TDI - past observations/limitations and improvements for 2016

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M. Taborelli, J. Uythoven, C. Yin Vallgren, W. Vollenberg
+ many more colleagues from EN/STI, EN/MME, TE/ABT, TE/VSC,
BE/OP, BE/ABP, BE/RF, ALICE, LHCb, ...

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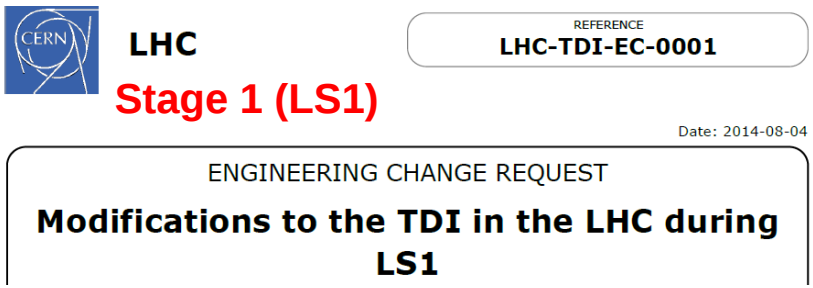
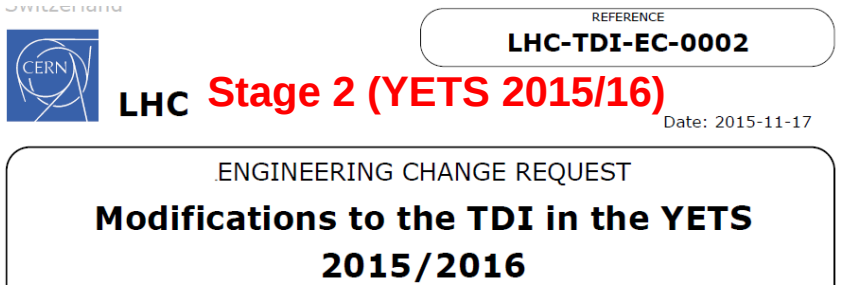
Introduction

- TDIs = primary injection protection absorbers located in cells **4L2** and **4R8**
  → intercept the beam in case of MKI malfunctions/timing errors
- In Run 1+2015, we encountered several issues and operational limitations
- The TDIs were modified in two stages to mitigate these problems where possible:

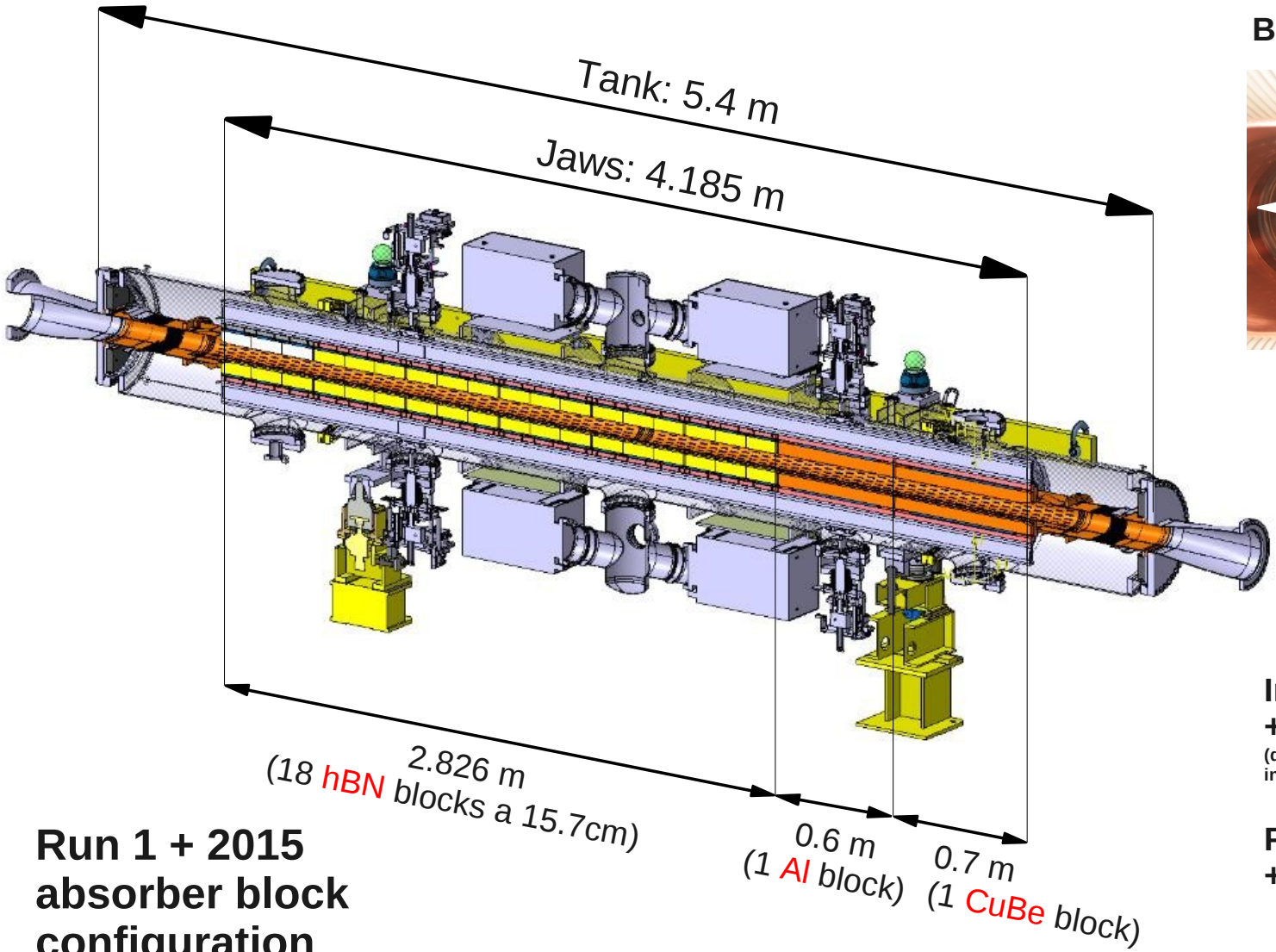

LHC
REFERENCE
LHC-TDI-EC-0001
Stage 1 (LS1)
Date: 2014-08-04
ENGINEERING CHANGE REQUEST
Modifications to the TDI in the LHC during LS1


REFERENCE
LHC-TDI-EC-0002
LHC
Stage 2 (YETS 2015/16)
Date: 2015-11-17
ENGINEERING CHANGE REQUEST
Modifications to the TDI in the YETS 2015/2016

→ before LS1, we had essentially no changes to the original design

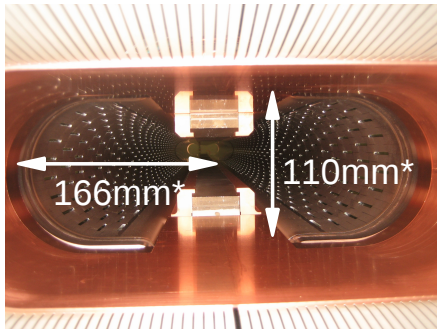
- This talk summarizes:
  - The main observations and limitations
  - Modifications in LS1 and the YETS 2015/16
  - Implications/expectations for 2016

The TDI interior as installed today



Run 1 + 2015 absorber block configuration

Beam screen:

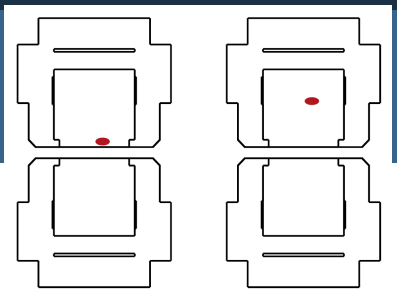


*ALICE ZDC requirements for spectator protons and neutrons

Injection settings:
+/-3.8 mm from beam
(different crossing and separation bumps in IR2/8)

Parking:
+/-55 mm

Machine protection



- The TDI is a critical machine protection element
- Several injection failures occurred in Run 1&2:

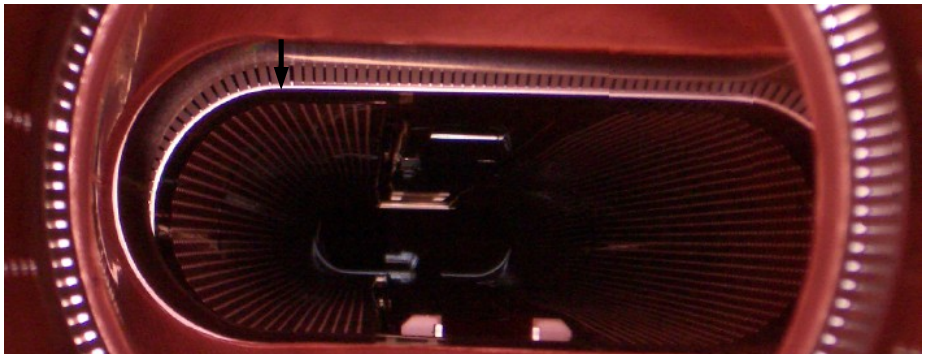
	Date	Beam	MKI failure	TDI impact	Lost bunches
Run 1	**2010**				
	23/10	1/inj.	not firing	large impact parameter	32
	2011				
	18/04	2/inj.	flashover	grazing	36
	23/04	1/inj.	not firing	large impact parameter	36
	27/04	2/inj.	not firing	large impact parameter	72
	28/07	1/inj.	erratic	large impact parameter	144
	28/07	1/circ.	erratic	grazing	176
	2012				
	26/03	2/inj.	erratic	large impact parameter	1
	30/11	2/inj.	B1 MKI fired	large impact parameter	20 (BCMS)
	12/12	1/inj.	timing error	large impact parameter	48 (BCMS)
	15/04	2/inj.	flashover	grazing	108
Run 2	**2015**				
	28/07	1/inj.	not firing	large impact parameter	144

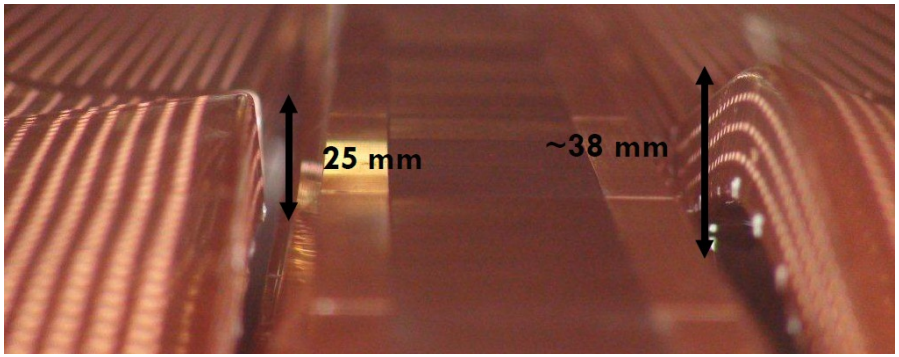
$\longrightarrow$ *TDI performed as expected*

Contents

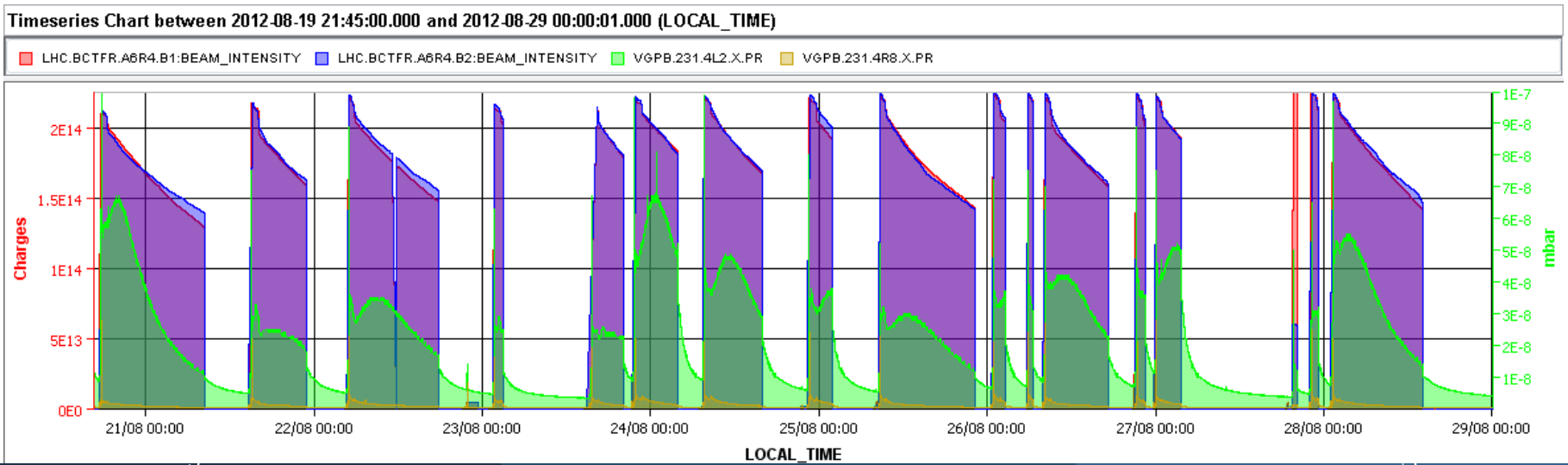
Main issues in Run 1 - a brief recap (1/2)

- Cu beam screens were found deformed and sliding contacts found blocked (both in **TDI.4L2** and **TDI.4R8**, discovered in winter stop 2011/2012)



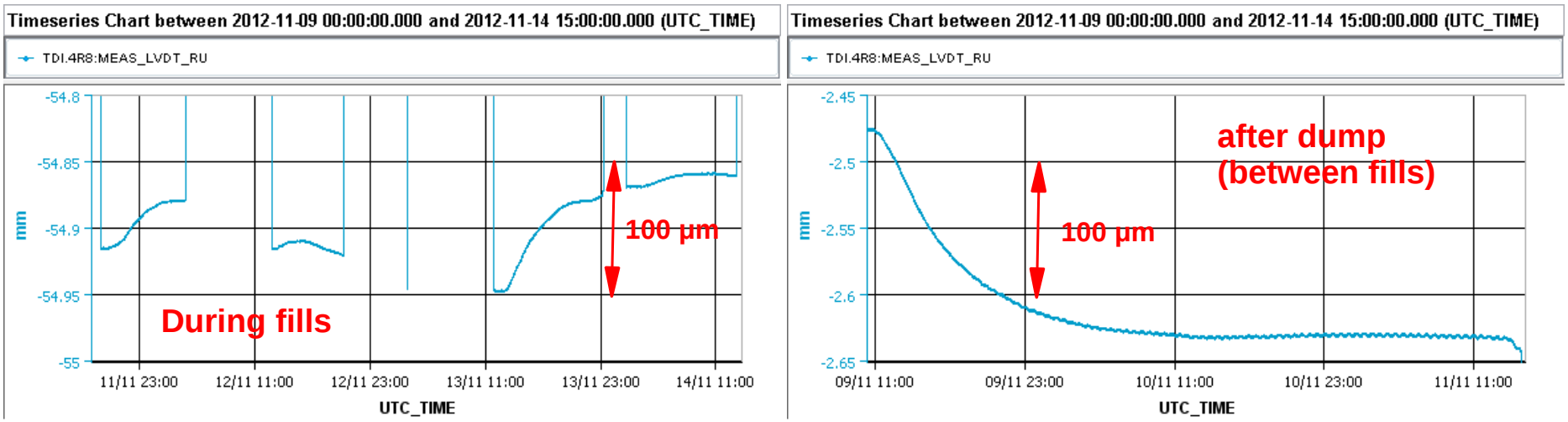


- Vacuum issues, in particular increased outgassing during fills in the **TDI.4L2** starting from mid-2012 $\rightarrow$ background issues for ALICE



Main issues in Run 1 - a brief recap (2/2)

- Thermal drift of jaw positions measured by LVDTs (**TDI.4L2** and **TDI.4R8**)
  → not straight forward to correlate with actual jaw deformation

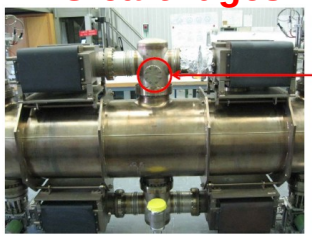


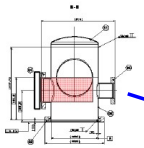
→ many of the issues in Run 1 were likely in one or another way related to beam-induced RF heating

→ synchr. phase shift measurements in 2011 with an almost full machine:
$\Delta P = P_{inj}$ - $P_{park} \approx$ 1kW
(E. Metral et al., Chamonix 2012)

Overview TDI modifications LS1

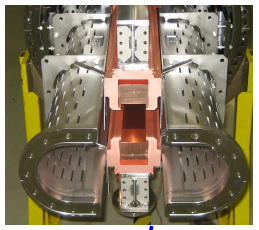
NEG cartridges

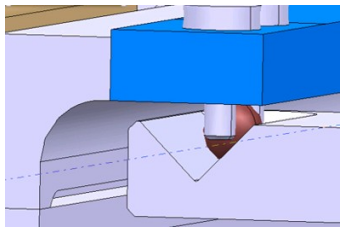




Ti coating on Aluminium blocks to reduce SEY

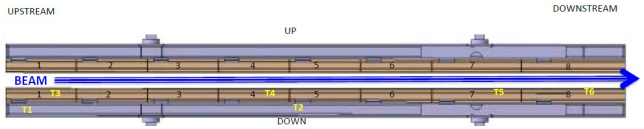
Reinforced beam screen made of stainless steel and **improved sliding contacts** (ceramic spheres)



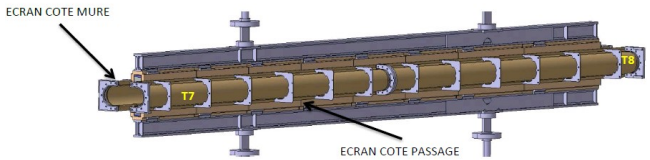


Refurbished mechanism for jaw displacement

Temperature probes on lower jaw (frame, beam girder) and beam screen



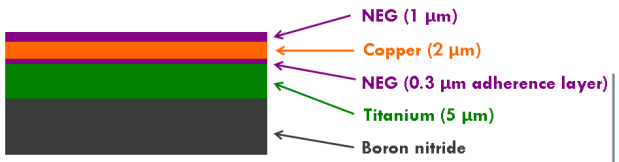
Sensor positions jaw



Sensor positions beam screen

Other modifications foreseen for LS1 but discarded/delayed

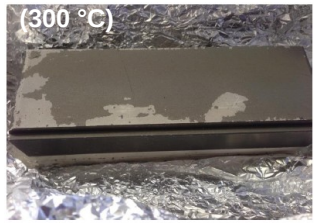
Additional coatings on top of the Ti-coated hBN blocks: Cu to reduce resistive heating, NEG to reduce SEY



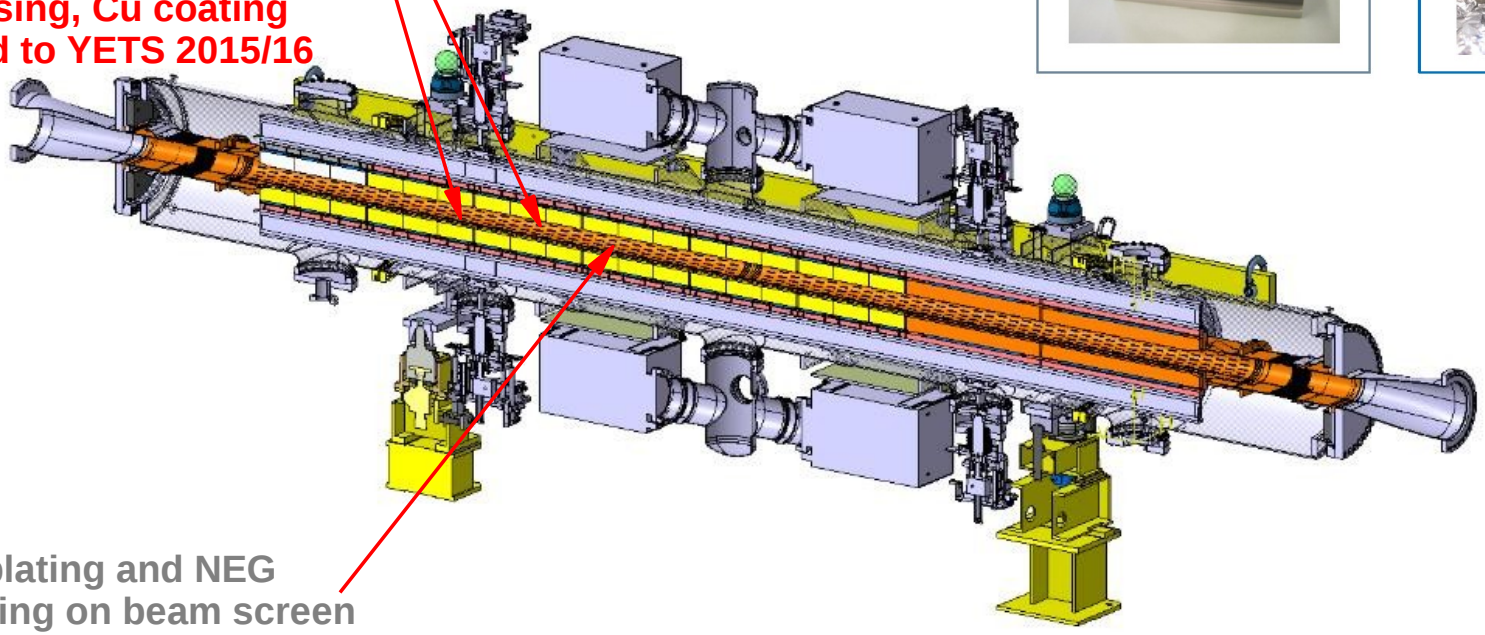
NEG discarded due to hBN outgassing, Cu coating delayed to YETS 2015/16

BN after coating

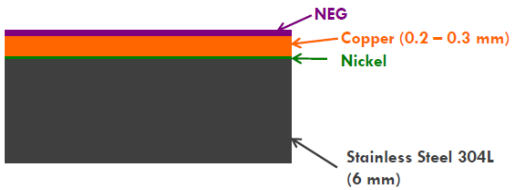
BN after bake-out



Mauro Taborelli



Cu plating and NEG coating on beam screen **discarded**



+ optical gap measurement system **delayed to YETS 2015/16 to complete qualification tests**

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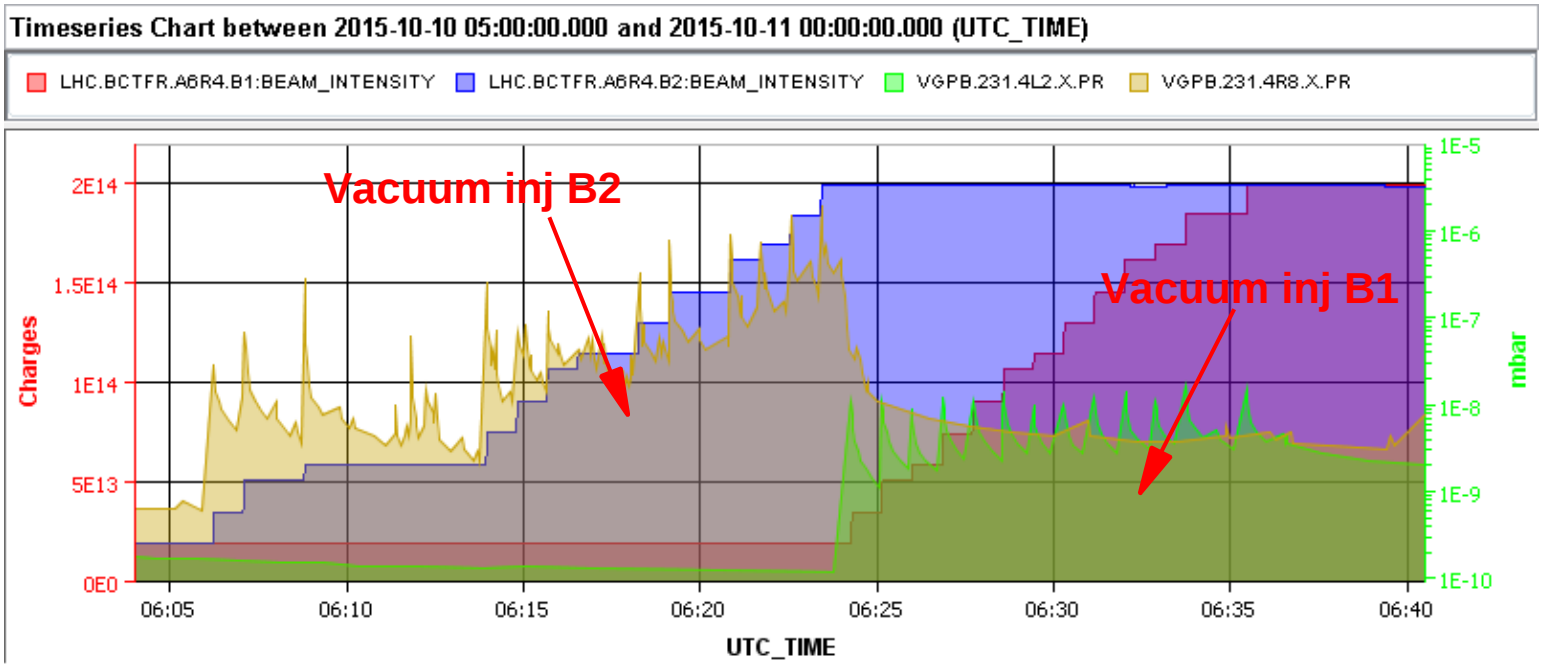
Vacuum spikes in the TDI.4R8 (1/2)



- One of the main issues in 2015: large vacuum spikes in the **TDI.4R8** during injections
  - Significant pressure build up when filling for physics
  - Spikes reached up to a few 10^{-5} mbar
  - Dumped several times on vacuum interlock
    $\rightarrow$interlock level was eventually raised to 10^{-5} mbar
- Spurious spikes also during fills (jaws retracted)

Vacuum spikes in the TDI.4R8 (2/2)

- The cause of the vacuum spikes is not yet understood, in particular the discrepancy between the **TDI.4L2** and **TDI.4R8**
- Also other differences were found between the two TDIs:
  - Beam measurements in 2015 showed that
    → the transverse impedance was 4 times higher for the **TDI.4R8**
    → the synchronous phase shift was 2 times higher for the **TDI.4R8**
    (B. Salvant et al., Impedance meeting 10/08/2015)
  - The temperature readings were higher for the **TDI.4R8**
    [*the temperature readings however showed some anomalies due to EM coupling between the PT100 probes and the beam through HOMs*
    (N. Biancacci et al., Impedance meeting 7/12/2015)]
- The differences are under investigation and both TDIs will be carefully checked after the exchange with the spares in the YETS

Quality issues with hBN blocks

- To achieve a better cleanliness before coating, hBN blocks for spare TDIs were treated in vacuum at higher temperatures in 2015 (R. Losito LMC #215):
  - 20% of blocks had cracks after cycle@800°C
  - 50% of blocks had cracks after cycle@1000°C
- Mainly attributed to unreacted binder material (B_2O_3) which has a melting point of 450°C
- In order not to risk damage to the blocks in the machine, had to limit #bunches/injection in 2015 (LMC #217):

Manufacturer specs: Tmax=1150° C (in inert atmosphere)

Limitation for 2015 physics beams →

Beam type	Bunch/Doublet intensity	Emittance (um rad)	Bunch/Doublet spacing (nsec)	Bunches/Doublets per batch	1 batch	2 batches	3 batches	4 batches
Standard 25 nsec	1.20E+11	2.6	25	72	***72 (1.8 usec)*** 206 deg C	***144 (3.8 usec)*** 352 deg C	***216 (5.8 usec)*** 483 deg C	***288 (7.8 usec)*** 606 deg C
BCMS	1.30E+11	1.3	25	48	***48 (1.2 usec)*** 239 deg C	***96 (2.6 usec)*** 408 deg C	***144 (4.0 usec)*** 560 deg C	
50 nsec	1.20E+11	1.5	50	36	***36 (1.8 usec)*** 160 deg C	***72 (3.8 usec)*** 277 deg C	***108 (5.8 usec)*** 378 deg C	***144 (7.8 usec)*** 473 deg C
Doublet(*)	1.60E+11	4	25	72	***72 (1.8 usec)*** 212 deg C	***144 (3.8 usec)*** 363 deg C		

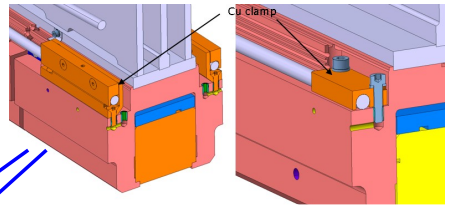
(*) Doublets consist of two bunches separated by 5 nsec.

Overview TDI modifications YETS 2015/2016

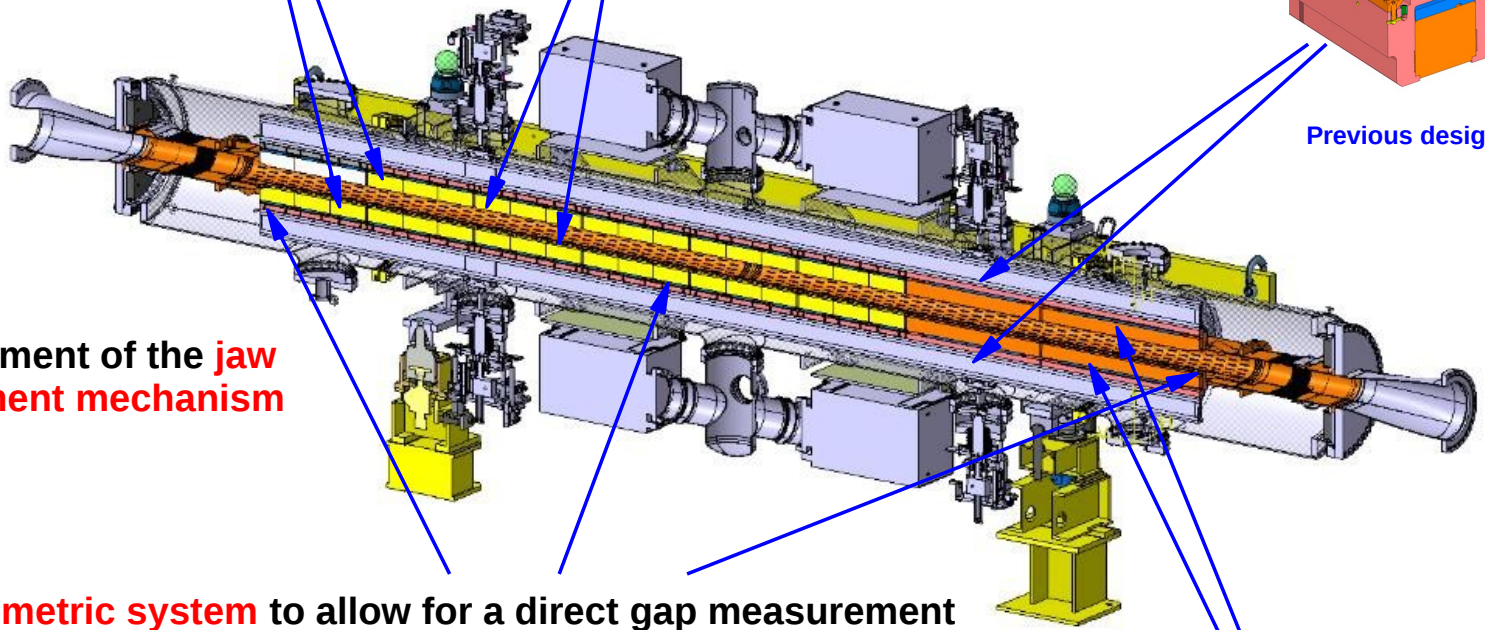
Replacement of the hBN blocks with Graphite R4550 blocks to improve the robustness to beam impact

2 µm Copper coating on R4550 blocks to reduce the resistive heat load (2015: 5 µm Ti on hBN)

Modified clamping of cooling pipes to improve their contact with the frame

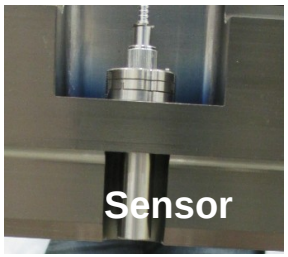


Previous design New design



Refurbishment of the jaw displacement mechanism

Interferometric system to allow for a direct gap measurement



Replacement of the CuBe blocks with CuCrZr blocks (CuBe blocks were found deformed after bake-out)

Contents

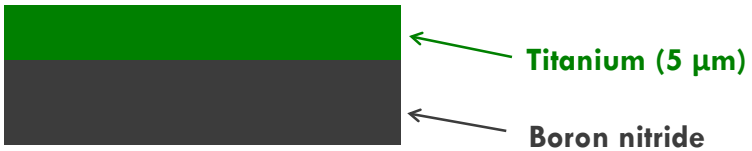
Outlook for 2016: Graphite blocks

- Outgassing tests (G. Bregliozzi, C. Yin Vallgren LMC #240):
  - Residual gas outside of the LHC vacuum specification → graphite porosity
  - However, the total outgassing at room temperature is 4 times lower than for the presently used hBN
  - Considered OK by TE/VSC
    NB: the same grade of Graphite (R4550) is also used in other devices (**TCDIs**, **TCLIA**, **TCDQ**)
- Injection limitations for 2016
  - The new R4550 blocks allow to lift 2015 limitations due to the hBN
  - For BCMS beams, a limitation however remains due to the attenuation of transfer line collimators (V. Kain Chamonix 2014):

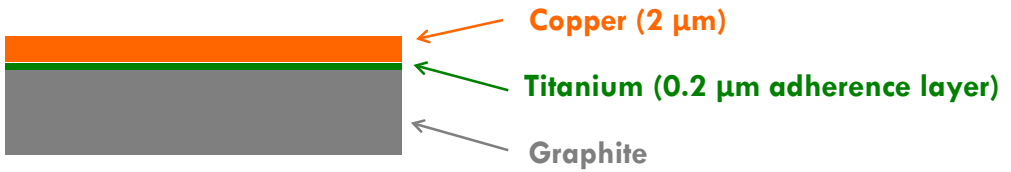
Beam type Run 2	**TDI limitation 2015 hBN**	**Outlook 2016**
Standard 25 nsec	144 bunches	288 bunches
BCMS 25 nsec	96 bunches	144 bunches (TCDIs)
50 nsec	108 bunches	144 bunches

Outlook for 2016: resistive power loss due to jaws

Run 1 + 2015:



From 2016:



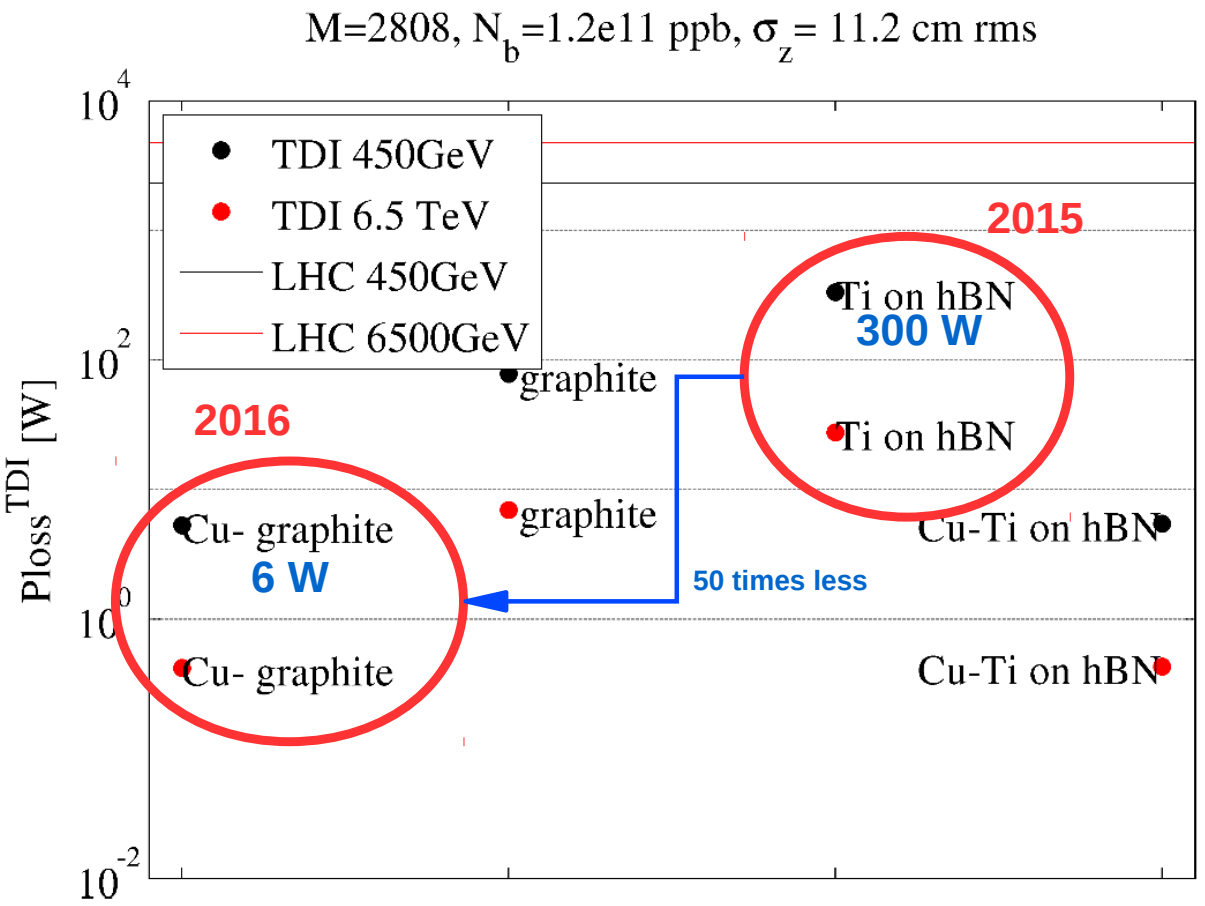


Figure: power loss due to resistive wall impedance of the TDI jaws – comparison of different coatings/block materials

Resistive heating expected to be much reduced in 2016

N. Biancacci et al.
LMC #215

Outlook for 2016: HOMs, instrumentation

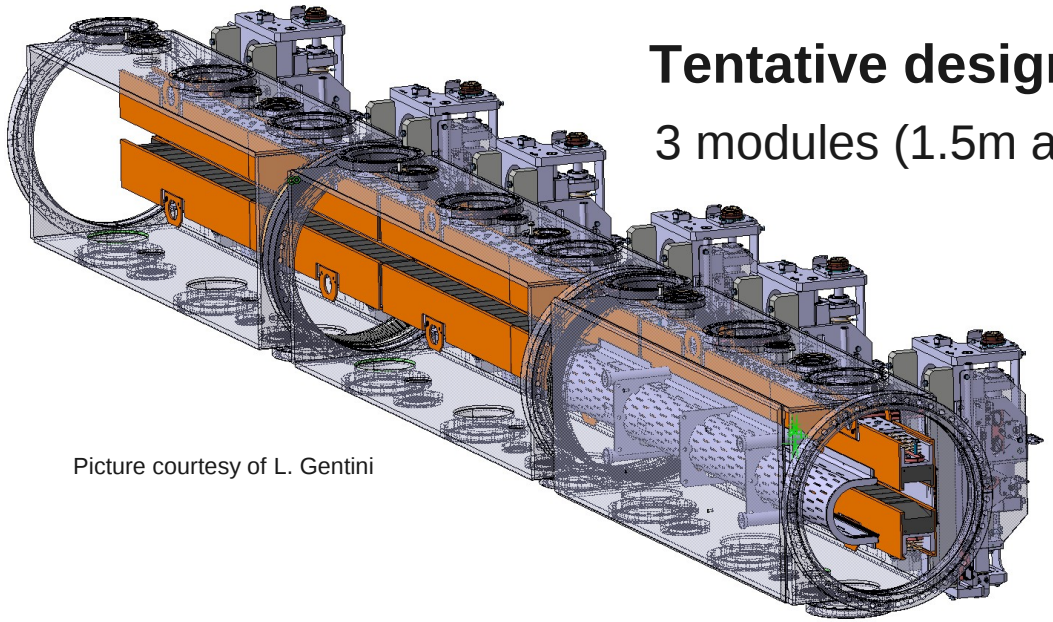
- Other source of heating: HOMs
  - The YETS modifications do not change the modes → *confirmed by impedance measurements on the TDIs to be installed in the YETs* (N. Biancacci et al., Impedance meeting 06/12/2015)
  - The modes are distributed from 31 MHz onwards, can heat different locations in the TDI (jaws, tank, transitions, AI frame, ...)
  - Power loss can be of the order of 10-100W per mode (A. Grudiev, Impedance meeting 30/10/2012).

  → 2016 operation will show how HOMs affect the TDI considering that resistive heating should be much reduced due to the Cu coating
- Instrumentation:
  - Should get a better understanding of possible jaw deformations with interferometric system → *new system, performance in operation to be evaluated*
  - The temperature readings might be affected by the same issues as in 2015

  → As in the past we will follow operation closely and monitor the TDI

Spares in 2016, outlook beyond Run 2

- The TDIs removed from the machine in the YETS will be carefully inspected and will then be modified to become the new spares
  → *the time needed for these modifications is about 6 months after the YETS, meaning that no spares will be available during this period*
- A new TDI (called **TDIS**) is being designed for LS2 (**HL-LHC WP14**)
  → *impedance improvements under discussion with BE/ABP*



Picture courtesy of L. Gentini

Tentative design of new TDIS

3 modules (1.5m active length)