DESIGN AND SIMULATION OF A HIGH FIELD COOLING CHANNEL

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BROOKHAVEN NATIONAL LABORATORY

Muon Accelerator Program

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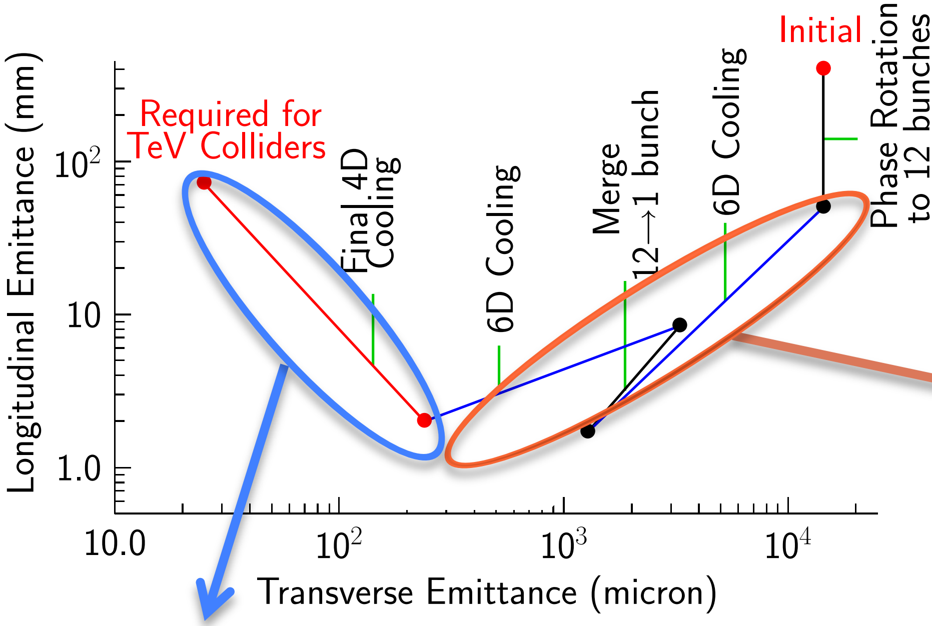
Layout & introduction

- Muon Collider cooling concept
- Final cooling starting point and goals
- High field cooling channel concept
- High field cooling channel design
- Simulation results for 40 – 30 – 25 T cooling channels
- Conclusion + to do list

MUON COLLIDER COOLING CONCEPT



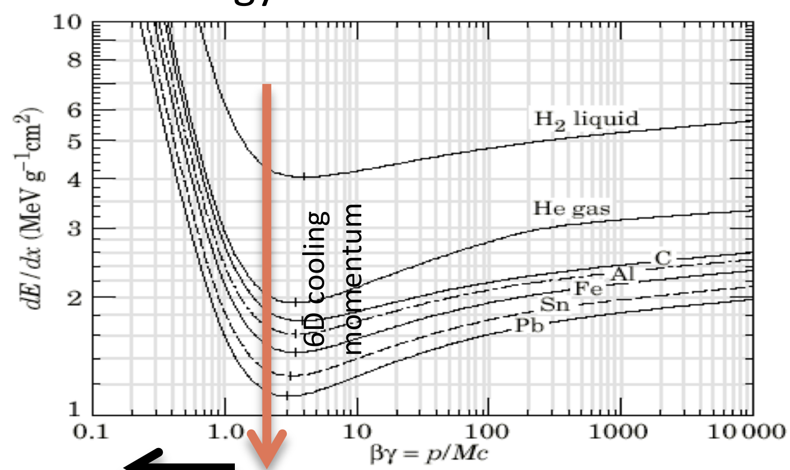
- Muon production
- Muon Capture
- Bunching into 12 microbunches
- Energy phase rotation of microbunches to a common central energy

6D cooling Channels:
Target : ε_T = 300 μm ε_L = 1.5 mm

- **High field cooling Channel (40 T solenoids)**
- **Target : ε_T = 25 μm ε_L = 72 mm**

New regiem:
High field + Low energy

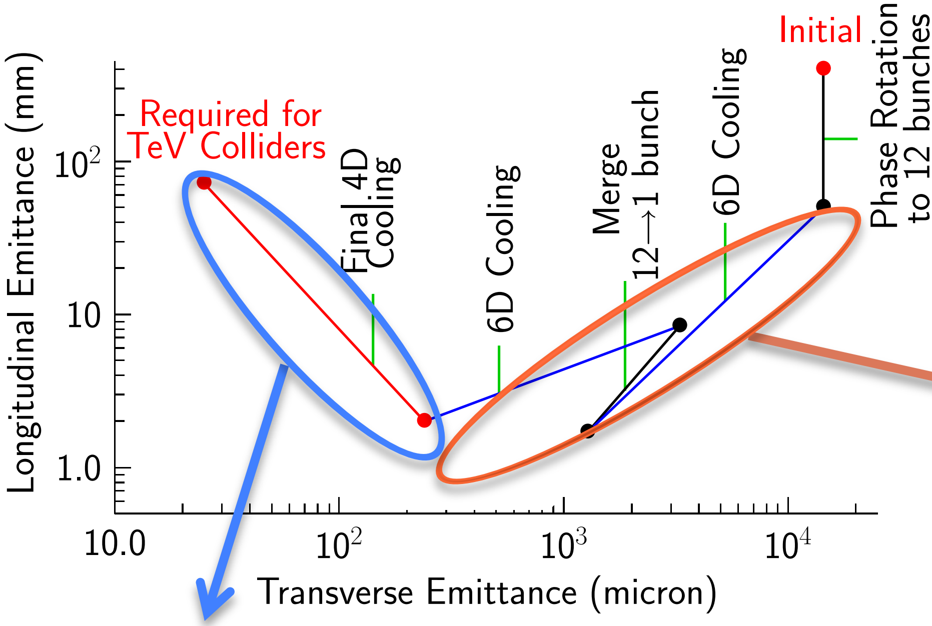
Energy loss in low z material



Final cooling

$$\epsilon_{equ,N} = \frac{\beta_\perp E_s^2}{2\beta mc^2 L_R (dE/ds)}$$

MUON COLLIDER COOLING CONCEPT



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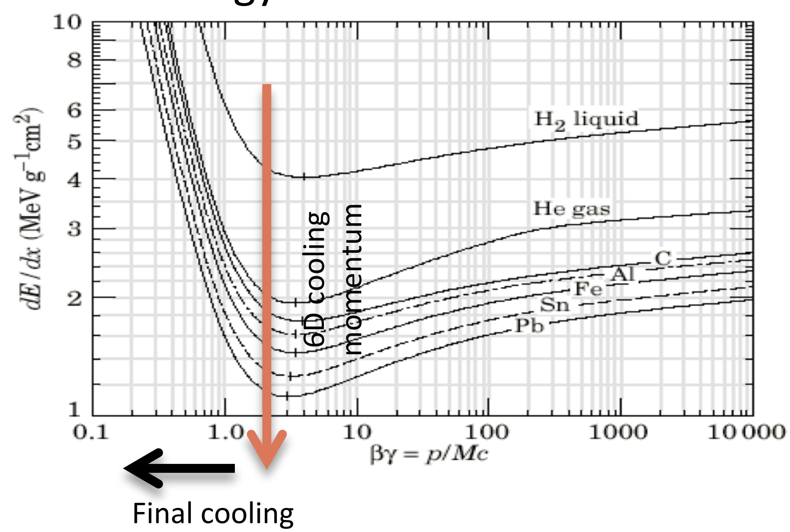
Reduction of **ε_T< 300 μm**
→ P < 135 MeV/c + strong focusing 50-25 T
P < 135 MeV/c → Positive slope of dE/dx
→ requires small initial ε_L to limit the expansion of σ_E & σ_t

Energy loss in low z material



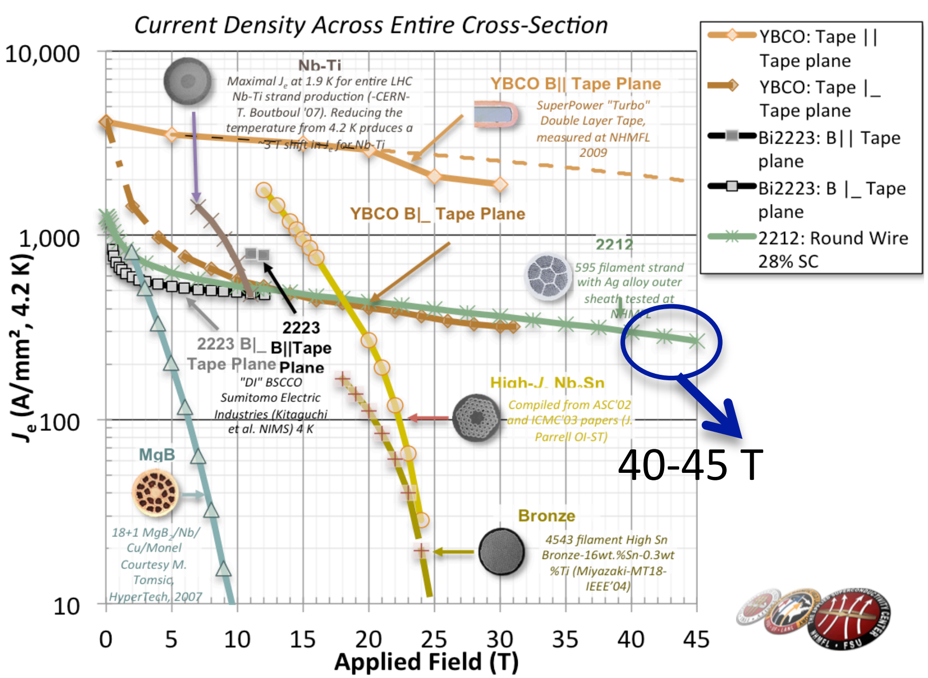
$$\epsilon_{equ,N} = \frac{\beta_\perp E_s^2}{2\beta mc^2 L_R (dE/ds)}$$

HIGH FIELD IONIZATION COOLING CONCEPT

Minimum emittance achievable in a long solenoid field

$$\epsilon_{\perp}(min) \propto \frac{E}{BL_R(dE/ds)}$$

B magnetic field at absorber location
L_R Material radiation length
dE/ds Energy loss in material



Experimental data from High Magnetic Field Laboratory show the possibility of 40 T fields.

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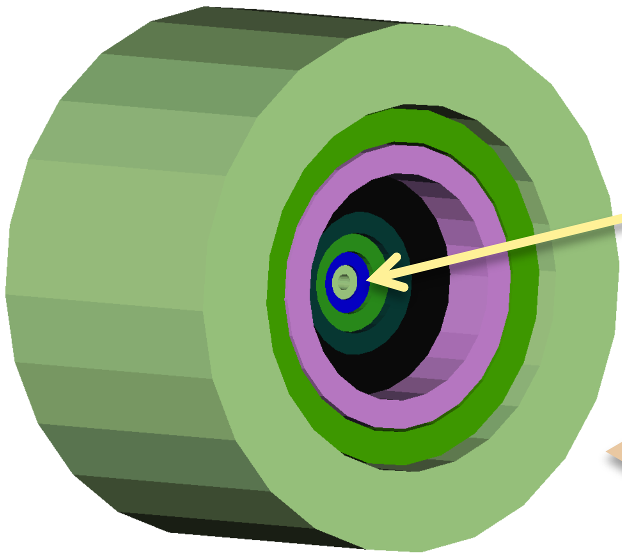
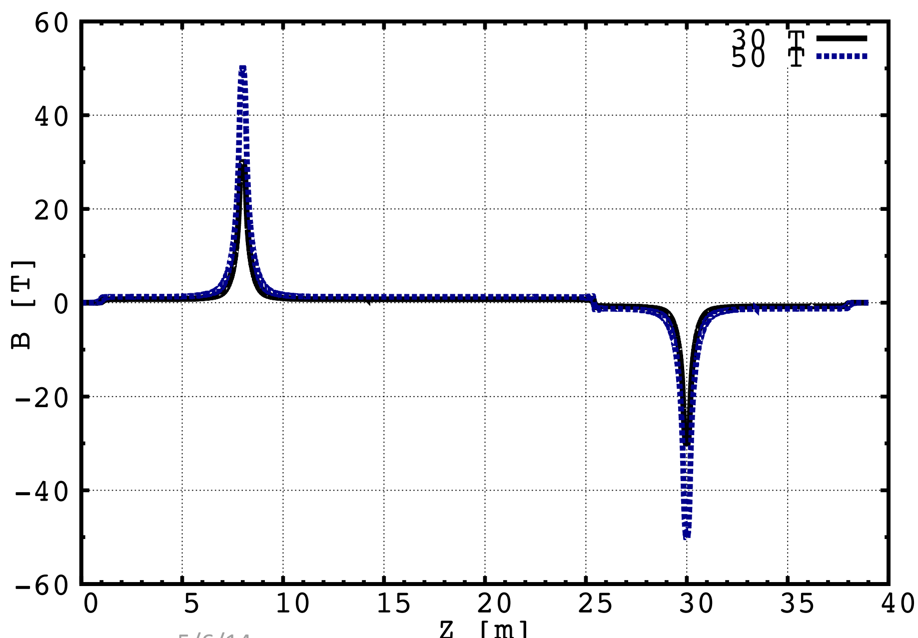
HIGH FILED 50 T MAGNET



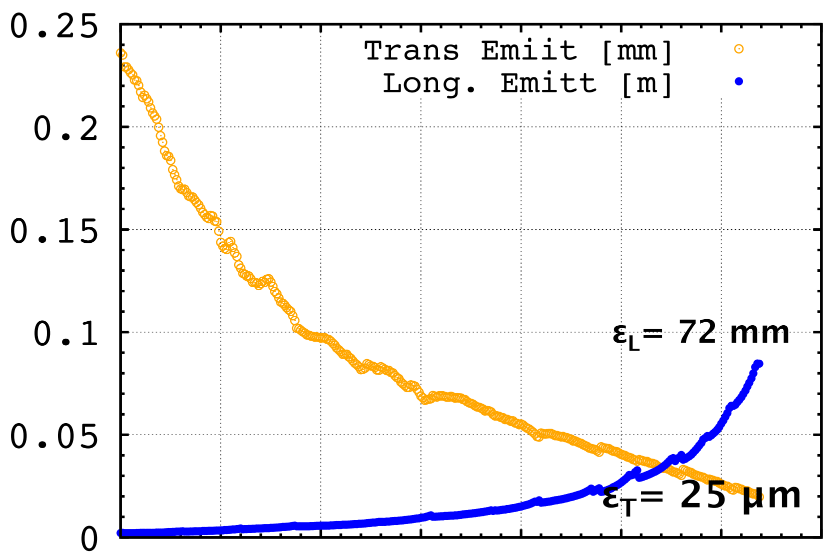
Length [m]	Inner radius [m]	Thickness [m]	I/A [A/mm^2]
0.317	0.025	0.029	164.26
0.337	0.055	0.041	142.43
0.375	0.098	0.056	125.88
0.433	0.157	0.067	119.07
0.503	0.228	0.120	85.99
0.869	0.355	0.089	39.60
0.868	0.454	0.104	44.30
0.992	0.575	0.252	38.60

R. Palmer – B. Weggel



HIGH FIELD IONIZATION COOLING CHANNEL DESIGN

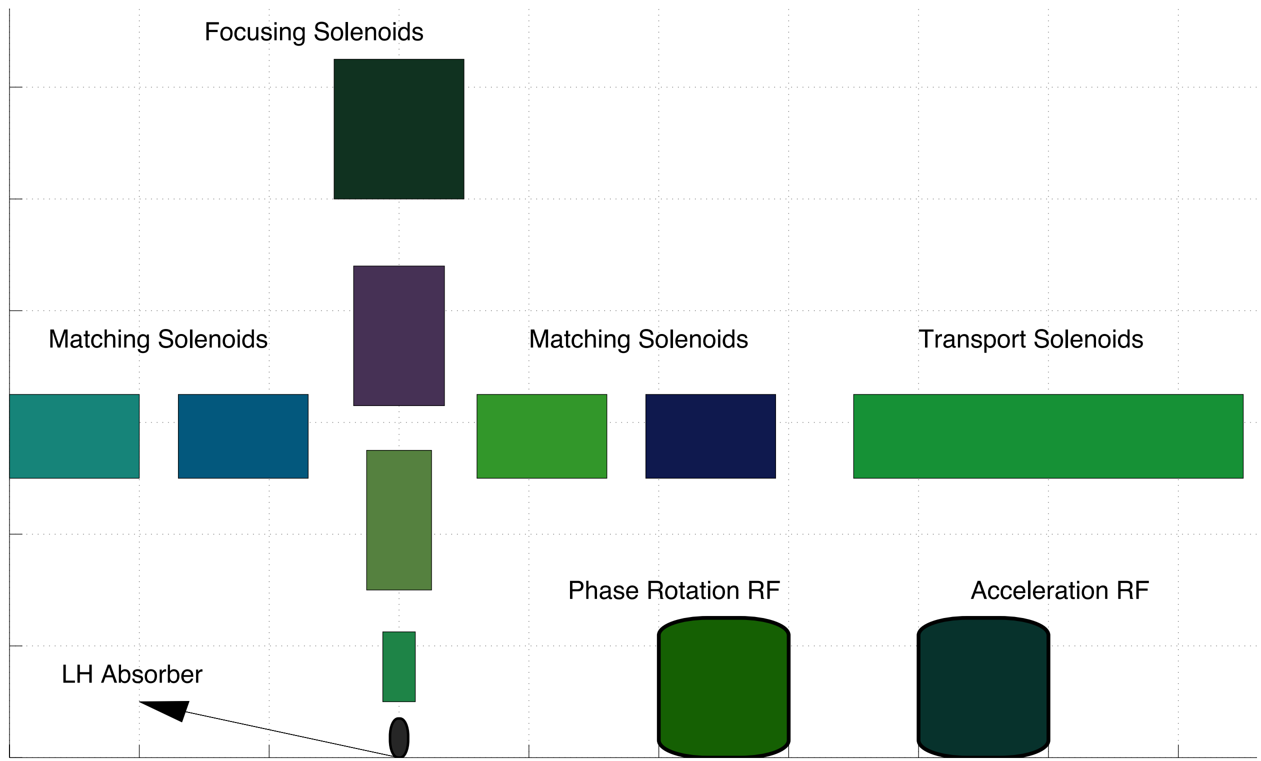
- Cool in the transverse dimensions while the longitudinal emittance grows
- Reduce energy gradually as we progress in the stages
- Reduce absorber length gradually
- Maintain energy spread within acceptable limits



Emittance reduction in absorbers excluding matching and acceleration

High field ionization cooling channel design

- Cool in the transverse dimensions while the longitudinal emittance grows
- Reduce energy gradually as we progress in the stages
- Anti-symmetric transverse match to and out of the high field solenoids
- Energy phase rotation to maintain low energy spread
  - → Increases bunch length
  - → Reduce the RF frequencies gradually



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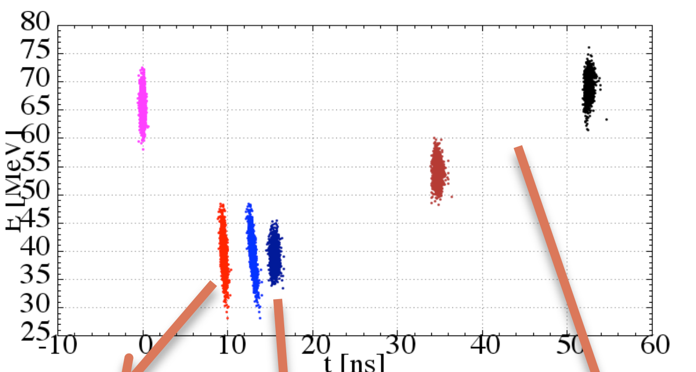
HIGH FIELD COOLING CHANNEL SIMULATIONS

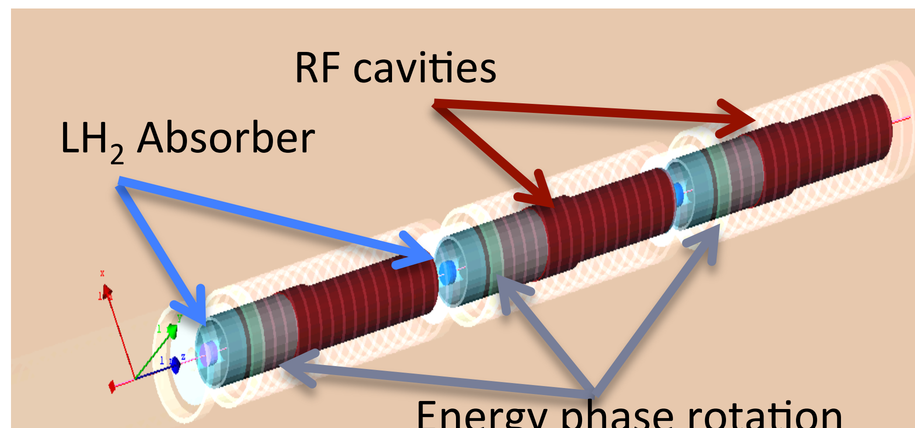
- Muon beam energy falls gradually 70 to 6 MeV
- LH_2 absorber length falls gradually from 65 cm to 12 cm
- Energy phase rotation to maintain the energy spread of the beam
- Bunch rms length rises from 5 cm to 300 cm
- RF cavities frequencies fall from 325 MHz to 4 MHz



Energy loss in LH_2

Energy phase rotation

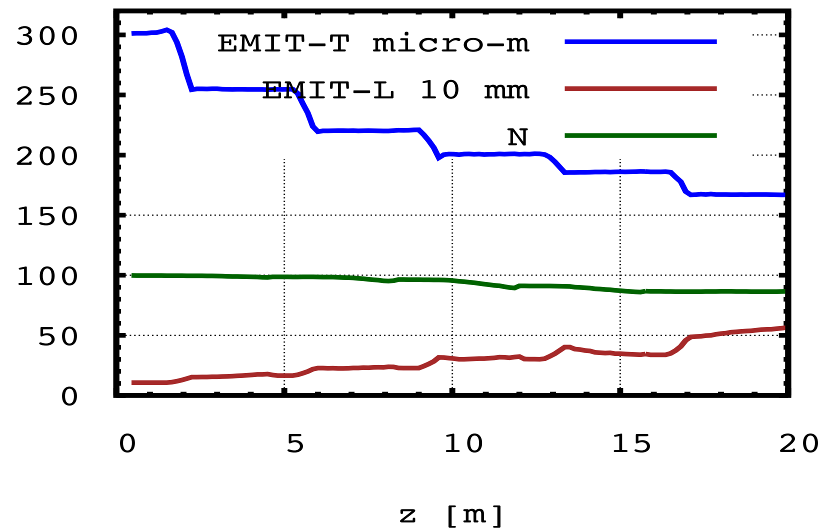
Acceleration



HIGH FIELD COOLING CHANNEL SIMULATIONS

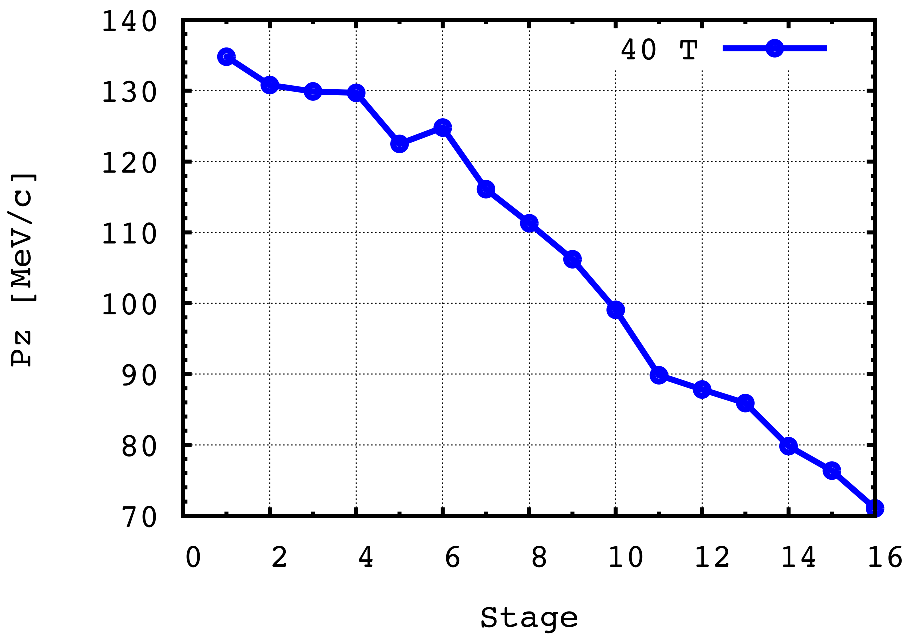
- Muon beam energy falls gradually 70 to 6 MeV
- LH_2 absorber length falls from 65 cm to 1 cm
- Energy phase rotation to maintain the energy spread of the beam
- Bunch rms length rises from 5 cm to 300 cm
- RF cavities frequencies fall from 325 MHz to 10 MHz

- Transverse emittance reduction in 40 T field
- Transverse matching
- Energy phase rotation
- RF acceleration



High field cooling concept

- Complete channel using 40 T focusing coils
- 3.0 T transport field between stages
- Drop momentum gradually



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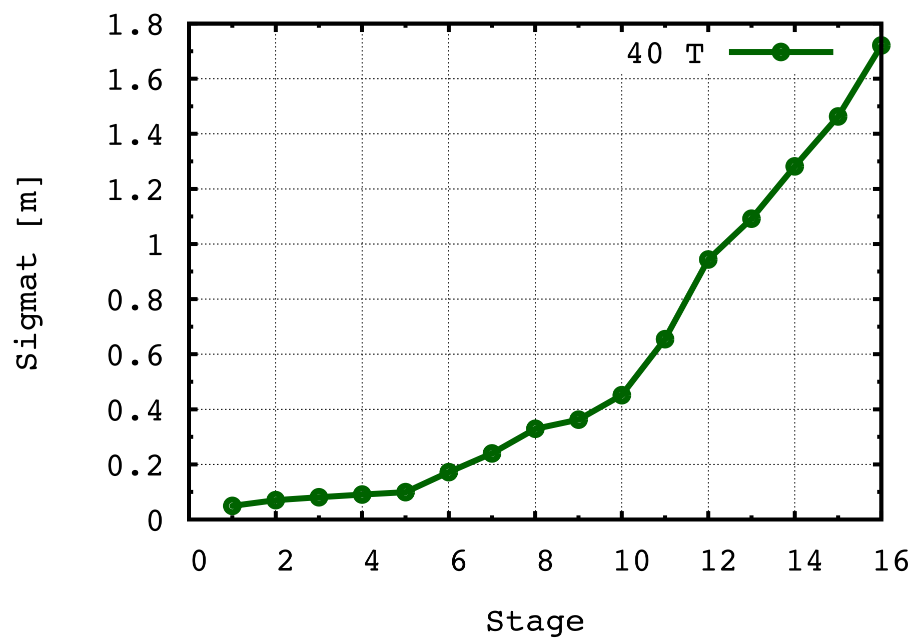
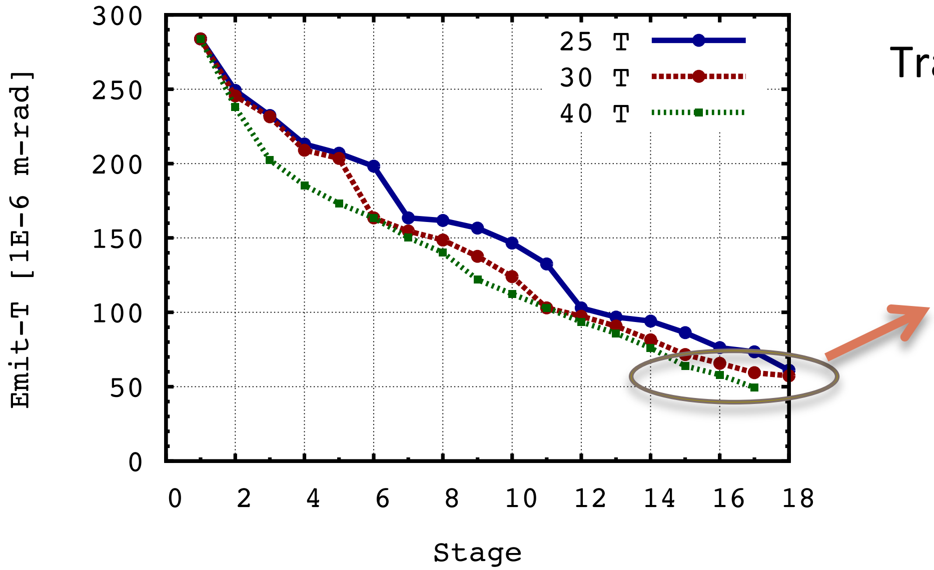
HIGH FIELD COOLING CONCEPT

- Complete channel using 40 T focusing coils
- 3.0 T transport field between stages
- Bunch length increases after energy phase rotation



25 - 30 - 40 T CHANNELS

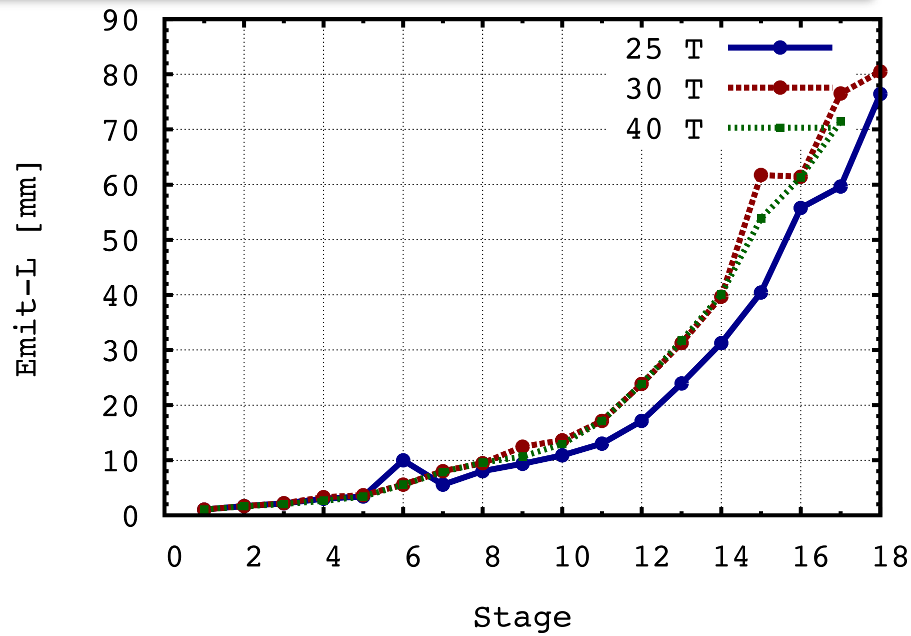


Transverse emittance [μm]

B = 25 T can achieve 60 μm without re-optmization

Equi. Emittance may limit further cooling

Longitudnal emittance [mm]



Transmission is ~ 40% in all channels

Conclusion & Summary

- Explore the concept of low energy - high field cooling channel with transverse and longitudnal matching
- A first pass of a complete design and simulation of a high field cooling channel

- → $\varepsilon_T = 50\ \mu m$ $\varepsilon_L \sim> 72\ mm$

- To do list
- Optmize the 30-25 T channels – find the lowest achievable emittance ?!
- Optmize the 40 T to achive the required 25 μm
- Improve transmission
- Replace the current sheets with the SC high field magnet