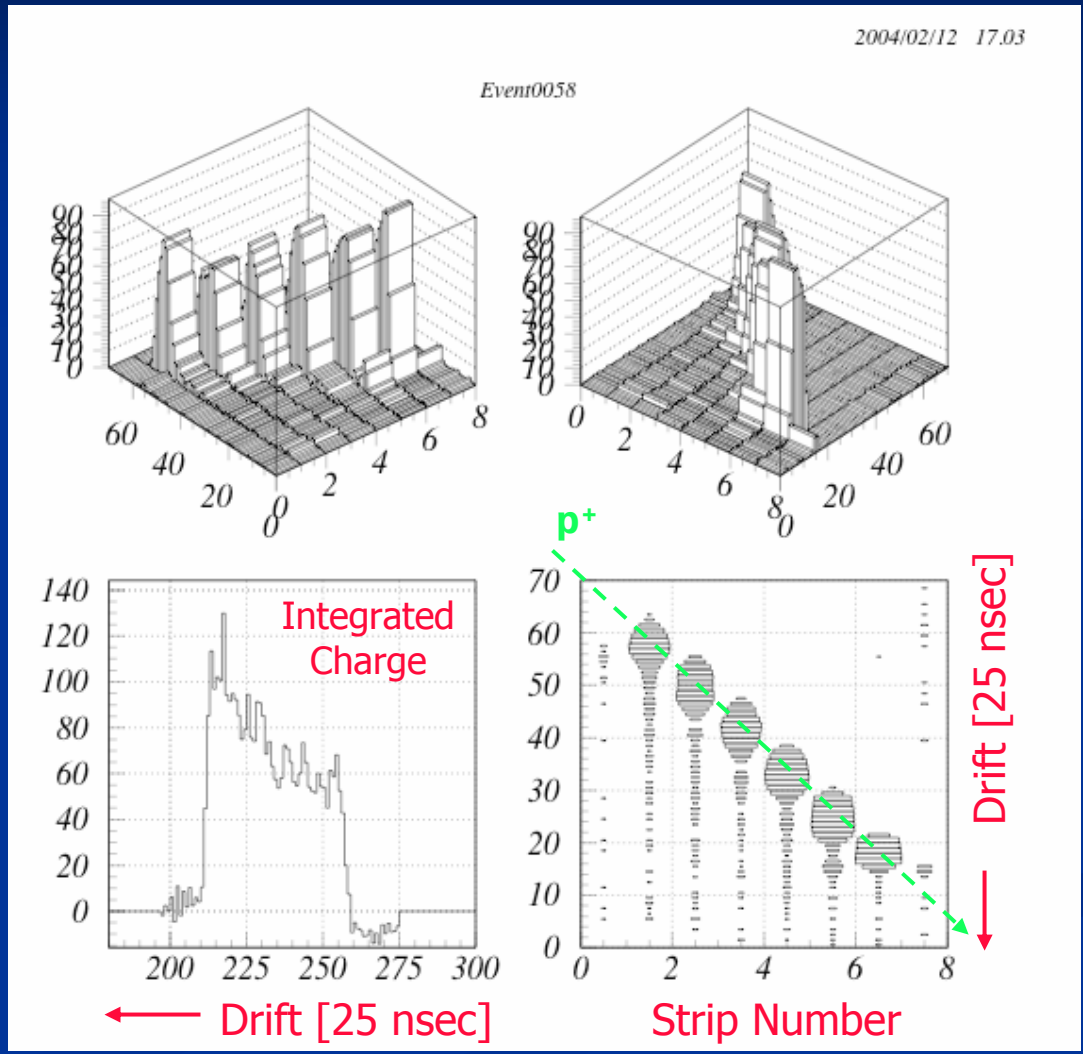
Test of Planar Prototype TPC

- Using slow 100 MeV/*c* secondary protons at TUNL
- Protons entering TPC straight
- Energy deposit mostly on one strip



Planar Prototype TPC at TUNL

- Tilted TPC sidewise → protons entering TPC under angle
- Energy deposit mostly on several strips, track reconstruction possible

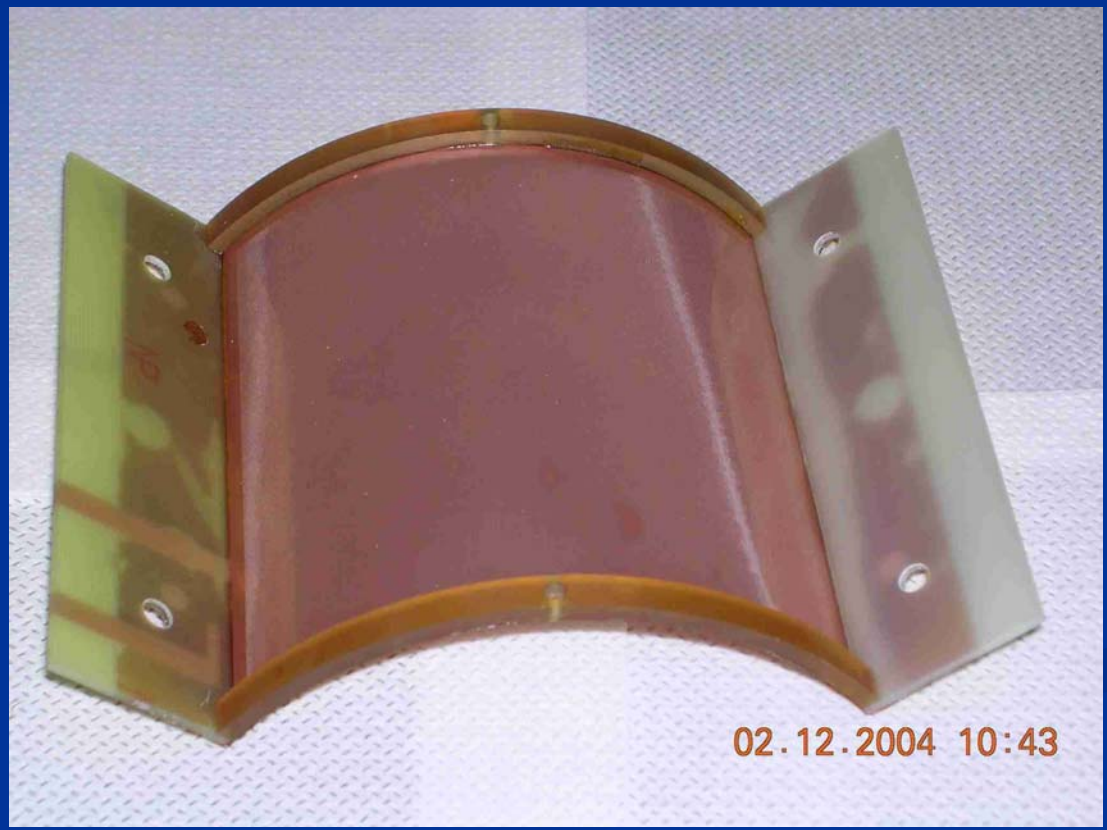


Prototype RTPC Drift Region

- Radial coverage 105° and 10 cm length (determined by GEM foil dimension)
- Entrance window 25 μm with etched ground and cathode planes

Prototype RTPC GEM Foil Plane

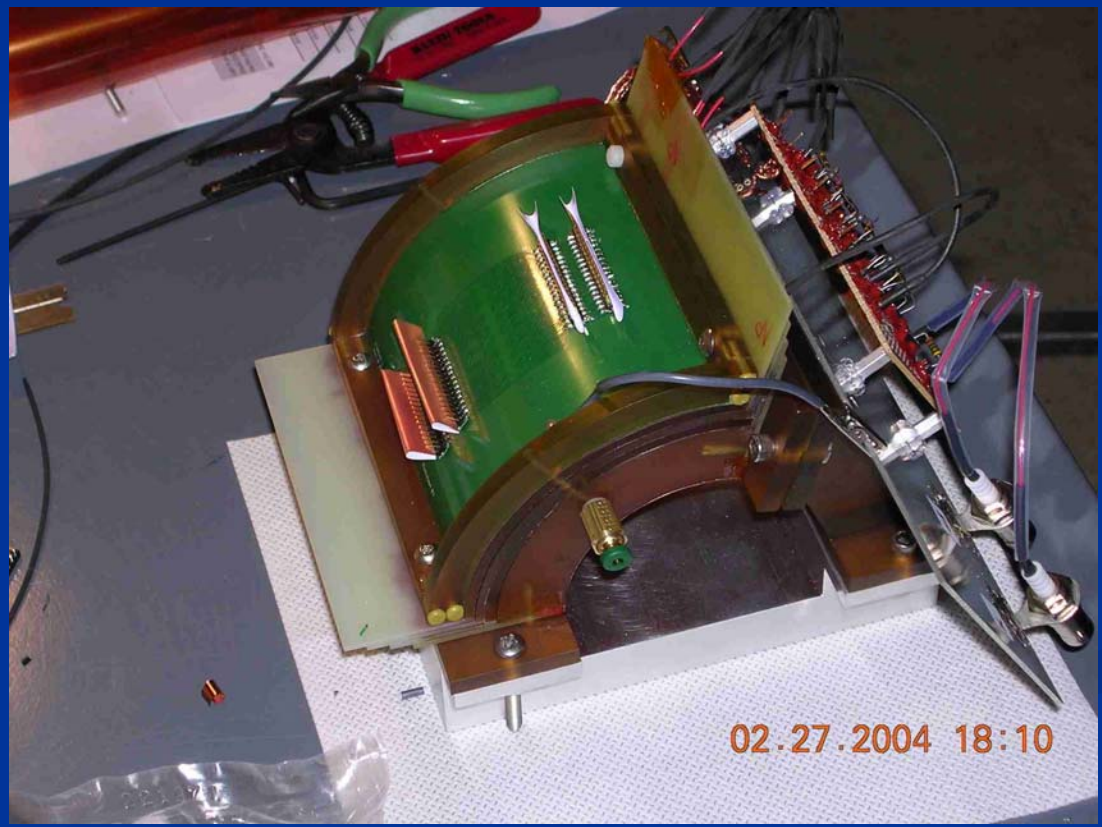
- Built three GEM foil planes using standard 10 x 10 cm^2 GEM foil from 3M Corp.
- GEM foils with gain >100
  (compared to previous 3M Corp. GEM foils with gain ~30)
- Successful high voltage test of GEM to 400 V



One of three GEM foil planes for prototype RTPC after gluing at ODU

Prototype RTPC Assembly

- Readout plane with 8 x 8 pads of 4 x 5 mm^2 size
  (compared to strip readout of planar prototype TPC)

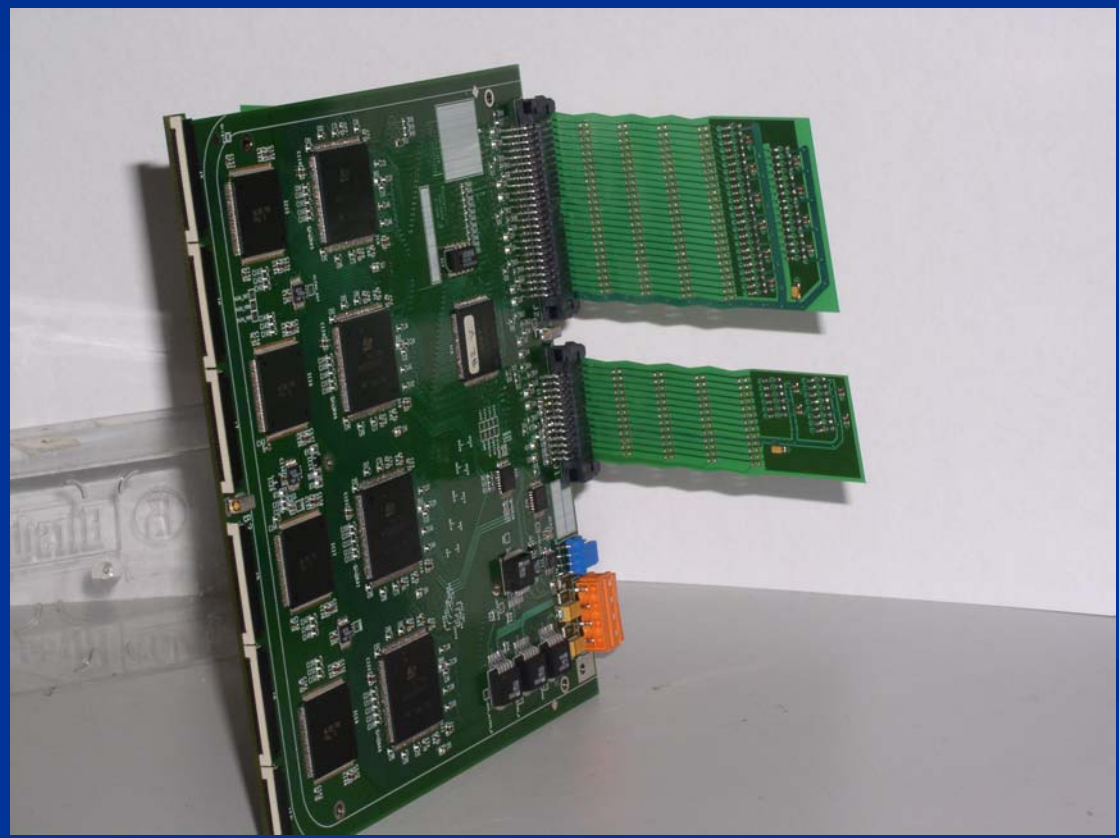


BoNuS Readout Electronics

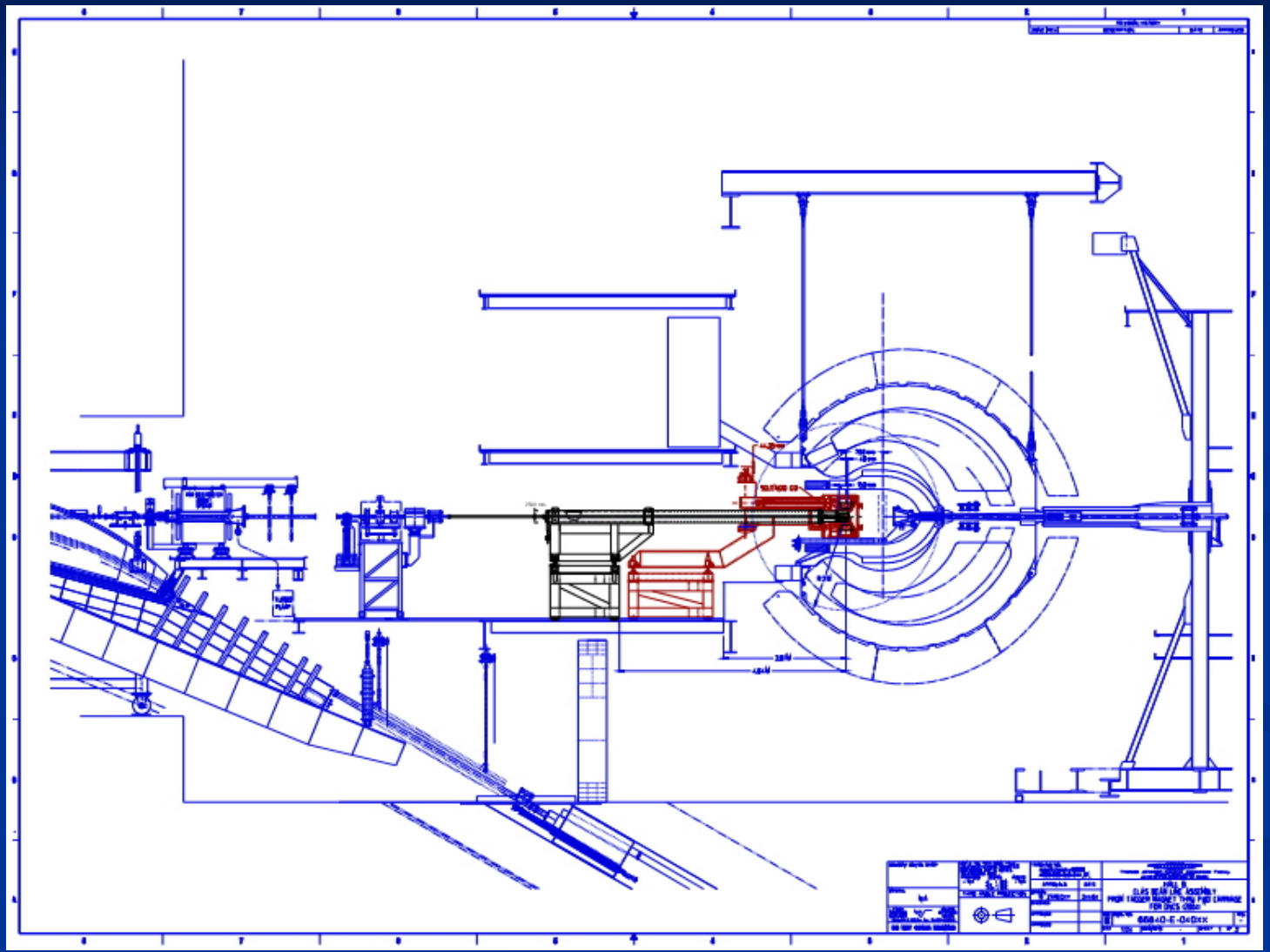
- Using ALICE TPC R/O electronics from CERN
  - Dynamic range 900:1 (up to 30 MIP energy loss)
  - 5 MHz sampling rate
- Features ALTRO chip
  - 16 channels
  - 10 bit A/D conversion
  - Baseline subtraction and zero suppression
  - Digital processing and event buffering
  - Expects positive input signal → need signal charge conversion on input
- Eight ALTRO chips per FEC → 128 input channels
- Need 32 FEC's for 4,096 readout pads
- FEC's interconnected via readout controller card
  (new version featuring USB port available to us at the end of March)

ALICE TPC Front End Card + Bus

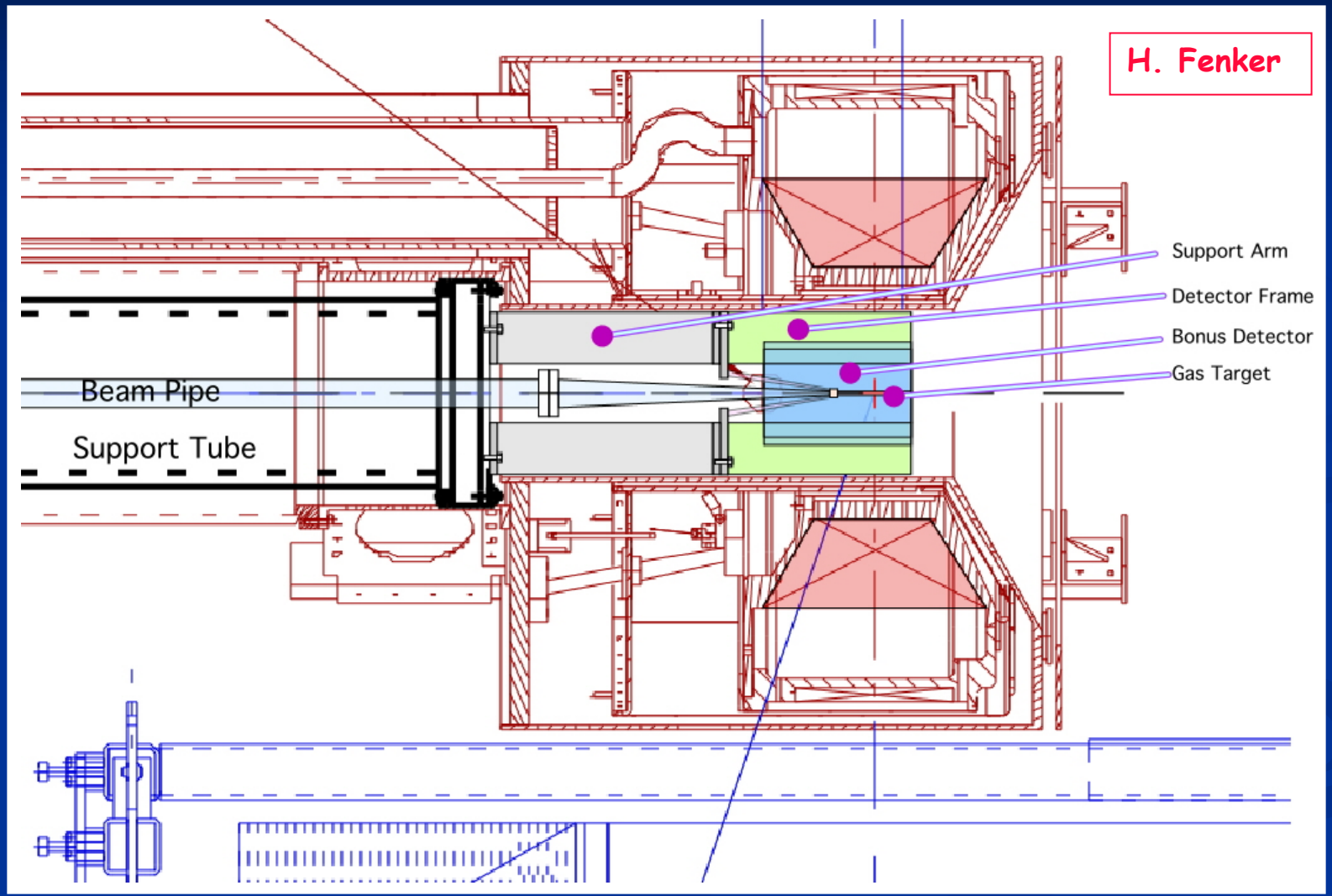
- Readout board for 128 channels
- Custom integration into CLAS
- Readout electronics can be used for TPC of different geometry



CLAS with Møller Solenoid and BoNuS



BoNuS Detector Inside Møller Solenoid



Timeline for the BoNuS Experiment

Spring 2004

- Construction and testing of prototype RTPC with test run at TUNL in April

Autumn 2004

- Ready for test run of prototype RTPC in conjunction with DVCS experiment

2005

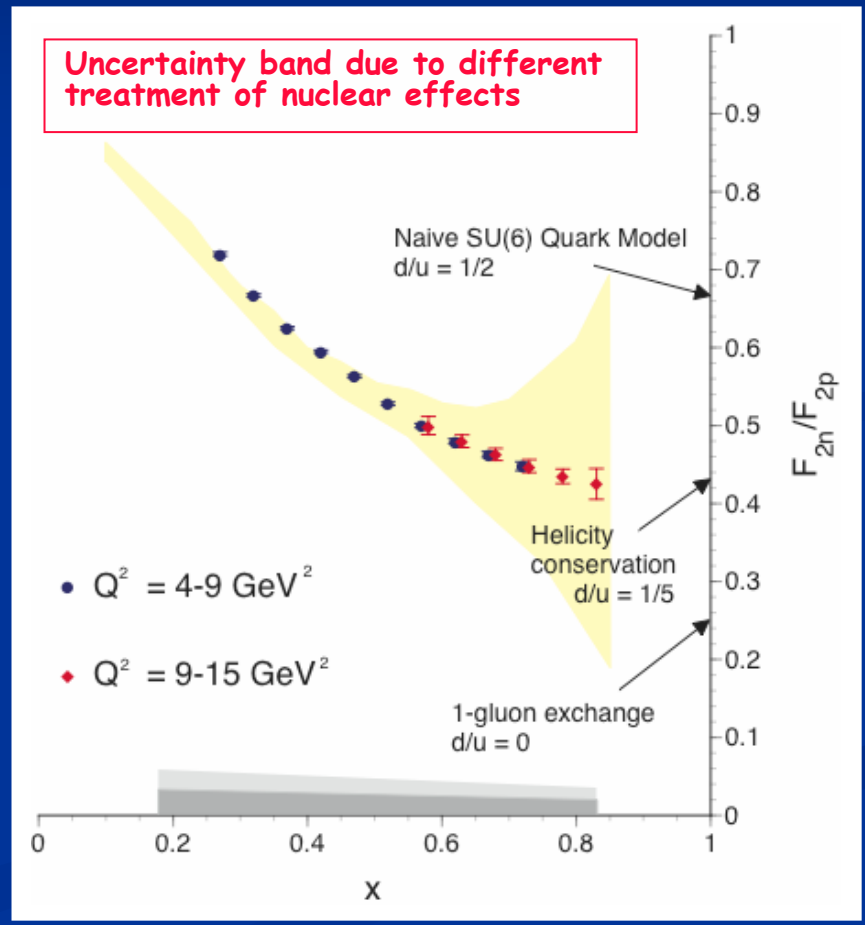
- Build RTPC to be ready in summer

Structure Functions at 11 GeV

Two measurements planned

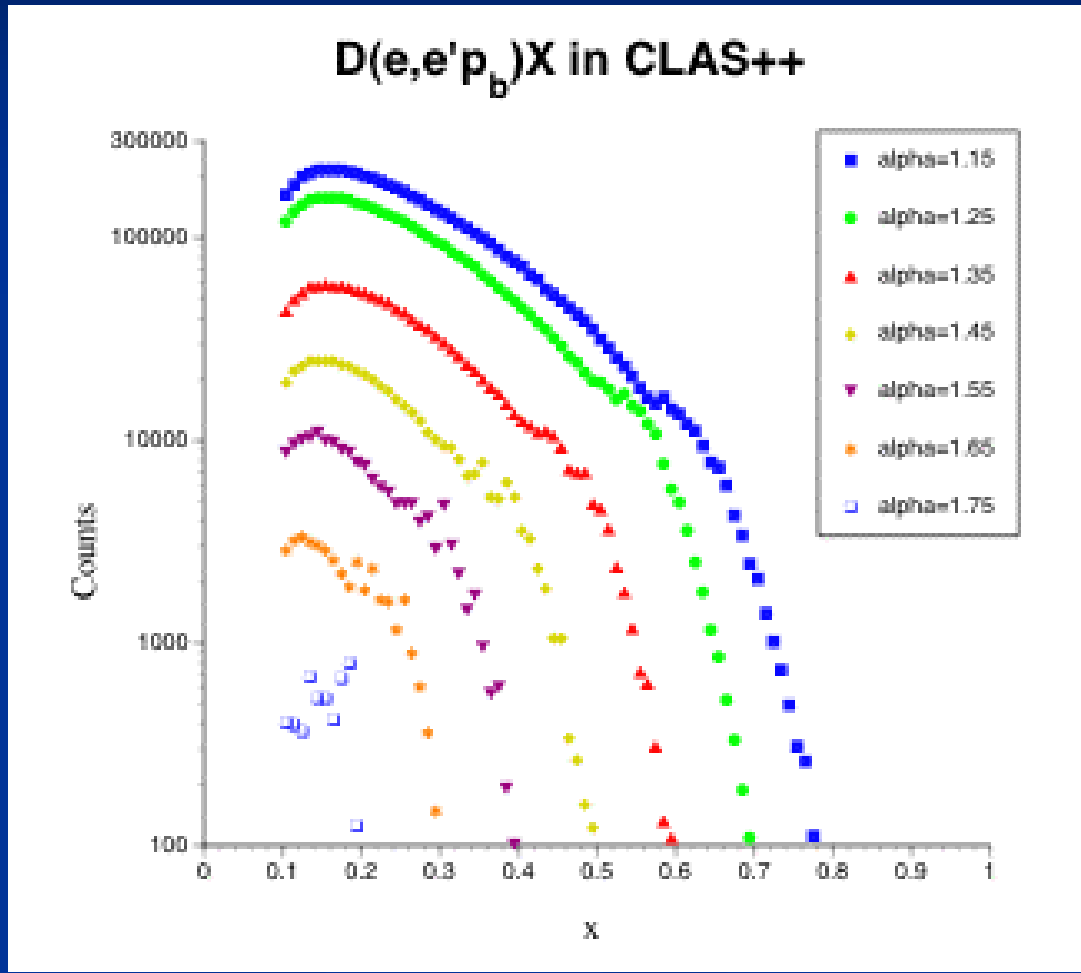
- Low momentum range
  - 70 - 100 MeV/c backward moving spectator nucleon

    (BoNuS recoil detector + CLAS++)
  - Luminosity $5 \cdot 10^{33}$ cm^{-2} sec^{-1}
  - $x_{Bj} < 0.8$
  - 5% measurement of F_2^n in 40 days
- High momentum range
  - 250 - 700 MeV/c (upgraded CLAS++)
  - Luminosity 10^{35} cm^{-2} sec^{-1}
  - Standard liquid deuterium target



Structure Functions at 11 GeV

- Cover large kinematical range electron (x_{Bj} and Q^2) and recoil proton (p_T and α_S)
- High momentum measurement
- 20 days of data taking



Neutron Structure Function at eRHIC

- Very large kinematic range
- Measure spectator proton at almost zero initial momentum (half of the deuteron momentum in EIC frame)
- Do not need to measure slow recoil protons