Temperature Estimates for the external LHC beam dumps (TDE)

M. Frankl, A. Lechner, C. Bracco, C. Wiesner
On behalf of HL-LHC WP14
Acknowledgments to: C. Schwick, J. Boyd

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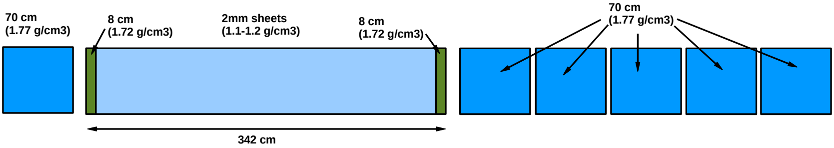
Introduction

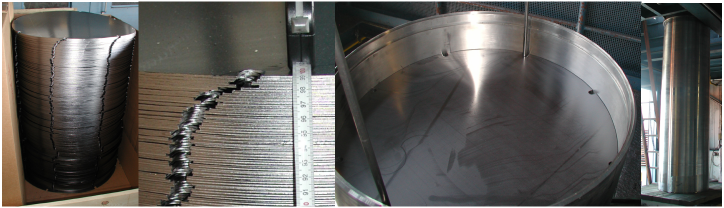
- **Brief overview:** TDE layout, beam energy deposition and beam parameter assumptions
- Comparison of **temperature estimates** for **Run 2** and **HL-LHC beams**:
  - **TDE core** and **up-/downstream windows**
  - **STD** and **BCMS** beams
  - **Regular sweeps** and combinations of **MKBH and/or MKBV failures**
- Possible approach for HighLumi: Installation of **2 additional MKBHs**
  - Peak temperatures in the **core**
  - **Regular sweeps** and **1/2 MKBH failures**
  - Energy density in the **stainless steel jacket**
- **MKB Retriggering:** Temperature estimates for core and windows

Contents

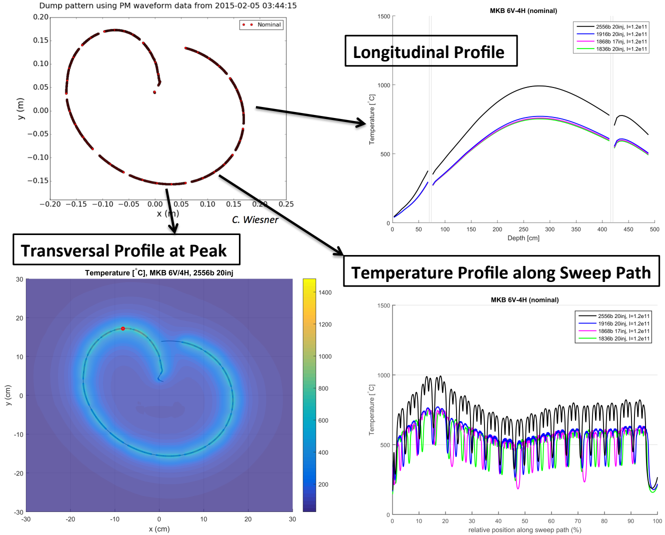
TDE layout (core)



- Segmented core consisting of **high- and low-density graphite absorbers**
- **Diameter** of **70 cm** and a total absorber **length** of **~7.6 m**
- **High-density** absorber blocks consist of **polycrystalline graphite**
- **Low-density** graphite absorber made of **2 mm** thick, flexible **graphite sheets**
- Graphite segments are shrink-fitted into a **12 mm** thick **stainless steel jacket**



Beam Energy Deposition



BCMS beam, 2556 bunches (Run2)

Beam Parameters and Filling Schemes

Simulations were carried out assuming the following **beam parameters**:

	RUN 2 (6.5 TeV)	HL-LHC (7 TeV)
BCMS	$I_b = 1.3 \times 10^{11}$ ppb	$I_b = 2.0 \times 10^{11}$ ppb
	$\varepsilon^n_{x,y} = 1.37\ \mu$m rad	$\varepsilon^n_{x,y} = 1.37\ \mu$m rad
STD	$I_b = 1.3 \times 10^{11}$ ppb	$I_b = 2.3 \times 10^{11}$ ppb
	$\varepsilon^n_{x,y} = 2.6\ \mu$m rad	$\varepsilon^n_{x,y} = 2.08\ \mu$m rad

Number of bunches and **total beam intensities**:

	RUN 2 (6.5 TeV)	HL-LHC (7 TeV)
BCMS	2556 b	2604 b
	$I_{tot} = 3.3 \times 10^{14}\ p^+$	$I_{tot} = 5.2 \times 10^{14}\ p^+$
STD	2556 b	2748 b
	$I_{tot} = 3.3 \times 10^{14}\ p^+$	$I_{tot} = 6.3 \times 10^{14}\ p^+$

(Simulations for Run 2 were performed using simulated MKB-waveforms assuming an upgrade of their capacitance (to be implemented in LS2). Nevertheless, the difference in the energy deposition calculations is only about 3 % wrt present waveforms)

Contents

Peak Temperatures in the TDE Upstream Window

- Window located **∼10 m upstream** of the core and exposed to swept proton bunches
- **Isolates** dump transfer line **vacuum** from **nitrogen atmosphere**
- **CfC** for **robustness** reasons, **leak tightness** assured by a **thin steel layer**

	Thickness	Material	Density
#1	15 mm	CfC (® SIGRABOND 1501G)	∼1.5 g/cm^3
#2	0.2 mm	Stainless steel (AISI 316L)	8 g/cm^3

- **Peak temperatures and stresses** in the **stainless steel foil** more critical than in CfC
- **BCMS-beam dumps** are **more critical** in terms of energy deposition **than STD-beam dumps** due to their **smaller transverse emittance**. This holds true also for HighLumi, even though STD-beams will have a higher beam intensity.

BCMS

RUN 2

°C		# active MKBV		
		6	5	4
# active MKBH	4	42	43	48
	3	47	48	49
	2	58	58	59

HighLumi

°C		# active MKBV		
		6	5	4
# active MKBH	4	56	57	62
	3	66	67	67
	2	83	84	85

Difference (in peak energy deposition)

%		# active MKBV		
		6	5	4
# active MKBH	4	+64	+60	+52
	3	+71	+66	+61
	2	+66	+67	+66

→ *Thermo-mechanical results presented in next talk (T. Polzin)*

Peak temperatures in the TDE graphite core

- **Peak temperatures** calculated in the **low-density graphite segment** of the TDE

BCMS

RUN 2

°C, # active MKBH	# active MKBV 6	5	4
4	1040	1080	1170
3	1190	1240	1300
2	1480	1500	1570

HighLumi

°C, # active MKBH	# active MKBV 6	5	4
4	1650	1670	1725
3	1980	2000	2050
2	2500	2540	2590

Difference (in peak energy deposition)

%, # active MKBH	# active MKBV 6	5	4
4	+79	+74	+64
3	+89	+82	+76
2	+90	+90	+83

STD

RUN 2

°C, # active MKBH	# active MKBV 6	5	4
4	1010	1040	1130
3	1140	1190	1250
2	1420	1440	1510

HighLumi

°C, # active MKBH	# active MKBV 6	5	4
4	1860	1900	1960
3	2240	2270	2330
2	2840	2890	2960

Difference (in peak energy deposition)

%, # active MKBH	# active MKBV 6	5	4
4	+117	+113	+100
3	+131	+121	+115
2	+133	+133	+125

→ *Already the peak temperature of a nominal HL-beam dump is higher than in case of 2 MKBHs missing in Run2.*

→ *Thermo-mechanical behavior of the low-density core to be analyzed. However, comprehensive material characterization is missing up to now.*

Peak temperatures in the TDE Downstream Window

- Downstream window located **∼13 cm downstream** of last high-density core segment
- Exposed to longitudinal shower tail from TDE core

	Thickness	Material	Density
#1	10 mm	Titanium Grade 2 (ASTM B265)	4.5 g/cm^3

RUN 2 — *HighLumi* — *Difference* *(in peak energy deposition)*

BCMS

RUN 2 (°C)

# active MKBH \ # active MKBV	6	5	4
4	90	95	100
3	100	105	115
2	120	130	140

HighLumi (°C)

# active MKBH \ # active MKBV	6	5	4
4	150	155	170
3	180	185	195
2	220	230	245

Difference (%)

# active MKBH \ # active MKBV	6	5	4
4	+92	+88	+80
3	+98	+94	+85
2	+97	+91	+86

STD

RUN 2 (°C)

# active MKBH \ # active MKBV	6	5	4
4	90	90	100
3	100	105	115
2	120	130	140

HighLumi (°C)

# active MKBH \ # active MKBV	6	5	4
4	170	175	190
3	200	210	220
2	245	260	275

Difference (%)

# active MKBH \ # active MKBV	6	5	4
4	+117	+113	+100
3	+131	+121	+115
2	+133	+133	+125

→ *Thermo-mechanical results presented in next talk (T. Polzin)*

Contents

6MKBHs: Operation with reduced Voltage (66 %)

- **66 %** of the possible kick strength for all **of 6 MKBHs** yield a total horizontal kick strength **equal to 4 MKBH operated at 100 %**
- Deploying 6 MKBHs (@ 66 %) instead of 4 MKBHs (@ 100 %), the **loss of one or more MKBHs is less severe**:

Total Horizontal Kick Strength

	missing MKBHs 0	1	2
MKB6V4H	100%	75%	50%
MKB6V$_{100\%}$6H$_{66\%}$	100%	83%	66%

Peak Temperature (low-density TDE core)

°C	missing MKBHs 0	1	2
MKB6V4H	1850	2240	2830
MKB6V$_{100\%}$6H$_{66\%}$	1860	2100	2420
Difference	+10	-140	-410

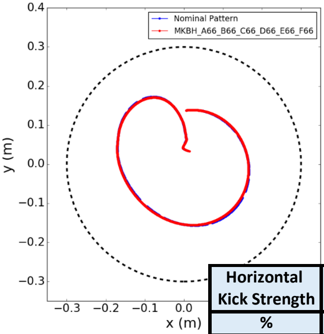
→ *In the (presumed) worst case of 2 MKBHs providing no kick, the remaining horizontal kick strength is 33 % higher*

→ *In this case, the peak temperature would be ∼ 400° C lower*

→ *Reduced sensitivity due to MKBH failure*

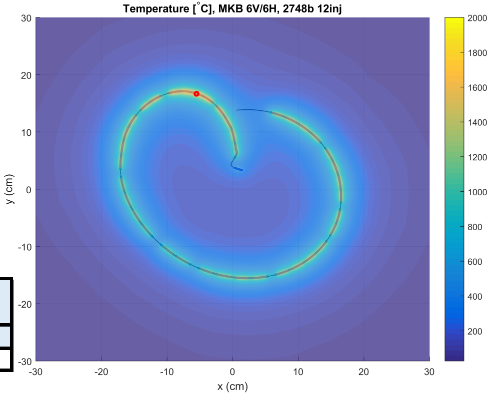
6 MKBHs: Additional Dilution

- 2 additional MKBHs also mean a **50 % higher potential horizontal kick strength**



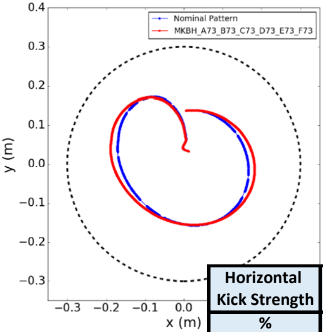
Horizontal Kick Strength	Temp.
%	°C
100	1860

100 %



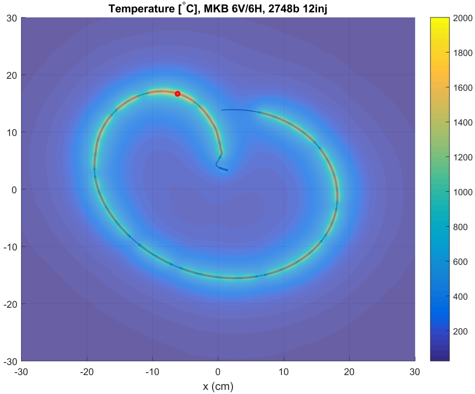
6 MKBHs: Additional Dilution +10 %

- 2 additional MKBHs providing a **50 % higher potential horizontal kick strength**



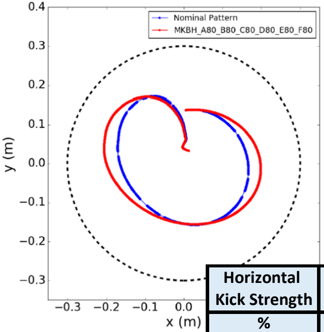
Horizontal Kick Strength	Temp.
%	°C
100	1860
110	1760

110 %

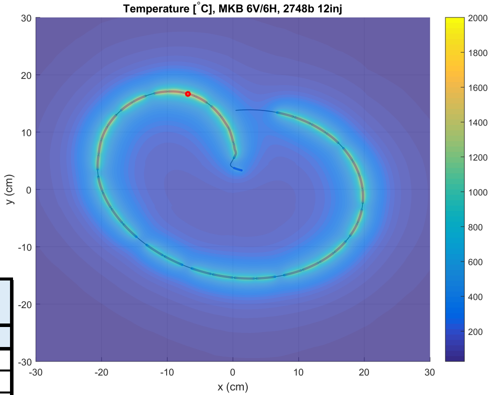


6 MKBHs: Additional Dilution +20 %

- 2 additional MKBHs providing a **50 % higher potential horizontal kick strength**



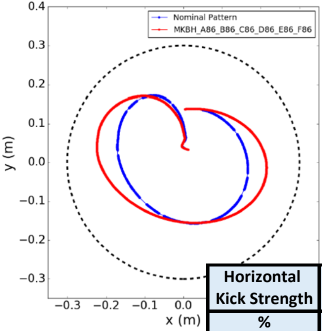
120 %



Horizontal Kick Strength	Temp.
%	°C
100	1860
110	1760
120	1660

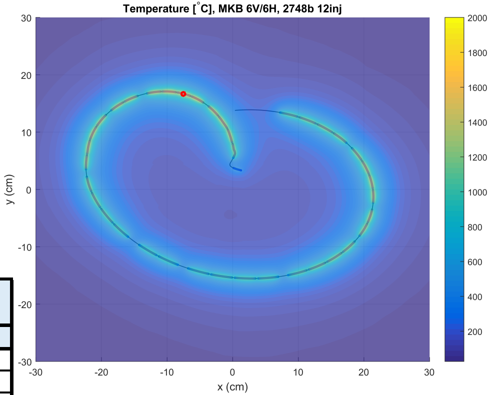
6 MKBHs: Additional Dilution +30 %

- 2 additional MKBHs providing a **50 % higher potential horizontal kick strength**



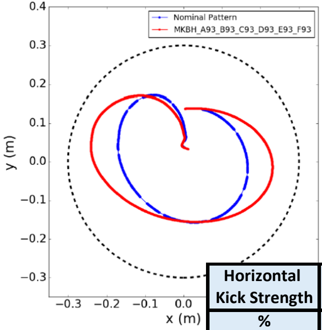
Horizontal Kick Strength	Temp.
%	°C
100	1860
110	1760
120	1660
130	1580

130 %



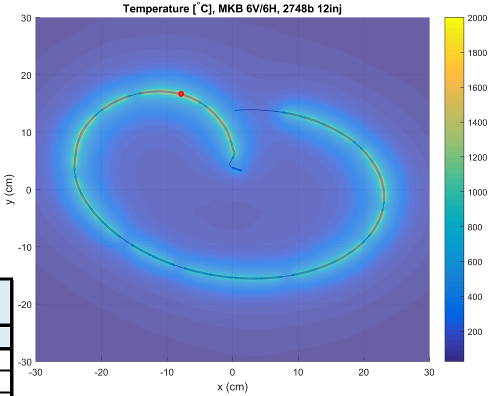
6 MKBHs: Additional Dilution +40 %

- 2 additional MKBHs providing a **50 % higher potential horizontal kick strength**



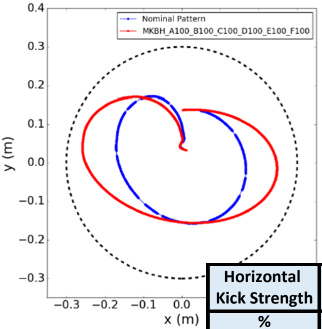
Horizontal Kick Strength	Temp.
%	**°C**
100	**1860**
110	**1760**
120	**1660**
130	**1580**
140	**1510**

140 %

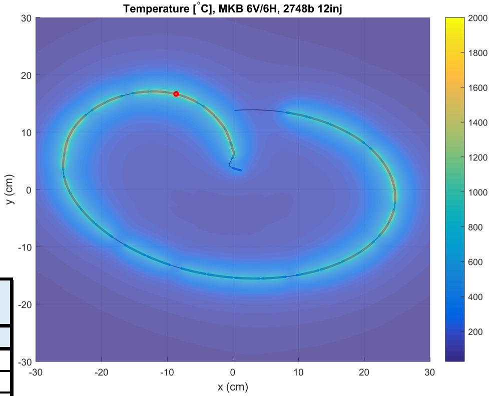


6 MKBHs: Additional Dilution +50 %

- 2 additional MKBHs providing a **50 % higher potential horizontal kick strength**



150 %

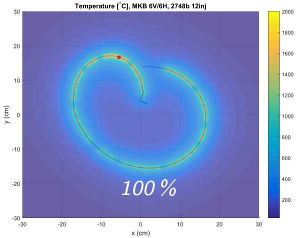


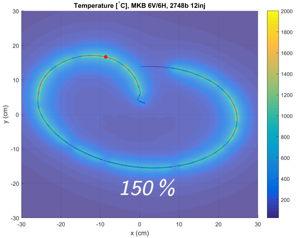
Horizontal Kick Strength	Temp.
%	°C
100	1860
110	1760
120	1660
130	1580
140	1510
150	1440

→ *Energy deposition in the steel jacket?*

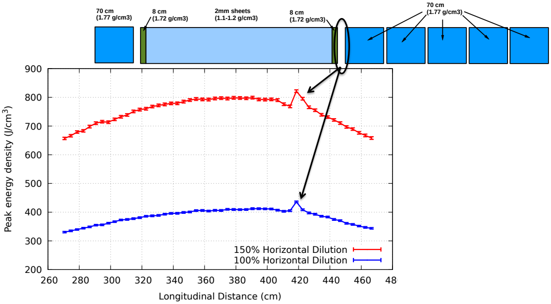
→ *Energy deposition in downstream flange?*

6 MKBHs: What about the Steel Jacket?





- Peak energy density calculated in the stainless steel jacket:



Peak energy density in the tube at 150 % horizontal dilution would roughly double compared to 100 %.

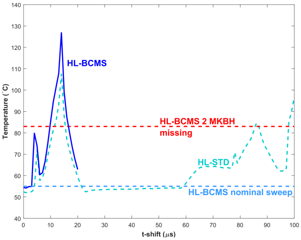
Acceptable? → Thermo-mechanical analysis required...

Contents

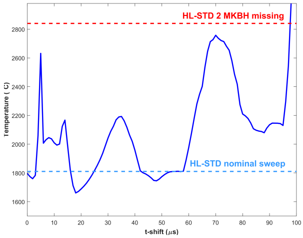
MKB-Retriggering: Temperatures in Core and Windows

- **Peak temperatures** calculated **depending on the time delay** between the retriggering and the arriving abort gap

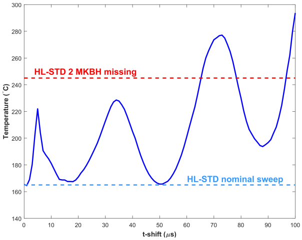
Upstream Window



Core



Downstream Window



- **Core:** For all relevant time delays **peak temperatures** stay **well below** the temperature level in the scenario of a HL-STD beam dump **missing the dilution of 2 MKBHs**
- **Windows:** **For most time delays** the peak temperature is **below the level of the case with 2 MKBHs missing**. In upstream window at $t_{delay} = 14\,\mu s$, however, a significantly higher temperature is expected.

→ *Thermo-mechanical responses to be analyzed*

→ *Results for the upstream window presented in next talk (T. Polzin)*

Contents

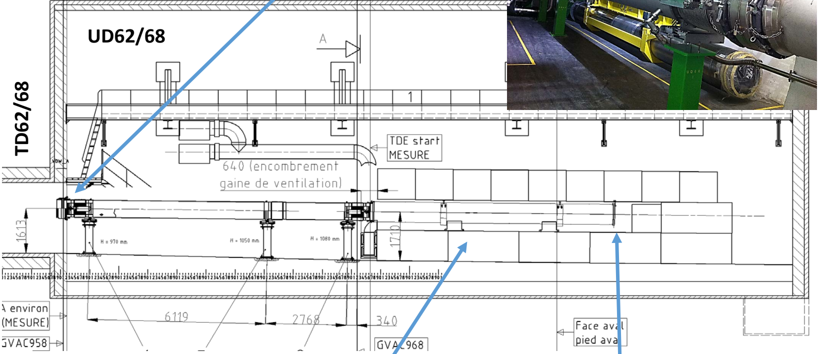
Summary & Conclusions

- **For a regular HL-STD beam dump peak temperatures are already close to 2000°C** in the low-density graphite core. **In case of 2 MKBHs missing** peak temperatures reach **almost 3000°C** with a corresponding risk of local damage.
- Possible approach: Installation of **2 additional MKBHs**
  - **6 MKBHs operated at 66 %** (= horizontal dilution of 4 MKBHs at 100 %):
    - **Failure of 2 MKBHs** would be **less severe**: **2420°C instead of 2830°C** peak temperature in the low-density segment
  - **6 MKBHs operated at 100 %** (= 150 % horizontal dilution wrt. now):
    - Horizontal dilution strength for the **2 MKBH failure** case would **correspond to a nominal sweep for 6 MKBHs** operated **at 66 %**: **1860°C** peak temperature
    - Peak temperature for a **regular dump** lower: **1440°C**
    - **Effects of higher energy density in the stainless steel jacket and downstream flange** to be assessed
- **MKB-Retriggering** requires a more detailed thermo-mechanical analysis especially for specific time delays with a more pronounced peak energy deposition.
- **Accuracy of temperature estimates**
  - Error in **energy deposition** calculations estimated as **10 %**
  - Error due to **assumed material properties** (density, specific heat) **10-15 %**

Contents

TDE location

CfC + SS support window



TDE Ti window

TDE graphite core

Material composition of the TDE windows

Upstream window: $\rightarrow$ *exposed to swept proton bunches*

- Located ~**10 m upstream** of TDE core
- **Isolates** dump transfer line **vacuum** from **nitrogen atmosphere**
- **CfC** for **robustness** reasons, **leak tightness** assured by a **thin steel layer**

	Thickness	Material	Density
#1	15 mm	CfC (® SIGRABOND 1501G)	~1.5 g/cm^3
#2	0.2 mm	Stainless steel (AISI 316L)	8 g/cm^3

Downstream window: $\rightarrow$ *exposed to longitudinal shower tail from TDE core*

- Located ~**13 cm downstream** of last high-density core segment

	Thickness	Material	Density
#1	10 mm	Titanium Grade 2 (ASTM B265)	4.5 g/cm^3

Specific Heat

- Calculation of a temperature increase based on the obtained distribution of the energy deposition
- Important: Taking into account the temperature dependency of the specific heat of graphite