Update on Rectilinear 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 C. Rogers

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zhuruihu@impcas.ac.cn

Lattice of the pre-merging section

- Cooling cells parameters (updated)

	Stage 1	Stage 2	Stage 3	Stage 4
Cell length (m)	1.8	1.2	0.8	0.7
Stage length (m)	104.4	106.8	64.8	81.9
Pipe radius (cm)	28	16	10	7
$B_{z,max}$ (T)	2.5	3.7	5.7	7.2
Transverse beta β_T (cm)	70	45	30	23
Dispersion (mm)	60	57	40	30
On-axis wedge length (cm)	14.5	10.5	15	6.5
Wedge apex angle (deg)	45	60	100	70
Wedge window thickness (μm)	100	100	100	100
RF frequency (MHz)	352	352	704	704
Number of RFs	6	4	5	4
RF length (cm)	19	19	9.5	9.5
Maximum RF gradient (MV/m)	25.8	25.8	31.4	31.7
RF phase (deg)	18.5	23.2	23.7	25.7
RF inner-radius (mm)	326.2	326.2	163.1	163.1
RF window thickness (μm)	50	50	50	50

- Cooling performance (updated)

	$\varepsilon_{T,sim}$ (mm)	$\varepsilon_{L,sim}$ (mm)	$\varepsilon_{6D,sim}$ (mm^3)	Transmission
Start	17.1	45.9	13500	
Stage 1	5.21	17.7	483	75.1%
Stage 2	2.45	6.65	40.6	84.3%
Stage 3	1.55	3.69	9.07	86.3%
Stage 4	1.26	1.75	2.96	92.1%

Match the initial emittance in bunch merging paper

http://dx.doi.org/10.1103/PhysRevAccelBeams.19.031001

Lattice of the post-merging section

➢ Cooling cells parameters (updated)

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8	Stage 9	Stage 10
Cell length (m)	2.3	1.8	1.4	1.1	0.8	0.7	0.7	0.65	0.65	0.632
Stage length (m)	55.2	61.2	77.0	70.4	53.6	49	34.3	48.1	31.85	42.33
Pipe radius (cm)	23	19	12.5	9.5	6	4.5	3.7	2.65	2.2	2.1
$B_{z,max}$ (T)	3.1	3.9	5.1	6.6	9.1	11.5	13.0	15.8	16.6	17.2
Transverse beta β_T (cm)	35	30	20	15	10	6	5	3.8	3	2.7
Dispersion (mm)										
On-axis wedge length (cm)	37	32	24	20	12	11	10	7	7.5	7
Wedge apex angle (deg)	110	120	115	110	120	130	130	140	140	140
Wedge window thickness (μm)	100	100	100	100	50	20	20	20	10	10
RF frequency (MHz)	352	352	352	352	704	704	704	704	704	704
Number of RFs	6	5	4	3	5	4	4	4	4	4
RF length (cm)	25	22	19	22	9.5	9.5	9.5	9.5	9.5	9.5
Maximum RF gradient (MV/m)	21.01	22.68	24.27	25.03	23.46	30.48	30.22	25.76	17.49	20.22
RF phase (deg)	28.22	30.91	29.76	29.48	23.81	19.65	18.31	14.37	19.42	14.69
RF inner-radius (mm)	326.2	326.2	326.2	326.2	163.1	163.1	163.1	163.1	163.1	163.1
RF window thickness (μm)	50	50	50	50	50	20	20	20	10	10

The final normalized ε_T is 0.136 mm. (0.28 mm in MAP)

What about the cooling efficiency?

➢ Cooling performance (updated)

	$\varepsilon_{T,sim}$ (mm)	$\varepsilon_{L,sim}$ (mm)	$\varepsilon_{6D,sim}$ (mm^3)	Transmission
Start	5.129	9.991	262.5	
Stage 1	2.844	8.933	73.36	85.1%
Stage 2	2.018	5.871	24.22	89.7%
Stage 3	1.265	4.304	7.046	89.2%
Stage 4	0.9027	3.349	2.845	90.9%
Stage 5	0.6746	2.995	1.384	91.4%
Stage 6	0.4800	2.335	0.5497	87.7%
Stage 7	0.3668	2.119	0.2828	89.3%
Stage 8	0.2556	1.927	0.1248	86.8%
Stage 9	0.1841	1.839	0.06143	83.5%
Stage 10	0.1364	1.636	0.03000	83.8%

Cooling efficiency

➢ Key point - luminosity

$$\mathfrak{L} \approx f_r n_b \frac{N_+ N_-}{(4\pi)^2 \sigma_\perp^2} \frac{\tau_\mu e \bar{B}}{m_\mu}.$$

$$\sigma_\perp = \sqrt{\frac{m_\mu c \beta_\perp^* \varepsilon_\perp}{p}}$$

Luminosity is proportional to $\frac{N^2}{\beta^* \varepsilon_T}$

- Factor 1:

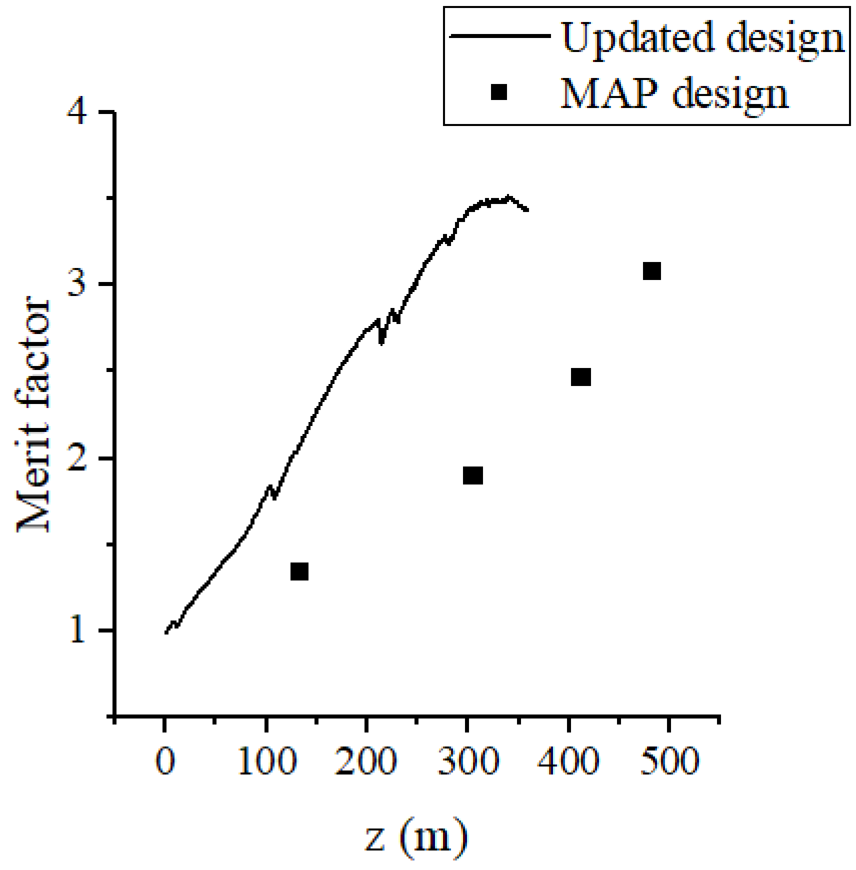
As β^* is the beta function at the collision point which is only decided by the final focusing quadrupoles , the merit is $\frac{N^2}{\varepsilon_T}$

- Factor 2:

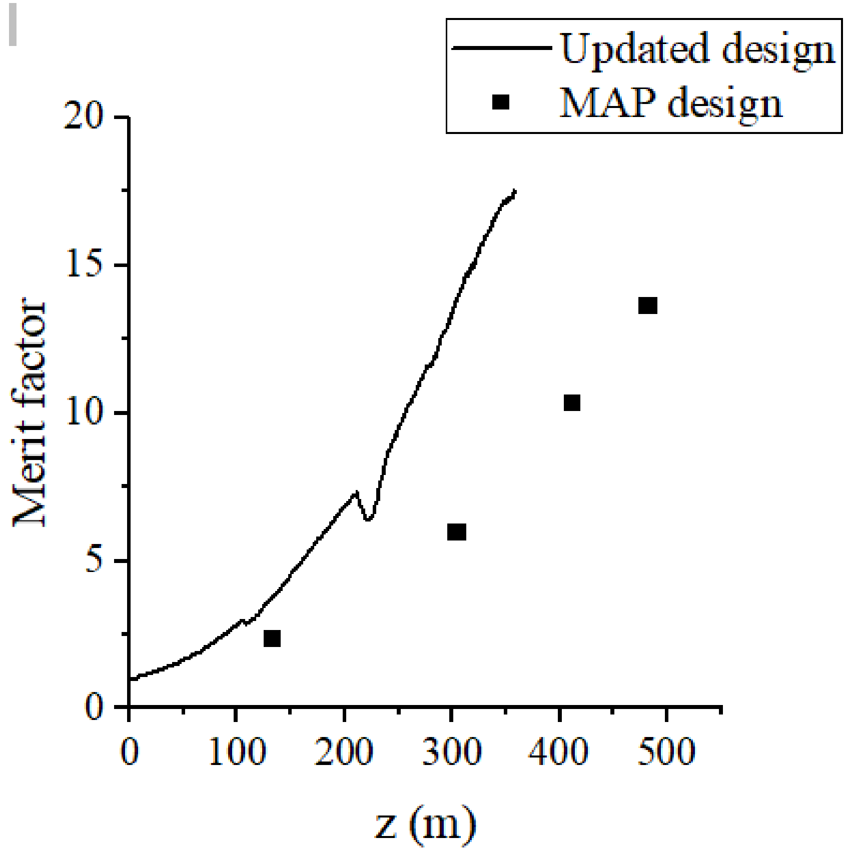
We let the β^* be σ_z. Also $\varepsilon_L = \sigma_z \sigma_\delta$. If we assume $\sigma_z \approx \sigma_\delta$, then the merit is $\frac{N^2}{\varepsilon_T \sqrt{\varepsilon_L}}$

Cooling efficiency (pre-merging)

- Merit 1: $\dfrac{\left(\frac{N(s)}{N(0)}\right)^2}{\varepsilon_T(s)/\varepsilon_T(0)}$

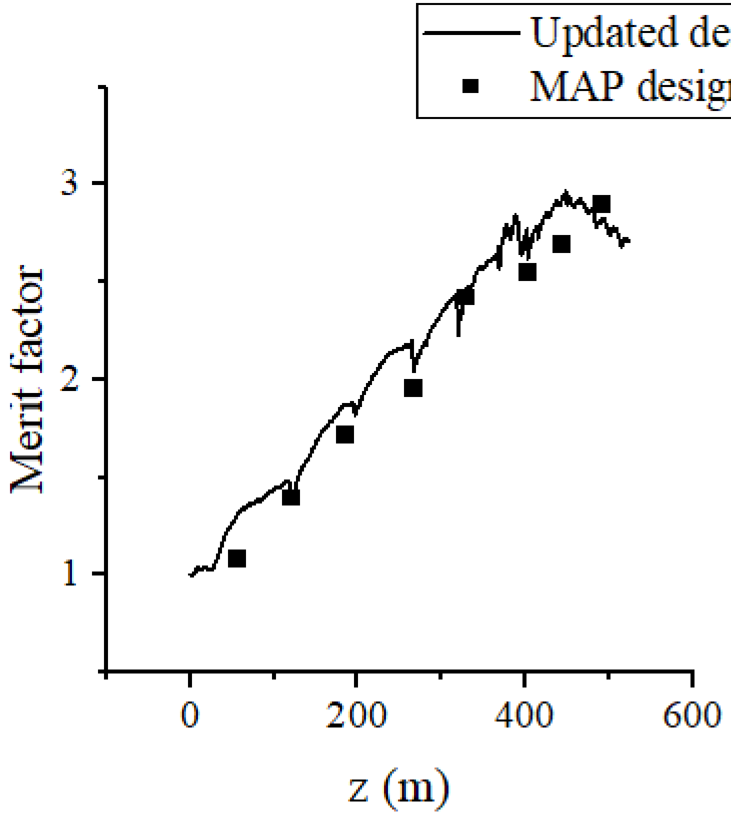


- Merit 2: $\dfrac{\left(\frac{N(s)}{N(0)}\right)^2}{\varepsilon_T(s)\sqrt{\varepsilon_L(s)}/(\varepsilon_T(0)\sqrt{\varepsilon_L(0)})}$

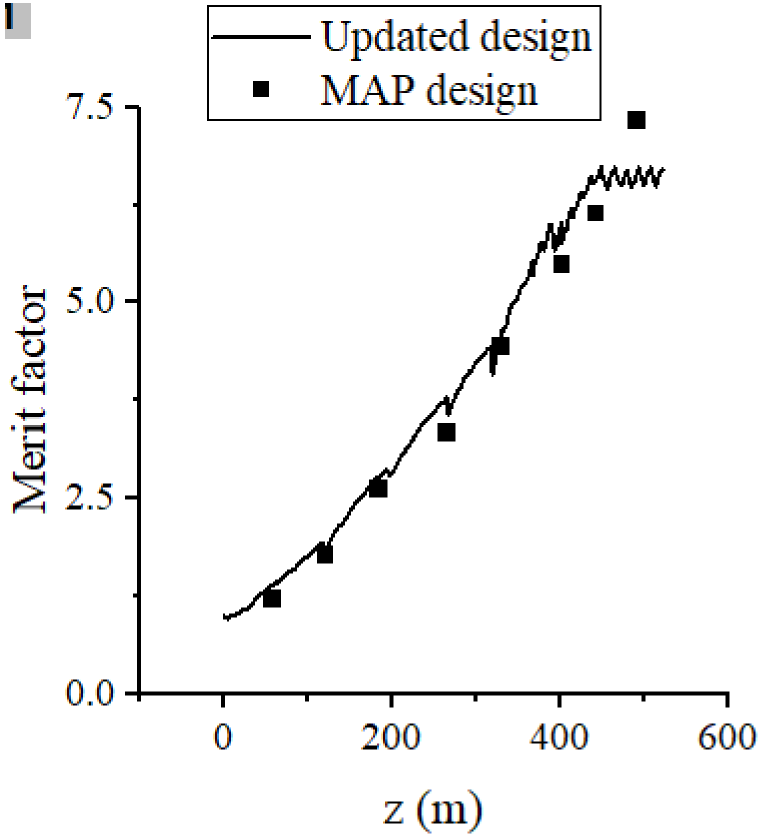


Cooling efficiency (post-merging)

- Merit 1: $\frac{\left(\frac{N(s)}{N(0)}\right)^2}{\varepsilon_T(s)/\varepsilon_T(0)}$



- Merit 2: $\frac{\left(\frac{N(s)}{N(0)}\right)^2}{\varepsilon_T(s)\sqrt{\varepsilon_L(s)}/(\varepsilon_T(0)\sqrt{\varepsilon_L(0)})}$



Questions

- Do we allow oscillation or slight reduction of the merit factor for the later stages in the rectilinear cooling?

- Is it possible if we use lower initial transverse emittance (0.136 mm) and we can reduce the output emittance of the final cooling by ~2 (25 μm to 12.5 μm)? Can we increase the luminosity in this way?

$P_{z,start}$ [MeV/m]	σE_{start} [MeV]	σt_{start} [mm]	$P_{z,end}$ [MeV/m]	σE_{end} [MeV]	σt_{end} [mm]	$\epsilon_{\|\|}$ [mm]	$\epsilon_{\perp}$ [μm]	N [%]
145.0	3.1	49.8	99.8	4.3	129.8	2.3	239.2	98
119.1	2.1	209.2	89.1	2.6	201.2	4.8	190.2	95
118.5	4.0	284.8	88.5	4.0	394.9	6.4	157.3	90
113.1	5.7	819.5	87.5	3.7	362.8	12.5	133.3	83
93.9	3.7	357.6	62.7	5.5	738.1	19.1	103.6	76
83.0	6.8	4606.2	58.0	2.7	1209.7	23.6	86.1	63
89.5	2.2	1378.5	55.3	3.0	1271.0	31.3	64.0	55
71.0	2.7	1785.7	56.4	3.1	1617.2	41.4	54.9	49
75.7	3.1	2120.8	52.3	3.5	1967.6	49.1	44.0	40
61.2	2.1	3199.0	43.5	2.8	2740.0	68.8	35.3	35
60.7	2.3	3456.5	49.5	2.9	3143.8	86.2	31.4	31

Final cooling lattice, 2024 IMCC Annual Meeting
https://indi.to/wpfZv