Beam Conditions Monitors for the CMS experiment at the LHC

Steffen Mueller

CERN / KIT Karlsruhe

on behalf of CMS Beam and Radiation Monitoring Group

BRM Subsystems

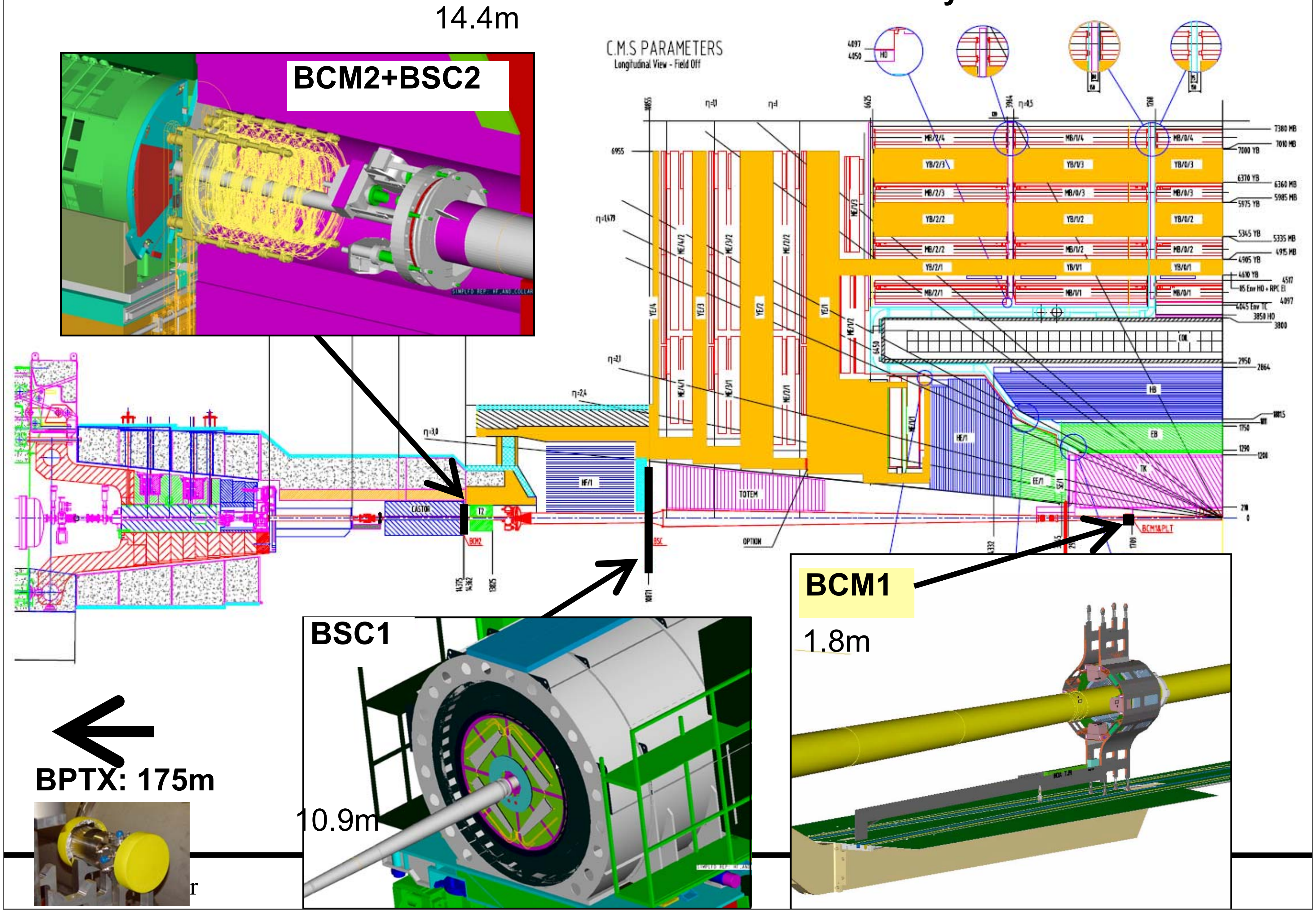
Subsystem	Location	Sampling time	Function	Readout + Interface
Passives TLD + Alanine	In CMS and UXC	Long term	Monitoring	---
RADMON	18 monitors around CMS	1s	Monitoring	Standard LHC
BCM2 Diamonds	At rear of HF z=±14.4m	40 us	Protection	CMS + Standard LHC
BCM1L Diamonds	Pixel Volume z=±1.8m	Sub orbit ~ 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

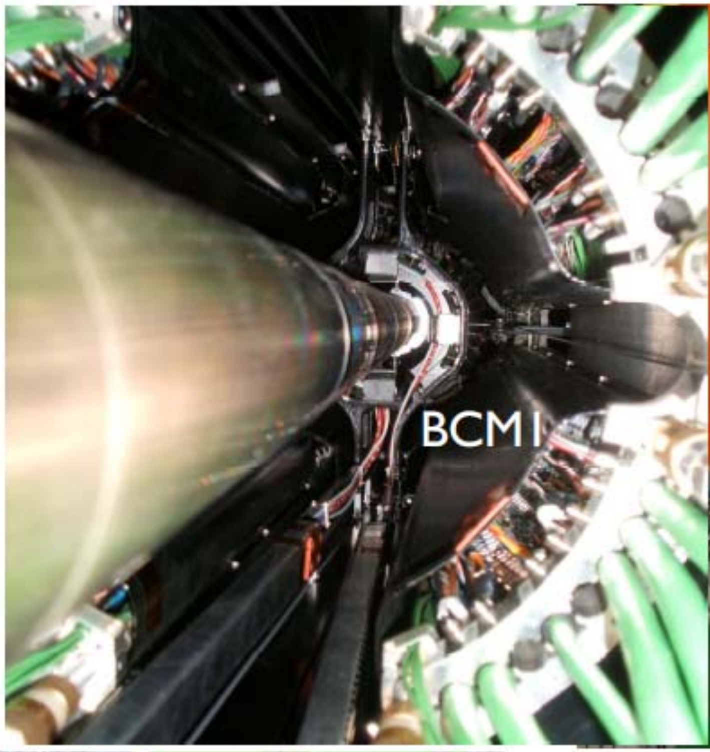
Total number of diamonds used: 32 pCVD and 8 sCVD

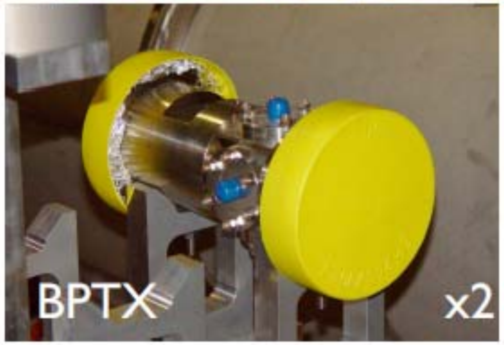
RADMON: 18 monitors around UXC

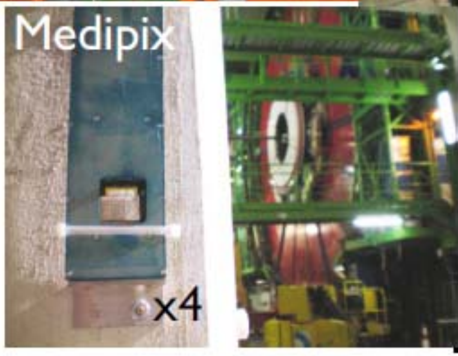
PASSIVES: Everywhere



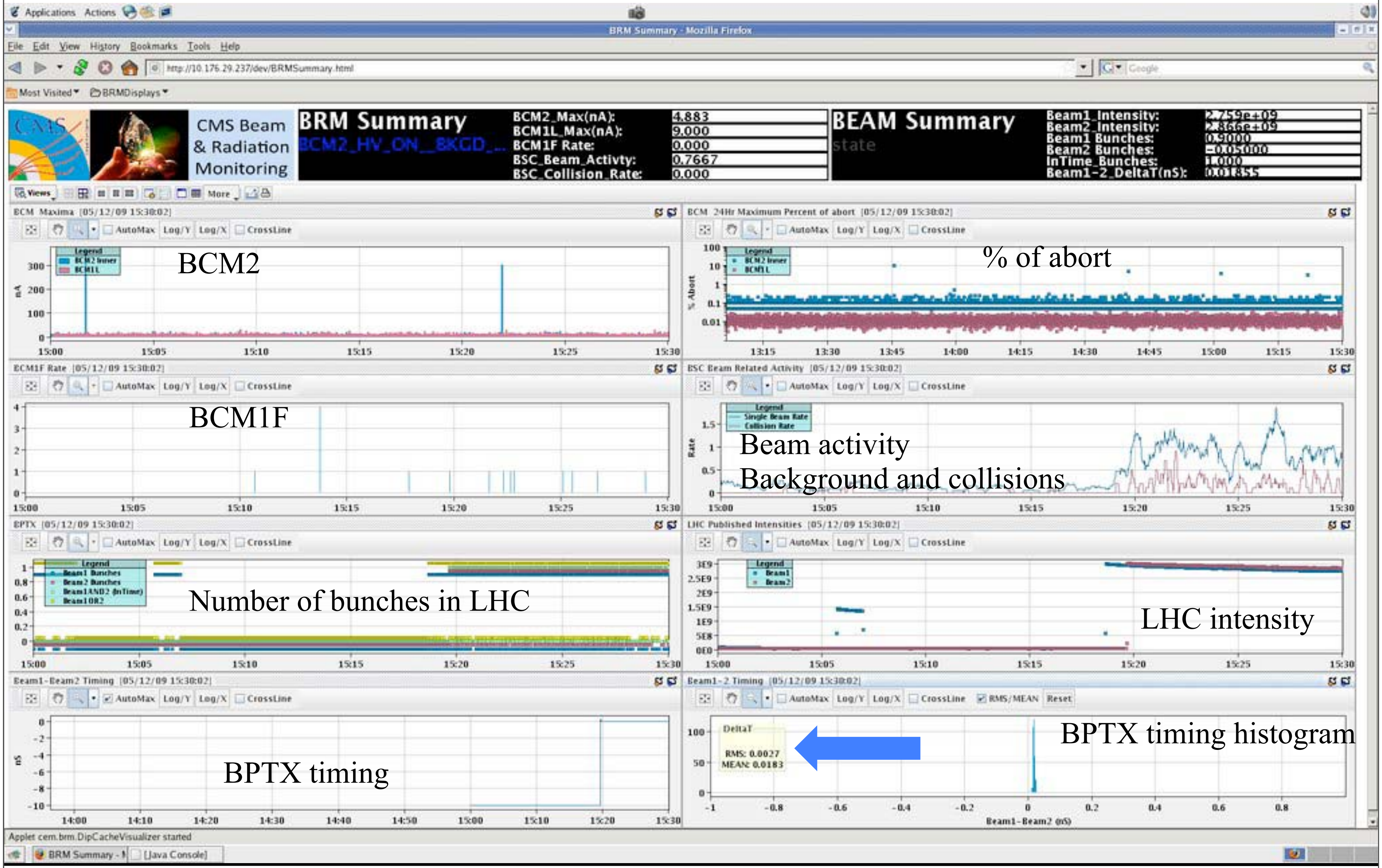
… and in reality



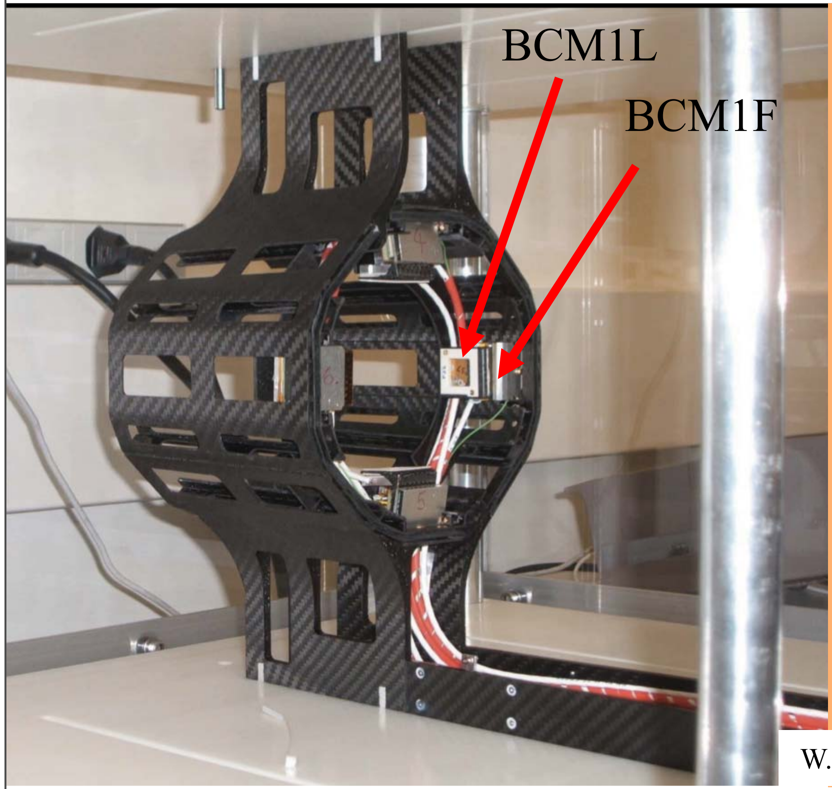




BRM summary online display – normal conditions

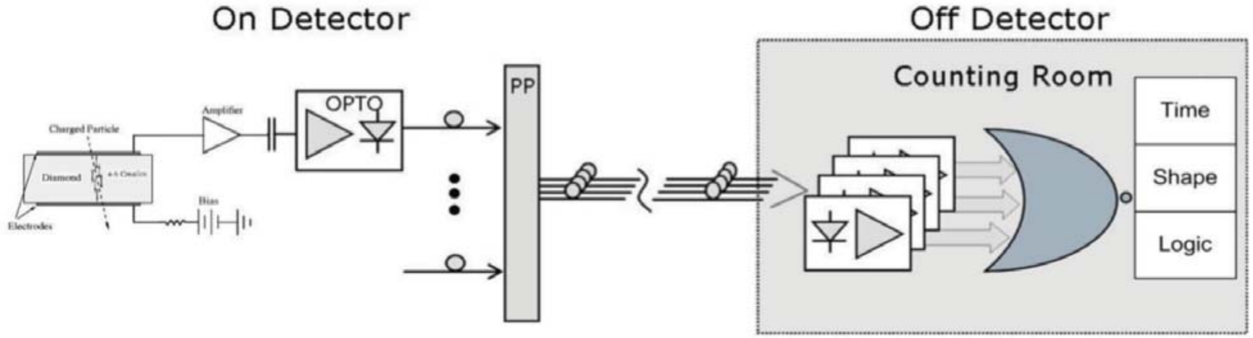


BCM1F / BCM1L



BCM1F

- Fast diagnostic tool for bunch by bunch monitoring of both beam halo and collision products.
- Located at Z+/- = 1.8m with a radius of 4.5cm.
- Detectors used are sCVD diamond with a size of 5x5x0.5mm



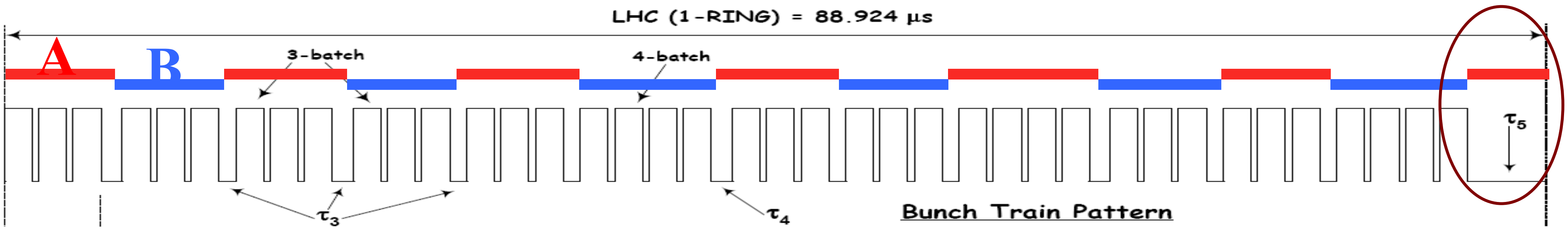
W.Lohmann et al, "Fast Beam Conditions Monitor BCM1F for the CMS Experiment", accepted NIM A (2009)

BCM1L

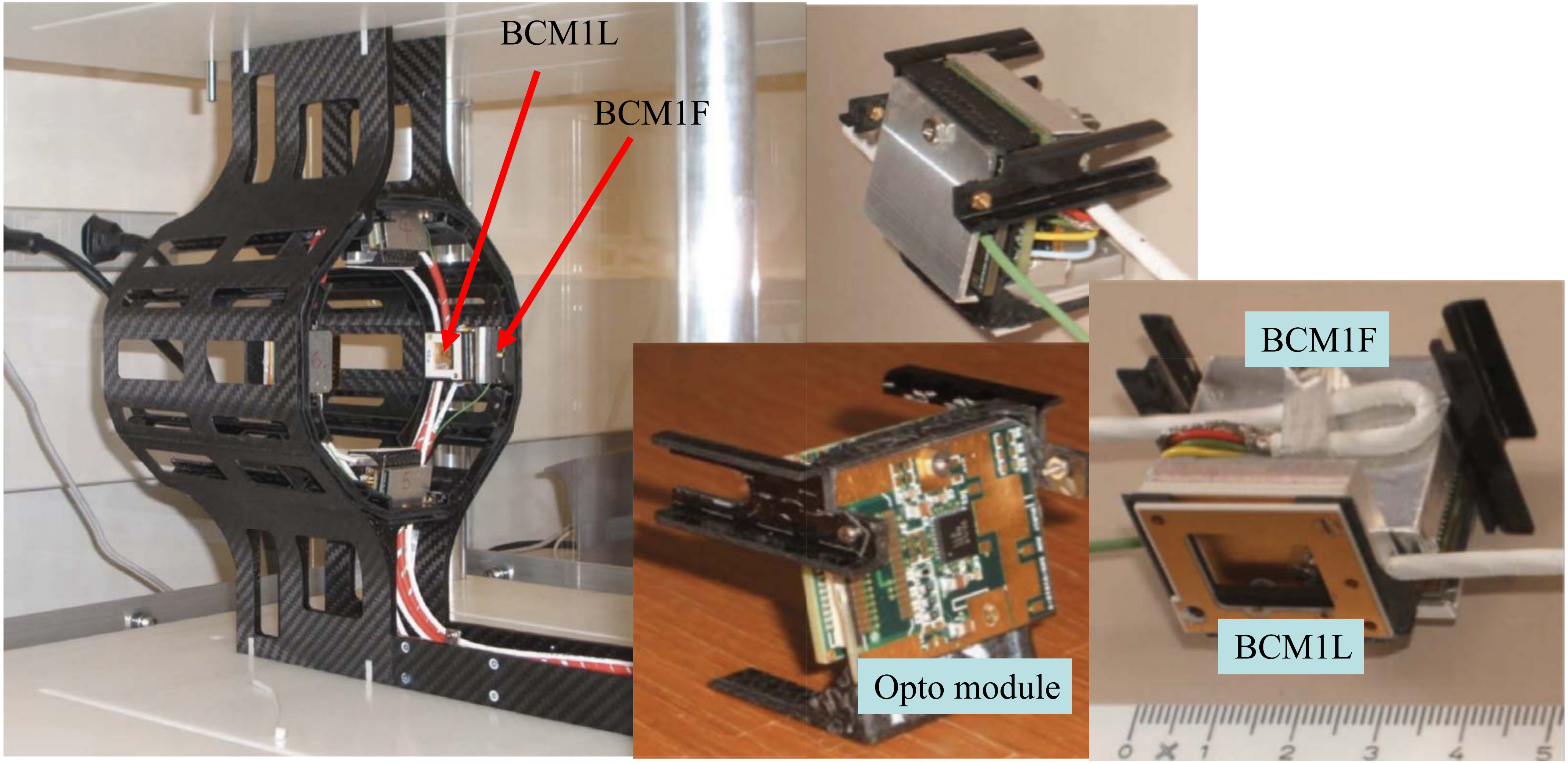
Leakage current monitor, 8pCVD, 1cm2

Readout: Standard LHC Beam Loss Monitor

Synchronized sampling of beam structure and abort gap
Integration time ~6us



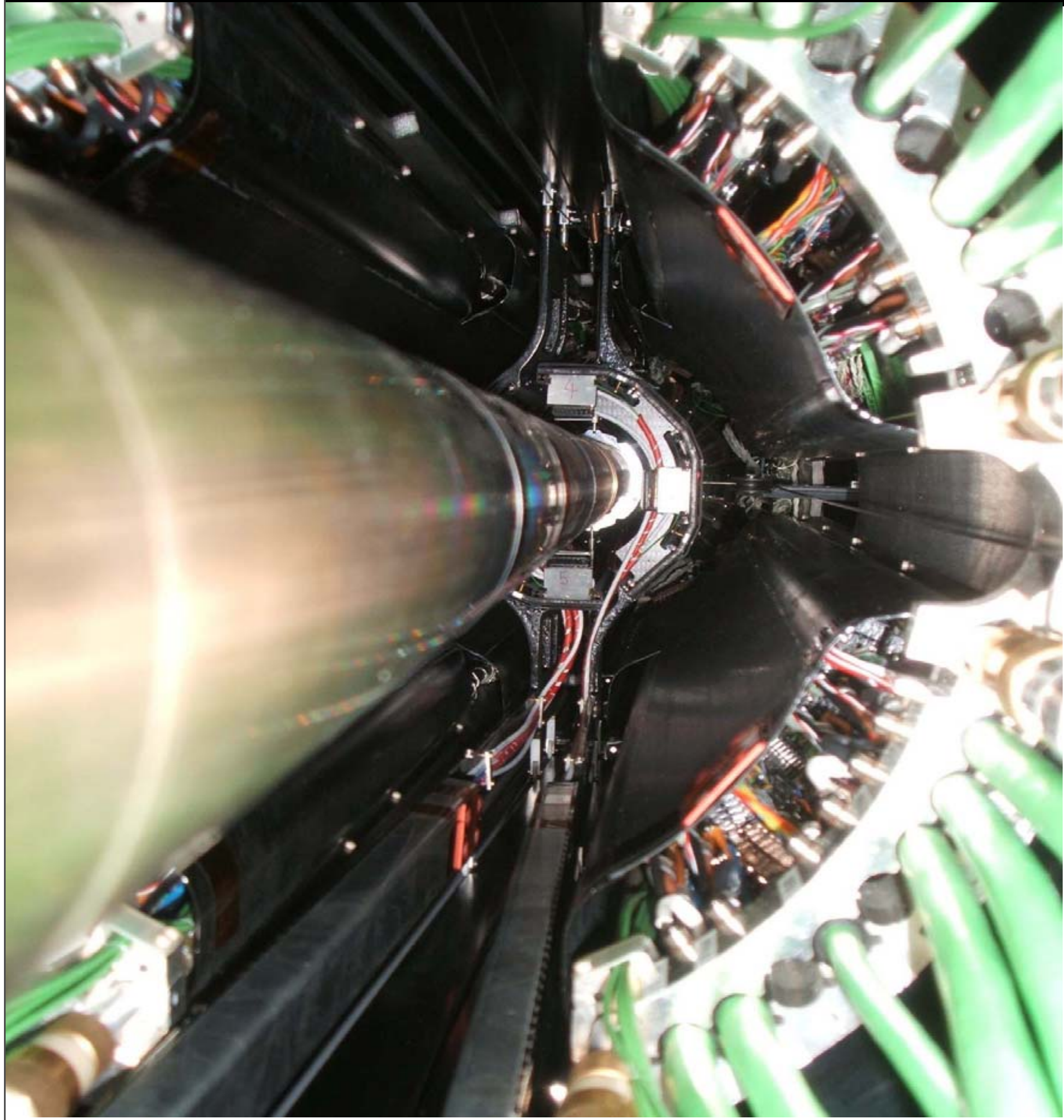
BCM1 integration



Main challenge was to integrate everything into very little space!

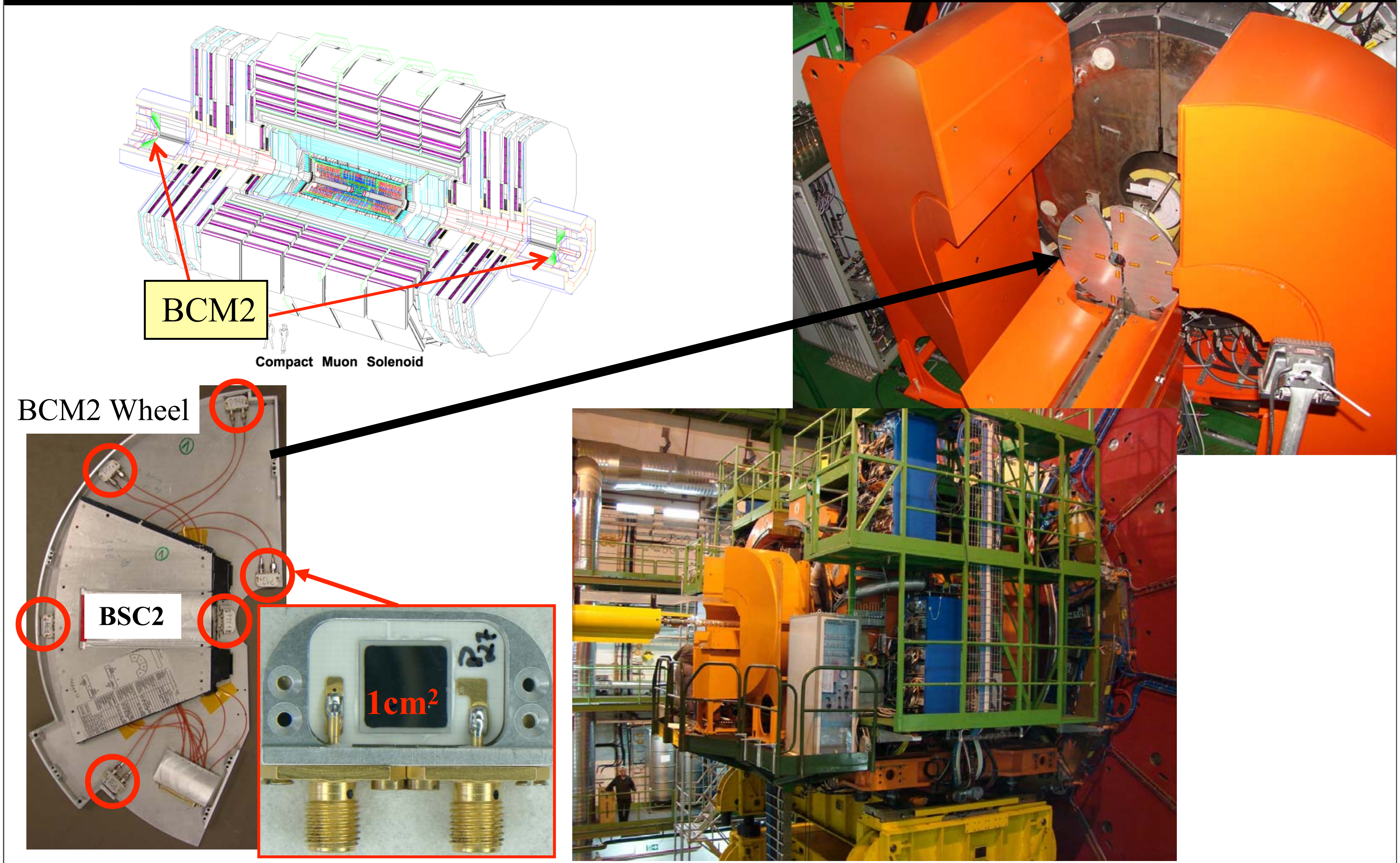
The PLT (Pixel Luminosity Telescope) detector will be installed later into the same carriage by Rutgers.

BCM1 completely installed

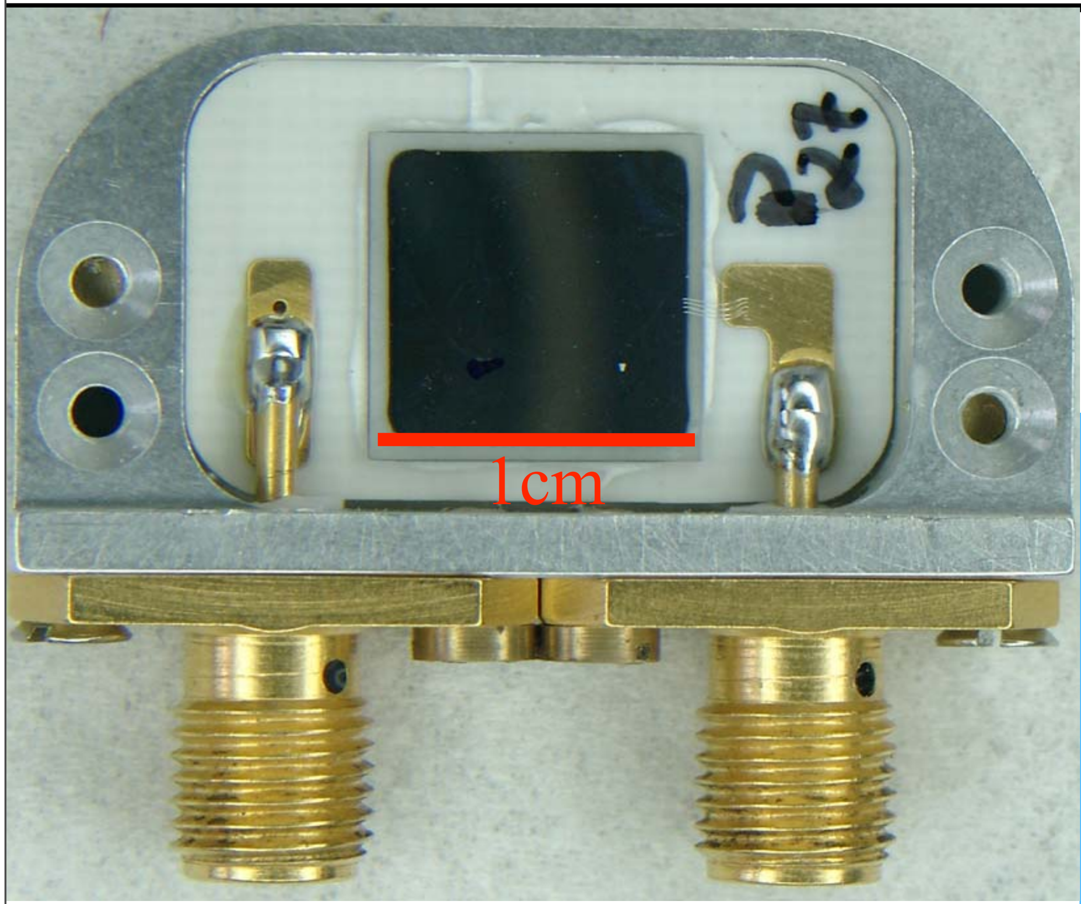


Big mechanical challenge!

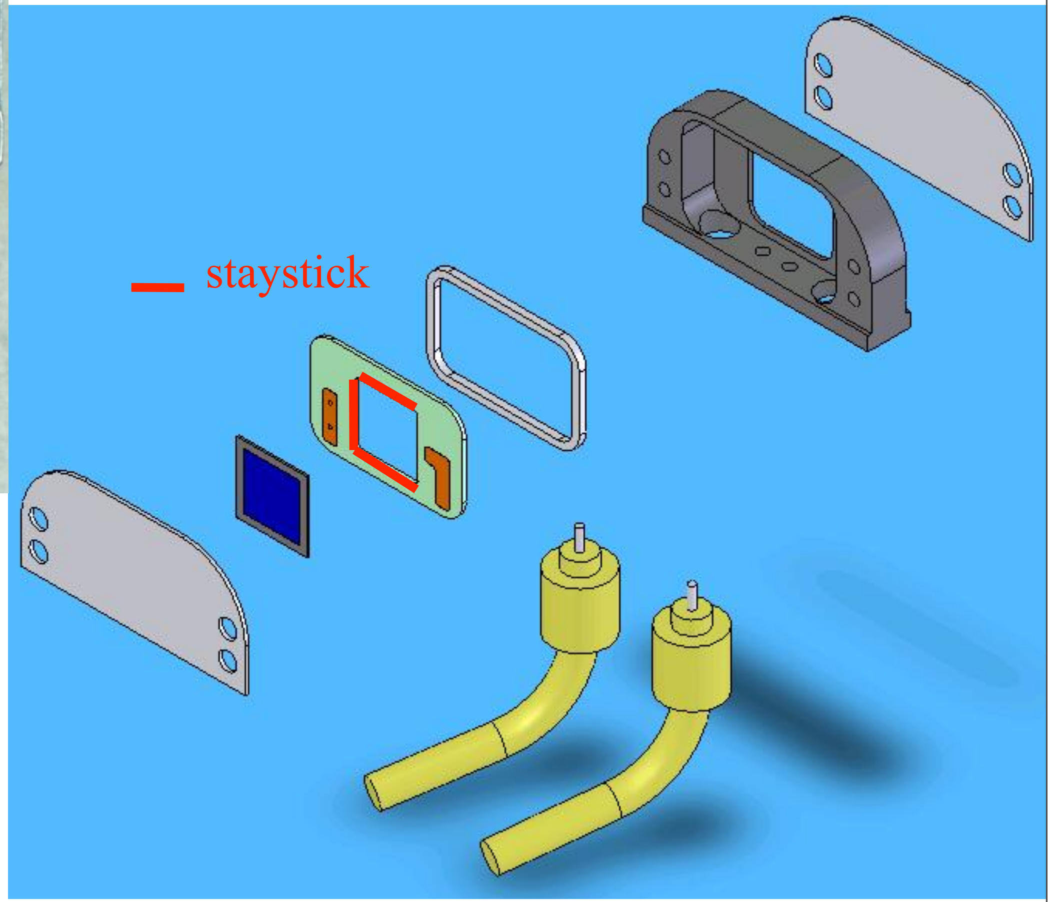
BCM2 Leakage current monitor



BCM2 Package



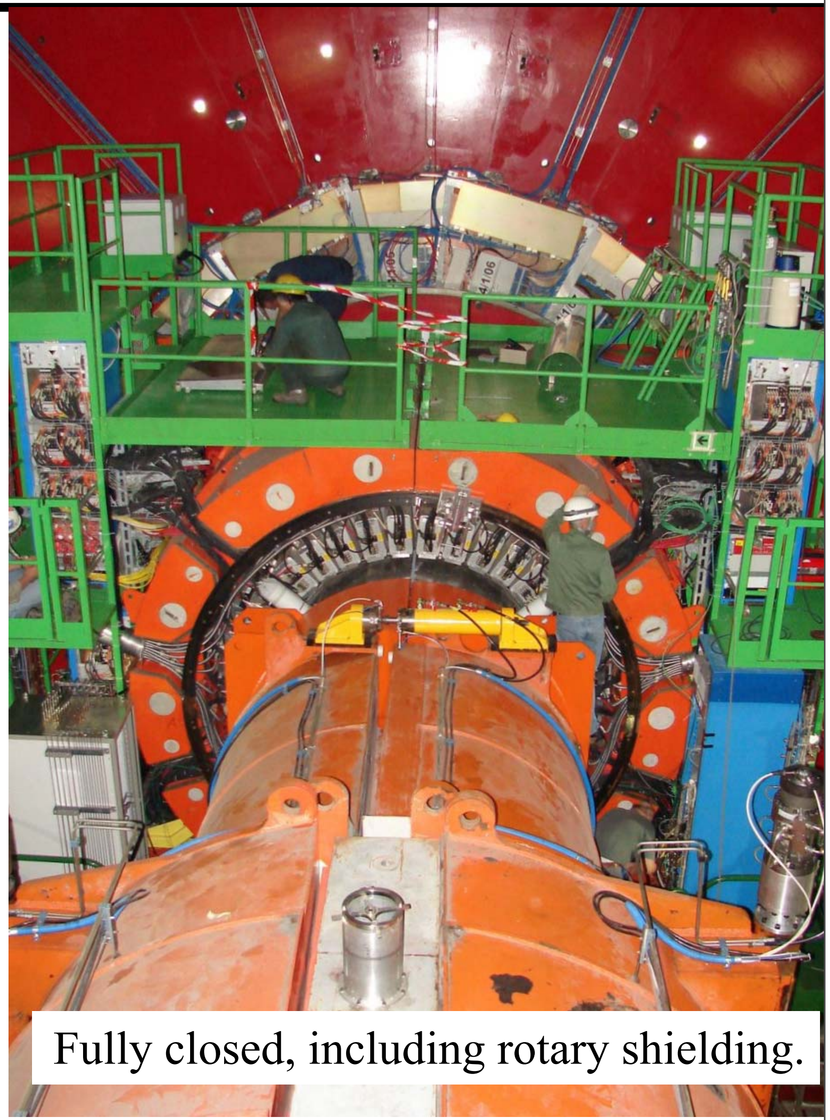
BCM2 detector is a 10x10x0.4mm^3 polycrystalline CVD diamond with Tungsten-Titanium metallization. The average charge collection distance is 230um@400V.



Baseplate material:
Rogers corp. woven glas reinforced ceramic filled thermoset material.

Other side with CASTOR and RS

Fully open with ½ Castor and Totem

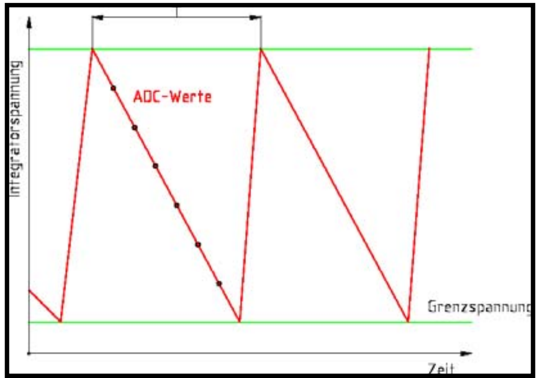


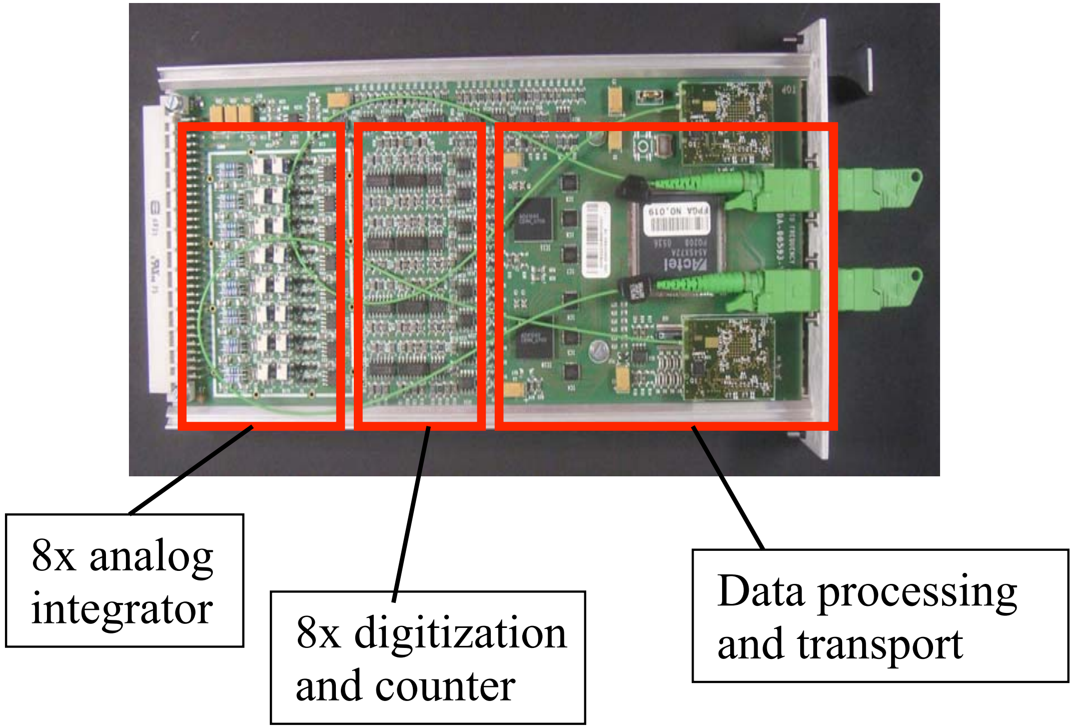
Fully closed, including rotary shielding.

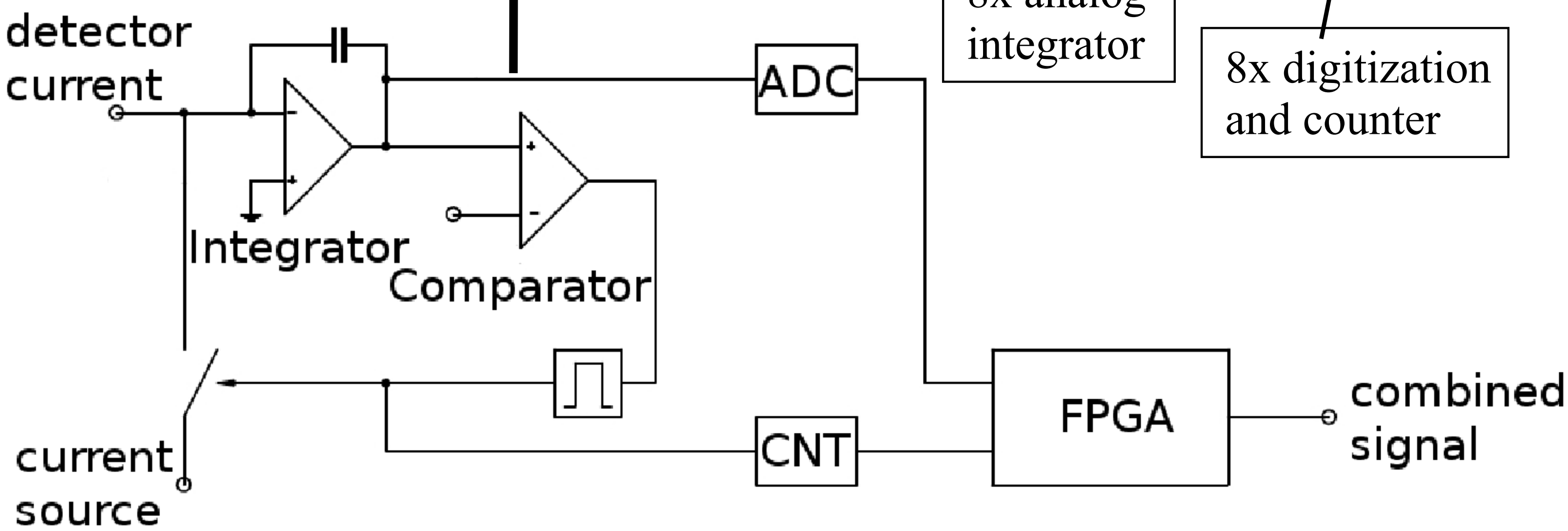
Installation happened one week before beam, due to CMS schedule. Despite this BCM was ready for first beam. Biggest challenge was to integrate detector in an area where there are three other subsystems (HF, CASTOR, TOTEM).

Front end electronics for BLM and BCM2

- BCM2 uses same readout electronics and data handling as LHC BLM
- Transparent extension of BLM into experimental areas
- Relative Particle Flux Monitor







Paper: E. Effinger, et al. "The LHC beam loss monitoring system's data acquisition card", Proceedings of LECC, Valencia 2006.

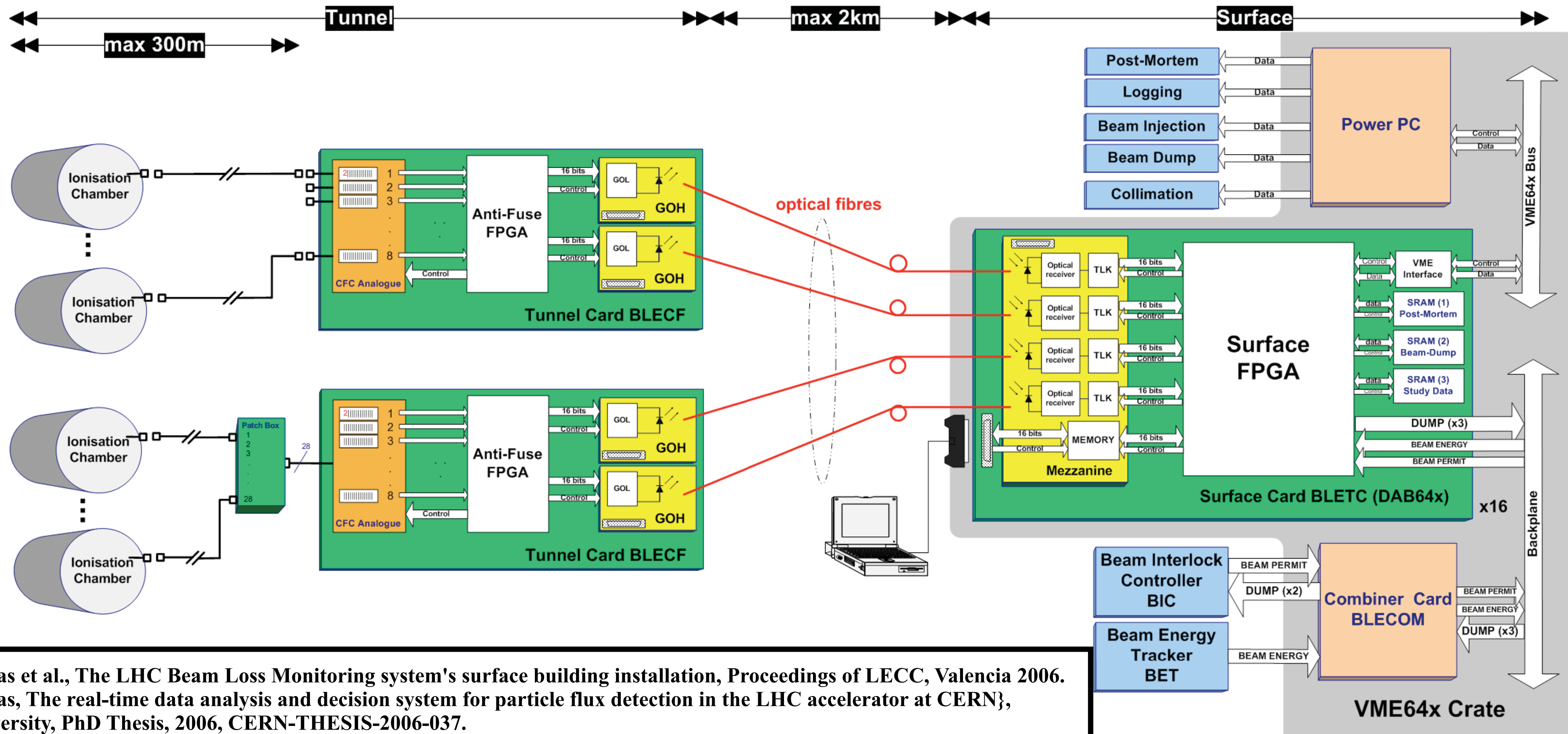
Data flow and abort in BCM2

- Abort implemented in Hardware
- All 40us readings taken into abort calculation
- Max RunningSums for Monitoring at a 1Hz rate
- Post Mortem analysis

Present abort thresholds

- 10^9 MIPs per cm**2 per 1- 100ns is expected damage level for detectors
- 3e5 MIPs per cm**2 per digitization (40us) is abort level
- This corresponds to 10uA.
- Slower abort level presently placed at 3 times nominal luminosity. (several 100nA= 1e8 per cm**2 per s) "Radiation Budget"

- Abort threshold defined by Si-Pixel and Strip tracker, with large safety factor.



C. Zamantzas et al., The LHC Beam Loss Monitoring system's surface building installation, Proceedings of LECC, Valencia 2006.
C. Zamantzas, The real-time data analysis and decision system for particle flux detection in the LHC accelerator at CERN}, Brunel University, PhD Thesis, 2006, CERN-THESIS-2006-037.

BRM Diamond Response, nominal machine

- Energy deposition is scored for diamond region.
- Ionization energy of diamond E_{ion}=13eV.
- Non Ionizing Energy Loss (NIEL) is negligible for signal.
- Conversion: $I_{dia} = E_{dep} V_{norm} CCD_{norm} Lumi_{norm} q_e / E_{ion}$

- Current from energy deposition 7TeV Beam, nominal luminosity:
  - BCM2inner: 394nA (~300e6)
  - BCM2outer: 33nA (~25e6)
  - BCM1F: 24nA (31e6)
  - BCM1L: 91nA (68e6)
- Signal is dominated by Luminosity and not by machine induced background.

Testbeams – excellent correlation with BLM tube

Elbe – Dresden 20MeV electrons

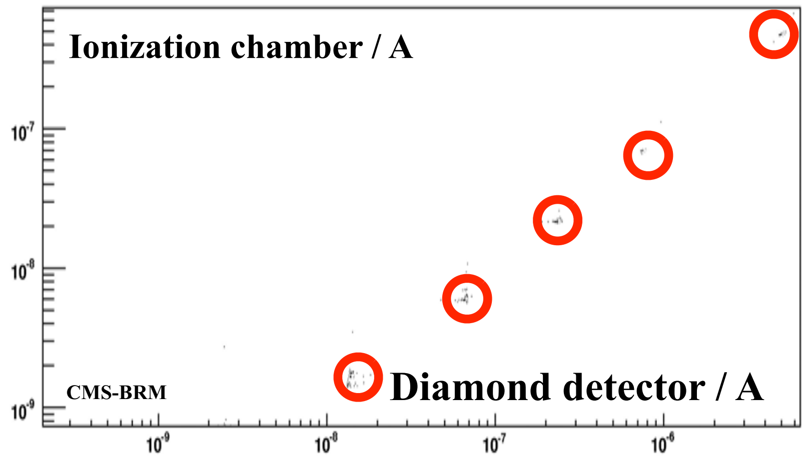
Covered more than 4 orders of magnitude

Good linearity at 200 V bias voltage

Good correlation between ionization chamber and diamond.

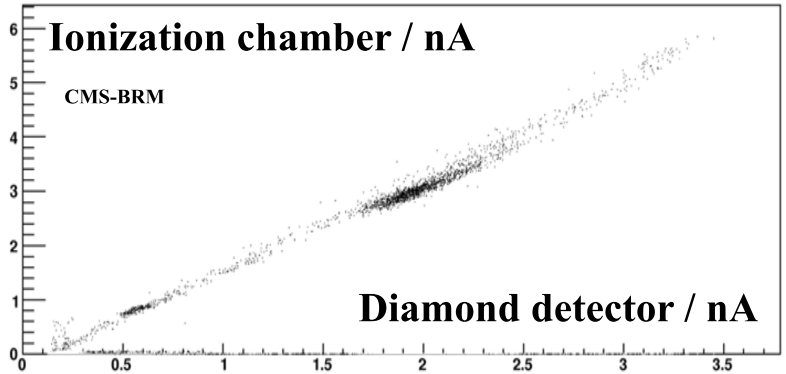
Crosscheck between LHCb, Alice and CMS BCM systems

Testbeam kindly organized by LHCb



PS: 2GeV Proton/Pions

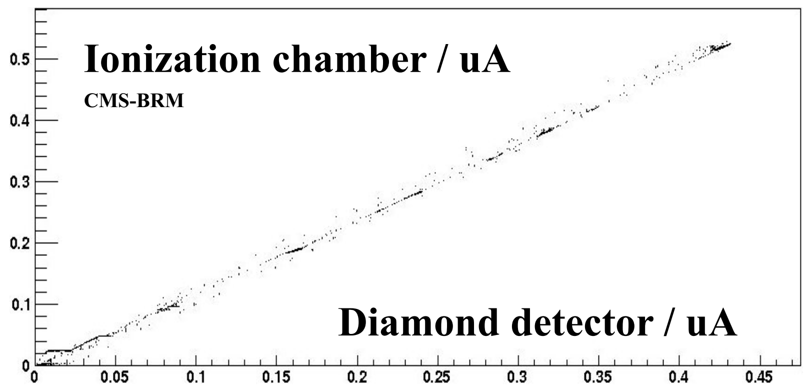
Excellent correlation between ionization chamber and diamond.



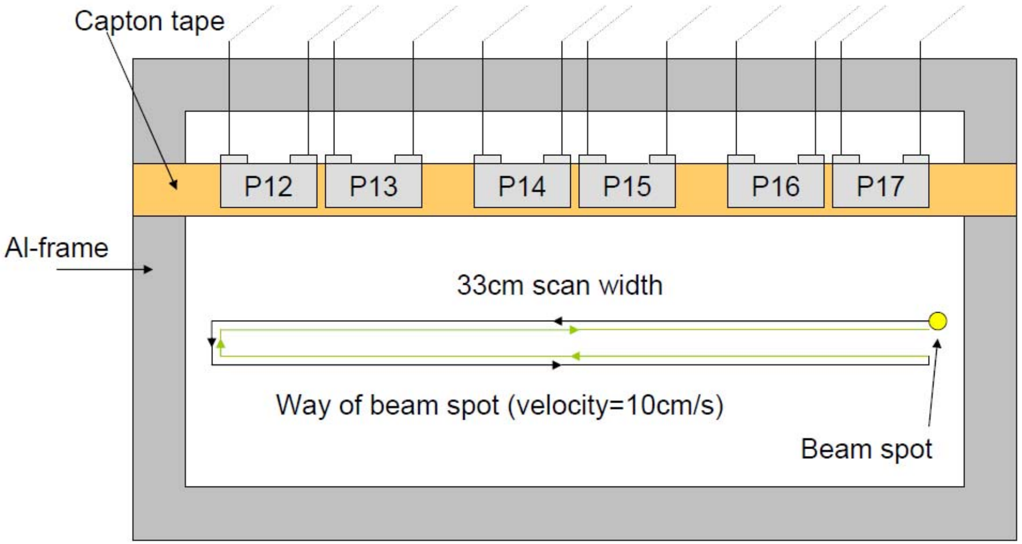
Louvain la Neuve – 21MeV fast neutrons

Excellent correlation between ionization chamber and diamond.

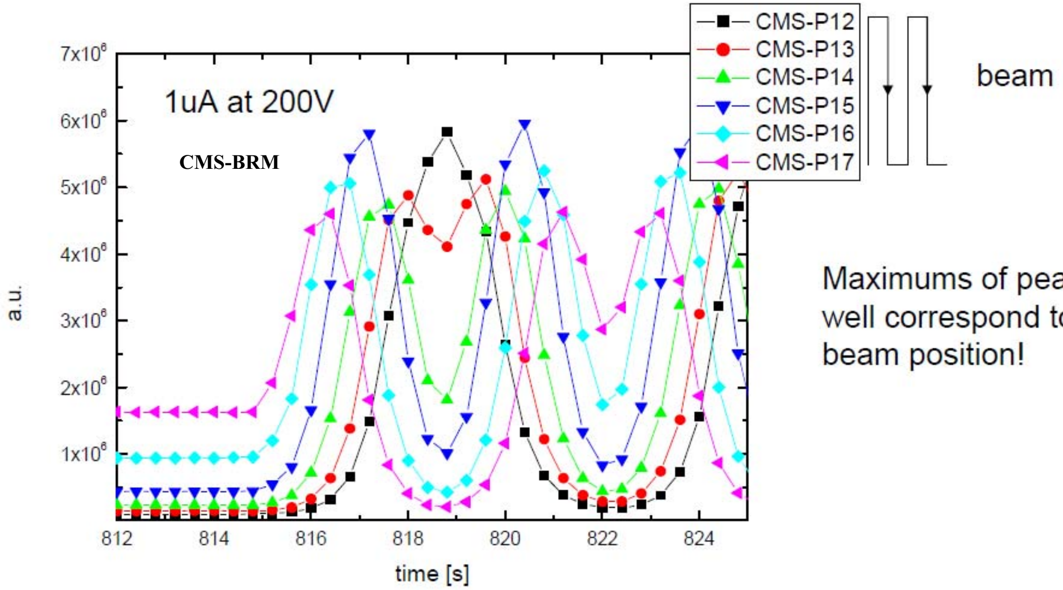
Almost identical ionization currents in both detectors for 400 um thick diamond



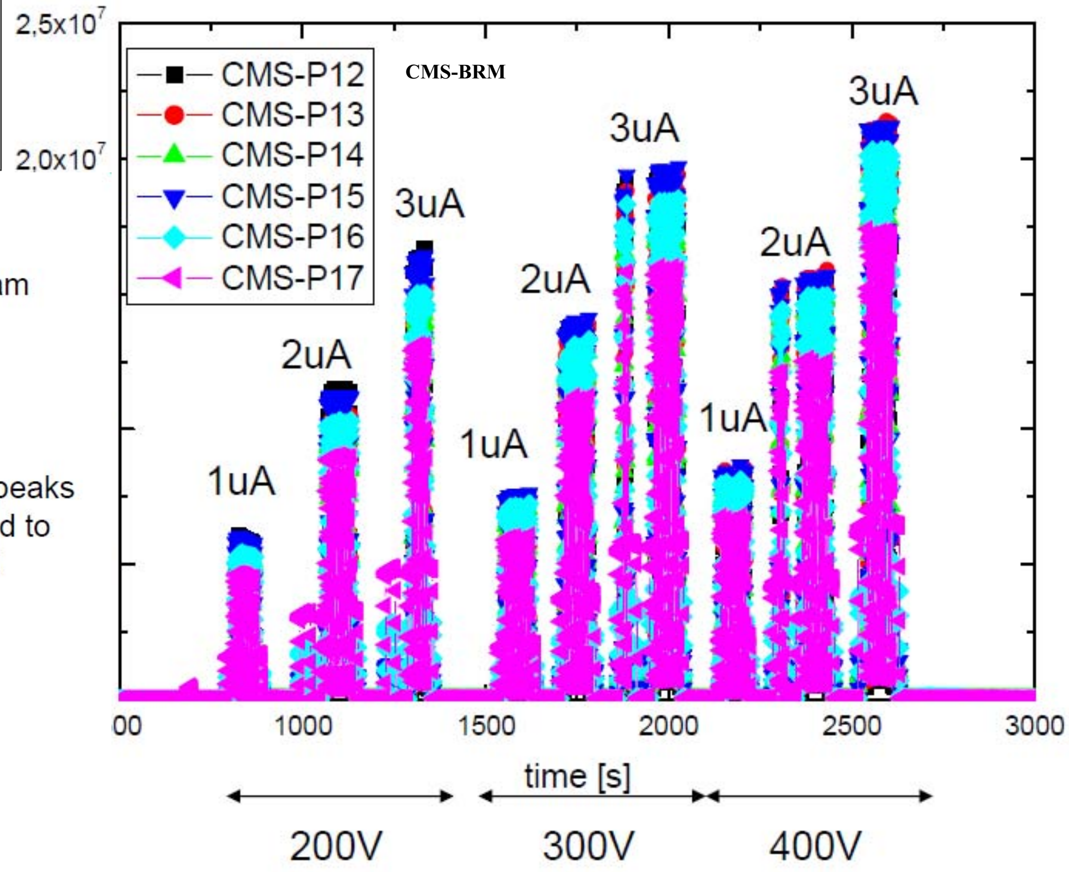
Cyclotron tests 26MeV protons



Test of dynamic range and linearity up to the abort level at different voltages.



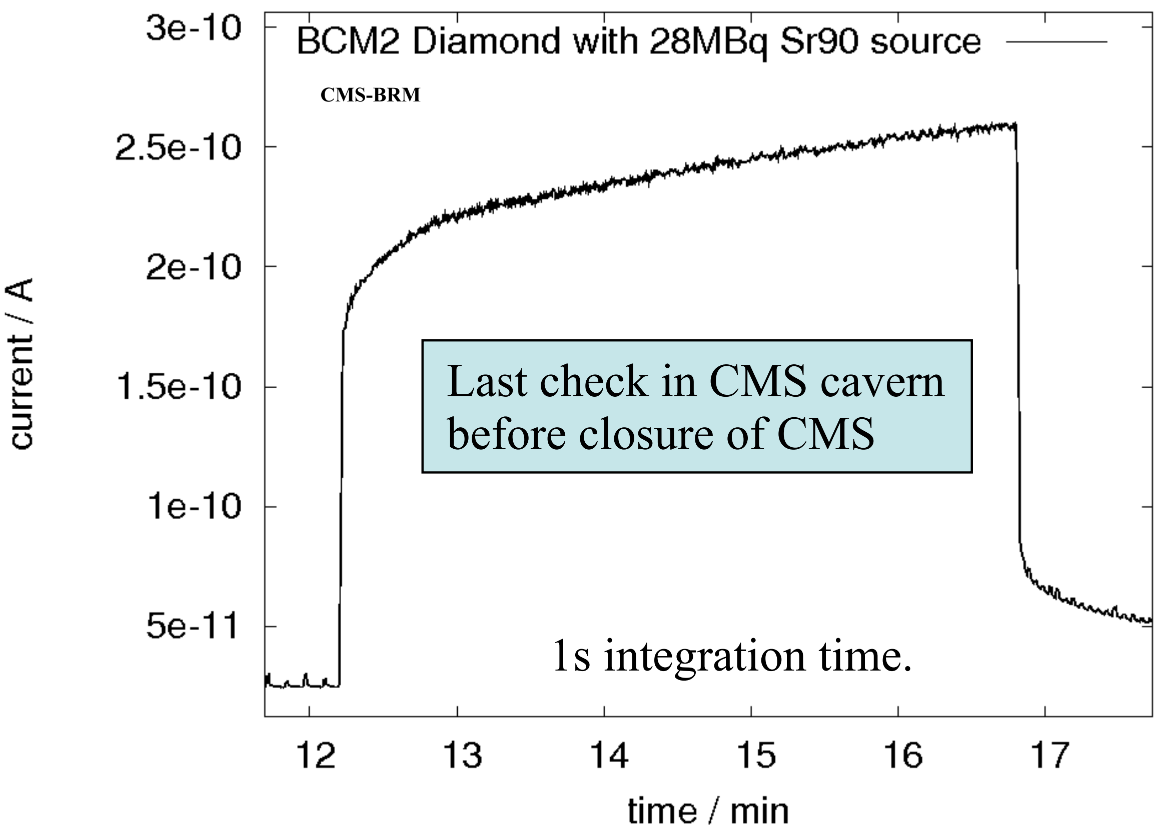
Maximums of peaks well correspond to beam position!



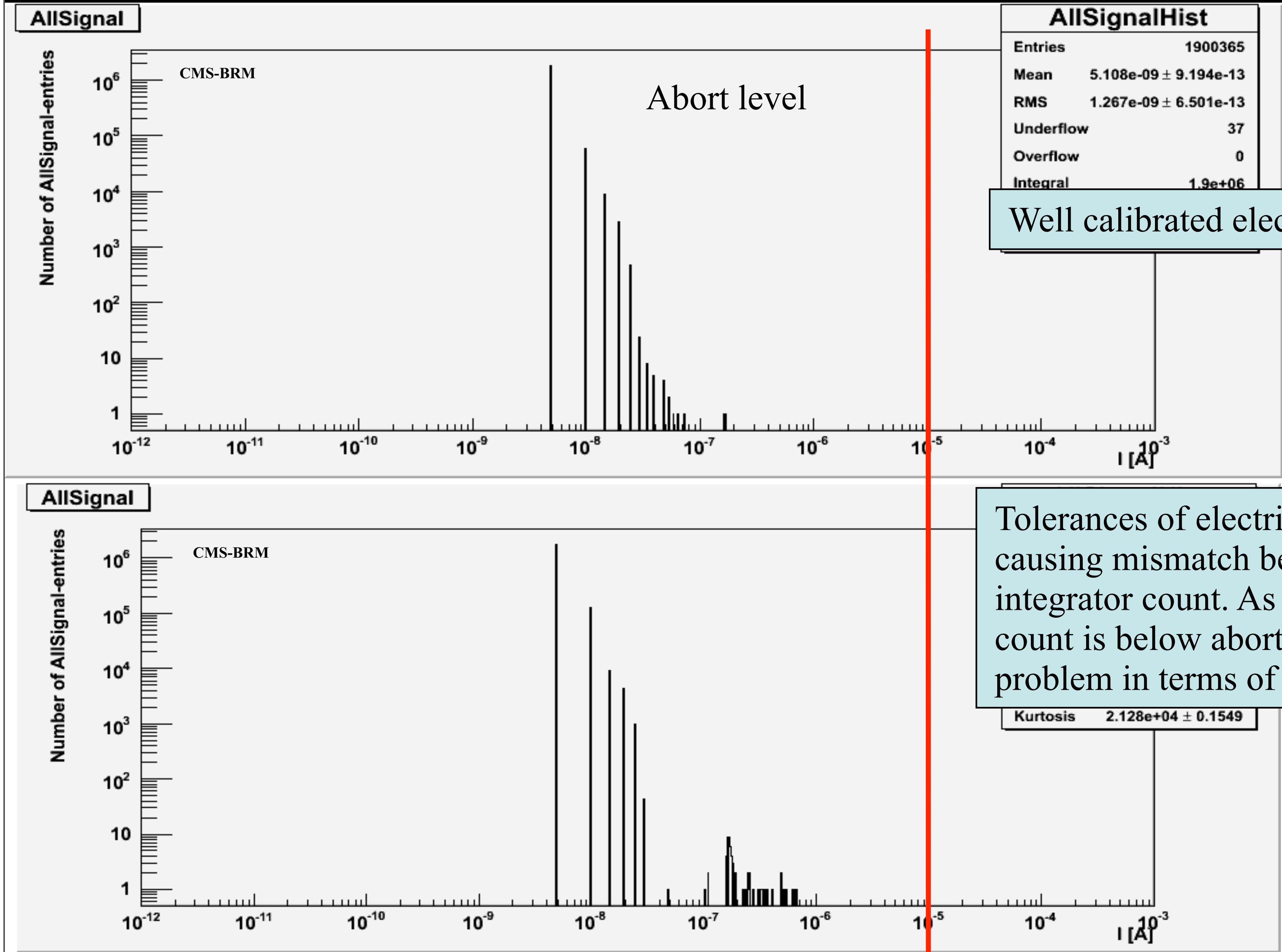
Substructure, due to beam scanning.

Sr90 Source tests in cavern

- All Diamonds tested with a 28MBq Sr90 source in Cavern as a final check before closure.
- Checks with what we have seen before in the lab.
- All diamonds responded nicely and as expected from lab measurements.



Noise studies: histogram for 22 days of data



Well calibrated electronics

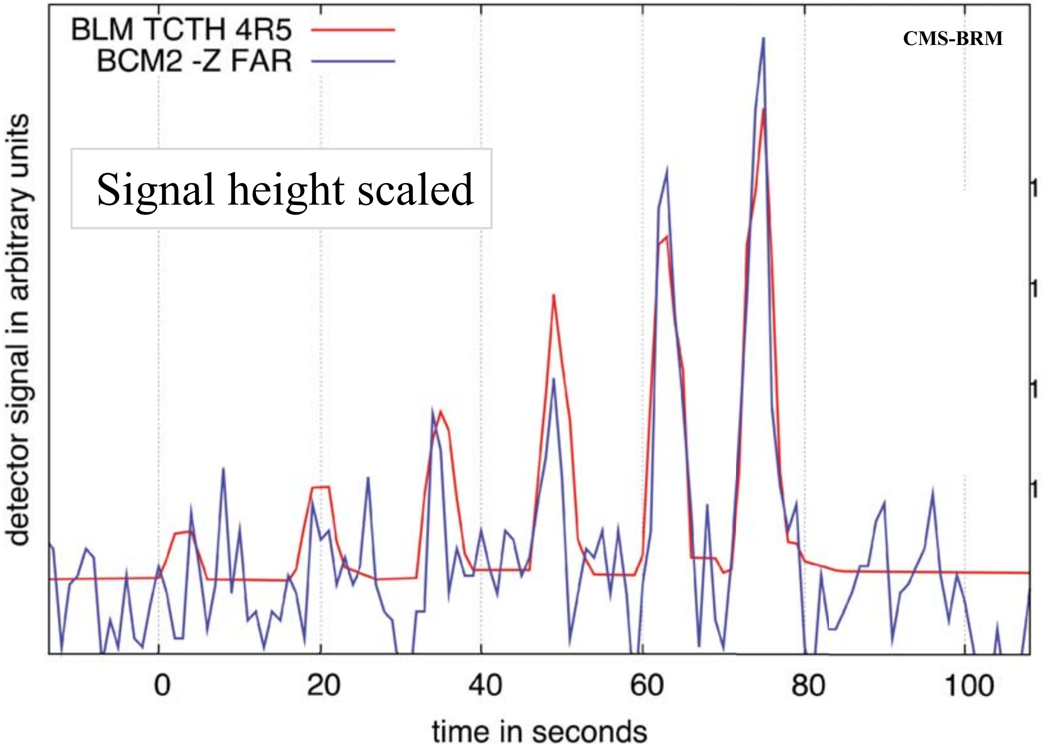
Tolerances of electric components causing mismatch between ADC and integrator count. As the max ADC count is below abort level, not a problem in terms of a false abort!

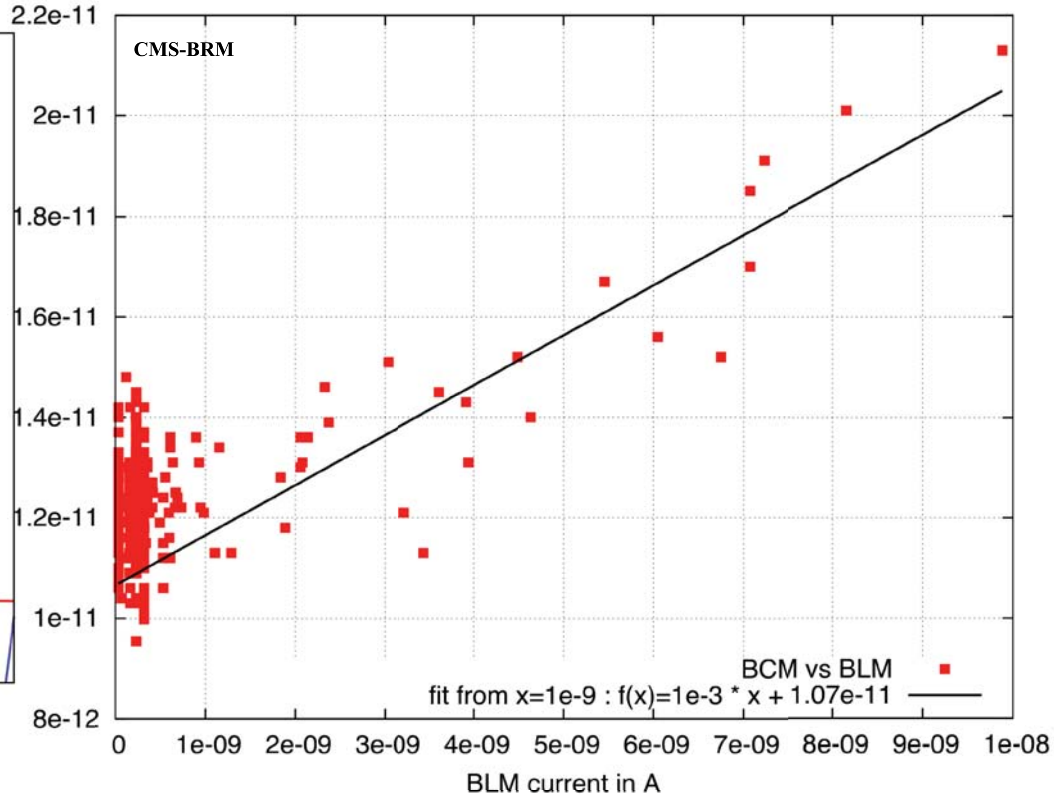
Intrinsic and normal pickup noise cannot lead to a false abort

BCM2 BLM correlation (Nov 23rd beam trimming)

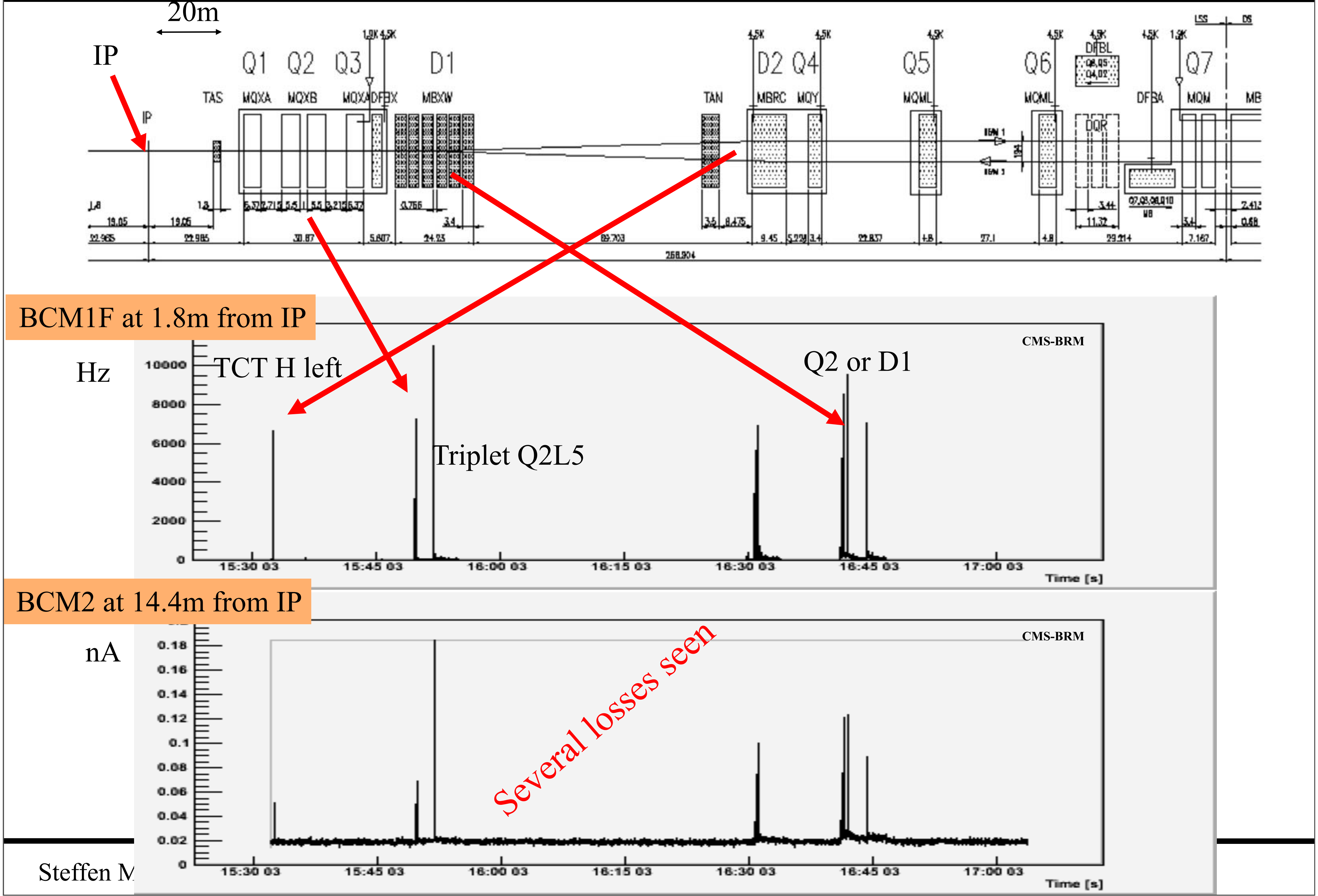
- Noise is biased due to readout algorithm (only in monitoring, not in abort)
  - Therefore only the signal excess is fitted.
- Shown is just example of ongoing work, correlations to other BLM locations is done at the moment.
- Got more data during the aperture scans, number of correlated detectors and quality will improve.
- A lot of topological information on the losses also available
- Aim: produce a set of correlations for each accident scenario as part of a tool to diagnose losses

Conclusive prove that CMS Beam condition monitors are working!

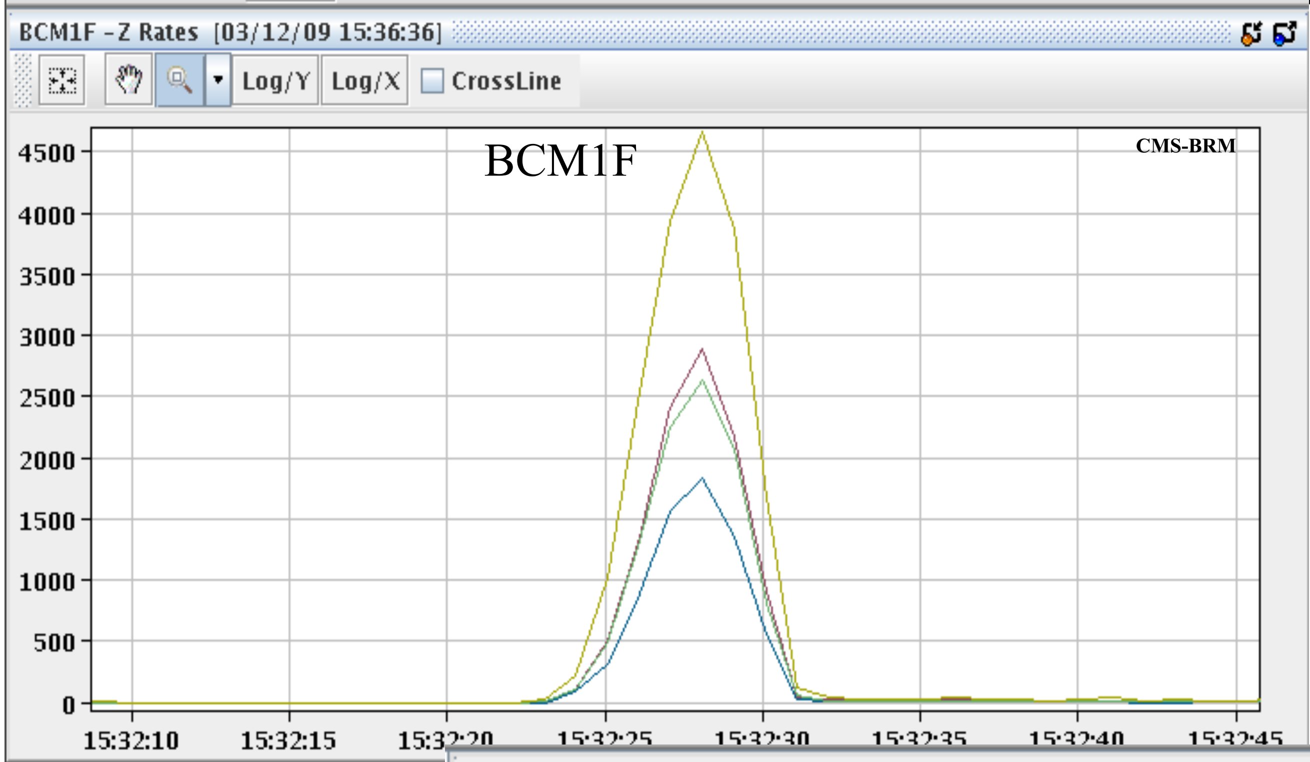




BRM Signals for Dec 3rd (Aperture scans)



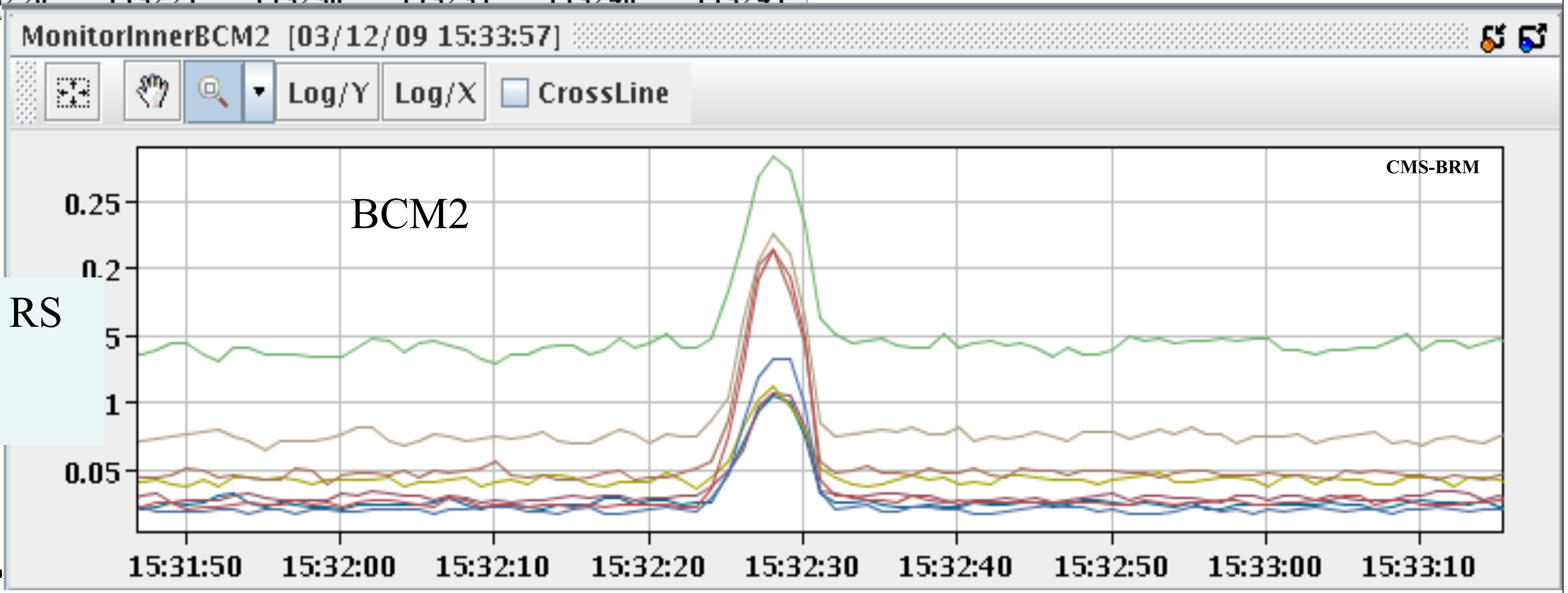
Online Displays BCM2 – BCM1F



The maximum reading occurred for the maximums of the RS06 sum (10ms) with a peak of 1.4nA (~10^4 MIPeq/cm^2).

For the 1s reading (RS09), the maximum was 0.5 nA (~400 000 MIPeq/cm^s/s).

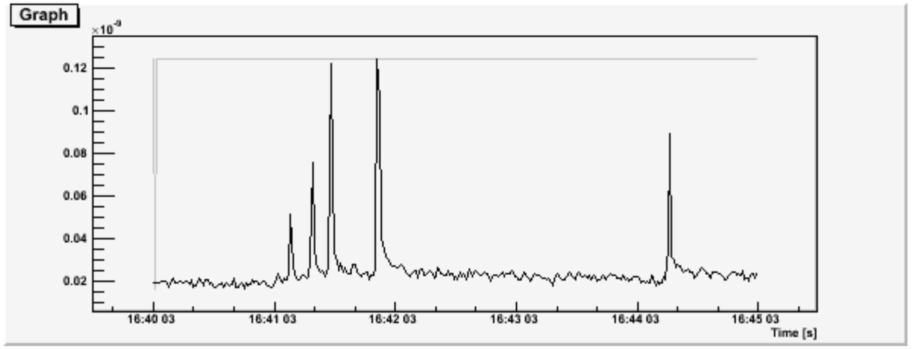
On shorter timescales than RS06 it was not possible to determine signals above the usual noise level (expected as this was a "slow" loss).



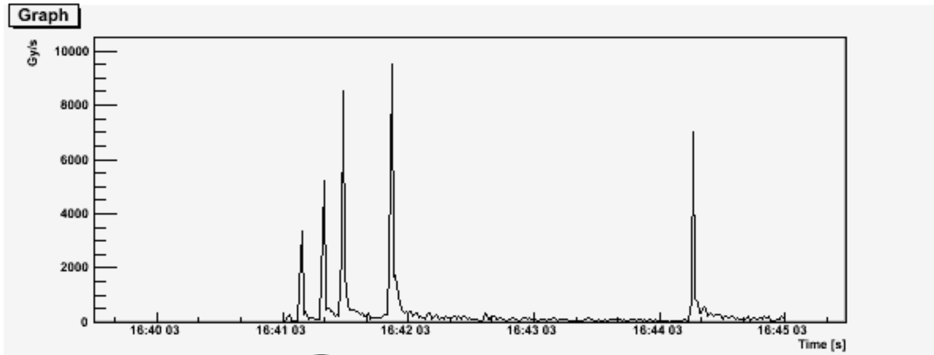
8 inner diamonds 1.3s RS (different, stable dark currents)

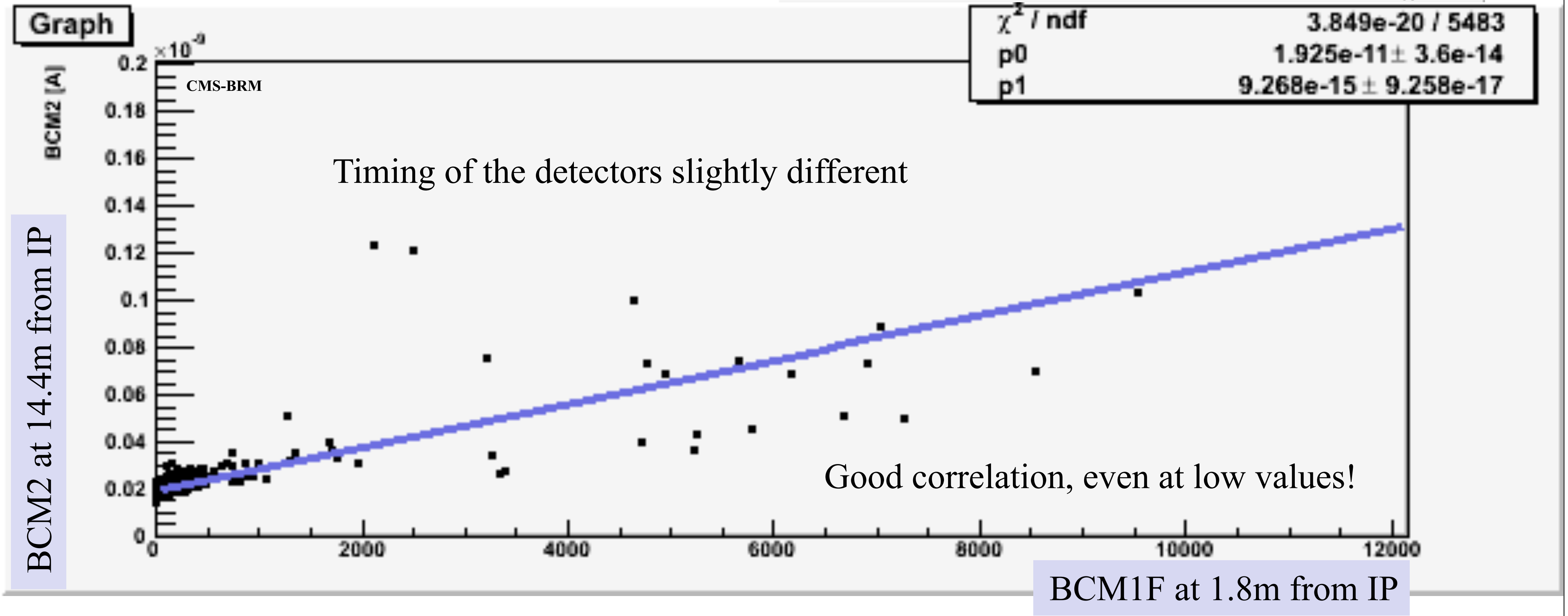
Correlation BCM2 and BCM1F for Dec 3^{rd}

BCM2 at 14.4m from IP

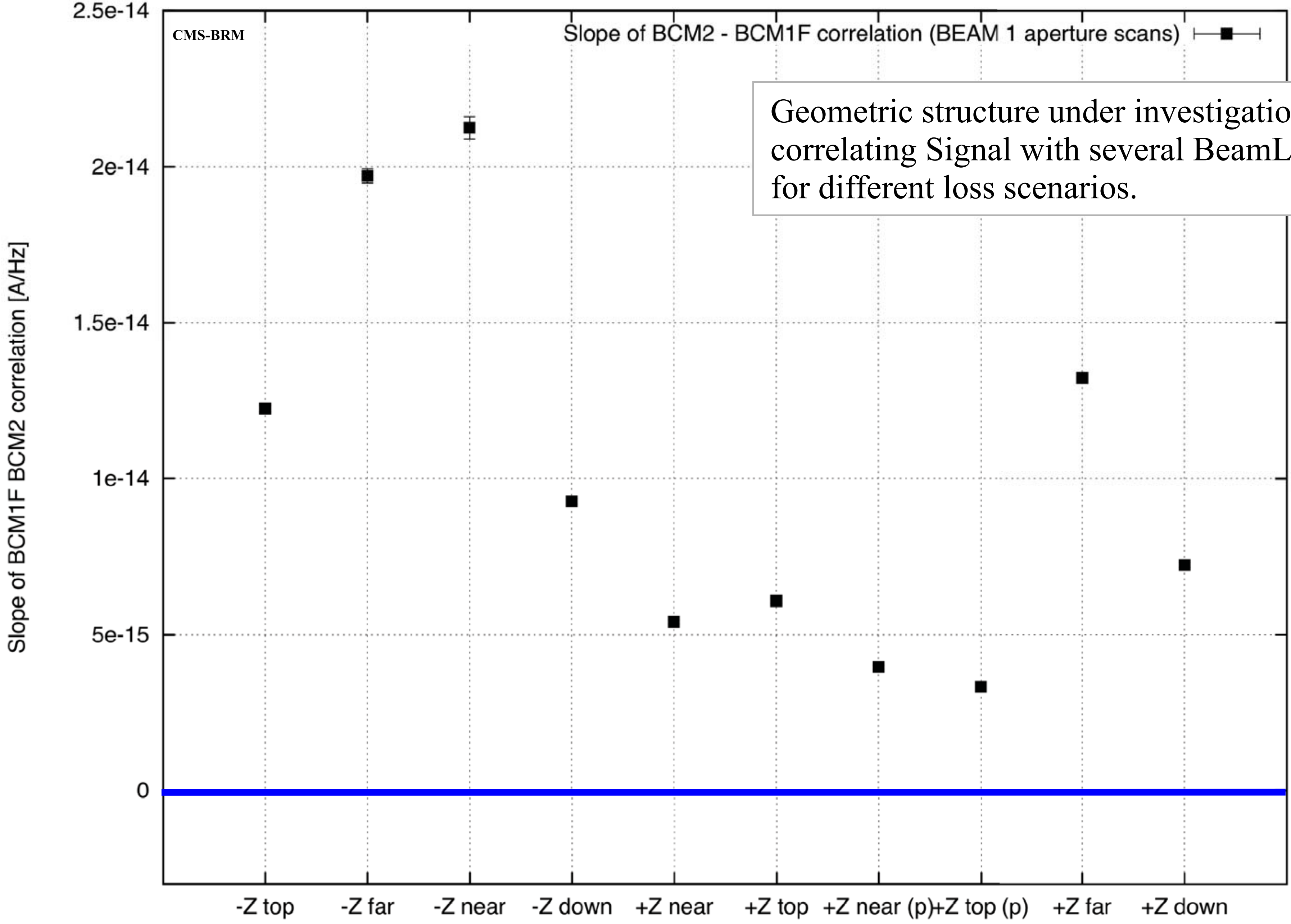


BCM1F at 1.8m from IP



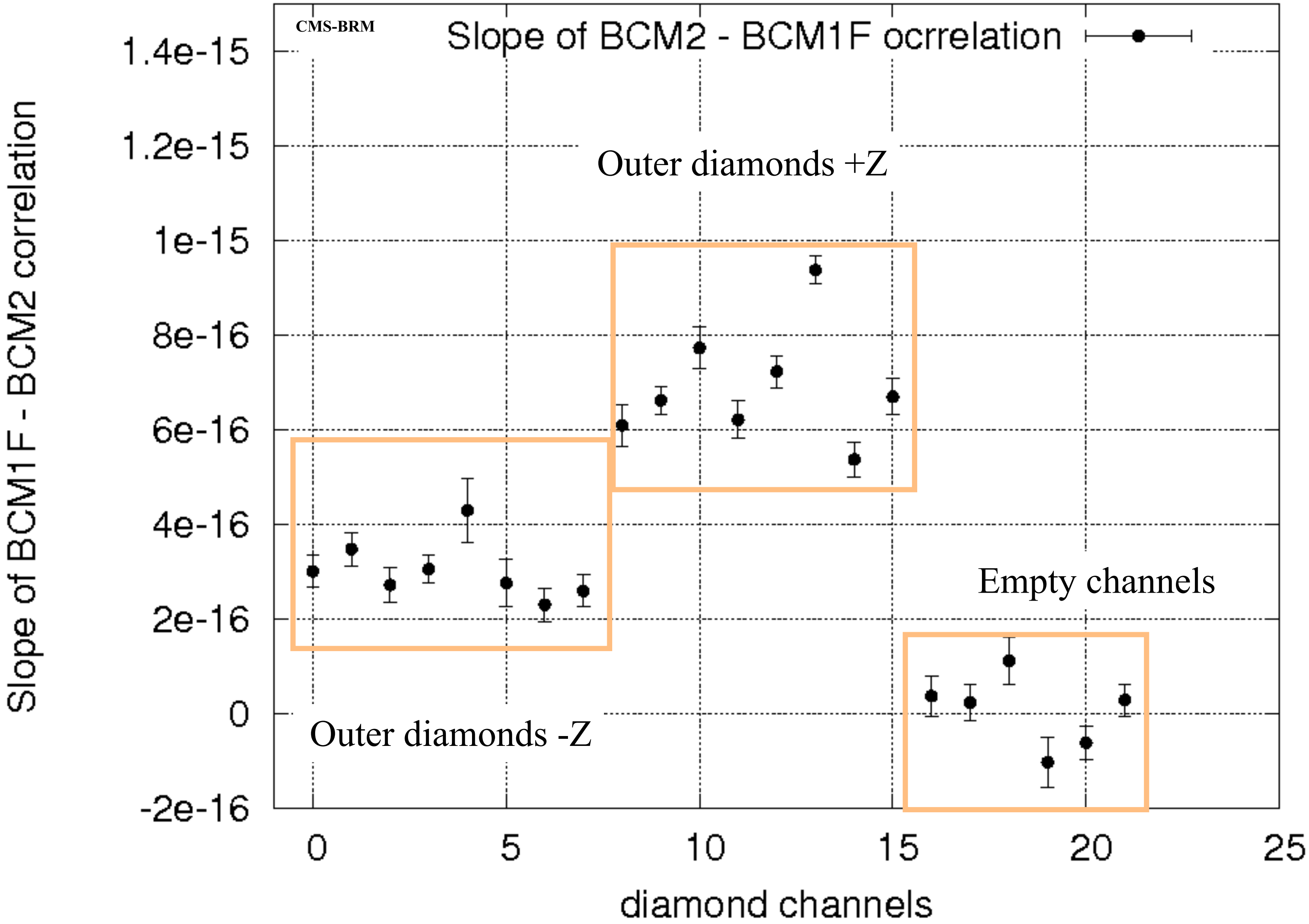


BCM2 all inner diamonds



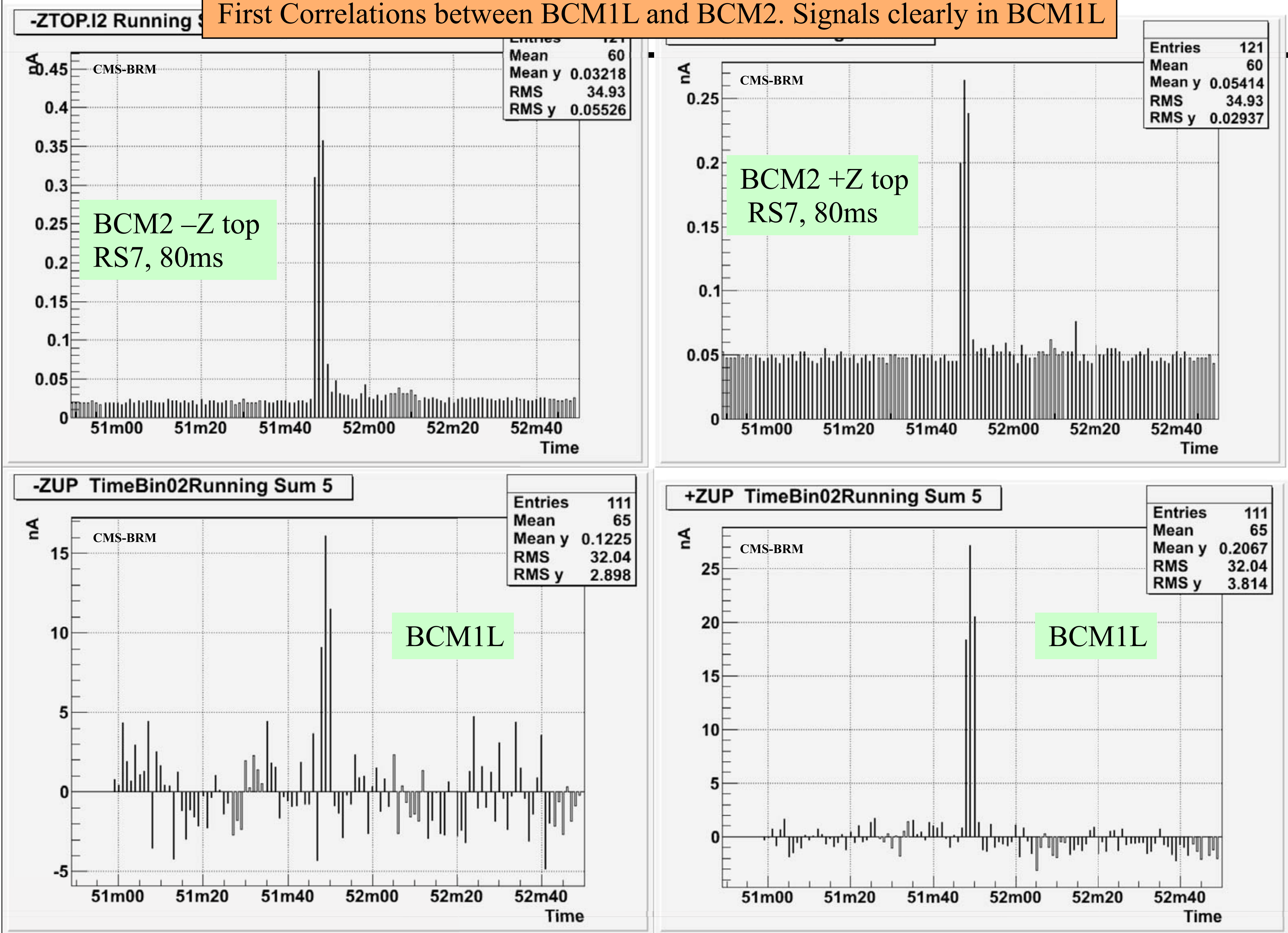
Geometric structure under investigation. Also correlating Signal with several BeamLossMonitors for different loss scenarios.

Outer compared with empty channels

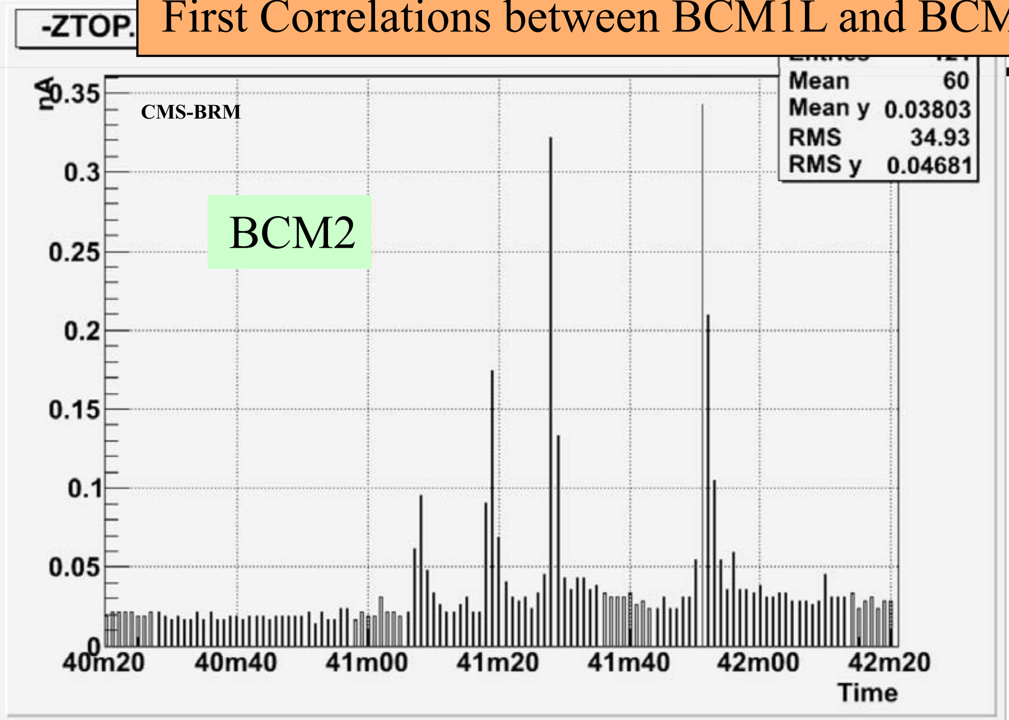


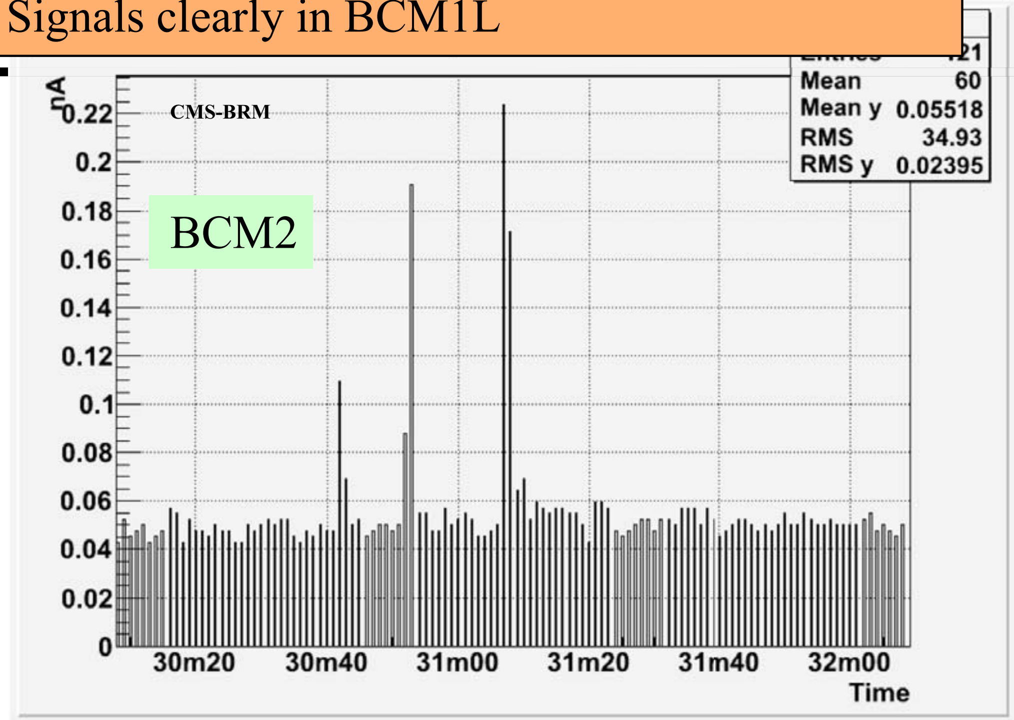
Significant signal seen in all outer Beam Conditions Monitor 2 diamonds

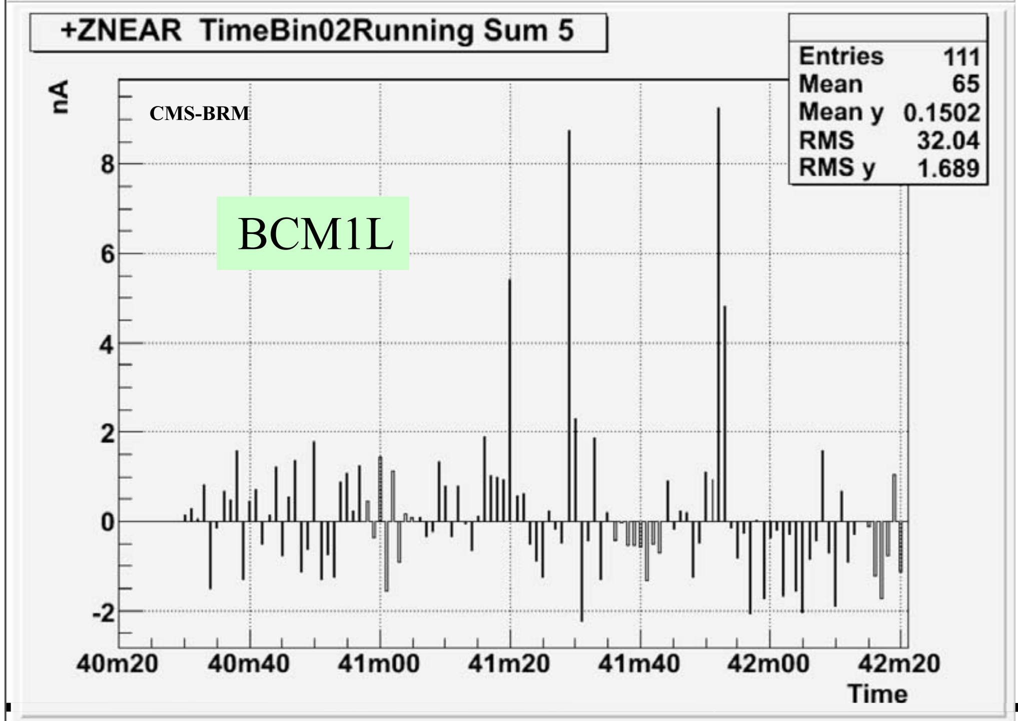
First Correlations between BCM1L and BCM2. Signals clearly in BCM1L

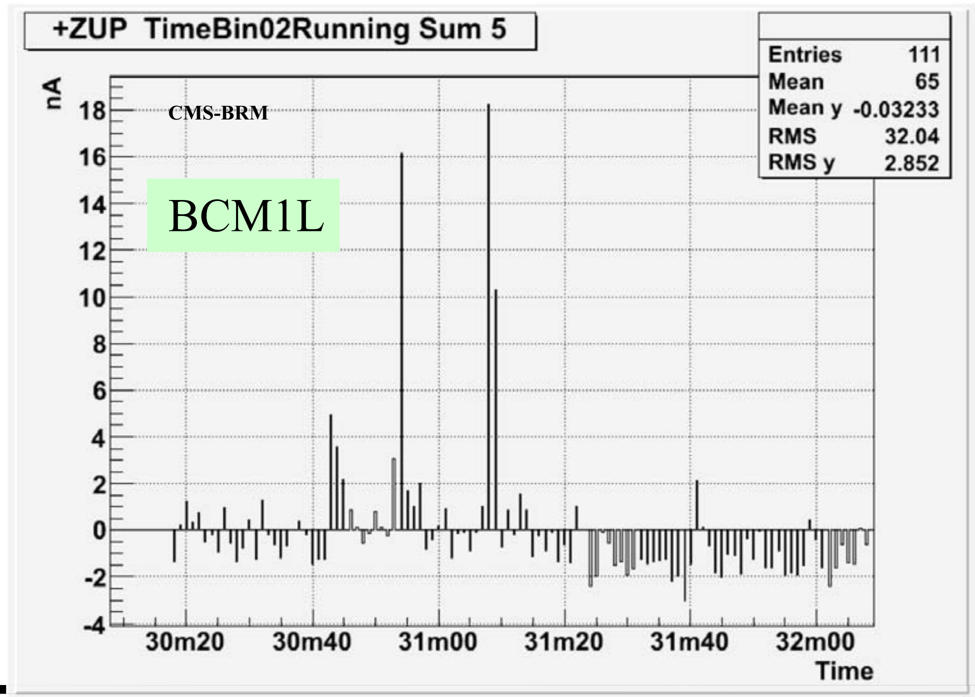


First Correlations between BCM1L and BCM2. Signals clearly in BCM1L



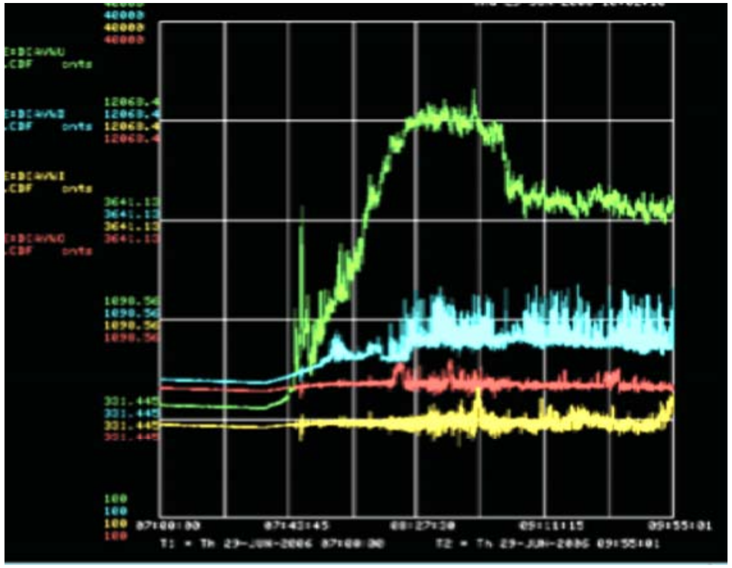


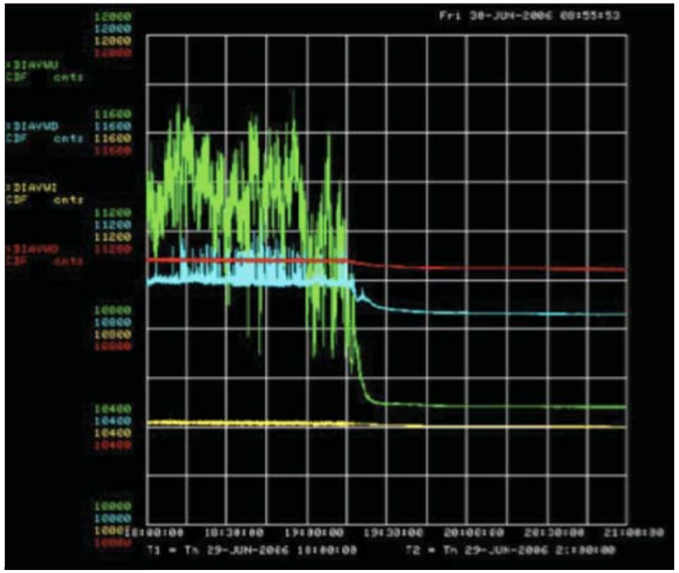




Leakage current in diamond as a function of the magnetic field

Erratic dark currents in diamond detectors





CDF: magnet trip caused erratic currents

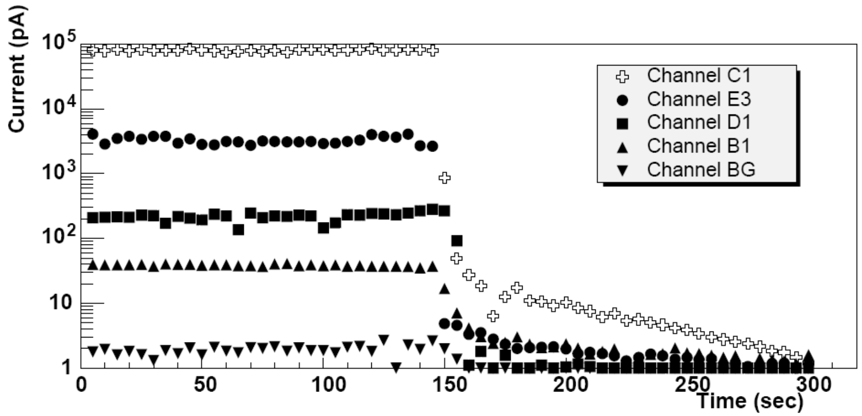


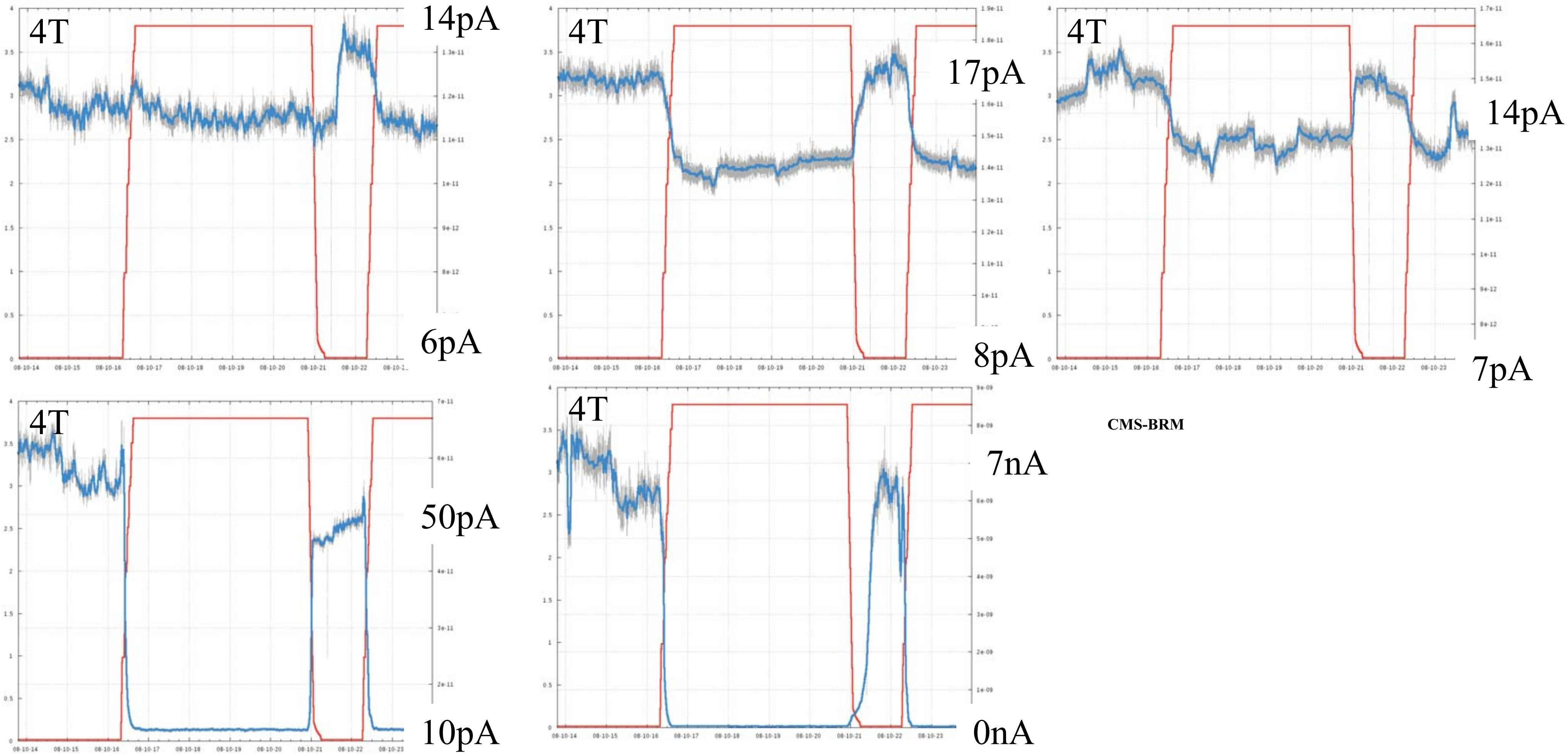
Figure 4. Suppression of erratic dark currents in a magnetic field. At $t = 150$ s a 1.5T magnet was switched on, resulting in the elimination of erratic dark currents in all of the sensors.

BaBar radiation monitoring

Effects also investigated in multiple test beams during 2006/2007

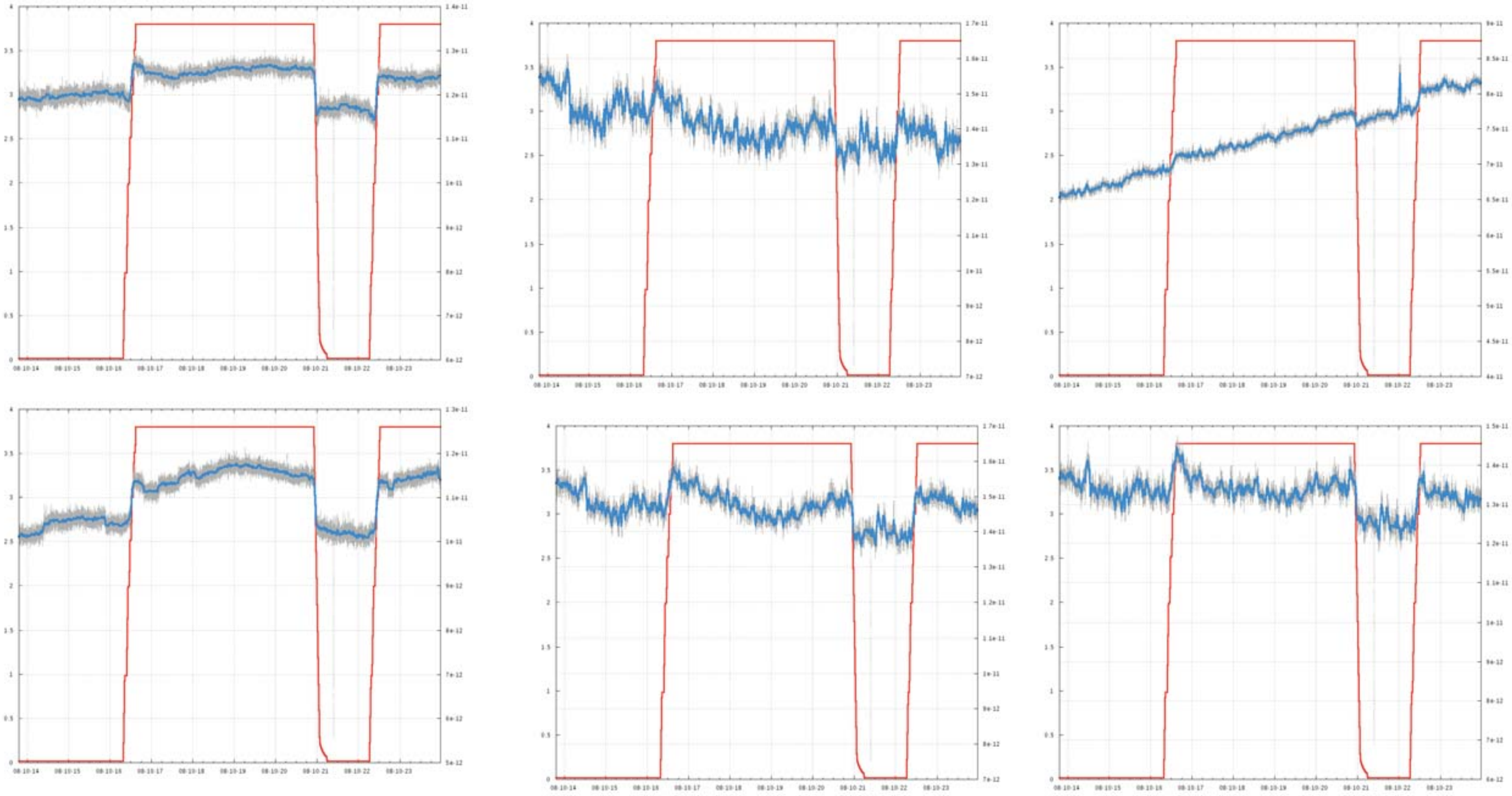
Paper: CVD Diamonds in the BaBar Radiation Monitoring System
M. Bruinsma,P. Burchat, A.J. Edwards, H. Kagan, R. Kass, D. Kirkby and B.A. Petersen

During CMS magnet ramping 08

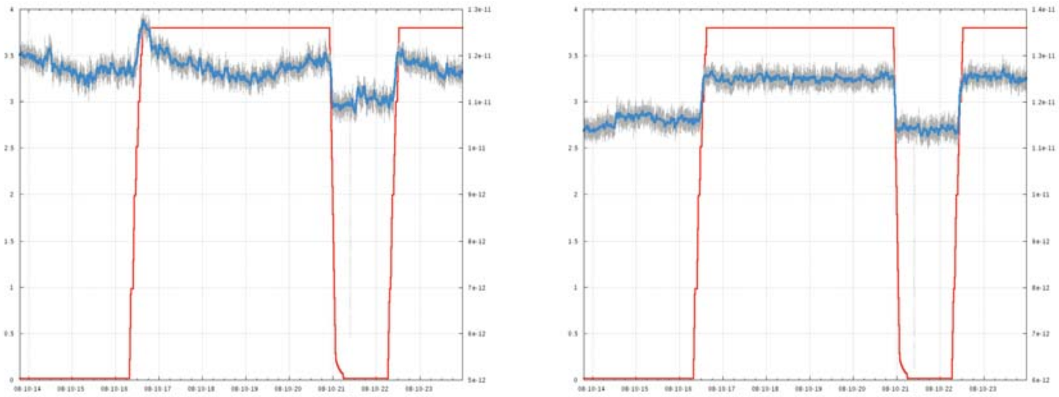


Suppression of erratic leakage current, mostly at the pA level, only one diamond shows a leakage current in the nA range.
This seems to be the same effect already seen at CDF and BaBar.

During CMS magnet ramping 08 cont.



CMS-BRM



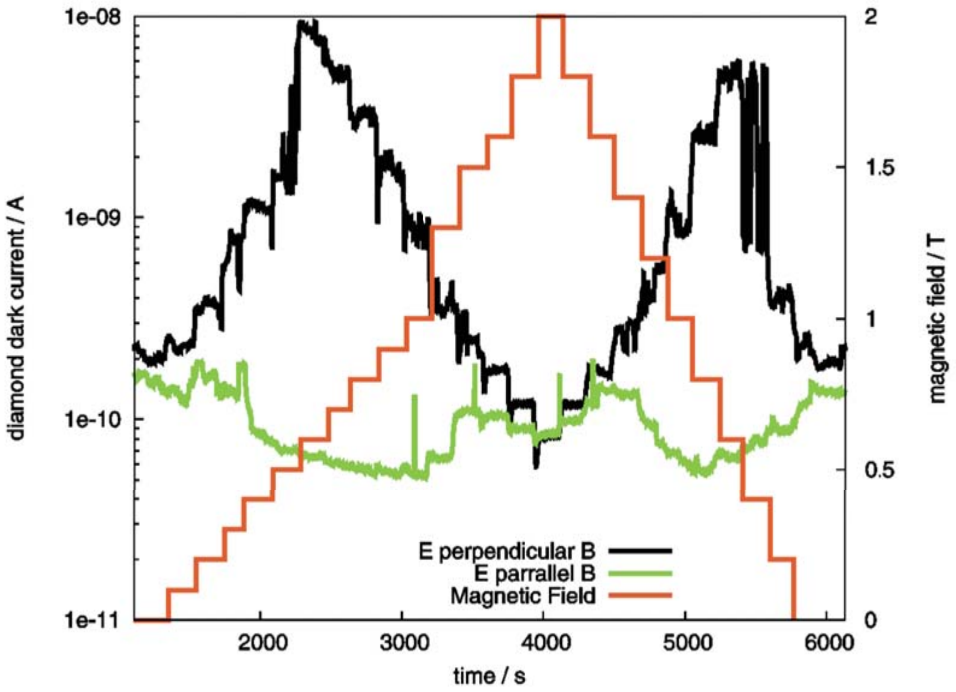
Increase of leakage current in presence of a magnetic field, seen in 8 out of 24 diamonds.
Effects are very small, max difference is one pA.

Lab measurements

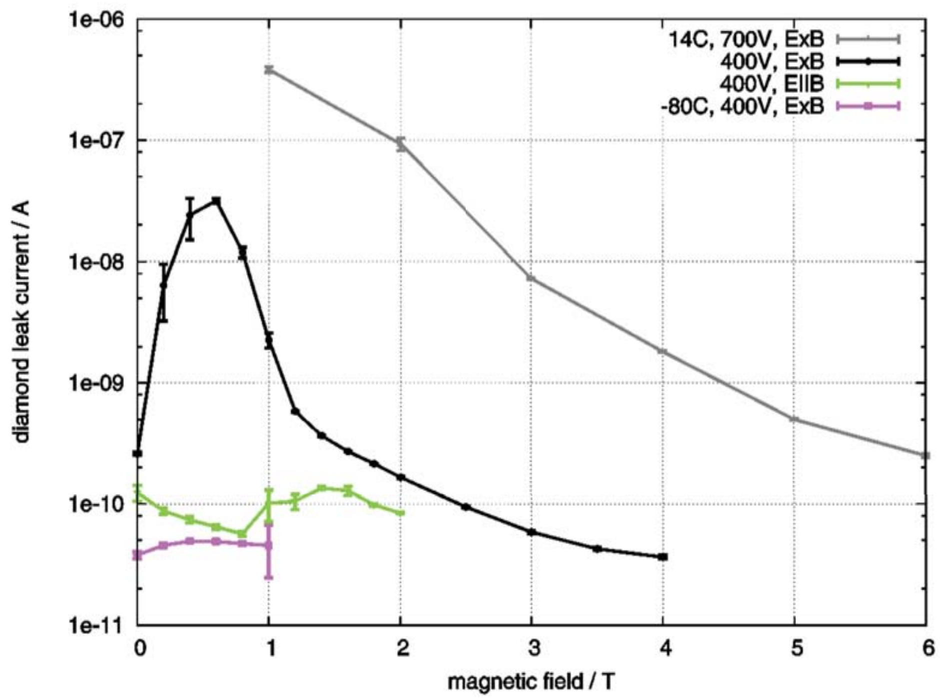
- **Magnet:**
  - **Jumbo at ITP, Karlsruhe**
  - **max. 10.0T @ 4.2K with warm 10cm bore**
  - **coil currents up to 3000A**
  - **DUT temperature: 72 – 300K**
    - **Cooling with cold N_2-Gas**
- **Diamond used for test:**
  - **CCD: 231um / 241um (rev.)**
  - **Leakage Current at 0.5V/um: 230pA /10pA(rev.)**
- **Measured two different magnetic field angles**
  - **E parallel B**
  - **E perpendicular B**

Thanks to M. Noe, T. Schneider, KIT/ITP, Karlsruhe, Germany

Results



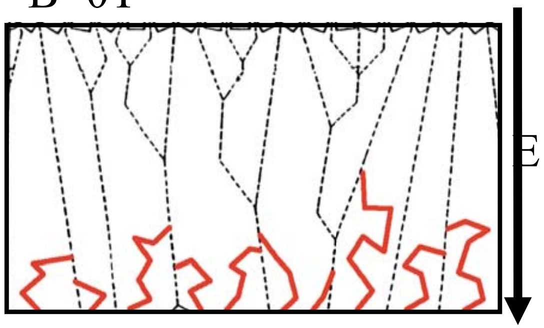
- E perpendicular B
  - Up to 0.8T the leakage current increased, above it starts to decrease again.
- E parallel B
  - Current decreases as function of B-field (opposite to perpendicular field).
- No effect measurable with reversed electric field.



Reproduced with a second diamond!

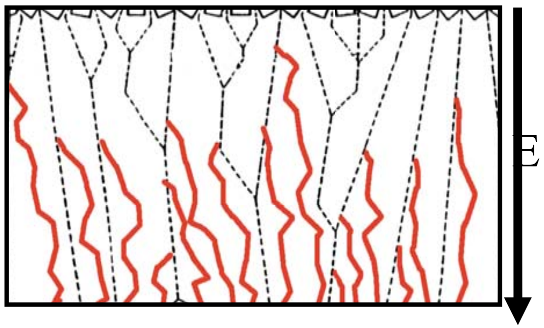
Preliminary model - 2

B=0T



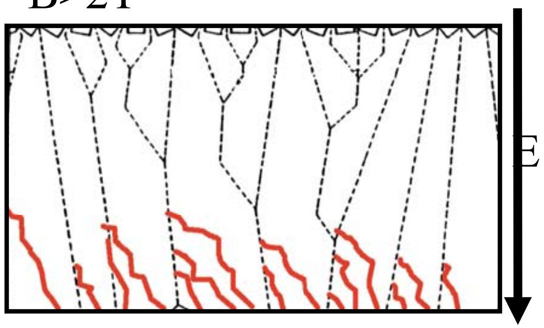
Drift with isotropic scattering every 1.7µm, good chances to hit a grain boundary where charge carriers recombine.

B~1T



Drift along small Lorentz angle with scattering every 1.7µm, transversal drift highly suppressed due to magnetic field, smaller chances to hit a grain boundary, higher leakage current.

B>2T



Drift along larger Lorentz angle, scattering every 1.7µm, higher chances to hit a grain boundary, smaller leakage current.

- **Leakage current is caused by injected electrons from the electrodes more likely at substrate site.**
- **The number of injected electrons is dependant of:**
  - **the electric field strength**
  - **the metal used for the contact**
  - **temperature**
- **The propagation of the electrons is dependant of:**
  - **Mobility**
  - **Magnetic field**
  - **Grain boundary configuration**

S. Mueller, Leakage current of diamond as function of a magnetic field, phys. Stat. sol. (a) 206, No. 9, 2091-2097 (2009)

Conclusion

- CMS Beam condition monitors are working excellently!
  - All systems seeing beam. This was not expected at these very low intensities.
- Good correlations between different detectors
- Diamond is the material of choice for this application.
- Integrating readout electronics of very high dynamic range and low noise available.

- Magnetic field effect observed, does not affect the operation of the safety systems.
- Preliminary model developed, but further tests needed for a conclusive understanding of the effect.