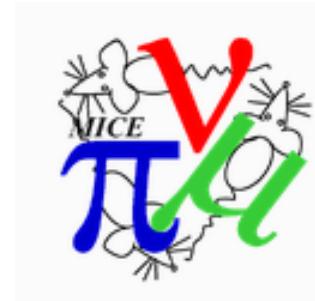
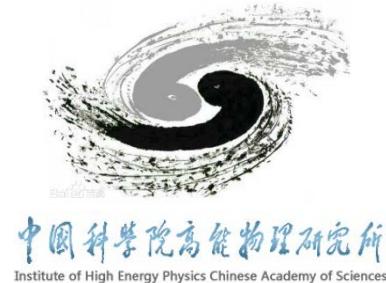

Magnet Alignment

Yingpeng Song

Feb 13, 2017



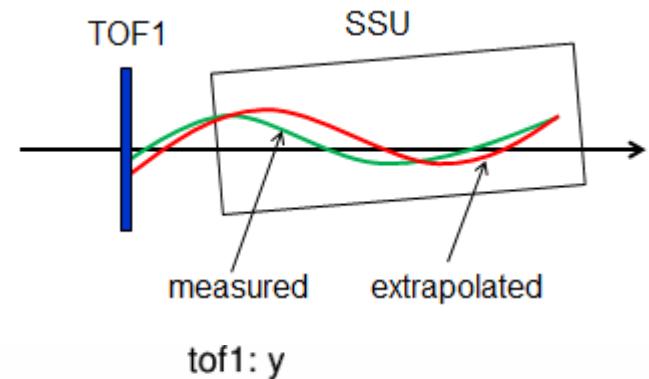
Motivation

► Beam center residual at TOF1 (run 7469)

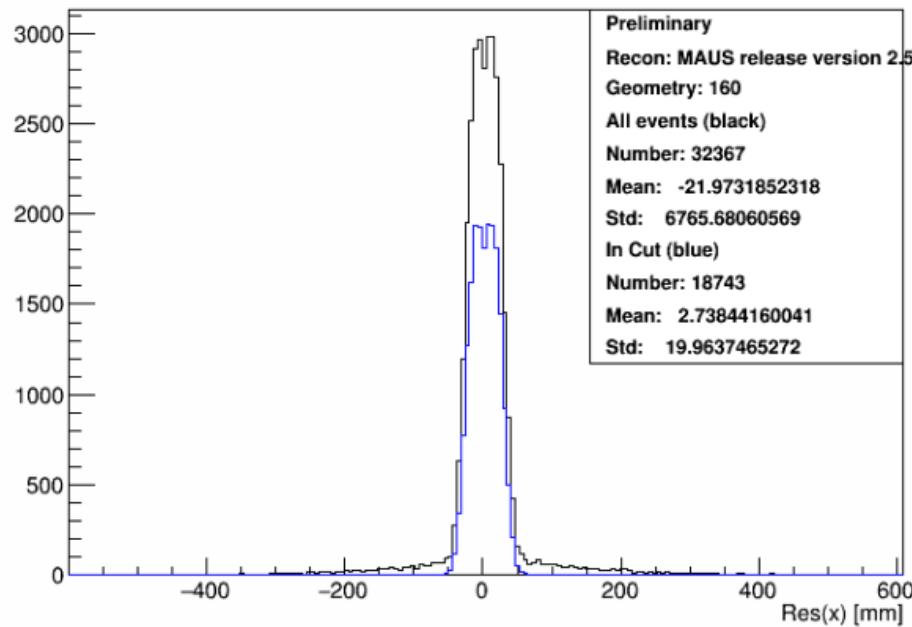
Residual = (measured – extrapolated)

Measured (data): field map in the hall

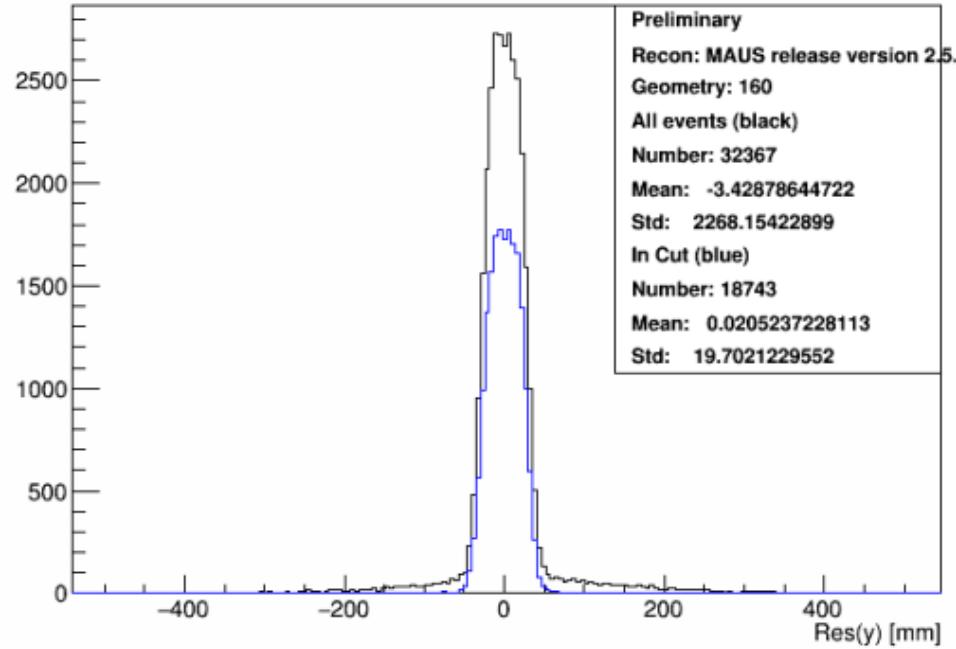
Extrapolated (MC): nominal field map



tof1: x



tof1: y



Methods

► Transfer matrix method

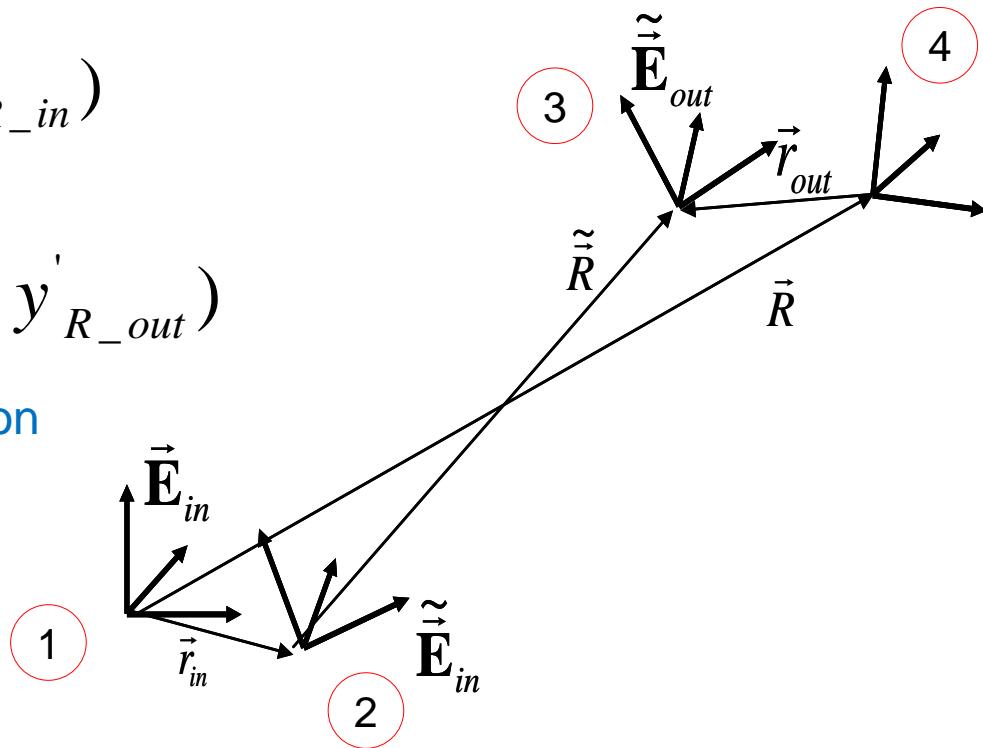
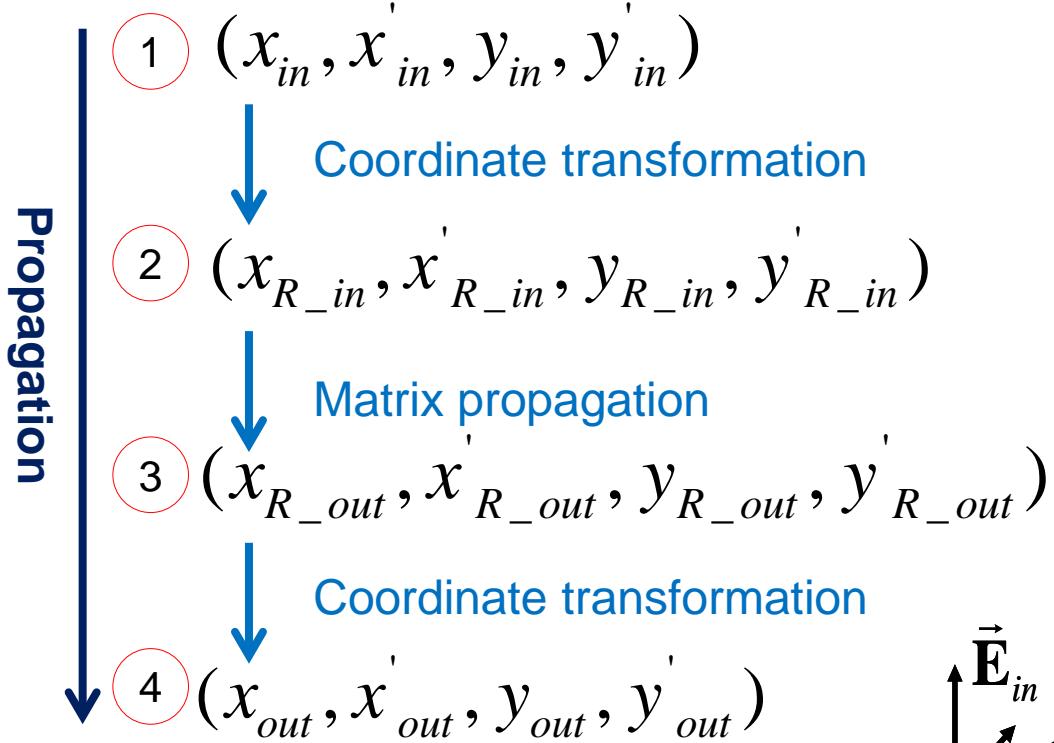
- Tracker alignment work based on straight track has been done by Francios
- Magnet alignment based on helical track
 - Magnet misalignment
 - Scattering effect
 - Beam scraping
 - High-order aberrations
 - Statistical error

► Multiparticle simulation method

- Comparing output residual with tweaking alignment variables of magnet

TM method

► Particle propagation in misaligned magnet



TM method

► Misalignment calculation for solenoid

Solenoid misalignment: $\Delta x, \Delta y, \phi_x, \phi_y$

Center offsets due to misalignment: $x_{off}, y_{off}, x'_{off}, y'_{off}$

The length of the field map: L

Matrix element: m_{ij}

$$\begin{bmatrix} x_{off} \\ y_{off} \end{bmatrix} = \begin{bmatrix} (1-m_{11})\Delta x - m_{13}\Delta y + \left(m_{14} - \frac{m_{13}}{2}L\right)\phi_x + \left(\frac{1+m_{11}}{2}L - m_{12}\right)\phi_y \\ -m_{31}\Delta x + (1-m_{33})\Delta y + \left(m_{34} - \frac{1+m_{33}}{2}L\right)\phi_x + \left(\frac{m_{31}}{2}L - m_{32}\right)\phi_y \end{bmatrix}$$

$$\begin{bmatrix} x'_{off} \\ y'_{off} \end{bmatrix} = \begin{bmatrix} -m_{21}\Delta x - m_{23}\Delta y + \left(-\frac{m_{23}L}{2} + m_{24}\right)\phi_x + \left(\frac{m_{21}L}{2} - m_{22} + 1\right)\phi_y \\ -m_{41}\Delta x - m_{43}\Delta y + \left(-\frac{m_{43}L}{2} + m_{44} - 1\right)\phi_x + \left(\frac{m_{41}L}{2} - m_{42}\right)\phi_y \end{bmatrix}$$

From Cai Meng , Error analysis and beam loss mechanisms of C-ADS linac , PhD thesis

Hard-edge mode

► Simulation method

- Single particle propagation in a single solenoid, with the same input vector, then calculate output vector of the particle by two methods, matrix method and field map method(G4BL).
- Discrepancy value = matrix method – G4BL simulation

Matrix definition used in simulation:

First-Order Solenoid Matrix *

Definitions:

L = effective length of solenoid.

$K = B_0/(2B\rho_0)$, where B_0 is the field inside the solenoid and $(B\rho_0)$ is the magnetic rigidity (momentum) of the central trajectory.

$C = \cos KL$

$S = \sin KL$

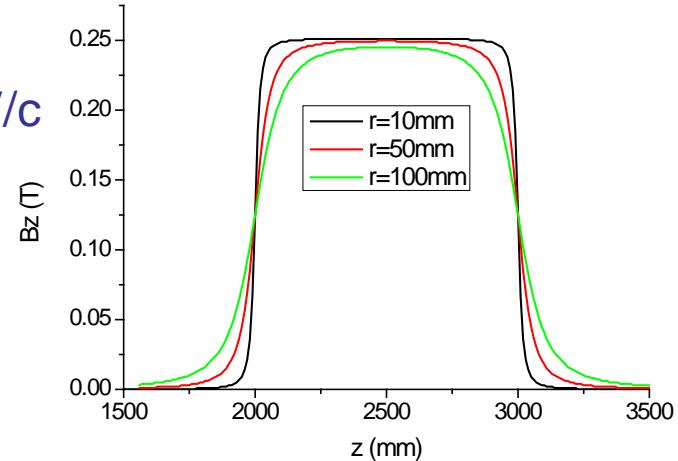
γ = relativistic factor

$$R(\text{Solenoid}) = \begin{pmatrix} C^2 & \frac{1}{K} SC & SC & \frac{1}{K} S^2 & 0 & 0 \\ -KSC & C^2 & -KS^2 & SC & 0 & 0 \\ -SC & -\frac{1}{K} S^2 & C^2 & \frac{1}{K} SC & 0 & 0 \\ KS^2 & -SC & -KSC & C^2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & \frac{L}{\gamma^2} \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

Hard-edge mode

► Test

- Single particle with momentum 100 MeV/c
- TM : Keeping $\int B^2 dl = C$ the same in TM and FM methods.
- FM : Real field map in G4BL

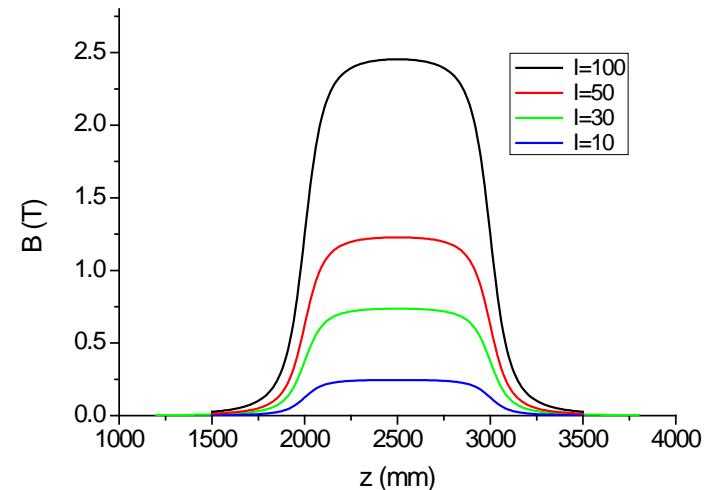


	input	output r_10	output r_50	output r_100			
		TM	FM	TM	FM	TM	FM
x (mm)	3	7.74	7.65	8.53	8.34	9.39	9.10
x' (mrad)	3	3.10	3.10	3.13	3.11	3.16	3.12
y (mm)	3	3.27	3.45	3.40	3.74	3.56	4.12
y' (mrad)	3	1.31	1.30	1.25	1.27	1.20	1.28

Hard-edge mode

► Test

- TM : Keeping $\int B^2 dl = C$ the same.
- FM : Real field map in G4BL
- L_sol=1m r=100mm



	input	output_10	output_30	output_50	output_100		
		TM	FM	TM	FM	TM	FM
x (mm)	3	9.39	9.10	4.83	4.68	0.08	-2.19
x' (mrad)	3	3.16	3.12	-2.05	-3.39	0.56	-5.61
y (mm)	3	3.56	4.12	-3.90	-1.58	1.00	4.12
y' (mrad)	3	1.20	1.28	1.66	1.13	6.56	10.60

Soft-edge Matrix check

► Results by different methods

Input particle $[x, x', y, y'] = [3\text{mm}, 3\text{mrad}, 3\text{mm}, 3\text{mrad}]$

Propagating from 2500mm to 4500mm

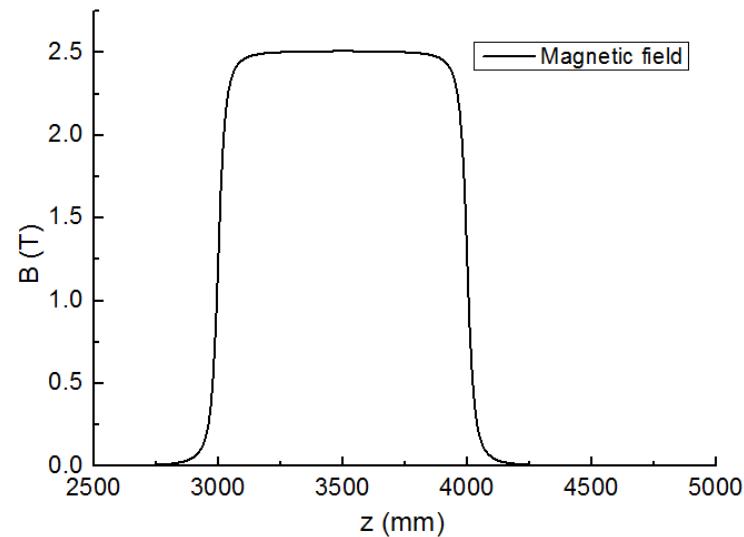
Soft-edge mode matrix:

1. Throwing a bunch of particles
into beamline.

2. Recording particles info

$[x_i, x'_i, y_i, y'_i]$ at arbitrary position.

3. Computing the matrix by least
squares fit method.



output	x(mm)	x'(mrad)	y(mm)	y'(mrad)
Hard-edge	2.1123	-5.8303	-1.6921	4.6706
Soft-edge	-1.7991	-5.4456	3.2885	9.8624
Fieldmap	-1.7984	-5.4445	3.2885	9.8635

Soft-edge mode Matrix

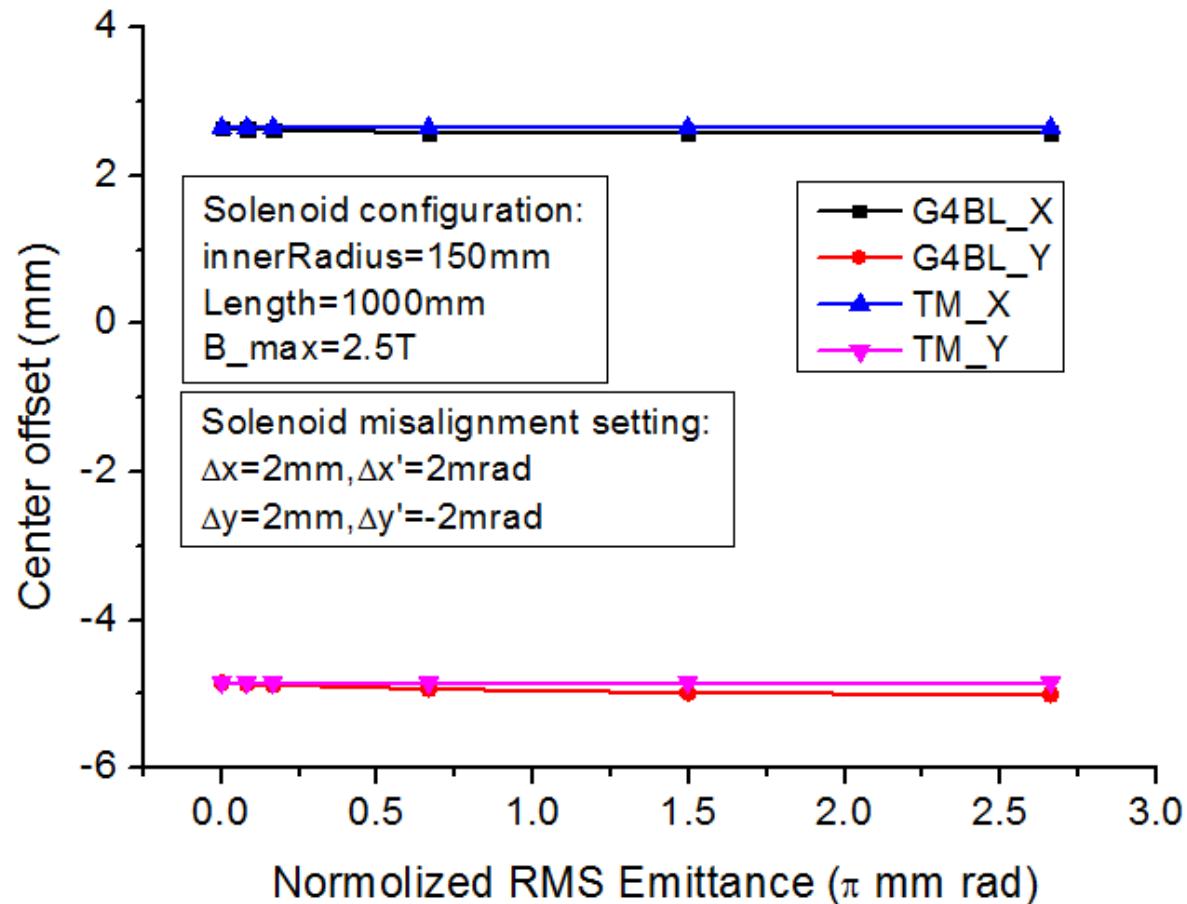
- Offset calculation caused by magnet misalignment

Solenoid setting : innerRadius=100mm Length=1000mm
Thickness=20mm currentDensity=100A/mm²

		x (mm)	y (mm)	x' (mrad)	y' (mrad)	all
Error setting		2	2	2	2	2
TM method	Offset_x	1.388	2.001	1.900	2.581	7.871
	Offset_y	-2.001	1.388	-2.581	1.900	-1.295
G4BL simulation	Offset_x	1.388	2.001	1.931	2.623	7.837
	Offset_y	-2.001	1.388	-2.623	1.931	-1.291

► Beam center offset calculation with different beam emittance

If there is particle loss during the propagation, the offsets should be corrected by doing simulation with survived particles, also taking into the initial offsets caused by beam scraping.

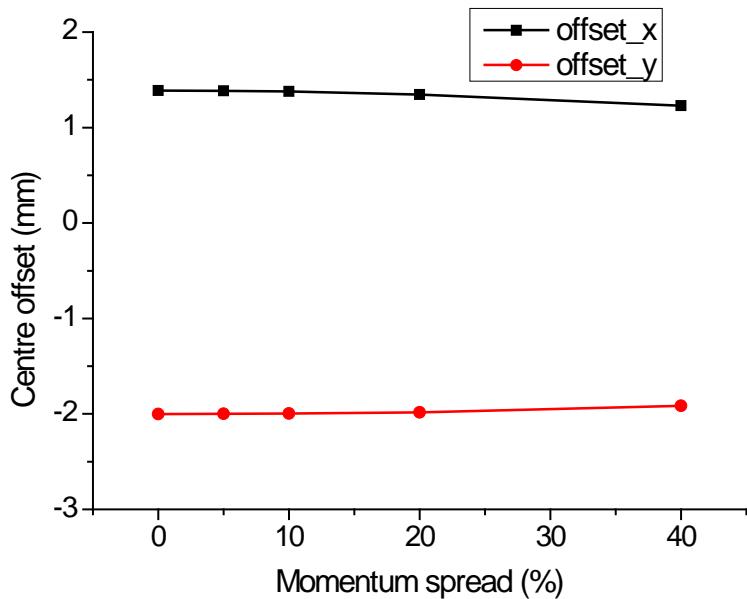


Soft-edge mode Matrix

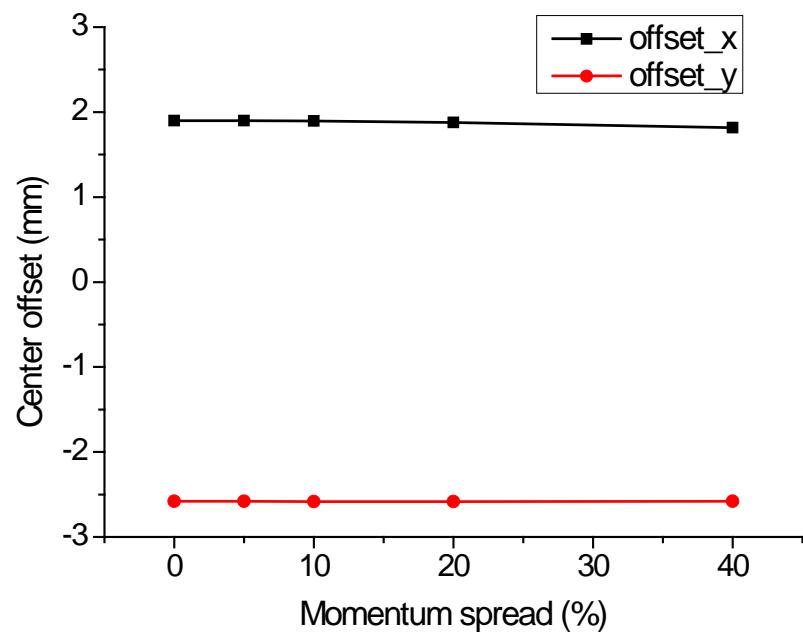
► Momentum spread sensitivity

Incident beam info: 1000 pion, uniform distribution

With RMS emittance $10\pi\text{mm mrad}$



With 2mm translation on x



With 2mrad rotation wrt x axis

► Simulation settings

Solenoid setting : innerRadius=150mm Length=1000mm

Thickness=20mm currentDensity=100A/mm²

Beam : RMS emittance 100 πmm mrad 200 MeV/c 100k particles

Error setting	error type	x (mm)	y (mm)	x' (mrad)	y' (mrad)	Beam offset
Error setting1	magnet	2	2	2	2	X: 7.756 Y: -1.036
	beam	0	0	0	0	
Error setting2	magnet	0	0	0	0	X: -9.079 Y: 5.868
	beam	2	2	2	2	
Error setting3	magnet	2	2	2	2	X: -1.291 Y: 4.877
	beam	2	2	2	2	
Error setting3 (1+2)	The offsets are calculated by adding setting 1 and setting 2 results up together.					X: -1.323 Y: 4.832

Statistical errors

► Simulation settings

Solenoid setting : innerRadius=150mm Length=1000mm

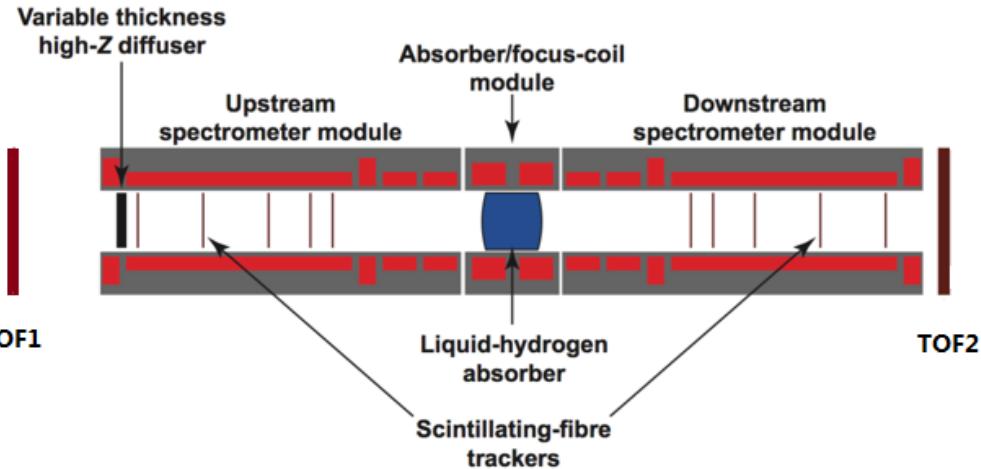
Thickness=20mm currentDensity=100A/mm²

Beam : RMS emittance 100 πmm mrad 200 MeV/c

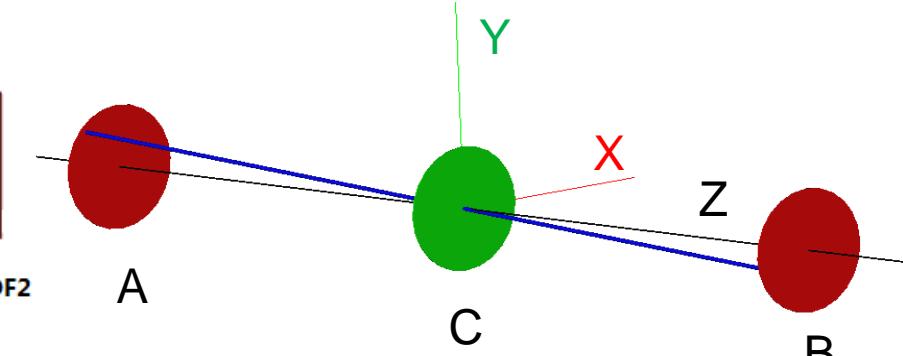
Magnet error setting [x,y,x',y'] = [2,2,2,2]

		x (mm)	y (mm)	x' (mrad)	y' (mrad)
G4BL	10k	7.671	-1.172	6.006	-5.573
	100k	7.756	-1.036	6.116	-5.168
TM		7.783	-0.976	6.232	-5.198
absolute error	10k	0.112	0.196	0.226	0.375
	100k	0.027	0.060	0.116	0.030

► Arbitrary field length alignment calculation



TKU_s5 to TOF1 or TKD_s5 to TOF2



Center correction:

$$\Delta x_i = - \left(\frac{L}{2} - \frac{L'}{2} \right) \tan \phi_y$$
$$\Delta y_i = \left(\frac{L}{2} - \frac{L'}{2} \right) \tan \phi_x$$

► Purpose

- To suppress the bias from scattering effect caused by tracker station
- Make it possible to do calculation with arbitrary field length

A toy check

► Solenoid and misalignment settings

Solenoid setting : innerRadius=150mm Length=1000mm

Thickness=20mm currentDensity=100A/mm²

Beam : RMS emittance 100 πmm mrad 200 MeV/c 10k

$$TM_{A-C} = \begin{bmatrix} 0.446 & 0.479 & 0.541 & 0.637 \\ -1.703 & -1.119 & -0.177 & 0.890 \\ -0.541 & -0.637 & 0.446 & 0.479 \\ 0.177 & -0.890 & -1.703 & -1.119 \end{bmatrix}$$

Error setting	x (mm)	y (mm)	x' (mrad)	y' (mrad)	Offset (mm)
G4BL	2	2	2	2	X:0.300 Y:2.532
TM	2-1	2+1	2	2	X:0.298 Y:2.529

Method application

► Methods

- TM calculation

Upsides:

1. time saving
2. good understanding about each factor

Downsides:

1. elusive derivation
2. sometimes the analytic solutions are not available

- Multiparticle simulation method

Upsides:

1. widely applied
2. easily conducted

Downsides:

1. time consuming [10 bins, 4 variables, --> 10^4]
2. black box

► Conclusions and to do lists

- Hard-edge mode approximation has a good performance when the KL value is small. $K = B_0/2B\rho_0$, L is the effective length of the solenoid. Under large KL case, we need use soft-edge mode, and the results indicate that it works well.
 - The TM solenoid alignment method works well within large emittance range and momentum spread.
 - Solenoid field alignment can be done by arbitrary field length.
-
- Scattering effect on magnet alignment calculation
 - Crosscheck TM method with simulation method, also compare alignment with straight track alignment result .
 - Do magnet alignment with data