

# Beam Optics Evolution in the Cooling Channel

Paul Bogdan Jurj

Imperial College London

*paul.jurj13@imperial.ac.uk*

May 16, 2018



# 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 and compare output with MC simulation and data



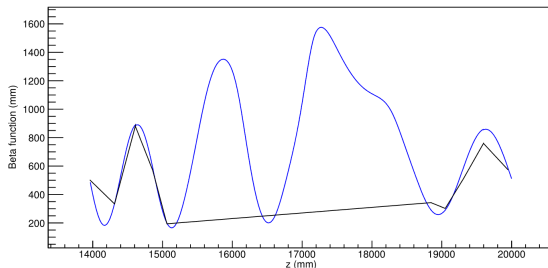
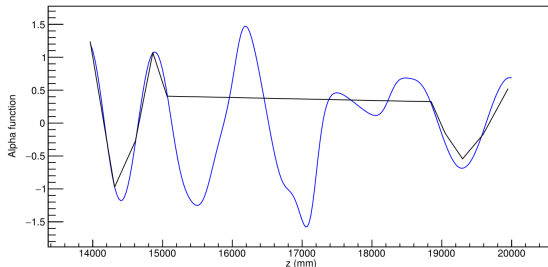
- Analysis H57a, Run 10448
- 2017-02-7 setting
- Flip mode, 3T in SSU (M1, M2 on), 2T in SSD (M1 off, **M2 on**)
- LiH Empty (None)
- 140 MeV/c, nominal emittance 3 mm,  $\beta_{\perp} = 500$  mm



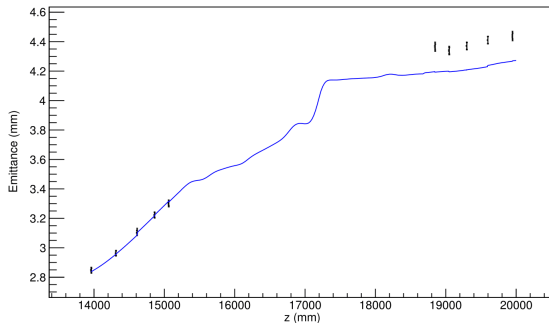
- Reconstruct beam optics in the trackers from real data, applying the following cuts:
  - $\text{TKU } \chi^2/\text{ndf} < 4$
  - TOF01 consistent with muon peak : 29 - 31 ns
  - TKU:  $135 \text{ MeV}/c < \text{total momentum} < 145 \text{ MeV}/c$
  - Transmission cut: analyse only events with 1 track 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 → 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 Tracking: Alpha, Beta



# MC Tracking: Emittance



- Good agreement in SSU, discrepancies in SSD needed further investigation

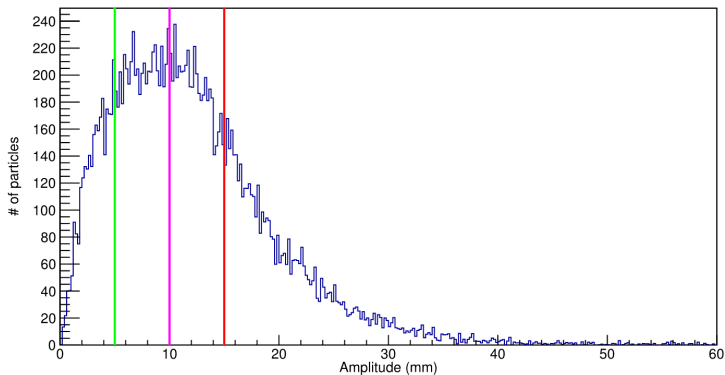


- In SSD beam optics calculations from data include particles that are deflected off the apertures, while in MC simulation such events get discarded → possible cause for the difference
- Applied amplitude cut to select the core of the beam → aimed to eliminate particles from data that had the potential to scrape the apertures

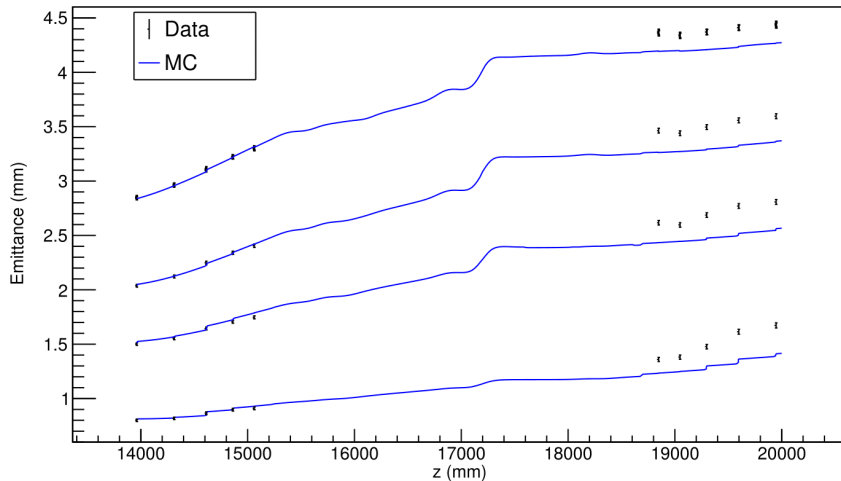


# Amplitude cut

- Applied cuts at 5, 10, 15 mm



# Results: Emittance

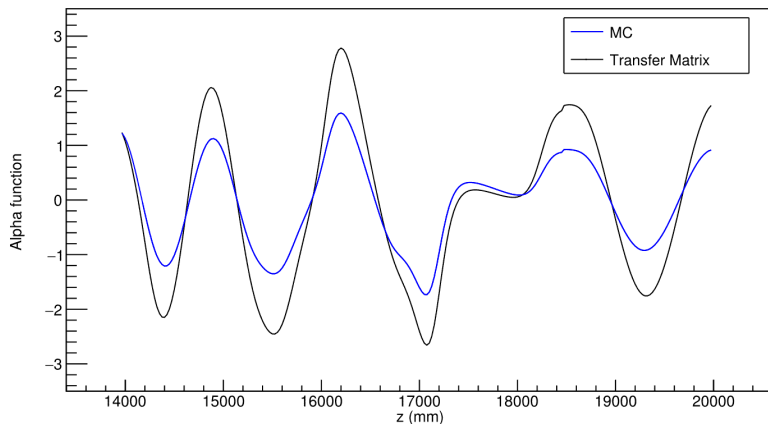


# Transfer matrix/map (TM)

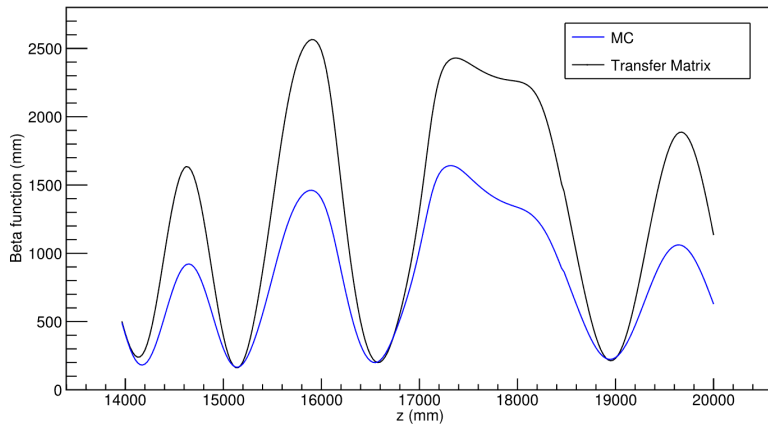
- A linear optics model for beam transport in the solenoidal cooling channel
- Transports the initial particle coordinate  $(x_0, x'_0, y_0, y'_0)$  at  $z = 0$  to  $(x, x', y, y')$  at  $z$
- Map at  $z$  is dependent on the following parameters:  
 $\beta_0, \beta(z), \alpha_0, \alpha(z), B_{z0}, B_z, p_{z0}, p_z$  (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



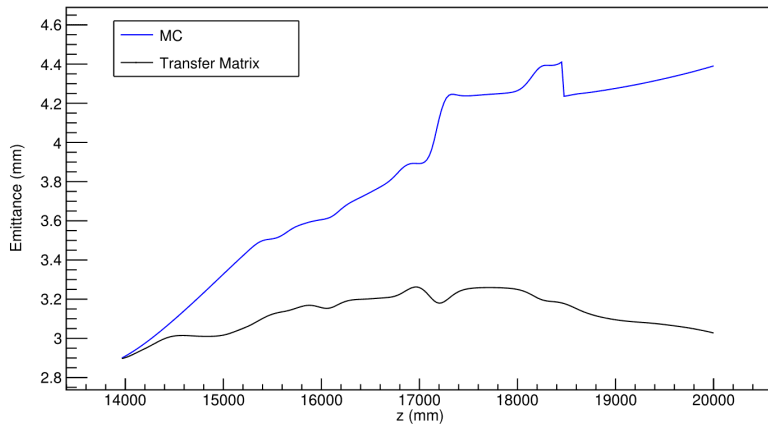
# Transfer matrix with data beam: Alpha



# Transfer matrix with data beam: Beta



# Transfer matrix with data beam: Emittance

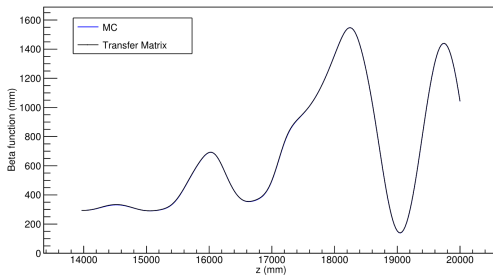
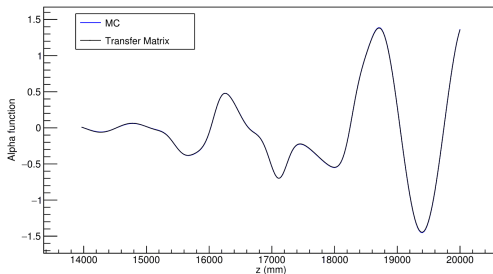


# Transfer matrix with data beam: Sanity check

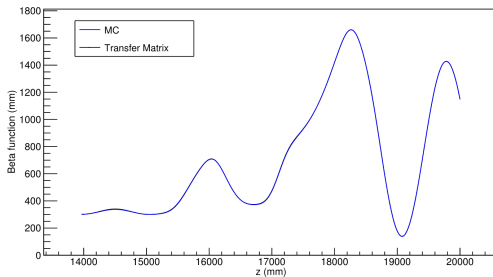
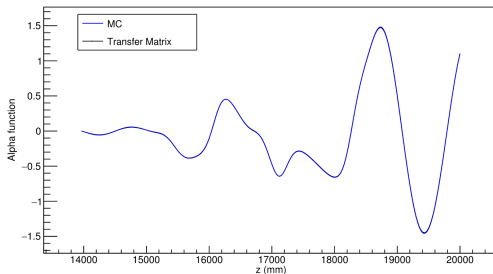
- Emittance from matrix model is expected to be conserved across the cooling channel (matrix is symplectic), while results show variation
- Alpha and beta also differ significantly from MC
- Decided to test the transfer map on beams that approach the linear regime
- Simulated beams with  $\alpha_0 =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



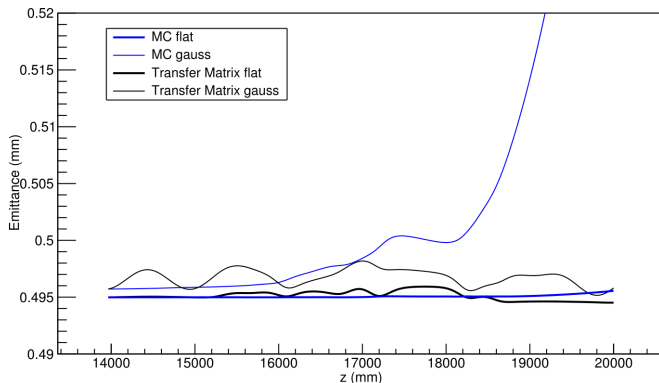
# TM with monochromatic 'perfect' beam: Alpha, Beta



# TM with gaussian 'perfect' beam: Alpha, Beta



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



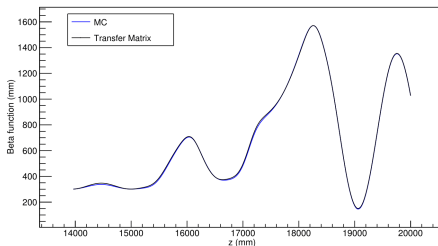
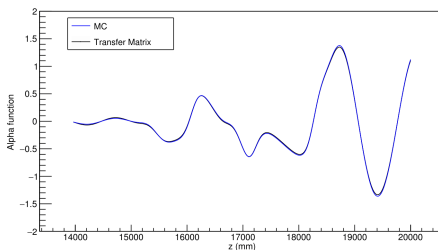
- Emittance growth in AFC and at SSD entrance ( $\sim 2.5\%$  at downstream reference plane)



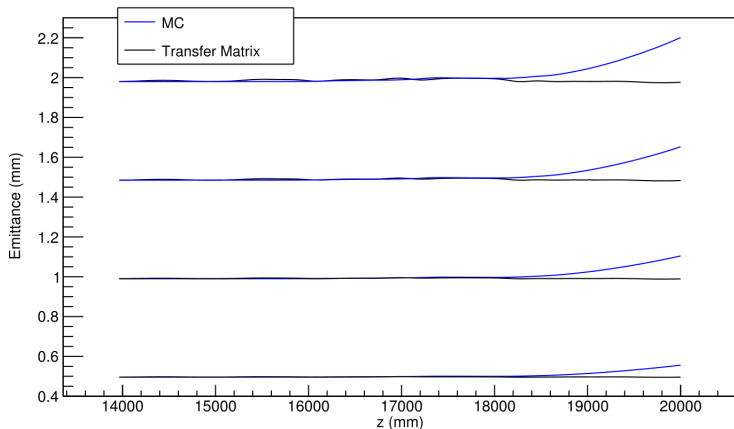
- Further decided to examine the optics evolution in both MC and matrix model as a function of the initial beam emittance (departure from linear regime)
- Kept the more realistic gaussian momentum distribution,  
 $\alpha_0 = 0, \beta_0 = 300mm$
- Varied initial emittance: 0.5, 1.0, 1.5, 2.0mm
- Even 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

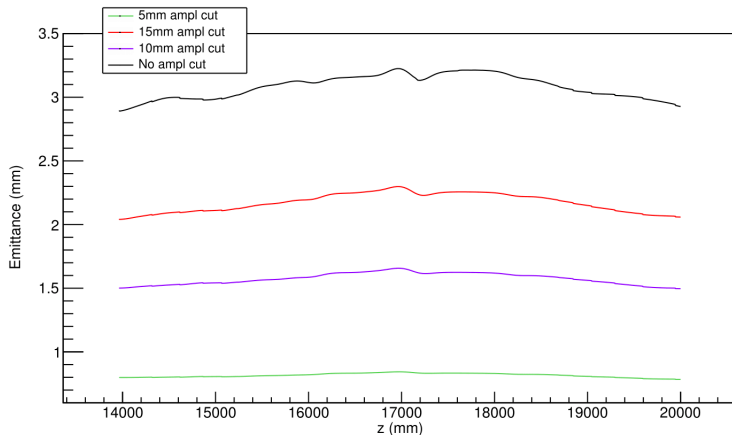


- Matrix model OK - constant emittance
- MC shows  $\sim 2.5\%$  emittance growth at downstream reference plane



# Transfer Matrix & amplitude cut: Emittance

- Applied matrix model to particle distributions that survived the amplitude cut - to study how the unexpected emittance variation changes as beam approaches the linear regime



- Good agreement in SSU, discrepancies in SSD persist even after amplitude cut is applied; can observe a reduction of the emittance growth in AFC as the cut into the core increases (approach 'ideal' beam)
- Matrix model seems to work 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
- Next steps
  - Determine the regime where optics ( $\alpha$ ,  $\beta$ ) calculated from MC and transfer map start to disagree significantly
  - Include standardised cuts plots
  - Apply the diffuser cut on the data
  - Implement matrix model with parameters from data



# Thank you!

