Optics and Tracking

Chandan Ghosh
Stony Brook University
March 5, 2019

Outline

- Necessity of Q2 measurement
- Optics calibration
- Optics reconstruction
- Dependence of Q2 on pileup, beam position
- Plan for PREX-II/CREX
- Background estimation from inelastic excitation
- Conclusions

Need of Q^2 measurement

$$A_{pv} = \frac{G_F Q^2}{4\pi\alpha\sqrt{2}}\left[1 - 4sin^2(\theta_w) - \frac{F_n(Q^2)}{F_p(Q^2)}\right]$$

Apv has strong dependence on Q^2.

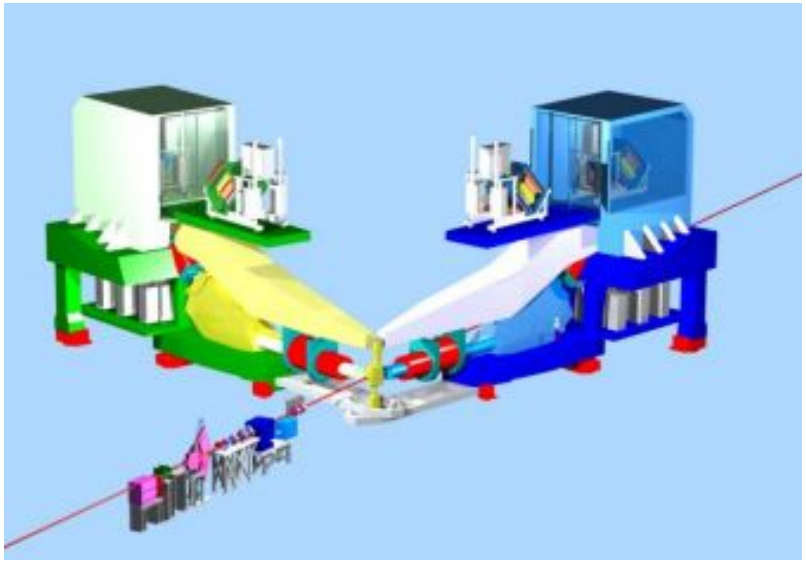
$$Q^2 = 2EE'(1 - cos\theta)$$

Parameters needed for Q^2 measurement

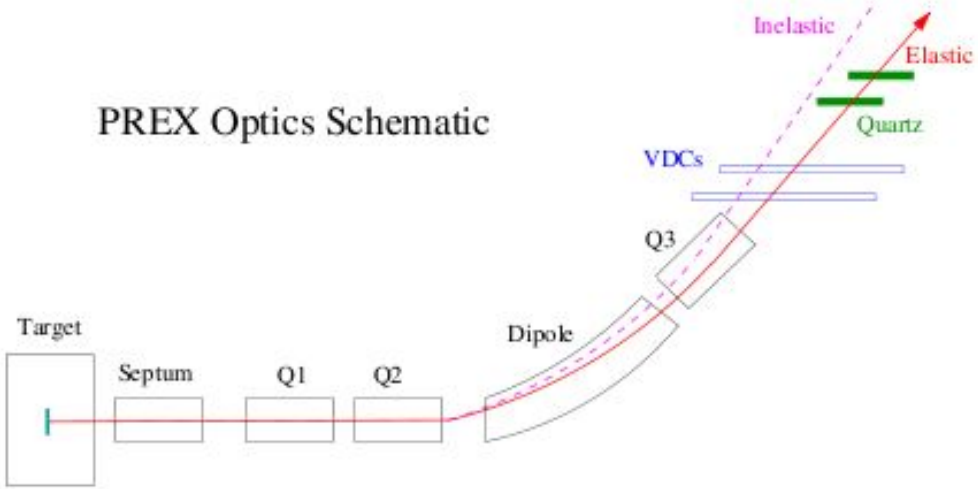
- Incident beam energy (E) - measured accurate to 3E-04 level.
- Energy of scattered electron (E')
- The scattering angle (θ)

Spectrometer

Hall A Spectrometer



Septum: to kick 5^{o} scattered electrons to 12.5^{o} - Need recalibration the spectrometers

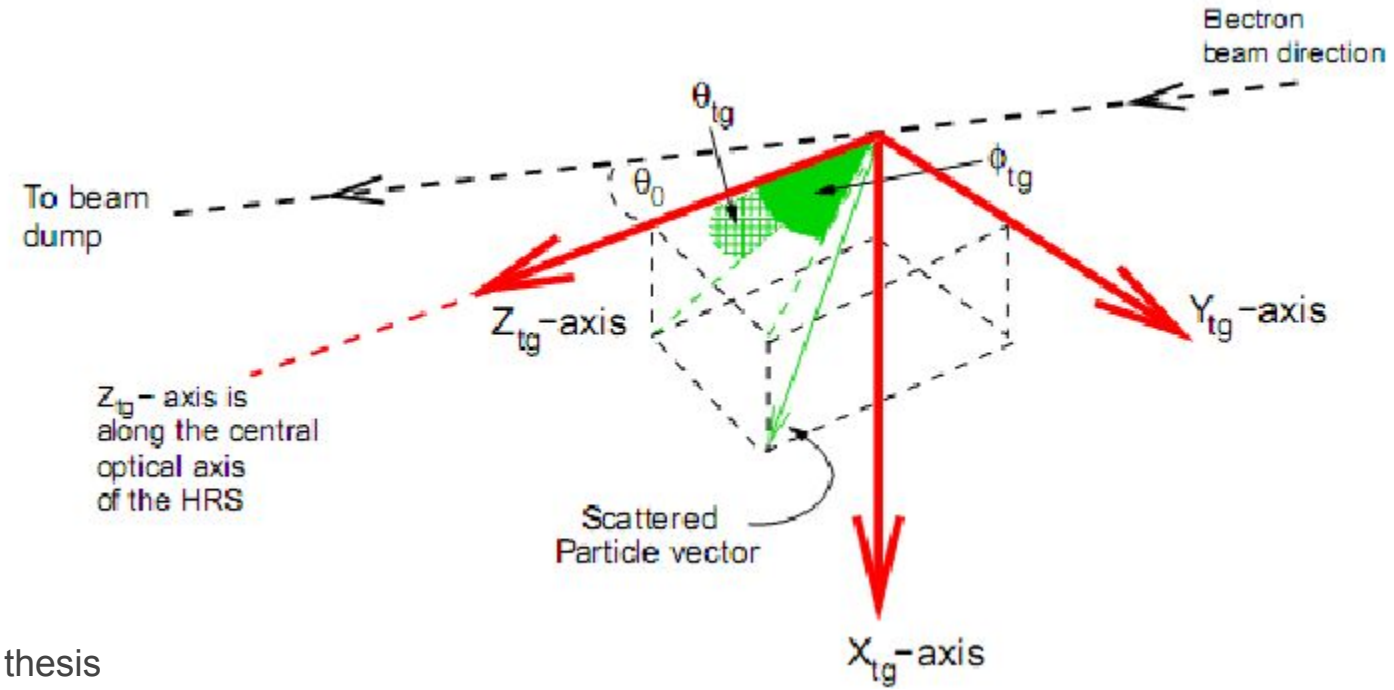


Momentum accuracy range - 3.E0-4 for 0.3 - 4.0 GeV
Minimum scattering angle =12.5^{o}

Scattering angle (θ) measurement

1. Spectrometer central angle (θ_0).
2. Target angles - (θ_{tg}, ϕ_{tg})

$$cos(\theta) = \frac{cos\theta_0 - \phi_{tg} sin\theta_0}{\sqrt{1+\theta_{tg}^2+\phi_{tg}^2}}$$



Spectrometer Central Angle

Use differential recoil in elastic scattering

$$E' = \frac{E - E_{loss}}{1 + \frac{2(E - E_{loss})sin^2(\frac{\theta}{2})}{M_t}} - E_{loss}$$

Water Cell target

$$\Delta E' = E'_O - E'_H$$

$$= E\left(\frac{1}{1 + \frac{2Esin^2(\frac{\theta}{2})}{M_O}} - \frac{1}{1 + \frac{2Esin^2(\frac{\theta}{2})}{M_H}}\right)$$

$$+ correction$$

- E': scattered energy
- E: beam energy
- E_{loss}: energy loss
- θ: scattering angle
- M_t: target mass

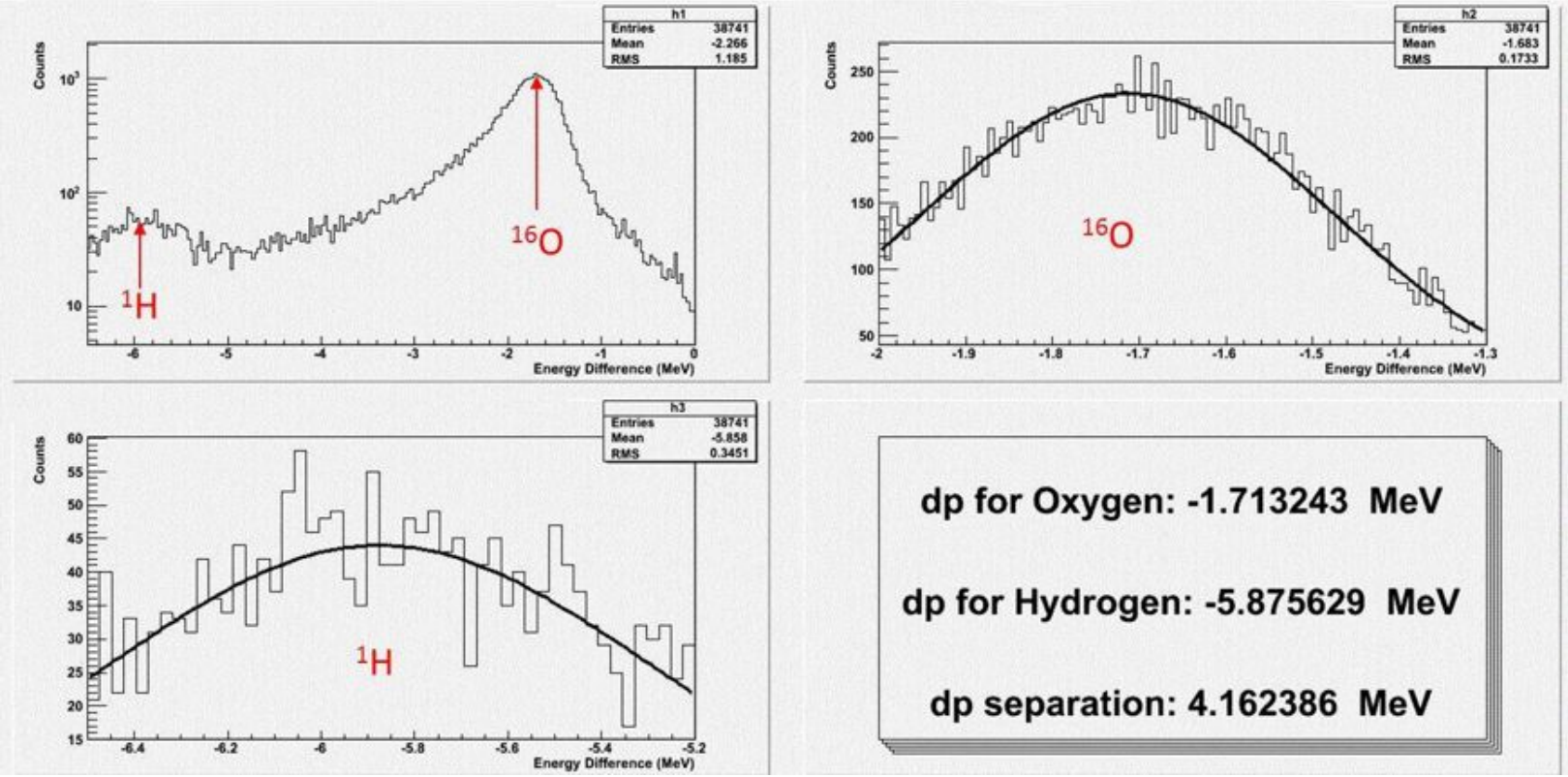
For 5° scattering angle(calculated):

$E-E'_{Pb}$ (MeV)	1.0
$E-E'_{O}$ (MeV)	1.7
$E-E'_{H}$ (MeV)	5.8

Advantages:

- Suppress E_{loss} (~1 MeV) uncertainly
- Eliminate run-to-run energy and beam position variations

PREX-I:Watercell target momentum spectrum

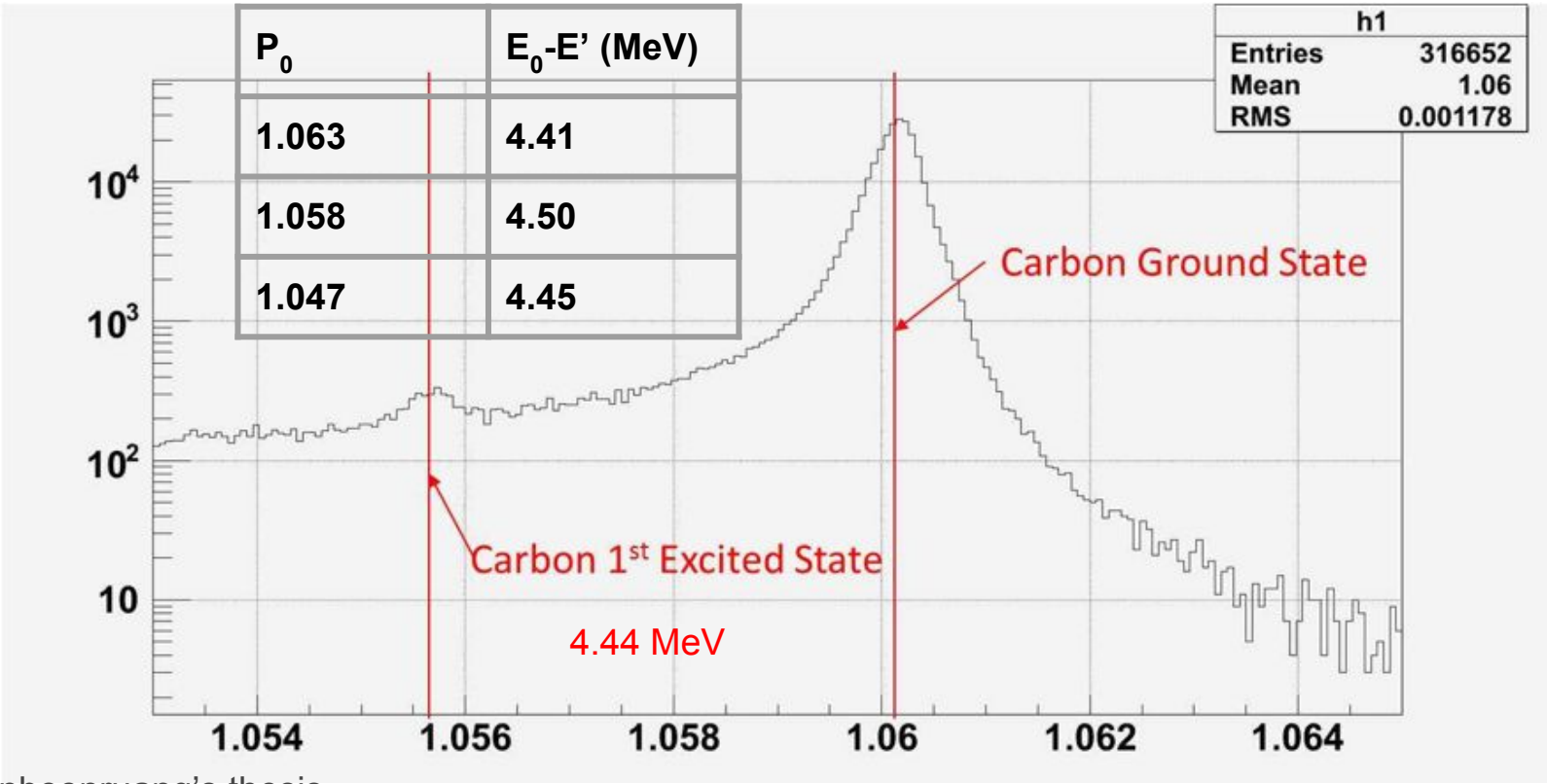


Extracted angle: Left HRS - 5.065 ∓ 0.020 deg; Right HRS - 5.007 ∓ 0.046 deg

Cross-check of momentum calibration

P_o: Central momentum setting

P_0	E_0-E' (MeV)
1.063	4.41
1.058	4.50
1.047	4.45



K. Saenboonruang's thesis

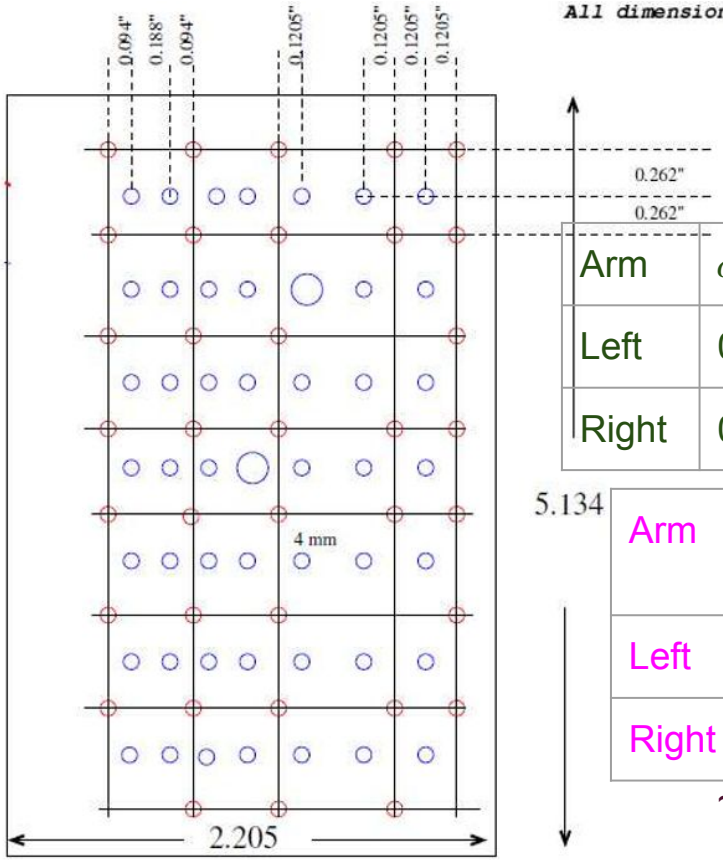
Spectrometer optics reconstruction

θ_0 measurement will allow to quote Q^2 value at θ_0. But PREX needs average Q^2 over the entire spectrometer acceptance - this requires optics reconstruction

$$\begin{pmatrix} \delta \\ \theta \\ y \\ \phi \end{pmatrix}_{\mathrm{tg}} = \begin{pmatrix} \langle\delta|x\rangle & \langle\delta|\theta\rangle & 0 & 0 \\ \langle\theta|x\rangle & \langle\delta|\theta\rangle & 0 & 0 \\ 0 & 0 & \langle y|y\rangle & \langle y|\phi\rangle \\ 0 & 0 & \langle\phi|y\rangle & \langle\phi|\phi\rangle \end{pmatrix} \cdot \begin{pmatrix} x \\ \theta \\ y \\ \phi \end{pmatrix}_{\mathrm{fp}}$$

Tools: sieve collimator in front of septum magnet, data using carbon, watercell, tantalum target

Sieve pattern

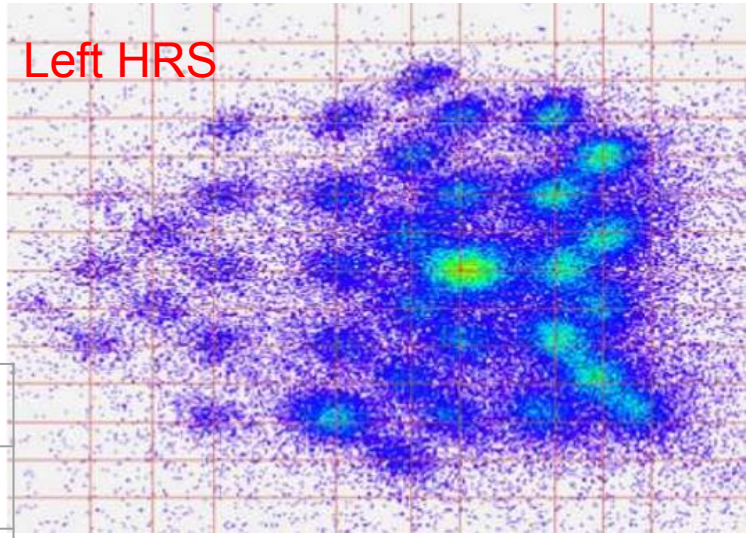


Arm	$\sigma_{\theta 0}$(°)	$\sigma_{\theta tg}$(°)	$\sigma_{\phi tg}$(°)
Left	0.020	0.066	0.017
Right	0.020	0.091	0.011

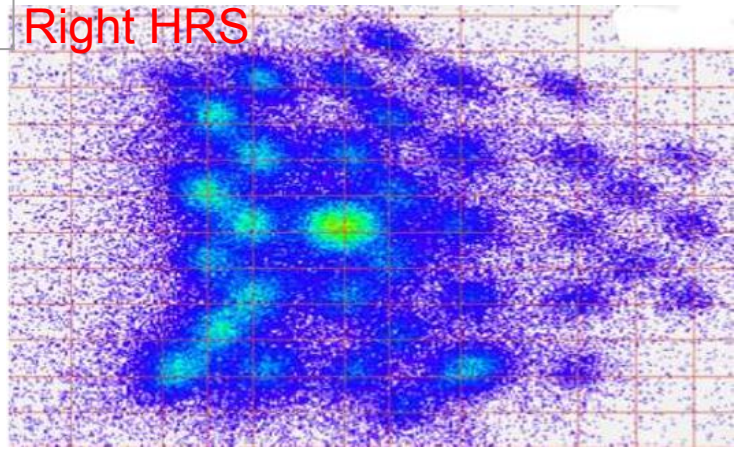
Arm	σ_θ (°)	σ_θ/θ(%)
Left	0.024	0.49
Right	0.021	0.43

~0.9% to δQ^2

Left HRS



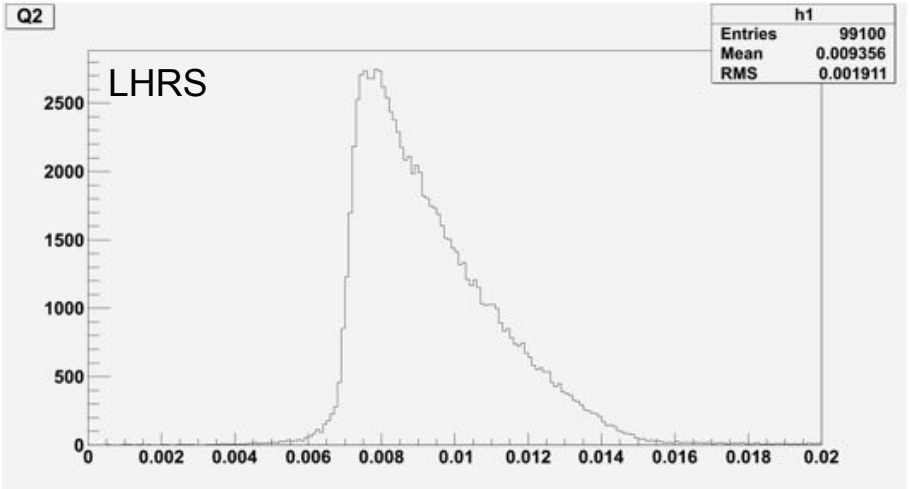
Right HRS

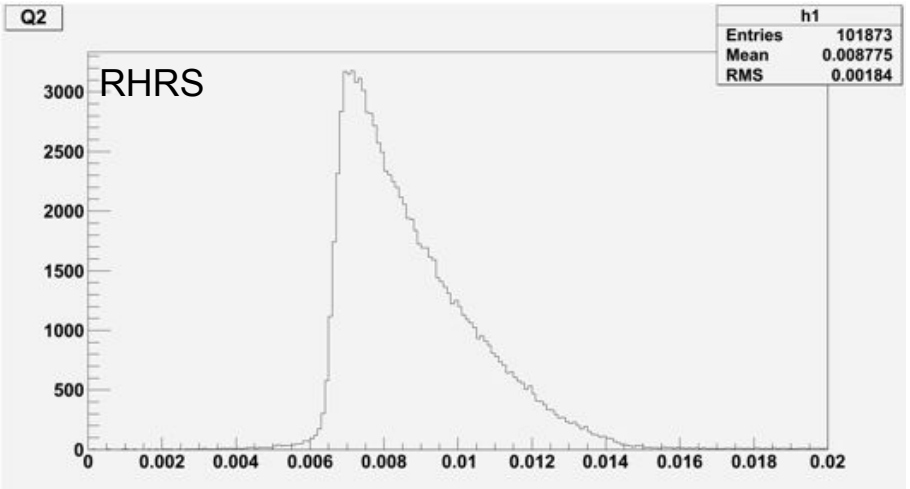


Average Q^2 analysis

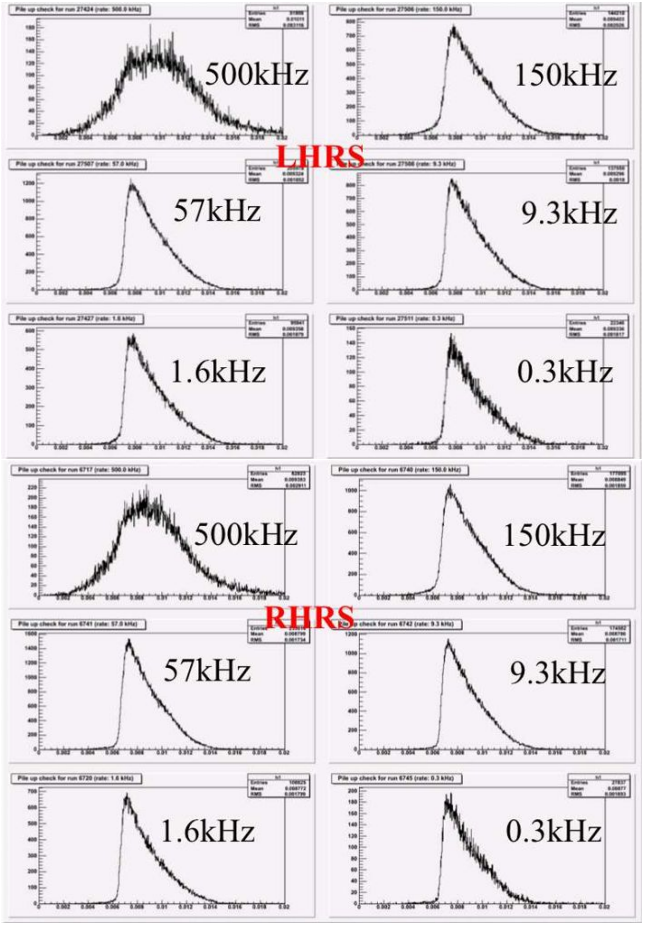
- Event having Quartz signal only used for Q^2 analysis
- Q^2 distribution changes with
  - Pileup
  - Beam position

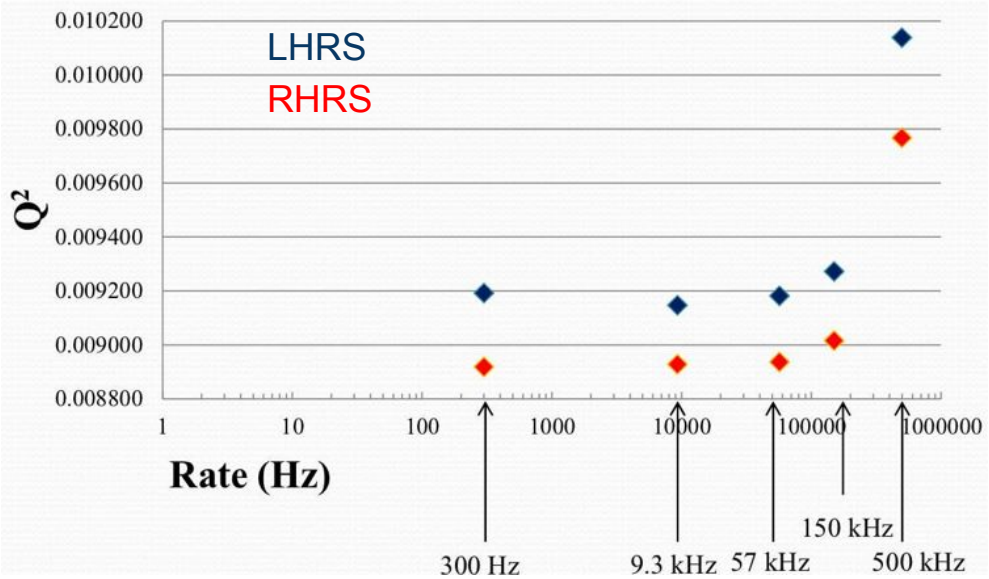
Q^2 distributions





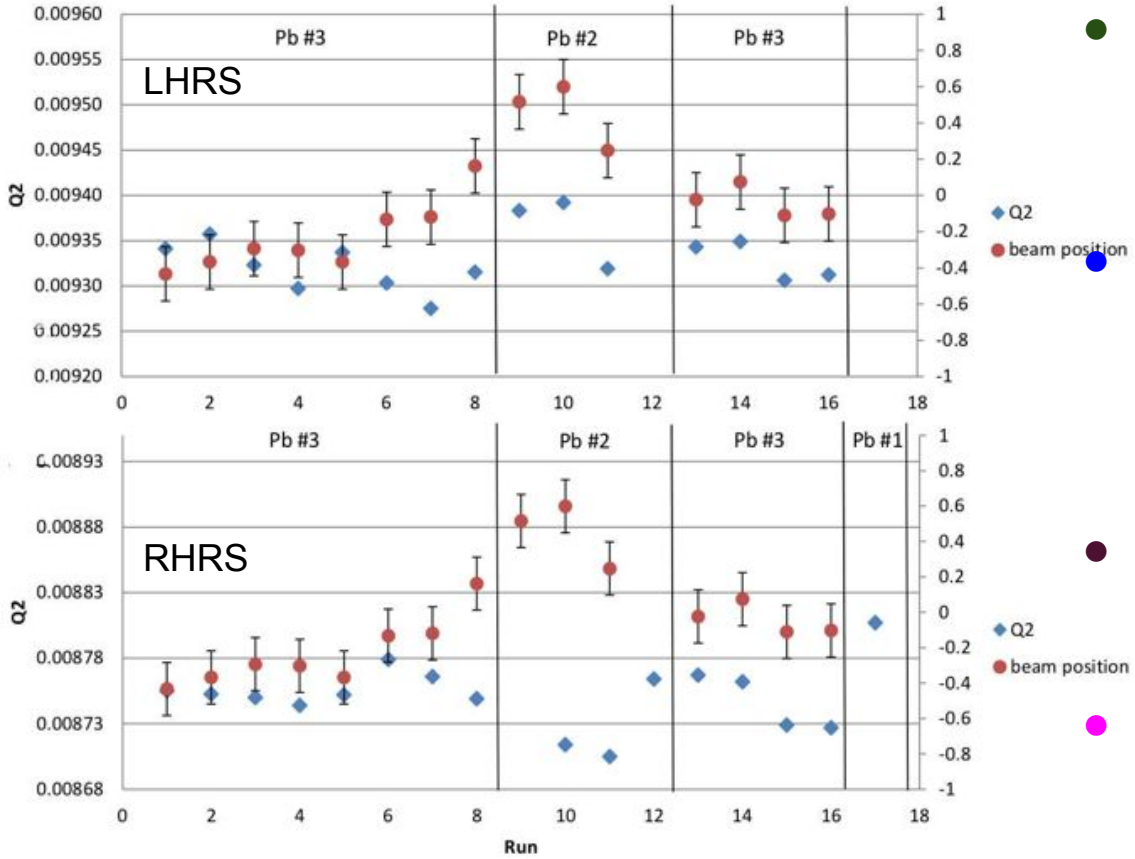
Q^2 distribution vs pileup





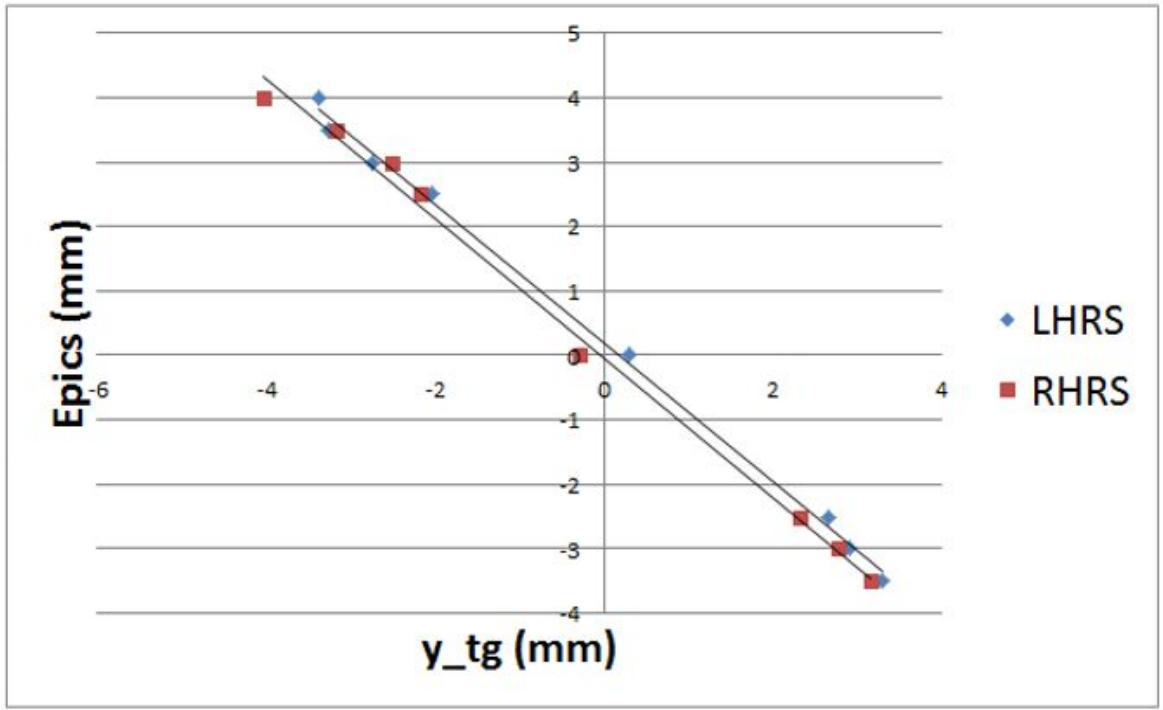
- Trigger rate <100 kHz is used for Q^2 measurement
- 1 track-cut shift average Q^2 by -0.06+0.05% - this is taken as systematic error.

Q^2 distribution vs beam position



- Normal operational limit of VDC ~ 10 kHz/cm^2. PREX (~50-100 μA) has ~ 50 MHz/cm^2!!
- The beam-position-monitors won't work at low current (~50 nA) required for Q^2 measurement using vertical drift chamber.
- Change in beam positon increase Q^2 in one arm and decrease in another
- GEM detectors will be used in PREX-II/CREX to avoid the low current limit

Q^2:Beam positon correction



Beam position and reconstracted y_tg are corellated

Error sources

Error Source	Percent Error in Q^2
Beam Energy	0.1%
Final Momentum	0.1%
Scattering Angle	0.9%
Pileup	<0.1%
Total systematic error	~1.0%
Statistical error	<0.1%

Average LHRS Q^2 (GeV2)	0.009330
Average RHRS Q^2 (GeV2)	0.008751
Average Q^2 (GeV2)	0.009066

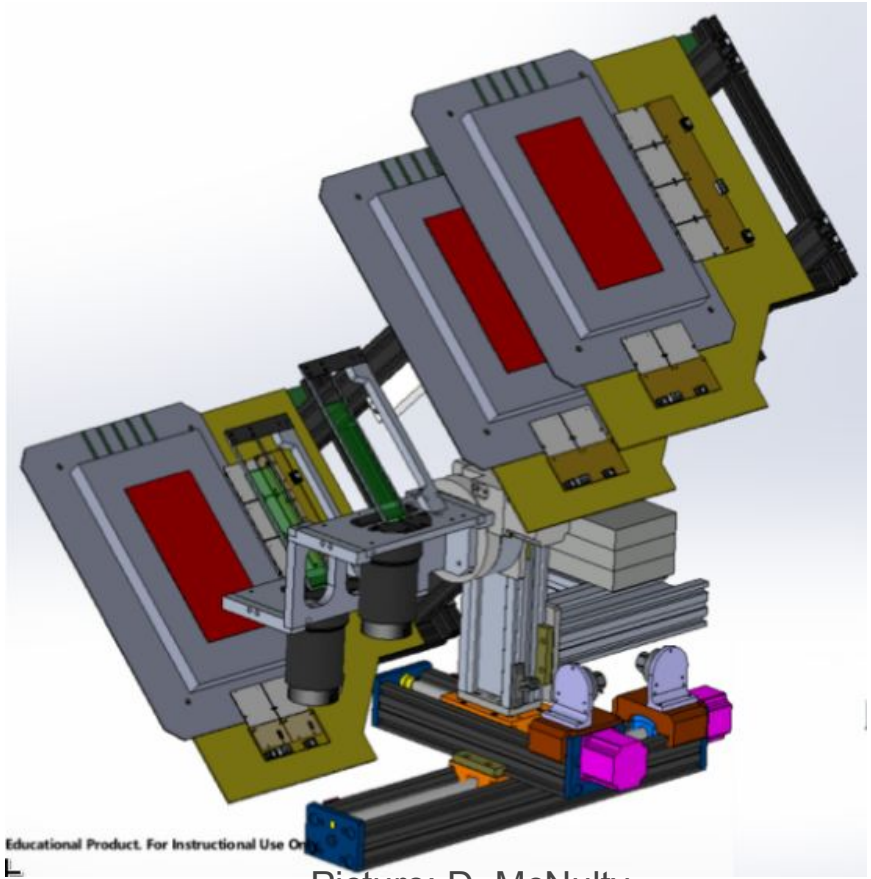
- Total systematic error ~ 1%.
- The uncertainty from scattering angle measurement was the main source the uncertainty in Q^2.

GEM detectors

Perfect candidate for replacing the VDCs

- Can handle ~ 105 Hz/mm
- Position resolution ~100 μm

This will allow Q2 measurement at high current - the BPMs will lock beam position.



Picture: D. McNulty

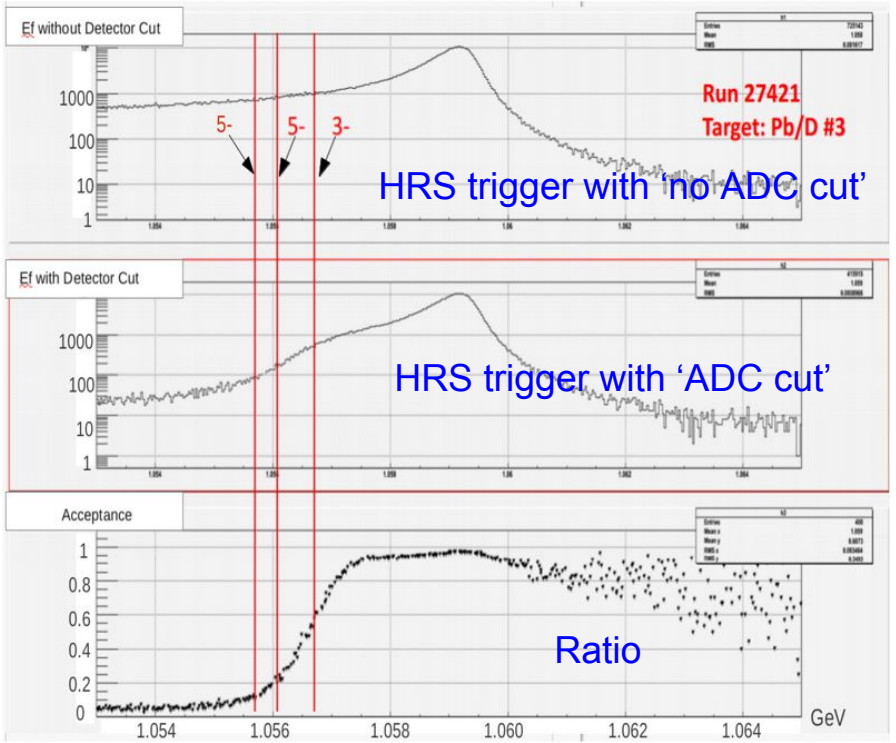
Background contribution from Inelastic excitations of target

The integrating mode data acquisition doesn't allow to separate contribution from elastic scattering and background from target inelastic excitation. From optics reconstruction for Pb target will give an estimate of excited state background.

State	Energy (MeV)	Acceptance (%)
Ground	0	~100
3^-	2.615	~60
5^-	3.198	~20
5^-	3.709	~10

$\sigma_{3^-}/\sigma_{elastic}$ (at q=0.47 fm^{-1}) ~0.1%

Background contribution from 3^- state is ~0.06%



K. Saenboonruang's Thesis

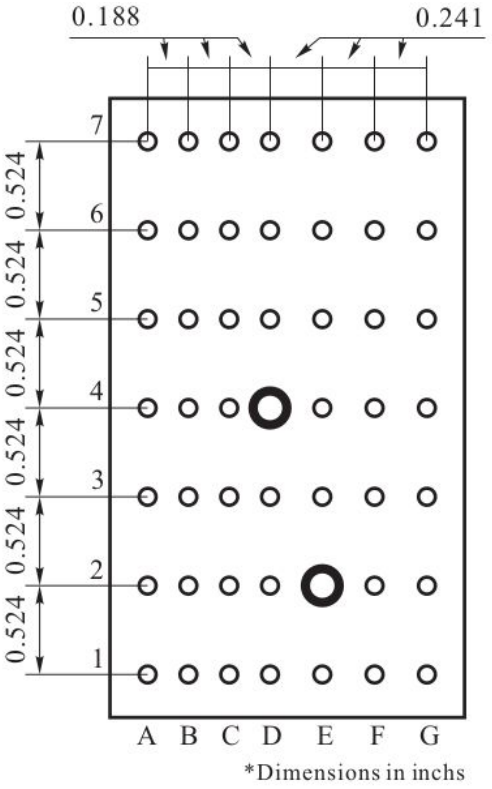
Conclusions

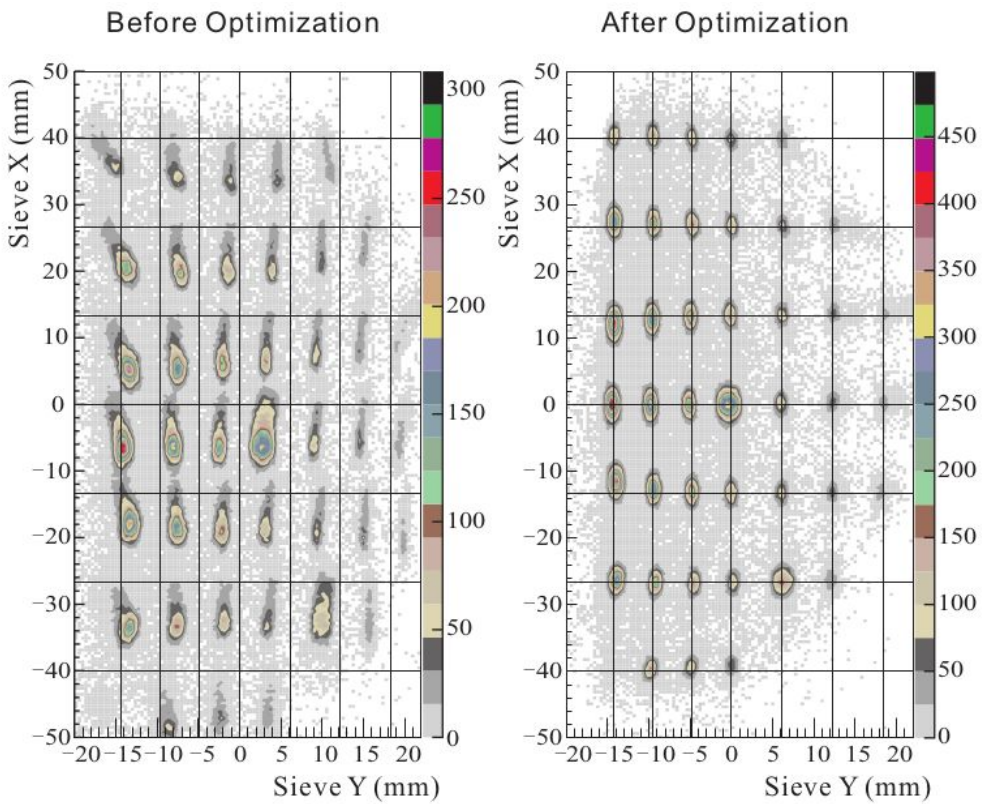
- 1% precision in Q^2 measurement is possible using differential recoil in elastic scattering
- The uncertainty from scattering angle measurement is the main source of uncertainty in Q^2 measurement
- GEM detectors will help to run the counting-mode-DAQ with higher beam current
- The optics reconstruction helps to estimate background contribution from target inelastic excitations.

Thanks for your attention

Backup slide

Sieve reconstruction





Finite acceptance correction