LBDS-Overview

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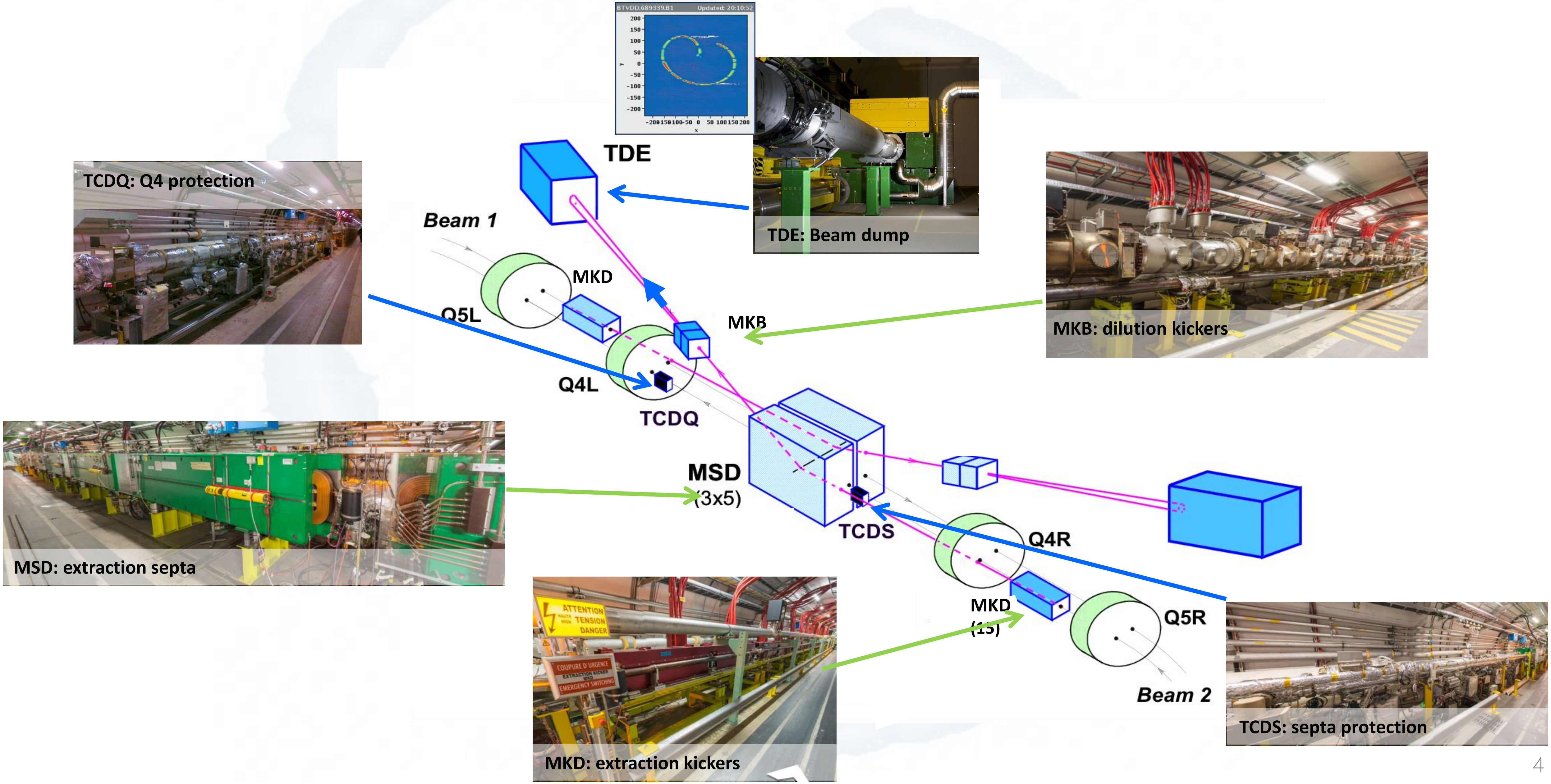
Acknowledgment: M.I. Frankl, M.A. Fraser, V. Rizzoglio and C. Wiesner

MPP Workshop 2019

Outline

- LBDS and failure scenarios
  - Generators/magnets
  - Impact of operation at 7 TeV
- Impact on beam absorbers and dump (TCDQ, TCDS and TDE)
  - Intensity limitations (Antonio's talk)
  - β* leveling at TCDQ and BETS limits
- Possible strategy vs timeline (LS2, EYETS and LS3)

The LBDS

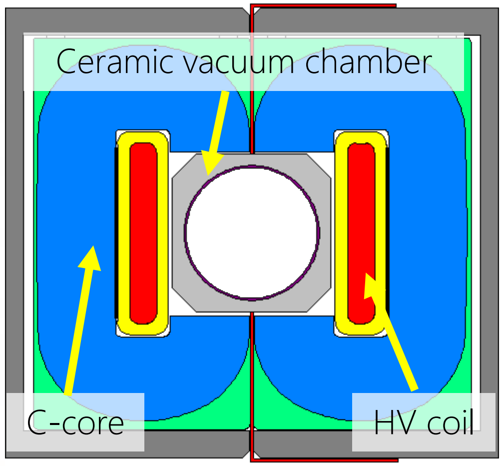

TDE
TDE: Beam dump
Beam 1
TCDQ: Q4 protection
MKD
Q5L
MKB
MKB: dilution kickers
Q4L
TCDQ
MSD
(3x5)
MSD: extraction septa
TCDS
Q4R
MKD
(15)
Q5R
Beam 2
TCDS: septa protection
MKD: extraction kickers
ATTENTION
HAUTE TENSION
HIGH DANGER
COUPURE D'URGENCE
EXTRACTION KICKER
EMERGENCY SWITCHING

MKD: Extraction Kickers

Erratic: spurious firing of GTO stack (discharge or SEB).
The higher the voltage the higher the risk!

After LS2 upgrade operation at **7 TeV** with lower voltage than pre-LS2 operation at 6.5 TeV
➔ **reduced risk of erratics!**

	Pre-LS2 (6.5 TeV)	Post-LS2 (7 TeV)
Number of magnets per ring	15	15
System deflection angle	0.275 mrad	0.275 mrad
Kick strength per magnet	0.397 Tm	0.428 Tm
Rise-time	< 2.7 µs*	< 2.7 µs*
Vacuum chamber inner diameter	56 mm	56 mm
Operating charging voltage	26.7 kV	25.6 kV
Flat-top duration	≥ 91 µs	≥ 91 µs
Magnetic length	1.4 m	1.4 m



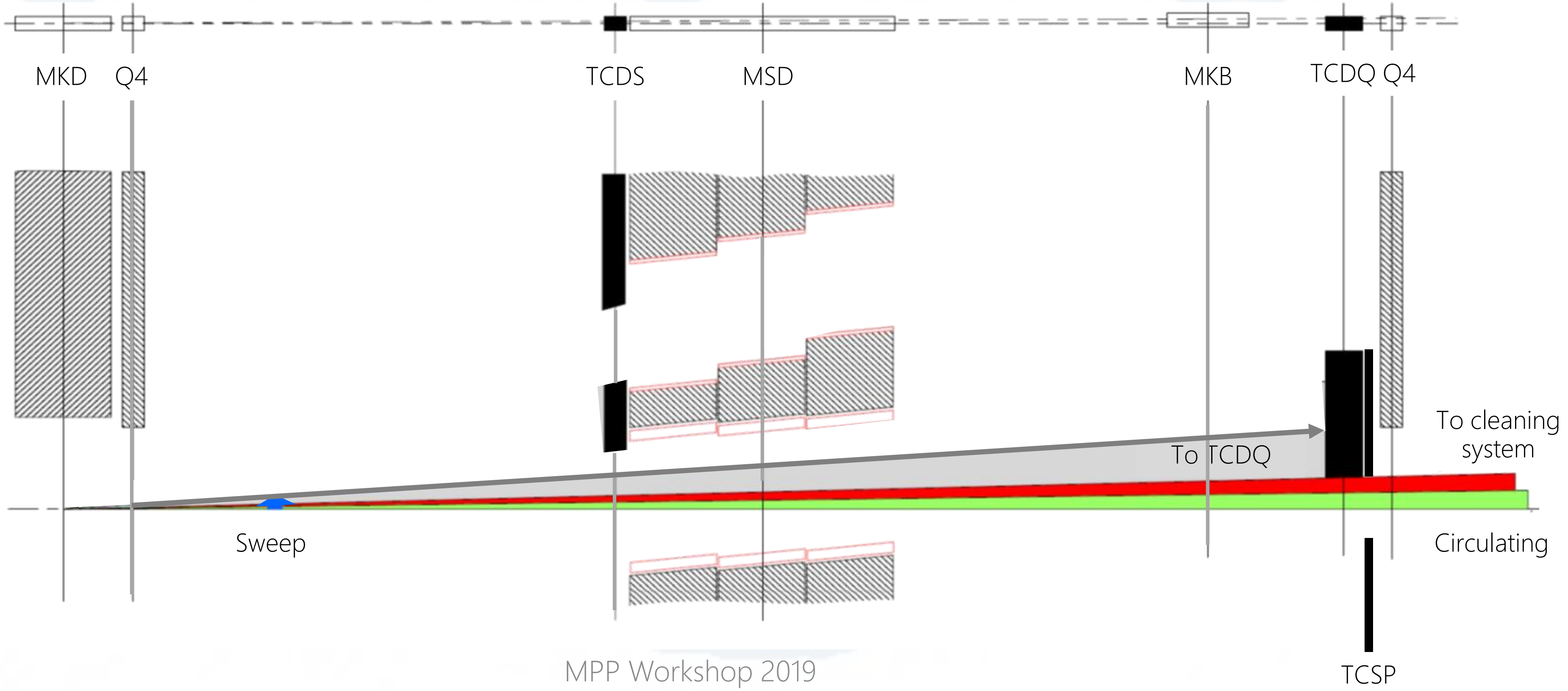
Magnets are built around a metallized ceramic vacuum chamber (no risk of flash-over)

*Abort gap duration=3 µs

MKD Erratic ➔ Asynchronous Beam Dump

- Total deflection given by the sum of each kicker plus Q4 contribution
- 1 kicker fires ➔ all remaining 14 are re-triggered (asynchronously wrt RF) within 1.3 μs ➔ avoid loosing ~all beam on TCDQ

Only one kicker firing



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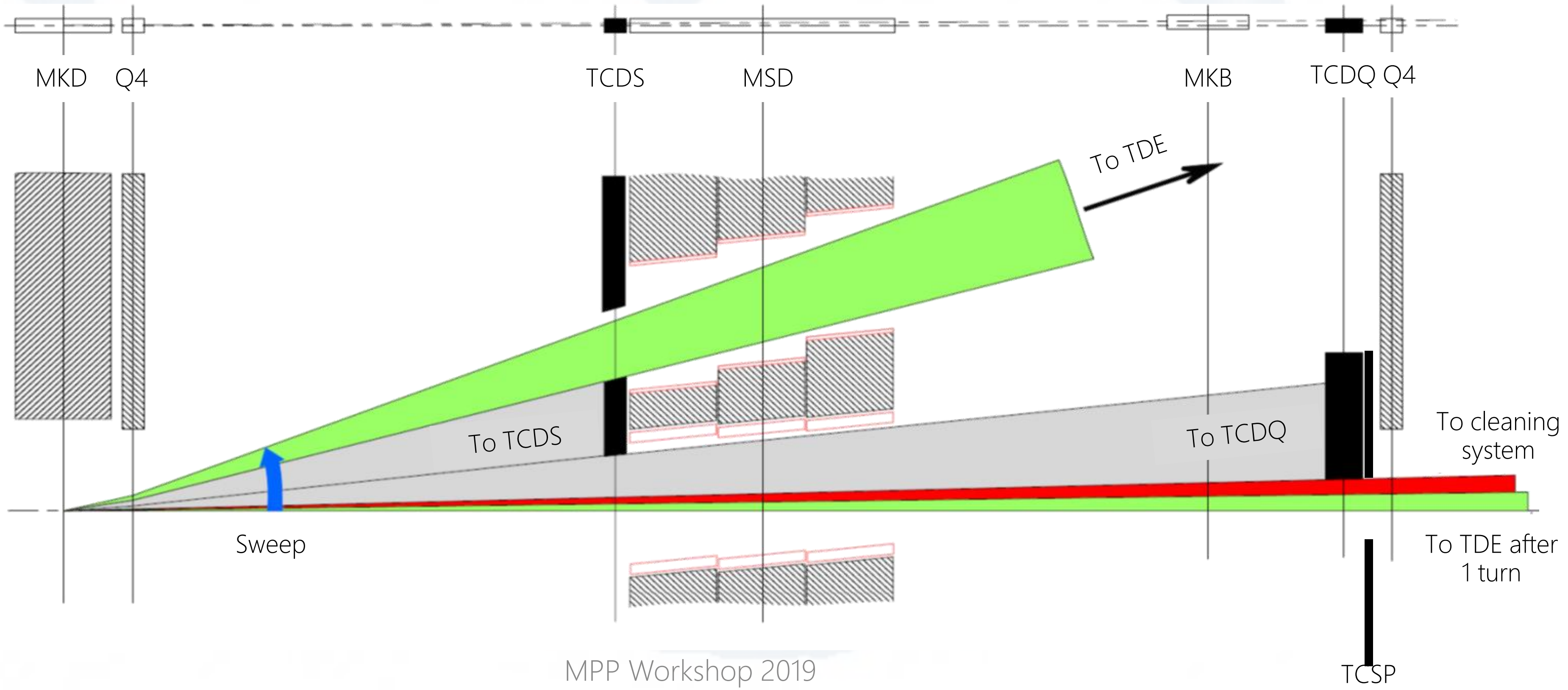
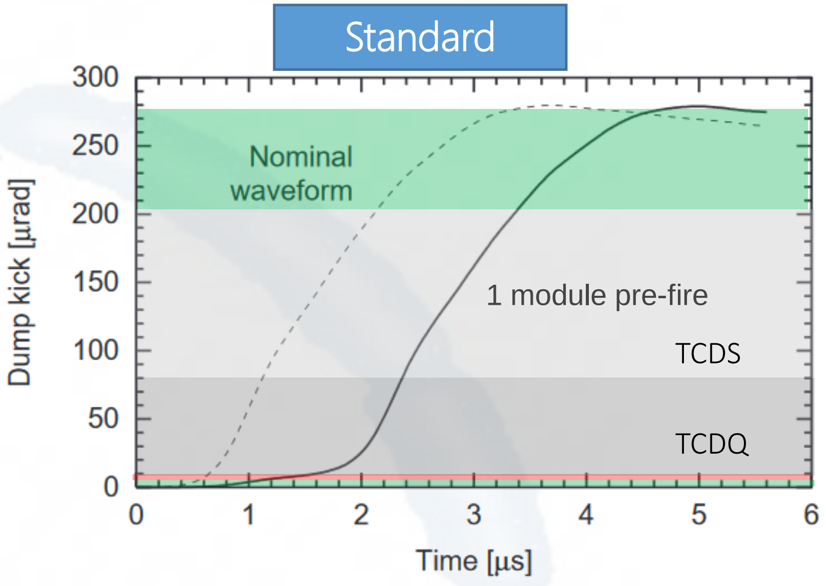
All kickers re-triggered



MKD Erratic Types

- Type 1 ("standard"):
  - Spurious firing of one GTO stack, slow commutation (rise-time> 2.7 μs)
  - Reaction time: ≤1.3 μs
  - Origin: sparking of charge accumulated on insulators, intermediates amplitude noise coupled to re-trigger line, Single Event Burnout (SEB).
- Type 2:
  - Fast commutation (rise-time ~2.4 μs, missing current in GTO stack)
  - Reaction time: ≥1.3 μs
  - Origin: direct sparking between metal surfaces with +HV and ground potential – accumulated dust/insect initiated streamer leading to arc
- Type 3:
  - ~Normal commutation of multiple generators
  - Reaction time: ≤1.3 μs
  - Origin: strong perturbation on retrigger line (observed once without beam with 3 generators fired)



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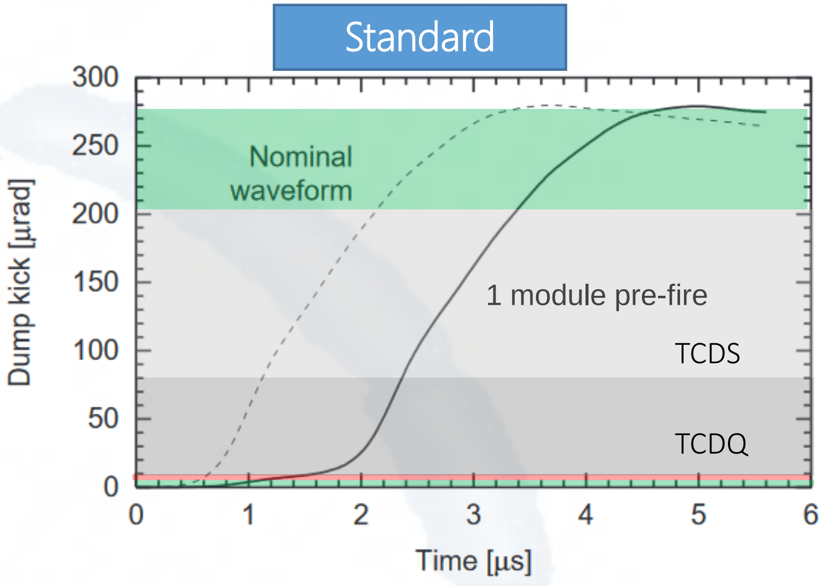

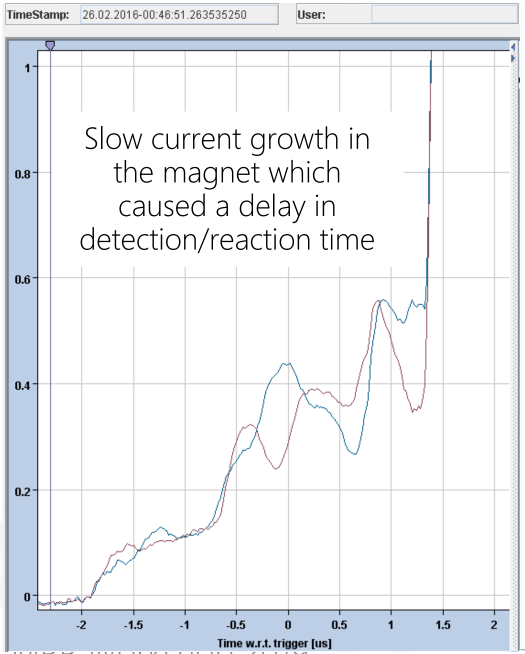

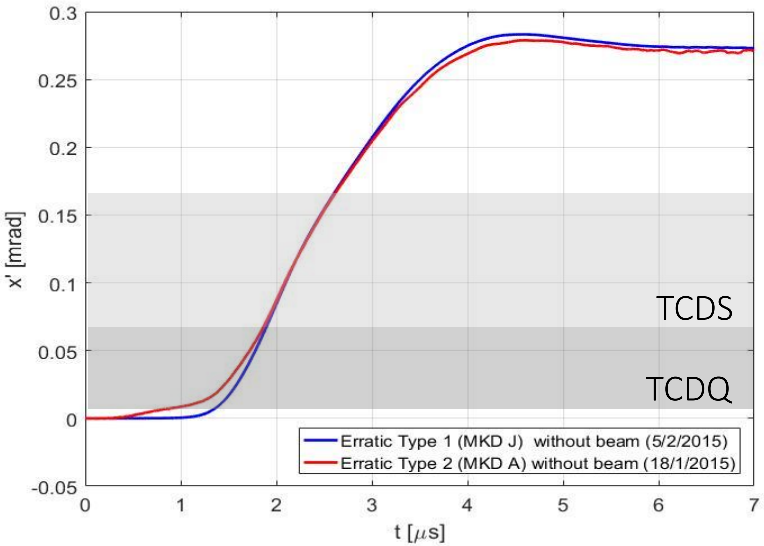

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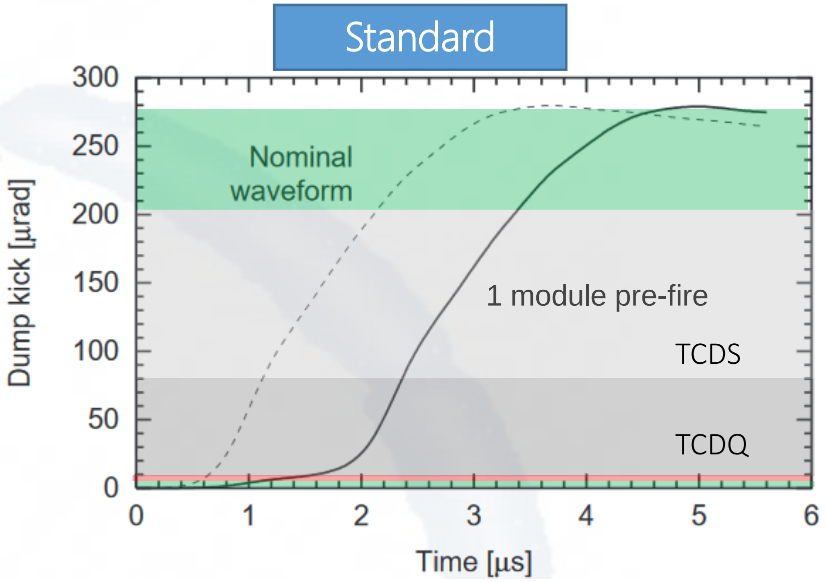

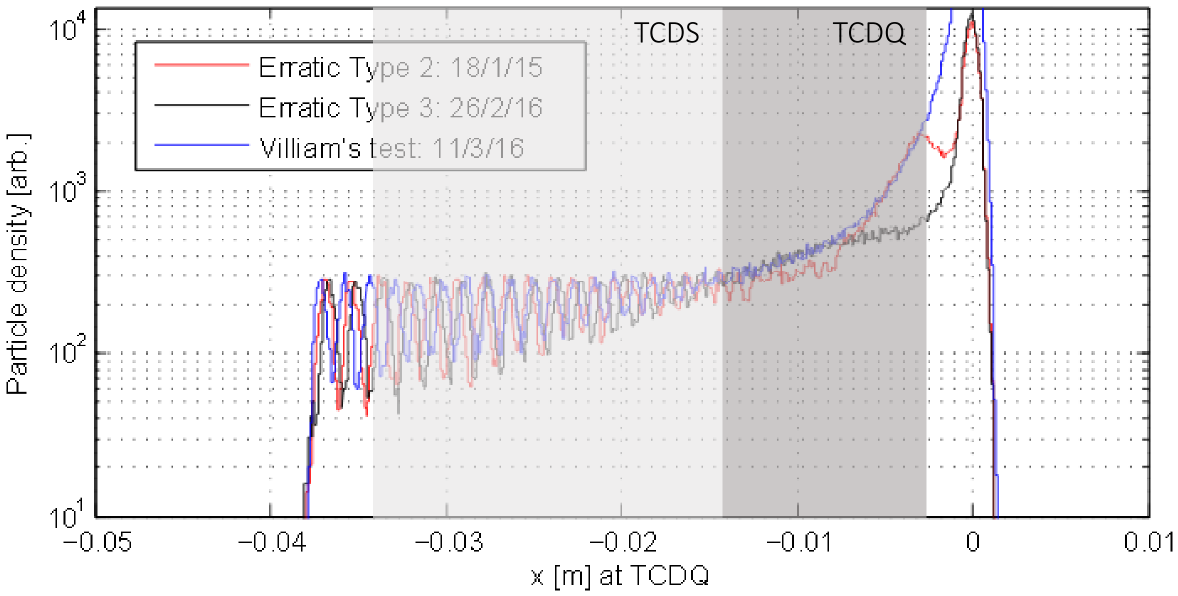

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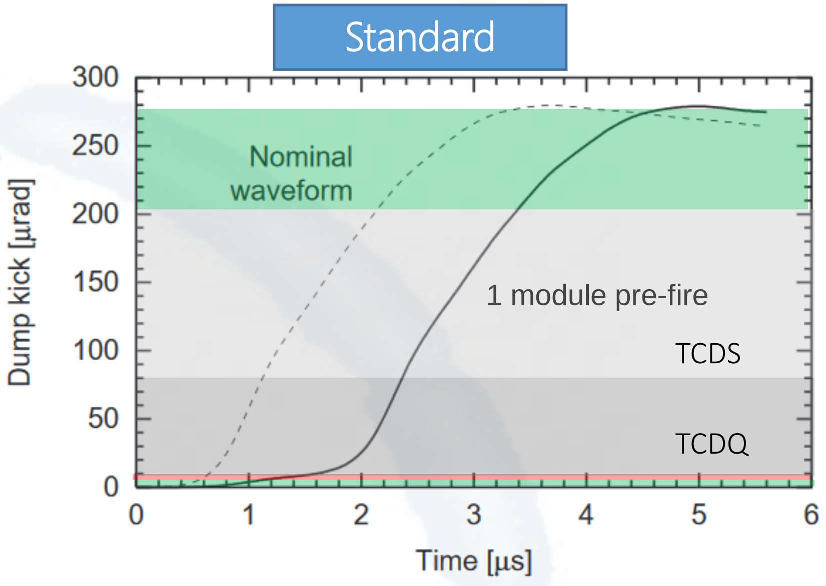
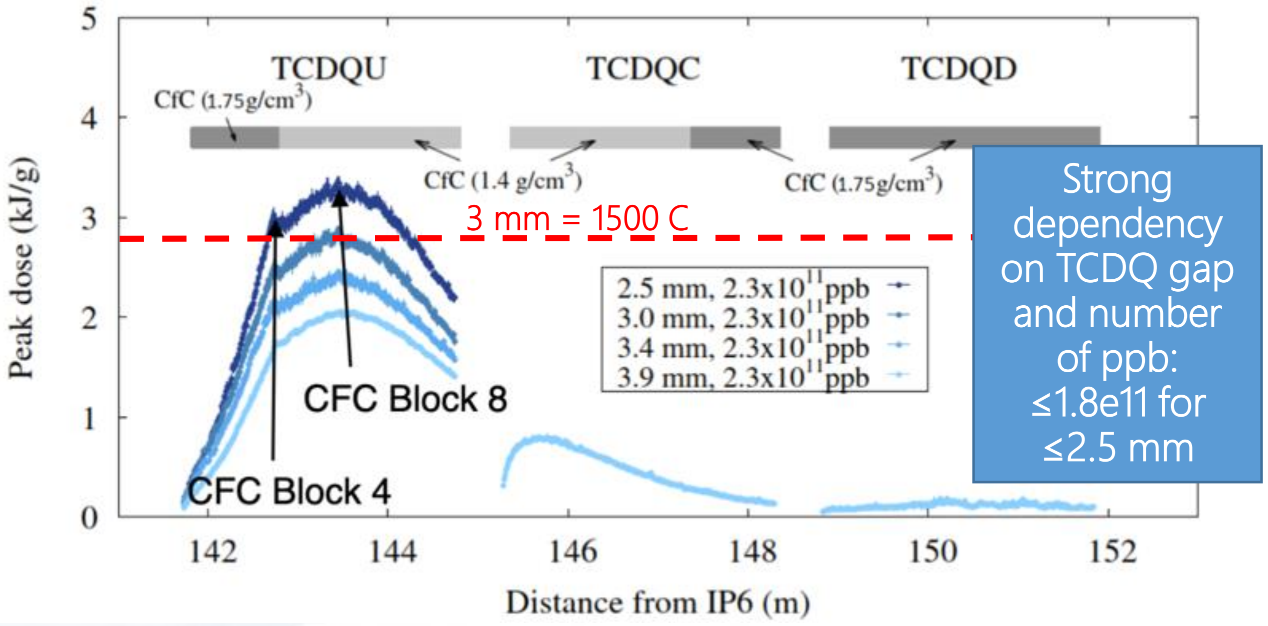
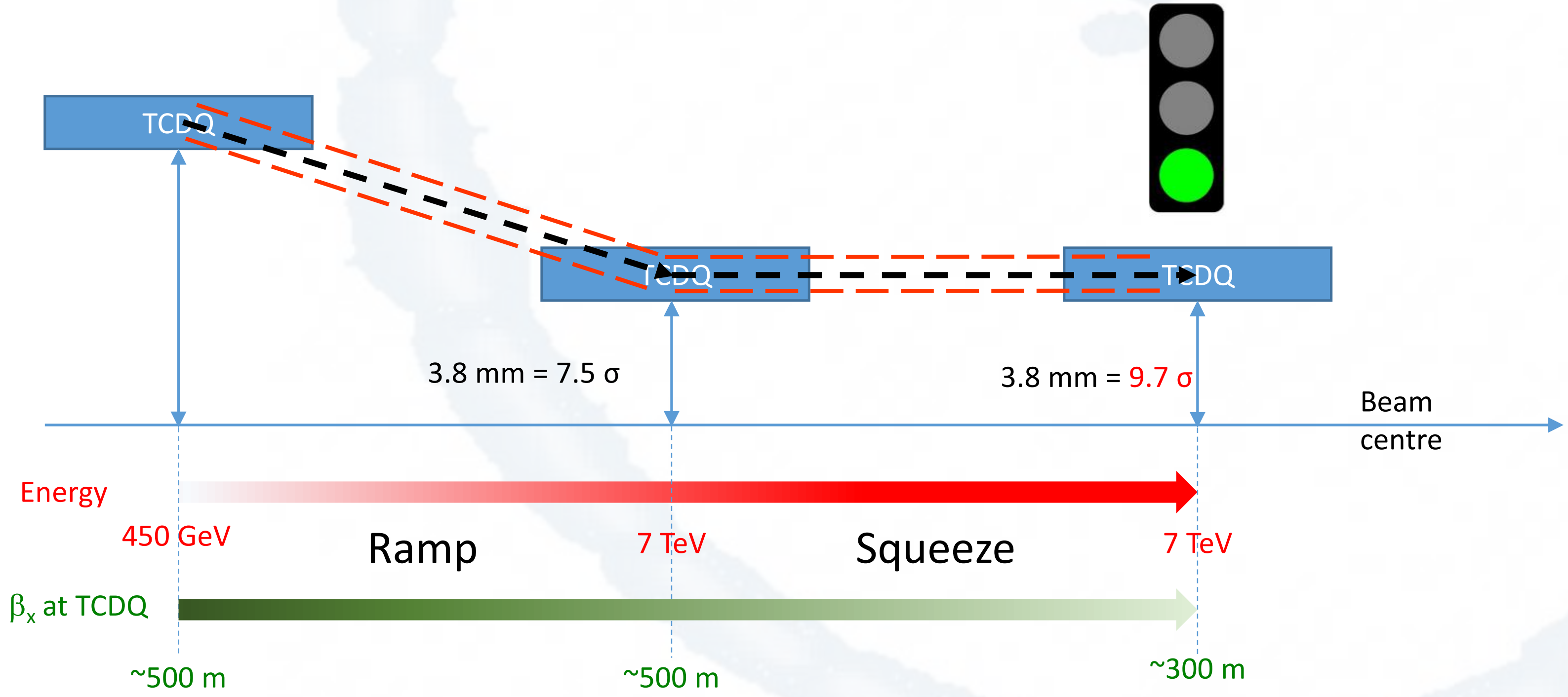




β* leveling at TCDQ and BETS limits

- In order to guarantee the correct TCDQ positioning during the ramp ➔ added **redundant HW interlock** (BETS TCDQ): **fully independent** check of **position wrt energy** (pre-defined functions and limits, ~ ± 1σ)
- **Not possible varying TCDQ position** outside BETS limits **during β* squeeze at fixed energy** ➔ impact on TCDQ aperture in σ ➔ protection ➔ β* reach

Can we set asymmetric limits? Not with present HW and no upgrade before LS3 but….



Arbitrary numbers to explain concept

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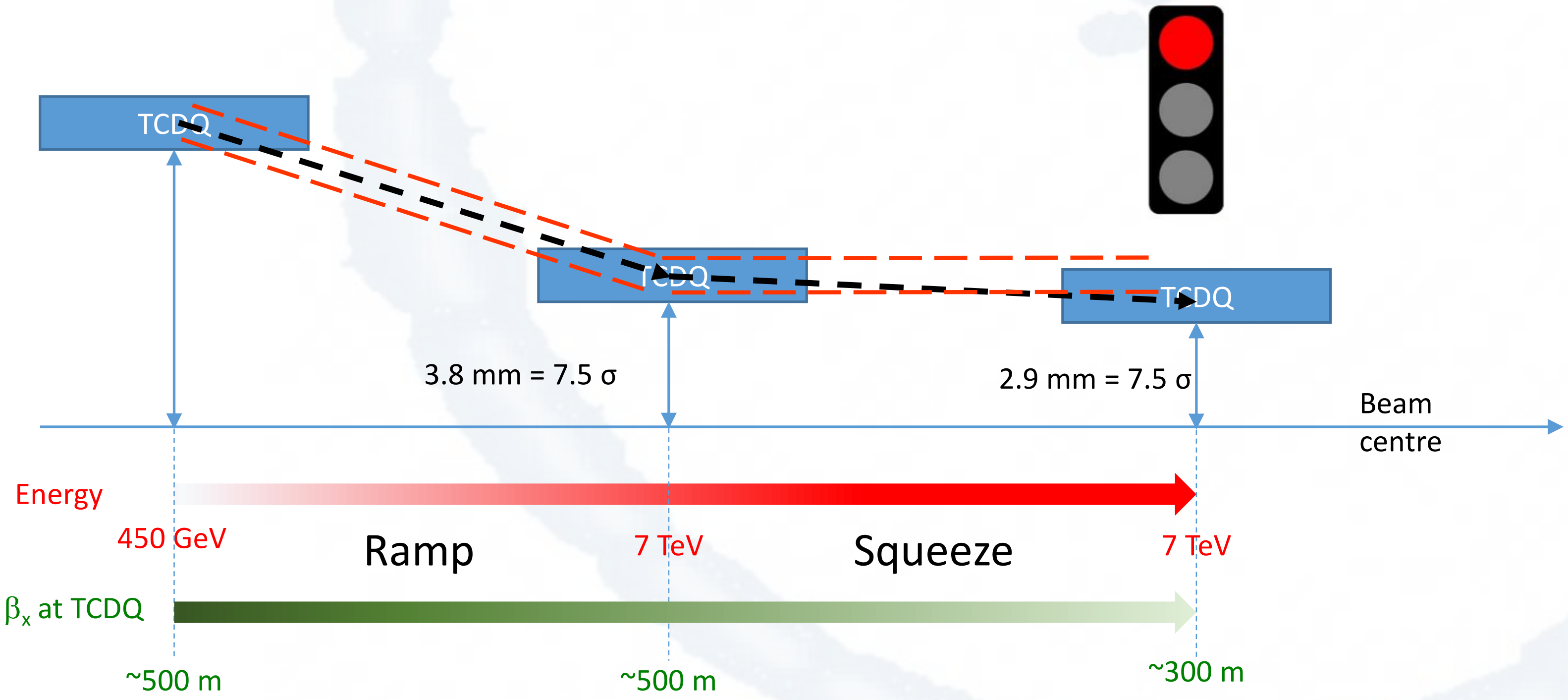

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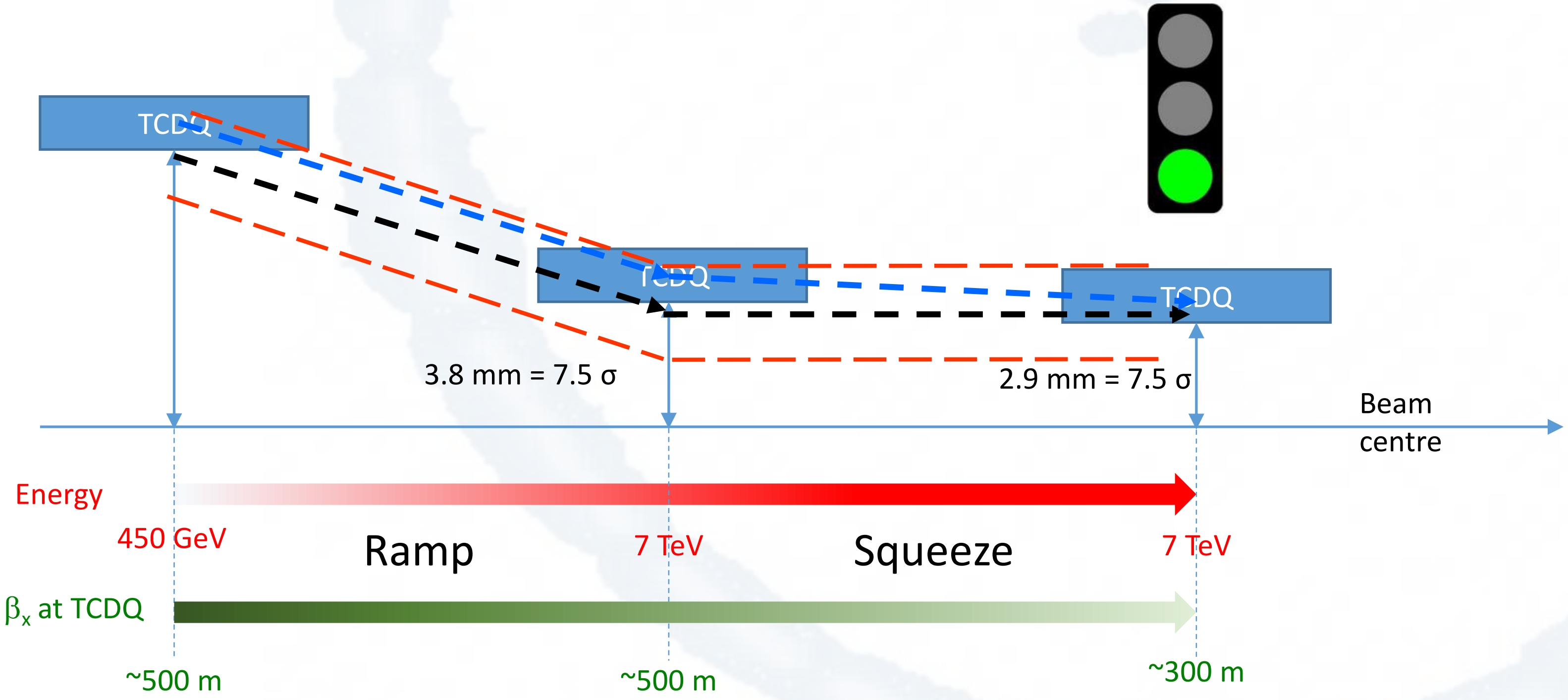
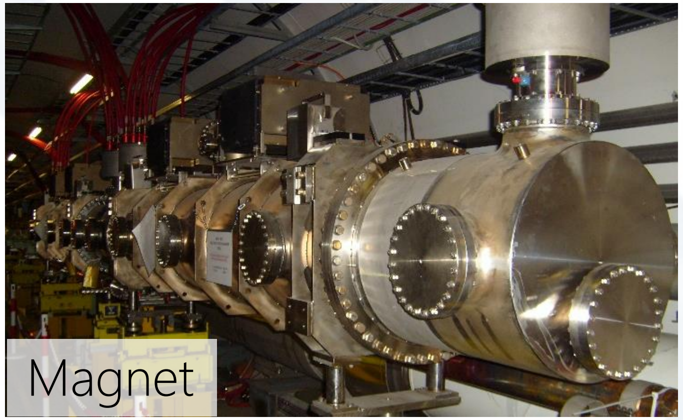


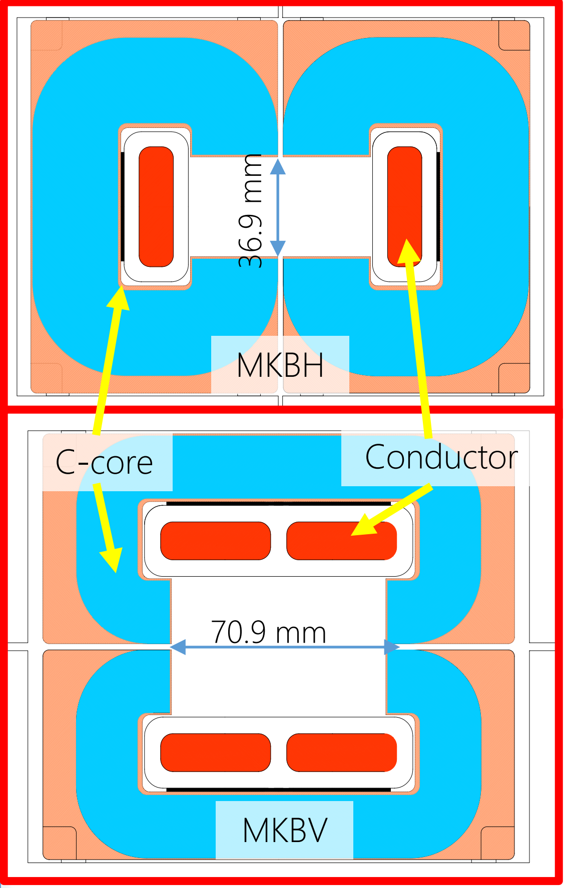
Arbitrary numbers to explain concept

Can we set asymmetric limits?
Not with present HW and no upgrade before LS3 but….

- Apply artificial offset between BETS **settings** and LVDTs
- Relaxed symmetric limits around settings (~± 2σ)
- Possible closing TCDQ during squeeze while insuring protection in case of asynchronous beam dump
- Position limits insure that hierarchy wrt other collimators is respected and that TCDQ not too close to the beam

MKB: Dilution Kickers





MKBH much more sensitive to erratics!

After LS2 upgrade operation at 7TeV with lower voltage than pre-LS2 operation at 6.5TeV ➔ reduced risk of erratics on MKBH!

	Pre-LS2 (6.5 TeV)	Post-LS2 (7 TeV)
Number of magnets per ring	6 V – 4 H	6 V – 4 H
System deflection angle	0.277 - 0.278 mrad	0.278 - 0.277 mrad
Kick strength per magnet	1.000 – 1.508 Tm	1.077 – 1.624 Tm
Magnet poles gap	70.9 – 36.9 mm	70.9 – 36.9 mm
Operating charging voltage	13.7 – 24.7 kV	14.8 – 23.5 kV
Field oscillating frequency	13.2 – 13.0 kHz	13.2 – 13.0 kHz
Magnetic length	1.2 – 1.9 m	1.2 – 1.9 m

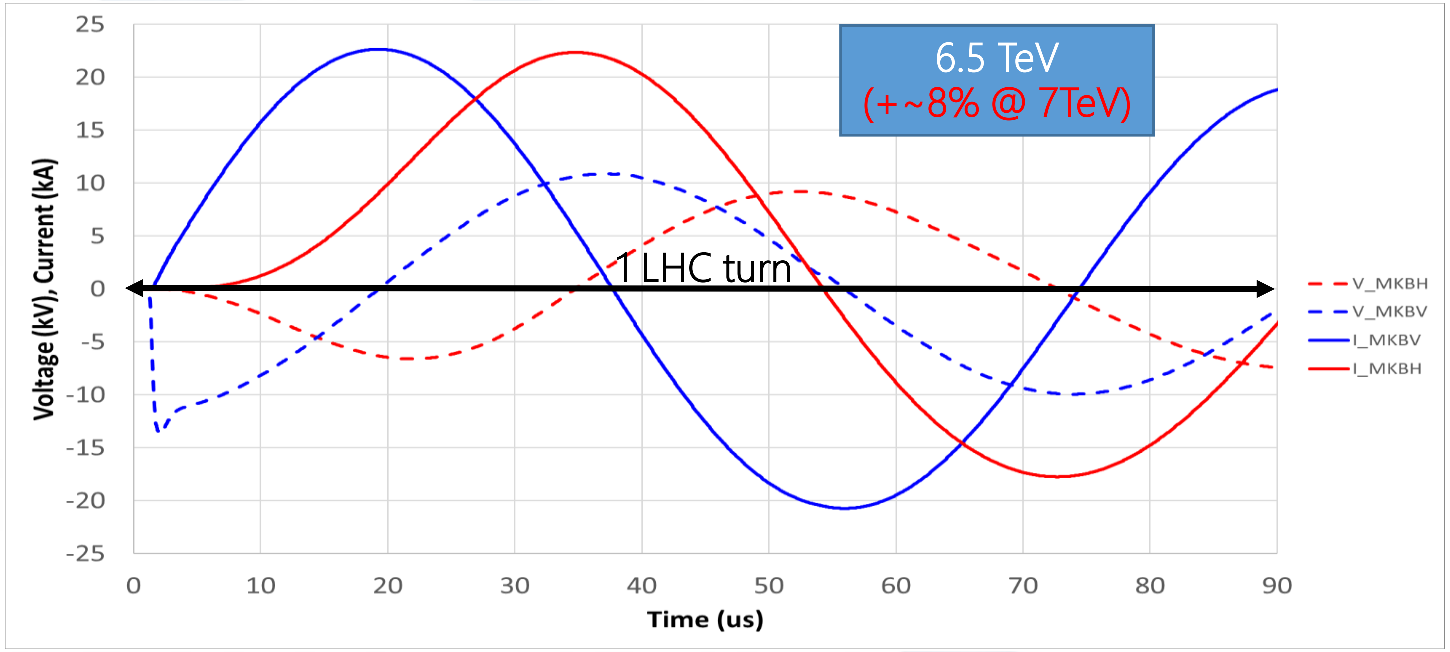
- No beam screen (no circulating beam)
- Magnet housed in a vacuum tank

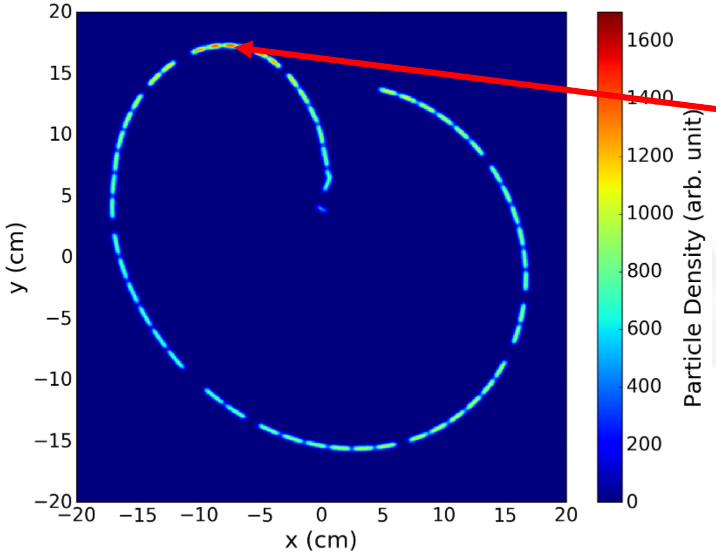
Risk of flash-over in magnet during nominal dumps!

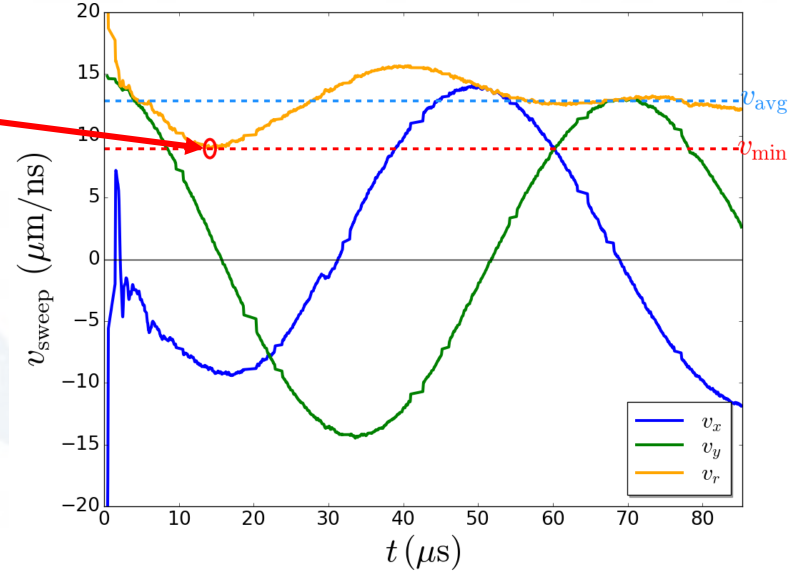
Increased risk of flashover at 7TeV!

MKB Waveform and Dilution Pattern @ TDE

MKBH and MKBV are powered with damped sinusoidal waveforms, shifted by 90° in phase, resulting in an e-shaped pattern at the TDE front face (~10% higher Voltage in MKBV than MKBH ➔ slightly higher risk of flashover)

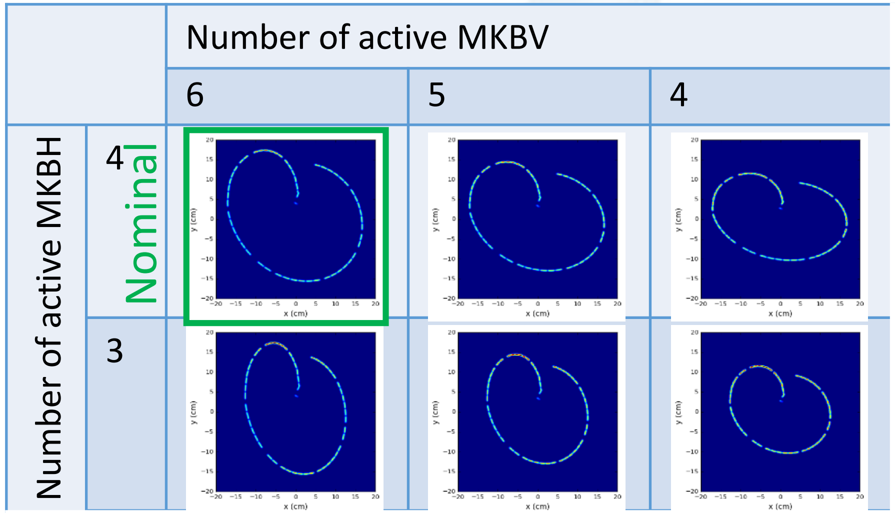






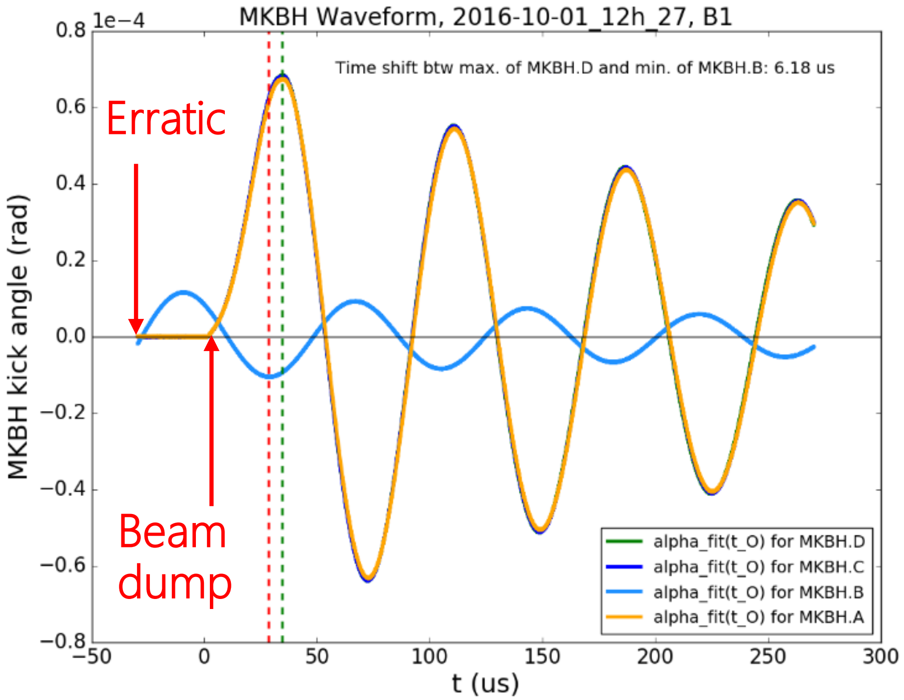
The proton density at the TDE strongly depend on the horizontal sweep velocity: maximum density corresponds to minimum velocity

MKB Erratic ➔ Missing Dilution

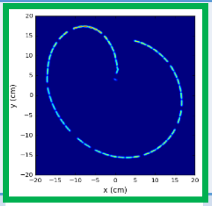
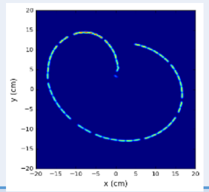
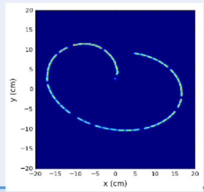
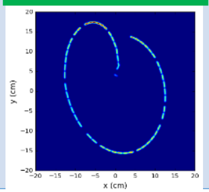
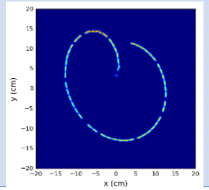
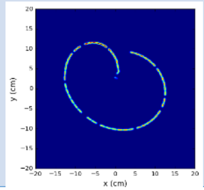


Pre-LS2: in case of MKB erratic no re-triggering of remaining kickers occurs ➔ synchronous beam dump request ➔ dump executed within 1 LHC turn

Original assumption: up to 2 missing MKBs in case of 1 MKB spontaneously firing and perfect anti-phase



MKB Erratic ➔ Missing Dilution

		Number of active MKBV		
		6	5	4
Number of active MKBH	4 Nominal			
	3			

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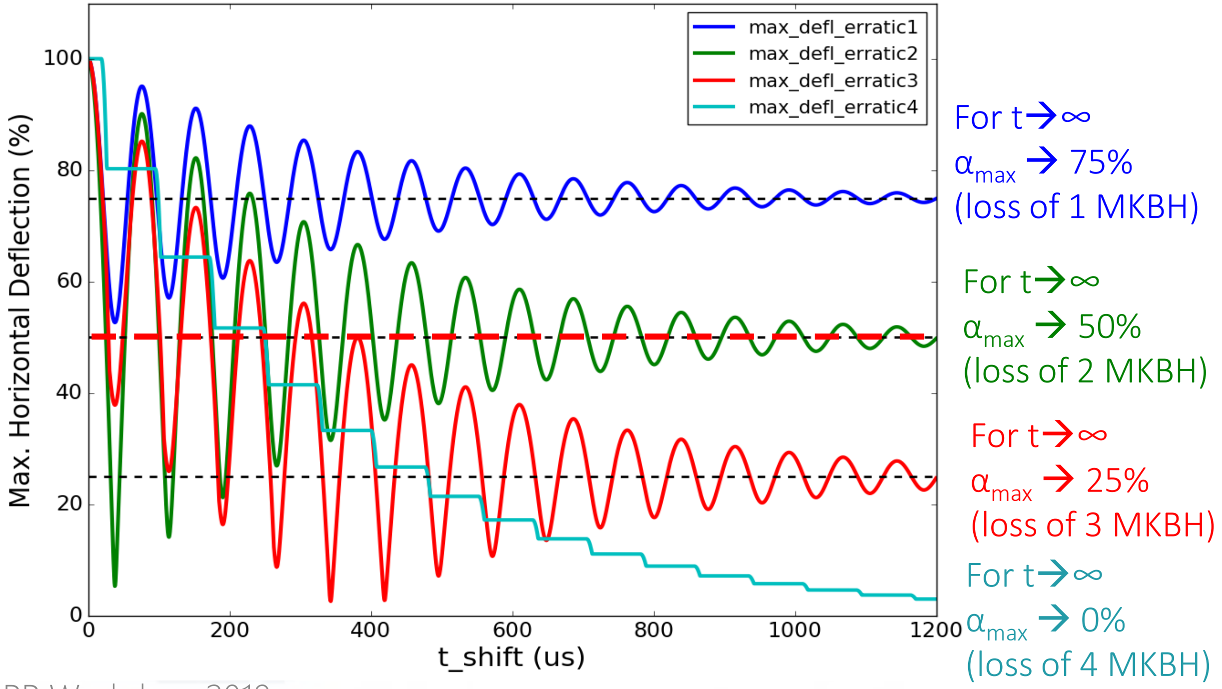
New failure: Erratic on MKBH during tests @ 7 TeV without beam ➔ Parasitic EM coupling through re-triggering line ➔ firing of neighboring generators ➔ Possible loosing ≥ 2 MKBs



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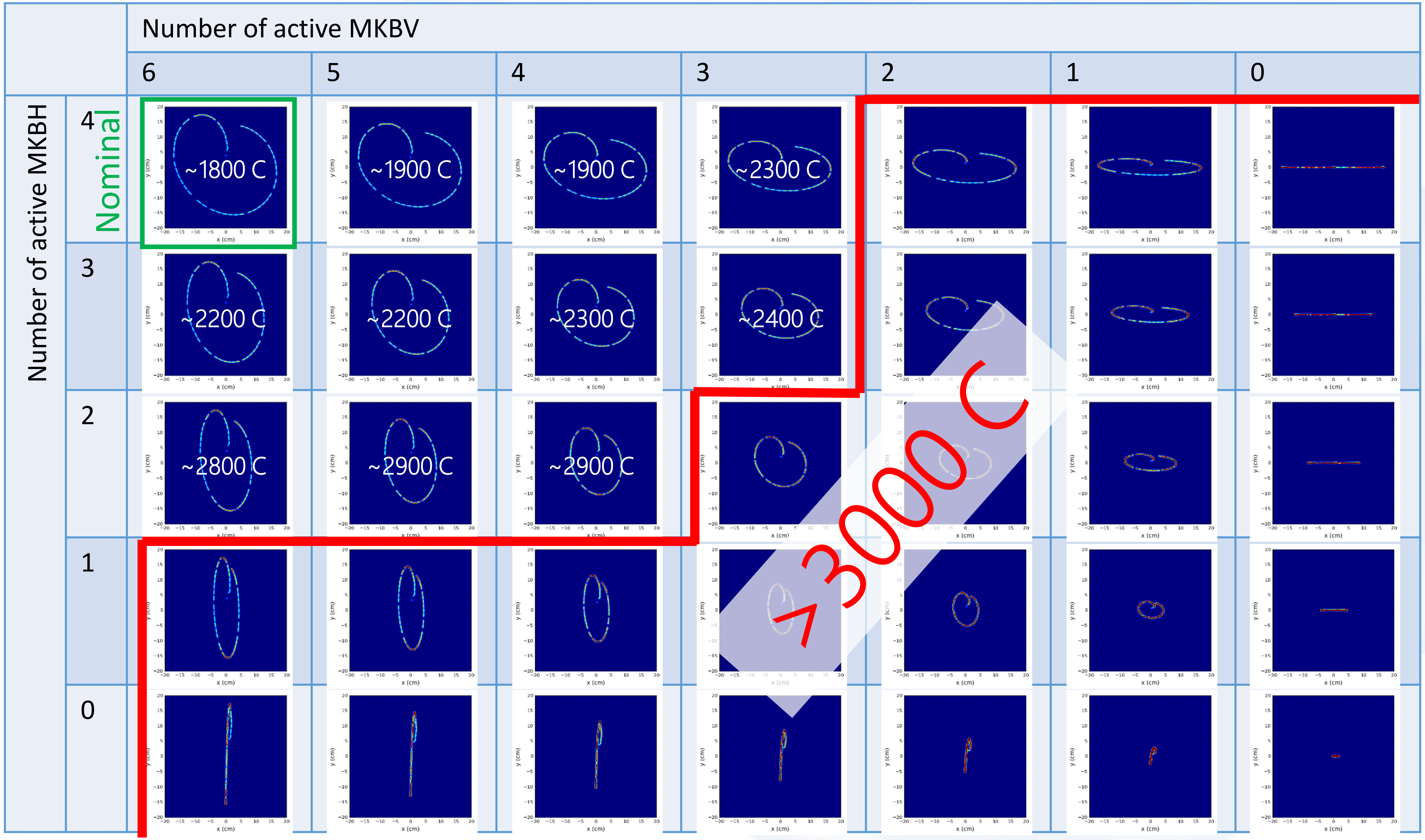


All possible patterns in case of loss of 1➔4 and 1➔6 dilution kickers and temperatures for HL-LHC beams (2.3e11 ppb) ➔ possible going above 3000 C

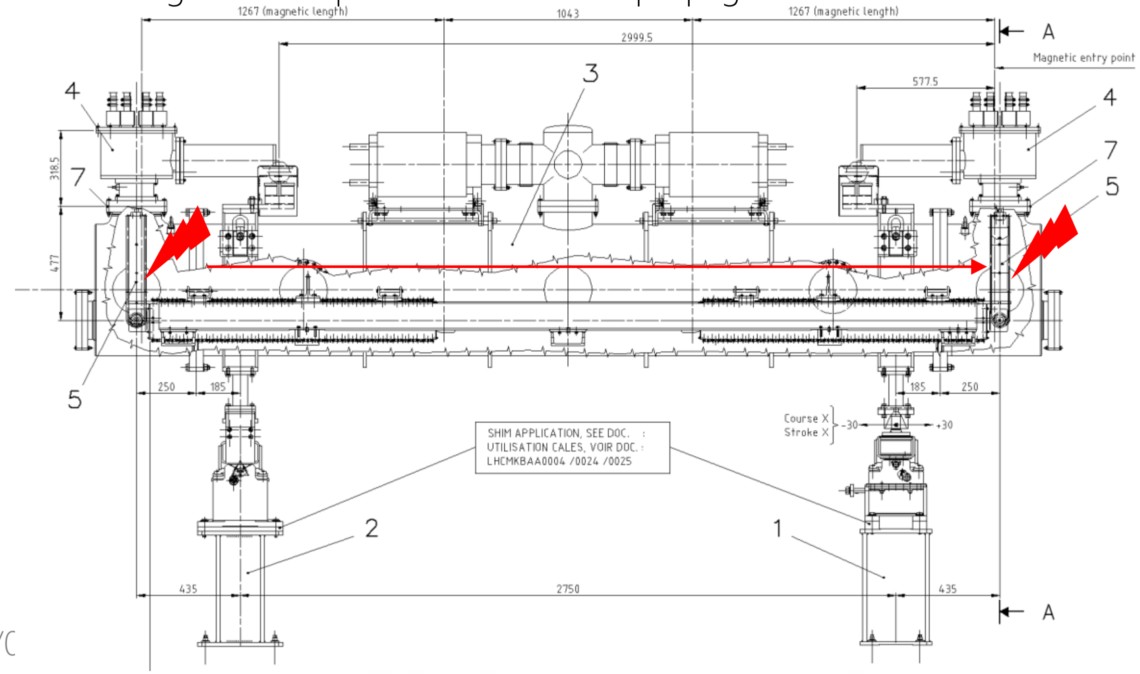
Loss of MKBH more likely (80% higher generator voltage than MKBV) and more critical (only 4 kickers)

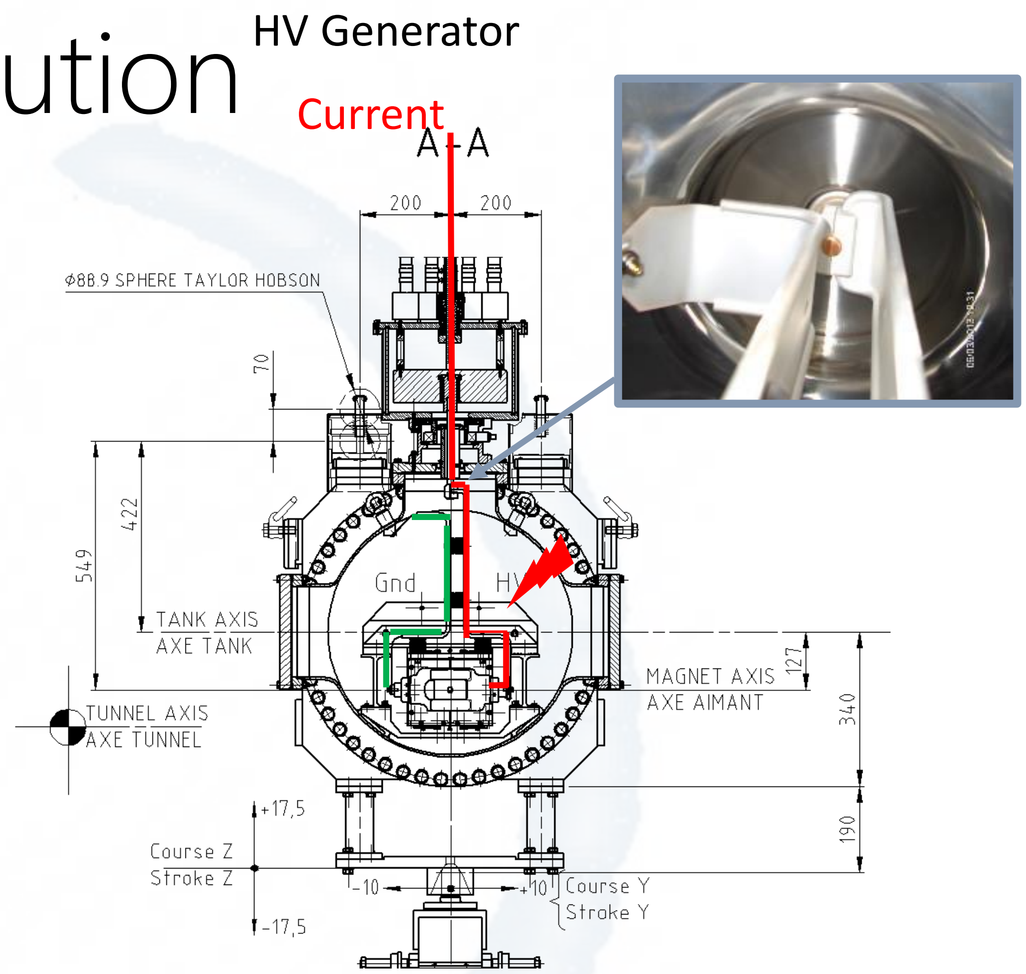
Possible limit on number of ppb and beam spot-size (front window)

MKB retriggering will be implemented in LS2 to avoid anti-phase in case of erratic (Nicola' s talk)

MKB Flashover – missing Dilution

- During a **nominal dump** a flash-over can occur:
  - Between HV and grounded bus-bar
  - Between HV and magnet ground
  - Between HV and vacuum tank
  - On the surface of an isolator
  - On the surface of the HV feedthrough
- The flash-over can propagate through the plasma to the magnet sharing the same vacuum tank
  - Original assumption: instantaneous propagation ➔ simultaneous loss of 2 MKBVs





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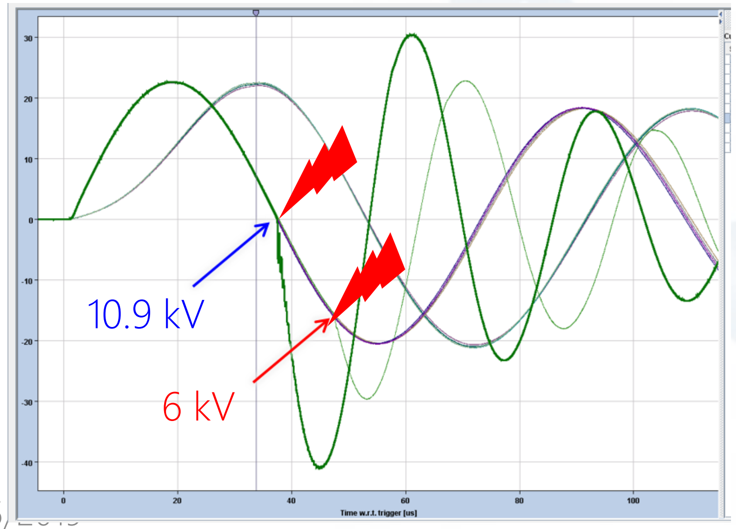

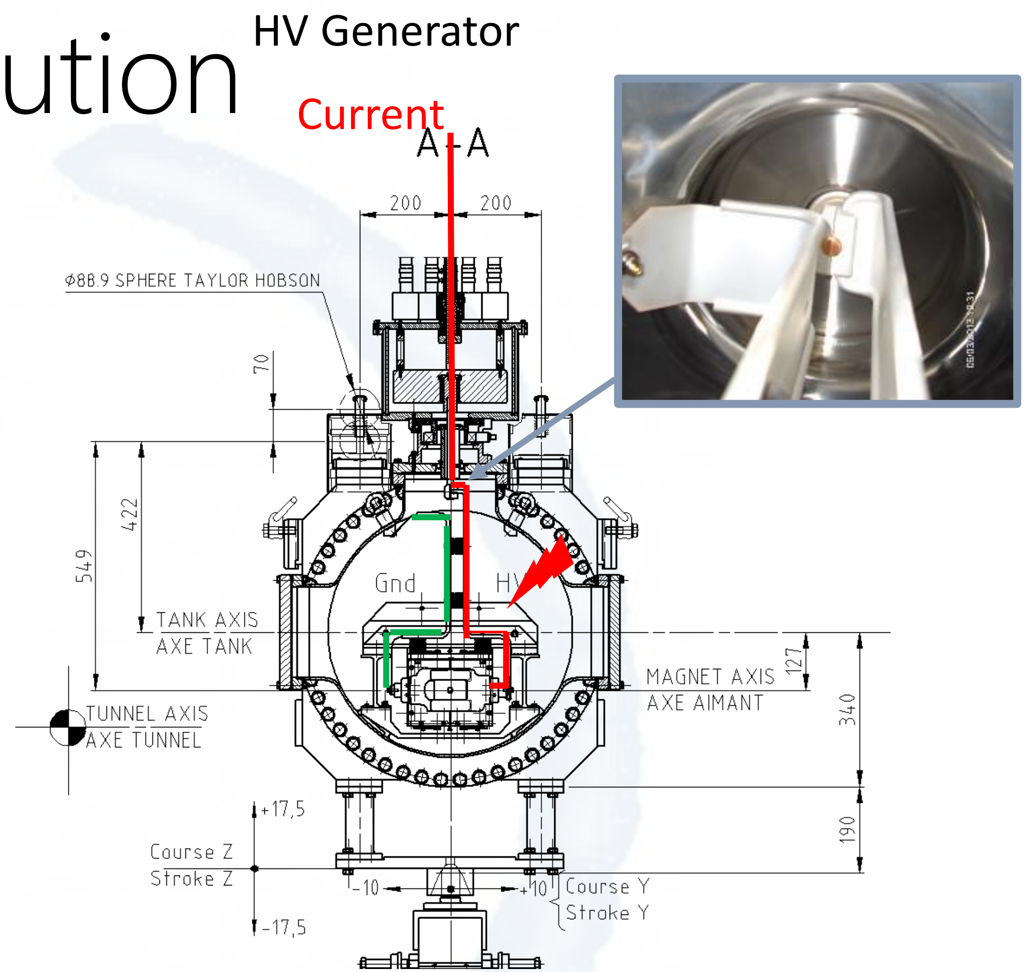

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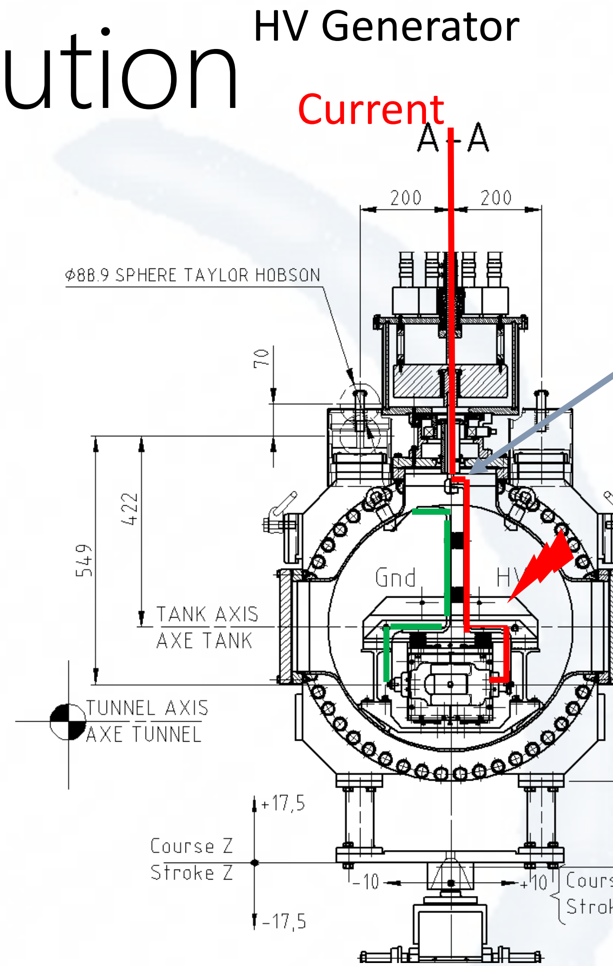

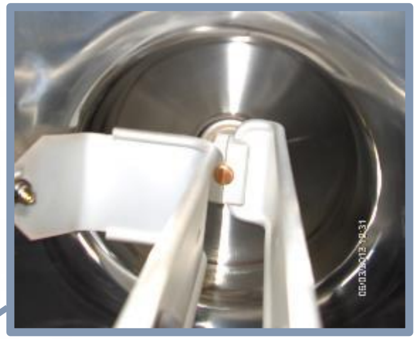

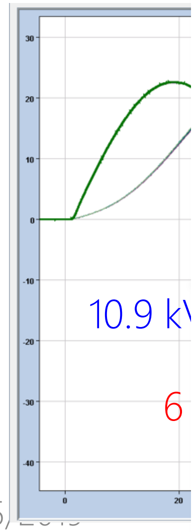

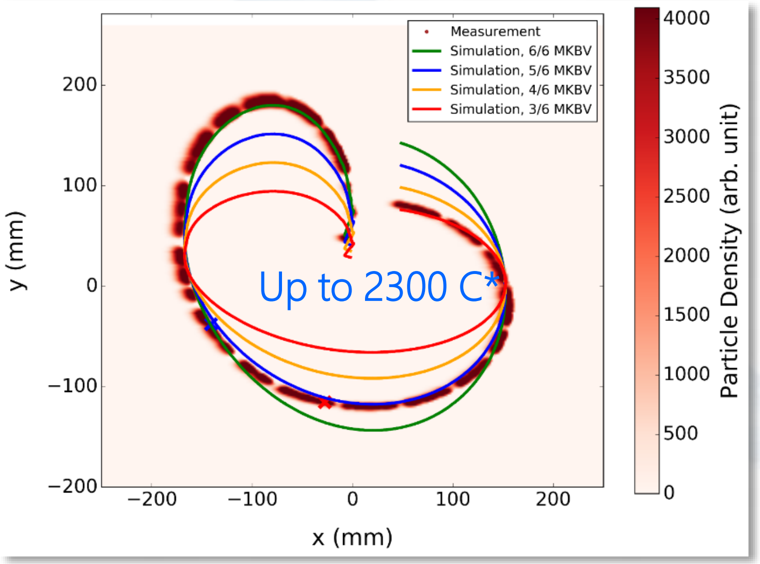

*HL-LHC beams

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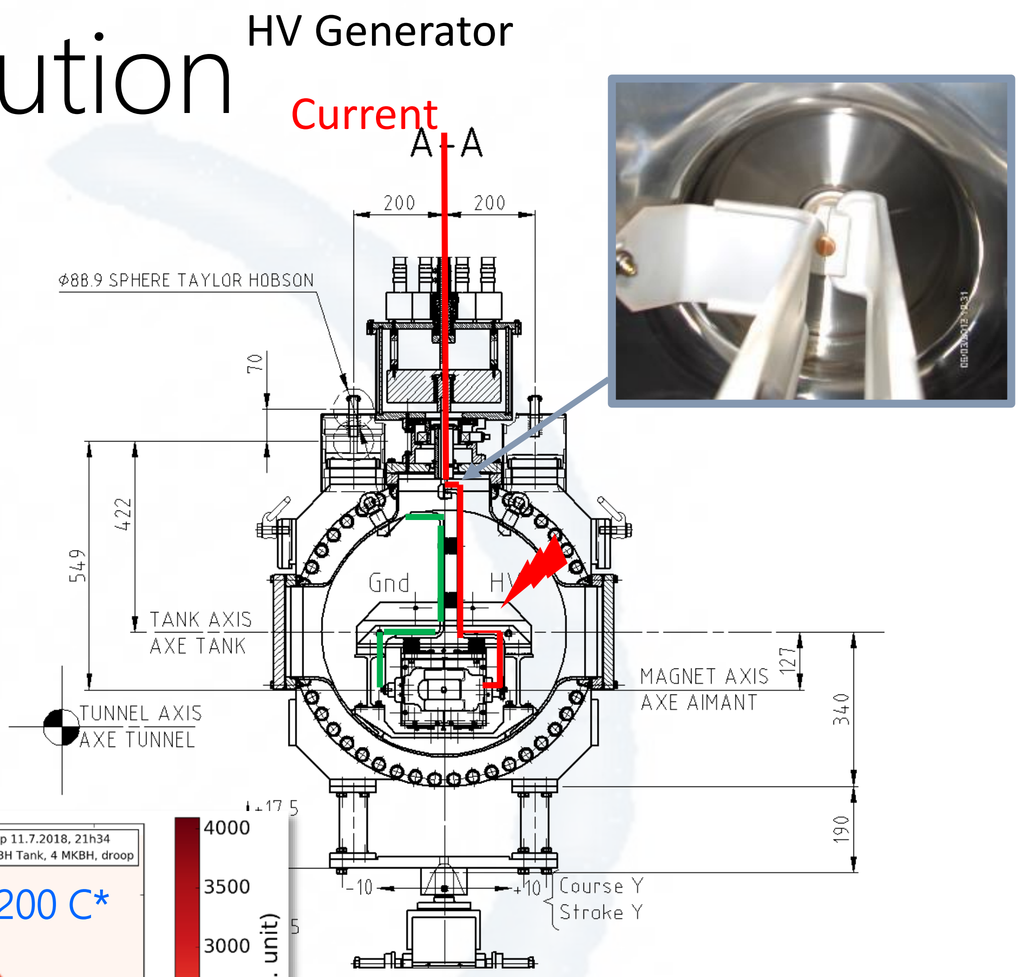
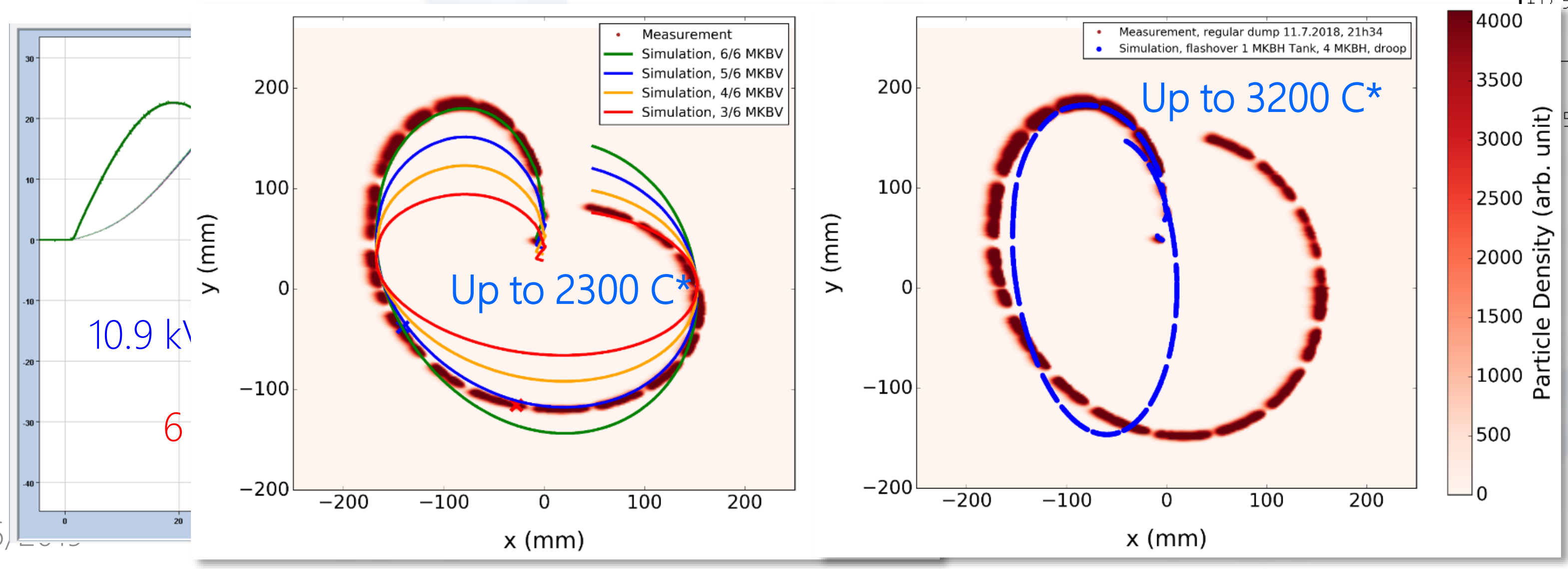
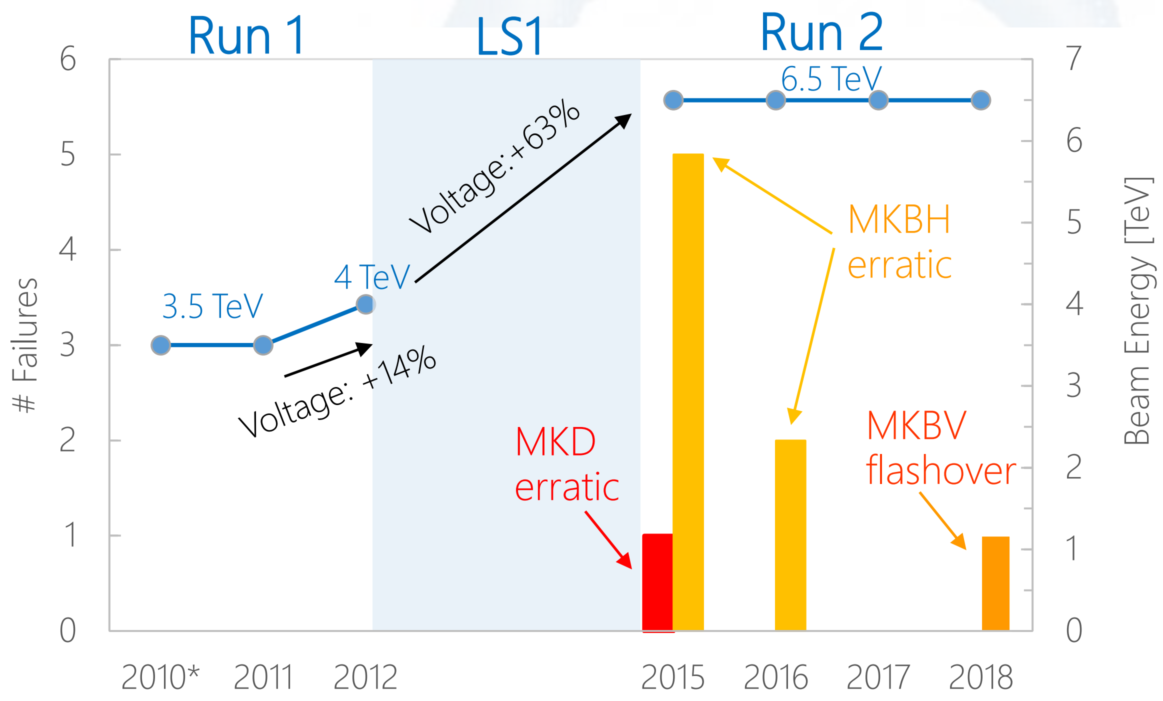




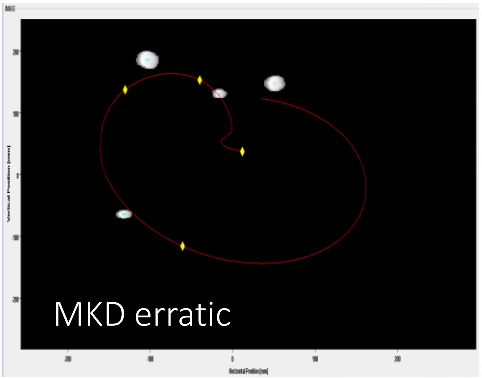
Higher risk for MKBV but more critical in MKBH (only 4 kickers)
Strong dependence on ppb and number of bunches: possible mitigating by non injecting last train.

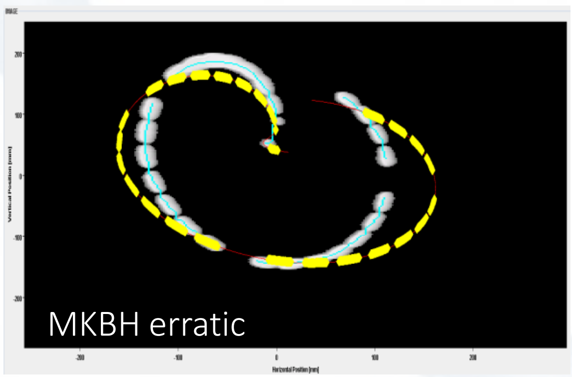
*HL-LHC beams

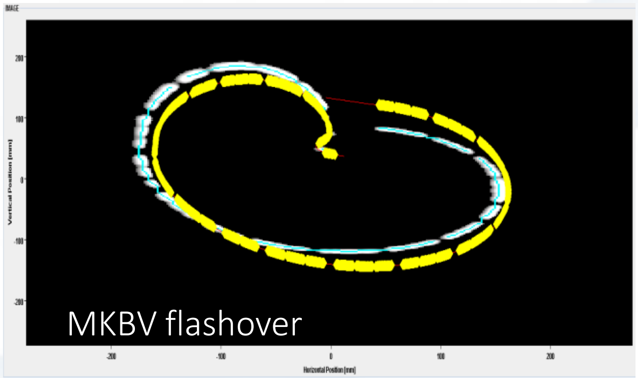
MKD/MKB Failure History



- ❑ 1 MKD erratic ➔ asynchronous beam dump with 4 nominal bunches in the machine ➔ no mis-kicked bunch and clean extraction
- ❑ 7 MKBH erratics ➔ loss of horizontal dilution. Clear correlation with dirt and sparking activities. During Run 2: Improved with improved cleaning, sealing and dust raps plus lower resistor on GTO gate-cathode (less sensitive to sparks)
- ❑ 1 MKBV flashover ➔ loss of vertical dilution. Magnet in lab ready for inspection (no clear sign of sparks with endoscopy)







As expected:
- Increased number of erratics when increasing generator Voltage (energy)
- Higher number of erratics on MKBH
- Higher number of flashover on MKBV

Strategy vs Time

Increase reliability: reduce risk of erratics (lower Voltage), monitor switch status and faster reaction in case of failures.

Goal: ≤1 asynchronous beam dump and partial dilution per beam per year at 7TeV

- Several upgrades foreseen on generators and control system in LS2 including MKB re-triggering (<erratics and no anti-phase, Nicola's talk)
- If needed, depending on MKBV inspection result, apply required modifications to improve HV bus-bars insulation in YETS
- If approved: add 2 MKBH per beam in LS3 ➔ reduce Voltage by 30% in generators (<erratic) and magnets (<flashover) ➔ less sensitivity to MKBH failures.