



# Experiment Protection in LHCb



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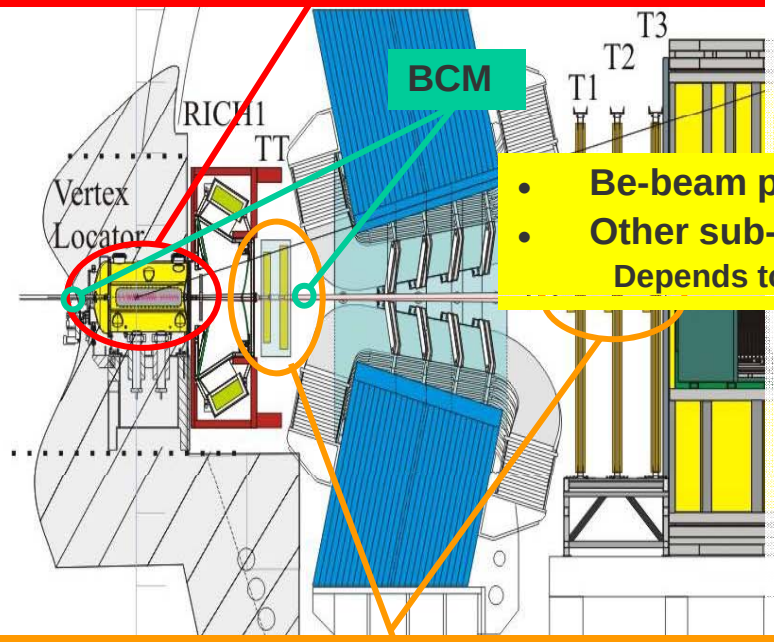
# The Achilles' heels in LHCb

**VErtex LOcator (VELO)**

- Close to beam line (30mm / 5mm)
- Can drive past nominal beam line
- Electronics in acceptance
- Integrated dose $\mathcal{O}(10^{14})$ 1 MeV $n_{eq}yr^{-1}cm^{-2}$




- Be-beam pipe at 25mm
- Other sub-detectors are of course sensitive too!

Depends to a large extent on what can happen?

**Silicon Tracker (ST)**

- Close to beam line (TT~50mm / IT ~ 90mm)
- Integrated total dose $\mathcal{O}(10^{14})$ and $\mathcal{O}(10^{13})$ 1MeV $n_{eq}$ $cm^{-2}$ for TT and IT
- CMS test showed survival at $10^9$ protons per $cm^{2(*)}$

** "Beam-loss-induced electrical stress test on CMS Silicon Strip Modules" NIM A Vol 518, 1 Feb 2004*

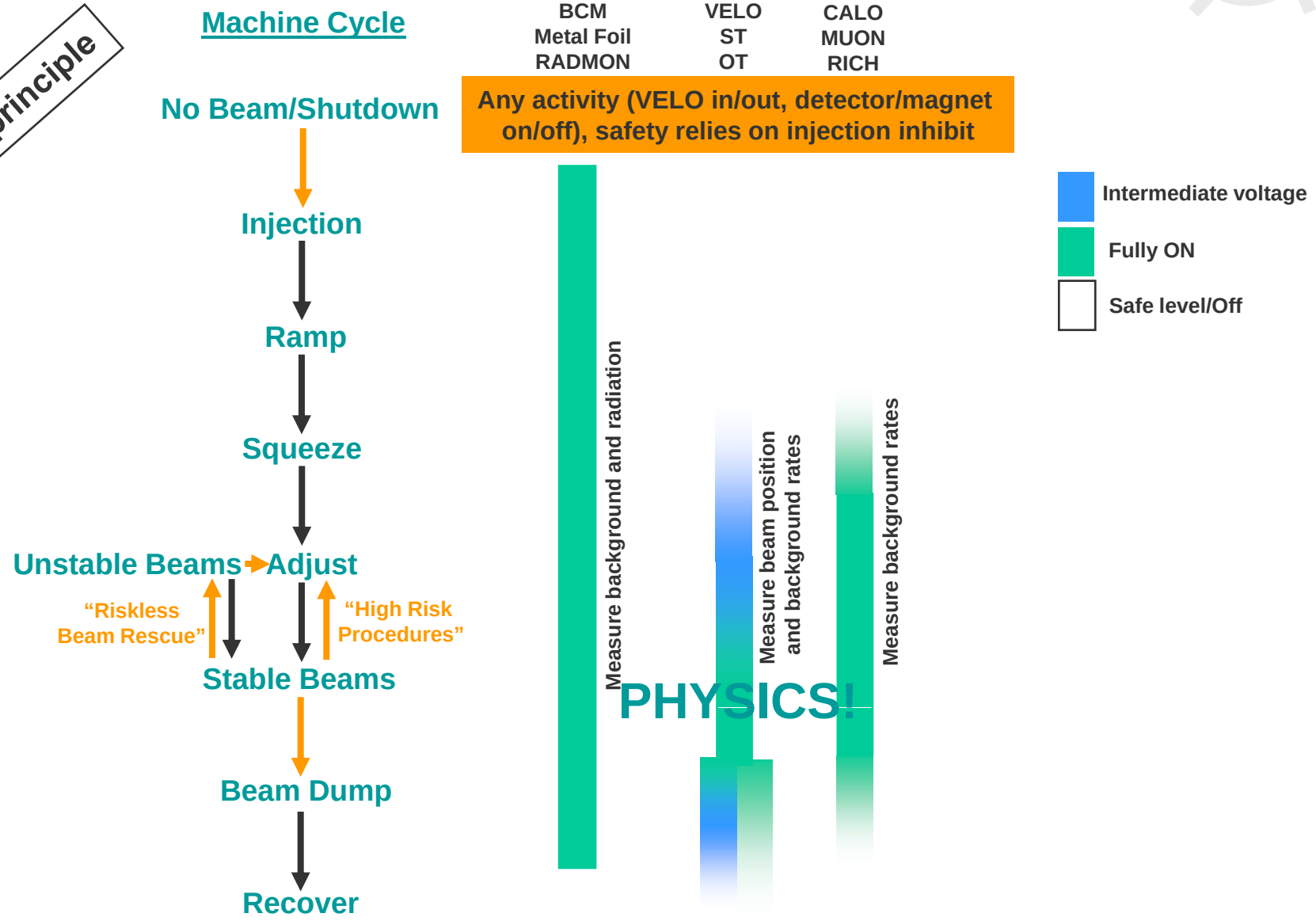
## Which protections do we have against:

- **Slow cooking**
  - "BKG1 and BKG2" based on normalized levels from
    - Beam Condition Monitors
    - Metal Foil Detectors
    - Active Radiation Monitors
    - Detector Rates/Multiplicities etc when ON
  - …using excessive
    - Inform (insist on) LHC operators…
    - Compare with LEP "Sliding integrated dose" was source of beam dump, now as well via HW/SW?
    - BKGx with sliding average/integrated dose?
- **Risk of being brought to boiling point rapidly**

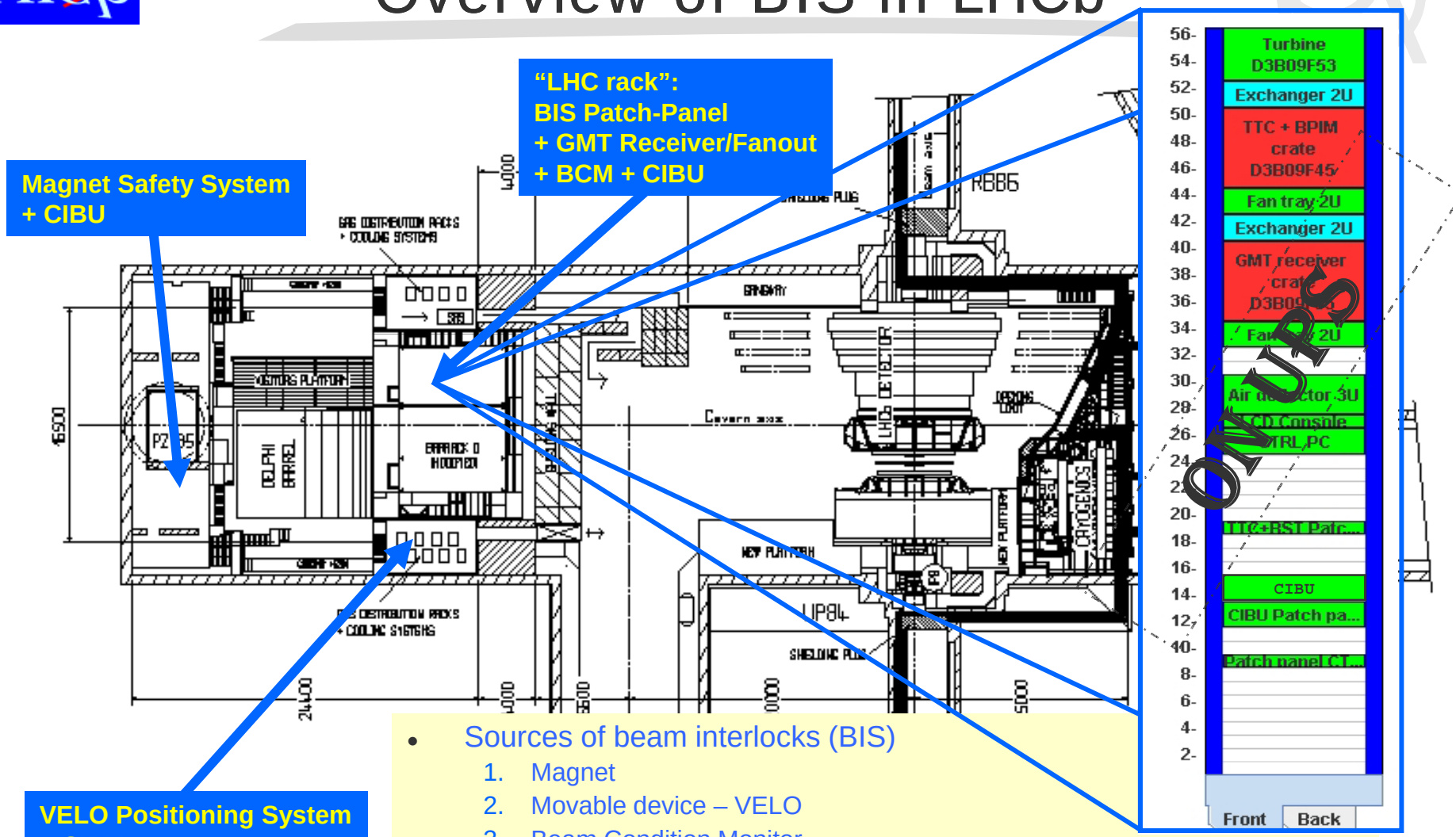
  Beam Interlock System
  - Magnet failure
  - VELO at the wrong/right place at the right/wrong time
  - Machine failures as detected by Beam Condition Monitors

# LHCb Operational Procedure

The principle



# Overview of BIS in LHCb



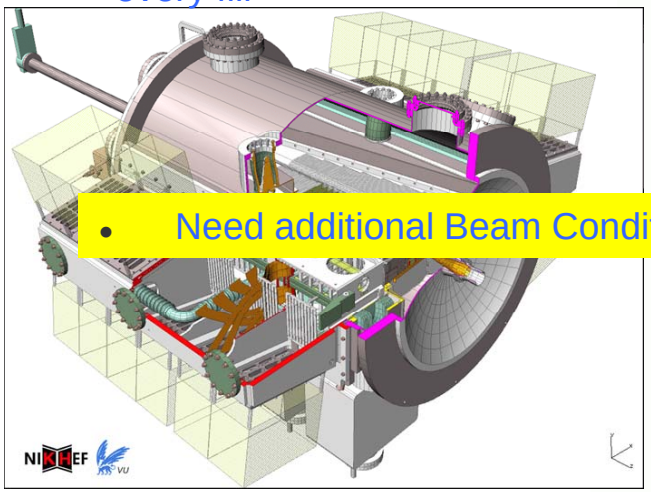

- Sources of beam interlocks (BIS)
  1. Magnet
  2. Movable device – VELO
  3. Beam Condition Monitor
- All are non-maskable and both beams (true also for magnet?)
- Source of injection inhibit (software)
  - Combination of detector settings (detector voltages, magnet settings, etc)

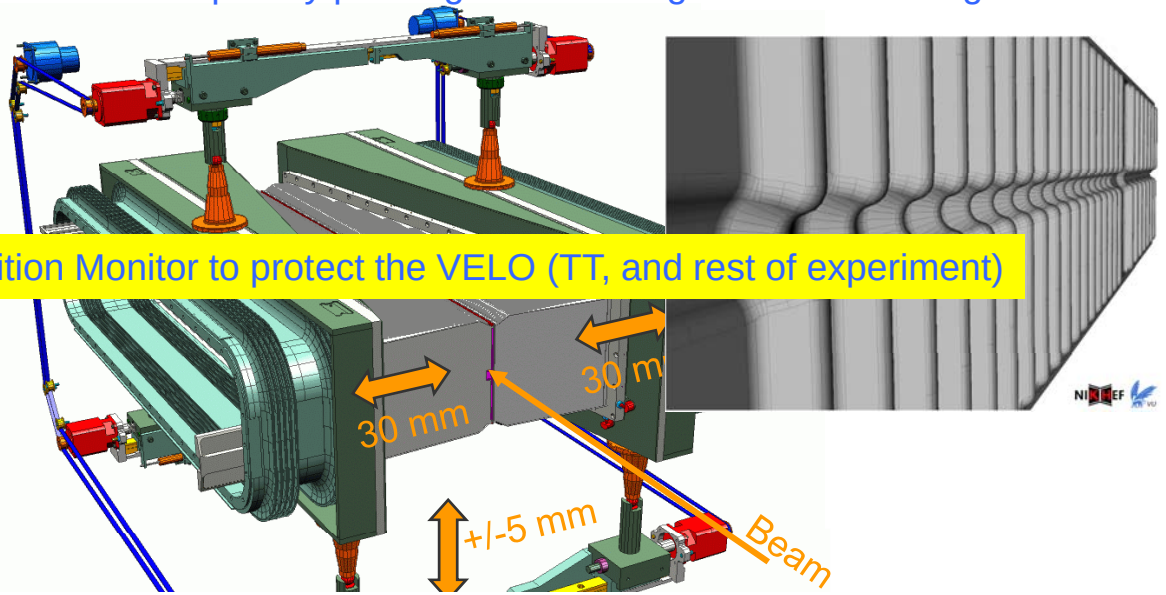
# LHCb Magnet Interlock

- LHCb Magnet failure
  - Slow influence on orbit, typically $\mathcal{O}(\sigma)$ in several 100 ms
  - Power converter: Reaction time to dump beam ~100 ms
  - Cooling failure: Transmit beam interlock 10ms before power converter switches off
- Developing the interlock system for all magnets responsibility of the PH/DT1 group as part of the MSS.
  - Current status: PLC is being developed and they will do test with CIBU in lab soon (N. Bourgeois)
  - BIS cable between patch-panel and MSS, and CIBU to be installed soon
- LHCb MSS on UPS but not diesel generator

# VELO

- VELO is a Movable Device:
  - Out position: 35mm from beam line
  - In nominal data taking position: 5mm from beam line
  - Data taking position determined with VELO open by profiling luminous region before moving in for every fill



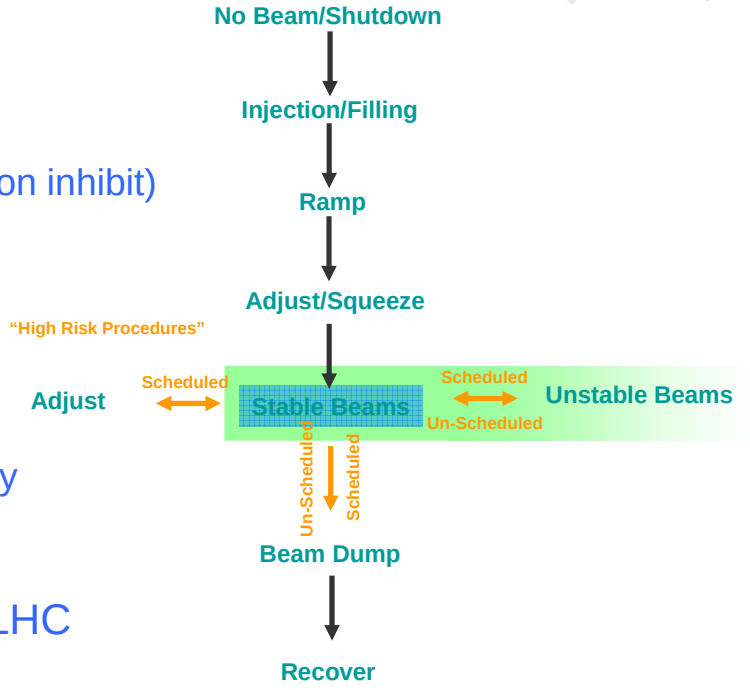



- Need additional Beam Condition Monitor to protect the VELO (TT, and rest of experiment)

- Concerns:
  - LHC may only be in Stable Beams and Unstable Beams with VELO IN, or the other way around
    - Limits the operations that are allowed on the beams
  - May drive across nominal beam line
    - Software bug, reproducibility with motion system, human error
  - Very exposed to abnormal beam conditions (sensors and electronics)
    - **Sensor tolerance $10^{12}$ MIPs/cm$^2$/s→ $\mathcal{O}$ (100) less than loss of $10^{12}$ protons!**
    - **Electronics tolerance $10^8$ MIPs/cm$^2$/s! (CDF experience, still to be investigated for VELO)**
    - **So far always damage on readout electronics, not sensors**

# VELO Beam Interlock

- VELO beam interlock
  - Out + safe/unsafe conditions : no interlock
  - In + safe conditions : no interlock
  - In + unsafe conditions : Interlock and beam dump (injection inhibit)
- End switch is definition of out (fully out)
  - IN is as soon as it leaves end position\
  - With 7mm/min means 4-5 minutes for full movement
  - Schedule changes of LHC modes (e.g. Stable Beam → Adjust/Dump) using “Ready For Adjust/Dump” followed by “Acknowledge” messages via DIP
- Definition of Safe/Unsafe according to the GMT Safe LHC Parameters Flags
  - “Safe Stable Beam”
  - “Movable Devices Allowed” (Stable Beam + Unstable Beam)
  - Flags and End Switch signal are combined in PLC to form the Beam Permit
- Initially(forever?) VELO will start moving out in Unstable Beams == Safe Stable Beam flag absent (shift confirmation/automatic)



# VELO Beam Interlock

- Open issues
  - Define allowed actions during “Unstable Beam” mode
    - “Beam rescue”
    - Agreed procedures
    - Take into account that movable devices are in
  - Beam displacements (luminous region)?
    - Fill to fill
    - During a fill
      - Stable beams → Unstable Beams(Adjust) → Stable Beams
  - VELO interlock system will take into account state of Beam Condition Monitor
    - If not operational → don’t move in if out/move out if in
- VELO is working on developing the PLC to drive the CIBU
  - CIBU already installed in the VELO rack
  - Will be tested stand-alone and reviewed together with AB/CO
  - VELO rack and entire positioning system on UPS
  - Difficult to respect 1 μs post-mortem UTC timing
    - Freeze buffers if a beam abort was generated easy
    - BICs best in place to know who fired first?
    - Receive post-mortem trigger via GMT to freeze buffers? (additional signal from GMT receiver)

# Backgrounds from beam failures?

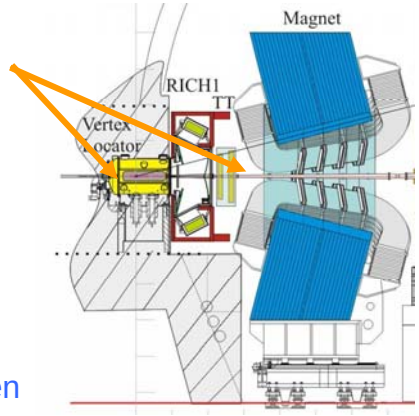
- We (I) need much more understanding for what type of machine failures lead to what in the experimental zone! “Rumours says”
  - Injection/dump kicker magnet
  - Dipole D1
  - Inner Triplets
  - Etc …
  - List of questions is very long…
  - Maybe we already have answers after the morning session? Then, more simulations in the experiment!

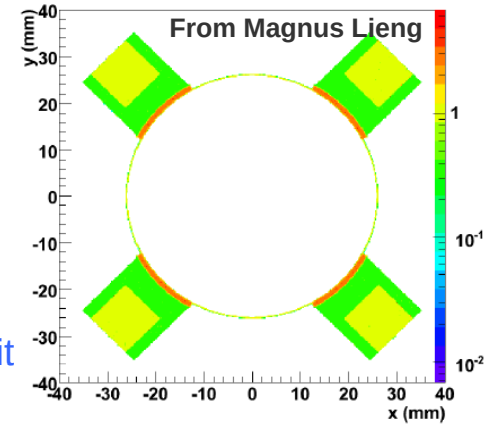
- We have an example with the induced machine background for the tertiary collimators (Talanov, Corti)
  - Lifetime 30h with nominal machine→ Loss rate $3 \times 10^9$ p/s in IR7 → $6 \times 10^6$ charged hadrons/s at IP8
    - With full shielding hundred times less (V. Talanov)
  - Minimum bias in LHCb 10 MHz x 20 particles = $2 \times 10^8$ particles/s
    - Takes “a while” before we see something really abnormal
  - Thus, background from a beam with a lifetime of 1h will be of the same order as minimum bias
    - >100 kW beam power into equipment, only short operation possible for machine (R. Smith)
    - Famous “No quench → no background”?

- What could make it worse and how fast?

# Beam Condition Monitors

- Based on CVD diamond detectors (Belle, BaBar, CDF, CMS, ATLAS, ALICE, LHCb…)
- Four double layer sensors located vertically in a cross on the beam pipe before VELO and behind the ST-TT
- Pupose
  - Fast real time background monitoring (integration over 40 μs)
  - Especially important as independent assistant to VELO positioning
    - Fast feedback needed if RF box scrapes beam halo
    - Signal in the diamonds becomes comparable with the minimum bias signal when the RF-foil separation is around 600 μm (or 7-8 σ for a beam sigma of 71 μm)
    - BCM OK signal to VELO positioning system
  - Fast beam dump for unacceptable beam conditions
- Readout front-end same as BLMs (CFC card + optical link)
- Single receiver board for processing and logic for all sensors
  - LHCb standard detector readout board ("TELL1")
  - Special mezzanine on general purpose connector produces beam permit signals to CIBU
  - Firmware loaded from on board configuration device
  - Directly interface to the LHCb experiment control system for readout and monitoring
- Entire BCM system on UPS



# BCM Open Issues

- ‘Erratic’ Dark Current seen first in BaBar
  - Not much magnetic field in the foreseen location
  - Should still be well below the signal expected from true real background levels and unacceptable beam conditions, and particular the dump level
  - Sensors will be put through long-term tests
- Simulations of response as function of VELO fluences in the current position in case of RF box scraping and realistic beam failure scenarios needed
- Readout board more complex(~fragile) than simple PLC as beam interlock
  - Thresholds in firmware, at least upper dump threshold!
  - Different thresholds at different stages of the machine cycle?
  - But how do we coordinate intervention on this BIC input? Reprogramming thresholds for instance will remove beam permit, OK during longer interfill period?
  - For hardware failures we have a good number of spares
- Commissioning
  - Test modes
  - Need for running in passive mode during learning
  - Produce beam permits via control interface, authentication code?…
- Post-mortem timing

# Conclusions (open issues)

- We (I) actually don't fully know (knew?) what we are protecting ourselves against
  - Of course we won't be able to know fully until D-day but…
  - LHC – Experiment simulations, simulations, simulations
  - To a large extent we also rely on machine protection
  - LHCb (VELO) sensitivity:
    - **In general stay well below $10^7$ MIPs/cm$^2$/s**
    - **Not direct dose of more than $10^{12}$ MIPs/cm$^2$, perhaps much less due to the electronics**

- Post-mortem
  - BIC is best in place to judge source of beam interlock
  - Distribute post-mortem trigger also to our user systems?
  - Format of post-mortem

- Commissioning and regular test procedures
  - How often including user systems and how?
  - Procedure for bypassing in case, just in case…?

- Software interlock for injection inhibit
  - In case of circulating beams, don't dump
  - Principal aim is to protect detector against first injection (VELO position, magnet setting, detector voltages, vacuum, what have you)
  - Reliability based on receiving back (published by LHC after taking into account) what we transmit.