Recent Advances in Diamond Detectors

- How Diamond detectors work
  - Growth, Signal, Characterisation, Progress
- Results from Prototypes
  - Tracker signals, irradiations
- Applications
  - Pixel Prototypes: ATLAS, CMS
  - Beam monitors: BaBar, Belle, CMS, ATLAS

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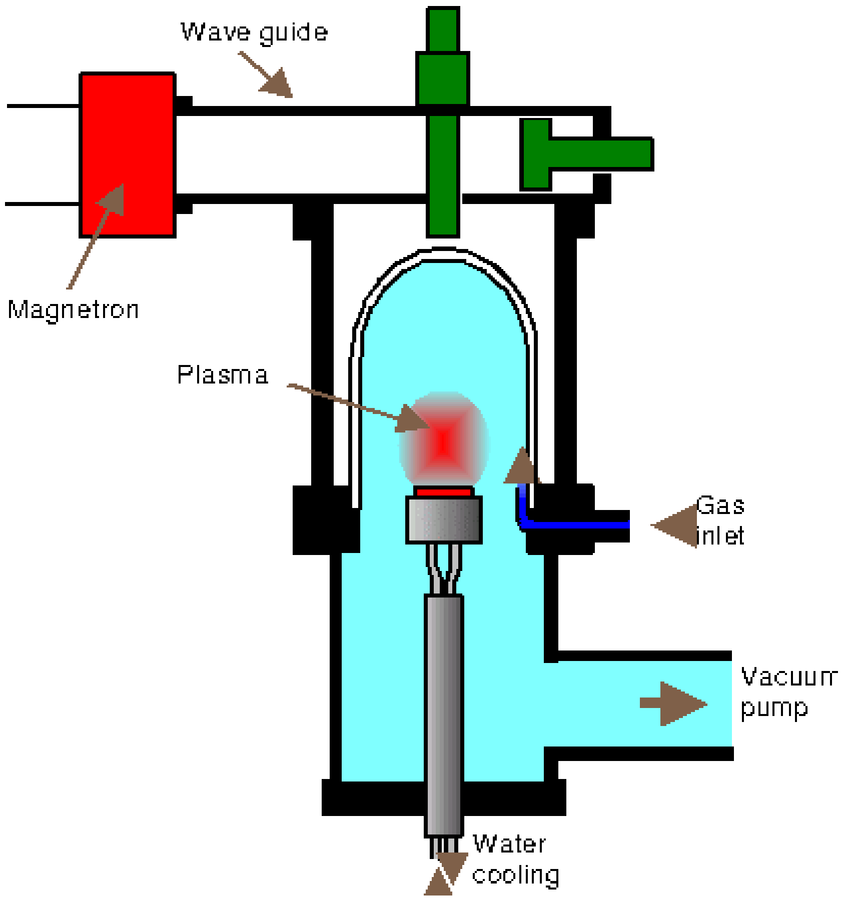
on behalf of the RD42 Collaboration

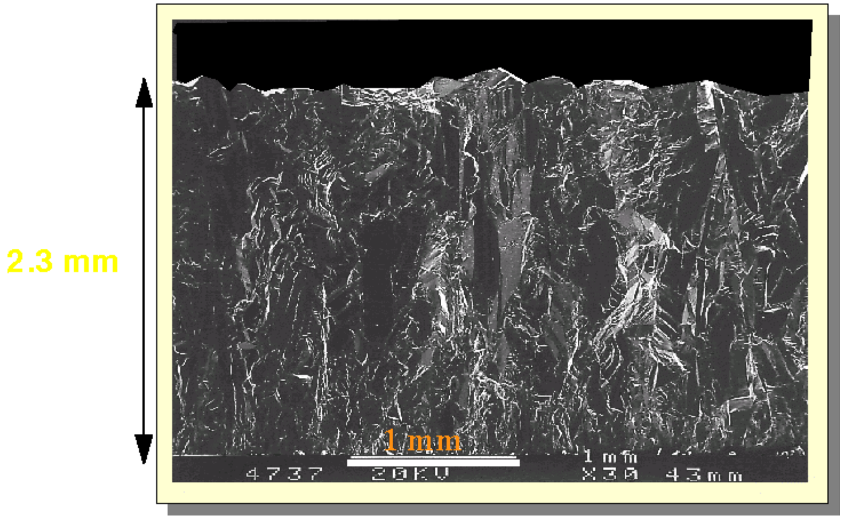
August 18, 2004

How CVD Diamond is Grown

- Microwave growth reactor



- Material copies substrate
- Dominant crystallites appear

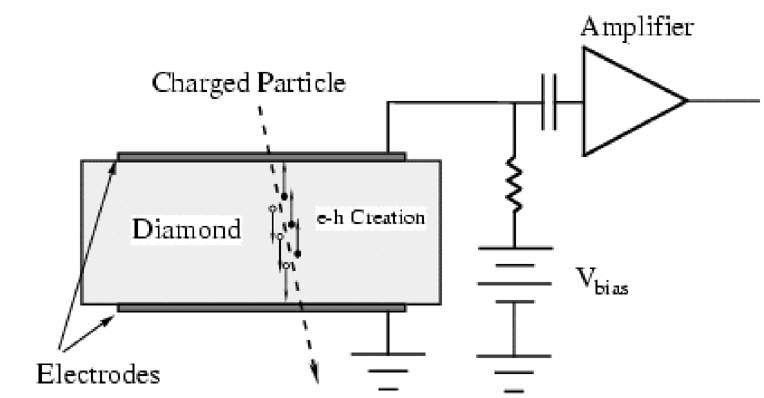


- Edge view of pCVD sample
  (Courtesy of Element6)

- Diamond synthesized from plasma

Signals from Diamond Sensors

- Image charge signal
  - induced on surface electrodes

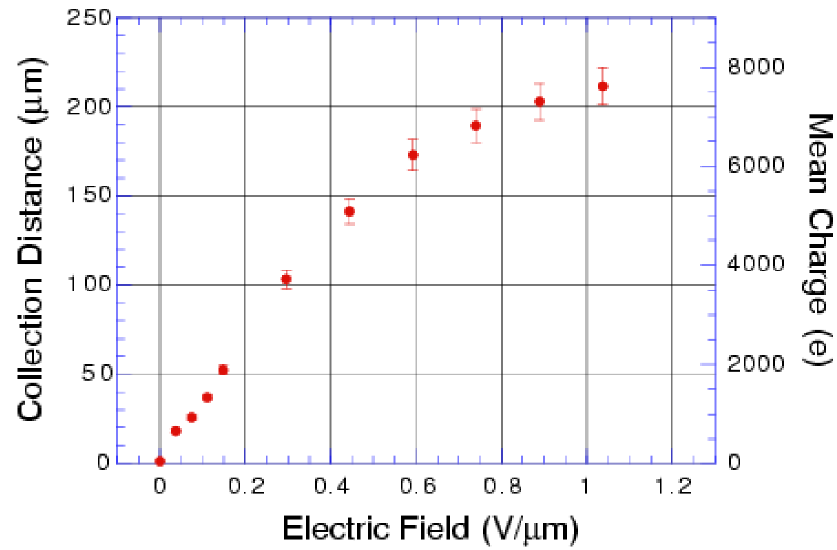


- Charge collected, Q

$$Q = \frac{d}{t}\ Q_0$$

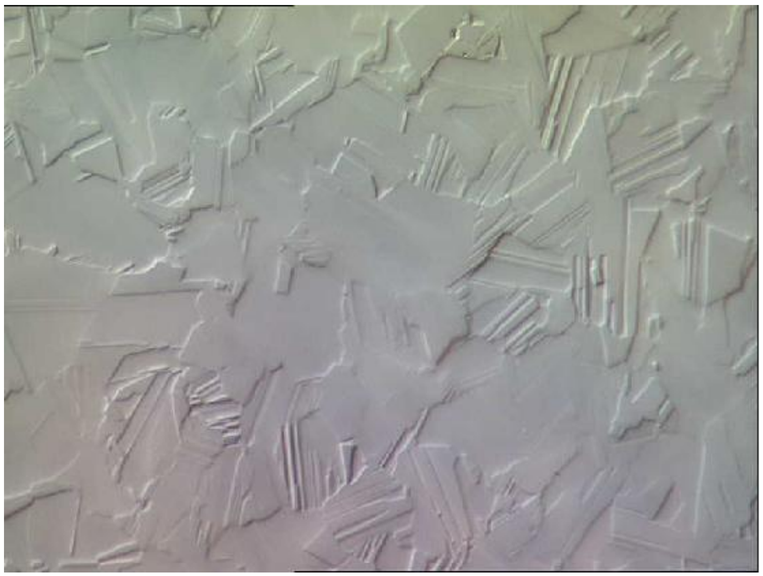
$$d \equiv (\mu_e \tau_e + \mu_h \tau_h)|\vec{E}|$$

- d is the Charge Collection Distance

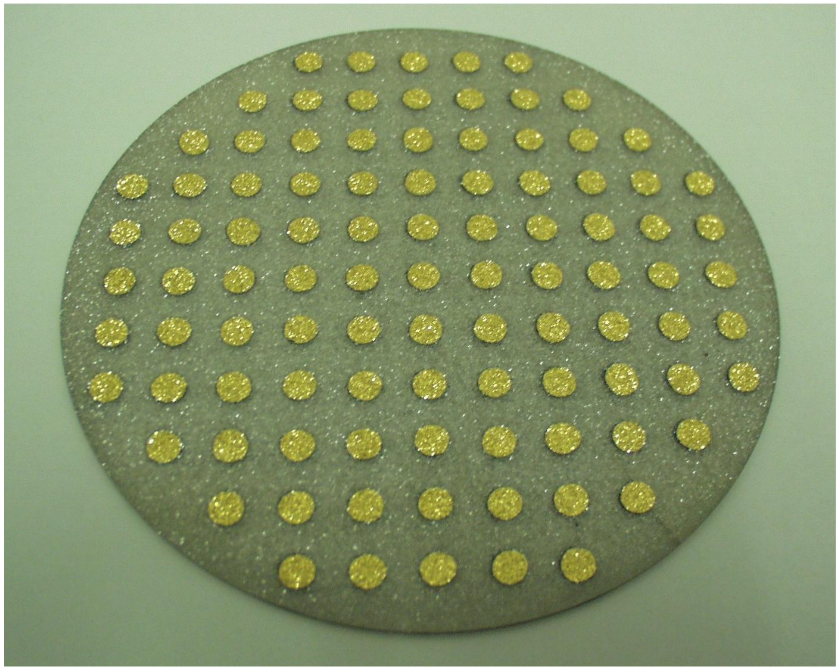


- Mobility saturates at $|\vec{E}| \approx 1V/\mu$m
- Operate typical sensor at 300-400 V

Examples of CVD Material



Surface image of pCVD sample
(Courtesy Element6)

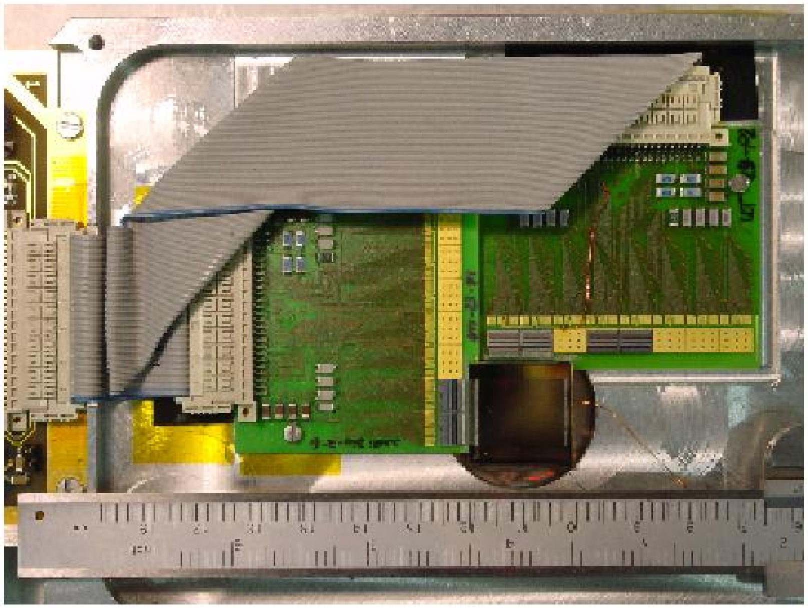


- pCVD diamond wafer
- Dots are on 1 cm grid

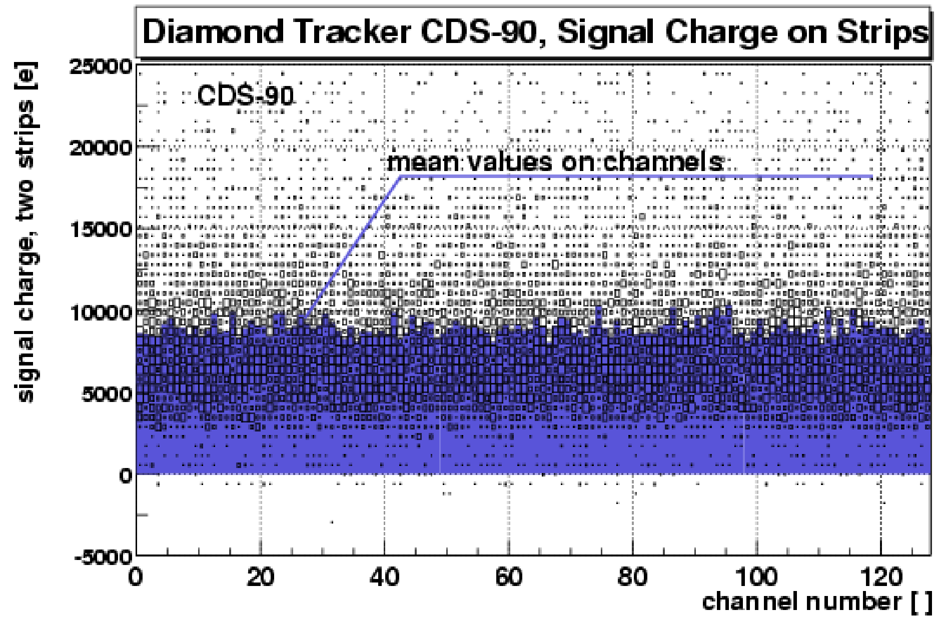
- High quality wafers grown 12 cm in diameter
- Best material from wafers grown up to 2 mm thick

Test Beam Studies of Diamond Strip Trackers

Two plane Diamond Tracker Station



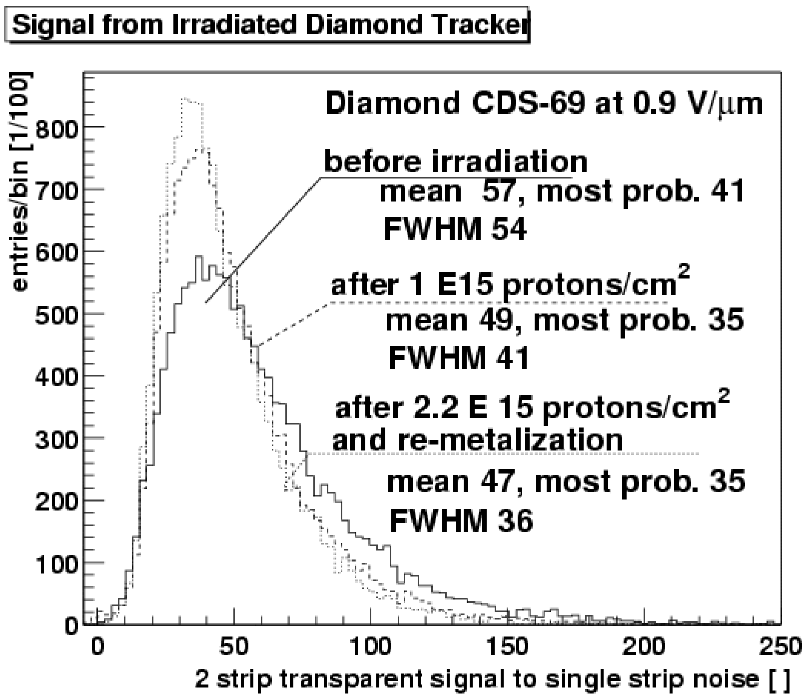
Pulse height observed vs. strip



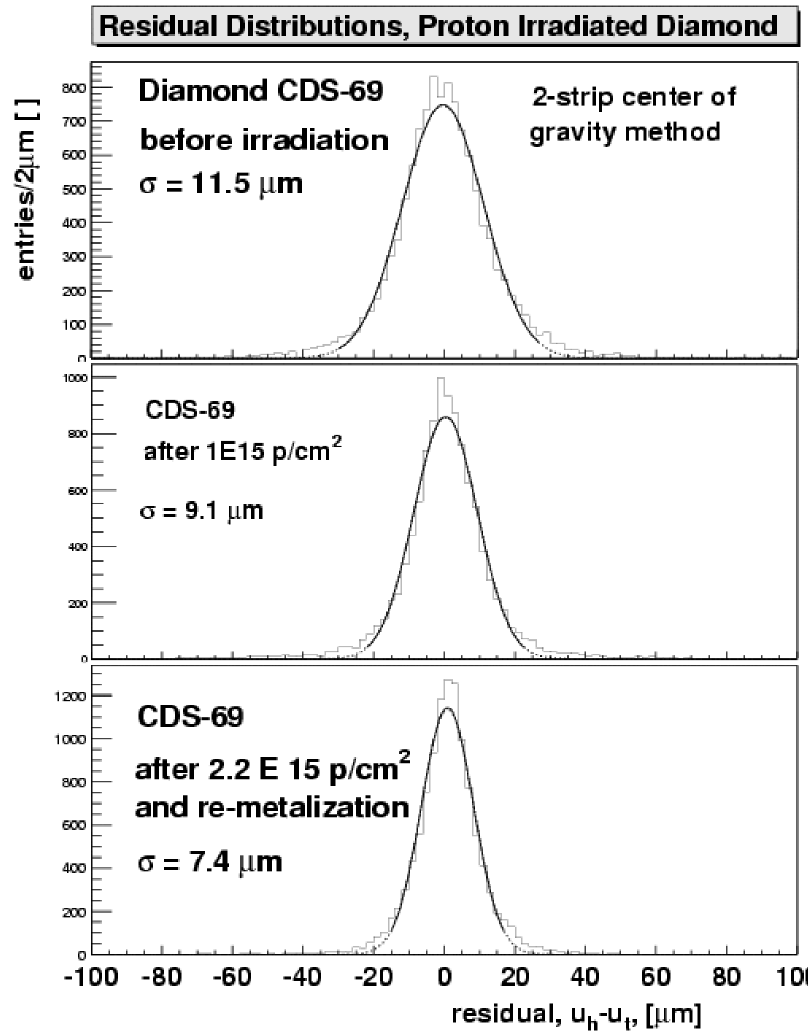
- Uses same readout electronics as silicon strip trackers
- Signal is uniform and well separated from pedestal on whole device
  - 99 % of hits have more than 2000 electrons signal
  - Most probable signal 6500 electrons

Irradiation of Diamond Trackers

Pulse height from testbeam MIPs



Hit residuals

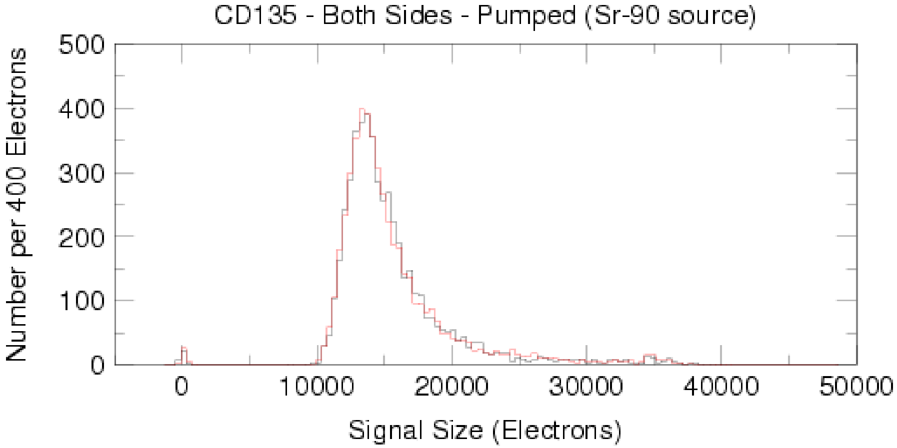


- S/N decreases but
- Position resolution improves
  - For fluences of 2×10^{15} cm^{-2}
- Irradiations up to 10^{16} underway

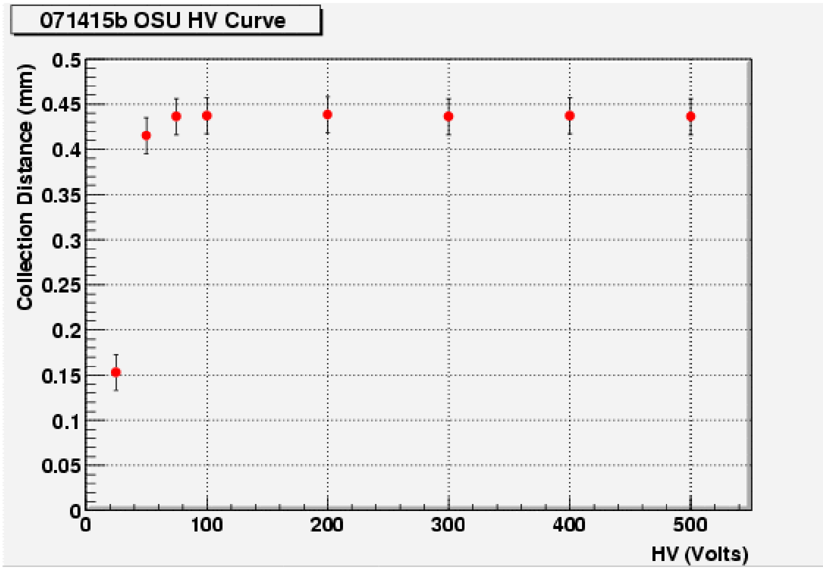
Single Crystal Diamond

- Improve material by
  - Removing grain boundaries, defects and charge traps
- Single Crystal CVD (scCVD) diamond exists

Isberg *et al*, Science 297 (2002), p1670



- Features of this material include
  - Full collection at 0.2 V/μm



  - Collection distance $\equiv$ thickness
  - Charge collection more uniform
- Grain boundaries limit pCVD

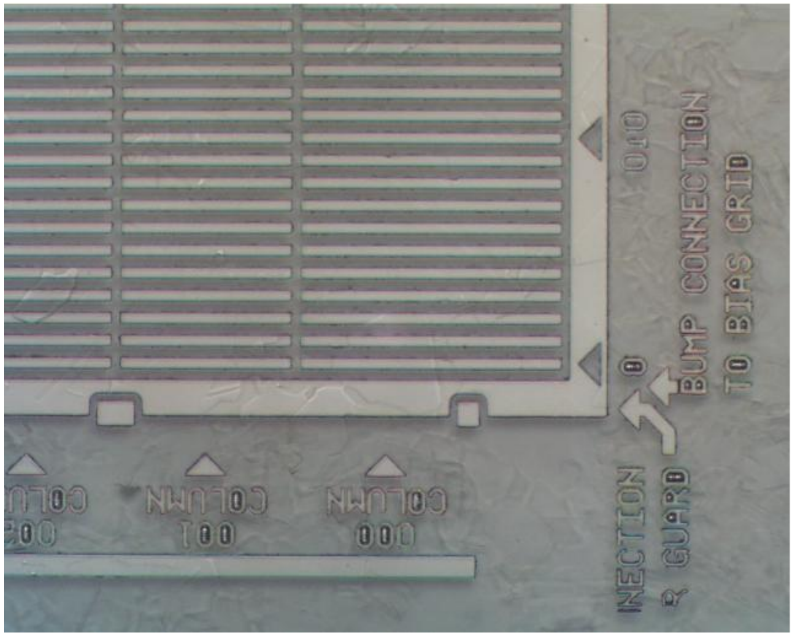
Applications of Diamond Sensors

- Several exciting applications for pCVD diamond sensors
  - High Energy Physics
  - Heavy Ion beam diagnostics
  - Synchrotron light source beam monitoring
  - Neutron and α detection

- Here I will discuss
  - Pixel detector prototypes from ATLAS and CMS
  - Beam monitoring at
    - SLAC/KEKb (BaBar and Belle)
    - LHC (ATLAS and CMS)

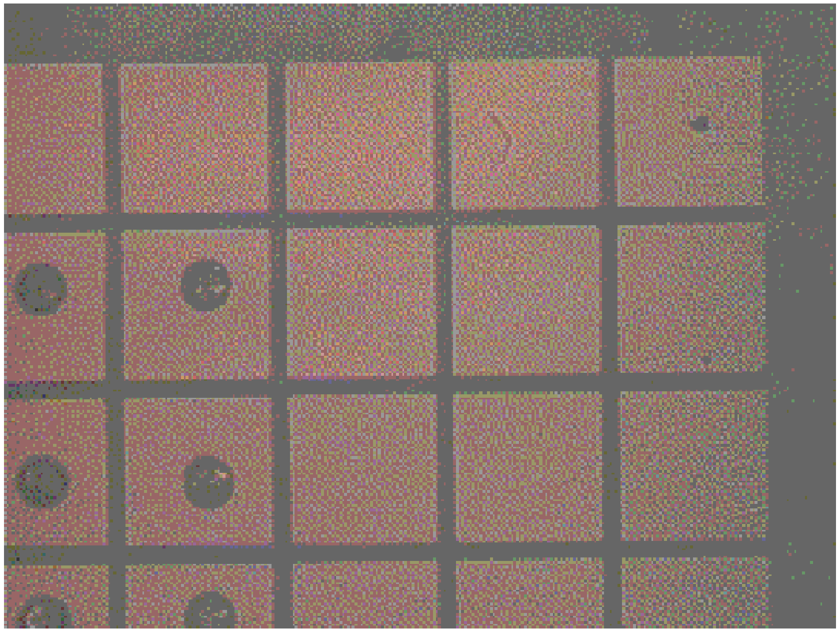
Pixel Sensor Prototypes

ATLAS FE-I   Al contacts



Prepared for Pb/Sn bumping at IZM

CMS Pixels   Ti/W contacts

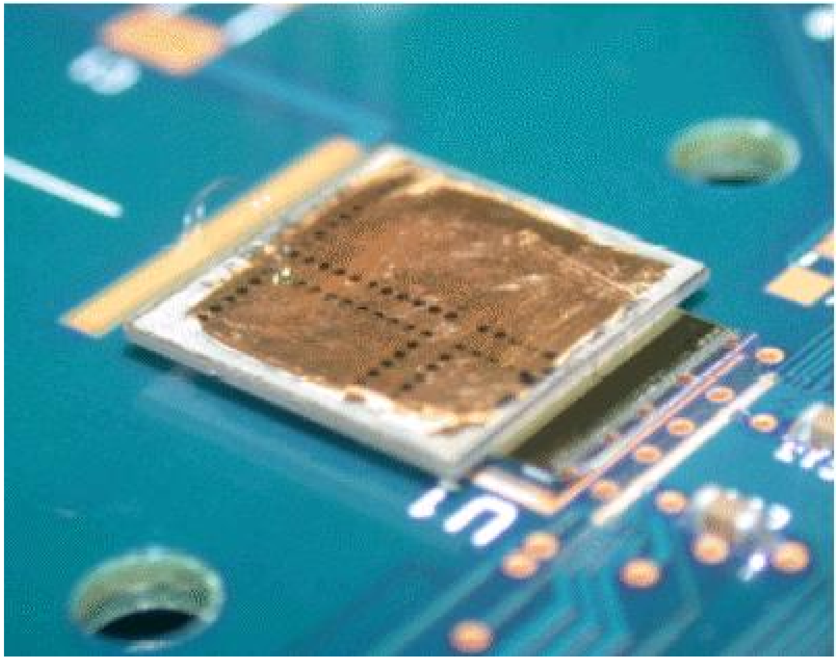


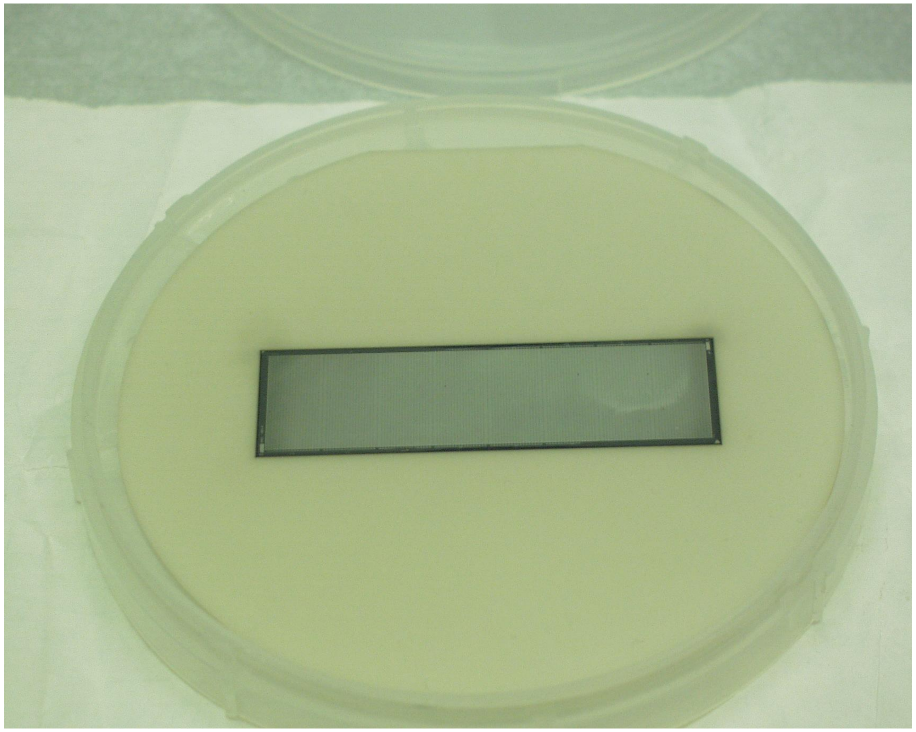
Prepared for In bumping at UCDavis

- Bump bonding yield now 100 % for both ATLAS and CMS solutions
- Prototype modules being prepared rad-hard electronics for both expts.

Recent ATLAS Pixel Assemblies

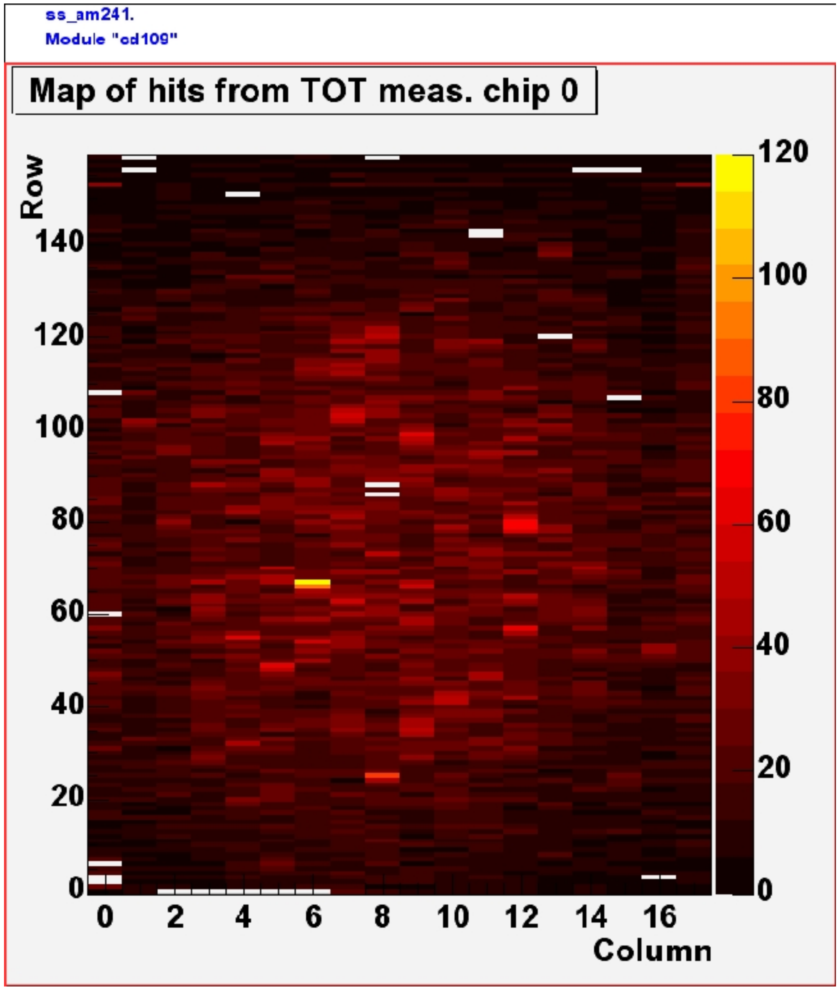
- Successful one-chip assembly
- Tested with sources and beam

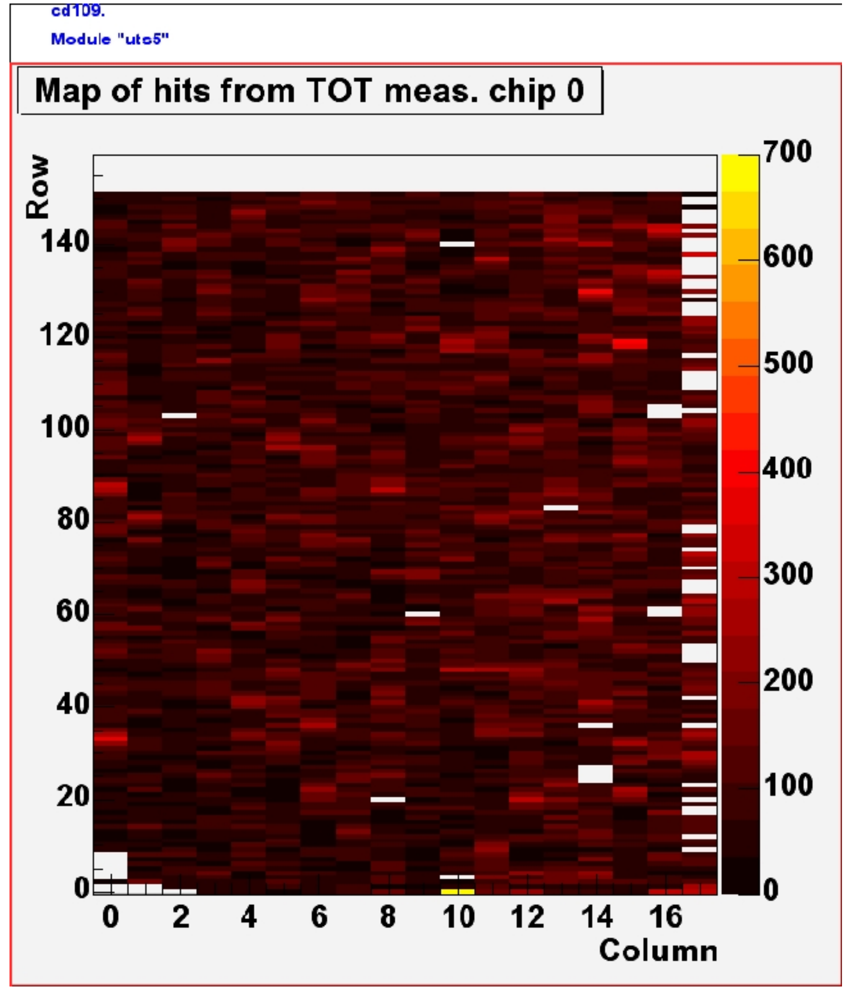




- Pre-tested wafer for this sensor
- Now making final preparations
  - Diamond surface finish
  - Metalisation
  - Bump-bonding
- Testbeam scheduled for this fall

Diamond Pixel Source Tests

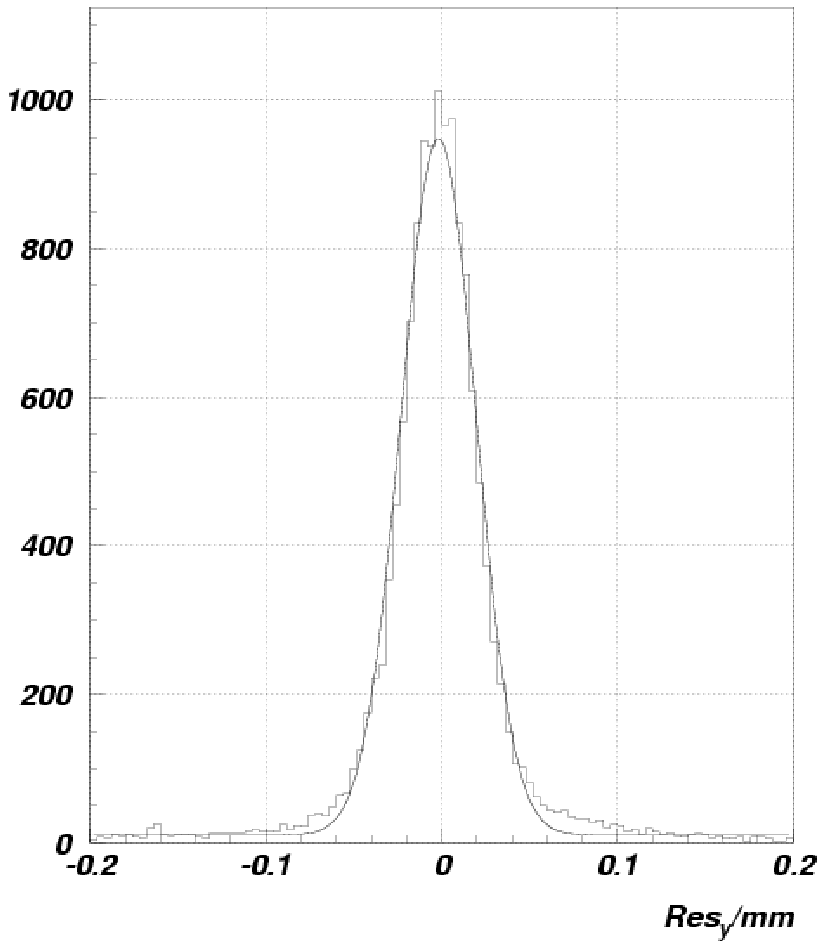




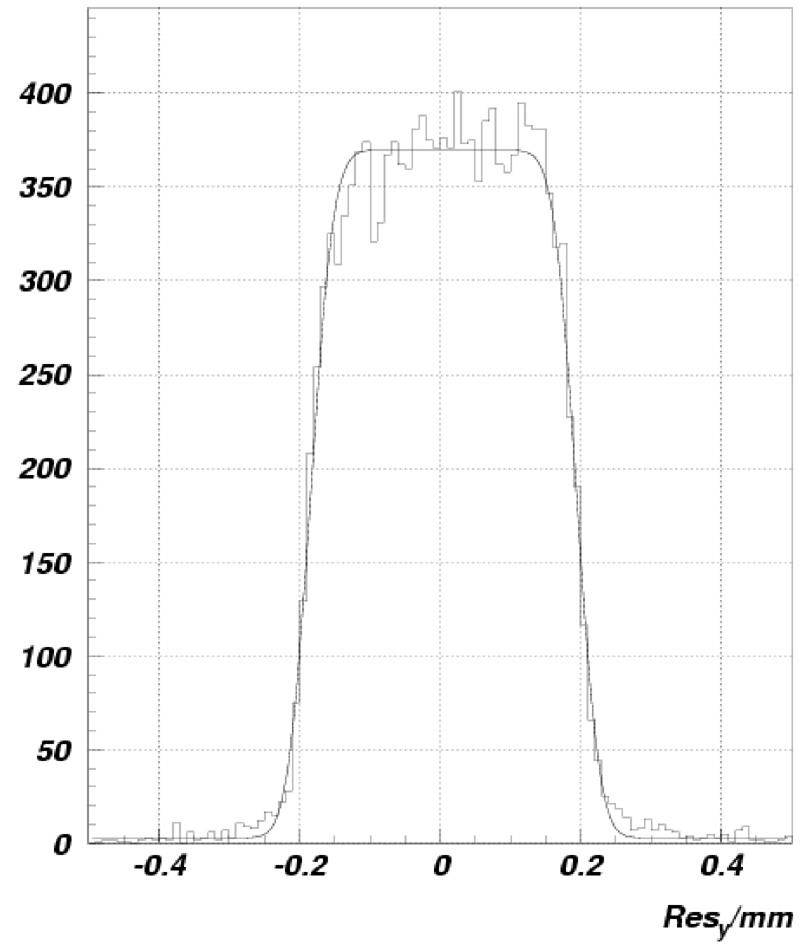
^{241}Am deposits $4600e$

^{109}Cd deposits $1700 - 1800e$

Diamond Pixel Source Tests

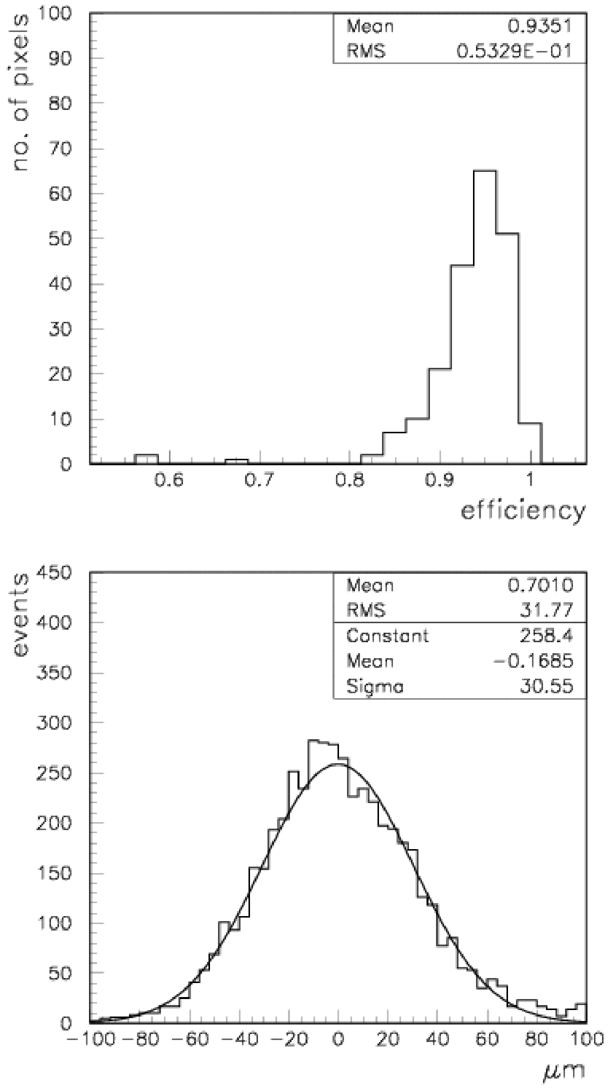


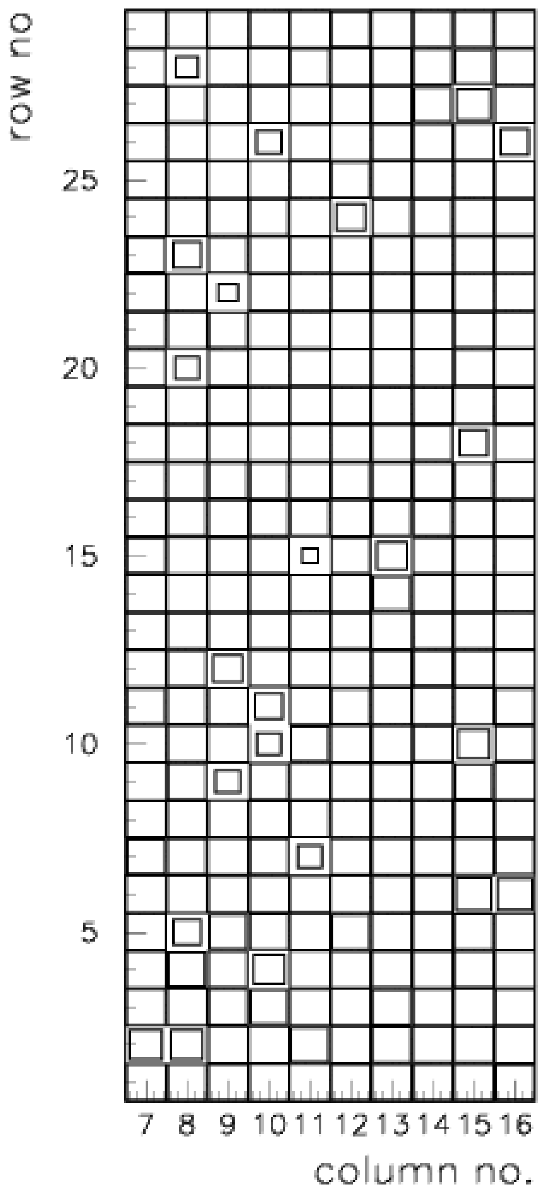
x residual, 50μm pitch



y residual, 400μm pitch

CMS Pixel Testbeam Results





- Spatial resolution of 31 μm for 125 μm pitch

Beam Monitoring with CVD Diamond Sensors

- Radiation monitoring crucial to protect investment in Si trackers
- Abort beam in presence of large current spikes or prolonged dose
- Require stably calibrated device for reliable beam monitoring

DC current monitoring

- Slow readout
- Requires low leakage current
- Allows simple readout/measuring

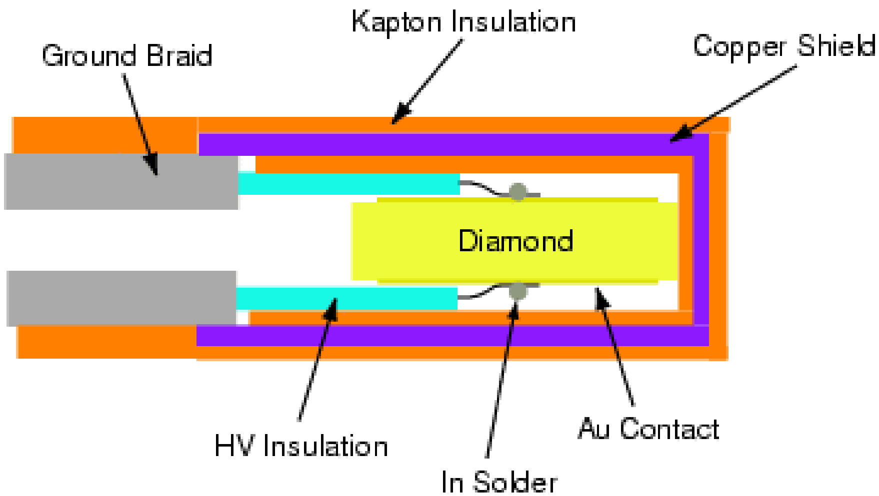
BaBar, Belle, CMS

Single particle counting

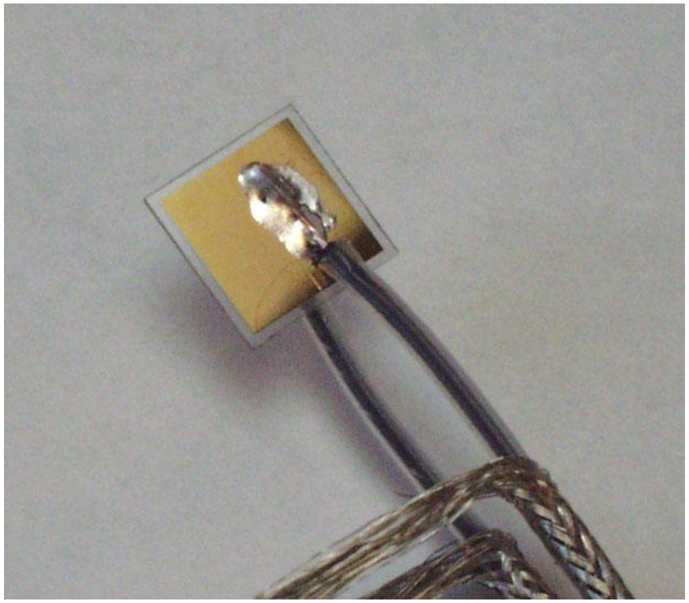
- Requires fast readout (GHz)
- Requires low noise
- Allows real-time correlations

ATLAS

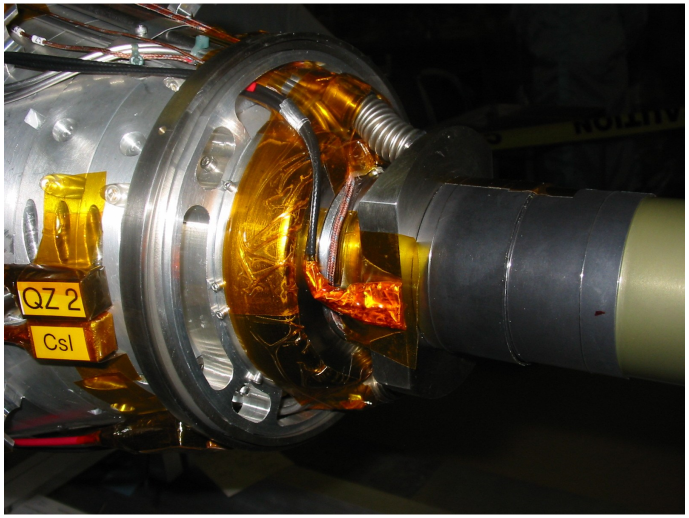
Examples of Beam Sensors from BaBar/Belle



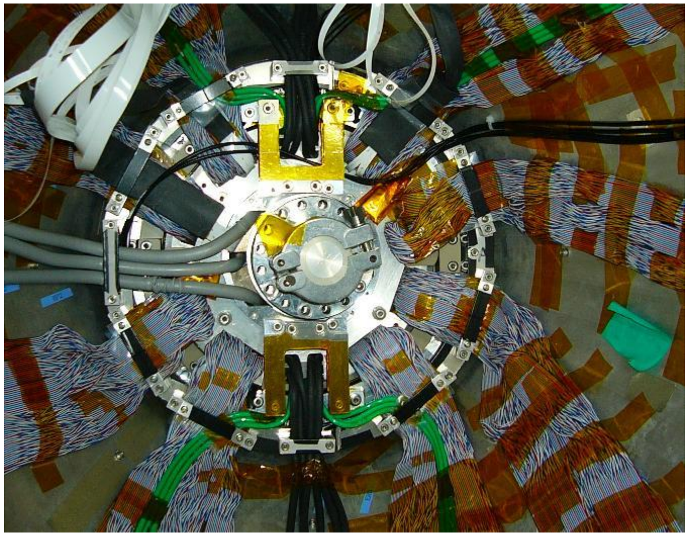
Typical beam monitoring sensor



The BaBar installation

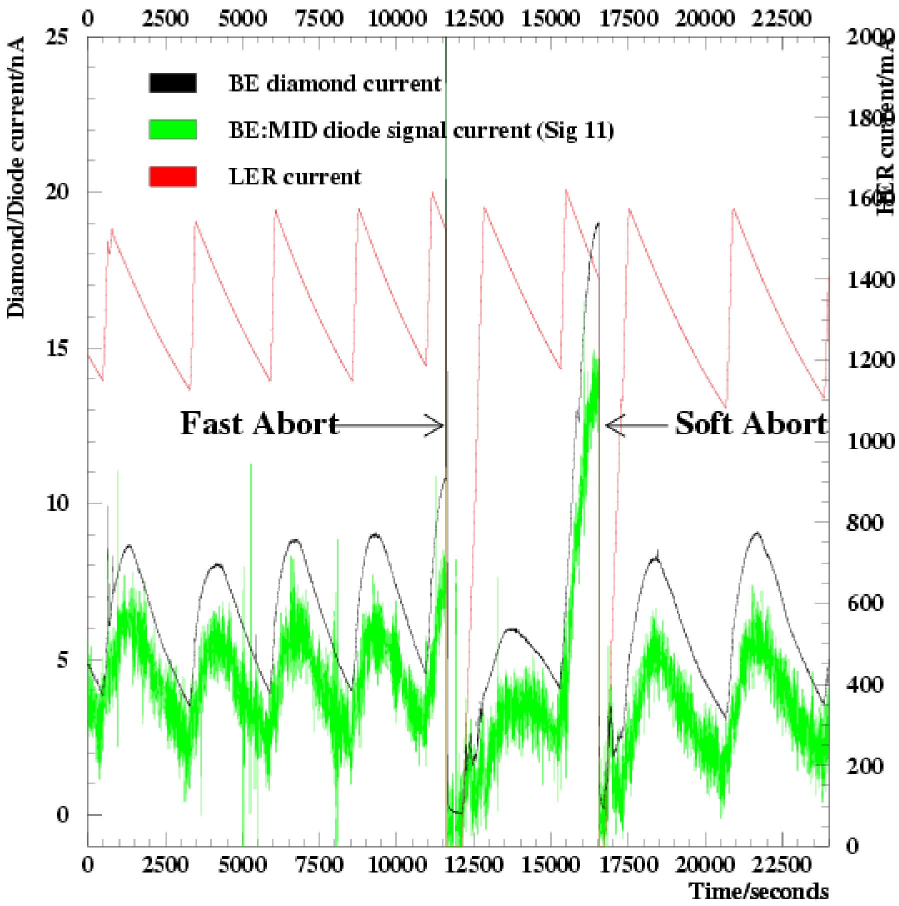


The Belle installation

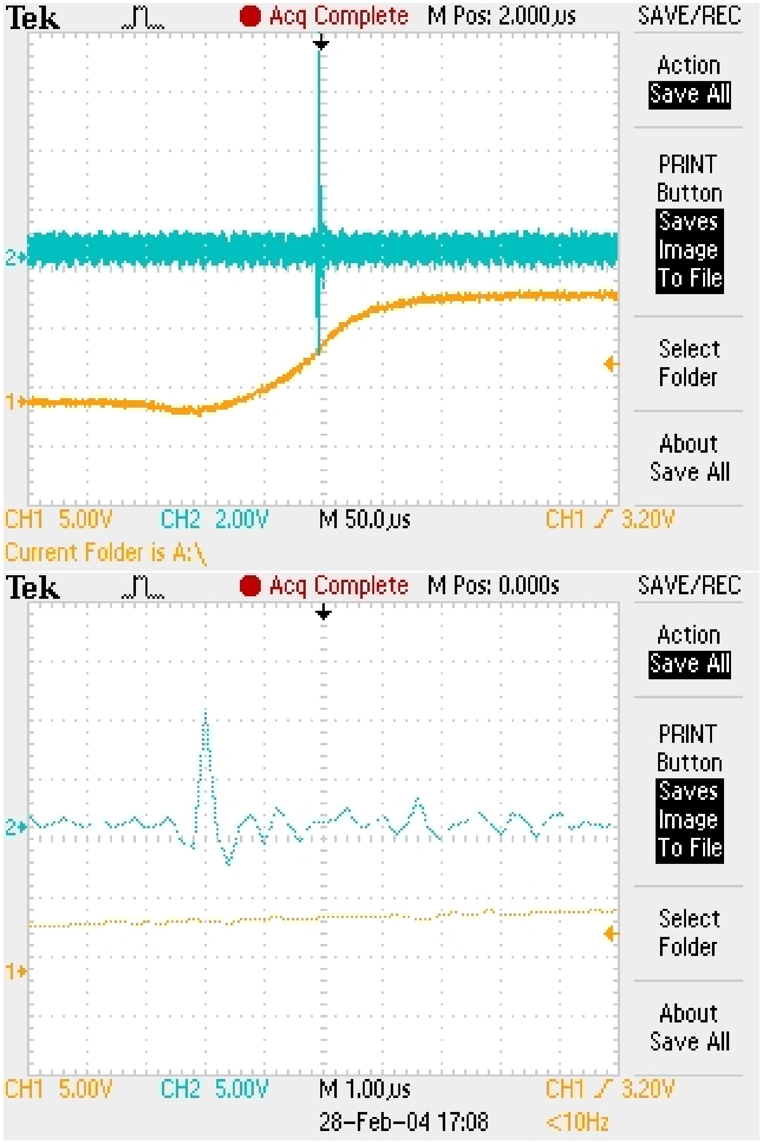


Beam Monitoring Results

- Stable operation in BaBar for 18 months

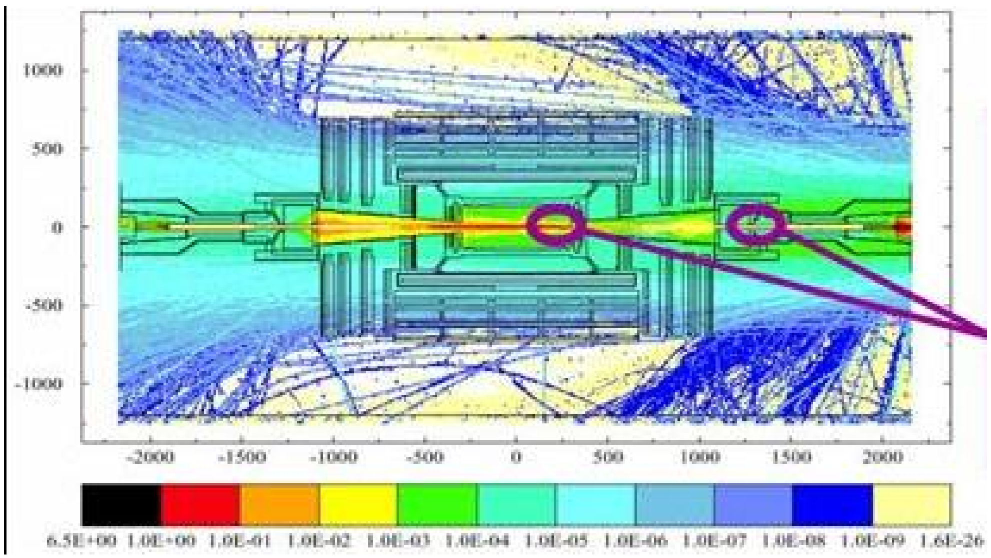


- Beam aborts in Belle

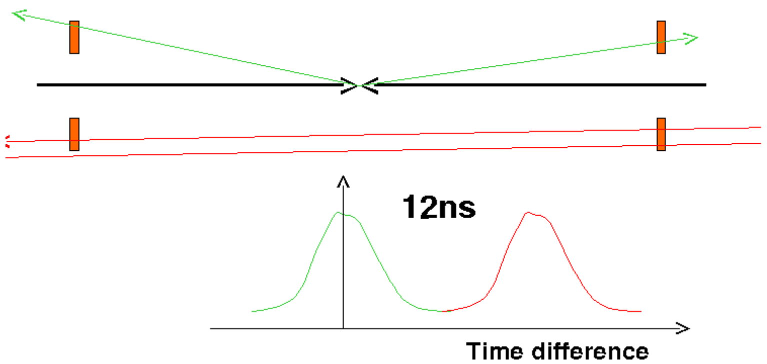


Plans for Beam Monitoring at the LHC

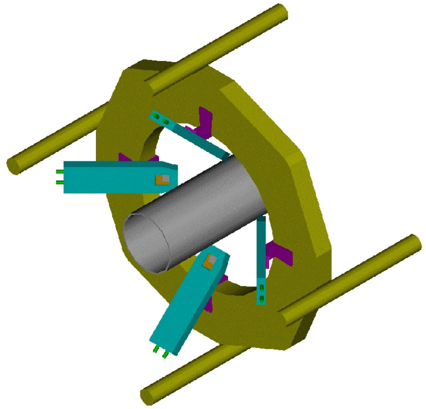
- CMS similar to BaBar/Belle
- Testbeam with 10^{12} lost in 260 ns
- Simulation of this 'event' looks like:



- ATLAS plans to use time of flight to distinguish beam collisions from background



- Sensors suspended from Pixels



Summary

- High quality pCVD with collection distances of 300 μm in large areas
- Have proven radiation tolerant up to 2×10^{15} particles per cm^2
- scCVD have been grown and show great promise
- Diamond sensors are finding applications in a number areas
  - Pixel module prototypes for LHC trackers
  - High intensity beam monitors
- In the future:
  - Test radiation hardness out to 10^{16} particles per cm^2
  - Full ATLAS pixel module coming soon
  - Further improve the uniformity of pCVD material
  - Working to increase the area of scCVD material