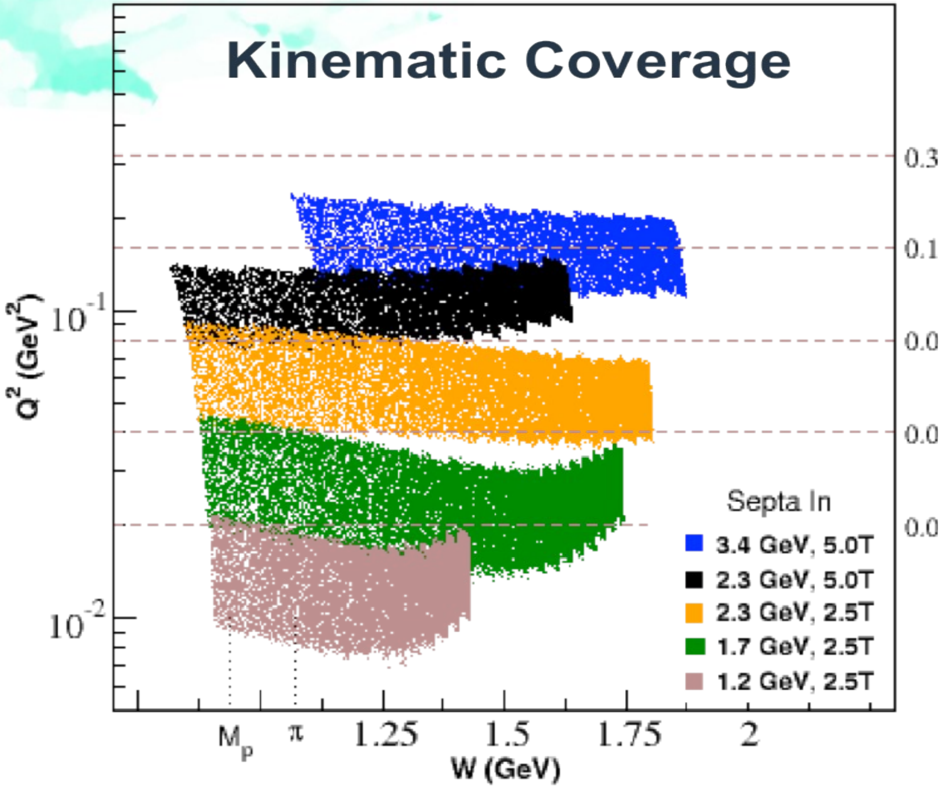
The Status of g2p & GEp(II) Analysis

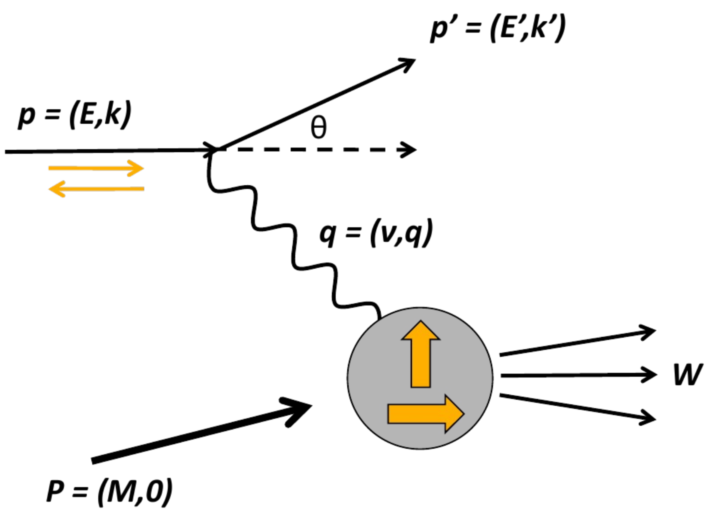
Pengjia Zhu

University of Science and Technology of China
On behalf of the E08-027(g2p)/E08-007(GEp) collaboration

Hall A Collabration Meeting, December 9th 2014

g2p motivation





$$\frac{d^2\sigma}{dE'd\Omega}(\downarrow\Rightarrow - \uparrow\Rightarrow) = \frac{4\alpha^2 \sin\theta}{MQ^2}\frac{E'^2}{\nu^2 E}\left[\nu g_1(x,Q^2) + 2E g_2(x,Q^2)\right]$$

Measure g_2 in the low Q^2 region ($0.02<Q^2<0.2\mathrm{GeV}^2$)

g2p motivation

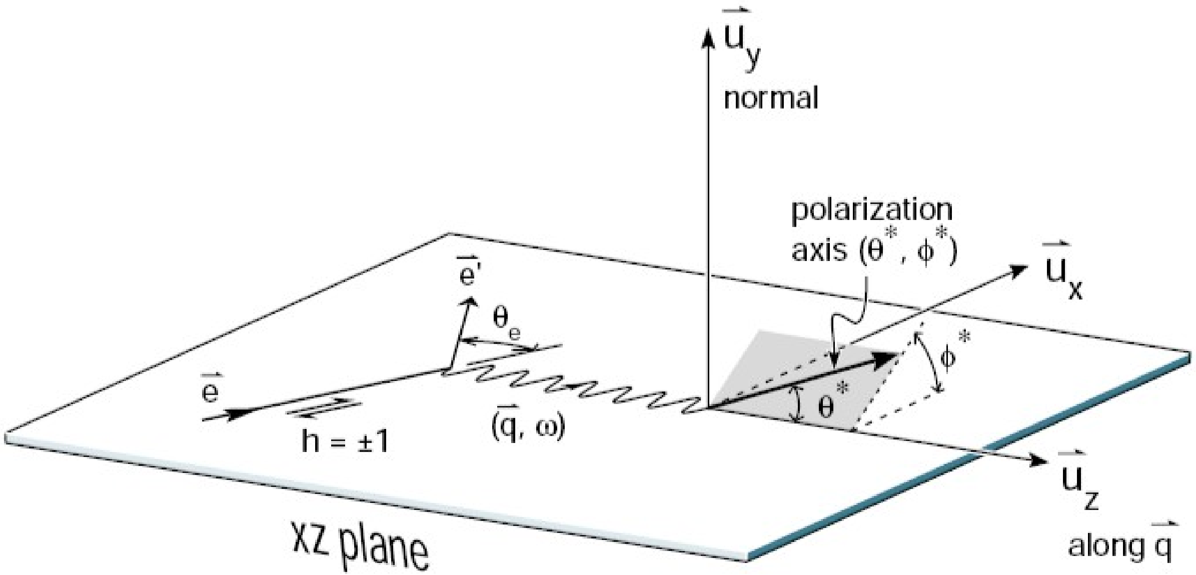
- **Extract longitudinal-transverse spin polarizability(δ_{LT})**
  benchmark test of χPT, discrepancy seen for neutron data
- **Test Burkhardt-Cottingham (BC) Sum Rule**
  violation suggested for proton in high Q^2(SLAC E155x)
- **Hydrogen hyperfine splitting**
  correction for proton structure contributes to uncertainty
- **Proton charge radius**
  contributions to uncertainty include proton polarizability

GEp motivation

(Part II)

Asymmetry

$$\mathcal{A} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$



$$\mathcal{A} = f P_b P_t \frac{\overbrace{a\, cos\theta^* G_M^2}^{A_T} + \overbrace{b\, sin\theta^*\, cos\phi^* G_E G_M}^{A_{LT}}}{c G_M^2 + d G_E^2}$$

$\longrightarrow \dfrac{G_E}{G_M}$

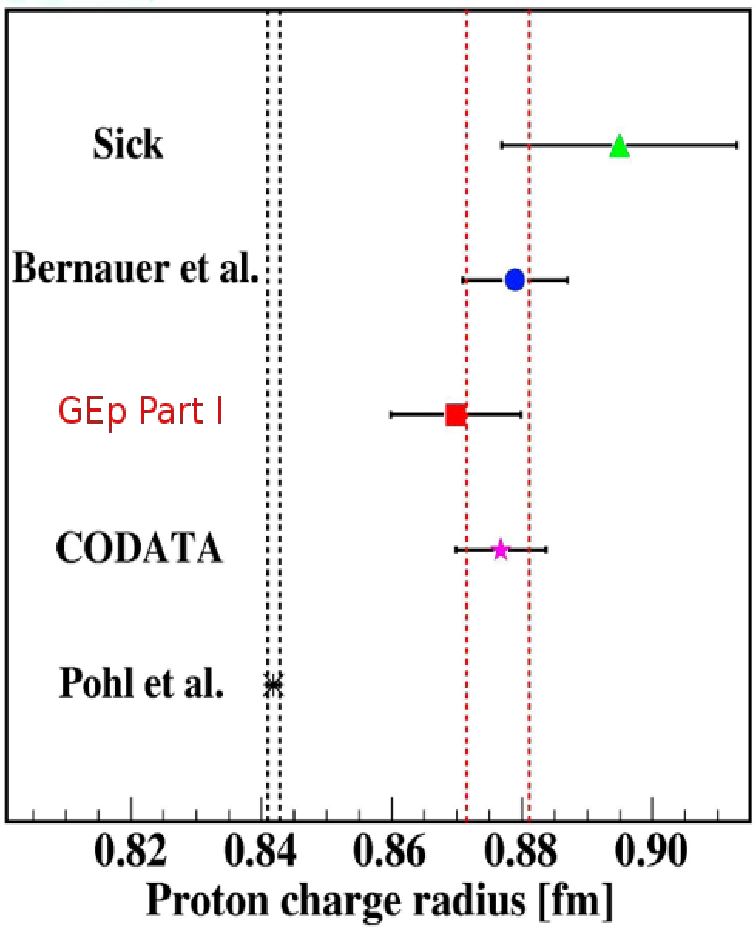
Elastic Form Factor Ratio

~2%-3% uncertainty at Q^2~ 0.015 - 0.06 GeV^2

GEp motivation

$$G_{E,M}(Q^2)=\int \rho(\vec{r})e^{i\vec{q}\vec{r}}d^3\vec{r}=\int \rho(\vec{r})d^3\vec{r}-\frac{\vec{q}^2}{6}\int \rho(\vec{r})\vec{r}^2 d^3\vec{r}+\ldots$$

The proton radius puzzle



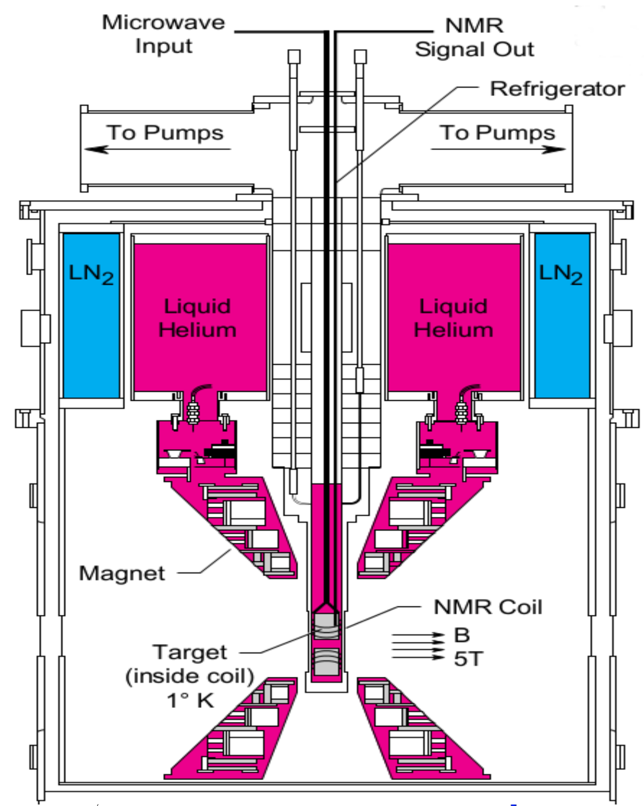
X. Zhan, et al. Phys. Lett. B 705(2011) 59

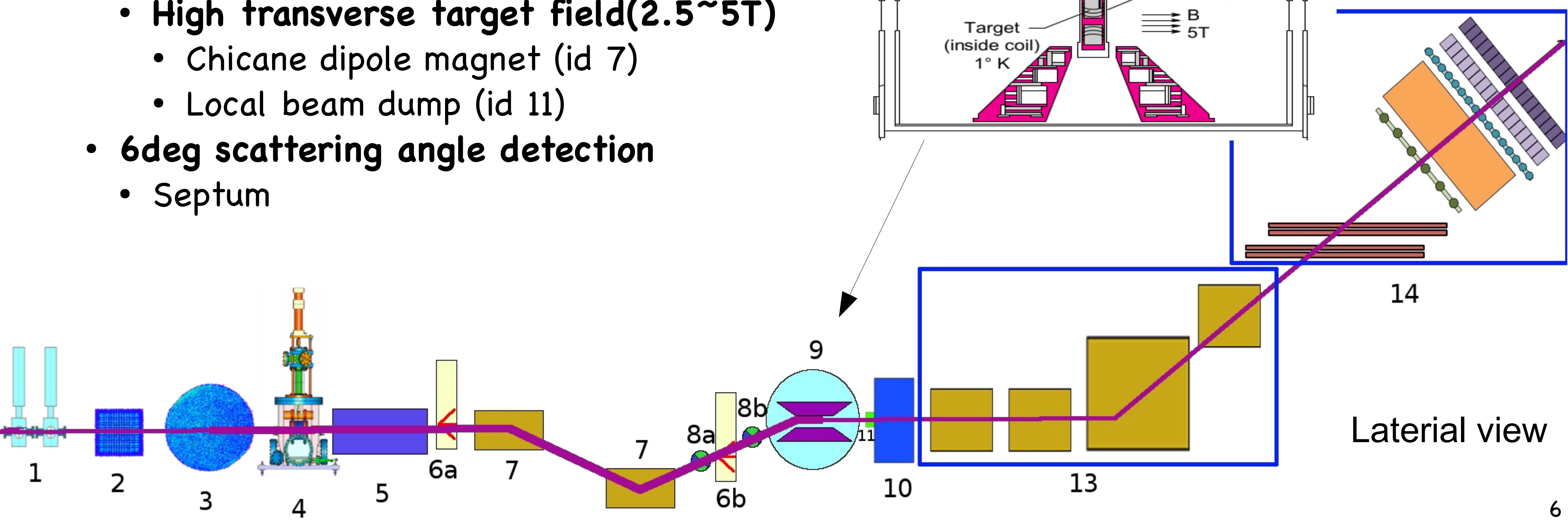
#	Extraction	Method	<rE>2 [fm]
1	Sick	ep scattering	0.895±0.018
2	CODATA		0.8768±0.0069
3	Mainz	ep scattering	0.879±0.008
4	GEp part I	ep scattering	0.870±0.010
5	Combined 2-4		0.8764±0.0047
6	Muonic Hydrogen	μH Lamb shift	0.842±0.001

Result from Lamb shift in muonic hydrogen disagree with other results

Experimental setup

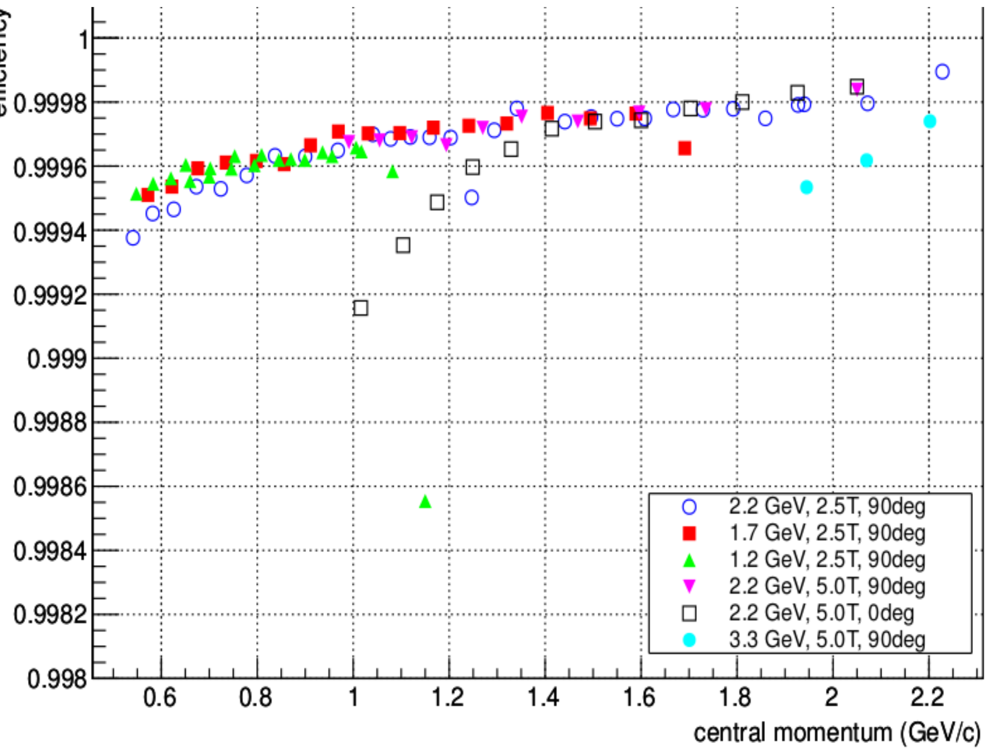
- **Polarized NH3 target**
  - Slow raster (id 3)
  - **Low current** (50~100nA for g2p, 5~10nA for GEp)
  - Super-harps (id 6)
  - Tungsten calorimeter (id 4)
  - New BPM/BCM receiver(readout)
    - Hall A Standard BCM/BPM (id 1/id 8)
  - **High transverse target field(2.5~5T)**
  - Chicane dipole magnet (id 7)
  - Local beam dump (id 11)
- **6deg scattering angle detection**
  - Septum



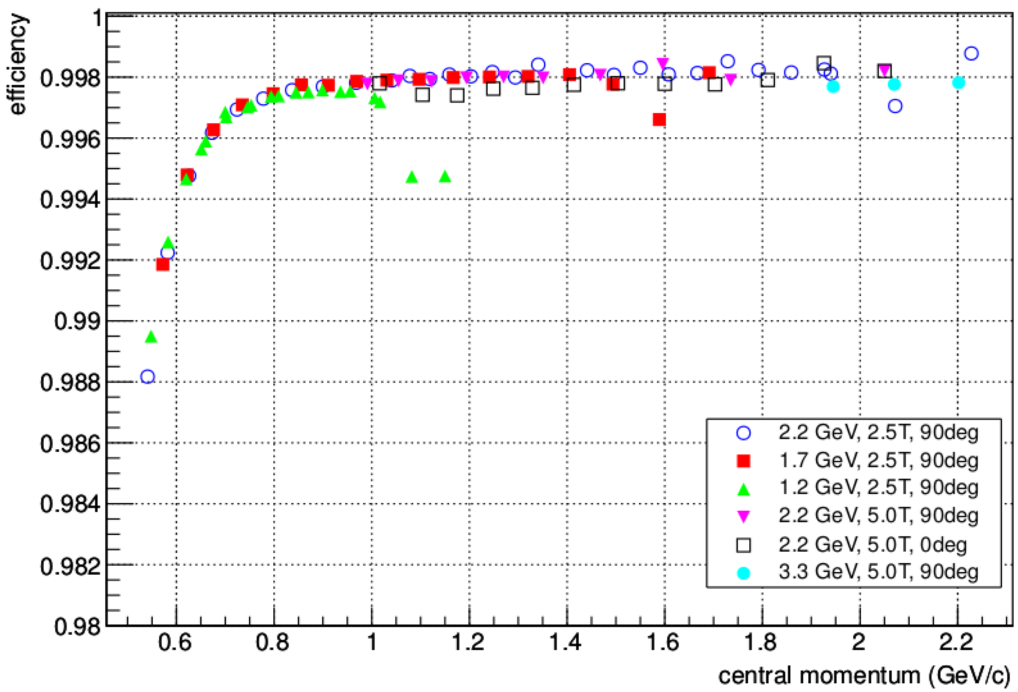


Detector efficiency

Cherencov efficiency ~99.96%



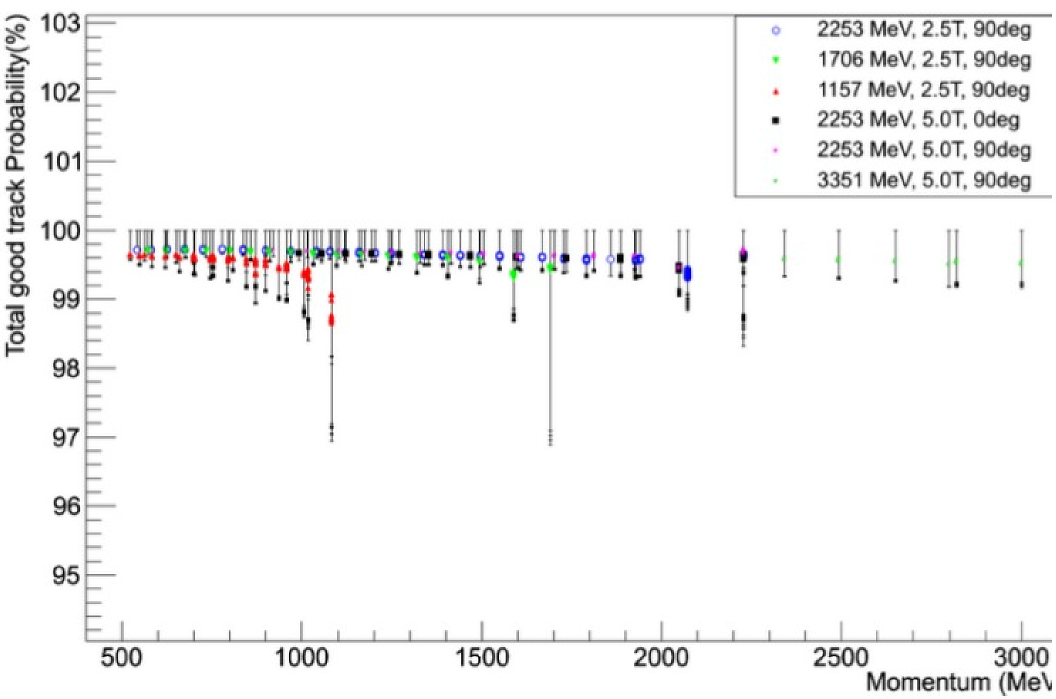
Lead glass efficiency ~99.6%



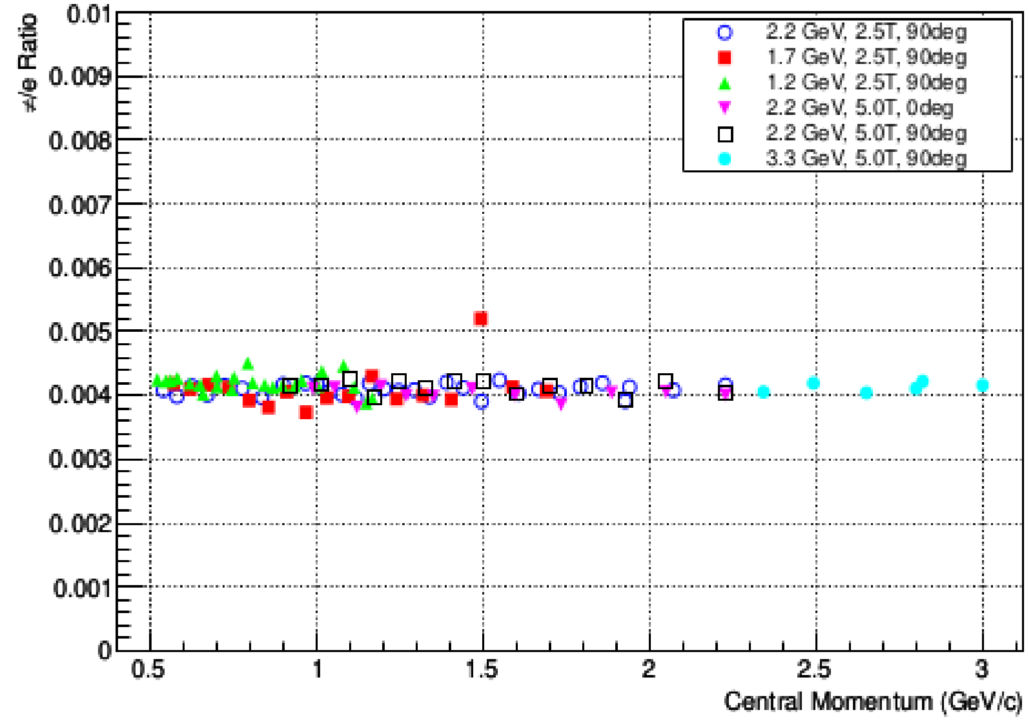
All of our detector efficiency is in very good situation

Detector efficiency

Track efficiency(with multi track) >99%

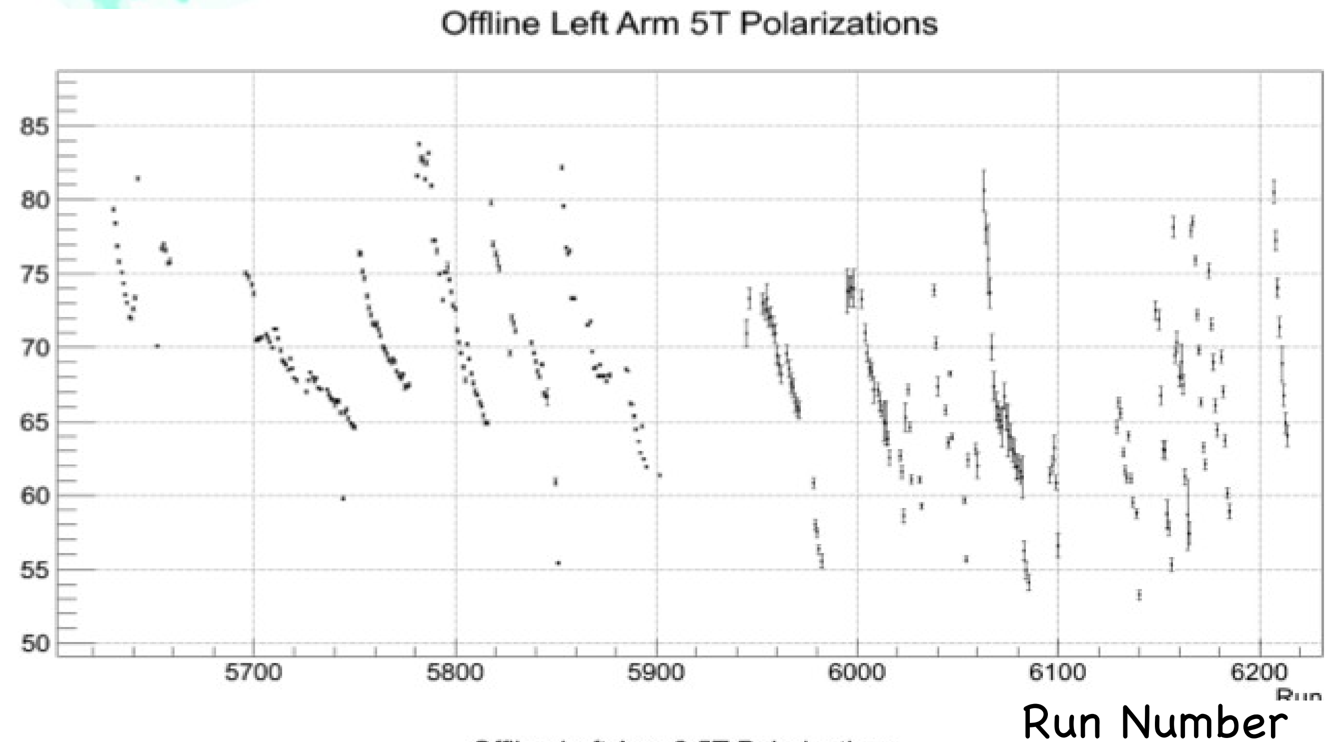


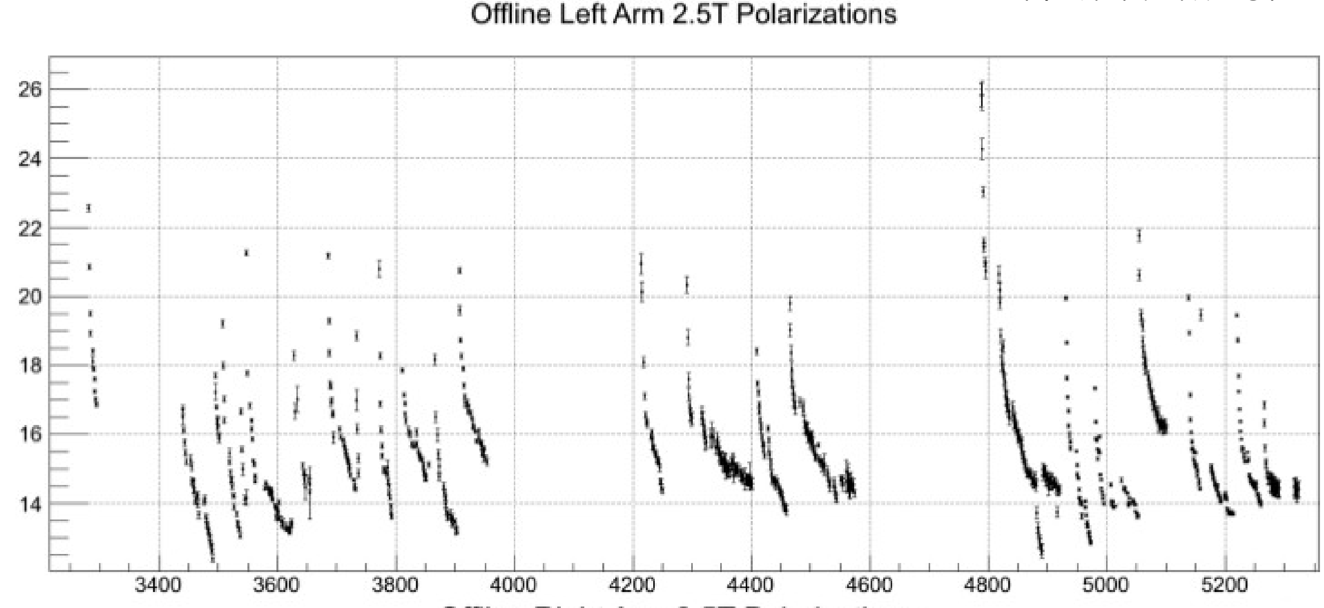
Pion rejection ~0.004



All of our detector efficiency is in very good situation

Target polarization





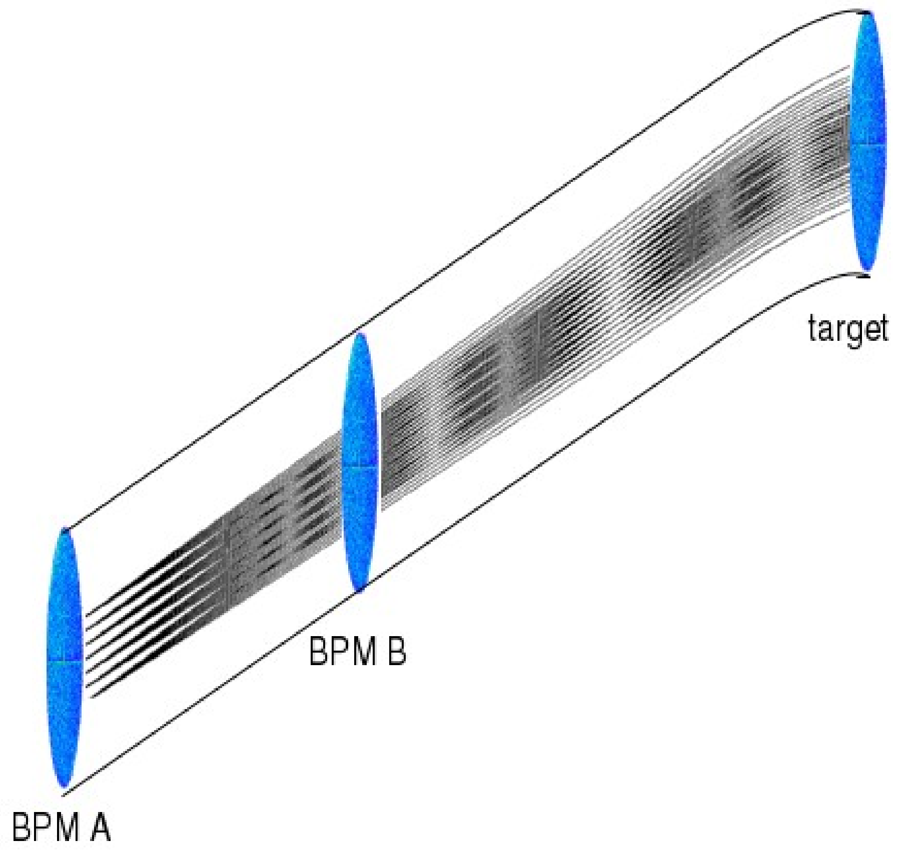
Average polarization:

5T: ~70%

2.5T: ~15%

Beam position reconstruction

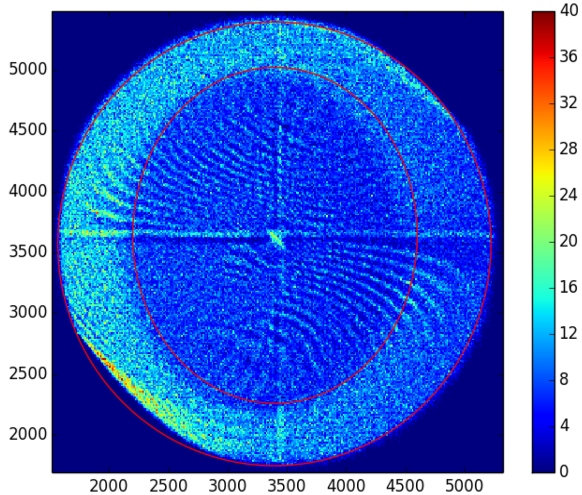
- **Beam position and angle at the target**
  - Fitted function from simulation to transport position from BPMs to target



Beam position reconstruction

- **Event by event position and angle**
  - Use BPM information as average beam position
  - Calibrate Raster magnet current information as position deviation from center position
  - Combine BPM, slow/fast raster magnet current informations

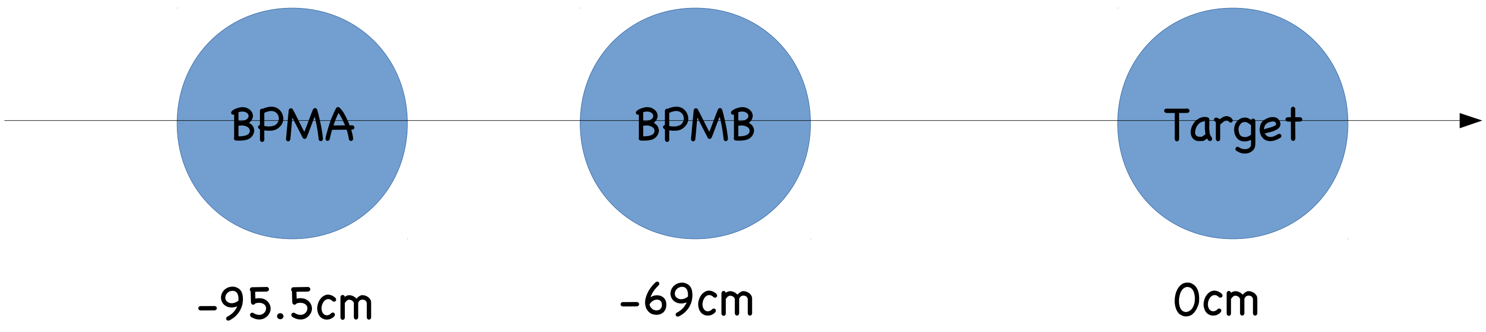
$$X = \langle X_{BPM} \rangle + X_{fast} + X_{slow}$$



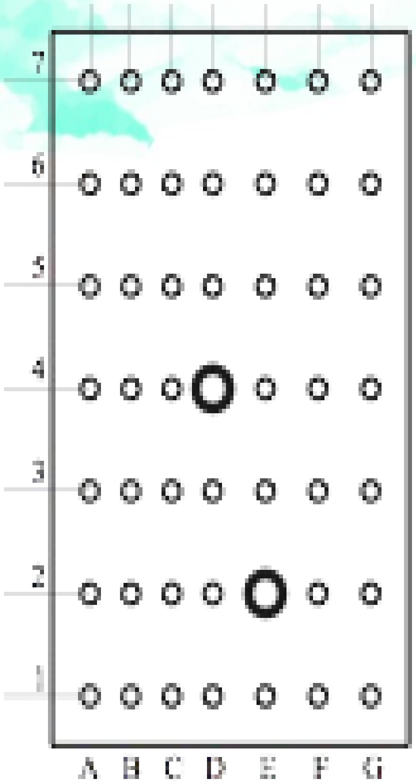
Use carbon hole to calibrate slow raster

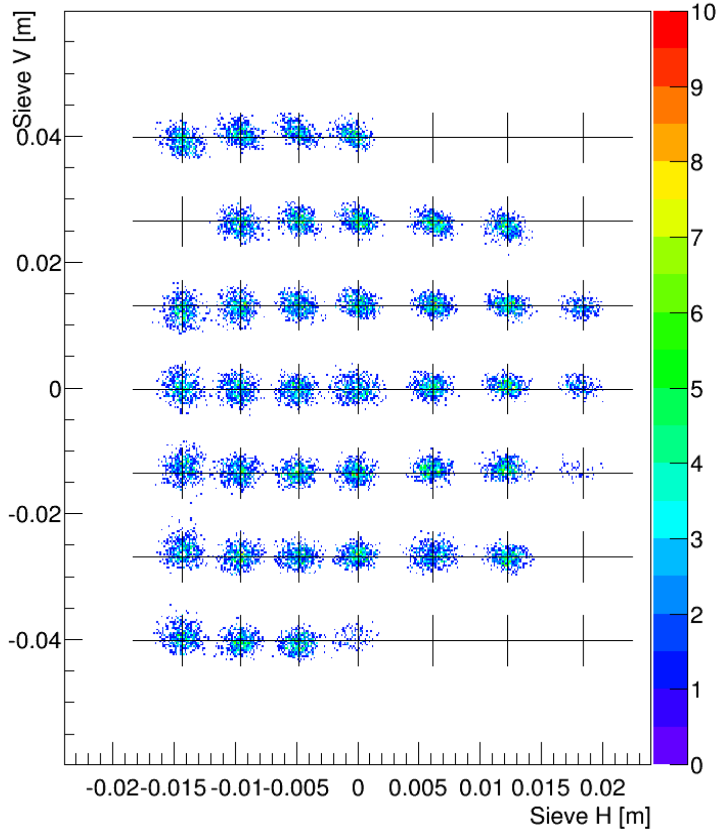
Beam position reconstruction

- **Uncertainty**
  - Best situation: 1mm for position, 1.1mrad for angle
  - Main uncertainty part:
    - Pedestal fluctuation
    - Too close for two BPMs -- 26.5cm difference



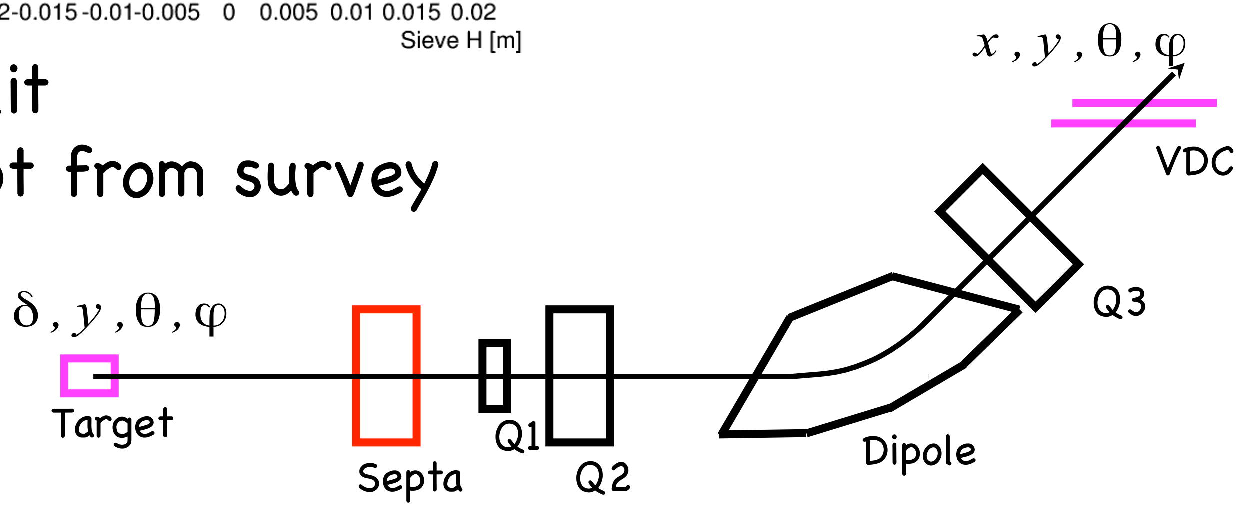
HRS Optics – without target field



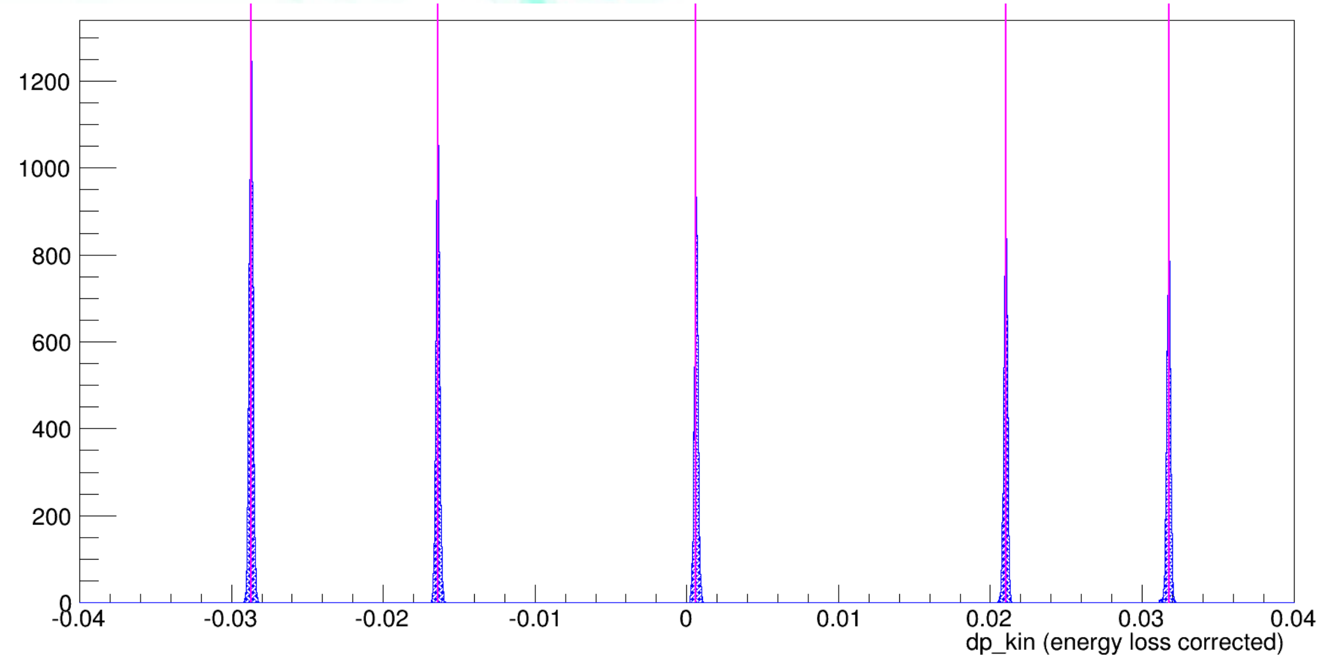


Angle matrix -- sieve slit

- Angle at sieve slit got from survey

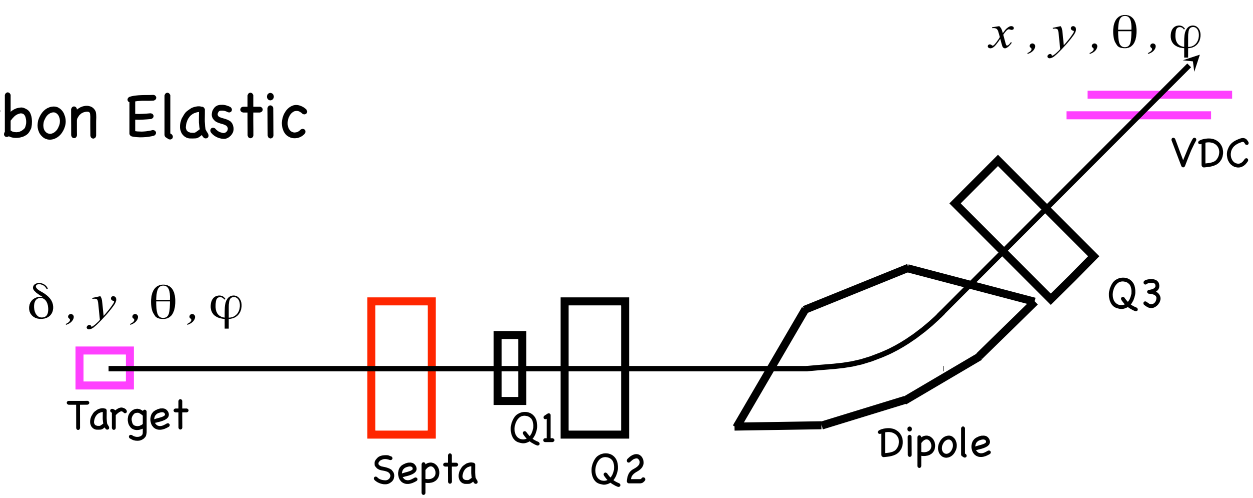


HRS Optics - without target field



δ matrix

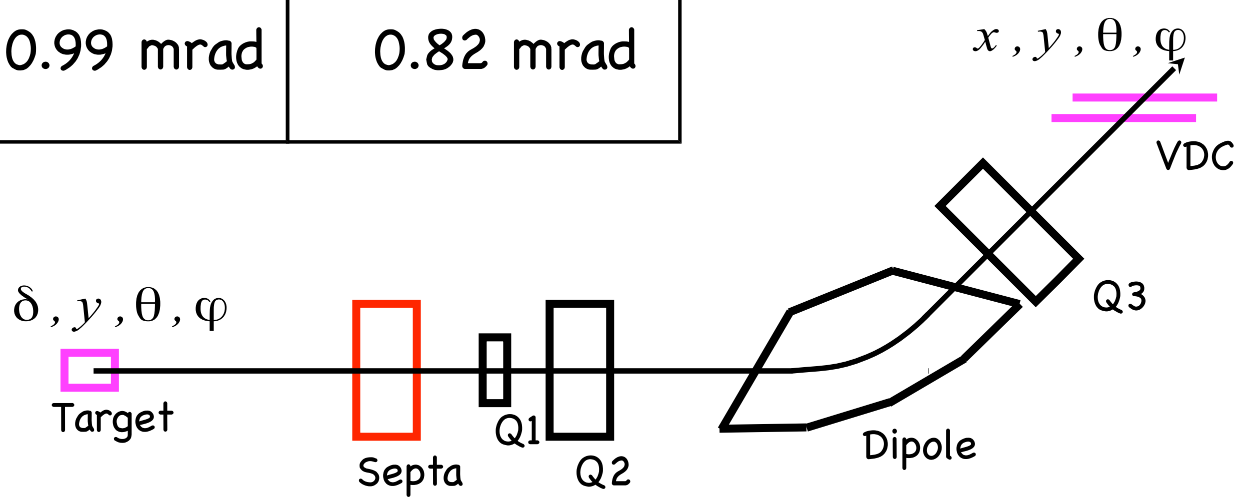
- δ calculated from Carbon Elastic



HRS Optics – without target field

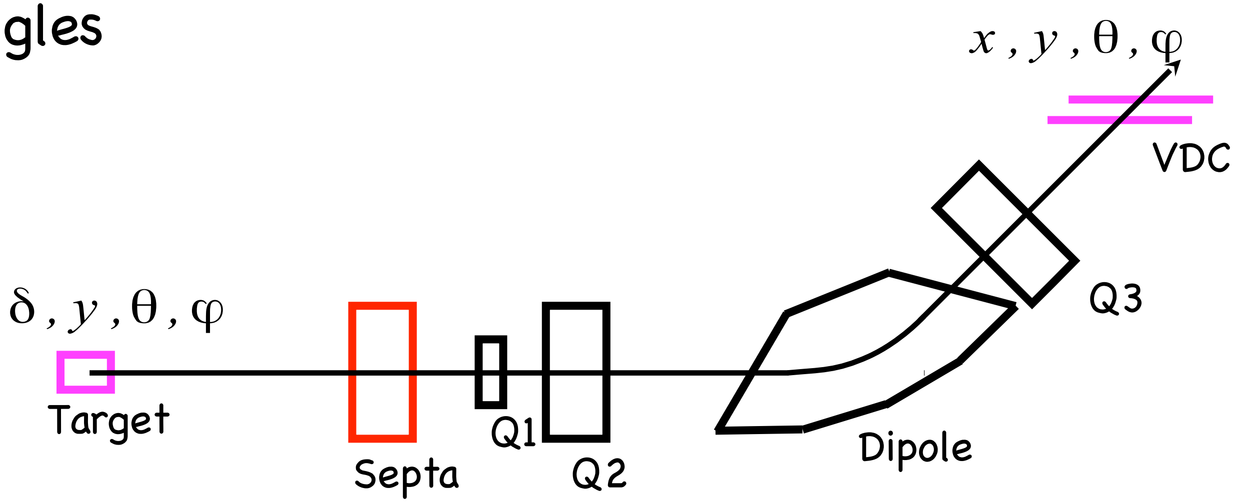
Performance summary of RMS values without target field

RMS	LHRS	RHRS
δ [dp]	1.5×10^{-4}	2.4×10^{-4}
Θ [out-of-plane angle]	1.59 mrad	1.57 mrad
y	3.3 mm	2.9 mm
φ [in-plane angle]	0.99 mrad	0.82 mrad



HRS Optics - with target field

- Septum broke during the experiment, need to use the dat taken with the broken septum to recalibrate angle matrix
- A simulation package is written to deal with the ray tracing in the target field
    - For the recalibration of the matrix, the simulation package is used to calculate reference angles
    - For reconstruction, the simulation package is used to calculate the real scattering angles



Acceptance

Unpolarized cross section

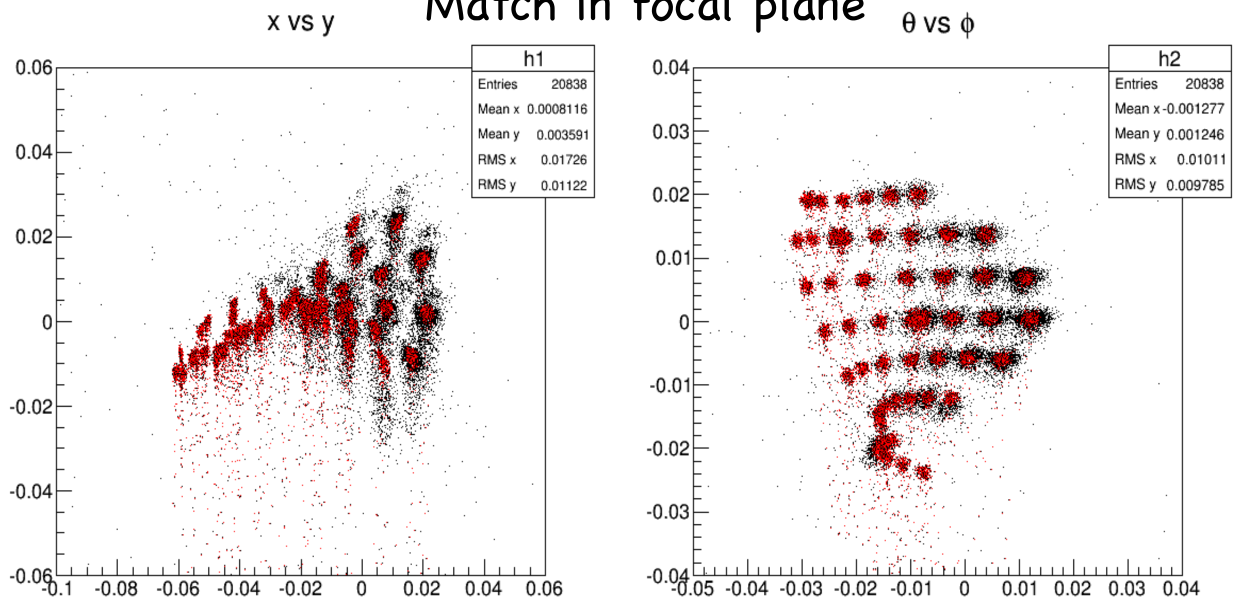
$$\frac{d\sigma^{raw}}{d\Omega dE'} = \frac{N * ps * RC}{Q/q * N_{tg} \mathrm{LT} * \epsilon_{det}} \frac{Acc}{\Delta\Omega \Delta E'}$$

Method:

- Match the simulation and data in all of planes
- Use simulation to get acceptance

$$\frac{Acc}{\Delta\Omega \Delta E'} = \frac{1}{\Delta\Omega^{MC} \Delta E'^{MC}} \frac{N^{MC}_{simu}}{N^{MC}_{acc}}$$

Match in focal plane



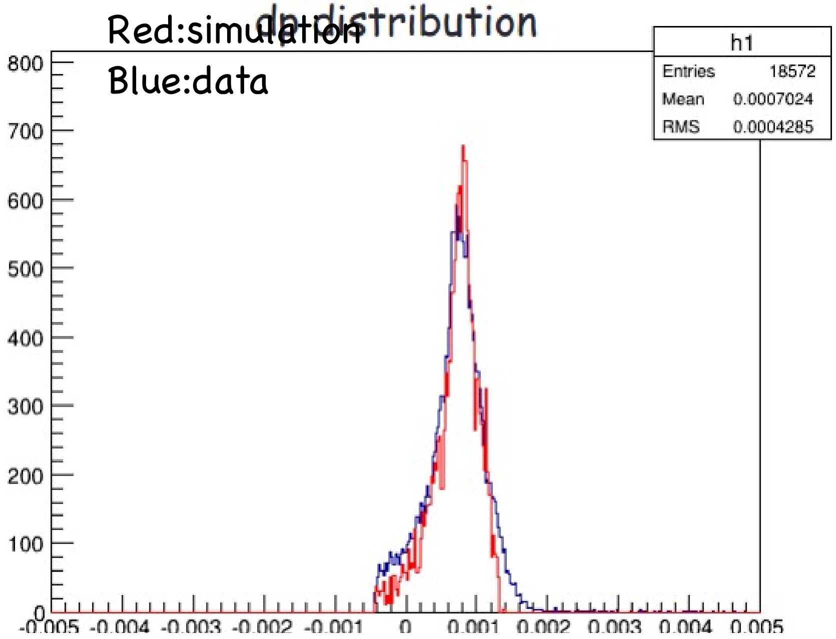
- we are working on obtaining the comparison of angles and momentum on target plane
- The simulation results match data on focal plane very well, and this will largely help the comparison on target plane.

Simulation

- Runge-Kutta method with self-adjusting step length to improve speed and accuracy
- HRS SNAKE models are included to get the focus plane variables
- Several cross-section models are also included, an event generator is written with these models
- Energy loss models included

Ongoing:

- Match data with simulation
- Packing fraction study with simulation

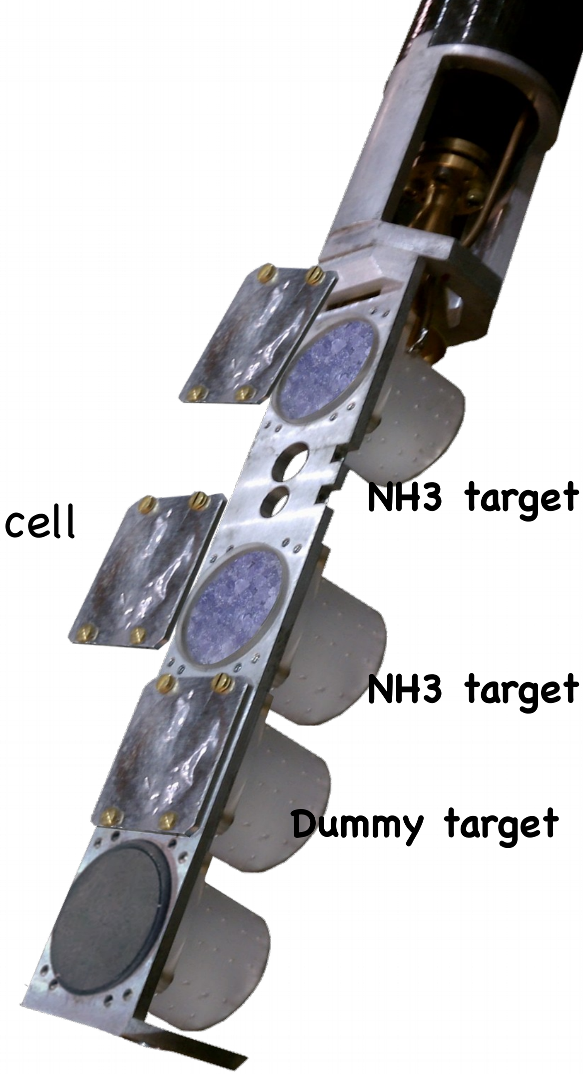


Comparison between simulated dp vs optics run dp

Packing fraction

-- effective NH3 target thickness

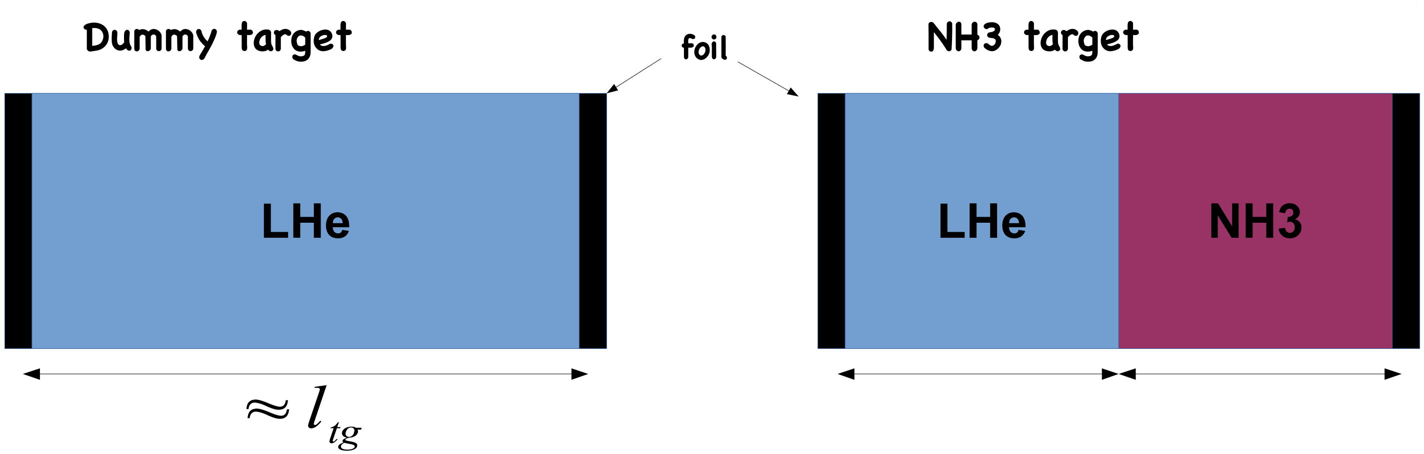
NH3 beads filled by liquid He



Define: $$p_f = 1 - \frac{Y^{\mathrm{in}}_{He}}{Y_{tg}}$$

Yield from He in dummy target cell

Yield from NH3 target cell

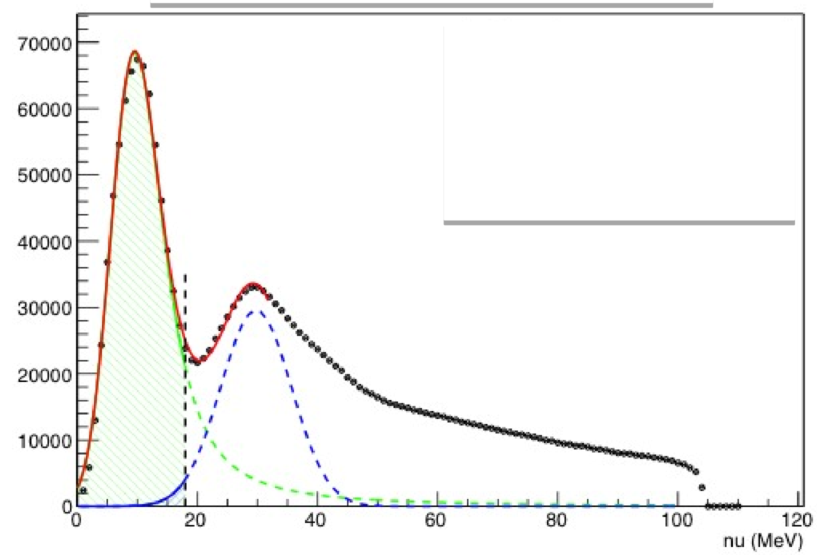


Packing fraction

- Only use elastic peak
  - Fitting routine to obtain level of contamination from QE peaks

- Ongoing
  - Radiation length matching between production and dummy runs
  - Updating fitting routine to include multiple contributions to second peak
  - Repeat analysis for other materials/energy settings

Fit to Elastic and QE Peaks – Production Run



Current Result:
(2.2 GeV, 2.5T Setting,Material 8)

$p_f = 0.551$

Dilution

Remove the Background from N,He,Aluminum foil

$$A_{raw}=\frac{Y_{+}-Y_{-}}{Y_{+}+Y_{-}+bg}$$

$$A_{phy}=\frac{1}{P_b P_t D}*A_{raw}$$

$Y_{+/-}$ Yield from proton

$bg=Y_N+Y_{He}+Y_f$ Yield from N, He, foil

$P_b P_t$ Polarization of beam and target

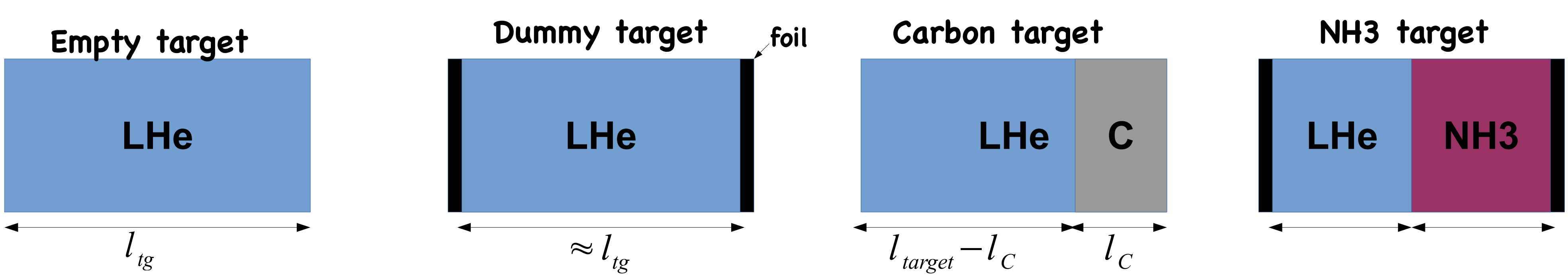
Dilution factor

$$D=1-\frac{bg}{Y_{total}}$$

Y_f: Extract from dummy and empty target

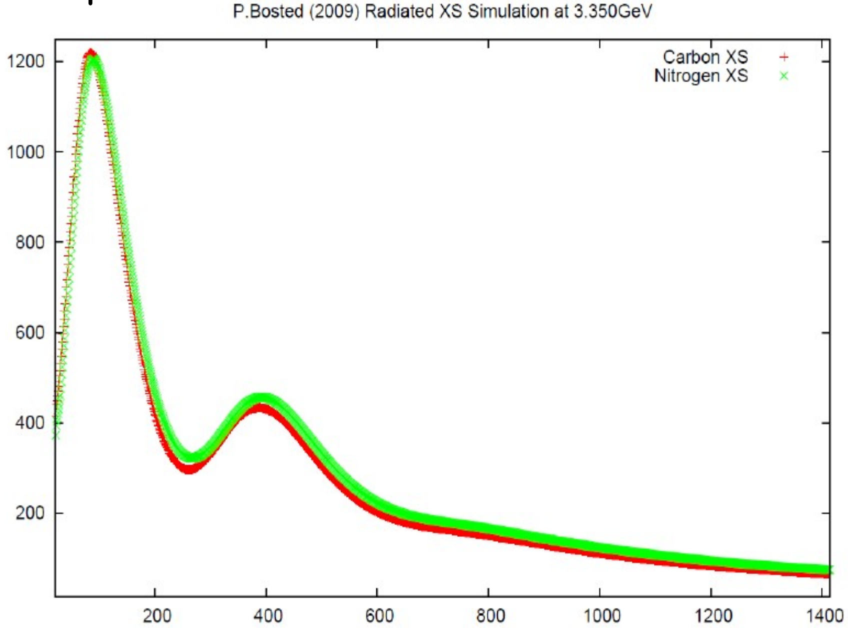
Y_{He}: Extract from empty target

Y_N: Extract from carbon target and scale it to nitrogen using P.Bosted cross section model



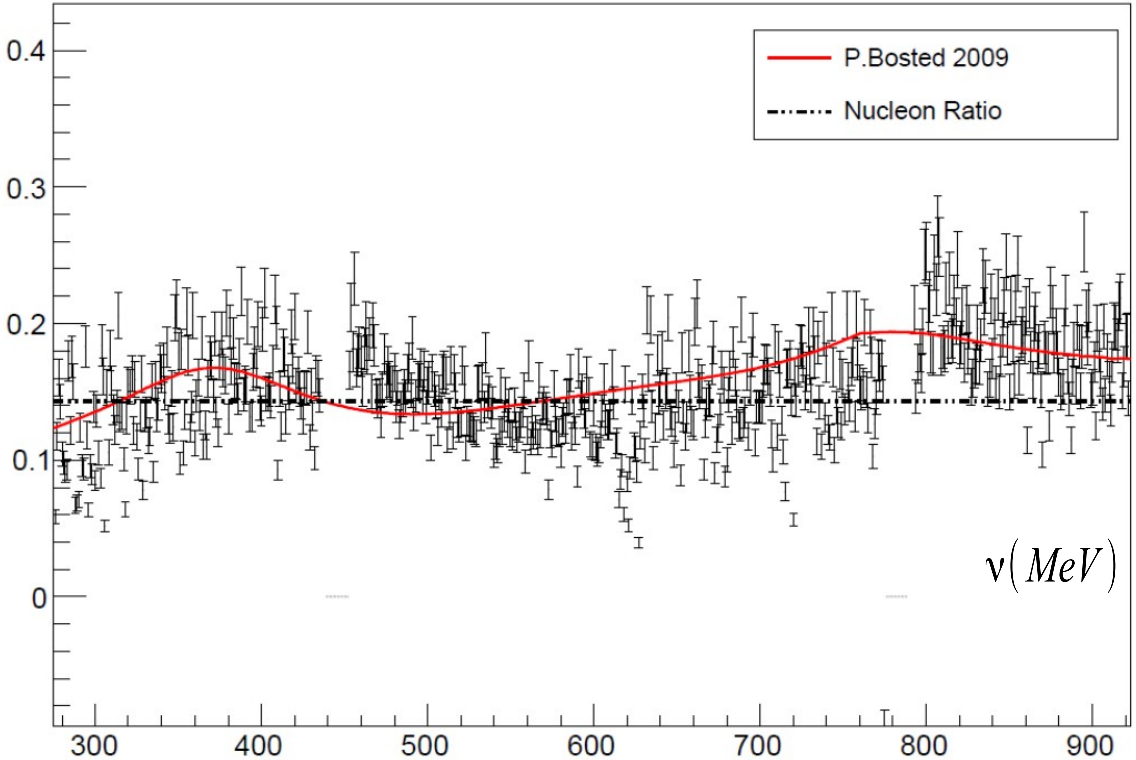
Dilution

Comparation of C&N XS from P.Bosted model



Current result:

3.350GeV 5T Transverse Dilution result

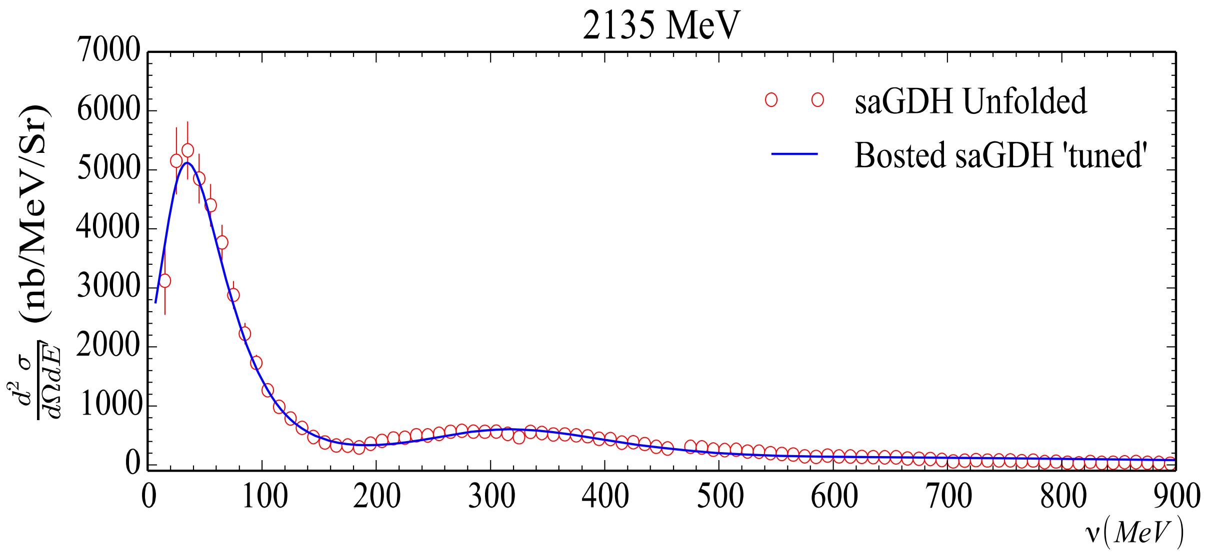


- Still Ongoing

Bosted model tuning using saGDH data

-- saGDH unpolarized radiative correction study

- saGDH has similar kinematics with g2p (0.02~0.2GeV2)
- saGDH has pure nitrogen data (gas nitrogen target)
- g2p only took dilution data on carbon, need to scale to match actual nitrogen background
- For the nitrogen background subtraction for dilution study



Summary for g2p Analysis status

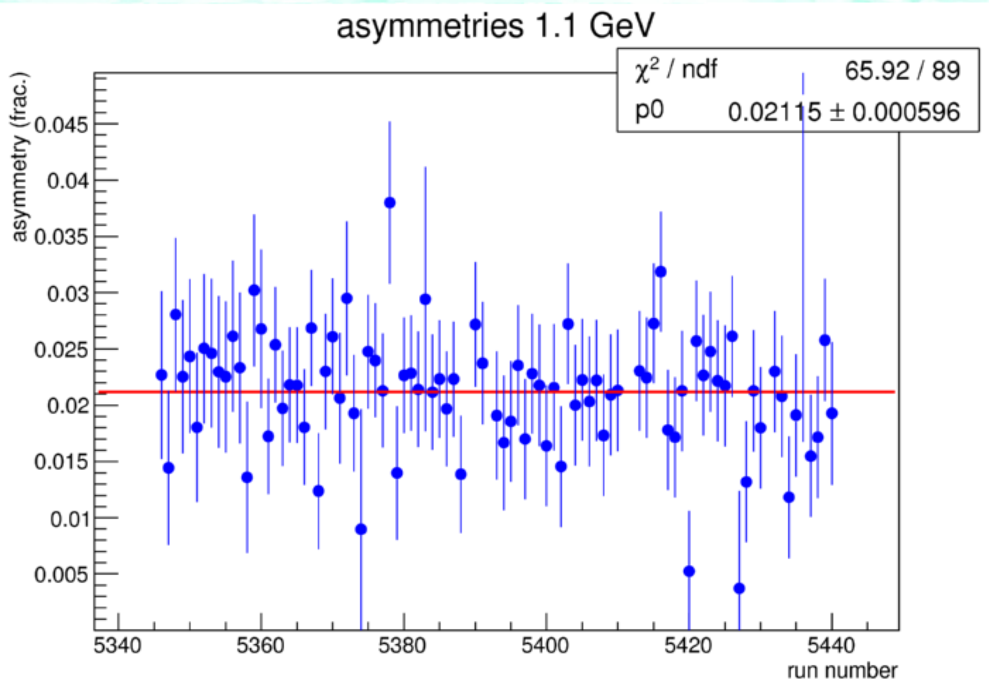
Completed:

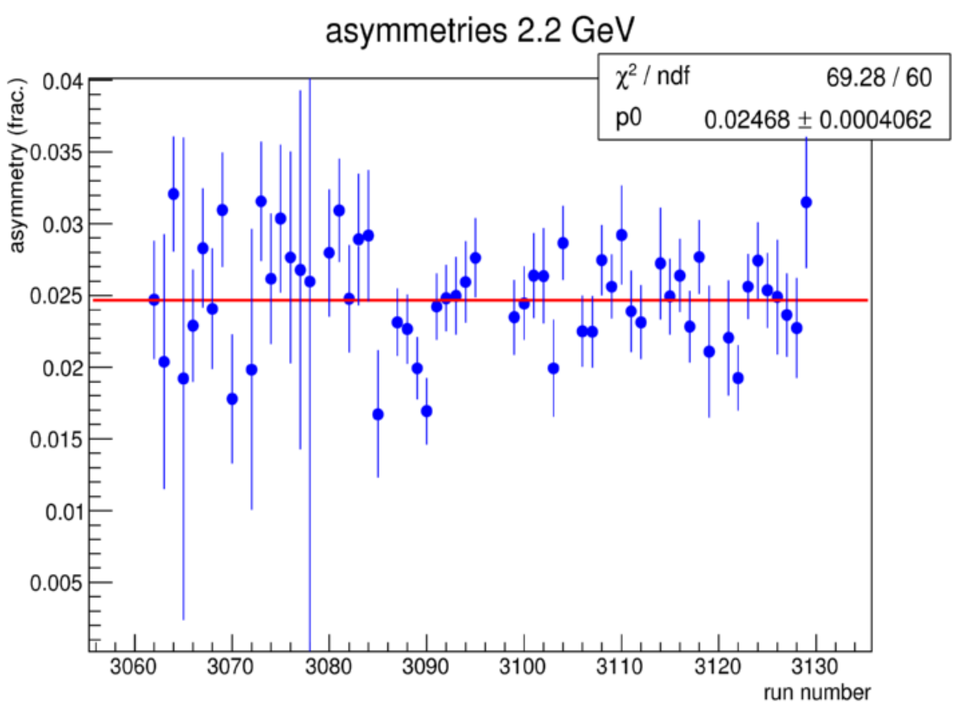
- Run database
- Beamline
  - BCM calibration
  - BPM calibration
  - Helicity decode
  - Dead time calculation
- Detector Calibration
  - Gas Cerenkov
  - Lead Glass
  - Trigger efficiency
- Target Polarization Analysis
- HRS Optics
  - Straight through
  - With target field -Left arm
- g2p simulation package:
  - Geometry and optics part for optics
  - Cross section models
  - Energy loss models

Ongoing:

- HRS Optics
  - With target field - Right arm
- Acceptance study
- Packing fraction
- Dilution
- g2p simulation
  - Match data with simulation

Summary for GEp Analysis status





Experimental asymmetries

Left arm		cut I		cut II	
energy (GeV)	Q2 (GeV2)	A (%)	ΔA/A (%)	A (%)	ΔA/A (%)
1.1	0.013	2.11	2.8	1.87	3.5
1.7	0.027	1.5	2.4	1.55	2.4
	0.039	2.32	2.7	2.44	3.18
2.2	0.045	1.78	1.5	1.91	1.7
	0.065	2.47	1.6	2.56	2.0

- Asymmetries behave as expected, although too low, probably due to dilution analysis procedure.
- Final uncertainties expected to be ~1%-2% statistical and ~3% systematical.

g2p collaboration

Spokesperson
Alexander Camsonne
Jian-ping Chen
Don Crabb
Karl Slifer

Post Docs
Kalyan Allada
Jixie Zhang
Vince Sulkosky
Ellie Long
James Maxwell

Graduate Students
Toby Badman
Melissa Cummings
Chao Gu
Min Huang
Jie Liu
Pengjia Zhu
Ryan Zielinski

Thank You!

Pengjia Zhu

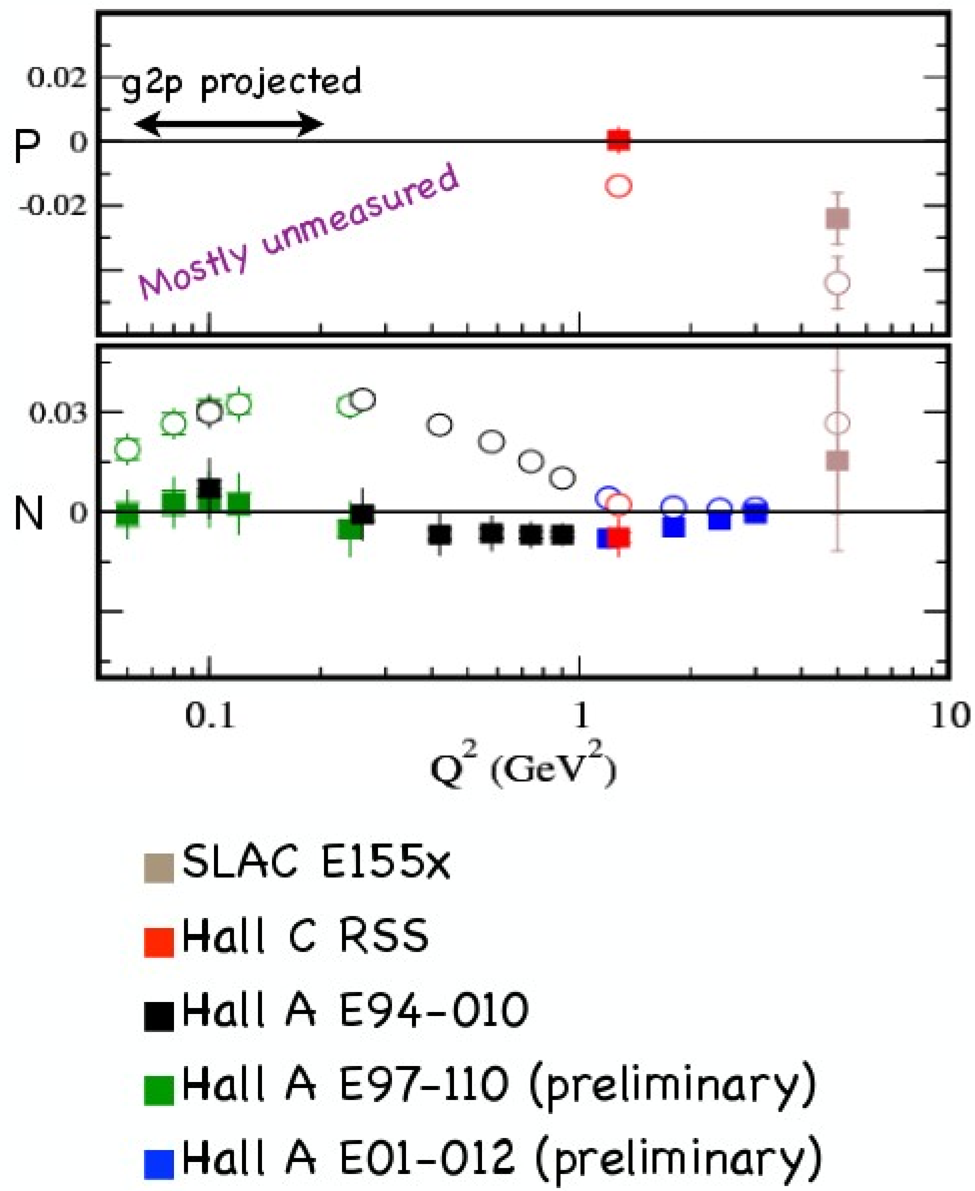
GEp collaboration

Spokesperson
Adam Sarty
Donal Day
Douglas Higinbotham
Guy Ron
John Arrington
Ronald Gilman

Graduate Student
Moshe Friedman

backup

g2p motivation



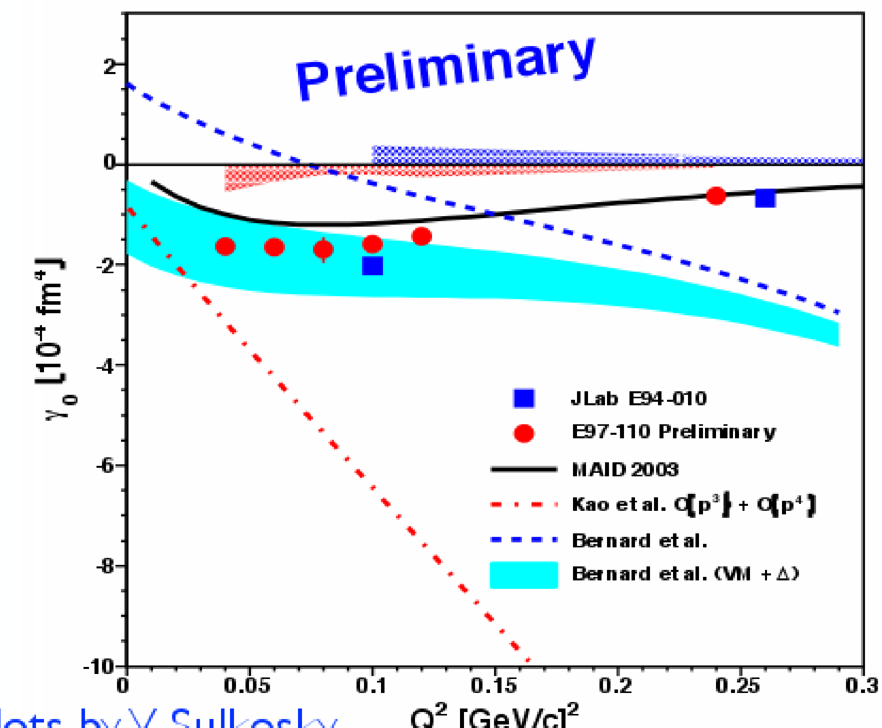
- BC Sum Rule

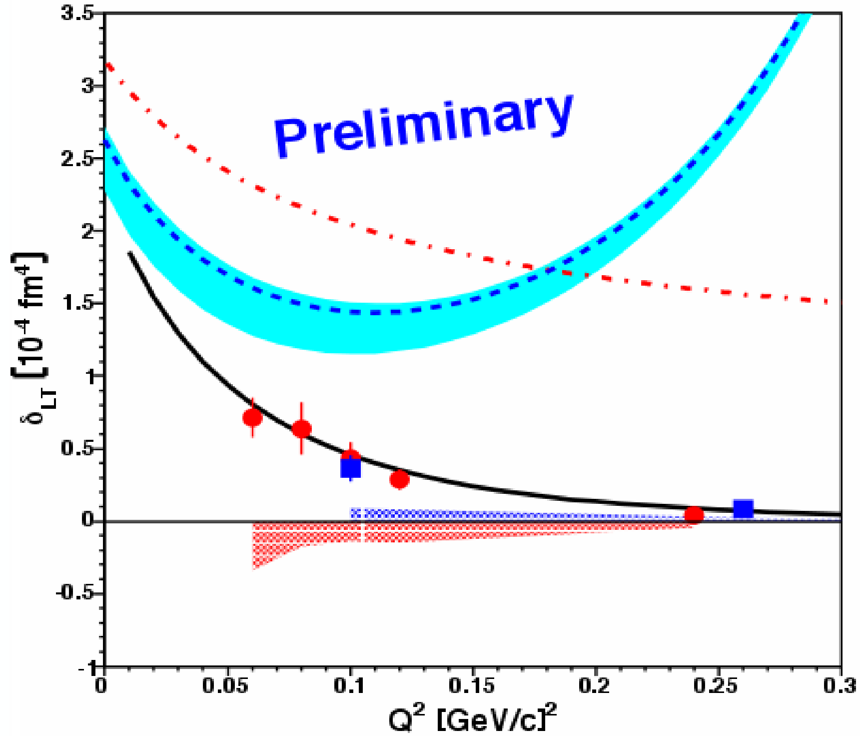
$$\int_0^1 g_2(x, Q^2)\mathrm{d}x = 0$$

g2p motivation

- δ_{LT} is seen as a more suitable testing ground of χPT – insensitive to Δ resonance
- Significant disagreement between data and both χPT calculations
- No proton data yet

$$\delta_{LT}(Q^2) = \frac{16\alpha M^2}{Q^6}\int_0^{x_0} x^2[g_1 + g_2]\mathrm{d}x$$





Plots by Y. Sulkosky

g2p motivation

Hydrogen Hyperfine Splitting

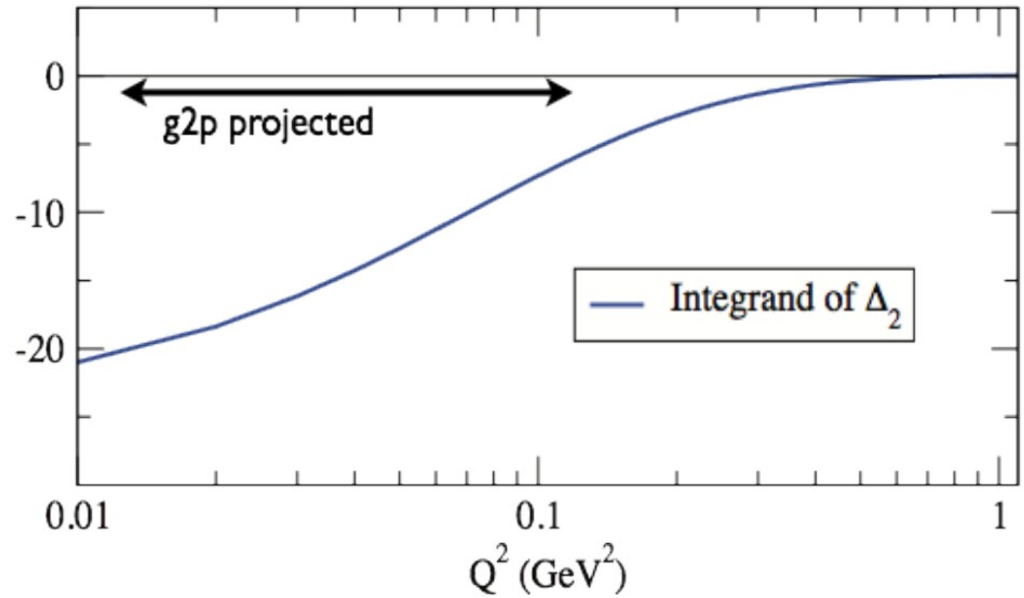
$$\Delta E = (1+\delta)E_F$$
$$\delta = \delta_{\text{QED}} + \delta_R + \delta_{\text{small}} + \Delta_S$$

δ_{QED}:QED radiative correction
δ_D:recoil effect
δ_{small}:hardronic/muonic vac pol,weak

- Δ_s is largest portion of theoretica

$$\Delta_S = \Delta_Z + \Delta_{pol}$$

$$\Delta_{\text{pol}} = \frac{\alpha m_e}{\pi g_p m_p}(\Delta_1 + \Delta_2)$$



Δ_2 is dominated by low Q^2 g_2^p

GEp motivation

(Part I)

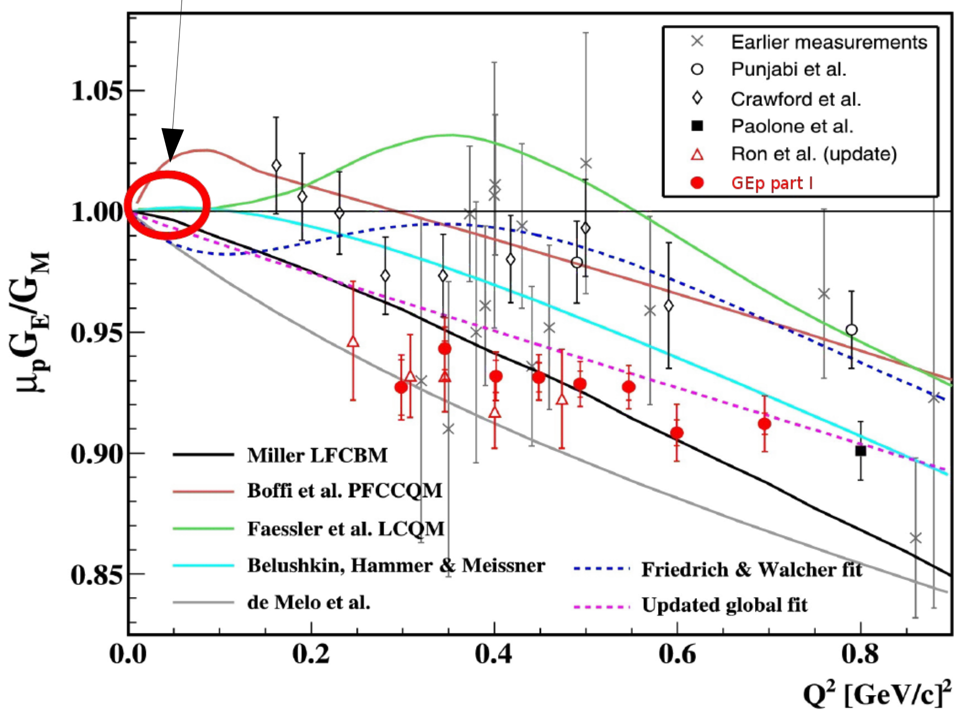
Recoil Polarization

$$I_0 P_t = -2\sqrt{\tau(1+\tau)}\,G_E G_M \tan\frac{\theta_e}{2}$$

$$I_0 P_l = \frac{E_e + E_{e'}}{M}\sqrt{\tau(1+\tau)}\,G_M^2 \tan^2\frac{\theta_e}{2}$$

$$\mathcal{R} \equiv \mu_p \frac{G_E}{G_M} = -\mu_p \frac{P_t}{P_l}\frac{E_e + E_{e'}}{2M}\tan\frac{\theta_e}{2}$$

GEp part II

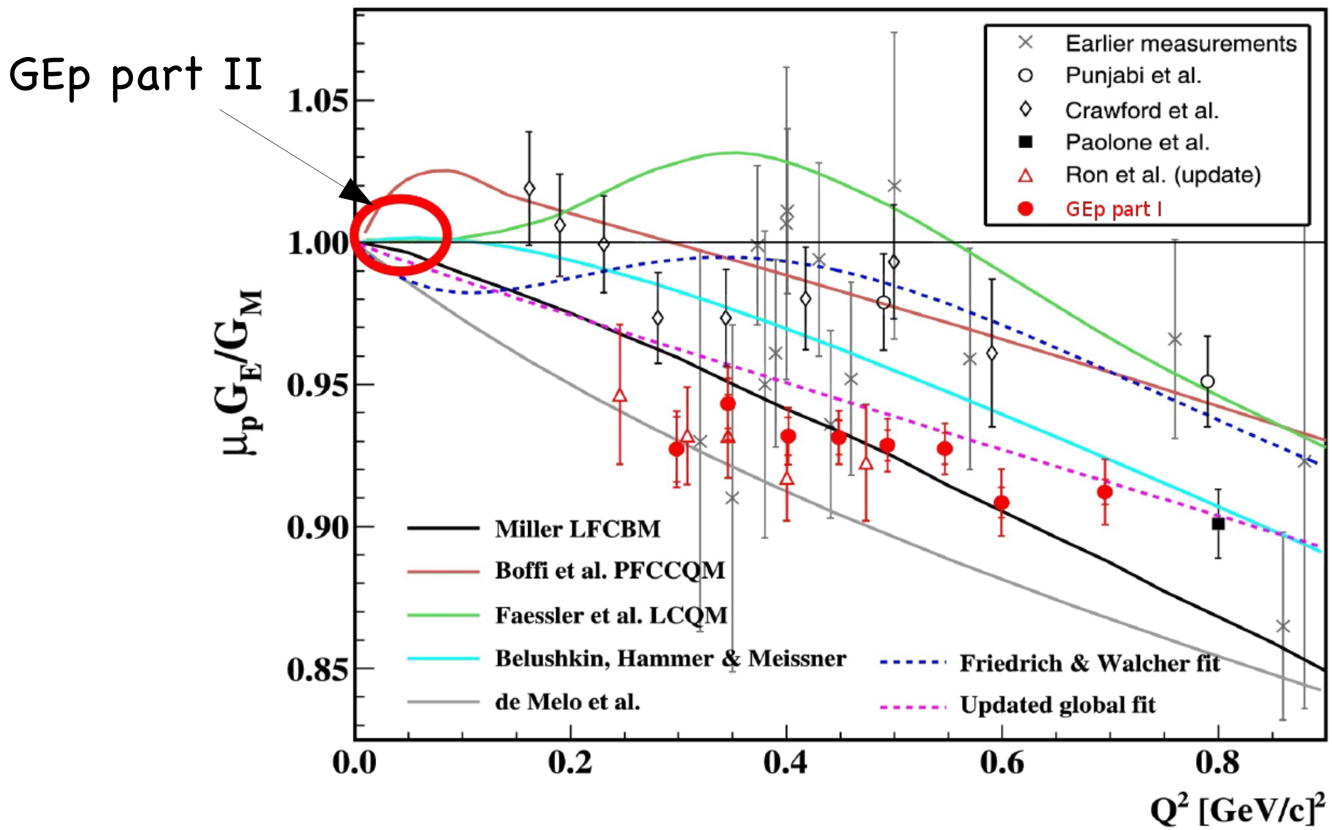


X. Zhan, et al. Phys. Lett. B 705(2011) 59

~1% uncertainty at Q^2~ 0.3 - 0.7 GeV^2

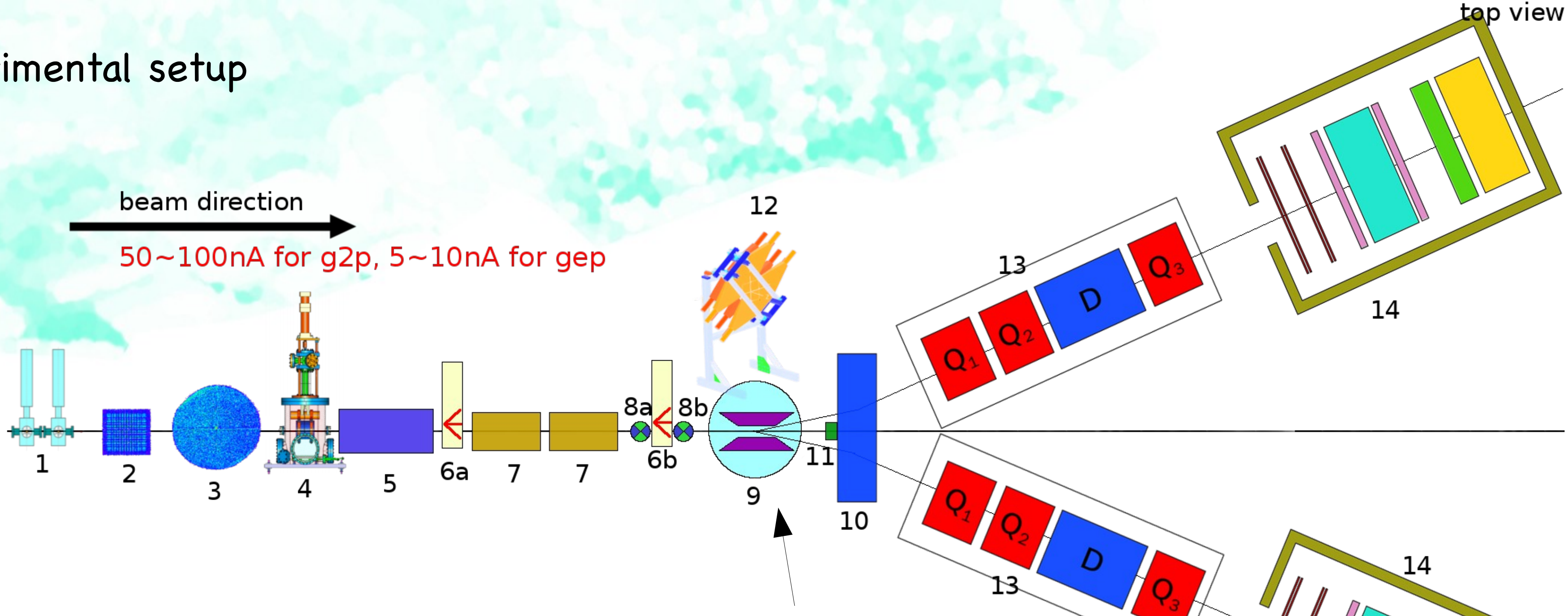
GEp motivation

~2%-3% uncertainty at Q^2~ 0.015 - 0.06 GeV^2

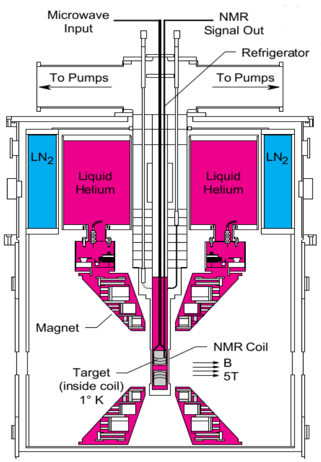


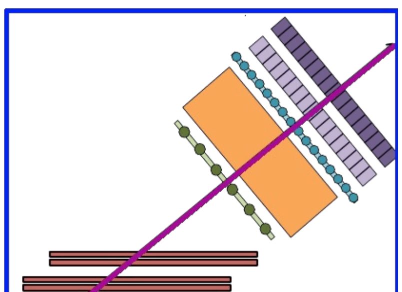
X. Zhan, et al. Phys. Lett. B 705(2011) 59

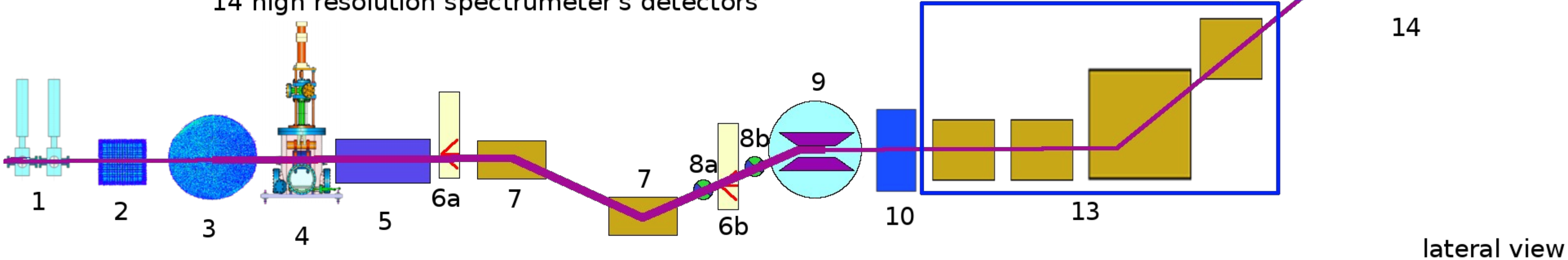
Experimental setup



1 beam current monitor
2 fast raster
3 slow raster
4 tungten calorimeter
5 moller polarimeter
6a super harp(named 1H04)
6b super harp(named 1H05A)
7 chicane dipole
8a beam position monitor(BPM A)
8b beam position monitor(BPM B)
9 NH3 target
10 septum magnet
11 local beam dump
12 third arm detector
13 high resolution spectrumeter's dipole and quadroples
14 high resolution spectrumeter's detectors

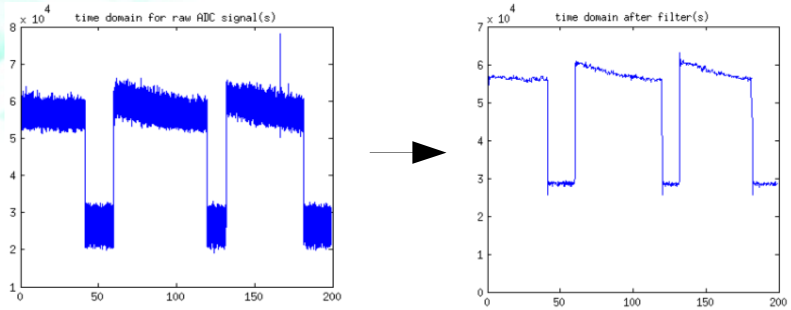




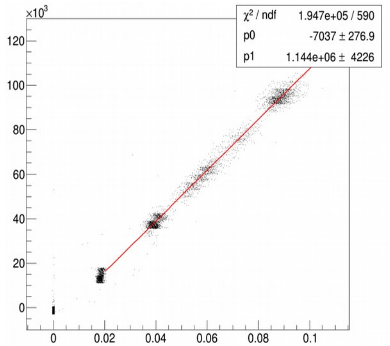


Beam position reconstruction

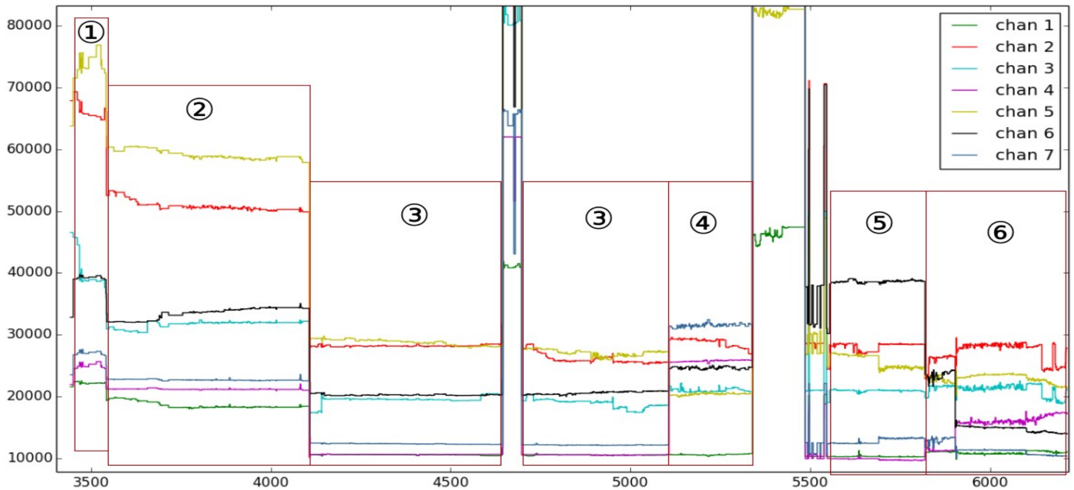
- **BPM Calibration**
  - 2Hz software filter
    - get better resolution
  - Current vs ADC value fit at same position
    - $\varphi = f(A - A_{ped}) = a(A - A_{ped} + b)$
    - remove current effect
  - BPM pedestal fluctuation during experiment
    - use nearest pedestal value for each run
- **Beam position reconstruction at target**
  - Fitted function using target field map to transport position from BPMs to target
  - Event by event position and angle at target position
    - $X = \langle X_{BPM} \rangle + X_{fast} + X_{slow}$
  - Use Carbon hole to calibrate slow raster
- **Uncertainty**
  - Best situation: 1mm for position, 1.1mrad for angle
  - Main uncertainty part:
    - Pedestal fluctuation
    - Too close for two BPMs – 95.5cm vs 69cm upstream of target



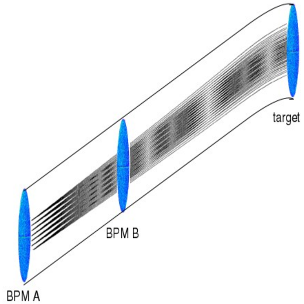
2Hz software filter



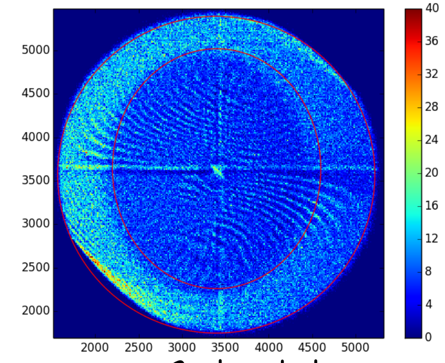
Current vs position



BPM pedestal fluctuation during experiment

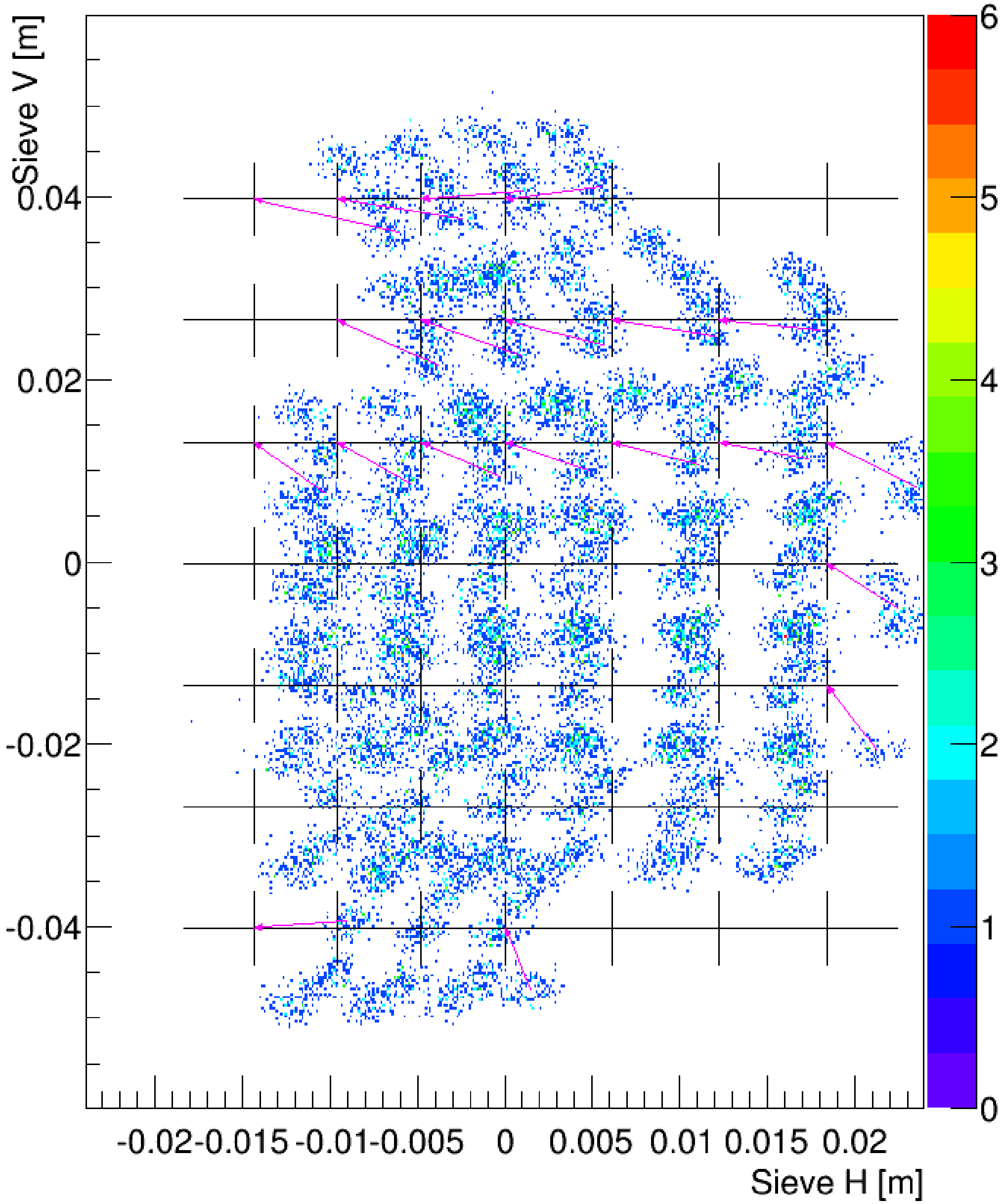


Position transport to target

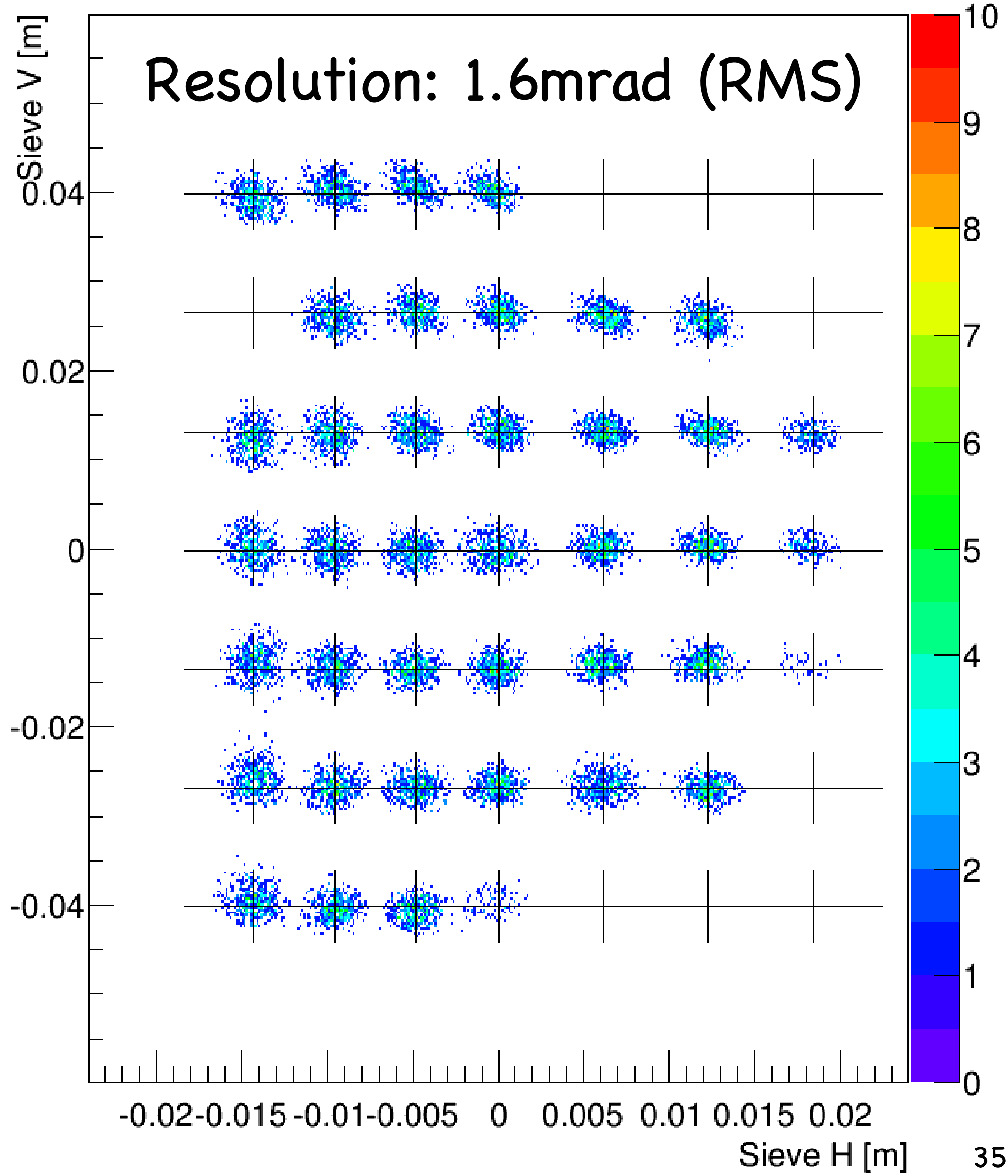

Carbon hole

Matrix Calibration: Angle

Before Calibration



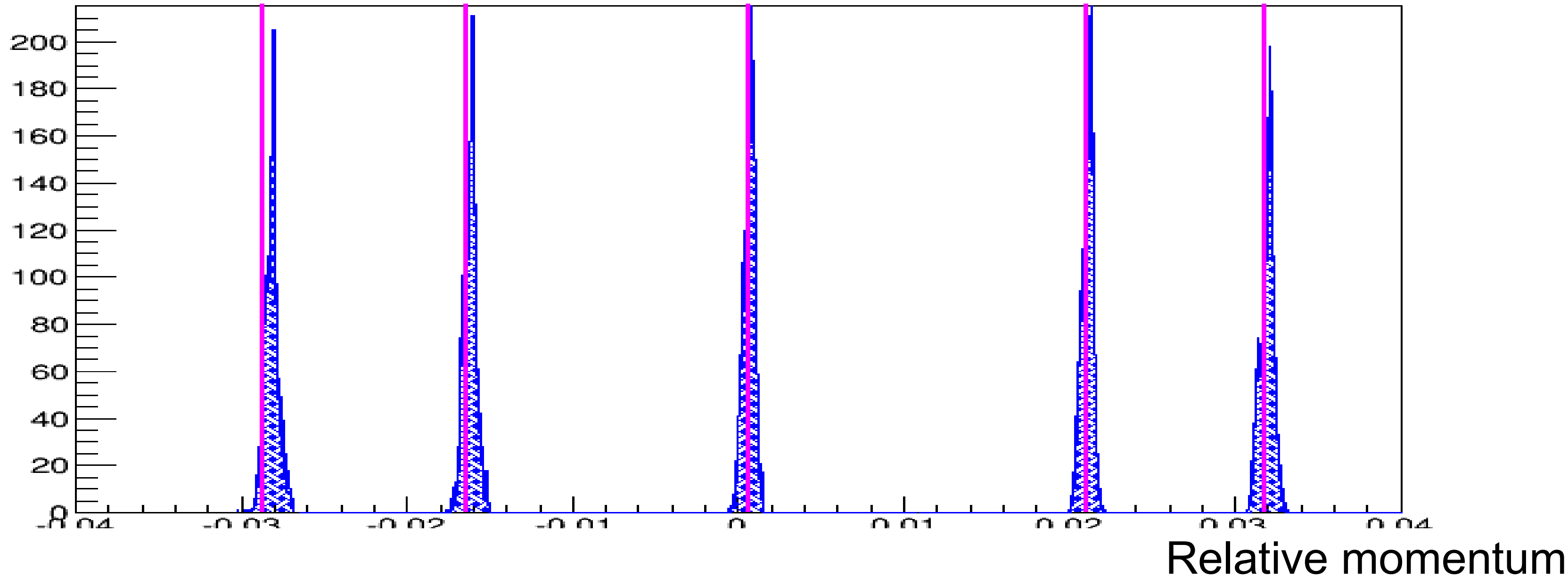
After Calibration



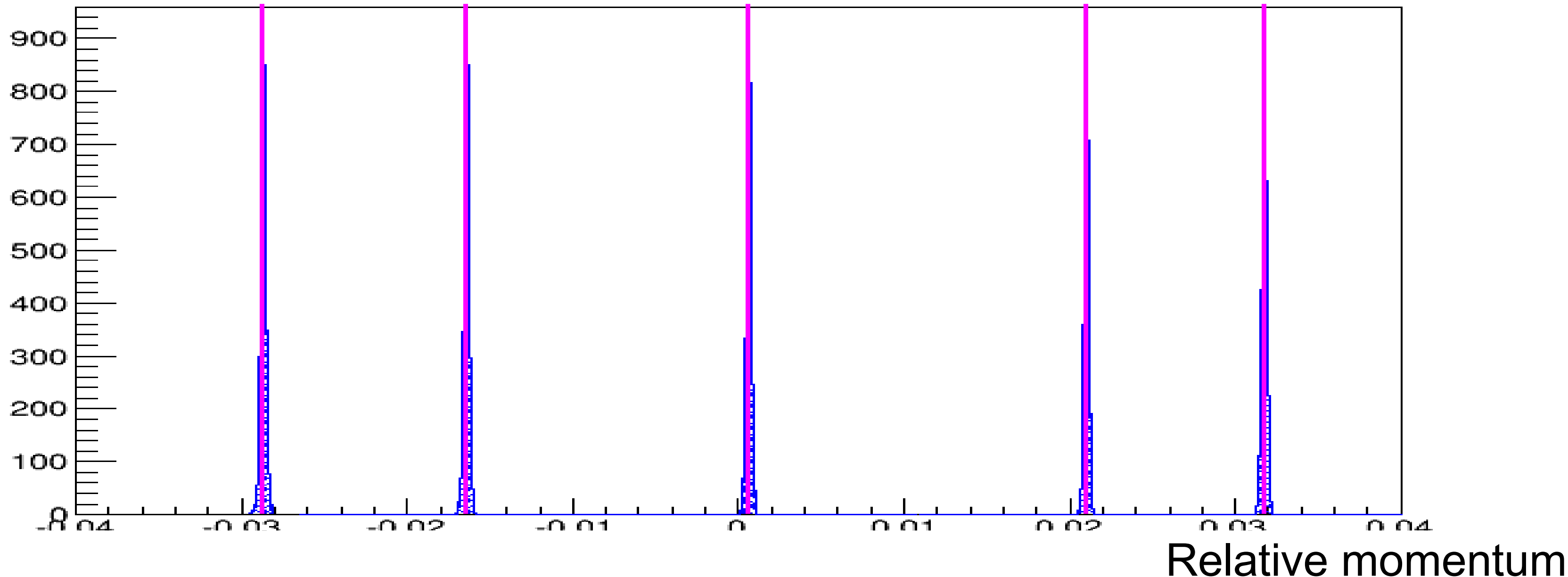
Matrix Calibration: Momentum

Before Calibration

RMS: 1.5×10^{-4}



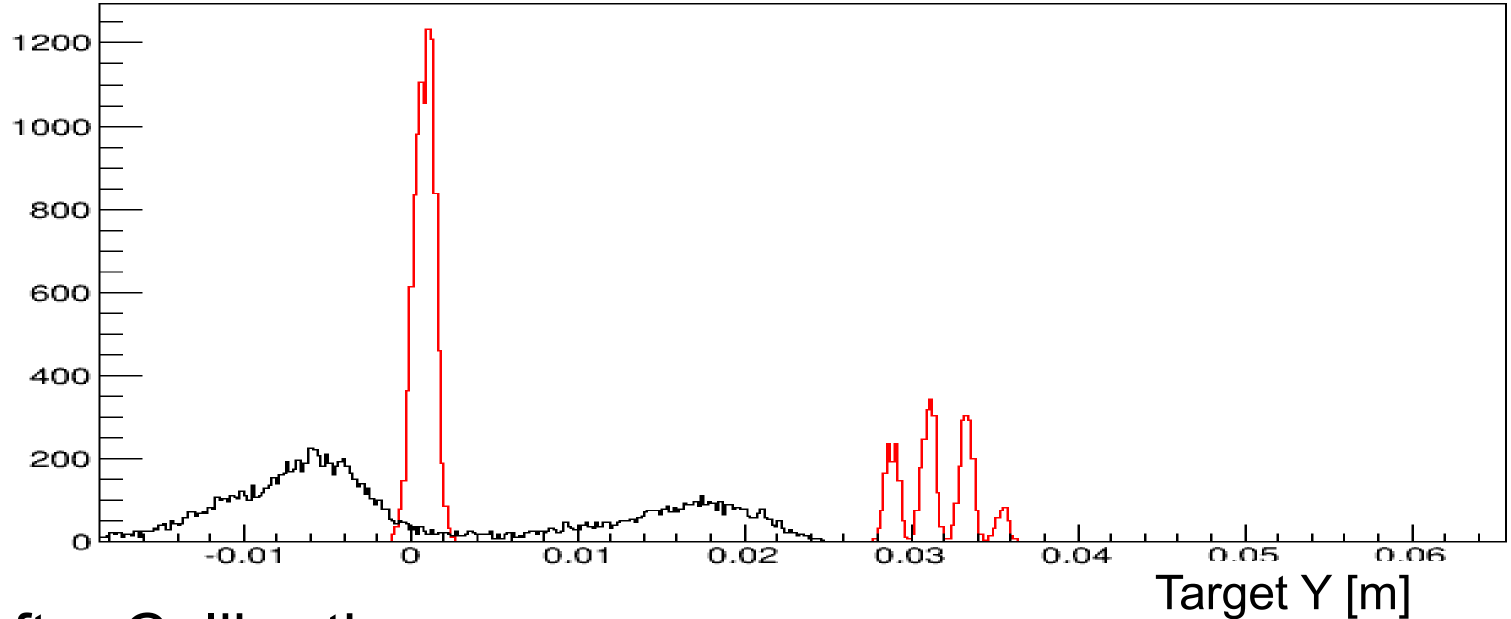
After Calibration



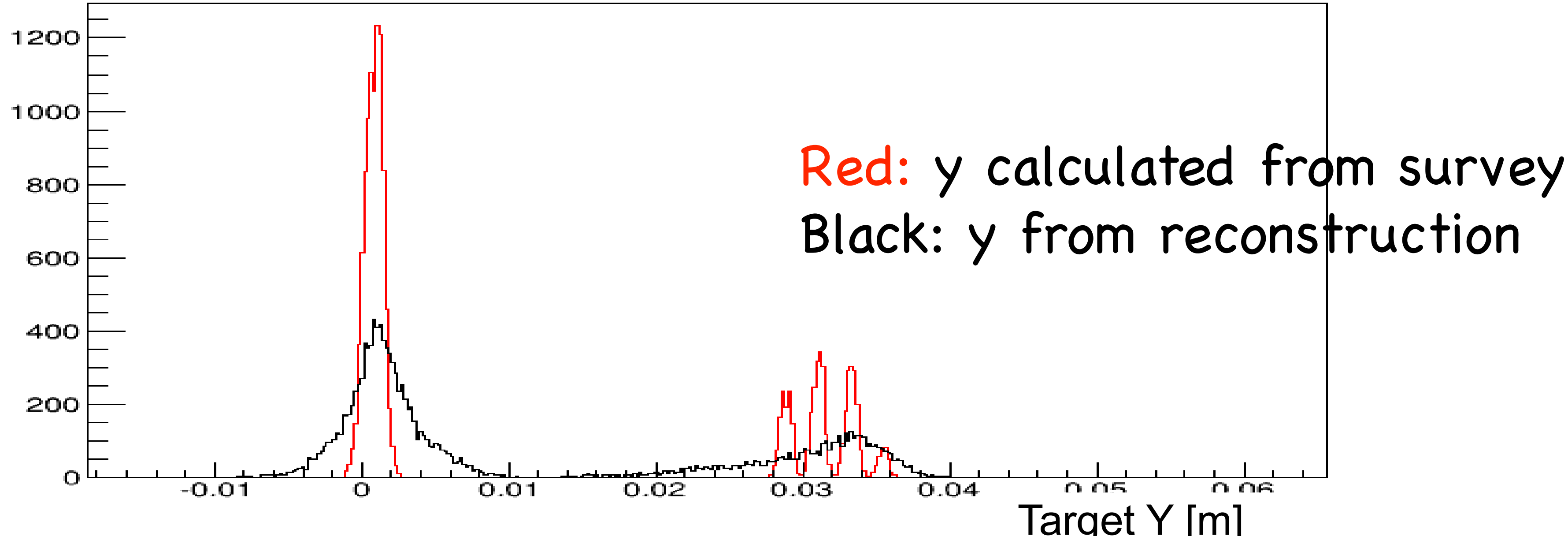
Matrix Calibration: y

Before Calibration

RMS: 3.3mm



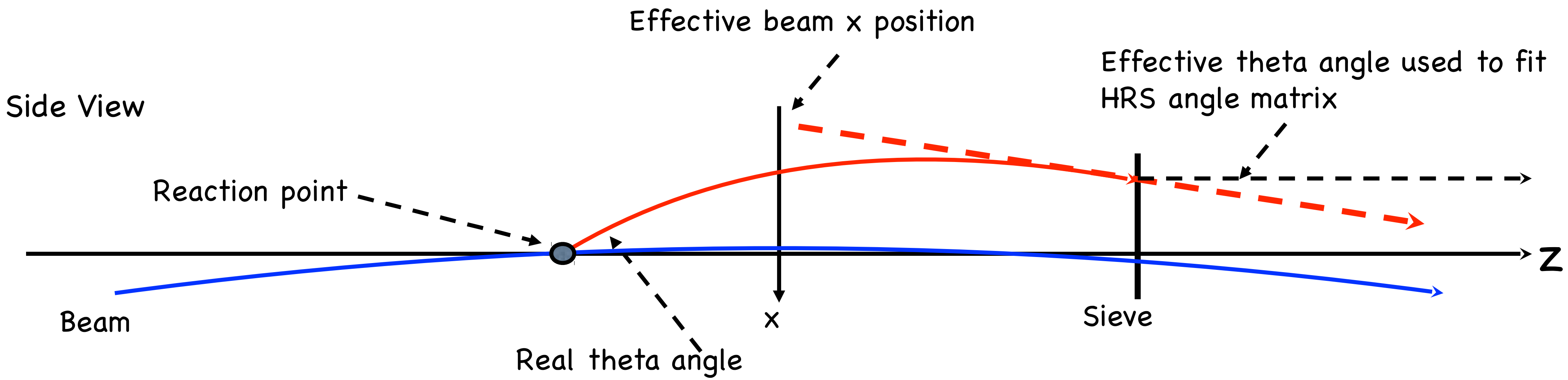
After Calibration



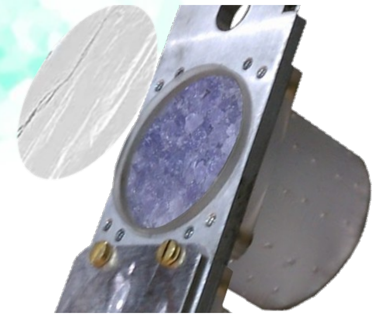
HRS Optics - with field

- Know beam position at reaction point , the position of sieve slit hole, and target field map
  - Get the effective angle at sieve slit
  - Linear backward position at sieve to target plan to get effective position
  - Fit matrix between effective variables and focal plan variables

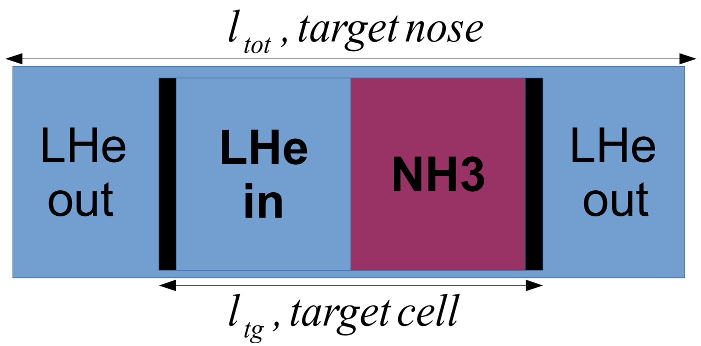
- Reconstruction for each production run:
  - Use fitted matrix to get effective variables at target plan for each events
  - Linear forward to sieve position
  - Use field map to traject the effective variables to real reacting variables



Packing fraction -> effective NH3 target thickness
NH3 beads filled by liquid He



Define: $p_f = 1 - \frac{Y_{He}^{\mathrm{in}}}{Y_{tg}}$



$$Y_{He}^{\mathrm{in}} = \frac{l_{tg}}{l_{tot}} Y_{dummy}$$

Yield from He inside cell if only He in cell

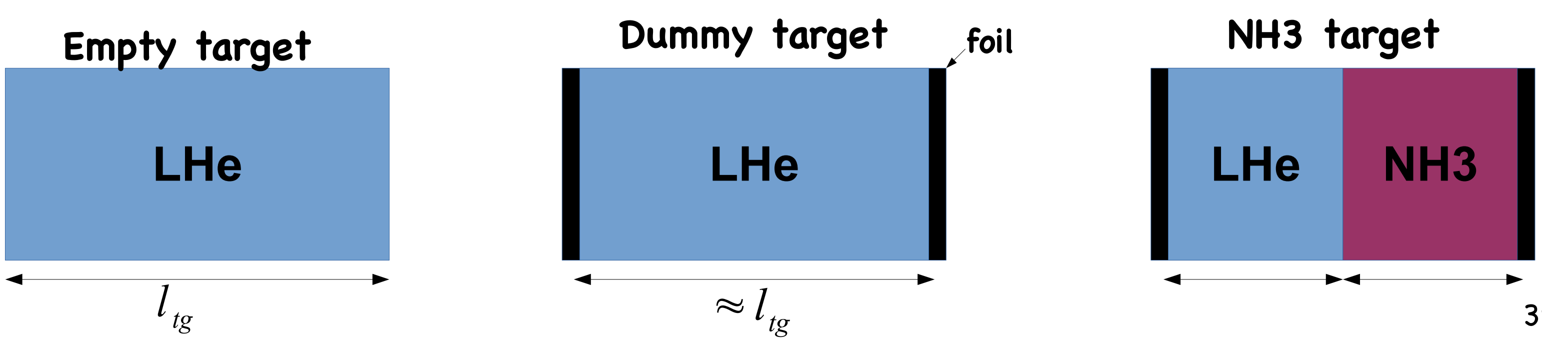
$$Y_{tg} = Y_{\mathrm{prod}} - Y_{He}^{\mathrm{out}}$$

Yield from materials within the target cell

$$Y_{He}^{\mathrm{out}} = \frac{l_{tot} - l_{tg}}{l_{tot}} Y_{dummy}$$

Assumes uniform acceptance throughout

$Y_{\mathrm{prod}}, Y_{dummy}$ From N and He elastic peak



Dilution

$$A_{raw}=\frac{Y_{+}-Y_{-}}{Y_{+}+Y_{-}+bg}$$

$$A_{phy}=\frac{1}{P_b P_t D}*A_{raw}$$

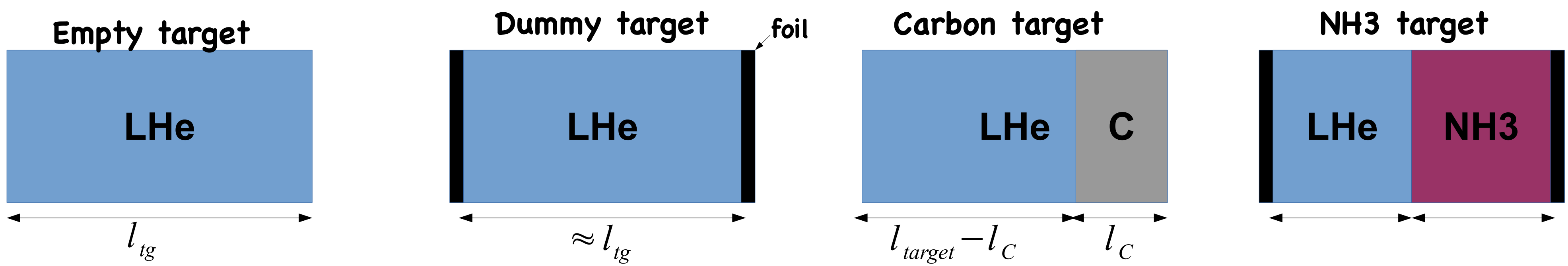
$$D=1-\frac{Y_N+Y_{He}+Y_f}{Y_{total}}$$

$Y_{+/-}$ Yield from proton

$bg=Y_N+Y_{He}+Y_f$ Yield from N, He, foil

$P_b P_t$ Polarization of beam and target

D Dilution factor



$$Y_f=Y_{dummy}-Y_{empty}$$

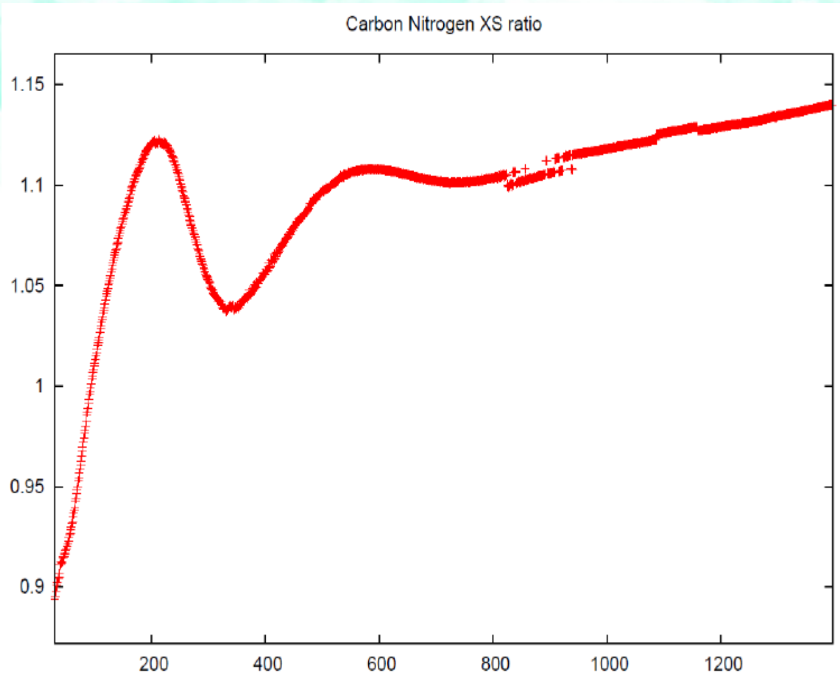
$$Y_{He}=(1-p_f)\alpha Y_{empty}$$

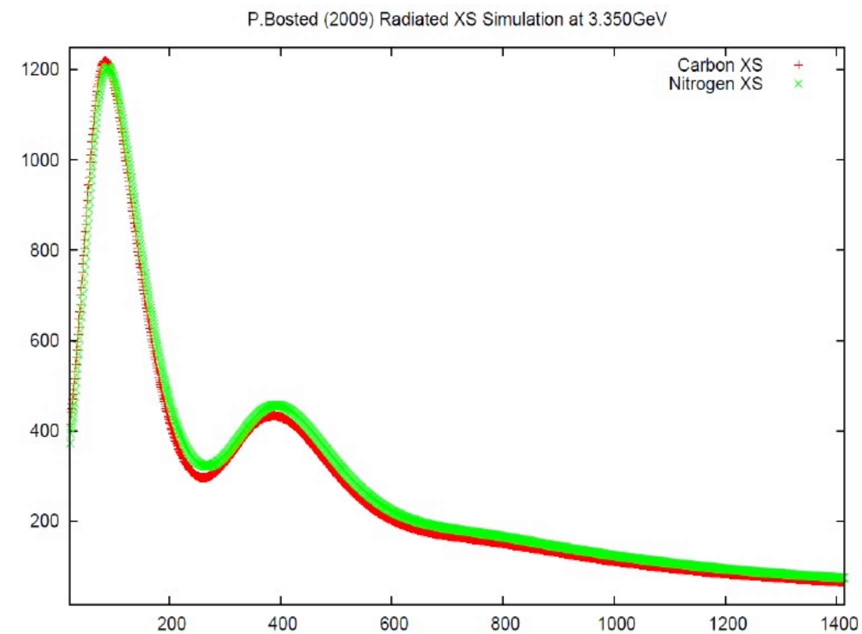
α,β,γ Used to scale material radiation lengths

$$Y_N=\gamma p_f\frac{\rho_N l_{tg} M_C}{\rho_C l_C M_N}\left(Y_C-\left(1-\frac{l_C}{l_{tg}}\right)\beta Y_{empty}\right)$$

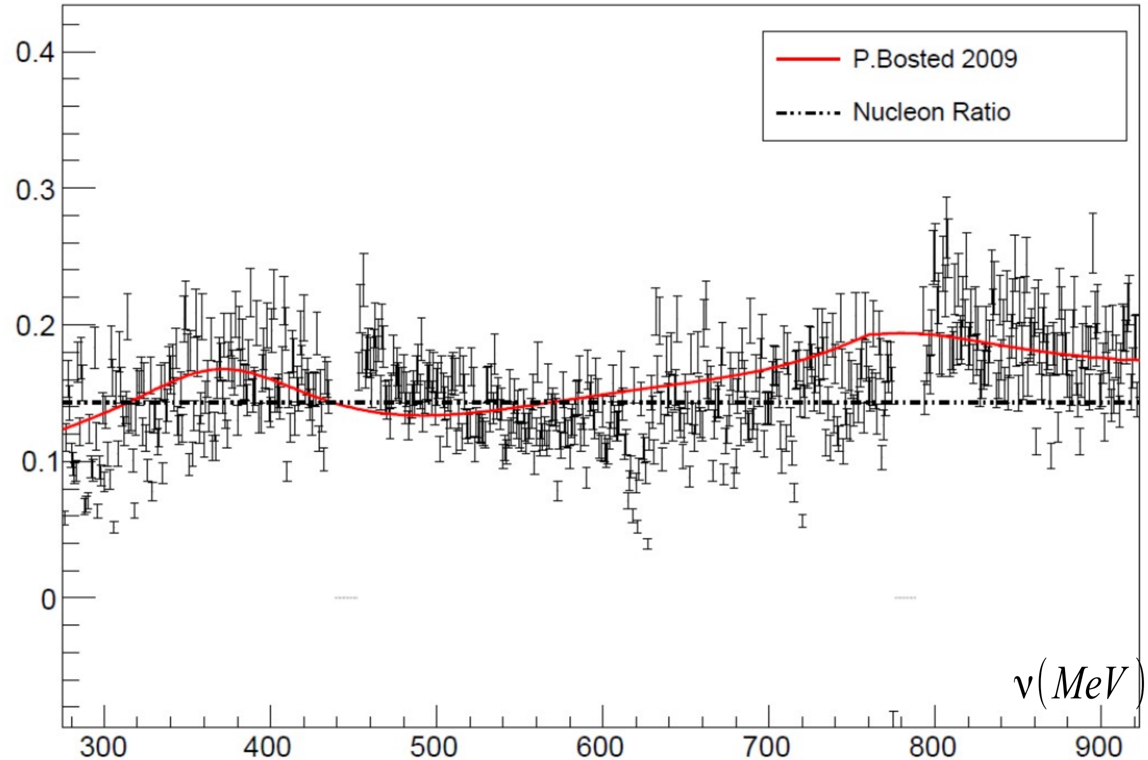
From carbon nitrogen xs ratio

Dilution





Current result:
3.350GeV 5T Transverse Dilution result



- Still Ongoing