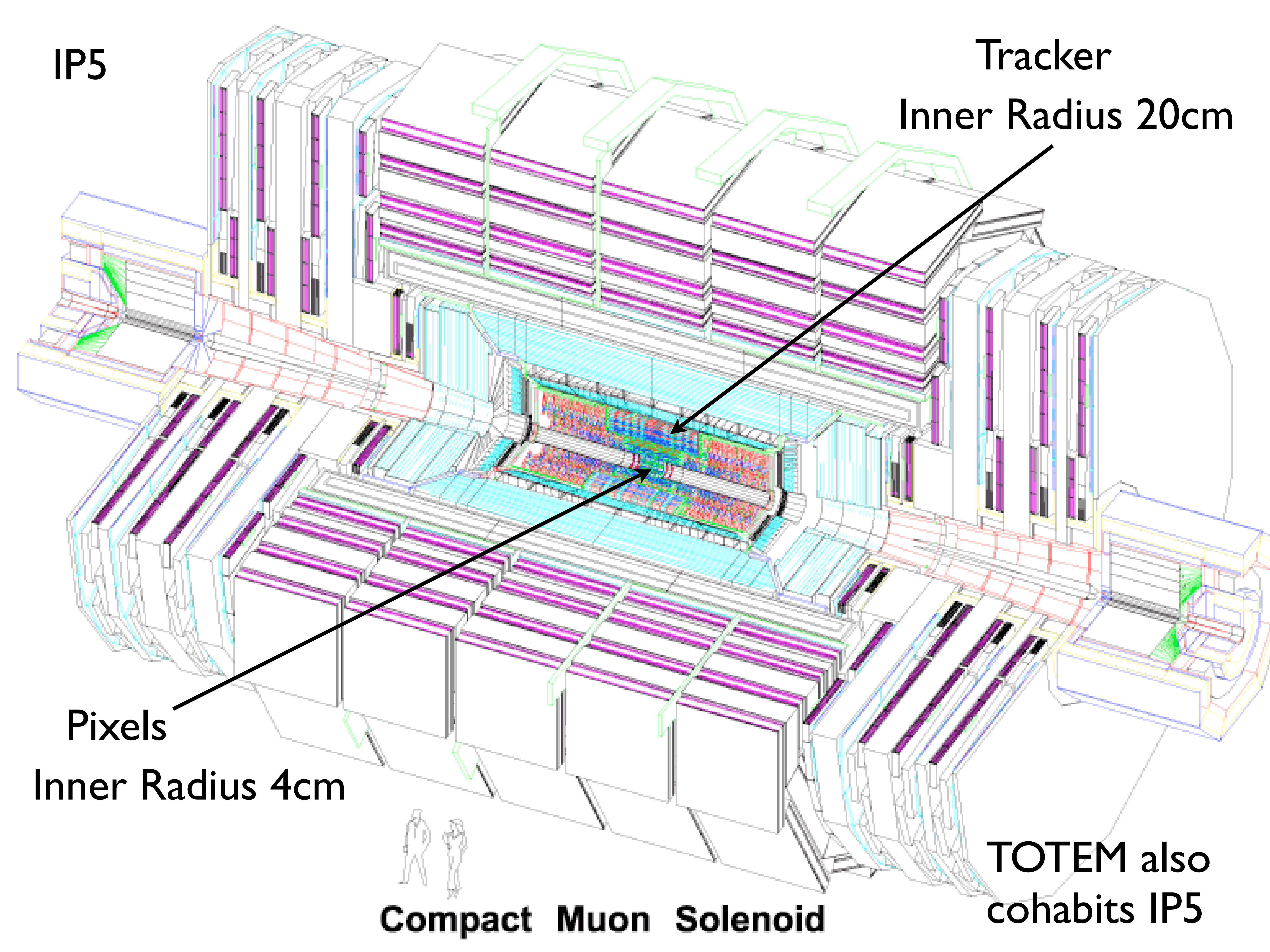
Joint LHC Machine-Experiments Meeting on Experiments Protection from beam failures

Report from CMS

Richard Hall-Wilton (TS/LEA)
CMS Beam Interlock SUpervisor - Alick Macpherson

Issues to be covered:

- Introduction to CMS
- Damage Levels
- Review of Simulation
- Beam Conditions Monitor
- Operational procedure
- Summary


IP5
Tracker
Inner Radius 20cm
Pixels
Inner Radius 4cm
TOTEM also
cohabits IP5
Compact Muon Solenoid

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 may blow chip

- 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

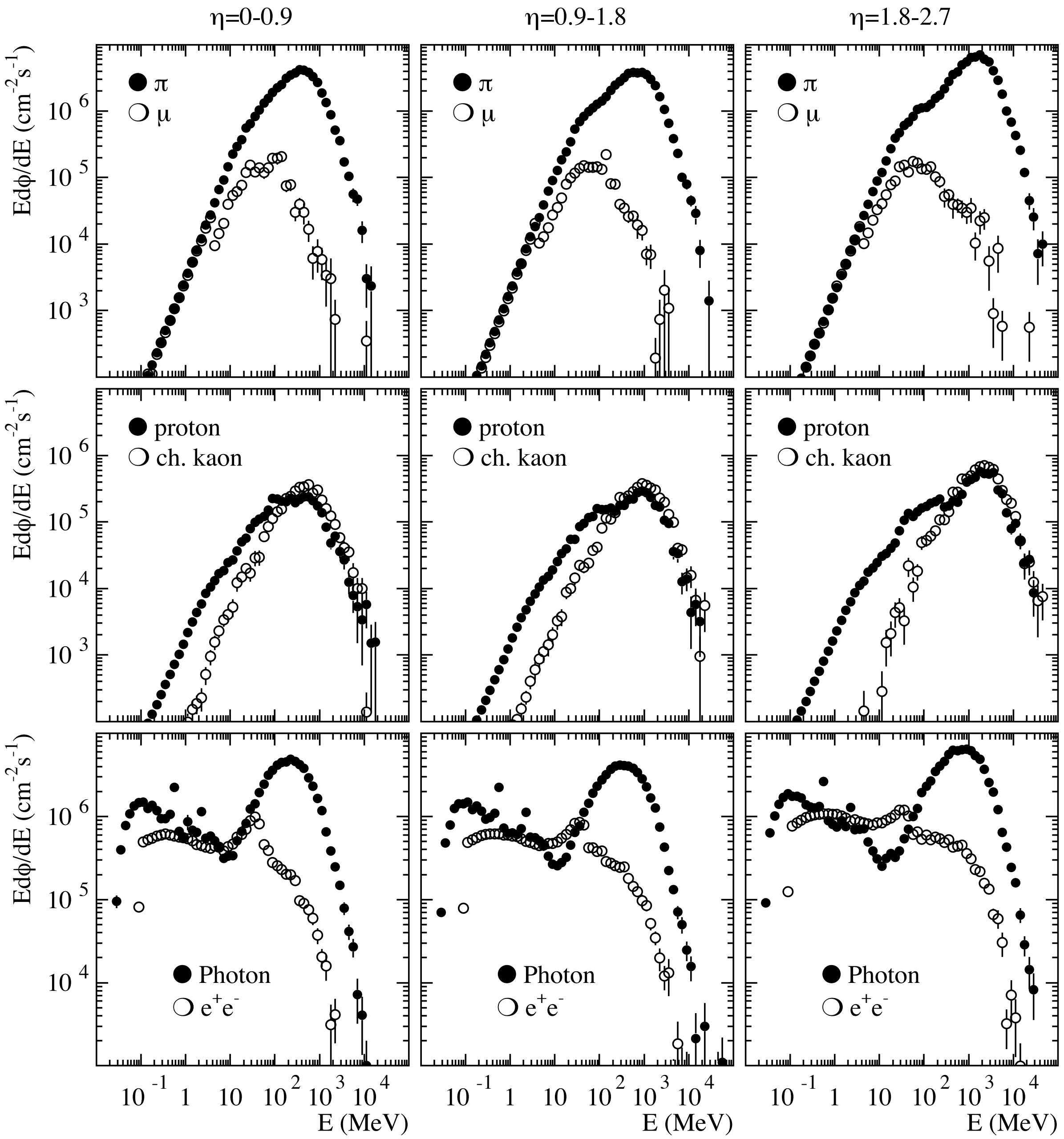
- Individual Modules tested - but not mass-testing
  - CDF experience - bursts with relatively low doses, short time scale - loss of chips
  - Mode of failure typically badly understood despite simulations and testbeams
  - Short bursts of losses a concern

- 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

Simulation: Normal Luminosity

From Tracker TDR:

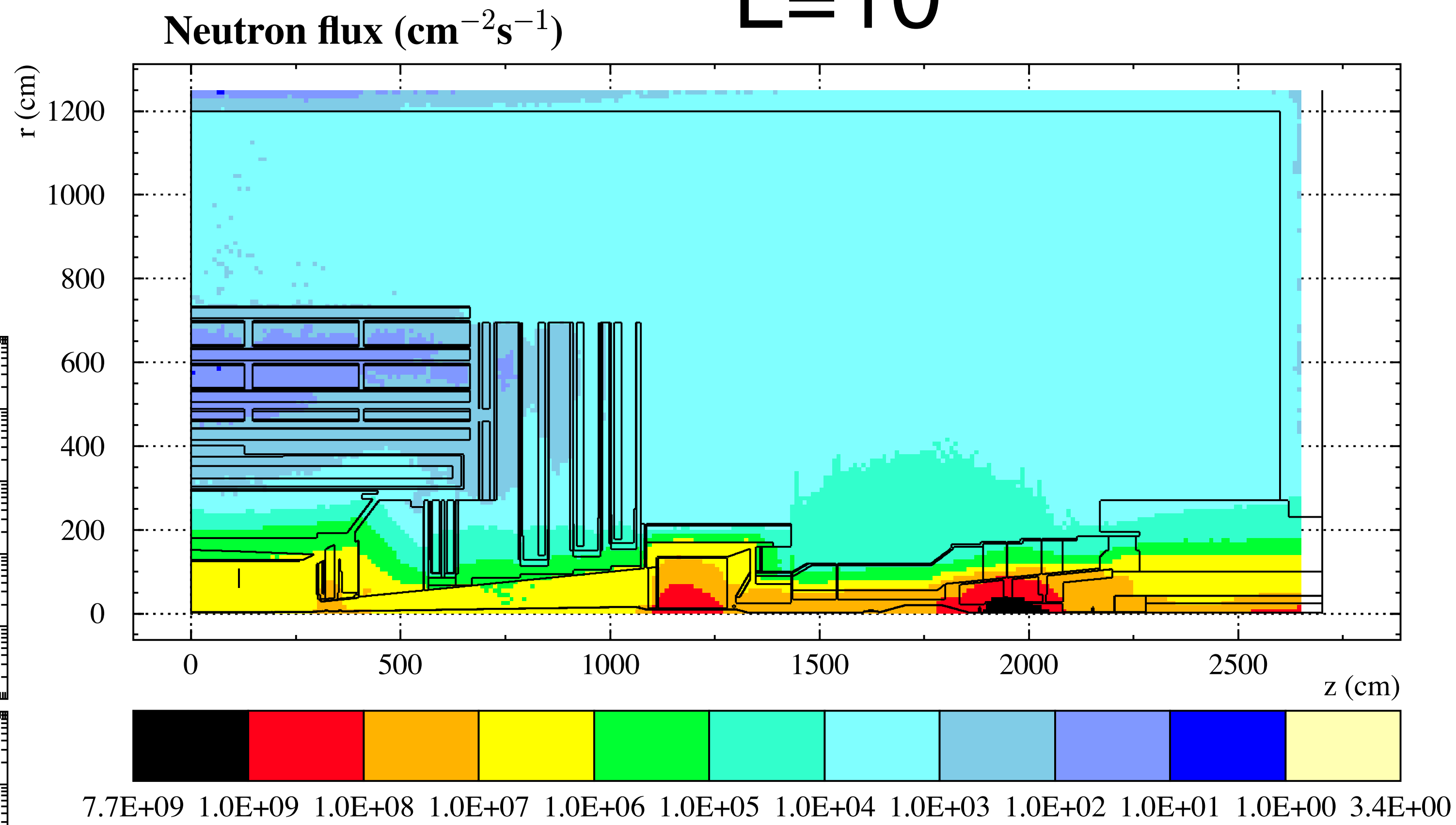


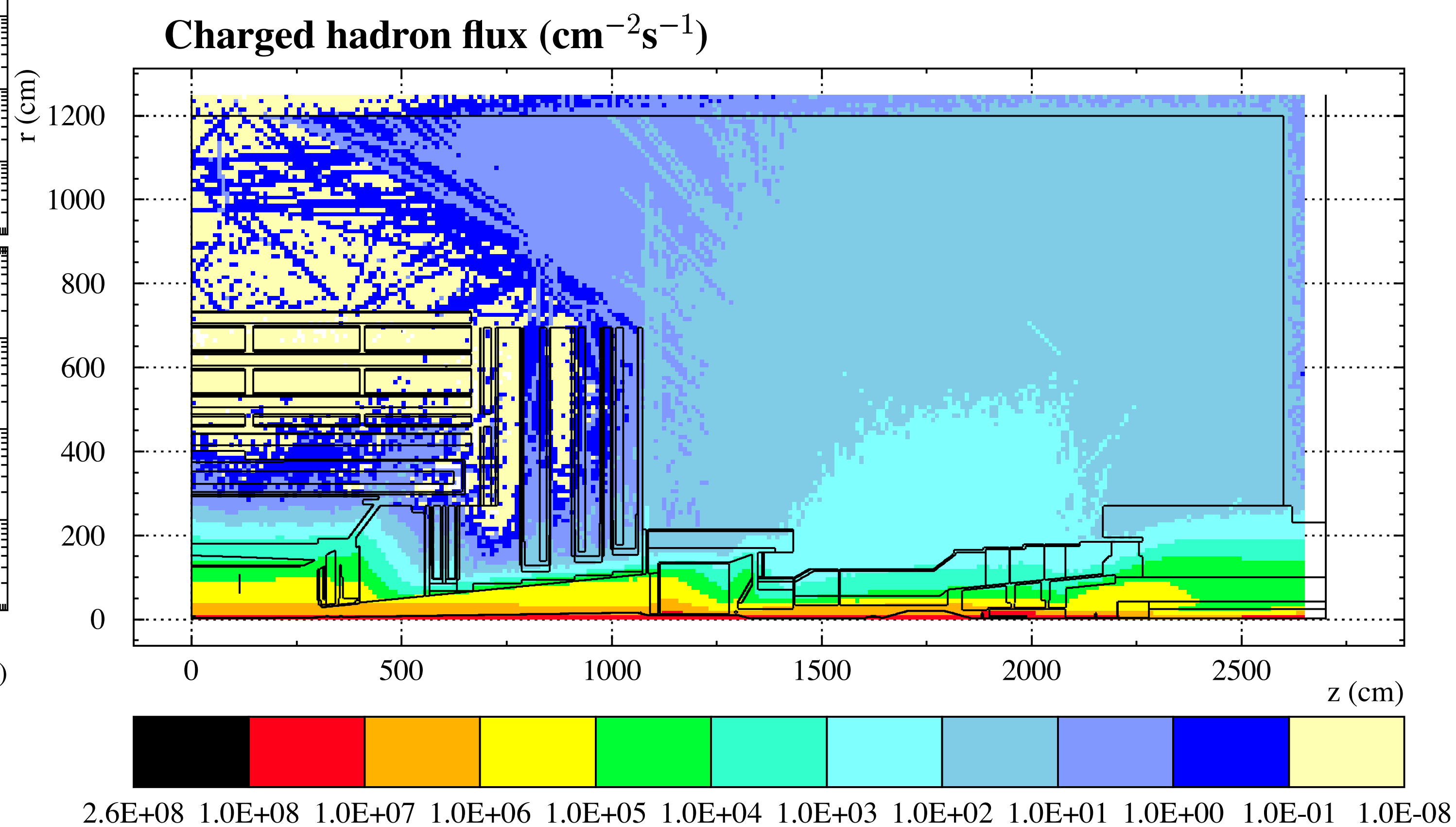
At nominal luminosity,
Fluxes 10^7 cm^{-2} s^{-1}

Radiation environment in CMS UXC

L=10^{34}

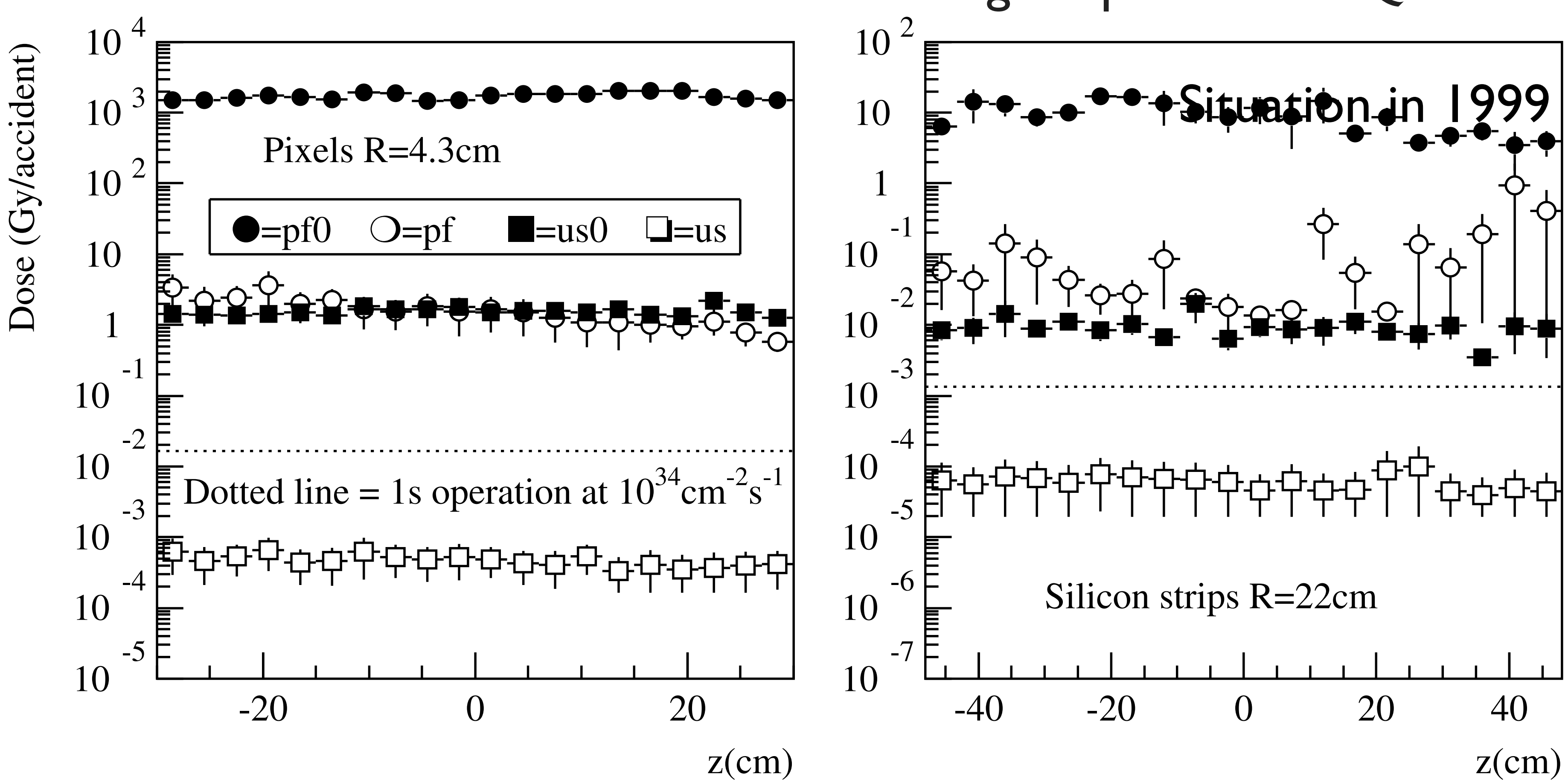
M.Huhtinen, June 2003)





Simulations: Possible Accident scenarios - Asynchronous ABORT

- Expected Scenario - kicker pre-fire not during ABORT gap
- CMS immediately downstream of dump (IP6) for beam 2
- A concern for CMS
- Original simulations showed potential for up to 12 bunches lost close to CMS, over 300 ns
  - Implies particle rates 10^8 higher than normal
  - Used as baseline for damage tests shown on tracker modules (ie all components for CMS tracker should be able to survive 1us of 10^8 higher than nominal rates)
- Since then TCDQ protective absorber added in IP6, and TCT in LSS5
  - Not realistic scenario now
  - There is a need to redo simulations to get realistic numbers
  - What is the realistic worst-case? eg misplaced TCDQ?



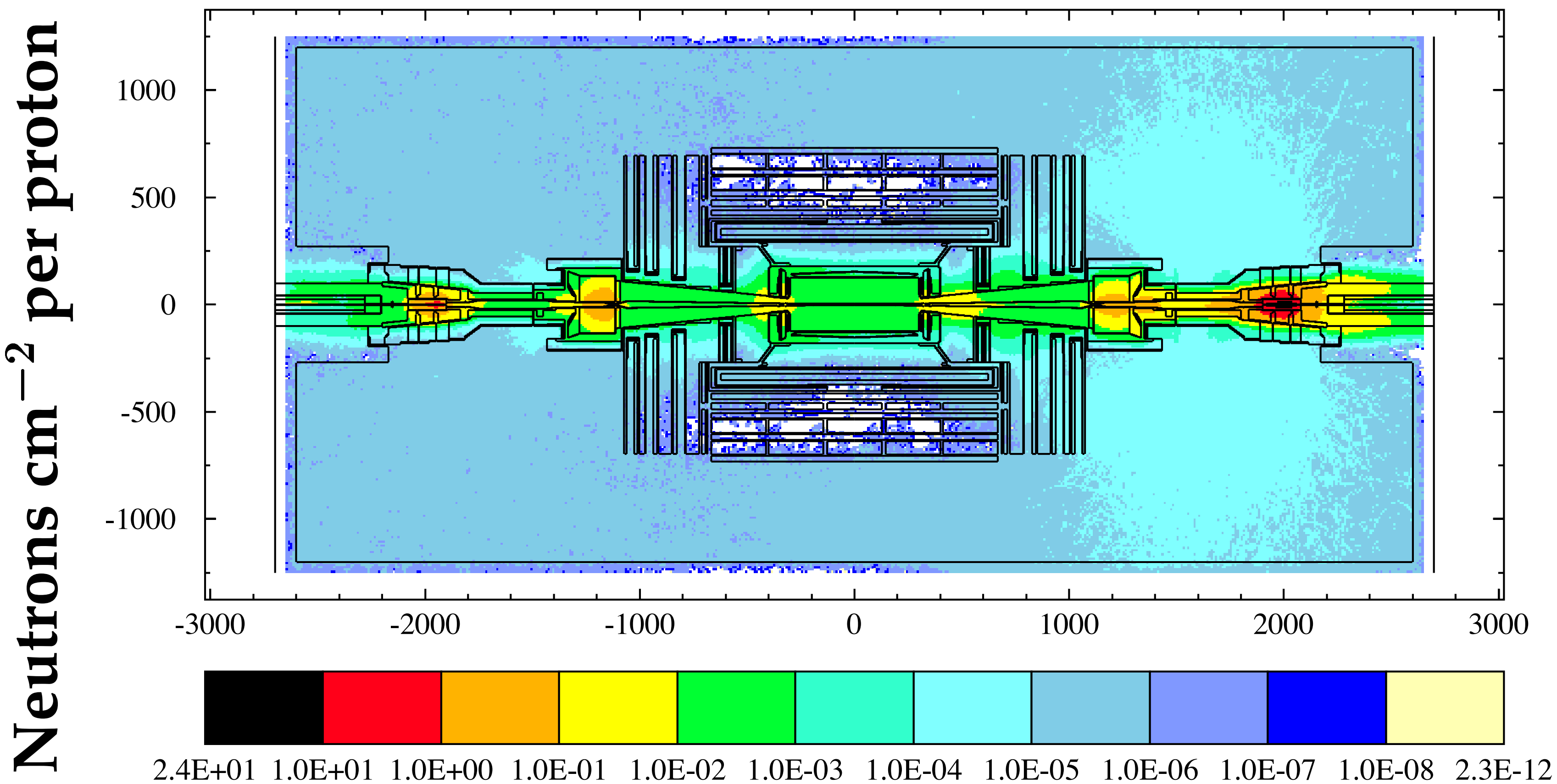
With addition of TCDQ and TCT, what is the situation now?

Simulations: Possible Accident scenarios - Injection Errors

- During injection (1st turn), possibilities for mis-steering greater:
  - Possible to steer bunches into CMS?
  - Onto the TAS?
- If so, what would be the maximum intensity possible
  - pilot bunch or nominal bunch?
  - More than 1 bunch possible?
  - Safe_Beam?
  - What are the timescales involved here?
  - i.e. what is the realistic worst-case scenario(s)?
- Input needed here to be able to perform simulations of realistic scenarios
- Some Concern over SAFE_BEAM level of 10^{12} protons

Simulations: Possible Accident scenarios - Protons on TAS

Neutron flux & dose from 7 TeV on TAS



Consider 7 TeV proton incident on TAS

Look at flux in CMS

Similarly for 450 GeV

Result: per proton incident on TAS, flux higher in cavern than asynchronous abort scenario

What about losses on triplets? On tertiary collimators?

Need for the simulations to provide typical particle species and energy spectra to be able to evaluate relative damage

Simulation strategy

- Simulations date from ca. 1999 (from Mika)
- Results need to be re-confirmed with:
  - New (as-built) geometry
  - New optics
  - Updated assumptions for realistic loss-scenarios

- Simulations also form an important input for the cross-calibration of the detectors monitoring conditions
  - Needed to understand relationship between measured rates and "true" fluxes at the pixels, tracker, etc
  - And vice-versa: to be able to benchmark the radiation field from data under accident scenarios to add confidence in the simulations

- Forward Pixel group are redoing simulations and damage tests on modules. Some time before final conclusions available.
  - No discrepancy in conclusions so far

CMS Strategy for Beam and Radiation Monitoring

- The Beam Monitoring should not be dependent on any particular loss-scenario
  - Try to be sensitive to any loss-topology
- Monitoring of conditions, in addition to active protection, essential to be able to provide post-mortem feedback
- As indicated previously, bursts of losses expected to be main danger to detectors
  - Emphasis on detectors that are relative flux monitors
  - But also measure absolute doses levels as well
- To simplify the interpretation of the loss data in LSS5, the monitoring is chosen to be as similar as possible to AB/BI equipment - use Beam Loss Monitor hardware
- The interface and communication between CCC and CMS control room, done with AB/CO tools and software (FESA+CMW)
  - In the main these are the tools used by the BLM group.

Beam + Radiation Monitoring Functionality

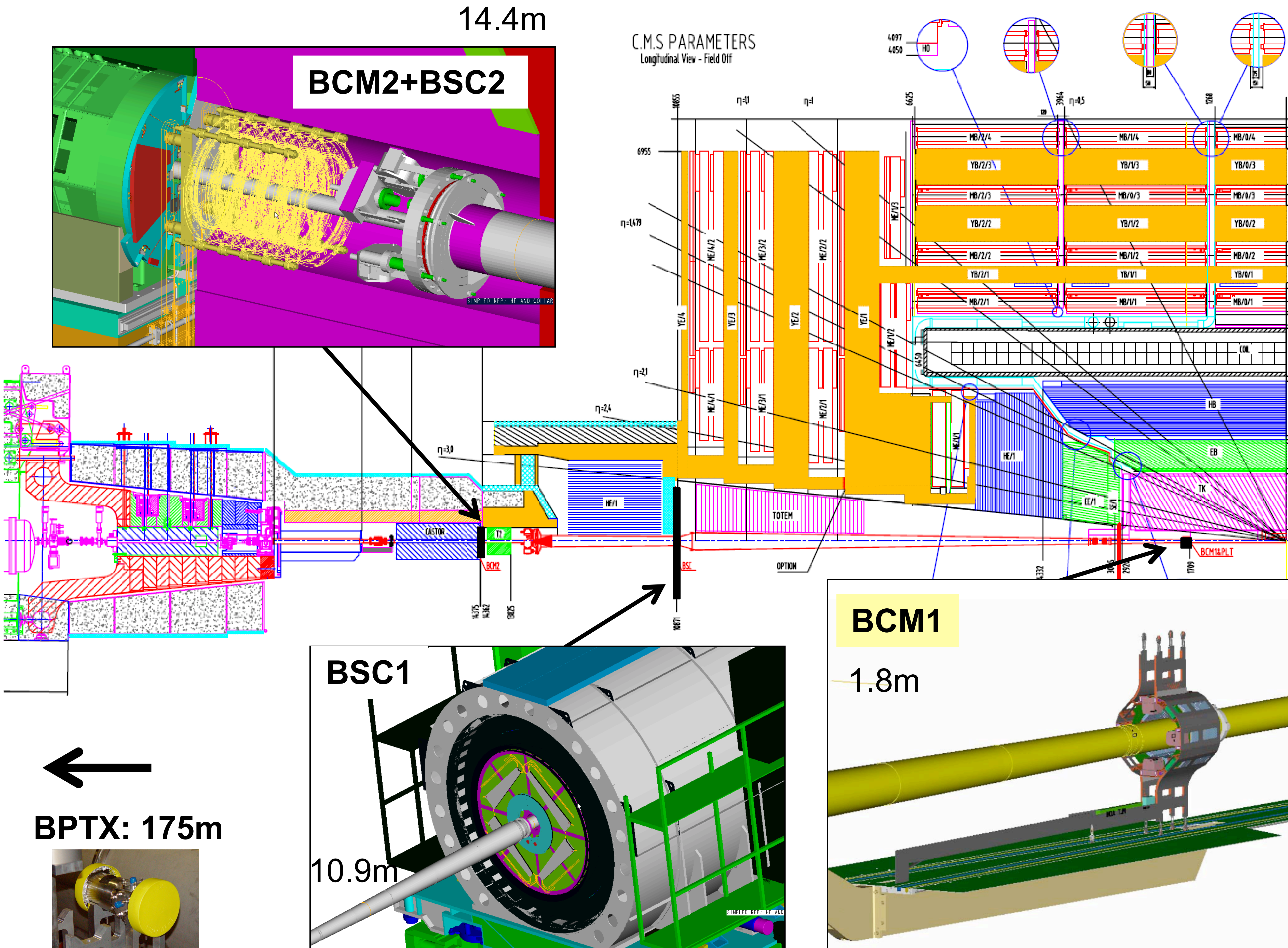
Provide monitoring of the beam-induced radiation field within the UXC55 cavern and the adjacent straight sections.

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

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

RADMON: 18 monitors around UXC



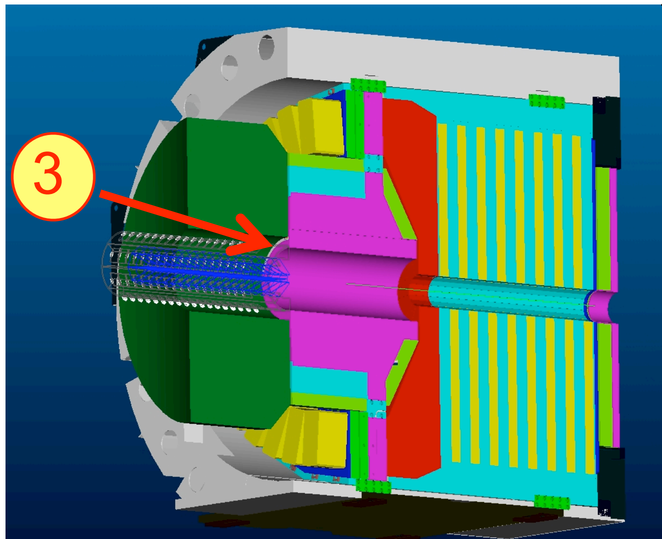
BRM Subsystem Summary

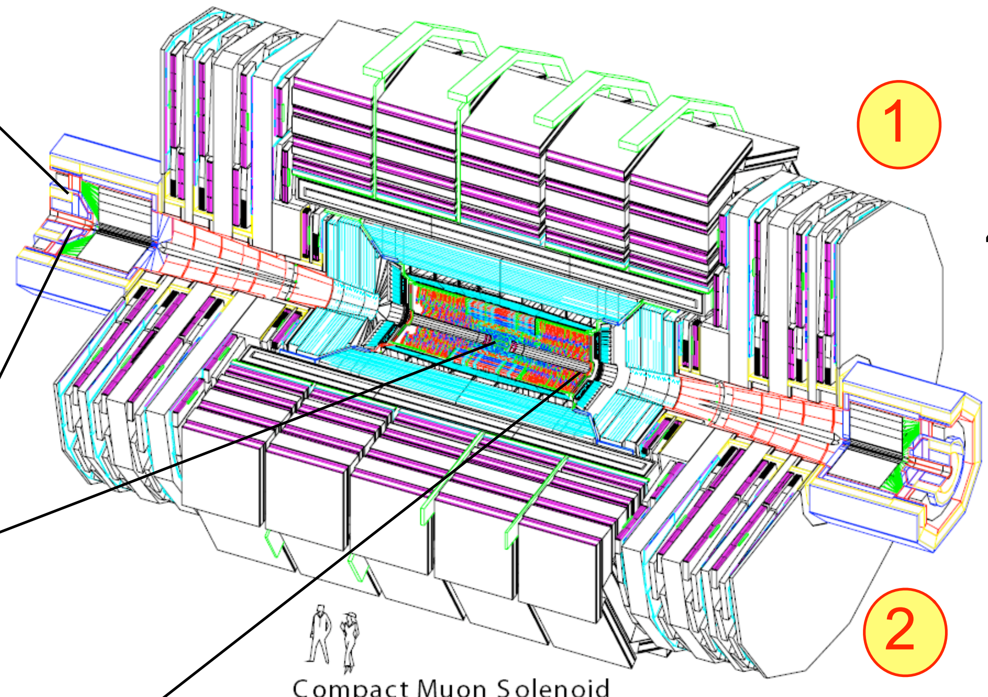
Subsystem	Location	Sampling time	Function	Readout + Interface
Passives TLD+Alanine	In CMS and UXC	Long term	Monitoring	---
RADMON	18 monitors Around CMS	1s	Monitoring	Standard LHC (FESA)
BCM2 Diamonds	At rear of HF 14.4m	40 us	Protection	Standard LHC (FESA)
BCM1L Diamonds	Pixel Volume 1.8m	Sub orbit ~ 5us	Protection	CMS + Standard LHC (FESA)
BSC Scintillator	Front of HF 10.9m	Bunch by bunch	Monitoring	CMS Standalone
BCM1F Diamonds	Pixel volume 1.8m	Bunch by bunch	Monitoring + protection	CMS Standalone

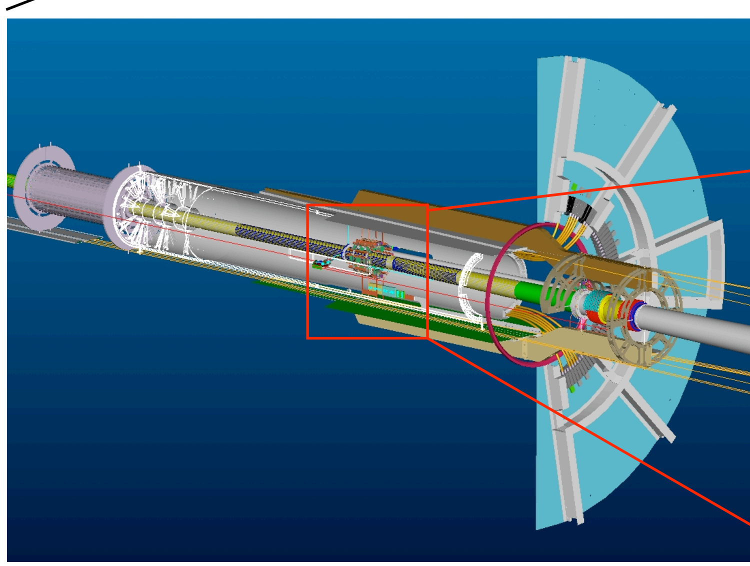
Increasing time resolution

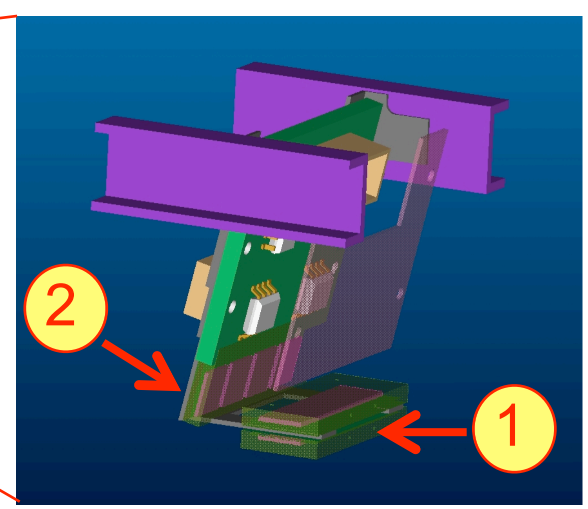
All online systems running when machine operational and possibility of beam in LHC
Systems are independent of CMS DAQ

BCM: Beam Conditions Monitors









CMS BCM Units

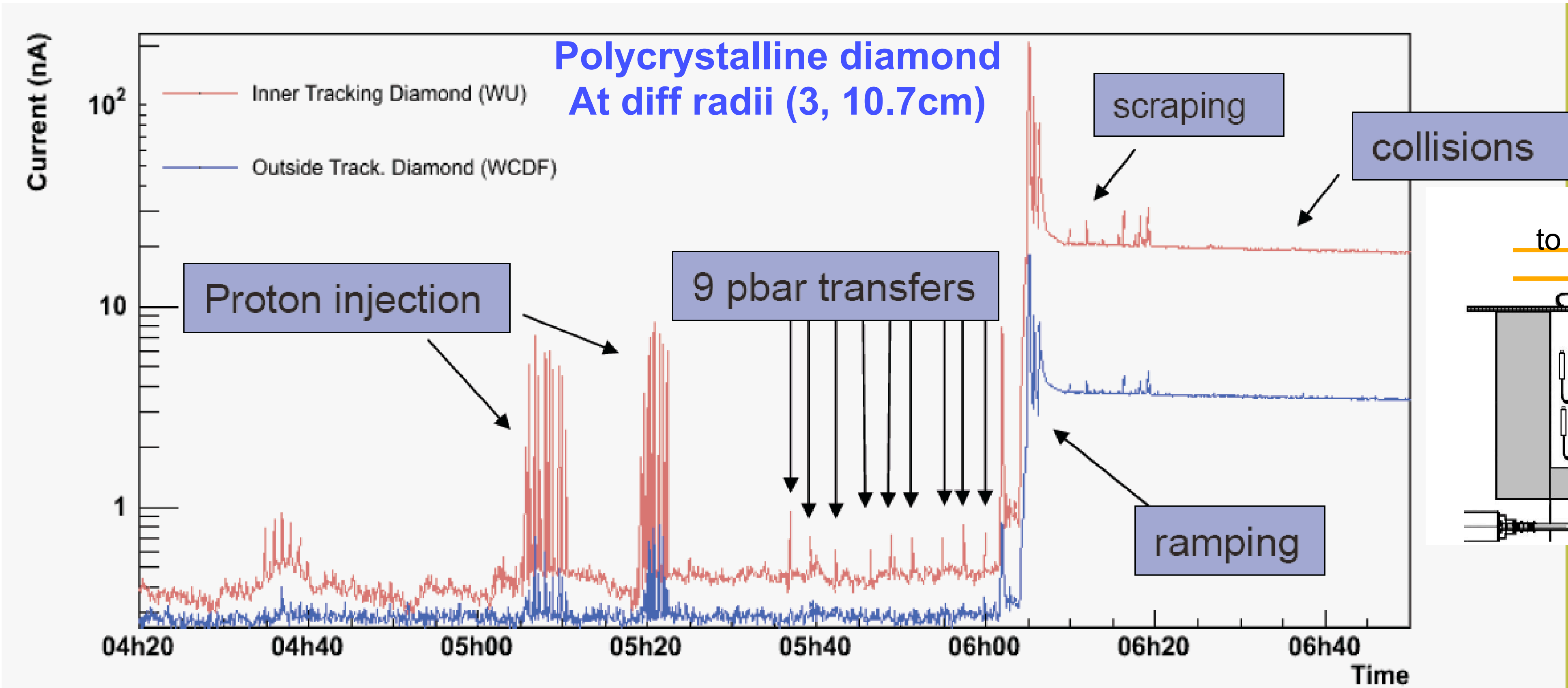
① **BCM1L: Leakage current monitor**
Location: z=±1.8m, r=4.5cm
4 stations in φ, 8 sensors total
Sensor: 1cm^2 PCVD Diamond
Readout: 200kHz / 5us
No front end electronics

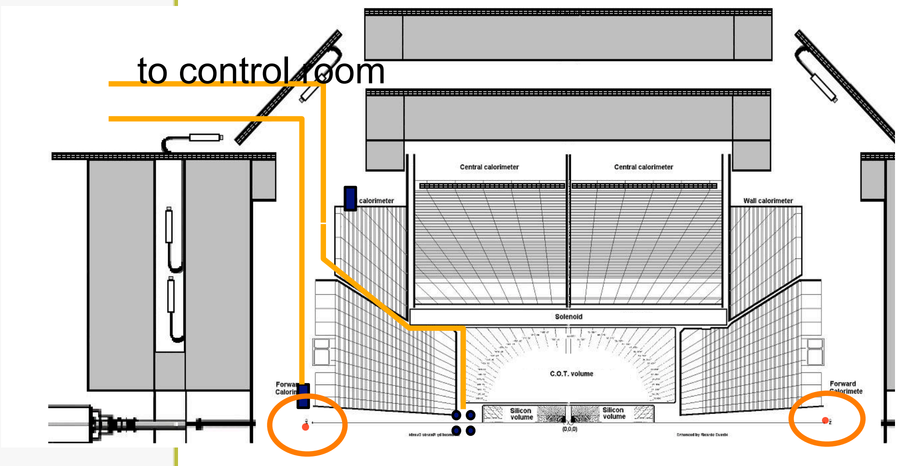
② **BCM1F: Fast BCM unit**
Location: z=±1.8m, r=4.3cm
4 stations in φ, 8 sensors total
Sensor: Single Crystal Diamond
Electronics: Analog+ optical
Readout: bunch by bunch (Asynch)

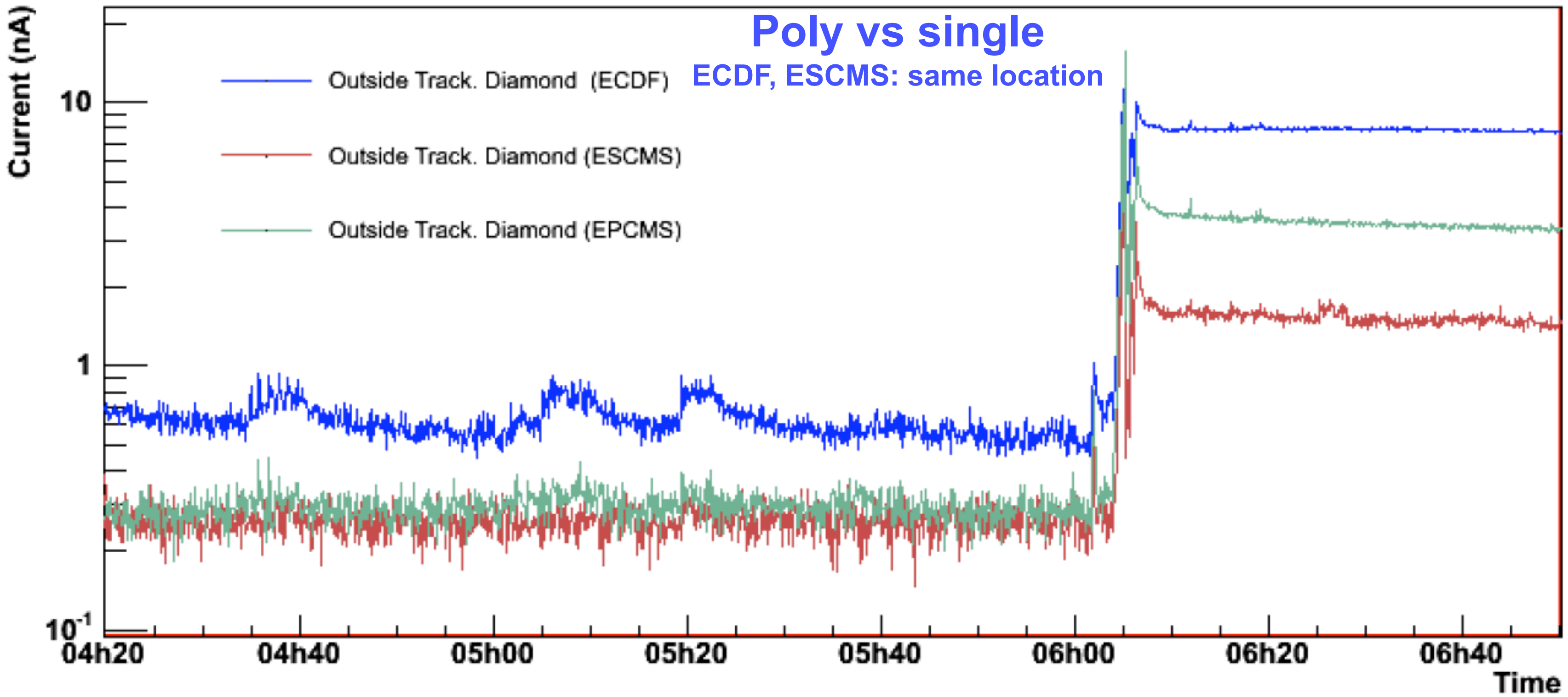
③ **BCM2: Leakage current monitor**
Location: z=± 14.4m, r=29cm, 5cm
8 stations in φ, 24 sensors total
Sensor: 1cm^2 PCVD Diamond
Readout: 25kHz / 40 us
16 Sensors shielded from IP
Off detectors electronics

2 Sensor Locations, 3 Monitoring Timescales

Example: CMS BCM Sensors in CDF- Online Monitoring Plots

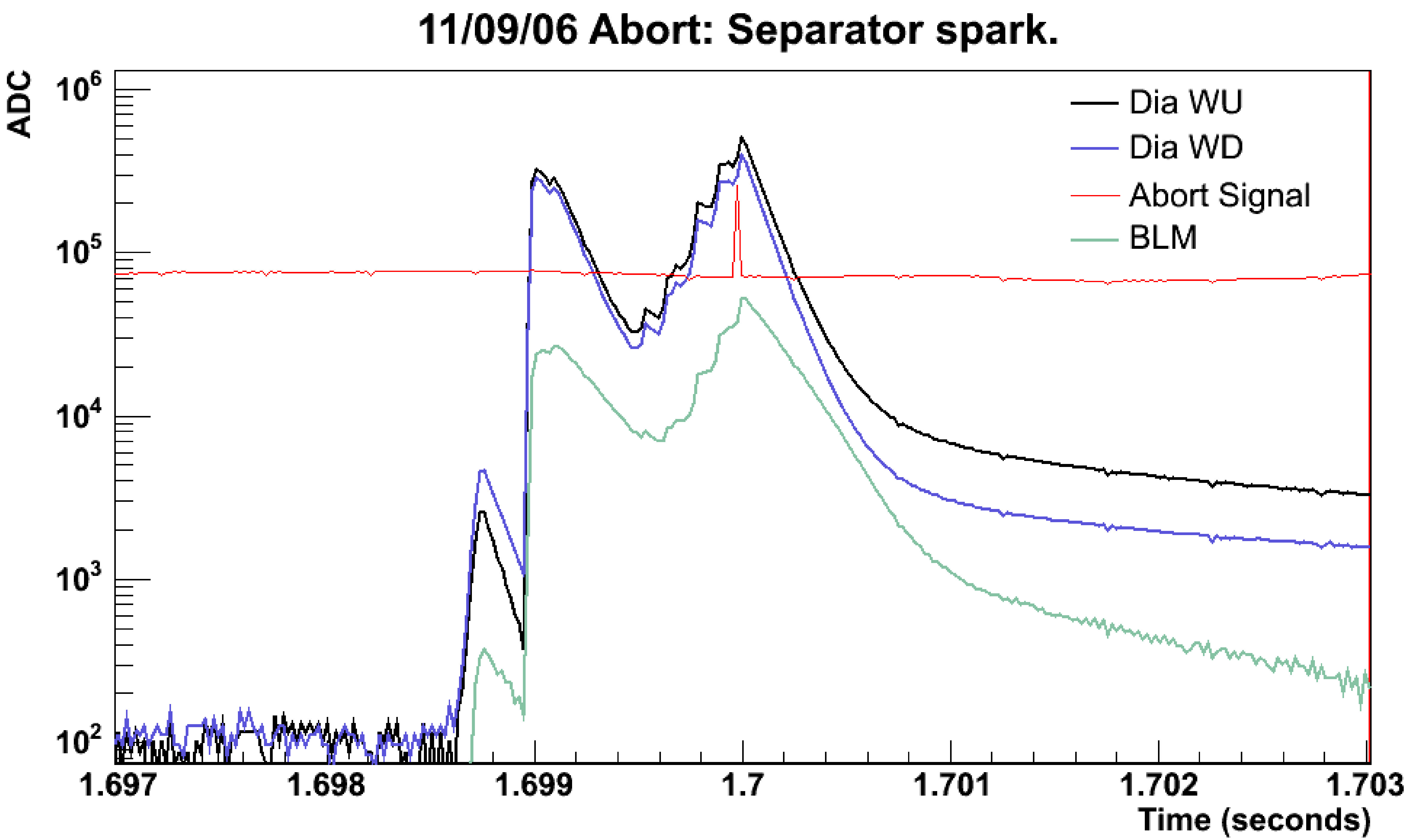






CMS BCM Sensors in CDF:
- Sensors + electronics in realistic hadron collider environ
- Cross calibrate with existing CDF beam monitoring (BLM and diamond based)
- **Uses 20us Sampling**

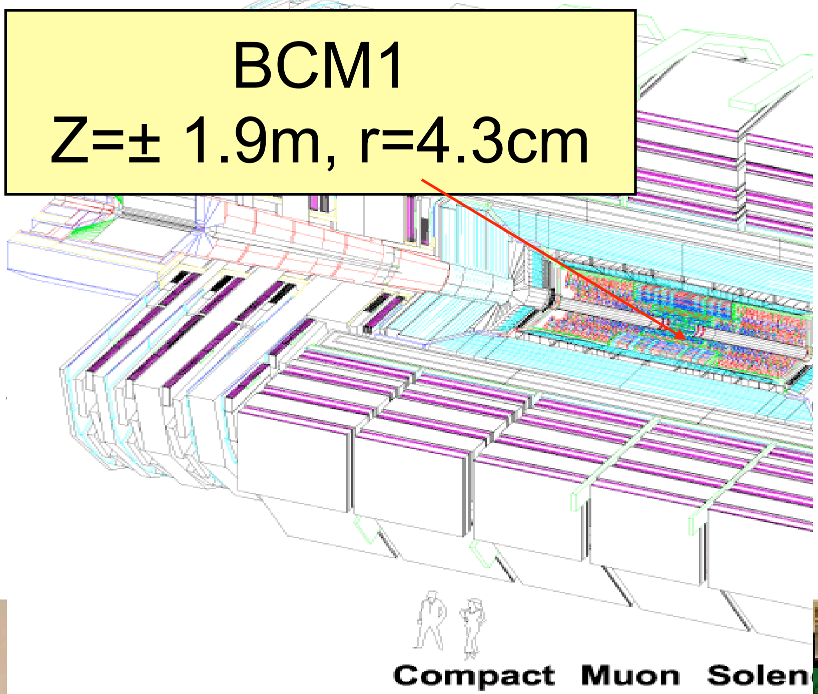
Example: CMS BCM Sensors in CDF- Online Monitoring Plots



Resolving time structure of the spark(s).

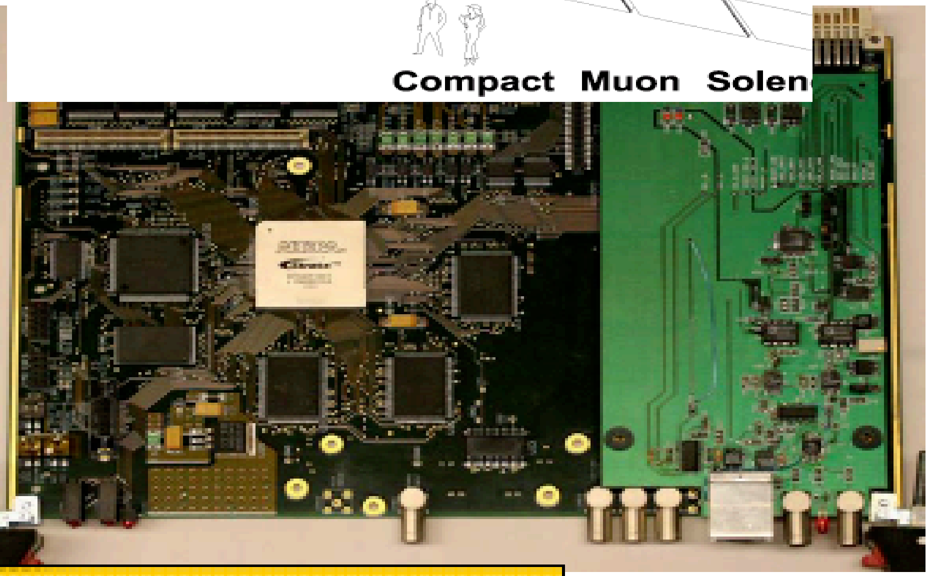
BCM1L: Leakage current monitoring

BCM1
Z=± 1.9m, r=4.3cm

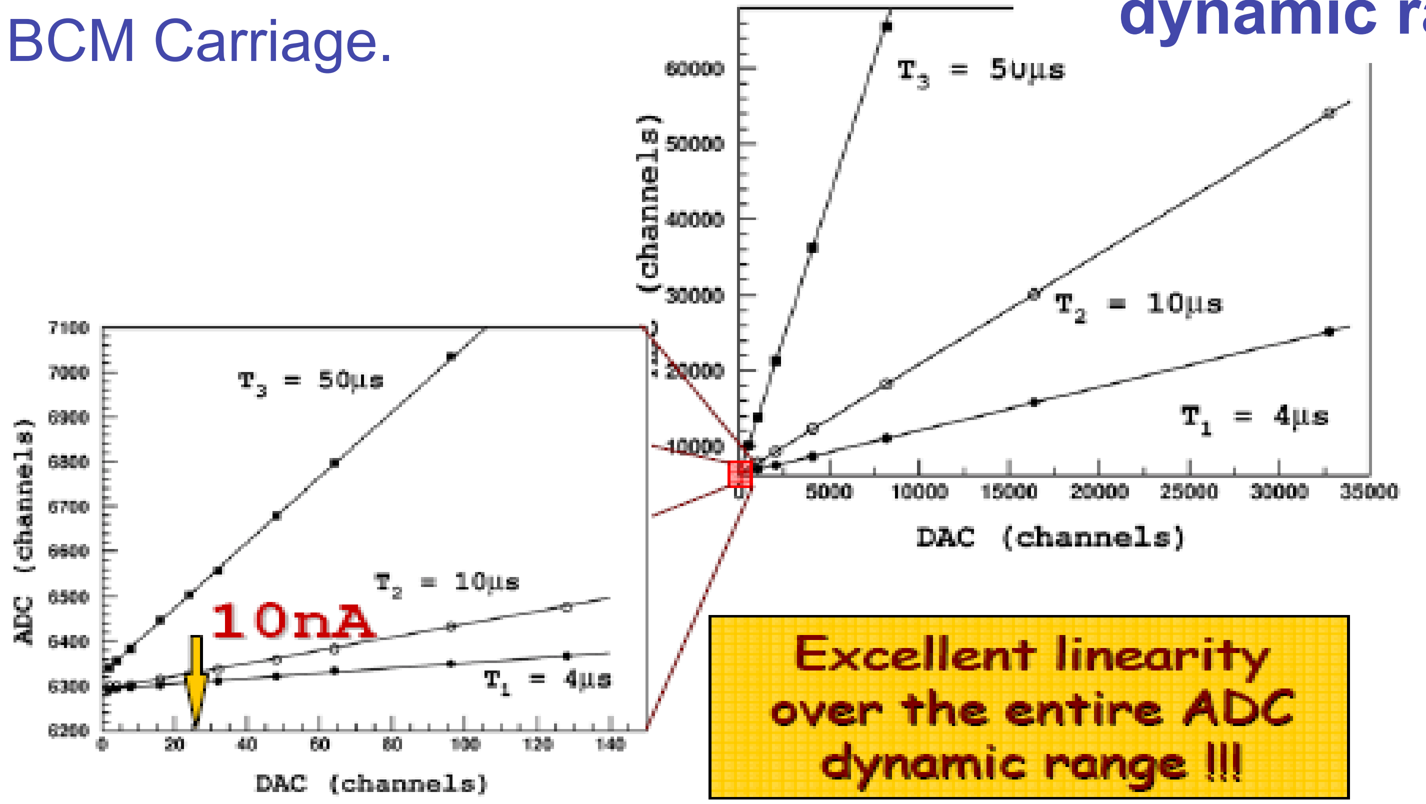


- Next to Pixels, ~ 4 cm in r from beam
- Consists of 4 units mounted on the BCM Carriage.

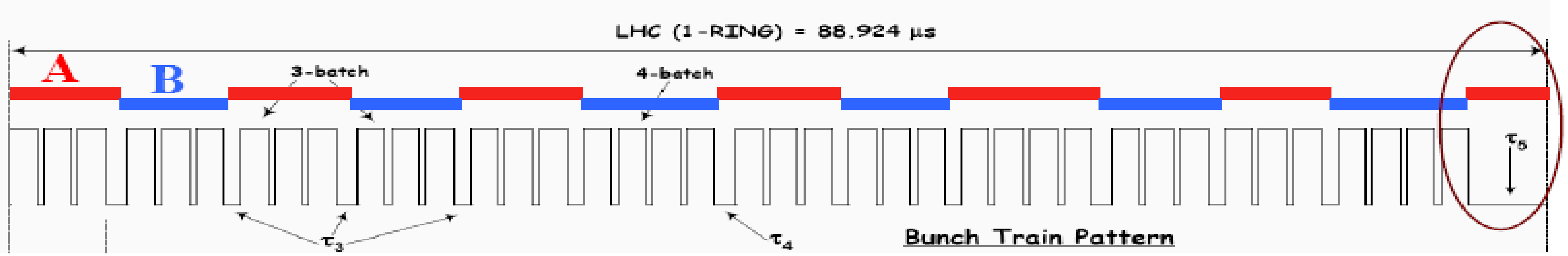
Linearity over the entire ADC dynamic range



Prototype board



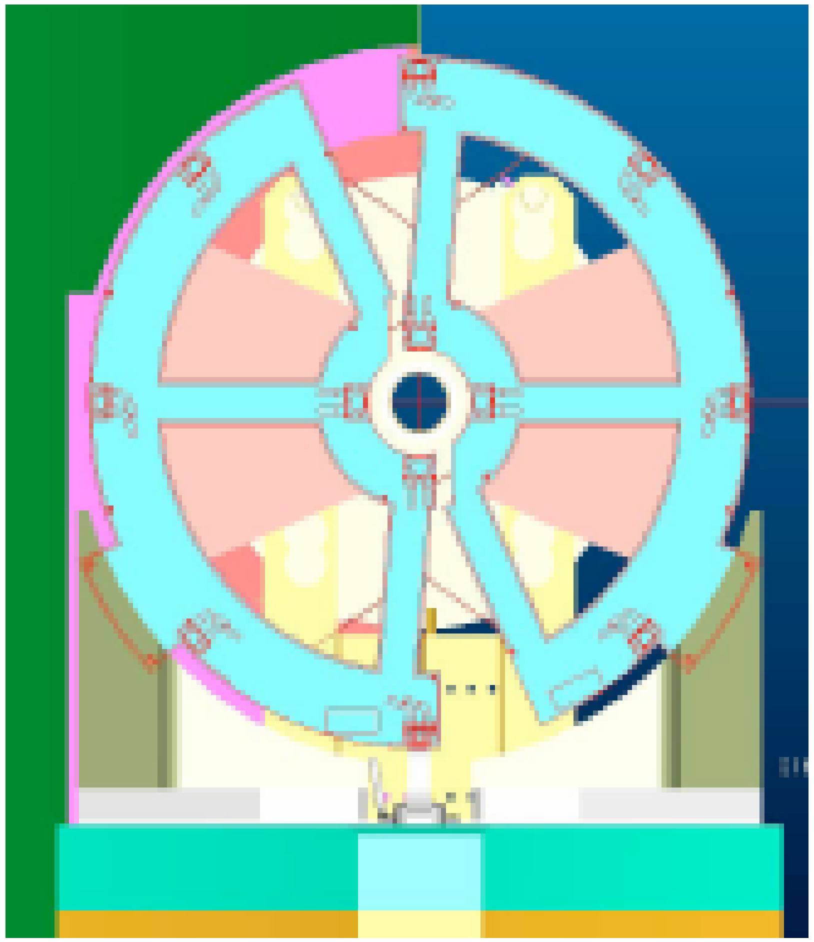
Excellent linearity over the entire ADC dynamic range !!!

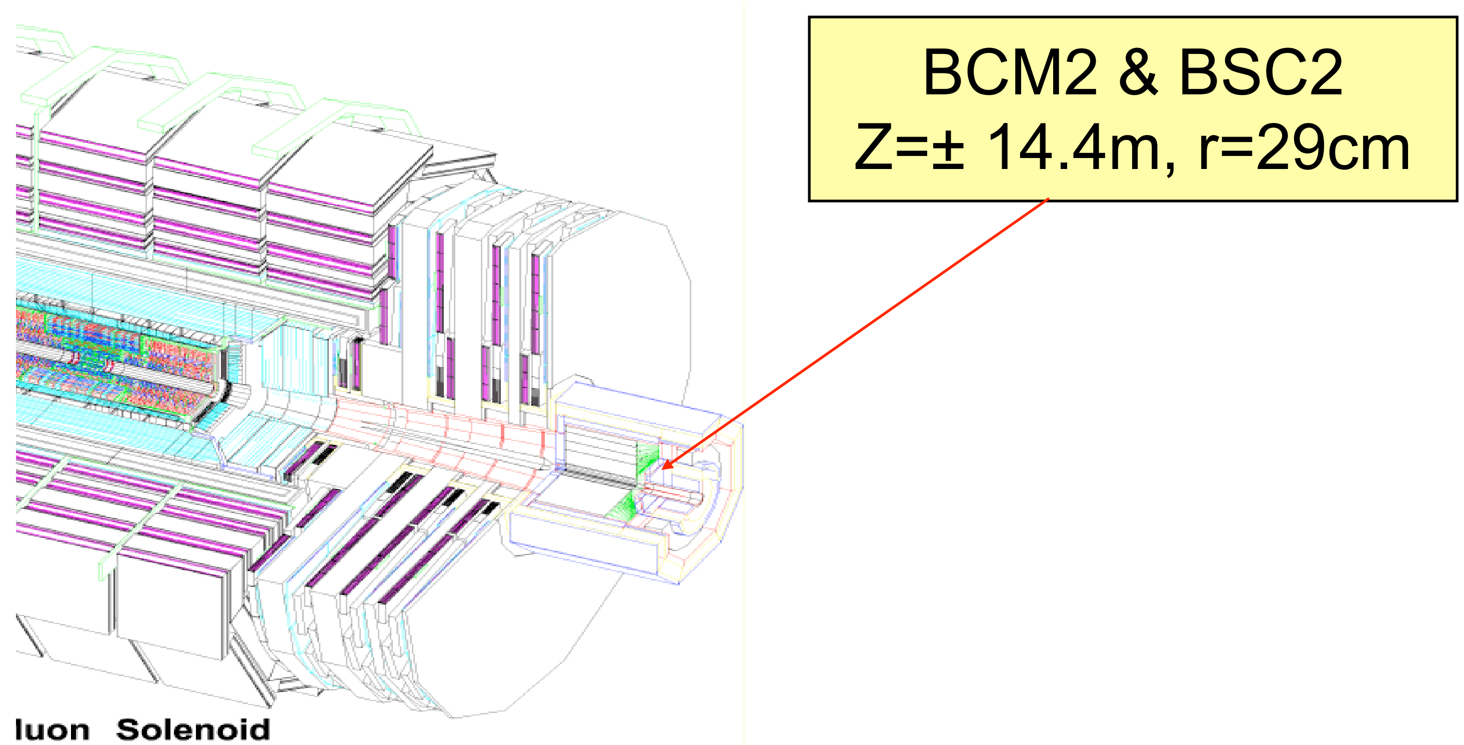


Synchonized sampling over LHC Bunch train structure and abort Gap

BCM1_L board tested using BLM style readout chain (DAB cards/FESA)

BCM2





- Inner Diamonds sensitive to luminosity products
- Outer diamonds sensitive to incoming background (shielded from IP)
- Standard BLM readout
  - Diamonds Frontend readout via Tunnel Card
  - Backend Readout DAB64 cards, FESA

- BCM2 sensors profile
  - 8 on outer ring
  - 4 on inner ring

CMS inputs into the BIC

CMS inputs into the BIS via CIBUs

- 1 Detector CIBU located in the USC55. This is an unmaskable input
- 1 Magnet CIBU role/functionality yet to be determined
- TOTEM has its own CIBUs

Input into the detector CIBU

- Inputs generated from CMS BCM system
  - Readout and alarm setting based on the BLM system
  - Input to CIBU via standard BLM combiner card
- Input into CIBU 100% hardware => immune to network problems
- Input to CIBU available whenever Machine power available

ABORT and Post-mortem reporting

- Done in exactly the same way as for BLM system
  - Any one channel above threshold fires the abort
  - CMS has 32 front end channels that input into the BLM Combiner card
- Thresholds configurable as per-BLM
  - Similar thresholds expected for pre-commissioning period
  - Clear understanding of thresholds expected due to cross-calibration measurements of BCM/BLM

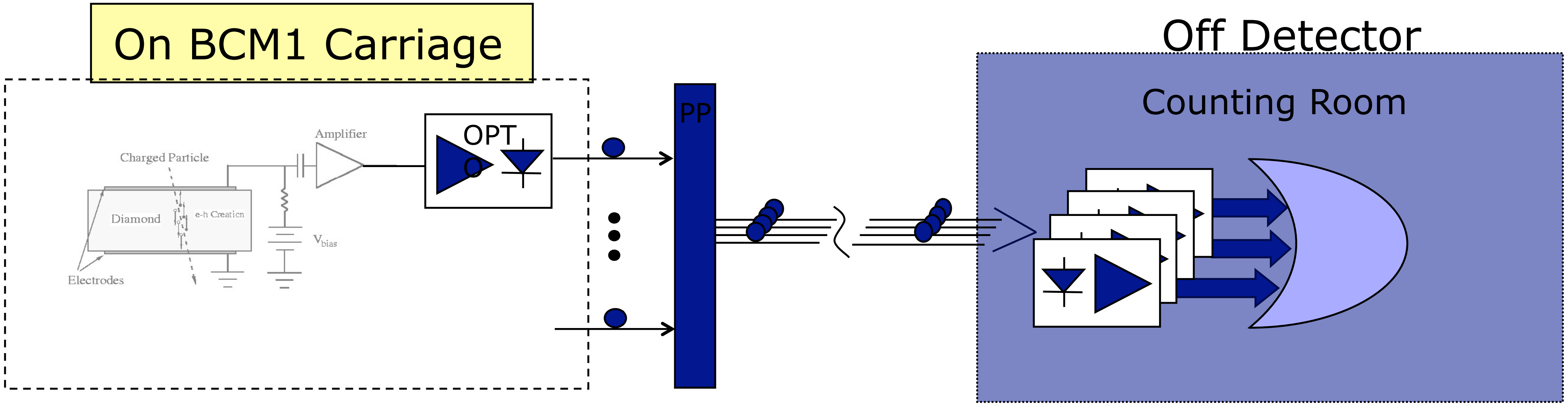
ABORT Thresholds

- Dependent on: Machine Mode + Energy + Measurement time (range us - s)

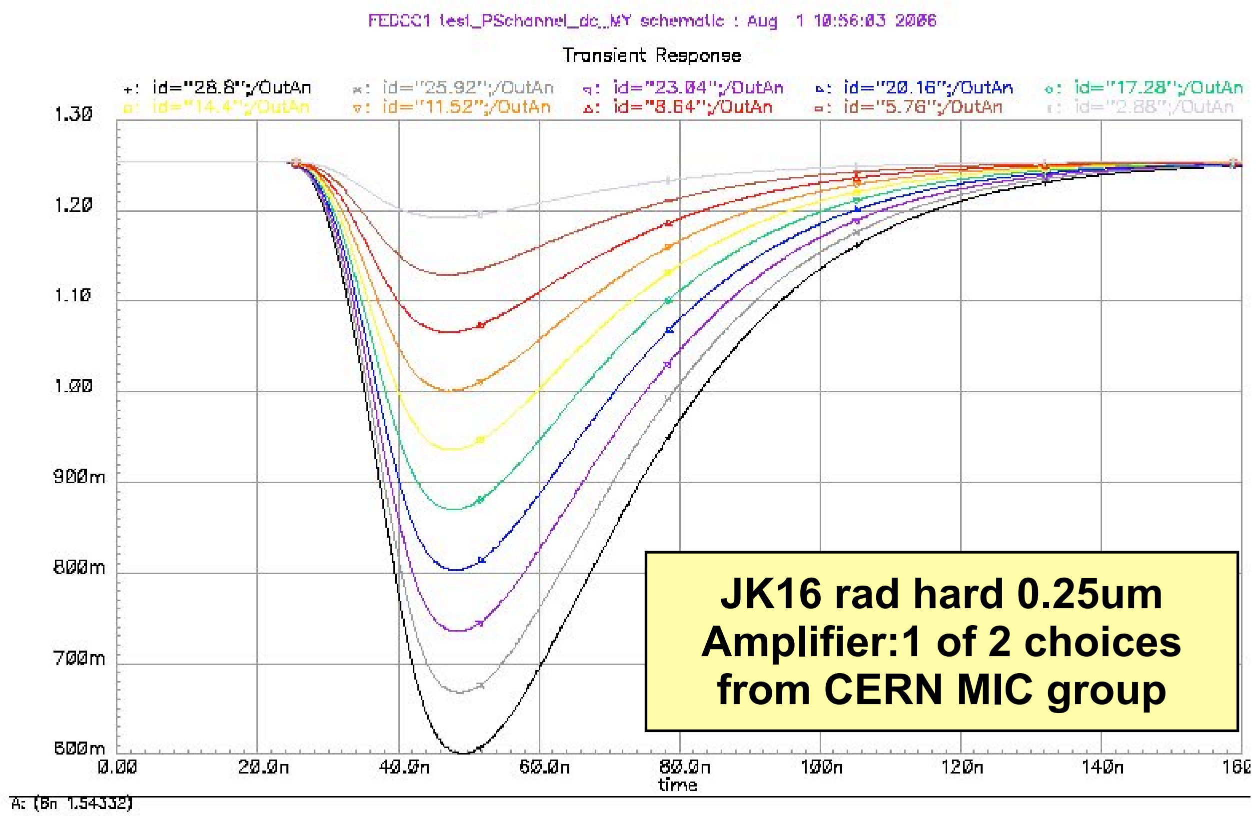
CMS wishes to set thresholds for the ABORT from Day 1

Threshold setting to be done in close collaboration with BLM group and CCC

BCM1F: Bunch by bunch monitoring



Simulation results for 1 to 10 MIP signals



JK16 rad hard 0.25um Amplifier:1 of 2 choices from CERN MIC group

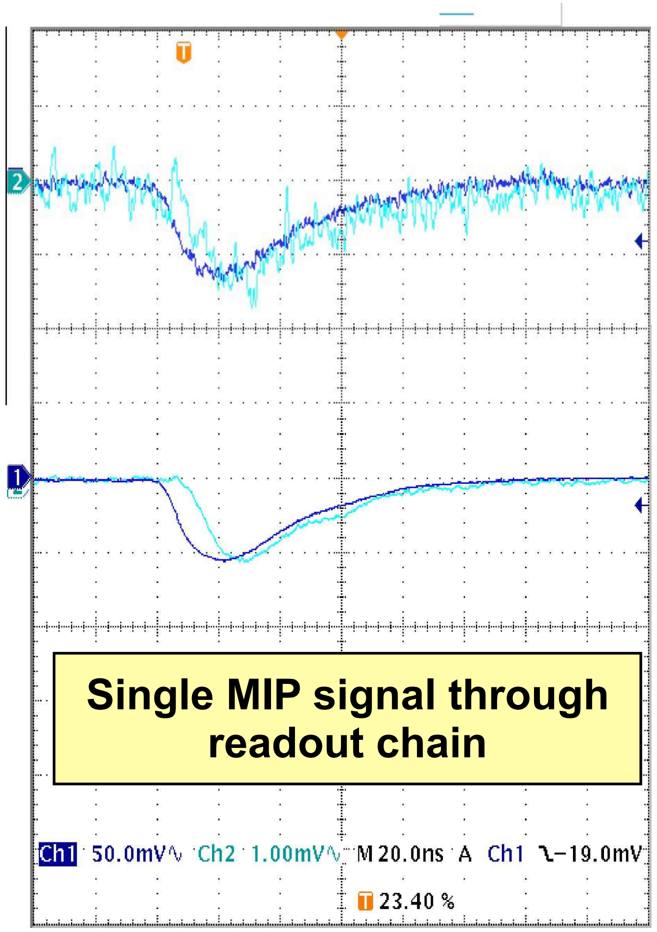
Need single MIP sensitivity

1 proton on TAS: 10^{-10} Gy/p

Normal pp at 10^{33}: 0.002Gy/s

100ns sampling => sensitive to loss of >2 protons on TAS

Tested against damage from unsynchronized beam aborts



Single MIP signal through readout chain

3fC response
JK16(Ch.1) and AOH (Ch.2)

Proof of principle for BCM1F readout chain
Tested with final design sensor

CMS Beam Scintillator Counters

- ✓ Simple standalone system: No front end electronics
- ✓ Simple to commission
- ✓ Monitoring Independent of CMS DAQ status

Readout:

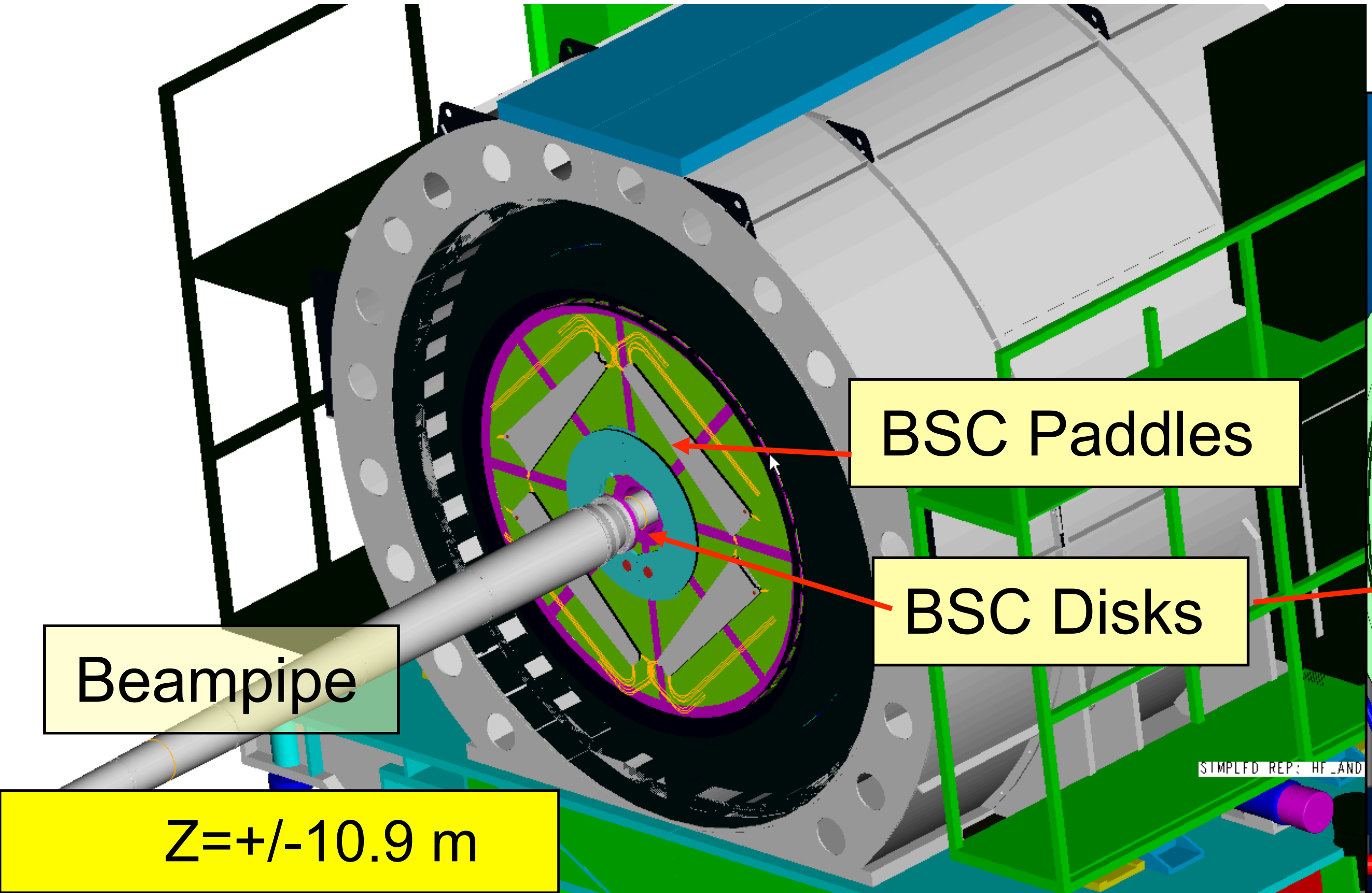
- PMTs mounted on side of HF, readout over long cables (80m) to USC.
- ADC & discriminator + TDC readout
  - Same back end as BCM1F

✓Output to CMS (+CCC?): statistical measurements

- Rate monitoring on sub orbit scales + bunch by bunch, inc. Abort gap monitoring
- Relative time measurements: incoming vs outgoing particles
- Should be sensitive during 450 GeV + pilot beam

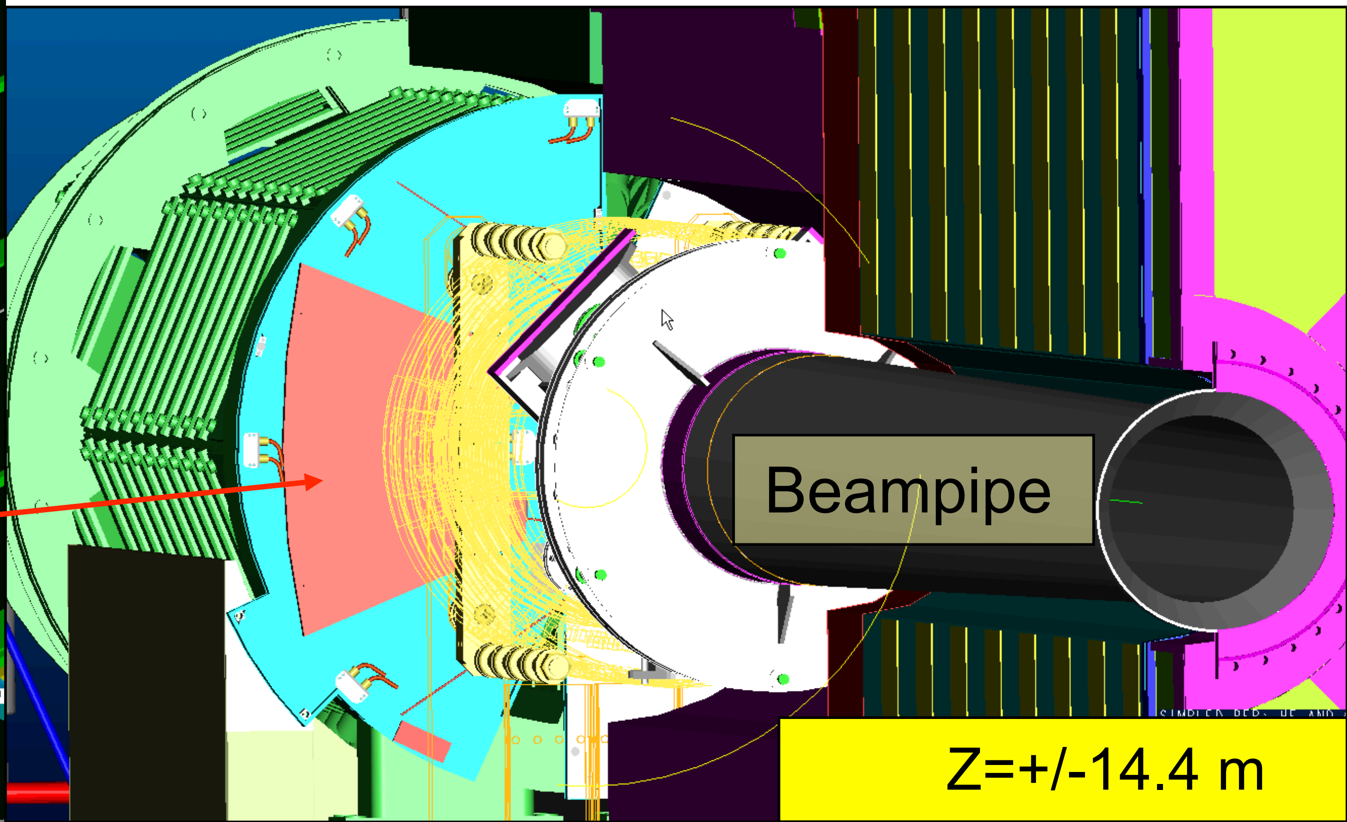
BSC1 --- 11 000 cm^2

Inner radius - 15 cm



BSC2 --- 1 000 cm^2

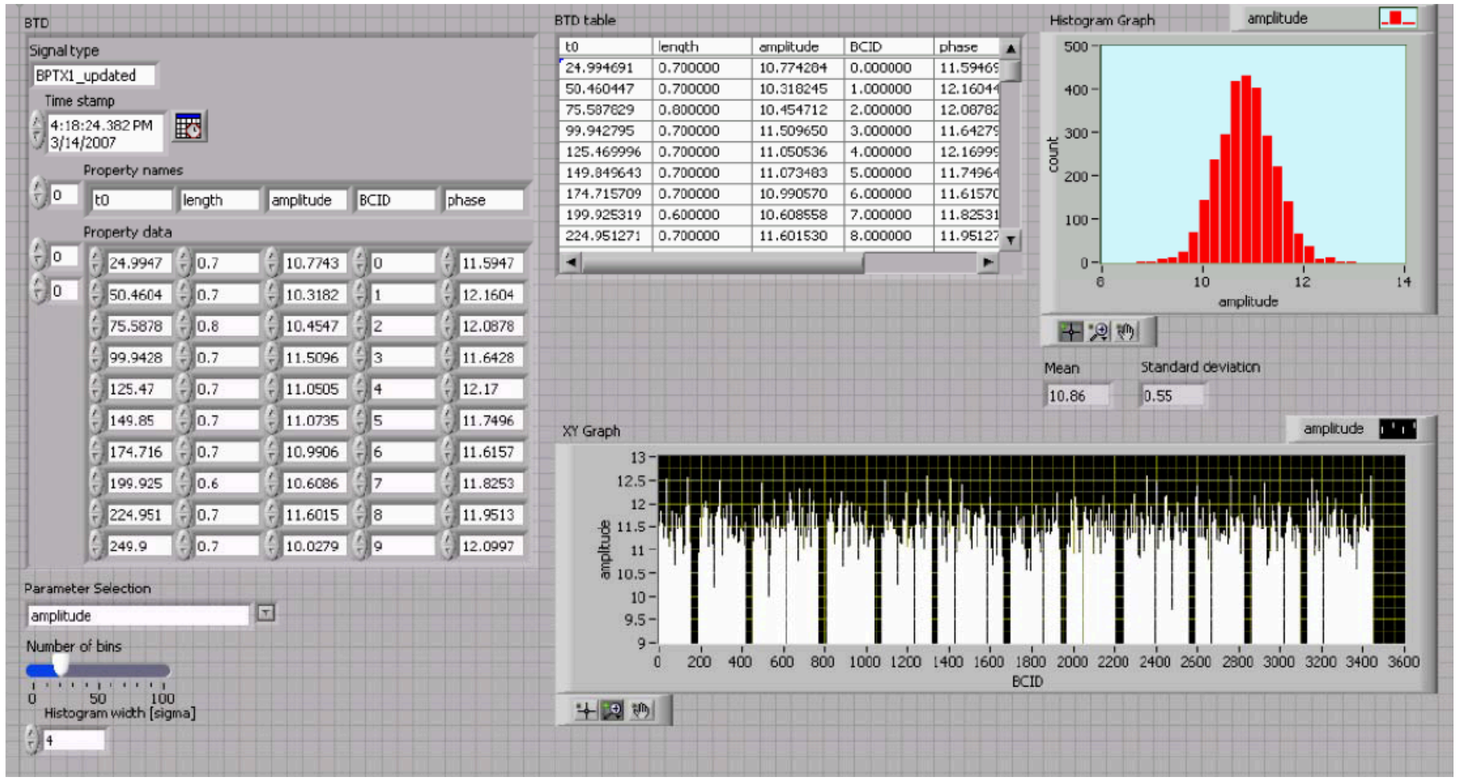
Inner radius - 5 cm

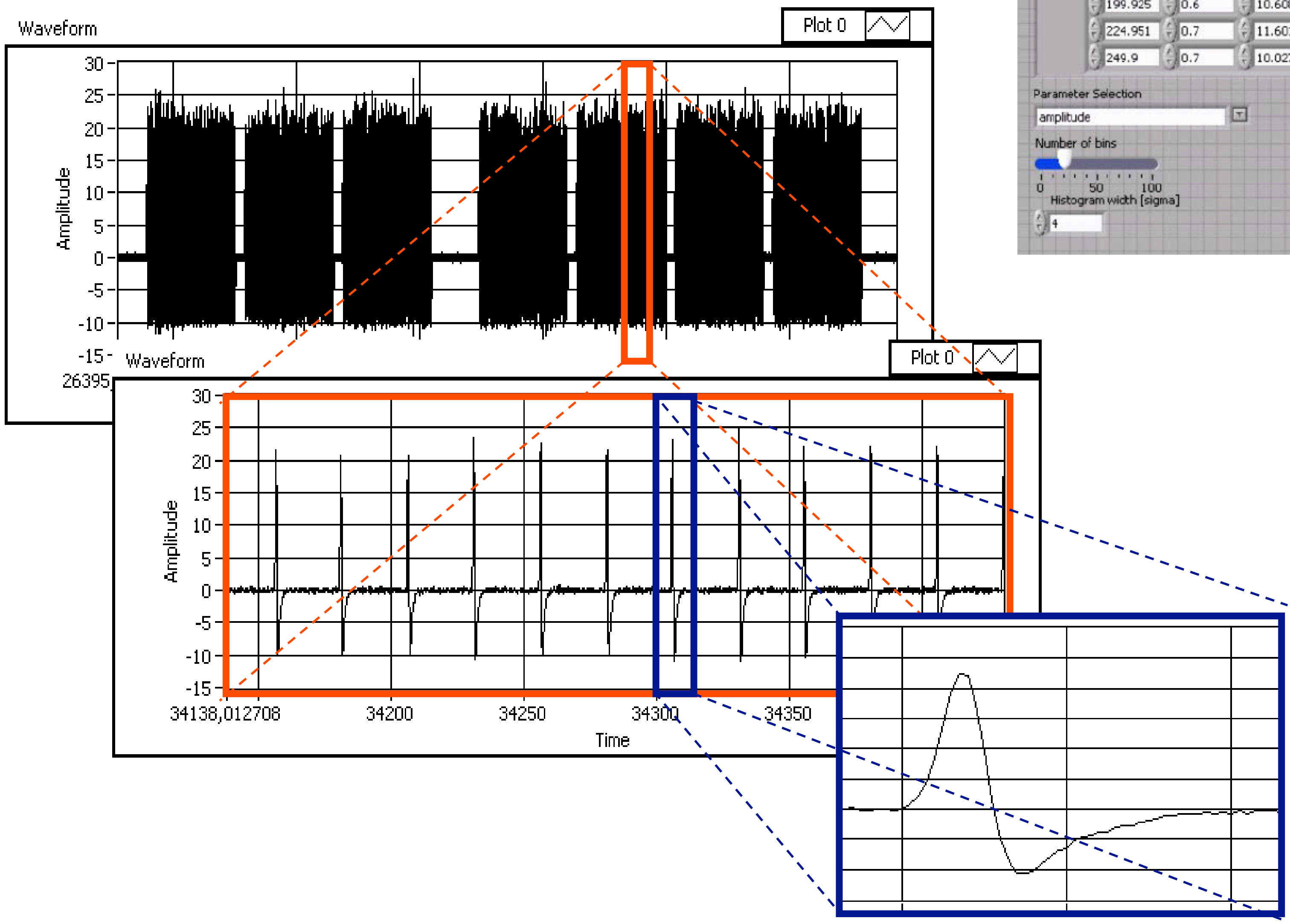


BPTX Readout

Scope based readout with stand alone readout+ technical trigger input
Same solution as ATLAS

Button electrodes sensitive even to first beam (2x10^9 per bunch)





Analog Signal: ~1ns FWHM

Orbit length= 89us

Samples entire orbit
Sampling at 10GSamples/sec

=>100ps sampling

Realiability, Efficiency and Availability of Beam and Radiation Monitoring

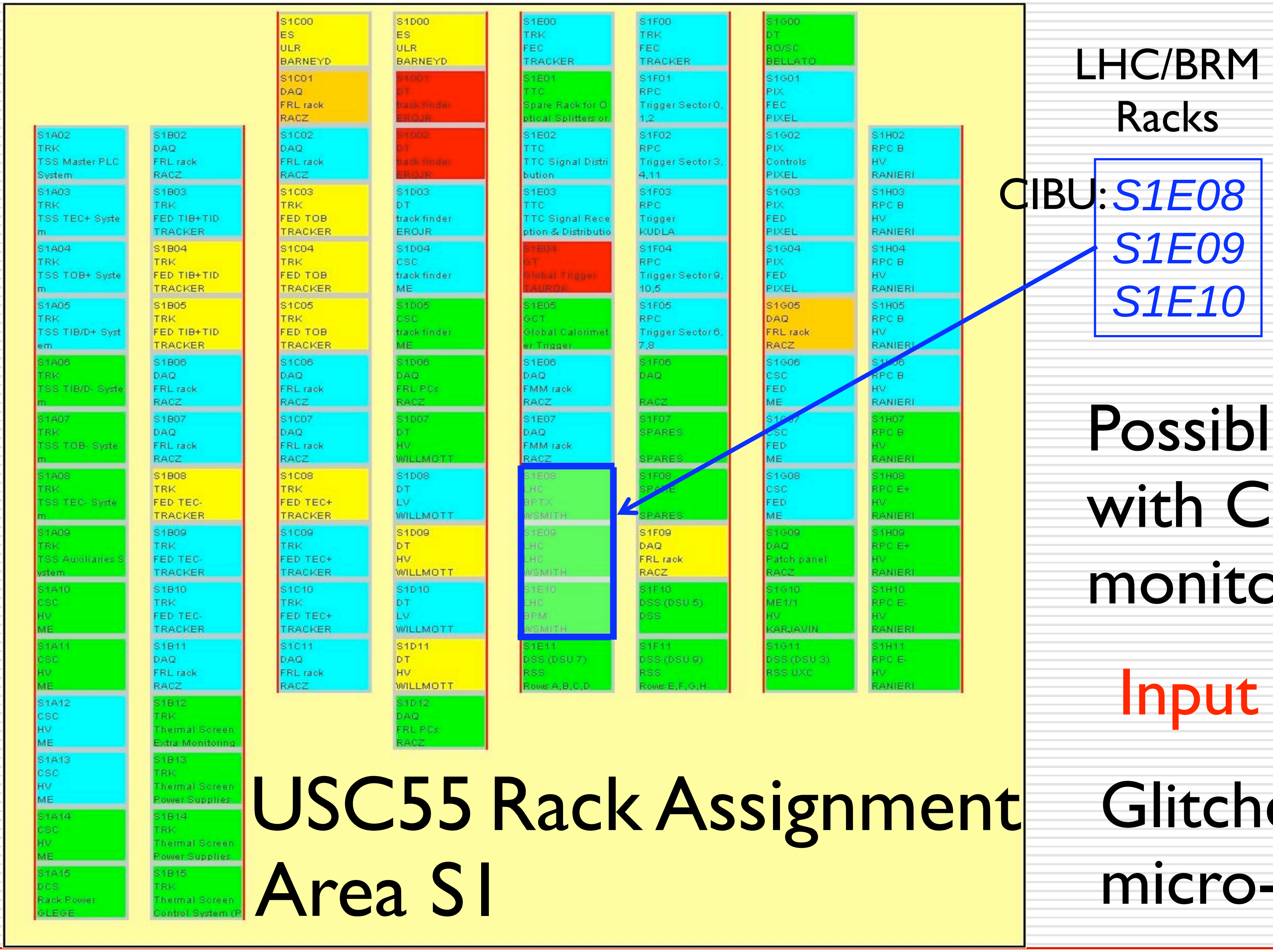
- Reliability:
  - Readout electronics for the inputs into the CIBU is almost exclusively LHC BLM
  - High reliability expected
- Efficiency:
  - Highly Redundent system
  - BCM1_L + BCM2 : 8 + 24 diamond sensors
  - Monitoring has similar redundancy built-in
- Availability:
  - CMS requires that the BCM is active in the ABORT, whenever there is the possibility of beam in the machine
  - Operational even when CMS is not
  - 100% by definition

Operational Procedures - Request

- After an ABORT has been issued, CMS will send to CCC and analyse itself post-mortem data from all monitoring systems to determine whether there were significant losses close to CMS cavern
- CMS wishes to hold BEAM_PERMIT off until CMS' post-mortem analysis is complete:
    - Confirm that there were no significant losses close to Pt 5.
    - In the event of significant losses, help to understand the loss with the CCC, to try and avoid its reoccurance
- BEAM_PERMIT will be re-asserted by the CMS shift leader
    - Typically this should be quick, and cause no operational delay
- Will look to try and formalise this request through LEADE

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



CMS investigating using machine power for BRM.

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

Input to ABORT still active

Glitches dealt with by micro-UPS

Open Issues from CMS

- Short bursts of losses are the main concern
- Updated simulations needed (with updated scenarios)
  - List of concievable failures?
- In case of ABORT failure, what are the worst cases for losses on TCT/Triplet/TAS in LSS5?
- What is the realistic worst case scenarios at injection?
- Some concern over SAFE_BEAM level of 10^{12} p
- CMS wishes to examine Post-Mortem data before re-asserting BEAM_PERMIT
- Powering for systems connected to CIBU