LHC Beam Dumping System
Status and Readiness for LHC Run II

Evian Workshop 2-4 June 2014

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On behalf of TE/ABT team.
Thanks to all my colleagues for their contributions!

OUTLINE

- Status of Upgrades Planned for LS1
- Latest Availability & Safety Estimates
- First Reliability Run Results
- First Dry Run Results
- Updated Planning for Dry Runs and Reliability Runs
- Requirements for Commissioning without Beam (Cold Checkout)
- Requirements for Commissioning with Beam
- Conclusion

STATUS OF UPGRADES PLANNED FOR LS1

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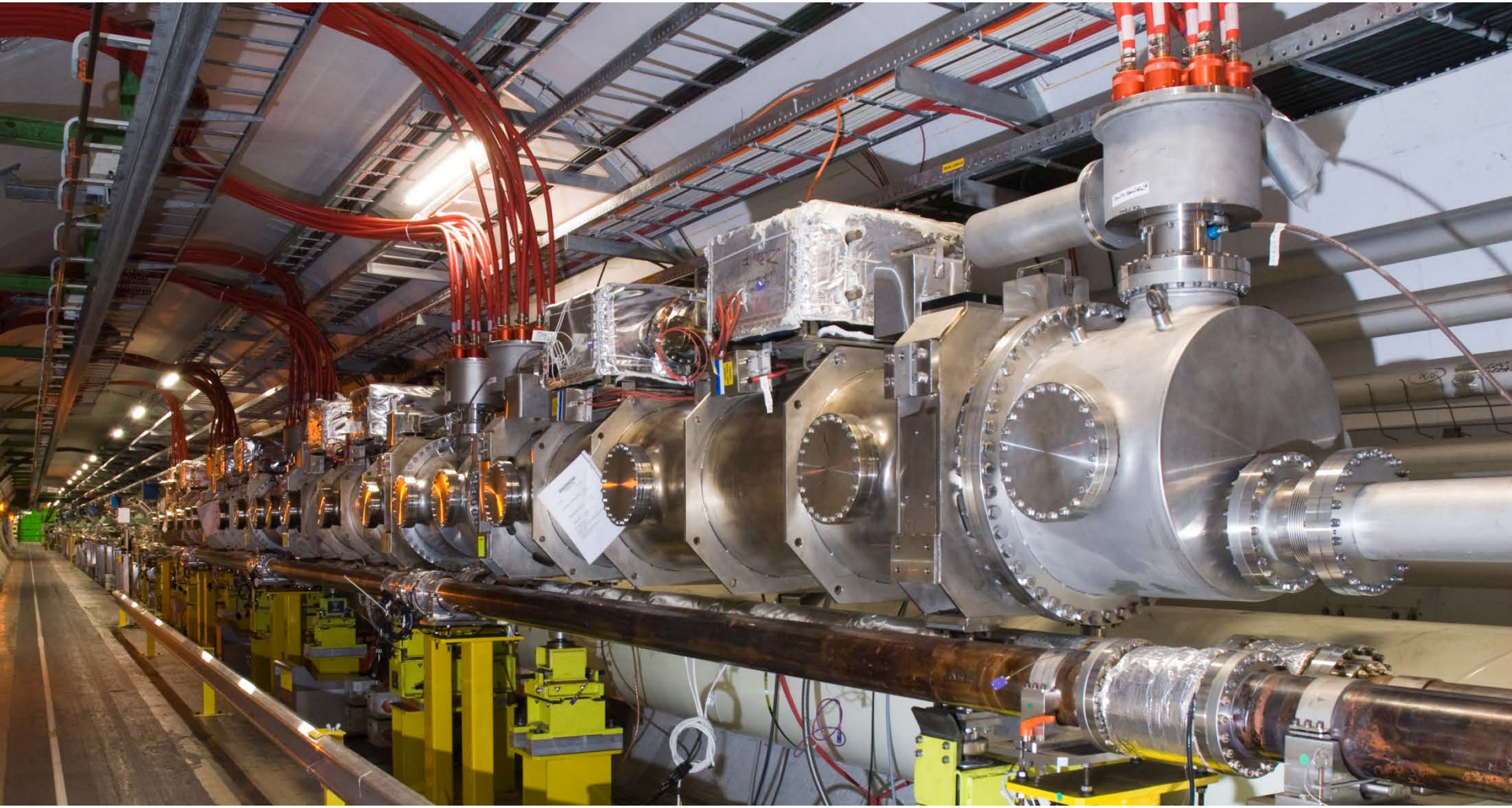
Addition of MKBV E&F kicker magnets

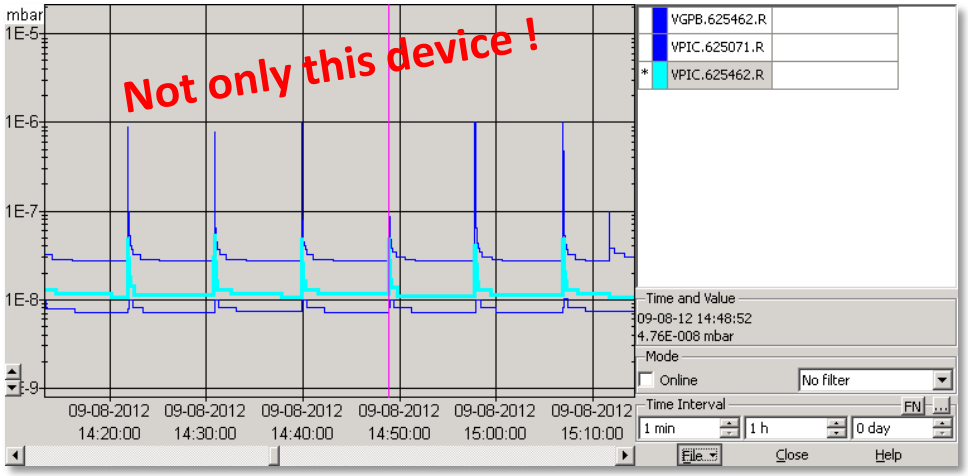
DONE !

- Tank not installed earlier to spread cost
- One tank MKBV E&F added per beam => Nominal dilution 4x MKBH + 6x MKBV



Vacuum reading problems

IN PROGRESS…



Vacuum group is taking this problem seriously, a lot of works as been done already:

- MKB vacuum gauges were replaced
- Problems with regular vacuum spikes (every 7 / 9 minutes) being investigated
  - Installation of test gauge outside beam vacuum
  - Effect not visible outside the vacuum chamber
  - Seems to be real and not a controls issue inside the chamber
  - **Source to be identified at start-up ?**
- ABT prefers to maintain present 2 out of 3 interlock logic per individual MKB tank
- Analog interlocks added by ABT for redundancy are removed
  => We now rely only on VAC logic for digital interlock.

MKD HV generator GTO stack renovation

DONE !

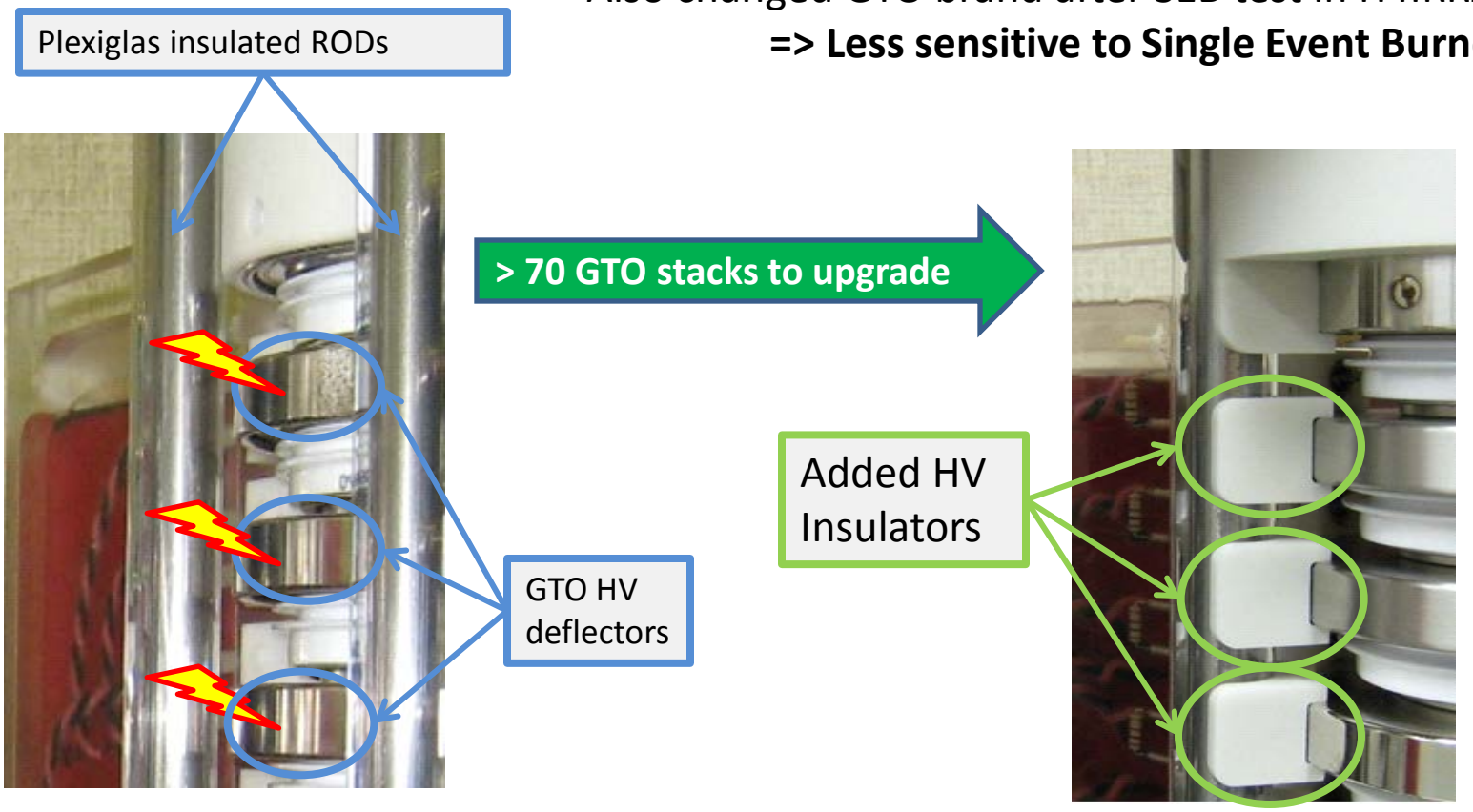
LHC Run I operation limited to 5 TeV due to electrostatic discharge on GTO stack

=> Spontaneous triggers

⇒ **Added insulator between Plexiglas insulated ground ROD and GTO HV deflectors.**

Also changed GTO brand after SEB test in H4IRRAD

=> Less sensitive to Single Event Burnout



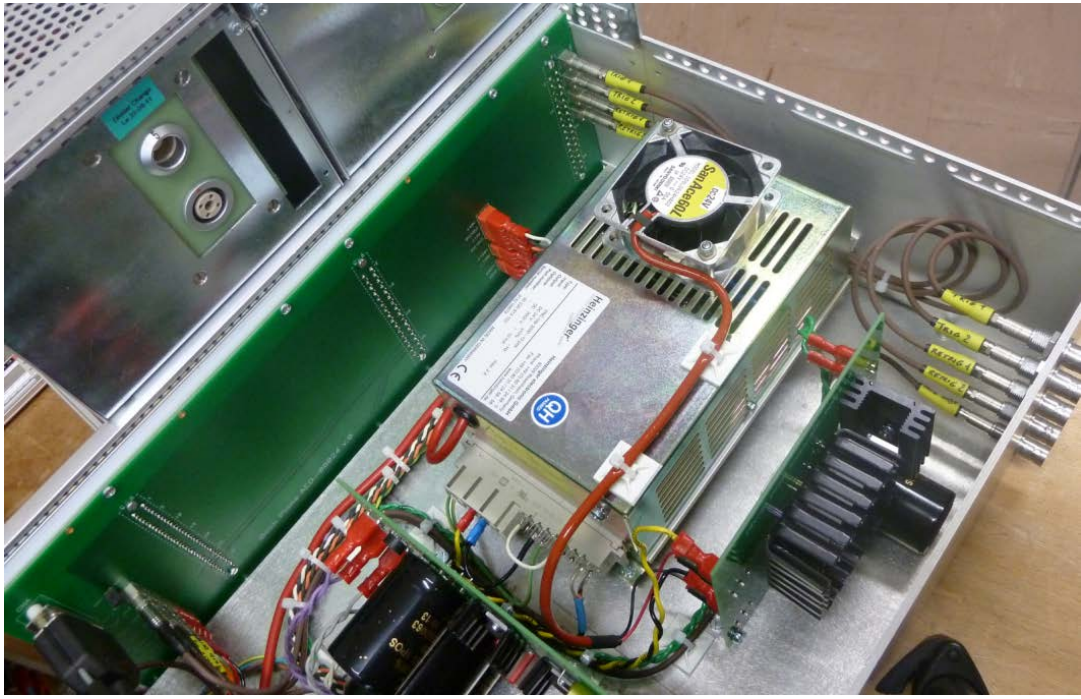
Increase of PTU voltage

DONE !

- Increase PTU maximum voltage from 3 kV to 4 kV => replacement of HVPS.
- Replace 1.2 kV IGBT with equivalent 1.7 kV type => better resistance to SEB
- Operate PTU at ~3500 V **constant voltage** to:

  => Increase GTO gate current
  => Increase GTO lifetime
  => Reduce kicker rise time
  => Stabilise pulse delay over energy range
  => Ease exchange of MKD Gen.

> 80 PTU to upgrade

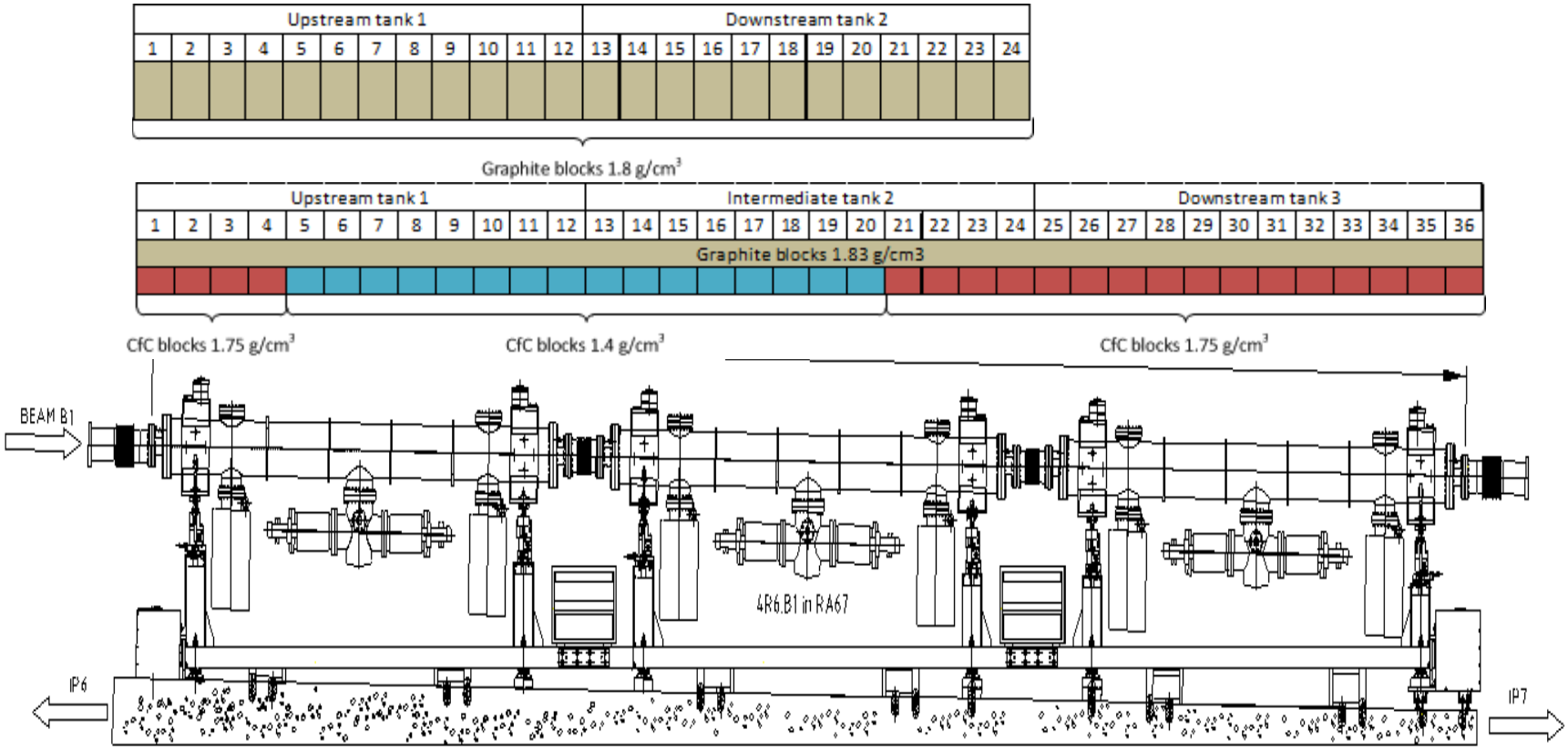


TCDQ – Absorber reinforcement

DONE !

- TCDQ length increased by 50% (added a third tank).
- The graphite absorbers were replaced by:
  A sandwich of graphite and Carbon Fiber reinforced Carbon (CFC)

  => Ready for HL-LHC

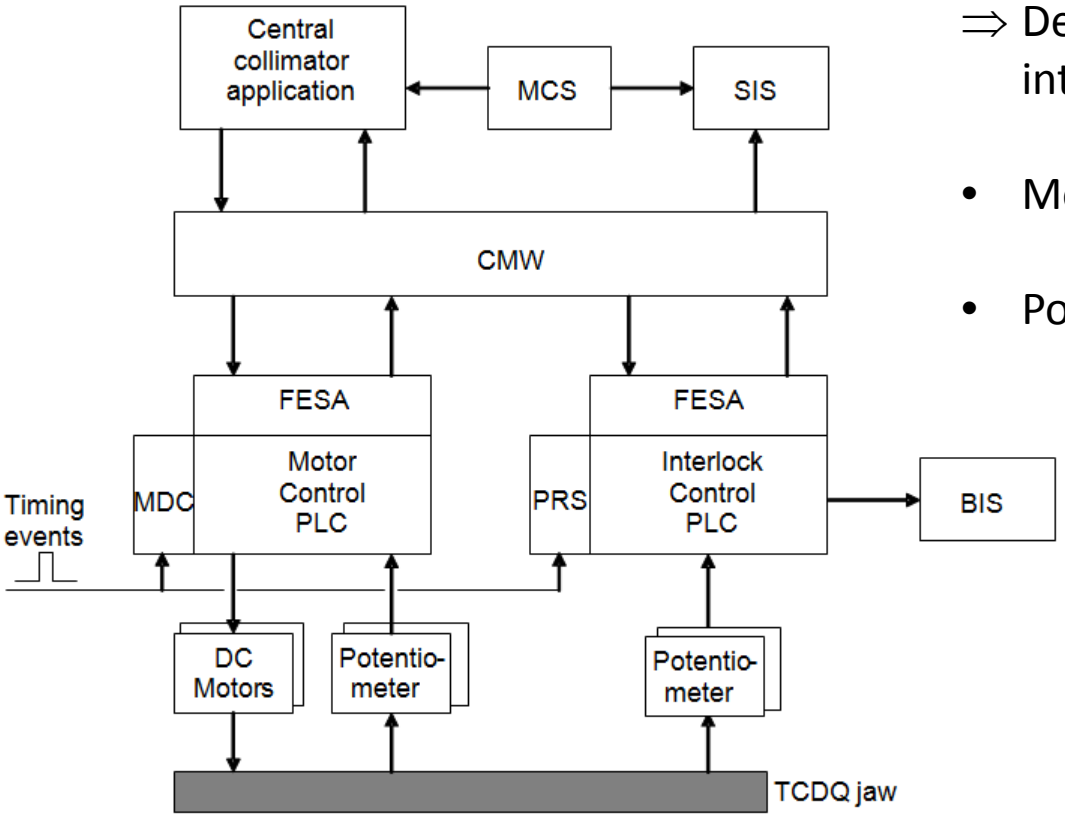


TCDQ – Control consolidation

IN PROGRESS…

Following external review of the TCDQ positioning system in 2009:

- Identification of a **common mode failure** of the PLC CPU that provides both position controls and supervision.



⇒ Deployment of the two functions into two separated PLCs:

- Motor Drive and Control (MDC)
- Position Readout and Survey (PRS)

Hardware is ready.
Installation is ongoing.
LOCAL commissioning finished by end of **June**

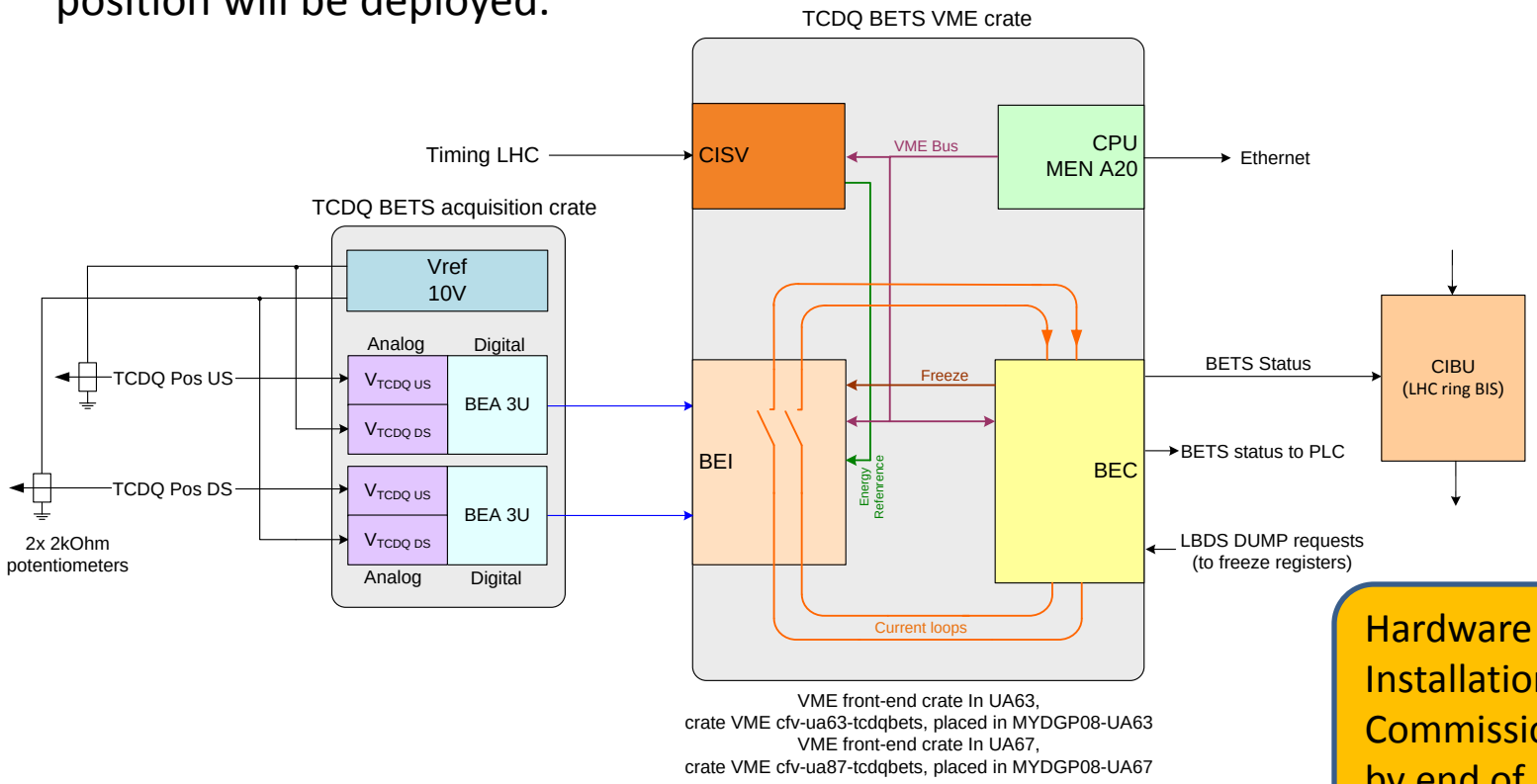
TCDQ – Beam Energy Tracking System

IN PROGRESS…

Following external review of the TCDQ positioning system in 2009:

- Failure of the timing distribution to transmit the start to the PLC.
- Failure of the Ethernet card to transmit set points to the PLC.

=> A new independent **Beam Energy Tracking System** to capture and survey the TCDQ position will be deployed.



Hardware is ready.
Installation is ongoing.
Commissioning finished by end of **July**

STATUS OF UPGRADES PLANNED FOR LS1

Shielding of cable ducts between UA and RA

IN PROGRESS…

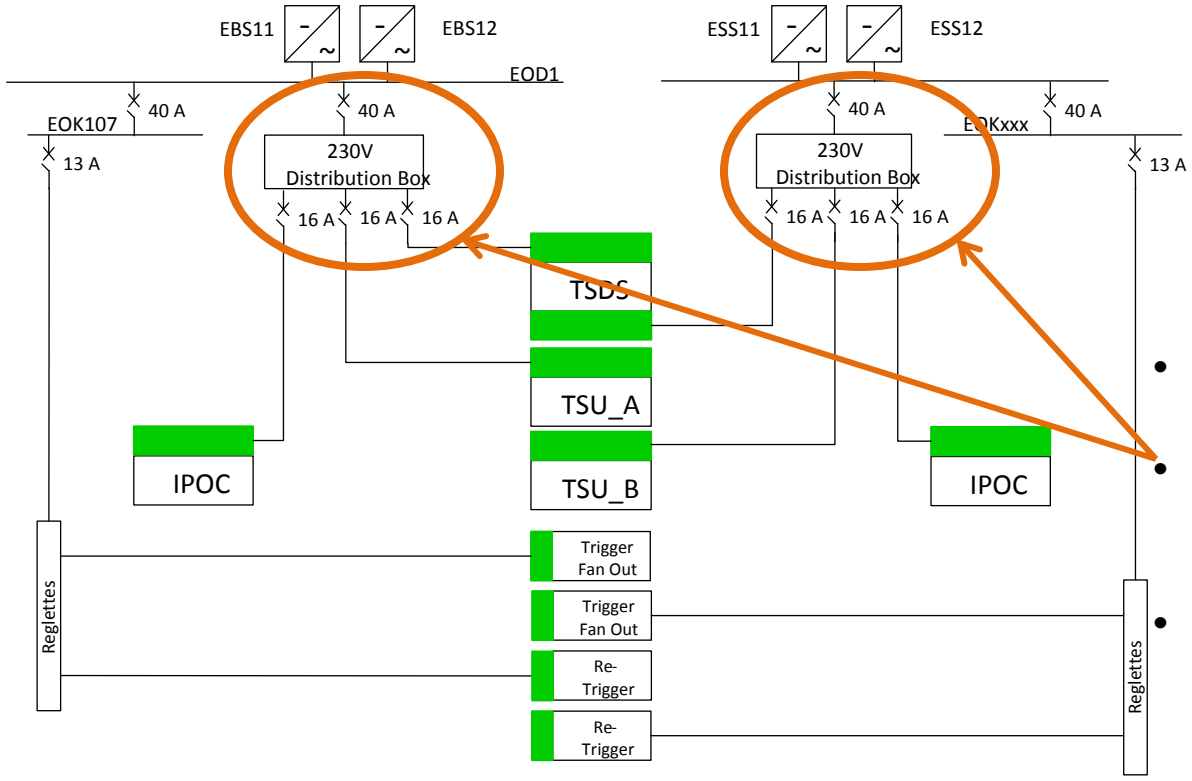
Cable ducts between UA and RA in front of MKD and TCDQ systems will be filled with iron rods to diminish radiations in UA, mainly due to TCDQ scattering.

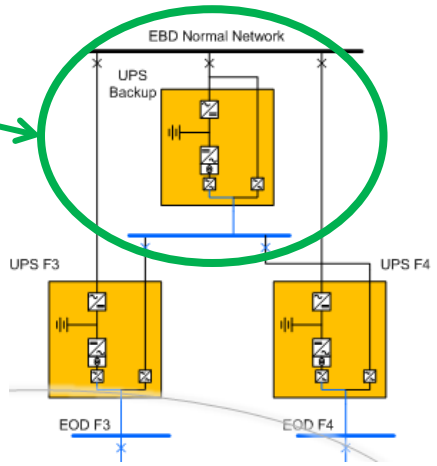
Installation should be planned for
end of July, beginning of August

Improvement of Power Distribution Architecture

DONE !

- Third UPS (backup) added everywhere





- Second UPS installed for LBDS (US65)
- Distribution Boxes with Separate circuit breaker for every crate PSU.
- Software monitoring of crate redundant PSU (DIAMON)
  => SIS request a dump in case of failure of redundant PSU.

- Power Cut Tests still to perform, with F3 and F4 off simultaneously
  (Not done in May, because LBDS2 was locked)
- Tests already performed successfully in 2013, at the end of LHC Run 1.

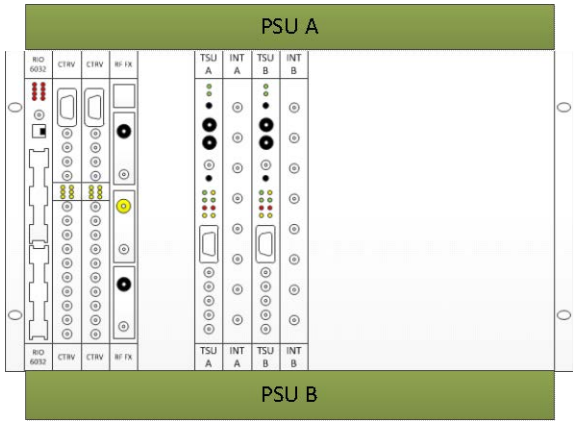
New TSU Deployment

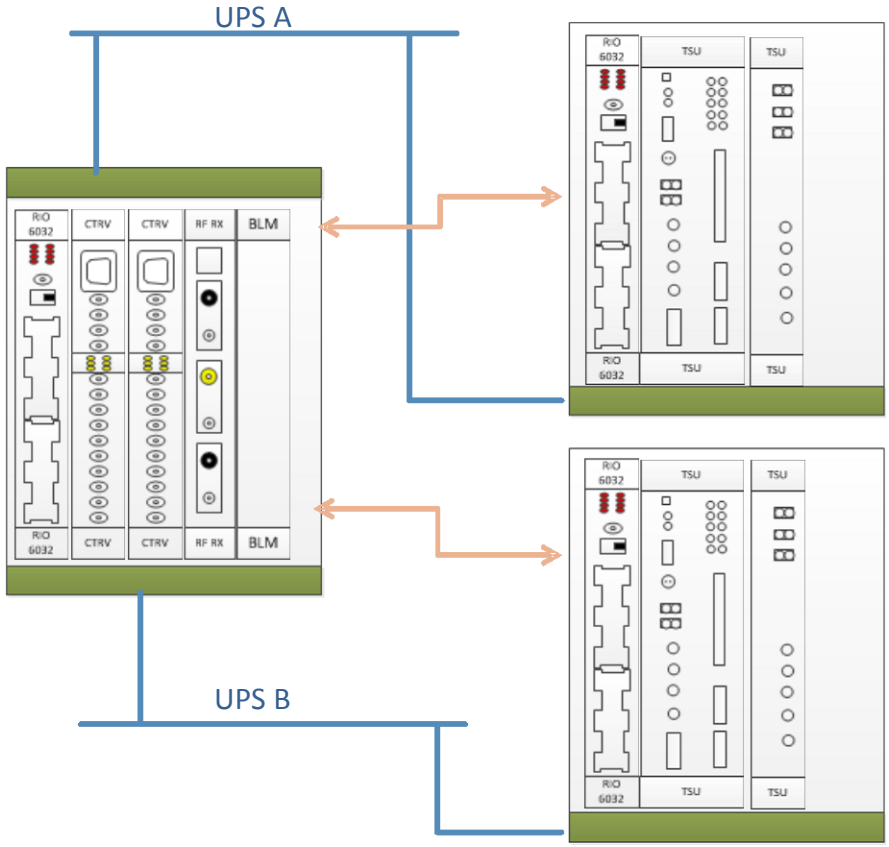
IN PROGRESS…

Change deployment from 1 VME crate to 3 VME crates.

Motivation:

- Internal review of LBDS Powering (2012)
- VME crate +12V problem (2012)





Installation is ongoing.
Progressive test during dry-run

TSU v3 Development

IN PROGRESS…

Motivation for new TSU v3 design:

- External review of TSU v2 cards (2010)
- CIBU powering filter problems (2011)
- Improvement of surveillance & diagnosis
- Deployment over 3 VME crates

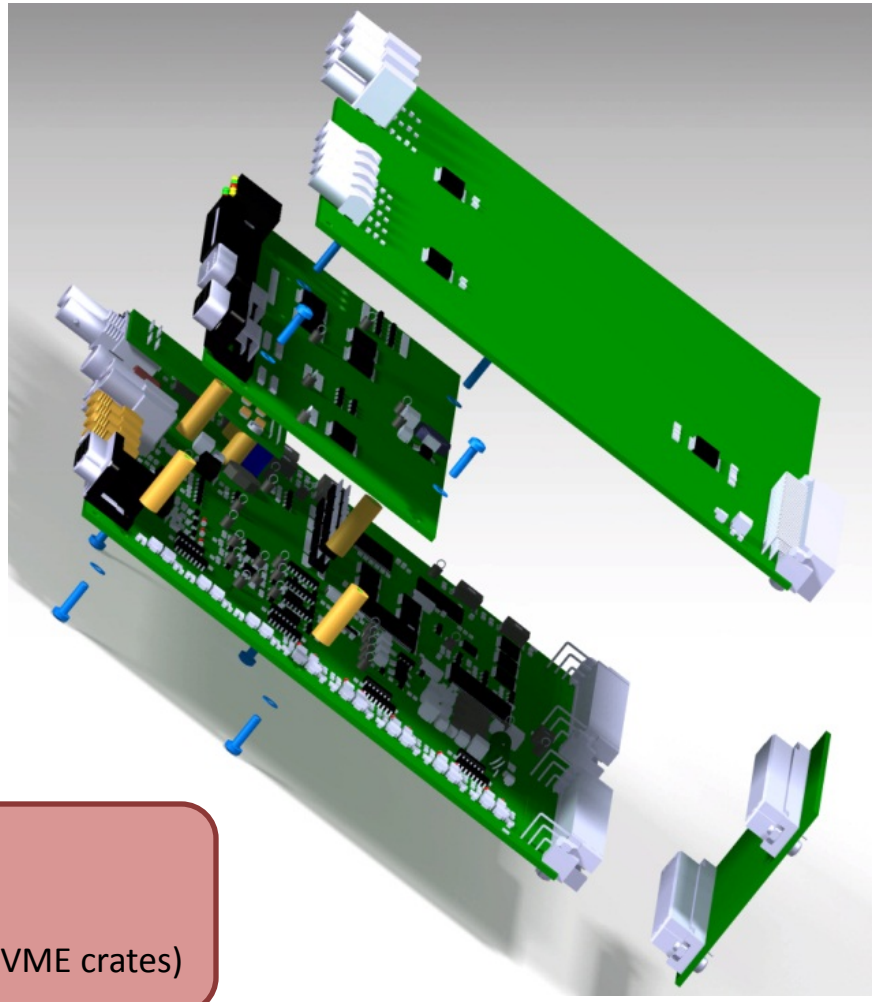
Project status:

- Hardware prototypes **validated**.
- Production of 12 cards **done**.
- Firmware development **still in progress…**

Planning:

- 1st step:
  TSU v3 hardware with TSU v2 firmware

- 2nd step:
  TSU v3 firmware with new features



IF 1st step is not ready in **middle July**:
⇒ **Start LHC Run II with TSU v2**
(design new backplane to adapt to deployment over 3 VME crates)

Direct connection from BIS to LBDS Retrigger-line

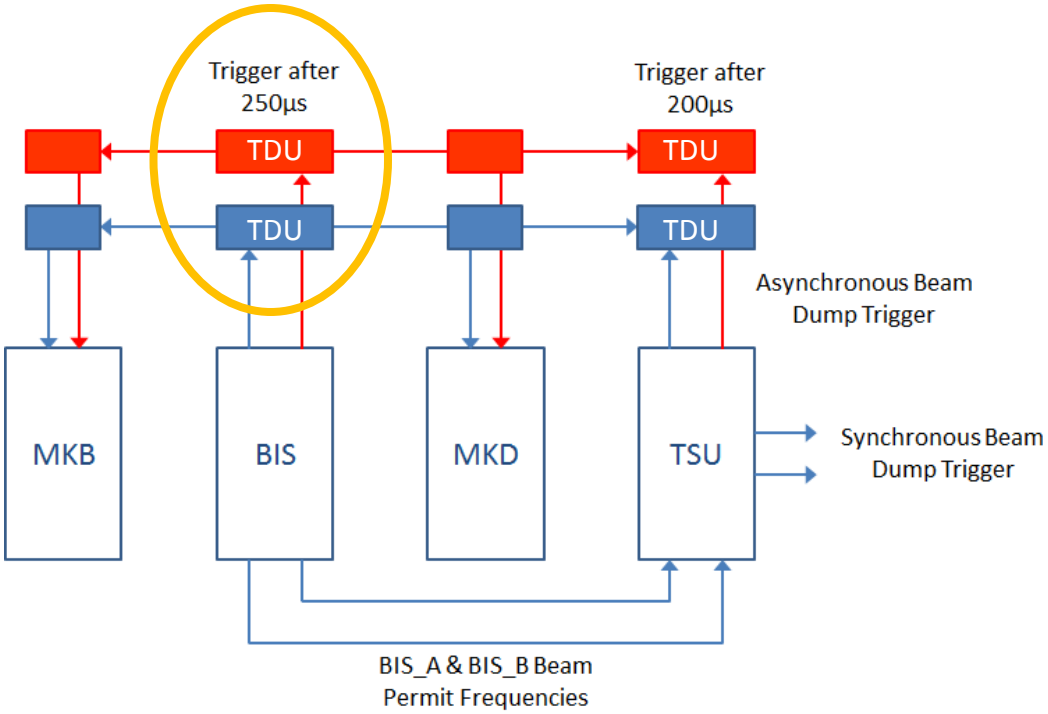
DONE !

In the case the TSU cards do not send triggers at all (unknown/new failure mode) ?

=> BIS generates retrigger pulses after 250 us

MPE designed a new **CIBDS** card, inserted between BIS and Re-Trigger delay boxes.

CIBDS and TDU250 are installed in UA63 and UA67



Software upgrades

IN PROGRESS…

Migration of all FESA 2.10 classes to FESA3:

- Already migrated:
  - LBDS State Control
- Under test in laboratory:
  - TSU Diagnosis
  - IPOC System
- Still under development:
  - BETS Systems
  - TCDQ MDC & PRS
- Adapt code after addition of MKBV E&F and operational energy > 5 TeV:
  - PLC software
  - LBDS Analysis & Calibration tools
  - XPOC

All software upgrades done by end of **July**

AVAILABILITY & SAFETY ESTIMATES

Safety & Availability Study Projects

- **Before LHC Run I:**

Ph.D. Thesis at CERN on LBDS System Analysis (R. Filippini, 2003-2006)

- The LBDS estimated to be **SIL 4**
- False beam dumps: **8 +/- 2 per year**
- Asynchronous beam dumps: **2 per year**

(Theoretical model, using TTF from manufacturer data or military handbooks)

- **After LHC Run I:**

Mandate given to same expert to update LBDS System Analysis (R. Filippini, 2013)

=> Analysis of 3 years of LHC operation 2010-2013 (**LHC-OP logbook**, and **LHC-TE/ABT logbook**):

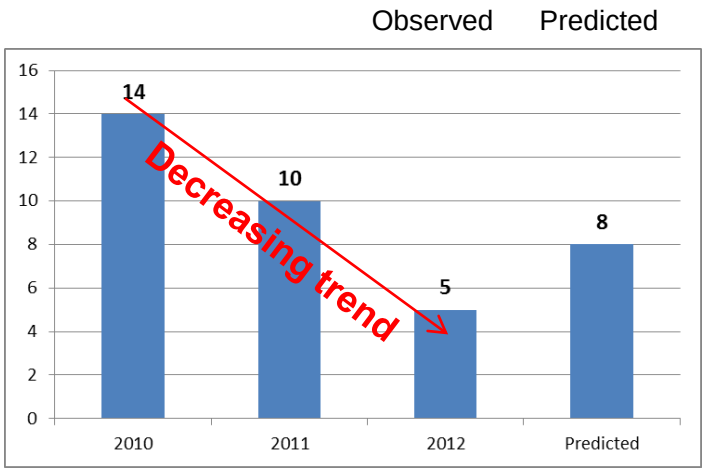
- **139 failure events** of which **90 internal** to LBDS
- Comparison of predictions vs. LHC Run I statistics
- New failure mechanisms discovered

=> Updated reliability prediction models:

=> LBDS estimated to be **min SIL3**

=> False beam dumps counted: **29** (24 foreseen)

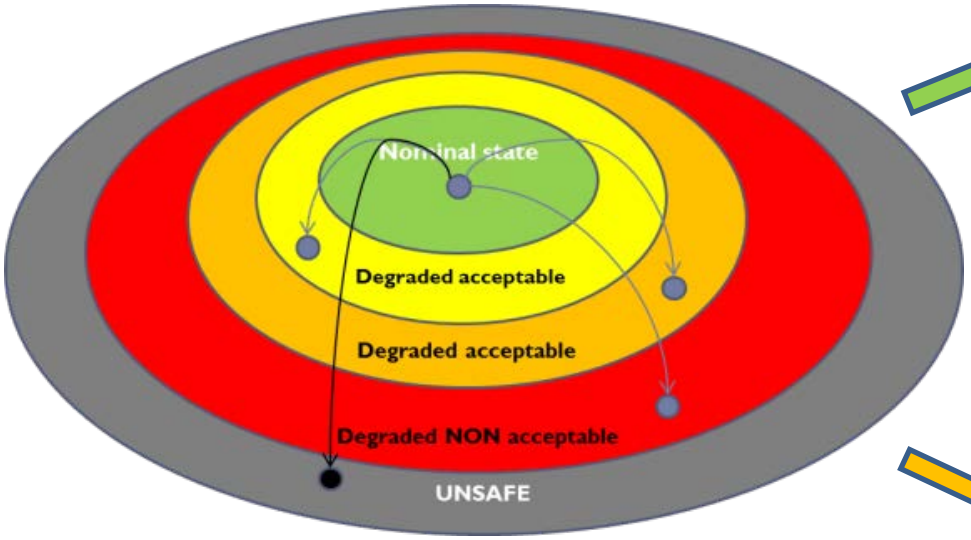
=> **Decreasing trend.**

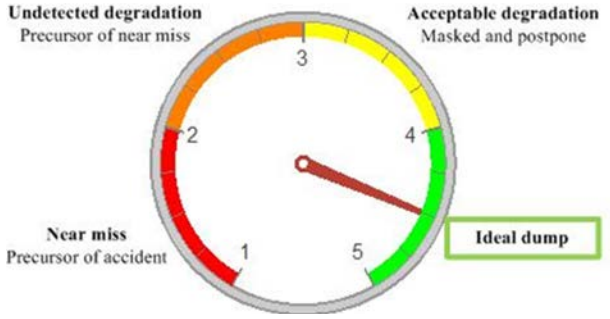


Safety Margin & Safety Gauge

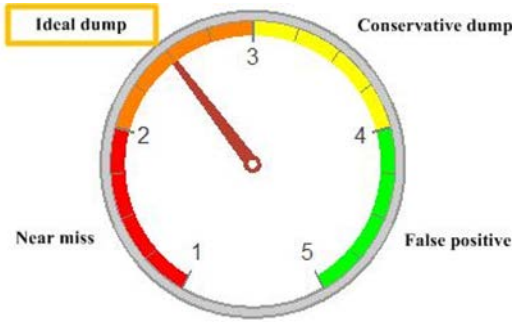
LBDS estimated to **SIL3 at least**, but:

How far from **Single Point of Failure** were we during last dump execution ?





Nominal beam dump
The system is fully available
or in an acceptable degraded state



False beam dump
The internal dump must be justified
→ safety margin about to be eroded

- Balance safety and availability:
  => Is the system protected or **over**protected?

- Quantify the safety margins after every beam dump
  => Safety gauge on LBDS Fixed Display ?

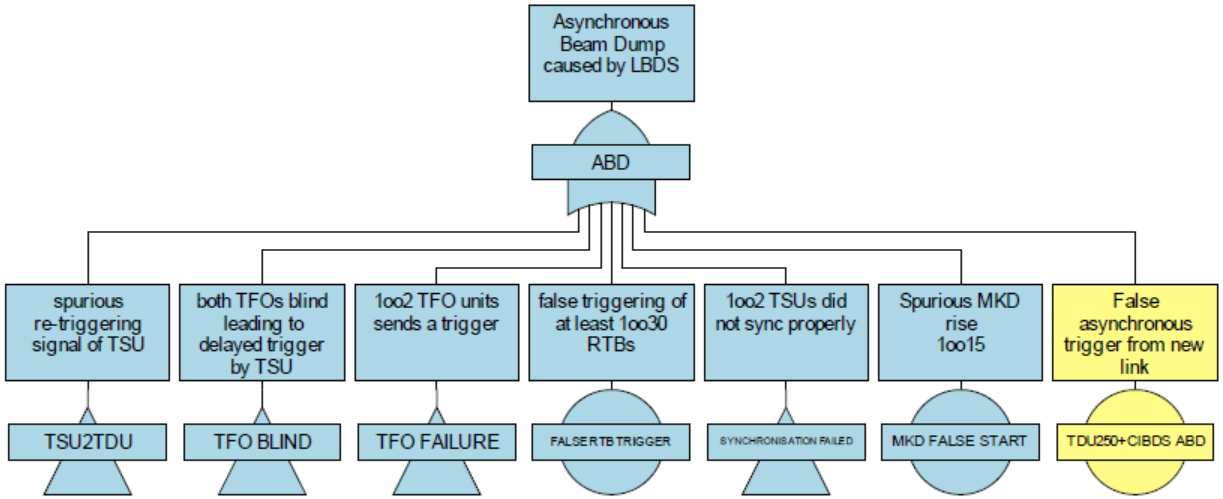
Would give valuable information for EIC and Experts to make decision on LHC operational conditions.

Direct Connection from BIS to LBDS Retrigger-Lines

Master Thesis at CERN on LBDS System Analysis (V. Vatansver 2014)
"Reliability of the Direct Link from the BIS to the LBDS Re-triggering Lines"

Reliability study scope:

- CIBDS card
- TDU250 box



RESULTS:

False **Asynchronous** beam dumps:

- Specified: 2 in 10 years
- Calculated: **0.025 in 10 years**

False **Synchronous** beam dumps:

- Specified: 2 per year
- Calculated: **0.01 per year**

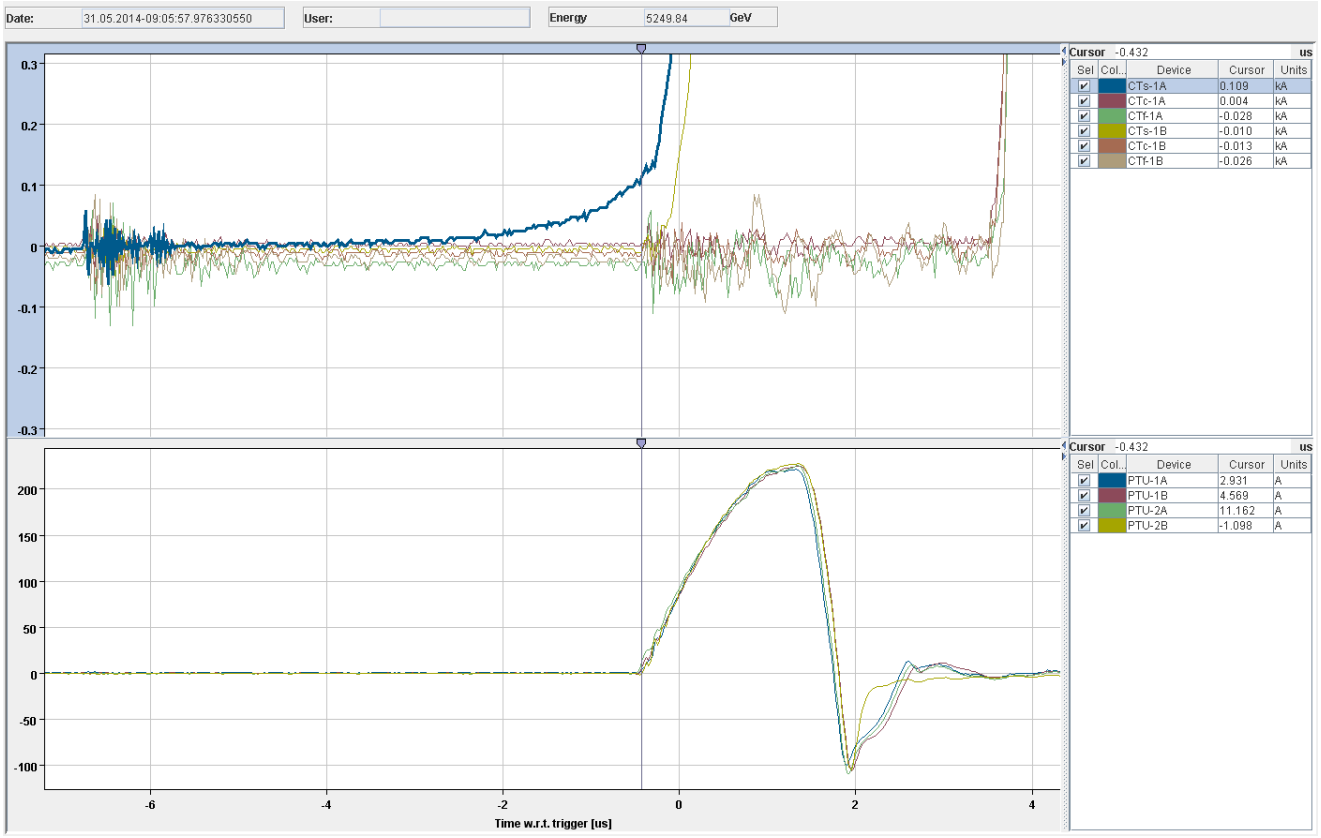
=> Direct Connection from BIS to LBDS Retrigger-Lines is largely reliable enough !

FIRST RELIABILITY RUN RESULTS

Spontaneous Triggering of MKD HV Generators

Stay at 7 TeV for long periods, trigger every 8h (?):

- Started tests with MKD Beam1 (08.2013): => 2 Gen. doing spontaneous triggers.
- Started tests with MKD Beam2 (11.2013): => 6 Gen. doing spontaneous triggers.



Problem is still due to small electrostatic discharges inside HV generator that provoke the triggering of the GTO stacks.

Understanding the Problem

After months of investigations:

1) **We found a workaround**:
   Adding resistance in parallel with G-C of GTO to reduce mutual coupling (via trigger transformers) => electrostatic discharges do not trigger the GTO stack anymore.
   => Resistances installed on all GTO trigger transformers.

2) **We identified one source of the problem**:
   An insulator tube gets charged slowly due to its geometry and surface properties, and eventually discharges through the top GTO A-G capacitance.
   - New tube series production launched.
   - 20 % of series will be tested in the laboratory.

   => Installation in the tunnel foreseen **end of July**.

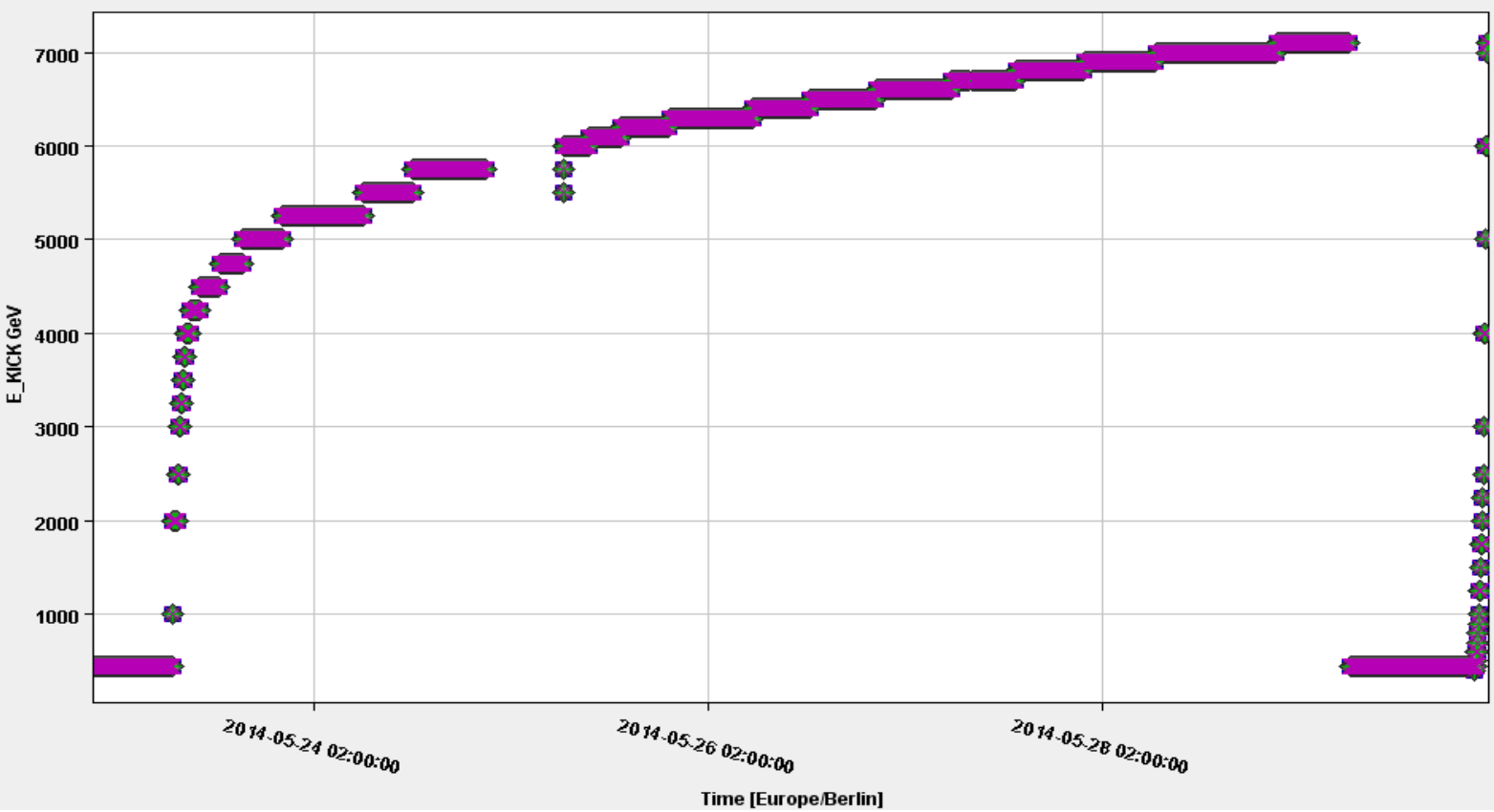
3) **We continue to explore the limits of electrostatic discharge:**
   'Dummy' generator with **very high voltage**, to increase the rate of spikes events.

Sand blasted Bakelite tube after sparking

MKB Conditioning

- MKB B2 conditioned up to 7.1 TeV.
  - Vacuum is in good shape (< 4e-7 mbar)
- MKB B1: Recovered well from aluminum foil pollution.
  - Presently at 6.6 TeV, also to be conditioned up to 7.1 TeV.

=> LBDS Ready for 6.5 TeV during Dry Run



FIRST DRY RUN RESULTS

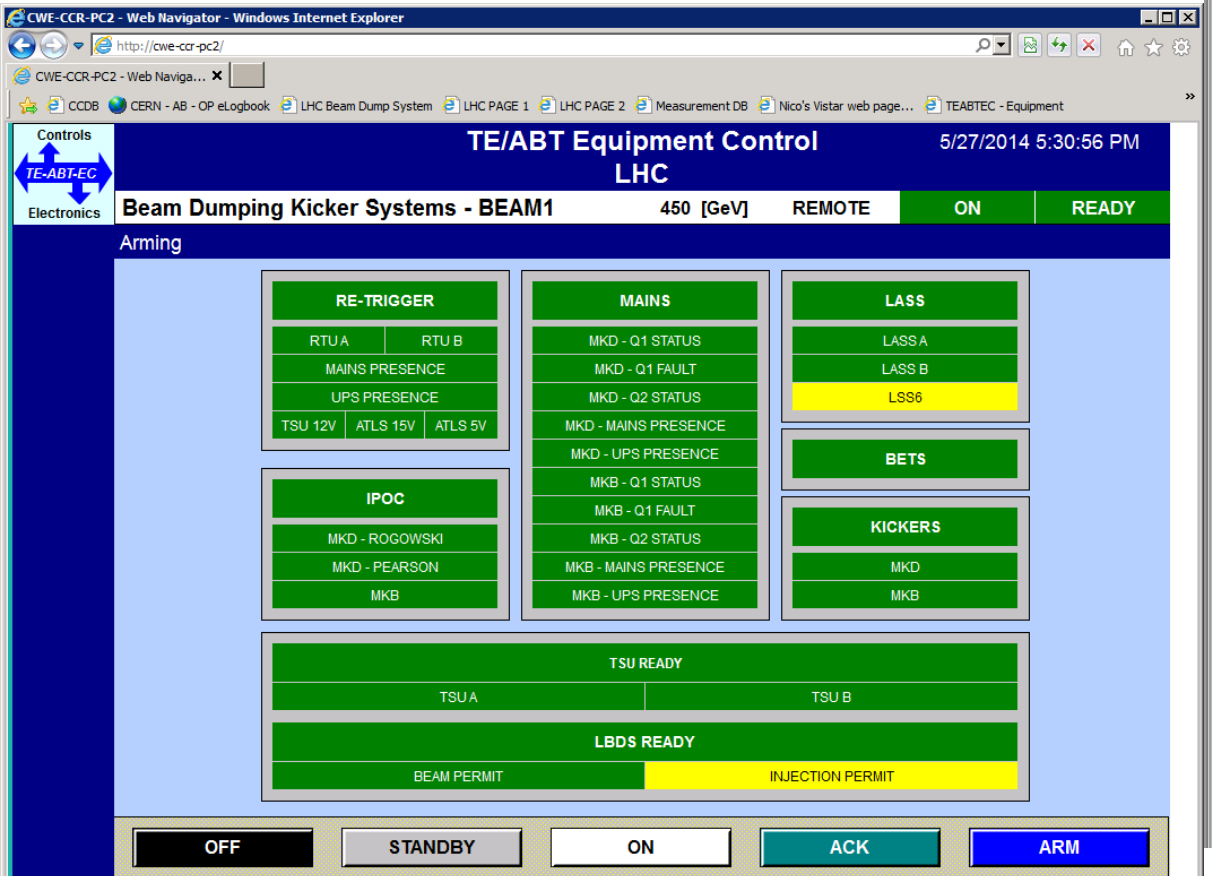
FIRST DRY RUN RESULTS

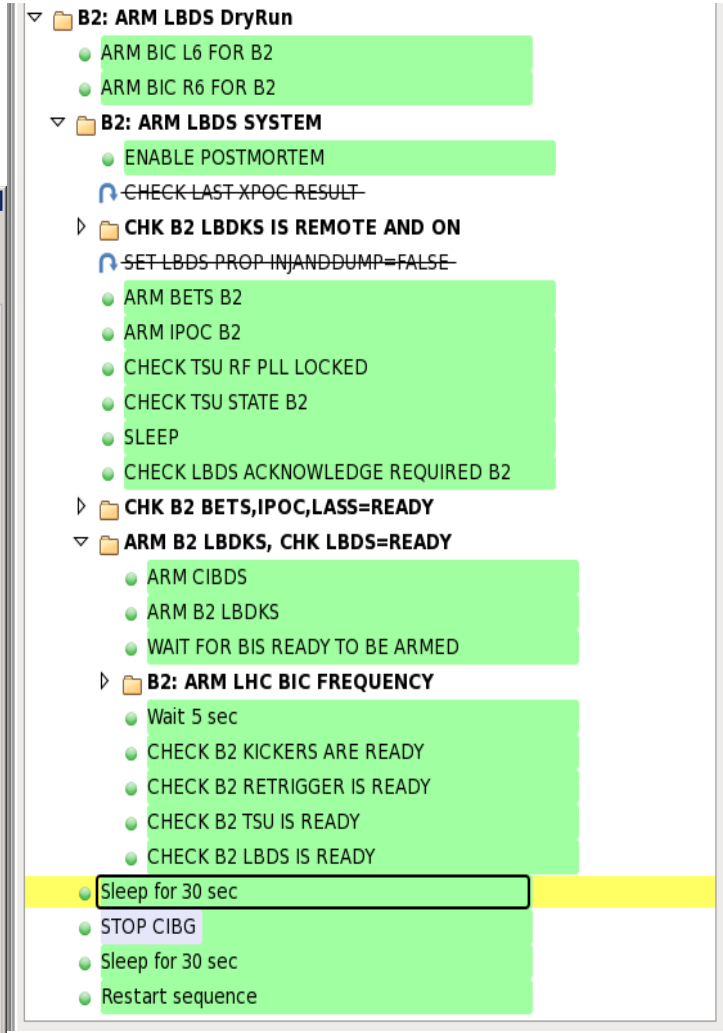
LBDS Armed in REMOTE

- Local BIS loop installed
- Signal Generator installed and connected to BETS
- BRF generated locally using CTR card

⇒ LBDS Armed at 450 GeV (MKB not conditioned)

⇒ Arm & Dump looping using LHC Sequencer





Direct Connection from BIS to LBDS Retrigger-Lines

- Asynchronous dump triggered by BIS has been tested.
- Presence of pulses from CIBDS and TDU250 will be checked by IPOC.

BIS retrigger pulse quite low after 15 MKDs.

- Enough to trigger LBDS
- Enough to be detected by IPOC

=> Nevertheless to investigate and improve

UPDATED PLANNING

Dates	Duration	Control	Activity
09-06-2014 21-07-2014	6 weeks	REMOTE	**Dry Run (+REMOTE Reliability Run):** - Local BIS Loops / BETS Simulator - Validate BIS-Retrigger - Ramp, Flat-Top 10h, Dump (= REMOTE Reliability Run) - UPS tests ?
22-07-2014 21-08-2014	4 weeks	LOCAL	**Consolidation of MKD Generators:** - Add new insulating tubes + Control & HV tests - **Latest date for New TSU deployment**
22-08-2014 **-> TBC by OP, MPE and planning**	4 weeks min.	REMOTE	**Dry Run (+REMOTE Reliability Run):** - **Test TSU** - **Validate Inject&Dump** - Test HV holding for long periods - Ramps & Energy-Scans - Validate FESA3 software (BETS/IPOC/XPOC/etc)
Date TBD by OP and MPE…		LOCAL	**LOCAL Reliability Run:** - Remove Local BIS / BETS Simulator - Test HV holding for long periods - Regular Ramps & Energy-Scans
11-2014 ?		REMOTE	**Sector Test (S78-S67)…**

We would like to keep LBDS in REMOTE with the LOCAL BIS loops as long as possible !

COMMISSIONING WITHOUT BEAM

We request 2 days in REMOTE with BIS closed to:

- Re-validate hardware
  (HV Generators, TSU, BETS, IPOC, TCDQ, Etc…)
- Re-validate of all software layers
  (SCSS, IPOC, XPOC, BETS, TSU, Etc…)
- Re-check arming sequences
- Test Injection Permit
- Test Inject and Dumps

PLUS perform updated Machine Protection Procedures for LBDS

COMMISSIONING WITH BEAM

- Re-synchronise MKD rising edge with dump of pilot bunch 1
  => Adjust TSU Trigger delay

- Re-synchronise BAGK with injection of pilot bunch 1
  => Adjust TSU BAGK delay

- Scan of MKD rising edge
  - Never done… Procedure to be approved !
  - 1 complete shift required ?

- Test of BLMDD TSU client
  - Never tested with beam… Procedure to be approved !

PLUS perform updated Machine Protection Procedures for LBDS

CONCLUSION

- Unforeseen complicated problems of spontaneous triggering of MKD HV generators encountered.
  After months of investigations we identified a possible source.
  => We are late on the original schedule ! (But we foresaw margin)

- We are ready for Dry Runs in REMOTE (MKB conditioned up to 7.1 TeV)

- A lot of changes have been performed during LS1.
  => Reliability Runs and Dry Runs needed

Thank you for your attention.

Spares slides / Removed…

TSU Test Bench

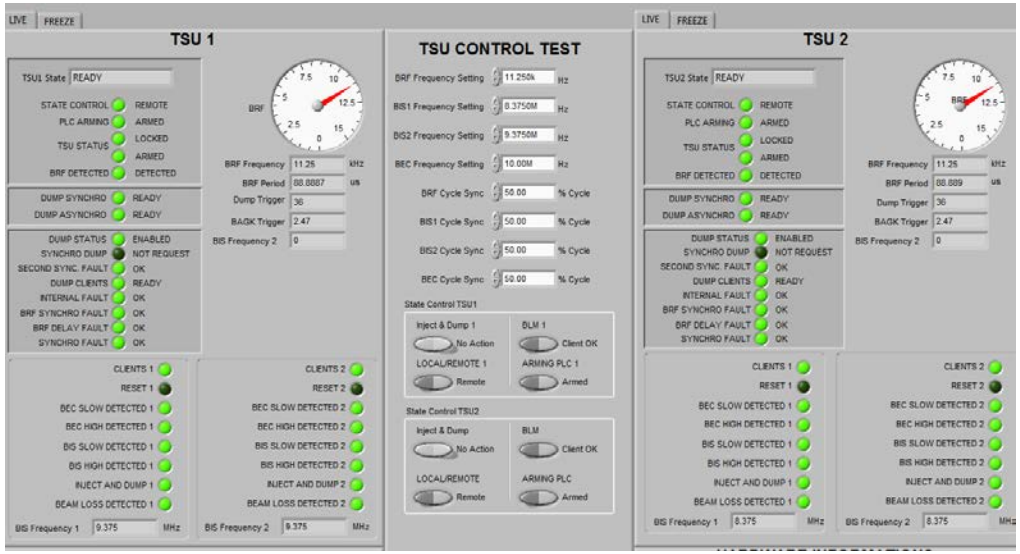
IN PROGRESS…

Motivation:

Careful validation of new firmware before use in operation.

Based on a National Instruments PXI system to:

- Generate all TSU input signals.
- Check all TSU output signals.
- Check IPOC analysis results.
- Various dump scenario (>100) executed in loop 24h/7d.



Comparison of Predictions vs. LHC Run I Statistics

Failure mode and identifier | **# components** | **Time to Failure** | **Hypothesis test** | **Time to recovery**

The underscored figure is the one validated. Population is counted for 2 LBDS. The raw estimate refers to [Years of operations] × [population] / [number of failures]. Hypothesis test is run with $\alpha = 0.05$.

#	*Failure mode*	*Model*	*Population*	*TTF (years)*				*TTR (h:mm)*
				Raw	Corrected	Rel. pred.	H. test	
1	MKD HV power supply breakdown	PSP1	30	3*30/7 = 12.8	β model	150		1:37
2	MKD PTU HV PS	HV	60	3*60/10 = 9	1-count 26	16	TRUE	2:18
3	MKD Compensation PS breakdown	PSOS1	30	3*30/6 = 15	1-count 18	113	FALSE	3:05
4	PTC tracking error	PTC, PTC3	80	3*80/2 = 120	1-count 240	103	TRUE	3:40 (singleton)
5	MKD Power switch degradation	SP2	60	3*60/3 = 60	P_D model	633	n.a. [1]	2:20
6	MKD PTC card failure	PTC1-3	80	3*80/1 = 240	-	1140	n.a.	1:44 (singleton)
7	MKB Power switch degradation	SW2	20	3*20/6 = 10	P_D model	633	n.a.	0:36
8	MKB HV power supply breakdown	PSH	20	3*20/1 = 60	-	152	TRUE	No data
9	MKB HV power supply degradation	Not in the model	20	3*20/3 = 20	1-count 60	114	TRUE	1:18
10	MKD PTC power supply	PTC	80	3*80/1 = 240	-	114	TRUE	2:03 (singleton)
11	MKB Magnet sparking	Not in the model	20	3*20/1 = 60	-	-	n.a.	No data
12	MKD Peltier cooling element	Not in the model	30	3*30/4 = 22.5	Removed	-	n.a.	No data

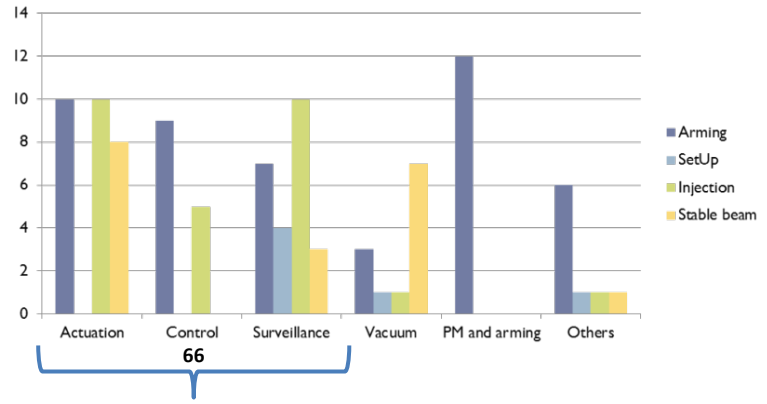
Validation
most conservative value is kept

Availability Updated Figures

- The LBDS counted **29 false beam dumps**, against 24 foreseen (8/year on average).
  - Actuation (15) then surveillance (12) and controls (2)

1- False dumps

66 apportioned to LBDS in every phase



2 - Filtering

- Only LBDS false beam dumps in the phases injection and stable beam
- No repetition of the same internal dump request