Measurement of the Proton Form Factor Ratio, G^P_E/G^P_M from Double Spin Asymmetries

Spin **A**symmetries of the **N**ucleon **E**xperiment

(E07-003)

Outline

- Introduction
- Physics Motivation
- Detector Setup & Polarized Target
- Data Analysis
- Future Work/Conclusion

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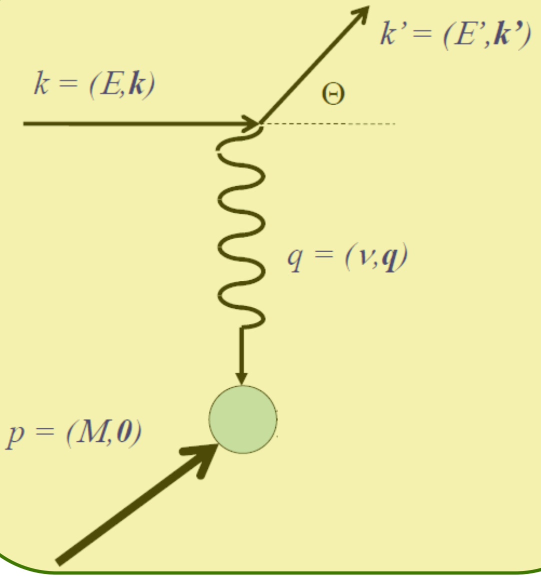
Introduction

From the elastic scattering of electron from the proton target,



The four-momentum transfer squared,

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

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

$G_E^P(q^2)$ and $G_M^P(q^2)$ →

- Elastic,
- Electric and Magnetic Form Factors (Sachs form factors)
- Provide the information on the spatial distribution of electric charge and magnetic moment within the proton
- Are functions of the four-momentum transfer squared, q^2

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

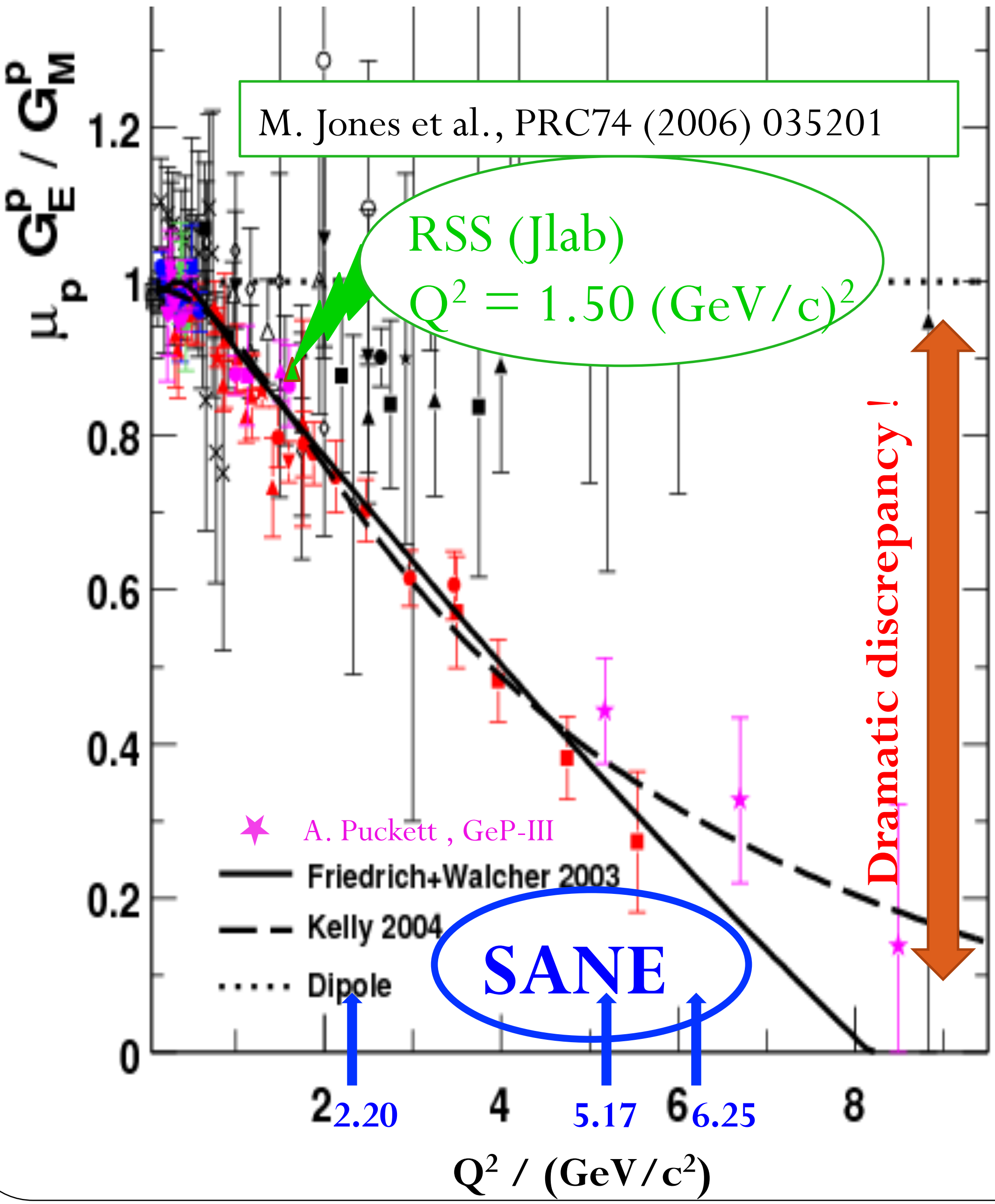
At $q^2 = 0$

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

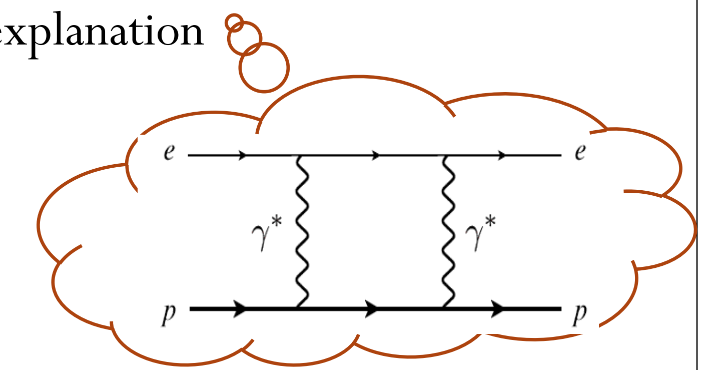
$$G_M(0) = \int \mu(\vec{r}) d^3\vec{r} = \mu_P = +2.79$$

$$\mu \, G_E^p / G_M^p = 1$$

Physics Motivation



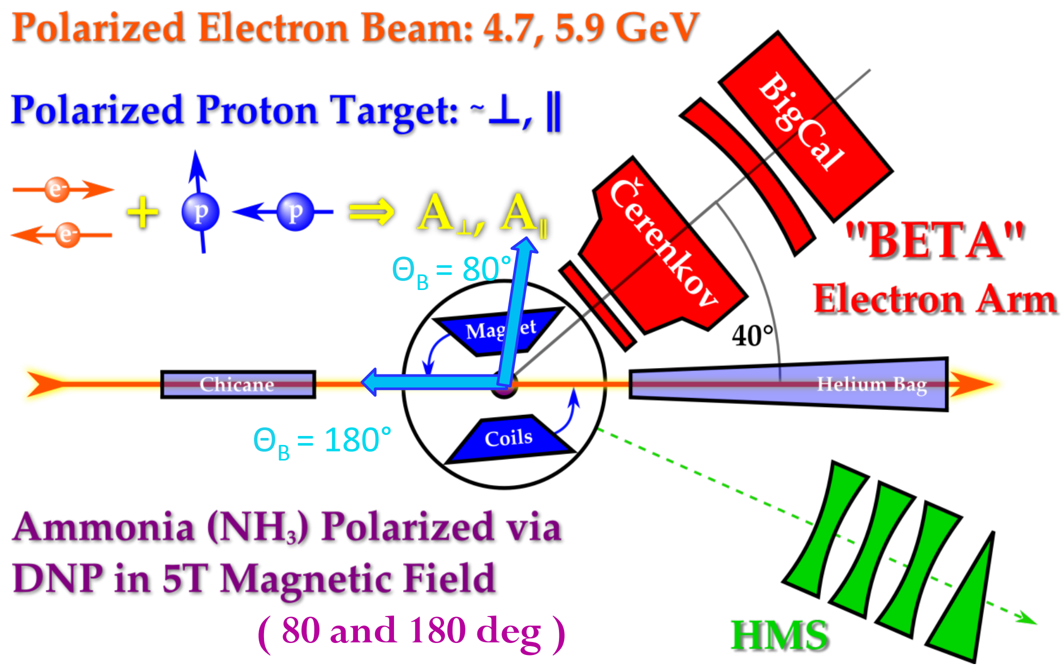
- Dramatic discrepancy between Rosenbluth and recoil polarization technique.
- Multi-photon exchange considered the best candidate for the explanation

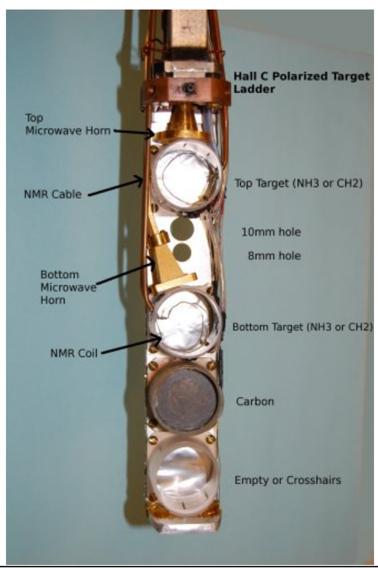


- **Double-Spin Asymmetry is an Independent Technique to verify the discrepancy**

Detector Setup/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





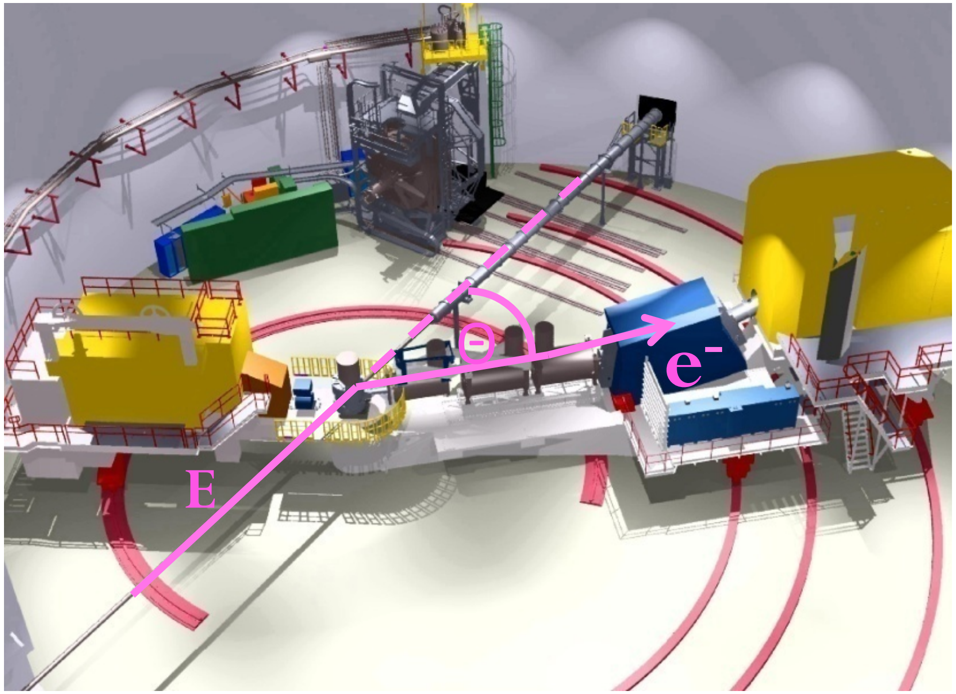
- Used only perpendicular magnetic field configuration for the elastic data
- Average target polarization is ~ 70 %
- Average beam polarization is ~ 73 %

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	~824	-

Electrons in HMS



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

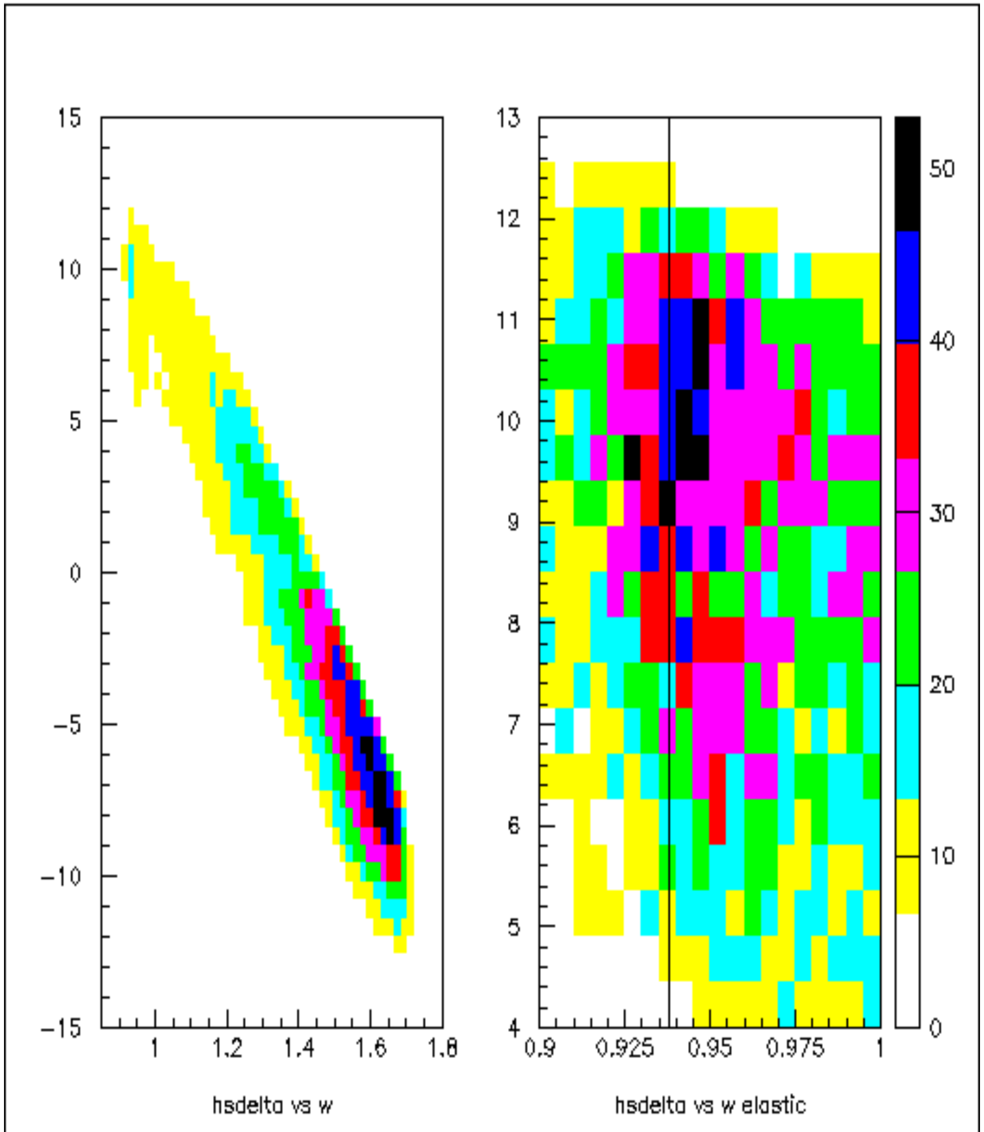
By knowing the incoming beam energy, E and the scattered electron angle, θ

$$E' = E \Big/ \left(1 + \frac{2E\sin^2\left(\theta/2\right)}{M}\right)$$

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

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

Momentum Acceptance



$$hsdelta = \left(\frac{P - P_c}{P_c} \right)$$

P -Measured momentum in HMS

P_c-HMS central momentum

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

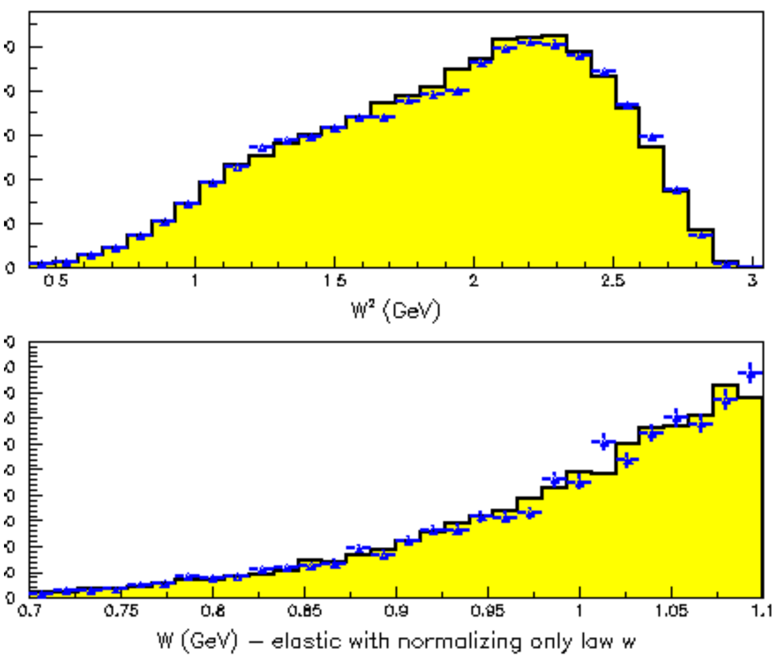
Because HMS reconstruction matrix elements work fine up to 10

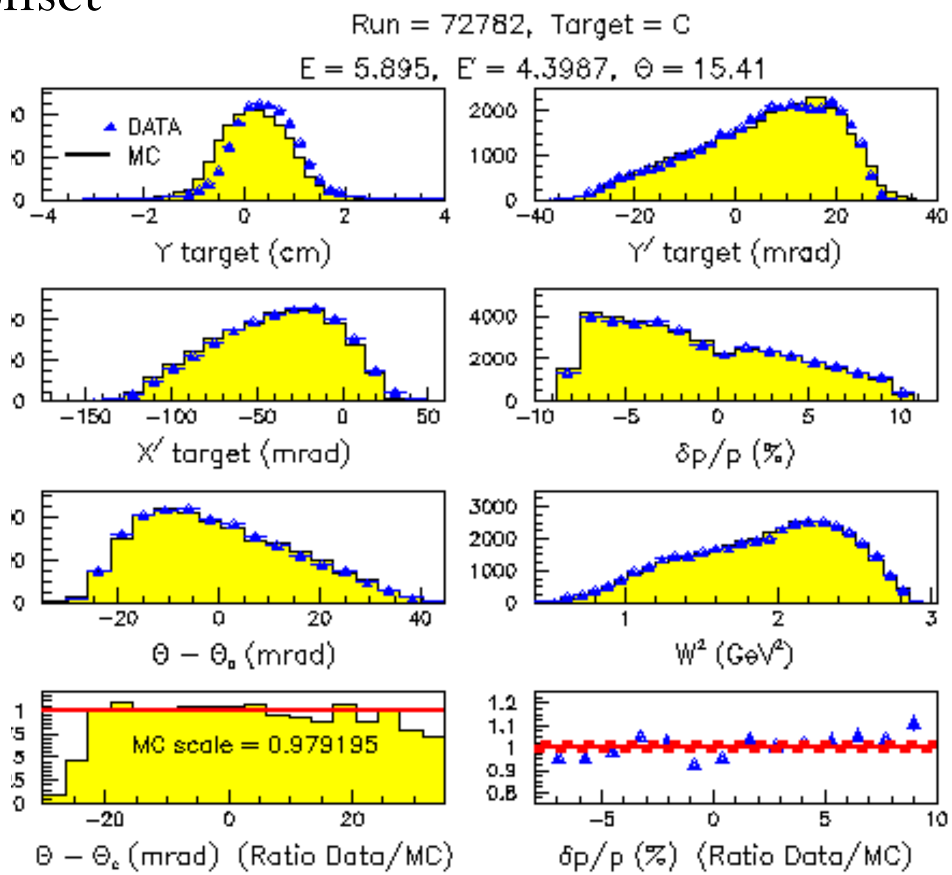
Use -8% < hsdelta <10%

- Find srast x/y offsets

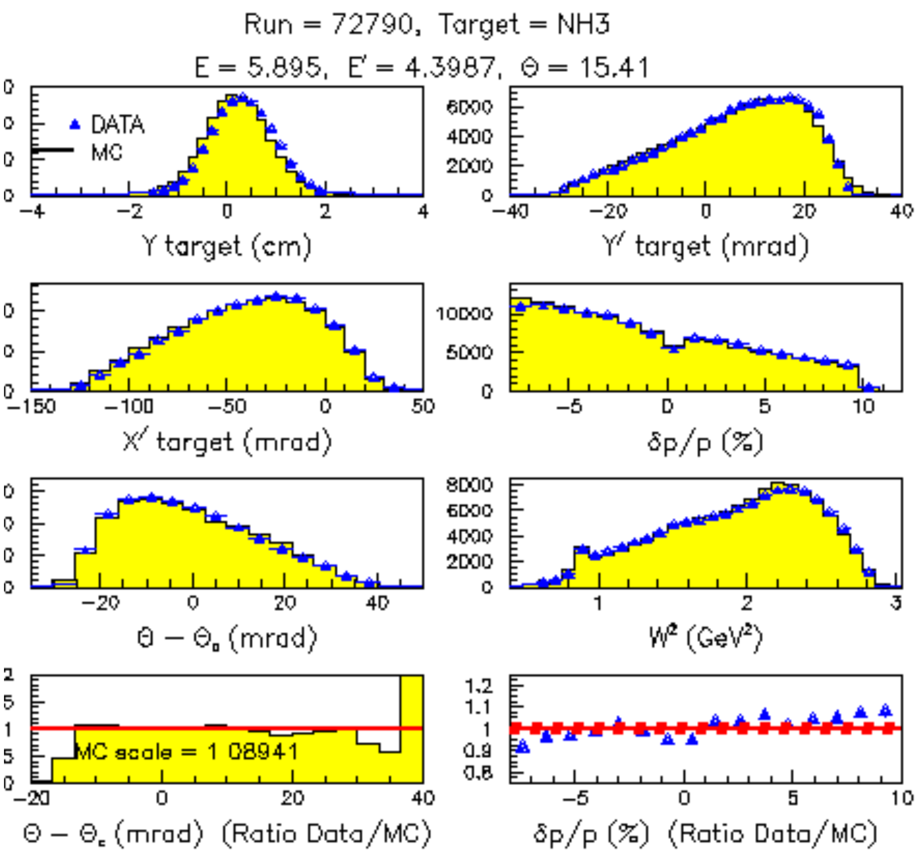
Used C run to find srast x/y offsets.

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

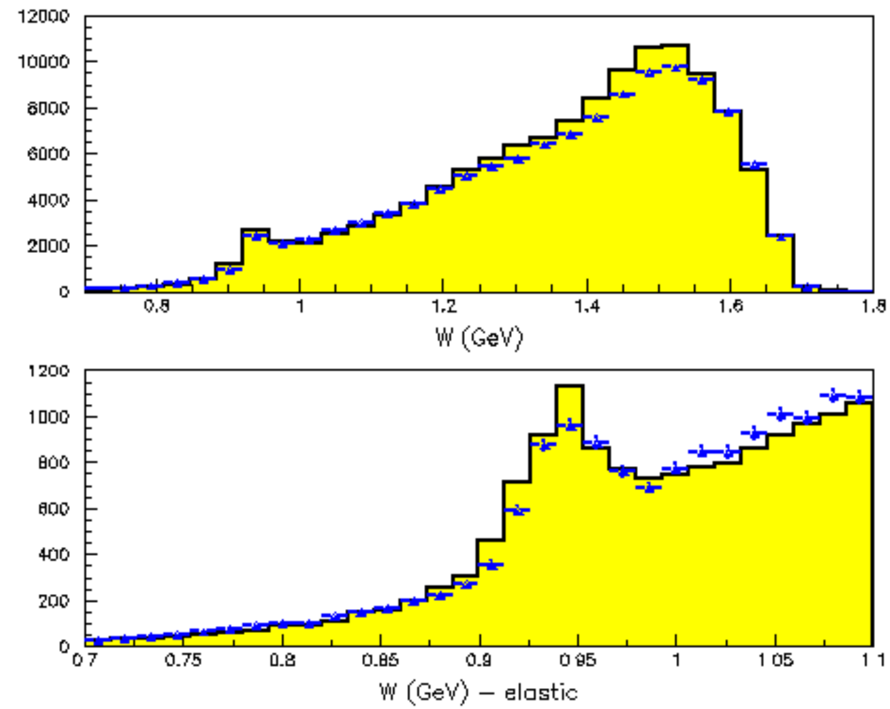




MC with NH3



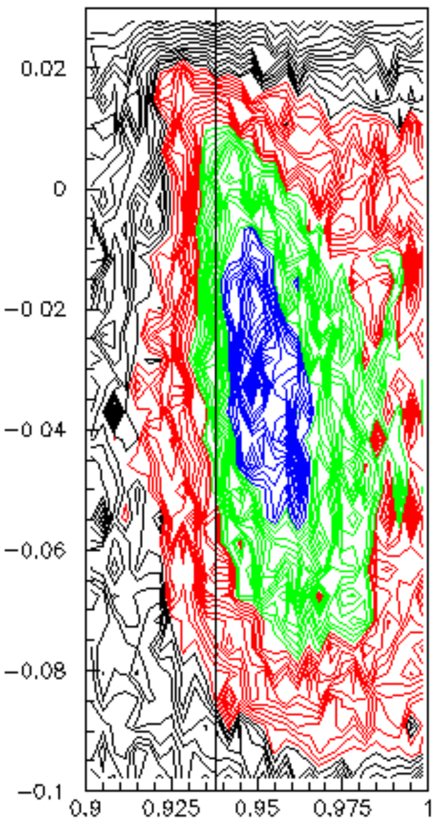
In order to consider NH3 target,
Used
N, H3 and He separately

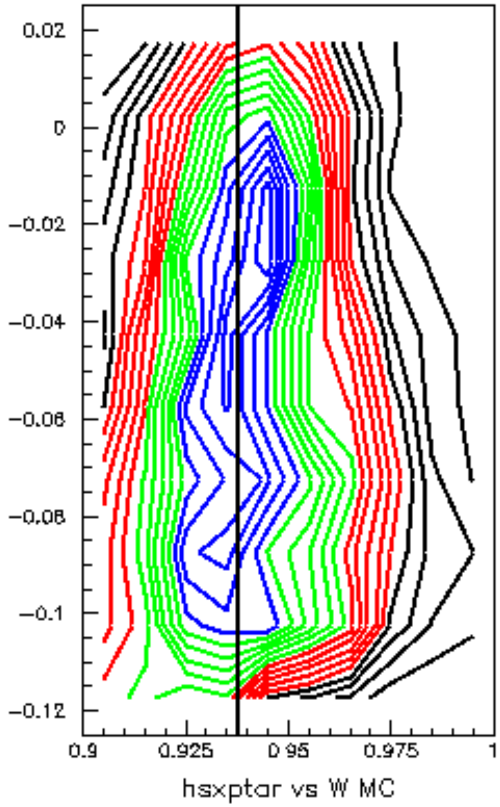


Check the srast x offsets with MC

Data

Srast x=0.4 cm

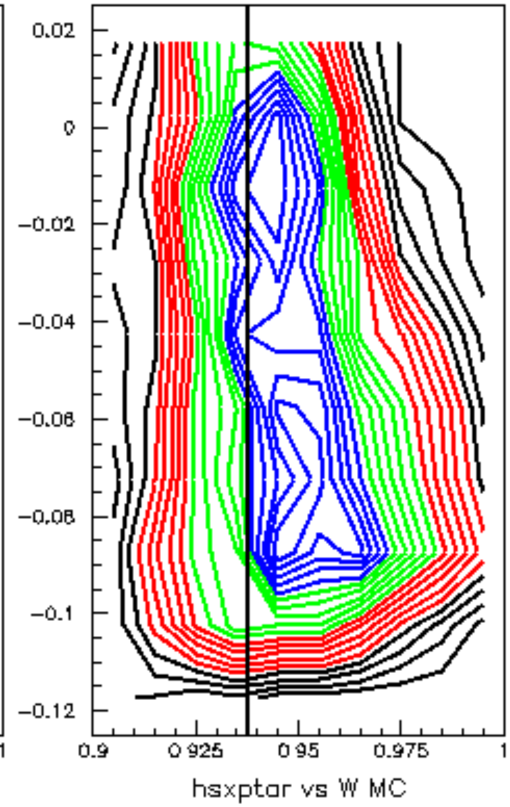




MC

Gen. Srast x=0.4 cm

Rec. Srast x=0.4cm



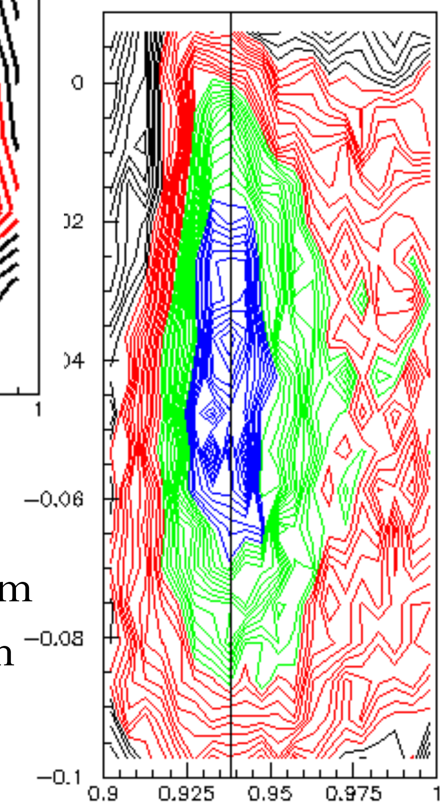
MC

Gen. Srast x=-0.4 cm

Rec. Srast x=0.4cm

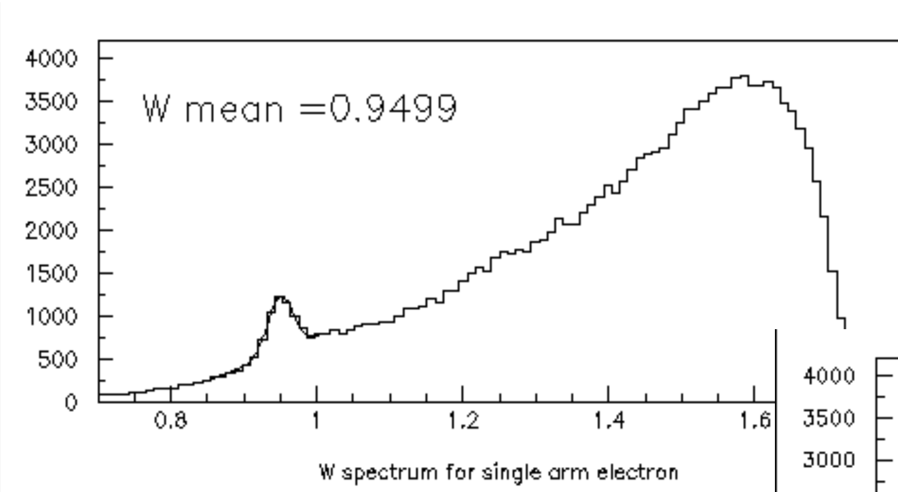
Data

Srast x=-0.4 cm

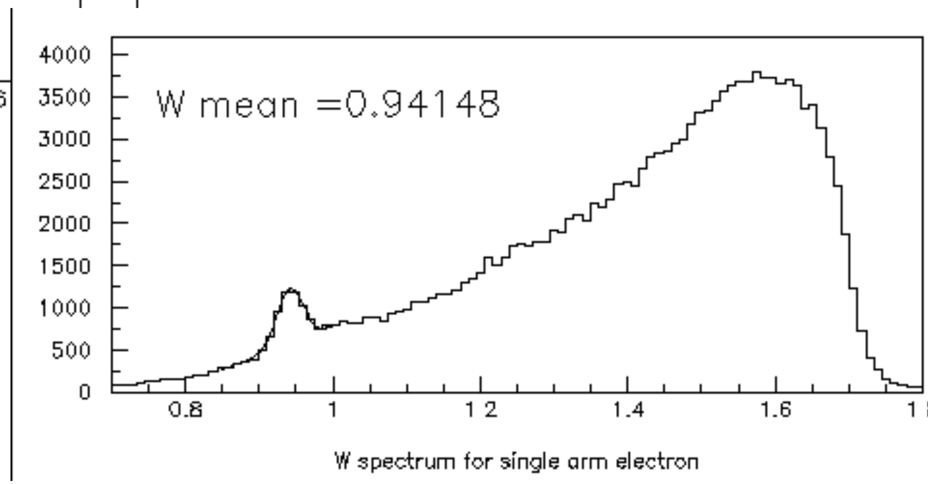


Kinematics Offset

The W peak is shifted by ~12 MeV.



It could be a combination of a vertical beam offset and the offset in the HMS central momentum of more like 1x10-3.



1 mm of vertical offset is 0.8x10-3.

So, 4.400*(1.001)=4.4044 for the central momentum and change the vertical by 2mm.

P_HMS = 4.4044 GeV

instead of 4.4000 GeV

srast y_offset = 0.2 mm

Extract the electrons

- Used only Electron selection cuts.

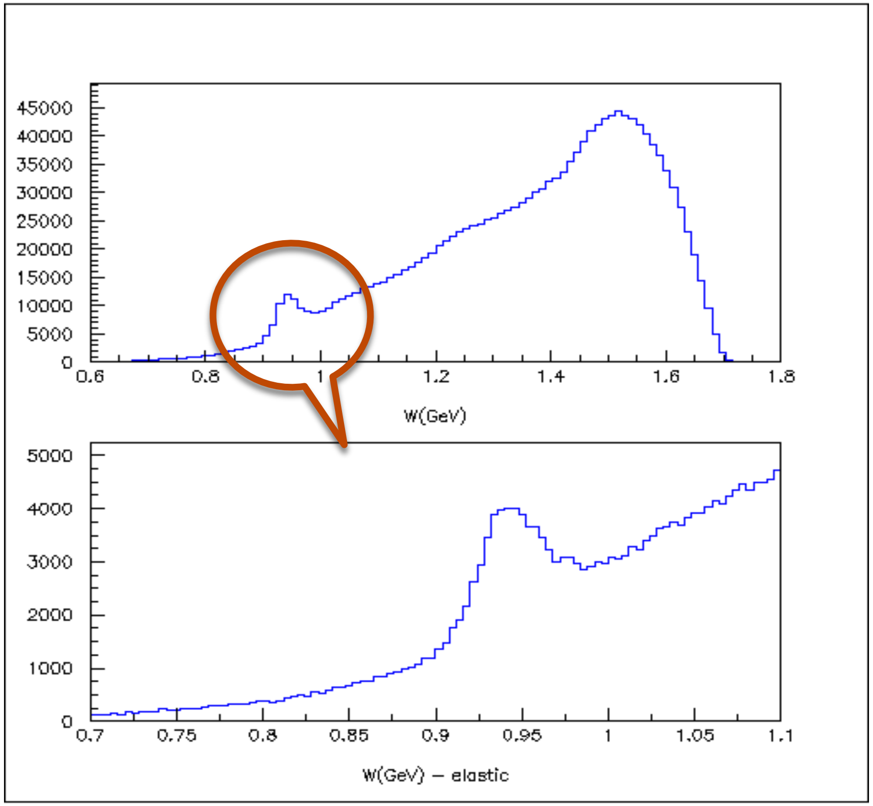
Cut	
# of Cerenkov photoelectrons > 2	- Cerenkov cut
$E_{sh}/E' > 0.7$	- Calorimeter cut
$\left(P - P_c / P_c \right) < 10$ and $\left(P - P_c / P_c \right) > -8$	- HMS Momentum Acceptance cut

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



Calculated the Raw Asymmetry .....

The raw asymmetry, A_r

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

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

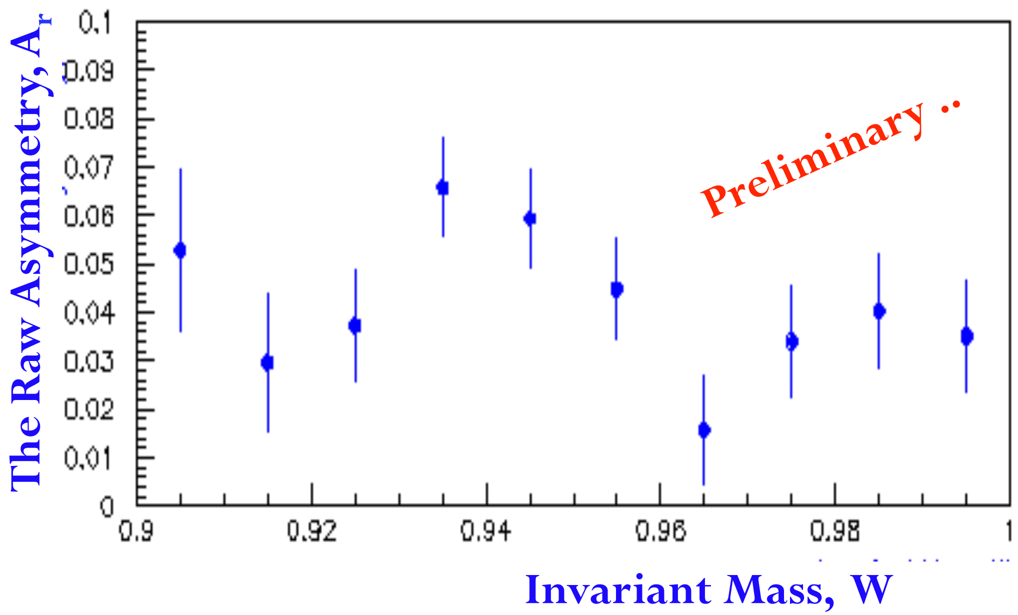
N^+ / N^- = Charge normalized counts for the +/- helicity

ΔA_r = Error on the raw asymmetry

$P_B P_T$ = Beam and Target polarization

N_c = A correction term

The Raw Asymmetries



Need dilution factor, f and backgrounds

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 $(GeV/c)^2$)

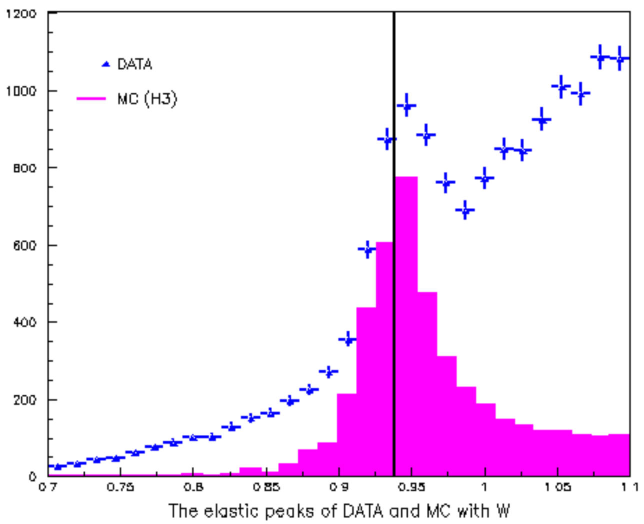
Determination of the Dilution Factor

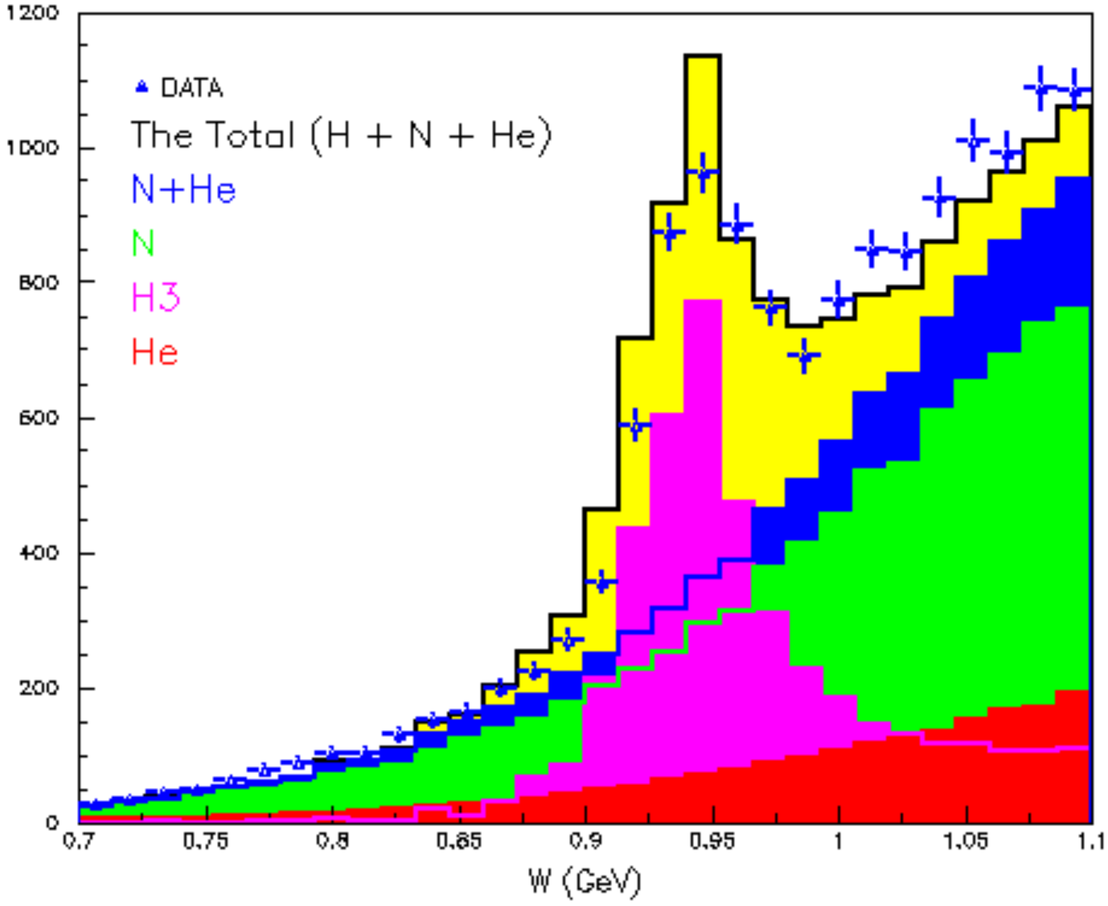
What is the Dilution Factor ?

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 and He)

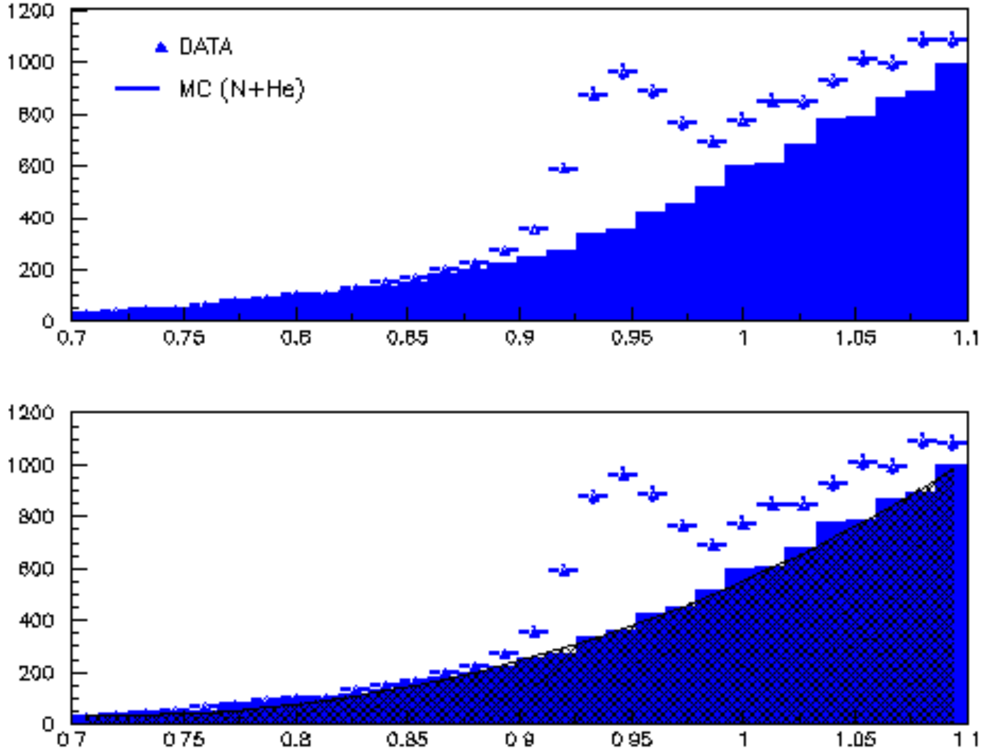
Dilution Factor,

$$F = \frac{Yield_{Data} - Yield_{MC}}{Yield_{Data}}$$



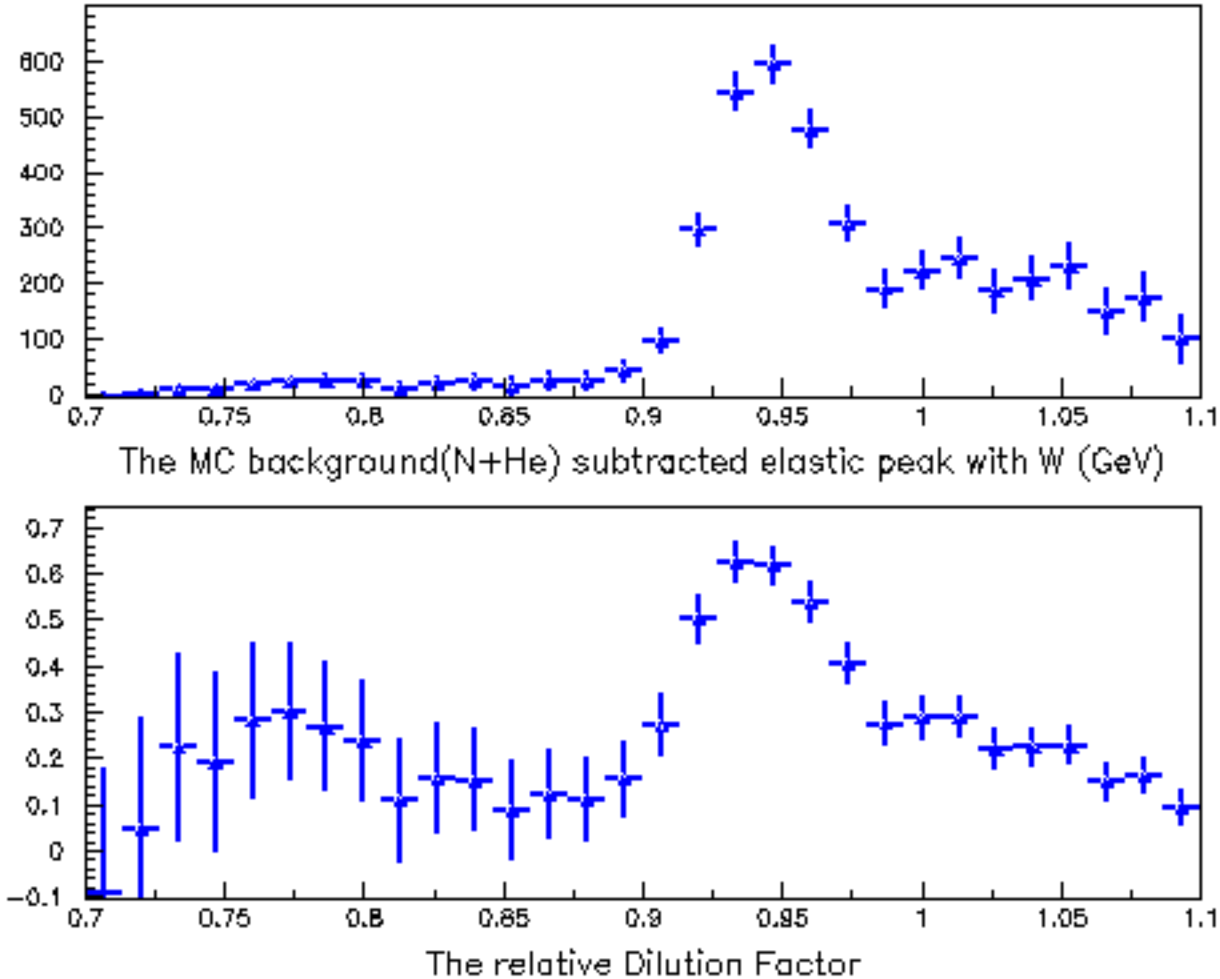


- MC Background contributions (Only He+N)



- Used the polynomial fit to N+ He in MC and
- Subtract the fit function from data

- The relative Dilution Factor **(Very Preliminary)**



Need To ..

- Improve the MC simulation and estimate the background
- Extract the physics asymmetry and the G^p_E/G^p_M ratio

Conclusion

- Extraction of G^p_E/G^p_M ratio from single-arm electron data are shown.
- Measurement of the beam-target asymmetry in elastic electron-proton scattering offers an independent technique of determining G^p_E/G^p_M ratio.
- This is an 'explorative' measurement, as a by-product of the SANE experiment.

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

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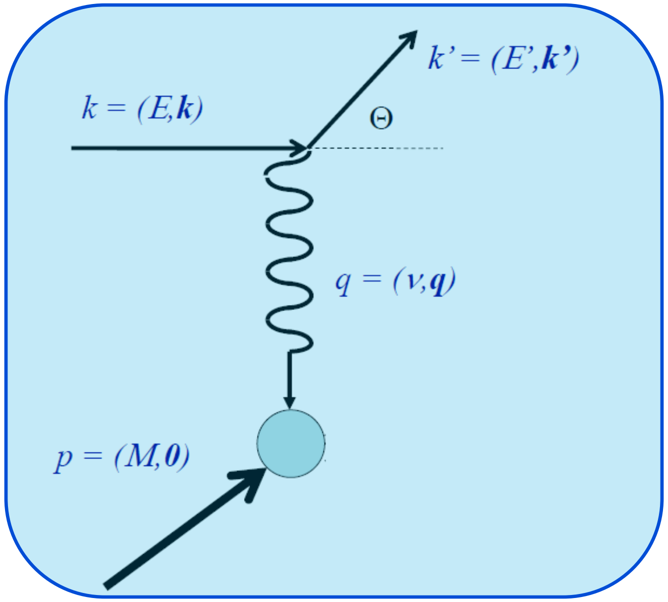
Backup Slides

Elastic Scattering



The four-momentum transfer squared,

$$q^2 = (k - k')^2 = k^2 + k'^2 - 2kk'$$

For electron, $k^2 = E^2 - k^2 = m_e{}^2 = 0$

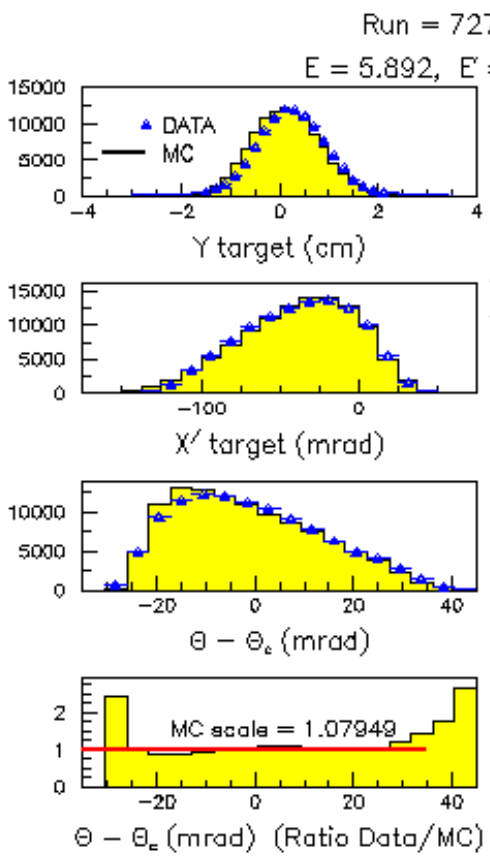
$$q^2 = -2kk' = -2(E,k)(E',k')$$

$$q^2 = -2(EE' - k \cdot k')$$

$$q^2 = -2EE'(1 - \cos\Theta)$$

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

Comparing MC for NH3 target



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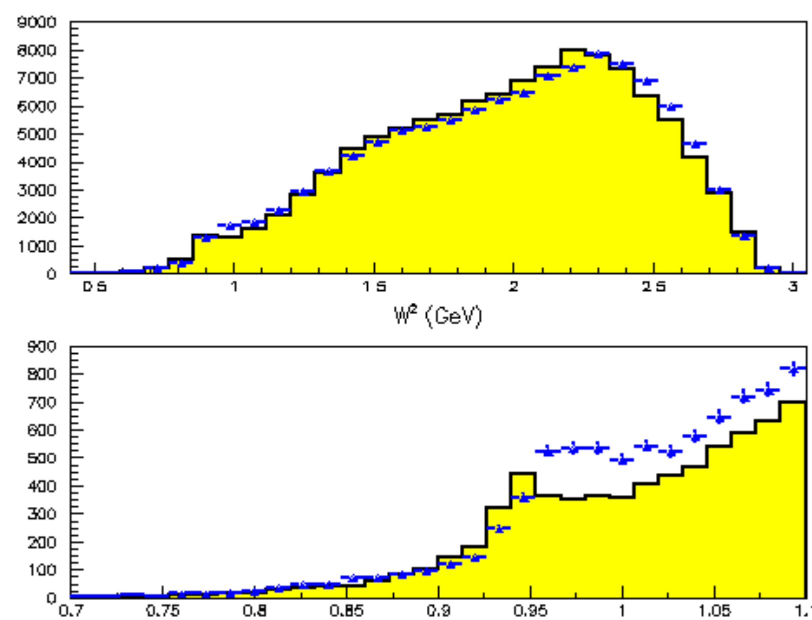

Invariant Mass, W (GeV)