MUON COLLIDER SIMULATION

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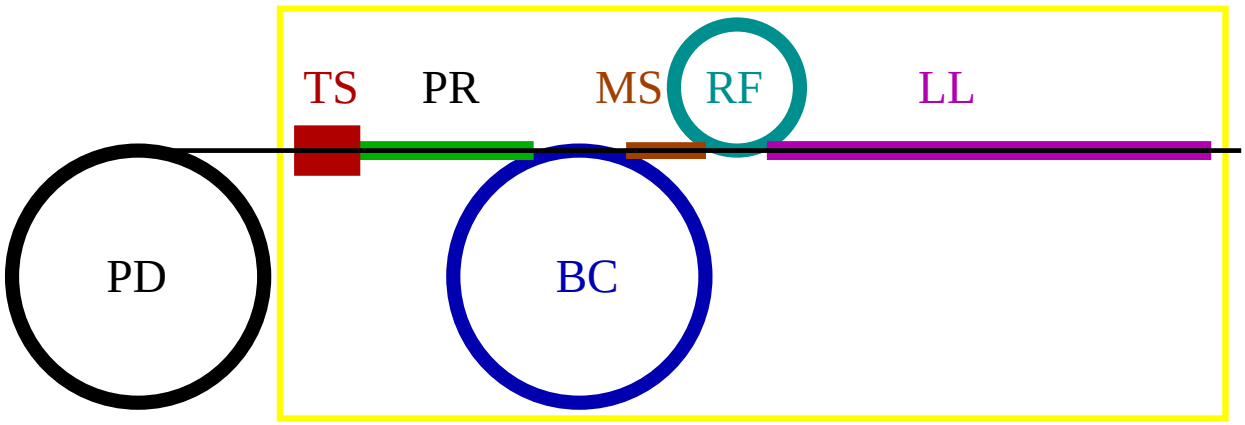
Optimal regime for a $\mu^+\mu^-$ collider

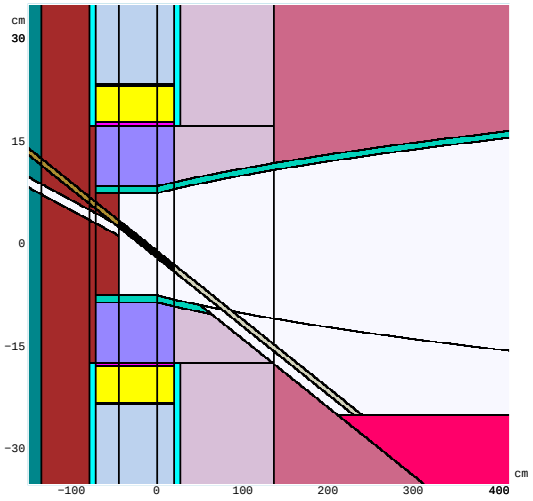
- All muons should be collected in a single bunch, because at given number of muons, luminosity is inversely proportional to the number of bunches.
- The bunch should be compressed longitudinally as fast as possible to be accepted by a high-frequency (high voltage) cooling system.
- A cooling is required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

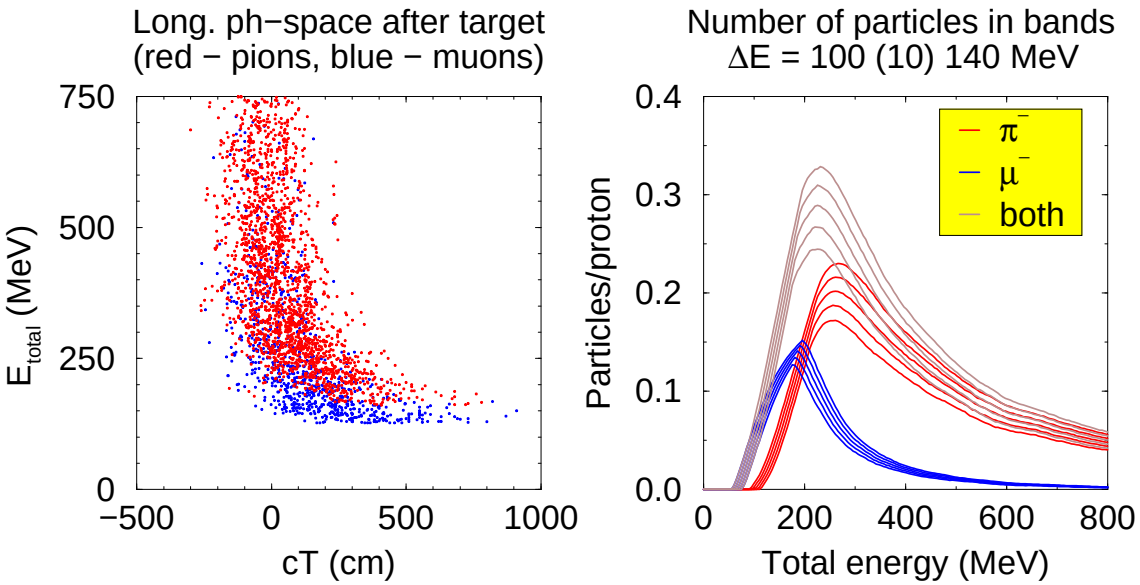
Bunch Production System



- **PD** – Proton Driver: 24 GeV.
- **TS** – Target Station:
  mercury jet in 20 $\rightarrow$ 4.4 T solenoid.
- **PR** – Phase Rotation channel:
  20 m, 4.4 $\rightarrow$ 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 $\rightarrow$ 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:
  92 m, $\sim$ 10 T Li lenses and solenoids, 201.25 MHz, 12-14 MV/m.

Target Station (N.Mokhov)





Conclusion: Phase rotation channel should be tuned on $p \simeq 200$ MeV/c.

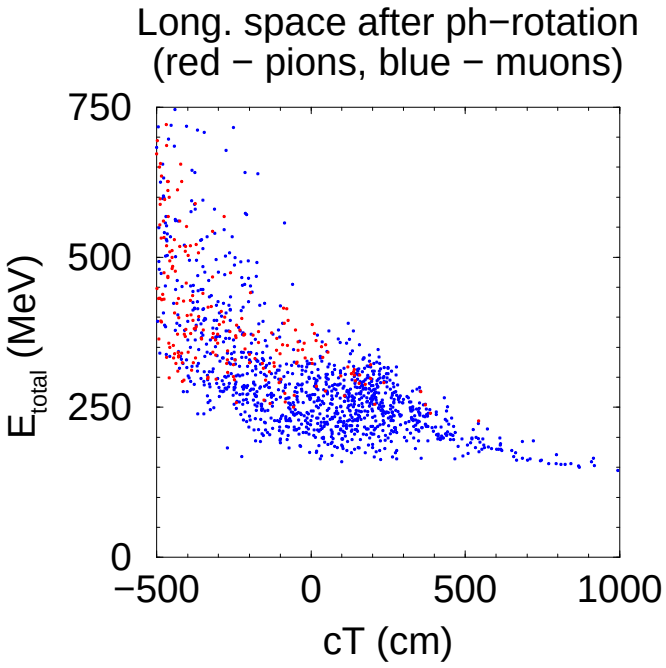
Phase Rotation - Decay Channel

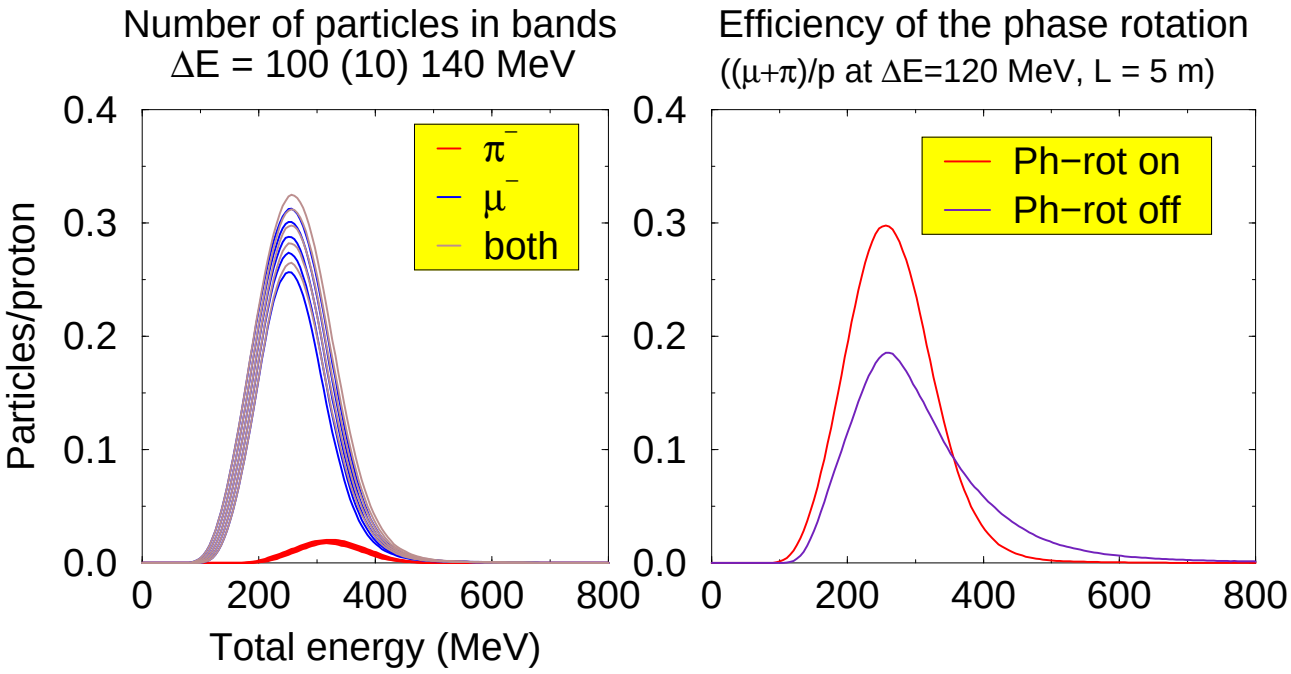
- It is reasonable to use the same RF both for phase rotation and bunch compression.
- Possible frequencies are $f = 3.637 \times h$ MHz:
  - ... 29.10, 32.74, 36.37, 40.01, 43.65 ...
- Presumed accelerating gradient

$$V' = 2\sqrt{n} \text{ MV/m}.$$

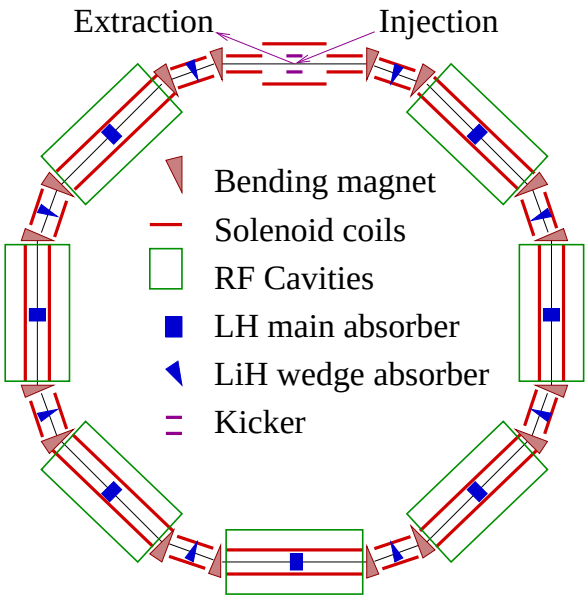
- Optimal frequency is 36.37 MHz ($h = 10$) $V' = 6.37$ MV/m.
- Lower frequency: more capture – slower cooling – more decay.
- Higher frequency: less capture – faster cooling – less decay.
- Channel: 20 m RF + 10 m drift = 30 m.
- Solenoid: $4.4 \rightarrow 1.75$ T on first 5 m.

Beam at the Phase Rotation

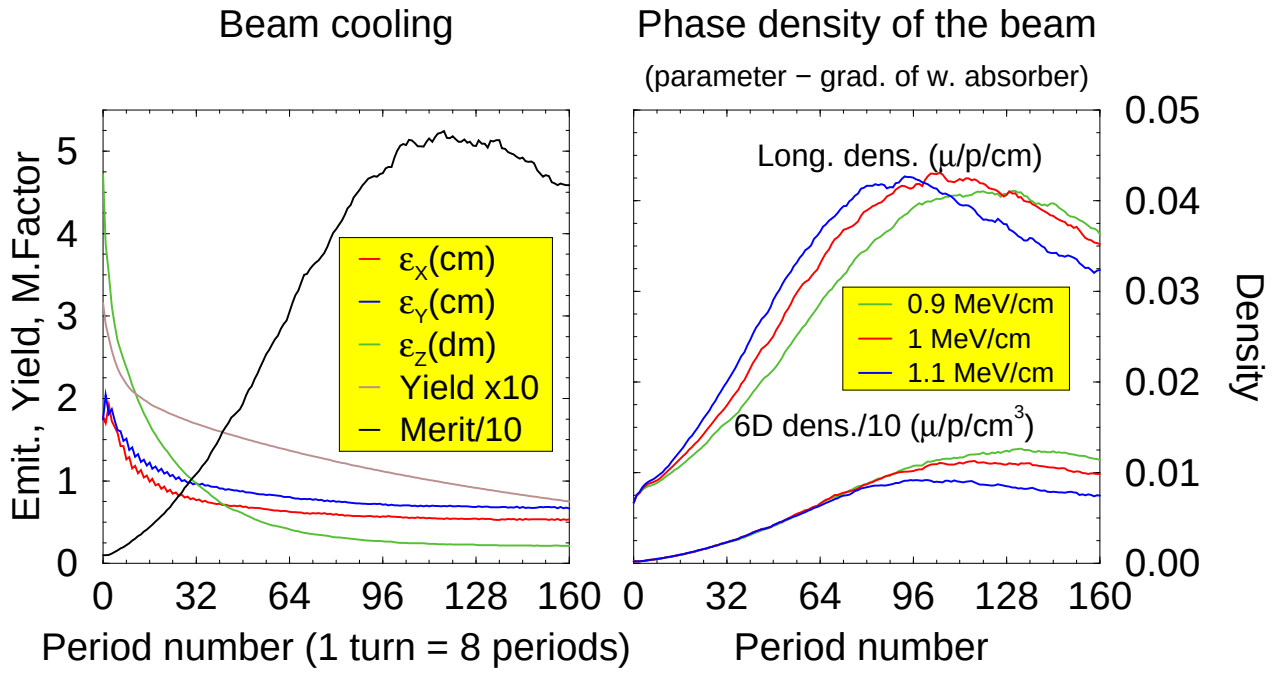




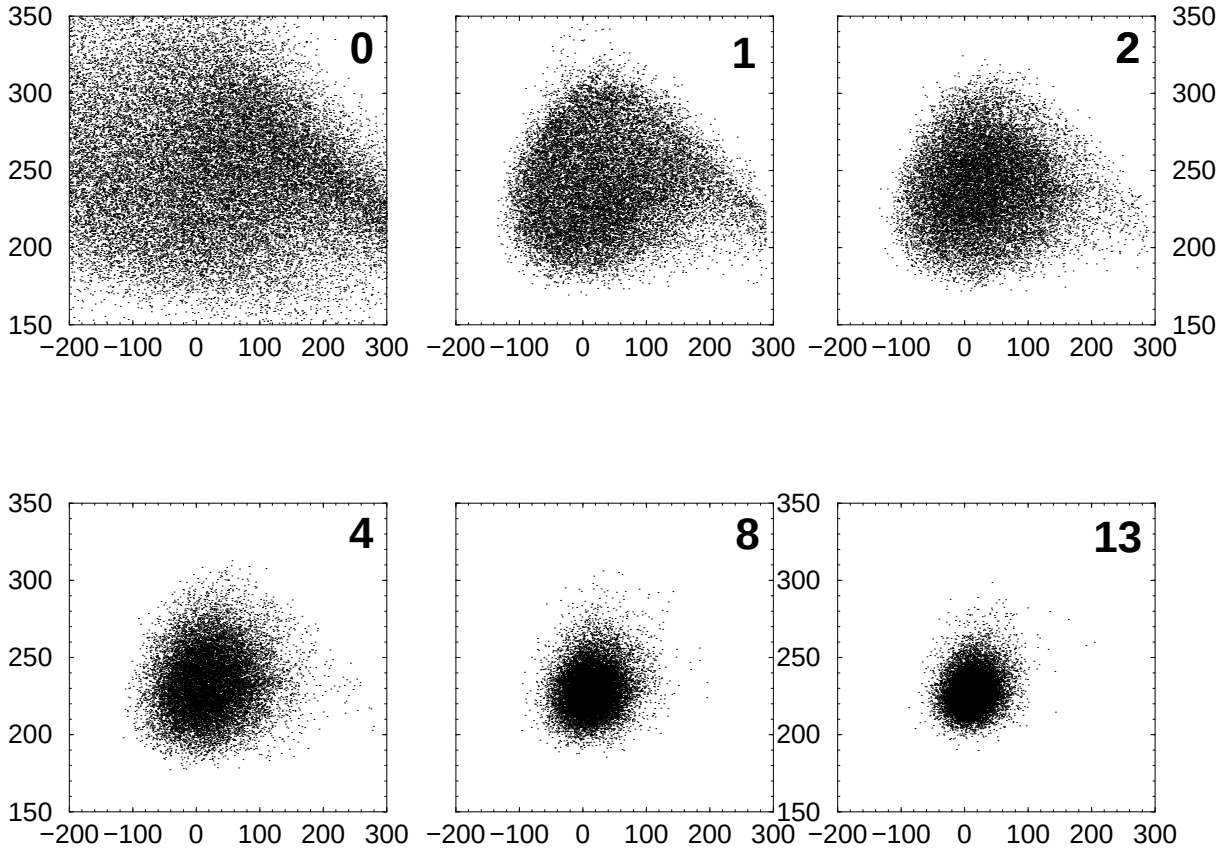
Bunch Compressor



Nominal energy	220 MeV
Circumference	72.291 m
Bending radius	52 cm
Bending field	1.238 T
Normalized field gradient	0.5
Length of short SS	1.948 m
Length of long SS	6.68 m
Short solenoid max field	2.35 T
Long solenoid field	1.75 T
Revolution frequency	3.637 MHz
Accelerating frequency	36.37 MHz
Accelerating gradient	6.4 MeV/m
Synchronous phase	30 deg
LH main absorber, length	54.5 cm
LiH wedge absorber, dE/dy	1 MeV/m



Long. Phase Space at Compression

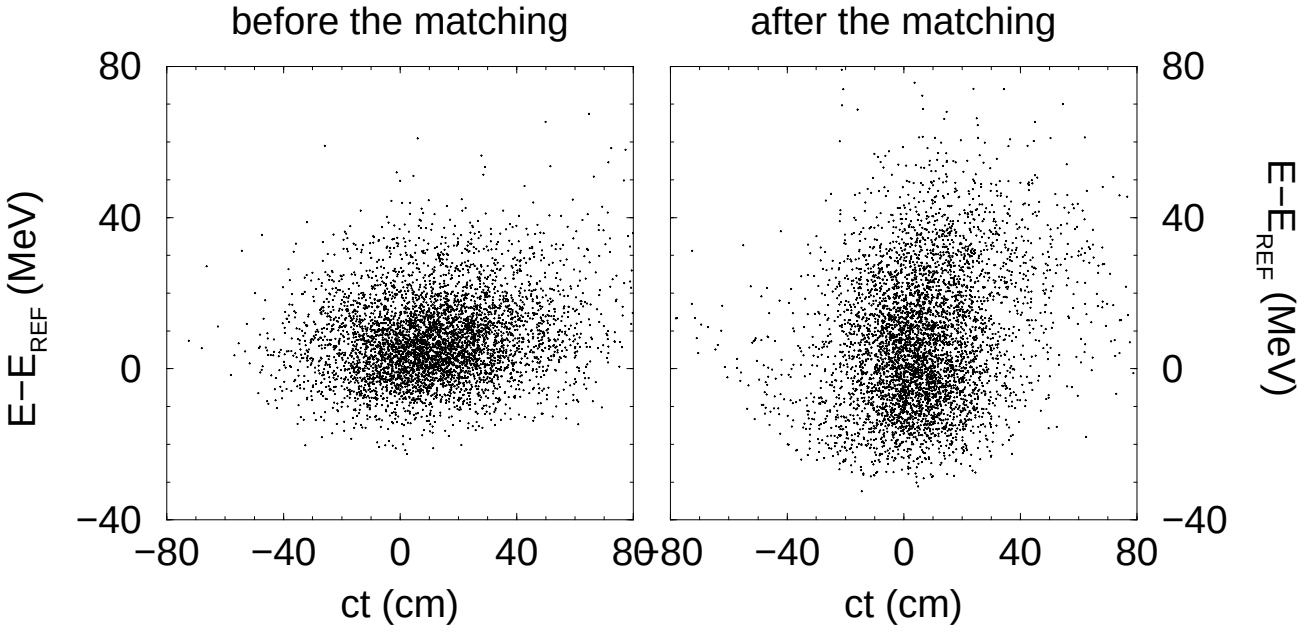


Horizontal axis – ct (cm), vertical – total energy (MeV). Number of turns is shown in each figure.

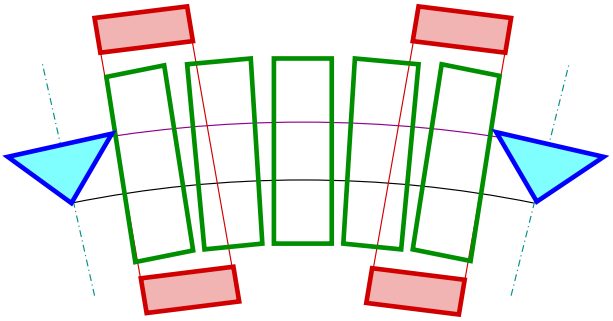
Matching Section

- The matching is required first of all because FR changes from 36.37 to 203.4 MHz.
- Axial magnetic field should increase from 1.75 to 3.5 T.
- 14 m long matching section contains 7 cavities 203.4 MHz, 4.8 MV.
- Magnetic field increases linearly.

Longitudinal phase space

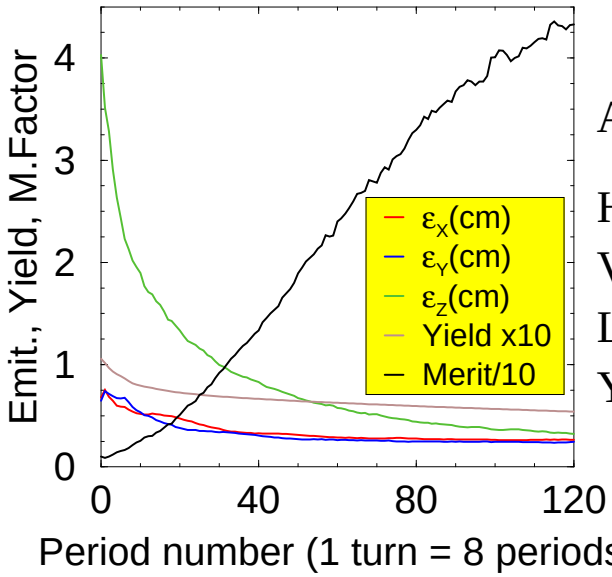


RFOFO Ring Cooler



Coil radius	77/88 cm
Coil length	50 cm
Coil tilting	52 mrad
Current density	95.27 A/mm2
Ac. frequency	203.4 MHz
Ac. gradient	16 MeV/m
Synch. phase	33 deg
Absorber (LH)	12.5 MeV, 1 MeV/cm

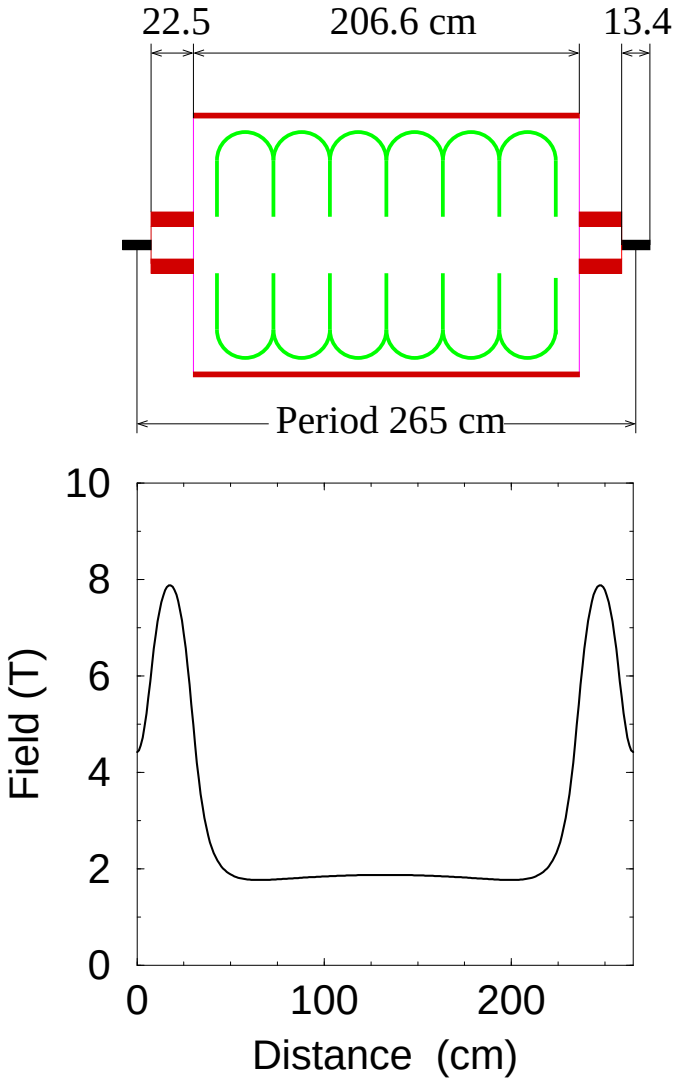
Beam parameters at cooling



After 10 turns:

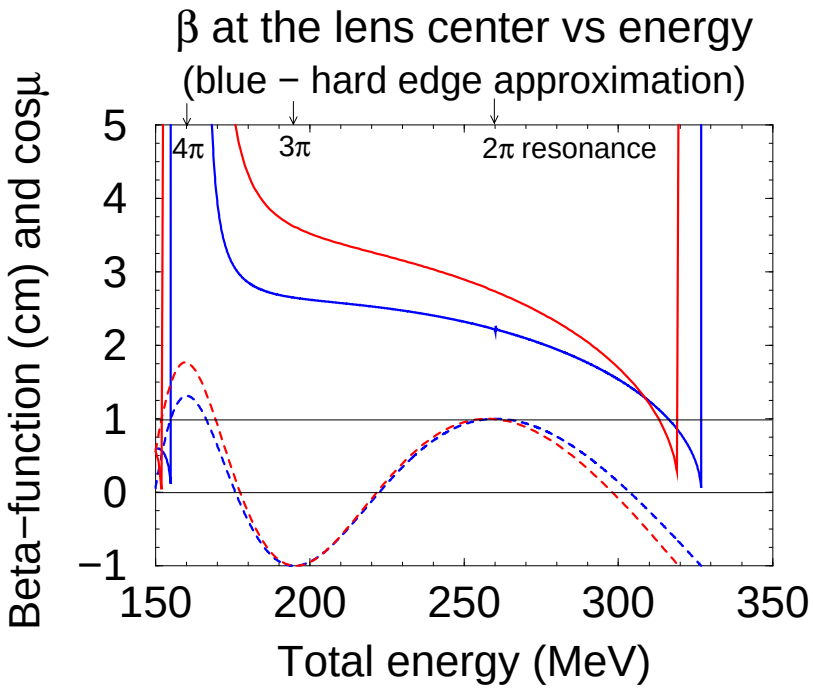
Hor. emit. 2.6 mm
Vert. emit. 2.4 mm
Long. emit. 3.2 mm
Yield 0.054 mu/p

Lithium Lens Cooler

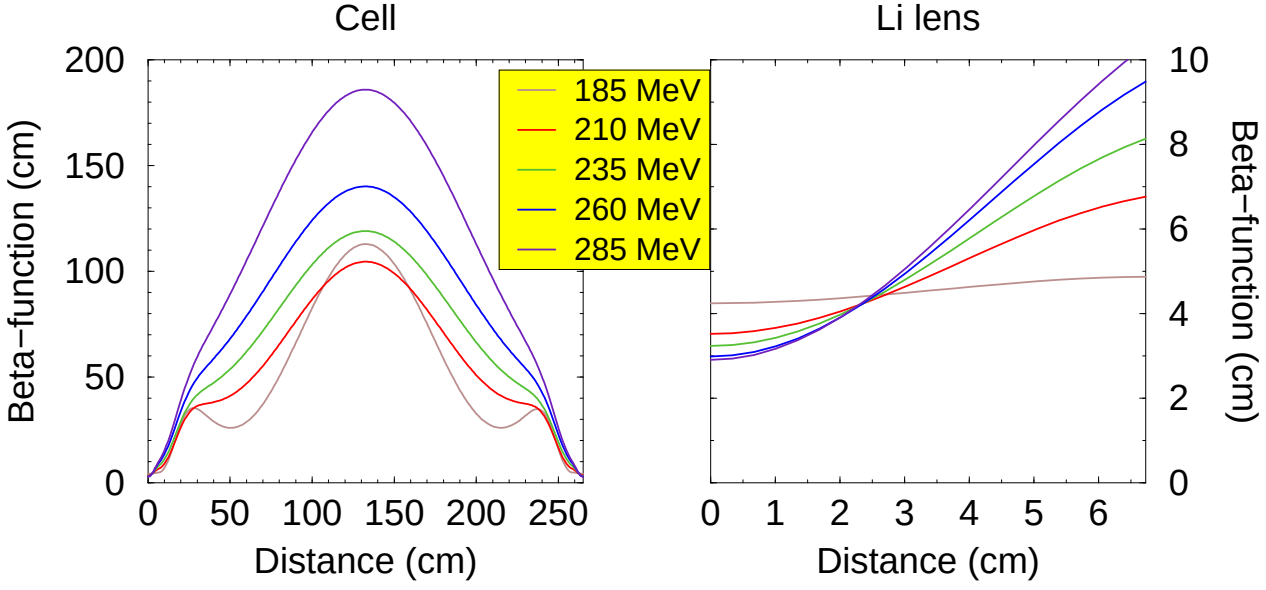


Element	Length (cm)	Radii (cm)	J (A/mm^2)
Li lens	13.45	0/3	355.0
High-field coil	22.45	6/14	84.62
Low-field coil	206.66	69/71	81.69

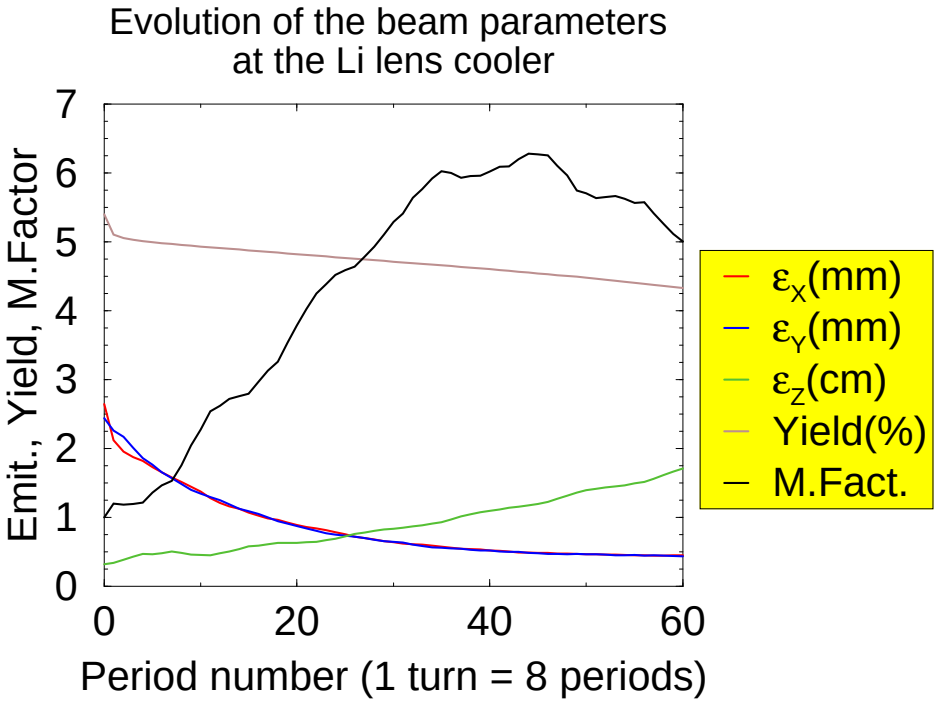
Li Lens Cooler: Beta-function



β-function *vs* z



Li Lens Cooler: Simulation



After 35 cells:

Trans. emittance (mm)	0.56
Long. emittance (mm)	9.3
Yield (muon/proton)	0.047

Conclusion

- Single muon bunch containing about 0.05 muons per incident proton can be obtained by means of described system.
- Its transverse emittance is about 0.6 mm what is still large for a muon collider.
- More transverse cooing is difficult because of longitudinal heating in the Li lens channel.
- Another serious restriction is high field matching solenoid. Longer Li lenses should be applied to use their ends with less gradient for the matching.

General Performances