International MUON Collider Collaboration

CERN

Parameters: MDI and radiation (collider)

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Introduction

- Radiation-related topics are addressed in different chapters of the parameter document (see below)
- We also tried to include parametric studies to motivate the choice of certain parameter values
- Chapter 10 (**Front-end**)
  - ▶ Pion/muon production (vs target and beam parameters)
  - ▶ Radiation load to solenoids and shielding requirements

  Discussed by C. Rogers last week and not repeated here
- Chapter 17 (**Radiation**)
  - ▶ Radiation load to collider ring arc magnets & shielding requirements → radial build in Chapter 6 (**Collider**)
  - ▶ Neutrino-induced dose in soil for mono-directional muons
- Chapter 24 (**MDI**)
  - ▶ Beam-induced background (BIB) and Machine-Detector Interface (MDI)

Note: some of the presented results are rather reference values than parameters

Focus is on 10 TeV collider, although some results for 3 TeV are also given

Radiation in the collider (Chapter 17)

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Basic assumptions concerning muon decays in the collider ring:

Table 1.4: Parameters for radiation studies (collider ring). The number of decays consider the contribution of both beams.

	3 TeV	**10 TeV**
Particle energy	1.5 TeV	5 TeV
Bunches/beam	1	1
Muons per bunch	2.2×10^{12}	1.8×10^{12}
Circumference	4.5 km	10 km
Muon decay rate per unit length	4.9×10^{9} $m^{-1}s^{-1}$	1.8×10^{9} $m^{-1}s^{-1}$
Power ($e^{\pm}$)/meter	0.411 kW/m	0.505 kW/m
Operational years	5	5
Operational time per year (average)	1.2×10^{7} s (=139 days)	1.2×10^{7} s (=139 days)
Total decays per unit length (all years)	2.93×10^{17} m^{-1}	1.08×10^{17} m^{-1}

From Chapter 6 (Collider), repeated here for completeness

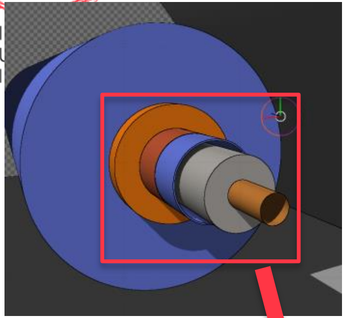
Derived from basic physics (note: e+/- carry on average 35% of the energy released in muon decays)

Note: with L_{inst} = 17x10^{34}cm^{-2}s^{-1} at 10 TeV (from Chapter 6) one gets 10 ab^{-1} after 5 years (for 1.2x10^{7} s/year)

Operational scenario – **shall be used consistently for all radiation studies**, e.g.:

- Cumulative radiation damage in collider magnets
- Cumulative radiation damage in detector (Chapter 24 (MDI))
- Radiation protection (environmental dose/year)

Radiation load to magnets (Chapter 17)



Parametric shielding study (collider arcs):

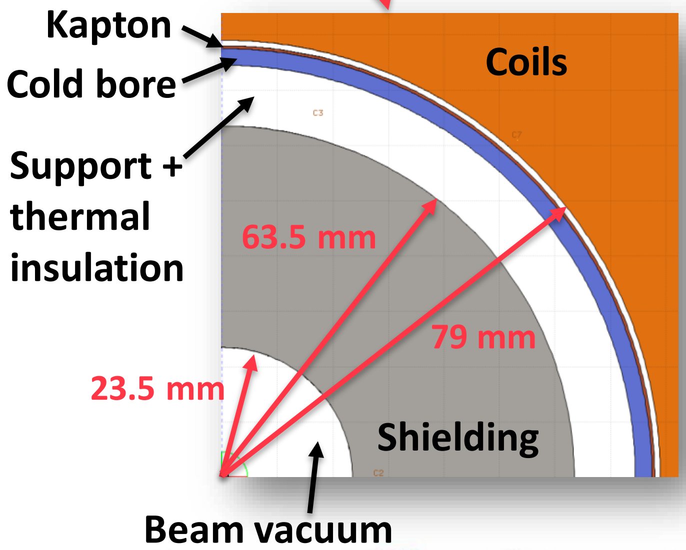


Table 1.5: Power load and radiation damage in collider ring arc magnets (10 TeV) as a function of the radial tungsten absorber thickness. The power penetrating the shielding does not include neutrinos, since they are not relevant for the radiation load to the machine; the percentage values are given with respect to the power carried by decay electrons and positrons. The results include the contribution of both counter-rotating beams.

	2 cm	3 cm	4 cm
Beam aperture	23.5 mm	23.5 mm	23.5 mm
Outer shielding radius	43.5 mm	53.5 mm	63.5 mm
Inner coil aperture	59 mm	69 mm	79 mm
Power penetrating tungsten absorber	19.1 W/m (3.8%)	8.2 W/m (1.6%)	4.1 W/m (0.8%)
Peak power density in coils	6.5 mW/cm^3	2.1 mW/cm^3	0.7 mW/cm^3
Peak dose in Kapton insulation (5 years)	56 MGy	18 MGy	7 MGy
Peak dose in coils (5 years)	45 MGy	15 MGy	5 MGy
Peak DPA in coils (5 years)	8×10^{-5} DPA	6×10^{-5} DPA	5×10^{-5} DPA

Decisive quantity

Radial build of arc magnets:

Table 1.2: Tentative 1D radial build of the collider arcs, defining the inner aperture of coils (10 TeV).

	Thickness	Outer radius
Beam aperture	23.49 mm	23.49 mm
Coating (copper)	0.01 mm	23.5 mm
Radiation absorber (tungsten alloy)	40 mm	63.5 mm
Shielding support and thermal insulation	11 mm	74.5 mm
Cold bore	3 mm	77.5 mm
Insulation (Kapton)	0.5 mm	78 mm
Clearance to coils	1 mm	79 mm

Radial build is included in Chapter 6 (Collider)

Neutrino cross section and dose kernels (Chapter 17)

G. Lerner

Table 1.7: Average macroscopic cross section in soil of neutrinos from positive and negative muon decays (based on the composition and density defined in Table 1.6) for different energies of the muon beam, obtained as the convolution between the energy distribution of the neutrinos and their macroscopic cross sections.

	μ^+ decay		μ^- decay	
Muon Energy	$\Sigma^{\nu_e}_{\text{avg}}$ **[cm^{-1}]**	$\Sigma^{\overline{\nu}_\mu}_{\text{avg}}$ **[cm^{-1}]**	$\Sigma^{\nu_\mu}_{\text{avg}}$ **[cm^{-1}]**	$\Sigma^{\overline{\nu}_e}_{\text{avg}}$ **[cm^{-1}]**
1.5 TeV	$4.56 \cdot 10^{-12}$	$2.87 \cdot 10^{-12}$	$5.27 \cdot 10^{-12}$	$2.47 \cdot 10^{-12}$
5 TeV	$1.39 \cdot 10^{-11}$	$9.22 \cdot 10^{-12}$	$1.60 \cdot 10^{-11}$	$7.96 \cdot 10^{-12}$

Dose kernels (peak, width) per decay to be folded with beam phase space distribution:

Table 1.9: Effective dose kernel parameters of neutrino-induced radiation in soil at different baseline distances from the muon decay, for a muon beam energy of 5 TeV. The peak dose per muon decay and the lateral width of the dose profile (σ) have been derived from Gaussian fits of the FLUKA results.

	μ^-		μ^+	
Distance	**Peak eff. dose [pSv/decay]**	σ **[m]**	**Peak eff. dose [pSv/decay]**	σ **[m]**
5 km	$1.57 \cdot 10^{-5}$	0.05	$1.63 \cdot 10^{-5}$	0.05
10 km	$4.86 \cdot 10^{-6}$	0.10	$5.38 \cdot 10^{-6}$	0.10
15 km	$2.54 \cdot 10^{-6}$	0.15	$2.70 \cdot 10^{-6}$	0.14
20 km	$1.56 \cdot 10^{-6}$	0.19	$1.55 \cdot 10^{-5}$	0.20
40 km	$4.80 \cdot 10^{-7}$	0.37	$4.62 \cdot 10^{-6}$	0.38
60 km	$2.33 \cdot 10^{-7}$	0.54	$2.22 \cdot 10^{-6}$	0.55
80 km	$1.38 \cdot 10^{-7}$	0.71	$1.31 \cdot 10^{-7}$	0.73
100 km	$9.16 \cdot 10^{-8}$	0.87	$8.63 \cdot 10^{-8}$	0.90

Note: we do <u>NOT</u> report absolute dose values in the parameter document (Sv/year)

Would depend on lattice as well as periodic movement of magnets.

MDI – nozzle geometry (MAP) (Chapter 24)

D. Calzolari

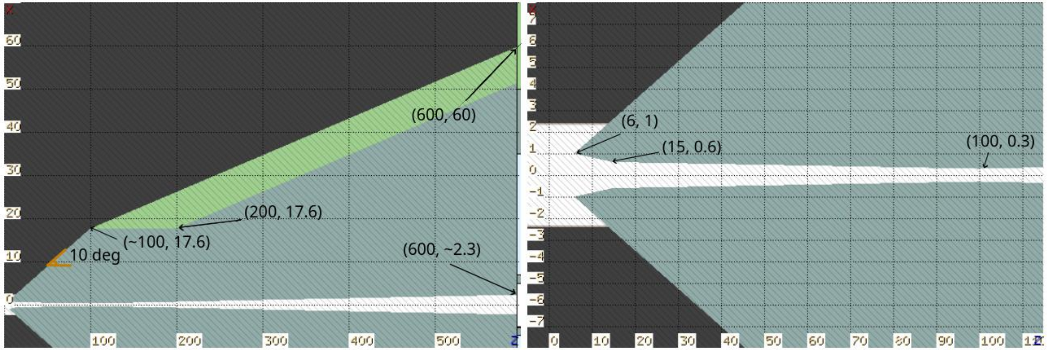


Fig. 1.1: Geometry of the right nozzle (from MAP). The left nozzle has the same shape, but is mirrored with respect to the interaction point (origin). The coordinates defining the nozzle geometry are included as numerical values in the figure (z, r). All numbers are given in cm. The beam pipe connecting the two opposite nozzles is made of beryllium, with an internal radius of 2.3 cm and a thickness of 1 mm.

Note: we still use the MAP nozzle (1.5 TeV), but the optimization for 3 TeV and 10 TeV will be an important task in the coming months

Coordinate points defining the nozzle and hence the beam aperture as well as the inner detector envelope (up to L*):

Table 1.2: Coordinates defining the inner aperture of the MAP-like nozzle used in the background studies. The first point corresponds to the nozzle tip.

z	r
6 cm	1 cm
15 cm	0.6 cm
100 cm	0.3 cm
600 cm	2.3 cm

Table 1.3: Coordinates defining the outer surface of the MAP-like nozzle used in the background studies. The first point corresponds to the nozzle tip.

z	r
6 cm	1 cm
100 cm	17.6 cm
600 cm	60 cm

Table 1.4: Material composition of the MAP-like nozzle used in the background studies.

Component	Density	Element	Atomic fraction
EM shower absorber	19.3 g/cm^3	W	1
Neutron absorber	0.918 g/cm^3	H	0.4
		C	0.2
		B	0.4

MDI – background particles entering detector (Chapter 24)

D. Calzolari

Table 1.5: Particle production and transport thresholds assumed in the background simulations.

Particle type	Threshold
Electrons, positrons and photons	100 keV
Hadrons and muons	100 keV
Neutrons	0.01 meV

Information about background particles kept to a minimum (for the future: need a better figure of merit for the background)

Table 1.6: Number of secondary particles (muon decay) entering the detector volume (10 TeV). Only particles above the threshold values in Table 1.5 were included. The multiplicities include only the contribution of one beam and correspond to one bunch crossing.

Particle type	10 TeV optics v4	10 TeV optics v6
γ	9.6×10^7	2.4×10^8
n	9.2×10^7	1.3×10^8
e^-	6.9×10^5	1.3×10^6
e^+	1.4×10^5	2.3×10^6

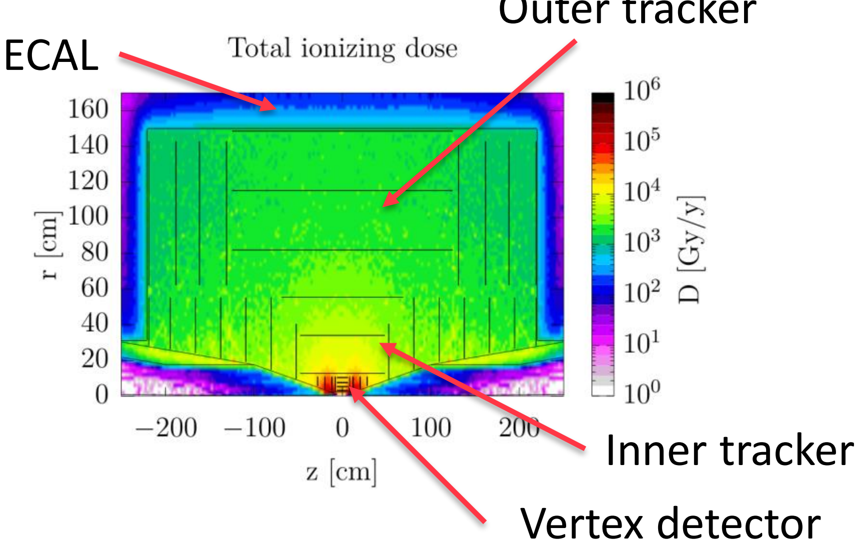
Longer straight section

Note: the calculations were done for a MAP-like nozzle

MDI – radiation damage in detector (Chapter 24)

D. Calzolari

Total ionizing dose (per year):



1 MeV neutron-equivalent fluence (per year):

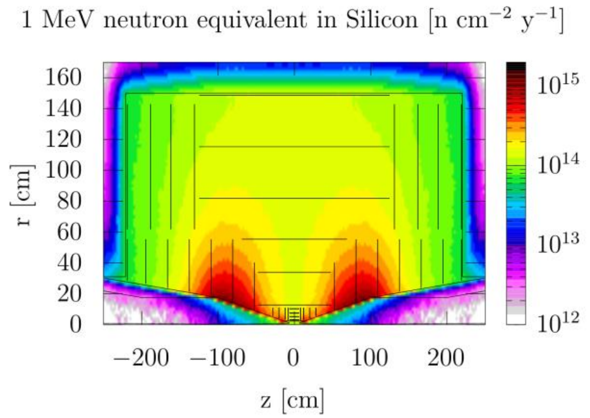


Table 1.6: Maximum values of the ionizing dose and the 1 MeV neutron-equivalent fluence (Si) in a CLIC-like detector. All values are per year of operation and include only the contribution of muon decay.

	Dose	1 MeV neutron-equivalent fluence (Si)
Vertex detector	200 kGy	3×10^{14} n/cm^2
Inner tracker	10 kGy	1×10^{15} n/cm^2
ECAL	2 kGy	1×10^{14} n/cm^2

Note: the calculations were done for a CLIC-like detector, assuming a MAP-like nozzle

Questions / open points

Not included in the document: Radiation estimates for accelerator (studies did not yet start)

Anything else missing, which should be included?

We still need to polish Chapter 17 and 24 (author list, references, …)