Muon RLA – Design Status and Simulations

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IDS Goals:

- Define beamlines/lattices for all components
- Matrix based end-to-end simulation (machine acceptance) (OptiM)
- Field map based end-to-end simulation: ELEGANT, GPT and G4Beamline
- Error sensitivity analysis
- Component count and costing
- Two regular droplet arcs replaced by one two-pass combined function magnet arc
Linear Pre-accelerator – 0.9 GeV

24 short cryos

24 medium cryos

1.5 Tesla solenoid

2 Tesla solenoid

NuFact’11, Univ. of Geneva, Aug. 1-6, 2011
Transit time effect – G4BL

The graph shows the Transit Factor defined as 
\[
\text{TransitFactor} = \frac{E_2 - E_1}{E_2 + L}
\]
versus the input \( P_z [\text{MeV/c}] \) for different input values. The plot includes a reference to "rf2.csv" and an exponential function \( \exp(f(x)) \). The data points are fitted to the curve with a green line.

C. Bontoiu
M. Aslaninejad
Linear Pre-accelerator – Longitudinal dynamics

72° before crest

Linear phase-space (s, Δp/p)

axis range: s = ±50 cm, Δp/p = ±0.3

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NuFact’11, Univ. of Geneva, Aug. 1-6, 2011
Initial distribution

\[ \frac{\varepsilon_x}{\varepsilon_y} = 4.8 \text{ mm rad} \]

\[ \varepsilon_l = \frac{\sigma_{\Delta p}}{\sigma_z} \frac{\sigma_z}{m_\mu c} = 24 \text{ mm} \]
Injection/Extraction Chicane

$L_c = 60 \text{ cm}$
$\theta_H = 9 \text{ deg.}$
$B_H = 10.2 \text{ kGauss}$

2.1 GeV
$\mu^+ \mu^-$
50 cm

0.9 GeV

$L_c = 60 \text{ cm}$
$\theta_V = 5 \text{ deg.}$
$B_V = 4.7 \text{ kGauss}$

1.5 GeV
$\mu^+ \mu^-$

Double achromat Optics

FODO lattice:
$90^0/120^0 (h/v)$
betatron phase
adv. per cell

3 cells

4 cells
Multi-pass Linac Optics – Bisected Linac

'half pass', 900-1200 MeV

initial phase adv/cell 90 deg. scaling quads with energy

1-pass, 1200-1800 MeV

mirror symmetric quads in the linac

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Multi-pass bi-sected linac Optics

Arc 1

\[ \beta_x = 3.2 \text{ m} \quad \beta_y = 6.0 \text{ m} \]
\[ \alpha_x = -1.1 \quad \alpha_y = 1.5 \]
\[ \beta_{x,y} \rightarrow \beta_{x,y} \]
\[ \alpha_{x,y} \rightarrow -\alpha_{x,y} \]

Arc 2

\[ \beta_x = 6.3 \text{ m} \quad \beta_y = 7.9 \text{ m} \]
\[ \alpha_x = -1.2 \quad \alpha_y = 1.3 \]
\[ \beta_{x,y} \rightarrow \beta_{x,y} \]
\[ \alpha_{x,y} \rightarrow -\alpha_{x,y} \]

Arc 3

\[ \beta_x = 7.9 \text{ m} \quad \beta_y = 8.7 \text{ m} \]
\[ \alpha_x = -0.8 \quad \alpha_y = 1.3 \]
\[ \beta_{x,y} \rightarrow \beta_{x,y} \]
\[ \alpha_{x,y} \rightarrow -\alpha_{x,y} \]

Arc 4

\[ \beta_x = 13.0 \text{ m} \quad \beta_y = 14.4 \text{ m} \]
\[ \alpha_x = -1.2 \quad \alpha_y = 1.5 \]
\[ \beta_{x,y} \rightarrow \beta_{x,y} \]
\[ \alpha_{x,y} \rightarrow -\alpha_{x,y} \]
Mirror-symmetric ‘Droplet’ Arc – Optics

2 cells out

transition

10 cells in

transition

2 cells out

Thomas Jefferson National Accelerator Facility

Kevin Beard

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Alternative multi-pass linac Optics

Arc 1
\(\beta_x = 3.2 \text{ m} \quad \beta_y = 6.0 \text{ m}\)
\(\alpha_x = -1.1 \quad \alpha_y = 1.5\)

Arc 2
\(\beta_x = 3.2 \text{ m} \quad \beta_y = 6.0 \text{ m}\)
\(\alpha_x = -1.1 \quad \alpha_y = 1.5\)

Arc 3
\(\beta_x = 3.2 \text{ m} \quad \beta_y = 6.0 \text{ m}\)
\(\alpha_x = -1.1 \quad \alpha_y = 1.5\)

Arc 4
\(\beta_x = 3.2 \text{ m} \quad \beta_y = 6.0 \text{ m}\)
\(\alpha_x = -1.1 \quad \alpha_y = 1.5\)

\(\beta_{x,y} \rightarrow \beta_{x,y}\)
\(\alpha_{x,y} \rightarrow -\alpha_{x,y}\)
Arcs ‘Crossing’ - Vertical Bypass

4 vertical bends:

\[ B = 1 \text{ Tesla} \]
\[ L = 10 \text{ cm} \]

4 cells (90° FODO)

\( \Delta y = 25 \text{ cm} \)
### ‘Droplet’ Arcs scaling – RLA I

<table>
<thead>
<tr>
<th>$i = 1 \ldots 4$</th>
<th>$E_i$ [GeV]</th>
<th>$p_i/p_1$</th>
<th>cell_out</th>
<th>cell_in</th>
<th>length [m]</th>
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- **Fixed dipole field:** $B_i = 10.5$ kGauss
- **Quadrupole strength scaled with momentum:** $G_i = \frac{p_i}{p_1} \times 0.4$ kGauss/cm
- **Arc circumference increases by:** $(1+1+5) \times 6$ m = 42 m

**Footprint**

- x [cm] from -5000 to 5000
- z [cm] from -5000 to 5000

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### ‘Droplet’ Arcs scaling – RLA II

**Table:**

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- Fixed dipole field: $B_i = 40.3$ kGauss
- Quadrupole strength scaled with momentum: $G_i = \frac{p_i}{p_1} 1.5$ kGauss/cm
- Arc circumference increases by: $(1+1+5) 12$ m = 84 m

**Footprint Diagram:**

- $x$ [cm]
- $z$ [cm]
- 5000
- 4000
- 3000
- 2000
- 1000
- 0
- -1000
- -2000
- -3000
- -4000
- -5000

- 0 2000 4000 6000 8000 10000
- -5000
- -4000
- -3000
- -2000
- -1000
- 0 2000 4000 6000 8000 10000

**Note:**

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## Component Count

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Two-pass Arc Layout

- Simple closing of arc geometry when using similar super cells
- 1.2 / 2.4 GeV/c arc design used as an illustration can be scaled/optimized for higher energies preserving the factor of 2 momentum ratio of the two passes

Droplet arc:
- 60° outward bend
- 300° inward bend
- 60° outward bend

C = 117.6 m

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Each arc is composed of symmetric super cells consisting of linear combined-function magnets (each bend: 2.5°)

1.2 GeV Optics

2.4 GeV Optics

θ = 60°
First few magnets of the super cell have dipole field component only, serving as Spreader/Recombiner.

* Trajectories are shown to scale

- **B** 1.7 Tesla
- **G** 28 Tesla/m
Summary

- Piece-wise end-to-end simulation with OptiM/ELEGANT (transport codes)
  - Solenoid linac
  - Injection chicane I (new more compact design)
  - RLA I + Injection chicane II + RLA II
- Alternative multi-pass linac optics
- Currently under study… GPT/G4beamline
  - End-to-end simulation with fringe fields (sol. & rf cav.)
  - Engineer individual active elements (magnets and RF cryo modules)
  - $\mu$ decay, background, energy deposition
- Strong synergy with muon collider program
Chicane - Double Achromat Optics

FODO quads:
L[cm] = 50
F: G[kG/cm] = 0.322
D: G[kG/cm] = -0.364

sextupole pair to correct vert. emittance dilution