
CERN

A final cooling scheme for muon colliders: a door opener for future discovery machines

Joint Annual Meeting of ÖPG and SPS 2021

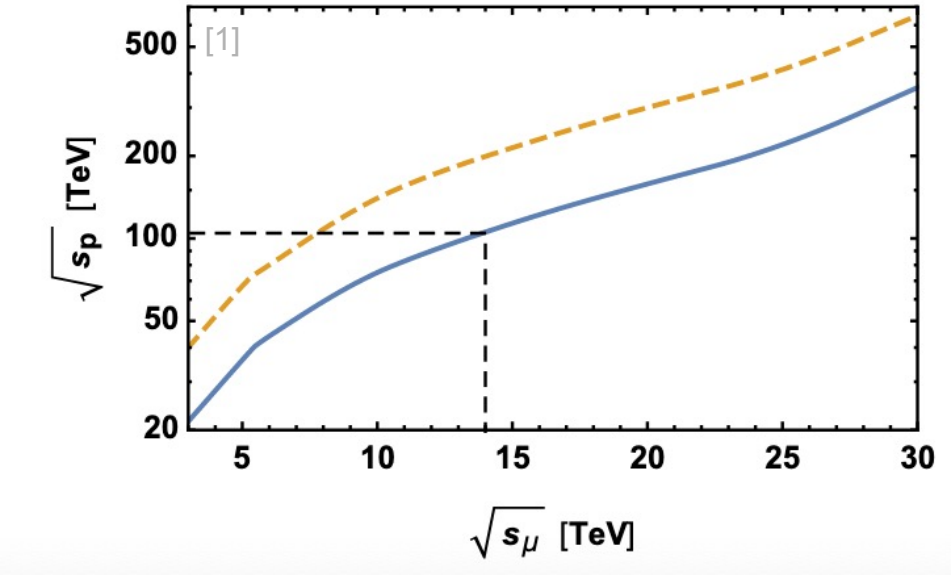
Bernd Stechauner[1,2], Elena Fol[2], Jochen Schieck[1,3], Chris Rogers[4] and Daniel Schulte[2]

[1]University of Technology Vienna,
[2]CERN, Geneva
[3]Institute of High Energy Physics, Vienna
[4]STFC Rutherford Appleton Laboratory, Didcot

Overview

1. **Muon collider motivation**
2. **Physics behind a final cooling cell**
3. **First emittance reduction simulations**

Motivation

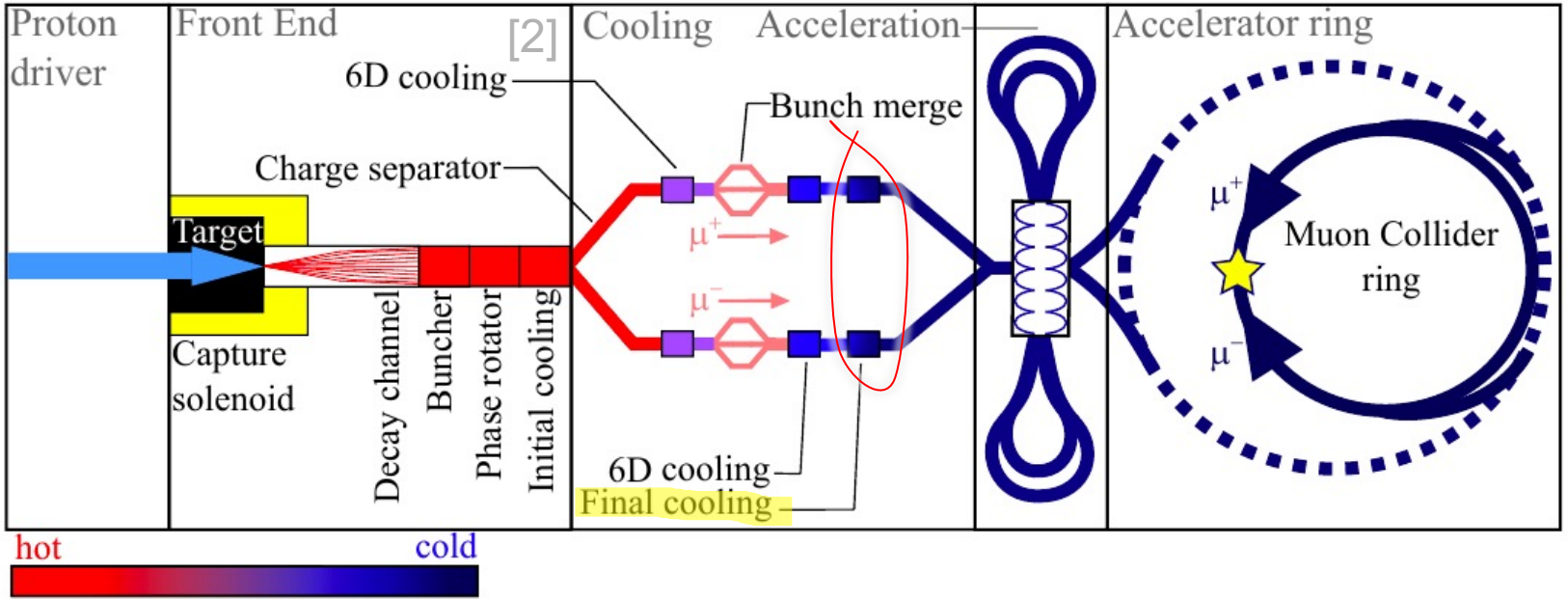


- Negligible synchrotron radiation: $\sim m^{-4}$
- Full collision energy available
- 100 pp = 14 TeV muon collider [1]

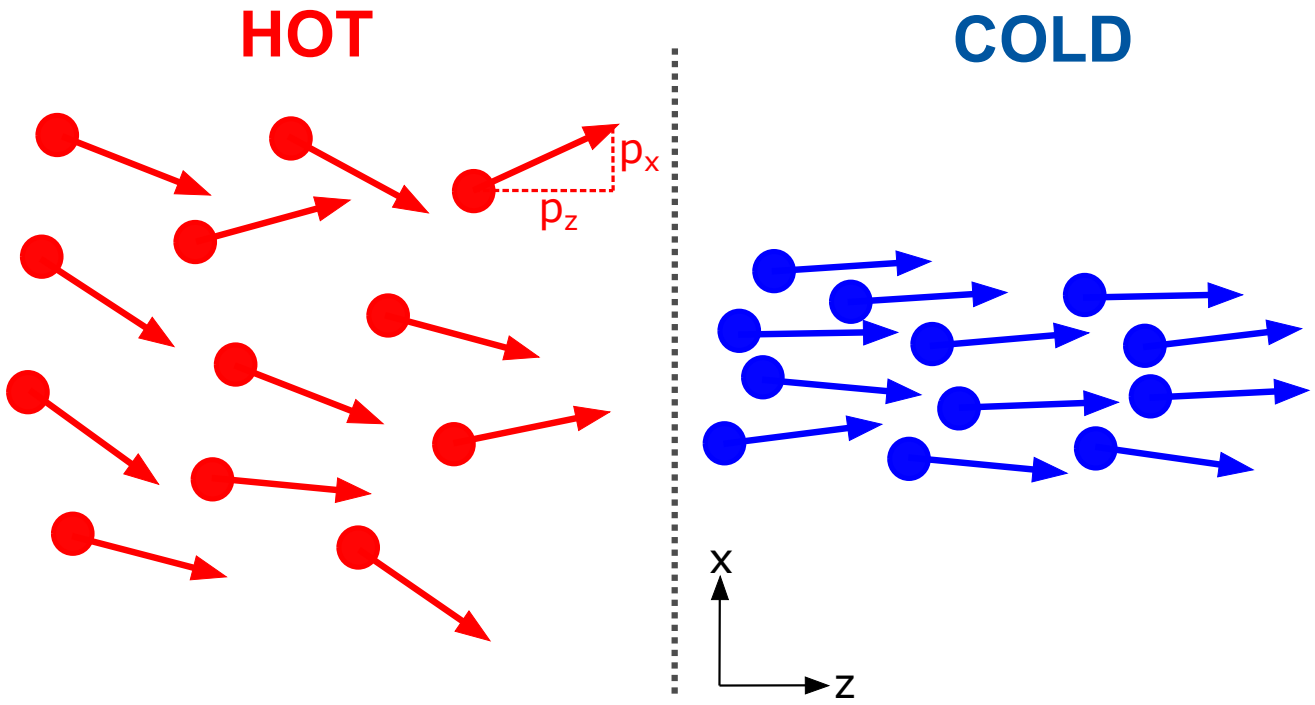
BUT: Lifetime $2.2 \mu s$

[1] arXiv:1901.06150v1

Current MC design



Emittance



Angle:

$$x' \approx \frac{p_x}{p_z}$$

Emittance:

$$\epsilon_x = \langle x \rangle \langle x' \rangle$$

LI. Emittance:

$$\epsilon_{x,\mathrm{N}} = \beta\gamma \langle x \rangle \langle x' \rangle$$

Target parameters

Table 1.1: Parameter list defined by the international muon collider collaboration.

Parameter	Symbol	Units	3 TeV	10 TeV	14 TeV
Luminosity	$\mathcal{L}$	$10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$	1.8	20	40
Muons/bunch	N	10^{12}	2.2	1.8	1.8
Repetition rate	f_r	Hz	5	5	5
Beam power	P_beam	MW	5.3	14.4	20
Collider circumference	C	km	4.5	10	14
Average bending field	$\langle B \rangle$	T	7	10.5	10.5
Norm. long. emittance	$\epsilon_\mathrm{L,N}$	MeV m	7.5	7.5	7.5
Energy spread	σ_E/E	%	0.1	0.1	0.1
Bunch length	σ_z	mm	5	1.5	1.07
Interaction point beta	β	mm	5	1.5	1.07
Norm. trans. emittance	$\epsilon_{\perp,\mathrm{N}}$	μm	25	25	25
Interaction point beam size	$\sigma_\perp$	μm	3.00	0.90	0.63

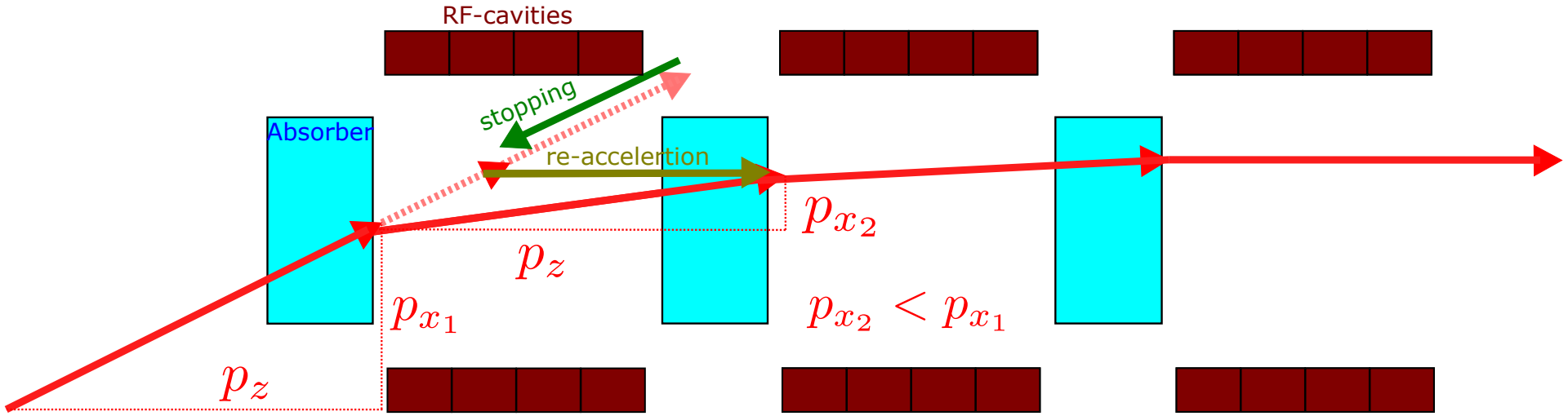
$$\mathcal{L} \propto \frac{\gamma^3}{C} \frac{N^2}{\epsilon_{\mathrm{L,N}} \epsilon_{\perp,\mathrm{N}}}$$

Emittance

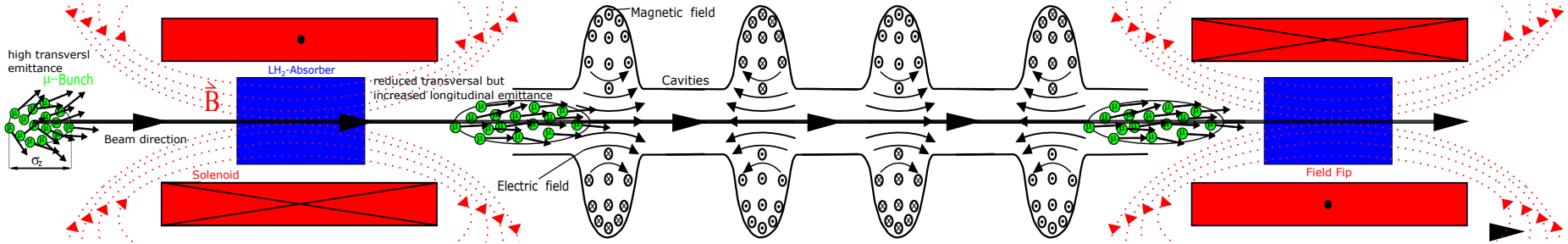
- In the past, $\epsilon_{\mathrm{trans}}$ = 55 microns was achieved [3]
- Goal is to reach 25 microns

[3] H. K. Sayed,10.1103/PhysRevSTAB.18.091001

Ionization cooling



Final cooling cell structure



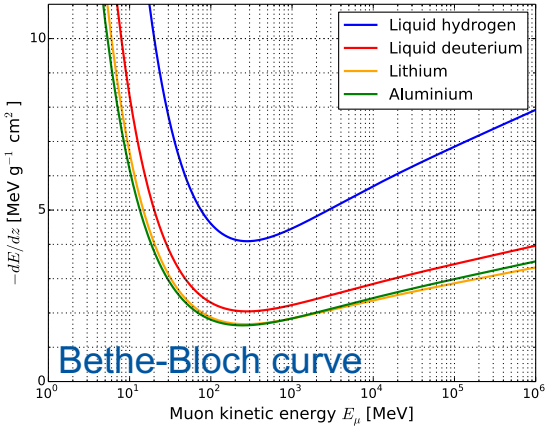
Cooling equation [4,5]:

$$\frac{d\epsilon_{\perp,\mathrm{N}}}{dz} = -\frac{\epsilon_{\perp,\mathrm{N}}}{E\beta^2}\left\langle\frac{\partial E}{\partial z}\right\rangle + \frac{\beta_\perp(13.6[\mathrm{MeV}])^2}{2\beta^3 Emc^2 L_\mathrm{R}} = \mathrm{cooling} + \mathrm{heating},$$

- $\beta_\perp$ … Betatron-function
- β, γ…Lorentz-factors
- L_R … Radiation length
- E … Energy

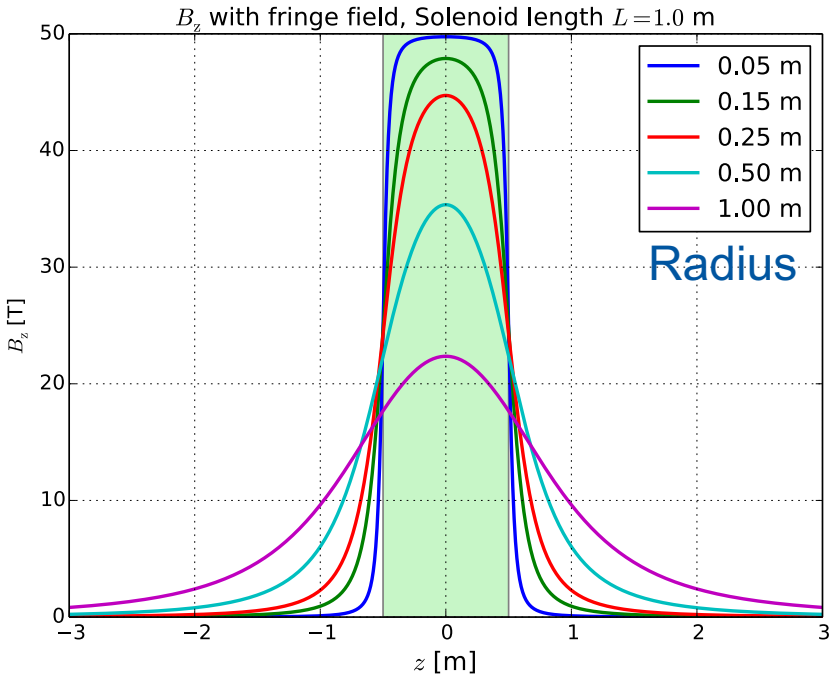
No correlations included!

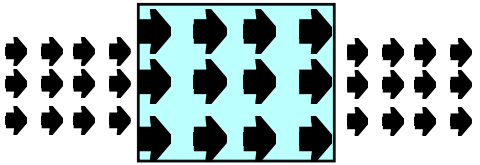
$$\langle xx' \rangle$$



[4] A. N. Skrinsky, V. V. Parkhomchuk 1981
[5] D. V. Neuffer 1993

Parameter manipulation





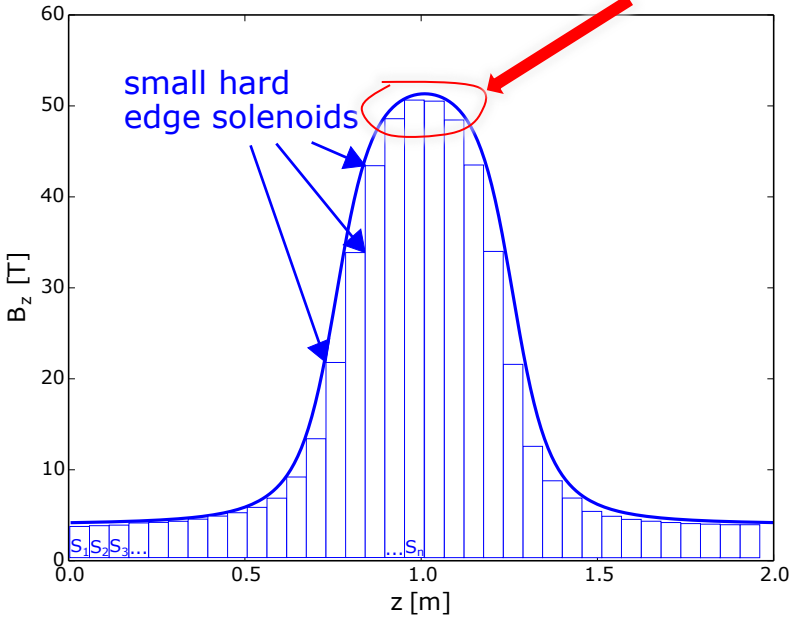
$$B(z) = \frac{B_0}{2}\left[\frac{z + L/2}{\sqrt{R^2 + (z + L/2)^2}} - \frac{z - L/2}{\sqrt{R^2 + (z - L/2)^2}}\right]$$

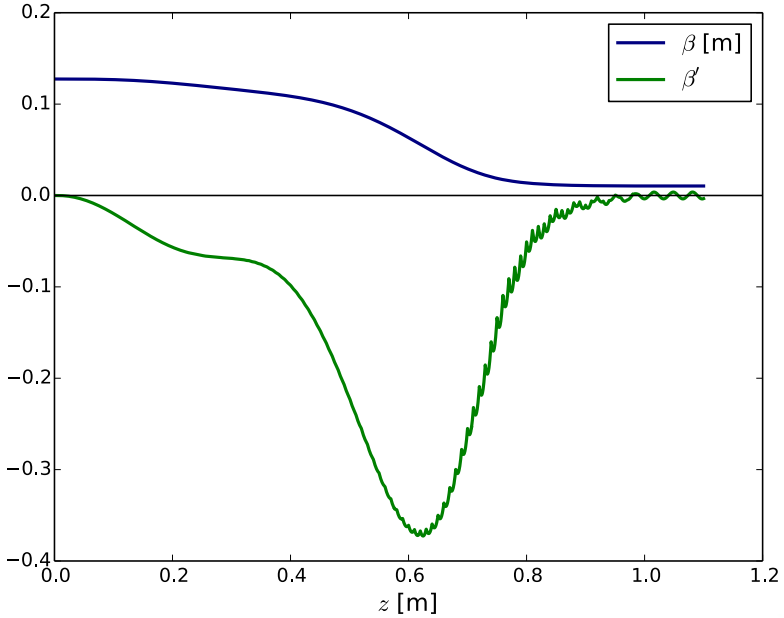
Constant L:

Fringe field length ∝ R

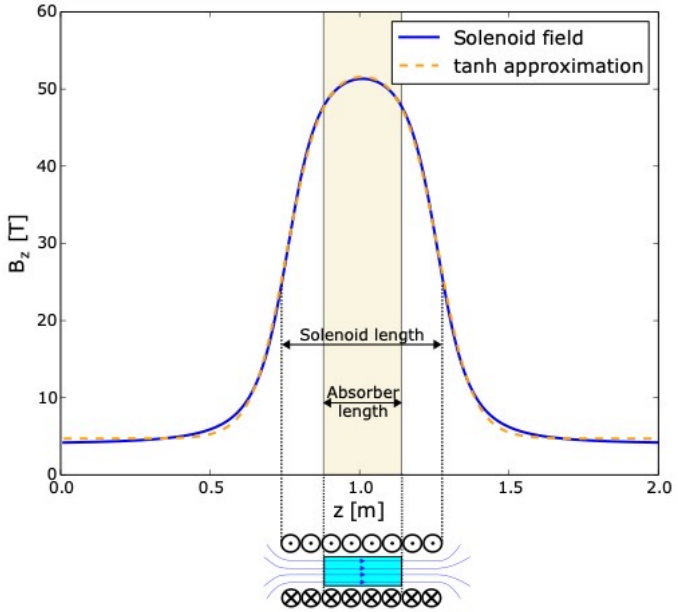
Fringe field optimization

Here: Minimize correlation

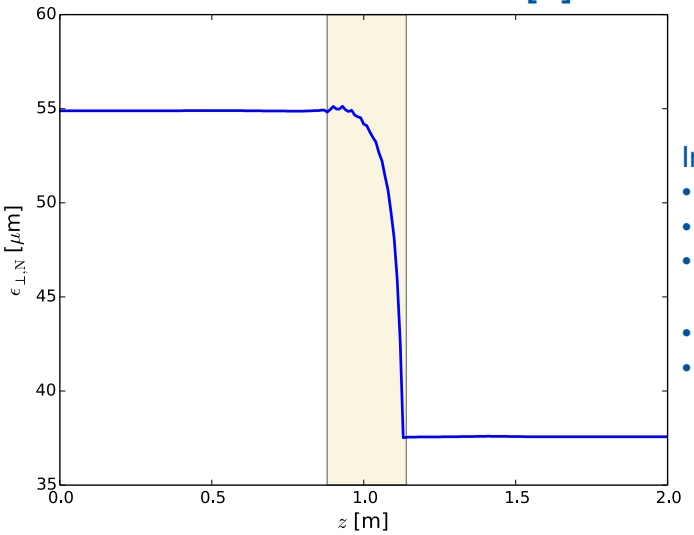




Cooling simulation



ICOOL simulation [6]



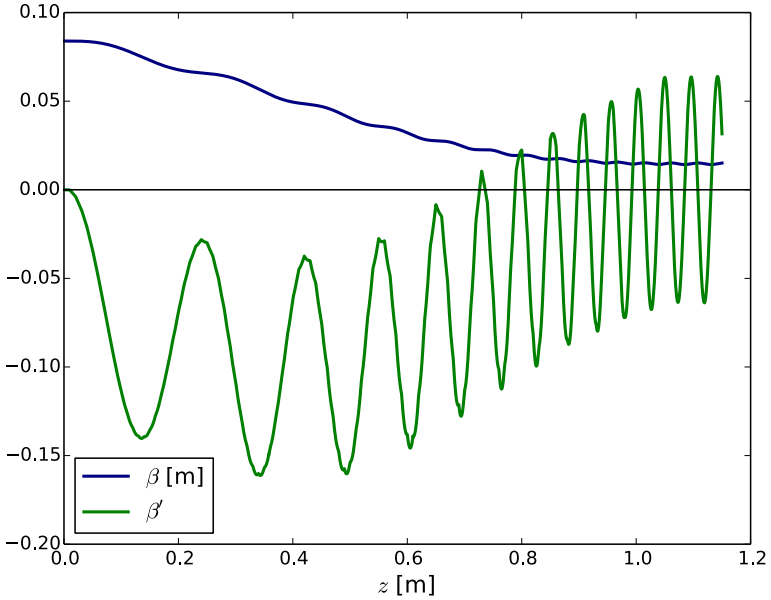
Initial beam parameters:

- P_z = 80 MeV/c
- Emittance = 55 microns
- Absorber: liquid Hydrogen 26 cm
- Cooling until 30 MeV/c
- 50 T solenoid

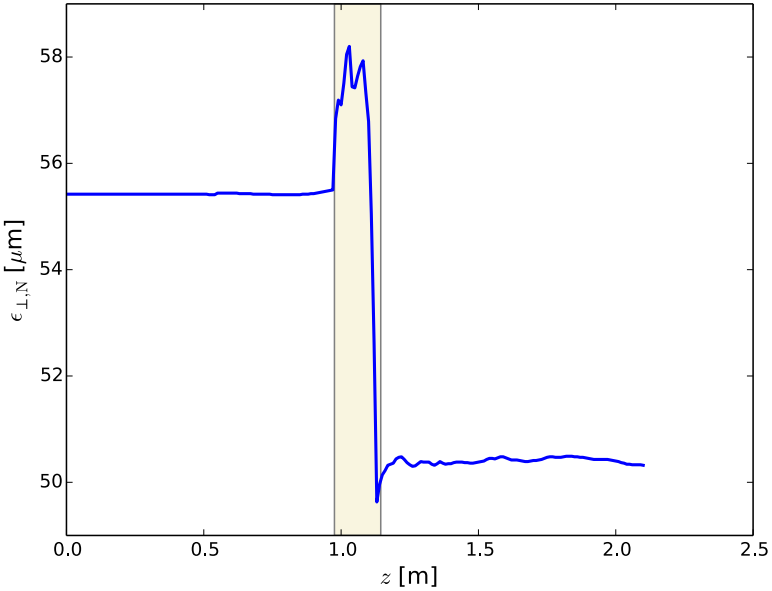
Cooling below 55 microns by means of higher fields possible

Bad fringe field optimization

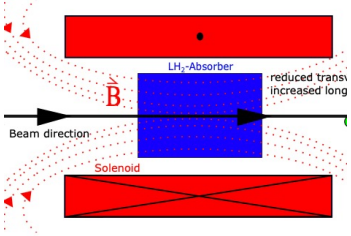
Analytical estimation



ICOOL simulation



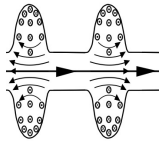
Summary and Outlook



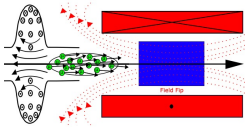
- Simulation of ionization cooling ✓
- Cooling under 55 microns possible ✓

Next steps:

- Reaccelerate the cooled beam



- Field flip

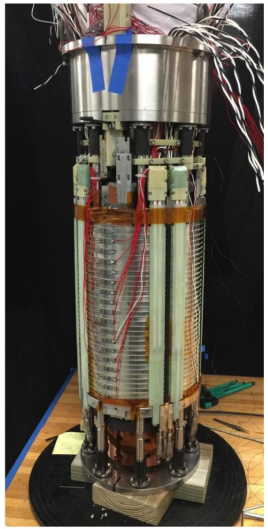


- Simulate couple of cooling cells

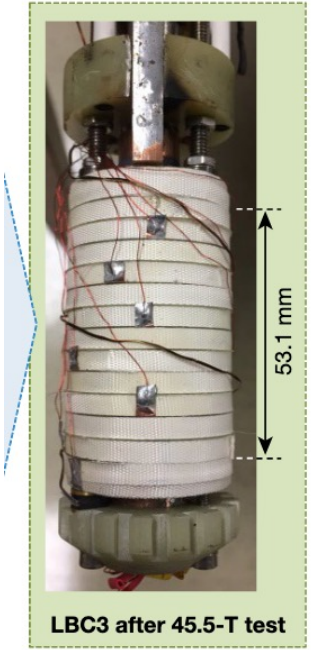

Questions?

Appendix

Industrial use of high-resolution NMR at 28.2 T [7]



32 T solenoid with low temperature HTS [8]



45 T !! [9]

[7] www.bruker.com
[8] 10.1109/TASC.2011.2174952
[9] 10.1038/s41586-019-1293-1