Accelerator R&D
Part II: Accelerator & Collider

R. Taylor

Showing work from A. Aksoy, D. Amorim, C. Bartoli, T. Bud, D. Calzolari, S. Fabbri, E. Fol, G. Lerner, D. Novelli, J. Osborne, L. Thiele, M. Topp-Mugglestone, M. Vanwelde

Workshop on UK Contributions to Muon Collider Detector R&D
University of Birmingham, 3rd July 2024

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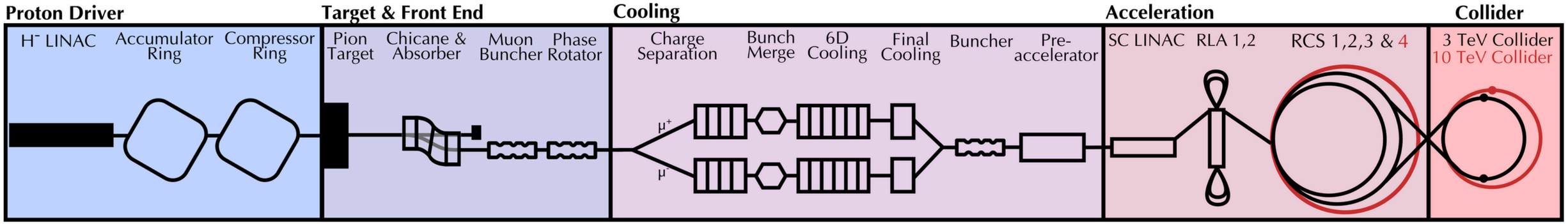
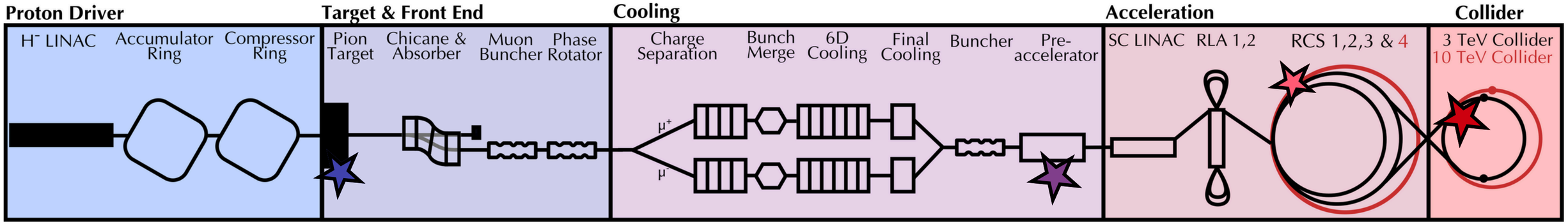
Overview


Proton Driver
Target & Front End
Cooling
Acceleration
Collider
H⁻ LINAC
Accumulator Ring
Compressor Ring
Pion Target
Chicane & Absorber
Muon Buncher
Phase Rotator
Charge Separation
Bunch Merge
6D Cooling
Final Cooling
Buncher
Pre-accelerator
μ⁺
μ⁻
SC LINAC
RLA 1,2
RCS 1,2,3 & 4
3 TeV Collider
10 TeV Collider

Final Cooling



Final Cooling Aims:

Allow longitudinal emittance to increase

1.5 mm ⟶ 75 mm

to further reduce transverse beam emittance

300 um ⟶ 25 um

and still retain reasonable transmission.

~80%

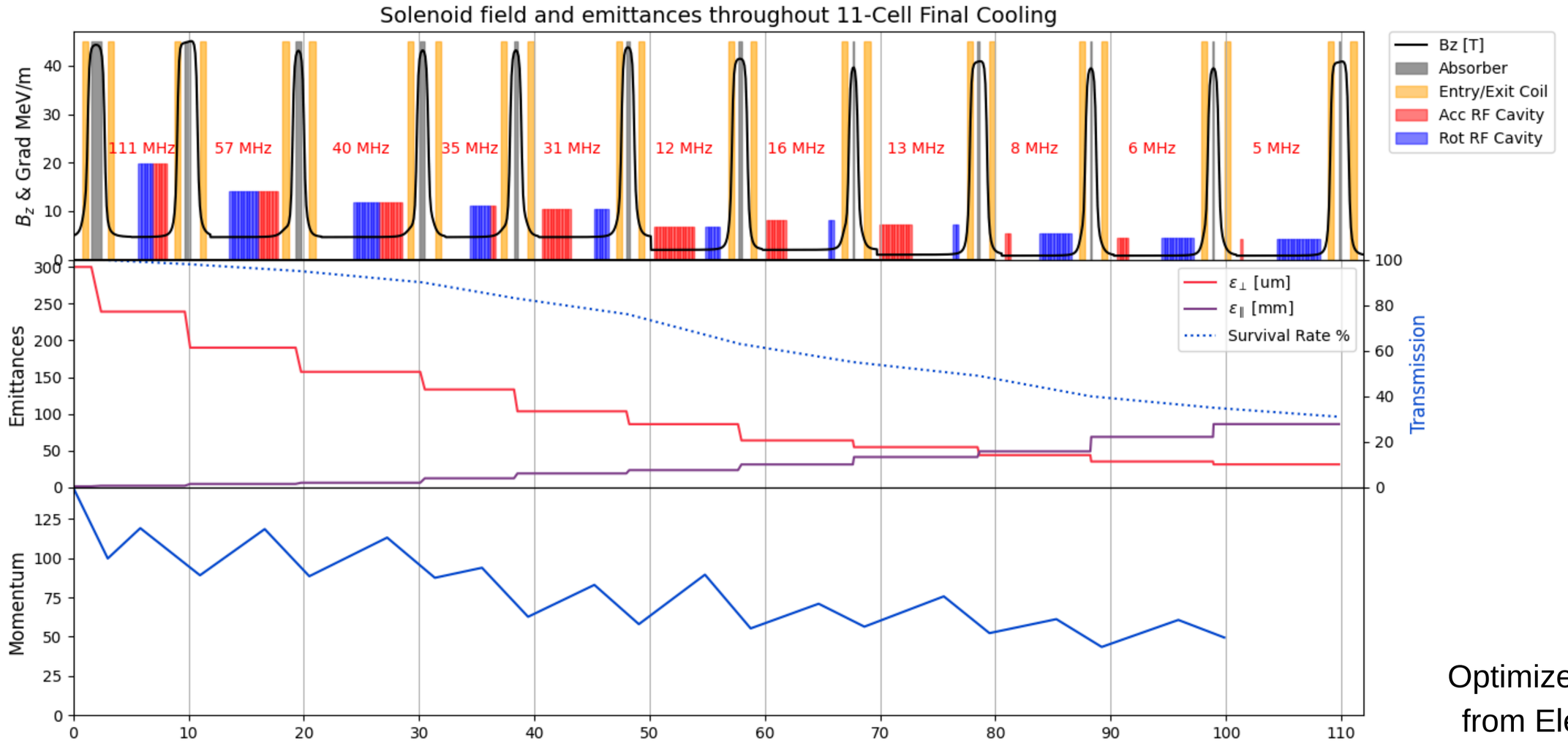
Higher energy spread affects **RF cavity** design downstream, and the **beta*** at the collider

Larger beam area affects **magnet aperture** and **luminosity** at the collider

$$\mathcal{L} = \frac{\gamma^3 \tau_0 c}{2C} \frac{N_0^2 \sigma_\delta}{4\pi \epsilon_{\perp,\mathrm{N}} \epsilon_{\mathrm{L,N}}} f_\mathrm{r}$$

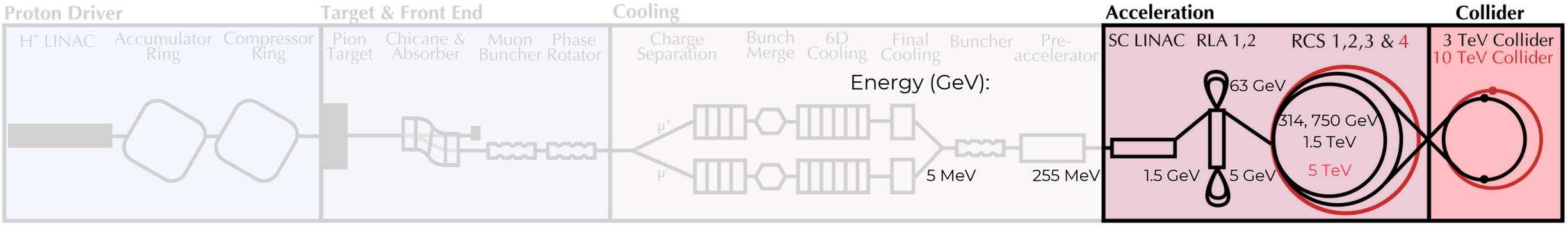
Number of particles affects **luminosity**. If transmission is insufficient, increased **beam power** at target required.

Final Cooling



Optimized lattice from Elena Fol

Acceleration & Collider



1) To accelerator to 5 TeV, as fast as possible

Parameter	unit	after Final Cooling	Inj. at 3 TeV	Inj. at 10 TeV
Beam total energy	GeV	0.255	1500	5000
Muons/bunch	10^12	4	2.2	1.8
RMS bunch length	mm	375	5	1.5
Av. grad (0.2GeV-1.5TeV)	MV/m		2.4	1.1

2) To collide with as much luminosity as possible

Current accelerator design

One Superconducting LINAC

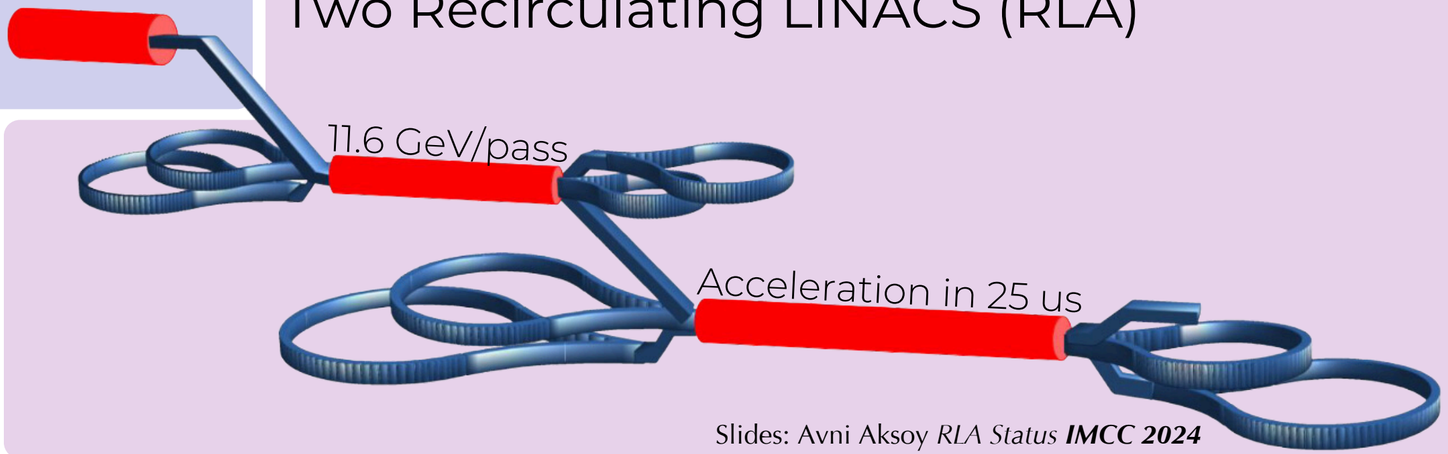
Low frequency (~88 MHz) due to long beam

Total lengths: (In progress)

SC LINAC:	82 m
RLA 1:	75 m
RLA 2:	1.9 km
RCS1,2:	6 km
RCS3:	10 km
RCS4:	35 km

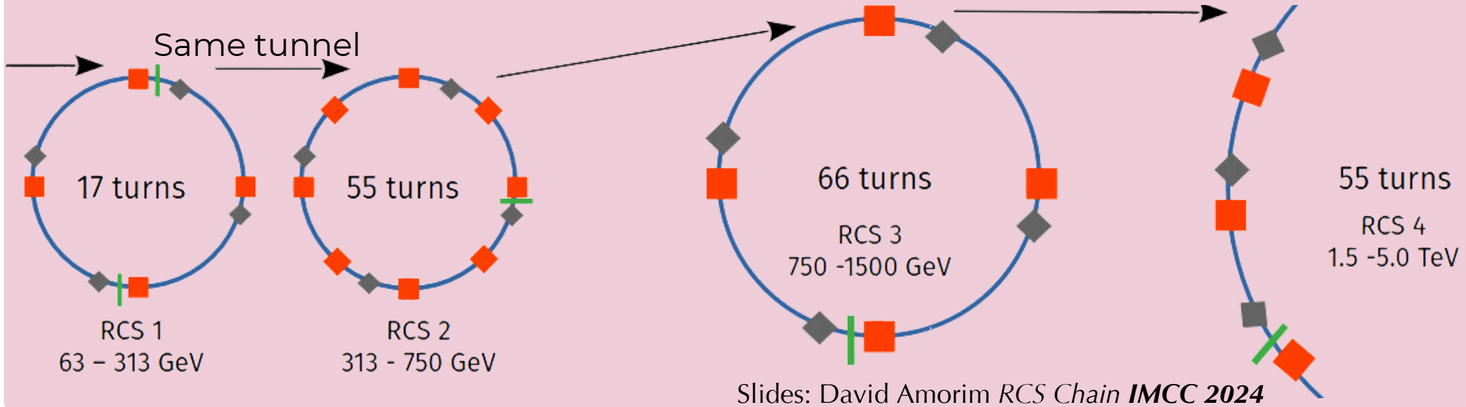
Target machine transmission: **>10%** (After capture)
Increase **acceleration time** and reduce **muon path** to increase muon survival rate.

Two Recirculating LINACS (RLA)



Slides: Avni Aksoy *RLA Status* ***IMCC 2024***

Four Rapidly Cycling Synchrotrons (RCS)

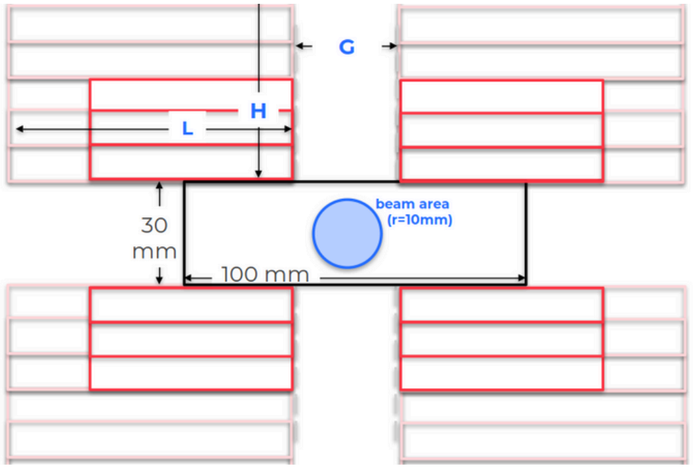


Slides: David Amorim *RCS Chain* ***IMCC 2024***

Why is acceleration challenging?

High T Magnets

with large transverse emittance

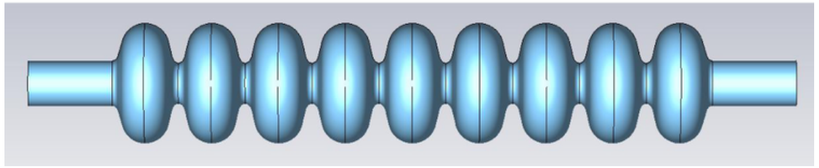


	J [A/mm^2]	Peak B [T]
1. Minimum Volume	655.5	12.7
2, Median Volume	239.4	11.0
3. Best Field Quality	207.1	10.9

Siara Fabbri *Initial Magnetic Design of Superconducting Dipoles in Acceleration Stage* ***IMCC 2024***

High Grad RF

Baseline 1.3 GHz 9-cell TESLA cavity



Two **high-intensity** beams cycling in opposite directions

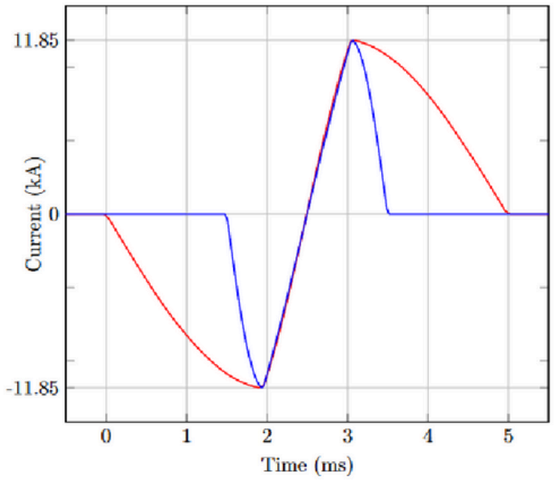
Short acceleration time with **high voltage** per turn.

207 klystrons and 4620 cavities from RCS 1-4

Leonard Thiele *RF parameter optimization in the high energy muon acceleration chain* ***RCS Workshop 2024***

Both ramped

Quasi-linear

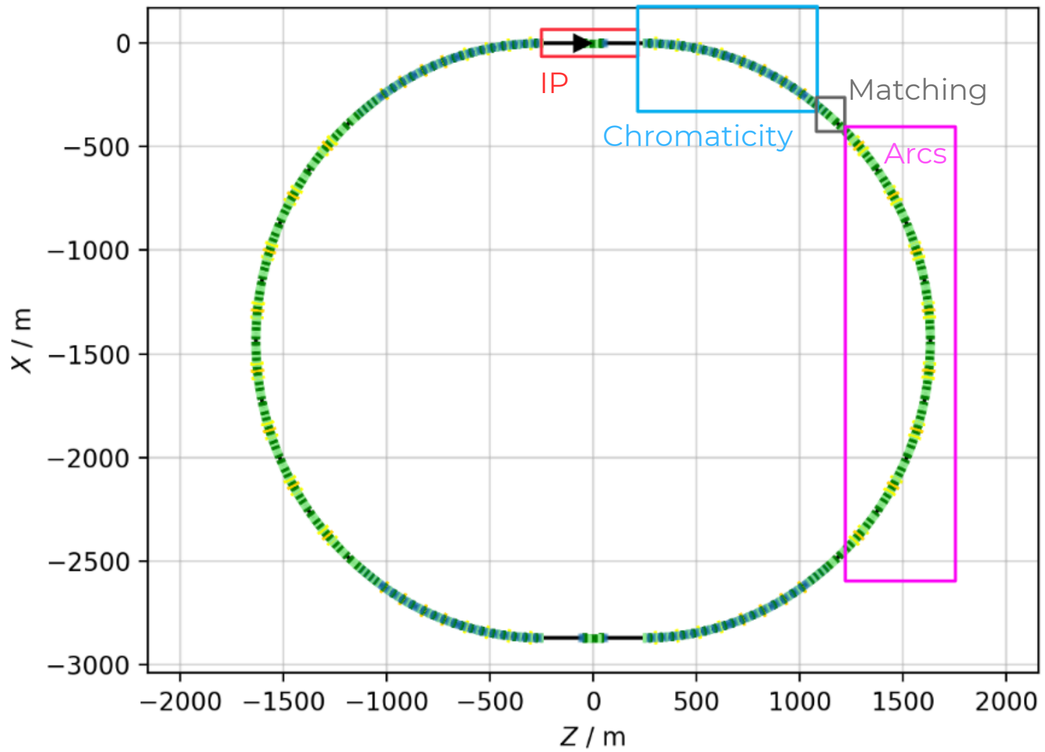


Changes in ramp shape requiring more RF cavities

C. Bartoli *Resistive magnets design and analysis baseline* ***IMCC 2024***

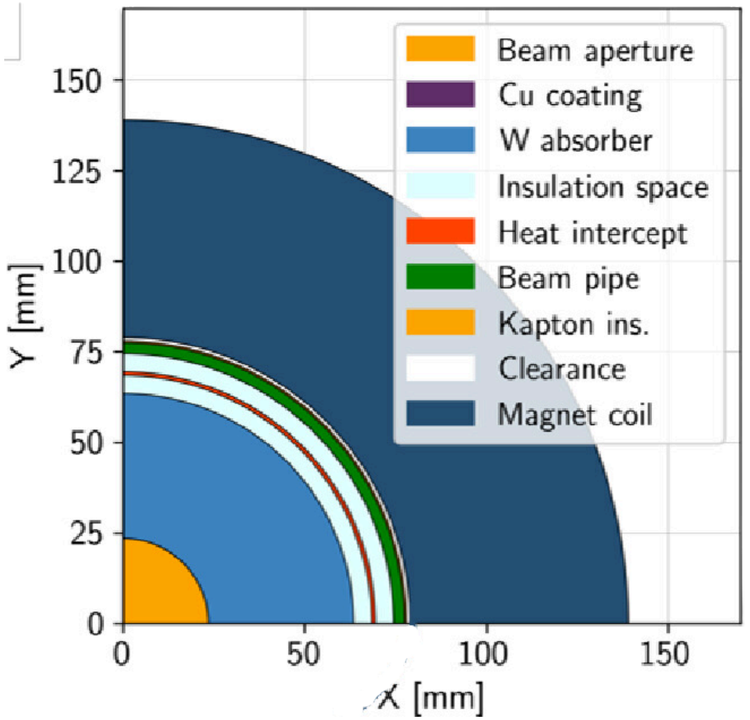
Current collider design

- 10 km collider ring
- 5 TeV particle energy
- 21 x 10^35 cm-2s-1 luminosity



Marion Vanwelde *Status of the 10 TeV center-of-mass collider lattice and IR design* ***MDI Workshop 2024***

- Dipole: **16 T**
  - 5m long REBCO hybrid
- Combined: **20 T**

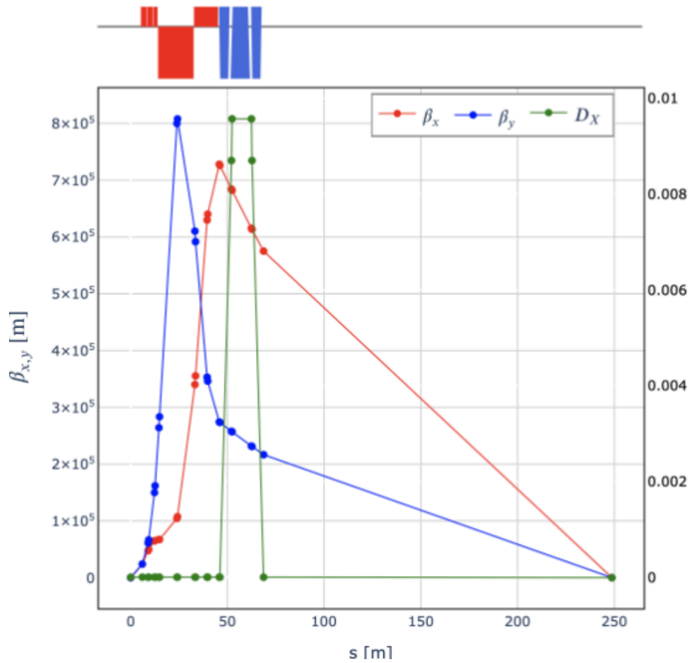


D. Novelli *Collider magnets study* ***IMCC 2024***

Why is colliding challenging?

Interaction Point

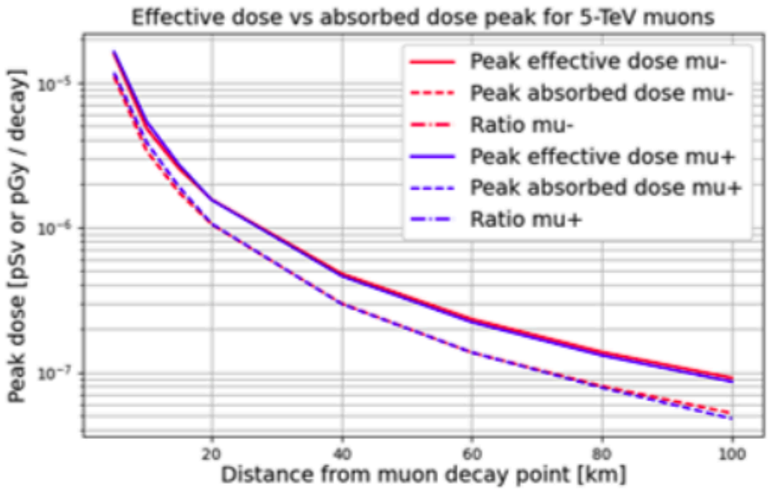
1.5 mm β* at interaction requires **strong-focusing quadrupoles**



Marion Vanwelde *Status of the 10 TeV center-of-mass collider lattice and IR design* ***MDI Workshop 2024***

Straight Sections

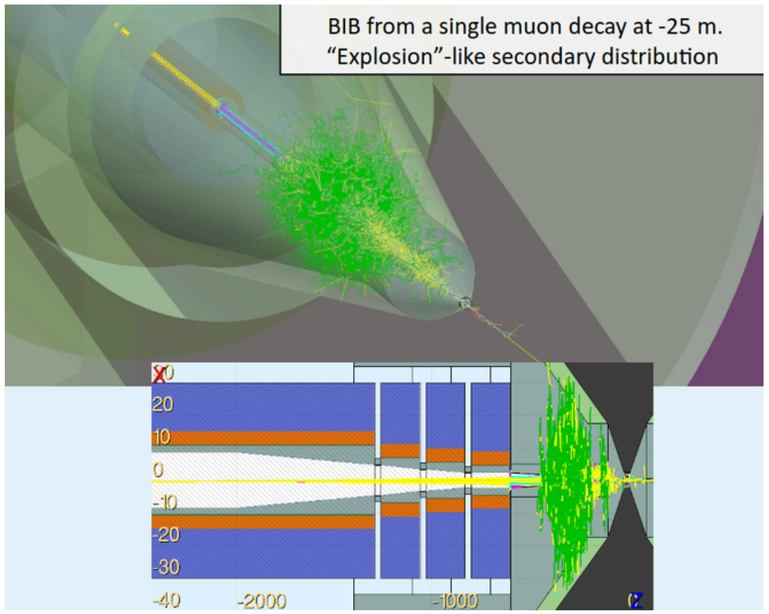
Minimizing **straight-sections** throughout collider to reduce **neutrino flux**.



G. Lerner *Update on neutrino studies with FLUKA* ***IMCC 2023***

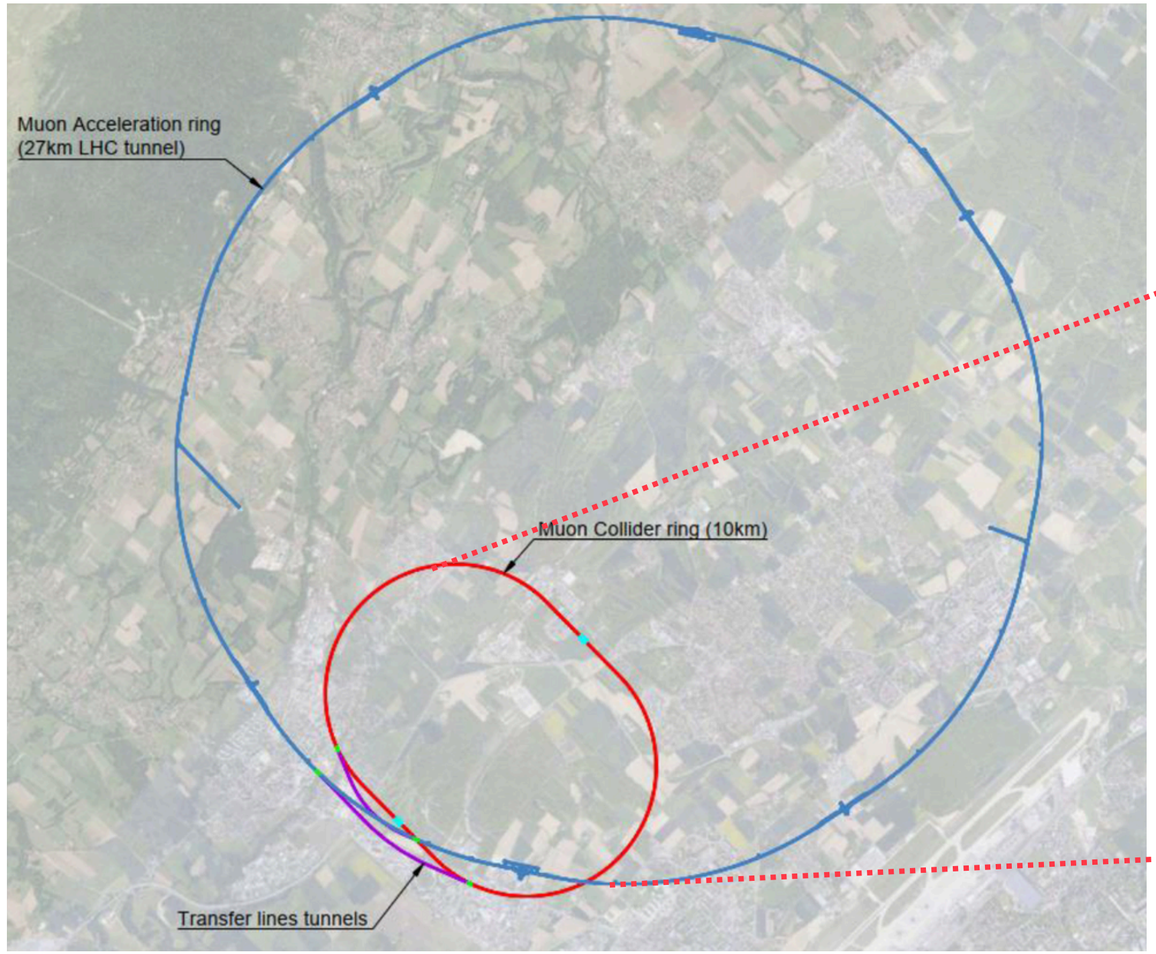
Beam Background

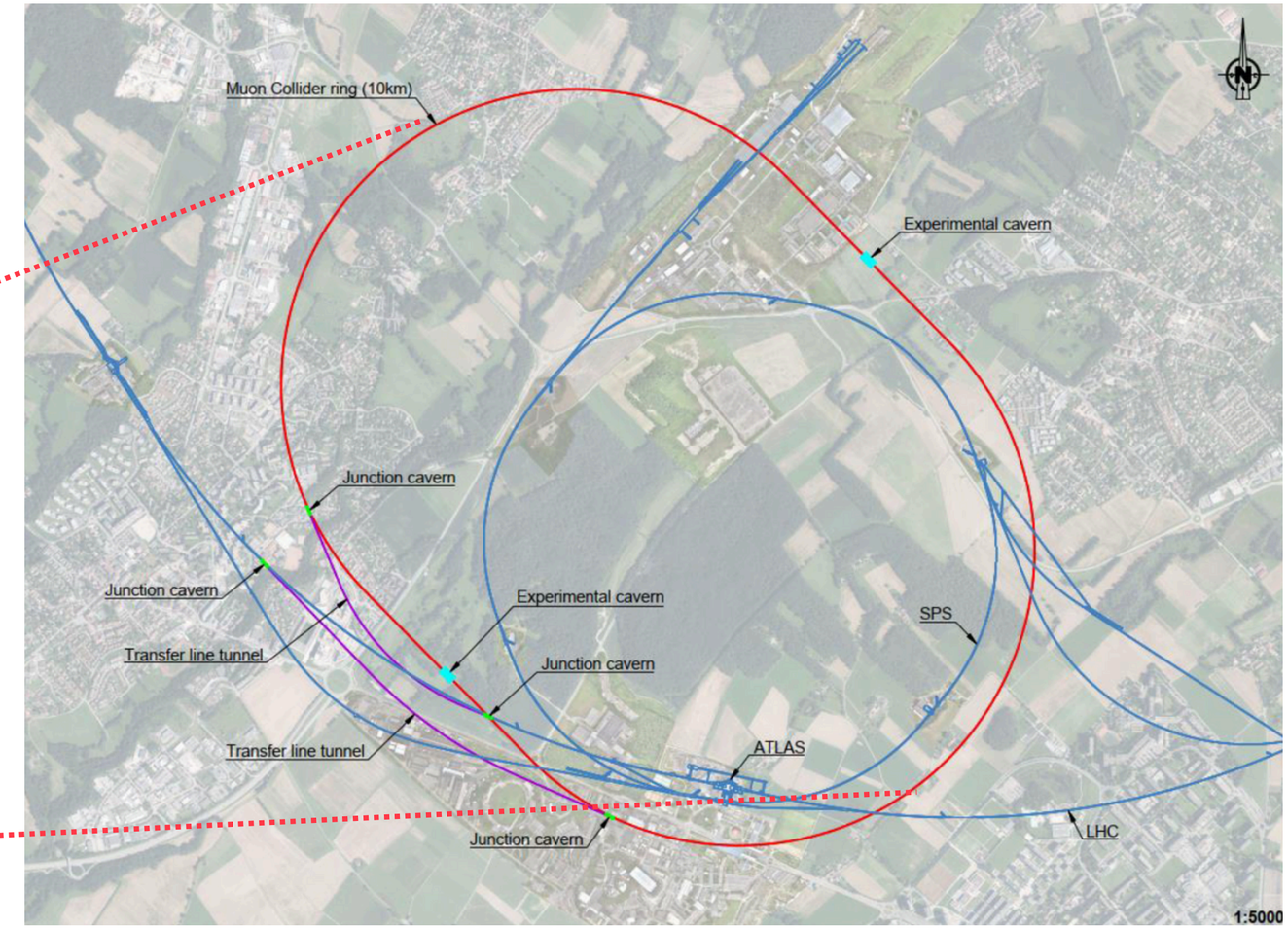
Chicane applied to reduce beam-induced background from muon decay products .



Daniele Calzolari *Machine-detector interface and beam-induced background studies for a 10 TeV muon collider* ***MDI 2024***

On-Site Design



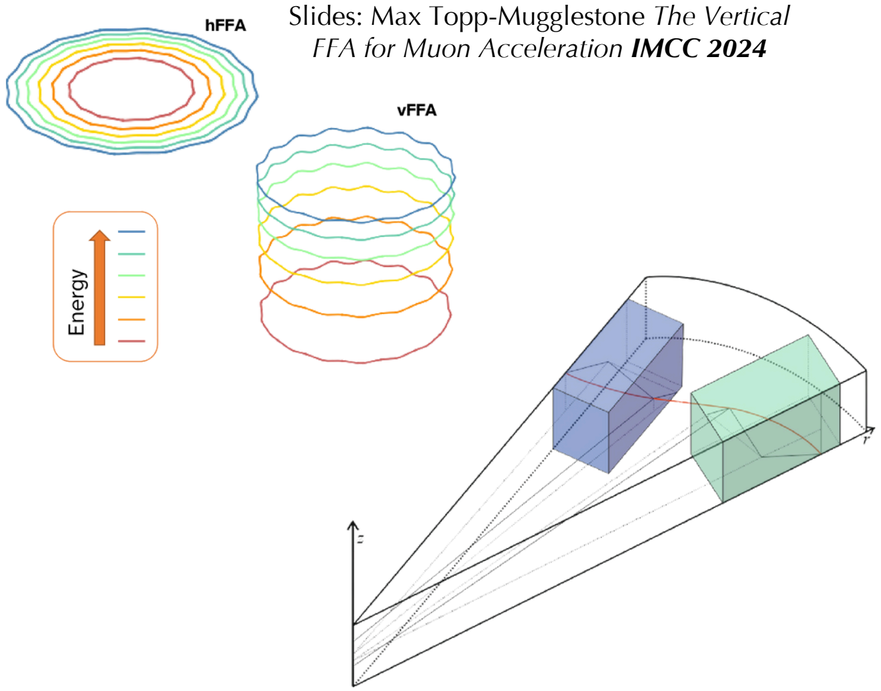


John Osborne, Tamara Bud *Muon Collider Civil Engineering Studies* ***2024***

UK Contributions

vFFA Alternative

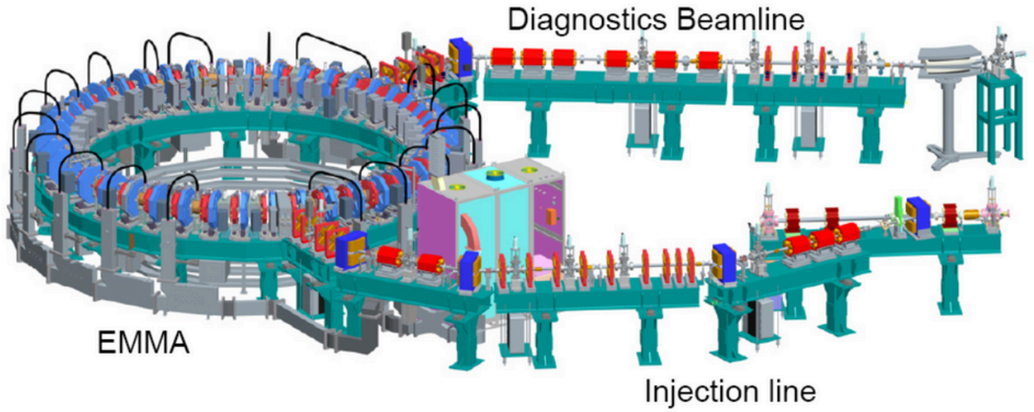
- Replacing RCS 1, 2 & 3 (from 0.05 -> 1.5 TeV)
- Circumference of LHC
- Large field (8.7 T peak)



Slides: Max Topp-Mugglestone *The Vertical FFA for Muon Acceleration* ***IMCC 2024***

EMMA

- Non-Scaling FFA demonstrator for muon applications
  - 10.5 to 20.5 MeV electron accelerator to model 10 GeV to 20 GeV muon acceleration



Summary

Final cooling affects transverse and longitudinal emittance (relating to β)

Multi-stage acceleration system has high R&D requirements on magnets and RF Cavities

$$\mathcal{L} = \frac{\gamma^2 \tau_0 c}{2C} \frac{N_0^2}{4\pi \epsilon_{\perp,\mathrm{N}} \beta_\perp^*} f_\mathrm{r}$$

Collider has strict requirements on IP optics and should minimize radiation background

Transmission across whole machine affects luminosity

Whole system could fit inside existing CERN complex - parameter redesign needed to adapt

Lots of challenging work ahead - would benefit from the strong UK accelerator community

Thank you

International MUON Collider Collaboration

MuCol

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