Beam Optics in the Cooling Channel

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Introduction

- Aim to evaluate the current understanding of the beam optics in the cooling channel
- Compare the beam optics (4D transverse emittance, beta function, alpha function) calculated from data and MC
- Implement a transfer matrix/map model to simulate the optics to first order and compare output with MC simulation and data

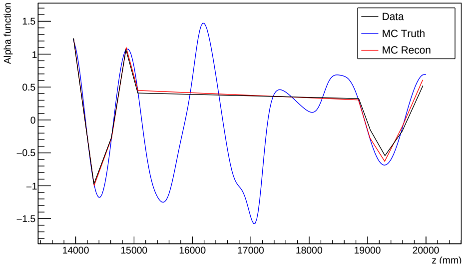
Data

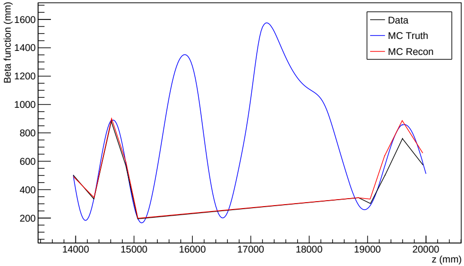
- Analysis H57a, Run 10448
- 2017-02-7 setting
- Flip mode, 3T in SSU (M1, M2 on), 2T in SSD (M1 off, **M2 on**)
- LiH Empty (None)
- 140 MeV/c, nominal emittance 3 mm, $\beta_\perp = 500$ mm

Analysis Procedure

- Reconstruct beam optics in the trackers from real data, applying the following cuts:
  - TKU Chi2/ndf < 4
  - TOF01 consistent with muon peak : 29 - 31 ns
  - TKU: 135 MeV/c $<$ total momentum $<$ 145 MeV/c
  - Transmission cut: analyse only events with 1 track in each tracker
- For all particles that survive the first three cuts above, extract their information at the first scifi plane in station 5 of TKU $\rightarrow$ feed it into the MC simulation
- Calculate beam optics of the MC simulated beam at a series of virtual planes along the cooling channel, between both stations 5 of TKU and TKD

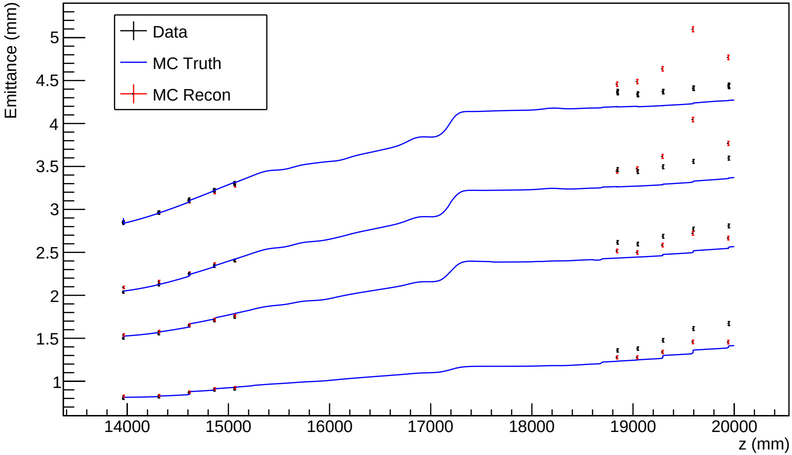
MC Comparison: Alpha, Beta





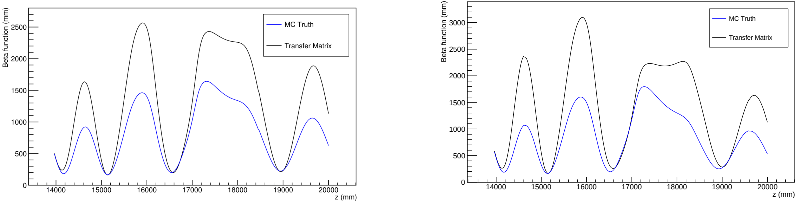
MC Comparison: Emittance

- Applied cuts at 5, 10, 15 mm

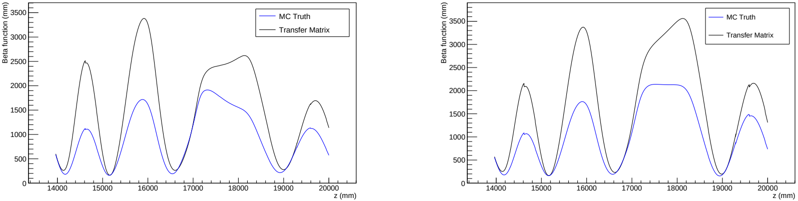


Transfer matrix/map (TM)

- A linear optics model for beam transport in the solenoidal cooling channel
- Transports the initial particle coordinate $(x_0, x_0^{'}, y_0, y_0^{'})$ at $z = 0$ to $(x, x^{'}, y, y^{'})$ at z
- Map at z is dependent on the following parameters: $\beta_0, \beta(z), \alpha_0, \alpha(z), B_{z0}, B_z, p_{z0}, p_z$ (obtained from MC)
- For maths insight: G. Franchetti, Linear Beam Optics in Solenoidal Channels, (2001)
- Applied the transfer map to each particle in the distribution extracted from data; computed beta, alpha and emittance



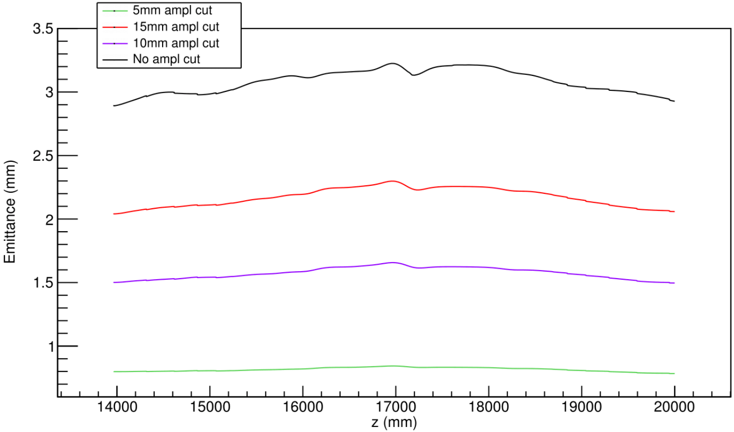
(a) No amplitude cut (L), Amplitude cut 15 mm (R)



(b) Amplitude cut 10 mm (L), Amplitude cut 5 mm (R)

Transfer Matrix: Emittance

- Applied matrix model to particle distributions that survived the amplitude cut



Transfer Matrix with parameters from reconstructed data

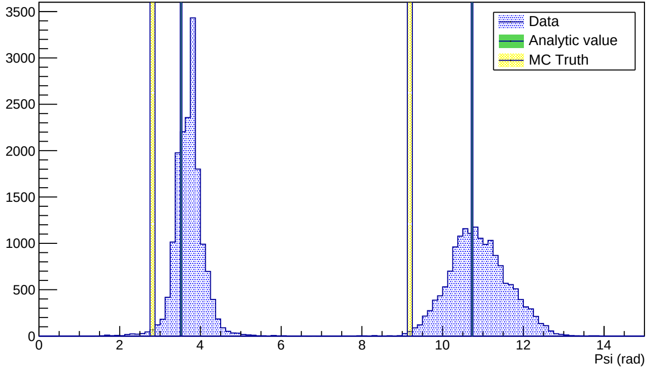
- Twiss parameters (α and β) and p_z taken from reconstructed data, B_z from geometry
- Phase advance ψ and Larmor angle ϕ are unknown, where

$$\psi(z) = \int_0^z \frac{1}{\beta(z')} dz'; \quad \phi(z) = \int_0^z \frac{S(z')}{2} dz' \quad \textit{where} \tag{1}$$

$$S(z) = \frac{qB_z(z)}{p_z(z)} \tag{2}$$

- Given two transverse phase space coordinates of a particle $(x_0, x_0^{'}, y_0, y_0^{'})$ at $z = 0$ and $(x, x^{'}, y, y^{'})$ at z use the Transfer Matrix model to fit for ψ, ϕ

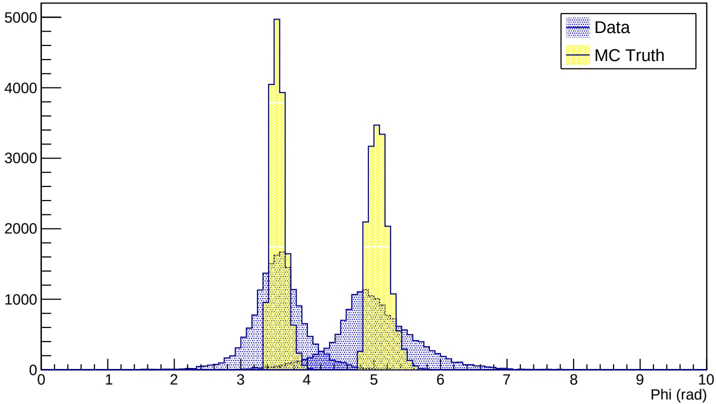
ψ at reference planes: Data vs MC Truth vs Analytic



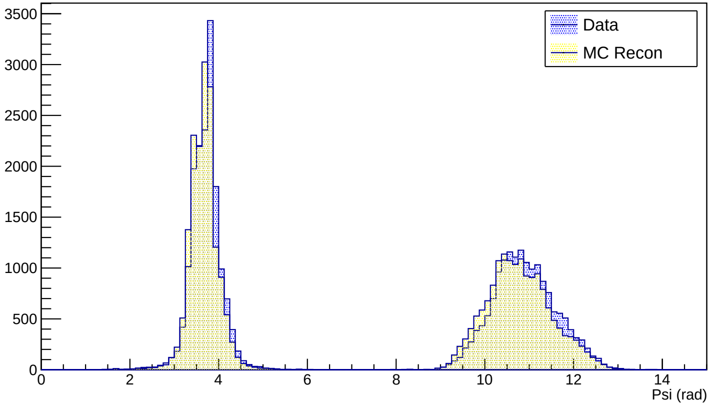
- 'analytic' ψ value calculated from

$$\frac{1}{2}\beta\beta'' - \frac{1}{4}\beta'^2 + \frac{S^2}{4}\beta^2 = 1$$

ϕ at reference planes: Data vs MC Truth



ψ at reference planes : Data vc MC Recon



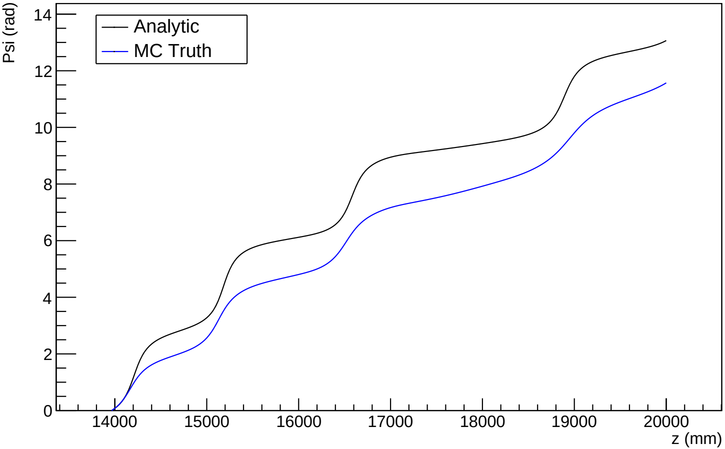
Conlcusions

- Good optics agreement in SSU, discrepancies in SSD persist even after amplitude cut is applied
- Matrix model works OK in the linear regime
- The emittance non-uniformity in matrix model suspected to be due to the fact that it is applied regions with high-gradient fields and fringe fields
- Discrepancy between ψ fitted from data and truth MC suspected to be caused by the same issue, also beam not cylindrically symmetric; this needs further study
- Next steps
  - Determine the the source of discrepancies
  - Apply the diffuser cut on the data
  - Introduce higher order terms in the matrix model

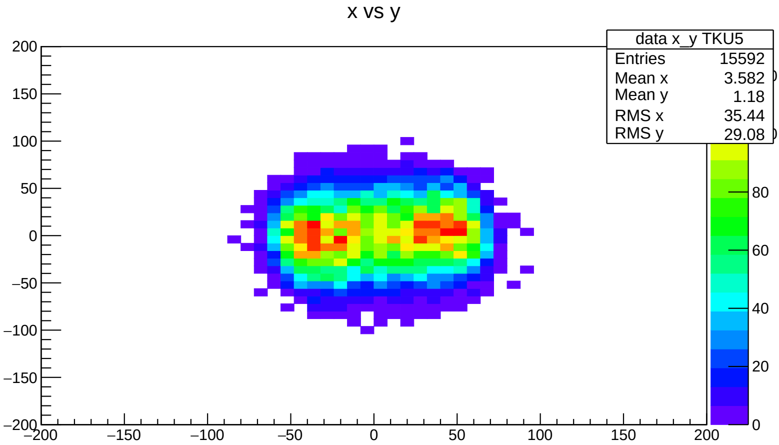
Thank you!

Backup

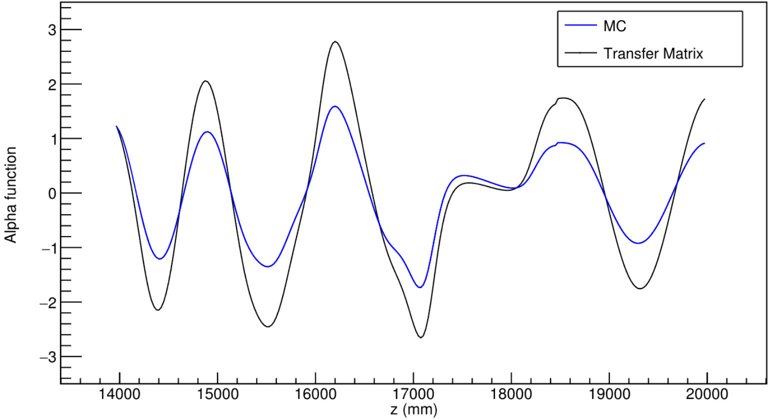
ψ: Analytic vs MC Truth



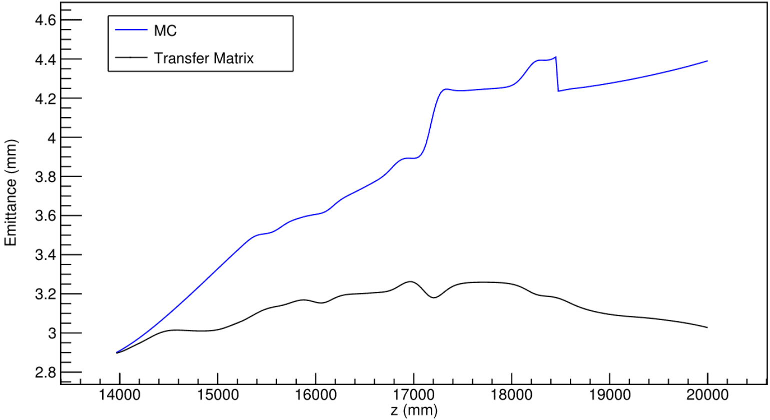
X Y Distribution at TKU5



Transfer matrix with data beam: Alpha



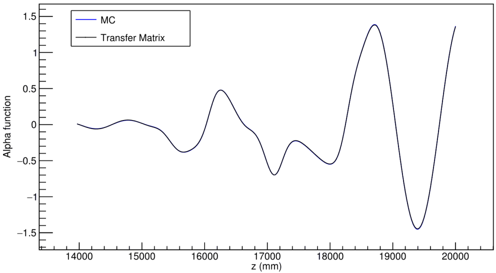
Transfer matrix with data beam: Emittance

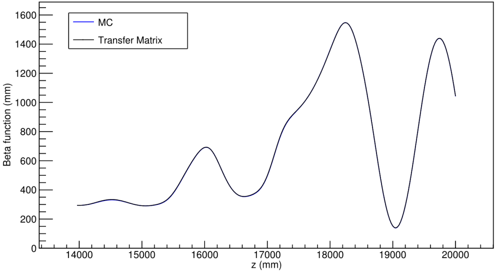


Transfer matrix with data beam: Sanity check

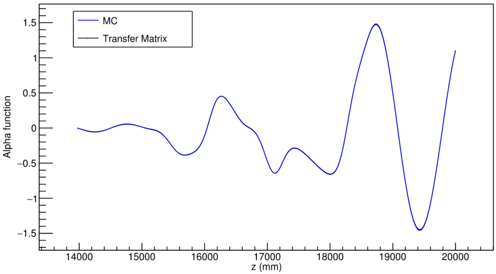
- Emittance from matrix model is expected to be conserved across the cooling channel (matrix is symplectic), while results show variation
- Alpha and beta also differ significantly from MC
- Decided to test the transfer map on beams that approach the linear regime
- Simulated beams with $\alpha_0 = 0$, $\beta_0 = 300mm$, $\epsilon_{\perp 0} = 0.5mm$ and with momentum distribution:
  - a) monochromatic: 140 MeV/c
  - b) gaussian centred at 140 MeV/c, 5 MeV/c RMS

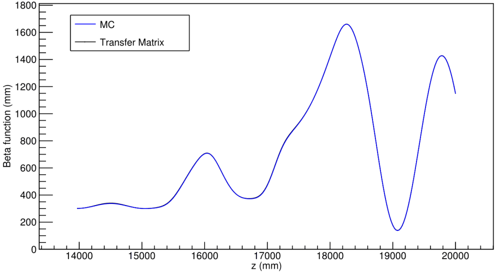
TM with monochromatic 'perfect' beam: Alpha, Beta



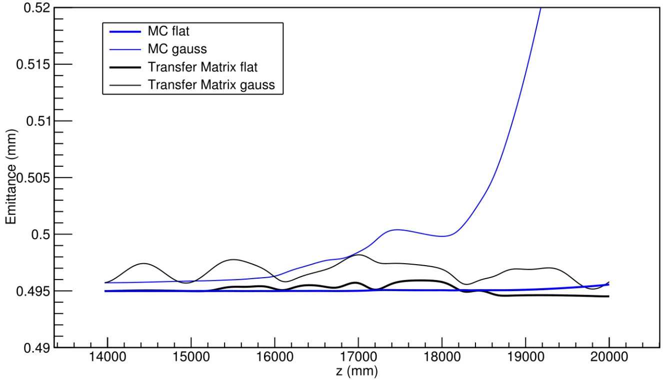


TM with gaussian 'perfect' beam: Alpha, Beta





TM with monochromatic & gaussian 'perfect' beam : Emittance



- Emittance growth in AFC and at SSD entrance ($\sim$ 2.5% at downstream reference plane)

TM: Further

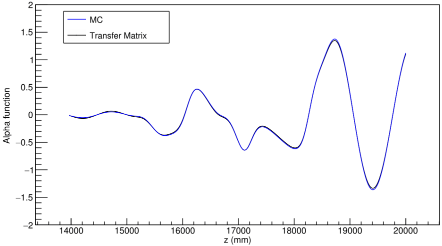
- Further decided to examine the optics evolution in both MC and matrix model as a function of the initial beam emittance (departure from linear regime)

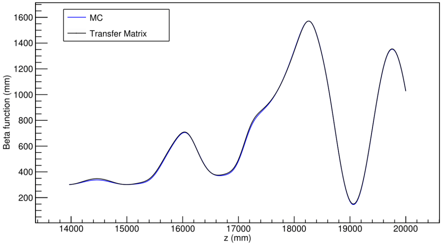
- Kept the more realistic gaussian momentum distribution, $\alpha_0 = 0$, $\beta_0 = 300mm$

- Varied initial emittance: 0.5, 1.0, 1.5, 2.0mm

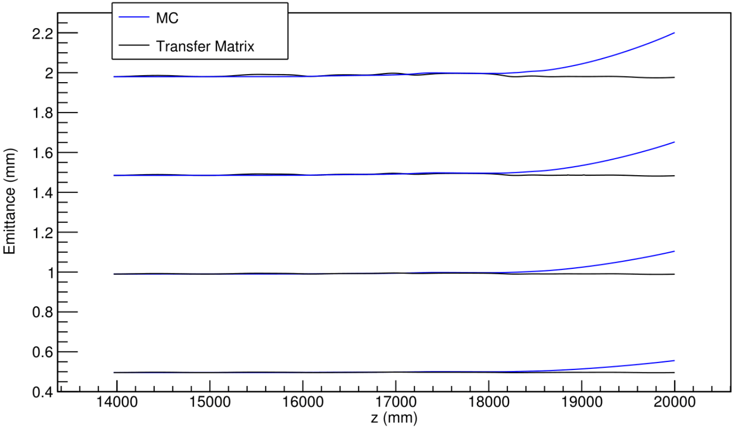
- Even with initial emittance of 2mm, alpha and beta calculated from MC and transfer map agree (next slide)

TM with monochromatic & gaussian 'perfect' beam: Alpha, Beta ($\epsilon_{\perp 0} = 2mm$)





TM with monochromatic & gaussian 'perfect' beam: Emittance conservation



- Matrix model OK - constant emittance
- MC shows $\sim 2.5\%$ emittance growth at downstream reference plane