Energy deposition studies for IR6 protection devices and the dump core

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On behalf of HL-LHC WP14

HL TCC
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Introduction

Scope of this talk:

- First assessment of the energy deposition in
  - → IR6 protection devices
  - → IR6 magnets and septa
  - → the dump core

  for HL beam parameters and HL optics (HLLHCV1.2)
- The goal is to give a first indication if we expect possible issues with
  - → present absorber materials
  - → the protection of equipment
- *Yet for a quantitative judgement about the absorber material robustness it is imperative to study the thermo-mechanical material response based on finite-element calculations (ANSYS)* → calculations have started, but will still require some time as we have to study numerous devices

Disclaimer:

- All temperature estimates presented in this talk assume adiabatic conditions (this is slightly conservative)

Assumed beam parameters

- Following emittances and intensities were assumed for
  → LIU protection/dump upgrades in SPS/TLs and
  → HL-LHC WP14 protection upgrades in the LHC injection regions

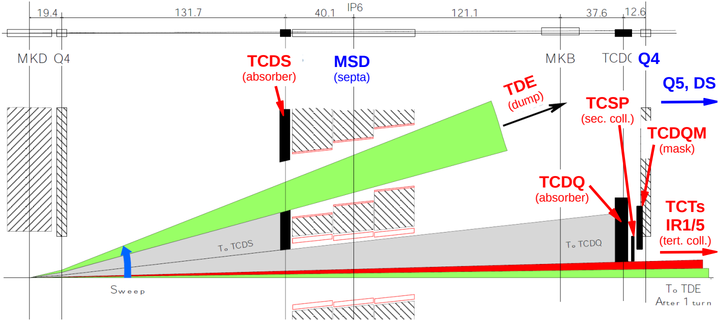
Beam	$\epsilon^n_{x,y}$	I_b
HL Std 25 nsec	2.08 μm·rad	2.3×10^{11}
LIU BCMS	1.37 μm·rad	2.0×10^{11}(*)

- Adopting a cautious approach, we kept the same parameters for studies of the dump system, i.e. we assumed no emittance growth and no intensity loss in ramp
- For comparison, selected results for Run 2 beams are also shown:

Beam	$\epsilon^n_{x,y}$	I_b
Run 2 Std 25 nsec	2.6 μm·rad	1.2×10^{11}

(*) These numbers differ from the HL-LHC beam parameters (V4.2.1) on the PLC webpage. Had a dedicated meeting (Feb 2016) with LIU and HL representatives where the parameters to be assumed for the design of protection devices were discussed (see https://edms.cern.ch/document/1584005/1)

Protection devices/dumps and failure scenarios



- Single MKD module prefire:
    - **TCDS** → **MSDs**
    - **TCDQ+TCDQM** → **Q4, Q5, DS magnets**
    - **TCTs** → **IR1/5 triplet,D1** (studied by WP5+WP10)
- Dilution failure:
    - **TDE core** and **window**

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

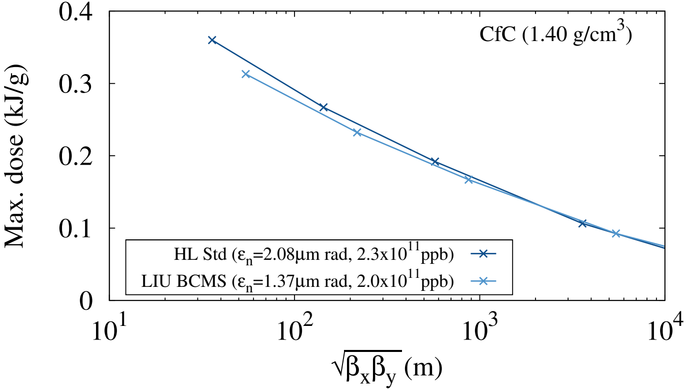
Considered optics and β-functions

- All studies presented here were carried out for HLLHCV1.2
- Selected the worst case for each device from flat/flat HV/round optics
- For comparison, selected results derived with Run 2 optics are shown

Device	**Optics**	β_x	β_y	$\sqrt{\beta_x \beta_y}$	**Remark**
TCDQ	HLLHCV1.2	497 m	167 m	288 m	flat, end of squeeze, B1
	Run 2 (2015)	484 m	161 m	279 m	collision, B1
TCDS	HLLHCV1.2	168 m	174 m	171 m	flat HV, squeeze step 20, B2
	Run 2 (2015)	155 m	231 m	189 m	collision, B1
TDE	HLLHCV1.2	5052 m	3714 m	4331 m	round, end of squeeze, B2
	Run 2 (2015)	5076 m	3713 m	4341 m	collision, B2

M. Fraser

Single 7 TeV bunch: max energy density in CfC vs $\sqrt{\beta_x\beta_y}$



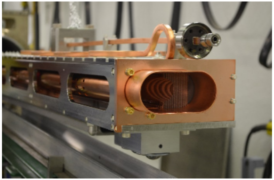
- A certain change of β and hence of the transverse bunch size might be digestable (yet there are other constraints for β)
- Note: the beam is swept across the TCDS/TCDQ/TDE front face
  → the peak energy density also strongly depends on the distance between neighbouring bunches in the sweep

Contents

1. Single MKD module pre-fire: load on TCDQ+Q4/Q5
2. Single MKD module pre-fire: load on TCDS+MSDA
3. Dilution failure during beam dump: load on TDE core
4. Summary & Conclusions

Some remarks on the TCDQ

- Was upgraded[†] in LS1 (2→3 modules, Gr→CfC)
- Upgrade studies[††] (FLUKA+ANSYS) considered HL beam parameters
- However, new observations in 2015/2016:
  1) "new" MKD erratics observed in 2015: particle density on TCDQ can be a factor two higher than assumed for LS1 upgrade studies (see also next page), increases also load on magnets
  2) quenched several magnets in the DS during an asynchronous beam dump test on the 15/05/2016 (but did not quench Q4/5)
- Requires a recheck of material robustness for these erratics + check of energy deposition in magnets up to DS (so far we only looked at Q4/Q5)

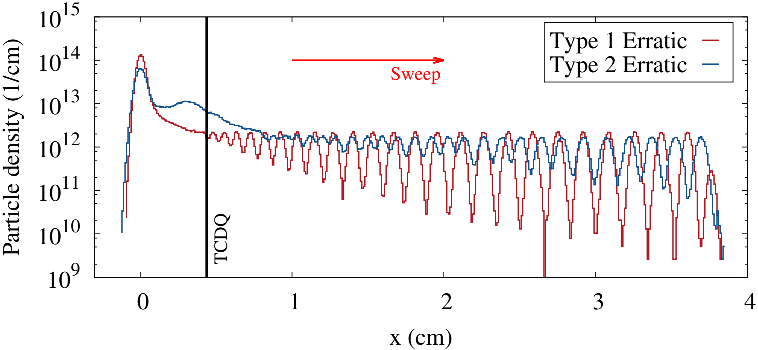


[†] See LHC-TCDQ-EC-0003-10-10

[††] See CERN-sLHC-Project-Note-0041, CERN-ATS-Note-2012-015 MD, CERN-ATS-Note-2012-084 MD

Effect of different erratics

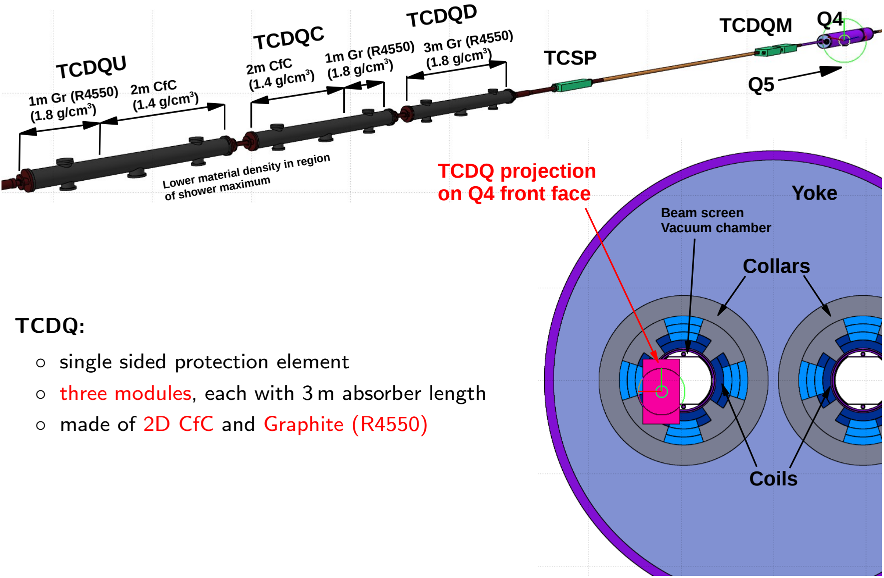
- Here we focus on the worst known type (Type 2)
- Worse than other erratics for **TCDQ** and **TCTs**, not much difference for **TCDS**



→ Figure shows Run 2 scenario, but similar difference for HL beams/optics

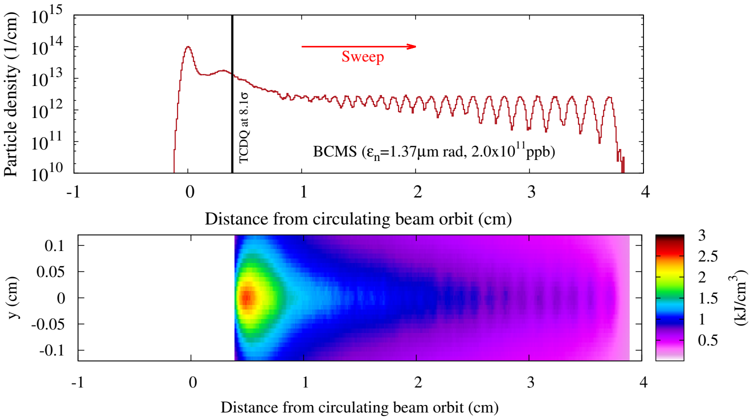
M. Fraser

TCDQ+Q4/Q5 model for energy deposition simulations



- **TCDQ:**
  - single sided protection element
  - three modules, each with 3 m absorber length
  - made of 2D CfC and Graphite (R4550)

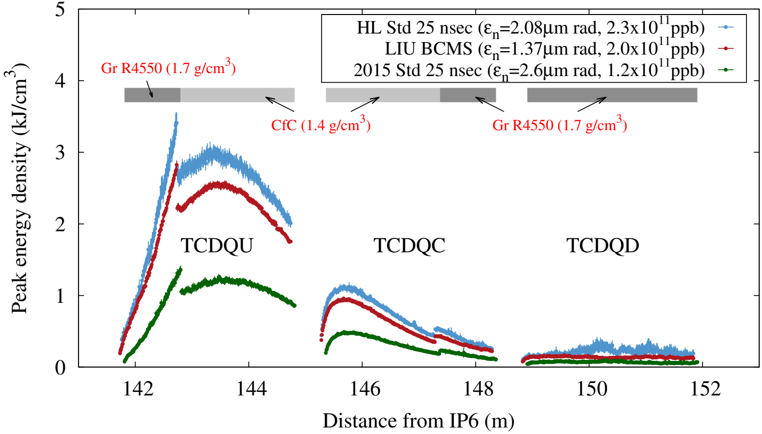
Some remarks on β_x



- β_x defines the position of the TCDQ
  - the smaller the gap, the higher the particle density at the TCDQ edge
  - affects both the load on the TCDQ and on downstream magnets

Peak energy density in TCDQ for a T2 MKD erratic

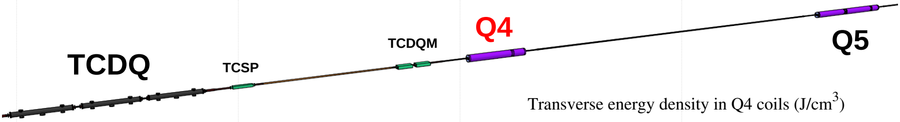
Assumed TCDQ half gap = 8.1σ (includes 0.5σ misalignment) *M. Frankl*

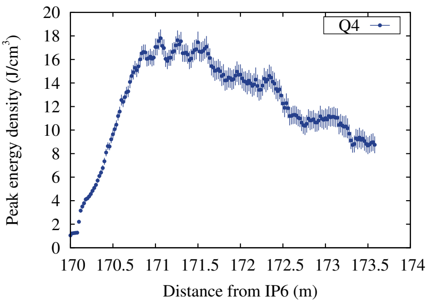


- HL-LHC std: max. energy density in low-density blocks: 3.0 kJ/cm^3 (~1300°C)
- LIU BCMS: max. energy density in low-density blocks: 2.6 kJ/cm^3 (~1200°C)

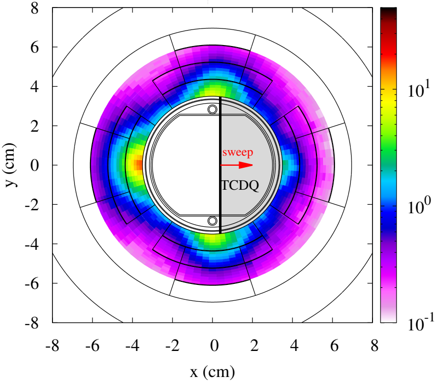
→ *stresses could be close to limits, cannot conclude without thermo-mechanical studies*

Peak energy density in Q4 coils for a T2 MKD erratic





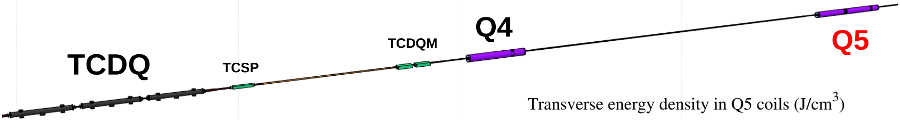
Transverse energy density in Q4 coils (J/cm^3)

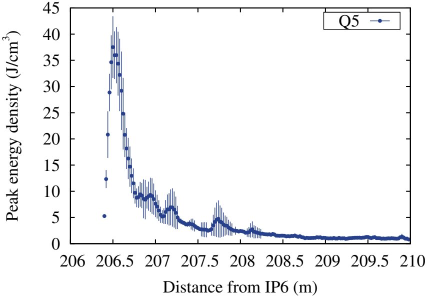


- Predicted peak energy density in Q4 coils: ~17 J/cm^3

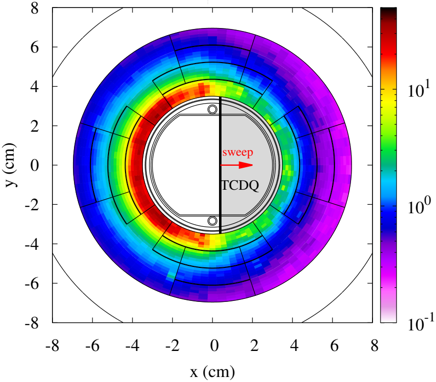
M. Frankl

Peak energy density in Q5 coils for a T2 MKD erratic





Transverse energy density in Q5 coils (J/cm^3)



- Predicted peak energy density in Q5 coils: ∼30–40 J/cm^3

M. Frankl

Remarks on the energy density in superconducting coils

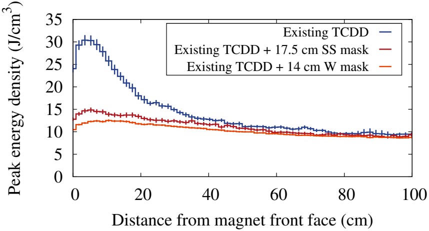
- Model calculations:
  - → Vacuum chambers just upstream of magnets can yield a non-negligible shielding of coils (can be up to a factor ∼2–3 reduction of the peak in the coils)
  - → Results depend on details of FLUKA geometry model of vacuum layout etc.
  - → *Should account for a sufficient margin (at least a factor 3 below damage limit)*

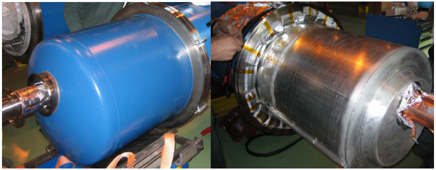
- Main issue: the damage limit of NbTi coils for ultra-fast losses is not exactly known
  - → During the design of LHC protection devices a value of ∼87 J/cm^3 was assumed, which however has to be revised
  - → HiRadMat test planned by colleagues from TE/MPE (V. Raginel, D. Wollmann et al.), scientific board took place last week
  - → In the injection regions, we plan to proactively improve the shielding of secondary showers from injection protection devices (upgrade in LS2) – see next slide
  - → *Depending on the outcome of the HiRadMat test, an improved protection might need to be considered also for the Q5 in IR6*

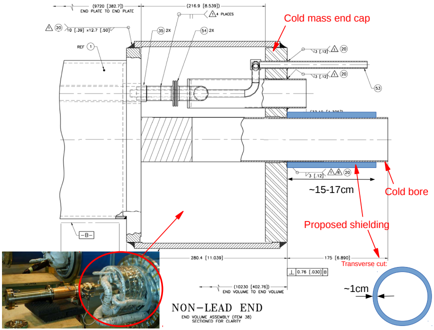
Comparison: load on magnets during injection failures

Showers from TDI (grazing impact):

- Most exposed magnet is the superconducting D1 in L2/R8
- Predicted peak energy density in coils is about 30 J/cm^3 (288b, std HL-LHC beams)
- Baseline solution: additional shielding inside insolation vacuum of D1
- Allows to reduce peak energy density in coils by about a factor 2







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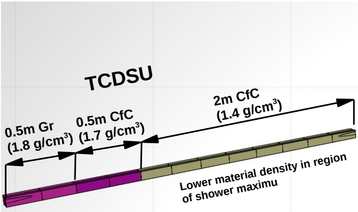
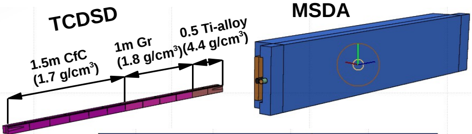
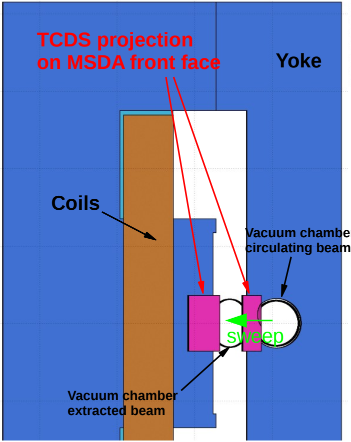
TCDS+MSD model for energy deposition simulations

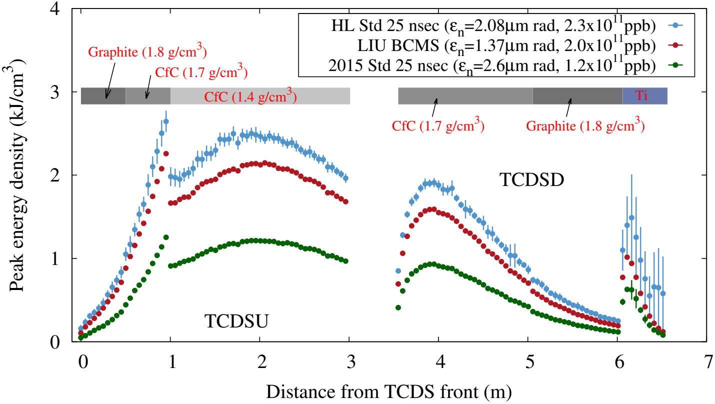






- **Existing TCDS:**
  - two modules, each with 3 m absorber length
  - each module has two jaws (one directly impacted in case of an asynch. beam dump)
  - made of Graphite/2D CfC blocks of different density + Ti-alloy block at the downstream end

Peak energy density in TCDS for a T2 MKD erratic

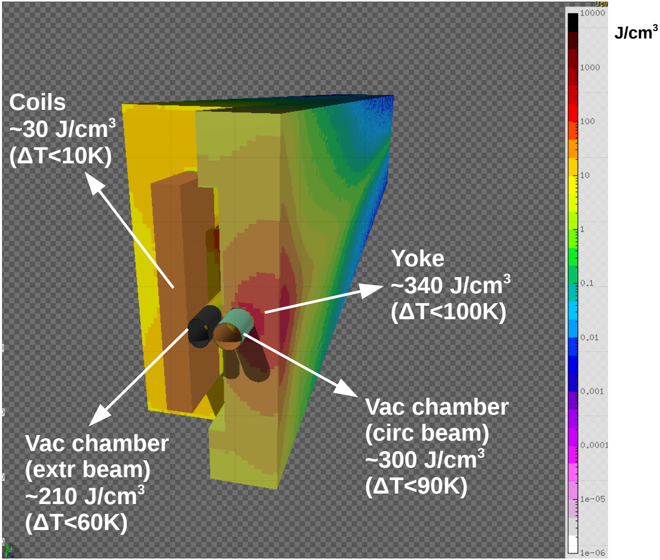


- HL-LHC std: max. energy density in low-density blocks: 2.5 kJ/cm^3 (∼1150°C)
- LIU BCMS: max. energy density in low-density blocks: 2.1 kJ/cm^3 (∼1030°C)

→ peak energy density/temperatures in CfC lower than in TCDQ, still need thermo-mechanical studies for a final judgement (most critical: Ti-alloy)

M. Frankl

Energy deposition in the MSD for a T2 MKD erratic



Coils
~30 J/cm^3
($\Delta T<10K$)

Yoke
~340 J/cm^3
($\Delta T<100K$)

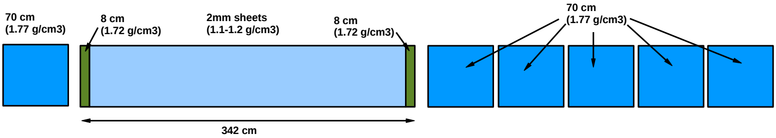
Vac chamber
(circ beam)
~300 J/cm^3
($\Delta T<90K$)

Vac chamber
(extr beam)
~210 J/cm^3
($\Delta T<60K$)

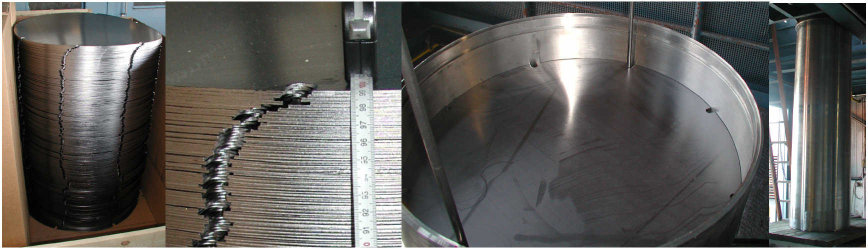
Contents

Material composition of the existing TDE core

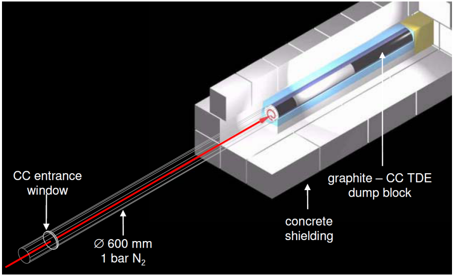
High and low-density segments:

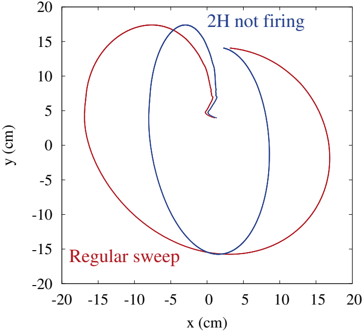


Low-density flexible Graphite sheets:



Assumptions for first energy deposition studies

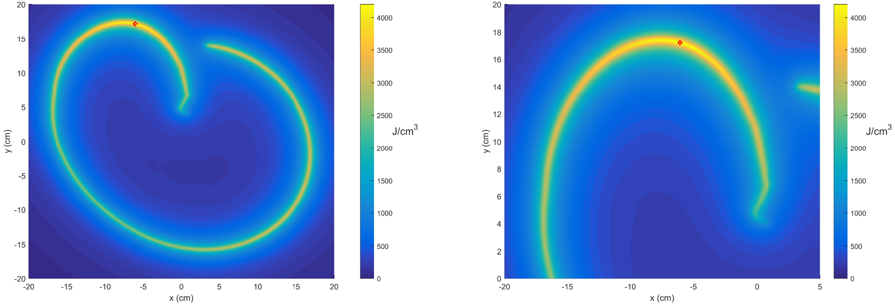




- To get a first assessment of the peak energy density in the TDE core we assumed:
  - that all RF buckets are filled, i.e. we did not make any specific assumption for the filling scheme *(this overestimates the peak energy density by roughly 10-15%)*
  - that 2H kickers are failing at the same time (i.e. 6V+2H instead of regular 6V+4H)

Transverse energy density profile in the TDE core

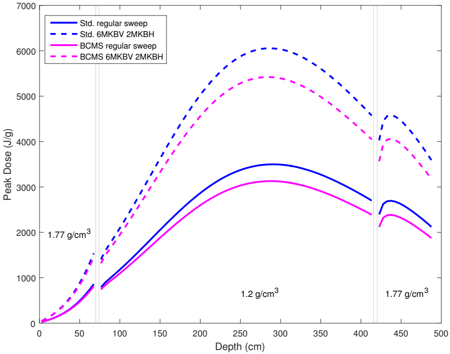
In 3 m depth:

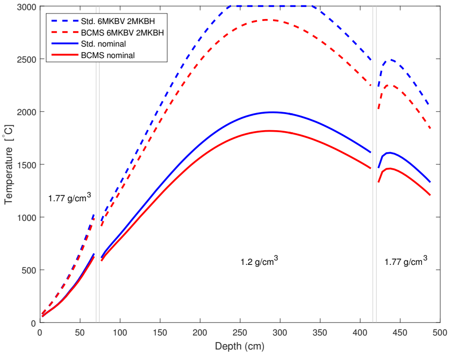


- Hot spot:
  - evidently depends on the minimum sweep speed along the sweep path
  - happens after about 15 μs when the vertical dilution changes direction
  - hence failure of H kickers more critical

Peak dose and temperature in the TDE core

M. Frankl





- HL-LHC std (regular sweep): max. dose of 3.5 kJ/g (∼2000°C)
- HL-LHC std (2H not firing): max. dose of >6 kJ/g (>3000°C)

→ *load in case of a partial dilution failure with 2H missing looks already very high, cannot conclude without thermo-mechanical studies*

Contents

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2. Single MKD module pre-fire: load on TCDS+MSDA
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Summary and required follow-up

TCDS/TCDQ/TCDQM:

- Stresses in TCDS/TCDQ blocks could be close to limits in case of a T2 Erratic (metallic block in TCDS likely the most critical)
- Need thermo-mechanical simulations for a final judgment, including also the TCDQM mask

MSD/magnet protection:

- MSD protection generally appears OK but some aspects still require further studies (e.g. aperture discontinuity at MSDA-MSDB transition)
- Might need additional protection for Q5 depending on the outcome of NbTi coil damage test in HiRadMat (by TE/MPE)
- Still have to extend our studies to the DS (unexpected observations in MPS test)

TDE (core+window):

- A first assessment of the core temperature indicates already quite high values for a partial dilution failure where 2H MKBs are not firing
- Need to establish a complete failure matrix: likelihood of different dilution failures vs consequences for TDE core/window
- Cannot exclude at the moment that additional dilution kickers might be necessary