Proton Form Factor Ratio, G^{P}_{E}/G^{P}_{M} *From* *Double Spin Asymmetries*

Spin
Asymmetries of the
Nucleon
Experiment
(E07-003)

Jefferson Lab
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Pizza seminar, October 17, 2012

Outline

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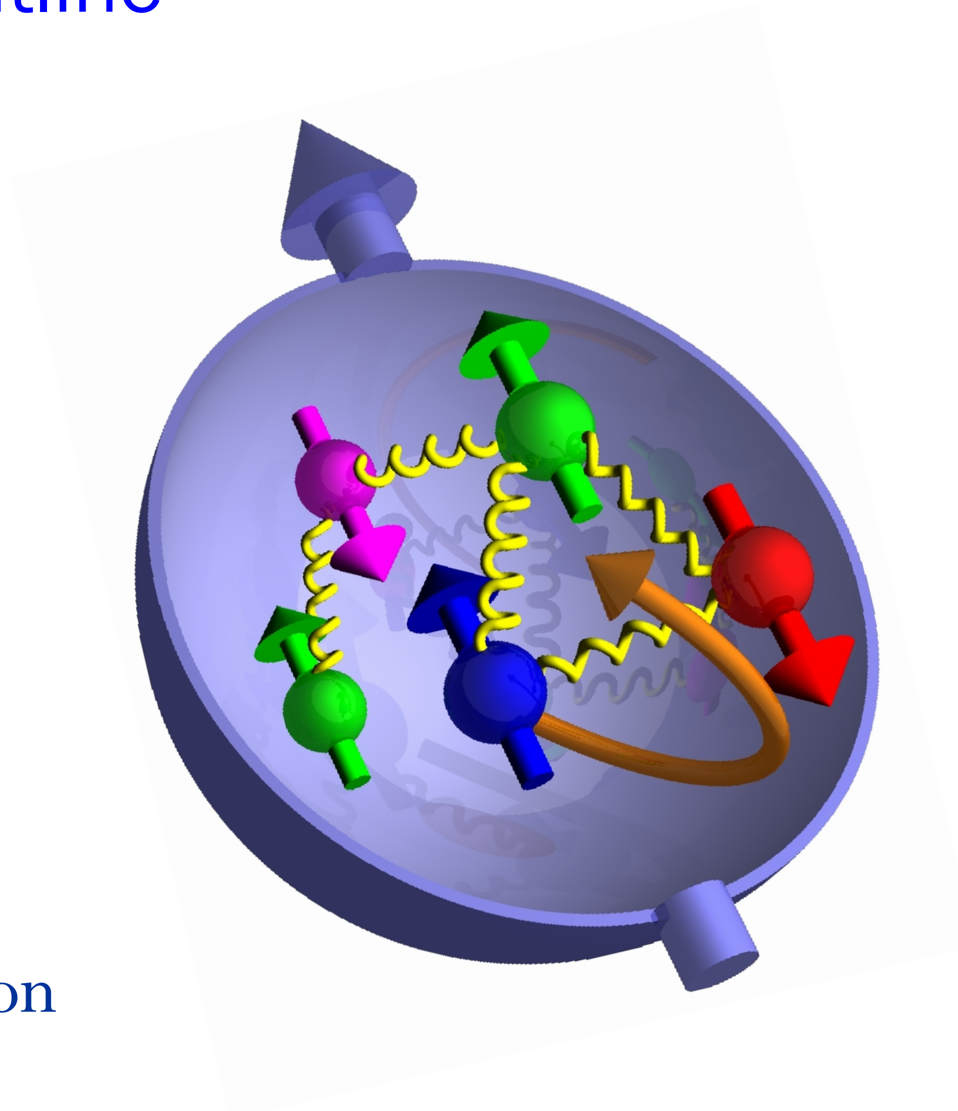
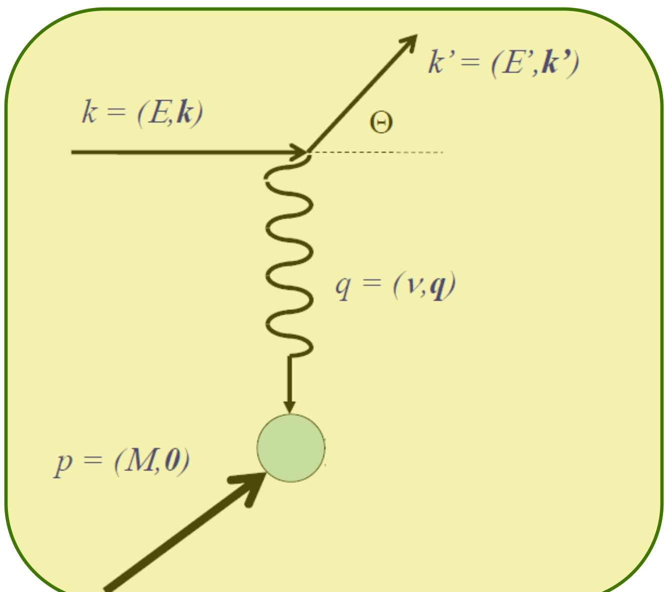


Introduction
Nucleon Elastic Form Factors

- Defined in context of single-photon exchange.
- Describe how much the nucleus deviates from a point like particle.
- Describe the internal structure of the nucleons.
- Provide the information on the spatial distribution of electric charge (by electric form factor, G_E) and magnetic moment (by magnetic form factor, G_M) within the proton.
- Can be determined from elastic electron-proton scattering.
- They are functions of the four-momentum transfer squared, Q^2



The four-momentum transfer squared,

$$Q^2 = -q^2 = 4EE'\sin^2\left(\frac{\Theta}{2}\right)$$

$$E - E' = Q^2/2M$$

General definition of the nucleon form factor is

$$\left\langle N(P')\left|J^{\mu}_{EM}(0)\right|N(P)\right\rangle = \bar{u}(P')\left[\gamma^{\mu}F_1^N(Q^2) + i\sigma^{\mu\nu}\frac{q_{\nu}}{2M}F_2^N(Q^2)\right]u(P)$$

Sachs Form Factors $G_E = F_1 - \tau F_2$; $G_M = F_1 + F_2$; $\tau = \dfrac{Q^2}{4M^2}$

F_1 – non-spin flip (Dirac Form Factor) describe the charge distribution
F_2 – spin flip (Pauli form factor) describe the magnetic moment distribution

At low $|q^2|$

$$G_E(q^2) \approx G_E(\vec{q}^{\,2}) = \int e^{i\vec{q}\cdot\vec{r}}\rho(\vec{r})d^3\vec{r}$$

$$G_M(q^2) \approx G_M(\vec{q}^{\,2}) = \int e^{i\vec{q}\cdot\vec{r}}\mu(\vec{r})d^3\vec{r}$$

Fourier transforms of the charge, $\rho(r)$ and magnetic moment, $\mu(r)$ distributions in Breit Frame

At $q^2 = 0$

$$G_E(0) = \int \rho(\vec{r})d^3\vec{r} = 1$$

$$G_M(0) = \int \mu(\vec{r})d^3\vec{r} = \mu_P = +2.79$$

$$\boxed{\mu\, G_E^p / G_M^p = 1}$$

Form Factor Ratio Measurements

1. Rosenbluth seperation method.

- Measured the electron - unpolarized proton elastic scattering cross section at fixed Q^2 by varying the scattering angle, θ_e.
- Strongly sensitive to the radiative corrections.

$$\frac{d\sigma}{d\Omega} = \underbrace{\frac{\alpha^2 E' \cos^2\frac{\theta_e}{2}}{4(1+\tau)E^3 \sin^4\frac{\theta_e}{2}}}_{\sigma_{Mott}/(1+\tau)} \left[G_E^2 + \frac{\tau}{\varepsilon} G_M^2 \right]$$

$$Q^2 = 2EE'(1-\cos\theta_e)$$

$$\tau = \frac{Q^2}{4M^2}$$

$$\varepsilon = \left[1 + 2(1+\tau)\tan^2\frac{\theta_e}{2} \right]^{-1}$$

$$\frac{d\sigma}{d\Omega} \cdot \frac{\varepsilon(1+\tau)}{\sigma_{Mott}} = G_E^2 \varepsilon + \tau G_M^2$$

$$Y = m\,X + C$$

The gradient $= G_E^2$, The Intercept $= \tau G_M^2$,

E - Incoming going electron energy
$E^{/}$ - Out going electron energy
θ_{e} – Outgoing electron's scattering angle
M – Proton mass

2. Polarization Transfer Technique.

- Measured the recoil proton polarization from the elastic scattering of polarized electron-unpolarized proton.
- Insensitive to absolute polarization, analyzing power.
- Less sensitive to radiative correction.

$$\frac{G_E}{G_M} = -\frac{P_T}{P_L}\frac{(E+E')\tan\left(\theta_e/2\right)}{2M_p}$$

E - Incoming going electron energy
E' - Out going electron energy
θ_{e-} Outgoing electron's scattering angle
M_P - Proton mass

$$P_L = M_P^{-1}(E+E')\sqrt{\tau(1+\tau)}G_M^2\tan^2(\theta_e/2)$$ → Polarization along q

$$P_T = 2\sqrt{\tau(1+\tau)}G_E G_M\tan(\theta_e/2)$$ → Polarization perpendicular to q (in the scattering plane)

$$P_N = 0$$ → Polarization normal to scattering plane.

3. Double-Spin Asymmetry.

- Measured the cross section asymmetry between + and – electron helicity states in elastic scattering of a polarized electron on a polarized proton.
- The systematic errors are different when compared to either the Rosenbluth technique or the polarization transfer technique.
- The sensitivity to the form factor ratio is the same as the Polarization Transfer Technique.

$$A_P = \frac{-br\sin\theta^*\cos\phi^* - a\cos\theta^*}{r^2 + c}$$

$$\frac{G_E}{G_M} = -\frac{b}{2A_p}\sin\theta^*\cos\phi^* + \sqrt{\frac{b^2}{4A_p^2}\sin^2\theta^*\cos^2\phi^* - \frac{a}{A_P}\cos\theta^* - c}$$

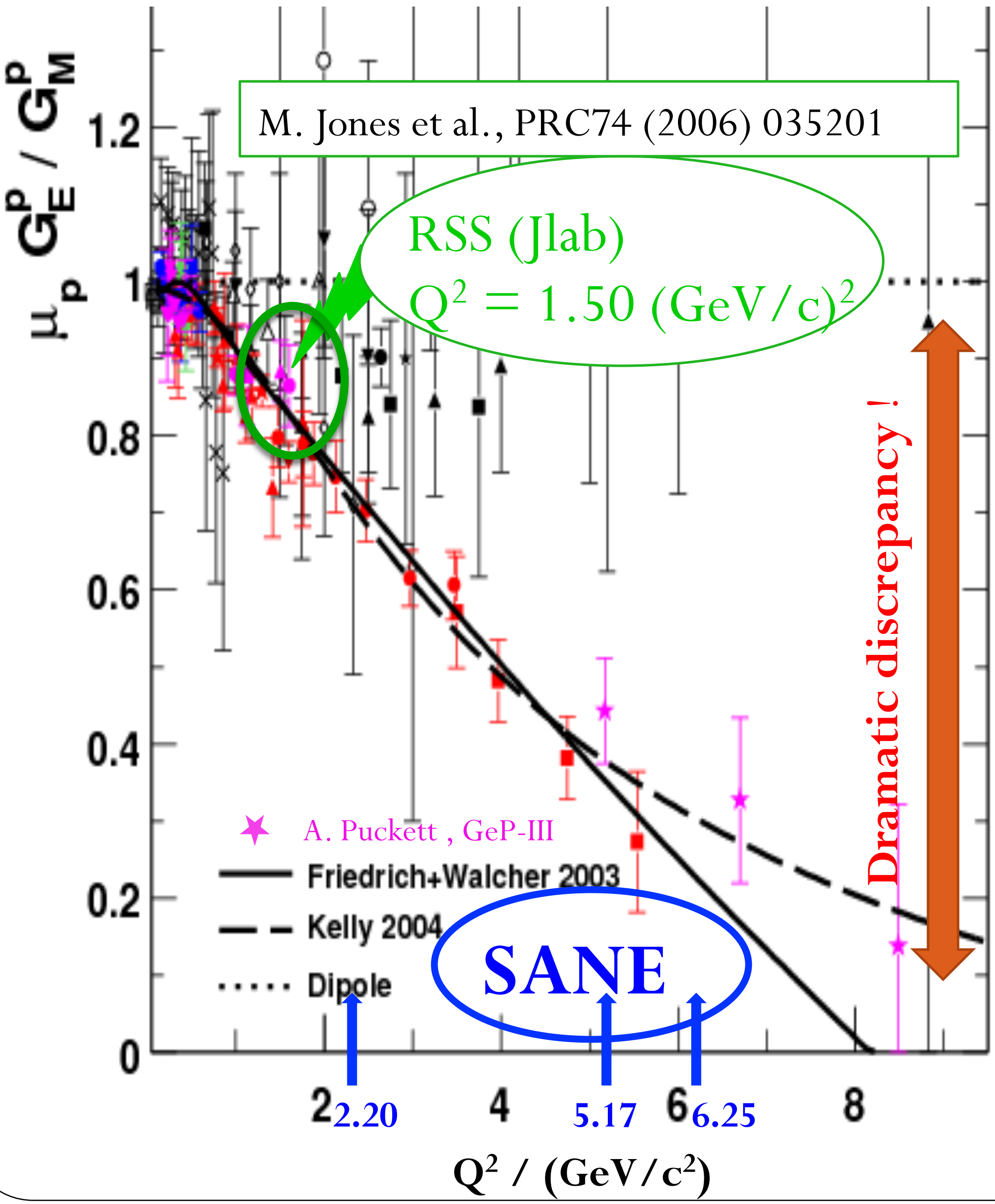
Here, $r = G_E/G_M$

$a, b, c = \textit{kinematic factors}$

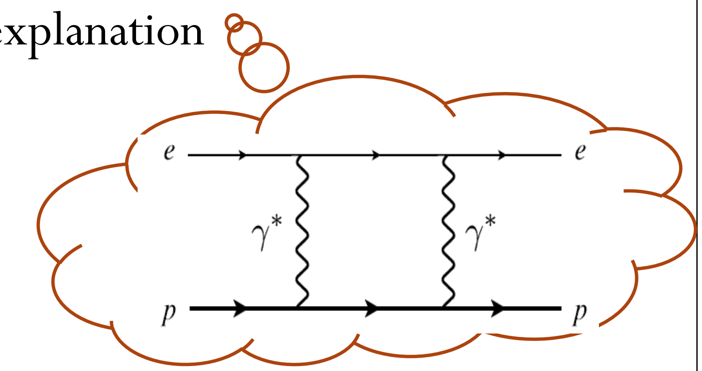
$\theta^*, \phi^* = \textit{pol. and azi. Angles between } \vec{q} \textit{ and } \vec{S}$

$A_p = \textit{The beam - target asymmetry}$

Physics Motivation

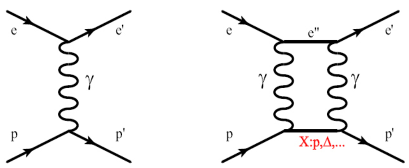


- Dramatic discrepancy between Rosenbluth and recoil polarization technique.
- Multi-photon exchange considered the best candidate for the explanation



- **Double-Spin Asymmetry is an Independent Technique to verify the discrepancy**

Two-Photon Exchange



- Both Rosenbluth method and the polarization transfer technique account for radiative correction, but neither consider two photon exchange.
- Contribution of the TPE amplitude has calculated theoretically and,

  has an ε dependence that has the same sign as the G_E contribution to the cross section and

  is large enough to effect the extracted value of G_E.

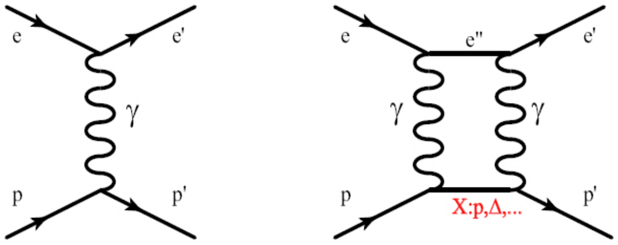
  Therefore, the extracted G_E/G_M for the Rosenbluth technique is reduced.

- The effect of TPE amplitude on the polarization components is small, though the size of the contribution change with ε
- The size of the TPE would measure by taking the ε dependence of the ratio of cross sections, R for elastic electron-proton scattering to positron-proton scattering at a fixed Q^2 and measuring the deviation from 1.

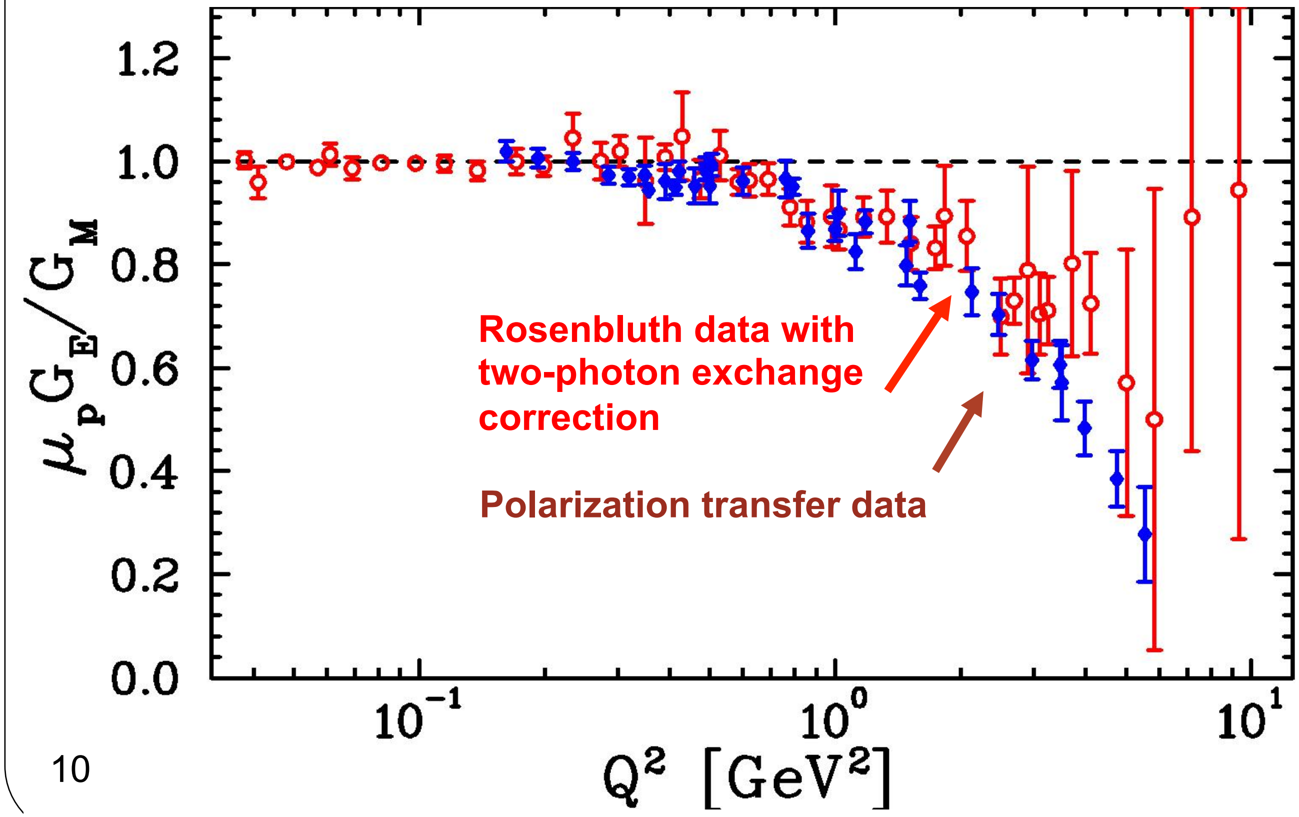
$$R = \frac{\sigma_{e+}}{\sigma_{e-}} = \frac{\left(A_{1\gamma} + A_{2\gamma}\right)^2}{\left(A_{1\gamma} - A_{2\gamma}\right)^2} \approx 1 + 4\,\mathrm{Re}\left(A_{2\gamma} \big/ A_{1\gamma} \right)$$

Two-Photon Exchange: Exp. Evidence

Two-photon exchange theoretically suggested



TPE can explain form factor discrepancy
J. Arrington, W. Melnitchouk, J.A. Tjon,
Phys. Rev. C 76 (2007) 035205



Asymmetry measurements

σ - Scattering cross section
σ_0- Scattering cross section at unpolarized target
σ_B- Scattering cross section from background
Δ σ - σ correction due to the spin
P_E – Beam polarization
P_T – Target polarization
f – Dilution factor

$$\sigma = \sigma_0 + P_E P_T \Delta\sigma$$

$$\Downarrow$$

$$\sigma_{++} = \sigma_0 + P_E P_T \Delta\sigma$$

$$\sigma_{+-} = \sigma_0 - P_E P_T \Delta\sigma$$

$$\frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = P_E P_T \cdot \frac{\Delta\sigma}{\sigma_0} = \frac{N_+ - N_-}{N_+ + N_-} = A_r$$

$$\frac{A_r}{P_E P_T} = \frac{\Delta\sigma}{\sigma_0} = A_p$$

Hence,
A_p, known as the physics asymmetry is the relative scattering cross section correction due to the spin.
A_r is the raw asymmetry

With background….

$$\sigma_{++} = \sigma_0 + P_E P_T \Delta\sigma + \sigma_B$$

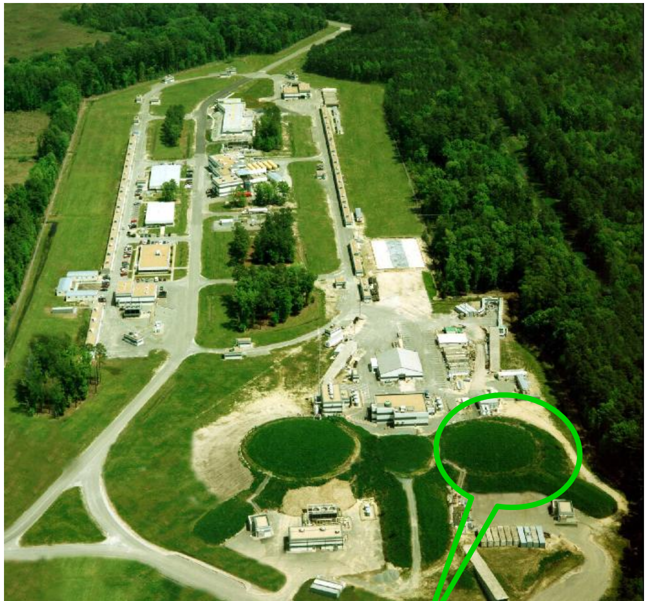
$$\sigma_{+-} = \sigma_0 - P_E P_T \Delta\sigma + \sigma_B$$

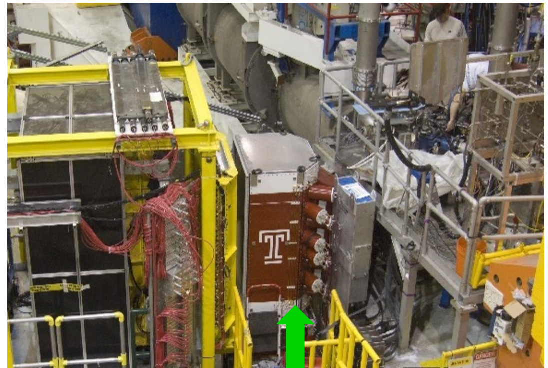
$$A_r = P_E P_T \cdot \frac{\Delta\sigma}{(\sigma_0 + \sigma_B)}$$

$$A_r = P_E P_T \cdot \frac{\Delta\sigma}{\sigma_0} \cdot \underbrace{\frac{\sigma_0}{(\sigma_0 + \sigma_B)}}_{f}$$

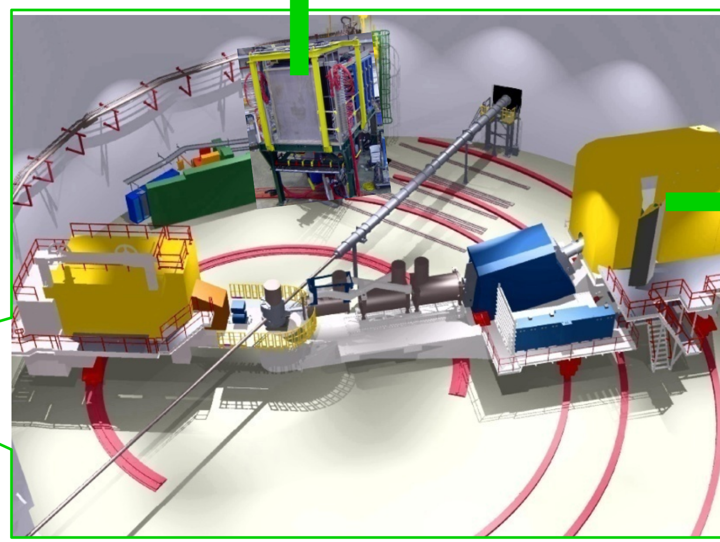
$$A_P = \frac{A_r}{f P_E P_T}$$

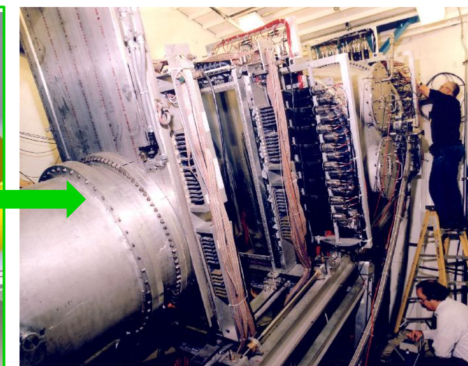
Experiment Setup





- BETA for coincidence electron detection
- Central scattering angle :40 °
- Over 200 msr solid angle coverage





Hall C at Jefferson Lab

- HMS for the scattered proton detection
- Central angles are 22.3° and 22.0°
- Solid angle ~10 msr

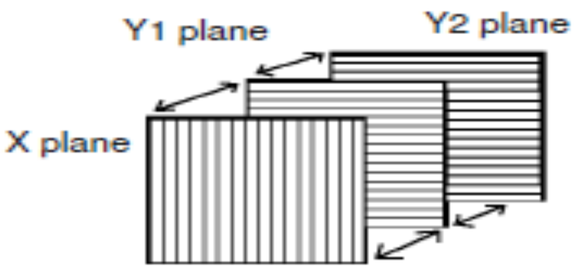
Elastic (e , e’p) scattering from the polarized NH_3 target using a longitudinally polarized electron beam

(Data collected from Jan – March ,2009)

Big Electron Telescope Array – BETA

Forward Tracker

- 3 planes of Bicron Scintillator provide early particle tracking

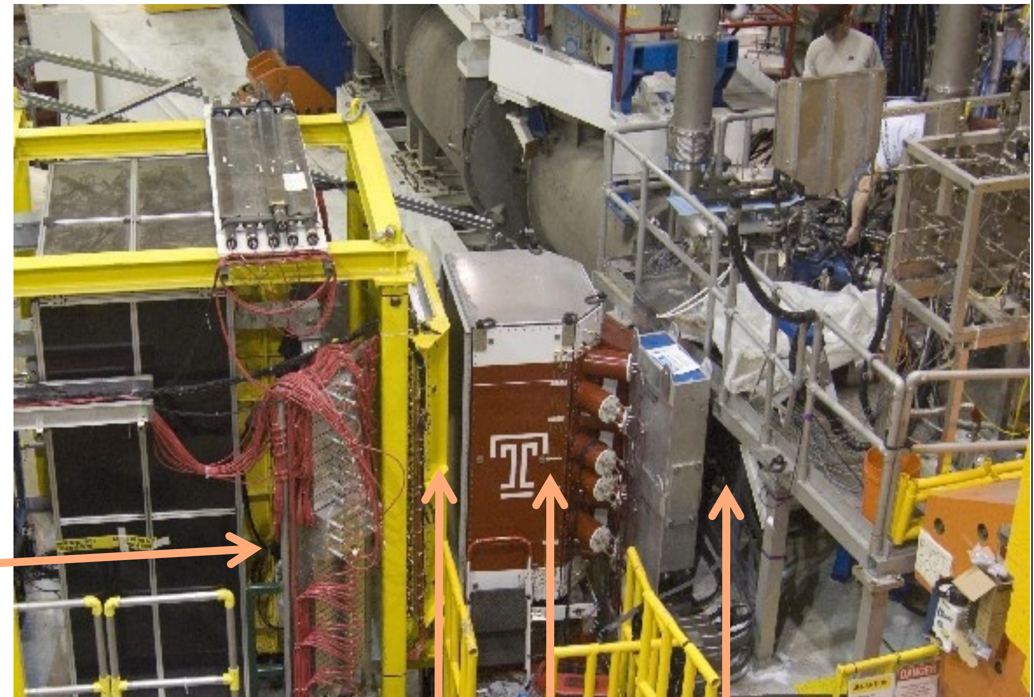


Cerenkov

- N_2 gas cerenkov
- Provides particle ID
- 8 mirrors and 8 PMTs

Lucite Hodescope

- 28 bars of 6cm wide Lucite
- Bars oriented horizontally for Y tracking
- PMTs on either side of bar provides X resolution



BigCal

Lucite Hodoscope

Tracker

Cherenkov

Big Cal (GEP III Collaboration)

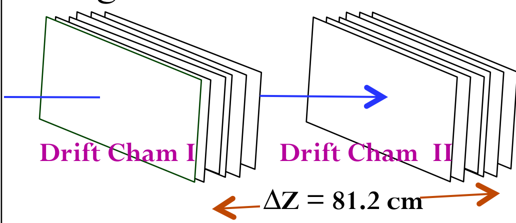
Lead glass calorimeter

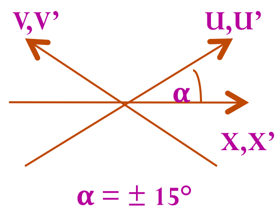
- 1744 blocks aprx. 4cm x 4cm
- energy and position measurement

High Momentum Spectrometer – HMS

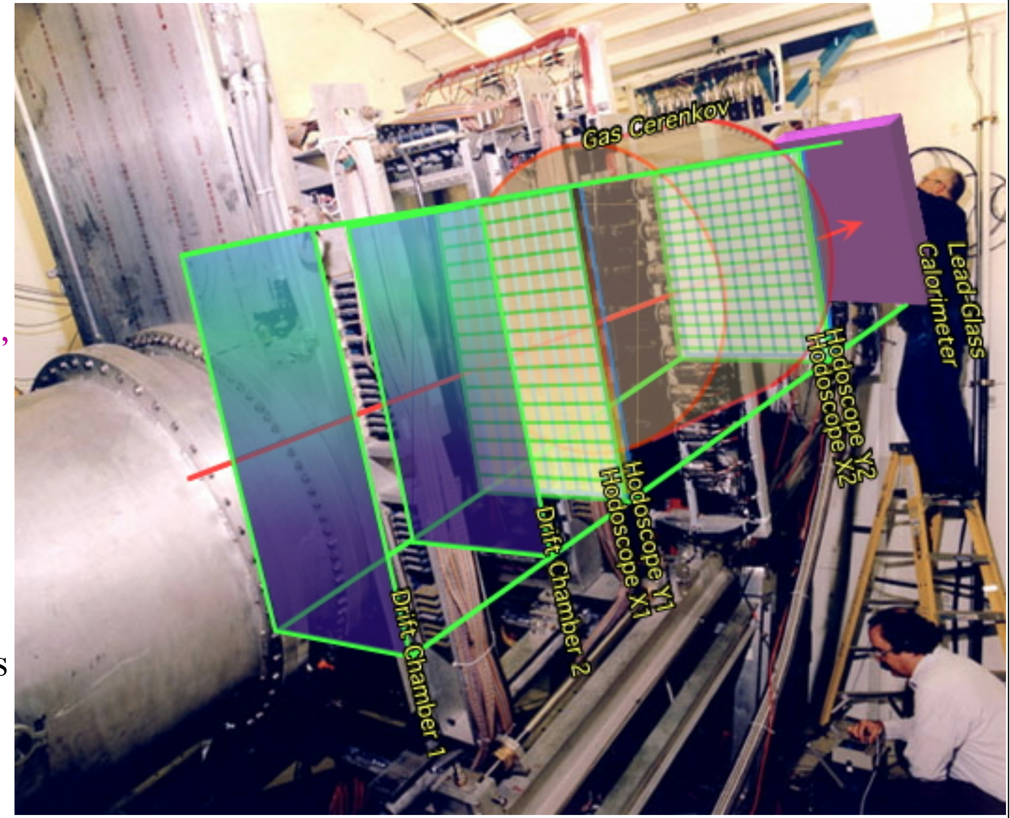
Drift Chambers

- Each plane has a set of alternating field and sense wires Filled with an equal parts Argon-Methane mixture



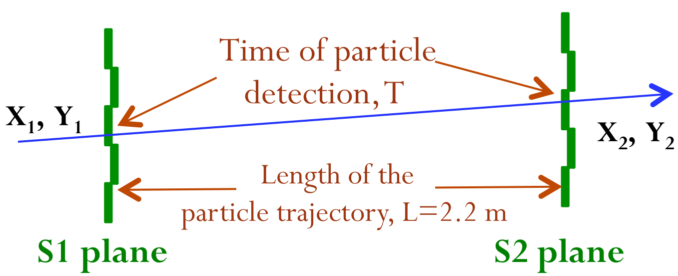


- Track particle trajectory by multiple planes.
- χ^2 fitting to determine a straight trajectory.



Hodoscopes

- Each plane contains 10 to 16 Scintillator paddles with PMTs on both ends
- Each Paddle is 1.0 cm thick and 8.0 cm wide



- Fast position determination & triggering
- Time of Flight (TOF) = T2-T1 determines β

(β = L/c x TOF)

Gas Cerenkov

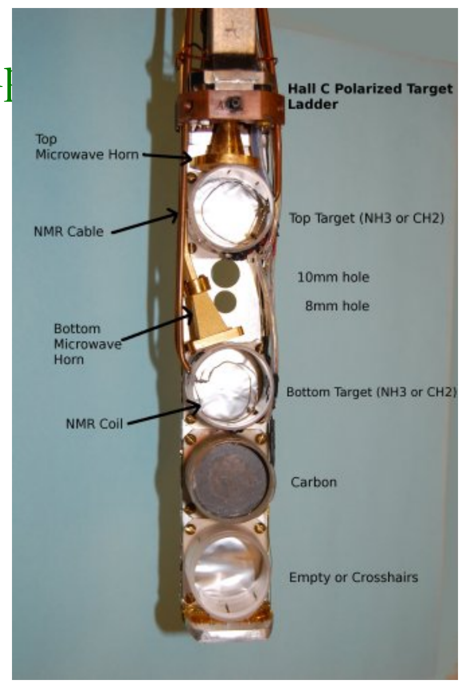
- Two mirrors (top & bottom) connected to two PMTs
- Used as a Particle ID

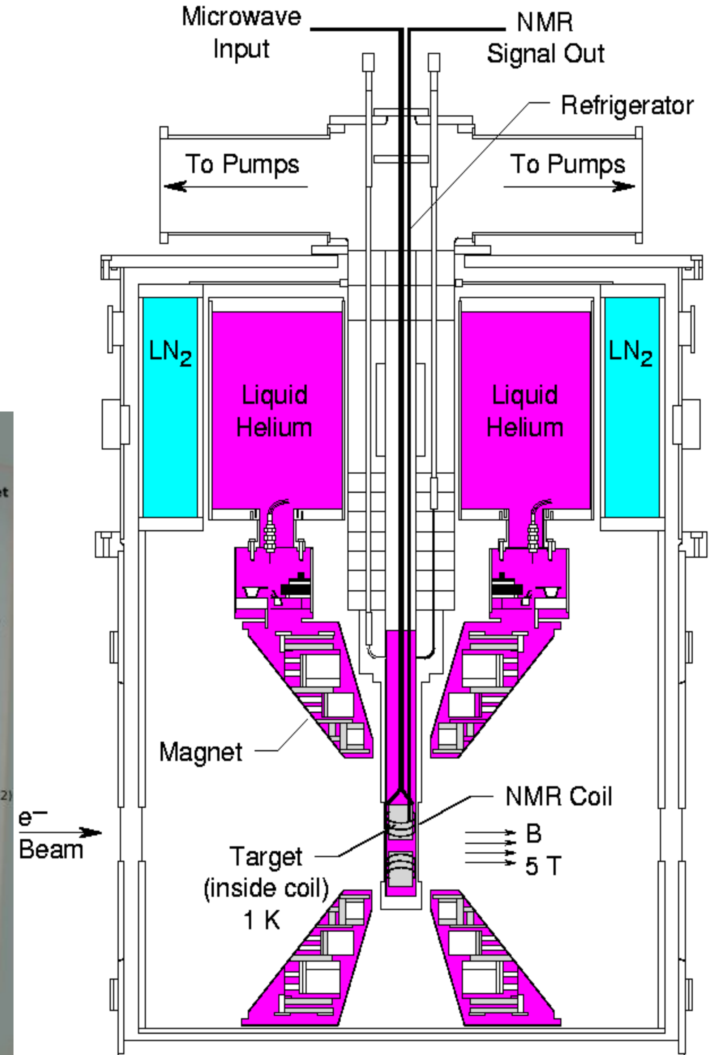
Lead Glass Calorimeter

- 4 layers of 10 cm x 10cm x70cm blocks stacked 13 high.
- Used as a Particle ID

Polarized Target

- C, CH_2 and NH_3
- Dynamic Nuclear Polarization (DNP) polarized the protons in the NH_3 target up to 90% at
  1 K Temperature
  5 T Magnetic Field
- Temperature is maintained by immersing the entire target in the liquid He bath
- Used microwaves to excite spin flip transitions
  (55 GHz - 165 GHz)
- Polarization measured using NMR coils
- To maintain reasonable target polarization, the beam current,
  - ➢ limited to 100 nA
  - ➢ Was uniformly rastered.

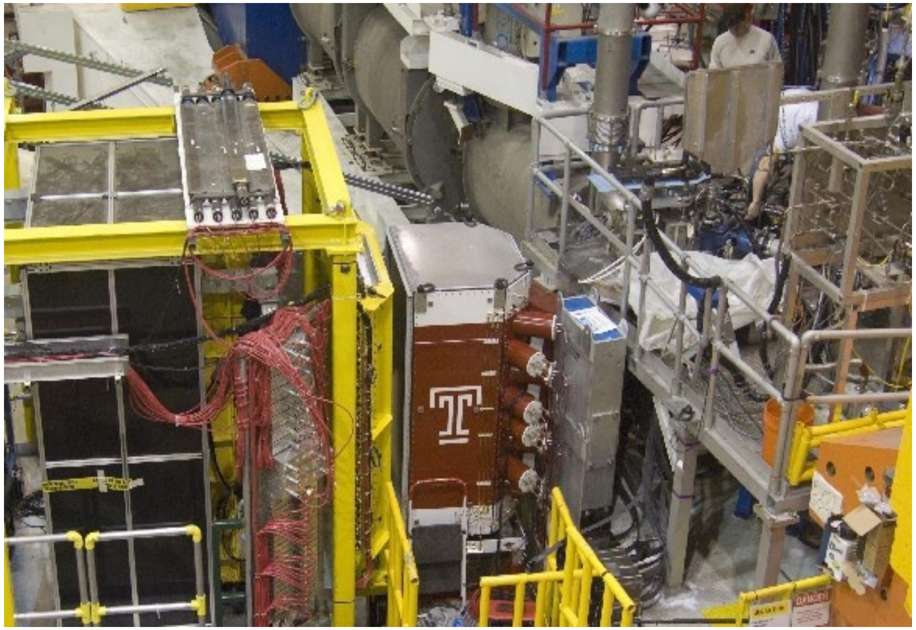




The Polarized Target Assembly

Goal Of The SANE

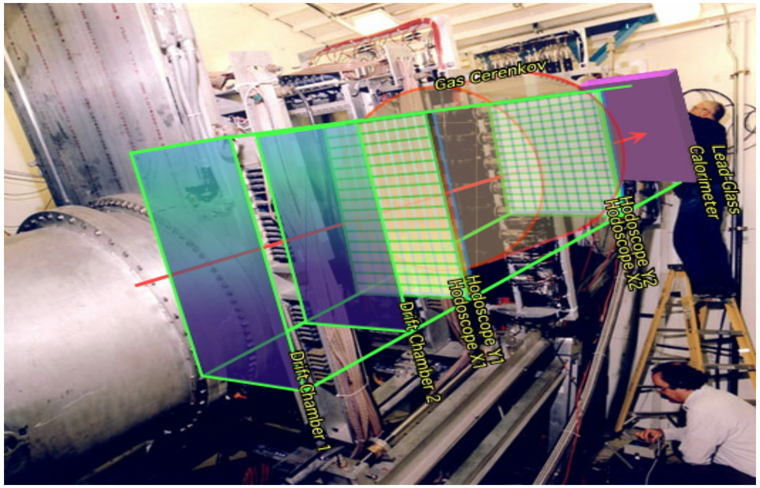
- SANE is a single arm inclusive scattering experiment. Used
  - **B**ig **E**lectron **T**elescope **A**rray – **BETA** In single arm mode
  - **H**igh **M**omentum **S**pectrometer – **HMS** in both single arm and coincidence mode



Physics from BETA:

- Measure proton spin structure function $g_2(X,Q^2)$ and spin asymmetry $A_1(X,Q^2)$ at four-momentum transfer $2.5 < Q^2 < 6.5$ GeV^2 and $0.3 < X < 0.8$ by measuring anti-parallel and near-perpendicular spin asymmetries.
- Study twist -3 effects (d2 matrix element) and moments of g_2 and g_1
- Comparison with Latice QCD, QCD sum rule
- Explore "High" X_B region: A_1 at $X_B \sim 1$

What HMS use for …..



Packing Fraction determination.

- It will detect electrons with momenta from 1 to around 5 GeV/c
- Use the ratio of data/MC yields of C and C+He.

- In single arm mode HMS can be used to measure accurate pair symmetric backgrounds from $\gamma \rightarrow e^+e^-$ pair production.

HMS will detect positrons up to 2.2 GeV/c.

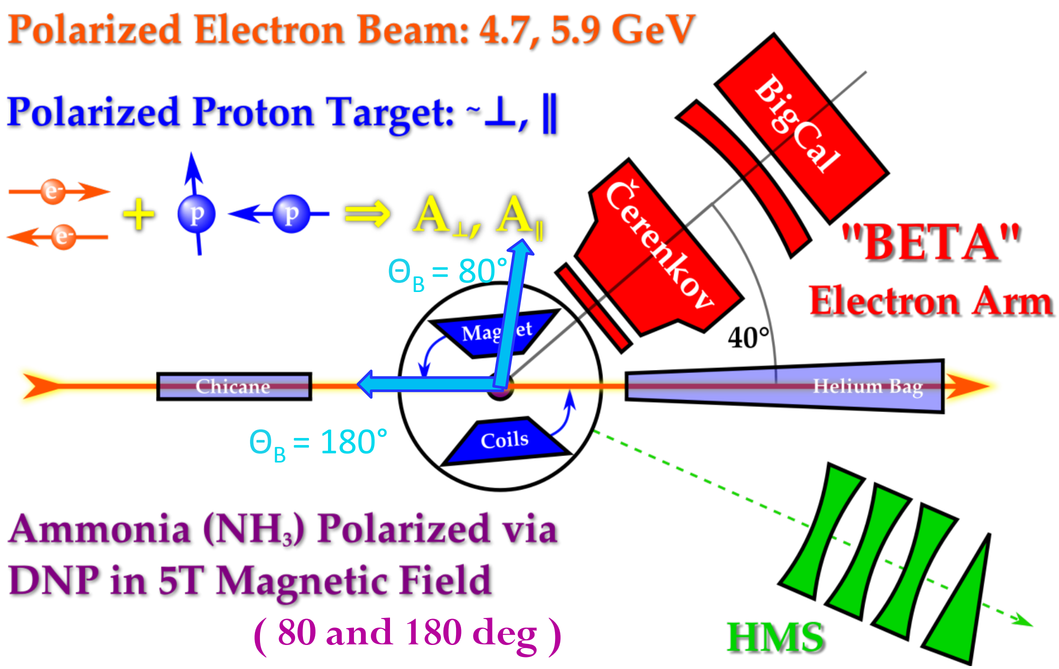
Asymmetries

- Inclusive Asymmetries;

  Q^2 of 0.8, 1.3 and 1.8 (GeV^2)

- Elastic Asymmetries at magnetic field of 80^0 and hence the ratio of form factors, G_E^p/G_M^p
  - From single arm data at $Q^2 = 2.2\ GeV^2$
  - From coincidence data at $Q^2 = 5.17$ and $6.25\ GeV^2$

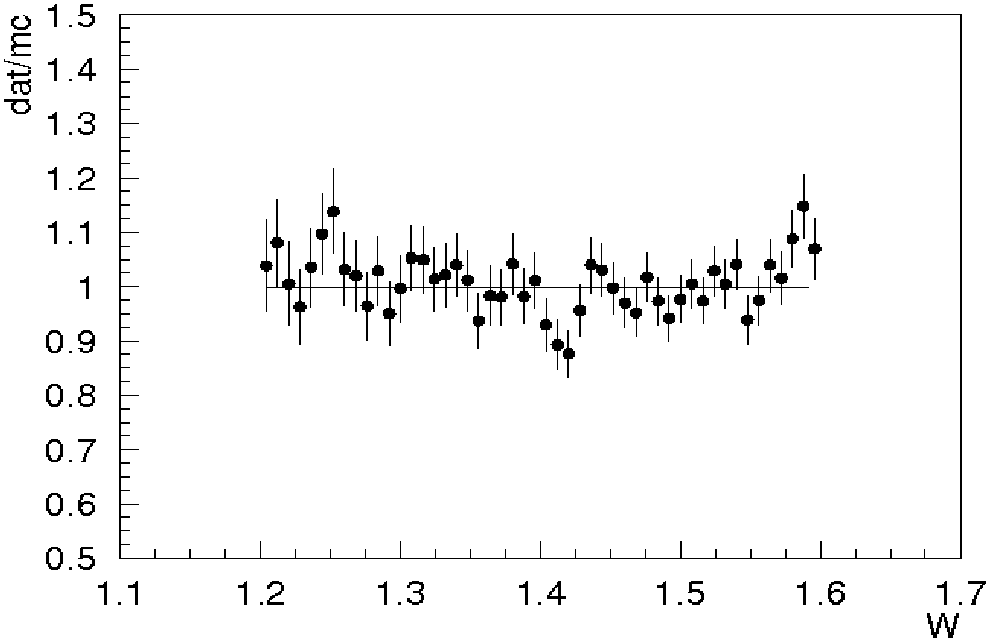
Polarized Target Magnetic Field



- Used only perpendicular magnetic field configuration for the elastic data
  - Average target polarization is ~ 70 %
  - Average beam polarization is ~ 73 %

Packing Fraction.

- Packing Fraction is the actual amount of target material used.
- Determined by taking the ratio of data to MC as a function of W.
- Need to determine the packing fractions for each of the NH3 loads used during the data taking.



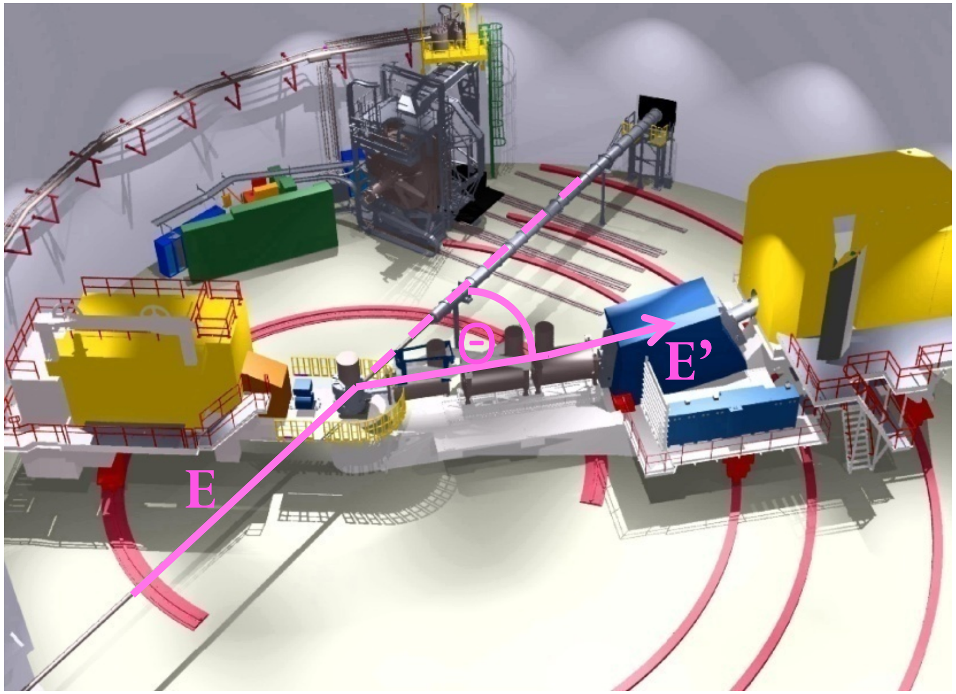
Elastic Kinematics

(From HMS Spectrometer)

Spectrometer mode	Coincidence	Coincidence	Single Arm
HMS Detects	Proton	Proton	Electron
E Beam GeV	4.72	5.89	5.89
P_{HMS} GeV/c	3.58	4.17	4.40
Θ_{HMS} (Deg)	22.30	22.00	15.40
Q^2 $(GeV/c)^2$	5.17	6.26	2.20
Total Hours (h)	~40 (~44 runs)	~155 (~135 runs)	~12 (~15 runs)
Elastic Events	~113	~1200	-

Data Analysis

Electrons in HMS



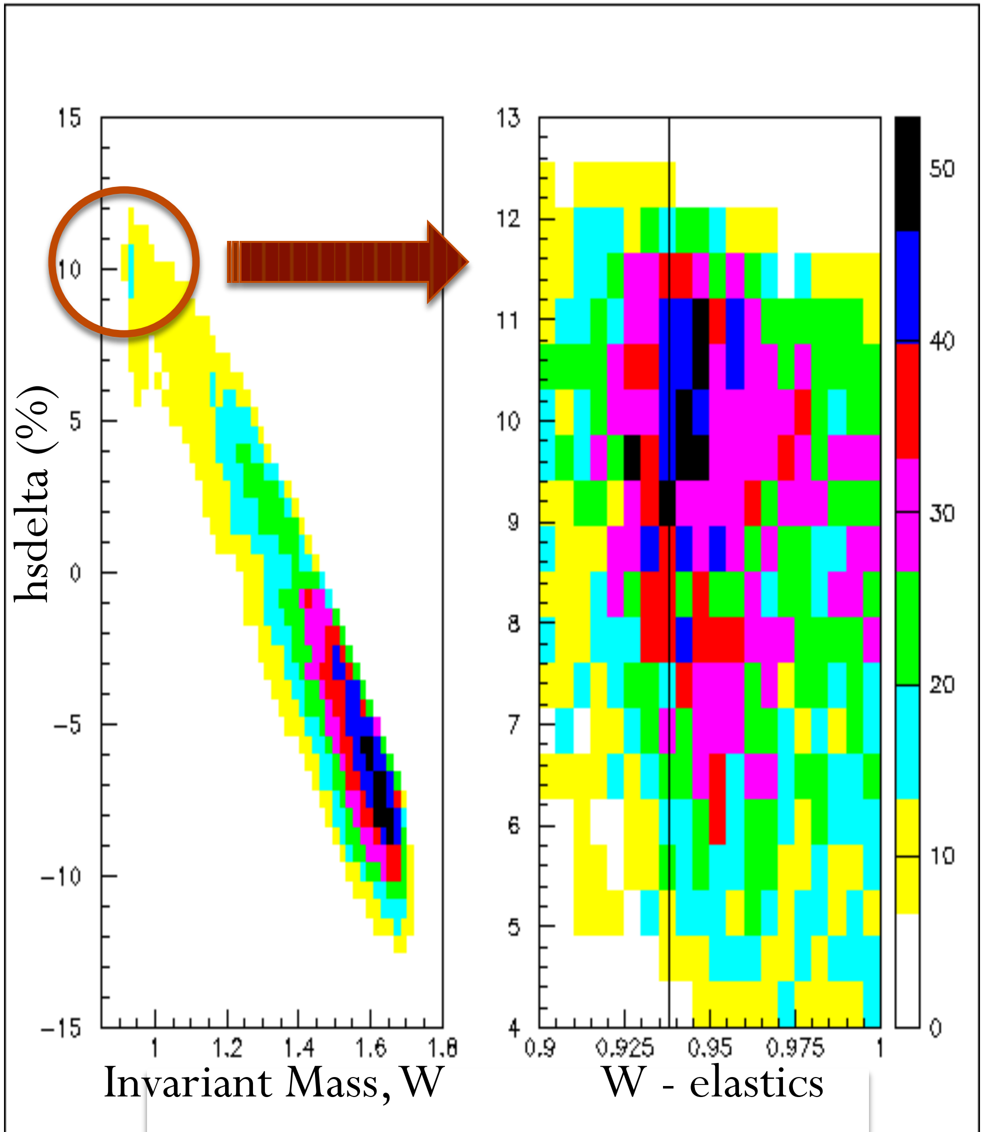
$\vec{e}^{-}\ \vec{p} \longrightarrow e^{-}\ p$

By knowing,
the incoming beam energy, E,
scattered electron energy, E'
and
the scattered electron angle, θ

$$Q^2 = 4EE'\sin^2\left(\frac{\theta}{2}\right)$$

$$W^2 = M^2 - Q^2 + 2M(E - E')$$

Momentum Acceptance



$$hsdelta = \left({P - P_c} \middle/ {P_c} \right) = \frac{\delta p}{p}$$

P -Measured momentum in HMS

P_c-HMS central momentum

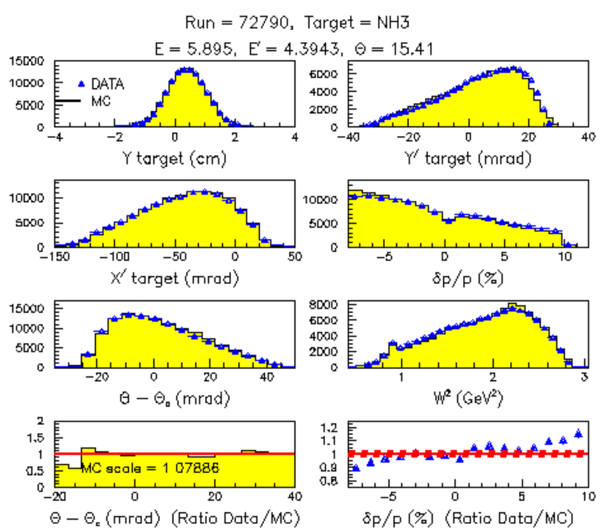
The elastic data are outside of the usual delta cut +/- 8%

Because HMS reconstruction matrix elements work fine up to 10

Use -8% < hsdelta <10%

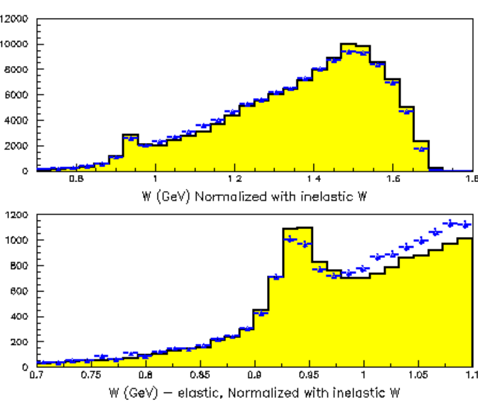
MC with NH3

- Generated N, H and He separately.
- Added Al come from target end caps and 4K shields as well.
- Calculated the MC scale factor using the data/MC luminosity ratio for each target type.
- Added all targets together by weighting the above MC scale factors.
- Used 60% packing fraction.
- Adjust acceptance edges in Ytar and yptar from adjusting the horizontal beam position.
- Adjust the vertical beam position to bring the W peak to 0.938 GeV



$$srast_x = -0.40 \text{ cm}$$

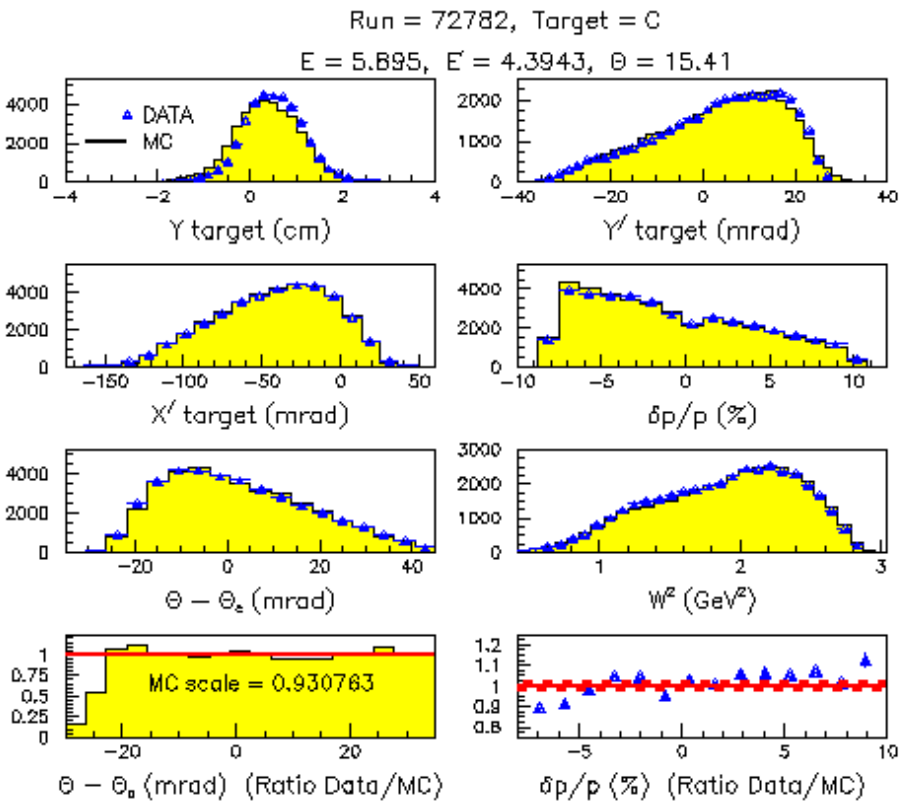
$$srast_y = 0.10 \text{ cm}$$

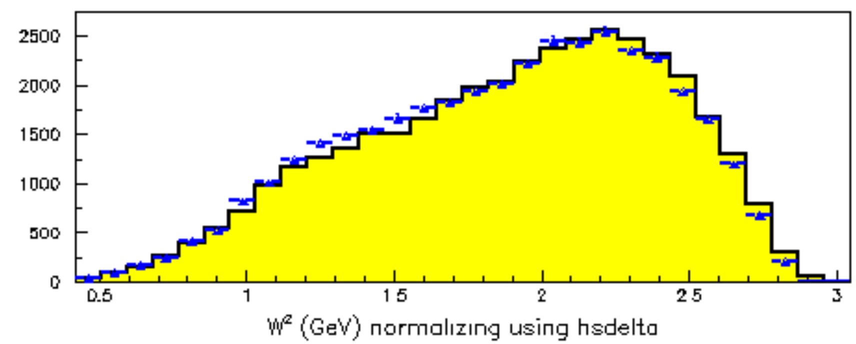


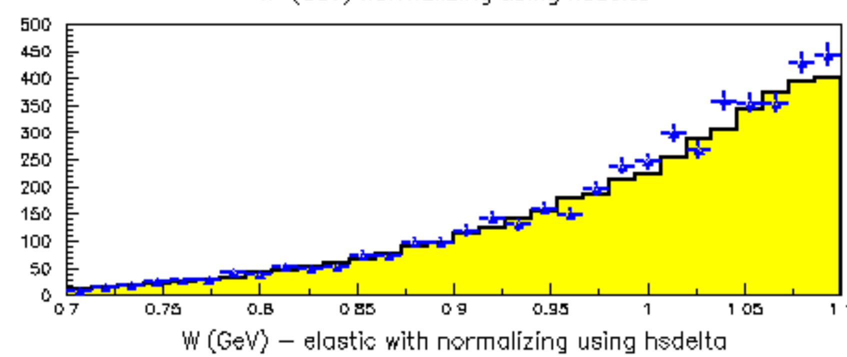
MC for C run

Srast x offset=-0.4 cm

Srast y offset=0.1 cm

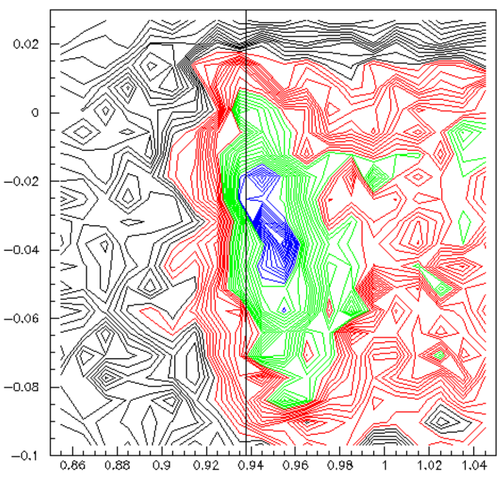






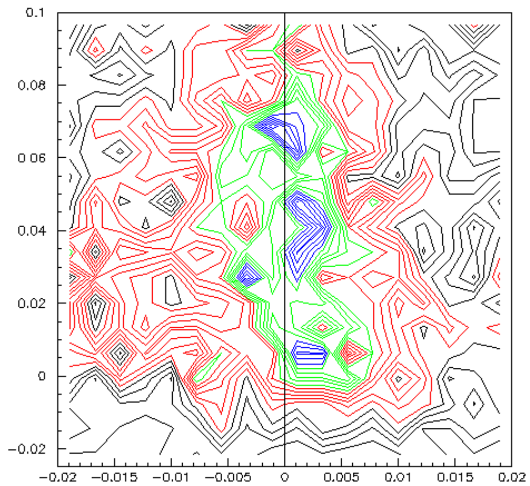
Perp. target magnetic field make some correlations….

In Single Arm electron data



Xptar vs W

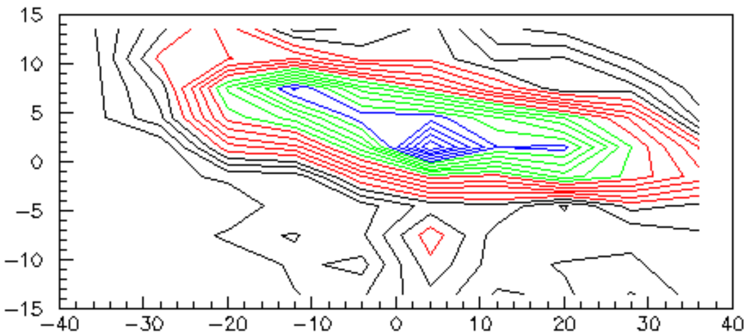
In COIN HMS data



Xptar vs dpel_hms

- Introduced an 'azimuthal angle correction' which correct the target magnetic field in vertical direction in terms of the azimuthal angle. (First make the same correlations on MC/SIMC by applying the correction only for the forward direction and then use the correction on data)
- Different corrections for different detector angles.

In COIN BETA data



Y_HMS-y_clust vs y_clust

Extract the electrons

- Used only Electron selection cuts.

$$\# \text{ of Cerenkov photoelectrons} > 2$$ - Cerenkov cut

$$E_{sh}/E' > 0.7$$ - Calorimeter cut

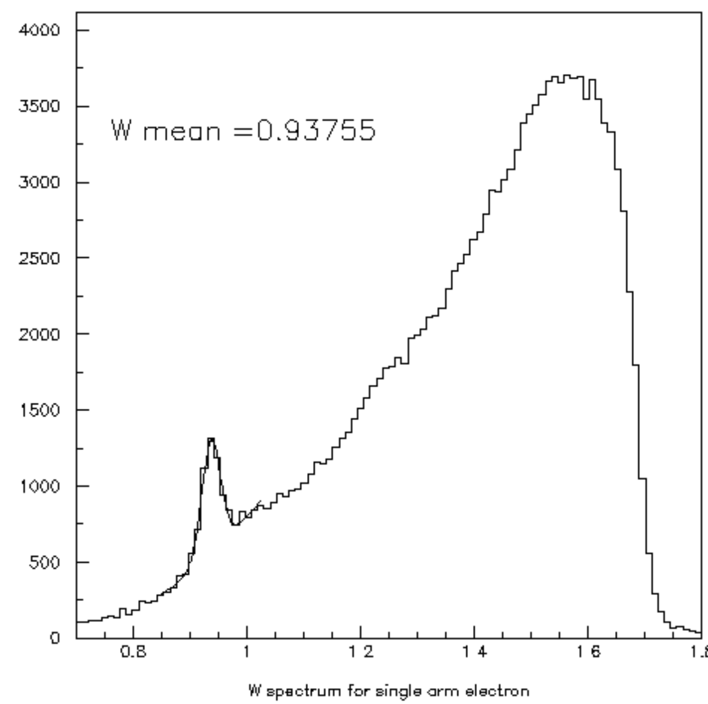
$$\left(P - P_c/P_c\right) < 10 \text{ and } \left(P - P_c/P_c\right) > -8$$ - HMS Momentum Acceptance cut

Here,

P / E' - Detected electron momentum/ energy at HMS

P_c - Central momentum of HMS

E_{sh} - Total measured shower energy of a chosen electron track by HMS Calorimeter



Extracted the Asymmetries .....

The raw asymmetry, A_r

$$A_r = \frac{N^+ - N^-}{N^+ + N^-}$$

$$\Delta A_r = \frac{2\sqrt{N^+}\sqrt{N^-}}{(N^+ + N^-)\sqrt{(N^+ + N^-)}}$$

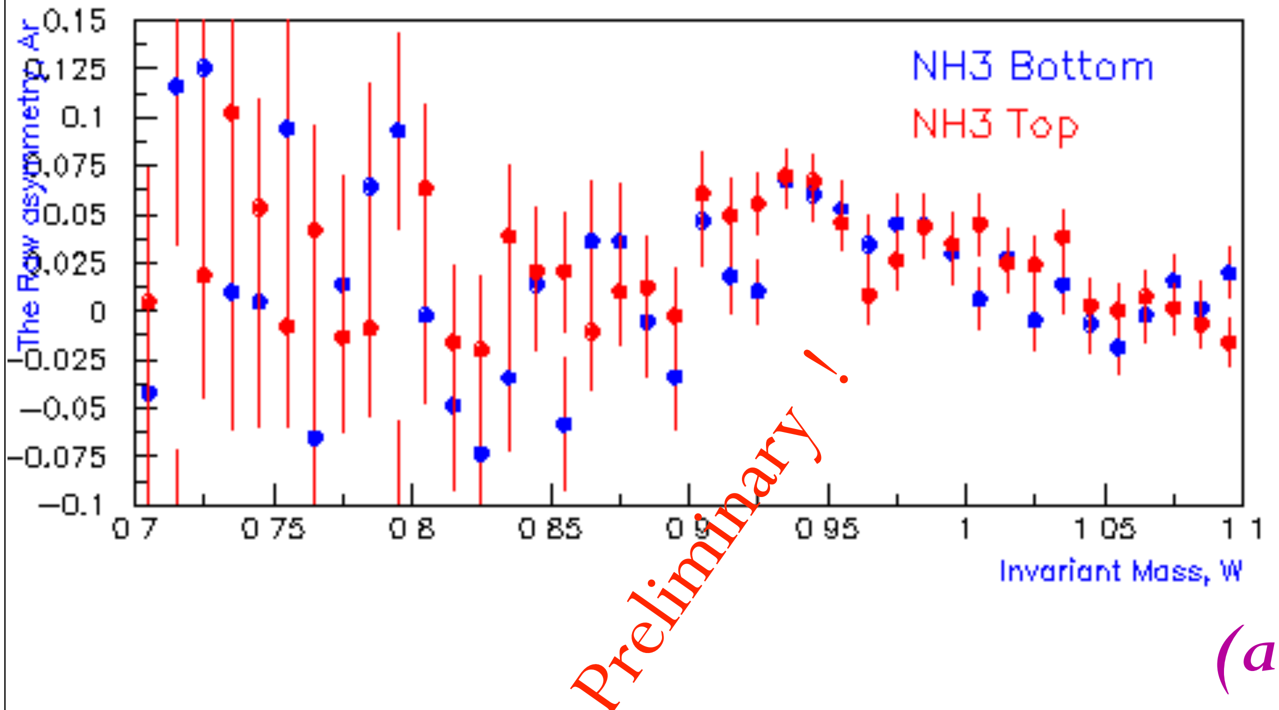
N^+ / N^- = *Charge and life time normalized counts for the +/- helicities*

ΔA_r = *Error on the raw asymmetry*

$P_B P_T$ = *Beam and Target polarization*

N_c = *A correction term to eliminates the contribution from quasi-elastic* ^{15}N *scattering under the elastic peak*

The Asymmetries



Need dilution factor, f

in order to determine the

physics asymmetry,

$$A_p = \frac{A_r}{f P_B P_T} + N_C$$

and G^p_E / G^p_M

(at Q^2=2.2 (GeV/c)^2)

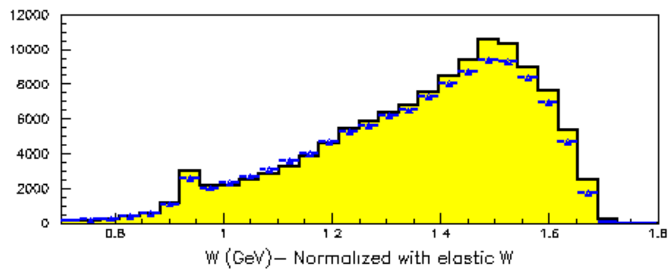
Determination of the Dilution Factor

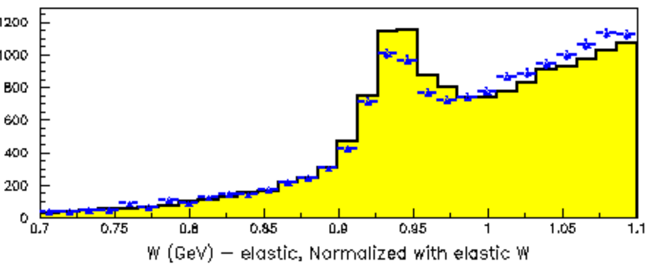
What is the Dilution Factor ?

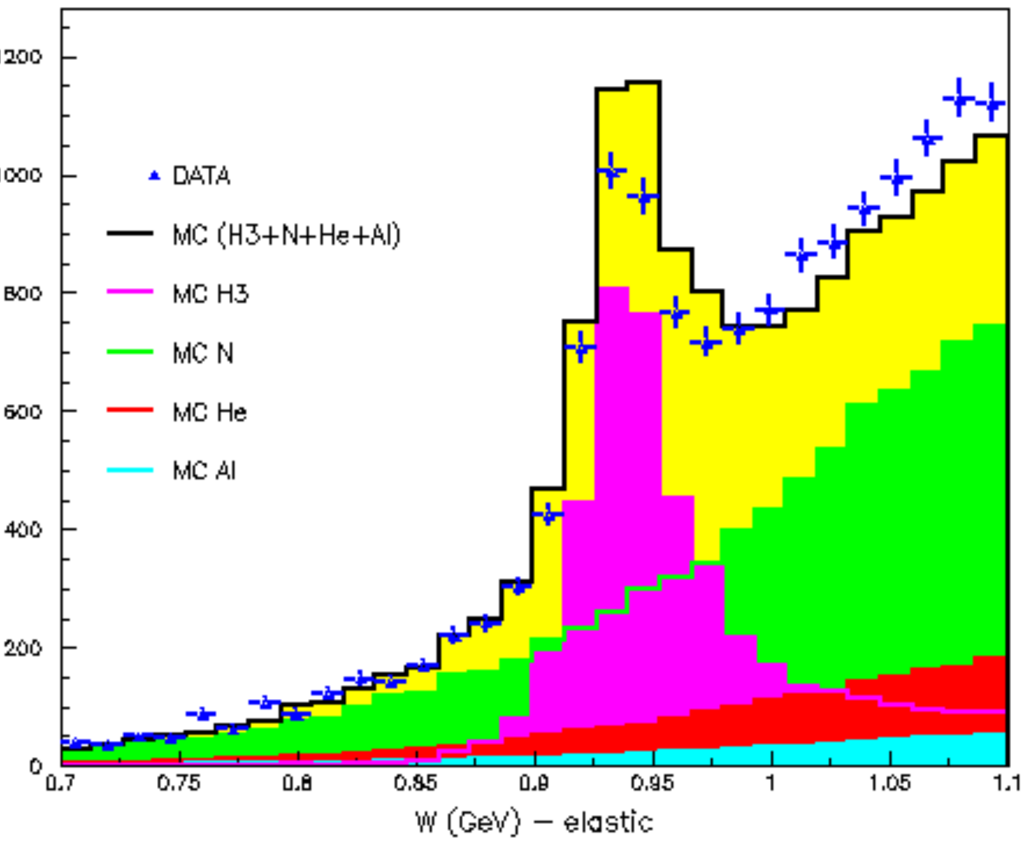
The dilution factor is the ratio of the yield from scattering off free protons(protons from H in NH_3) to that from the entire target (protons from N, H, He and Al)

Dilution Factor,

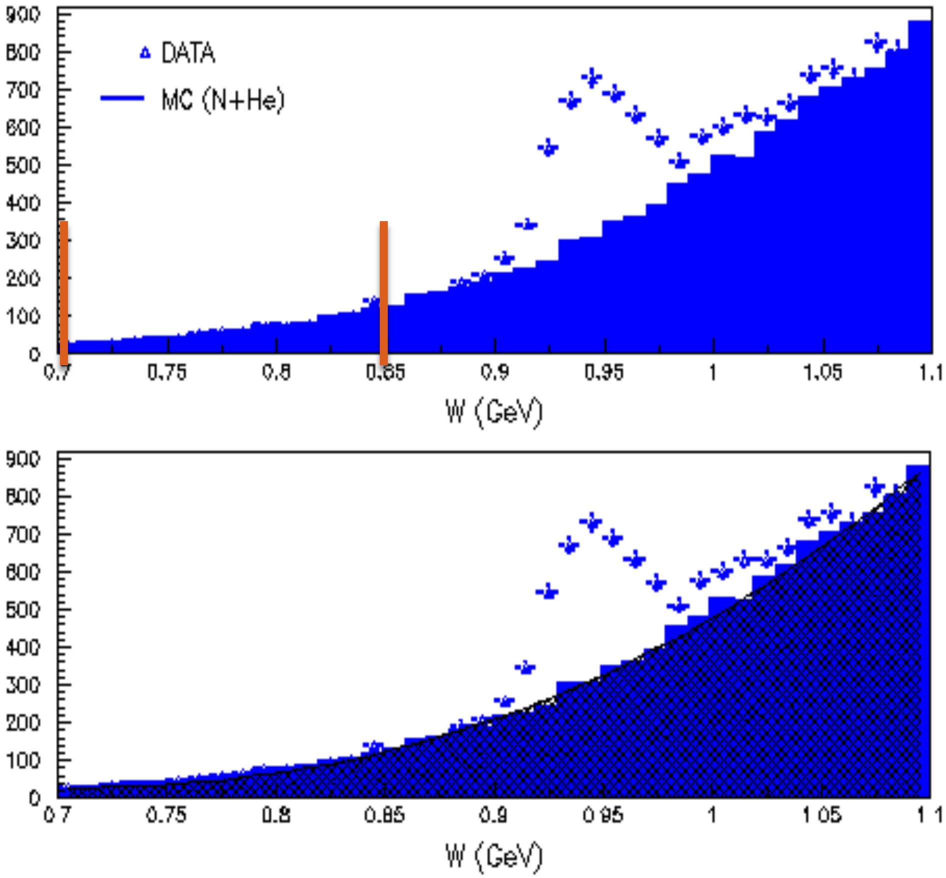
$$F = \frac{Yield_{Data} - Yield_{MC(N+He)}}{Yield_{Data}}$$







- MC Background contributions (Only He+N+Al)



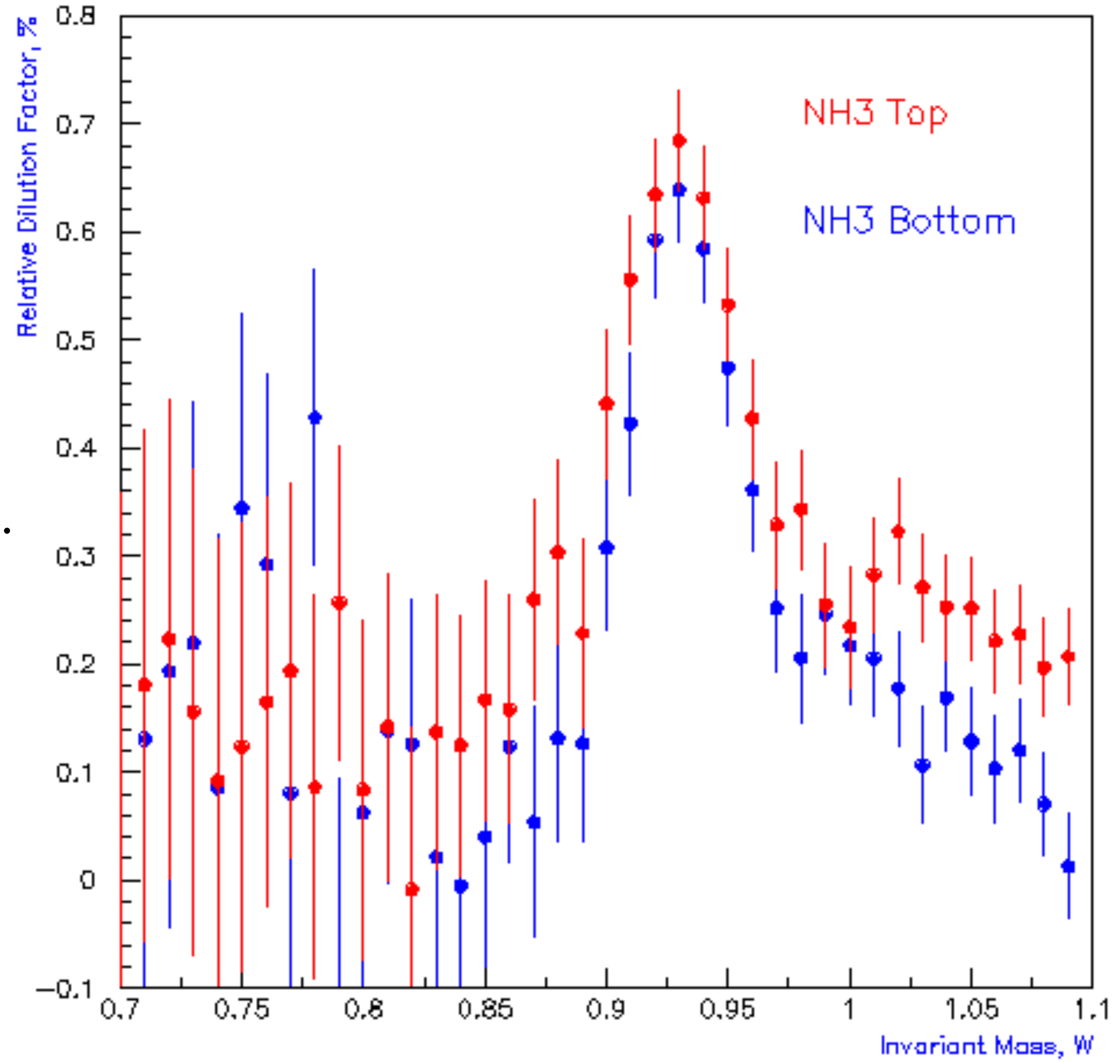
- Calculate the ratio of $\text{Yield}_{\text{Data}}/\text{Yield}_{\text{MC}}$ for the W region $0.7 < W < 0.85$ and MC is normalized with this new scaling factor.
- Used the polynomial fit to N+ He+Al in MC and
- Subtract the fit function from data

▪ The relative Dilution Factor (**Preliminary**)

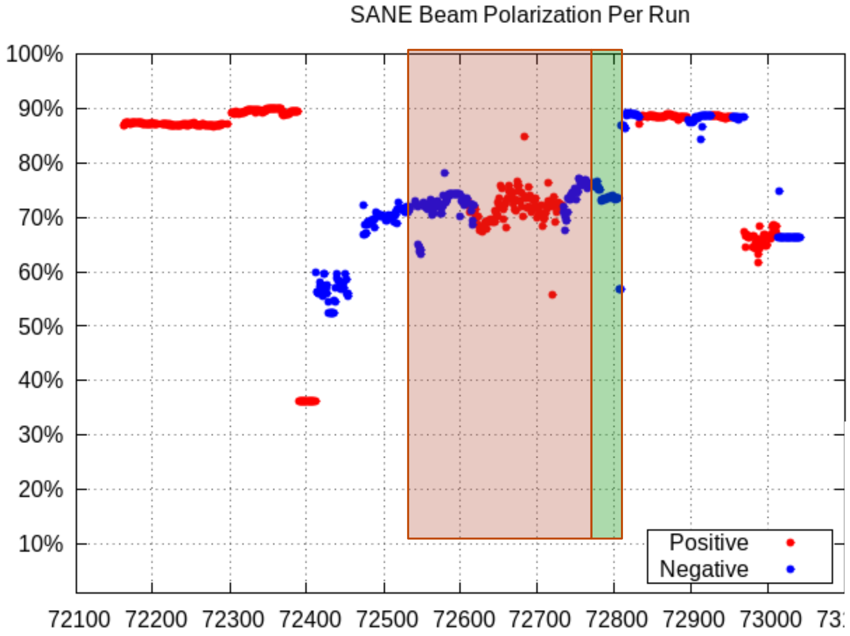
Dilution Factor,

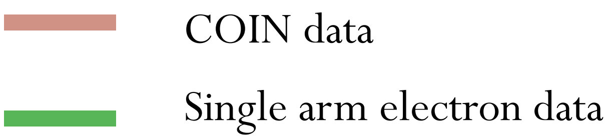
$$F = \frac{Yield_{Data} - Yield_{MC(N+He)}}{Yield_{Data}}$$

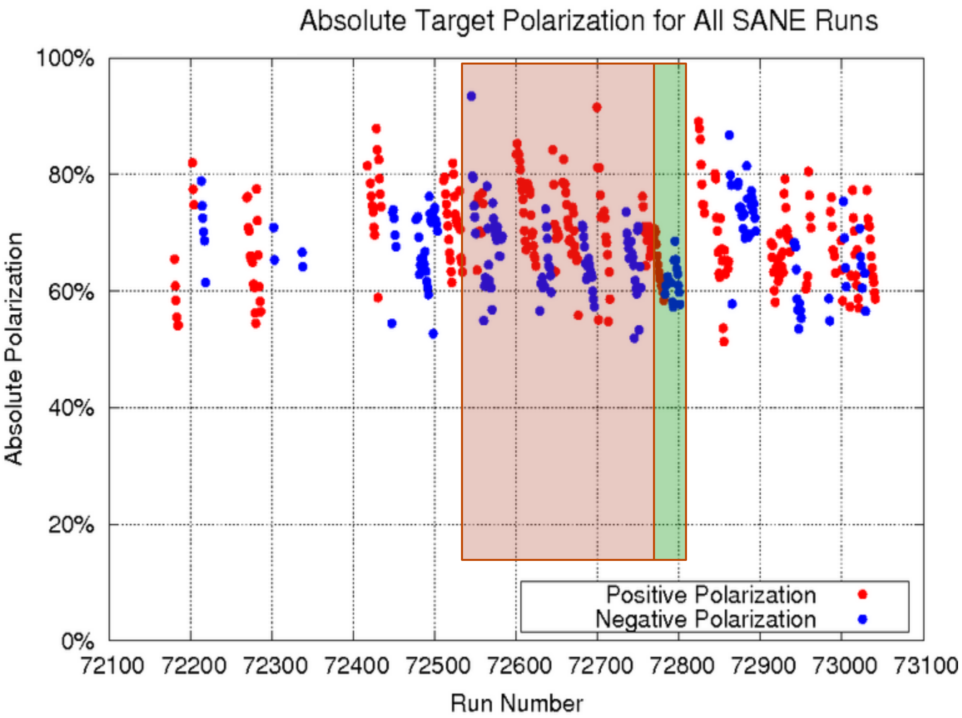
- We have taken data using both NH3 targets, called NH3 top and NH3 bottom.
- NH3 crystals are not uniformly filled in each targets which arise two different packing fractions and hence two different dilution factors.



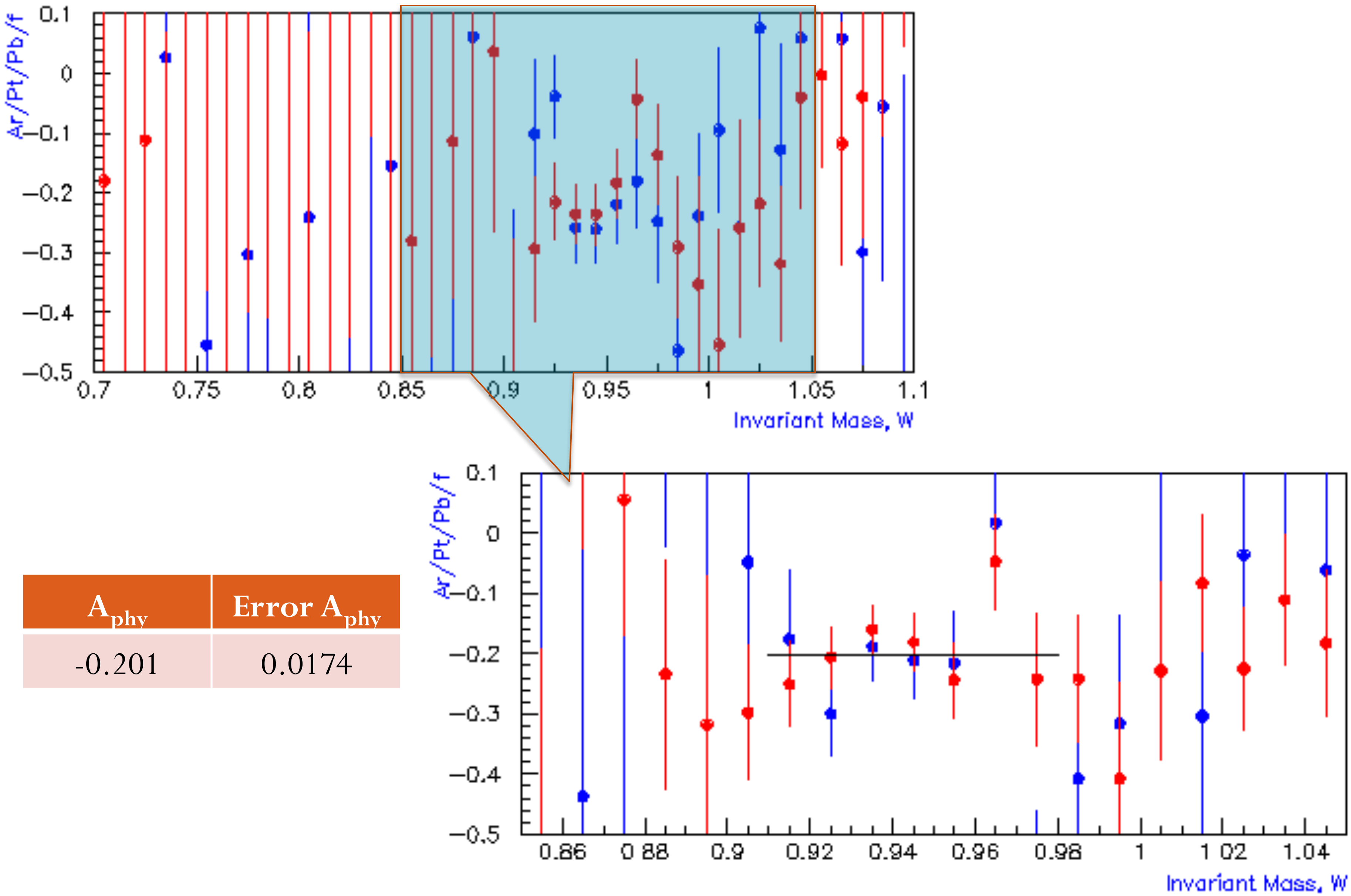
Beam / Target Polarizations







▪ The Physics Asymmetry (**Preliminary**)



A_{phy}	Error A_{phy}
-0.201	0.0174

The beam - target asymmetry, A_p

$$A_P = \frac{-br\sin\theta^*\cos\phi^* - a\cos\theta^*}{r^2 + c}$$

$$\frac{G_E}{G_M} = -\frac{b}{2A_p}\sin\theta^*\cos\phi^* + \sqrt{\frac{b^2}{4A_p^2}\sin^2\theta^*\cos^2\phi^* - \frac{a}{A_P}\cos\theta^* - c}$$

Using the exeperiment data at

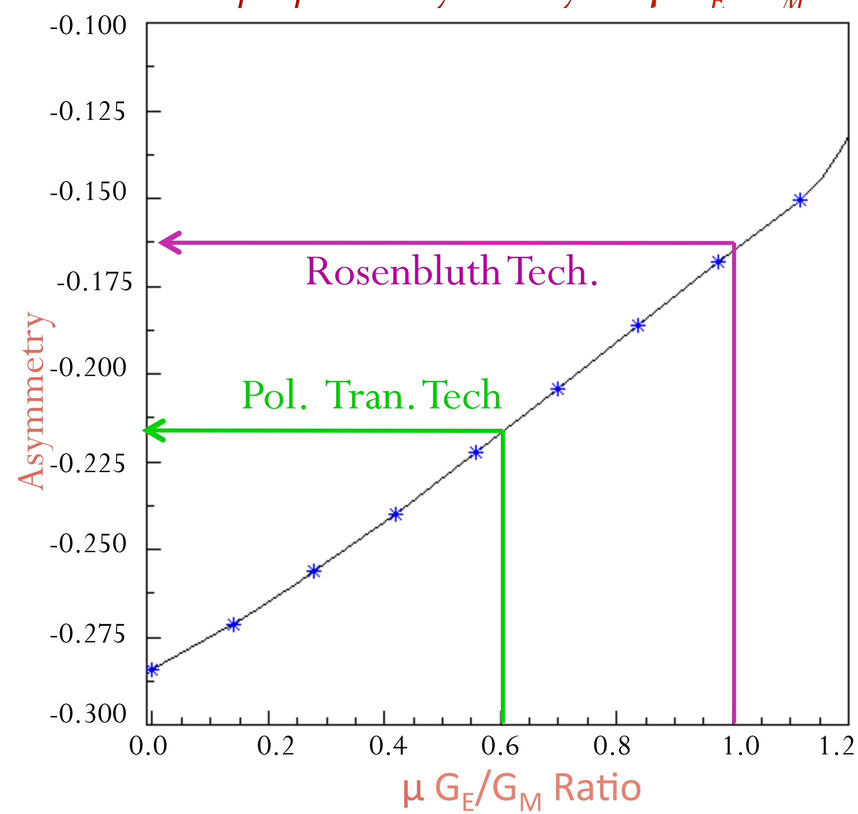
$Q^2 = 2.2\ (\mathrm{GeV/c})^2$

$\theta^* \approx 34.55°$ *and* $\phi^* = 180°$

From the HMS kinematics, $r^2 << c$

$$A_P = \frac{-b\sin\theta^*\cos\phi^* r}{c} - \frac{a\cos\theta^*}{c}$$

The projected asymmetry vs $\mu G_E/G_M$



Using the exeperiment data at Q^2=2.2 $(GeV/c)^2$ and by knowing the Ap=-0.201,

$$r = \left(\frac{G_E}{G_M}\right) = 0.2416$$

$$\mu r = \mu\left(\frac{G_E}{G_M}\right) = 0.674$$

Where , μ – Magnetic Moment of the Proton=2.79

- Error propagation from the experiment

$$A_P = \frac{-b\sin\theta^* \cos\phi^* r}{c} - \frac{a\cos\theta^*}{c}$$

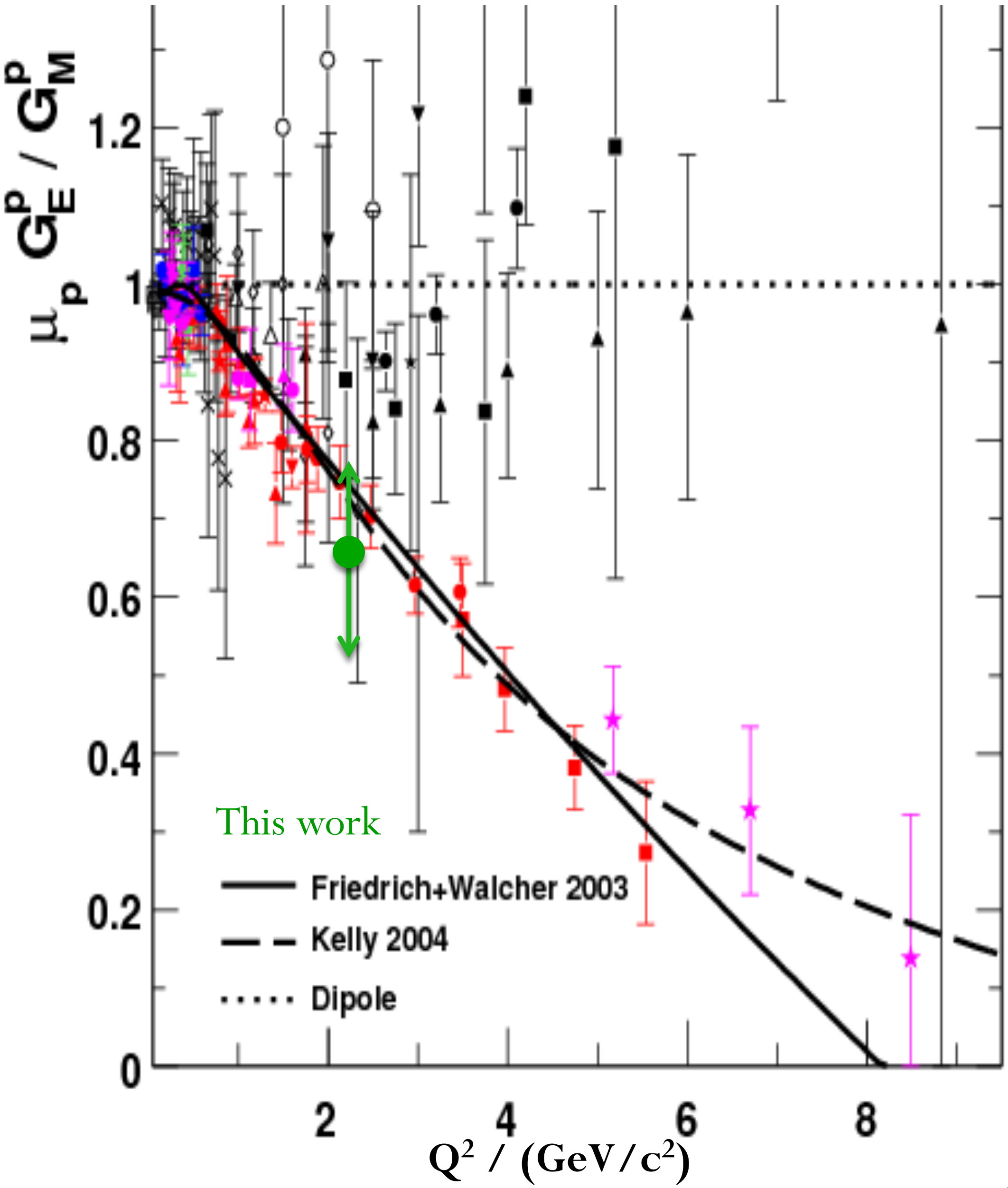
$$\Delta r = \Delta\left(\frac{G_E}{G_M}\right) = \left|\frac{c}{b\sin\theta^* \cos\varphi^*}\right| \Delta A_p$$

By knowing the Δ Ap=0.017,

$$\Delta(\mu r) = \Delta\left(\mu\frac{G_E}{G_M}\right) = 0.13$$

Preliminary …..

$\mu\, G_E/G_M$	$\Delta(\mu\, G_E/G_M)$
0.674	0.13



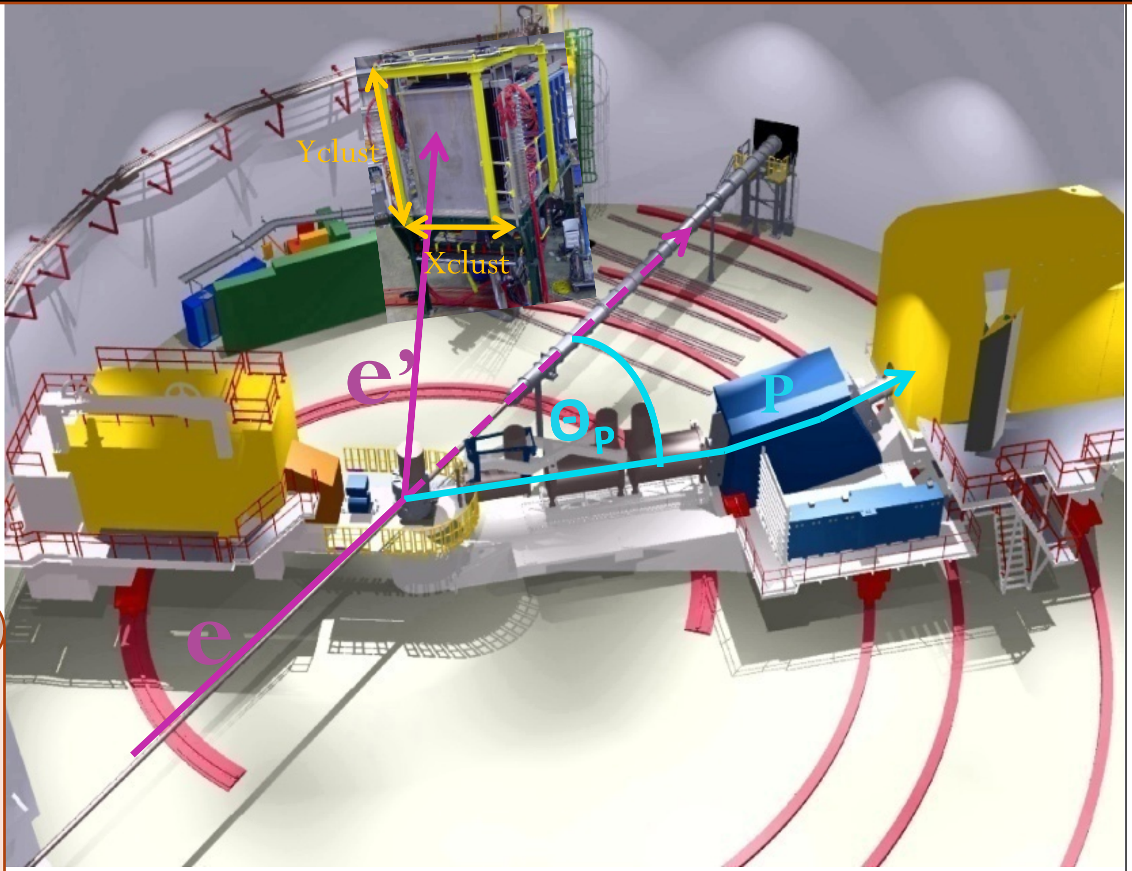
Coincidence Data
(Electrons in BETA and Protons in HMS)

<u>Definitions :</u>

X/Yclust - Measured X/Y positions on the BigCal

- *X = horizontal / in-plane coordinate*
- *Y = vertical / out – of – plane coordinate*

Eclust - Measured electron energy at the BigCal



By knowing
the energy of the polarized electron beam, E_B
and
the scattered proton angle, Θ_P

We can predict the
- X/Y coordinates - X_HMS, Y_HMS and (Target Magnetic Field Corrected)
- The Energy - E_HMS

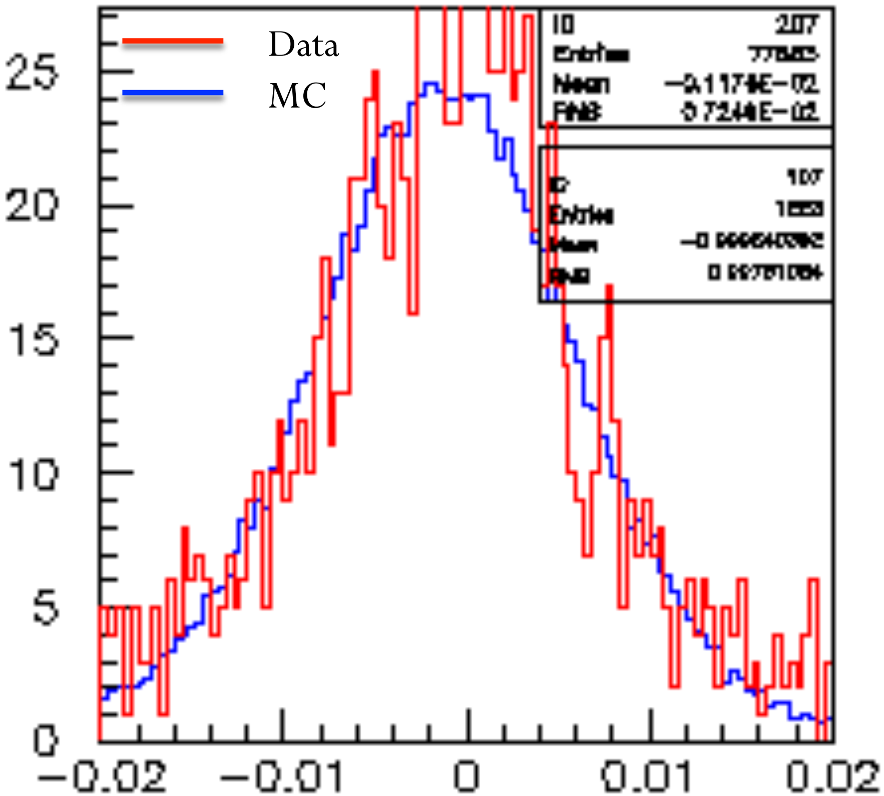
of the coincidence electron on the BigCal

Elastic Kinematics

(From HMS Spectrometer)

Spectrometer mode	Coincidence	Coincidence	Single Arm
HMS Detects	Proton	Proton	Electron
E Beam GeV	4.72	5.89	5.89
P_{HMS} GeV/c	3.58	4.17	4.40
Θ_{HMS} (Deg)	22.30	22.00	15.40
Q^2 $(GeV/c)^2$	5.17	6.26	2.20
Total Hours (h)	~40 (~44 runs)	~155 (~135 runs)	~12 (~15 runs)
e-p Events	~113	~1200	-

Fractional momentum difference



dPel_hms %

$$dPel\_hms = \frac{P_{HMS} - P_{Cal}}{P_{cent}}$$

$$P_{Cal} = \sqrt{\left(\nu^2 + 2M\nu\right)}$$

$$\nu = \frac{Q^2}{2M}$$

$$Q^2 = \frac{4M^2E^2\cos^2\theta}{M^2 + 2ME + E^2\sin^2\theta}$$

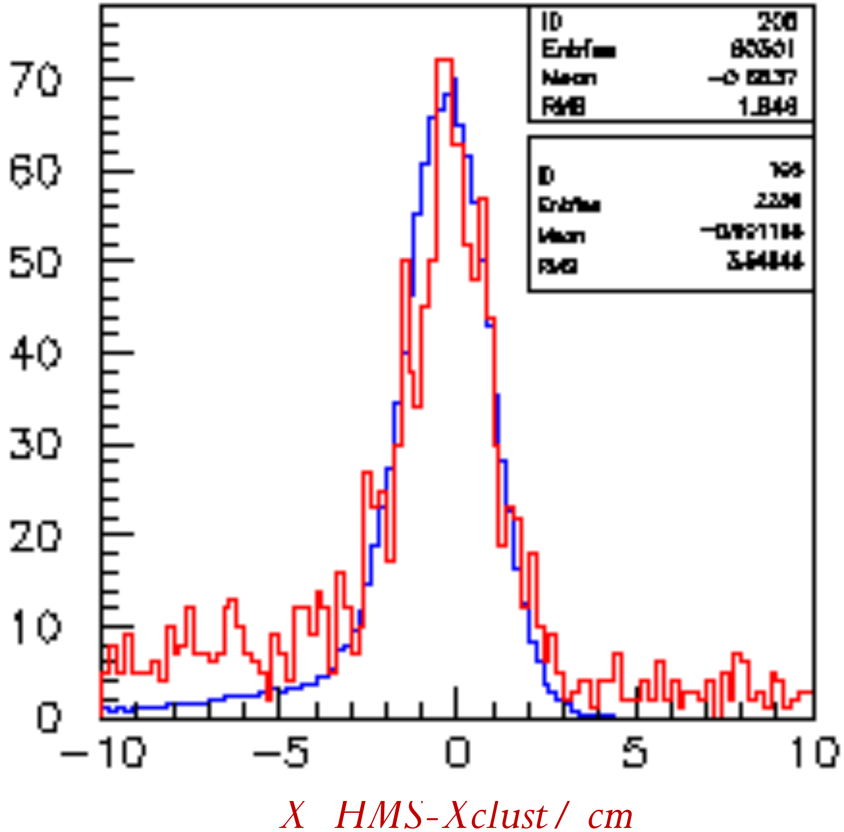
P_{HMS} – *Measured proton momentum by HMS*

P_{cal} - *Calculated proton momentum by knowing the beam energy, E and the proton angle,* Θ

P_{cent} – *HMS central momentum*

X/Y position difference

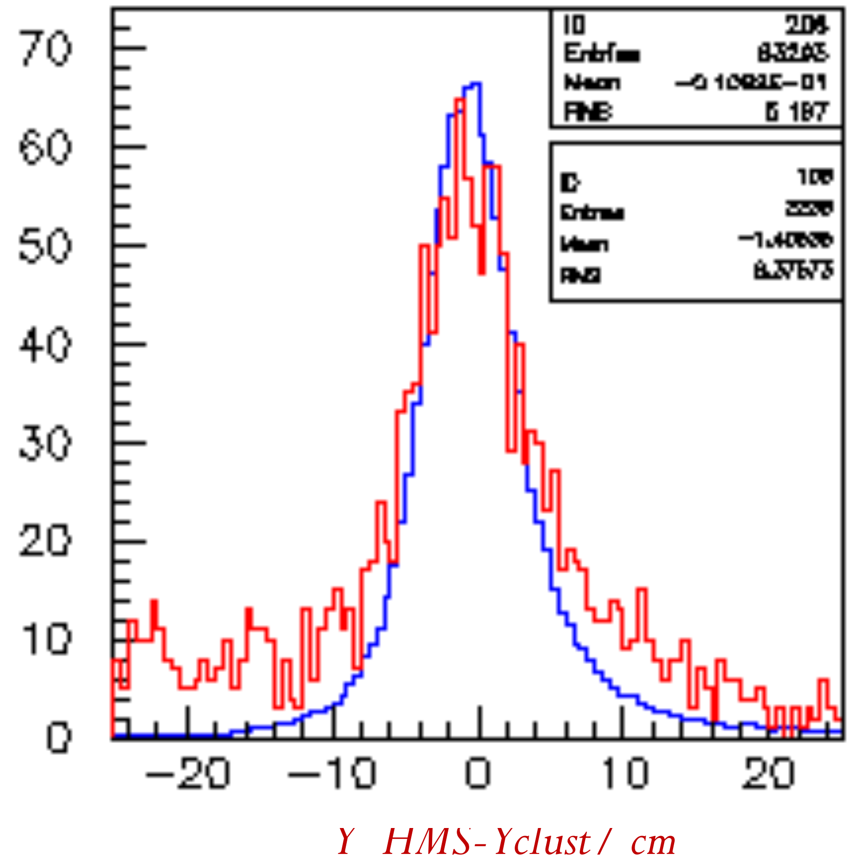
X position difference



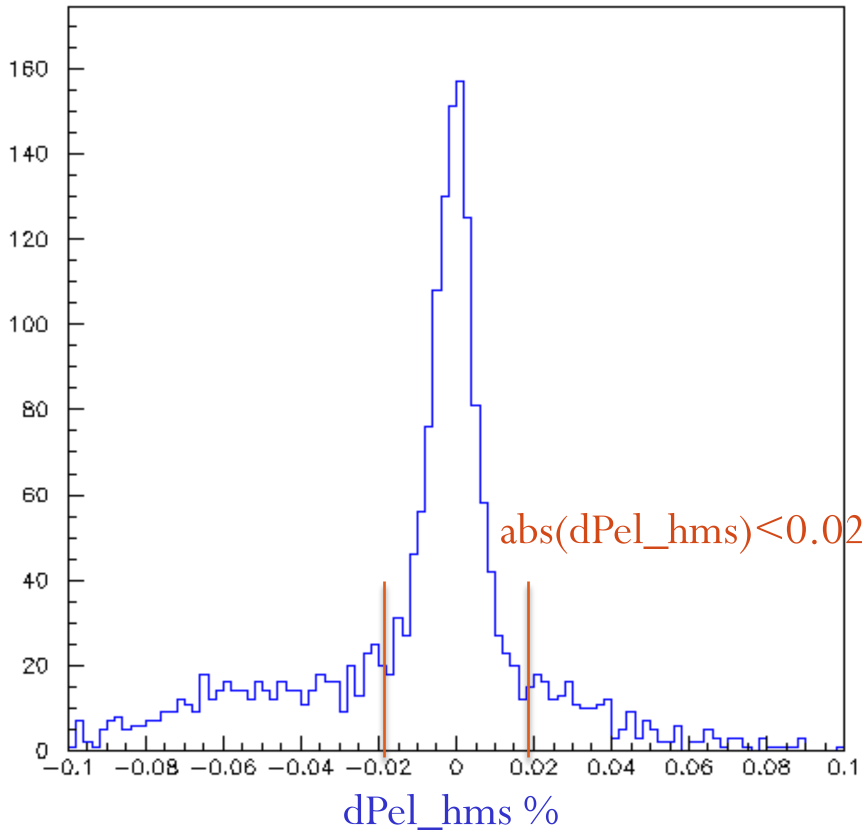
Data

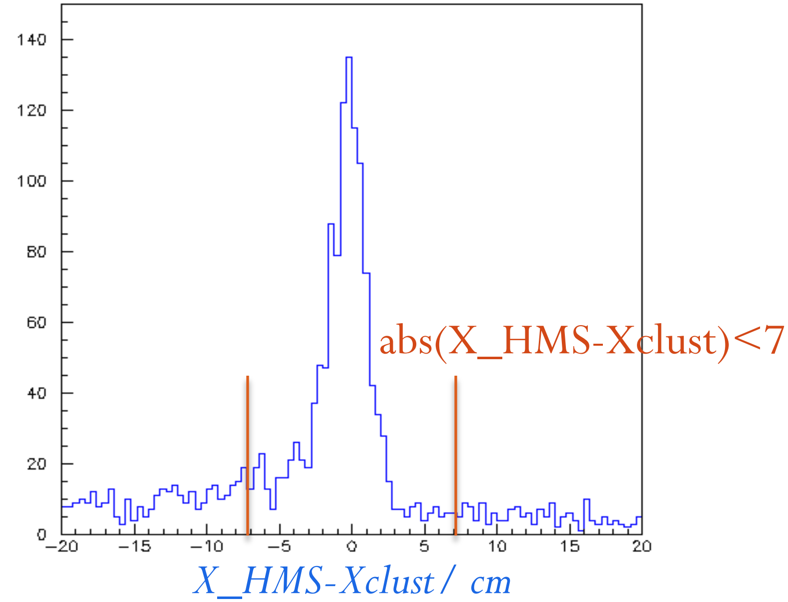
MC

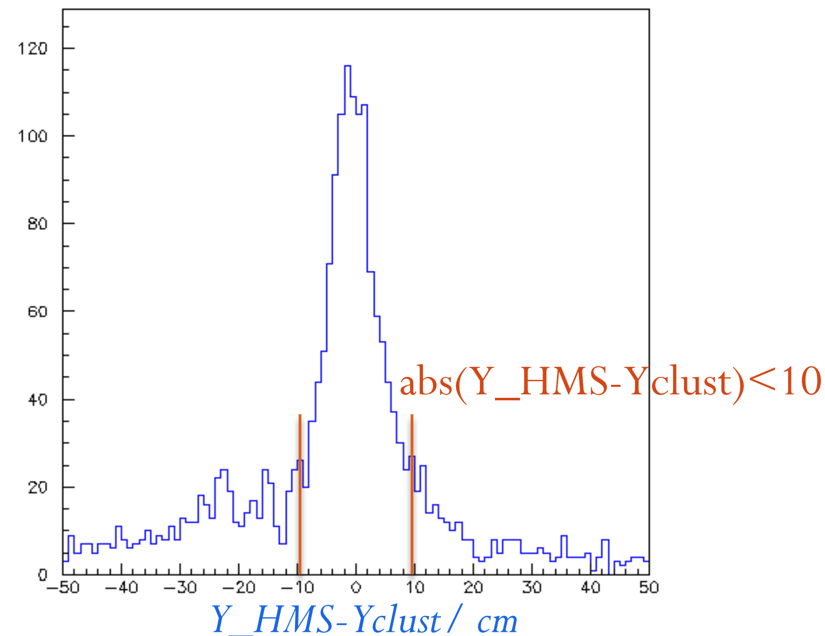
Y position difference



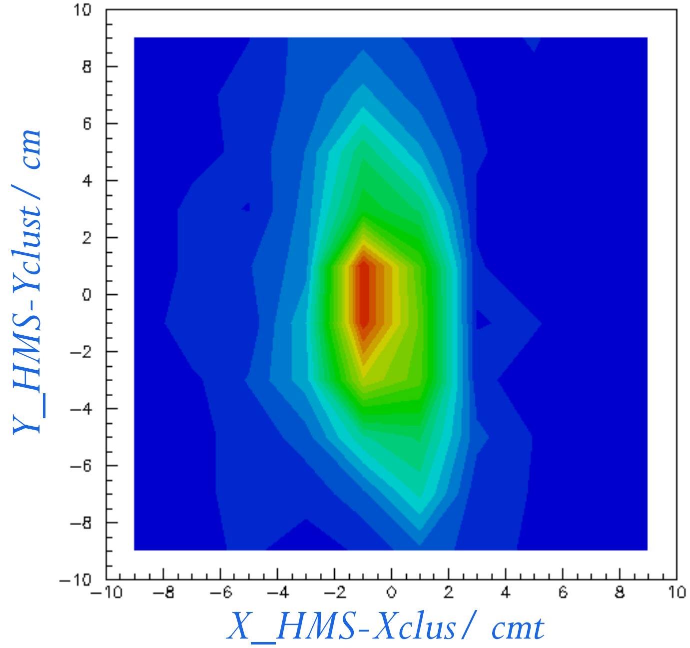
Applied the coincidence cuts

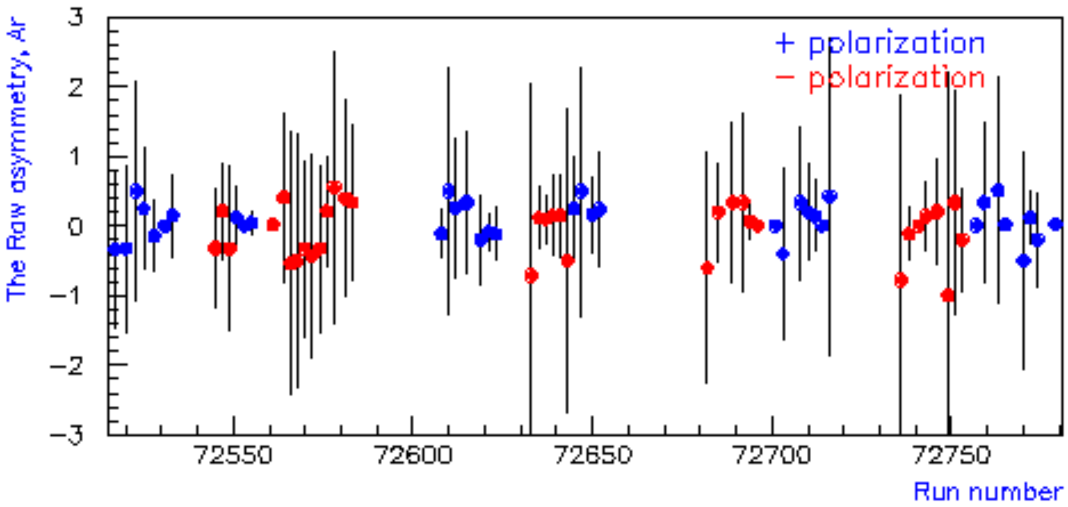






Extract the asymmetries





Need

dilution factor, f

in order to determine the

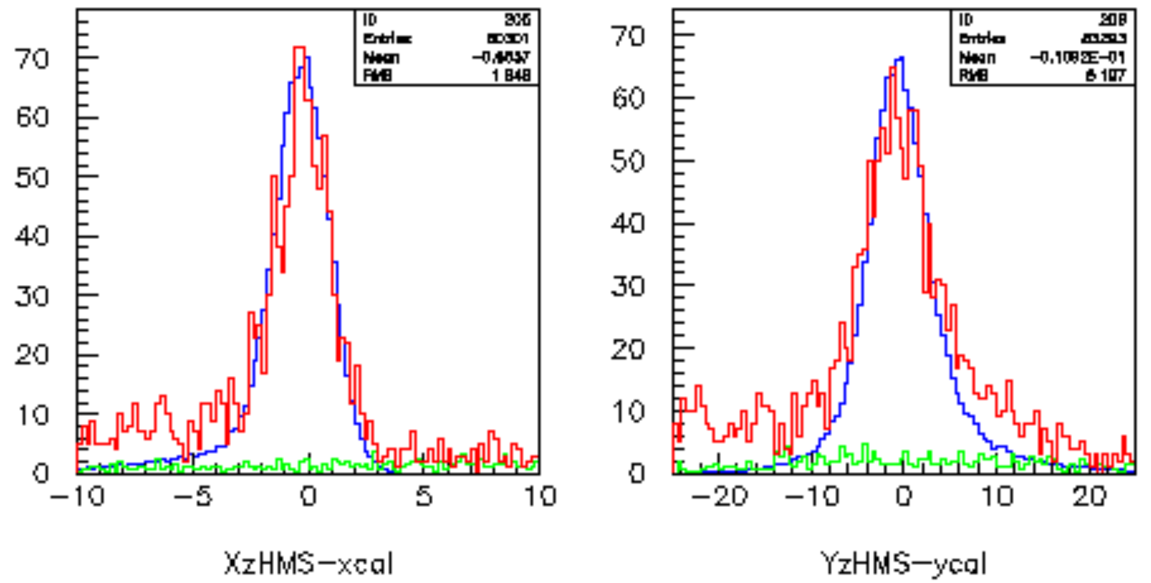
physics asymmetry,

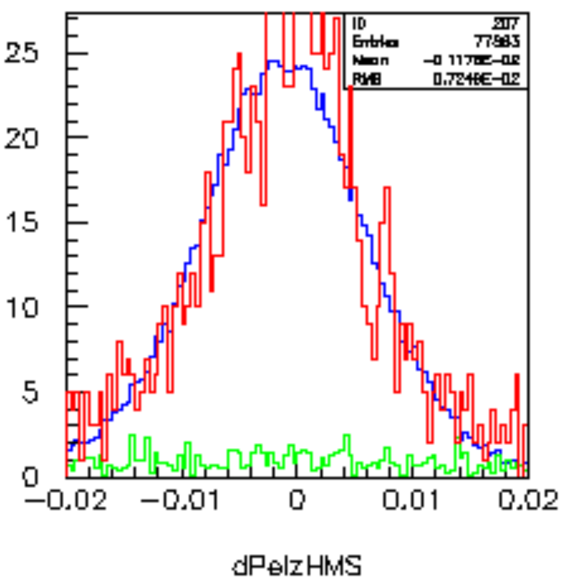
$$A_p = \frac{A_r}{fP_BP_T} + N_C$$

and G^p_E / G^p_M

(*at* Q^2=6.26 (GeV/c)^2)

Estimate the background





- Use Carbon simulation.
- This is an effort to determine the dilution factor.
- Still working on it.

Conclusion

- Measurement of the beam-target asymmetry in elastic electron-proton scattering offers an independent technique of determining the G_E/G_M ratio.
- This is an 'explorative' measurement, as a by-product of the SANE experiment.
- Extraction of the G_E/G_M ratio from single-arm electron data are shown.
- The preliminary data point at 2.2 $(GeV/c)^2$ is very consistent with the recoil polarization data (falls even slightly below it)
- The preliminary data points from the coincidence data at 5.17, 6.26 $(GeV/c)^2$ will become available soon.

SANE Collaborators:

Argonne National Laboratory, Christopher Newport U., Florida International U., Hampton U., Thomas Jefferson National Accelerator Facility, Mississippi State U., North Carolina A&T State U., Norfolk S. U., Ohio U., Institute for High Energy Physics, U. of Regina, Rensselaer Polytechnic I., Rutgers U., Seoul National U., State University at New Orleans ,Temple U.,Tohoku U., U. of New Hampshire, U. of Virginia, College of William and Mary, Xavier University of Louisiana, Yerevan Physics Inst.

Spokespersons: S. Choi (Seoul), M. Jones (TJNAF), Z-E. Meziani (Temple), O. A. Rondon (UVA)

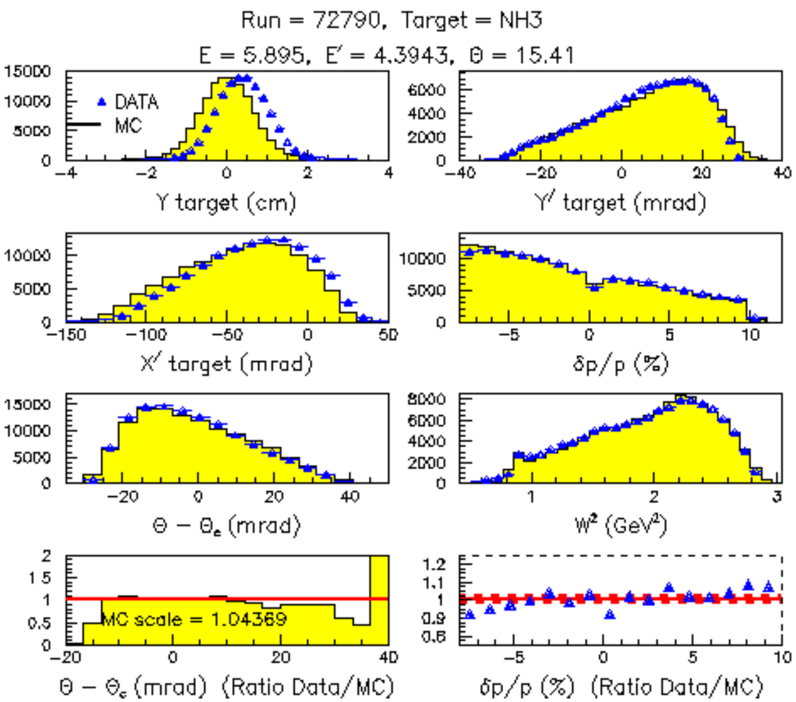
Thank You

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Backup Slides

MC with NH3

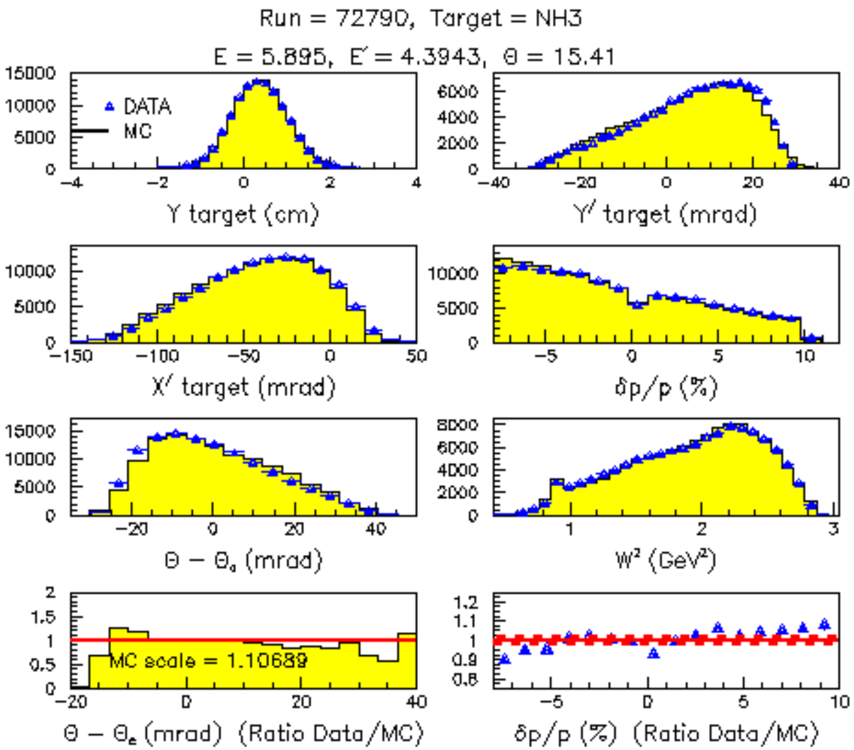
- Generated N, H and He separately.
- Added Al come from end caps and 4K shields as well.
- Calculated the MC scale factor using the data/MC luminosity ratio for each target type.
- Added all targets together by weighting the above MC scale factors.
- Used 60% packing fraction.



Srast x – Horizontal beam position (pointing beam left)

Srast y – Verticle beam position (pointing up)

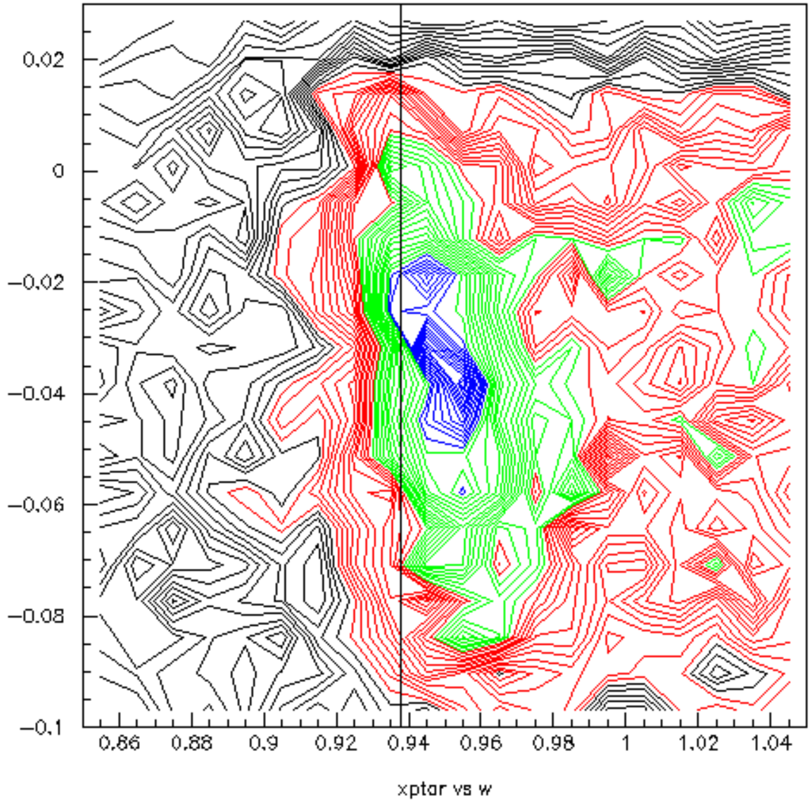
- Adjust acceptance edges in
  Ytar and y' from adjusting srast x offset



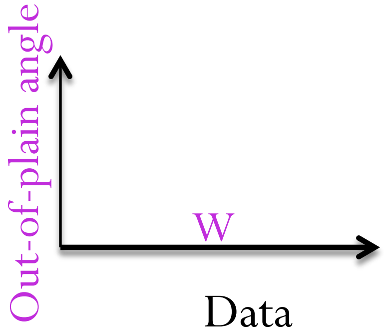
Srast x offset=-0.4 cm

Srast x offset= 0.0 cm

But shows the xptar vs w correlation.

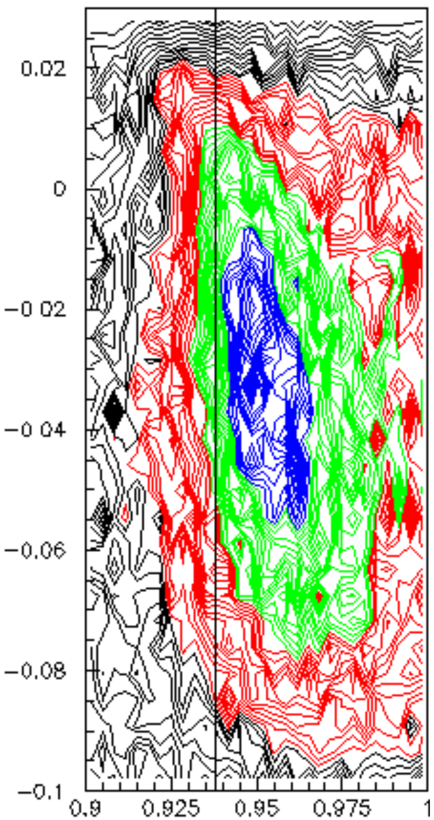


Check the srast x offsets with MC



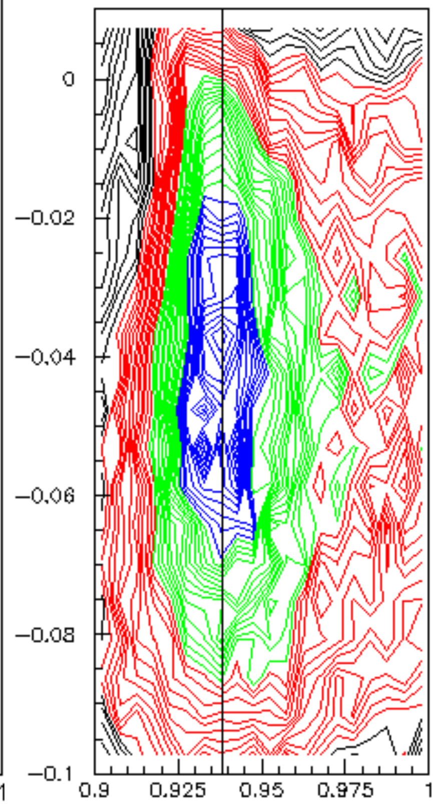
Data

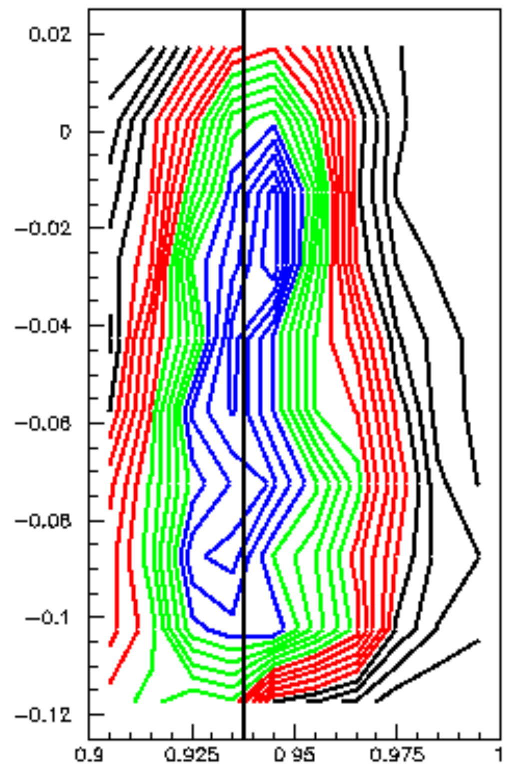
Srast x=0.2 cm



Data

Srast x=-0.9 cm

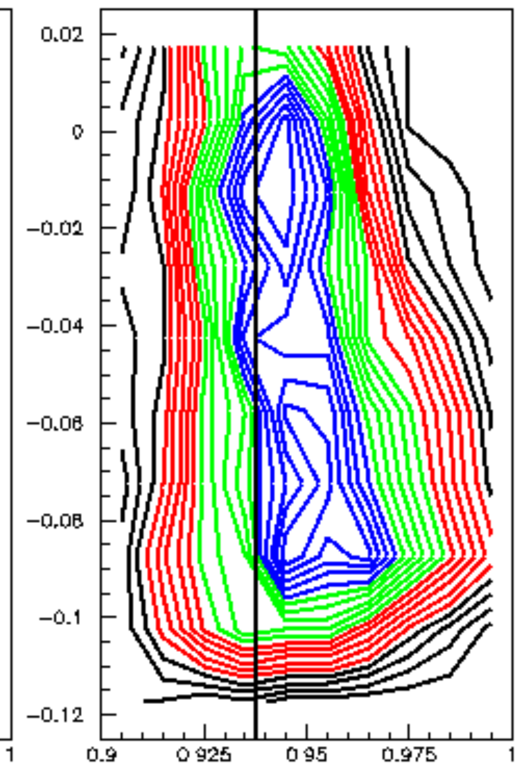




MC

Gen. Srast x=-0.2 cm

Rec. Srast x=-0.2cm



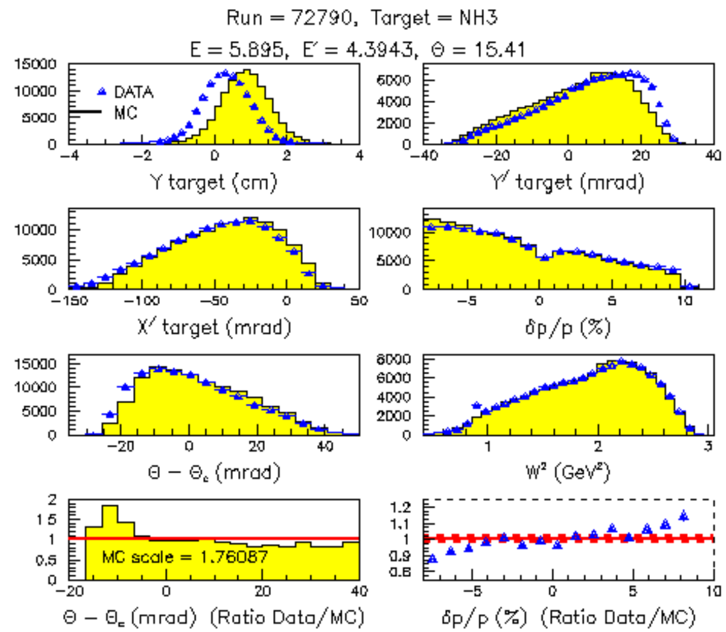
MC

Gen. Srast x=-0.9 cm

Rec. Srast x=0.2cm

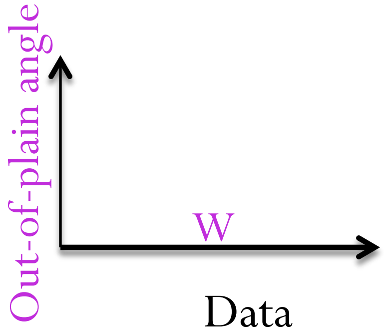
Srast x offset=-0.9 cm ? Too BIG

It does not match with the MC either.



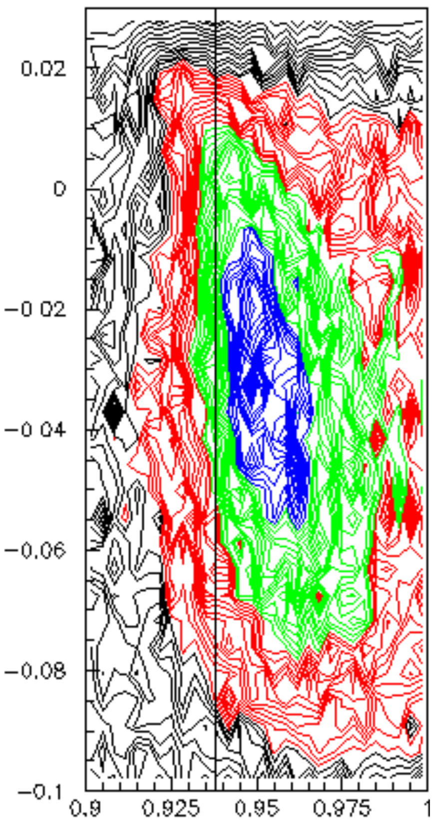
Therefore, this xptar vs w correlation can be a combination of srast_x and something else……

Check the srast x offsets with MC



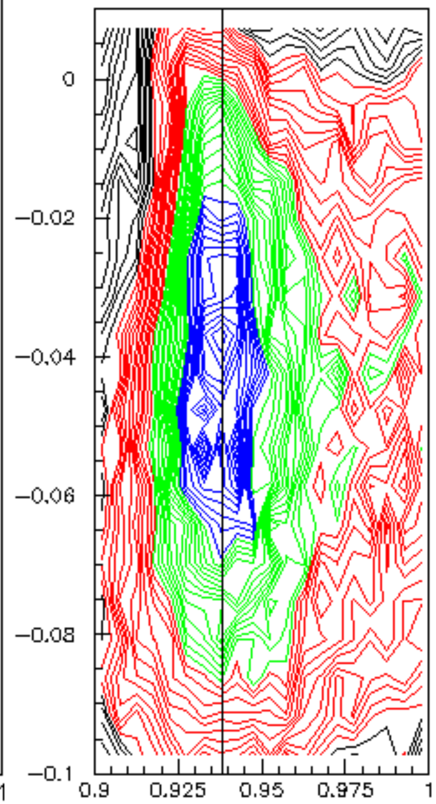
Data

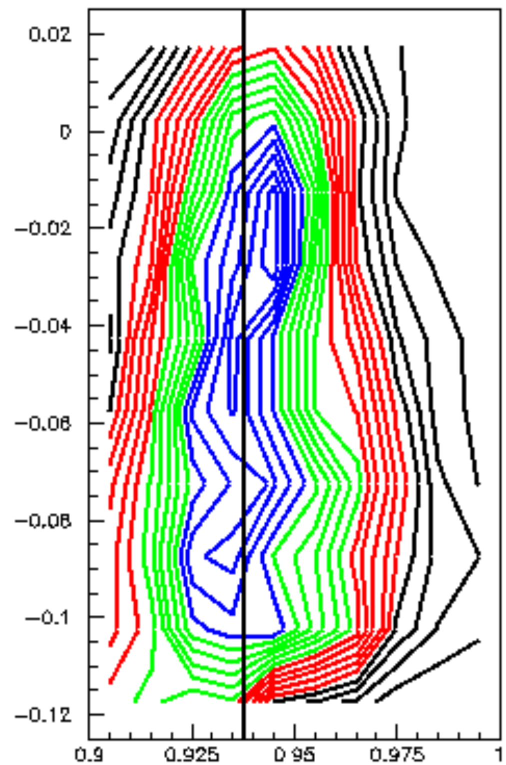
Srast x=0.2 cm



Data

Srast x=-0.9 cm

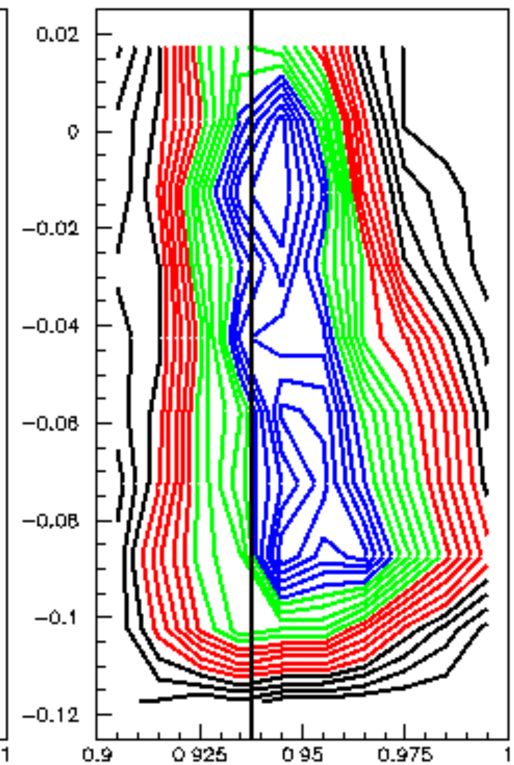




MC

Gen. Srast x=-0.2 cm

Rec. Srast x=-0.2cm



MC

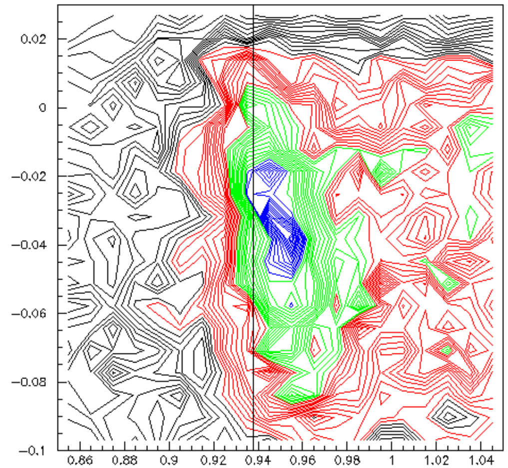
Gen. Srast x=-0.9 cm

Rec. Srast x=0.2cm

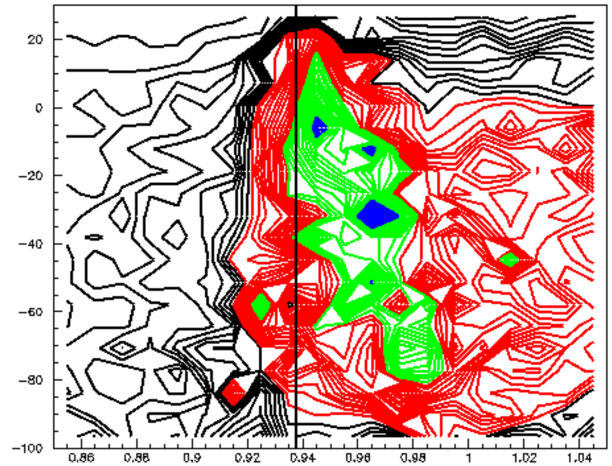
Introduced an azim. Angle correction

We assume that the target magnetic field is symmetric around the target.
In practically, It might not.
So, Introduced the Out-Of-Plane angle (azimuthal angle) dependence field correction.
B_corr = (azim-az0)*az_corr
Applied the field correction on MC only for the forward direction and changed the parameters “az0” and “az_corr” to make the same xptar vs w correlation as seen on the data.
B_scale = 5.003/(5.003+abs(B_corr))
B(3) = B(3)+B_corr !B(3) is along Z direction of the field
B(3) = B(3)*B_scale
B(1) = B(1)-B_corr !B(1) is x component pointing down
B(1) = B(1)*B_scale

Then use that correction on data.



xptar vs w



hsxptar vs W MC

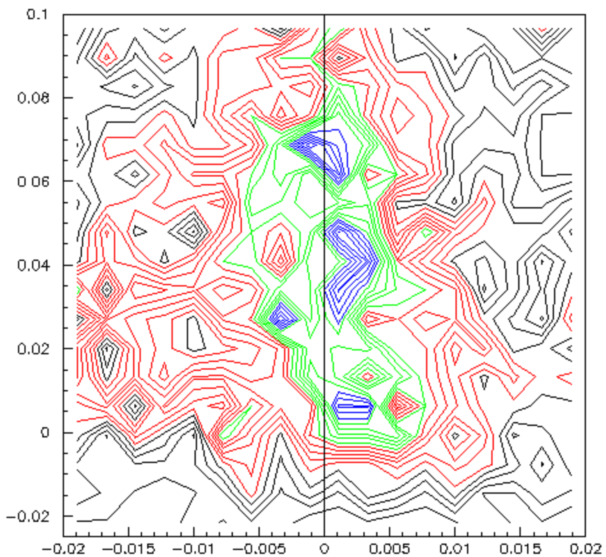
Determine the azimuthal angle correction

Because the azimuthal angle correction depend on the horizontal angle as well,
We need to find the different correction parameters for the HMS and BETA.

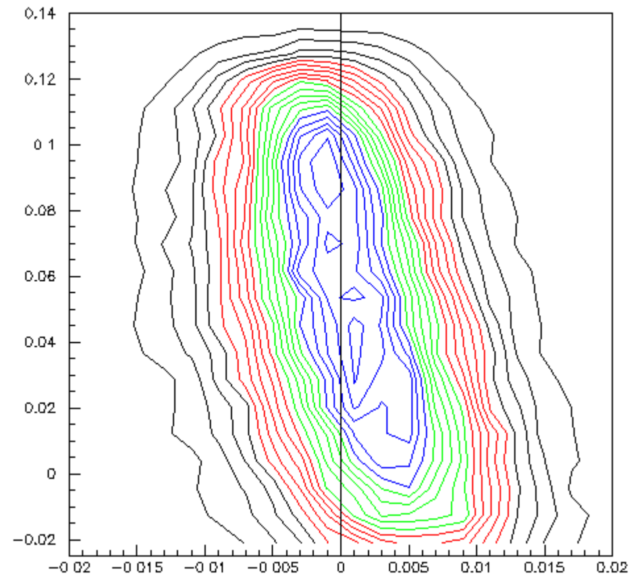
For HMS

By looking at the xptar vs dpel_hms correlation on the data, make the same correlation on SIMC by using the azimuthal angle correction only for the forward direction and changing the "azo" and "az_corr" parameters.

Data



SIMC



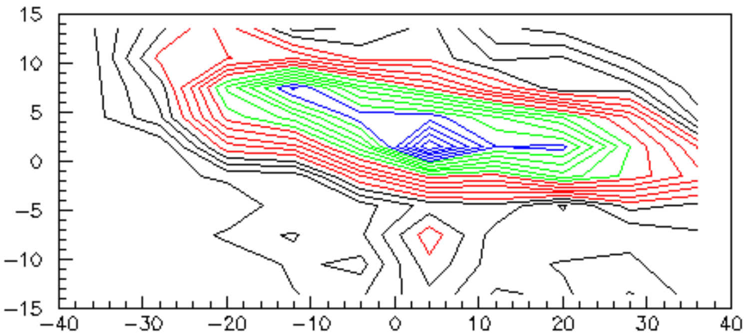
Apply the correction for the HMS side for the data

For BETA

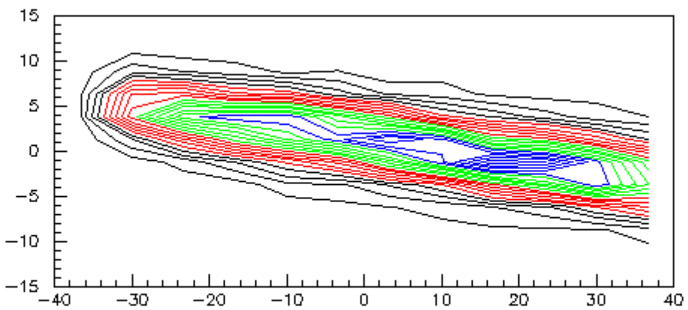
Looked at the ydiff vs y_clust correlation on the data. Use the azimuthal angle correction on HMS side.

Make the same correlation on SIMC by changing the “az0” and “az_corr” parameters for BETA side.

Data

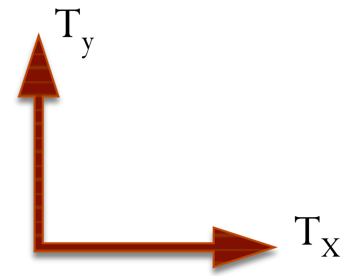


SIMC



Apply the correction for the HMS side for the data

Calibrate the EPICS T_x and T_y



- EPICS T_x – BPM horizontal (cm)
- EPICS T_y - BPM vertical (cm)

$$T_X + offset_X = srast_X$$
$$T_Y + offset_Y = srast_Y$$

$$-2.361 + offset_X = -4.00(mm)$$
$$+0.580 + offset_Y = +1.00(mm)$$
$$offset_X = -1.64(mm)$$
$$offset_Y = +0.42(mm)$$

- Used the above EPICS calibration constants, $offset_{x/y}$ to determine the real beam positions, $srast_{x/y}$ for the other runs for the known T_X and T_Y.

$$T_X - 1.64 = srast_X$$
$$T_Y + 0.42 = srast_Y$$

$$srast_X = ?$$
$$srast_Y = ?$$

NOTE:

EPICS calibration constants, *offset*$_{x/y}$ change with the magnetic field

The girder that hold the BPM is moved when going from perp to parallel.

- **In the perp configuration,**

  the electron beam is deflected by different amounts at different beam energies by the target magnetic field and so the girder position had changed. so, It gives different epics Tx and Ty at different beam energies and hence we should have different epics calibration constants.

- **In the parallel configuration,**

  the beam is not deflected by the target field and so the girder position remains same at different beam energies. Therefore, the epics Tx and Ty and hence the epics calibration constants are the same at different beam energies.

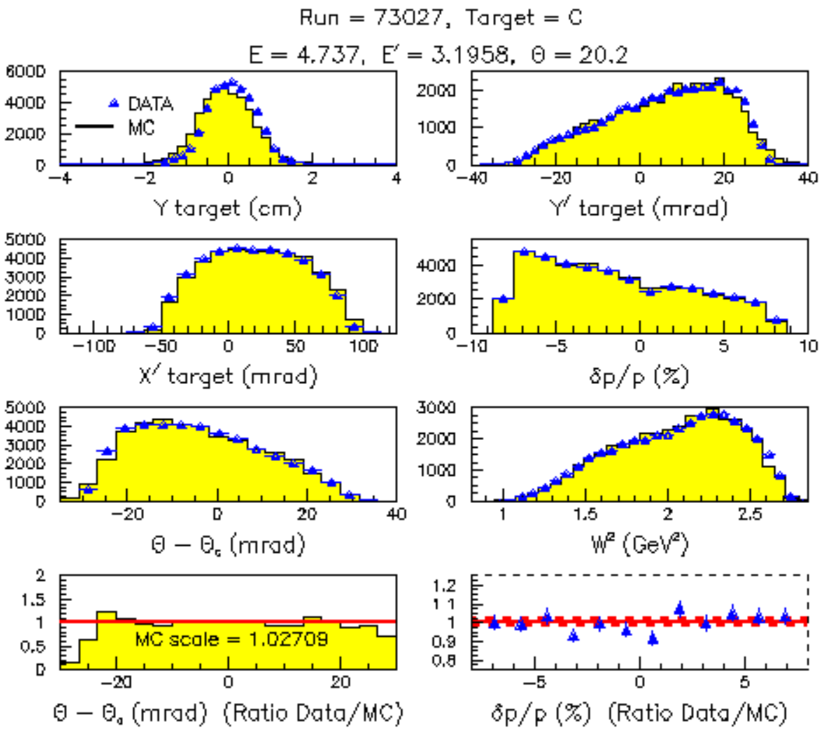
Parallel field Magnetic Configuration

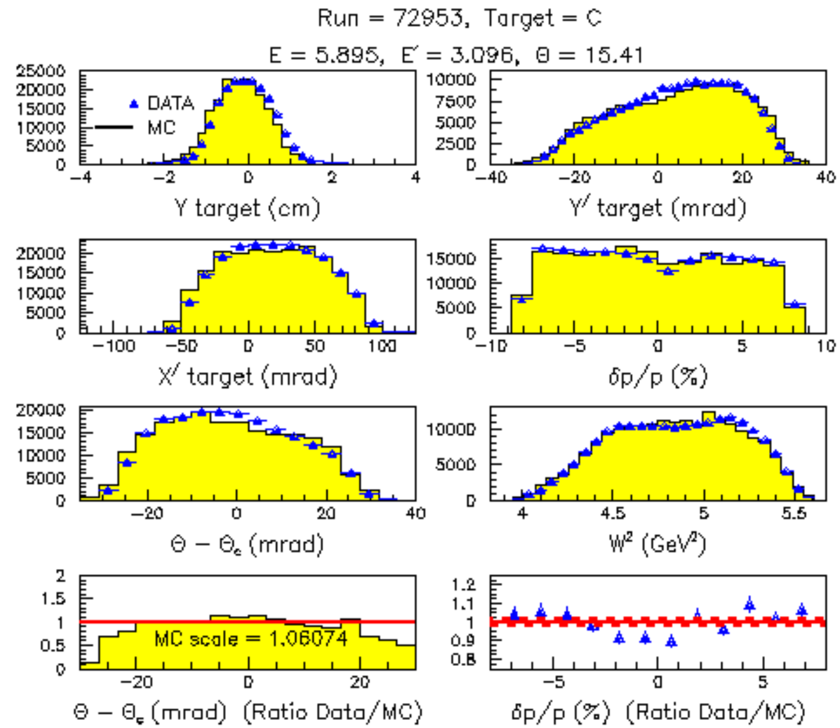
C run 73027 (No He)
(ebeam = 4.733 GeV, P=3.2 GeV/C,
θ =20.2^0)

C run 72953 (ebeam = 5.895 GeV,
P=3.1 GeV/C, θ=15.41^0)

$srast_x$ = 0.10 cm
$srast_y$ = -0.10 cm

$srast_x$ = 0.18 cm
$srast_y$ = -0.02 cm

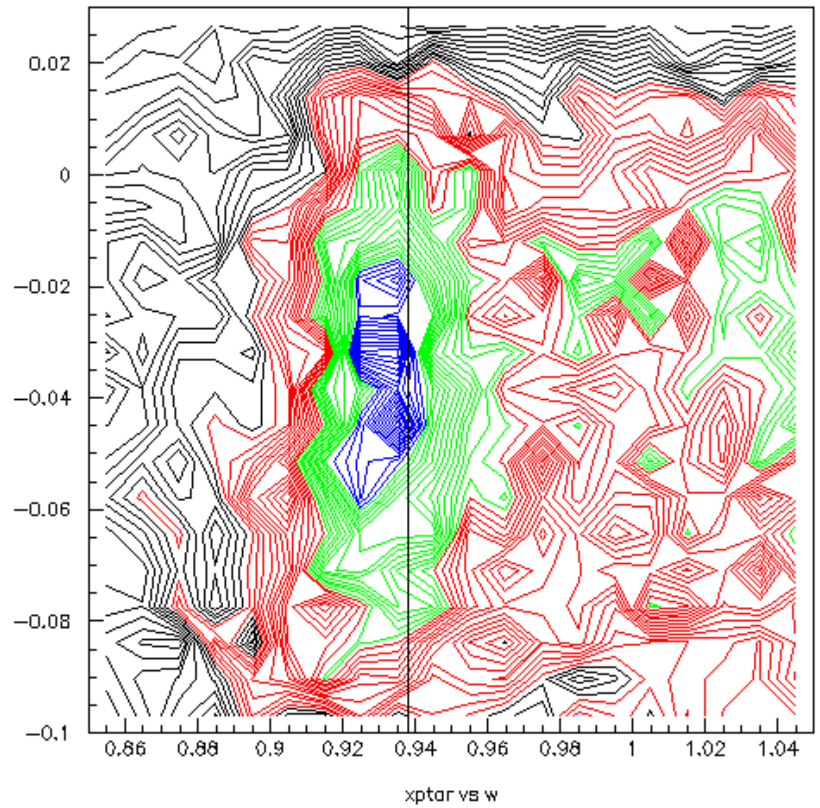


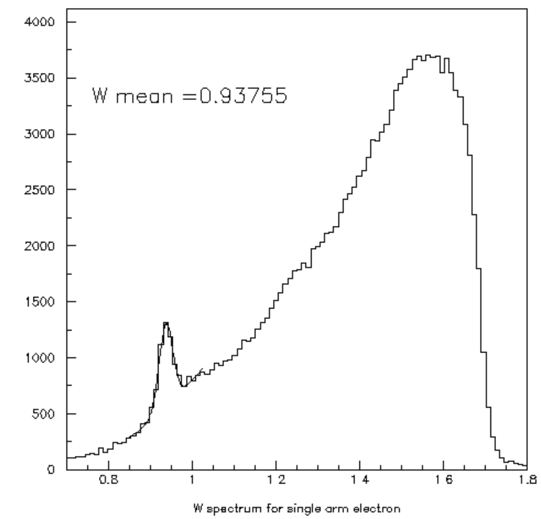


The azimuthal angle correction fix the xptar vs w correlation on the data.

But, w peak is shifted. (~0.93 GeV)
Changed srast_y offset to bring the W peak to 0.938 GeV

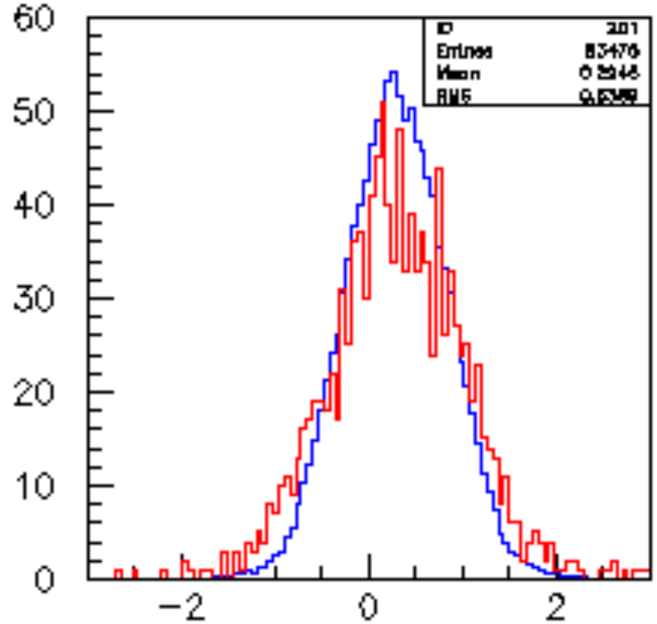
Srast y offset=0.1 cm





Find the beam offsets

Changed the srast_x offsets to match ‘hsytar” of data to SIMC each other.



Changed the srast_y offsets to match ‘dpel_hms” of data to SIMC each other.

$$srast_x = -0.25 \text{ cm}$$
$$srast_y = -0.20 \text{ cm}$$

Beam Time

	Energy GeV	Θ_N	Time (Proposal FOM h) Proposal	Actual	Fraction
Calibration	~~2.4~~	~~off, 0 ,180~~	~~47~~	~~25~~	~~53%~~
Production	4.7	180	70	20	29%
	4.7	80	130	98	75%
	5.9	80	200	143	72%
	5.9	180	100	≥35	≥35%

	Proposal	Actual
Commissioning [calendar days]	14.0	99
Total [calendar days]	70.0	141