LHC TDI

GianluigiA, EliasM, BenoitS…

- Reminder: BS's talk at Evian2011 (https://indico.cern.ch/getFile.py/access?contribId=33&sessionId=7&resId=1&materialId=slides&confId=155520)
- Some pictures
- 2011' s beam-based observations
- Visual inspection requested:
  - Check the hBN metallization + shielding foil (large imp. meas)
  - Identify possible aperture restrictions for B1 between TDI and TCTVB left of point 2 evidenced by the aperture measurements conducted in preparation of the 2011 ion run
  - => Some surprises: deformation of the beam screen in P8 mainly and to a smaller extent in P2 also
- Some questions to try and answer

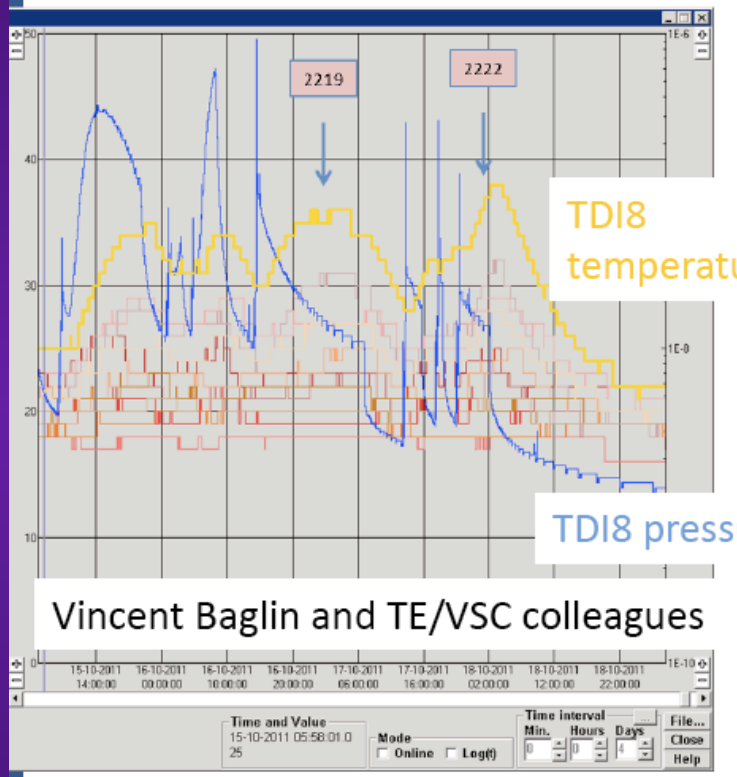
BS's talk at Evian2011 (1/3)

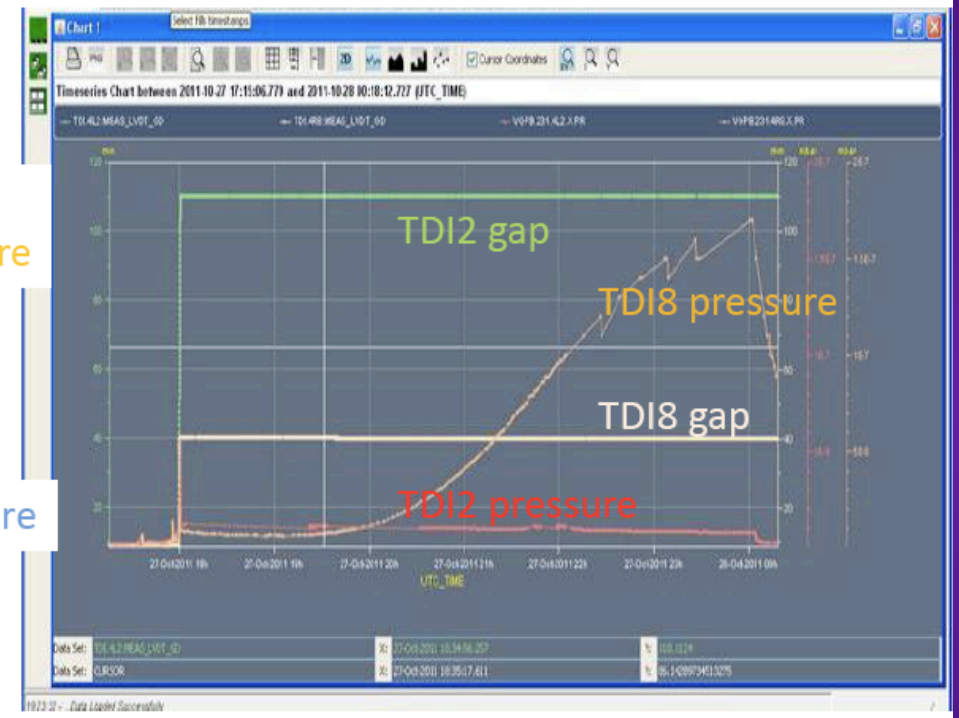
	observable	Cooling?	Limits operation?	better if bunch length increased	improves with time?	Is it happening to all similar devices
TCP_B6L7_B1	temperature	water	Yes, dump in Sept 17th interlock increase from 55 to 70 degrees	yes	no	No (1/6)
TCTVB.4R2	temperature	water	Yes, dump in October 9th interlock increase from 50 to 70 degrees	Yes	Not obvious	No (1/4)
TDI	Vacuum Temperature (outside tank)	no	Not anymore, should be put in parking position	?	no	Yes (2/2)
MKI	Temperature and Rise time and delay (soon)	no	Yes (kick strength), and temp interlock increased from 50 deg to 62 deg. Needed to wait 4h in Oct 2011	Yes	no	All are heating but MKI-8D seems to be heating more No (1/8)
Beam screen	Heat load computed from regulation response	yes	No, except in one cell Q6R5	Yes	no	No (only one)
ALFA	Temperature on the roman pots	no	Not yet (18deg increase in temperature in 2011, with margin of 40 degrees)		?	Cooling was needed in TOTEM
VMTSA	Vacuum Spring broken after May	no	Yes (spring broken and dangling fingers)		?	Yes
BSRT Mirror	Jitter in BSRT measurement		mirror is deforming and RF heating is suspected			N/A
BGI	Vacuum		Probably not a heating issue		No data	N/A

BS's talk at Evian2011 (2/3)

TDI pressure and temperature

- Pressure and temperature increase in both TDIs during physics fills





Increasing the gap of the TDI from +/-20mm to +/-55mm from fill 2219 damped the pressure increase, but not the temperature increase.

Decreasing the gap on B2 back to +/-20mm for fill 2261 generated pressure again. Clear correlation with the gap.

- For the last fills, TDI gap was put to +/-37.5mm for B2 but no significant difference with +/-55mm was observed

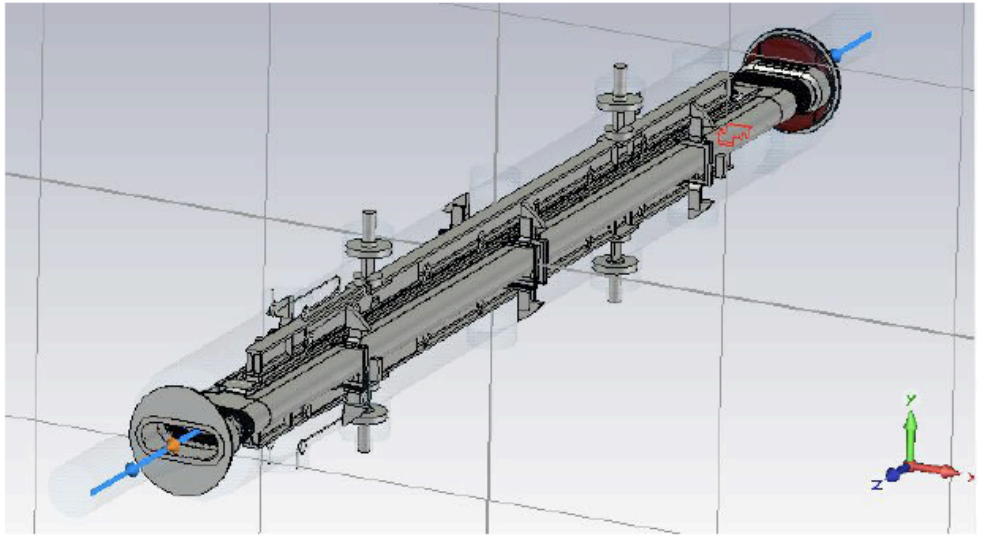
- problem seems solved for now!

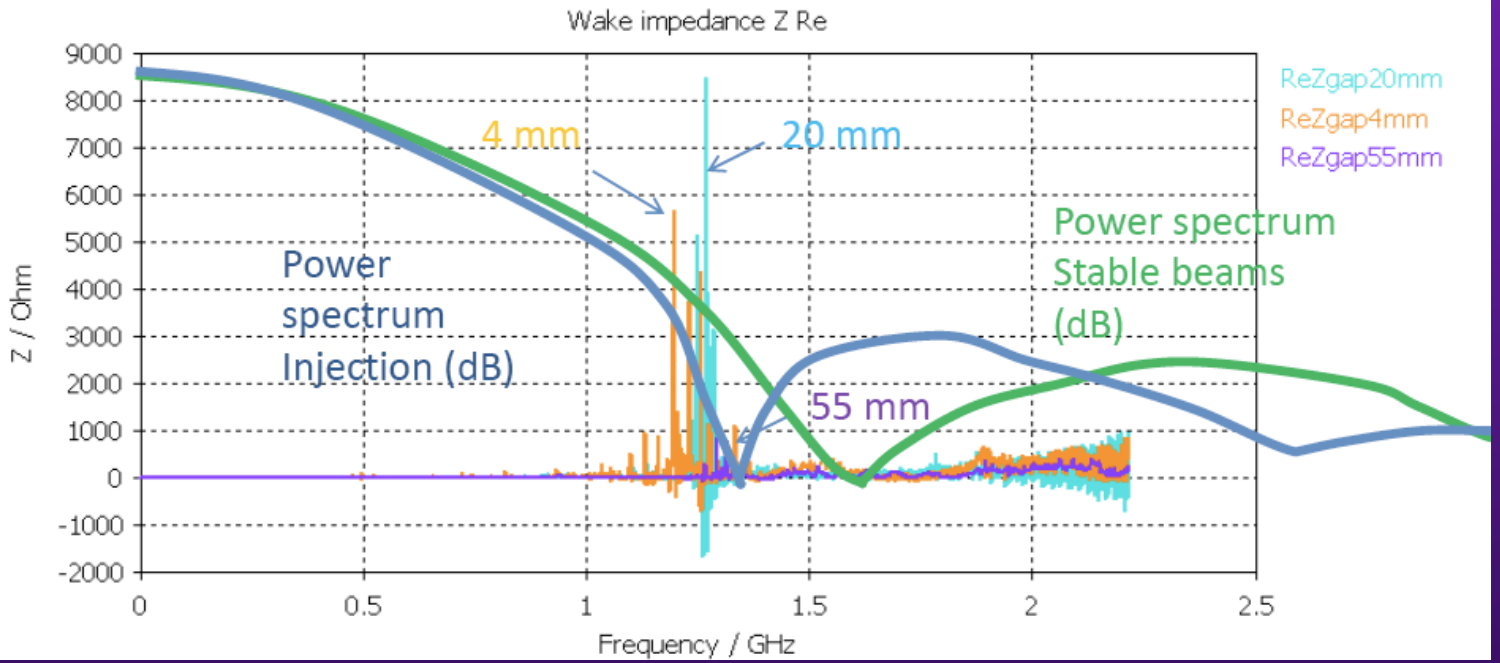
BS's talk at Evian2011 (3/3)

Impedance simulations for the TDI

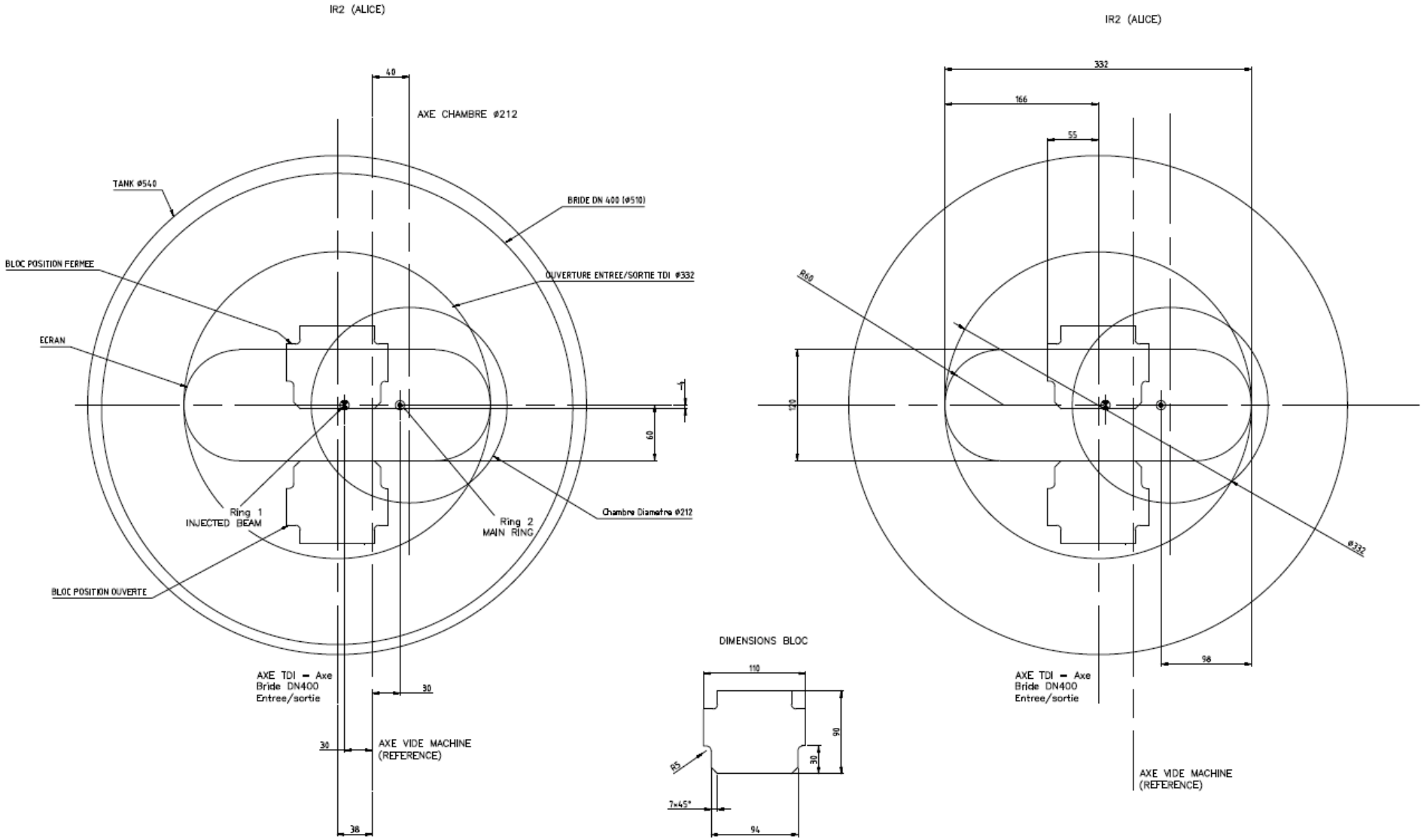
Sharp narrow band resonances

Estimated power loss is divided by 10 when putting the TDI half gap from 20 mm gap to 55 mm

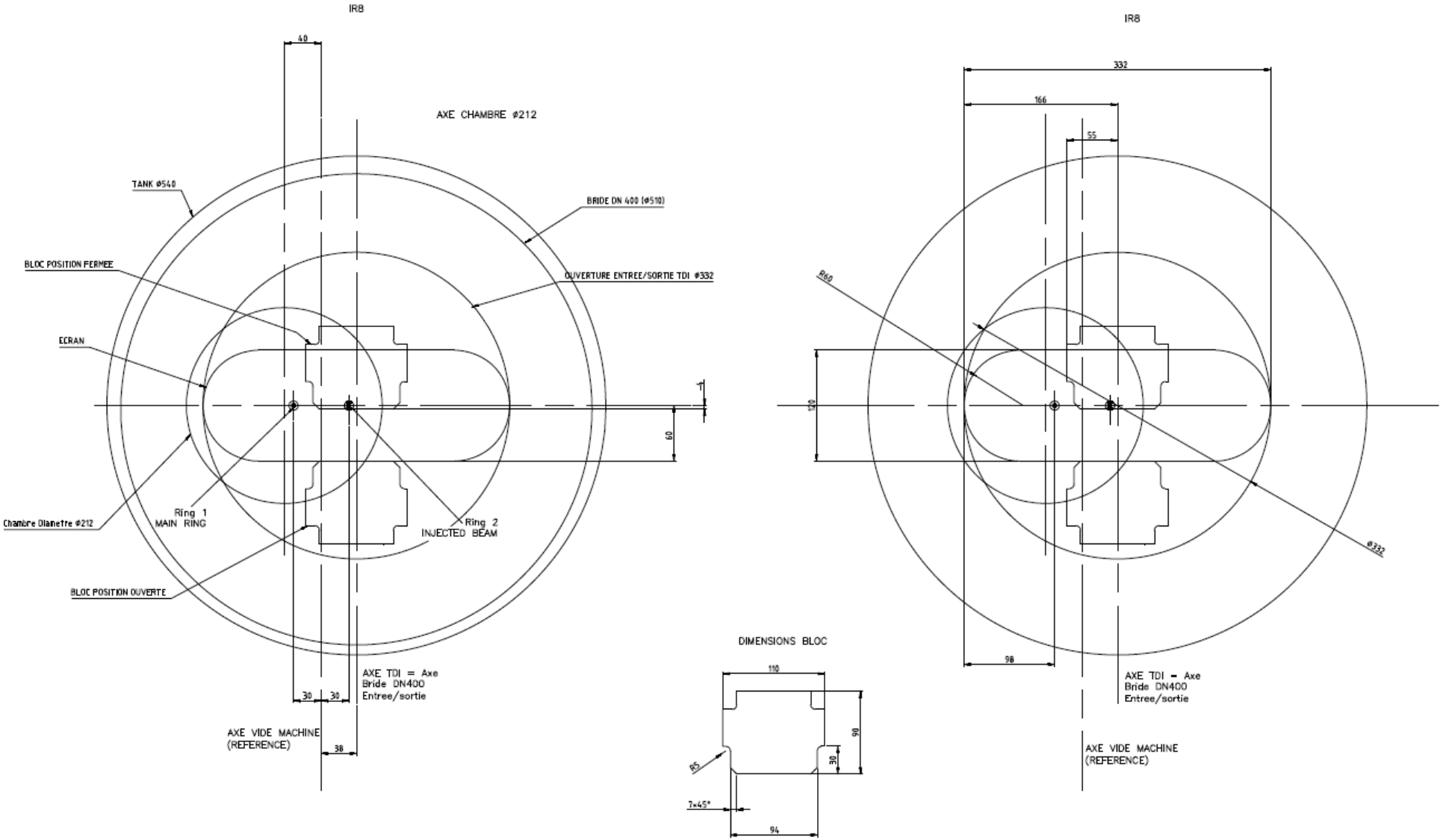




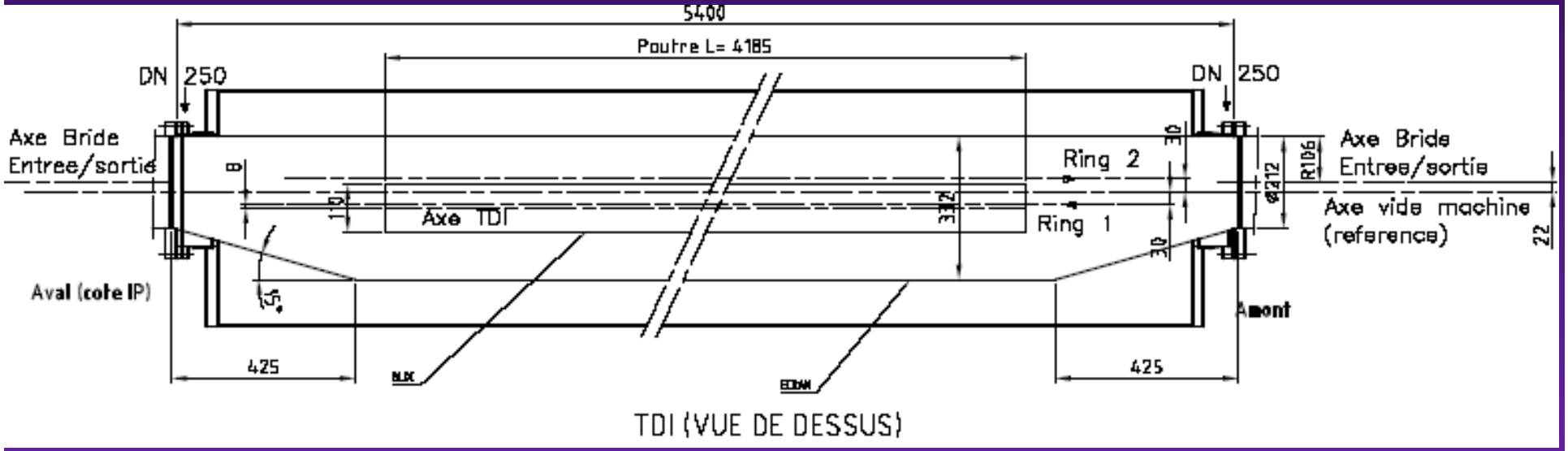
Some pictures (1/6)

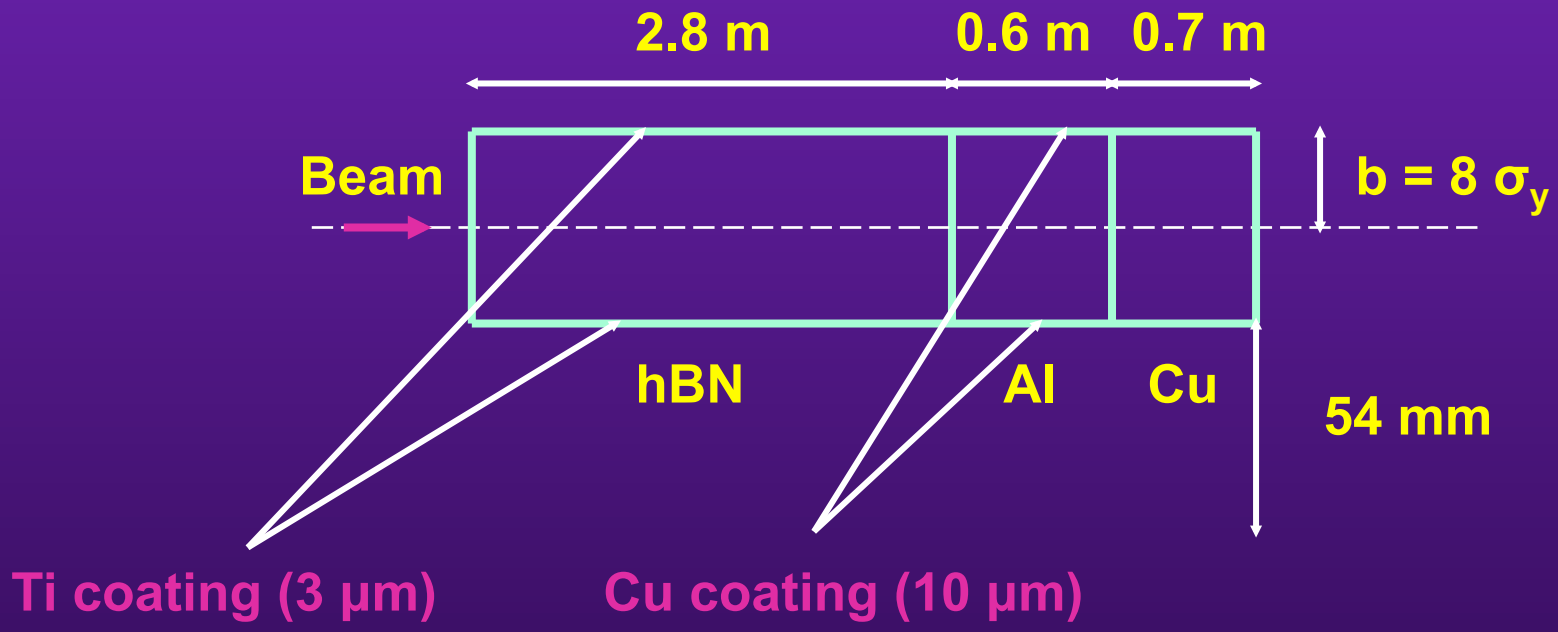


Some pictures (2/6)

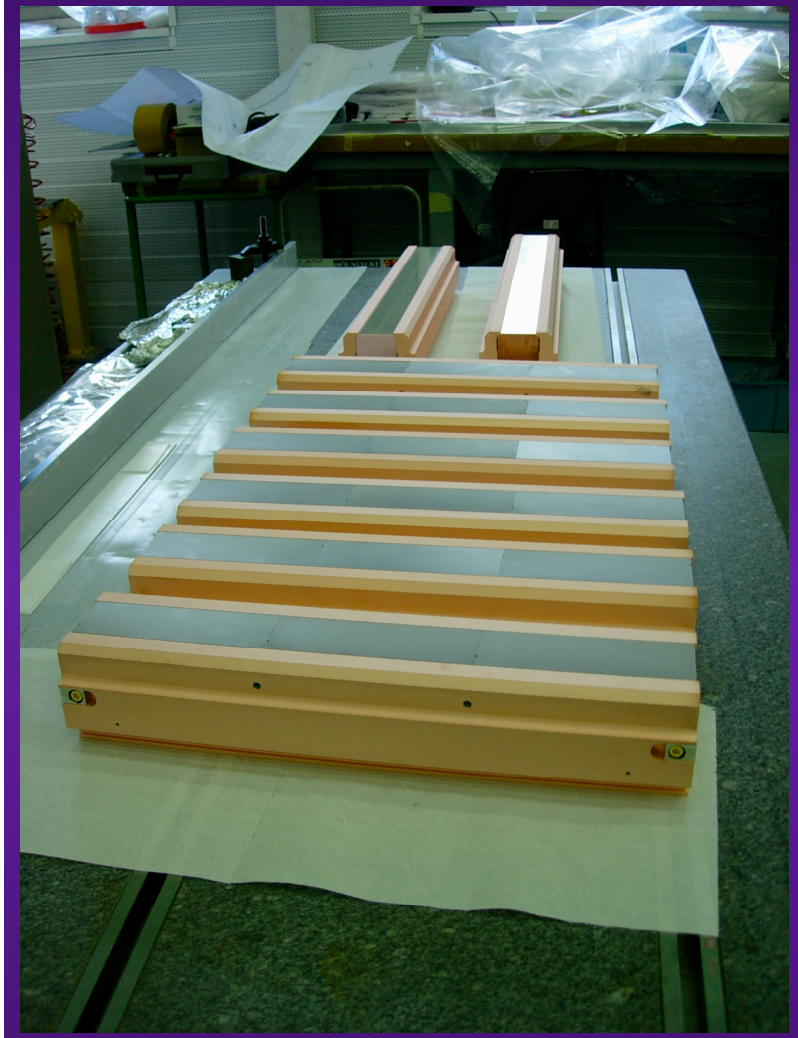


Some pictures (3/6)

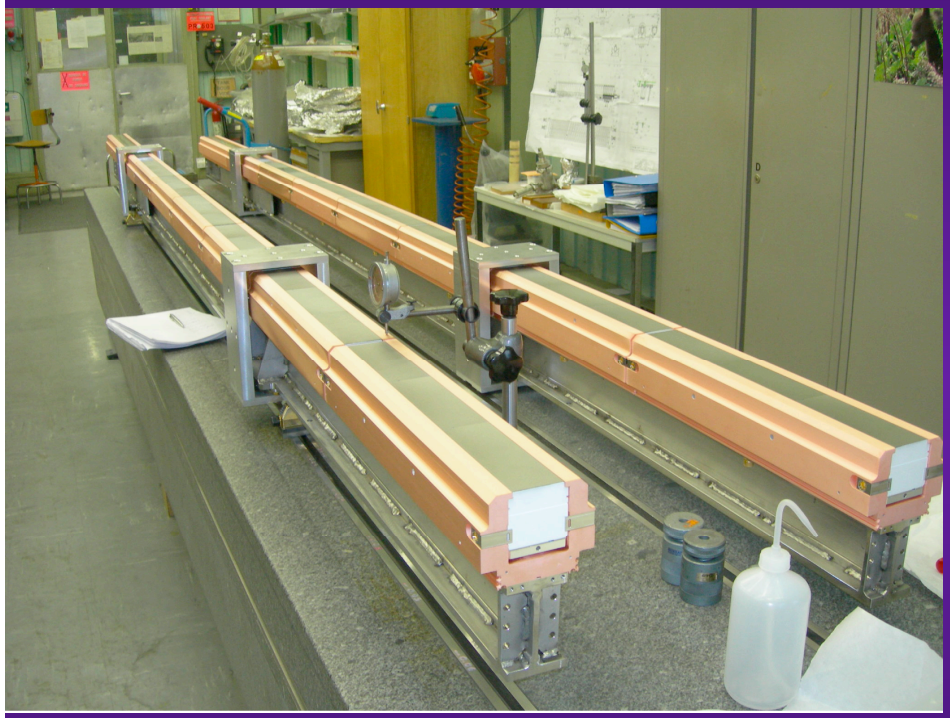


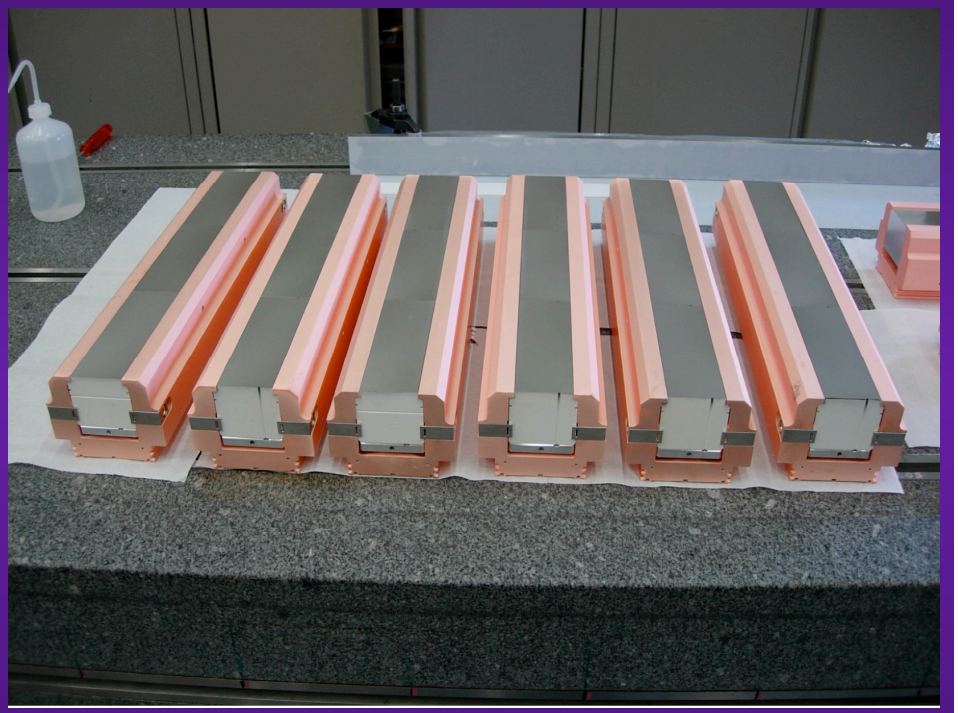


Some pictures (4/6)

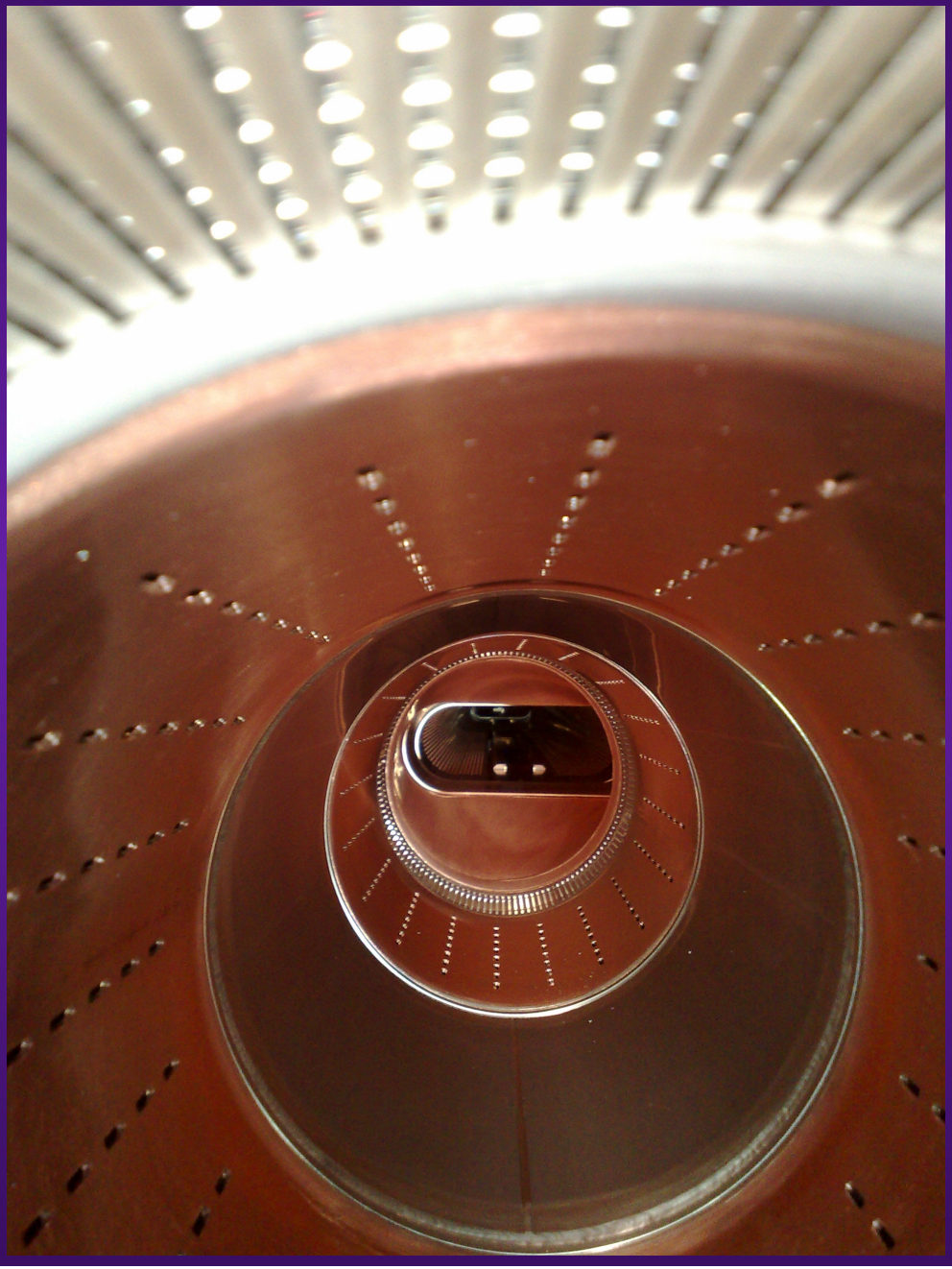


Some pictures (5/6)





Some pictures (6/6)



2011's beam-based observations (1/24)

- **Summary:**
  - Vacuum pressure increase after ~ 1-2 h in stable beam, maximum reached and then decrease (starting from fill 2092)
  - Heating at both extremities (with both small and large gaps) on TDI.8R => From 8 to 17 deg
  - Higher impedance than expected from simulations and from previous measurements in 2010
  - Unstable positions measurements
  - Unexpected aperture restriction in P2
  - Etc.

2011's beam-based observations (2/24)

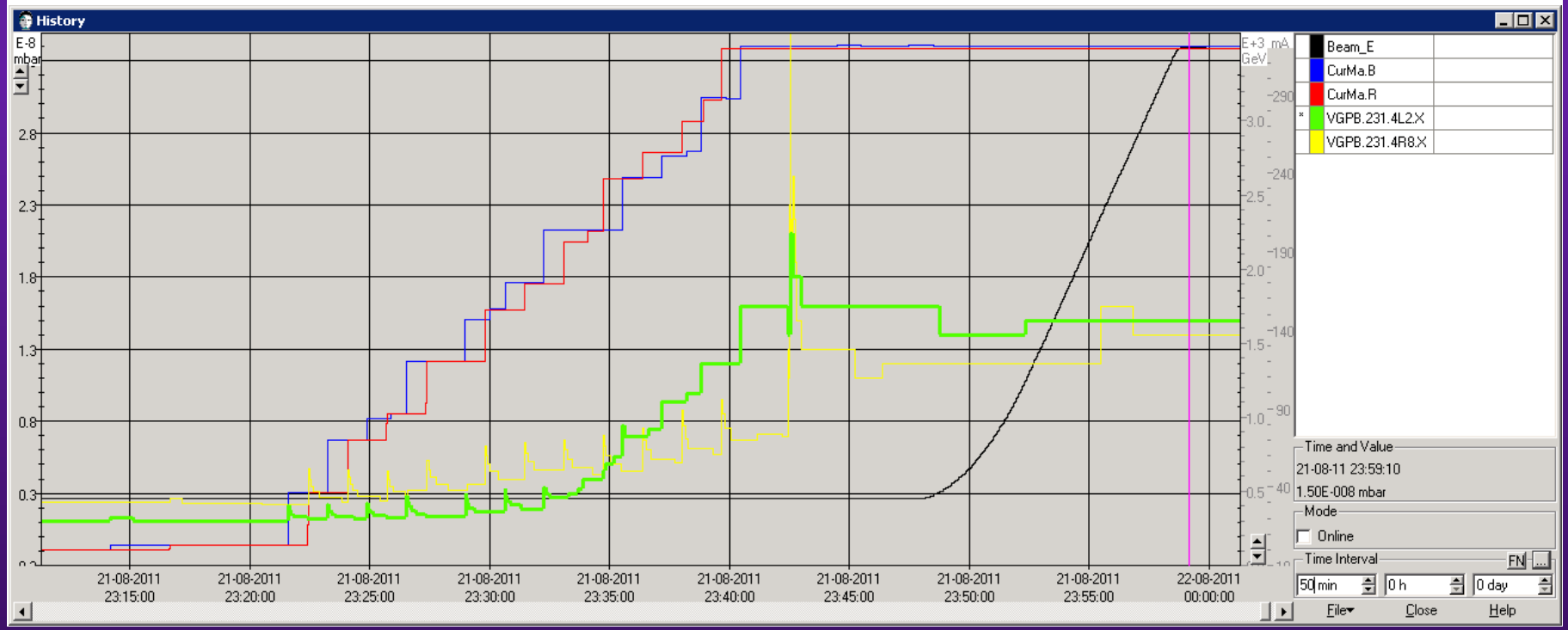
Fill 2040 : Injection

Vincent Baglin

- A pressure increase is observed at each injection shot
  - DeltaP @ TDI8R = 2 to 2.5 10^{-9} mbar
  - DeltaP @ TDI2L = 1 to 1.5 10^{-9} mbar

A pressure in the range of a few 10^{-8} mbar correspond to a proton loss of some 10^{10}

- Pressure increase slopes are different between TDI2L and TDI8R
- At 23h42 pressure increased in both TDI : moving injection collimators out
- Final values at 3.5 TeV are the same.

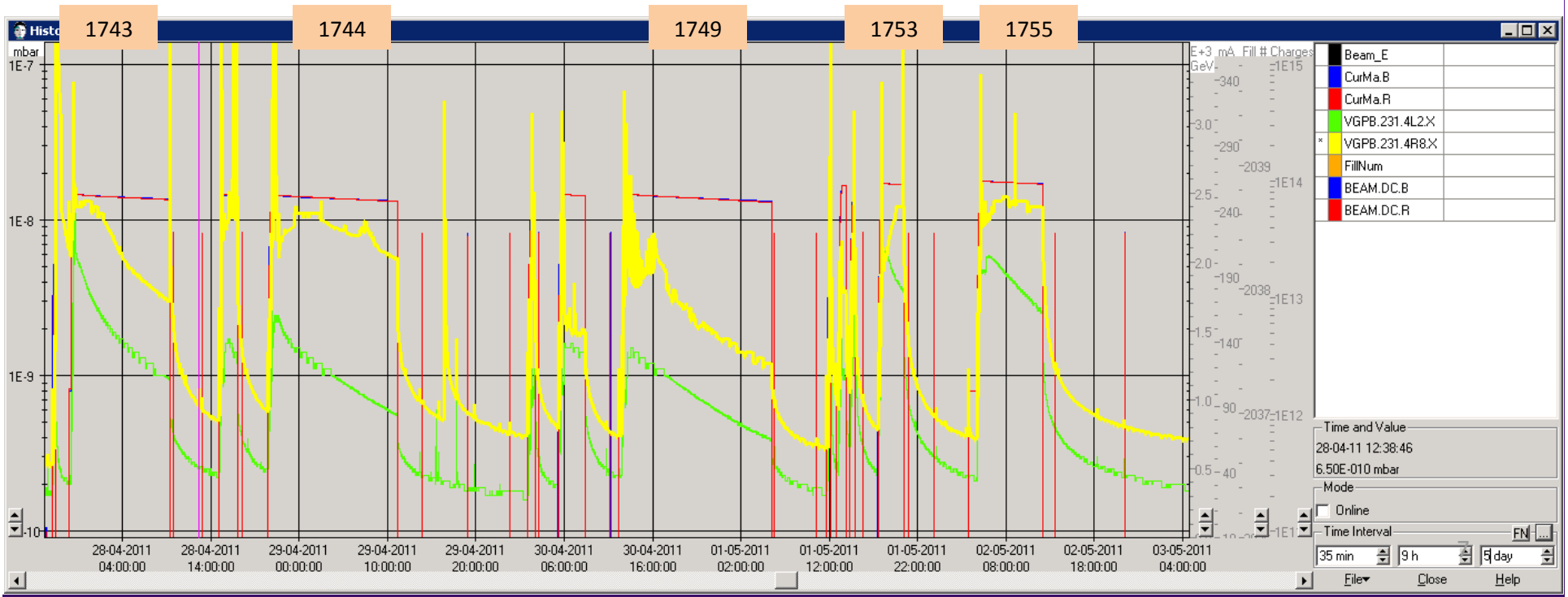


2011's beam-based observations (3/24)

Vincent Baglin

	mA	TDI2L	TD8R	kb	ppb (x10^{10})
1743		↘	↘	624 b	12.0
1744		↘	↘	624 b	11.9
1749		↘	↘	624 b	12.1
1753		↘	↗	768 b	12.1
1755		↘	↗ ?	768 b	12.6

May 1st, 2011 (TDI.4R8)

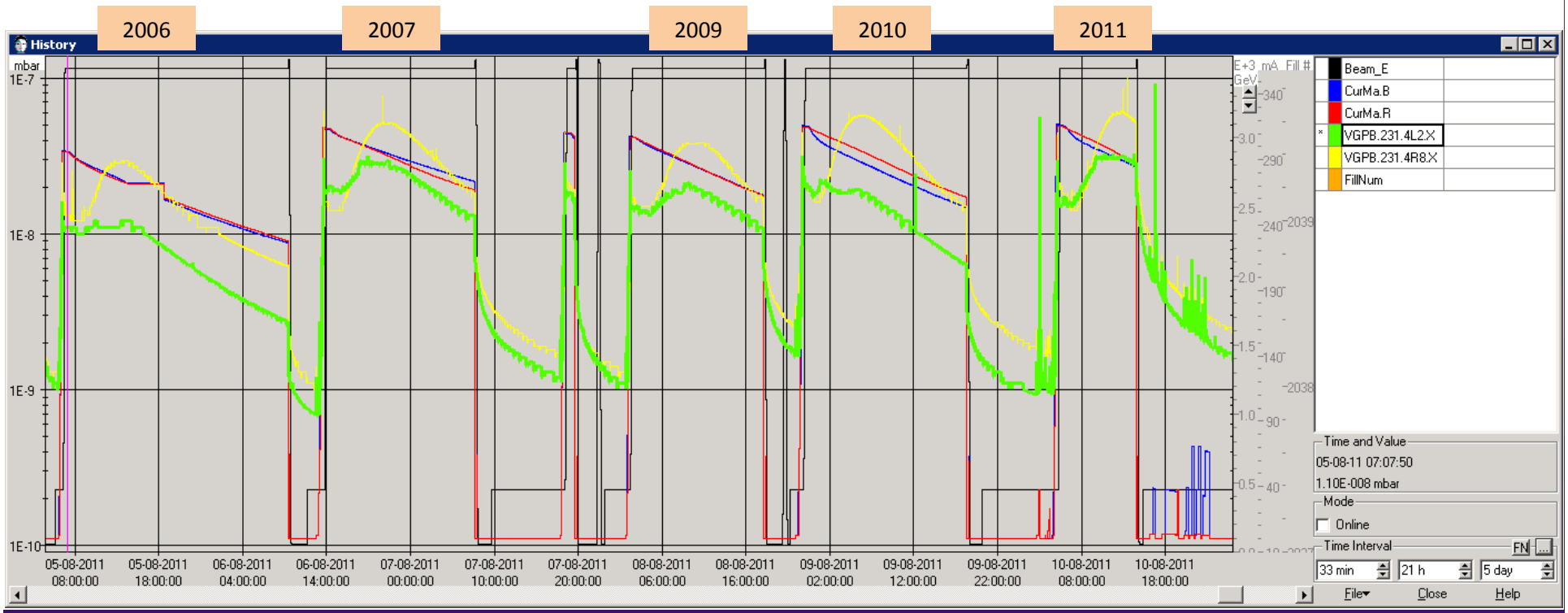


2011's beam-based observations (4/24)

	mA	TDI2L	TD8R	ppb (x10^{10})
2006	296	↘	↗	11.9
2007	313	↗	↗	12.5
2009	306	↗	↗	12.3
2010	316	↗ ?	↗	12.7
2011	316	↗	↗	12.7

Vincent Baglin

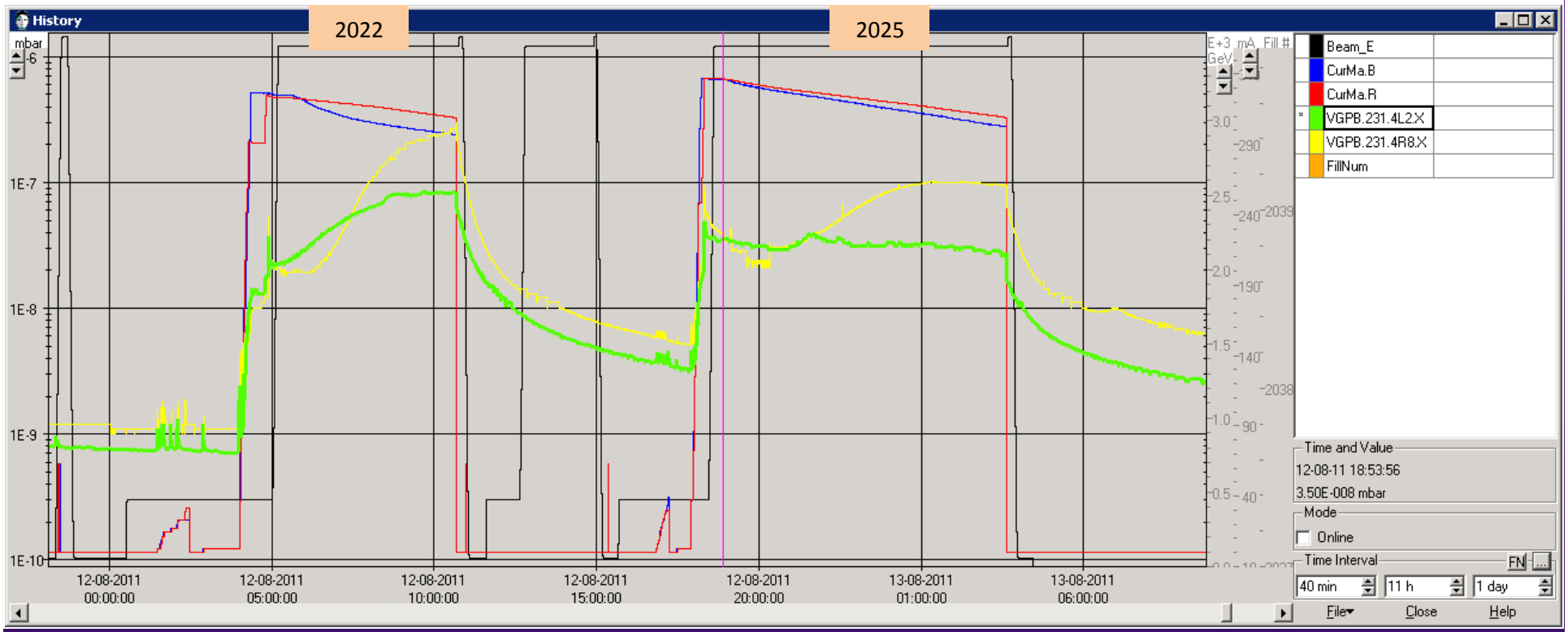
August 6th, 2011 (TDI. 4L2)



2011's beam-based observations (5/24)

Vincent Baglin

	mA	TDI2L	TD8R	ppb (x10^{10})
2022	325	↗	↗	13.0
2025	336	3 10^{-8}	↗	13.5
Long stop	4 days			



2011's beam-based observations (6/24)

Vincent Baglin

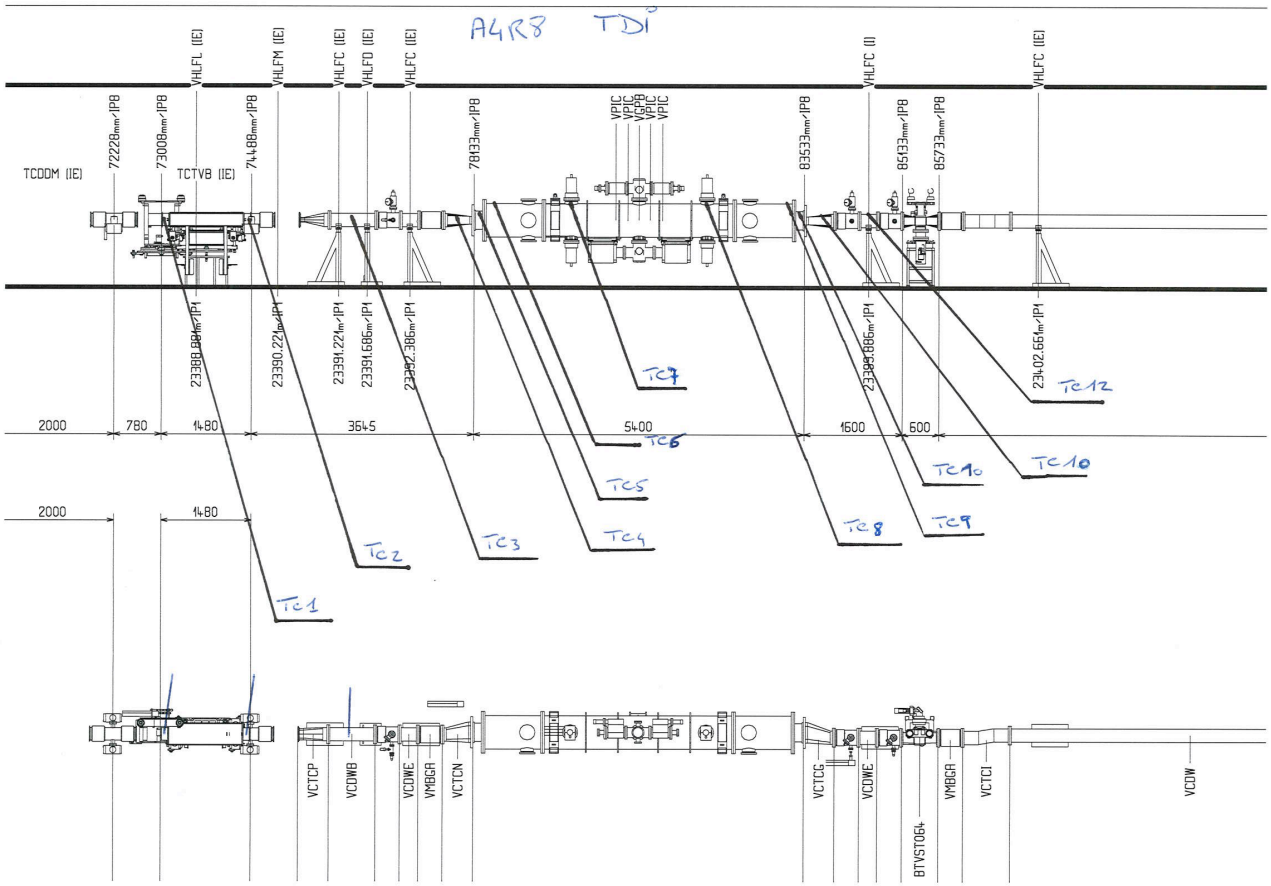
	mA	TDI2L	TD8R	ppb (x10^{10})
2028	301	1 10^{-8}	1.5 10^{-8}	12.1
2029	310	↗ ?	↗	12.4
2030	303	1 10^{-8}	1.5 10^{-8}	12.1
2031	305	1 10^{-8}	1.0 10^{-8}	12.2
2032	318	↗	↗	12.7

2011's beam-based observations (7/24)

TS4-2011

Vincent Baglin

- During the TS 4, wk 35, the TDI.8R and TCTVB.8R were equipped with thermocouples
- TC1 and TC2 are located on TCTVB.8R
- TC 4 and TC11 are located are located on TDI.8R transitions
- TC5,6,9 and 10 are located on TDI.8R extremity
- TC 7,8 are located at the centre of TDI.8R
- TC3 and TC12 are located at reference vacuum chambers NEG coated.
- Pressure is measured at TDI by VGPB.231.4R8.X



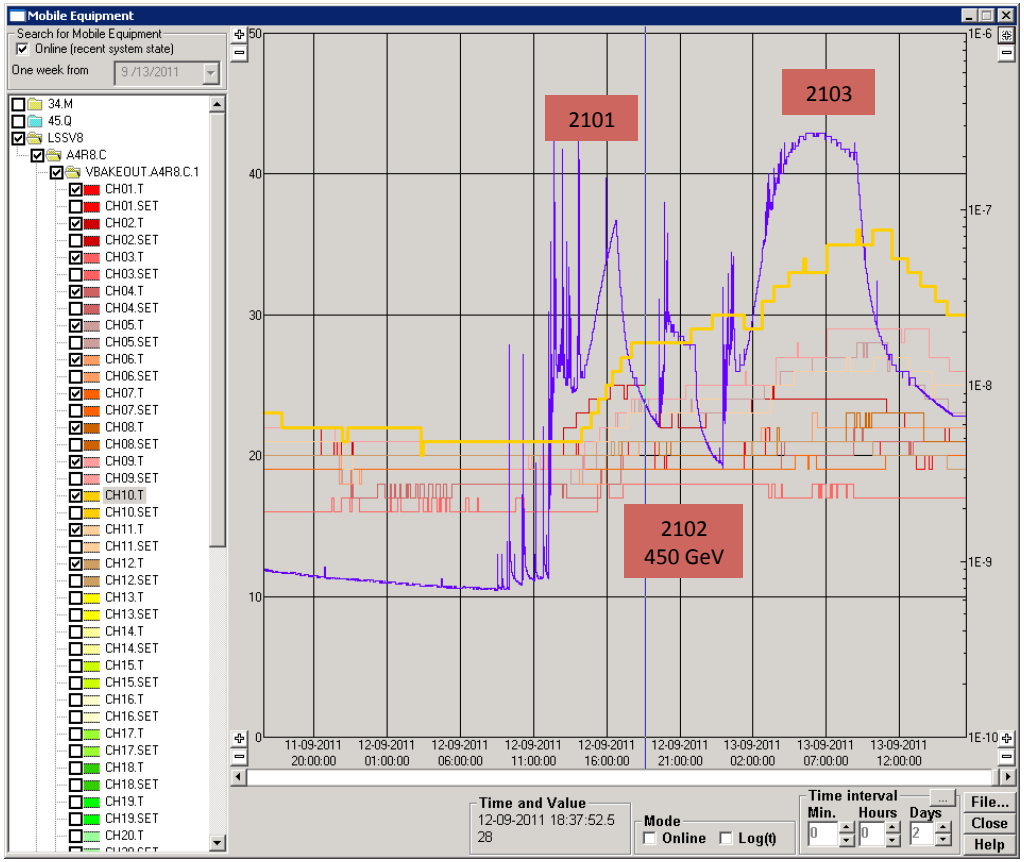
2011's beam-based observations (8/24)

"Nominal" fills

Vincent Baglin

- Temperature increased 1h30 and 45 min after machine full for fills 2101 and 2103 respectively.
- For fill 2103, pressure started to decrease again after having increased.
- TC10 reached 36 deg
- TC9 reached 29 deg
- TC5 reached 27 deg

Fill	2101	2102	2103
Nb	1380	1380	1380
I (mA)	330	334	332
Ppb (x1E11)	1.33	1.34	1.33

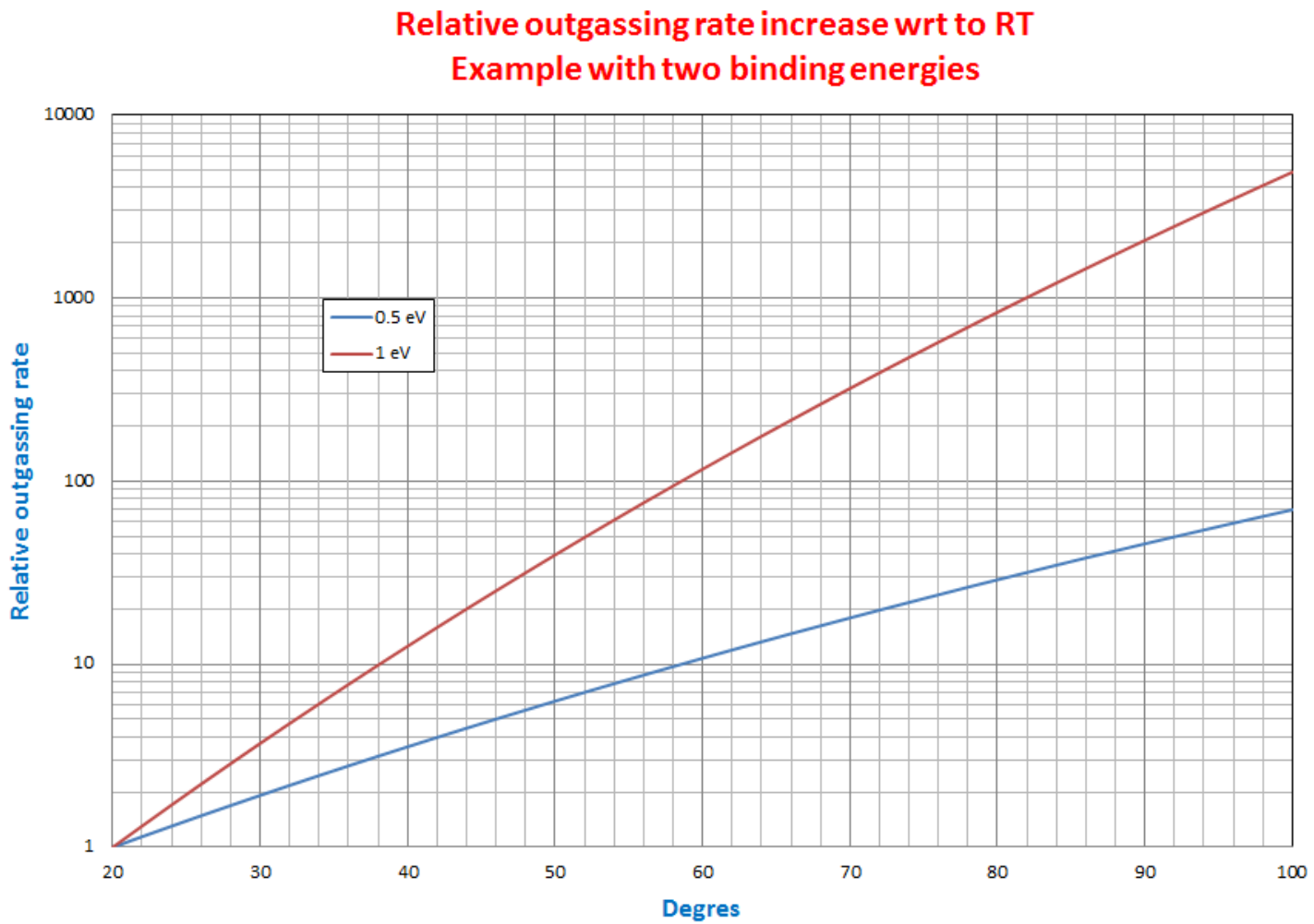


TC	deg	Delta	What ?
1	21	3	TCTVB
2	24	4	TCTVB
4	21	3	VCT @TDI
11	26	8	VCT@ TDI
5	28	10	TDI extremity
10	36	17	TDI extremity
6	22	3	TDI extremity
9	29	10	TDI extremity
7	19	0	TDI centre
8	22	3	TDI centre
3	17	1	Reference
12	21	2	Reference

Effect on outgassing rate

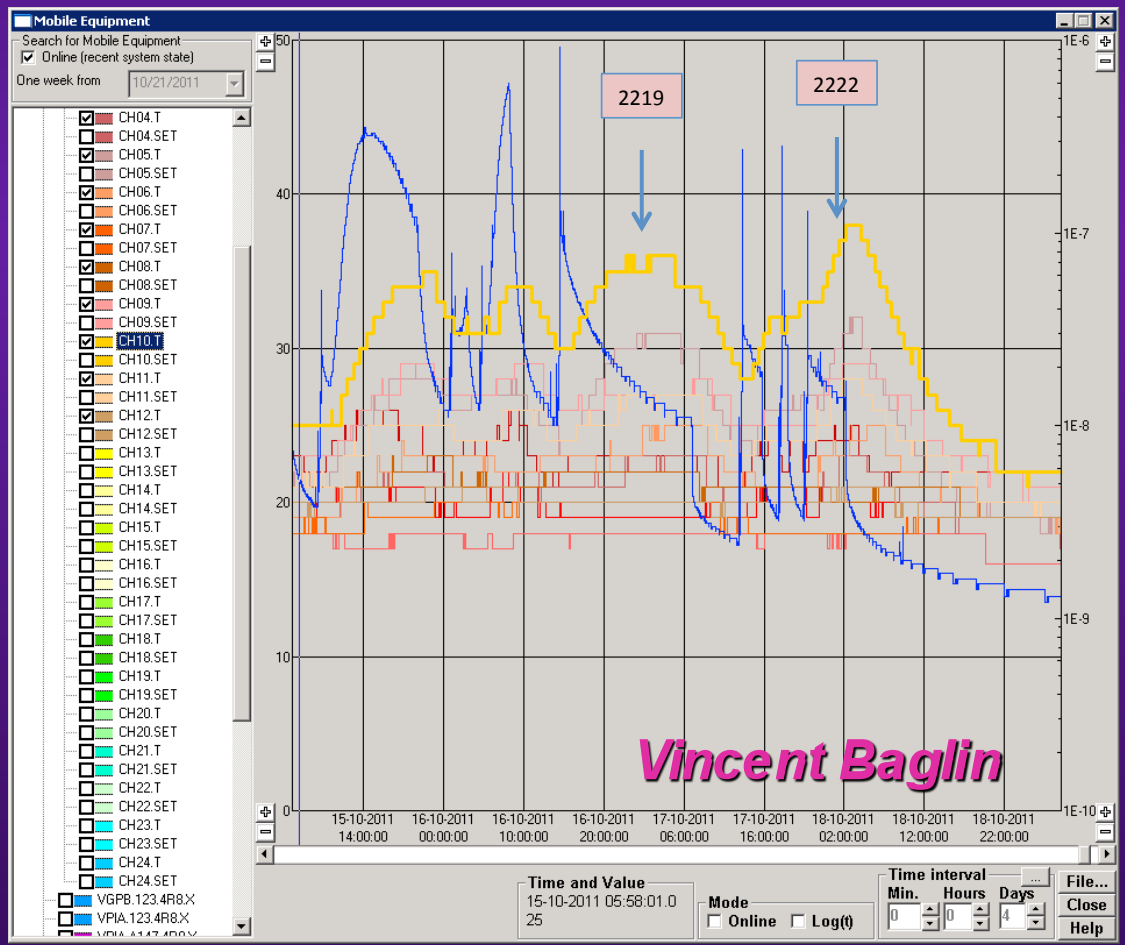
Vincent Baglin

• A temperature increase of ~ 50 degrees increase the outgassing rate by one order of magnitude



2011's beam-based observations (10/24)

- **Since fill # 2219 (16/10) the TDI ½ gap was increased from 22 mm to 55 mm (parking position)**
  - **Pressure => Remains in the few 1E-8 mbar range**
  - **BUT, temperature increase remains**



2011's beam-based observations (11/24)

- **Summary from TDI meeting organized by BrennanG on 24/08/11:**
  - After the 2 erratics with 144b deposited on P2 TDI, see similar behaviour – pressure does not decrease through fill, rather increasing to a peak about 2 h after ramping, before decreasing again. Reaching several e-8 mbar and above.
  - The observed pressure rise would need something (BN blocks?) to heat up to 50-100C, for this level of outgassing
  - Past prediction: ~ 200 W per TDI from resistive wall, with gaps closed to ~ ±8 sigma (±5 mm). Trapped modes initially gave 3-5 kW in transitions at extremities => New transition designs and RF fingers to the jaw supports to reduce the trapped modes
  - Water cooling present on the Al frame holding the blocks – but clamped, not brazed. Capacity 20 kW – should know how much cooling this gives at block surfaces
  - Heat transfer from blocks to cooling could maybe be tested in lab by pumping hot water through cooling channels and checking block temperature rise with thermal imaging

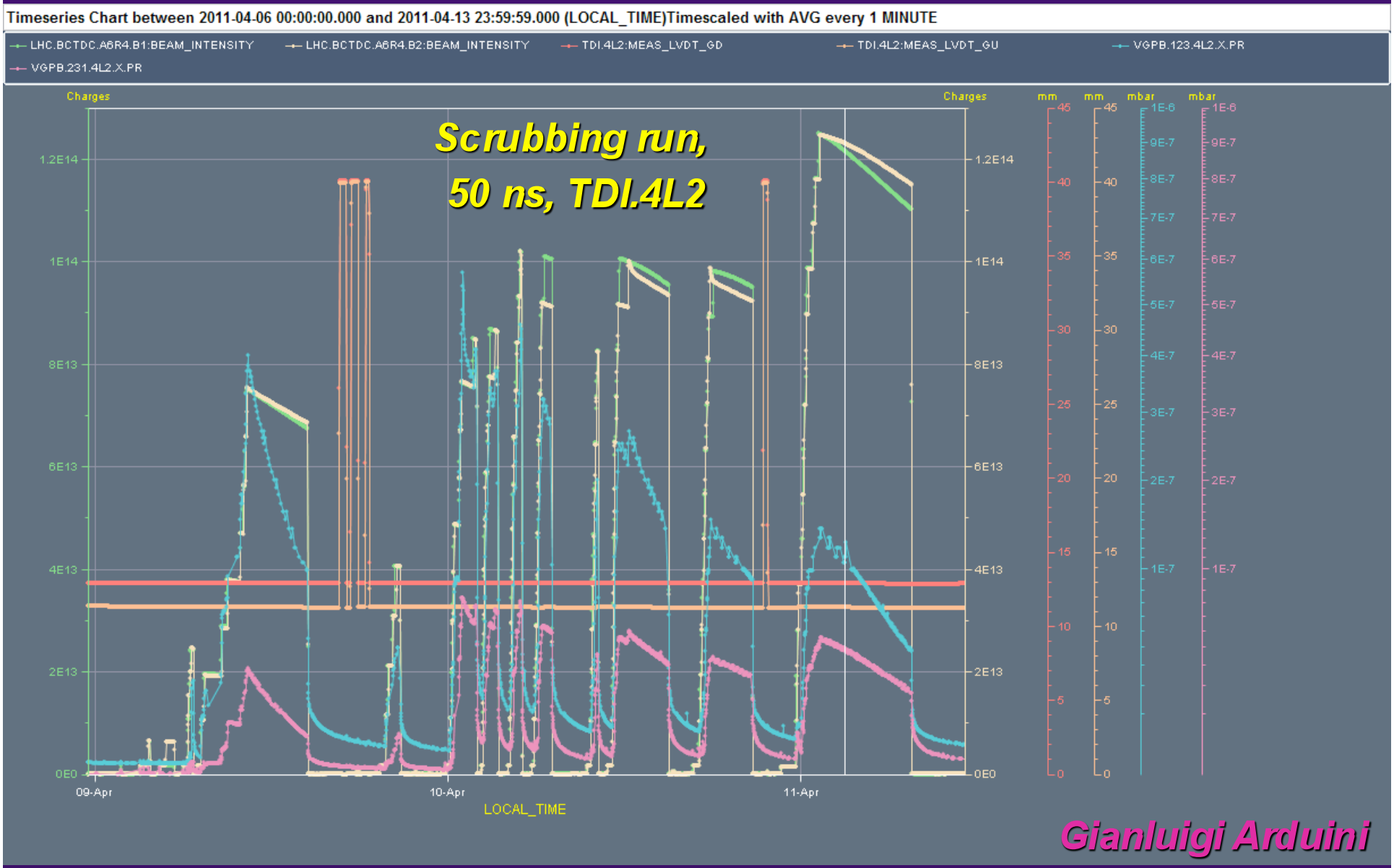
2011's beam-based observations (12/24)

- Redo trapped modes simulations with the real 3D model (which had to be done first) => Alexej Grudiev and Benoit Salvant

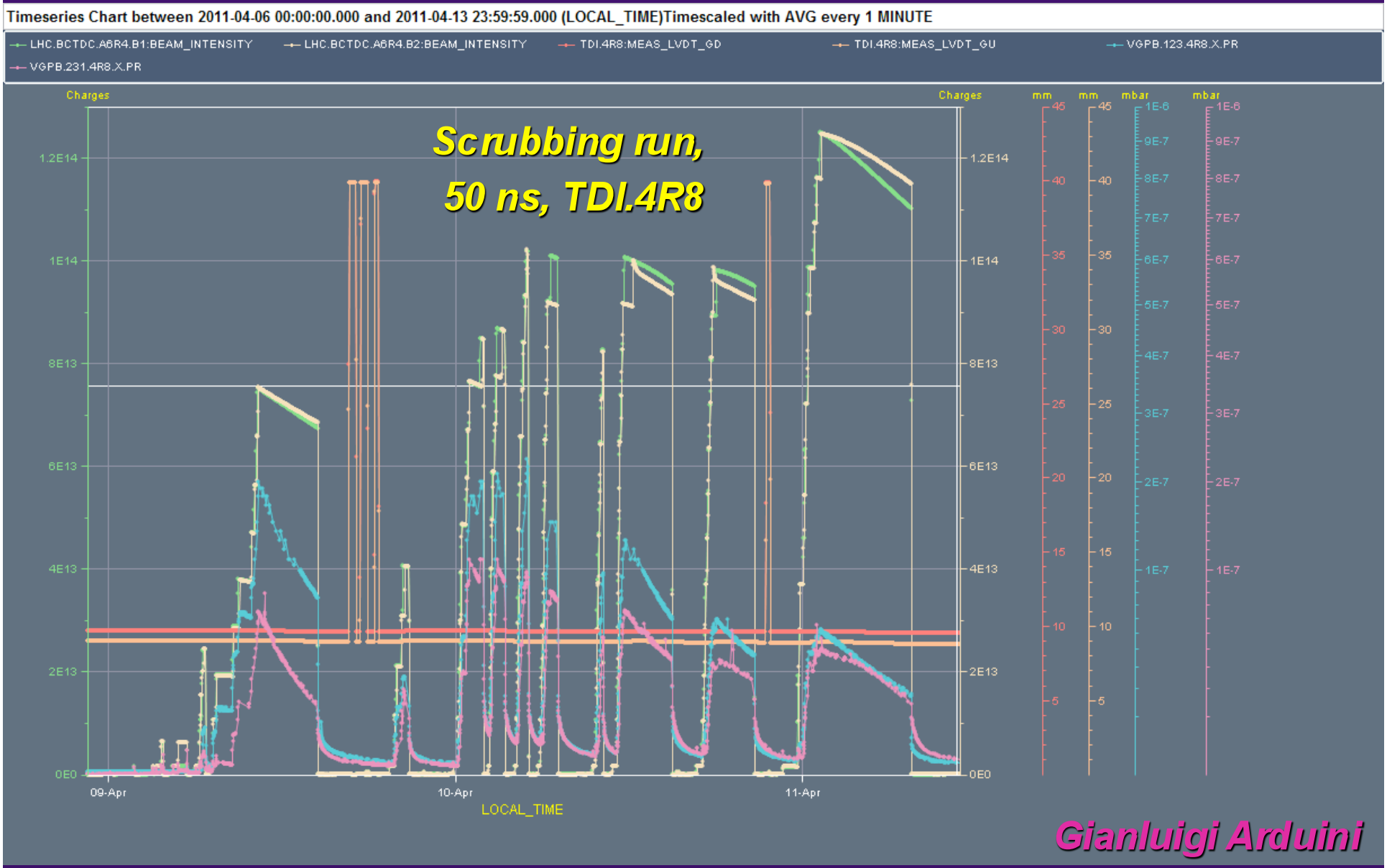
2011's beam-based observations (13/24)

- **Other measurements made during the 50 ns and 25 ns scrubbing runs:**
  - **50 ns (April 2011):**
    - **Maximum of 1020 bunches (1.2E11 p/bunch) injected. The gap of the TDI was kept at injection settings (~ 12 mm) for the whole period when the beam was circulating to guarantee injection protection**
    - **Pressure rise => Decreasing with time in spite of the increasing intensity (only conditioning?)**
  - **25 ns:**
    - **Up to 1020 b per beam on 14/10/11**
    - **Up to 2100 b on B1 and 1020 on B2 on 25/10/11**

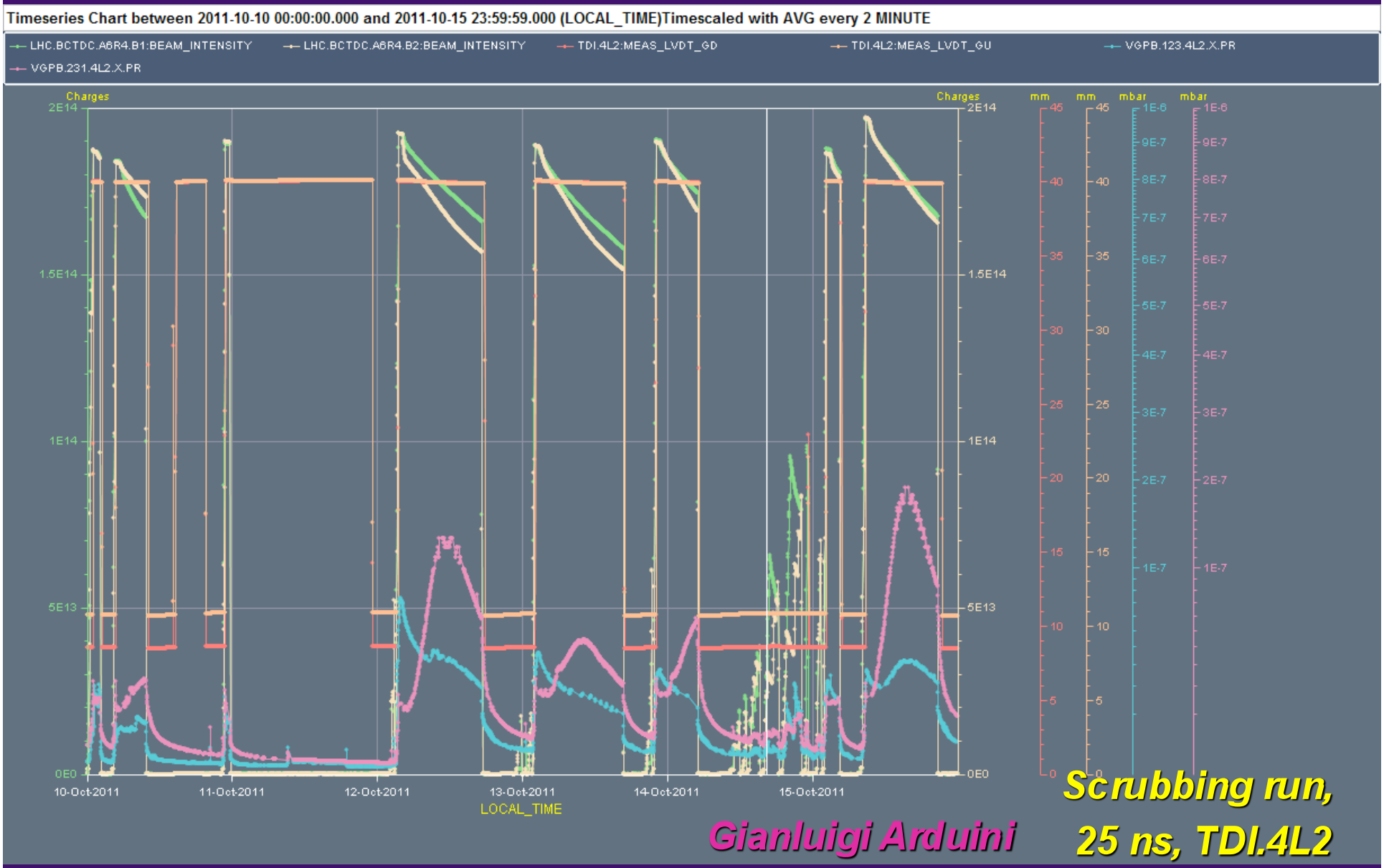
2011's beam-based observations (14/24)



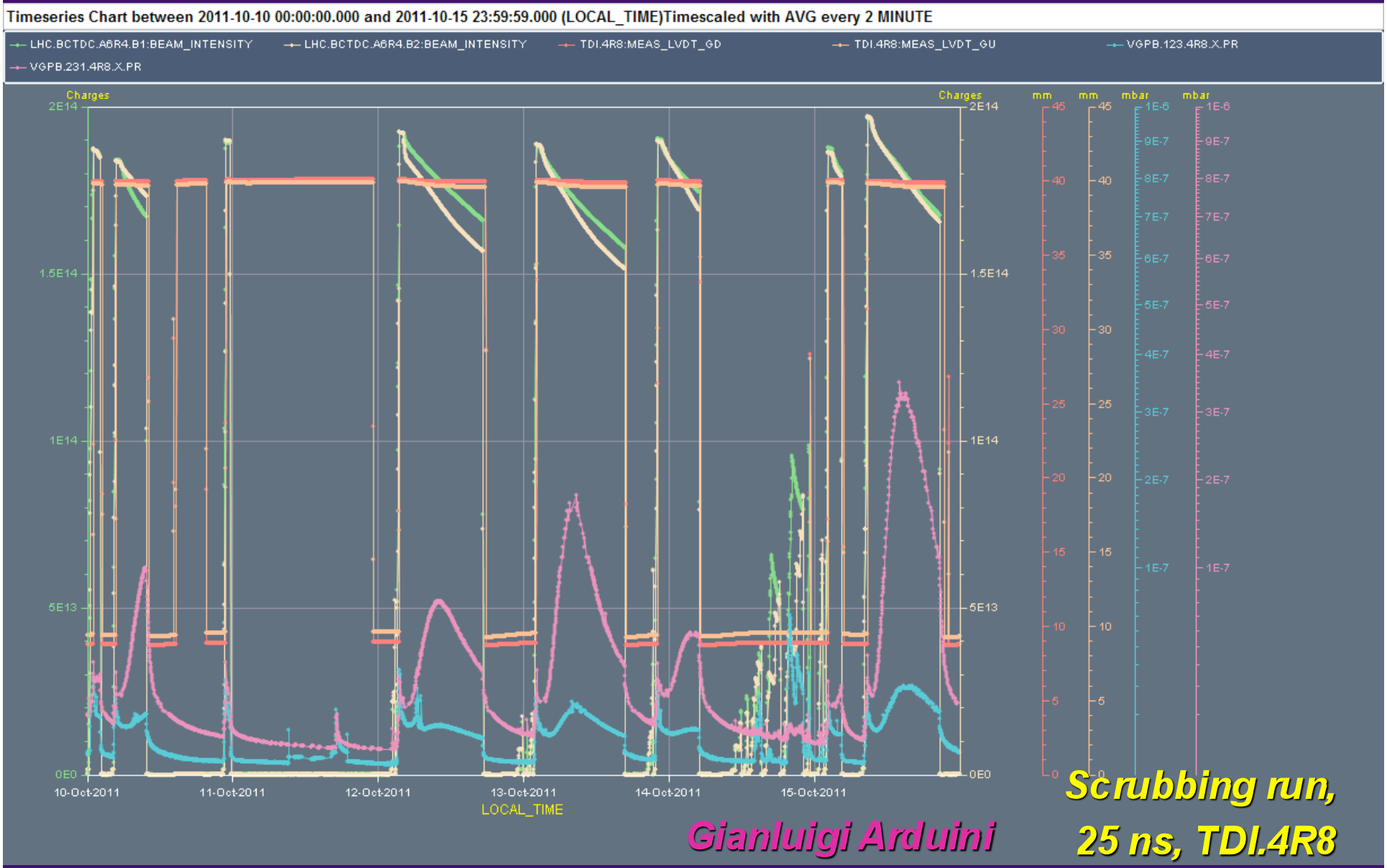
2011's beam-based observations (15/24)



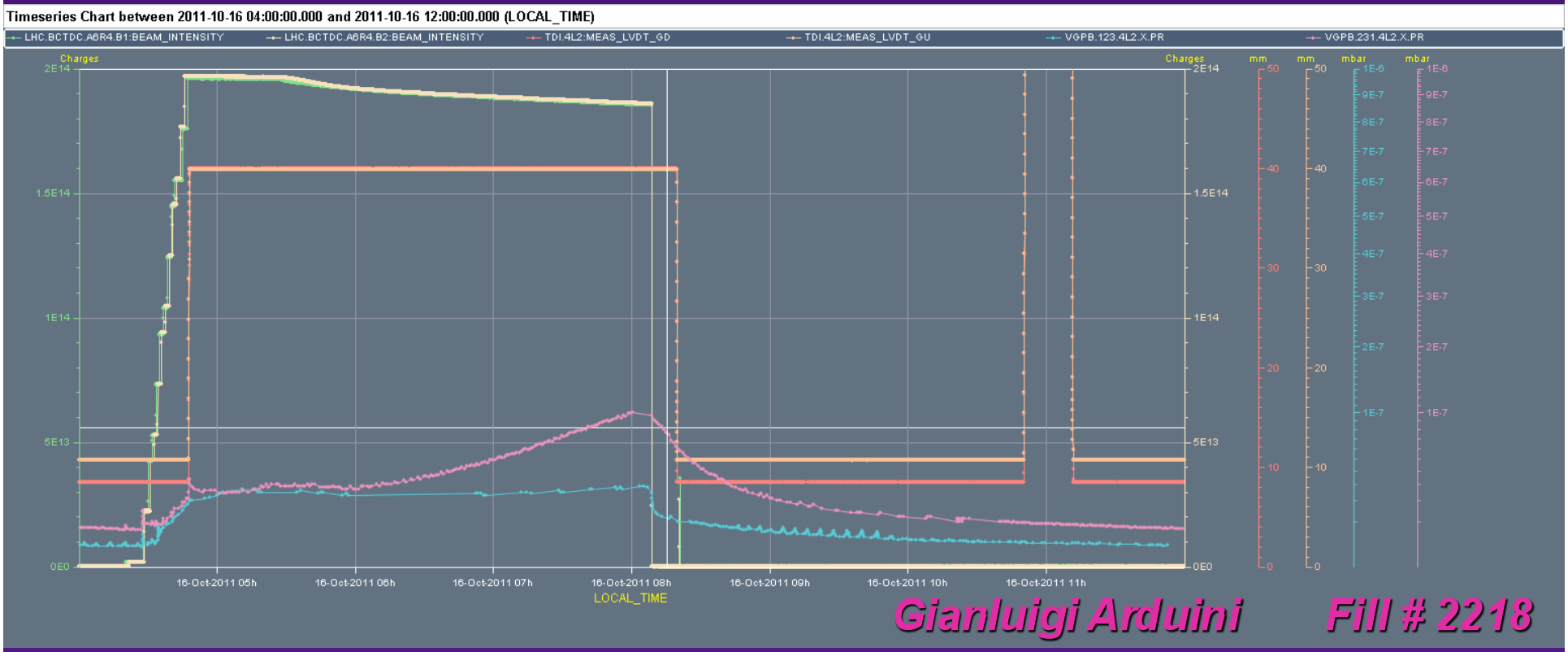
2011's beam-based observations (16/24)



2011's beam-based observations (17/24)



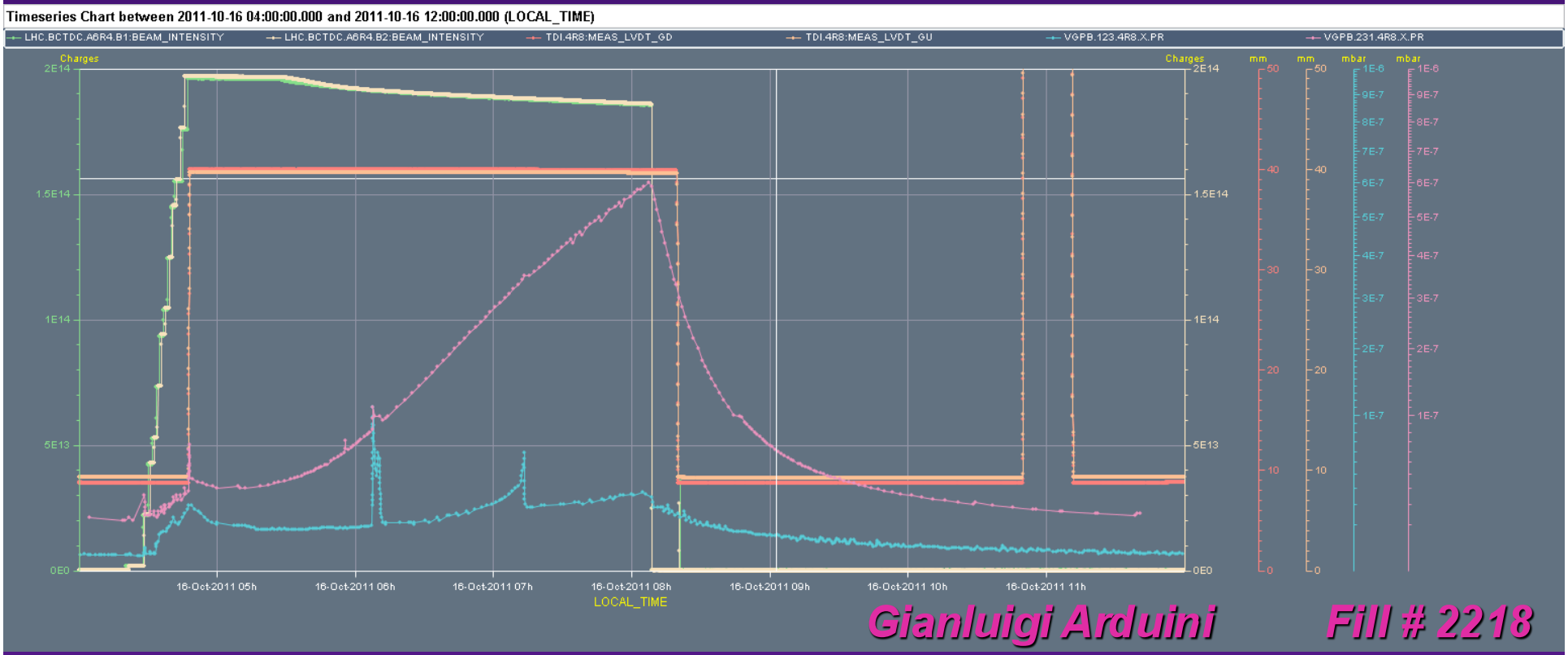
2011's beam-based observations (18/24)



Gianluigi Arduini *Fill # 2218*

Scrubbing run, 25 ns, TDI.4L2

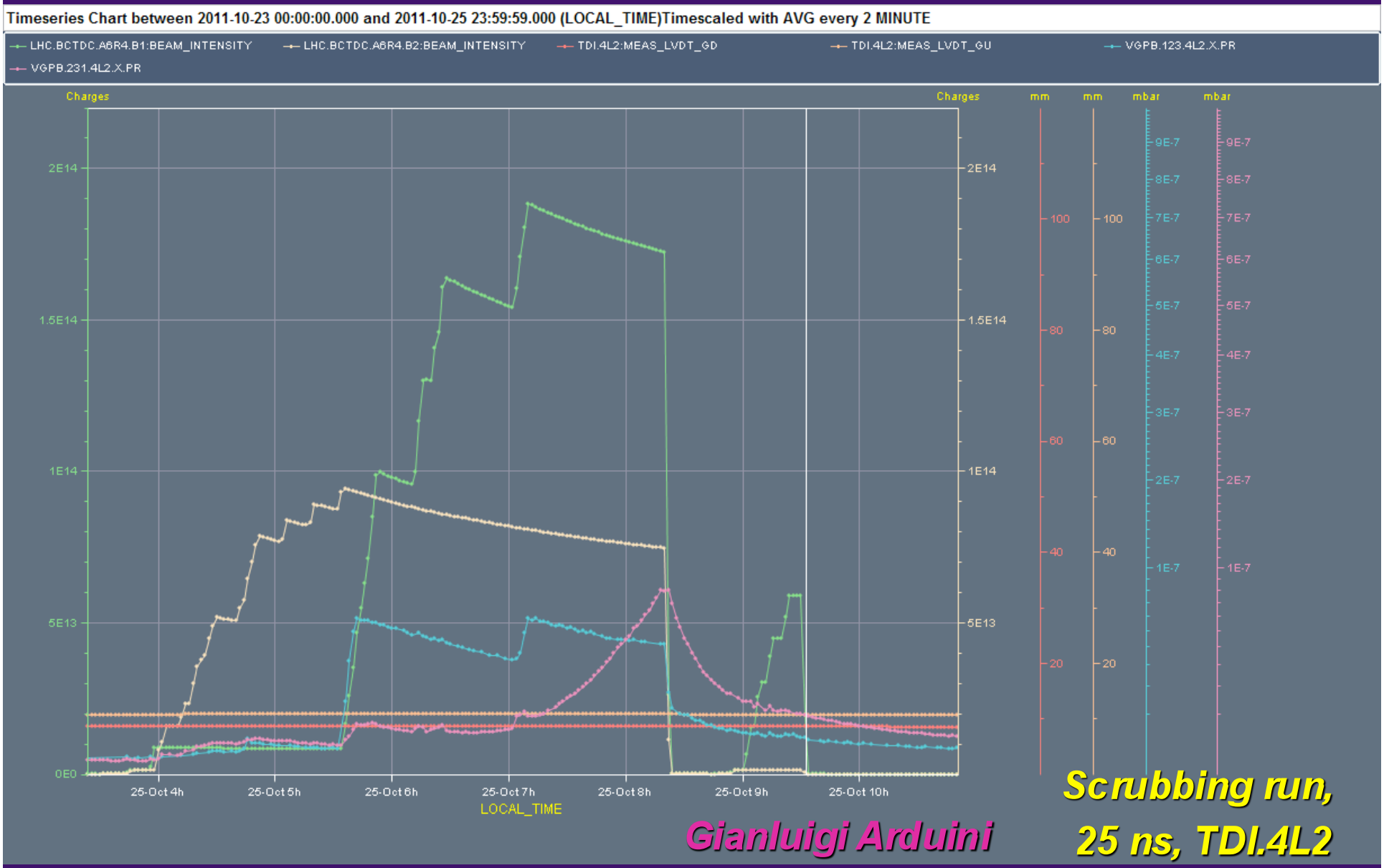
2011's beam-based observations (19/24)



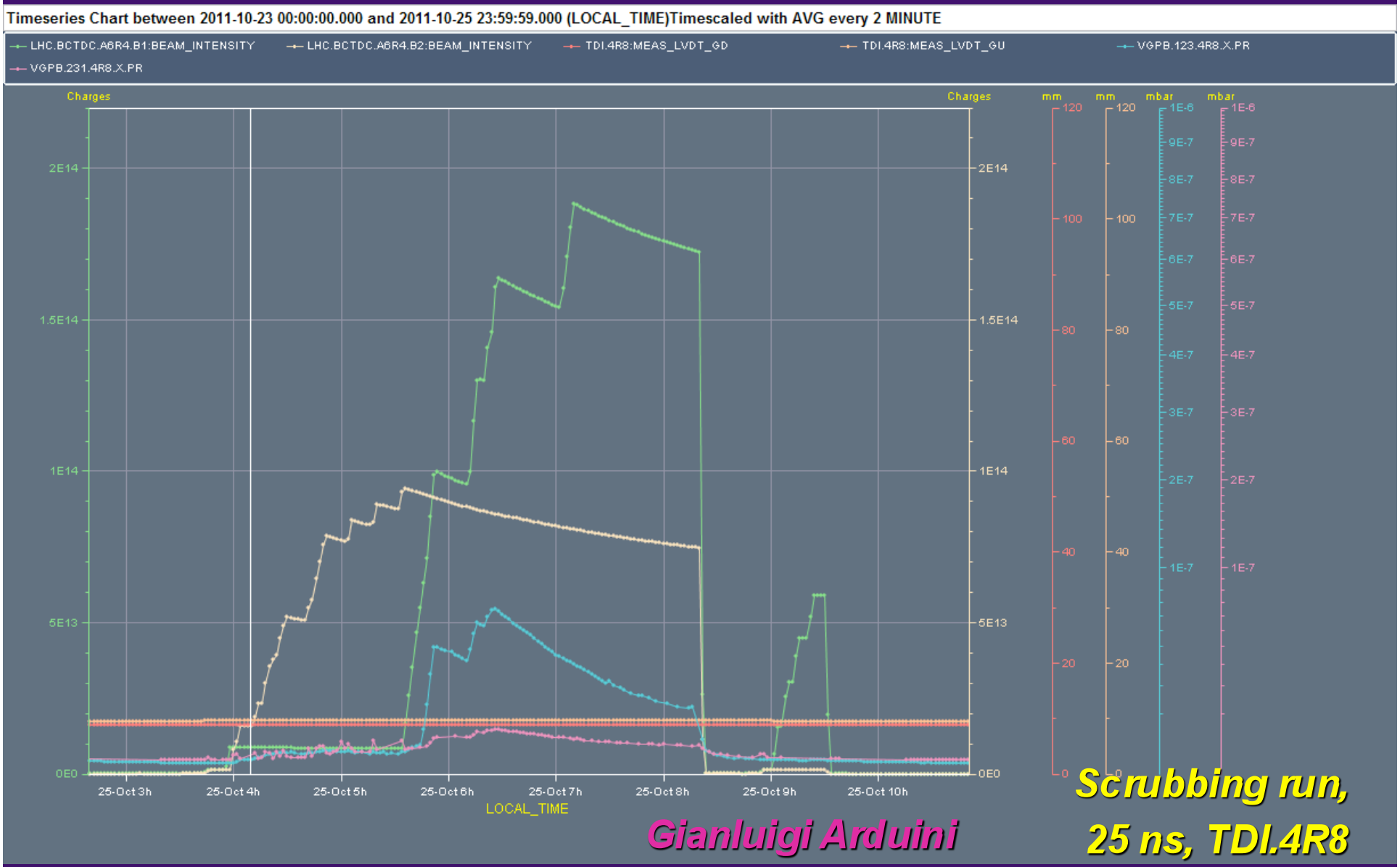
Gianluigi Arduini *Fill # 2218*

Scrubbing run, 25 ns, TDI.4R8

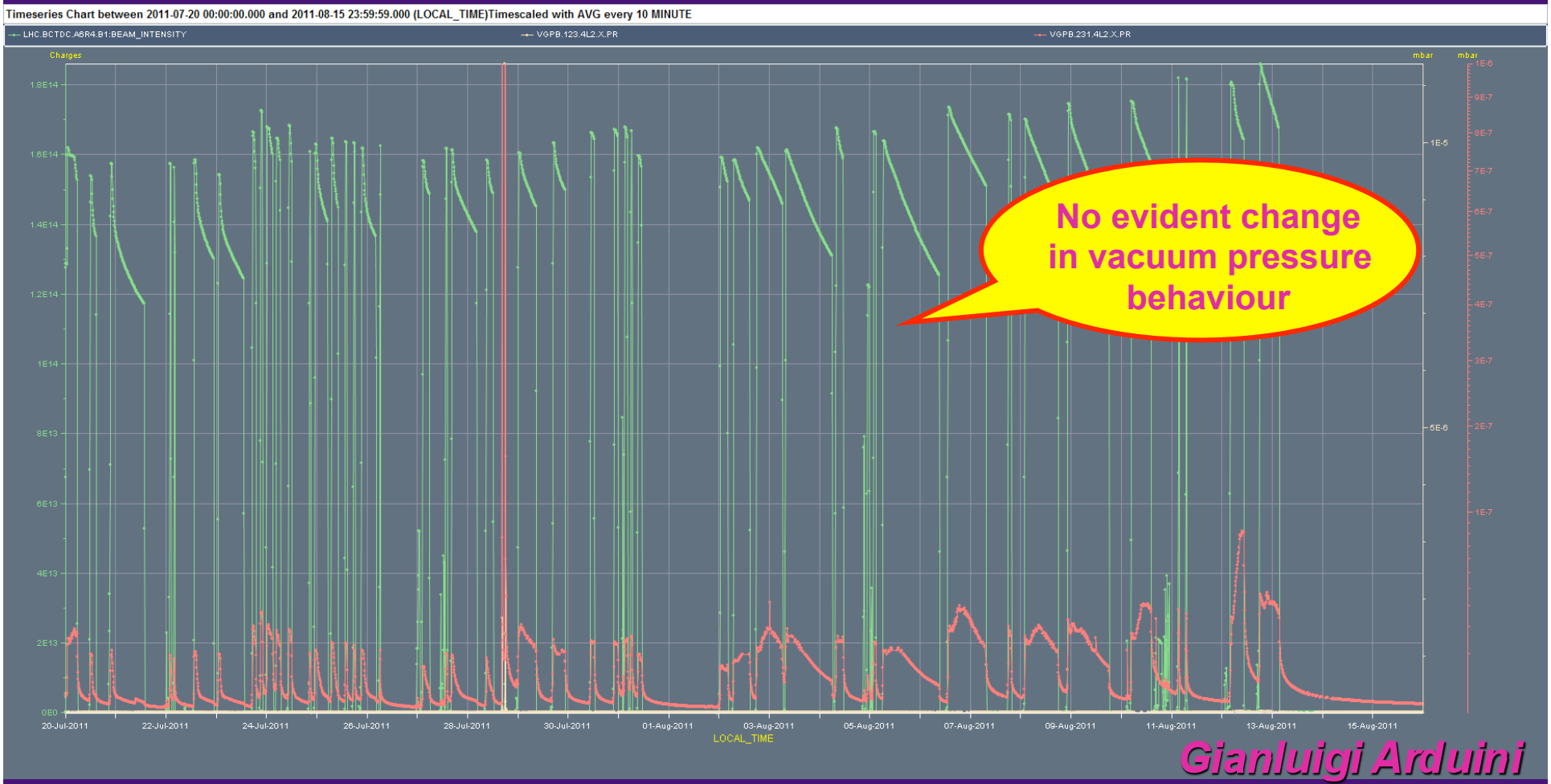
2011's beam-based observations (20/24)



2011's beam-based observations (21/24)

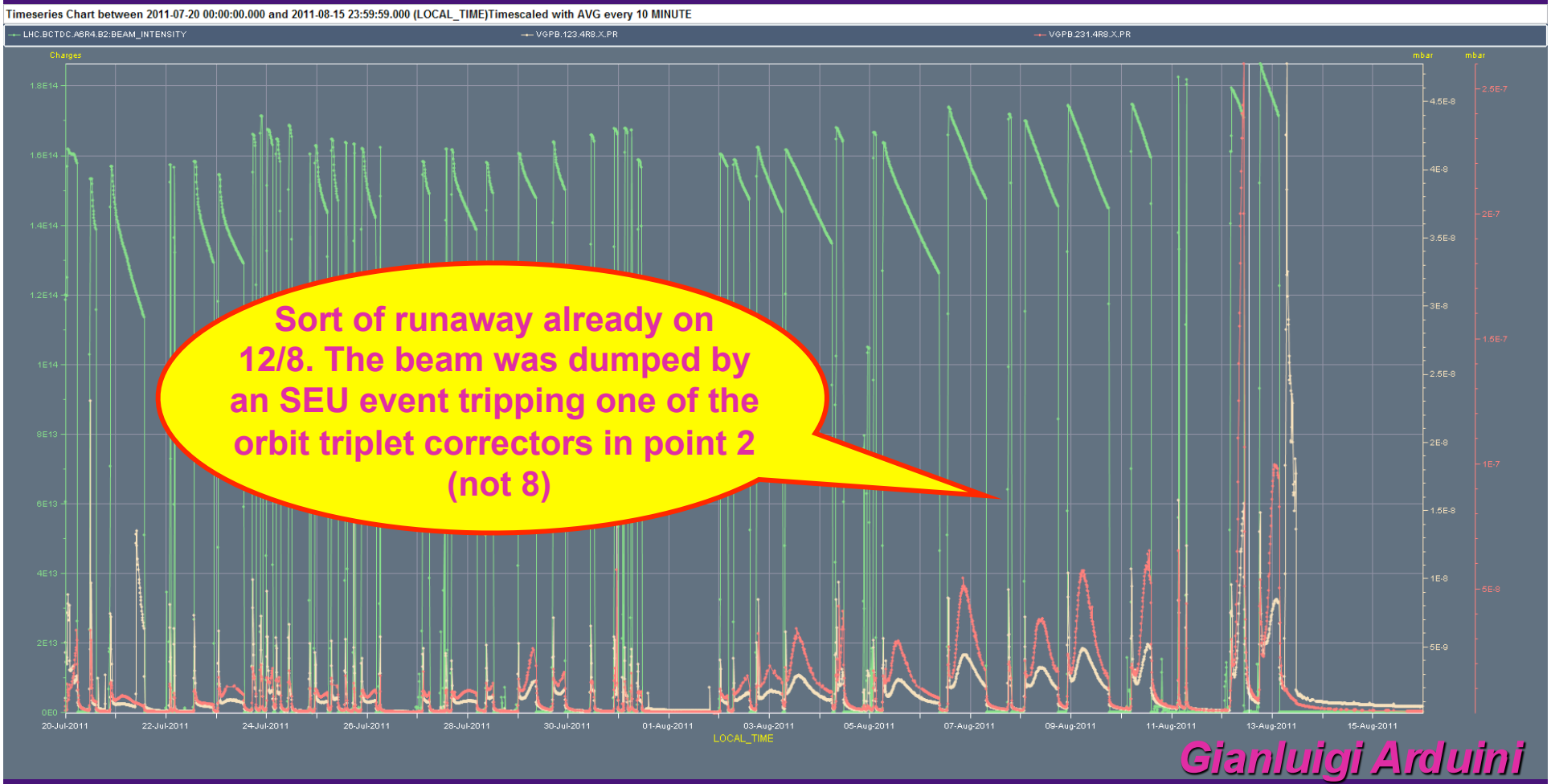


2011's beam-based observations (22/24)



TDI.4L2 before and after the beam impact of 144 bunches

2011's beam-based observations (23/24)

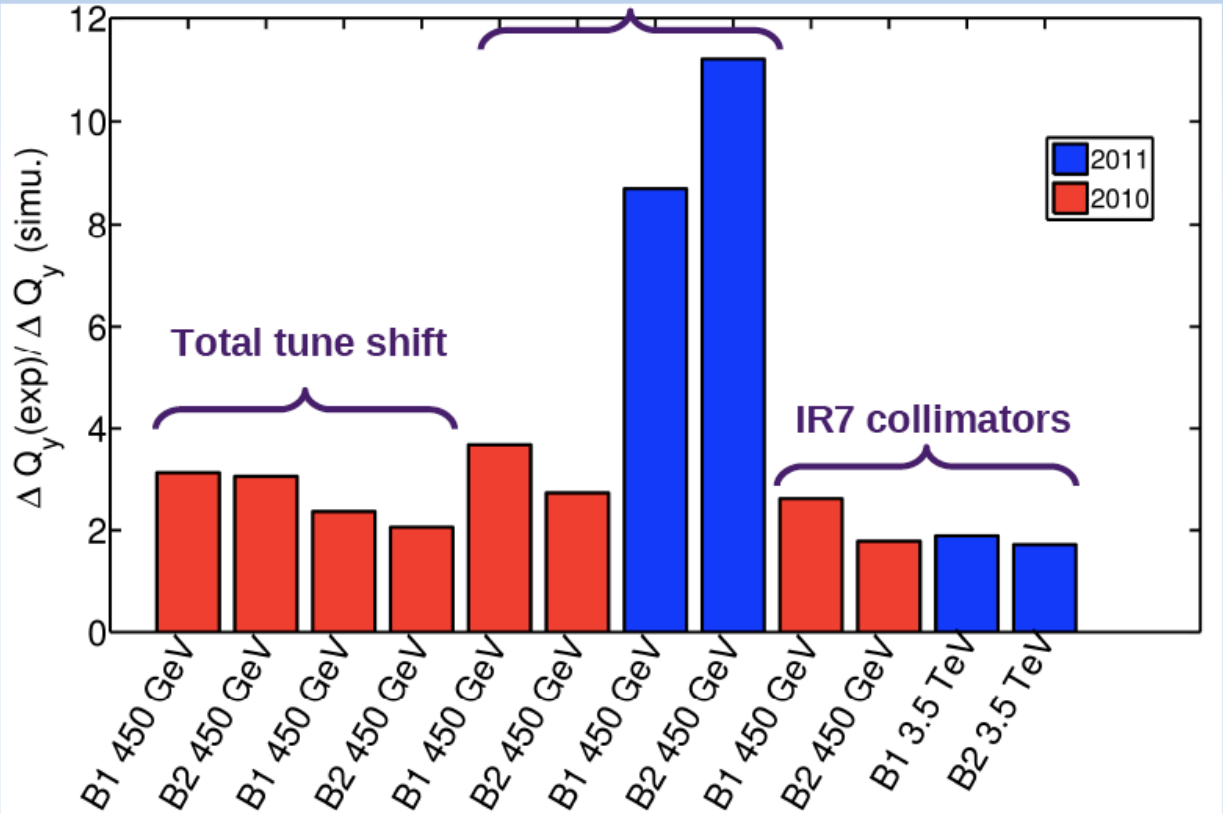


TDI.4R8 before and after the beam impact of 144 bunches

2011's beam-based observations (24/24)

Comparisons between beam-based measurements and impedance model

- Single-bunch: review of tune shifts measurements of the last two years → discrepancy factor between measurements and impedance model

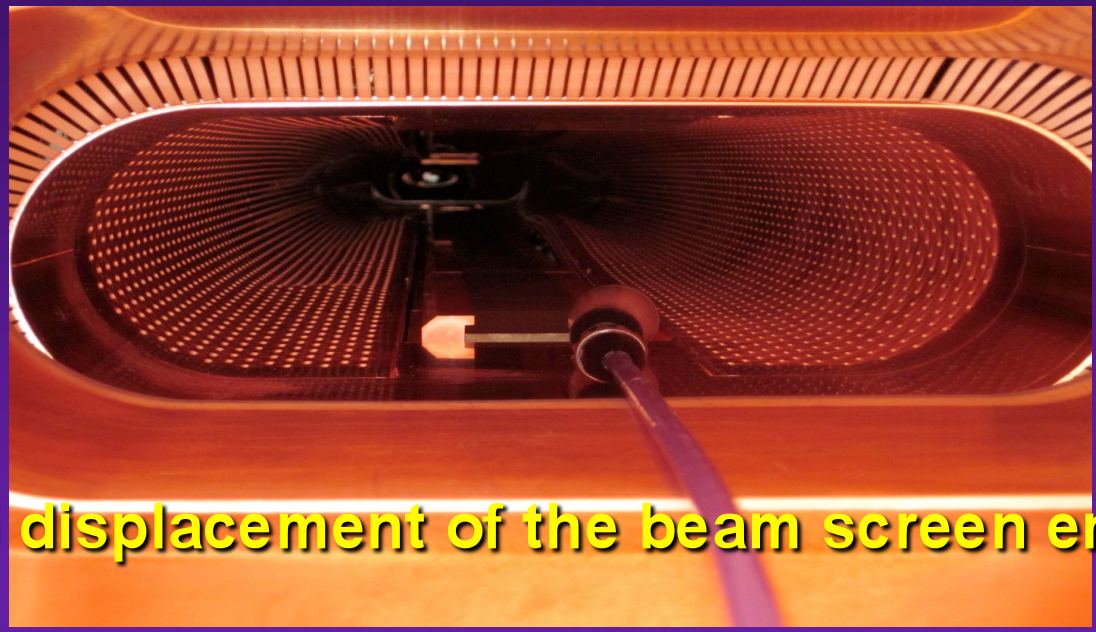


→ Total and graphite collimators tune shifts → factor ~2-3 (~2 at top energy),
→ For the TDI, higher discrepancy, and got worse during 2011.

Note: including the geometrical impedance of the TDI decreases the 2011 discrepancy to a factor ~3.

Nicolas Mounet

Winter stop's inspection of the 2 TDI (1/4)

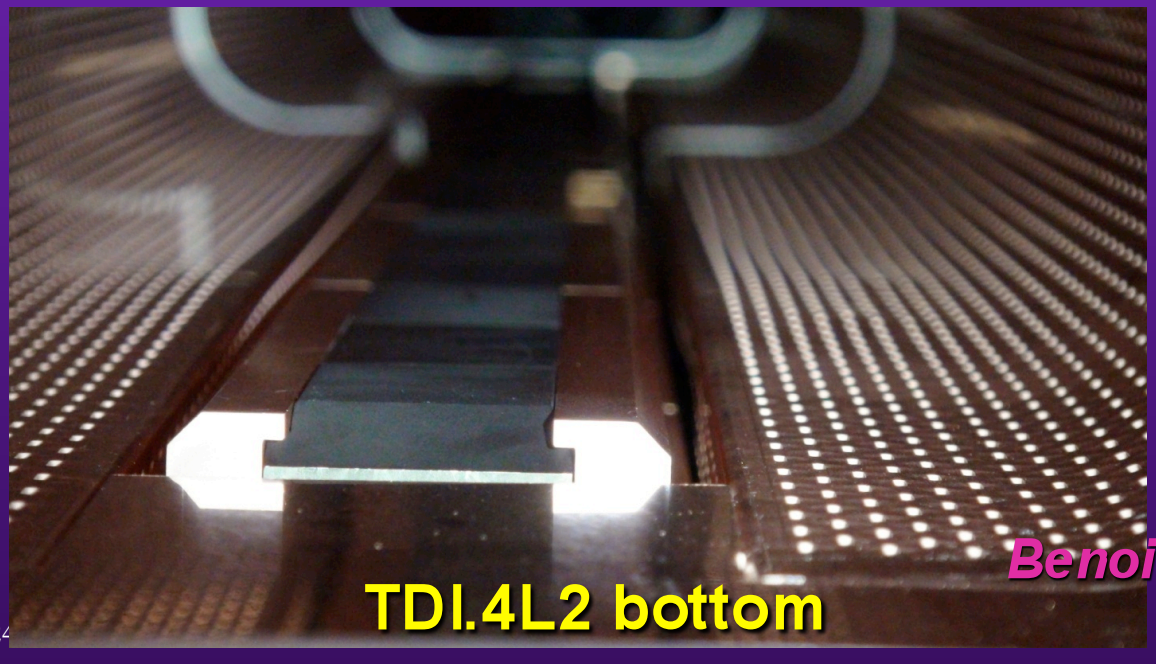


TDI8 overall displacement of the beam screen entrance

TDI2 beam screen total displacement towards the lower part

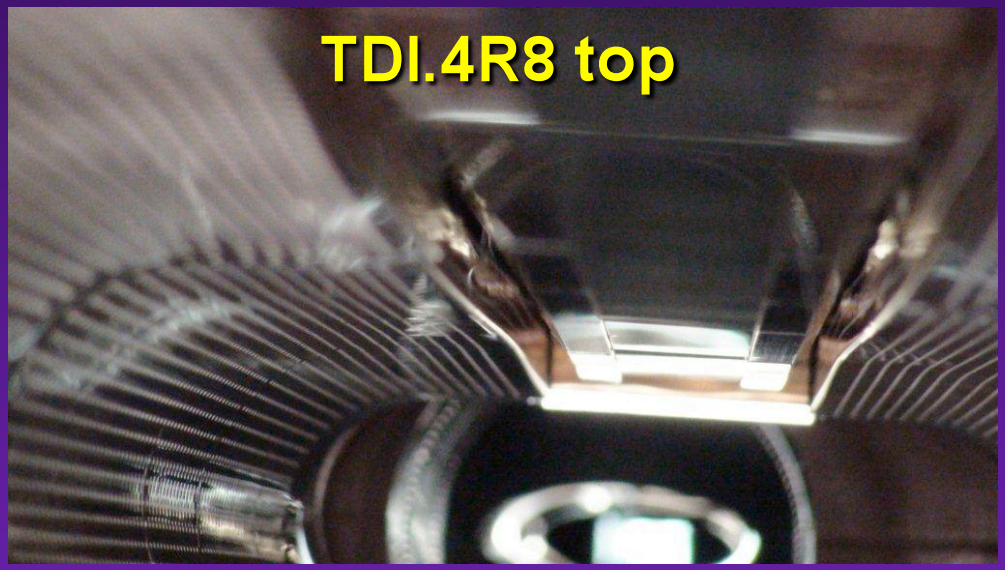
Benoit Salvant et al.

Winter stop's inspection of the 2 TDI (2/4)



Benoit Salvant et al.

Winter stop's inspection of the 2 TDI (3/4)



Benoit Salvant et al.

Winter stop's inspection of the 2 TDI (4/4)

- **Summary of observations (with also talk by RobertoL at last LMC):**
  - The beam screen was designed to be made of Copper coated non magnetic Stainless Steel but in reality it is made of copper and therefore it is softer
  - TDI.4R8 => Bump in the lower part of the beam screen of up to 38 mm at the level of the 3rd hBN block and 15 mm in the upper part (in LHC Design Report => In case of beam impact the 3rd block would suffer the largest temperature increase)
  - TDI.4L2 is also deformed but to a lesser extent
  - TDI design => Block would survive but not the beam screen
  - Design temperature for bake out = 300 deg C
  - Miguel Jimenez => It is not a Ti coating but a "flash of Ti metal" => Seems OK

Some questions to try and answer (1/7)

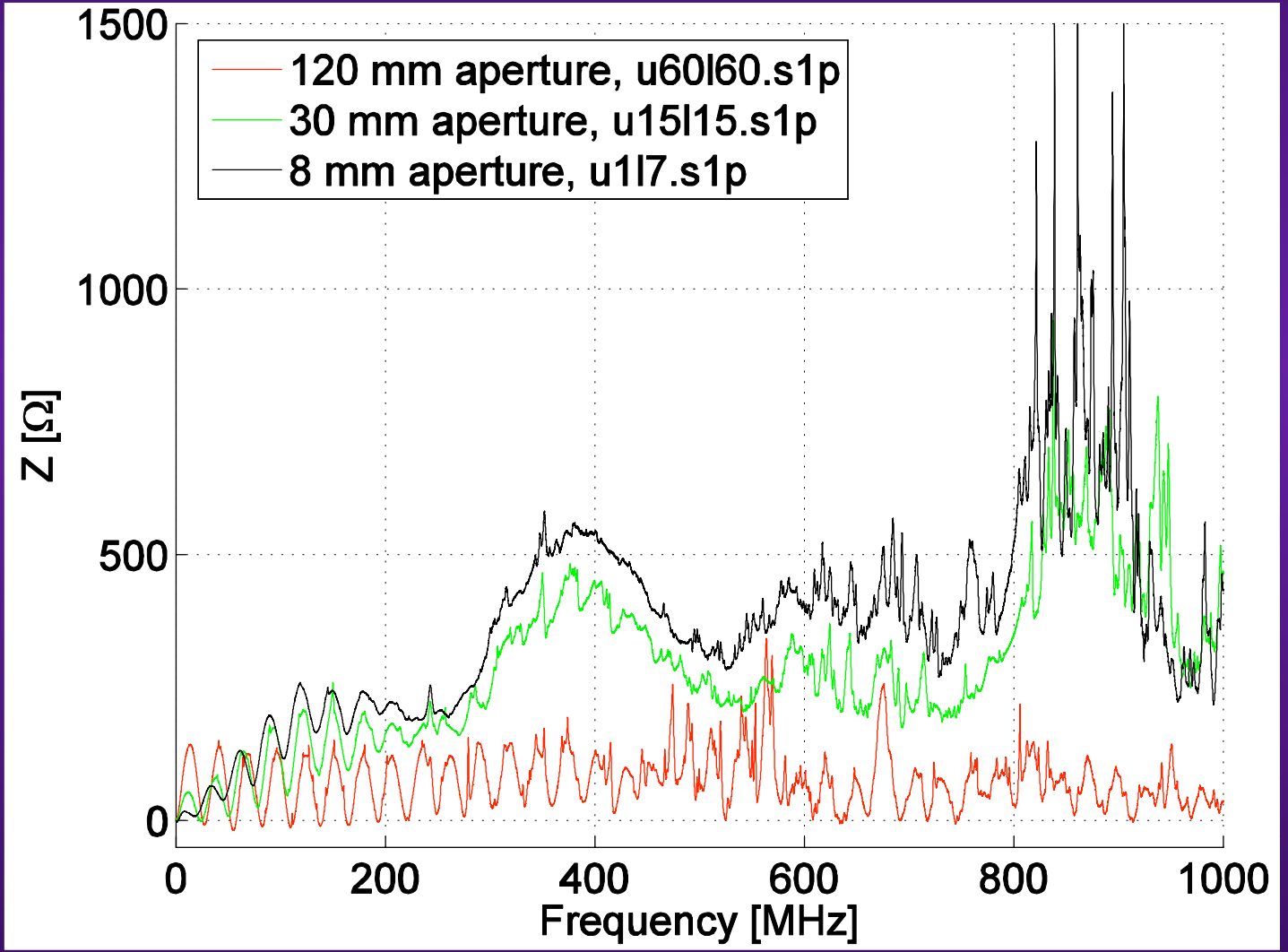
- **Possible origin of this (beam screen) deformation:**
  - **1) bake-out?**
  - **2) heating during a beam impact?**
  - **3) RF heating?**
  - **4) Mechanical movement? etc.**
- **No sign of deformation of the jaws has been noted => Are we sure?**

Some questions to try and answer (2/7)

- **Impedance calculations and RF heating => Elias, Alexey, Benoit…**
  - Theoretical estimates of the RW part => ~ 200 W (located in the hBN). It is inversely proportional to the gap. All this to be checked, but this is our current knowledge
  - For the trapped modes, it was assumed to be much smaller as normally the TDI was expected to be used for only ~ 20 min at injection and then it was in parking position
  - With smallest gap:
    - AlexeyG made some simulations in the past (with a previous design in 2005 without RF fingers) and found trapped modes in the transition region leading to few kW of power loss. There were also meas. from TomK and FritzC (see next slide)
    - Ferrite was installed at both end to damp transverse modes and not for the RF heating
    - AlexeyG is currently estimating the power loss with the real 3D model (which was done in fall 2011) => Main driver: injected and/or circulating?
  - Dependence of power loss with intensity => It is linear for the RW and quadratic for the trapped modes with Q > few 100s (with respect to number of bunches. It is always quadratic vs. the bunch intensity)

Some questions to try and answer (3/7)

- Some measurements made in the past by FritzC and TomK on a previous version of the TDI



Some questions to try and answer (4/7)

- The behaviour of TDI2 could indicate some heating effect after the injection of 2100 bunches with 25 ns, as the pressure at the TDI is increasing with time in spite of the reduction of the intensity of B1 (no such behaviour is observed for TDI8 which is the most strongly damaged) => Can the observed evolution of the vacuum during the scrubbing run on TDI2 and during the fill 2218 on TDI2 and 8 be compatible with an increase in temperature of the beam screen? The beam screen should have a low thermal inertia, differently from the jaws. Is this due to a direct heat load on the beam screen or via the jaw? ⇒ Vincent, Miguel

Some questions to try and answer (5/7)

- Do we have the possibility of analyze the stable phase change when we had 1380 circulating bunches with maximum intensity. This could give a measurement of the deposited power and provide a comparison with the simulations ⇒ Juan, Elena
- Was the cooling active in 2011? How does the above heat loads translate in terms of temperature of the beam screen and jaws when the cooling of the jaws is active and when it is not active? => Oliver + ?
- What is the time constant of the heating when the above powers are deposited steadily on the jaws and beam screens? => ?
- How does this temperature compares with the temperature reached by the beam screen during the bake out? Was the cooling off during this period? ⇒ Miguel, Vincent, Oliver

Some questions to try and answer (6/7)

- What was the pressure evolution during the last bake-out? ⇒ Miguel, Vincent
- Can we determine the expected vacuum pressure evolution as a function of the temperature? ⇒ Vincent, Miguel (slide 19?)
- How the temperature measured at the transitions relates to the temperature of the beam screens?
- Others?

Some questions to try and answer (7/7)

- **Possible actions:**
  - Do we have the possibility of installing temperature gauges on the beam screen? ⇒ Oliver
  - Keep the monitoring of the transitions ⇒ Vincent
  - Action towards safe operation:
    - How long can we stay at injection with the quoted heat loads?
    - Is lengthening of the bunches right at injection helpful?
    - Can we afford a scrubbing run? Is it sufficient to move out the TDIs once we stay at constant intensity for a given time?
    - Do we have to put an interlock on cooling of the TDI?
    - In any case => Try and fully retracted it whenever possible
    - ?

Many thanks to

All the people working on the LHC TDI: B. Henrist, G. Cattenoz, E. Page, V. Baglin, O. Aberle, F. Loprette, R. Losito, M. Donze, B. Goddard, C. Bracco, B. Salvant, G. Arduini, A. Grudiev, F. Caspers etc.