Collider Ring Parameters

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- Luminosity
- Collider Ring Parameters
- Summary

Luminosity

- Luminosity per IP given by: $L = \frac{N^2}{4\pi\, \varepsilon_{ph} \beta^*} f_{hg}\, f_r \frac{\gamma\, T_\mu}{2T_{rev}}$

  for round muon beams and one bunch per beam and with
  - f_r the complex repetition rate, N the number of muons in bunch
  - $\varepsilon_{ph} = \varepsilon_n/\gamma$ the physical rms emittance with $\varepsilon_n = 25\ \mu\mathrm{m}$ the normalized rms emittance and γ the relativistic Lorentz factor
  - β^* the Twiss betatron function at the IP, σ_z the rms bunch length
  - $T_\mu \approx 2.2\ \mu s$ the muon life-time at rest, T_{rev} the revolution time
  - f_{hg} the “hourglass” luminosity reduction factor a function of σ_z/β^* (for short bunches $f_{hg}(\sigma_z \ll \beta^*) \approx 1$)
- Assumptions
  - Bunch length $\sigma_z = \varepsilon_L/(\gamma\, \sigma_\delta)$ expressed by geometric longitudinal rms emittance ε_L and rms relative momentum spread
  - $\beta^* = \sigma_z$ giving moderate luminosity loss due to hourglass effect $f_{hg} = 0.758$
  - Revolution time $T_{rev} = 2\pi \frac{\gamma\, E_\mu}{e\, c^2\, \bar{B}}$ with $E_\mu = 105.658\ \mathrm{MeV}$ the muon rest energy and $\bar{B}$ the average bending field

→ gives luminosity per IP $L = \frac{e\, c^2\, T_\mu}{16\, \pi^2\, E_\mu} \frac{f_r\, N^2\, \gamma^2\, \sigma_\delta\, \bar{B}\, f_{hg}}{\varepsilon_n\, \varepsilon_L}$

Luminosity

Incoming beam

- Emittances determined by ionization cooling
- Luminosity per beam power increase with beam power ∝ $(f_r\,N\,\gamma)$ under assumptions made
- Large bunch population N gives higher lumi and corresponds to lower repetition rate for given beam power => nominal N/ε_n close to beam-beam limit

Constant $11.83\ \mathrm{T}^{-1}$

$$L = \overbrace{\frac{e\,c^2\,T_\mu}{16\,\pi^2\,E_\mu}}\ \overbrace{\frac{(f_r\,N\,\gamma)\,N\,\gamma}{\varepsilon_n\,\varepsilon_L}}\ \underbrace{\sigma_\delta\,\bar{B}\,f_{hg}}$$

Few collider parameters to maximise luminosity

- Large (average bending) magnetic field helps
- Large longitudinal acceptance to operate with large rms momentum spread σ_δ => corresponds to small $\beta^* = \sigma_z$ - both a challenge for lattice design

- Consequence of assumption and optimizations made:
  - Bunch length σ_z and β^* decrease with energy
  - Divergence at IP independent of energy!
  - Lattice design becomes more difficult for higher energies (higher beam rigidity, longer innertriolet, more chromatic effects …)

Nominal 10 TeV com Collider Parameters

Parameter	Symbol	Value
Beam energy	E	$5000\ \mathrm{GeV}$
Relativistic Lorentz factor	γ	$47\,322$
Circumference	C	$\approx 10\,000\ \mathrm{m}$
Magnetic (average bending) field	$\bar{B}$	$\approx 10.48\ \mathrm{T}$
Repetition rate	f_r	$5\ \mathrm{Hz}$
Bunch intensity (one bunch per beam)	N_μ	$1.8 \cdot 10^{12}$
Beam power for both beams together	P_B	$14.4\ \mathrm{MW}$
Power from muon decays to W absorber	P_L	$\approx 5\ \mathrm{MW}$
Power from decays to cold mass (40 mm W)		$\approx 5\ \mathrm{W/m}$
Normalized transverse rms emittance	ε_n	$25\ \mu\mathrm{m}$
Physical transverse rms emittance	ε_{ph}	$0.528\ \mathrm{nm}$
Long. geometric rms emittance $\gamma\ \sigma_z\ \sigma_\delta$	ε_L	$70\ \mathrm{mm}$
Rms relative momentum spread	$\sigma_\delta = \sigma_p/p$	$1 \cdot 10^{-3}$
Rms bunch length	σ_z	$1.5\ \mathrm{mm}$
Twiss betatron function at the IP	β^*	$1.5\ \mathrm{mm}$
Rms beam size at IP	$\sigma_{\perp,IP}$	$0.89\ \mu\mathrm{m}$
Luminosity	L	$19.5 \cdot 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
Beam-beam tune shift per IP		0.078

Summary

- Parameters driven by maximization of luminosity
  - Little (no?) margin to change without lumi reduction
- Collider design challenging
  - Optics for small β^* with large beam rigidity and momentum spread
    - Large chromatic effects with strong quadrupoles at location with large β’s
    - Challenging chromatic compensation scheme and neg. momentum compaction arcs
  - Energy deposition and radiation from muon decay products
  - Radiation due to neutrinos reaching Earth’s surface
    - “Wobbling” scheme – challenging mechanical system, impact optics design
  - Beam induced background to experiment
- Some of the impacts on hardware
  - High field, large aperture magnets, most of the them combined function (e.g., horizontal bending, quadrupolar component and small vertical bending for “wobbling”)
    - Stringent field quality requirements for some magnets conflicting with feasibility?
    - Short straight sections between magnets – Feasible field versus position profiles?
  - Showers from muon decay products mostly stopped by W absorber
    - Cryogenic system to remove residual heat load to cold mass (and W absorber ..)
  - Precise (how?) mechanical magnet movement system for wobbling .. feasibiliy?