# Energy deposition studies for extraction protection devices/dump

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21 September 2022
HL-LHC Collaboration Meeting

# Outline

- **TDE**
  - Expected energy density deposition in nominal and failure scenarios in HL-LHC

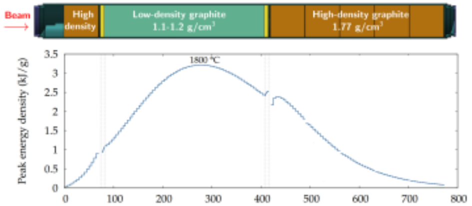
- **TCDS/MSD:**
  - Energy density deposition in TCDS blocks, frame and MSD magnets after asynchronous beam dump
  - Assessment of septa protection in view of possible exchange of TCDS titanium block with graphite or CSiC materials

- **TDE**

# HL-LHC dump design

- Extensive work carried out in recent years (LS2 Upgrades, Autopsy, HiRadMat-HED, material R&D) constitutes a **solid foundation** upon which we can tackle the challenges in view of HiLumi

- Resistance of core materials to increased peak energy deposition – across 1000s of pulses

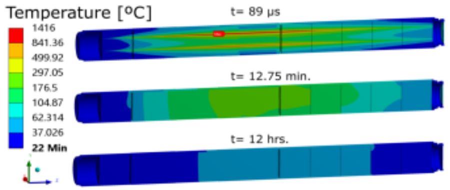



- Wide array of materials already tested in HiRadMat-HED, with promising results
- Strong understanding of industrial landscape
- HiRadMat-HED2 in 2024, up to 500 high-intensity pulses
- Study of optimal inner atmosphere (N2, Ar, ..)

- Increase in vessel vibration due to higher energy deposition

- Simulation package in strong agreement with data, to be benchmarked further during Run 3
- Study of alternative vessel materials (Ti Gr5)

- Cooling inefficiency: dump-to-dump temperature buildup and possible impact on machine availability




- Initial studies on improved cooling systems already carried out in 2021
- Alternative materials for Low-Density sector could allow strongly improved heat transfer

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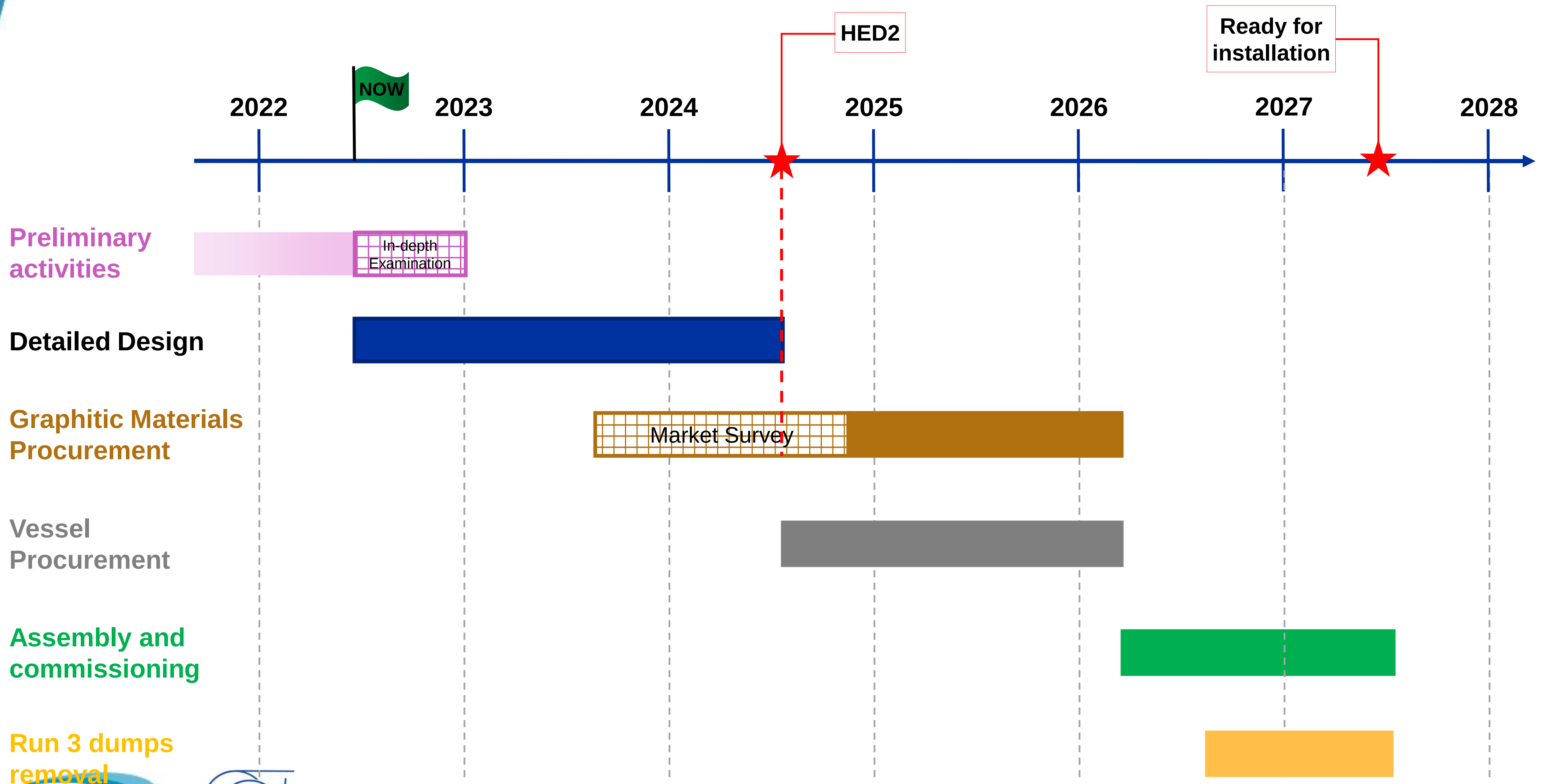
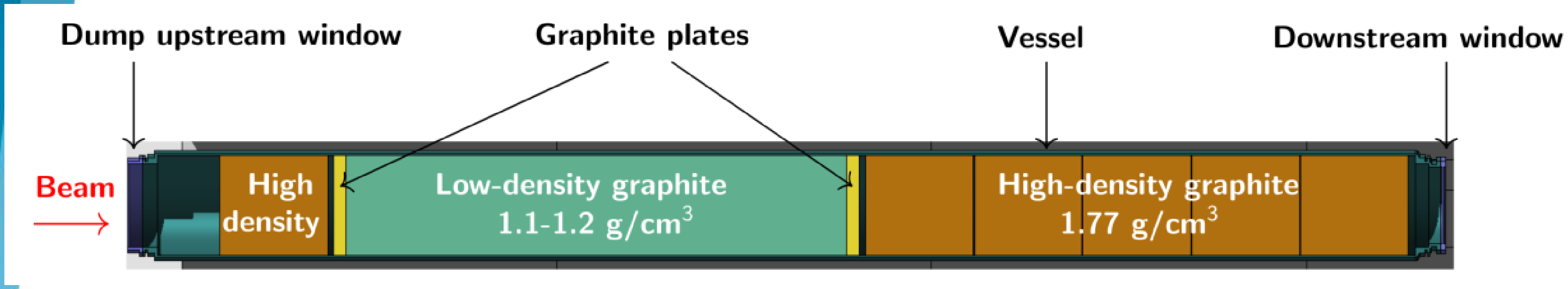
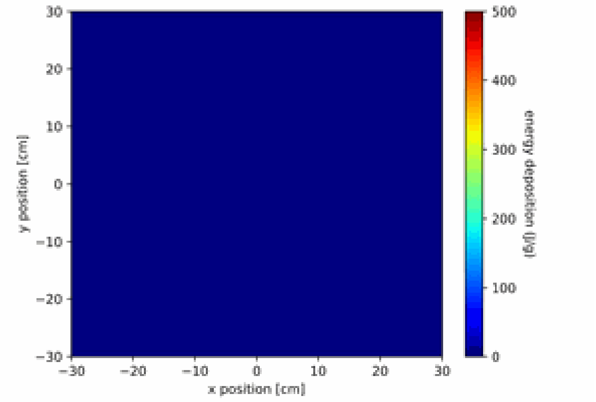
# Project Roadmap

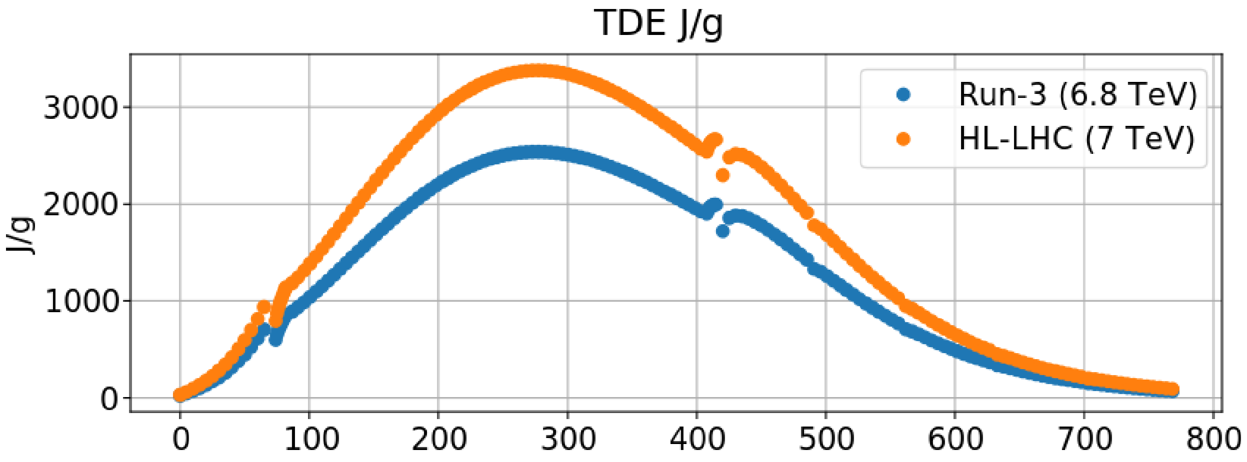


# Core energy deposition in present dump




**Present dump design**




| | Peak Energy density in Sigraflex [kJ/g] | |
|---|---|---|
| Run-1 | **0.6** | |
| Run-2 | **1.5** | Autopsy |
| Run-3 | **2.5** | HRMT-56 |
| HL-LHC | **3.4** | |

**Run 3:** **1.8e11 ppb**
**HL-LHC:** **2.3e11 ppb**

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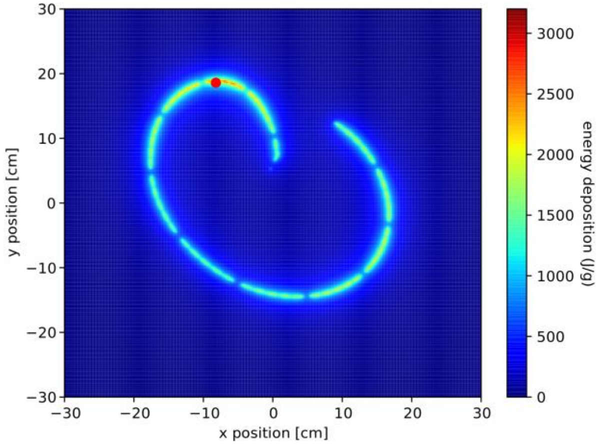
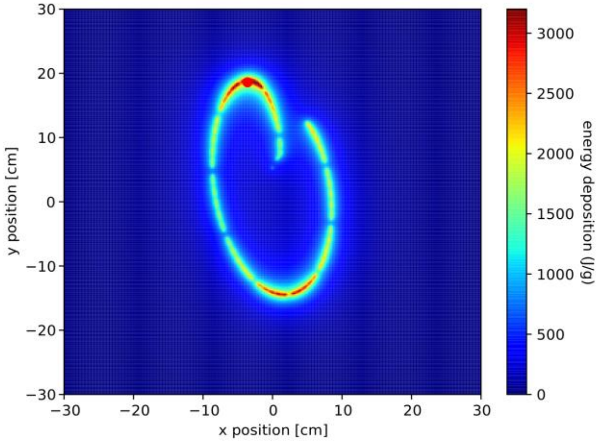
# Dilution failure scenario

### Regular sweep



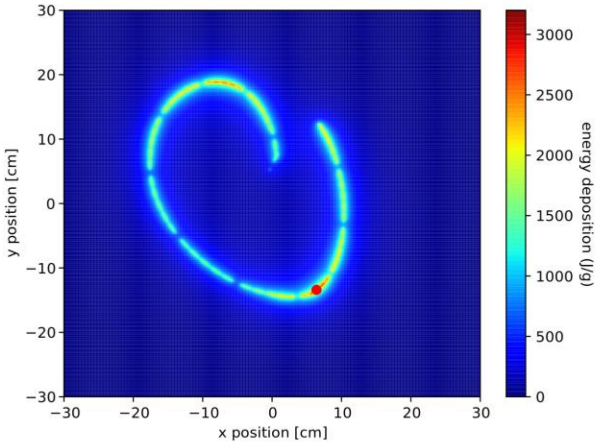

**MKBs** dilution as expected

### 2 MKBHs missing




**2/4 MKBHs missing** →classical failure case considered in the past

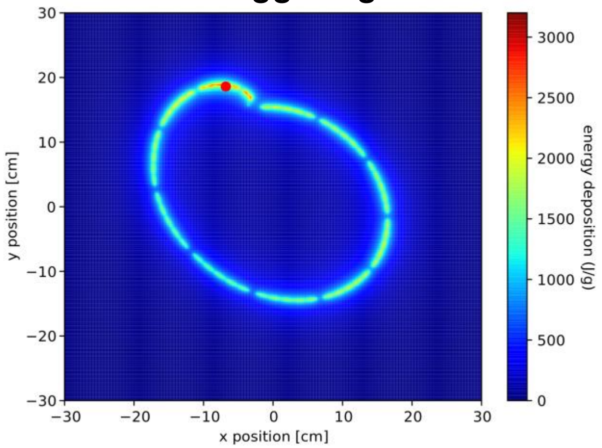
### Flash-over in a kicker tank




**Possible loss of 2 MKBs in the tank**

→2 kickers missing (TOP right) **was chosen to be a representative case**

### MKBs re-triggering




**1 MKB fires after erratic, all remaining fire at abort gap**

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# Core energy deposition in present dump – Failure scenario – Kickers missing

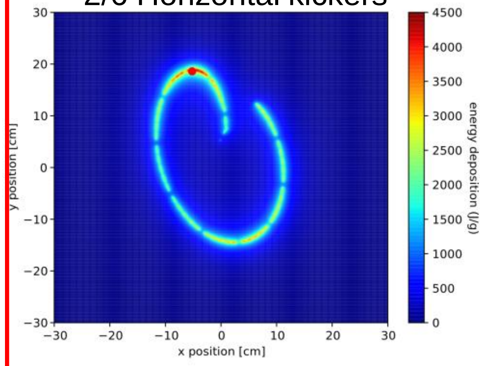
**All calculations performed considering 4 MKBHs for HL**

**2 MKBHs leads to up to 50% dilution loss in H plane**
Up to **5.7** kJ/g

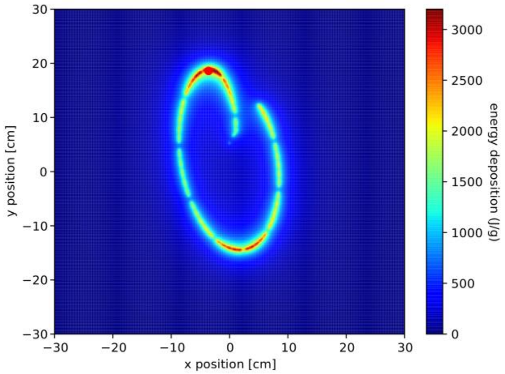
# missing MKBH (columns) / # missing MKBV (rows)

| | 0 | 1 | 2 |
|---|---|---|---|
| **0** | **3.4** | **4.2** | **5.7** |
| **1** | **3.4** | **4.3** | |
| **2** | **3.5** | | |

2/6 Horizontal kickers




2/4 Horizontal kickers




Just for comparison..

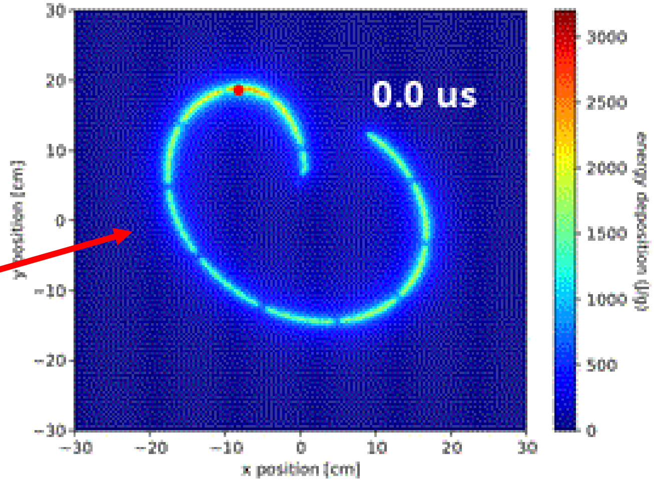
Maximum energy density deposited by considering 2 out of **6** horizontal kickers missing: **4.6 kJ/g**

**HL-LHC: 2.3e11 ppb**

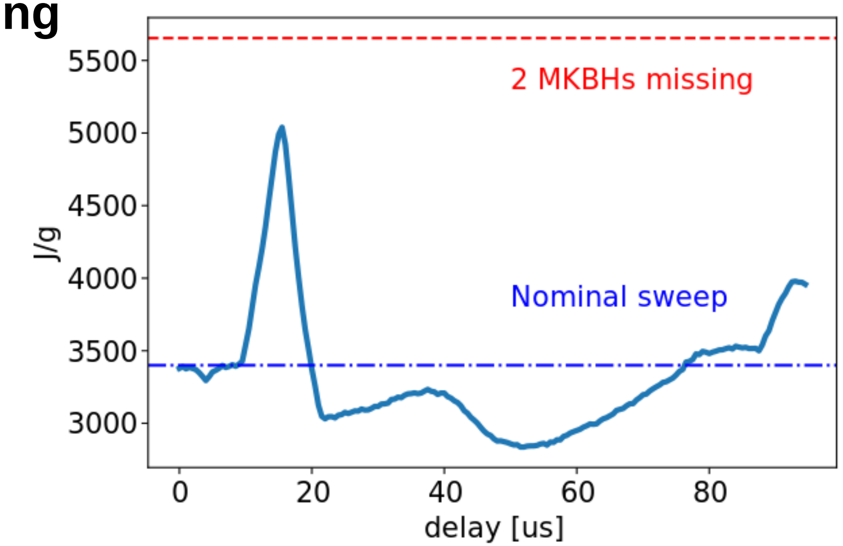
# Core energy deposition in present dump – Failure scenario

**1 MKB fires after erratic**, all remaining fire at abort gap
→ execute synchronous beam dump

Dilution pattern changes as a function of eventual **retriggering delay!**




**2/4 MKBHs missing**



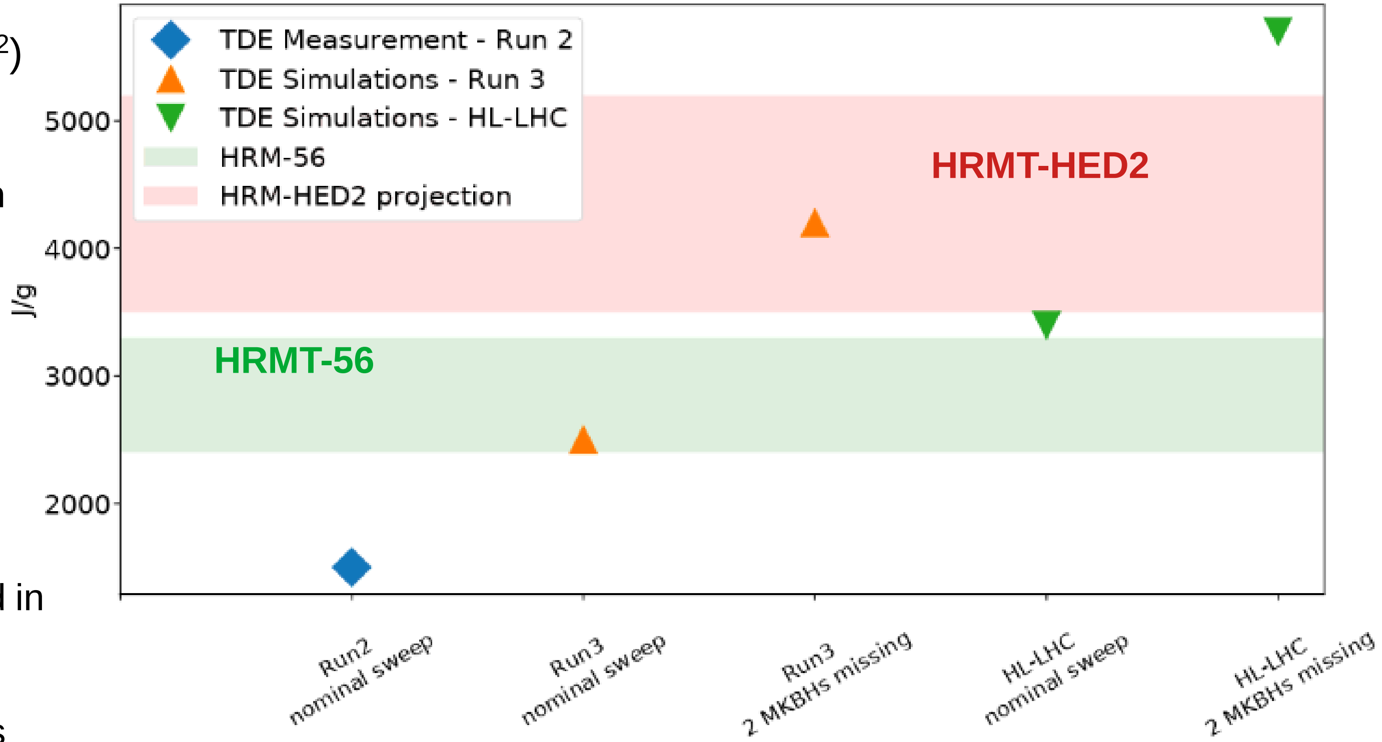

Total time delay (<96 μsec) =
reaction time (<6 μsec) +
delay until abort gap arrives (<89 μsec)

# HRMT-HED2

- **In 2022 HRMT-56 experiment was performed:**
  - **Sigraflex** targets have been exposed to energy density almost comparable to peak energy density in HL-LHC nominal sweep (above **3200 J/g**, symmetric beam 0.25x0.25 $mm^2$)

- **In 2024 HRM-HED2 is planned to test materials in view of HL-LHC:**
  - Bunch intensity increase expected
  - Preliminary results suggests an energy density of **5200 J/g** can be within reach if bunch intensity of 2.1e11 is achieved in HRM
  - Endurance test with many shots will be performed in nominal scenario
  - Key step for the qualification of graphitic materials from upcoming Market Survey

**Run 3: 1.8e11 ppb**
**HL-LHC: 2.3e11 ppb**



- **TCDS**

# TCDS - Introduction

The septum protection absorber TCDS consists of 2 modules, each with 3 m absorber length:

- It protects the extraction septa in case of asynchronous beam dumps
- It has originally been designed for LHC ultimate beams (3.75 um, $1.7 \times 10^{11}$ ppb)

The original WP14 baseline considered adding a third TCDS module for the HL-LHC era:

- Energy deposition studies showed that the temperature rise in the first septum **remains acceptable** even with 2 modules (HL-LHC annual meeting 2021)
  - An update of this study, **including all the septa** is given in this presentation

- C2020 blocks will be exchanged with similar density CfC since they are not robust enough for HL-LHC beams

- The replacement of the last two **titanium blocks** may be envisaged as well

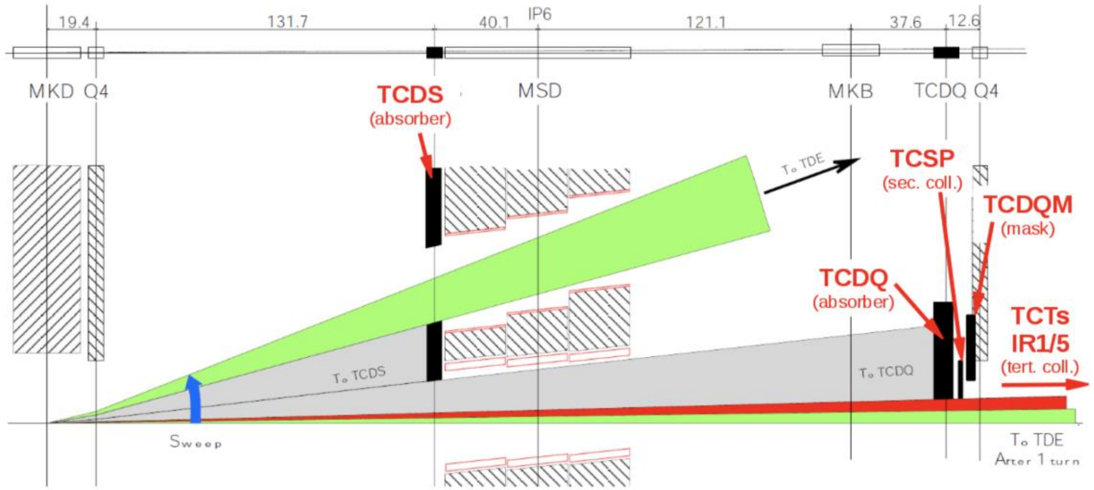
  → In this respect the effect on the septa has been assessed for 3 different candidates (C, CSiC with different densities)

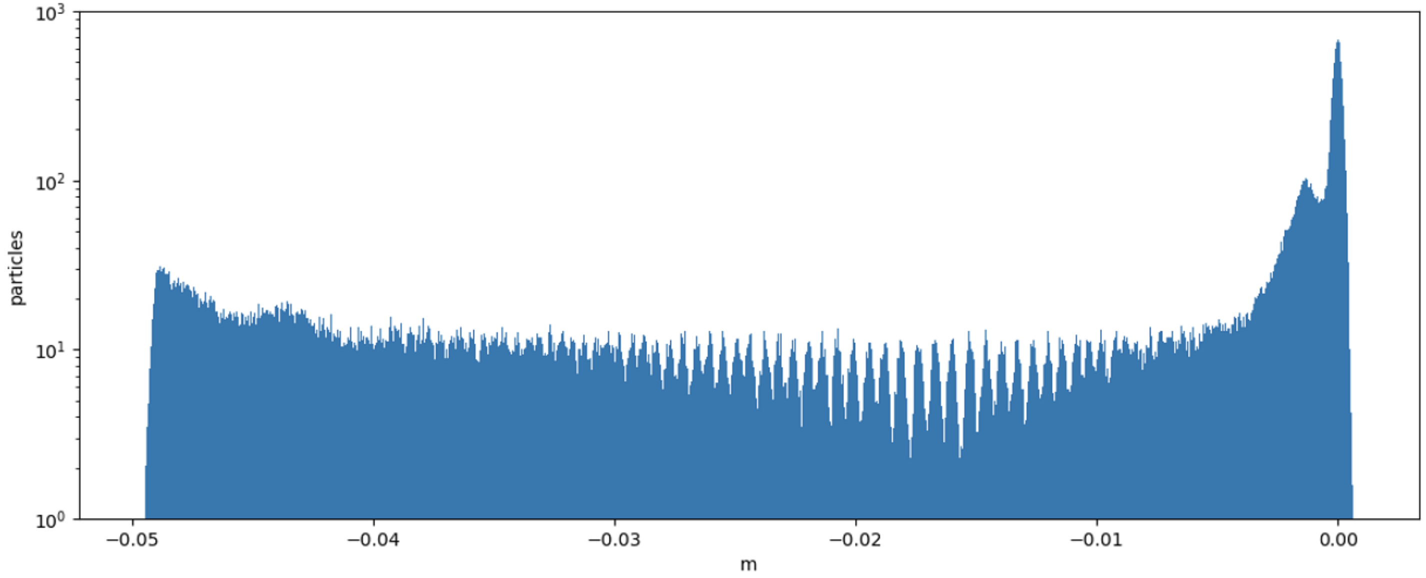
# TCDS – asynchronous beam dump particle distribution

- Particle distribution for an **asynchronous beam dump** (type 2 erratic)

- **BCMS** beam considered (1.37 µm·rad 2.3x$10^{11}$ ppb)
  - No emittance growth and no intensity loss in ramp considered
  - Beam energy of **7 TeV**

- Bunch intensity**: 2.3E11**



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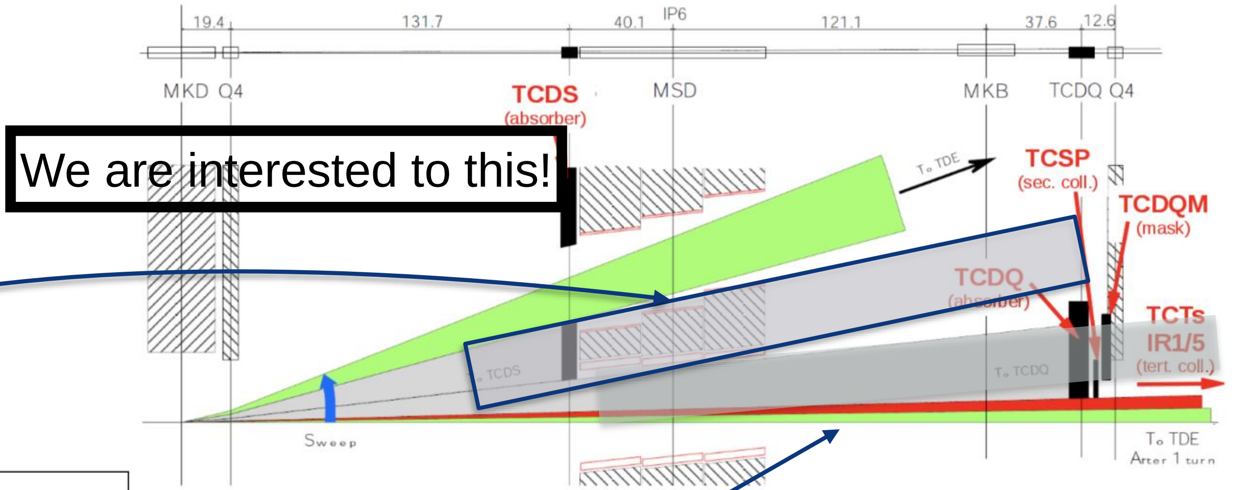
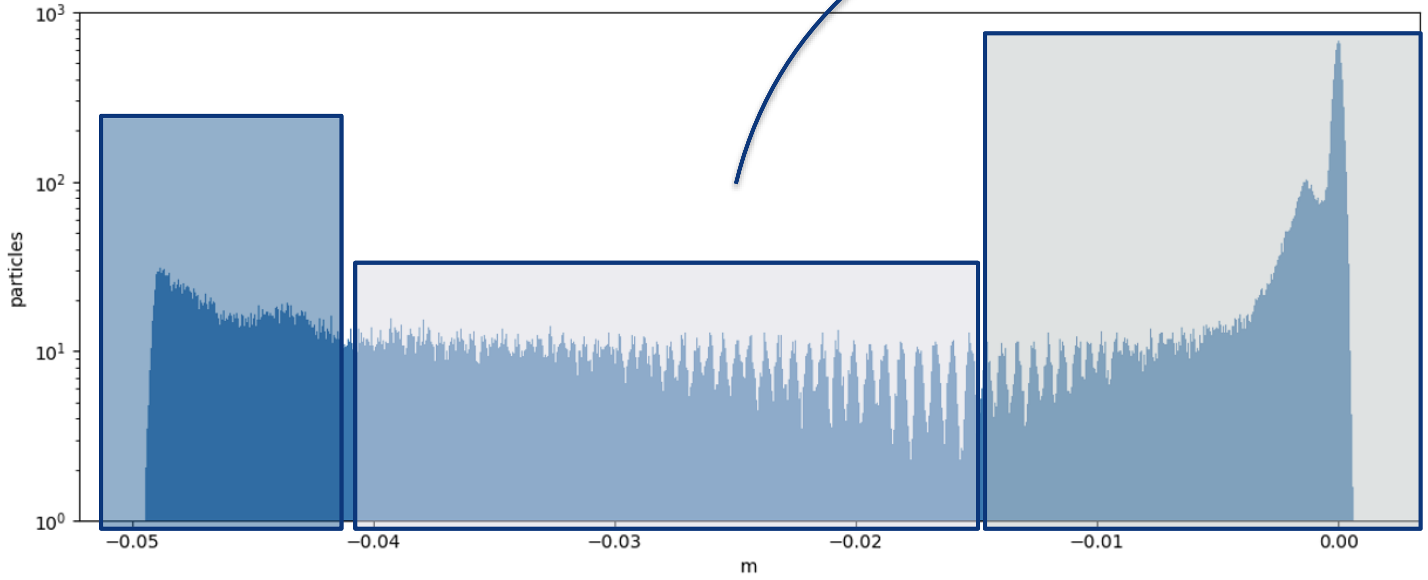


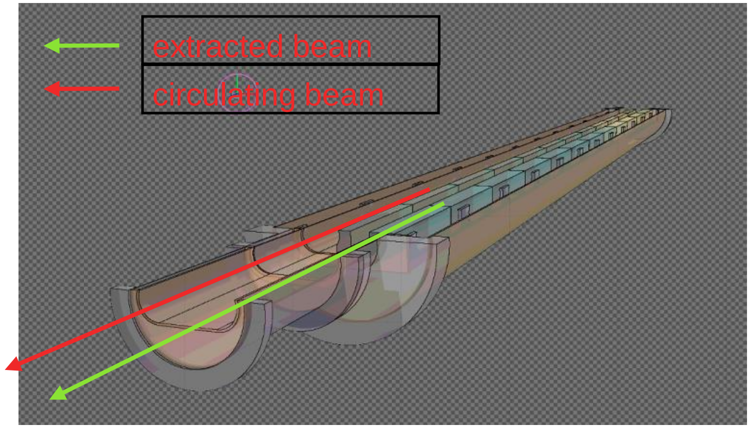



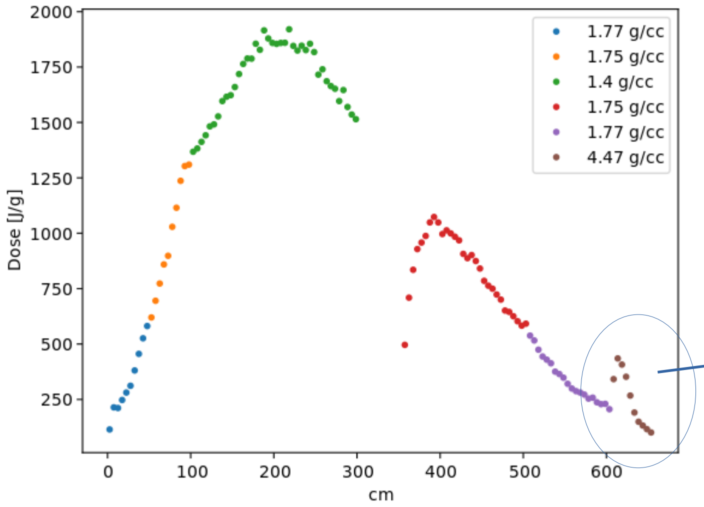
# TCDS – replacement of Titanium blocks

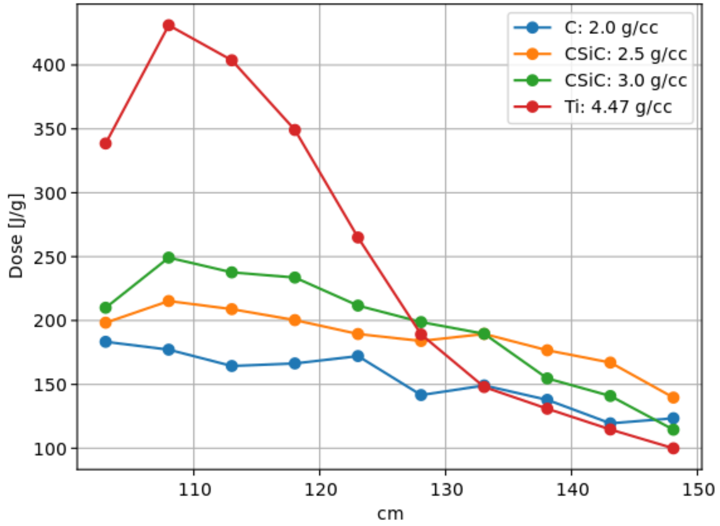
Peak energy deposition in the TCDSU and TCDSD extensively studied in the past:

- **1800 J/g** in the low-density CfC absorber blocks
- **450 J/g** in the Titanium blocks (730 C degrees)

- Several possible replacements for the last two titanium blocks have been considered:
  - Graphite: 2 g/cc
  - CSiC: 2.5 g/cc - (52% SiC – 38% C – 10% Si)
  - CSiC: 3.0 g/cc - (68% SiC – 22% C – 10% Si)



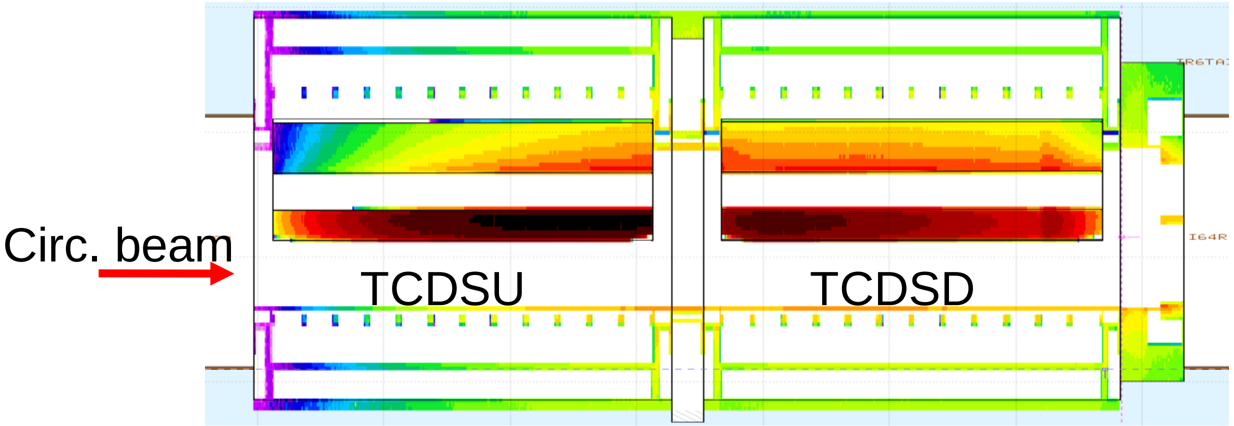




Dose in last blocks decreases by factor 2

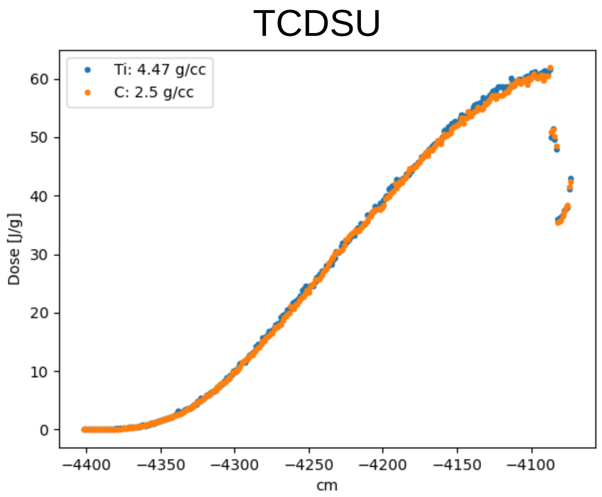
# TCDS – Asynchronous beam dump – effect on TCDS frames

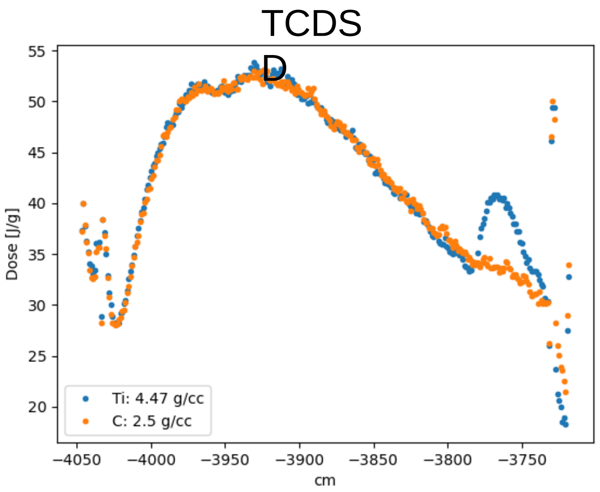
Energy deposition in the stainless-steel frame has been assessed in case of a.b.d leading to:

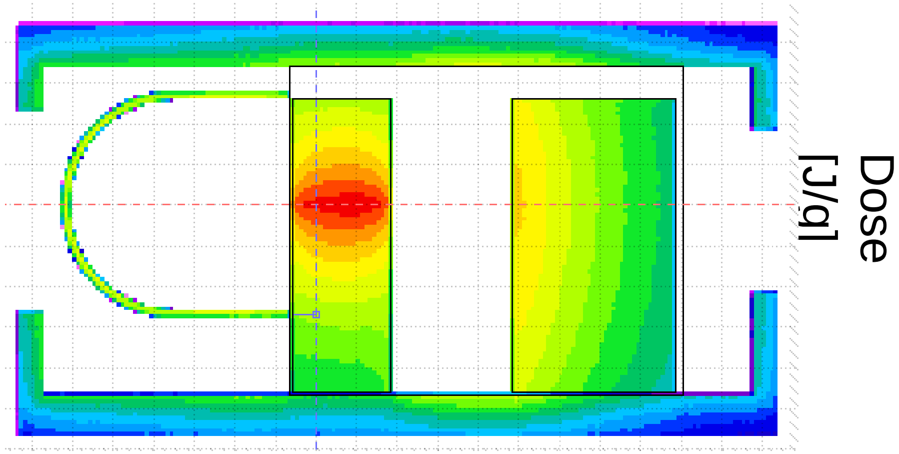
- Max 60 J/g, equivalent to 150 Celsius degrees
- Stresses and plastic deformation to be assessed




Energy density deposition in the frame



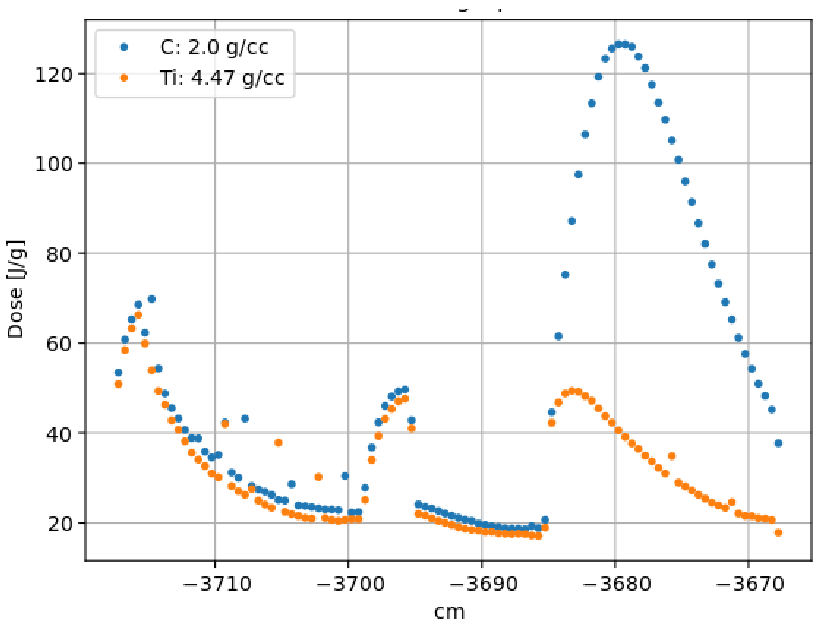



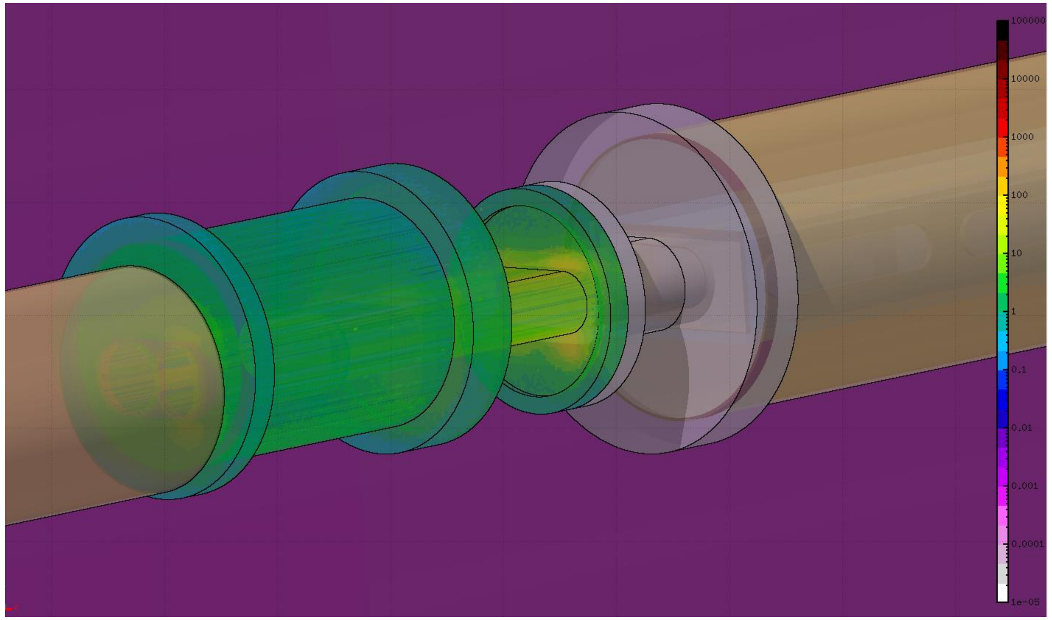



# TCDS – Asynchronous beam dump – effect on interconnect TCDS-MSDA

Energy deposition in the TCDS-MSD interconnect has been assessed in case of an a.b.d leading to:

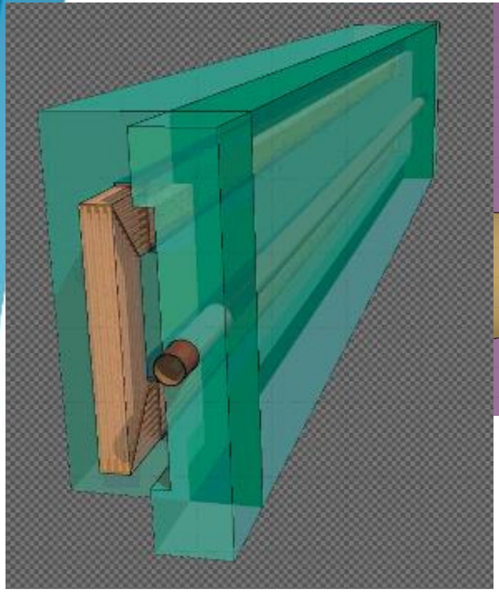
- Max 70 J/g, equivalent to 160 Celsius degrees, with titanium blocks
- By replacing the last two blocks with graphite (2 g/cc), vacuum chamber and flanges receive higher energy densities (factor 2 higher)
- Discussion with vacuum group will be initiated

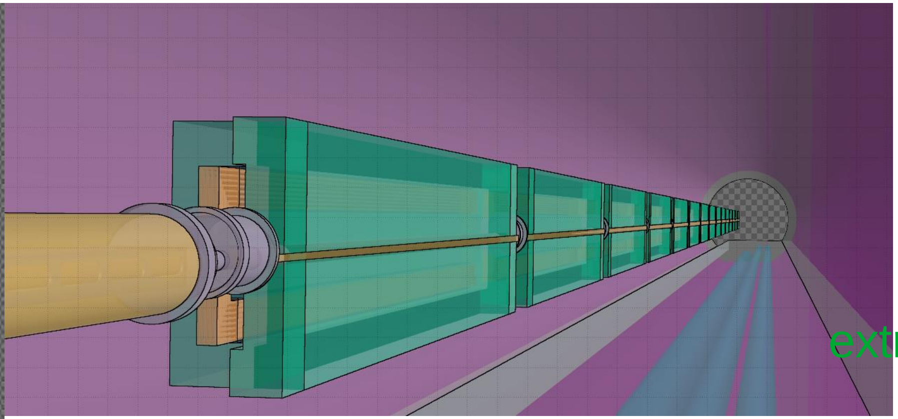


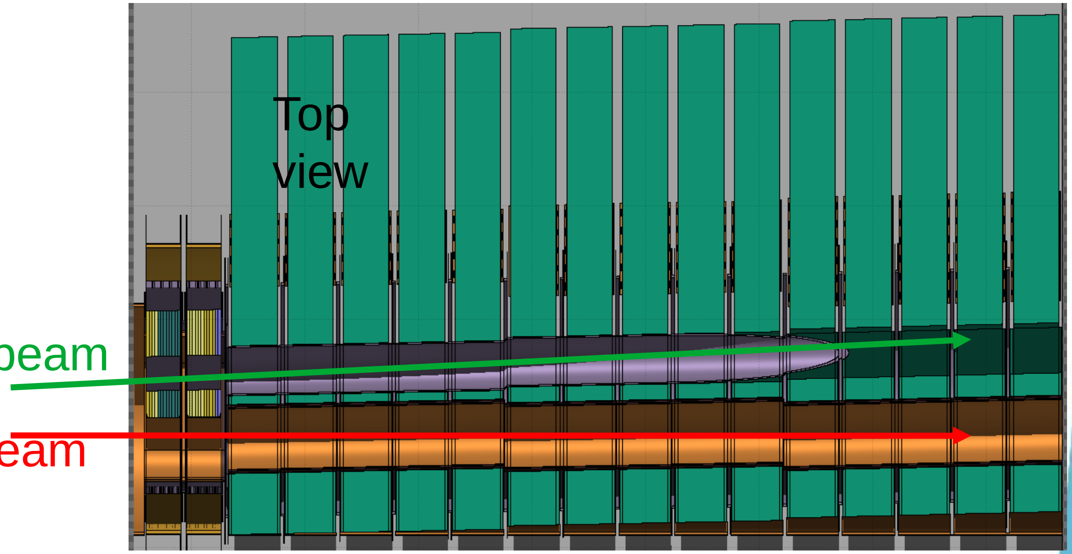



- **MSD**

# MSD – FLUKA model



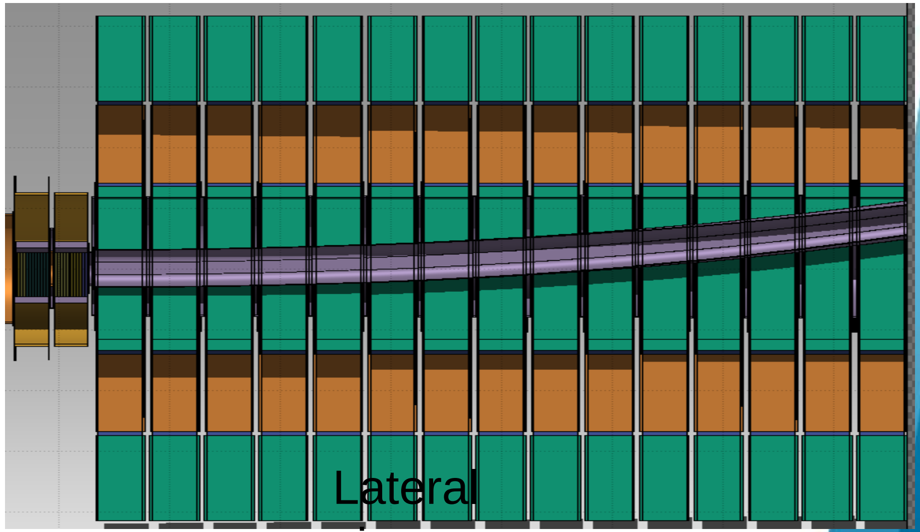





Extraction vacuum chamber position and orientation vary vertically from MSD module to module, form **0.010** to **0.13** degrees.

Horizontal rotation of MSD magnets with respect to the circulating beam of **0.011** (MSDA/B) and **0.014** (MSDC) degrees is also considered.

Dedicated interconnects between each MSD module have been also implemented.

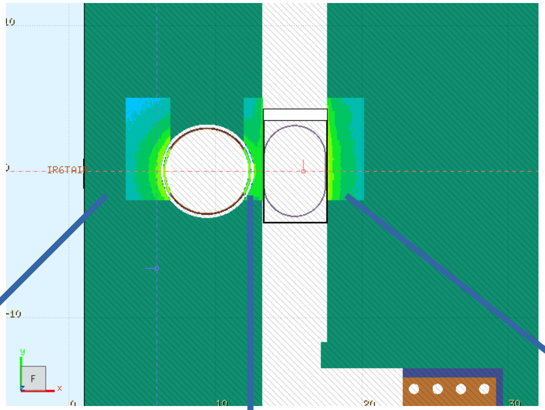


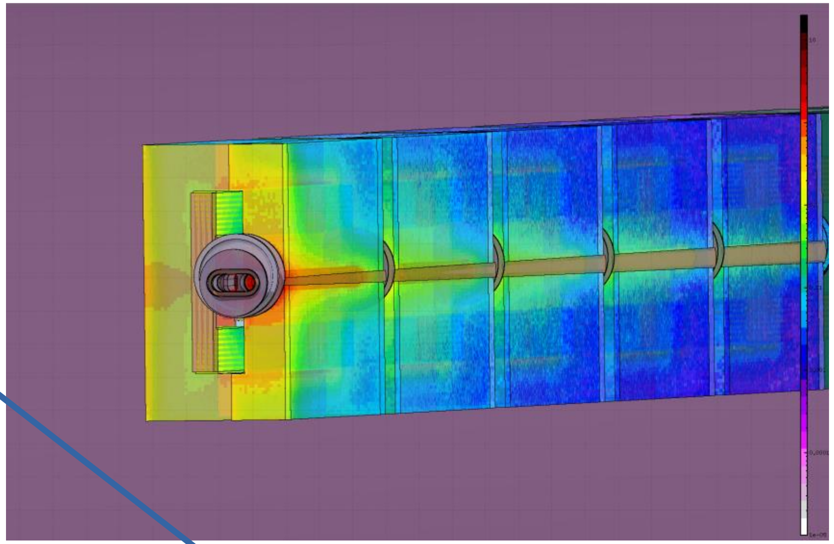
# MSD – Dose in septa

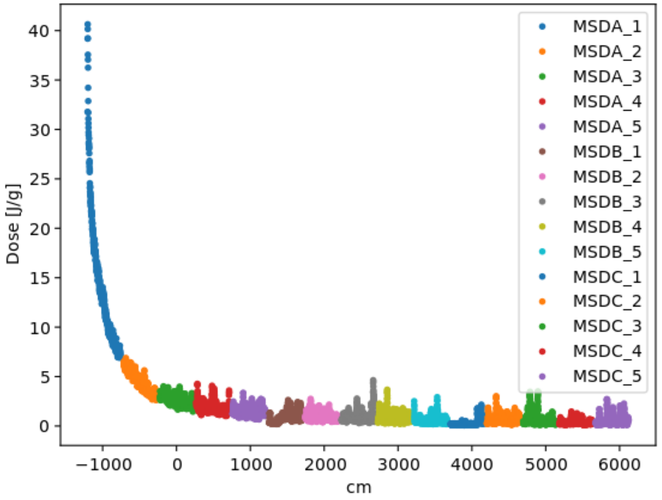
Previous analysis already highlighted the most sensitive regions around the circulating and extracted beams:

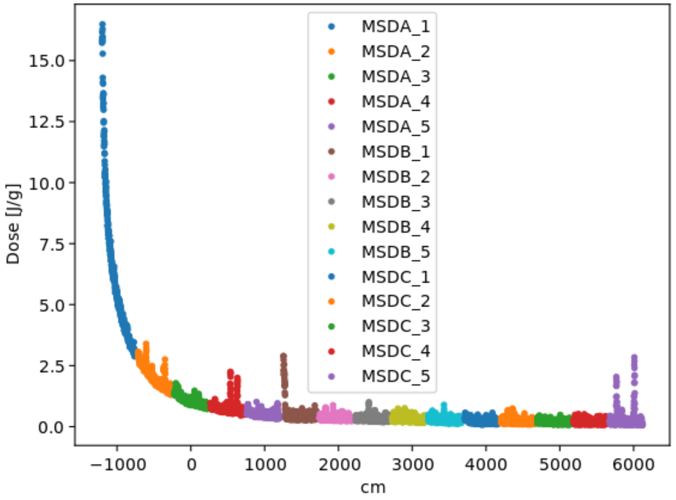
- Maximum temperature in lowCSTL: 110 Celsius [7.87 g/cc, 0.5 J/(g*K)]

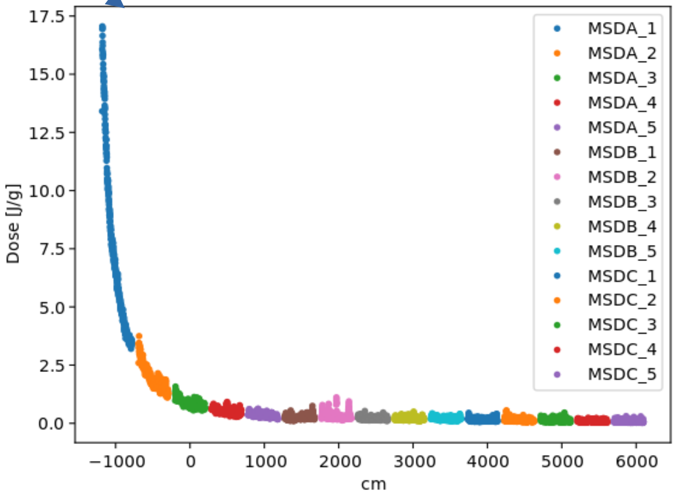
- **No secondary hot-spots in the MSDB/MSDC septa found**







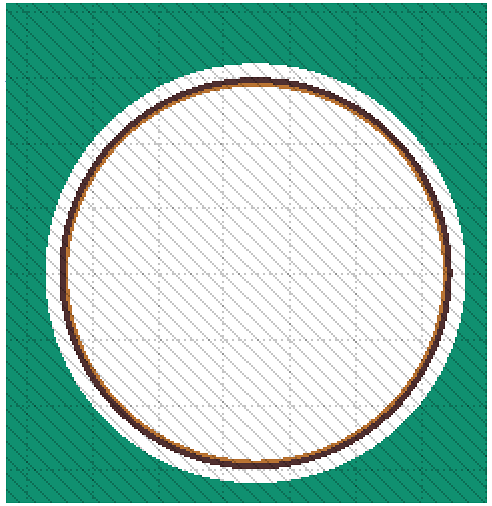



# MSD – Dose in circulating and extracted beam vacuum chambers

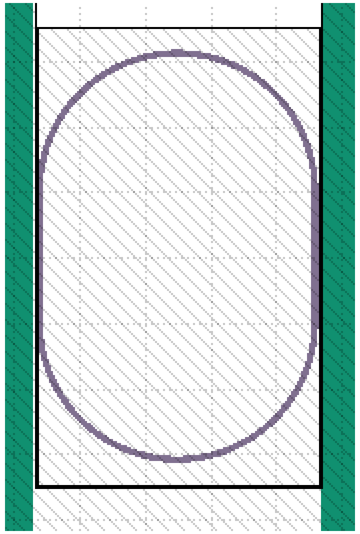
**Circulating beam vacuum chamber**

**max Cu → 35 J/g**
**Max Mu-Metal → 40 J/g**

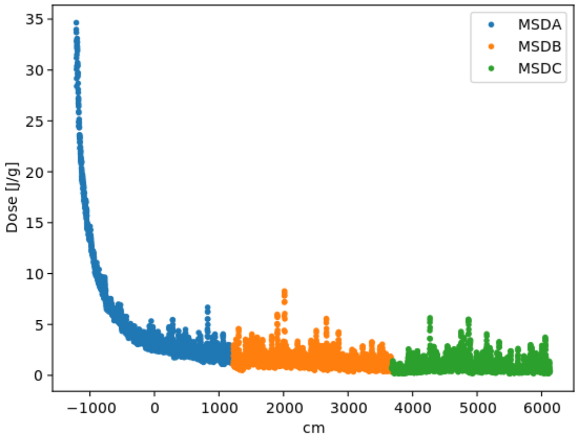


**Extracted beam vacuum chamber**

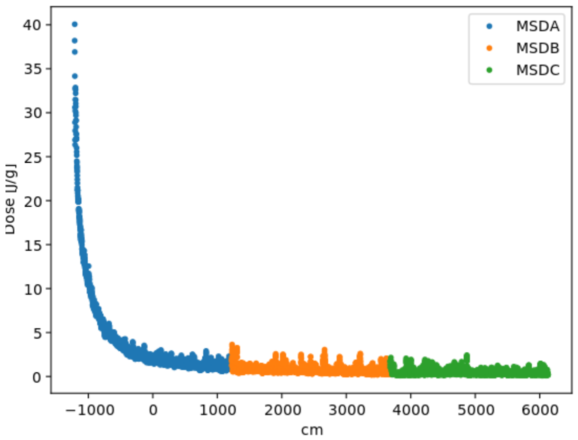
**→ max 25 J/g**

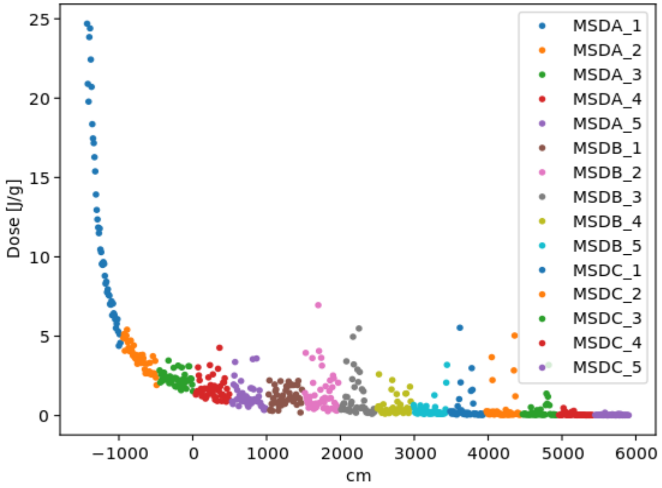


Copper



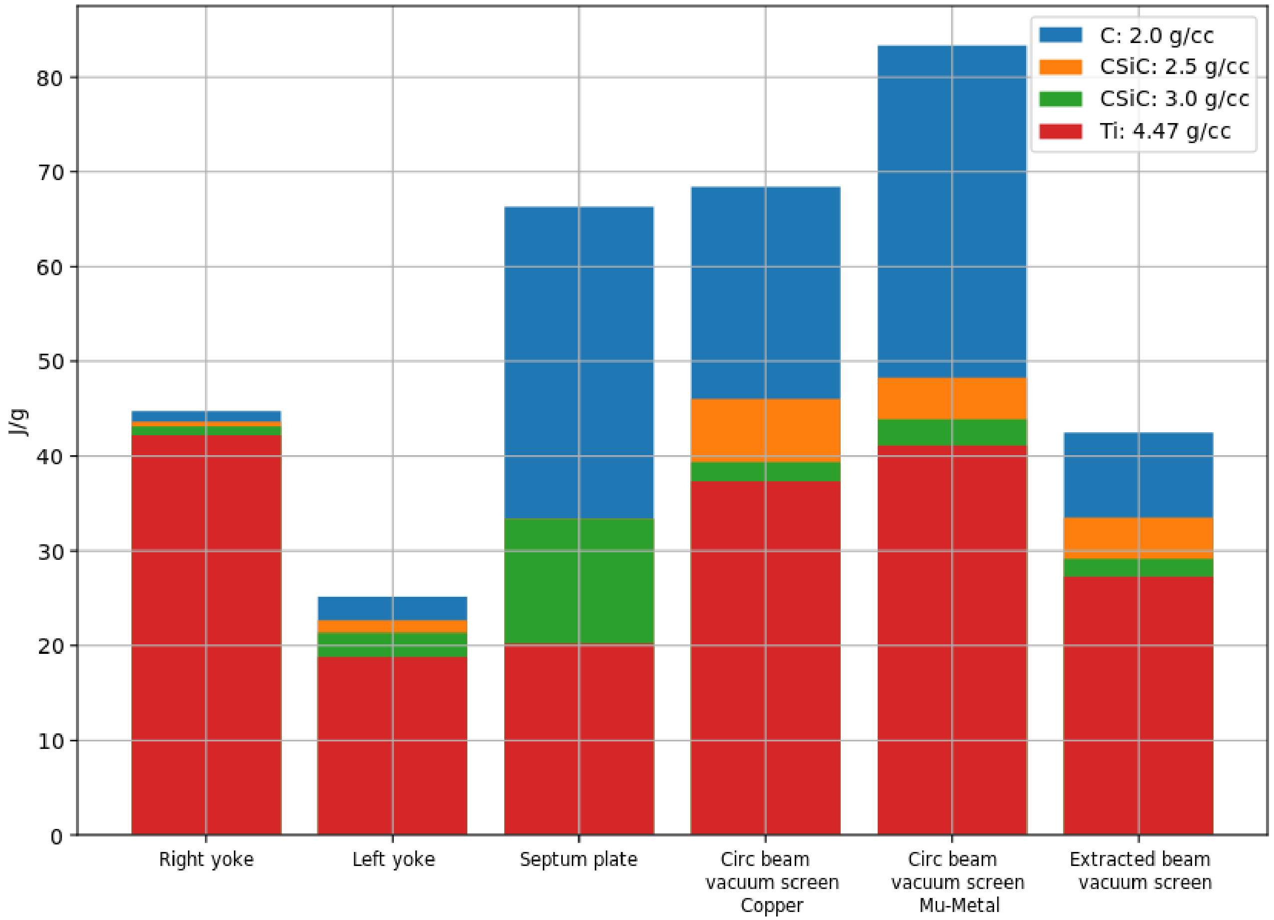

Mu-metal



# MSD – effect on septa from titanium TCDS blocks replacement

The replacement of the titanium blocks induces an increase of dose deposited in the septa in particular in the circulating beam vacuum chamber and in the septum plate.



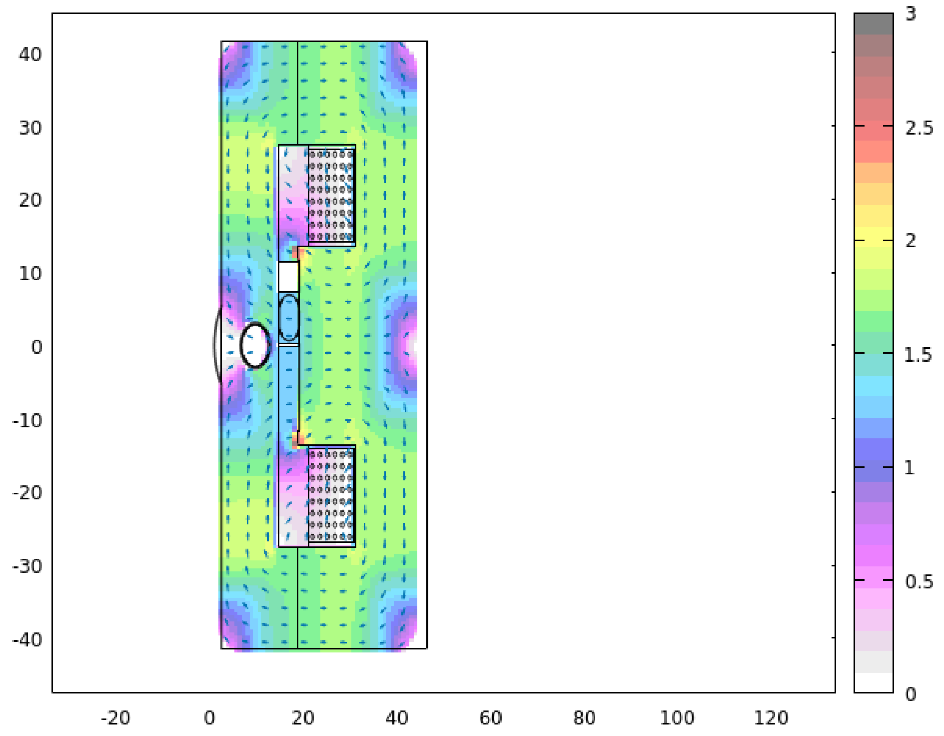
# Conclusions

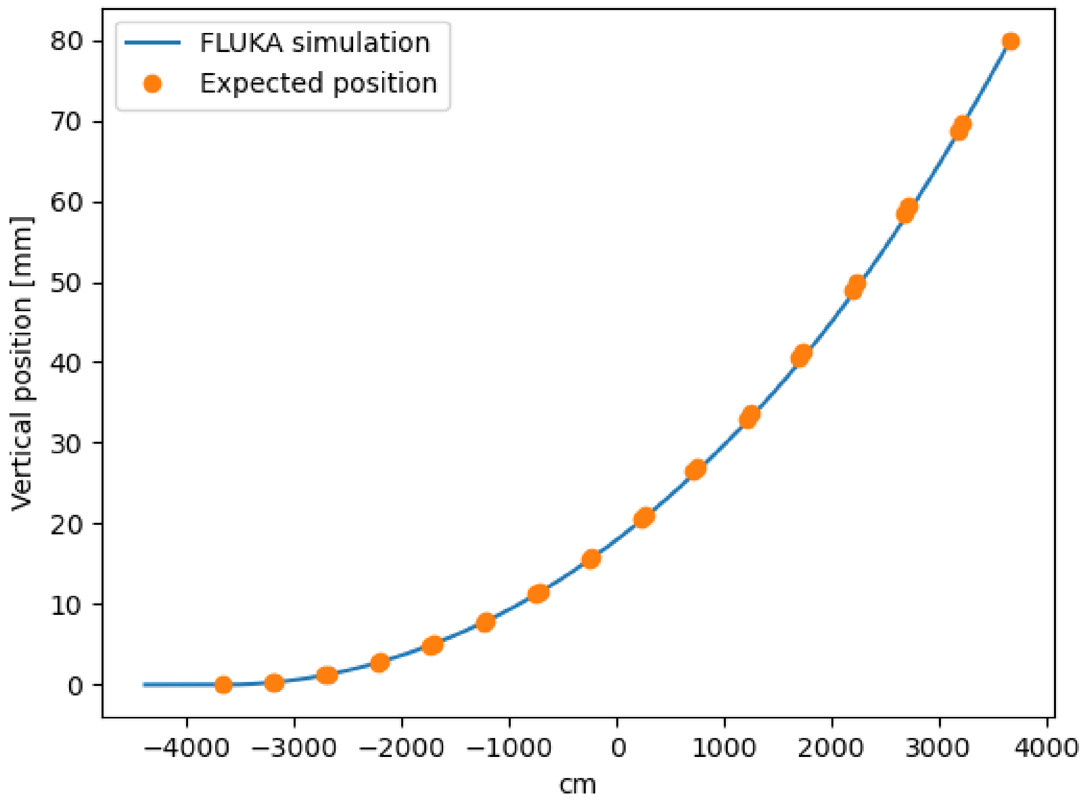
- **TDE**
  - Energy density peak of 3.4 kJ/g is expected in HL-LHC, with the present dump design
  - In the worst dilution failure scenario (2 MKBH) an energy density peak of **5.7 kJ/g** is expected
  - An improved TDE design is being developed
  - It is very important to perform the HRM-HED2 experiment in order to qualify the graphitic materials for these energy densities

- **TCDS/MSD:**
  - Complete simulation of MSDA – MSDB – MSDC confirmed previous results: no further hot-spots identified in the septa
  - Comprehensive summary of the energy density deposited in the TCDSU/D frame and interconnects have been reported
    - ➔ Max 160 C scored in the TCDS frame and interconnect
    - ➔ Max 200 C degrees expected in the beam screen
  - TCDS C2020 blocks will be replaced; a replacement of the last two titanium blocks can be also foreseen:
    - ➔ Several possible materials replacing the TCDS titanium blocks have been assessed in terms of septa protections
  - To be followed-up by thermo-mechanical simulations for the TCDS frame and possibly interconnects

- **BACKUP**

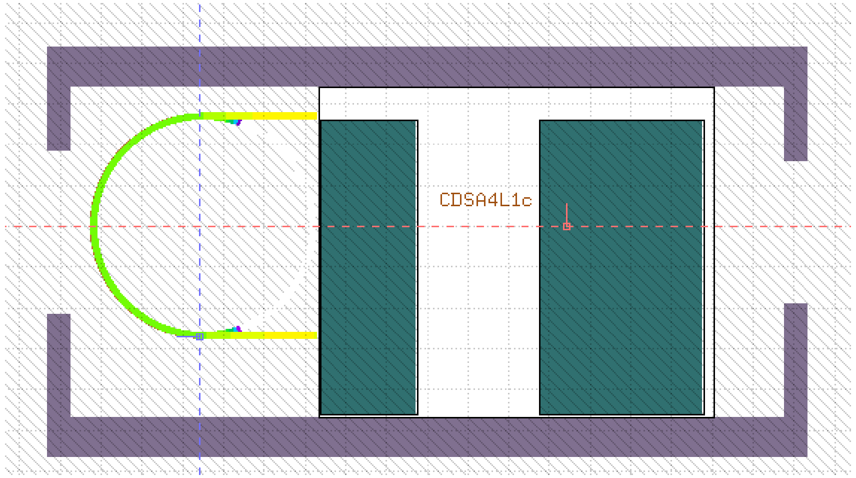
# MSD – magnetic field and trajectory check



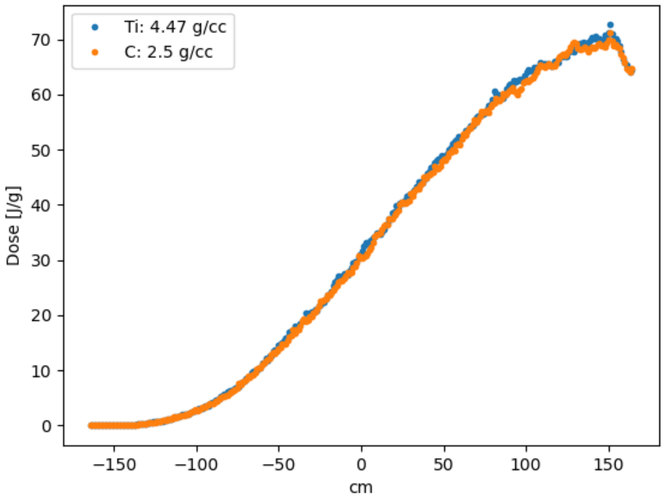

Excellent agreement between expected (MAD-X) and simulated particle position

# TCDS – Asynchronous beam dump – effect on beam screen - BACKUP




The maximum expected dose deposited in the copper vacuum screen is 70 J/g, equivalent to about 200 Celsius final temperature

TCDS




TCDS