Cooling Performance Comparison Using G4MICE

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Outline

- Aim & Motivation
- Initial Beam Conditions
- Characteristics of:
  - MICE-like cell
  - FS2A cell
  - Singlet cell
  - Doublet cell
- Cuts
- Results
- Conclusion
- Future Plans

Aim & Motivation

- For the future Neutrino Factory, muon cooling is essential. The only viable cooling technique for muons is ionization cooling.
- 4 different lattices are compared on their cooling dynamics → **Find** which of these 4 lattices gives the **optimum cooling** for the Neutrino Factory.
- The lattices that are compared:
  - MICE-cell
  - FS2A
  - Singlet
  - Doublet

(Singlet and Doublet:)

- **Lower Bz at position of RF's.**
- **Doublet also results to a lower beta at position of absorbers**

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Initial Beam Conditions

- For all lattices the initial beam was:
  - 10 mm Transverse Emittance and
  - 0.63 ns Longitudinal Emittance

- All cells had P mean 232 MeV/c except for the MICE-like cell that had 200 MeV/c (because of the low P acceptance MICE-cell has)

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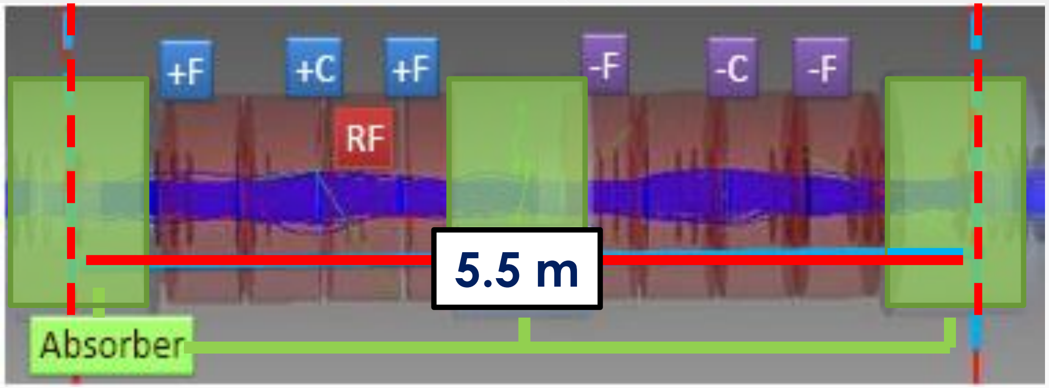
MICE-like cell

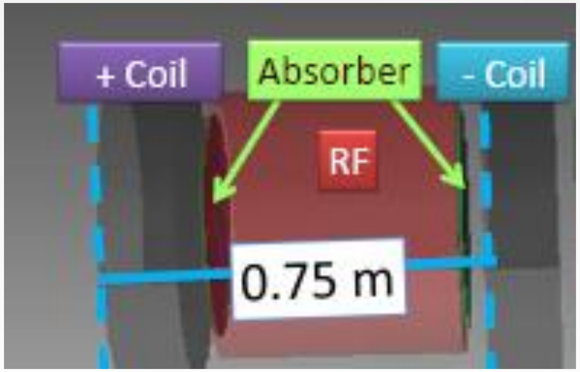
- Each cell consists of:
  - 2 liquid H_2 absorbers
  - 2 sets of 4 RF cavities (201.25 MHz)
  - 4 focusing and 2 coupling coils
- Peak Electric Field*: 12.46 MV/m, phase: 40°
- Cell's length: 5.5 m



- ***The Peak Electric Field was chosen such as to keep the energy of the reference particle constant, i.e. energy lost in absorbers=energy gained by RFs***

FS2A cell

- Each cell consists of:
  - Coil → LiH absorber → 200 MHz RF → LiH absorber
- Peak Electric Field: 13.077 MV/m, phase: 40°
- Cell's length: 0.75 m

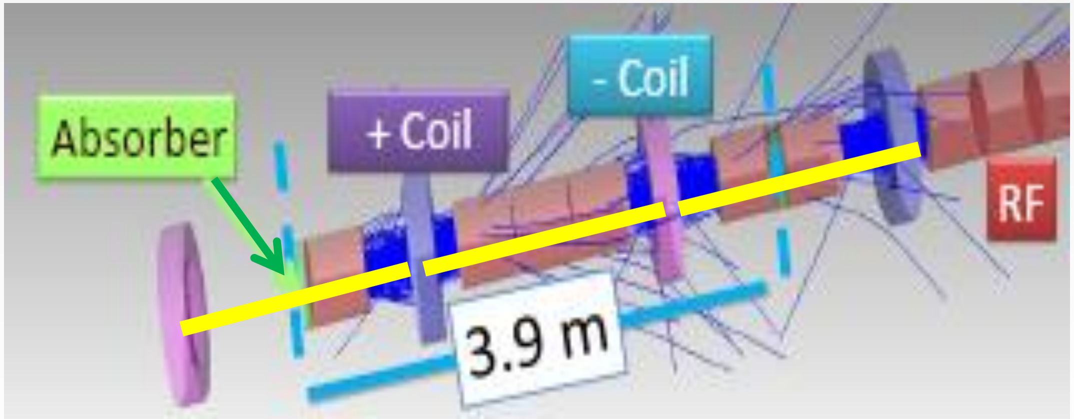


- *Polarity of coils alternates with every repeat*

Singlet cell

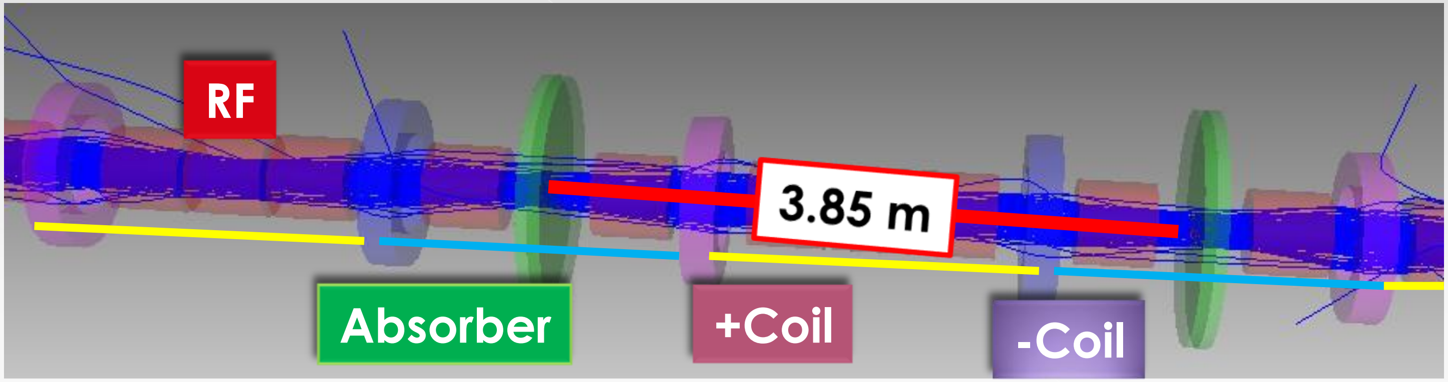
- Each cell consists of:

  LiH absorber → 200 MHz RF → Positive Coil → 3 RFs → Negative Coil → RF
- RF Peak Electric Field: 8.62 MV/m, phase 40°
- Cell's length: 3.9 m



Doublet cell

- Same components as Singlet cell
- Peak Electric Field: 16 MV/m, phase: 45°
- Cell's length: **3.85 m, i.e. only 5 cm different than Singlet**



- *Distance between coils of opposite polarity in one cell **is not** the same as the distance of opposite-polarity coils of next cell (picture explains it better: yellow and light blue lines have different lengths)*

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Cuts

- **R**<30 cm
- **P**: ±100 MeV/c *(total momentum)*
- For the tracking results, only particles that made it to the end of the lattice were taken into account.

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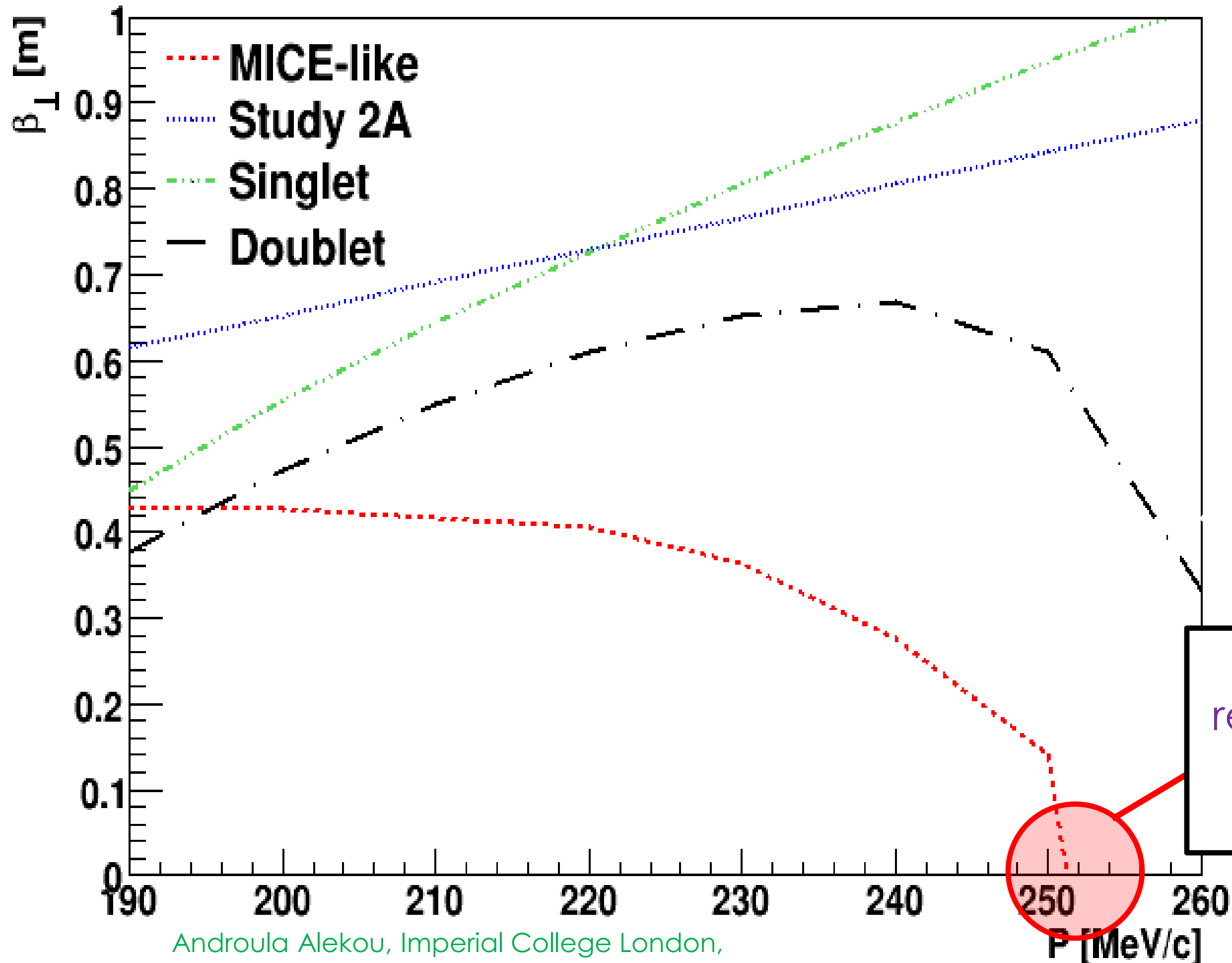
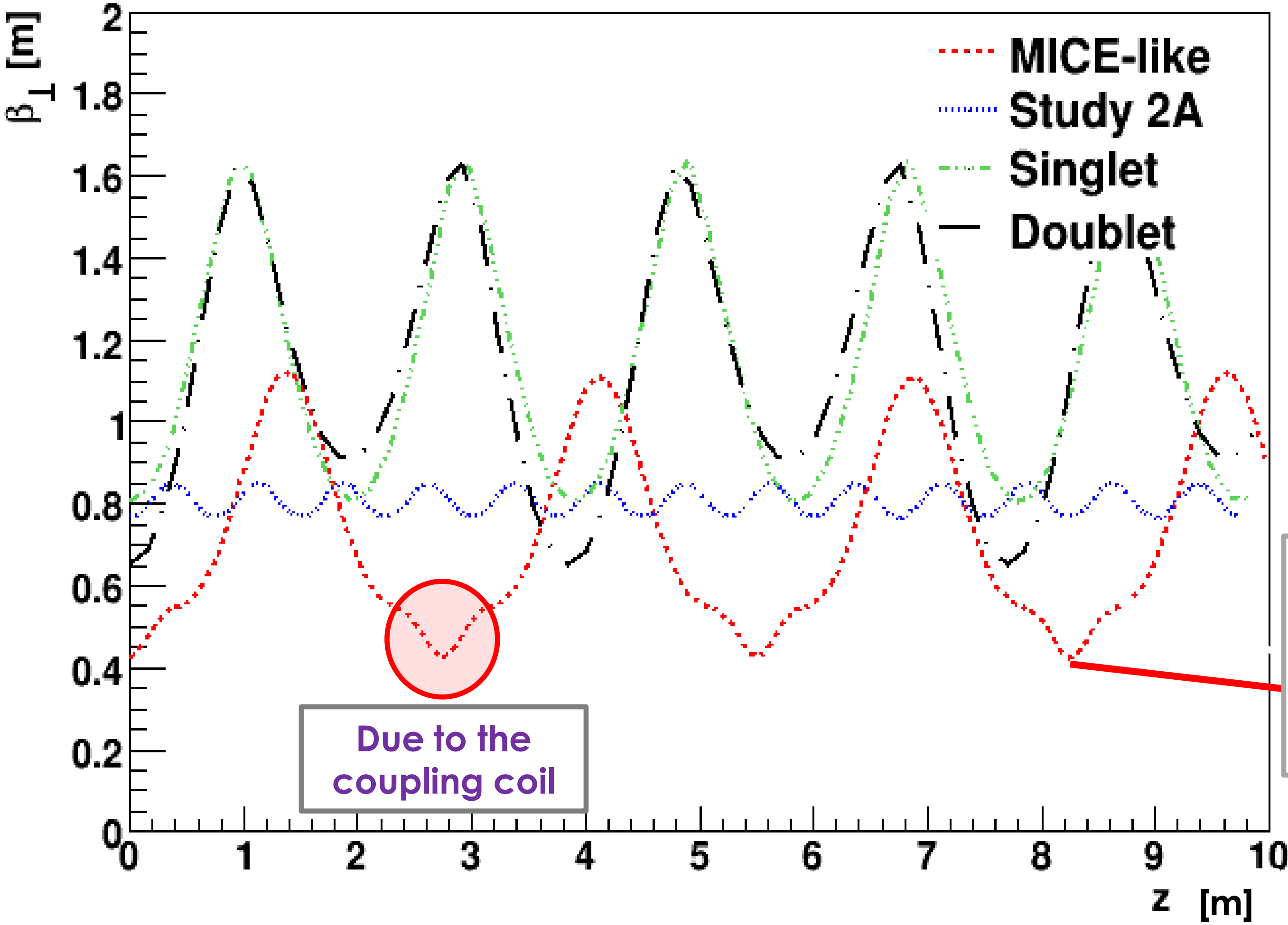
Results-Optics



Low momentum resonance explains the P selection of 200 MeV/c

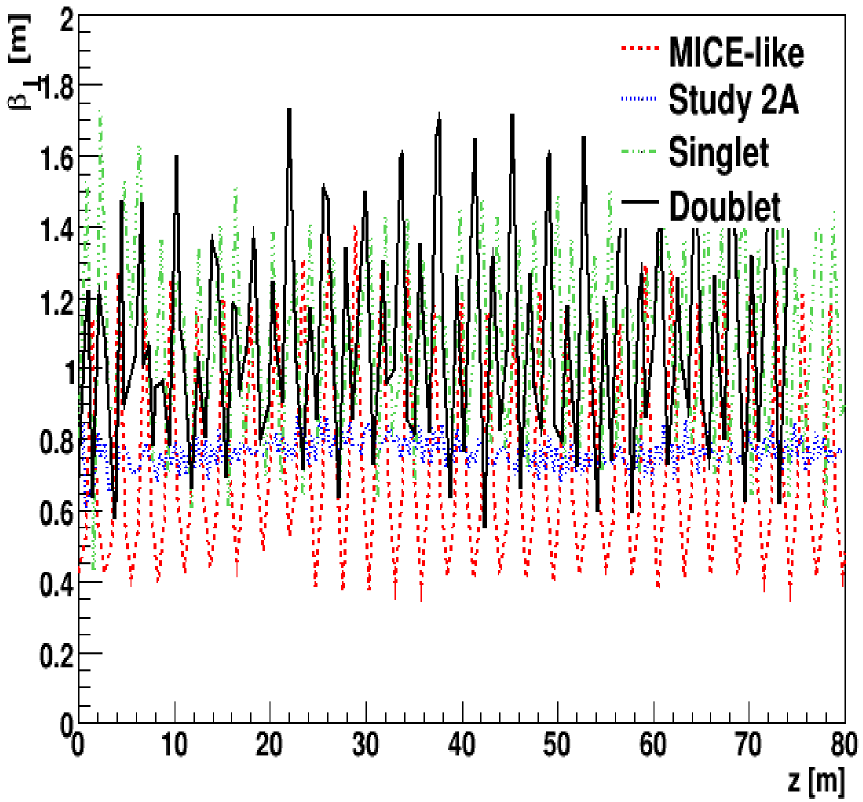
Results-Optics

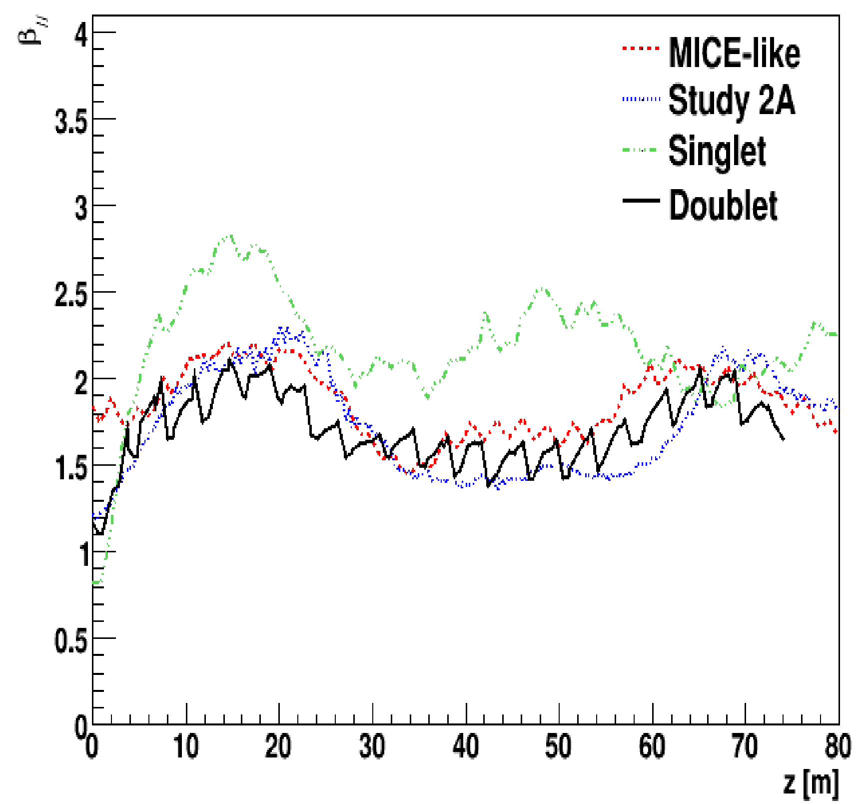


Note the shape difference of Singlet and Doublet (because of the difference in coils distance)

Lower beta compensates with lower P acceptance

Results-Tracking





Results-Tracking

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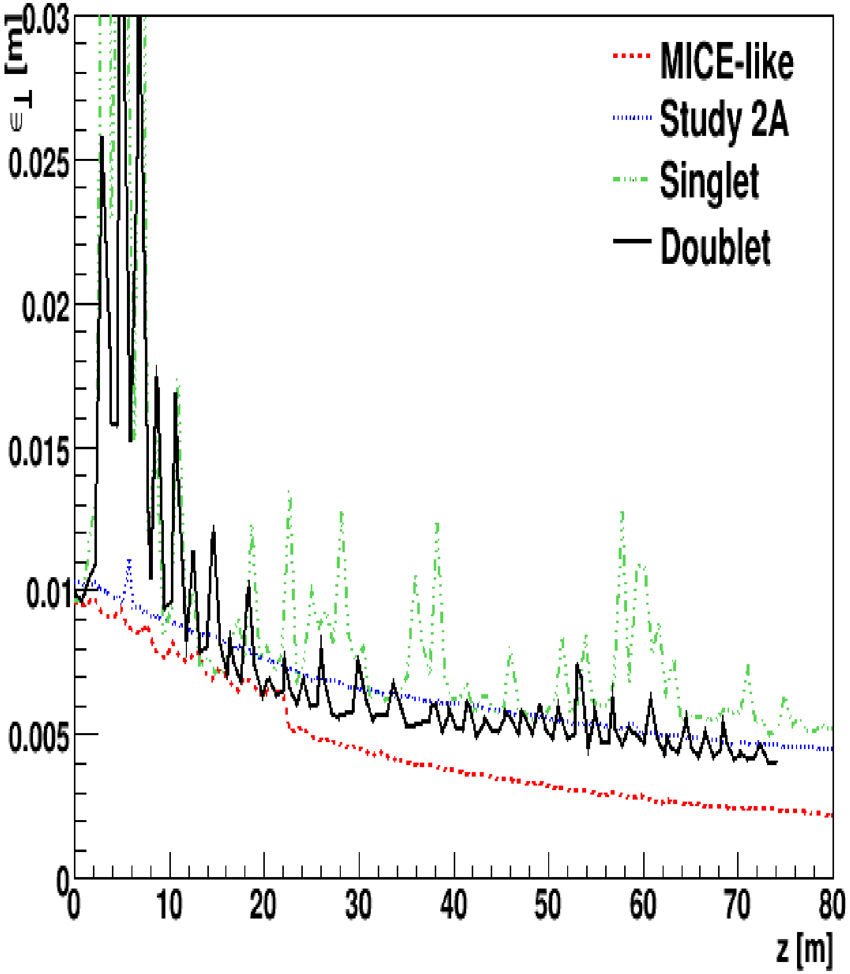
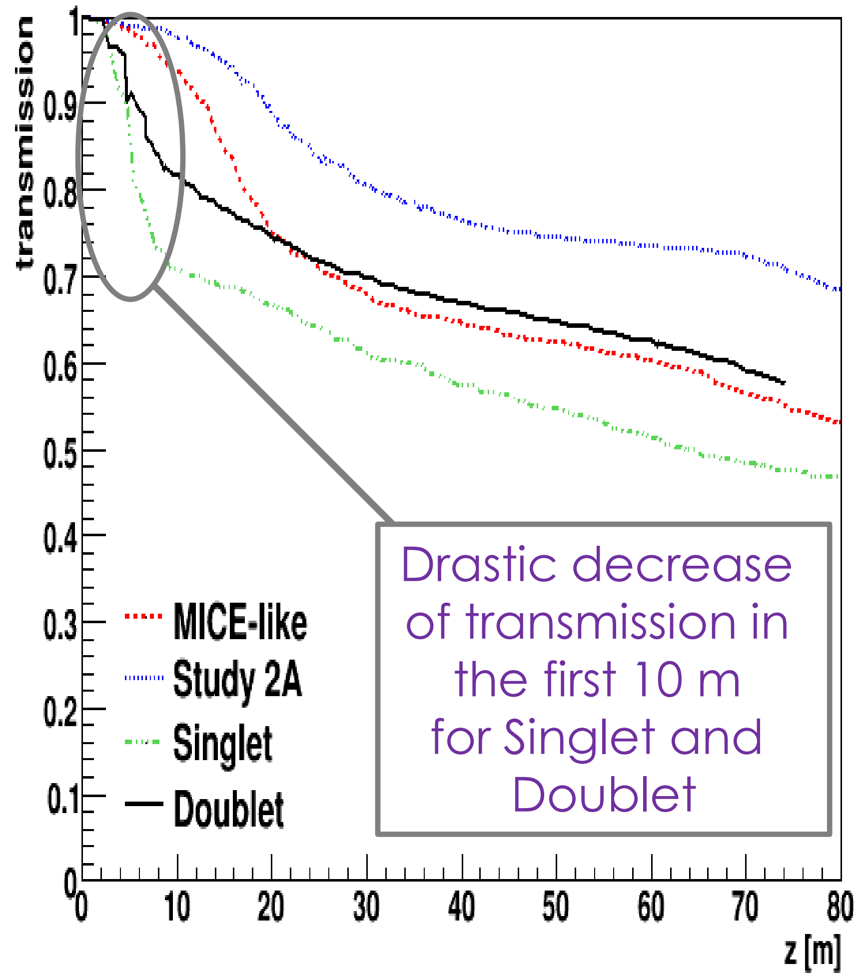




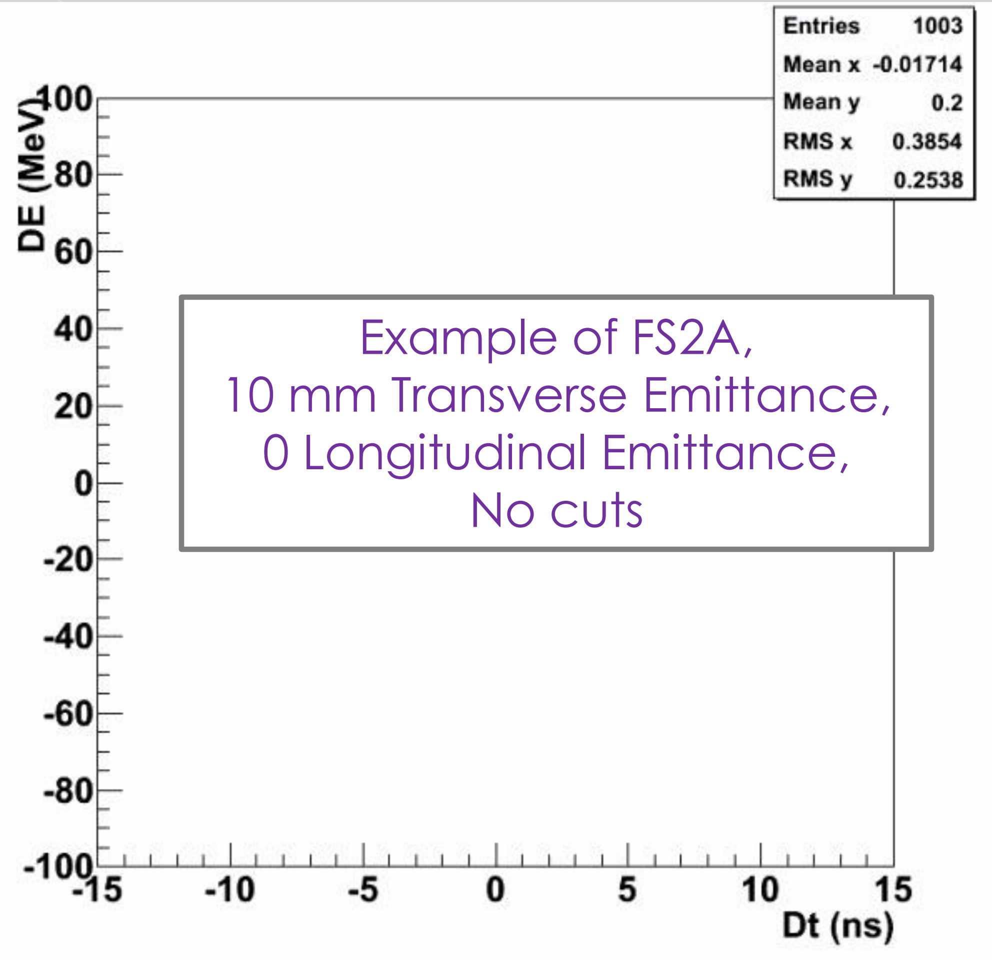
Results

- Number of particles lost because of
  - P cuts: ~0
  - R cuts: 0

Most of the losses are due to particles that don't make it to the end of the lattice. This may be due to longitudinal heating.

Check how the longitudinal phase space is behaving

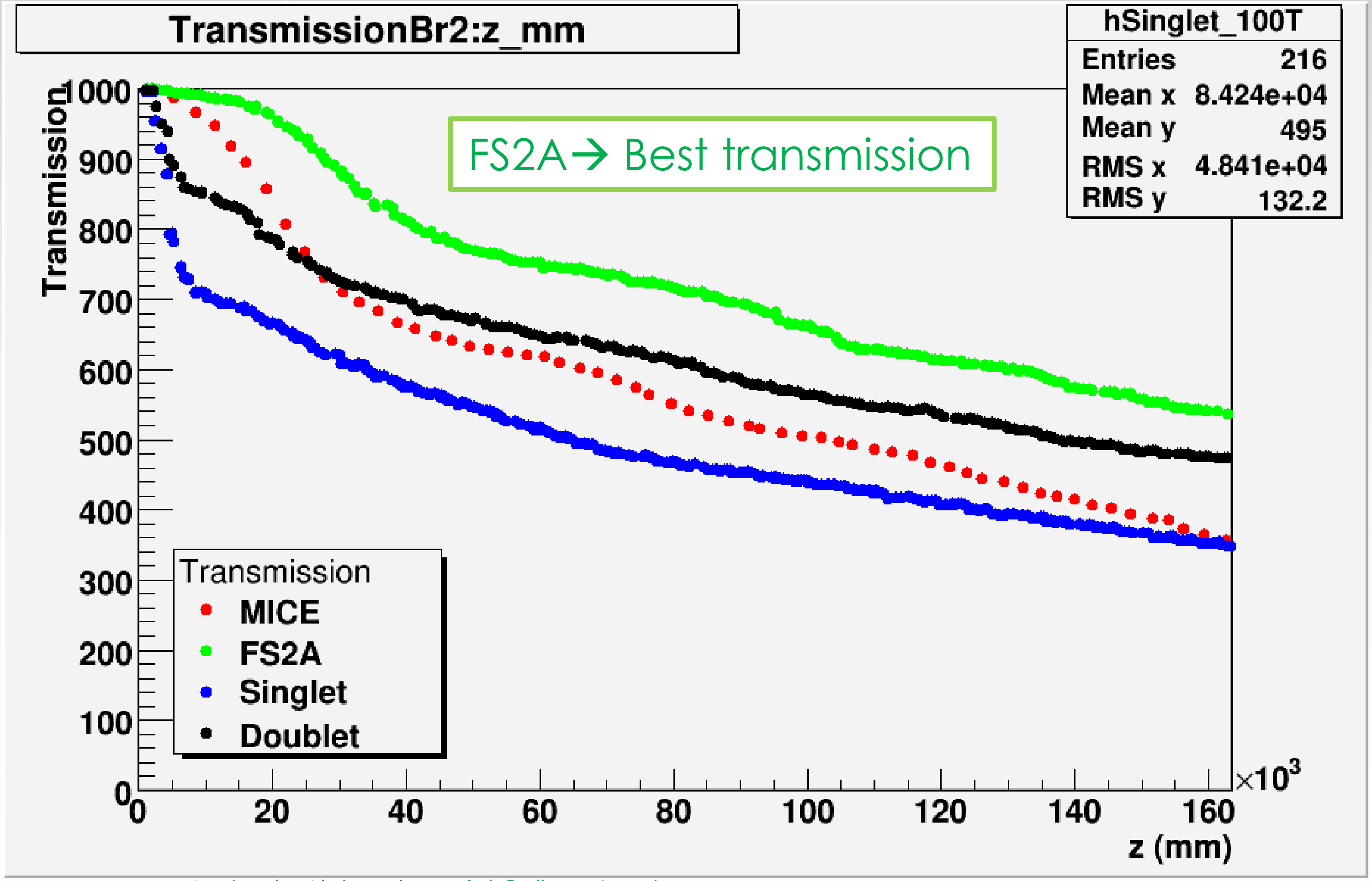
Longitudinal Heating Example



Transmission for different cuts

- Remove P cuts
- Apply on each plane radius cuts R<30 cm (i.e. If a particle R>30 cm on one plane it wont be taken into account further downstream)
- Remove the global cut (i.e. Don't take only the particles that make it to the end of the lattice)

Only R Cuts

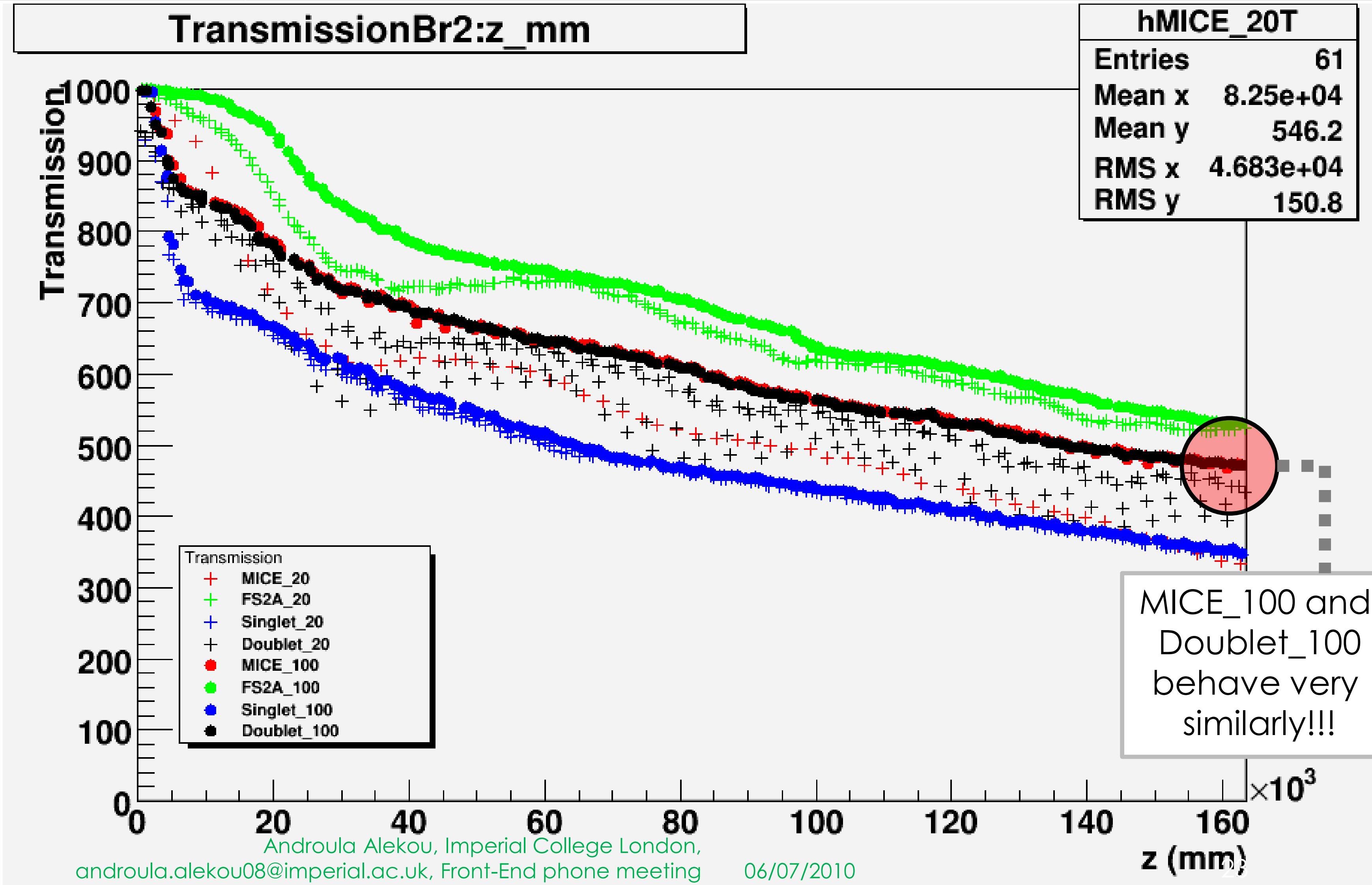


TransmissionBr2:z_mm
hSinglet_100T
Entries 216
Mean x 8.424e+04
Mean y 495
RMS x 4.841e+04
RMS y 132.2
FS2A→ Best transmission
Transmission
1000
900
800
700
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
160
×10³
z (mm)
Transmission
MICE
FS2A
Singlet
Doublet

Transmission for different cuts

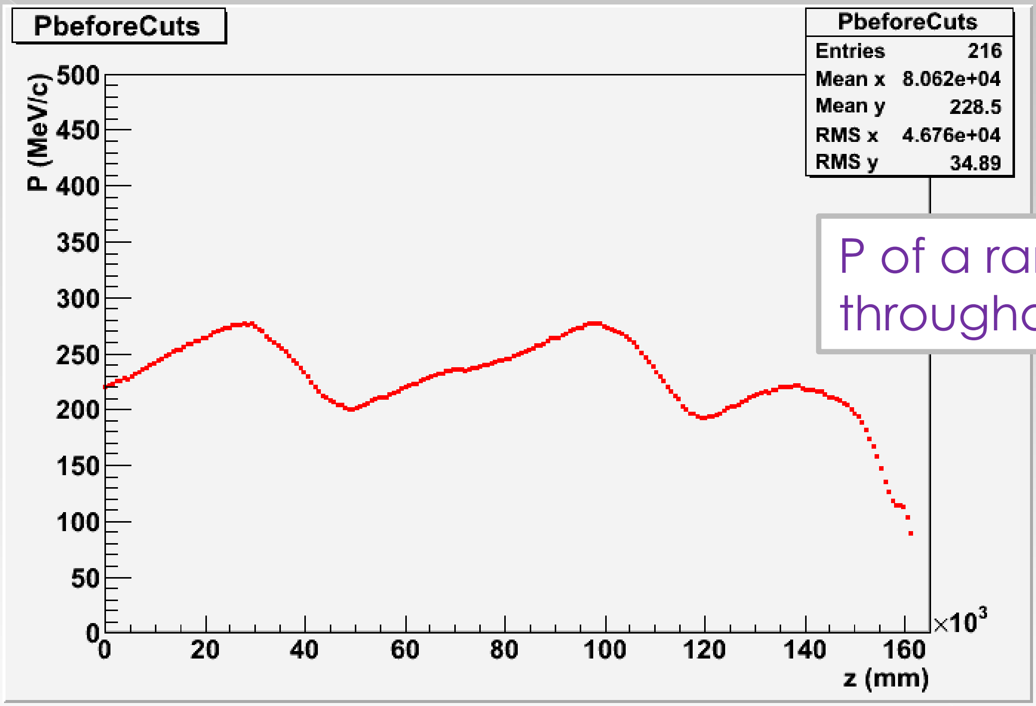
- Take into account particles with R<30 cm (again, if a particle has R>30 cm on a plane it wont be taken into account further downstream).
- Then apply on each plane a P cut (but if a particle doesn't make the P cuts on a plane its P will **still** be checked further downstream)→ Check for:
  - P±20% and
  - P±100 MeV/c

R and P Cuts



MICE_100 and Doublet_100 behave very similarly!!!

In the ± 20% case, we have oscillations because of the way the P of the particles behave:



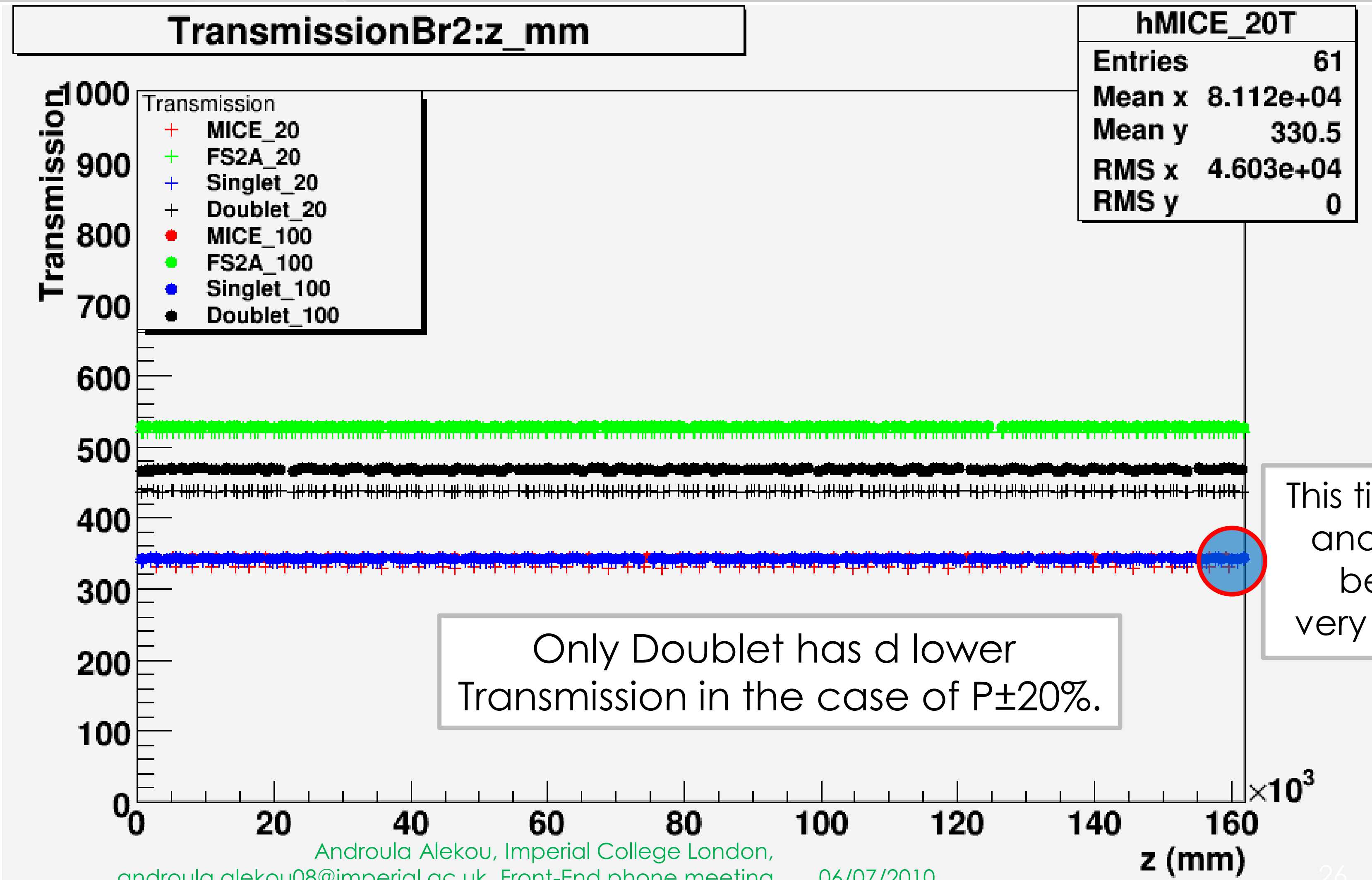
P of a random particle throughout FS2A lattice

Although the P oscillates, it stays below 300 MeV/c and above ~100 MeV/c, i.e. It stays within the limit of the P±100 MeV/c cut! This is the reason we don't have these P oscillations in the case of P±100 MeV/c.

Transmission for different cuts

- Take the particles that **on the last plane** have P±20% and P±100%.
- Out of those particles reject **on each plane** those with R>30 cm.

More global cut



Only Doublet has d lower Transmission in the case of P±20%.

This time MICE and Singlet behave very similarly!!

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Conclusion

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- **MICE-like, FS2A, Singlet and Doublet cells:** compared with respect to the cooling dynamics each provides, in order to find the optimum cooling lattice for the Neutrino Factory.
- **Siglet and Doublet:** designed to obtain low magnetic field in the RF cavities so the distance between the coils was larger than in the other lattices →Increase of distance caused increase of betatron function at the position of the coils → **higher beam size modulation with respect to FS2A lattice**.
- **MICE-like cell** → Lowest beta BUT low momentum acceptance.
- **FS2A beta** function: **higher** than the other lattices **BUT transmission is better** and acceptable emittance reduction.
- Transmission oscillations appear when reducing the P cuts; they go away when P cut becomes more global. We need to understand the transmission results (with the new cuts) better.
- **The results of this study indicate that out of these 4 lattices, the most suitable for the needs of the Neutrino Factory is the FS2A lattice.**

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Future Plans

- Understand the drastic transverse emittance increase of Singlet and Doublet.
- Try to decrease the Bz at the position of the RFs
- Introduce longitudinal cooling as it can:
  - reduce the muon losses
  - stabilise the dynamics in the longitudinal plane
  - facilitate the matching with the downstream accelerators

  → Introduce the dispersion function into the lattice (e.g. by introducing dipoles and wedge absorbers).

THANK YOU!

Any questions?