HRS Optics in the APEX Test Run

● Optics General ● Test Run Calibration ● Comment on Full Runs

Trying to collect materials from three years ago. May NOT present the full picture.

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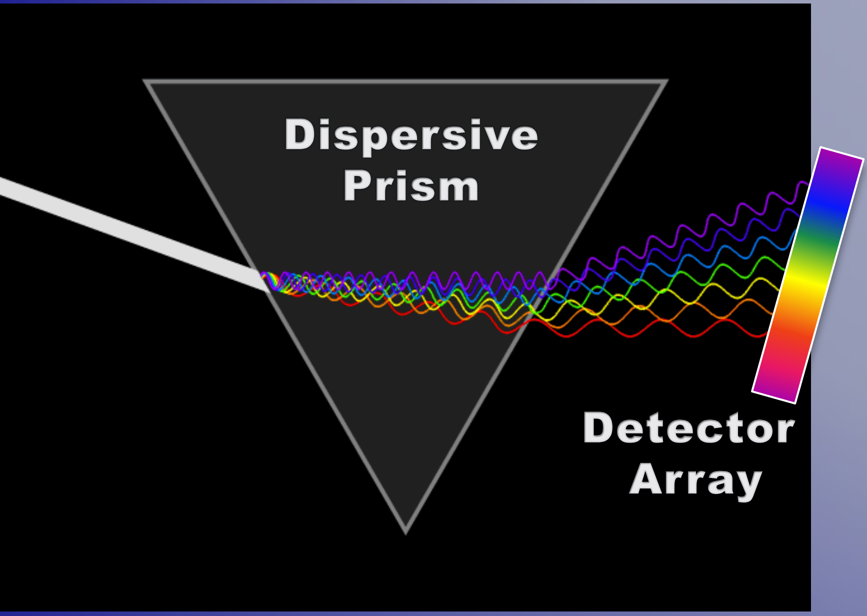
Optics As Everyone Knows



- Dispersive prism + detector
- Analyze wavelength (momentum) of incoming light

- Optics Reconstruction:

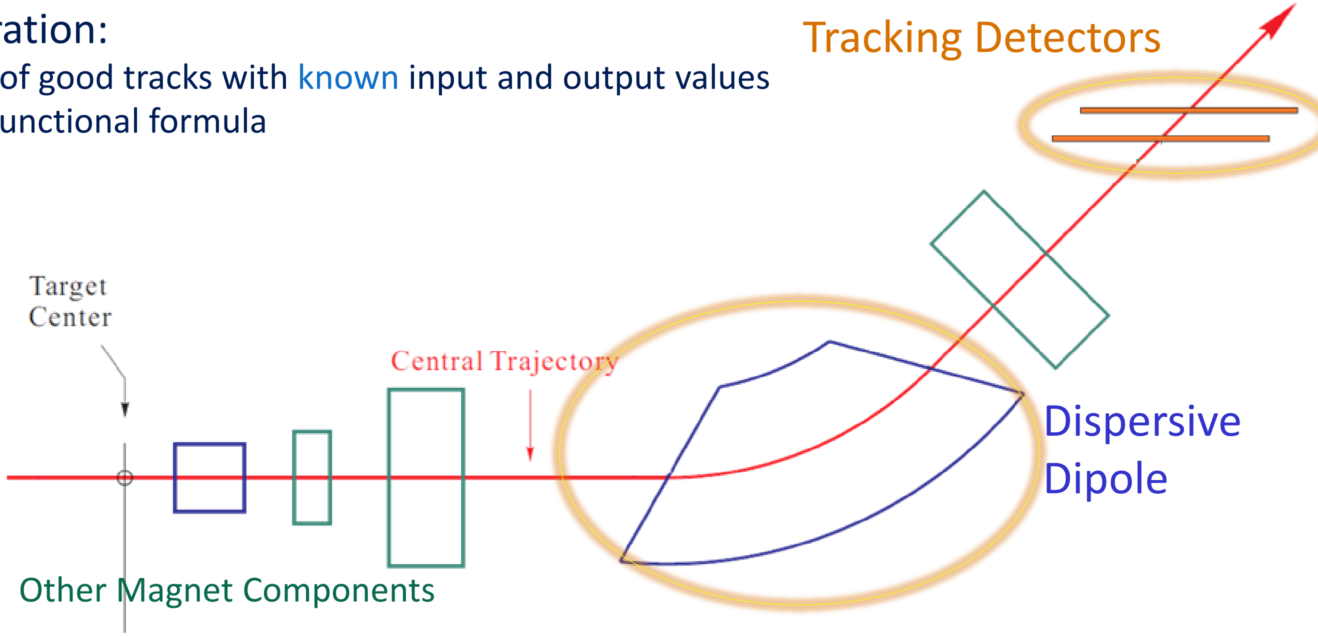
@ Detector
- Position
- Direction

Inverse Prism Transportation

@ Source
- Momentum
- Direction

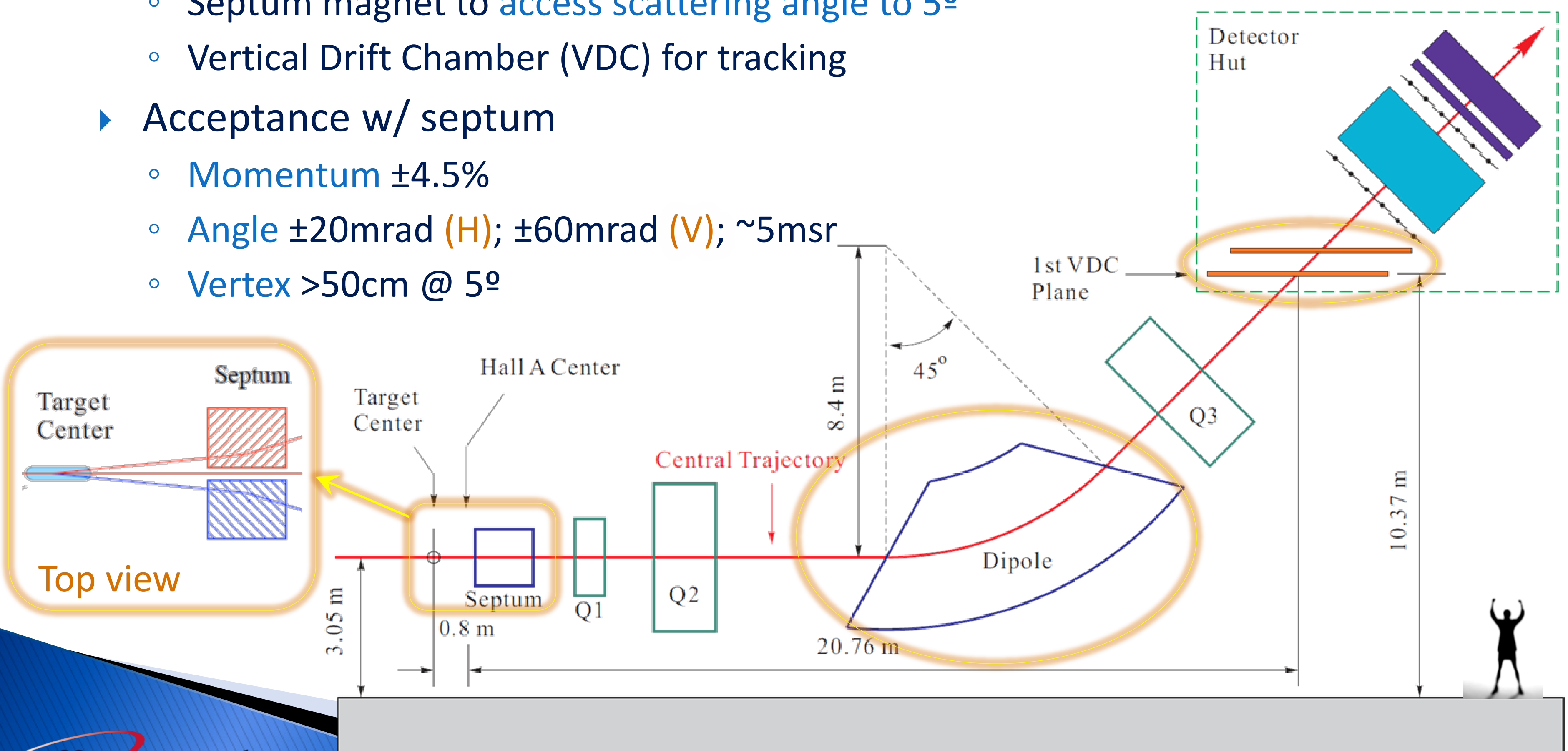
Magnetic Spectrometer Optics

- Dispersive Dipole Magnets + Tracking Detectors
- Input: measured position (2D) + direction of particle (2D) @ detector
- Output : charged particle momentum and position at vertex
  - Momentum (3D Vector)
  - Vertex Position (1D vertex z location)
- Optics = A functional formula map detector -> vertex
  - Multivariable, 4 input -> 4 output
- Optics calibration:
  - Need a set of good tracks with known input and output values
  - Fit for the functional formula

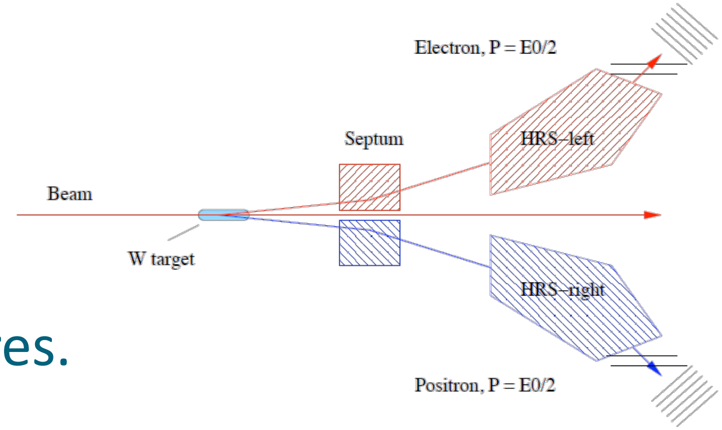


High Resolution Spectrometer (HRS) for APEX

- Setup
  - QQDQ vertical bending 45º, well studied over years
  - Septum magnet to access scattering angle to 5º
  - Vertical Drift Chamber (VDC) for tracking
- Acceptance w/ septum
  - Momentum ±4.5%
  - Angle ±20mrad (H); ±60mrad (V); ~5msr
  - Vertex >50cm @ 5º



Optics for APEX



- Use tracking information on VDC
  - 2D hit position/2D angle
- Reconstruct target side
  - Small acceptance, large size → Fine res.
  - Momentum $\sigma \sim 1\times10^{-4}$(Rel. to p_0)
  - Angle $\sigma \sim 0.4$mrad (H) , ~2mrad (V) , APEX tune
  - Vertex $\sigma \sim 1$cm, Trans. Pos. $\sigma \sim 1$mm
  - +Target multi-scattering (~0.4mrad on angles)
- Uncertainty contribution
  - Tracking precision – not included in this talk
  - Optics calibration precision

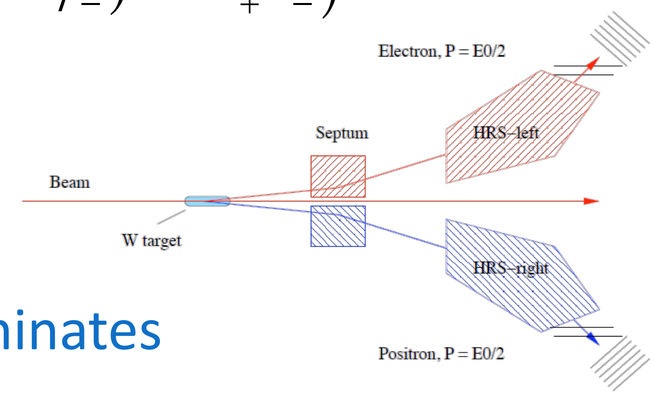
Early estimation on uncertainties in optics

θ_0	Central angle
$dp_\pm$	Momentum dev.
$(\phi_+ - \phi_-)$	H. angle diff
$\theta_\pm$	V. angles

- Inv mass uncertainty (ex. Kine A)
  - To leading order:

$$m^2 \approx p_0^2\left(4\theta_0^2 + 4\theta_0^2 dp_+ + 4\theta_0^2 dp_- + 8\theta_0\left(\phi_+ - \phi_-\right) + 2\theta_+\theta_-\right)$$

  - Momentum Contribution is small
    - σ~1×10^{-4} → δm~20keV
  - Vertical angle res. is minor too
    - σ~1mrad → δm<120keV
  - Resolution of horizontal angles res. dominates
    - σ~0.5mrad → δm~570keV
    - Sum of horizontal angles -> high order
    - Systematic offset of diff -> do not contribute to peak width
  - +Target multi-scattering
    - ~0.4mrad (~500keV on δm), target design dependant

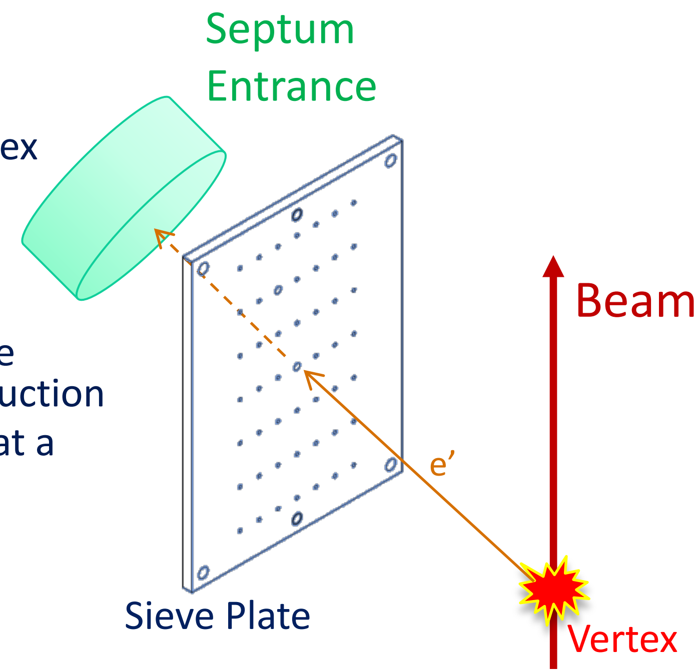


Calibrating optics

- Reconstructing optics
  - Input: Track position/direction @ VDC, Beam location
  - Output: 3D momentum at vertex side, vertex
  - Formula: 4D polynomial fitting & interpolation
  - Calibration: Minuit2 based Chi2 fit with central bias correction
- Calibration require clean tracks with known value on the vertex and VDC side and cover acceptance used in analysis
- Calibration is separating into 3 groups calibration to calibrate each component of optics reconstruction
  - Tracks with known angles from vertex: Sieve slit data
  - Tracks with known momentum (dp = momentum/central -1): Elastic data
  - Tracks with known vertex: Multi-foil data
- The result polynomial constant and description: APEX Elog 63
- Calibration tools setup (not including calibration data): JLabFarms:/work/halla/apex/disk1/jinhuang/optics/

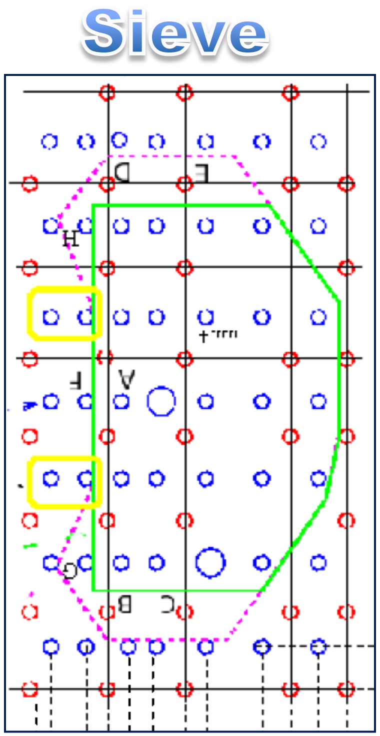
Test Run Calibration / Angles

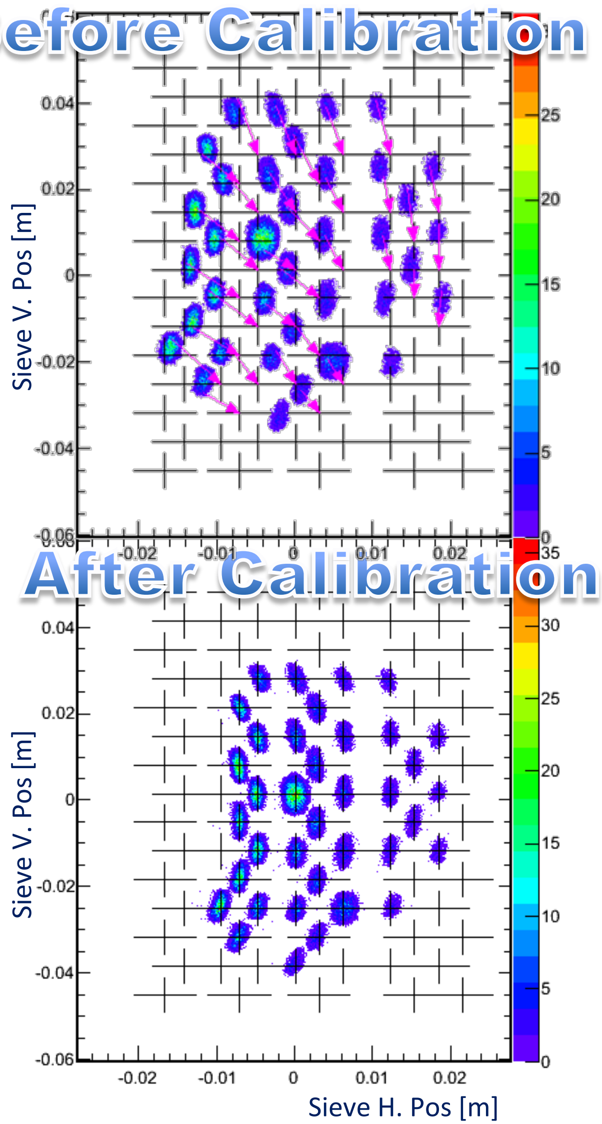
- Calibration data set
  - Elastic-near elastic scattered electrons
  - Sieve slit, to calculate vertex angle using holes and vertex
    - Great to have active detector here
  - Scan through momentum acceptance
- Improvement for future: septum polarities
  - In test run, calibrated in septum anti-parallel field mode leads to large correction for parallel field mode in production
  - In future, we can calibrate in parallel field for one arm at a time or use sci-fi detector
- Improvement for future: sieve plate/sci-fi survey
  - “Central Angle” is arbitrarily defined
  - Relative distance between two sieves → offset of angle difference
  - Possible improvement: single sieve slit for both arm or specific survey
  - Other contribution (δm less sensitive to)
    - Beam position
    - Foil location



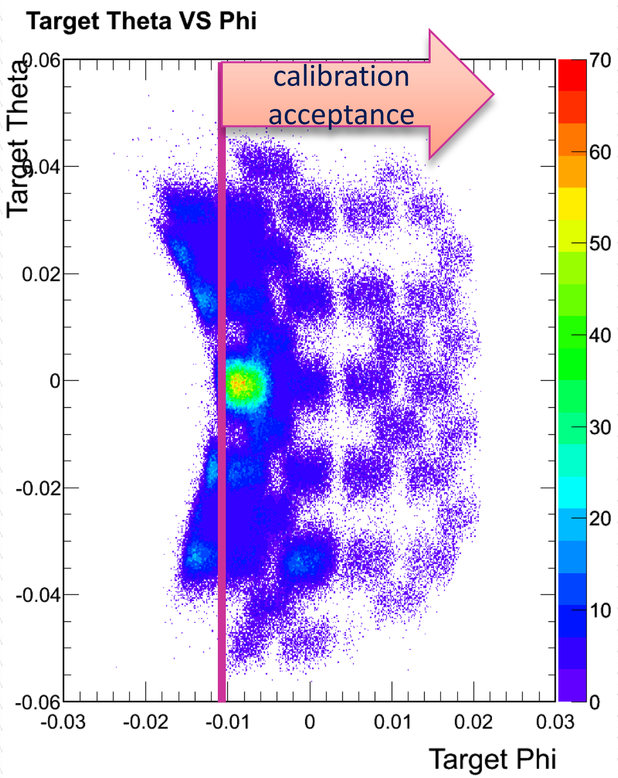
Test Run Calibration / Angles

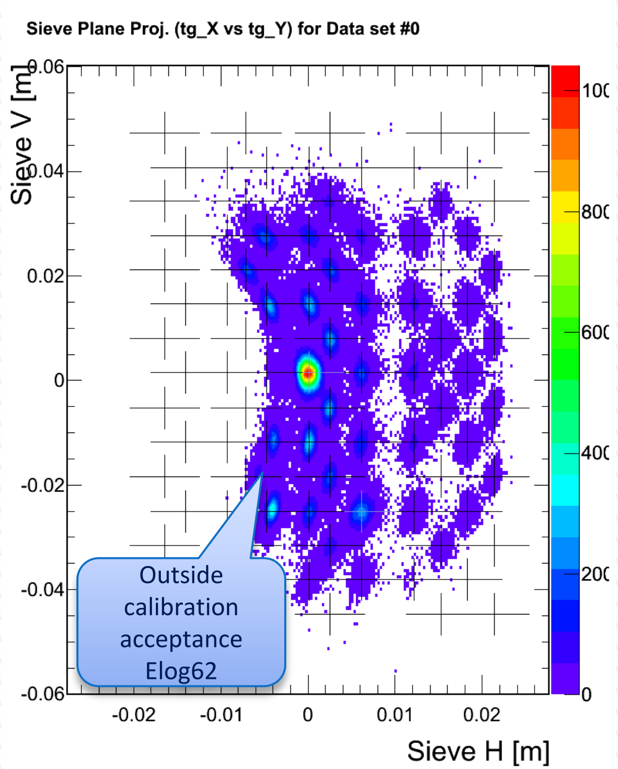
- Calibrated with 2010 test run data
  - Elastic peak + Elastic tails events
  - Only calibrated in negative charged mode on both arm
  - Acceptance reduced
    - PREX collimation
  - Full running : larger acceptance, opposite charge mode
- Calibration
  - Example plots ->
  - Max polynomial order:
    - LHRS: 8 ϕ-columns, polynomial order<=4, 51 non zero terms
    - LHRS: 14 ϕ-columns, polynomial order<=6, 95 non zero terms
  - Robust fit
    - we identified errors on Sieve drawing, confirm with rulers Elog 45
- Study alignment error by check average deviation of holes away from the expected location
  → Horizontal ~0.1mrad
  Vertical ~ 0.2mrad





Optics was verified with large beam raster too
Run 1896 18973, 4x4mm MCC raster





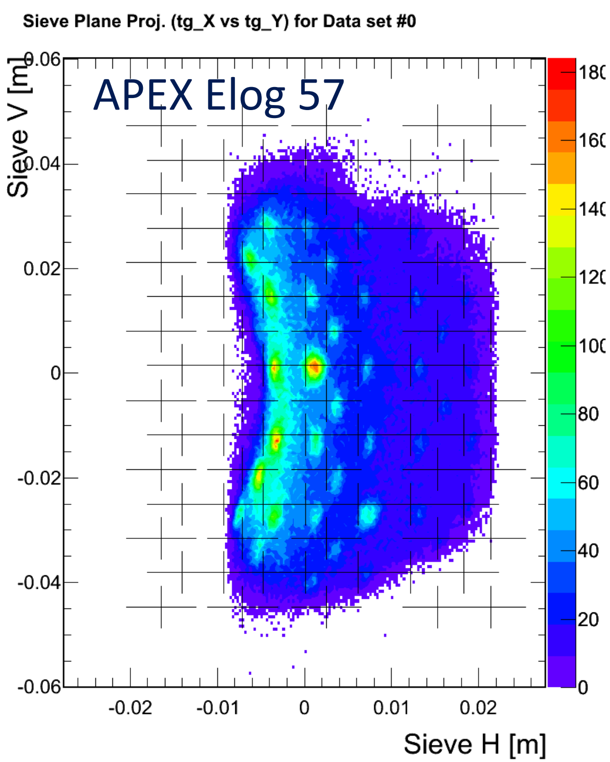
Many steps are checked to make it right: raster size/direction, beam position corrections, optics

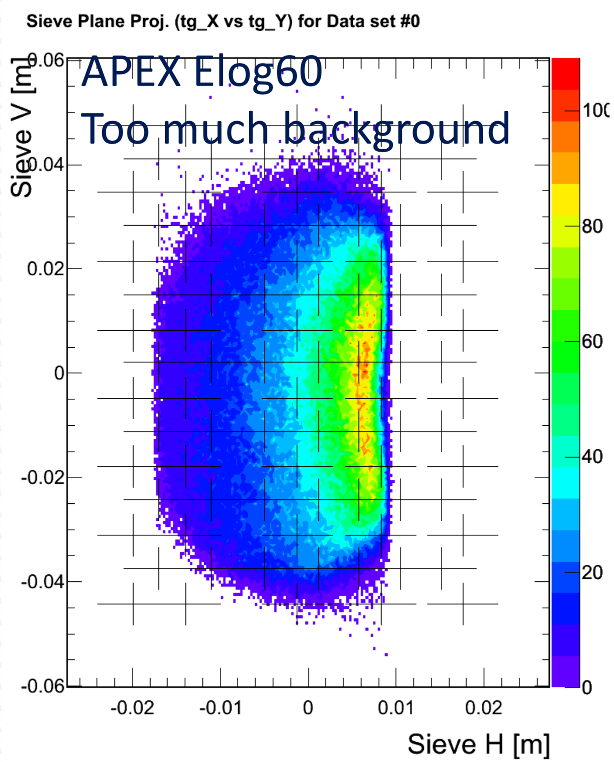
Angular space : theta VS phi

Track projection to Sieve slit hit location

Septum field effect check in test run

Calibrated in septum anti-parallel field mode, check for parallel field mode (production mode)
Two pass data was available but with higher punch through rate





Compare to sieve pattern→1.3mrad shift with variation of ~0.3mrad from hole to hole

L-HRS with electrons

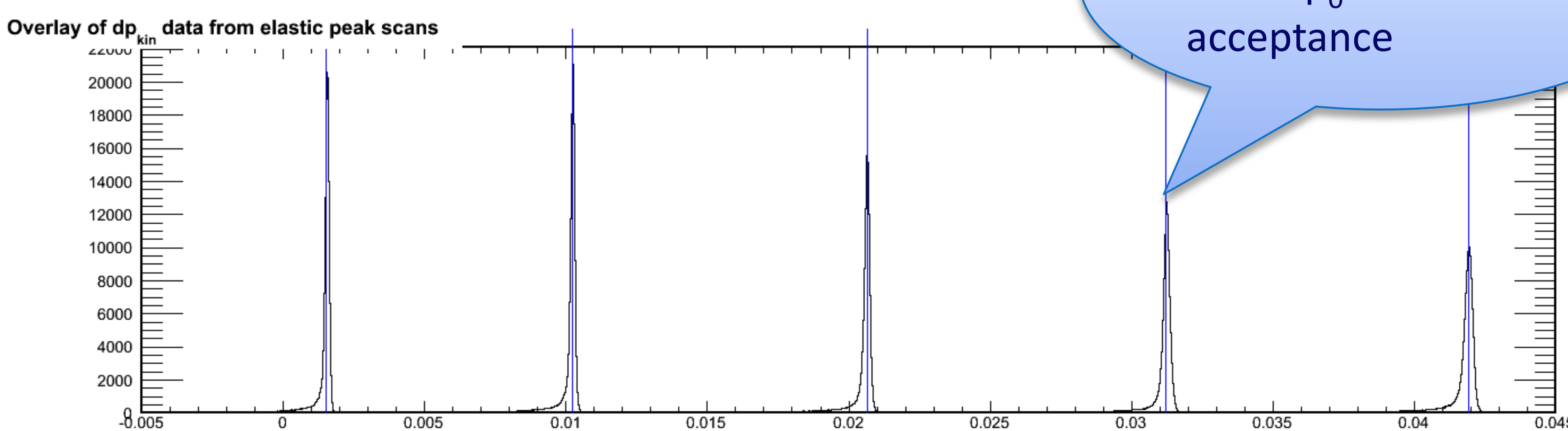
Sieve can be observed with heavy punch through

R-HRS with positrons with Sieve

No obvious difference with Sieve in, half-in and out

Test Run Calibration / Momentum

- Few 10^{-3} level good out of box
- Ideal calibration
  - Select elastic scattered electrons events
  - Fit reconstructed momentum →elastic calc.
- 2010 test run data
  - limited to 0%<=dp<=4% due to septum current limit
  - Used past-calibrated HRS optics + linear (a+b*x) correction
  - Data list: APEX Elog 82
- Well developed procedure for full running

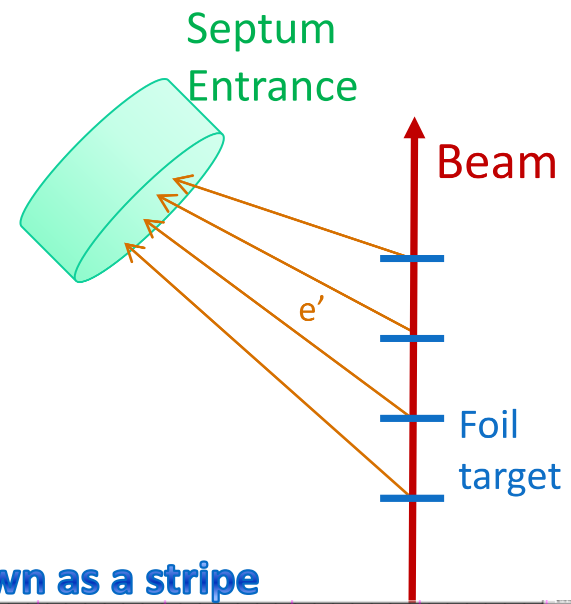


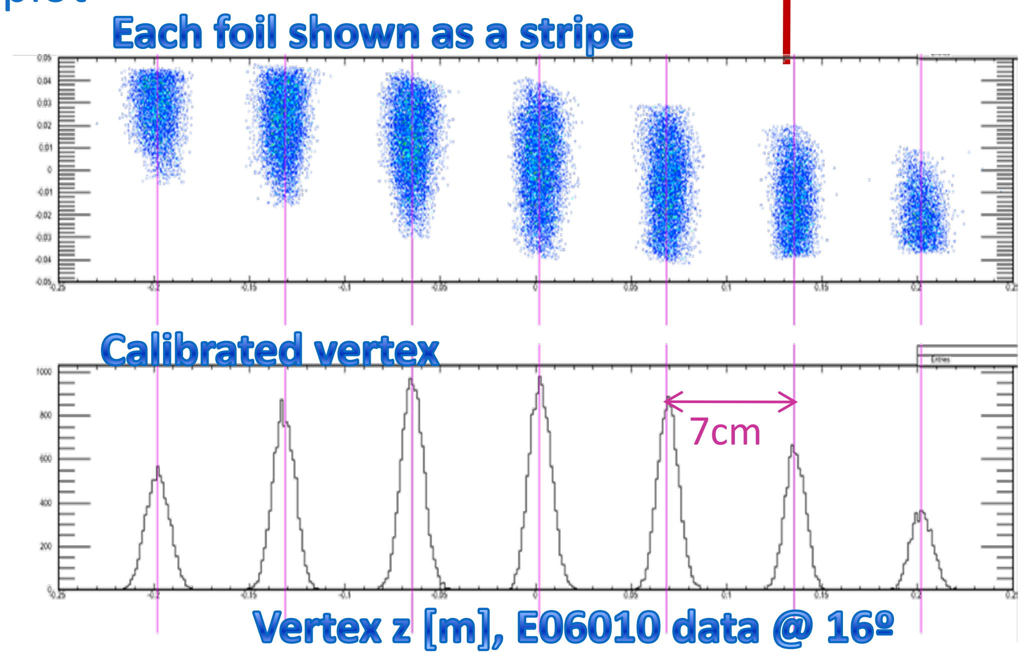
•One elastic peak
• scan p_0 to calib. Full acceptance

$(p/p_0\text{-}1)$– elastic angular dependence

Calibration / Vertex

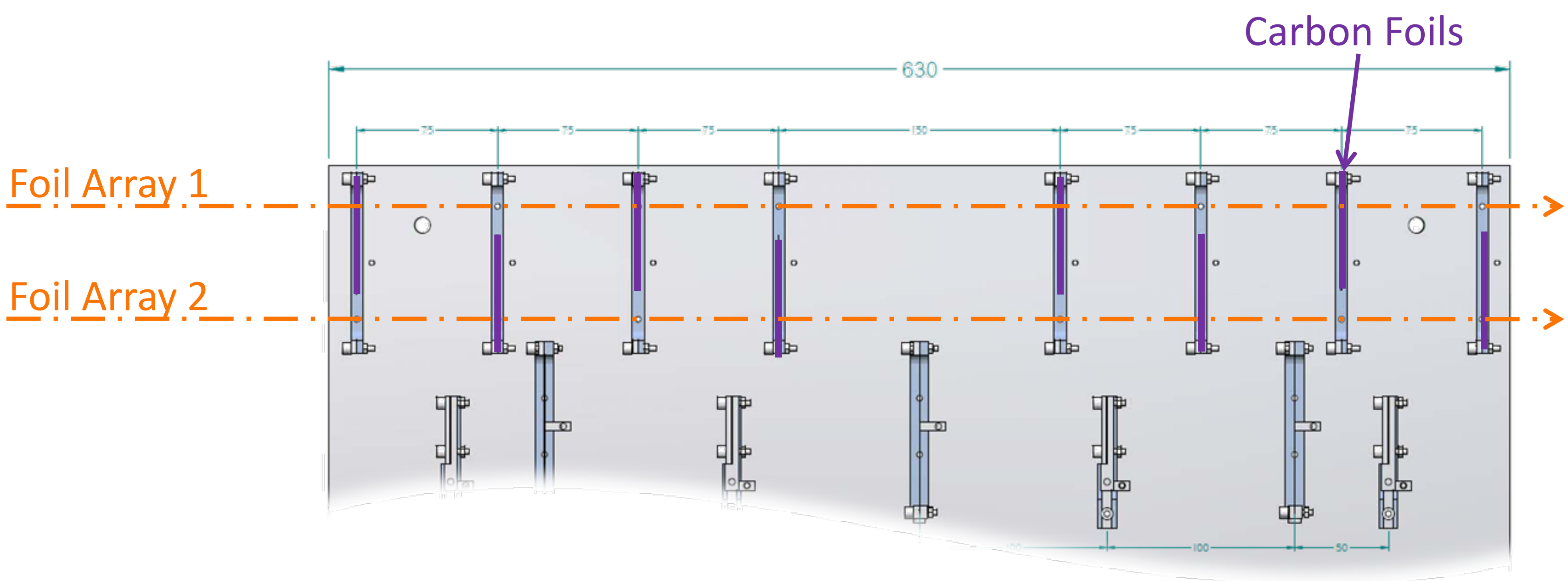
- Not included in test run
  - Old optics target
  - A single foil presented in main data
- Calibration method
  - Separated foil target
  - Each foil form a stripe on 2D plot
    - Horizontal angle
    - Horizontal position
  - Calibration
    - Select each stripe
    - Fit towards surveyed foil location





2010 optics target design

- Multi-array target needed
  - Significantly improve foil separation during calib.
  - Enough foils for reliable interpolation



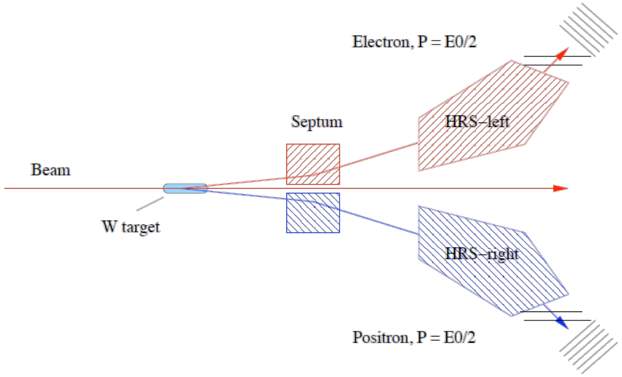
Beam Position Correction

- Two part optics reconstruction
  1. Approximate target variable construction with ideal beam
  2. Apply correction with beam location
- Leading beam correction on 3D momentum
  - 0.5 mrad on vertical angle / 1mm vertical beam shift
  - 0.2×10^{-3} on dp / 1mm vertical beam shift
  - 0.04mrad on horizontal angle / 1mm vertical beam shift
  - Rest correlation are 2nd order or higher
- Calibrating the correction coefficients
  - Theory calc. : 2009 Hall A Analysis Workshop talk
  - Fit from data
  - Consistency between methods (tested w/o septum)

Early estimation for optics calibration for full scale running

- Only based on experience from test run
- Optics data
  - Two data sets: 5.0º @ 1pass, 5.5º @ 2pass
  - Each HRS, data taken separately (septum parallel field mode)
    - May not necessarily do so with sci-fi detector
  - Elastic scan on 2 carbon foils arrays, w/ sieve
    - 7 mom. point: 0%, ±2%, ±3%, ±4% relative to central p_0
    - Momentum and angular calibration
  - Inelastic run on 2 carbon arrays, w/o sieve
    - Vertex calibration
  - + beam correction check
- Beam time
  - 2× (2×~1Shift+Conf. Change) $\lesssim$ 2 day

Conclusion



- APEX HRS spectrometers

	Acceptance	Resolution as σ
Momentum	±4.5% (Rel. to p_0)	1×10^{-4} (Rel. to p_0)
Horizontal Angle	±20mrad	~0.4mrad
Vertical Angle	±60mrad	~2mrad
Vertex	>50cm	1cm (along beam)

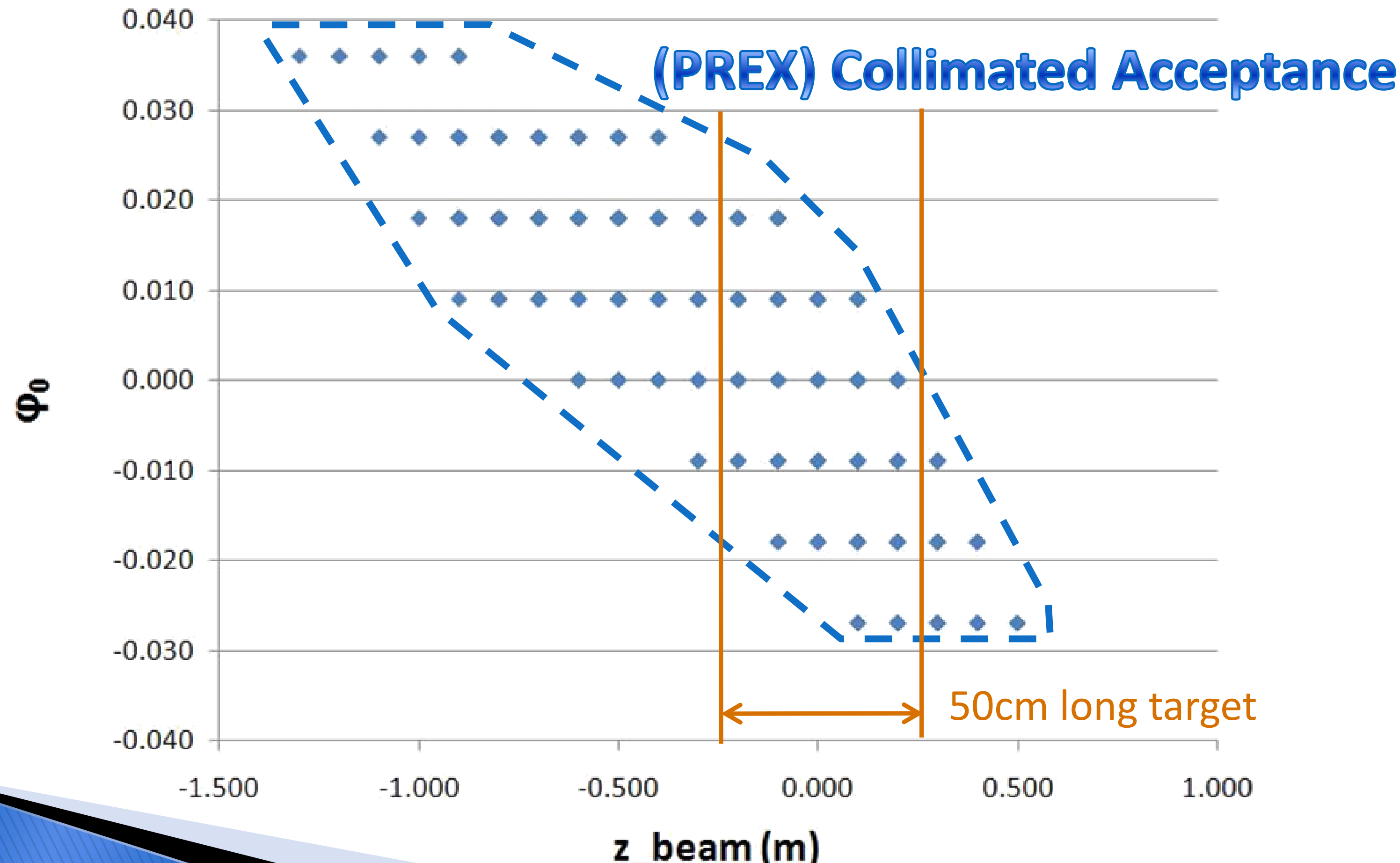
  - Resolution of diff. between H. angle dominants δm
- 2010 test run
  - Optics calibration precision (point to point)
    - 0.2mrad (V. Angle), 0.1mrad(H. Angle)
  - Calibrated in septum anti-parallel field mode leads to large uncertainty in corrections for parallel field mode in production
  - Learned toward better preparing full production optics

Back up slides

- Vertex acceptance
- 1st order matrix

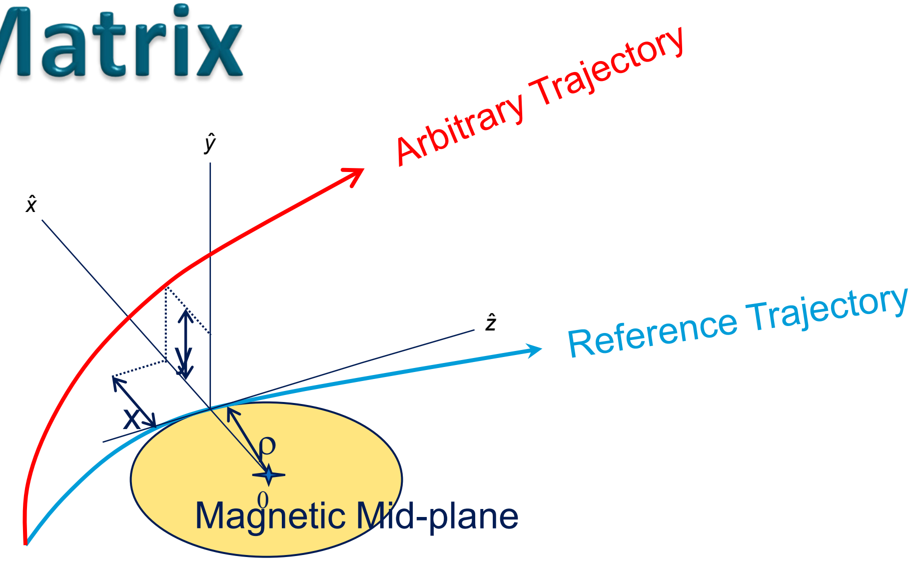
Vertex acceptance

- Correlated with horizontal angular acceptance



1st Order Optics Matrix

- Define of optics variables
- APEX optics tune



Target side variable

x0	θ0	y0	φ0	δ	Detector side variable
-2.1742	-0.00432	-0.03602	-0.03618	13.39705	x
-0.23112	-0.45977	0.000884	0.003852	2.319847	θ
0.020057	0.024489	0.008417	-1.74647	-0.2411	y
0.018126	0.021383	0.575993	-0.72164	-0.22927	φ

: New w/ septum and APEX tune

Inverse polarity

- Repeatability of HRS polarity inversion
- Guild line from John Lerose
- Special cycling precedure
- Verified in June test run, under analysis