Experience with diamond based beam condition monitoring systems at CMS during 2011

CARAT workshop 14.12.2011

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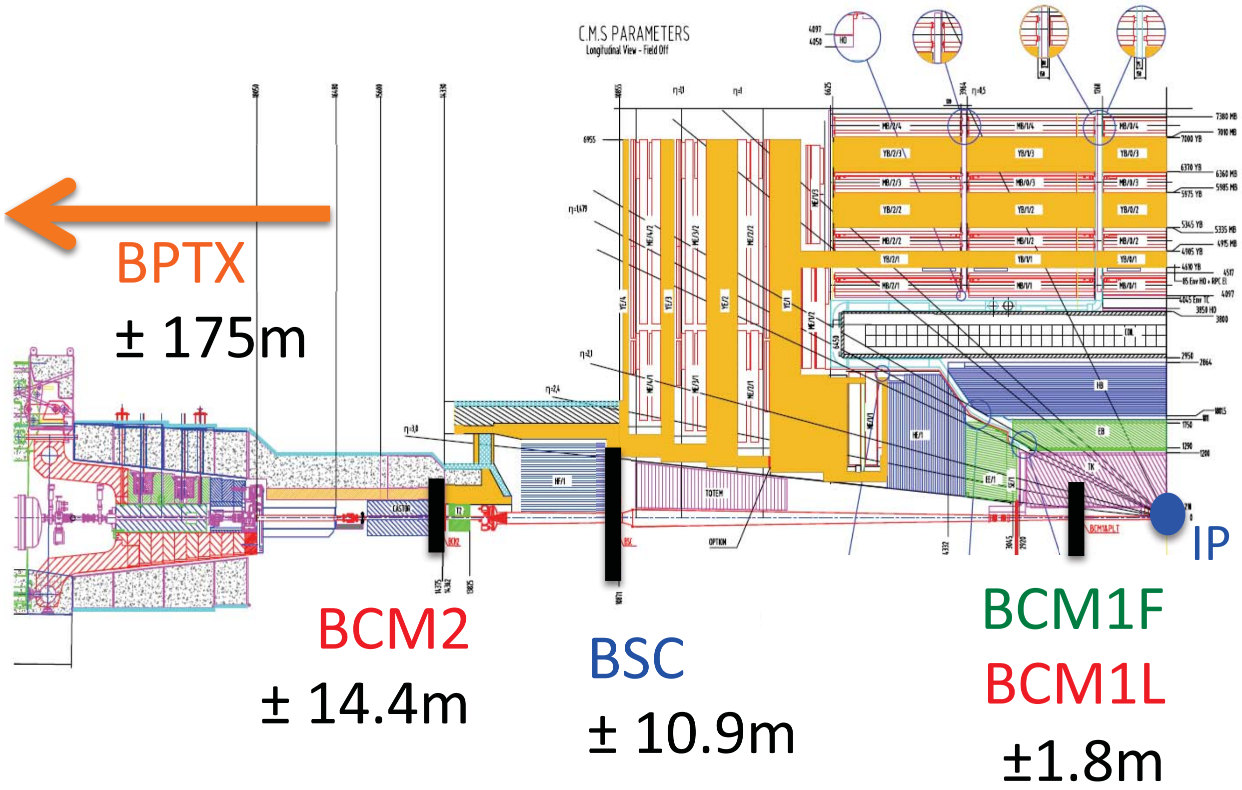
Overview

- Introduction to the diamond based CMS BCM system.
- Performance during 2011 running.
- Radiation damage to diamonds.
- Signal loss of BCM detectors due to radiation damage.
- Status of the Pixel Luminosity Telescope project.

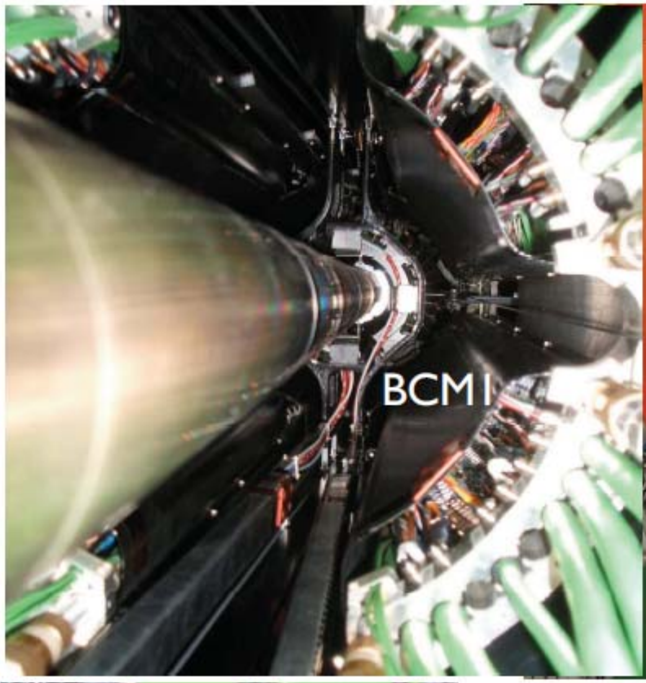
BRM Systems



- BCM1F:
  - diamond detector
  - Fast MIP counter
  - monitoring
- BSC:
  - Scintillators
  - For Lumi < $3x10^{32}cm^{-2}s^{-1}$
  - Trigger for HI
- BPTX:
  - Bunch pickup -> trigger Signals

- BCM2/1L
  - diamond detector; leakage current measurement
  - BCM2: inner: 4 diamonds (r=5cm), outer: 8 diamonds (r=28cm)
  - BCM1L: 4 diamonds (r=4.5cm)
  - Protection, monitoring possible

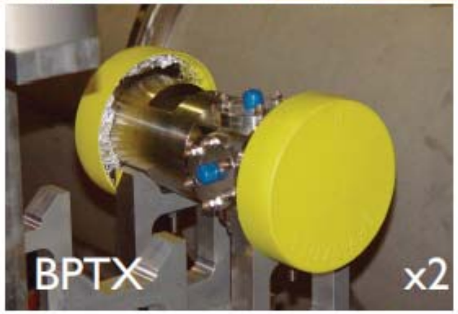
- Active and passive radiation monitoring devices

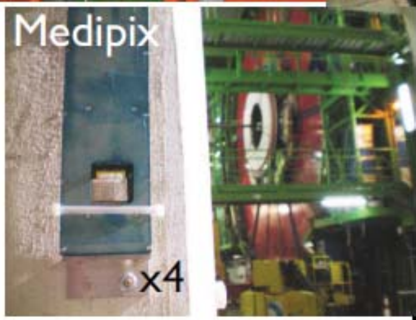

BCM1


BCM2
BSC2


BSC1

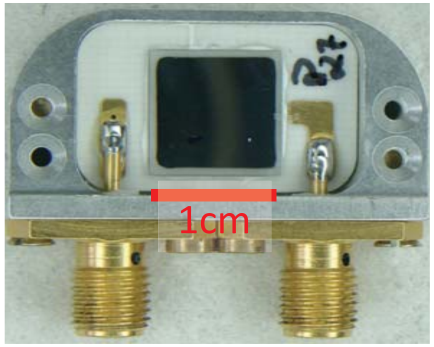

RADMON
x20

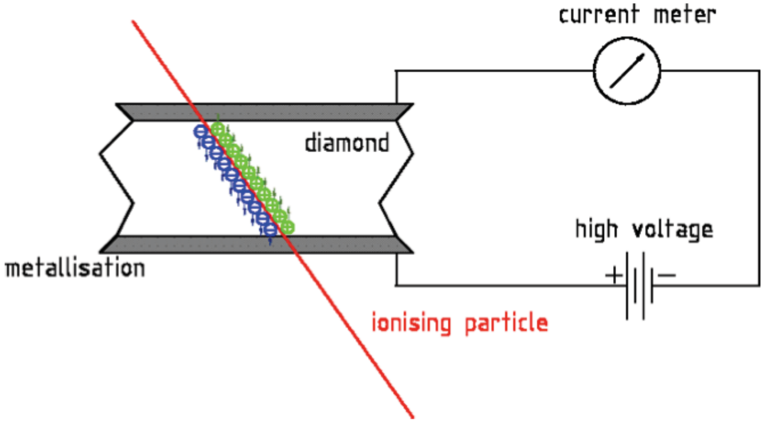

BPTX
x2

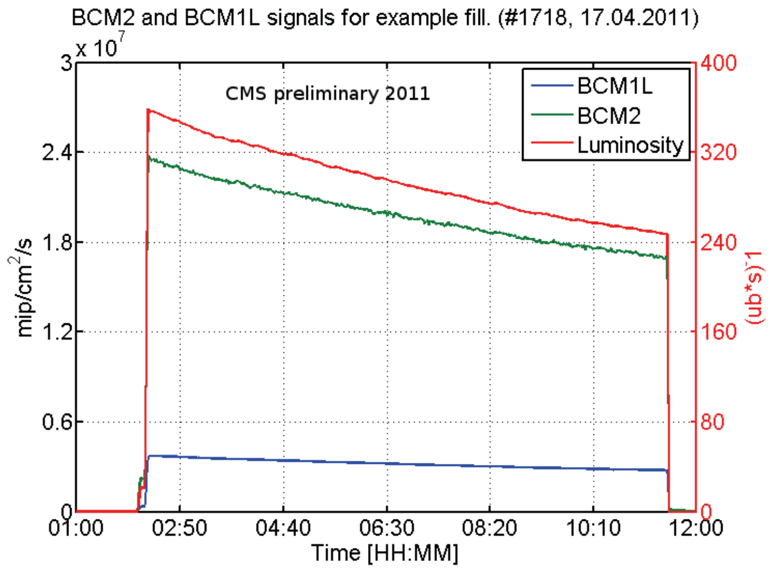

Medipix
x4


Passives
x160

BCM system overview



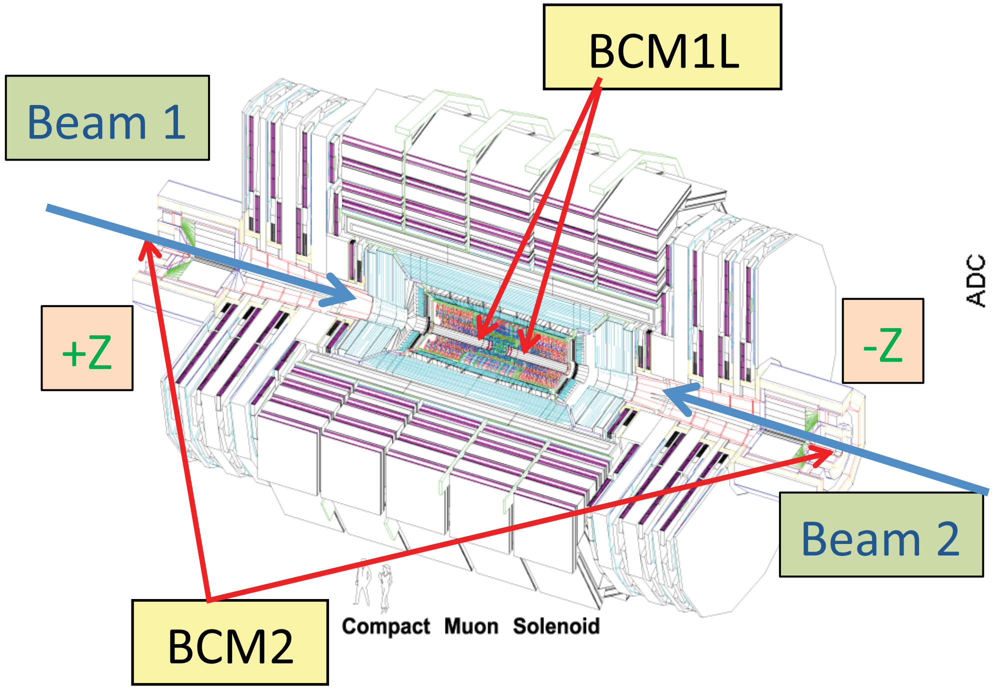


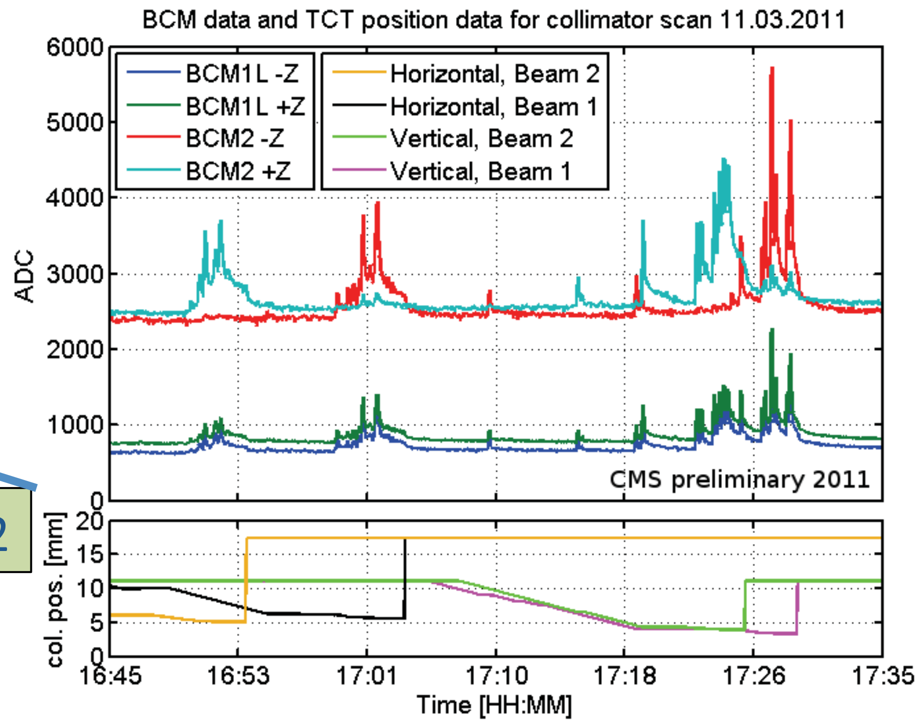


BCM1L and BCM2 correlate well with Luminosity.
BCM2 has factor ~6 higher signal than BCM1L

- pCVD diamonds in leakage current measurement.
- Size: 10x10x0.4mm^3, average CCD 210 um. HV: 200V (~0.5V/um)
- Same electronics as LHC Beam Loss Monitor system.
- Used for protecting Si Tracker and Pixel from catastrophic beam loss events.

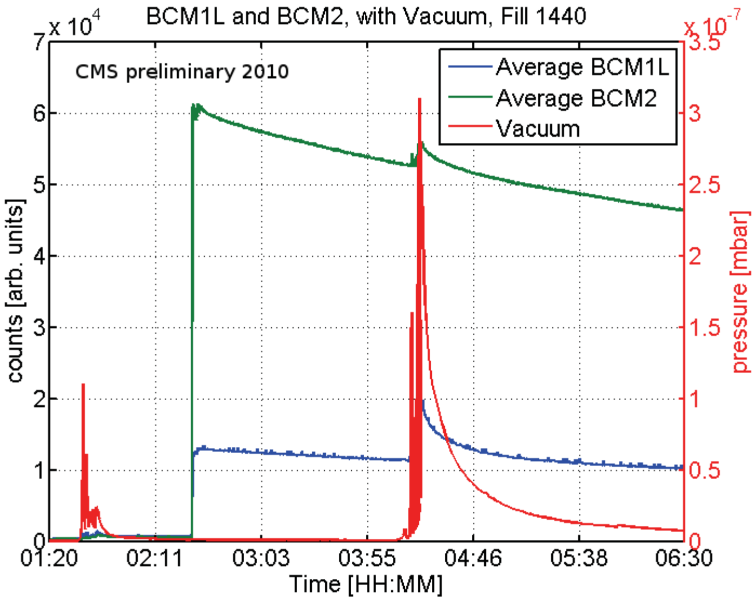
Beam Loss Event

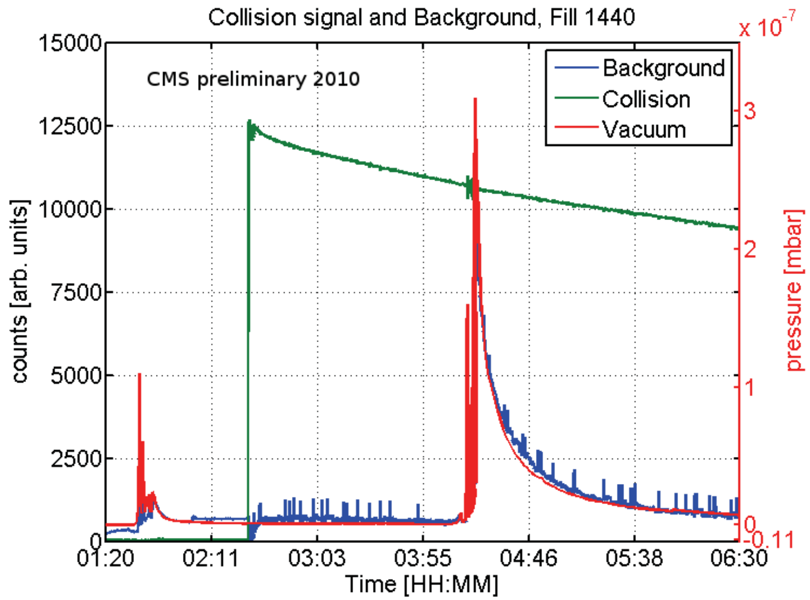




- Collimator scans during machine commissioning early 2011.
- Signals visible in BCM2 and BCM1L.
- BCM1L +Z and –Z measure the same. BCM2 sees signal mostly downstream.
- No Horizontal/Vertical correlation. We detect particle showers that develop in all phi directions.

Background discrimination





- This event shows a sudden degradation of vacuum producing higher signals in the BCM2 and BCM1L detectors.
- Due to different positions both detector groups have different sensitivities towards collision products and machine induced background.
- Inclusion: (c_b and c_p are relative sensitivities towards collision and background)
  - $\text{measurement}_{BCM1L}$ = background + collision
  - $\text{measurement}_{BCM2}$ = background * c_b + collision * c_p
- These equations can be solved for background and collisions (luminosity).
- Online background measurement available in CMS control room.

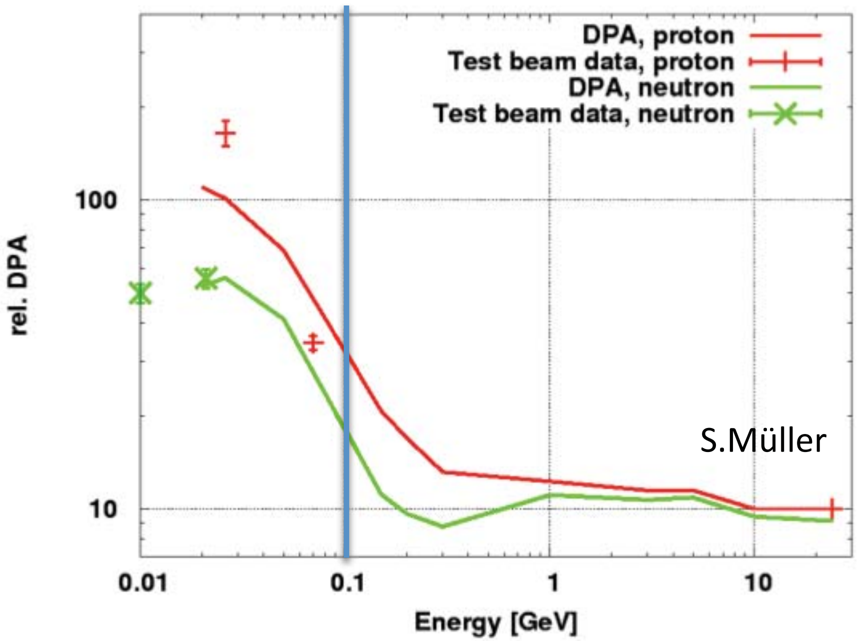
Radiation damage (I)

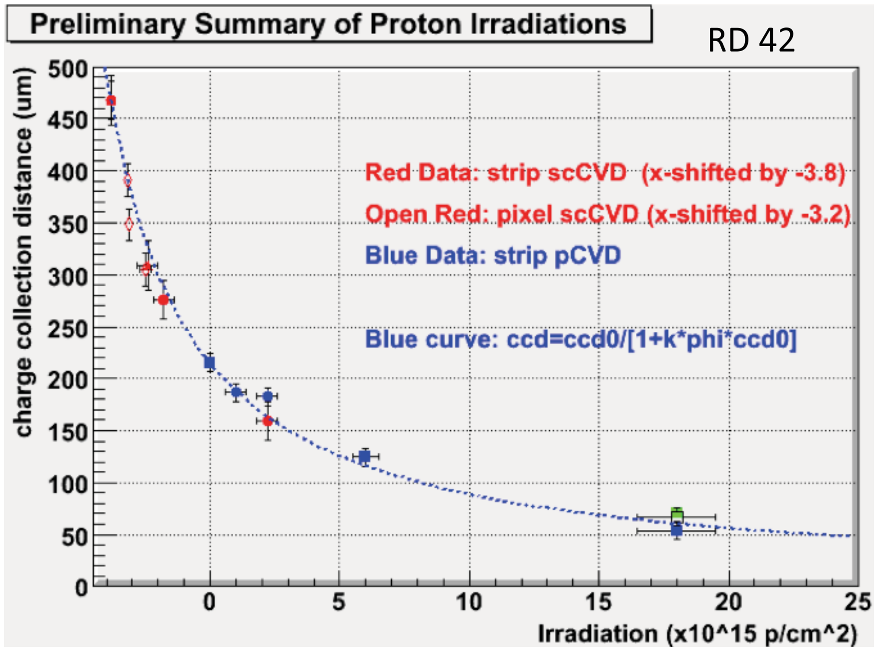
- Radiation introduces traps hence CCD gets lower with radiation damage:

$$CCD(\Phi) = \frac{CCD_0}{1 + k \cdot \Phi \cdot CCD_0}$$

- Damage parameter k is different for different particle types and energies.
  - k values are bigger for low energies.
- Hyperbolic curve implies less signal loss when detector already damaged.
- Signal loss can also be due to polarisation effects or damage in metallisation.

Radiation damage (II)

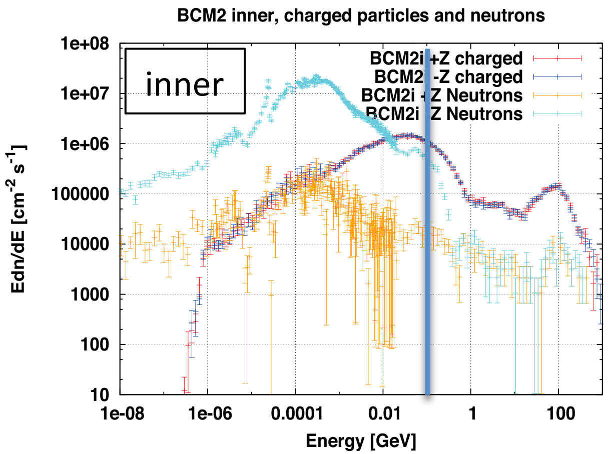


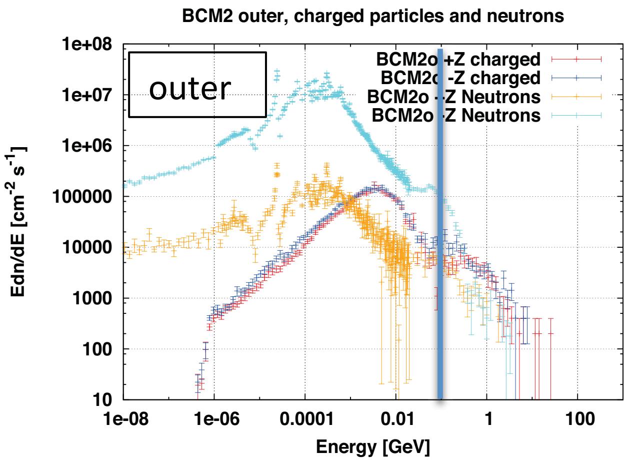


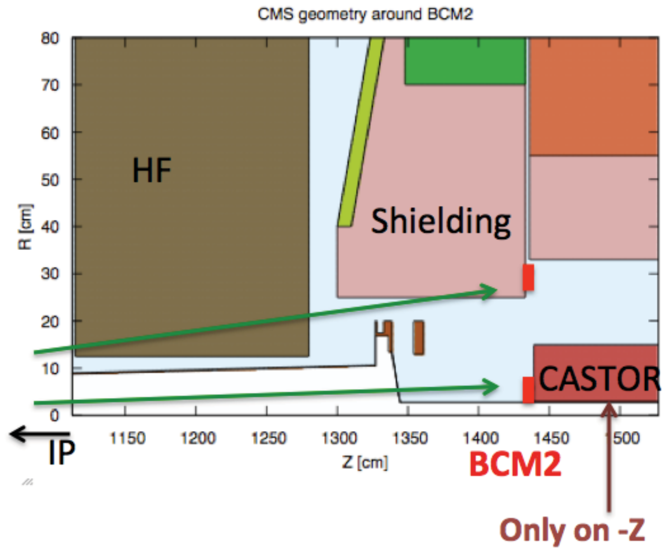
- k values for protons and diamonds normalised to 24GeV protons.
- More damage at lower energies (<100MeV).

- Example of hyperbolic damage curve. (24GeV protons.)
- A poly crystal diamond starts at a lower CCD. -> It behaves like a damaged single crystal.
- Poly crystal loose less signal when exposed to the same radiation.

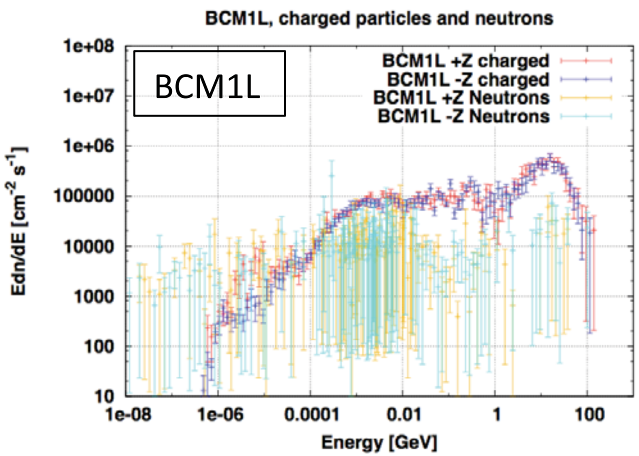
Energy spectra at BCM positions





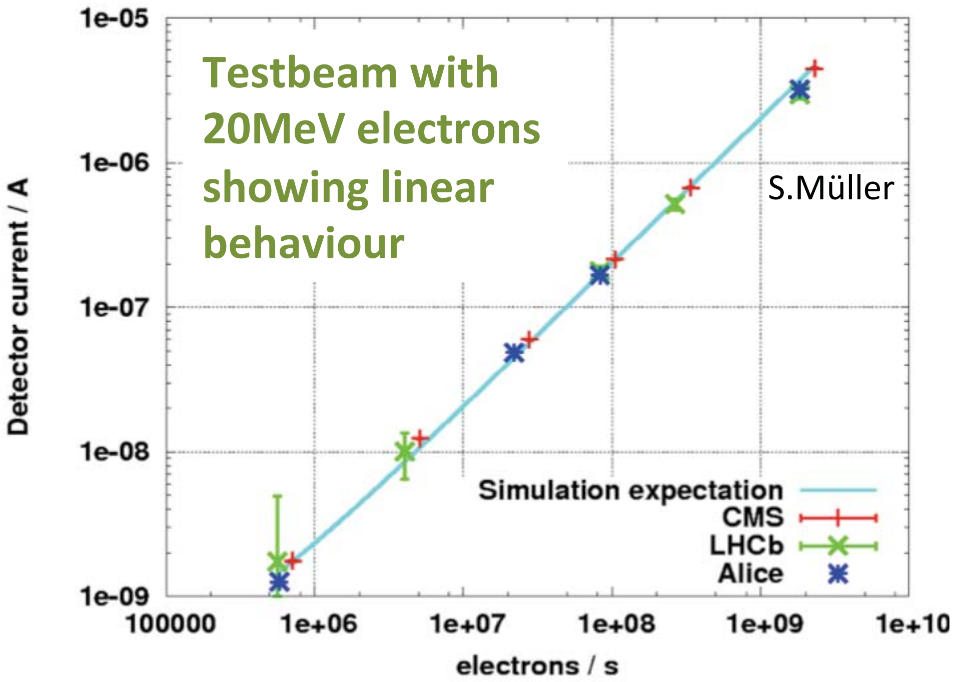


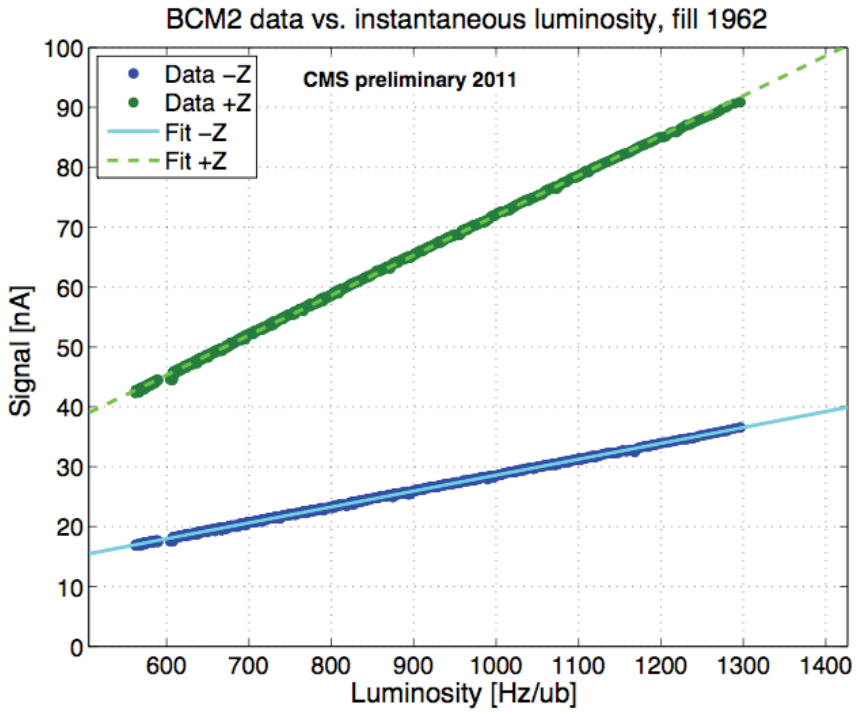
+Z: Charged particles Neutrons
-Z: Charged particles Neutrons



- BCM2:
  - Charged particle flux is the same for +Z and –Z.
  - Neutron flux at inner and outer diamonds very similar. (For both sides.)
  - Flux of low energetic neutrons is factor 100 higher on –Z compared to +Z
  - On –Z: below 10MeV spectrum is dominated by neutrons.
- BCM1L
  - Neutron level very low

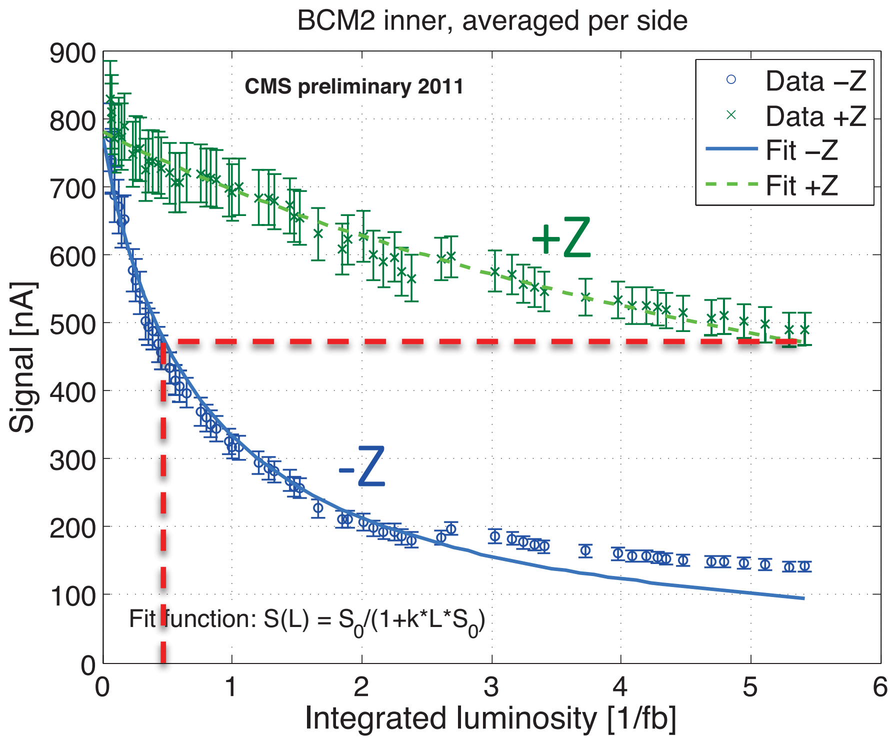
Normalisation of fills





- Testbeams showed linear behavior of the diamonds up to the abort threshold. [1]
- To be able to track radiation damage the signals have to be normalised to luminosity.
- This is done by plotting signal vs. instantaneous luminosity and extrapolating via a linear fit to a instantaneous luminosity of 10^{34} $cm^{-2}s^{-1}$.

Radiation Damage to BCM2 inner

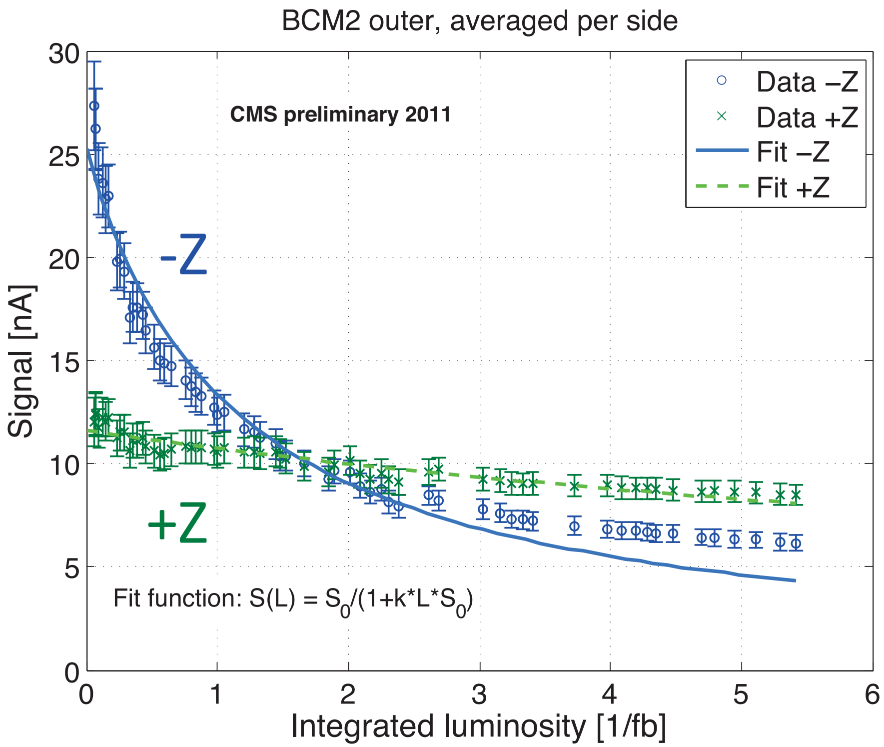


Simulated radiation environment

	+Z	-Z
MIP flux [$cm^{-2}s^{-1}$] at 10^{34}	2.7×10^{8}	2.4×10^{8}
Neutron flux [$cm^{-2}s^{-1}$] at 10^{34}	1.1×10^{7}	8.0×10^{8}
Hadron fluence after $5.5fb^{-1}$	2.3×10^{13}	4.5×10^{14}

- Plotted is evolution of normalised signal with integrated luminosity.
- Much higher damage on –Z side (factor ~10).
  - CASTOR, a very heavy calorimeter, is only on –Z.
  - Backscattered low energetic neutrons are very damaging.
- Loss in signal higher than expected. Not yet fully understood.
- The small step at $2.5fb^{-1}$ is not a recovery of signal but a change in online luminosity. This shifts the data slightly.

Radiation Damage to BCM2 outer



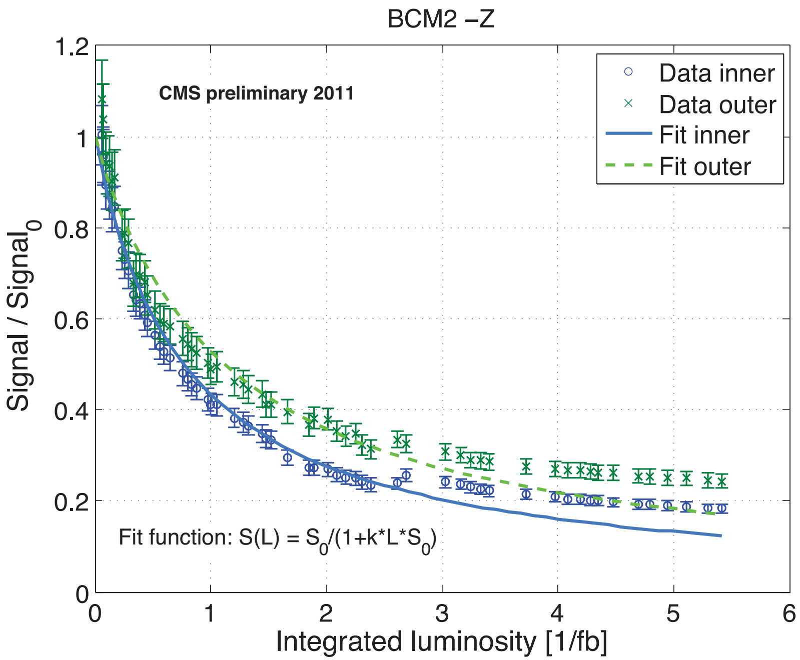
Simulated radiation environment

	+Z	-Z
MIP flux $[cm^{-2}s^{-1}]$ at 10^{34}	4.98×10^6	7.63×10^6
Neutron flux $[cm^{-2}s^{-1}]$ at 10^{34}	7.2×10^6	6.6×10^8
Hadron fluence after $5.5fb^{-1}$	7.6×10^{12}	3.6×10^{14}

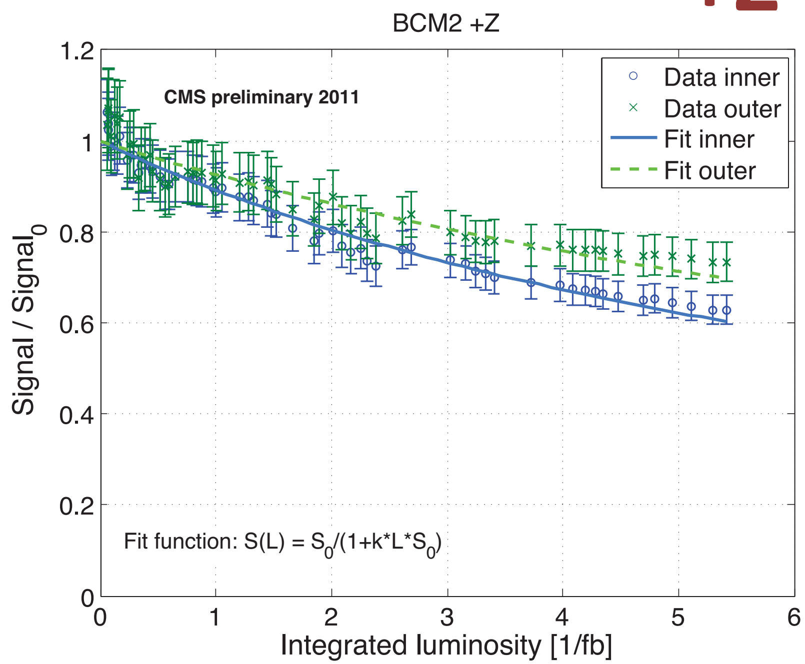
- Plotted is the average of all diamonds an –Z side and +Z side.
- Diamonds shielded from IP by Hadron Forward calorimeter.
  - Signal much lower than in BCM2 inner.
- Similar behaviour to inner diamonds, but initial signal on –Z higher than on +Z.
- Signal due to CASTOR neutrons is comparable with MIP signal. (Inner diamonds have dominating MIP signal.)

Inner/outer compared

-Z

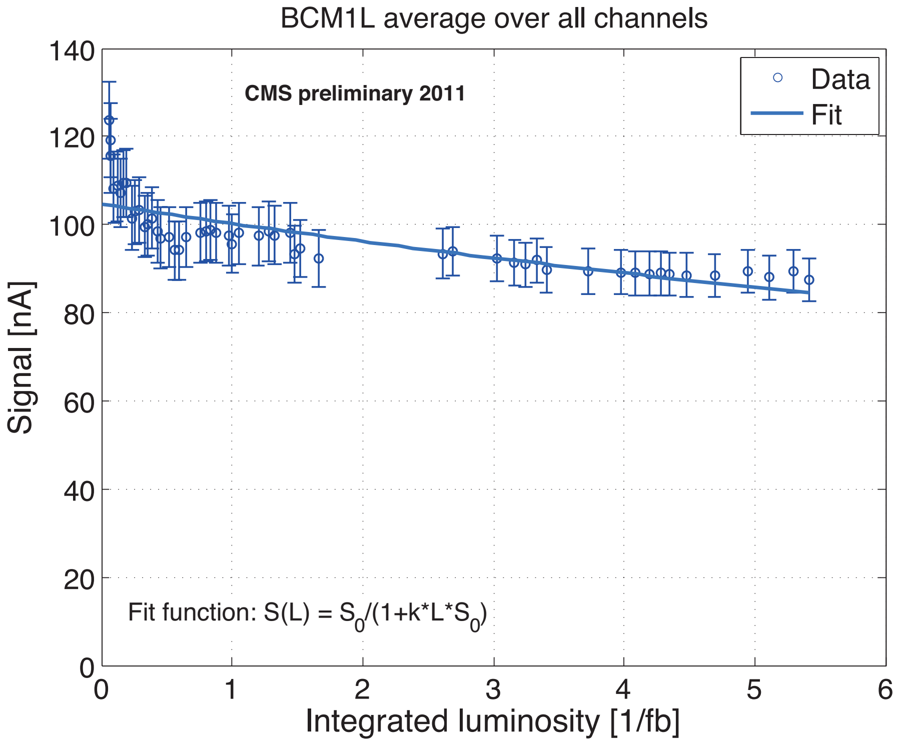


+Z



- Almost same damage for inner and outer.
- Difference might be due to higher proton flux at the inner position.

BCM1L



Simulated radiation environment

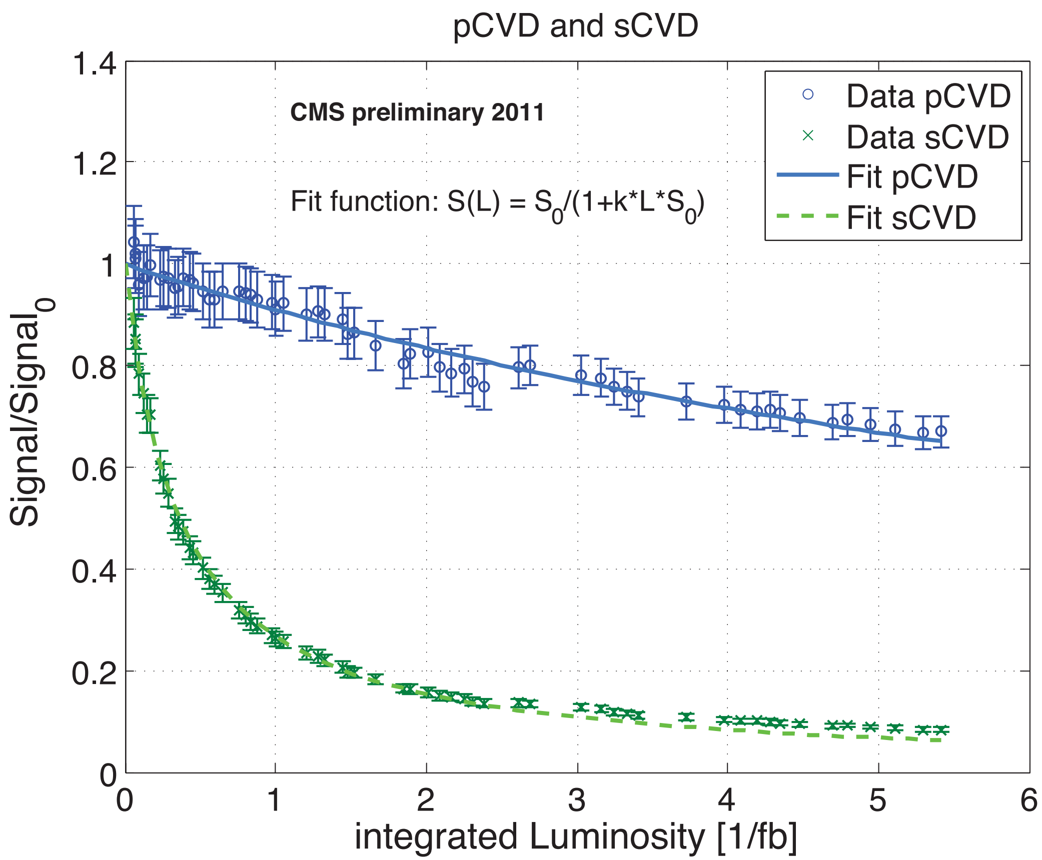
	+Z, -Z
MIP flux [$cm^{-2}s^{-1}$] at 10^{34}	4×10^7
Neutron flux [$cm^{-2}s^{-1}$] at 10^{34}	3.9×10^6
Hadron fluence after $5.5fb^{-1}$	2.1×10^{13}

Comparable with BCM2 inner +Z, but low energy neutron content is much lower.

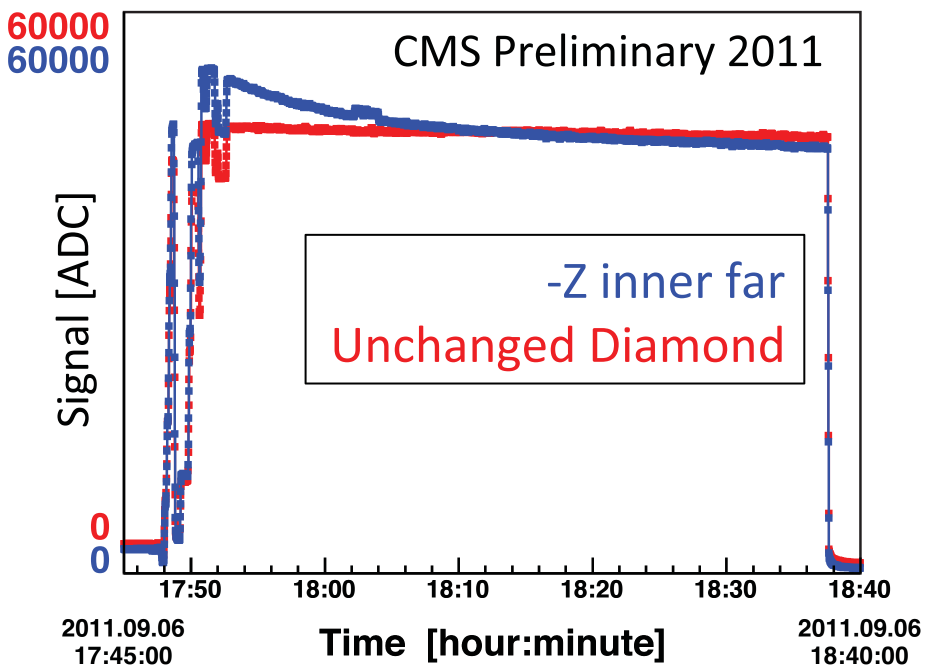
- Here averaged over all BCM1L diamonds.
  - CMS is Z symmetric inside the barrel region.
- Drop in BCM1L signal very small.

Single crystal diamond

- On top of a normal BCM2 polycrystalline diamond (**+Z inner near**) a single-crystal was installed.
- The signal of the single crystal drops much faster than the poly-crystal.
- This is expected:
  - Poly- and single-crystal diamonds follow the same damage curve.
  - The single-crystal has a much higher CCD.
  - The poly-crystal behaves like a damaged single-crystal.
  - The poly-crystal losses much less signal since its on the flat part of the curve.



Test for polarisation



- During a technical stop the polarity of a diamond (-Z inner far) was changed.
- Shown is the signal of this diamond together with a unchanged diamond during the very first collisions after the technical stop. (Some days passed.)
- Slightly increased signal that goes down to normal level after ~20 minutes.

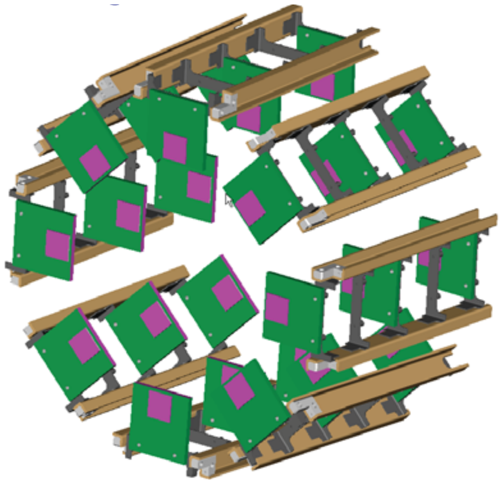
Measurement Plan for removed diamonds (pCVD and sCVD)

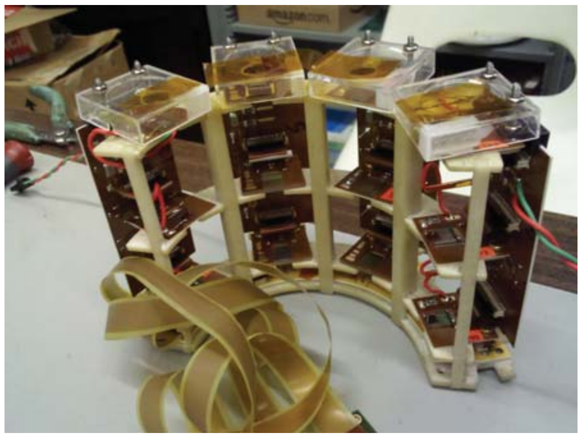
- One pCVD from –Z inner and the sCVD will be replaced during this shutdown.
- Probably activated. -> Might need time in buffer zone.
  - Monitor activation.
- Measure signal with Sr source at CERN
  - Study pumping behavior and signal output. (Old Sr measurements available.)
  - Expose to light. Change in signal? (package might not be light tight.)
- Measure IV, CCD(t), CCD(HV) (@DESY?)
- TCT measurement
- Remove metallisation and take crosspolarised pictures.
- Remetallise (@GSI?)
- Measure IV, CCD(t), CCD(HV) (@DESY?)

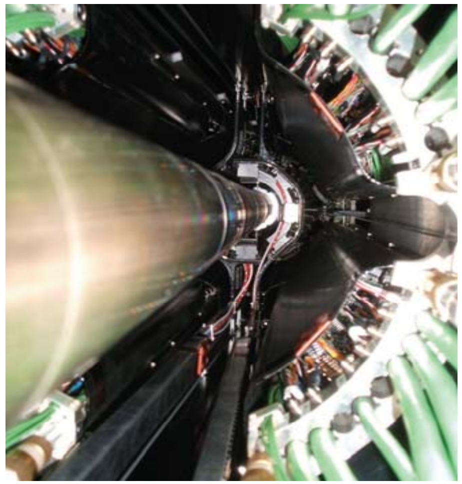
The PLT

Steve Schnetzer

- Dedicated, stand-alone luminosity monitor
- Eight 3-plane telescopes each end of CMS
- 1.6^0 pointing angle r = 4.8 cm, z = 175 cm
- Diamond pixel sensors pixel area: 3.9 mm x 3.9 mm
- Count 3-fold coincidences fast-or signals (40 MHz)
- Full pixel readout pixel address, pulse height (1 kHz)
- Stable 1% precision on bunch-by-bunch relative luminosity







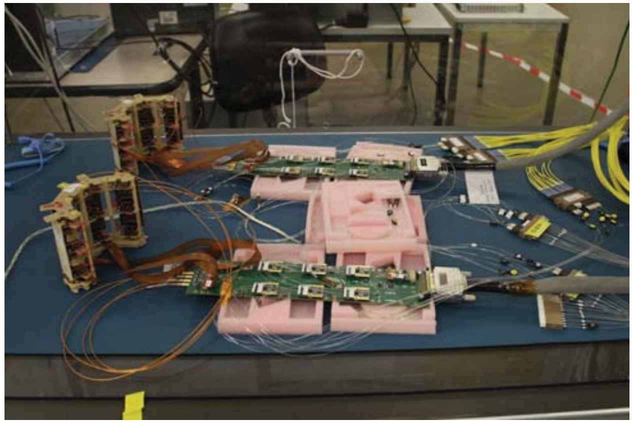
PLT Status

Two full cassettes (each 4 telescopes)
under continuous, stable operation at CERN

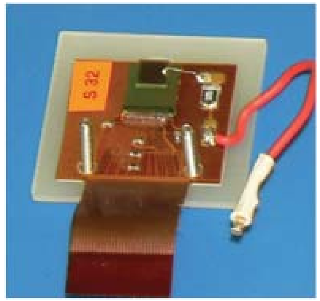
full system set up

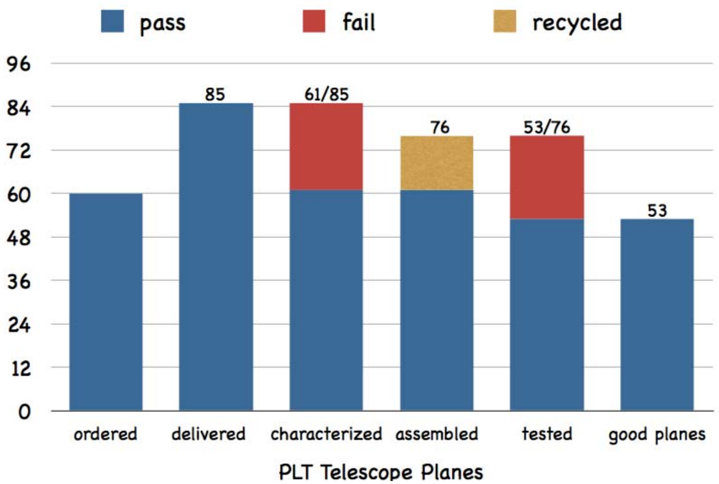
near flawless operation (24 planes total)

both studied in October test beam



Will install two cassette in the region downstream of the HF, 15m from the IP, during the coming technical stop





70% acceptance rate of bumped planes

72% acceptance rate of sensors

Complete 61 by end of year

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All planes for full PLT produced

Summary

- BCM2 diamonds show loss of efficiency with increased exposure to radiation.
  - Diamonds suffer from radiation damage due to extremely intense radiation field where they are placed. Analysis of data ongoing.
- Conclusions on radiation damage:
  - Mostly bulk damage (hyperbolic curve, sCVD more damaged than pCVD)
  - Inflicted by neutrons (+/- asymmetry, inner outer similar)
  - Polarisation effects visible. Seems small but not quantified yet.
  - Not an electronics effect. Frontend electronics were changed.
- Fluka studies ongoing to bring predictions and data together.
- Laboratory analysis of damaged diamond soon.
- Protection functionality not endangered
  - Even on –Z still enough signal.
  - The CASTOR detector (enhanced neutron flux) will not be present during high luminosity any more.