Reliability of CMS Beam Conditions Monitor

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Machine Protection Working Group

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Joint Machine – Experiments Workshop on Protection from Beam Failures

- All experiments have unmaskable inputs into the BIC

- “CMS requires that if there is the possibility of beam in the LHC then the CMS Protection System (BCM) must be operational to ensure safety of the Detector.”

- This was termed “CMS Protection Policy”:
  - Beam is always allowed if the CMS protection is ON independently of the status of the CMS detector
  - Conversely, no beam allowed in the LHC (CMS BEAM_PERMIT = FALSE) if the CMS protection system is not operational
- Believe that this is a natural consequence of having unmaskable experimental inputs into the BIC
  - Similarly to machine protection, do not want to provide an override mechanism to these inputs
  - i.e. if the protection system is to afford protection for the CMS detector, it MUST be functional and operational
- Would like to formalise this
- This places tight constraints on operation of the CMS Protection System:
  - ca. 100% availability
  - ca. 100% reliability
  - in turn implies that the protection system must be independent of the powering and DAQ of the CMS DAQ
- Ensuring reliability is taken very seriously by CMS protection system

Overview

- CMS Protection System
  - Design Considerations for the System
  - Choice of Chemical Vapour Deposition (CVD) Diamond
  - Beam Conditions Monitors (BCM)
  - Reliability of hardware
  - Powering Scheme
- Detector Response
  - Slices Tests of the Final System
  - Calibration of Detectors
  - Noise and Dark Current
  - Expected Signals
  - Initial Proposal for Threshold Settings
- Summary

CMS Protection System

Design Concept for CMS Protection System

- Explicit choice made to be compliant with the machine protection system
- Readout and detector technology selected for reliability
  - Readout - Beam Loss Monitor taken as most appropriate choice
  - CVD diamond is the standard choice for experimental protection
- Redundancy implemented in depth to ensure there is minimal chance of single point failure disabling entire system:
  - Locations
  - Choice of 2 Front End Electronics: BLM Tunnel Card + None
  - Many diamonds installed at each location
- Input to the ABORT is independent of software
- The whole protection system is independent of CMS DAQ

Beam + Radiation Monitoring Functionality

Provide monitoring of the beam-induced radiation field within the UXC55 cavern and the adjacent straight sections.

Provide information on the state of the machine, and hence helps determine whether sub-detectors should be turned on.

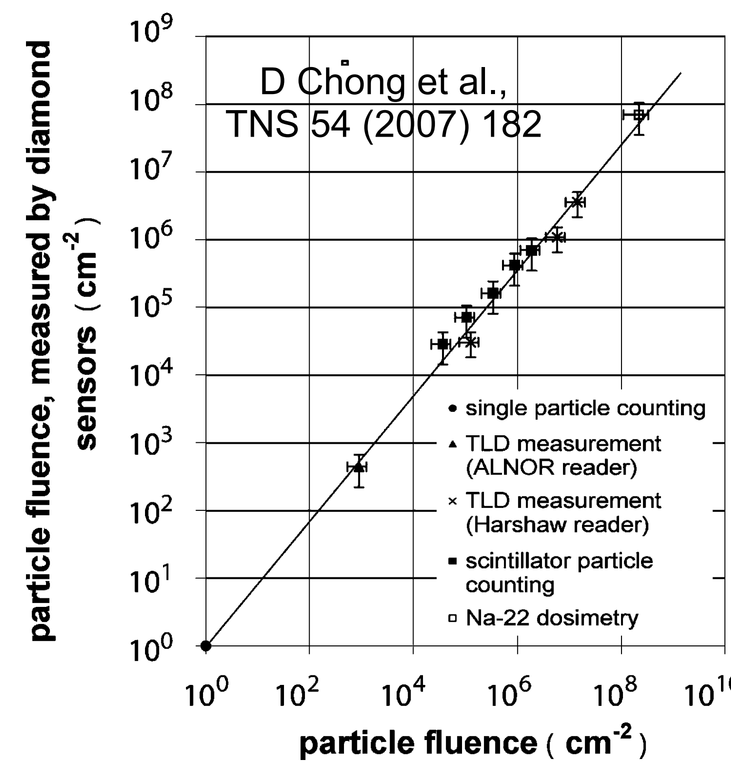
Provide real-time fast diagnosis of beam conditions and initiate protection procedures in the advent of dangerous conditions for the CMS detector

- System features include:
  - Active whenever there is beam in LHC
  - Ability to initiate beam aborts
  - Provision of warning & abort signals to CMS subdetectors (ie ramp down LV and HV)
  - Postmortem reporting
  - Provision of online and offline beam diagnostic information to CMS + LHC
  - Bench-marking of integrated dose and activation level calculations
  - Integration of all online beam diagnostic information (including subdetectors).
    - Updating at ≥1 Hz

- **Philosophy**:
  - CMS requires that if LHC is running then the CMS Protection System (BCM) must be operational to ensure safety of the Detector.

Why CVD Diamond?

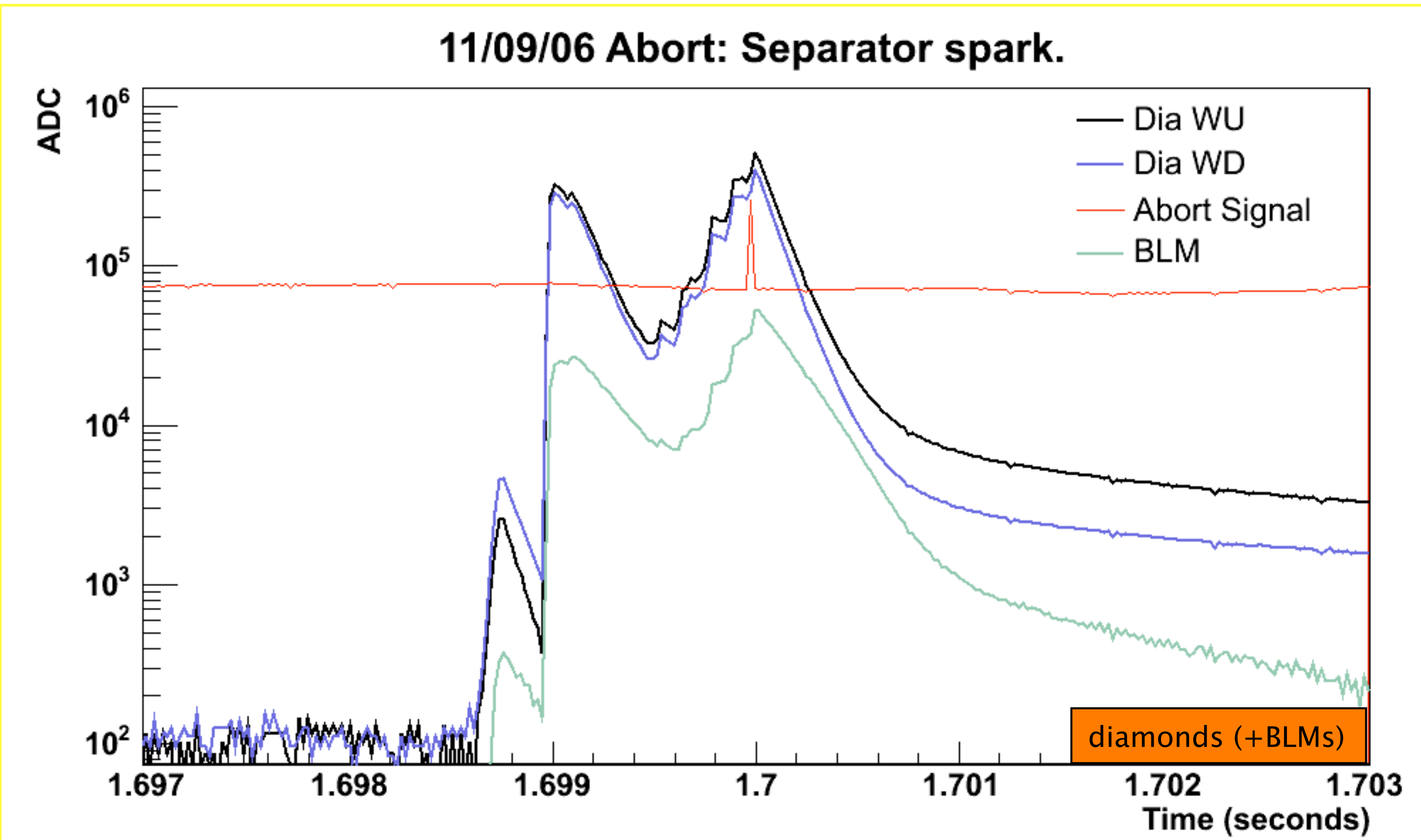
- BLM ionisation chambers too big to be installed inside CMS
  - 9cm diameter, 60cm long
- CVD Diamond is now standard choice at other experiments (installed in CDF, BaBar, Belle, ZEUS)
  - Relative flux monitors
- Radiation hard - tolerant beyond LHC nominal luminosity close to IP
- Low maintanance, constant operating conditions, relatively insensitive to environmental conditions, compact size
- Linear response to particle flux



Protection Systems – Beam Conditions Monitor

CVD Diamond used extensively elsewhere for radiation monitoring – CDF, BaBar, Belle, ZEUS

Example from CDF:



- LHC Beam Loss Monitor readout chosen
  - Robust, reliable, extensively tested
  - Trusted by CCC
  - Implementation approved through AB/BI technical board
- Output to beam ABORT is fully hard-wired

CMS Diamonds have also been installed in CDF
Development program ongoing since many years within CMS

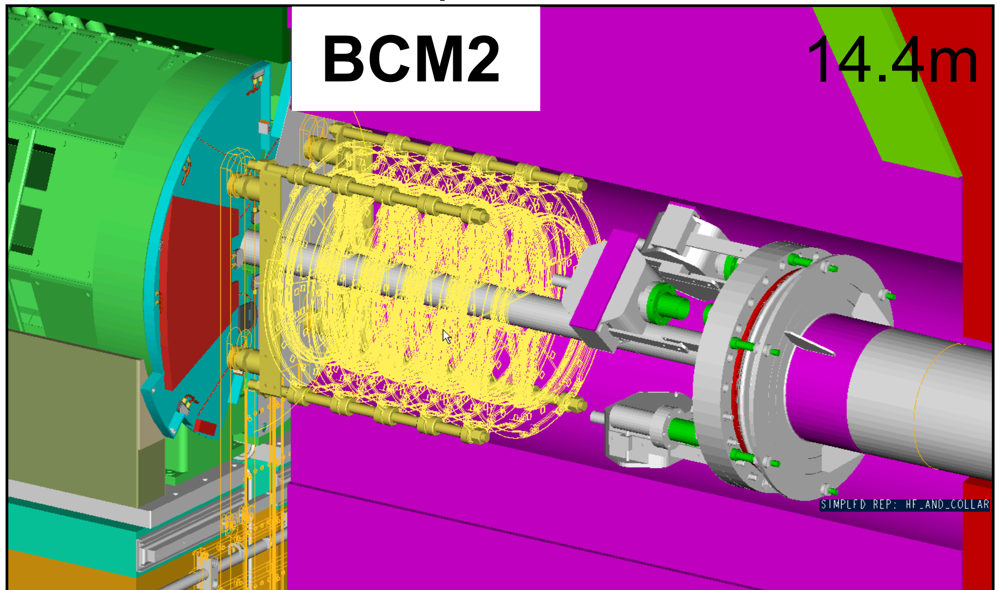
BCM2: Leakage current monitor

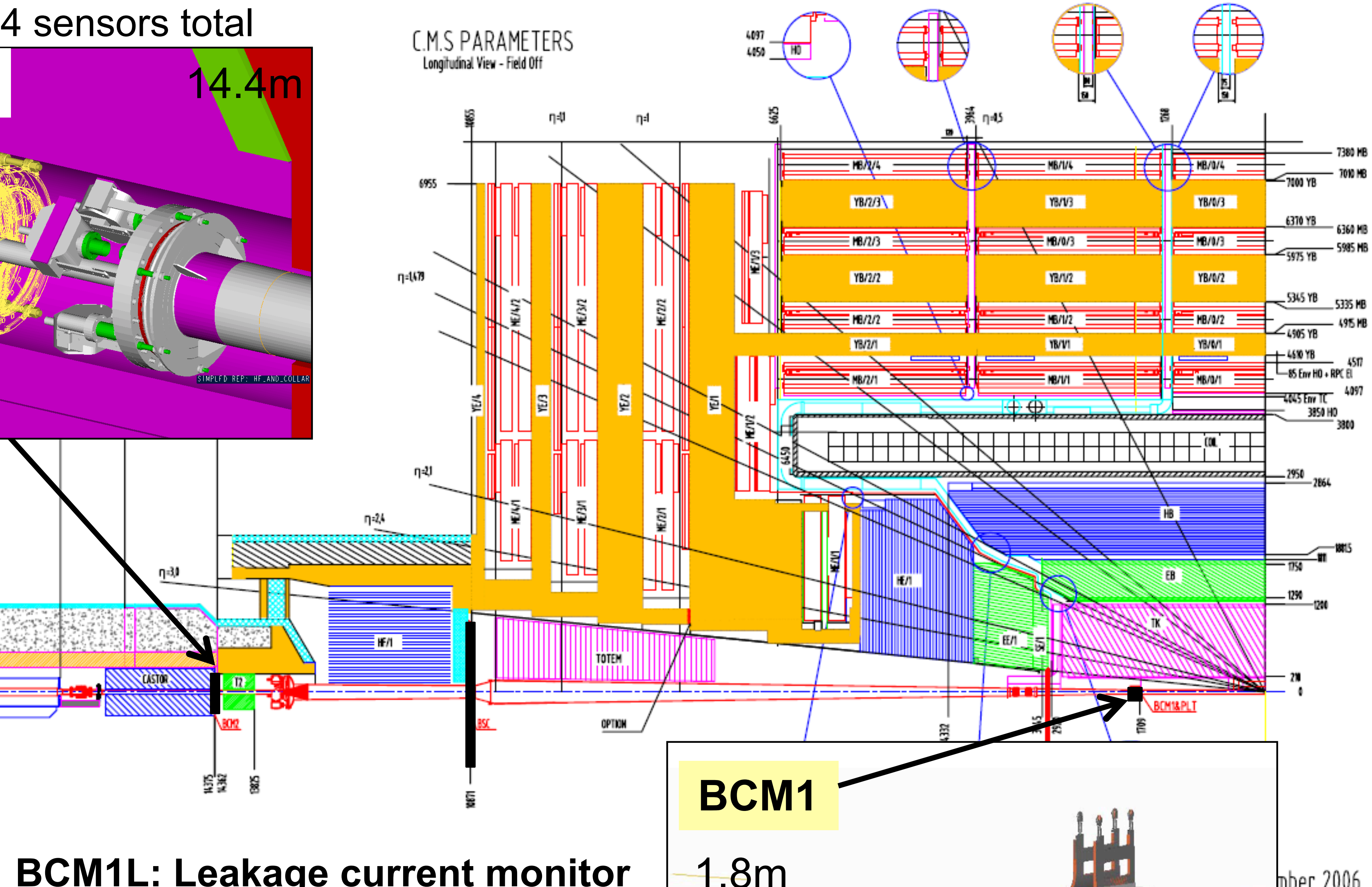
Location: z=± 14.4m, r=29cm, 5cm

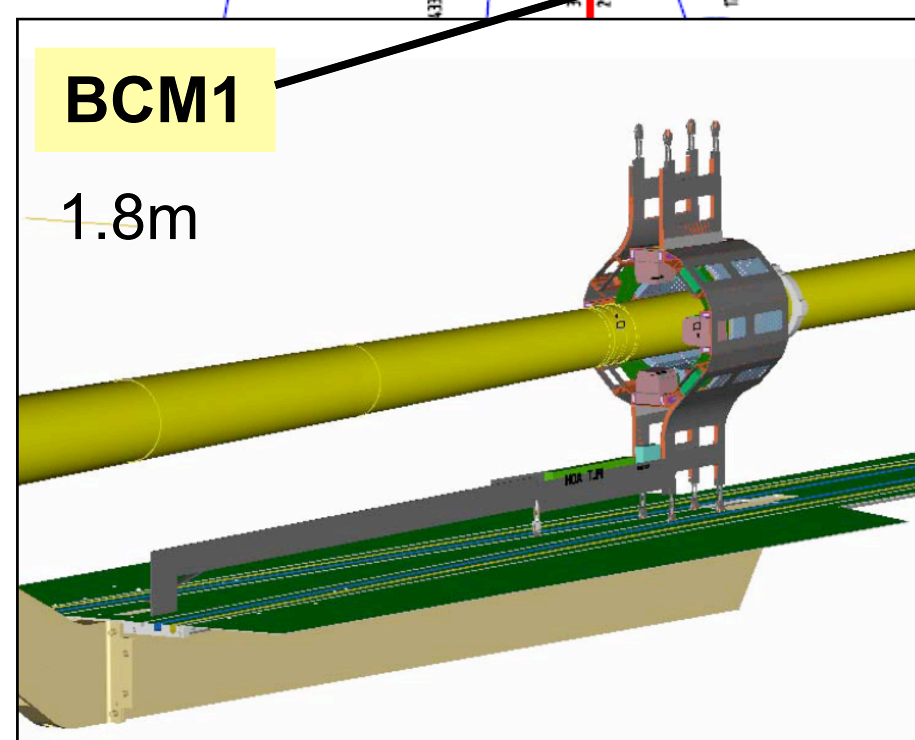
8 stations in φ, 24 sensors total

Readout: 25kHz / 40 us

Front End: BLM tunnel cards







BCM1L: Leakage current monitor

Location: z=±1.8m, r=4.5cm

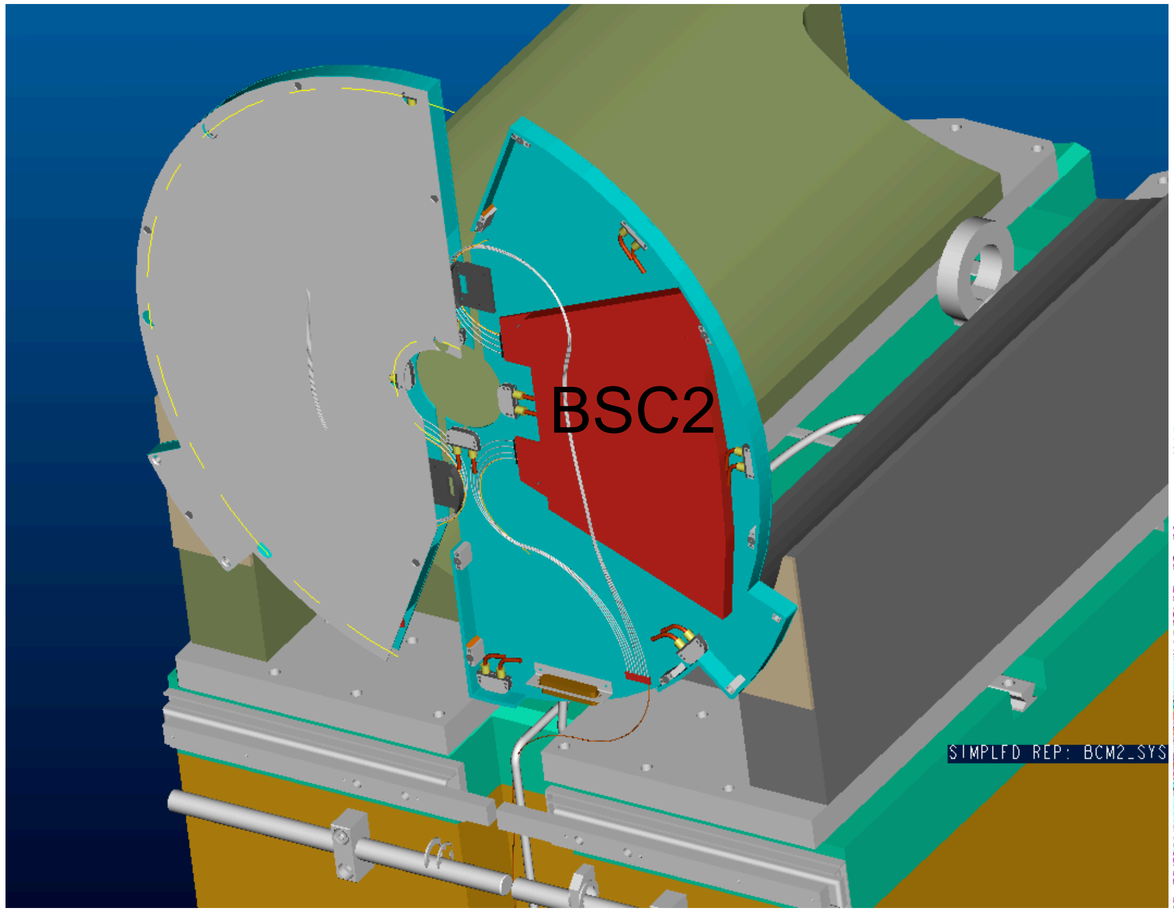
4 stations in φ, 8 sensors total

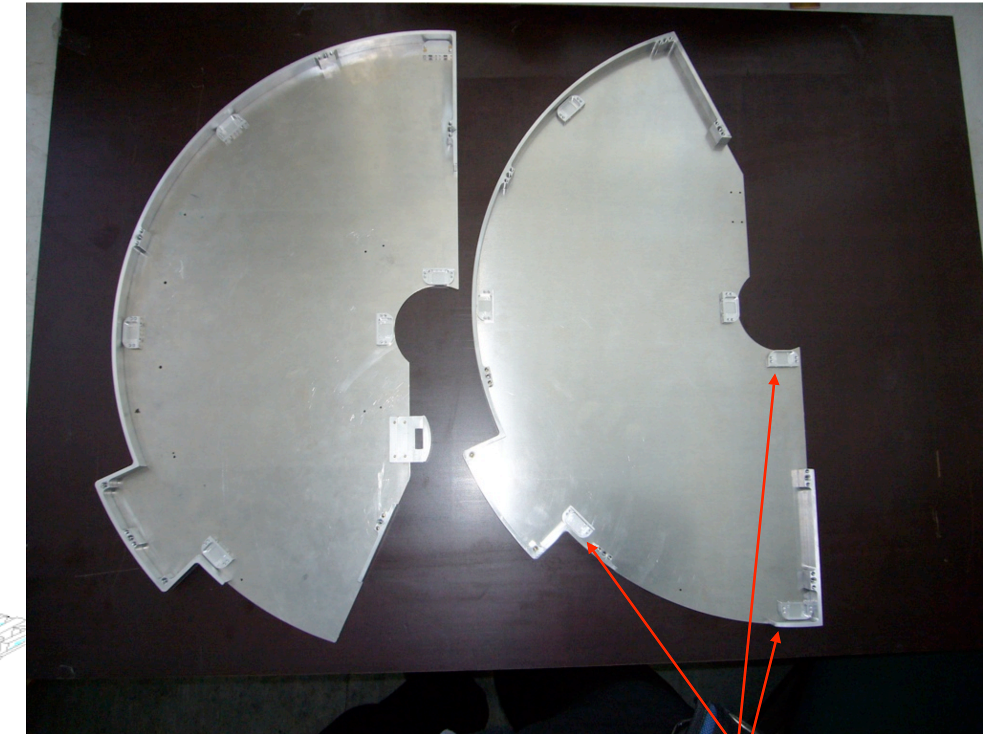
Readout: 200kHz / 5us

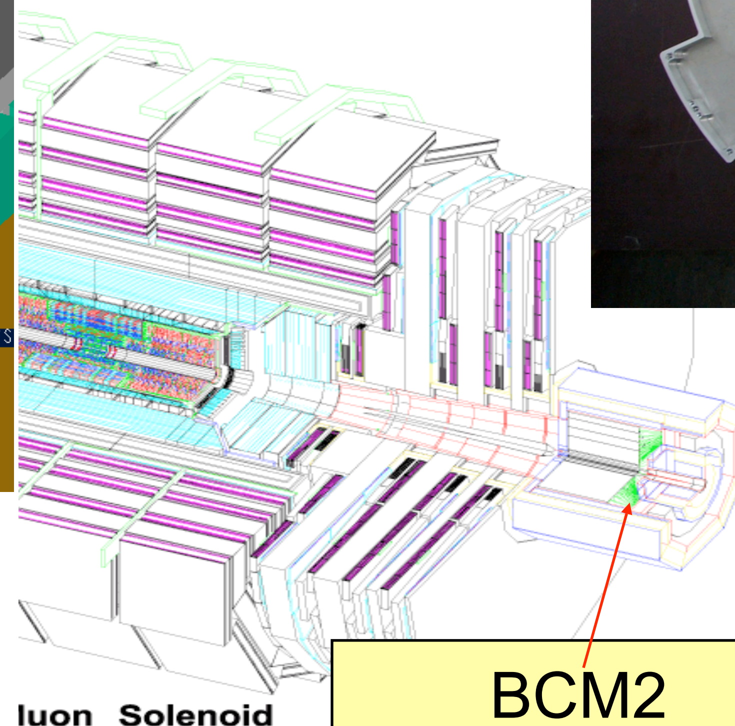
No front end electronics

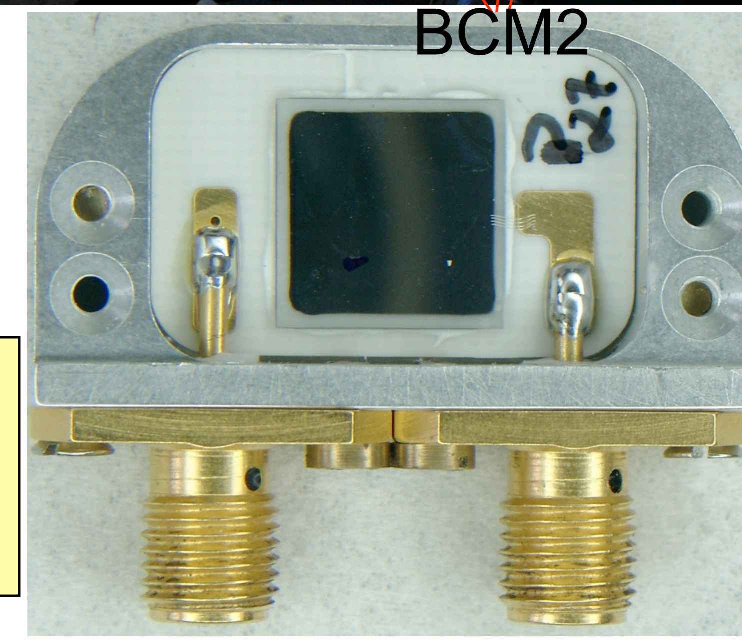
Sensors: 1cm^2 polycrystalline cvd Diamond

BCM2









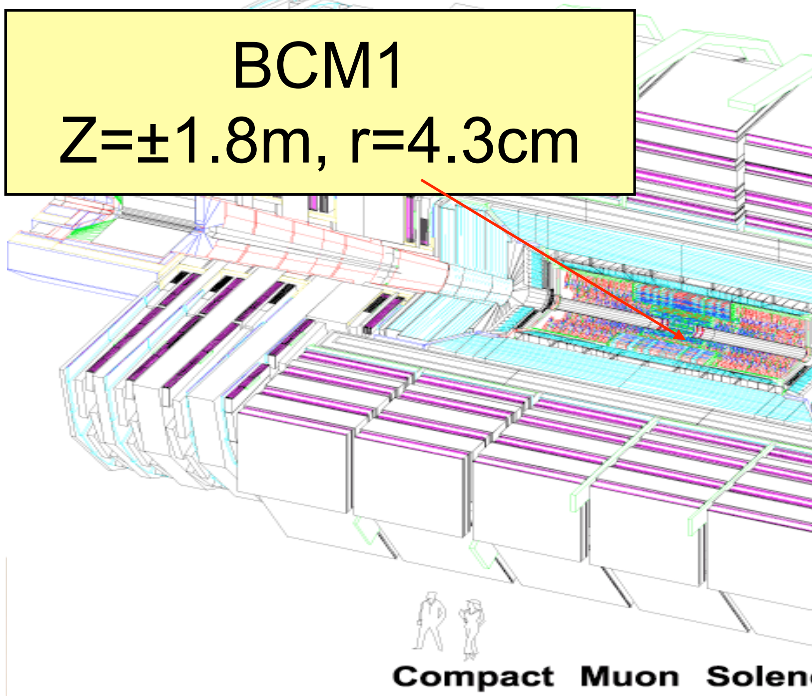
BCM2
Z=± 14.4m,
r=5, 29cm

- Behind TOTEM T2
  - Mounted on CASTOR installation table
- BCM2 sensors profile (per end)
  - Inner Diamonds (4) sensitive to luminosity products
  - Outer diamonds (8) sensitive to incoming background (shielded from IP)
- Standard LHC Beam Loss Monitor readout
  - Diamonds Frontend readout via rad. hard LHC readout for BLM
  - Backend Readout: DAB64 cards, FESA
  - For CCC looks identical to Beam Loss Monitors

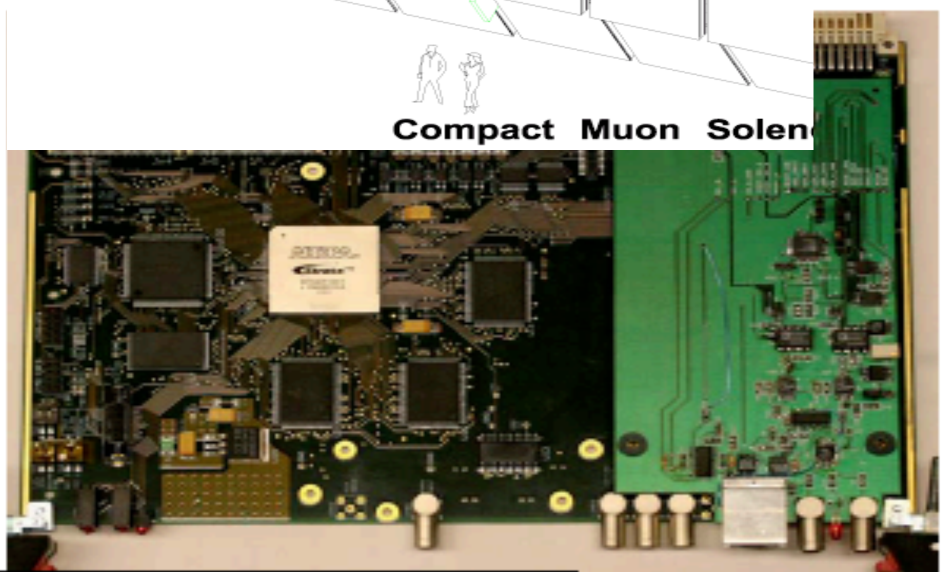
From Day 0,
will be active in ABORT

All components needed in hand
Assembly, calibration and
testing ongoing at Karlsruhe
Installation schedule on time

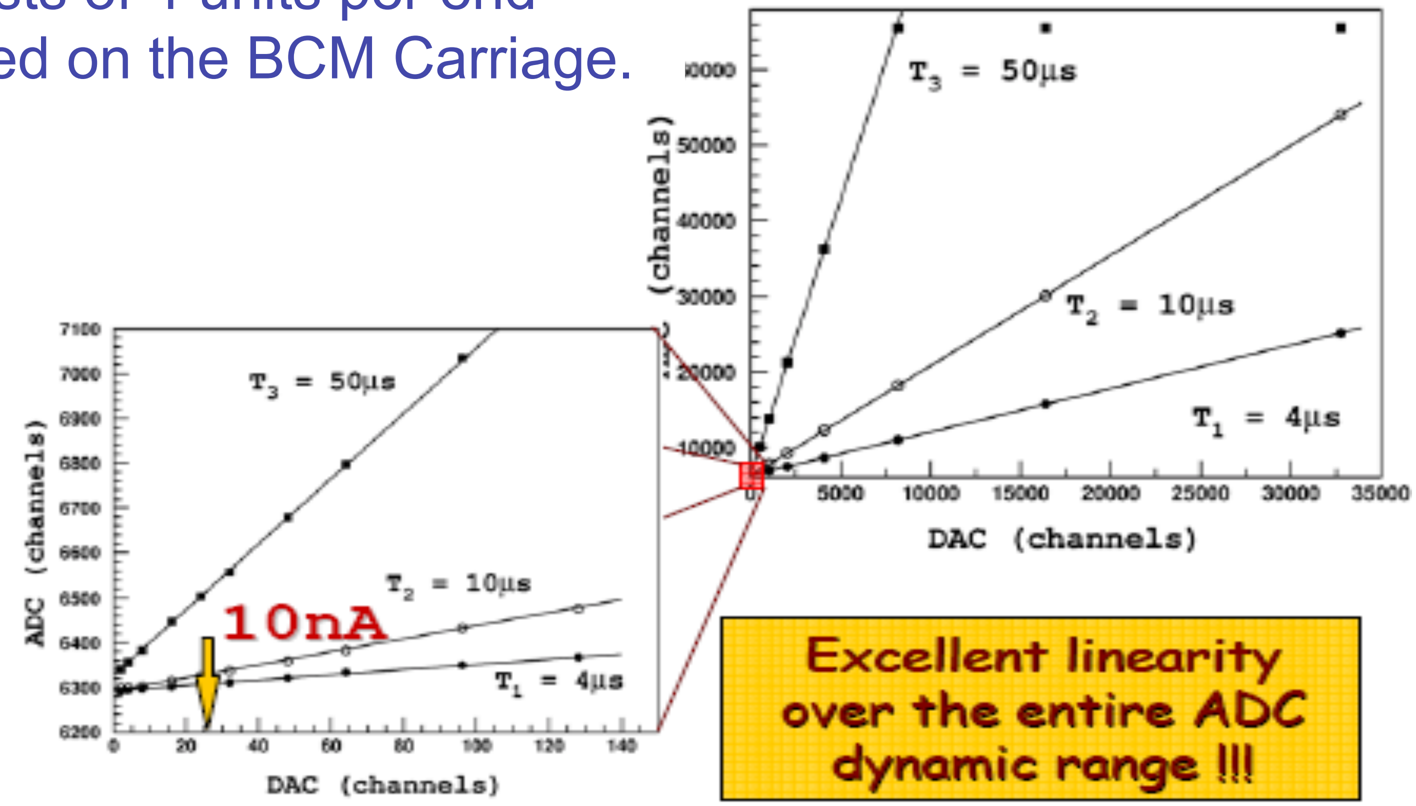
Protection systems:
BCM1L: Leakage current monitoring

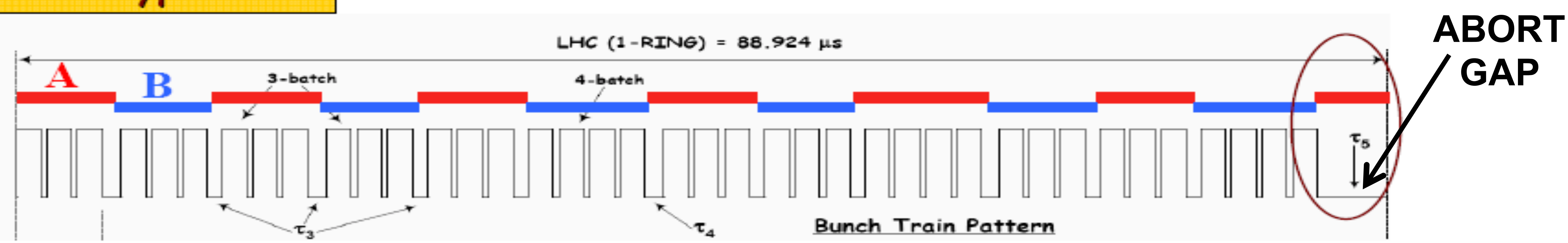


- Consists of 4 units per end mounted on the BCM Carriage.



Prototype board





Synchonized sampling over LHC Bunch train structure and abort Gap

Mezzanine board tested using Beam Loss Monitor readout chain

Wish to enable in BEAM_PERMIT decision early in first running period

Assembly diamonds started at Princeton
Ready to mount on carriage end this year

Reliability of CMS Protection System

Beam Conditions Monitors Readout

- Readout of BCM done via standard BLM readout electronics
  - "BI type-B" VME crate, DAB64 cards, AB standard type PPC
  - BCM2 using full chain including front-end BLM tunnel cards
    - BCM2 is initial system providing BEAM_PERMIT
  - BCM1L: BLM tunnel cards replaced by a dedicated mezzanine board digitising leakage current mounted on DAB64 card.
  - Logging, data format, post-mortem, etc BLM standard and provided by standard FESA framework
- Software for readout is BLM standard
  - NO software development done within CMS BRM group
  - NO changes from BLM software
- CMS BCM implementation and subsequent purchase of hardware approved by BI technical board, November 2006
- Reliability of readout therefore similar to that of Beam Loss Monitors

Redundancy

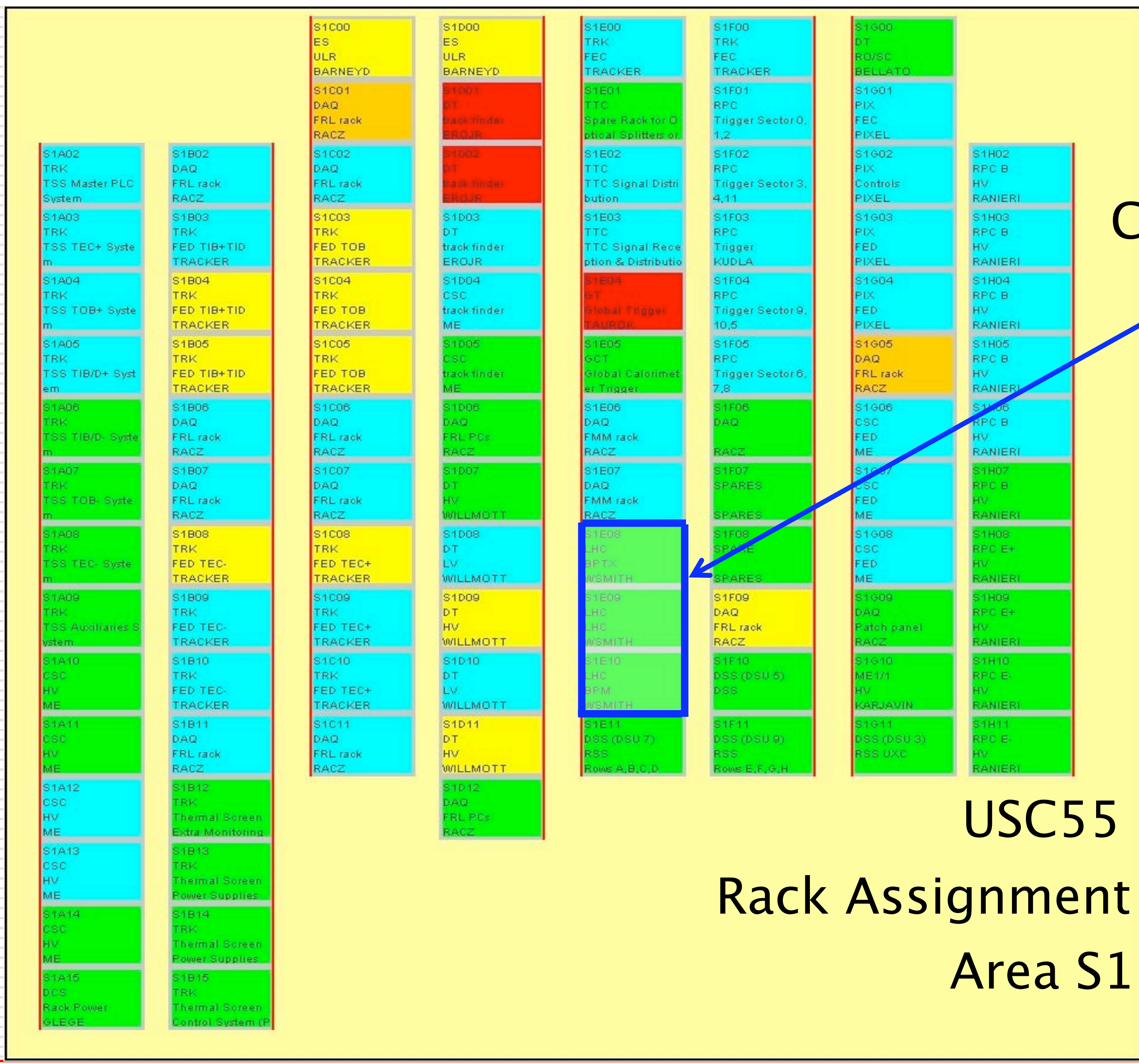
- BCM2 and BCM1L are independent systems
    - Independent crates
    - An individual problem with 1 crate does not leave CMS unprotected - still able to assert the BEAM_PERMIT
- Similarly there are a total of 32 diamonds providing active protection
    - A problem with a single/several diamonds still affords CMS protection and ability to assert the BEAM_PERMIT
    - Minimal operational system: 4 active diamonds (2 per end)
- In addition, there is redundancy in cables, tunnel cards, etc.
- Effect of single point failures on whole system minimised
- Complete set of spares purchased and available in-hand

Testing the Hardware Reliability

- Initial successful slice test of readout in March 2006
- Operated final configuration for BCM2 in PS T11 testbeam September – November 2007
  - No reliability issues encountered
- Final assembly ongoing – predicted that BCM1 and BCM2 will be complete mid-February
- Intend to operate whole system for at least 2 months (Feb--) before installation to prove reliability of the final system from detectors to readout electronics in the final configuration
- Hardware test of correct assertion of BEAM_PERMIT awaiting availability of the BLM COM card.
- Request for test with pilot beam: to lower thresholds and abort single bunch
  - Quick test of all aspects of protection system (BEAM_PERMIT, PM, logging, etc)

Powering Issues

- CIBUs require active assertion of BEAM_PERMIT
  - Without UPS: CMS local power cut = Beam Abort
  - Possible to imagine scenarios where there is a CMS local power cut (USC/UXC) with machine power unaffected



LHC/BCM Racks

CIBU: *S1E08* *S1E09* *S1E10*

CMS using UPS machine power for BCM – waiting for final approval

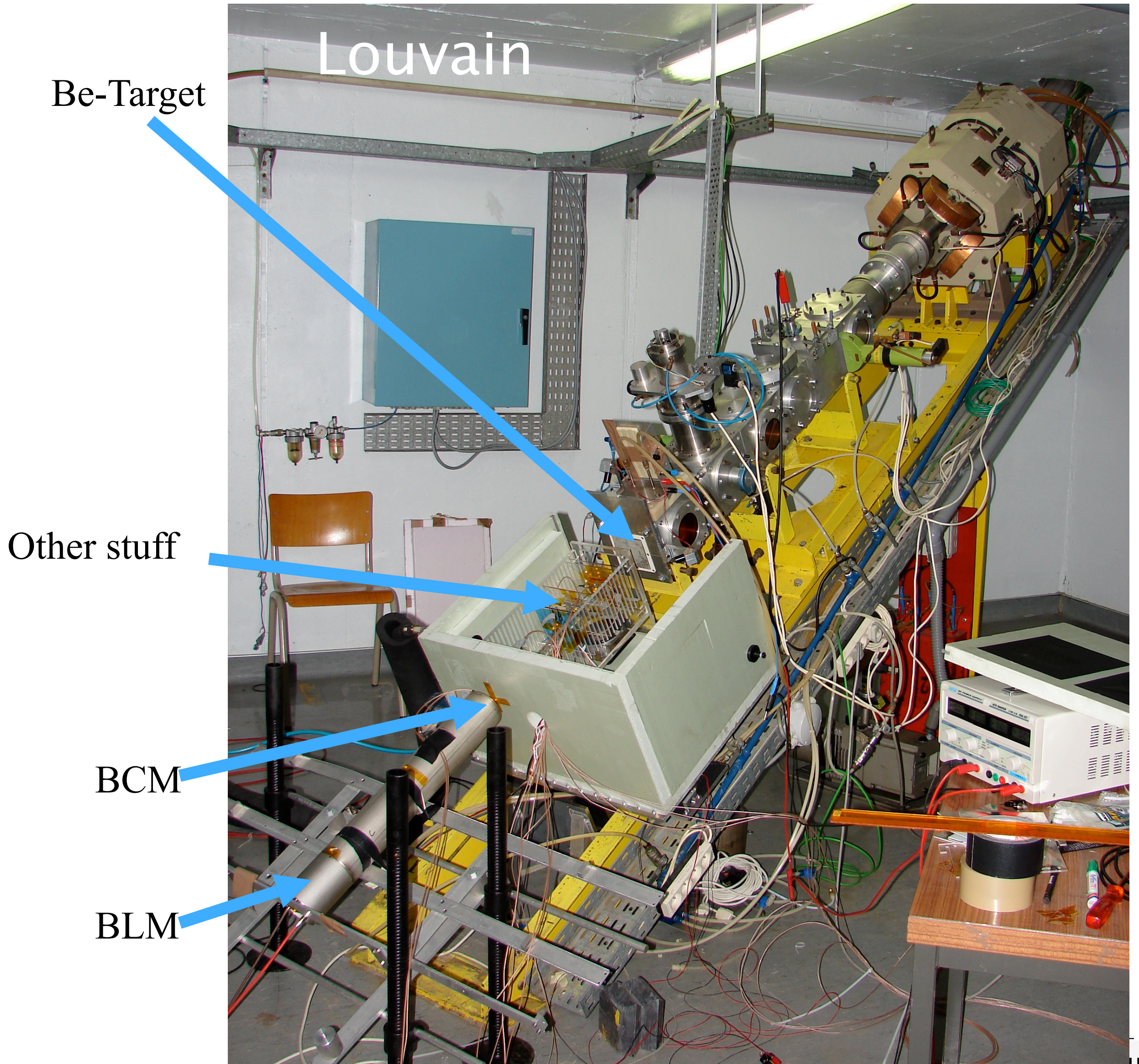
Possible to operate machine with CMS off, but CMS still monitors beam conditions with protection system still active

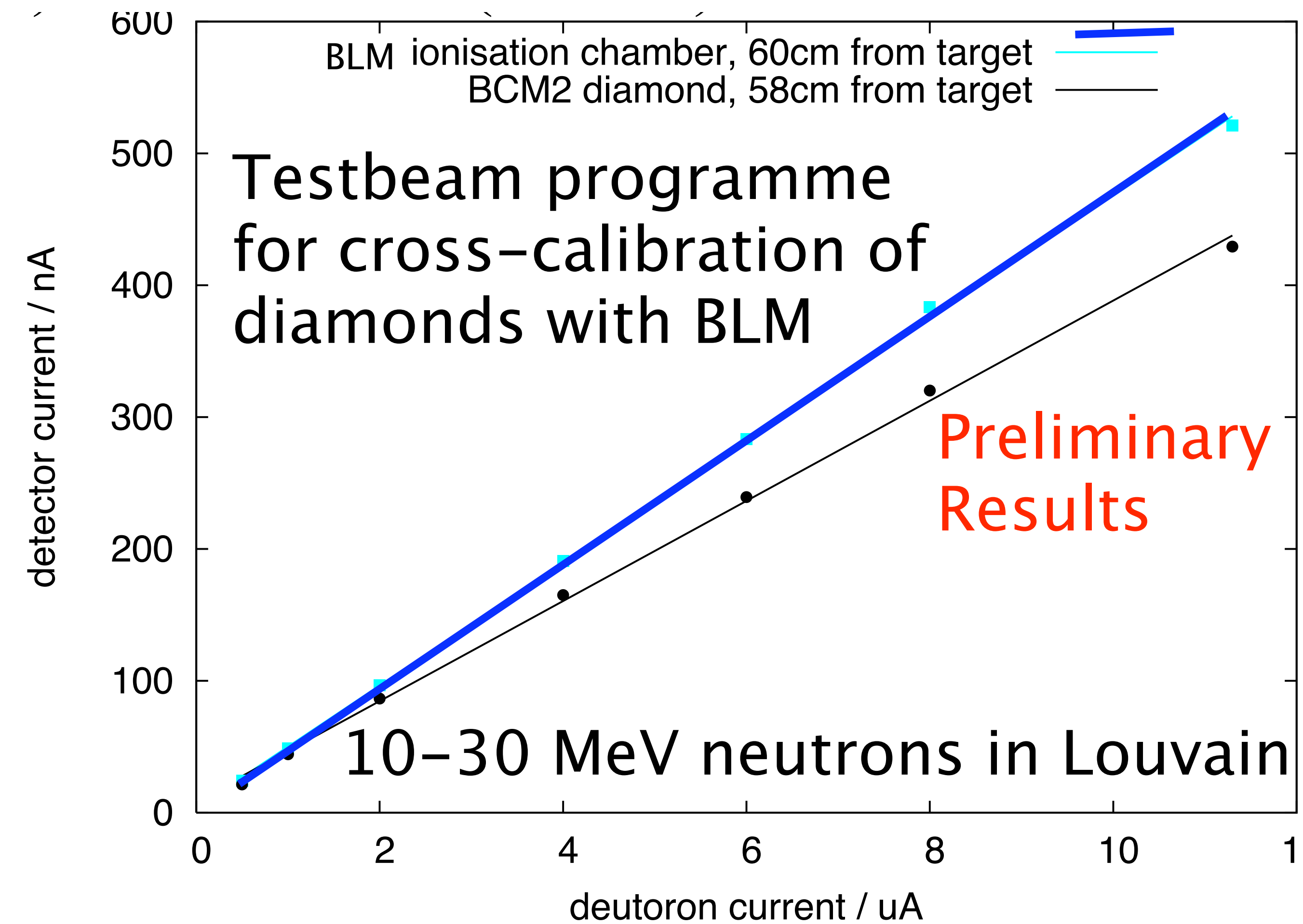
Input to ABORT still active

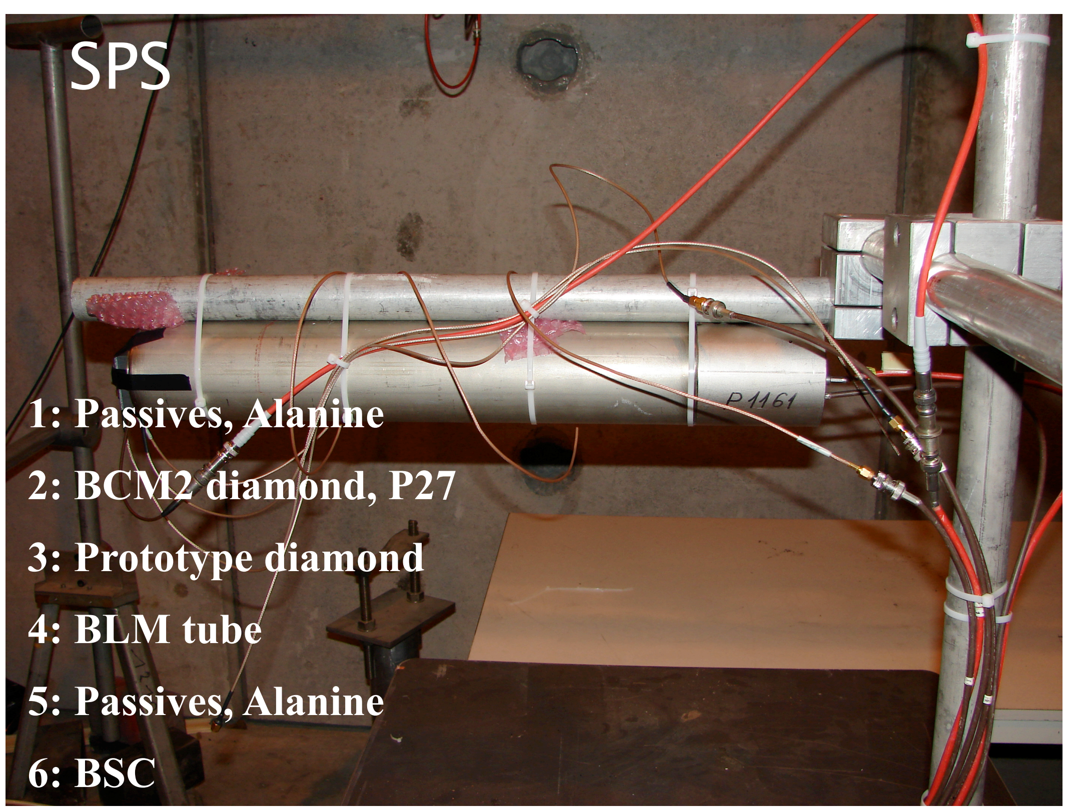
Glitches dealt with by micro-UPS

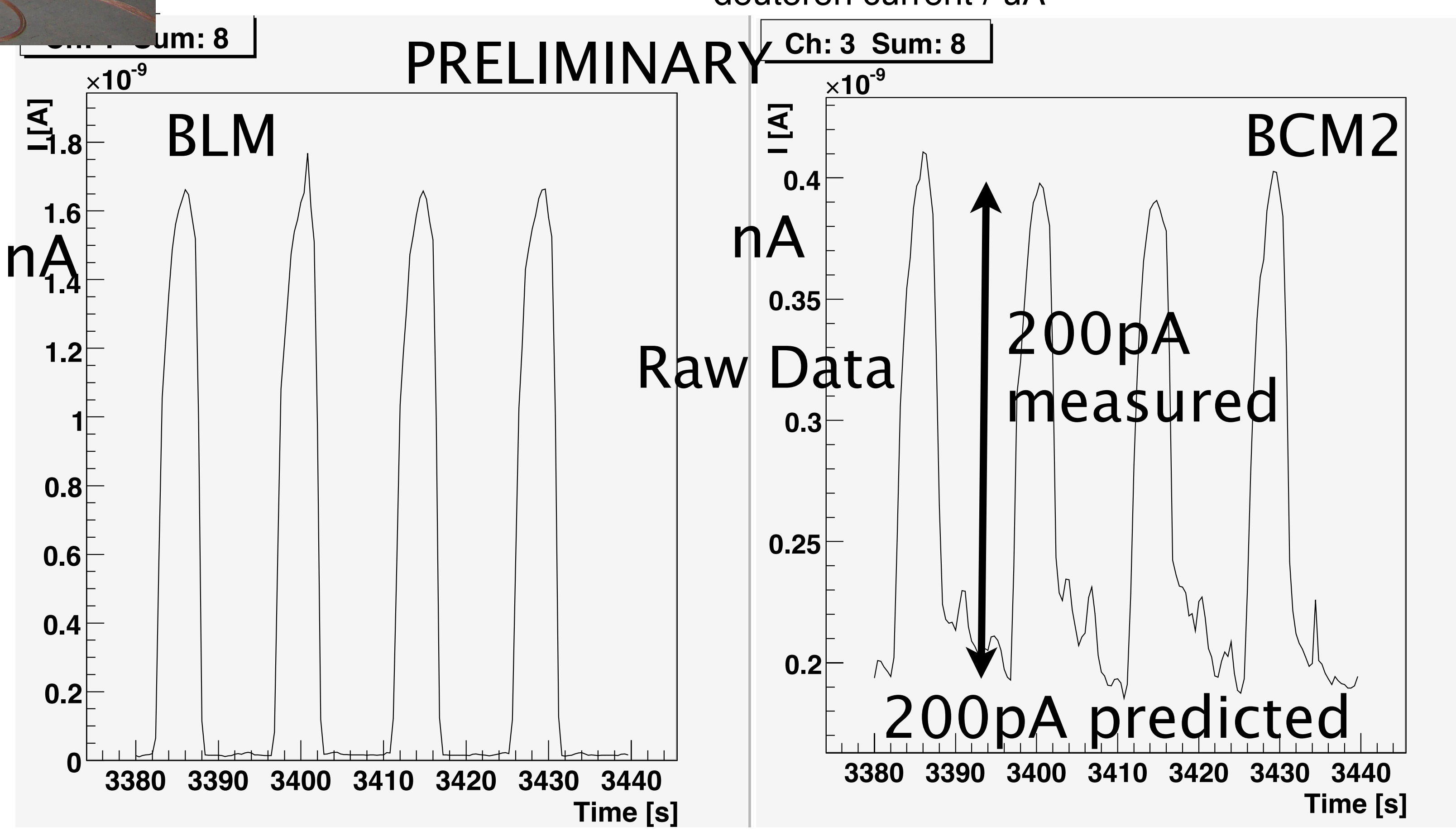
Detector Response of CMS Protection System

Cross Calibration of Detectors



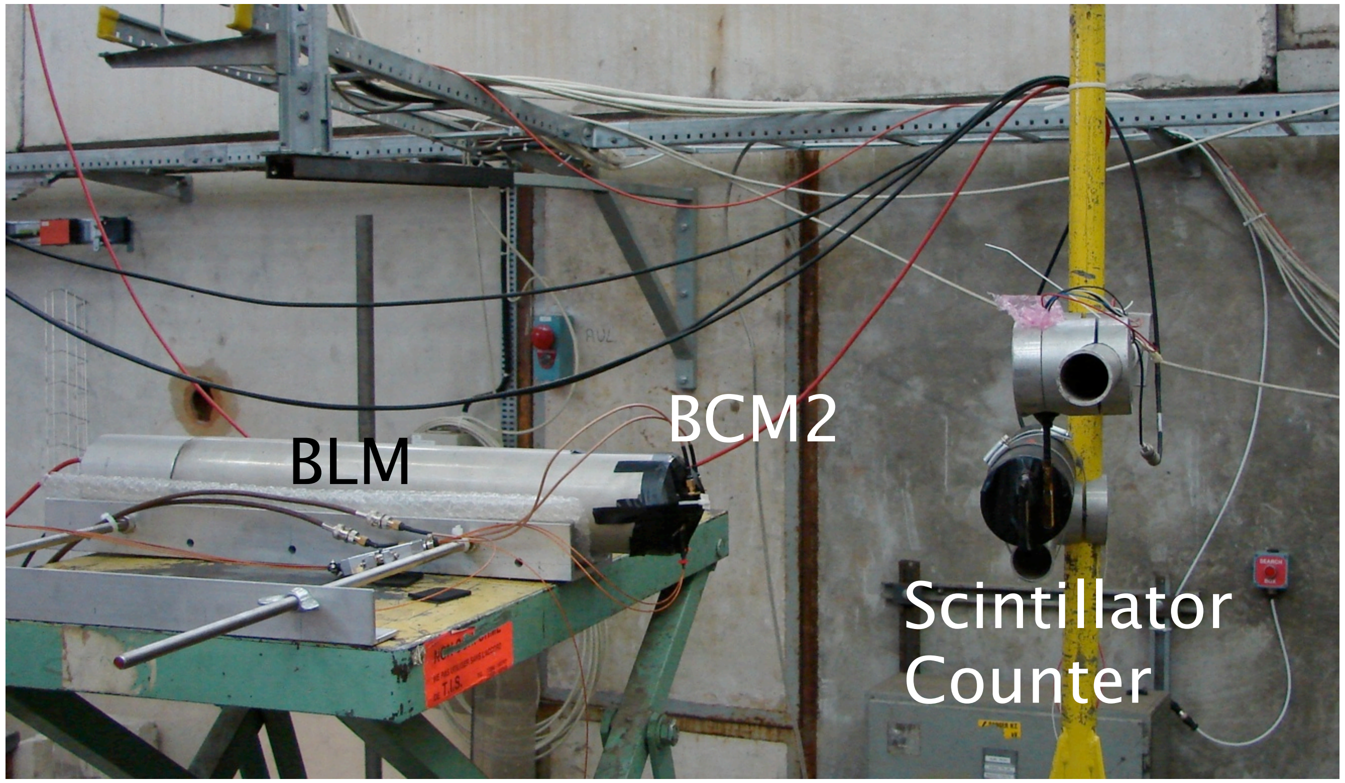


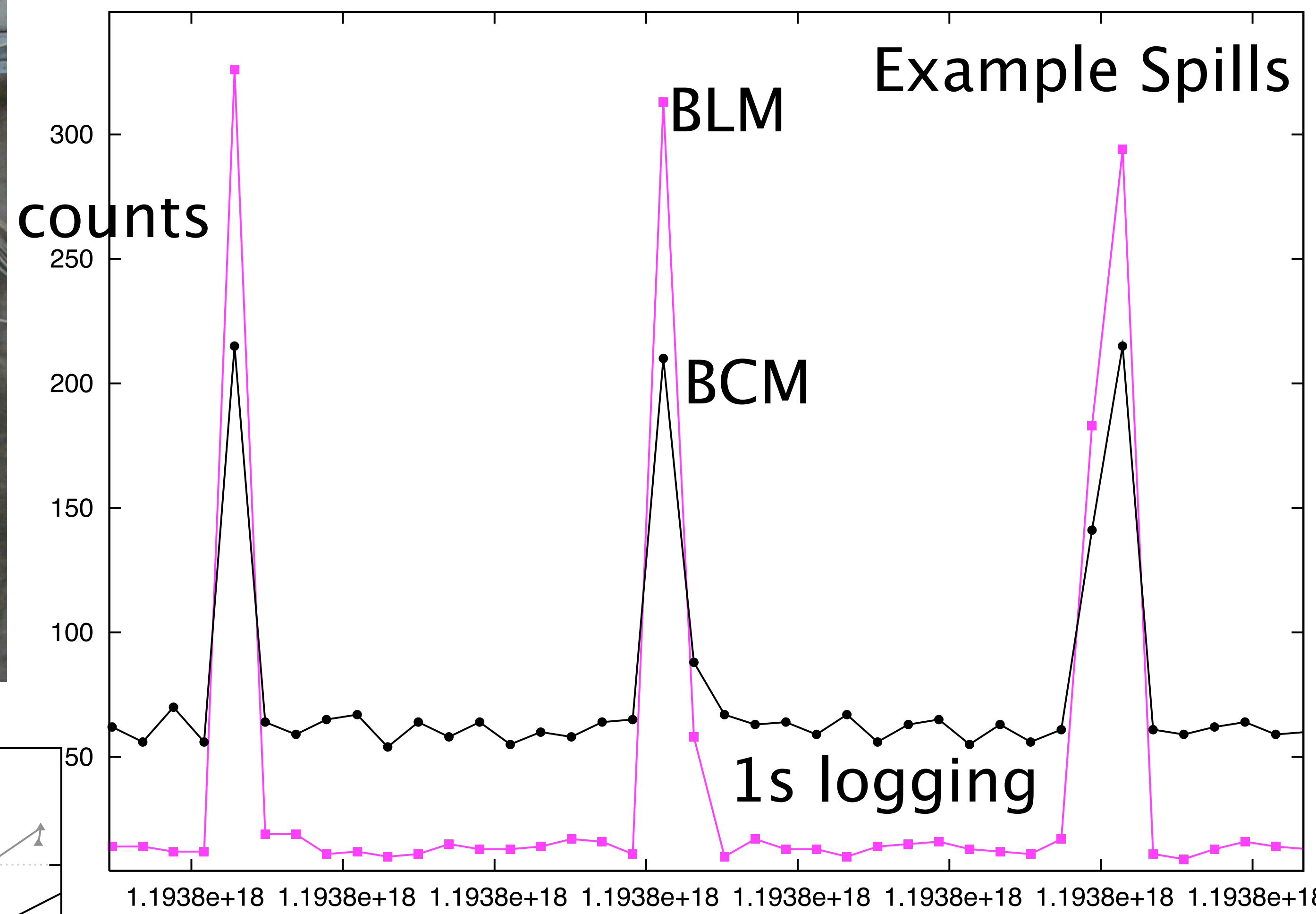


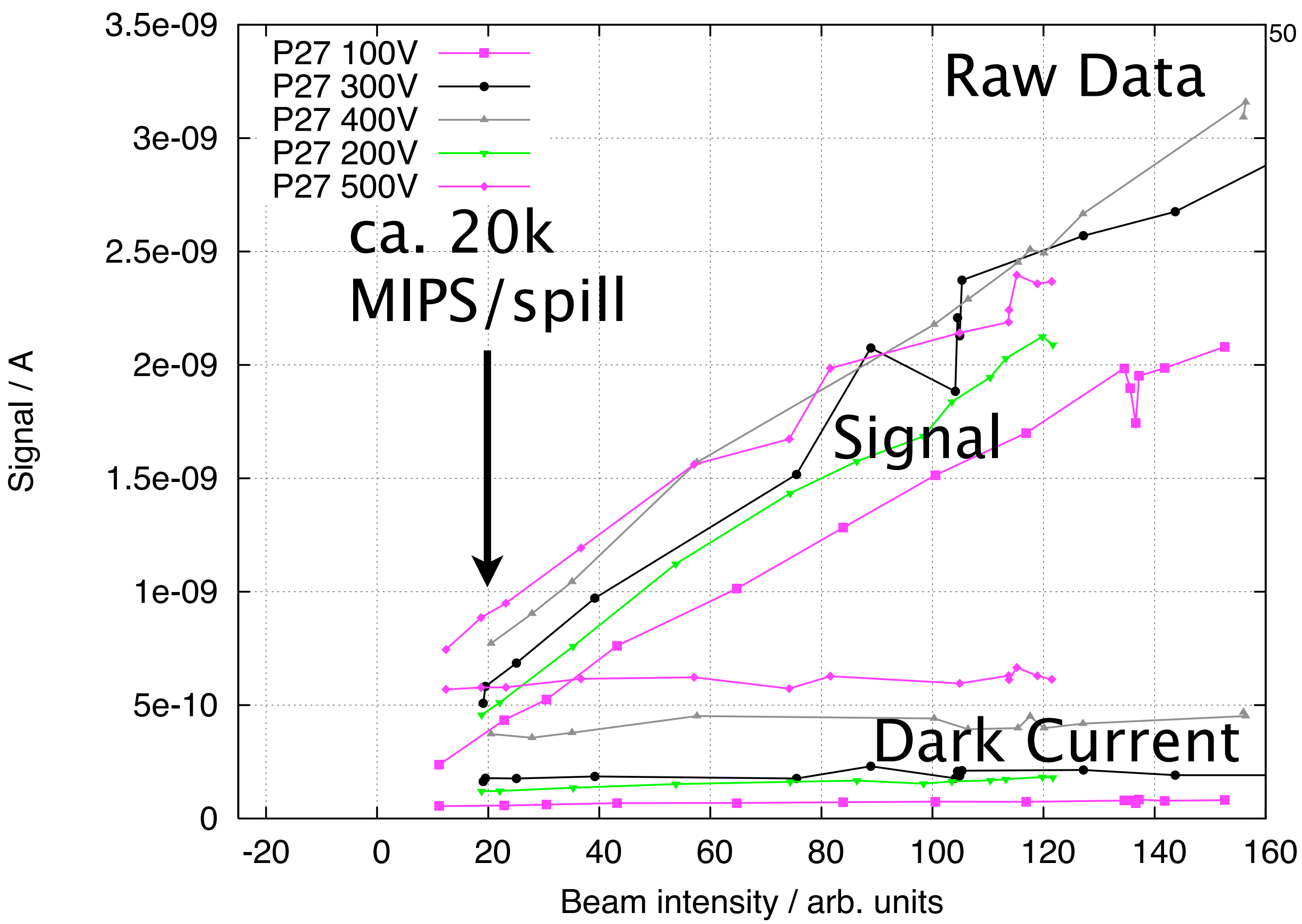


Cross Calibration of Detectors

2 month testbeam programme just finished in T11 area of PS







Slice test of BCM2

Final readout

Final BCM1 and BCM2 diamonds

BLM used for cross-calibration

Good S:N even at lowest intensities

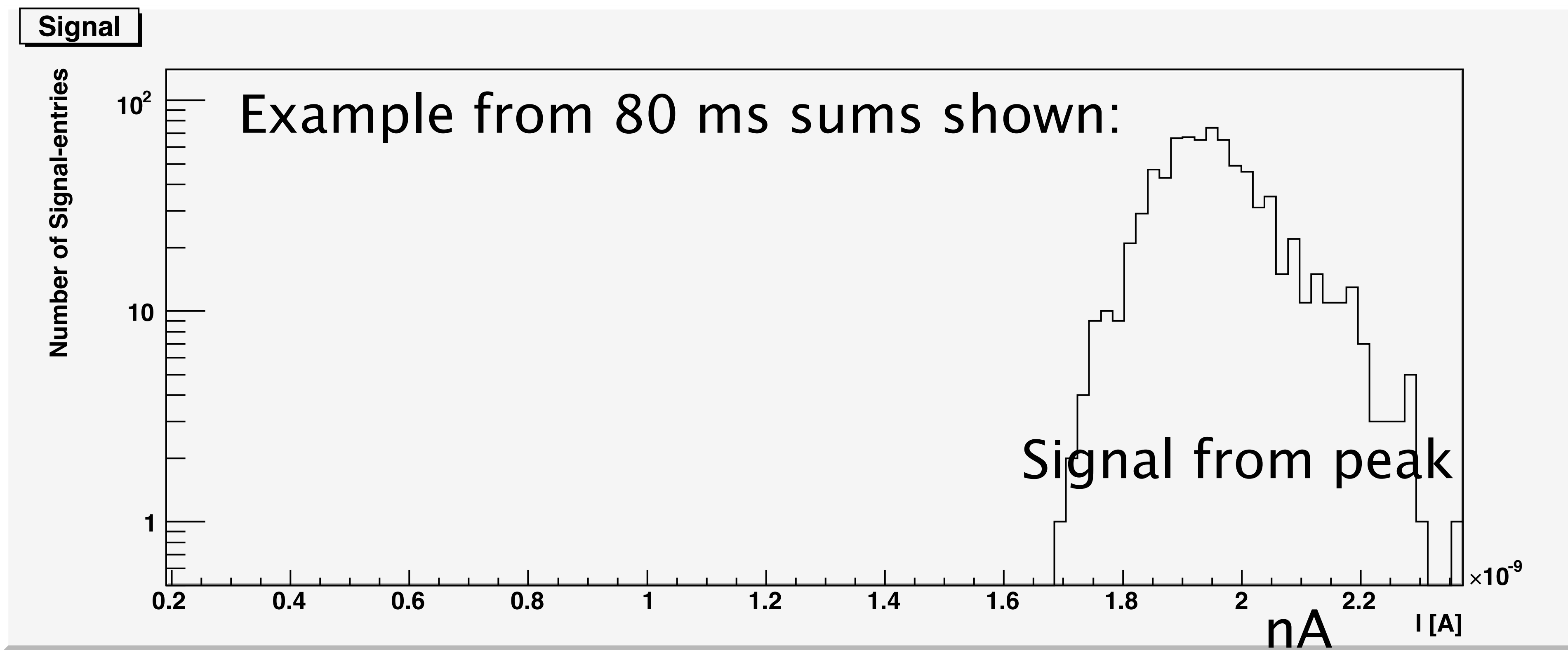
Good Signal Size down to 100V Bias

Wide operational range

Signal and Noise during T11 Testbeam

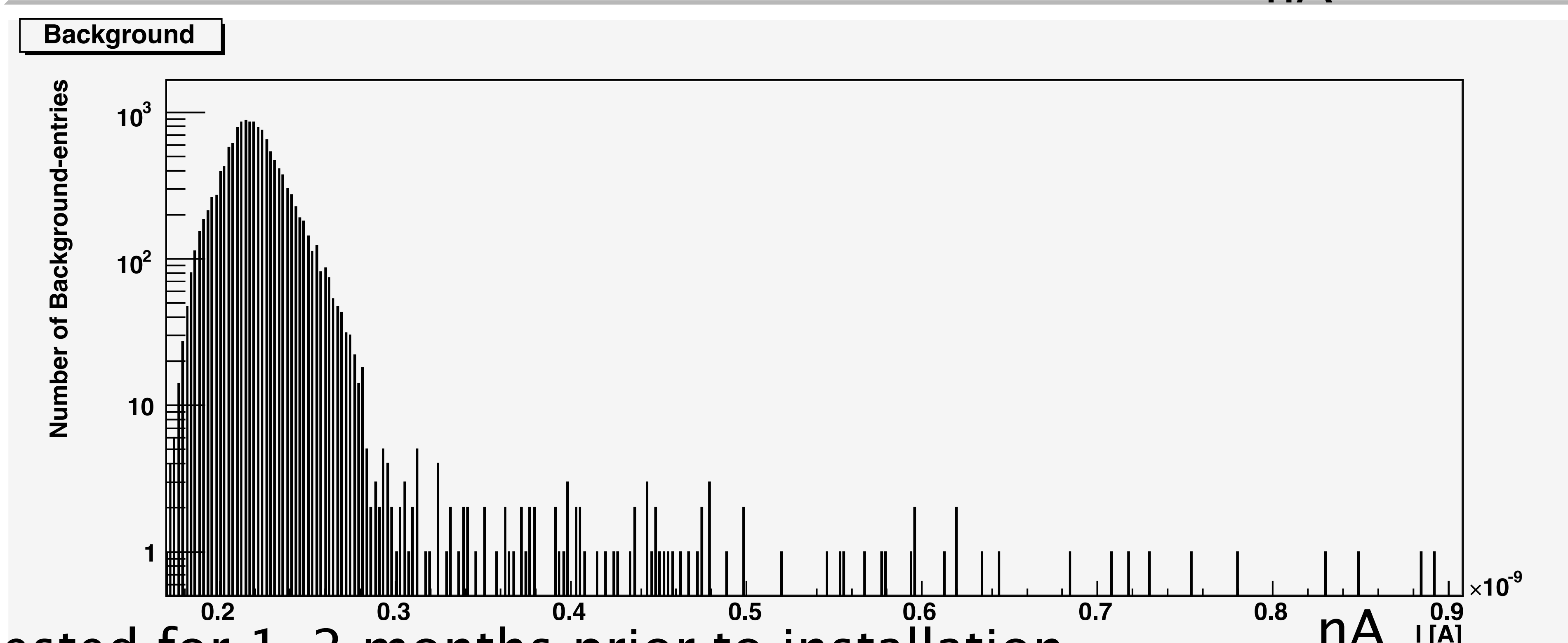
- Example from 1 day of running:

At fluxes of $10^4 cm^{-2}s^{-1}$, signal is well separated from background



Noise well under control

NO noise excursions beyond 1 nA during stable running



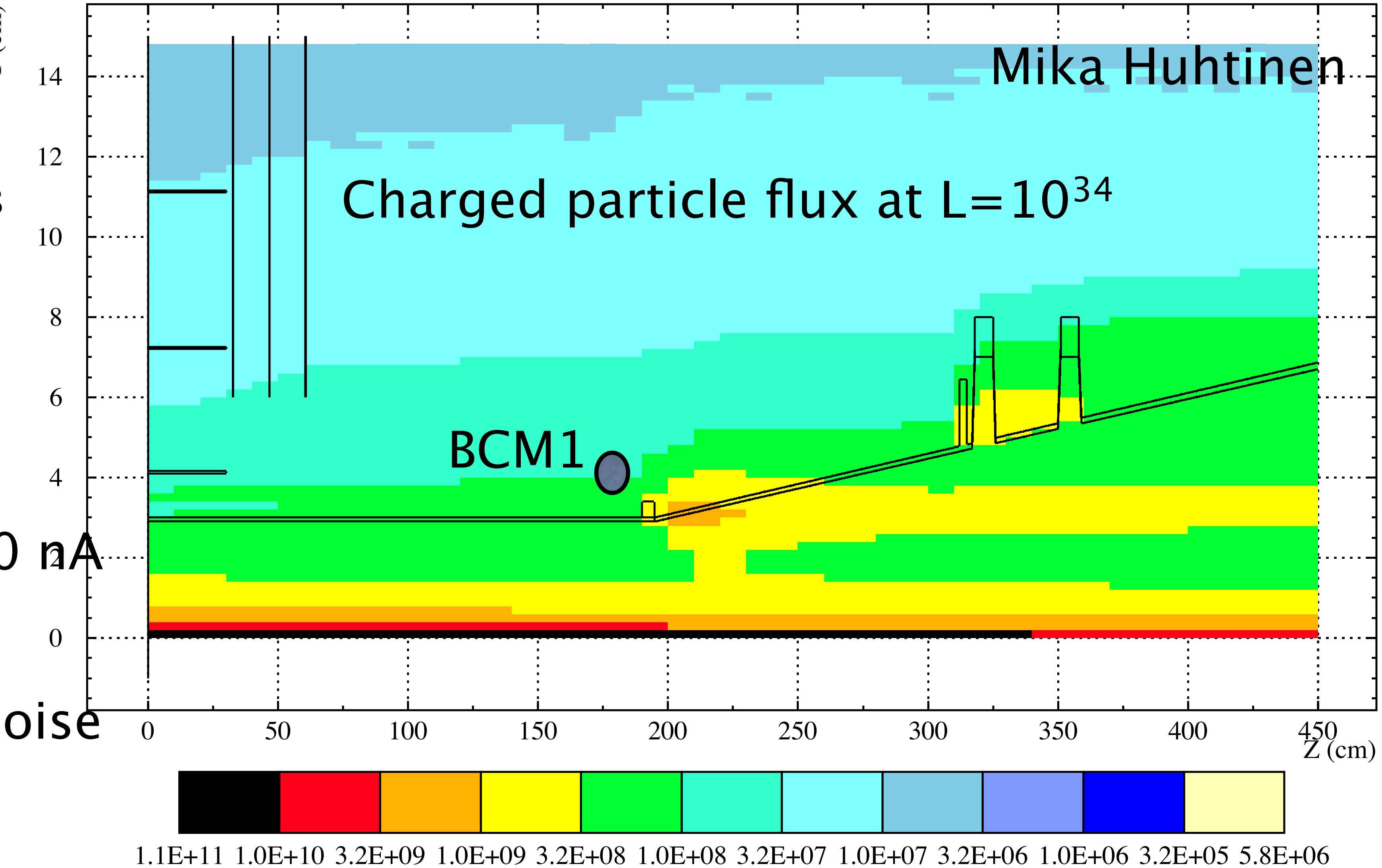
Analysis ongoing

Further testbeams planned at Louvain, Karlsruhe

All diamonds will be tested for 1-2 months prior to installation

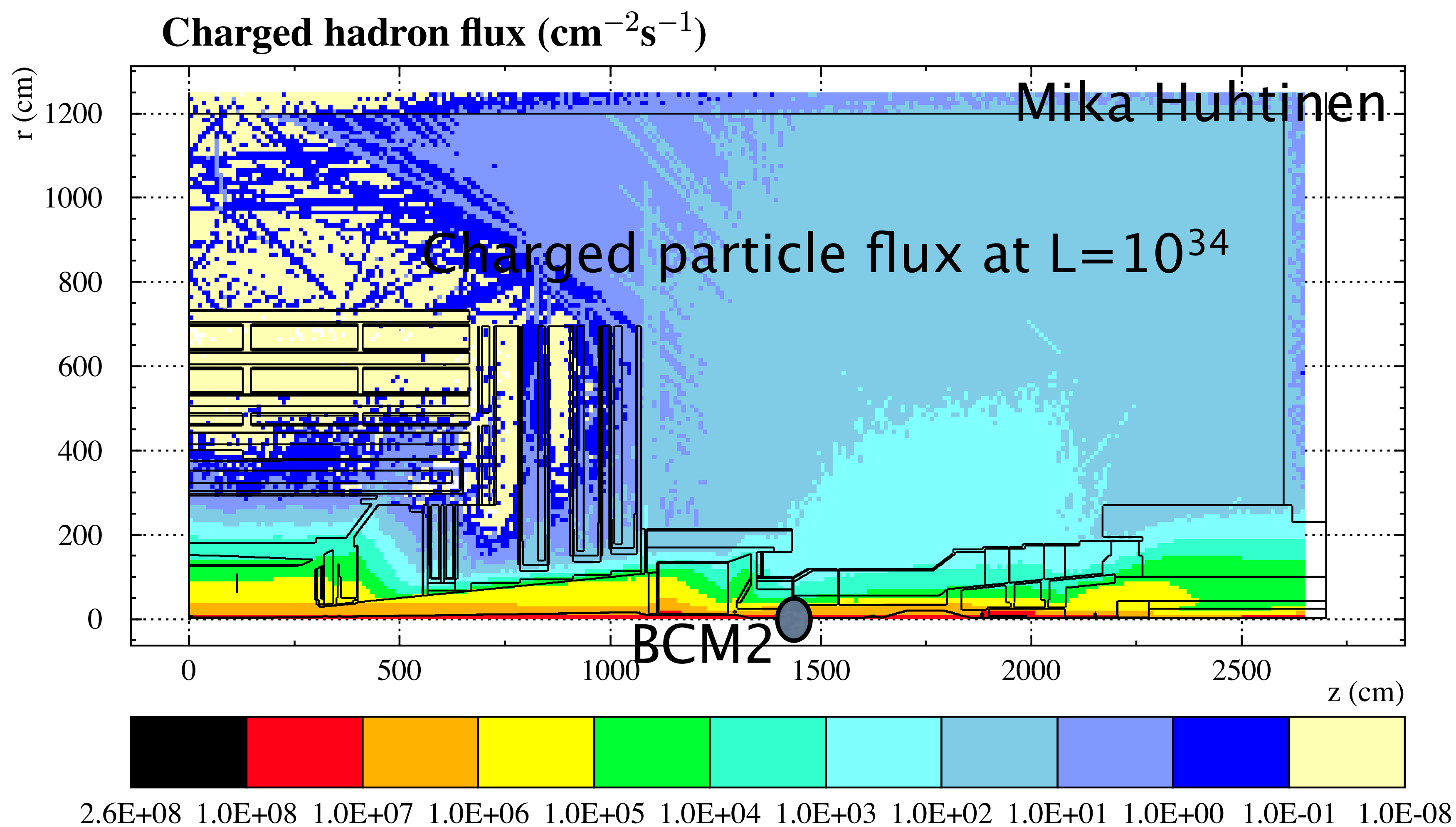
Expectations for Diamond Currents during Nominal Luminosity

- BCM1
- Estimate rate: 1–3.2 10^8 cm^{-2} s^{-1}
- Diamond 1 cm^2
- Expected signal current (assume MIPS) of ca. 200 nA
- Greater than 200 times higher than maximum noise excursions



Expectations for Diamond Currents during Nominal Luminosity

- BCM2:
- Rate from simulations:
- inner: 10^8 cm^{-2} s^{-1}
- outer: 10^6 cm^{-2} s^{-1}
- Diamond 1 cm^2
- Expected signal current:
- inner: ca. 100 nA
- outer: ca. 1 nA
- Inner ca. 100 times higher than maximum noise excursions



Damage Levels

- The integrated dose from collisions is expected to dwarf any losses from background
  - Even loss of entire beam equivalent to approx. 100s luminosity
  - Integral dose of beam losses should be negligable
    - Accidents are more an issue of short timescale “rate” than long-timescale “dose”
- High flux of particles -
  - Potential overload on chips eg huge charge input to amplifier
- Silicon Tracker modules (sensors+front end electronics) were tested in PS in 2001
  - HV + LV on
  - Tested to 10^9 times nominal rates
  - 10^{10} protons / cm^2 in 42ns burst
  - Modules survived multiple bursts, with no pinholes, no dead channels
- Individual Modules tested - but not mass-testing
  - CDF experience - bursts with relatively low doses, short time scale - loss of chips
  - Mode of failure typically badly understood despite simulations and testbeams
  - Short bursts of losses a concern
- Sensors much less sensitive to losses with HV+LV off
  - Damage Level not fully understood, but physical damage gives upper limit
- Worry particularly about high rates of loss rather than integrated dose
- Time-scale of losses important

Initial Proposal for Threshold Settings

- CMS Protection System wishes to be active in ABORT from day 0
  - Actively assert the BEAM_PERMIT using BCM2

- Expect to set thresholds initially:
  - Sensitive enough to protect CMS detector
  - High enough not to affect LHC running efficiency

- Present intention is to set initial values of thresholds based upon 2 considerations:
  - Expected BCM current at nominal luminosity
  - Corresponding cross-calibrated values used in BLMs nearby in LSS5, in particular on the inner triplets

- Thresholds will be tuned with operational experience

Summary

- Explicit choice made in CMS protection system to be compliant with the machine protection system
- Readout and detector technology selected for reliability
    - Beam Loss Monitor chosen as model for CMS protection system
- A programme of calibration and cross-calibration of the BCM diamonds with Beam Loss Monitors ongoing
- Final system will be tested for 2 months prior to installation to prove reliability
- Initial proposal for setting values of thresholds made