The Physics of CLAS

Bernhard A. Mecking
Jefferson Lab

20th Student Workshop on Electromagnetic Interactions
Bosen, August 31 – September 5, 2003

CEBAF at Jefferson Lab
CLAS
- technical
- physics program
- planned upgrades

CEBAF upgrade plans

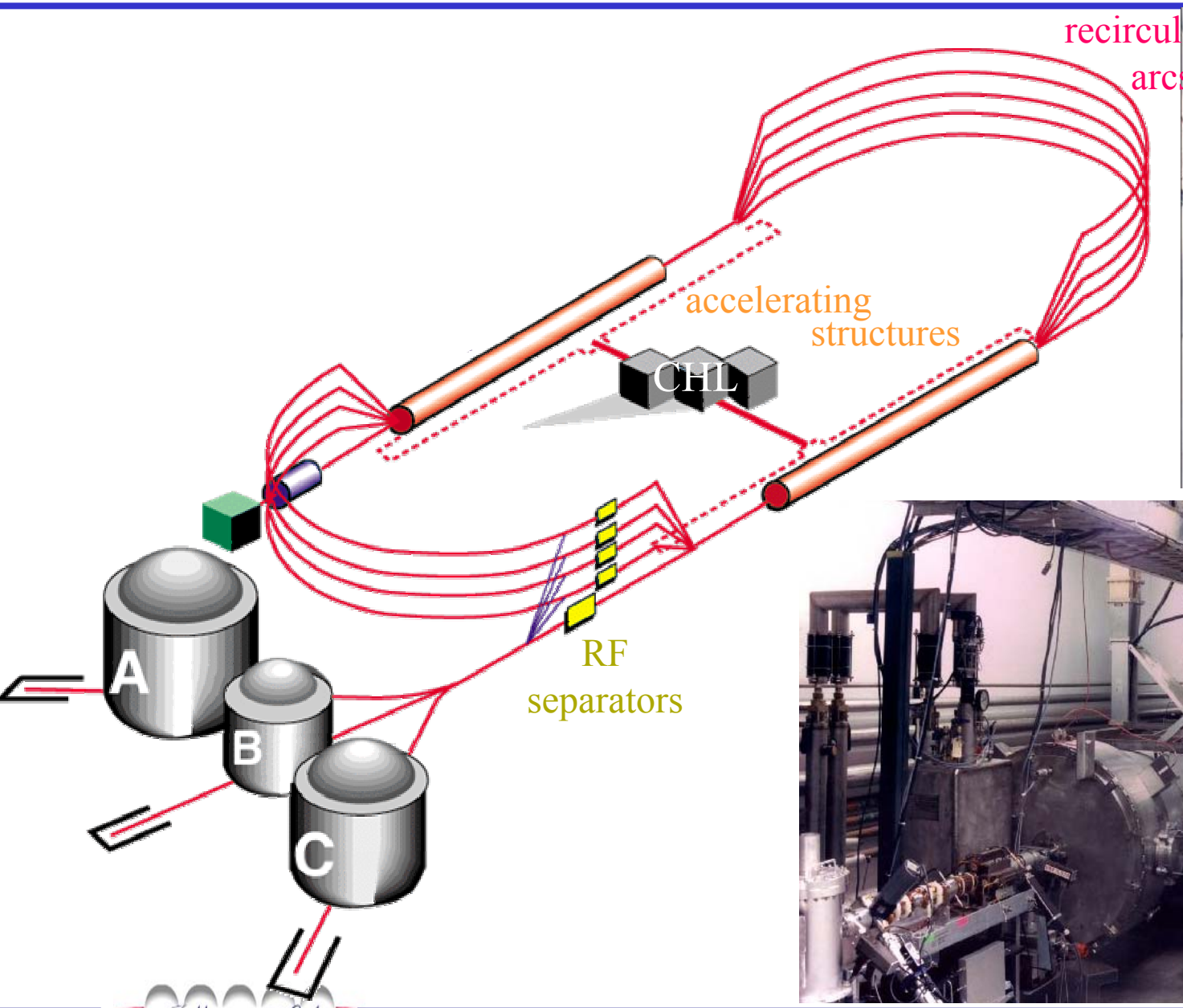
CEBAF @ Jefferson Lab

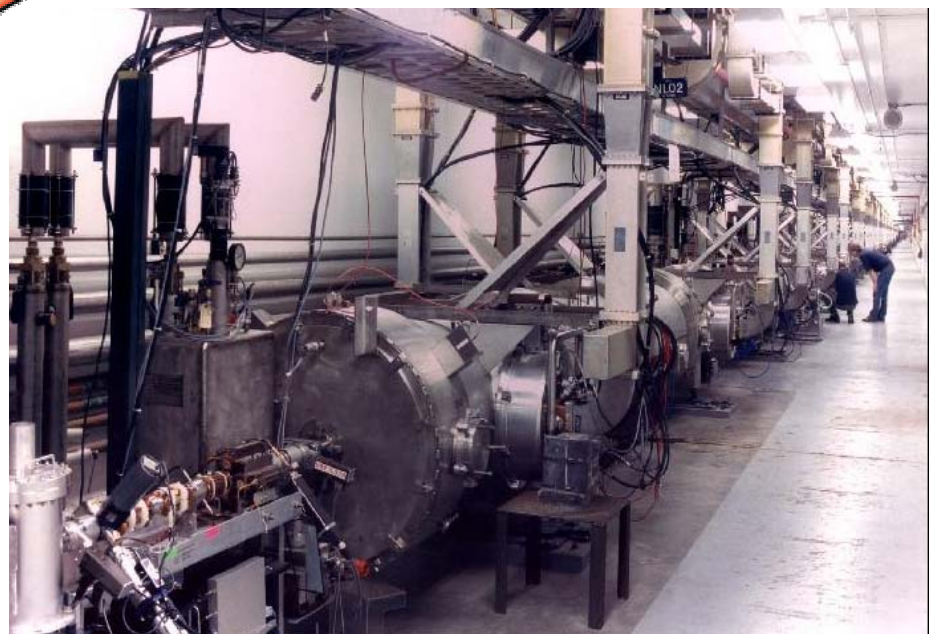
- Main physics programs
  - nucleon electromagnetic form factors (incl. strange)
  - $N \rightarrow N^*$ electromagnetic transition form factors
  - spin structure functions of the nucleon
  - form factors and structure of light nuclei

- Superconducting recirculating electron accelerator
  - max. energy 5.7 GeV
  - max current 200 μA
  - e polarization 80%

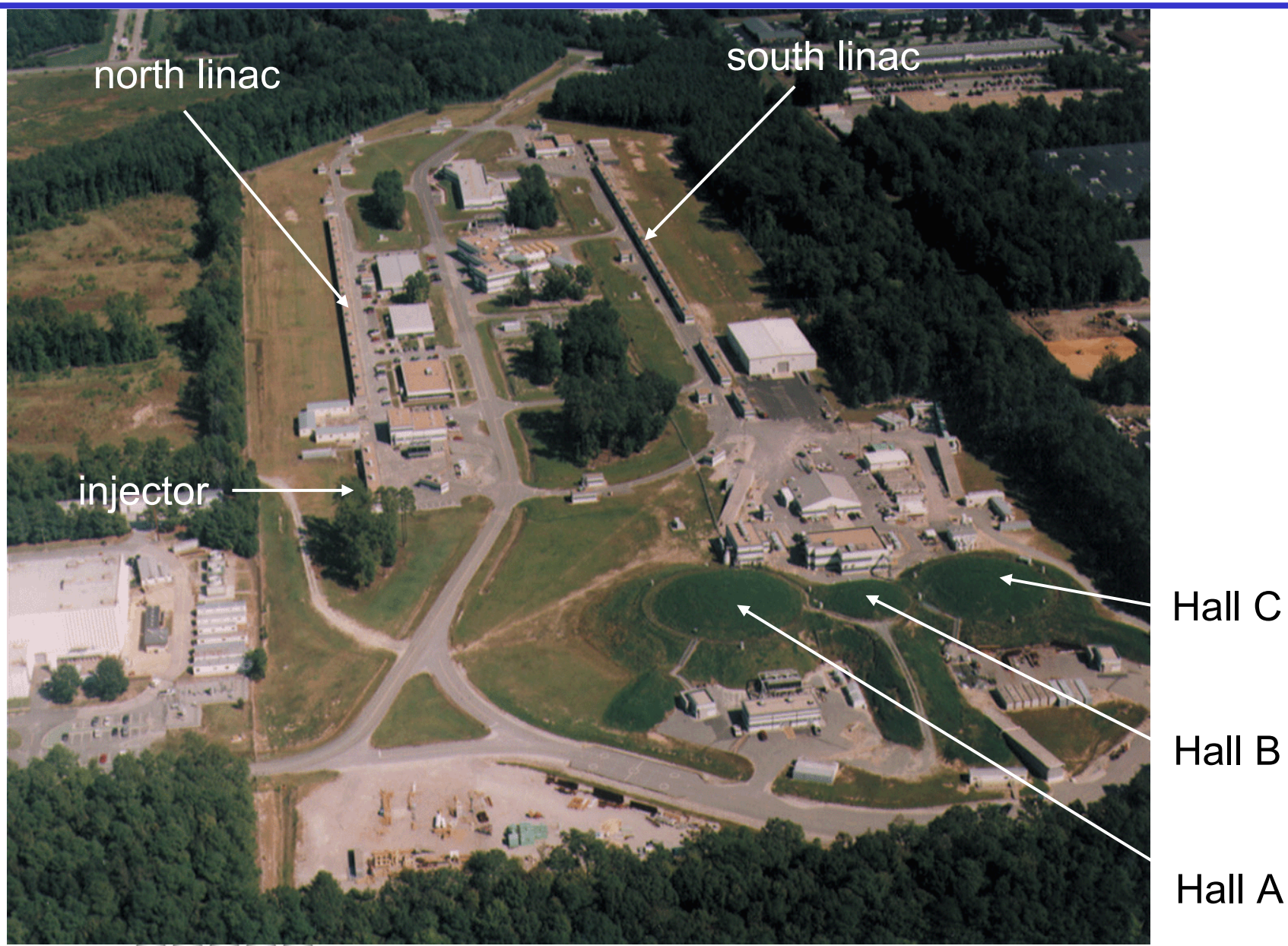
- Experimental equipment in 3 halls (simultaneous operation) L[$cm^{-2}s^{-1}$]
  - 2 High Resolution Spectrometers (p_{max}=4 GeV/c) 10^{39}
  - 2 spectrometers (p_{max}=7 and 1.8 GeV/c) + special equipment 10^{39}
  - Large Acceptance Spectrometer for e and γ induced reactions 10^{34}

CEBAF Continuous Electron Beam Accelerator Facility





CEBAF Site



Electron Beam Properties

Beam properties

- injector produces 3 separate beams via 3 pulsed (500 MHz) lasers on a common photocathode
- intensity ratio up to 10^6:1 (100μA in A/C vs. 100pA in B)
- energies in halls need to be a multiple of common linac energy setting

- max. beam power 1MW (e.g. 200μA at 5 GeV)
- typical beam spot size 100μm, momentum spread 10^{-4}

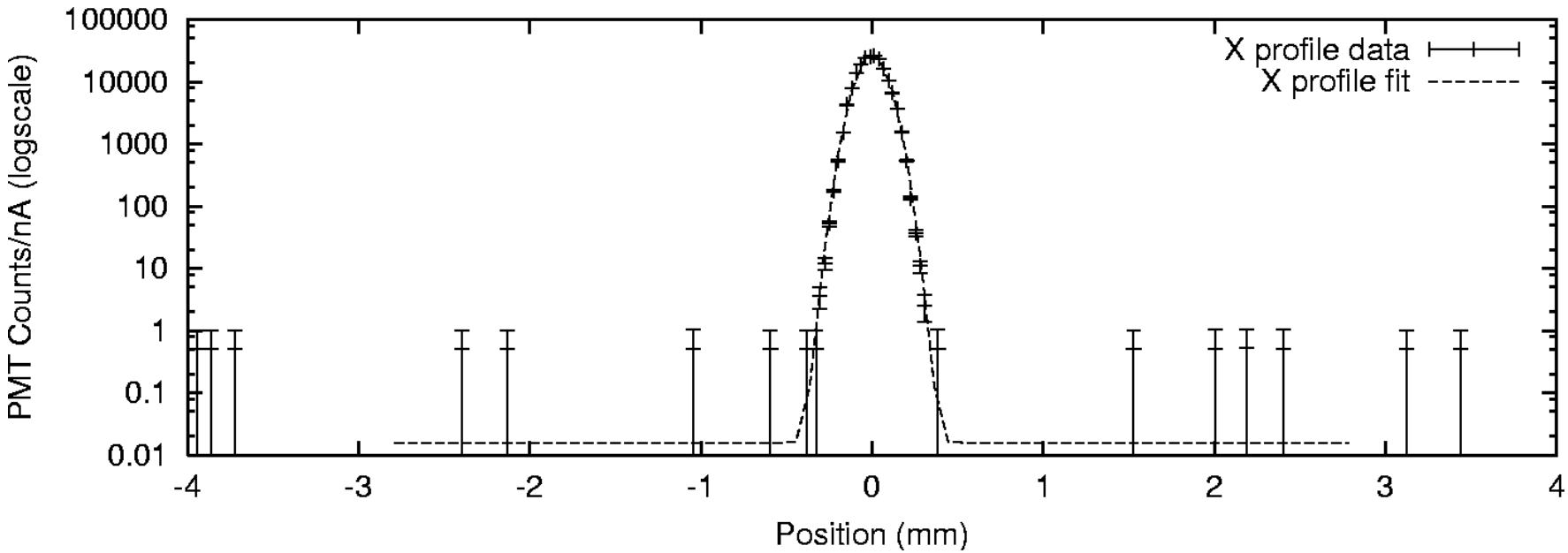
Polarization

- strained GaAs photocathode gives polarization up to 80%
- spin precession controlled by combination of Wien filter and linac energy setting (allows perfect spin alignment for two-hall operation, approximate for 3 halls)

Electron Beam Profile

measurement performed moving 25μm wire through beam

using downstream photomultipliers as radiation detectors



Hall B Physics Program

Areas Covered

- excitation of N* resonances (elementary and off nuclei)
- nucleon spin structure functions
- hadronic final states in electron scattering off nuclei

Common Experimental Requirements

- detection of >2 loosely correlated particles in the final state
- high counting rates for experiments that have luminosity limitations due to:
  - tagged photon beam (intensity limited by accidental coincidences)
  - polarized target operation (current limited by cooling + radiation damage)

Hall B Instrumentation

CEBAF Large Acceptance Spectrometer, CLAS

- for operation with electron and photon beams
- use missing mass technique -> good resolution for charged particles
- good particle identification
- high luminosity operation

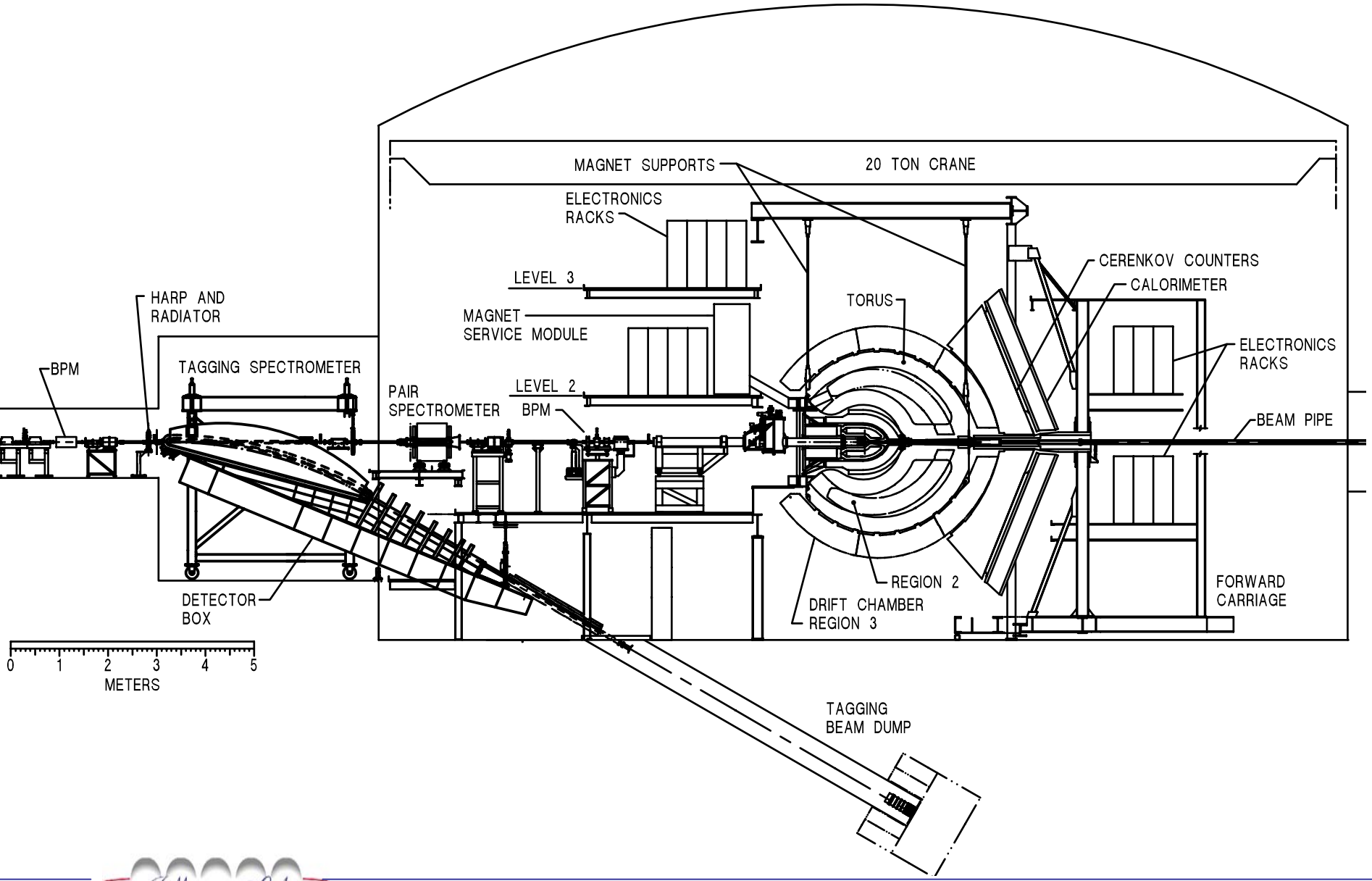
Trigger and Data Acquisition

- programmable flexible trigger
- high-speed data acquisition system

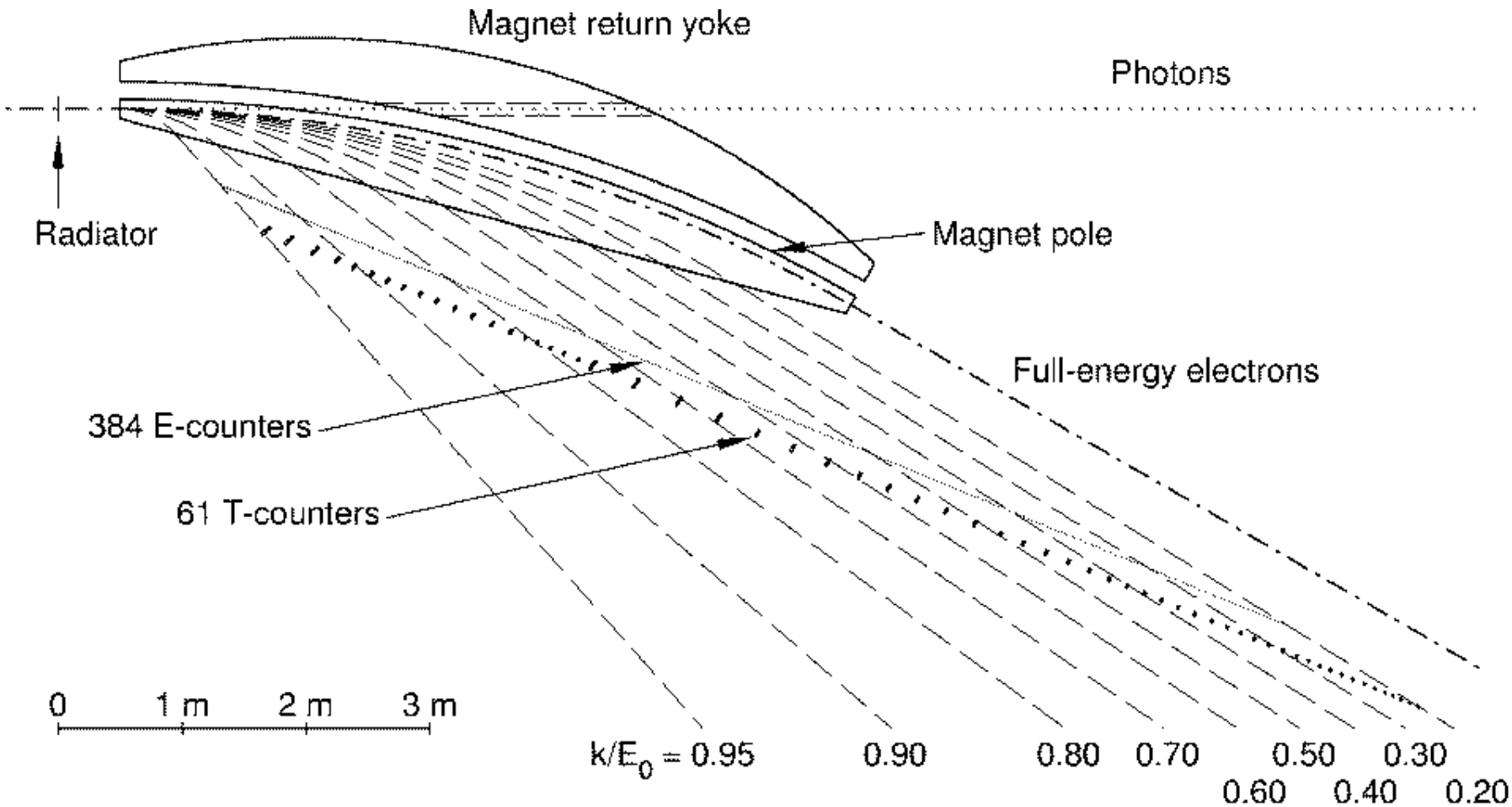
Beam Line Equipment

- beam position, current, and polarization monitoring
- polarized photon beam and bremsstrahlung tagging system

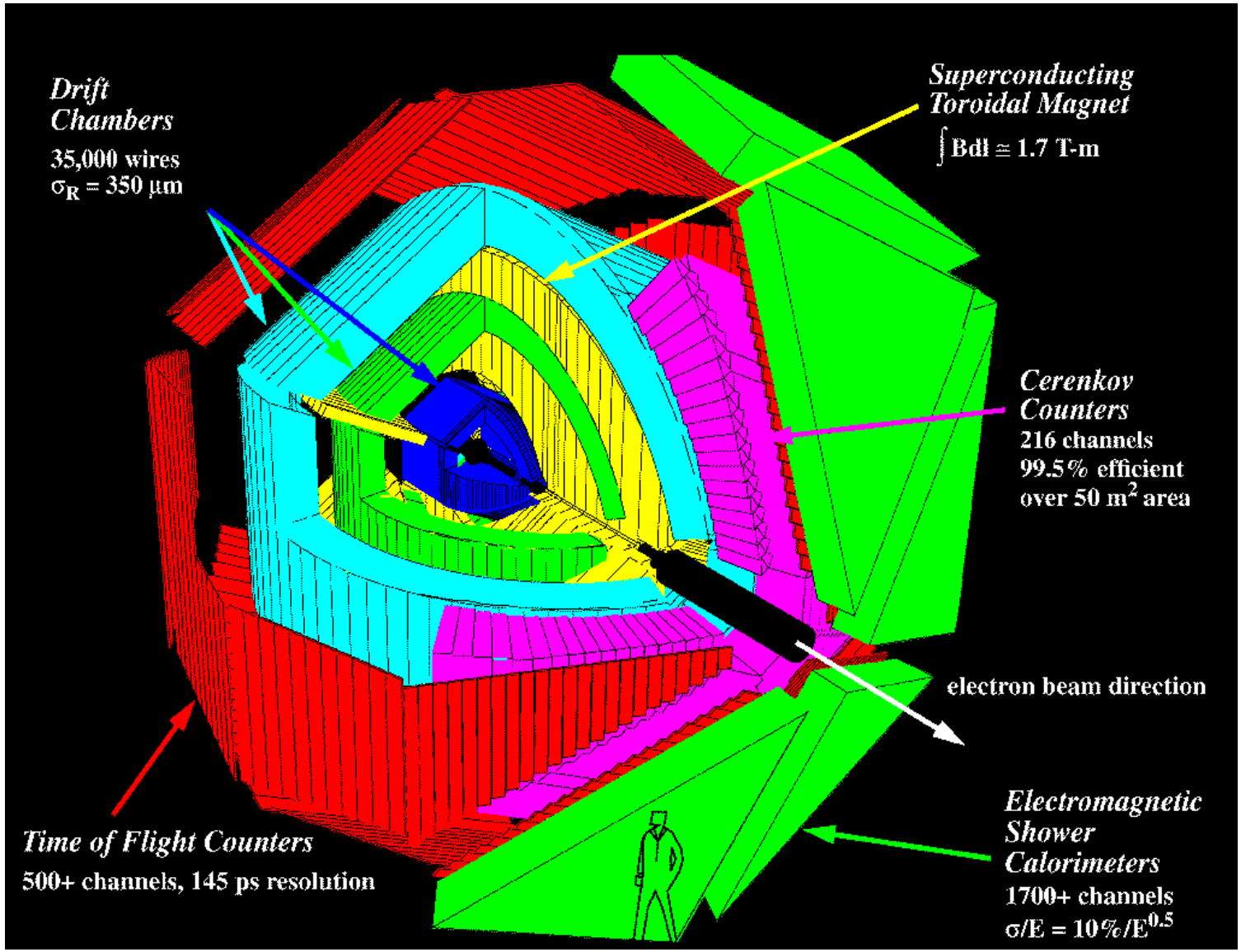
Hall B Side View



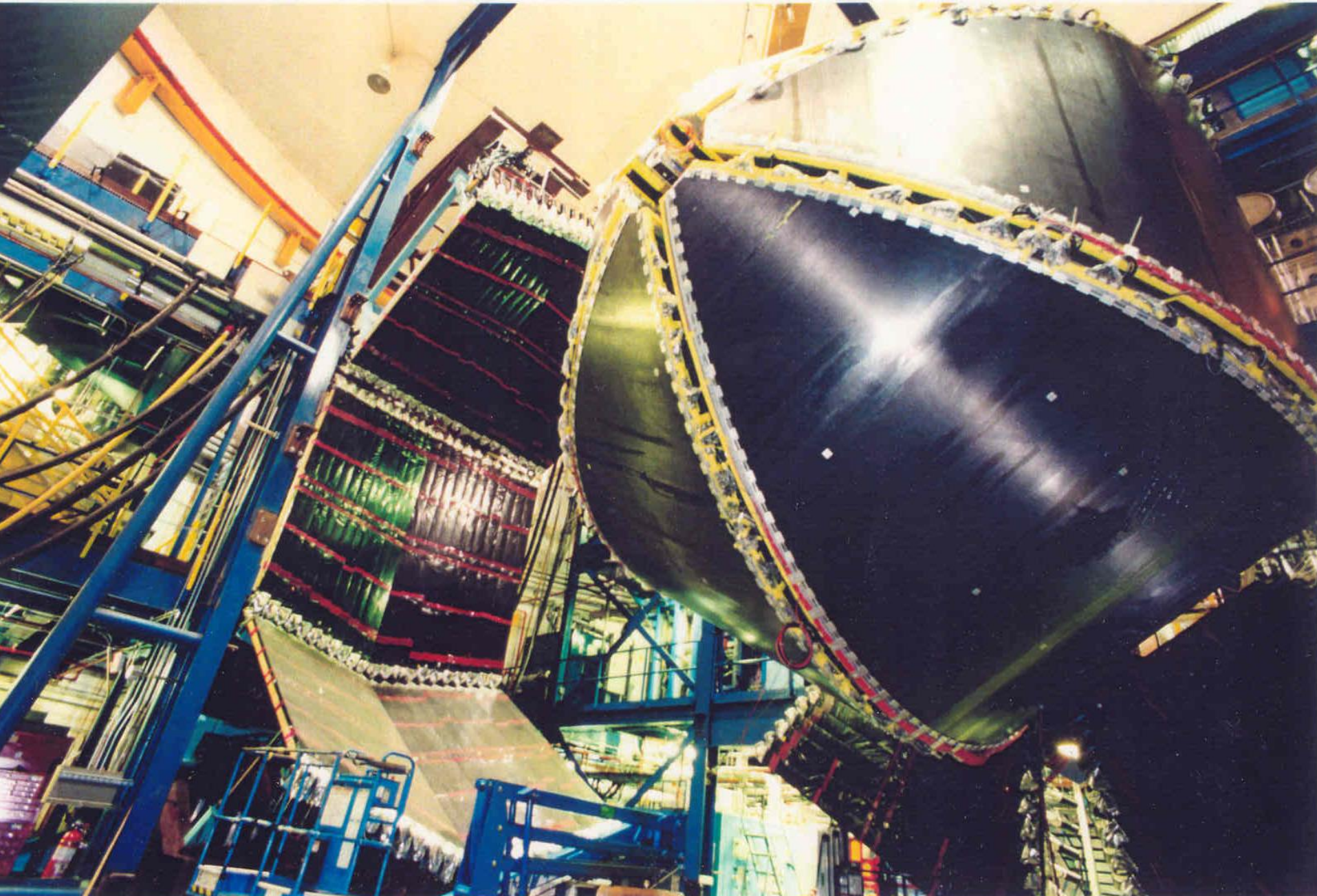
Bremsstrahlung Tagging System Layout



CLAS 3-D View


Drift Chambers
35,000 wires
σ_R = 350 μm
Superconducting Toroidal Magnet
$\int Bdl \cong 1.7$ T-m
Cerenkov Counters
216 channels
99.5% efficient
over 50 m^2 area
electron beam direction
Electromagnetic Shower Calorimeters
1700+ channels
$\sigma/E = 10\%/E^{0.5}$
Time of Flight Counters
500+ channels, 145 ps resolution

CLAS in Maintenance Position



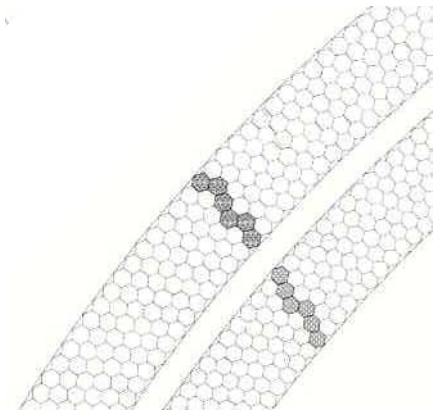
Characteristics of CLAS Components

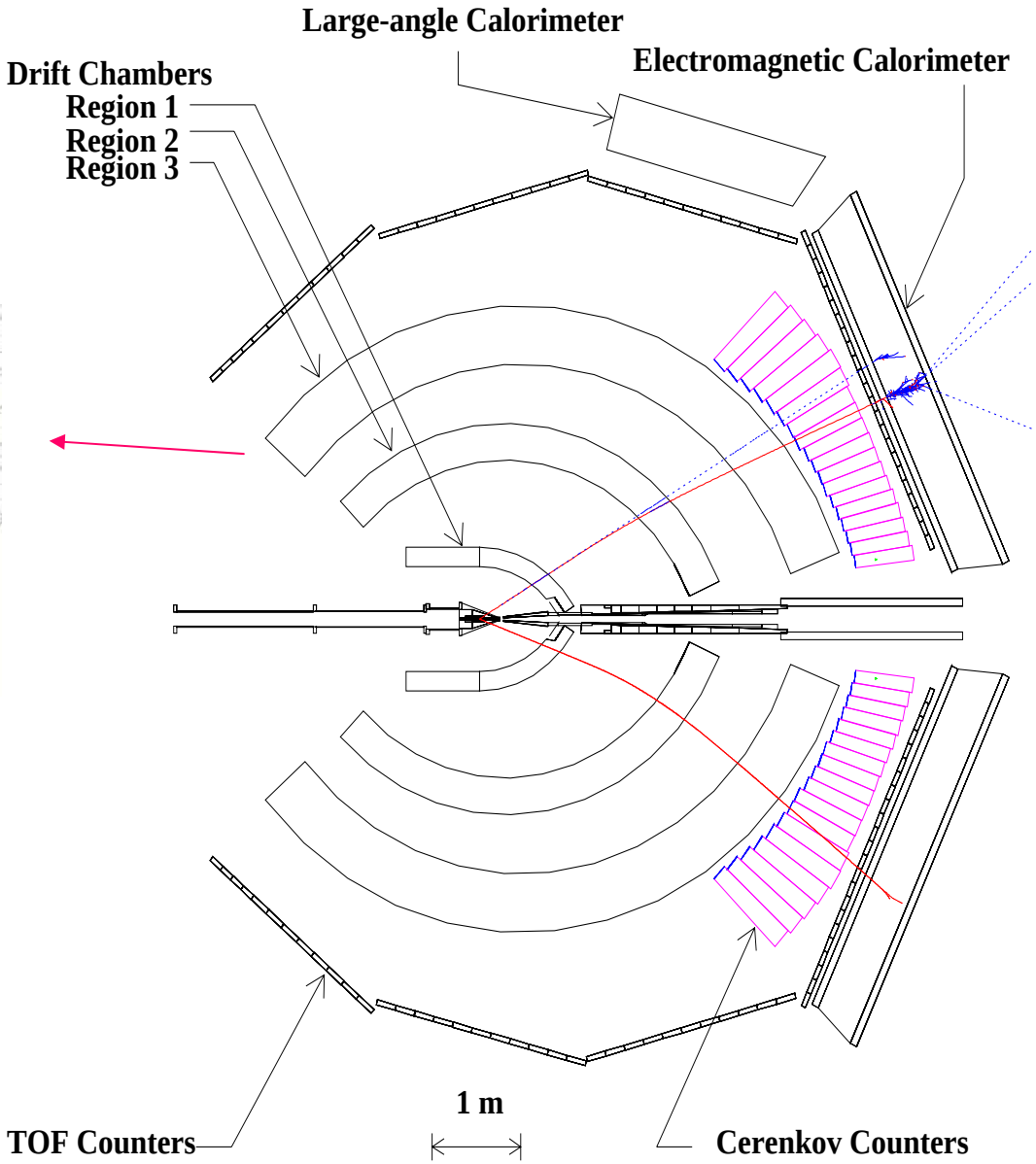
- Charged particle tracking in six independent sectors
  - 3 drift chamber packages per sector
  - 34 layers (axial and stereo)
  - drift time recorded from 35,000 sense wires
- Threshold Cerenkov counters for e identification
  - C_4F_{10} gas radiator
  - focussing mirror system
  - 250 PMT's, time and charge recorded
- Scintillation time-of-flight counters
  - 5 cm thick scintillators with PMT's at both ends
  - 600 PMT's, time and charge recorded

CLAS Components (cont'd.)

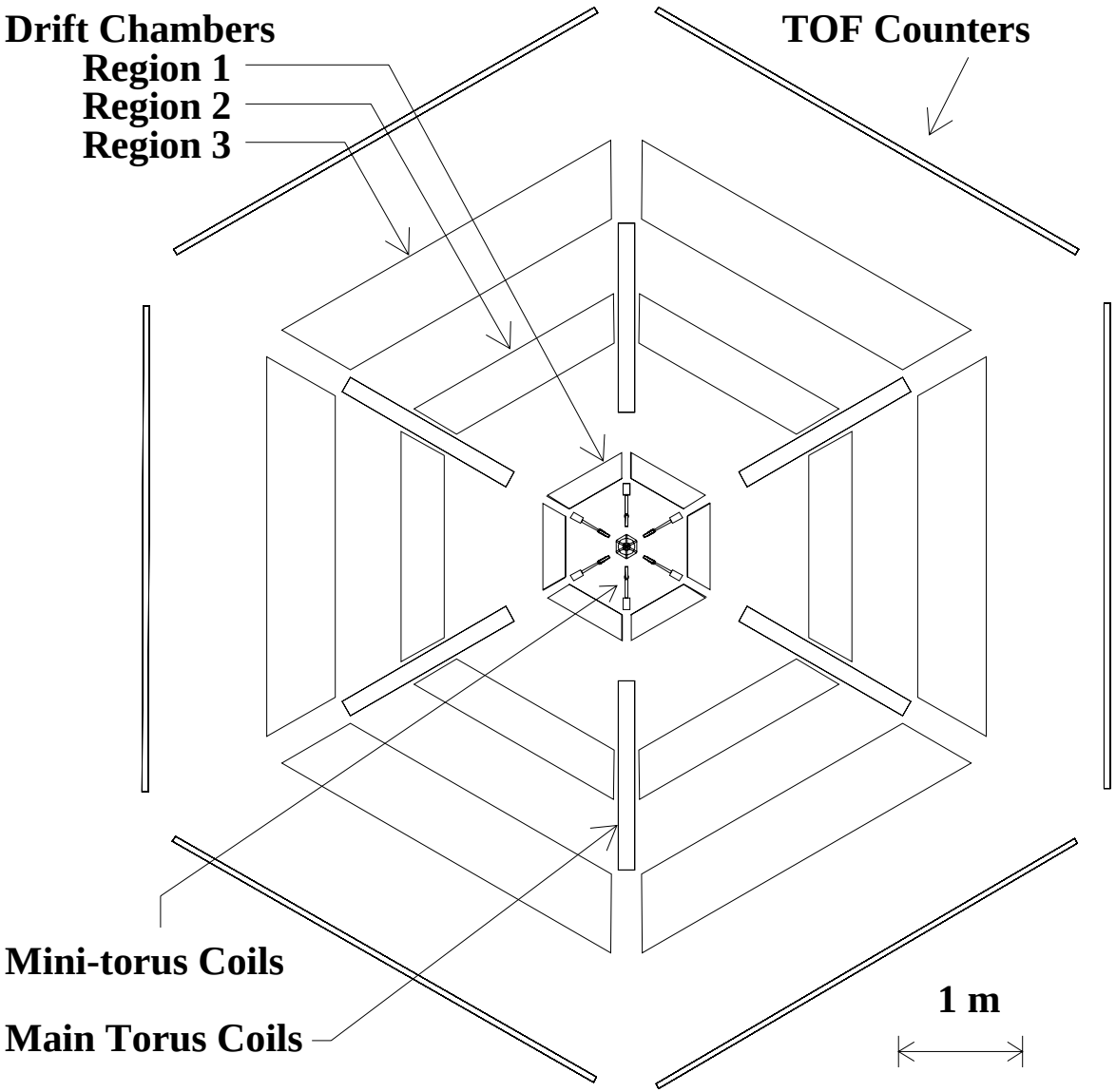
- Electromagnetic calorimeters
  - lead-scintillator sandwich construction, 39 layers
  - 1,300 PMT's, time and charge recorded
- Beam line equipment
  - Møller polarimeter to measure electron polarization
  - bremsstrahlung tagging system with crystal radiator, 500 PMT's
  - cryogenic (H, D, ^{3,4}He) or polarized targets (H, D)
- Electronics and data acquisition
  - programmable two-level trigger system (custom design)
  - mostly commercial data conversion modules (18 FastBus, 5 VME crates)
  - parallel data readout into multi-processor on-line DAQ system

CLAS Top View





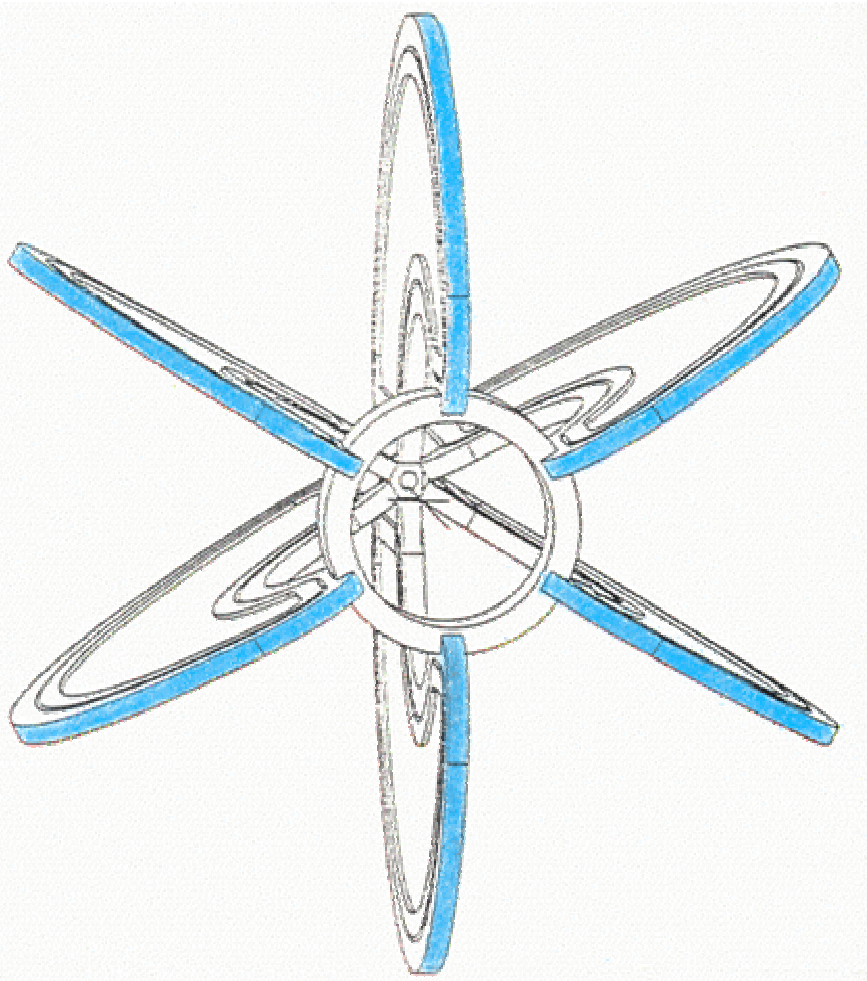
CLAS Rear View

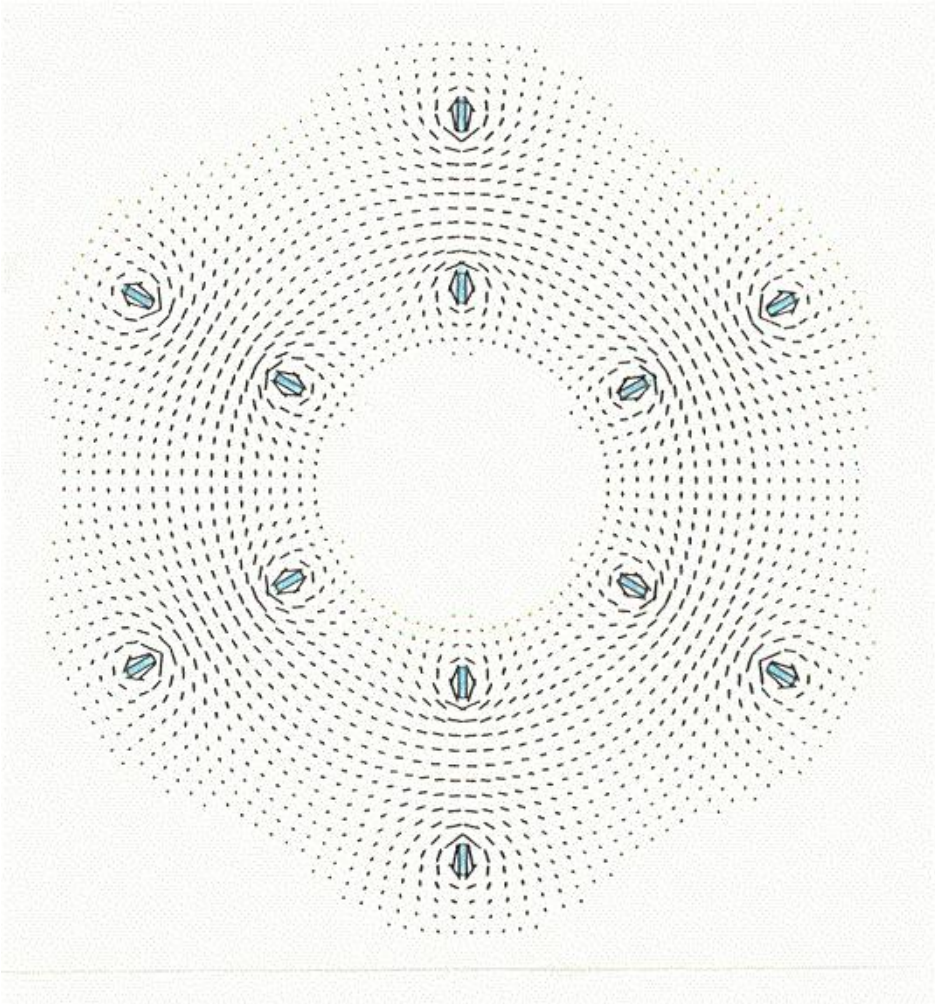


Characteristics of CLAS Components

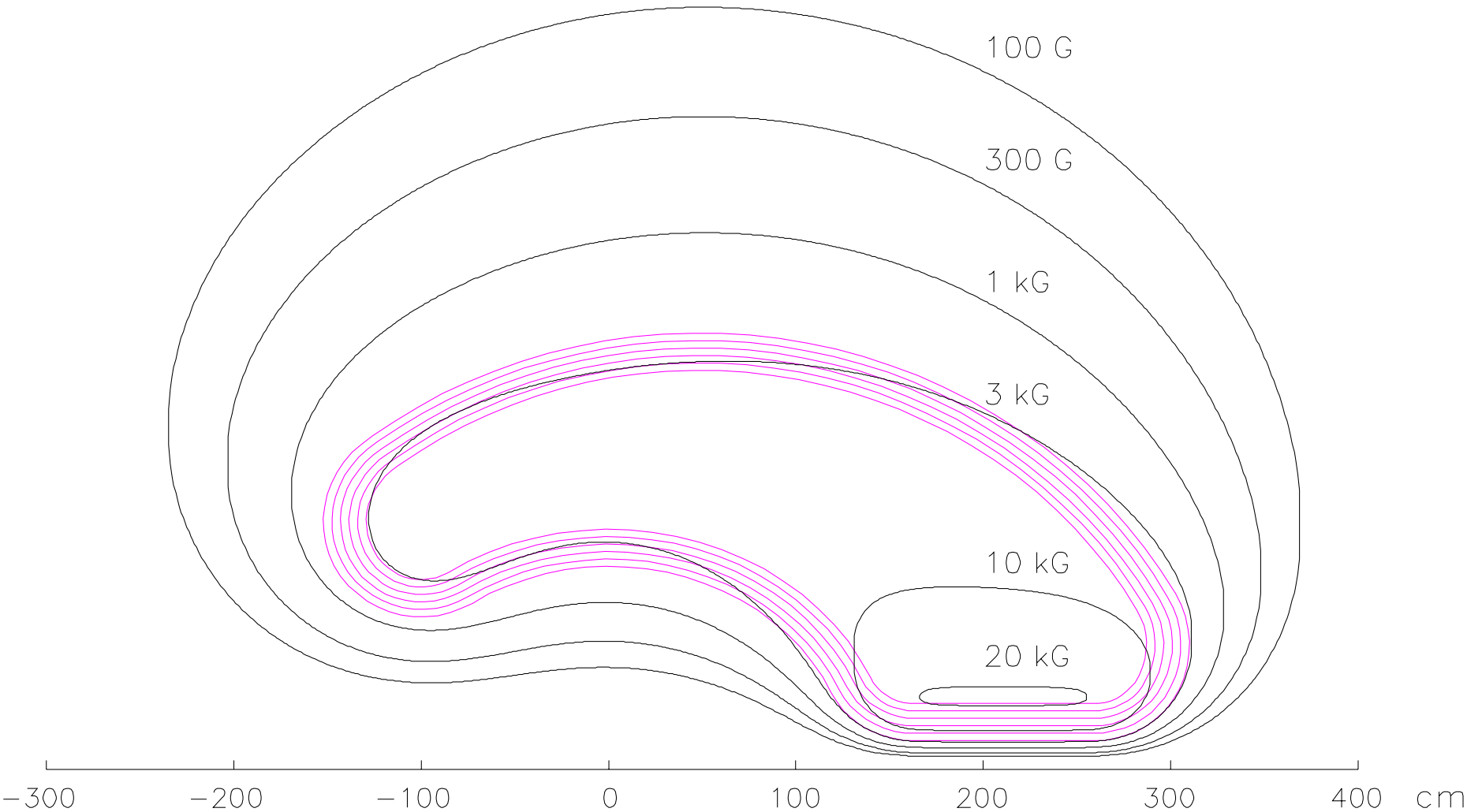
Super-conducting toroidal magnet with six kidney-shaped coils

5 m diameter, 5 m long, 5 M-Amp-turns, max. field 2 Tesla

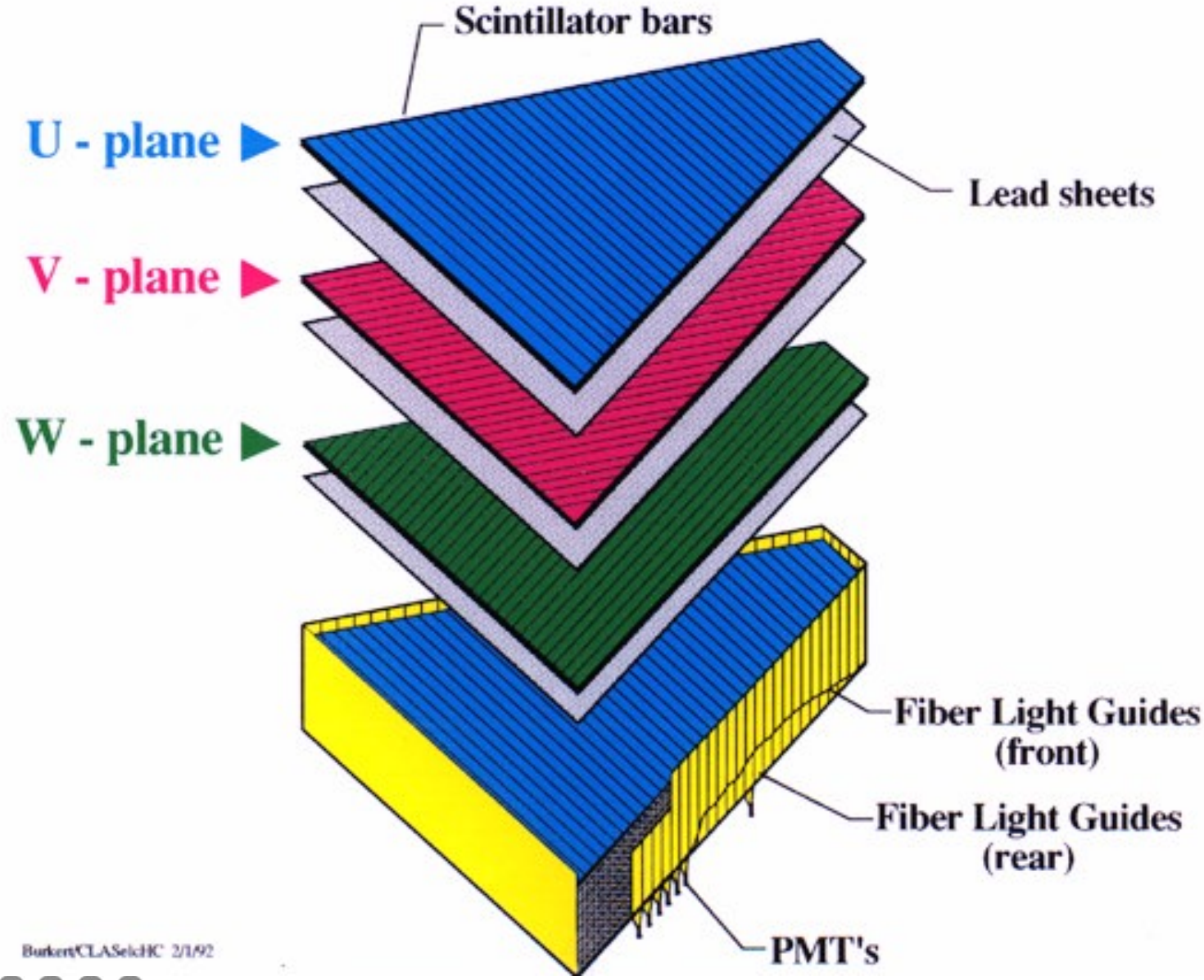




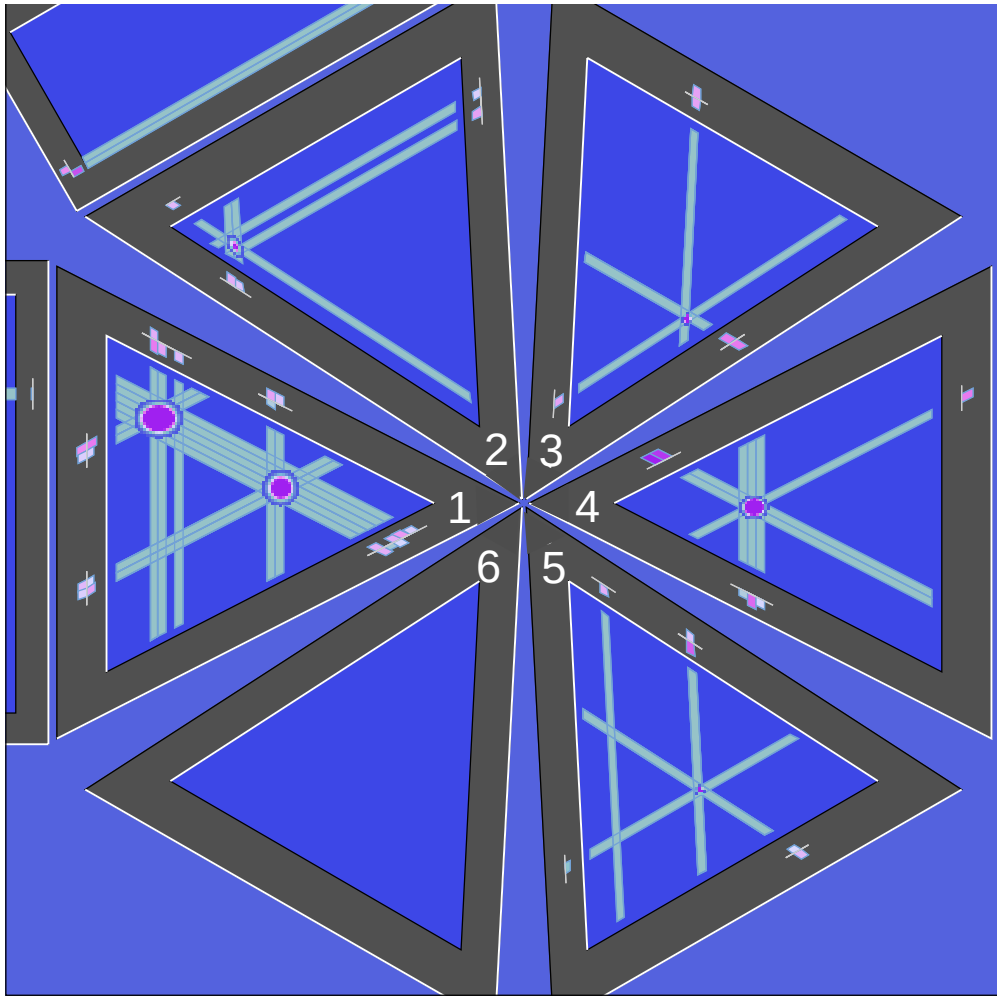
CLAS Lines of Constant Field



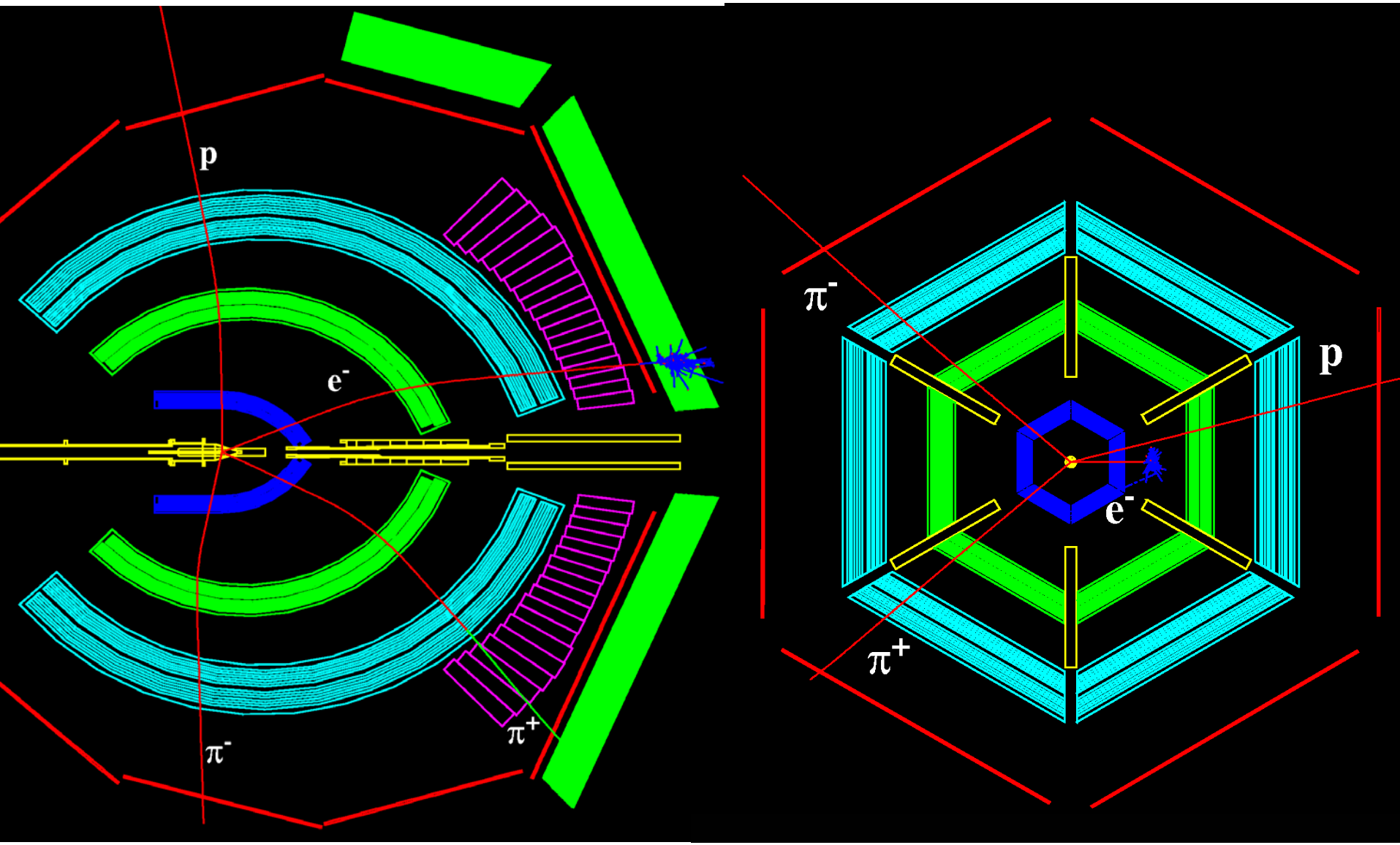
CLAS Forward Calorimeter Layout



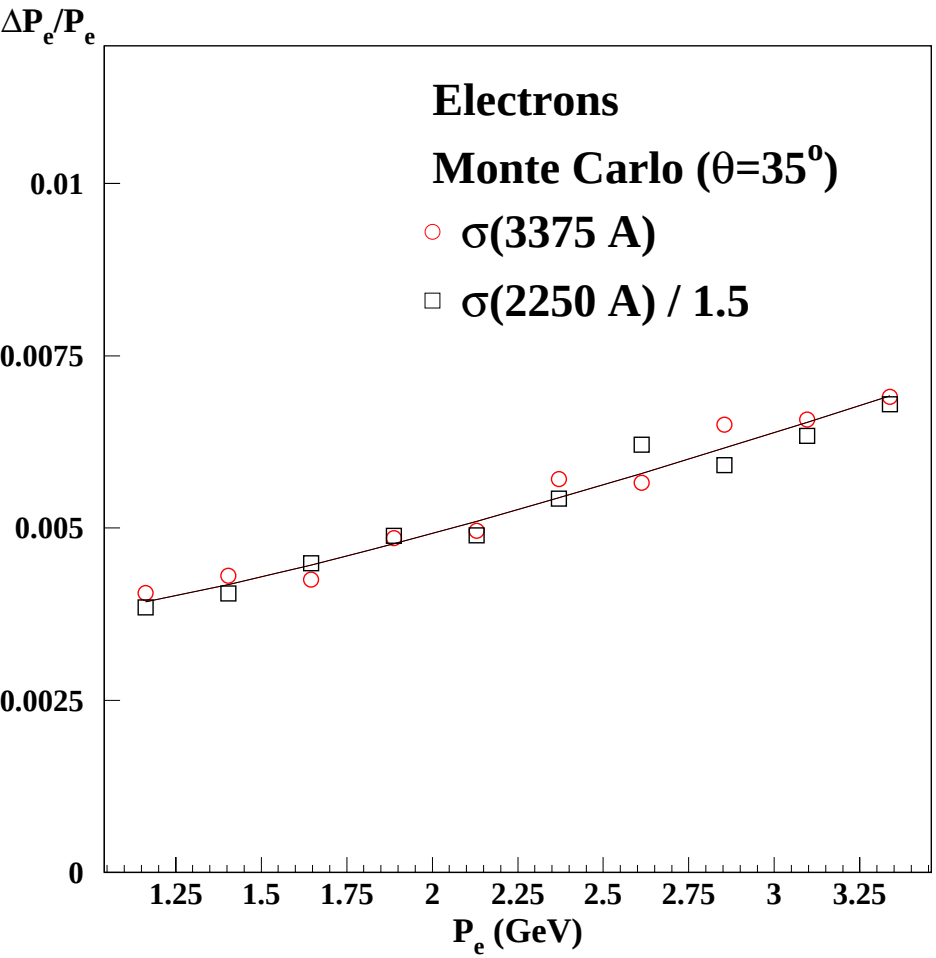
Forward Calorimeter Hit Pattern

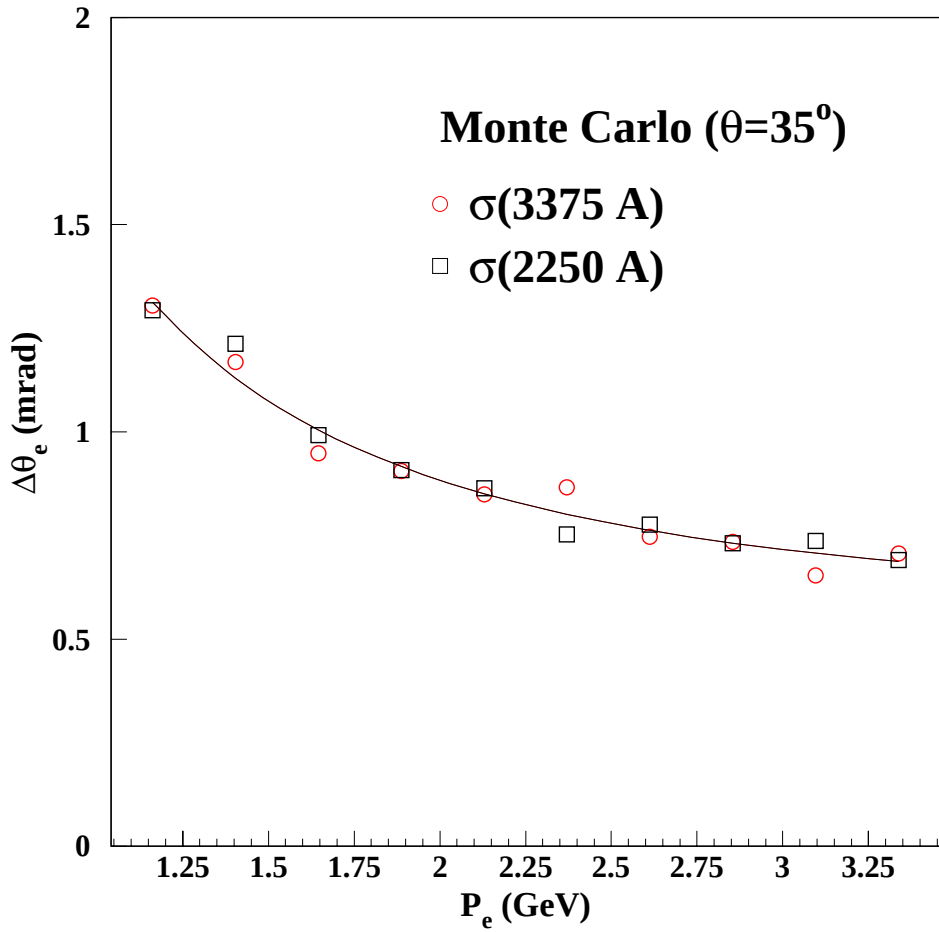


CLAS Single Event Display

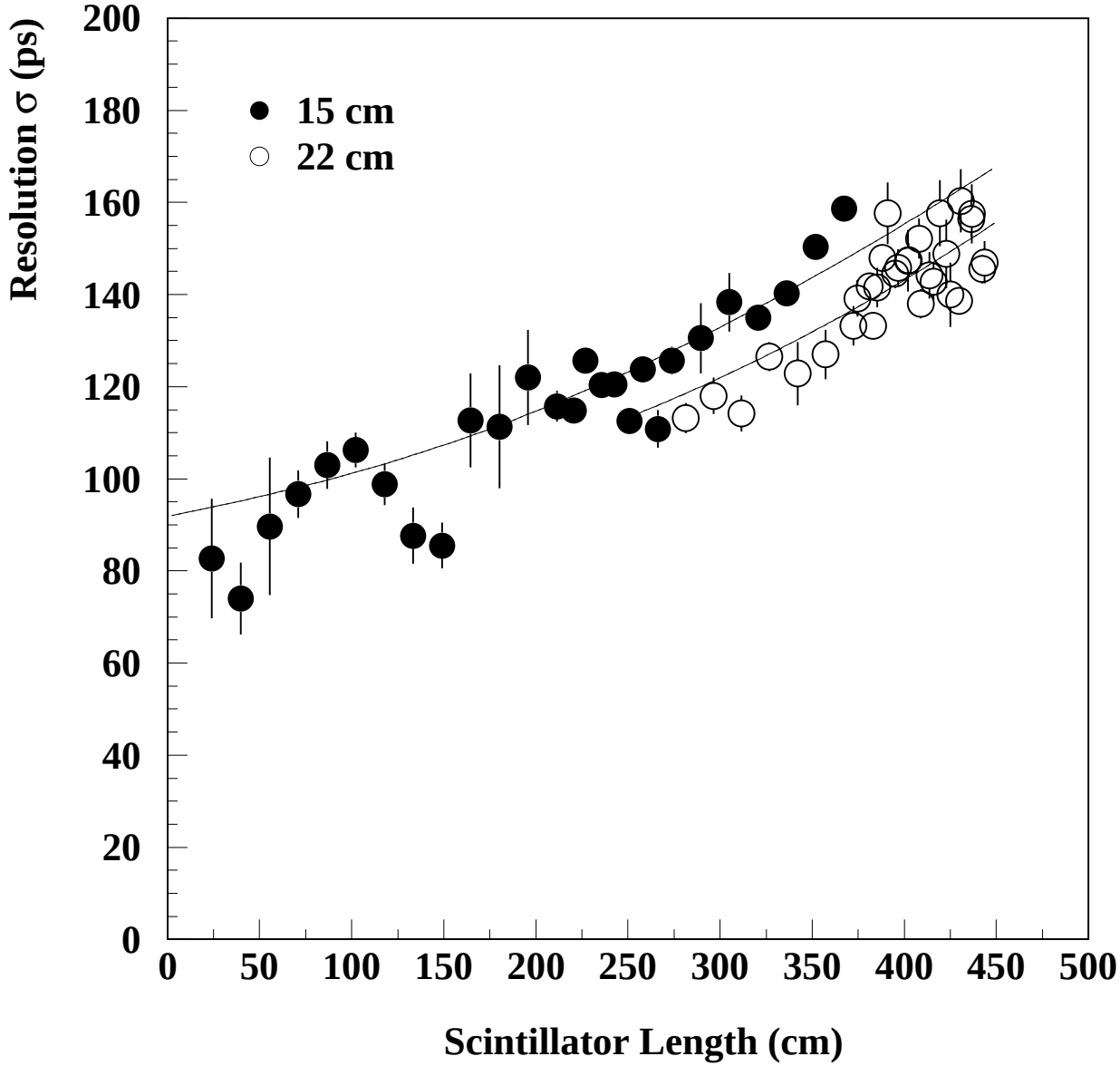


Trajectory Reconstruction Resolution

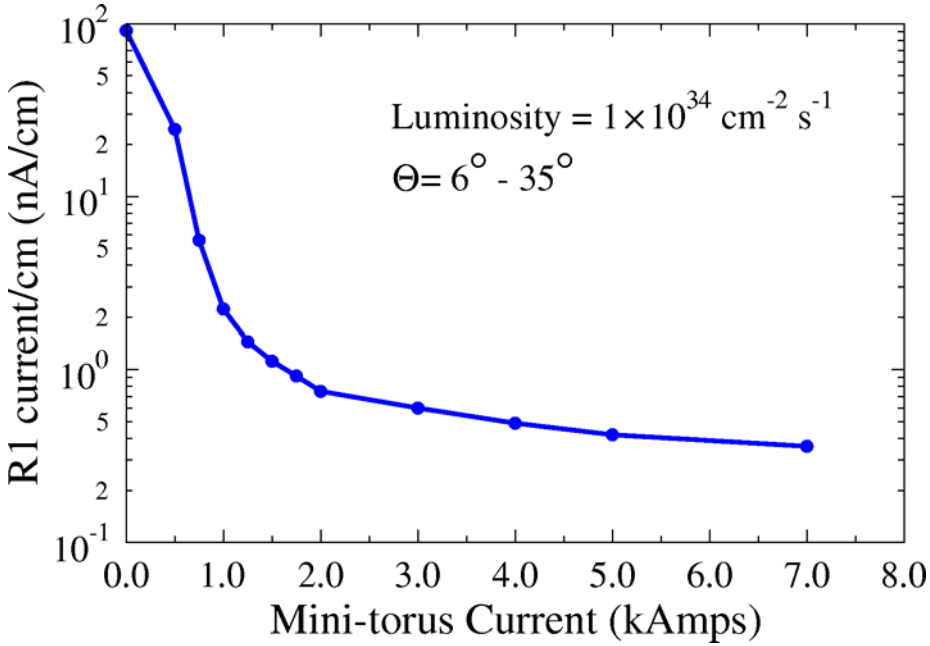


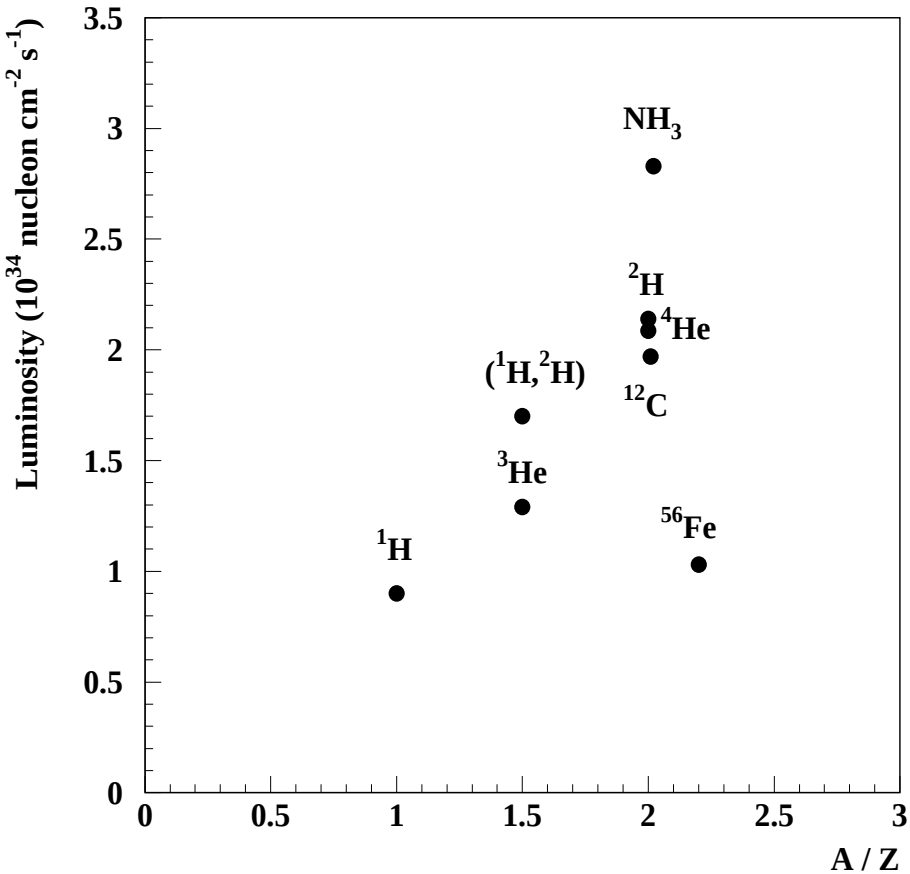


Scintillation Counter Timing Resolution

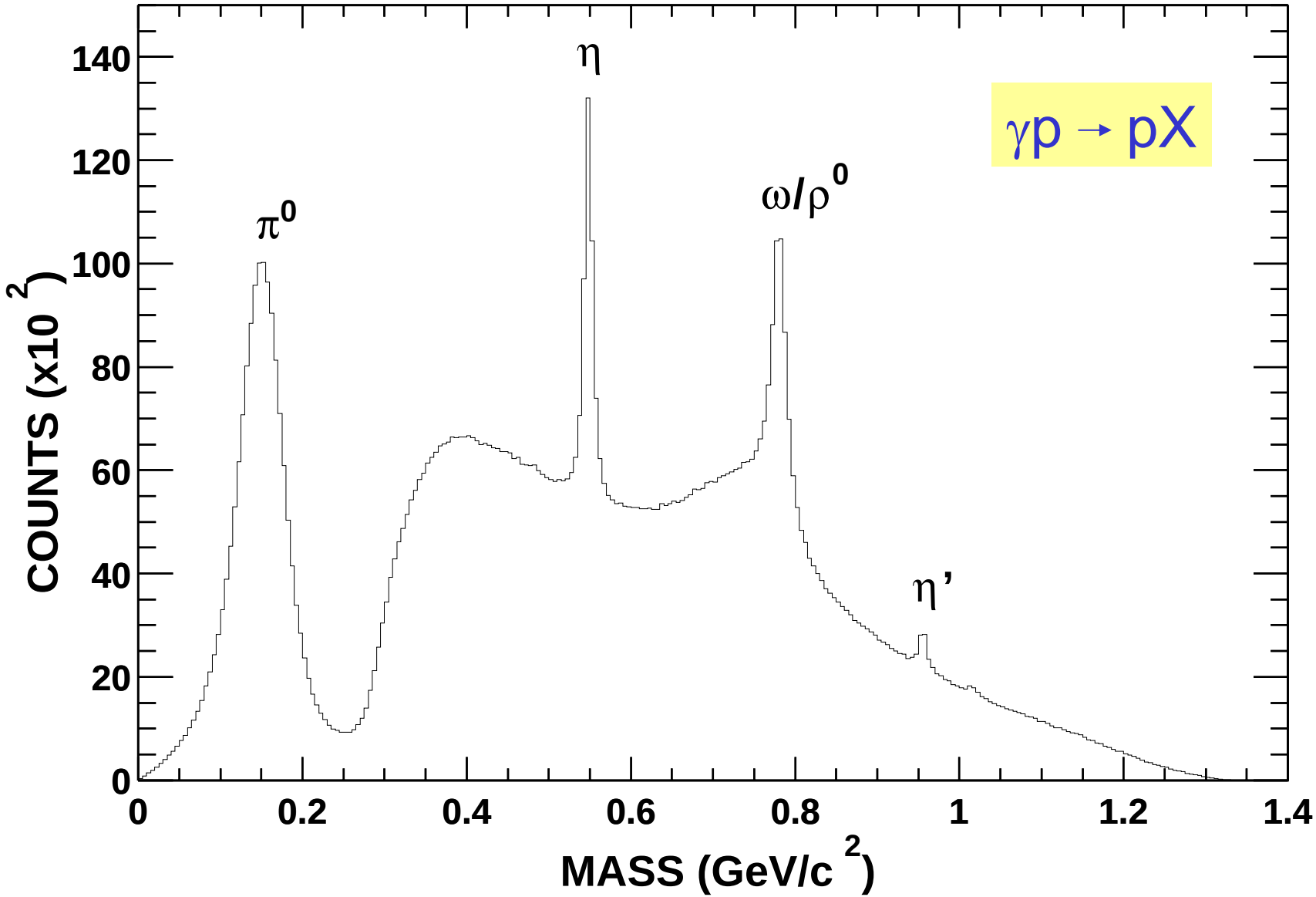


CLAS Luminosity for e^-

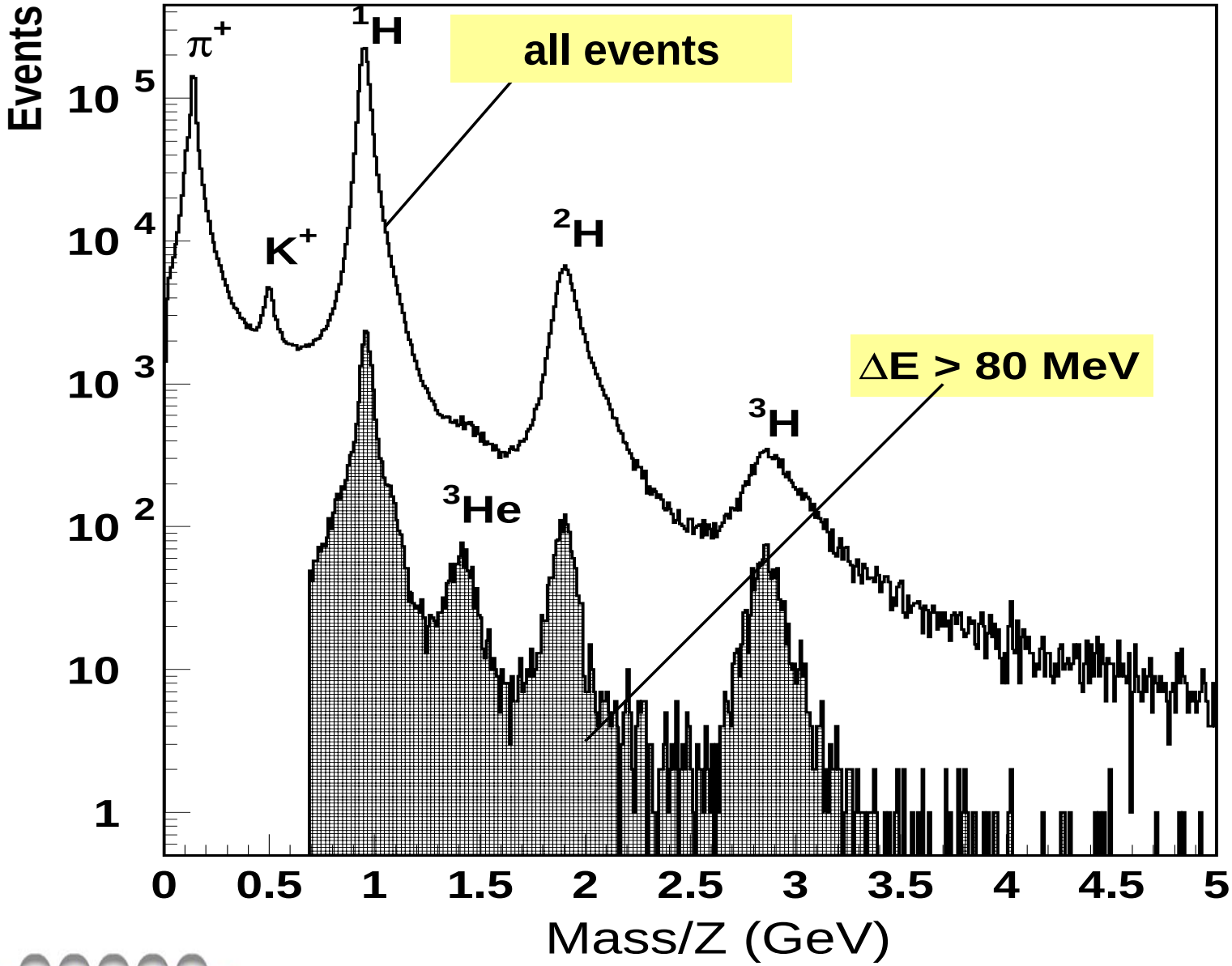




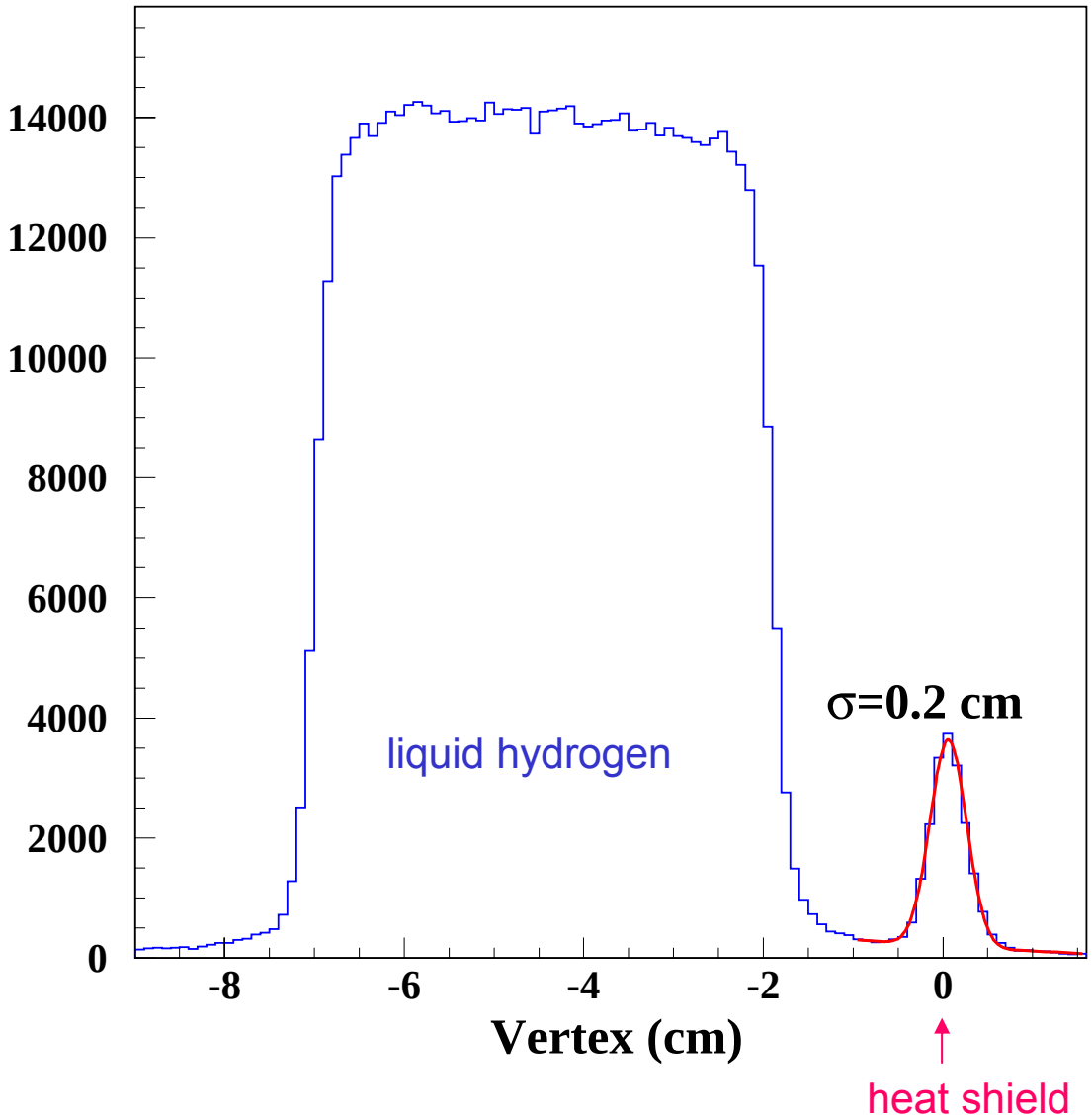
Missing Mass Distribution



Mass Determination from p and β



z-Vertex Determination from Tracking



vertex determination used routinely for experiments with multiple targets in the beam:

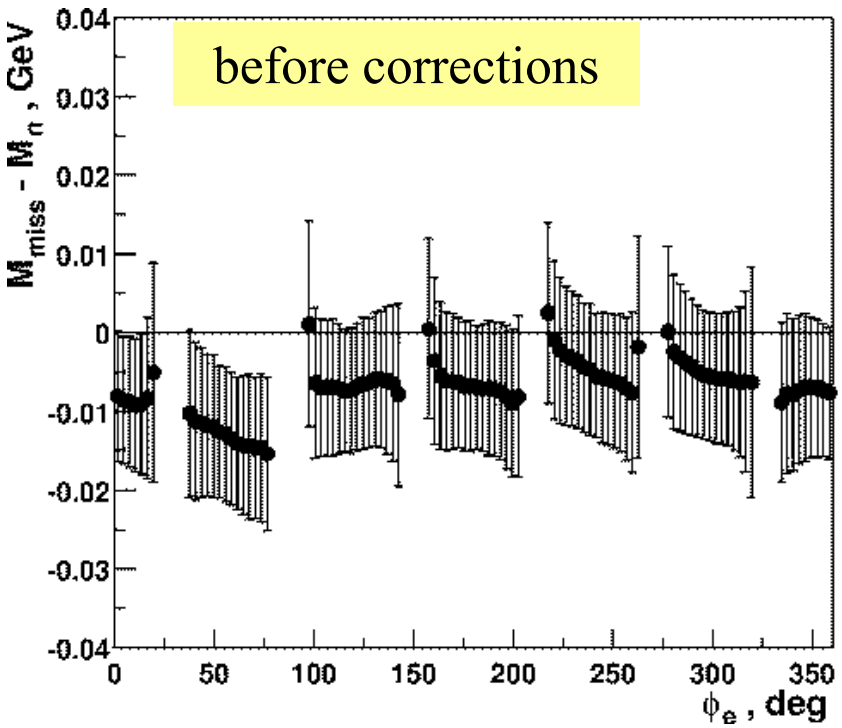
- simultaneous LH_2 and LD_2
- multiple target foils

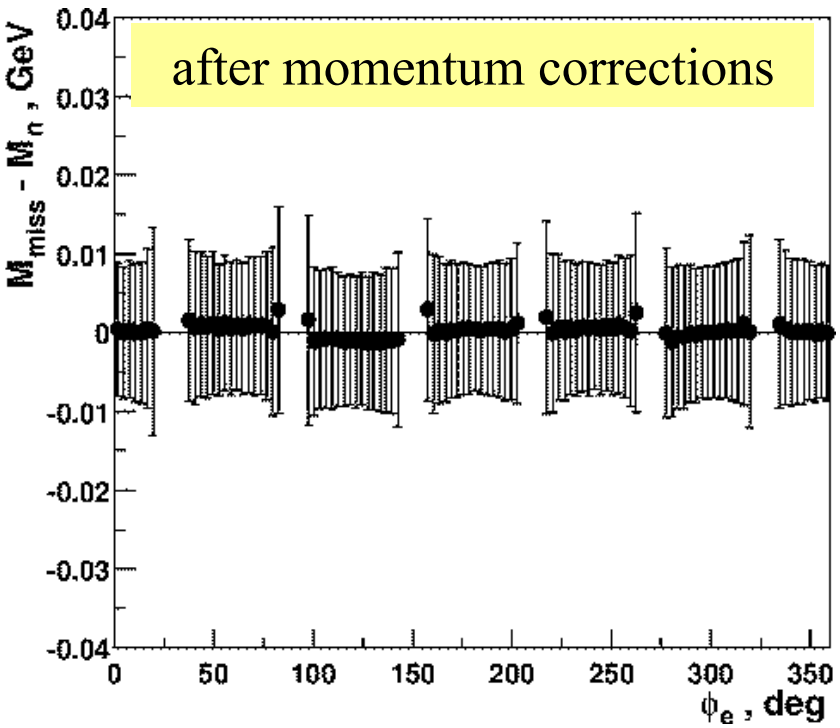
Trajectory Reconstruction Distortions

Explored in $e\,p \rightarrow e'\pi^+\,(n)$

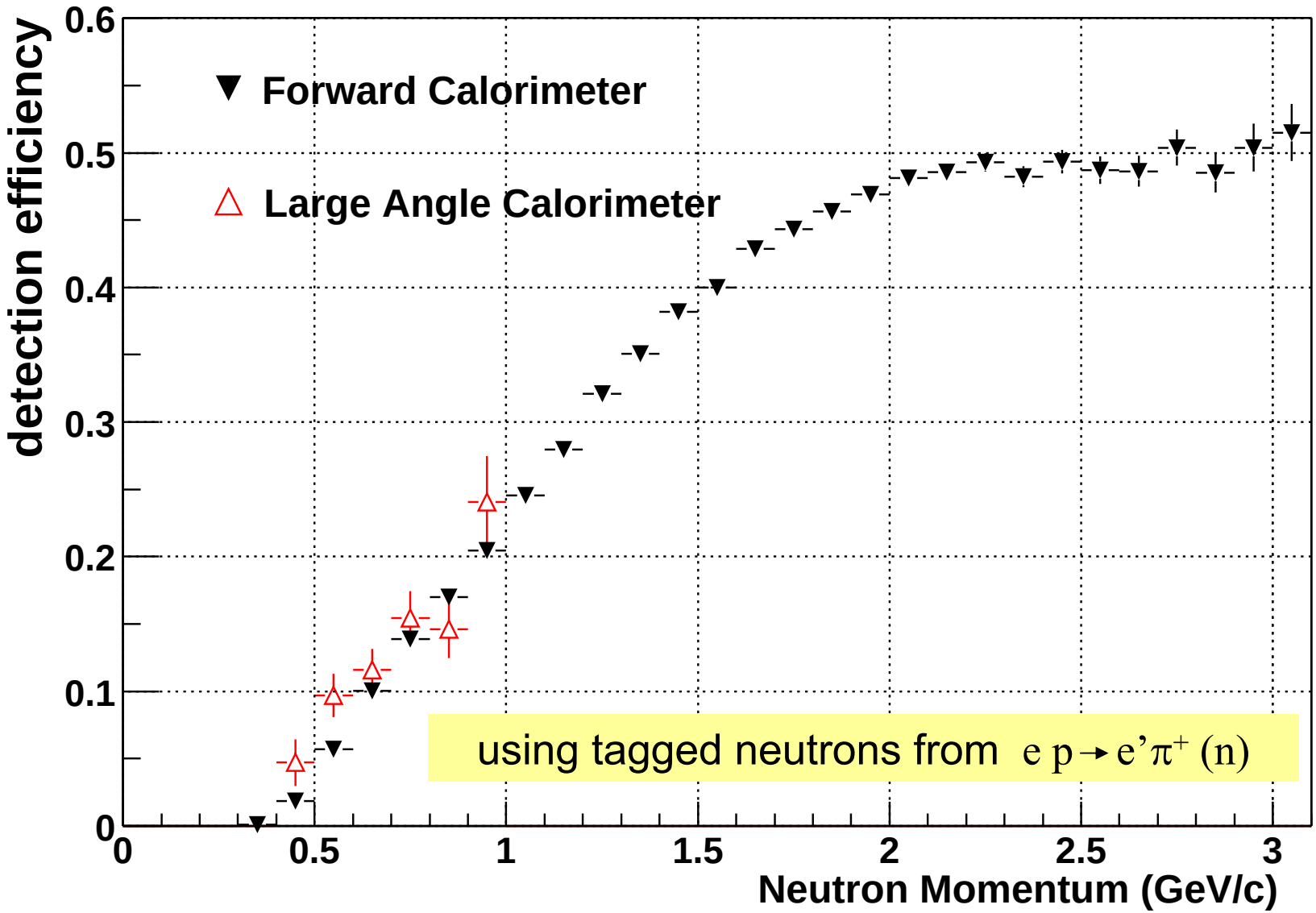
Possible reasons

- drift chamber positions not known perfectly
- uncertainties in magnetic field

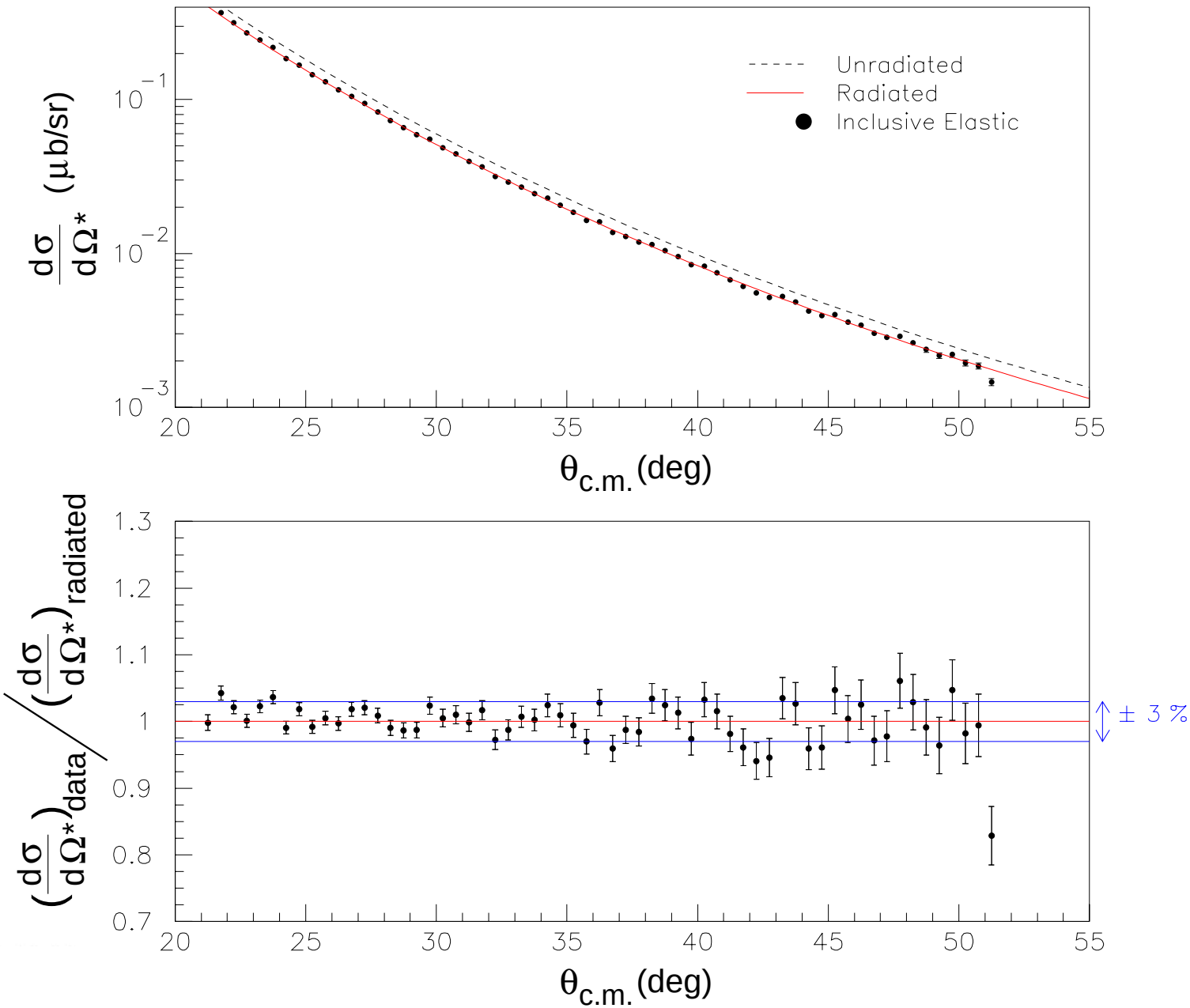




Calorimeter Detection Efficiency for n



Cross Section for e-p Scattering



CLAS Run and Analysis Conditions

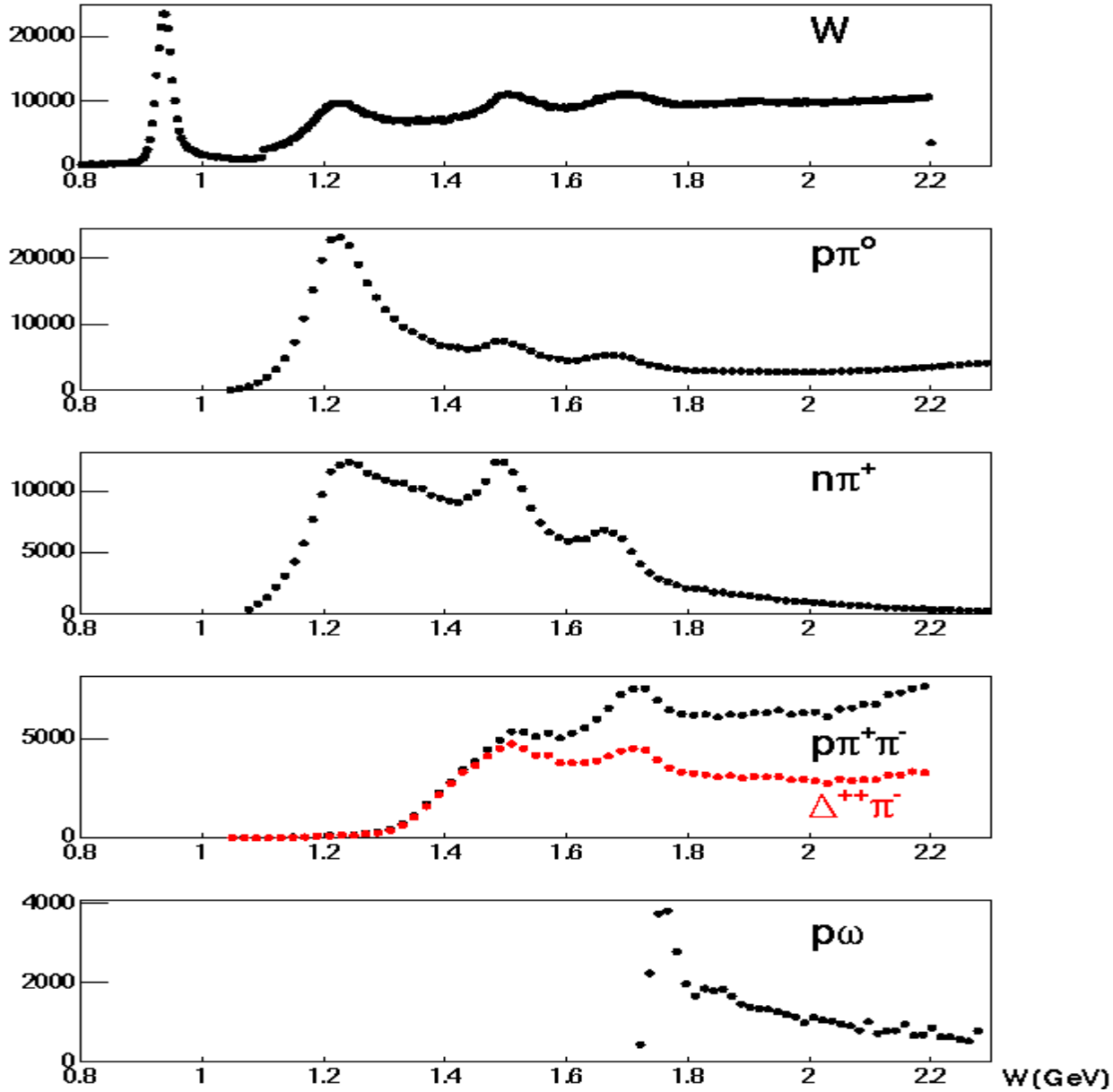
Run

luminosity	10^{34} cm^{-2} s^{-1}
electromagnetic rate	10^{9} / s
hadronic production rate	10^{6} / s
trigger (Level I)	on e^- candidates (Cerenkov + calorimeter)
trigger rate (max.)	4,000/s
data rate to disk (max.)	25 MB/s (~BaBar, CLEO, ½ RHIC STAR)
data volume to silo (max.)	1 TeraByte/day)
personnel	2 on shift,
	on call: 7 system experts + engineering-on-call

Analysis

first-pass analysis	at JLab compute farm
physics analysis	at JLab for full data set
	at outside institutions for filtered data

W-Dependence of Selected Channels at 4 GeV



p(e,e')X
(trigger)

p(e,e'p)X

p(e,e'π+)X

p(e,e'pπ+)X

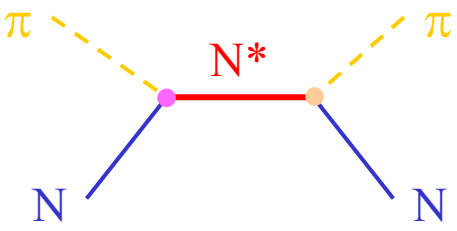
p(e,e'pπ+)X

N* Program Physics Goals

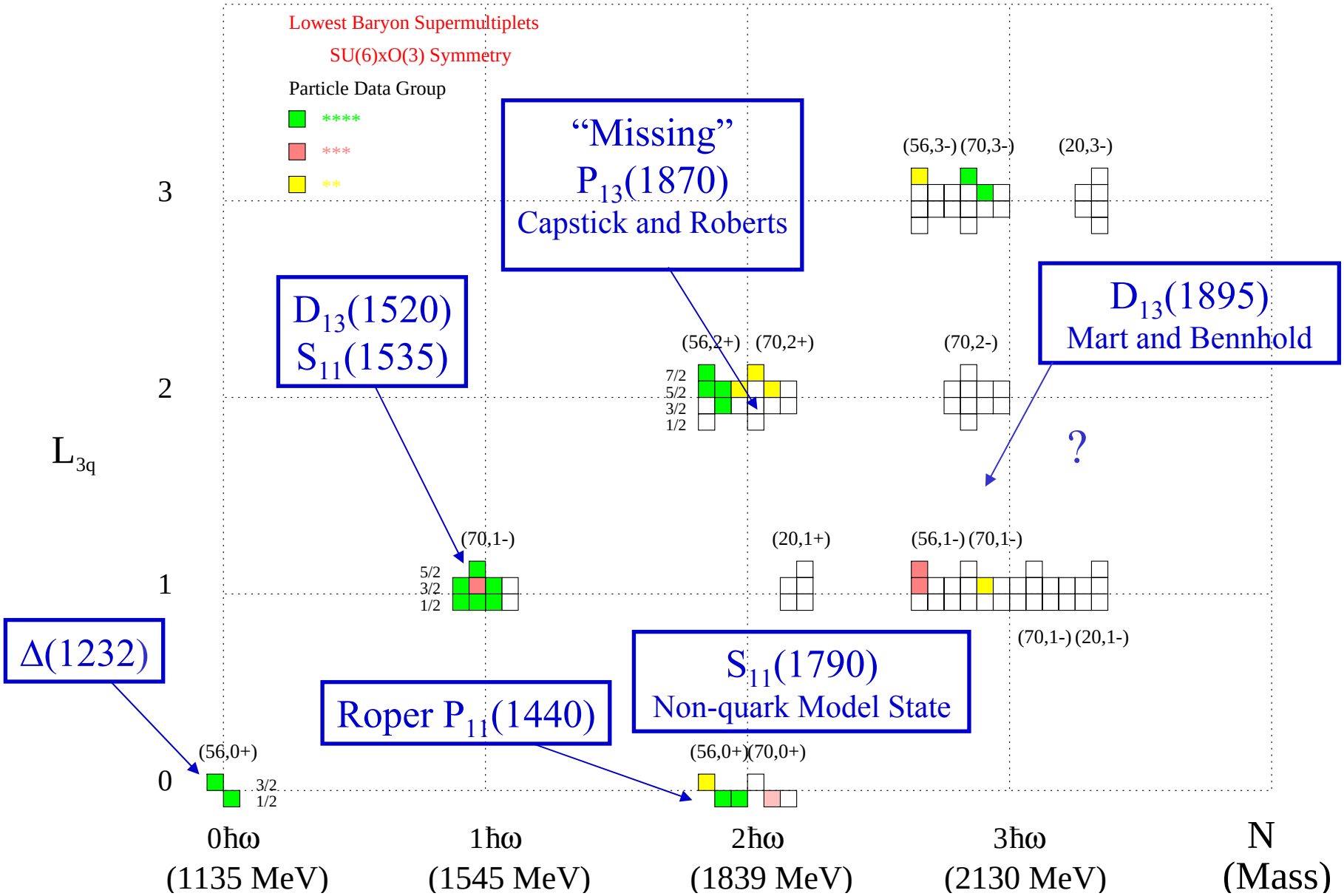
- Understand QCD in the strong coupling regime
  - example: bound qqq systems
  - mass spectrum, quantum numbers of nucleon excited states
  - what are the relevant degrees-of-freedom
  - wave function and interaction of the constituents

- Source of information
  - dominated by pion-induced reactions (mostly $\pi N \rightarrow \pi N$)
  - advantage:
    - strong coupling $\rightarrow$ large cross sections
    - simple spin structure
    - good quality beams
  - disadvantage: no structure information

    insensitive to states with weak πN coupling



Quark Model Classification of N*



Theoretical Models for N* Resonances

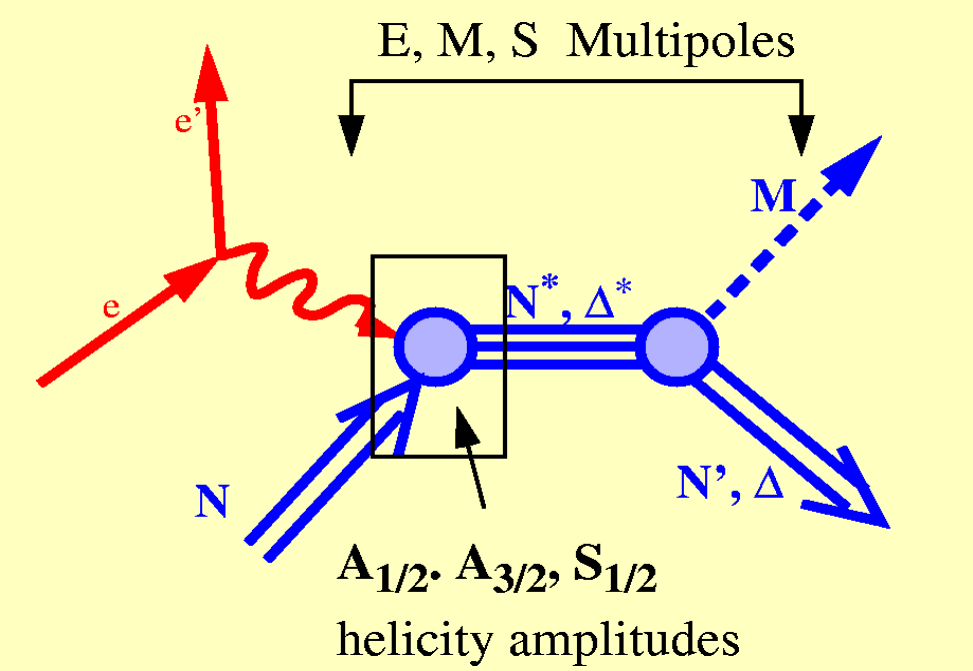
- Constituent quark model
  - 3 constituent quarks
  - all 3 contribute to number of states
  - non-relativistic treatment (typically)

- Refinements of the constituent quark model
  - restore relativity
  - hadronic form factors
  - coupling between decay channels

- Lattice gauge calculations

Electromagnetic Excitation

- helicity amplitudes very sensitive to the difference in wave functions of N and N*
- can separate electric and magnetic parts of the transition amplitude



- varying Q^2 allows to change the spatial resolution and enhances different multipoles
- sensitive to missing resonance states

N* Program Requirements

Experiment

large high-quality data set for N* excitation covering

- a broad kinematical range in Q^2, W, decay angles
- multiple decay modes (π, $\pi\pi$, η, ρ, ω, K)
- polarization information (sensitive to interference terms)

Analysis

$\Delta(1232)$: full Partial Wave Analysis possible
(isolated resonance, Watson theorem)

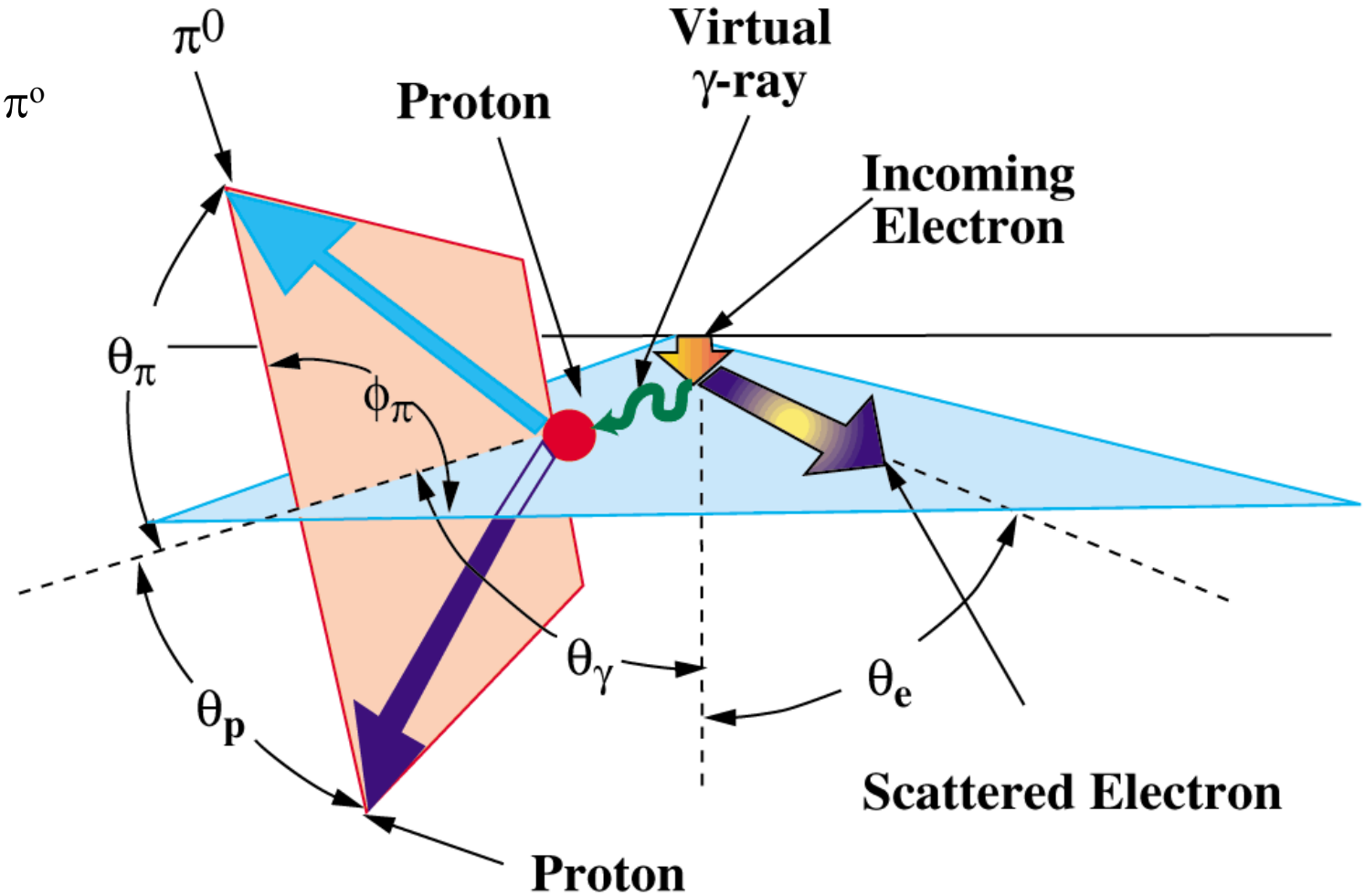
higher resonances

- need to incorporate Born terms, unitarity, channel coupling
- full PWA presently not possible due to lack of data (polarization)
  (substitute by assuming energy dependence of resonance)
- skills required at the boundary between experiment and theory

Kinematics and Cross Sections

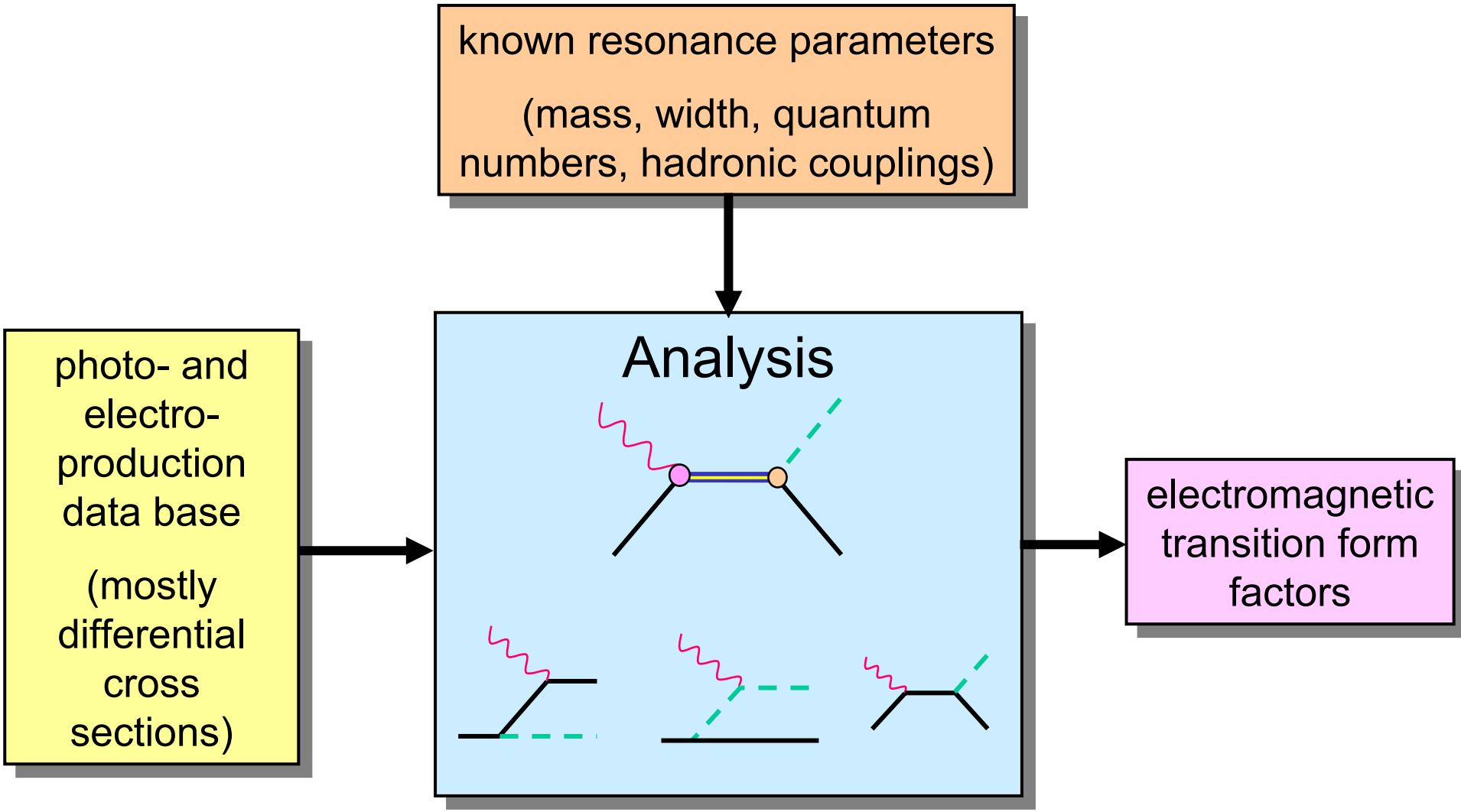
example:

$e\,p \rightarrow e'\,p\,\pi^o$

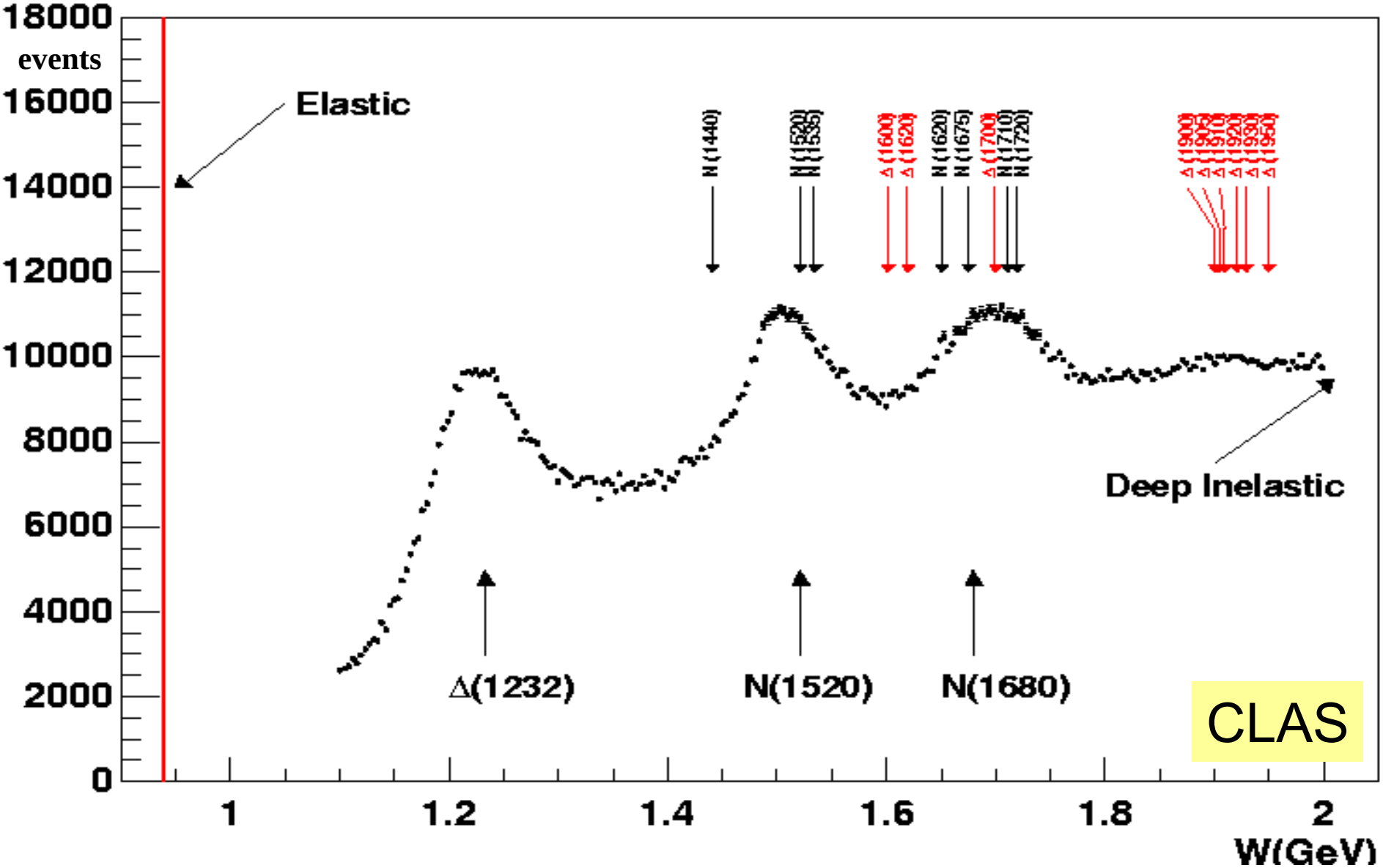


$$\frac{d\,\sigma}{d\Omega_e dE'_e d\Omega_\pi} = \Gamma_t\,(\,\sigma_t + \varepsilon\sigma_l + \varepsilon\sigma_{tt}\cos 2\phi_\pi + \sqrt{2\varepsilon\,(\varepsilon+1)}\,.\,\sigma_{tl}\cos\phi_\pi)$$

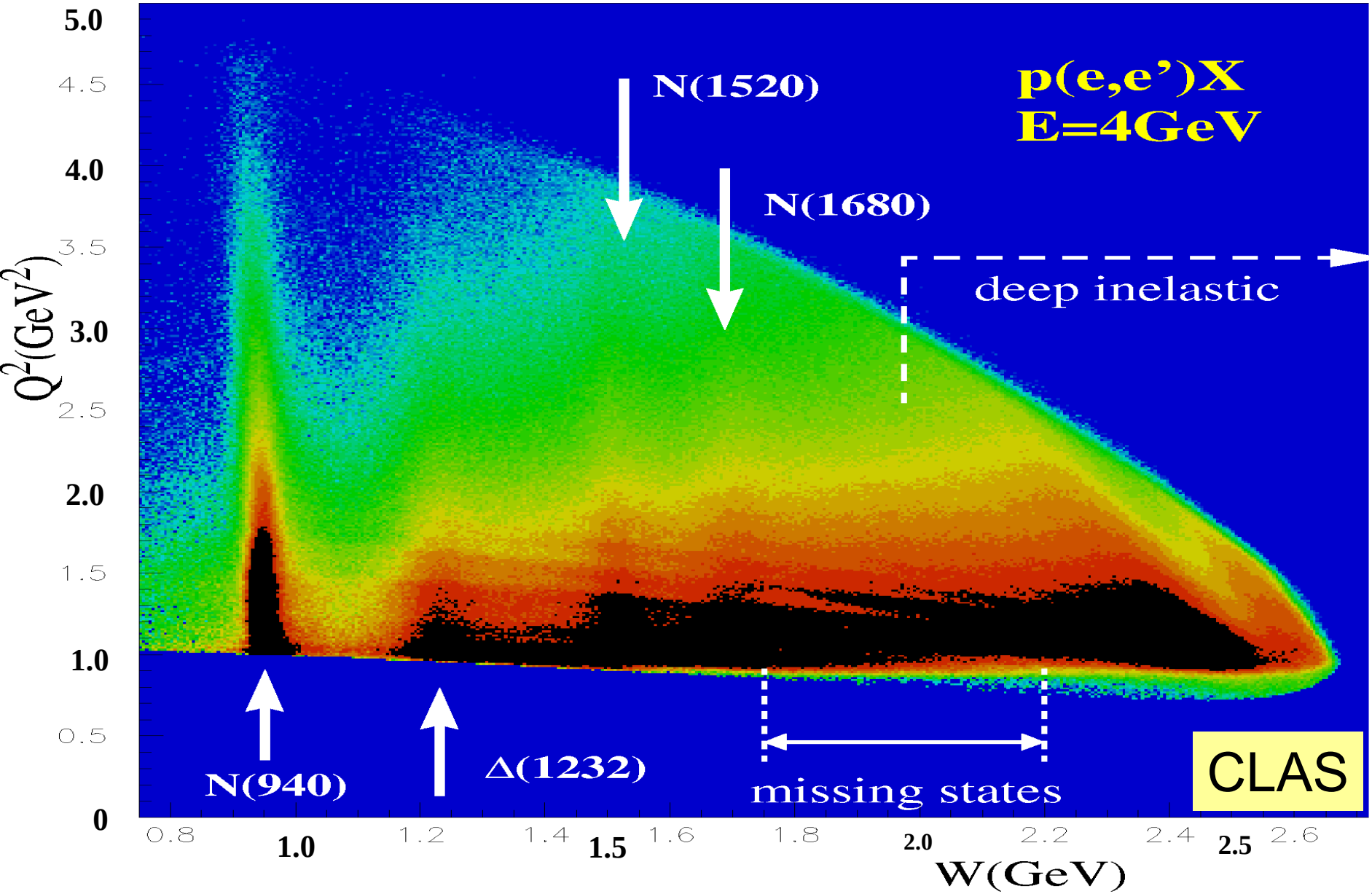
Standard Analysis Approach



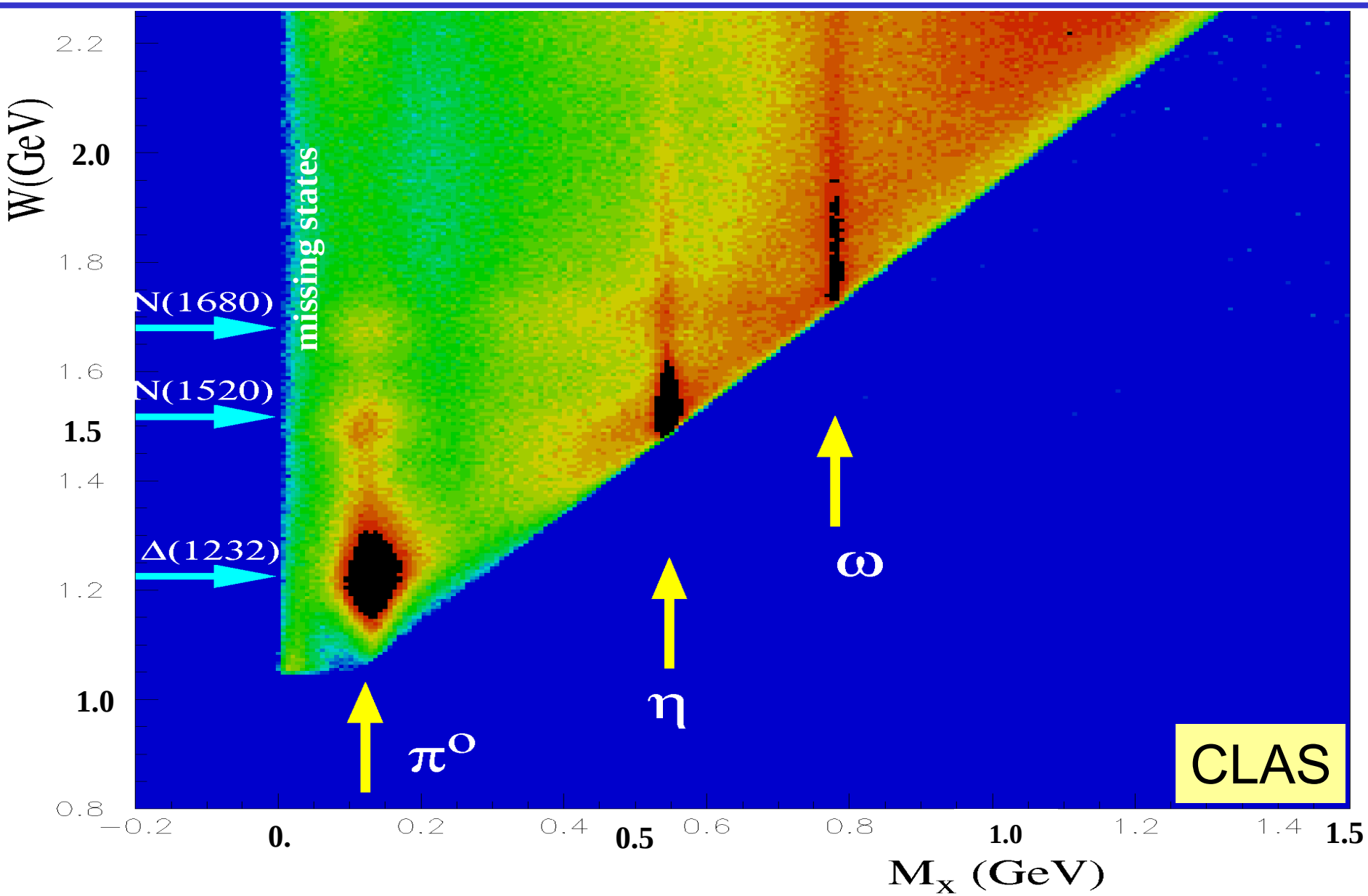
e p → e X at 4 GeV


18000
events
16000
14000
12000
10000
8000
6000
4000
2000
0
Elastic
N(1440)
N(1520)
N(1535)
Δ(1600)
Δ(1620)
N(1620)
N(1675)
Δ(1700)
N(1710)
N(1720)
Deep Inelastic
Δ(1232)
N(1520)
N(1680)
CLAS
1
1.2
1.4
1.6
1.8
2
W(GeV)

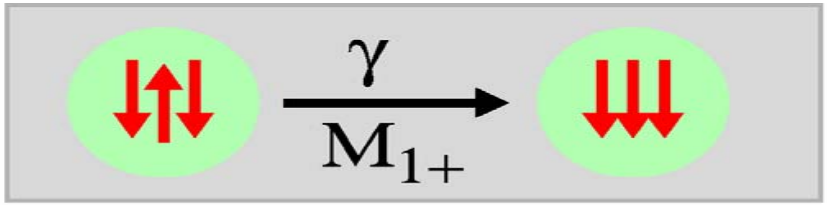
CLAS Coverage for e p → e' X



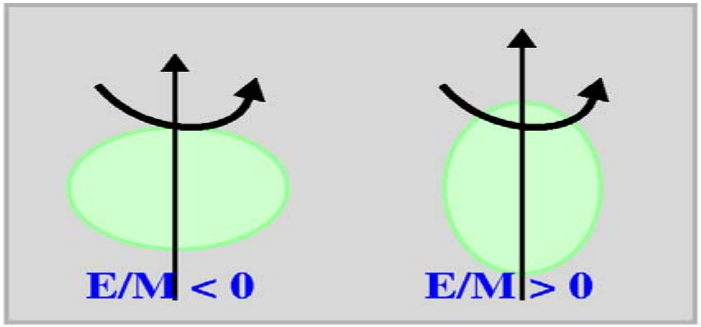
CLAS Coverage for $e\,p \rightarrow e'\,p\,X$, E=4 GeV



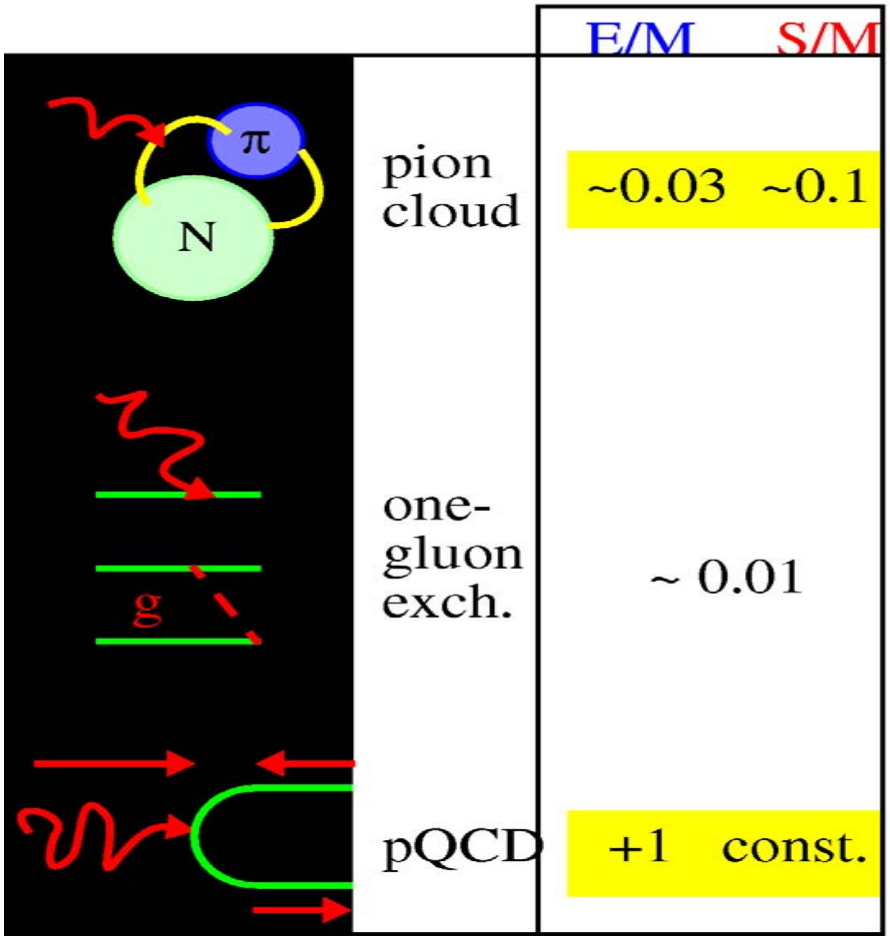
N→ Δ(1232) Transition Form Factors



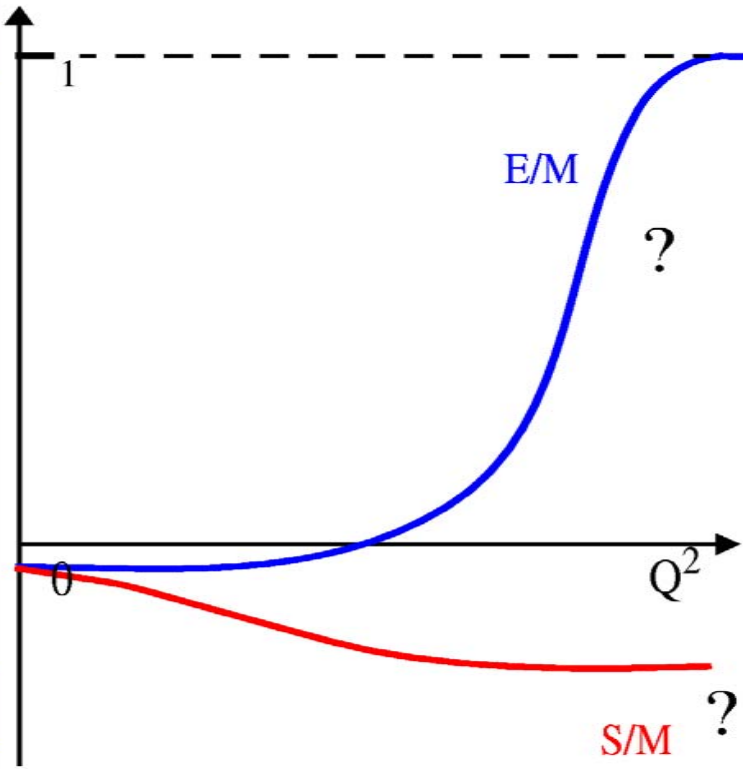
SU(6): $E_{1+}=S_{1+}=0$



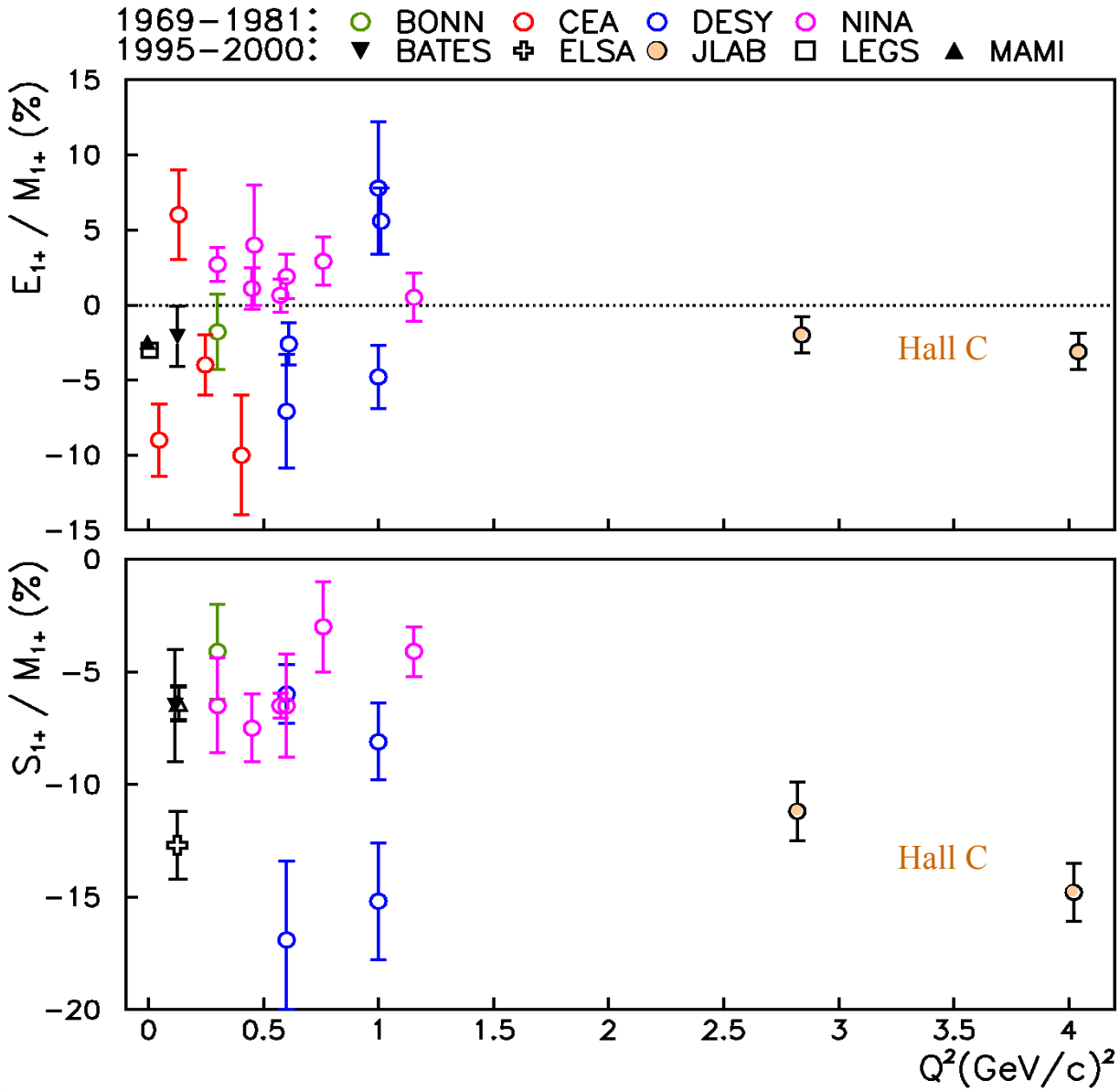
(A. Buchmann, E. Henley, 2000)



	E/M	S/M
pion cloud	~0.03	~0.1
one-gluon exch.	~ 0.01	
pQCD	+1	const.



Multipoles E_{1+}/M_{1+}, S_{1+}/M_{1+} (before 2001)



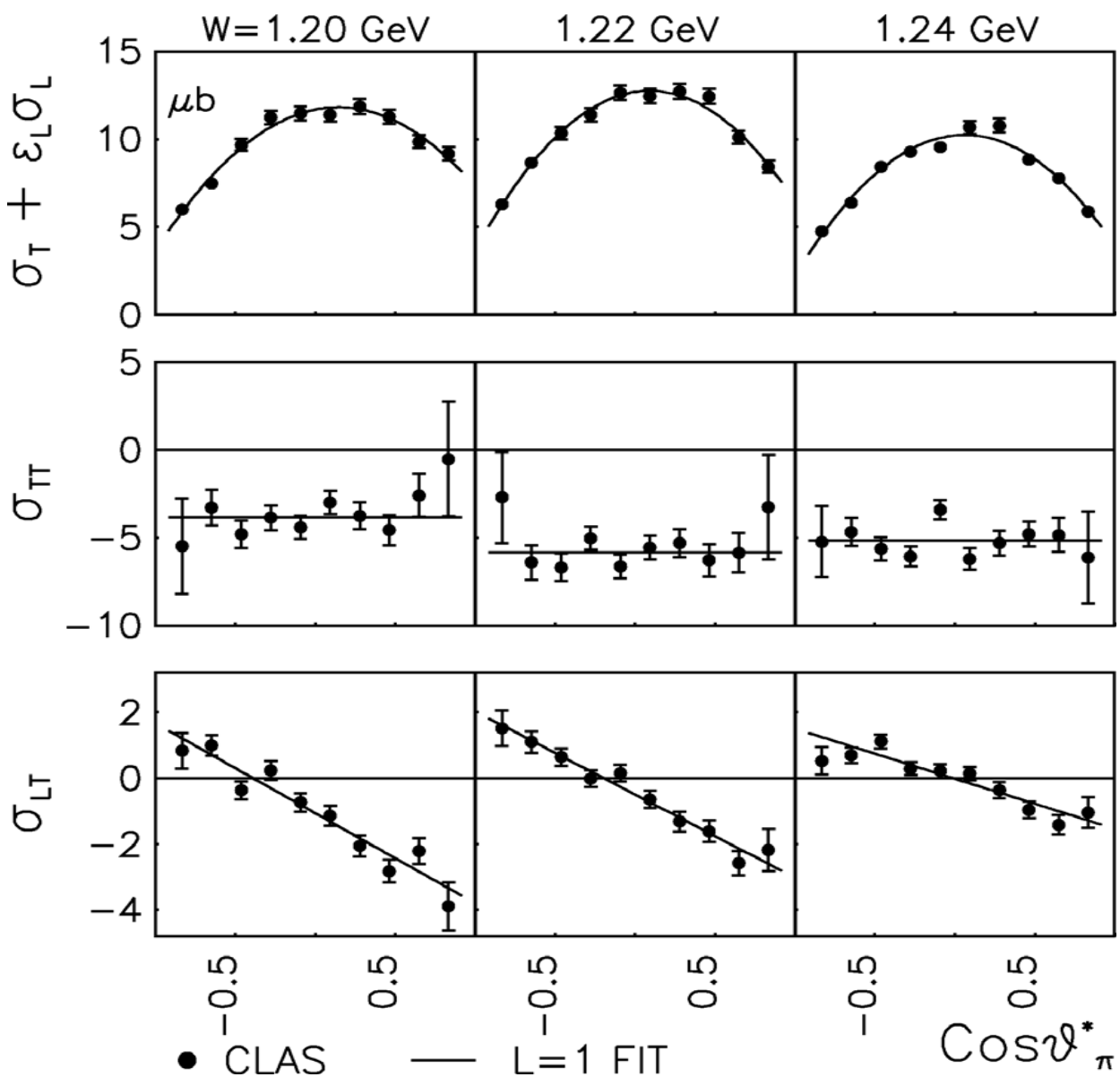
CLAS

$Q^2=0.40(GeV/c)^2$, $\Delta Q^2=0.100(GeV/c)^2$

Multipole Analysis for $\gamma^* p \rightarrow p\,\pi^o$

CLAS

$Q^2 = 0.9\ GeV^2$



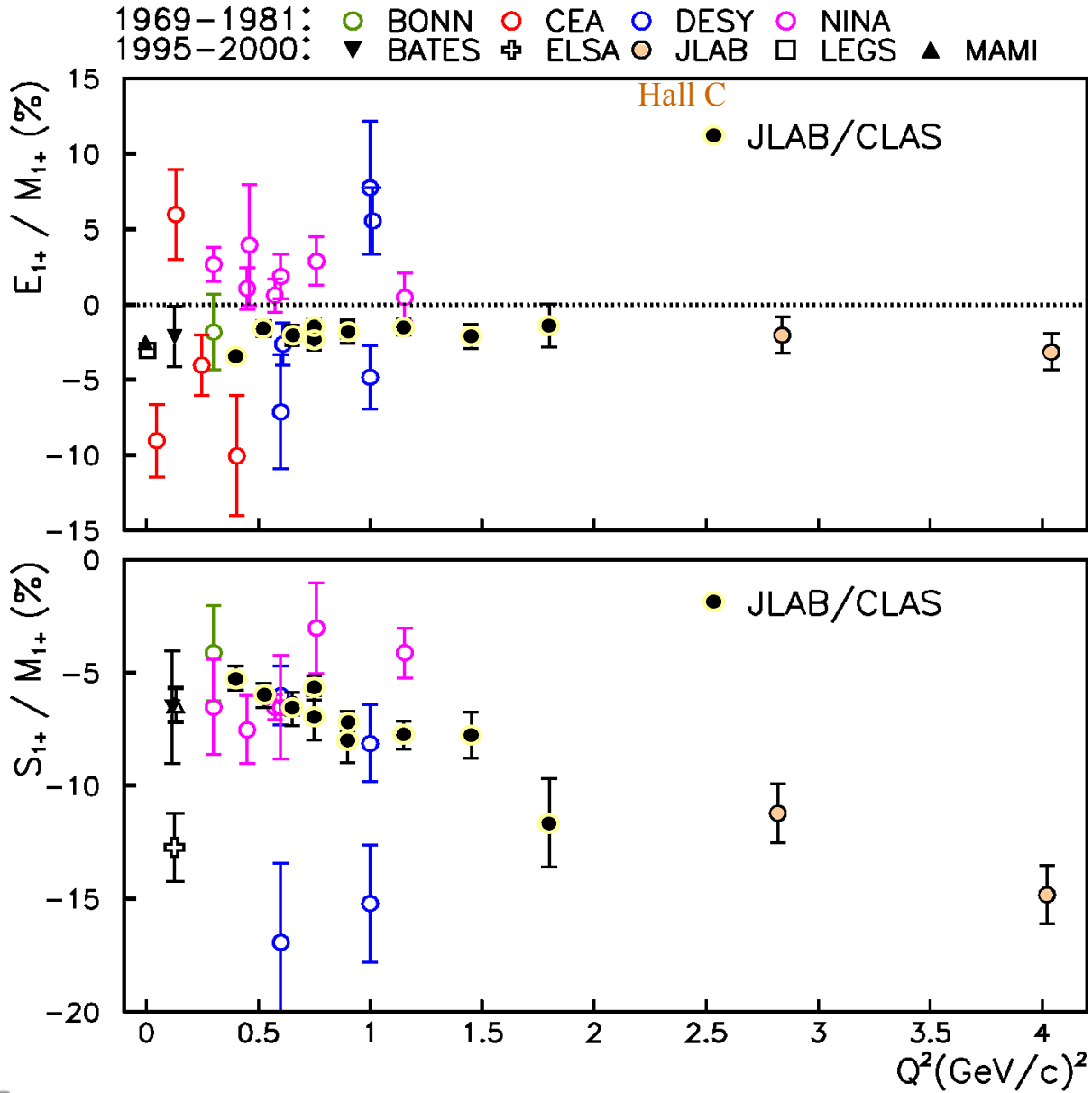
$|M_{1+}|^2$

$Re(E_{1+}M_{1+}^*)$

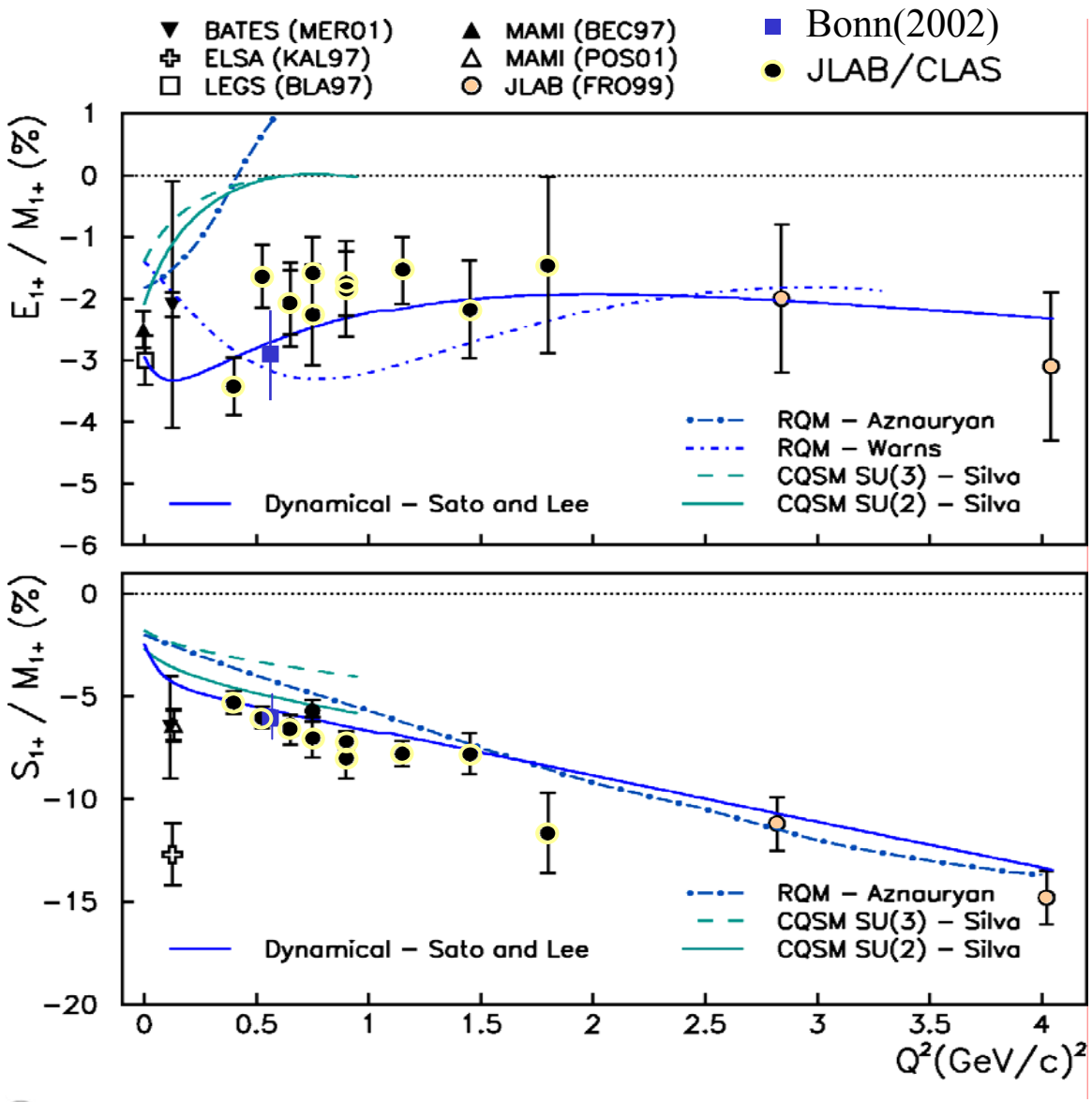
$|M_{1+}|^2$

$Re(S_{1+}M_{1+}^*)$

Multipoles E_{1+}/M_{1+}, S_{1+}/M_{1+} (2002)



Theoretical Interpretation of E_{1+}/M_{1+}, S_{1+}/M_{1+}



$N \rightarrow \Delta$ Transition, what's next?

- systematic uncertainties in extraction of E_{1+}/M_{1+} from $ep \rightarrow e'p\ \pi^o$ around 0.5%
  - differences in treatment of background terms (models not constrained)
  - will become more severe for higher Q^2 (Δ dropping faster)

- more experimental information in hand (analysis in progress)
  - cross sections $e\,p \rightarrow e'p\ (\pi^o)$ $Q^2 = (1.5 - 5.5)\ GeV^2$ — CLAS
  - single-spin asymmetry σ_{TL}, for $\vec{e}\,p \rightarrow e'p\ (\pi^o)$ and $\vec{e}\,p \rightarrow e'\ \pi^+\ (n)$ — CLAS
  - polarization transfer in $\vec{e}\,p \rightarrow e'\ \vec{p}\ (\pi^o)$ — Hall A
  - differential cross sections for $e\,p \rightarrow e'\ \pi^+\,n$ (Δ less important) — CLAS

- experiments in the near future
  - extend Q^2 range to 0.05 GeV^2 (end of 2002) — CLAS
  - extend Q^2 range to ~7 GeV^2 (1st half of 2003) — Hall C

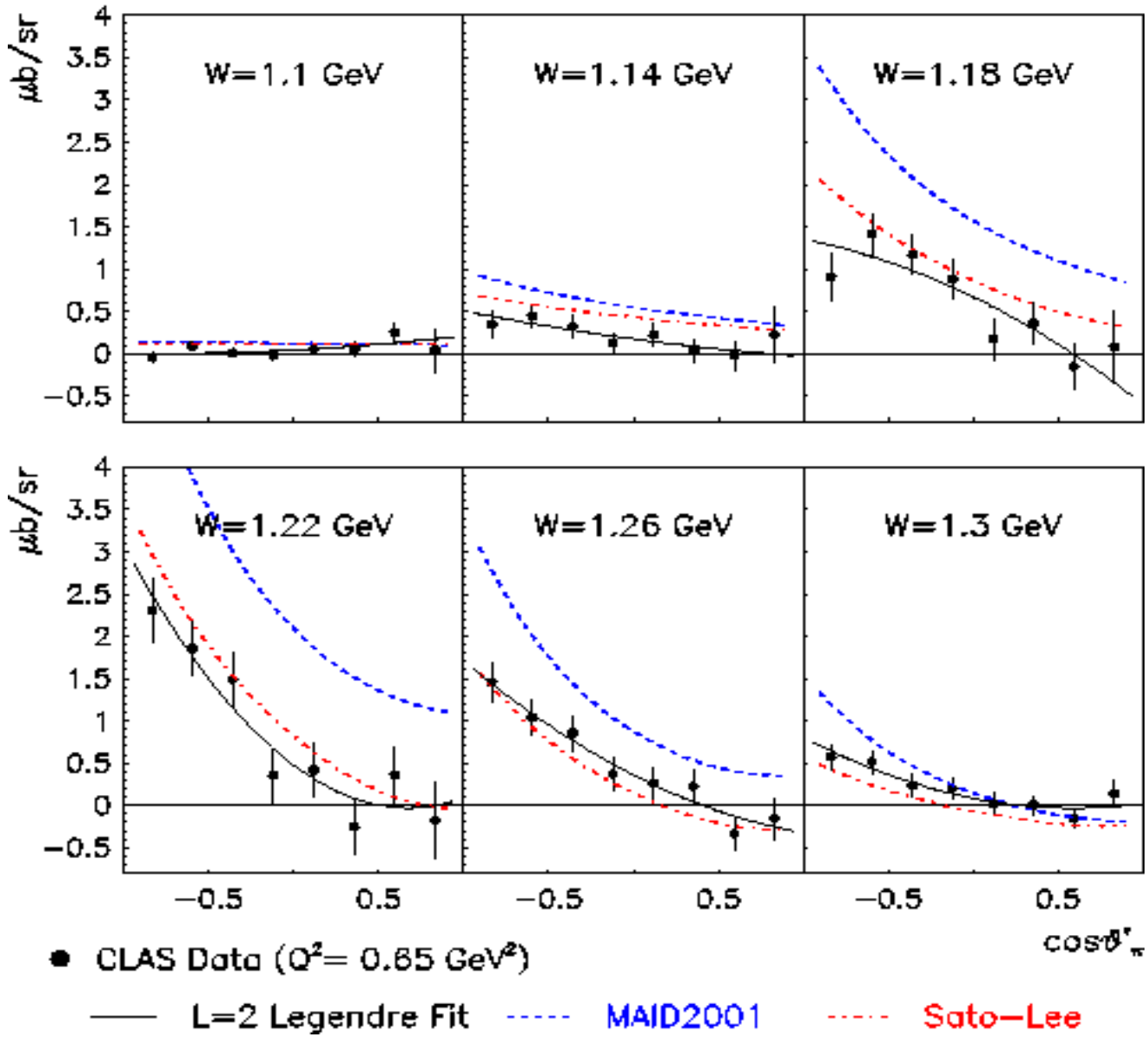
Polarized Beam Observables

CLAS

$\sigma_{LT'}$ response function for

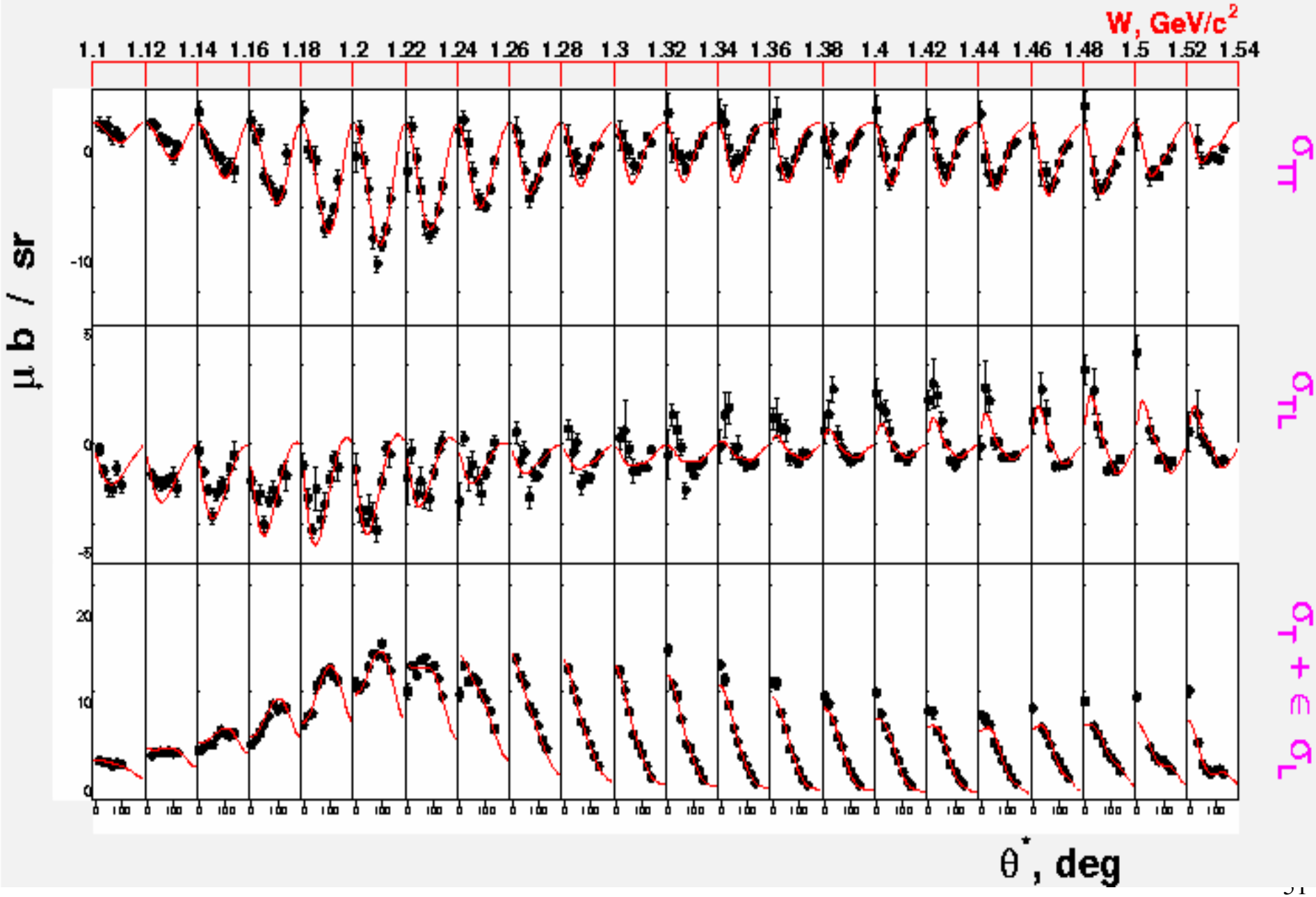
$$\vec{e}\, p \rightarrow e\, p\, \pi^o$$

$\sigma_{LT'} = 0$ if only a single diagram contributes (sensitive to the interference between Δ and background)



CLAS

π^+ Electroproduction



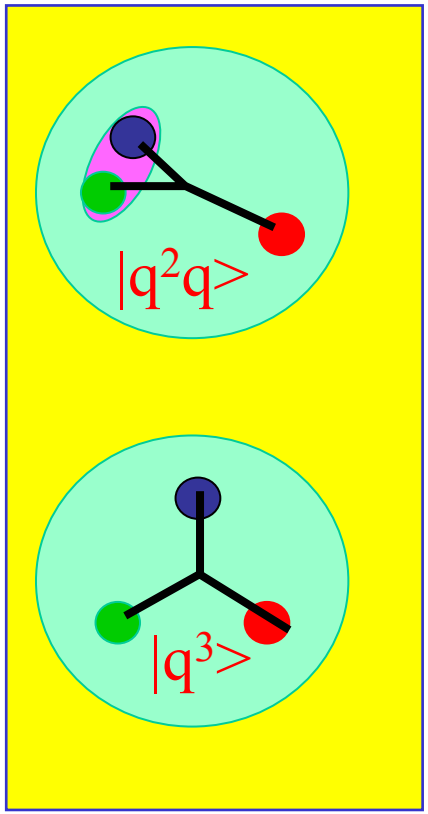
"Missing" Resonances, where are they?

Problem: symmetric CQM predicts many more states than have been observed (in πN scattering)

Two possible solutions:

1. di-quark model
   fewer degrees-of-freedom
   open question: mechanism for q^2 formation?

2. not all states have been found
   possible reason: decouple from πN-channel
   model calculations: missing states couple to
   $N\pi\pi$ ($\Delta\pi$, $N\rho$), $N\eta$, $N\omega$, KY



γ coupling not suppressed $\rightarrow$ electromagnetic excitation is ideal

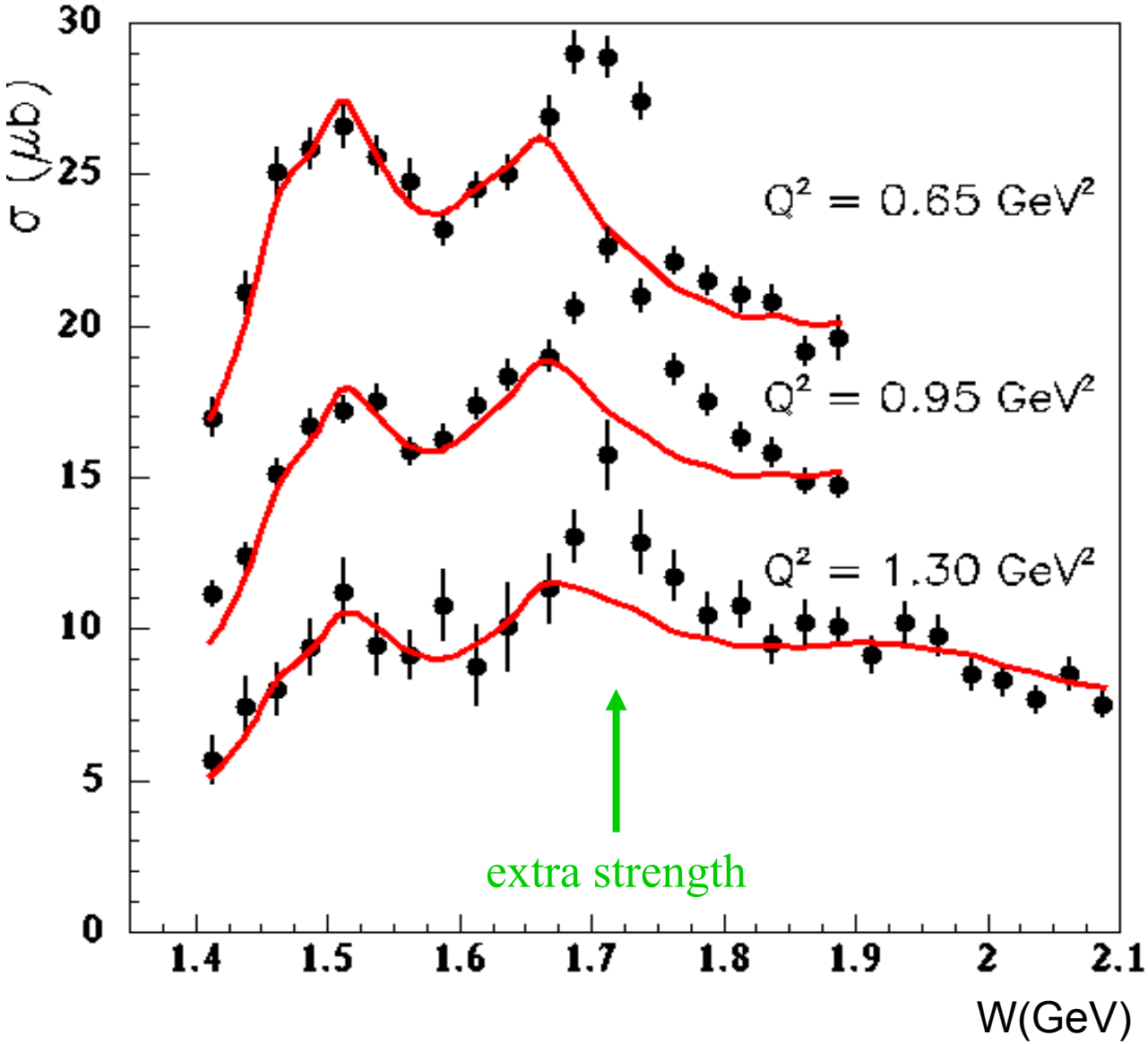
Resonances in $\gamma^* p \longrightarrow p\pi^+\pi^-$

Analysis performed by Genova-Moscow collaboration

step #1:

use the best information presently available

$\Gamma_{N\pi\pi}$ from PDG
$\Gamma_{N\gamma}$ AO/SQTM



Attempts to fit observed extra strength

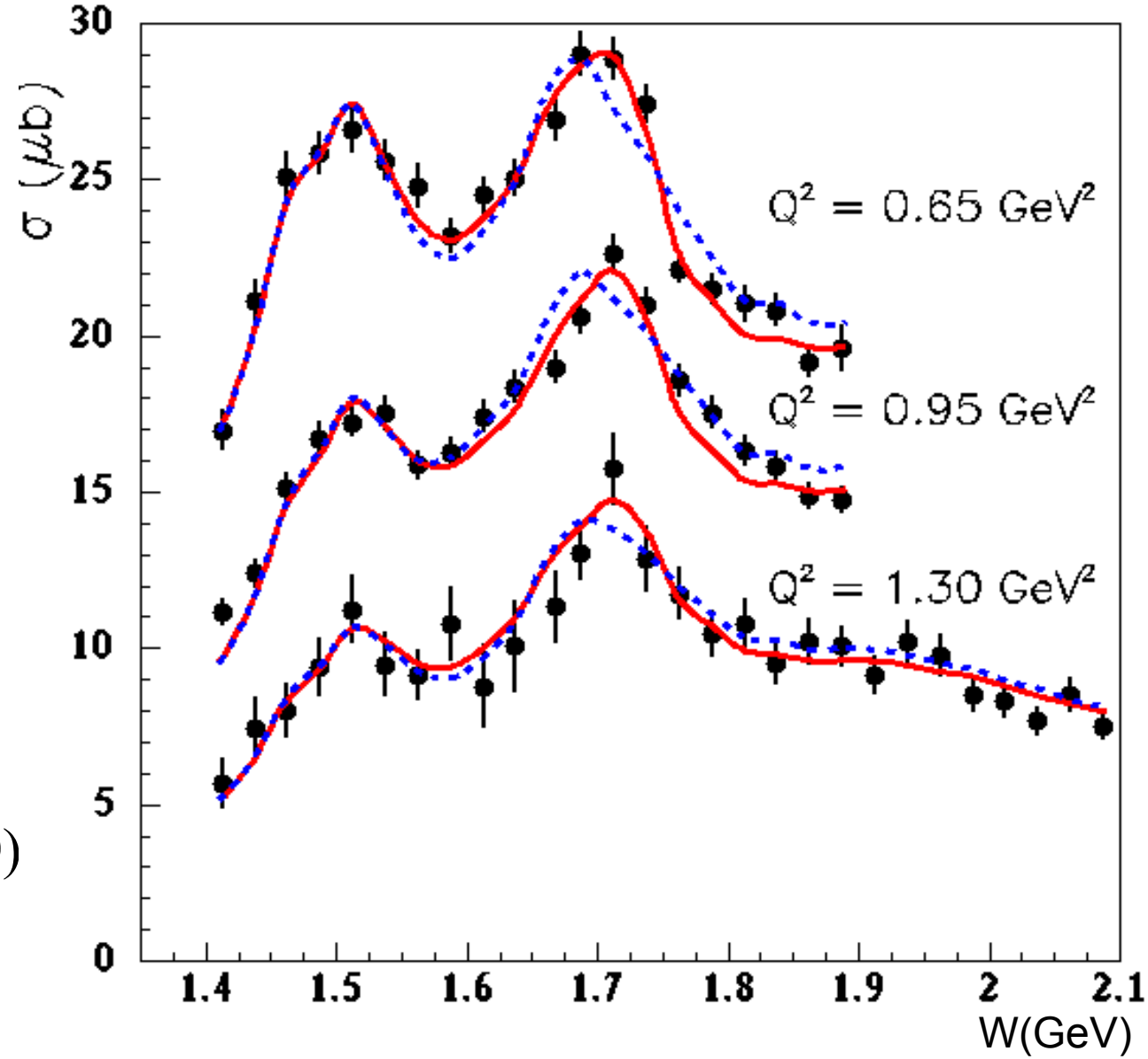
CLAS

Analysis step #2:

- vary parameters of known D_{13}

  or

- introduce new P_{13}



P_{13}

$D_{13}(1700)$

Summary of $\gamma^* p \rightarrow p\, \pi^+ \pi^-$ Analysis

CLAS data at variance with N* information in PDG

Describing data requires

- major modifications of the parameters of known resonances, or
- introduction of new P_{13} resonance with

  (consistent with "missing" P_{13} state, but mass lower than predicted)

$M = 1.72 +/- 0.02$ GeV

$\Gamma_T = 88 +/- 17$ MeV

$\Delta \pi : 0.41 +/- 0.13$

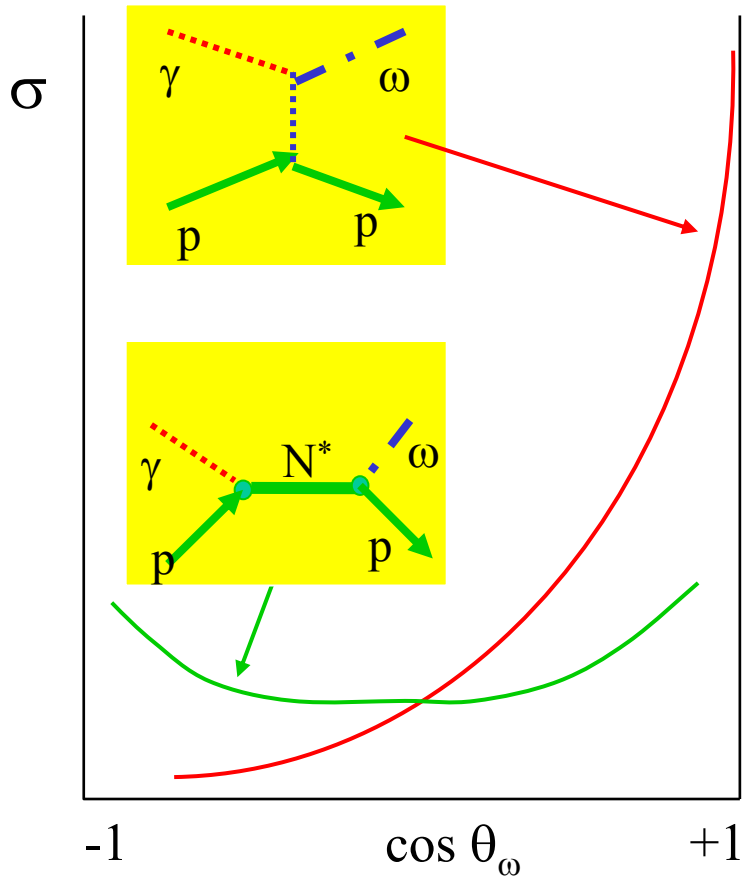
$N \rho : 0.17 +/- 0.10$

Next steps:

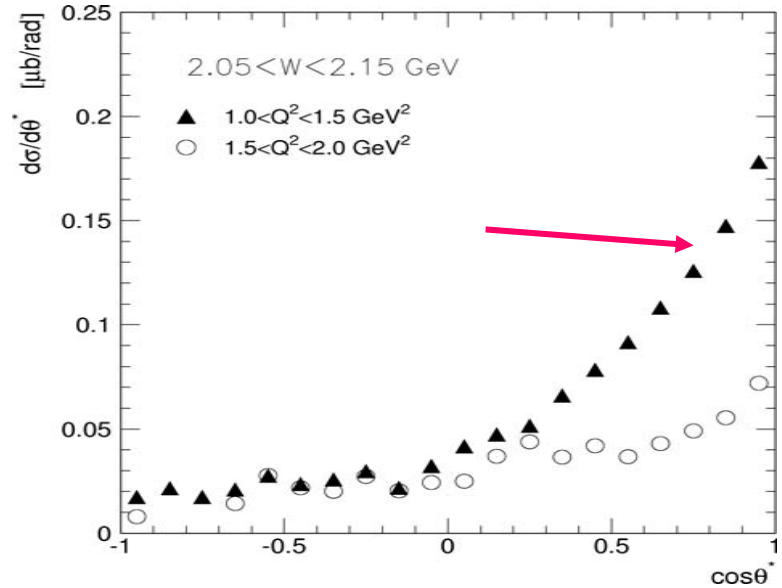
- more experimental data already in hand
- combined analysis with other decay channels: πN, ηN, $K \Lambda$

Resonance Contributions to $\gamma^* p \rightarrow p\omega$?

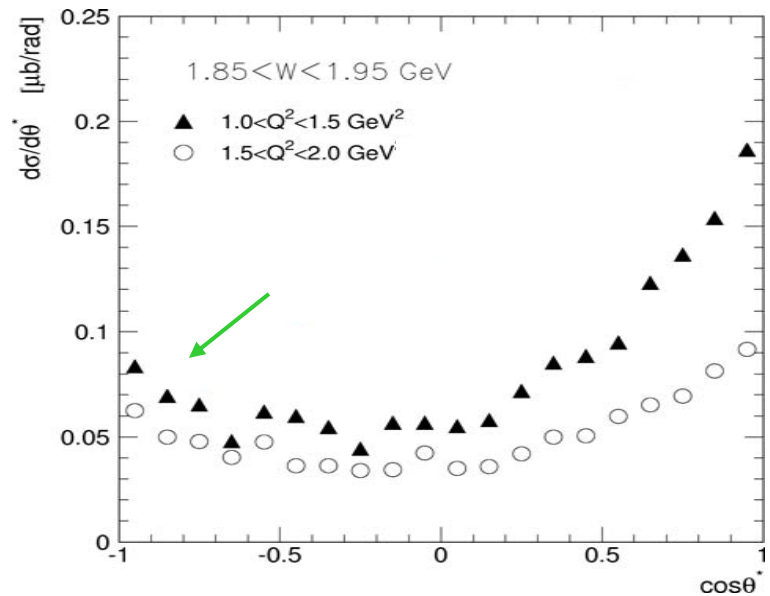
CLAS



above resonance region

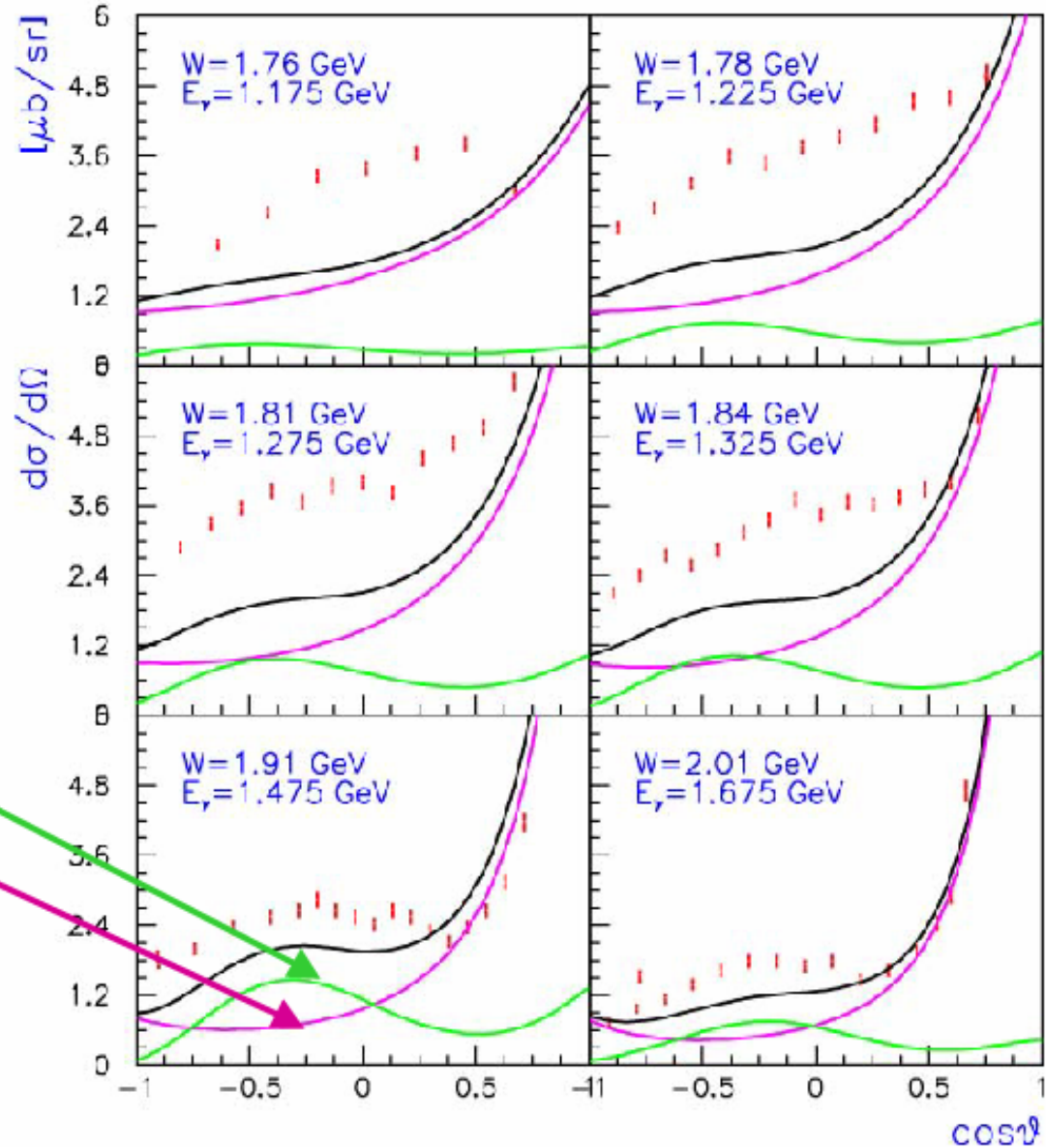


in resonance region



Resonances in ω Photoproduction?

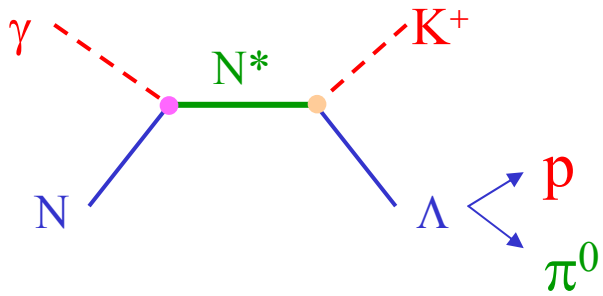
- Old data only showed forward angle peaking (Regge)
- PDG lists no N*→ ωp decays
- Strong signal with e, γ beam
- Vector particle provides interesting observables with polarized beam/target
- Calculations from Y. Oh- 'good' representation of t-chan+res.
- Results preliminary- strong resonance contribution, but no single signature for a single state

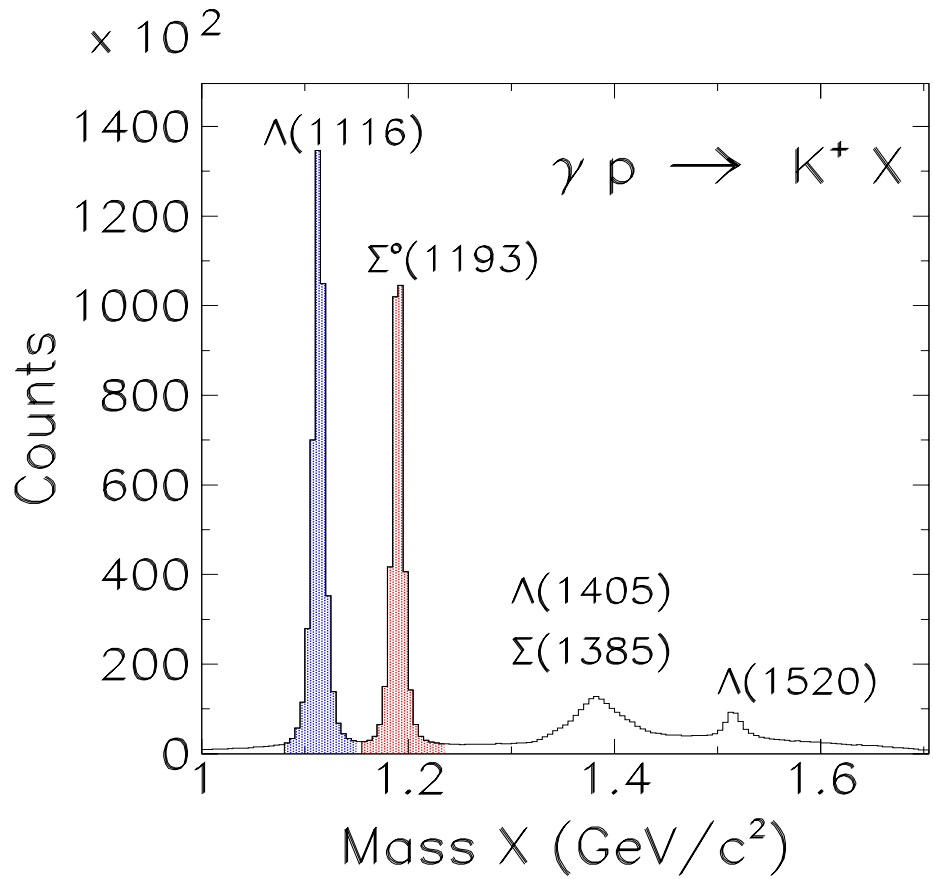


Hyperon Photoproduction off the Proton

Goal: Λ and Σ differential cross sections for 1.6 GeV < W < 2.3 GeV

Technique: K identified by time-of-flight, hyperons via missing mass





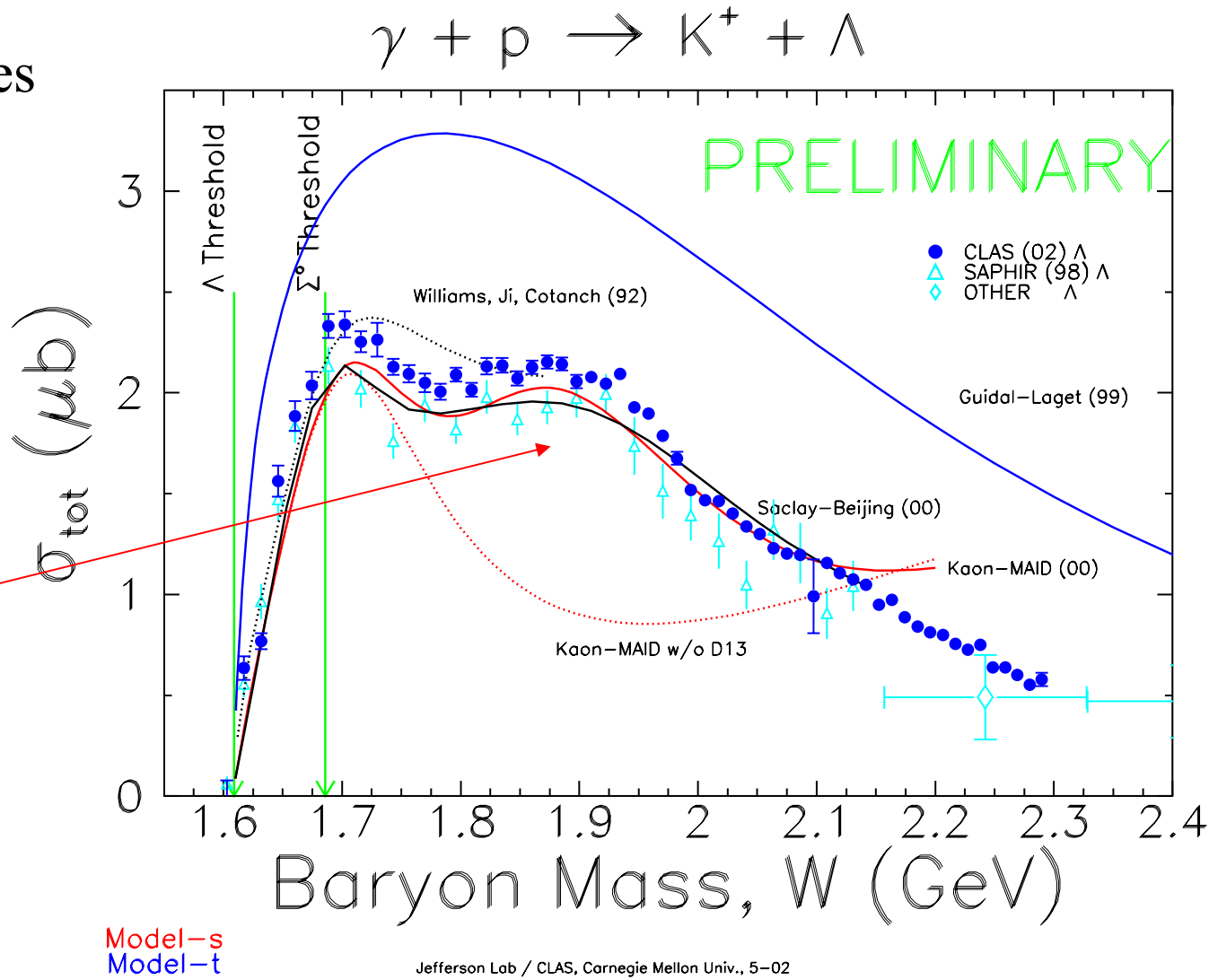
Λ and Σ polarization measured via self-analyzing weak decay and proton detection

Λ Photoproduction off the Proton

Dominant resonances

$S_{11}(1650)$
$P_{11}(1710)$
$P_{13}(1720)$

Bump at 1.9 GeV
$D_{13}(1895)$?

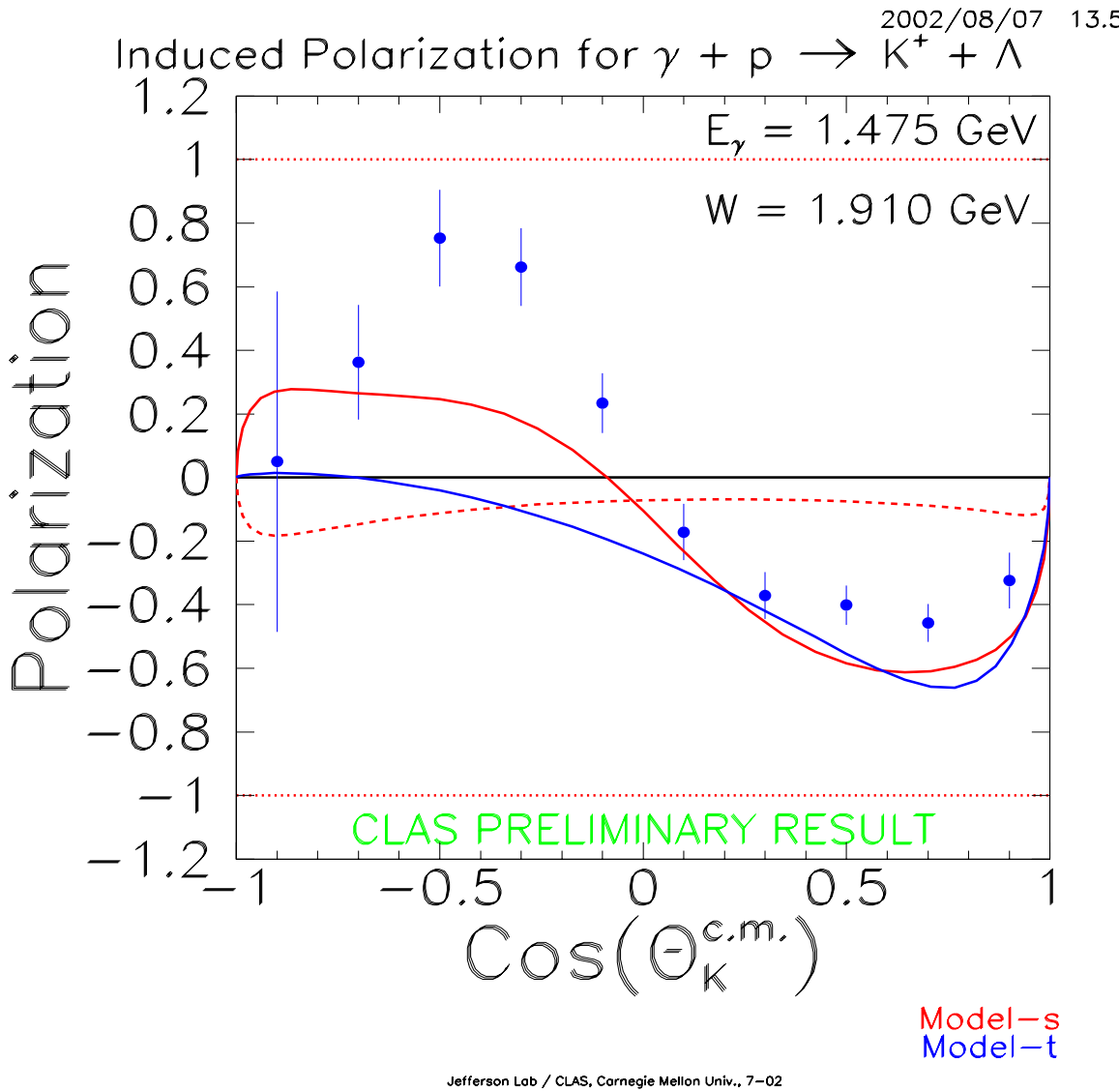


Carnegie Mellon

Polarization of Photoproduced Λ

Model-s (hadrodynamic) Resonances, plus K and K* exchange

Model-t (Regge) has K and K* interference, misses at back angles



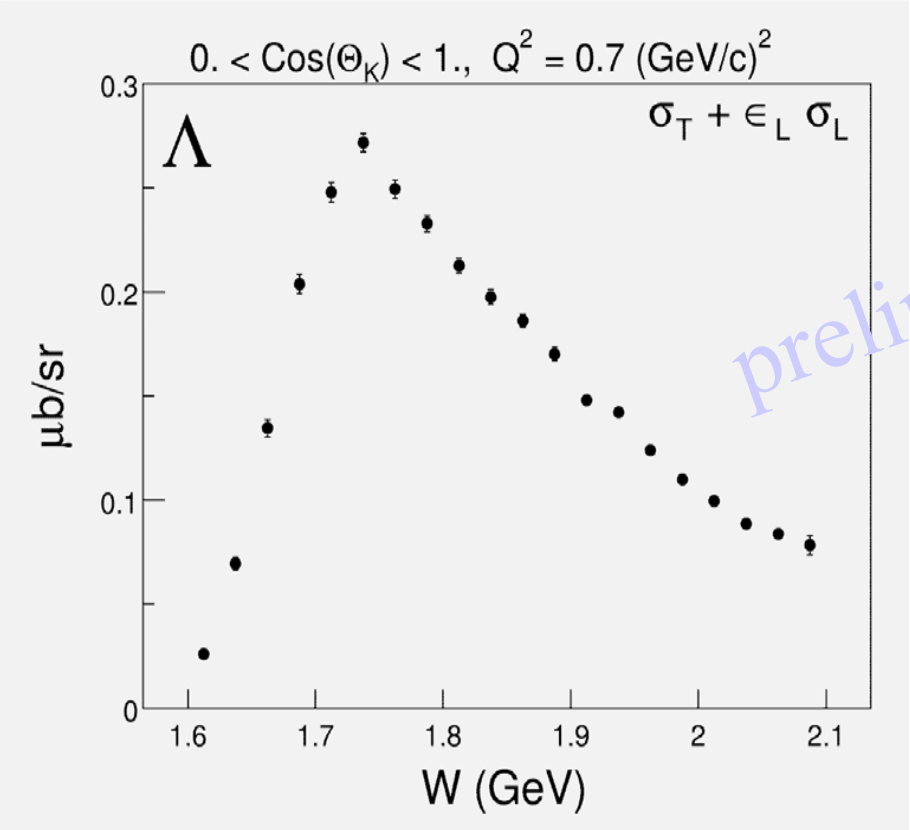
Carnegie Mellon

Resonances in Hyperon Electroproduction?

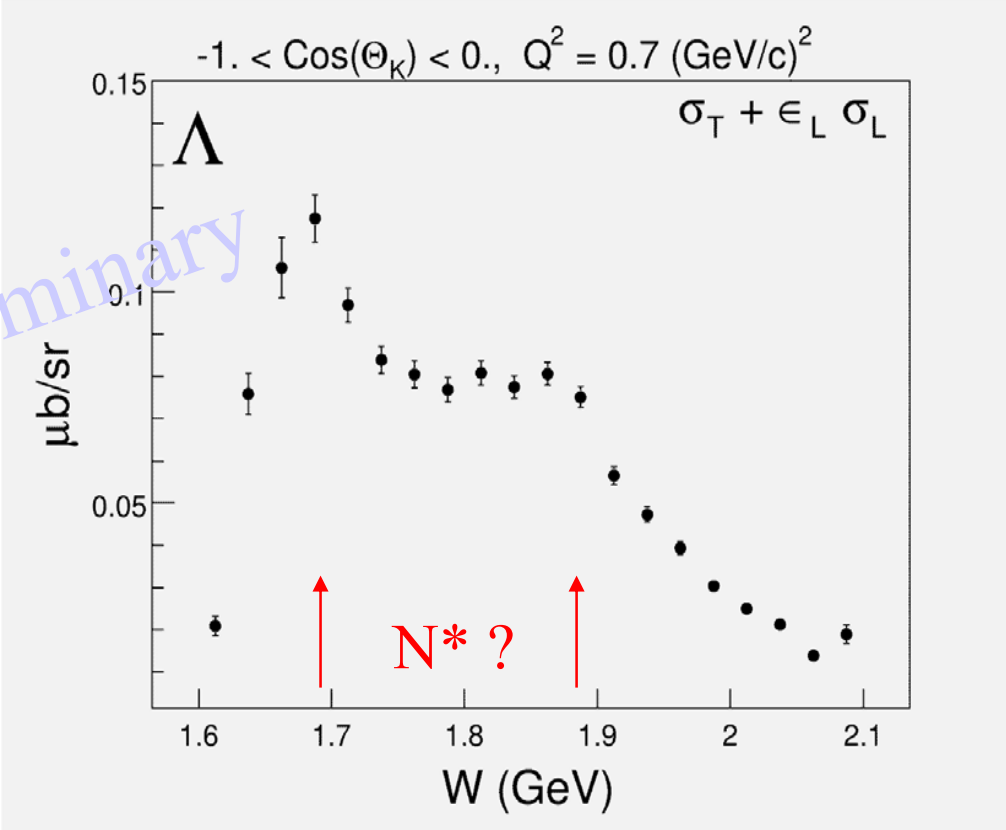
CLAS

$$\gamma^* p \longrightarrow K^+ Y$$

forward hemisphere



backward hemisphere



preliminary

Next Steps in Missing Resonance Search

- Needed: a coherent, consistent analysis of the data from a broad variety of channels, from photo- and electro-production, and for the available values of Q^2
- Important to incorporate consistently available data obtained using hadronic beams
- JLab has requested support for an analysis center to be created as part of the theory group

Integrals over Spin Structure Functions

Bjorken Sum Rule ($Q^2 \to \infty$):

Basic assumptions: isospin symmetry,
current algebra or Operator Product Expansion within QCD

$$\int_0^1 [g_1^p(x) - g_1^n(x)]dx = \frac{1}{6}|g_A/g_V|$$

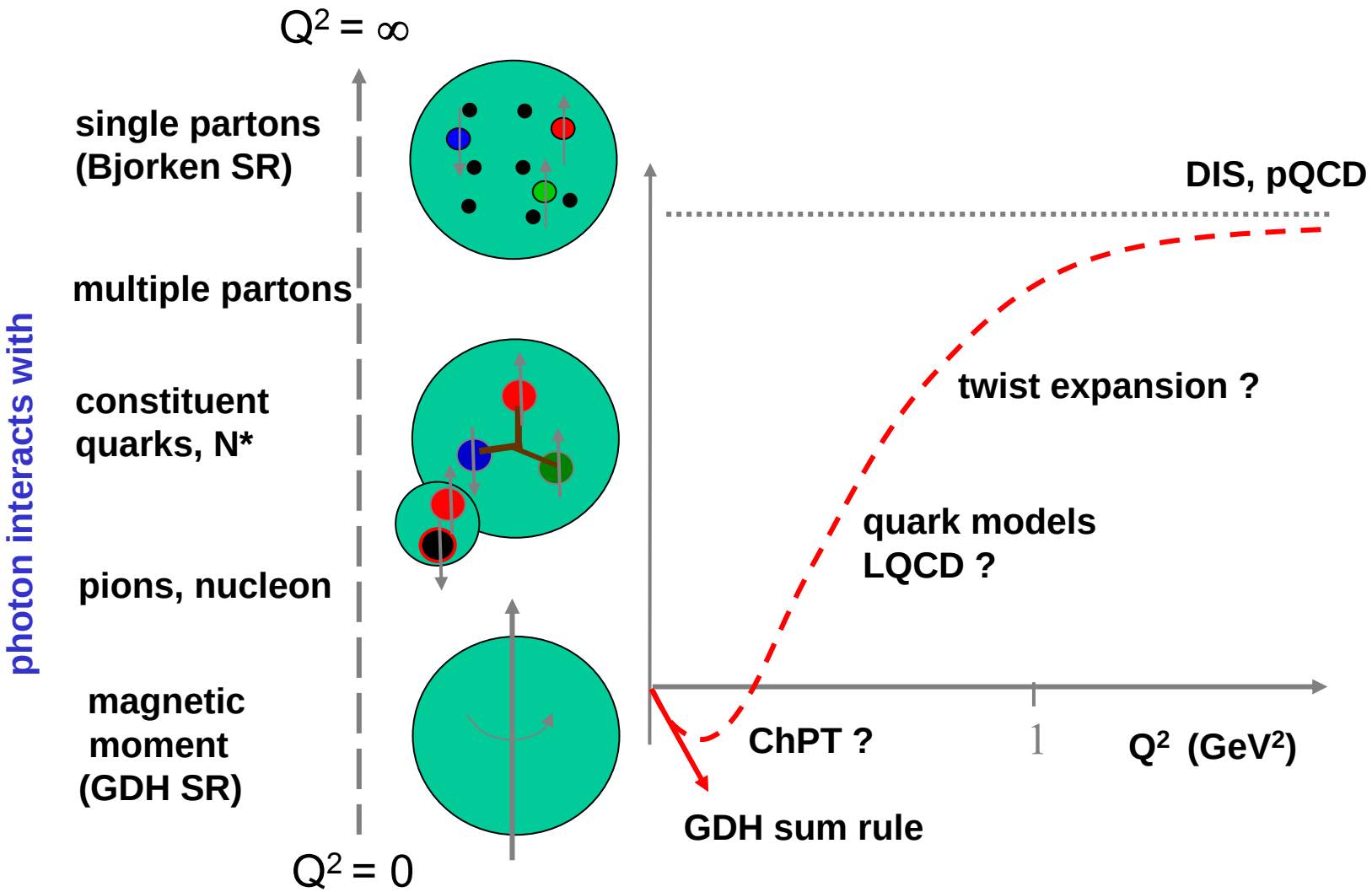
GDH Sum Rule ($Q^2 \to 0$):

Basic assumptions: Lorentz invariance, gauge invariance, unitarity,
dispersion relation applied to forward Compton amplitude

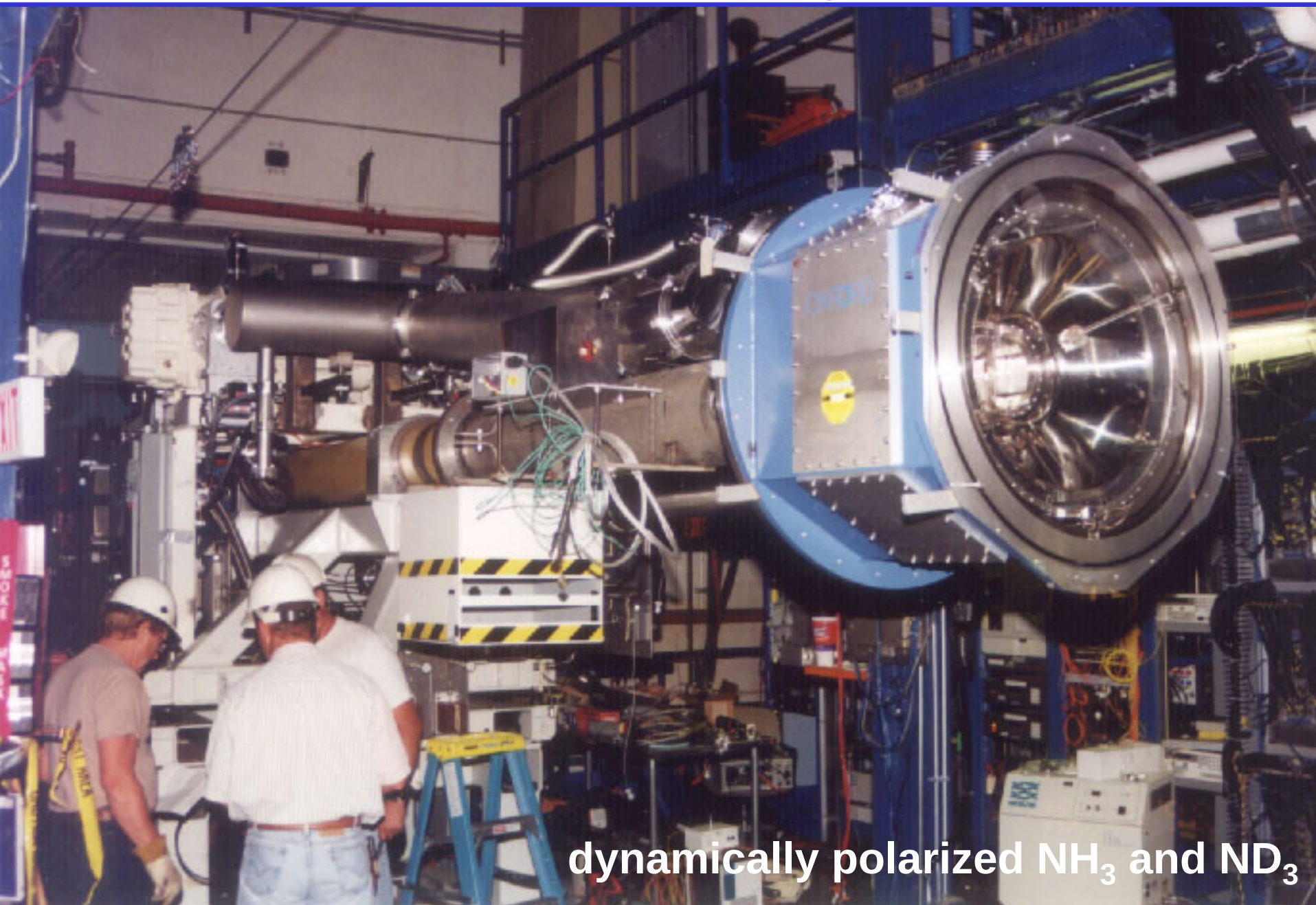
$$\int_{k_{thres}}^{\infty} [\sigma_{3/2}(k) - \sigma_{1/2}(k)] \frac{dk}{k} = \frac{2\pi^2\alpha}{m^2}\kappa$$

κ = nucleon anomalous magnetic moment

Q^2 Dependence of the Moments

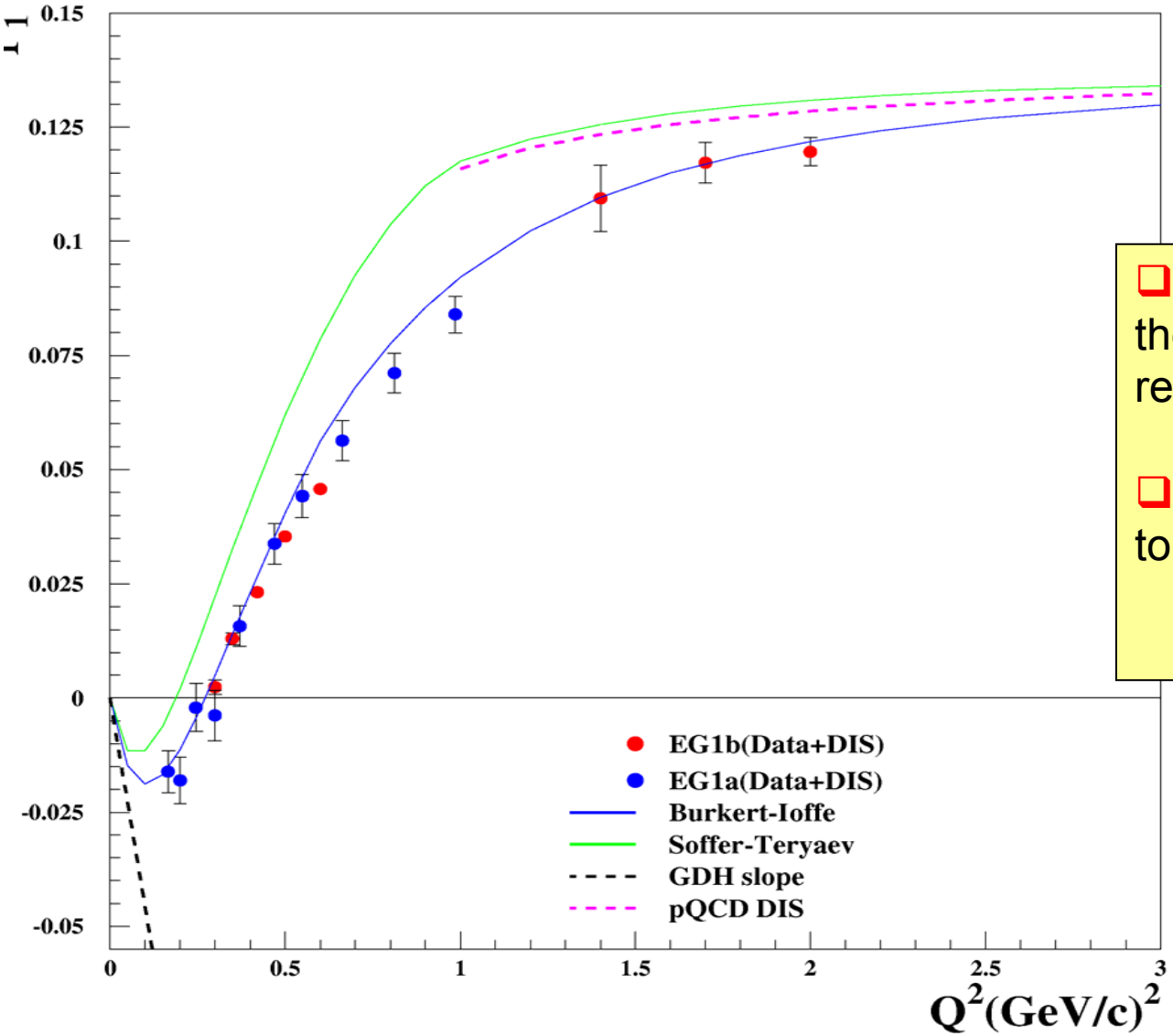


Polarized Solid State Target for *CLAS*



CLAS: First Moment $\Gamma_{1p} = \int g_1(x,Q^2)dx$

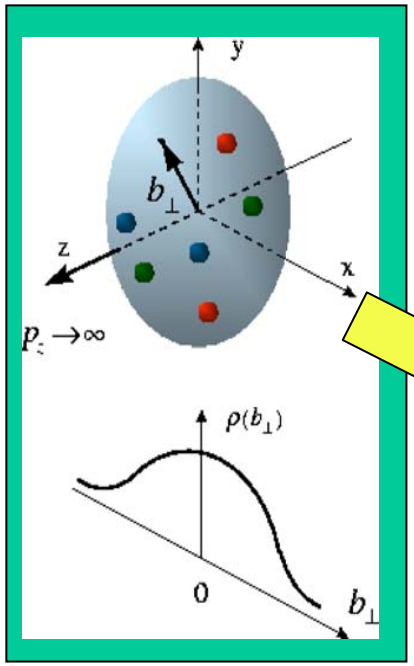
VERY PRELIMINARY

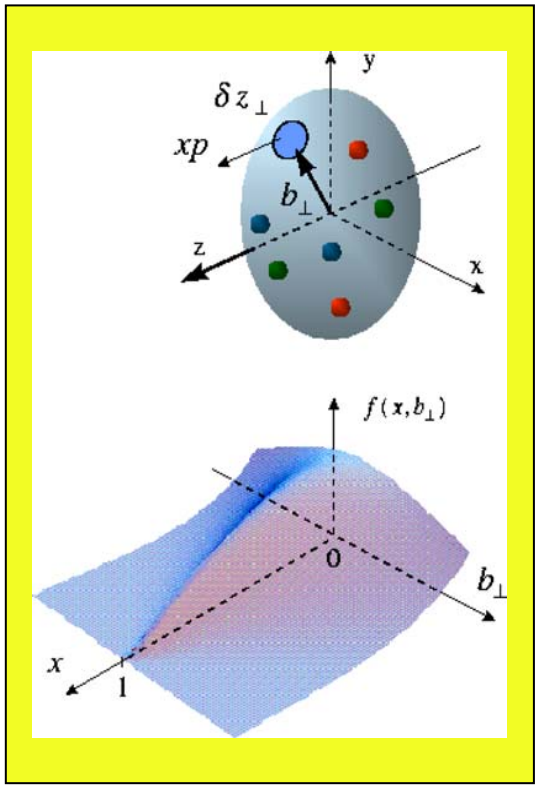


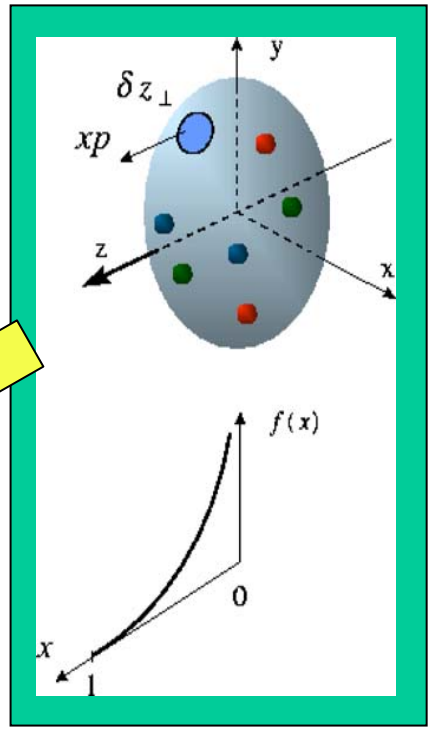
- Q^2 evolution of G_{1p} reveals the importance of nucleon resonances.
- Resonances are needed to explain
  - fall-off for $Q^2 < 1.5$ GeV^2
  - zero-crossing

Generalized Parton Distributions (GPDs)

developed by X. Ji, D. Mueller, A. Radyushkin (1994-1997)







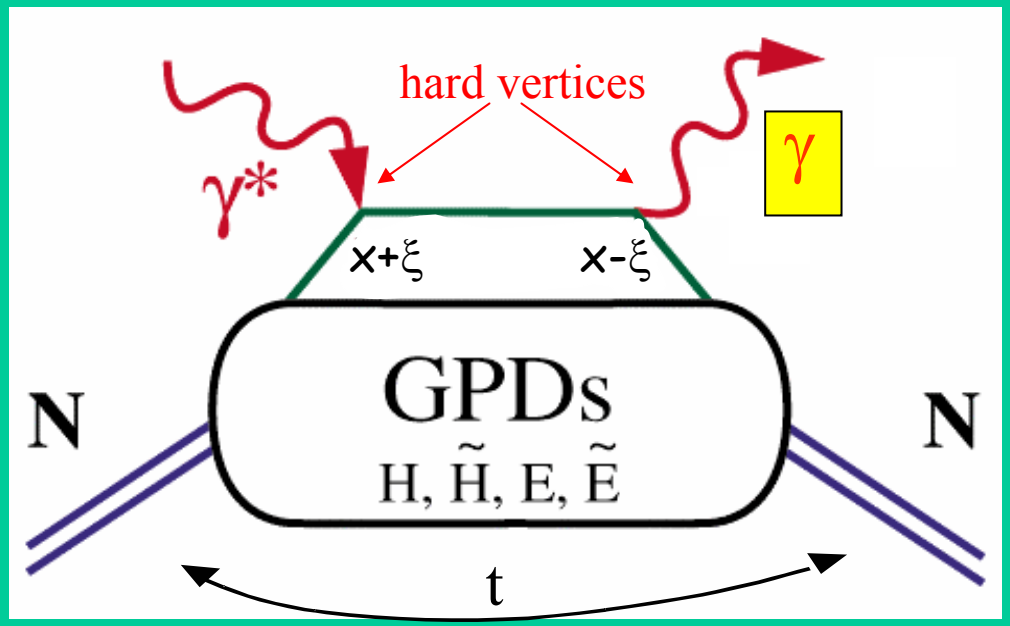
Proton form factors, transverse charge & current densities

Correlated quark momentum and helicity distributions in transverse space - GPDs

Structure functions, quark longitudinal momentum & helicity distributions

GPDs & Deeply Virtual Exclusive Processes

e.g.: Deeply Virtual Compton Scattering (DVCS)



x – quark momentum fraction

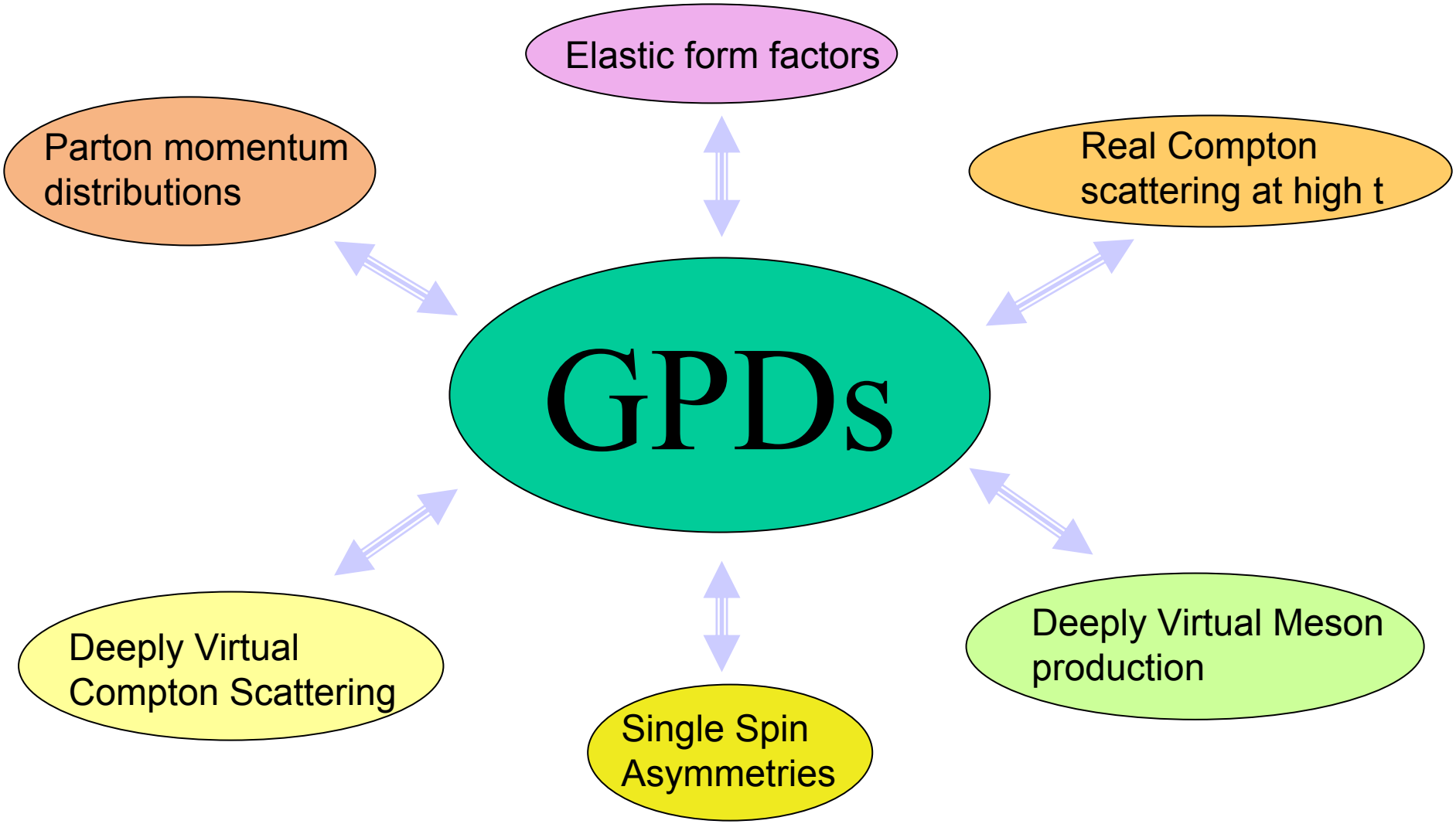
ξ – longitudinal momentum transfer

$\sqrt{-t}$ – Fourier conjugate to transverse impact parameter

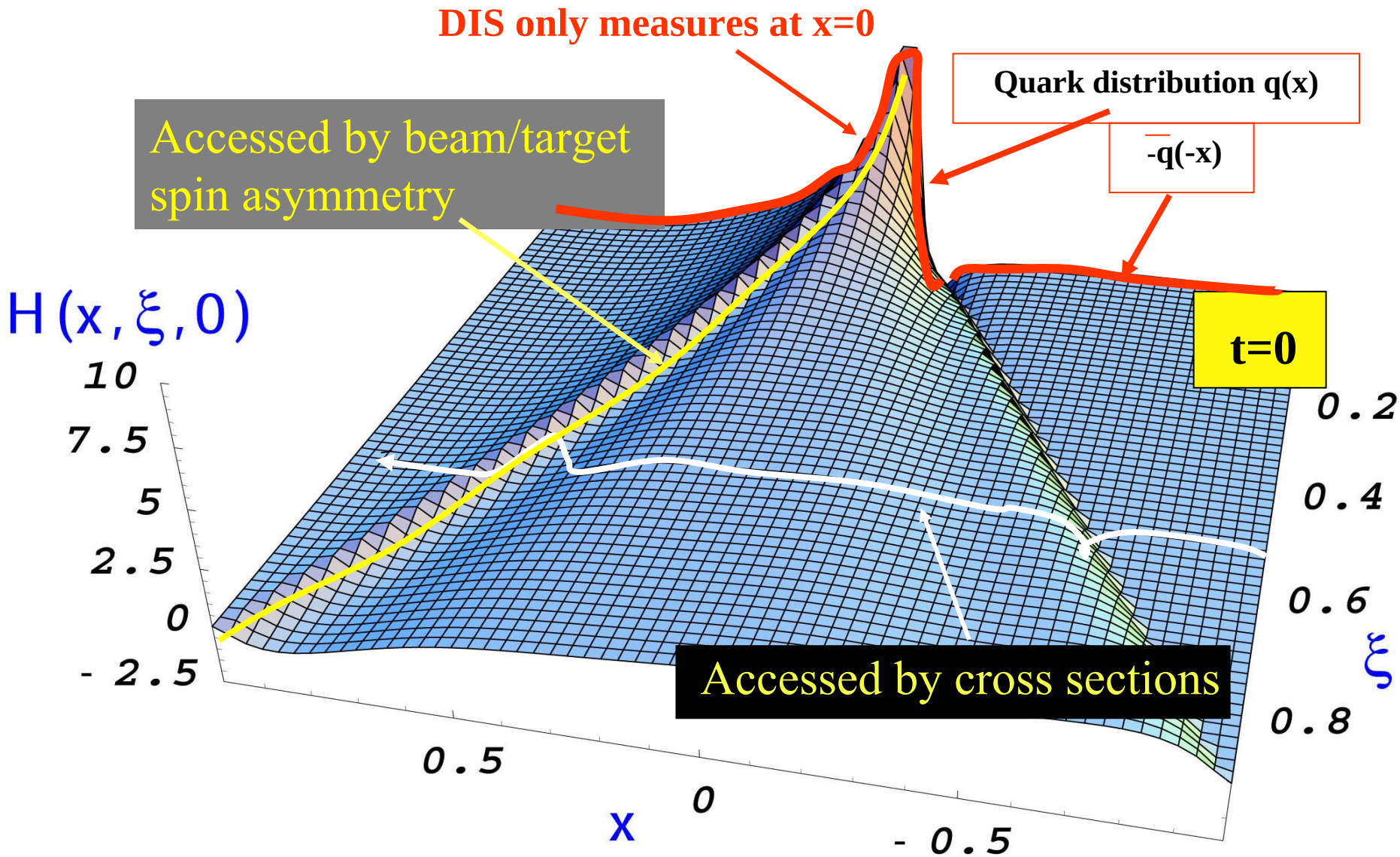
"handbag" diagram

$H(x,\xi,t)$, $E(x,\xi,t)$, . .

Universality of Generalized Parton Distributions

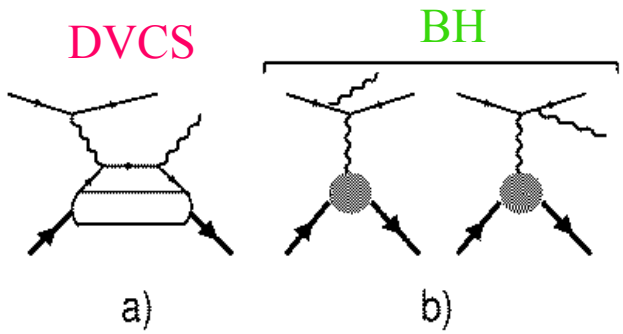


Experimental Access to GPDs



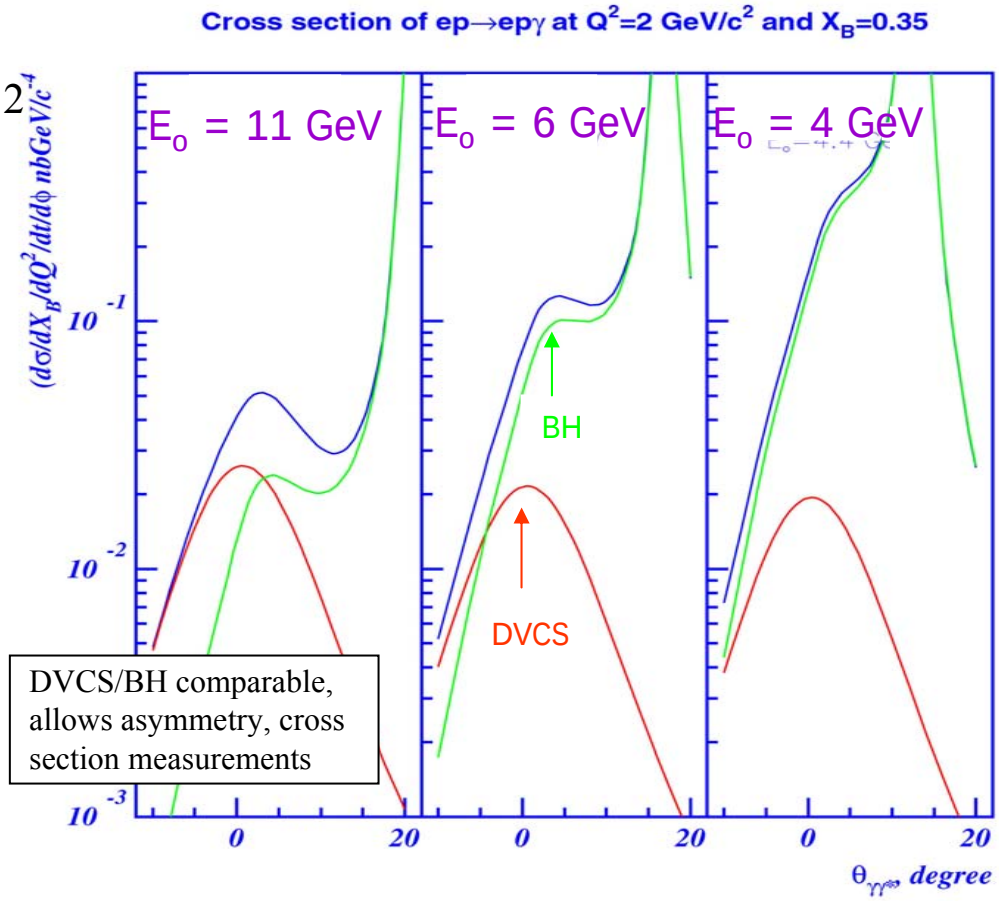
Access GPDs through DVCS

$$\frac{d^4\sigma}{dQ^2 dx_B dt d\phi} \sim |T^{DVCS} + T^{BH}|^2$$



T^{BH} : determined by Dirac & Pauli form factors

T^{DVCS}: determined by GPDs

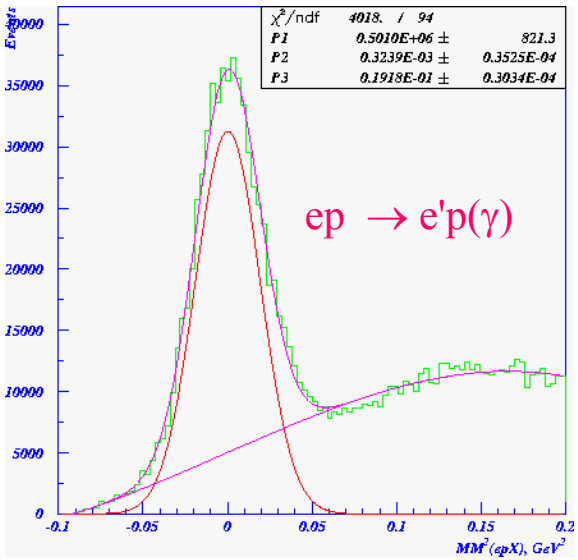


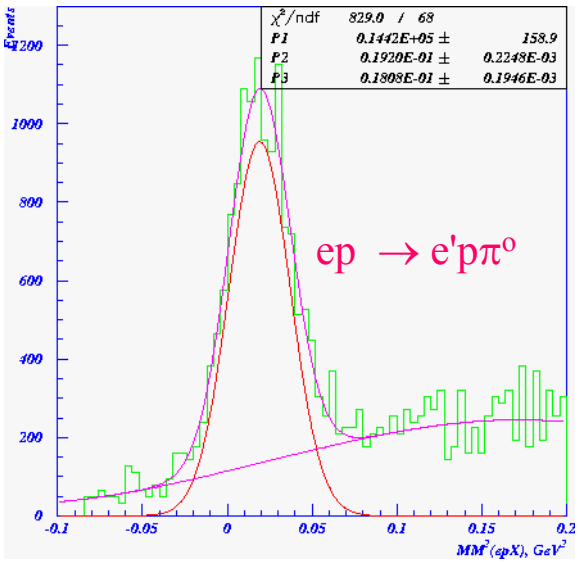
DVCS/BH comparable, allows asymmetry, cross section measurements

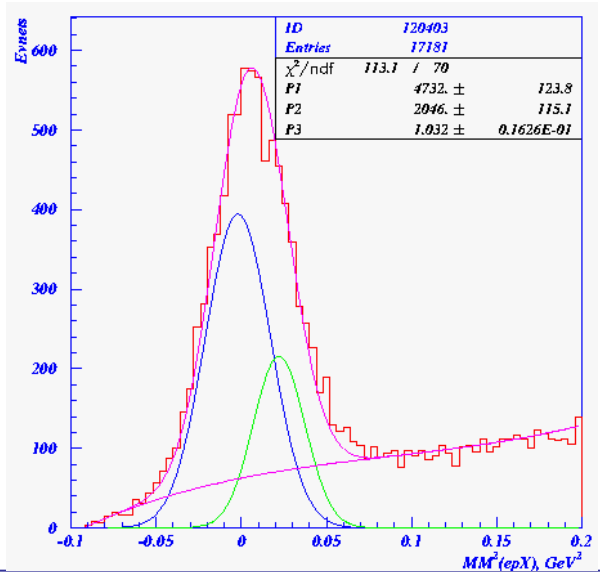
Helicity difference: $\Delta\sigma \sim \sin\phi \, \mathrm{Im}\{(F_1 H(\xi,\xi,t) + k_1(F_1+F_2)H(\xi,\xi,t) + k_2 F_2 E(\xi,\xi,t)\} d\phi$

ep → e'pX - Missing Mass Analysis

Calibrate missing mass using radiative elastic and exclusive ep → e'pγγ events



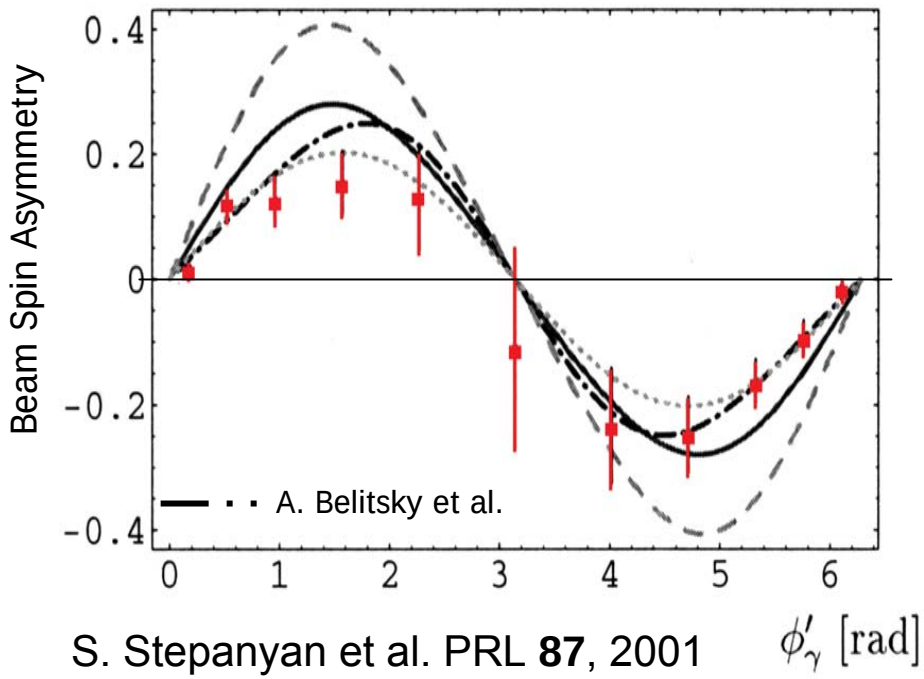




exclusive ep → e'pγ

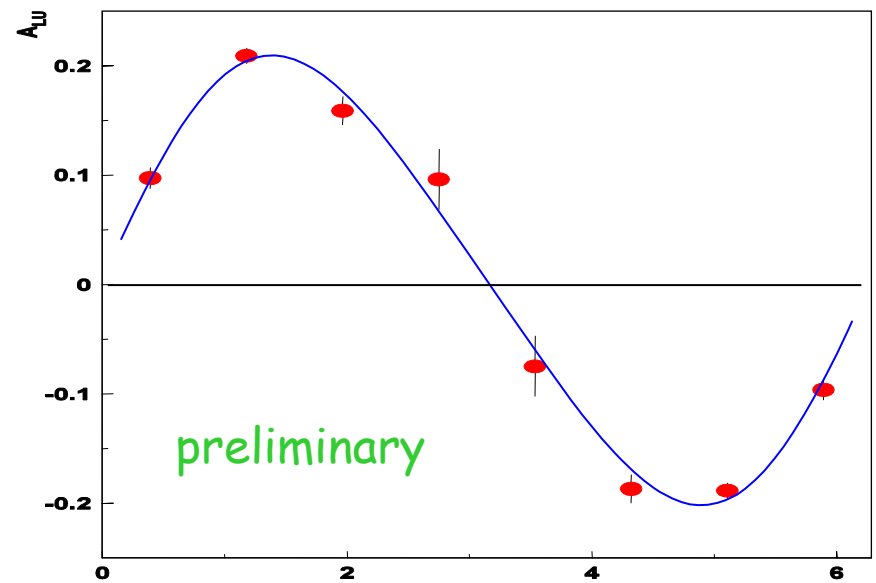
Measurement of exclusive DVCS

1999 data, E=4.2GeV, $\langle Q^2 \rangle = 1.3 GeV^2$



S. Stepanyan et al. PRL **87**, 2001

2001 data, E=5.75GeV, $\langle Q^2 \rangle = 2.5 GeV^2$



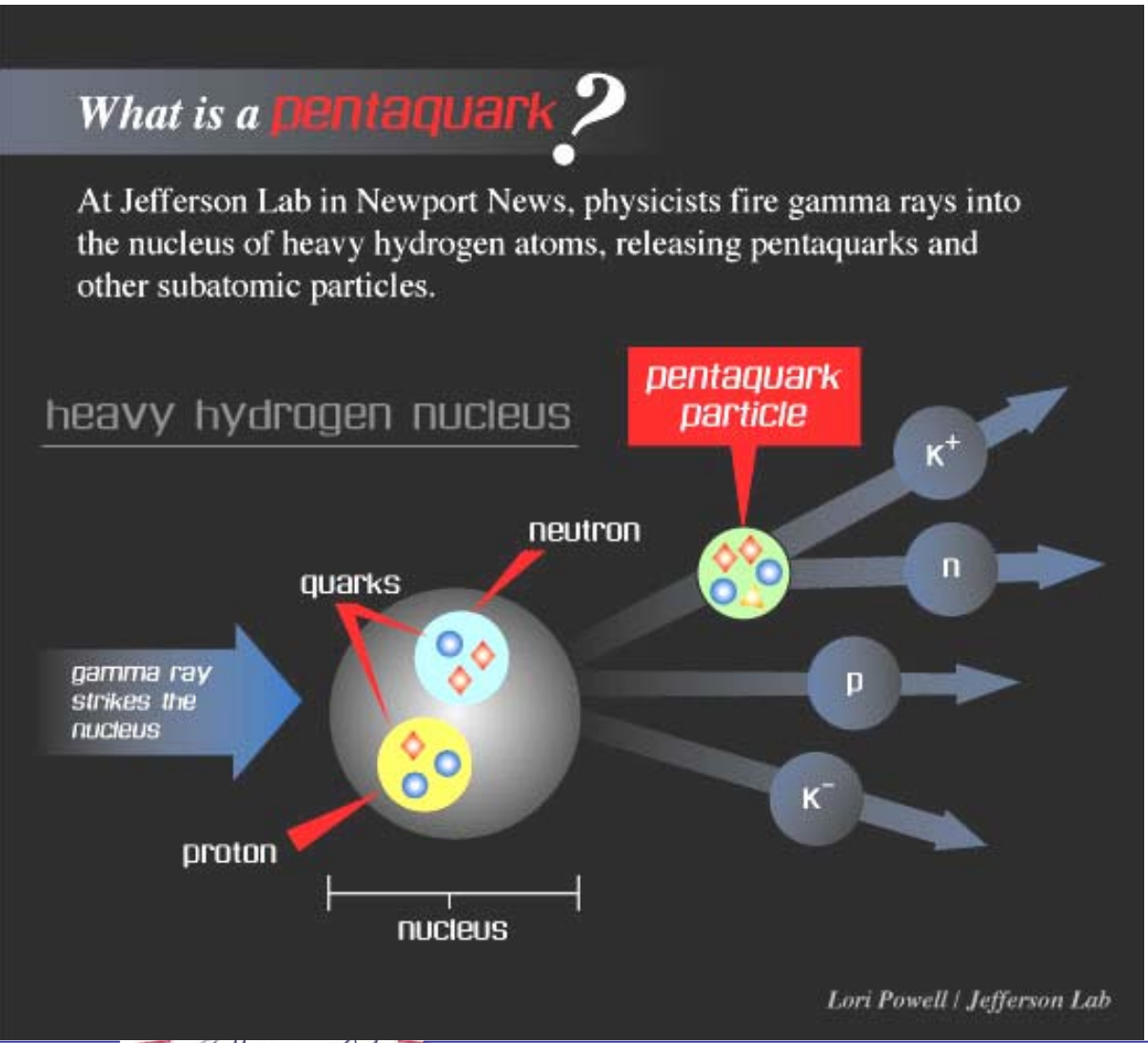
$$A(\phi) = \alpha \sin\phi + \beta \sin 2\phi$$

- $\alpha = 0.202 \pm 0.028^{stat} \pm 0.013^{sys}$
- $\beta = -0.024 \pm 0.021^{stat} \pm 0.009^{sys}$

- Higher energy increases kinematics range.
- Higher statistics allows binning in Q^2, t, ξ

Pentaquark: Baryon with five quarks

Goal: Determine quark content of colorless hadrons

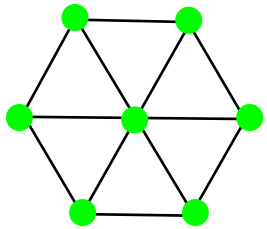


Expectation from the quark model is that the properties of baryons are determined by three valence quarks (qqq)

Hadron Multiplets

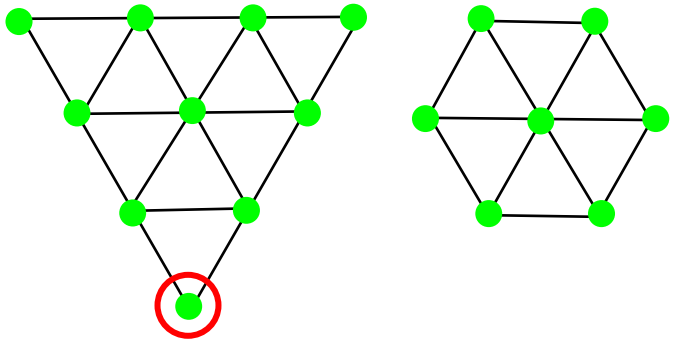
Mesons $q\bar{q}$

$$3 \otimes \bar{3} = 8 \oplus 1$$



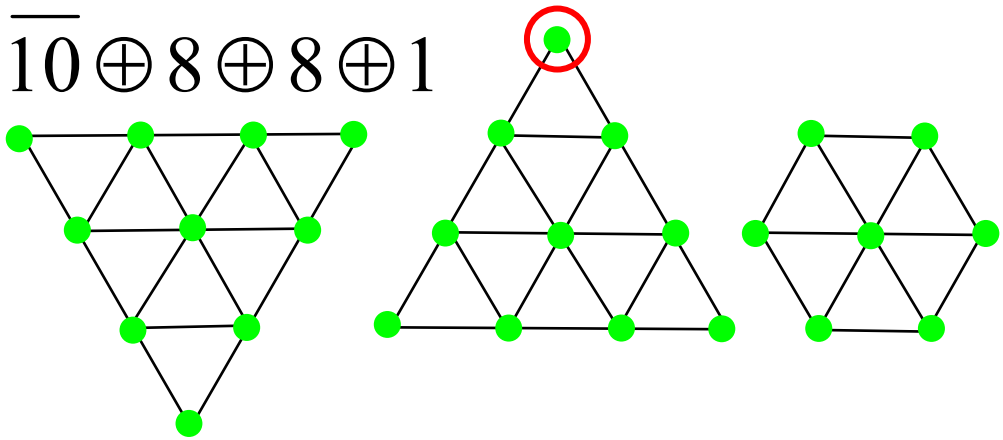
Baryons qqq

$$3 \otimes 3 \otimes 3 = 10 \oplus 8 \oplus 8 \oplus 1$$



Baryons built from meson-baryon basis

$$8 \otimes 8 = 27 \oplus 10 \oplus \overline{10} \oplus 8 \oplus 8 \oplus 1$$



What are Penta-Quarks?

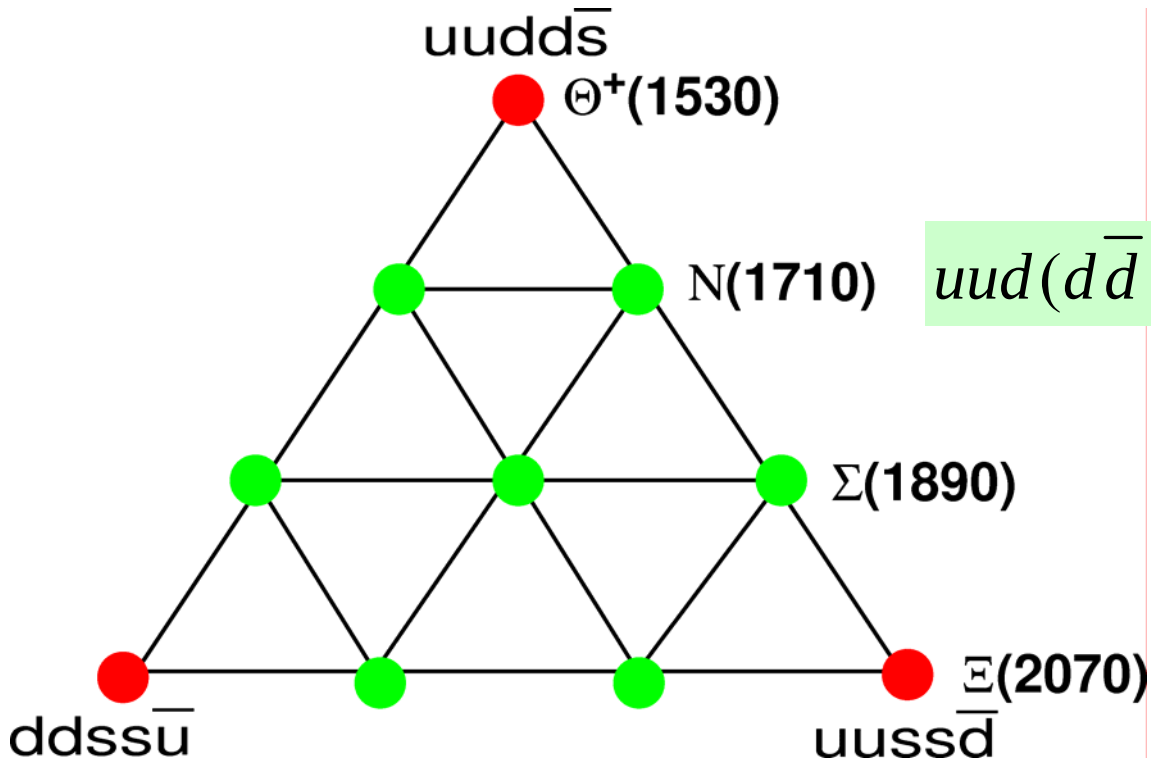
- Minimum quark content is 5-quarks.
- Anti-quark has different flavor than any of 4-quarks ($qqqq\bar{Q}$).
- Quantum numbers can not be defined by 3-quarks.

- General idea of a five-quark states has been around since late 60's.
- However, searches did not give any conclusive results.
- PDG dropped the discussion on pentaquark searches after 1988.

Exotic Baryon Search

The chiral soliton model by D. Diakonov, M. Petrov, M. Polyakov predicts an anti-decuplet of penta-quark baryons.

The lightest state is predicted to be a baryon state with exotic quantum number S=+1, and M=1.53GeV, Γ=15MeV.

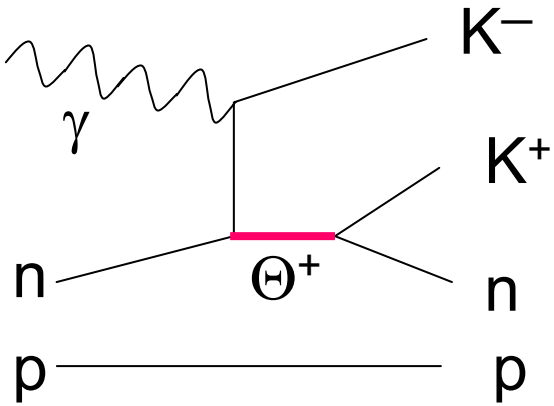


$$uud(d\bar{d}+s\bar{s})$$

Θ^+ Photoproduction and Competing Reactions

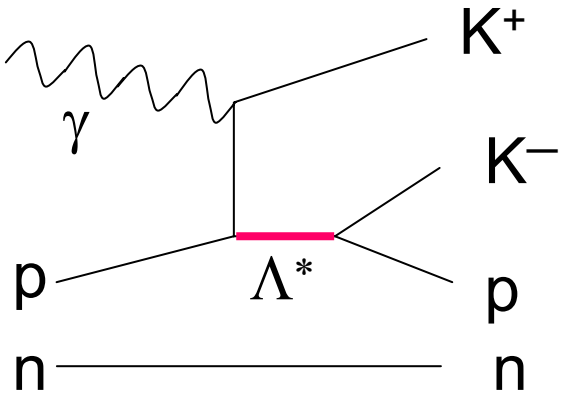
$$\gamma n(p) \rightarrow \Theta^+ K^-(p)$$

$$\Theta^+ \rightarrow K^+ n$$



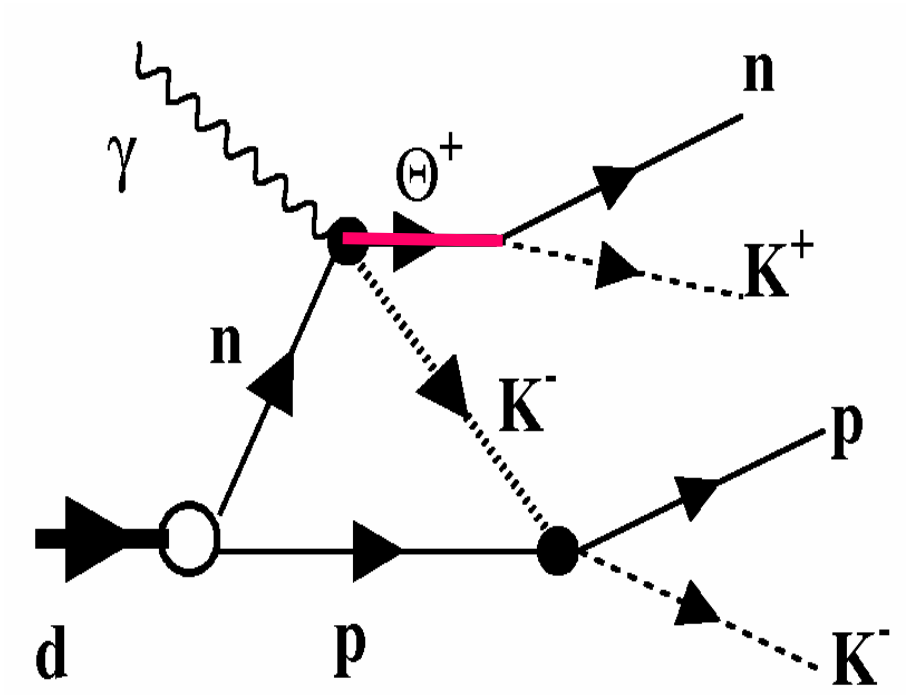
$$\gamma p(n) \rightarrow \Lambda^*(1520) K^+(n)$$

$$\Lambda^*(1520) \rightarrow K^- p$$



$$\gamma N \rightarrow \phi(1020)\, N \rightarrow K^+ K^- N$$

Exclusive γd Measurement



CLAS Collaboration

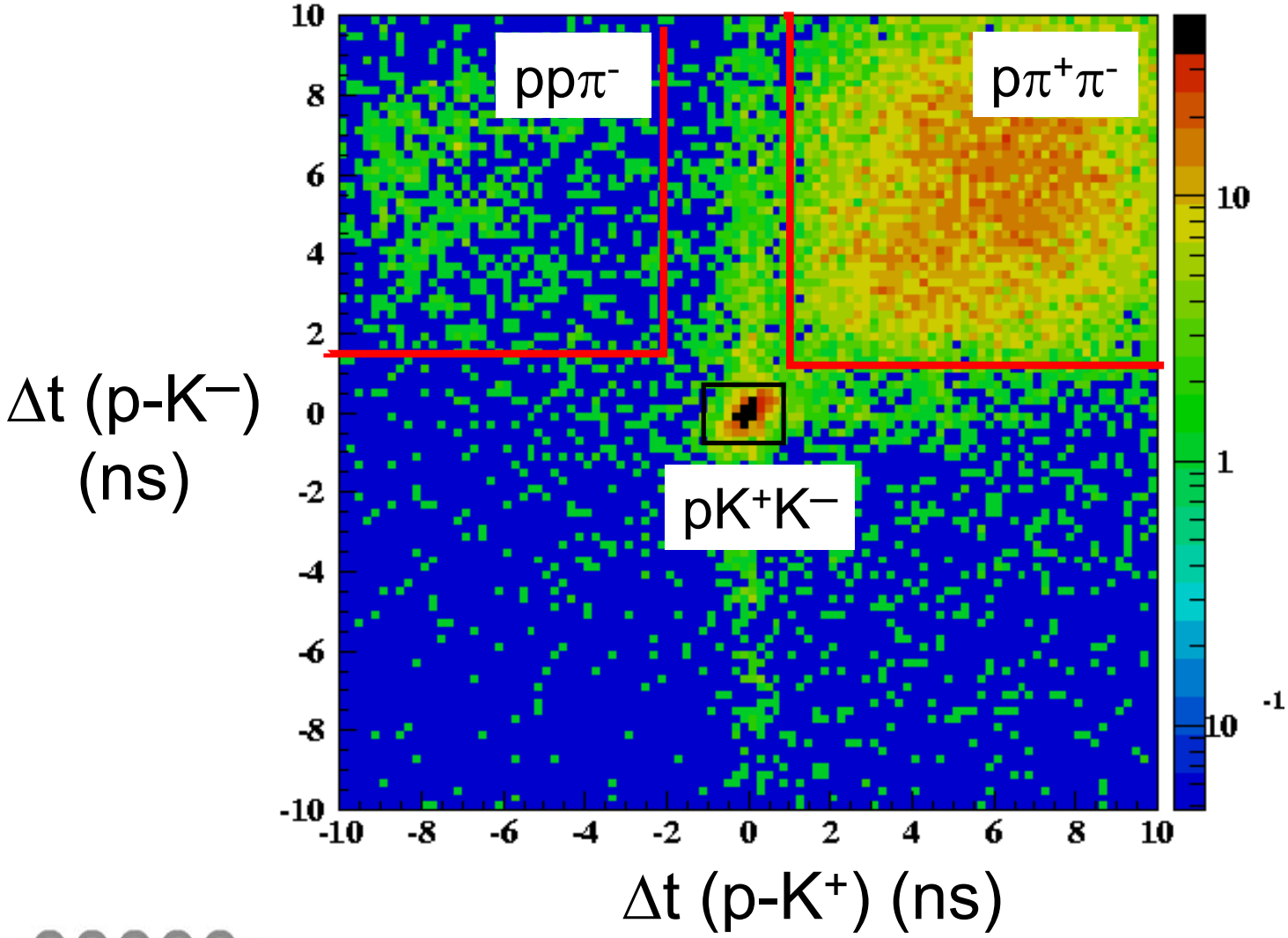
(S. Stepanyan, K. Hicks, *et al.*), hep-ex/0307018

requires FSI – both nucleons involved

- no Fermi motion correction necessary
- FSI puts K^- at larger lab angles: better CLAS acceptance
- FSI not rare: in ~50% of $\Lambda^*(1520)$ events both nucleons detected with p > 0.15 GeV/c

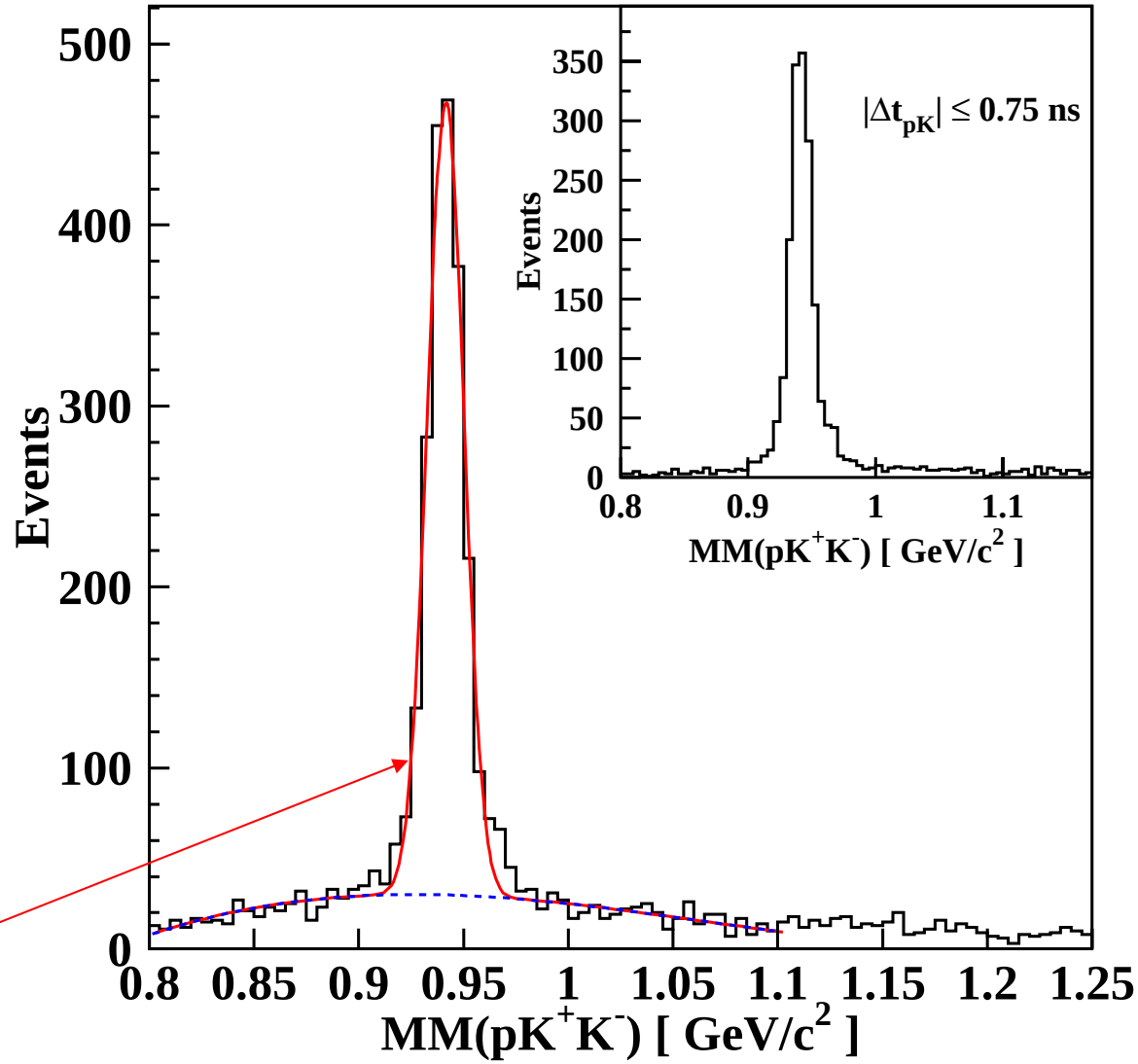
Kaon start times relative to the proton

$$\Delta t_K = t - \frac{R}{\beta_c \cdot c}; \beta_c = \frac{p}{\sqrt{p^2 + m_K^2}}$$



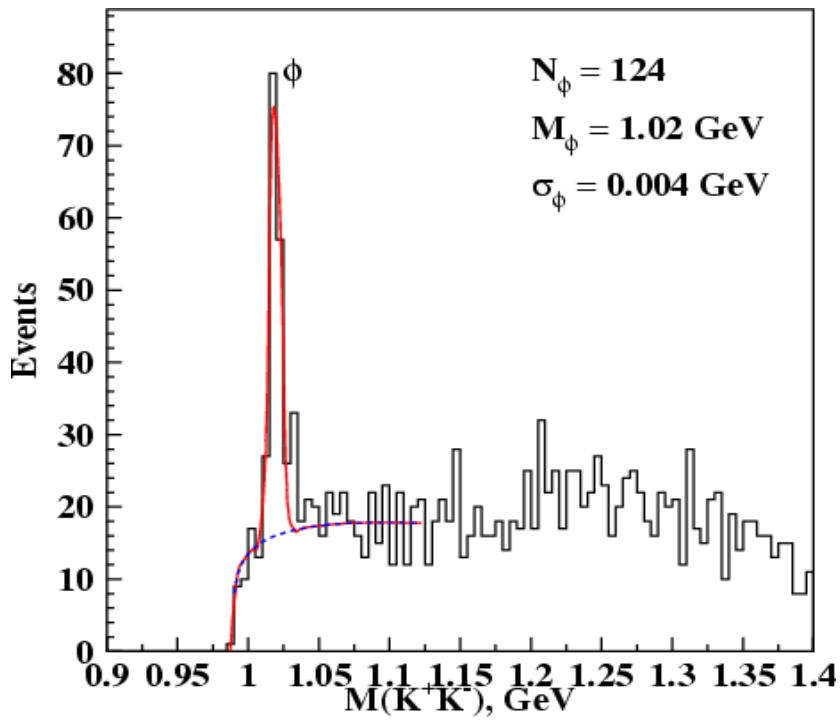
Reaction $\gamma d \rightarrow pK^+K^-(X)$

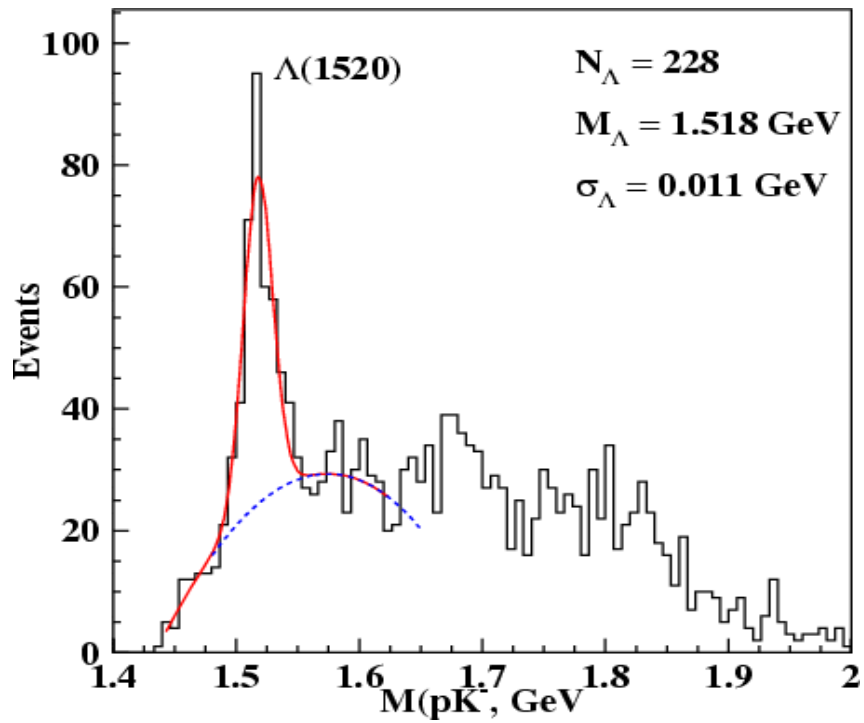
- clear peak at neutron mass
- 15% non-pKK events within $\pm 3\sigma$ of the peak
- background under the neutron peak can be further reduced by tight timing cut



reconstructed neutrons

Removal of known resonances

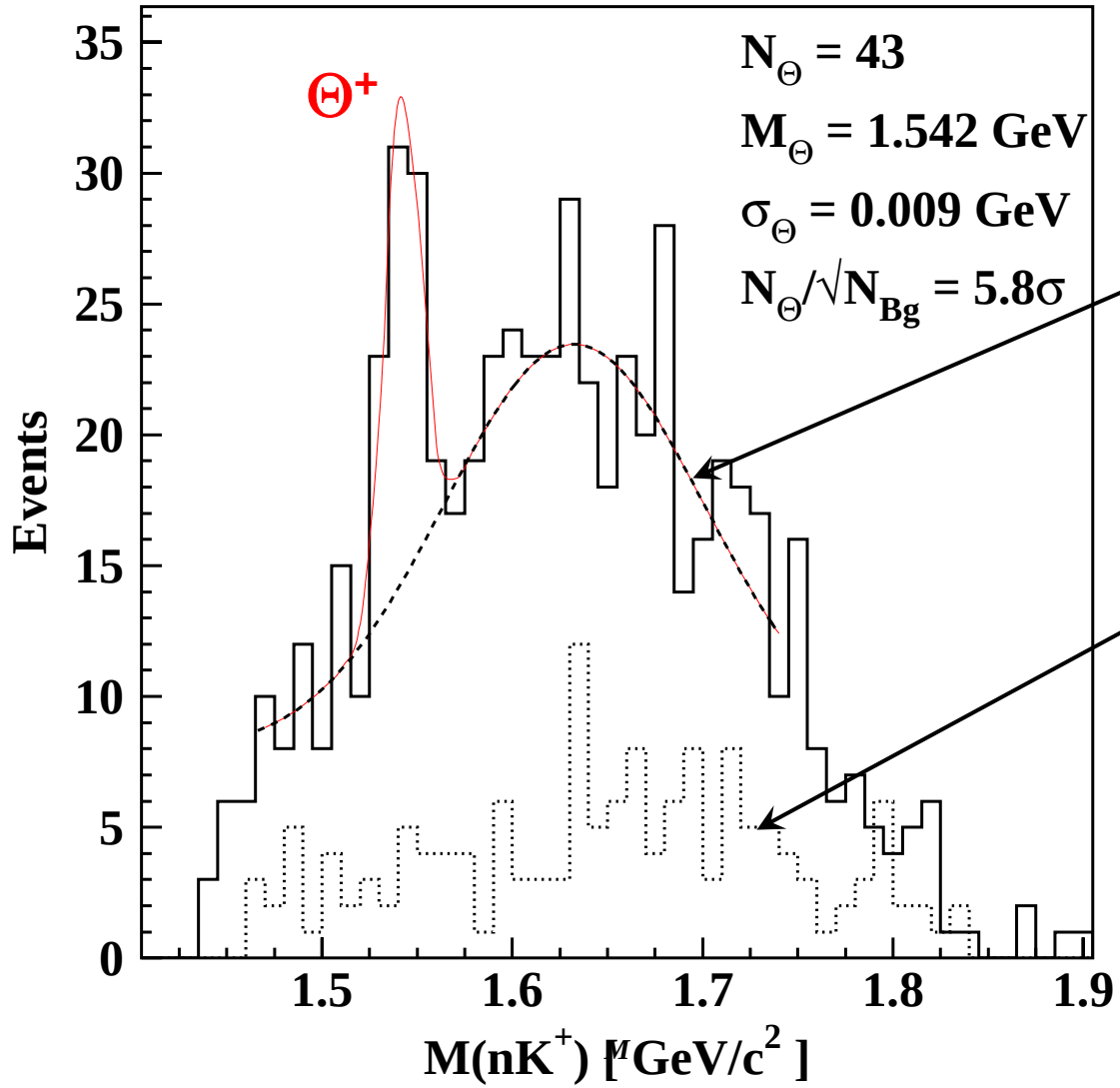




Cuts

- remove events with $IM(K^+K^-) \rightarrow \phi(1020)$ by IM > 1.07 GeV
- remove events with $IM(pK^-) \rightarrow \Lambda(1520)$
- limit K^+ momentum due to $\gamma\, d \rightarrow p\, K^-\, \Theta^+$ phase space **p_{K^+} < 1.0GeV/c**

(nK$^+$) Invariant Mass Distribution



$$F(M) = G_{\Theta+} + G_{Bg} + P_0$$

distribution of Λ(1520) events

Θ^+ Experimental Status

Experimental evidence for Θ^+ has been reported by four groups:

- LEPS at Spring-8 (Japan), January 2003 - peak in the invariant mass of the nK^+ at 1.54 GeV with statistical significance of 4.6σ
- DIANA at ITEP (Moscow), April 2003 – peak in the invariant mass of pK^o at 1.538 GeV, statistical significance 4.4σ
- CLAS at JLAB, July 2003 – peak in the invariant mass of the nK^+ at 1.542 GeV, statistical significance 5.3σ
- SAPHIR at ELSA, August 2003 – peak in the invariant mass of the nK^+ at 1.54 GeV, statistical significance 4.8σ

All experiments observe a narrow width

Penta-Quark 2003 Workshop at JLab
November 6-8, 2003

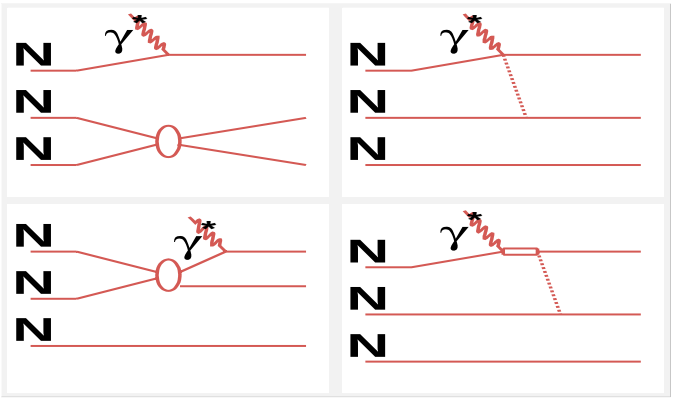
Nucleon-Nucleon Correlations

Observable: NN-pair with

- large relative momentum
- small total momentum

→ need to distinguish between Correlations and Currents

Correlations Currents



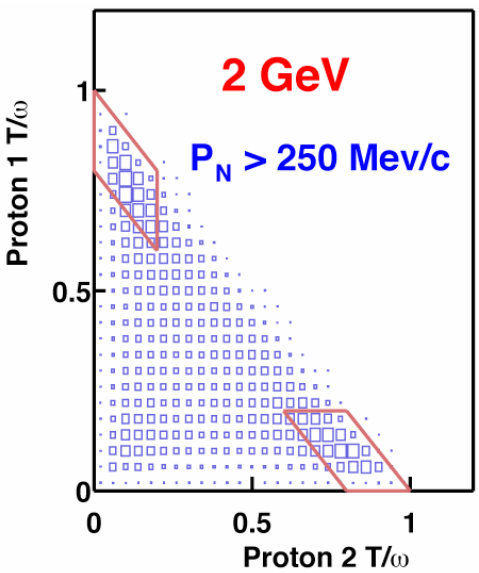
MEC

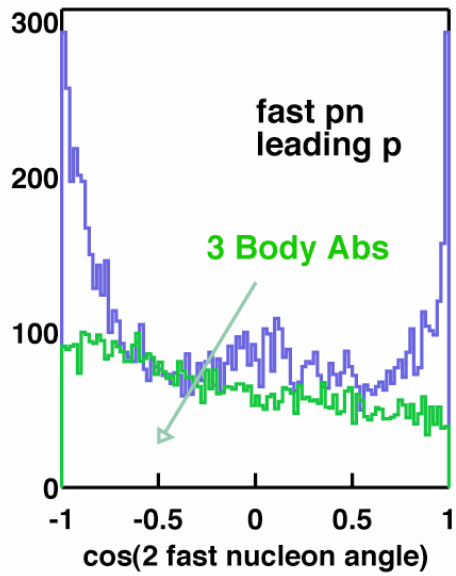
IC

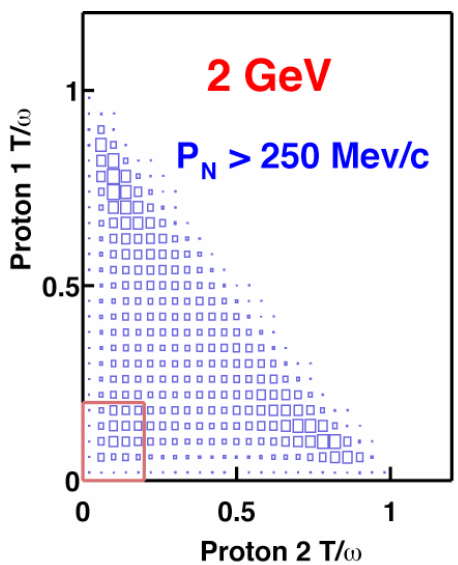
Two-Body Currents (MEC + IC)

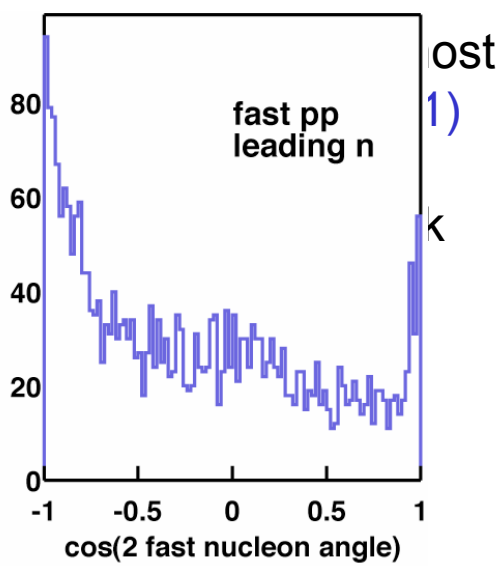
- not a Correlation
- strongly enhance effect of correlation

Three-Body Break-up of ^{3}He









ost
1)
k

$^3He(e,e'pp)n$

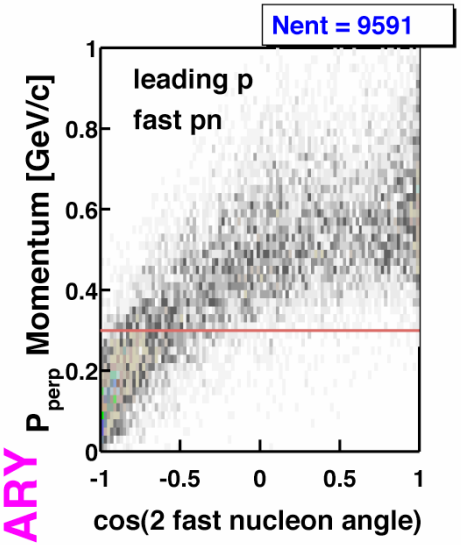
Two protons detected with p > 250 MeV/c > p_{Fermi}

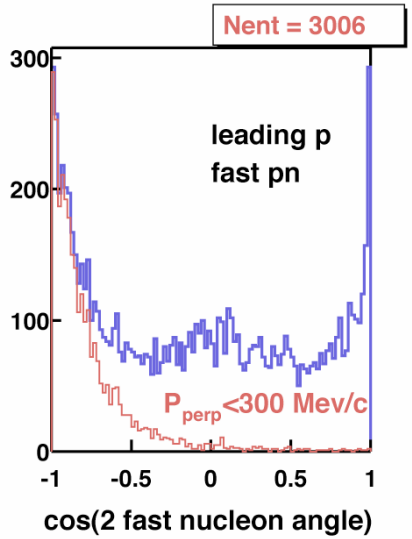
Reconstruct neutron via missing mass

Select proton/neutron with almost all transferred energy ($TN/\omega \approx 1$)

Clear evidence of back-to-back excess over three-body absorption followed by phase-space decay simulation

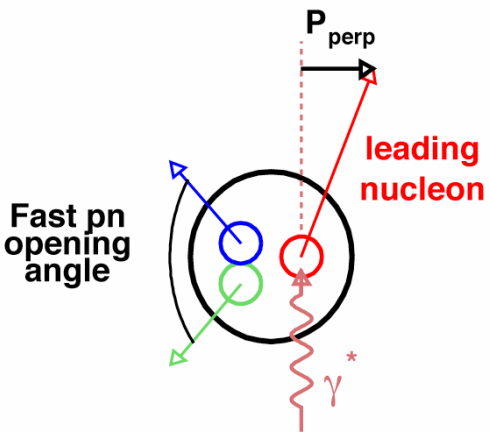
Angular Distribution of Emitted NN-Pair

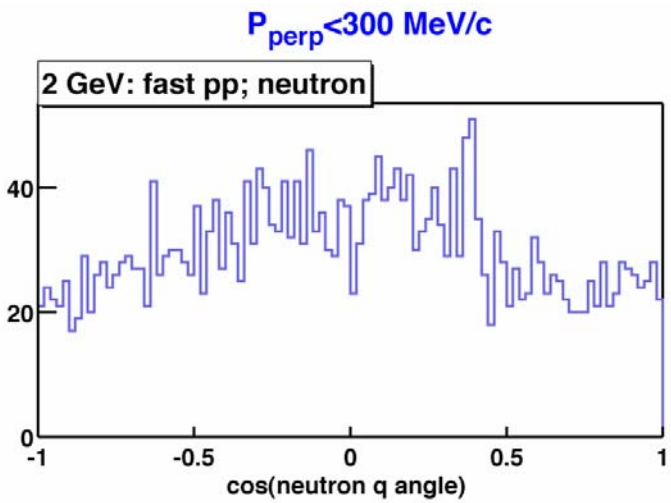




PRELIMINARY

Cut on leading nucleon P_{perp} < 300 MeV/c to select quasifree knockout (reduce FSI)

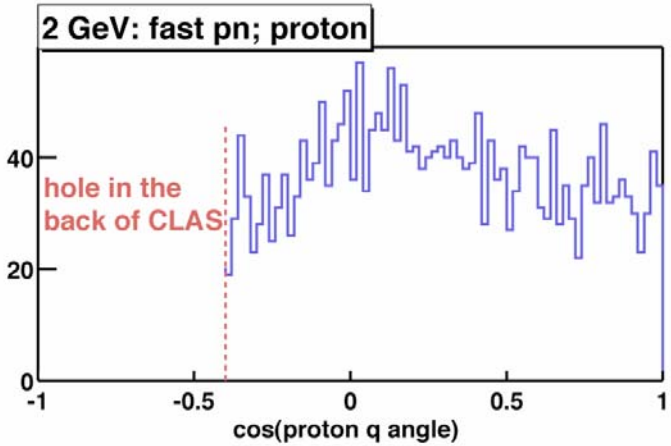




PRELIMINARY

Isotropic Fast Pairs

-> Pair not involved in REACTION!



Conclusions from $^3He(e,e'pp)n$ Experiment

If one selects a fast leading nucleon in ^{3}He(e,e'pp)n then the remaining (fast) NN pair:

- is back-to-back
- is isotropic with respect to momentum transfer q
- has small momentum along q

➔ Fast NN pair is not involved in the reaction

Total and relative momentum distributions similar for:

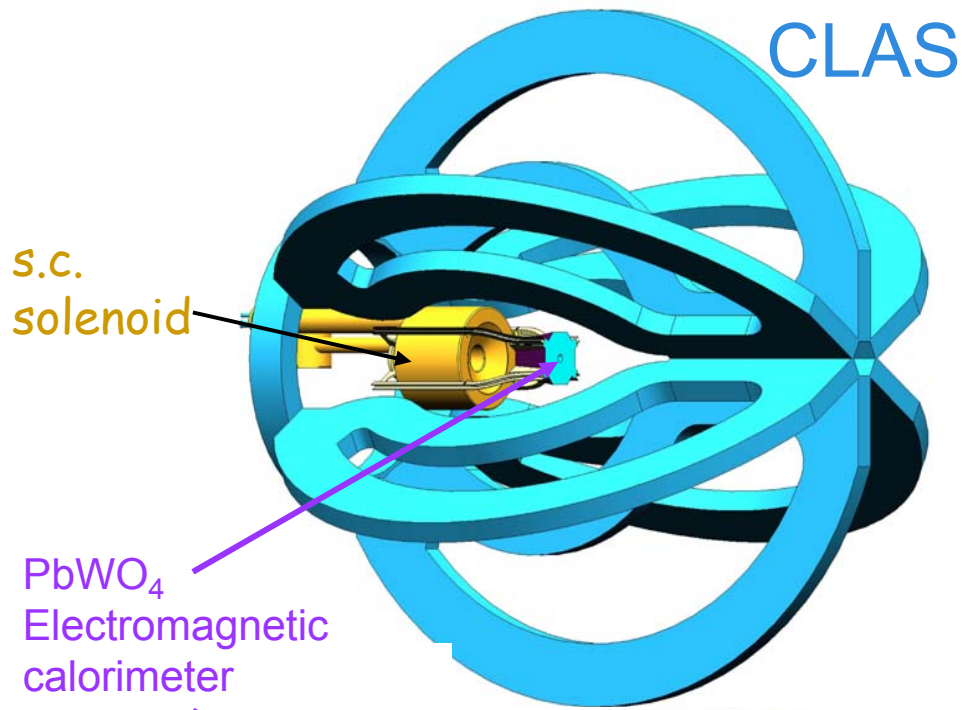
- pp and pn pairs
- $0.5 < Q^2 < 1$ and $1 < Q^2 < 2$ $(GeV/c)^2$

- WE ARE OBSERVING BOUND-STATE CORRELATIONS!

Setup for Deeply Virtual Compton Scattering

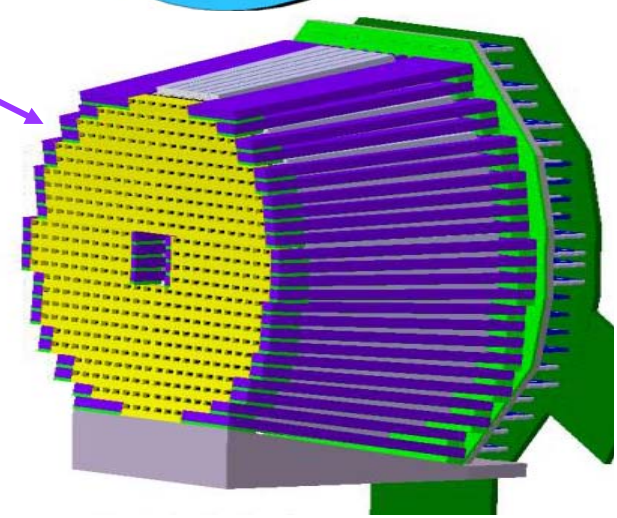
Physics Goal

measure ξ, t, Q^2 - dependence of $ep \rightarrow e'p\gamma$ in a wide kinematics range to constrain GPD models.



Technical Problem

- need to detect all final state particles to identify process
- double luminosity to 2×10^{34} cm^{-2} s^{-1}



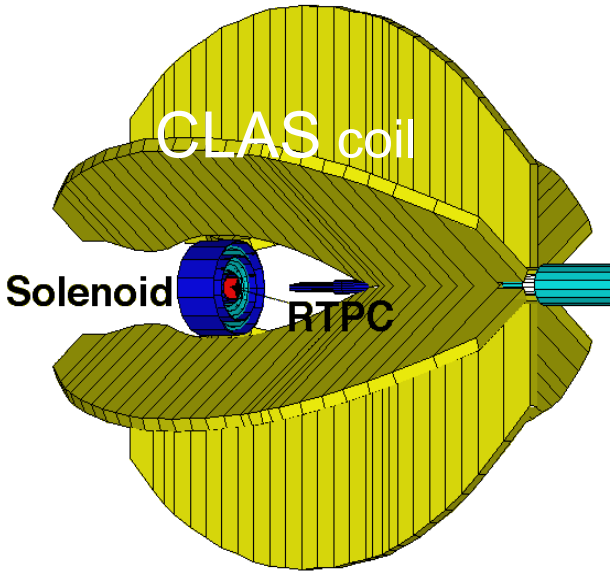
Technical solution

- add forward calorimeter (436 lead tungstate crystals)
- readout via avalanche photodiodes (APD)
- SC 5Tesla solenoid Moller shield

Bound Nucleon Structure (B O N U S)

Physics issue:

tag process off a neutron bound in deuterium by detecting the spectator proton in coincidence with the scattered e'



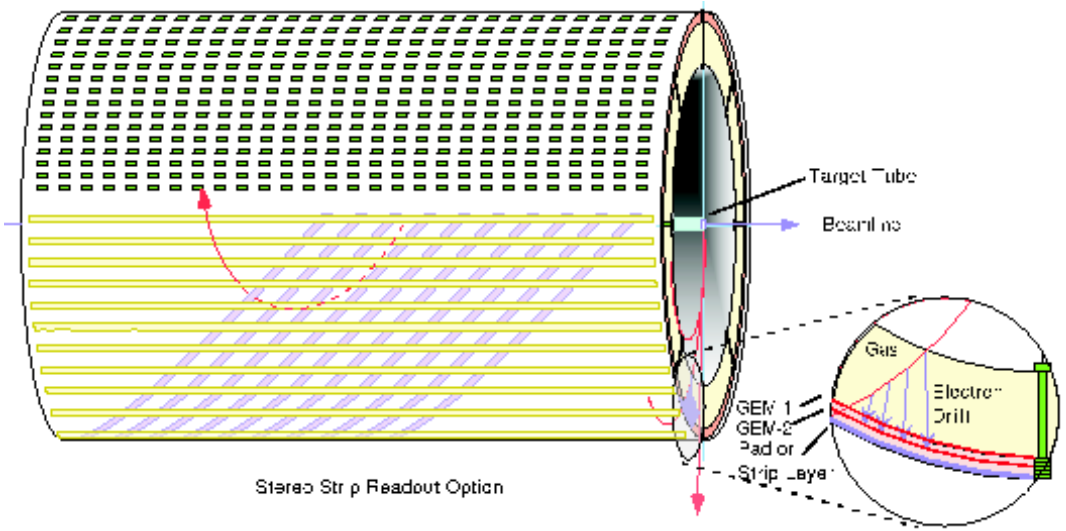
Technical problem:

spectator protons have

- low momentum and low range
- isotropic angular distribution (no correlation)
- high rate

Solution:

- high pressure gas target
- surrounded by radial drift chamber
- GasElectronMultiplier gap



Frozen Spin Target for CLAS

Technical problem:

build polarized target for tagged photon beam

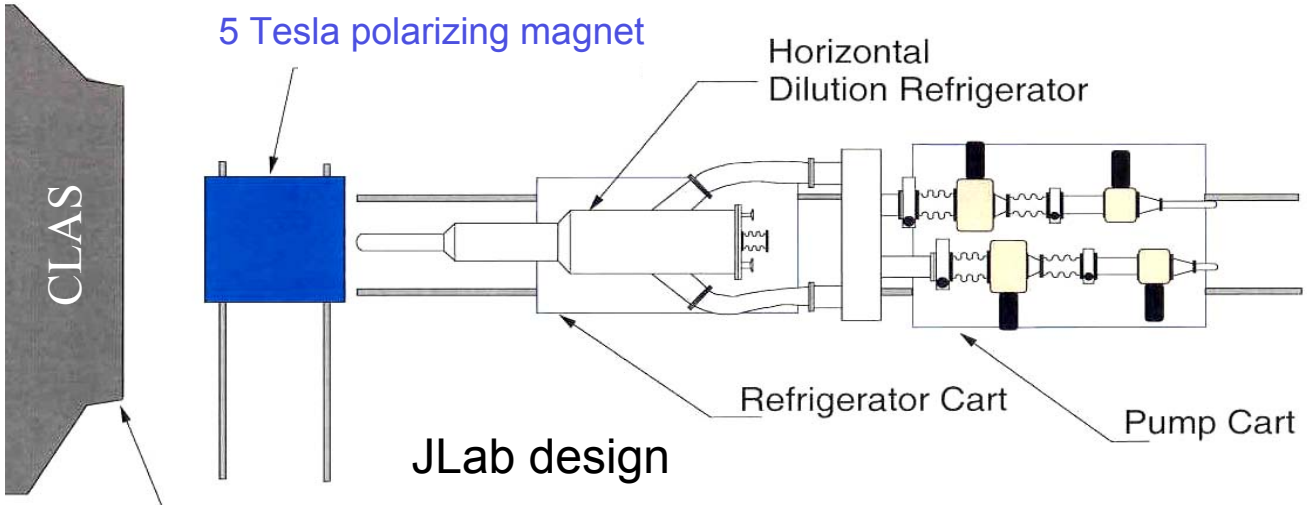
- minimum obstruction of CLAS solid angle
- low distortion of particle trajectories in magnetic field

Solution:

- frozen spin target
- temperature 50mK
- magnetic field 5kG

Status:

- design in progress at JLab
- procurement started for polarizing magnet



JLab design

Physics Drivers for CEBAF Upgrade

- New capabilities
  - search for origin of confinement (J^{PC} exotic mesons)
  - determine parton distributions (high Q^2 and W) via
    - polarized and unpolarized inclusive scattering
    - semi-inclusive (tagged) structure functions
    - exclusive processes (DVCS, meson production)

- Push present program to higher Q^2
  - form factors of mesons, nucleons, and light nuclei

CEBAF Upgrade Plan

- Upgrade accelerator to 12 GeV max. energy
  - maintain 100% duty cycle
  - keep beam power constant (1MW) $\longrightarrow$ max. current 80μA
- Build new experimental hall for meson spectroscopy (Hall D)
  - polarized tagged photon beam (coherent bremsstrahlung)
  - large acceptance detector for real photons only
- Upgrade existing 3 halls for higher beam energy

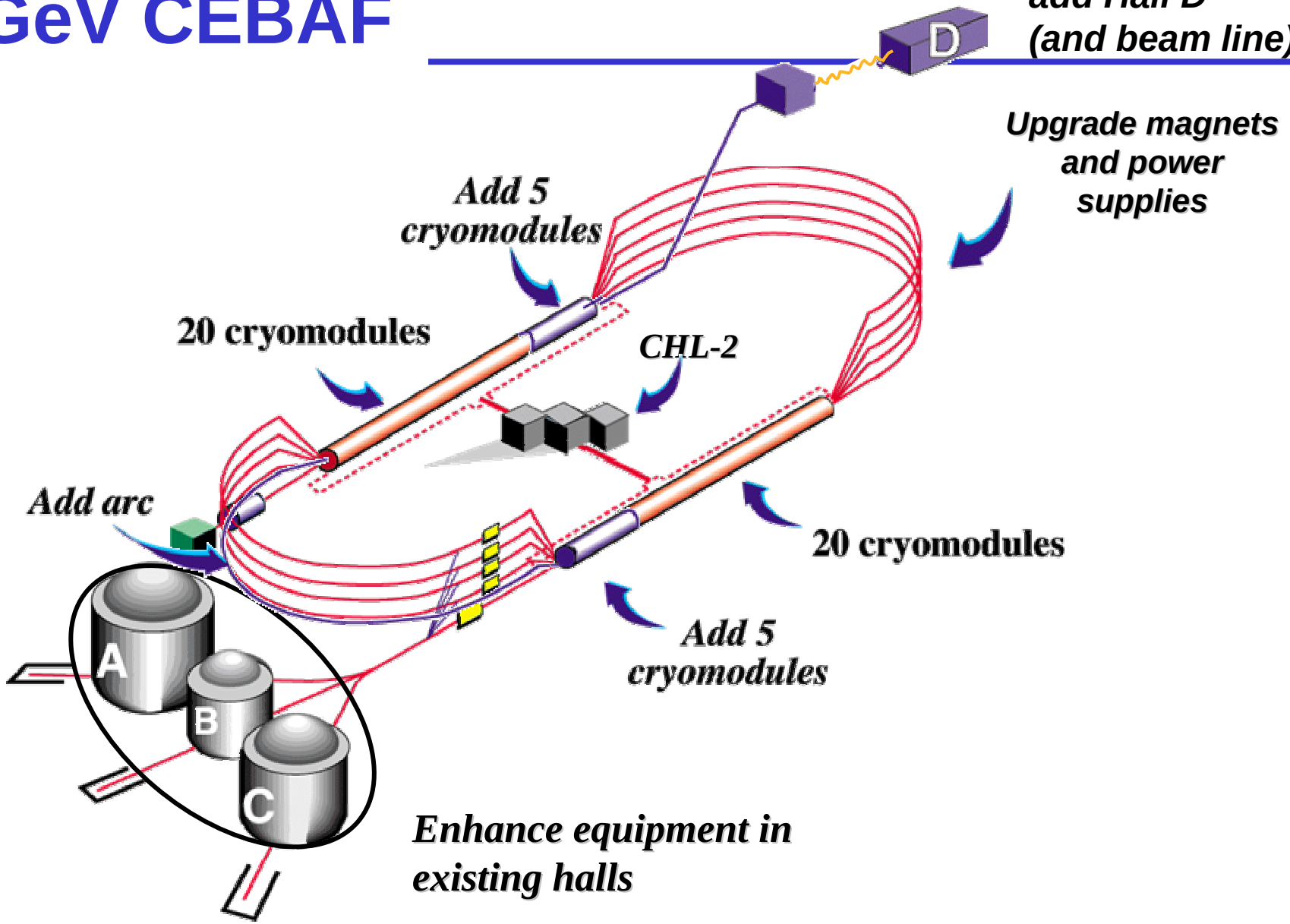
CEBAF Accelerator Upgrade

- keep present accelerating system

- add ten new cryomodules at 100MeV energy gain
  - present cryomodules provide ~30 MeV
  - increased performance can be achieved by
    - increased effective cavity length (5-cell $\Rightarrow$ 7-cell)
    - Increased average gradient (7.5 MV/m $\Rightarrow$ 17.5 MV/m)

- double cryogenic system capacity
- upgrade recirculating arcs
- add new beam line to Hall D

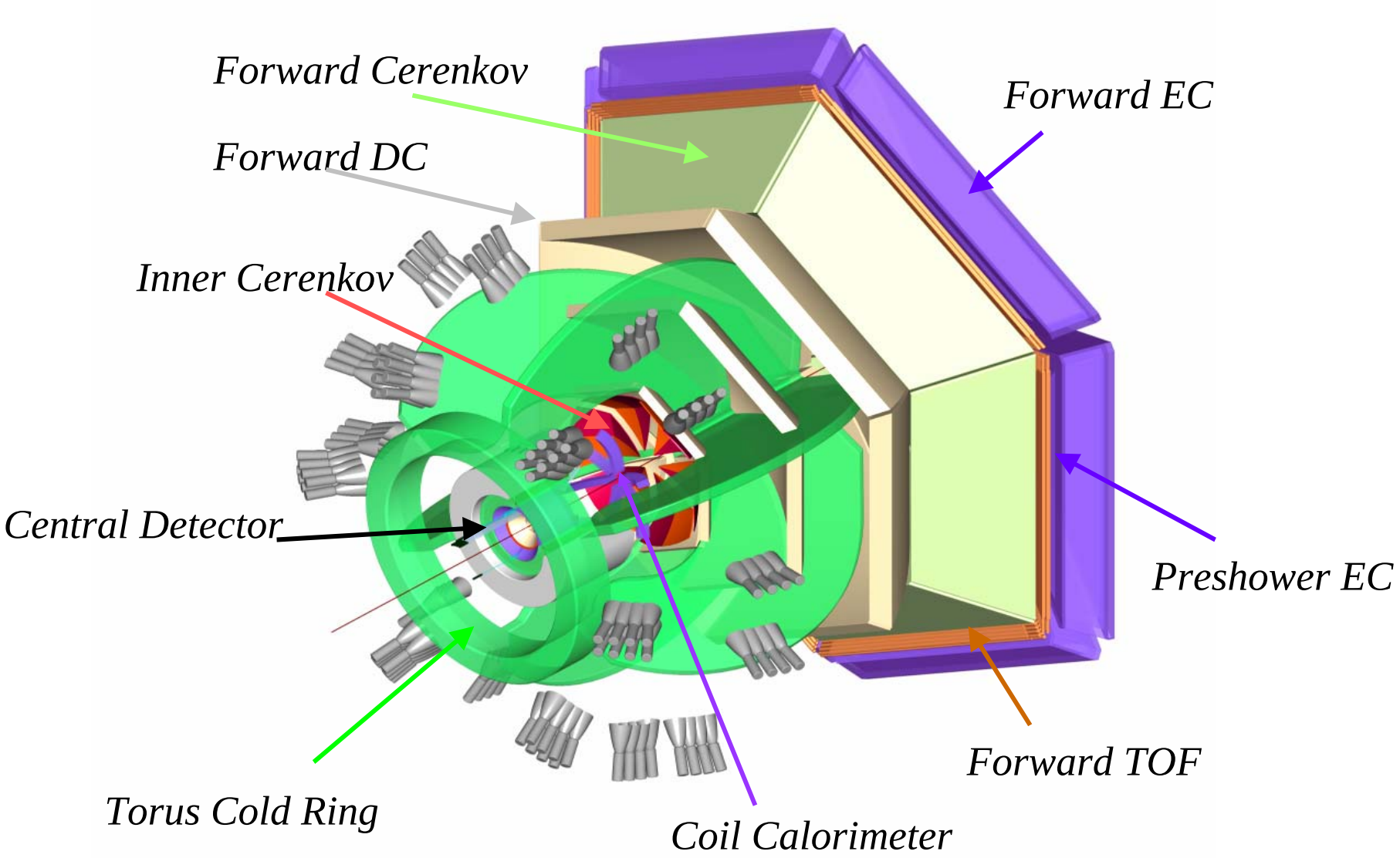
12 GeV CEBAF


add Hall D
(and beam line)
D
Upgrade magnets
and power
supplies
Add 5
cryomodules
20 cryomodules
CHL-2
Add arc
20 cryomodules
Add 5
cryomodules
A
B
C
Enhance equipment in
existing halls

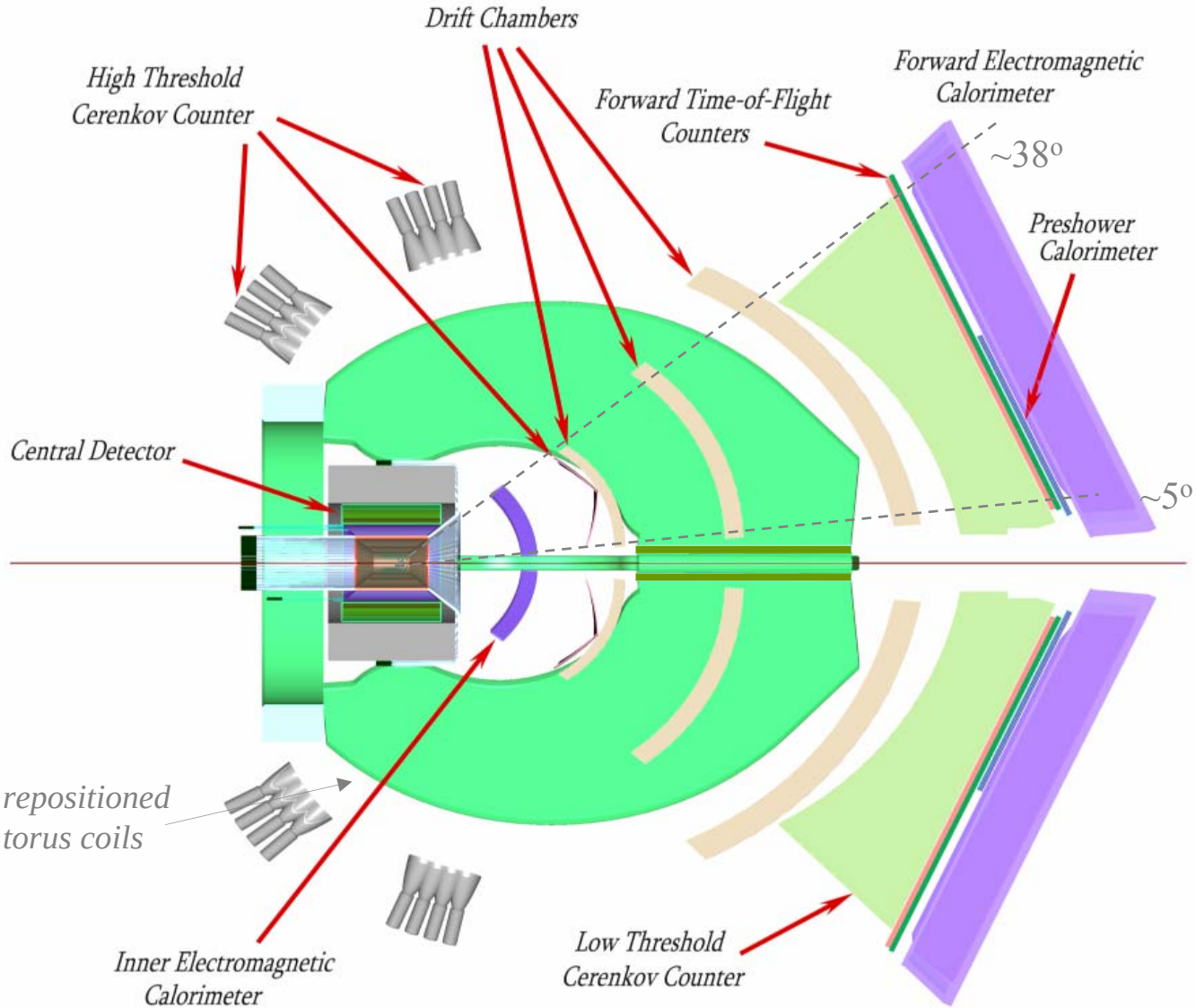
CLAS Physics Program at 12 GeV

- **Quark-Gluon Dynamics and Nucleon Tomography**
  - Deeply Virtual Compton Scattering (DVCS)
  - Deeply Virtual Meson Production (DVMP)
  - High-t DVCS and π^0/η production
- **Valence Quark Distributions**
  - Proton and Neutron Spin Structure
  - Neutron Structure Function $F_{2n}(x,Q^2)$
  - Tagged Quark Distribution Functions
  - Novel Quark Distribution Functions (tranversity, e(x),..)
- **Form Factors and Resonance Excitations**
  - The Magnetic Structure of the Neutron
  - Resonance Excitation Dynamics
- **Hadrons in the Nuclear Medium**
  - Space-Time Characteristics of Hadronization
  - Color transparency
- **Physics with quasi-real Photons**

Upgraded CLAS (CLAS^{++})



CLAS^{++} - 2-dimensional Cut



12 GeV Upgrade Project Status

- Developed by User Community in collaboration with JLab
- Nuclear Science Advisory Committee, NSAC
  - plan presented during last 5-year Long Range Plan
  - recommended by NSAC for new construction
- Plan presented to Department of Energy
  - presently waiting for CD-0 (determination of 'mission need')
- Construction
  - estimated costs: $158M (in FY02$)
  - construction start expected in FY2007 (October 2006)
  - 3 year construction project

Long-Term Future @ JLab

Study underway for an electron-light ion collider at JLab to investigate

- inclusive and semi-inclusive DIS
- deep exclusive reactions (GPD's)

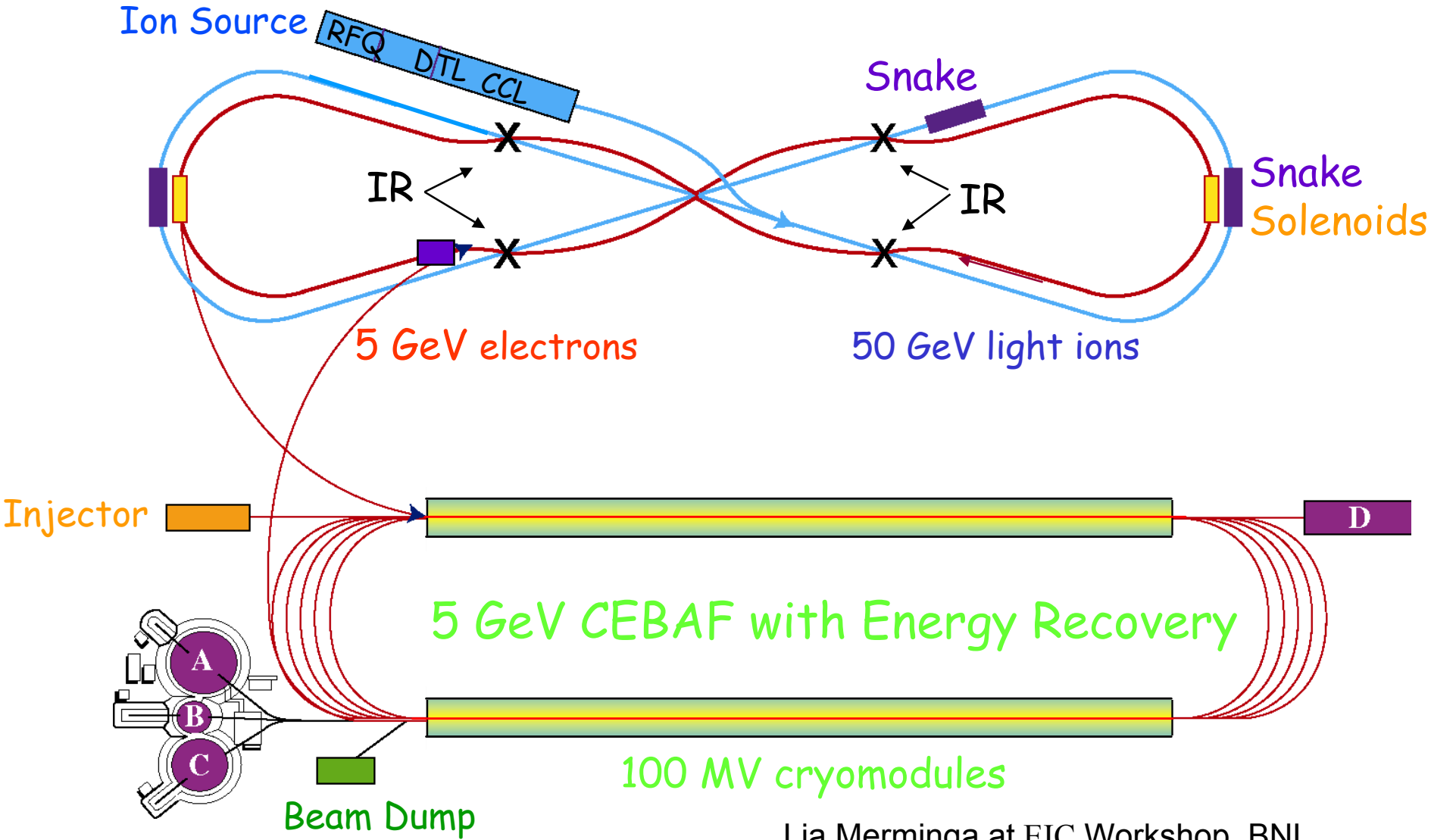
Parameters

electrons	3 - 5 GeV
ions (p, d, ^{3}He)	30-50 GeV
luminosity	$\leq 6 \times 10^{34}$ cm^{-2} s^{-1}

Design maintains fixed target capability with

- 25 GeV external beam
- luminosity ~10^{38} cm^{-2} s^{-1}

Electron-Light Ion Collider Layout



Lia Merminga at EIC Workshop, BNL

02/27/2002