Precision Spectrometer Optics for GMp Experiment

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The College of William and Mary
For E12-07-108 Collaboration

2015 APS April meeting

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Jefferson Lab

Manpower

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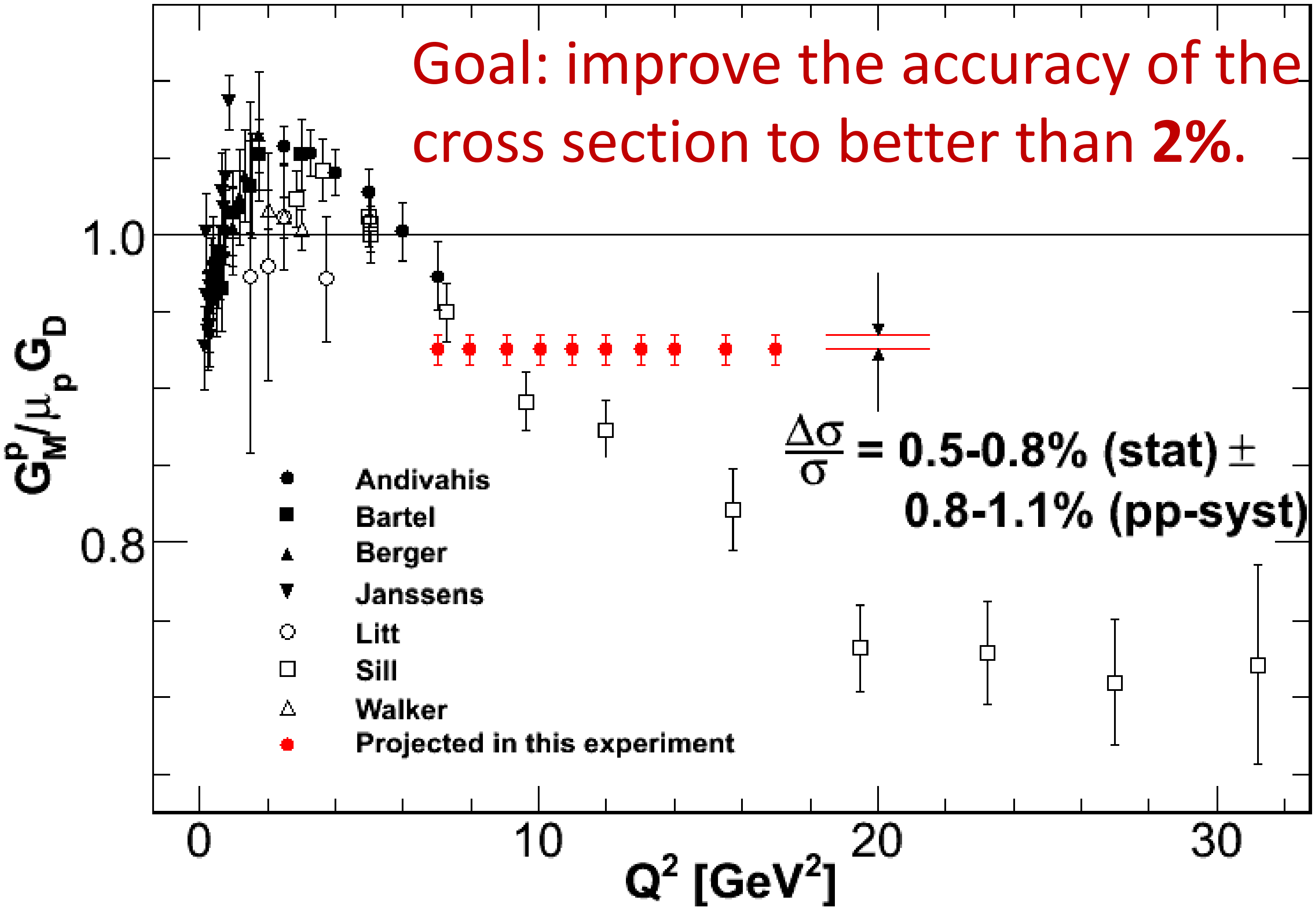

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Motivations

- Accurately measure e-p elastic cross section in kinematics similar to other JLab form factor measurements ($Q^2 = 7\text{–}14\ \text{GeV}^2$).
- Aim to improve the accuracy of the cross section to better than 2%.
- Important for all form factor measurements, and many of other experiments where elastic scattering is used for cross section normalization.

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Optics requirements

$$|Form\ factors|^2 = \frac{\sigma(structured\ object)}{\sigma(pointlike object)} = \frac{\sigma(\theta_{ep})}{\sigma_{Mott}}$$

$$\sigma(\theta_{ep}) = \frac{N_{event}}{\Delta\Omega \cdot \int L dt \cdot L_{target}}$$

where $\int L dt$ is the integrated luminosity and L_{target} is the target length.

$$\frac{\delta\sigma}{\sigma} \leq 2\% \rightarrow \begin{cases} \frac{\delta\Delta\Omega}{\Delta\Omega} \leq 0.5\% \rightarrow \frac{\delta\Delta\theta_{tg}}{\Delta\theta_{tg}} \leq 0.35\%,\ \frac{\delta\Delta\phi_{tg}}{\Delta\phi_{tg}} \leq 0.35\% \\ \frac{\delta\theta_{ep}}{\theta_{ep}} \leq 0.2\% \rightarrow \delta\theta_{ep} \leq 1.15 mrad, \delta\phi_{tg} << 0.98 mrad \end{cases}$$

with $\delta\theta_{central} \leq 0.60 mrad$

Optics requirements:

$$\delta\Delta\theta_{tg} \leq 0.35\% \times 100 mrad = 0.35 mrad$$

$$\delta\Delta\phi_{tg} \leq 0.35\% \times 50 mrad = 0.18 mrad$$

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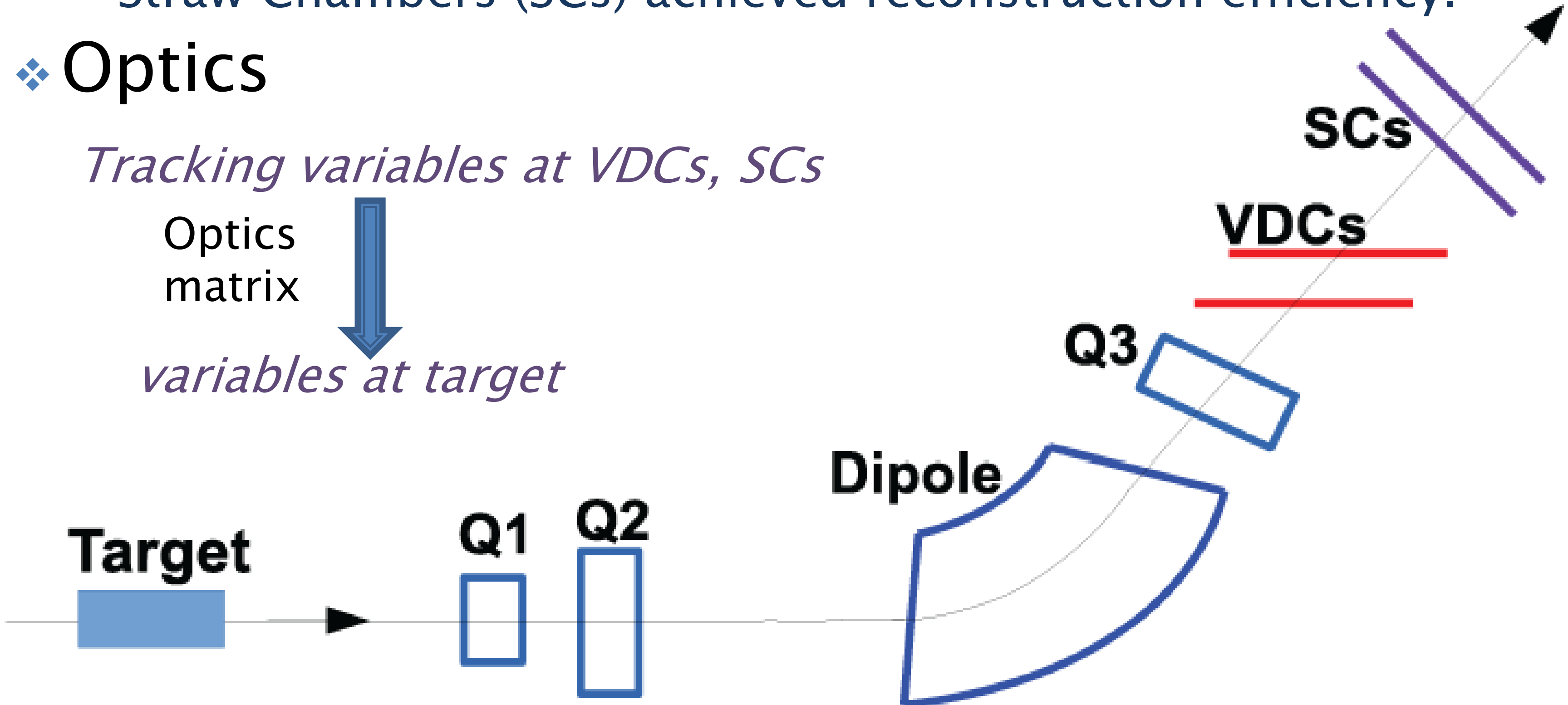
Magnetic Spectrometer Optics

- Setup
  - QQDQ, vertical bending 45 degrees.
  - Vertical Drift Chambers (VDCs) for tracking.
  - Straw Chambers (SCs) achieved reconstruction efficiency.
- Optics

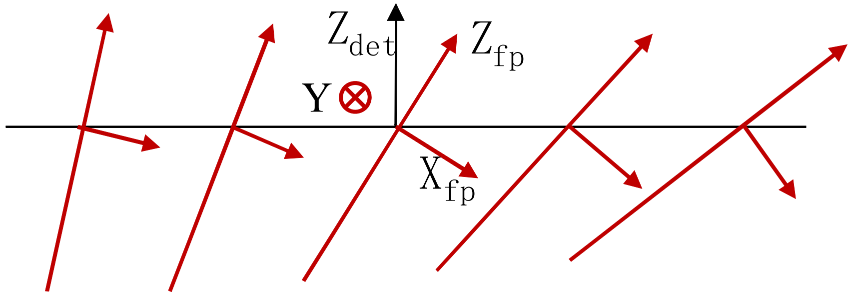
Tracking variables at VDCs, SCs

Optics matrix ↓

variables at target



Magnetic Spectrometer Optics

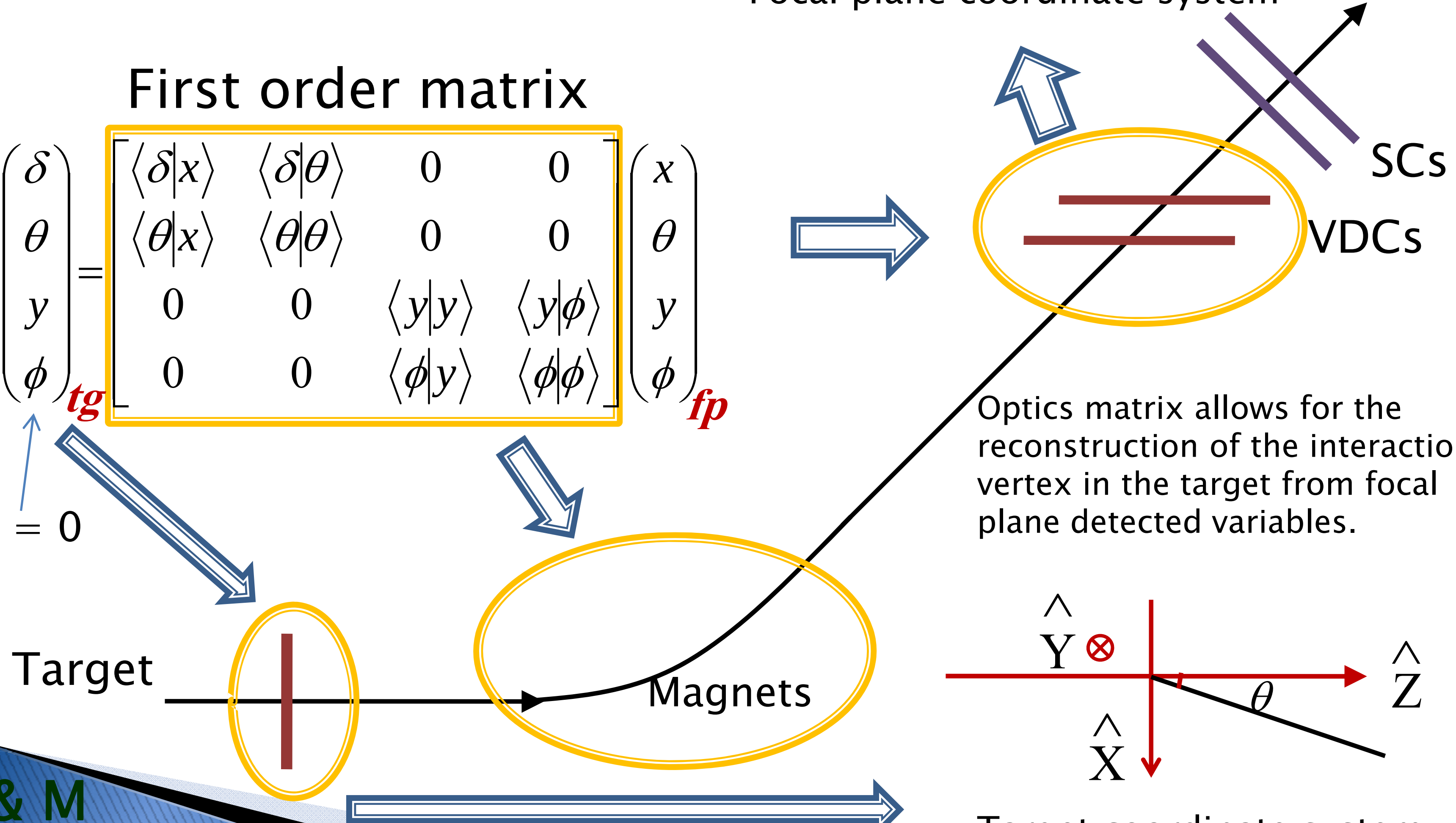


Focal plane coordinate system

First order matrix

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

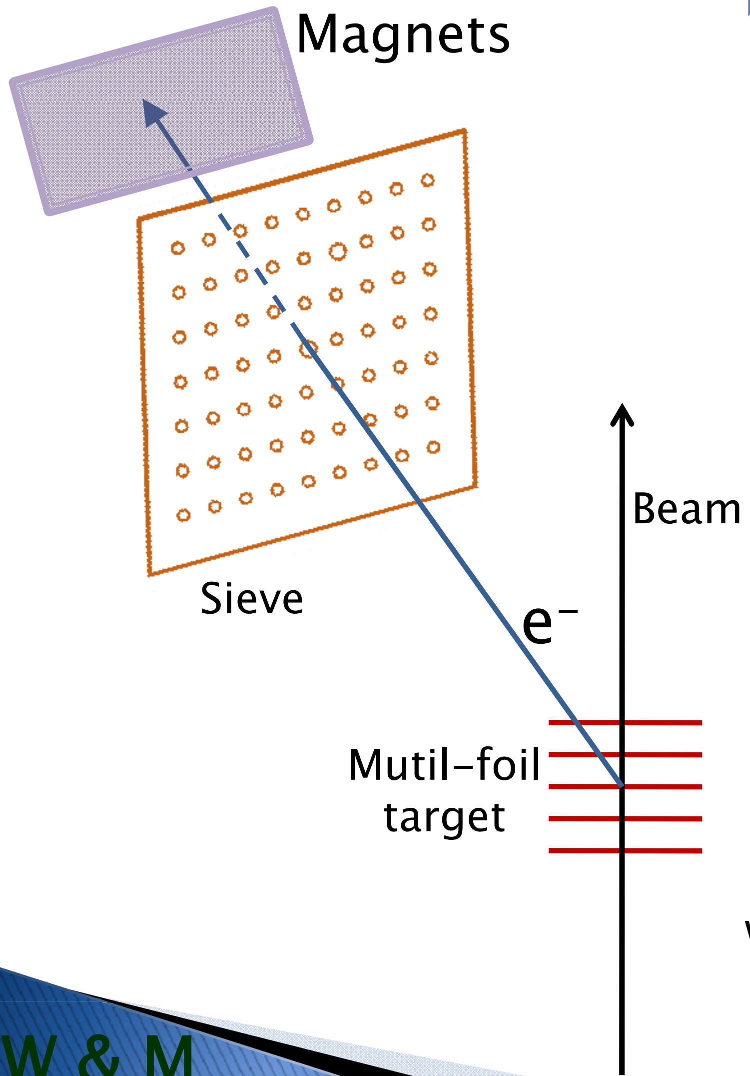
X = 0



Optics matrix allows for the reconstruction of the interaction vertex in the target from focal plane detected variables.

Target coordinate system

Optics Matrix Calibration



- 3 groups of calibration
  - Angles: θ_{tg}, ϕ_{tg}
    Sieve slit data
  - Vertex: y_{tg}
    Multi-foil targets data
  - Momentum: $\delta = p / p_{central} - 1$
    Elastic data

$$x_{tg} = \sum_{i=0}^{m} C^{x}_{i,j,k,l} \, x^{m}_{fp} \sum_{j,k,l} \theta^{j}_{fp} y^{k}_{fp} \phi^{l}_{fp}$$

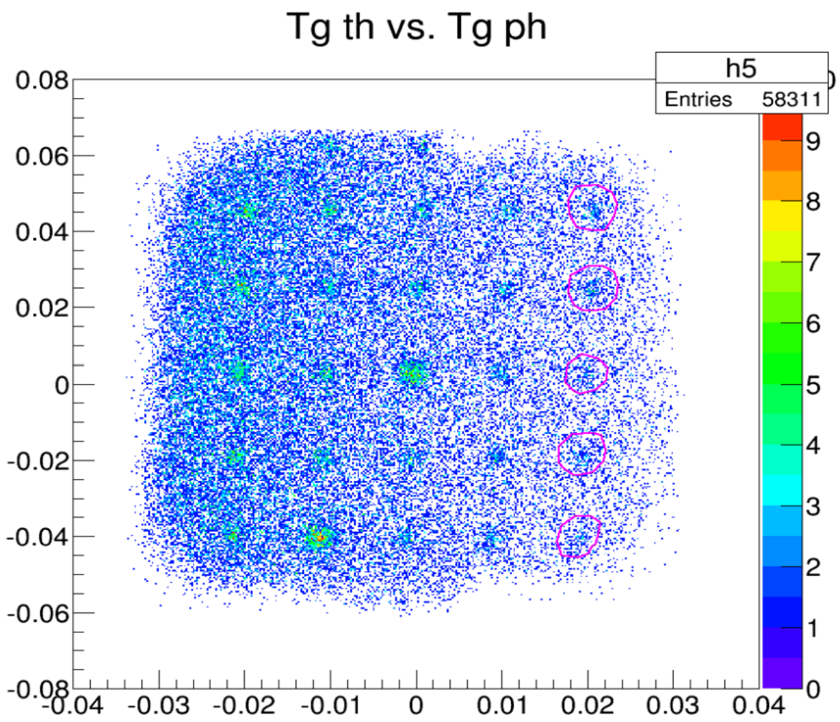
$$\sigma^{2}(x_{tg}) = \sum_{i=1}^{m} \sum_{j=1}^{n} (x^{\text{recon.}}_{i,j} - x^{\text{survey}}_{i})^{2}$$

where X_{tg} can be any target variables $\theta_{tg}, \phi_{tg}, y_{tg}, \delta$

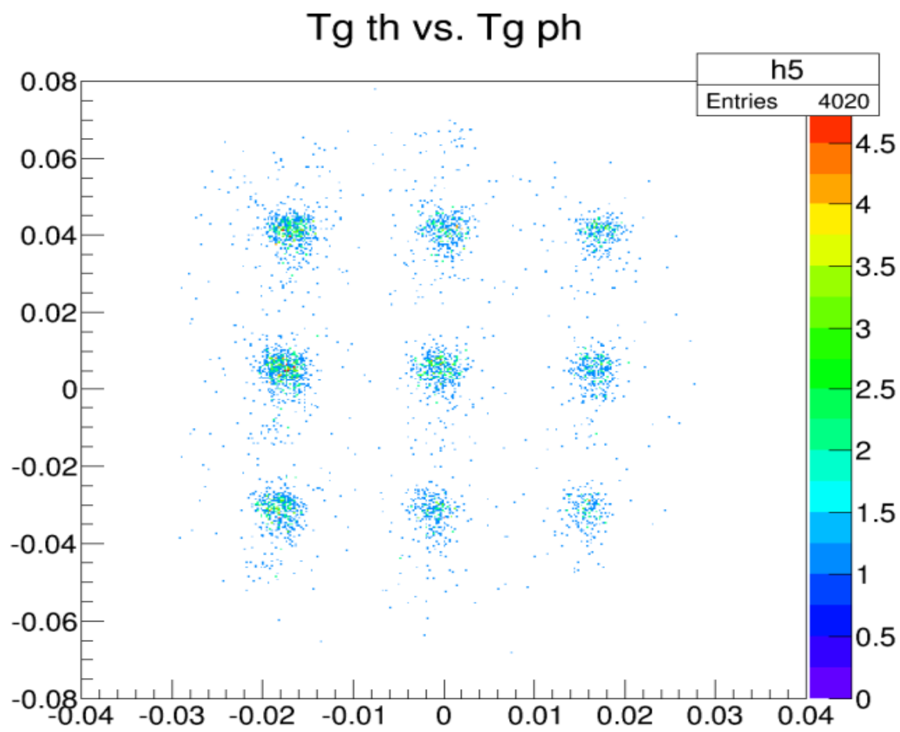
Varying $C^{x}_{i,j,k,l}$ to minimize $\sigma^{2}(x_{tg})$

GMp optics

- High beam energy -> DIS run for optics calibration



5mm stainless steel sieve slit, 7x7
March, 2014



1.5 inch lead sieve slit, 5x5
March, 2014

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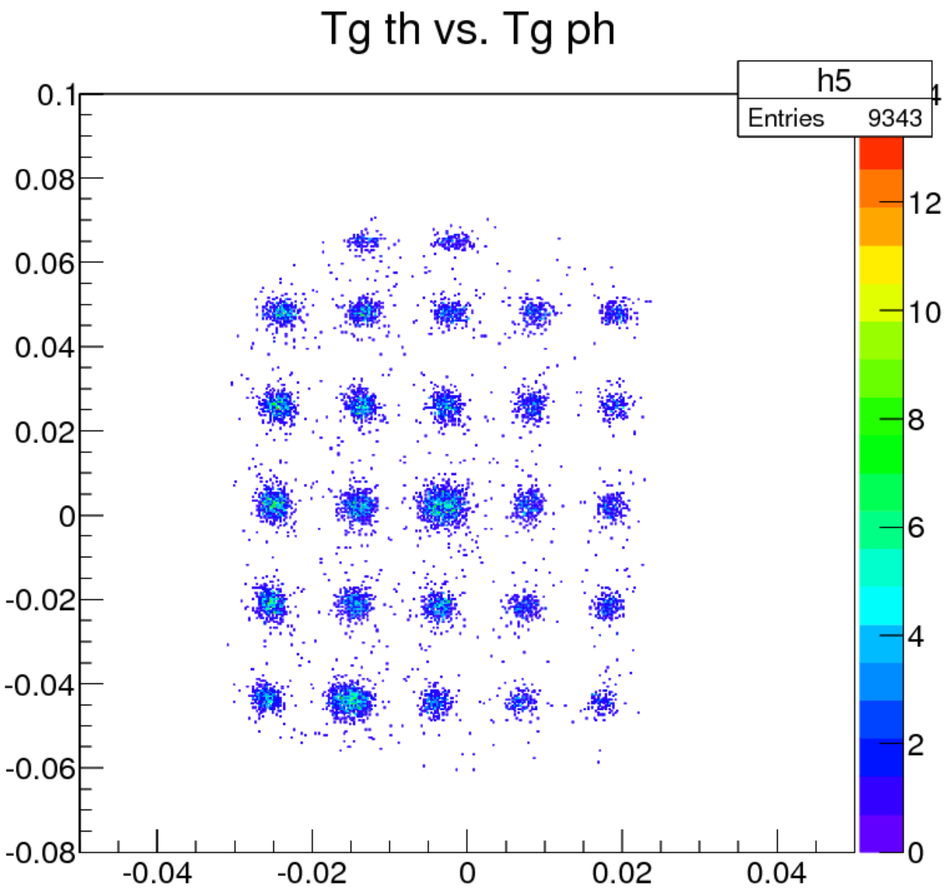
GMp optics

- With a new designed sieve, the electron events which punched through the holes are clearly distinguished from the background.



New sieve:

2 inch thick,
lead,
7 rows,
9 collumns

Dec, 2014

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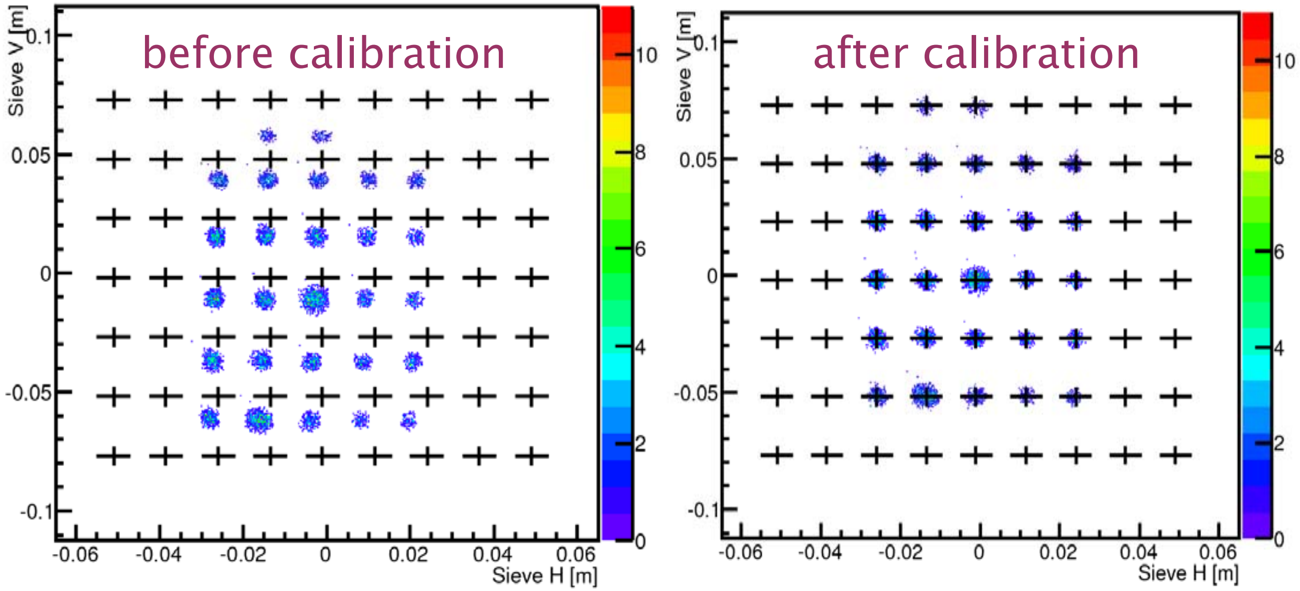
Angle calibration results

Sieve hole radius = 2mm



$\sigma(\theta_{tg})=8.51mm$

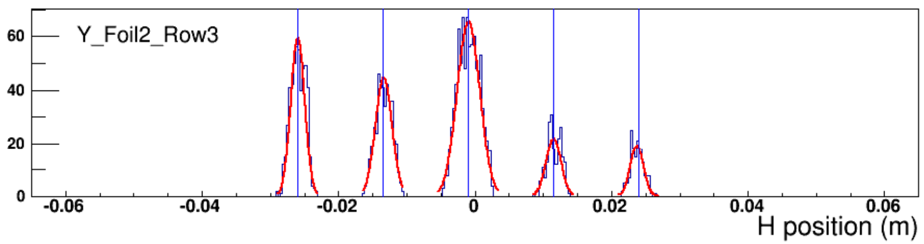
$\sigma(\phi_{tg})=2.07mm$

calibration

$\sigma(\theta_{tg})=1.75mm$

$\sigma(\phi_{tg})=1.07mm$

Optics precision study:



-Gaussian fitting
- survey position

- project reconstructed points to horizontal and vertial directions.
- make a Gaussian fitting for each sieve hole
- compare with the surveyed hole center

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Optics precision

Tables of differences between reconstructed positions and surveyed hole centers in vertical and horizontal directions

V direction, require $\delta V \leq 0.35\text{mm}$

Unit (mm)	Col3	Col4	Col5	Col6	Col7
Row1	0.23	0.12	-0.04	0.27	-0.14
Row2	0.01	0.25	-0.02	0.07	-0.06
Row3	0.07	-0.21	0.00	0.30	-0.11
Row4	0.06	0.59	-0.11	-0.05	-0.16
Row5	0.34	0.43	0.18	0.65	-0.06

Vertical distance of sieve holes next to each other is 25.0 mm

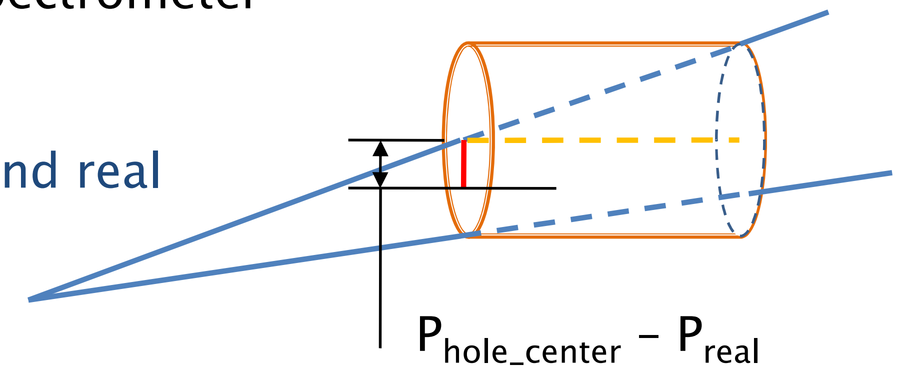
H direction, require $\delta H \leq 0.18\text{mm}$

Unit (mm)	Col3	Col4	Col5	Col6	Col7
Row1	0.29	-0.14	-0.10	-0.04	-0.37
Row2	0.17	0.04	-0.03	0.22	-0.07
Row3	0.03	0.13	0.04	0.03	-0.27
Row4	0.17	-0.03	-0.02	0.14	-0.16
Row5	0.36	-0.16	0.03	0.18	-0.69

Horizontal distance of sieve holes next to each other is 12.5 mm

Possible reasons accounting for the worse uncertainty towards the edge of the spectrometer acceptance.

- not enough data
- difference between hole center and real distribution center



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Summary

- Developed analysis allows for optics angle calibration with required precision.
- Spring 2015:
  - some production data.
  - perform precision study of optics vertex calibration.
- Fall 2015 and spring 2016
  - more production data.

Thank you!

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