Quark – Gluon correlations and Color Polarizabilities in the Nucleon

A precision measurement of the neutron d_2

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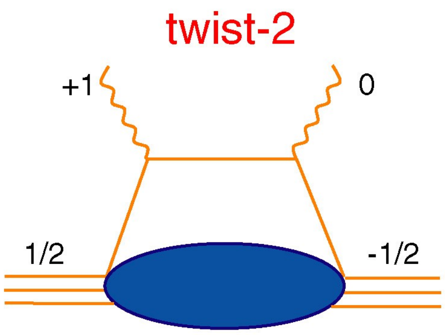
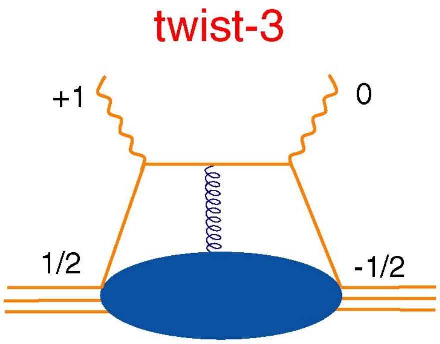
g_2 and Quark-Gluon Correlations



Carry one unit of orbital angular momentum

QCD allows the helicity exchange to occur in two principle ways



Couple to a gluon

$$g_2(x,Q^2) = g_2^{WW}(x,Q^2) + \bar{g}_2(x,Q^2)$$

- a twist-2 term (Wandzura & Wilczek, 1977):

$$g_2^{WW}(x,Q^2) = -g_1(x,Q^2) + \int_x^1 g_1(y,Q^2)\frac{dy}{y}$$

- a twist-3 term with a suppressed twist-2 piece (Cortes, Pire & Ralston, 92):

$$\bar{g}_2(x,Q^2) = -\int_x^1 \frac{\partial}{\partial y}\left(\frac{m_q}{M}h_T(y,Q^2) + \xi(y,Q^2)\right)\frac{dy}{y}$$

transversity → h_T; quark-gluon correlation → ξ

Moments of Structure Functions (continued)

$$\mu_4(Q^2) = \frac{M^2}{9}\left[a_2(Q^2) + 4d_2(Q^2) + 4f_2(Q^2)\right]$$

Twist - 2 (TMC) Twist - 3 Twist -4

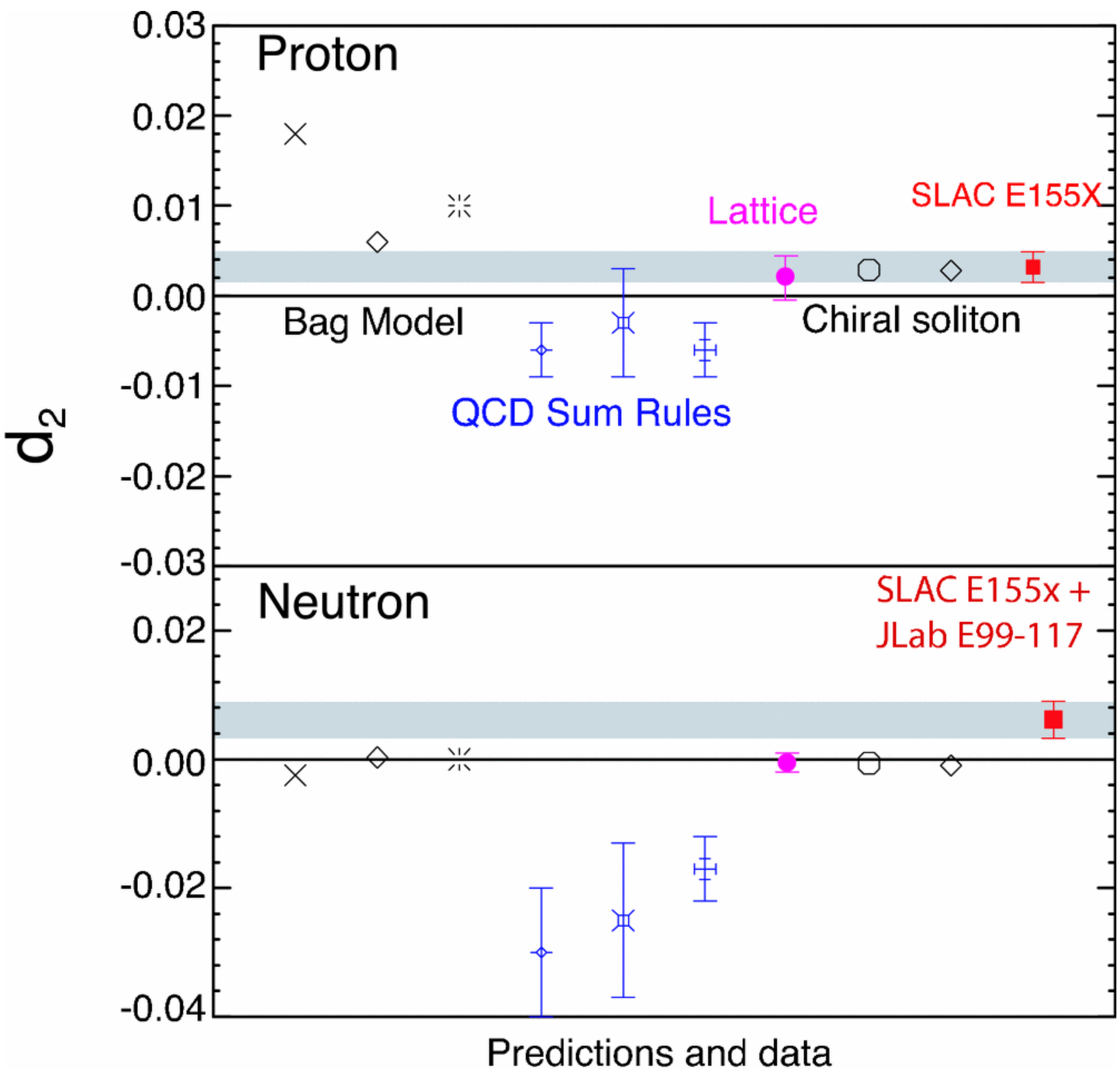
where a_2, d_2 and f_2 are higher moments of g_1 and g_2

e.g. $$d_2(Q^2) = \int_0^1 x^2[2g_1(x,Q^2) + 3g_2(x,Q^2)]dx = 3\int_0^1 x^2\,\overline{g_2}(x,Q^2)dx$$

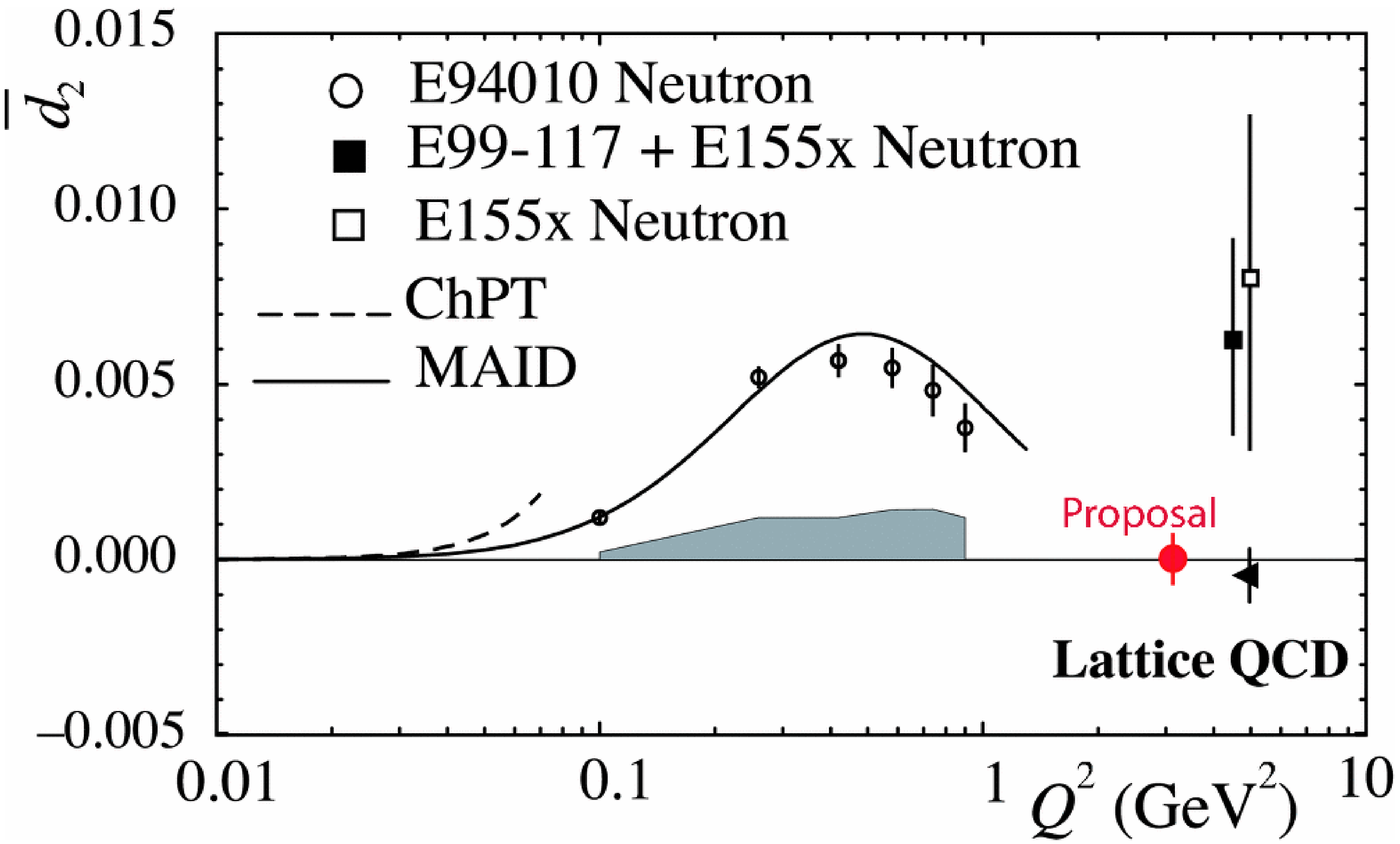
$$a_2(Q^2) = \int_0^1 x^2 g_1(x,Q^2)\,dx$$

- To extract f_2, d_2 needs to be determined first.
- Both d_2 and f_2 are required to determine the color polarizabilities

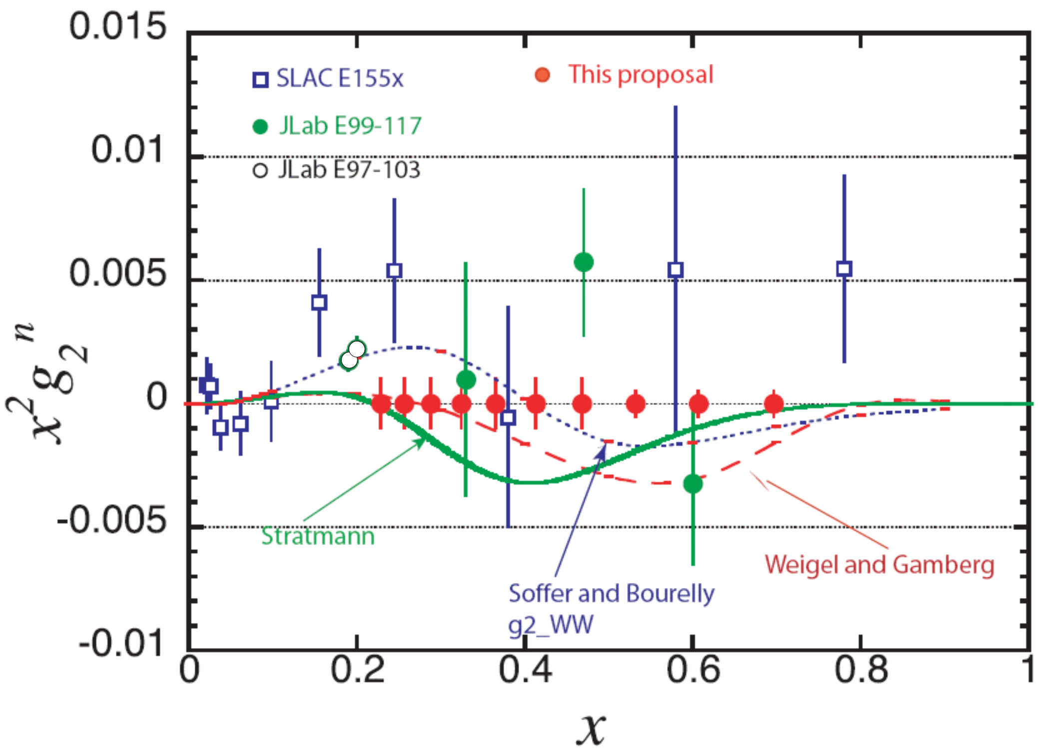
Model evaluations of d_2



Expected Error on d_2



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



- g_2 for ^{3}He is extracted directly from L and T spin-dependent cross section 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

The Experiment

- A 4.7 and 5.9 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 conjunction 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,

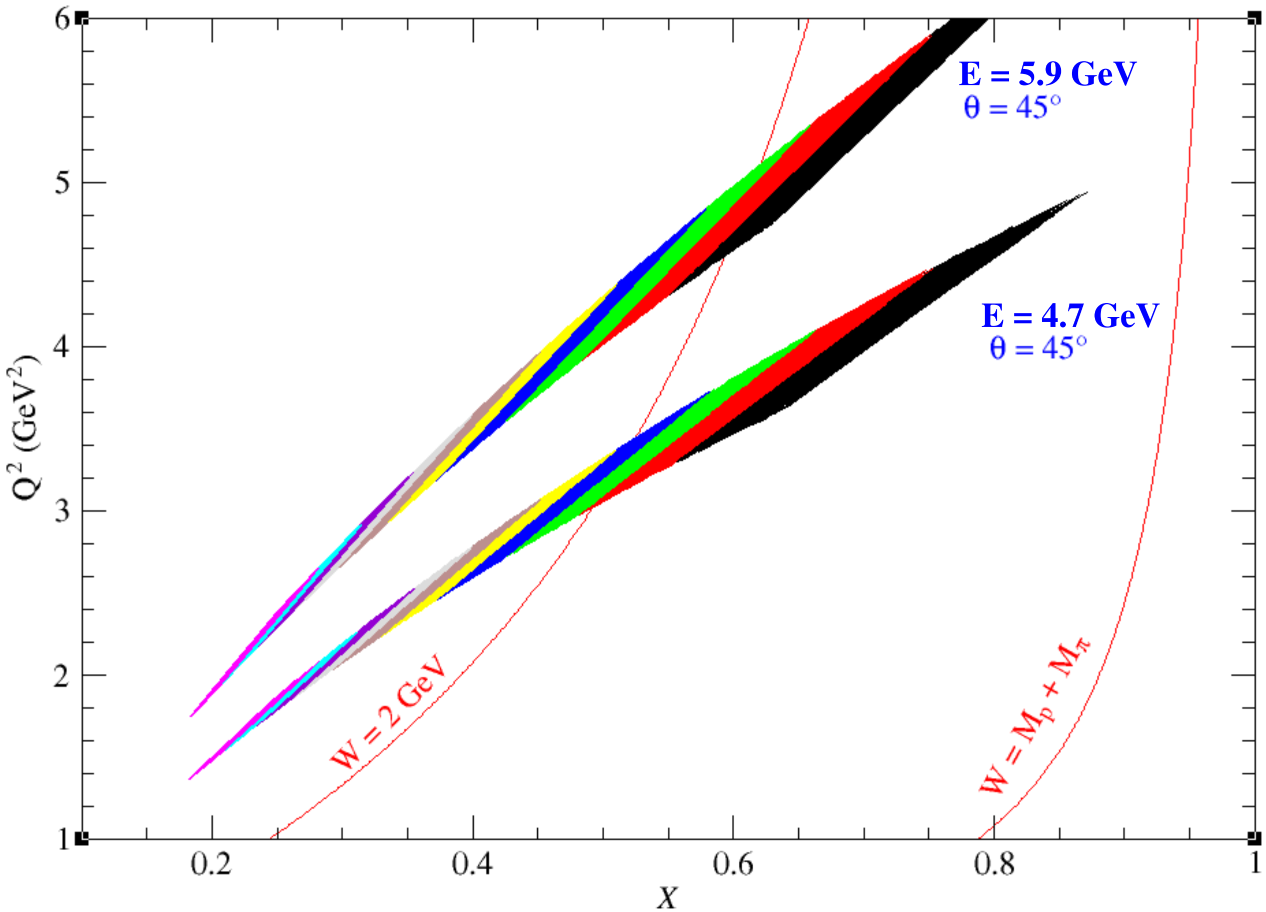
$$A_\perp = \frac{\sigma^{\downarrow\Rightarrow}-\sigma^{\uparrow\Rightarrow}}{2\sigma_0} \qquad A_\parallel = \frac{\sigma^{\downarrow\Uparrow}-\sigma^{\uparrow\Uparrow}}{2\sigma_0}$$

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

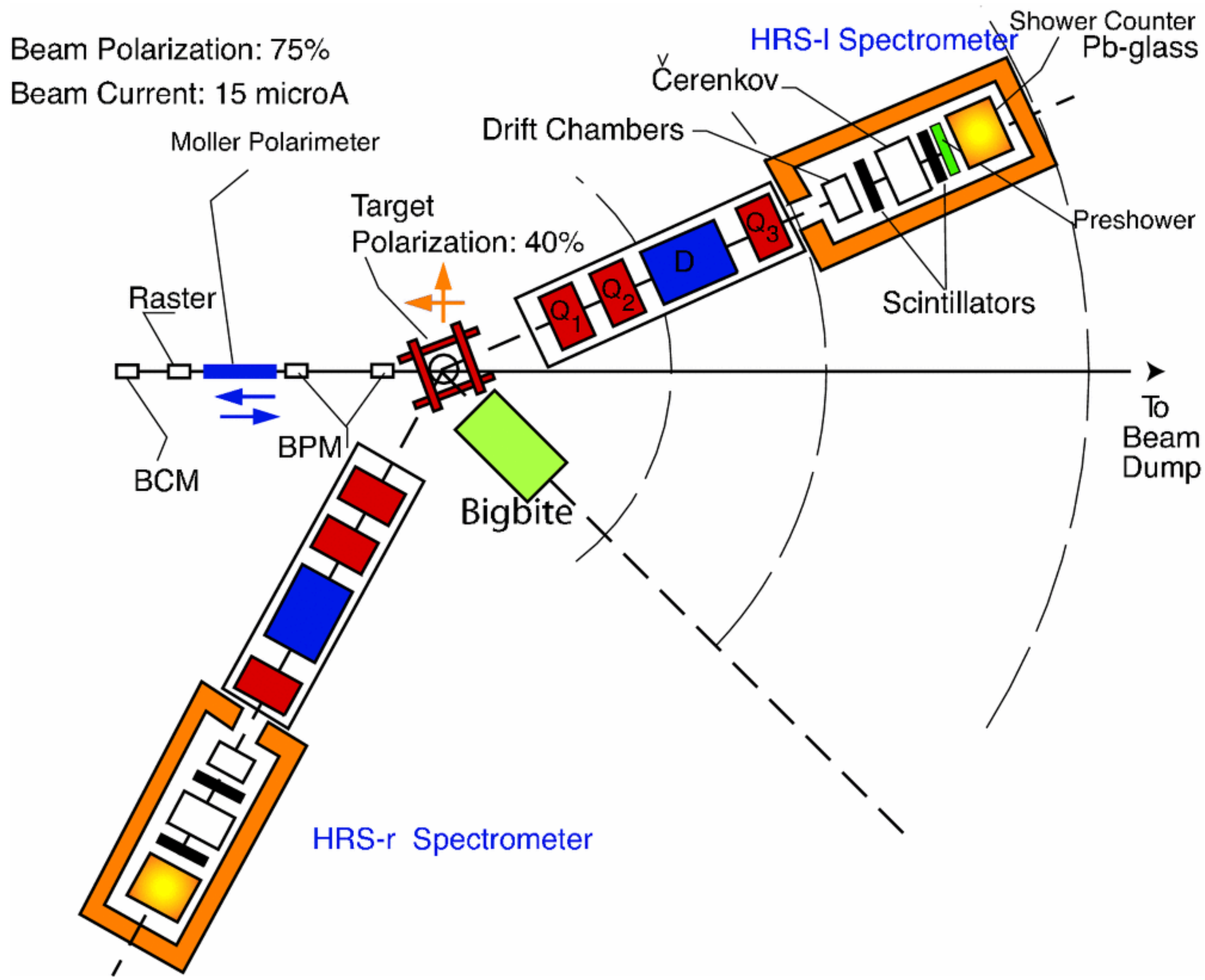
$$\Delta_\perp = \frac{(N^{\uparrow\Rightarrow}-N^{\uparrow\Rightarrow})}{(N^{\uparrow\Rightarrow}+N^{\uparrow\Rightarrow})} \qquad \Delta_\parallel = \frac{(N^{\downarrow\Uparrow}-N^{\uparrow\Uparrow})}{(N^{\downarrow\Uparrow}+N^{\uparrow\Uparrow})}$$

Kinematics of the measurement

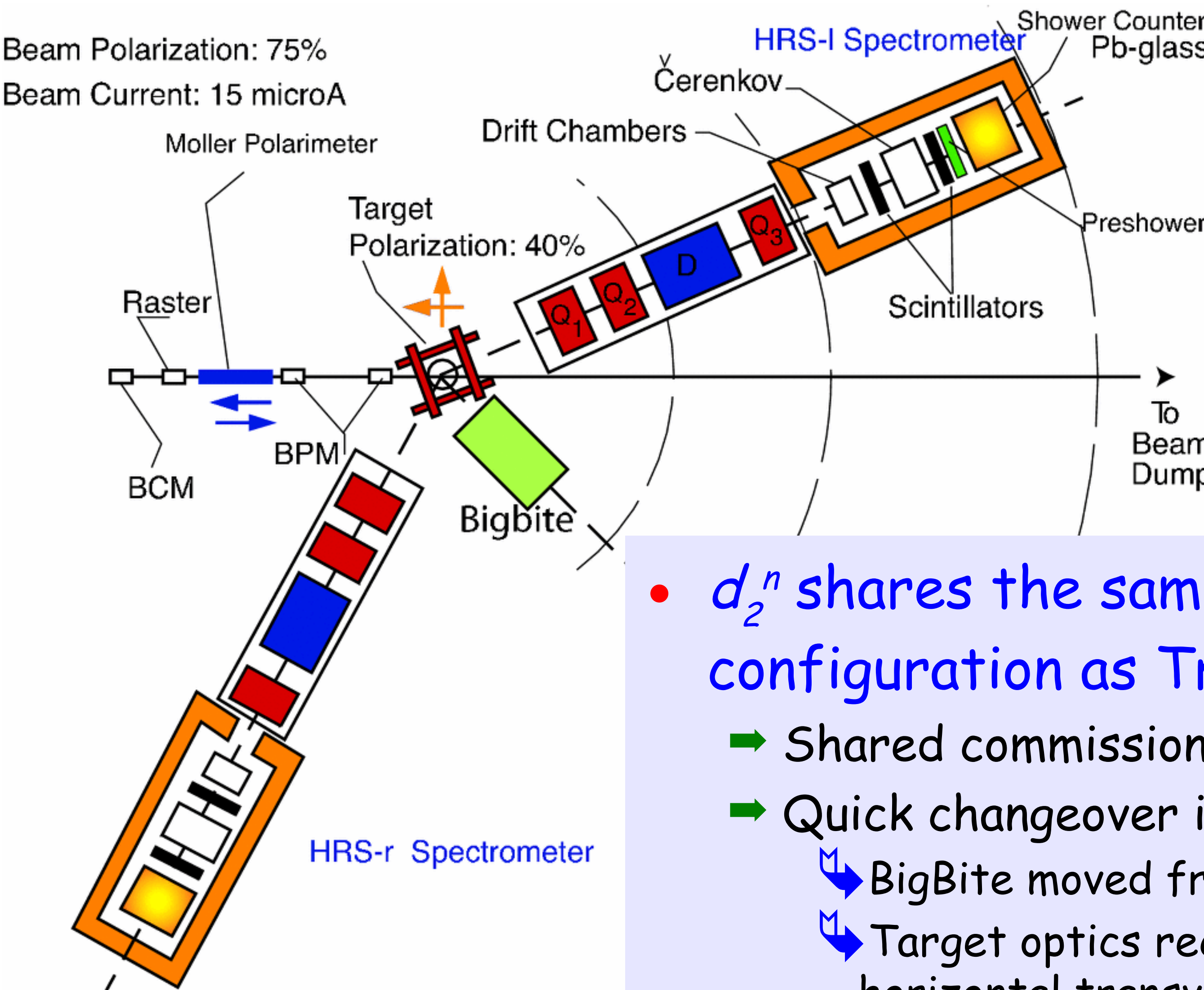
- Two beam energies
  4.7 and 5.9 GeV
  (4 pass, 5 pass)
- BigBite fixed at single scattering angle (θ=45°)
  (data divided into 10 bins during analysis)
- Avoid resonance region as much as possible.



Floor configuration for d_2^n

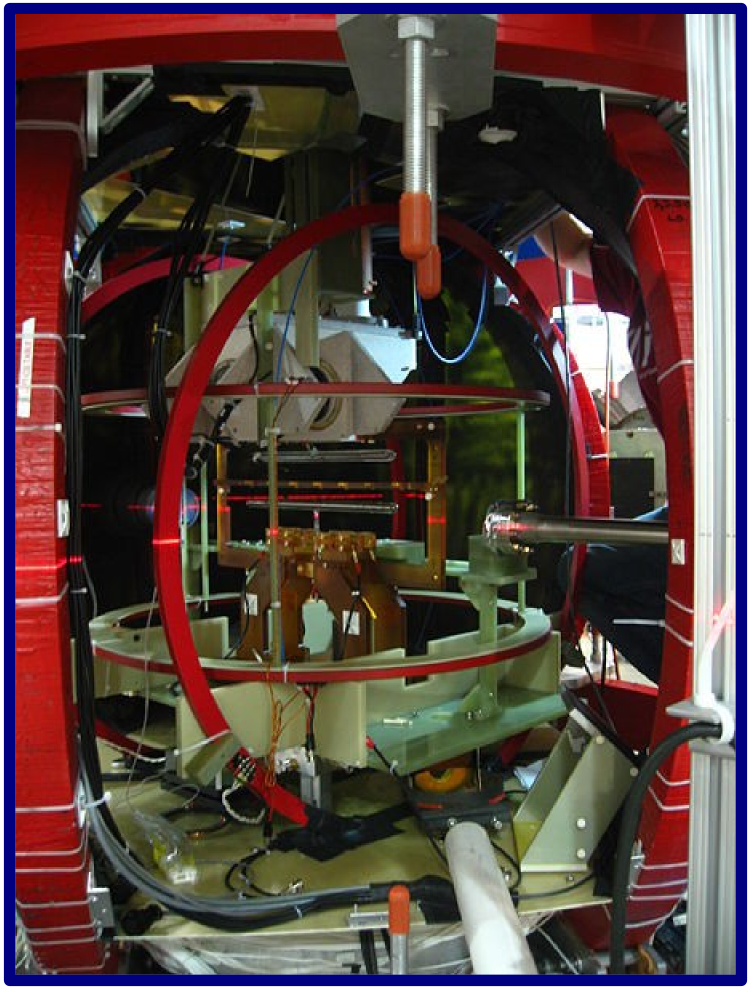


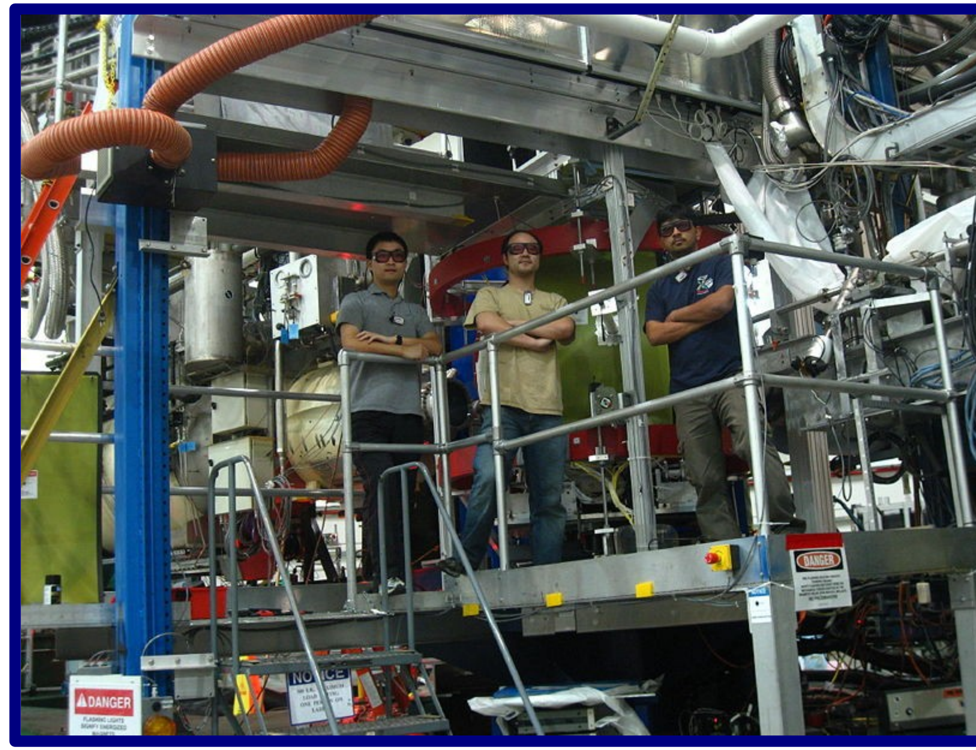
Floor configuration for d_2^n



- d_2^n shares the same detector configuration as Transversity.
  - Shared commissioning in Nov.
  - Quick changeover in Feb. 2009
    - BigBite moved from 30° to 45°
    - Target optics reconfigured to allow horizontal transverse and longitudinal polarization

Pol ^{3}He Target Commissioning





- *It Works!*

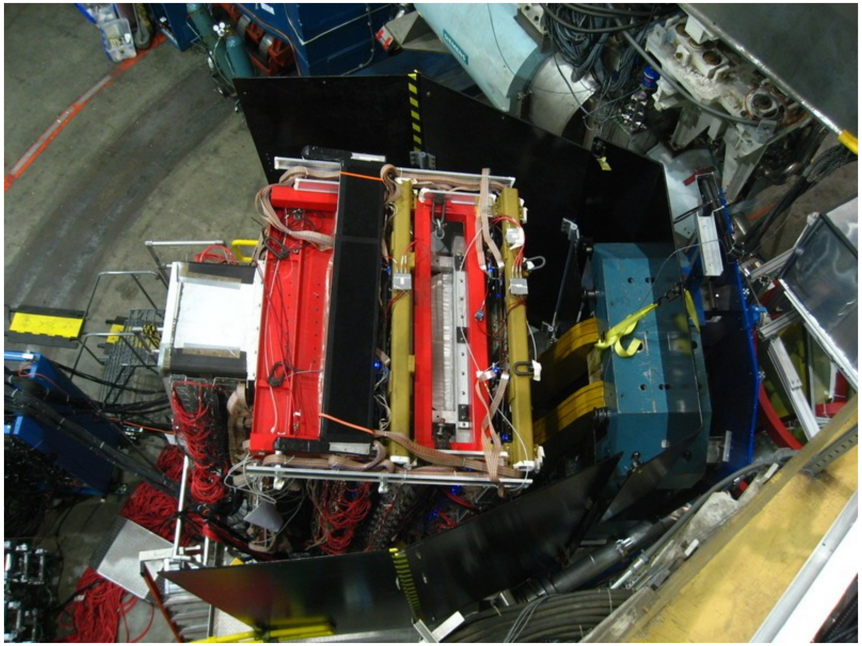
(Yi's talk has details.)

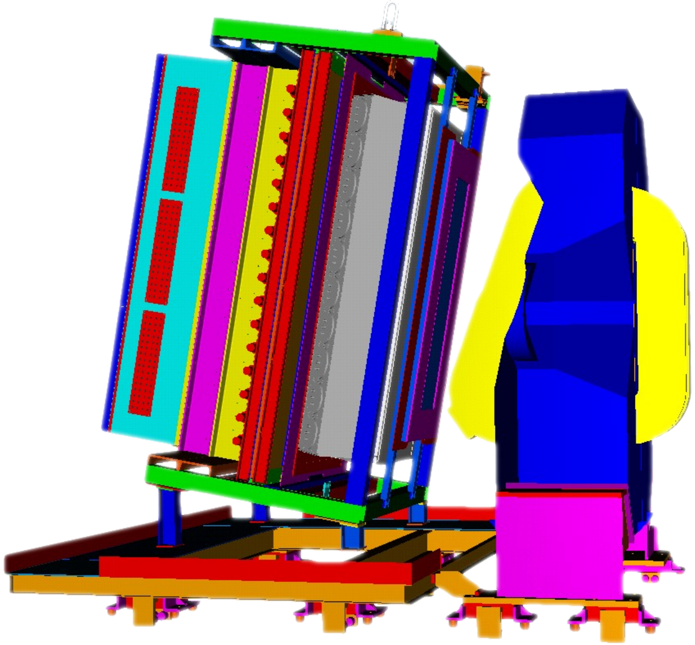
LHRS Commissioning

- RICH (not used for d_2^n)
- S1 scintillators
- Gas Cerenkov
- S2M scintillators
- Aerogel Detectors
- Pion Rejectors

➡ All systems successfully recommissioned

BigBite Commissioning

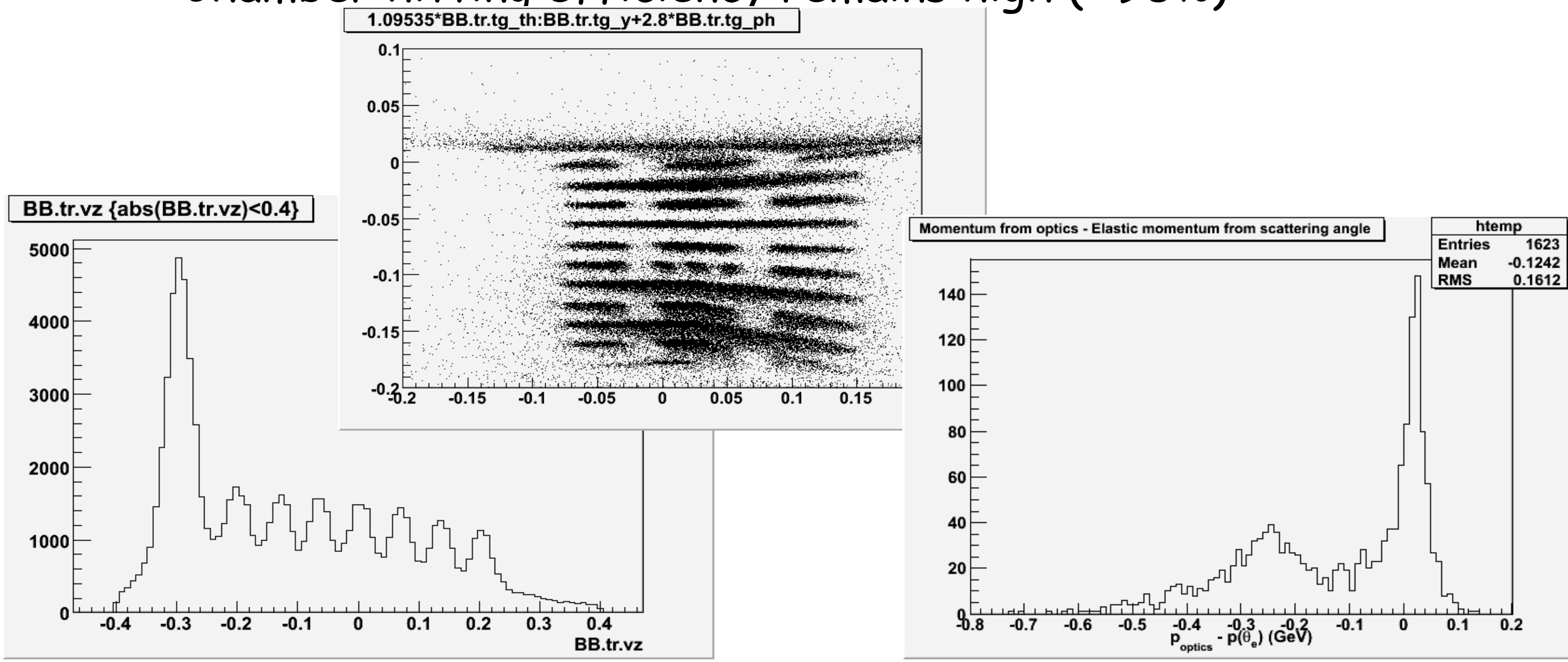




- BigBite detector package:
  - ➡ 3 MWDCs,
  - ➡ Scintillator plane
  - ➡ Pb-glass Calorimeter (Pre-shower + Shower)
  - ➡ Gas Cherenkov (new)

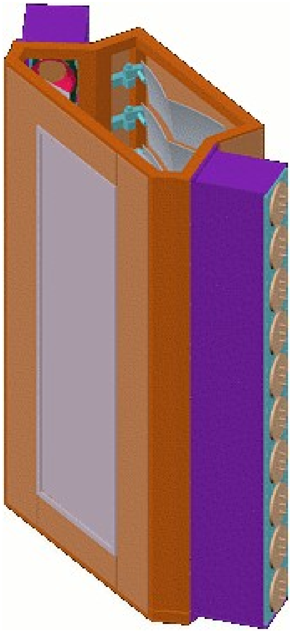
BigBite Commissioning during Transversity

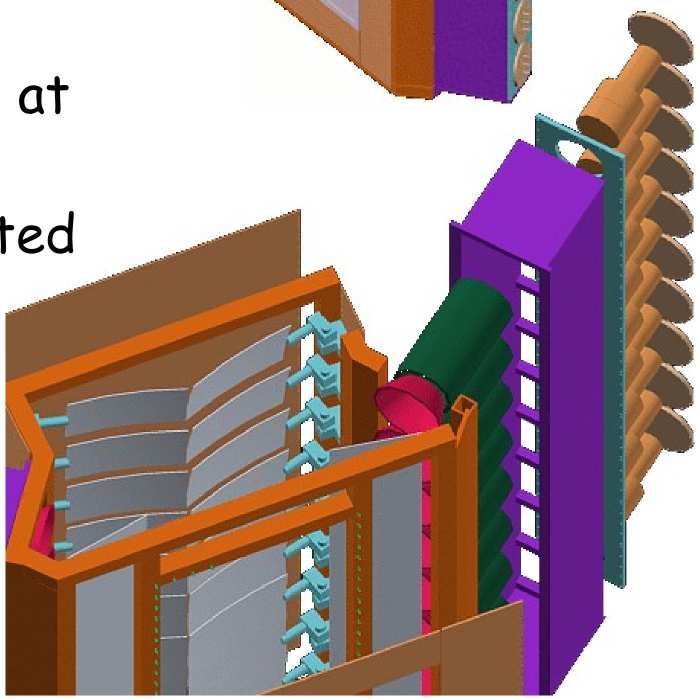
- Multi-wire Drift Chambers (MWDCs)
  - Backgrounds: ~2x higher then anticipated
  - Now running 12 uA on 3He target
    - background rate: 60 MHz (~5 MHz / uA)
  - New track reconstruction algorithm working well
  - Chamber hitting efficiency remains high (> 98%)



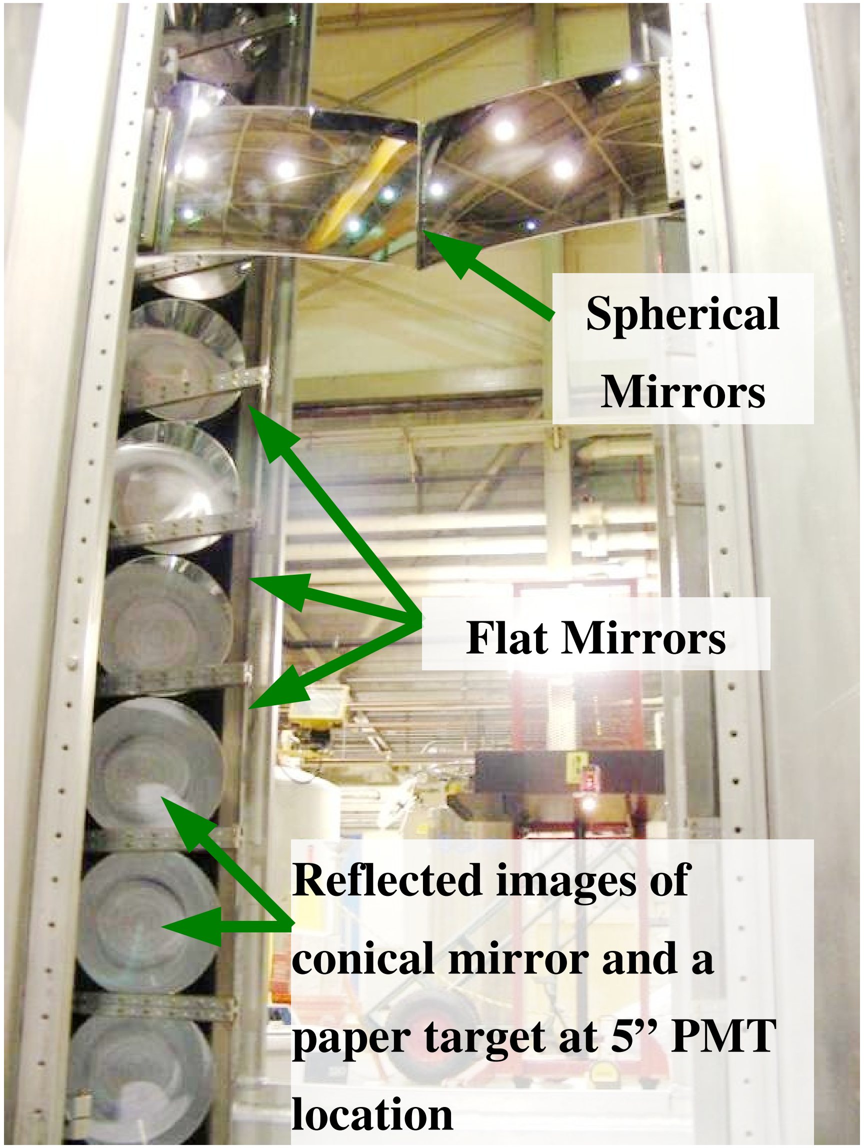
Cherenkov Design Parameters

- Dimensions: 200cm x 60cm x 60cm
  - ➡ sandwiched between wire chambers
- Radiator gas: C_4F_8O
  - ➡ π threshold: 2.51 GeV/c
  - ➡ ~18 photo-electrons / 40 cm electron track
    - Quartz PMTs
    - mirror reflectivity: ~90%, 10% loss at PMT-gas interface
    - Assume additional 10% loss associated with optics change after adding mu-metal shield modifications.





BB Cerenkov During Assembly (viewed from rear)



BB Cherenkov Commissioning

- First beam during Low-Q² G_e^p run in Summer 2008
  - ➡ failed to observe any clear Cherenkov ADC spectra
- Studied the problem over the Summer:
  - ➡ tested the gas (C_4F_8O) for UV transparency: Good
  - ➡ checked mirror reflectivity (limited scope): Good
  - ➡ checked optics/alignment: Good
  - ➡ checked system with cosmics (CO_2): Good
  - ➡ checked magnetic shielding: *Fail*
    - existing shielding not sufficient (15G → 1G only)
- Modified PMT mounts to accommodate scavenged mu-metal shields.
  - ➡ small change in optics introduces additional ~10% p.e. loss
  - ➡ all PMT+shield combos tested using Helmholtz coil apparatus.
  - ➡ added an LED flasher system to Cherenkov for in-situ tests

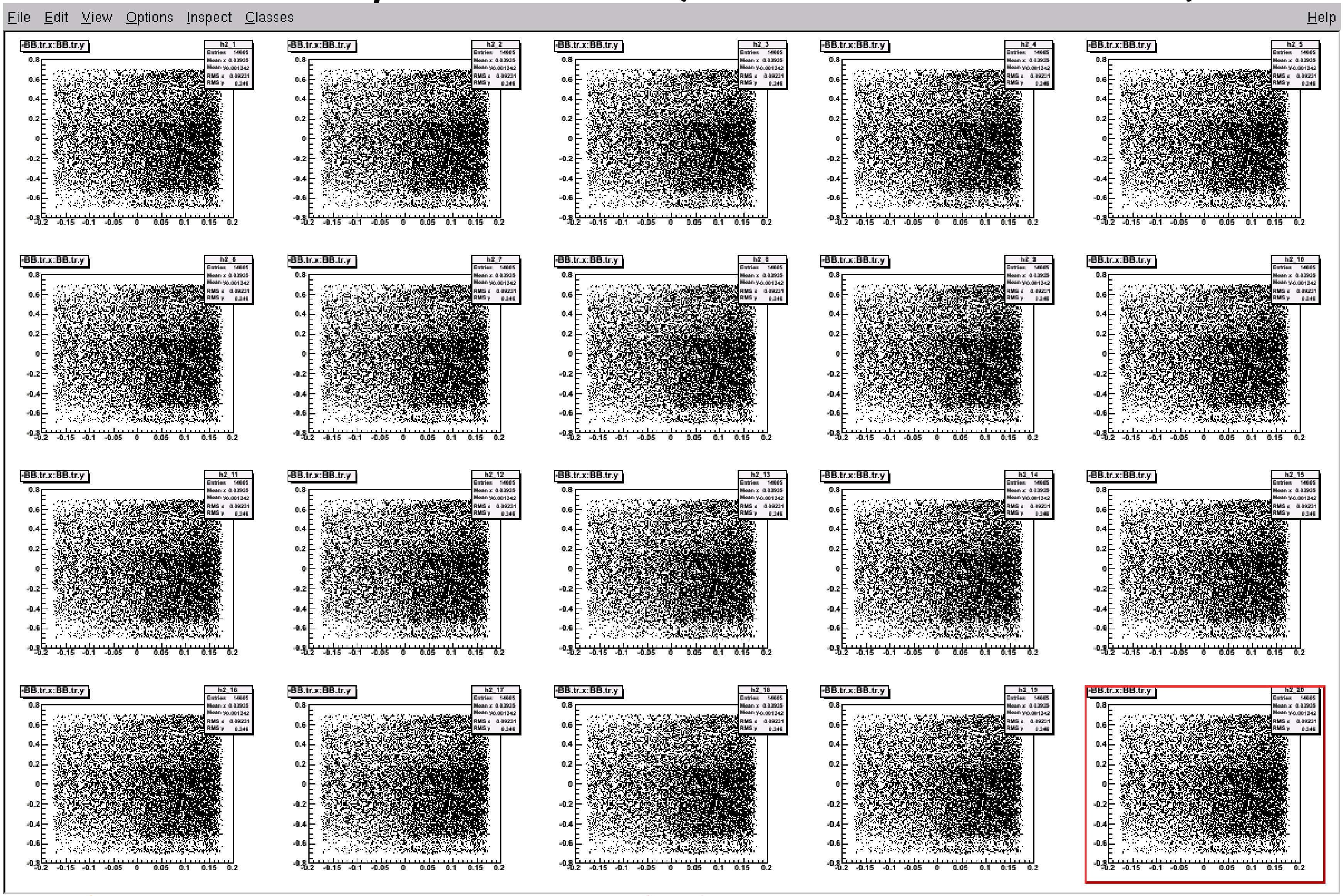
BB Cherenkov Commissioning

- Parasitic commissioning during Transversity
  - *Very* high background rates in PMTs
    - ^{3}He cell at 5.9 GeV, 12 uA
      - several 100 kHz on beam-right side
      - several 1000 kHz on beam-left side (nearest beamline)
        - MHz rate too large to run in Transversity configuration (ie. 30°)
    - Appears to be direct interaction of 'something' with the photo-cathode (ie. *not* scintillation in the radiator gas or knock-ons/δ-rays)
    - So far shielding hasn't changed the situation much
      - not from target or beamline
        - at least, not the bits we've shielded
      - not low energy (<100 MeV/c) charged particles
      - neutrons? gammas?

- Nevertheless, there is hope!

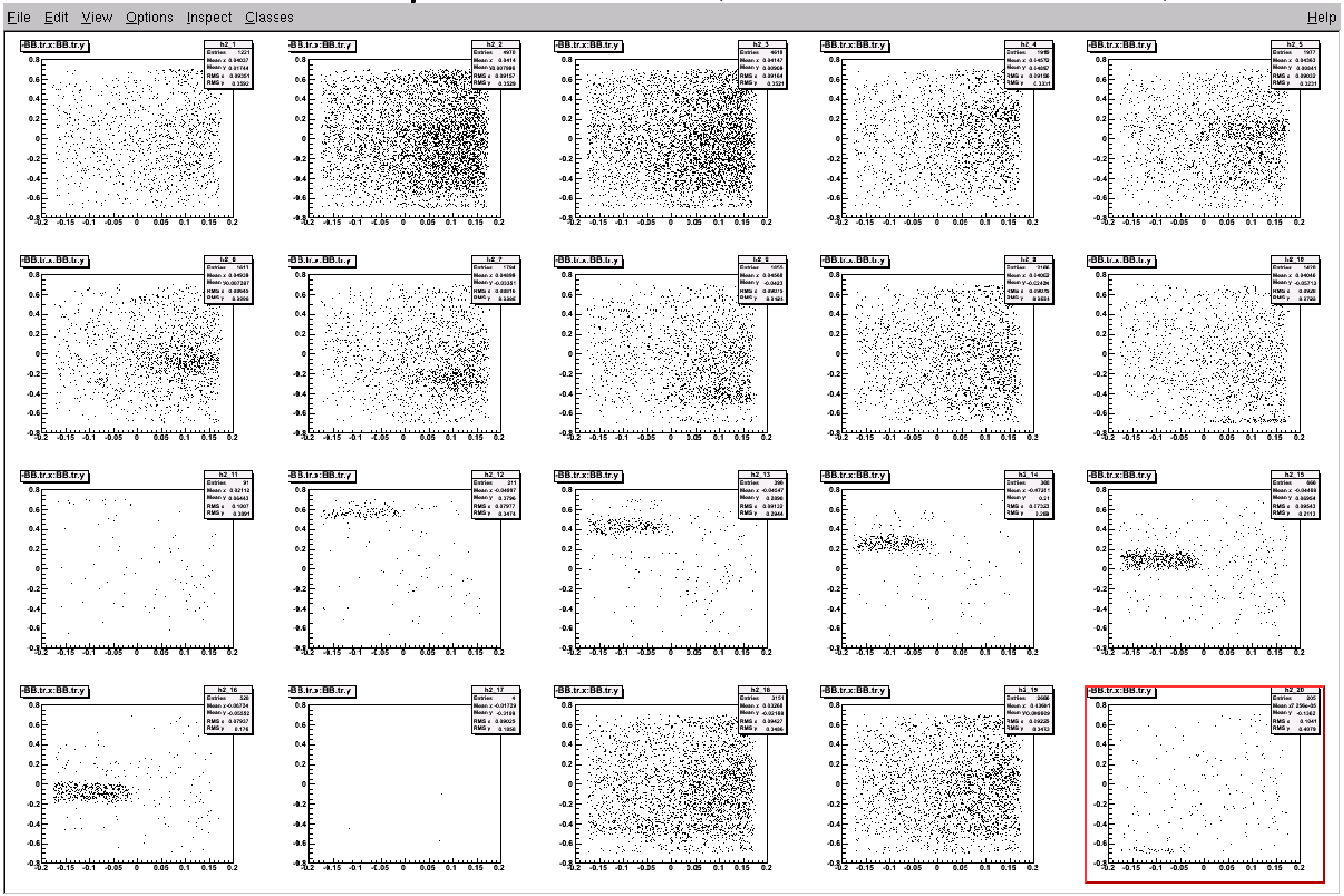
BB Cherenkov Commissioning

- MWDC x vs. y coordinate (No Cerenkov ADC cut)



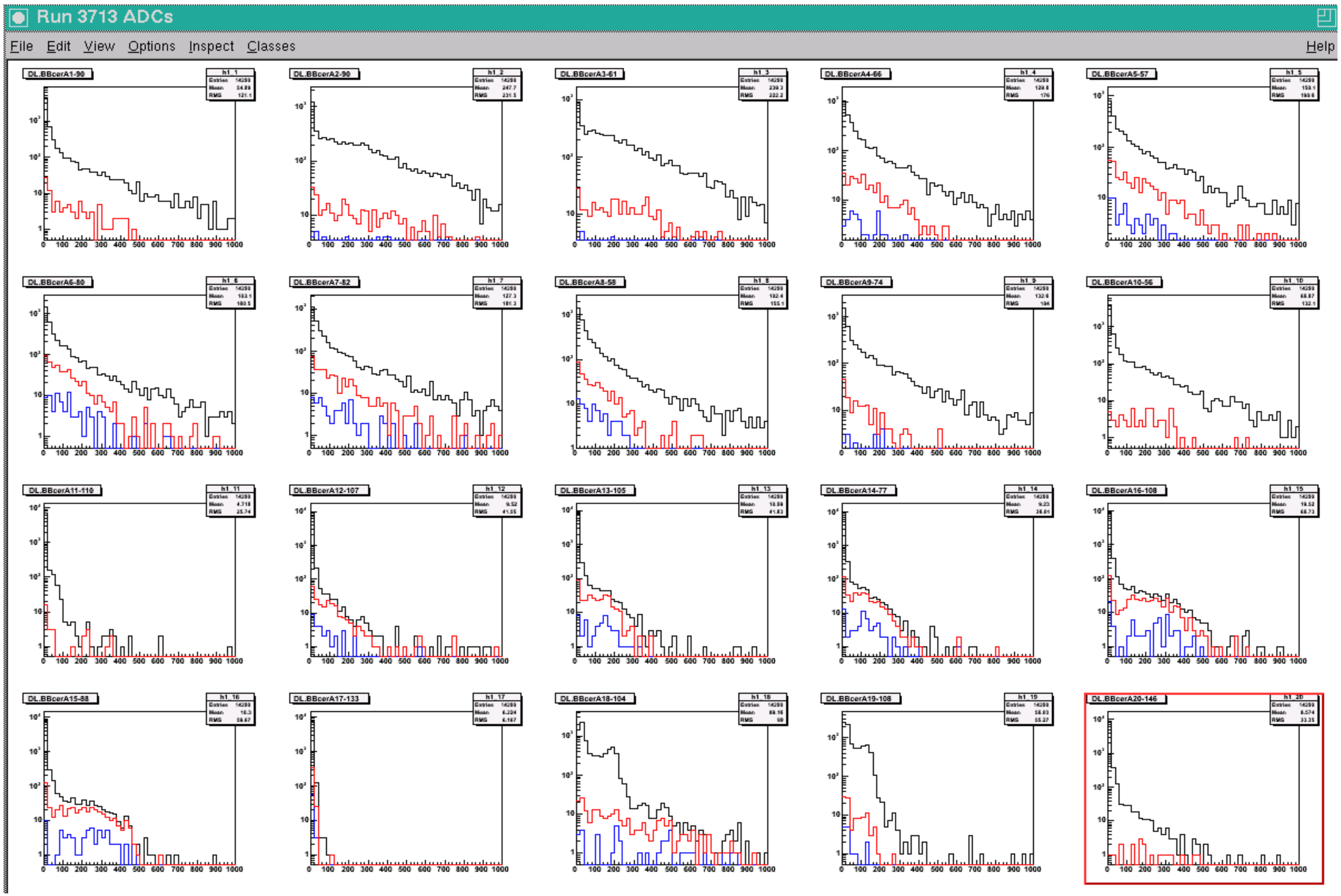
BB Cherenkov Commissioning

- MWDC x vs. y coordinate (Cerenkov ADC > 70)



BB Cherenkov Commissioning

- Cerenkov ADC w/ cut on MWDC track
  - ➡ cut: central mirror coord ± 50% of mirror size
  - ➡ cut: central mirror coord ± 15% of mirror size



BB Cerenkov electron efficiency estimate

- A "clean" electron sample in BigBite single-arm trigger was approximated by selecting particles:
  - ➡ had a good track,
  - ➡ "high" reconstructed momentum,
  - ➡ "high" energy deposition in shower (π:e^- ratio falls fast vs. E)

- Define "Efficiency" =

$$\frac{\text{particles with track that passed through center of a mirror}}{\text{particles that deposited > 2 p.e. of energy in ADC}}$$

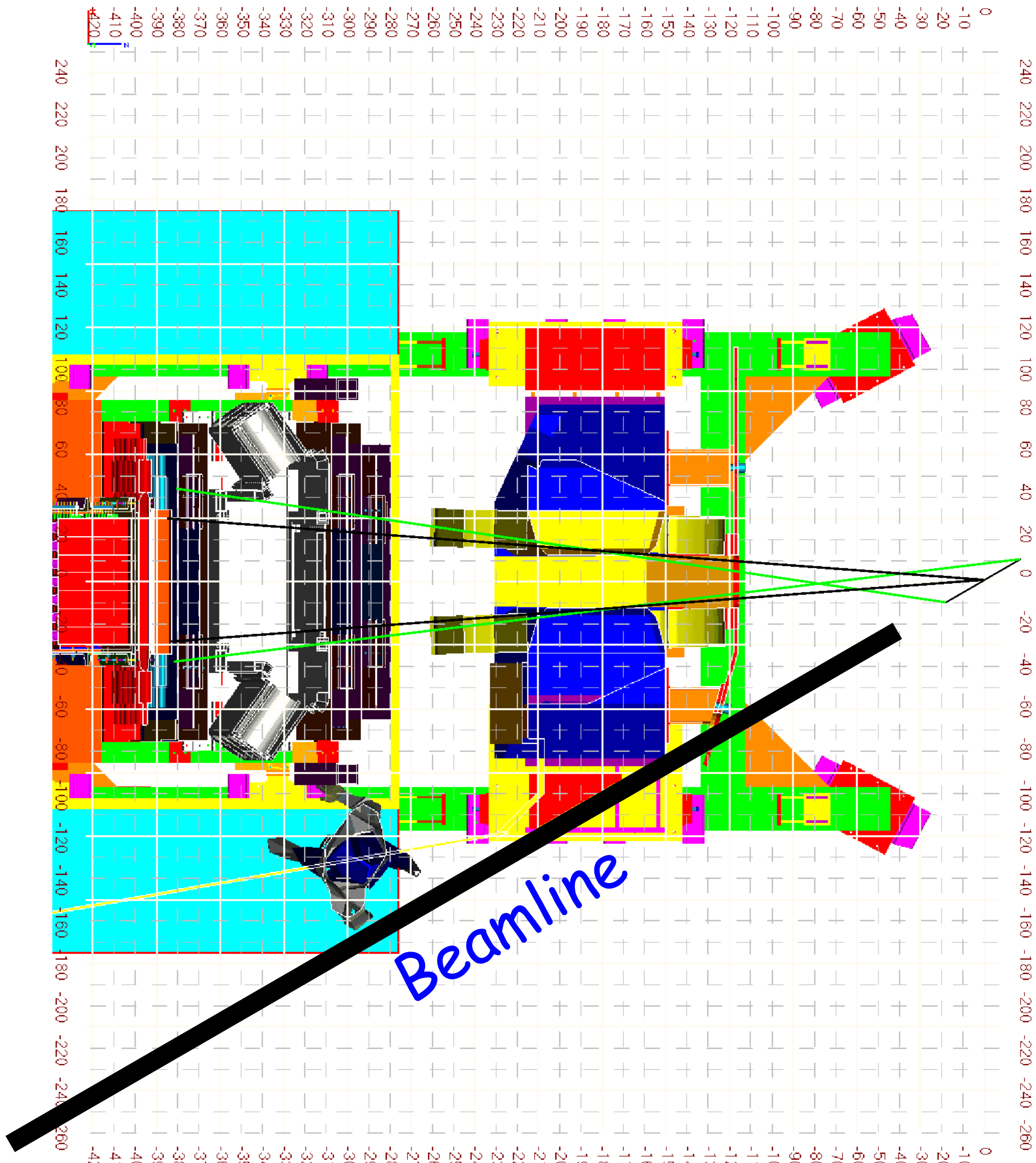
- For beam-right side, efficiency: 60-70%
- For beam-left side, efficiency: 20-40%
  - ➡ Very high rates, PMT could be pulling too much anode current and gain is drooping. We will test this using LED system.

Still to do...

- Extract quantitative meas. of the BB Cherenkov performance
  - ➡ obtain estimates of pion rejection, electron efficiency vs. threshold, etc.
- Understand the nature of the background
  - ➡ Worst case: we can live with current situation
    - d_2^n: BigBite moves to 45° from 30°
      - Right-side PMTs are worst case scenario for d_2^n detector pos and are already adequate for an asymmetry measurement.
  - ➡ Potential PMT gain droop due to high rate will be measured
    - Address by dropping HV and increasing amplifier gain.
- During January down:
  - ➡ Repair the PMTs that are showing poor signals.
  - ➡ Improve shielding, if possible.
- **We will be ready for February 9, 2009.**

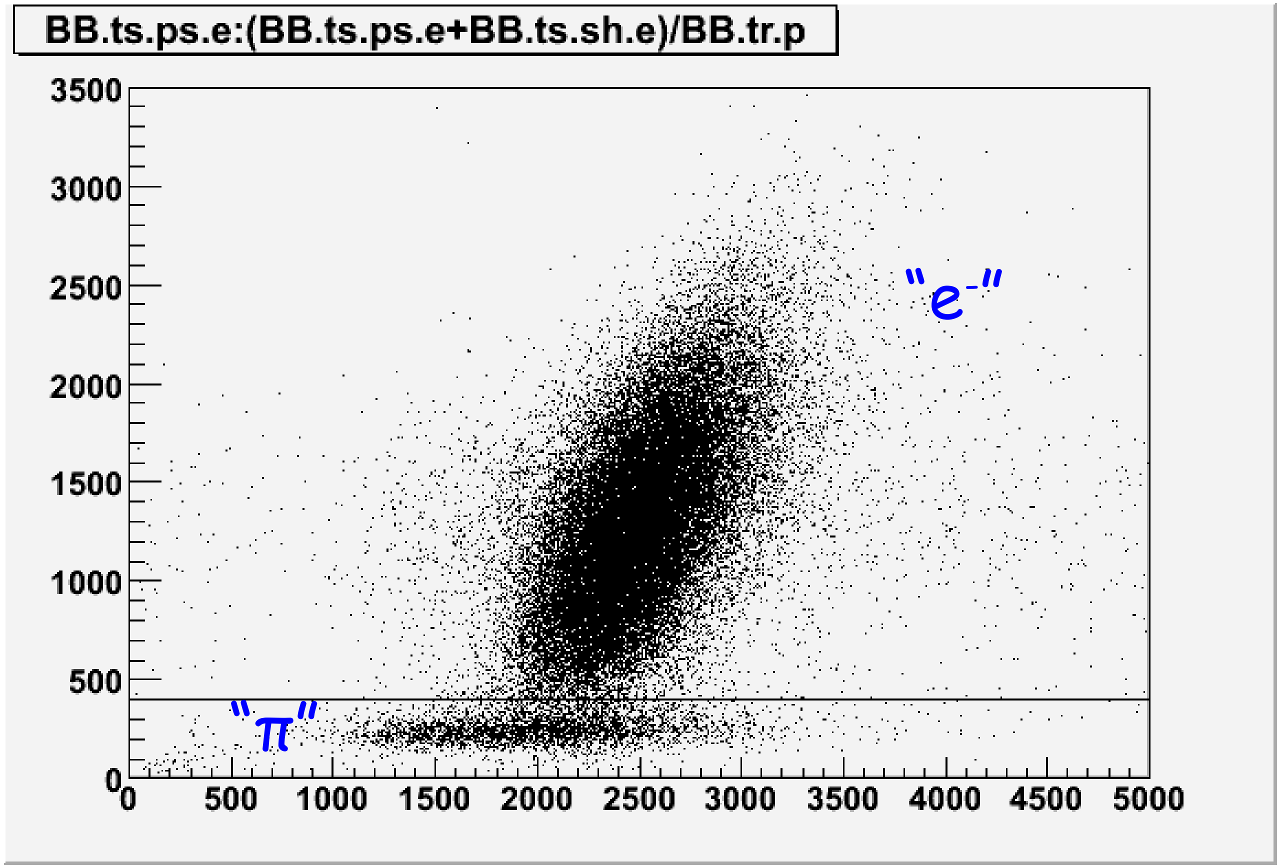
Extra Slides

BigBite/Target Geometry



BigBite Commissioning during Transversity

- Calorimeter (Shower + Pre-shower)
  - ➡ seems to be working well
    - Preshower vs. Shower Energy deposition @ 1 pass on H_2



Experiment Summary

- We will 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 statistical 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

- **Scheduled for February 9 to March 11, 2009.**

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

Color "polarizabilities"

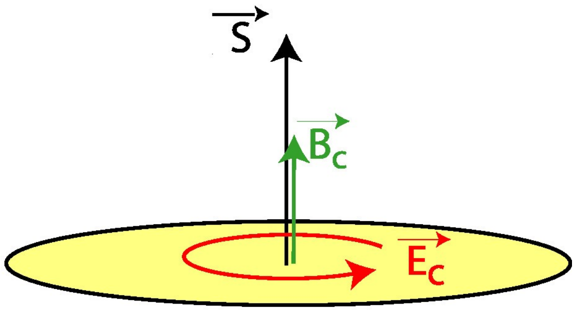
How does the gluon field respond when a nucleon is polarized ?

Define color magnetic and electric polarizabilities (in nucleon rest frame):

$$\chi_{B,E}\, 2M^2 \vec{S} = \langle PS | \vec{O}_{B,E} | PS \rangle$$

where $\vec{O}_B = \psi^\dagger g \vec{\boldsymbol{B}} \psi$

$$\vec{O}_E = \psi^\dagger \vec{\alpha} \times g \vec{\boldsymbol{E}} \psi$$



$$\chi_E^n = (4d_2^n + 2f_2^n)/3$$
$$\chi_B^n = (4d_2^n - f_2^n)/3$$

χ_E and χ_B represent the response of the color $\vec{B}$ & $\vec{E}$ fields to the nucleon polarization

Systematic Error Contributions to d_2^n

Item description	Subitem description	Relative uncertainty
Target polarization		3 %
Beam polarization		3 %
Asymmetry (raw)		
	• Target spin direction (0.1°)	$< 5 \times 10^{-4}$
	• Beam charge asymmetry	$<$ 50 ppm
Cross section (raw)		
	• PID efficiency	$\approx$ 1 %
	• Background Rejection efficiency	$\approx$ 1 %
	• Beam charge	$<$ 1 %
	• Beam position	$<$ 1 %
	• Acceptance cut	2-3 %
	• Target density	$<$ 2%
	• Nitrogen dilution	$<$ 2%
	• Dead time	$<$1%
	• Finite Acceptance cut	$<$1%
Radiative corrections		$\leq$ 5 %
From ^{3}He to Neutron correction		5 %
Total systematic uncertainty		$\leq$ 10 %
Estimate of contributions to d_2 from unmeasured regions	$\int_{0.003}^{0.23} \tilde{d}_2^n \, dx$	4.8×10^{-4}
	$\int_{0.70}^{0.999} \tilde{d}_2^n \, dx$	5.0×10^{-5}
Projected absolute statistical uncertainty on d_2		$\Delta d_2 \approx 5 \times 10^{-4}$
Projected absolute systematic uncertainty on d_2 (*assuming* $d_2 = 5 \times 10^{-3}$)		$\Delta d_2 \approx 5 \times 10^{-4}$

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

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