Injection and Dump System Status

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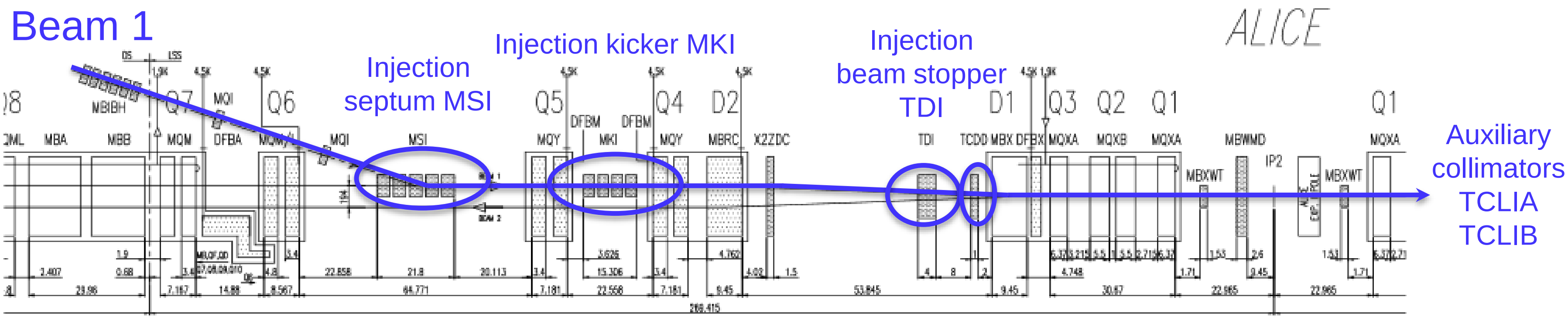
6th HiLumi Meeting;14-16 November 2016 - Paris

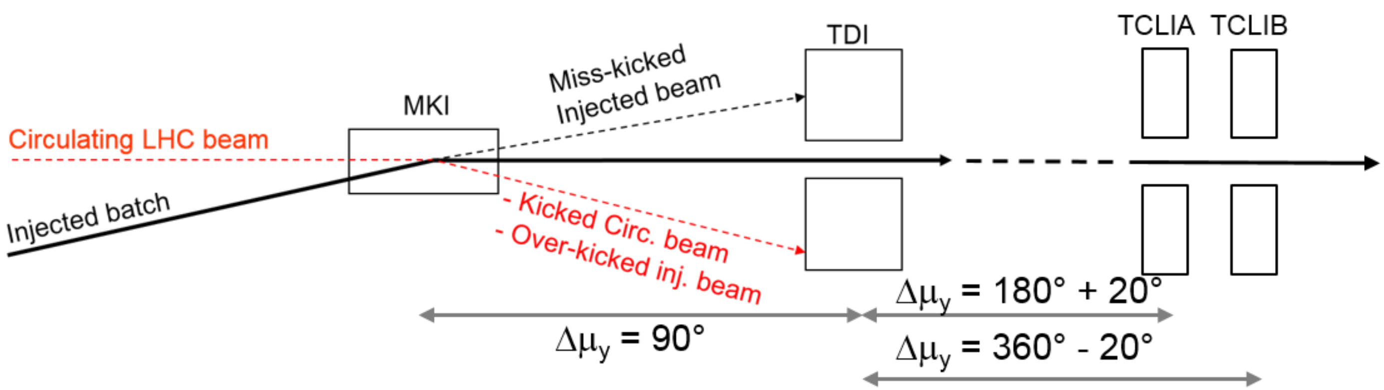
Scope and Outlook

Scope: upgrade of the LHC injection and extraction system to adapt to increased beam brightness and intensity

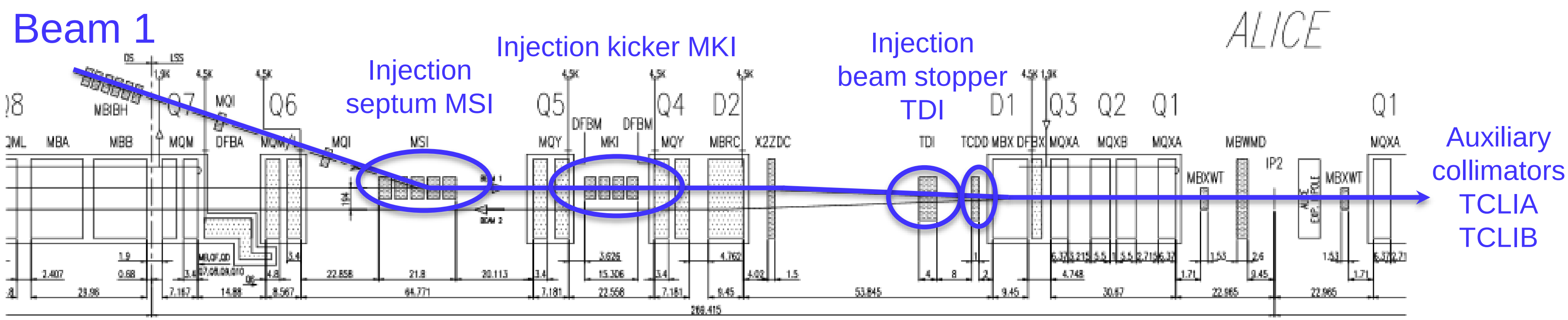
- Injection system:
  - TDI
  - MKI
- LBDS:
  - MKD switches and controls
  - TCDS and TCDQ
  - MKB-TDE
- Summary and major upcoming milestones

Injection System





Injection System



MKI: **beam induced heating**, **vacuum** and **e-cloud improvements**. Prototype development ➔ installation in baseline (**2018 YETS**). Installation of new **MKI series** in **LS3**

TDI: upgraded with a new segmented hardware (**TDIS**), IP2 & IP8 ➔ installation in **LS2**

D1 (TCDD): **shielding** insert in D1, IP2 and IP8 ➔ installation in **LS2**

Diamond BLMs: additional detectors and acquisition (**on-going**)

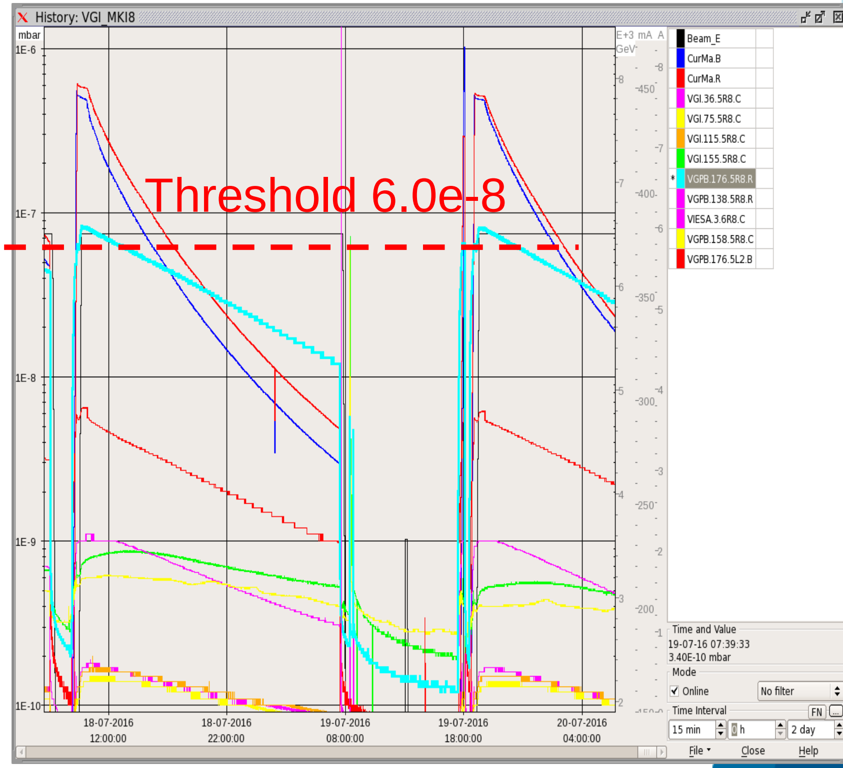
TCLIA: possible displacement toward IP (IP2 only) and increase full gap ➔ **LS2**

MKI Injection Kickers - Vacuum

- **E-cloud** results in **high pressure** adjacent to and in the kicker magnet tanks which, when **pulsing the kickers**, **increases** the **probability** of an **electrical breakdown ➔ Interlock** on **instantaneous** pressure adjacent to and in kicker tanks and also **integrated** pressure in kicker tanks.

- Interconnect on Q5 end of MKI8 presently limiting operation, due to e-cloud ➔Increase the limit from 6e-8 to 6.3e-8 mbar and to **limit bunch charge to 1.19e11 ppb**

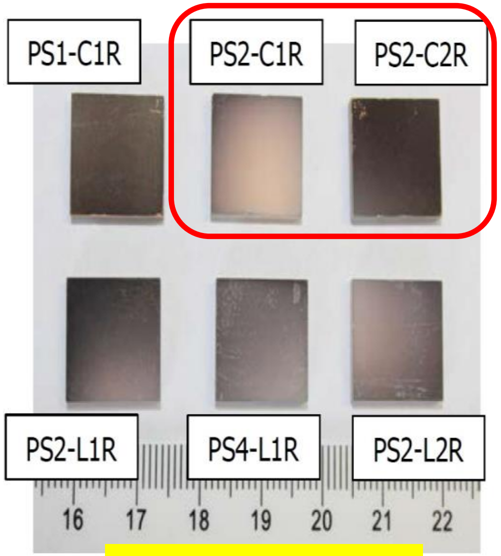
- During EYETS 2 x 400 l/s **NEG cartridges** will be added next both kicker systems ➔ expected **x2-3 reduction** in vacuum pressure ➔ expected max. pressure of **3e-8 mbar** with 2808 nominal bunches



MKI Injection Kickers - Vacuum

Treatment of ceramic chambers to reduce SEY (**target SEY = 1.4**). Note: “naked” ceramic has an SEY of ~10.

- Six **treated samples** of **high purity alumina** received from **University of Dundee** (UK) ➔ SEY measurements and microscopy performed. Next: larger samples for vacuum and HV behaviour investigations.



Courtesy: A.T. Perez Fontenla

Table 1: maximum values and remarks for each sample

sample	SEY max	remarks
PS1_C1R	2.2	
PS2_C1R	1.6	
PS2_C2R	1.7	outlier 1.9
PS2_L1R	1.9	inhomogenous
PS2_L2R	2.2	
PS4_L1R	2.5	

Courtesy: H. Neupert

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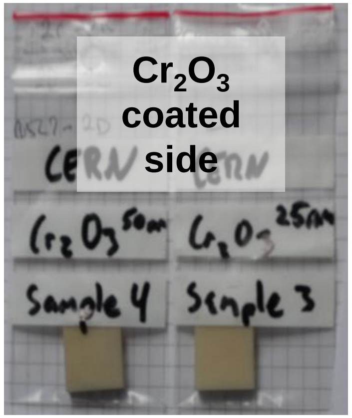
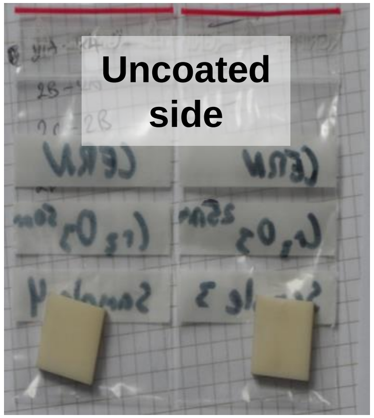
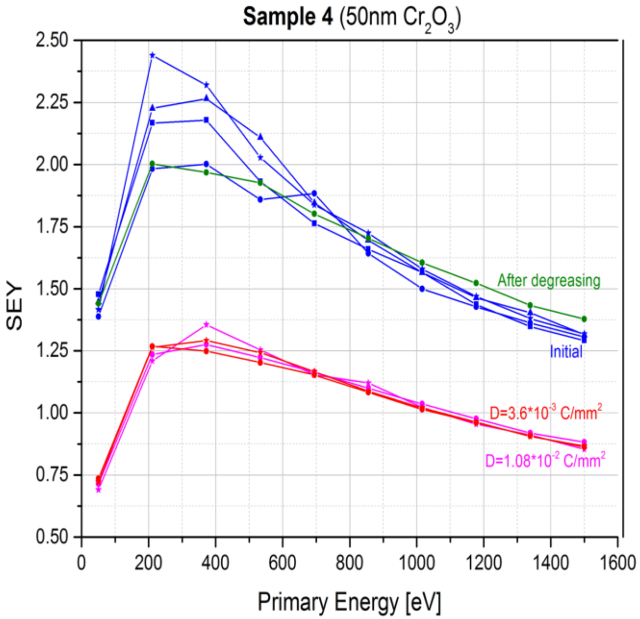
- Two **high purity Alumina** samples have been **Cr_2O_3 coated** (25 and 50 nm thick coating) by **Polyteknik** (Denmark):







M. Barnes

E. Garcia-Tabares Valdivieso

MKI Injection Kickers - Vacuum

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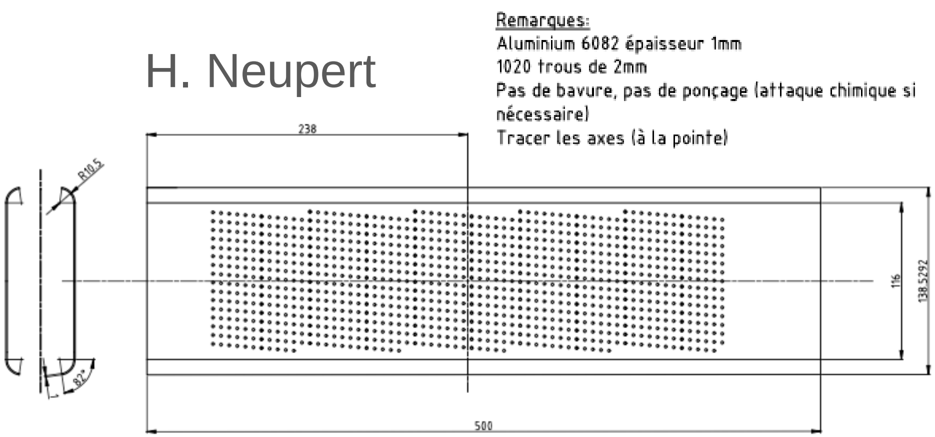
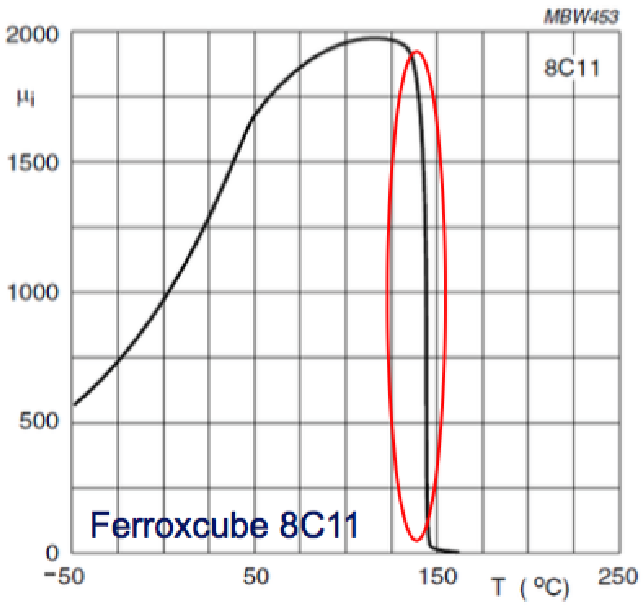
  - Preparing to install a **short coated liner** in the **SPS** (2017 EYETS) with suitable e-cloud monitoring to qualify the coating with beam before coating a ceramic chamber for an MKI kicker magnet.
  - Next step: coat a **3 m long chamber** for the **prototype** to be installed in YETS 2018.

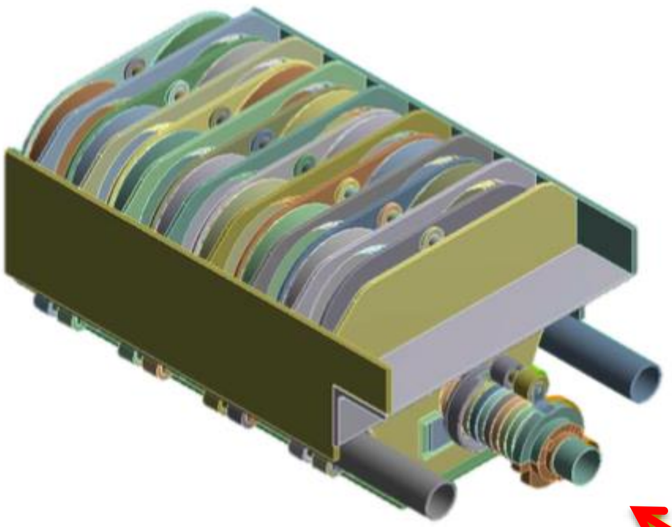
H. Neupert



M. Barnes

MKI Injection Kickers – Beam Induced Heating



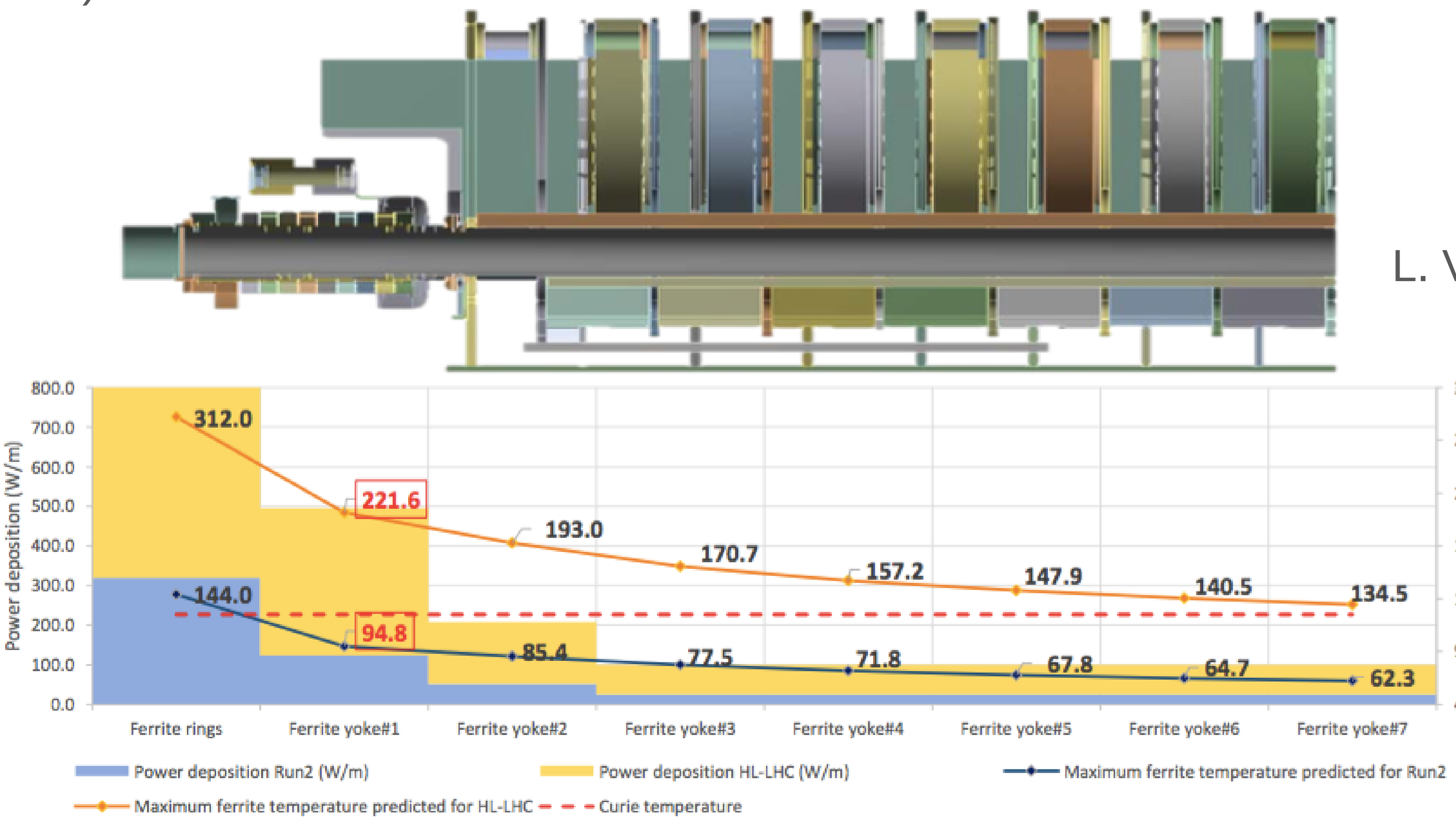


- **Magnetic permeability** falls very quickly when the temperature reaches the **Curie point.**
- For the type of ferrite used in the LHC MKI the Curie temperature is **125 °C.** During operation temperature has to be **always below this limit to avoid a mis-injection of the beam.**

MKI Injection Kickers – Beam Induced Heating

Thermal simulation studies with **improved ANSYS model** (7 cells, Post-LS1+**ferrite ring** design)

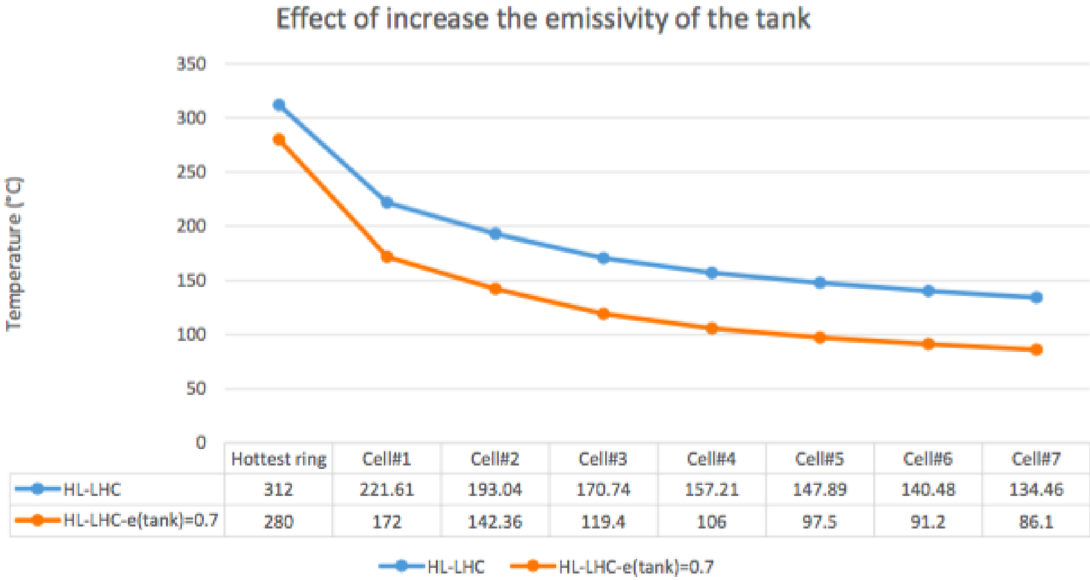
Beam impedance simulations, with CST, show **highly non-uniform power deposition** along the length of MKI ferrite yoke (**confirmed** with **temperature measurements** in the LHC)



L. Vega Cid

MKI Injection Kickers – Beam Induced Heating

Very shiny surface of the tank: low thermal emissivity



	Hottest ring	Cell#1	Cell#2	Cell#3	Cell#4	Cell#5	Cell#6	Cell#7
HL-LHC	312	221.61	193.04	170.74	157.21	147.89	140.48	134.46
HL-LHC-e(tank)=0.7	280	172	142.36	119.4	106	97.5	91.2	86.1

- As a result of the very good vacuum within the tank, and the design of the kicker magnet, **cooling** is mainly by **thermal radiation** between the ferrite and the tank
- Presently the **limiting factor** to radiative cooling of the ferrite is the **low emissivity** of the inner side of the vacuum tank. Hence there is a strong interest to increase this emissivity (without degrading the vacuum properties)
- **Several techniques** are being investigated (coating, electro-chemical attack, laser treatments): the goal is to treat vacuum tank of prototype to be installed in YETS 2018- coating to be firstly vacuum qualified

MKI Injection Kickers – Beam Induced Heating

New ferrite with higher Curie Temperature and **improved cooling.**

Four ferrite samples ordered and received, from National Magnetics Group Inc., for outgassing measurements (3 pcs of plates 10mm x 50mm x 50mm) and for magnetic measurements (3 pcs of toroids 23.2mm OD x 14.7mm ID x 7.7mm Ht):

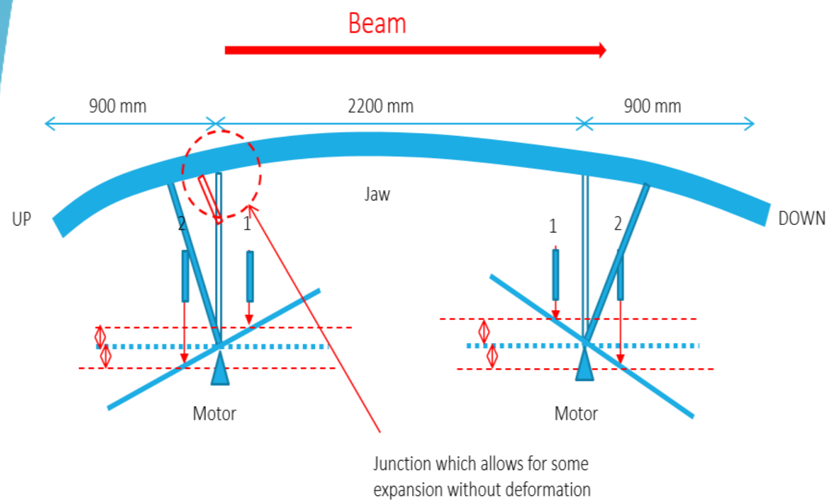
Outgassing measurements being carried out by M. Dinc and C.Y. Vallgren (VSC) at CERN

- Undesirable having high temperature (increased outgassing)
- Ferrite in first 5 cells (of 33 total) could be changed

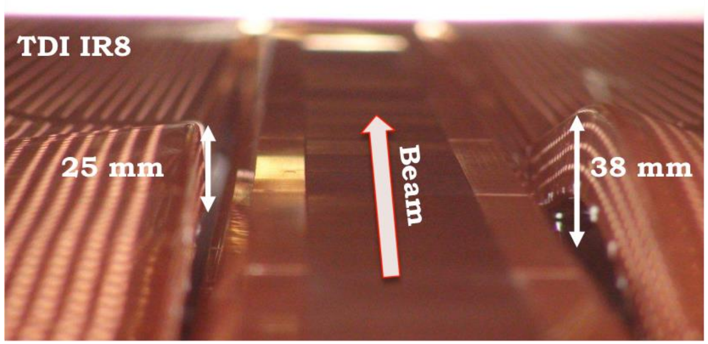
Ferrite	Tc (˚C)	Bs (T)	Br (T)	Hc (A/m)	Denisty (g/cc)	u'
CMD5005	**130**	**0.33**	0.13	9.5	**5.27**	**1150**
CMD10	250	0.43	0.29	28.6	5.2	650
CN20	185	0.4	0.26	15.9	5.24	650
CMD5005/CMD10 50/50 blend (average of above values)	190	0.38	0.21	19.10	5.24	**900**

TDI – Operational Issues

Beam induced heating and consequent **deformation** of the beam screen (plastic) and the jaws (elastics)



Not possible to define a direct correlation between LVDT drift (no loss of protection estimated by measuring the position of the "warm" jaw wrt the beam)



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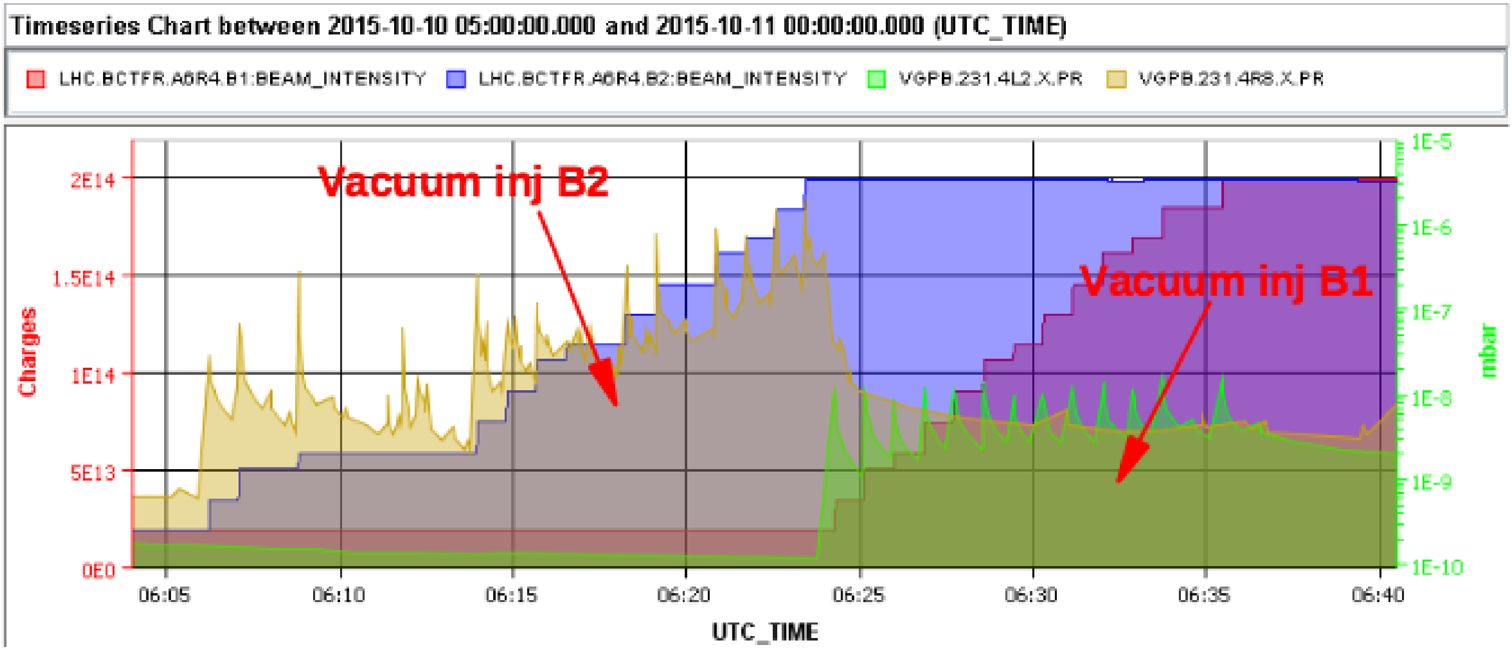
Beam induced heating and consequent **deformation** of the beam screen (plastic) and the jaws (elastics)

Significant pressure rise during injection and spurious spikes during fill with jaws retracted (hBN blocks non conformities limiting maximum allowed injected intensity in 2015)



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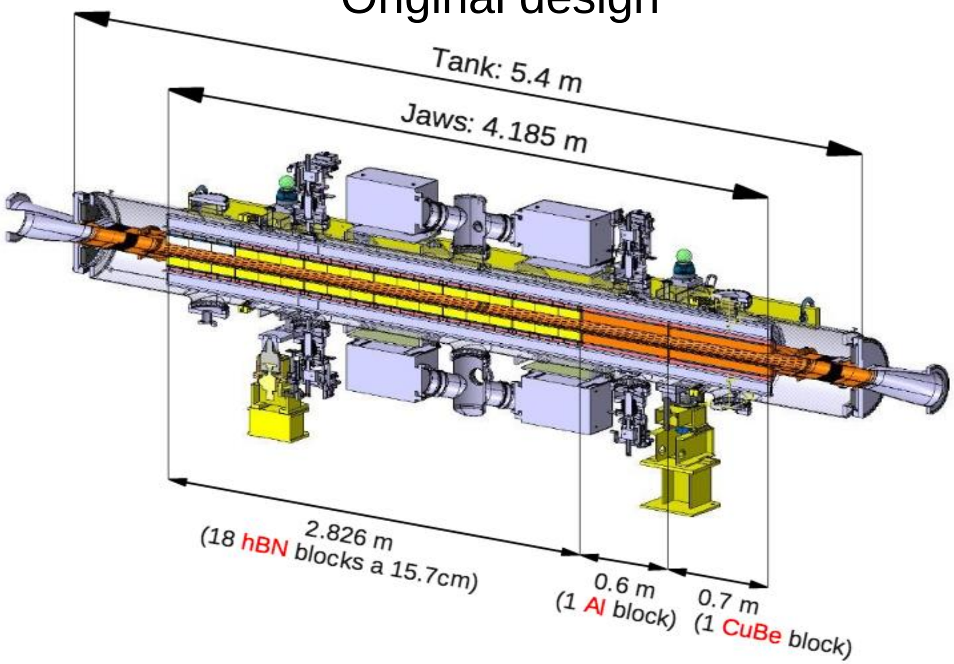
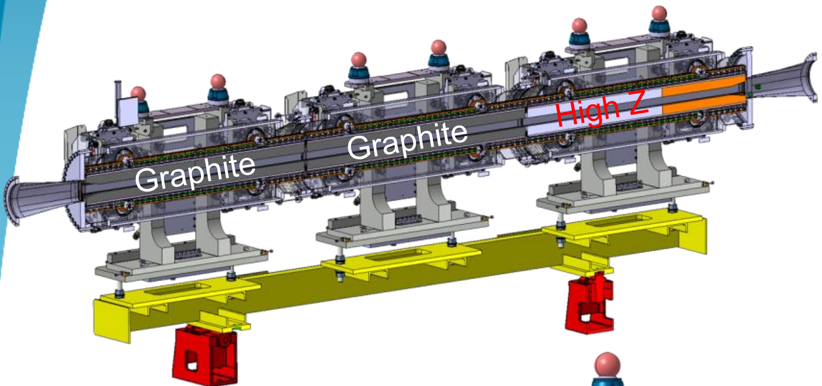
Original design

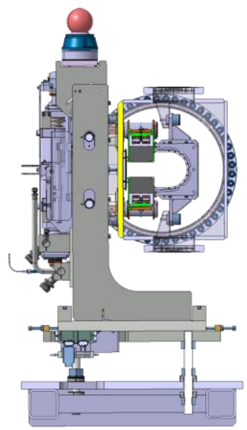


Presently applied changes:

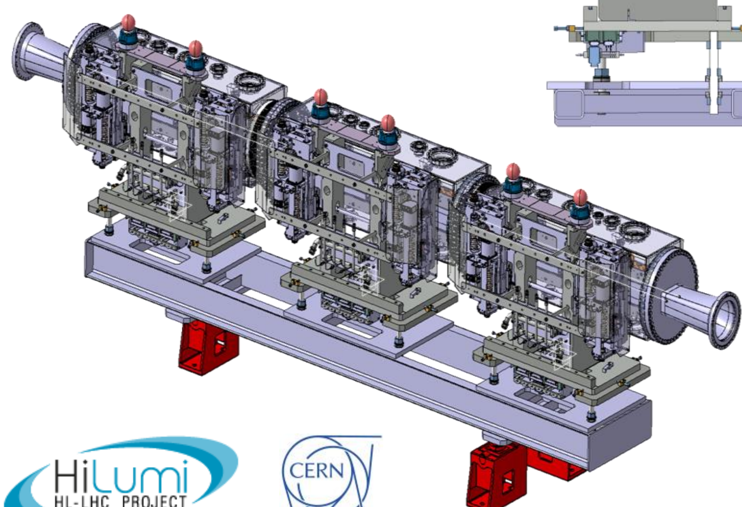
- Reinforced stainless steel beam screen
- Ti coating on Al block (reduce SEY)
- hBN replaced with graphite R4550 with Cu coating
- Improved contact of cooling pipes
- CuBe blocks replaced by CuCrZr
- Interferometric system for direct gap measurement

New Hardware: TDIS (segmented)





A. Perillo Marcone
L. Gentini



Three independent shorter modules (1.5 m each) ➔ improve **alignment accuracy** and **reduce beam induced deformation.**

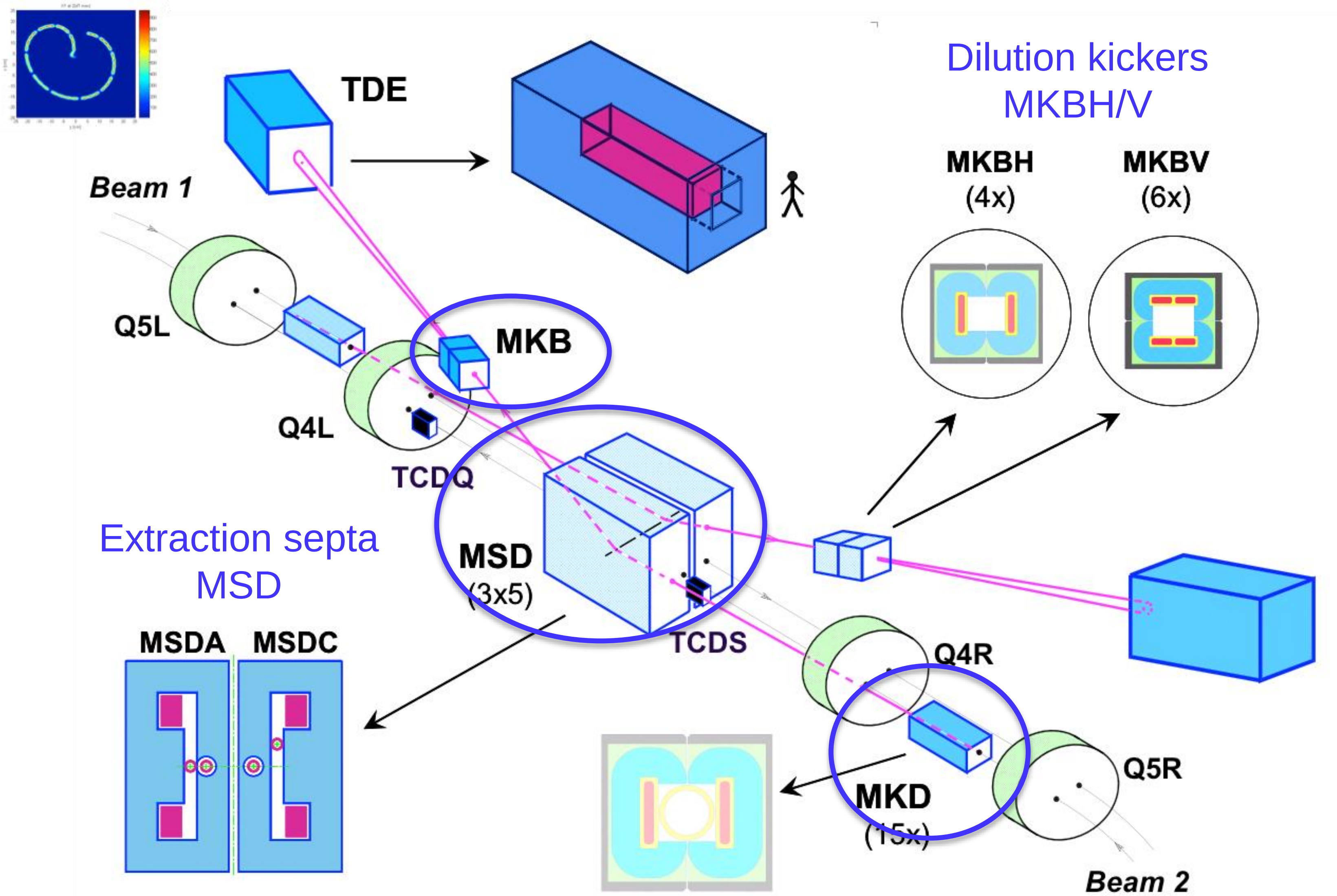
The modules are installed on a common girder, aligned on surface and transported as a single device in the tunnel (spares under vacuum and ready for installation with reduced bake out in the tunnel).

Design being finalised:
- Materials (graphite or 3D-CFC)
- RF fingers between adjacent modules.
- Cu coating for impedance reduction
- Coating against e-cloud
- …

Internal review on December 1st 2016 at CERN

HiRadMat tests (on hold due to SPS TIDVG issues)

LHC Beam Dump System (LBDS)



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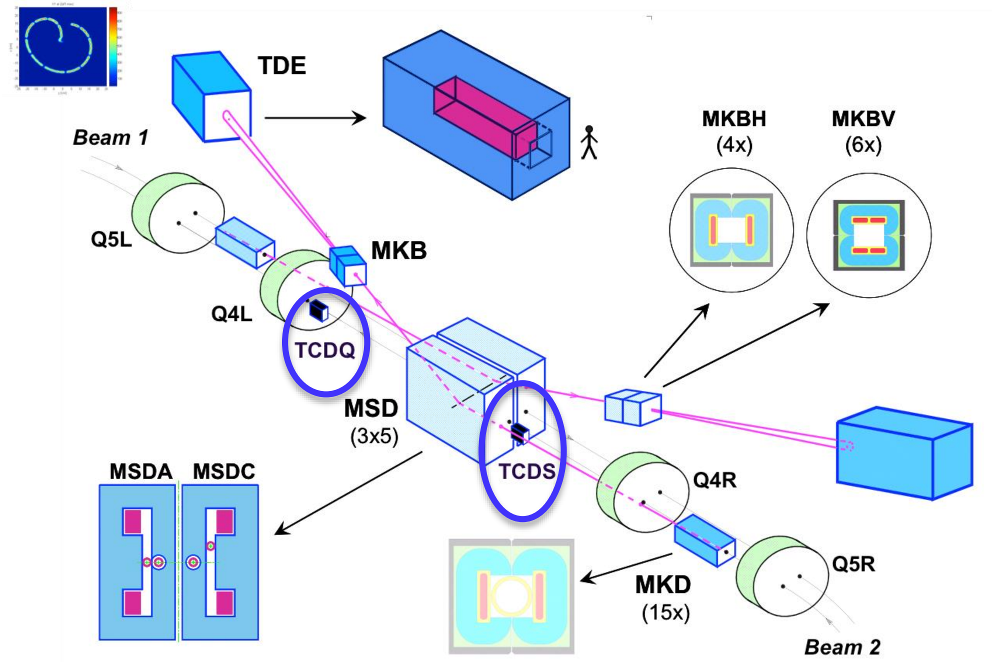
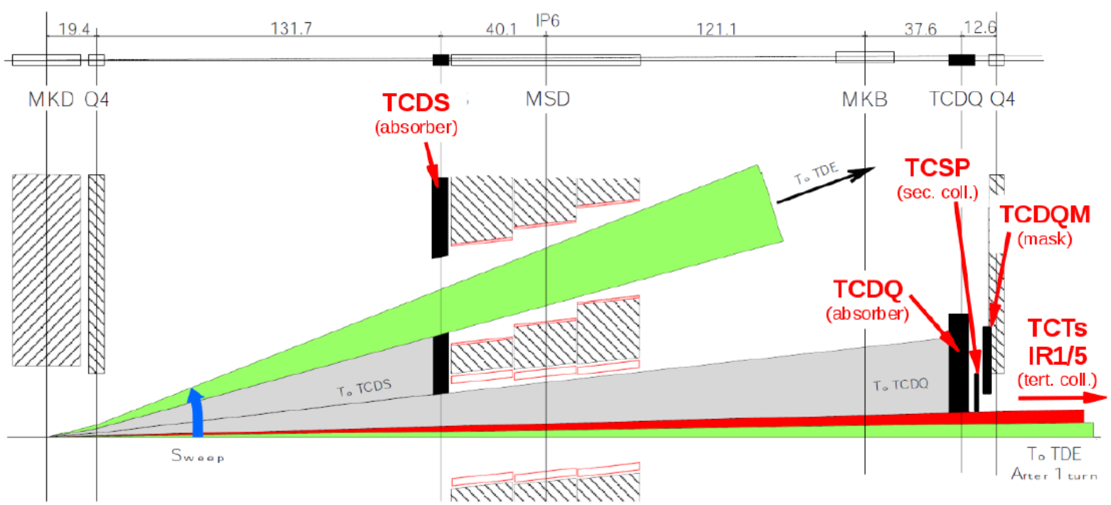




MKD: switch, triggering and controls upgrades. Strongly linked to switch consolidation (**LS3).**

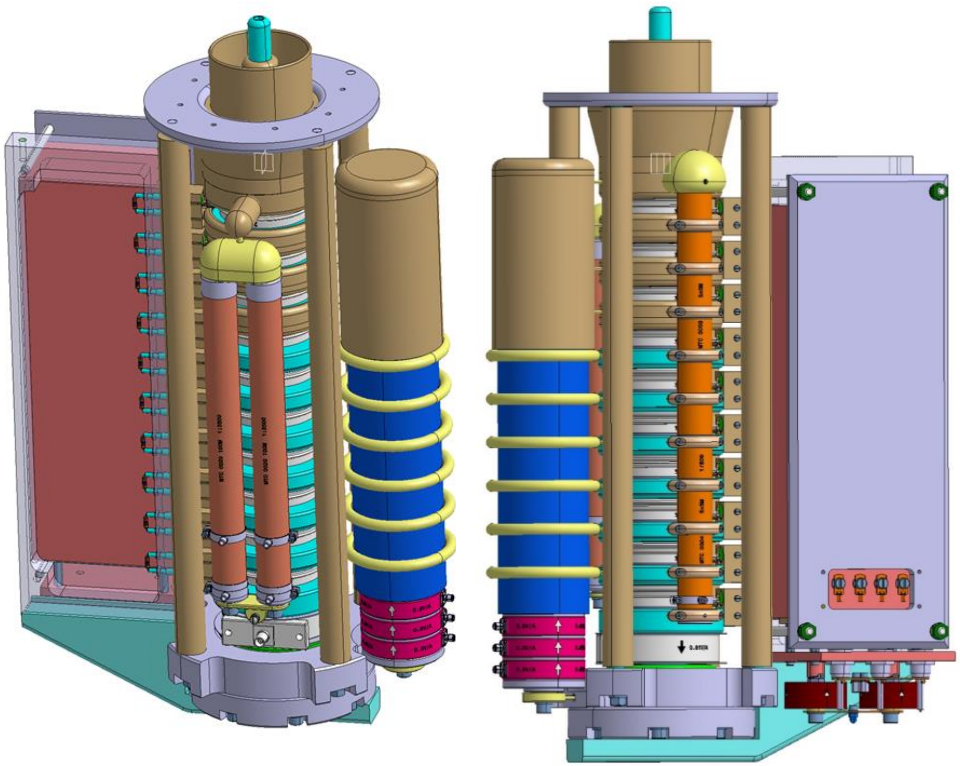
TCDS: upgraded with new version (third module). Install in **LS3.**

TCDQ: performance validation

On going studies **MKB-TDE**: need for additional dilutors or dump upgrade?

MKD Switches and Control Upgrade

- **Present operational margins** (in terms of electric breakdowns) **too small for reliable operation at 7TeV** (now and in the HL-LHC era) ➔ redesign of the switch stack of MKD generators ongoing to keep electrical field below 1.5 MV/m in all areas



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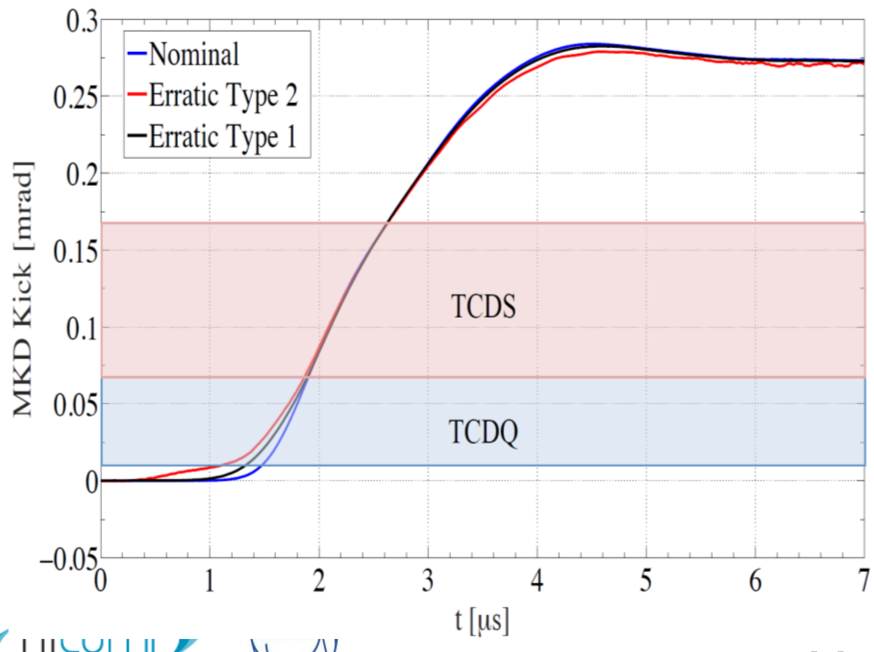
- **Upgrade of present Power Trigger Module** (PTM): several internal modifications done resulting in **1.7 kA peak** and **2 kA/us** at **3 kV** (**today 500A** peak and **400A/us** at **3.5 kV**) ➔ **increase lifetime** of the GTO switches and make the **power trigger less sensitive to radiation.**

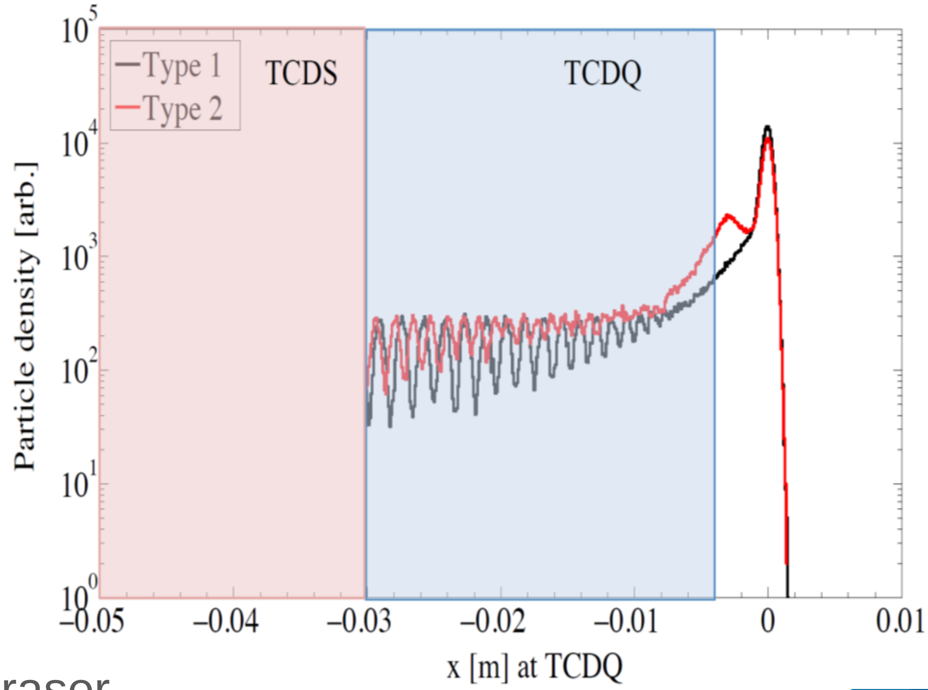
- **Upgrade of the retrigger system** which triggers all the extraction and dilution kickers in case of an erratic triggering of an extraction kicker ➔ **reduce retrigger delay from 900 ns to 700 ns** ➔ **reduce the load on the ring elements**, in particular the **tertiary collimators**, in case of an asynchronous dump. **Replace obsolete electronics** of the retriggering system

MKD New Erratic Type

Identified new type of erratic (type 2):

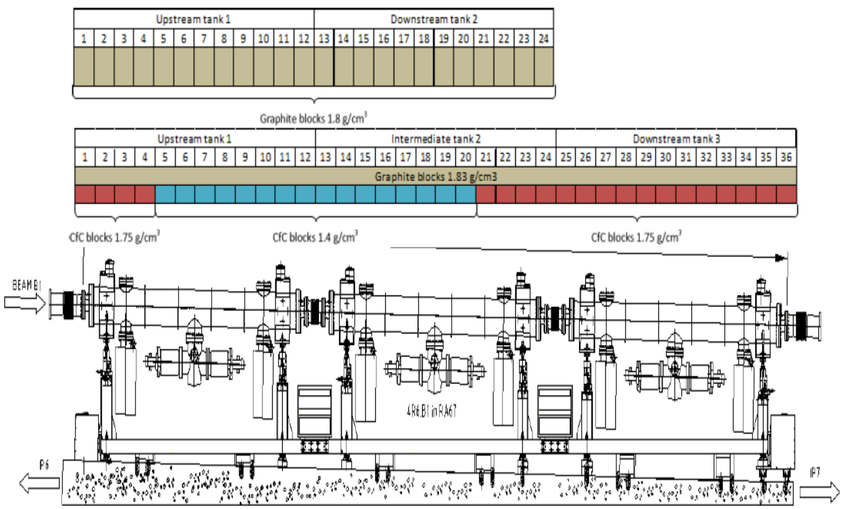
- During an asynchronous beam dump, part of this energy is deposited on the TCDS and the TCDQ:
  - 16-32 bunches intercepted by TCDQ ➔ up to 3.8 MJ (nominal LHC beam intensity @ 6.5 TeV) with a maximum close to the jaw surface.
  - 28 bunches intercepted by TCDS ➔ up to 3.3 MJ (nominal LHC beam intensity @6.5 TeV) almost uniformly distributed.
- HL-LHC: 7 TeV, up to 2.3E11 ppb ➔ up to 7MJ on TCDS and 8 MJ on TCDQ.

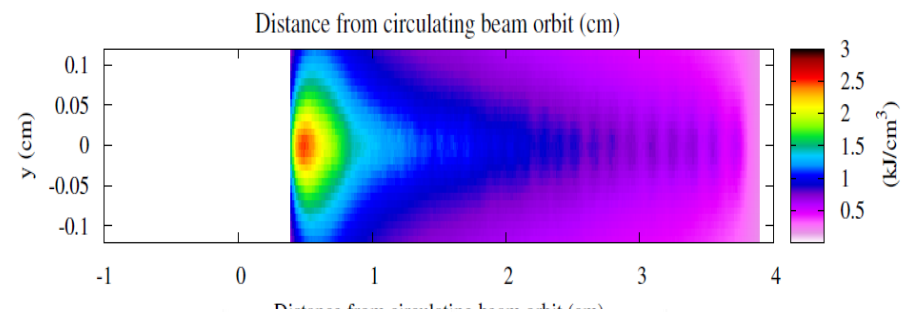


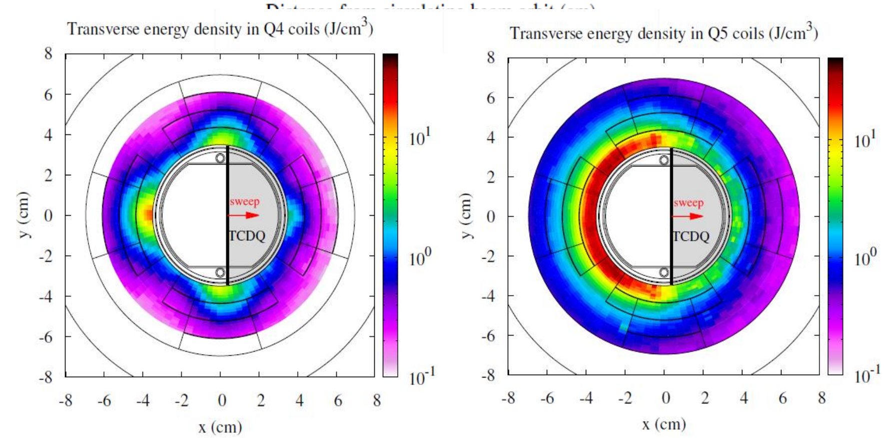


TCDQ Performance Validation

- **TCDQ** was upgraded during LS1 to withstand impacts of up to 2.3E11 ppb in case of a Type 1 erratic. FULKA and ANSYS Studies were performed to validate the robustness of the TCDQ and the protection to the downstream elements (Q4-Q5) for all failures (Type 2) and smaller beam sizes.







Material	C-C 1.75	C-C 1.4	Graphite R4550
Max. Temp. [°C]	1138	1280	28
Min. Princ. [MPa]	-30,3	-30,8	-3
Compr. Strength	**-69.6**	**-69.6**	**130**
Max. Princ. [MPa]	35	28	2
Tensile Strength	**61**	**61**	**40**

Need to assess Q4-Q5 damage limit (possible adding a mask in front of Q5 if needed)

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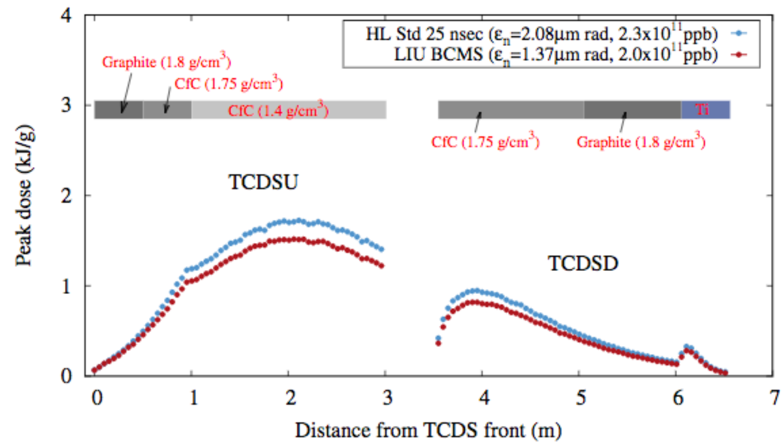
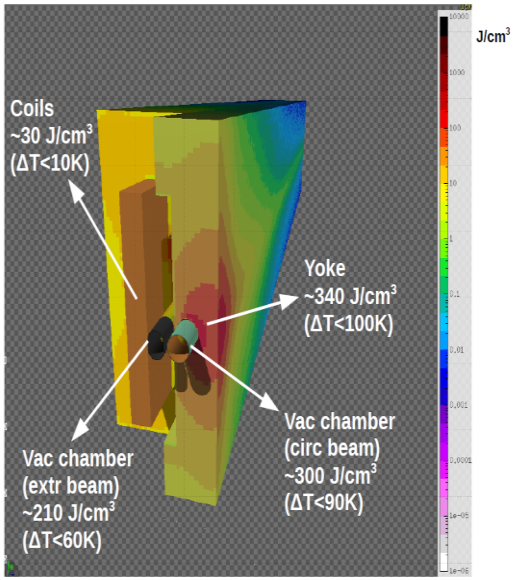
TCDS Performance Validation

- FLUKA and ANSYS simulation studies done to define energy deposition on the **TCDS** absorber and the downstream MSDA (type 2 erratic).
- Maximum energy deposition:
  - **1.7 kJ/cm3** on high density **CFC**: OK
  - **0.4 kJ/cm3** on **Ti**: not OK (plastic deformation) ➔ **different material needed?**



- **Temperature increase at MSDA yoke**:
  - 87 K ➔ 110˚C absolute temperature. **Not critical for change in magnetic properties** of ferrite (ok up to 150˚C)
  - Peak temperature in plate and instantaneous ➔ **no issue for coil insulation**
  - Temperature increase at the vacuum chamber up to 83 K for the stored beam ➔ **critical for Mu-metal layer**
  - Quantify energy deposition and temperature increase of water in MDS **cooling pipes** ➔ **risk of a pressure rise** and possible consequent **shockwave**
  - **A third module** will be added to further reduce energy deposition on MSDA.



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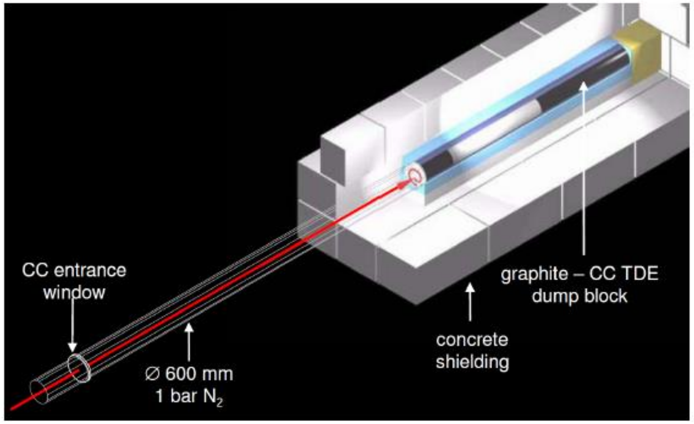
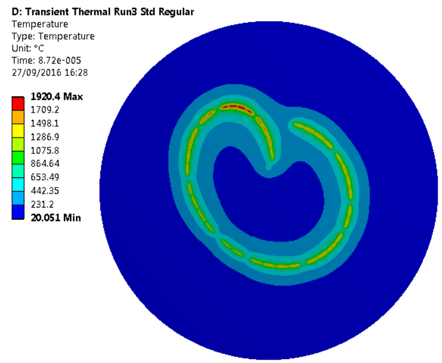
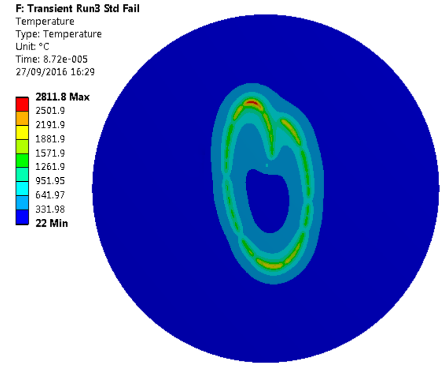
MKB Failures and TDE Upgrade





E. Lopez Sola



2 missing MKBH

Component	Regular sweep Maximum temperature	1H Kicker failure Maximum temperature	2H Kicker failure Maximum temperature
Dump core	1920°C	2150°C	2810°C ⚠
Titanium window	170°C	200°C	250°C
CFC window	43°C	46°C	68°C
Stainless steel foil	48°C	63°C	75°C

Close to sublimation temperature!

Downstream Ti window

Case	Max temperature	Max Von Mises eq. Stress	Minimum yield strength	Safety factor
Regular sweep	170°C	113 MPa	180 MPa	1.6
1H Kicker failure	200°C	124 MPa	150 MPa	1.2!
2H Kicker failure	250°C	142 MPa	130 MPa	0.9 ⚠

Stainless steel foil

Case	Max temperature	Maximum VM eq. stress	Safety factor
Regular sweep	48°C	65 MPa	2.6
1H Kicker failure	63°C	125 MPa	1.4
2H Kicker failure	75°C	140 MPa	1.2 ⚠

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Summary and Major Upcoming Milestones

- **LS2**: upgraded **injection elements** installed in the LHC
  - **TDIS**: internal review in Dec. 2016 ➔ **final decision on materials**, impedance related mechanical aspects (RF fingers, ferrite, etc.) ➔ **prototype ready in 2018**.
  - **MKI**: **HV** and **vacuum qualification** of **Cr_2O_3 coatings** to be completed in 2017 together with vacuum qualification of vacuum tank treatment ➔ **prototype** in LHC YETS 2017-2018 ➔ decision on series production of coated chambers and treated vacuum tanks.

- **LS3**: upgraded **dump elements** plus new **MKI series** installed in the LHC
  - Feasibility studies for **integration of two additional MKBHs** to be completed by the end of **2016 or further mitigations**.
  - **Possible TDE upgrade studies** completed by end **2020.**

Thank you for your attention!