Initial State Helicity Correlation in Wide Angle Compton Scattering

E05-101

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Hall C Workshop
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Outline

- Introduction
- Theoretical Motivation

  Why do we want to do this experiment?
- Experimental Technique

  How we will do the experiment?
- Beam Request

  What did we request from the PAC?

Physics goals of this experiment complement those of E99-114 and benefits from its experience with the RCS experimental technique.

Real Compton Scattering: Introduction

- Key element in Program of Hard Exclusive Reactions

  RCS

  Elastic Form Factors

  DVCS

  DVMP

- Common issues:

  interplay between hard and soft processes

  Onset of asymptotic regime

  Role of hadron helicity flip

- Uniqueness
  - Vary both s and t
  - Weighting of quarks, e_q^2
  - independent integral of GPD's, x^{-1}

Real Compton Scattering: Introduction

Compton Scattering off nucleons provides information on the substructure of nucleon in terms of quark and gluon d.o.f. $\longrightarrow$ extremely complicated

Compton scattering in various kinematical regions

- low energy

  $\longrightarrow$ dominated by nucleon as a whole

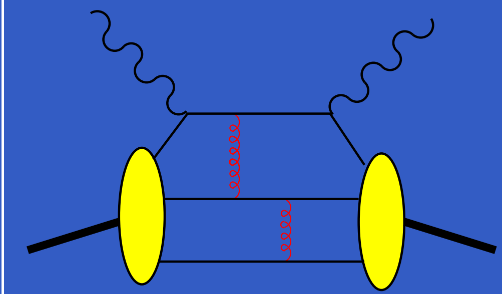
- deeply virtual CS; low $\mid t \mid$, large Q^2

  $\longrightarrow$ handbag diagram involving skewed parton distributions

- 'wide angle' CS; low Q^2, large $\mid t \mid$ and s ensures dominance of short distance behaviour

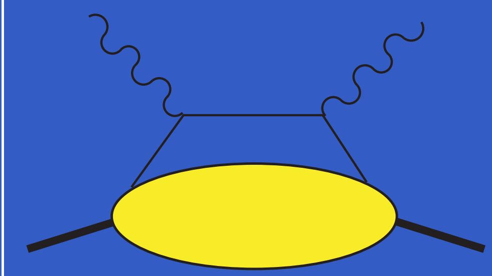
  What is the reaction mechanism?

What is the reaction mechanism?



hard gluon exchange

- 3 active quarks
- 2 hard gluons
- 3-body "form factor"

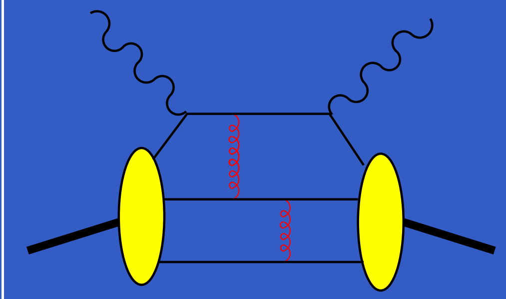


handbag

- 1 active quark
- 0 hard gluons
- 1-body "form factor"

- Which, if either, dominates at few GeV?
- We will be able to distinguish among the competing mechanisms.

Asymptotic (pQCD) Mechanism



hard gluon exchange

Brodsky/Lepage
Kronfeld, Nizic
Vanderhaeghen, Guichon
Brooks, Dixon, ...

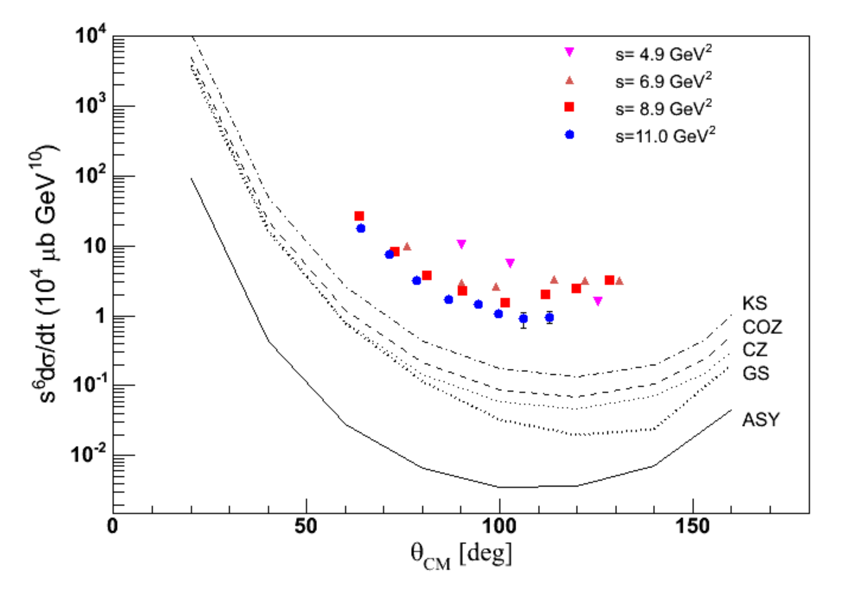
- momentum shared by hard gluon exchange
- 3 active quarks
- valence configuration dominates
- soft physics in distribution amplitudes, $\Phi(x_1, x_2, x_3)$, $\Phi(y_1, y_2, y_3)$
- constituent scaling: $\frac{d\sigma}{dt} = f(\theta_{CM})/s^6$
- Must dominate at "sufficiently" high energy(?)
- Has predictions for polarization observables, $K_{LL} = A_{LL}$

Constituent Scaling

$\gamma p \to \gamma p$

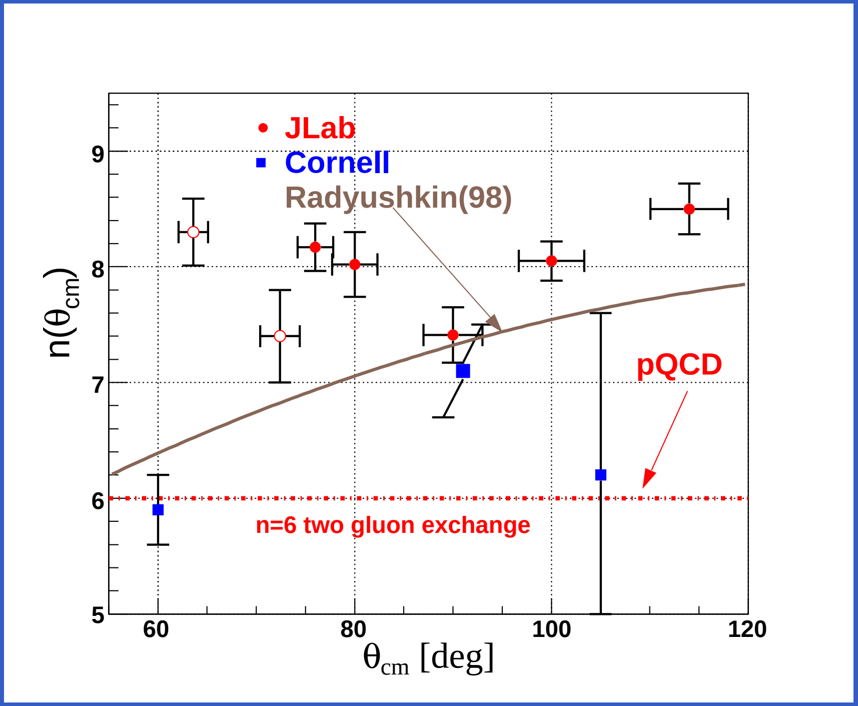
Approximate scaling

$\frac{d\sigma}{dt} = f(\theta_{CM})/s^6$



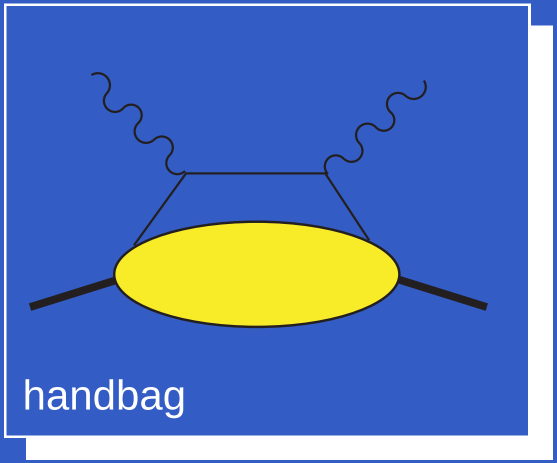
Brooks&Dixon Phys.Rev.D62:114021,2000

Cornell data approximately support scaling but . . .



Asymptotically we expect pQCD to be dominant, but when?

Handbag Mechanism for $(s, -t, -u) \gg M^2$



Radyushkin

Diehl, Feldman, Jakob, Kroll

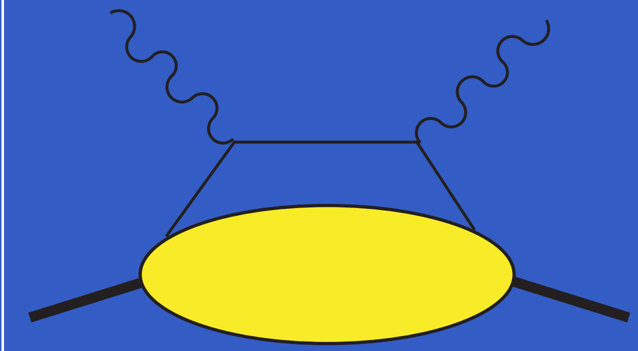
- One active parton
- Momentum shared by soft overlap
- Feynman mechanism

  struck quark nearly real ($x \sim 1$) (co-linear with proton)
- Form factor like expression

  $$\frac{d\sigma}{dt} = \frac{d\sigma}{dt}\Big|_{KN} f(t)$$
- Straightforward predictions for polarization observables

Handbag Approach and GPD's

Radyushkin
Diehl, Feldman, Jakob, Kroll



handbag

- Factorize into hard scattering on single quark and moments of GPD's at skewness $\xi = 0$
- hard scattering: Klein-Nishina from nearly on-shell parton
- Soft physics: Compton form factors $R_V(t), R_A(t)$ and $R_T(t)$ relating emission and reabsorption of struck quark in the proton

Compton form factors:

$$R_V(t) = \sum_a e_a^2 \int_{-1}^{1} \frac{dx}{x} \mathbf{H^a}(\mathbf{x}, \mathbf{0}, \mathbf{t})$$

$$R_A(t) = \sum_a e_a^2 \int_{-1}^{1} \frac{dx}{x} \operatorname{sign}(x)\, \mathbf{\hat{H}^a}(\mathbf{x}, \mathbf{0}, \mathbf{t})$$

$$R_T(t) = \sum_a e_a^2 \int_{-1}^{1} \frac{dx}{x} \mathbf{E^a}(\mathbf{x}, \mathbf{0}, \mathbf{t})$$

Elastic form factors:

$$F_1(t) = \sum_a e_a \int_{-1}^{1} dx\, \mathbf{H^a}(\mathbf{x}, \mathbf{0}, \mathbf{t})$$

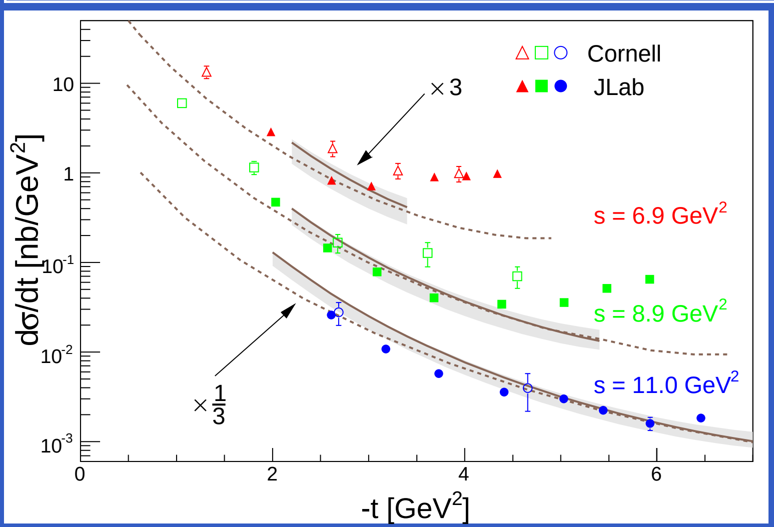
$$G_A(t) = \sum_a \int_{-1}^{1} dx \operatorname{sign}(x)\, \mathbf{\hat{H}^a}(\mathbf{x}, \mathbf{0}, \mathbf{t})$$

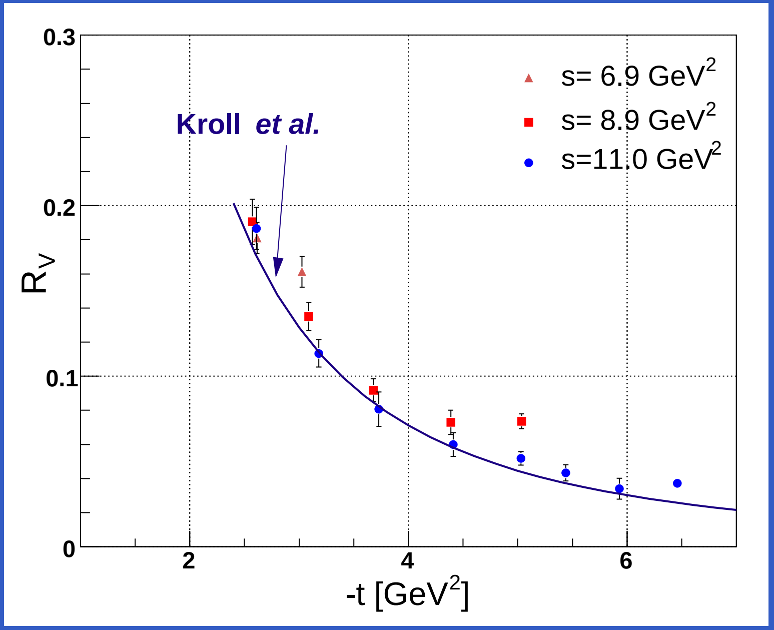
$$F_2(t) = \sum_a e_a \int_{-1}^{1} dx\, \mathbf{E^a}(\mathbf{x}, \mathbf{0}, \mathbf{t})$$

Handbag Predictions for WACS

Cross section from E99-114

$$\frac{d\sigma}{dt} = \frac{d\sigma_{KN}}{dt}\left[f_V R_V^2(t) + (1 - f_V)R_A^2(t)\right]$$



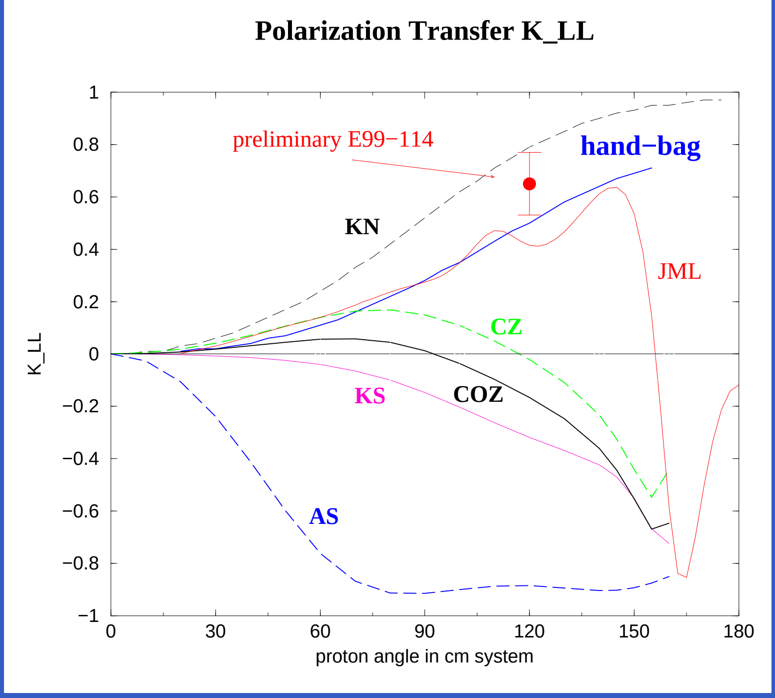


Polarization Observables

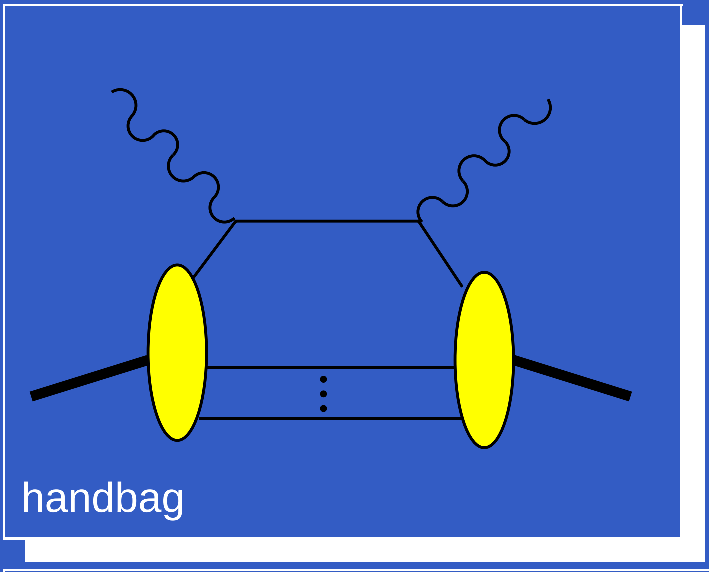
$$A_{LL}\frac{d\sigma}{dt} = \frac{1}{2}\left[\frac{d\sigma(++)}{dt} - \frac{d\sigma(+-)}{dt}\right]$$

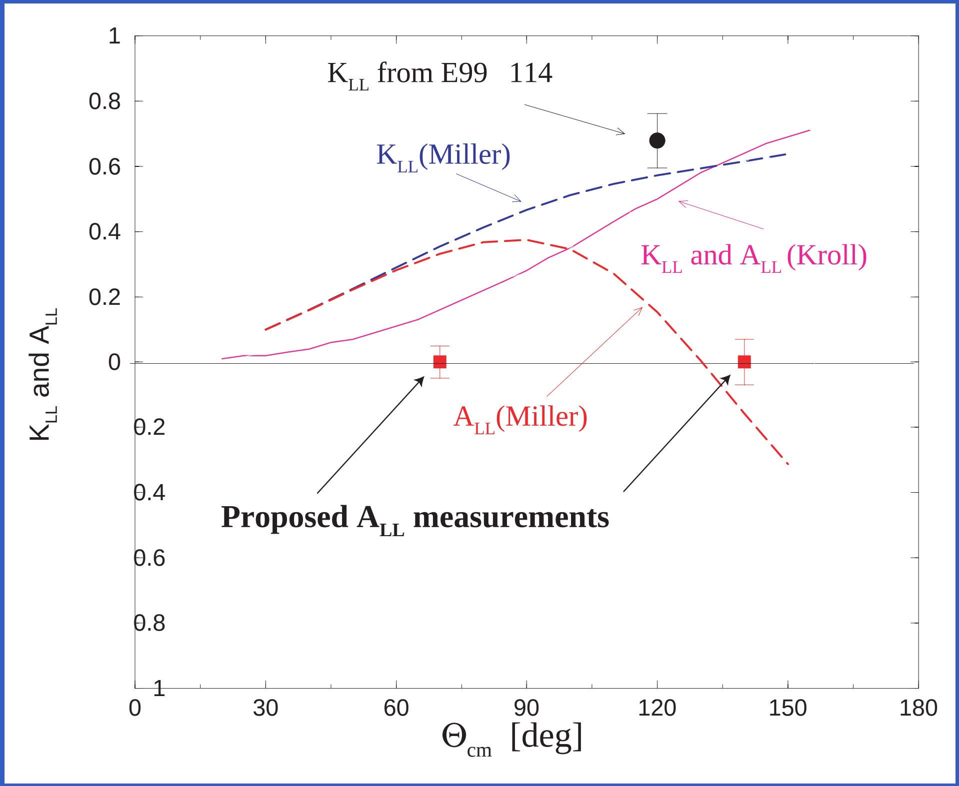
$$A_{LL} = K_{LL} \approx K_{LL}^{KN}\frac{R_A(t)}{R_V(t)}$$

Related to $\frac{\Delta u}{u}$ at moderate to high x.



Handbag in CQM





Miller in IA approximation of handbag.

- Massive quark
- Model wave function same as for E/M form factors
- Orbital angular momentum and nonconservation of proton helicity
- Good agreement with cross section data
- But $A_{LL} \neq K_{LL}$, backward angles
- $A_{LL} \simeq -K_{LL}$

Physics Goals

- Measure A_{LL} (never been measured) at two scattering angles:

  $\theta_\gamma^{CMS} = 70^\circ$ corresponding to $-t = 2.4$ (GeV/c)^2

  $\theta_\gamma^{CMS} = 140^\circ$ corresponding to $-t = 6.4$ (GeV/c)^2

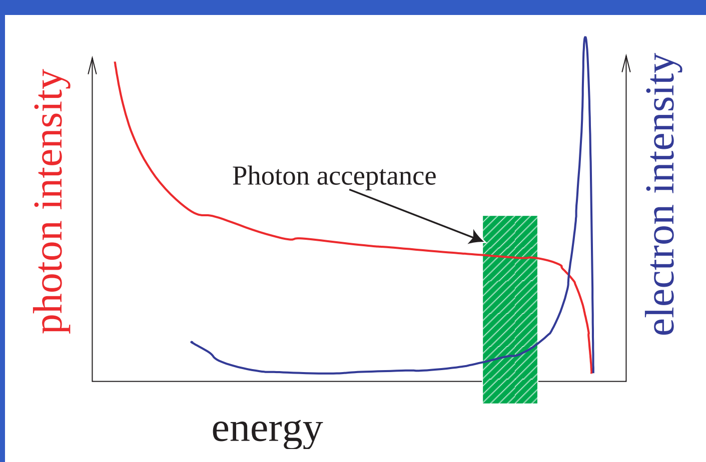
- Provide an experimental test of the RCS reaction mechanism: does the photon interact with a constituent or a current quark?
- Provide an additional test for hadron helicity conservation and pQCD

Experimental Layout

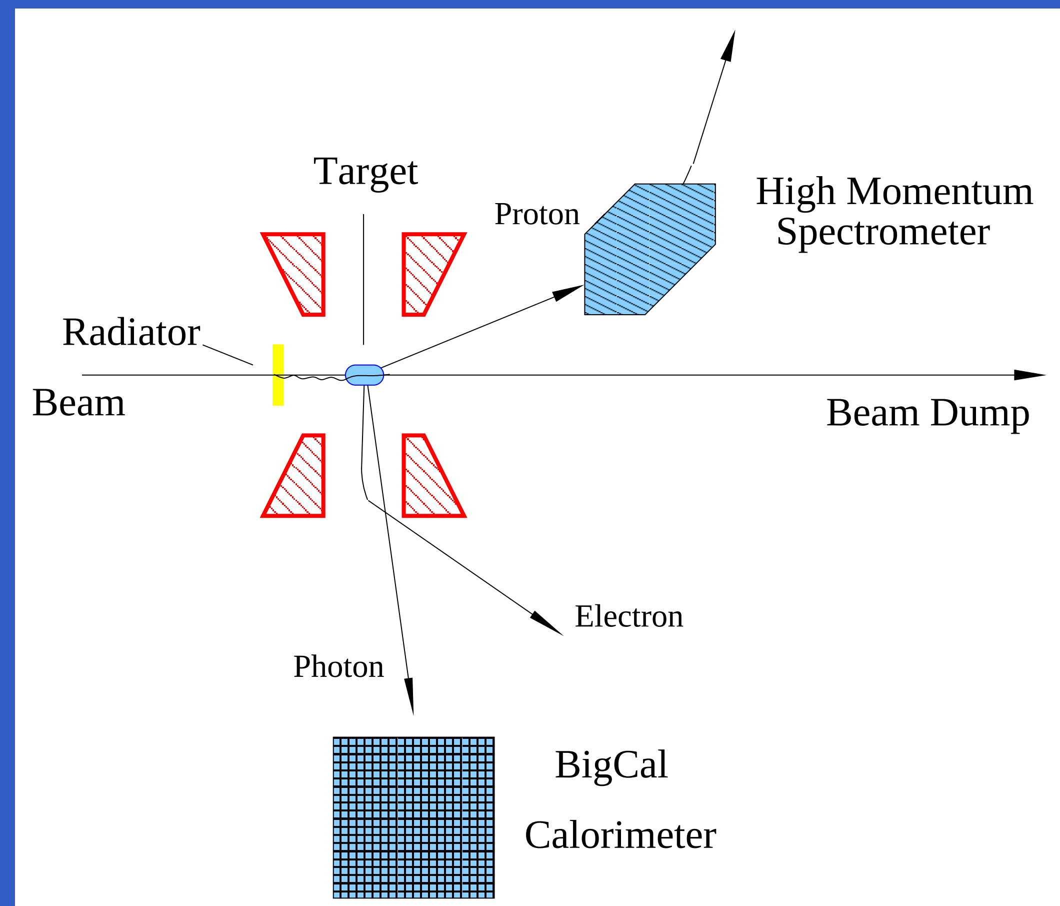
Kinematic Range

$E_\gamma = 4.3$ GeV, $s = 9$ GeV^2
$\theta^{\mathrm{cms}} = 70^\circ, 140^\circ$

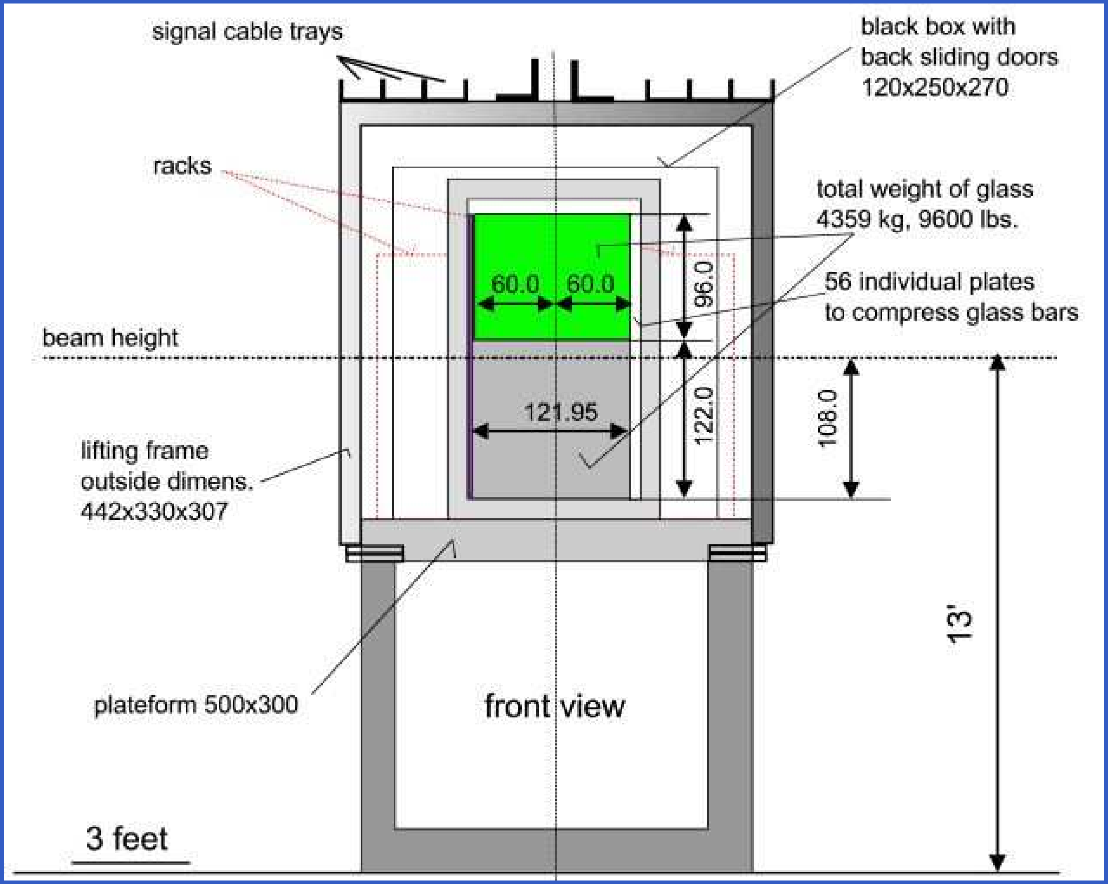
- mixed $e - \gamma$ beam
  $\rightarrow$ $e - p/RCS$ discrimination needed
  $\rightarrow$ control of backgrounds
- good angular resolution
- Polarized target



Require HMS trigger only



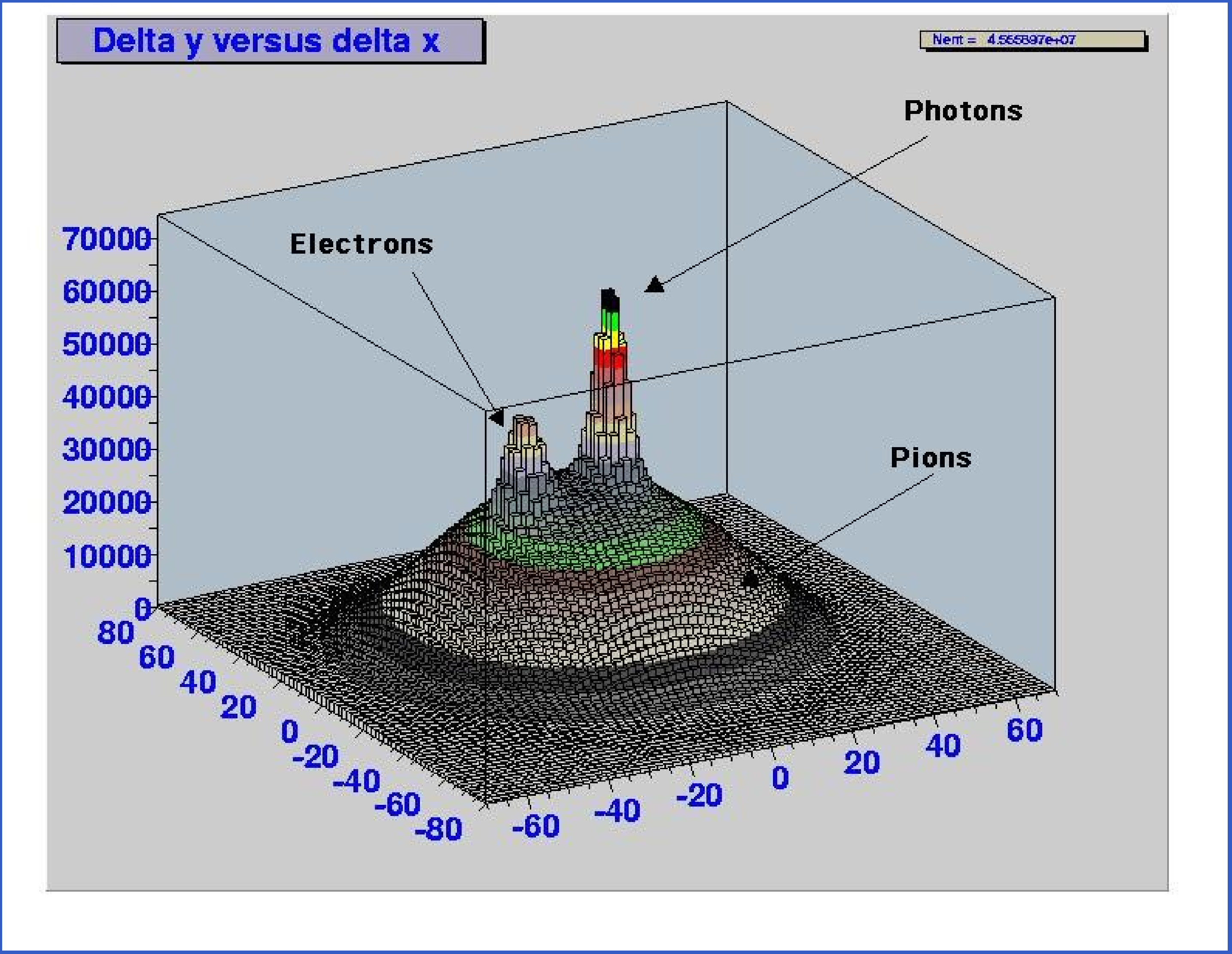
Calorimeter



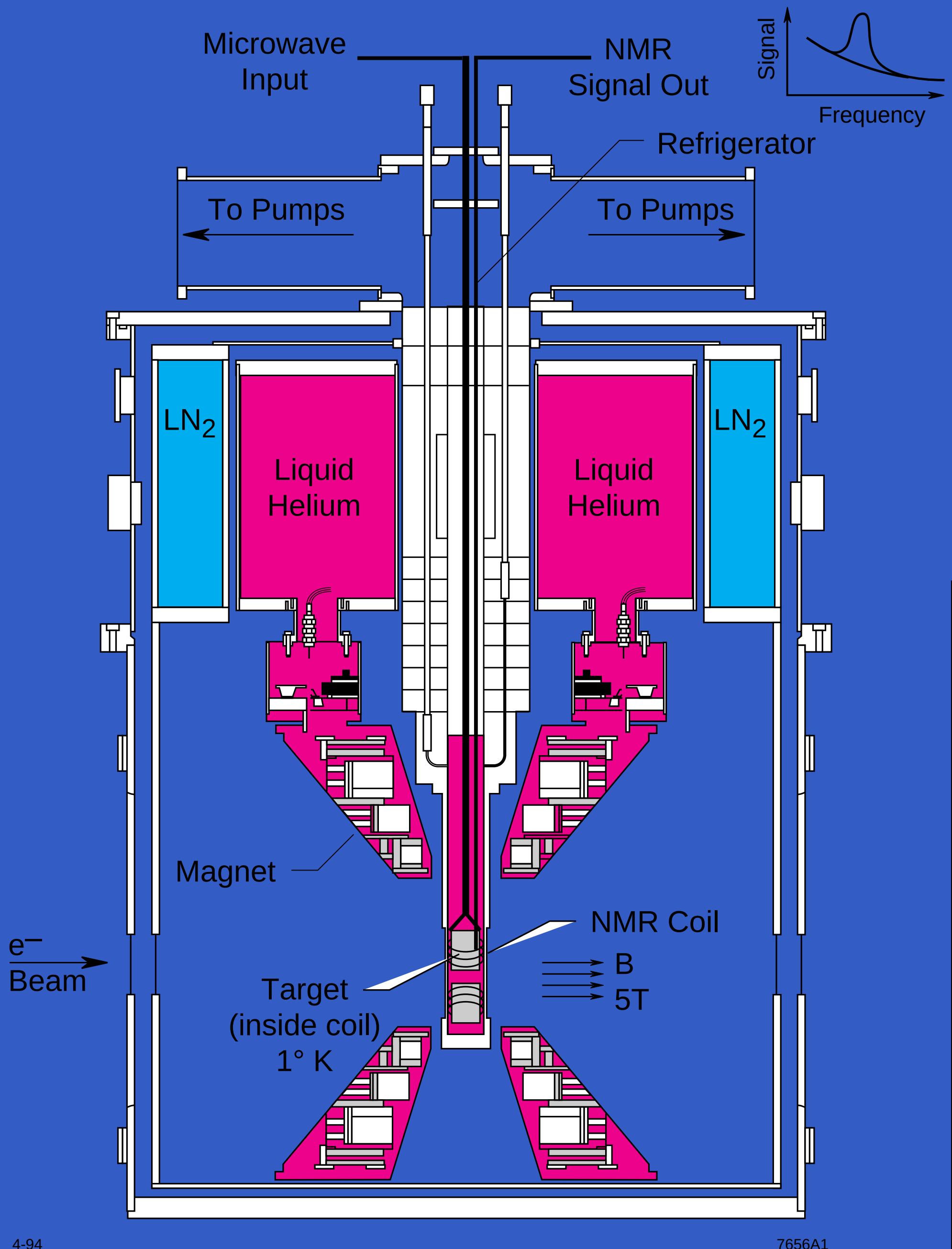
- 1750 lead glass blocks, TF-1 type
- Arranged as 56 rows in 32 columns
- Approximately 1.2 meters by 2.1 meters
- Built by GEP-III, to be used by SANE and SemiSANE (BETA) and E03-003

Discrimination of $e - p/RCS$

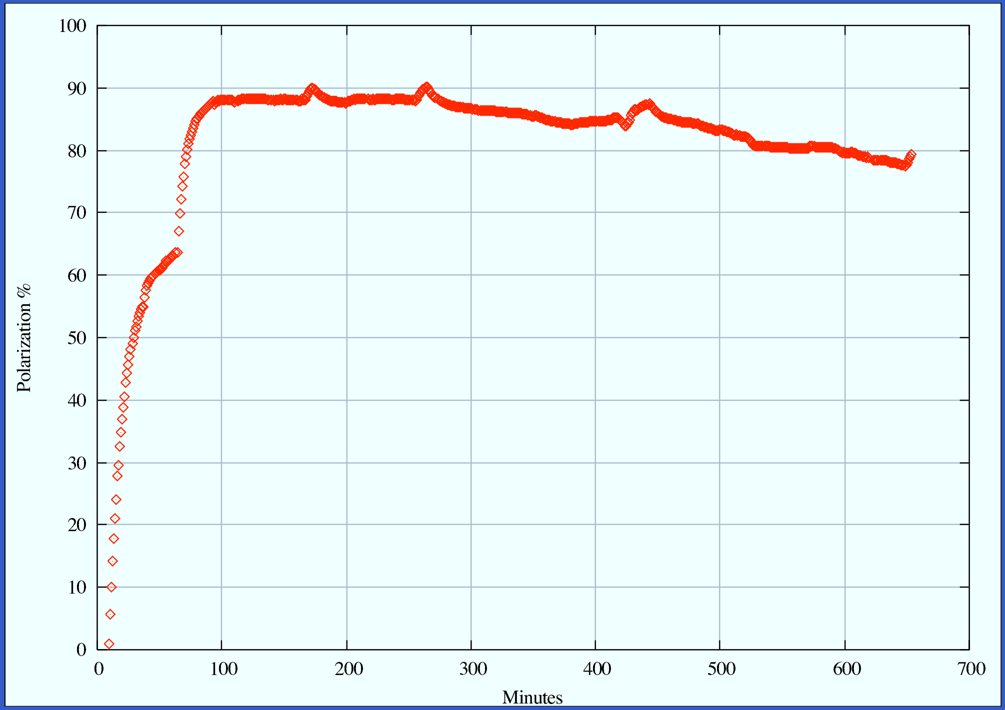
Deflection of electrons by magnetic field.



Polarized Target



- frozen(doped) NH_3
- ^4He evaporation refrigerator
- 5T polarizing field
- remotely movable insert
- dynamic nuclear polarization



Kinematics

kin. P#	t $(\mathrm{GeV/c})^2$	θ_γ^{lab} degree	θ_γ^{cm} degree	θ_p^{lab} degree	E_γ^{lab} GeV	p_p GeV/c	L m
P1	-2.4	25	70	39	3.00	2.02	7.0
P2	-6.4	82	140	12	0.87	4.25	2.5

kin. P#	θ_γ^{lab} degree	t $(\mathrm{GeV/c})^2$	θ_γ^{cm} degree	$\frac{d\Omega_\gamma}{d\Omega_p}$	D	N_{RCS} total	ΔA_{LL}
P1	25	-2.4	70	0.58	1.6	1850	**0.05**
P2	82	-6.4	140	24.5	5.5	3250	**0.07**

kin. P#	θ_V^e degree	θ_V^p degree	HMS degree	p(proton) GeV/c	θ^{rms} mrad
1	1.7	4.1	39	2.02	1.75
2	15.4	0.6	12	4.25	0.83

Beam Request

Kin. P#	Procedure	beam, nA	time hours
P1	BigCal calibration	1000	8
P1	RCS data taking	90	176
P2	RCS data taking	90	240
	Packing Fraction Measurements	90	16
	Moller Measurements	200	18
	Beam Time		458
	BigCal angle change		8
	Target Anneals		52
	Stick Changes		36
	Overhead Time		96
	Requested Time		506

Error Budget

Asymmetry measurement relaxes demands on some systematic error sources (solid angles etc) which cancel but requires attention to others. The largest sources are:

Target polarization	2%
Beam polarization	2%
π^0 subtraction(shape)	3%
$ep\gamma$ subtraction	1%
Total	4.2%

Conclusions

- Experiment straightforward - based on experimental data and extensive experience.
- Test onset of handbag approach in terms of GPD's.
- Positive indications for handbag allows extraction of non-perturbative structure of hadrons in form of GPD's.
- Explore role of finite quark masses in polarization observables.
- Shed light on nature of quark helicity flip processes.
- As byproduct A_{LL}^{π} will also be measured.
- Scheduling with SANE and Semi-SANE captures setup savings.

PAC 28 Recommendation

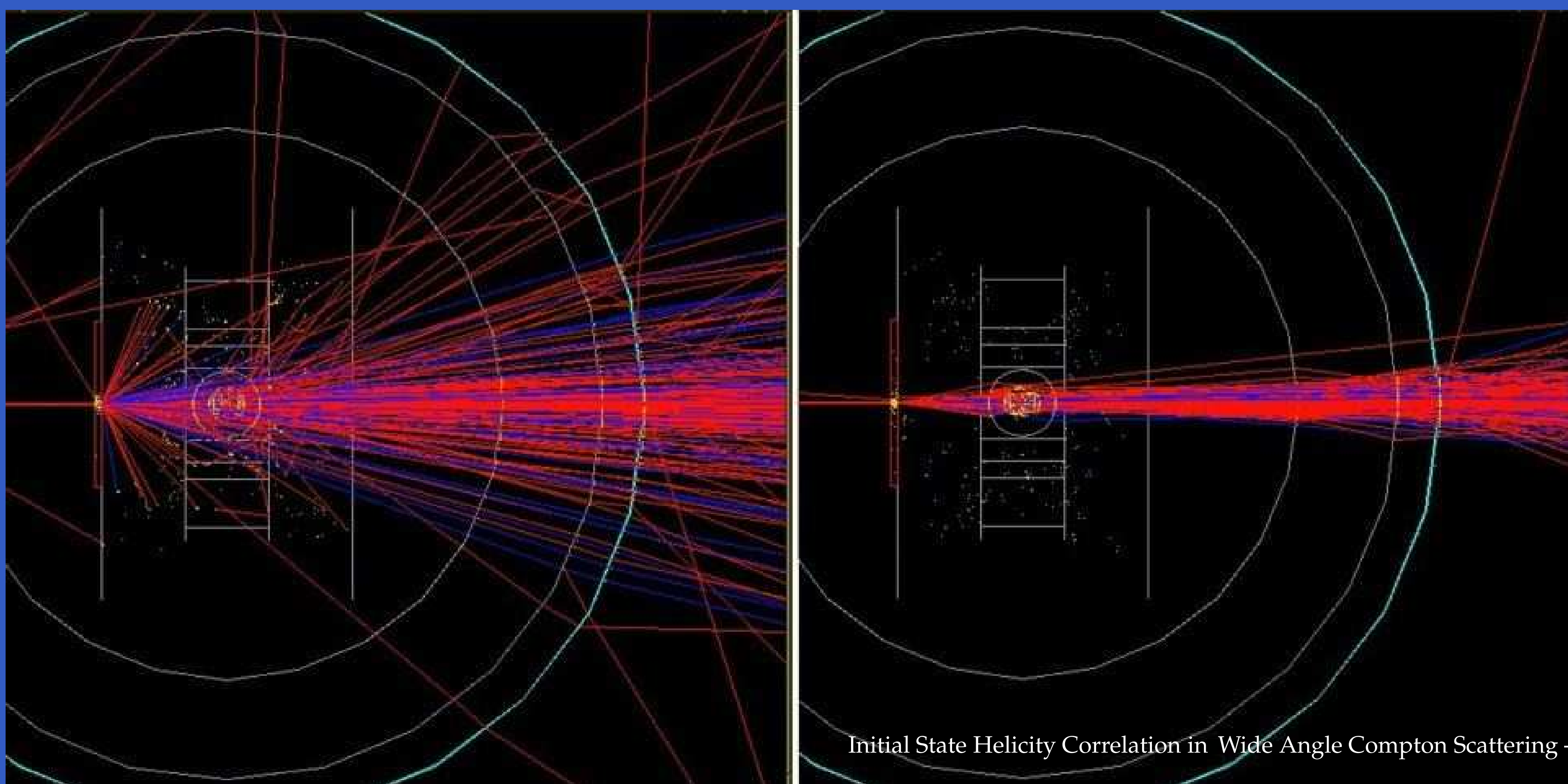
Merely due to lack of available beam time, the PAC recommends that only the kinematic point in the backward hemisphere be measured.
Approved with A^{-} *rating for 14 days.*

Simulation

- Presence of radiator creates unique conditions
  - Beam blows up
  - Large number of secondary particles (electrons, photons) - implications for rates in calorimeter; where to place shielding.
  - Include target magnetic field
- Physics backgrounds
  - Elastic electron scattering
  - Quasielastic electron scattering
  - $\pi^0 \rightarrow 2\gamma$ from proton and target materials
  - Include target magnetic field

Status

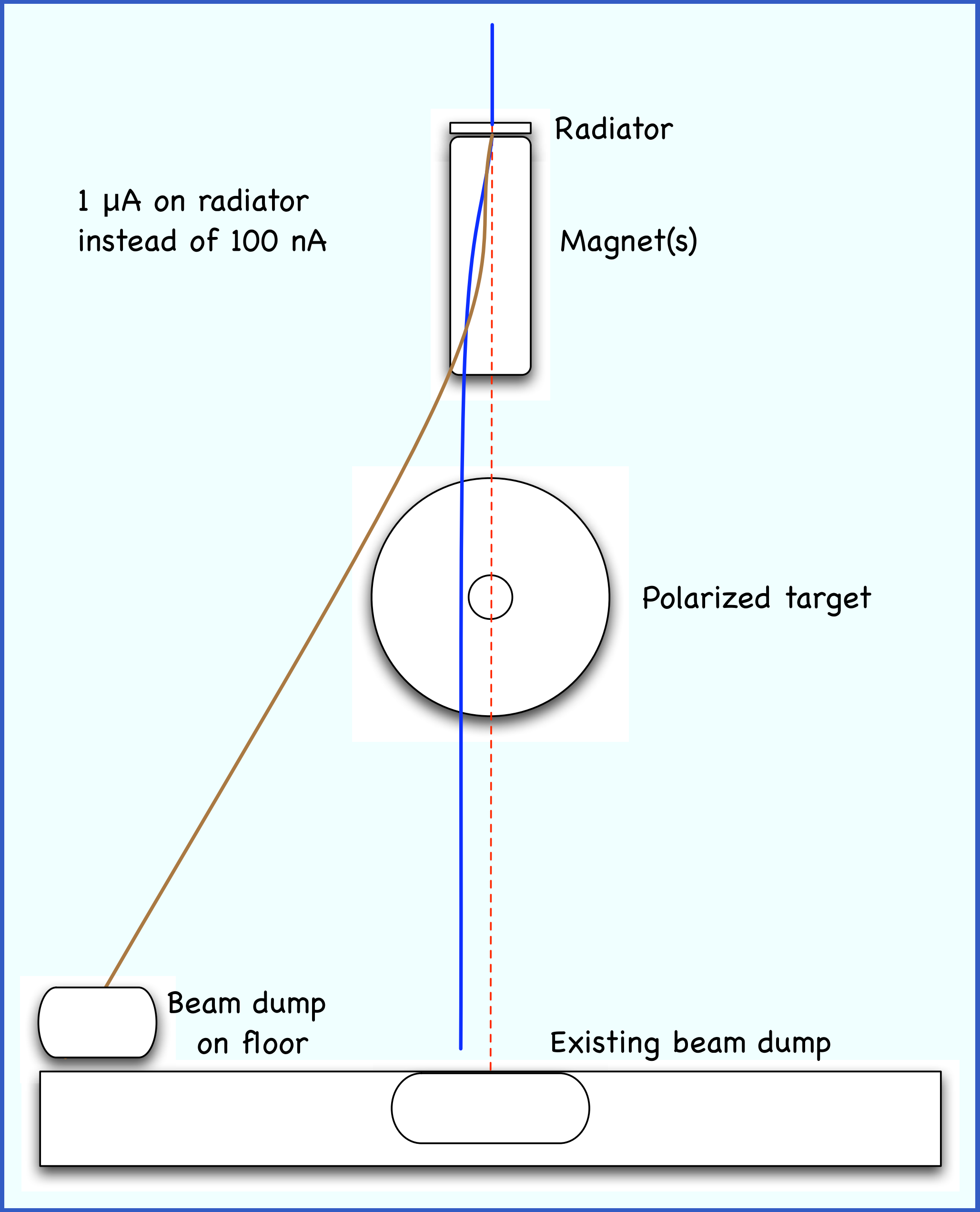
- GEANT4 - Justin Wright, UVA graduate student
- Electromagentic part moving along well
- Second part hindered by lack of the physics in GEANT4
- Also by our unfamiliarity with the standard practice for incorporating new physics.



GEANT4 Simulation

- Geometry
  - Upstream beam pipe
  - Downstream beam pipe (Helium bag or flaring Aluminum tube)
  - Upstream copper radiator (10%)
  - Target can (simplified), including the target cell and magnet
  - Big Cal
  - Simple plane detectors to represent the solid angle openings of the Calorimeter and the HMS
- Fields
  - The target magnet's field (read in from a table)
- Electromagnetic processes as currently implemented by the Geant4 collaboration
  - Electron Ionization
  - Electron Bremsstrahlung
  - Photo Electric Effect
  - Compton Scattering (from electron)
  - Pair Production
  - Annihilation
- Data collection and analysis
  - Each primary electron represents a single event
  - All daughter particles are tracked fully
  - All physical objects can be treated as perfect detectors, recording all interactions
  - Separate code converts this data into root trees or paw ntuples

Pure Photon Beam



Details

HMS resolution	$< 0.1\%$
HMS acceptance	$\pm 27(h) \pm 70(v)$ mr
HMS $\frac{\Delta p}{p}$	$\pm 9\%$
Angle Resolution	0.9 mr (h) 0.9 mr(v)
HMS vertex resolution	± 1 mm
Photon fluence	$\frac{dk}{k}(0.10 + 0.018 + 0.01)$
BigCal block sizes	4×4 cm
BigCal σ_E	$5\%/\sqrt{E}$
BigCal	1.2×2.1 m
Möller	$< 1.5\%$
Target thickness	1.5 g/cm^2 of NH3, 0.3 of He
Multiple scattering	1.7 (P1), 0.8 (P2) mr

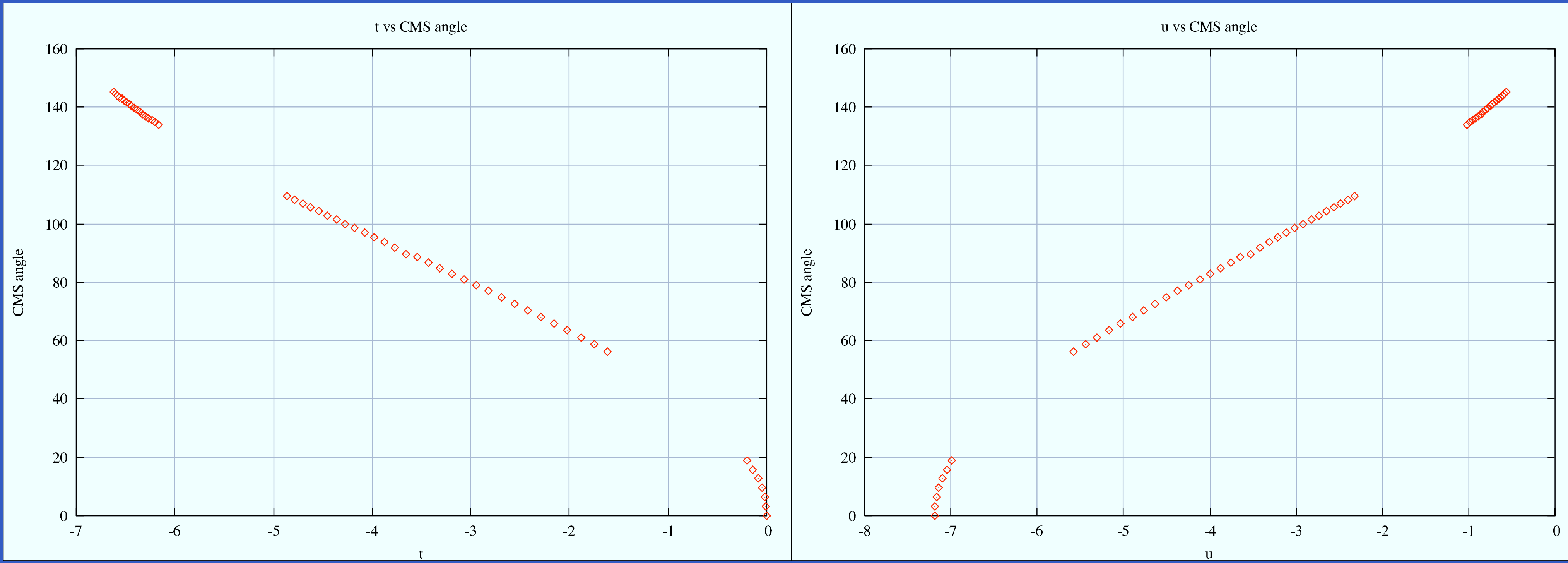
Lucite Cerenkov hodoscope

	thick cm	horiz. cm	vert. cm	#
x	1.25	80	12.5	16
y	2.5	12.5	160	8

10 p.e. 11% r.l., $x^{rms} = 3.6$ cm

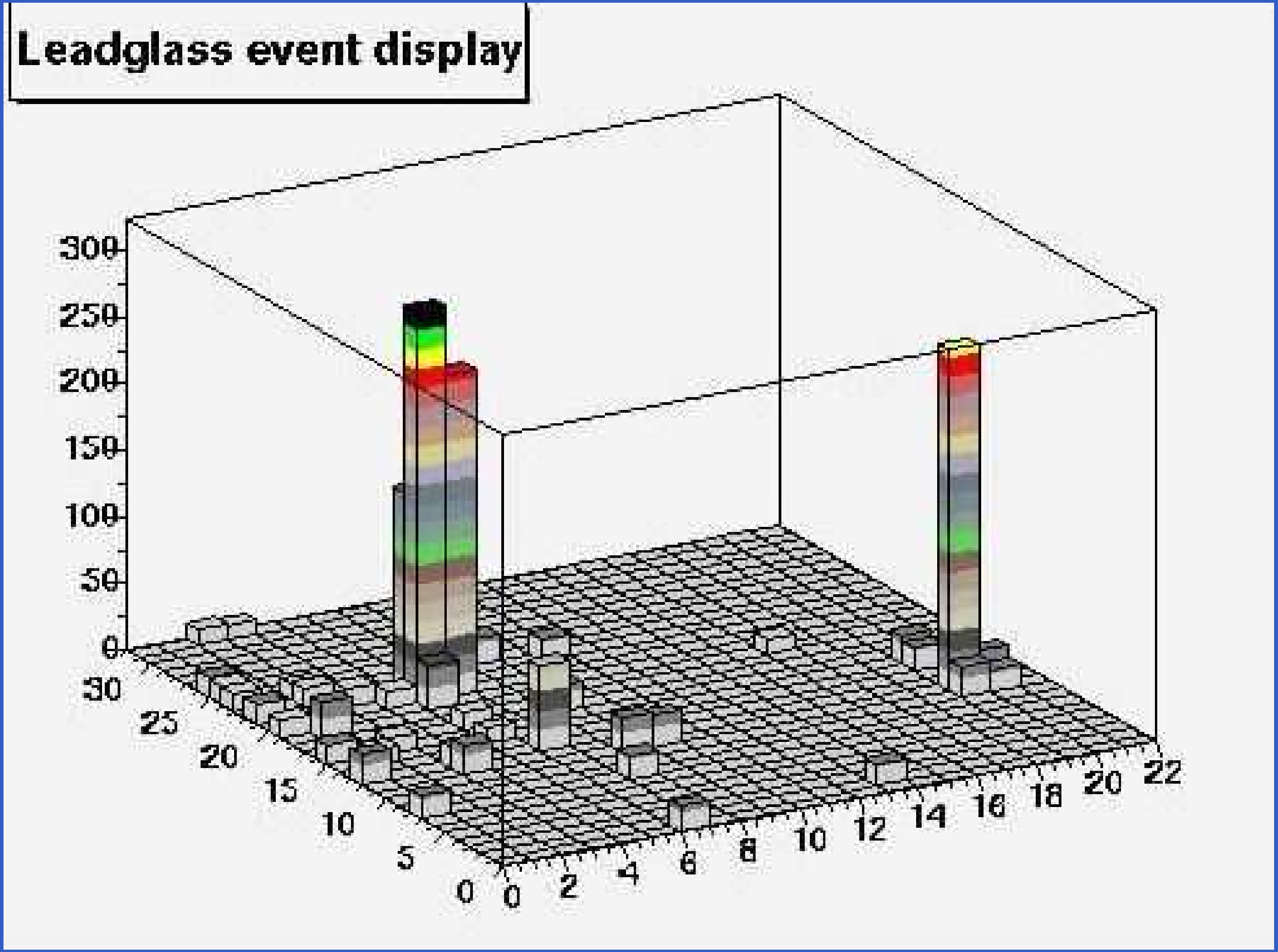
kin. P#	t (GeV/c)^2	u (GeV/c)^2	θ_γ^{lab} degree	θ_γ^{cm} degree	θ_p^{lab} degree	E_γ^{lab} GeV	p_p GeV/c	L m
P1	-2.4	-4.8	25	70	39	3.00	2.02	7.0
P2	-6.4	-0.75	82	140	12	0.87	4.25	2.5

Coils restrict access



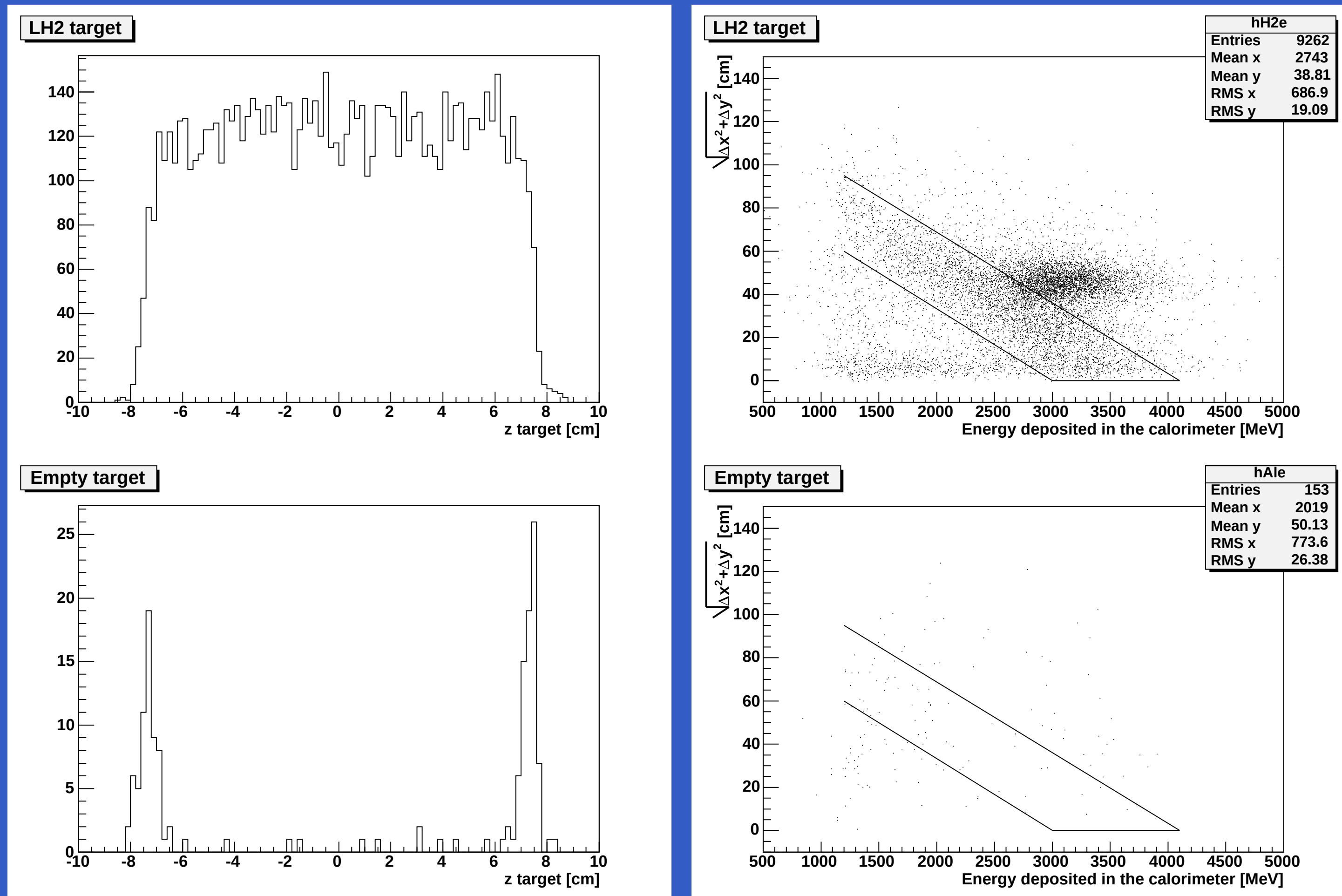
Magnet coils restrict access to range of angles: here the field direction is along the beam line.

π^0 photons



Leadglass event display
300
250
200
150
100
50
0
30
25
20
15
10
5
0
0
2
4
6
8
10
12
14
16
18
20
22

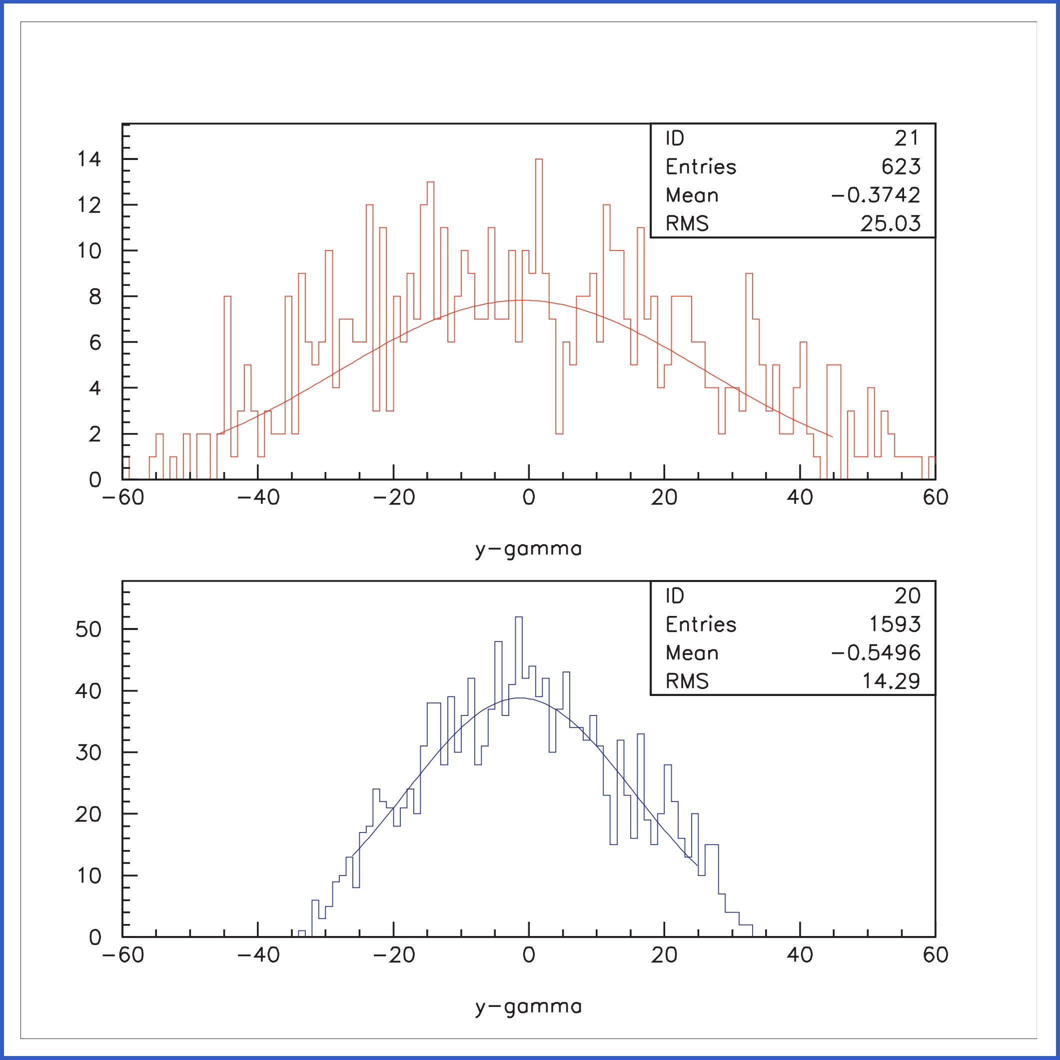
Dilution from other materials - Hall A Al data



Run Number	Target	Charge Coulomb	Thickness g/cm^2	Integrated $e-$N Luminosity	N_{pion} and Electrons
2377	Al	0.065	0.54	$2.1 \cdot 10^{22}$	57 (total)
2390	LH2	0.040	1.13	$2.7 \cdot 10^{22}$	3635+4300

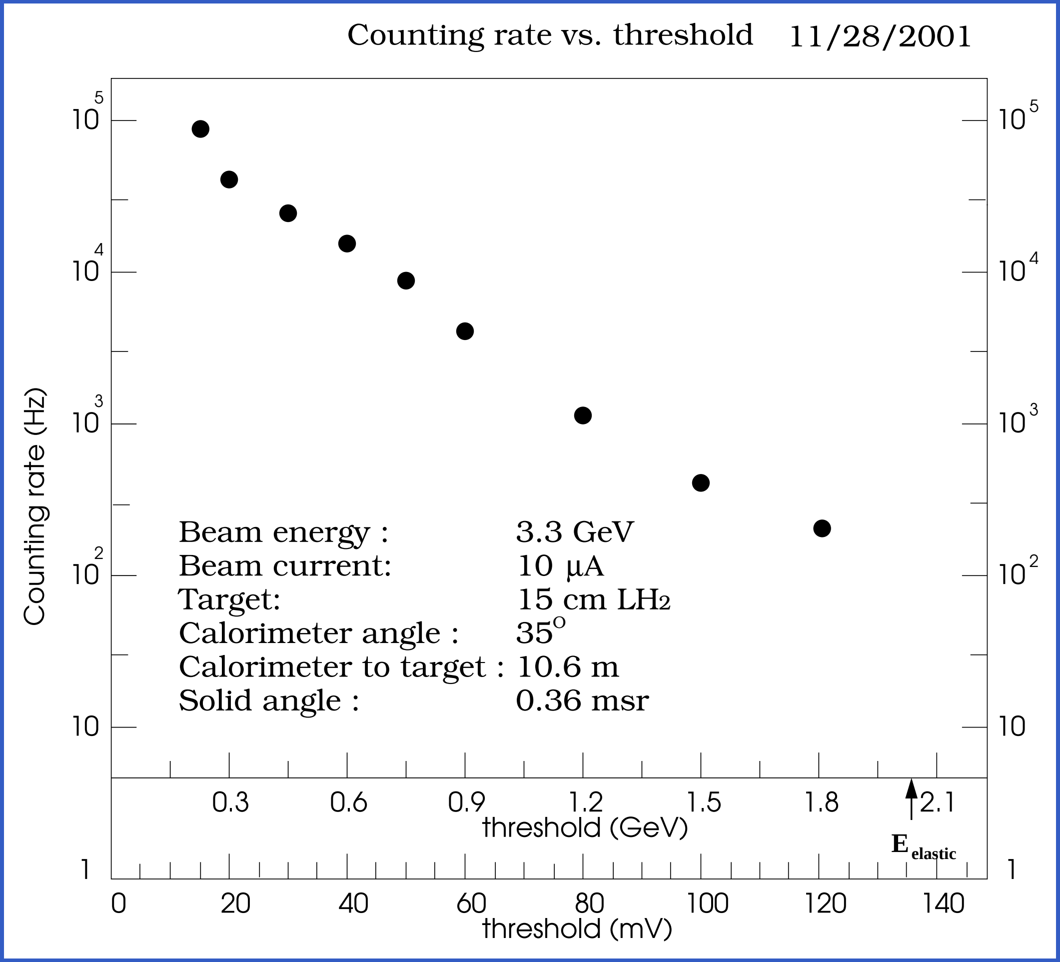
$$N_{quasi}/N_{free} \times (P_N + P_{He})/P_{free} = 0.02 \times (7 + 2.4)/3 \simeq 0.06$$

Dilution from other materials - Simulation results



$$F = \frac{N_p^\pi}{N_{\mathrm{free}\,p}^\pi} \times T_p \times T_\pi \times CL \times (P_N + P_{He})/P_{\mathrm{free}} = \frac{1}{3.5} \times 0.55 \times 0.4 \times \frac{1}{2} \times (7 + 2.4)/3 \sim 0.10$$

Rate test



Counting rate vs. threshold 11/28/2001
Counting rate (Hz)
Beam energy : 3.3 GeV
Beam current: 10 μA
Target: 15 cm LH2
Calorimeter angle : 35°
Calorimeter to target : 10.6 m
Solid angle : 0.36 msr
threshold (GeV)
E elastic
threshold (mV)

Miller approach compared to Huang et al.

Miller

- constituent quark model
- soft physics embodied in wave function (power law)
- $m_q \simeq 350$ MeV
- non-zero quark-helicity flip
- $\Rightarrow K_{LL} \neq A_{LL}$

Huang *et al.*

- current quarks
- proton helicity flip non-zero
- $\Phi_2 = -\Phi_6$; double-flip amplitudes
- Φ_2, Φ_6 are non-zero with α_s corrections, without both are zero.
- $\Rightarrow K_{LL} = A_{LL}$

Miller's quark helicity flip implies $\Phi_2 \neq -\Phi_6$ even with α_s corrections, and large compared to non-helicity flip