BUNCH PRODUCTION FOR A MUON COLLIDER

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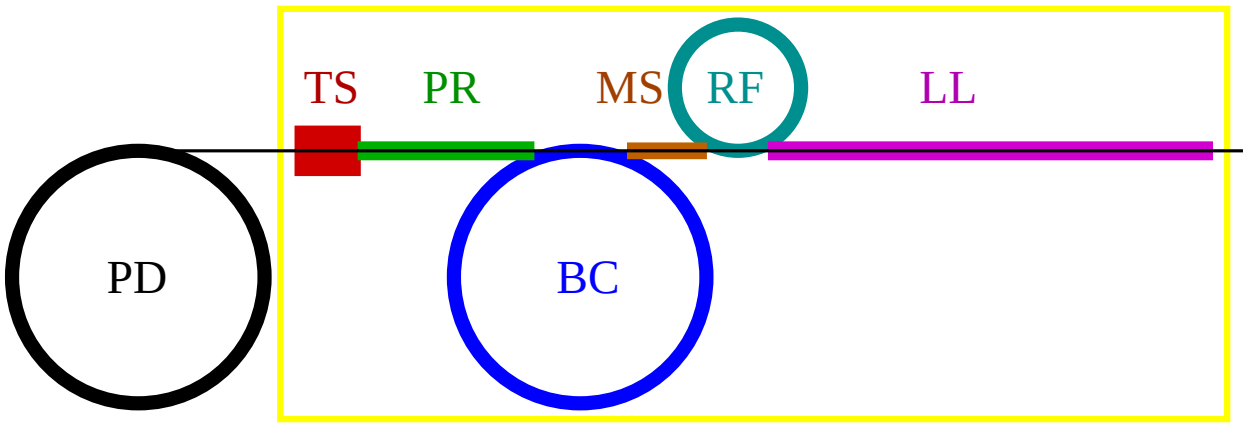
Optimal regime for a $\mu^+\mu^-$ collider

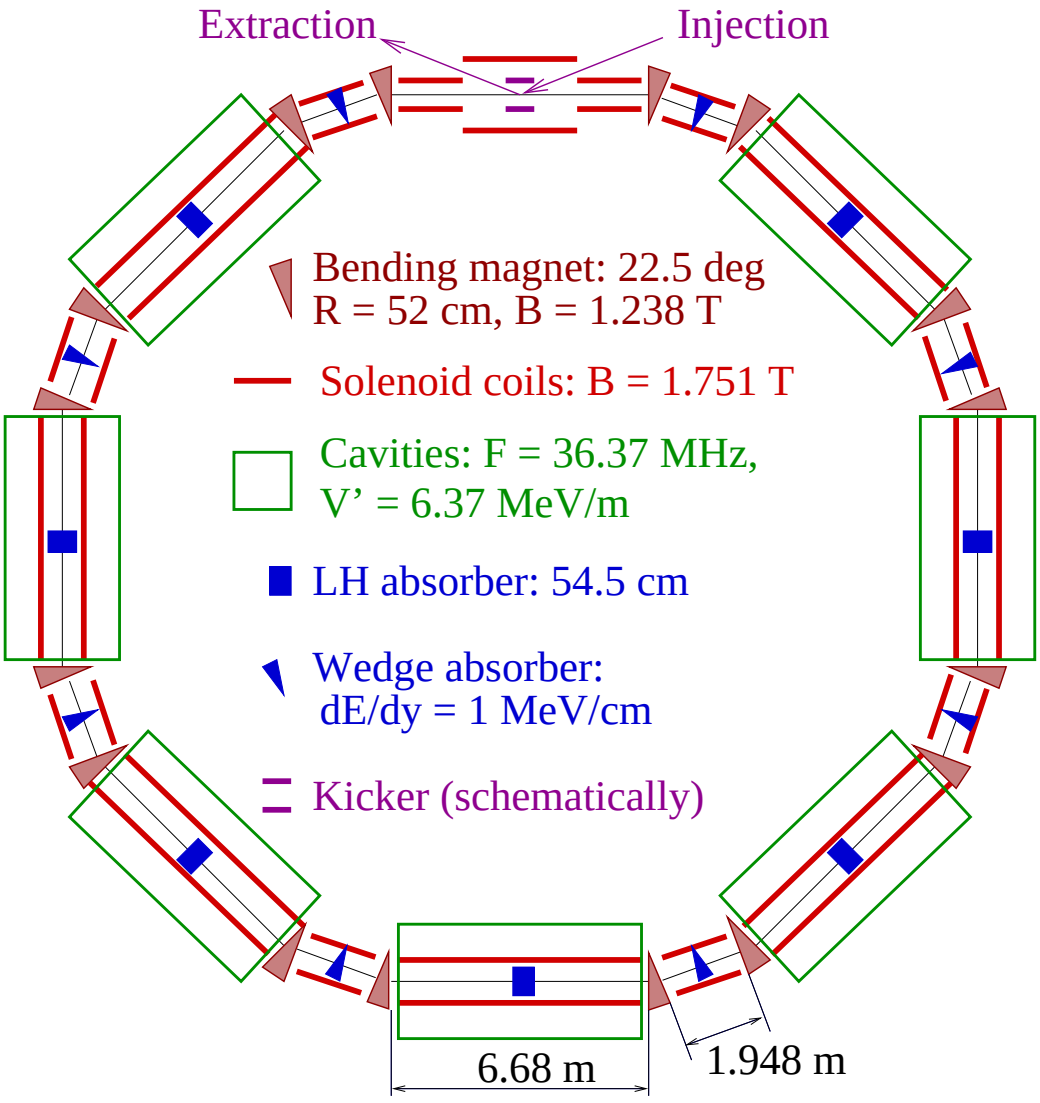
- All muons should be collected in a single bunch, because at given number of muons , luminosity is inversely proportional to the number of bunches.
- The bunch should be compressed longitudinally as fast as possible to be accepted by a high-frequency (high voltage) cooling system.
- A cooling is required at the compression because particles populate a very diffuse phase space, and initial beam length and energy spread shoud be large to capture more muons.

General Layout



- **PD** – Proton Driver: 24 GeV.
- **TS** – Target Station: mercury jet in 20 → 4.4 T solenoid.
- **PR** – Phase Rotation channel: 20 m, 4.4 → 1.75 T, 36.37 MHz, 6.37 MeV/m, + 10 m drift.
- **BC** – Bunch Compressor: ring cooler 72.3 m, 1.75 T, 36.37 MHz, 6.37 MeV/m LH_2 absorbers, LiH wedge absorbers.
- **MS** – Matching Section: 14 m, 1.75 → 3.5 T, 203.4 MHz, 7×4.8 MV cavities.
- **RF** – RFOFO ring cooler: 33 m, ± 2.74 T, 203.4 MHz, 16 MeV/m, LH_2 wedge absorbers.
- **LL** – Li Lens cooling channel: 70-90 m, $\sim$ 10 T Li lenses and solenoids, 201.25 MHz, 12-14 MV/m.

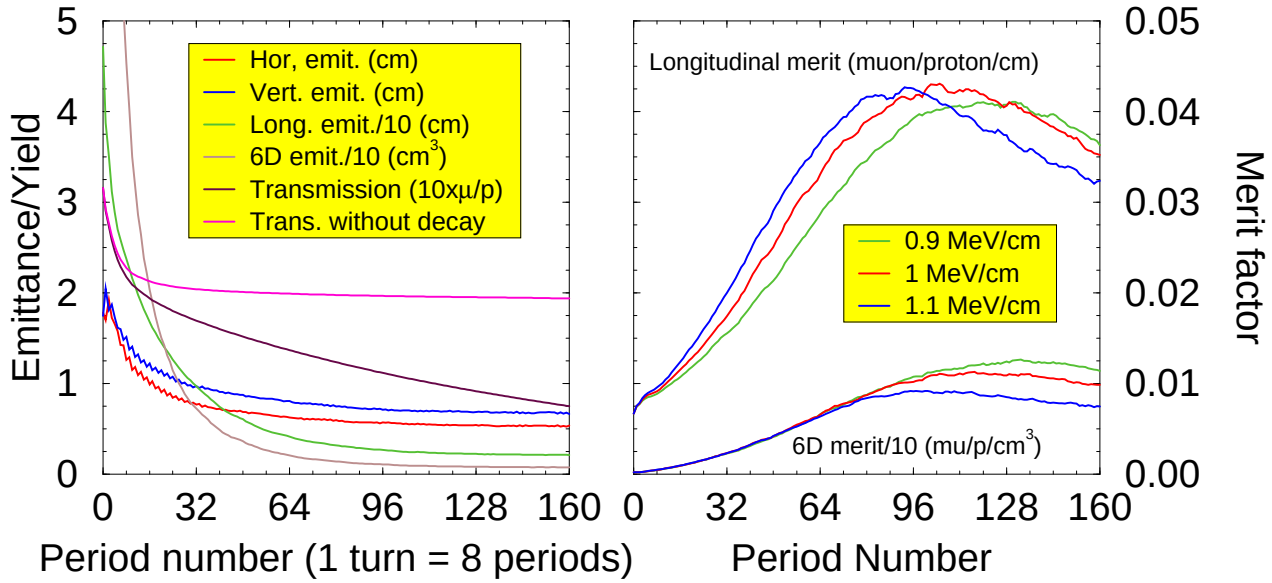
Bunch Compressor: Layout



Bunch Compressor: Parameters

Circumference	72.291 m
Nominal energy (total)	220 MeV
Bending radius	52 cm
Bending field	1.2378 T
Normalized field gradient	0.5
Length of short SS	1.948 m
Length of long SS	6.68 m
Axial field of the long solenoid	1.7506 T
Revolution frequency	3.637 MHz
Accelerating frequency	36.37 MHz
Accelerating gradient	6.37 MeV/m
Synchronous phase	30°
LH_2 main absorber, length	54.5 cm
LiH wedge absorber, dE/dy	1 MeV/cm

Beam Cooling and Compression

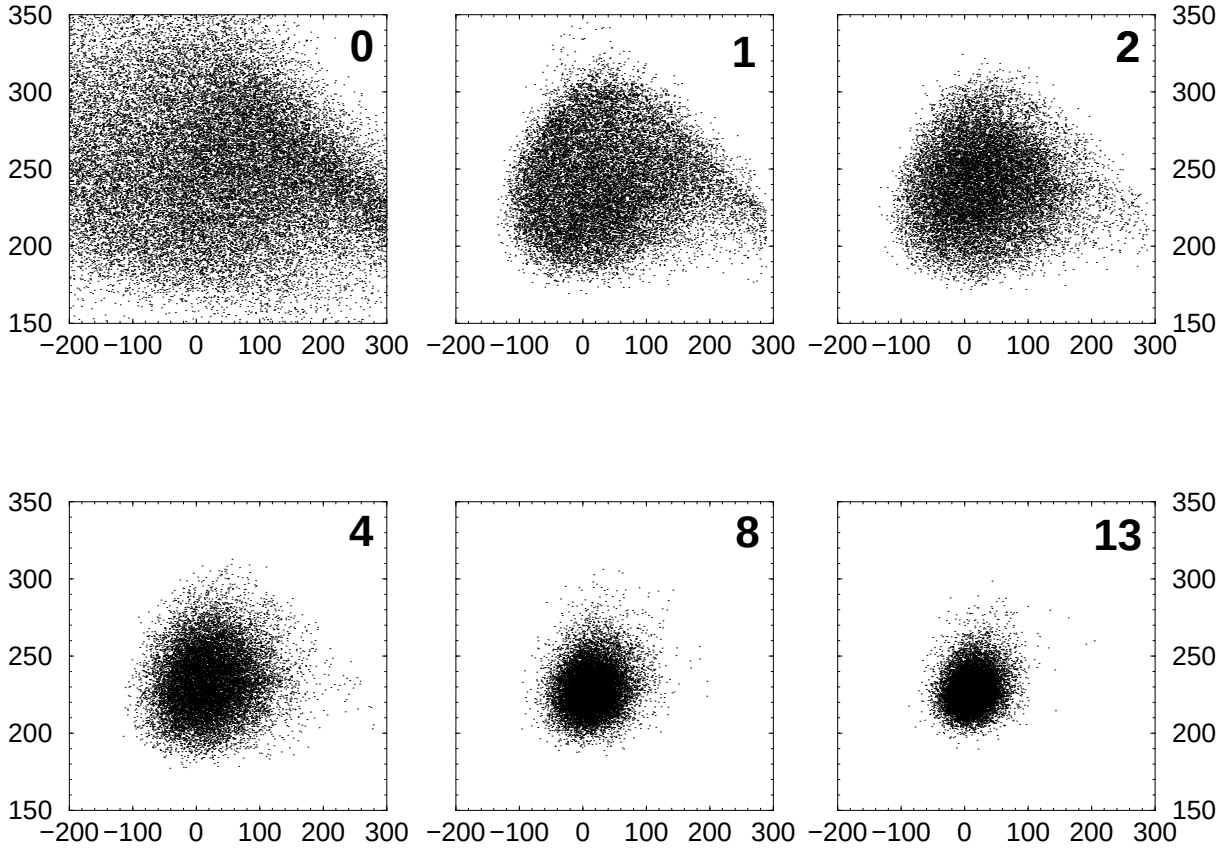


Evolution of beam parameters in the ring cooler-compressor. Left – emittances, transmission, and yield, right – merit factors.

M.F. = Yield/Emittance

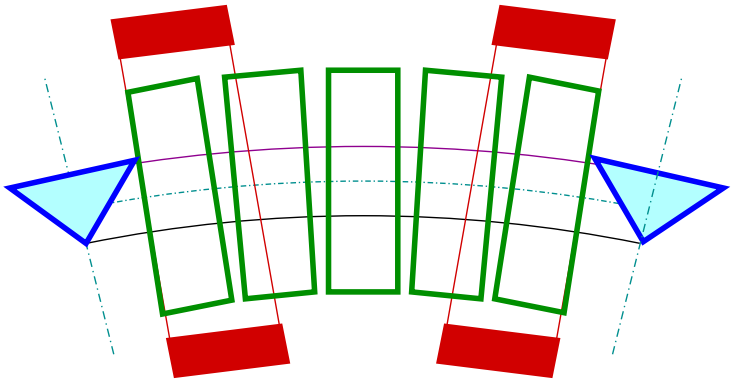
Parameter – gradient of energy loss in wedge absorber. The best results obtained after 13 turns at $dE/dy = 1$ MeV/cm.

Longitudinal Phase Space at the Compression



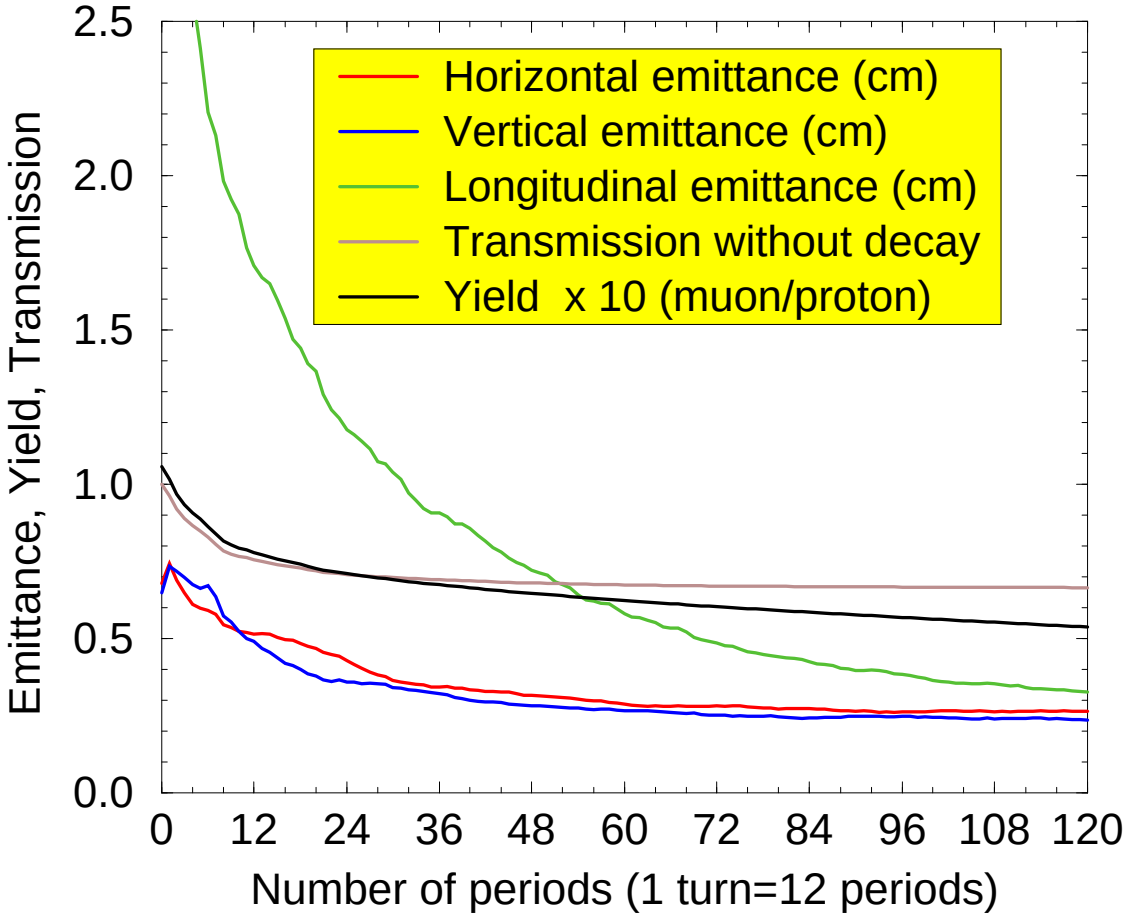
Horizontal axis – ct (cm), vertical – total energy (MeV). Number of turns is shown in each figure.

RFOFO Ring – Layout and Parameters



Inner radius of coils	77 cm
Outer radius of coils	88 cm
Coil length	50 cm
Current density	± 95.27 A/mm^2
Tilting angle of the coil	± 52 mrad
Accelerating frequency	203.4 MHz
RF harmonic number	25
Accelerating gradient	16 MeV/m
Synchronous phase	33°
Absorber thickness at the center	28.5 cm
Energy loss at the center	12.52 MeV
Gradient of energy loss dE/dy	1 MeV/cm

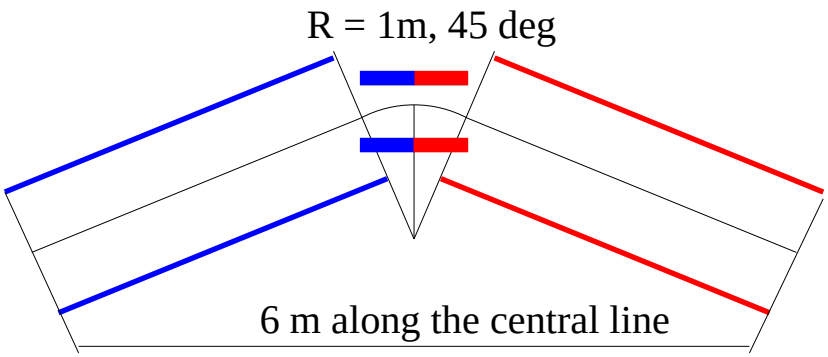
RFOFO Ring: Cooling



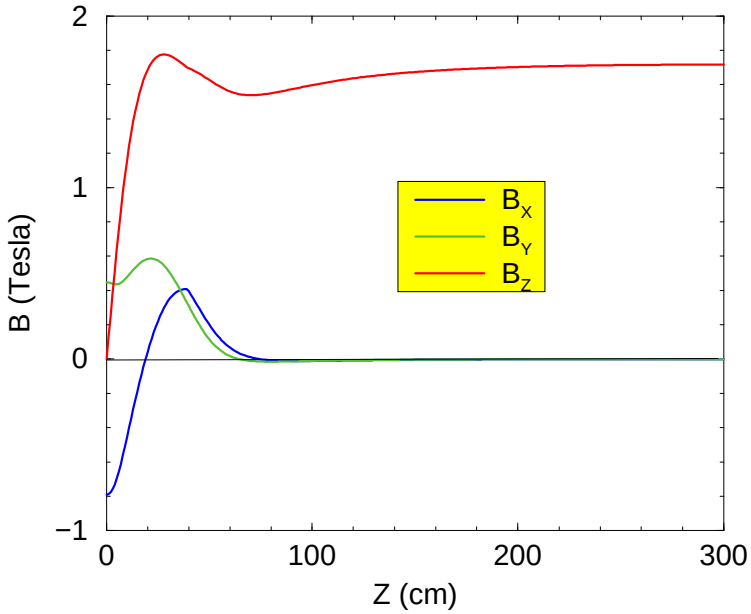
After 10 turns:

Horizontal emittance	2.6 mm
Vertical emittance	2.4 mm
Longitudinal emittance	3.2 mm
6D emittance	21 mm^3
Yield	0.054 μ/p

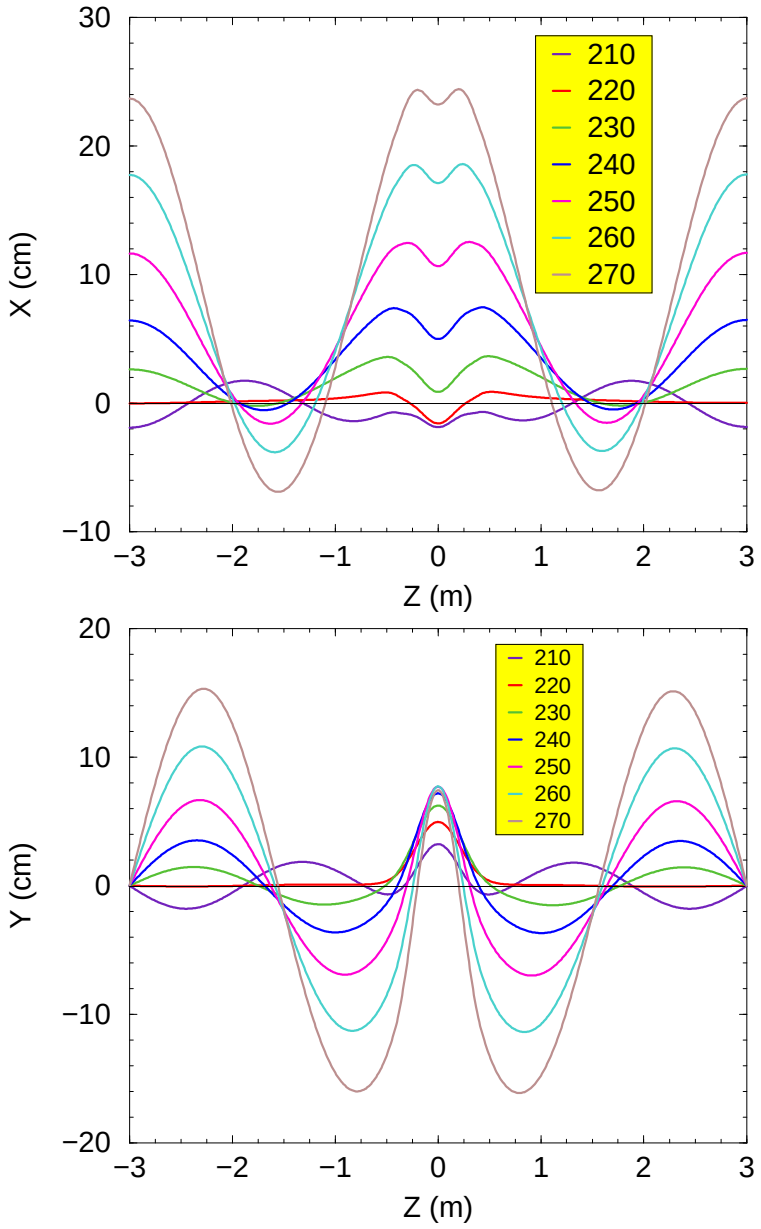
Solenoid Based Compressor



Layout of the compressor (1/2 cell = 1/8 ring, schematically). Blue/red – coils with +/– current. Small coils are tilted vertically on ±20°.

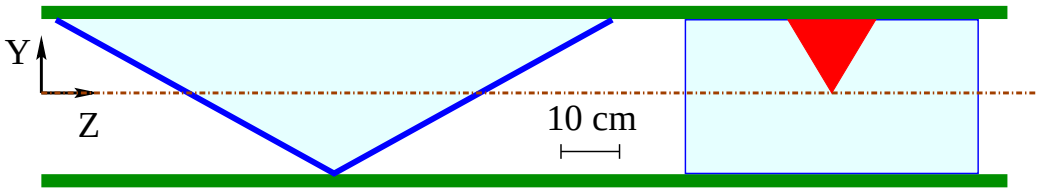


Magnetic field on the axis.



Horizontal and vertical dispersion vs longitudinal coordinate and aenergy.

Hybrid Absorber for the RFOFO Cooler



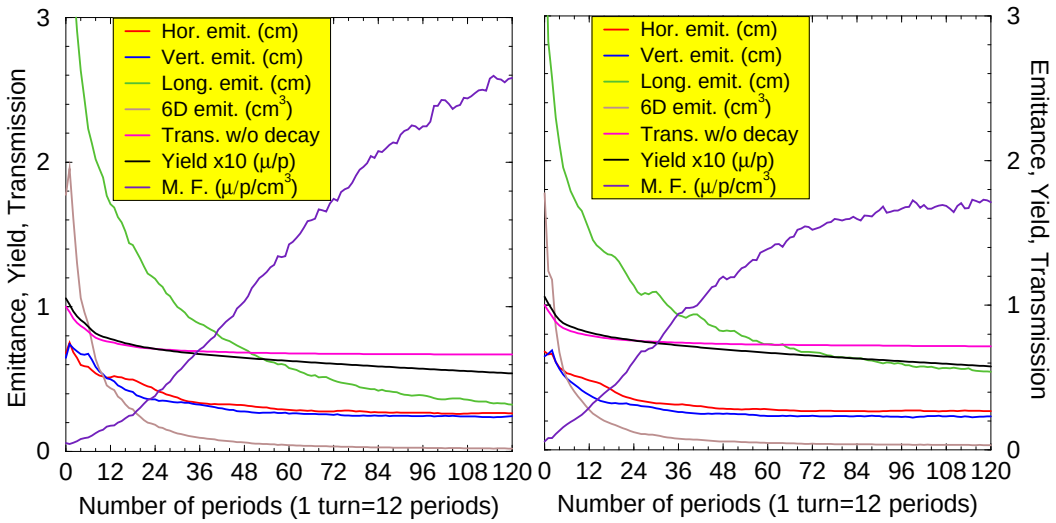
Schematic of absorbers: left – traditional, right – hybrid. Blue – liquid hydrogen, red – lithium hydride, dark blue – aluminum walls, green – beam pipe, brown dashed line – beam axis.

Basic LH_2 absorber (no Al windows)

Maximal length	96.4 cm
Length along central orbit	48.2 cm
Distance from the center to edge	12.5 cm
Angle at the edge	125°
Energy loss on central line at E = 220 MeV	15.1 MeV
Gradient of the energy loss dE/dY	1.21 MeV/cm

Basic hybrid absorber (no Al windows)

Length of the absorber	48.2 cm
Maximal length of LiH insertion	14.4 cm
Angle at the edge	60°
Energy loss on central line at E = 220 MeV	15.1 MeV
Gradient of the energy loss in LiH absorber	2.00 MeV/cm



Evolution of the beam parameters at the cooling. Left – LH_2 absorber, right – hybrid absorber (no windows).

Beam parameters in the beginning and after 10 turns

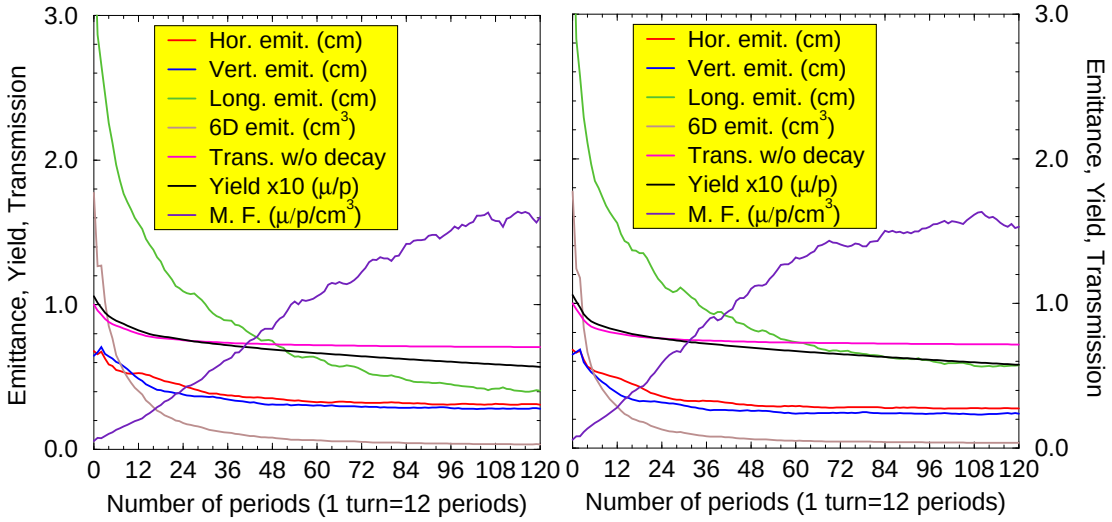
Parameter	Beg.*	LH_2	Hybrid
Horizontal emittance (cm)	.633	.265	.270
Vertical emittance (cm)	.613	.244	.232
Longitudinal emittance (cm)	2.50	.324	.541
6D emittance (cm^3)	.968	.0209	.0337
Transmission w/o decay	1	.671	.716
Yield (muon/proton)	.107	.0540	.0578
6D merit factor (cm^{-3})	.105	2.58	1.71

(*) window -25 cm $< ct <$ 50 cm

Effect of Aluminum Windows (R = 10 cm)

Beam parameters after 10 turns

Absorber	LH_2	LH_2	LH_2	Hyb.	Hyb.	Hyb.
Al window (mm)	0	0.25	0.5	0	0.1	0.22
Hor. emit. (cm)	.265	.310	.356	.270	.276	.286
Vert. emit. (cm)	.244	.282	.324	.232	.239	.247
Long. emit. (cm)	.324	.407	.516	.541	.573	.585
6D emit. (cm^3)	.0209	.0356	.0595	.0337	.0377	.0413
Trans. w/o decay	.671	.708	.688	.716	.717	.712
Yield (μ/p)	.0540	.0572	.0555	.0578	.0576	.0574
6D MF (cm^{-3})	2.58	1.61	.934	1.71	1.53	1.39



Evolution of the beam parameters at the cooling. Left – LH_2 absorber with 0.25 mm Al window, right – hybrid absorber with 0.1 mm Al window.

Summary

- Single muon bunch containing about 0.058 muons per incident proton can be obtaine d.
- Its transverse/longitudinal emittance is about 0.25/0.55 mm after compression and cooling in RFOFO ring.
- Muon yield is strongly restricted by decay at the bunch compression. Higher accelerating gradient is desirable to overcome it (H_2 gas?).
- Hybrid absorber with flat Al windows of thickness 0.1 mm can be used in the RFOFO ring. providing about the same performances as triangular LH_2 absorber with 0.25 mm windows.
- Problem of bending magnet for the bunch compressor is nor solved yet.