Upgrade of the rectilinear 6D cooling channel

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Motivation

Last version of the rectilinear channel:

4-stages cooling channel of length 450 m with RF 325 MHz / 25 MV/m,
LH_2 absorbers in 1-2 stages and LiH absorbers in 3-4 stages.

Cooling: ε_{trans} = 20 mm → 0.31 mm ε_{long} = 20 mm → 1.5 mm

Transmission – 90% without decay, 62% with decay

Required magnetic field is accessible for NbTi - NbSn technology.

Drawbacks:

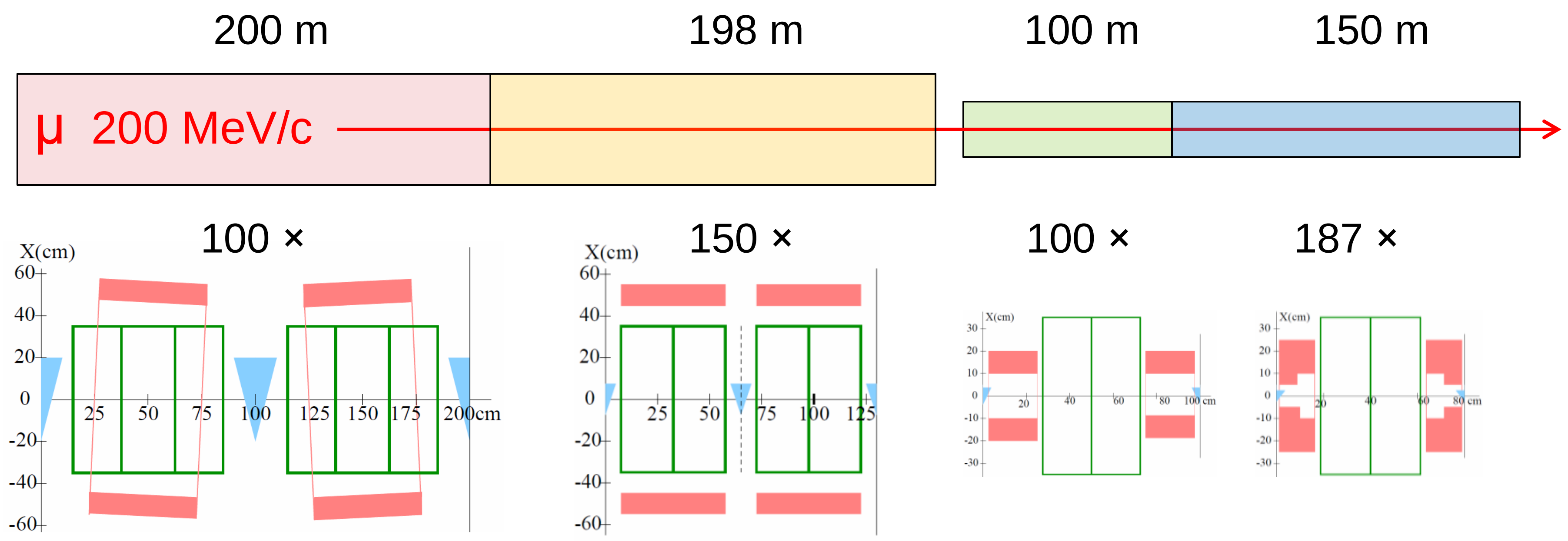
High accelerating gradient 25 MV/m. Recommended $17\sqrt{F/201.25} \approx$ 21.6 MV/m

Bad adjustment: overlapping of some parts (noticed by Diktys)

Updated version:

4-stages cooling channel of length 650 m with the same cells and accelerating gradient 21.6 MV/m provides about the same cooling with a bit less transmission.

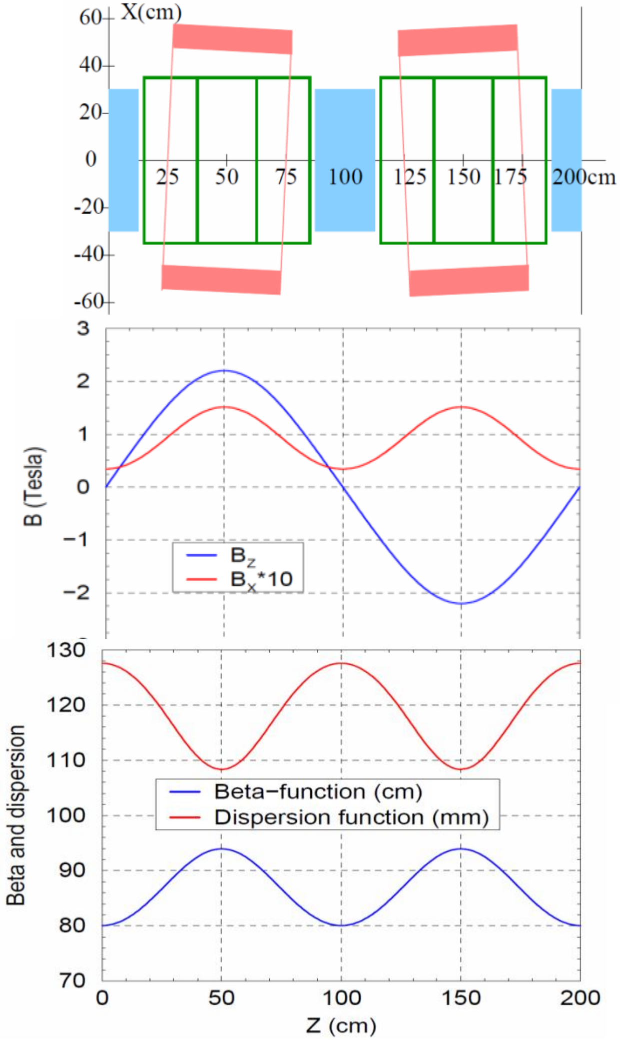
Outline of the channel

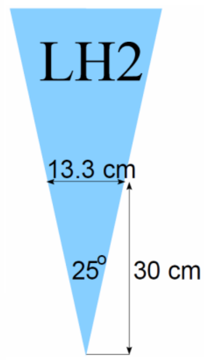


Axial field:	2.2 T	5.3 T	9.4 T	13 T
Coil field:	3.7 T	12 T	11 T	15.6 T
Beta:	80 cm	26 cm	6.2 cm	3.6 cm
Dispersion:	13 cm	4.5 cm	1.7 cm	1.3 cm

1st stage parameters

Ref. momentum 200 MeV/c, RF 325 MHz / 21.6 MV/m

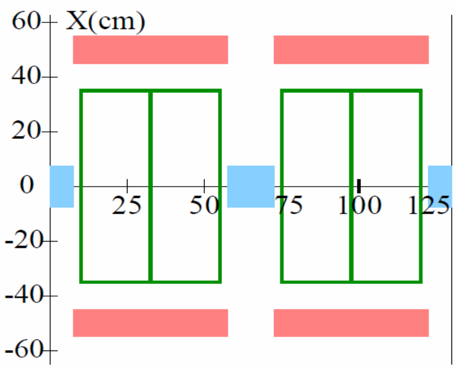


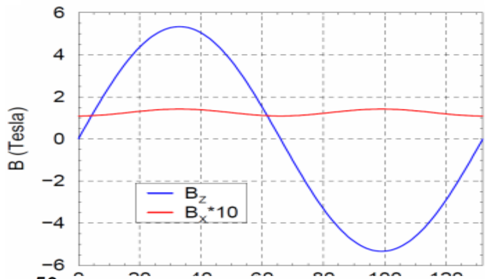


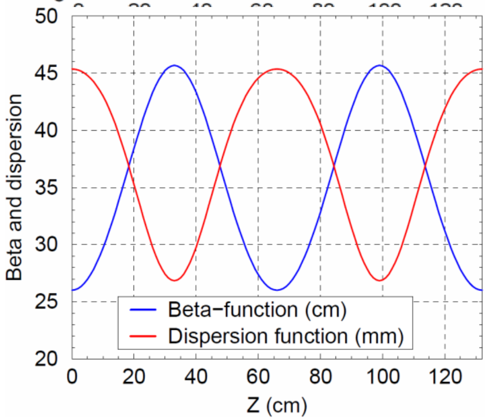
Stage length	150 m
Number of cells	187
Cell length	200 cm
Coil length	50 cm
Coil inner radius	45 cm
Coil thickness	10 cm
Coil tilt	60 mrad
Current density	48.3 A/mm^2
The coil maximal field	3.73 T
Cavity length	24 cm
Gaps	~1cm
Synchronous phase	17.5^0
LH_2 absorber center thickness	13.3 cm
Absorber opening angle	25^0

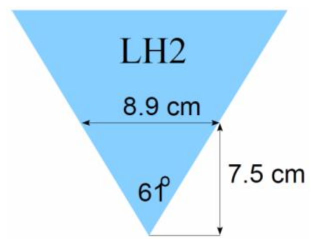
2^{nd} stage parameters

Ref. momentum 200 MeV/c, RF 325 MHz / 21.6 MV/m





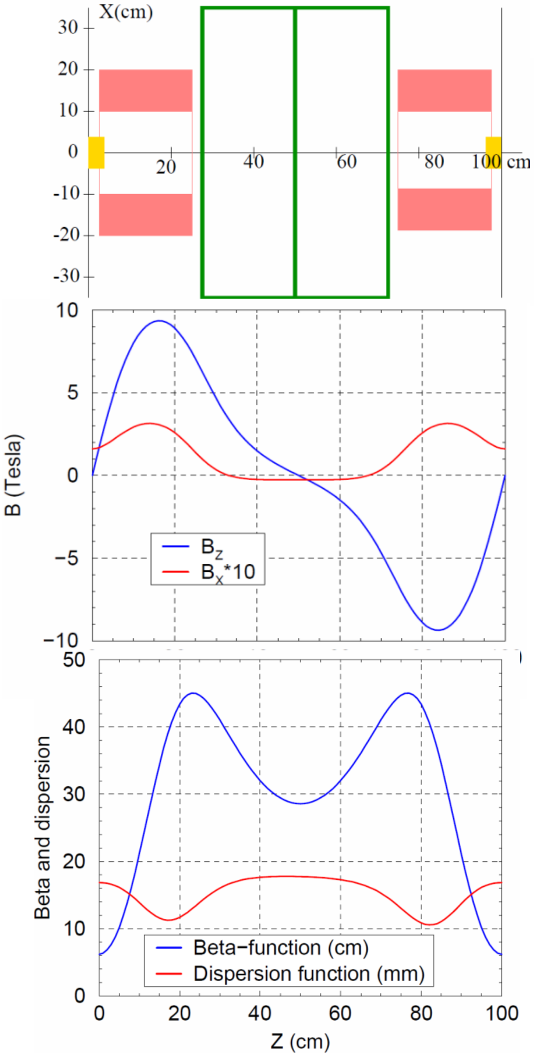


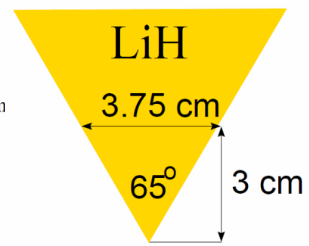


Stage length	198 m
Number of cells	150
Cell length	132 cm
Coil length	50 cm
Coil inner radius	45 cm
Coil thickness	10 cm
Coil tilt	15 mrad
Current density	175 A/mm^2
The coil maximal field	12.3 T
Cavity length	24 cm
Synchronous phase	17.5^0
LH_2 absorber center thickness	8.9 cm
Absorber opening angle	61^0

3rd stage parameters

Ref. momentum 200 MeV/c, RF 325 MHz / 21.6 MV/m

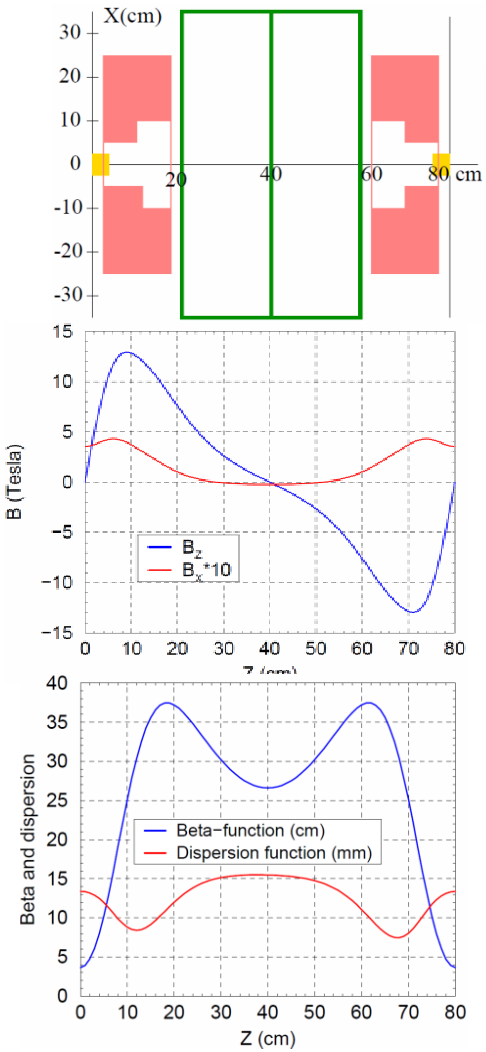


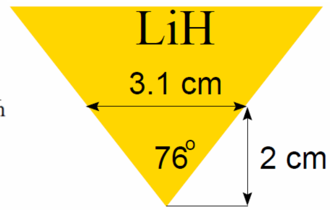


Stage length	100 m
Number of cells	100
Cell length	100 cm
Coil length	24 cm
Coil inner radius	10 cm
Coil thickness	10 cm
Coil tilt	30 mrad
Current density	139 A/mm^2
The coil maximal field	11 T
Cavity length	24 cm
Synchronous phase	45^0
LH_2 absorber center thickness	3.75 cm
Absorber opening angle	64^0

4^{th} stage parameters

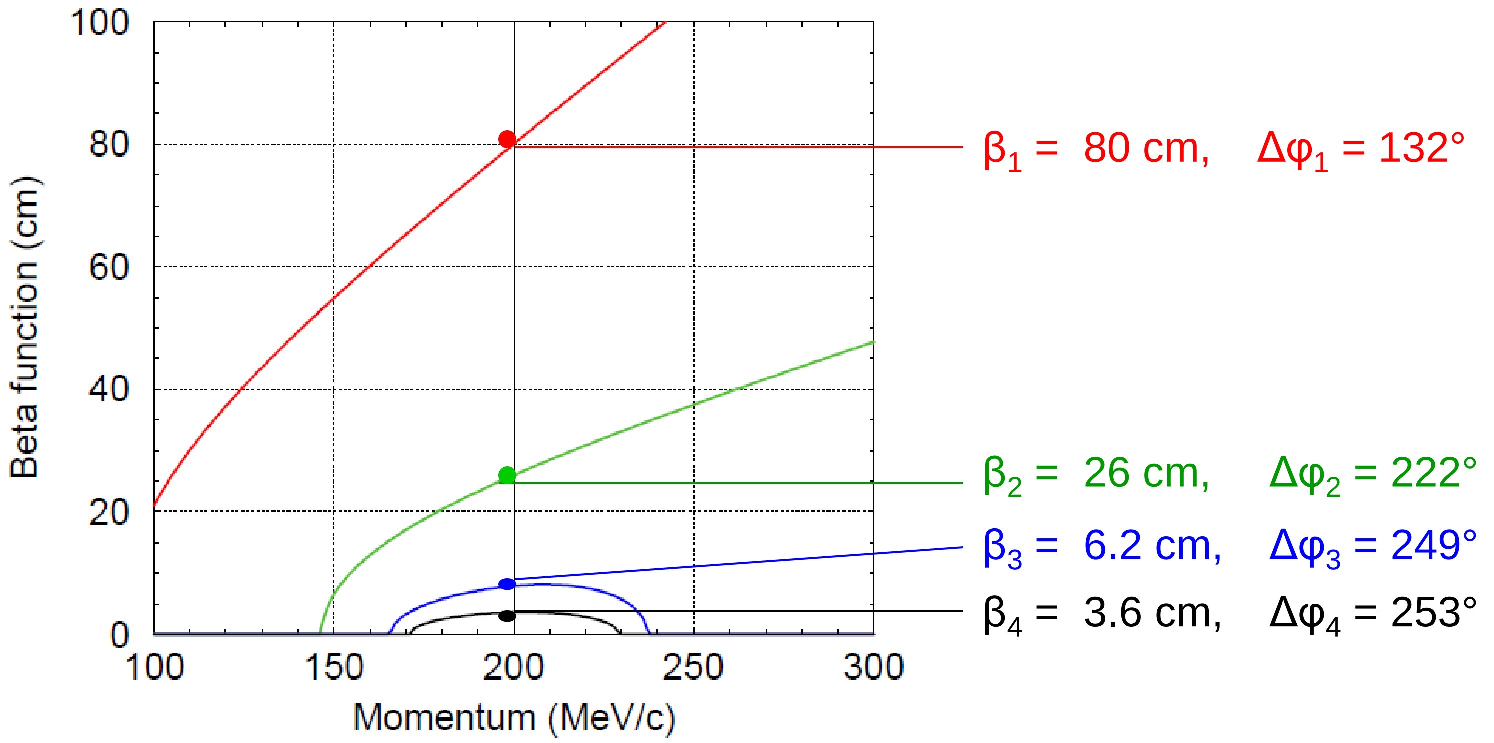
Ref. momentum 200 MeV/c, RF 325 MHz / 21.6 MV/m





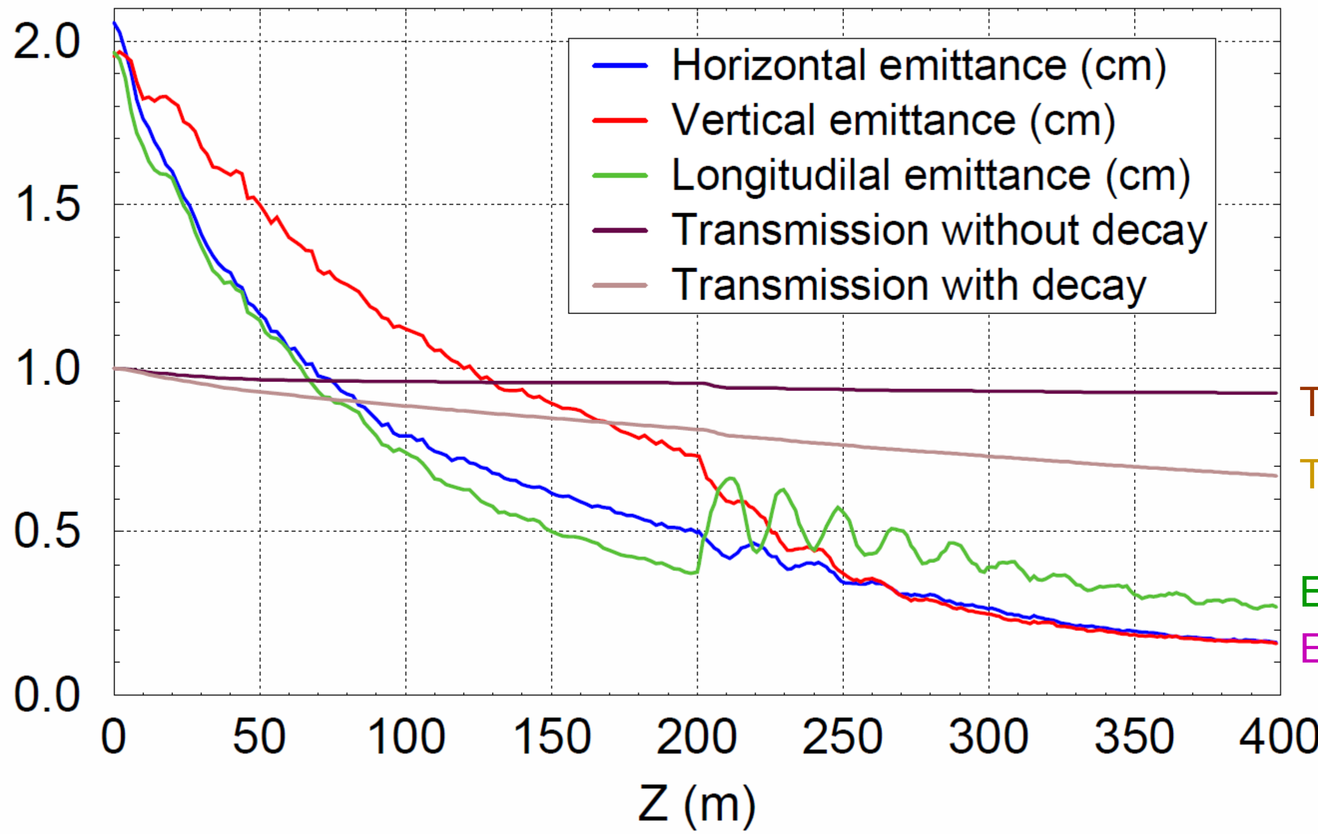
Stage length	100 m
Number of cells	187
Cell length	80 cm
Coil length	16 cm
Coil inner radius	10&5 cm
Coil thickness	15&20 cm
Coil tilt	20 mrad
Current density	185 A/mm^2
The coil maximal field	15.6 T
Cavity length	20 cm
Synchronous phase	45^0
LH_2 absorber center thickness	3.12 cm
Absorber opening angle	76^0

Beta-function against particle momentum



- Cells of 1st and 2nd stages have symmetrically arranged coils.
  They provide large momentum acceptance but should have coils of big radius for cavities.
- Coils of 3rd and 4th stages have small radius and asymmetrical arrangement providing ultimately small beta-function and a lot of room for cavities between the coils. However, its momentum acceptance is rather small being bounded by strong π and 2π resonances.

Cooling by 1st and 2nd stages: emittance and transmission (self-consistent initial distribution, 0.76 m matching section)



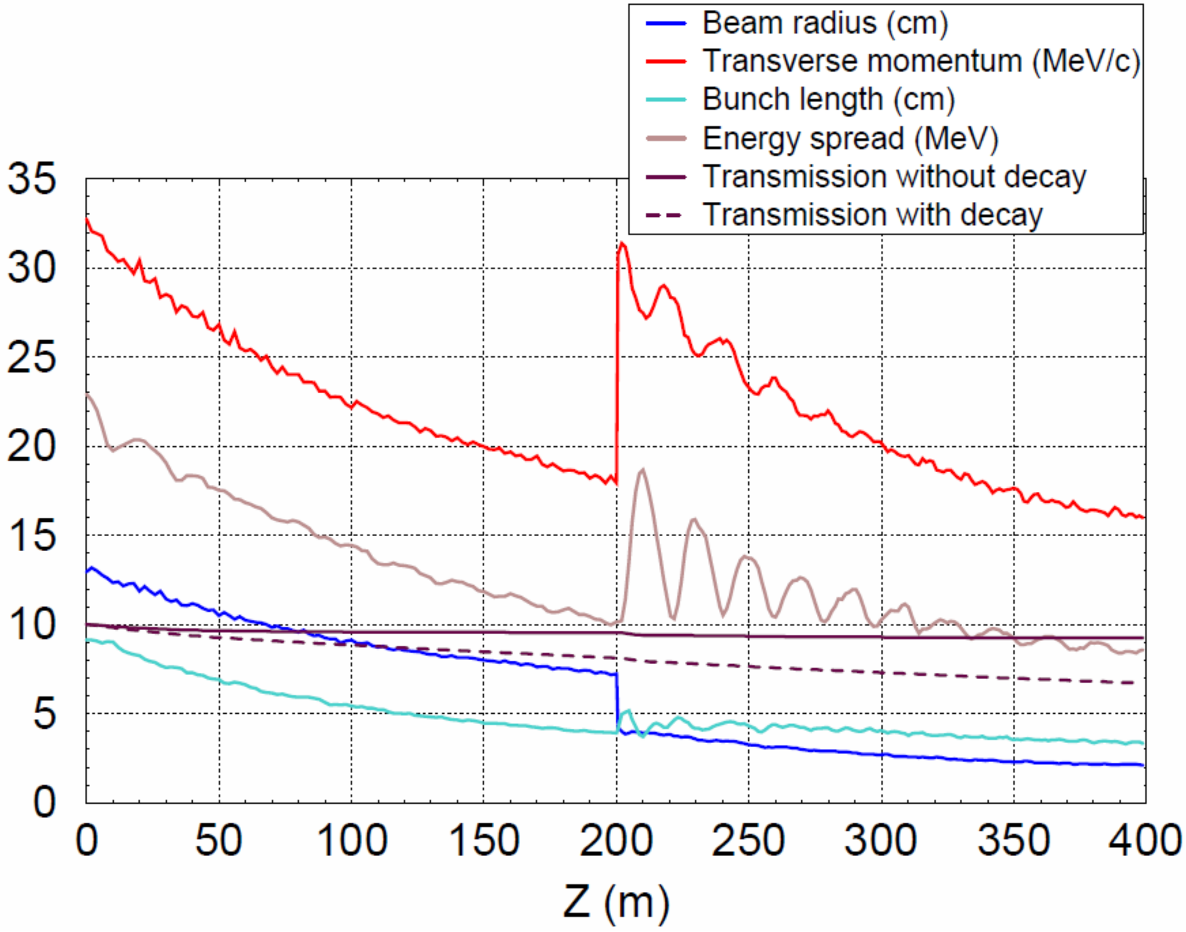
Tr_1 = 92%

Tr_2 = 67%

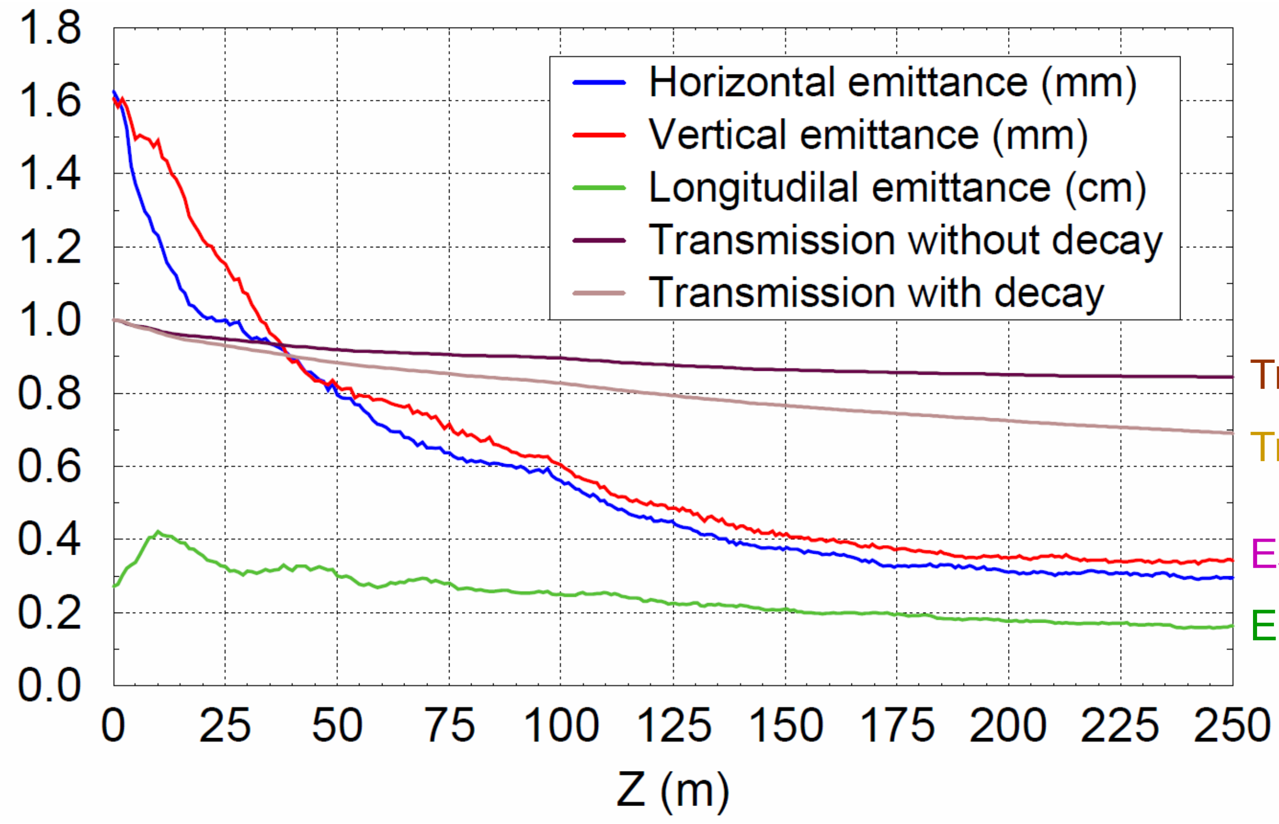
E_{long} = 2.7 mm

E_{trans}= 1.6 mm

Cooling by 1st and 2nd stages: beam size and transmission



Cooling by 3rd and 4th stages: emittances and transmission
(distribution after 1-2 stages is transformed by matrix and used for injection)



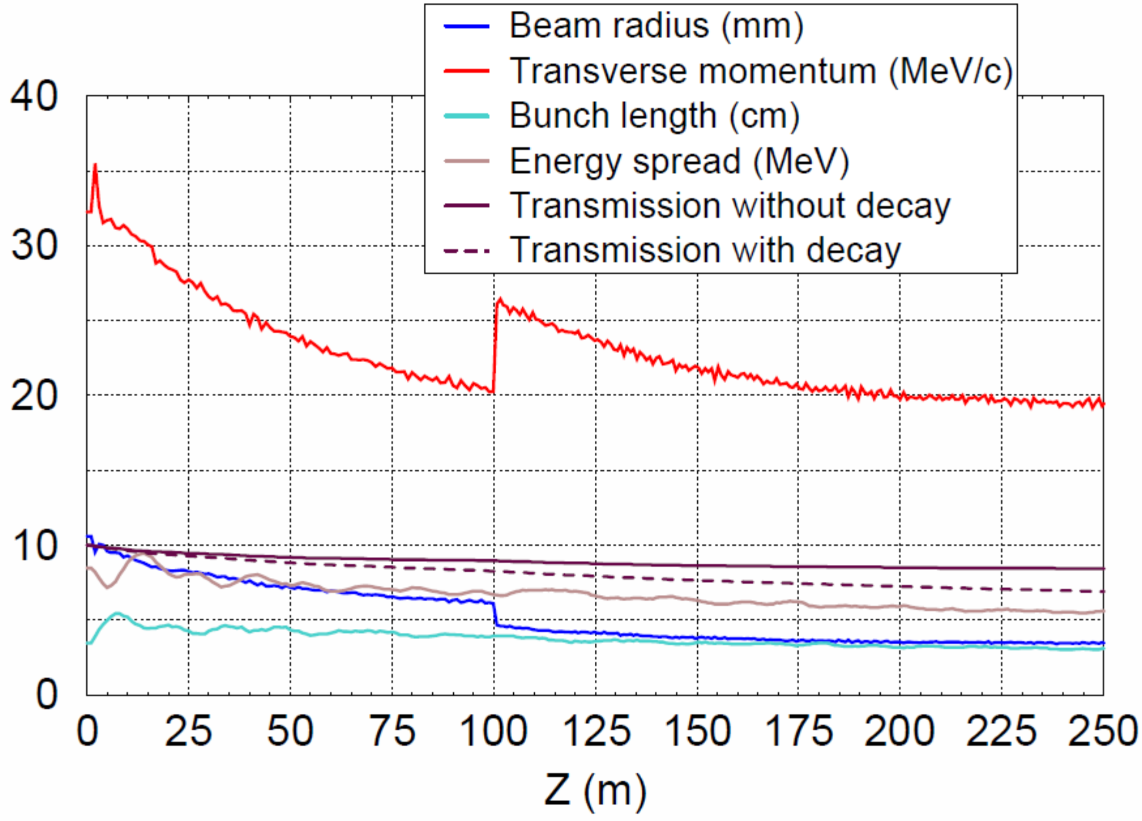
Tr_1 = 84%

Tr_2 = 69%

E_{trans}= 0.32 mm

E_{long} = 1.6 mm

Cooling by 3rd and 4th stages: beam size and transmission

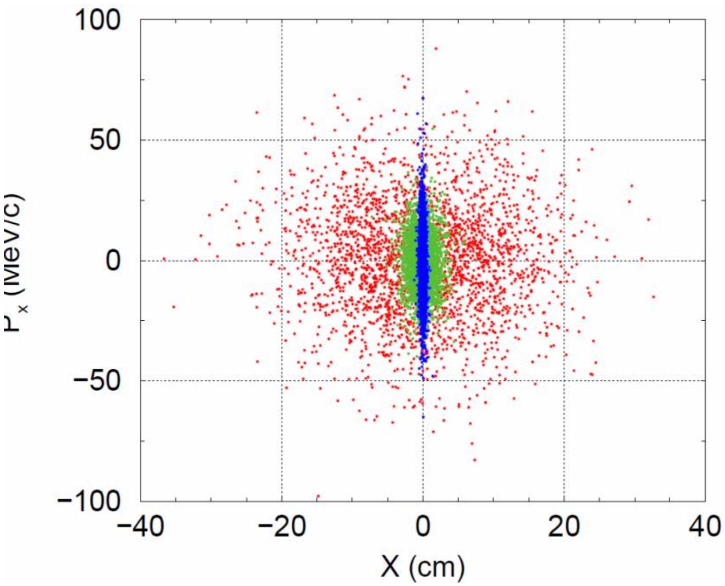


Transverse momentum is about 25% more than with previous design (because of less beta-function).

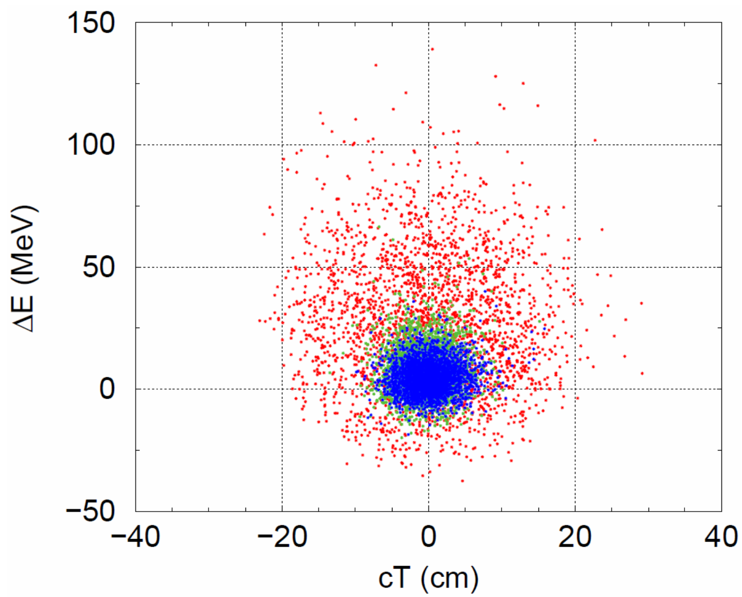
Probably, it explains a bit higher particle loss. Additional optimization is needed.

Phase space at the cooling

Transverse $X-P_x$ space



Longitudinal $cT-\Delta E$ space

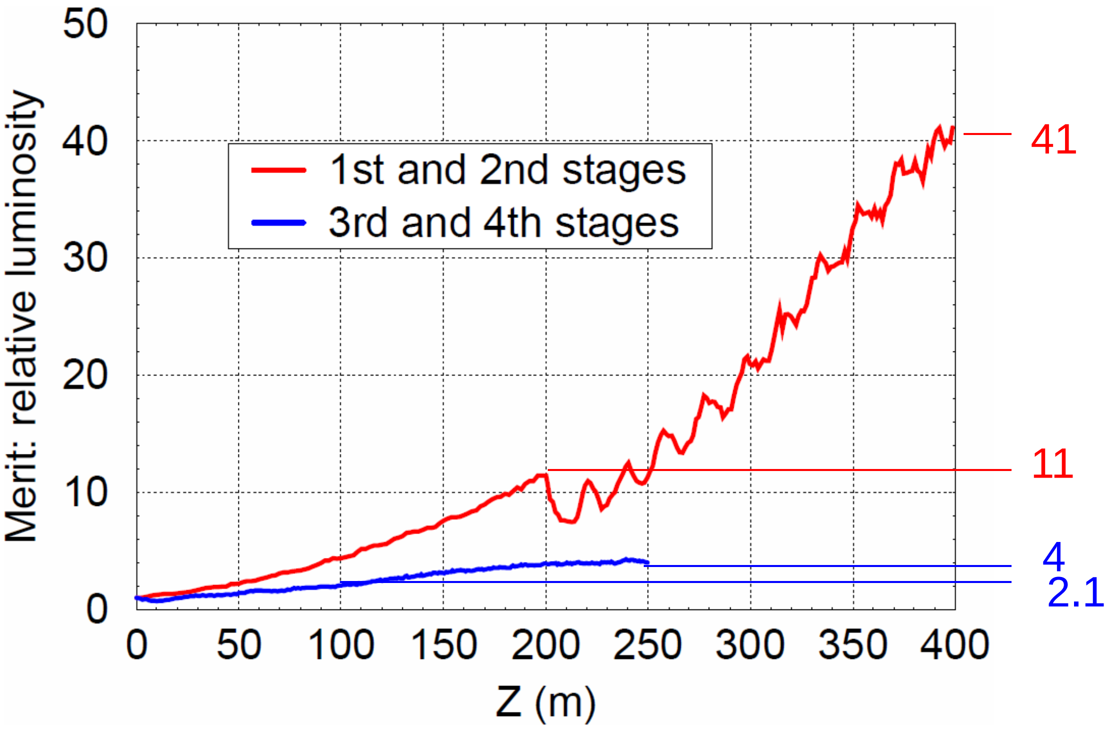


Red – injected beam, green – after 2nd stage, blue – at the end of the channel.

Longitudinal phase space is non-Gaussian because synchronous energy depends on betatron amplitude. The dependence is too complicated to control it.

Luminosity merit factors

$$L_B \propto \frac{N^2}{\sqrt{\varepsilon_x \varepsilon_y}\,\varepsilon_z} \propto \frac{(Transmission)^2}{\varepsilon_{trans}\varepsilon_{long}}$$



Summary and Conclusion

- Multistage rectilinear channel can be applied for ultimate 6D cooling
- Using of a unified RF system is possible and expedient
- Lithium hydride wedge absorbers are applicable for finale cooling
- Required magnetic field is accessible for NbTi - NbSn technology
- Based on these principles, 4-stages channel is designed having the parameters: length 650 m, RF 325 MHz, absorbers LH_2 and LiH, and providing the cooling:

  transverse emittance – from 20 mm to 0.32 mm
  longitudinal emittance – from 20 mm to 1.6 mm
  transmission w/o decay – 92% in stages 1-2, 84% in stages 3-4
  transmission with decay – 67% in stages 1-2, 69% in stages 3-4
- Luminosity merit factor is:

	partial	entire
1^{st} stage	11.4	11.4
2^{nd} stage	3.6	41
3^{rd} stage	2.1	85
4^{th} stage	1.9	164

- Longitudinal matching of the stages remains the main problem