Update on Final Cooling Lattice

Ruihu Zhu (瑞虎 朱)
Institute of Modern Physics, Chinese Academy of Sciences
University of Chinese Academy of Sciences

Supervisor: Jiancheng Yang (建成 杨)
Special thanks to Chris Rogers

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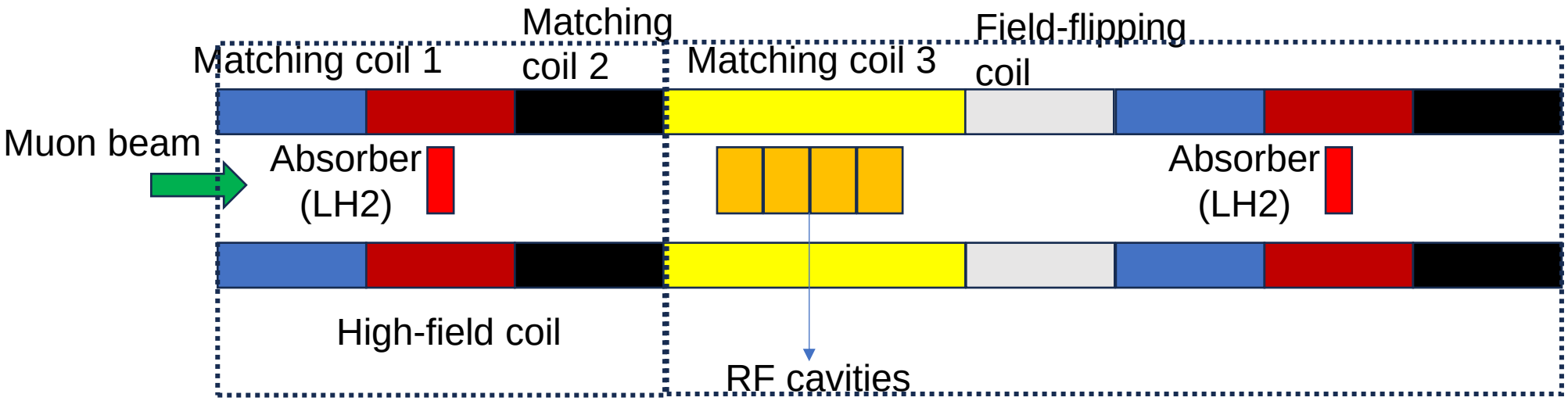
zhuruihu@impcas.ac.cn

Layout of final cooling cell



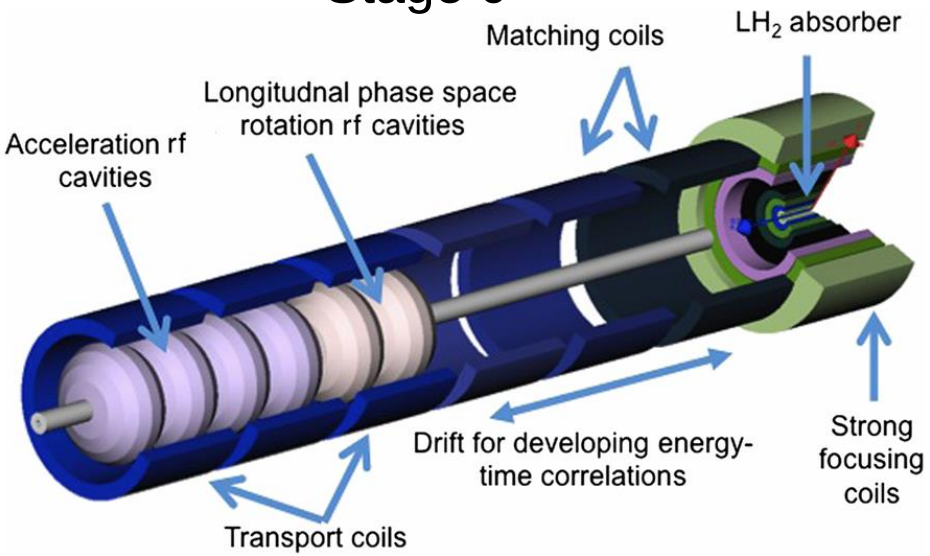
Beam pipe radius: 2 cm

Coil radius: 5 cm

Each cooling stage includes only one cooling cell.

Stage 0

Stage 1, 2,…

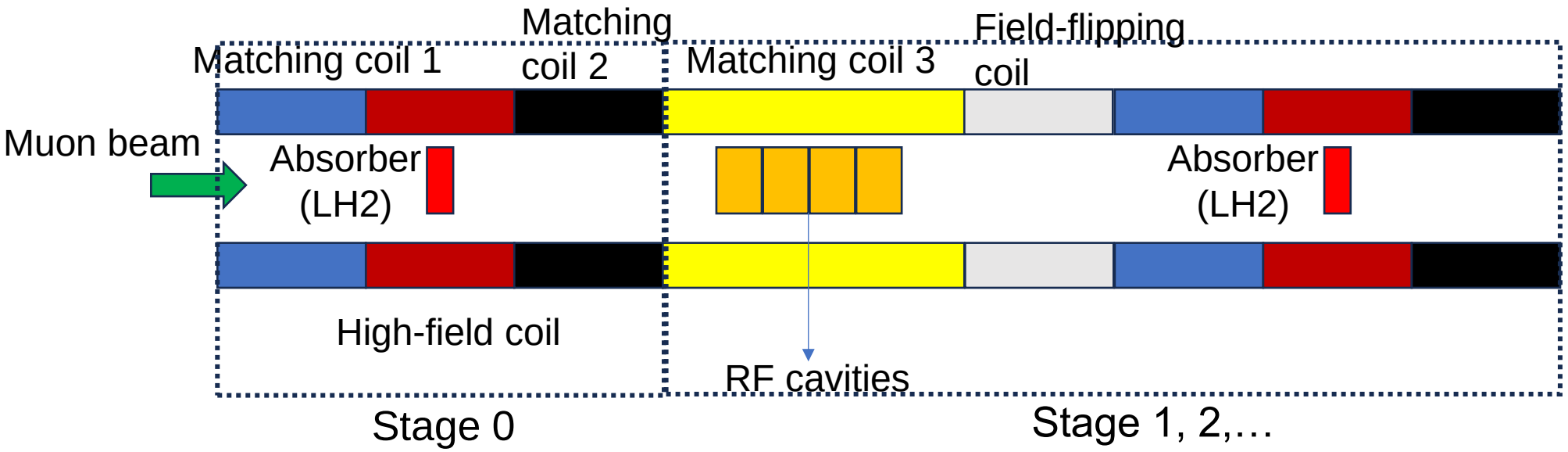


Final cooling cell in baseline of MAP

Changes compared to baseline:

- ✓ No separate phase rotation RF cavities (RF phase is 0)
- ✓ Stage 0 has no RF cavities.
- ✓ Field flips in every stage.
- ✓ Each cooling cell starts at the matching coil 3 and ends at the matching coil 2.

Method to design final cooling



- Using differential evolution algorithm to minimize the target function: $\frac{\varepsilon_{T,final}}{\varepsilon_{T,initial}} + 0.75 \times \frac{N_{initial}}{N_{final}} + 0.25 \times \frac{\varepsilon_{L,final}}{\varepsilon_{L,initial}}$

- 14 parameters to adjust:

✓ Solenoid coils current and length
✓ Absorber length
✓ RF gradient, phase and number of RF cavities

Final cooling performance

Updated final cooling lattice

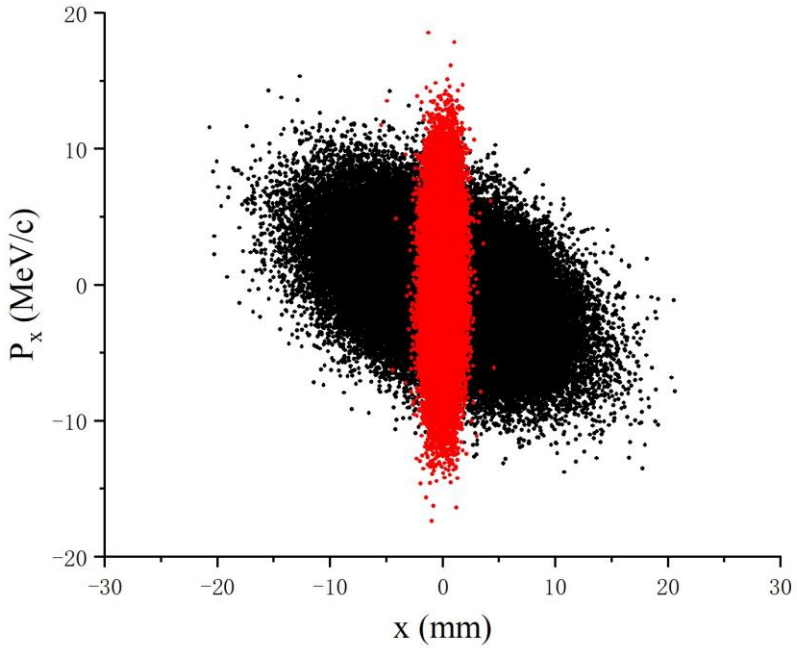
	ε_T (mm)	ε_L (mm)	ε_{6D} (mm^3)	Overall transmission
Start	0.1399	1.519	0.02972	
Stage 0	0.124	1.953	0.03022	99.6%
Stage 1	0.09702	4.207	0.0398	96.4%
Stage 2	0.0781	5.291	0.03274	86.9%
Stage 3	0.04755	10.73	0.02447	71.2%
Stage 4	0.03227	16.46	0.01743	62.5%
Stage 5	0.02239	24.77	0.01278	54.6%

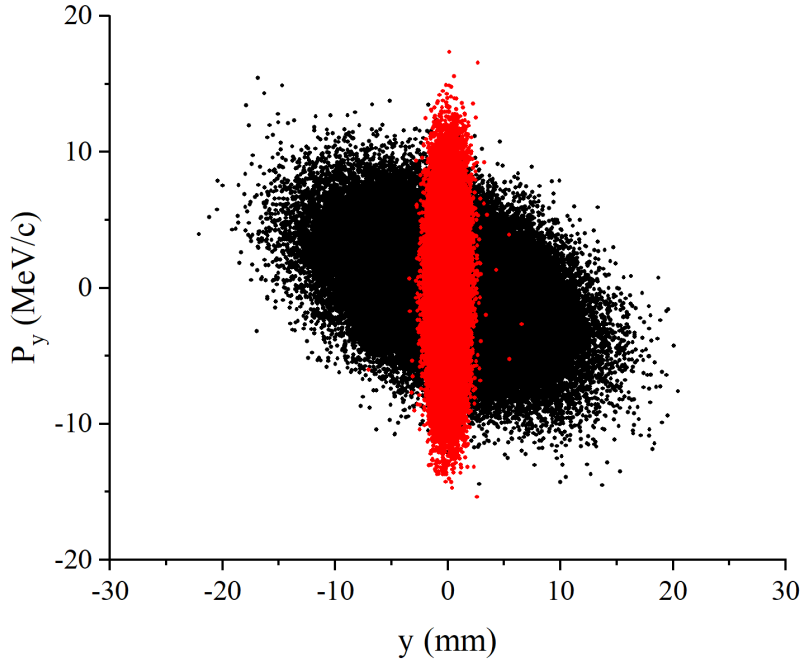
Final cooling lattice at CERN

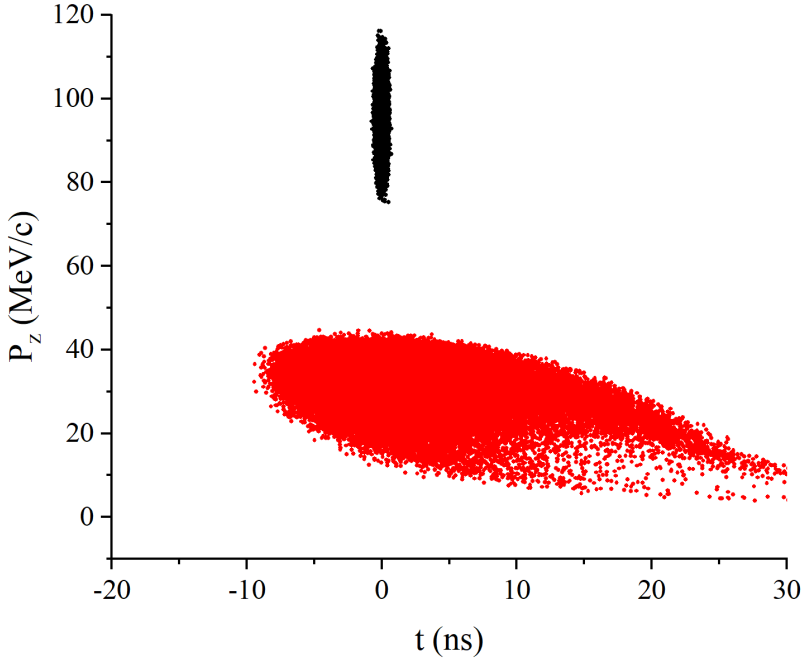
Cell	Transverse emittance [um]	Longitudinal emittance [mm]	6D emittance [mm]	Cumulative transmission [%]
1	275.2	2.7	586.1	97.5
2	212.7	5.9	645.4	94.1
3	170.4	6.8	582.8	88.9
4	138	12.4	617.5	81.9
5	102.5	20.6	600	74.4
6	81.3	25	548.8	61.1
7	59.5	32.7	486.9	53.1
8	50.8	43.6	482.8	46.9
9	41.2	48.4	434.2	37
10	32.9	66.1	414.6	31.7
11	29.5	82	414.5	28.5

- ✓ Initial emittance is from the output of stage 10 of the updated 6D cooling https://arxiv.org/abs/2409.02613
- ✓ Reduce the transverse emittance to ~22.5 μm with longitudinal emittance of 25 mm.

Particle distribution in phase space







Parameters of final cooling lattice

Stage	Stage length (m)	Peak on-axis Bz (T)	LH absorber length (m)	RF frequency (MHz)	Number of RF cells	Maximum RF gradient (MV/m)	RF phase (°)	RF cell length (m)
Stage 0	1.564	38.5	0.2028					
Stage 1	3.1978	-24.5	0.2486	107.2	4	12.01	22.95	0.25
Stage 2	3.8672	46.5	0.05543	82.1	2	7.84	33.44	0.25
Stage 3	4.5955	-41.6	0.04289	28.2	3	6.09	6.96	0.25
Stage 4	4.4233	47.4	0.03439	12.3	5	5.06	55.33	0.25
Stage 5	4.6552	-50	0.029	11.2	8	2.8	41.93	0.25

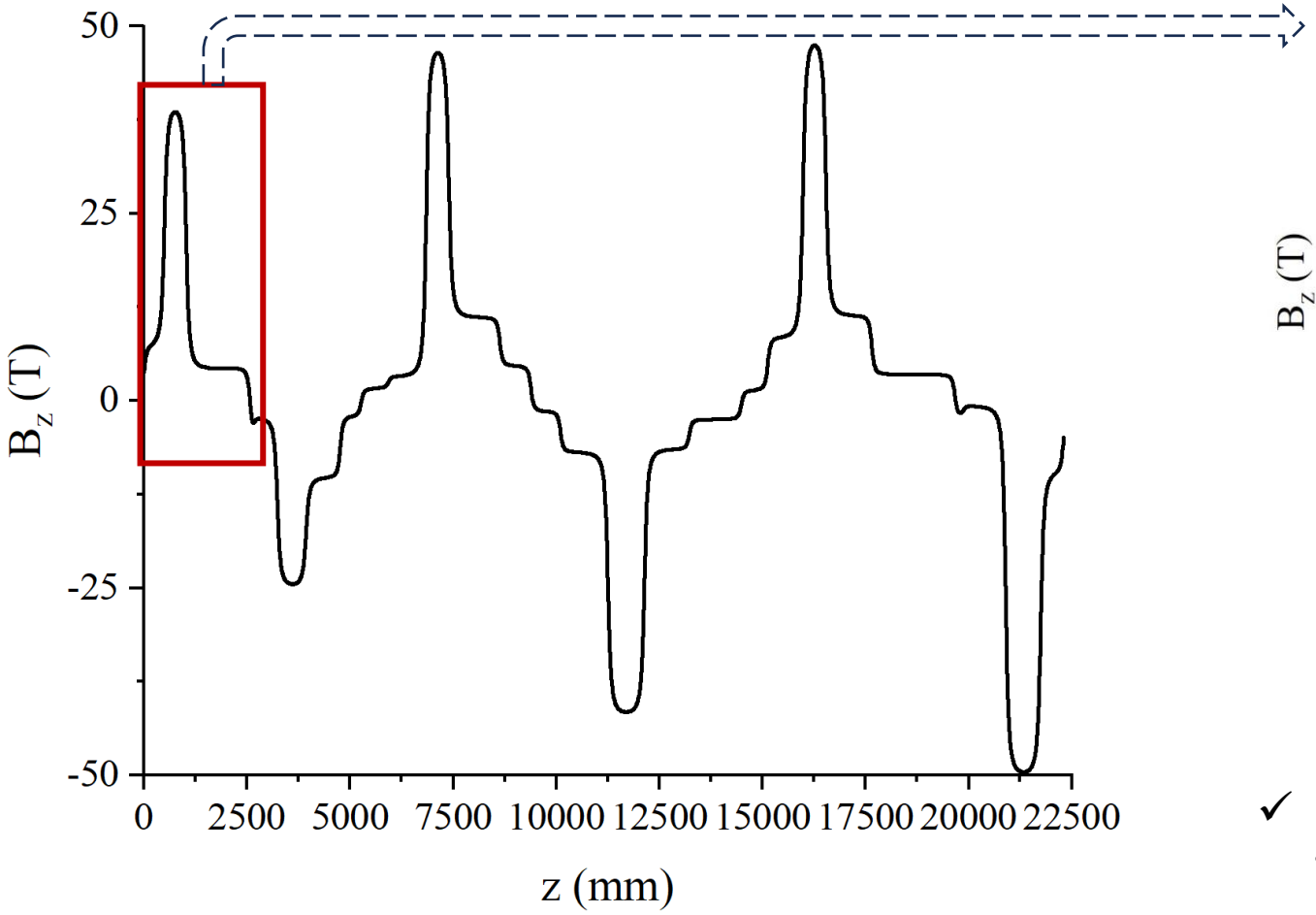
Updated final cooling lattice

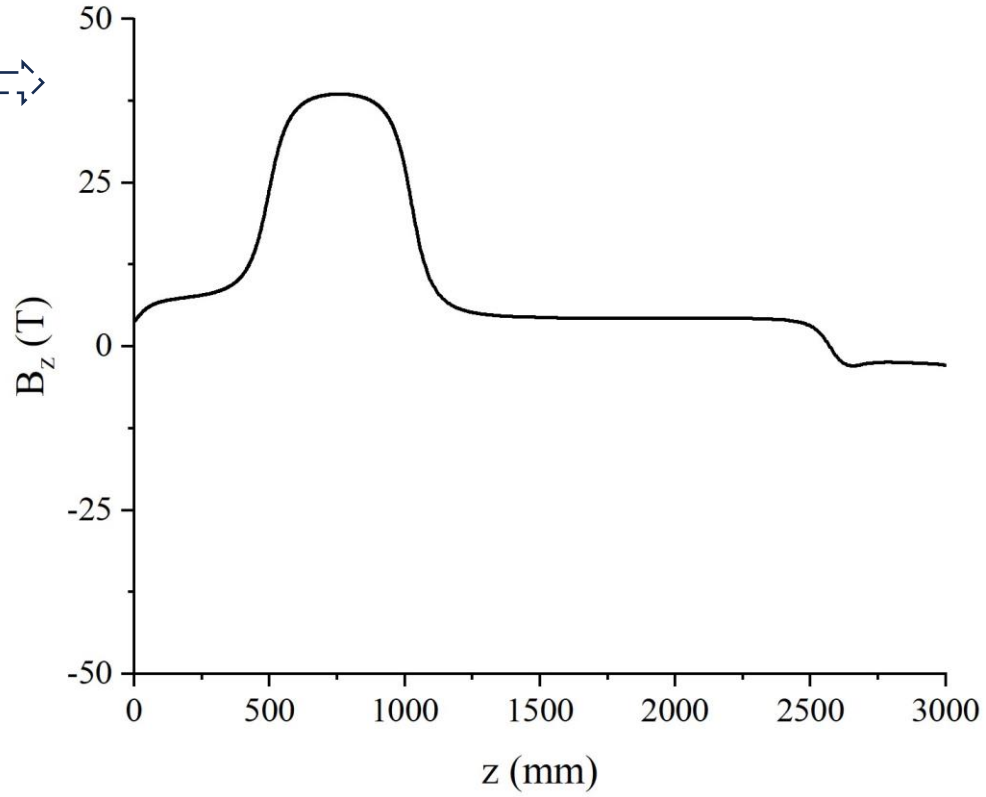
Stage length [m]	Solenoid Bz field on axis [T]	Low Bz drift field on axis	LH length [m]	RF frequency [MHz]	Number Accelerating RF	Number Rotating RF	RF tot length [cm]	Max. RF gradient [MV/m]	RF phase [deg]
1.4766	44.63	4.629	0.85	0	0	0	0	0	0
4.5738	44.63	4.629	0.466	111.06	5	5	2.5	19.81	-180
6.613	44.63	4.629	0.46958	56.85	7	10	4.25	14.17	90
7.75	44.63	4.629	0.4	40.13	8	9	4.25	11.9	51
5.0858	44.63	4.629	0.3	34.91	2	7	2.25	11.11	-10
6.863	44.63	4.629	0.25	30.61	10	5	3.75	10.4	-54
7.064	42	2	0.3	11.637	14	5	4.75	6.823	-82
6.6964	42	2	0.1	16.17	7	2	2.25	8.04	67
8.37	41	1	0.17	13.38	11	2	3.25	7.32	67
6.755	40.8	0.8	0.08	8.226	2	11	3.25	5.39	-6
7.595	40.8	0.8	0.0541	5.676	4	11	3.75	4.48	-96
~100									

Final cooling lattice at CERN

- ✓ Field in stage 5 of updated final cooling goes up to 50 T. (for better transmission)
- ✓ RF frequency varies from 107 to 11 MHz.

On-axis Bz





- ✓ Field is continuous in each stage and field-flipping region.

Conclusion

- Updated final cooling lattice reduces the transverse emittance to 22.5 μm with longitudinal emittance of 25 mm.
- Need 50 T field in the last stage.
- Will add windows for the RF cavities and absorbers and check its impact on cooling performance.

Stage	Transverse emittance (mm)	Longitudinal emittance (mm)	6D emittance (mm^3)	Cumulative transmission	Stage length (m)	Peak on-axis Bz (T)	LH absorber length (m)	RF frequency (MHz)	Number of RF cells	Maximum RF gradient (MV/m)	RF phase (°)	RF cell length (m)	Final Pz (MeV/c)	Final enrgy spread (MeV)	Final c*σt (m)
Start	0.1399	1.519	0.02972										95	3.35	0.04794
Stage 0	0.124	1.953	0.03022	99.60%	1.564	38.5	0.2028						77.1	4.218	0.07809
Stage 1	0.09702	4.207	0.0398	96.40%	3.1978	-24.5	0.2486	107.2	4	12.01	22.95	0.25	52.3	2.857	0.2445
Stage 2	0.0781	5.291	0.03274	86.90%	3.8672	46.5	0.05543	82.1	2	7.84	33.44	0.25	45.8	1.957	0.5265
Stage 3	0.04755	10.73	0.02447	71.20%	4.5955	-41.6	0.04289	28.2	3	6.09	6.96	0.25	30.1	1.455	0.9423
Stage 4	0.03227	16.46	0.01743	62.50%	4.4233	47.4	0.03439	12.3	5	5.06	55.33	0.25	32.35	1.503	1.4118
Stage 5	0.02239	24.77	0.01278	54.60%	4.6552	-50	0.029	11.2	8	2.8	41.93	0.25	30.9	1.606	1.7784