Development of CVD Diamond Tracking Detectors for Experiments at High Luminosity Colliders

RD42 Status Report

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for the RD42 Collaboration

LHCC Meeting - March 23, 2011
CERN, Geneva Switzerland

Outline of Talk

- RD42 Collaboration
- LHCC Milestones 2010
- Material and Manufacturers
- Radiation Hardness
- Devices for Experiments
- Plans and Request

The 2011 RD42 Collaboration

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93 → 100 Participants

28 → 32 Institutes

Motivation

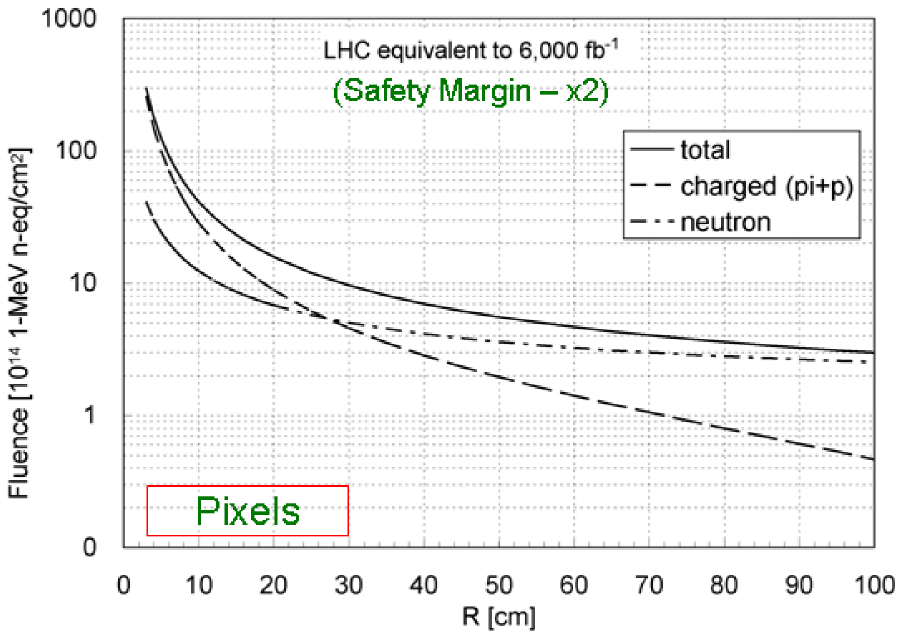
Tracking Devices Close to the Interaction Region of Experiments at the LHC and more importantly at sLHC

- Radiation Hardness (possibly survive to end of experiment)
- Low dielectric constant → low capacitance
- Low leakage current (even after large irradiation) → low readout noise
- Room temperature operation
- Fast signal collection

Scale is 10^{16} cm^{-2}

Pixels at r=4-30 cm

Below r=25cm charged particles dominate



LHCC Milestones/Priorities of Research-2010

- Test radiation hardness of highest quality pCVD and scCVD diamonds
- Develop diamond pixel modules useful at the LHC. Industrialize the module process.
- Perform beam tests with diamond strip and pixel detectors.
- Continue the development of pCVD and scCVD material. Develop additional suppliers.

Work with Manufacturers

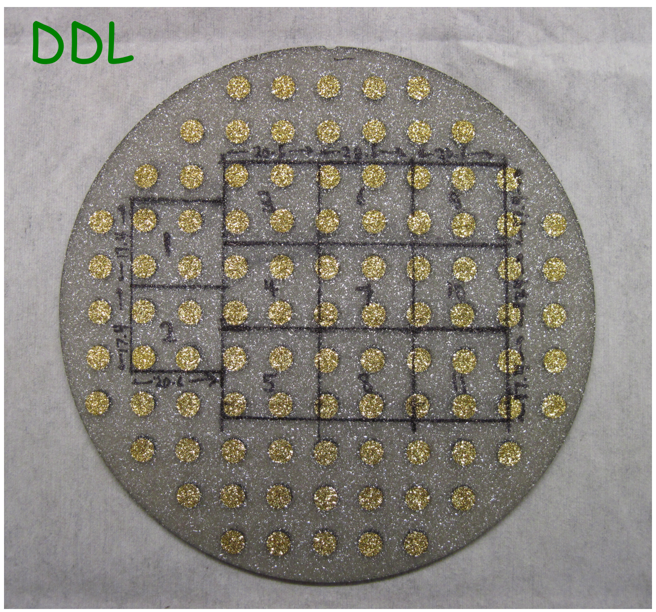
Important Parameters for Manufacturers:

- production capability
- part size
- as-grown collection distance
- final part collection distance

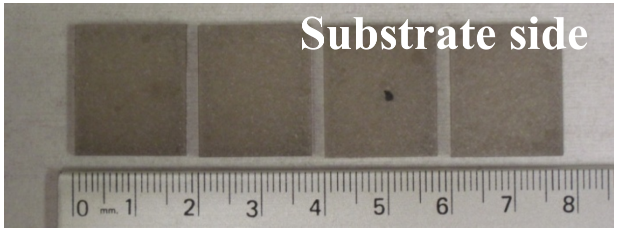
Work with Manufacturers

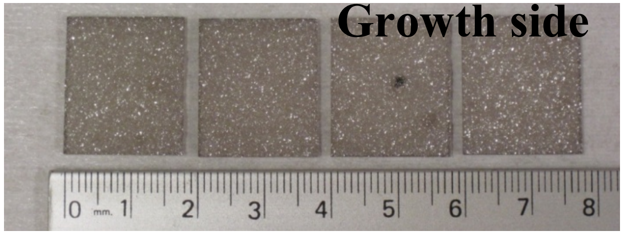
- Many large (~2cmx2cm) samples delivered in the last year:
  - DDL – 6+11 ATLAS Pixel Sensors received
    4 LHCb Pixel Sensors received
  - II-VI - 4 ATLAS Pixel Sensors received

- Now in the position to build devices with 30-50 large parts



II-VI

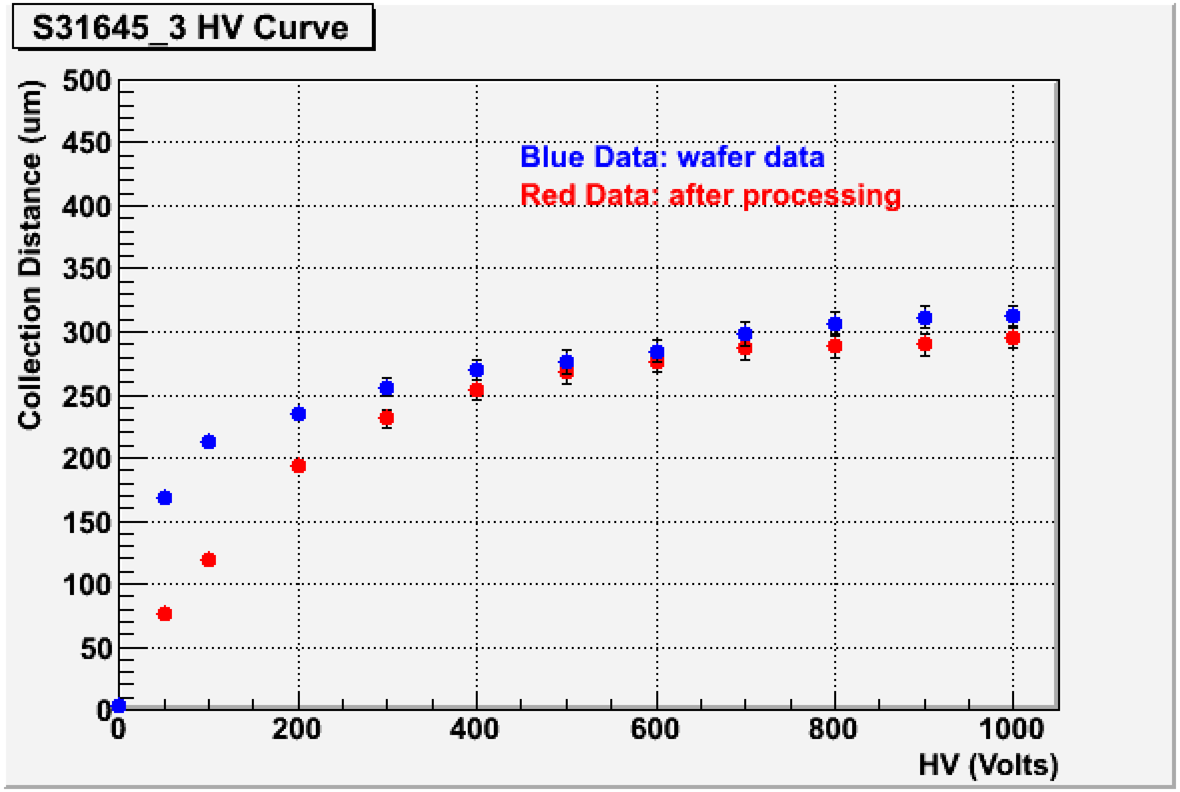




Work with Manufacturers

- Collection distance of new sensors

  300 μm both before and after processing!



Radiation Hardness

Important Parameters for Radiation Hardness:

- binding energy
- displacement energy
- mean free path
- elastic, inelastic, total cross section

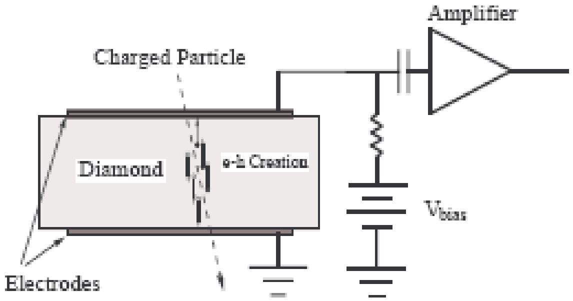
Signal from diamonds

- No processing: put electrodes on, apply electric field
- Traps determine signal size
  - much like in heavily irradiated silicon
- Introduce Charge Collection Distance, defined by

$d = d_e + d_h = (\mu_e \tau_e + \mu_h \tau_h)E$

$Q_{col} = Q_{created}\ d/t$ d=ave distance eh move apart

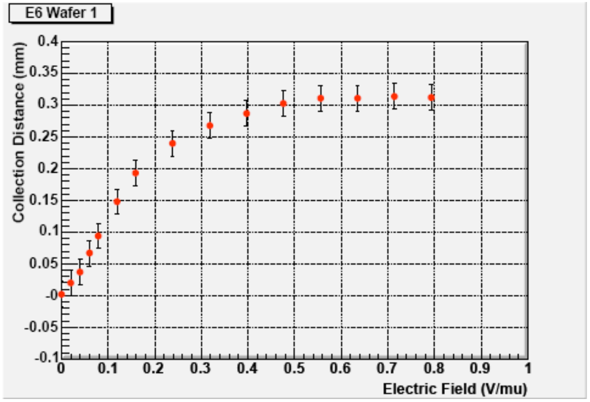
t = detector thickness



- CCD = average distance e-h pairs move apart
- Coincides with mean free path in infinite ($t \gg CCD$) detector

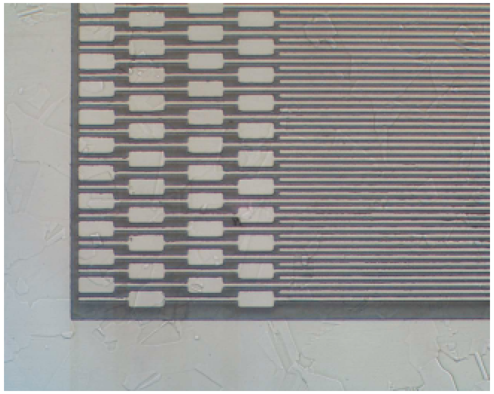
$CCD=Q_{col}/(36e/\mu m)$

CCD related to **mean** not **most probable charge**

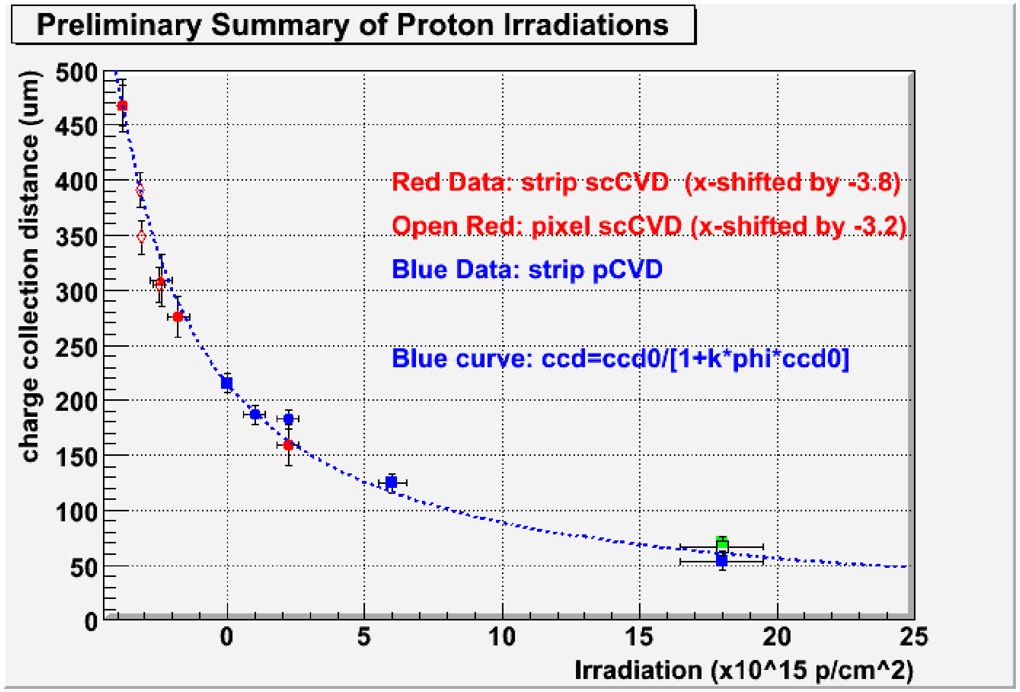


CCD measured on recent 1.4 mm thick pCVD wafer

Diamond Radiation Tolerance: 24GeV protons



$$\frac{1}{CCD} = \frac{1}{CCD_0} + k \times \Phi$$



Test beam data

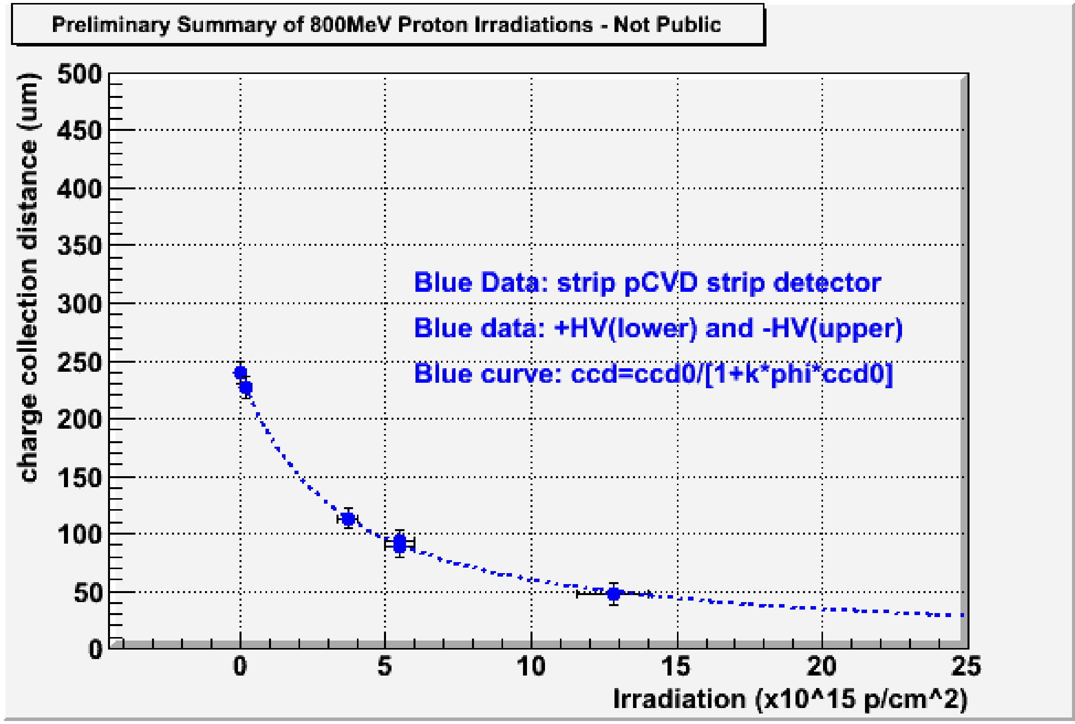
- CCD_0 initial traps in the material, ***k*** is the damage constant
- Test beam data shown – source data over-estimates damage!
- Single-crystal CVD and poly CVD fall along the same damage curve
- Larger CCD_0 performs better at any fluence
- Proton damage well understood, ***k***~**0.7×10^{-18} $\mu m^{-1} cm^{-2}$**

Diamond Radiation Tolerance: 800MeV protons

Recent Irradiation with 800 MeV protons at LANSCE Facility in Los Alamos, US

- Result: 800 MeV protons 1.9x more damaging than 24 GeV protons

  $k \sim$ **1.3x10^{-18} µm^{-1}cm^{-2}**
- NIEL prediction 1.8x
- 1 more data point being analyzed



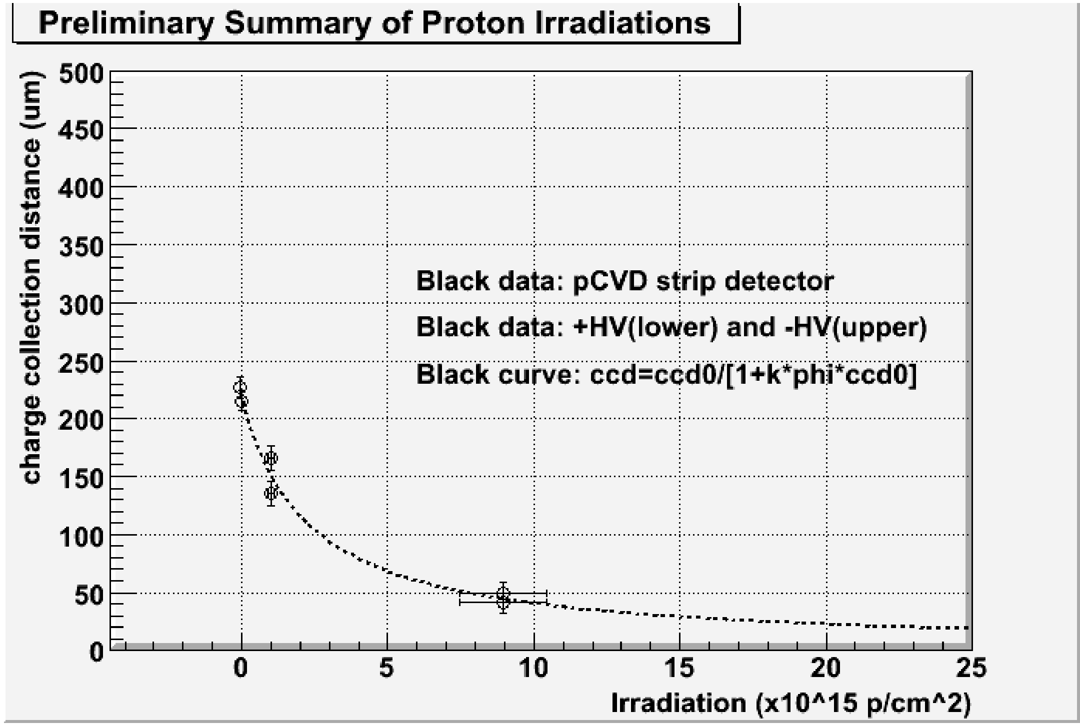
Preliminary Test beam Results

Diamond Radiation Tolerance: 70MeV protons

Recent Irradiation with 70 MeV protons at Cyric Facility in Sendai, Japan

- Result: 70 MeV protons 3x more damaging than 24 GeV protons

  $k \sim 2\text{x}10^{-18}\ \mu\text{m}^{-1}\text{cm}^{-2}$
- NIEL prediction 6x
- Awaiting 1 sample from Japan



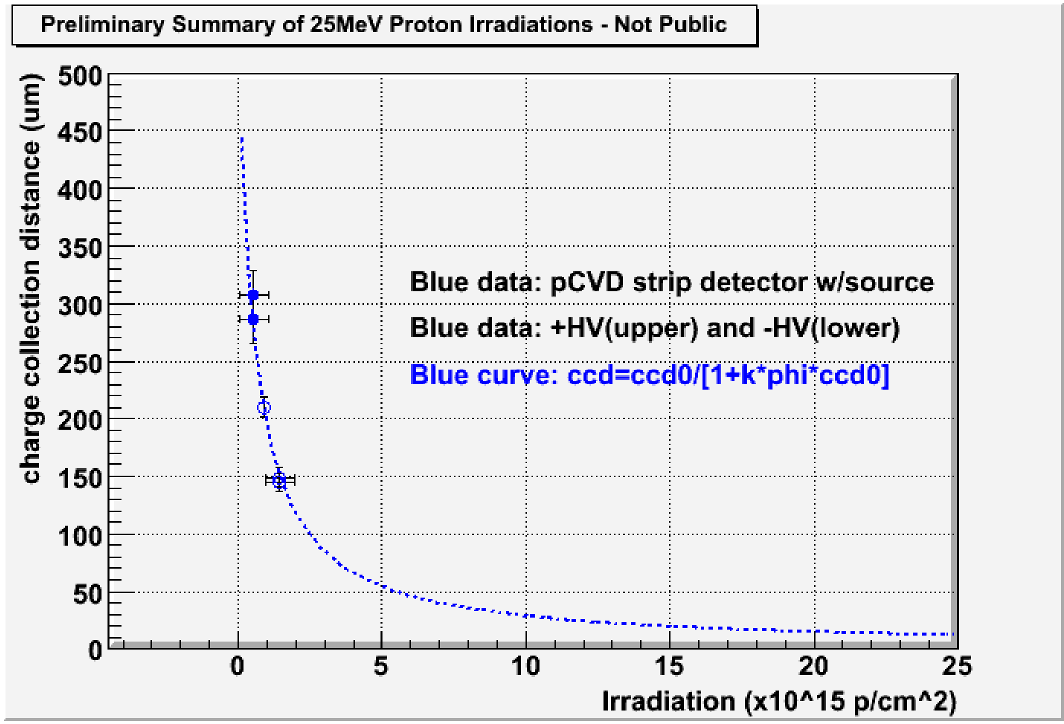
Preliminary Test beam Results

Diamond Radiation Tolerance: 25MeV protons

Recent Irradiation with 25 MeV protons at Karlsruhe Facility in Karlsruhe, Germany

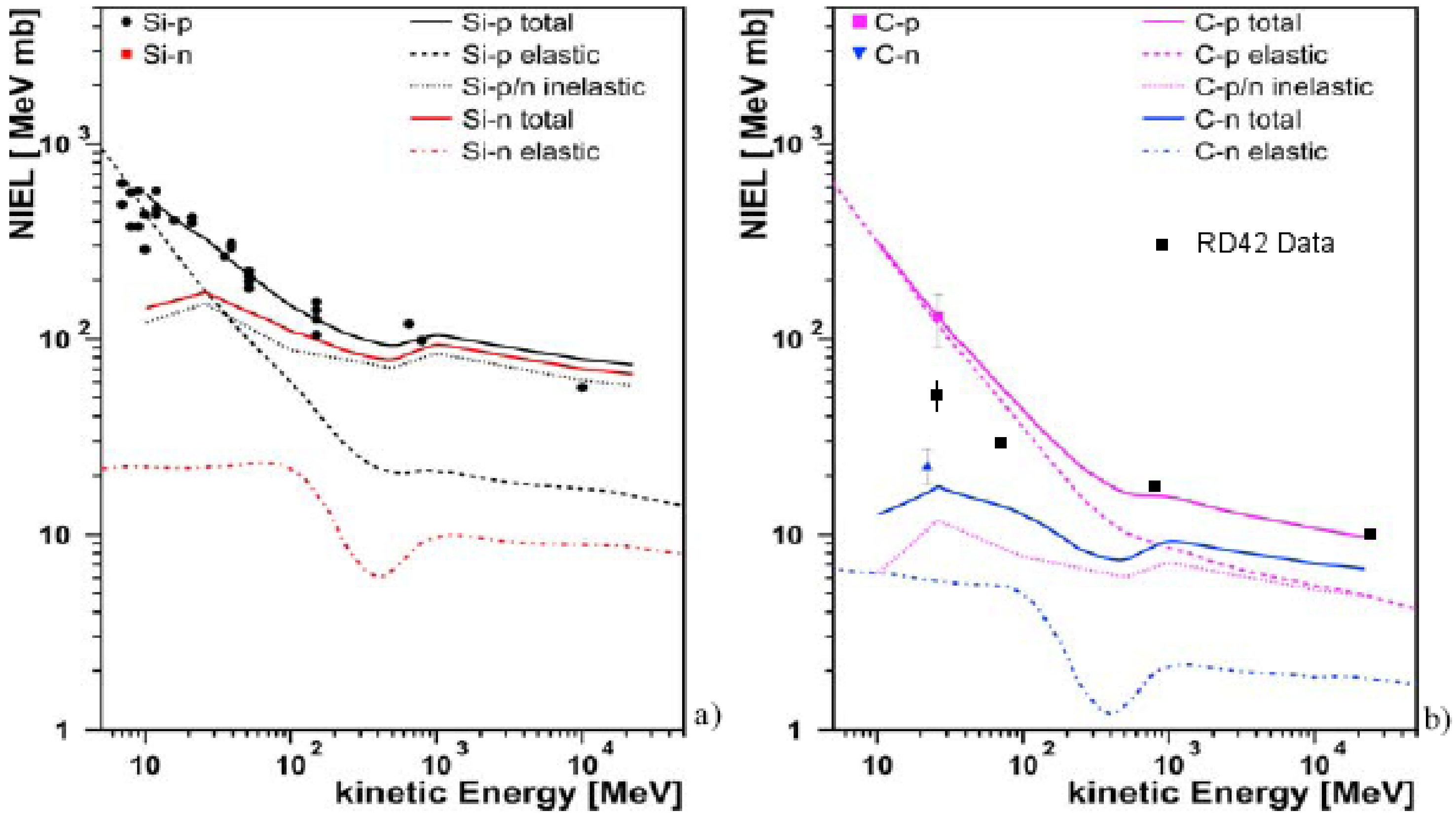
- Result: 25 MeV protons 5x more damaging than 24GeV protons

  $k \sim 3.3 \times 10^{-18}\ \mu m^{-1} cm^{-2}$
- NIEL prediction 15x
- Work in progress



Preliminary Test beam/source Results

Diamond Radiation Tolerance



- New results from low energy irradiations
- Deviation from calculated NIEL at low energy? NIEL violation? or is the theory incorrect?

Damage Constant from scCVD Data

When CCD~thickness of material use Mean Free Path

$$\frac{1}{mfp} = \frac{1}{mfp_0} + k \times \Phi$$

Relation between CCD and Mean Free Path:

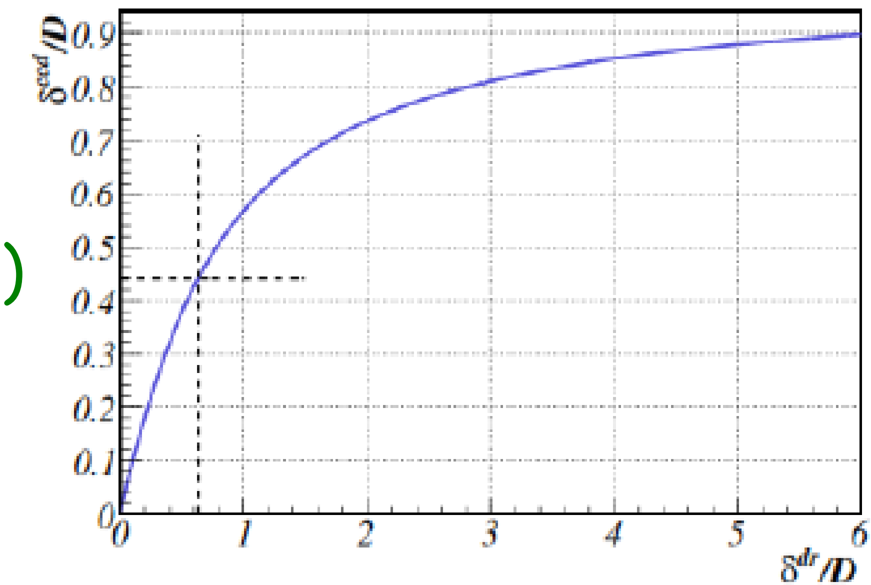
$$\delta^{ccd} = \sum_{k=e,h} \delta_k^{dr} \left[1 - \frac{\delta_k^{dr}}{D} \left(1 - e^{-D/\delta_k^{dr}} \right) \right]$$

δ^{ccd} = CCD; δ^{dr} = Mean Free Path; D = thickness of material

Damage Constant from scCVD Data

In scCVD diamond charge collection is uniform
Assume equal mean free path for electrons and holes

- Convert CCD to mean free path
- Use initial mean free path as large (essentially infinite)
- Calculate k based on mean free path after irradiation



Results:

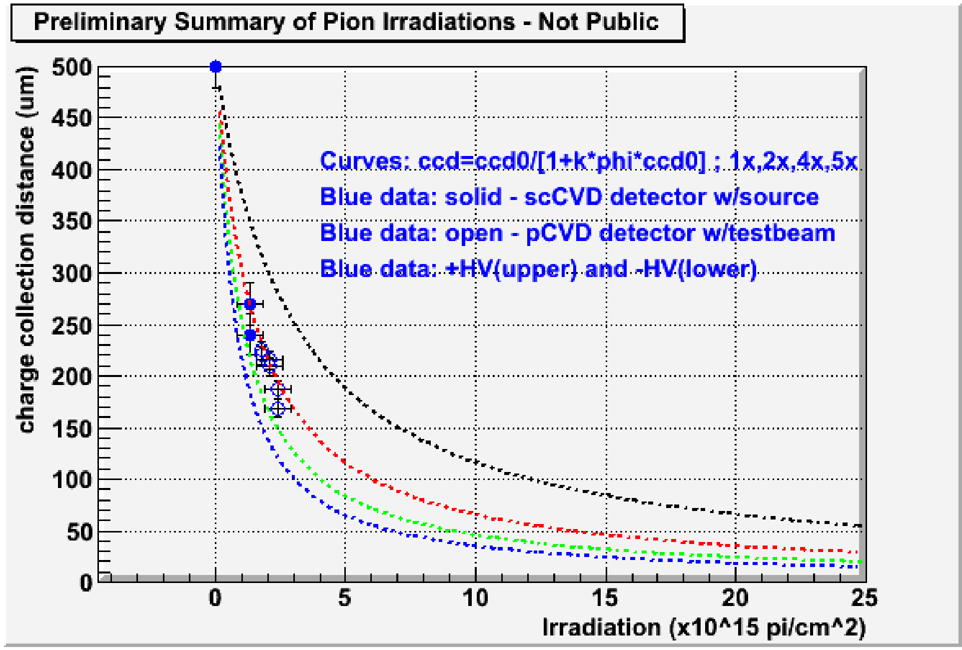
24GeV p $k = 0.9\times10^{-18}\mu m^{-1}cm^{-2}$ ~ $k = 0.7\times10^{-18}\mu m^{-1}cm^{-2}$

25MeV p $k = 3.0\times10^{-18}\mu m^{-1}cm^{-2}$ ~ $k = 3.3\times10^{-18}\mu m^{-1}cm^{-2}$

Work in progress but looks quite good!

New Results in Progress - π

- pCVD with PSI 300MeV π up to 6×10^{14} p/cm^2 tested in CERN test beam
  - $k \sim 2\text{-}4\times10^{-18}\ \mu m^{-1}cm^{-2}$
- scCVD up to 1×10^{15} π/cm^2 Samples tested in source and CERN test beam
  - $k \sim 2\text{-}4\times10^{-18}\ \mu m^{-1}cm^{-2}$



$$\frac{1}{CCD} = \frac{1}{CCD_0} + k \times \Phi$$

scCVD Mean Free Path Analysis

$k=2.8\times10^{-18}\mu m^{-1}cm^{-2}$

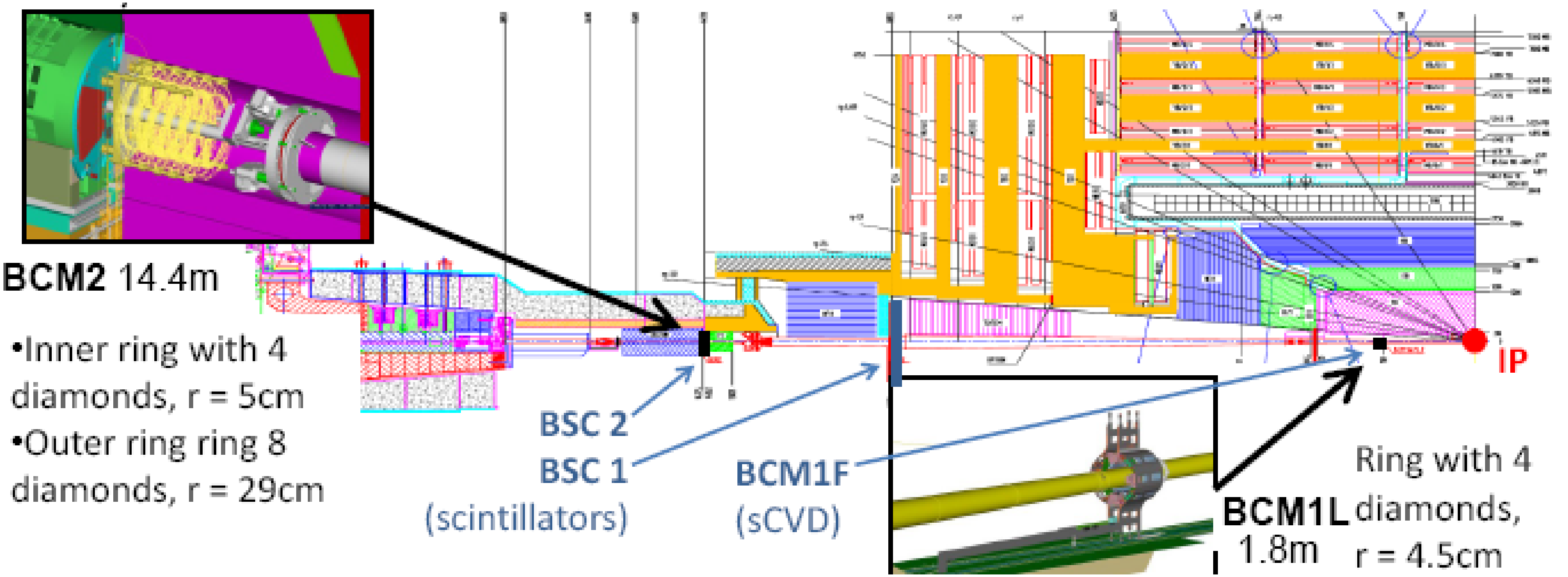
Diamond Devices for Experiments

Diamond in LHC experiments:

- ATLAS, CMS, LHCb, Alice diamond BCM/BLM
- CMS PLT and ATLAS DBM forward pixels
- ATLAS, CMS, LHCb upgrade studies

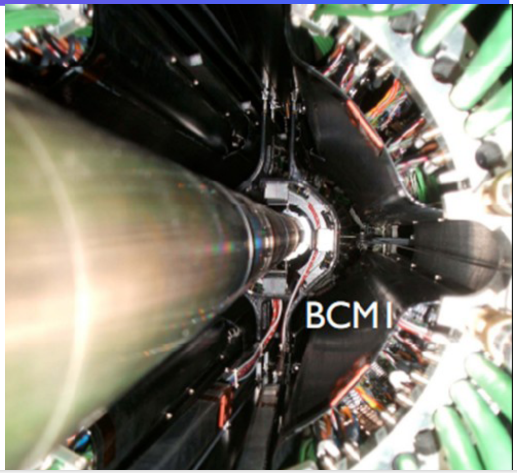
CMS BCM/BLM's

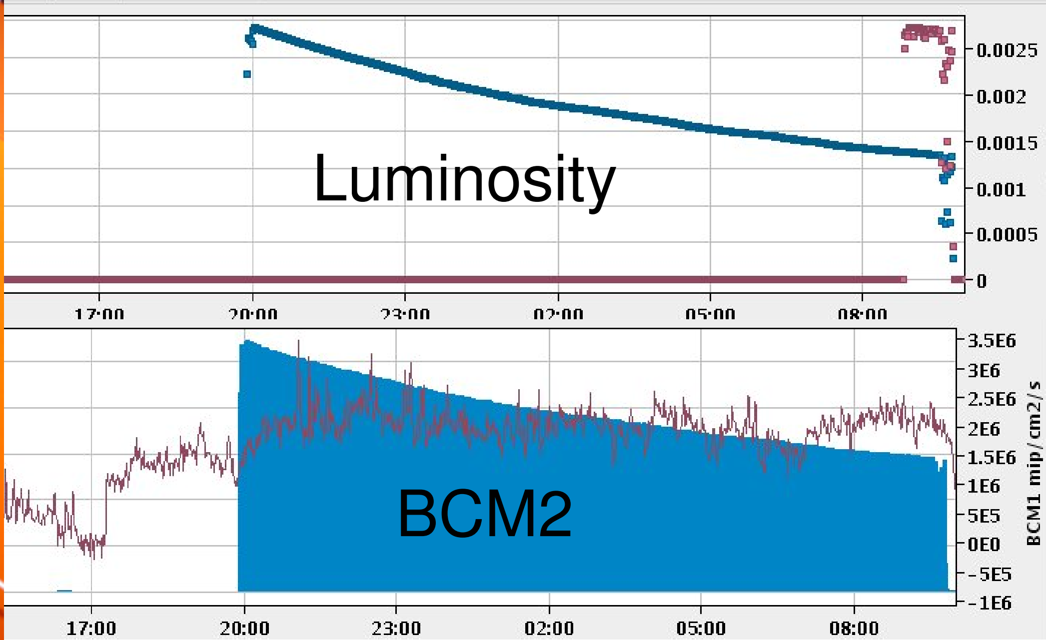
- Diamonds: pCVD 1x1cm^2, 400μm thick, CCD~200μm, HV=200V
- Measuring leakage current i.e. MIP-eq/cm^2/s
- Detector rings at 2 distances from IP: BCM2 (14.4m), BCM1L(1.8m)



Running System

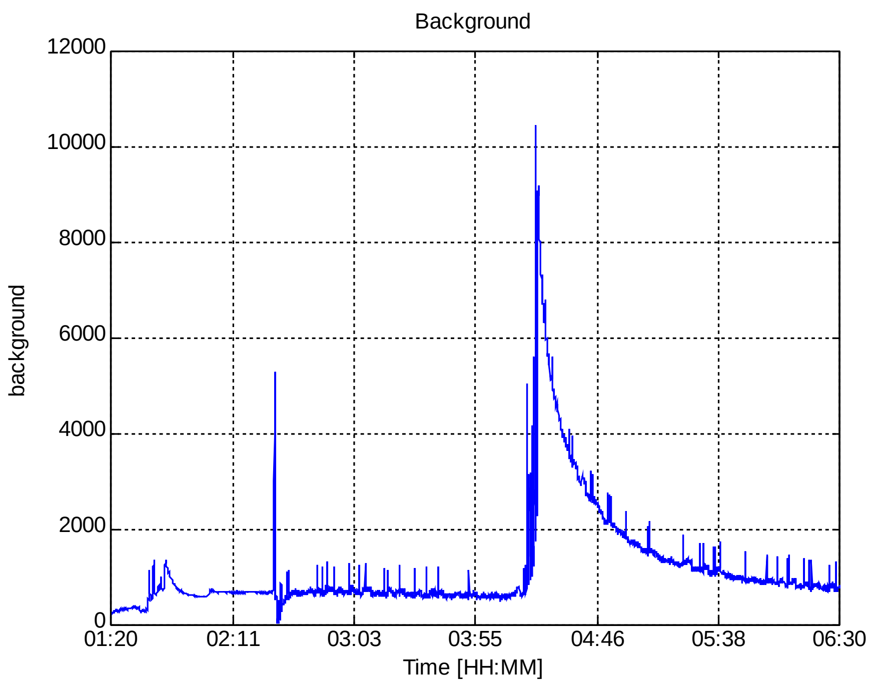
- BCM2 correlated with Luminosity

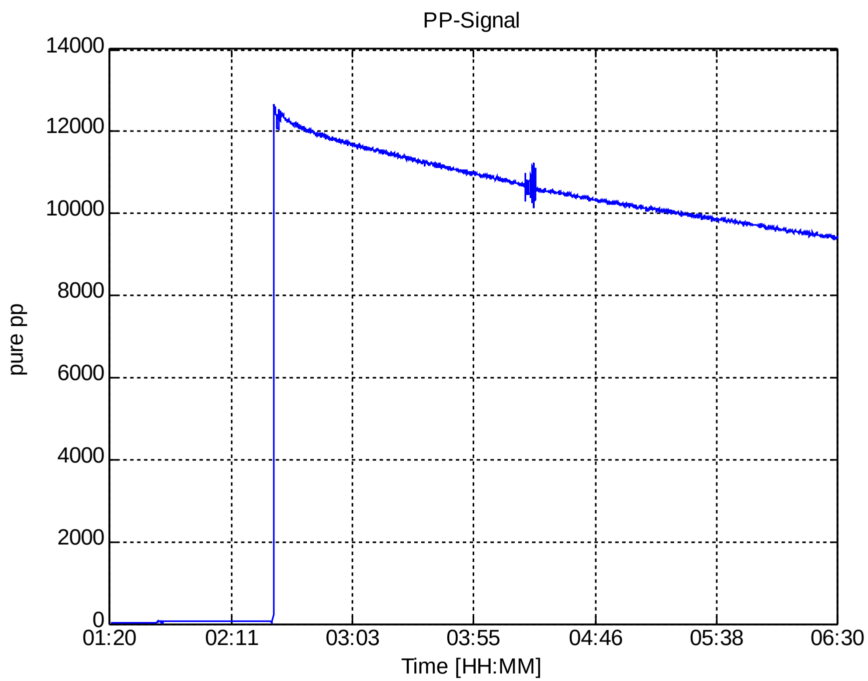




CMS Calculation of Real-time Background

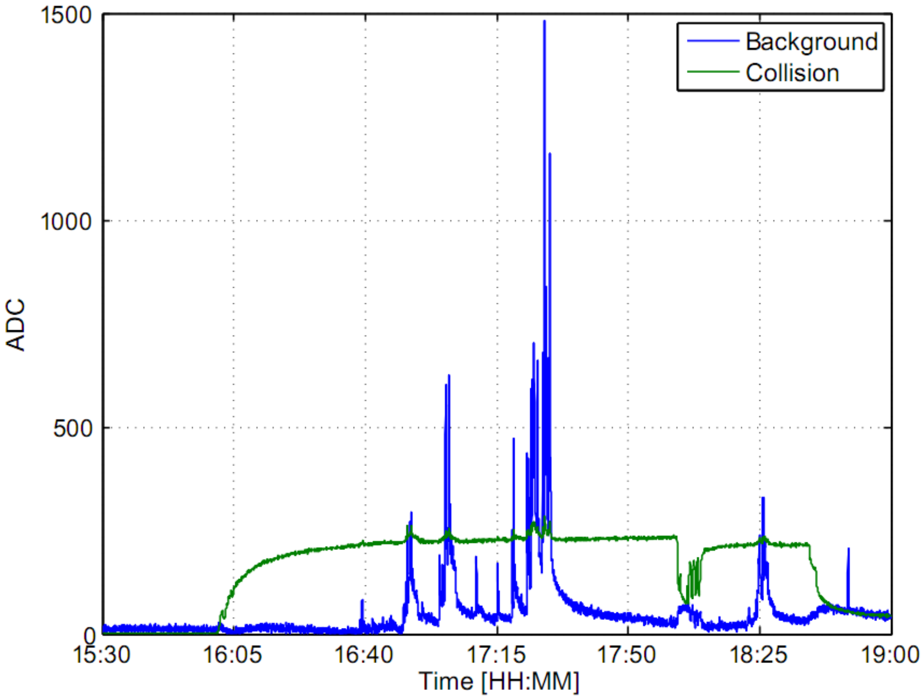
- Signal in detectors is sum of collision signal and machine induced bkg
- BCM2 and BCM1L have different sensitivities
- Both Signals used to discriminate bkg from pure collision signal
- Calculation of Ave particle flux in MIP-equiv/cm^2/s
- Method under investigation-considered a good way of measuring bkg





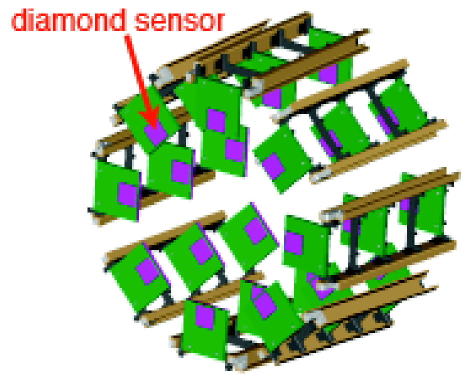
First Collisions of 2011 in CMS BCM

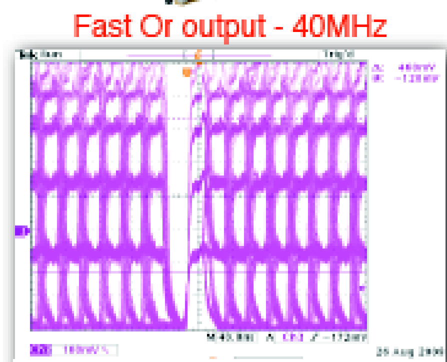
- First test collisions in 2011
- No stable beam
- Signal rises slowly – pumping
- Luminosity signal clear
- Beam loses show up in bkg
- Extraction of bkg works well

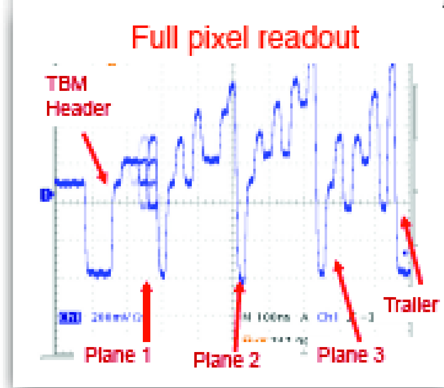


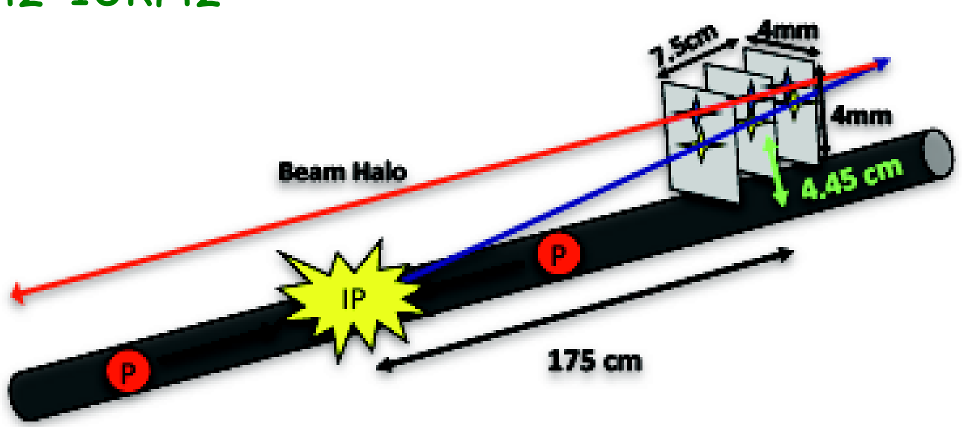
CMS Pixel Luminosity Telescope Project

- PLT is a dedicated luminosity monitor for CMS
- 8 Telescopes (3 planes each) on each side of IP
- Each plane contain a pixelated scCVD diamond
- Designed to measure relative luminosity to 1%
- Dual readout mode
  - FastOR mode for Luminosity at 40MHz
  - Full pixel readout for calibration, diagnostics and systematic correction of fast or mode 1kHz-10kHz





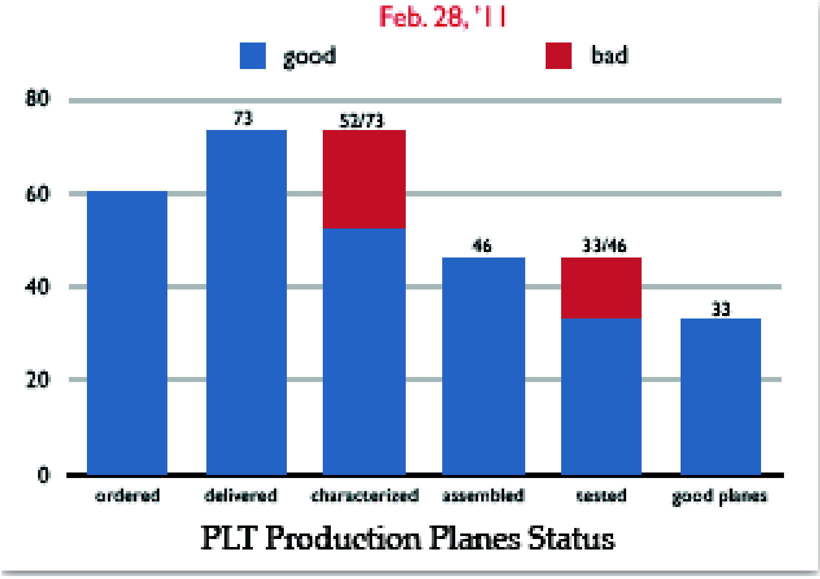




CMS PLT Status and Schedule

48 single crystal diamond sensors (4.7 mm x 4.7 mm) are needed for the PLT

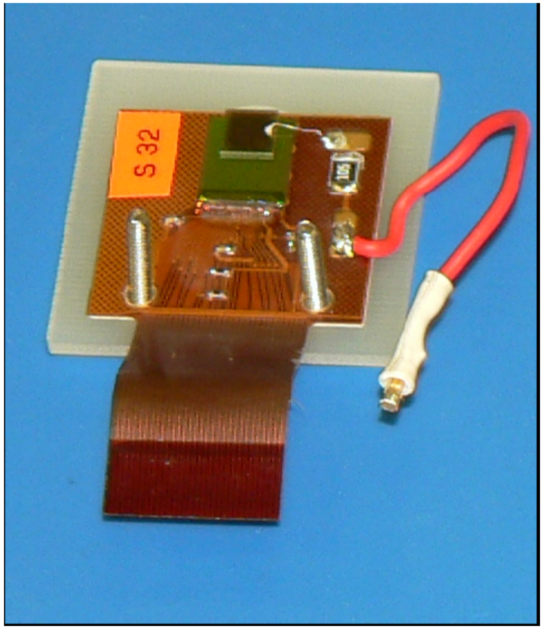
- 52 good production diamond sensors delivered + waiting for 8 replacements.
- 33 good planes produced.
  - 15 more to complete PLT end of April!
  - Another 12 spares - end of June.



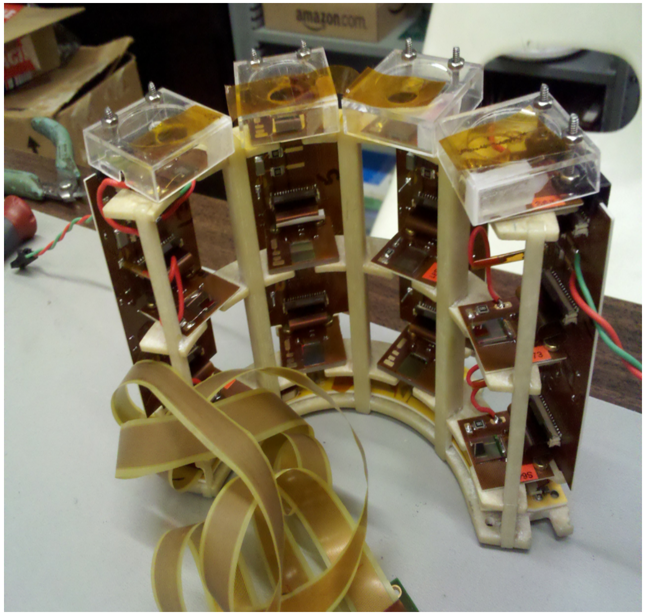
- End of May all PLT components transfered to CERN.
  - complete PLT system (48 telescopes) will be assembled and "burned in" before the installation.
- Will install during 2011-2012 shutdown, if it turns into extended shutdown!
  - 10 days needed to install on +z side and 7 days - to install on -z side.

PLT in Pictures

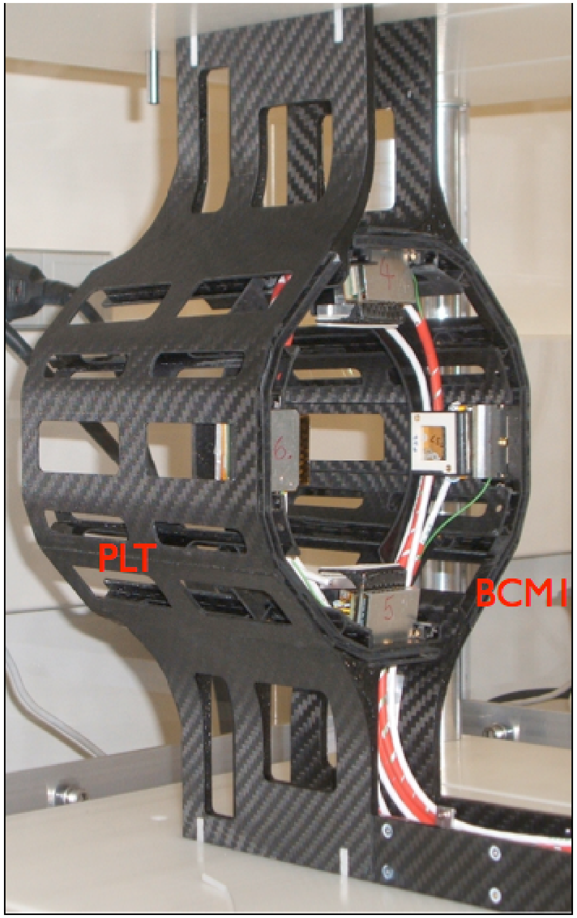
PLT Hybrid board



PLT Setup



PLT/BCM Carriage



RD42 Research Priorities for 2011

- Complete irradiation of highest quality pCVD and scCVD diamonds with protons, pions and neutrons of various energies.
- Characterize irradiated samples in test beams and compare the results to silicon and NIEL hypothesis.
- Continue to develop additional diamond manufacturers to expand production capabilities.
- Perform beam tests with diamond strip and pixel detectors.
- Continue to support LHC upgrade pixel projects.

Request of CERN LHCC

The RD42 Role at CERN

- Irradiations, development of new manufacturers, sample procurement, test beams
- Central facilities for all experiments ➔ this worked for BCM's
- CERN Group in RD42 to be maintained

RD42 Request to CERN/LHCC

- RD42 is supported by many national agencies:
  - ➔ continuation of official recognition by CERN critical
  - ➔ 25kCHF from CERN matching ~200kCHF from outside CERN
- RD42 requires access to CERN facilities:
  - ➔ maintain the present 20 m^2 of lab space (test setups, detector prep, ...)
  - ➔ maintain present office space
  - ➔ test beam time critical for next generation of proposals

RD42 & CERN play a critical role in diamond development

Summary

- Radiation hardness of CVD diamond is nearly quantified
  - pCVD and scCVD have the same damage constant.
  - Dark current decreases with dose. NIEL?
  - Pion data being analyzed; Neutrons soon
- Large high quality part are being produced
  - Successfully produced wafers with >300μm collection distance
  - Successfully processed large parts without losing ccd
- Devices in experiments working very well
  - Abort, luminosity and background functionality in all LHC expts
  - Backgrounds and collisions look separable
  - First pixel projects nearing completion
  - CMS Precision Luminosity Telescope nearly ready
  - ATLAS working on Diamond Beam Monitor (DBM) using FE-I4
  - RD42 played a large role in making this happen!