Energy deposition studies for D1 and Q5 masks

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with input from M. Fraser

WP14 Meeting
June 27$^{\text{th}}$, 2017

Introduction

Scope of this talk:

- **D1 protection** downstream of the TDIS in case of **injection kicker failures**: Effects of
  - **TCDD**
  - Vacuum modules and transition tubes
  - Additional shielding **(TCMD)** for D1

  on the **energy deposition in the D1 coils**

- **Q5 protection** downstream of the TCDQ in case of **asynchronous beam dumps**: Additional shielding for the Q5 and effect on the **energy deposition in the Q5 coils**

Contents

Scenario and Boundary Conditions

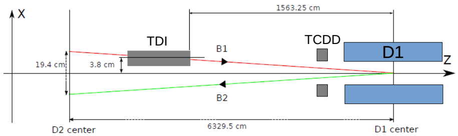
- Beam Parameters for Run 3:

	STD	BCMS
$\epsilon^n_{x,y}$	2.08 μm·rad	1.37 μm·rad
I_b	2.3×10^{11} ppb	2.0×10^{11} ppb

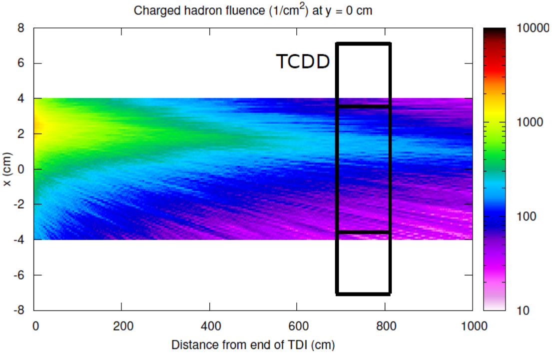
- p+ simulated with **injection energy of 450 GeV**
- Simulation of a **STD beam impact on the TDIS with impact parameter 1 σ** ($\rightarrow$ worst case in terms of energy deposition in the D1 coils) due to injection kicker failure
- Scoring of the energy deposition in the D1 coils as result of particle showers emerging from the TDIS

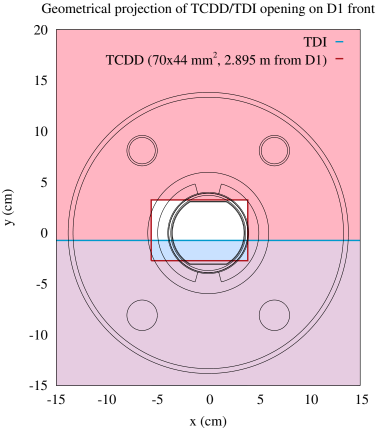
Injection failures: protecting the superconducting D1

TDI located between separation dipoles:



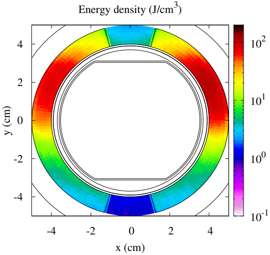
- → Beams have a horiz. angle of ∼1.5 mrad
- → TCDD opening sym. around machine axis
- → Provides asym. protection of D1 coils



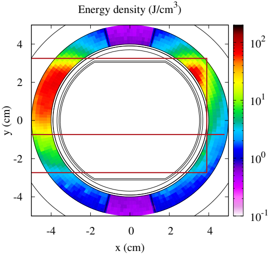


Efficacy of the existing TCDD (grazing impact on TDI)

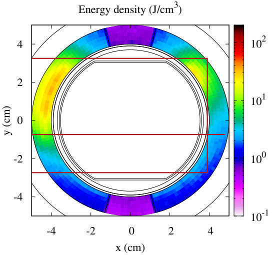
No TCDD:



With TCDD:

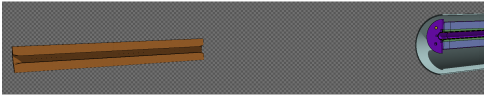


With TCDD+vacuum tubes:

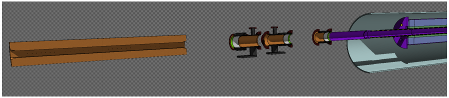


Figures: Transverse energy density profile at longitudinal maximum in D1 coils, for 288 bunches (2.3×10^{11} ppb) impacting on lower TDI jaw with an impact parameter of 1σ. No mask (left), present TCDD (center), and present TCDD + vacuum modules/transition tubes between TCDD and D1 (right).

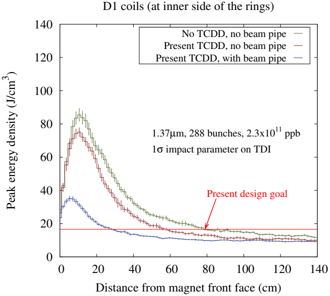
FLUKA model with TCDD only:

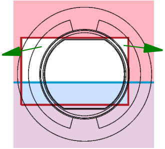


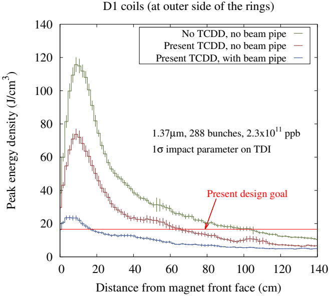
FLUKA model with TCDD and vacuum layout:



Efficacy of the existing TCDD (grazing impact on TDI)





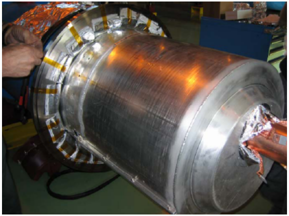


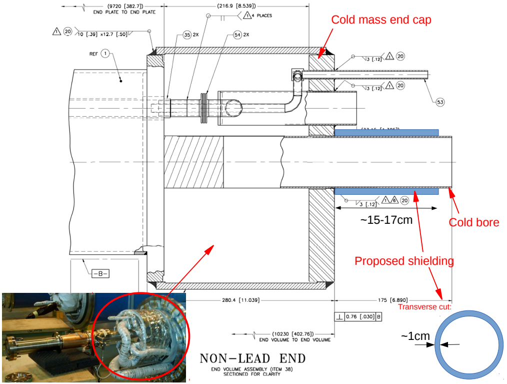
- Mask does not reduce much the load on D1 coils at inner side of the ring (@negative x)
  - → due to asymmetry, quite large mask aperture, and large distance from D1 front face
- Significant shielding by vacuum modules and cold-warm transition tube
  - → yields a factor ∼2–3 reduction compared to case with TCDD only
  - → results depend on details of FLUKA geometry model of vacuum layout
  - → should stay with a sufficient margin (factor 3) below damage limit
- Main issue: the damage limit of NbTi coils for ultra-fast losses is not known
  - → HiRadMat test by TE/MPE

Shielding inside D1 insulation vacuum

Complementing the existing TCDD with a shielding inside the D1 cryostat

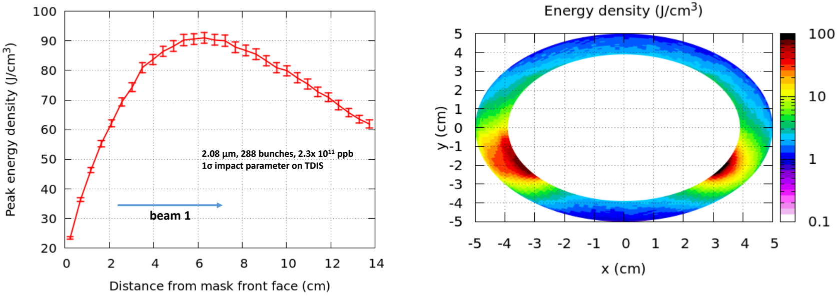
- Offers the advantage of intercepting shower particles closer to the magnet
- Would not affect the present machine aperture
- Allows to reduce peak energy density in D1 coils by about a factor 2





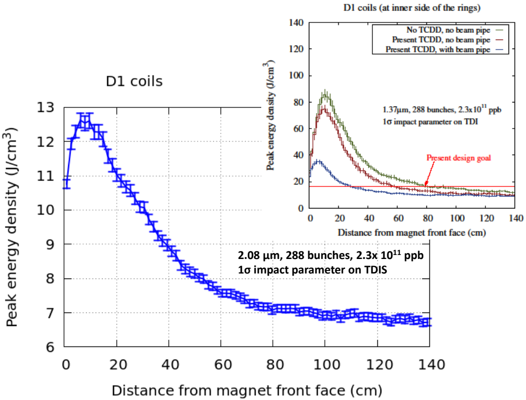
Energy density in the D1 mask (grazing impact on TDIS)

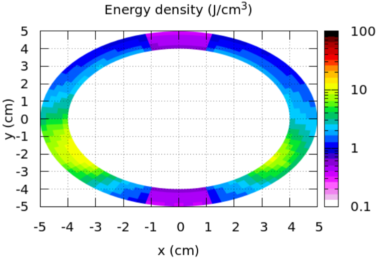
- Simulation of the energy deposition in the D1 mask located directly in front of the cold mass end cap of the D1
- Scenario of a grazing ($1\,\sigma$) HL-STD beam impact on the new TDIS



- The modeled mask is 14 cm long mask, 1.1 cm thick and in direct contact with the beam pipe
- Thermo-mechanical issues to be addressed by STI/TCD → *T. Polzin*

Efficacy of the D1 mask (grazing impact on TDIS)





- Shielding by the mask leads to a reduction of the peak energy density in the D1 coils by a factor of ~2-3
- Peak energy density of ~12.5 J/cm^3 in the D1 coils with a presumably good safety-margin → effective protection of the D1 coils

Contents

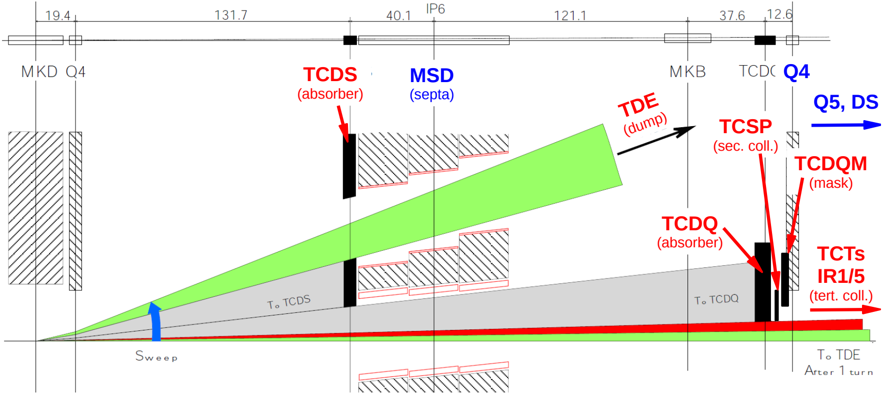
Scenario and Boundary Conditions - ABD

- Beam Parameters for Run 3:

	STD	BCMS
$\epsilon^n_{x,y}$	2.08 μm·rad	1.37 μm·rad
I_b	2.3×10^{11} ppb	2.0×10^{11} ppb

- p+ simulated at **top energy of 7 TeV**
- **Sweep of a STD beam over the TCDQ** due to an asynchronous beam dump
- Scoring of the energy deposition in the Q5 coils as result of particle showers emerging from the TCDQ

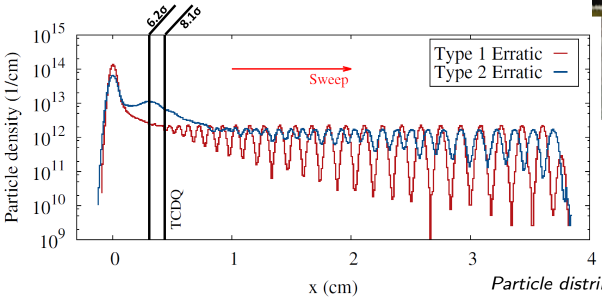
IR6: Protection devices/dumps

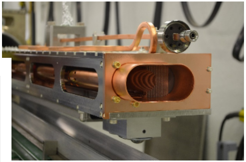


red = need to check material robustness
blue = need to check if sufficiently protected

Particle Distribution on the TCDQ

- **"New" MKD erratics observed in 2015**: particle density on TCDQ can be 2× higher than assumed for LS1 upgrade studies





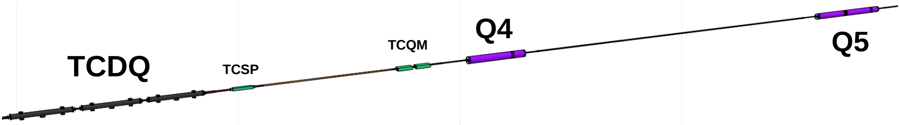
Particle distribution by M. Fraser

→ *New studies carried out for a Type 2 erratic (worst case)*

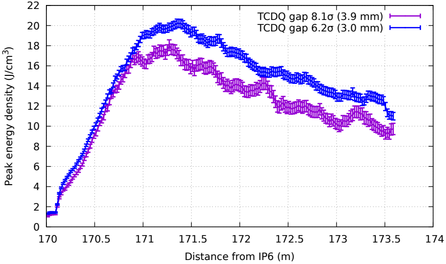
→ *Simulations with TCDQ half gaps of 8.1σ (3.9 mm) and 6.2σ (3.0 mm) including 0.5σ misalignment*

→ *Investigation of the effects, i.e. energy densities in downstream equipment*

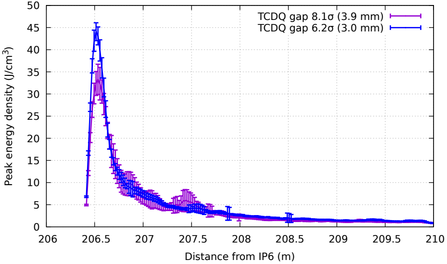
Energy density in Q4/Q5: 3.9 mm vs. 3.0 mm half gap



Energy density in Q4 coils

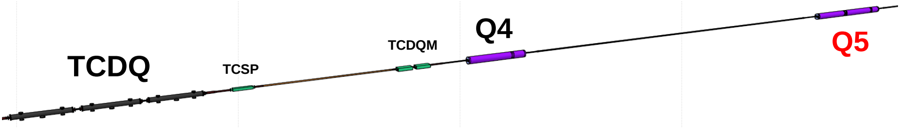


Energy density in Q5 coils

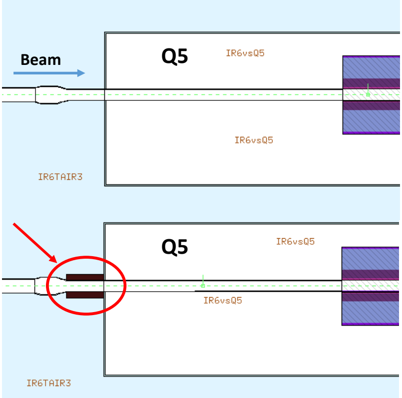


- Predicted peak energy density in Q4 coils increases from ∼17 J/cm^3 to ∼20 J/cm^3 (+15 %) with a reduction of the TCDQ half gap from 3.9 mm to 3.0 mm
- Predicted peak energy density in Q5 coils increases from ∼30–35 J/cm^3 to ∼40–45 J/cm^3 (+30 %)

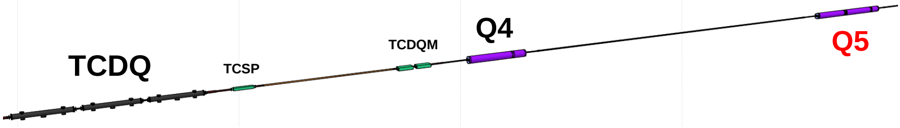
Proposed additional passive shielding for the Q5



- Modeling of a **mask directly upstream of the Q5-cryostat** shielding its coils:
  - Stainless Steel (SS316LN)
  - Inner radius: 3.325 cm (no gap between mask and beam pipe)
  - Outer radius: 6.957 cm

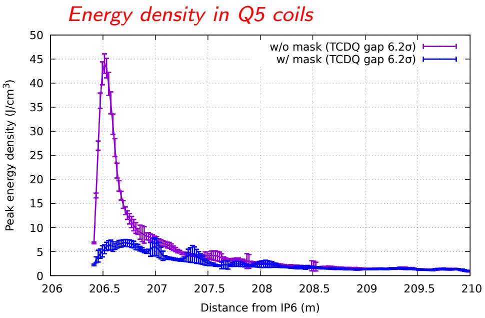


Peak energy density in Q5 coils w/ and w/o mask



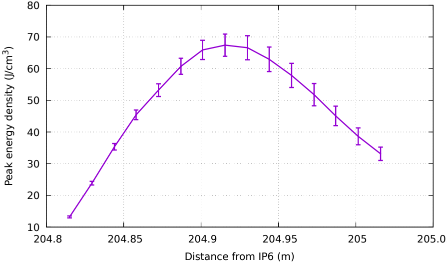
- Significant reduction of the peak energy density in the Q5 coils by the mask
- Peak energy density drops by a factor of ∼6-7 from ∼40–45 J/cm^3 to ∼7 J/cm^3
- The value of ∼7 J/cm^3 is well below the present design goal

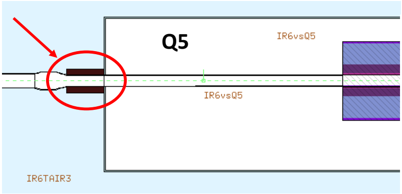
→ The proposed mask offers effective protection of the Q5 coils

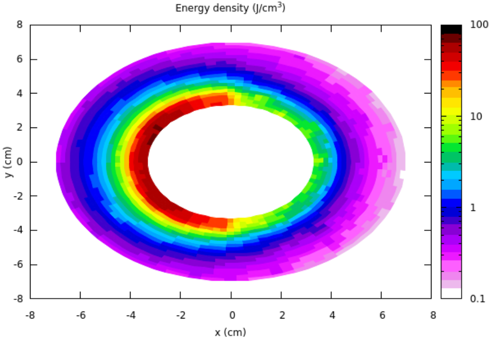


Peak energy Density in the Q5-mask

Longitudinal energy density profile







- Peak energy density in Q5-mask reaches $\sim 65\,\mathrm{J/cm^3}$
- For comparison: Peak energy density in Q5-mask is lower than in D1-mask ($\sim 90\,\mathrm{J/cm^3}$) in the worst case of an injection kicker failure

Contents

Remarks on the energy density in superconducting coils

- **Model calculations:**
  - → **Should account for a sufficient margin** (at least a factor 3 below damage limit)
- **Main issue: the damage limit of NbTi coils for ultra-fast losses is not exactly known**
  - → During the design of LHC protection devices a value of **$\sim$87 J/cm^3** was assumed, which however has to be revised
  - → **HiRadMat test** on SC cables carried out by colleagues from TE/MPE in Sep 2016 (at room temperature), another test planned at cryogenic temperatures

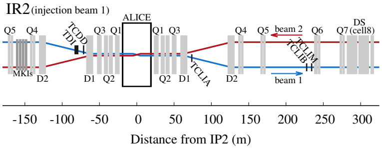
LHC injection protection devices

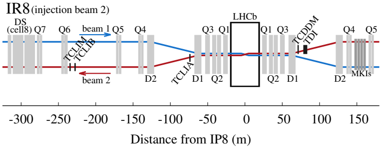
Existing protection devices in IR2/8:

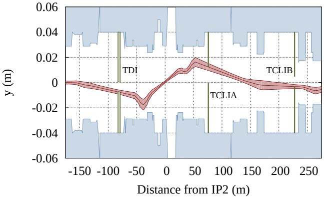
- intercept bunches in case of injection kicker (MKI) failures
  - misinjections (no kick of inj. beam)
  - accidental kicks of the stored beam
- primary injection beam stopper (TDI) at $\Delta\mu \approx 90^\circ$ from MKIs (vertical)
- auxiliary collimators (TCLIA/TCLIB) at $\Delta\mu \approx n \times 180^\circ \pm 20^\circ$ from TDI (vertical)
- complemented by masks (TCDD/M, TCLIM) intercepting secondary showers from absorbers

HL-LHC (→upgrades in LS2):

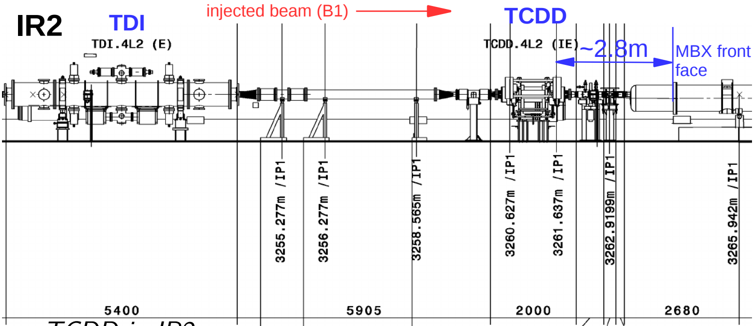
- Layout remains essentially the same
- New design of the TDI
- Additional passive protection for D1



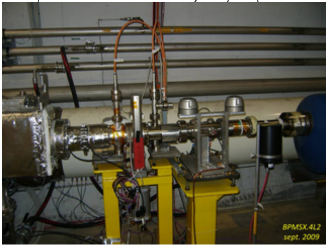




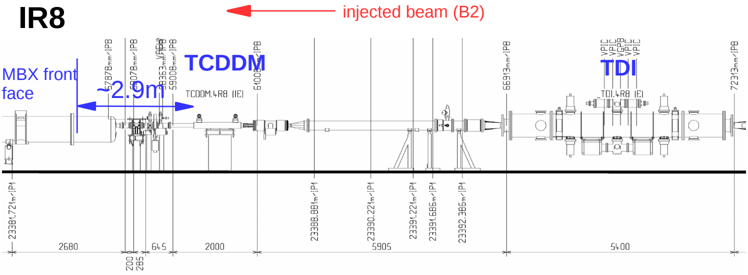
Present layout IR2: TDI+TCDD



TCDD in IR2:



Present layout IR8: TDI+TCDD



TCDDM in IR8: