What are the issues with injecting unsafe beam into the LHC ?

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Acknowledgments: BLM, OP, CO, Collimation team

Outline

- Failures:
  - Examples during 2010 operation
- Intensity limitations:
  - Possible solutions
  - Machine protection related issues
- Injection system upgrades
- Summary and Conclusions

Injection Failure Scenarios

- All injection failures are SINGLE TURN FAILURES:
  - Injection with wrong settings in the LHC
  - Failures in SPS extraction or Transfer Line
  - MKI failures (BETS, erratic kicks, kick wrong length and timing, missing kick, kicker timing, magnet sparks, terminating resistor breakdowns)

- Solutions:
  - Interlocks with tight thresholds.
  - Passive protection in the transfer line (TCDI) and in the **ring** (**TDI**, TCLI)

2010 Failures

- Abort Gap Keeper (AGK) prevented MKI from firing ➔ Train of 32 bunches dumped on upper TDI jaw ➔ showers to ALICE

- Losses in ALICE in agreement with simulations (further benchmarking data from TDI grazing tests) ➔ ALICE ready for 288 bunches on TDI

- LHCb, only grazing tests with TDI

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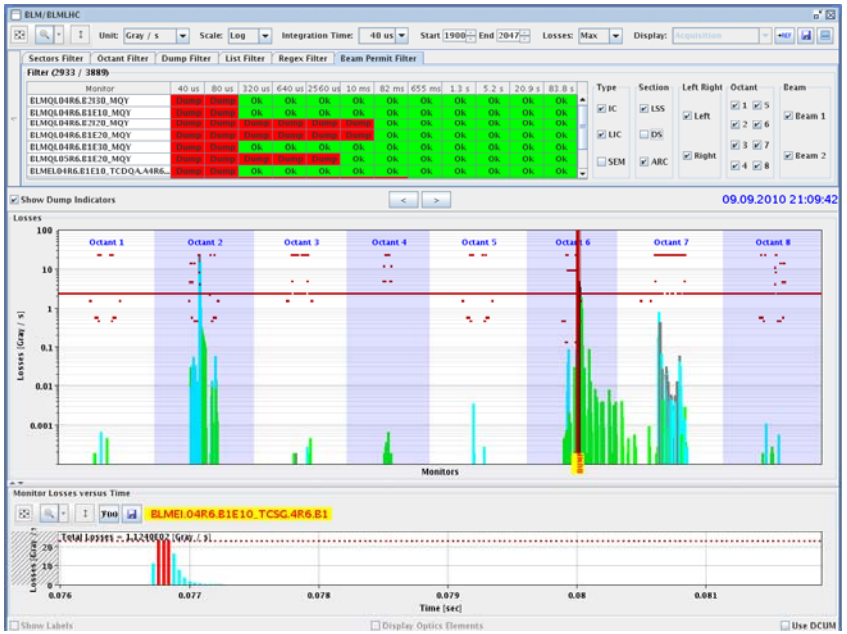
No indication of limits on injected intensity: 288 bunches OK! **BUT TDI must be correctly set up!!**

2010 Failures

- TCDQ collimator at 3.5 TeV setting while injecting 24 bunches (< 4 σ)
  - Slow movement (through ramp function induced by timing event) of TCDQ jaw and thresholds when pilot beam in the machine ➔ no visible losses in point 6 before injecting 24 bunches ➔ beam dump
  - Possible solution:
    - Energy interlock also on minimum allowed gap
    - Online aperture measurements to identify bottlenecks
    - State machine
    - Always re-inject a pilot after any machine change



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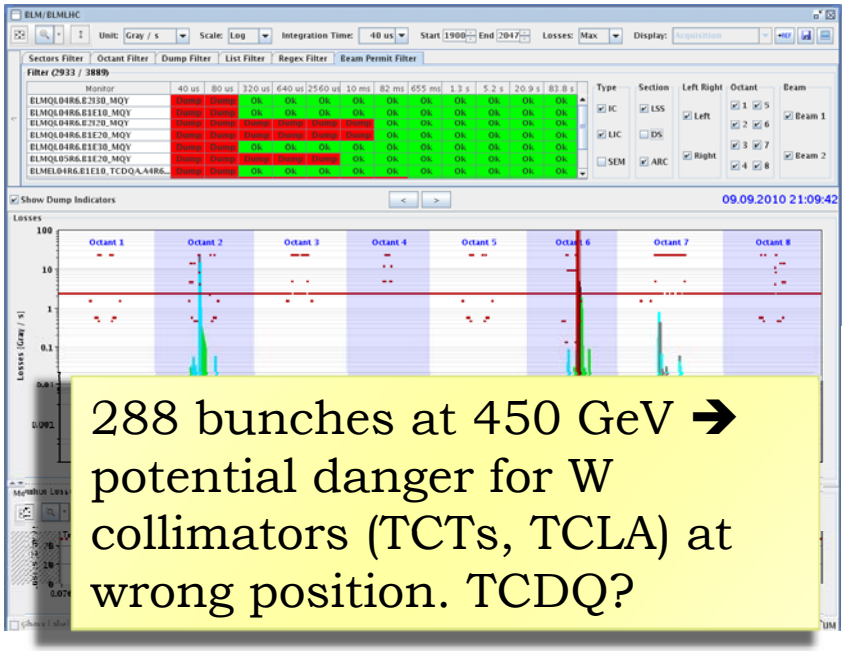


Losses at Injection and Intensity Limitations

- Loss maxima per injected intensity (Verena's talk)

2010 | 2011

Loss type	Losses in % of dump threshold B1/B2						
	8b	**16b**	**24b**	**32b**	**48b**	***96b***	***144b***
TCDI shower	1/2	3/5	4/6	5/8	23/24	*<50?*	*<75?*
Uncaptured beam	4/2	12/3	12/5	16/8	20/8	*<40?*	*<60?*

Unsafe beam (> 1×10^{12} p^{+})

Linear extrapolation for 2011 operation, still ok without mitigation

Operation related intensity limitations, **no machine protection issue!!**

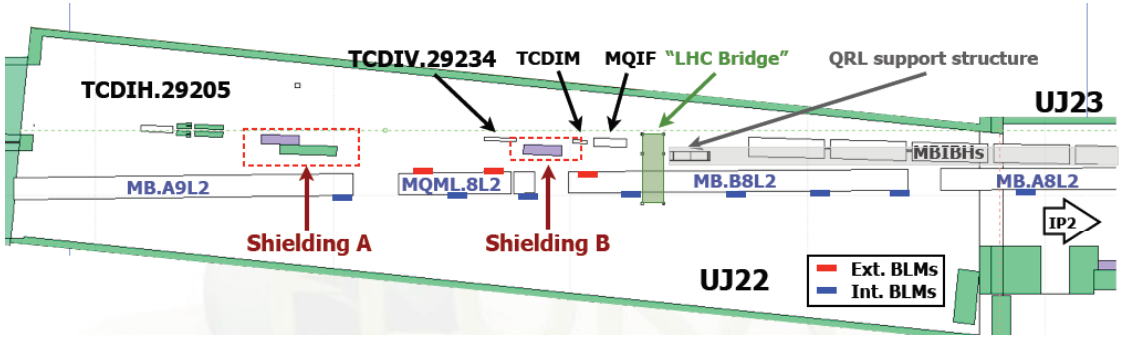
- Possible solutions for higher intensity:
  - Uncaptured beam:
    - Abort gap and injection cleaning (Verena's talk)
    - Improved injectors diagnostics
    - TDI Shielding (×10 reduction at MQX BLMs)
    - BLM sunglasses
  - Cross-talks from TCDI:
    - TCDI shielding
    - TCDI larger aperture
    - BLM sunglasses
    - Increase BLM thresholds for short running sums

TCDI shielding

- Shielding the LHC BLMs from the TCDI showers.
- Shielding investigated for TCDIs directly next to SC magnets
  - TI 2: TCDIH.29205, TCDIV.29234
  - TI8: TCDIH.87904
- Expected loss reduction with shielding:
  - TCDIV.29234 – factor 8
  - TCDIH.29205 – factor 5
  - TCDIH.87904 – factor 4

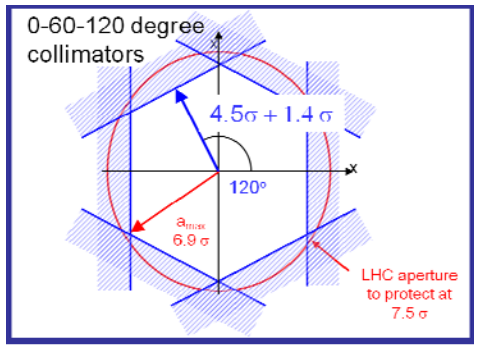
Not critical from MP point of view!

- Shielding for TI 8 tricky due to lack of space
- Shielding installed for TI 2



TCDI Aperture

- TCDI Coverage: GENERIC single pass protection system → full phase space coverage required
  - Optics and space constraints → only 3 collimators (double jawed) per plane and per line
  - As close as possible to the LHC → at the end of the line

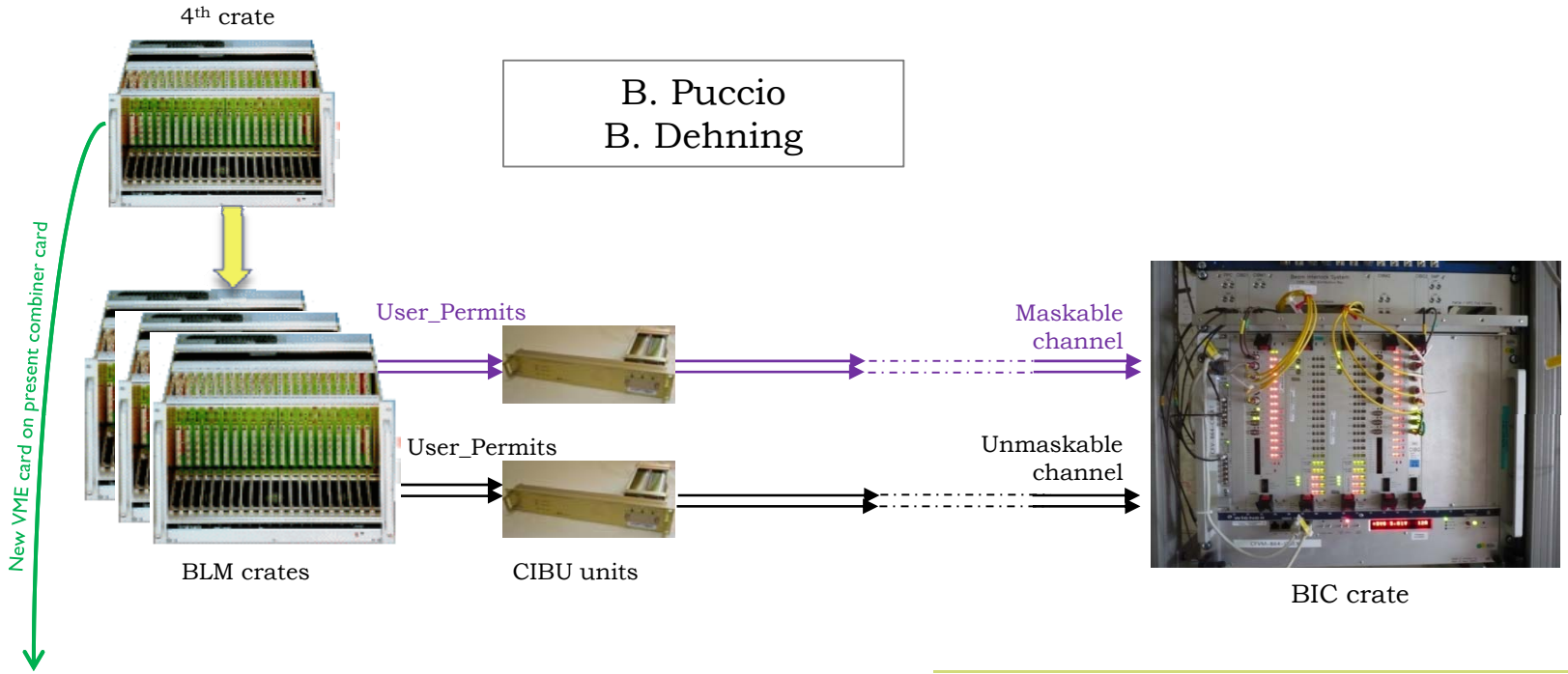


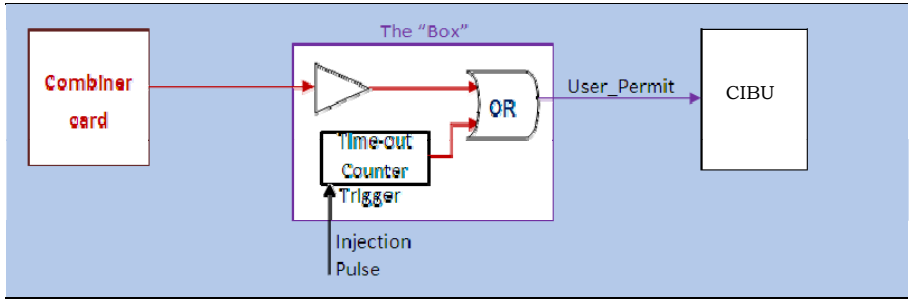
- Setting depends on LHC aperture for INJECTED beam (not circulating beam)
  - 4.5 σ – 5 σ setting for 7.5 σ aperture: now 4.5 σ, too conservative?
  - Determined by orbit (2 mm)and injection oscillations (1.5 – 2 mm) tolerances + energy offset

- MP validation tests were successfully done with TCDI at 5 σ and phase space coverage should not depend on beam intensity

- Further checks are needed during startup in 2011

BLM Sun Glasses: Basic Functional Block Diagram





Combiner card Output	Time-out counter Output	CIBU input	
TRUE	TRUE	TRUE	
TRUE	FALSE	TRUE	
FALSE	TRUE	TRUE	**Masked**
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Aim: temporary masking the BLM interlocks affected by cross-talks (from TCDI losses) and from uncaptured beam losses during injection.

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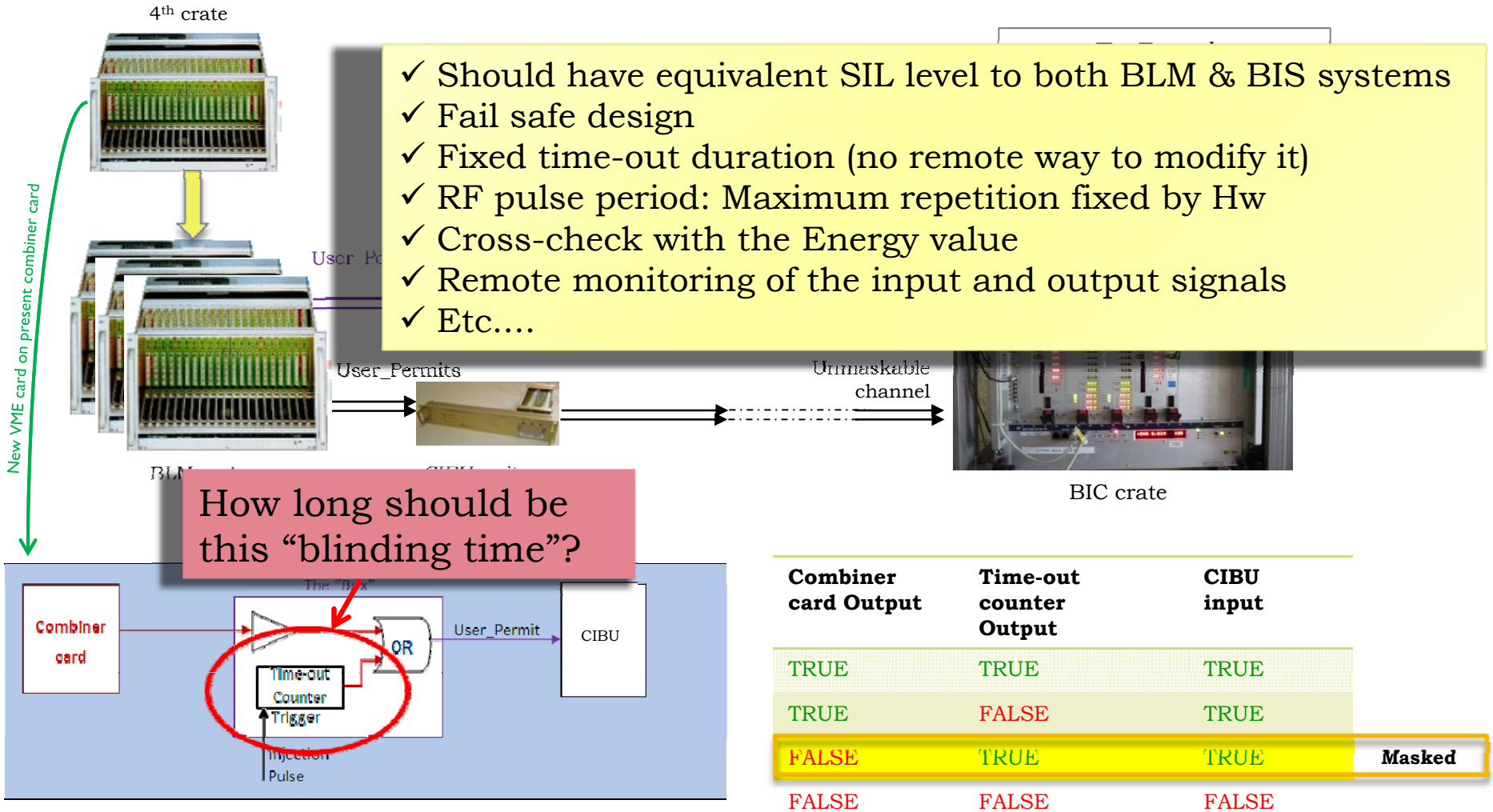

- ✓ Should have equivalent SIL level to both BLM & BIS systems
- ✓ Fail safe design
- ✓ Fixed time-out duration (no remote way to modify it)
- ✓ RF pulse period: Maximum repetition fixed by Hw
- ✓ Cross-check with the Energy value
- ✓ Remote monitoring of the input and output signals
- ✓ Etc….

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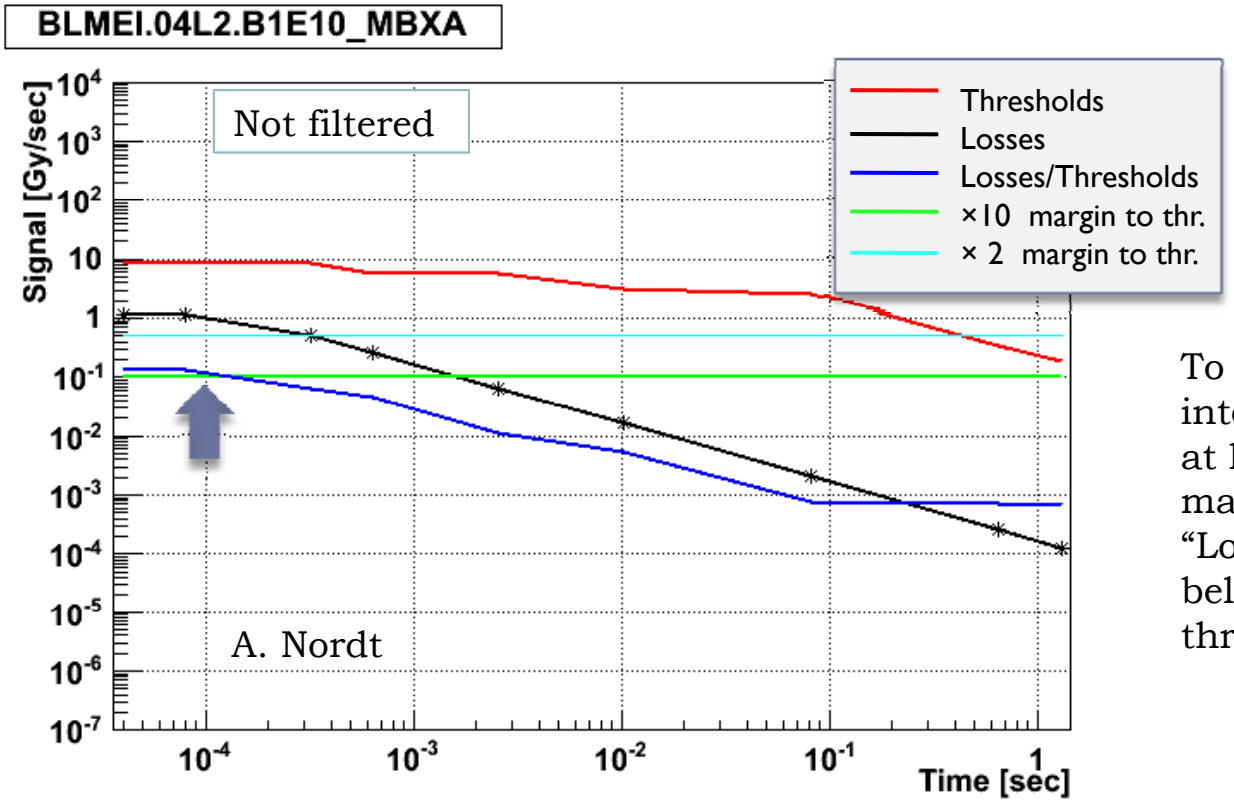
Examples of "Good Injection"

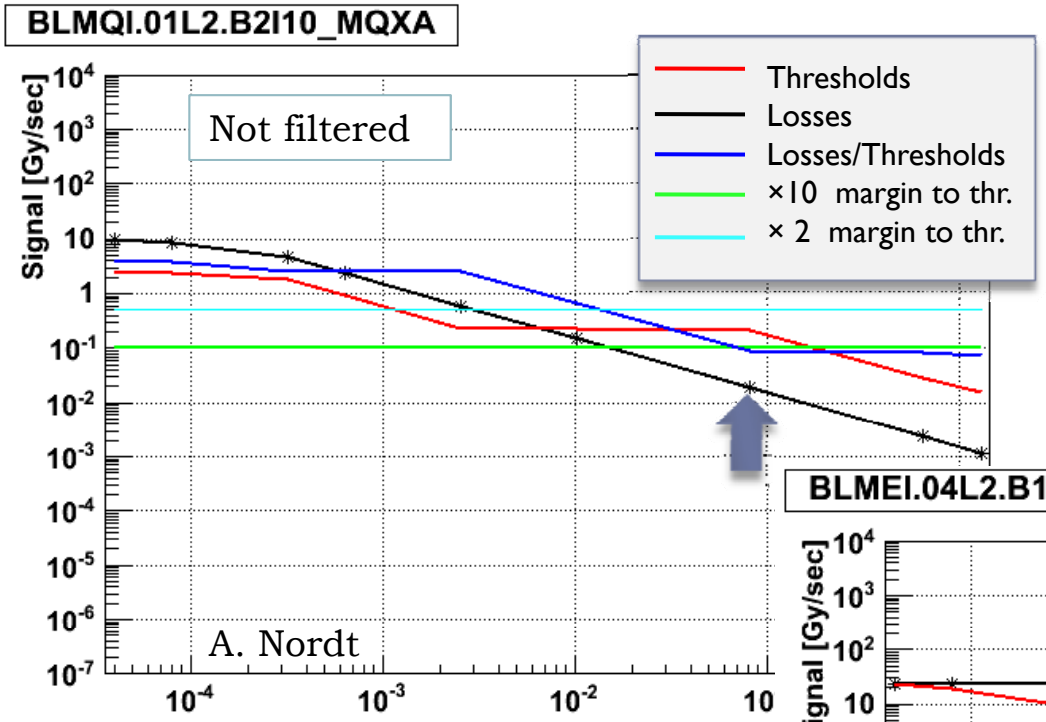


To go to full nominal intensity we should have at least a factor of 10 margin from thresholds ➔ "Losses/thresholds" curve below "×10 margin to thresholds" curve

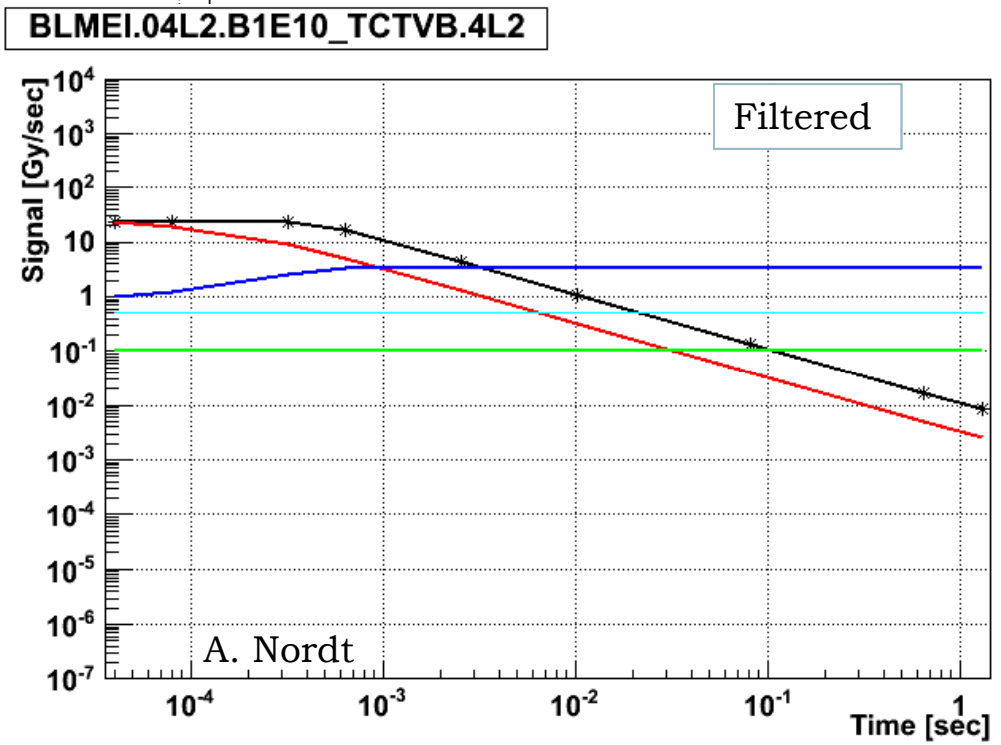
- BLM should be masked for running sum 1 and 2: up to 80 μs < 1 turn ➔ acceptable!

- Full data analysis ongoing to evaluate, in case of good injection, if BLM signal above thresholds for longer running sums ➔ what is acceptable for MP issue? 320 μs?

Examples of "Bad Injection"



Bad: long waiting time between injections due to problem with injectors ➔ high level of debunched beam



- losses/thresholds > ×10 margin to thresholds until running sum 7(655 ms): we don't want to be blind for such losses!
- Filtered monitors have longer time for collecting charges, do they have to be connected to the new crate?
- Customize BLM thresholds?

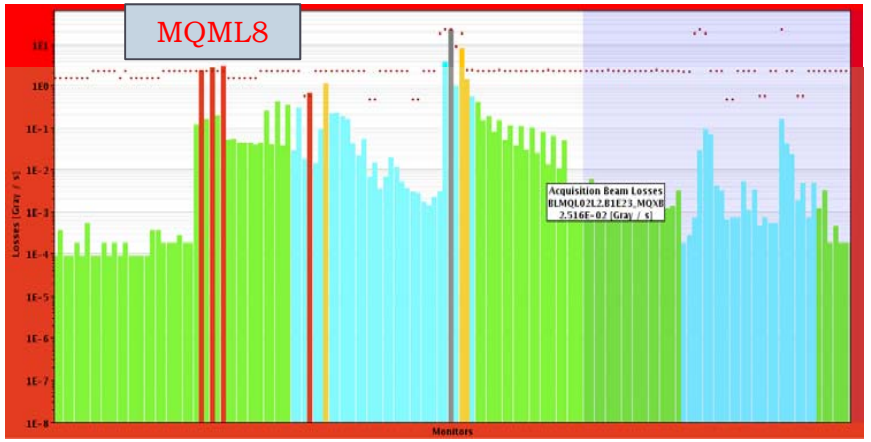
How Many Critical Monitors?

- Uncaptured beam:
  - TCTVB
  - MQX
  - MBX
  - TCLI + TDI

Which of these BLMs have to be connected to “Sunglasses” crate? All?

Can we profit of redundancy from other BLMs located nearby the masked ones (IP2-IP8) to be sure we are not missing real dangerous losses ?

- Cross-talks from TCDI:
  - MQML6
  - MQM7
  - MQML8
  - MSIA-MSIB



How Many Critical Monitors?

- Uncaptured beam:
  - TCTVB
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  - TCLI + TDI
- Cross-tal
  - MC
  - IA-MSIB

Which of these BLMs have
connected to "Sungl
Can we pr
BLM
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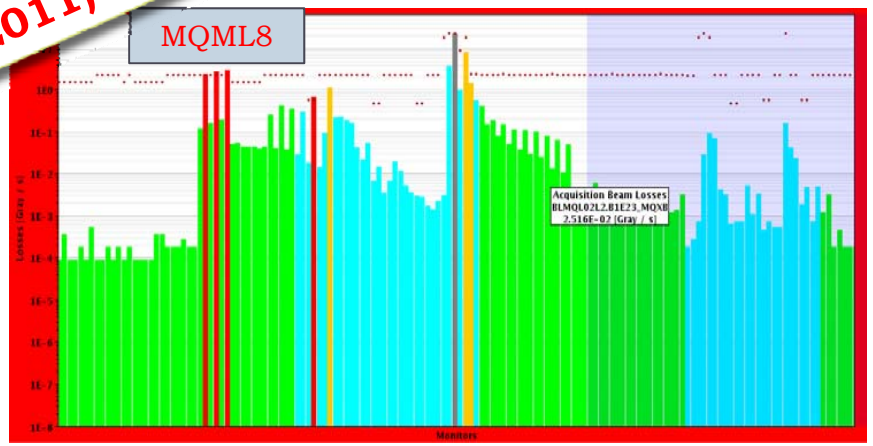
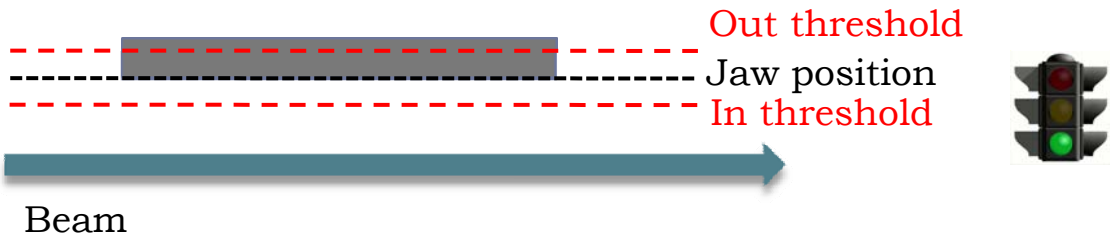
es ?

- Very first preliminary studies
- Many questions still to be addressed and more to be answered
- Special MP review when studies completed before eventual implementation and commissioning (middle/late 2011)



Old Logic for Injection Collimators Position Interlock

- Same logic as for all other collimators:



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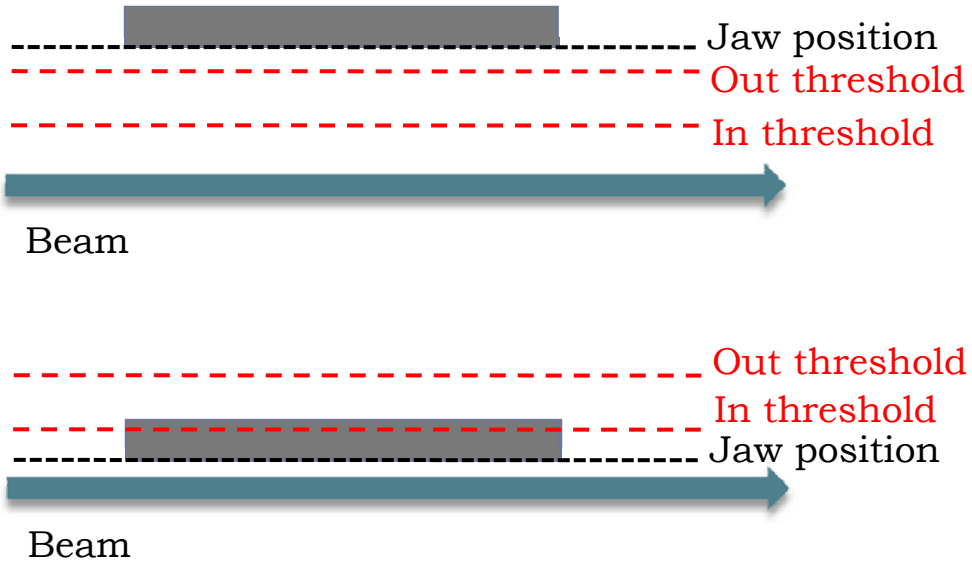

Jaw movement is blocked and:

✓ TCDI ➔ Injection inhibit
✓ TDI and TCLI ➔ Injection inhibit

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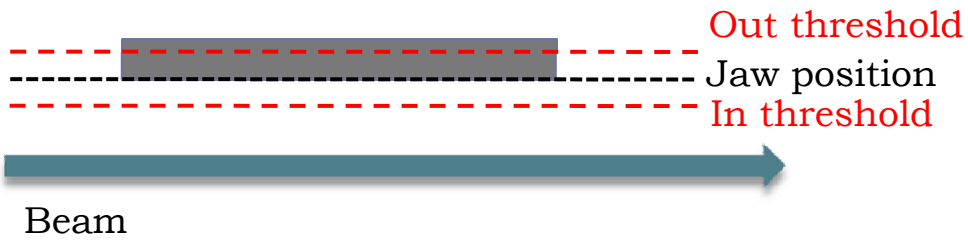

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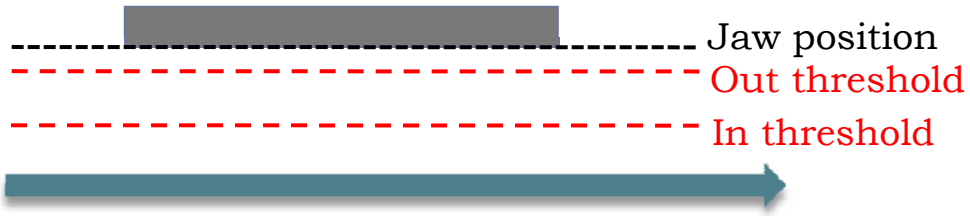

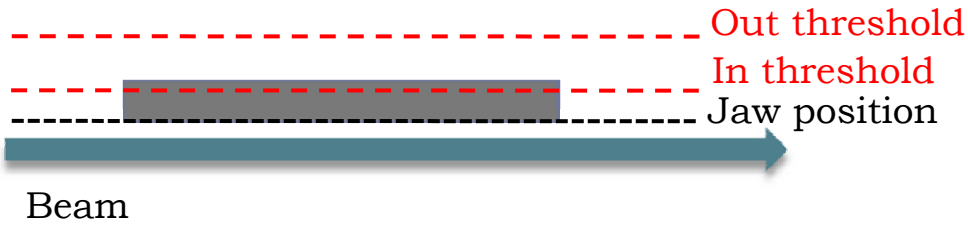

Impossible to move the collimator jaws out of thresholds ➔ thresholds have to be moved to parking position to open the injection collimators (i.e. TDI and TCLI after injection, before the ramp).

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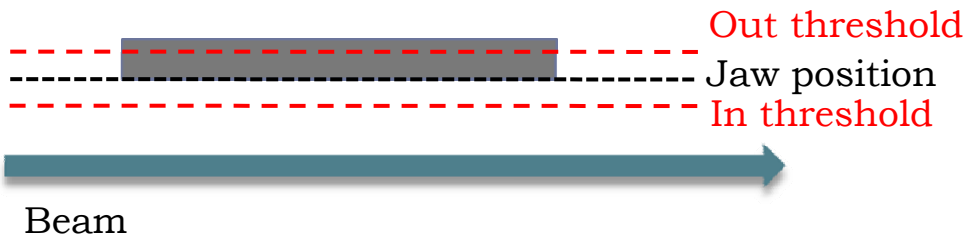

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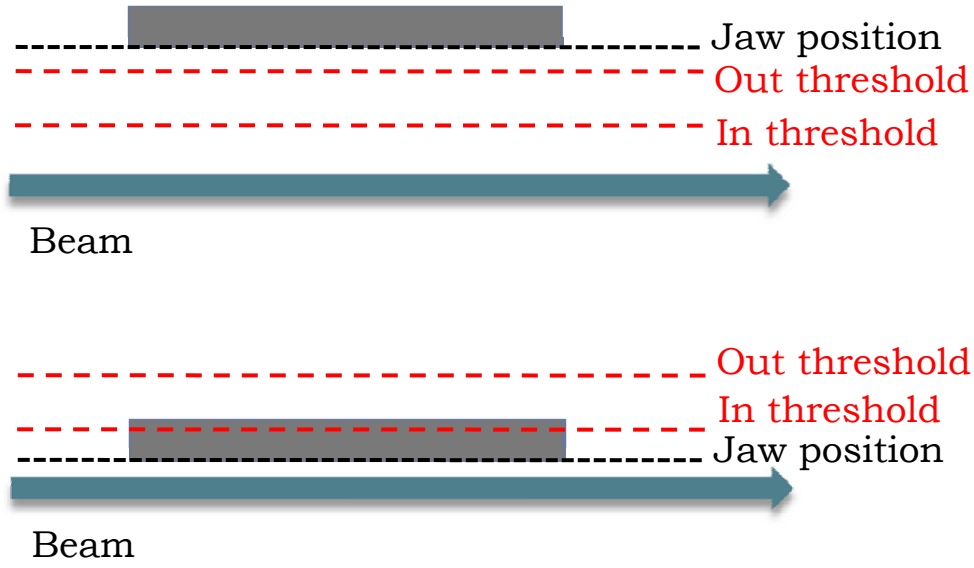

blocked and:

Potential danger: Jaw positions and thresholds set to parking (no interlock violation) ➔ beam injected with open TCDI, **TDI** and TCLI

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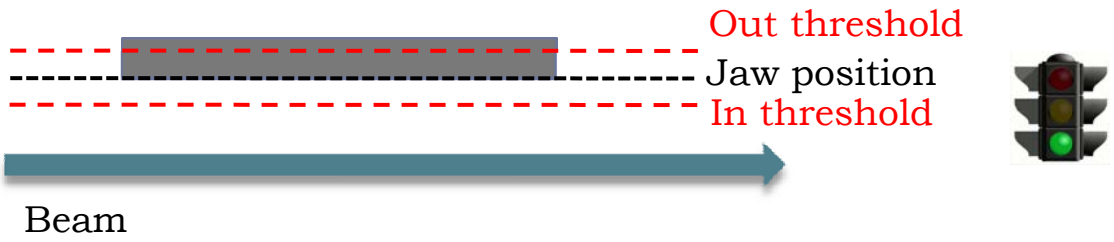

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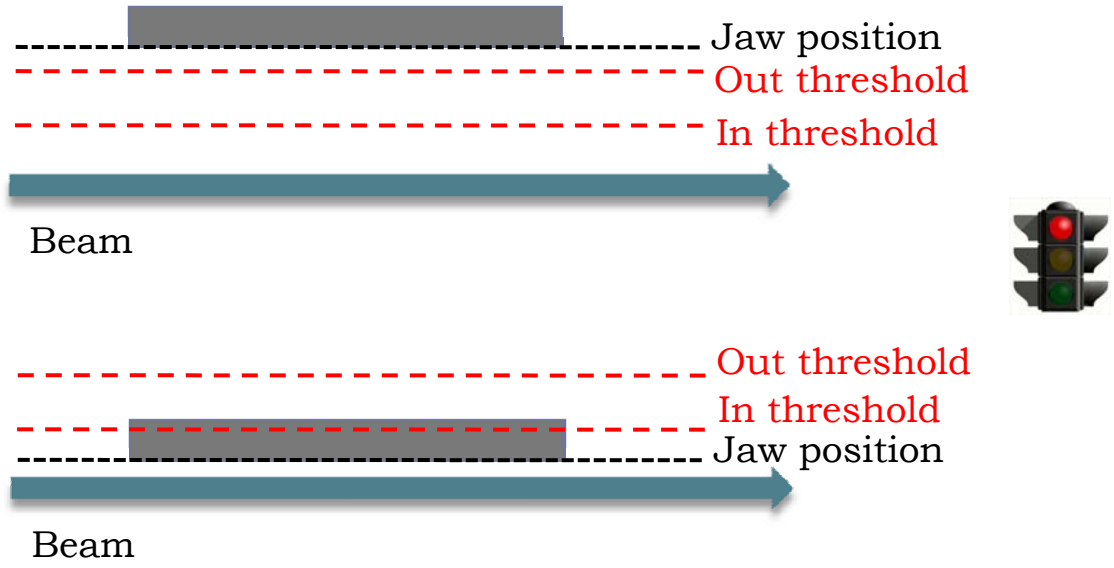

TCDI:
Jaw movement is not blocked + Injection inhibit

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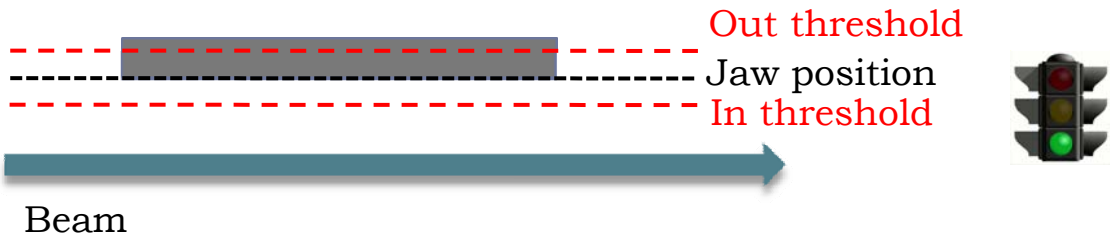

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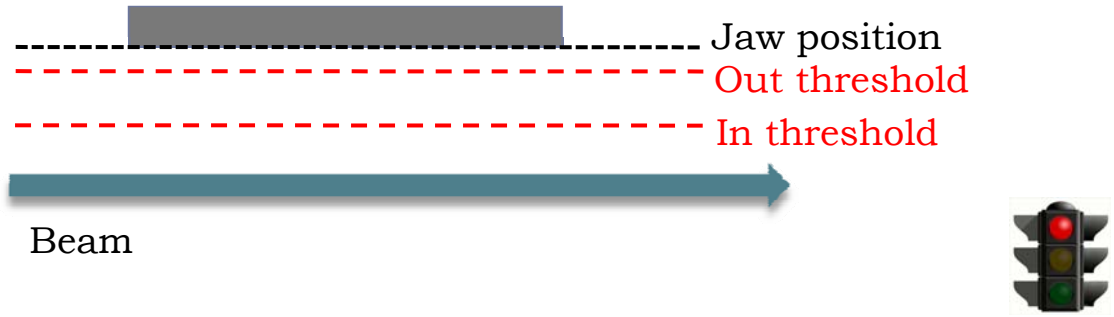

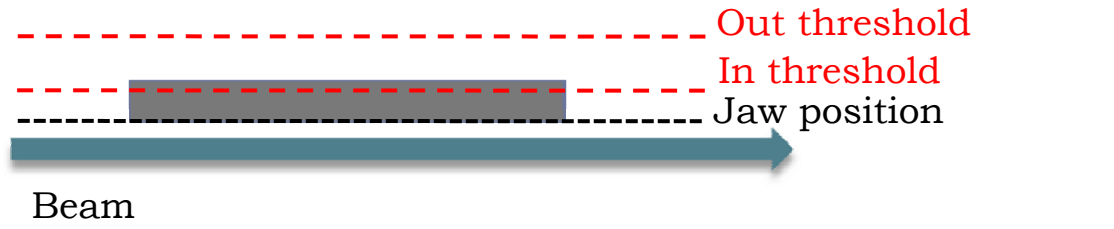

TDI and TCLI:

Jaw movement is not blocked
+ Injection inhibit

Jaw movement is blocked
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New Logic for Injection Collimators Position Interlock

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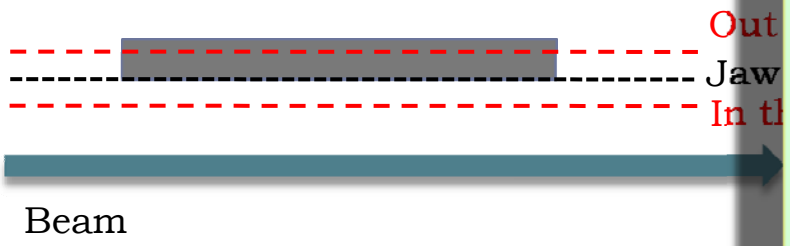

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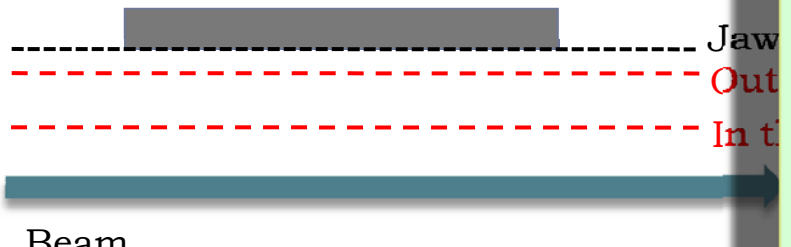

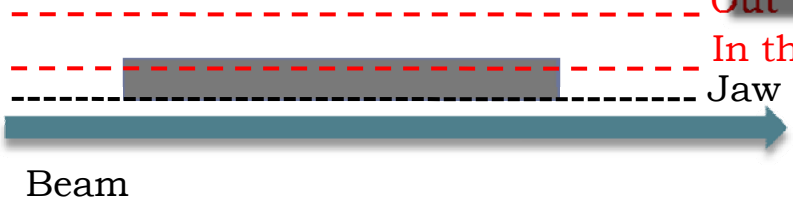

✓ **Thresholds** do not have to be changed during operation to open injection collimators ➔ **always kept at injection setting**

✓ When injection collimators out of thresholds ➔ injection inhibit

✓ **Energy interlock** implemented for **TDI and TCLI** (injection inhibit if gap bigger than defined thresholds)

✓ **MKI set to standby** before opening TDI and TCLI (software interlock) ➔ beam dumped at TDI in case of erratic kicks

Jaw movement is blocked
+ Injection inhibit

Injection Oscillations Interlock

- Need to control injection oscillations when injecting high intensity beam
- A new interlock will be added:
  - In case the injection oscillations module fails ➔ only intermediate intensity allowed
  - In case of good injection oscillation result ➔ high intensity injections allowed
- This requires thorough testing and stability of the IQC module (it needs commissioning time with beam)

Summary and Conclusions

- Fundamental importance of **correct**:
  - **State machine**
  - **Setup of injection protection collimators** (in particular TDI) ➔ safe machine also in case of failures of other systems (for example MKI)
- We ran already with **unsafe beam in 2010, 144 bunches** limit for **2011** operation
- **LHCb and Alice ready for 288 bunches** dumped on the TDI
- Predicted **intensity limitations** come mainly from **operational more than machine protection** related issues
- Possible **solutions** to go to higher intensity have been presented
  - Uncritical:
    - Shielding
    - Abort gap and injection cleaning
    - Improved diagnostic
  - Critical:
    - BLM sunglasses ➔ very preliminary studies, many questions addressed ➔ MP review before eventual implementation and commissioning
    - BLM increased thresholds
    - TCDI larger apertures ➔ to be validated for higher intensity
- **Upgraded and safer logic** for operation of **injection protection collimators** have been presented (already in place, MP tests to be performed)
- **Interlock for injection oscillations** ready to be implemented and commissioned