Muon Collider Overview

International
MUON Collider
Collaboration

Chris Rogers on behalf of WP4

Science & Technology Facilities Council
ISIS

WP4

- WP4 Covers
  - Target region
  - Capture solenoid beam physics
  - Chicane and proton absorber
  - Longitudinal capture system
    - Multi-frequency buncher and phase rotator
  - Charge separation
  - Rectilinear cooling
  - Bunch merge
  - Final cooling
  - Some elements of cooling Demonstrator

WP4 – Parameters Document

- WP4 Covers
  - Target region
  - Capture solenoid beam physics
  - ~~Chicane and proton absorber~~
  - ~~Longitudinal capture system~~
    - ~~Multi-frequency buncher and phase rotator~~
  - ~~Charge separation~~
  - Rectilinear cooling
    - MAP parameters
    - Partial IMCC parameters
  - ~~Bunch merge~~
  - Final cooling
    - MAP parameters
    - IMCC parameters
  - ~~Some elements of cooling Demonstrator~~
- This is a snapshot – optimisations/lattice design is ongoing

Target Region

Proton driver beam parameters		
	Baseline	**Range**
Beam power [MW]	2	1.5 - 3.0
Beam energy [GeV]	5	2 - 10
Pulse frequency [Hz]	5	5 - 50
Pulse intensity [10^{14} ppp]	5	3.7 - 7.5
Bunch per pulse [bpp]	1	1
Pulse length [ns]	2	1 - 2
Beam size σ_p [mm]	5	1 - 15
Impinging angle [deg]	0.0	0.0 - 10

	Yield per unit energy proton beam [10^{-2}/GeV/p]							
E_p [GeV]	3.0	4.0	**5.0**(B)	6.0	7.0	8.0	9.0	10.0
μ^+	2.8	2.6	2.4	2.3	2.2	2.1	1.9	1.9
μ^-	1.8	1.8	1.8	1.8	1.7	1.7	1.7	1.7
π^+	1.3	1.2	1.1	1.1	1.0	0.98	0.92	0.90
π^-	0.84	0.81	0.84	0.82	0.83	0.80	0.80	0.81

Table 10.3: Baseline engineering parameters of the Carbon target systems.

Production Target	
Material	Isostatic graphite
Dimensions	D30 x L800 mm
Cooling	Static Helium, 1 bar, Indirect cooling via vessel
Integration	CFC transversal supports, attached to cylindrical frame

Target Vessel

Table 10.5: Muon and pion yield per primary proton varying the proton beam size (target radius = 3 σ_p).
Table 10.6: Muon and pion yield per primary proton varying the target radius ($\sigma_p = 5$ mm).
Table 10.7: Muon and pion yield per primary proton varying the target length.
Table 10.8: Muon and pion yield per primary proton varying the target angle with the solenoid axis.

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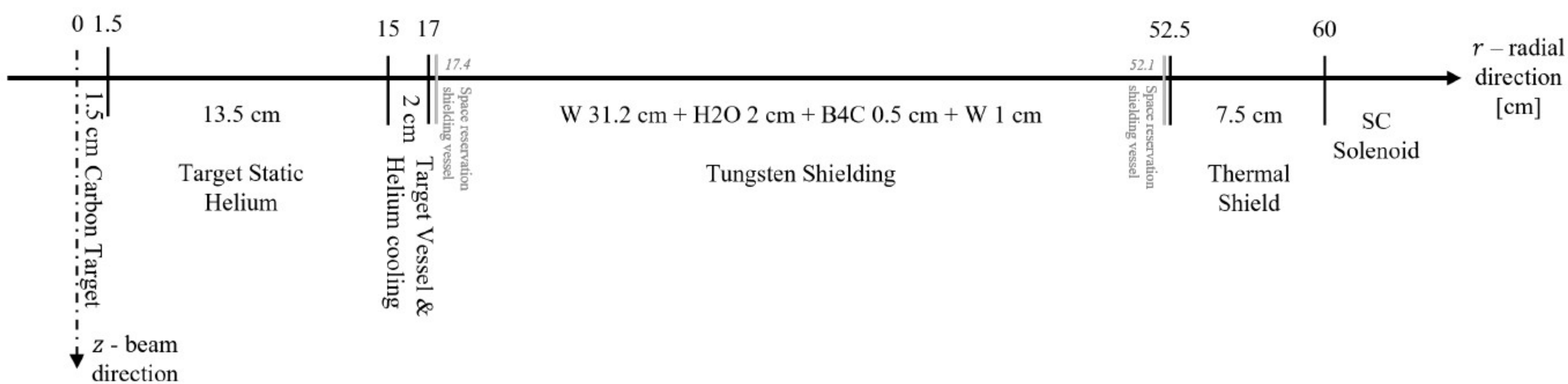
Target Region (2)

Inner radius of the magnet coils	Shielding thickness around the target	DPA/year [10^{-3}]	Dose [MGy/year]
Pure Tungsten			
60 cm	W 34.7 cm	3.10 ± 0.03	10.0 ± 0.3
65 cm	W 39.7 cm	1.70 ± 0.02	5.9 ± 0.2
70 cm	W 44.7 cm	0.93 ± 0.01	3.3 ± 0.1
75 cm	W 49.7 cm	0.51 ± 0.01	1.9 ± 0.1
80 cm	W 54.7 cm	0.28 ± 0.01	1.1 ± 0.1
85 cm	W 59.7 cm	0.16 ± 0.00	0.6 ± 0.1
Tungsten + Water + Boron-Carbide			
60 cm	**(B)W** 31.2 cm **+ H_2O** 2 cm **+ B_4C** 0.5 cm **+ W** 1 cm	1.70 ± 0.02	10.0 ± 0.3
65 cm	W 36.2 cm + H_2O 2 cm + B_4C 0.5 cm + W 1 cm	0.90 ± 0.02	5.6 ± 0.2
70 cm	W 41.2 cm + H_2O 2 cm + B_4C 0.5 cm + W 1 cm	0.49 ± 0.01	3.1 ± 0.1
75 cm	W 46.2 cm + H_2O 2 cm + B_4C 0.5 cm + W 1 cm	0.29 ± 0.01	1.9 ± 0.1
80 cm	W 51.2 cm + H_2O 2 cm + B_4C 0.5 cm + W 1 cm	0.16 ± 0.01	1.0 ± 0.1
85 cm	W 56.2 cm + H_2O 2 cm + B_4C 0.5 cm + W 1 cm	0.09 ± 0.01	0.6 ± 0.1

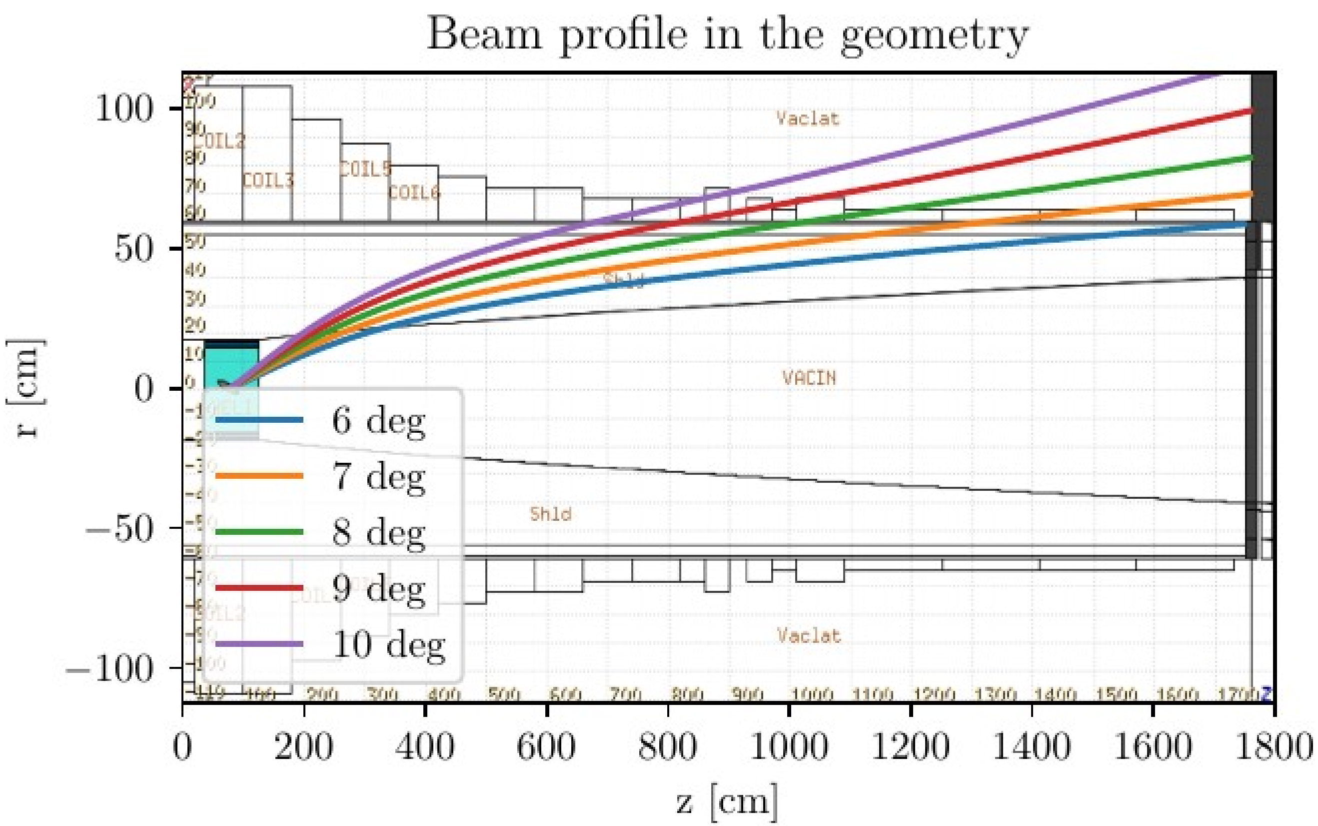


Target Region (2)

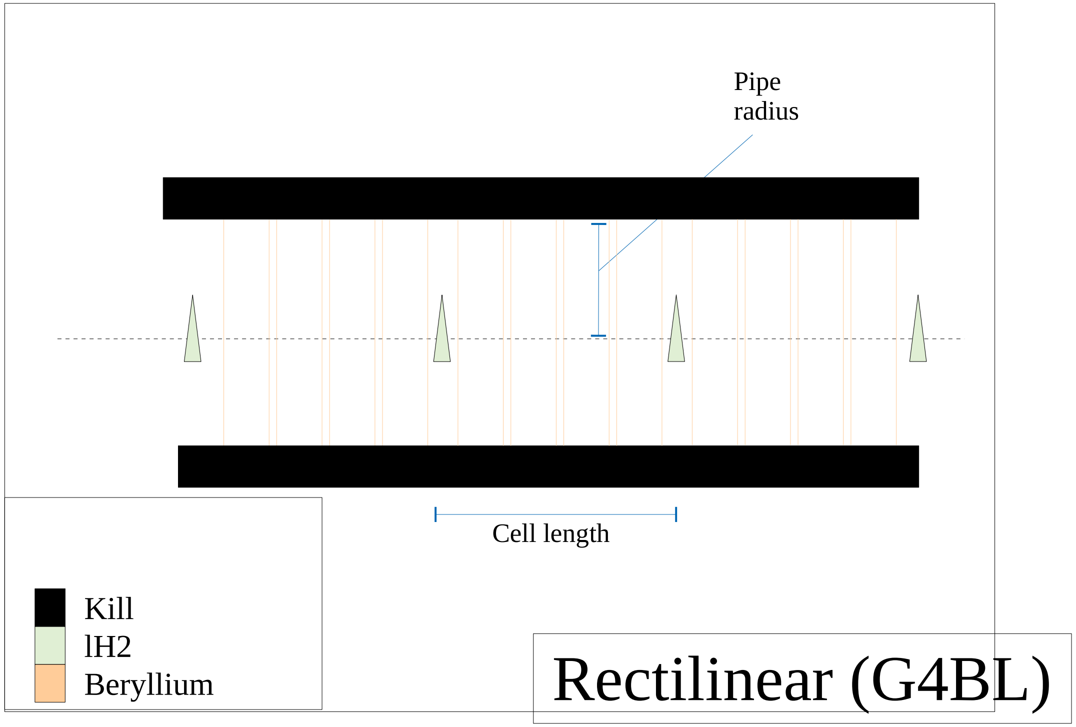
Table 10.10: IMCC Frontend Solenoid parameters (inner radius = 600 cm).

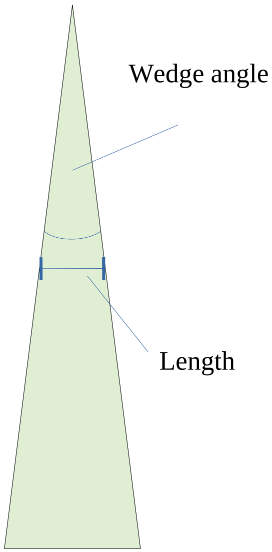
Magnet	R_c [m]	Z_c [m]	Δr [m]	Δz [m]	NR	NZ	I [A]
SC1	0.849	-1.185	0.498	0.830	12	20	58905
SC2	0.870	-0.335	0.540	0.830	13	20	60710
SC3	0.870	0.515	0.540	0.830	13	20	60392
SC4	0.808	1.365	0.415	0.830	10	20	51654
SC5	0.766	2.215	0.332	0.830	8	20	47469
SC6	0.704	3.065	0.208	0.830	5	20	46504
SC7	0.745	3.708	0.291	0.415	7	10	46293
SC8	0.704	4.423	0.208	0.415	5	10	53168
SC9	0.662	5.065	0.125	0.830	3	20	43280
SC10	0.662	5.915	0.125	0.830	3	20	42146
SC11	0.642	6.765	0.083	0.830	2	20	49452
SC12	0.642	7.615	0.083	0.830	2	20	44183
SC13	0.642	8.465	0.083	0.830	2	20	39567
SC14	0.642	9.315	0.083	0.830	2	20	32713
SC15	0.642	9.958	0.083	0.415	2	10	46717
SC16	0.642	10.673	0.083	0.415	2	10	45905
SC17	0.621	11.315	0.042	0.830	1	20	52310
SC18	0.621	12.165	0.042	0.830	1	20	56056
SC19	0.621	13.015	0.042	0.830	1	20	51602
SC20	0.621	13.865	0.042	0.830	1	20	51376
SC21	0.621	14.715	0.042	0.830	1	20	50471
SC22	0.621	15.565	0.042	0.830	1	20	52861
SC23	0.621	16.415	0.042	0.830	1	20	57438

Target Region (2)



Rectilinear Cooling





Rectilinear Cooling (MAP)

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Table 9.2: Parameters for each of the different cells in the rectilinear cooling system, reproduced from [5].

Stage	Cell Length [m]	Total Length [m]	RF frequency [MHz]	RF gradient [MV/m]	RF #	RF length [cm]	Coil tilt [deg]	Pipe radius [cm]	Dispersion [cm]	Wedge angle [deg]	Peak B_z T
A1	2.000	132.00	325	22.0	6	25.50	3.1	30.0	10.7	39	2.4
A2	1.320	171.60	325	22.0	4	25.00	1.8	25.0	6.8	44	3.5
A3	1.000	107.00	650	28.0	5	13.49	1.6	19.0	4.2	100	4.8
A4	0.800	70.40	650	28.0	4	13.49	0.7	13.2	1.9	110	6.0
B1	2.750	55.00	325	19.0	6	25.00	0.9	28.0	5.2	120	2.7
B2	2.000	64.00	325	19.5	5	24.00	1.3	24.0	5.0	117	3.7
B3	1.500	81.00	325	21.0	4	24.00	1.1	18.0	4.6	113	4.9
B4	1.270	63.50	325	22.5	3	24.00	1.1	14.0	4.0	124	6.1
B5	0.806	73.35	650	27.0	4	12.00	0.7	9.0	1.4	61	9.8
B6	0.806	62.06	650	28.5	4	12.00	0.7	7.2	1.2	90	10.8
B7	0.806	40.30	650	26.0	4	12.00	0.8	4.9	1.1	90	12.5
B8	0.806	49.16	650	28.0	4	10.50	0.6	4.5	0.6	120	13.6

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Rectilinear Cooling (updated)

Stage	Cell Length [m]	Total Length [m]	RF frequency [MHz]	RF voltage [MV]	Peak B_y [T]	Peak B_z [T]	Pipe radius]m	Wedge length [m]	Wedge angle [degree]
S1	2.3	XX	352	30.485	0.300	3.1	0.280	0.37	110
S2	1.8	XX	352	22.983	0.375	4.1	0.220	0.32	120
S3	1.4	XX	352	16.913	0.425	4.8	0.126	0.24	115
S4	1.1	XX	352	12.928	0.450	6.2	0.110	0.20	110
S5	0.8	XX	704	10.687	0.350	8.8	0.090	0.12	120
S6	0.8	XX	704	8.556	0.300	10.7	0.090	0.11	130
S7	0.7	XX	704	6.906	0.350	13.6	0.080	0.09	130
S8	0.7	XX	704	6.773	0.350	15.1	0.070	0.08	120
S9	0.7	XX	1408	6.174	0.150	16.9	0.060	0.073	120
S10	0.7	XX	1408	6.131	0.100	19.2	0.044	0.07	120

Table 9.3: Performance for the updated cooling system.

Stage	$\varepsilon_\perp$ [mm]	$\varepsilon_{//}$ [mm]	ε_{6D} [mm^3]	Trans [%]
initial	5.13	9.91	260	
S1	2.85	8.74	71.13	85.9
S2	1.97	6.08	23.79	91.2
S3	1.42	3.43	7.21	87.8
S4	1.09	2.53	3.12	92.4
S5	0.72	2.24	1.22	88.9
S6	0.49	2.14	0.56	89.5
S7	0.35	2.16	0.27	89.6
S8	0.24	2.23	0.13	85.4
S9	0.19	1.81	0.067	79.0
S10	0.14	1.69	0.034	77.5

Final cooling (MAP)

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Table 9.6: Longitudinal parameters for the final cooling system, reproduced from [3].

Stage (Solenoid)	P [MeV/c]	Energy spread [MeV]	LH2 thickness [cm]	Drift length [m]	rf length [m]	rf frequency [MHz]	Field flip
1 (I)	135.0	2.29	65	0.434	2.25	325	Yes
2 (I)	130.0	2.48	60	0.459	2.25	250	Yes
3 (I)	129.0	2.78	60	0.450	2.5	220	No
4 (I)	129.0	3.10	59	0.458	2.5	201	No
5 (II)	122.0	3.60	57	1.629	5.0	201	Yes
6 (II)	124.0	4.90	53	2.22	4.5	180	No
7 (II)	116.0	3.40	42	2.21	3.25	150	No
8 (II)	111.0	3.90	40	2.0	3.5	150	No
9 (III)	106.0	3.50	40	3.13	5.0	125	Yes
10 (III)	98.0	3.07	35	3.13	5.0	120	No
11 (III)	89.4	3.11	20	3.12	5.0	110	No
12 (III)	87.9	2.76	20	3.1	8.0	100	No
13 (IV)	85.9	2.67	20	3.0	7.5	100	Yes
14 (IV)	79.7	3.08	15	2.7	7.0	70	No
15 (IV)	71.1	4.0	15	2.6	6.0	50	No
16 (IV)	71.0	3.80	13	2.5	6.0	20	No

Table 9.5: Parameters for the final cooling solenoids. FWHM denoted the Full-Width Half-Maximum of the B_z field profile on the axis of the solenoid. Parameters are reproduced following figure in [3].

Stage	Peak B_z [T]	Min. B_z [T]	FWHM [m]	Number of Cells
Part I	26.8	3.9	1.1	4
Part II	27.0	4.0	1.2	4
Part III	30.0	2.0	0.9	4
Part IV	28.8	1.6	0.9	4

Final cooling (Updated)

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Cell	$\sigma_{t,LH}$ [mm]	f_{RF} [MHz]	G [MV/m]	$N_{rot.}$	$N_{accel.}$	$P_{z,end}[MeV/c]$
1	98	159.88	15.17	5	7	135
2	191	78.24	10.62	1	9	140
3	218	68.75	9.95	2	6	129.4
4	271	55.3	8.92	3	2	120
5	365	41.05	7.69	4	8	128
6	499	30.02	6.57	2	4	109.4
7	639	23.5	5.81	8	3	95
8	1019	14.7	4.6	7	2	91
9	1412	10.61	3.9	6	1	78

Cell	$\epsilon_{\perp} \mu m$	$\epsilon_{\parallel} [mm]$	σE [MeV]	σ_t [mm]	ΔN %	LH [m]
1	241	2.2	1.25	189	97.8	0.85
2	201	3.8	1.9	213	96.3	0.6
3	183	6	2.6	245	94.8	0.582
4	161	9.1	2.9	330	93.3	0.598
5	146	14.4	3.2	475	91.9	0.5
6	138	26.1	4.7	587	90.5	0.564
7	119	42.4	4.1	1082	89.1	0.33
8	95	50.6	3.9	1352	87.7	0.15
9	56	59.7	3.8	1672	84.1	0.137
10	18	83.3	3.1	2800	77.4	0.15

Conclusions

- Current parameters documented
  - Target geometry
  - Rectilinear cooling
  - Final cooling
  - All a work in progress
    - Target/beam dump under investigation
    - Longitudinal/RF needs more development
- Some work still needed
  - More detail on magnet parameters in "updated" lattices
  - This is a snapshot - optimisations are still ongoing
- Seek to store lattices somewhere
  - Prepared https://github.com/orgs/MuonCollider-WG4
    - Should be writeable by anyone, given suitable permissions
  - Tag a release somewhere
  - A lab-supported git repo would be better