Asynchronous Dumps

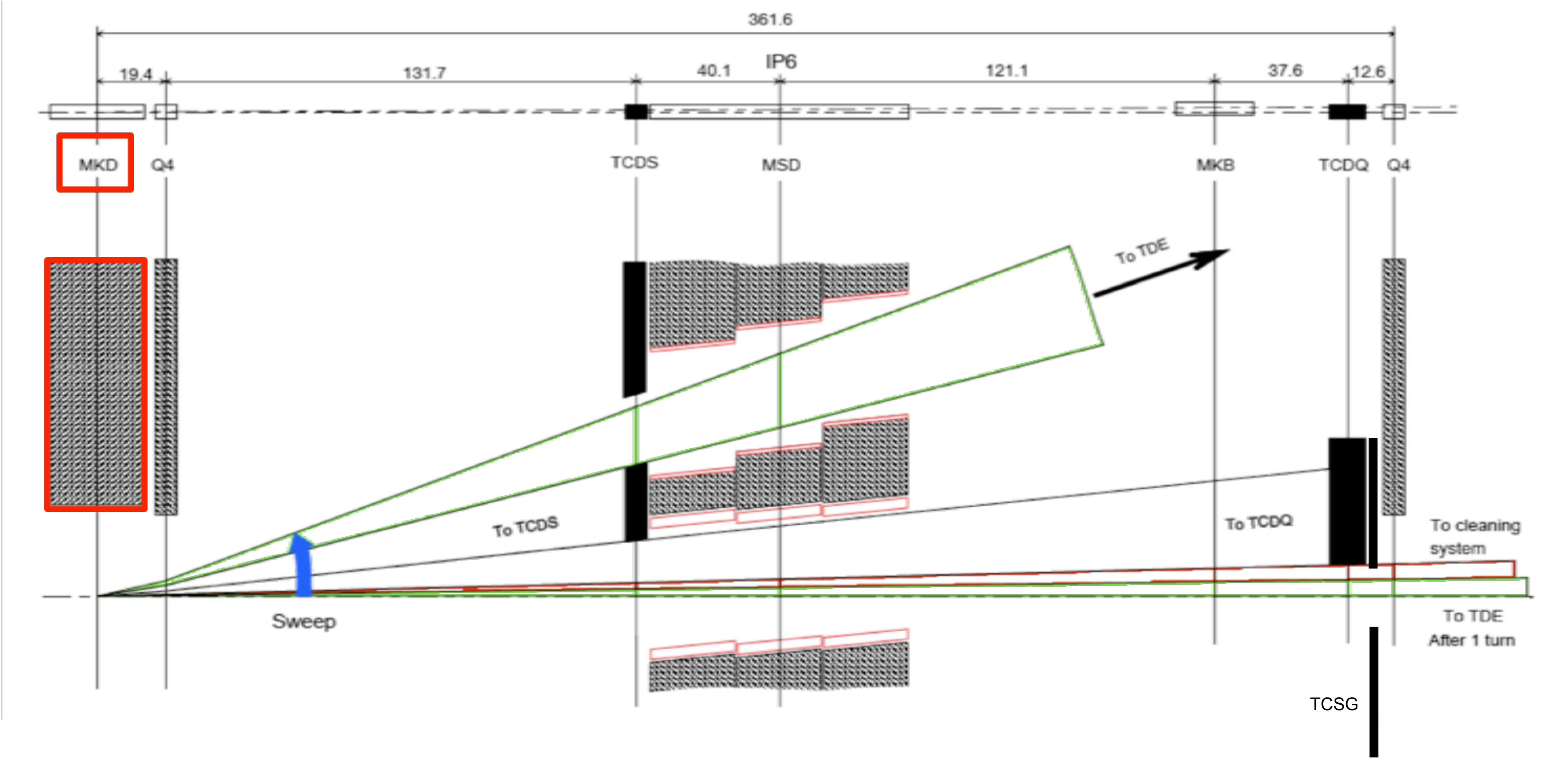
W. Bartmann, C. Bracco, E. Carlier,
B. Goddard, V. Kain, M. Meddahi, V. Mertens, J. Uythoven

External Review on LHC Machine Protection 07-09-2010

Outline

- What is an asynchronous beam dump and how to protect the machine
- System Performance
  - HW/SW issues, upgrades
  - Tests of asynchronous beam dump (different energy, intensity, with/without orbit offset, with/without energy offset)
  - BLM saturation and RC filters
- TCDQ leakage: simulations with SixTrack
- Abort gap population measurements and cleaning

What is an Asynchronous Beam Dump?



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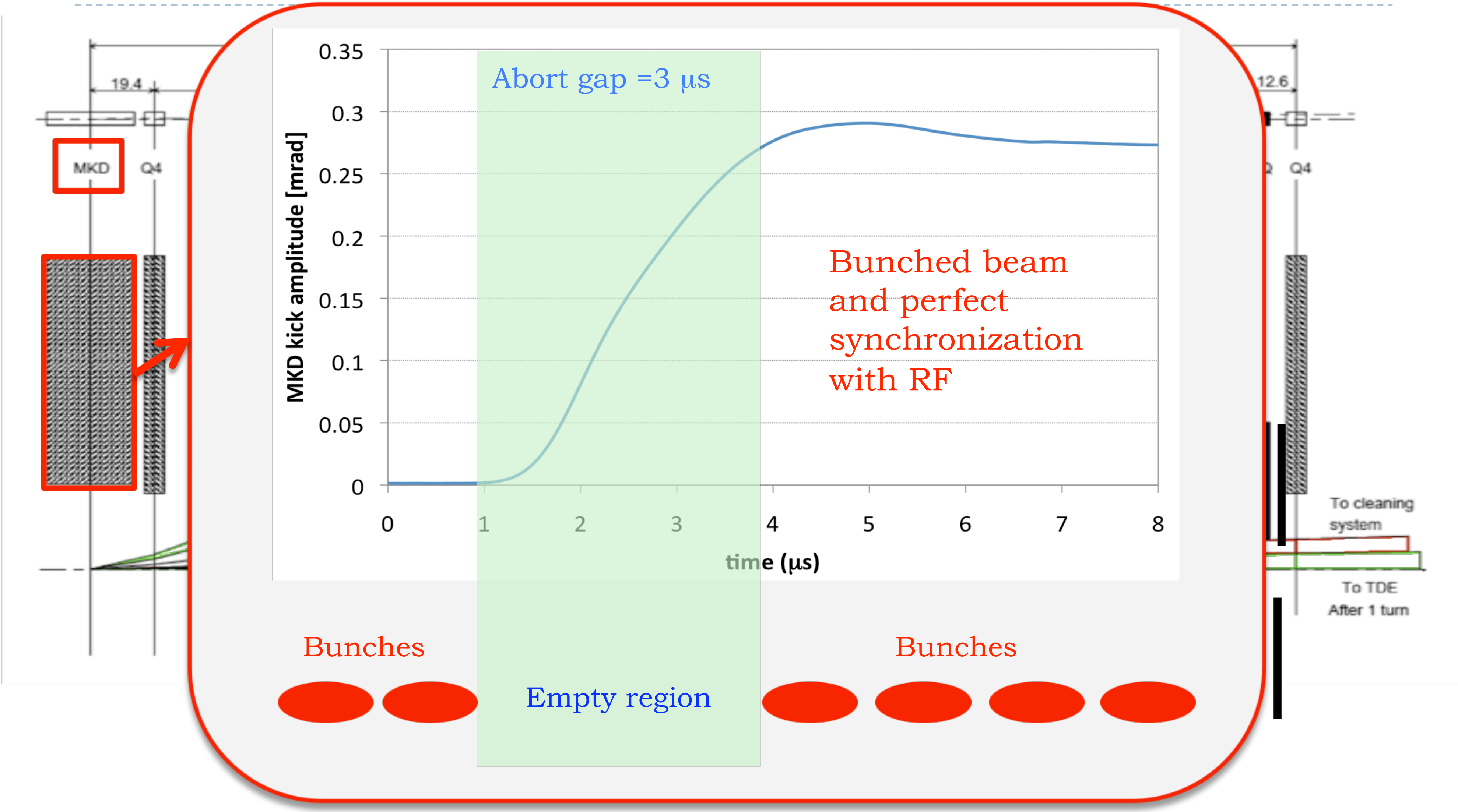

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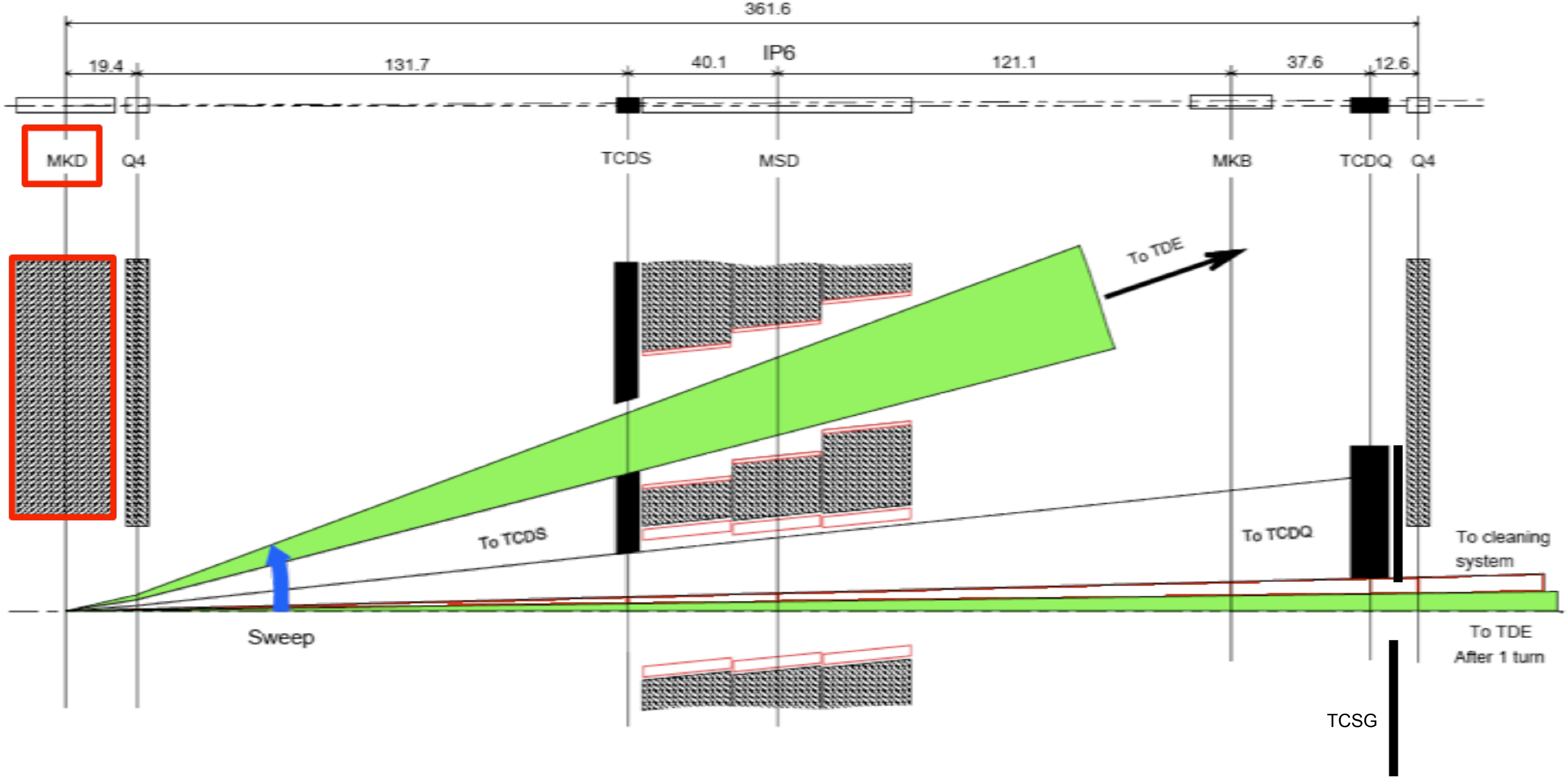

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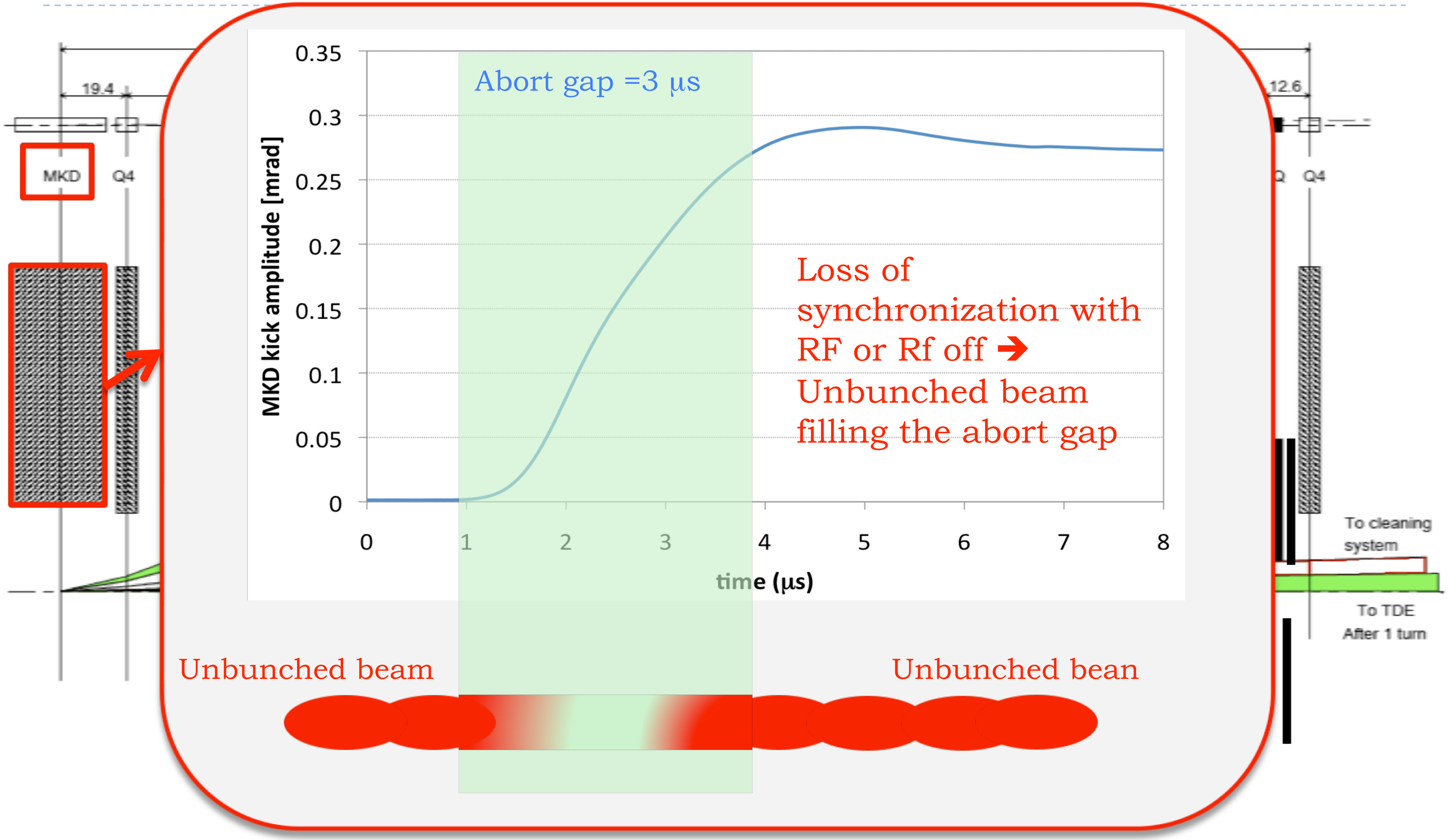
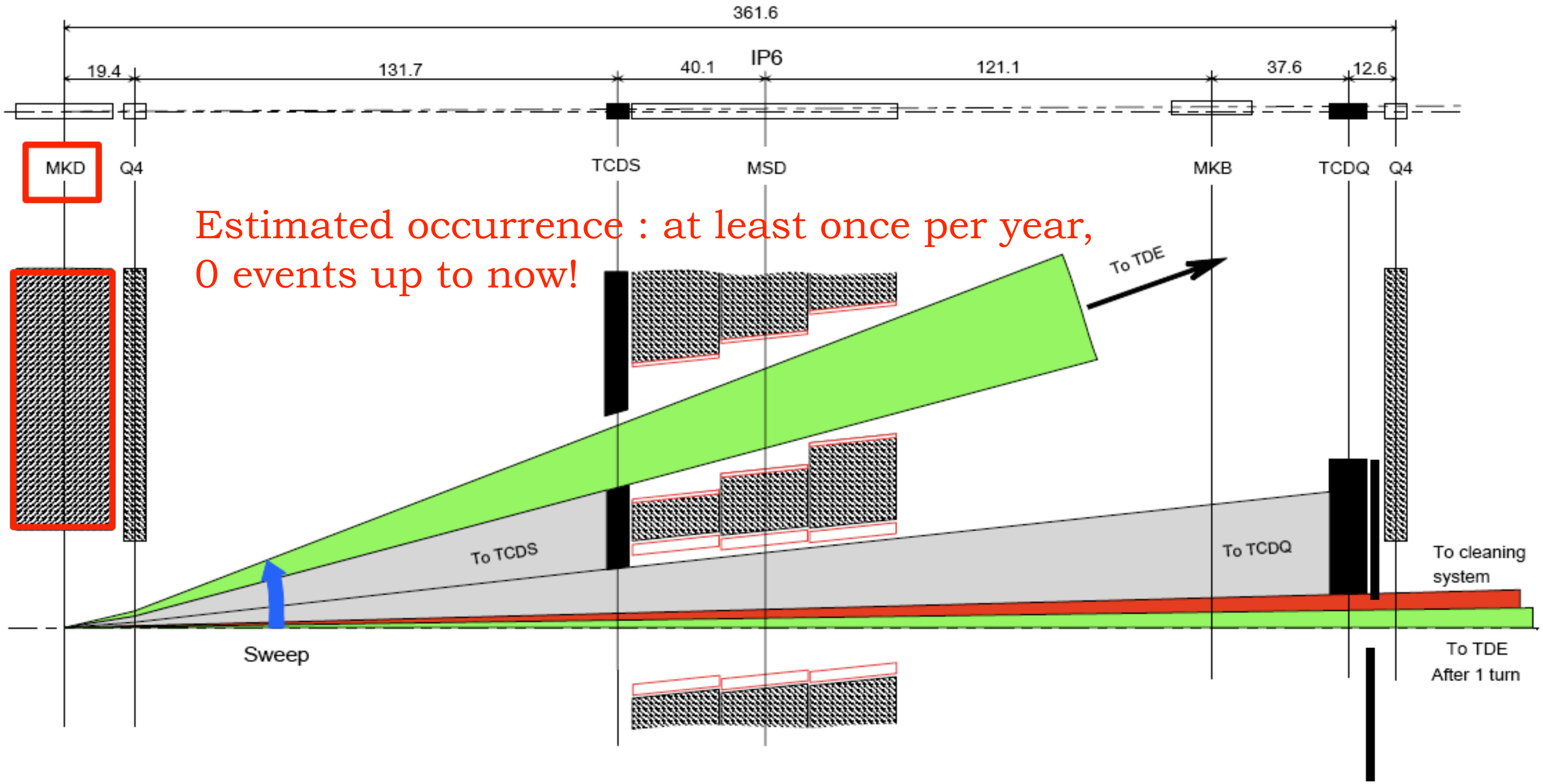
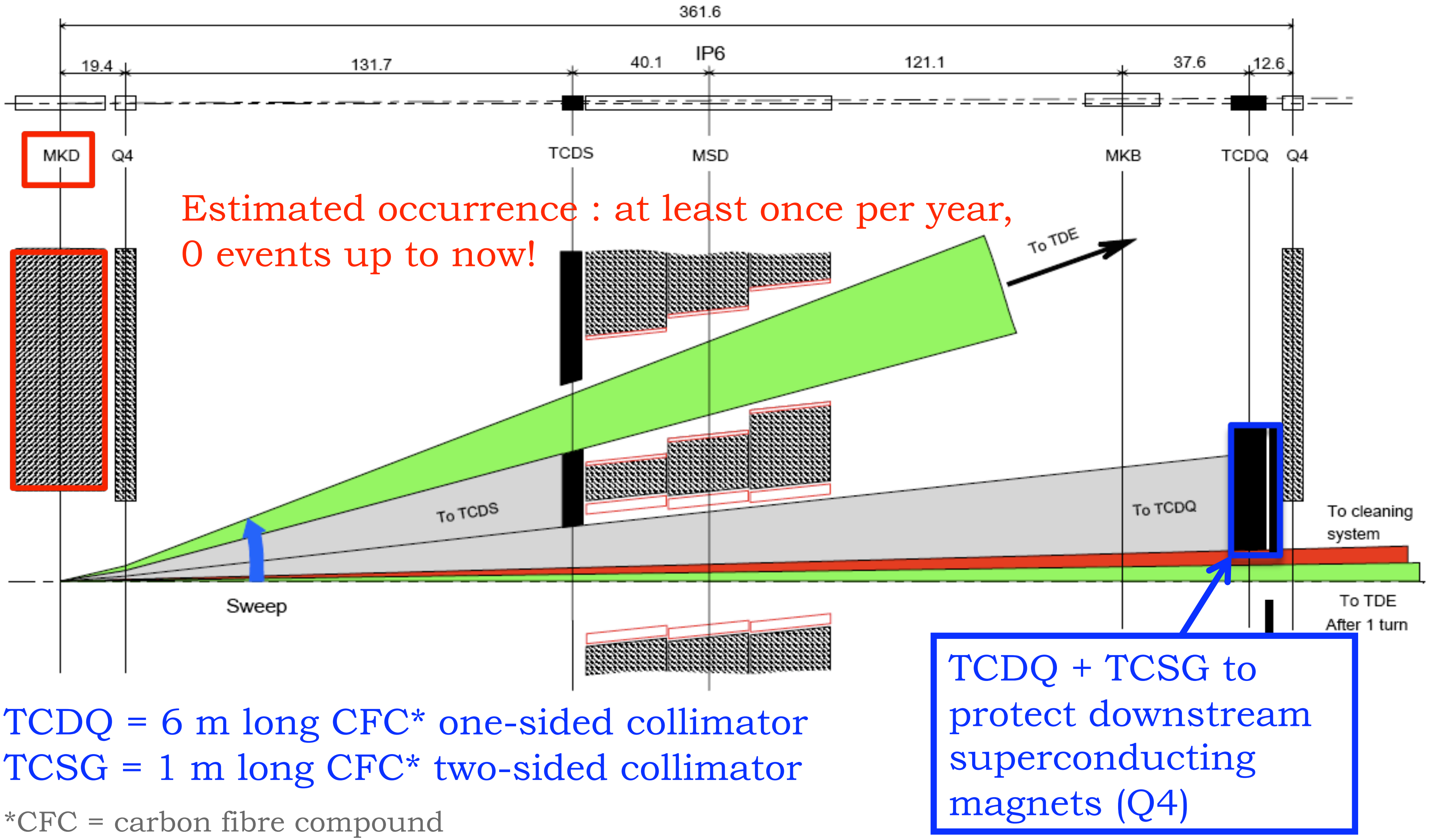


What is an Asynchronous Beam Dump?

Estimated occurrence : at least once per year,
0 events up to now!



How to Protect the Machine in Case of an Asynchronous Beam Dump?



TCDQ = 6 m long CFC* one-sided collimator
TCSG = 1 m long CFC* two-sided collimator

*CFC = carbon fibre compound

Other possible failure scenarios

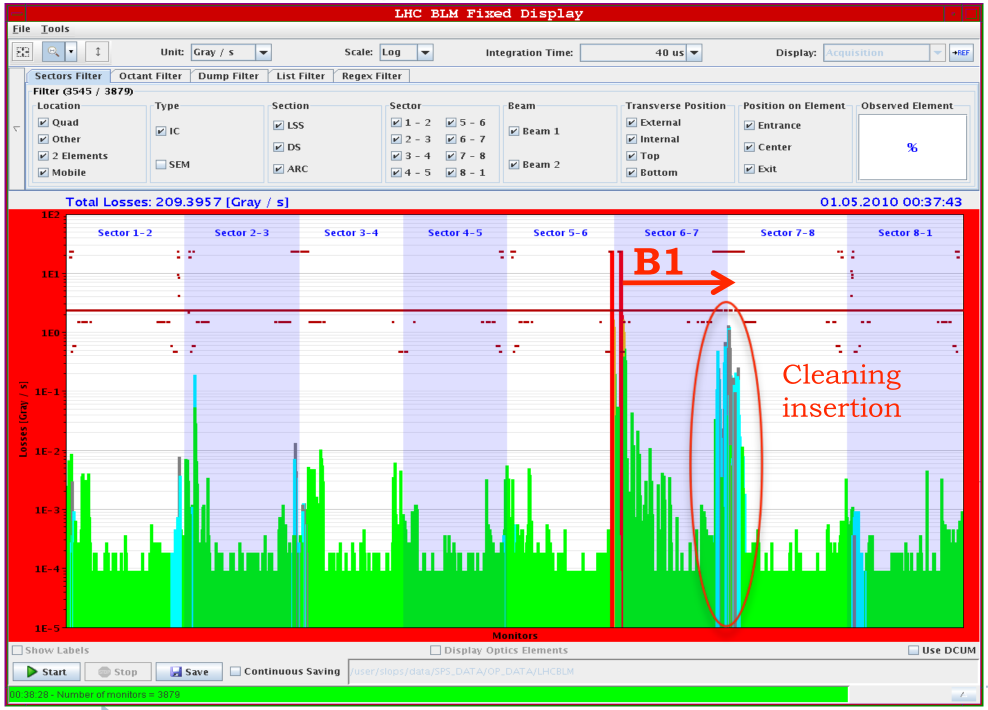
- Spontaneous trigger of one of the 15 MKD dump kickers ➔ re-trigger of the 14 other modules within 1.2μs (450 GeV) 0.7 μs (7 Tev) (see J. Uythoven's and B. Goddard's talk):
  - Generally out of phase with respect to the beam abort gap
- Estimated occurrence: at least once per year, 2 events happened during 5 TeV commissioning without beam.
- Worst failure scenario: high leakage rate from TCDQ+TCSG (bad orbit or protection device position) ➔ possible damage of TCTs
- Not possible to test this pre-trigger scenario during beam commissioning

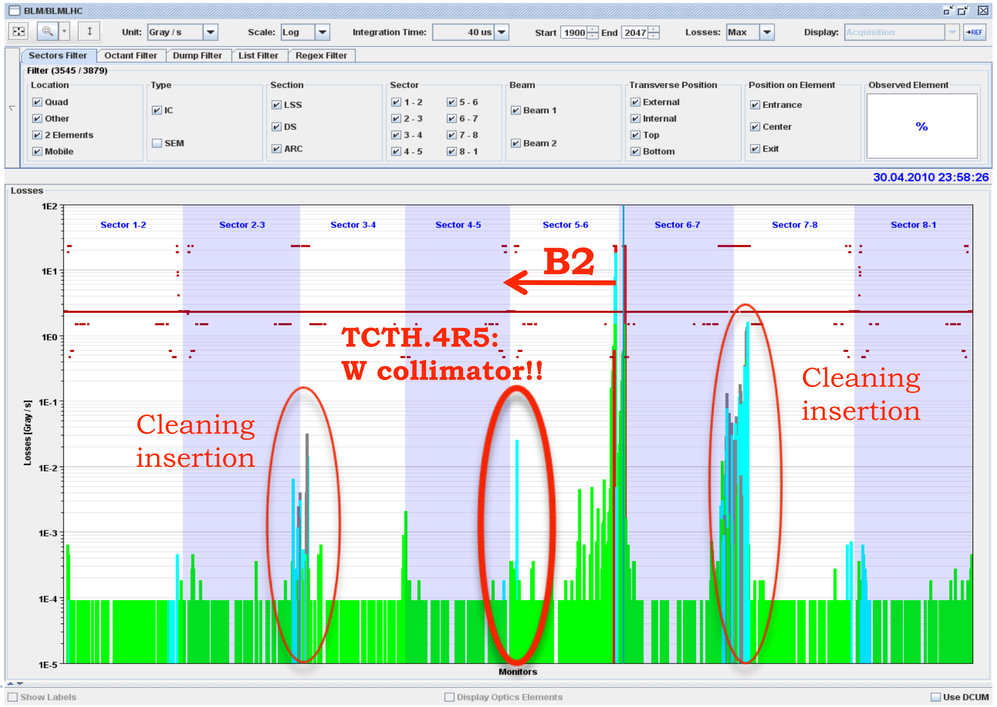
TCDQ hw/sw issues

- TCDQ setup:
  - 0.1 mm resolution acceptable? Now yes, for the 7 TeV nominal operation more critical (see later)
  - TCDQ positioning reproducibility: ok (no interlock seen when setting collimators via the sequencer).
  - Positioning errors during ramp acceptable? Now yes. When increasing beam intensity setup tolerances will be reduced ➔ to be checked.
  - Use of same CPU for positioning and interlocking - potential common mode failure?
  - Position vs beam energy SW interlocking safe enough? Is a HW interlock needed (integration within BETS?)
- TCDQ robustness
  - Will be damaged by impact of 28 nominal intensity bunches at 7 TeV (25 ns spaced
  - to be resolved in 2012 shutdown by upgrade - in progress

Test with Debunched Beam

- Method for simulating asynchronous dump
  - Switch off the RF
  - Let the beam debunch for about 90 seconds ($\Delta E/E$ = 0.01%) ➔ population of the abort gap
  - Trigger a beam dump





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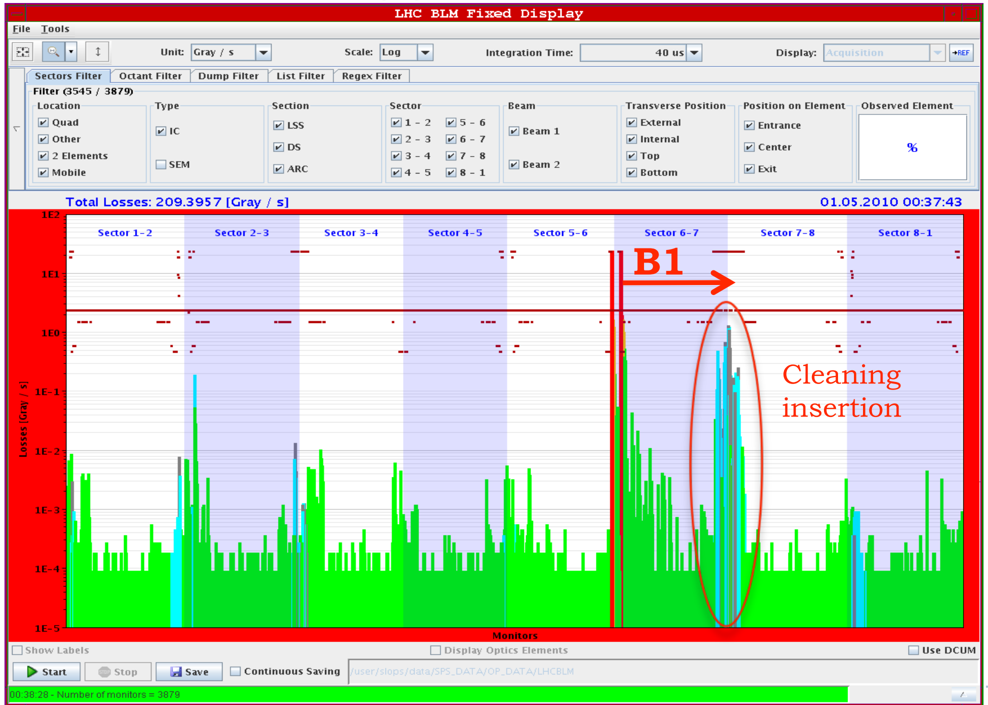

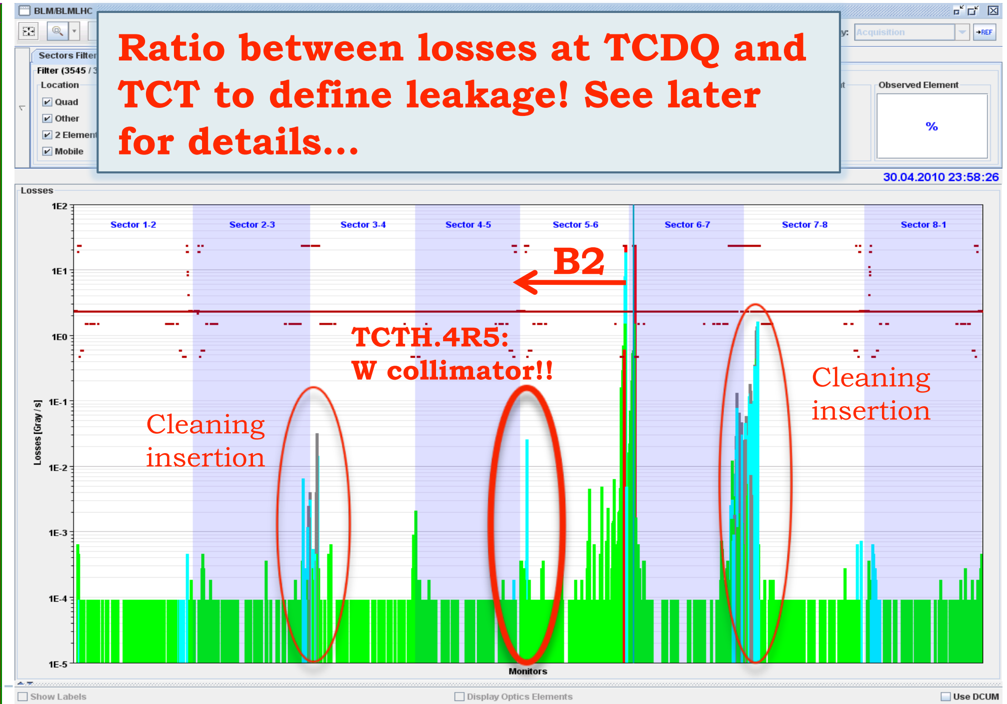

Problems with BLM saturation

- When increasing the beam intensity the BLM at the collimators in point 6 saturate
  - no quantitative information to define the leakage to the TCT in point 5
- RC filters have been installed at the BLM with the highest reading on the TCDQ (TCDQB)
- A new BLM with RC filter has also been installed at the TCSG during the last technical stop (week 35)
- Introduces different BLM HW types – issues of configuration management

Abort Gap Population and BLM Calibration

- 36/120 of abort gap population impacts TCDQ
- Uniform abort gap population (pending deeper analysis!)
- 1e12 p+/Gy response for BLMs at TCTs, TCSG and TCDS
- Measured response at TCDQ: 1 – 5 e11 p+/Gy

Results of Tests Performed (Beam 2)

450 GeV			3.5 TeV		
Intensity [p+]	**Other**	**TCT/TCDQ**	**Intensity [p+]**	**other**	**TCT/TCDQ**
9e9		No losses at TCT	1e10		No losses at TCT
9e9	±4mm orbit offset	No losses at TCT	2e10	Squeeze 2m β* 2mm offset	All BLM P6 saturated
1.2e10		No losses at TCT	2e10	Squeeze 3.5m β* 2mm offset	4e-4 RC filter TCDQB
1e11		5e-4 RC filter TCDQB	7e10	Squeeze 3.5m β*	9e-4 RC filter TCDQB
1e11	+4mm orbit offset	1e-4 RC filter TCDQB			
1e11	-3.5mm orbit offset	3e-4 RC filter TCDQB			

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1e11	+4mm orbit offset	1e-4 RC filter TCDQB			
1e11	-3.5mm orbit offset	3e-4 RC filter TCDQB			

3.5 TeV, 2m b*, 2mm (=1σ) offset

IR6 saturated
IR7 15Gy/s
TCTH.4R5.B2 0.6 Gy/s
➔ 2E7 p+

Leakage from TCDQ **~2E-2** from BLMs (but saturated).

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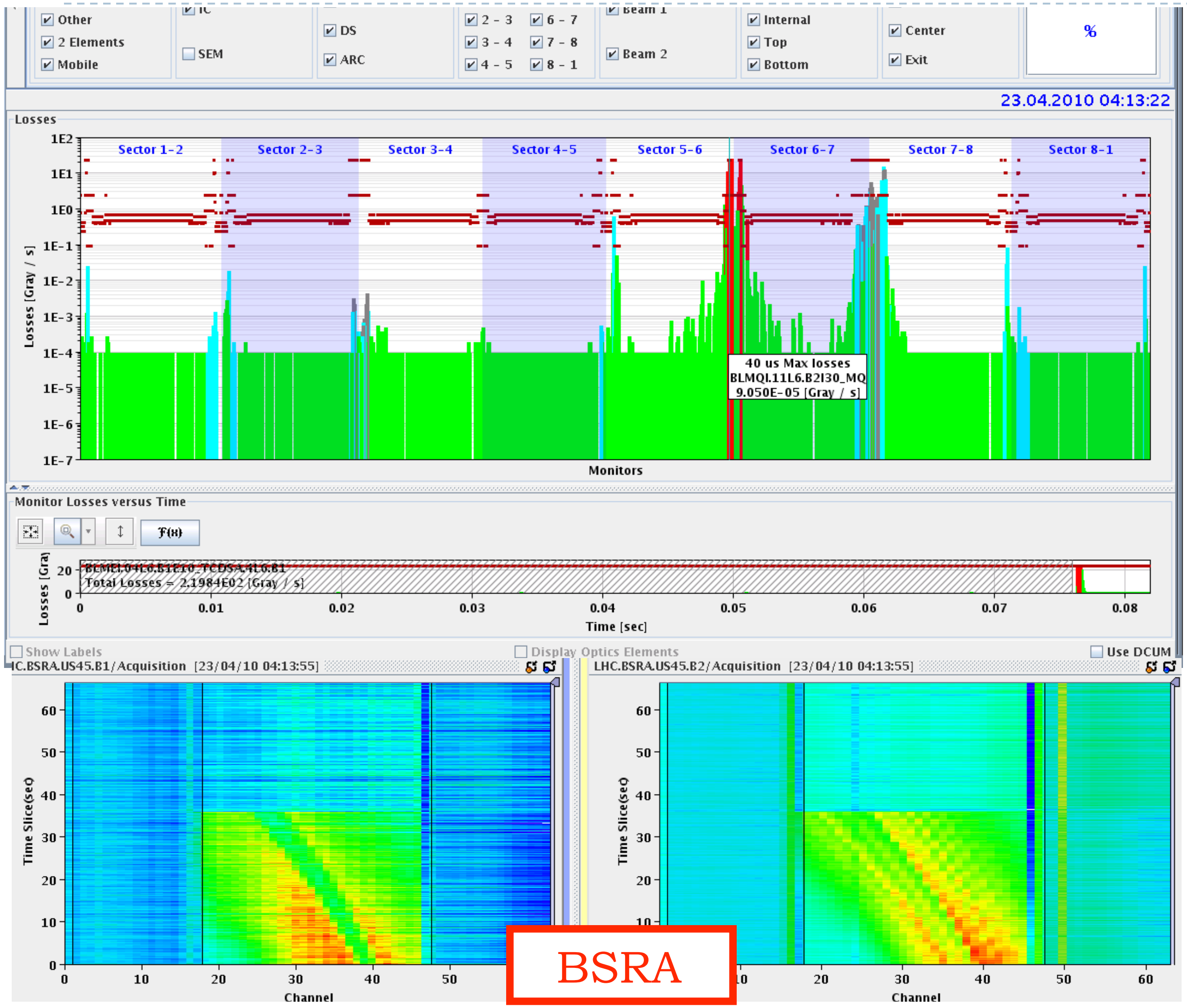

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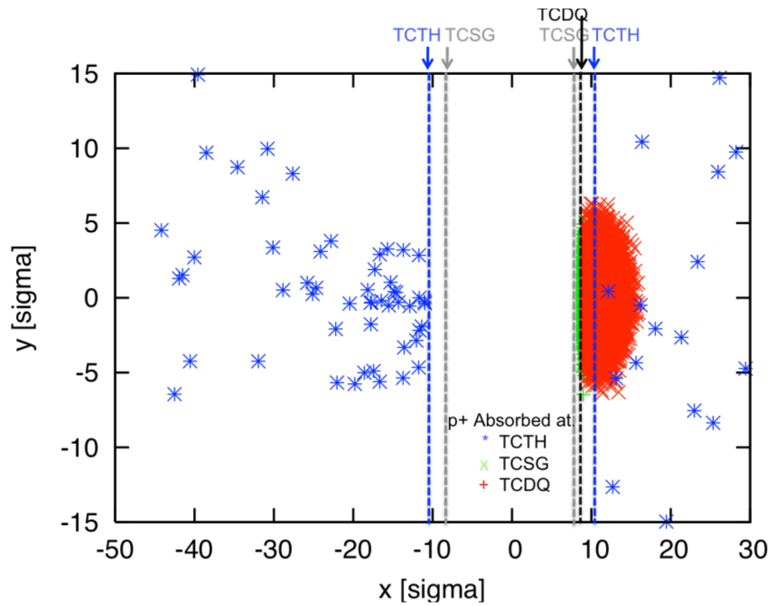
IR7 15Gy/s
TCTH.4R5.B2 0.6 Gy/s
➔ 2E7 p+

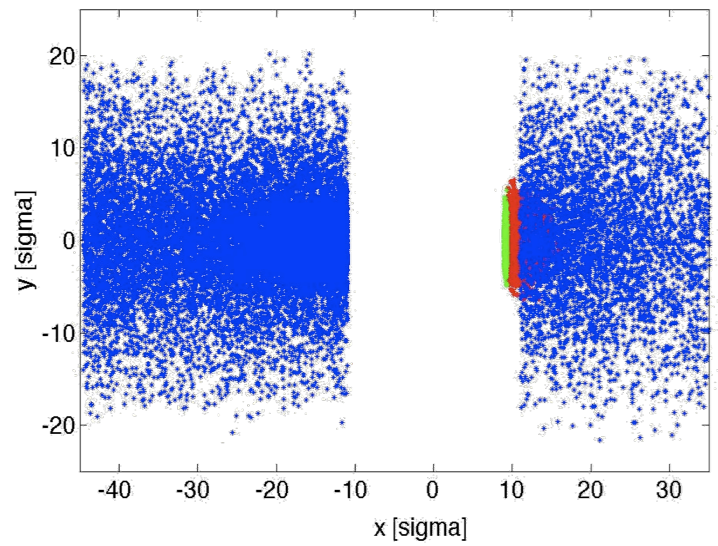
Leakage from TCDQ **~2E-2** from BLMs (but saturated).

Measured ~4e9 p+ with abort gap monitor (AGM) at moment of dump (see later for details)

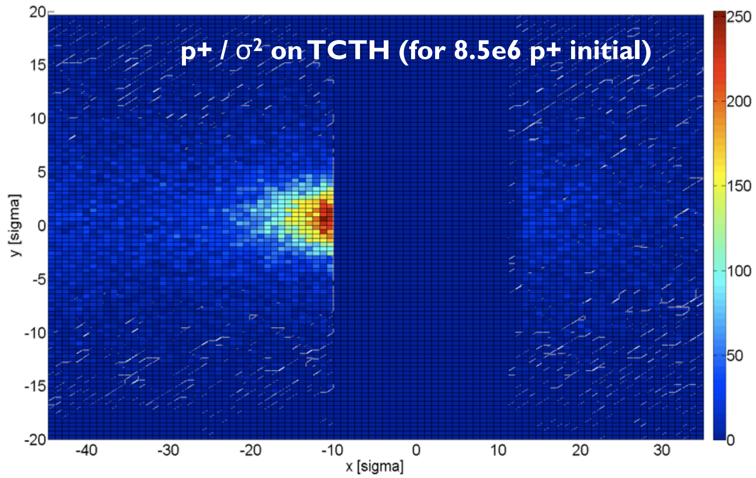
Using abort gap population and, according to our assumptions, the leakage from TCDQ is **~2E-3**

Leakage from dump protection – SixTrack simulations





- All losses come from p+ scattered through TCSG which fill acceptance with scattered primaries
- Total p+ on TCTH is 0.3% of single bunch (8% impacting TCSG in this simulation) or 3.3×10^8 p+
- Peak p+ density is about 0.016% of single bunch (equivalent to 2.5×10^6 p+ with nominal $\varepsilon_{x,y}$)
- Consistent with expectations - full bunch on TCSG would be attenuated by ×10, and have ×180 emittance increase

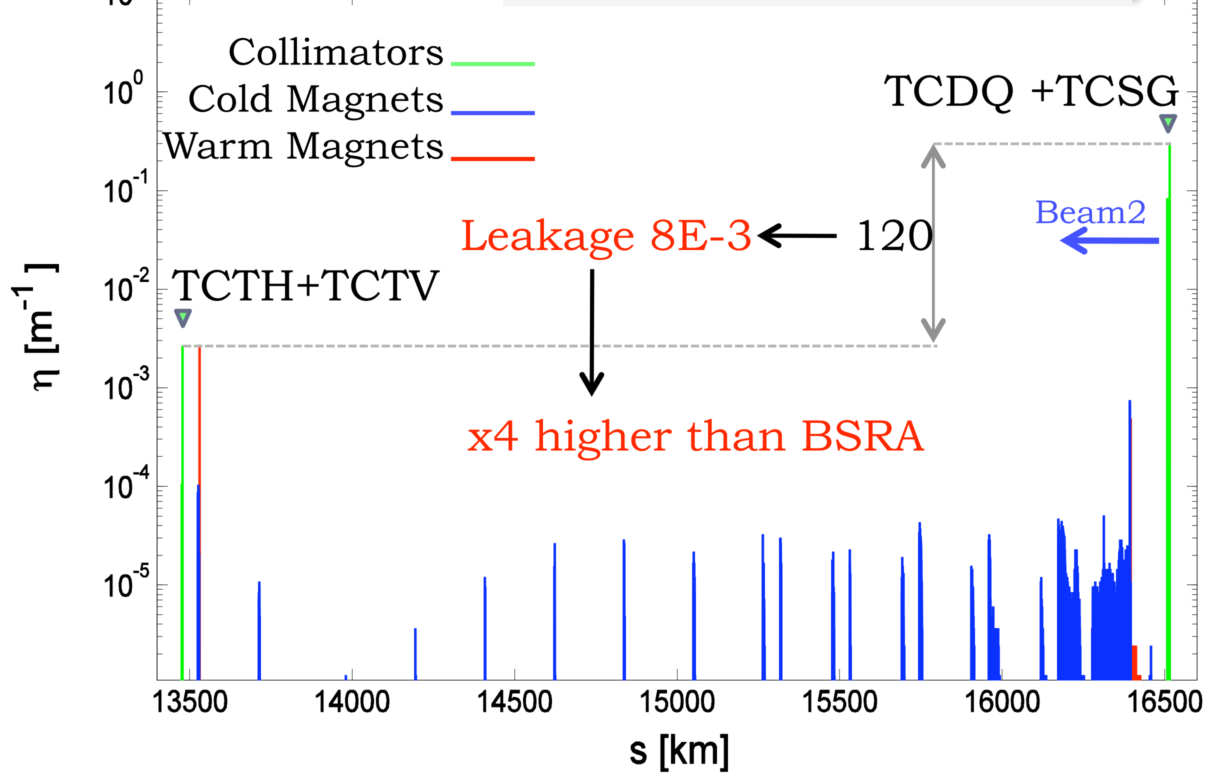


Loss Map for Beam 2, 3.5 TeV, 2m β* in IP5

From SixTrack simulations:

Local cleaning inefficiency:

$$\eta = \frac{\#\ \text{particles lost in Ds}}{\text{Ds} \times \text{Tot}_{abs}}$$



Only primary protons losses.

Ds = 10 cm @ magnets
Ds = 1 m @ collimators (jaw length)
Tot_{abs} = 8'463'489

1 bunch case

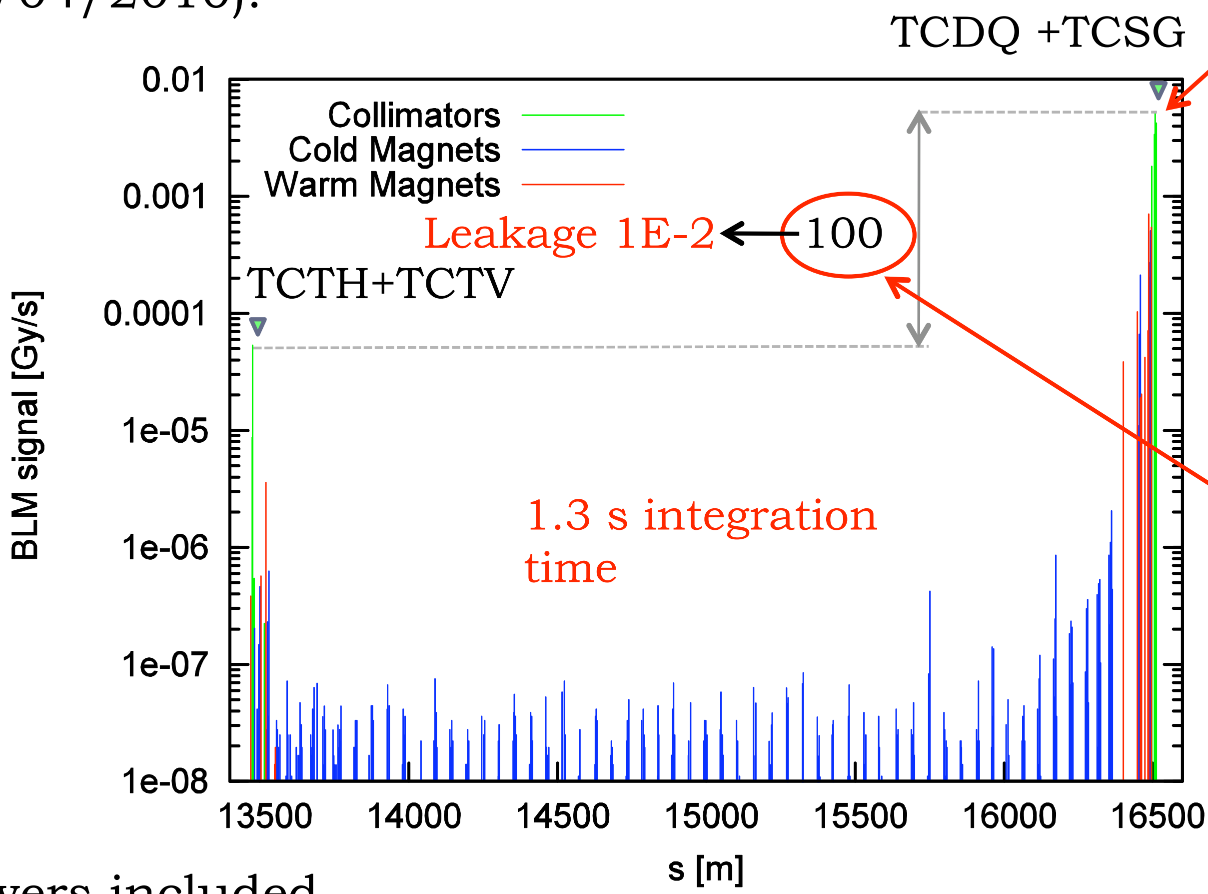
Collimator	N [p+]	% Tot_{abs}
TCDQ	7'639'643	90
TCSG	697'298	8
TCTH	22'186	0.3
TCTV	875	0.01

Statistical error = $1/\sqrt{N}$ ➔ max = 0.03

Nominal bunch (1.1E11 p+): 3.3E8 p+ on TCT

Loss Map for Beam 2, 3.5 TeV, 2m β* in IP5

From Measurements during asynchronous beam dump (23/04/2010):



BLM at TCDQ and TCSG saturated for 40 μs and 80 μs integration time!

At least a factor of 100 between losses in point 6 and TCT in point 5.

1) It seems to be consistent with simulations (not worse).

Showers included

Results of Tests Performed (Beam 2)

450 GeV			3.5 TeV		
Intensity [p+]	Other	TCT/TCDQ	Intensity [p+]	other	TCT/TCDQ
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1e11	+4mm orbit offset	1e-4 RC filter TCDQB			
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Simulations show a factor ~10 higher losses - measurements in good direction

Tolerance at TCDQ

Retraction of TCT wrt TCDQ 3.5 TeV

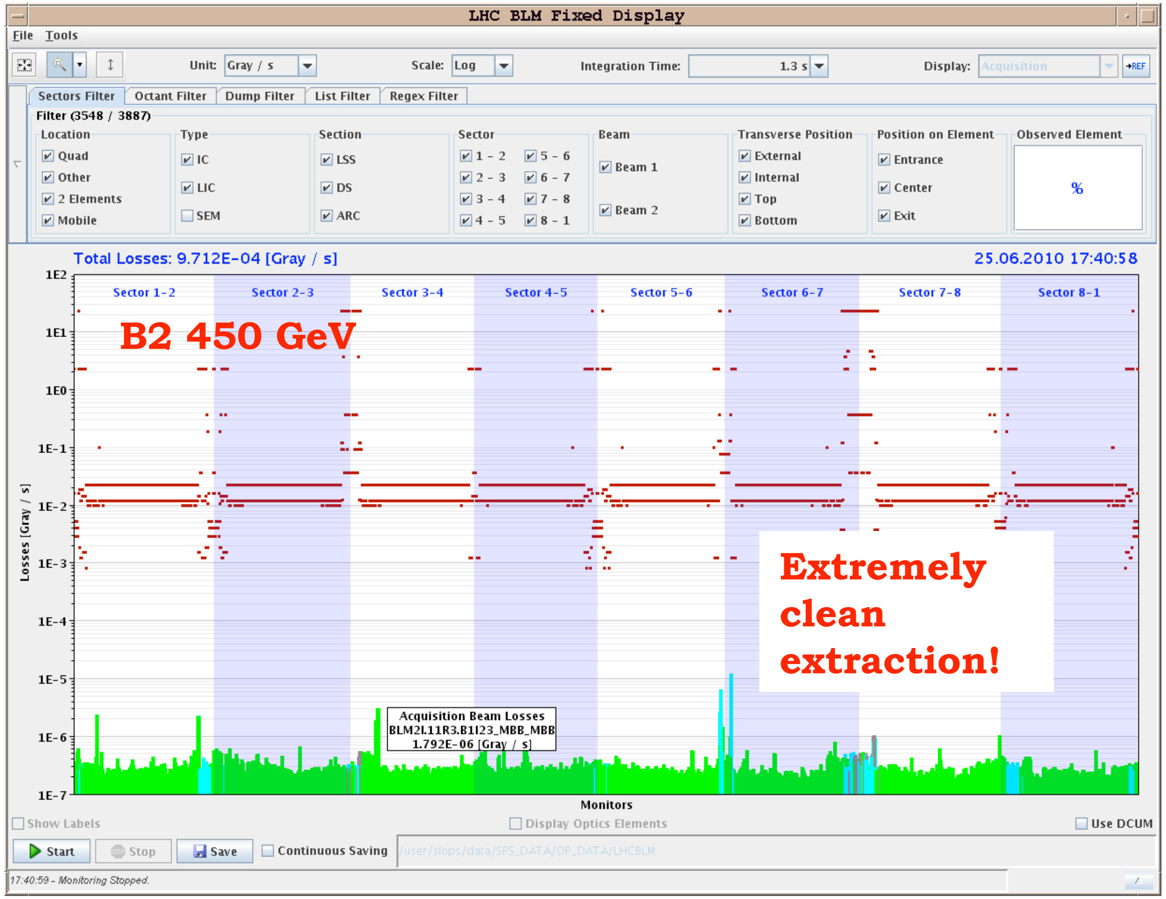
Contribution	[σ]
orbit measurement error at TCDQ	0.7
orbit change at TCDQ (SIS interlocked)	2.5-3.0
TCDQ setting up error	1.0
dynamic beta beat	0.5
TCT setting up error	0.5
total	**5.2 - 5.7**

Agreement to 5σ retraction TCT-TCDQ

Nominal retraction at 7 TeV, 0.55m β*: 0.5σ = 250 μm at the TCDQ !!! Reminder: 100 μm resolution……

One more test……

- Beam dump with +4 mm and -3.5 mm orbit offset and 200Hz RF offset (interlock limit)

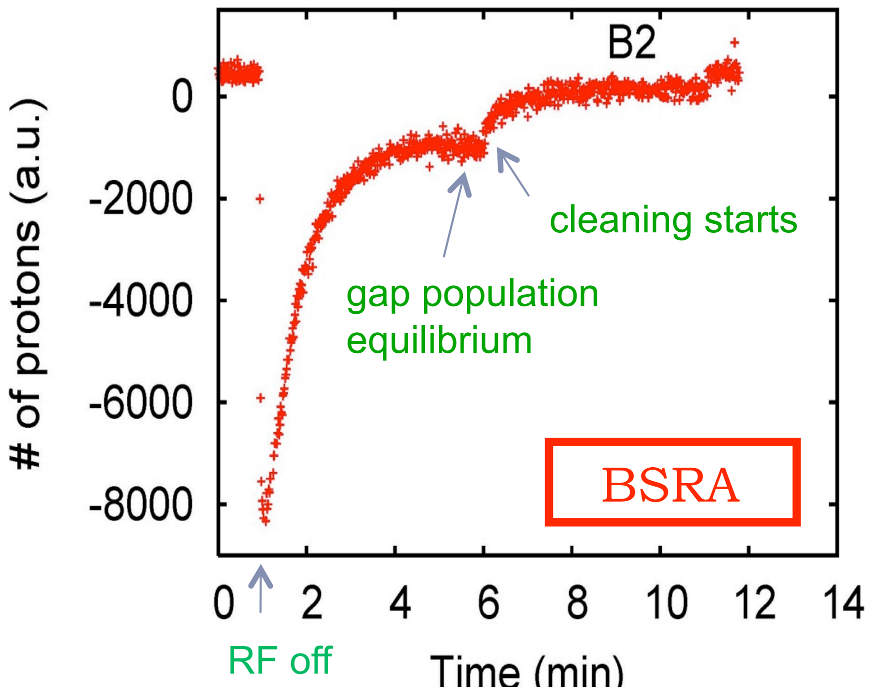


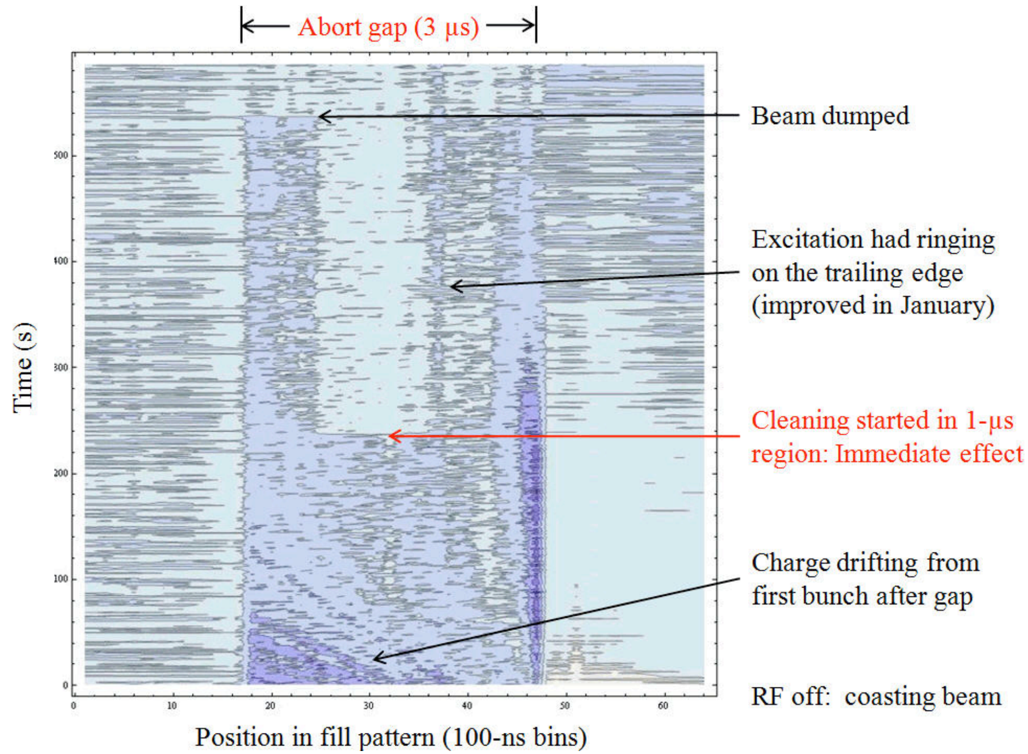
Abort Gap Cleaning: Results From 2009 Test

(A. Boccardi, E. Gianfelice-Wendt, W. Höfle, T. Lefevre …)

Cleaning test of a coasting beam done, on 16-17 Dec.'09

- 4 bunches of 2.5e10 protons
- RF switched off
- After 5 minutes, started cleaning using swept frequency around Q_v





Abort Gap cleaning: Ingredients and Status

- BSRA monitor measuring the abort gap population – Andrea Boccardi and team.
  - Calibration work in progress – almost done-
  - Overall system in commissioning, cannot be declared operational yet – data to be taken daily and analyzed
- Transverse damper system: Wolfgang Höfle
  - Modifications implemented on the ADT to reduce the tail of the abort gap cleaning pulse and improve the shape of the pulse
  - Beam 1 and 2 : systems ready and calibrated
  - Cleaning efficiency still to be established, and tested at 3.5 TeV
- Cleaning strategy : simulations performed, strategy defined and tested, more tests required– Eliana Gianfelice-Wendt
- Interlocking in SIS – not yet ready
- Overall : system not yet commissioned, experience then needed to make operational
- Risk of TCT damage (for huge population) or Q4 quenches

Conclusions 1/3

- TCDQ hardware issues: resolution and setup accuracy need to be improved in view of operation with nominal intensity and energy.
- Tolerances: a factor of 10 must be recovered by improving orbit stability, collimator setup and beta-beat.
- One TCDQ CPU? "BETS style" HW interlock needed?
- Problem with saturation of BLM was solved by installing RC filters at the TCDQ and TCSG BLM.
- Asynchronous beam dump tests were performed in several conditions (energy, intensity, squeeze, w/wo orbit and energy offset): leakage from TCDQ to TCT, for beam 2, was measured to be between 1E-4 and 1E-3

Conclusions 2/3

- Asynchronous beam dump simulations for a single bunch (worst case) at 3.5 TeV (2m β^* in point 5) have been performed with SixTrack for beam 2.
  - Losses at the TCT come from particles scattered at the TCSG, no direct losses of primary protons are observed
  - Simulations allowed to visualize the distribution of particles absorbed at the TCT: peak density is equivalent of 0.016% of full bunch with nominal emittance
- Simulations compared to measurement:
  - Measurements are consistent and not worse than simulations

Conclusions 3/3

- First Abort Gap Cleaning tests were performed in Dec 09 with encouraging results
- BSRA abort gap monitor: Overall system in commissioning, cannot be declared operational yet
- Transverse damper system: system ready and calibrated, cleaning efficiency still to be established and tested at 3.5 TeV. Interlocking in SIS – not yet ready