CMS Beam and Radiation Monitoring

Richard Hall-Wilton (CERN - TS/LEA)

On Behalf of CMS and the CMS Beam Conditions and Radiation Monitoring Group

LHC Radiation Workshop

Thursday 29th November 2007

Remit of Talk - "Vertical Slice Test"

"Investigate how the different systems covered might be used by operations. All systems are measuring particle losses one way or another, and so should be able to provide complementary information to the CCC.

We would like to propose that each presentation includes the following
- brief overview of the system architecture (in terms of data flow)
- where the data comes from around the LHC
- the data acquisition / data publishing rate
- the data content (what it is, format, units, timestamp)
- how the data could be used and made available in the CCC
  - Displays
  - Applications (generic service, specific tool)
- short and long term logging (needs, filtering, data reduction)
- present status of the system
- plans for 2008 (tests foreseen, commissioning, integration)"

- Will talk about monitoring of beam losses, dynamic range and identify tools available for commissioning
- Will not talk explicitly in detail about "protection", i.e. provision of beam_permit
- Will not address issue of luminosity measurement

Overview

- CMS Beam and Radiation Monitoring
  - RADMON
  - Beam Conditions Monitor
  - Beam Scintillator Counters
  - BPTX - Beam Timing for the Experiments
- Dynamic Range of Detectors
- Data to be monitored
- Summary

CMS Beam and Radiation Monitoring

Who are the BRM Group?

- BRM Group is run as a sub-project within CMS Technical Coordination
- Institutes involved: Auckland, Canterbury, CERN, DESY-HH, DESY-Zeuthen, Karlsruhe, Princeton, Rio de Janeiro, Rutgers, Tennessee, UCLA, UC-Davis, Vienna, Uni Hamburg
- Approx 40 People involved within last 18 months:

Thomas Aumeyr, Ed Bartz, Austin Ball, Alan Bell, Anthony Butler, Joel Butler, Phil Butler, Maria Chamizo, Jesse Cornelissen, Wim De Boer, Elies Ennabli, Stephan Farry, Alexander Furgeri, Alexei Garmash, Richard Gray, Richard Hall-Wilton, Mark Hashimoto, Matthew Hollingsworth, Uwe Holm, Rob Knegjens, David Krofcheck, Wolfgang Lange, Jose Lazo-Flores, Alick Macpherson, Daniel Marlow, Steffen Mueller, Heinz Prause, Nuno Rodrigues, Vladimir Ryjov, David Schaffner, Steve Schnetzer, Patrice Siegrist, Jeff Spalding, Stefan Spanier, David Stickland, Robert Stone, Wojciech Szklarz, Emmanuel Tsesmelis, Rainer Wallny, Sam Whitehead, Jenny Williams, Wolfram Zeuner

Includes experts previously involved in Radiation Monitoring at experiments at LEP, HERA, TEVATRON, BABAR

Core group of 8-10 people at CERN

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

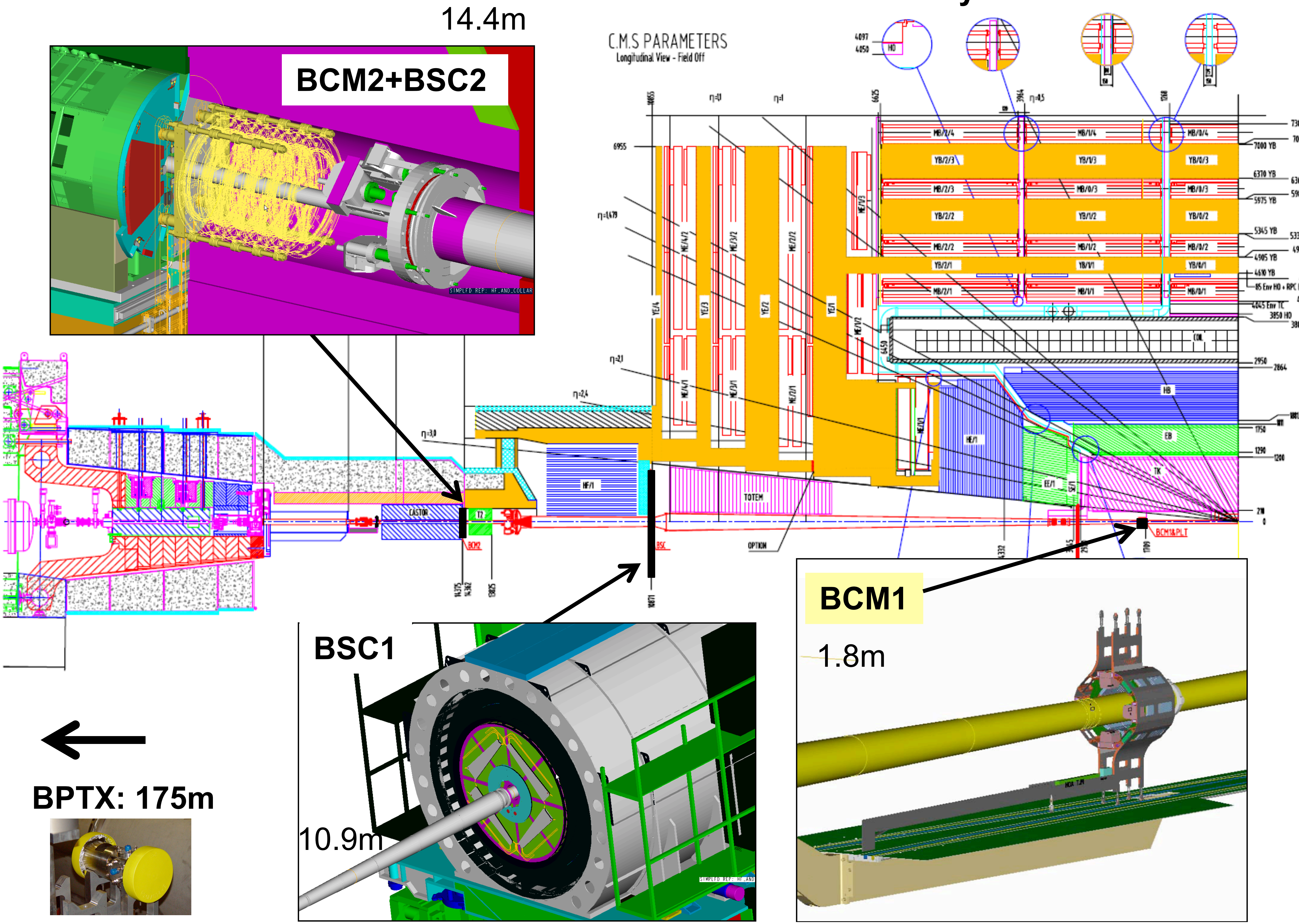
- **Philosophy**:
  - CMS requires that if LHC is running then the CMS Protection System (BCM) must be operational to ensure safety of the Detector.

Design Concept for CMS Beam and Radiation Monitoring System

- Explicit choice made to be compliant with the machine monitoring and protection system
  - Use as standard devices where possible to avoid duplication of systems
  - Readout wherever possible LHC standard
  - Data available via LHC standard publish/subscribe mechanisms (FESA, CMW, DIP)
- Protection task: Readout and detector technology selected for reliability
  - Readout - Beam Loss Monitor taken as most appropriate choice
  - Chemical Vapour Deposition Diamond is the standard choice for experimental protection
- Redundancy in monitoring implemented where possible:
  - Emphasis on extensive monitoring capability to allow understanding of beam losses and adverse events
  - Cross-calibration between devices
  - Confirmation of beam conditions and losses from several devices
  - Generally 1 Hz monitoring to make data useful for tuning conditions
- The whole protection and monitoring system is independent of CMS DAQ
- All data available to both CCC and CMS

RADMON: 18 monitors around UXC

PASSIVES: Everywhere



BRM Subsystem Hardware Summary

Emphasis on detectors that are relative flux monitors

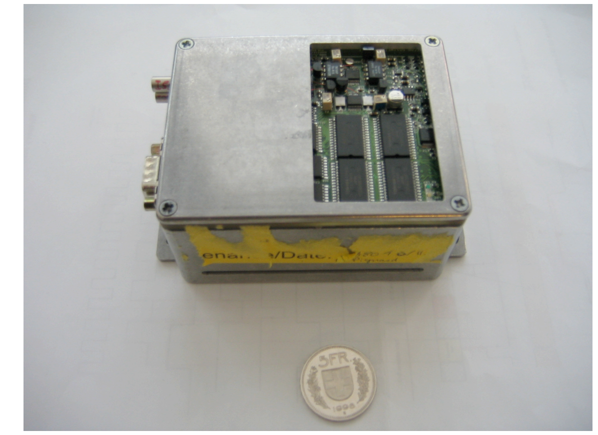
Subsystem	Location	Sampling time	Function	Readout + Interface
Passives TLD + Alanine	In CMS and UXC	Long term	Monitoring	---
RADMON	18 monitors around CMS	1s	Monitoring	Standard LHC
BCM2 Diamonds	At rear of HF z=±14.4m	40 us	Protection	CMS + Standard LHC
BCM1L Diamonds	Pixel Volume z=±1.8m	Sub orbit ~ 5us	Protection	CMS + Standard LHC
BSC Scintillator	Front of HF z=±10.9,14.4 m	(sub-)Bunch by bunch	Monitoring	CMS Standalone
BCM1F Diamonds	Pixel volume z=±1.8m	(sub-)Bunch by bunch	Monitoring + protection	CMS Standalone
BPTX Beam Pickup	175m upstream from IP5	200ps	Monitoring	CMS Standalone

Increased time resolution

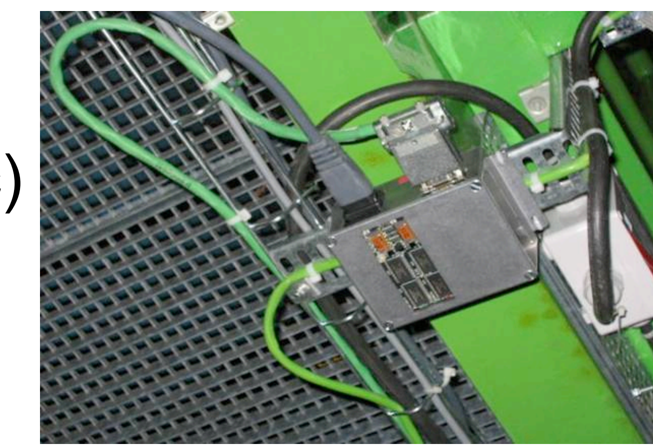
Systems are independent of CMS DAQ, and on LHC UPS power

RADMON

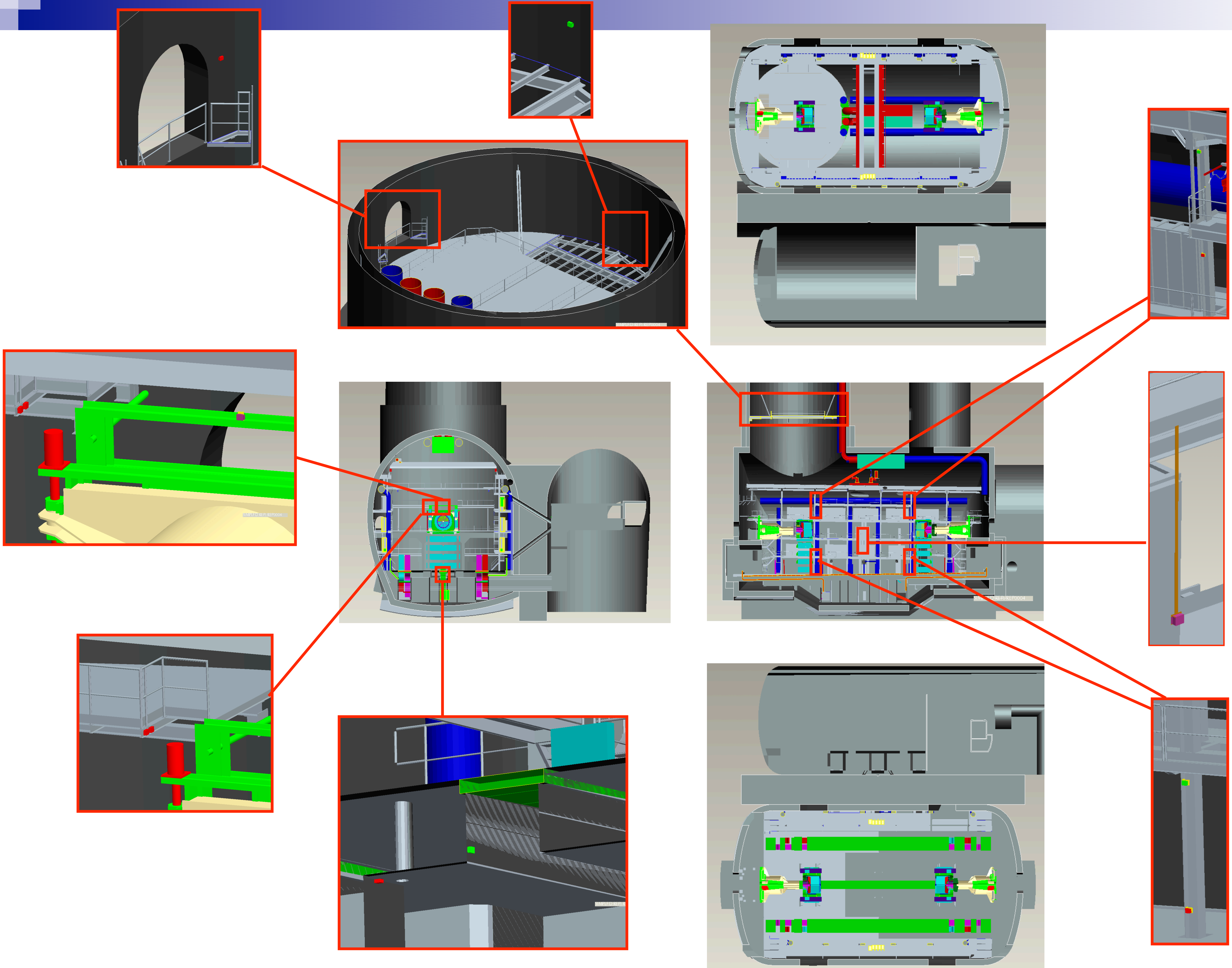
LHC RADMON Monitors



- **LHC RADMON Units (In conjunction with TS-LEA)**
  - Measures
    - Dose, dose rate using RadFETs
    - Hadron (E>20 MeV) flux and fluence, SEU rate via SRAM
    - 1 MeV equiv neutron fluence via pin diodes (α >100keV fluence)



  - 18 Monitors deployed around CMS (UXC +USC)
    - Locations chosen mostly close to equipment (PSUs, etc)
    - Also close to shielding to determine effectiveness
    - Data reported back to the RADMON database
    - Installation of RADMON infrastructure started
  - **Used for Online benchmark points for verification of simulations**
- **Implementation Data Format and Data Flow exactly the same as for other monitors around LHC**
  - No changes in implementation, data stored in LHC database(s)
  - See Thijs' talk for details



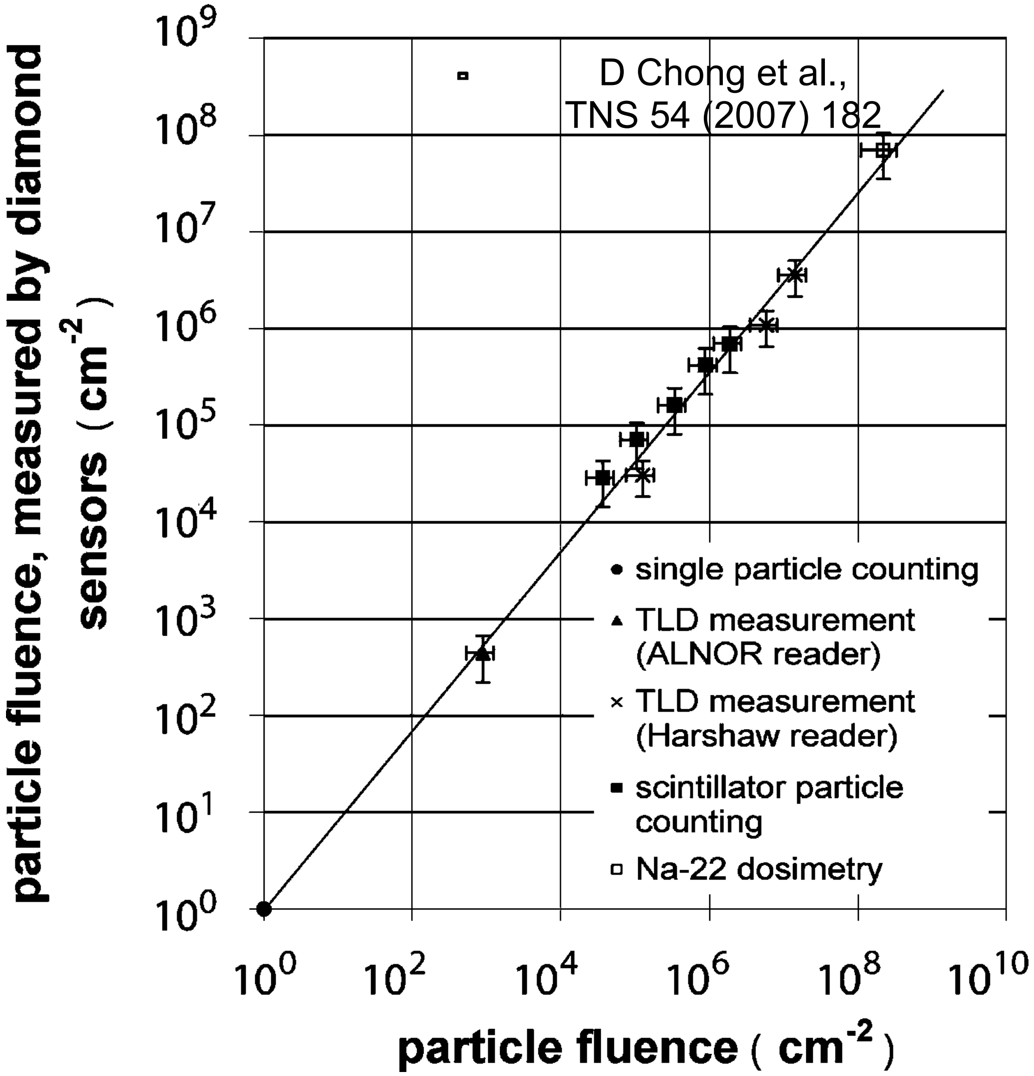
CMS Beam Conditions Monitors

Primary function is experimental protection through provision of LHC BEAM_PERMIT

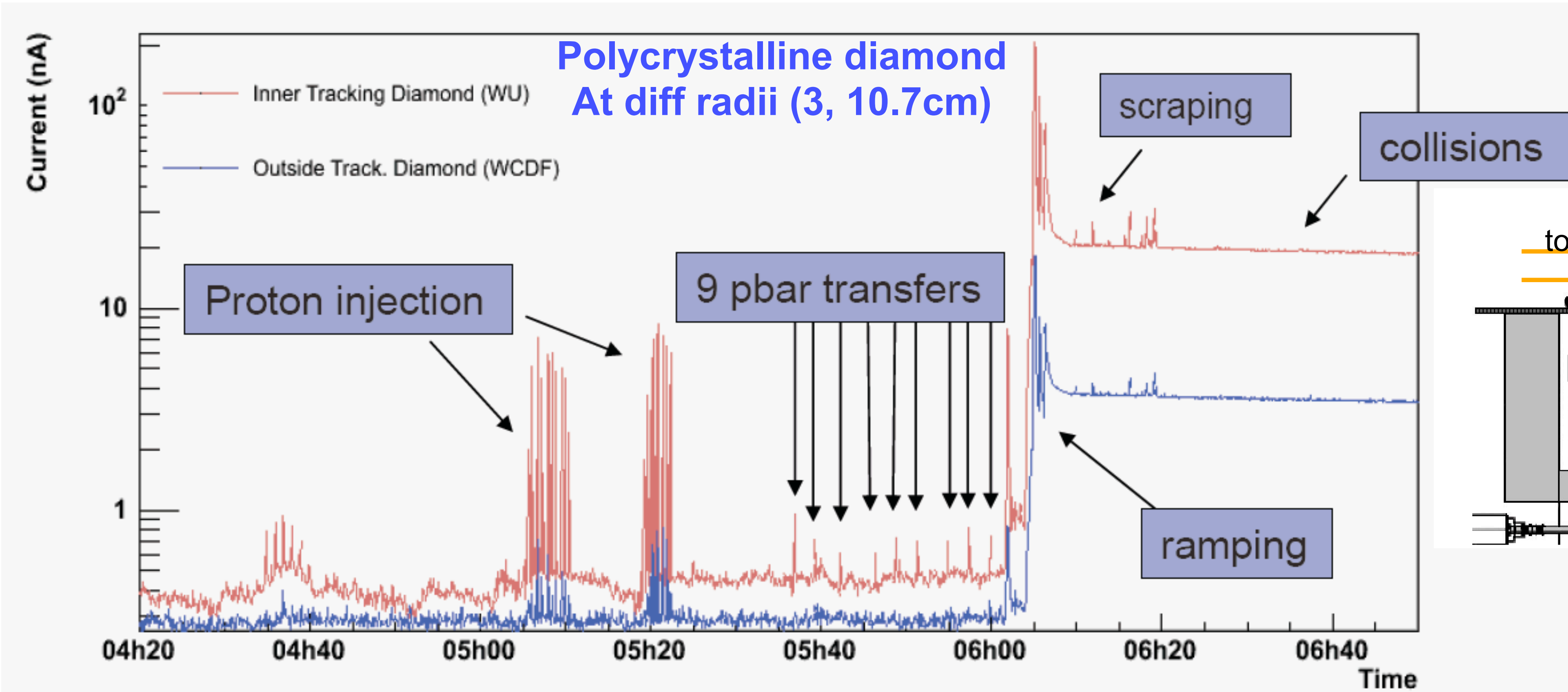
Also provide extensive monitoring of beam conditions

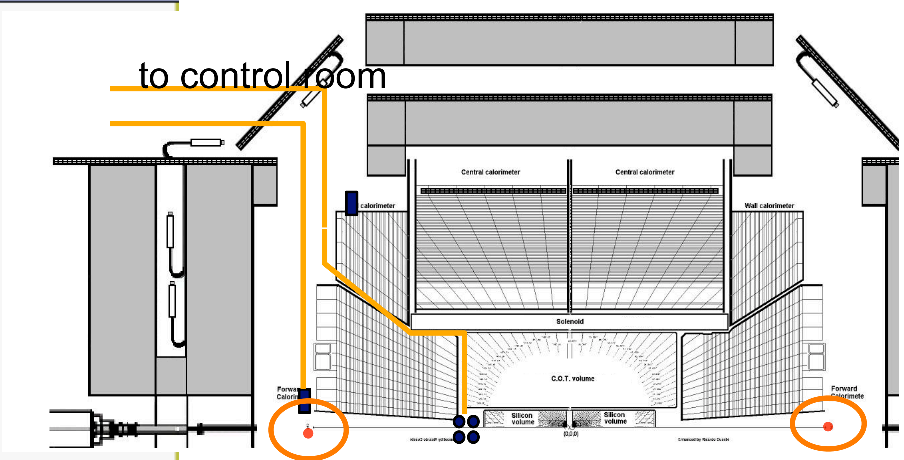
Why CVD Diamond?

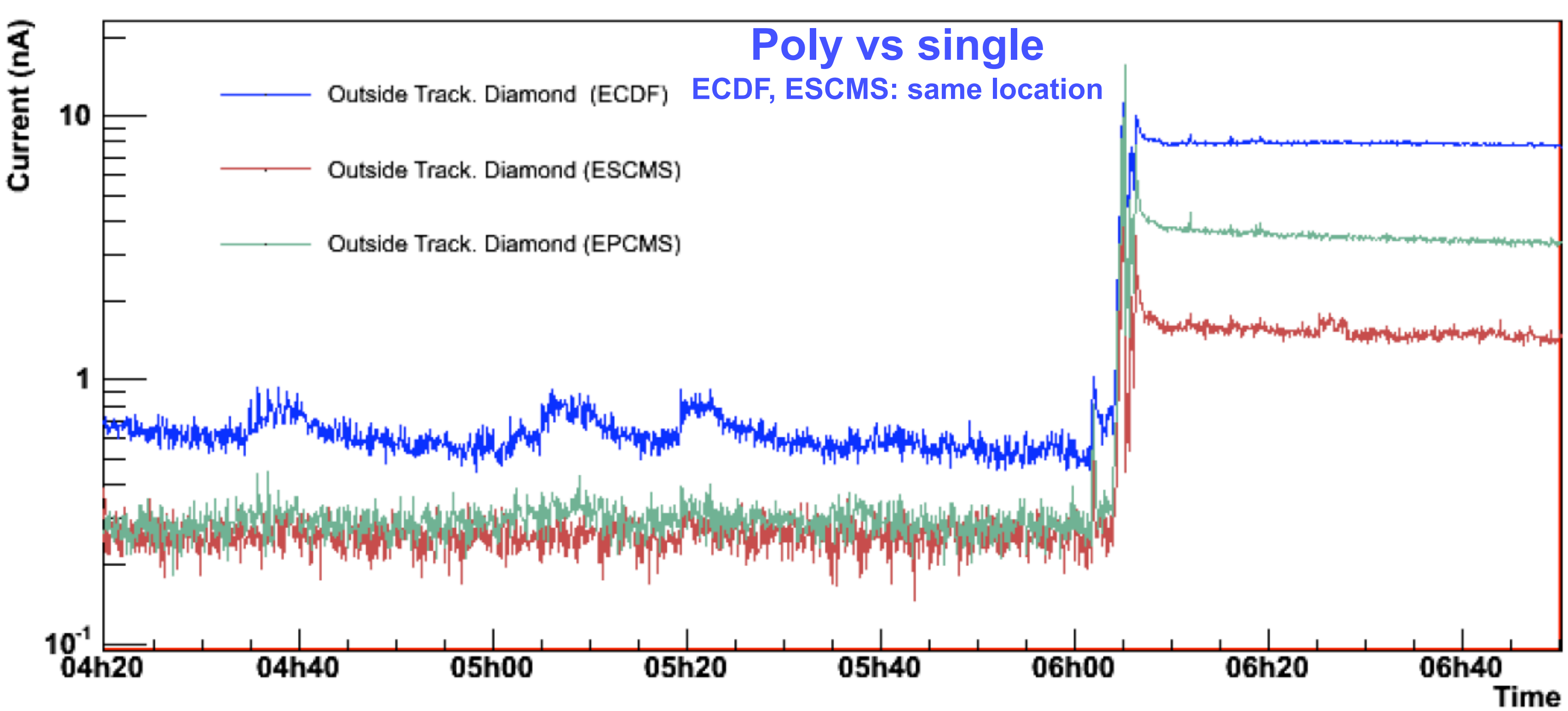
- LHC Beam Loss Monitor ionisation chambers physically too big to be installed inside CMS
  - 9cm diameter, 60cm long
- Chemical Vapour Deposition Diamond is now standard choice at other experiments
  - Installed in CDF, BaBar, Belle, ZEUS
  - ALICE, ATLAS, LHC-B will also install
  - Relative flux monitors
  - Radiation hard - tolerant beyond LHC nominal luminosity close to IP
  - Low maintainance, constant operating conditions, relatively insensitive to environmental conditions, compact size
  - Linear response to particle flux



Example: CMS BCM Sensors in CDF- Online Monitoring Plots







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

Development program ongoing since many years within CMS

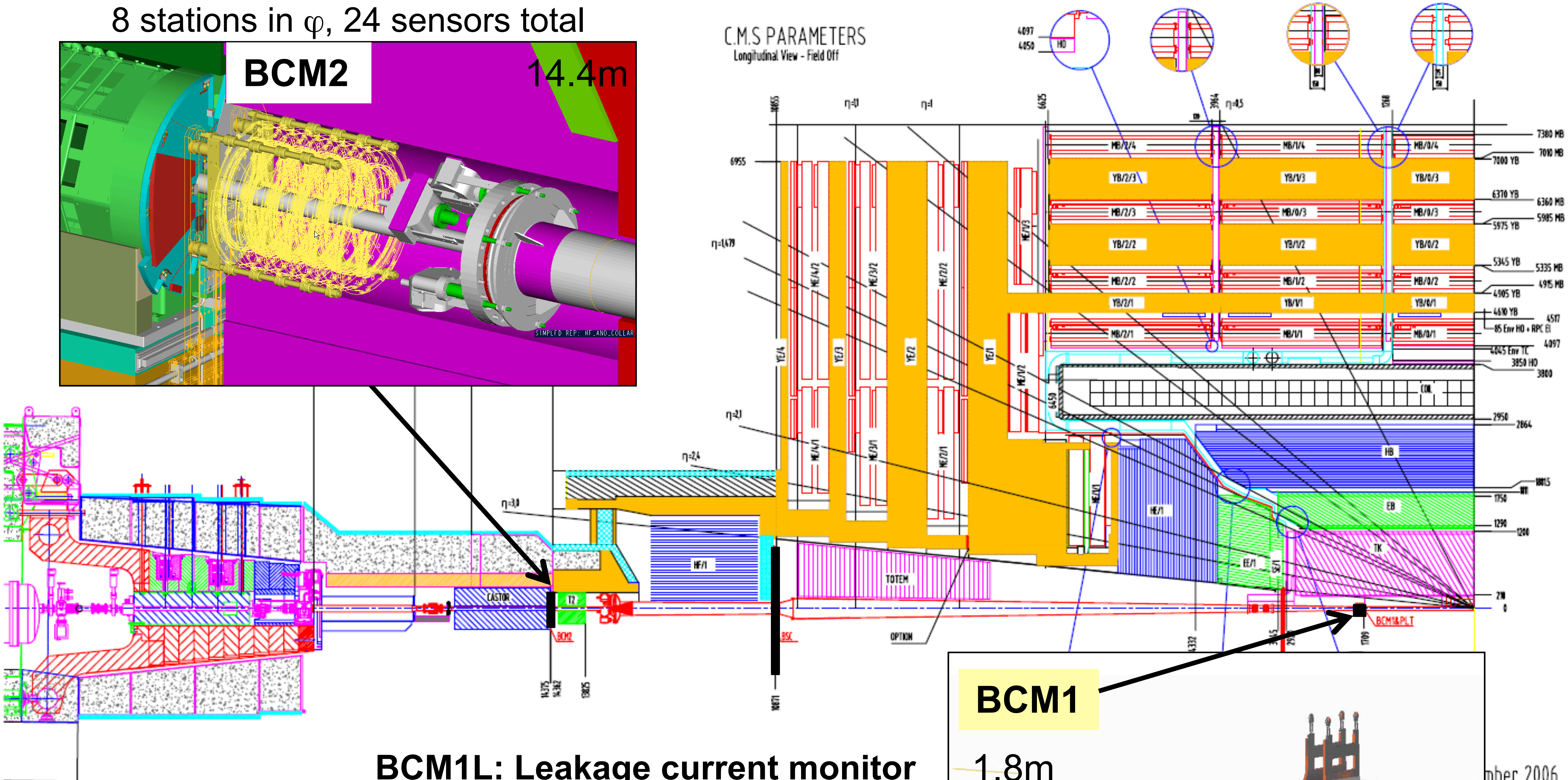
BCM2: Leakage current monitor

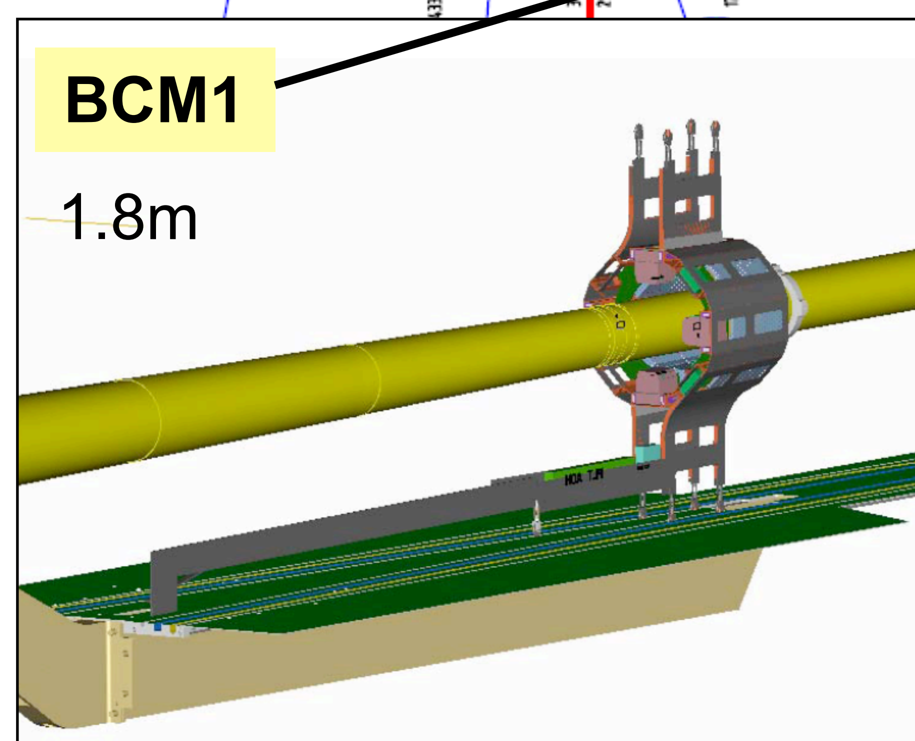
Location: z=± 14.4m, r=29cm, 5cm

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

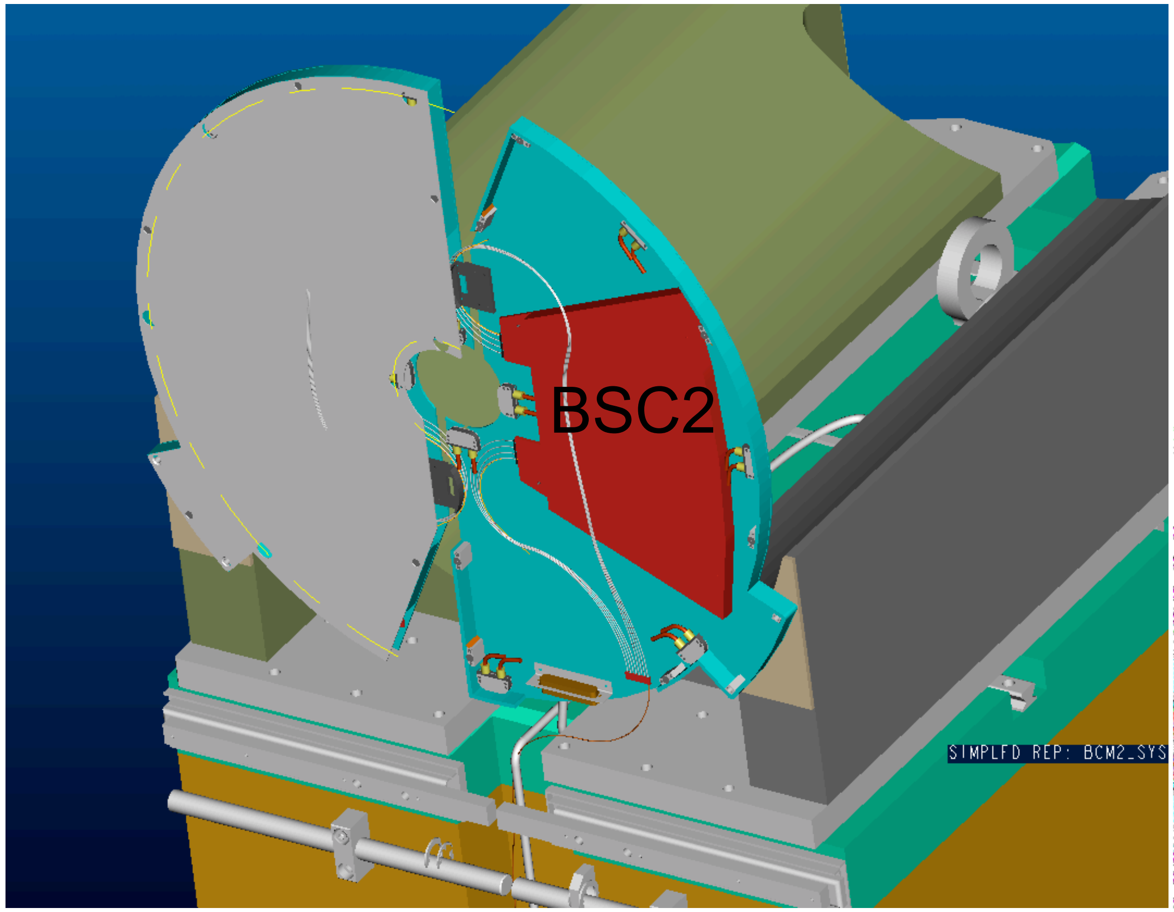
4 stations in φ, 8 sensors total

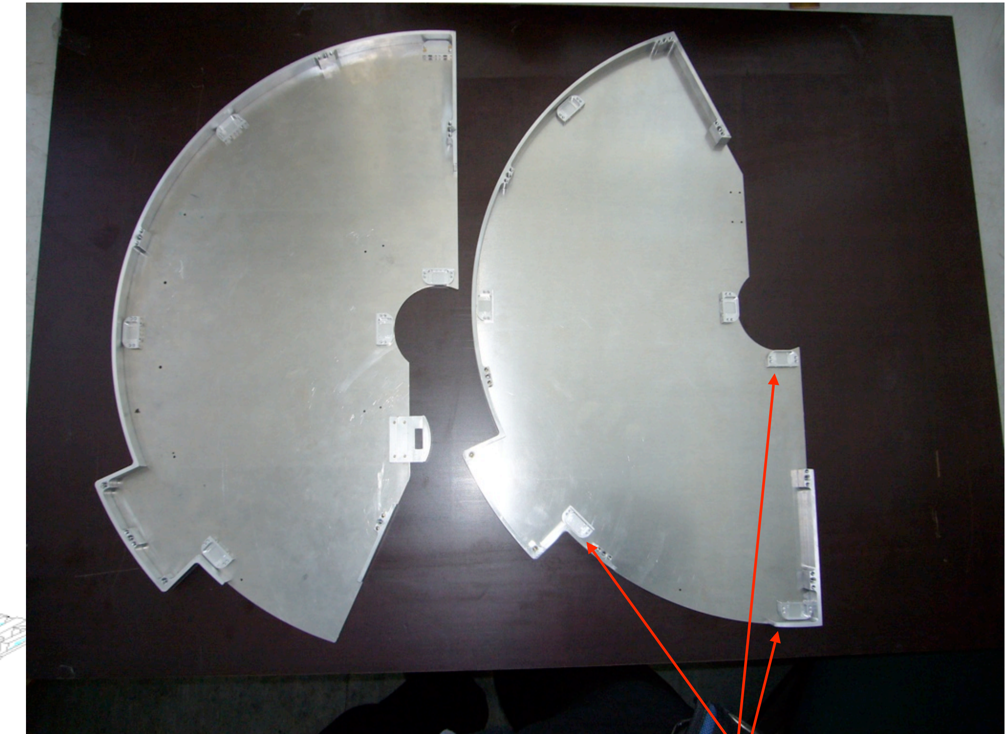
Readout: 200kHz / 5us

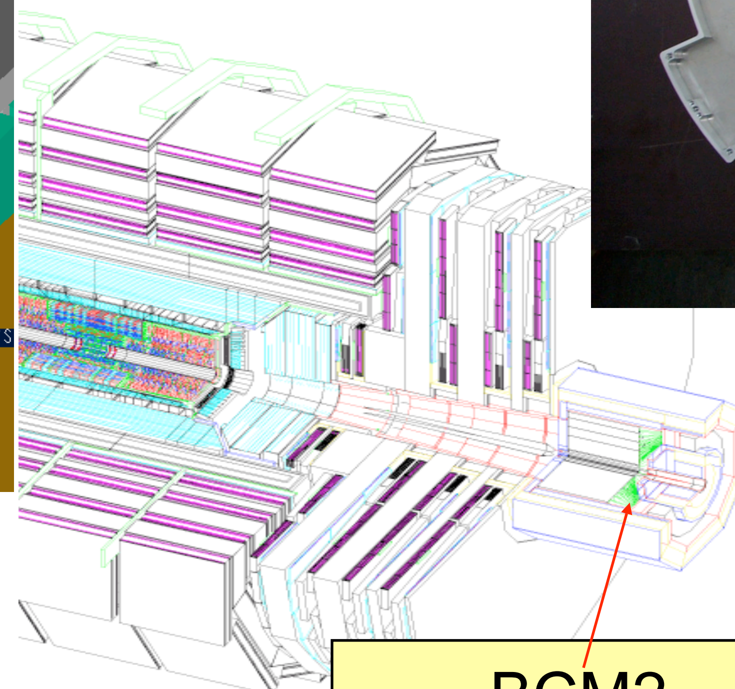
No front end electronics

Sensors: 1cm^2 polycrystalline cvd Diamond

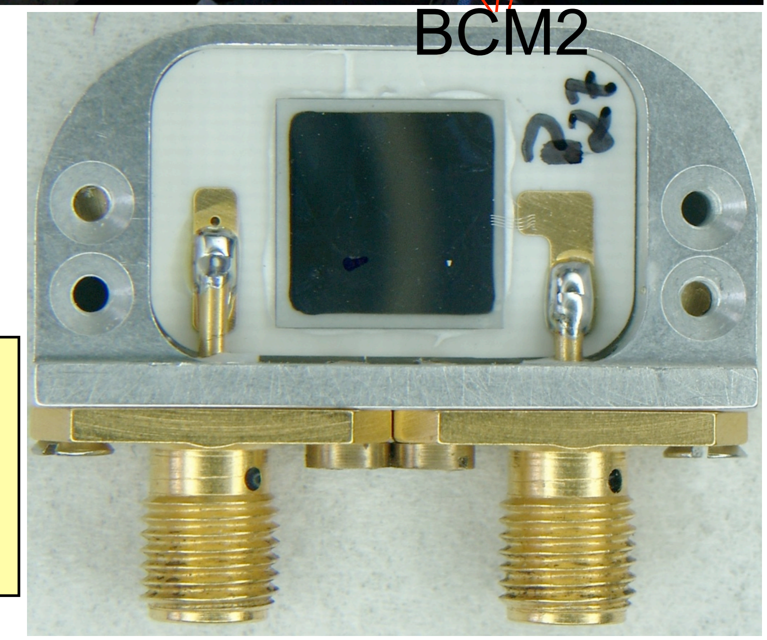
BCM2







BCM2



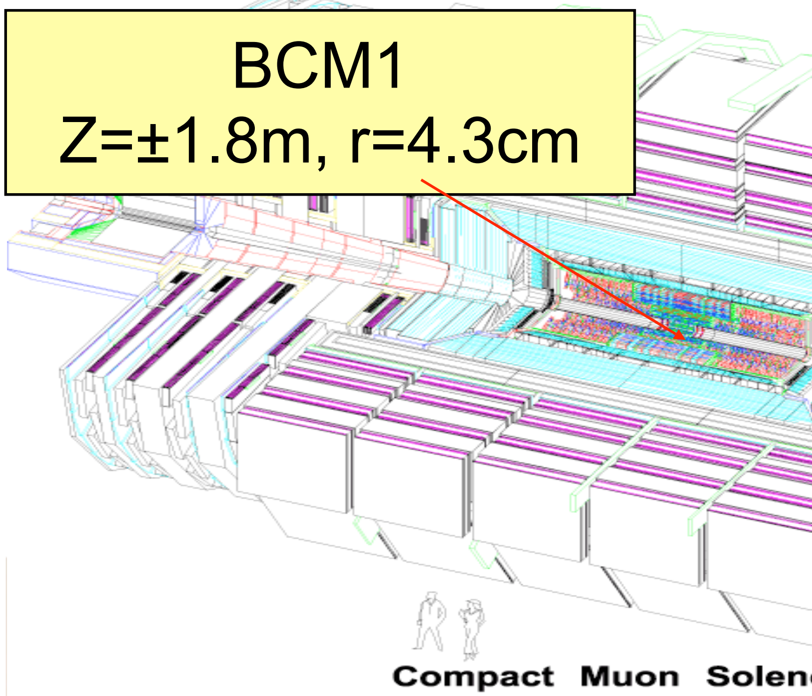
BCM2
Z=± 14.4m,
r=5, 29cm

- 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

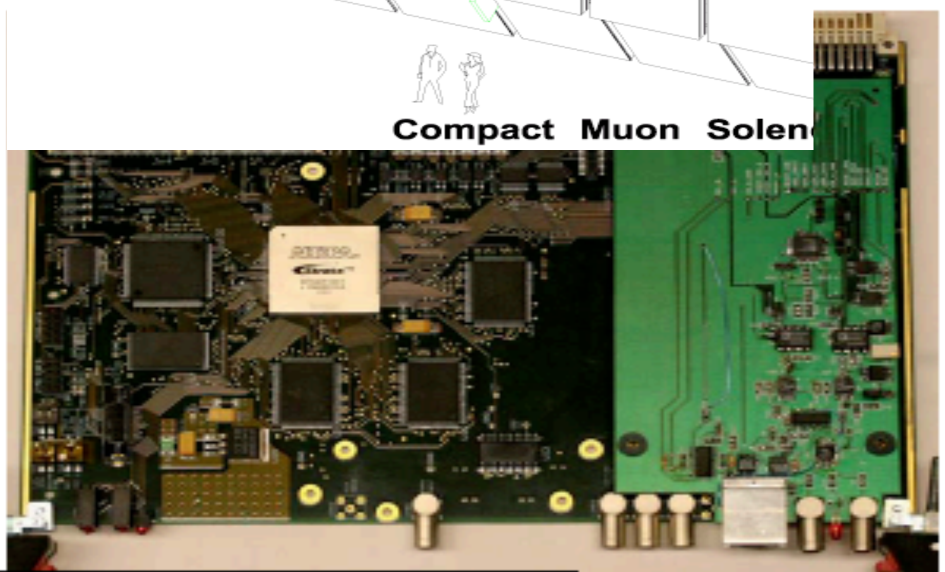
All components needed in hand
Assembly, calibration and
testing ongoing at Karlsruhe
Installation schedule on time

BCM1
Z=±1.8m, r=4.3cm

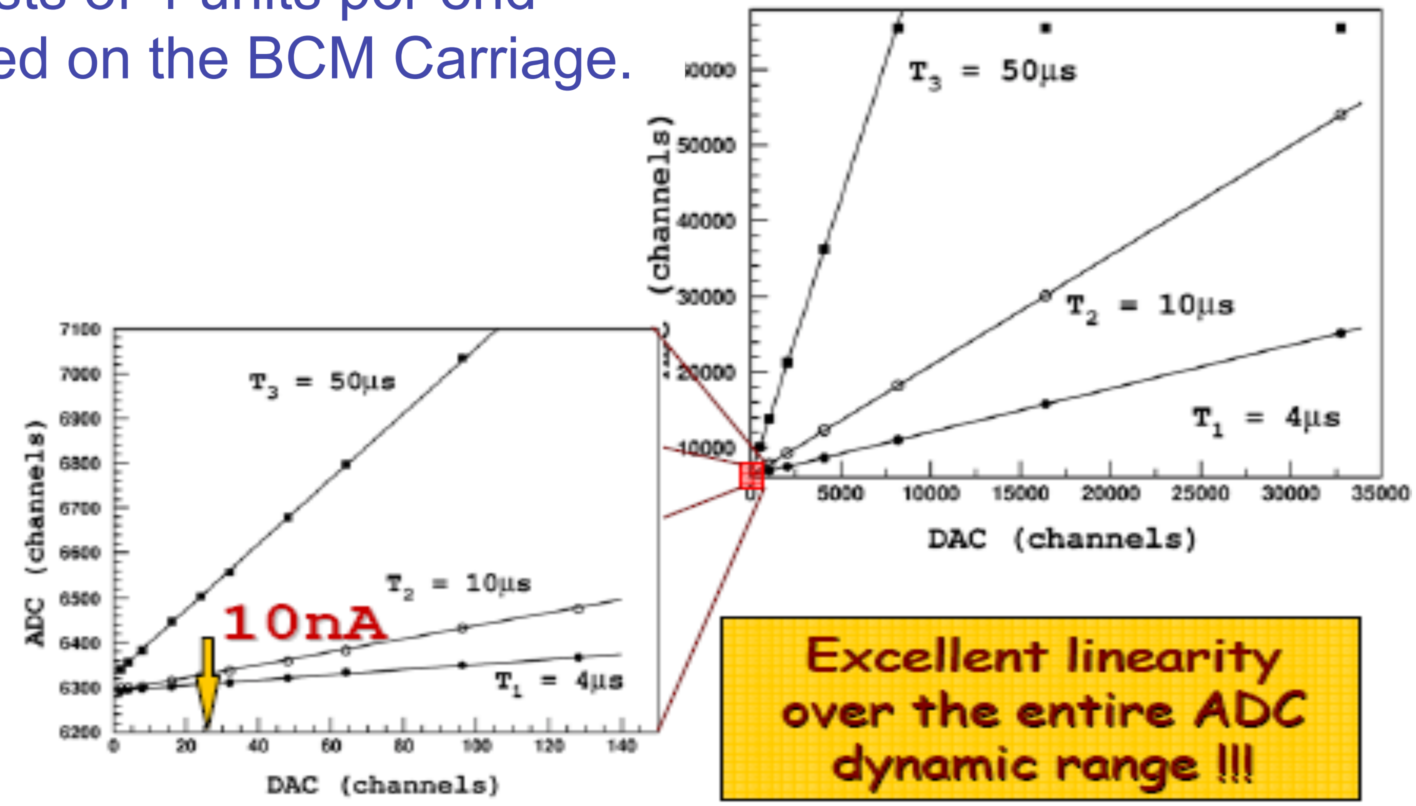


Protection systems:
BCM1L: Leakage current monitoring

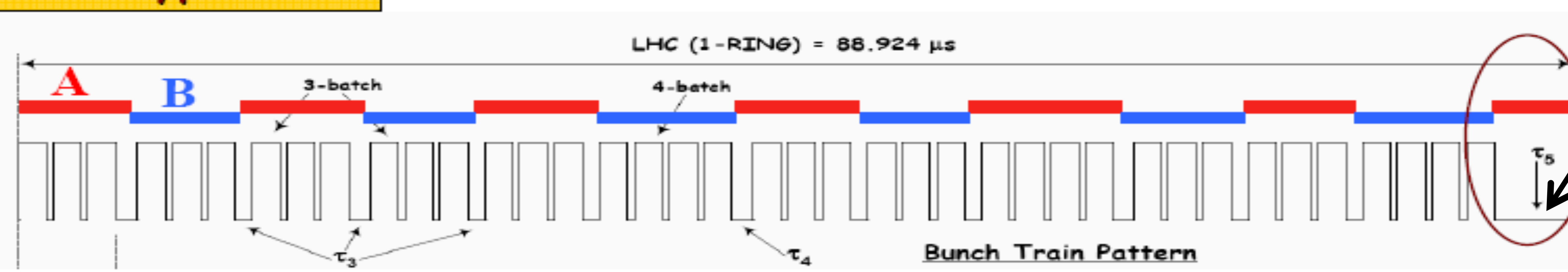
- Consists of 4 units per end mounted on the BCM Carriage.



Prototype board



Excellent linearity over the entire ADC dynamic range !!!



ABORT GAP

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 early next year

Beam Conditions Monitor Readout

- Standard LHC Beam Loss Monitor readout chosen
  - "BI type-B" VME crate, DAB64 cards, AB standard type PPC
    - LHC timestamps
    - Robust, reliable, extensively tested
    - Trusted by CCC
    - CMS Implementation approved through AB/BI technical board
- Software for readout is BLM standard
  - NO software development done within CMS BRM group
  - NO changes from BLM software
  - Logging, data format, post-mortem, etc BLM standard and provided by standard FESA framework
- Logging data, Post-Mortem and Study/Snapshot Data available in exactly the same format and manner as LHC BLM data
  - CMS BCM Data looks EXACTLY the same as BLM data
  - Completes the picture of losses in LSS5
- Full details of data format and data flow - see Christos' talk
- Copy of data logged to database also within CMS

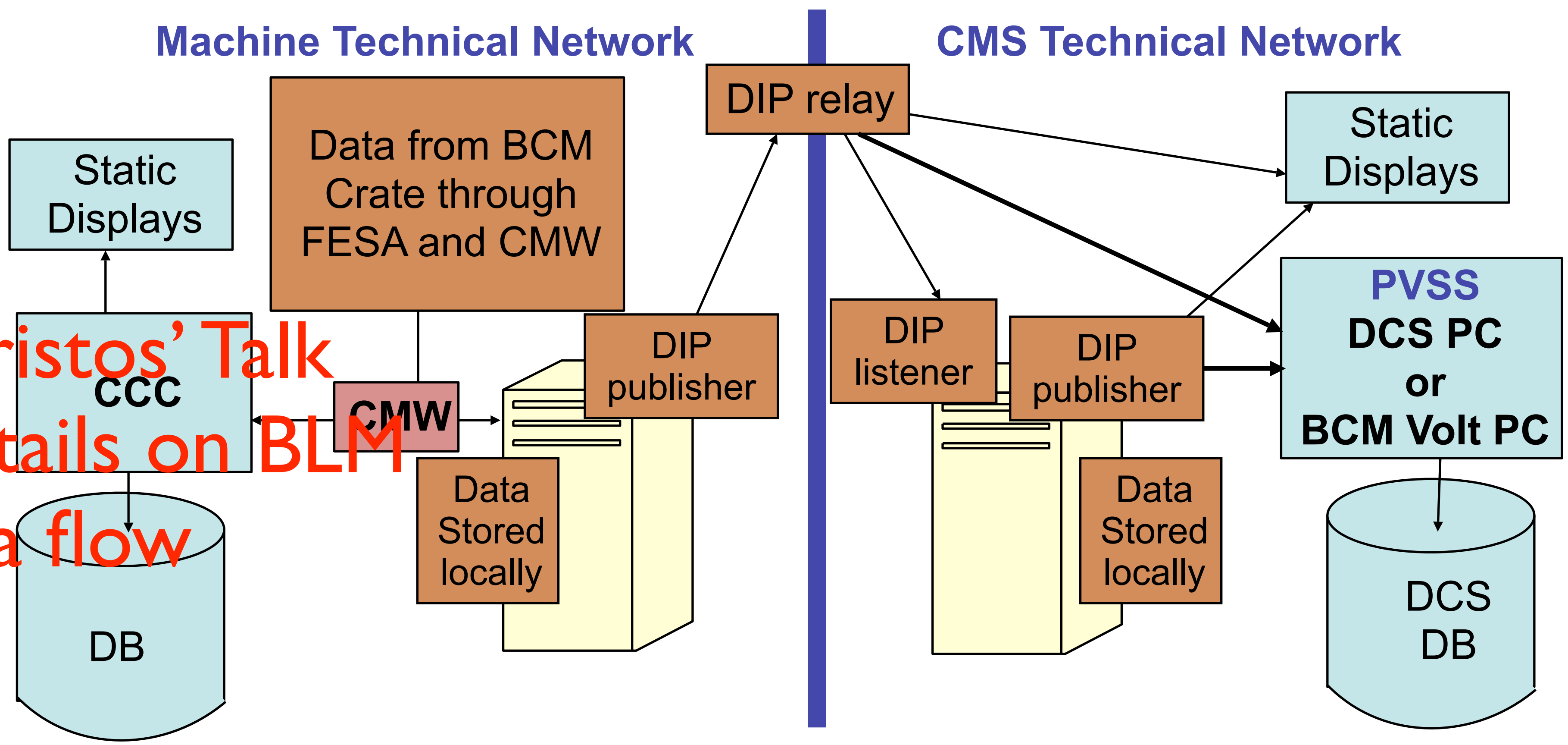
Interface with CMS and LHC Databases

Software Framework used by BRM based upon AB/CO standards

Interface to LHC database(s) is Beam Loss Monitor standard

Interface to CMS database(s) is DCS

Tested in BCM2 Slice Test (CMS Internal Note 2007-037)



See Christos' Talk for full details on BLM data flow

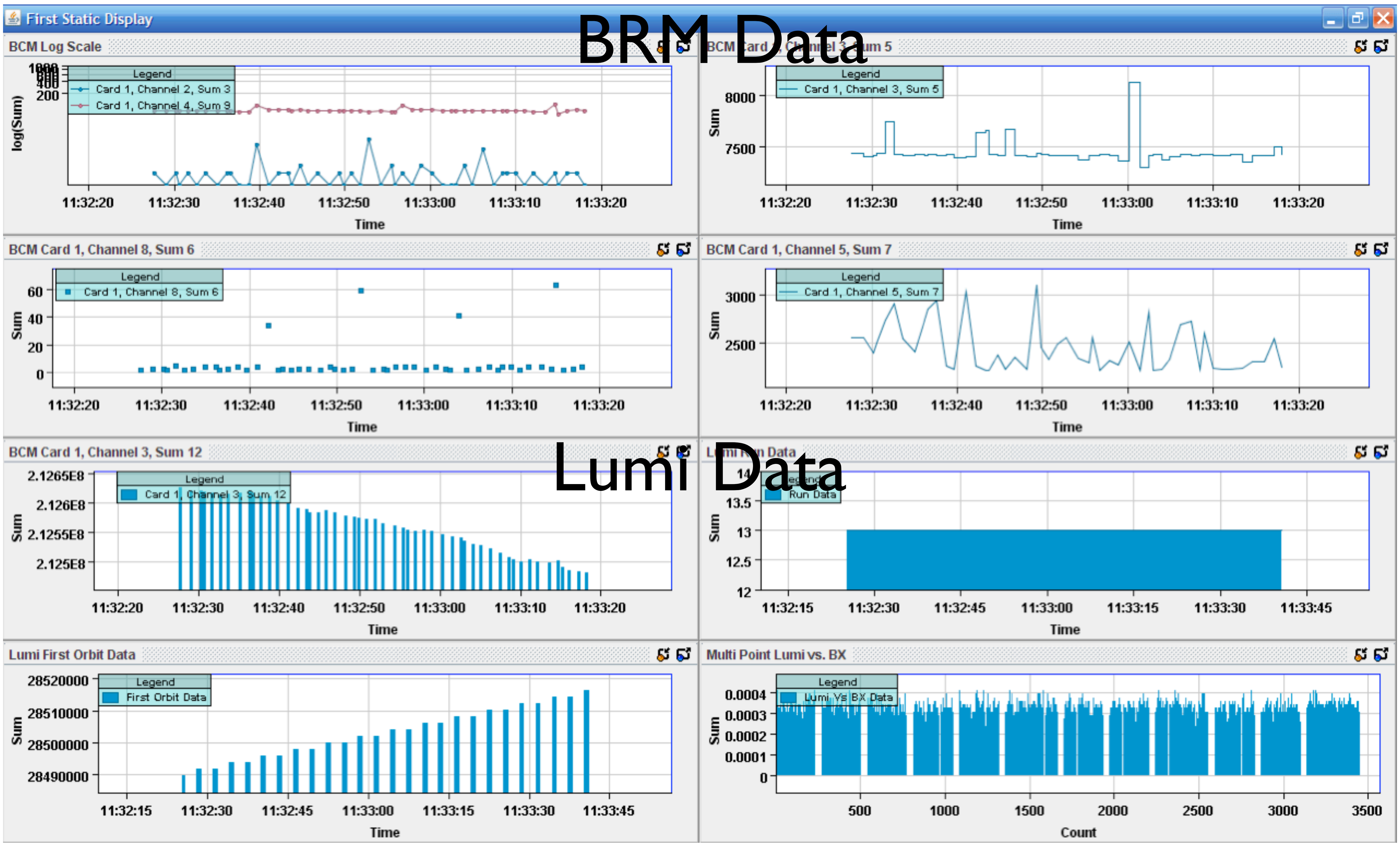
(ROOT based) Analysis of data foreseen for logging, post-mortem and snapshot data

CMS Beam Conditions Monitors: Monitoring, Calibration and Expected Response

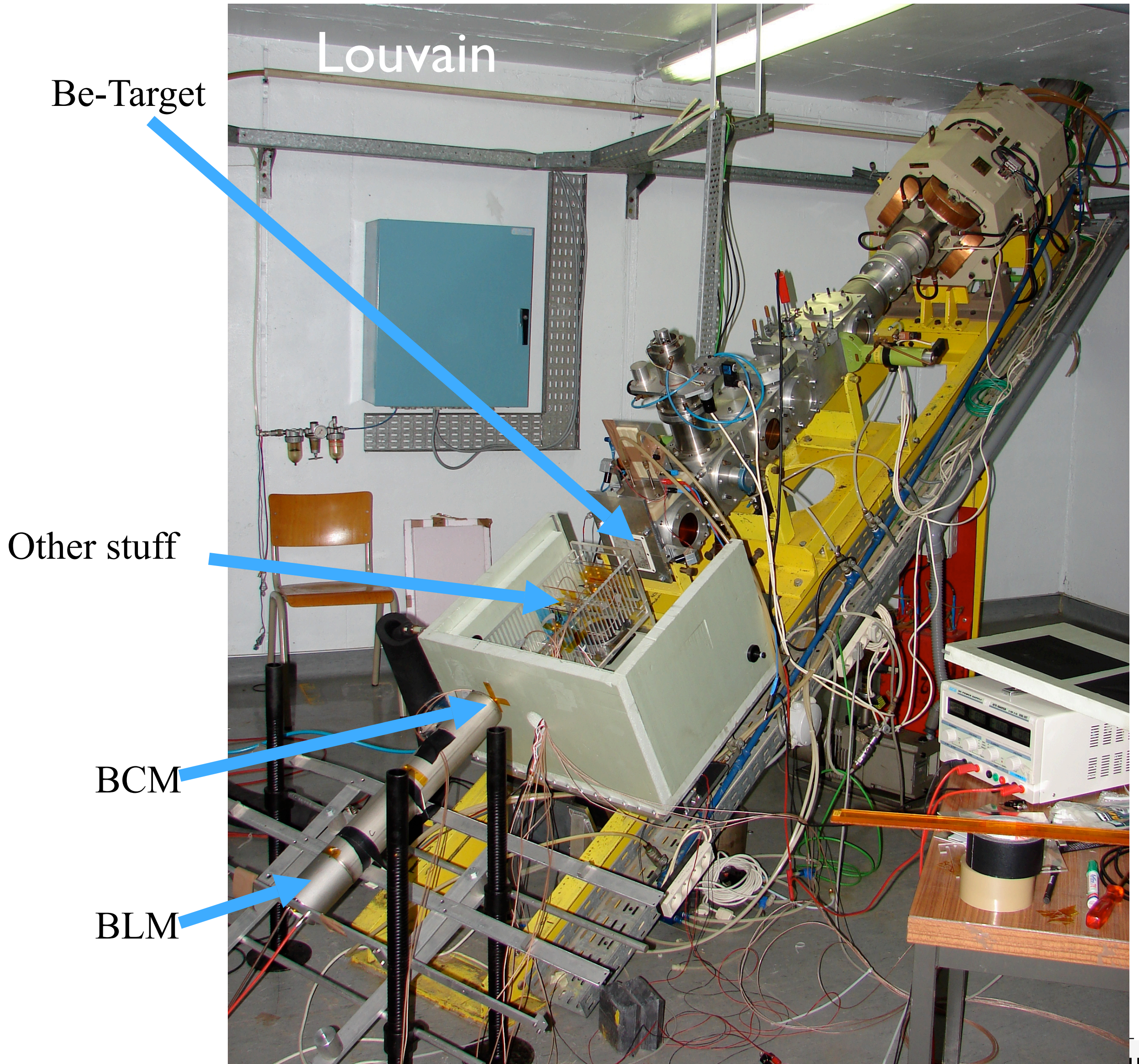
CMS Static Display for LHC - use AB/CO Standards

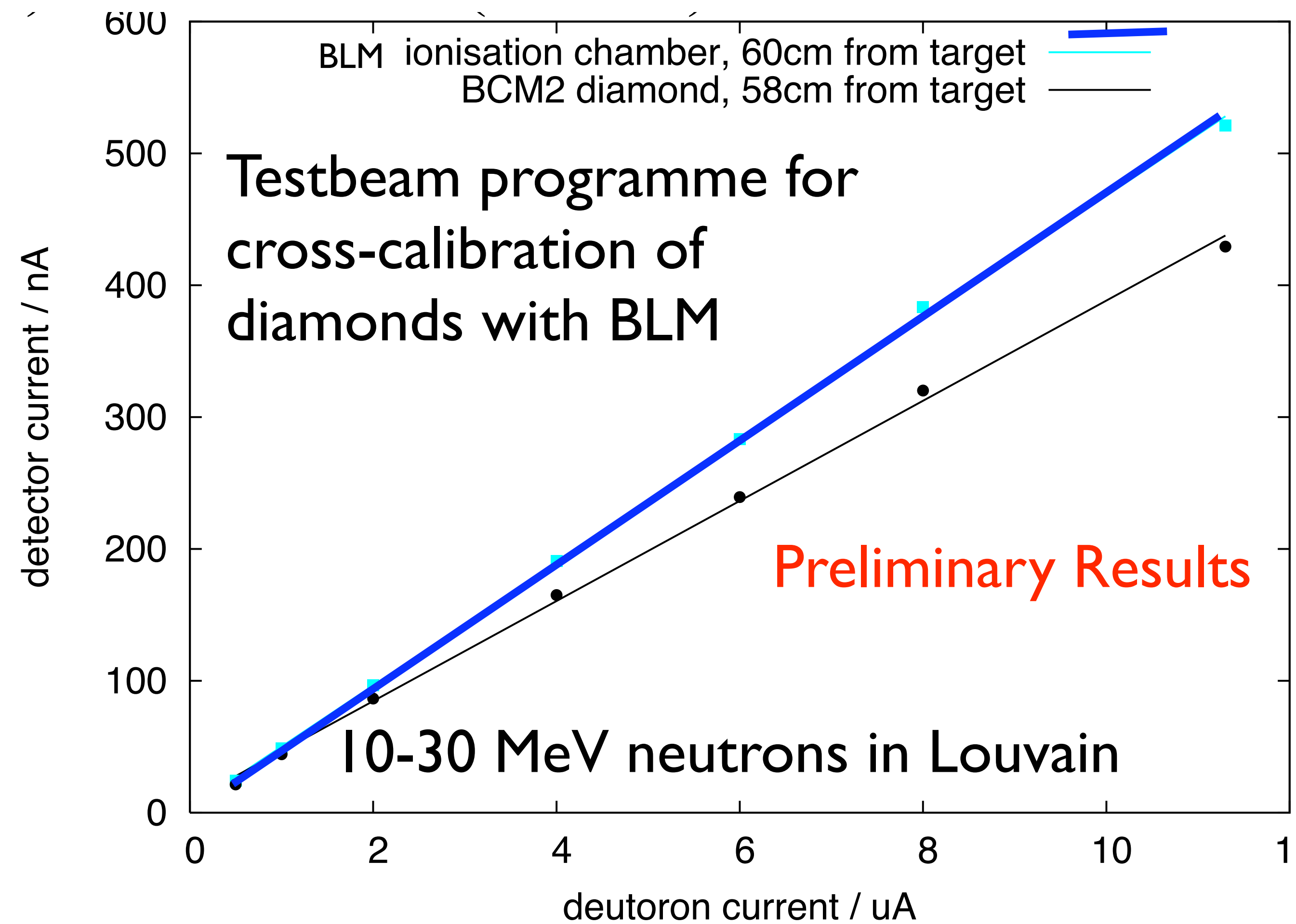
Displays - developed with AB/CO

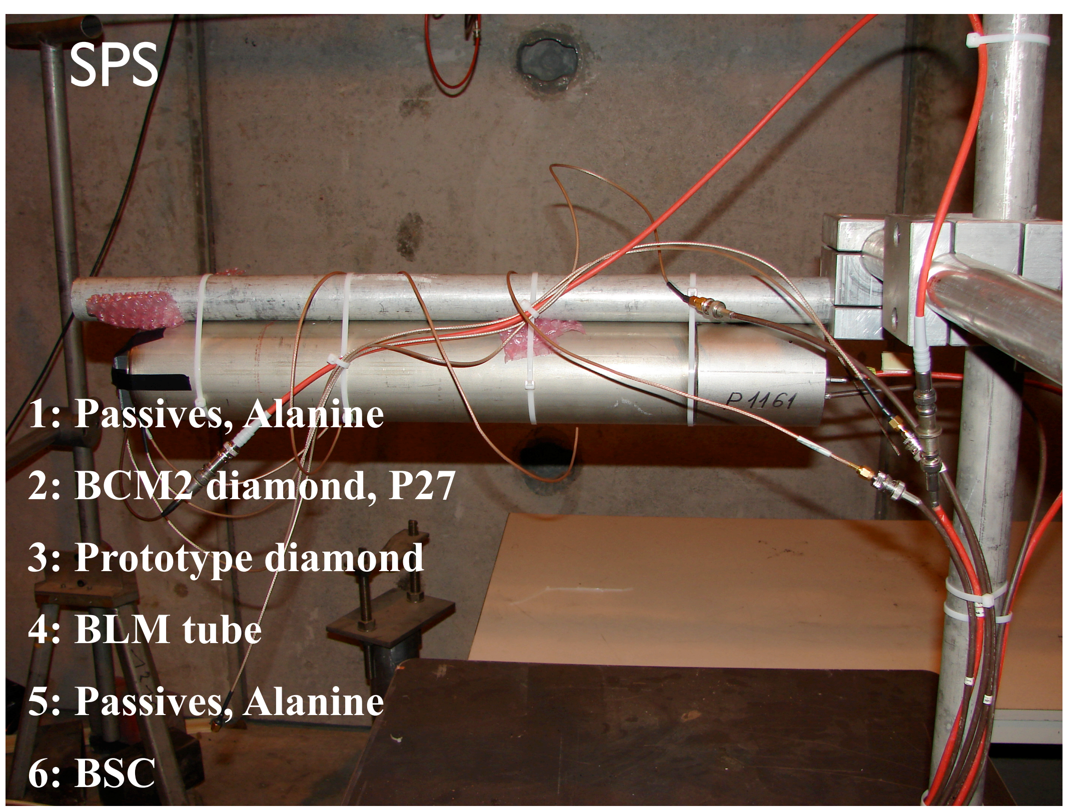
Collaborating with CMS Luminosity Group for combined display

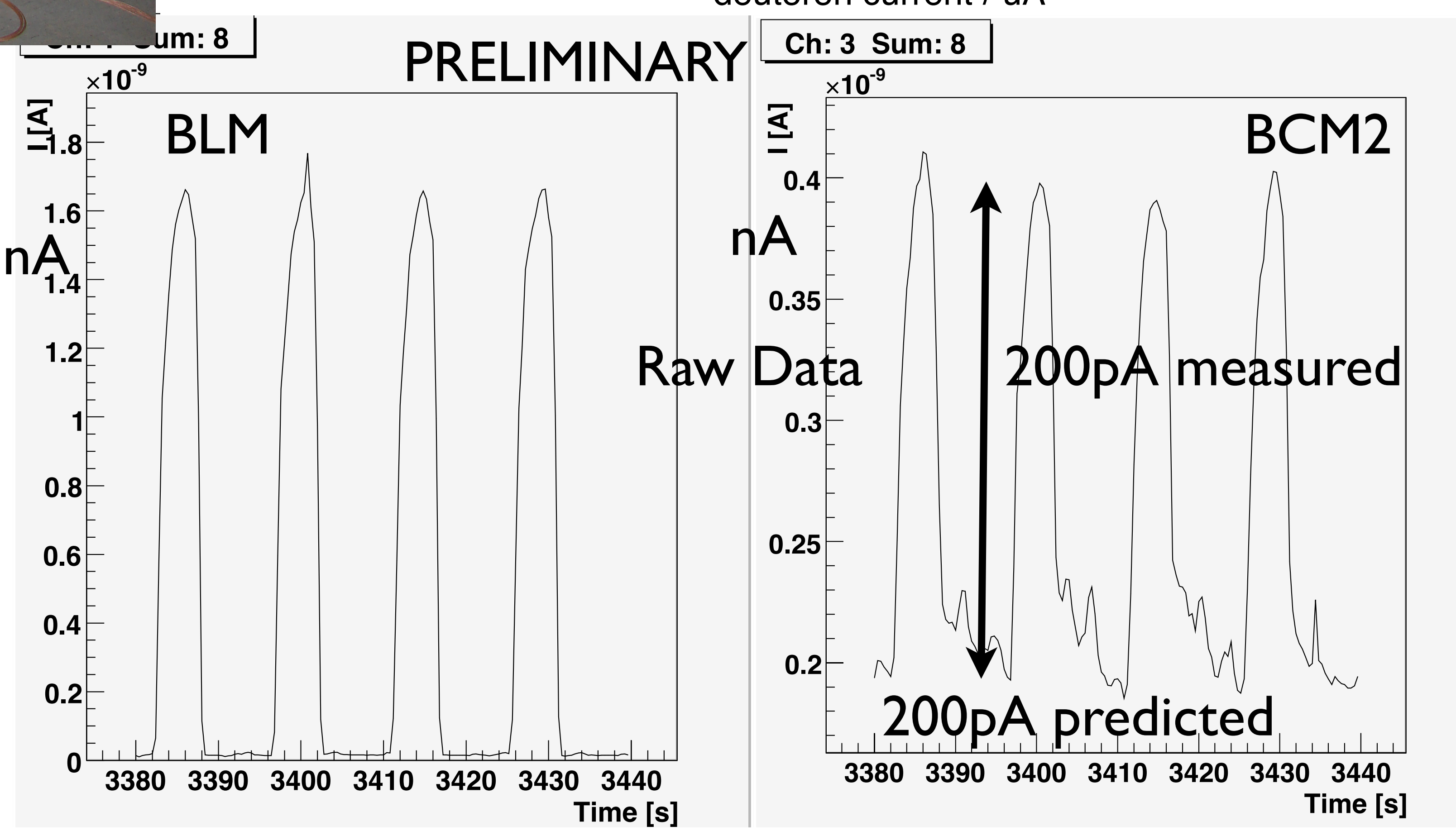


Cross Calibration of Detectors



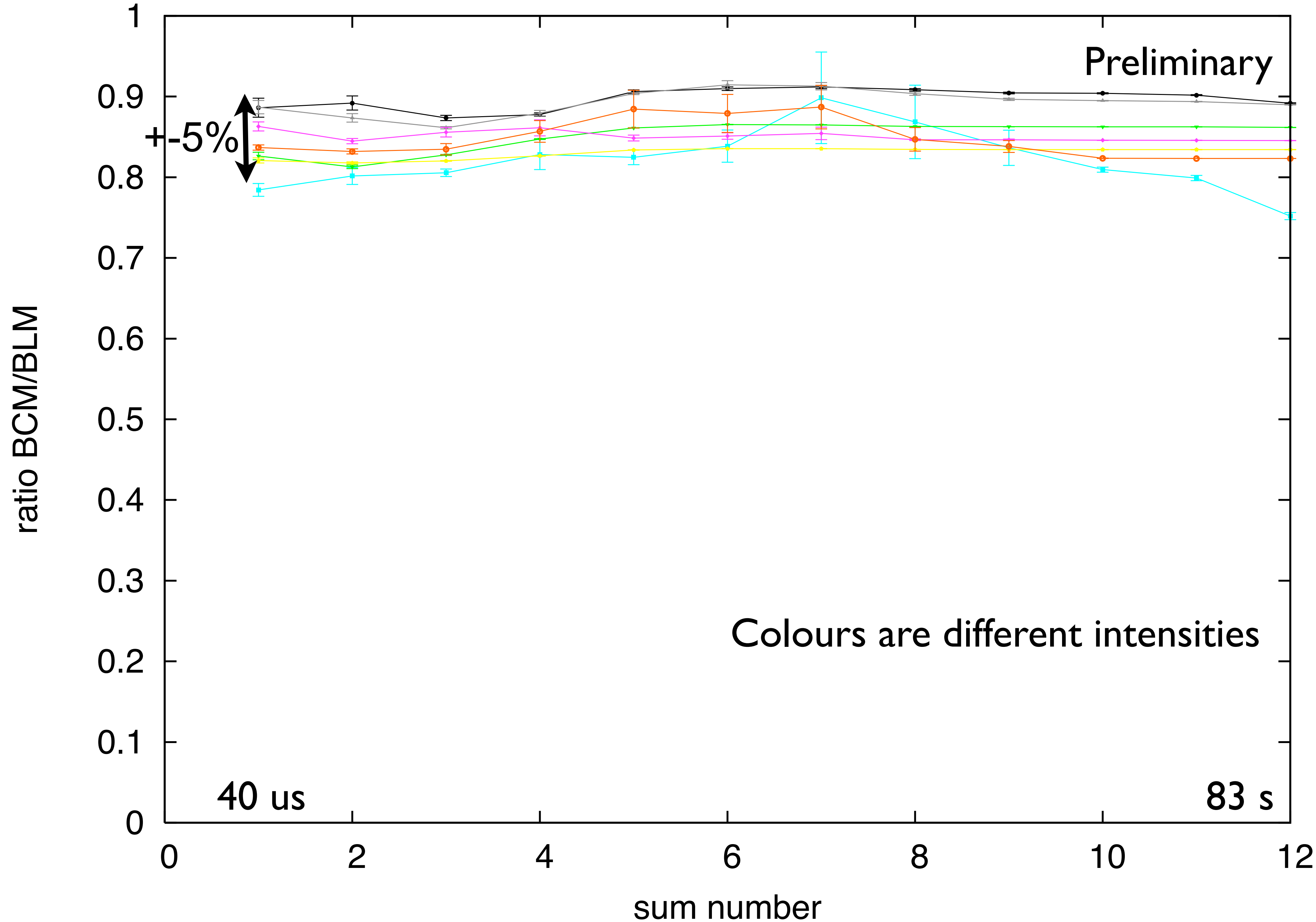






BLM - BCM Cross Calibration

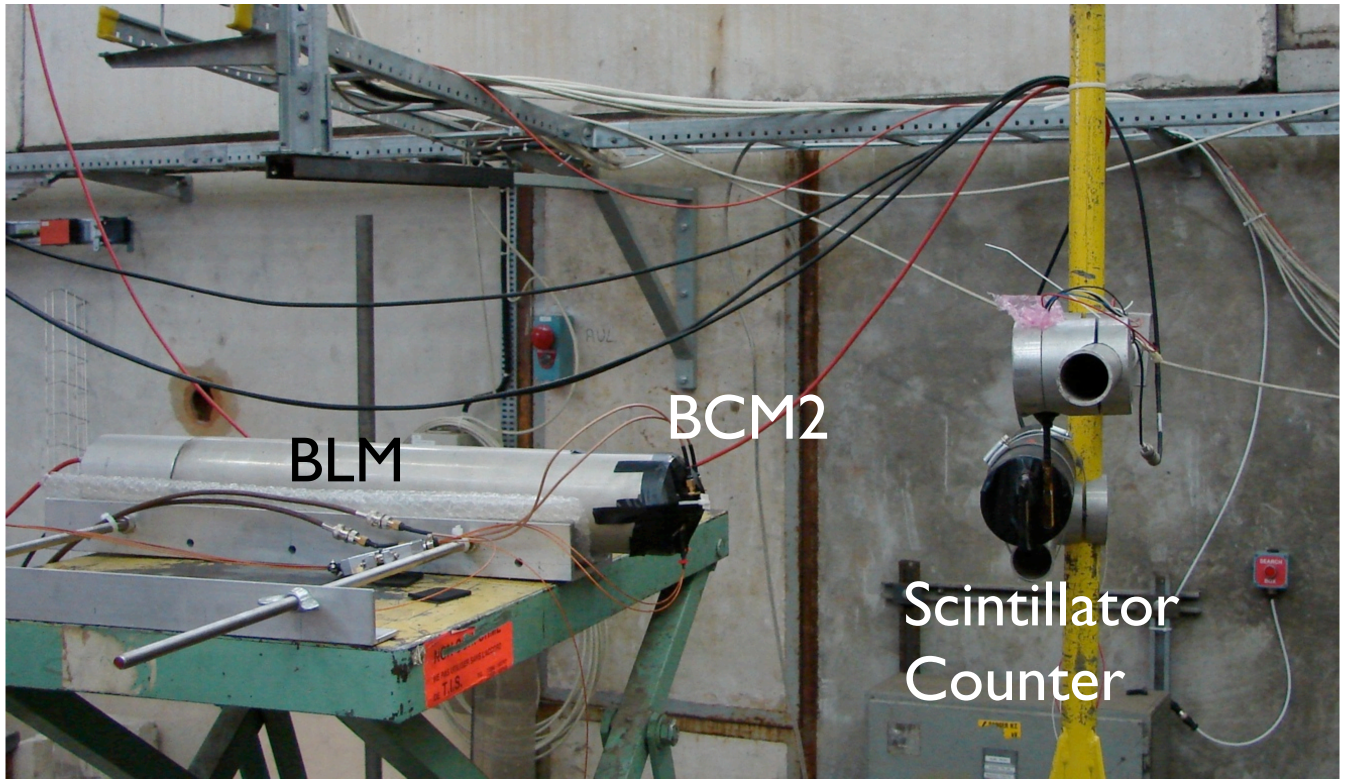
Louvain neutron testbeam

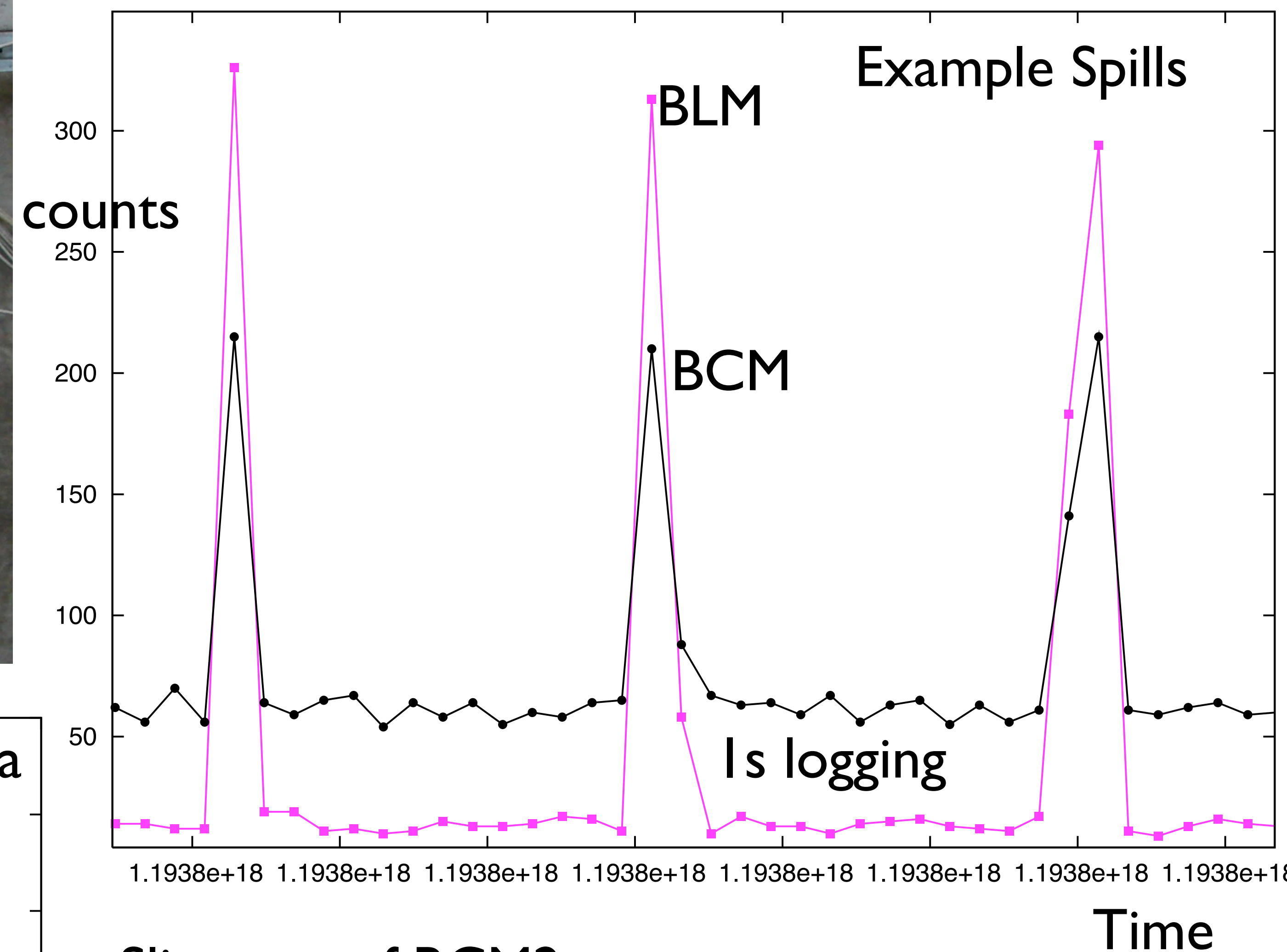


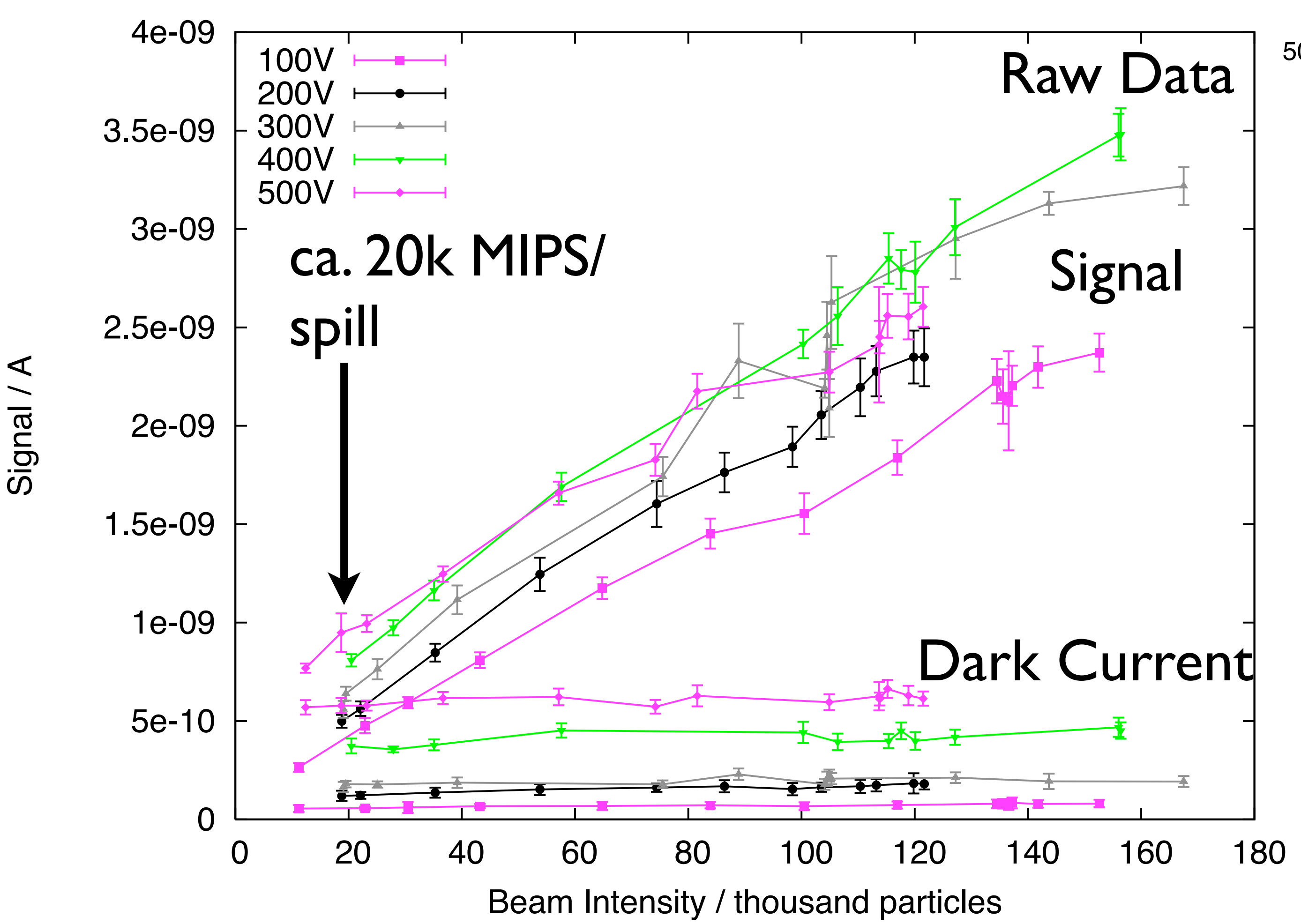
- BLM - BCM response constant to +-5%
- Over all intensities and time periods (40us - 83 seconds)
- Behaviour very similar

2 month testbeam programme just finished in T11 area of PS

Cross Calibration of Detectors







Slice test of BCM2

Final readout

Final BCM1 and BCM2 diamonds

BLM used for cross-calibration

Good S:N even at lowest intensities

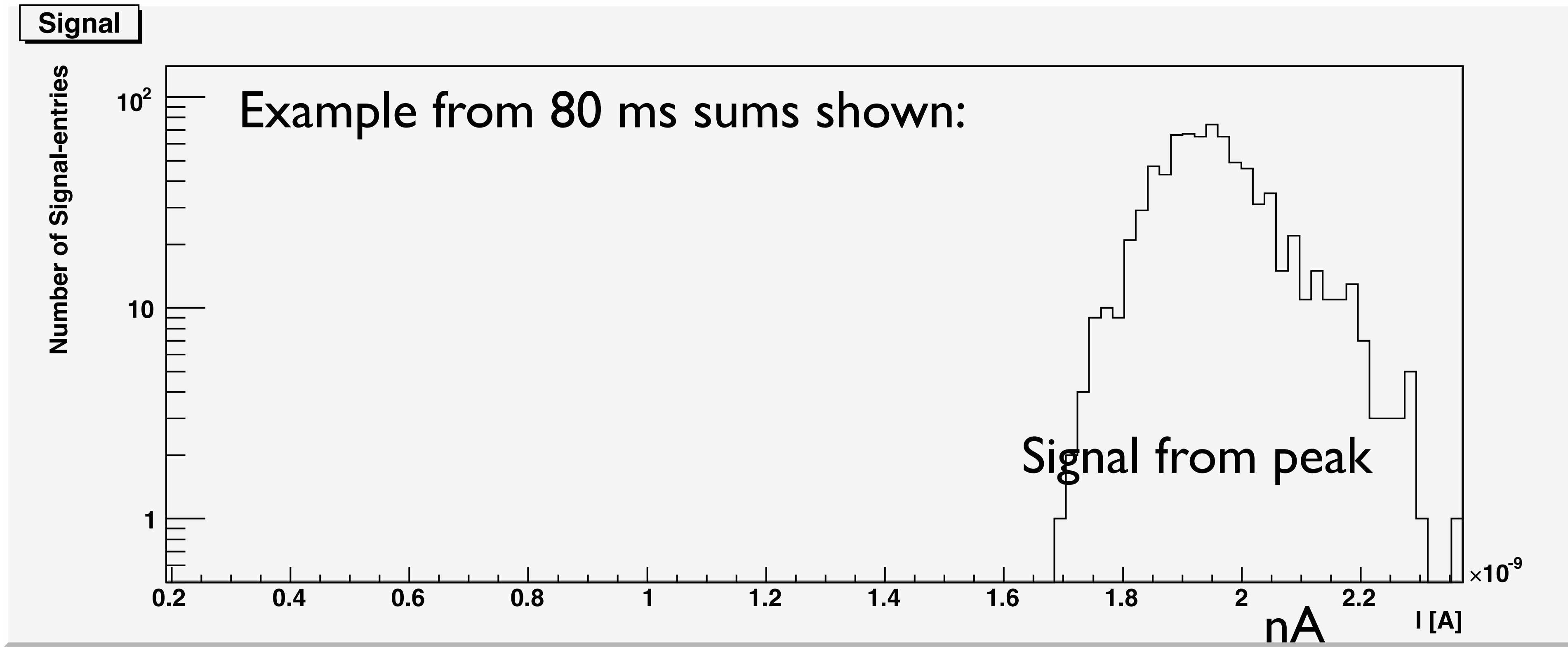
Good Signal Size down to 100V Bias

Wide operational range

Signal and Noise during T11 Testbeam

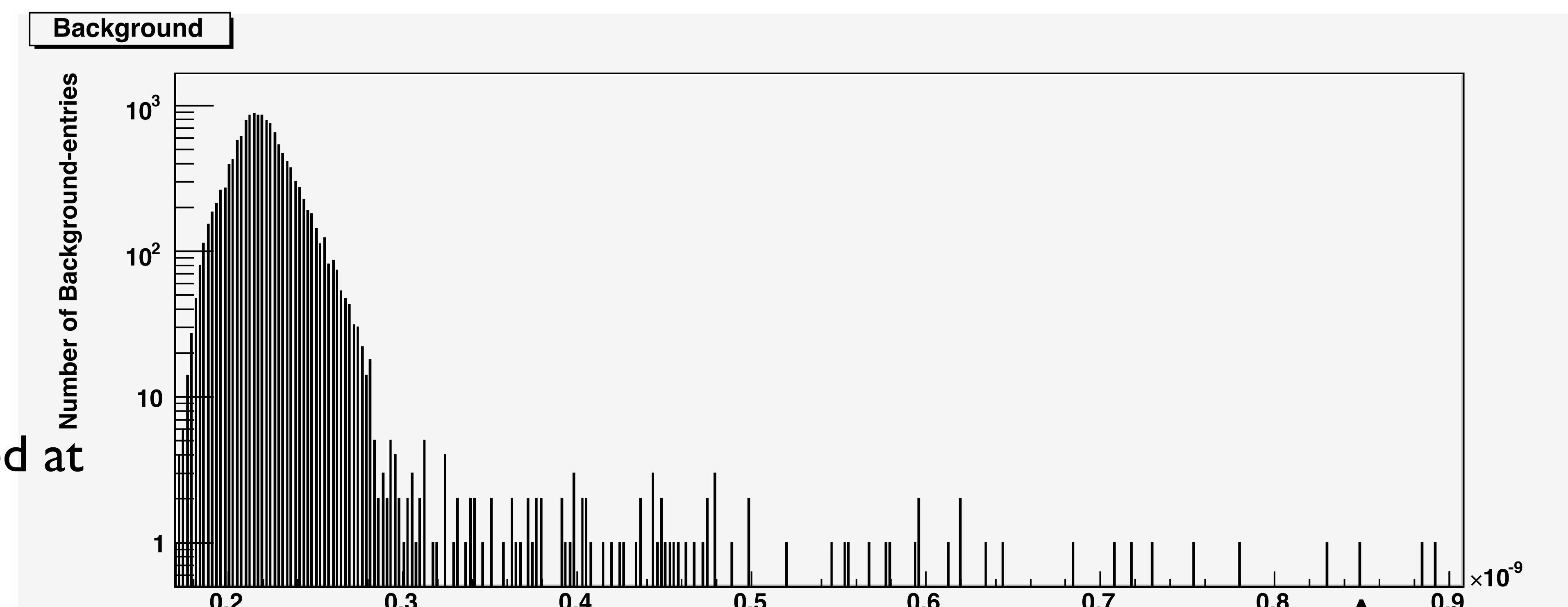
- Example from 1 day of running:

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



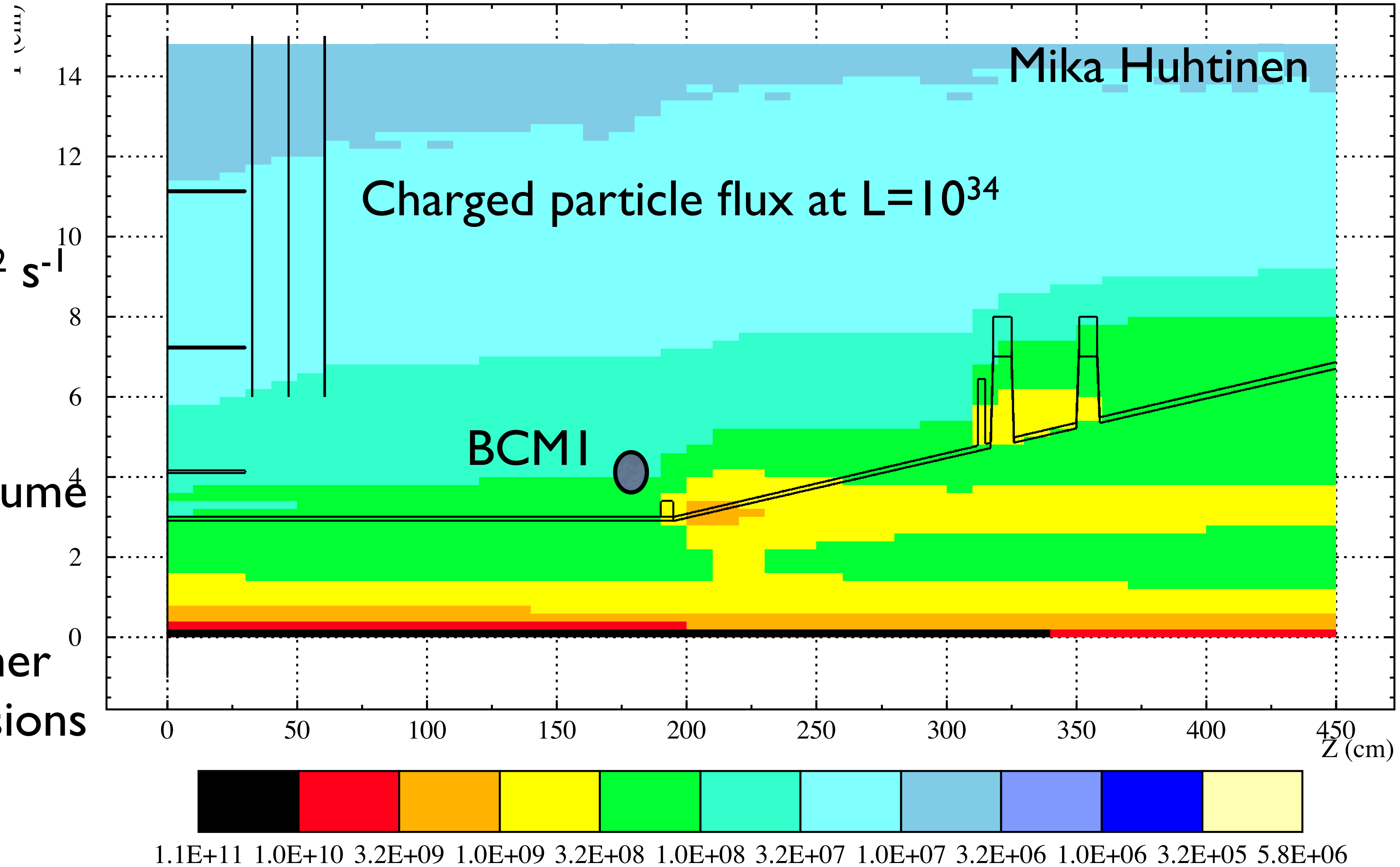
Analysis ongoing

Further testbeams planned at Louvain, Karlsruhe

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

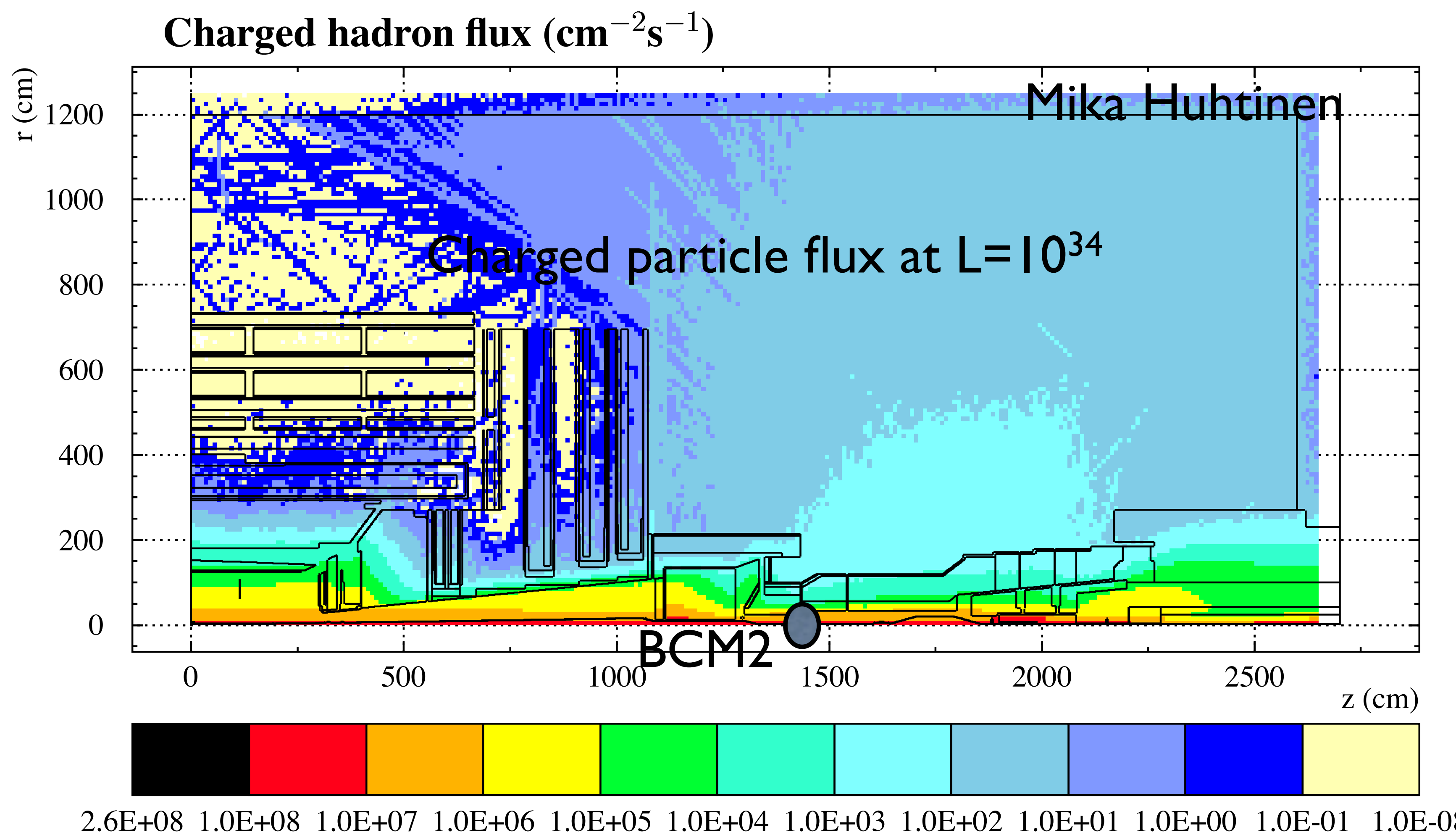
Expectations for Diamond Currents during Nominal Luminosity

- 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



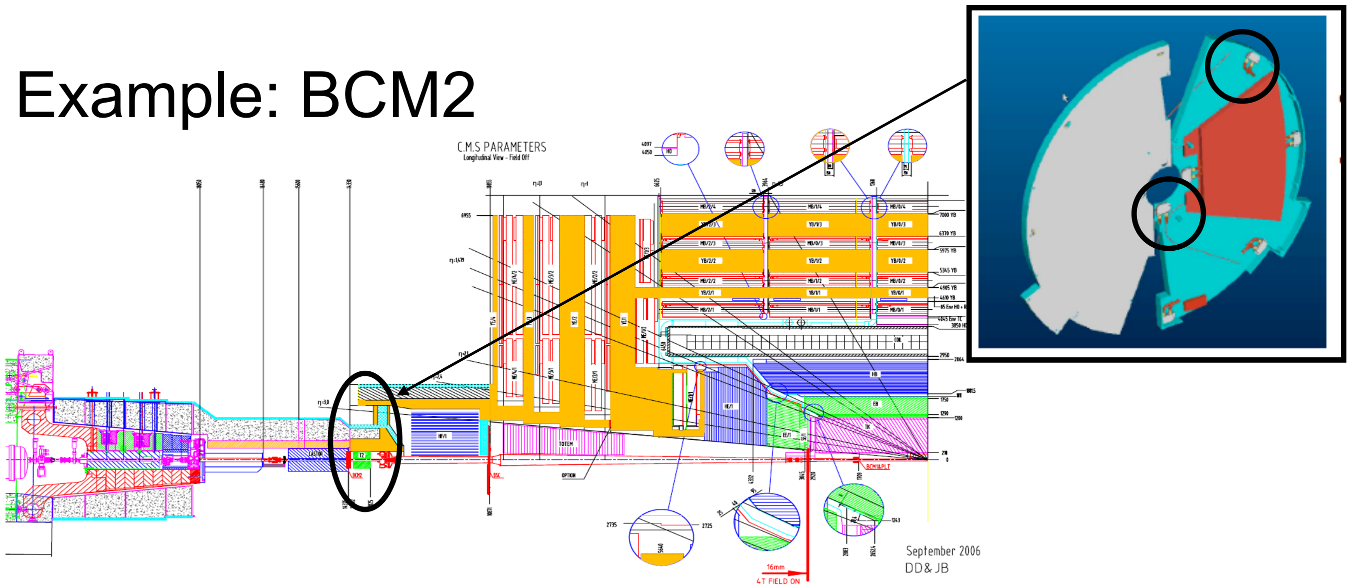
Expectations for Diamond Currents during Nominal Luminosity

- 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



Simulations

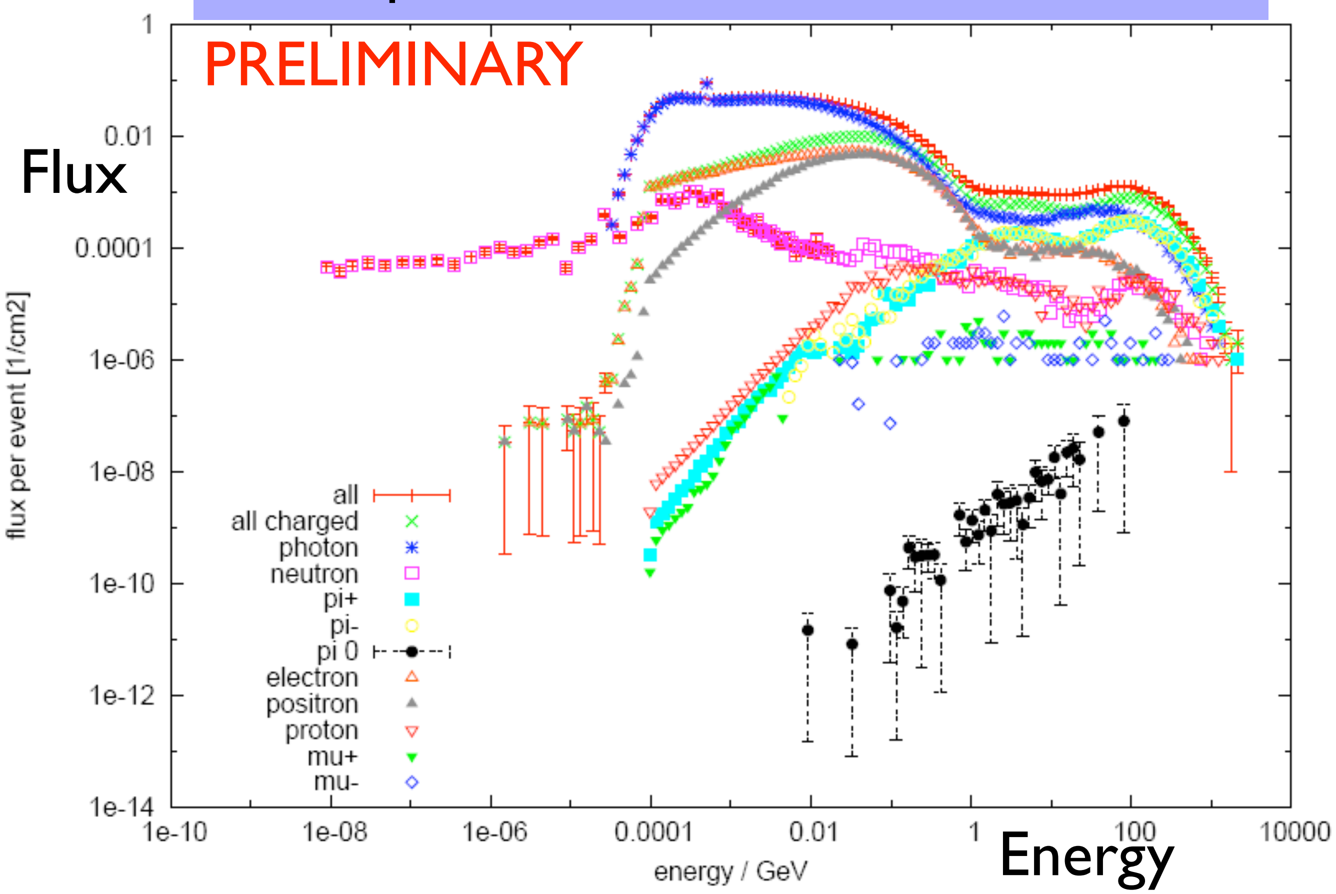
Example: BCM2



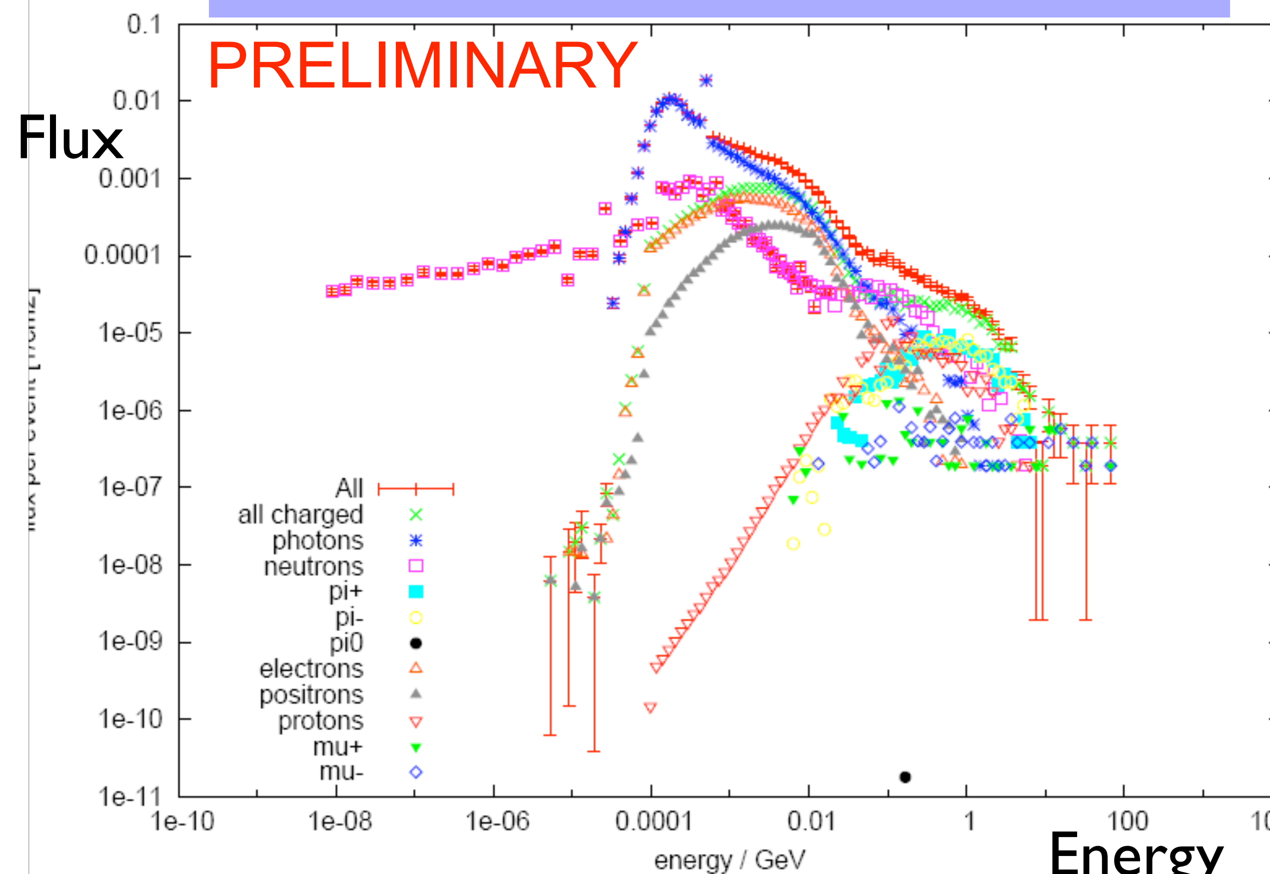
Two locations for BCM2 monitoring
r =5cm and r= 29cm
Outer position has ~O(100) increase in sensitivity to beam halo

- Aim to understand how relative rates seen in BCM locations correlate to rates in, eg, pixel detector
- Trying to determine particle species and spectra that will be seen by diamonds
- Initial results seem to confirm expected shadowing of outer BCM2 diamonds from collision products
- Ratio BCM2 OUTER/INNER sensitive to incoming beam losses

Inner position: Unshielded from IP

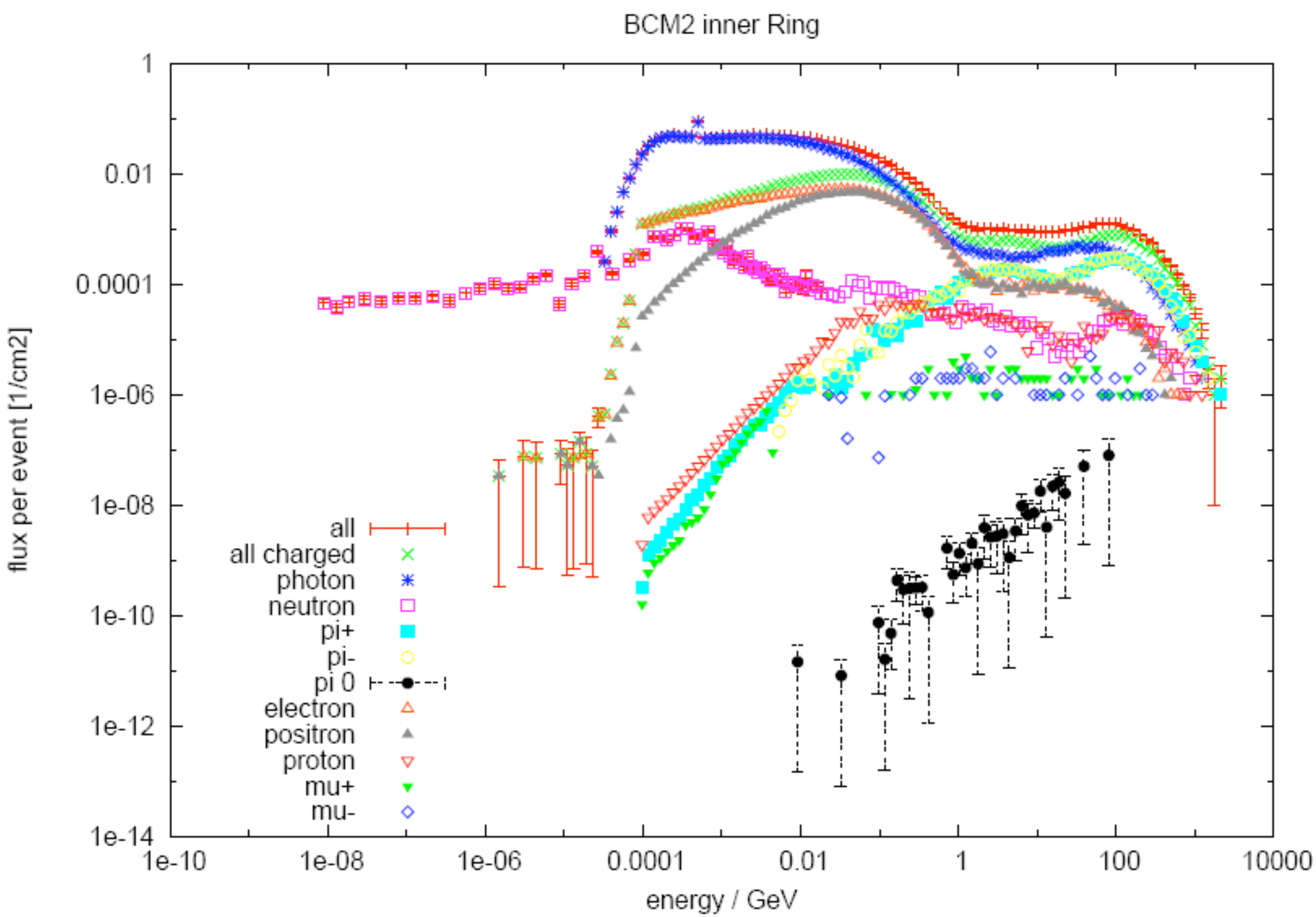


Outer Position: Shielded from IP



Particle Species

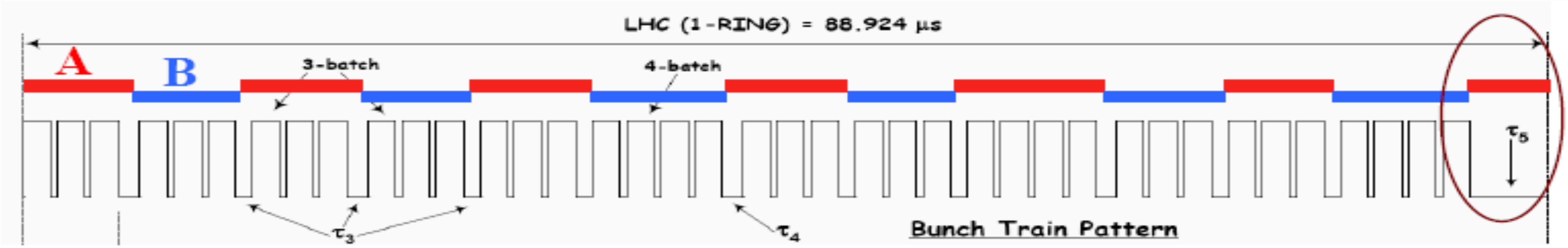
- Dominated by charged particles towards higher energies
- Dominated by photons at low energies
- In contrast to tunnel where there is more of a neutron “fog”



Beam Conditions Monitor: BCM2 Dynamic Range

- BCM2 Inner Position
- Nominal luminosity expected fluxes of charged particles 10^8 $cm^{-2}s^{-1}$
- Lower end of sensitivity < fluxes of 10^4 $cm^{-2}s^{-1}$
  - Corresponds to sensitivity to collisions at luminosity ca. 10^{30} $cm^{-2}s^{-1}$
  - "See" beam losses comparable to this level
- Upper end of dynamic range limited to 1mA measured
  - Fluxes of ca. 10^{10}-10^{11} $cm^{-2}s^{-1}$
  - 2-3 orders of magnitude above "nominal" luminosity
- During Pilot Physics Run (Stage A) - 43x43 bunches to 156x156 bunches
  - Target luminosity 6.10^{30} $cm^{-2}s^{-1}$
  - Limit luminosity 10^{32} $cm^{-2}s^{-1}$
  - EDMS doc 876824, commissioning procedures Stage A
- BCM should become sensitive as a monitoring device during the pilot physics run

Beam Conditions Monitor: Sub-Orbit Monitoring



Synchonized sampling over LHC Bunch train structure and abort Gap

- Natural unit for BLM (and BCM2) is 40 us
  - Not synchronised with the LHC orbit marker
- BCM1L offers sub-orbit monitoring
  - Information on beam losses patterns within the orbit
- Up to 15 measurements of the orbit
  - Each sample 3-6 us long
  - Configurable
  - 1 sample is the sum of the losses over the entire orbit
  - BLM Readout of the data is unchanged
  - Appears as different “channels” in the Monitoring
  - Similarly to BLM, information over several time periods is reported
  - 1 orbit - many seconds
- Of particular interest to CMS is the abort gap monitoring
  - Immediately downstream of dump for beam 2 ...

CMS Beam Scintillator Counters

CMS Beam Scintillator Counters

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

Will need replacement at some point

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 (+LHC?): 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

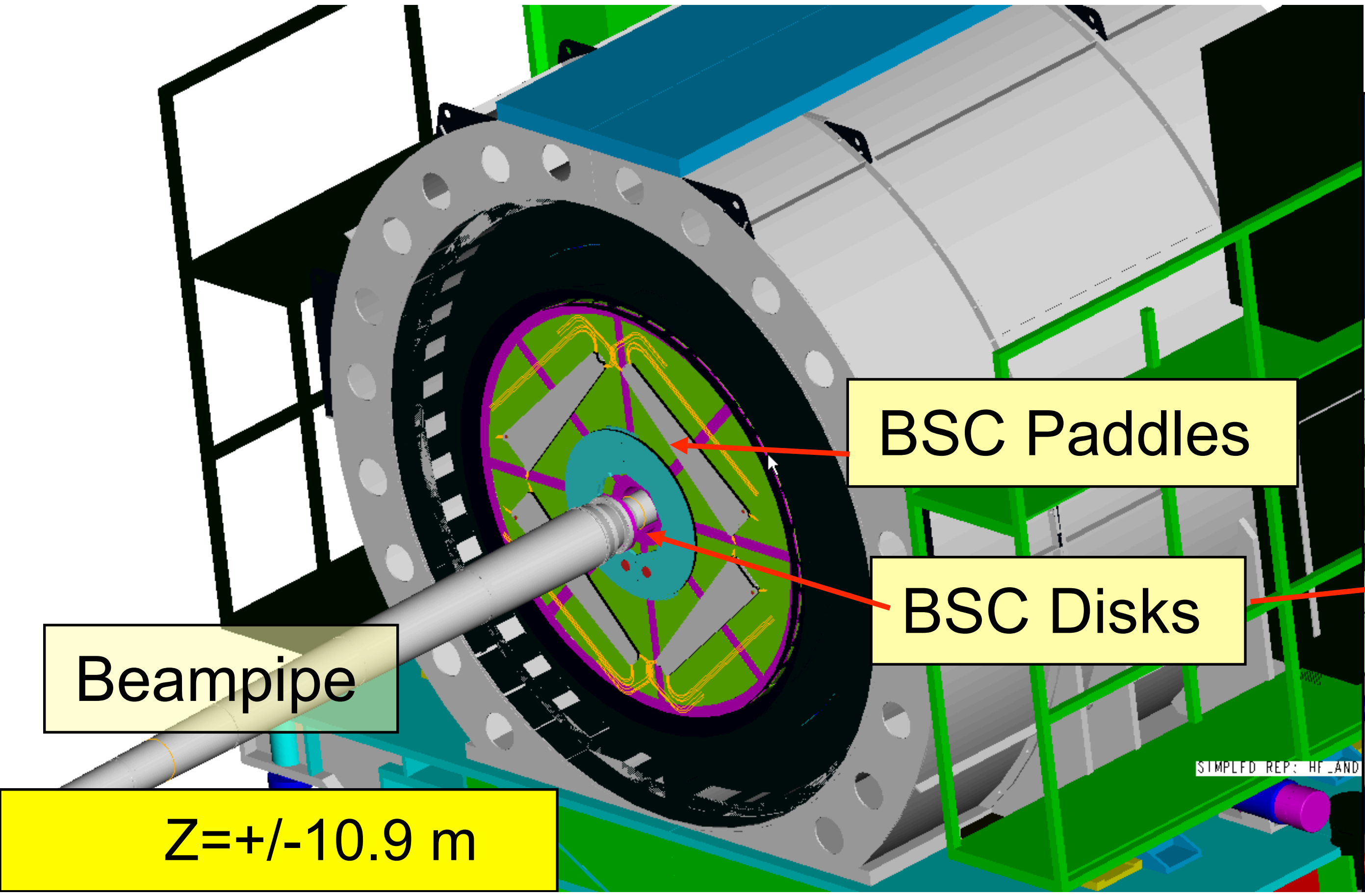
✓ Installation on schedule

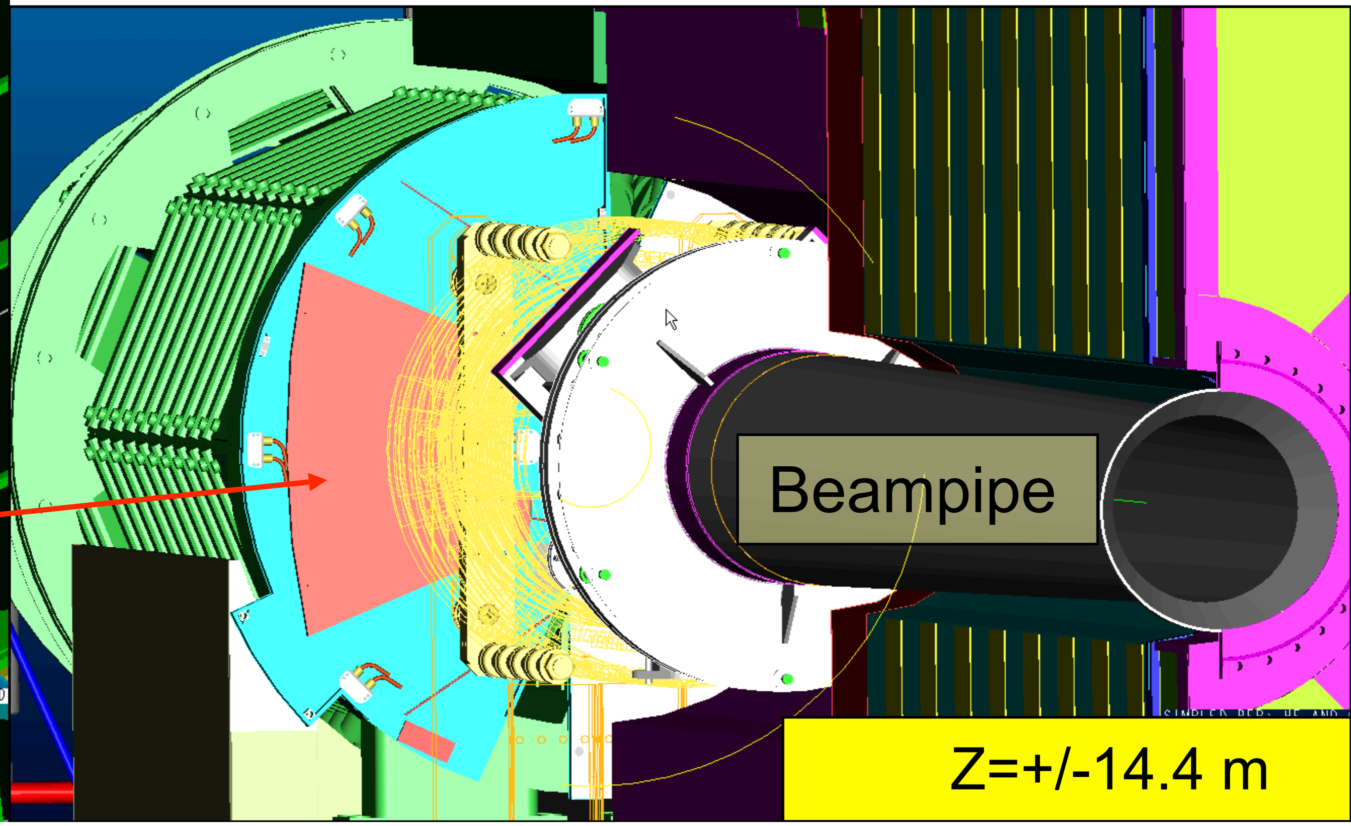
BSC1 --- 11 000 cm^2

Inner radius - 15 cm

BSC2 --- 1 000 cm^2

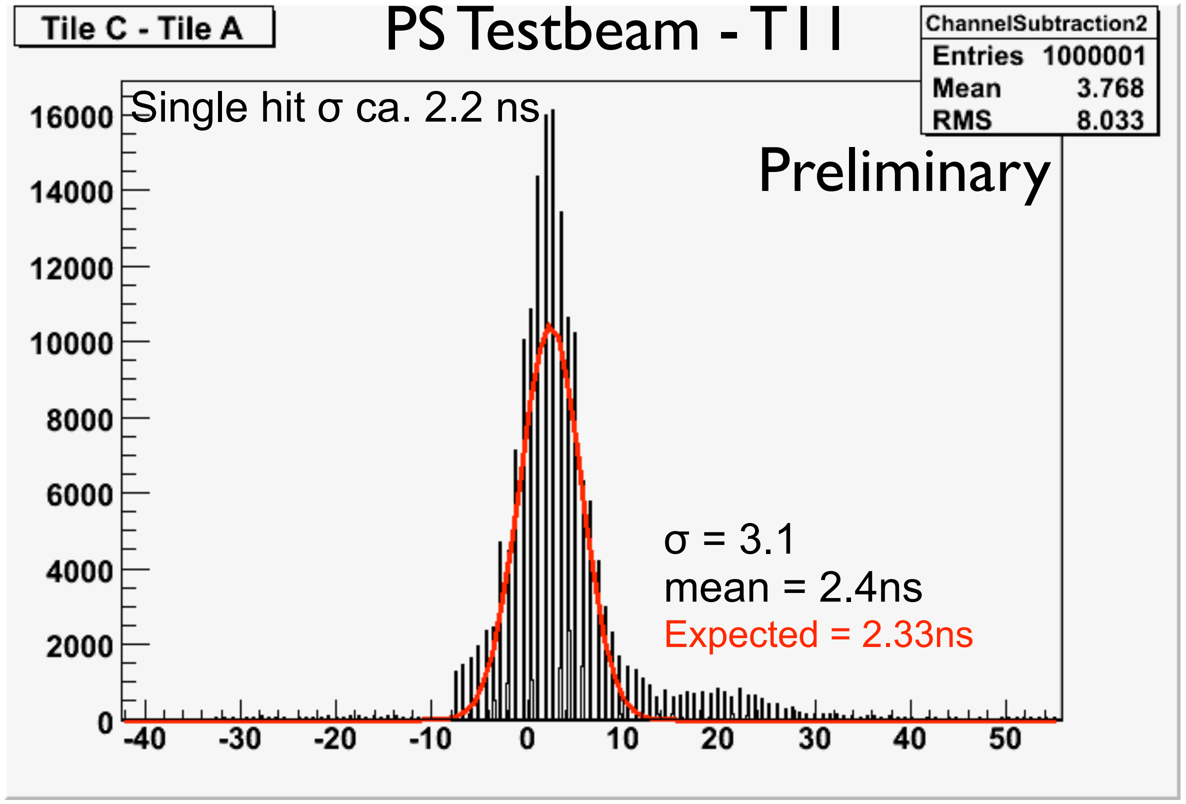
Inner radius - 5 cm



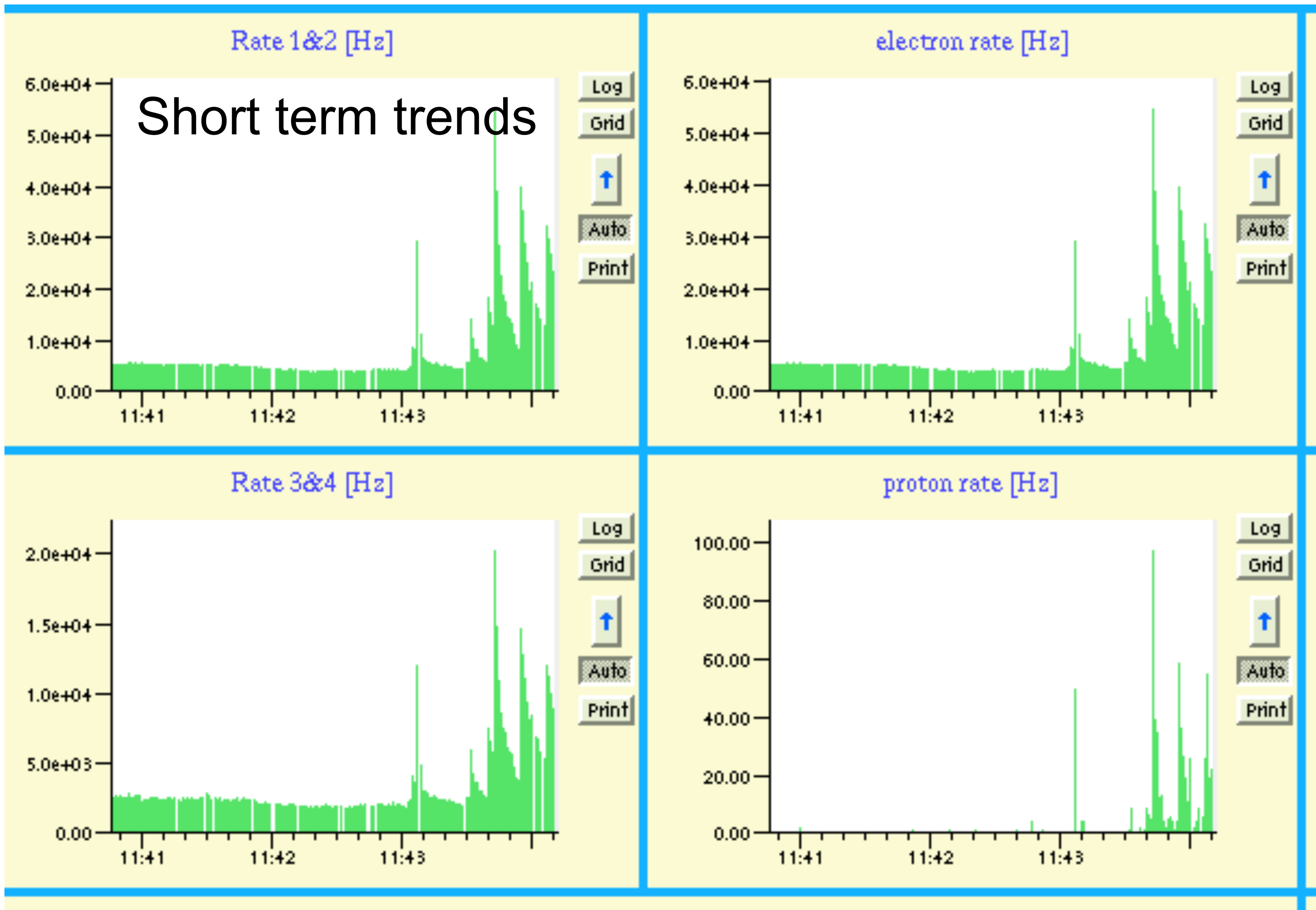


Beam Scintillator Counters

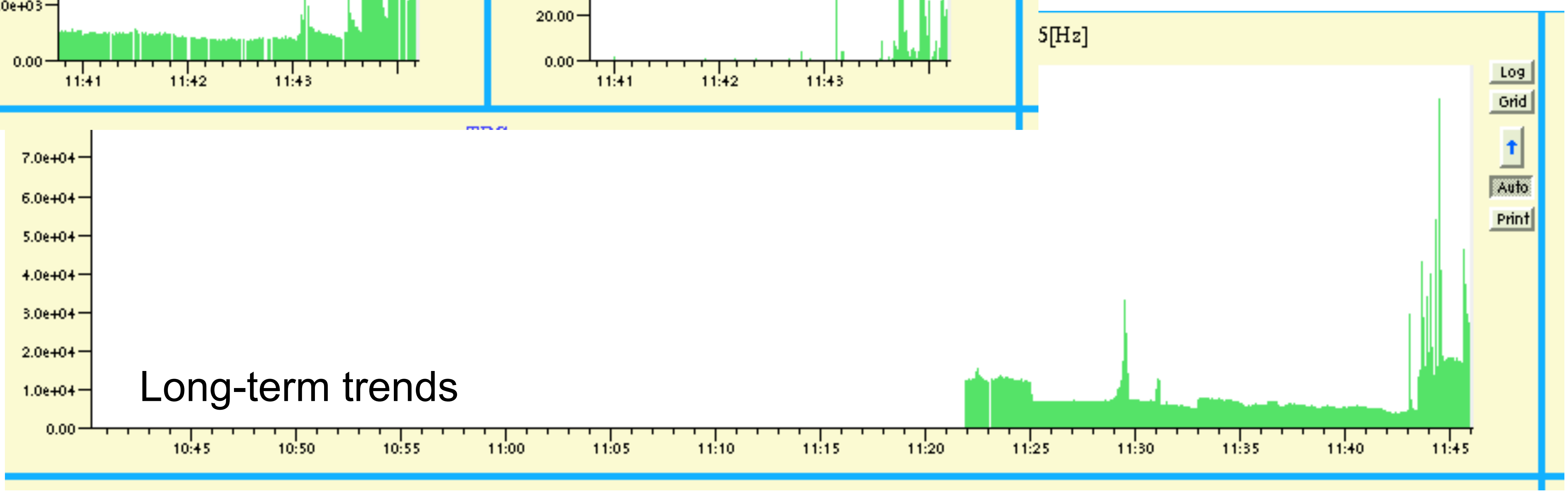
- Beam Scintillator Counters foreseen as a commissioning tool
  - First 1-2 years
  - Not radiation hard technology - expected to survive 1-2 years
  - Possible replacement depending upon usage
- Lower end dynamic range - MIP sensitive
  - Sensitive to pilot bunch
  - Upper end dynamic range
  - Initial readout limited to expected losses during luminosity at $L=10^{32}$
- Data from BSC available via DIP at ca. 1 Hz
  - Hit rates from tiles
  - Geometrical distribution of losses
  - Coincidences between tiles (halo muons)
  - Timing of hits - timing of losses within orbit
    - Bunch structure and ABORT GAP occupancy
  - Timing of hits - discrimination between in-going and out-going particles - dt(in-out):
    - Single hit timing resolution 2-3ns
    - BSC1 2.3ns ; ok for pilot-run only
    - BSC2 4.3ns - possible for 25ns spacing



Rate Monitoring - Examples from ZEUS



- Design of BSC based upon similar devices at other previous experiments
- Examples of what the short-term and long-term trending might look like shown here
- Rate monitoring similar to this expected for hit-rate and coincidence rate
- Also for gated-rates of in-going and out-going particles



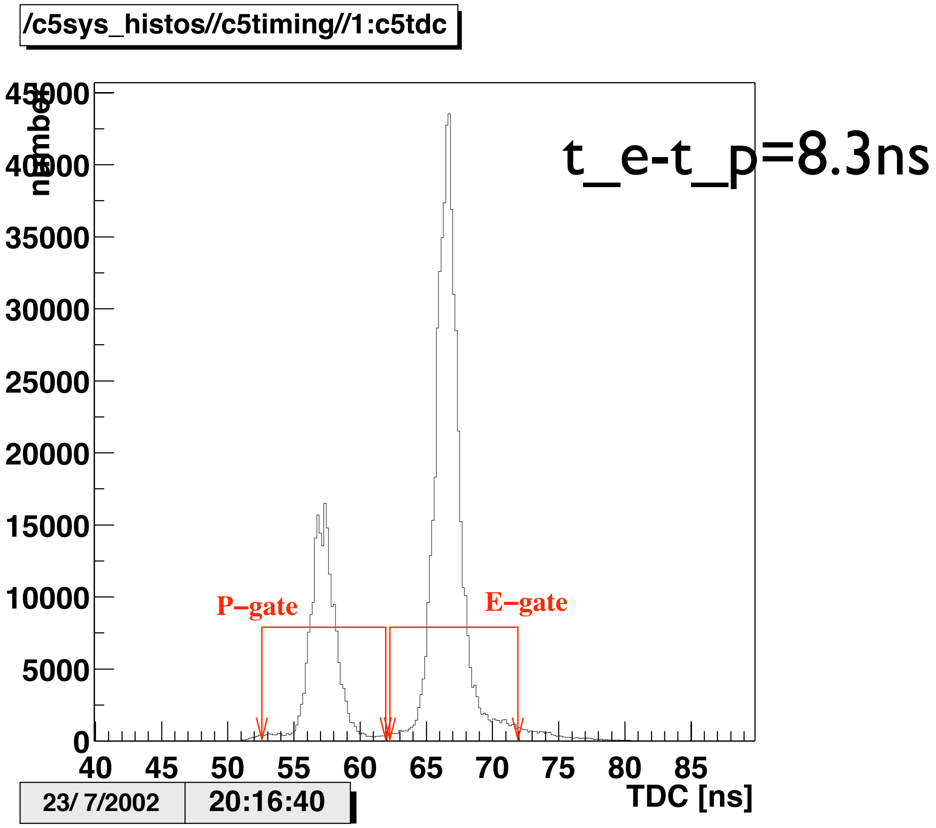
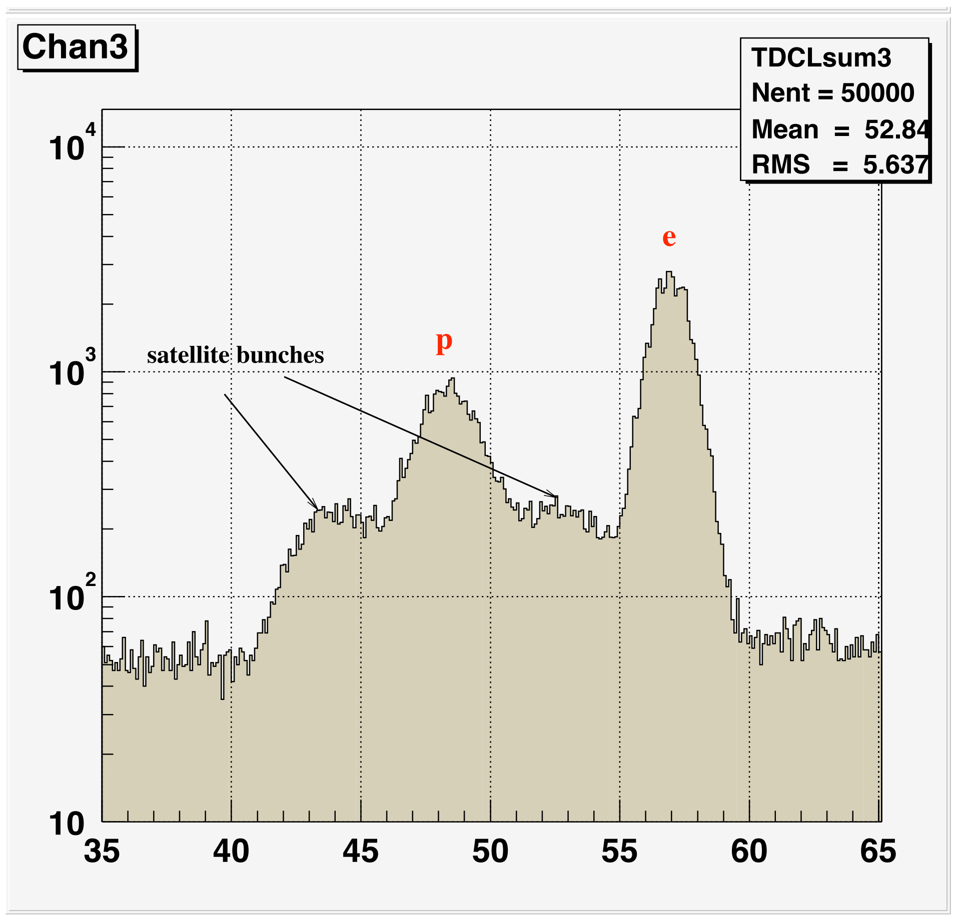
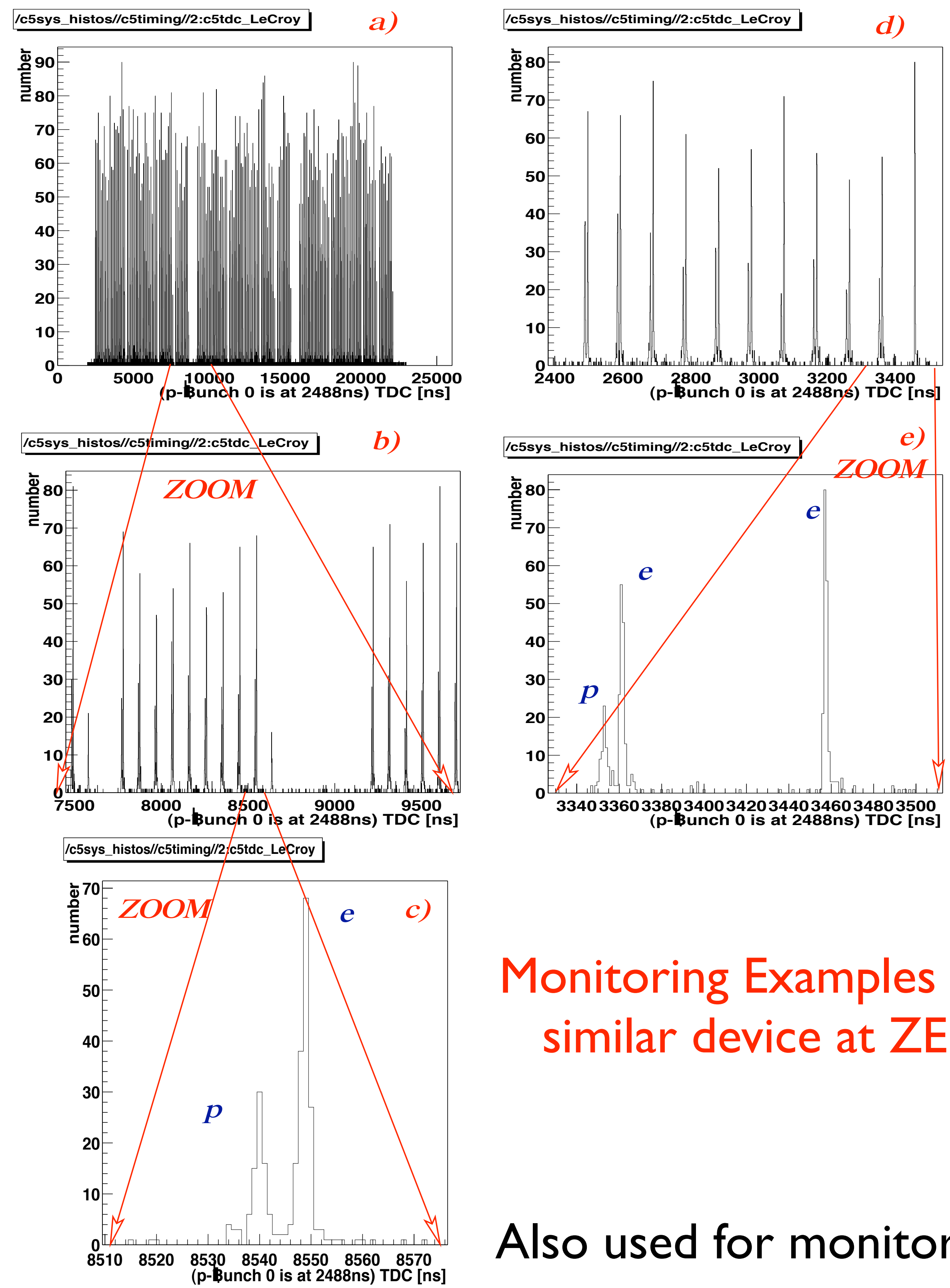


Figure 4.11: Timing spectrum with electron (right) and proton (left) beam.





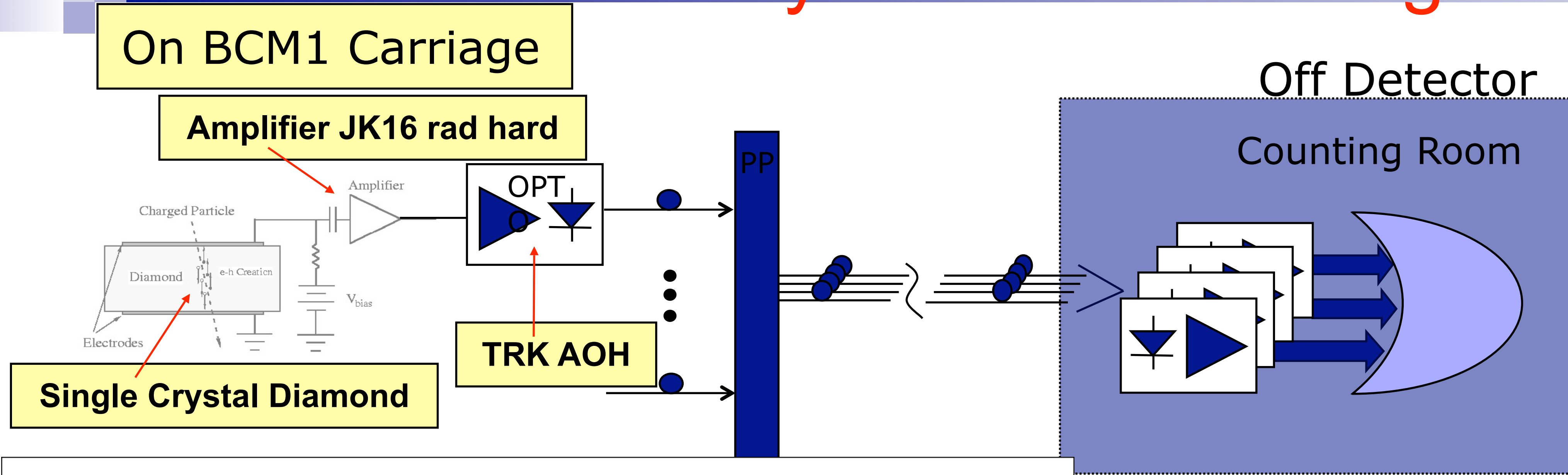
Monitoring Examples from similar device at ZEUS

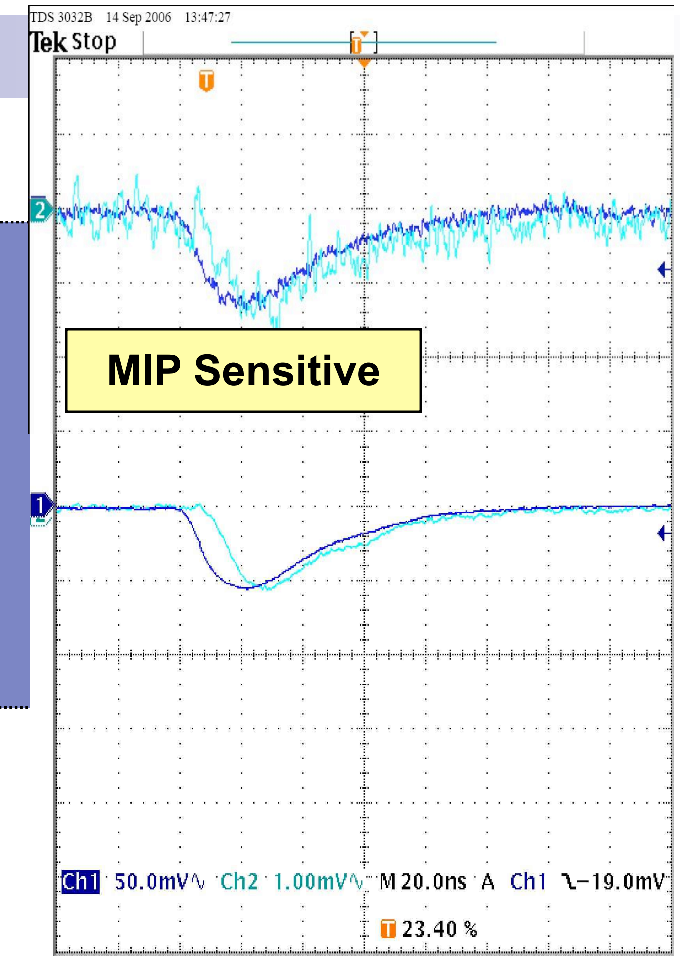
Also used for monitoring z vertex

Figure 4.12: LeCroy TDC histogram. a) Full HERA bunch train. b) Zoom plot with empty bunches c) zoom plot with only one bunch filled with electrons and protons. d) Plot with first HERA bunches. e) Zoom plot with *ep* bunch and *e* only bunch. In all plots 1 bin = 1 ns.

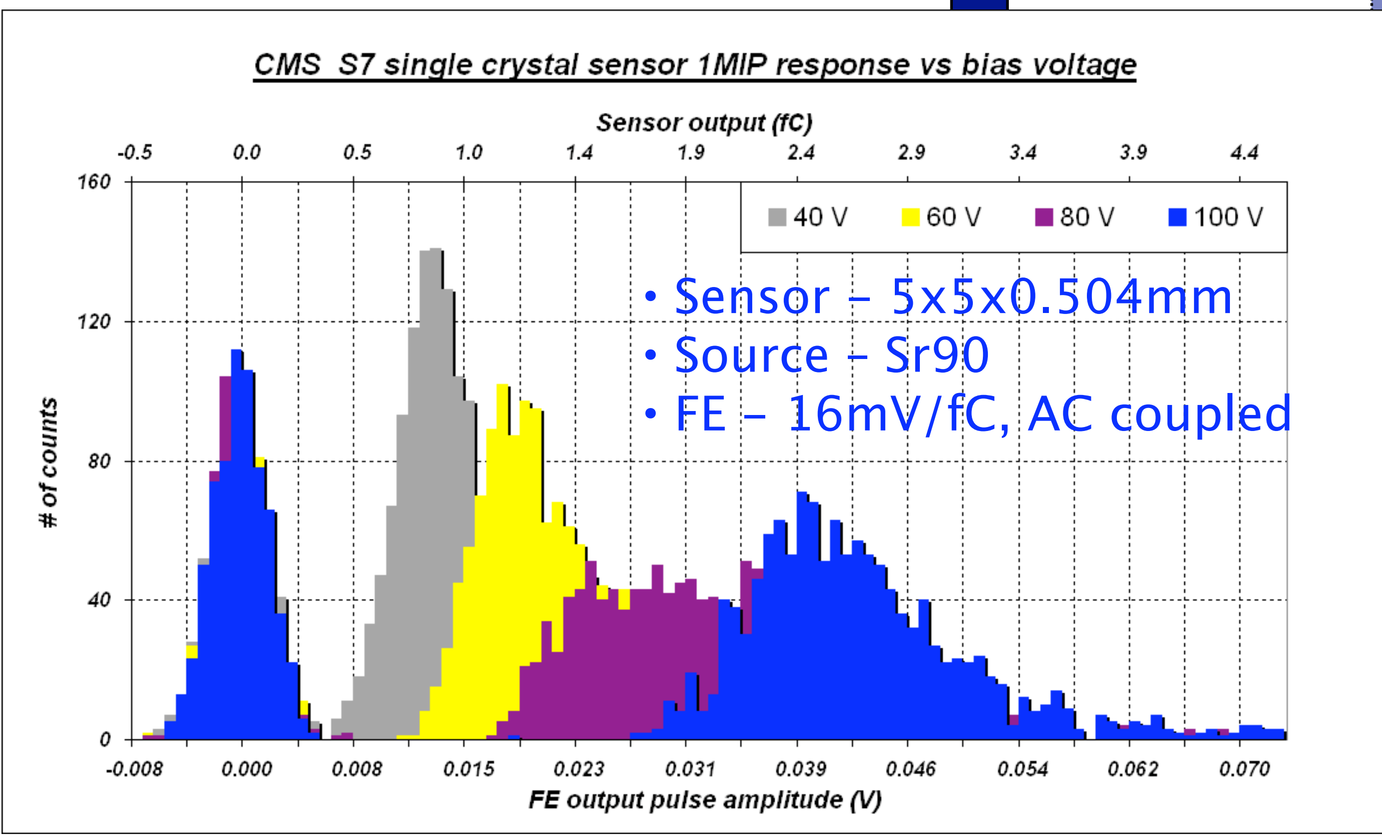
J. Fourletova's, DESY-THESIS-2004-046

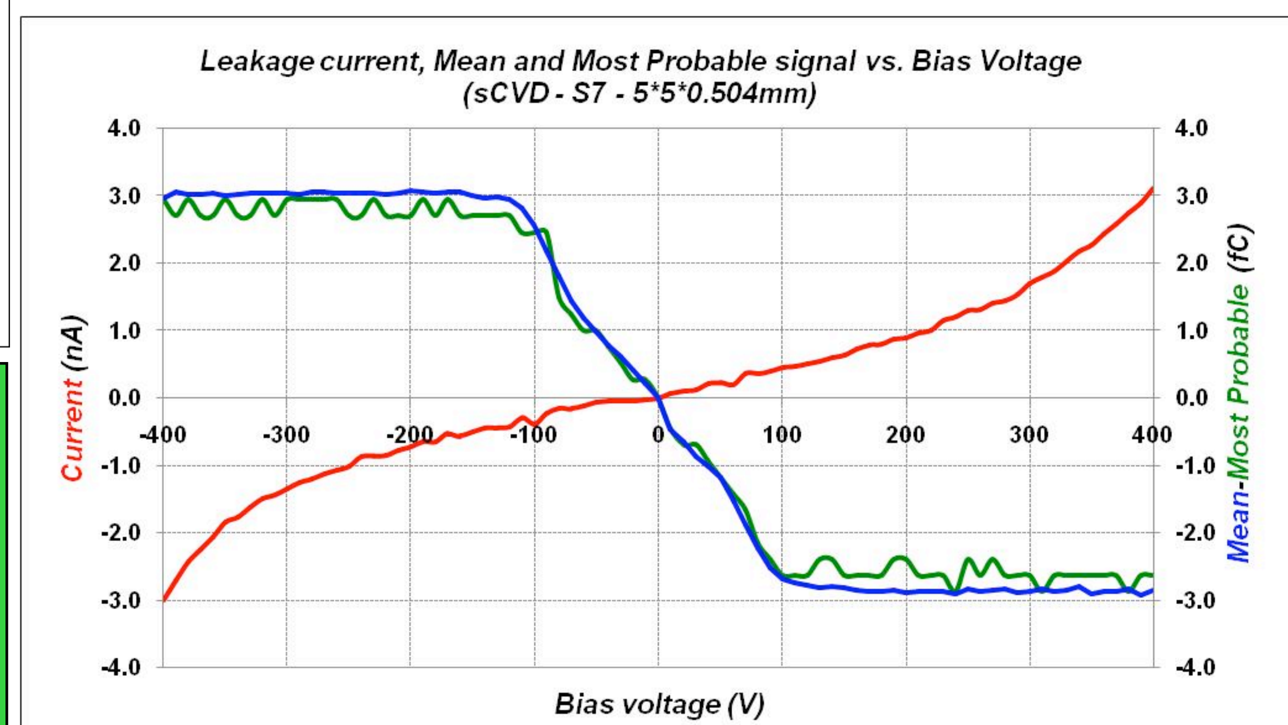
BCM1F: Bunch by bunch monitoring





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





BCM1F readout chain tested with final design sensor, Front End board

Assembly, testing, calibration of FE boards ongoing at CERN

Will be ready to mount early next year

38

CMS BPTX

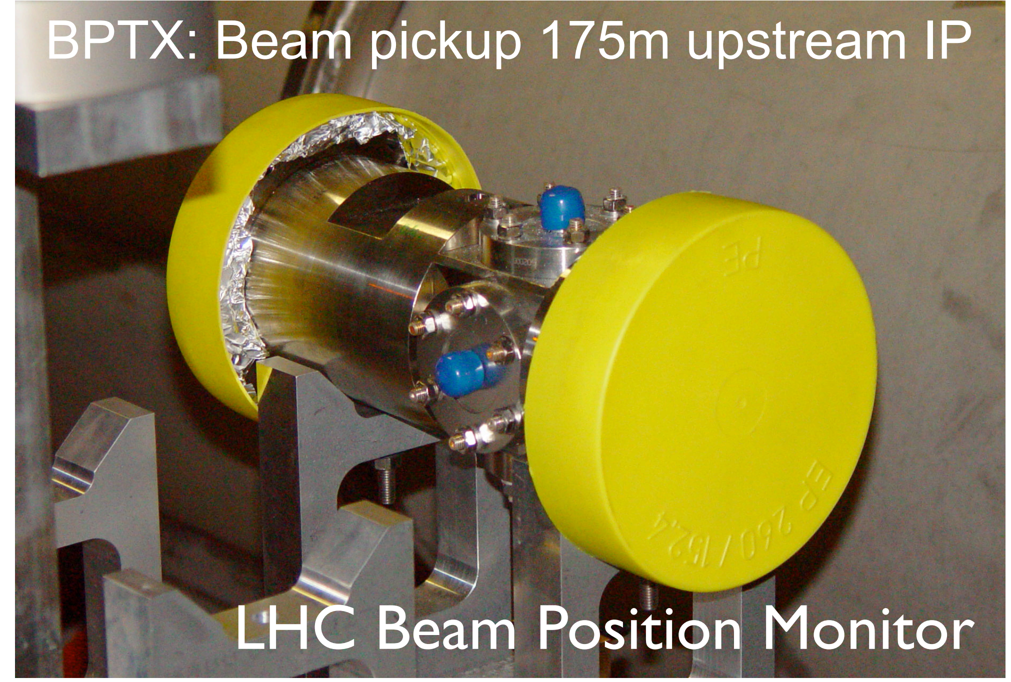
Beam Timing for the eXperiments

CMS Implementation developed jointly with ATLAS

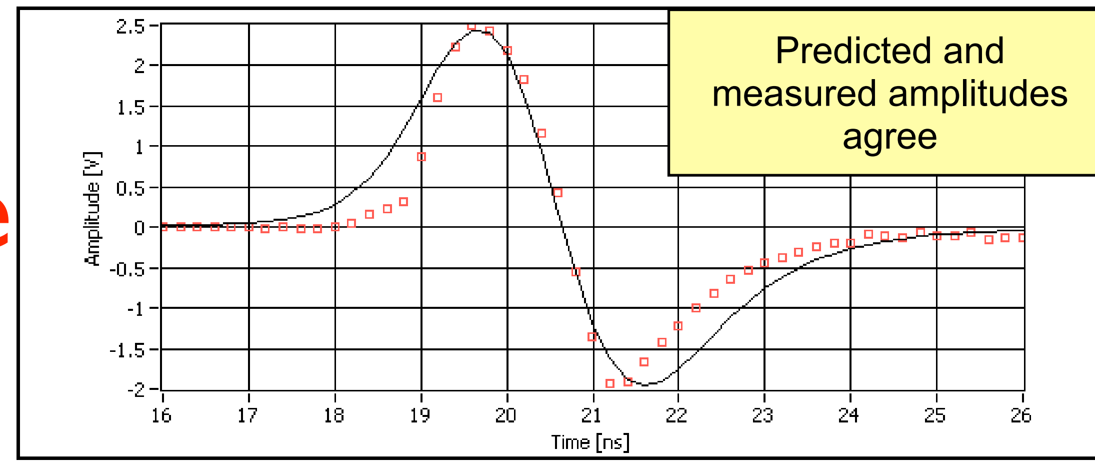
Monitoring: BPTX

Beam Timing for the Experiments

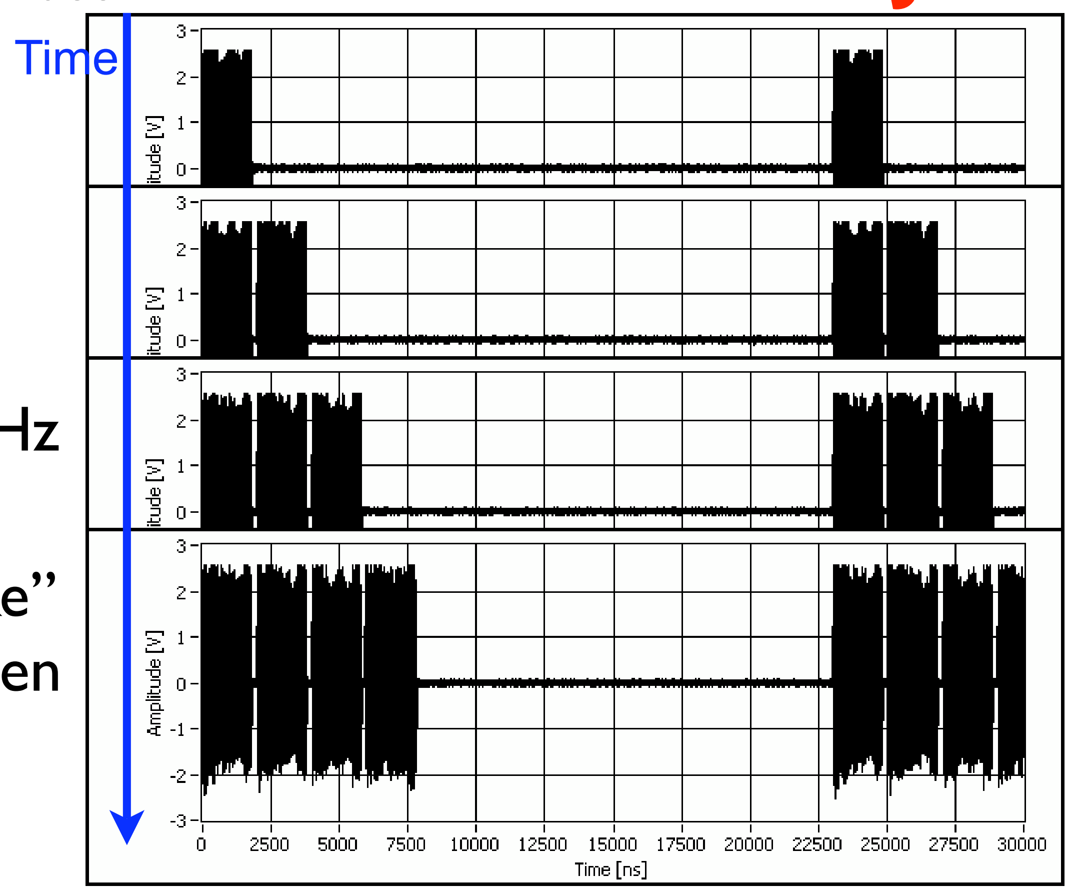
- Trigger on orbit marker
  - Measure **phase** between bunch and 40MHz Expt clock
  - Check **filling scheme;** bunches in correct RF buckets.
  - Check abort gap is empty.
  - Check for **satellite bunches** in neighbouring RF buckets
  - Measure the **intensity** (or amplitude) of each bunch
  - Measure the **period of the clock**
- Scope-based readout chosen jointly with ATLAS
  - Will also check phases of different clocks
  - Calculate z position of IP
  - Technical Trigger input
  - Sensitive to first beam



Analog Signal: ~1ns FWHM
Orbit length= 89us Samples entire orbit
Sampling at 5GSamples/sec =>200ps sampling



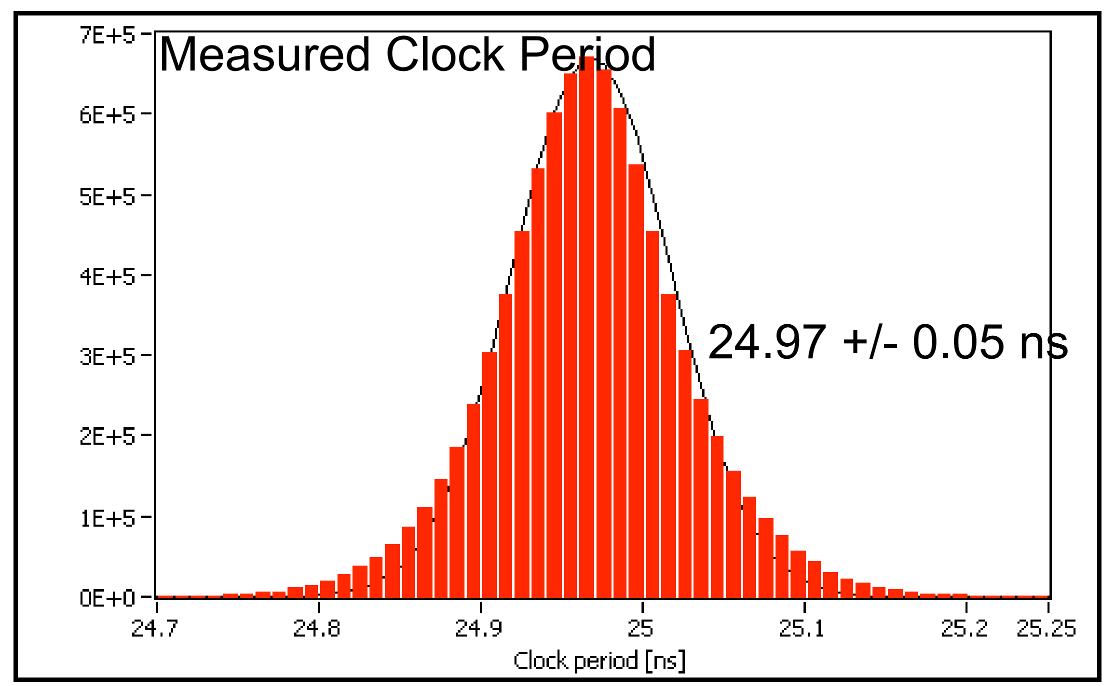
SPS Testbeam - June



Data broadcast over DIP

Rate ca. 0.2-0.5 Hz

“Oscilloscope-like” display also forseen



Summary

- CMS Beam and Radiation Monitoring will be installed and complete from day 0
- Data format and logging as similar to LHC standard as possible

Dynamic Range	BCM	BSC	BCM1F	BPTX
Minimum Sensitivity	$<10^4$ cm^{-2}s^{-1}	MIP	MIP	< Pilot bunch
Minimum Luminosity	ca. 10^{30} cm^{-2}s^{-1}	Pilot	Pilot	Pilot
Maximum Luminosity	> nominal	ca. 10^{32} cm^{-2}s^{-1}	> nominal	> nominal

- Individual pieces of information available from each monitoring device outline in talk
- However, aim is to put this into a framework, where the data from several monitoring devices is drawn together to answer the specific questions of interest, such as:
  - What is the state of the machine?
  - What is the bunch structure/occupancy?
  - What is the luminosity?
  - Level of the beam halo?
  - Cleanliness of the abort gap?
  - Conditions in whole of LSS5?
  - Conditions in the CMS UXC Cavern