Dynamics Design and Optimization of CiADS Muon Beamline

Muon **S**cience and **T**echnology application platform at CiADS (**MuST-CiADS**)

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Outline

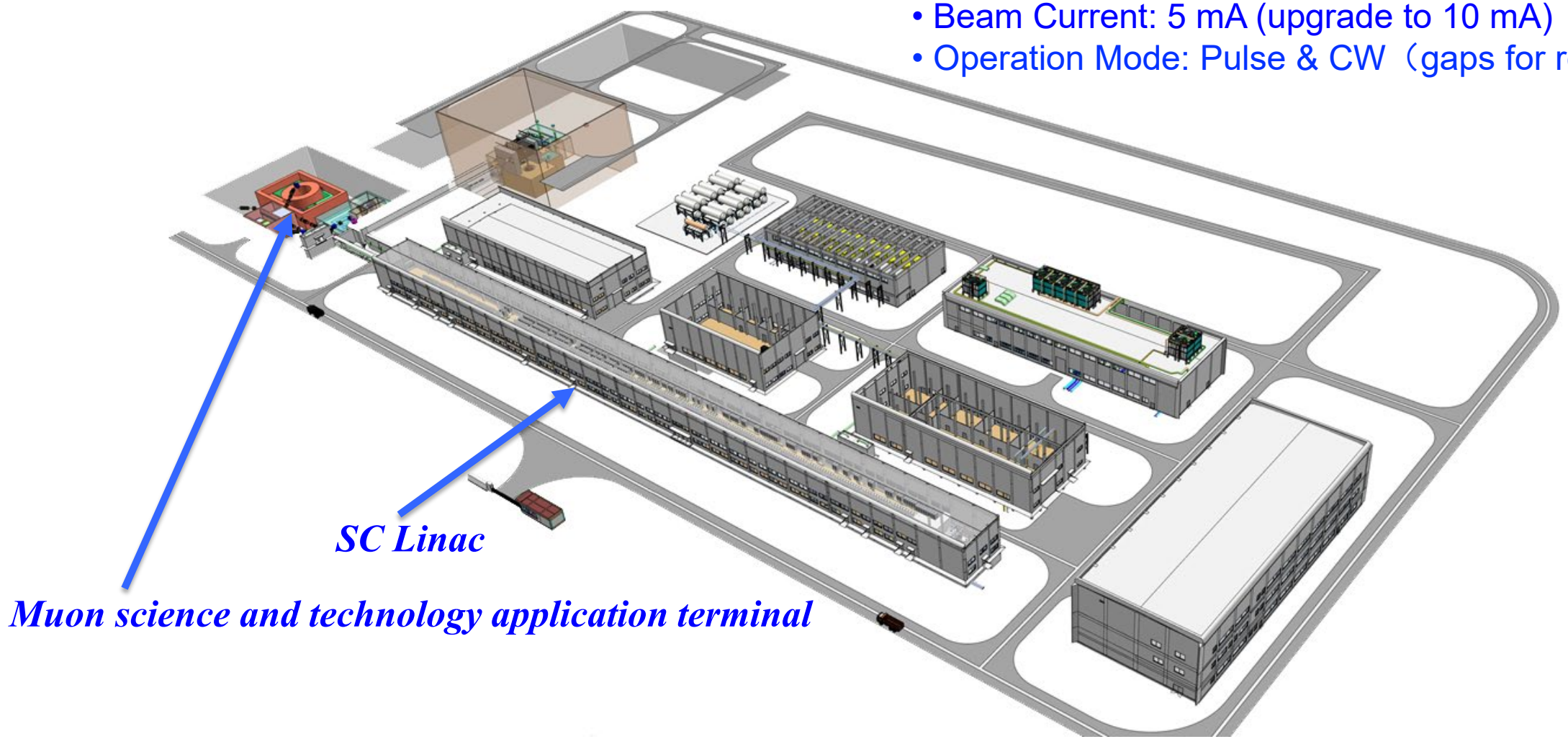
- CiADS project and design specifications
- Dynamics design and optimization of CiADS muon beamline
- Summary

CiADS Project and Design Specifications

CiADS project and design specifications

China Initiative Accelerator Driven System (CiADS)

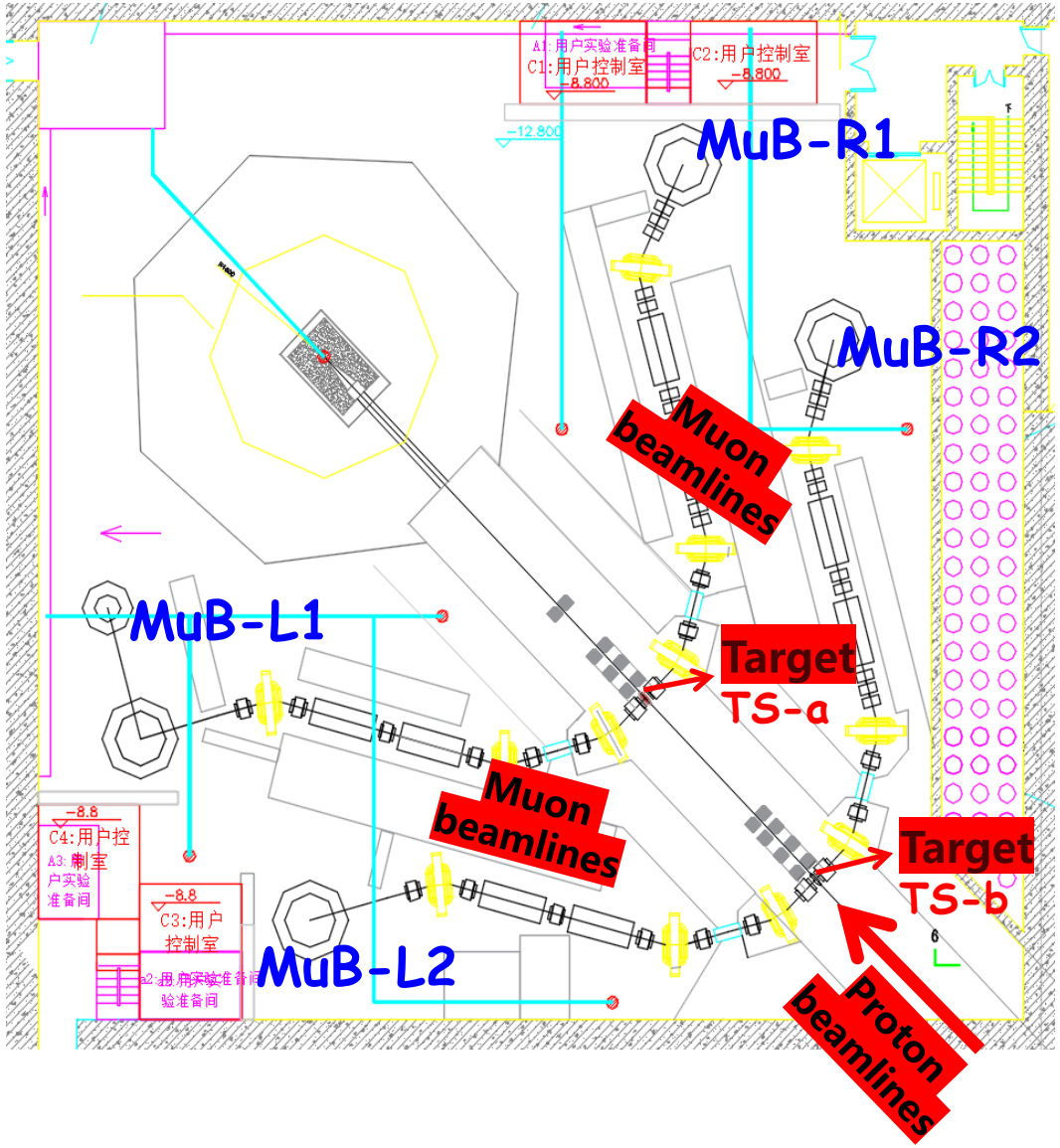
- Beam Energy: 500 MeV (upgrade to 2.0 GeV)
- Beam Current: 5 mA (upgrade to 10 mA)
- Operation Mode: Pulse & CW（gaps for reactor monitor）



Plan for CiADS muon source

- **Objective:** Chinese first continuous muon source based on a superconducting linear accelerator beam. Pushing muon intensity up to 1×10^{9} (or even 1×10^{10}) μ/s, in a long run.
- **Construction plan in two phases:**

Phase	Target	Muon type	Main applications
Phase-I 2025~2028	Target Station – a	R1: surface	μSR
		L1: surface/decay/slow	μSR/MIXE/part. phys.
Phase-II 2029~2032	Target Station – b	R2: surface	μSR
		L2: surface/decay/slow	μSR/MIXE/part. phys.

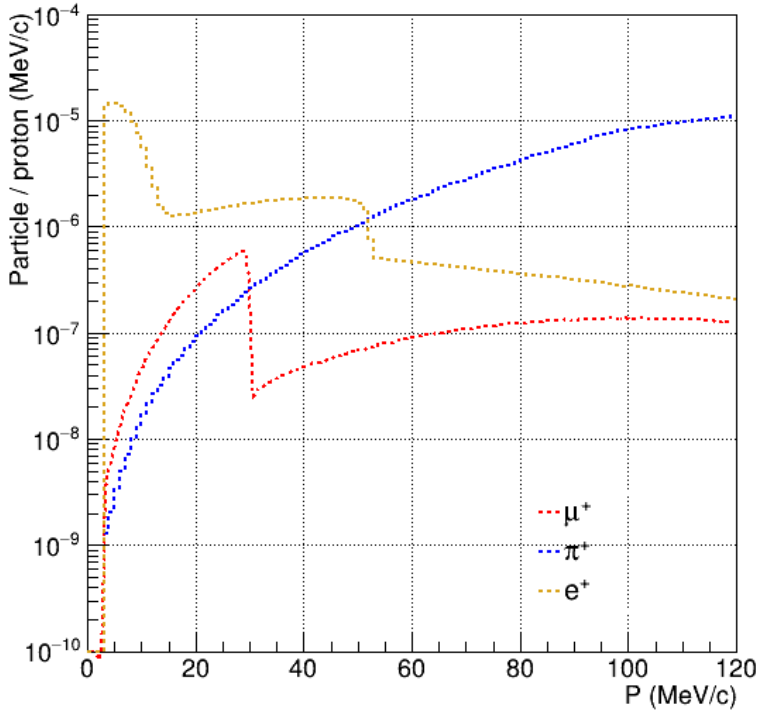


Dynamics Design and Optimization of CiADS Muon Beamline

Challenges

Muon beamline entrance transverse phase space parameters (0-30MeV/c)

Parameters	Value
Mean momentum P_0/momentum spread σ_P	23.0MeV/c / 5.3MeV/c
Horizontal position <x>/width σ_x	-9.01mm / 44.75mm
Horizontal divergence <x'>/width σ_x'	-142.9mrad / 744.8mrad
Horizontal normal rms emittance	5199.21 πmm·mrad
Vertical position <y>/width σ_y	0.02mm / 45.96mm
Vertical divergence <y'>/width σ_y'	0.54mrad / 754.04mrad
Horizontal normal rms emittance	5523.79 πmm·mrad
Mean polarizability	66.91%



Challenges

Surface Muon beamline design parameter:

- **Beam spot** $\sigma_x \sim \sigma_y \sim 30$mm
- **Muon flux** 10^9 μ/s(or even 10^{10}μ/s)
- **Polarization rate** >90%
- **Background rate** < 1%

- Improve transmission efficiency
- Reduce beam size
- Lower background rate
- Increase polarization rate

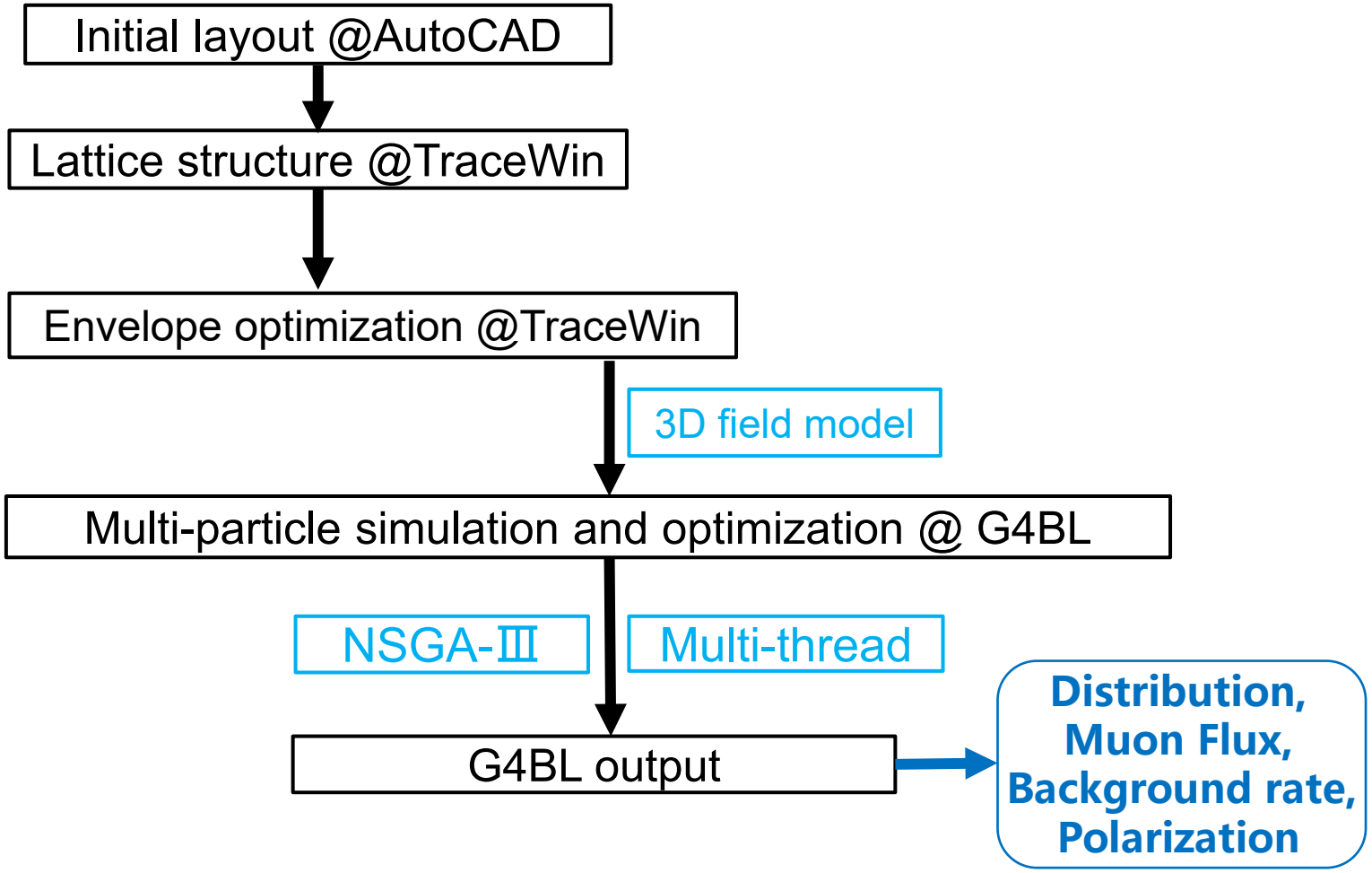
Design and optimization framework

Design methodology

- Based on muon beamline type and terminal objectives, **develop an empirical conceptual layout**
- Conduct preliminary optical design, **establish field models, and perform envelope optimization**
- Execute many-objective optimization using G4BL and **evolution algorithm (NSGA-III)**

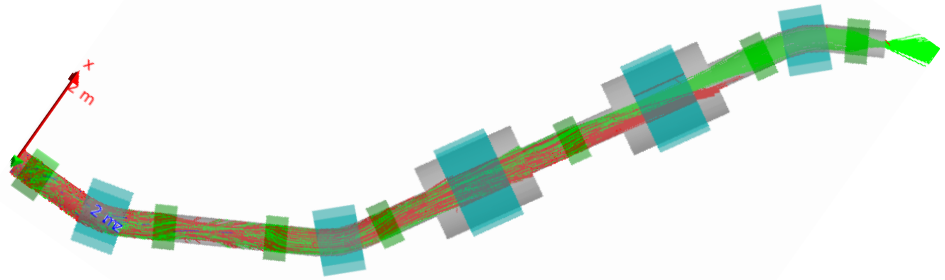
Continuous Improvements

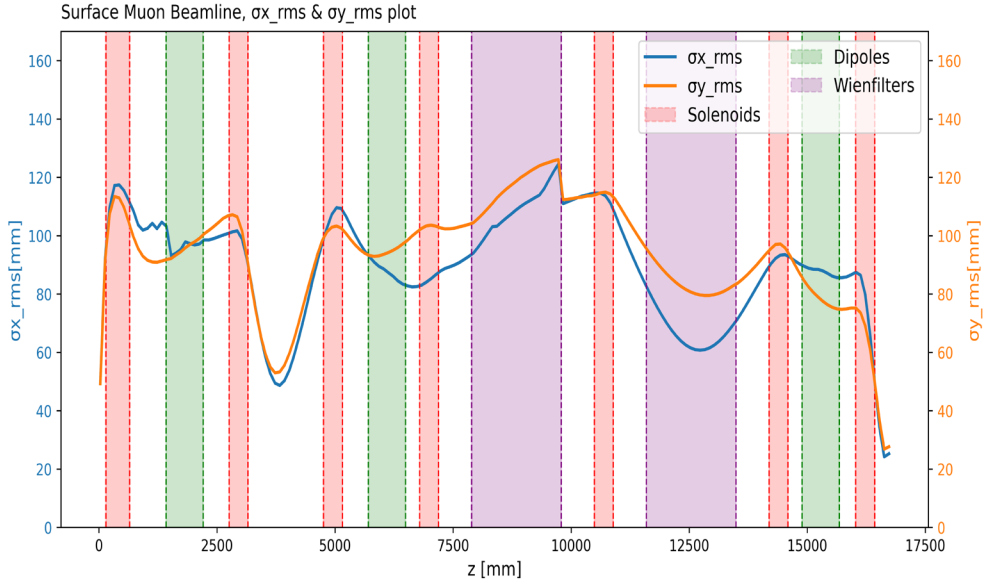
- More design flexibility
- Higher iteration efficiency

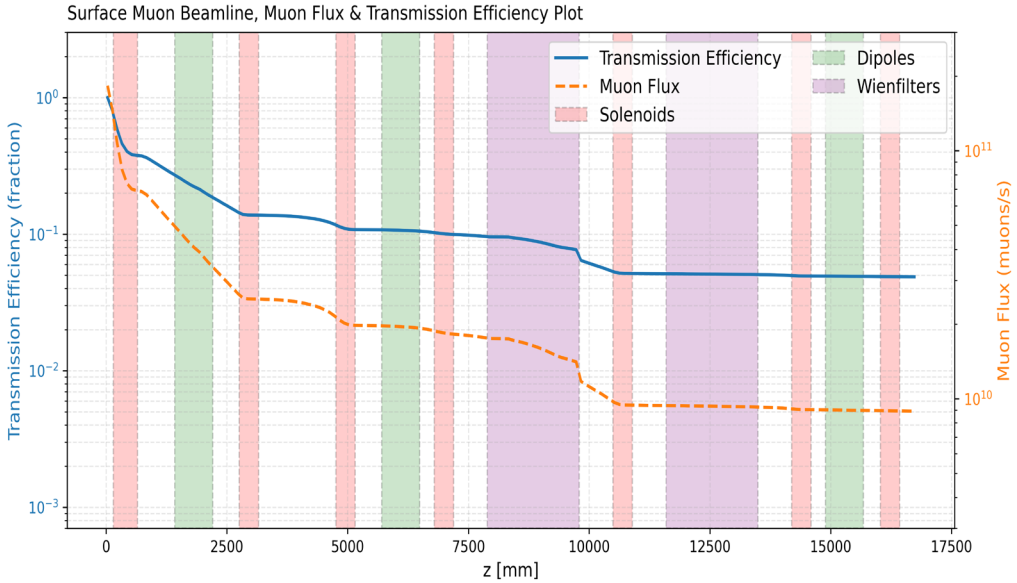


Surface Muon beamline design

- ***Muon beam type***: high-flux surface muon (<30MeV/c),
- ***Objective applications***: μSR, high-precision muon physics
- ***Beam bending***: bending magnet configuration of "+ + -"
  to balance space and shielding effectiveness
- ***Focusing***: 6 transport solenoids

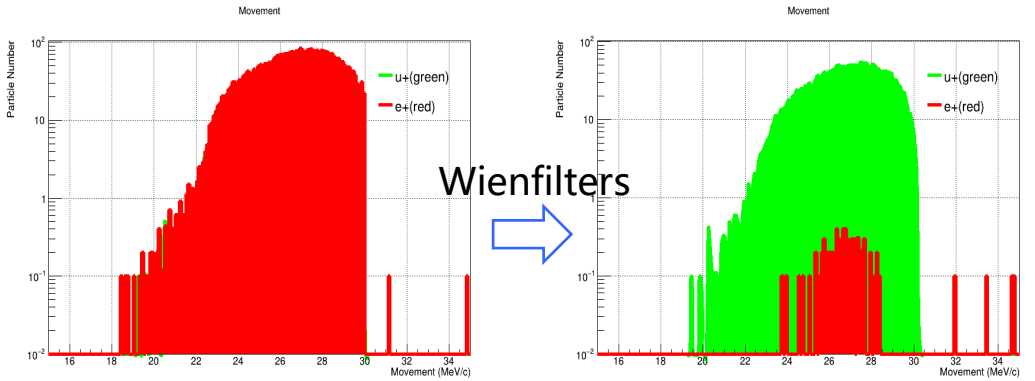


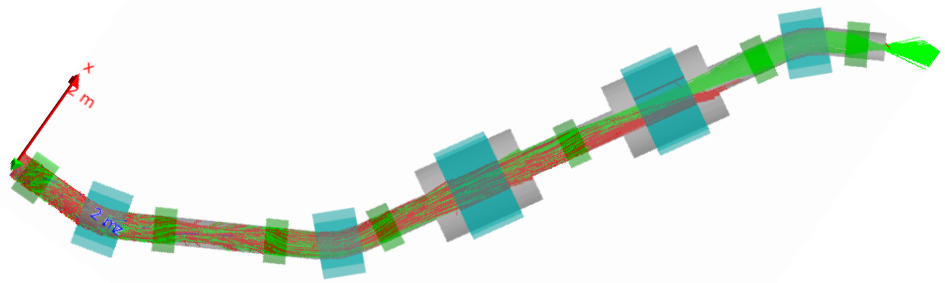




Muon beamline design

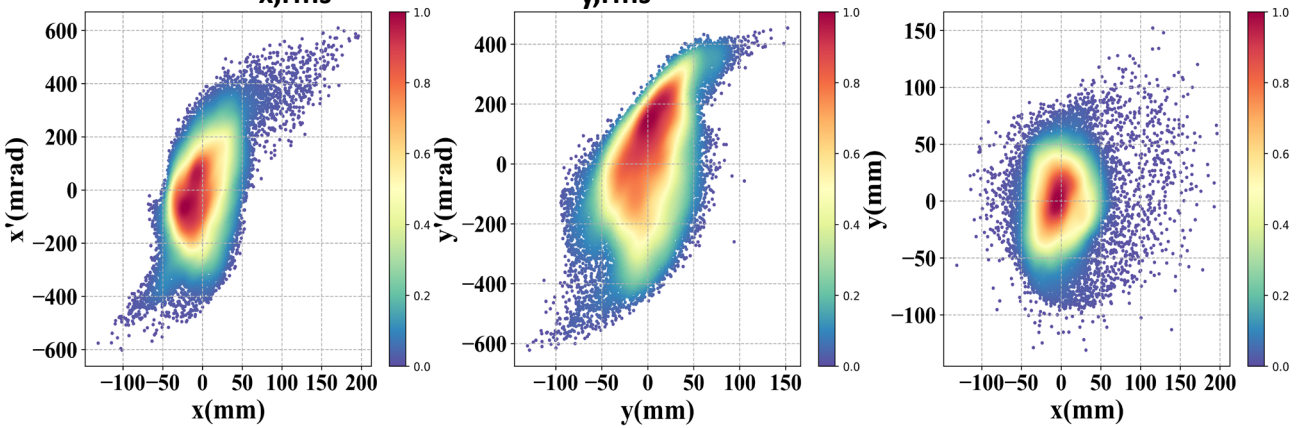
- ***Background separation***: double Wien filters, **background rate < 0.32%, Polarization ~92%(Φ100mm)**





Muon beamline exit transverse phase space distribution

(Φ500mm $\sigma_{x,rms}$=28.0mm , $\sigma_{y,rms}$=30.8mm)



Beam spot	Efficiency	Intensity (μ+/s)	Momentum (MeV/c)	Polarization rate	Background rate
Φ500mm	4.8%	8.8e9	26.7±1.8	91.1%	<1.7%
Φ100mm	3.9%	7.2e9	26.8±1.7	91.7%	<0.32%
Φ50mm	1.5%	2.8e9	26.8±1.7	91.7%	<0.03%
Φ30mm	0.64%	1.2e9	26.8±1.6	91.9%	<0.03%
Φ20mm	0.31%	5.7e8	26.8±1.6	92.3%	<0.06%
Φ10mm	0.08%	1.5e8	26.8±1.6	92.0%	<0.01%

Future plan of MUH2 beamline @ PSI:

- ~1.13x$10^{10}$$\mu^+$/s at 28 MeV/c
- Beam spot at final focus: σ_x ~σ_y ~ 45 mm

[Andreas Knecht. PSI – future plans & extensions. EXA/LEAP 2024, Vienna, Austria.]

Summary

Summary

The CiADS superconducting linear accelerator offers the potential for building a continuous muon source with advanced performances.

The optimized performance of the surface muon beamline features a background rate below 0.4%, a polarization rate above 91%, and a flux of 7.2×10^{9} muons per second within a Φ100mm area, achieved through the application of G4BL and NSGA-III algorithm.

Thanks for your attention!