CMS Beam Condition Monitor

- testbeams and calibration -

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- On behalf of the CMS BRM group -

Thanks to: All our friends in AB/BI /CO /OP…

And also thanks to all people which made the testbeams in Louvain and at SPS/PS possible.

Outline

- CMS BRM system
  - Design outlines
  - Damage scenarios for CMS detectors
- BRM in detail
  - Subsystems
  - Detectors and packaging
  - Readout electronics
- Testbeams for calibration
  - Neutron beam in Louvain
  - Proton/Pion beam at SPS
  - Proton/Pion beam at PS
- Absolute and relative calibration of BLM and BCM2 detectors.
- Diamond features
- Some initial thoughts on how to set abort thresholds
- Simulation of BRM detectors within CMS

- Please note all data shown is preliminary and still being analyzed.

Design Concept for CMS Protection System

- Explicit choice made to be compliant with the machine protection system
  - The CMS protection system is an extension of the Beam Loss Monitor systems into the CMS experimental cavern.
- Readout and detector technology selected for reliability (BLM readout electronics)
- CVD diamond is the standard choice for experimental protection
- Redundancy implemented in depth: ensuring minimal chance of single point failure disabling entire system.
- The whole protection system is independent of CMS DAQ

Functionality:

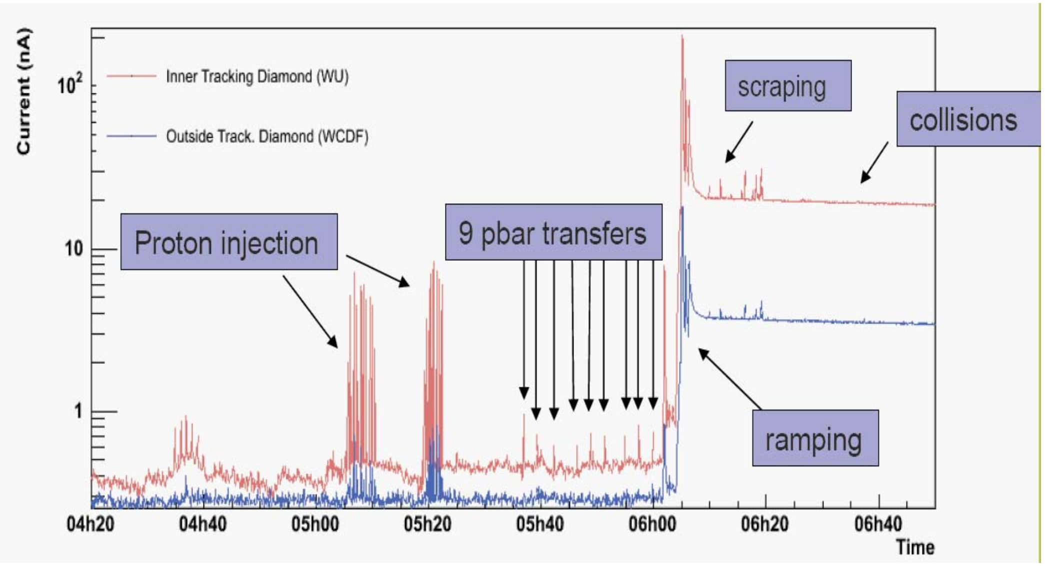
- Provide monitoring of the beam-induced radiation field within the UXC55 cavern and the adjacent LSS.
- Provide information on the state of the machine, and hence helps determine whether sub-detectors should be turned on.
- Provide real-time fast diagnosis of beam conditions and initiate protection procedures in the advent of dangerous conditions for the CMS detector
- System features include:
  - Active whenever there is beam in LHC
  - Provision of warning & abort signals to CMS subdetectors (ie ramp down LV and HV)
  - Postmortem reporting

Damage levels for CMS detectors

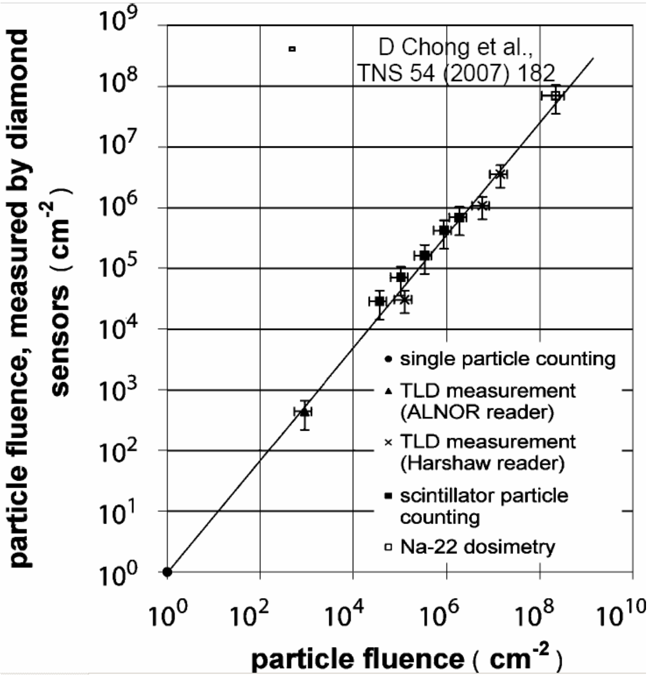
- The integrated dose from collisions is expected to dwarf any losses from background. Even loss of entire beam equivalent to approx. 100s luminosity.
- Integral dose of beam losses should be negligible.
- Accidents are more an issue of short timescale “rate” than long-timescale “dose”
- High flux of particles:
    - Potential overload on chips (eg huge charge input to amplifier may blow chip)
    - CDF experience - bursts with relatively low doses, short time scale - loss of chips
    - Mode of failure typically badly understood despite simulations and testbeams
    - Quantitative numbers of merit coming soon…
- Sensors much less sensitive to losses with HV+LV off

Why CVD Diamond?

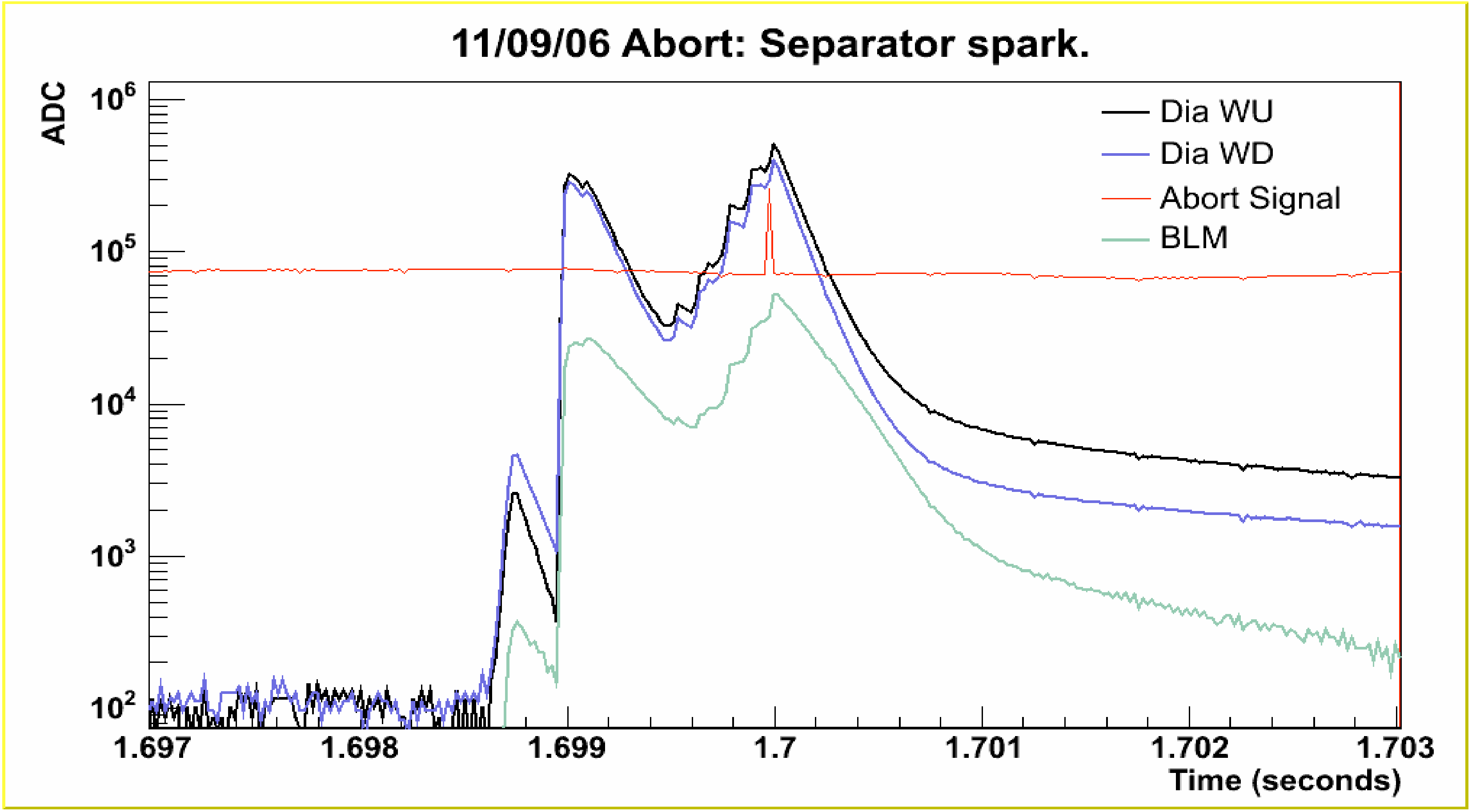
- BLM ionisation chambers too big to be installed inside CMS
  - 9cm diameter, 60cm long
- CVD Diamond is now standard choice at other experiments
  - installed in CDF, BaBar, Belle, ZEUS
- Relative flux monitors
- Radiation hard - tolerant beyond LHC nominal luminosity close to IP
- Low maintenance,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



CDF pCVD diamonds at r=3cm and r=10.7cm



Another example from CDF



BRM Subsystems

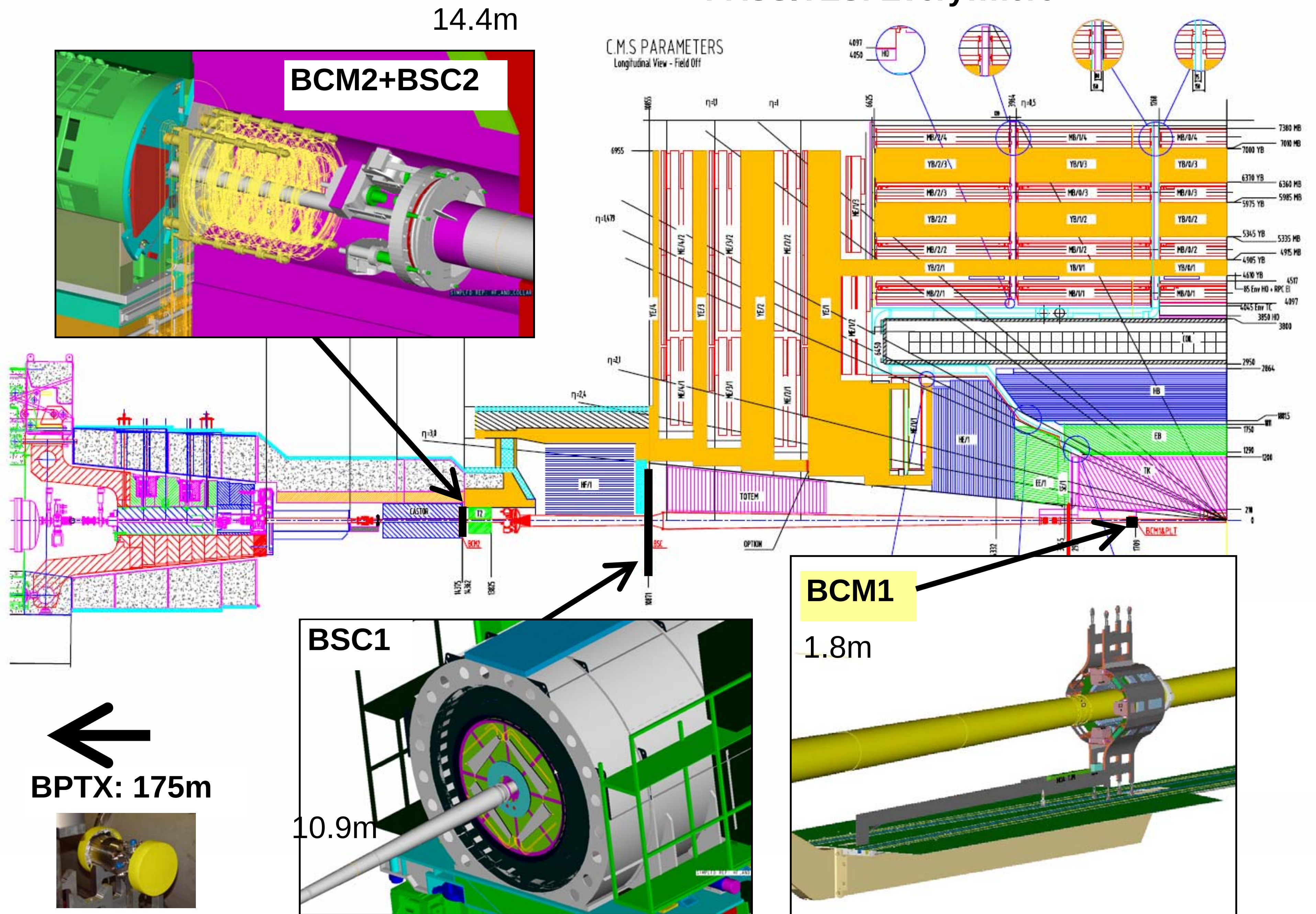
Subsystem	Location	Sampling time	Function	Readout + Interface
Passives TLD + Alanine	In CMS and UXC	Long term	Monitoring	---
RADMON	18 monitors around CMS	1s	Monitoring	Standard LHC
BCM2 Diamonds	At rear of HF z=±14.4m	40 us	Protection	CMS + Standard LHC
BCM1L Diamonds	Pixel Volume z=±1.8m	Sub orbit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

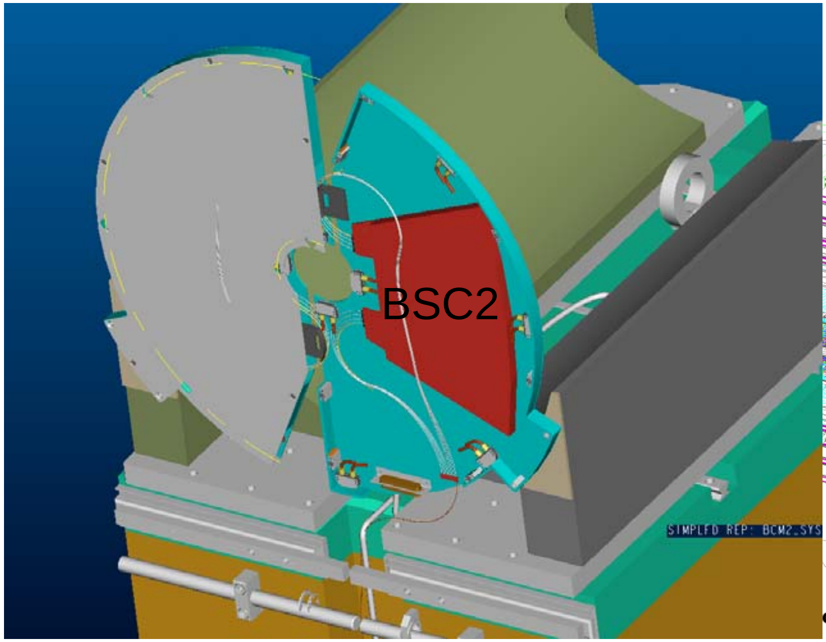
Total of 32 pCVD and 8 sCVD

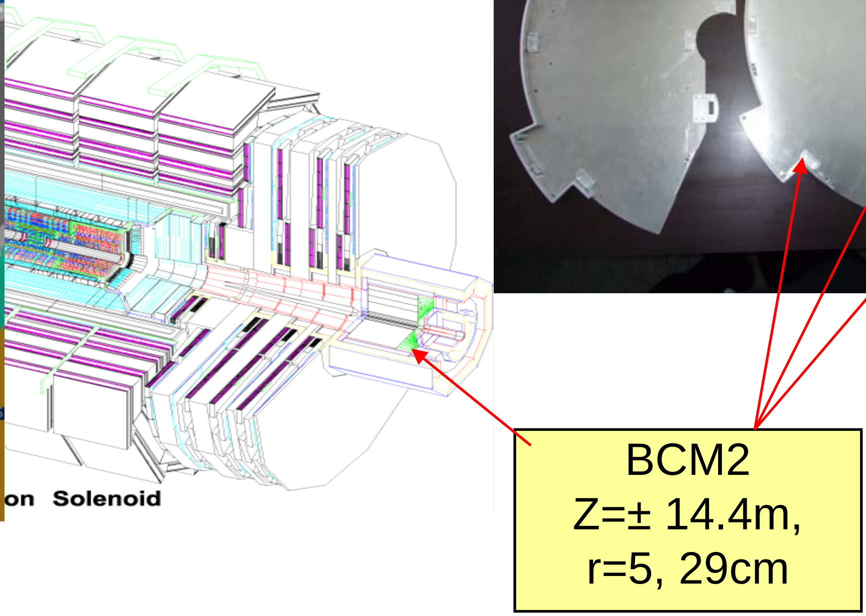
RADMON: 18 monitors around UXC

PASSIVES: Everywhere



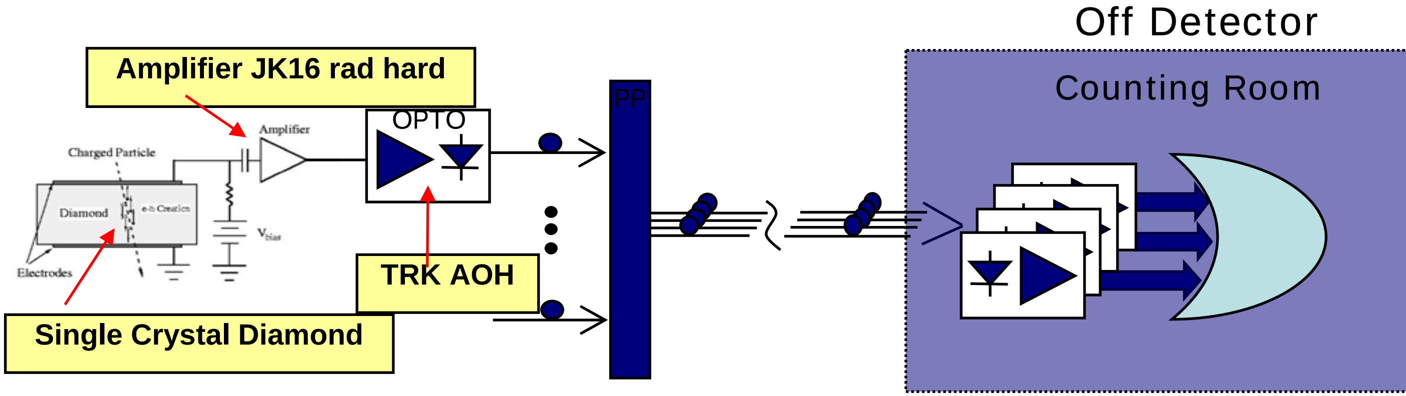
BCM2

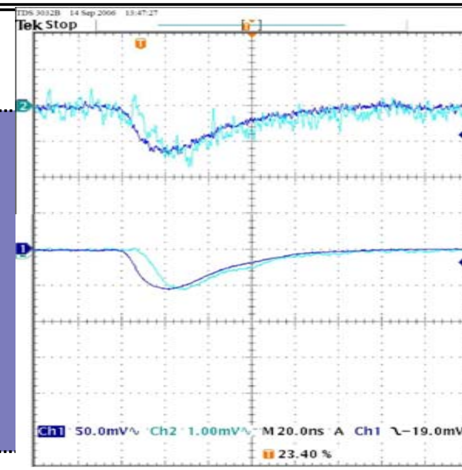




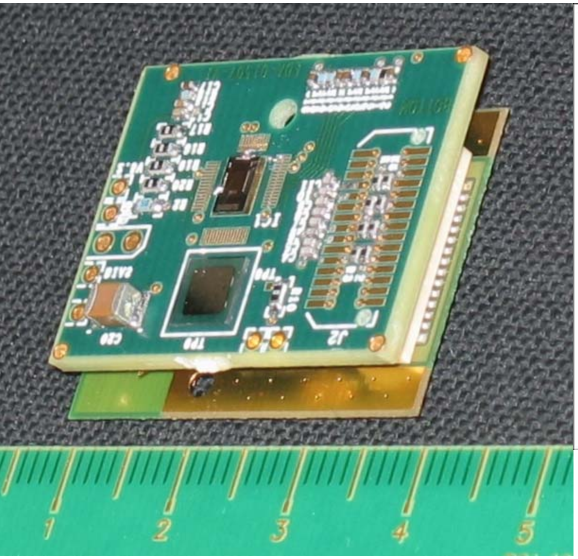
- Will be active in abort from day 0
- BCM2 sensors profile (per end)
  - Inner Diamonds (4) sensitive to luminosity products
  - Outer diamonds (8) sensitive to incoming background (shielded from IP)
- Standard LHC Beam Loss Monitor readout
  - Diamonds Frontend readout via rad. hard LHC readout for BLM
  - Backend Readout: DAB64 cards, FESA
  - For CCC looks identical to Beam Loss Monitors

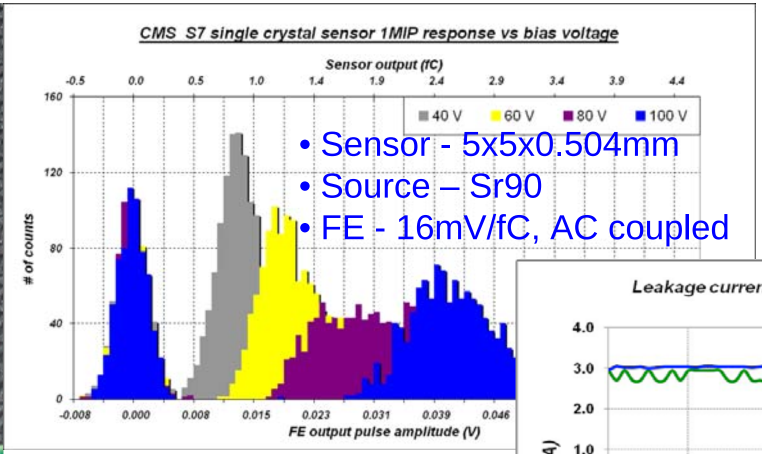
BCM1 F



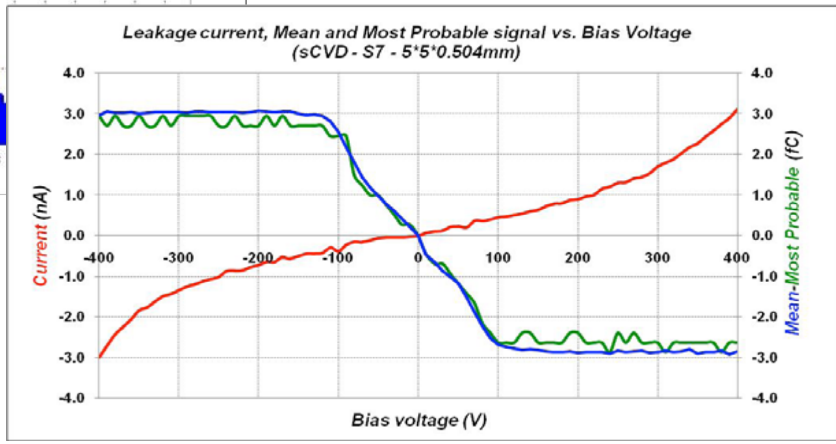


3fC response
JK16(Ch.1) and
AOH(Ch.2)

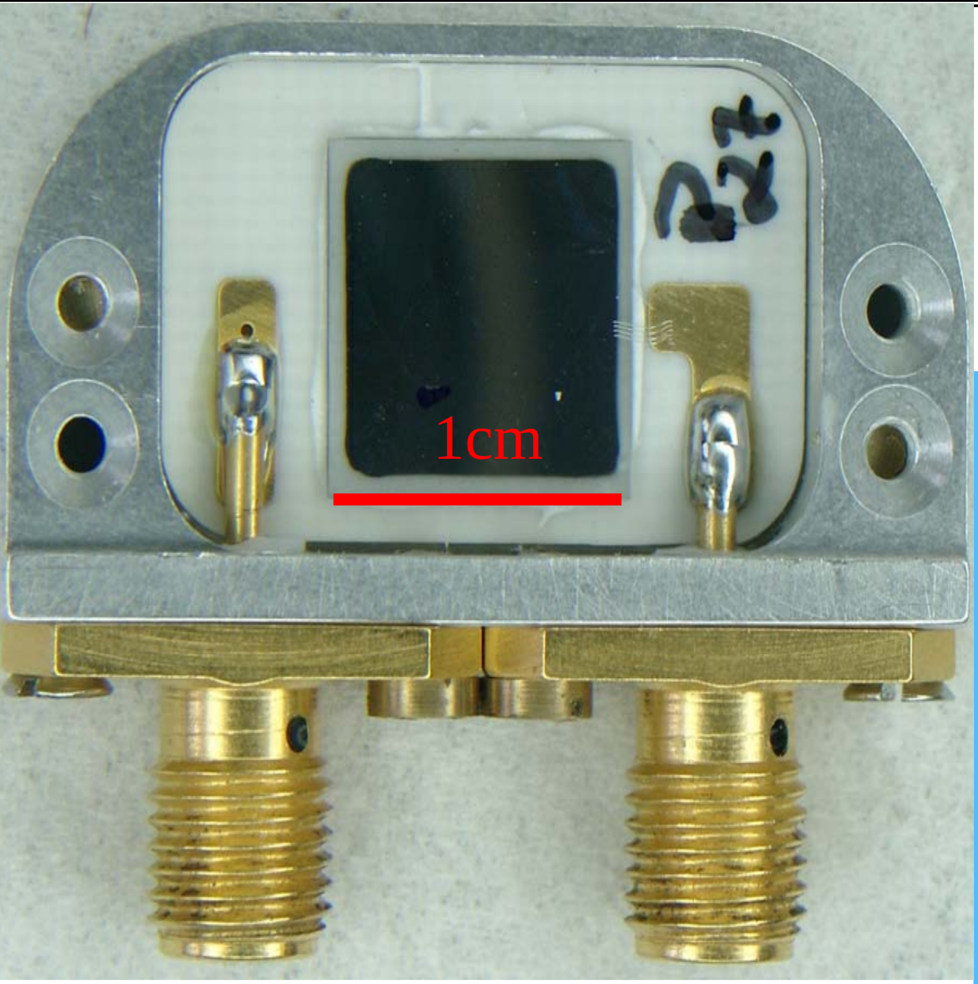




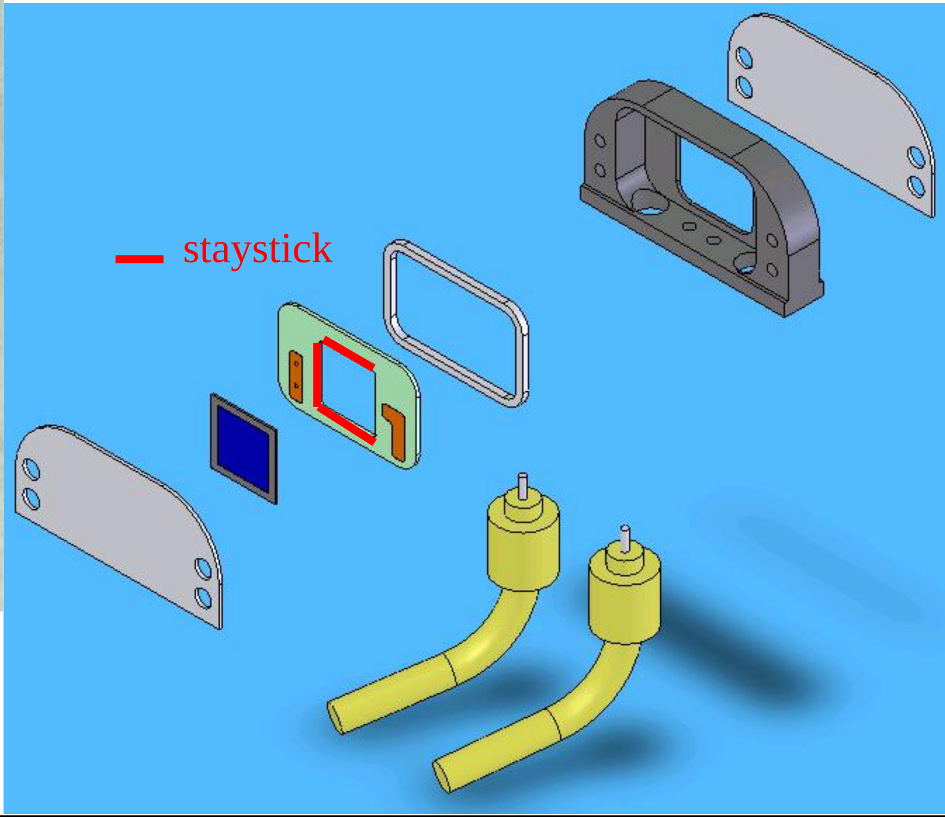
- Sensor - 5x5x0.504mm
- Source – Sr90
- FE - 16mV/fC, AC coupled



BCM2 Package

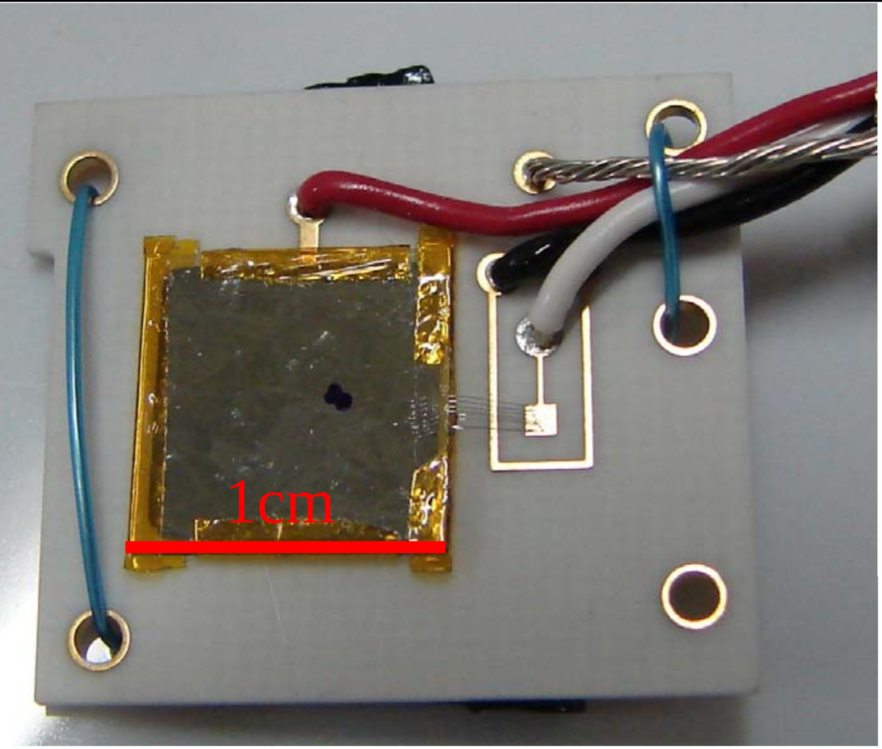


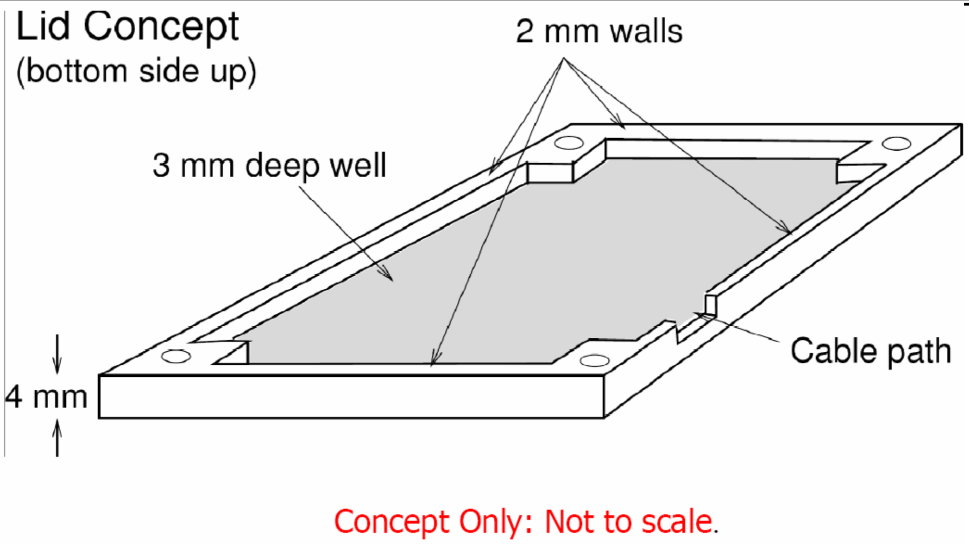
BCM2 detector is a $10x10x0.4mm^3$ polycrystalline CVD diamond with Tungsten-Titanium metallization. The average charge collection distance is approximately 220um.



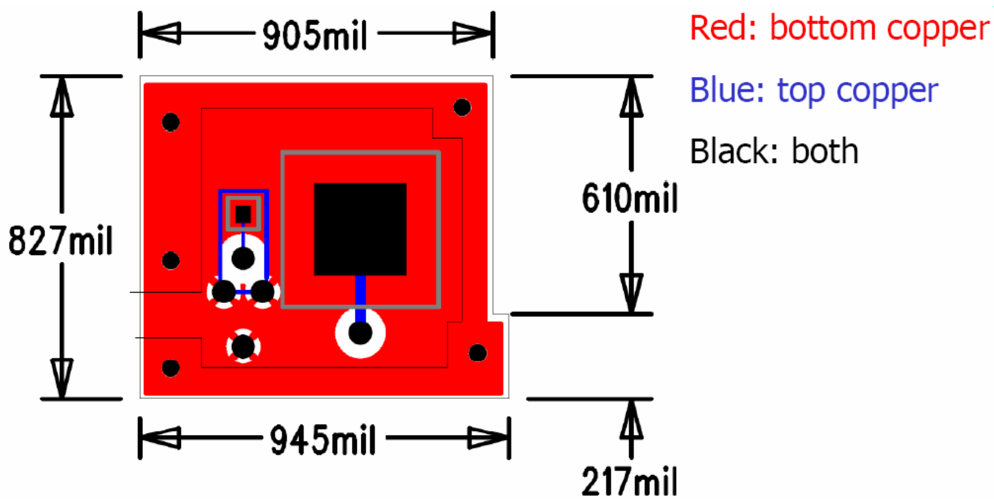
Baseplate material:
Rogers corp. woven glas reinforced ceramic filled thermoset material.

BCM1 L Package



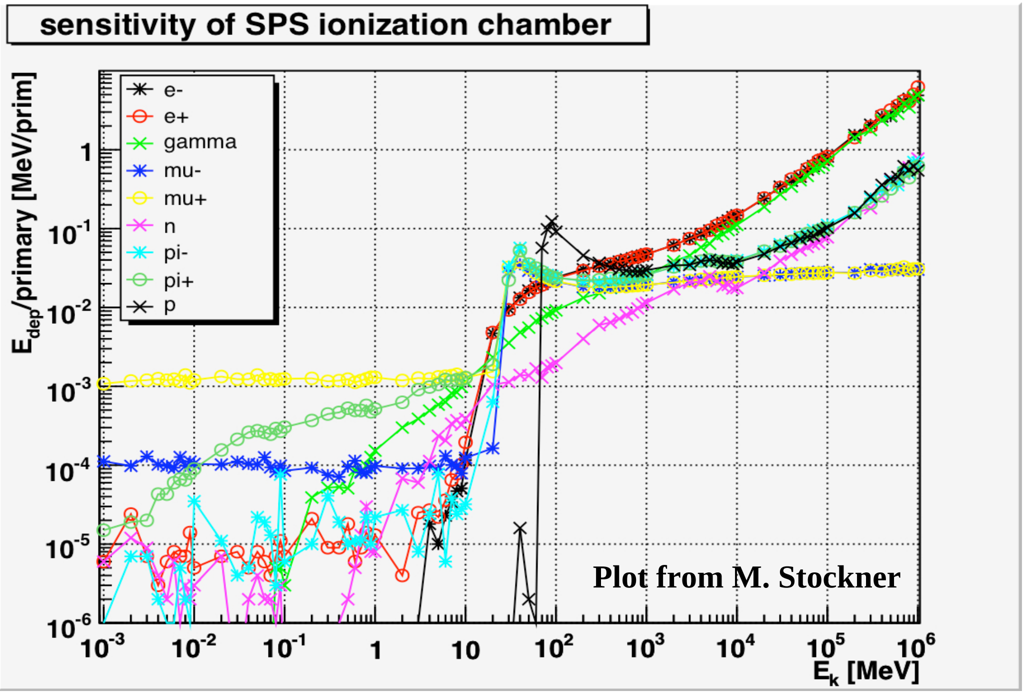


BCM1 prototype-board



Reference detector: BLM Tube

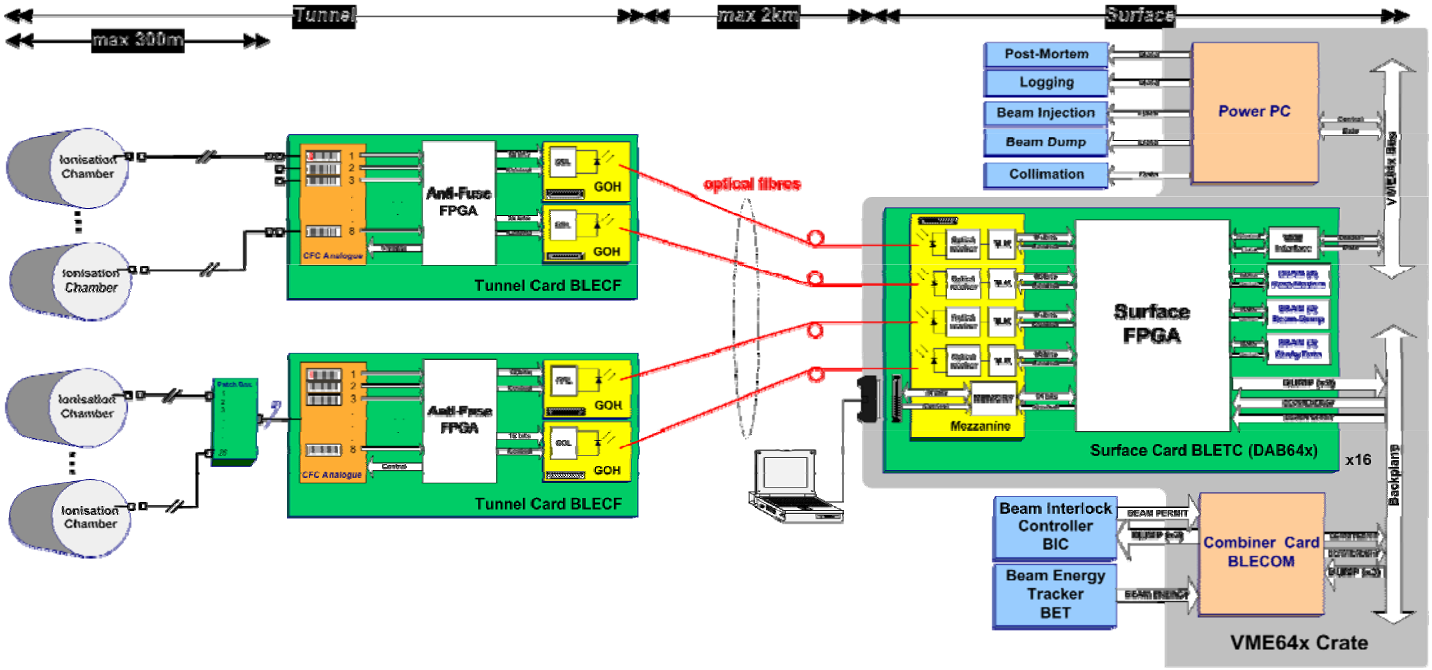
- Ionization Chamber
- 60cm long, 9cm diameter
- ~3700 around ring
- Main machine protection device - connected to beam dump system
- Quench prevention
- Beam Diagnostics

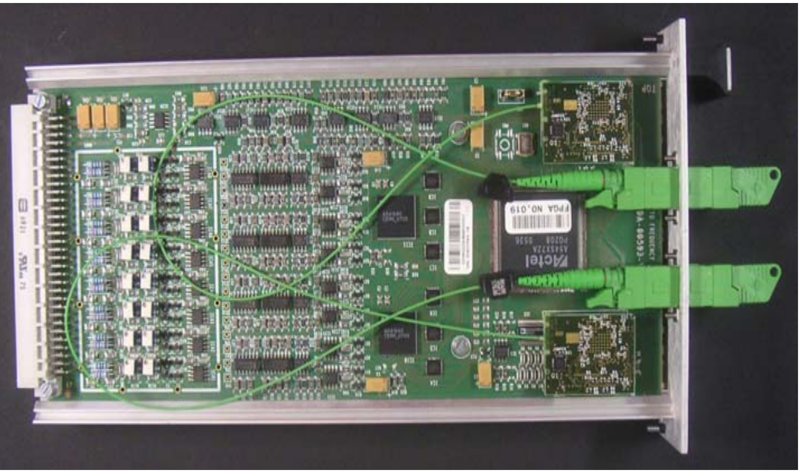


Relative Signal depends upon particle type and energy.
Shown here for SPS type chamber

High energy and low energy response very Different Simulation assumes particles incident parallel to axis of detector

Readout electronics for BLM and BCM2





Current-to-Frequency Converter

- Measuring range 2.5 pA to 1 mA (8 decades – 160dB)
- Radiation tolerant up to 500 Gy (20y - LHC lifetime)
- Reliability level SIL3 (10^{-6} to 10^{-7} failure/h)

ADC

- Increase of accuracy
- Radiation tolerant up to 10 KGy

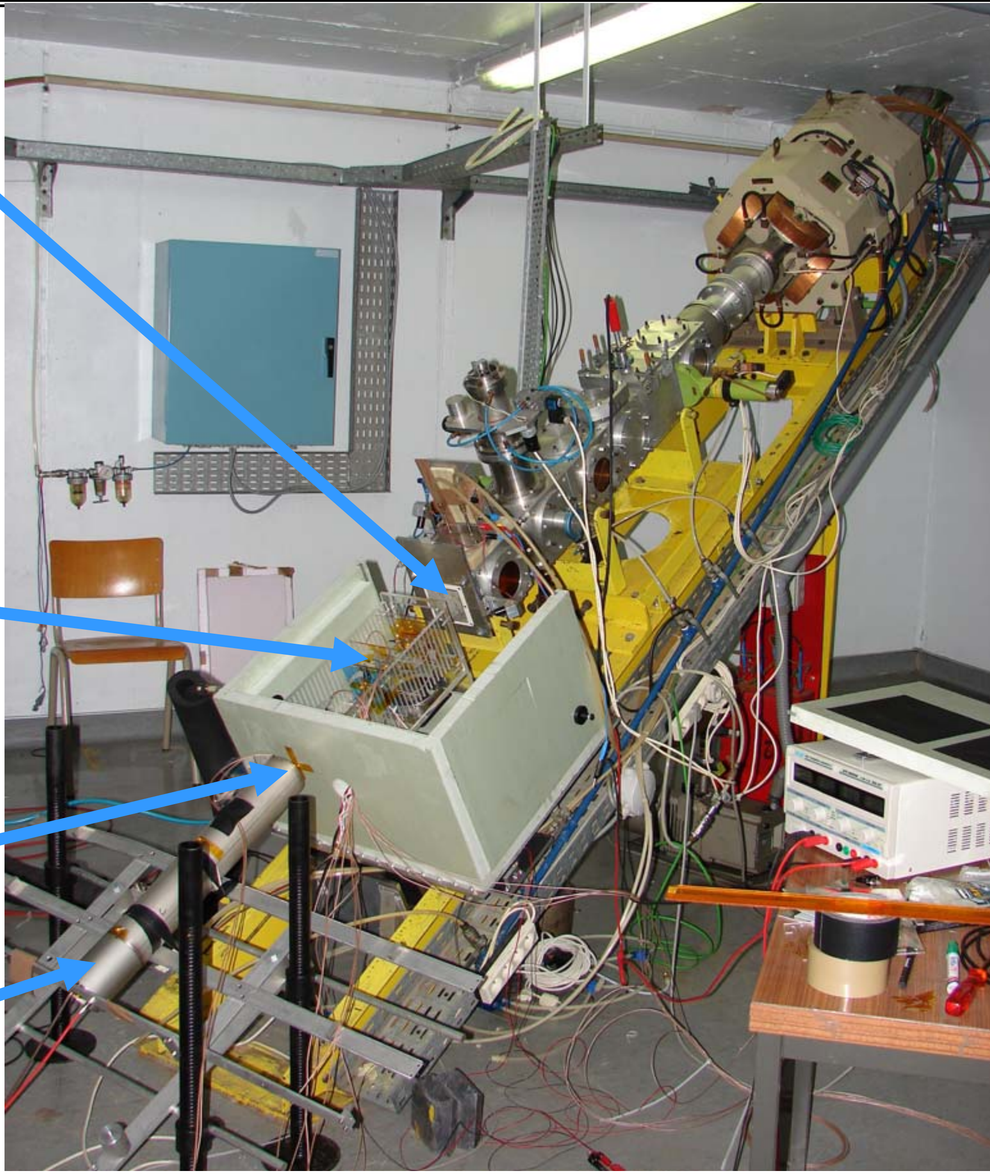
Slide stolen from Christos

Testbeam program

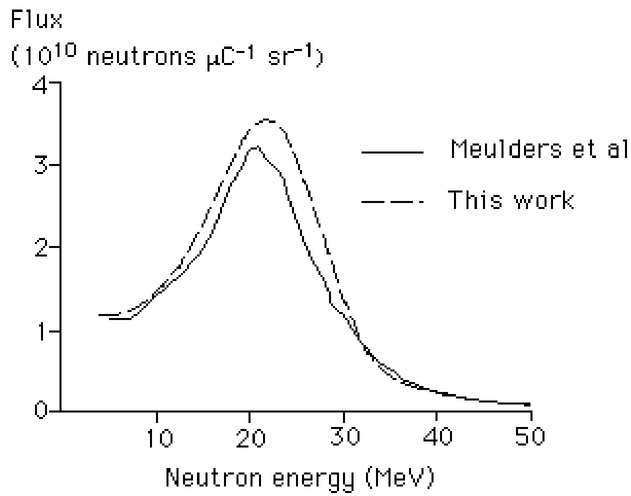
- BCM2 should be a ‘transparent’ replacement for BLM within the experimental cavern.
- Signal readout and data format absolutely identical, but:
- Different detector (Diamond instead of ionization chamber), therefore:
  - At least relative calibration,
  - better absolute detector response desirable.
- This is part of input for initial threshold calculations.
- Signal simulations for nominal CMS operation and accidental scenarios.
- Testbeams also served as a test of prototype assemblies, reliability of detectors and final readout scheme.

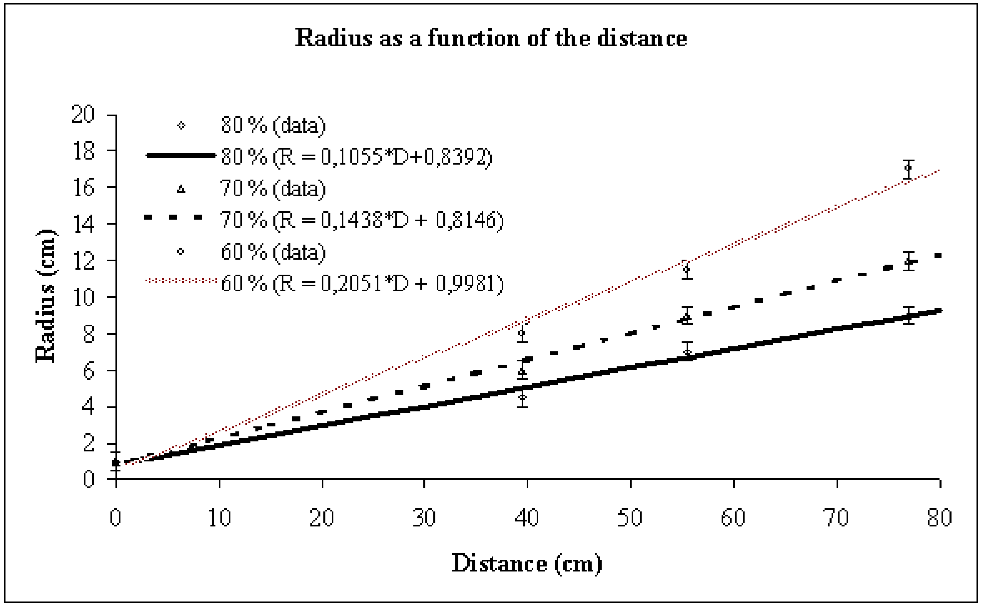
Louvain neutron beam: Beamline setup

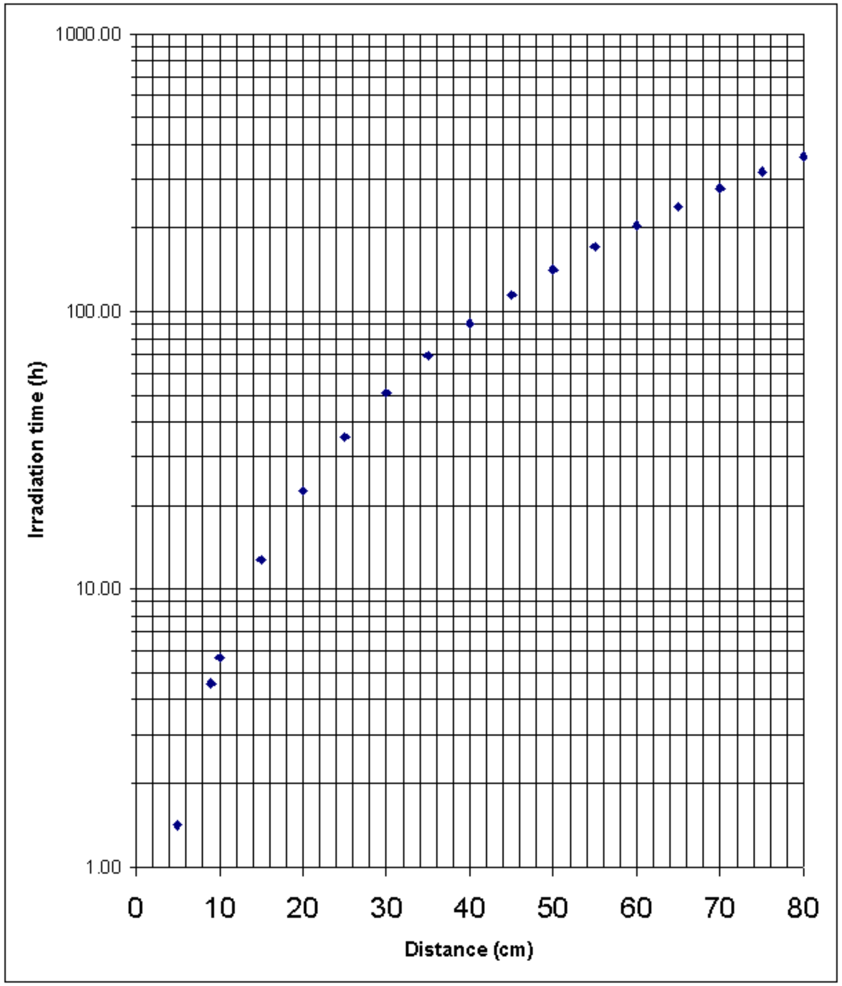
- BLM Tube:
  - 60.5 cm from target
  - Bias 1.5kV
- BCM2 diamond P25
  - 59cm, in front of BLM
  - Bias 500V
- Dosimeters at following positions
  - 58cm (IC0, center of beam)
  - 85cm (IC1, off center)
  - 111cm (IC2, off center)
  - 122 cm (IC3, center)
- TC channel layout (distance from target)
  - 1: BLM tube, 60.5cm
  - 2: BCM2 diamond, 59cm
  - 3: Si-diode, 33cm
  - 4: Si-diode, 48cm
  - 5: sCVD, 120um, 3cm
  - 6: sCVD, 330um, 8cm
  - 7: sCVD, 320um, 17cm
  - 8: sCVD, 480um, 25cm



Beam parameters Louvain

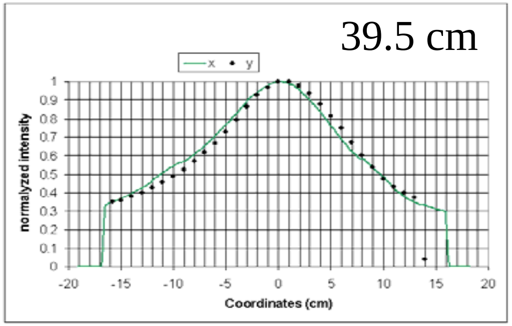


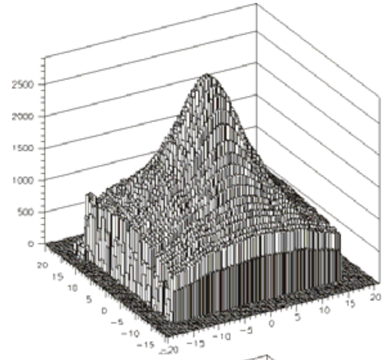


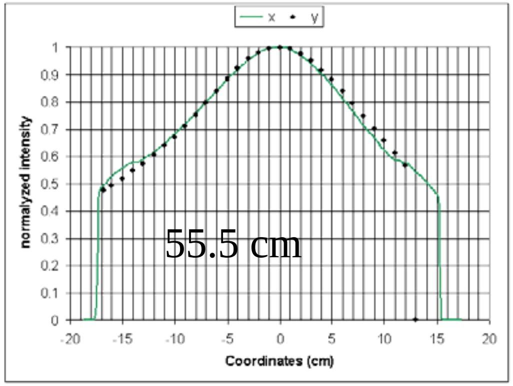


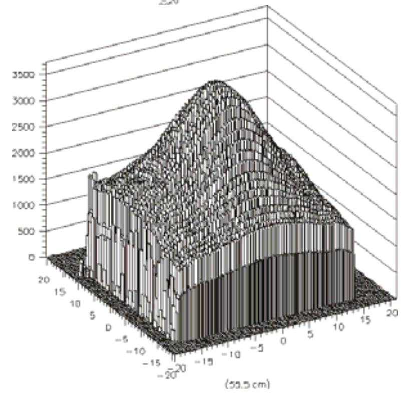
Time needed for 1e14n/cm**2 as function of distance to target for 1uA deuteron current

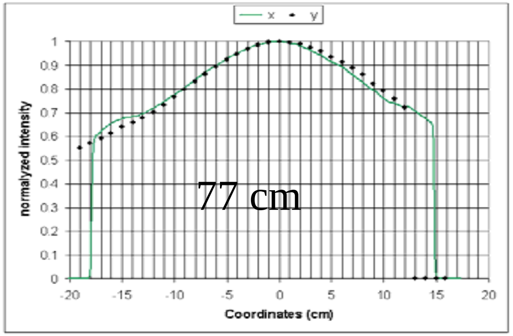
Beam parameters cont.

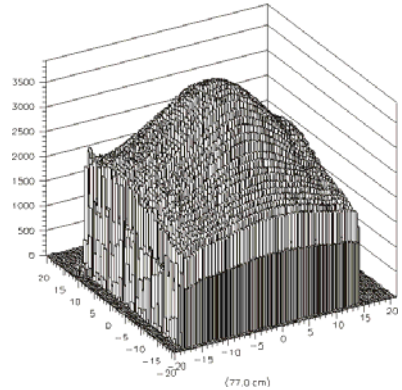










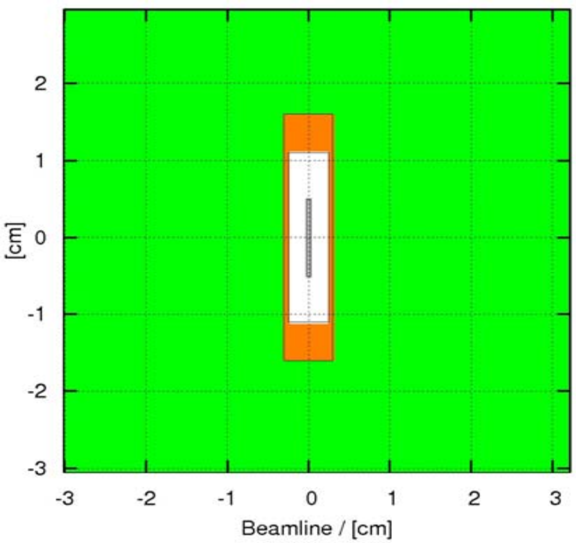


Beam contamination:

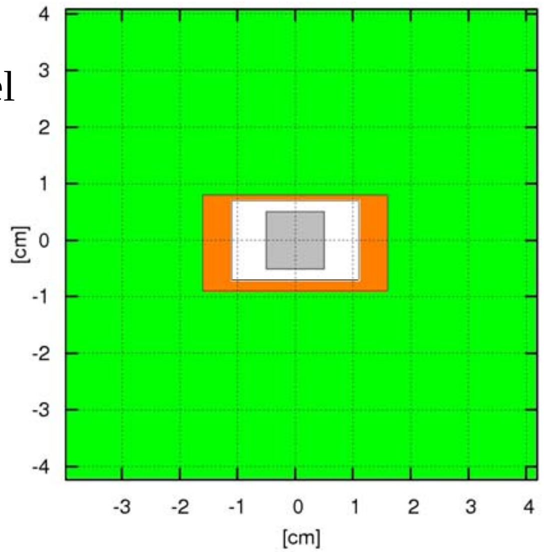
Ratio	Before the filter	After the filter
Gamma/neutron	1.2 %	2.4 %
Charged particles/neutron	0.08 %	0.03 %

Particle type	Fraction	Average energy (MeV)	Maximum energy (MeV)
Neutron	1.0	20	50
Proton	$1.5\ 10^{-4}$	12.61	25
Electron	$1.6\ 10^{-4}$	1.57	6
Gamma	$2.4\ 10^{-2}$	1.93	10

Effects of beam contamination – Fluka simulation



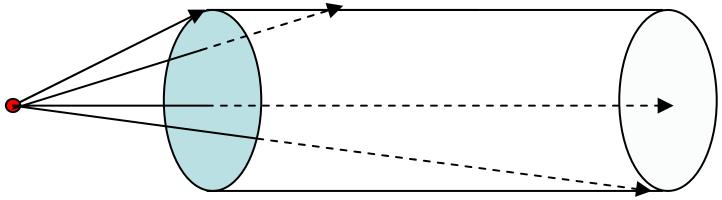
BCM2 package model



Particles	Energy deposit [GeV]	energy deposit [%]	Particle fraction [%]
Protons	1.581E-08	0.783	0.015
Photons (γ)	6.949E-09	0.344	2.34
Electrons	2.086E-11	0.001	0.016
Neutrons	**1.996E-06**	**98.871**	**97.63**
Total	*2.019E-06*	*100*	*100*

Energy deposit is dominated by Neutrons, so we have first indication that beam contamination in Louvain didn't affect the signal to much (~1%). But further investigation needs to be done to find the ratio for ionizing and non ionizing energy loss for Neutrons and other particles.

Flux correction for BLM tube



- Number of paths proportional to area of front endface the neutrons go through
- Path length, ***f(r)***, is a function of radial distance ***r*** from centreline that neutrons enter the detector
  - 50cm at r =0, and 0cm at r =4.5cm
- At radial distance r, number of paths is proportional to area contained in annulus of radius ***r***, and thickness ***dr***.

For each annulus, calculate: *number paths X length of path*
This is equivalent to: *area of annulus X length of path*
Normalise by dividing by the total number of paths – i.e. divide by the area of the endface of the detector.

For uniform flux:
r is radial distance from cylinder centre where neutron enters cylinder
R is radius of cylinder, f(r) is path length through cylinder for a neutron entering cylinder at radial distance r from centreline.

$$\frac{\int_0^R f(r)2\pi r dr}{\pi R^2}$$

$$\frac{\int_0^R f(r)h(r)2\pi r dr}{\int_0^R h(r)2\pi r dr} = apl$$

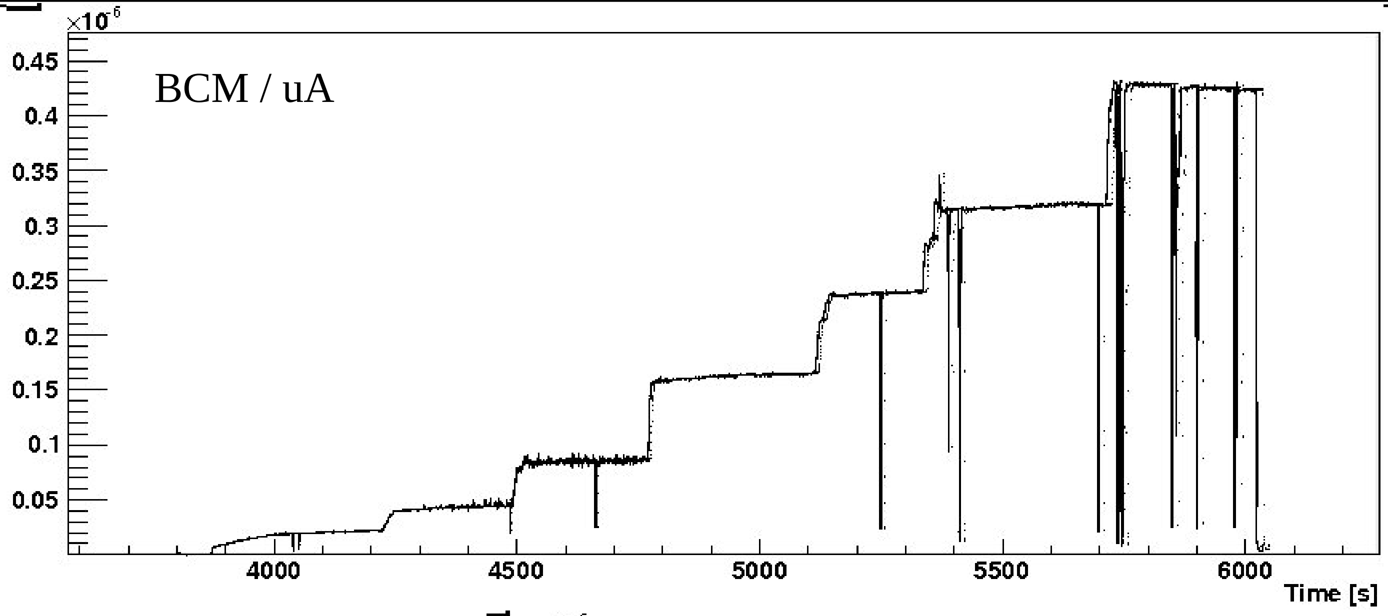
Non uniform flux:
Where *h(r)* is a Gaussian fitted to the 55cm beam profile to represent the non-uniform flux of neutrons entering the detector . **For this test beam, the average path length is 27.9cm.**

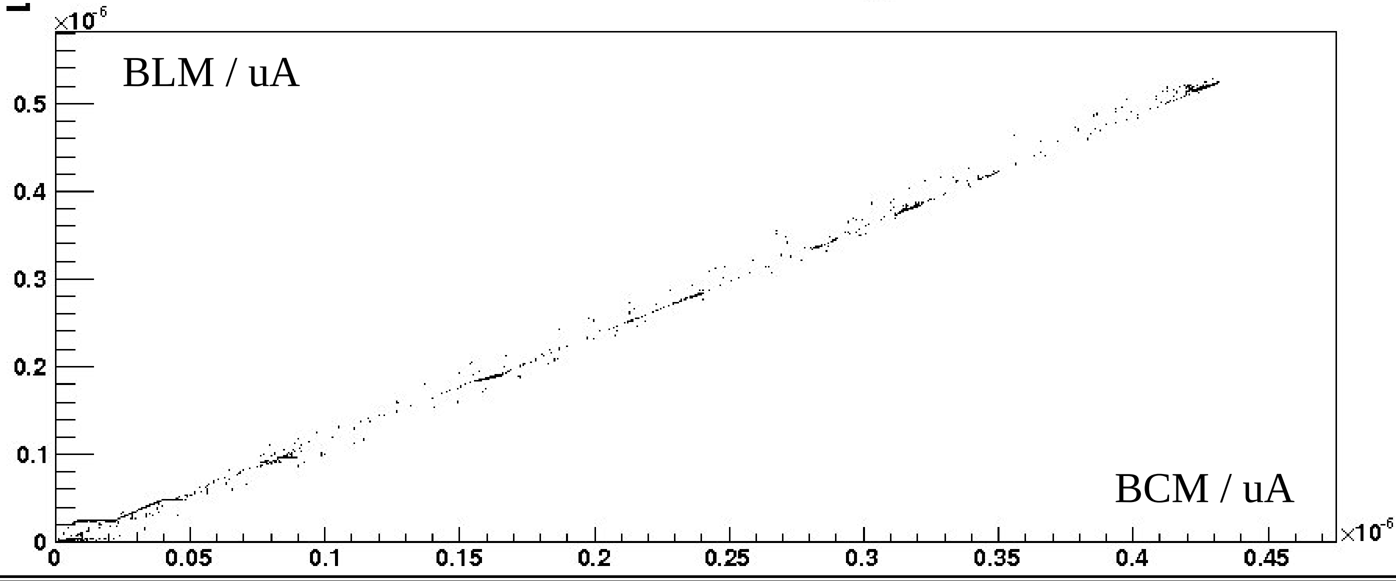
Testbeam procedure

Vary deuteron current in various steps. Each step's duration is about 4 minutes. Estimated fluxes for a given deuteron current for BCM and BLM are given below.
For BLM the Flux at the beginning of the tube (60.5cm) is shown.

Deuteron current [uA]	BCM [n/(cm2 *s)]	BLM [n/(cm2 *s)]
0.5	7.02e7	6.68e7
1	1.40e8	1.34e8
2	2.81e8	2.67e8
4	5.62e8	5.35e8
6	8.43e8	8.02e8
8	1.12e9	1.07e9
11.3	1.58e9	1.51e9

Signal and Correlation BLM/BCM

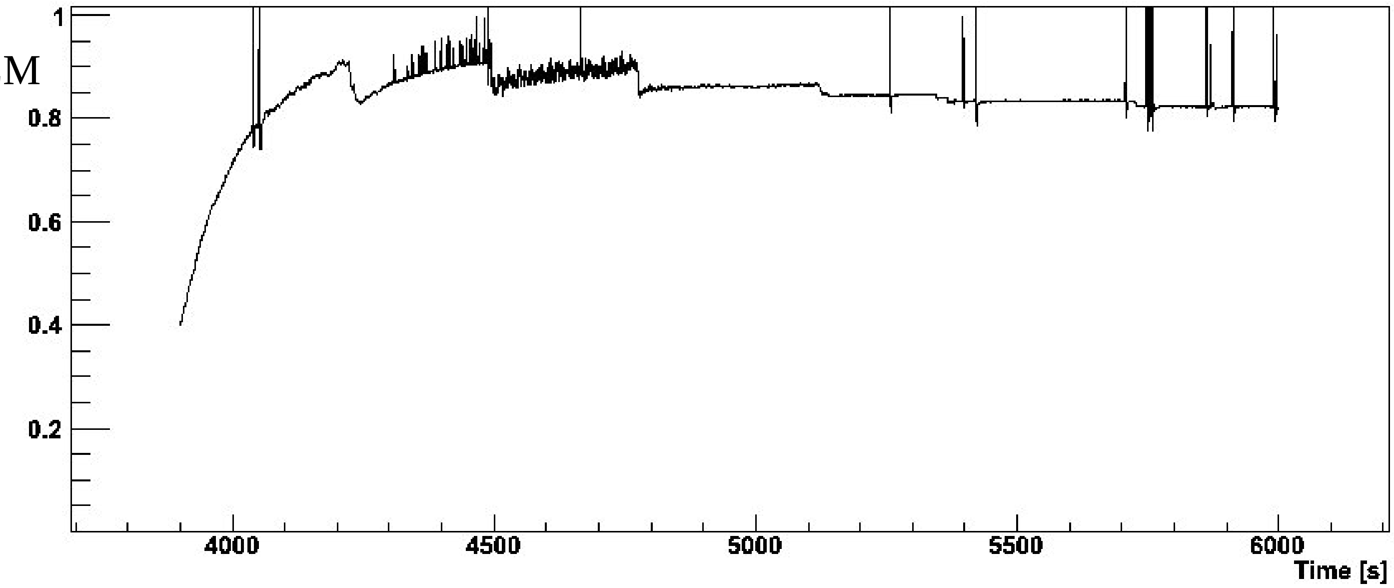




Ratio BCM/BLM

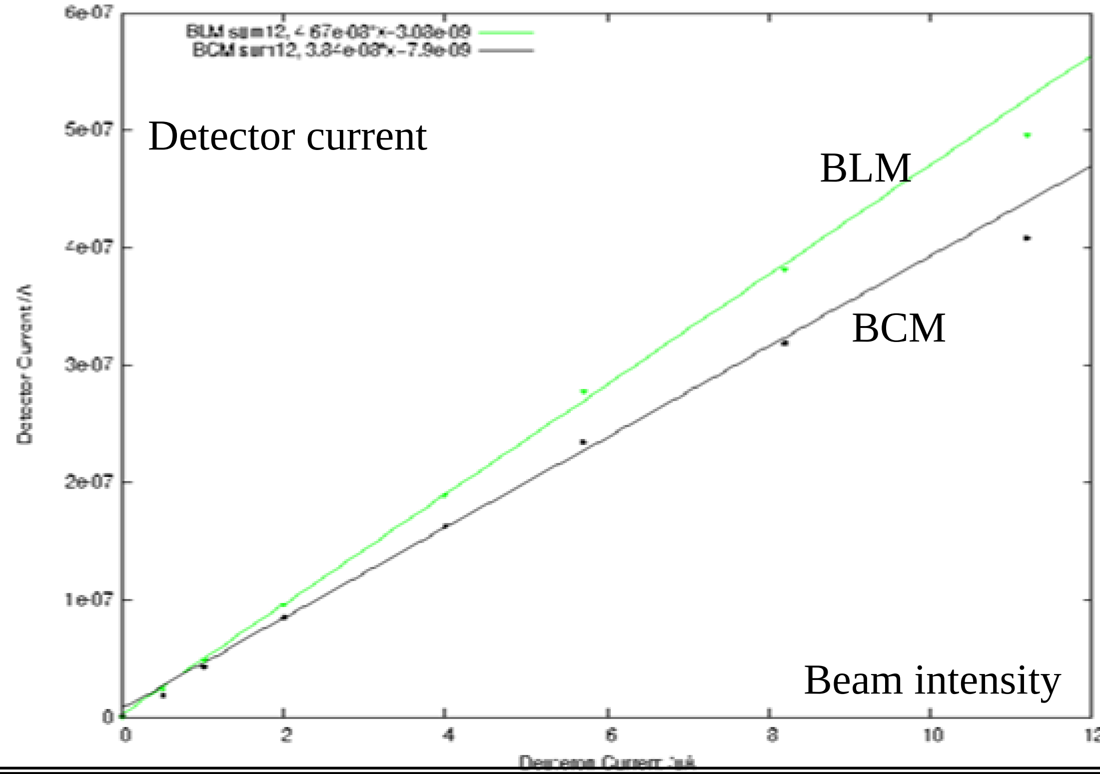
- Ratio useful to cancel out most of the beam effects (dropouts, intensity fluctuations)
- Positive slope in BCM/BLM ratio is due to pumping
- Negative slope would be diamond degradation (not seen here)
- Pumping ends approx. after third step
- Slight decrease in ratio, either stronger BLM or weaker BCM signal at higher beam intensities.

Ratio BCM/BLM

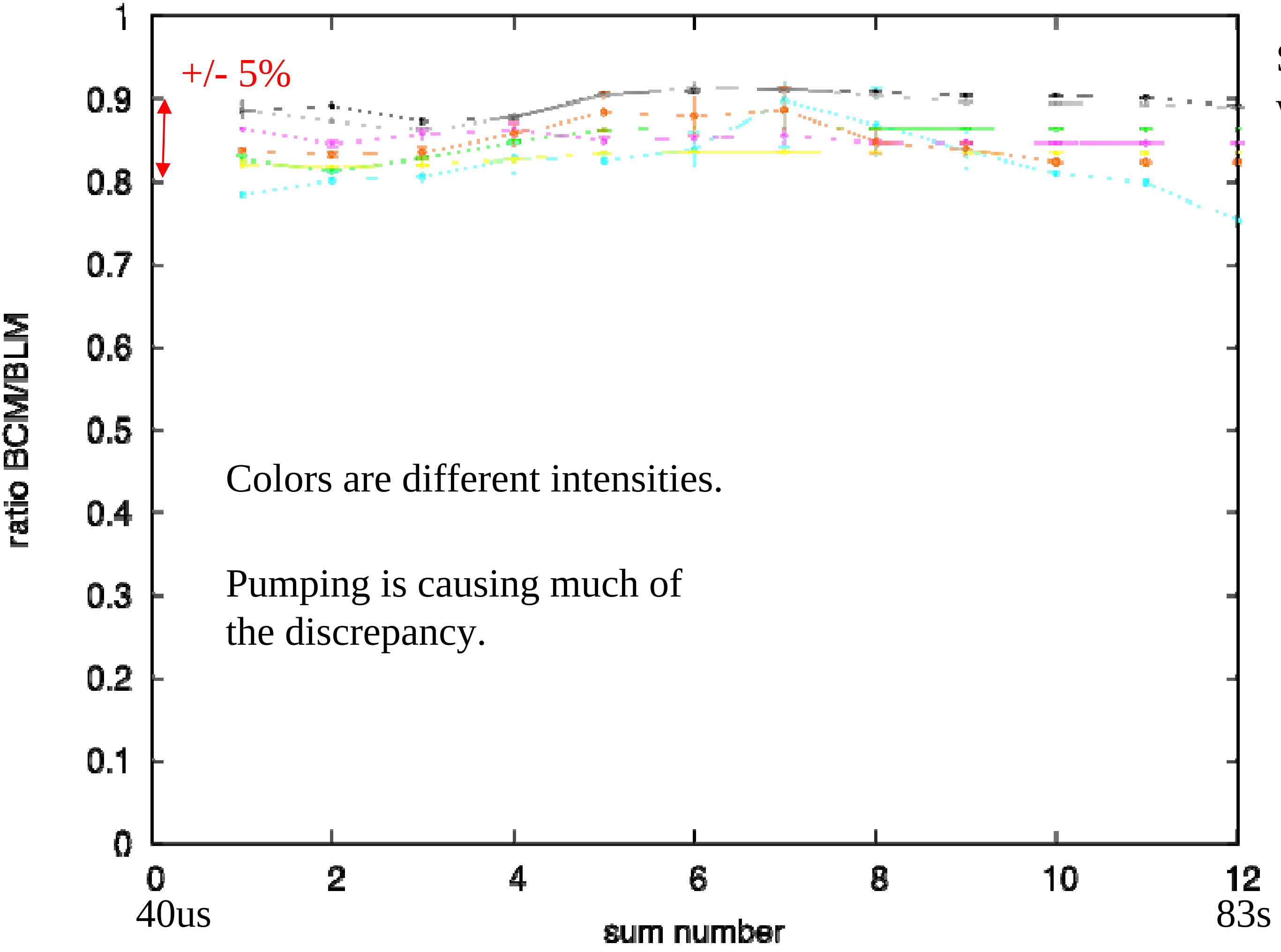


Detector Response BLM and BCM

- BLM: S=46.7 (+/- 0.94)nA/(1.34e8N*(27.94/50))/(cm**2 s)*DC+ 3.08 (+/- 4.65)nA
  - Response: 9.8e-18C/N
  - Simulated response from Markus: 7e-18C/N (preliminary).
    - Assumptions: single energy Neutrons, 22MeV, parallel beam
    - Possible reason for discrepancy might be beam contamination in Louvain, to be checked.
- BCM2: S=38.4 (+/- 0.95)nA/1.4e8N/(cm**2 s) * DC + 7.9 (+/- 4.7)nA
  - Response: 274.29e-18C/N
  - Error of beam current not known.

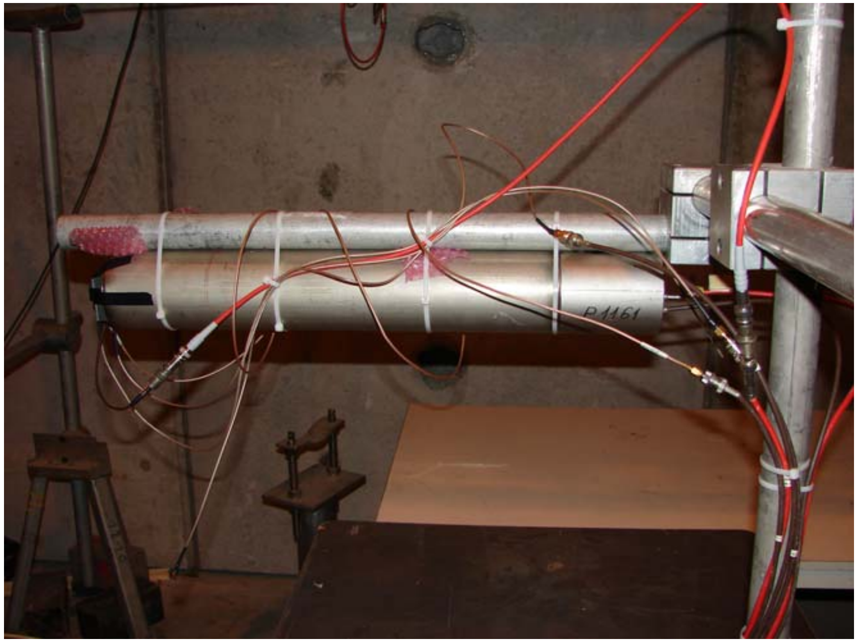


Ratio of BCM/BLM for all sums



Signals of BLM and BCM within 5%

SPS beamline setup



1: Passives, Alanine

2: BCM2 diamond, P27 mounted on final baseplate

3: Labdiamond

4: BLM tube (bias 1.5kV)

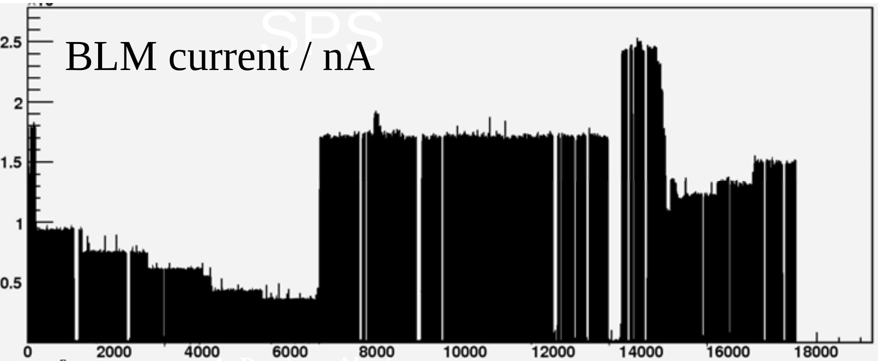
5: Passives, Alanine

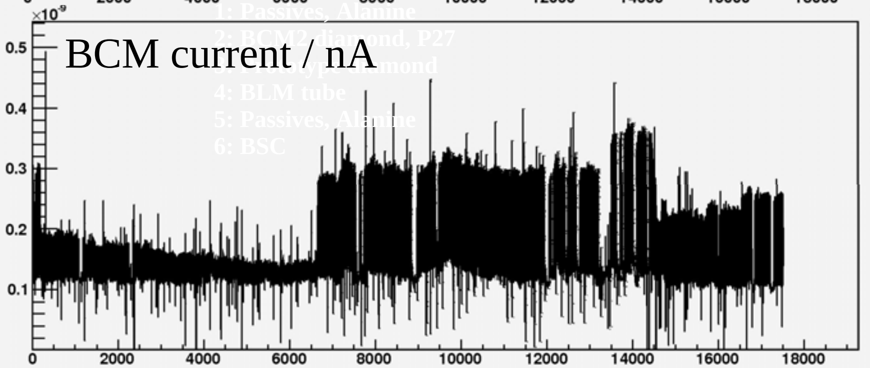
- This was first beam test with ‘final’ packaging
- Especially for Packaging and grounding/shielding we have learned a lot during this test.
- Test led to some changes in packaging.
- PS testbeam proved that changes were a success.

Beam characteristics

- ~10^5 / 4.8s proton/pion beam 180GeV
- Beam size: 7.7 x 12.9 mm (one sigma values)

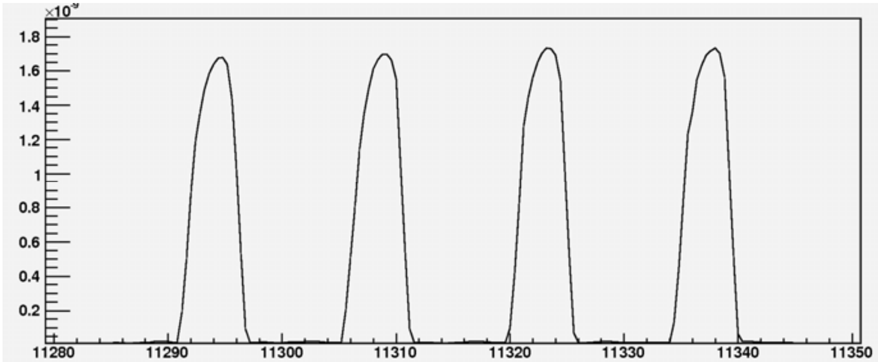
Signals



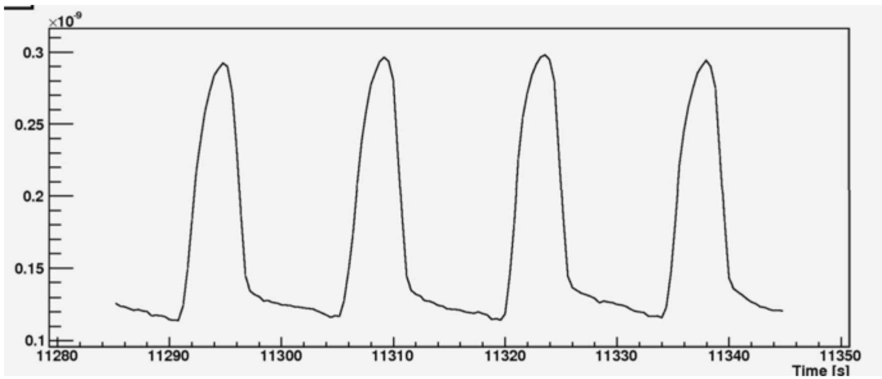


Time /s

BLM

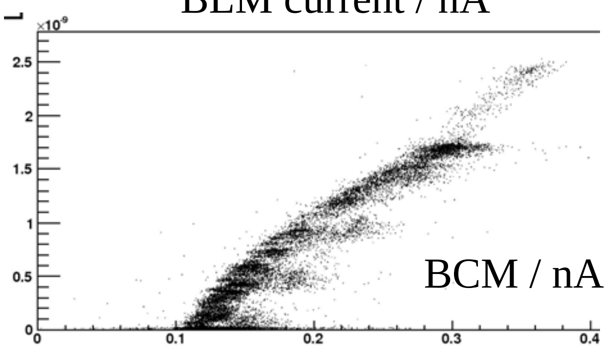


BCM



Time /s

BLM current / nA



SPS was a very noisy environment. Had to rethink parts of our initial packaging and grounding.

By the end of the testbeam a good correlation and calibration could be achieved.

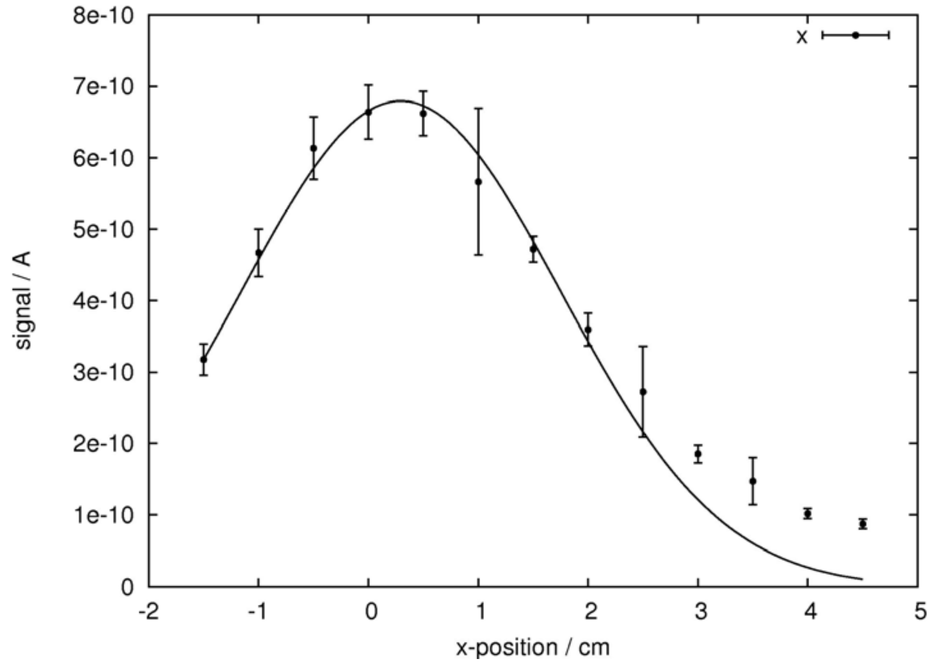
NB: BCM signal currents were max. 300pA (nominal signal 100nA).

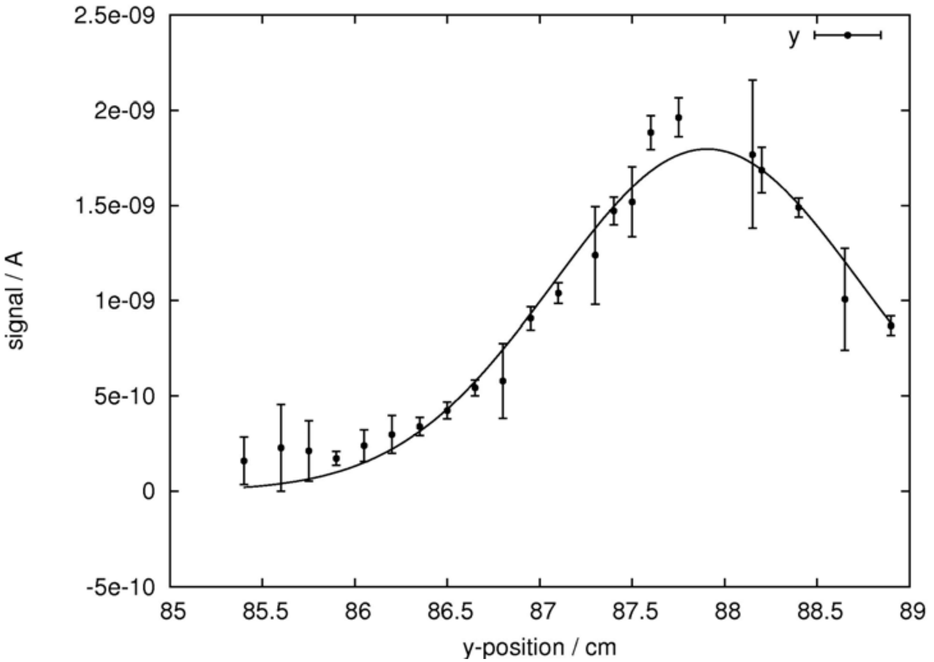
PS beam line setup

- Two scintillators in coincidence for measurement of beam intensity.
    - 5 x 5 mm2
    - 50 x 50 mm2
- Two BCM2 diamonds
- One BCM1_L diamond
- BLM tube

2GeV Proton Pion beam
Beam intensity up to 10^6 p/400ms

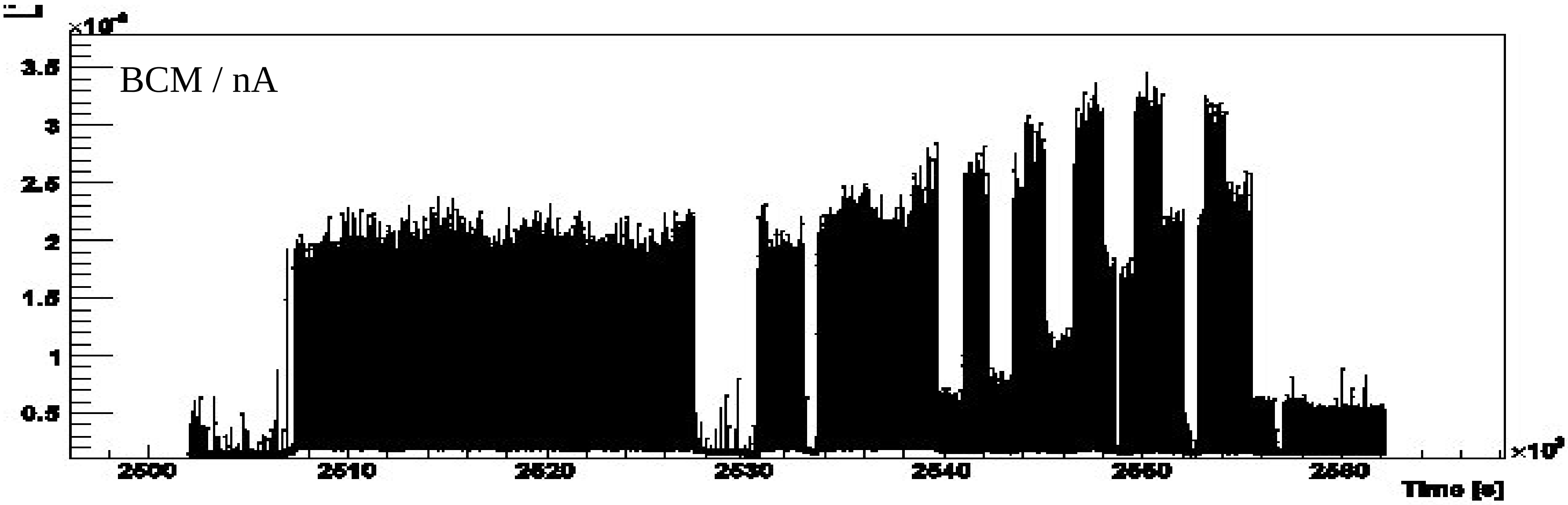
Beam Profile

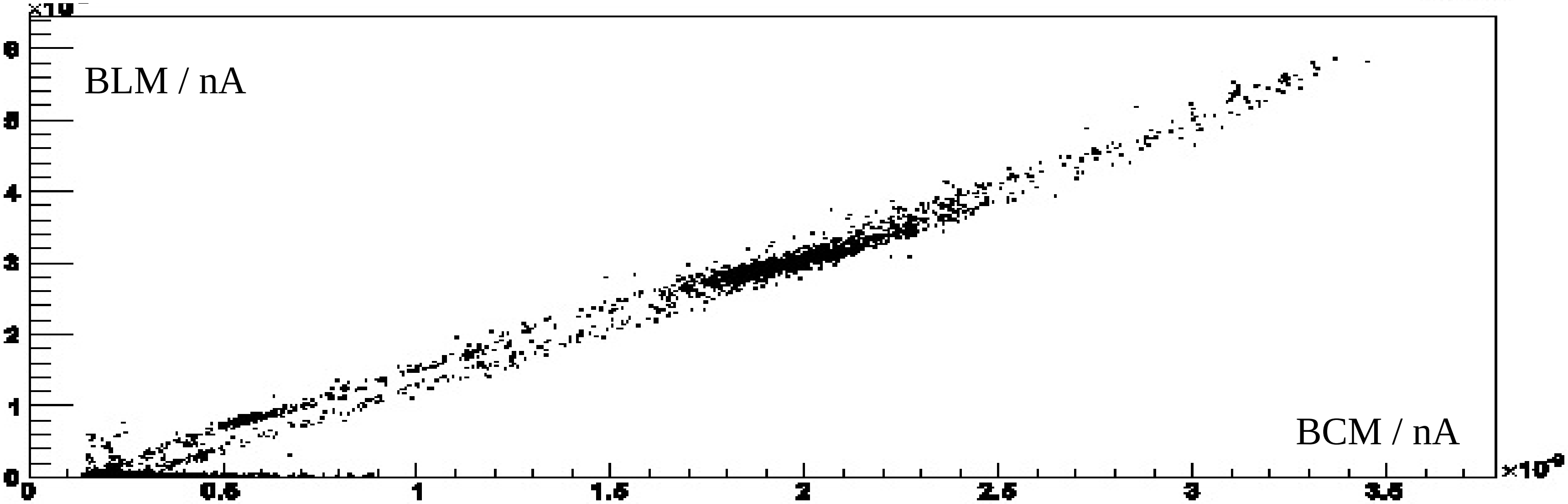




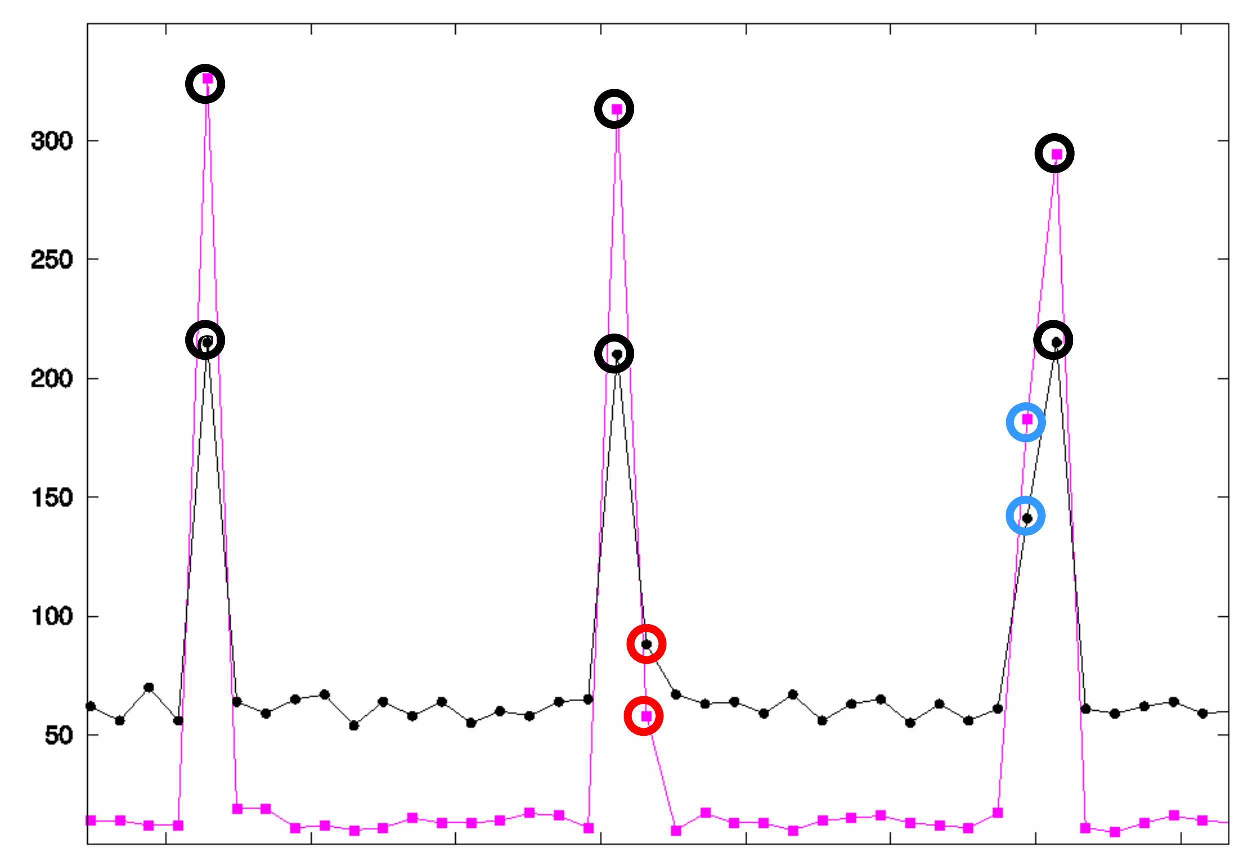
- Beam profile as measured by the BCM2 diamond
- There are more independent measurements for crosscheck purposes (work ongoing)
- Gaussian fit: beam tails not modeled:
  - Beam width (one sigma): 1.45 x 0.83cm
- Need to deconvolute sigma with 9mm detector size

Correlation BLM/BCM



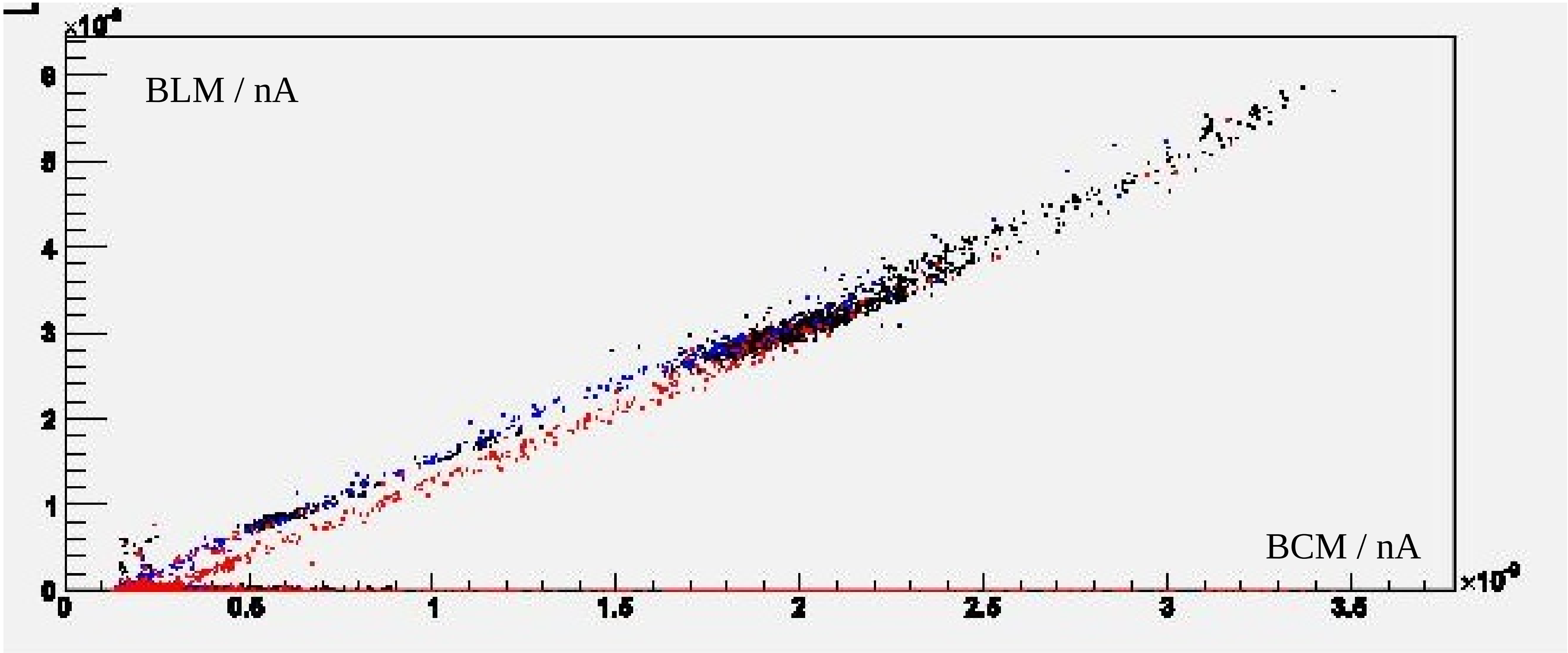


Signal



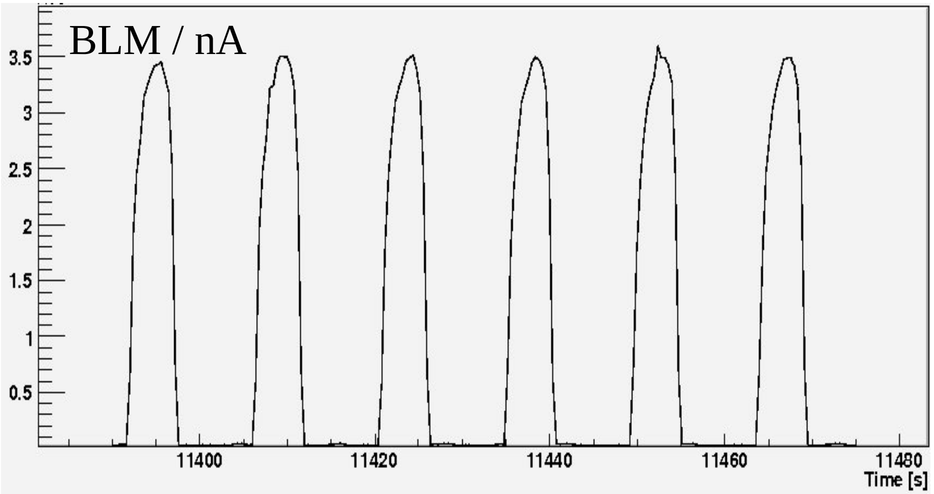
Due to the sampling time of DAQ and spill length, there are three possibilities how the signals look like. Depending on the detector features, different points have different features. On the next slide a correlation plot of BLM and P27 is shown, in there following color tags were used:

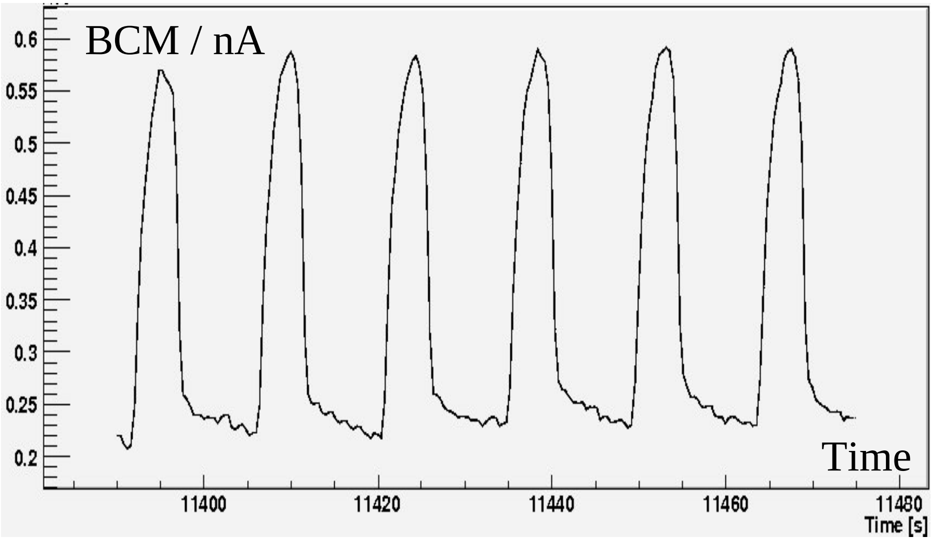
Maximum: black
Trailing edge: red
Leading edge: blue

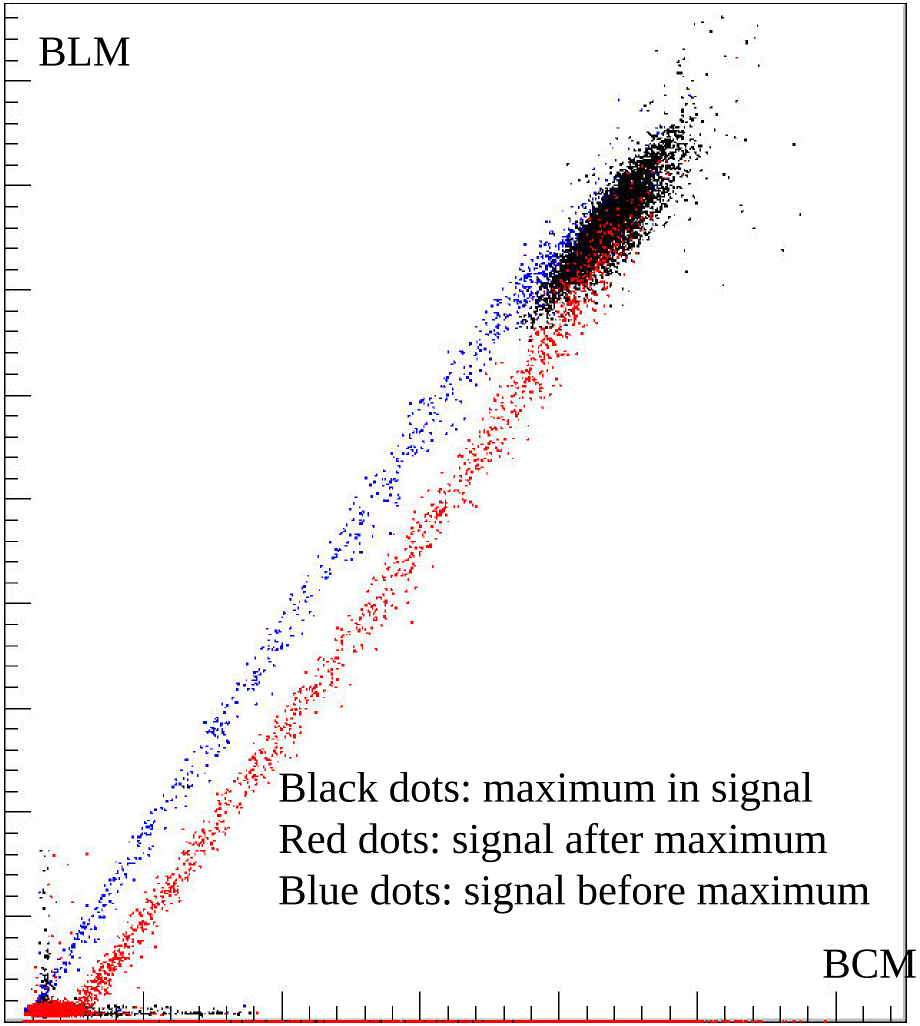


Timing of signals different for BLM and P27. The correlation for maximum seems to be the same as for the leading edge. The blue and black points are forming one line.
But the diamond shows a longer time constant in trailing edge, therefore a second line shows up (red) in the correlation plot between BLM and P27.

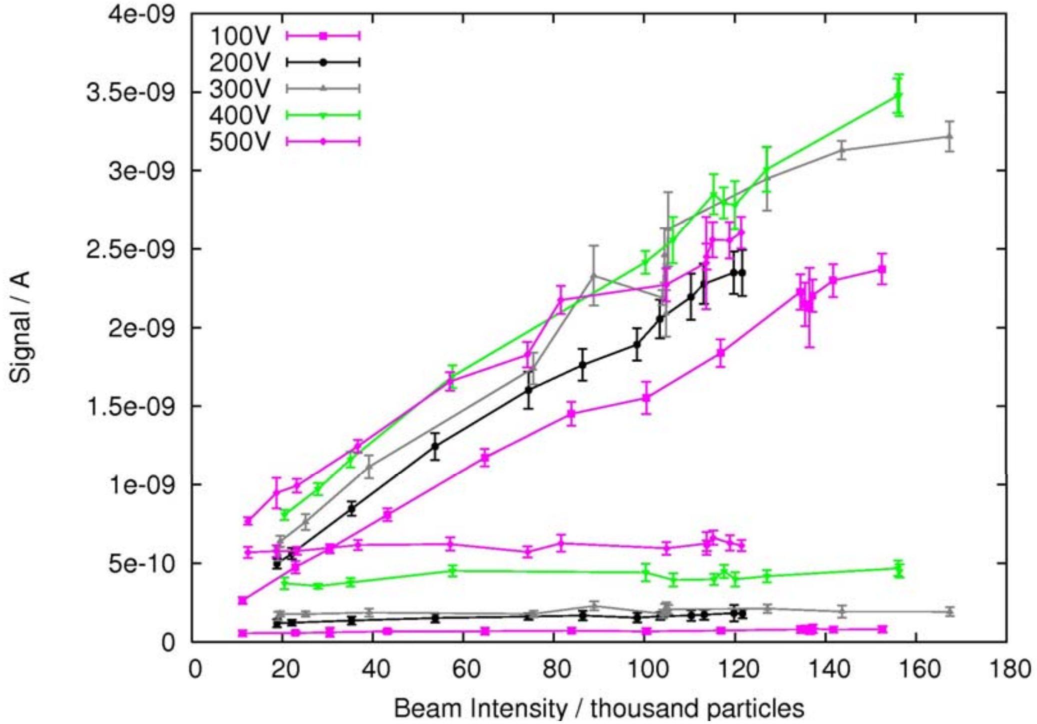
Explanation Baseline of diamond







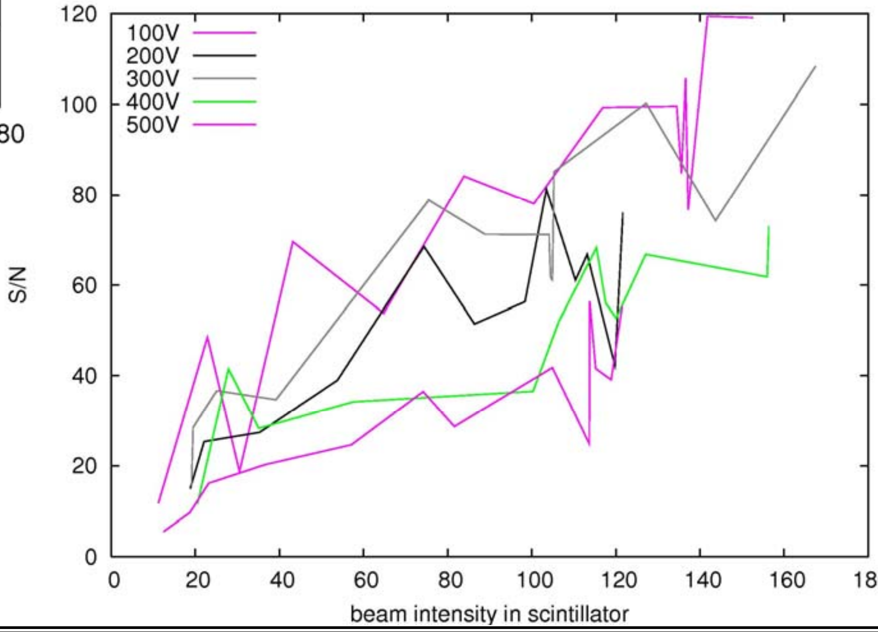
Signal vs. Intensity: BCM



•S/N is good at 100V, 200V.

•Degradation in S/N above 300V.

•Looking to operate at lower voltages.



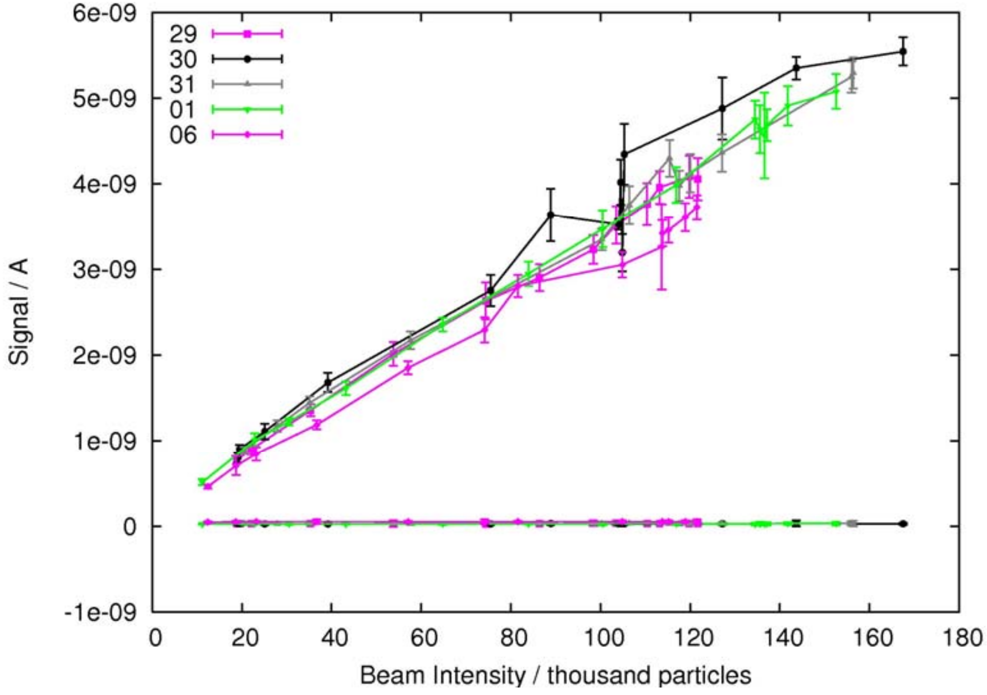
•Minimum sensitivity for BCM ~ < 10000 particles/0.4s

•Diamond 1cm2, rates in "per cm2" units

•Final calibration for beam ongoing. (correction factor O(2))

- •Several independent crosschecks of beam profile/rates.

Signal vs. Intensity: BLM



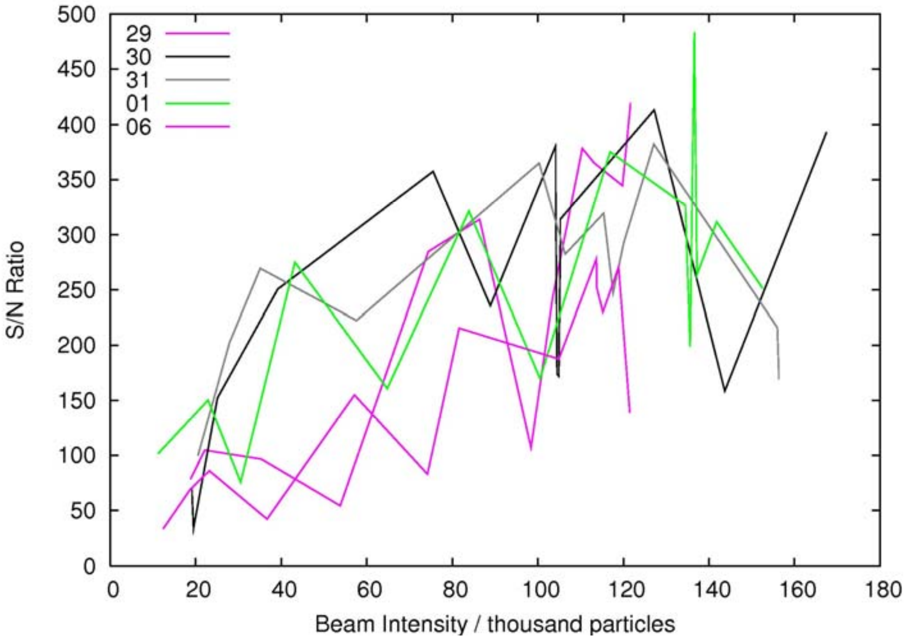
No change in operating conditions for the BLM

•Minimum sensitivity for BLM ~ < 10000 particles/0.4s

•BLM ca. 60cm2 active area, normalization non trivial.

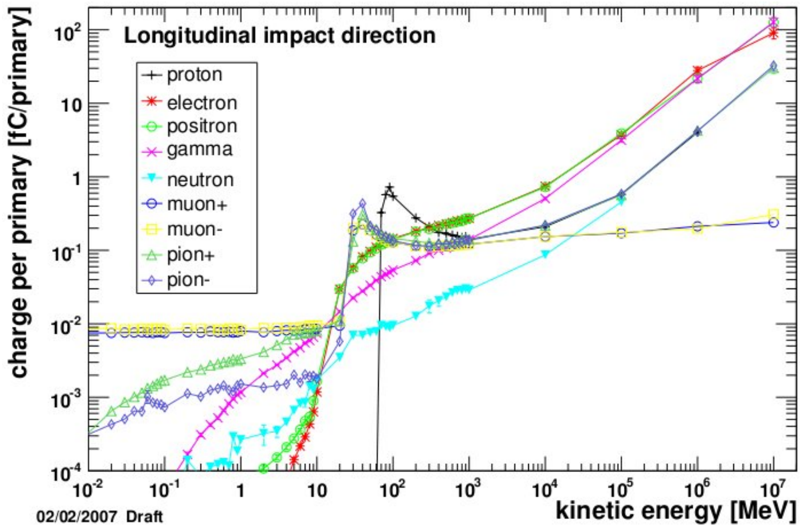
•Final calibration for beam ongoing. (correction factor O(2.7))

•Under same proton flux BLM and BCM response comparable.



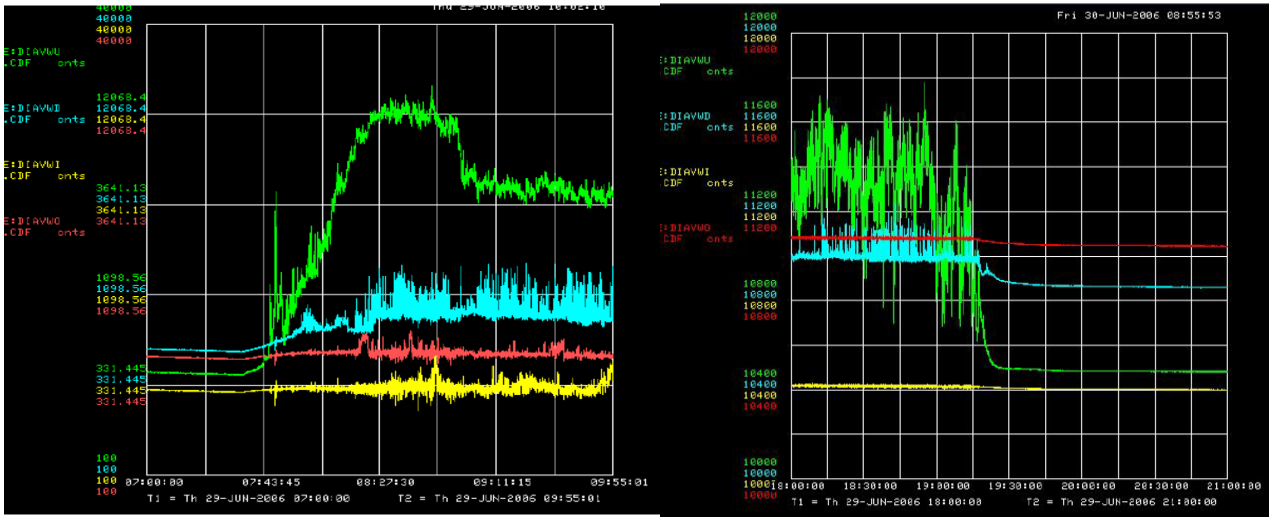
Detector response

- Louvain (neutrons)
  - BLM: 9.8e-18C/n (predicted 7e-18C/n)
  - BCM: 274.2e-18C/n
- SPS (180GeV proton/pions)
  - BLM: 2e-15 (prediction 2e-15C/p)
  - BCM: 4.75e-16 C/p (mip prediction 1.2e-15 C/p)
- PS (2GeV proton/pions)
  - Beam profile normalization preliminary.
  - BLM: 3.9e-15 C/p (prediction 4e-16C/p)
    - Extra correction factor O(2-7) that needs to be evaluated. No conclusion yet.
  - BCM: 3.3e-15 C/p (1V/um) (~3.5 mips)
  - Beamline setup simulation needed, to give further confidence in results
- Good understanding of Louvain and SPS data. PS needs further work.

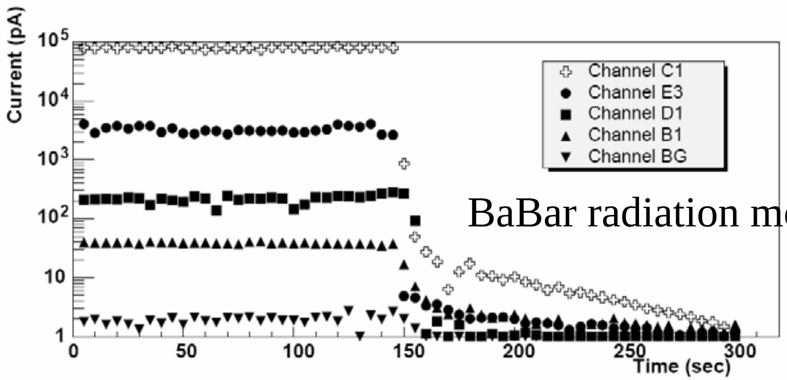


Simulated detector response for SPS tube. (Markus Stockner)

"Anomalous" dark currents



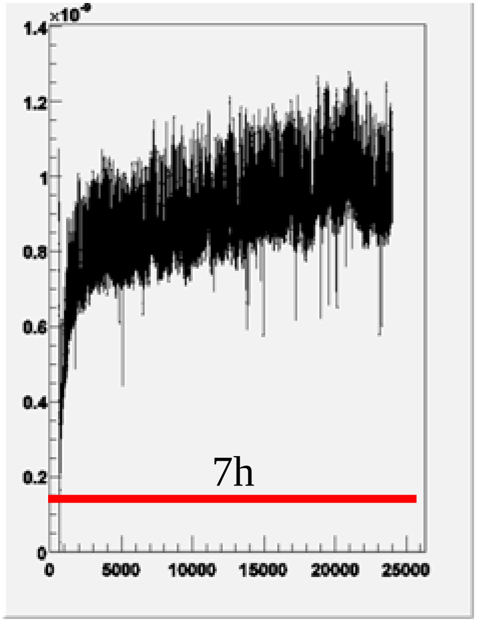
CDF: magnet trip caused erratic currents



BaBar radiation monitoring

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.

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



CMS: P25 at 400V with high field, sudden rise in current. (SPS beam)

"Anomalous" dark currents (cont.)

- These effects has been studied in various experiments:
  - CDF
  - Babar
  - CMS TB in T7 area, summer 2007
- Conclusions:
  - Suppressed by magnetic field. 0.5T adequate (several independent observations).
  - does not occur at lower fields (~ at 0.5V/micron). Where it starts at higher fields is diamond dependent.
- Implications:
  - BCM1L works in 4T field - no issue. Possible issue when solenoid ramping up or down, or off. Need determine exact behaviors during these circumstances, but we do NOT expect this to cause a anomalous abort. However monitioring might be degraded at these times.
  - BCM2 works in small stray magnetic field. Therefore will operate at lower voltages, which will even increase S/N (as seen in the PS testbeam)
  - Extensive QA (~months) will also be done on all diamonds prior to installation.

- To ensure that there are no stray currents on surface, extensive QA at each mounting step is done.

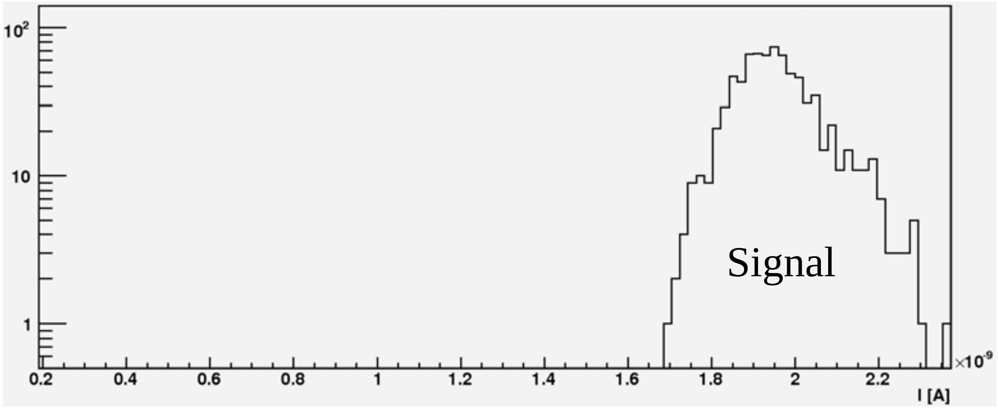
Threshold setting

- 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:
    - Rate from simulations: charged hadrons (simulations from Mika Huhtinen).
      - inner: ~10^8 cm^{-2} s^{-1}
      - outer: ~10^6 cm^{-2} s^{-1}
    - Expected signal current (based on rough estimations):
      - inner: ca. 100 nA, outer: ca. 1 nA
      - inner ca. 100 times higher than maximum noise excursions
      - Once detailed particle spectra is known for BRM detectors a more precise attempt to calculate signals can be made. This is work in progress.
  - Corresponding cross-calibrated values used in BLMs nearby in LSS5, in particular on the inner triplets
- Thresholds will be tuned with operational experience

Headroom on threshold settings

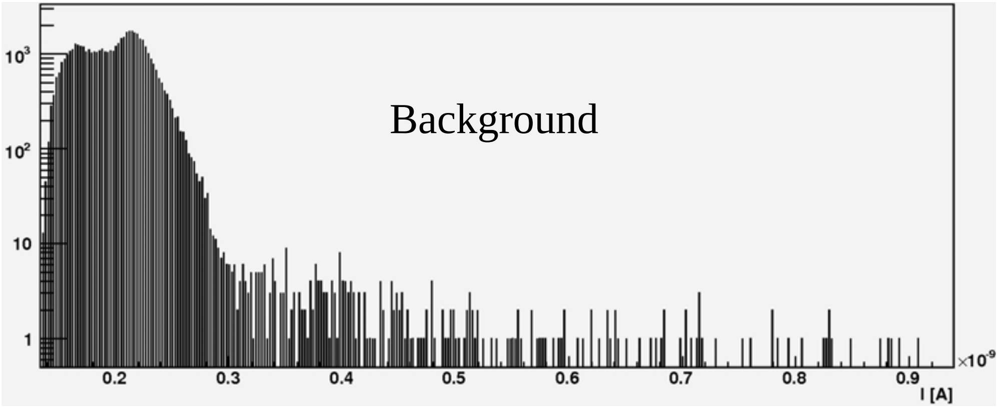
- No noise excursions beyond 1nA (1% of nominal luminosity operation) during stable running.
- A few times this, should be safe for threshold settings, in terms of false aborts.
- Intended thresholds are several orders of magnitude above this.

entries



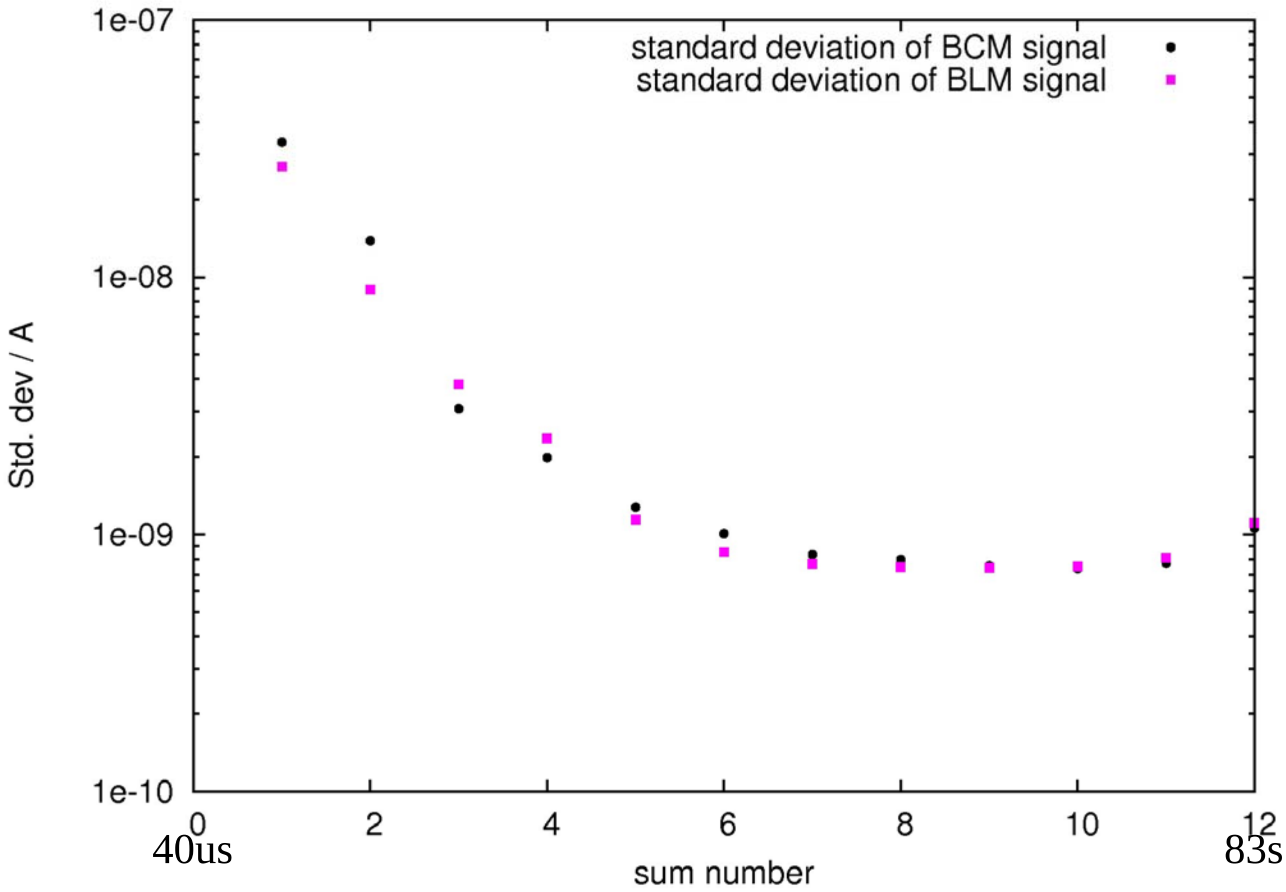
Current /nA

entries



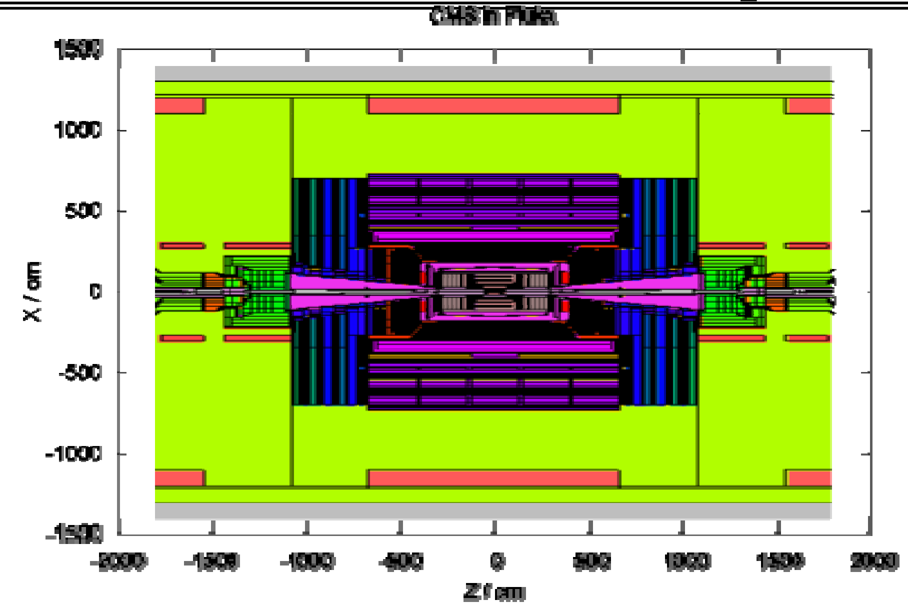
Current /nA

Noise studies for different time scales



Minimum sensitivity varies upon time scale. Louvain data (constant beam) shows an increase of noise of a factor of O(10) for shorter time scales. Noise analysis for SPS and PS testbeam ongoing, not yet fully understood features.
This has to be taken into account for short time scale threshold settings.

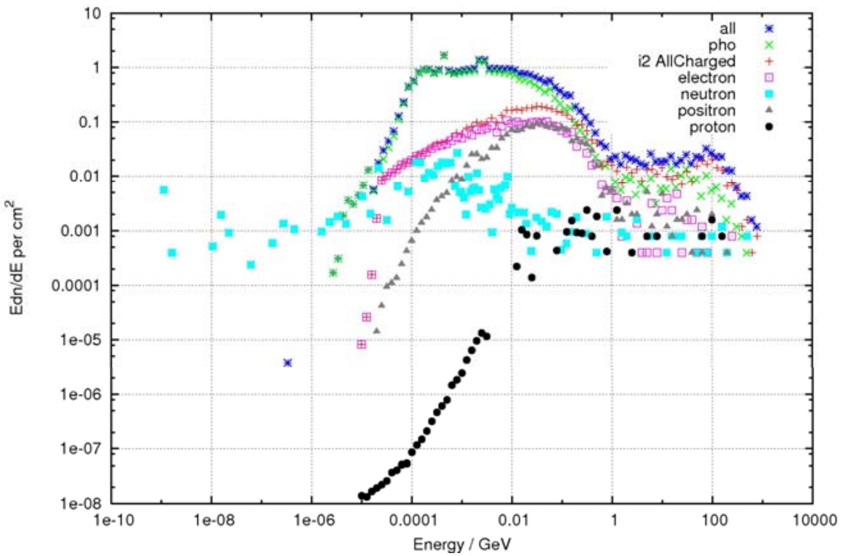
Simulations to obtain particle spectra for BRM detectors

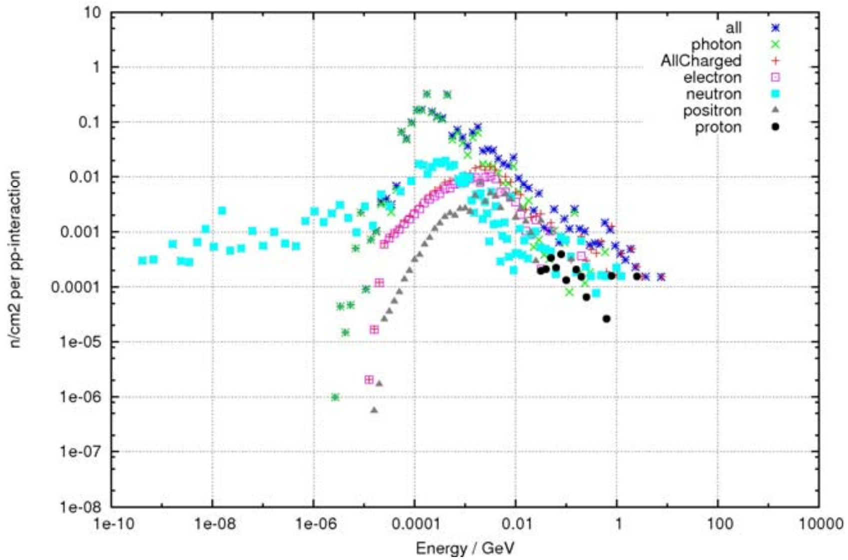


Particle spectra for BCM2 location

Also planned for all other BRM systems,

Needed, to initially set thresholds, and to calibrate between BRM and other detector threshold settings.





Conclusion

- Final diamond packaging tested in beams in Louvain, PS and SPS.
- Cross calibration was done with the BLM.
- Diamond response is comparable with the BLM.
- Proved a wide operational range for the diamond.
- Final absolute calibration is being understood,
  - for BLM response measurements agree with Markus simulations.

Outlook

- First ideas of a threshold setting presented
  - Developing these.
  - We remain in close discussion with BLM group.
- Calibration is ongoing
  - Analysis on taken data:
    - PS beam normalization
    - further noise studies
    - …
  - More testbeams
  - Simulations to:
    - help understand PS features
    - get an idea of nominal and accidental beam loss signal for LHC
- BRM systems ready to install in Feb08
  - Looking forward to the first LHC beams.