Energy deposition studies for accidental beam losses during and injection and beam dump

A. Lechner, with input from C. Bracco, R. Esposito, M. Frankl, M. Fraser, L. Gentini, B. Goddard, A. Perillo Marcone, I. Lamas Garcia, V. Raginel, N.V. Shetty, E. Skordis, J. Uythoven, F.M. Velotti, D. Wollmann, ...

5th Joint HiLumi LHC-LARP Annual Meeting

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Introduction

- This presentation summarizes FLUKA studies done within HL-LHC WP14
- The main focus of this talk is on the energy deposition in superconducting coils during injection failures and asynchronous beam dumps due to showers from protection devices

  a) TDIS (+TCDD/M) → D1 (L2, R8)
  b) TCLIA → D2 (R2, L8)
  c) TCLIB (+TCLIM) → Q6 (R2, L8)
  d) TCDQ (+TCSP+TCDQM) → Q4, Q5 (L6, R6)

  (please note that some results are still preliminary and will be updated in the coming months)
- I will only briefly comment on the upgrade of devices themselves; some more details on material selection, impedance etc are discussed in other talks [1 – 3]

[1 J. Uythoven, "Lessons learnt from LHC operation for the upgrade of the injection and beam dumping systems", Tue PM
[2 N. Biancacci, "Impedance and beam stability", Wed AM
[3 F-X. Nuiry, "Material testing for injection and transfer line absorbers", Wed PM

Contents

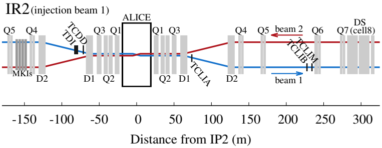
LHC injection protection layout

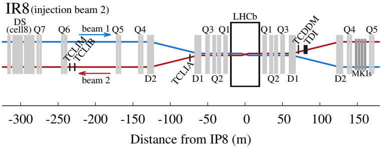
Existing protection devices in IR2/8:

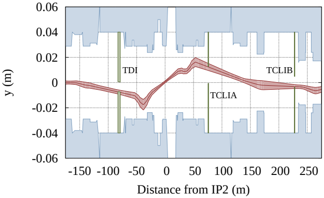
- intercept bunches in case of injection kicker (MKI) failures
  - misinjections (no kick of inj. beam)
  - accidental kicks of the stored beam
- primary injection beam stopper (TDI) at $\Delta\mu \approx 90^\circ$ from MKIs (vertical)
- auxiliary collimators (TCLIA/TCLIB) at $\Delta\mu \approx n \times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

HL-LHC (→upgrades in LS2):

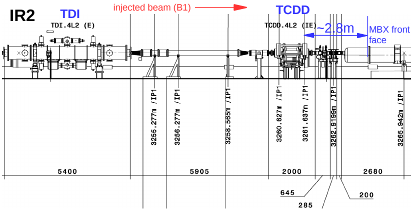
- Layout remains essentially the same
- New design of the TDI
- Additional passive protection for D1

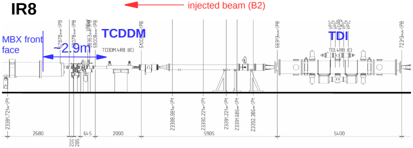




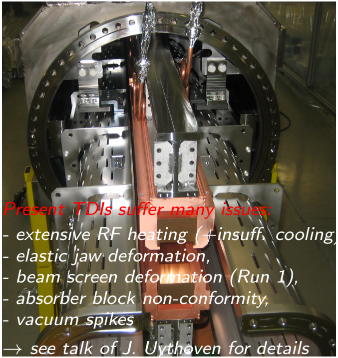


Existing TDI+TCDD





TDI in IR2/8:

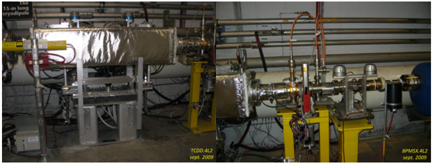


Present TDIs suffer many issues:

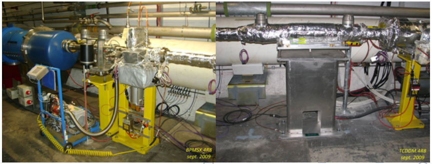
- *extensive RF heating (+insuff. cooling)*
- *elastic jaw deformation,*
- *beam screen deformation (Run 1),*
- *absorber block non-conformity,*
- *vacuum spikes*

→ see talk of J. Uythoven for details

TCDD in IR2:



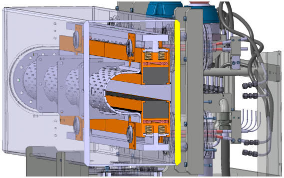
TCDDM in IR8:

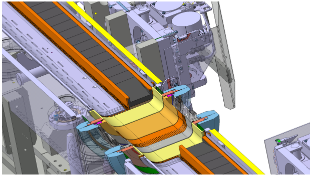


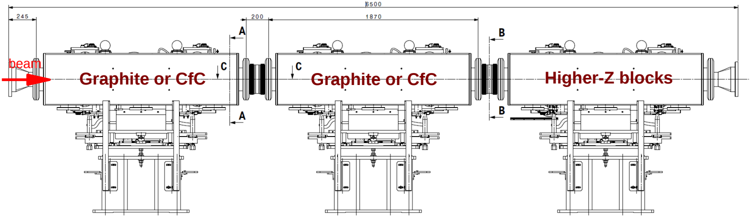
New TDIS design (→ Segmented)

TDI is being completely redesigned to adapt to HL parameters and to overcome past issues:

- 3 pairs of jaws, each with an active length of 150 cm
    - No significant increase of total absorber length (grazing beams → downstream masks more relevant than TDI length)
- All jaws have the same engineering design, but accommodate different absorber materials:
    - 2 pairs with light, robust materials
    - 1 pair with higher-Z blocks
- Tank and interconnect design mainly driven by impedance aspects (see talk of N. Biancacci Wed AM)



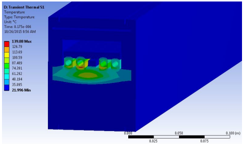


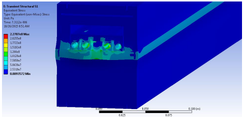


Figures courtesy of L. Gentini (EN/MME).

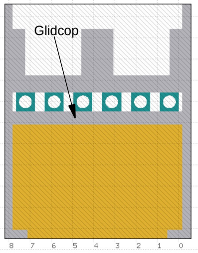
Injection failures: load on TDIS

- Absorber materials need to sustain impact of 288 BCMS bunches at small impact parameters ($\rightarrow$ highest stresses)
  - Material choice to be finalized in autumn 2016, based on HRMT-28 and other qualification tests (see talk of F-X Nuiry Wed PM)
- Stiffener, cooling pipes need to sustain load from 288 bunches at large impact parameters (up to 4 cm)
  - Design and material optimization ongoing

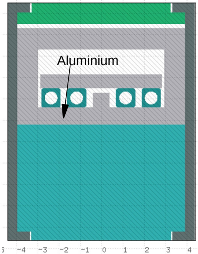


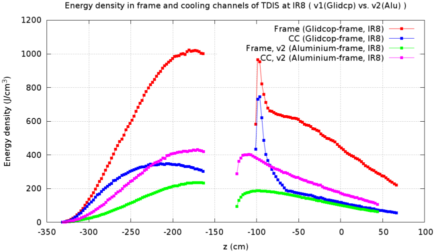


TDIS$_{v1}$



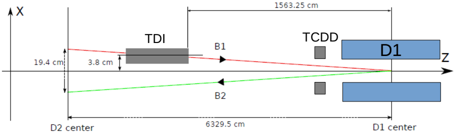
TDIS$_{v2}$



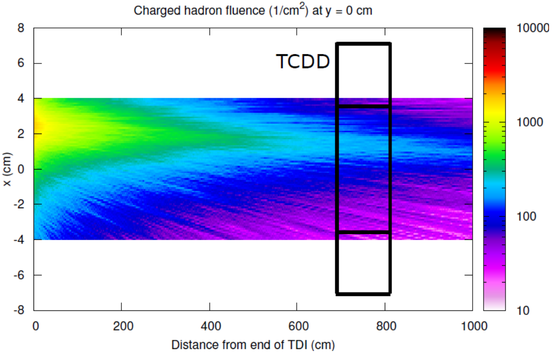


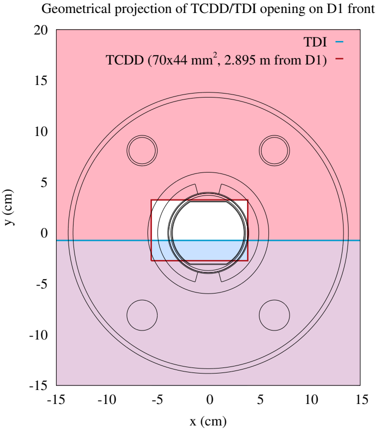
Injection failures: protecting the superconducting D1

TDI located between separation dipoles:



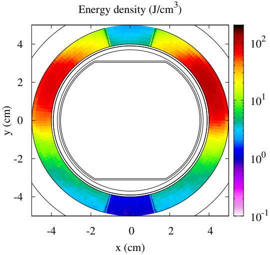
- → Beams have a horiz. angle of ∼1.5 mrad
- → TCDD opening sym. around machine axis
- → Provides asym. protection of D1 coils



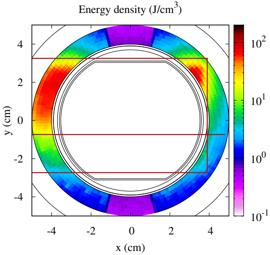


Efficacy of the existing TCDD (grazing impact on TDI)

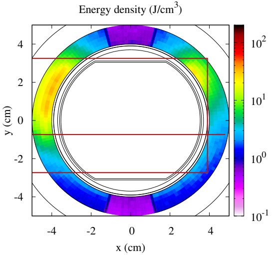
No mask:



Present mask:

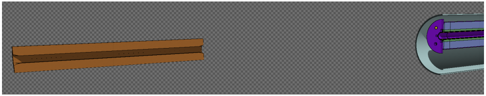


Present mask+vacuum tubes:

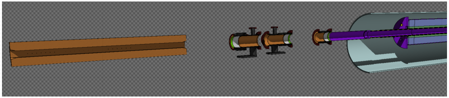


Figures: Transverse energy density profile at longitudinal maximum in D1 coils, for 288 bunches (2.3×10^{11} ppb) impacting on lower TDI jaw with an impact parameter of 1σ. No mask (left), present TCDD (center), and present TCDD + vacuum modules/transition tubes between TCDD and D1 (right).

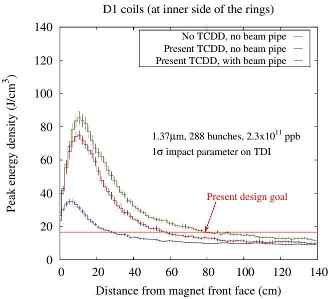
FLUKA model with TCDD only:

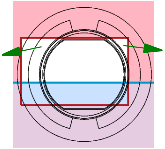


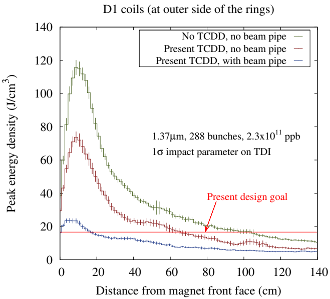
FLUKA model with TCDD and vacuum layout:



Efficacy of the existing TCDD (grazing impact on TDI)



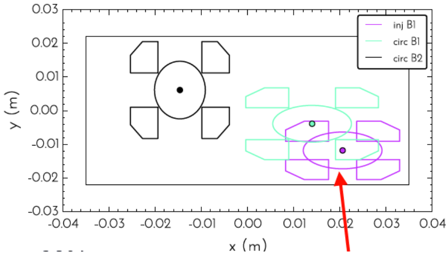


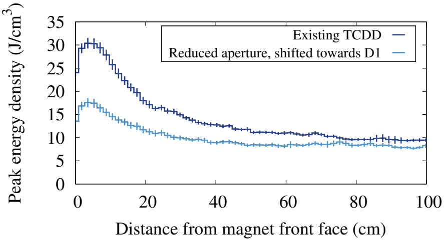


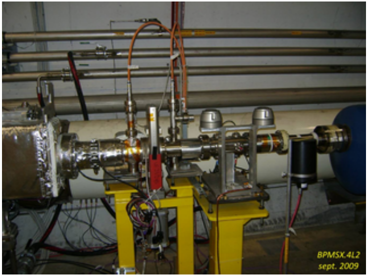
- Mask does not reduce much the load on D1 coils at inner side of the ring (@negative x)
  - → due to asymmetry, quite large mask aperture, and large distance from D1 front face
- Significant shielding by vacuum modules and cold-warm transition tube
  - → yields a factor ∼2–3 reduction compared to case 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 planned (see talk of V. Raginel), but we meanwhile continue with our plans to proactively improve the shielding of secondary showers from the TDI

Option 1: modifying the TCDD

- Option 1: modifying the TCDD
  - The effectiveness of the TCDD in shielding shower particles can only be sufficiently improved if
    - a) its opening is reduced <u>and</u>
    - b) it is moved closer to the D1
  - Not much room for modifications due to aperture requirements & space constraints
  - Could in principle achieve a 40% reduction of peak in D1 coils



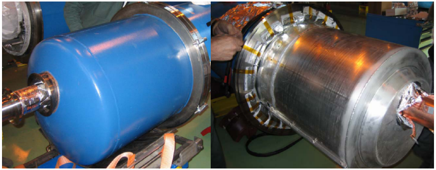


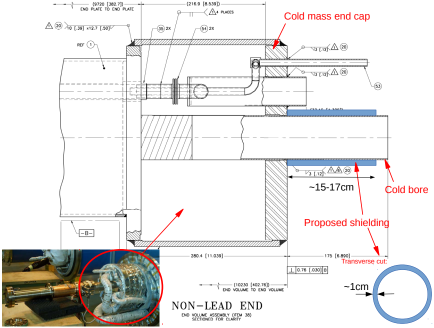


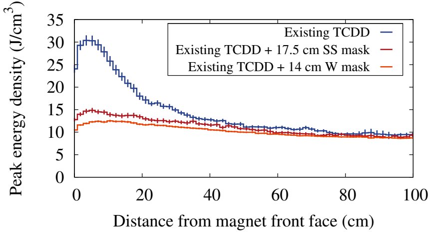
Option 2: shielding inside D1 insulation vacuum

Option 2: 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
- Option 2 is the present baseline







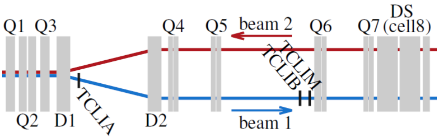
TCLIA: showers to D2

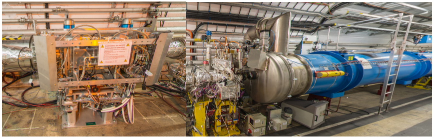
Auxiliary collimator TCLIA:

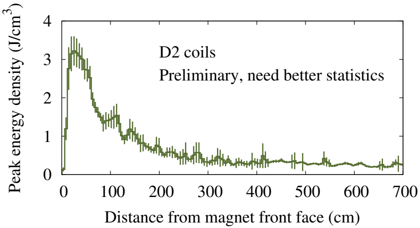
- 1 m active length (Graphite R4550), hosts both circulating beams
- No change foreseen, except minor modification to improve ALICE ZDC acceptance in IR2
  - increase stroke by 1 mm
  - displacement by ∼1.8 m towards IP

Kicker malfunction/timing error:

- Scattering+tracking simulations indicate that, in the worst case, we get few 10% of a full SPS bunch train on the TCLIA (see talk of F. Velotti Wed PM)
- The long distance TCLIA-D2 (47 m) implicitly offers protection by diluting showers
- First preliminary FLUKA simulations indicate no risk of D2 damage for HL beams (no beam pipes included in model to be conservative!)







TCLIB: showers to Q6

Auxiliary collimator TCLIB:

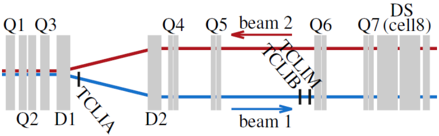
- 1 m active length (2D C-C AC 150K), design identical to present secondary collimator
- No modifications foreseen

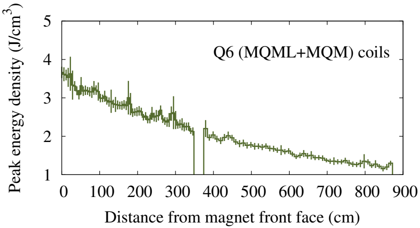
Mask TCLIM:

- 1 m active length (steel)

Kicker malfunction/timing error:

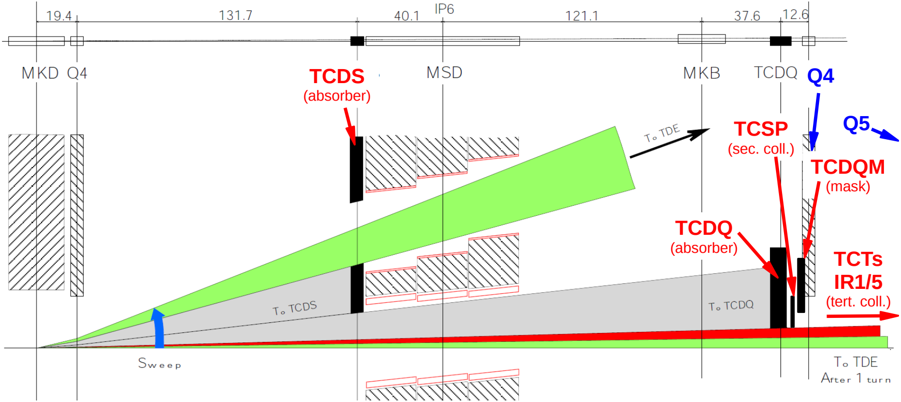
- As for TCLIA, in the worst case, we get few 10% of a full SPS bunch train on the TCLIB (see talk of F. Velotti Wed PM)
- As for D2, FLUKA simulations suggest no risk of Q6 damage for HL beams (same Q6 model has been used for analysis of quench tests)





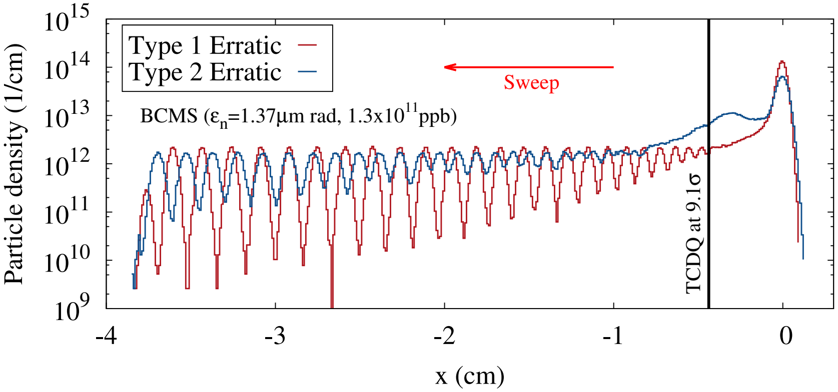
Contents

LHC protection layout in the dump region



Asynchronous beam dump – single module pre-fire

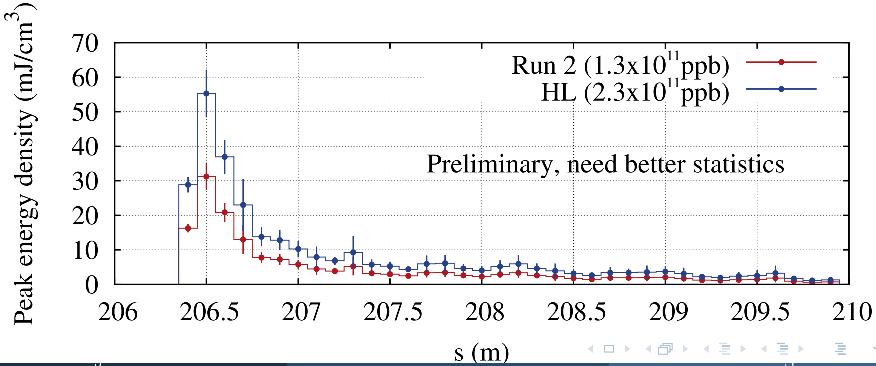
- Different types of erratics – Type 1 and Type 2 (M. Fraser):
  - Current flows either through switch or around switch
  - Rise time of pre-firing kicker much faster in case of Type 2 Erratic
  - Type 2 worse for **TCDQ** and **TCTs**, not much difference for **TCDS**



→ Type 2 studied for the first time this year!

Type 2 Erratic: showers to Q5

- Simulations suggest that energy deposition is more critical in Q5 than for Q4
- First preliminary results from shower simulations indicate quite a high energy deposition in the Q5 coils for Type 2 Erratics
  - Need to refine the FLUKA vacuum layout between Q4-Q5 to predict more realistically the shielding effect of beam pipes
  - Still, should start to think if further passive protection would be feasible



Contents

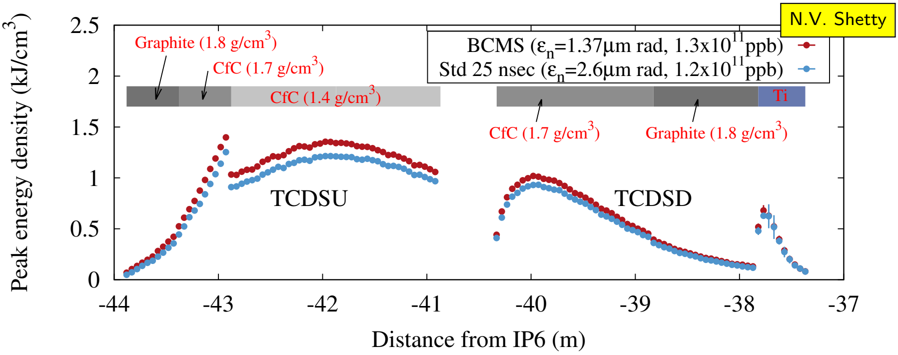
Summary and outlook

- IR2/8/6 magnet protection for HL era due to showers during injection failures and asynchronous beam dumps:
  a) TDIS (+TCDD/M) → D1 (L2, R8)
     → passive protection proactively in planning for LS2
  b) TCLIA → D2 (R2, L8) → don't expect issues
  c) TCLIB (+TCLIM) → Q6 (R2, L8) → don't expect issue
  d) TCDQ (+TCSP+TCDQM) → Q4, Q5 (L6, R6)
     → energy density looks quite high in Q5, need more follow-up studies

  → **not to forget, everything depends on what we consider safe ...**
- Other important points:
  - Need to address in more detail the energy deposition in the septa downstream of the TCDS
  - Need to study the robustness of IR6 protection devices (TCDQ, TCDS), the beam dump window and the dump core (TDE) for HL beam intensities and emittances
    → similar studies have recently been carried out for Run 2 parameters (see backup slides), but not yet for HL

Contents

TCDS in Run 2: Type 1 Erratic@7TeV (very similar for Type 2 Erratic)



- BCMS vs Std beams: peak energy densities do not differ too much
- BCMS beams in Run 2 (R. Esposito):
  - Temperatures and stresses in Graphite and CfC well below material limits
  - VM stresses in Ti close to yield strength, but acceptable

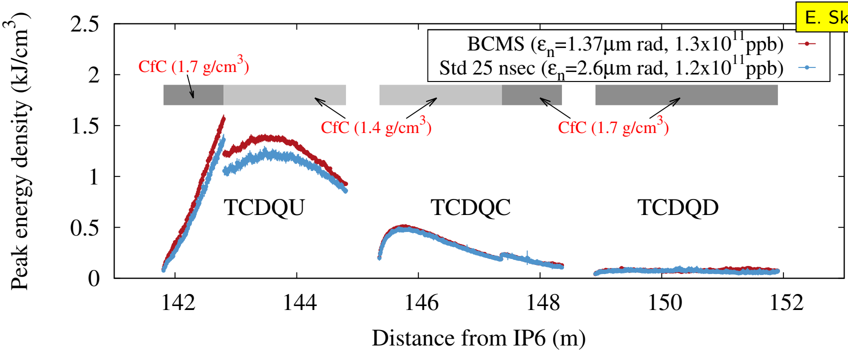
Table: Temperatures and stresses for BCMS beams (Type 1 Erratic)

Material	Graphite	C-C 1.75	C-C 1.4
Max. Temp. [°C]	251	528	718
Min. Princ. [MPa]	12	5	22
Compr. Strength	**60**	**70**	**70**
Max. Princ. [MPa]	12	7	12
Tensile Strength	**30**	**45**	**45**

R. Esposito

TCDQ in Run 2: Type 2 Erratic@7TeV – TCDQ at 8.6σ (0.5σ misalignment)

E. Skordis



- Like for TCDS, peak energy densities don't differ too much
- BCMS beams in Run 2 (R. Esposito):
  - Temperatures and stresses remain well within material limits for Run 2

Table: Temperatures and stresses for BCMS beams (Type 2 Erratic)

Material	C-C 1.75	C-C 1.4
Max. Temp. [°C]	679	724
Min. Princ. [MPa]	-12	-16
Compr. Strength	**-70**	**-70**
Max. Princ. [MPa]	10	12
Tensile Strength	**45**	**45**

R. Esposito