Replacement of the Fast Beam Condition Monitor (BCM1F) sensors at CMS

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on behalf of the Beam Radiation Instrumentation and Luminosity project (BRIL) of CMS

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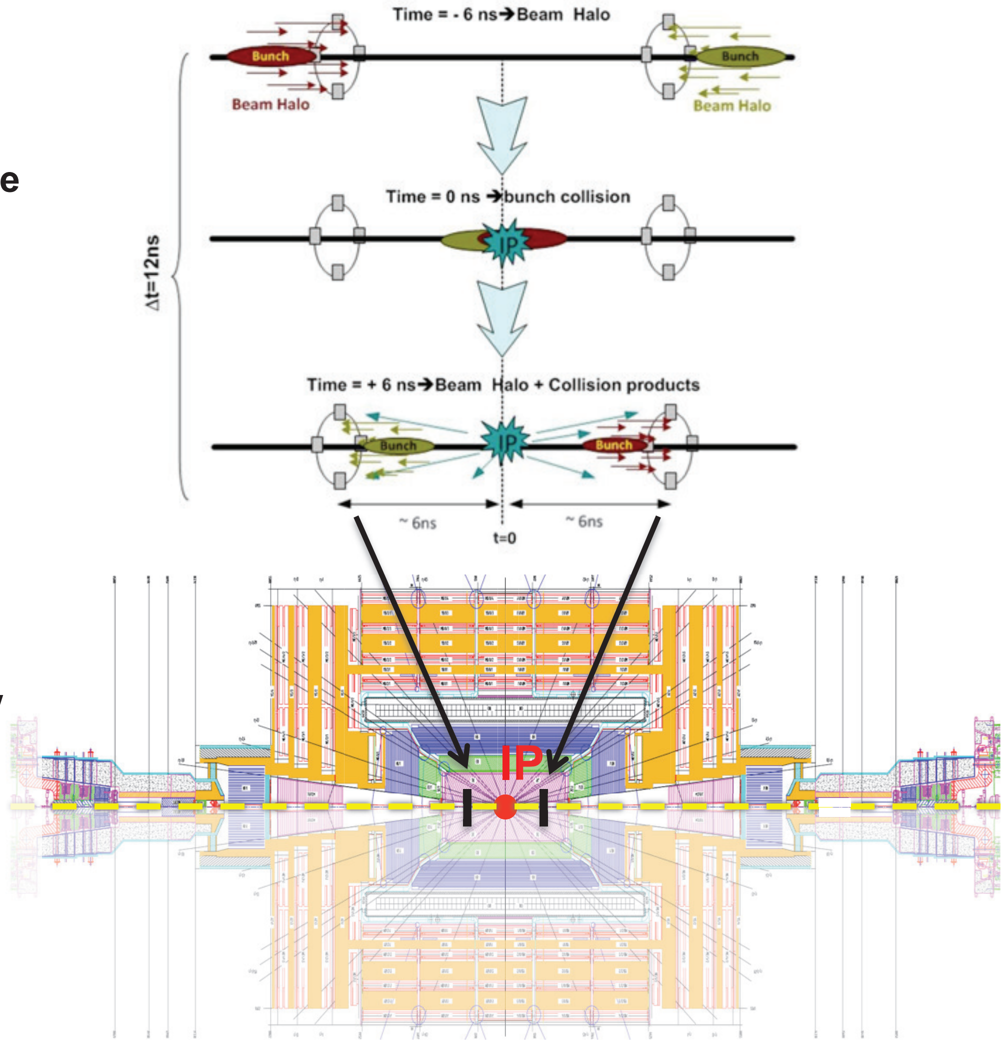
Overview

- BCM1F detector
- Performance during 2015 & 2016
- Replacement plans and design modifications.
- Characterizations of new sensors.
  - Leakage current
  - Charge collection
  - Test beam

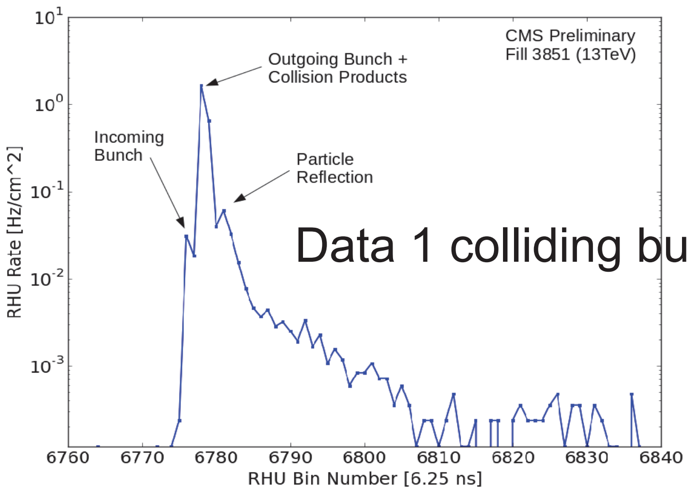
BCM1F detector concept

- **Application:**
  - Luminosity measurement
  - Machine induced background measurement (several orders of magnitude below luminosity)
- **Concept:**
  - Fast particle counter
  - Utilize time of arrival to separate different contributions
- **Requirements:**
  - Hit counting with 160MHz time binning
  - Sufficient statistical precision at low rate
    - Calibration at low rate (VdM scan)
    - Machine induced background generally low rate
  - Good linearity from low rate to high rate conditions (O(100MHz/cm2))
    - Extrapolate calibration to high rate environment.
  - Low dead time
    - E.g. pulse pileup could lead to train effects.

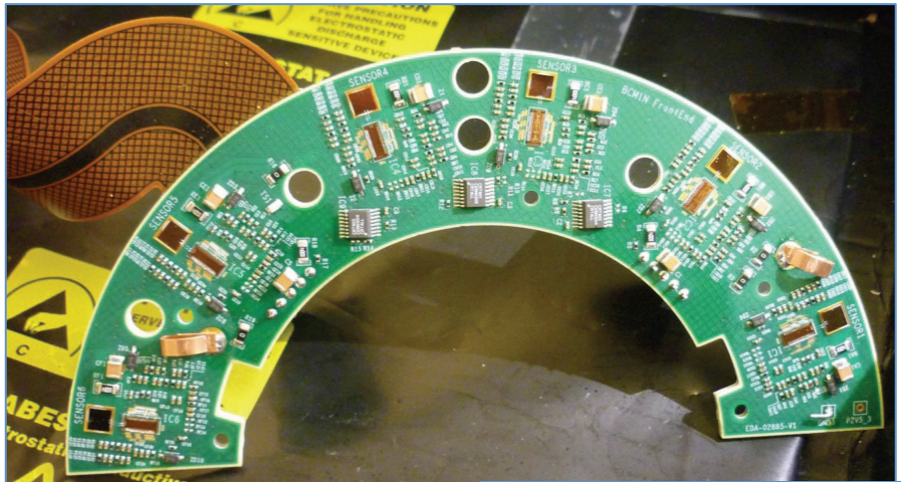


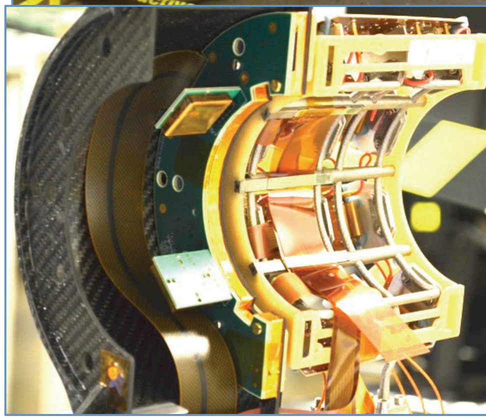
Sensors and readout

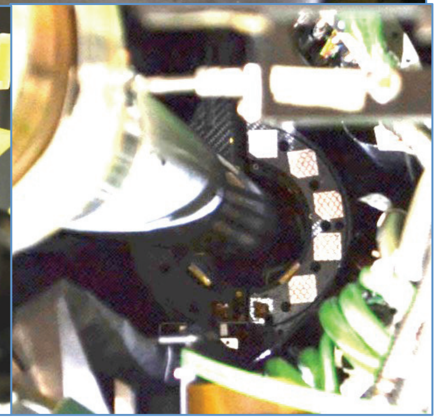
- **Detector:**
  - 5x5mm^2 sCVD, 500um thick
  - Two pad metallization to reduce pile up.
- **Electronics:**
  - Fast preamp
    - 4 channels (2 used)
    - 7ns rise time, 10ns FWHM
  - Analog optical signal transmission
  - Counting: Discrimination + time histogram
  - ADC for pulse shape analysis
  - FPGA based signal processing (under development)



Data 1 colliding bunch

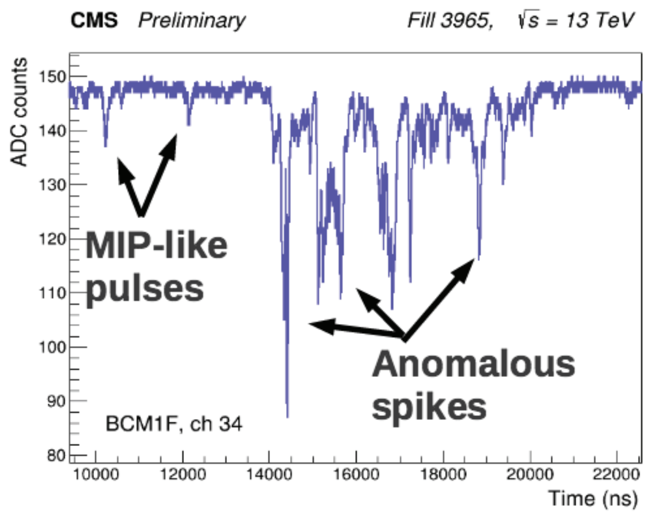


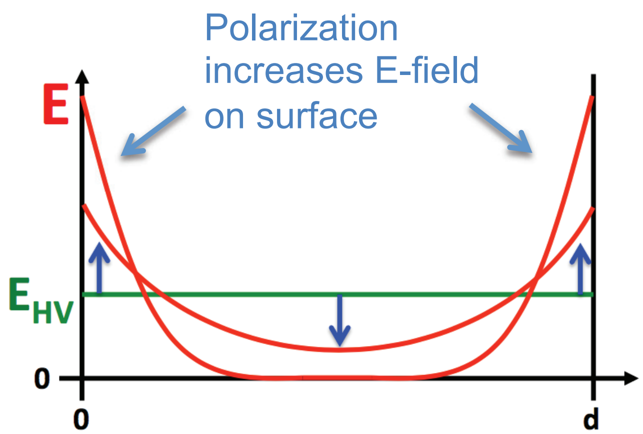




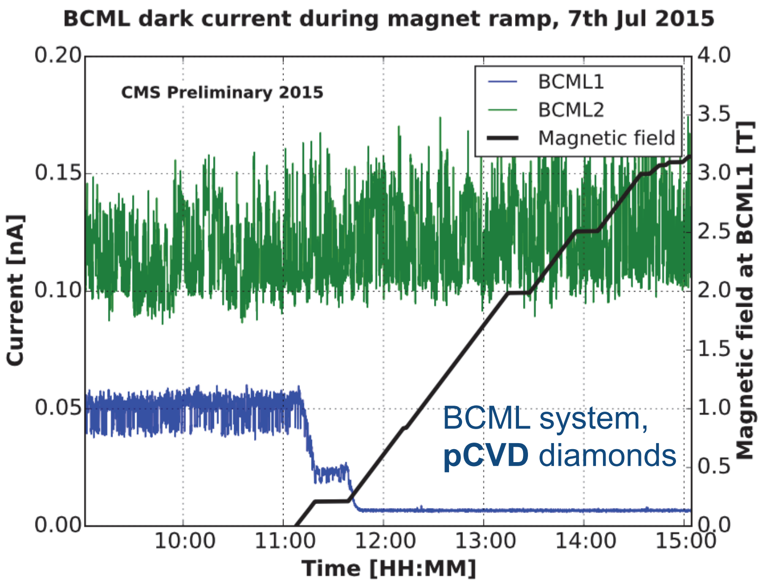
Performance problems

- Erratic currents occur at high rate
  - Reduced HV stability
- Increased problem with radiation fluence.
  - Hypothesis: Charge create at surface defects, electric field increases at surface due to radiation damage induced polarization.
  - Lab tests of removed diamonds are planned to study the cause of the instabilities.
- At end of run many diamonds at 0V, highest ~150V

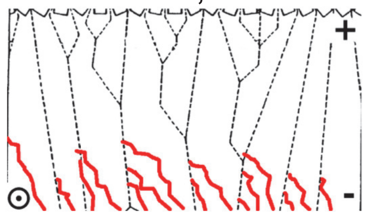


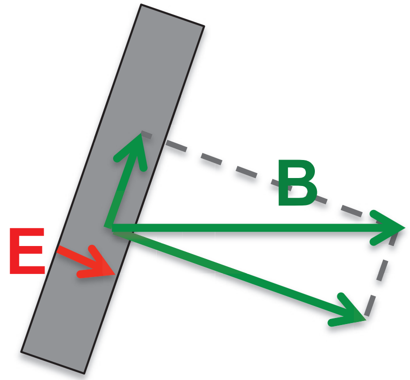


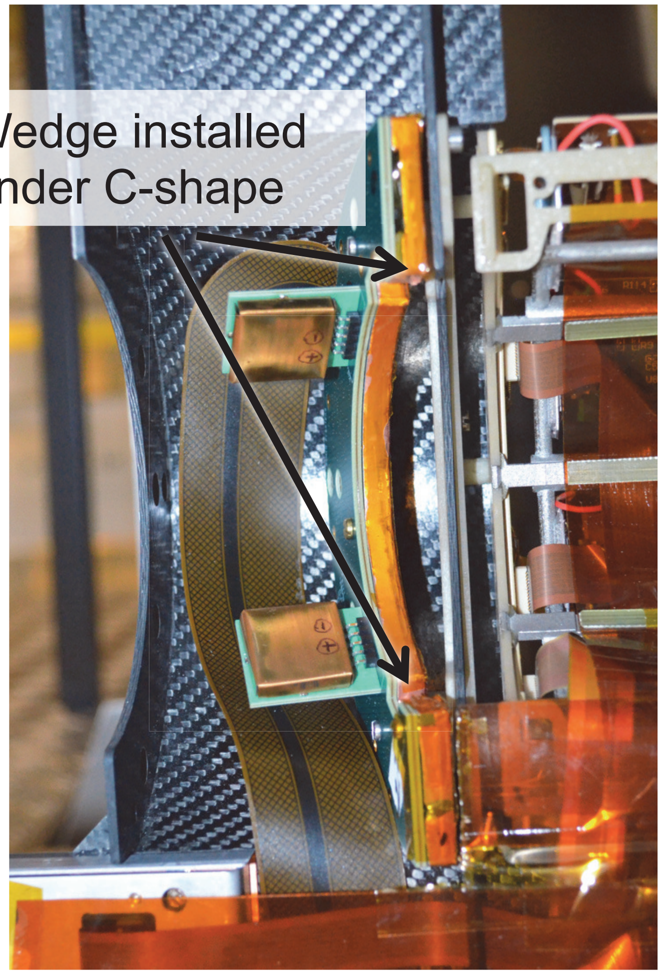
Tilting the detector



S. Müller, PhD thesis



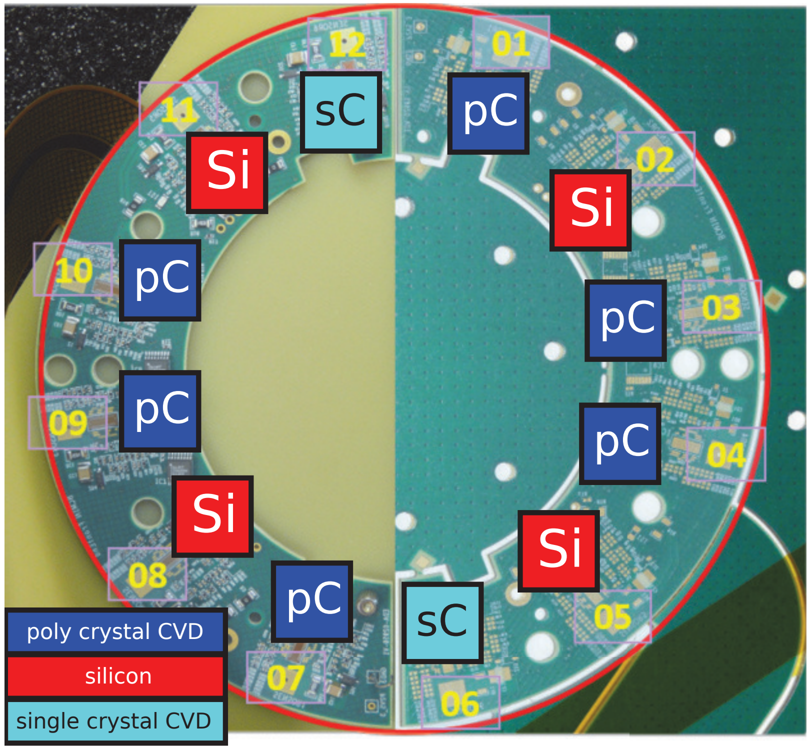




- **Benefit of magnetic field on erratic behavior known.**
  - **Seen in CMS with BCML (pCVD leakage current measurement)**
- **Hypothesis: Lorentz angle lets charge carriers drift into grain boundaries. Stops current.**
- **Attempt to tilt current BCM1F with only sCVD diamonds was not successful.**
  - **15° should give 980mT perpendicular in a total field of 3.8T**
- **Replacement system could use pCVD diamonds.**

Detector replacement, sensor mix

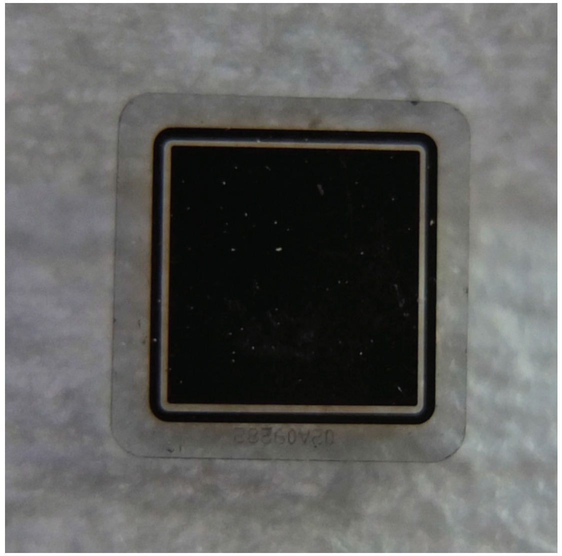
- **BCM1F accessible early 2017**
- **Decision to replace all front end detectors taken during summer this year.**
  - ➢ **No time for re-design of the system.**
  - – **Production of identical PCBs launched, received components ~2 weeks ago.**
- **Sensor options:**
  - – **single-crystal diamonds. Expected to work well un-irradiated, but to degrade quickly.**
  - – **poly-crystalline diamonds. Expected to be more stable (with fluence and rate), but low charge collection.**
  - – **silicon diodes. Unknown performance, FE-ASIC not designed to handle leakage current.**
  - ➢ **Best chance to have working detectors by installing all of the options.**

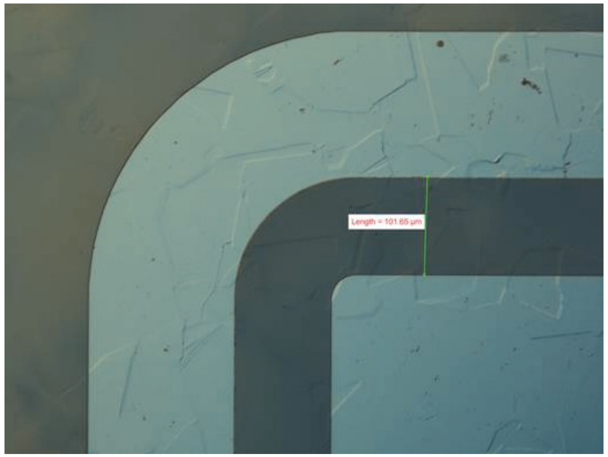


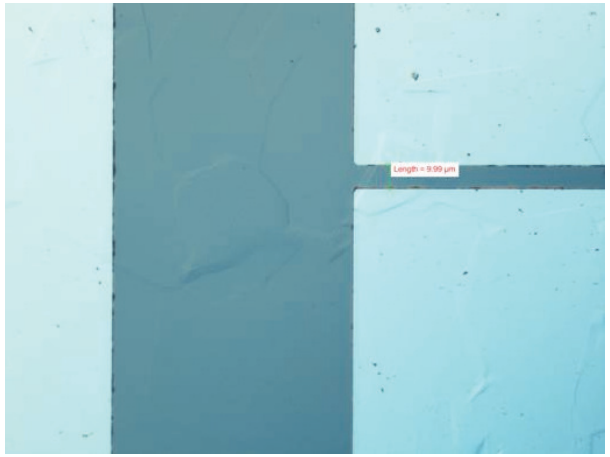
Metallization geometry

- **New design:**
  - Split pad only on readout side.
  - Round corners
  - Guard ring (passive)
  - More space to edges of the diamond

- **Metal:**
  - Single pad (HV): Cr/Au made in OSU
  - Split pad (readout): W/Ti made in Princeton



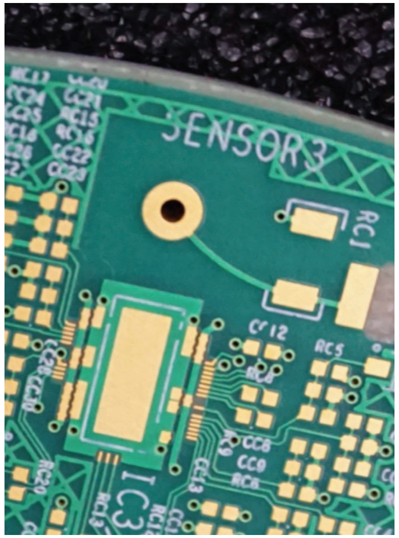


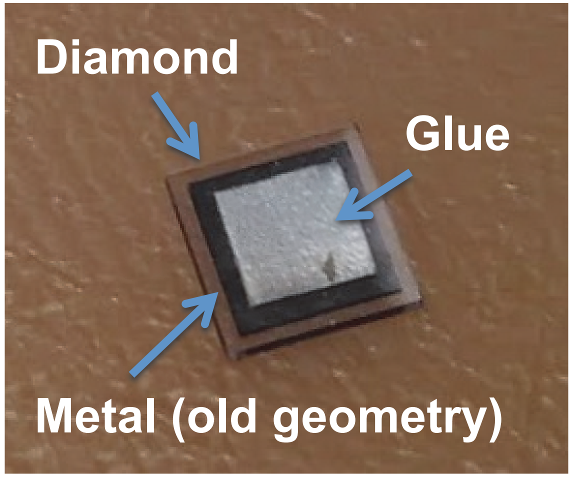


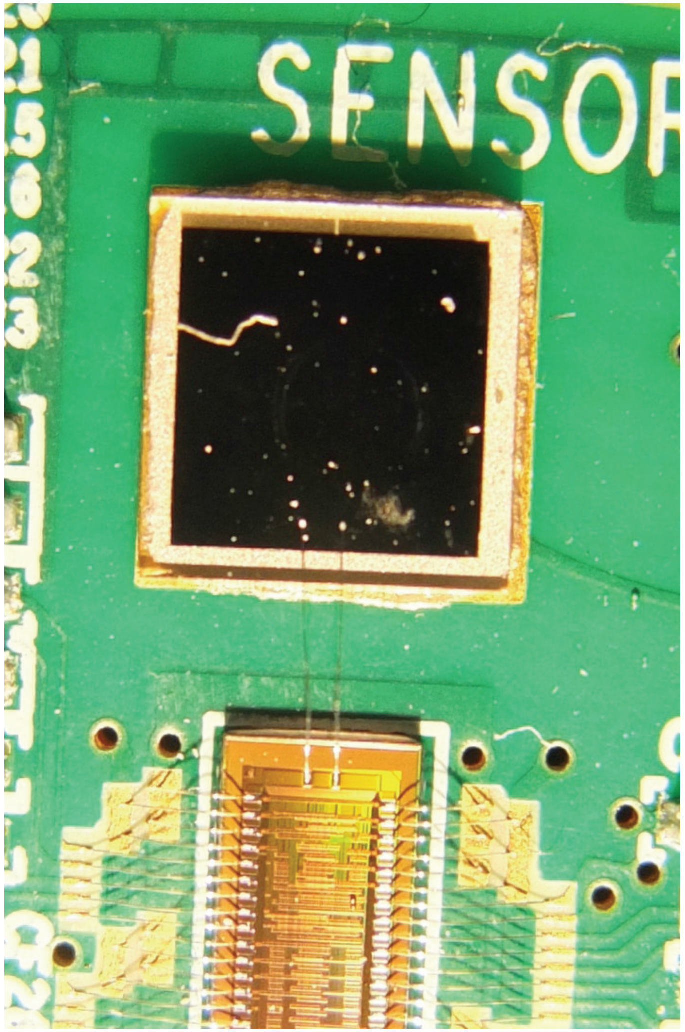
Sensor gluing and HV pad

- HV pads were > 5x5mm^2.
- Conductive glue spread over the edged
- ➢ Like metallizing to the edges

- Smaller HV pad size
- Use different glue (staystik pads)
- ➢ Try to avoid leakage over edges







Detector characterizations

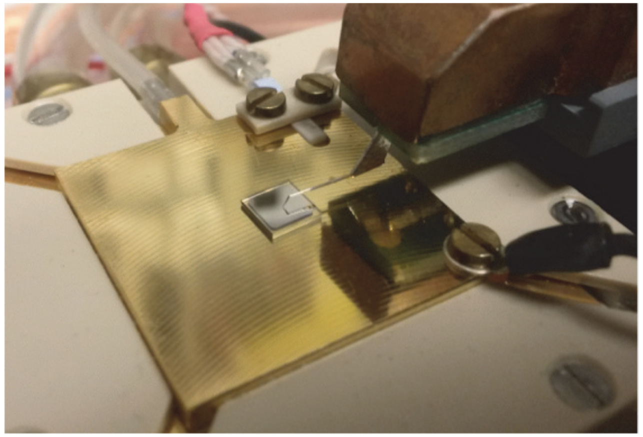
- Main stability criteria: low leakage current.
- Good charge collection desired.

- Leakage current tests:
  - Hot Sr90 source (130MBq), illuminating the whole diamond (incl. edges!)
  - Thin PCB plate to absorb low energetic particles.
  - 200V-1h, 500V-2h, 750V-4h, 1000V-4h

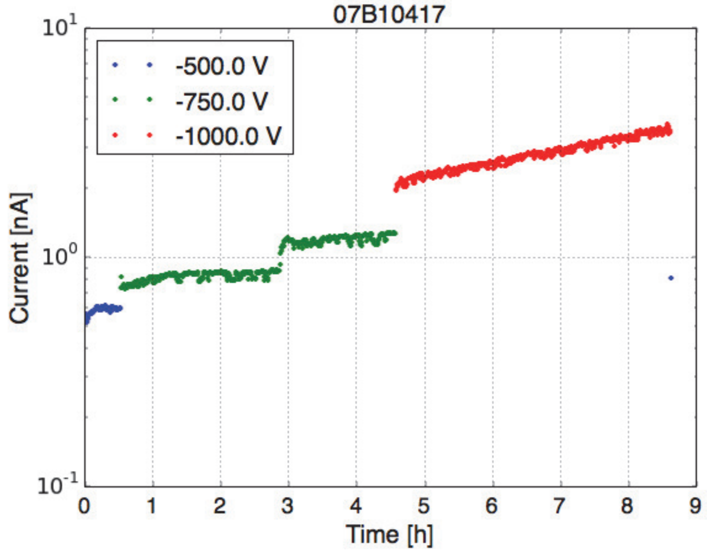
- Charge collection.
  - Source (Sr90 37MBq) collimated
  - Measure 500V, 750V, 1000V as function of time

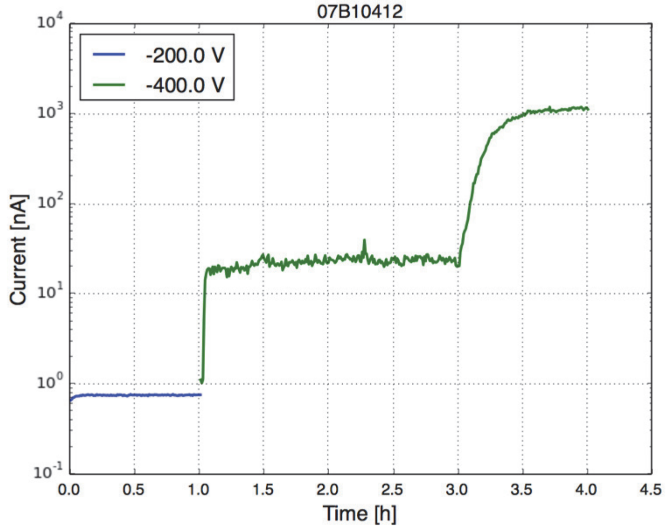
- Only few detectors measured so far. Being worked on at the moment.

CC measurement setup

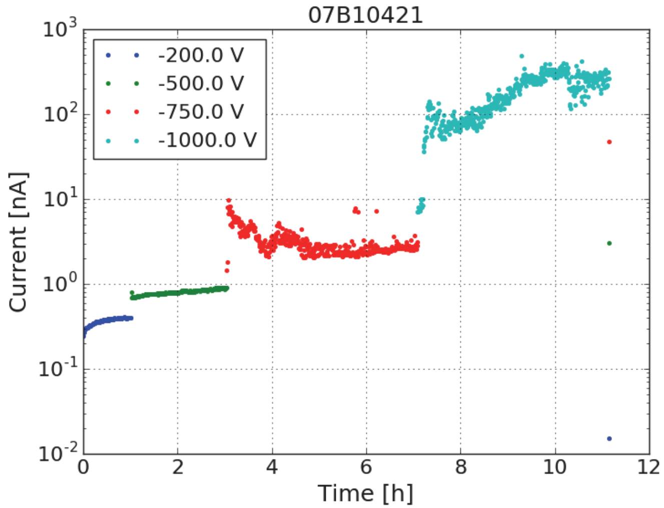


Current over time measurements

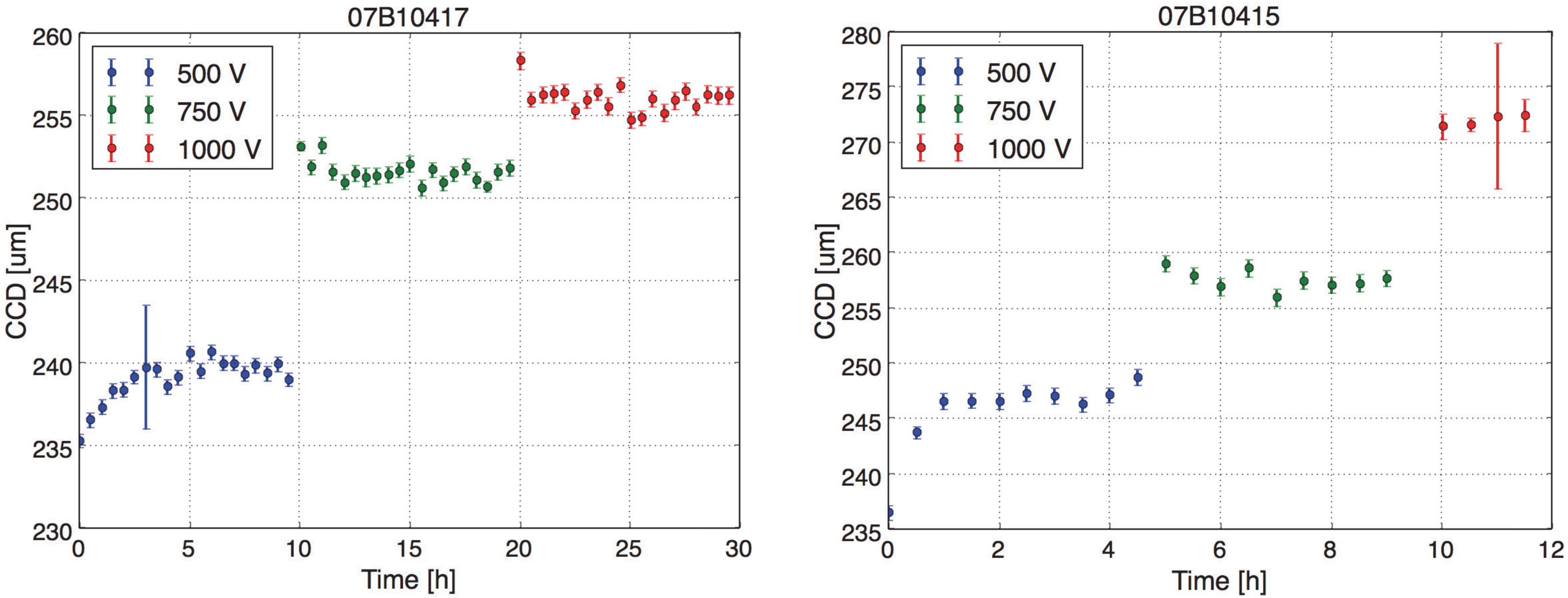




- Stability varies strongly.
- Max HV between ~200V and 1000V.
- Just enough diamonds to equip all places.
  - No margin for selection



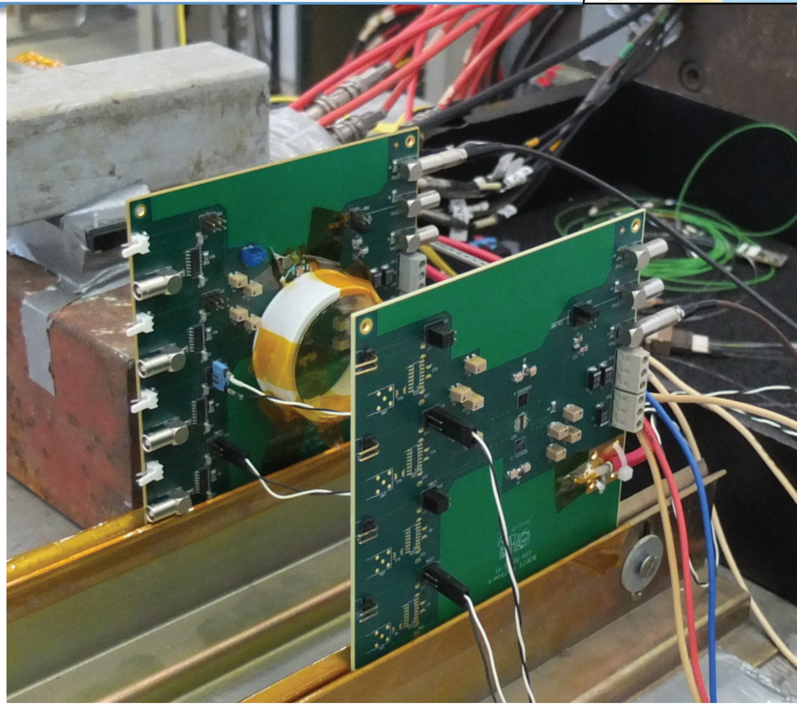
Charge collection measurements

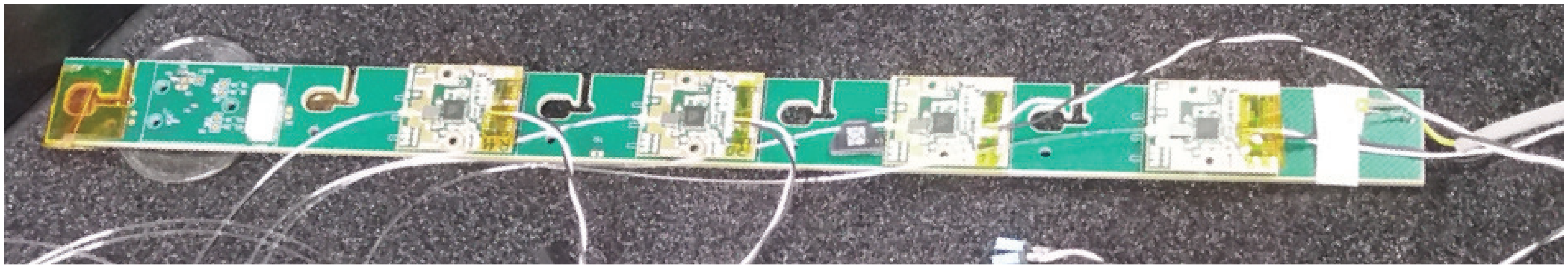


- **Measure CCD as function of time to make sure efficiency is stabilized.**
- **CCD > 250um (9000 e-, 1.4fC) above 750V**

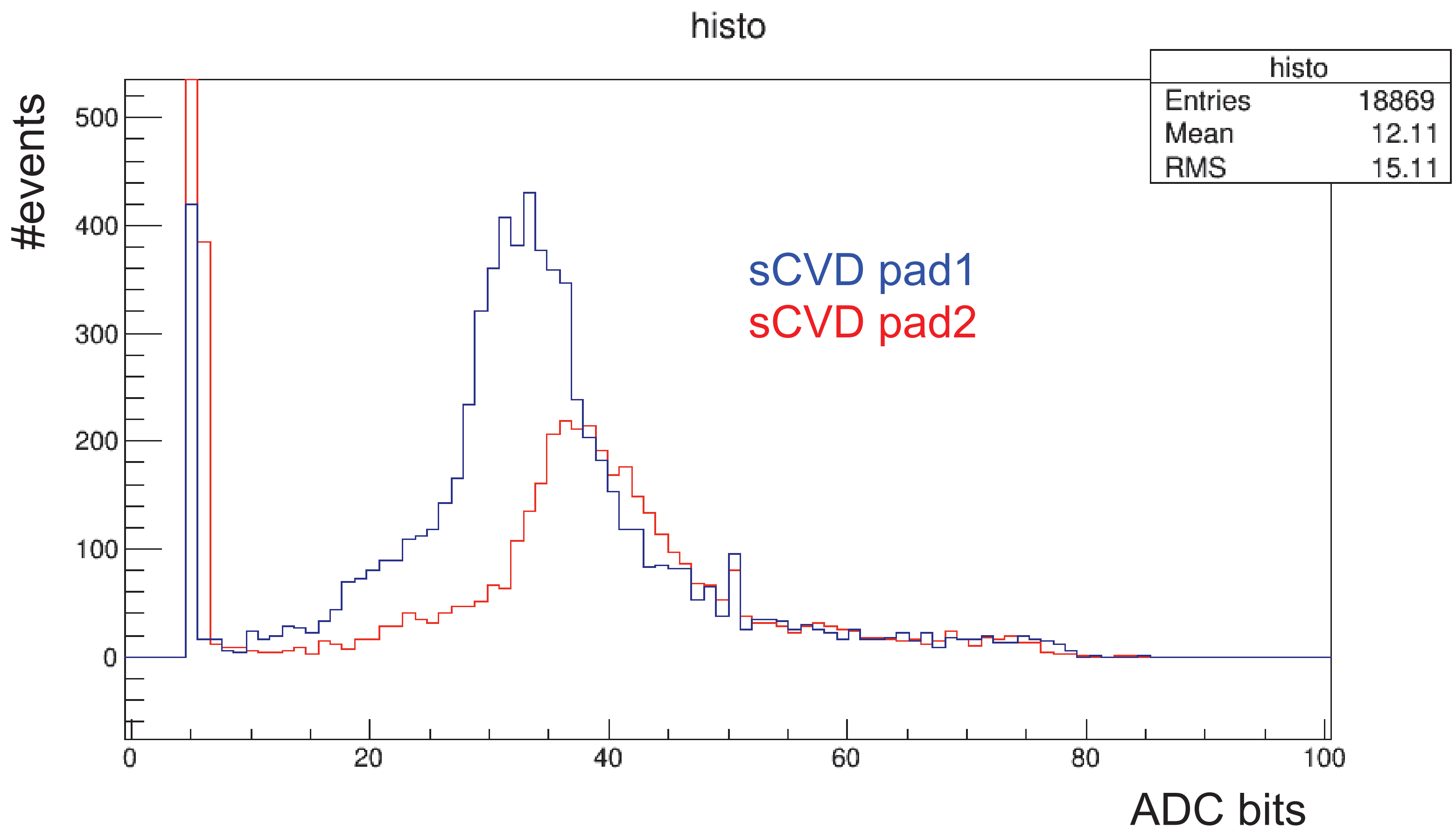
Test beam

- Test of pCVD diamonds in BCM1F type system.
- Two pCVD diamonds, and one old (two-pad) sCVD diamonds as reference.
- Readout reflects full BCM1F system:
  - Analog optical conversion
  - Discriminator + scaler
  - ADC for pulse height analysis



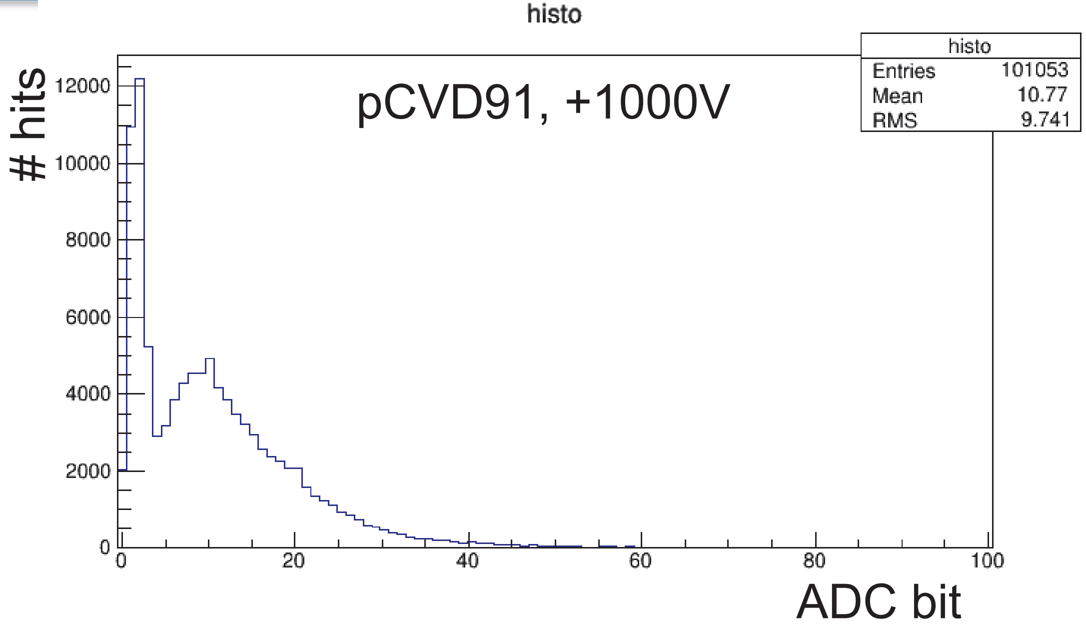


sCVD pulse height



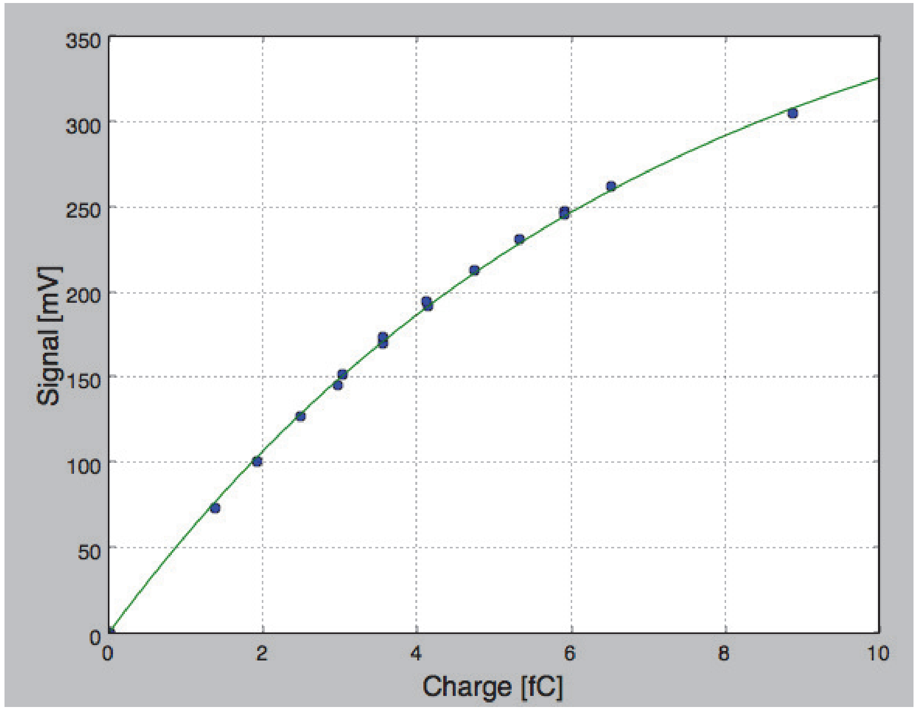
- sCVD shows clear peaks, well separated from noise.
- Difference in peak height is due to efficiency of the optical chain.

pCVD peak height



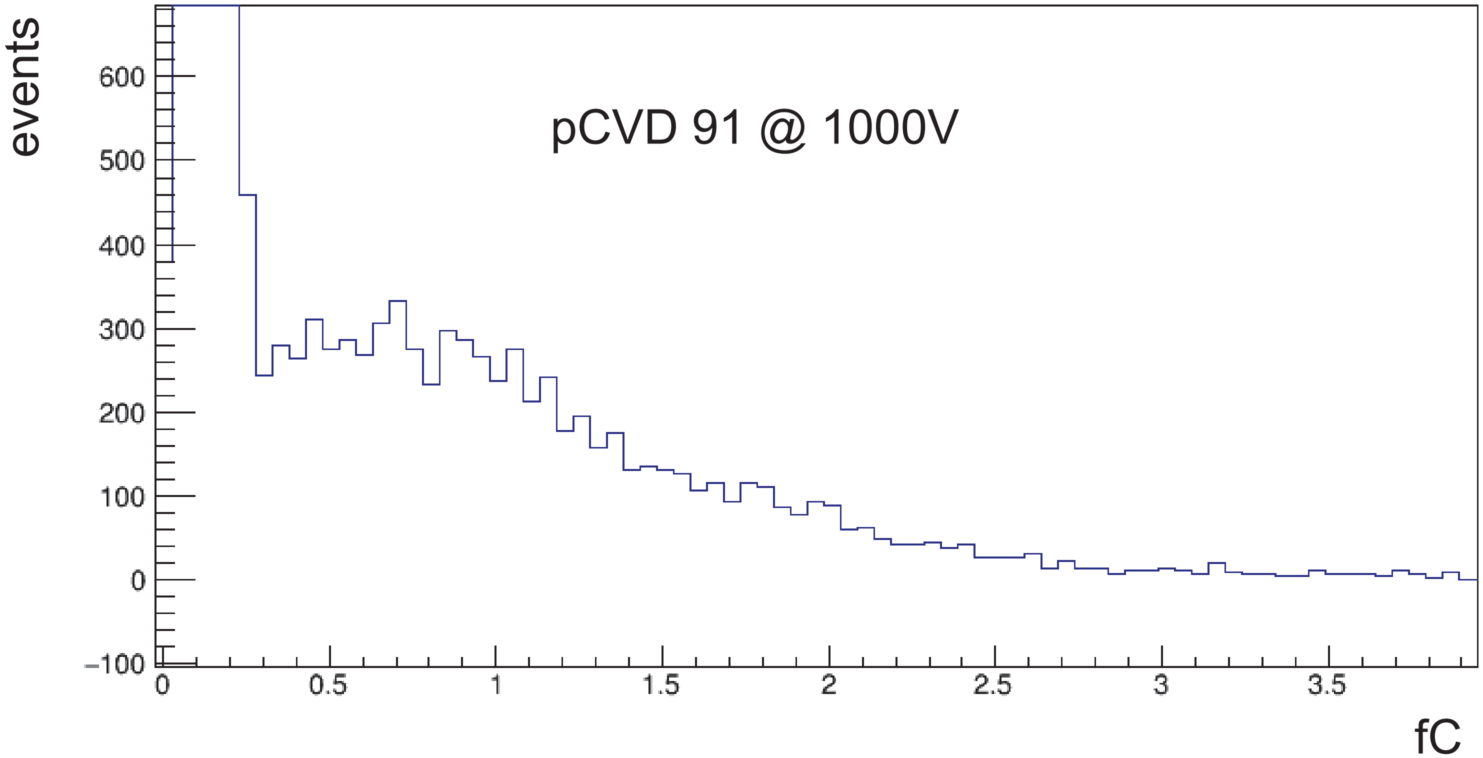
- **Use sCVD to trigger processing of pCVD data.**
  - **Self triggering difficult due to high noise**
- **Noise peak still visible due to imperfect alignment.**
  - **(some hits in sCVD where there is nothing in the poly)**
- **Clear peak separated from noise.**
  - ➢ **Can apply threshold for MIP sensitivity -> stable operation expected**

Calibration



- Use external test pulse input to calibrate the results
- Use parametric fit to saturating slope
- Can use this to convert peak height to charge collection.

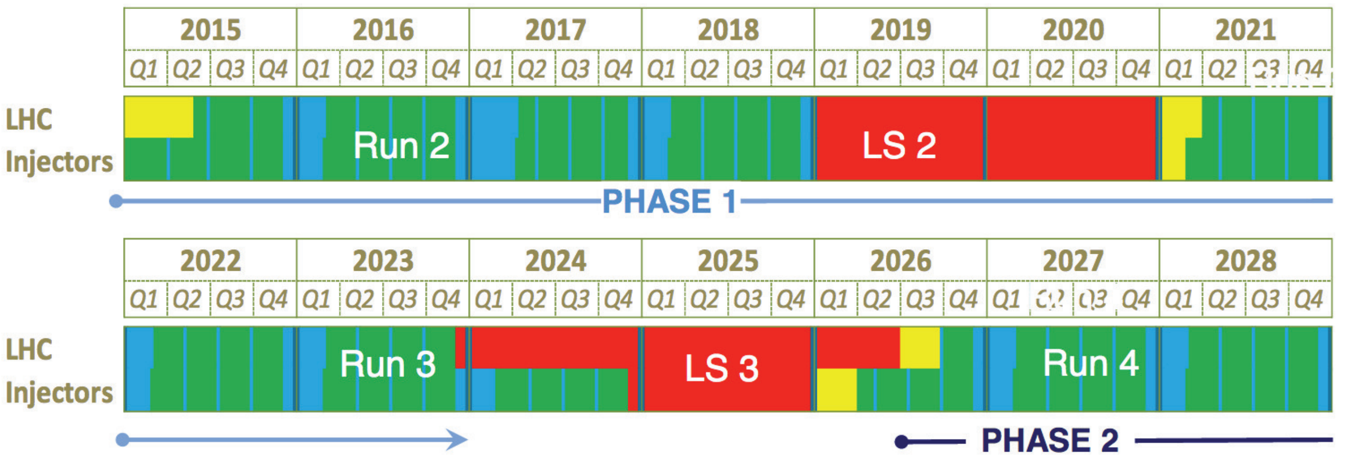
Calibrated results



- **Use calibration curve to convert peak height to charge.**
- **Mean at ~ 1.2 fC -> 208 um CCD.**
  - **Lower than expected, lab measurement showed: ~250-270um**

Potential follow up detector system

- Lifetime of new system:
  - Hopefully lasts until LS3 (2024), then replacement necessary due to CMS phase-2 upgrade.
  - Next chance for access in LS2 (2019). If again performance degradation occurs, intermediate solution necessary.
- Replacement being build at the moment uses very last available spare components.
- Conceptual change necessary
  - No technology for radiation hard analog optical signal transmission available.
  - New system needs to be digital.
    - Should try to exploit available radiation hard (LHC) technologies. Challenging to find suitable FE electronics (needs to be faster than standard 40MHz)



Summary and outlook

- Replacement of BCM1F necessary
  - Only very low HV can be applied to detectors
  - Detector not sensitive to MIPs any more.
  - Strong change in efficiency with radiation fluence
  - Cross calibration to luminosity allows correction, but high correction factors result in high systematic errors.
  - Same system will be re-built (no time and funds for major design improvements)
- Change of detector type:
  - pCVD should be more stable in terms of: leakage current (at least with magnetic field), radiation damage and rate dependence.
  - Smaller metallization area to reduce pulse pileup even further.
  - sCVD installed as reference while they can operate reliably.
    - Maybe improvements to surface processing and gluing allows higher HV than last iteration.
  - Exploring Si diodes as alternative, however system is not designed to handle leakage current.

THANK YOU

Special thanks to:

Harris Kagan, Ohio State University

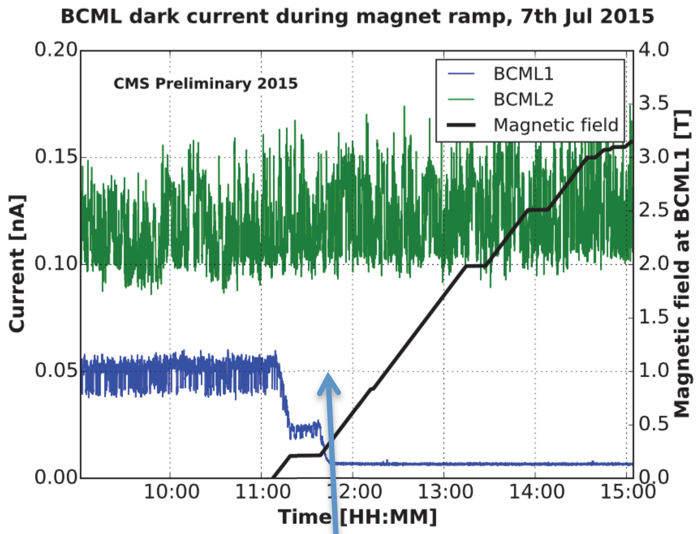
Dmitry Hits, ETH Zürich

ExtreMe Matter Institute for travel support

BACKUP

Magnetic field and HV stability

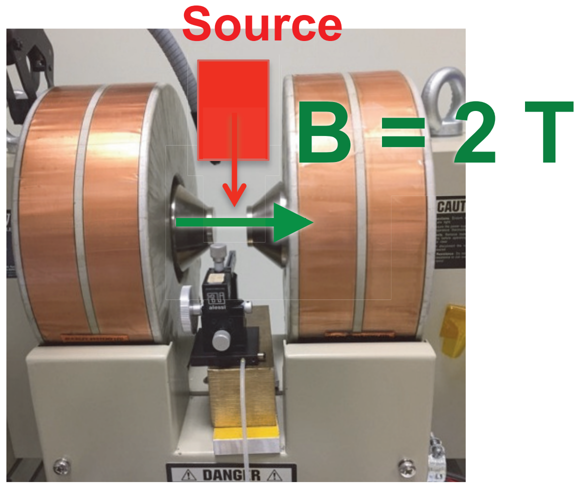
- **Known effect that magnetic field perpendicular to E-field prevents erratic currents in poly-crystalline diamond.**
  - **BCML1 profits from CMS magnet, BCML2 does not since it is outside of the field.**
- **BCM1F build with B parallel to E**
  - **2015 experience: detectors have higher HV stability with magnet ON.**
  - **Have to reduce ~100V when magnet is switched off.**
- **Can we improve HV stability in BCM1F with tilting sensors?**
  - **Improvement not expected since sCVD do not have grain boundaries.**
  - **We tried anyways…..**

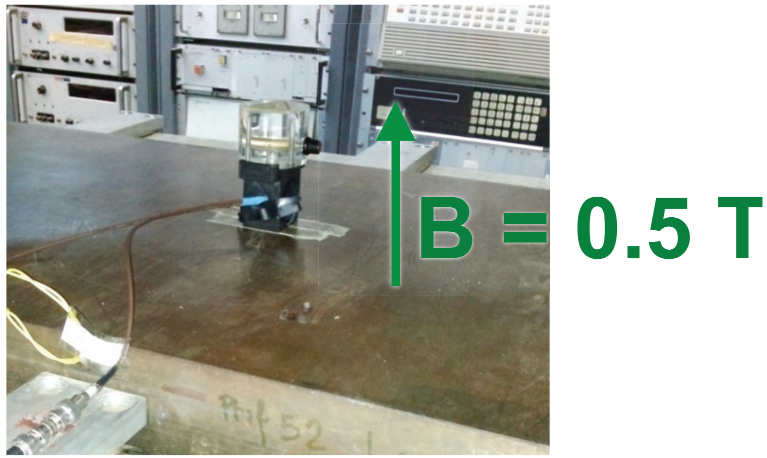


BCML system, pCVD diamonds, Not from BCM1F!

Tests in magnetic field

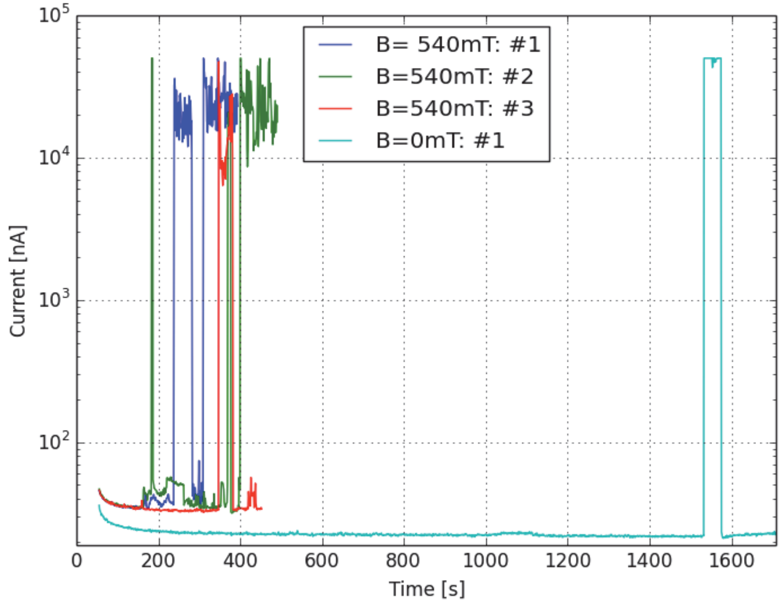
- Erratic current behavior has to be tested with source applied.
  - Occurrence of erratic behavior scales with rate environment.
- First attempt: Particles perpendicular to B-field.
  - No particles at detector with B on.
- Second attempt with bigger magnet: particles parallel to B-field.
  - Higher rate at detector with B on.
- Extremely difficult to make comparative study.





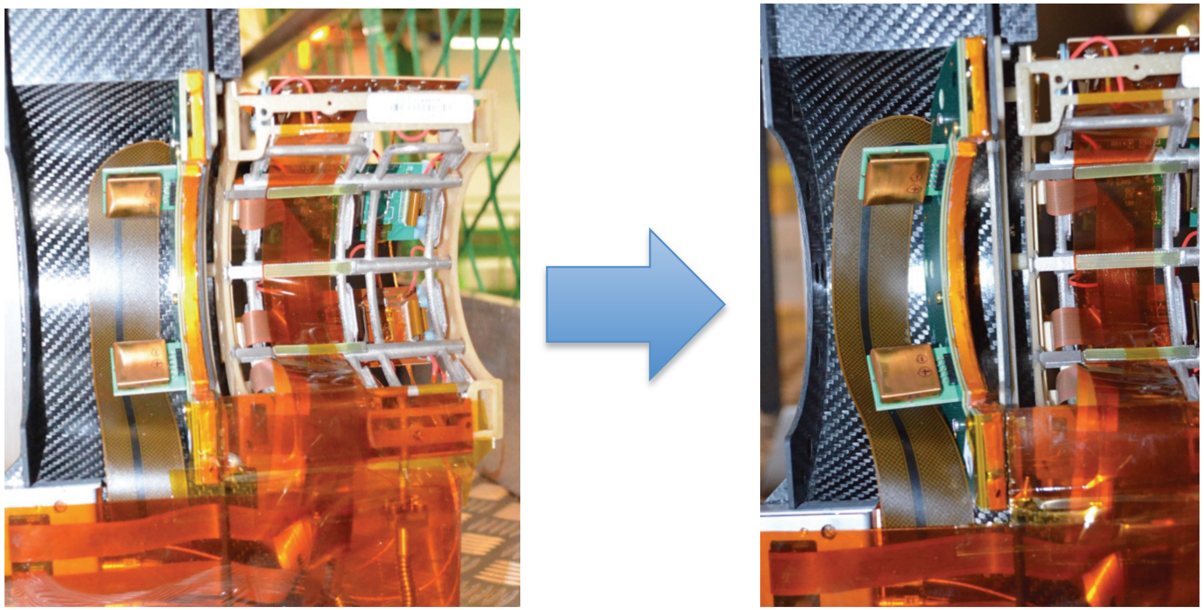
Tests with magnetic field

- Used BCM1F sensor rejects (split pad metal) on test PCB (one side glued, one side bonded).
- Electrical and magnetic field oriented perpendicular
- Magnetic field focuses more ionizing particles on diamond -> increased signal current.
  - Faster occurrence of breakthrough, likely due to higher rate environment.
  - No beneficial suppression of erratic currents with magnetic field visible.



Tilting of C-shape

- CMS was opened in YETS2015 to investigate a water leak.
  - Access to BCM/PLT carrier on the +Z end.
- Detectors were removed and a wedge was inserted under BCM1F to create an angle of 15°.
- Unfortunately no clear improvement in HV stability.
  - Detailed HV scans planned, but expectations are low.



Current after irradiation

Measurements at KIT, F. Kassel

Two current symptoms:

- **High DC current**
  - **Almost on all diamonds on one polarity**
  - **Reduces with irradiation**
- **"Break through": fast increase in current**
  - **Very random**
  - **Some have it more some less, some don't**
  - **Tends to increase with irradiation.**

Zeuthen_2499089-2

Tests done with source applied

Bonded on both sides, no conductive glue applied