Precision Measurement of the neutron d_2: Towards the Electric χ_E and Magnetic χ_B Color Polarizabilities

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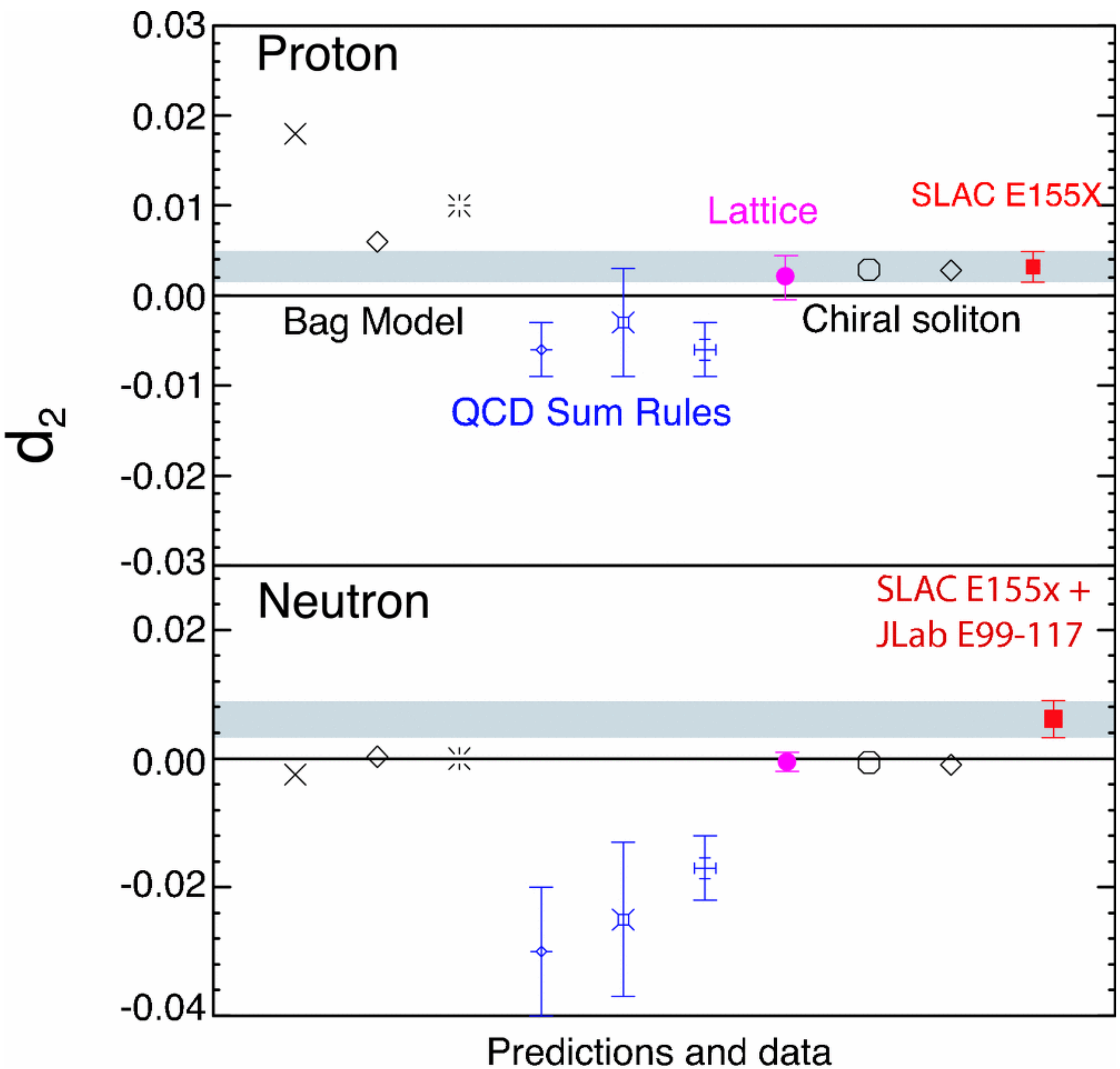
Hall A collaboration proposal

- Goals:
  - ➡ Determine the neutron d_2 at $\langle Q^2 \rangle = 3$ GeV^2

$$d_2^n(Q^2) = \int_0^1 x^2 \left[2g_1^n(x,Q^2) + 3g_2^n(x,Q^2)\right] dx$$

  - ➡ Directly measure Q^2 evolution of $g^2(x)$
- An Experiment in Hall A:
  - ➡ A polarized electron beam of 4.6, 5.7 GeV and polarized ^{3}He target
  - ➡ Measure unpolarized cross section for $^3\vec{\mathrm{He}}(\vec{e},e')$ reaction $\sigma_0^{^3\mathrm{He}}$ in conjuction with the transverse asymmetry $A_\perp^{^3\mathrm{He}}$ and the parallel asymmetry $A_\parallel^{^3\mathrm{He}}$ for $0.2 < x < 0.65$ with $2 < Q^2 < 5$ GeV^2.
- Beam Request:
  - ➡ **13** days to achieve an overall uncertainty of $\Delta d_2^n = 5 \times 10^{-4}$

Model evaluations of d_2



The proposal

- A 4.6 and 5.7 GeV polarized electron beam scattering off a polarized ^{3}He target
- Measure unpolarized cross section for $^3\vec{\mathrm{He}}(\vec{e},e')$ reaction $\sigma_0^{^3\mathrm{He}}$ in conjuction with the parallel asymmetry $A_\parallel^{^3\mathrm{He}}$ and the transverse asymmetry $A_\perp^{^3\mathrm{He}}$ for $0.23 < x < 0.65$ with $2 < Q^2 < 5$ GeV^2.
  - ➡ Asymmetries measured by BigBite at a single angle: $\theta = 45°$
  - ➡ Absolute cross sections measured by L-HRS
- Determine d_2^n using the relation

$$\begin{aligned}\tilde{d}_2(x,Q^2) &= x^2[2g_1(x,Q^2)+3g_2(x,Q^2)] \\ &= \frac{MQ^2}{4\alpha^2}\frac{x^2y^2}{(1-y)(2-y)}\sigma_0\left[\left(3\frac{1+(1-y)\cos\theta}{(1-y)\sin\theta}+\frac{4}{y}\tan\frac{\theta}{2}\right)A_\perp+\left(\frac{4}{y}-3\right)A_\parallel\right]\end{aligned}$$

where,

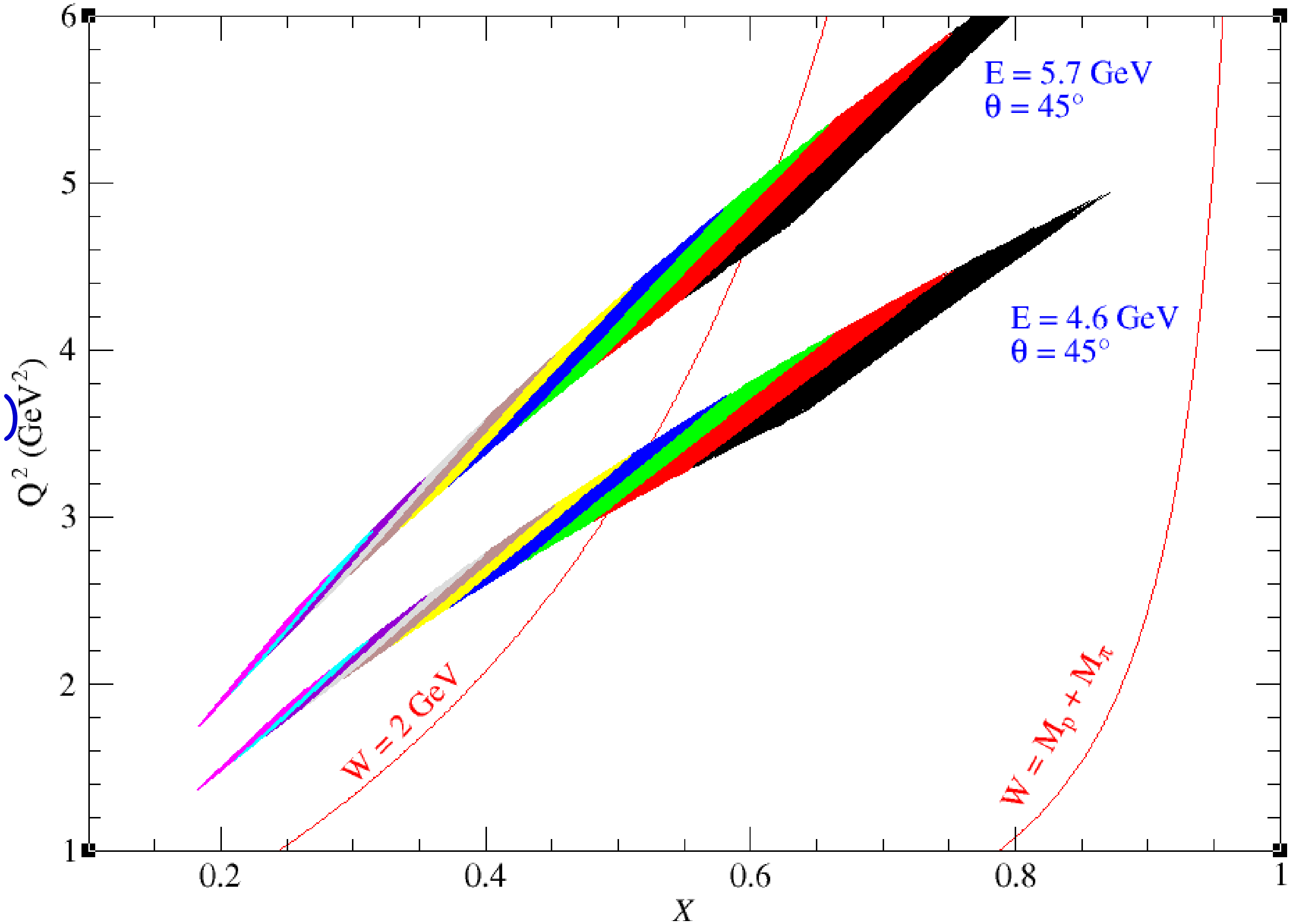
$$A_\perp = \frac{\sigma^{\downarrow\Rightarrow}-\sigma^{\uparrow\Rightarrow}}{2\sigma_0} \qquad A_\parallel = \frac{\sigma^{\downarrow\Uparrow}-\sigma^{\uparrow\Uparrow}}{2\sigma_0}$$

$$A_\perp^{^3He} = \frac{\Delta_\perp}{P_bP_t\cos\phi} \qquad A_\parallel^{^3He} = \frac{\Delta_\parallel}{P_bP_t}$$

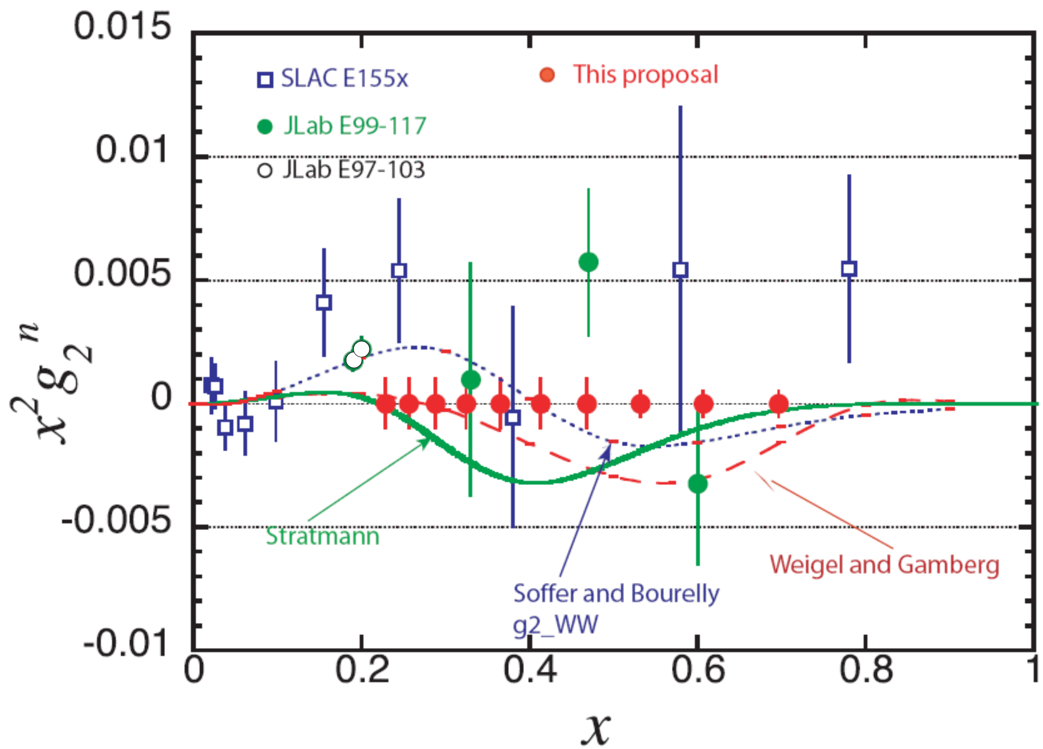
$$\Delta_\perp = \frac{(N^{\uparrow\Rightarrow}-N^{\uparrow\Rightarrow})}{(N^{\uparrow\Rightarrow}+N^{\uparrow\Rightarrow})} \qquad \Delta_\parallel = \frac{(N^{\downarrow\Uparrow}-N^{\uparrow\Uparrow})}{(N^{\downarrow\Uparrow}+N^{\uparrow\Uparrow})}$$

Kinematics of the proposed measurement

- Two beam energies
  4.6 and 5.7 GeV
  (4 pass, 5 pass)
- BigBite fixed at single scattering angle (θ=45°)
  (data divided into 10 bins during analysis)
- Avoid resonance region as much as possible.

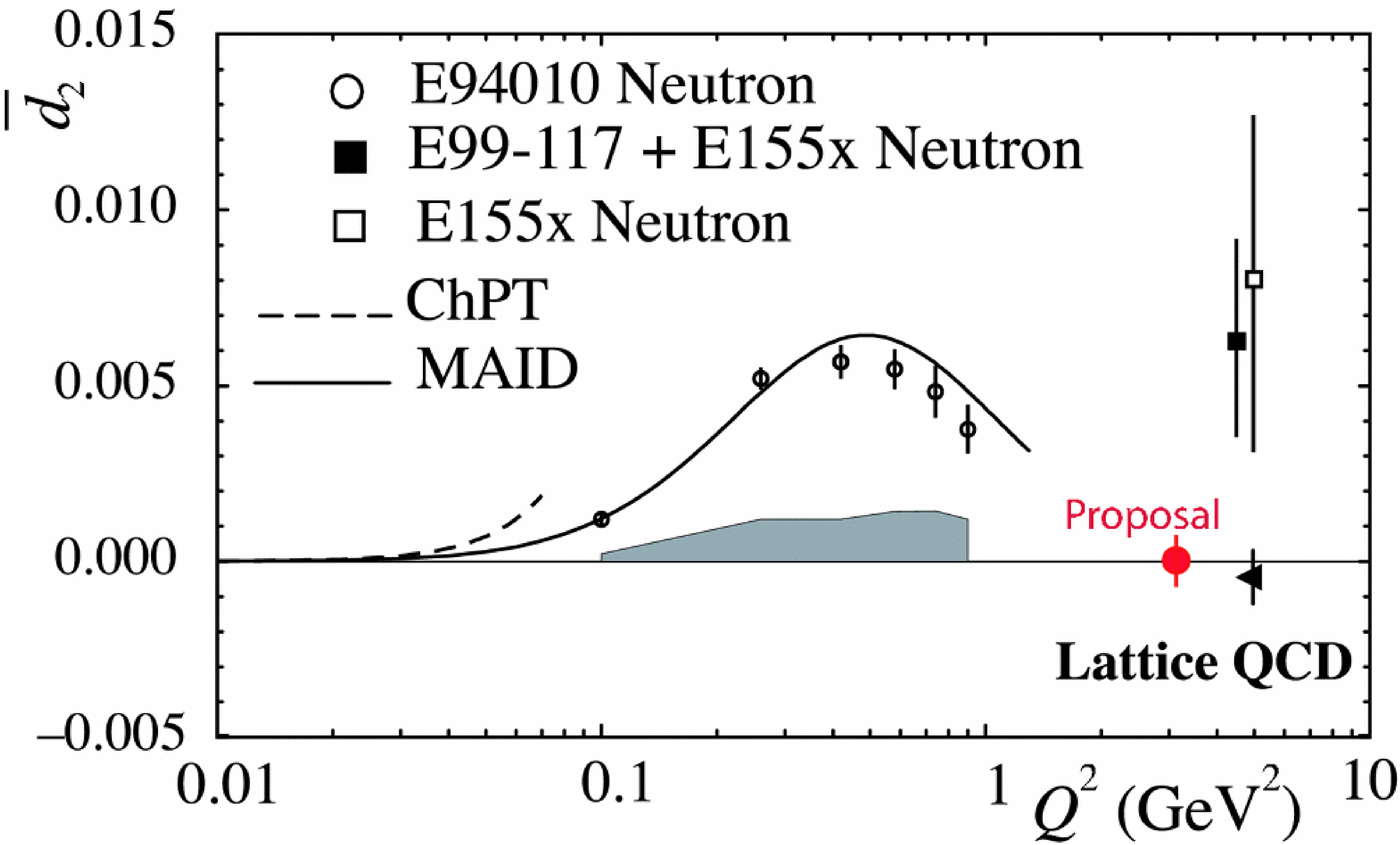


Projected $x^2g_2(x,Q^2)$ results

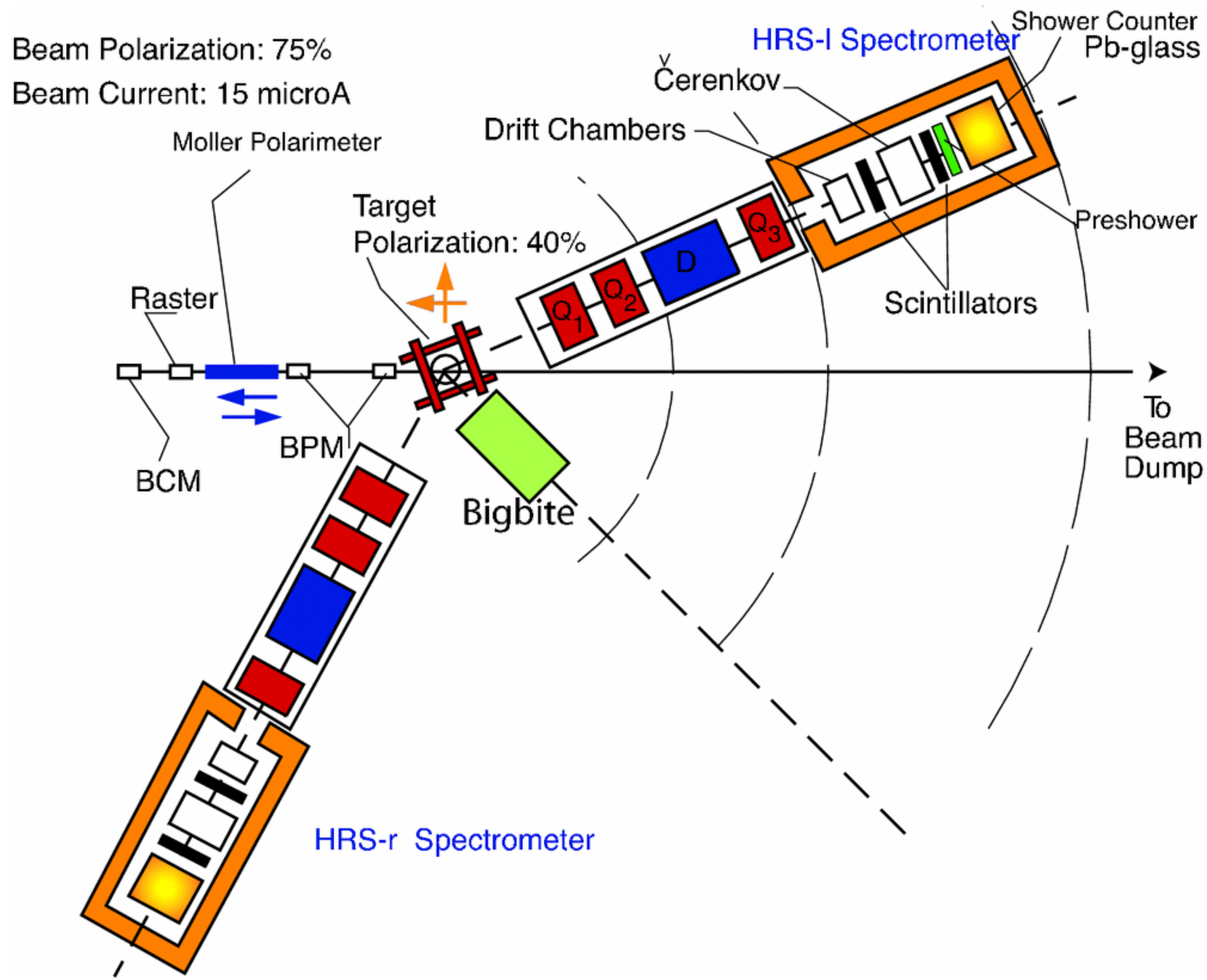


- g_2 for ^{3}He is extracted directly from L and T spin-dependent cross sections measurements within the same experiment.
- The nuclear corrections will be applied to the moments not to the structure functions.
- SLAC E155x g_2 data points at high x are evolved from Q^2 as large as 16 GeV^2 to 5 GeV^2

Expected Error on d_2



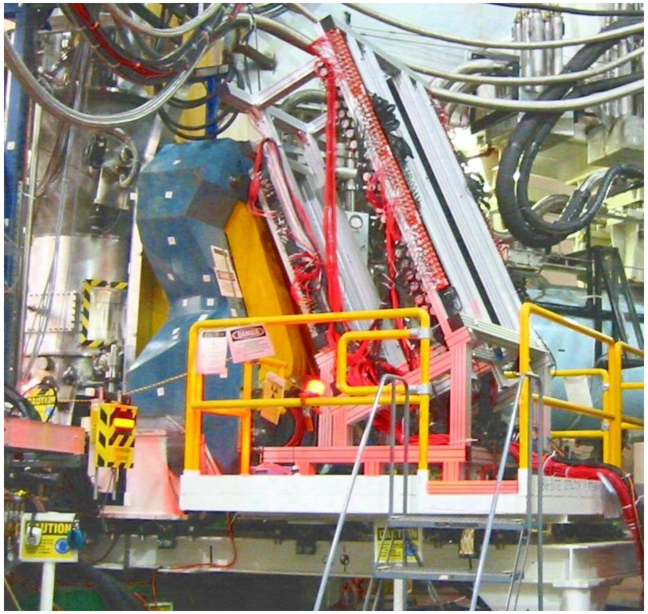
Floor configuration for this proposal

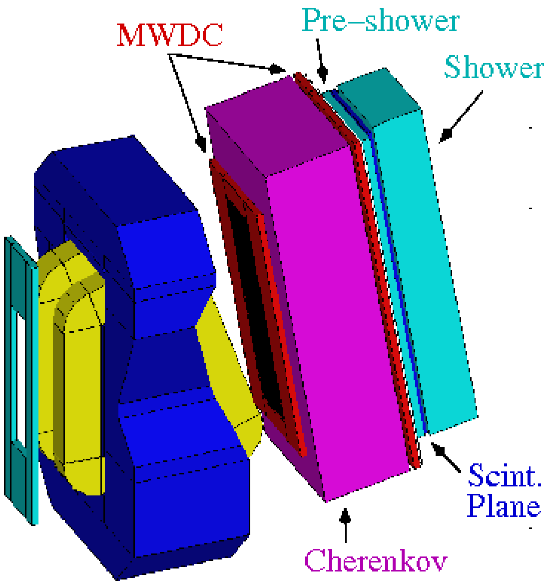


Target Cell

- Polarized ^{3}He Target
  - 40 cm glass cell, “standard design”
  - require longitudinal and transverse (in-plane) polarization
- Target chamber considerations
  - Field clamp
  - Addition of GeN tungsten collimator to shield BB from target windows
  - Exit windows in target chamber for
    - BigBite at 45 degrees on RHS
    - HRS at 45 degrees on LHS

BigBite Configuration





- non-focusing, large acceptance, open geometry
- $\Delta p/p$ = 1 – 1.5% (@ 1.2 T) $\sigma(W)$ = 50 MeV
- angular resolution 1.5 mr, extended target resolution 6 mm
- large solid angle: ~64 msr
- detector package
  - ➡ 2 MWDCs, segmented trigger, Pb-glass shower
  - ➡ Gas Cherenkov (new)

BigBite Considerations

- New frame?
  - Not on critical path, but will impact final design
- Optimize DAQ for speed (want >2 kHz!)
  - Replace FB hardware with VME
  - Pay attention to tuning read-out code
- Examine 'real-life' performance of GeN trigger after data arrive in a few months
  - Can we improve it?
    - modify front-end logic?
    - identify optimal HW thresholds on shower/pre-shower for our kinematics
  - Pay attention to experience gathered during GeN
    - consider getting some students familiar with the BB analyzer (much work can be done with the GeN data)

Cherenkov Design Parameters

- Dimensions: 200cm x 60cm x 60cm
  - ➡ located in gap between first and second wire chamber with minimal modifications to existing BigBite frame
- Radiator gas: C_4F_{10} (or Freon12)
  - ➡ n = 1.0015 (1.0011)
  - ➡ π threshold: 2.51 GeV/c (2.98 GeV/c)
  - ➡ ~28 (18) photo-electrons / 40 cm electron track
    - Quartz PMT (Photonis XP4318 or equiv.)
    - mirror reflectivity: ~90%, 10% loss at PMT-gas interface
  - ➡ >99% efficient with 4-5 p.e. threshold
    - negl. pion contamination

      minimum π/e rejection ratio 1000:1 online

Background Rates

- MC simulation by Degtyarenko et al. (tested in Halls A and C)
- Online cuts include:
  - BB magnet sweeps particles with p < 200 MeV/c
  - GEN BB trigger: shower+pre-shower+scint
    - provide ~10:1 online hadron rejection (or better)
  - ~550—600 MeV threshold on shower
  - 4—5 p.e. threshold on Cherenkov
    - heavily suppress random background
    - negl. pion contamination (~100 Hz knock-ons)
- Total estimated trigger rate (GEN trig + Cherenkov): 2—5 kHz

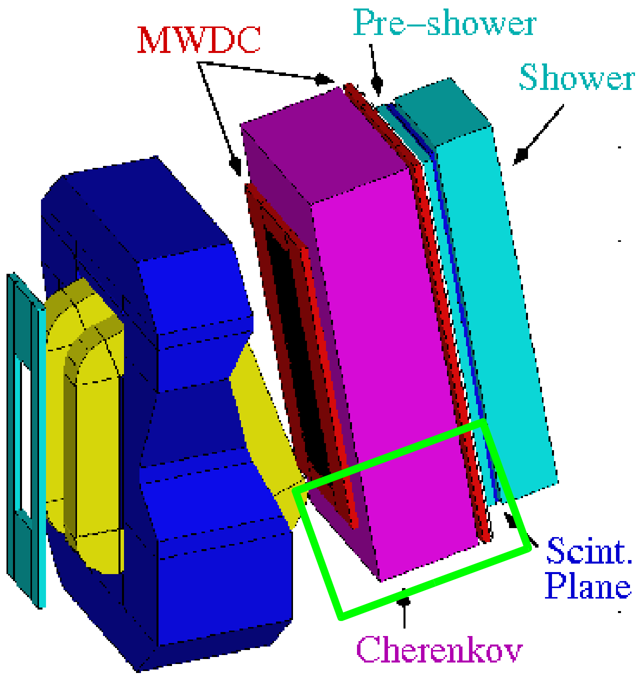
Online triggers

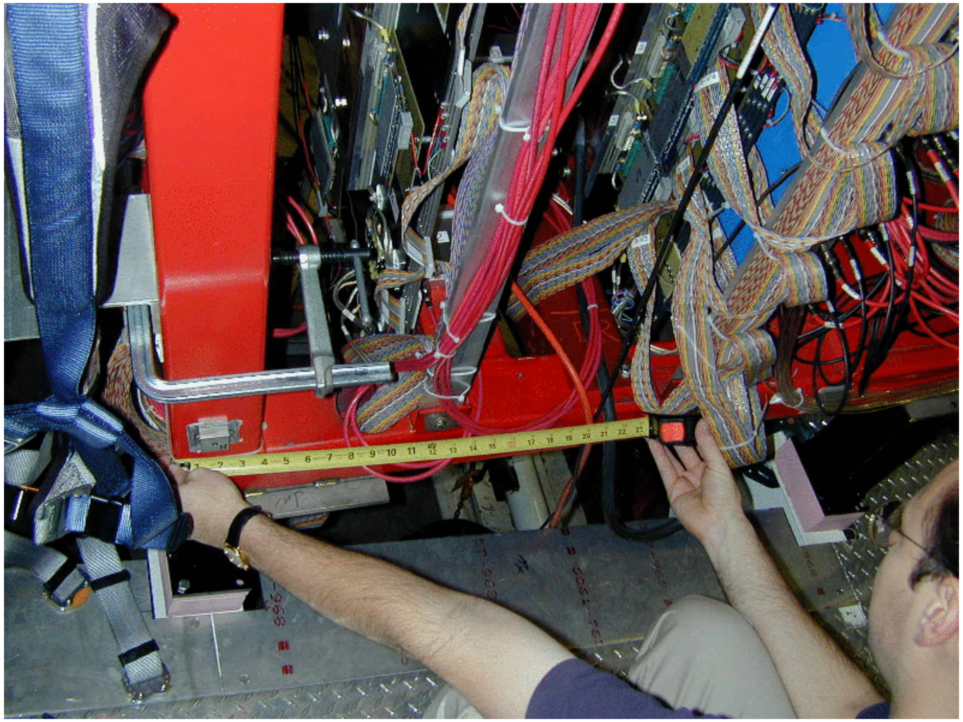
e-	2-5 kHz
e+	<1 kHz

Removed via online cuts

π-	90 kHz
π+	90 kHz
p	50 kHz
n	50 kHz

Cherenkov Construction (prelim.)

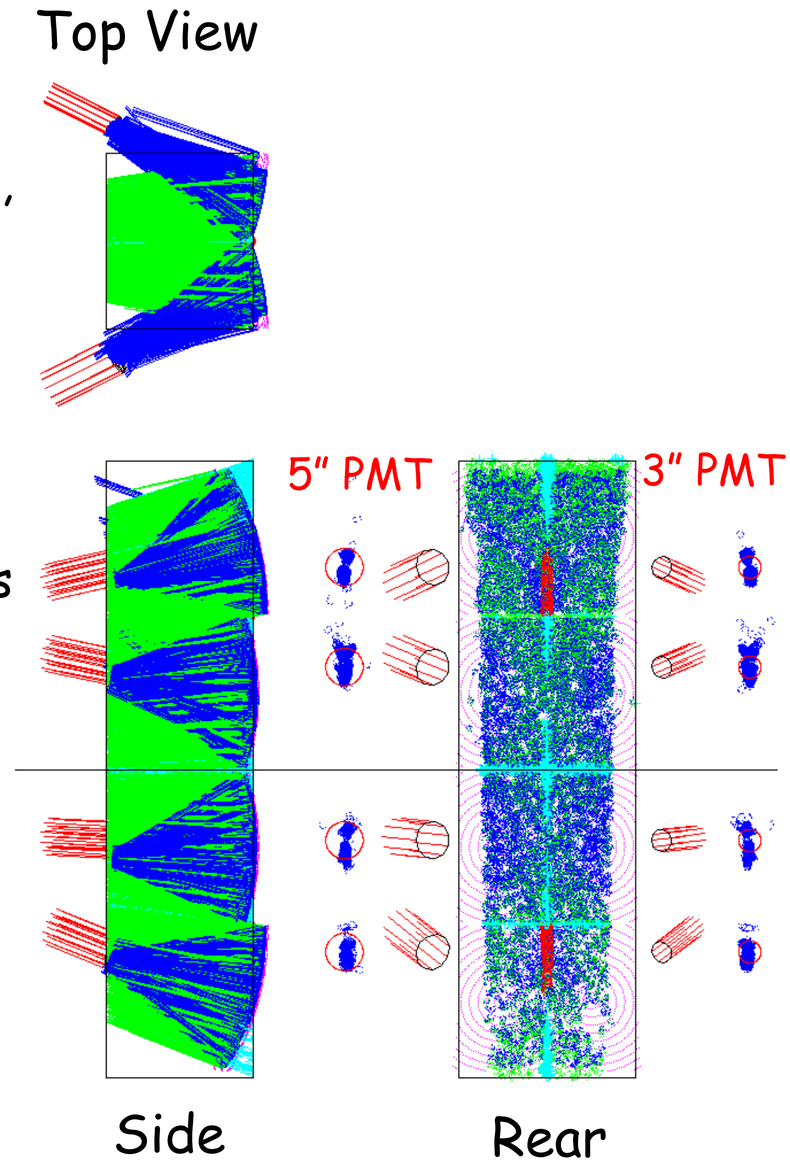




- Fringe field at Cherenkov PMTs expected to be ~few Gauss
- Frame gap: 60 cm is nominal, only ~50 cm is useable in current frame
  - ➡ Shorter path would still work well, assume 50 cm gap for now
    - (how certain is new frame?)

Cherenkov Construction (prelim.)

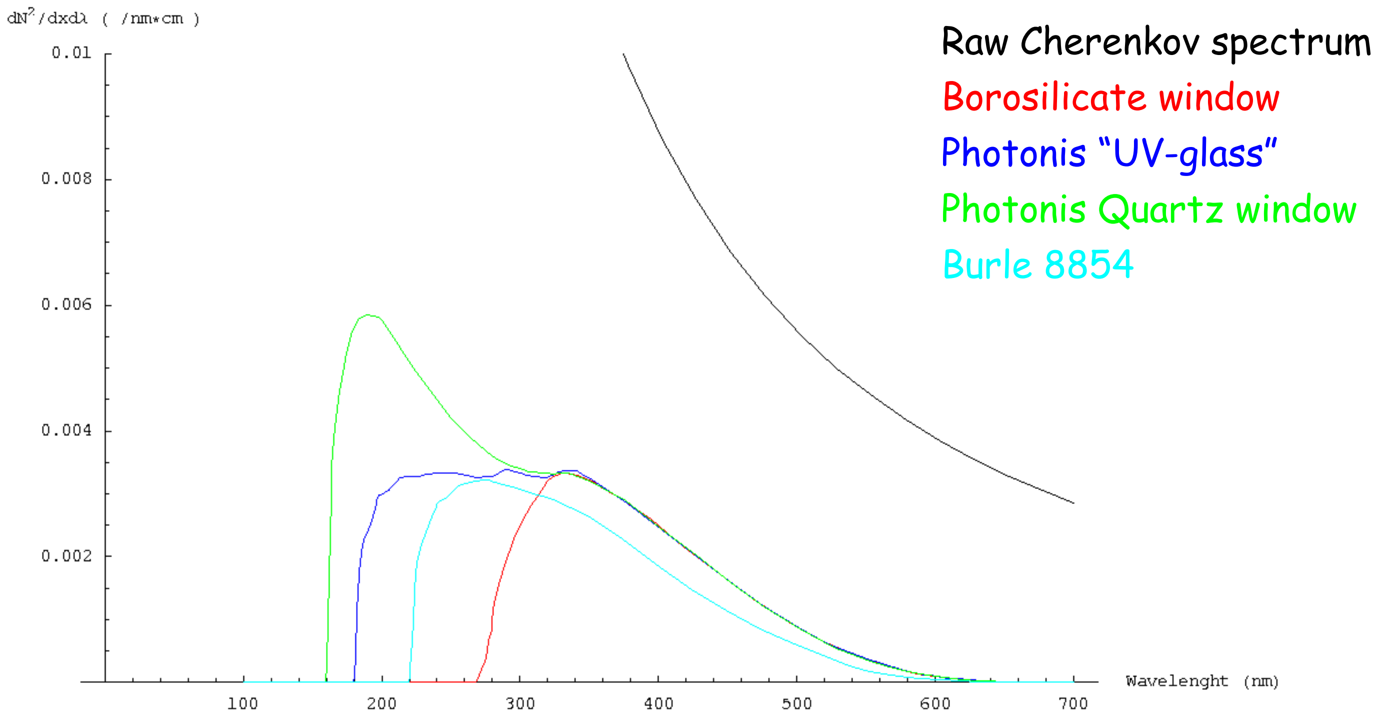
- Minimal design has 8 mirrors in 2x4 grid
- Electron paths (not shown) from MC simulation using scattered electrons of 0.6, 1.0 and 1.4 GeV from extended target
  - ➡ Cherenkov photons are green
  - ➡ reflected rays are blue
- Can capture roughly 90-95% of the rays in 5″ PMTs with 'simple design'
  - ➡ total incident electron angle envelope is inconveniently large due to BB momentum acceptance
- Possible solutions:
  - ➡ increase segmentation (2x5, 2x6?)
  - ➡ two-bounce design?
    - second set on upstream edge can focus vertically
  - ➡ Winston cones



Cherenkov Construction (prelim.)

- Significant overlap with Cherenkov for SANE in Hall C
  - Mechanical design of mirror mounts
  - Already have samples of some components to work with (3" PMTs, mirror mounts)
  - In contact with several mirror manufacturers (Glass Mountain, SESO, others)
    - smaller BigBite mirrors should allow spherical design (cheaper, simpler to manufacture)
  - Leverage existing relationships with engineers, machine shops, etc.
- Components needed:
  - PMTs, mirrors, mirror mounts, gas box
    - (overlap with SANE detector)
- Gas handling system (leverage experience from Hall B)
- C4F10 vendor (pester Hall B again)
- DAQ hardware (only 8 channels for Cherenkov)

Photo-electrons over 40cm of C_4F_{10}

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n[55]:= len = 40;

n[56]:= NIntegrate[{dN[λ], dN[λ] *PEboro2[λ], dN[λ] *PEuv2[λ], dN[λ] *PEsilica2[λ], dN[λ] *PEburle2[λ]},
        {λ, 300, 650}, Method → QuasiMonteCarlo] *len * .9 * .9

ut[56]= {81.399, 16.4312, 16.7439, 16.7129, 12.8788}

n[57]:= NIntegrate[{dN[λ], dN[λ] *PEboro2[λ], dN[λ] *PEuv2[λ], dN[λ] *PEsilica2[λ], dN[λ] *PEburle2[λ]},
        {λ, 200, 650}, Method → QuasiMonteCarlo] *len * .9 * .9

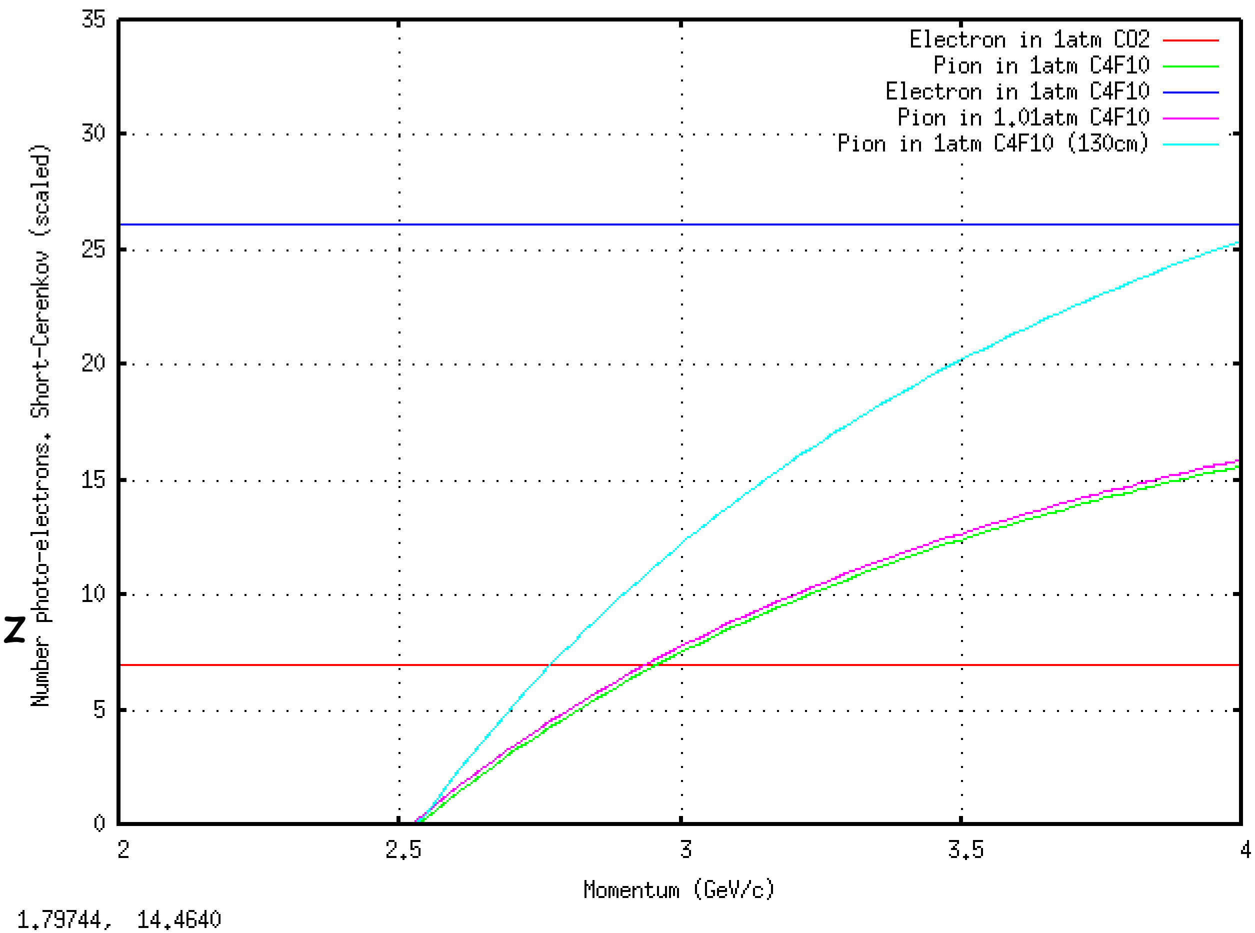
ut[57]= {156.984, 17.809, 27.3785, 30.7759, 20.2527}

n[58]:= NIntegrate[{dN[λ], dN[λ] *PEboro2[λ], dN[λ] *PEuv2[λ], dN[λ] *PEsilica2[λ], dN[λ] *PEburle2[λ]},
        {λ, 165, 650}, Method → QuasiMonteCarlo] *len * .9 * .9

ut[58]= {205.083, 17.809, 28.816, 36.9273, 20.2527}
```

Photo-electrons estimated from short HRS Cherenkov

- Rob F. took the observed p.e. yield for the short HRS Cherenkov using CO2 (red line) and scaled it by the appropriate factor for C4F10 (blue line)
- Path length is 80 cm
- PMTs are Photonis ??? (probably 3", not quartz windows)
- Factor of 2 lower than what's predicted by 'theory'
  - PMT response?
  - Optics?



Summary

- We propose to precisely measure the neutron d_2^n at $Q^2 \approx 3.0$ GeV^2.
  - ➡ Determine asymmetries in conjunction with an absolute cross section measurement over the region ($0.23 < x < 0.65$)
  - ➡ Also, measure Q^2 evolution of $x^2\bar{g}_2$ over the same x region

- Provide a benchmark test for theory (lattice QCD).
  - ➡ we can achieve a overall uncertainty of $\Delta d_2^n = 5 \times 10^{-4}$
    - four times better then existing world average!
- Dramatically improve our knowledge of $g_2^n(x)$
  - ➡ double the data points for $x > 0.2$, all with better precision

- Utilize standard Hall A equipment with one addition:
  - ➡ new Gas Cerenkov detector for BigBite

We request

- 13 days of polarized beam divided between 4.6 and 5.7 GeV.
  - ➡ 244 hours of transverse settings, 16 hours of longitudinal settings, and 48 hours of overhead and calibration.