
CERN

LBDS - Changes during LS2

MPP Workshop 07.05.2019 – Nicolas Magnin for TE-ABT

With the precious help of my TE-ABT colleagues, many thanks to all of them !

Plan

- Present Limitations and Actions Taken
- Upgrade of HV Generators
- Upgrade of Re-Triggering System
- Commissioning Plan
- Summary

Present Limitations and Actions Taken

Main limitation on generator side is "Erratic" trigger of HV generators

- Risk of erratic firing strongly depends on voltage
  - Could be an issue for operation at 7.0 TeV
- An erratic on MKD causes an asynchronous dump with risk to protection devices
  - With higher beam intensity and energy, MKD re-trigger time should be reduced
- An erratic on MKB causes a partial dilution with risk to dump block
  - Missing MKB kicker cases should be limited

Two types of action taken during LS2:

- Limit the occurrence of erratic (= Upgrade of HV generators)
- Limit the consequences of erratic (= Upgrade of re-triggering system)

HV Generator Upgrade

HV Gen Upgrade: Add 3rd Capacitor

Increase of the principal capacitor value by ~18%

→ reduction of voltage by ~9% for the same current:

- 7 TeV: 28.7 kV today vs. 26.6 kV modified
  (~ 6.4 TeV today)
- 7.5 TeV: 31 kV today vs. 28.4 kV modified
  (~ 6.9 TeV today)

Pros:
significant reduction of probability of SEB and sparking related failures wrt today situation

Cons:
Rise time increase by ~ 220 ns

Cost effective solution – adding 3rd small capacitor

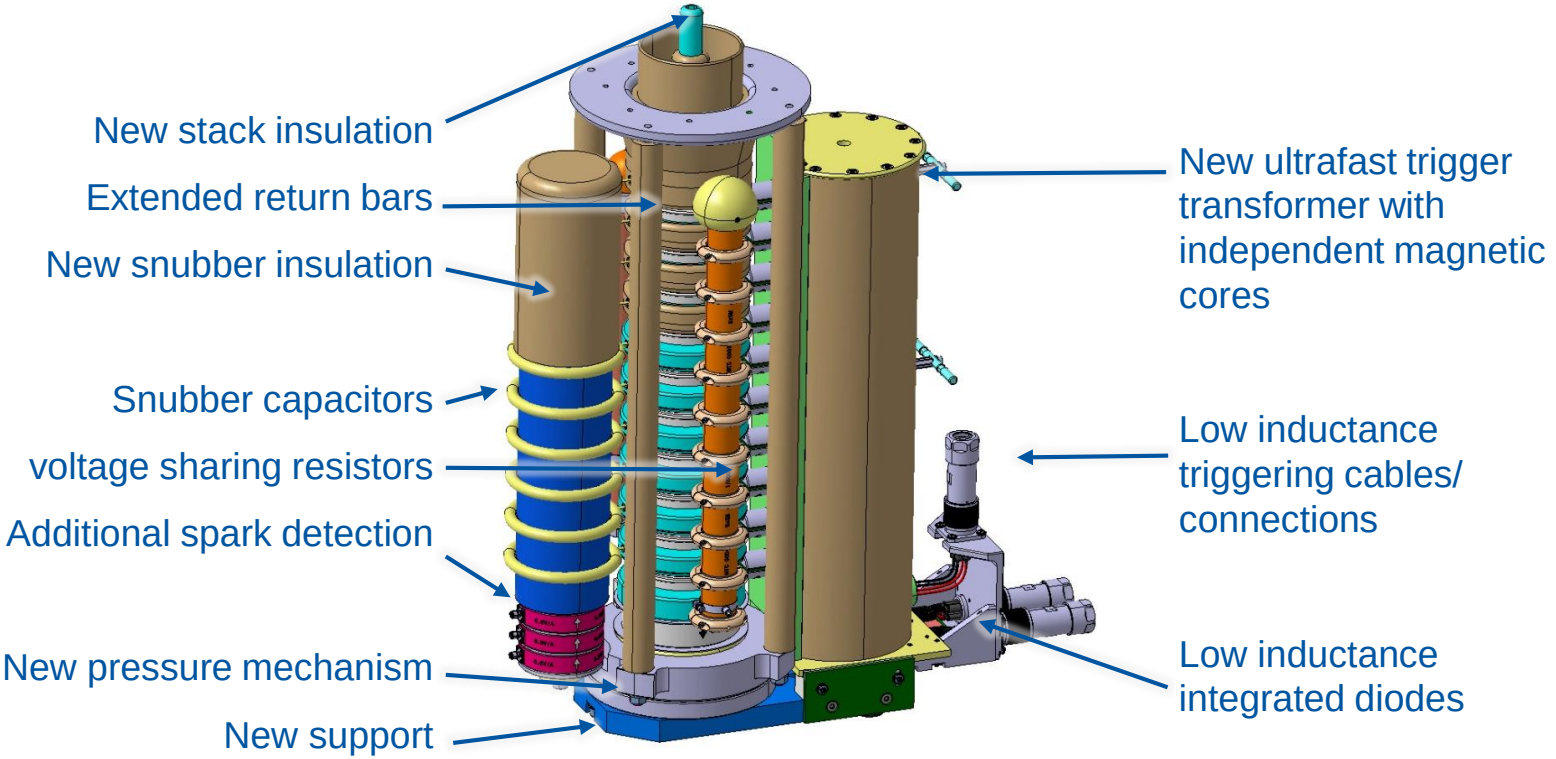
HV Gen Upgrade: New GTO Stack

Re-design of the GTO stack and its accessories

(voltage sharing resistors, snubber capacitors, HV dividers) in order to:

- Reduce the E-field down to < 1.5 MV/m (1/2 of air ionisation limit)
- Increase its sparking immunity in case of pollution
- Simplify its maintenance

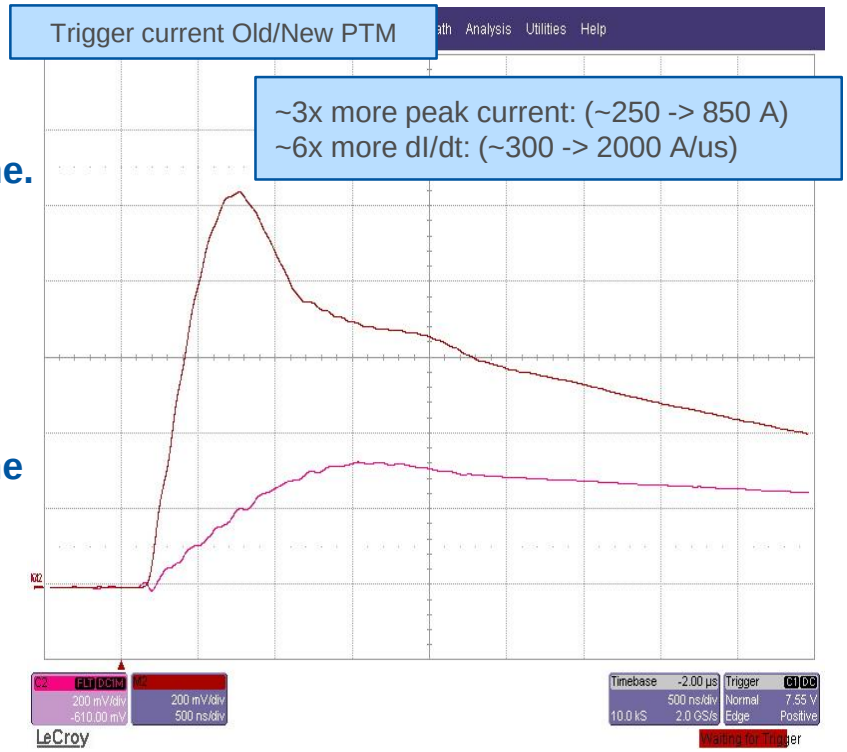
Cons: increased stack inductance (165 nH vs 132 nH today) – **rise time increase by ~ 15 ns**



HV Gen Upgrade: New PTM

New Power Trigger Module (PTM):

- Increase trigger current and dI/dt for a better GTO switching
  => Increased lifetime of GTOs.
  => Lower turn-on delay and magnet current rise-time.
- Reduce propagation delays in low voltage electronics
  =>Lower global LBDS Re-Trigger time.
- Precise fixed Re-Trigger input level
  => Avoid partial triggering of PTM (could damage the stack)
- Improve diagnosis of output current and HV IGBT state
  => Detect IGBT problems before breakdown (PTM erratic)



Gain on trigger propagation delay in low voltage electronics:

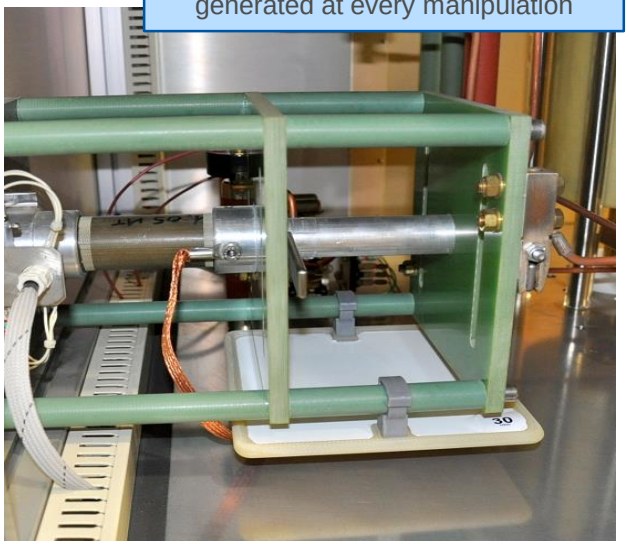
~50 ns faster than actual PTM

HV Gen Upgrade: Other Improvements

Reduction of dust generation and protection from ingress:

- Separation of sensitive compartments
- Dust trap under mechanical earthing switch
- Modification of electromechanical safety relay supply
  Relay powered with 50 Hz AC current:
  Vibrations of spring generates metallic dust inside HV generators
  => Relay powered by DC current now.

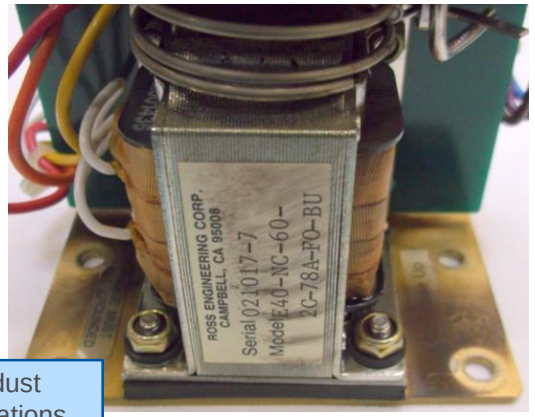
Manual Earthing Switch: Metallic dust generated at every manipulation



New compensation capacitor:

- First pulse at 450 GeV after a pulse at 6.5 TeV slightly different (Problem of magnetization of capacitor metallic case)

- **Not a safety issue,** but many XPOC error on this first pulse at 450 GeV, we had to increase the tolerance.



Safety relay: Metallic dust generated by spring vibrations

Impact of upgrade on AG length

All time measurements depend on energy or generator:

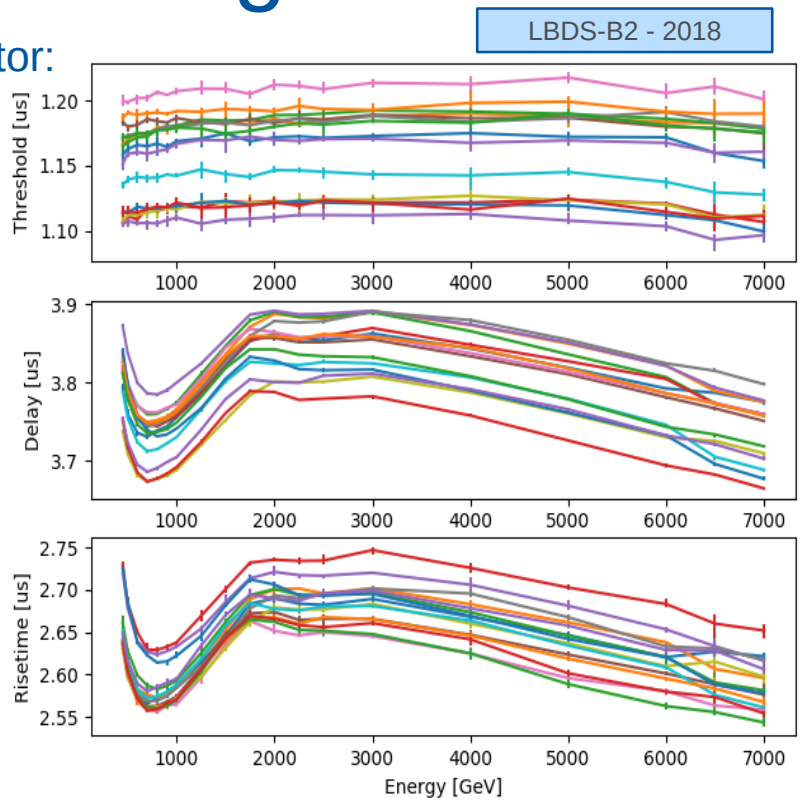
- Threshold time
- Delay time
- Rise time = (Delay - Threshold)

Min AG length = Max(Delay) - Min(Threshold)
Over all energy range and all generators

On first 2 upgraded generators:

- Small increase ~70ns of Min AG length, but can be optimised and margin is sufficient

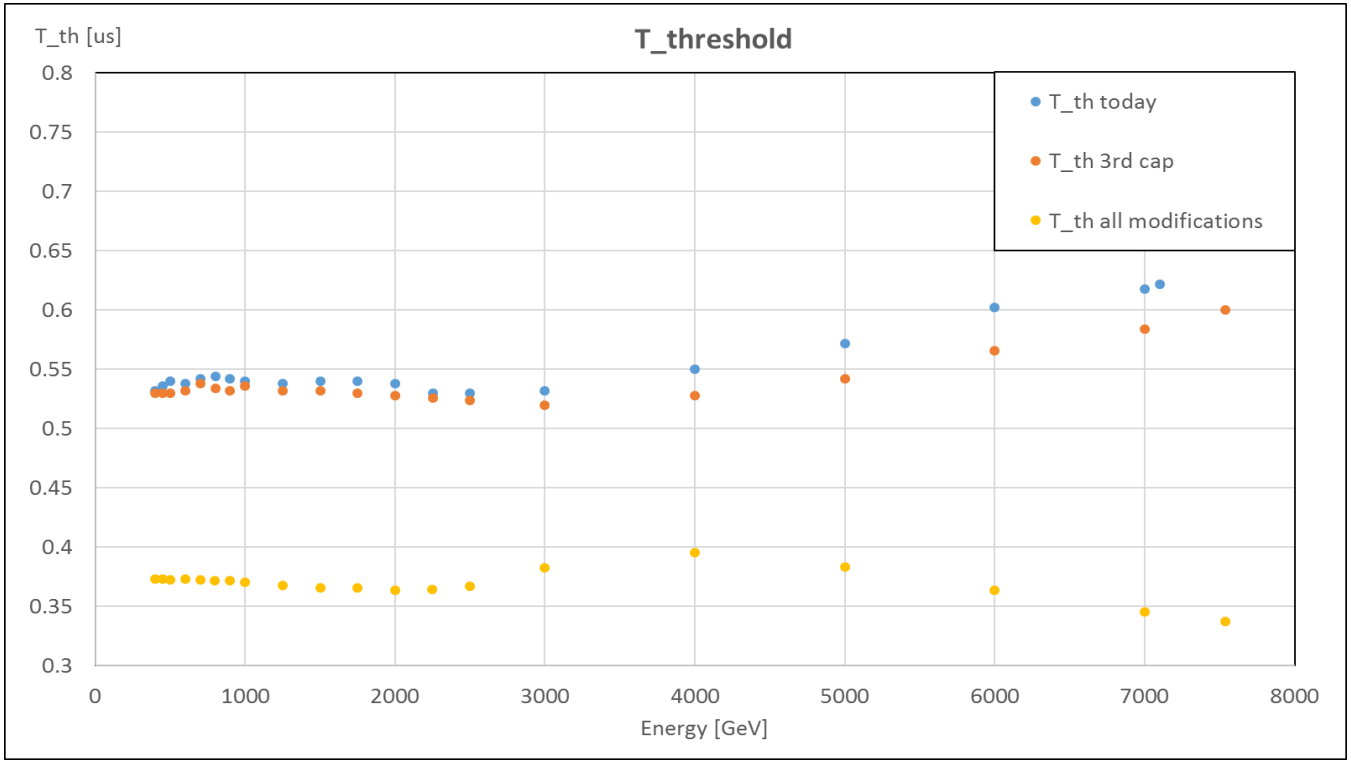
=> no request for more AG length = 3us



Measured between 450 – 7000 GeV:

System	Min Rise time [us]	Max Rise time [us]	Min AG length [us]
JU3 (series #1)	2.708	2.799	2.822
JU4 (series #2)	2.633	2.738	2.756
LBDS-B1 2018 (15 Generators)	2.535	2.731	2.751
LBDS-B2 2018 (15 Generators)	2.543	2.747	2.762

Impact of upgrade on Trigger Delay



Combination of increased capacitor and new triggering system:

Threshold time = Trigger Delay **lowered by >100ns (= Faster Re-Trigger time)**

(Measured only on 1 generator, before / after upgrade
it may vary with coming series of 30 generators…)

HV Gen Upgrade Summary

(MKBV works at lower voltage than MKD/MKBH, so operational voltage unchanged)

Generator	MKD	MKBH	MKBV
Increased Main capacitor equivalent +18% total for -9% operating voltage	x	x	
New GTO switch assembly	x	x	
New ultrafast trigger transformer	x		
New HV trigger cables and connectors	x	x	x
New Power Trigger Module	x	x	x
New Safety Relay DC Power	x	x	x
New compensation capacitor	x		
Segmented panels independent access to non-sensitive compartments		x	
Dust trap & protection	x	x	

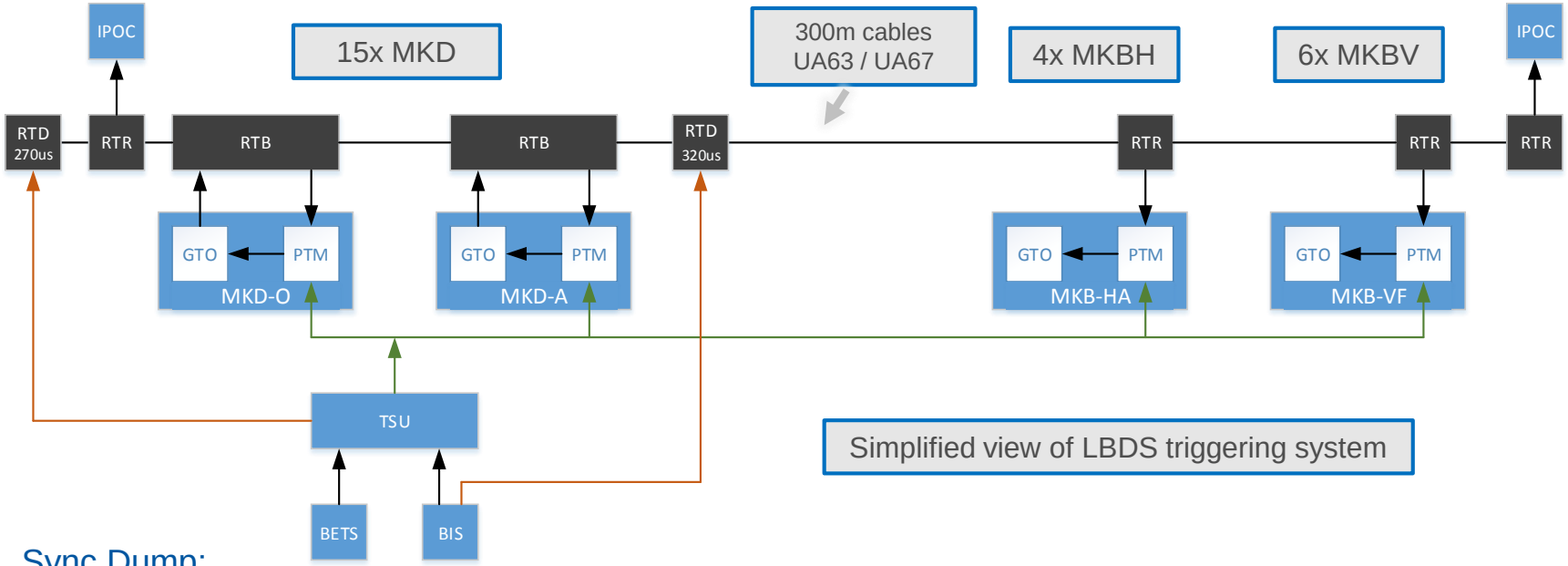
HV Gen Upgrade - Impact on RUN 3

	RUN 2 6.5 TeV	RUN 3 7.0 TeV	
MKD nominal voltage	26.7	25.6	kV
MKD rise time *	2.65	2.75	µs
Abort gap requested	3	3	µs
Total SEB failure rate probability MKD **	0.1	0.005	y^{-1}
Number of asynchronous dump / beam	<1	<1	y^{-1}
MKBH nominal voltage	24.7	23.5	kV
MKBV nominal voltage	13.7	14.8	kV
Total SEB failure rate probability MKB **	0.15	0.0003	y^{-1}
Number of partial dilution / beam	<1	<1	y^{-1}

*) Combined effect of loss in stack, loss in capacitor increase, gain with trigger transformer and with power trigger
**) HEH estimated: 5e-4 HeH/cm2/y. No measurements to confirm this value…

Re-Trigger System Upgrade

Current Re-Triggering System



Sync Dump:

- TSU cards receives Dump Request, and issue S-TRIG and A-TRIG (270us)
- When BIS goes faulty, CIBDS cards issue A-TRIG (320us) – In case of total TSUs failure

Async Dump – MKD erratic:

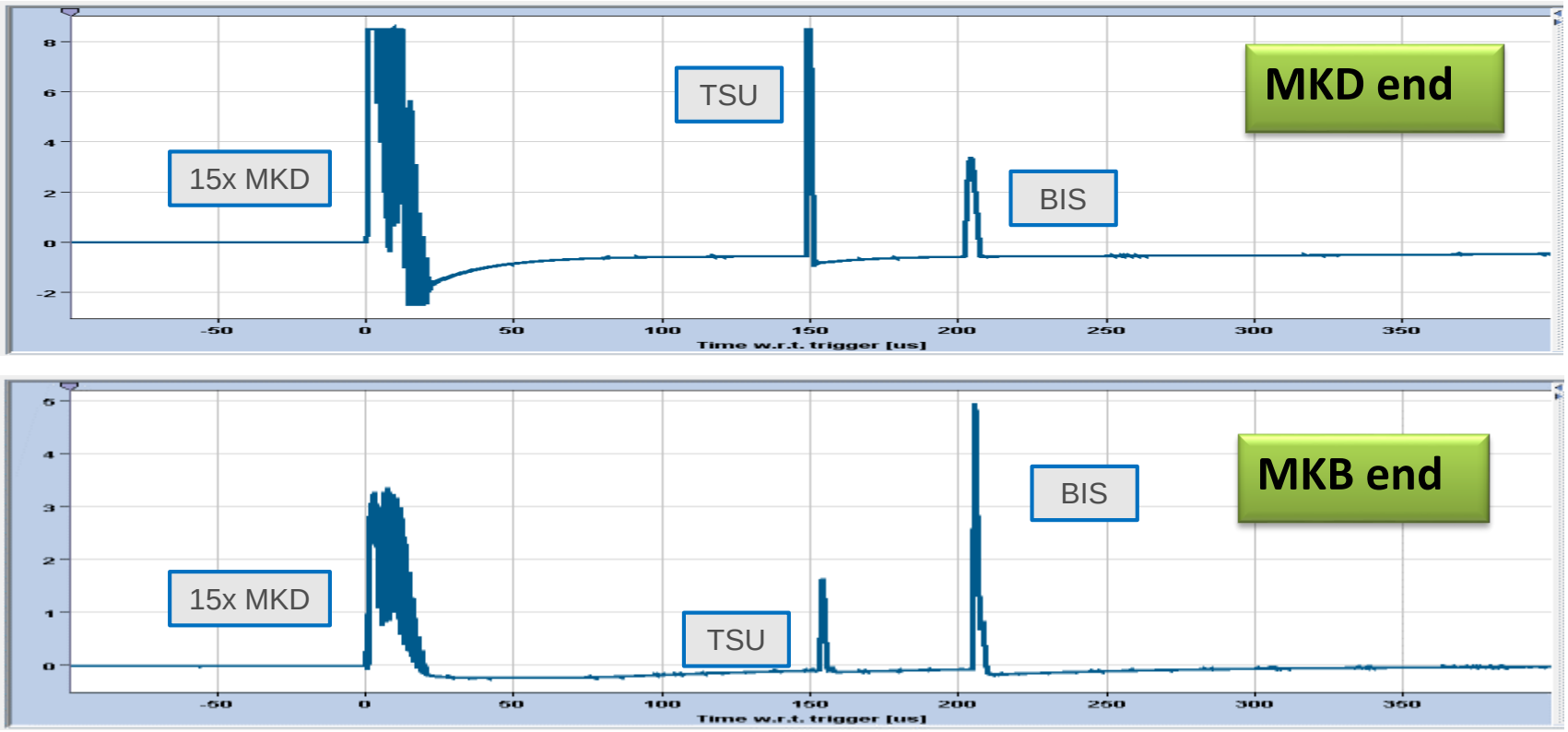
- MKD Re-Trigger boxes: Inject energy on the RTL in case of MKD erratic

Diagnosis: IPOC at both ends to the RTL

- Validation of RTL continuity
- Check TSU/BIS pulses presence (Redundant pulses not participating to normal dumps)

Re-Trigger Line Diagnosis - IPOC

Synchronous dump at **450 GeV**



Redundant pulses do not participate to normal dump, how do we know that they are OK ?

=> IPOC checks continuity of RTL, and correct amplitude/position of TSU /BIS pulses

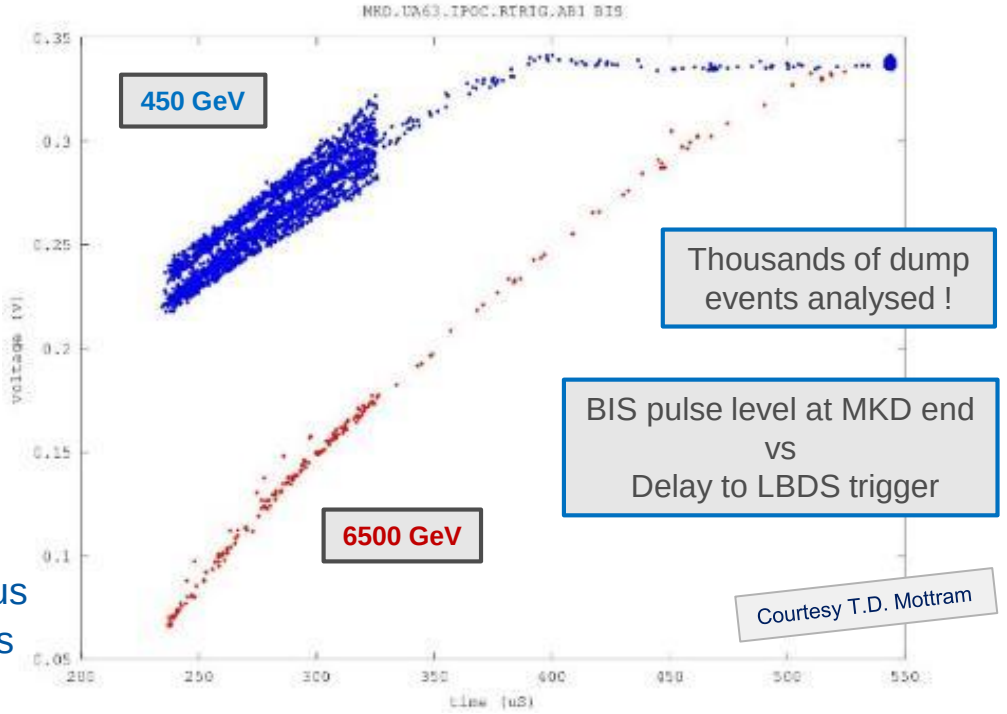
We see big attenuation of TSU / BIS pulses on the RTL

Attenuation of TSU / BIS Pulses

Problem of pulses attenuation is a **diagnosis** issue, **not a safety** issue
(Attenuation of pulses AFTER trigger of LBDS)

Attenuation of pulses on the RTL depends:
- Beam energy (Generators Voltage)
- Position of pulse wrt LBDS trigger

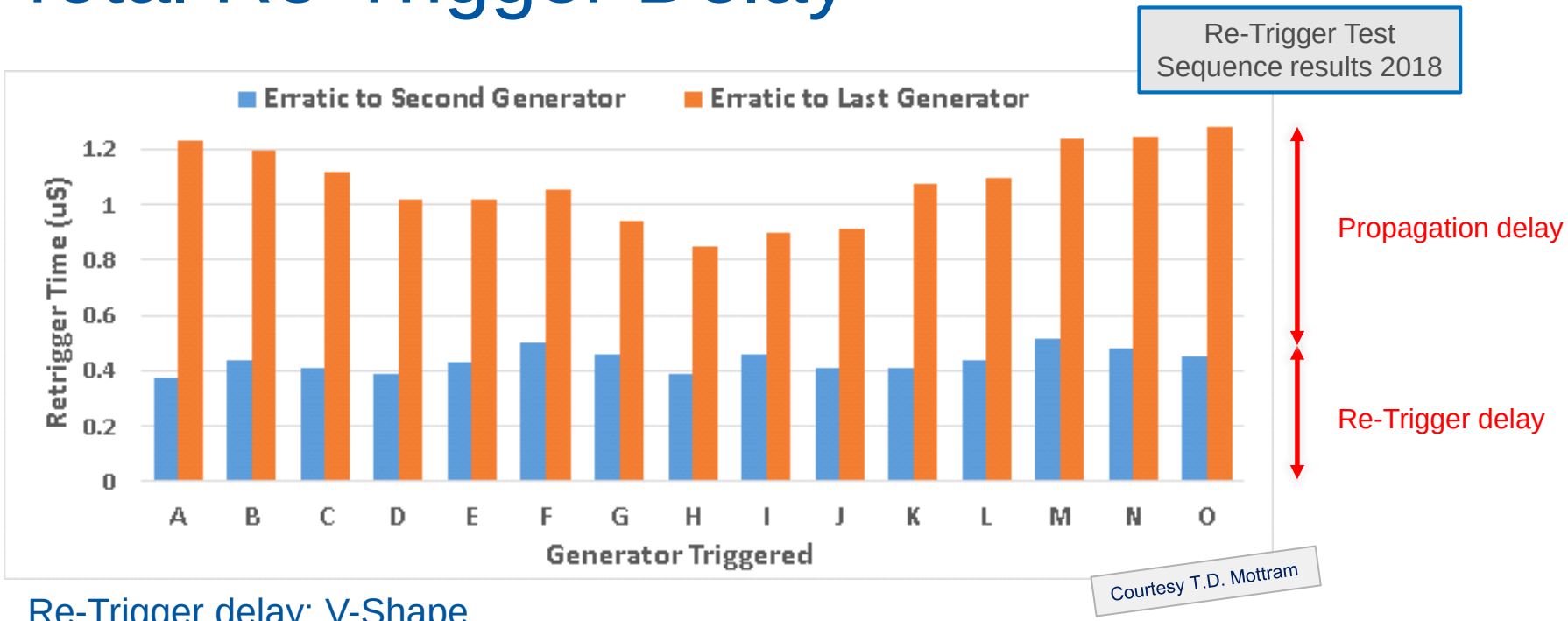
Due to TSU resynchronisation with beam and BIS loop A/B delays:
- TSU pulse (270us) moves between ~180-270 us
- BIS pulse (350us) moves between ~230-540 us



After simulations and measurements, this problem is understood:
It is due to **saturation of the output transformers in RTB**.
- Pulse propagated after dump see saturated transformers -> Strong attenuation
- With higher energy, the transformer saturates more -> Stronger attenuation
- Transformers desaturate slowly, so pulses sent later are less attenuated

=> New MKD RTB design is needed to eliminate this diagnosis problem.

Total Re-Trigger Delay



Re-Trigger delay: V-Shape

- Detection delay is almost constant (<500 ns)
- Propagation delay depends on which generator self-triggered (~900 ns -> ~1300 ns)

To diminish energy deposition on absorbers, shortest total re-trigger delay is desirables.

- Detection/Trigger delay cannot be improved more (>100ns gained with New HV generator)
- Propagation delay could be improved: Shorten RTL cables !

Reduce Re-Trigger Line Cable Length

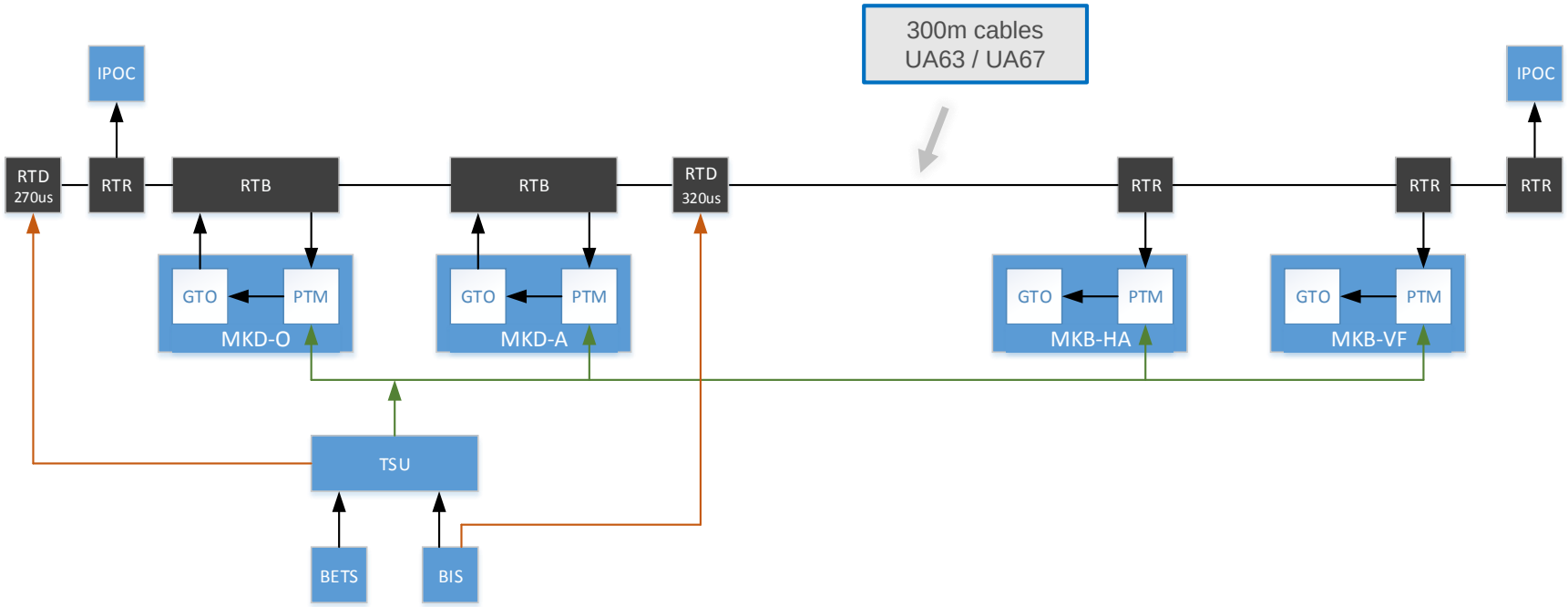
RTL cable is very long. From 1 RTB to the next one, it goes up into the cable tray…

With a shorter connection between RTBs, we might gain ~50m of cables

=> ~200 ns propagation delay removed

With >100ns on new MKD gen:
=> >300ns less total re-trigger time !

Current Re-Triggering – MKB Erratic



Sync Dump – MKB erratic:

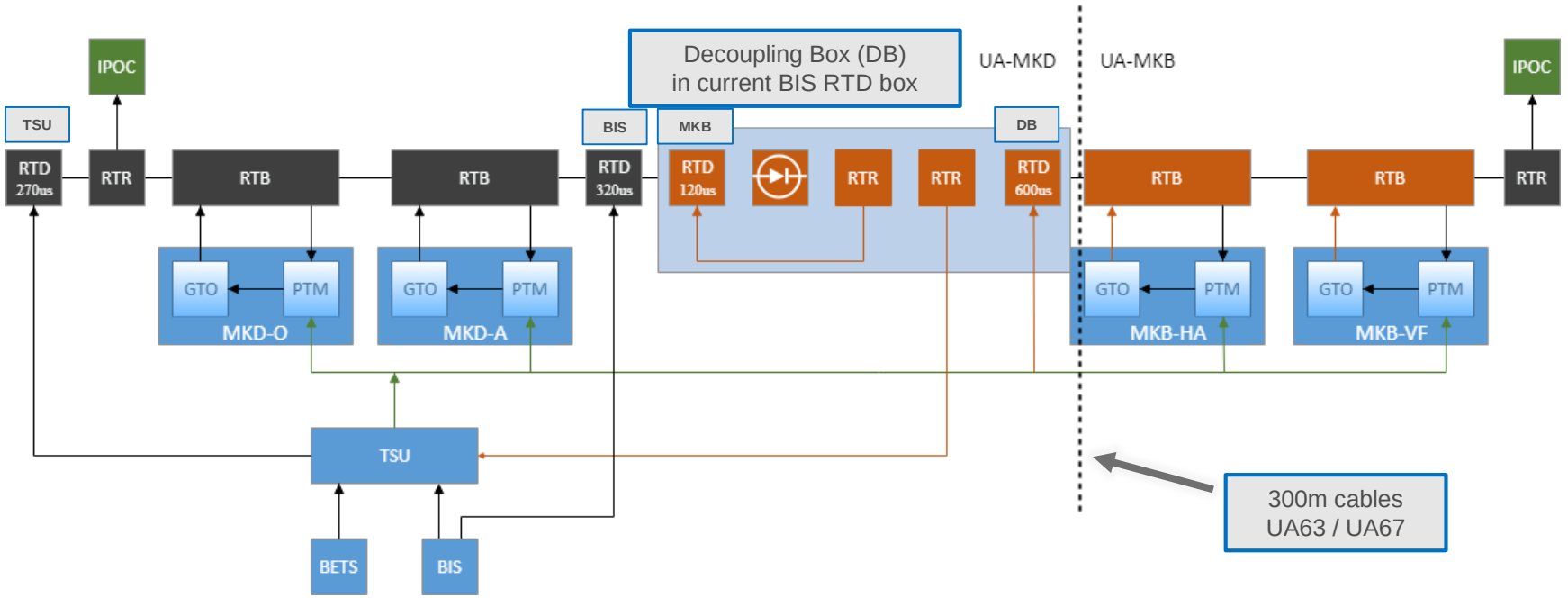
- No MKB re-trigger boxes, so no systematic re-triggering of other kickers.
- BETS detects voltage drop in the generator triggered erratically (Slow detection, typ 1ms)
- BETS requests dump to TSU, then sync trigger all MKD / MKBs

⇒ This could yield in phase opposition between MKB magnets !

⇒ + Problem of coupling between MKBH HV generators = loss of more than 2 MKBH !

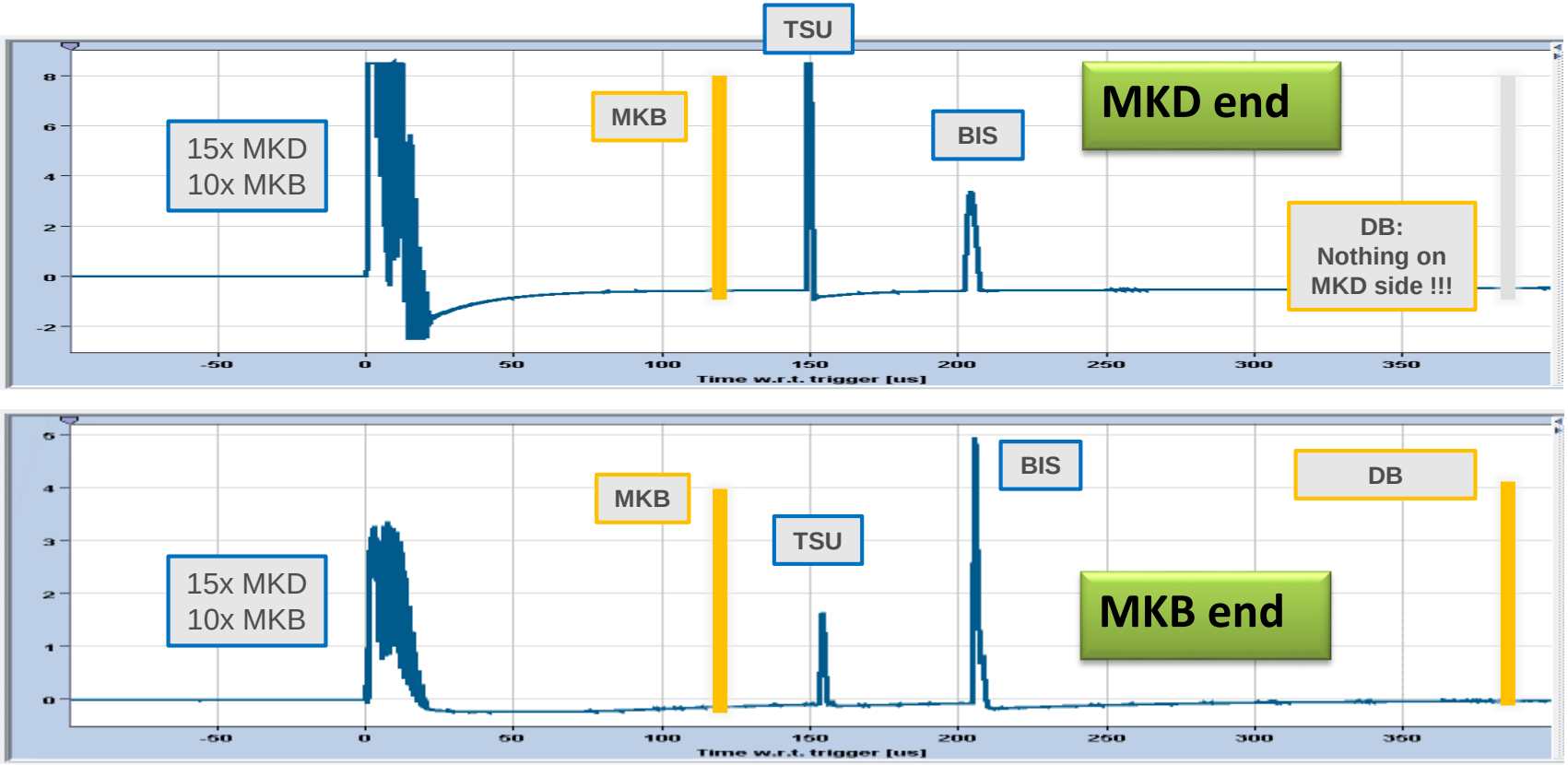
=> We need a MKB Re-Triggering System

New MKB Re-Triggering System



- MKB Re-Trigger boxes: Inject energy on the RTL in case of MKB erratic
- Decoupling Box: Allows MKD->MKB, but blocks MKB->MKD RLT pulses
- New RTR to detect MKB erratic, and request a sync dump to TSUs
- New RTD 120 us to do async dump in case TSU do not react in <1 revolution
- New RTD 600 us to check decoupling diodes are blocking MKB erratic.

New MKB RTL Diagnosis – IPOC



More redundant pulses to be validated on RTL !

- 'MKB' pulse: Check that RTD pulse 120 us after MKB erratic is OK
- 'DB' pulse: Check that the DB diodes are still blocking MKB erratic pulses after the dump execution

=> Problem of attenuation of pulses on the RTL must be solved: **We need a new MKD Re-Trigger Box !**

Reliability Analysis of MKB Re-Trigger

Reliability analysis of this solution was performed:

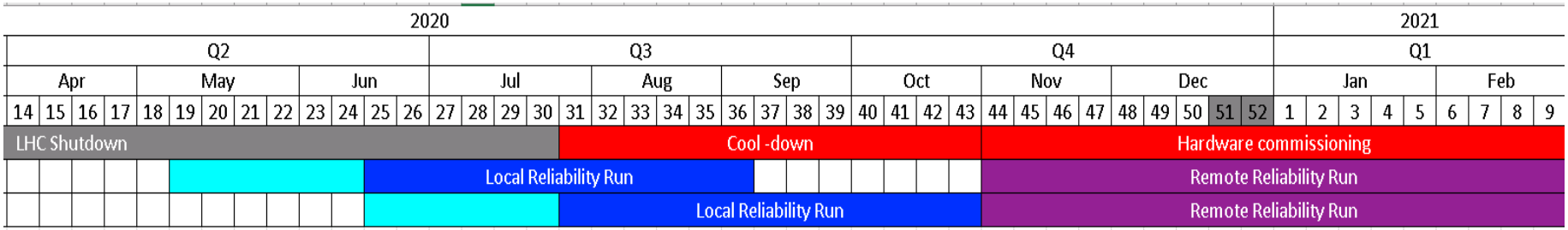
- Calculated probability for “no dilution” failure is negligible (MTTF ~1e12 years)
- Expected increase in asynchronous dumps per year is very small (1 per 1000 years and beam)

Remark:

- This Re-Trigger line upgrade means increasing the complexity of LBDS, to solve limitations on the TDE…

Recommissioning Plan

- Individual System Tests (IST)
  - 6 weeks: Validation/calibration of all generators individually
- LOCAL Reliability Run (LRR):
  - 3 month: Test of full systems, ramping up/down, long flat-tops. LBDS not armed
- REMOTE Reliability Run (RRR):
  - 4 month: Local BIS loops to validate the LBDS armed in REMOTE. BETS connected to MB simulator.
- Cold Checkout:
  - 1 week (?): Reconnection of BETS to MB, TSU to BIS. Revalidation of all interlocks
- Commissioning with Beam:
  - Synchronisation of LBDS: Scan of rising edge. Validation of TSU synchronisation delays.



Summary

- Upgrades on generators and switches will further improve system reliability and availability for RUN 3 at 7 TeV operating energy

- No increase of Abort Gap length required

- Reduction of Re-Trigger delay expected with the new PTM and RTL cable length reduction

- Upgrade of MKD Re-Trigger Boxes:
  To solve redundant pulses attenuation = Diagnosis problem for IPOC (Not safety issue)

- Upgrade of MKB Re-Trigger System:
  To avoid antiphase between MKBs, and mask generator coupling problem

All modifications should maintain present specified failure rate for operation at 7 TeV:

< 1 asynchronous dump / beam and year

< 1 partial dilution / beam and year

Full recommissioning of LBDS needed after these numerous upgrades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Spares

LBDS – Extraction Overview

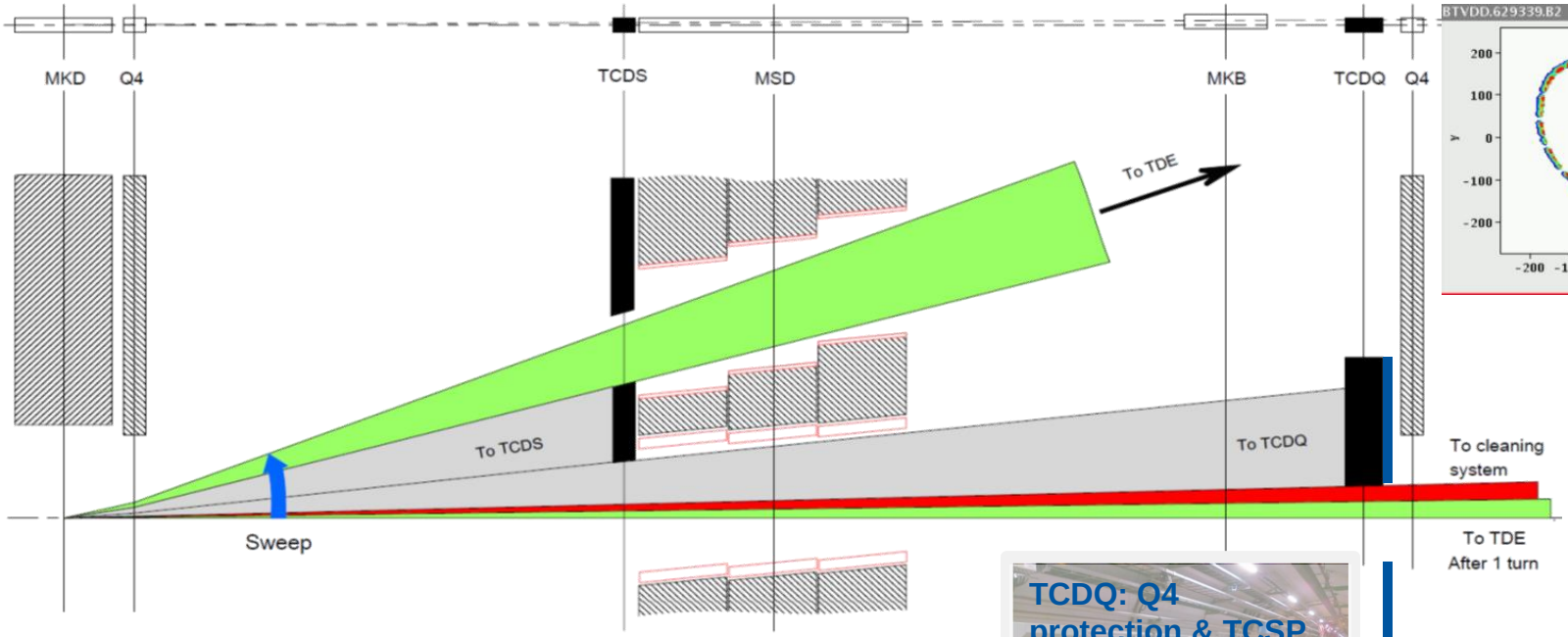
15 MKD: extraction kickers

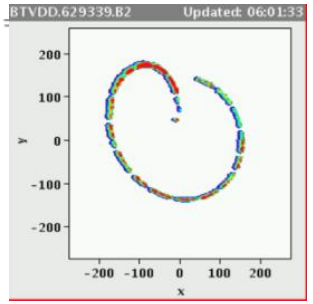
TCDS: septa protection

MKB: dilution kickers

MSD: extraction septa

TDE: Beam dump

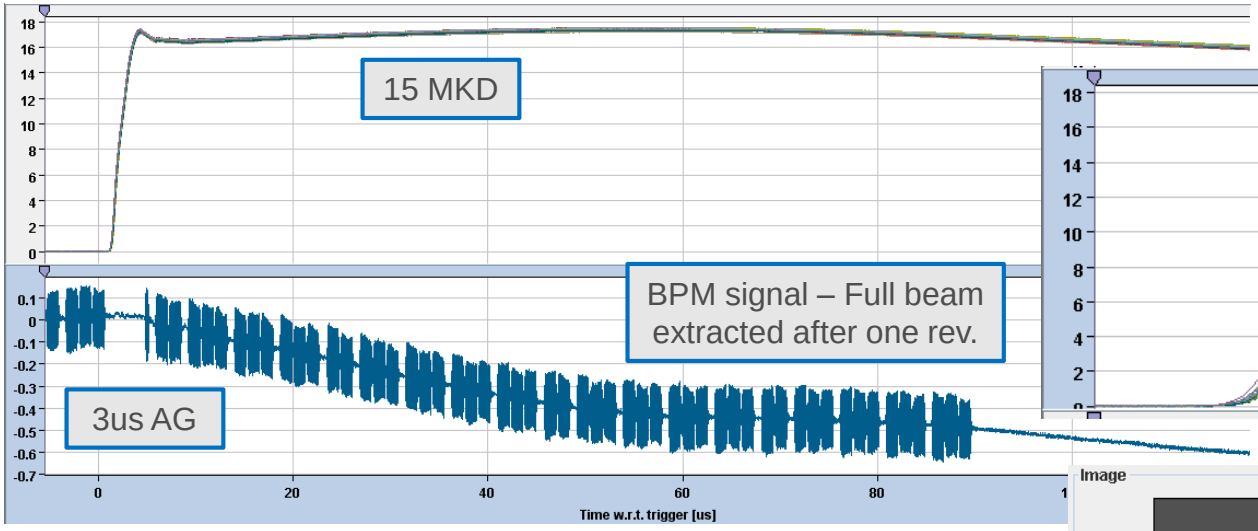


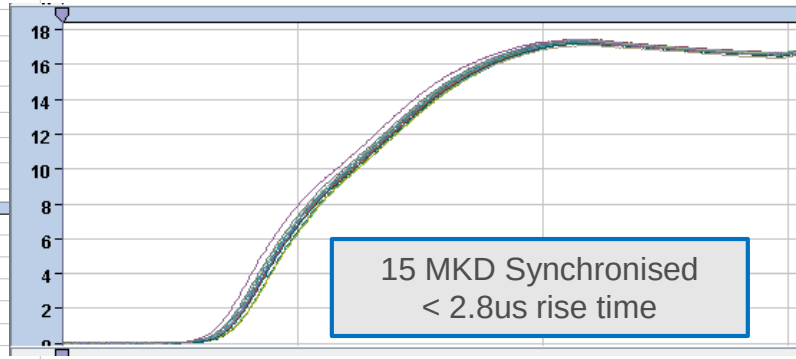


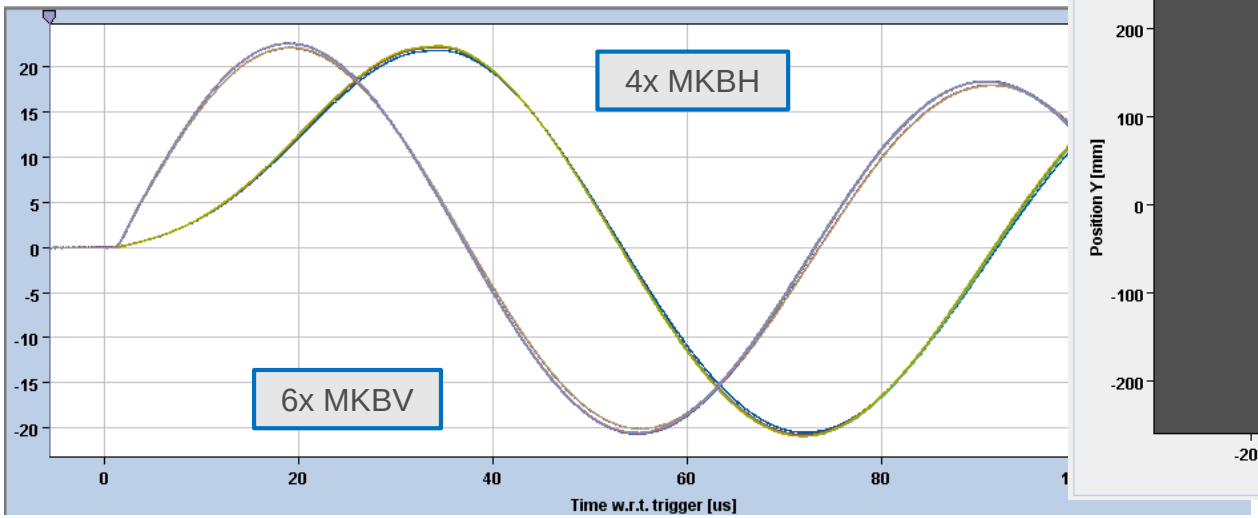
TCDQ: Q4 protection & TCSP

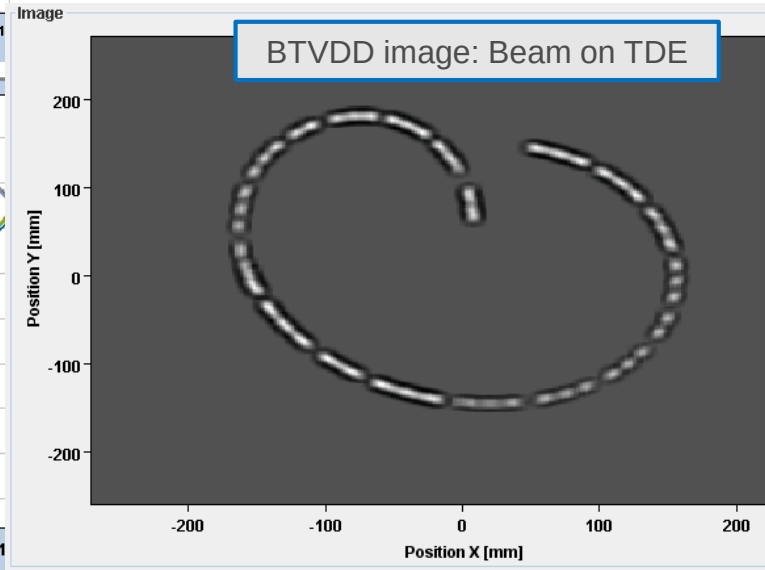
MKD / MKB Waveforms – Sync Dump

01.10.2018 – 04:43





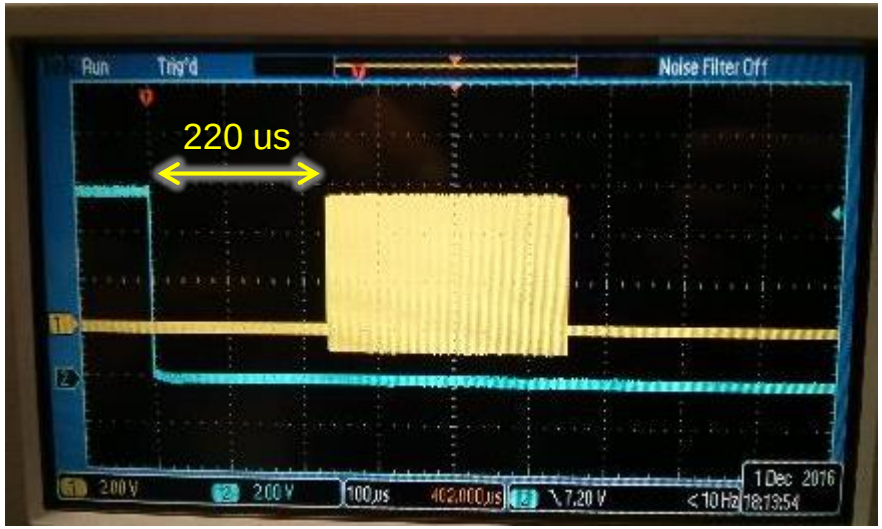




BETS Reaction Time

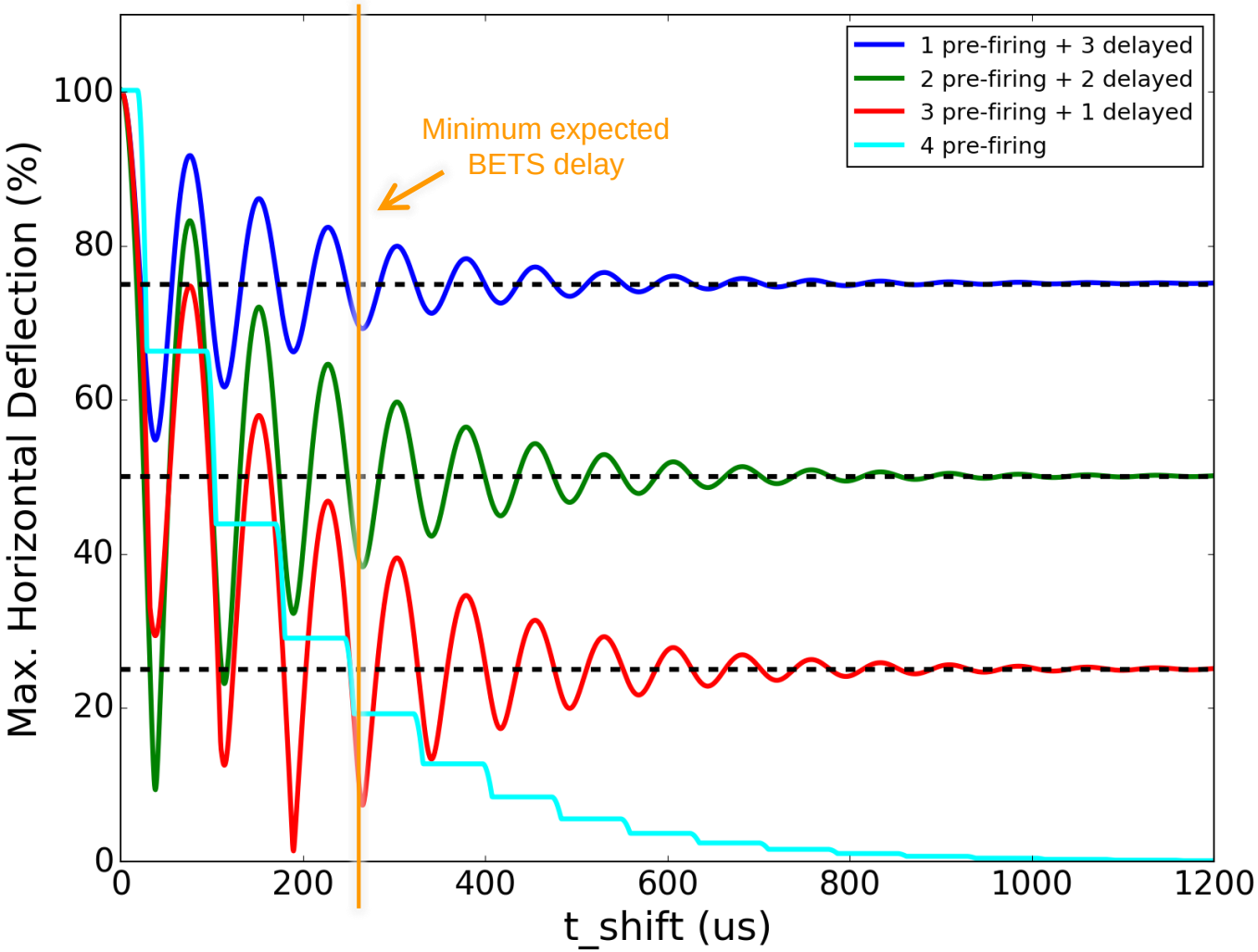
Minimum **measured** delay time from voltage drop to dump request:

≈ 220 us over >10e5 pulses

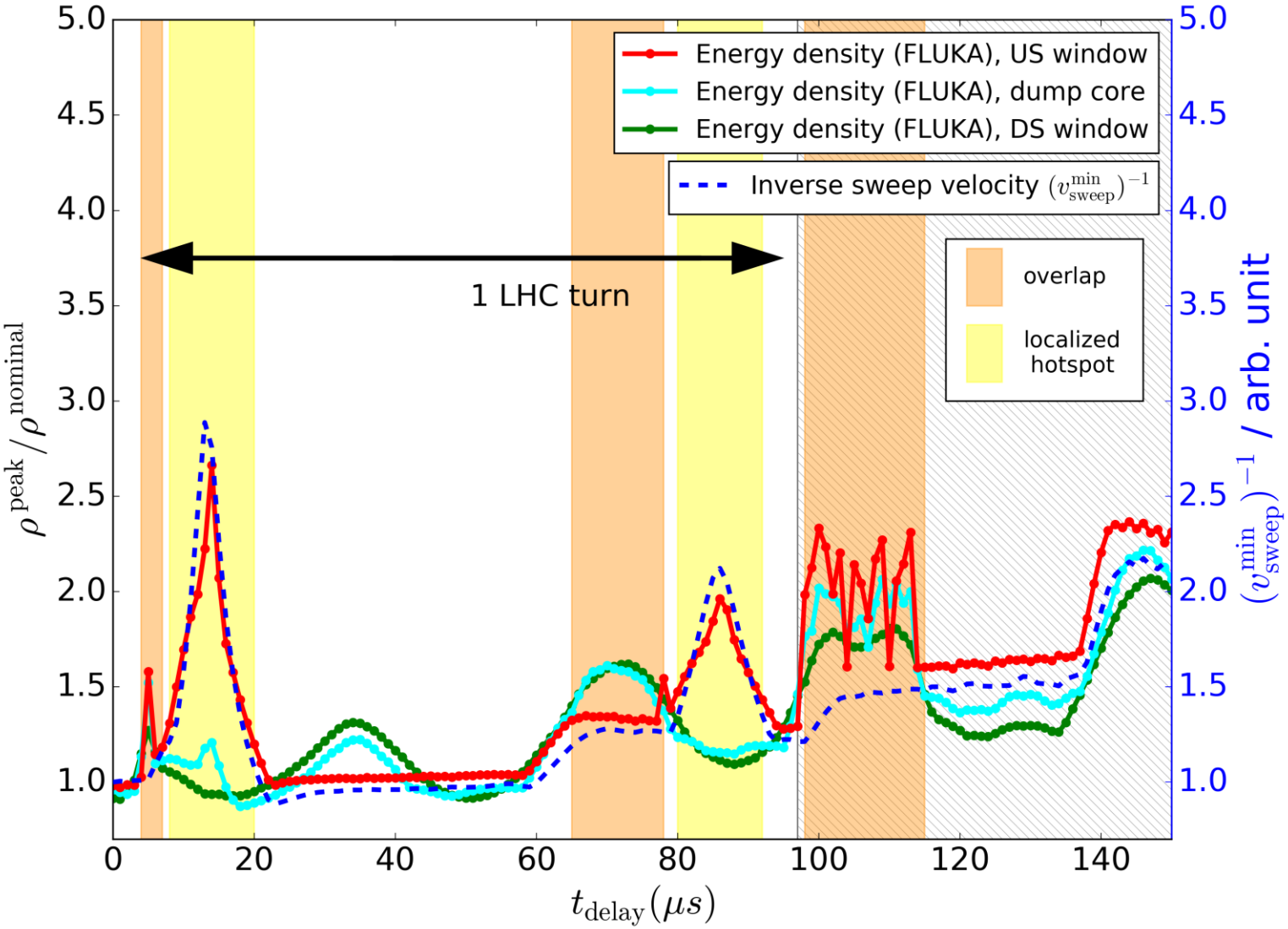


So delay from MKB erratic to LBDS Sync trigger is variable, much more than 1 LHC rev

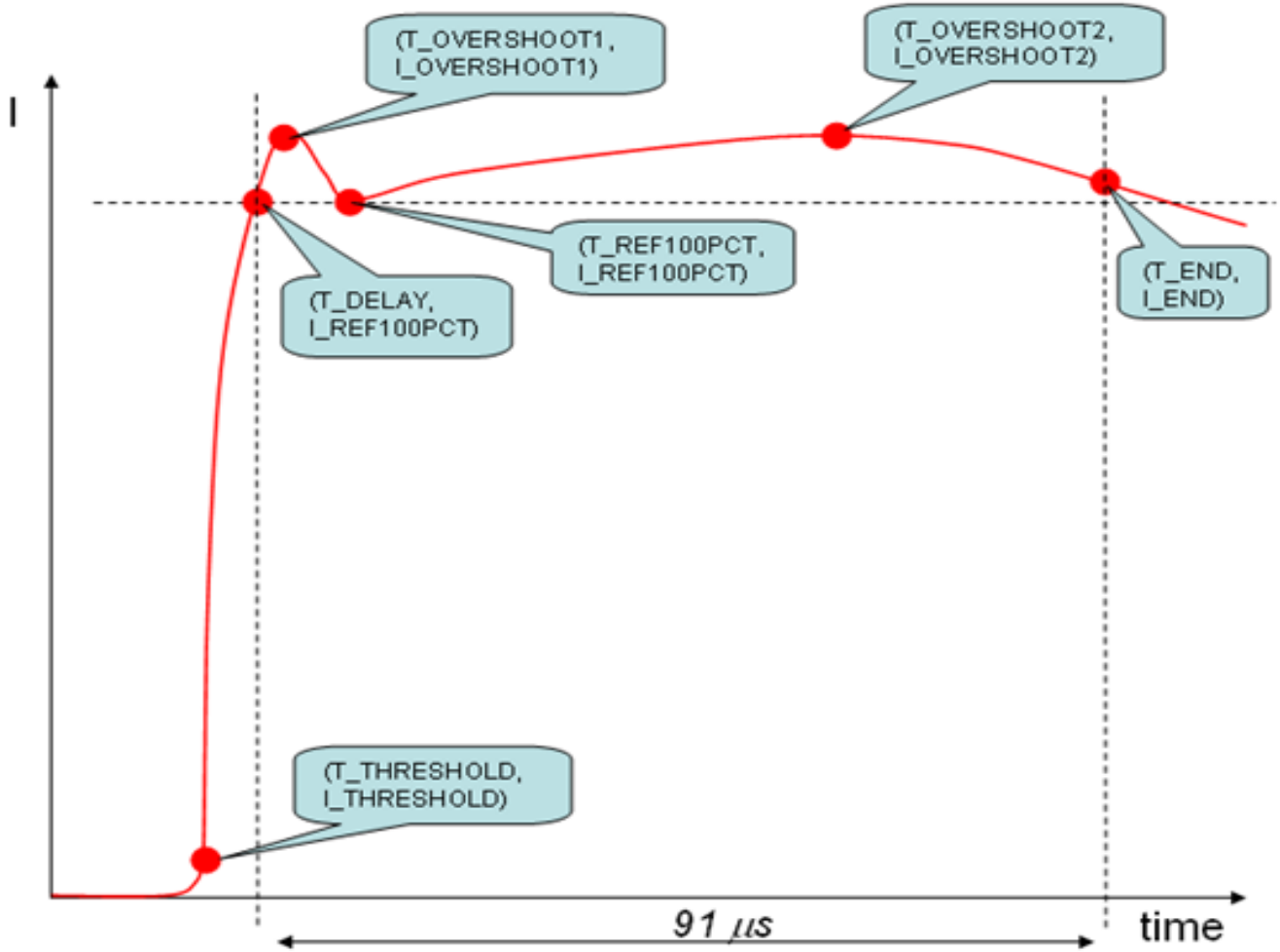
MKB Erratic / BETS detection delay



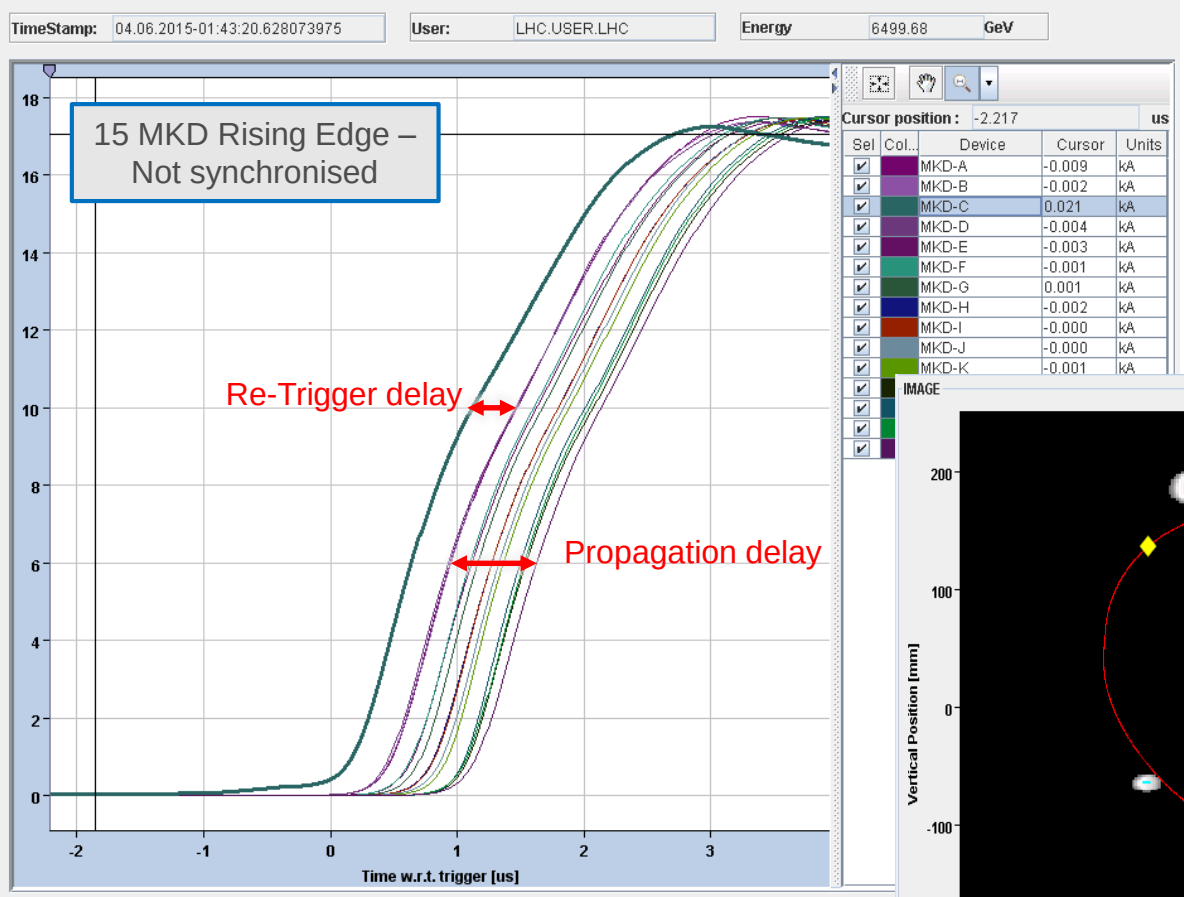
MKB Erratic – TDE Studies



Extraction pulse definition

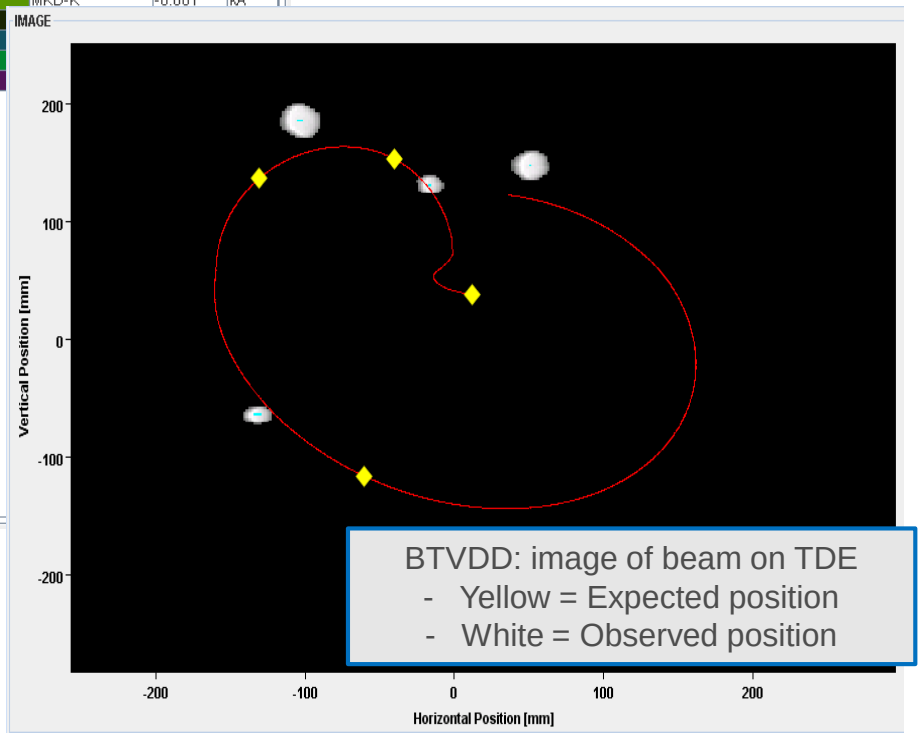


MKD erratic - Async Dump



Last MKD erratic:
04.06.2015 – 01:43

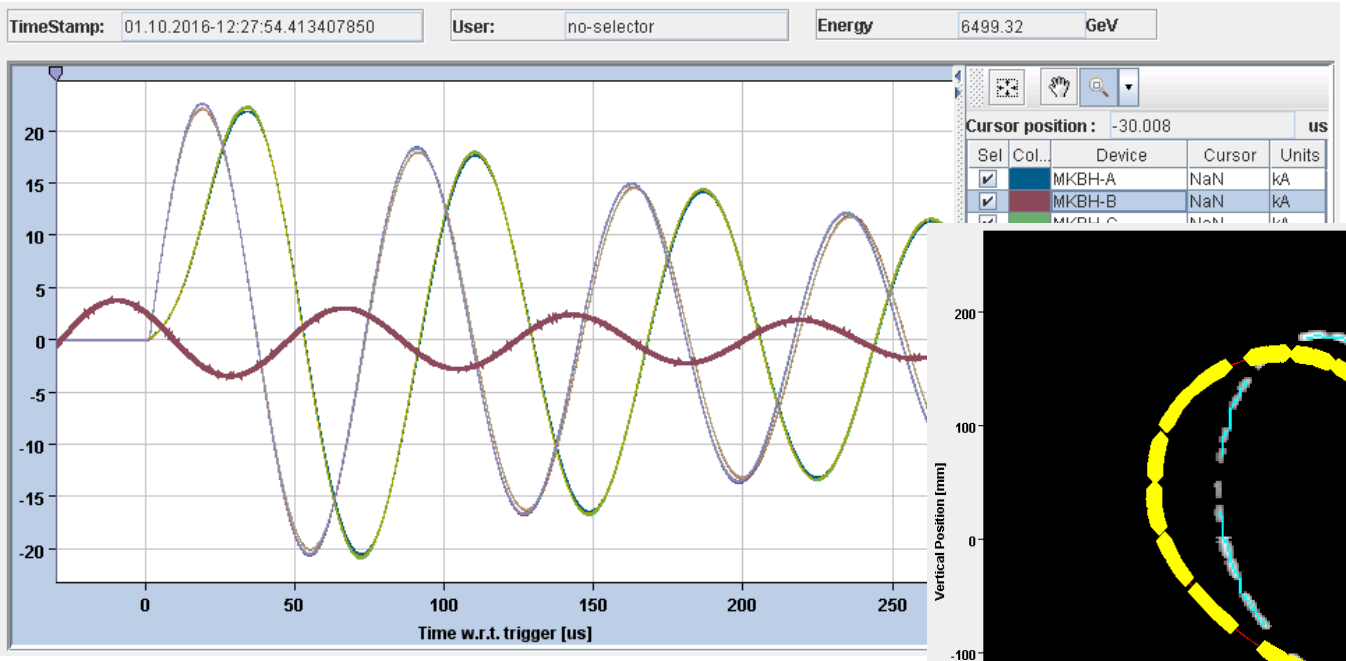
Luckily only 4 bunches in the LHC.
No beam on MKDs rising edge:
-> Clean dump



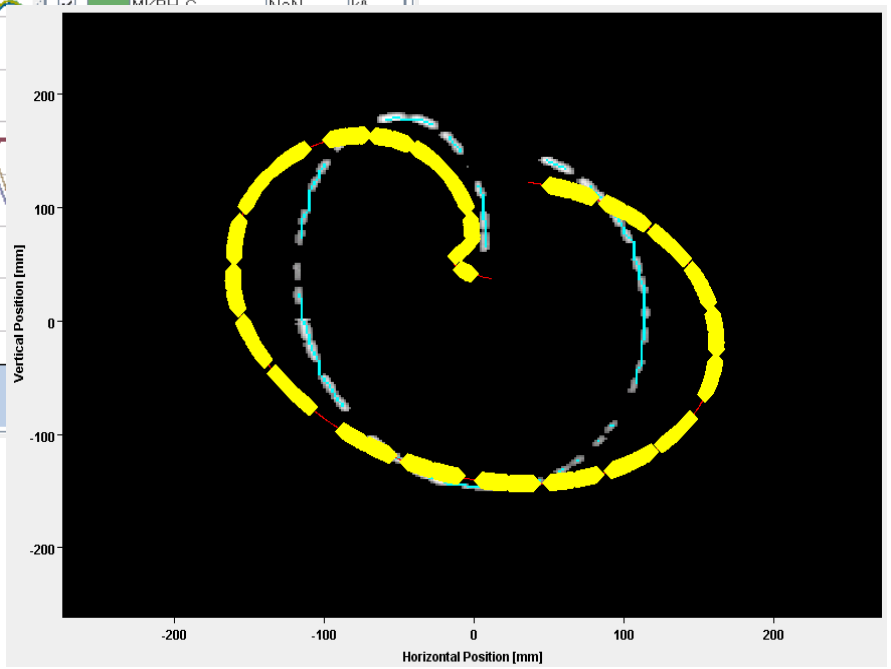
MKD-C erratic trigger, all MKDs are re-triggered.

- Re-Trigger delay (Erratic to second generator)
- Propagation delay (Second to last generator)

MKB erratic – Phase opposition



MKBH.BB1 erratic
01.10.2016



Erratic detected by BETS, Sync Trigger after ~ 1ms.

MKBH.BB1 not completely discharged, and in phase opposition with other MKBs.

=> Lost more than 1 MKBH (~1.2 in this case)

MKD RTB

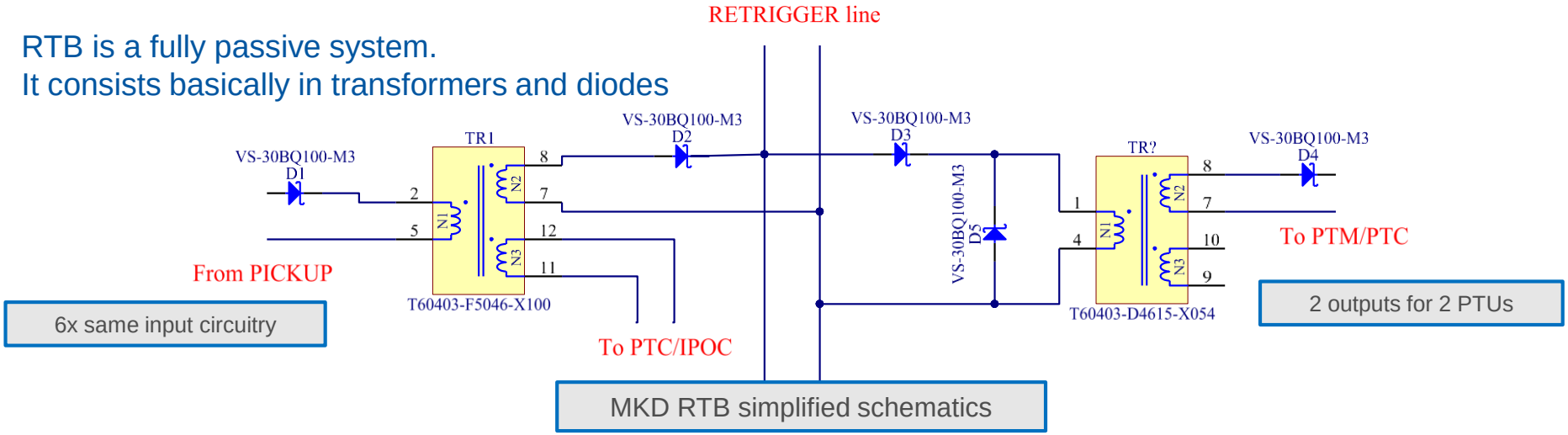
2 MKD Re-Trigger Box (RTB) for 2 RTL

MKD generators are fully redundant, 2 ‘branches’:
- 2 Main switches, with each 2 snubber CTs
- 2 Compensation switches, with each 2 snubber CTs
- 2 Main capacitors in parallel

Each box has 5 inputs (+ 1 spare):
- CTs A/B: Main switch snubber current - Branch A/B
- CTf A/B: Free-wheel current – Branch A/B
- VRD: Main capacitor Voltage Retrigger Detector

MKD RTBs on top of MKD generator
2 boxes for 2 RTL

RTB is a fully passive system.
It consists basically in transformers and diodes



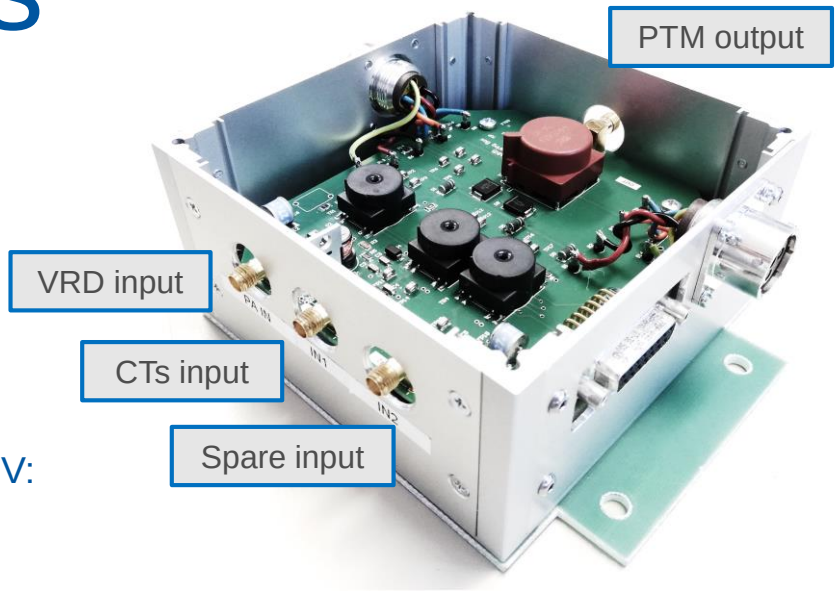
6x same input circuitry

2 outputs for 2 PTUs

MKD RTB simplified schematics

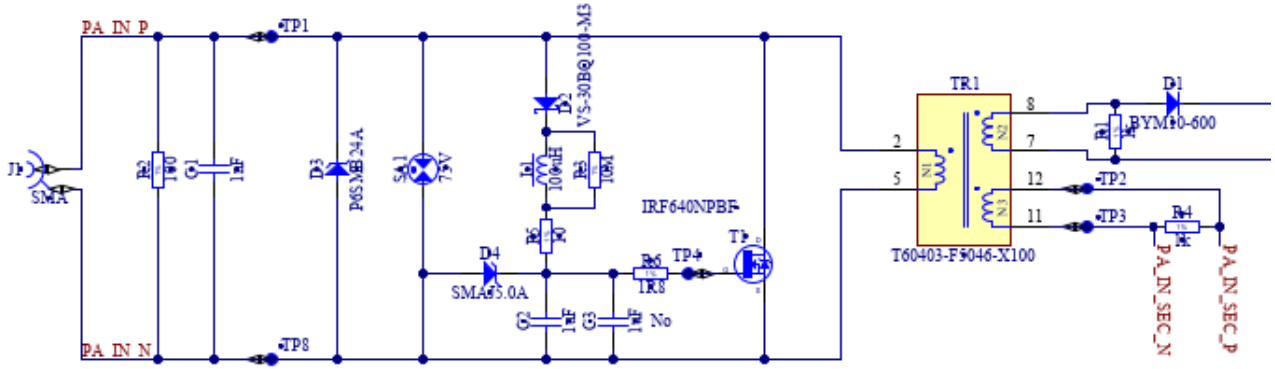
MKB RTB - Status

- Measures / Simulations of MKB pickups done
- Prototype build, measurements in LBDS done
- Schematics finalised
- PCB / Mechanics ongoing



To avoid polluting the RTL with periodic pulses from MKBV:

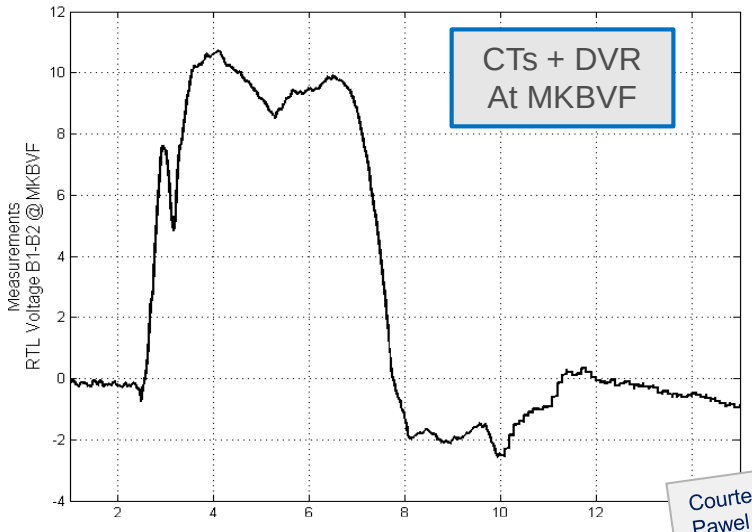
- Crowbar circuit at the DVR input of MKB RTB:

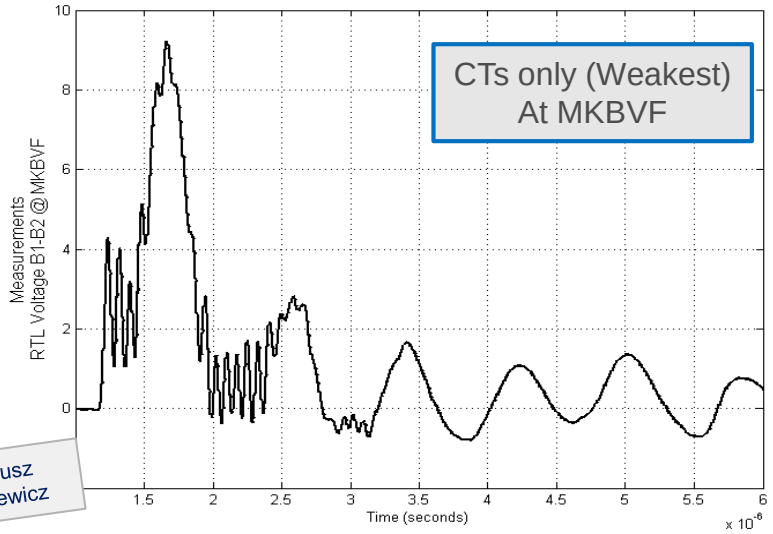


Courtesy Janusz Pawel Rodziewicz

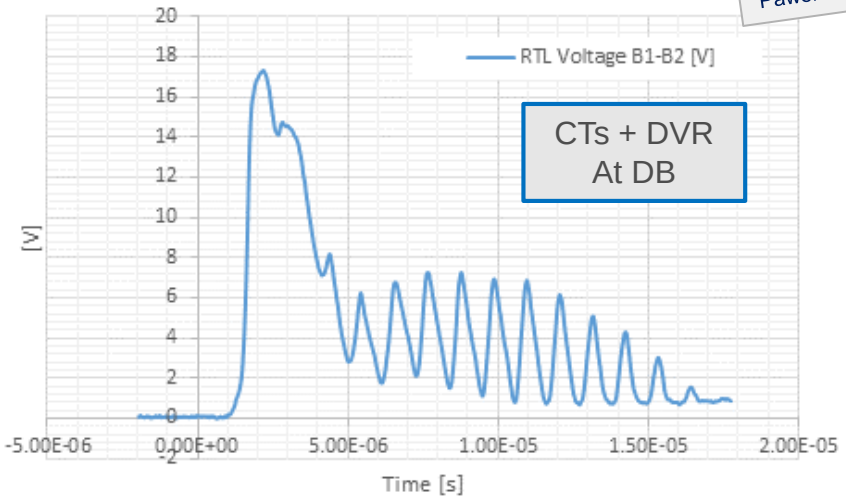
VRD input schematic:
Crowbar circuit to limit pulse length

MKB RTB – Proto in LHC





Courtesy Janusz
Pawel Rodziewicz



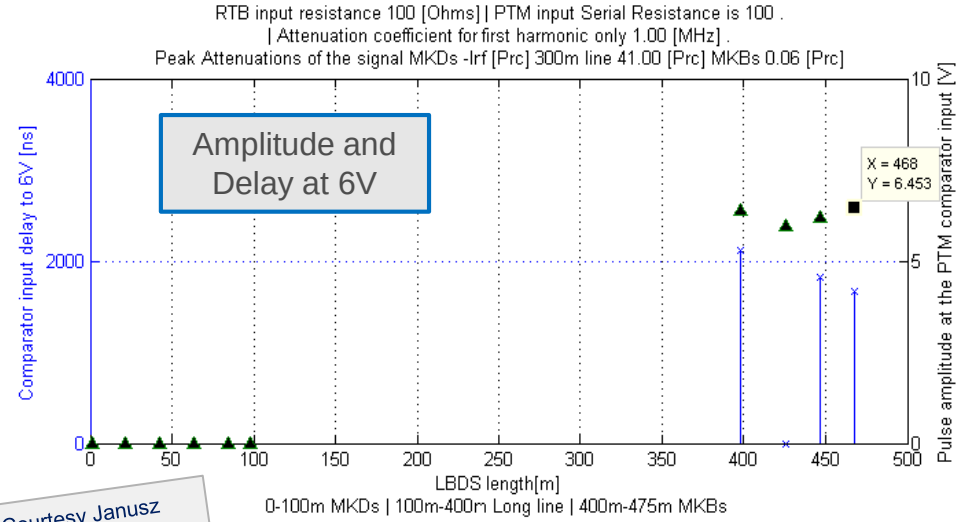
Test conditions: 450 GeV

- MKBV.F pulsing alone
- VRD installed in MKBV.F
- DB installed before MKD.A

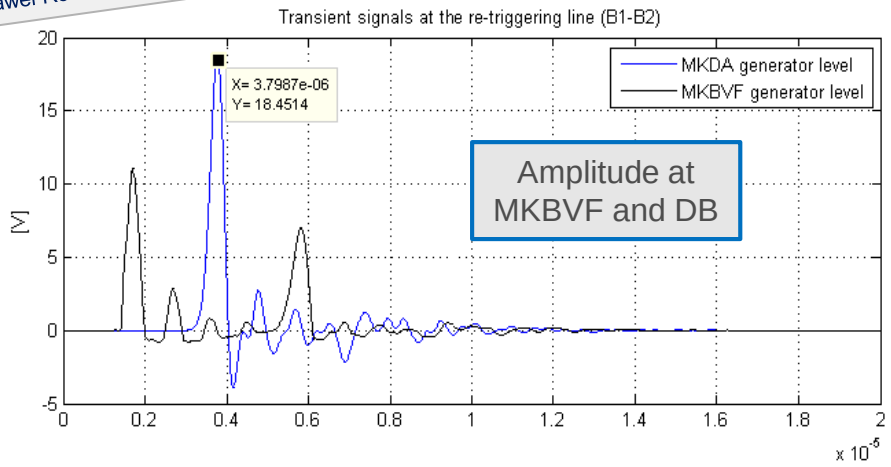
Thanks to the 'Decoupling box' (DB), the pulse amplitude will be doubled at the 'DB'.

Level at DB is enough to be detected for TSU dump request !

MKB RTB – Simulation of RTL



Courtesy Janusz Pawel Rodziewicz



Simulation conditions: 450 GeV

- MKBV.F pulsing alone
- DB installed before MKD.A

Simulation takes into account:

- New MKD RTBs (new transformers)
- New PTMs (Higher input impedance, 6V threshold)

CTs only (weakest) pick-up scenario:

- One MKB will not be re-triggered.
  -> Needs domino effect at 450 GeV

With CTs + DVR, no domino effect.

R2E related items

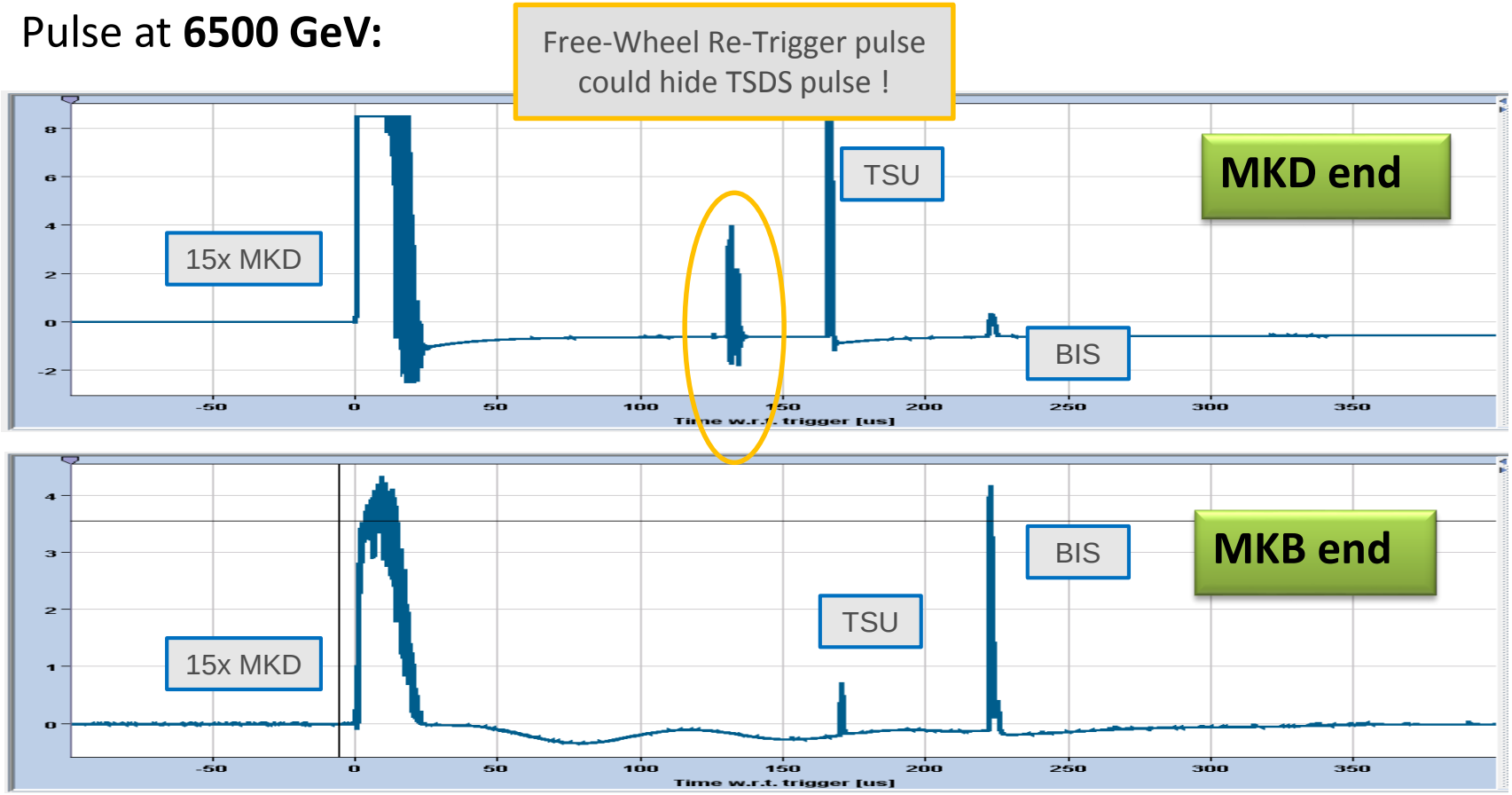
SEB failure rate probability:

	Today setup @6.5 TeV PTM = IXGN100N170	Today setup @7.5 TeV PTM = IXGN100N170	Proposed modifications @7.5 TeV PTM = IXGN200N170
	2.68 kV/GTO (MKD) 2.47 kV/GTO (MKBH) 1.17 kV/IGBT (MKD+MKB)	3.1 kV/GTO (MKD); 2.87 kV/GTO (MKBH) 1.17 kV/IGBT (MKD+MKB)	2.84 kV/GTO (MKD); 2.58 kV/GTO (MKBH) 1.14 kV/IGBT (MKD+MKB)
MKD (600 GTO) [y^{-1}]	6e-3	1.8	9e-2
MKD (360 IGBT) [y^{-1}]	9e-2	9e-2	1.8e-2
MKBH (80 GTO) [y^{-1}]	1.2e-1	1.2	1.6e-1
MKB (120 IGBT) [y^{-1}]	3e-2	3e-2	6e-3
Total AD (MKD GTO + IGBT) [y^{-1}]	0.1	1.9	0.11
Total SD (MKB GTO + IGBT) [y^{-1}]	0.13	1.23	0.17

Failure rate probability at 7.5 TeV comparable to current one at 6.5 TeV

Re-Trigger Line Diagnosis - IPOC

Pulse at **6500 GeV:**



Stronger attenuation of TSU / BIS pulses on the RTL at higher energy !

Free-Wheel RTB input generates at ~130 – 160 us, should not hide redundant re-triggers

-> Delays of TSU /BIS pulses moved from 200 / 250 us to 270 us / 320 us