MKI Cool

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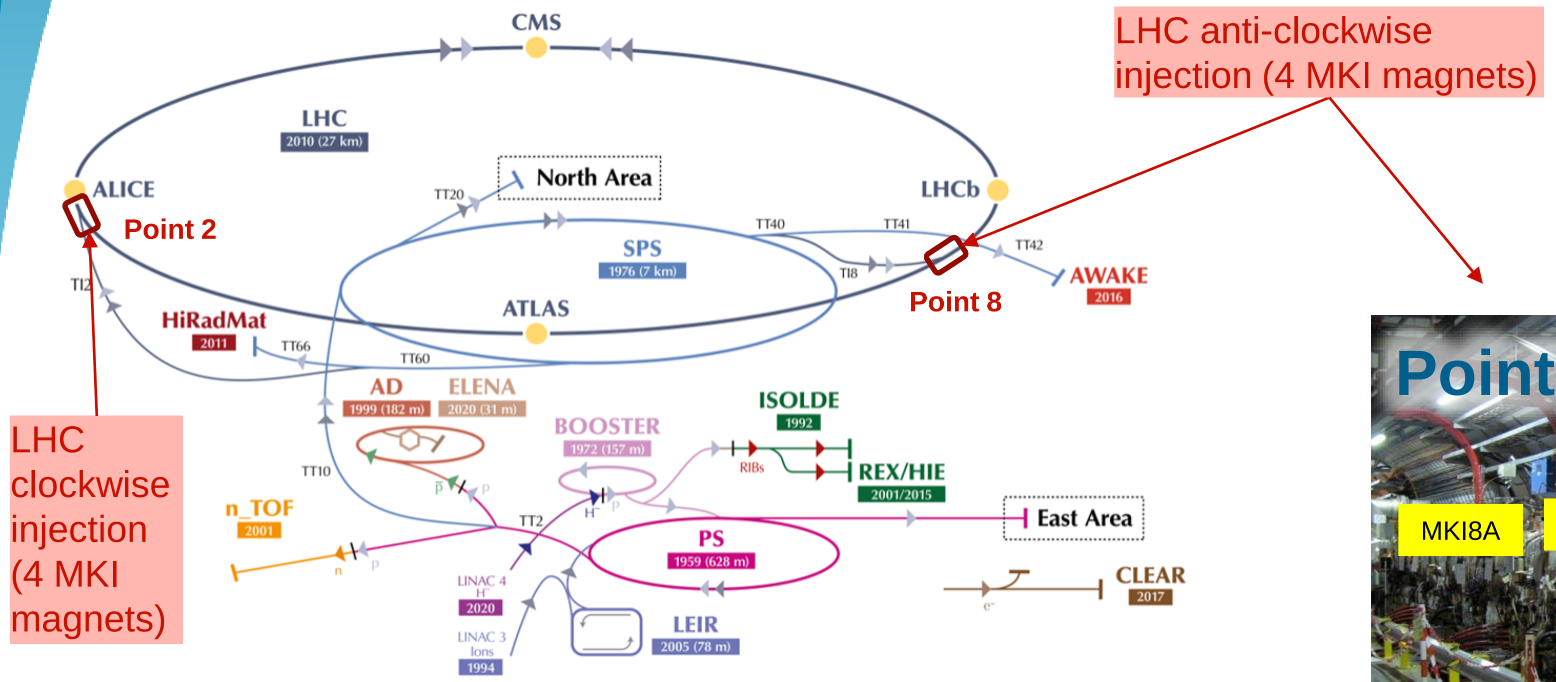
Uppsala – September 19th to 22nd 2022

Outline

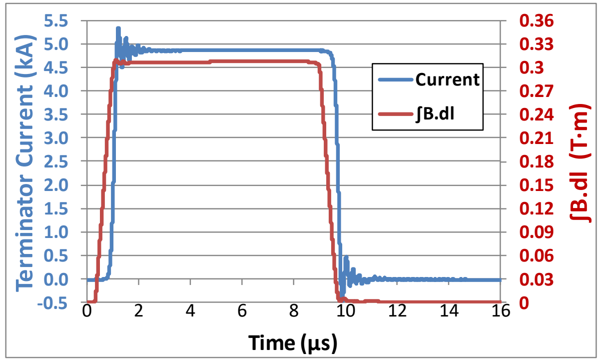
1. Context
   - MKI purpose and design
   - Cr_2O_3 coating
   - Damping element and MKI cool
2. Issues – now solved
   - HV breakdowns
   - Unsuccessful conditioning
3. Issue – understood
   - Mis-manufactured alumina tubes
   - Present work
4. Status of first MKI cool to be installed in LHC
5. Conclusions

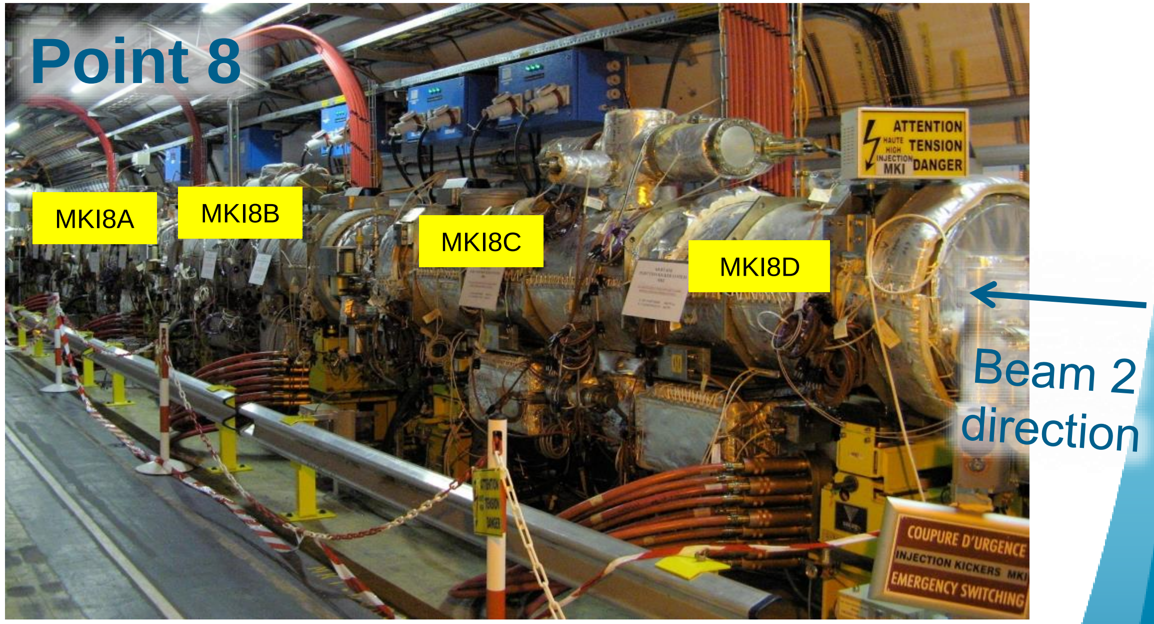
1. Context

MKI: Injector kicker magnets for the LHC



Typical MKI pulse





Planning of MKI cool installation

1 MKI cool (proto)	2 MKI cools	2 MKI cools	2 MKI cools	1 MKI Cool
YETS 22/23	YETS 23/24	YETS 24/25	Start of LS3	During LS3

1. Context

Screen conductors inside MKI

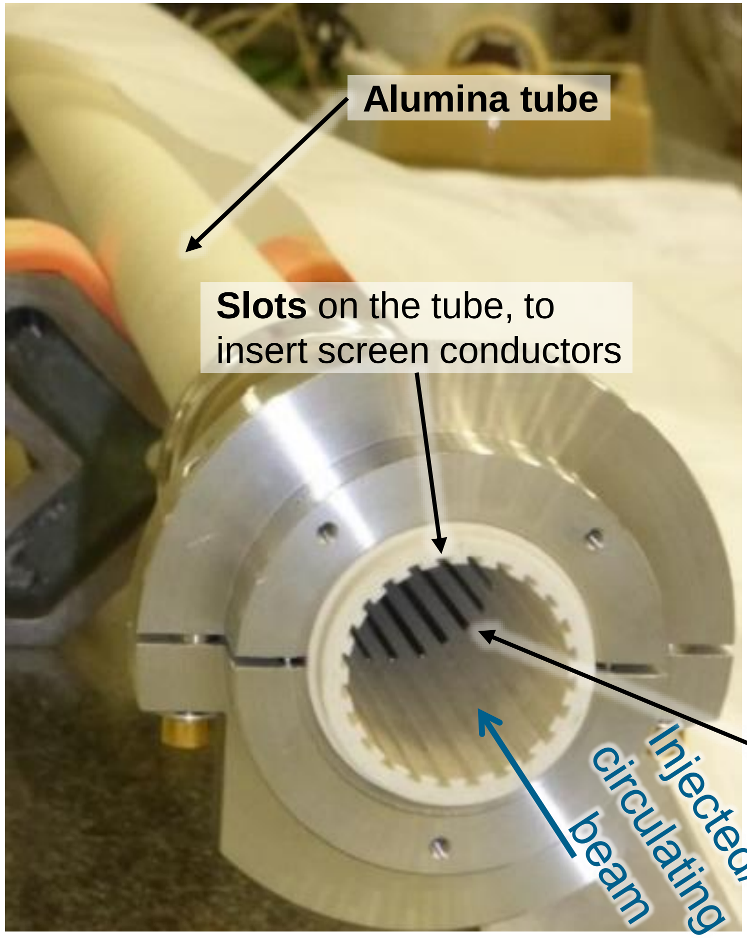
- Screen conductors **carry image current** of **circulating beam**

⇓

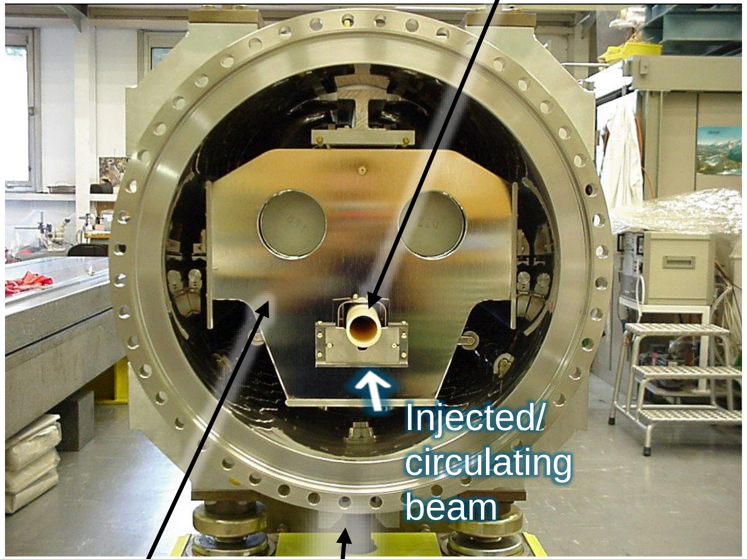
- **Lower beam** induced **heating**

- Conductors are **supported** and electrically insulated **by alumina tube** (high SEY)

- 2017-18 YETS upgrade of MKI8D: Alumina **tube** is **coated on the inside with Cr_2O_3:** has a **low SEY**, does not produce UFOs and is high voltage compatible



Alumina tube
(installed in MKI)



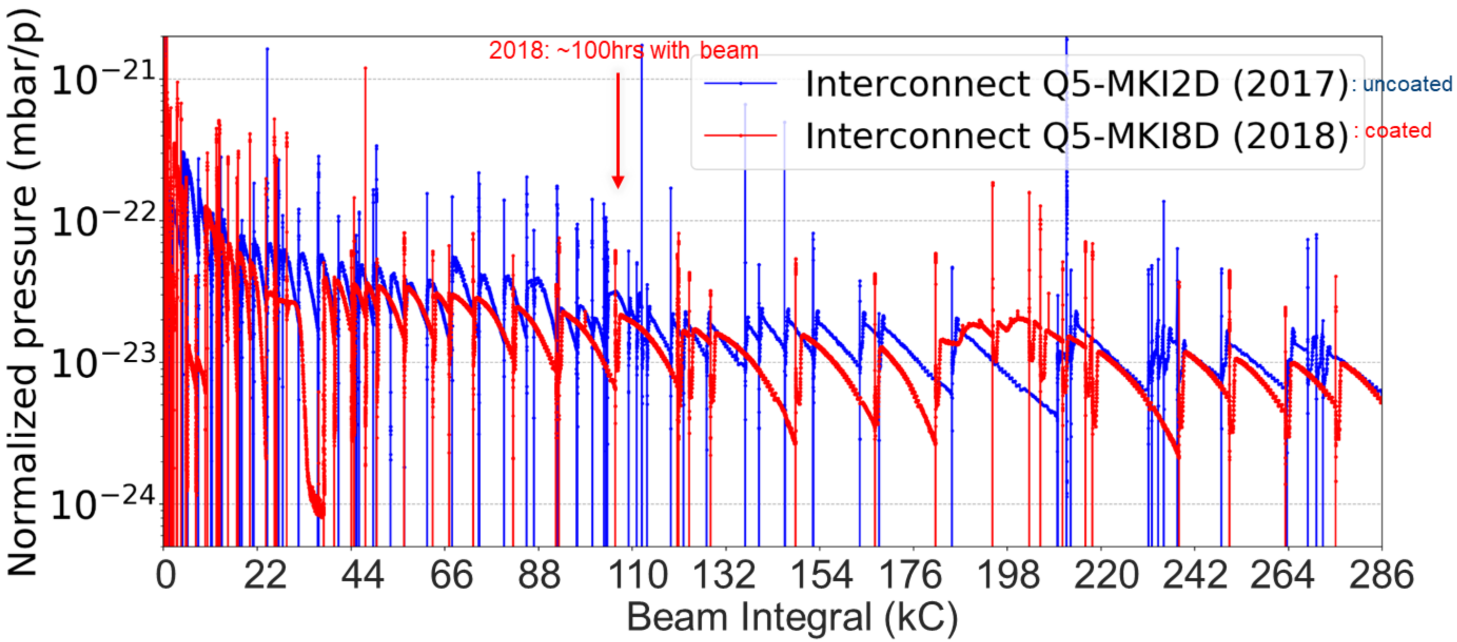
MKI magnet

Vacuum tank

24 screen conductors
(one each 15 degrees, since LS1)

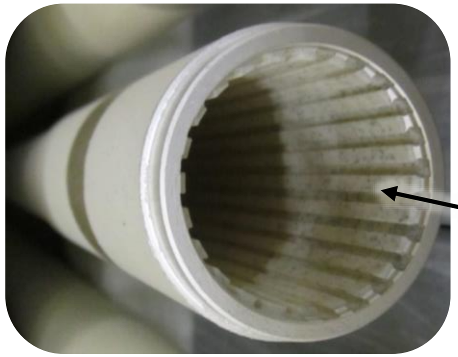
1. Context

Cr_2O_3 coating in MKI8D, installed in YETS 17-18



- **Before**:
  Pressure in **MKI8D** interconnect used to be a factor of ~**3** (2012, 2015 and 2017) and ~**12** (2016) **higher than** that of **Q5-MKI2D**

- **After**:
  This **factor** is **not observed** anymore.
  No other vacuum modifications were done, **so pressure reduction** is **attributed to Cr_2O_3 coating** 👍



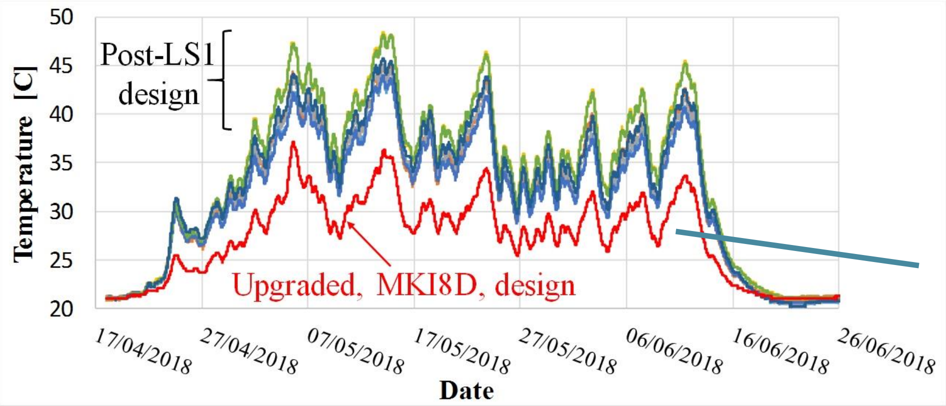
Alumina tube with **Cr_2O_3 coating** on the inside

1. Context

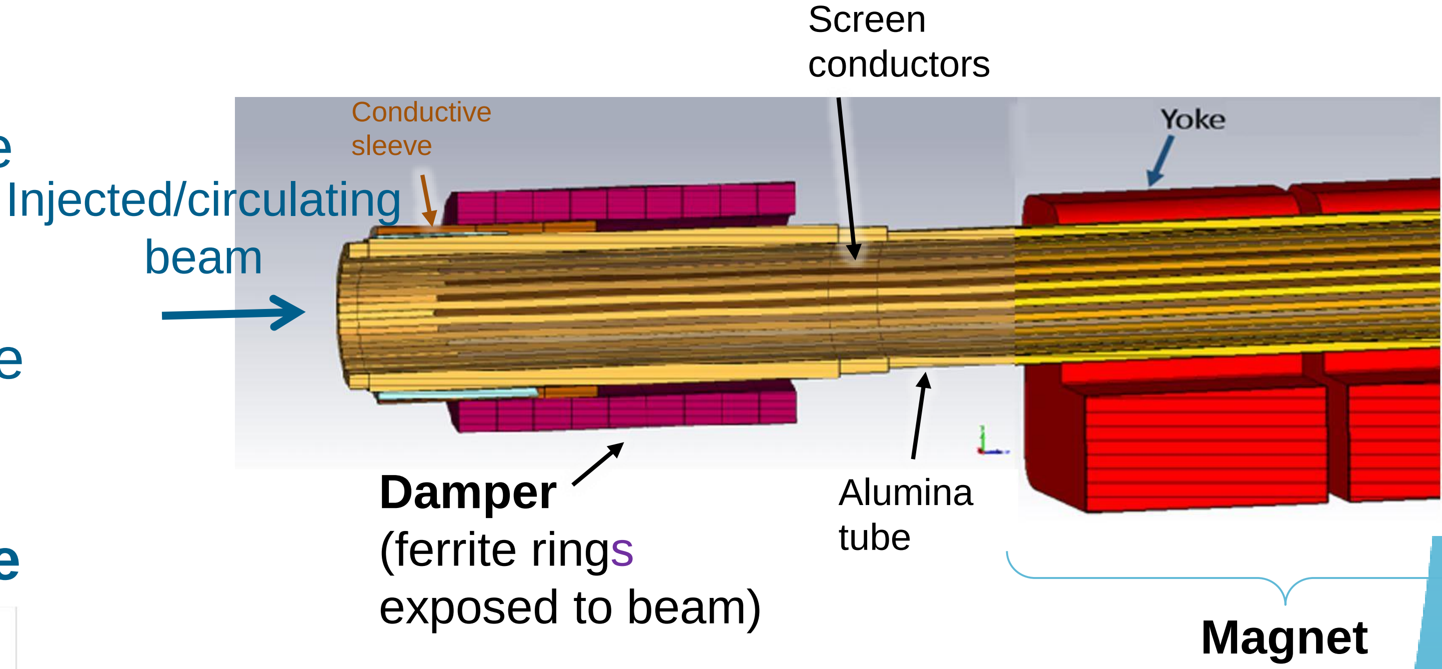
Damping element: the origin of MKI cool

- Redesigned **ferromagnetic rings (damper)**, placed on the alumina tube outside of the magnet aperture**, re-locates beam induced power deposition** from the ferrite yoke to the damper

- Damper is **not at** pulsed **high voltage**



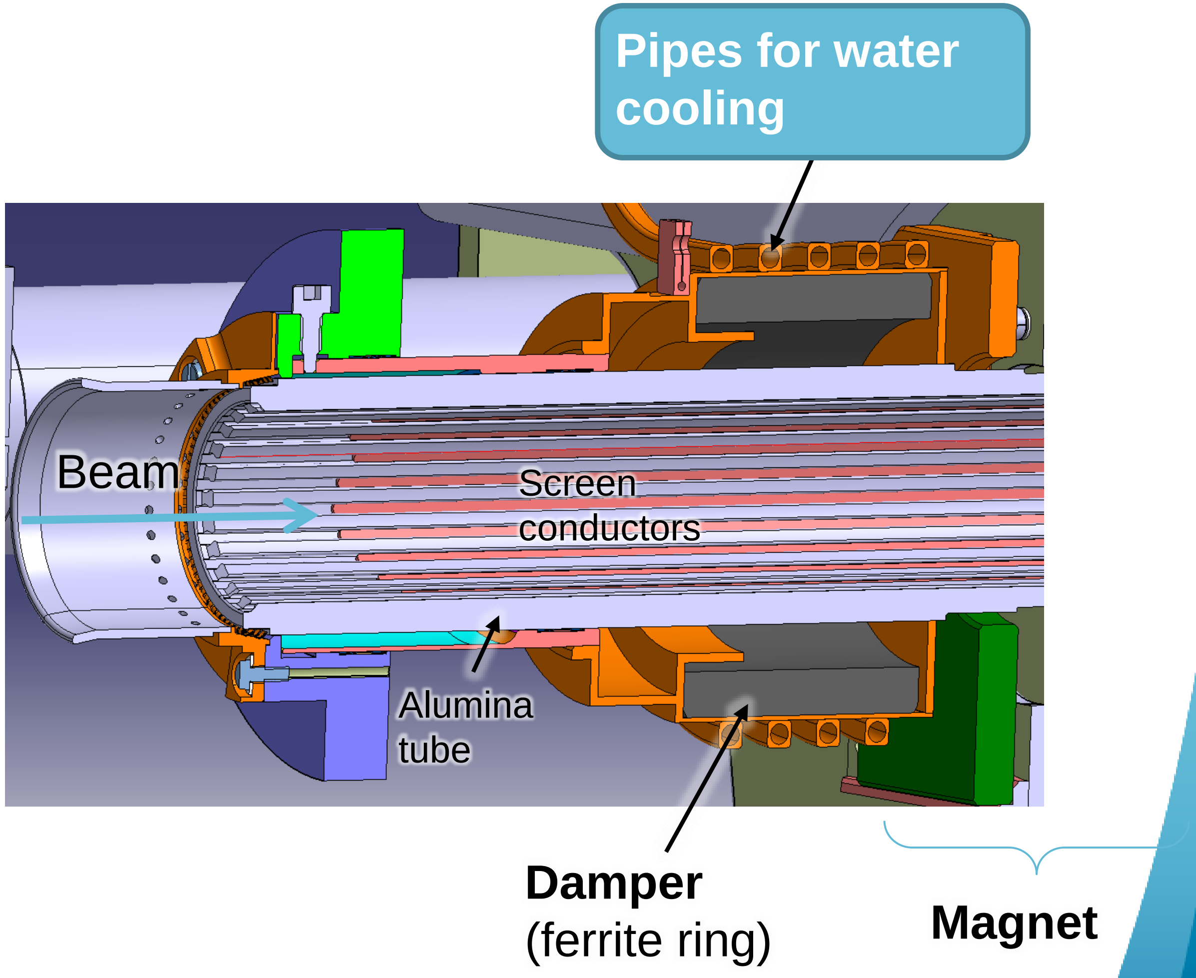
Reduced heating of ferrites



1. Context

MKI cool = damping element + water cooling

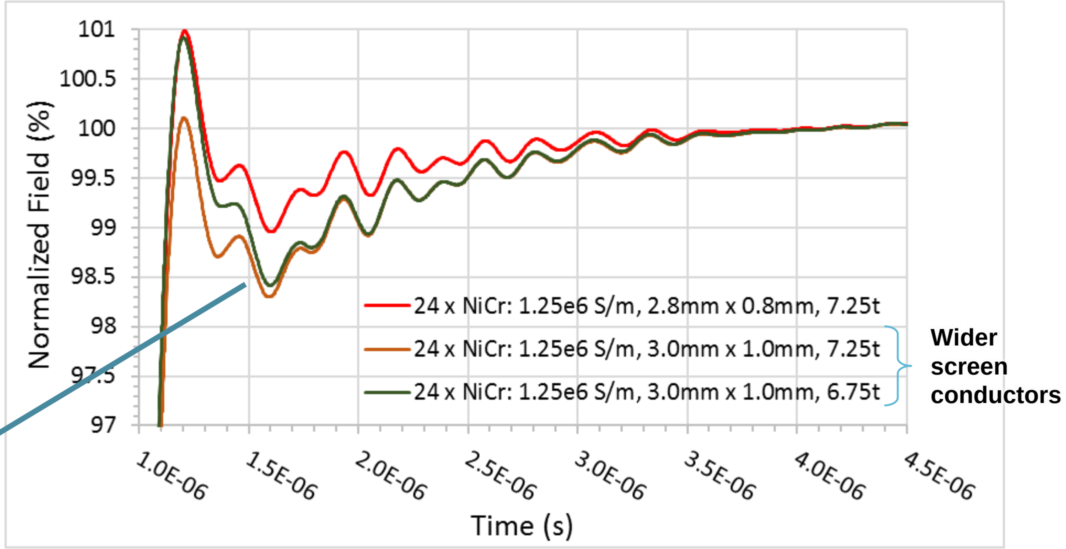
- **Damping element fulfils** the **function** of **re-locating** beam induced **power**
- **BUT, with HL-LHC beam**, it would reach the Curie temperature, and (temporarily) **stop working**
- The idea of the **MKI cool** is to cool the damper with **water** to remove heat



2. Issues – now solved
During 2019

Non-conformity of **slots** in alumina **tubes purchased during 2017**: slots were too wide. Thus, it was necessary to use **screen conductors** with a small **zig-zag**

[HL-NCR: https://edms.cern.ch/document/2440015/1.0]

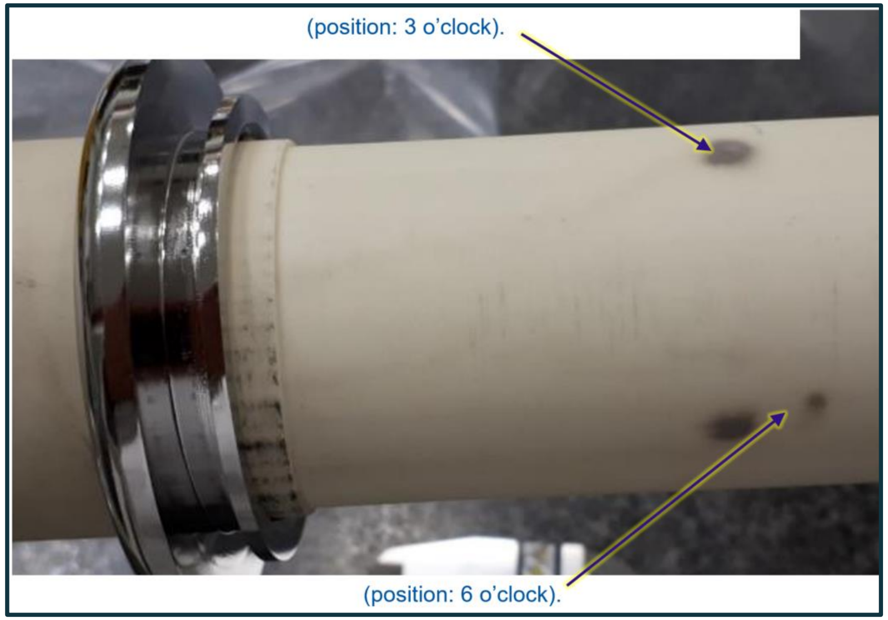


Using **wider screen conductors** was **discarded** due to **influence** on **magnetic field** (eddy currents)

HV pre-conditioning of MKI cool **failed**:

[HL-NCR: https://edms.cern.ch/document/2440015/1.0]

- 18 **strong sparks** occurred over two weeks
  Conditioning plateaued at ~**45kV** (**goal=56.1kV**)
- Three **black marks** from HV **breakdowns to** alumina tube

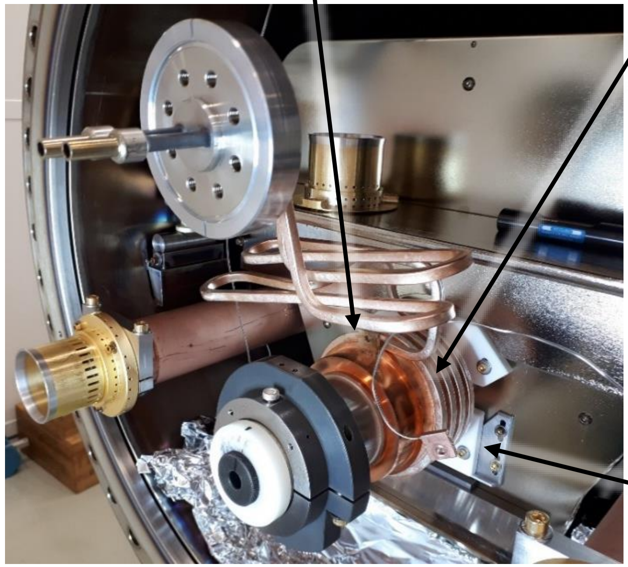


2. Issues – now solved

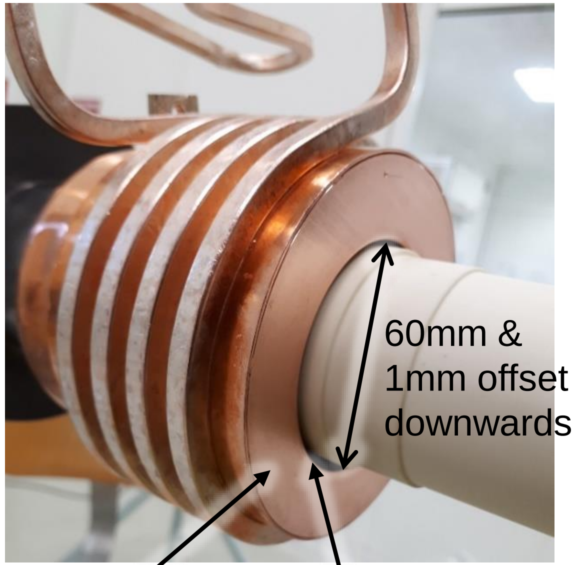
During 2019. Actions carried out

RF damper structure was modified to mitigate HV breakdowns:

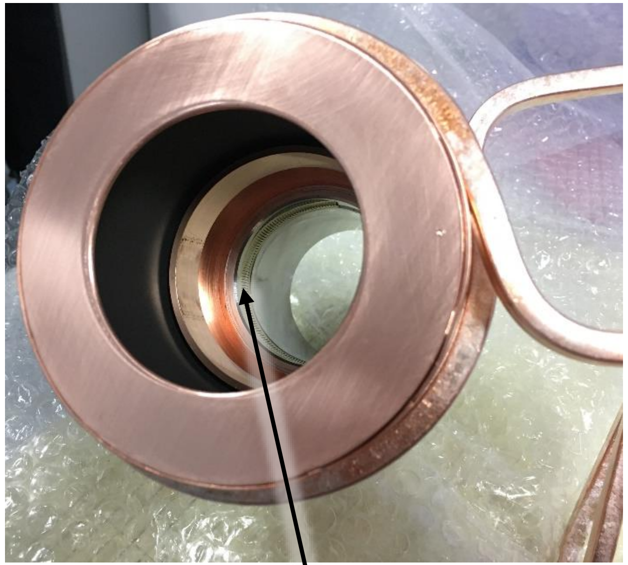
1. Metal **supports** for **tube** replaced by **macor**



2. RF damper end **cap inside diameter enlarged** (from 56mm to 60mm), to **increase distance to** alumina **tube**



3. **Sharp edge** on stainless steel short eccentric tube removed (manufacturing error)

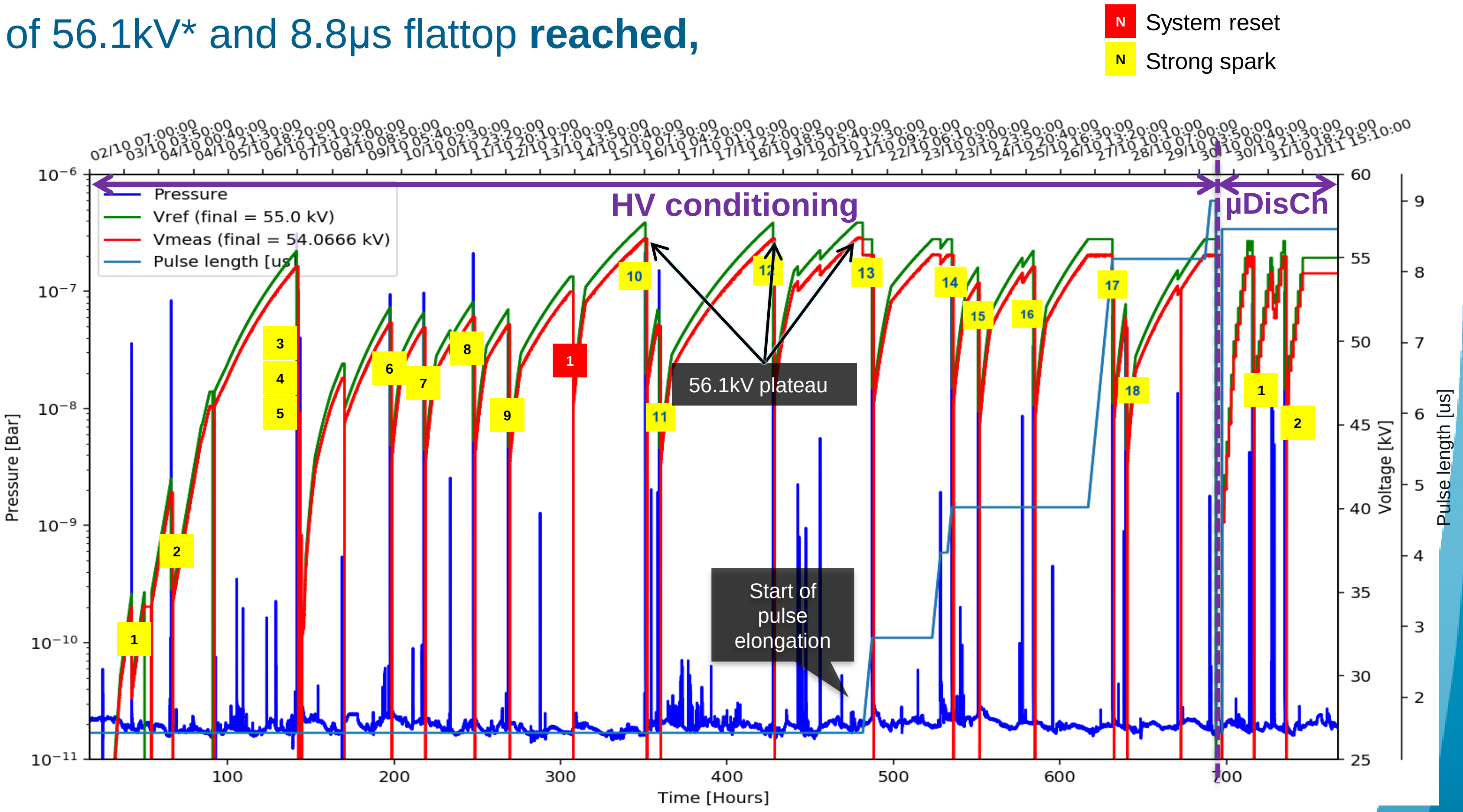


2. Issues – now solved

During 2020. HV conditioning

Conditioning **completed** and **target** of 56.1kV* and 8.8µs flattop **reached, BUT:**

- Conditioning **required 230k pulses** (usually 50k to 100k)
- **18 strong sparks** were observed (usually <6)
- For the first time, **two** strong **sparks** during **micro-discharge** test
- Hence, magnet was **not installed**, but opened and **inspected** instead

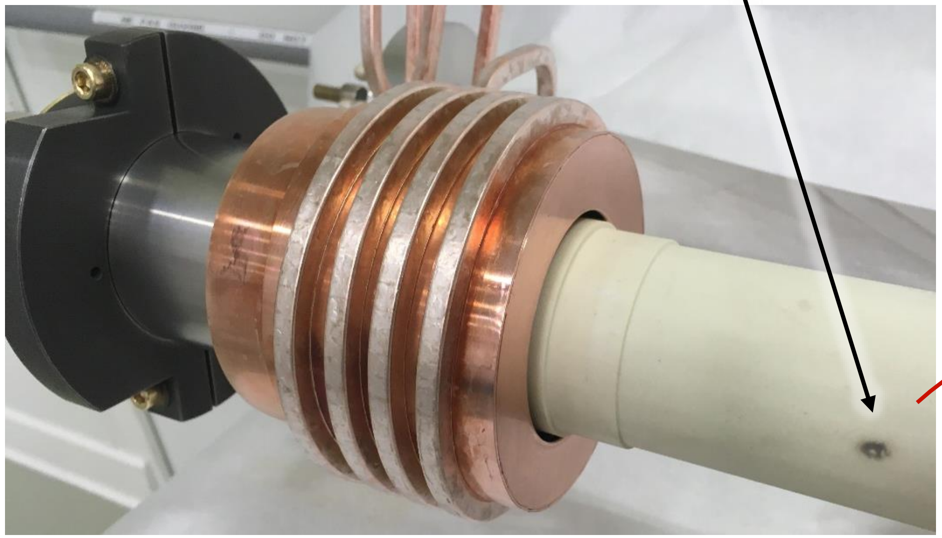


*: 56.1kV is ~10 % above Point 8 operational voltage (51.3kV)

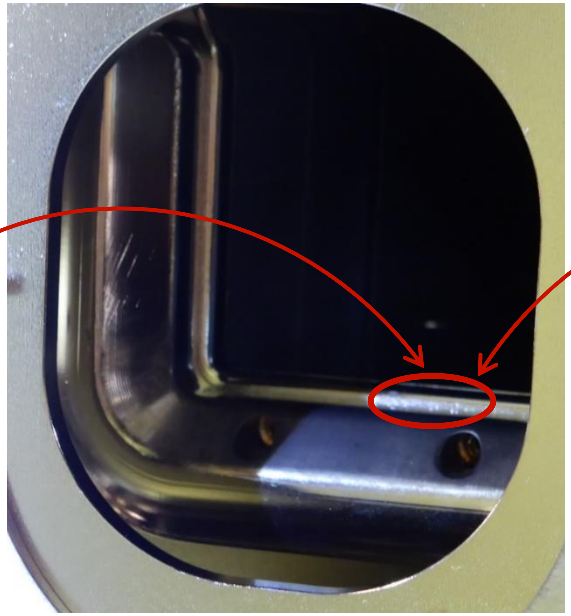
2. Issue – now solved
Inspection after conditioning (November 2020)

First observation: Still one **black mark** seen **on** the **tube**, at the end (3 marks in 2019)

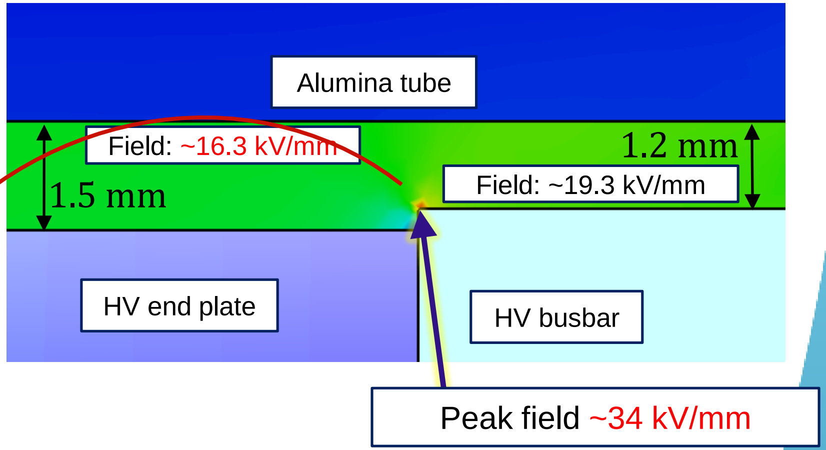
The **reason** was a **sharp edge** due to **mis-alignment of HV busbar** of the magnet → **Solved** with correct alignment



Alumina tube **outside of magnet**



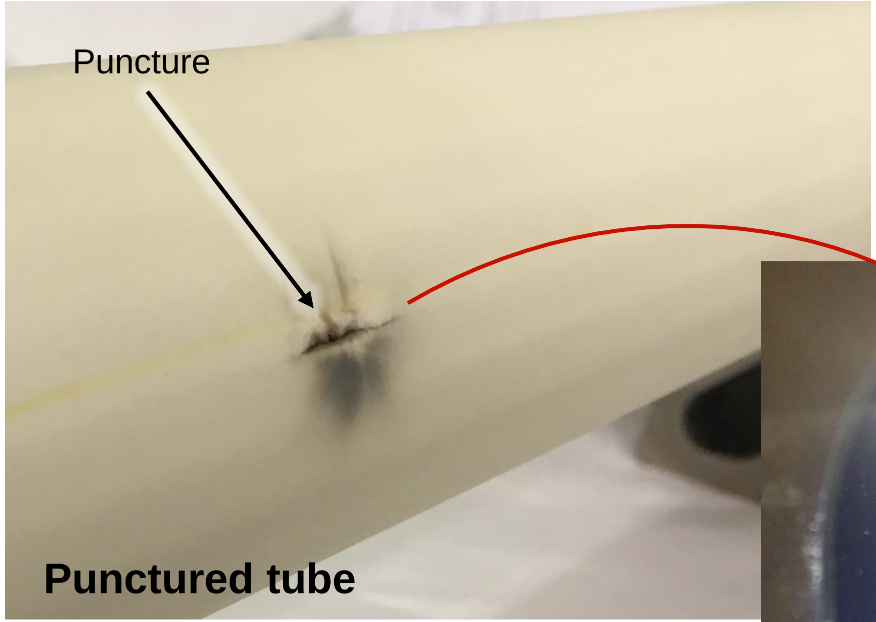
End of magnet, without tube



Enhanced electric **field** (~doubled) **due to dealignment** of HV busbar

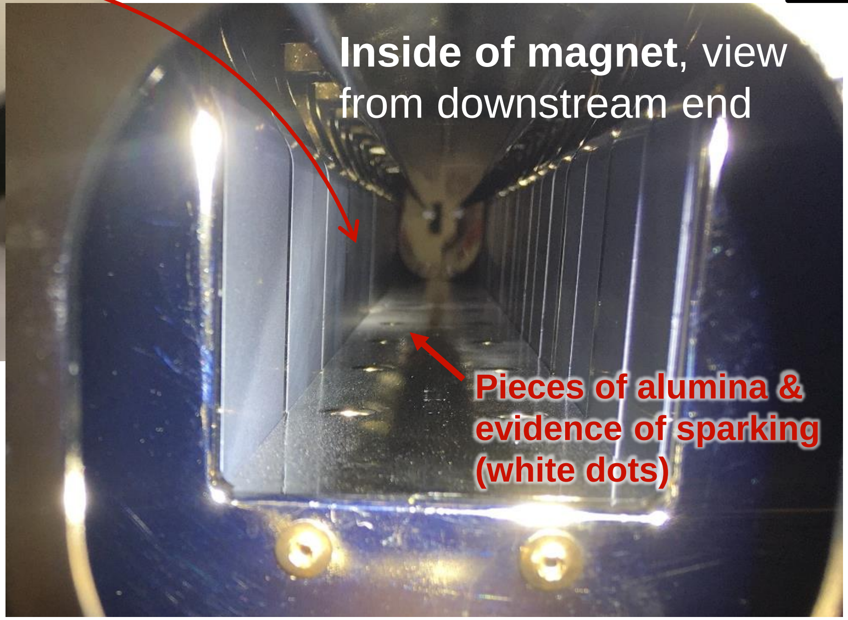
3. Issue – understood
Inspection after conditioning (November 2020)

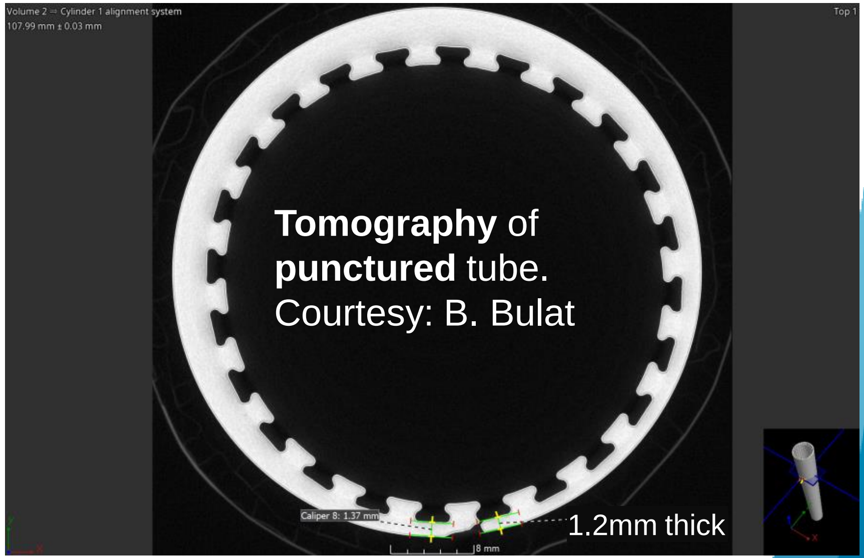
Second observation: alumina **tube** was **punctured**, **inside** of the **magnet** (52cm from downstream end)



Reasons of puncture:

- **High voltage** difference during pulse
- **Tube** extremely **thin** at that position (mis-manufactured)



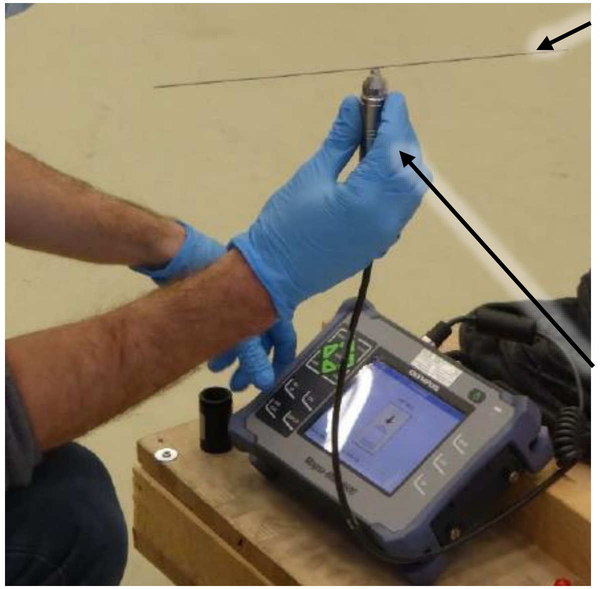


3. Issue – understood: mis-manufactured alumina tubes

Puncture triggered study of tube thickness of 2017 batch

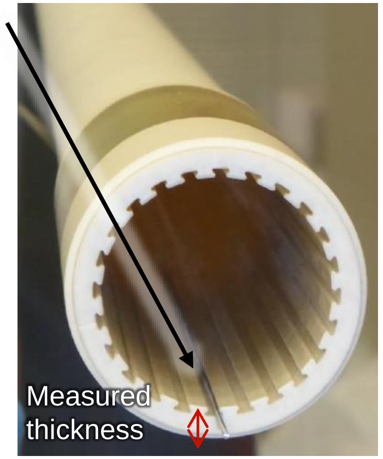
All 2017 **tubes** were **measured**

Magnetic gauge measures **wall thickness** all along the tube

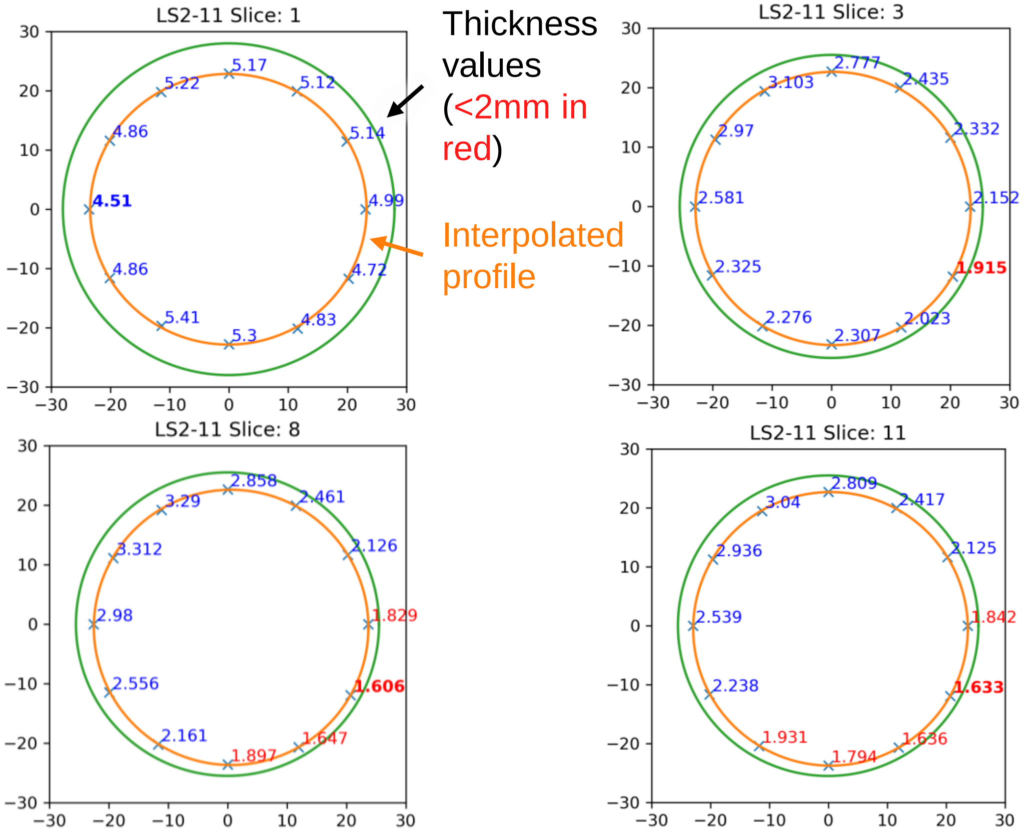


Magnetic rod

Probe connected to device



A dedicated **Python programme** was developed, to **show the inner profile** of the **tubes**



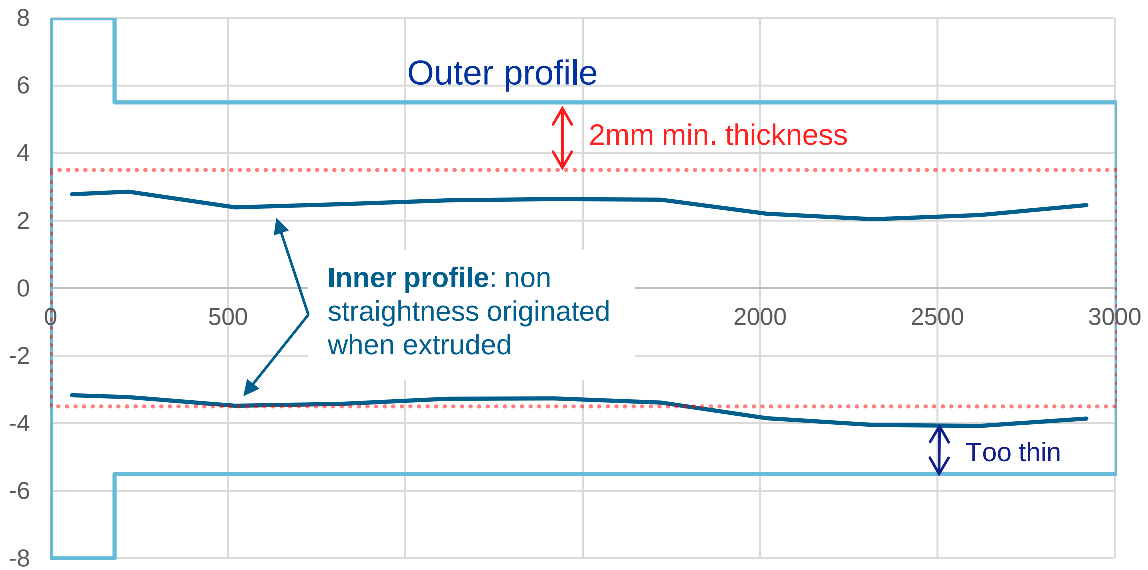
3. Issue – understood: mis-manufactured alumina tubes
Discussions with manufacturer + conclusions of study

For manufacturing, tube is **extruded with final inner profile**, but larger outer diameter

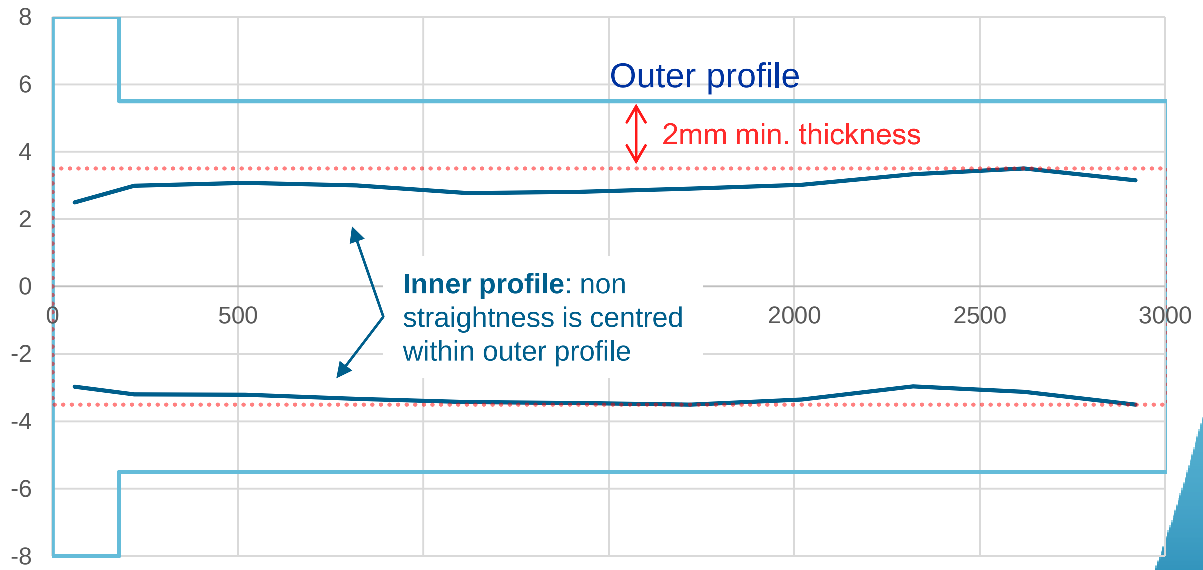
Afterwards, the **outside** surface is **machined**

1. **No tubes, from 2017 batch**, with required **minimum wall thickness** (**2mm**)
2. **Axis** for **machining** the tube could be **better chosen**, to have **more uniform** wall **thickness**

Longitudinal **profile** of tube (LS2-11)



Theoretical **optimal machining** (LS2-11)

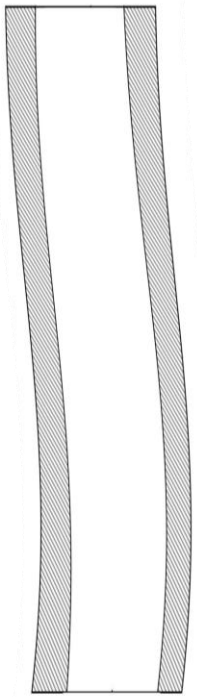


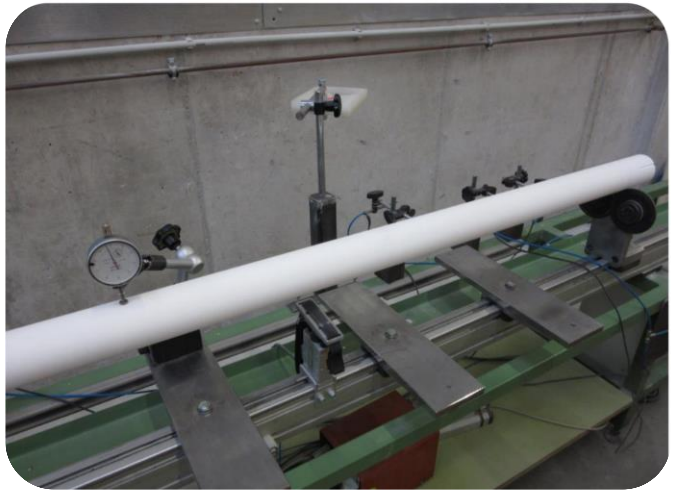
3. Issue – understood: mis-manufactured alumina tubes

Current work: determining the optimal machining axis

Shape of tube **after extrusion** is **imperfect**

Extruded tube
(exaggerated deformation)

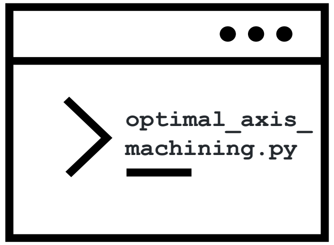




Outer profile characterisation

Wall thickness measurement
(before machining)

Future



$$Optimal\ axis\ for\ machining = \{x_1, y_1, x_2, y_2\}$$

Before

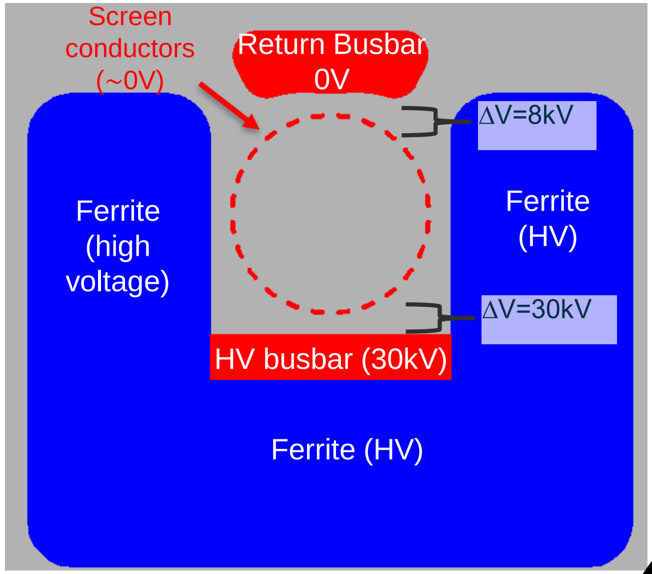
Machined tube

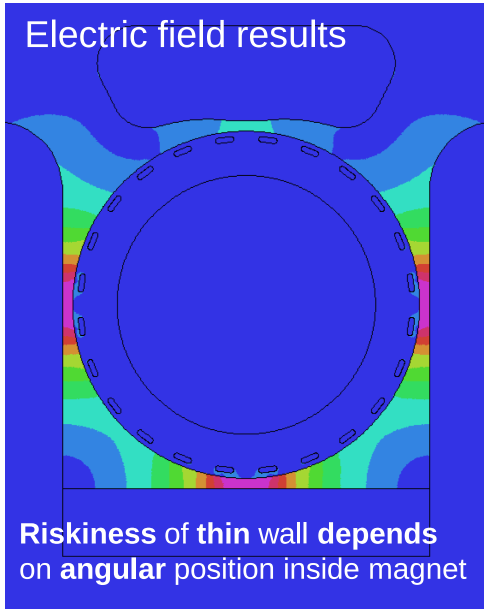
3. Issue – understood: mis-manufactured alumina tubes

Optimization of tube rotational angle for installation

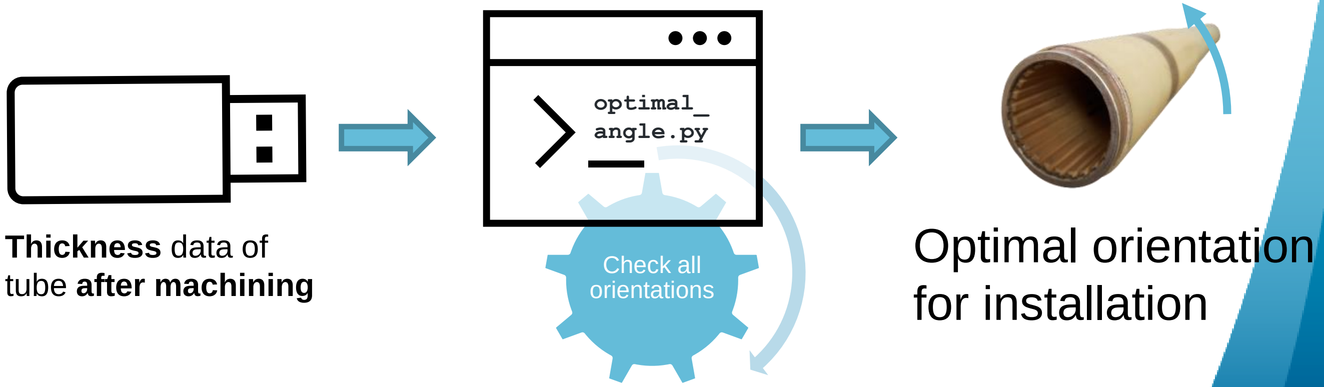
- **Angle** for installing of the tube **can be chosen**
- **Electric field data,** predicted by **simulations**, depends on:
  - Wall **thickness** of the tube (d)
  - **Angular position** of screen conductor (θ)
- **Python** programme to check every orientation (0, 15, … 345 deg.) and calculate electric field
- **Orientation** with lowest E field is chosen for installation
-

Minimised risk of breakdown





$$E_{\theta,d} = f(\theta, d)$$



4. Status of first MKI cool to be installed in LHC

- **Installation** planned for **YETS 22/23**

- **Successful HV pre-conditioning**

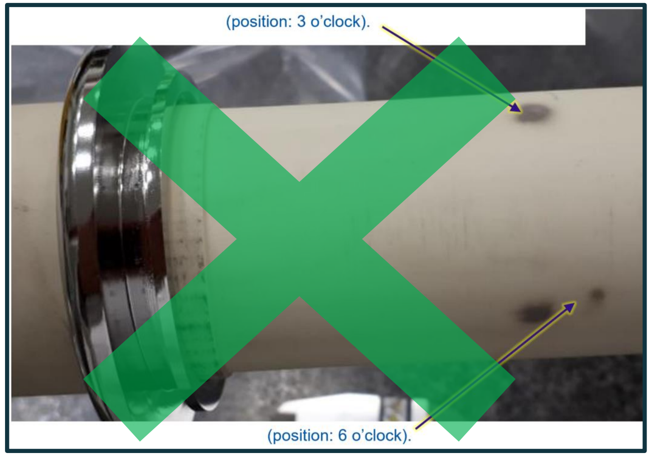
- **Planning** has been **delayed** due to a **vacuum leak**.
  The **seal** is being replaced.
  But still in schedule, for YETS 22/23, at location MKI8C

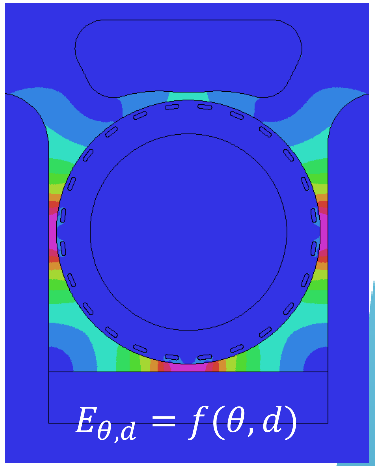
MKI cool in test cage

5. Conclusions

- **High voltage issues** during 2019 and 2020 have been **successfully solved**

- The **remaining issue** is the **risk** of puncture due to **non-conforming** alumina **tubes:**
  - The issue is well **understood** and a there is good **collaboration** with the manufacturer
  - **Detailed measurements** of the tubes prior to machining will result in achieving minimum of 2mm wall **thickness**
    - **Remeasuring** the tubes after machining will **validate correct machining**, and therefore **thickness**
  - **Optimizing angular** position, for installation in an MKI, will serve as an extra **protection** against HV breakdowns through the tube wall





Thanks for your attention !

Spare slides

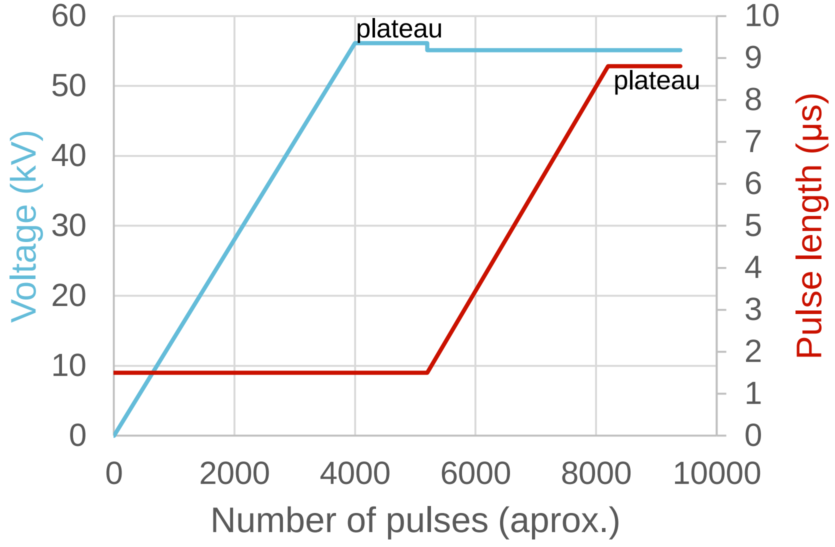
Context

MKI conditioning information

- Operational voltage of MKIs is 49.6 kV at Point 2 and 51.3 kV at Point 8
- All MKIs are conditioned to ~10 % above Point 8 voltage = 56.1 kV

- During HV conditioning:
- Voltage is ramped up to 56.1kV at a fixed pulse length of 1.5µs;
- Ramping is followed by a plateau (1.5µs at 56.1kV for 1200 pulses);
- Plateau is followed by enlarging mode (1.5µs to 8.8µs) at 55.1kV;
- Finally, a plateau with 8.8µs at 55.1kV for 1200 pulses

Simplified conditioning schematic



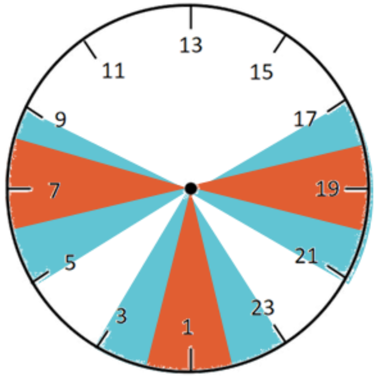
- HV conditioning is followed by a micro-discharge test, for validating the MKI:
- Voltage is quickly ramped up to 55kV* at a fixed pulse length of 8.6µs, 500 pulses per step

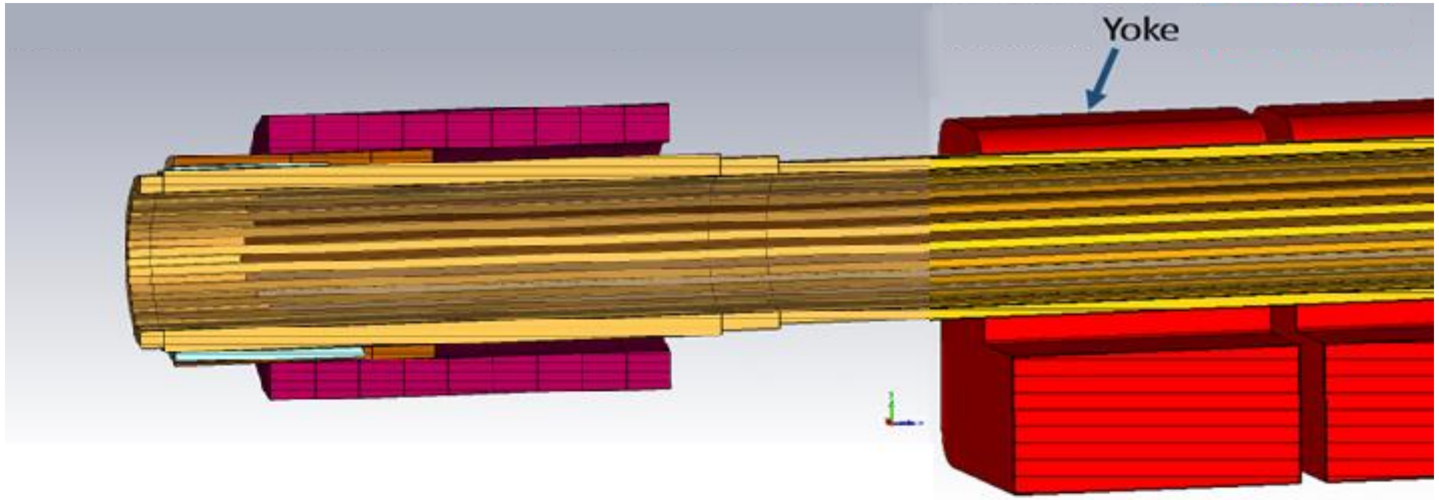
- Notes:
- *: 1 kV above the maximum SoftStart PFN voltage at Point 8
- A pressure rise is considered a micro-discharge (energy dissipated in the magnet or beam screen is relatively low) when the pressure takes a few minutes (e.g. 3 minutes) to recover to its pre-breakdown level.

Alumina tube measurements summary

	Tube	Absolute mininum thickness (mm)	Longitudinal position (cm) of the minimum thickness (starting from Ø56mm end)	Average hole radius (mm)	Average offset of centre of hole (mm)	**Relaxed** criteria Thinnest point on critical angles (± 15° inc.) after optimization (mm)	**Exigent** criteria Thinnest point on critical angles (± 30° inc.) after optimization (mm)
Old tubes	*MKI2B*	*1.98*	*112*	*22.85*	*0.43*	*2.24*	*2.24*
	LS1-1	1.75	22	22.93	0.27	2.25	1.955*
	LS1-2	1.36	202	22.96	0.82	1.75	1.48
	LS1-3	2.04	112	22.86	0.39	2.39	2.39
New tubes	LS2-1	1.23	52	23.12	0.71	1.79	1.65
	LS2-2	0.95	202	23.23	0.68	1.64	1.25
	LS2-3	1.44	232	23.11	0.42	1.72	1.72
	LS2-4	1.42	232	23.09	0.57	1.82	1.82
	LS2-5	1.68	82	23.12	0.52	1.84	1.84
	LS2-6	1.15	262	23.08	0.51	1.85	1.56
	LS2-7	1.04	262	23.08	0.91	1.32	1.18
	LS2-8	0.78	262	23.08	0.61	2.06	1.36
	LS2-9	0.93	202	23.08	1.06	1.21	1.00
	LS2-10	1.34	262	23.07	0.65	1.62	1.34
	LS2-11	1.43	262	23.12	0.49	2.04	1.61
	LS2-12	0.82	262	23.08	0.59	1.93	1.45
	LS2-13	0.70	262	23.13	0.91	1.16	1.16
	LS2-14	0.98	262	23.11	0.52	2.06	1.35
					Number of good tubes	(2 of 3 2013 + 3 of 14 2017) = 5	(2 of 3 2013 + 0 of 14 2017) =**2**

Notes:
LS1-? = 2013 batch
LS2-? = 2017 batch




Yoke

Reminder of the HL-LHC Goals

From FP7 HiLumi LHC Design Study application in 2010

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