Status of the MAGIX Spectrometer Design

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MAGIX collaboration meeting 2017

Magneto Optic Design

Requirements

- relative momentum resolution
  $\frac{\Delta p}{p} < 10^{-4}$
- resolution of the scattering angle
  $\Delta\theta < 0.05°\ \ (0.9\ \mathrm{mrad})$

Assumptions for the design

- MESA beam spot size of $100\ \mu\mathrm{m}$
- detector resolution $50\ \mu\mathrm{m}$
- multiple scattering in the detector $\Delta\theta = \Delta\varphi \approx 0.2°$

Design process

Analytical calculation
- calculate magnetic field
- determine geometry

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Construction of a 3D model

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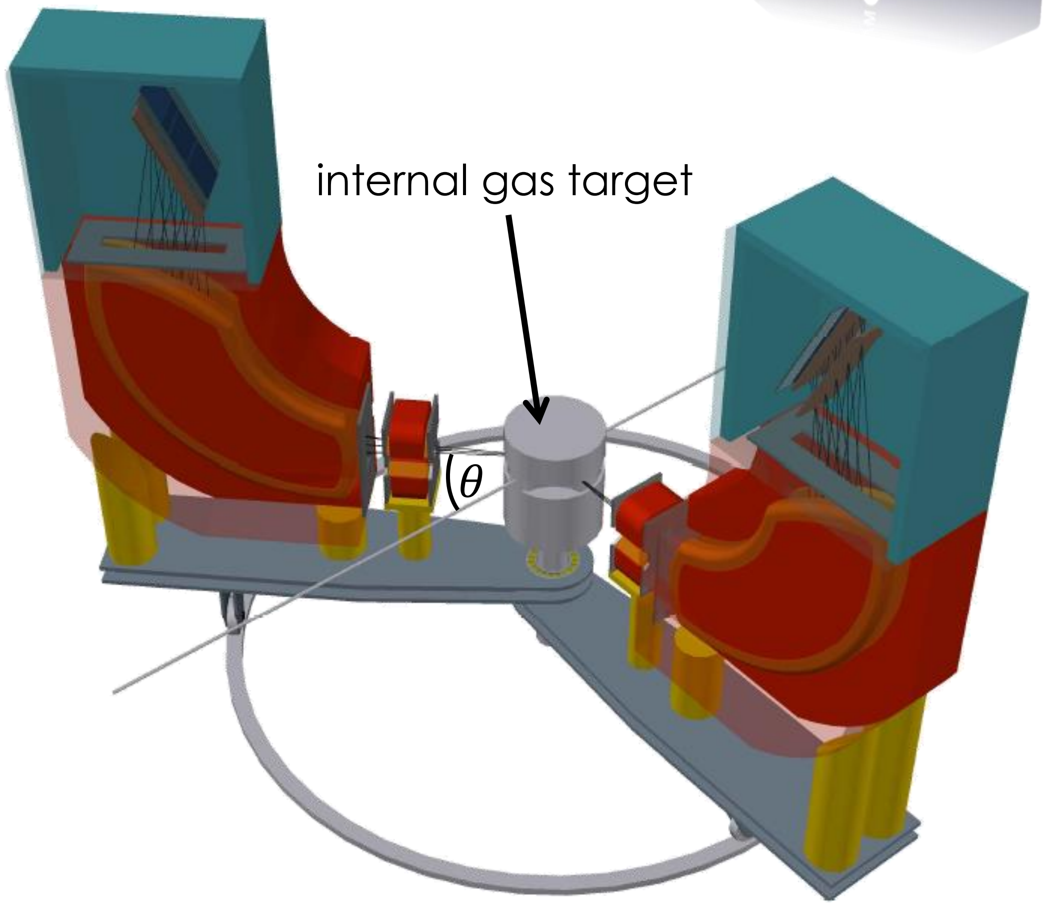
Finite elements simulation
- improve 3D model
- obtain field data

↓

Compare simulation and analytical calculation

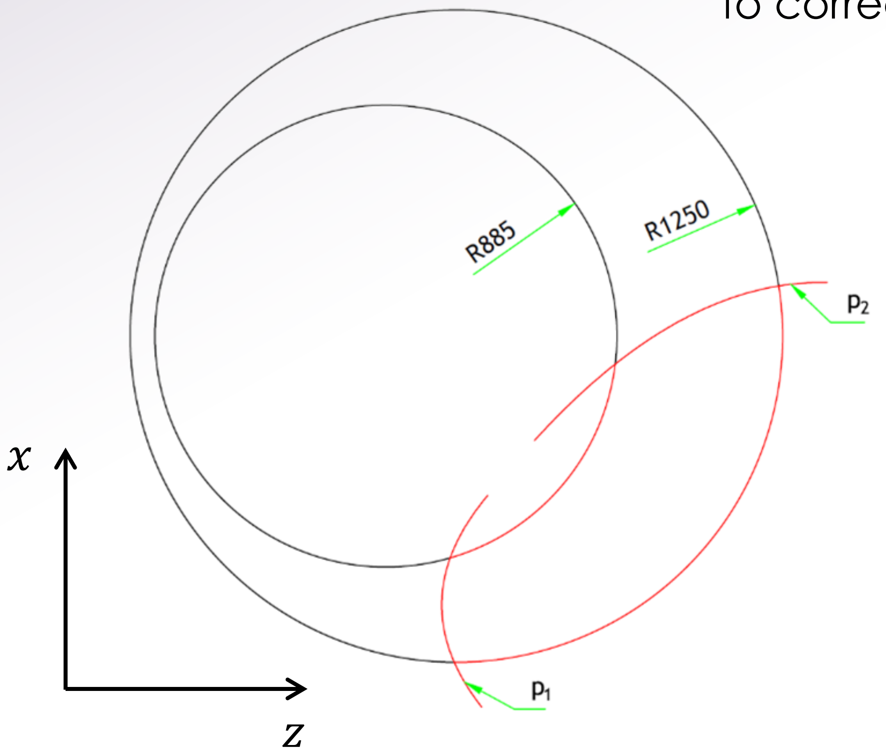


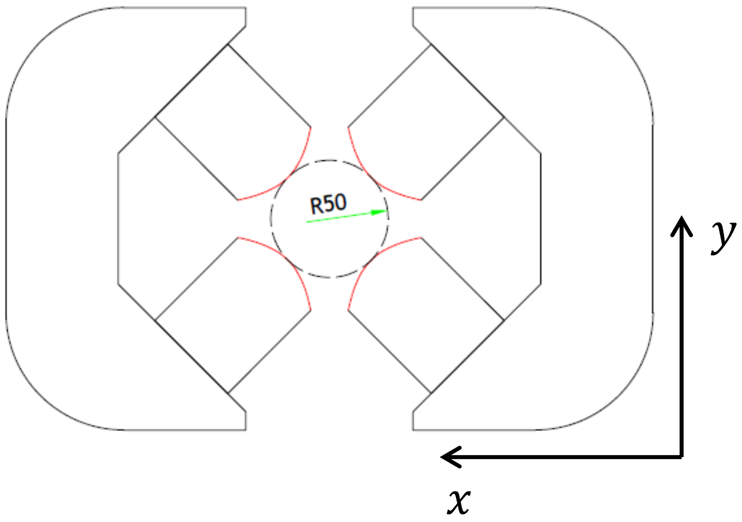
Design for a central momentum of $p = 200\ \mathrm{MeV/c}$!

Field Calculations

Dipole

- uniform field $B = 0.7\ \mathrm{T}$
- pole gap $100\ \mathrm{mm}$
- 2nd order polynomials p_1, p_2 to correct for aberrations

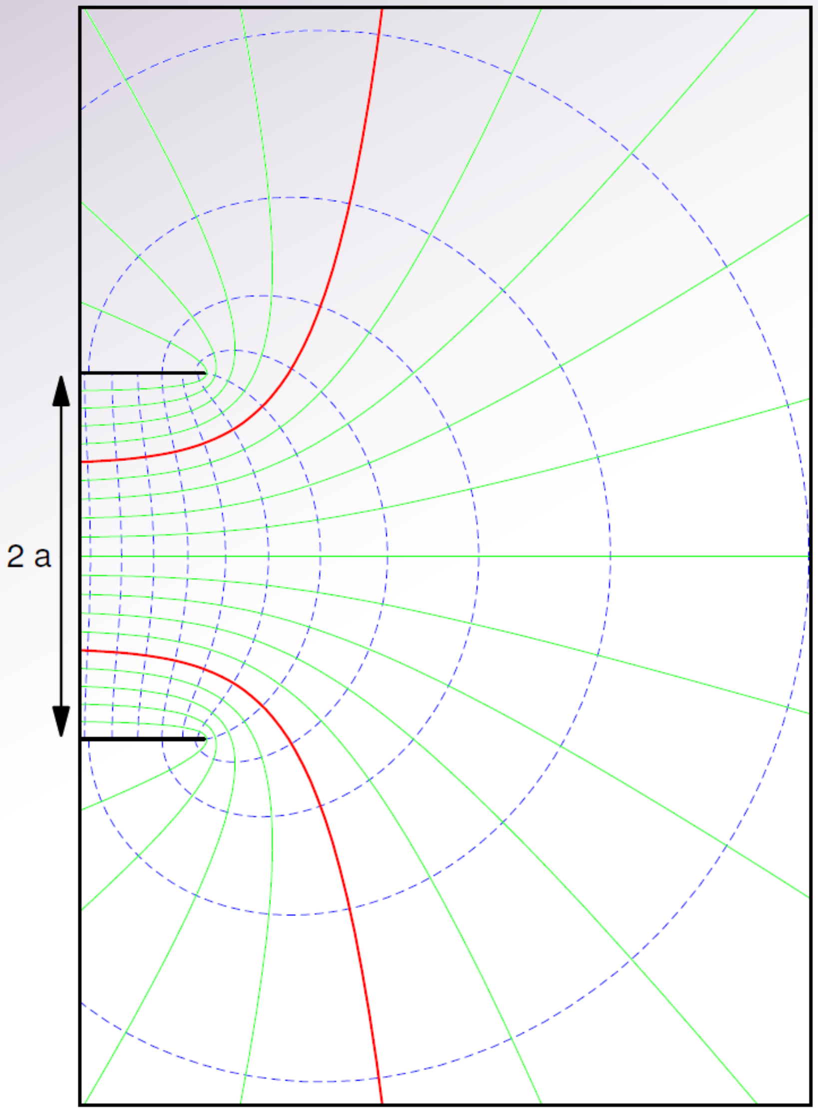




Quadrupole

- axial symmetry $B = g\ r$
- $g = 2.02\ \frac{\mathrm{T}}{\mathrm{m}}$
- hyperbolic shaped poles

Field Calculations



Field between two thin electrodes

- avoid field enhancement at the edges
- round of the edges in the shape of an equipotential line
  ⇒ Rogowski-Profiles

Rogowski-Profiles

- describe field between two electrodes

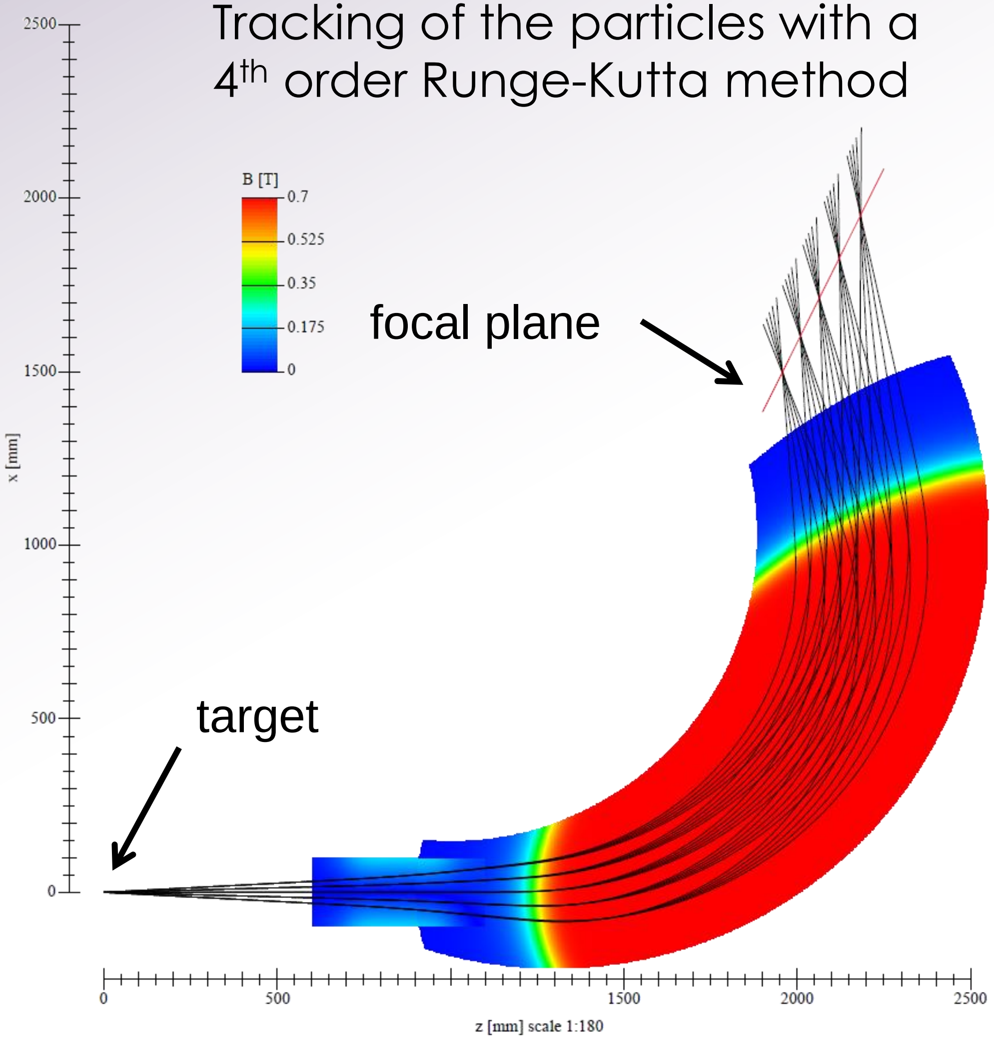
$$x = \frac{a}{\pi}(\varphi + e^{\varphi}\cos\psi), \qquad y = \frac{a}{\pi}(\psi + e^{\varphi}\sin\psi)$$

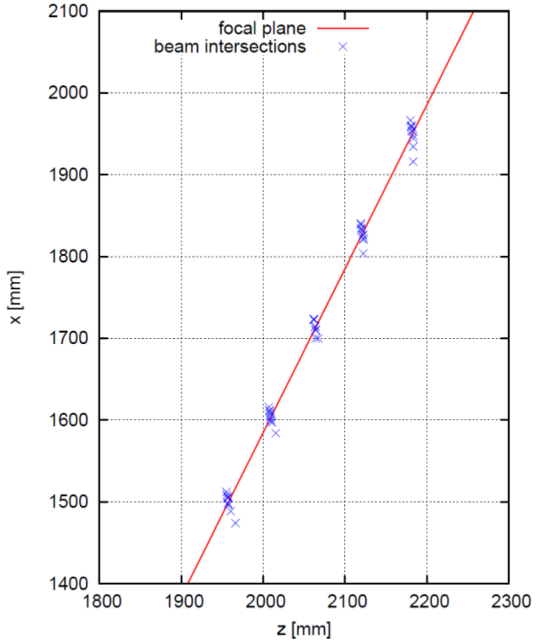
  field lines for $\varphi = const.$ (blue)
  equipotential lines for $\psi = const.$ (green)
- no field enhancement along the 90°-Rogowski-Profile (red)

$$x = \frac{a}{\pi}\varphi, \qquad y = \frac{a}{\pi}\left(\frac{\pi}{2} + e^{\varphi}\right)$$

Magnet Optics in the Midplane

Tracking of the particles with a 4^{th} order Runge-Kutta method

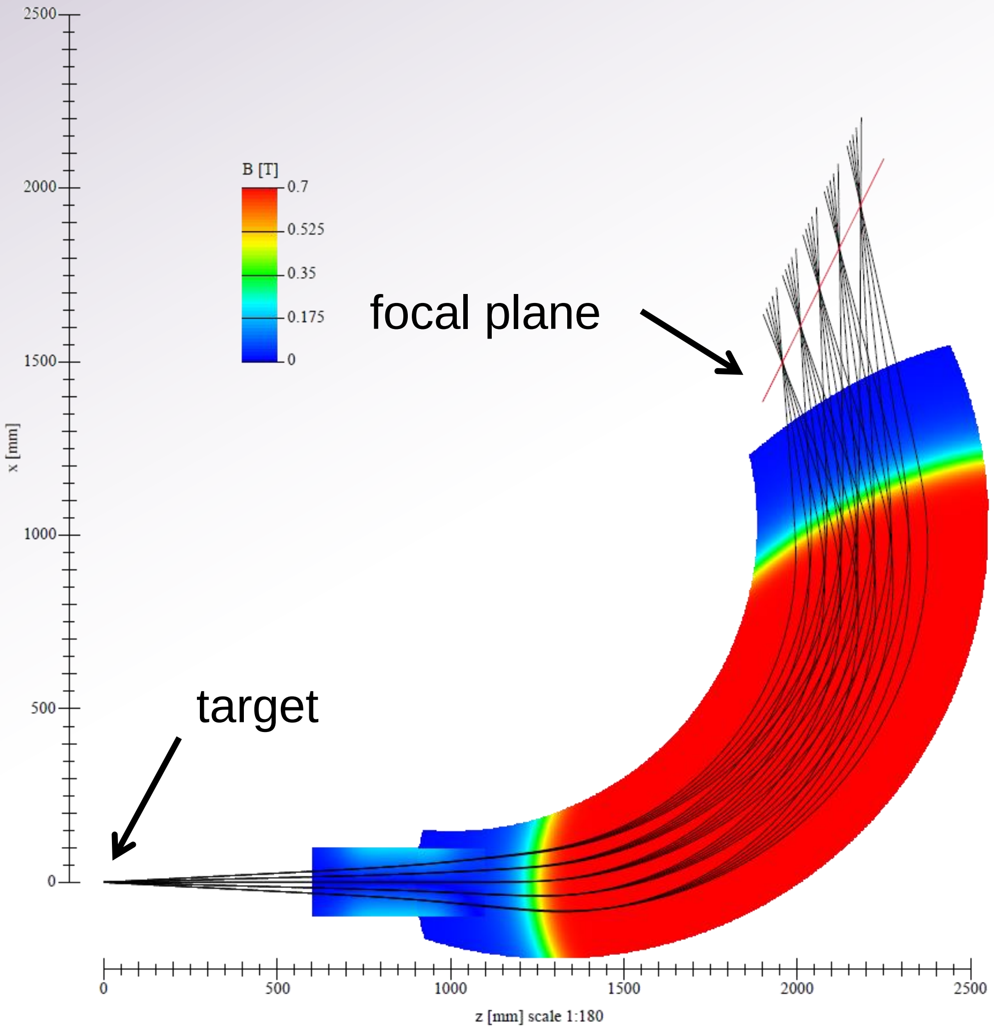




Midplane

- symmetry plane of the spectrometer
- the magnetic field is perpendicular everywhere
- parallel to the dispersive plane

Magnet Optics in the Midplane



Determine transfer matrices

- $\begin{pmatrix} \Delta x \\ \Delta\varphi \\ \Delta y \\ \Delta\theta \end{pmatrix}_F = \begin{pmatrix} & A_{4\times4} & \end{pmatrix} \begin{pmatrix} \Delta p \\ \Delta\varphi \\ \Delta y \\ \Delta\theta \end{pmatrix}_T$

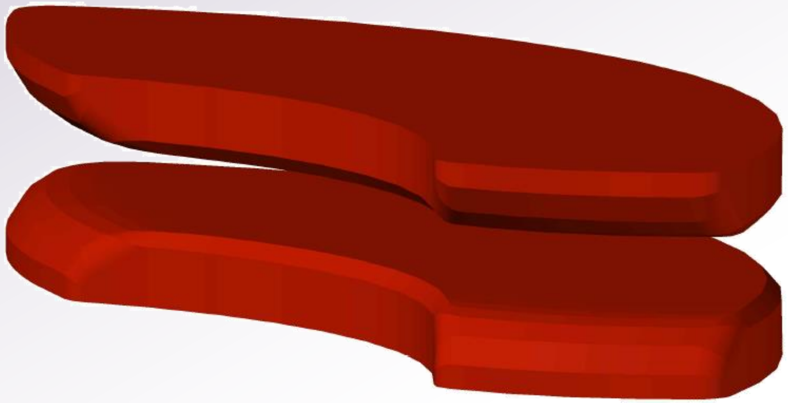
  entries in A: $\frac{dx_F}{dp_T}, \frac{dx_F}{d\varphi_T}, \ldots$
- local approximation to the mapping of the spectrometer
- different A for each particle track

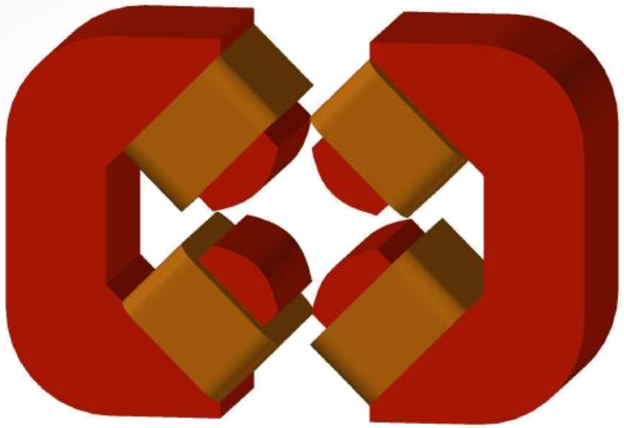
Resolution

- resolution out of the inverse map

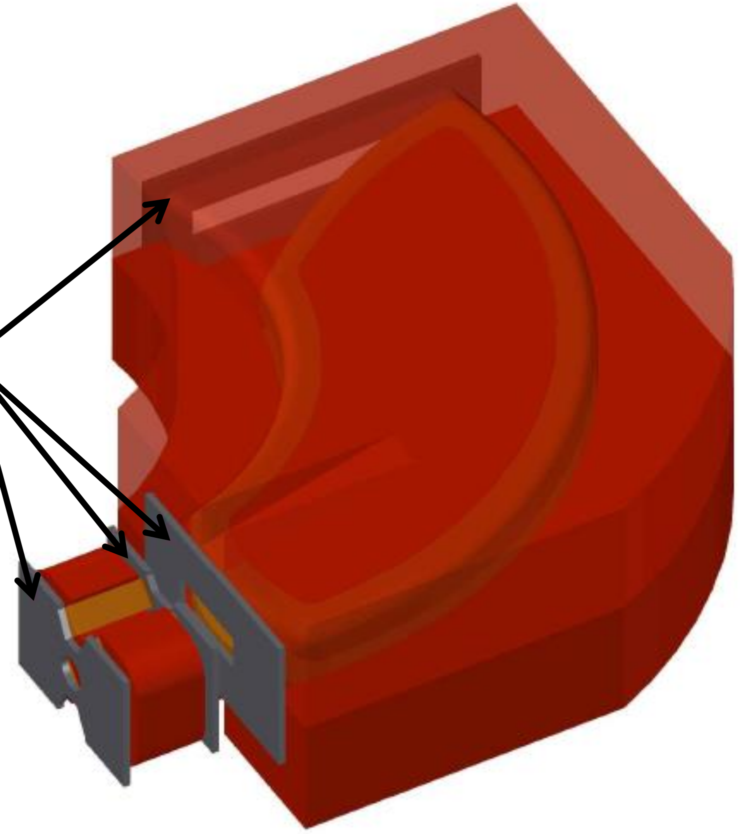
  $$\Delta_T = A^{-1}_{4\times4}\Delta_F$$
- Δ_F fixed by: focal plane detector, beam spot size
- $\frac{\Delta p}{p} = 6.11 \times 10^{-5}$ (on average)
- $\Delta\theta = 0.013°$ (on average)

Construction of a 3D Model



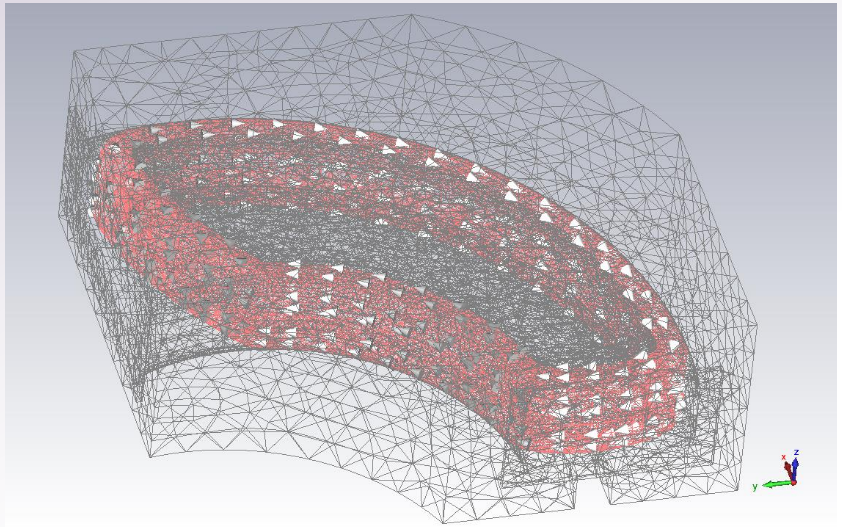


Mirror plates
- reduce fringe fields
- magnetic shielding



Drawings are not in scale!

Finite Elements Simulation with CST

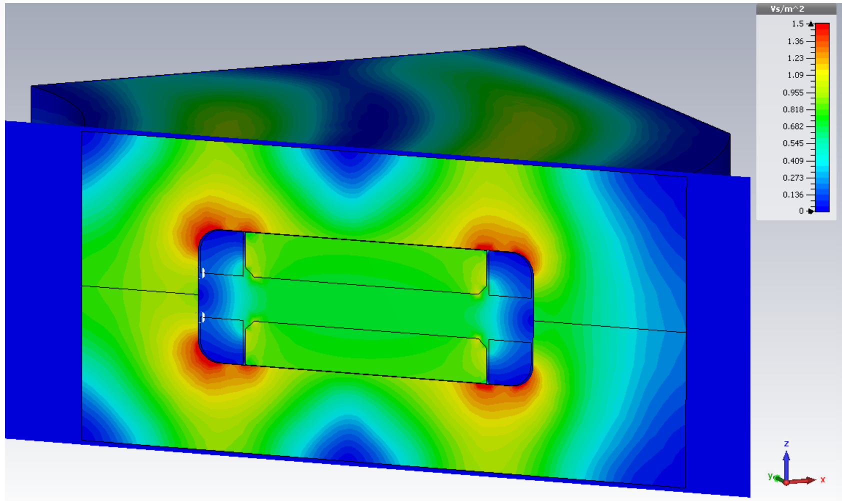


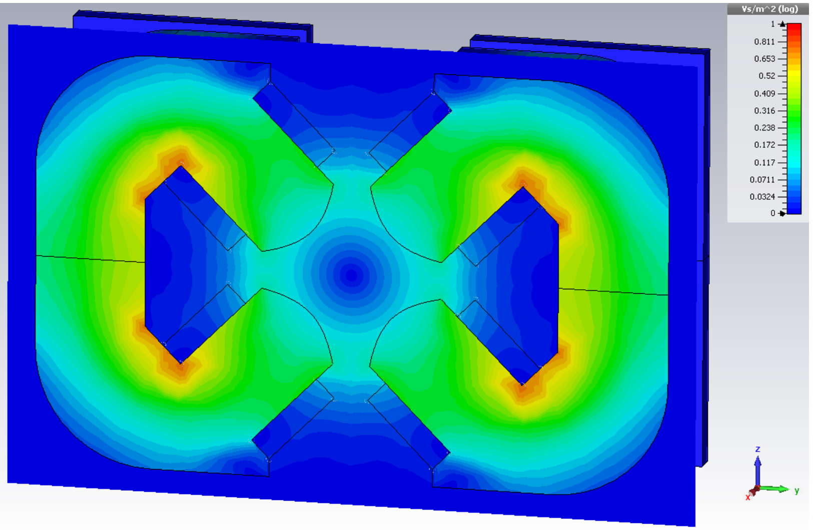
Dipole Magnet

- 1 mm air gap between the iron yoke and the pole pieces
- no saturation

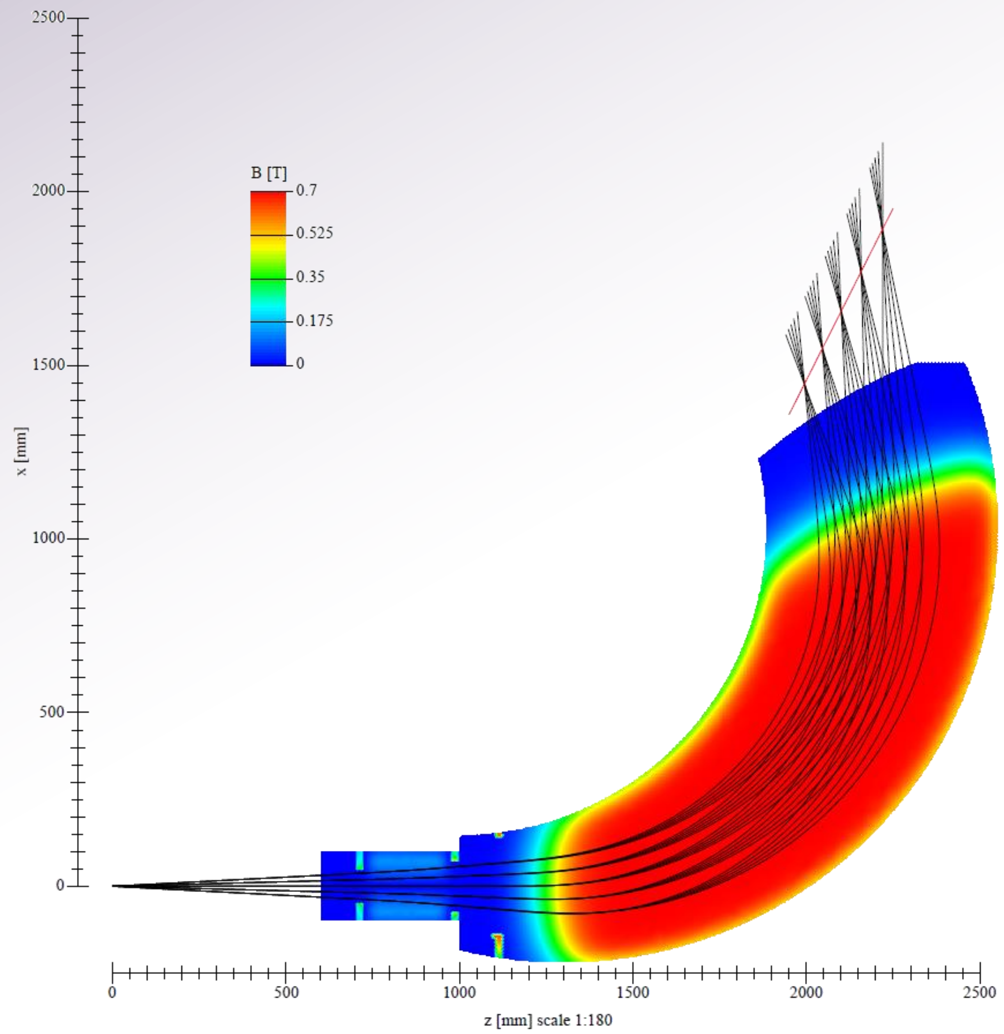
Quadrupole Magnet

- can be designed smaller
- room for improvement





Magnet Optics with the Field Data



Interpolation of the field data

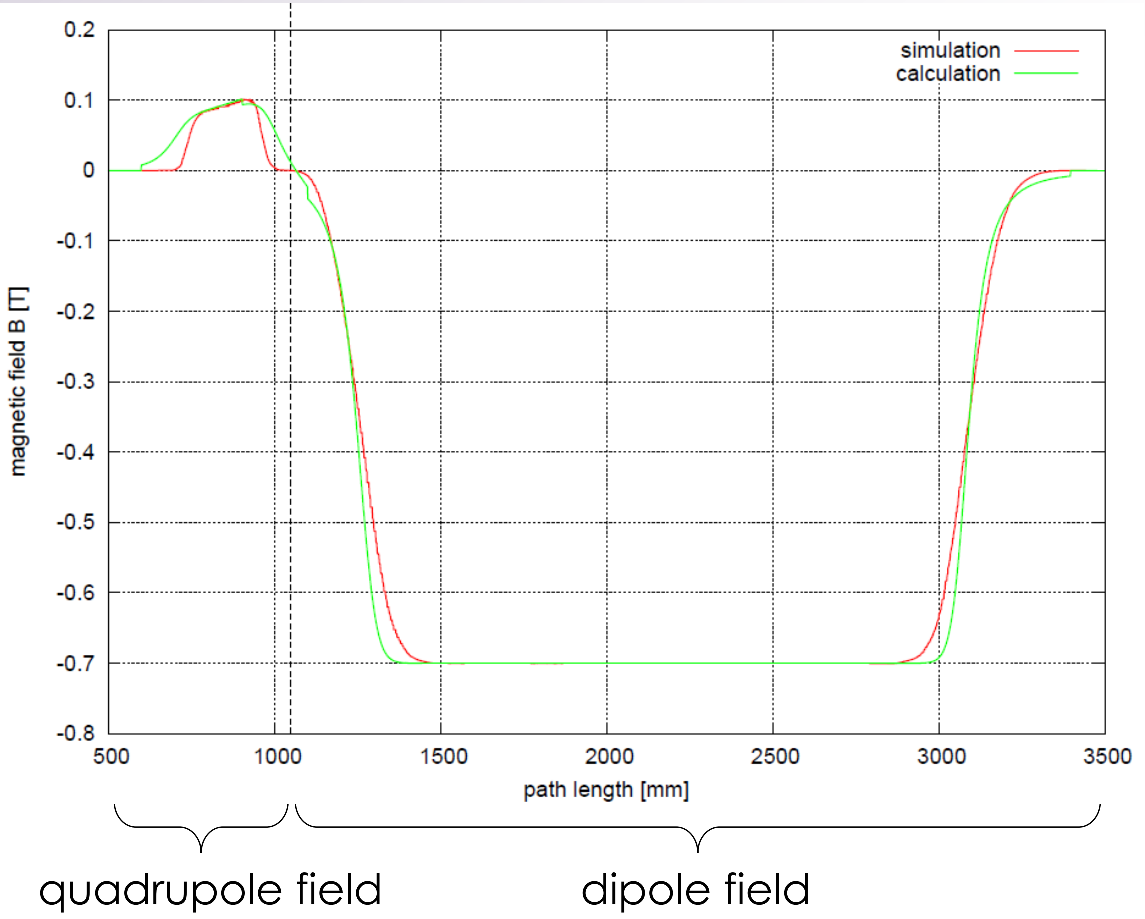
- 3D grid of data points, 1 cm distance between two points
- interpolation of the surrounding data points

Resolution

- lower resolution compared to the calculated field
- additional numerical errors caused by the interpolation

⇒ Avoid numerical errors by a fit of the fringe fields (only accurate in the midplane)

Comparison of the two Methods



Resolution

- calculation $\frac{\Delta p}{p} = 6.11 \times 10^{-5}$
- simulation (and fit) $\frac{\Delta p}{p} = 6.14 \times 10^{-5}$
- comparable results with both methods
- angular resolution is still bad

Results of the first Design

- Our goals for the resolution can be achieved with this setup
- First estimation of the acceptance

$$\frac{\Delta p}{p} = 45\% \,,\ \Delta\varphi = \pm 3.4° \,,\ \Delta\theta = \pm 1.6° \,,\ \Delta y = \pm 50\ \mathrm{mm}$$

- Focal plane size of 120 x 30 cm^2
- Minimum angle 14° (considering only the geometry)
- Size of the experiment: 6 m in diameter

Things to do

Optics

- Field map studies for different field intensities for momenta of 100 MeV/c and lower
- Detailed simulations for a better reference

Magnets

- Reduce the size of the magnets?
- Optimize the geometry of the dipole and the quadrupole
- No shielding for the beam pipe yet

Spectrometer

- Vacuum chamber, connection to the scattering chamber
- Infrastructure: cooling, vacuum pumps, collimator, drive, …
- Detector housing

THANK YOU FOR YOUR ATTENTION!

http://magix.kph.uni-mainz.de

SFB 1044

PRISMA

Massachusetts Institute of Technology

University of Ljubljana

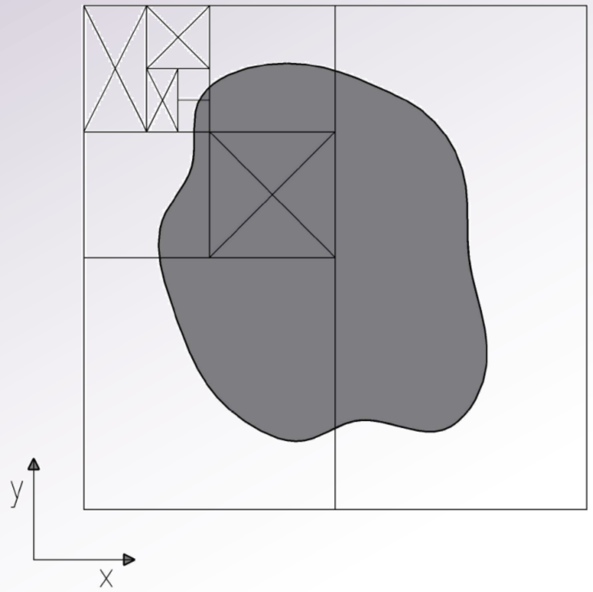
Westfälische Wilhelms-Universität Münster

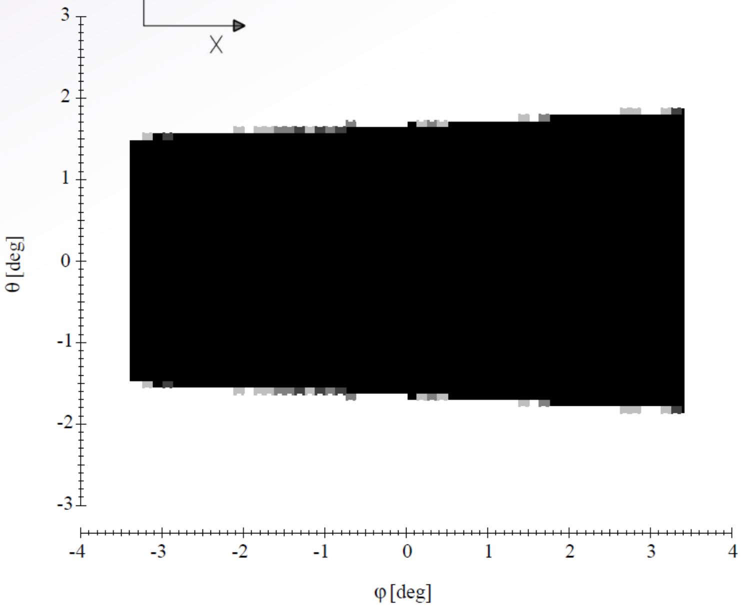
Johannes Gutenberg Universität Mainz

Comparison with the A1 Spectrometers

	MAMI/A1			MESA
Spectrometer	A	B	C	S_1 , S_2
Configuration	QSDD	D	QSDD	QD
Height (without detectors) [mm]	5500	5160	4750	1830
Length of one arm [mm]	7865	8400	6400	2800
Central Momentum [MeV/c]	665	810	490	200
Minimum Angle	18°	15.1°	18°	14°
Momentum Acceptance	20%	15%	25%	45%
Solid Angle [msr]	28	5.6	28	6.8
Rel. Momentum Resolution	10^{-4}	10^{-4}	10^{-4}	$< 10^{-4}$
Angular resolution at Target [mrad]	< 3	< 3	< 3	< 0.9

Acceptance of the Spectrometer





Acceptance

- parameter space in which incoming particles can be detected
- compact 4D space with the coordinates p, φ, y, θ
- only the shape of the boundary is important

Calculation

- generate particle tracks with random initial parameters
- divide area in half, alternately for each coordinate
- areas were all tracks hit, or all tracks missed can be ruled out

Results after 24 iterations

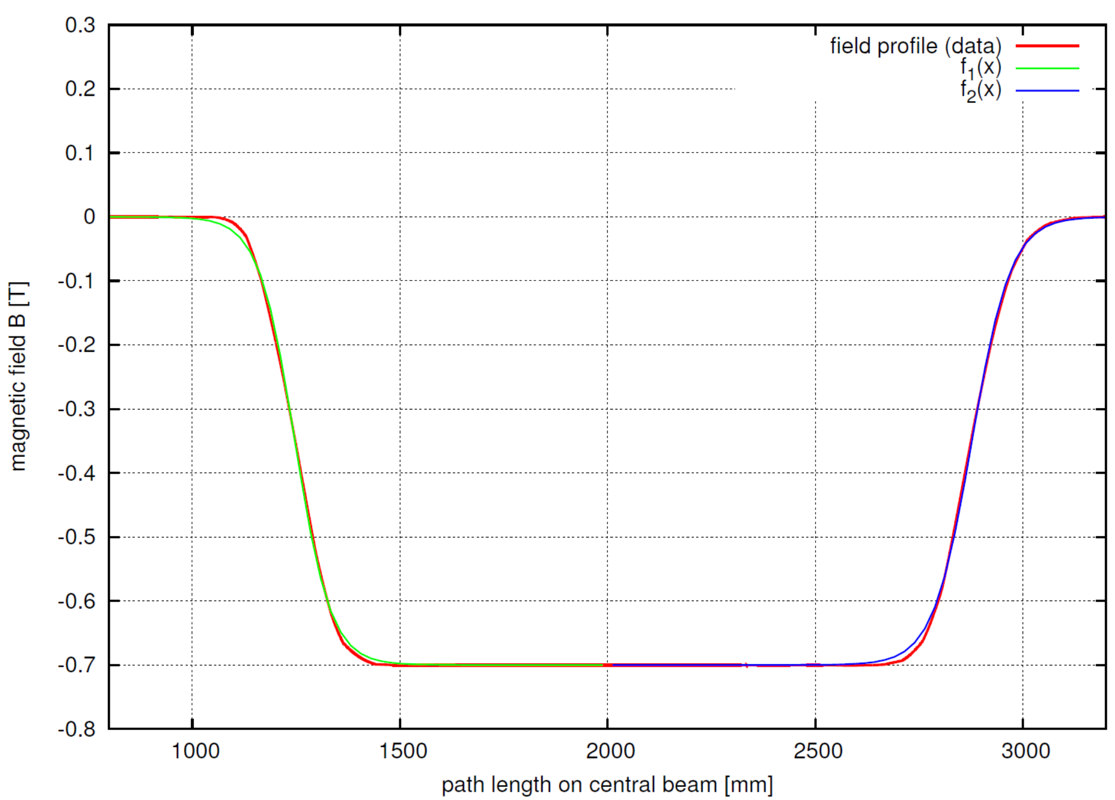
$$\frac{\Delta p}{p} = 45\%$$

$$\Delta\varphi = \pm 3.4°$$

$$\Delta y = \pm 50 \text{ mm}$$

$$\Delta\theta = \pm 1.6°$$

Fit of the Fringe Fields



Fit functions

- $$f_1(x) = B_{\max}\left(\frac{1}{e^{\frac{x-p}{b}}+1} - 1\right)$$
  $$f_2(x) = B_{\max}\left(\frac{1}{e^{\frac{p-x}{b}}+1} - 1\right)$$
- fits only accurate in the midplane

Resolution

- $\frac{\Delta p}{p} = 6.14 \times 10^{-5}$
- no improvement of $\Delta\theta$ with the fit

$f_1(x)$ and $f_2(x)$ can also be used for the quadrupole field

Magneto Optic Design

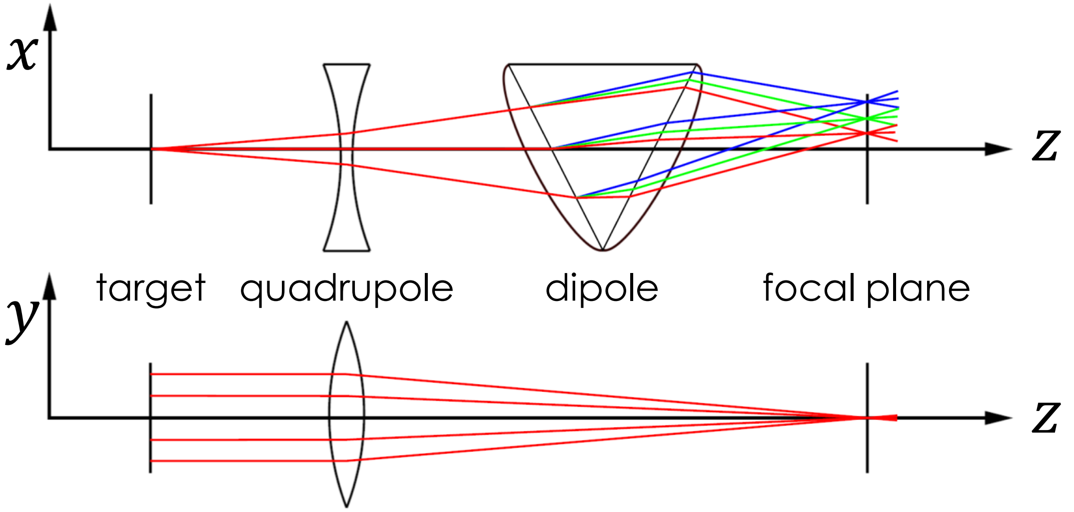
Dipole
- like a prims in geometric optics
- splits up incoming particles by their momenta
- dispersion

$$D = \frac{\Delta x_F}{\Delta p_T}$$

- curved edges to correct for aberrations

Quadrupole
- like a lens in geometric optics
- one focusing and one defocusing direction

Dispersive plane x-z
- point-to-point focusing
- high momentum resolution at focal plane, the first detector plane



Non-dispersive plane y-z
- parallel-to-point focusing
- determination of the scattering angle θ by measuring y in the focal plane