Update on energy deposition studies for the beam dump

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A. Perillo Marcone and M. Calviani

9th HL-LHC Collaboration Meeting

October 15, 2019

1. Introduction: TDE layout and input parameters
2. Upstream window
3. Downstream window
4. TDE Core
5. Conclusions and outlook

Outline

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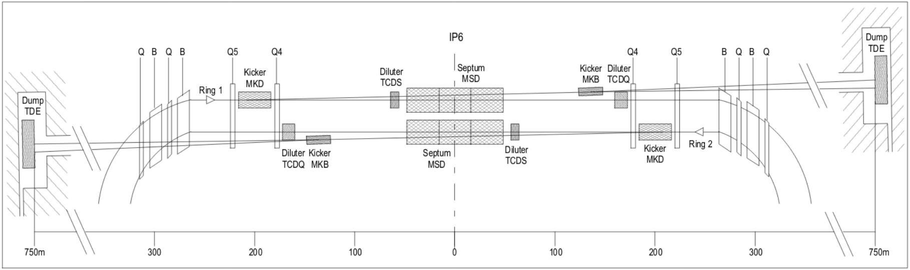
Introduction: LHC beam dump system



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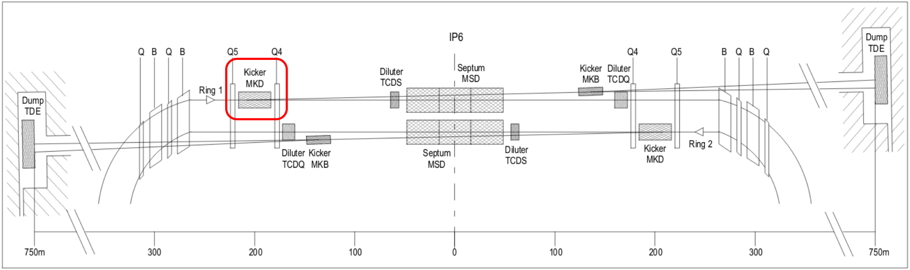

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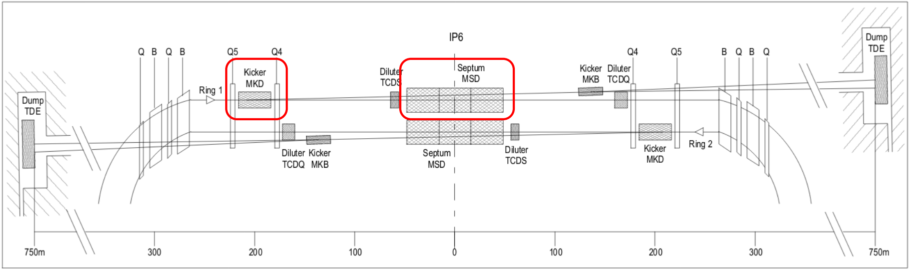

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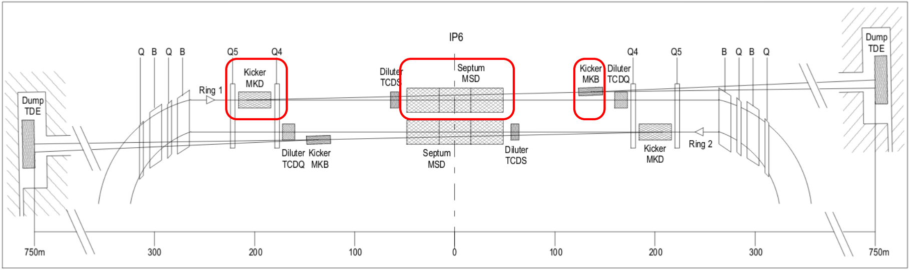

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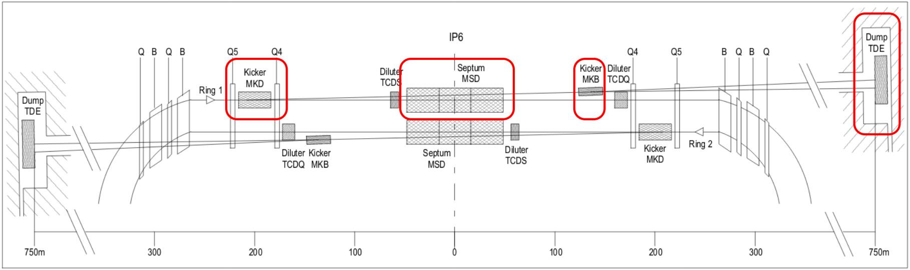


Dump cavern

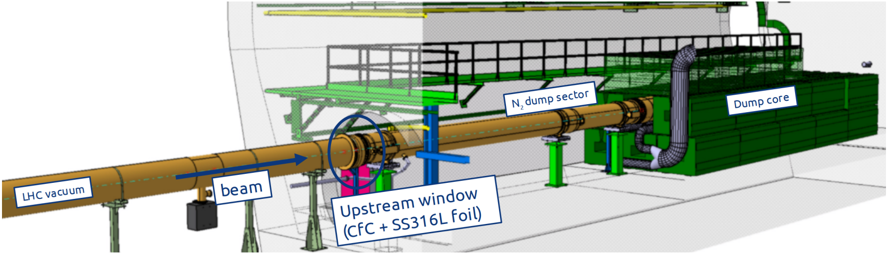
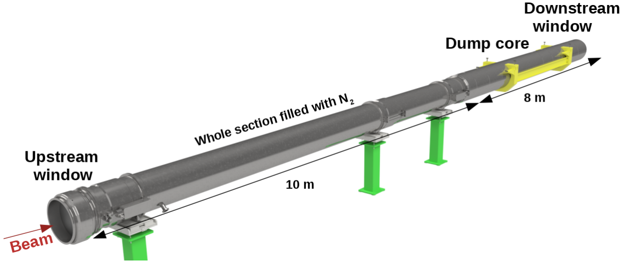


Figure from A. Perillo Marcone, "LHC Dump Assembly - Operational Feedback and Future Prospective", 9th LHC Operations Evian Workshop, 2019

TDE upstream and downstream windows



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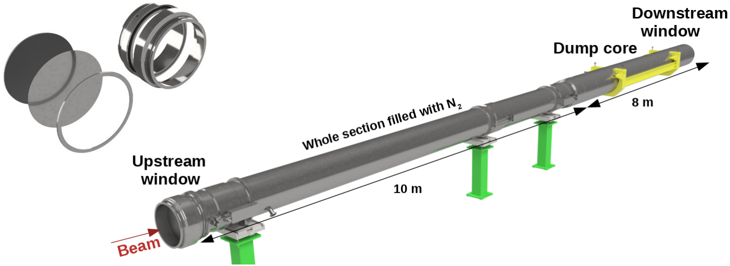

Upstream window

Thick.	Material	Density
15 mm	CfC SIGRABOND 1501G	1.5 g/cm^3
0.2 mm	Stainless steel SS316L	8 g/cm^3

isolate the vacuum of LHC extraction line from nitrogen gas

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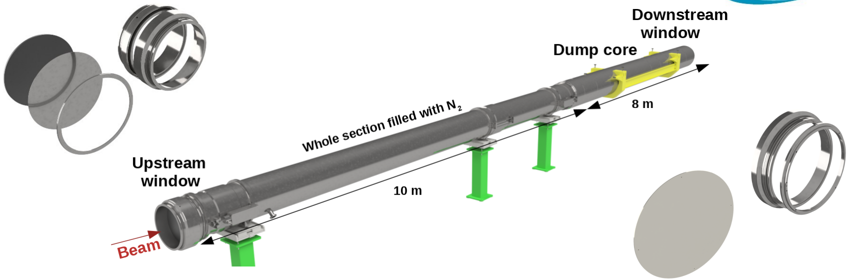

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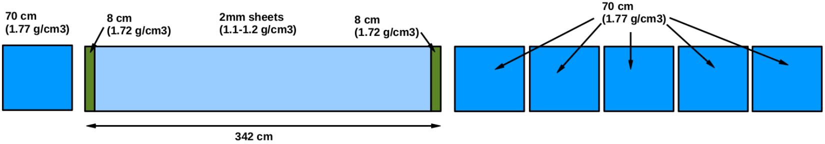
Downstream window

Thick.	Material	Density
10 mm	Titanium Grade 2	4.5 g/cm^3

exposed to the shower from the dump

Figures from T. Polzin, "Updates on the thermo-mechanical studies of the TDE dump block assembly", HL-LHC 8th Collaboration meeting, 2018

TDE core: low and high density graphite segments



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- **Total absorber length** → ≈ 7.6 m

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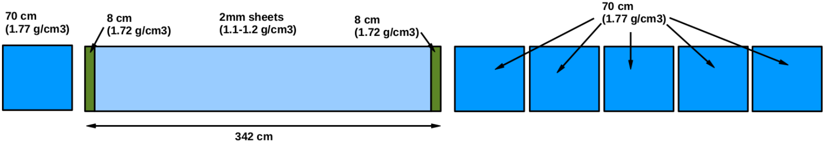

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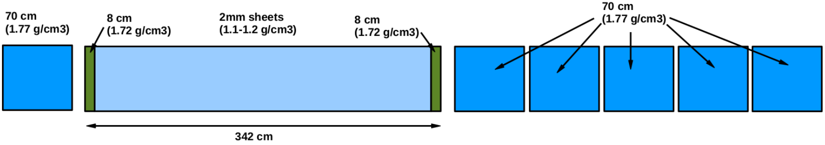

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SIGRAFLEX FOIL
Characteristic data for a graphite bulk density of 1.0 g/cm³

Thermal stability		Can be used from -250°C up to approx. 3000°C (in protective gas)
Sublimation temperature	°C	> 3000

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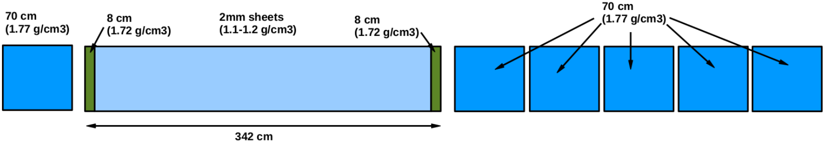

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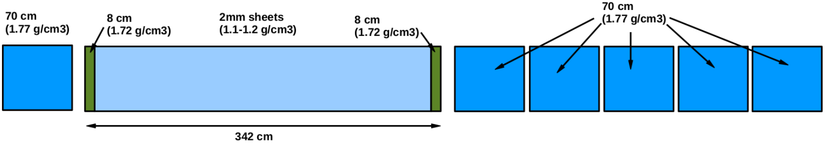

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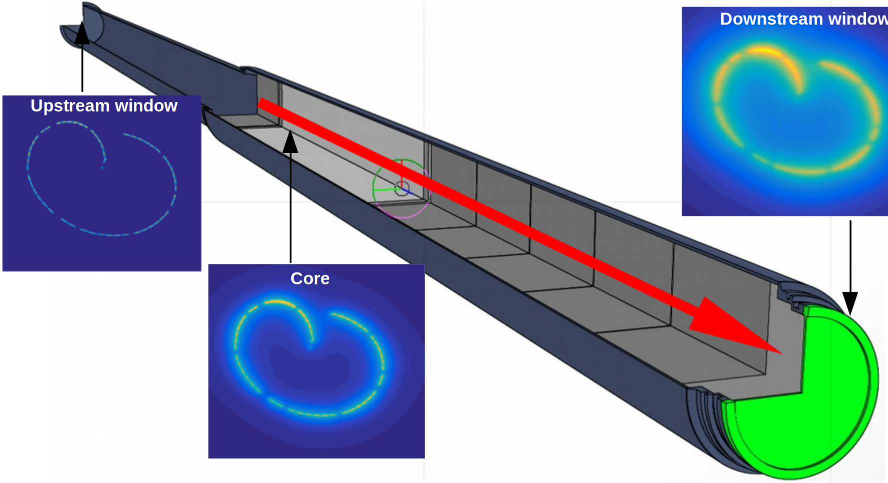
- **Shell** → 12 mm thick stainless steel jacket

Effect of particle showers



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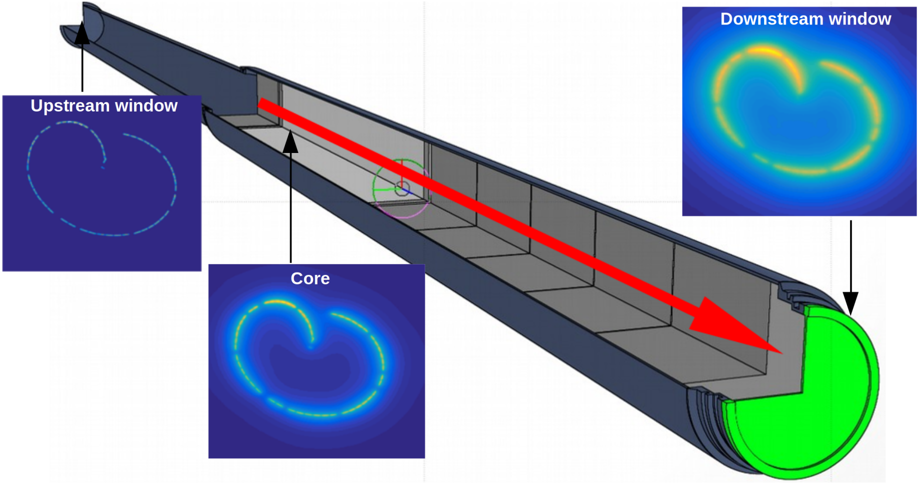


Peak energy density

Upstream window → transverse spot size and bunch intensity

Downstream window → **only** bunch intensity

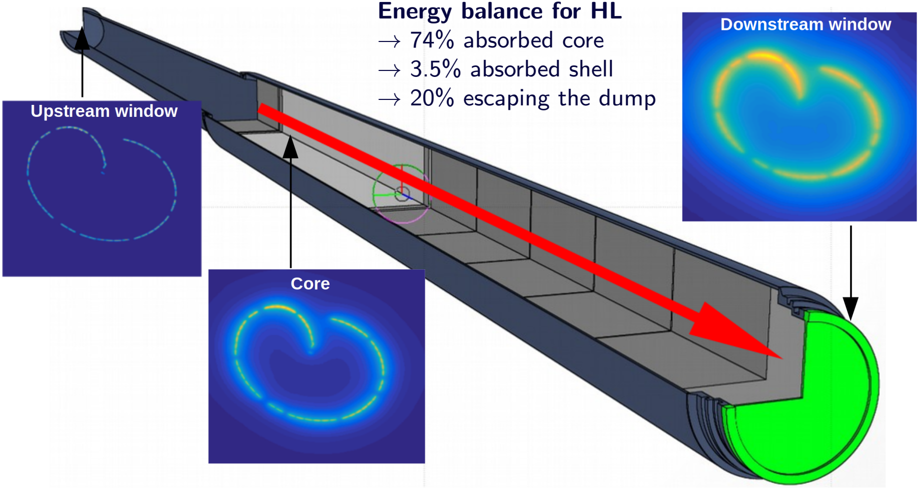
Effect of particle showers

Energy balance for HL

→ 74% absorbed core

→ 3.5% absorbed shell

→ 20% escaping the dump



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Beam parameters from Run2 to HL-LHC

Beam	$\epsilon^n_{x,y}$ at Inj	I_b at Inj	$\epsilon^n_{x,y}$ at FT	I_b at FT
LHC design				
Nominal *[1]*	3.40 μm·rad	$1.2 \cdot 10^{11}$	3.75 μm·rad	$1.15 \cdot 10^{11}$
Ultimate *[1]*	3.40 μm·rad	$1.8 \cdot 10^{11}$	3.75 μm·rad	$1.7 \cdot 10^{11}$
Run 2				
2018 *[2]*	1.3-1.4 μm·rad	$\approx 1.2 \cdot 10^{11}$	1.7-2.1 μm·rad	$1.2 \cdot 10^{11}$
Run 3				
BCMS 2020 *[3]*	1.3 μm·rad	$1.4 \cdot 10^{11}$	1.8 μm·rad	$1.4 \cdot 10^{11}$
BCMS 2021/22 *[3]*	1.3 μm·rad	$1.8 \cdot 10^{11}$	1.8 μm·rad	$1.8 \cdot 10^{11}$
HL-LHC				
STD *[4]*	2.08 μm·rad	$2.3 \cdot 10^{11}$	2.5 μm·rad	$2.2 \cdot 10^{11}$
BCMS [4]	1.7 μm·rad	$2.3 \cdot 10^{11}$	2.5 μm·rad	$2.2 \cdot 10^{11}$

Conservative approach $\rightarrow$ no emittance growth and no intensity loss in ramp

[1] LHC design report, [2] Y. Papaphilippou, LHC Emittance Preservation WG, [3] S. Fartoukh, Run III Configuration WG

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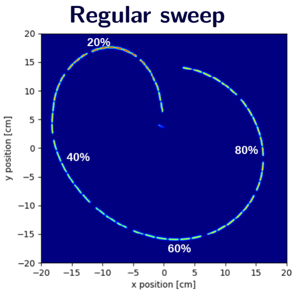
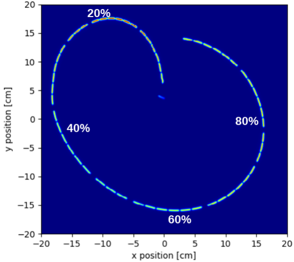
Sweep patterns and failure scenarios

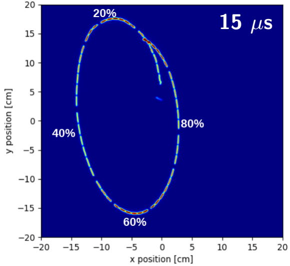


Sweep patterns and failure scenarios

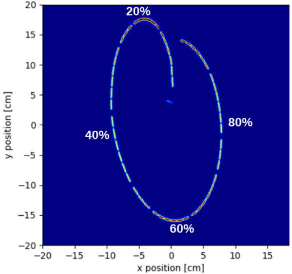
Regular sweep



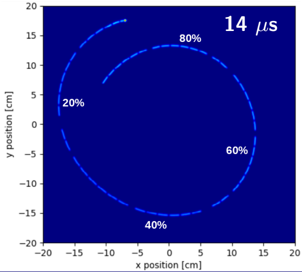
Failure: flashover



Failure: 2 MKBH missing



Failure: retrigger



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Upstream window in Run 3 and HL-LHC

Stress evaluation in SS316L foil

Run 3

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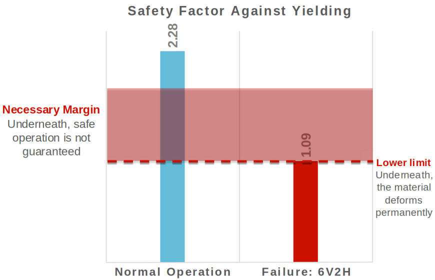
$$\epsilon_n = 1.7\ \mu\text{m mrad}$$



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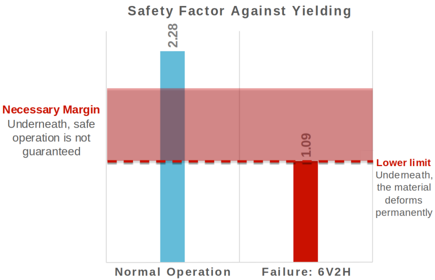

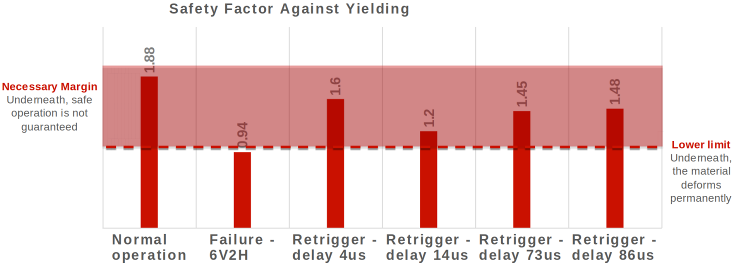

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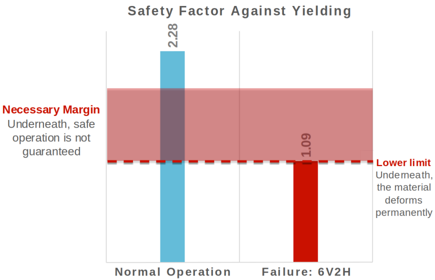
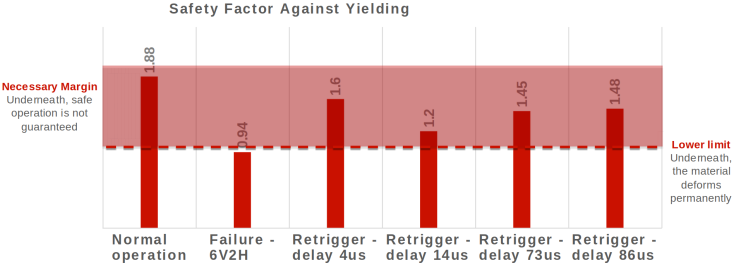
$\Rightarrow$ Expected stress levels are too high for a long-term and reliable operation





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Present design of upstream window

- increase β-functions up to 10-20 km

(default $\beta_x = 5.052$ km, $\beta_y = 3.714$ km)

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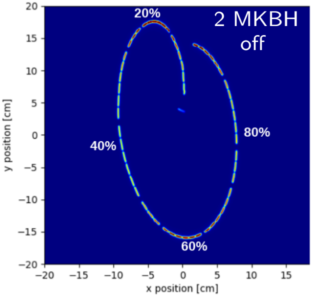

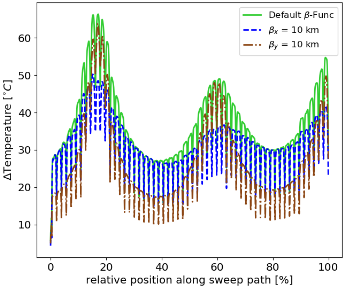

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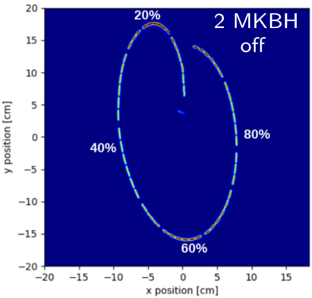
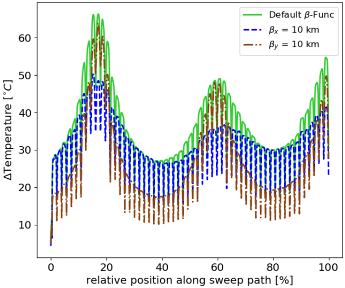
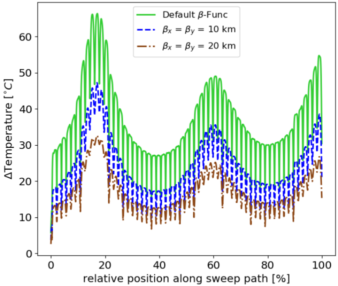
$\Rightarrow$ reduction in temperature increase

$\Rightarrow$ Regular sweep - def. β: **37.9 °C**
(safety factor 1.88)

2 MKBH off - $\beta_{x,y}$=20 km: **32.6 °C**







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Maximum energy density
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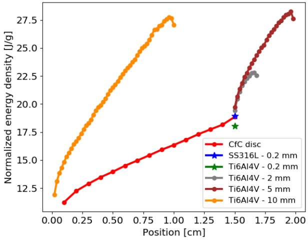
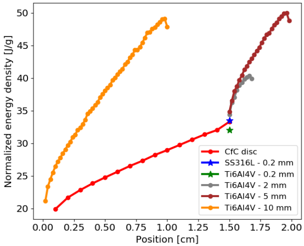


Failure: 2 MKBH off



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⇒ Thermo-mechanical studies ongoing

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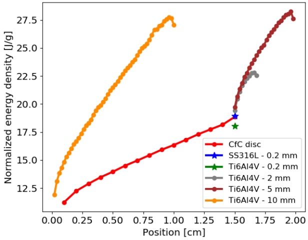

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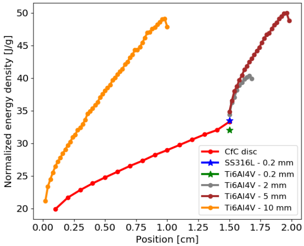

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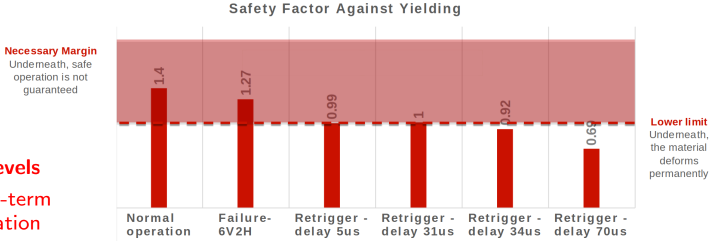

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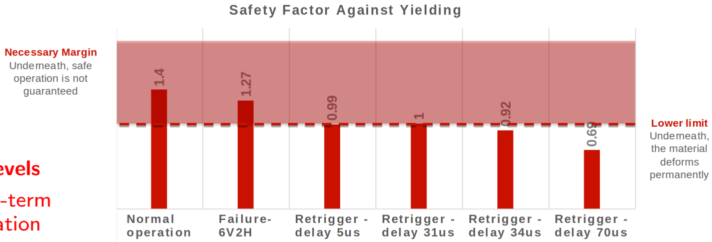

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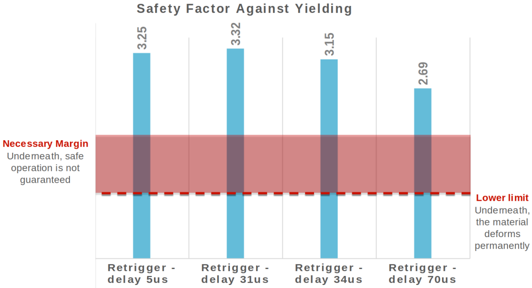

New material

Titanium Grade 5 (Ti6Al4V)

⇒ **acceptable stress levels**

for the considered load cases

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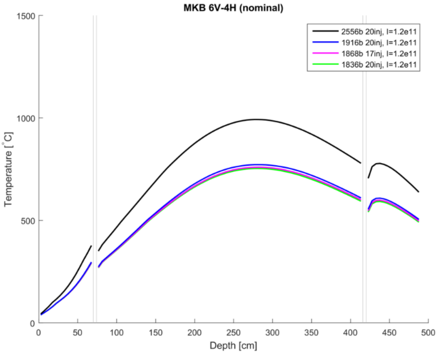
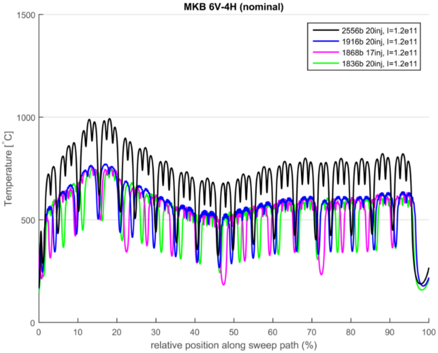
Regular sweep: temperature for Run 2 at 6.5 TeV

Longitudinal peak temperature profile



Temperature along sweep path at 2.8 m depth

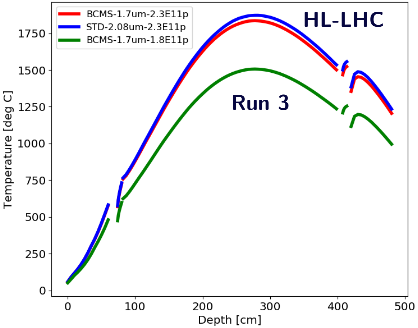


Regular sweep → reached up to **1000°C** in cases when beams were dumped early in 6.5 TeV fills in 2017/18

Figures courtesy of M. Frankl

Regular sweep: temperatures for Run 3/HL at 7 TeV

Longitudinal peak temperature profile



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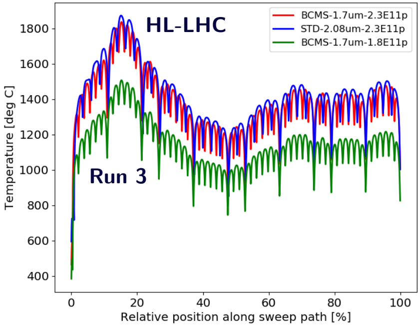

Regular sweep → Run 3 expected ≈**1500°C** for $1.8 \cdot 10^{11}$ ppb

→ HL-LHC expected ≈**1800-1900°C** for $2.3 \cdot 10^{11}$ ppb

Regular sweep: temperatures for Run 3/HL at 7 TeV

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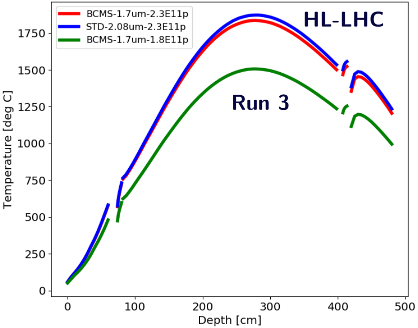

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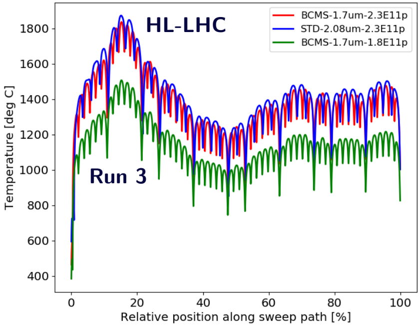

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↓ **Acceptable ?**

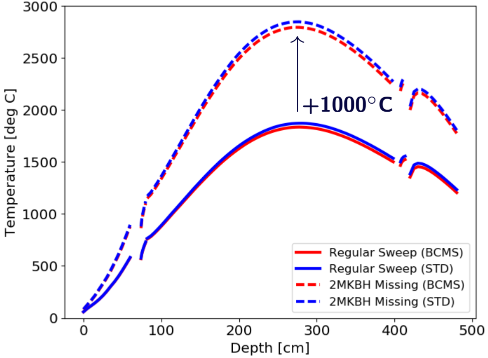
material characterization → collaboration with NTNU/SINTEF (Norway) institute

Failure case: reduced dilution

Dilution kickers → 4 horizontal (MKBH) and 6 vertical (MKBV)

→ higher voltage for the horizontal kickers

→ MKBH failures more critical for TDE



Peak temperatures

# active MKBH	# active MKBV: 6	5	4
4	1840 1860	1860 1880	1920 1950
3	2200 2240	2240 2270	2280 2310
2	2800 2840	2840 2880	2900 2960

HL BCMS: $2.3 \cdot 10^{11}$ ppb, 1.7 μm

HL STD: $2.3 \cdot 10^{11}$ ppb, 2.08μm

2 MKBH failure → peak temperature reaches **3000°C** for HL-LHC

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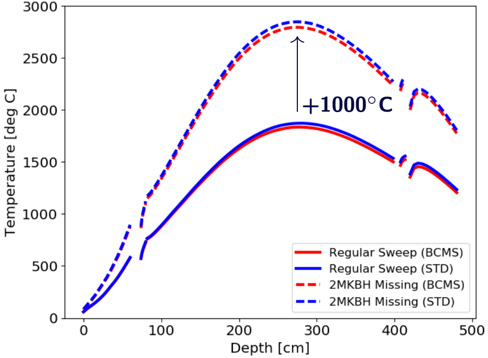

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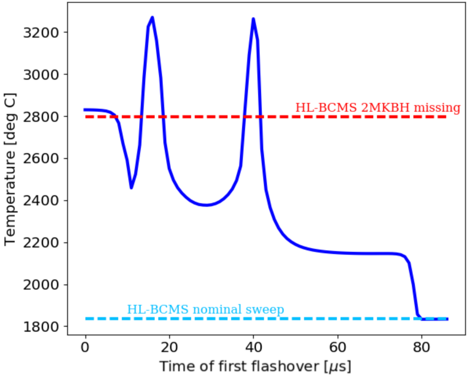
Acceptable? → material characterization

Failure case: flashover

Flashover → magnets in the same vacuum tank
→ loss of 50% in horizontal plane
→ crossing sweep if current persists in the magnet

HL BCMS: 1.7μm, 2.3$\cdot 10^{11}$ ppb



Flashover → temperature exceeds **3200°C**

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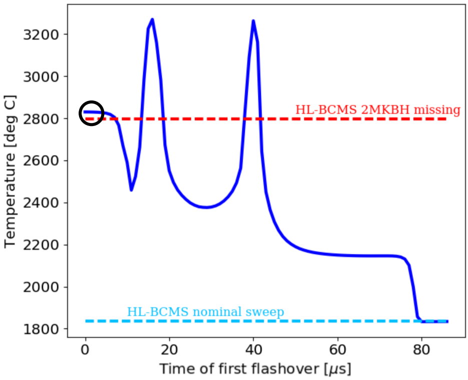

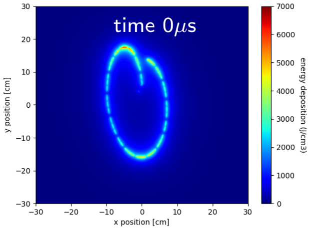

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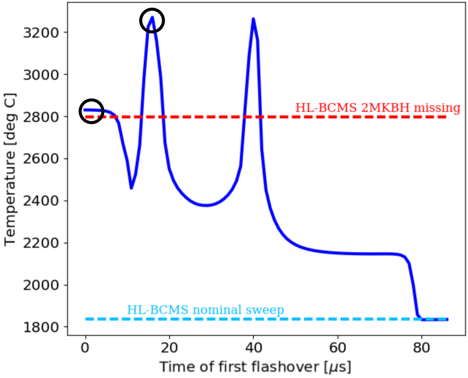

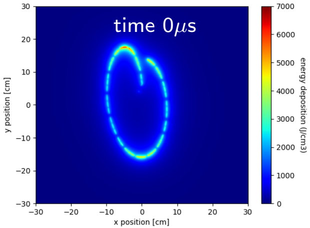

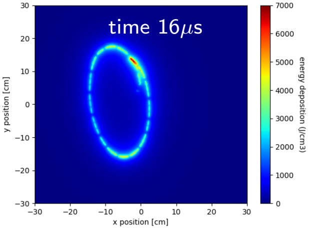

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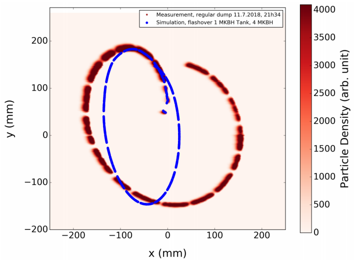
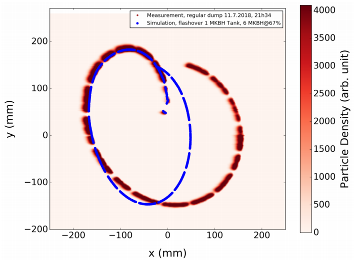
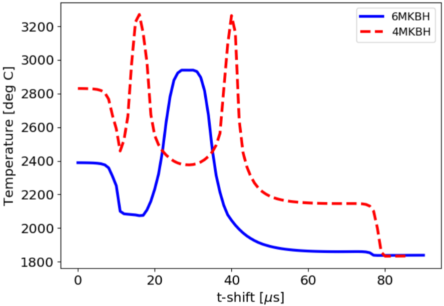
4 MKBH vs 6 MKBH in case of flashover







Two additional MKBHs

- reduce the effect of a flashover
- temperatures still very high
- enlargement of dilution pattern

↓

⇒ effect on the shell

New possible TDE core configuration (hypothetical)

Constraints

- total core length = 8 m
- length of low density part to 5 m made by graphite of density 0.7 g/cm^3
- total number of inelastic length = 15.6 (present dump)
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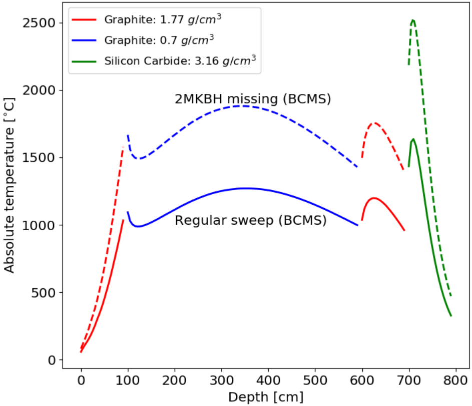

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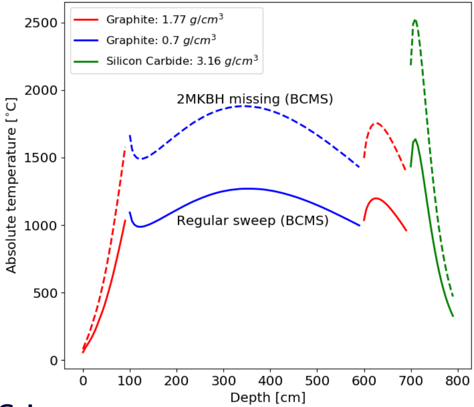

Gain

max temp. 2MKBH missing (new) ≈ max temp. regular sweep (now)

Challenges

find appropriate downstream material to sustain high temperature and attenuation (if 8 meters length)

Outline

1. Introduction: TDE layout and input parameters
2. Upstream window
3. Downstream window
4. TDE Core
5. Conclusions and outlook

Conclusions and Outlook

- **Upstream window**
  - **Titanium disc** $\rightarrow$ overcomes manufacture limitation of thin foil
    $\rightarrow$ marginal temperature increase w.r.t. the foil configuration
    $\rightarrow$ thermo-mechanical studies ongoing
  - **Beta function variation** $\rightarrow \approx$ 50% reduction in the temperature increase
    $\rightarrow$ unfeasible solution from optics point-of-view
- **Downstream window**
  - Upgrade with Titanium Ti6Al4V during LS2
- **Graphite core**
  - **Regular dump** $\rightarrow \approx$**1500°C** for Run 3 and $\approx$**1800-1900°C** for HL beams
  - **Flashover** $\rightarrow \approx$ **2500°C** for Run 3 and $\approx$ **3200°C** for HL beams
  - **Material characterization** $\rightarrow$ understand graphite behavior at high temperature
  - Preliminary (hypothetical) studies on a new dump configuration

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Thank you for your attention