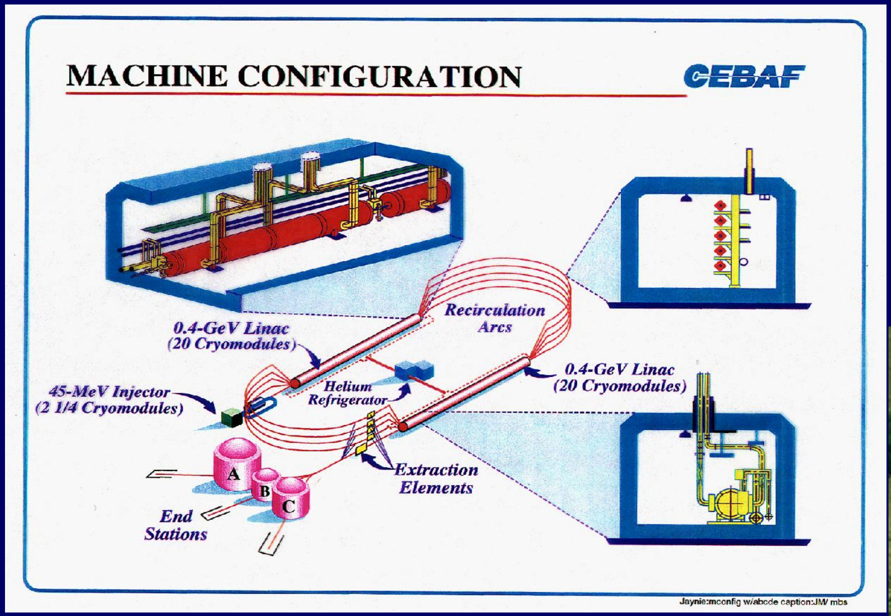
The CLAS experiment: physics with a toroidal magnet

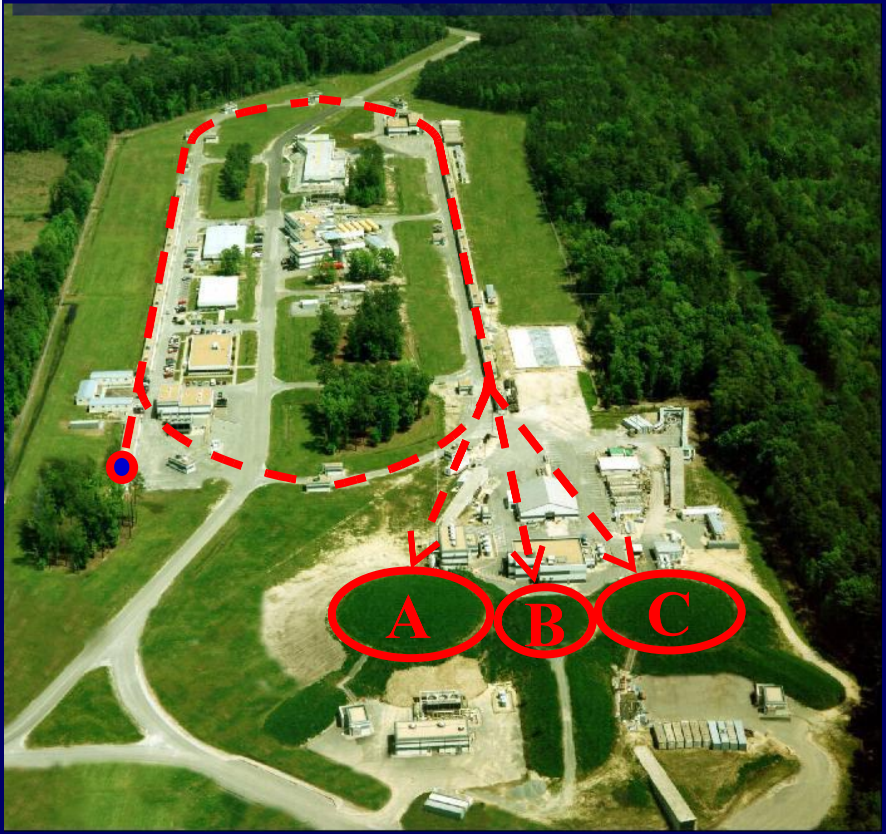
R. De Vita

INFN - Genova

Jefferson Lab



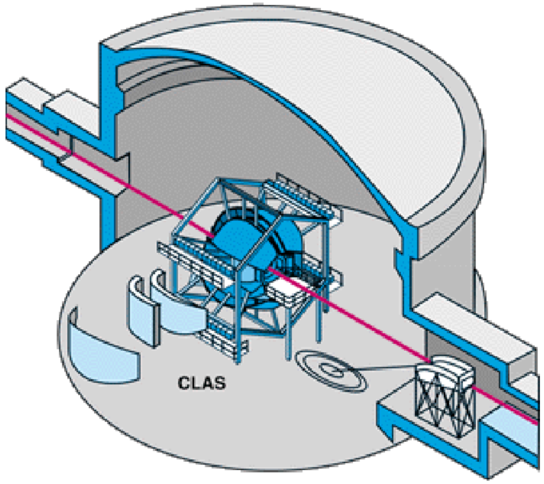
The core of Jefferson Lab is the CEBAF accelerator



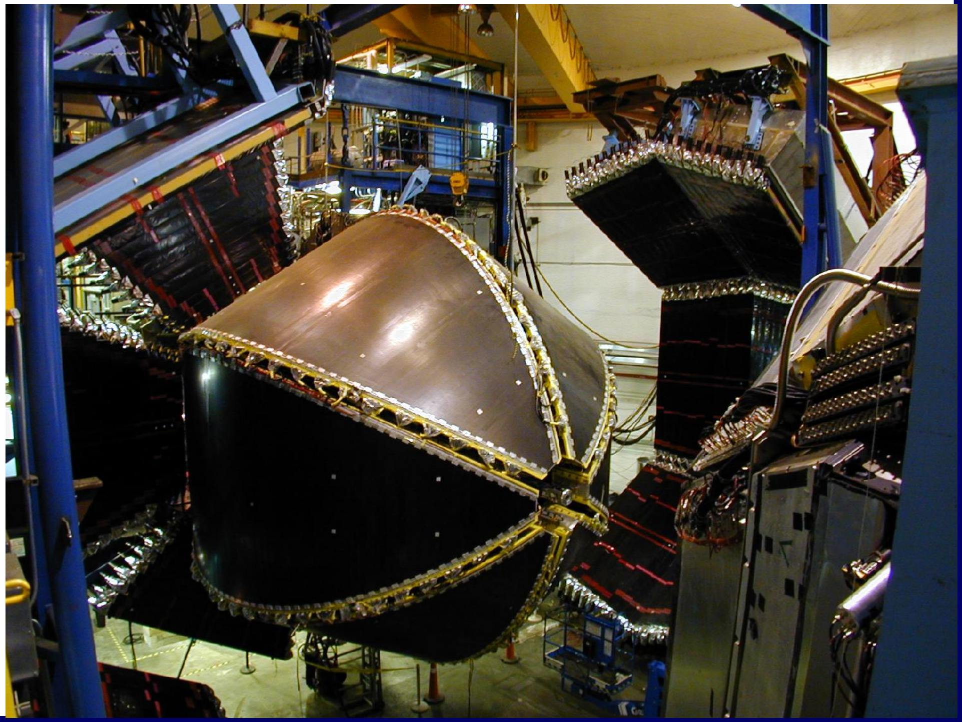
CEBAF is a superconductive electron accelerator

- continuous beam (RF cavities at 1.5 GHz)
- high longitudinal polarization (85%)
- energy range $\rightarrow$ 0.75 –5.9 GeV
- max current $\rightarrow$ 200μA
- simultaneous delivery to 3 halls

The CLAS Spectrometer



CEBAF
Large
Acceptance
Spectrometer



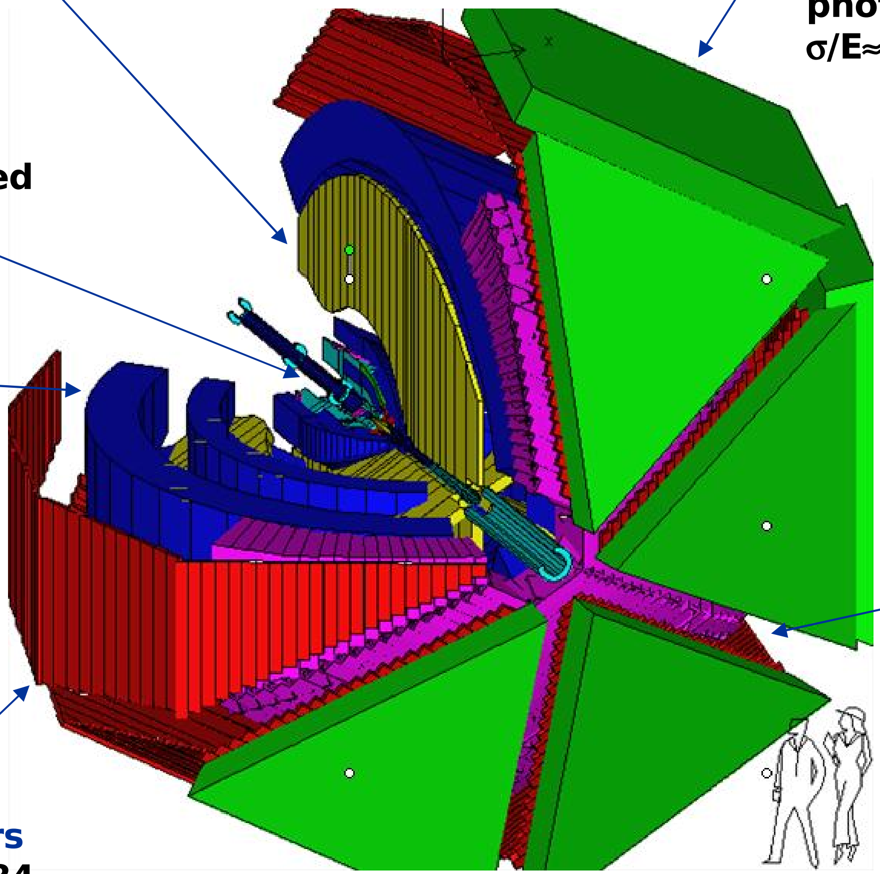
- *magnetic spectrometer based on six-coil toroidal field*
- *large kinematical coverage*
- *high luminosity: $10^{34} cm^{-2} s^{-1}$*
- *simultaneous measurement of exclusive and inclusive reactions*
- *central field-free region well suited for the insertion of a polarized target*

The CLAS Spectrometer

Torus Magnet
6 superconducting coils
$\int B \cdot dl \approx 1.7$ Tm

Electromagnetic Calorimeters
Lead/scintillator, 1296 photomultipliers
$\sigma/E \approx 10\%/\sqrt{E}$

Target+
γ start counter
e minitorus or polarized target magnet



Drift Chambers
argon/CO_2 gas,
35000 cells
300 μm resolution

Gas Cerenkov Counter
e/π separation,
256 PMTs
99.5% efficient over 55 m² area

Time of Flight Counters
plastic scintillators, 684 Photomultipliers
σ=80-200 ps

B. Mecking et al, Nucl. Inst. Meth., A 503 (2003)

Physics Program at CLAS

- ***Valence Quark Distribution***
  - *Proton and Neutron structure function $F_2(x,Q^2)$ and $g_1(x,Q^2)$*
  - *Spin distribution in proton and neutron*
  - *TMD quark distribution functions in SIDIS*

- ***GPD's and the 3D-Imaging of the nucleon***
  - *Deeply Virtual Compton Scattering (DVCS)*
  - *Deeply Virtual Meson Production at low/high t*

- ***Form Factors and Resonance Excitations***
  - *The magnetic structure of the neutron G_M^n*
  - *N* Transition form factors*
  - *Search for missing states*

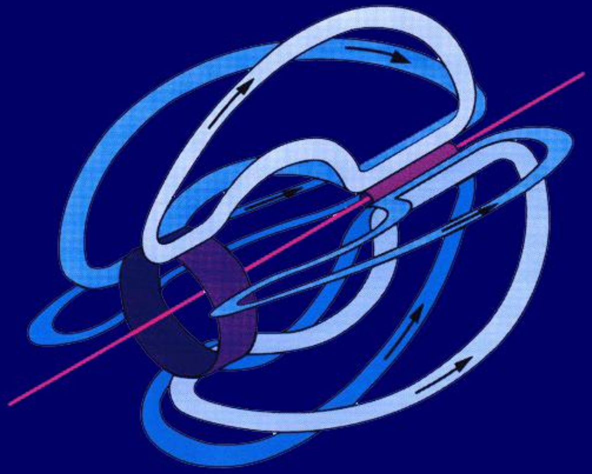
- ***Hadron spectroscopy***
  - *Hyperon production*
  - *Search for exotic baryon and meson states*

- ***Hadrons in the Nuclear Medium***
  - *Space-Time Characteristics of Quark Hadronization*
  - *Color Transparency*
  - *Multi-Nucleon Correlation in Nuclei*
  - *Short Distance Dynamics of Light Nuclei*

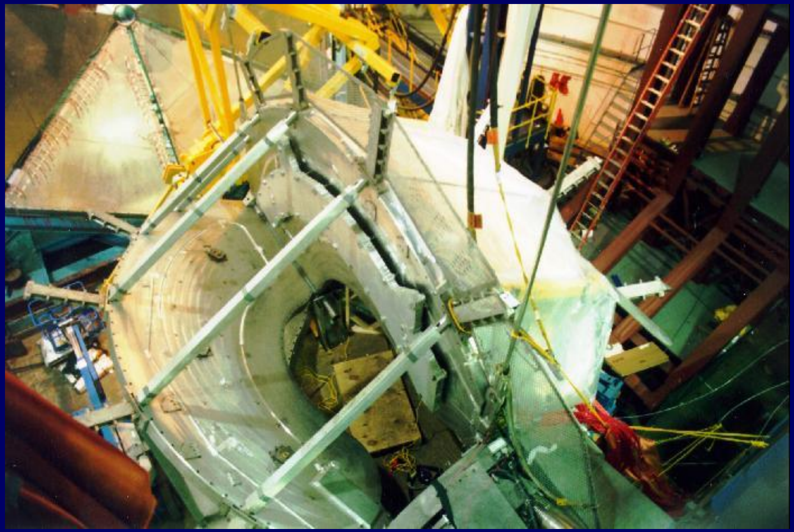
Detector Design Requirements

- *Homogenous coverage of a large angular range for charged and neutral particles*
- *Good momentum and angular resolution*
- *Good particle identification*
- *High luminosity but low electromagnetic background:*
  - *Deflect low momentum particles emitted at large angles like Moeller electrons away from the chambers*
  - *Don't deflect high momentum forward going particles like electron from Bremsstrahlung and e^+e^- pairs into the detector, i.e. no transverse field at the target*
- *Operation of a polarized target*
- *Symmetry around the beam axis*

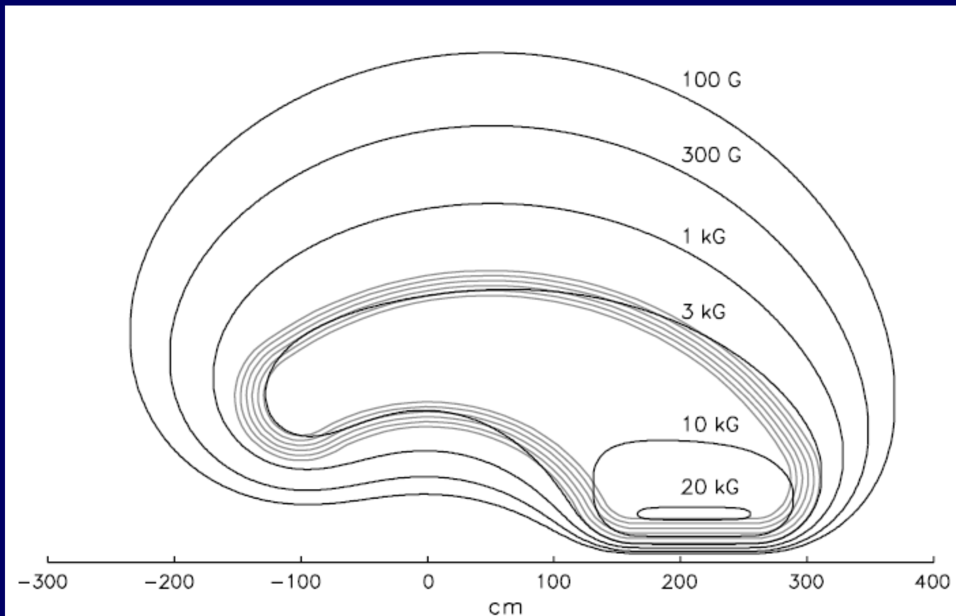
The Toroidal Magnet



- 6 coils located in separate cryostats
- Aluminum stabilized NbTi/Cu conductor
- Cooling to 4.5 K accomplished by forced supercritical helium flow
- Overall current of 5×10^6 A for max. field
- Kidney shape coils to produce stronger field at forward angles
  - 2.5 Tm @ 15°
  - 0.6 Tm @ 90°



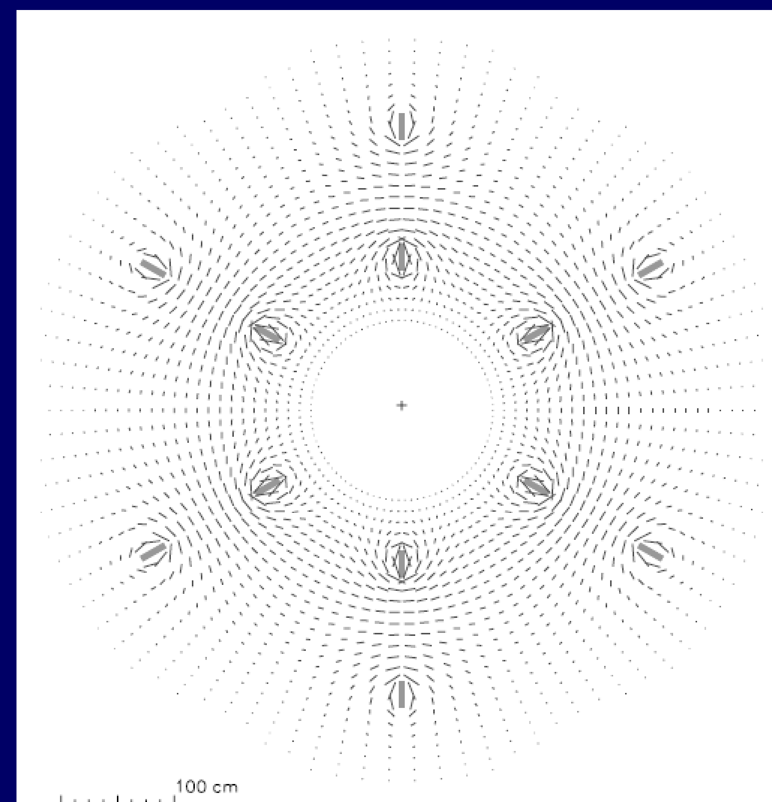
The Toroidal Magnet



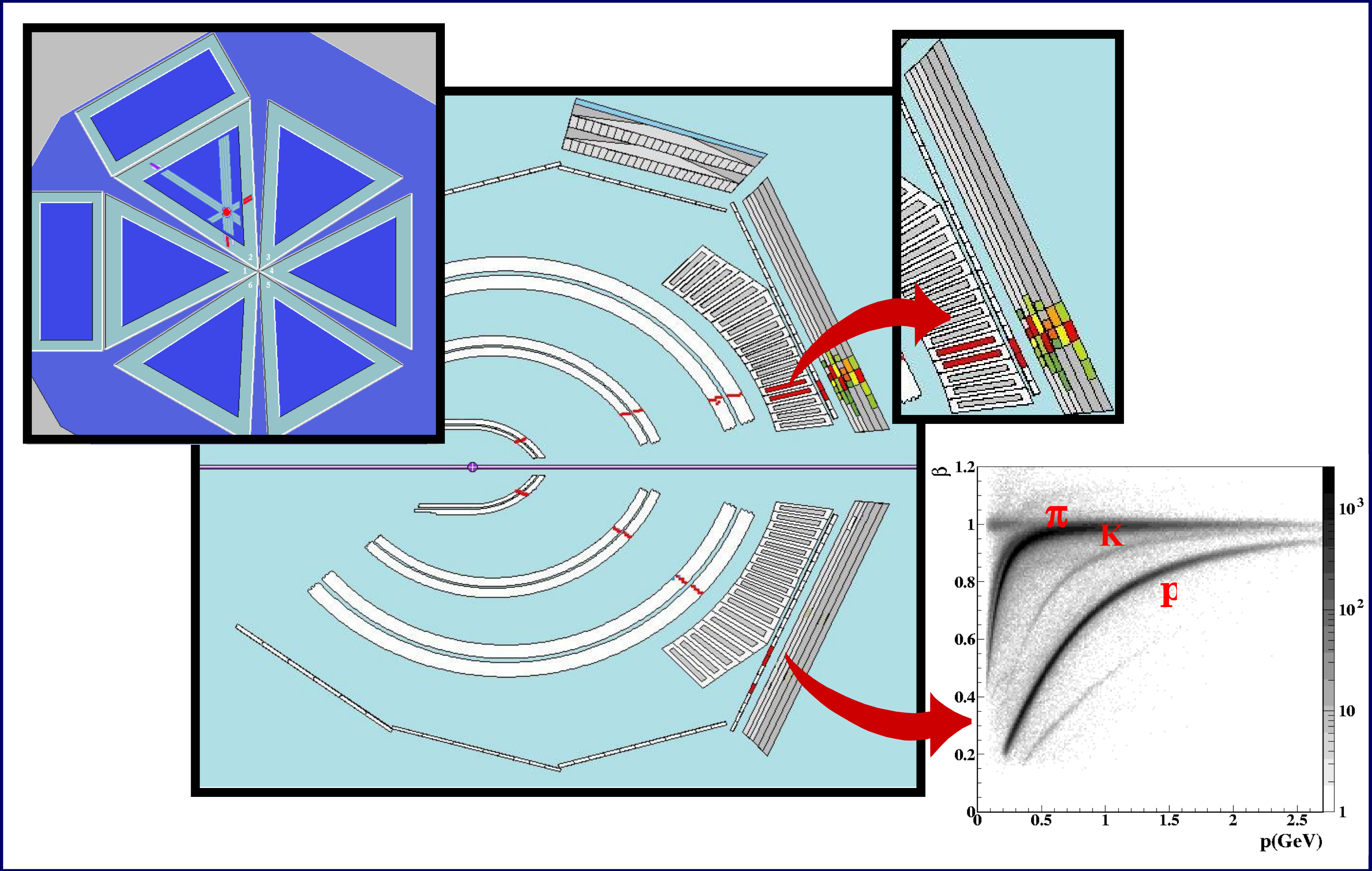
The coil shape was designed to provide uniform momentum resolution

The resulting field is in the ϕ-direction, i.e. always transverse to the particle momentum

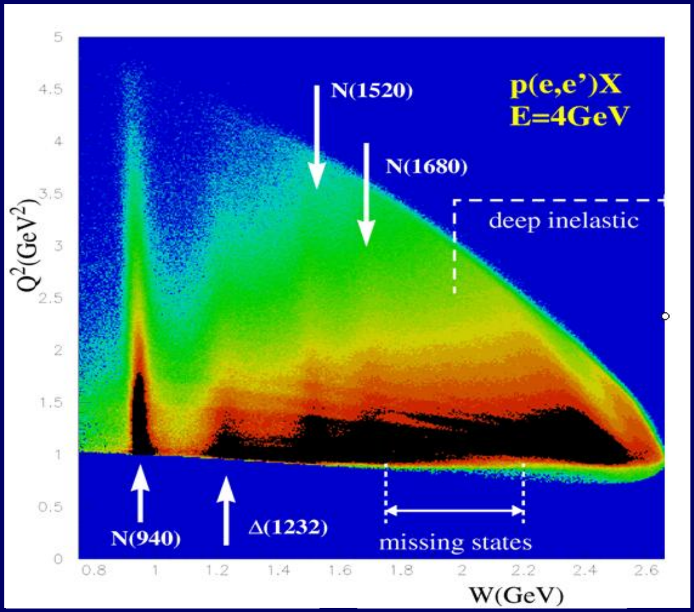
Deviations close to the magnet coils are minimized by the circular inner shape of the coil

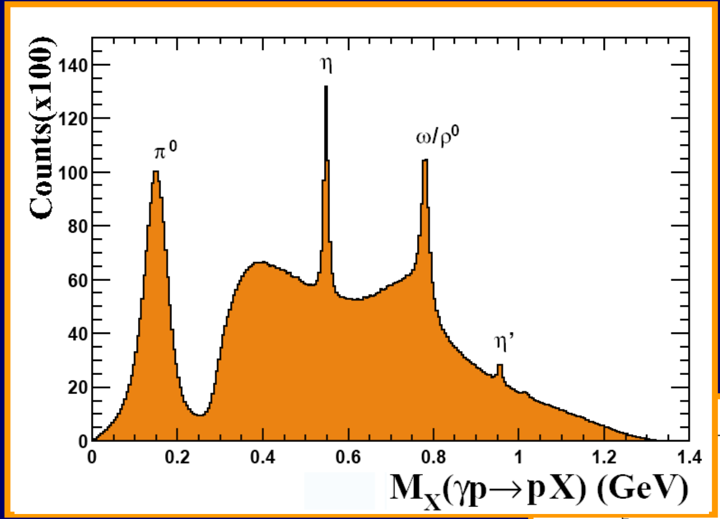


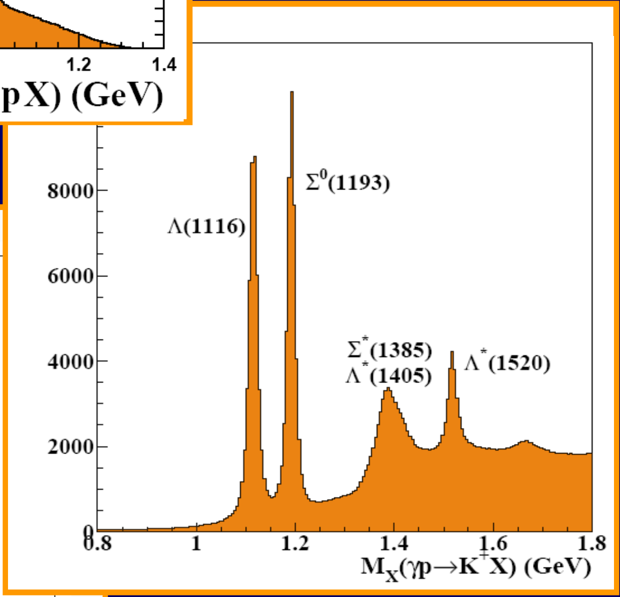
Event Reconstruction

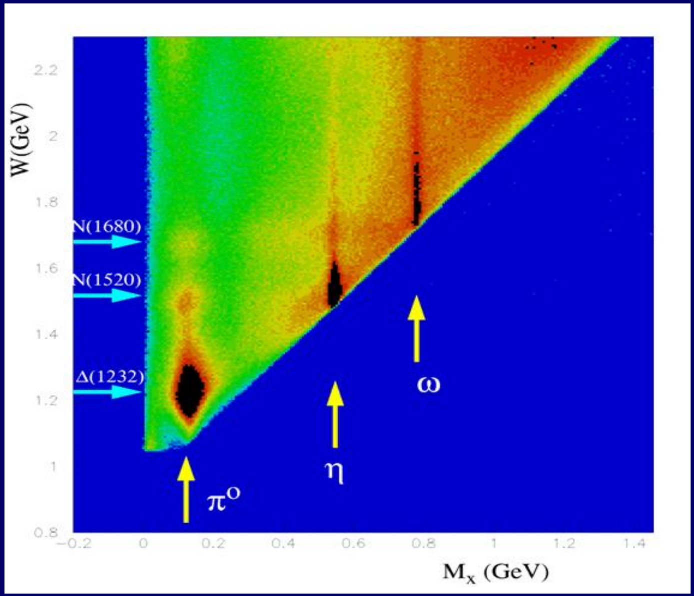


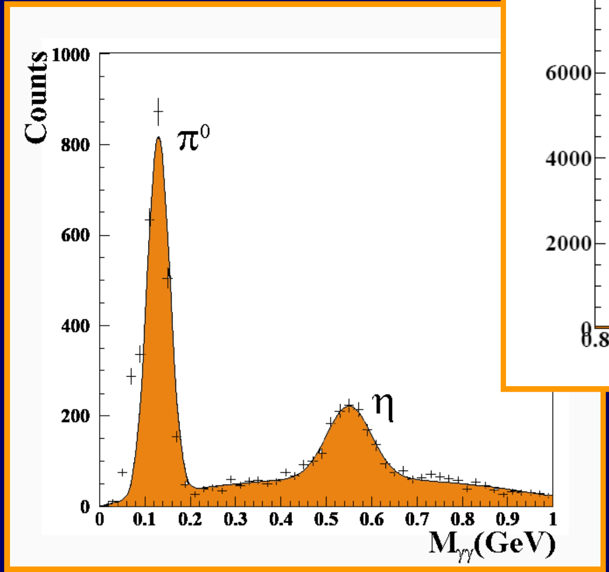
CLAS Performance



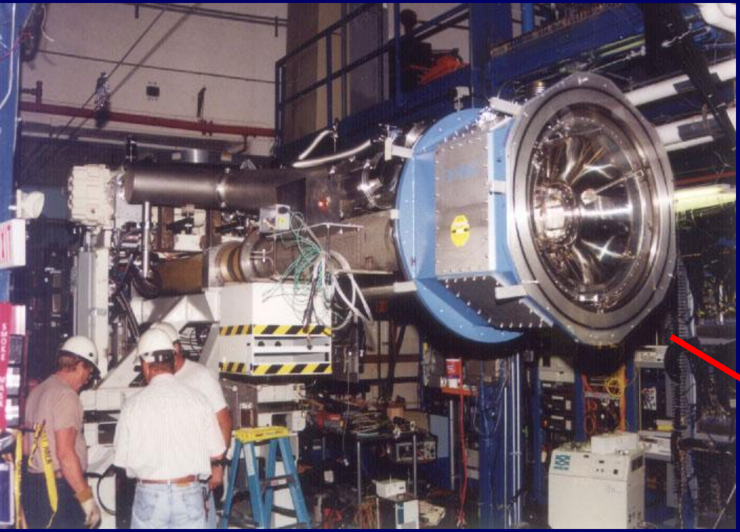




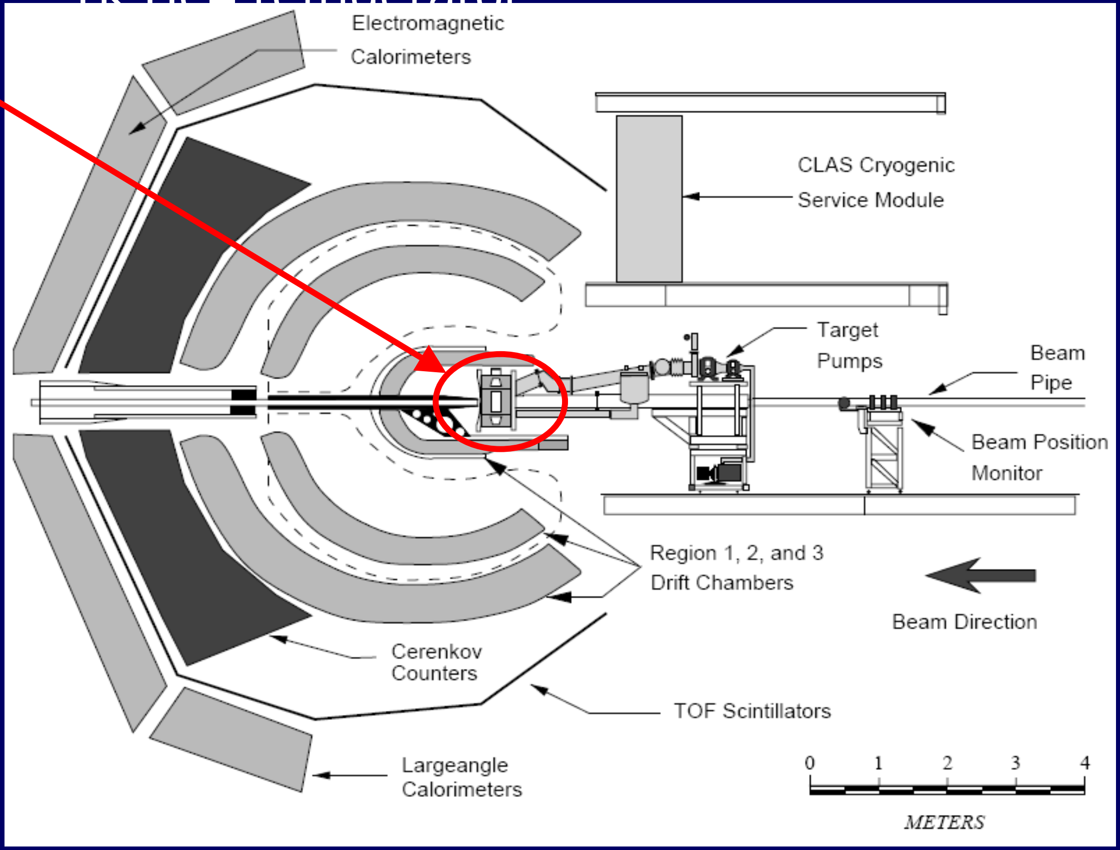




Operation with polarized target



- Solid NH3/ND3 target polarized via DNP
- 5 T longitudinal field generated by Helmoltz coil magnet
- 1K He4 refrigerator

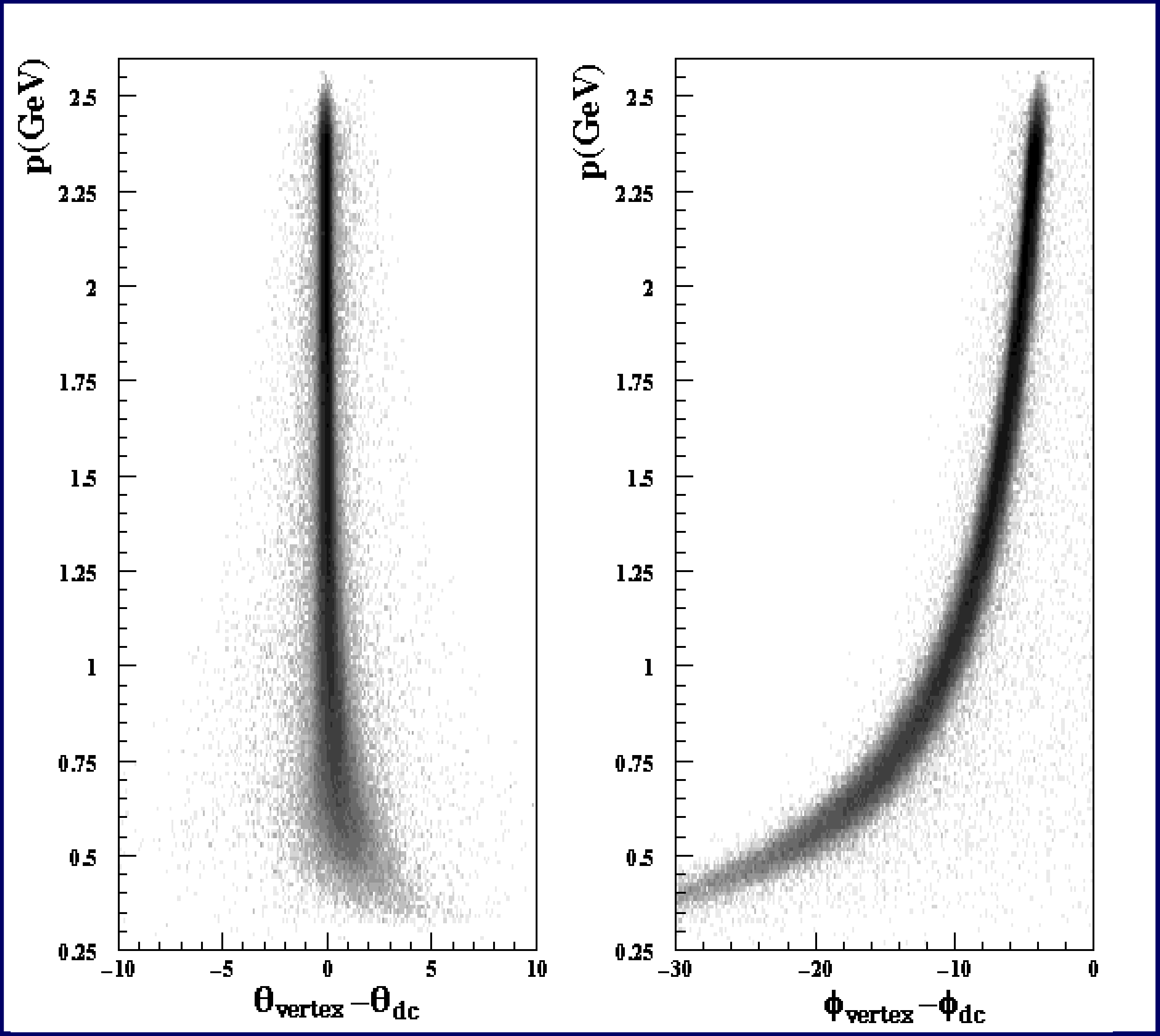


- Mechanical structure designed to fit in the CLAS drift chambers
- Target magnetic field is negligible in the tracking region
- Possible use of HD-Ice target in transverse configuration (0.5 T) is being studied

Effect of the Target Field

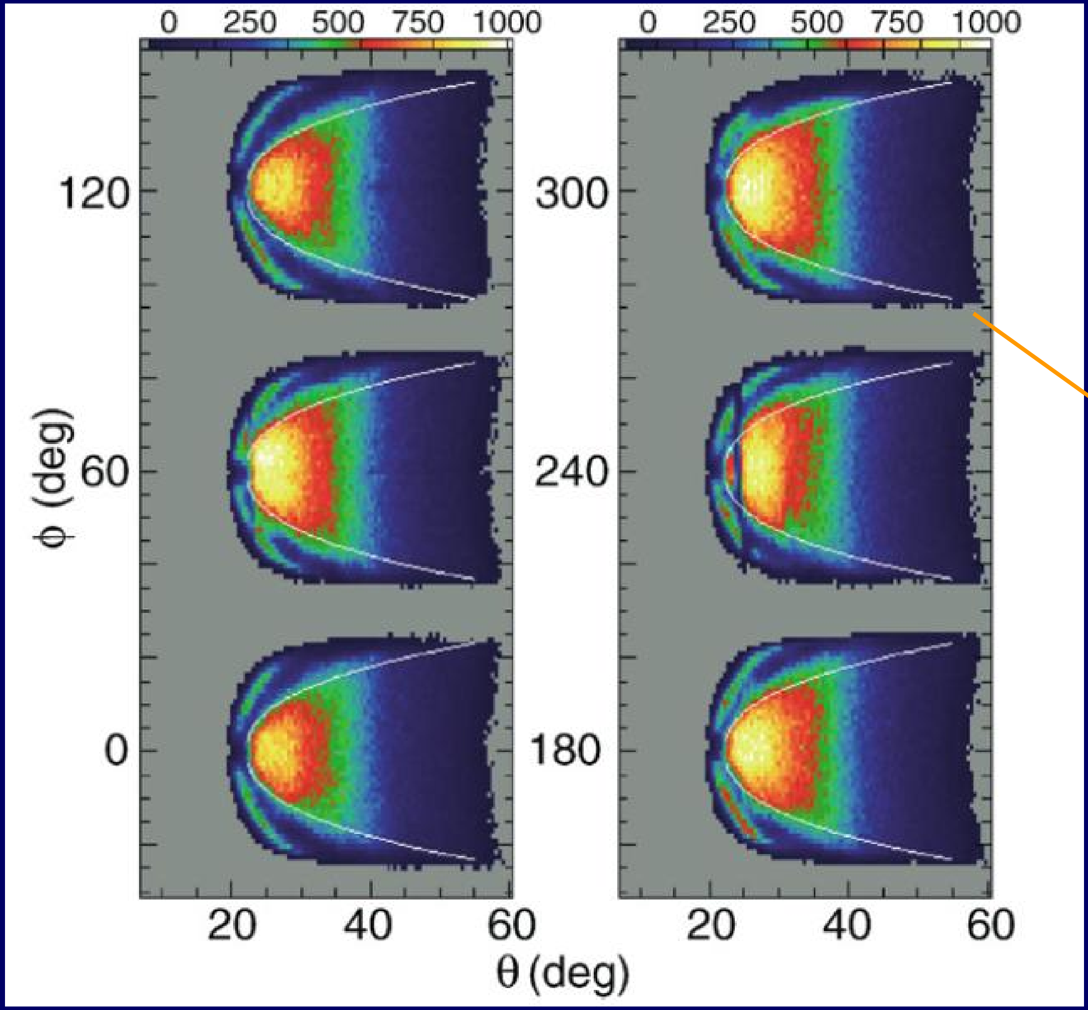
The polarized target field bends charged particles before they enter in the drift chambers:

- shift of the azimuthal angle
- negligible effects on the polar angle



Single Particle Acceptances

Acceptance for electrons



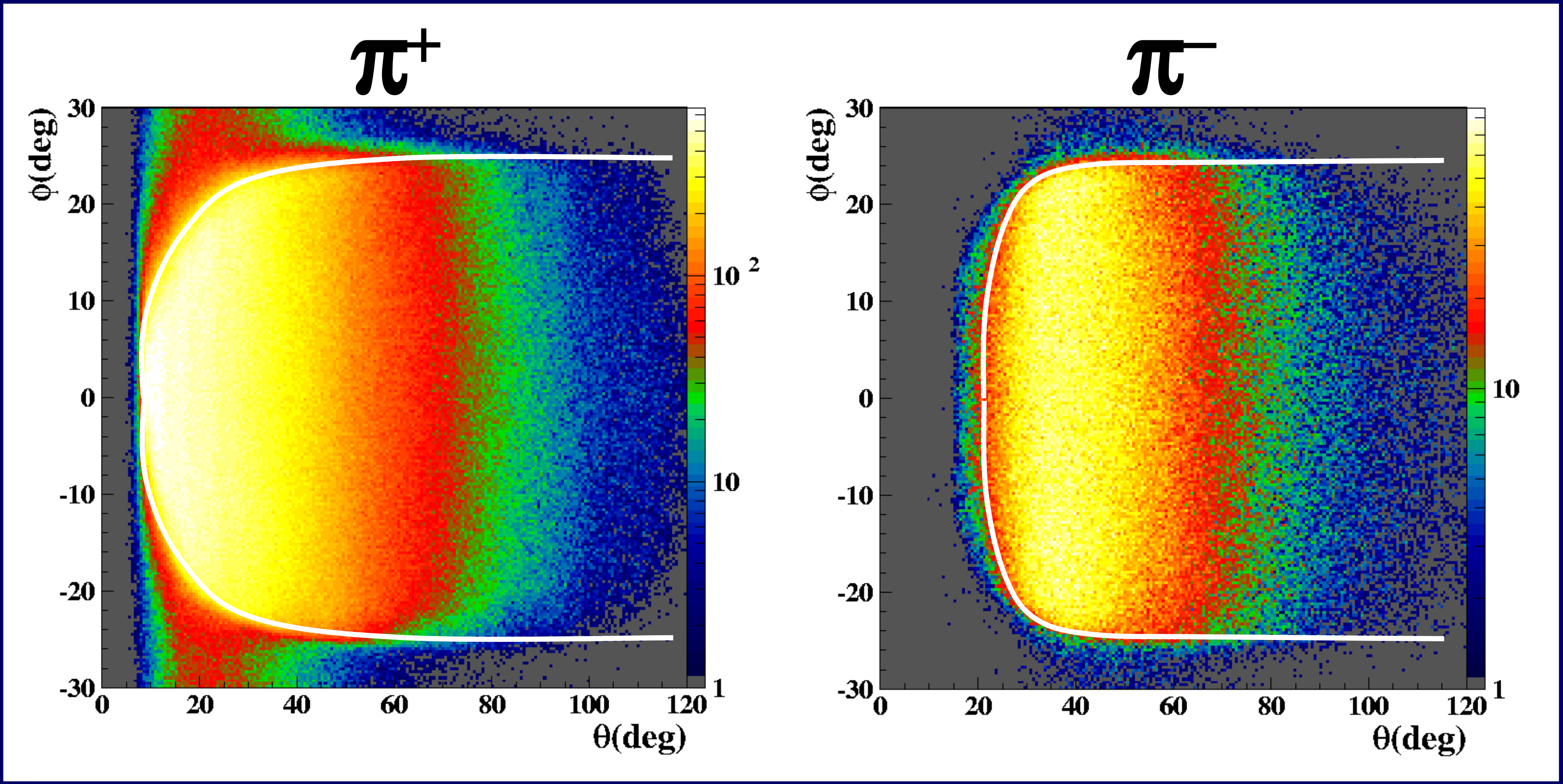
fiducial volumes

Particles are missed in the regions of the torus coils

Actual acceptance depends on torus field intensity, target position, particle charge

Single Particle Acceptances

Acceptance for positive and negative pions

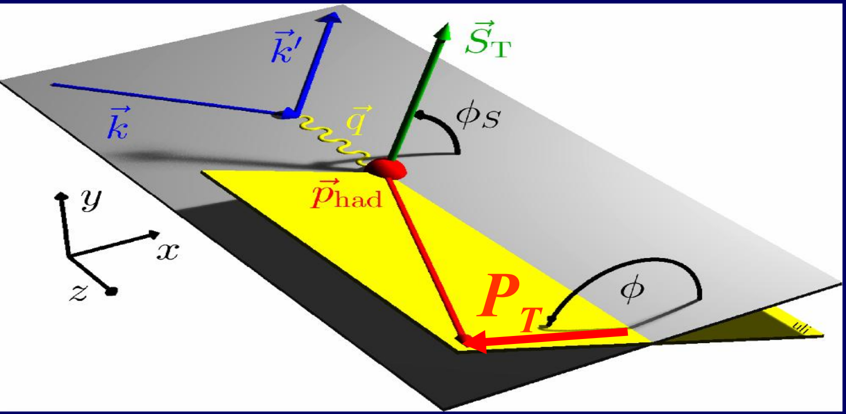


Acceptance for multiparticle final states

- **Semiinclusive pion production in DIS (SIDIS)**
- **Deeply Virtual Compton Scattering**
- **Meson spectroscopy**

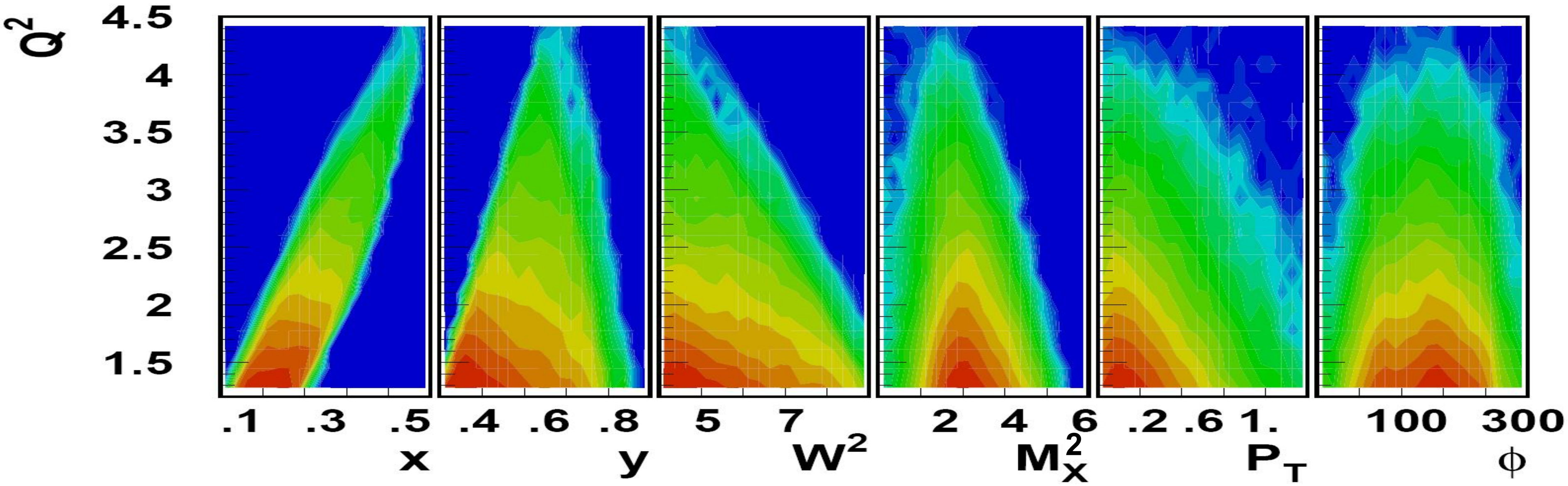
Semi Inclusive DIS

Trento Conventions
Phys.Rev. D70, 117504 (2004)



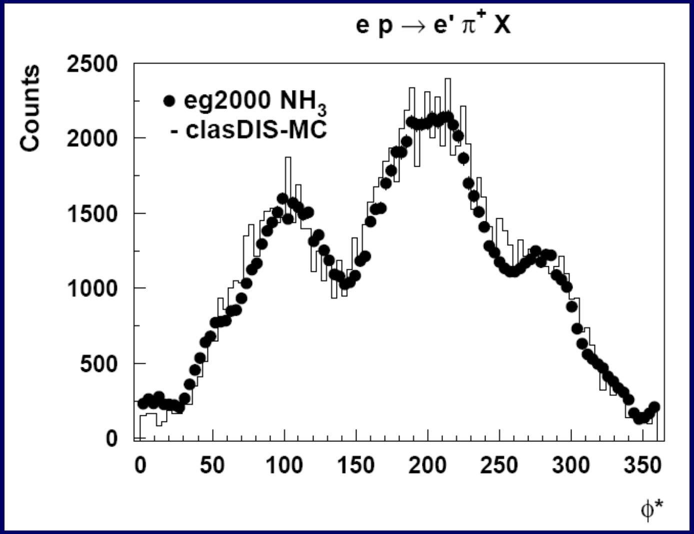
Access to TMD parton distribution

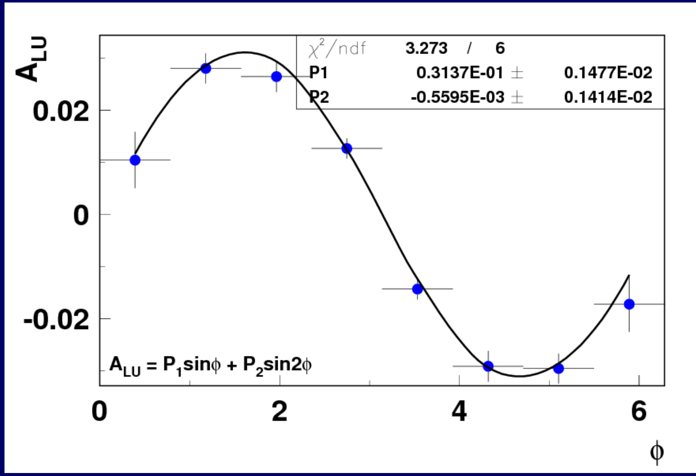
Azimuthal asymmetries are due to correlations of spin and transverse momentum of quarks and appear as moments of ϕ



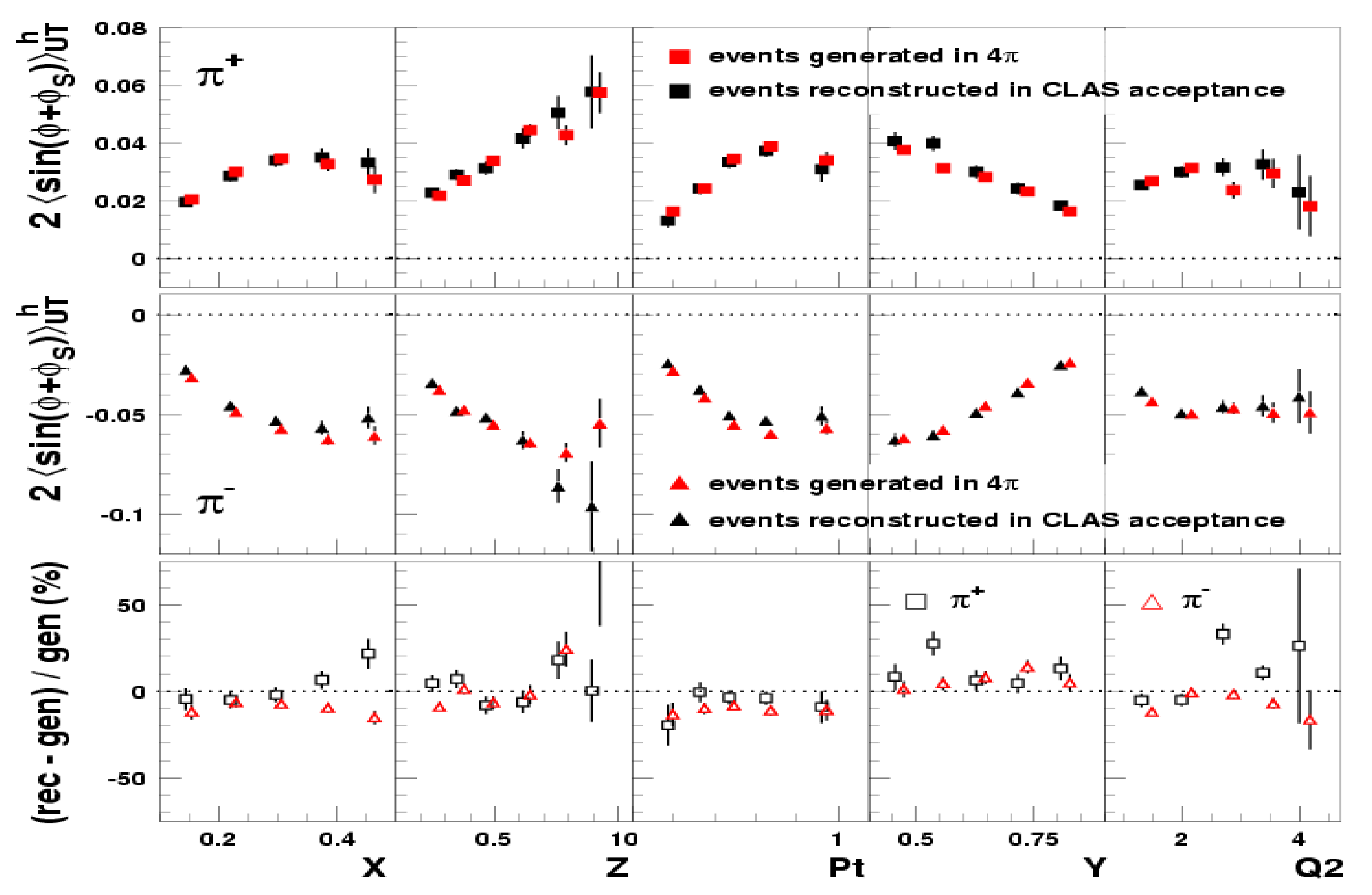
Semi Inclusive DIS

- ☹ Acceptance of the torus magnet affects the azimuthal distribution of measured events
- ☹ The size of the corrections can be large
- ☺ Phi coverage is complete or almost complete
- ☺ MC simulations reproduce the modulation of real data and are used to correct for acceptance and extract cross sections
- ☺ Effects on beam and/or target asymmetry is small
- ☺ Acceptance modulations average out for multiparticle final states





Semi Inclusive DIS



Estimated acceptance corrections for CLAS using HERMES analysis chain (GMCtrans)

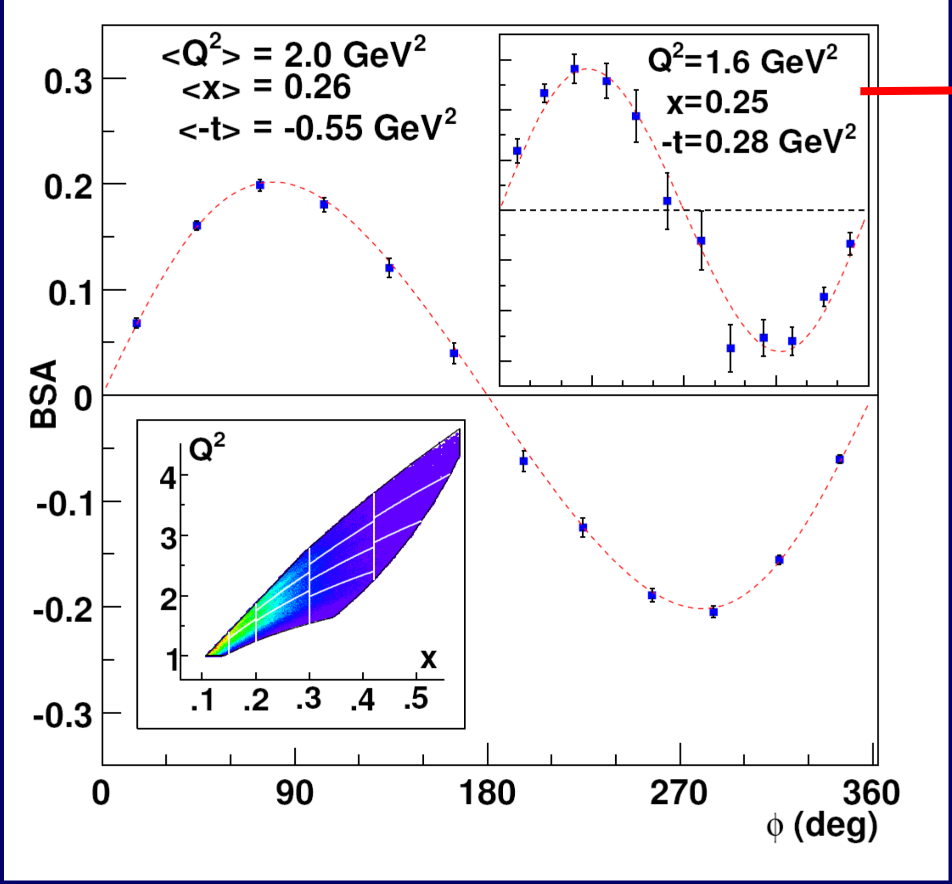
Acceptance for multiparticle final states

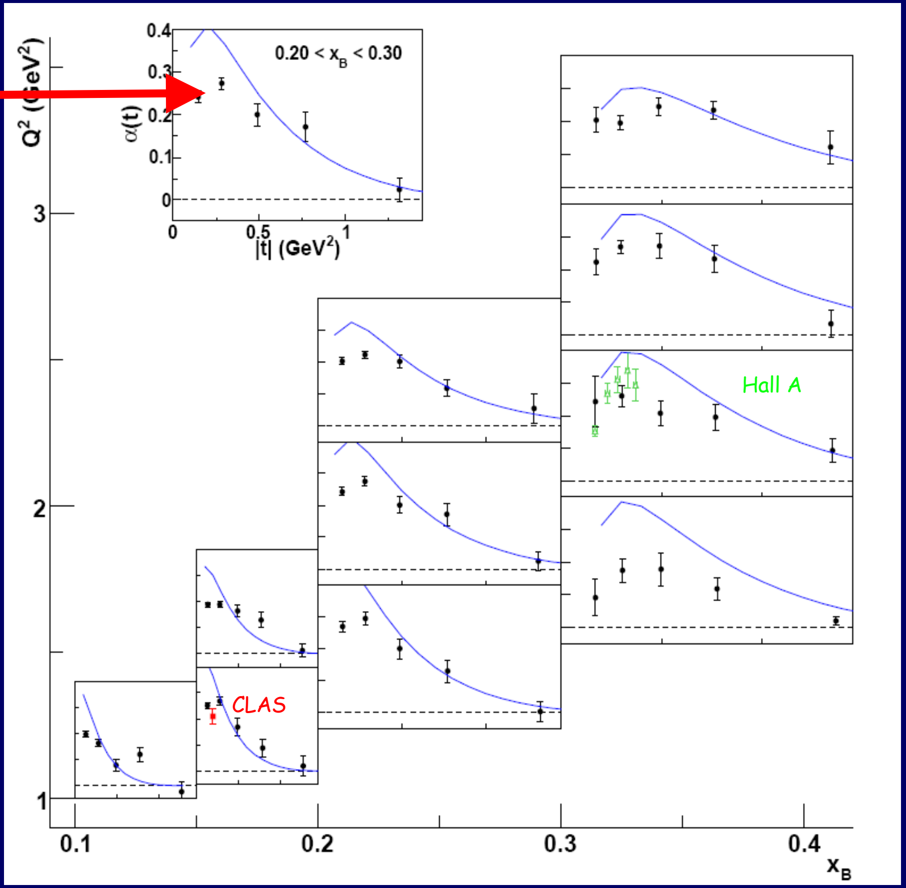
- Semiinclusive pion production in DIS (SIDIS)
- Deeply Virtual Compton Scattering
- Meson spectroscopy

Deeply Virtual Compton Scattering

F.X. Girod et al. (CLAS Collaboration), arXiv:0711.0755 (PRL submitted)

First DVCS BSA in large kinematics range in Q^2, t, x_B





Fully integrated asymmetry and one of 65 bins in Q^2, $x=\xi$, t.

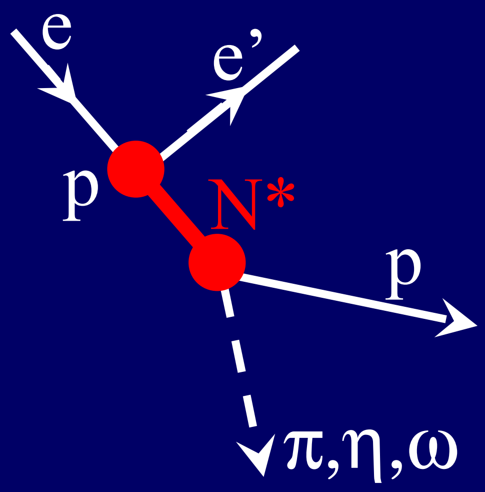
Fit: $A_{LU} = \alpha\sin\phi/(1 + \beta\cos\phi)$

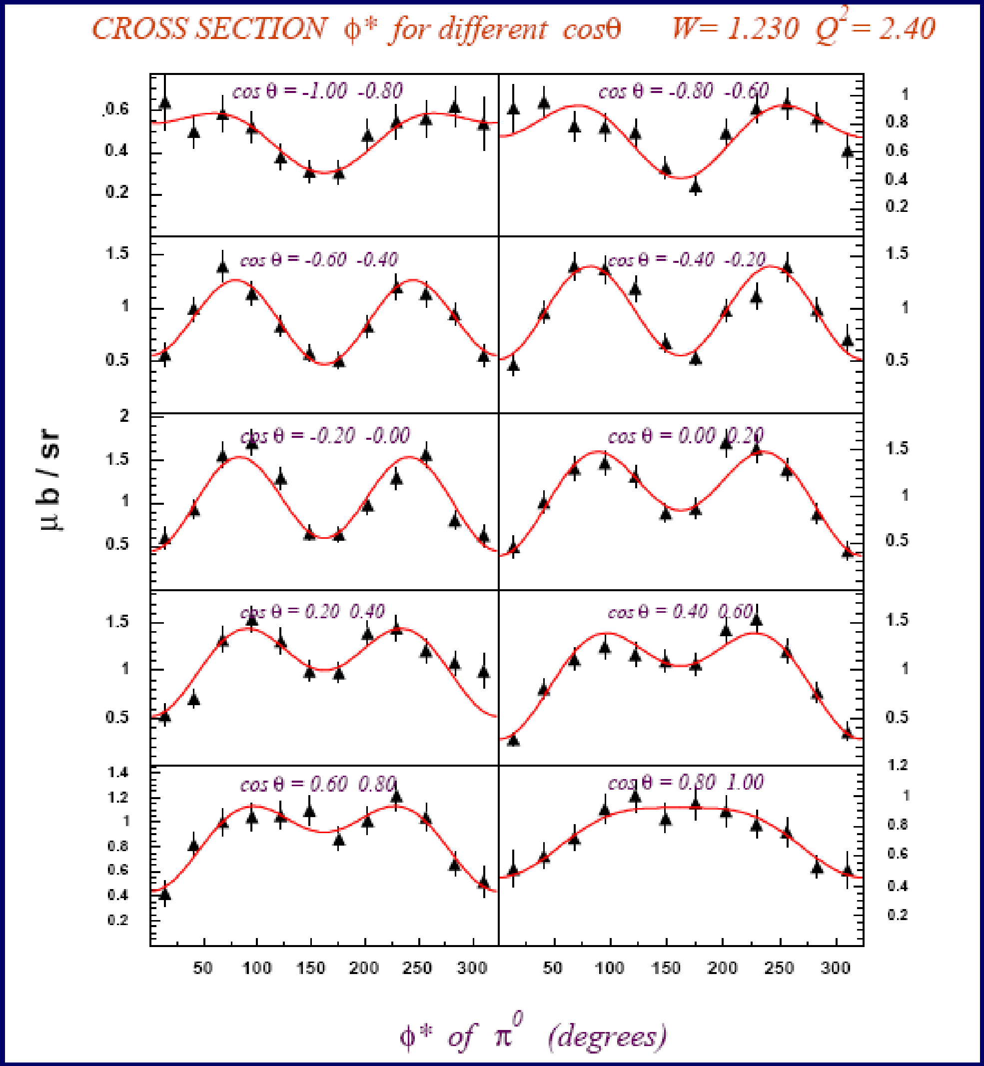
Acceptance for multiparticle final states

- Semiinclusive pion production in DIS (SIDIS)
- Deeply Virtual Compton Scattering
- **Hadron spectroscopy**

ep→pπ⁰ and the study of N*

The study of the N→N* transition form factors is attained through precise measurement of differential cross section in exclusive final states

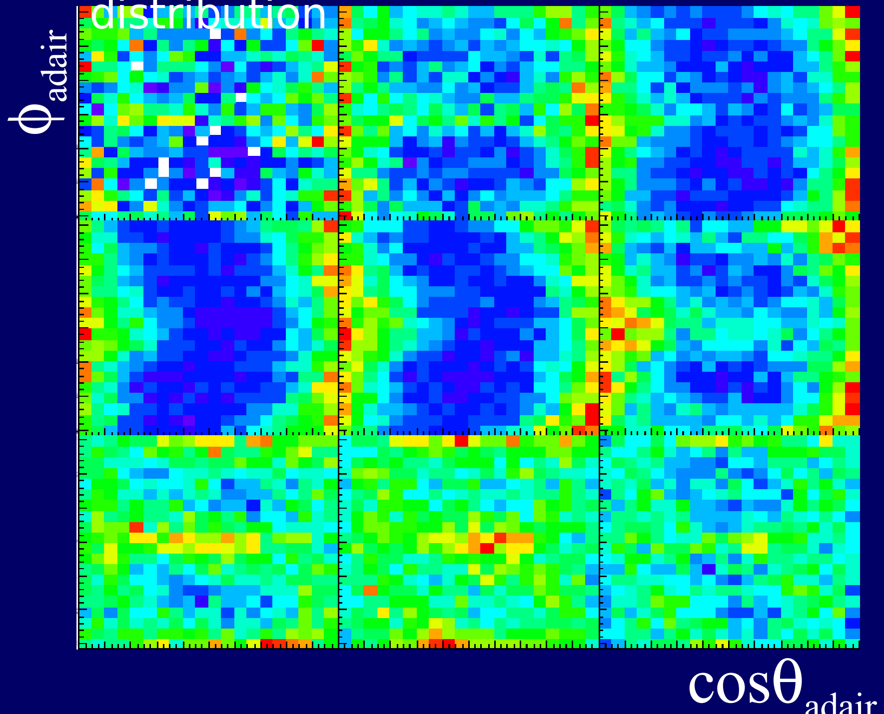


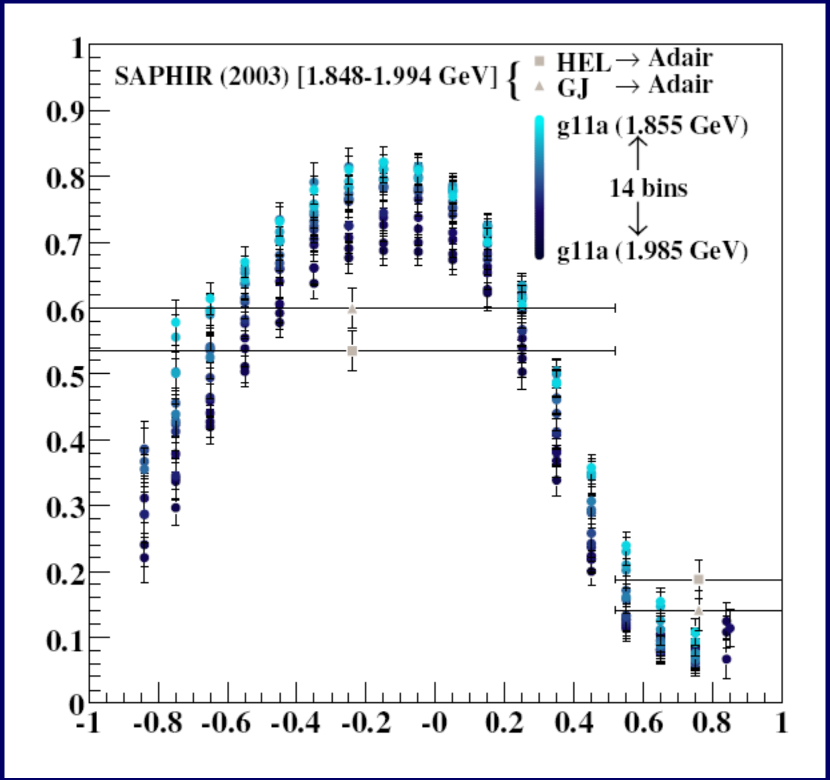


Hadron Spectroscopy

$\gamma p \rightarrow p\ \omega$
$\quad\quad\quad\quad \rightarrow \pi^+\pi^-\pi^0$

Information on the dynamics of the reactions can be obtained from the study of the omega decay angular distribution

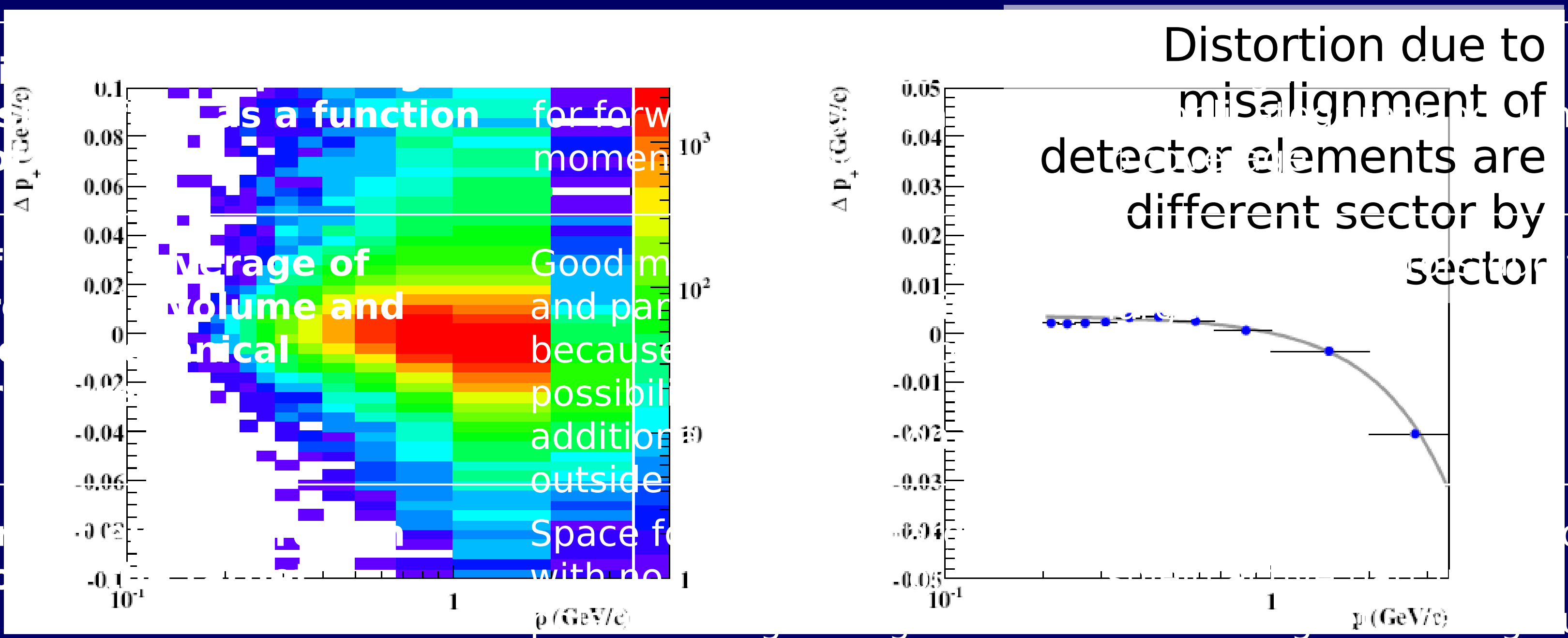




The spin density matrix elements have been extracted through a PWA with remarkable precision

Pro & Con of the toroidal field

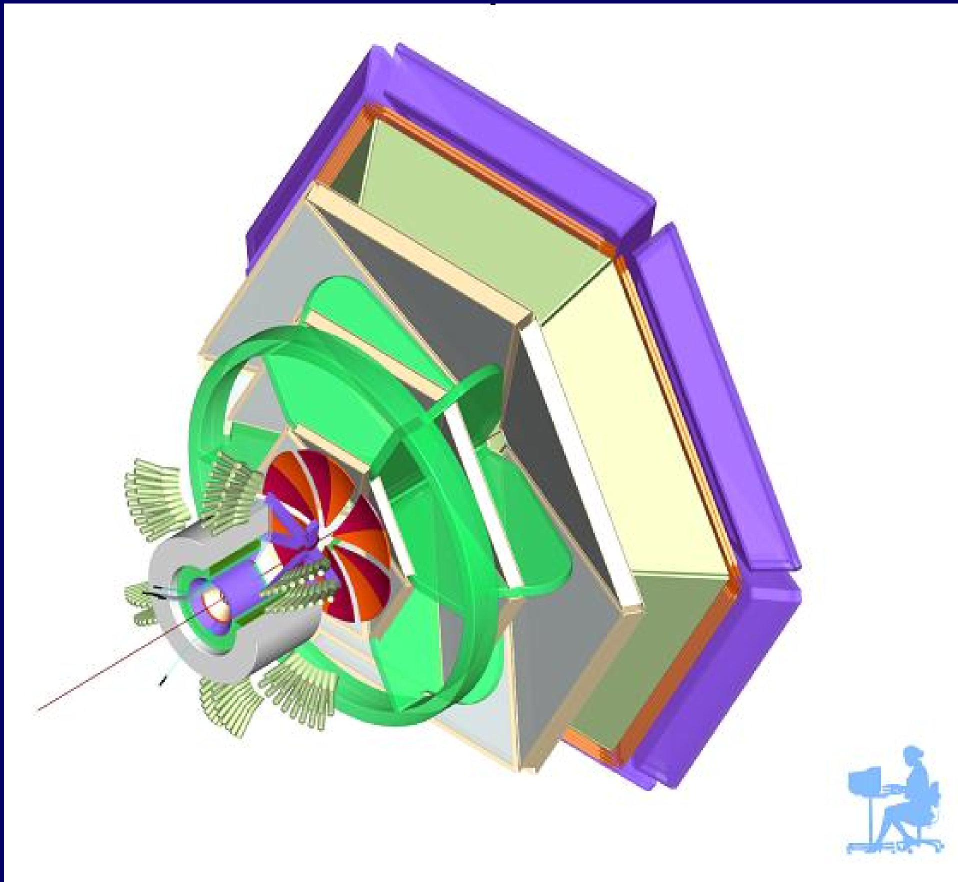
Feature	Advantage	Drawback
Magnetic field always transverse to the particle track	Efficient use of the installed field, reconstruction of azimuthal angle is decoupled from other tracking variables	Need independent detection system for each sector → large number of detector systems → alignment and distortion more difficult to control
Co[illegible] de[illegible] as a function o[illegible]	for forw[illegible] momen[illegible]	[illegible]nited
Eff[illegible] lar[illegible] [illegible]verage of [illegible]volume and op[illegible] [illegible]nical str[illegible]	Good m[illegible] and par[illegible] because[illegible] possibili[illegible] addition[illegible] outside[illegible]	[illegible] to
Lar[illegible] aro[illegible]	Space f[illegible] with no[illegible] [illegible] field	[illegible]d to [illegible]und



CLAS12

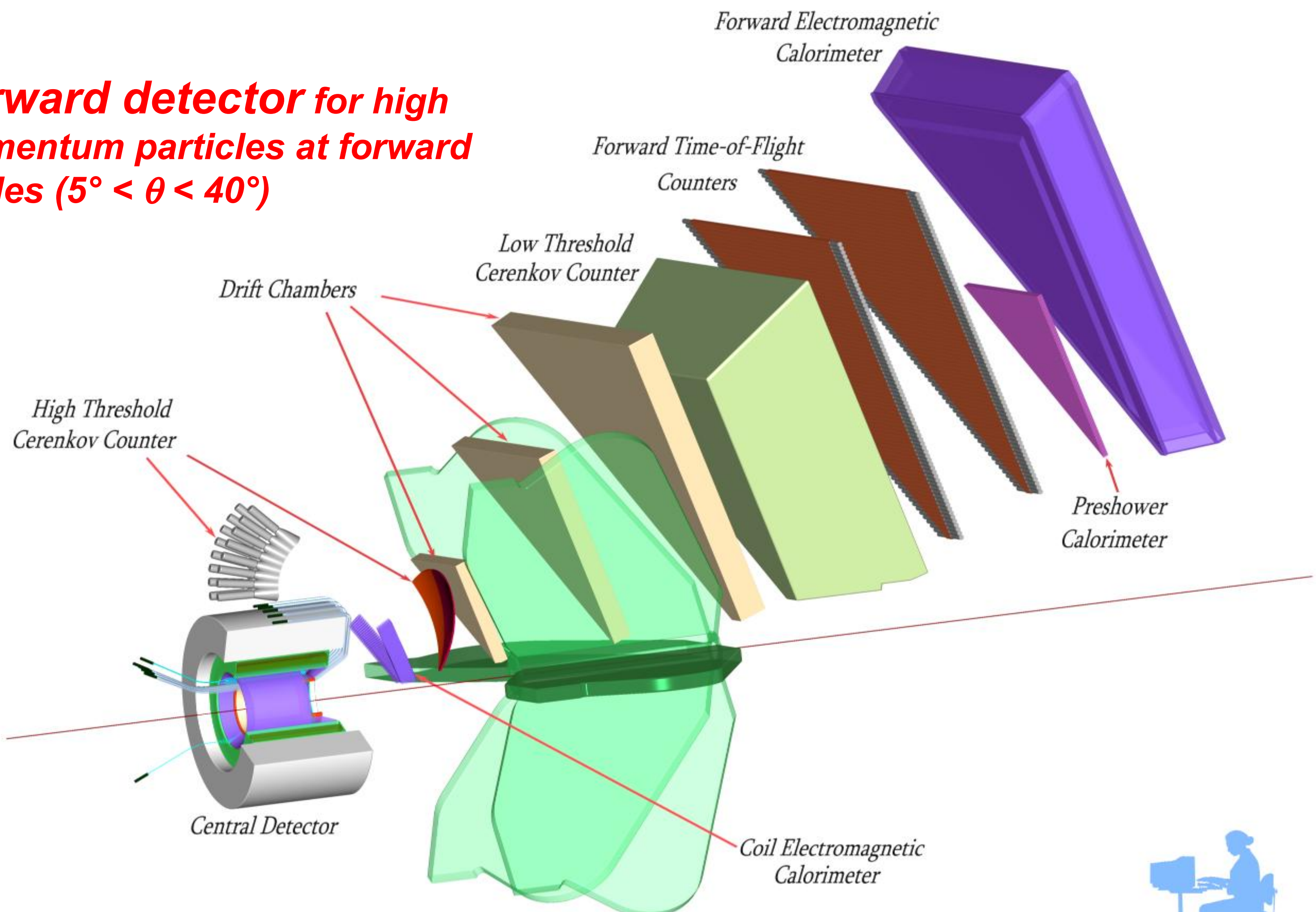
New CLAS12 detector designed for operation with 11 GeV electron beam

- *Magnetic spectrometer based on 6-sectors toroidal field*
- *Maximum luminosity of $L \approx 10^{35} cm^{-2} s^{-1}$*
- *Large momentum range for separation of electrons, pions, kaons and protons*
- *Operation with polarized target*



CLAS12

Forward detector for high momentum particles at forward angles ($5° < \theta < 40°$)



Central Detector for detection of particles at large angles ($\theta > 35°$)

New Toroidal Magnet

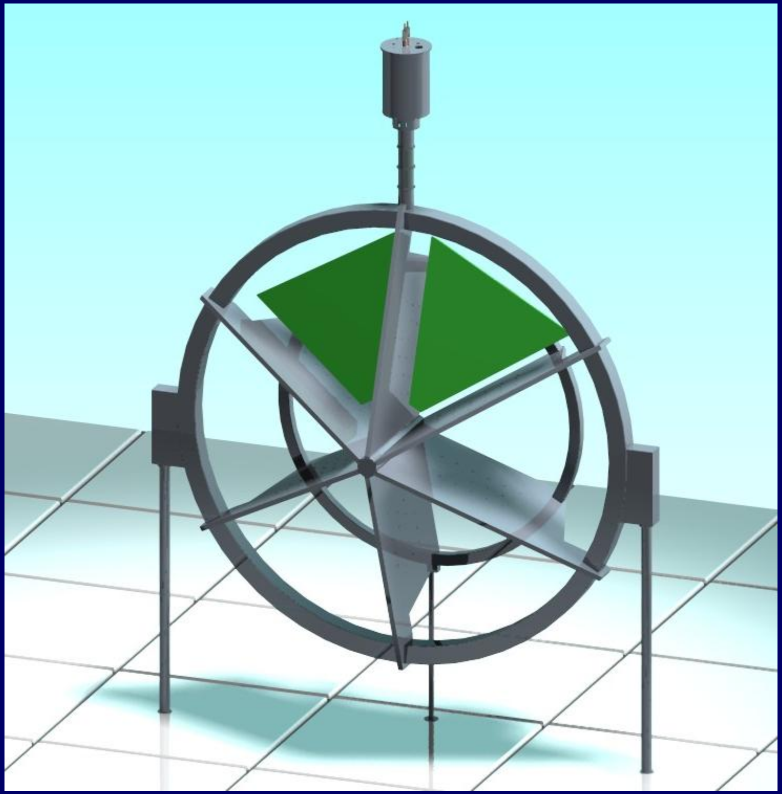
Design of a new toroidal magnet commissioned to ITEP/Efremov Institute (St.Petersburg)

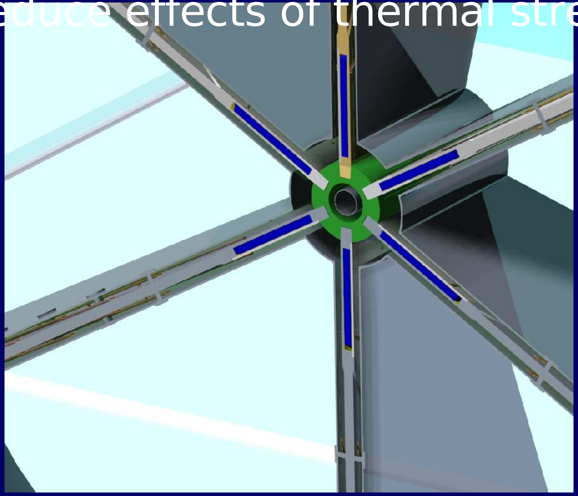
Use of NbTi de-keystoned cable from SSC

Increased field to achieve resolution <1% with 11 GeV beam (3-4 Tm @ 5° ; 0.5-1Tm @ 40°)

Reduced impact on acceptance by minimizing front face (<10 mm)

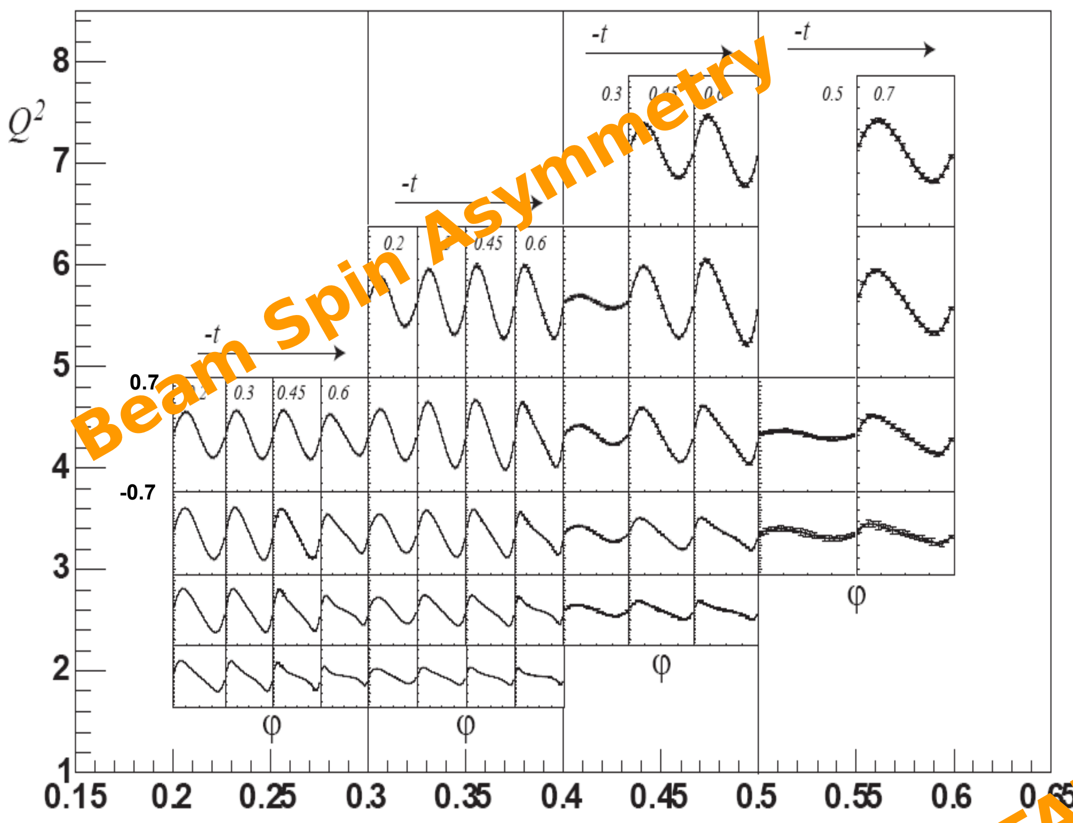
Connection of 6 cryostat through cold hub to reduce effects of thermal stresses





Design is complete and companies have been contacted to solicit interest in actual construction

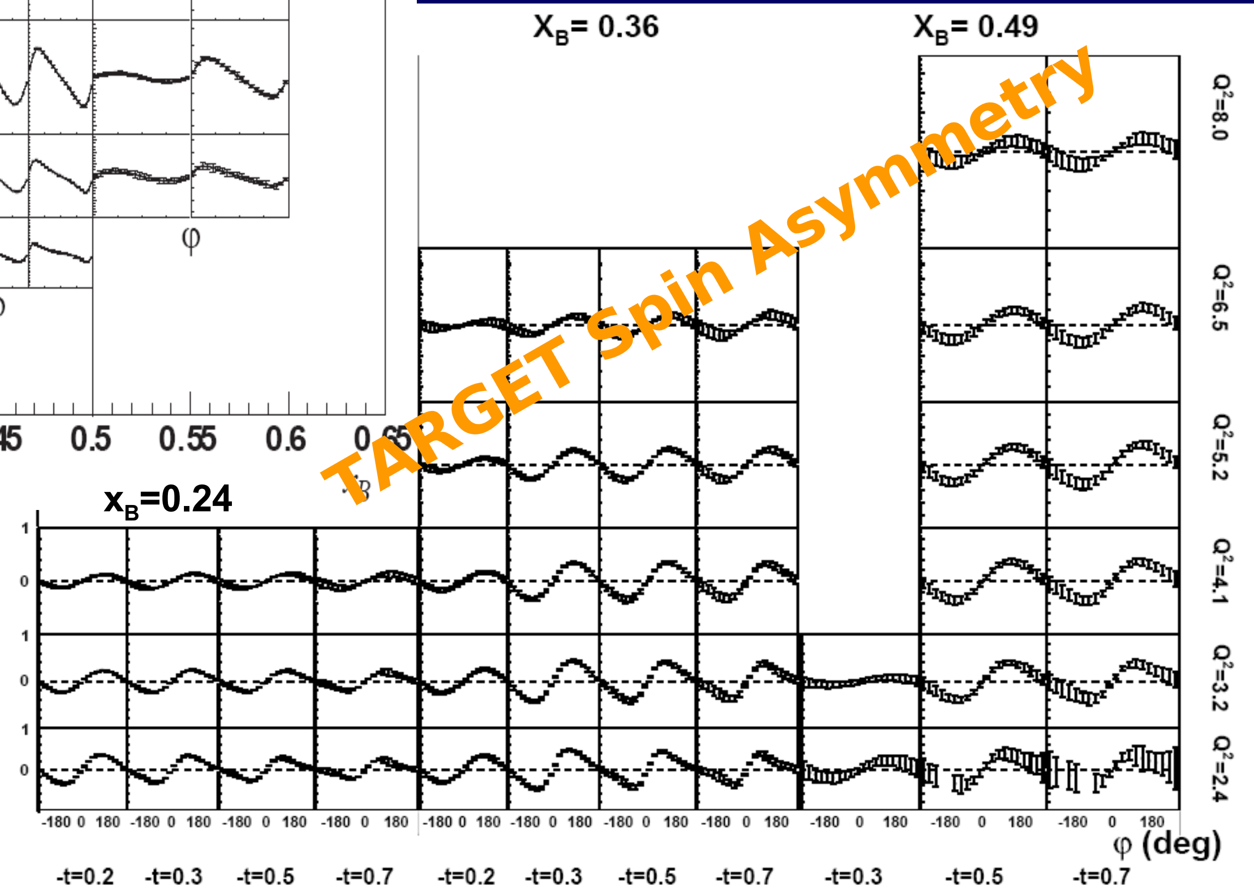
DVCS at CLAS with 12 GeV



Projected data

80 days at L=10^{35} cm^{-2} s^{-1}

PR12-06-119



100 days at
L=2 ·10^{35} cm^{-2} s^{-1}

Summary

The CLAS Spectrometer was designed for the measurement of multiparticle final state with large kinematic coverage

The choice of a toroidal magnet was determined as the best compromise between the desired performance and the requirement of maintaining a field free region at the target for the installation of a polarized target

Achieved performances are consistent with original design parameters

Results obtained for several reaction channels show that the complex acceptance arising from the six-sector structure is well understood and can be corrected for to determine absolute cross section and angular distributions

New CLAS12 spectrometer for the Jefferson Lab 12 GeV upgrade is being designed maintaining the toroidal structure of the CLAS detector

CLAS12

Forward detector

Cerenkov detector and time of flight systems for PId

< 40°)

***Central Detector** for detection of particles at large angles (θ > 35°)*