E12-07-108 (GMp)
Precision Measurement of the Proton Elastic Cross Section at High Q^2

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On behalf of the GMp Collaboration

Hall A Collaboration Meeting
January 18, 2017

GMp collaboration

- Hall A collaboration, physics staff, technical staff, accelerator team and shift taker
- Spokesperson: J. Arrington, E. Christy, S. Gilad, V. Sulkosky, B. Wojtsekhowski (contact)
- Postdoc: Kalyan Allada (MIT)
- Graduate students: Thir Gautam (Hampton U.), Longwu Ou (MIT), Barak Schmookler (MIT), Yang Wang (W&M)

Preview

- Highlights:
  - → Better than 2% statistics
  - → High Q^2(up to 16 GeV/c^2)
  - → Relatively low ϵ: the contributions from G_E^p is smaller than those for the large ϵ SLAC data
  - → Multiple kinematic settings over the range of Q^2
- Calibration of detectors is nearly complete
- First pass analysis is in progress
- We project data analysis to be completed in a year

Outline

- Physics and experimental goals of GMp
- Hall A beamline, spectrometer and detectors
- Statistics collected
- Calibration and data analysis status
- Preliminary cross-section results
- Status and timeline to complete

Proton magnetic form factor

- Form factors encode electric and magnetic structure of the target

→ At low Q^2, form factors characterize the spatial distribution of electric charge and magnetization current in the nucleon

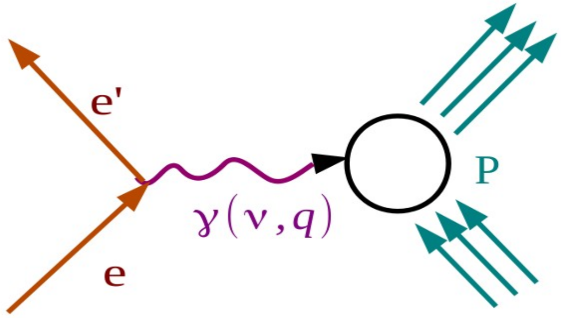
$$|\text{Form Factor}|^2 = \frac{\sigma(\text{Structured object})}{\sigma(\text{Point like object})}$$

$$\mathcal{J}_{\text{proton}} = e\bar{N}(p')\left[\gamma^{\mu}F_1(Q^2) + \frac{i\sigma^{\mu\nu}q_{\nu}}{2M}F_2(Q^2)\right]N(p)$$

$$G_E = F_1 - \tau F_2 \qquad G_M = F_1 + F_2$$

- In one photon exchange approximation the cross-section in *ep* scattering when written in terms of G_M^p and G_E^p takes the following form:

$$\frac{d\sigma}{d\Omega} = \sigma_{Mott}\frac{\epsilon(G_E^p)^2 + \tau(G_M^p)^2}{\epsilon(1+\tau)}, \quad \sigma_{Mott} = \frac{\alpha^2\cos^2\frac{\theta}{2}}{4E^2\sin^4\frac{\theta}{2}}\frac{E'}{E}$$



Where,

$$\tau = \frac{Q^2}{4M^2}, \quad \epsilon = [1 + 2(1+\tau)\tan^2(\frac{\theta}{2})]^{-1}$$

Goals of GMp experiment as approved

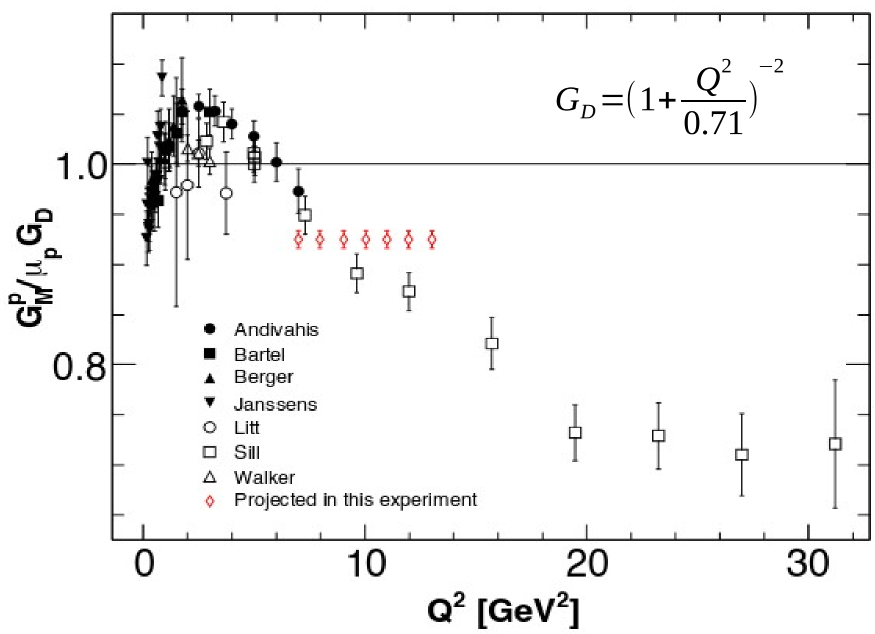
- Precision measurement of the elastic *ep* cross-section in the Q^2 range of 7-14 GeV^2 and extraction of proton magnetic form factors

➢ To improve the precision of prior measurement at high Q^2

➢ To provide insight into scaling behavior of the form factors at high Q^2

Statistical: Better than 2%

Systematic:
Point to point: 0.8-1.1%
Normalization: 1.0-1.3%
Total Error Budget: 1.2 -2.6%



Need a good control on:

- Beam charge
- Beam position
- Scattering angle, target density, ...

Hall A beamline, spectrometer and detectors

→ RHRS SOS Quad is replaced by new quad

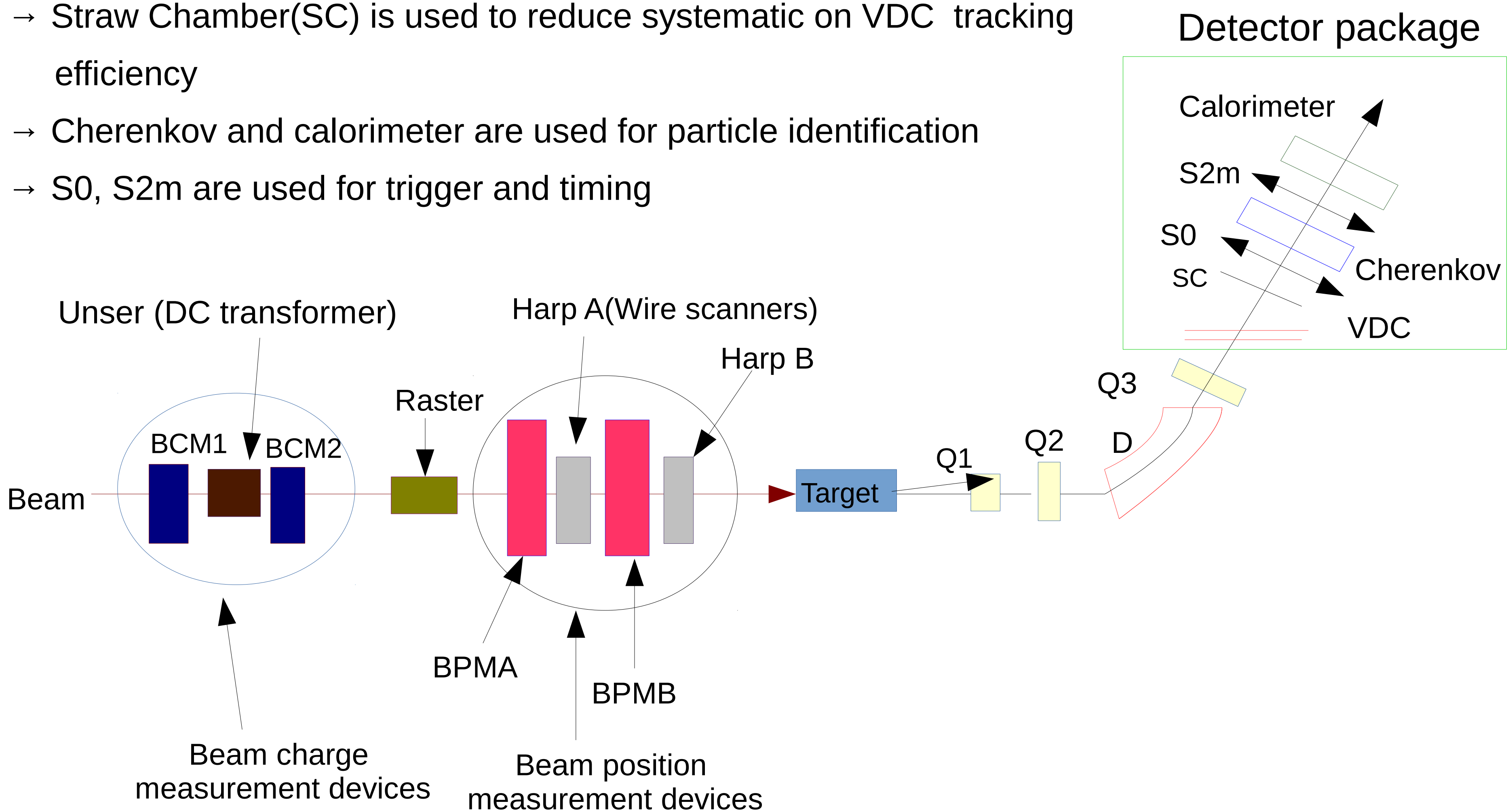
→ The SOS Quad is installed in LHRS

→ VDC is used for tracking information

→ Straw Chamber(SC) is used to reduce systematic on VDC tracking efficiency

→ Cherenkov and calorimeter are used for particle identification

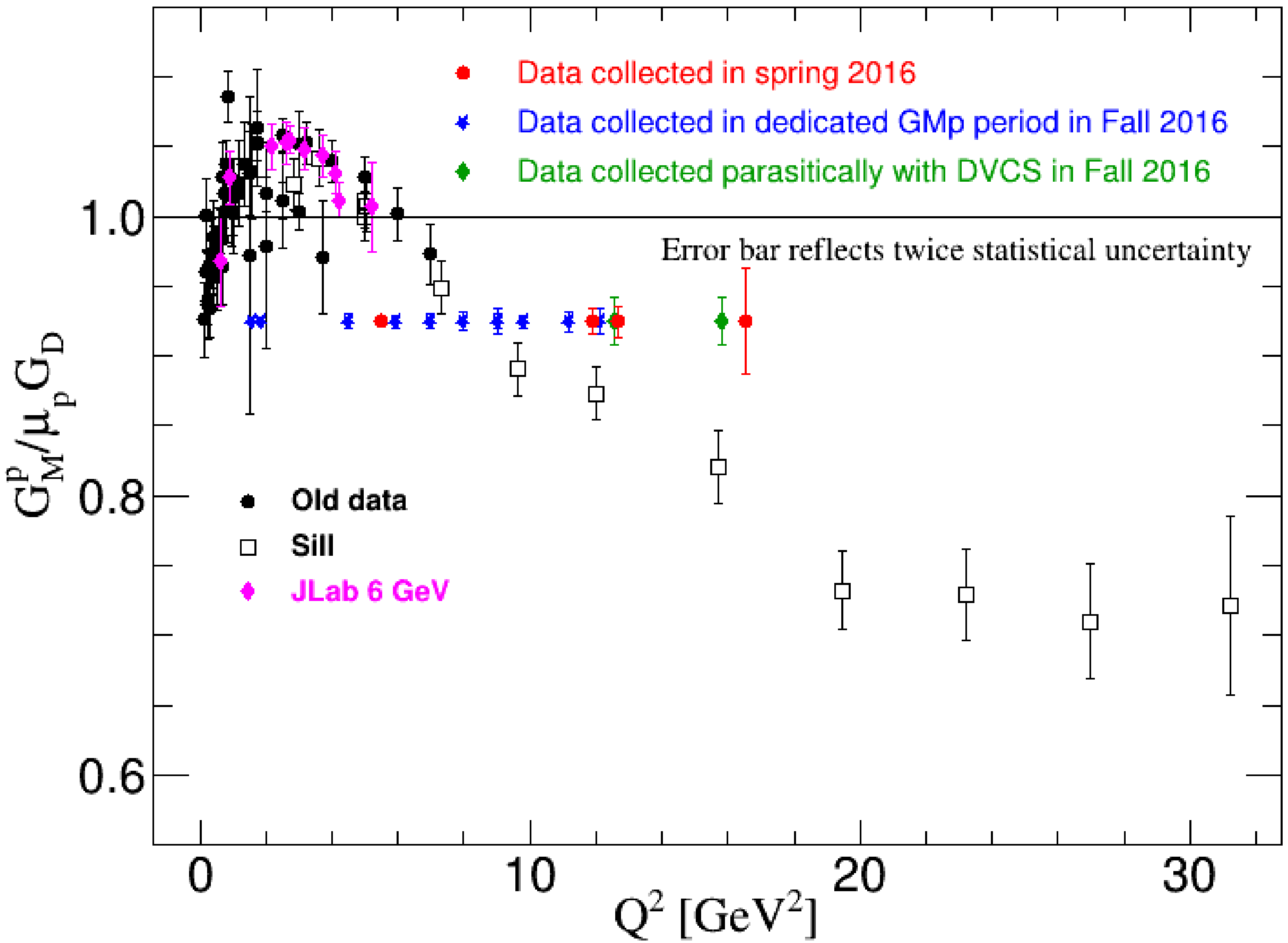
→ S0, S2m are used for trigger and timing



GMp calibration and systematic studies

- Calibration of beamline components
  - → Beam position: BPMs and raster
  - → Beam charge and current: Unser and BCMs
- Calibration of spectrometer optics
  - → Multifoil carbon target with and without sieve slits
  - → Spectrometer momentum (Delta scans)
- Beam energy measurements
- Target boiling studies
- Detector acceptance, efficiency and reconstruction analysis

GMp collected statistics



Summary of GMp collected data (I)

Spring 2015:

E_{beam} (GeV)	HRS	P_0 (GeV/c)	Θ_{HRS} (deg)	Q^2 $(GeV/c)^2$	Events(k)
2.06	R	1.15	48.7	1.65	157
2.06	L	1.22	45.0	1.51	386
2.06	L	1.44	35.0	1.1	396
2.06	L	1.67	25.0	0.66	405

Spring 2016:

E_{beam} (GeV)	HRS	P_0 (GeV/c)	Θ_{HRS} (deg)	Q^2 $(GeV/c)^2$	Events(k)
4.48	R	1.55	52.9	5.5	108
8.84	R	2.10	48.8	12.7	8
8.84	L	2.50	43.0	11.9	11
11.02	R	2.20	48.8	16.5	0.7

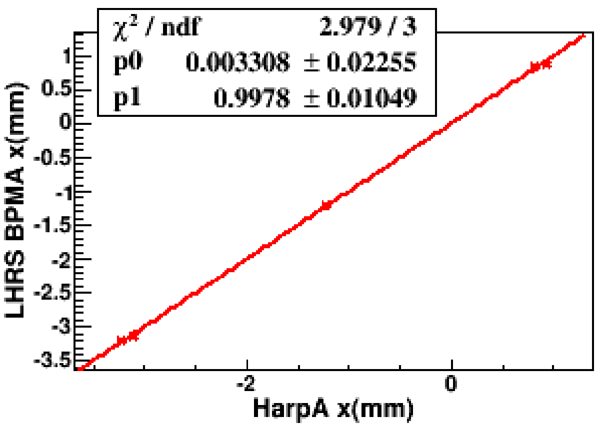
Summary of GMp collected data (II)

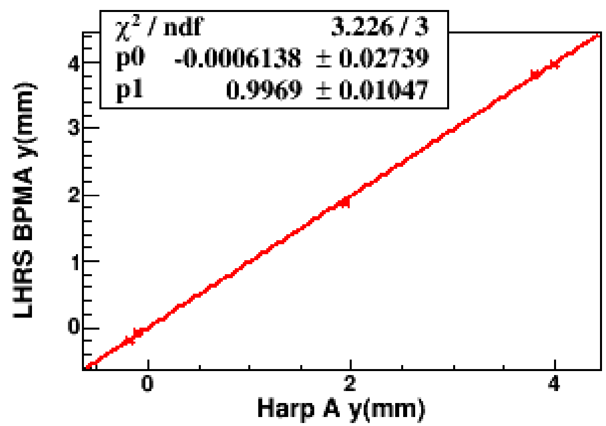
Fall 2016:

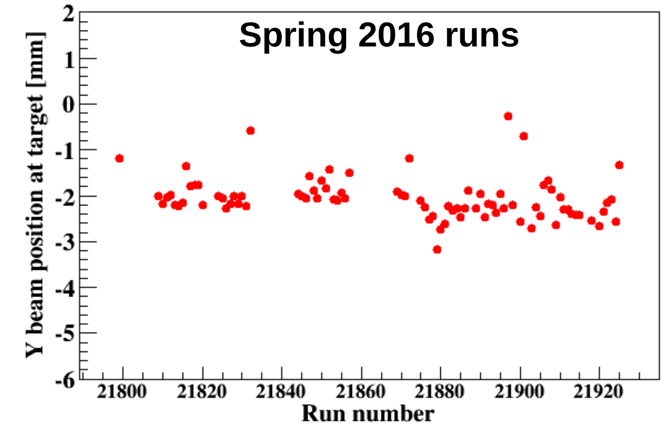
E_{beam} (GeV)	HRS	P_0 (GeV/c)	Θ_{HRS} (deg)	Q^2 $(GeV/c)^2$	Events(k)
2.22	R	1.23	48.8	1.86	356
2.22	L	1.37	42.0	1.57	2025
8.52	L	2.53	42.0	11.2	18.9
8.52	L	3.26	34.4	9.8	57.6
8.52	L	3.69	30.9	9.0	11.6
6.42	L	3.22	30.9	5.9	48.6
6.42	L	2.16	44.5	8.0	27.2
6.42	L	3.96	24.3	4.5	30.5
6.42	L	2.67	37.0	7.0	41.4
6.42	R	1.59	55.9	9.0	11.6
8.52	R	2.06	48.6	12.1	11
8.52	R	1.80	53.5	12.6	3.4
10.62	R	2.17	48.8	15.8	3.6

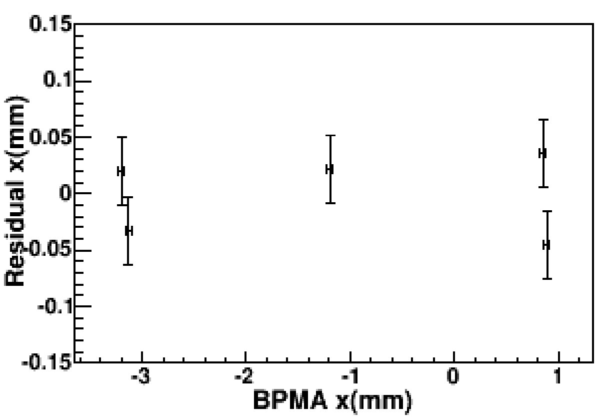
Beam position calibration

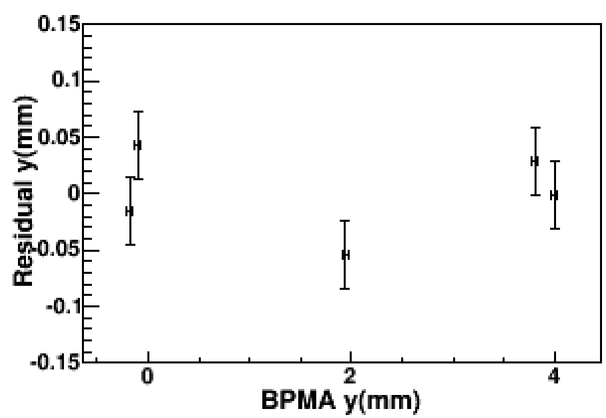
- BPMs are calibrated in Bull's eye scan runs against beam position from wire scanners
- The stability of average beam position was monitored at each kinematics

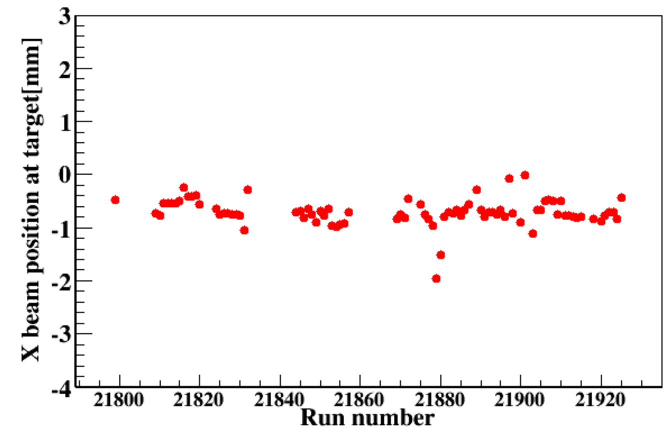












Beam charge calibration

- Multiple instruments of charge measurement: Unser and two BCMs

→ Two BCMs: Upstream and Downstream with multiple receiver per BCM

- Old style (analog): x1: u1 and d1

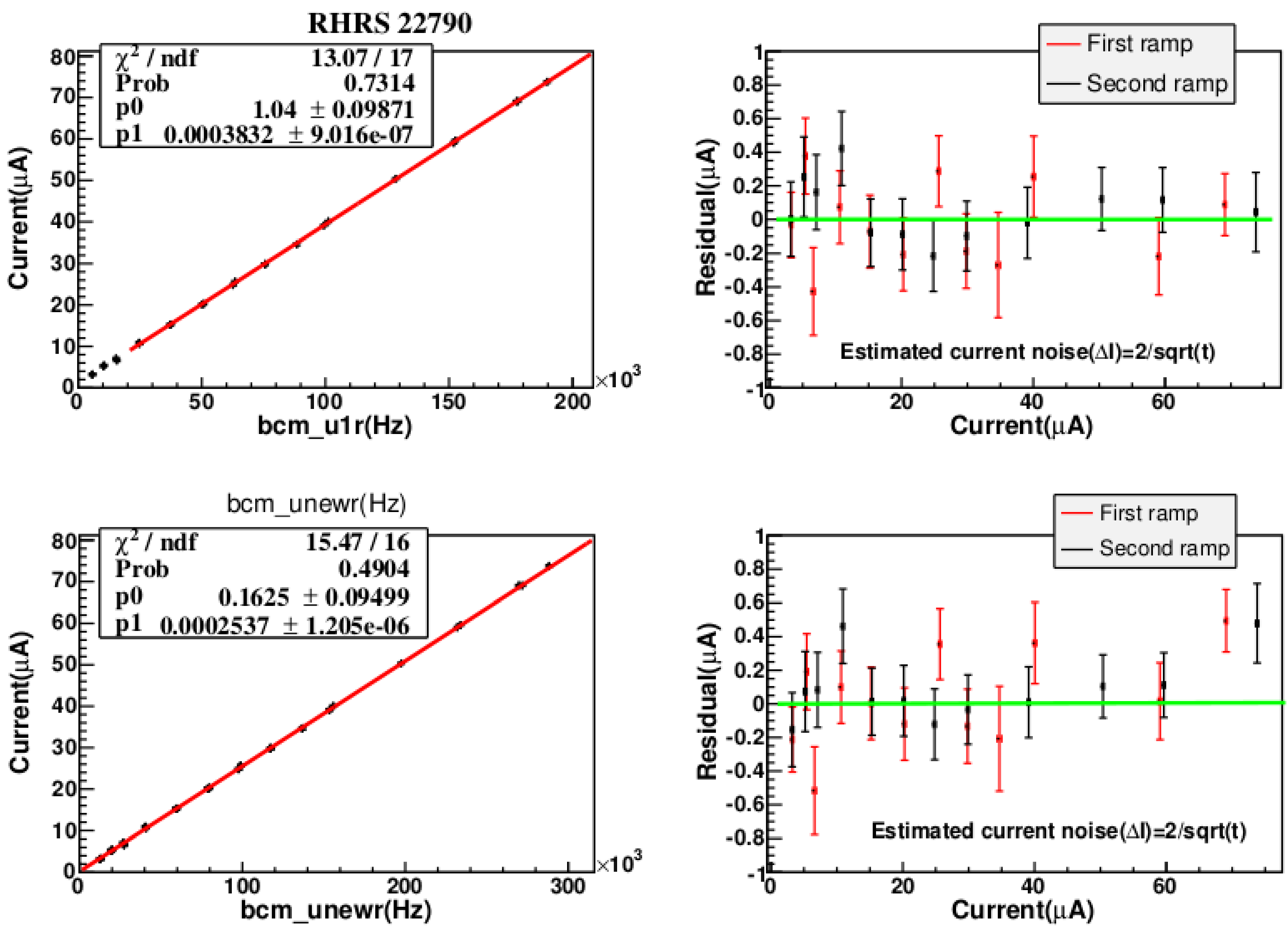
  x3: d3

  x10: d10

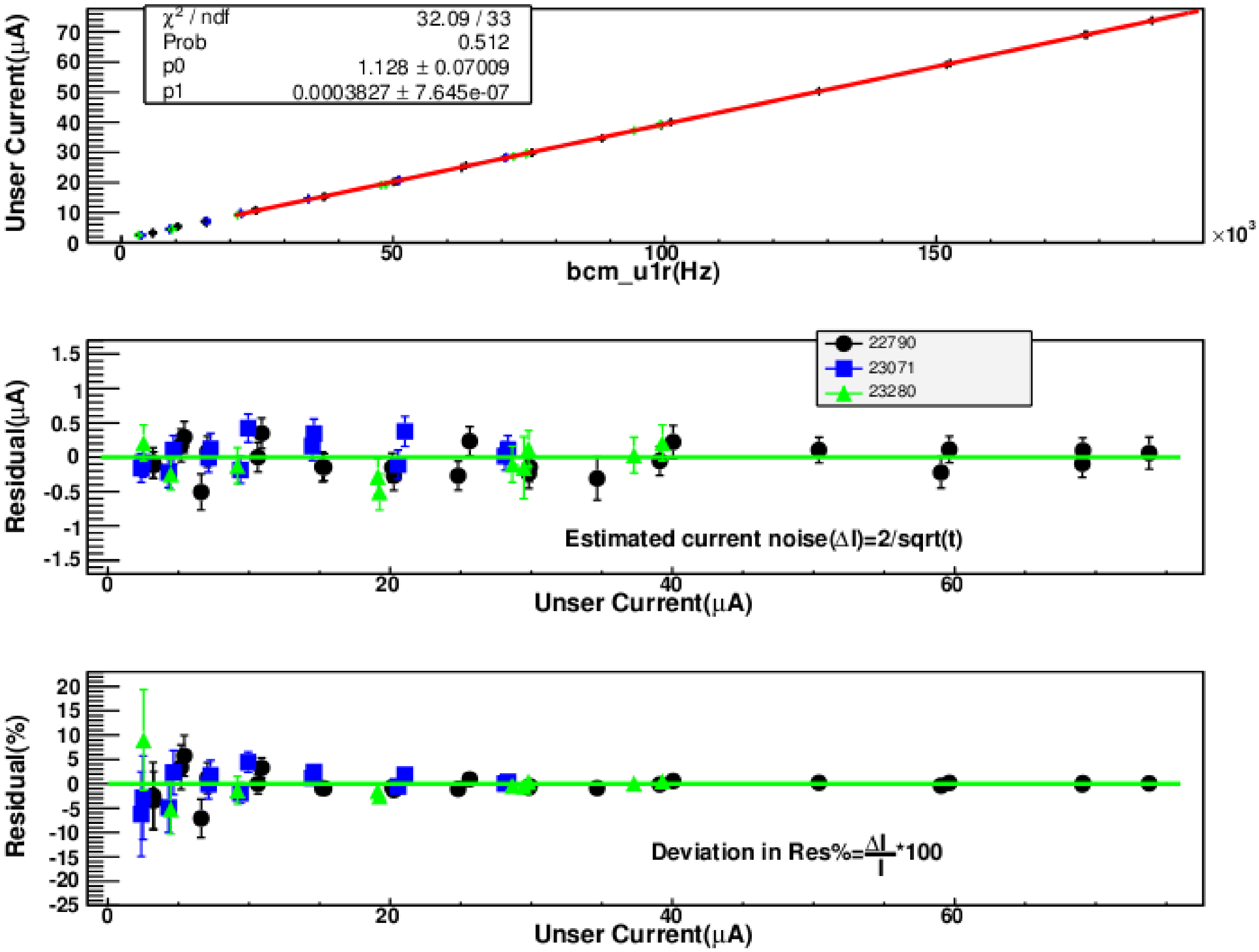
- New style (digital): unew and dnew.

- Calibrated BCMs against unser up to 73 µA in Fall 2016
- Calibration coefficients from multiple measurement have negligible drift within uncertainties
- Beam current determination is much better than 1%
- Estimated Current uncertainty in GMp experiment is ~0.06 µA

Beam charge calibration



BCM global calibration

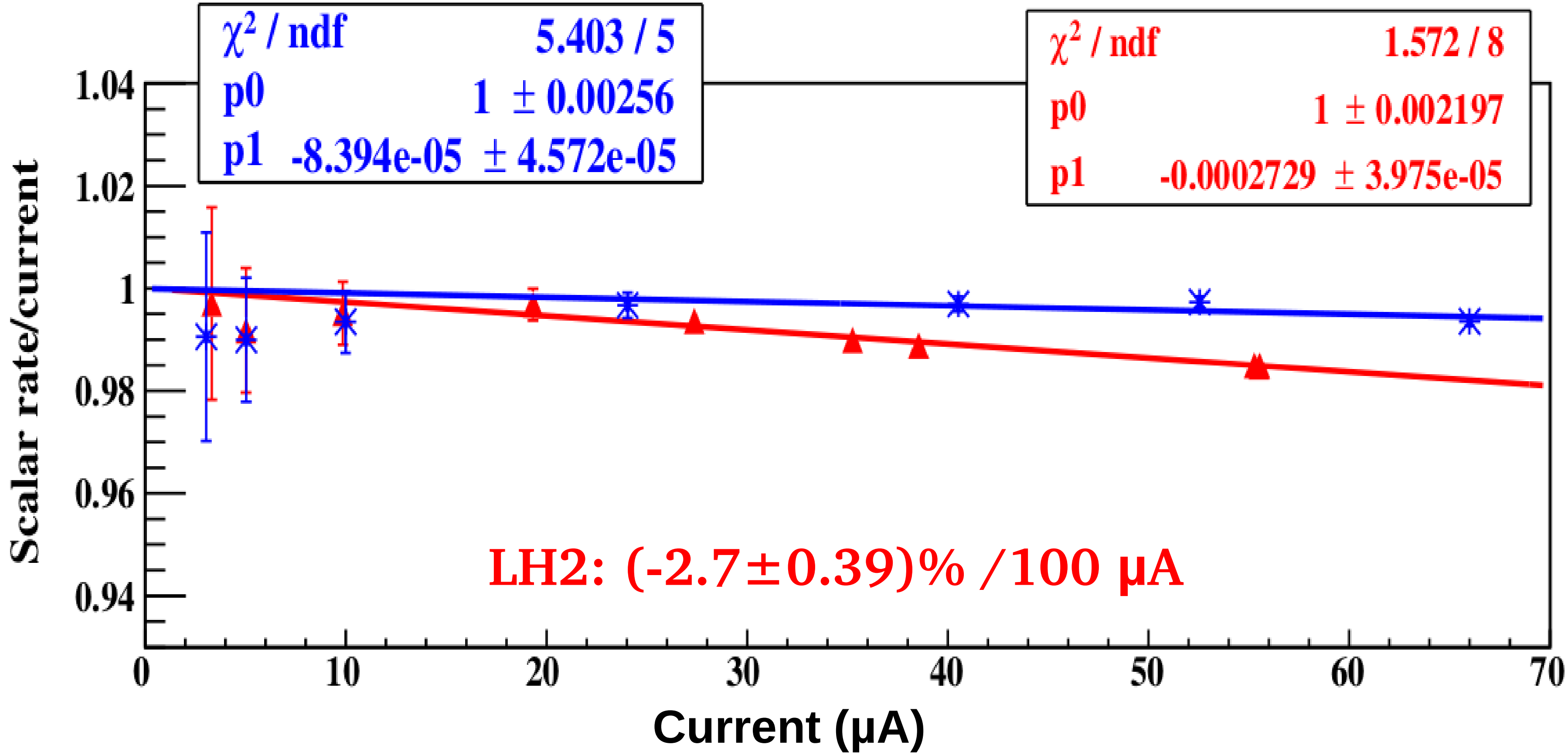


Target boiling studies

- Target used: 15 cm LH2 target in Loop2 and single foil carbon target
- Carbon target is used to separate possible rate systematic from boiling

→ Range of beam current: 3-67 μA

→ Raster size: 2×2 mm²



Precision calibration of optics for extended target

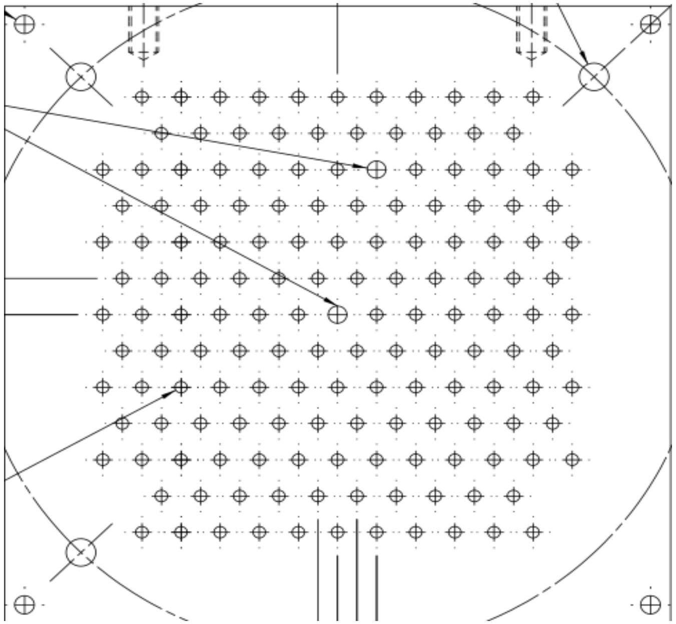
Angles (in-plane φ and out-of-plane θ) and vertex calibrations

→ new sieve (hole density approximately double to traditional HRS sieve)

→ 9 carbon foil targets

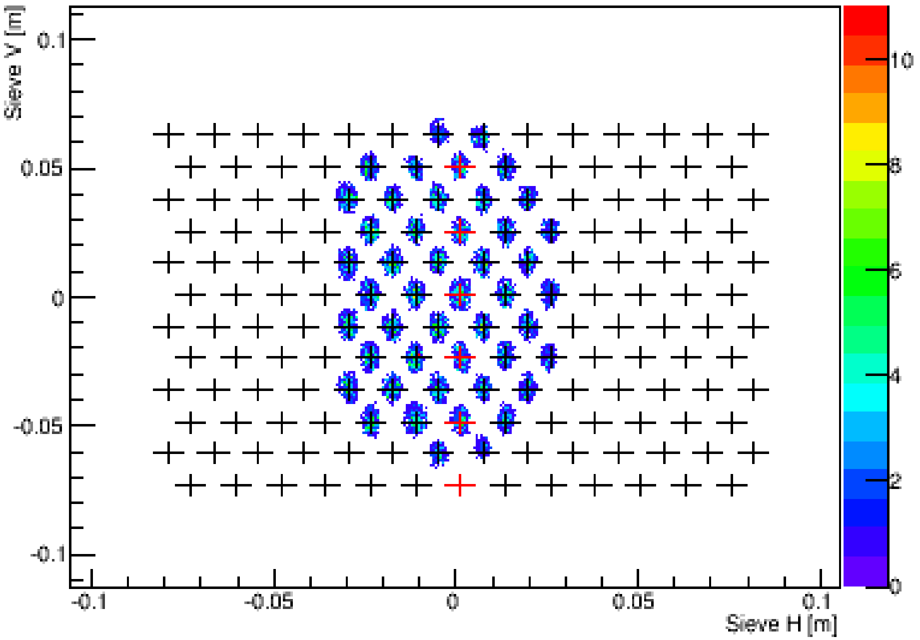
Delta calibration

→ LH_2 target



New sieve used for GMp optics

Sieve pattern of central carbon foil target

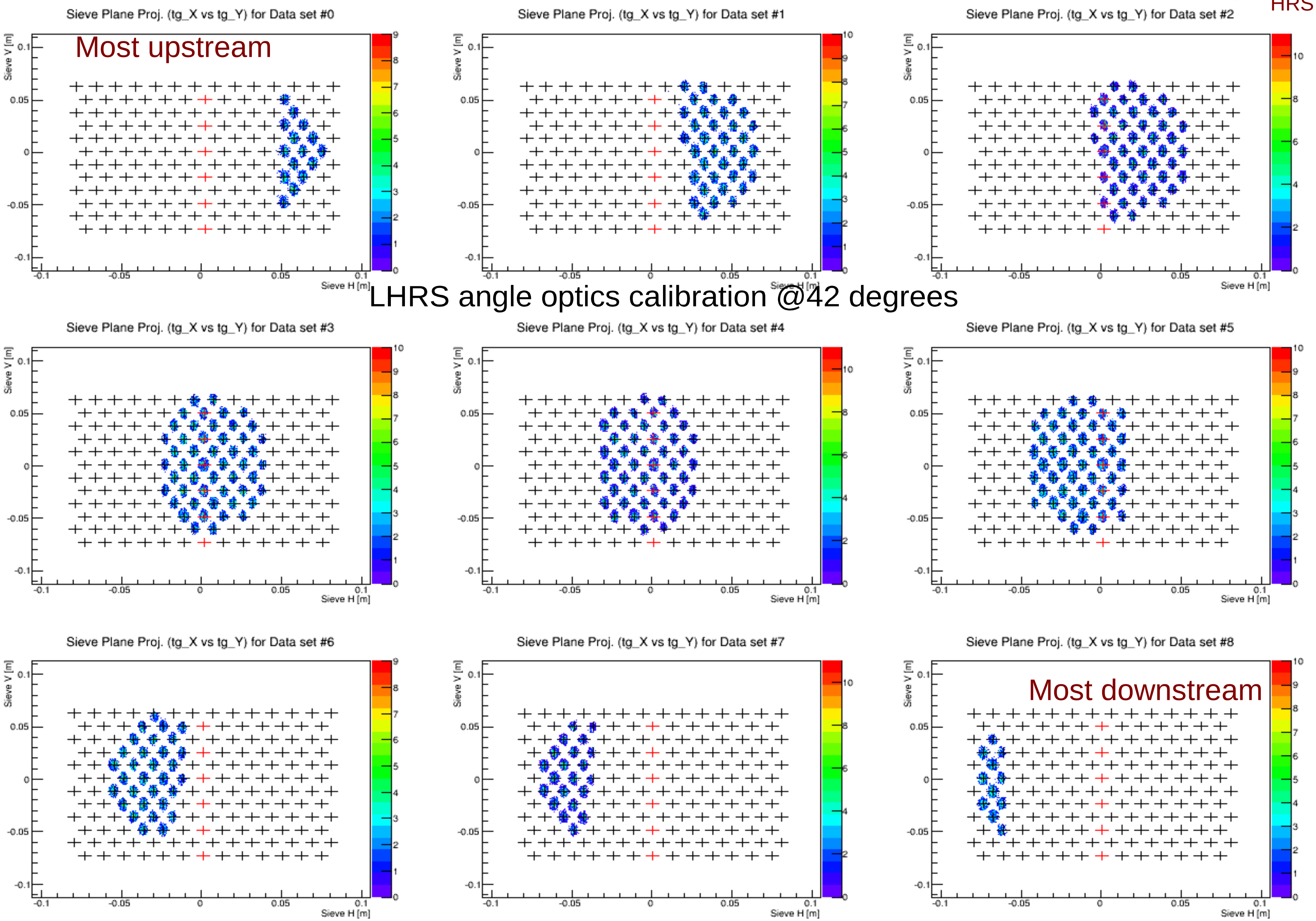


Crosses indicate the hole centers
Positions at the sieve plane are reconstructed by θ and φ

Reconstructed sieve pattern from multi-foil carbon targets

LHRS, $\theta_{HRS} = 42^{o}$

LHRS angle optics calibration @42 degrees

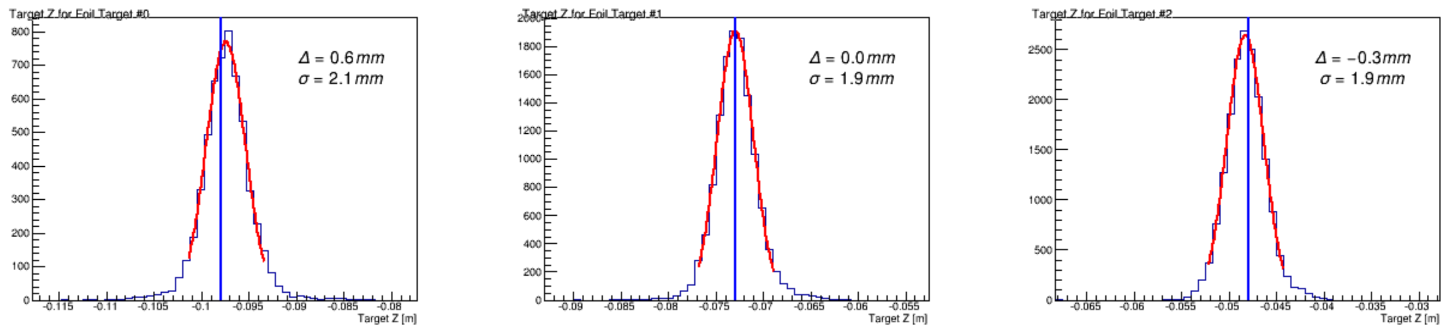


$\Delta\theta < 0.6$ mrad, $\Delta\varphi < 0.3$ mrad

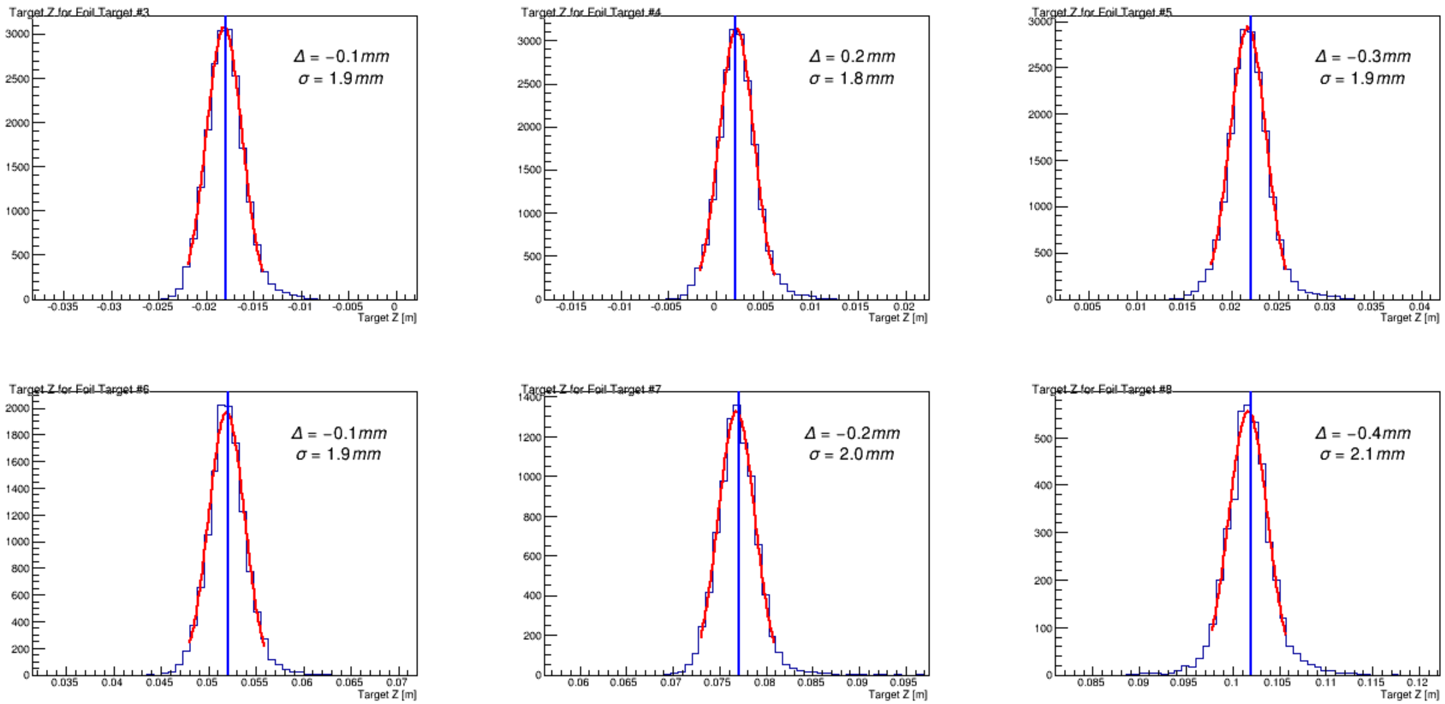
HRS vertex calibration

→ Blue lines indicate the real foil target positions

→ Δ shows the difference between the data gaussian fitting center and real position



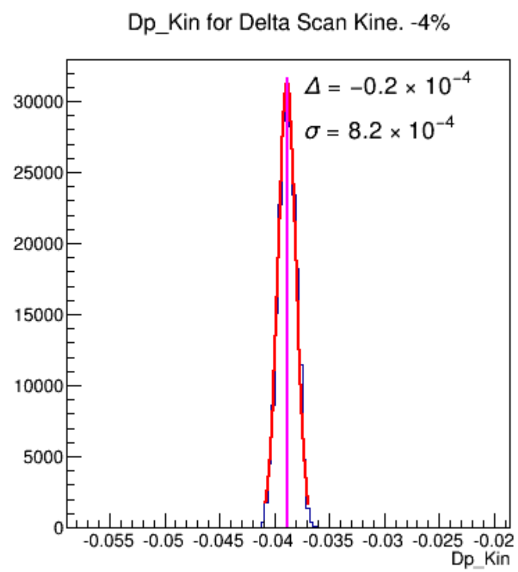
LHRS vertex optics calibration @42 degrees

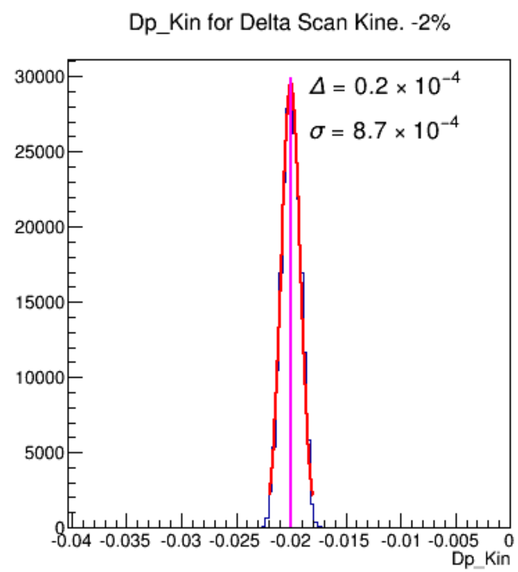


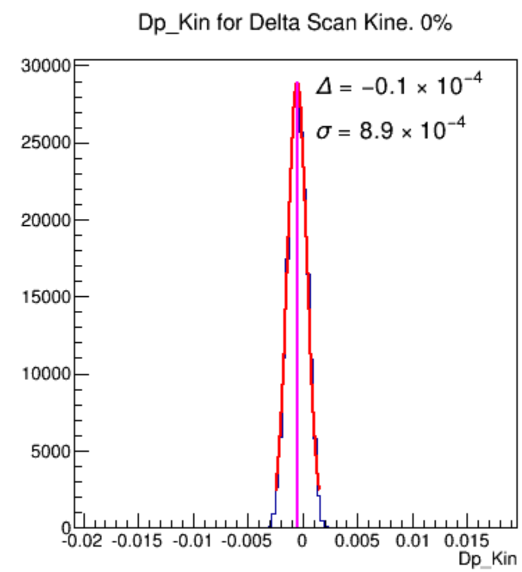
Target z (m)

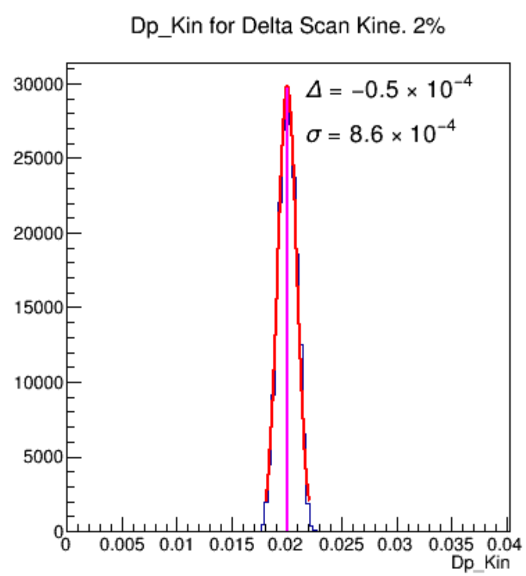
HRS Momentum Calibration

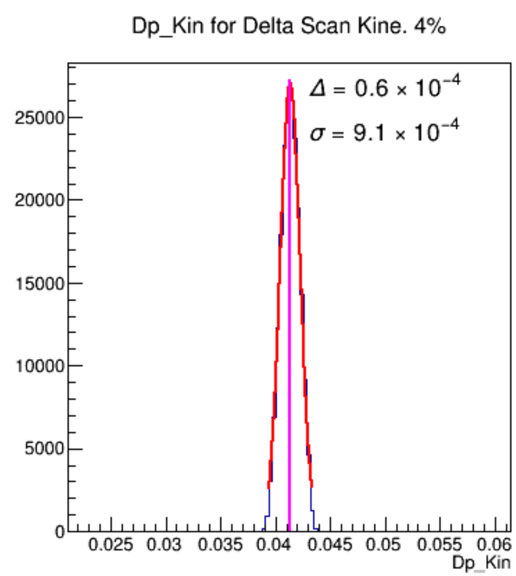
- We took delta scans at ±4%, ±2% and 0% dipole setting
- Clearly, the optimization readout is in the order of 10^{-4}











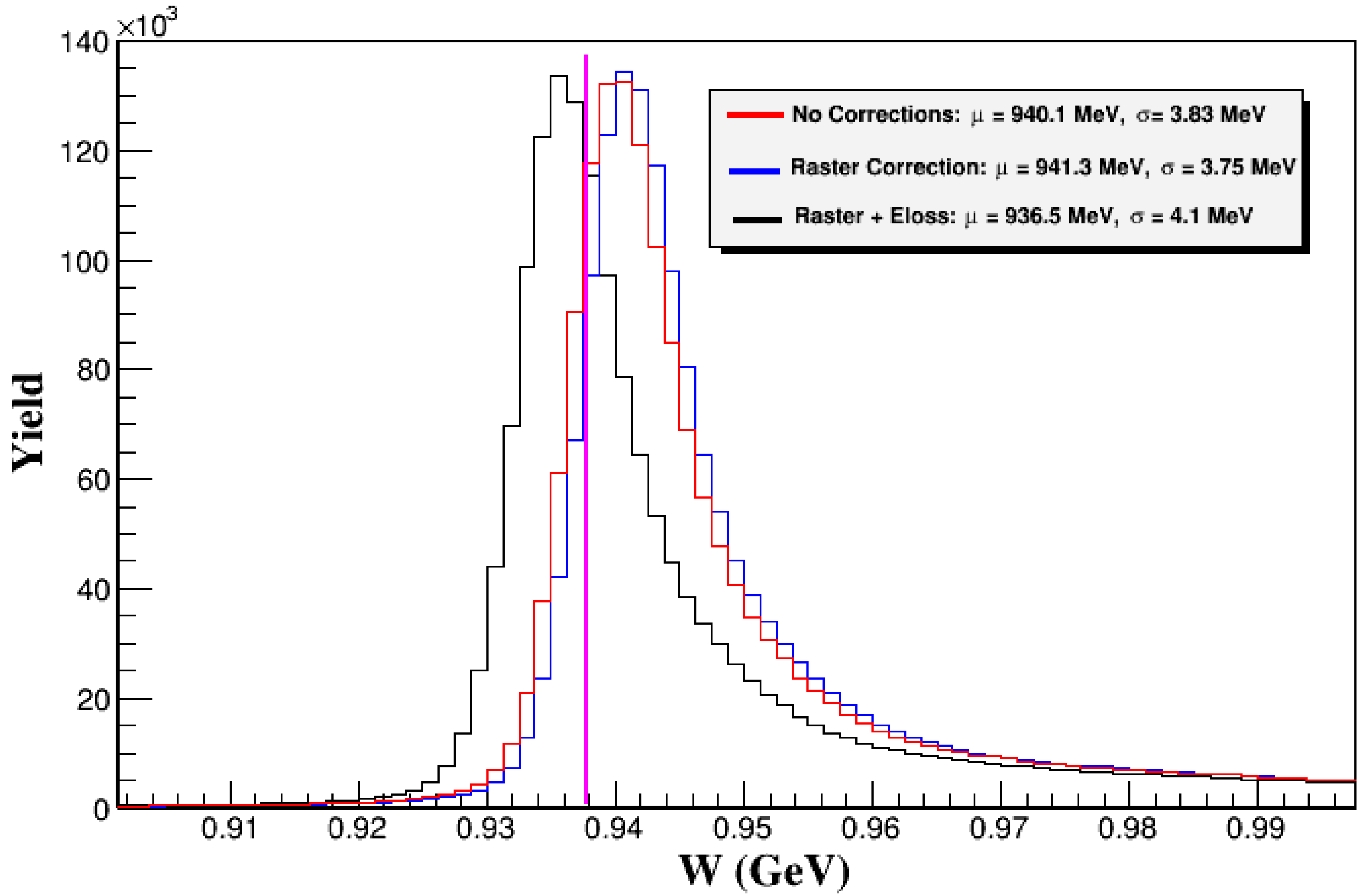
$$DpKin_{Real} = \frac{P_{\theta_{HRS}} - P_{Central}}{P_{Central}}$$

$$DpKin = dp - \frac{(P_{\theta} - P_{Loss}) - P_{\theta_{HRS}}}{P_{Central}}$$

$$DpKin - DpKin_{Real} = dp - \frac{(P_{\theta} - P_{Loss}) - P_{Central}}{P_{Central}}$$

Reconstructed invariant mass

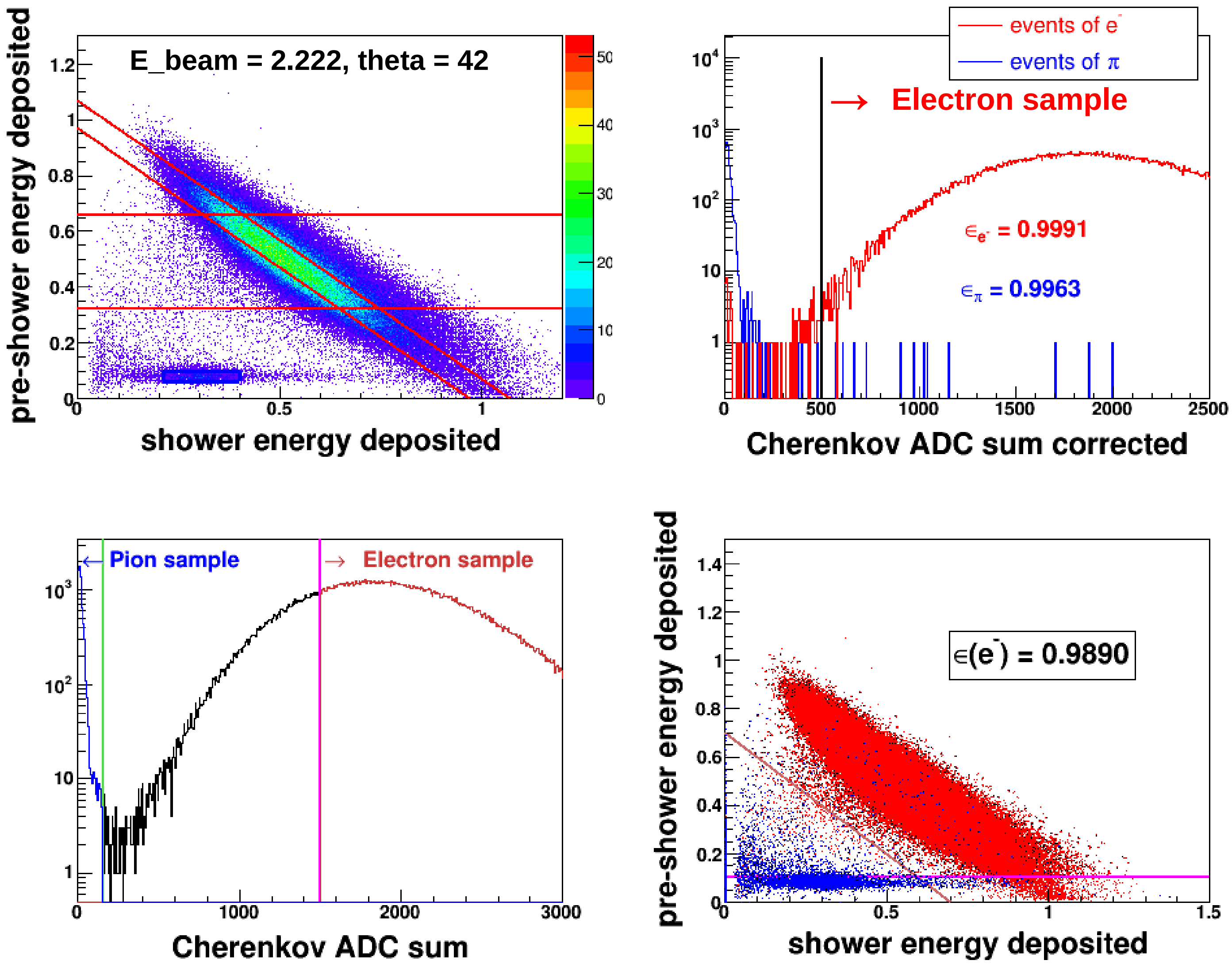
- This plot is from a one pass run on the Left HRS during Fall 2016 after optics calibration
- Clearly, the raster and ionization energy loss correction shifted the invariant mass peak by ~1.5 MeV from proton mass



Particle identification analysis

→ We did particle identification studies using Cherenkov and calorimeter

→ Got preliminary PID efficiency at one pass and the cuts were set to select good electrons



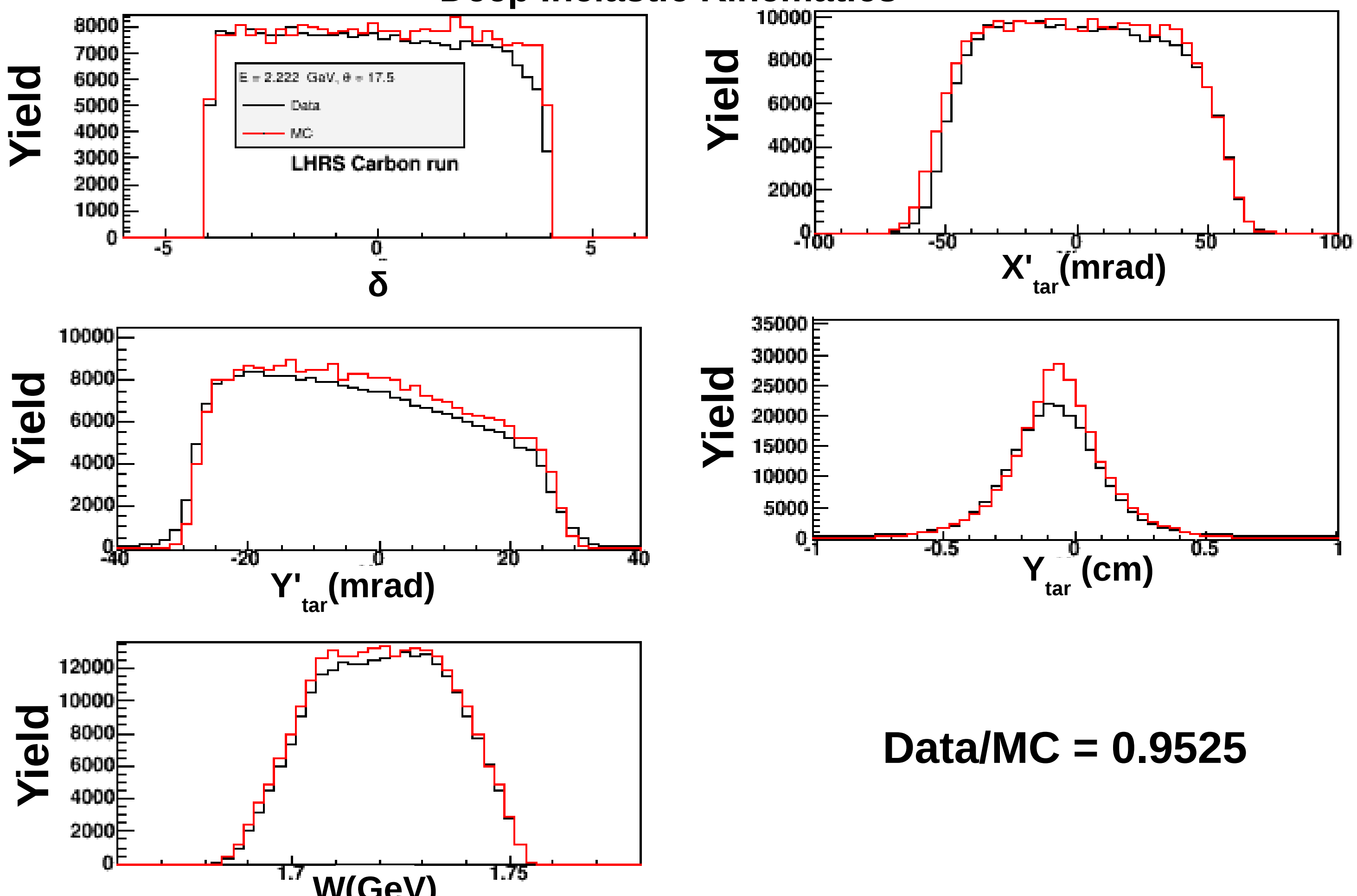
Status of acceptance study

→ Took data on single foil carbon target to study the acceptance of the spectrometer

→ Used single arm simulation which gives an uniformly distributed phase space for carbon target without physics weighting

→ Used external code to get physics weighting which is the ratio of born cross section to radiative correction factor

Deep Inelastic Kinematics



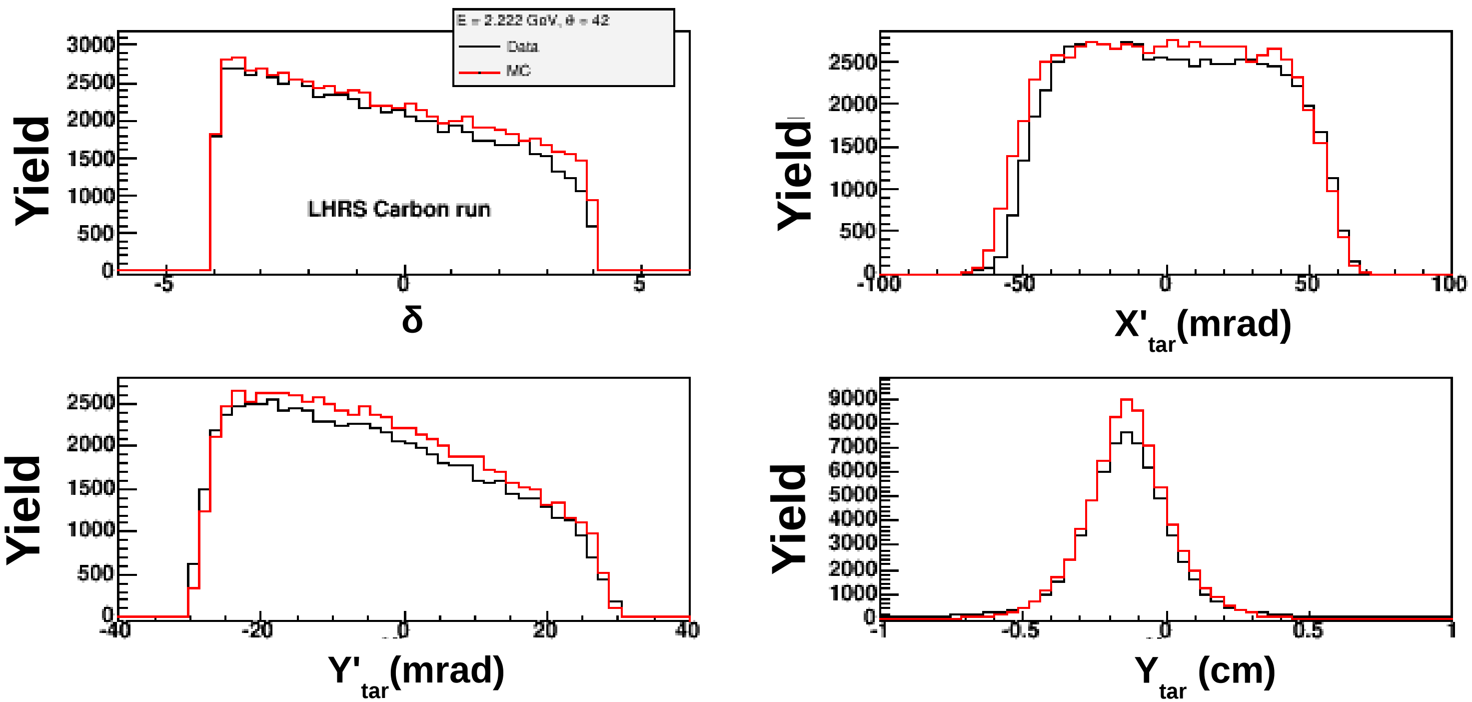
Data/MC = 0.9525

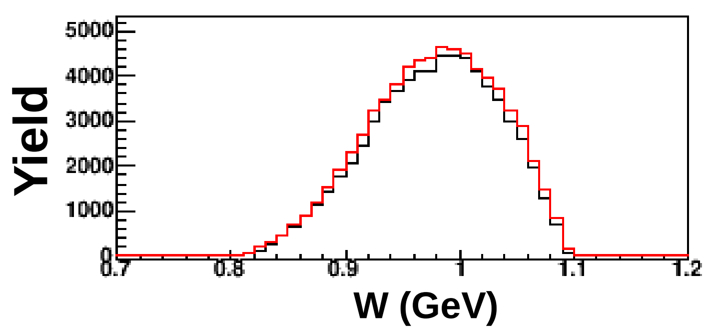
Status of acceptance study

→ Shapes are consistent at very different kinematics

→ The discrepancy observed in high delta probably comes from spectrometer model

Quasi elastic Kinematics





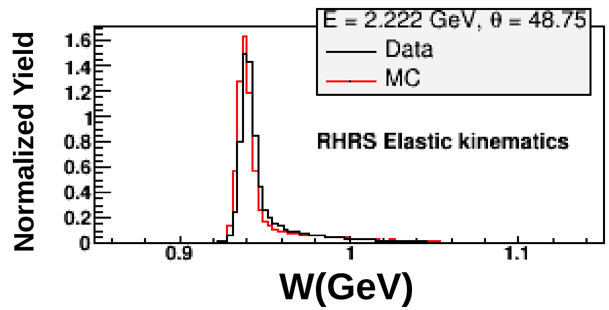
Data/MC = 0.9395

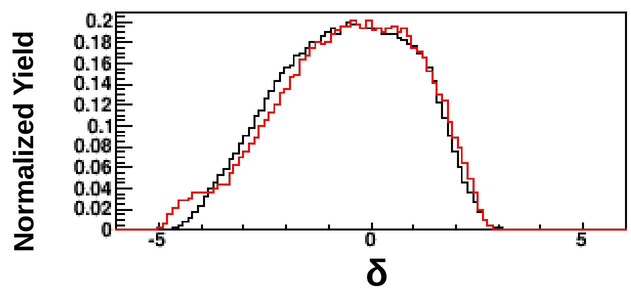
Data to SIMC comparison at 1pass LH2

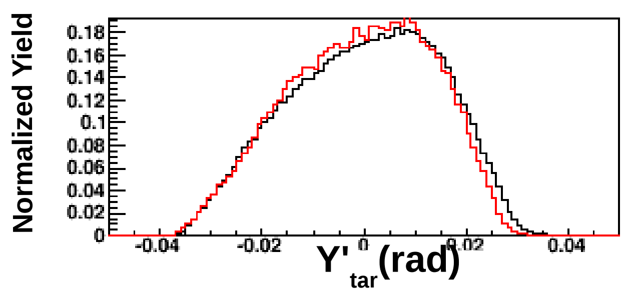
→ SIMC uses same model of spectrometer as single arm but includes all radiative contribution within the code

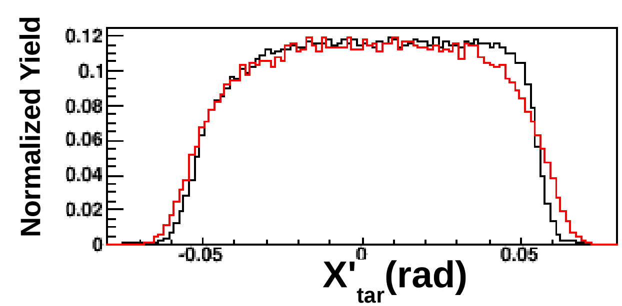
→ Data and SIMC distribution integrals are reasonably consistent

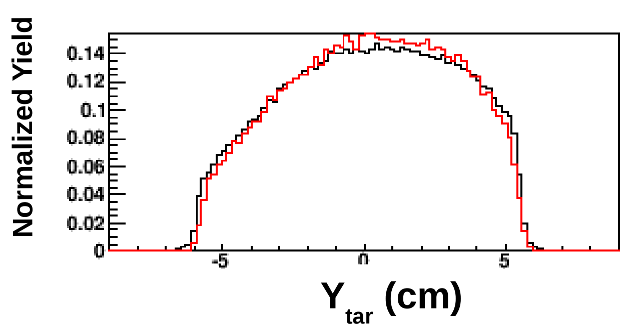
→ Improvement of spectrometer model is ongoing











Data/MC = 1.00289

Punch list

System calibration	Status
BCM	Completed for first pass analysis
BPM	80% completed
Raster	Completed for first pass analysis
Optics	Completed for first pass analysis
Cerenkov	Completed for first pass analysis
Calorimeter	Completed for first pass analysis
VDC/Straw	75% completed
Detector Position Study	Completed for first pass analysis

Data analysis	Status
Acceptance	60% completed
Tracking efficiency	60% completed
Trigger efficiency	50% completed
Particle identification	70% completed
Time of flight	80% completed
DAQ dead time	40% completed
Data analysis at First pass	70% completed

Summary

- 12 GeV GMp experiment data taking completed successfully
- Equipment operated stably and satisfactorily
- First pass data replay is close to completion
- Projected milestones:

  → Preliminary cross-section results in four months

  → First publication to be submitted by the end of 2017

Thank you everybody!

Reduction of track reconstruction systematics

- The standard tracking system of two VDCs in HRS cannot resolve u-v matching ambiguities when multiple clusters are presented, resulting in increased probability of mis-reconstructed events
- Straw chamber was installed as a third readout plane to reduce systematics of track reconstruction efficiency
- Potential tracks formed by matching VDC clusters are projected and compared with hit position in the straw chamber plane
- This procedure was tested with 2 pass beam and improved the track reconstruction efficiency to 98%