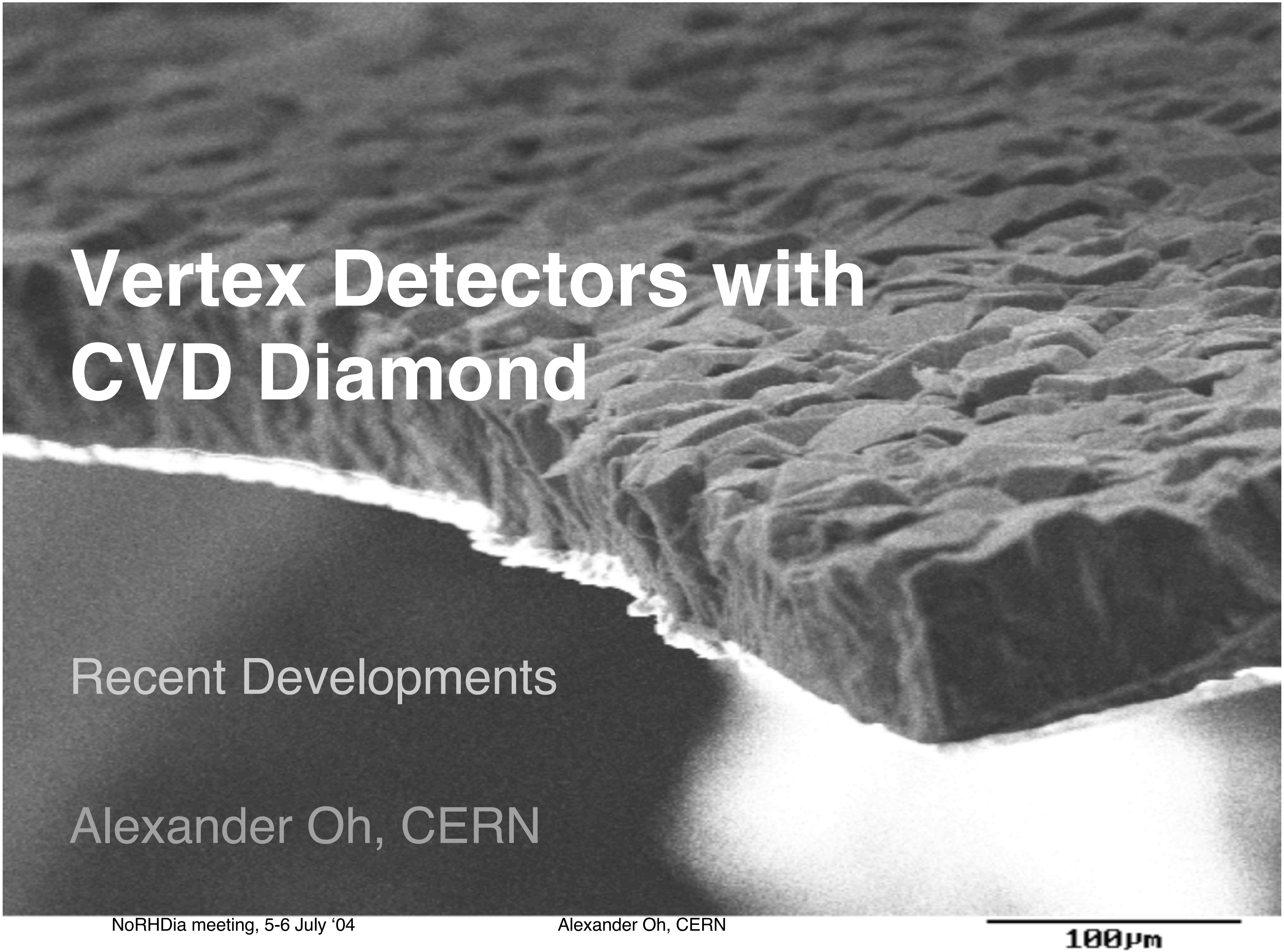


Vertex Detectors with CVD Diamond

Recent Developments

Alexander Oh, CERN

Outline

- Introduction
- Particle Detector Prototypes
  - Strip Detectors
  - Pixel Detectors
- Applications in HEP
- Summary

Sources

- RD42 Collaboration
- University Bonn
- BaBar, SLAC
- CMS, CERN

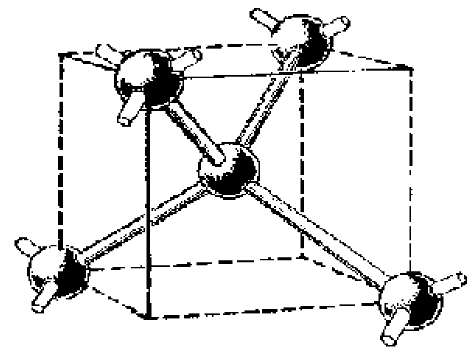
Introduction

- Motivation
  - LHC and SLHC radiation levels at inner tracking layers O(10^{15} n cm^{-2})
  - Detectors close to IP or at low rapidity
    - Vertexdetector
    - Beam monitoring

- Some advantageous properties of Diamond compared to Silicon :

Introduction: Diamond properties

Property	Diamond	Silicon
band gap	5.47	1.12
mass density [g/cm^3]	3.5	2.33
dielectric constant	5.7	11.9
resistivity [Ωcm]	>10^{11}	2.3e5
breakdown [kV/cm]	1e3...20e3	300
e mobility [cm^2/Vs]	2150	1350
h mobility [cm^2/Vs]	1700	480
therm. conductivity [W / cm K]	10..20	1.5
radiation length [cm]	12	9.4
Energy to create an eh-pair [eV]	13	3.6
ionisation density MIP [eh/μm]	36	89
ion. dens. of a MIP [eh/ 0.1 ‰ X_0]	450	840

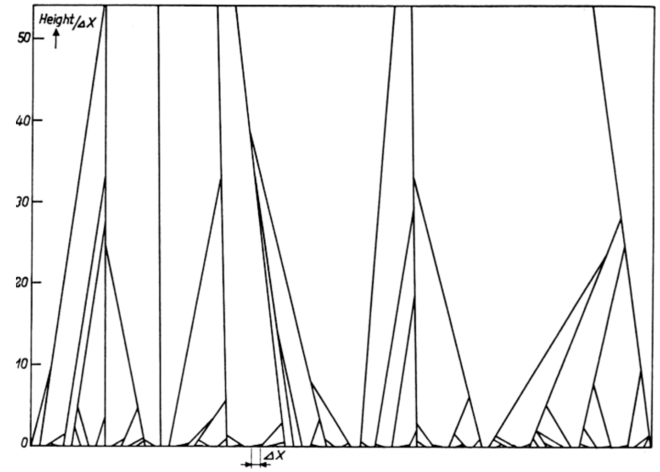


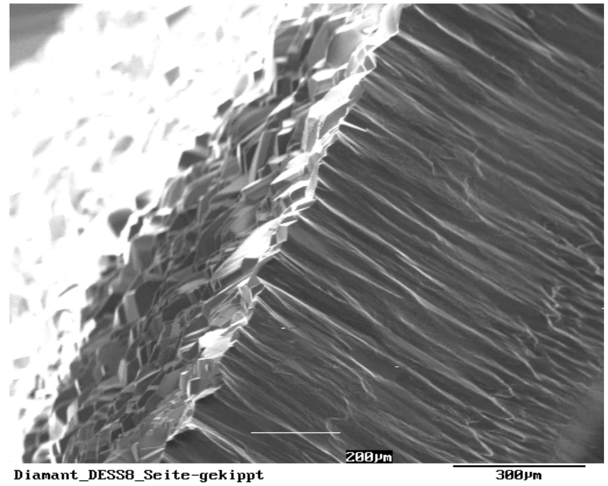
- Low ε -> low capacitance
- Low I_{leak} -> low noise
- Room temperature operation
- Fast signal collection time

- MIP signal 1.9 smaller for same X_0
- Collection efficiency < 100%

Introduction

- Diamond material
  - Synthetic diamond
  - Chemical Vapor Deposition
  - Polycrystalline films

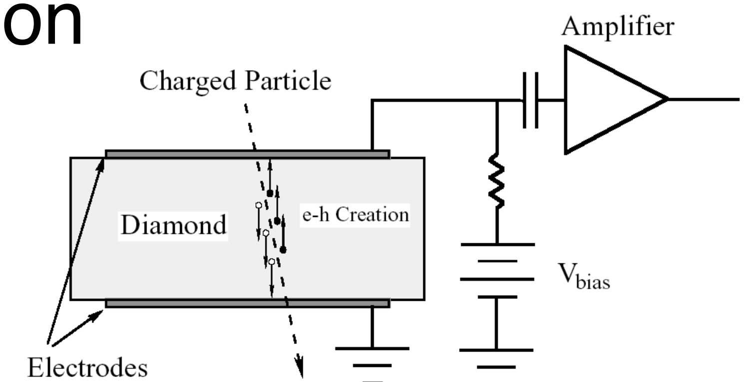


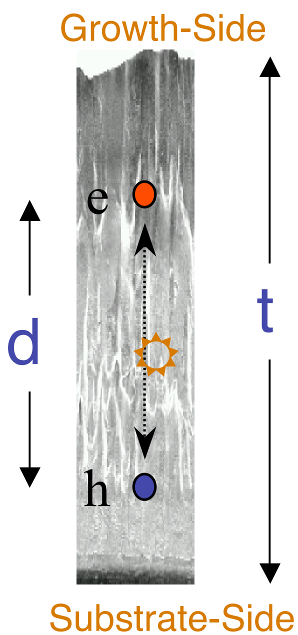


  - Recently: large homo-epitaxic mono-crystalline films

Introduction

- Principle of detector operation





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

$d = \mu E \tau$ "collection distance"

$\mu = \mu_e + \mu_h$

$\tau = \frac{\mu_e \tau_e + \mu_h \tau_h}{\mu_e + \mu_h}$

$\varepsilon = Q / Q_0$ collection efficiency

Particle Detector Prototypes

Particle Detector Prototypes

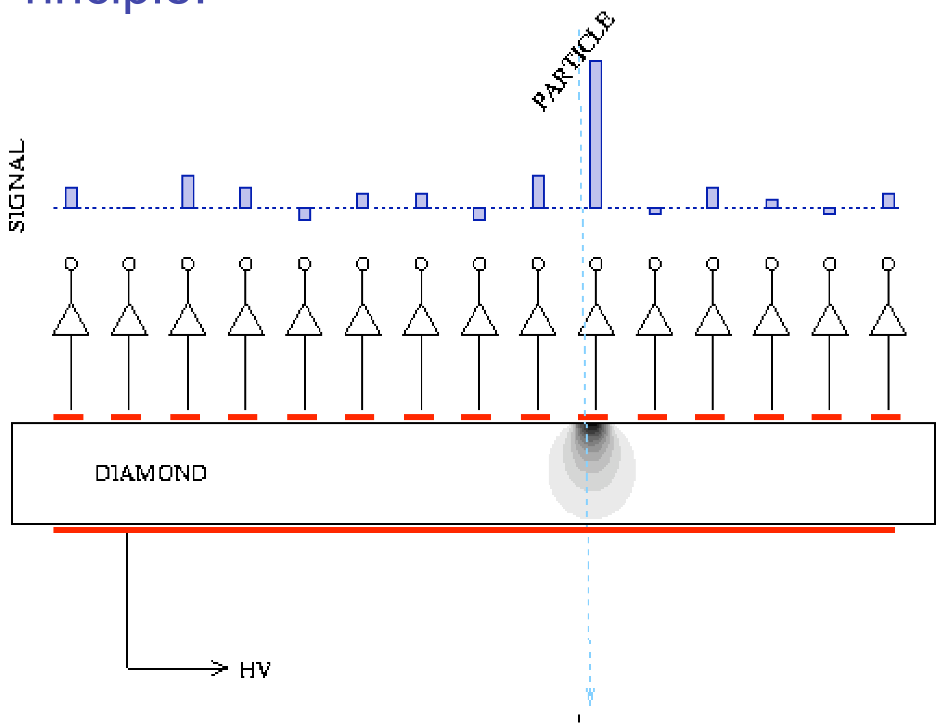
- Dot detectors
  - Characterization
- Strip detectors
  - Tracking
  - Slow VA2 and fast LHC electronics
- Pixel detectors
  - Tracking
  - CMS and Atlas patterns / electronics

Strip Detectors

Principle

- A sample with a Collection Distance of 130 μm was perpared with a patterned metallisation to serve as a position sensitive detector.

- Principle:



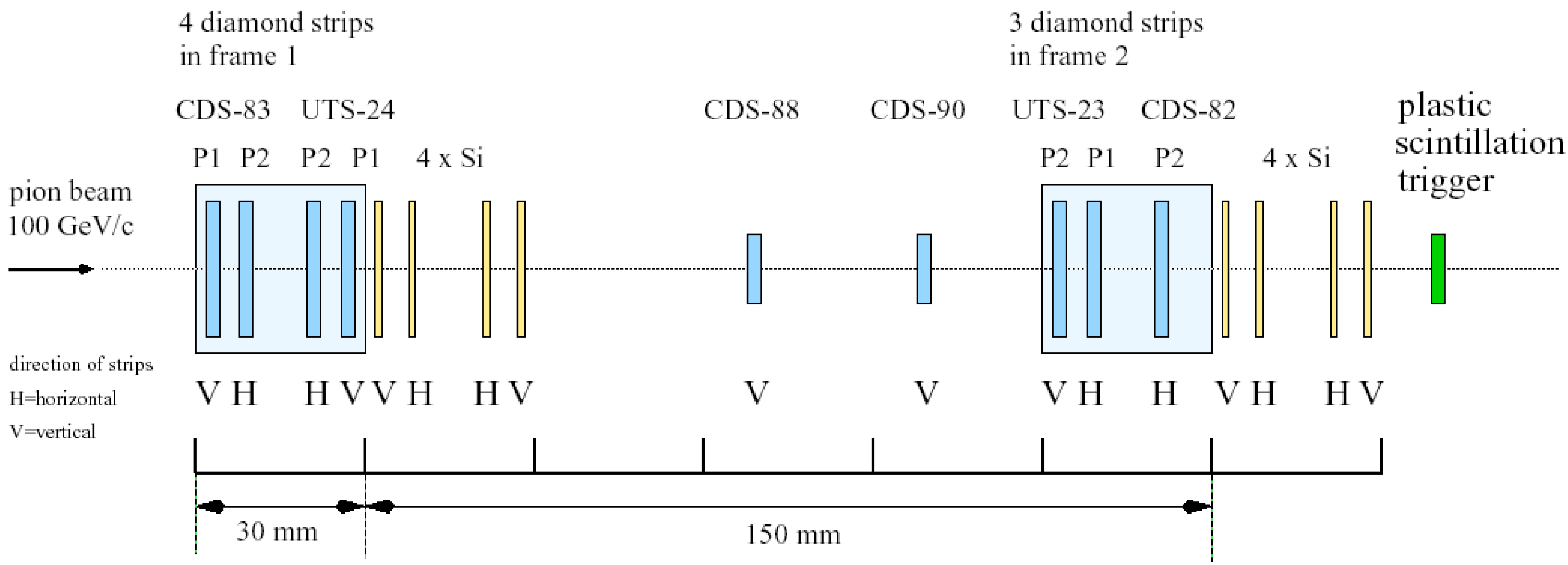
- The charge signal is picked up by the strip(s) next to the particle track.

- The charge is shared by multiple strips if the charge collection is incomplete.

- The position of the particle track can be reconstructed by calculating the charge weighted impact point (Center of Gravity)

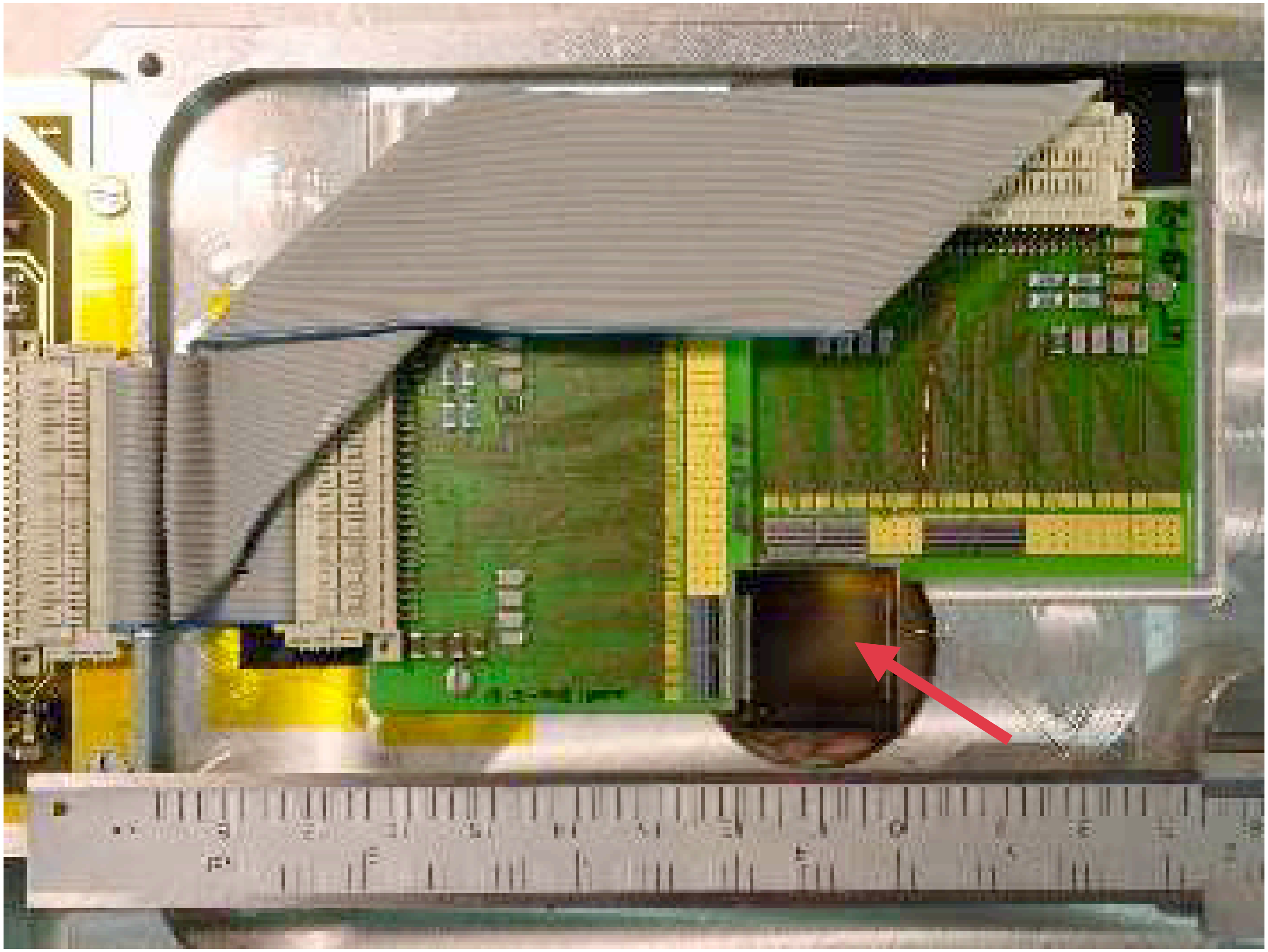
$$x = \frac{\sum x_i q_i}{\sum q_i}$$

- CERN test-beam Setup for Diamond Telescope

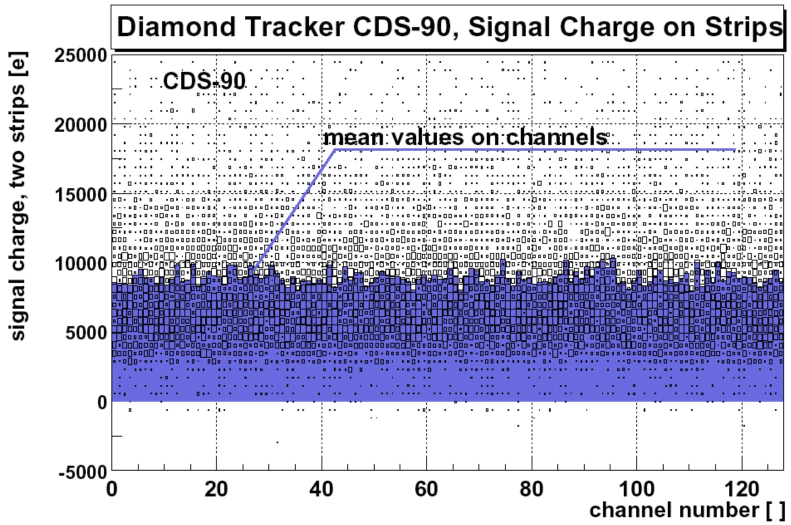


- 100 GeV/c pion/muon beam
- 7 planes of CVD diamond strip sensors each 2cm $\times$ 2cm
- 50μm pitch, no intermediate strips $\longrightarrow$ new metalisation procedure
- 2 additional diamond strip sensors for test
- Several silicon sensors for cross checks
- Strip Electronics (2 μsec) $\longrightarrow$ ENC $\approx 100e + 14e/$pF

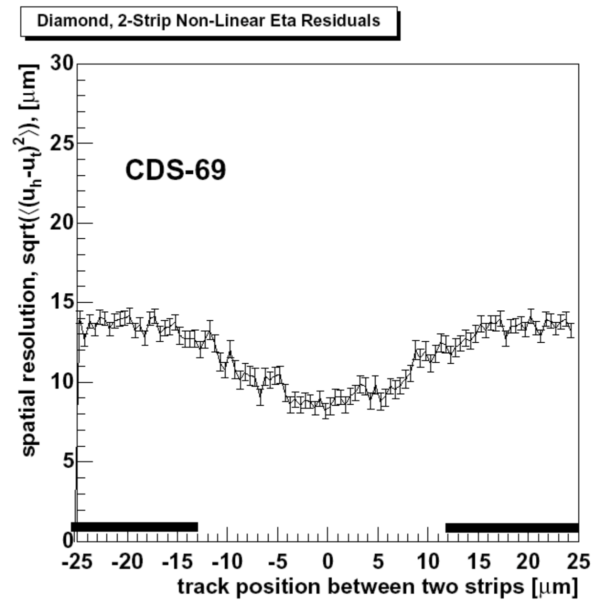
- Two planes of the Diamond Telescope



PH Distribution on each Strip



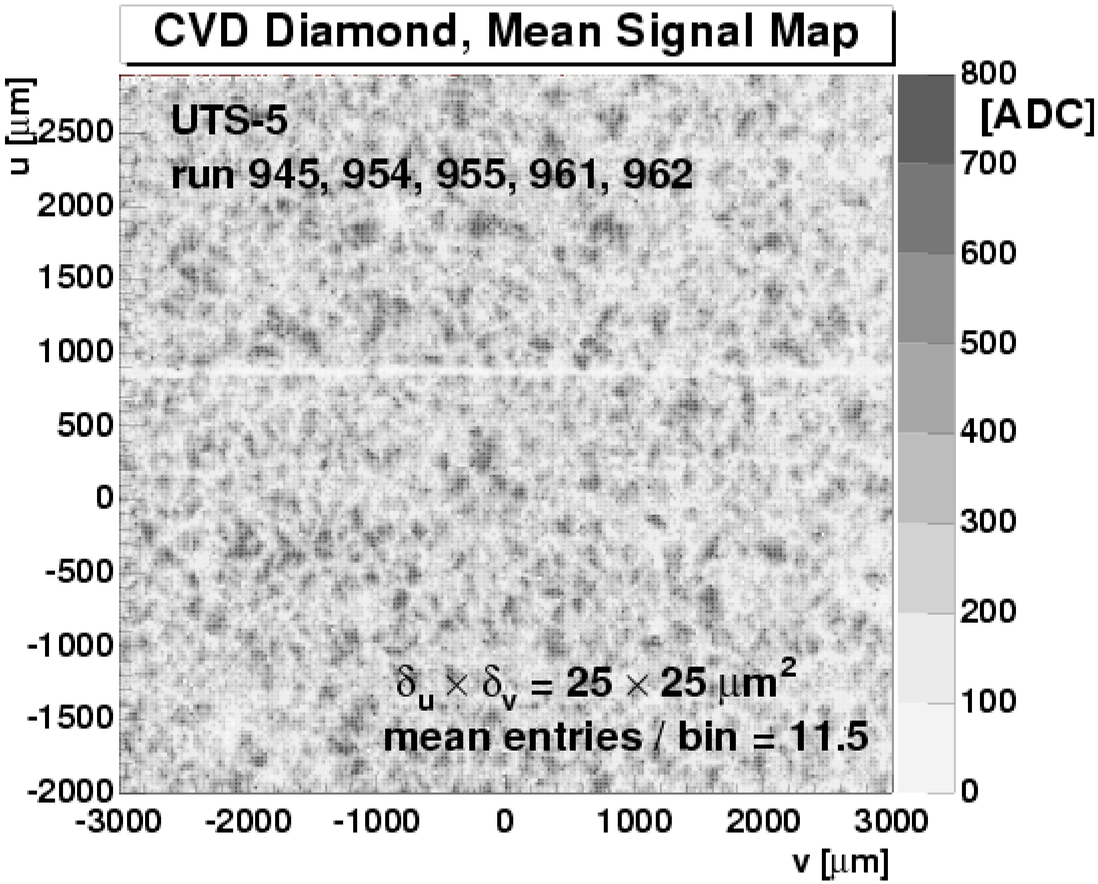
Residual versus Track Position



- Uniform signals on all strips $\longrightarrow$ new metalisation
- Pedestal separated from "0" on all strips
- 99% of entries above 2000 e
- Mean signal charge $\sim$ 8640 e $\longrightarrow$ new metalisation
- MP signal charge $\sim$ 6500 e

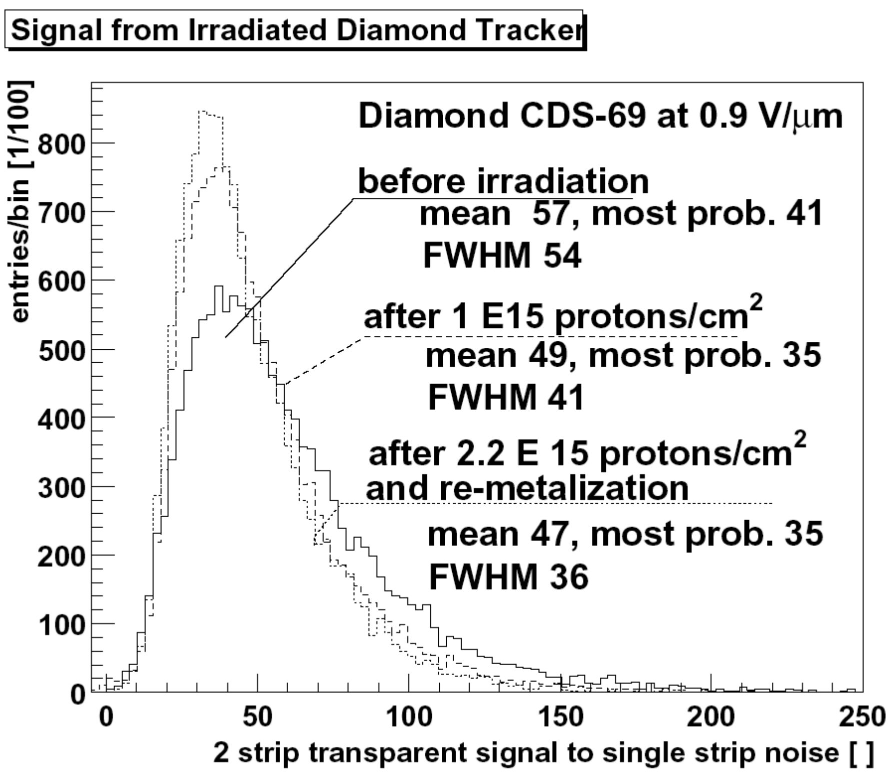
Uniformity in Charge Collection of CVD Diamonds

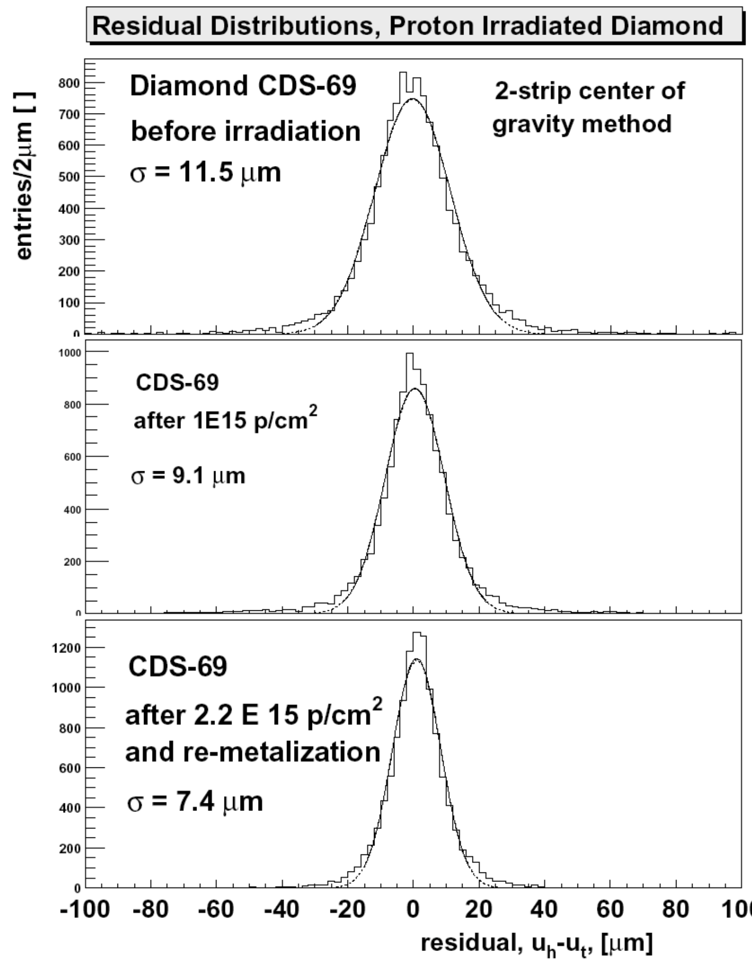
- Measured with MIPS
- Similar patterns observed as with photon beam measurement



Irradiated Strip Detectors

- Proton Irradiation



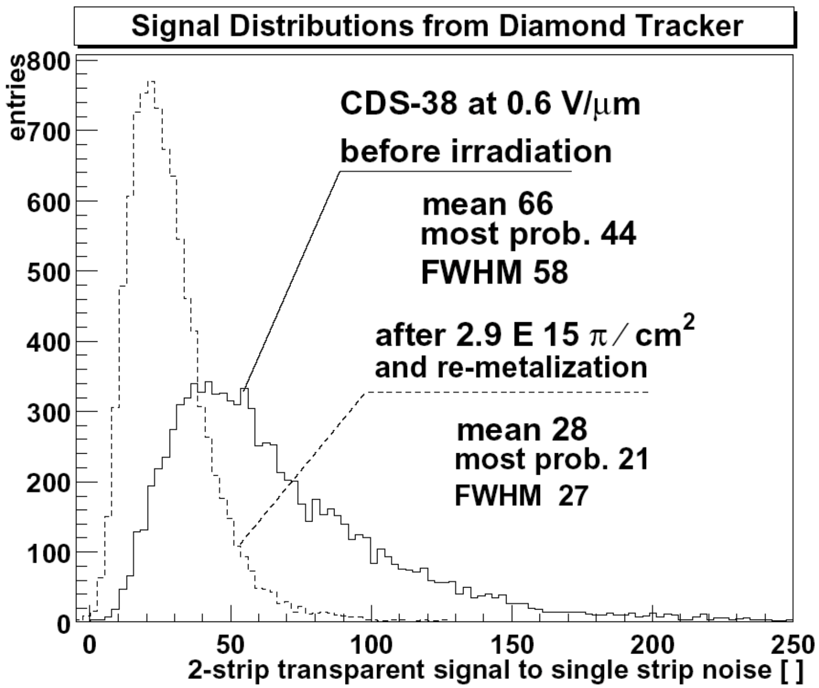


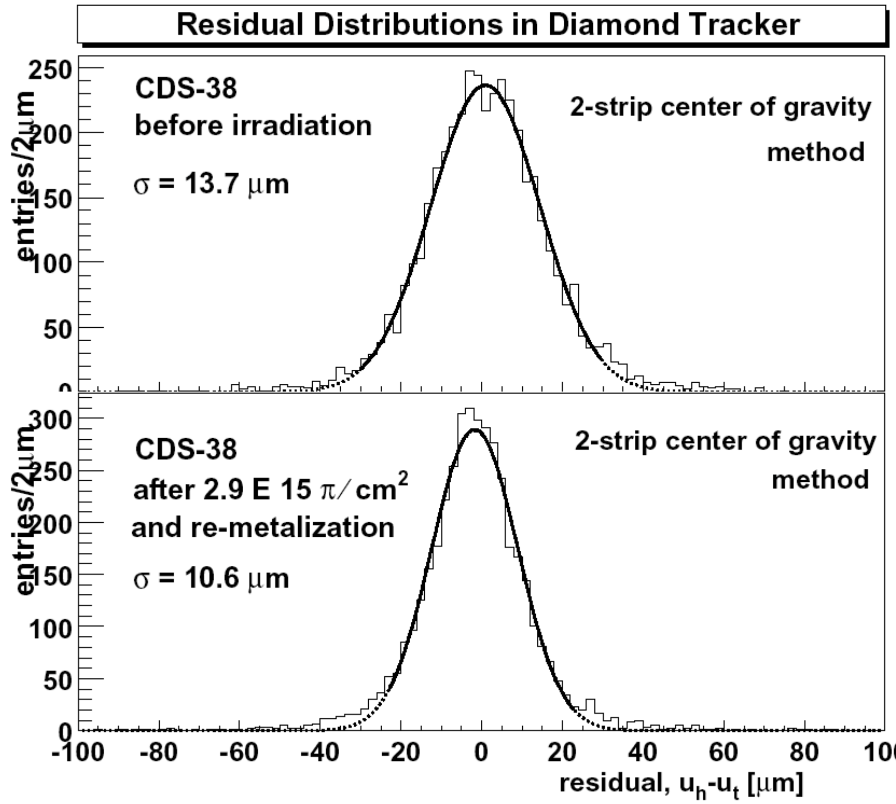
15% loss of S/N

35% improvement in resolution

Irradiated Strip Detectors

- Pion Irradiation

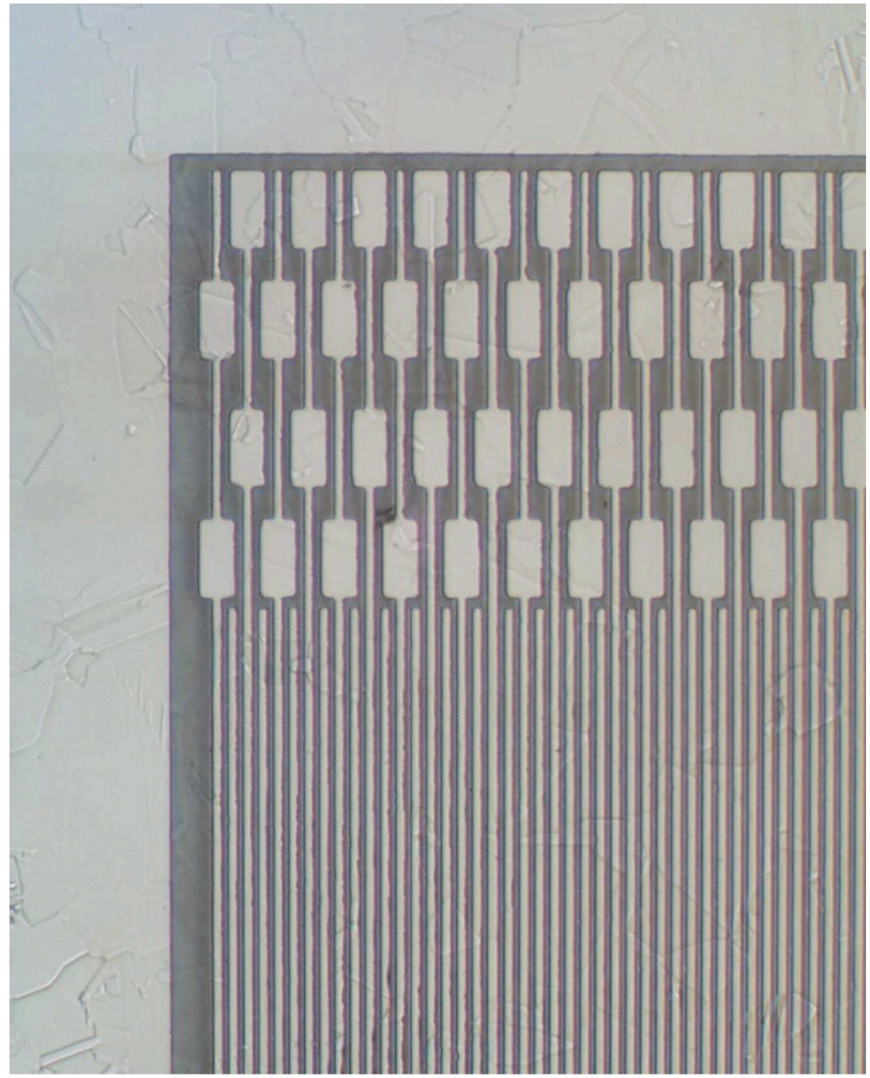




52% loss of S/N

23% improvement in resolution

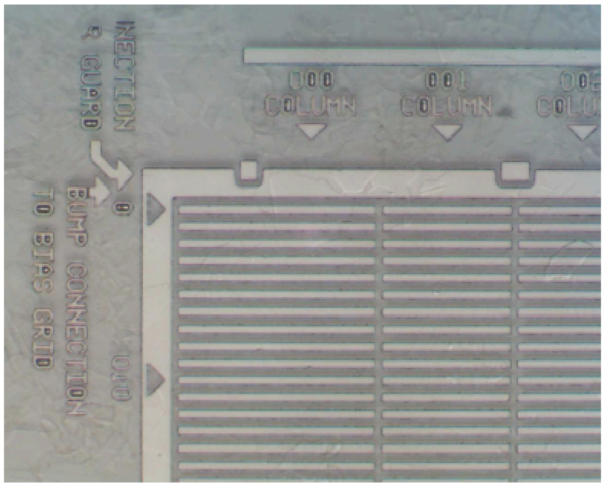
- Next Step:
- Biased intermediate strips to benefit from charge sharing.
- Should improve resolution.



Pixel Detectors

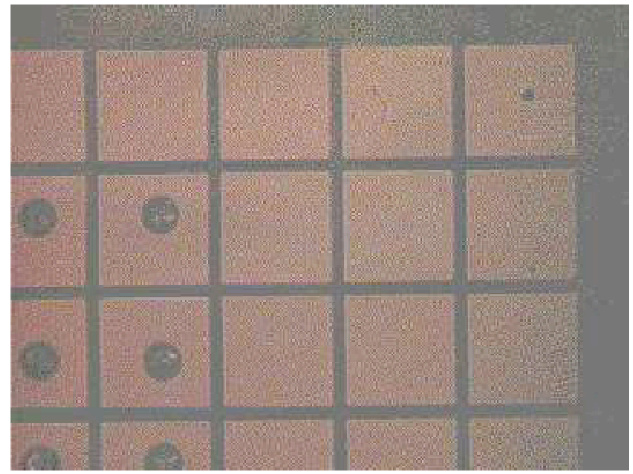
Diamond Pixel Detectors

ATLAS FE/I Pixels (Al)



- Atlas pixel pitch 50μm $\times$ 400μm
- Over Metalisation: Al
- Lead-tin solder bumping at IZM in Berlin

CMS Pixels (Ti-W)



- CMS pixel pitch 125μm $\times$ 125μm
- Metalization: Ti/W
- Indium bumping at UC Davis

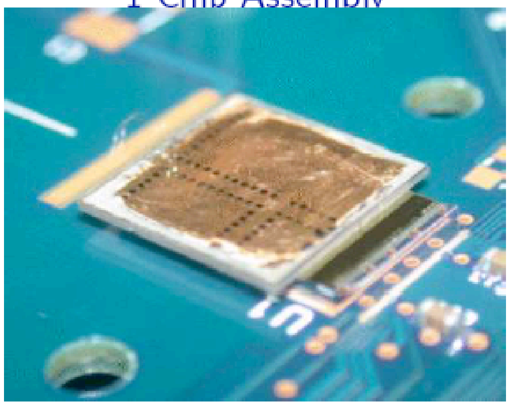
$\rightarrow$ Bump bonding yield $\approx$ 100 % for both ATLAS and CMS devices

New radiation hard chips produced this year.

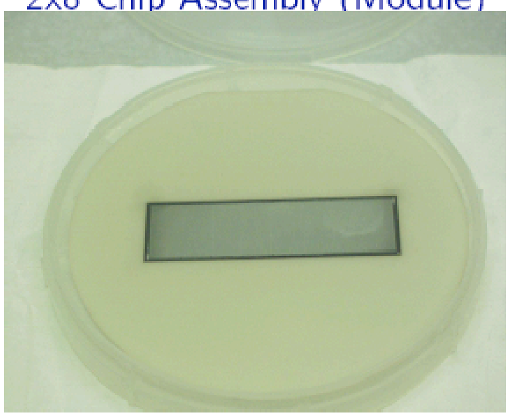
Diamond Pixel Detectors

Results from an ATLAS pixel detector

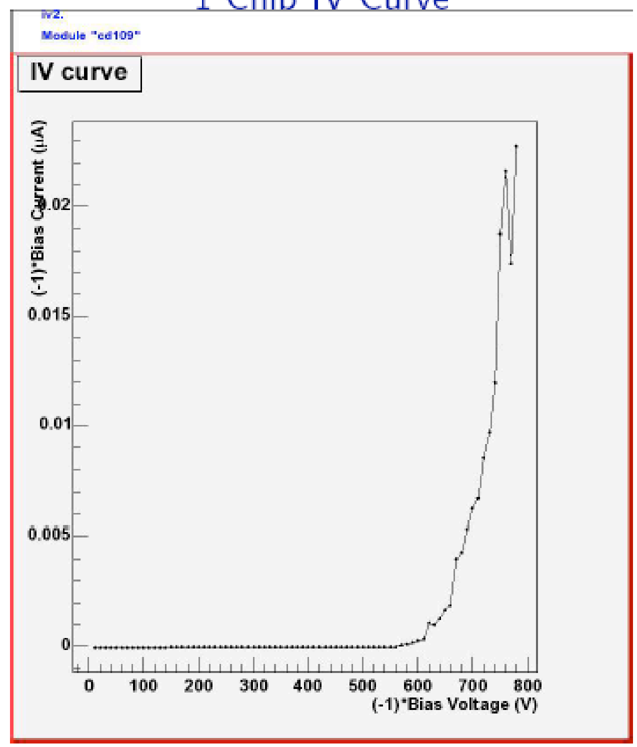
1 Chip Assembly



2x8 Chip Assembly (Module)



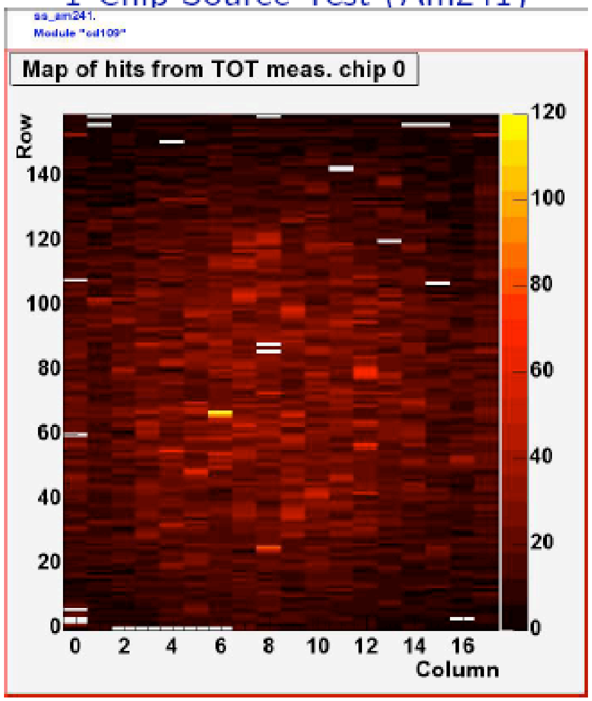
1 Chip IV Curve



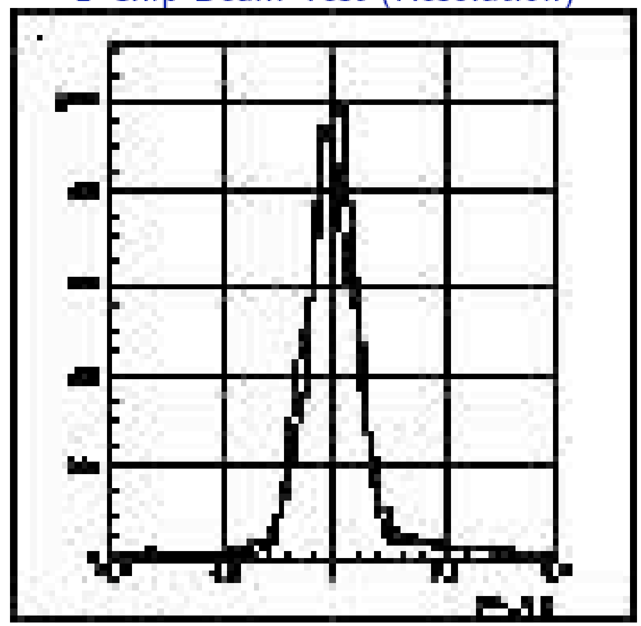
Diamond Pixel Detectors

Results from an ATLAS pixel detector

1 Chip Source Test (Am241)



1 Chip Beam Test (Resolution)

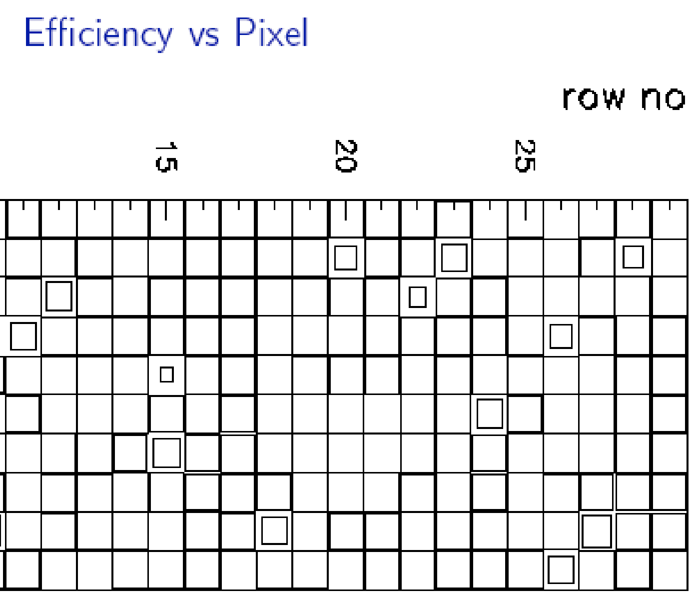


Americium 241 deposits $\approx 4600e$

Spatial Resolution $\approx$ pitch/$\sqrt{12}$ (pitch 50μm $\times$ 400μm

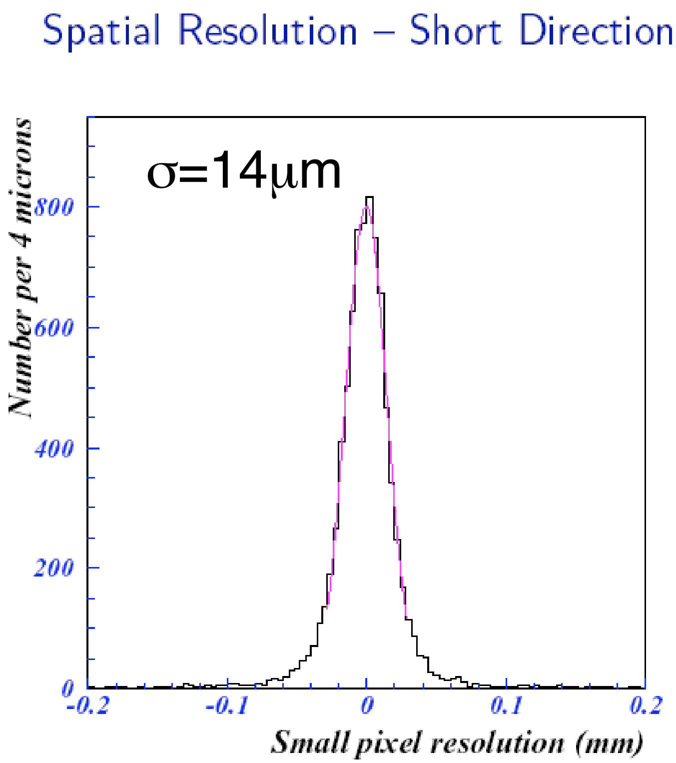
Diamond Pixel Detectors

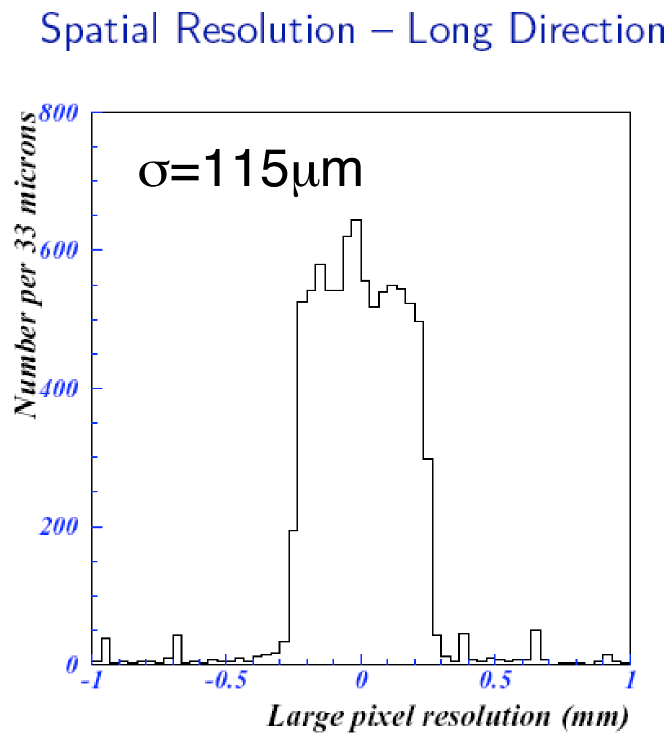
Results from a CMS pixel detector



- Inefficient pixels due to bump bonding and/or electronics - shown in pulser tests
- Excellent correlation between beam telescope and pixel tracker data!

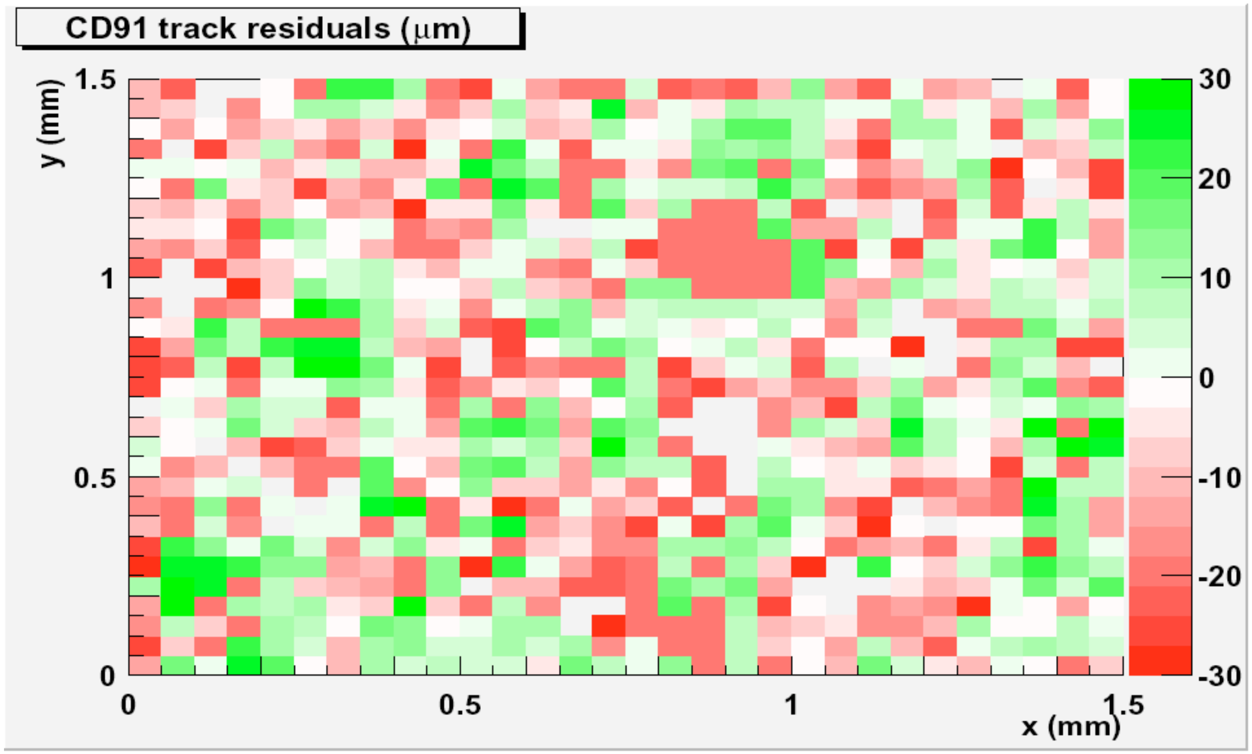
• Results from Atlas Diamond Pixel Detectors





- Efficiency = 80%
- Resolution = digital

- Results from Atlas Diamond Pixel Detectors



Tommaso Lari (INFN)
Alexander Oh (CERN)
Norbert Wermes (University Bonn)

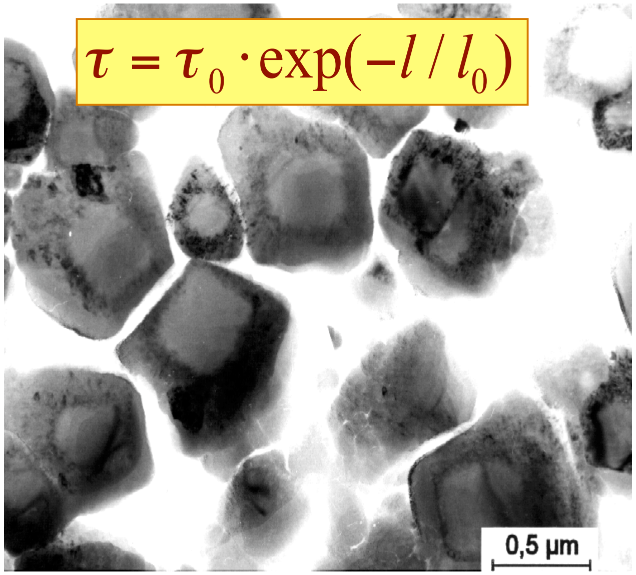
- Large track residuals
- Non-uniformity of response qualitatively reproduces by modeling

- Modelling

- Task: Find a simple model to explain the peculiarities of CVD diamond
  - priming
  - polarisation
  - non-uniformities
- First Step: Make an assumption about the spatial distribution of carrier lifetime
  - lifetime correlates to the crystallite structure
  - lifetime depends on the distance to the nearest grainboundary
  - lifetime can be parametrized by

$$\tau = \tau_0 \cdot \exp(-l / l_0)$$

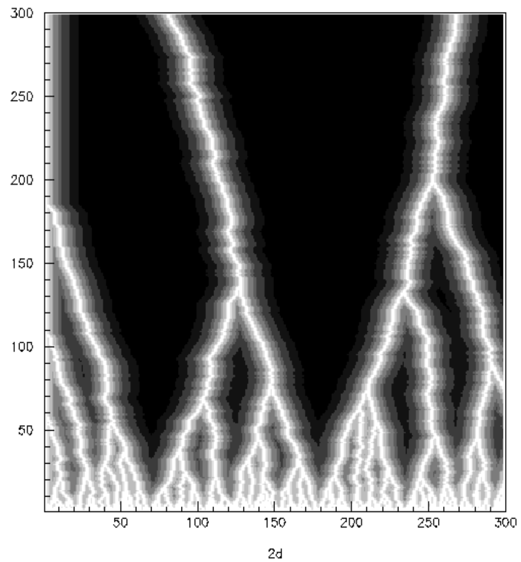
- Second Step: Develop a simple growth model to approximate the growth morphology found in CVD diamond
  - in 3D crystallites start to grow with equal probability with a given seed density
  - the space points claimed by concurring seeds are conquered randomly
  - the probability to sucessfully claim is weighted with the crystallites size



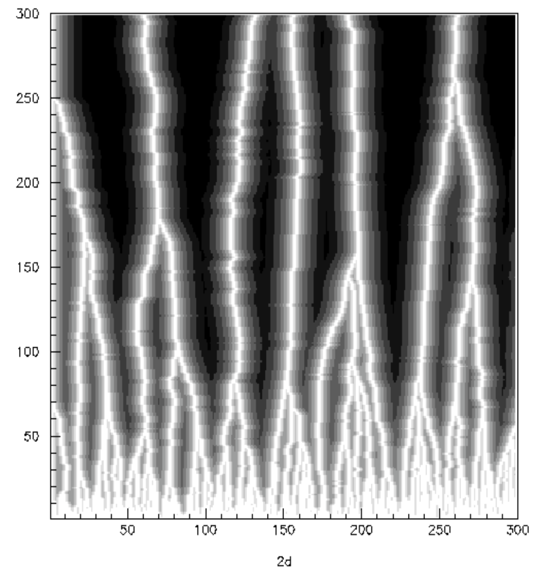
S. Waidmann, Inst. f. Festkorper und Werkstofforschung, Dresden

• Modelling

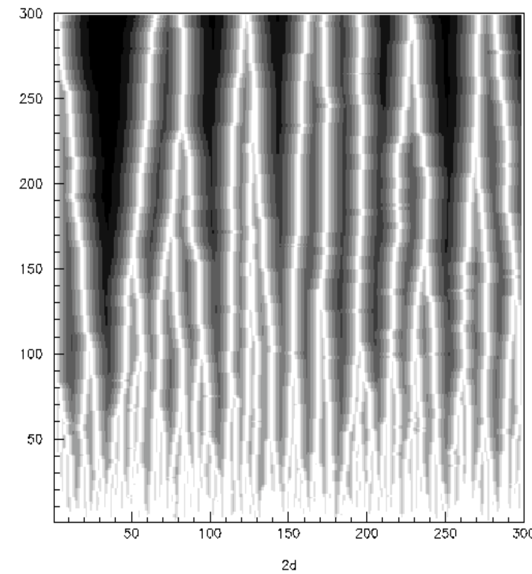
• The Growth Generator can be adjusted for different lateral growth speeds:



k=0.5



k=0.8

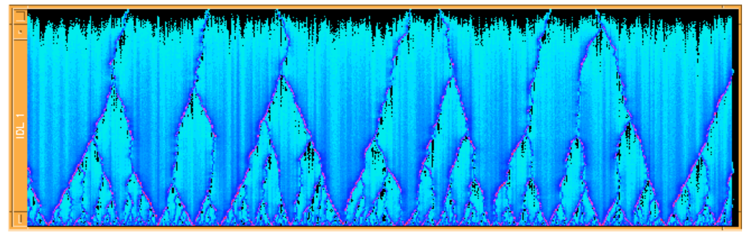


k=0.9

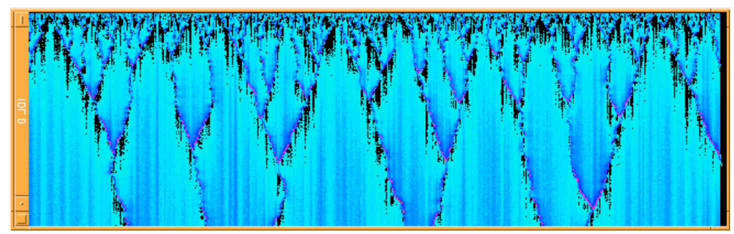
$k=2\ v_{vert}\ v_{lateral}^{-1}$

Modelling

- The carrier drift process is simulated for single carriers (electrons and holes) accordingly to the lifetime distribution.
- Recombination and trapping is distinguished.
- The electric field due to trapped charge is calculated.
- The drift path for each carrier is determined by the local electric field and thermal diffusion with 1μm resolution.

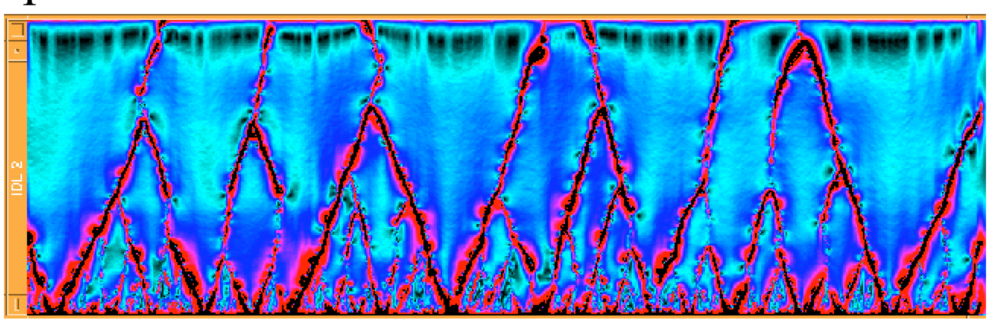


trapped electrons



trapped holes

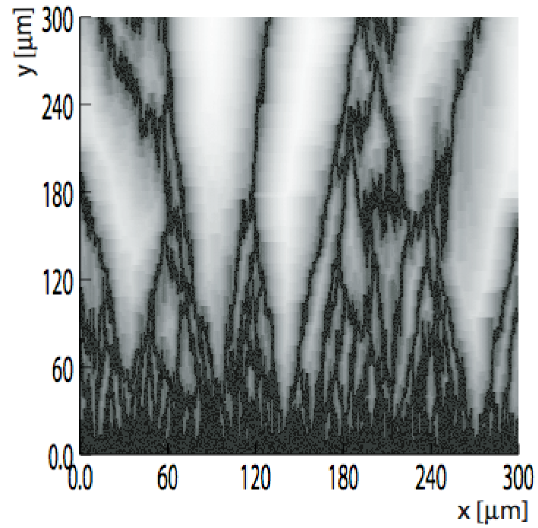
polarisation field

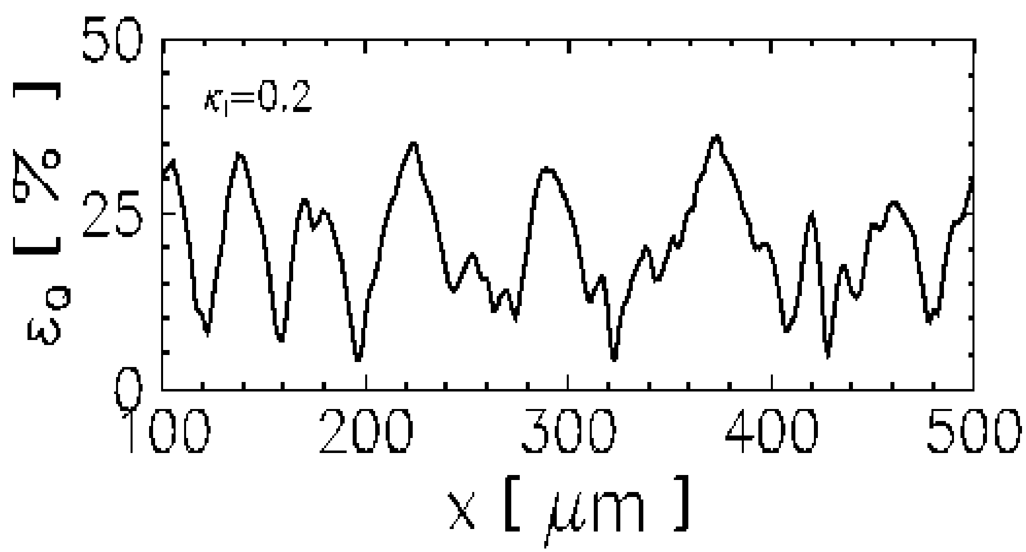


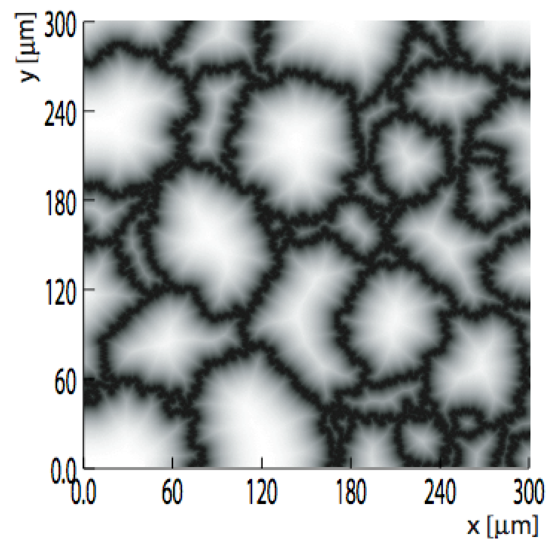
- Recombination and trapping is distinguished, priming effect can be modelled….

Material Studies

- Non Uniformities qualitatively reproduced by modeling



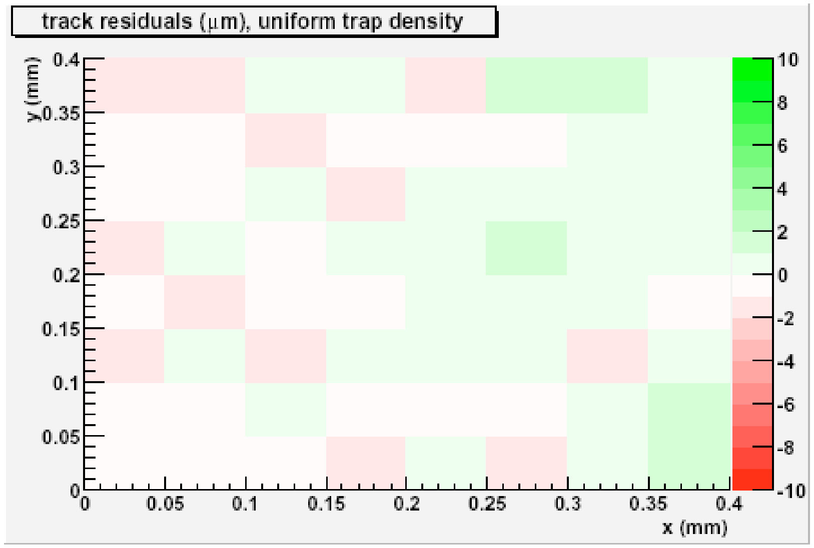


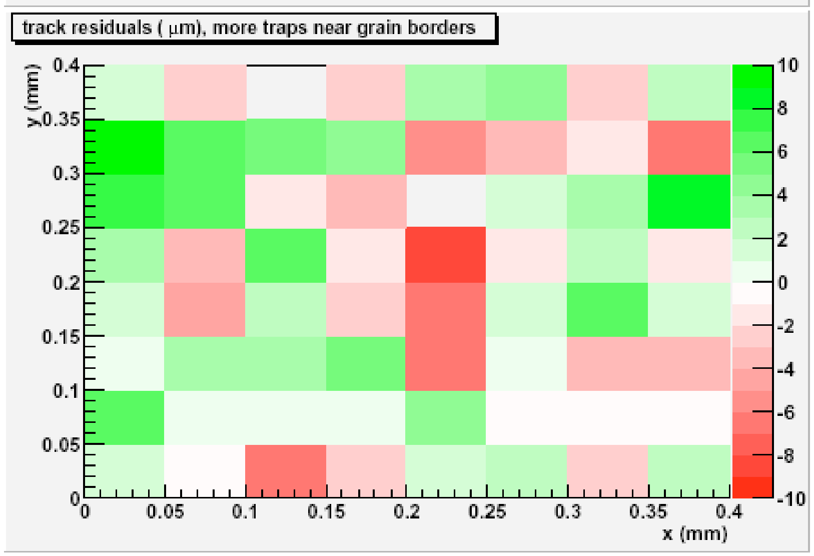


Modelling

- Comparison of track residuals in the model with and without grain structure

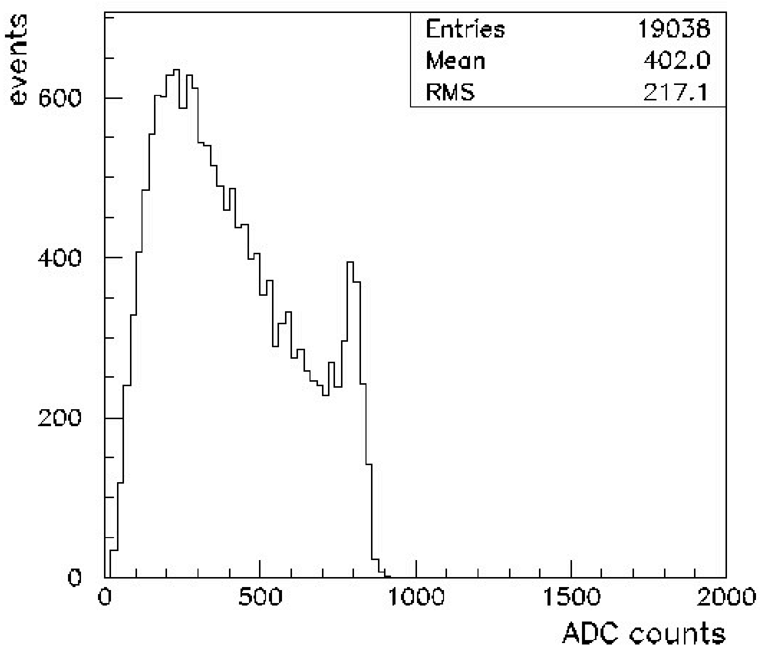
- Model with grain structure can qualitatively reproduce residuals observed with diamond pixel detectors.

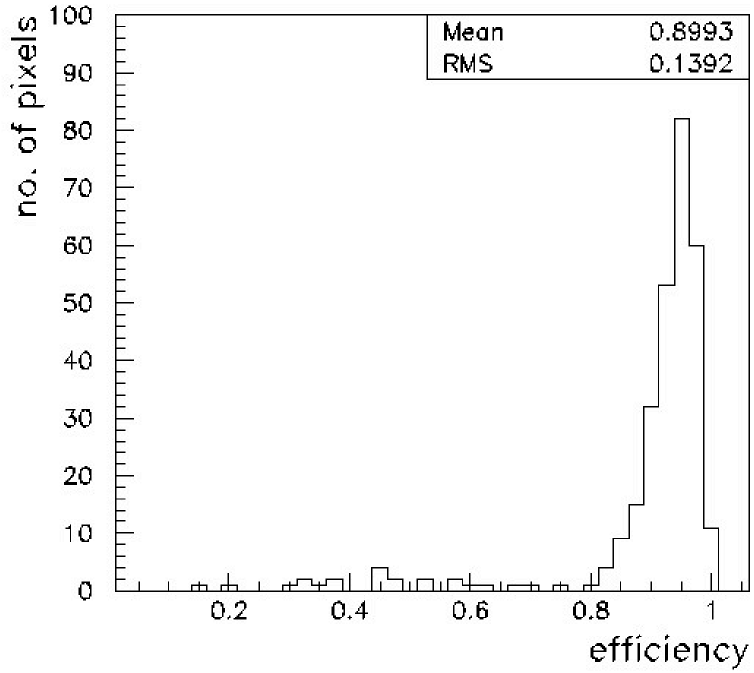




Tommaso Lari (INFN)
Alexander Oh (CERN)
Norbert Wermes (University Bonn)

- Results from CMS Diamond Pixel Detectors





- Efficiency = 89%
- Resolution = digital

Applications in HEP

Applications in HEP

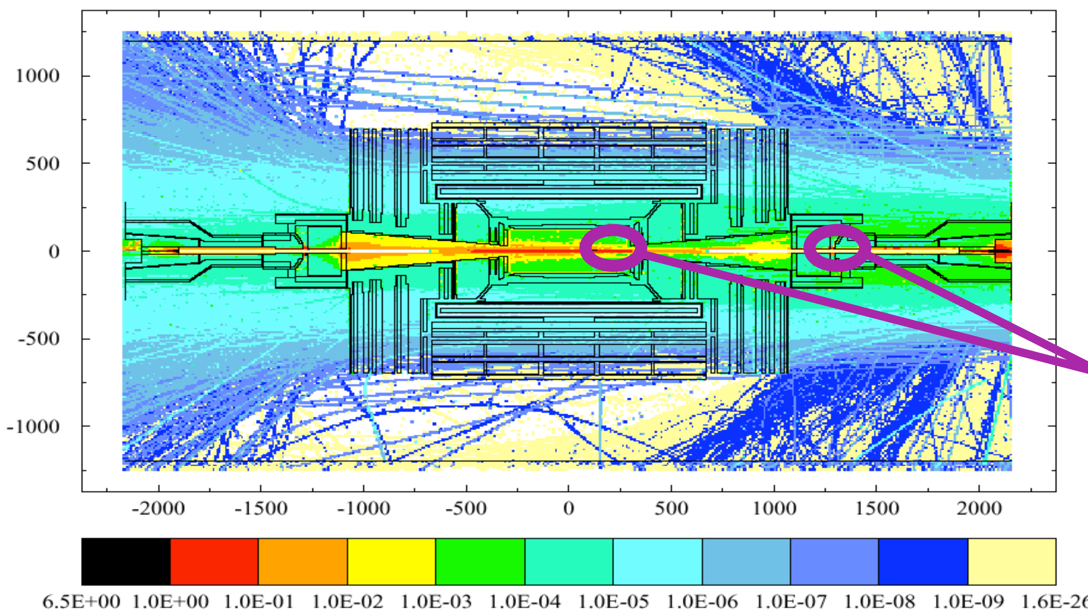
- Vertex detectors with CVD Diamond are not considered yet as an option for LHC.
- For Beam monitoring CVD Diamond is an option for CMS and ATLAS at the LHC.
- BaBar and Belle test already CVD Diamond in their beam monitoring system.

Beam monitoring

- For Silicon Vertex systems careful monitoring is crucial.
- Inherently, beam monitors have to be radiation hard.
- Abort Beam when monitors signal dangerous beam conditions.
  - False signals must be avoided.
  - Monitor must be reliable.
- Requirements on the monitoring system depend on the accelerator and vertex system.

CMS beam monitor

- Diamond activity started.
- Possible location of Beam Condition Monitors (BCM) in CMS.



Mika Huhtinen, CERN

Beam condition monitors

Looking for increase over normal rate

Monitors to be within CMS volume and feed into machine interlock

Expected dose per accident
~1 Gy <=> 10^{12} protons

BCM: First test beam program

Test of response to beam loss: T7 PS testbeam

Beam:

Train of 40ns-wide bunches from CERN PS with 262ns gap
Used to emulate an asynchron beam abort at CMS

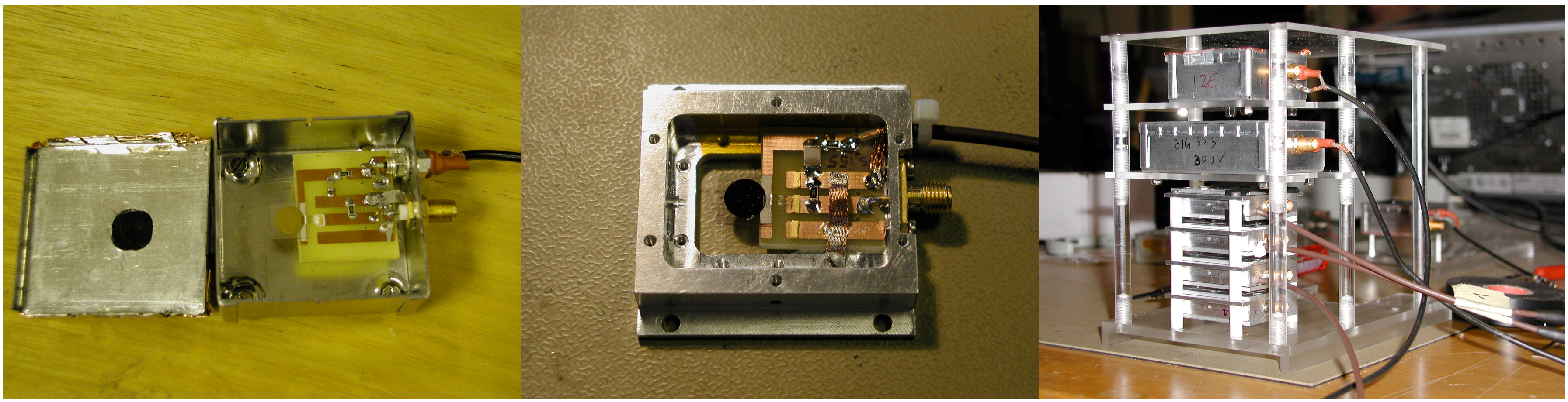
Beam intensity:

~8x10^{11}protons per bunch (24GeV)
~4x10^{10} protons/cm^2/bunch at the centre of the beam spot
~1x10^{8} protons/cm^2/bunch in the halo

Samples:

Polycrystalline diamond samples for response to conditions in CMS/ATLAS

BCM tests done by
Vladimir Cindro
Luis Fernandez Hernando
Christoph Ilgner
Alick Macpherson
Alexander Oh
Heinz Pernegger
Terry Pritchard
Bob Stone
Steve Worm



Read out through 16m long RG58 cable connected directly to diamond (no electronics close to beam).

BCM Preliminary Results

_Diamond signal response to high intensity bunch

Single pulses from diamond

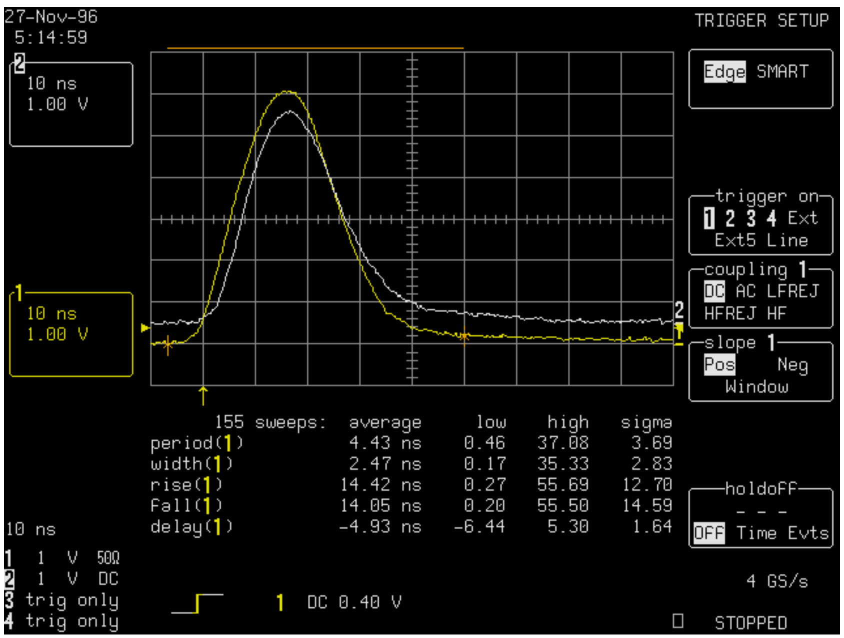
Bias on Diamond = +1 V/um

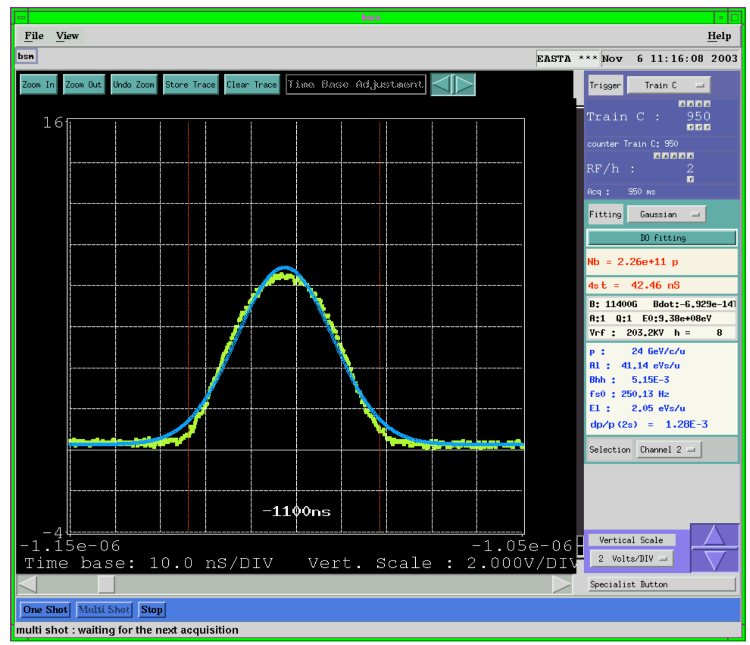
Readout of signal:

16m of cable, no electronics

Attenuation on signal cables at scope input
Ch 1:20dB (factor 10)   Ch 2: 24dB (factor 16)

Almost identical diamond response to PS beam monitor response (pulse length 40ns)

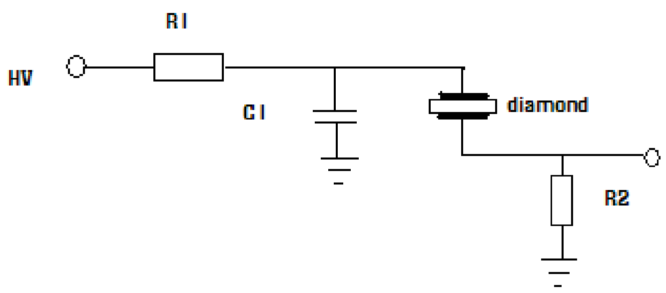


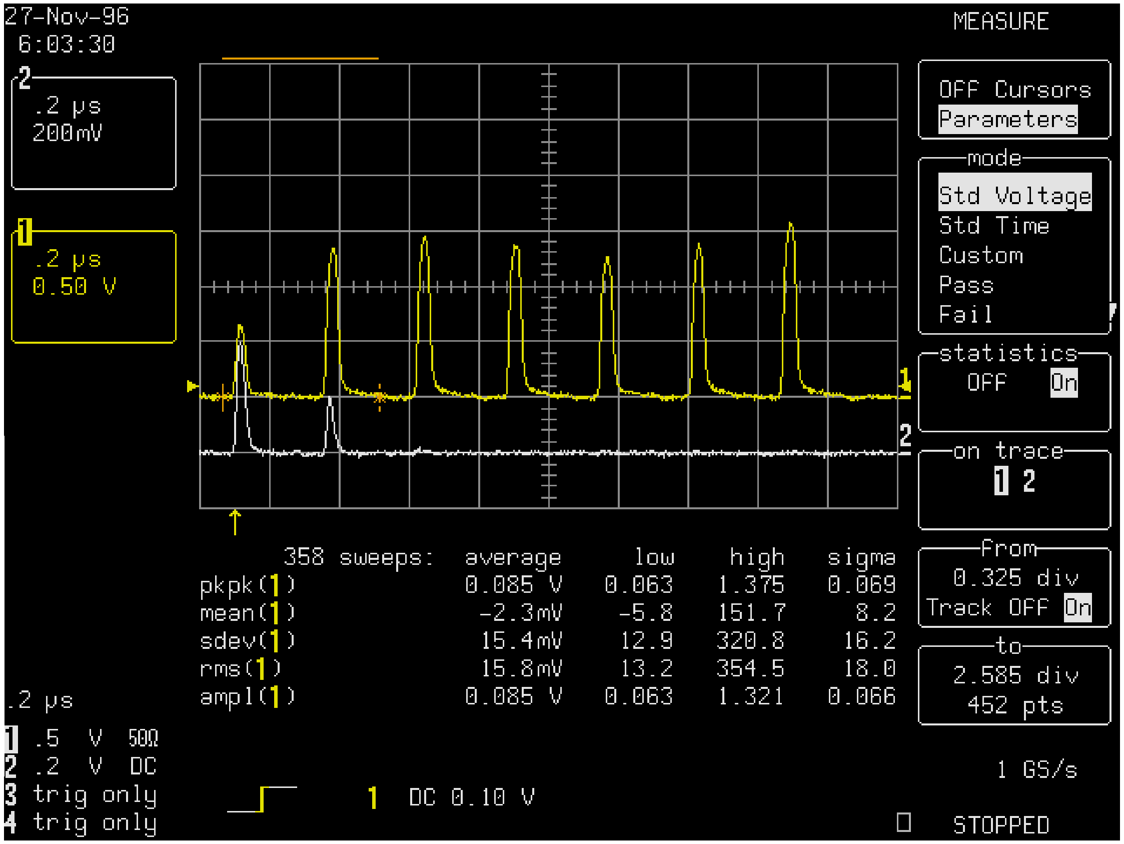


BCM Preliminary Results

_Diamond signal response to high intensity bunch

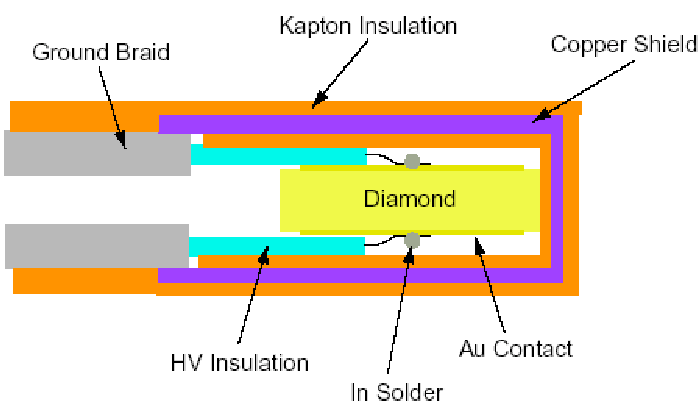
- Bunch train of 7 bunches resolved
- Signal stable over bunch train if electric field can be maintained

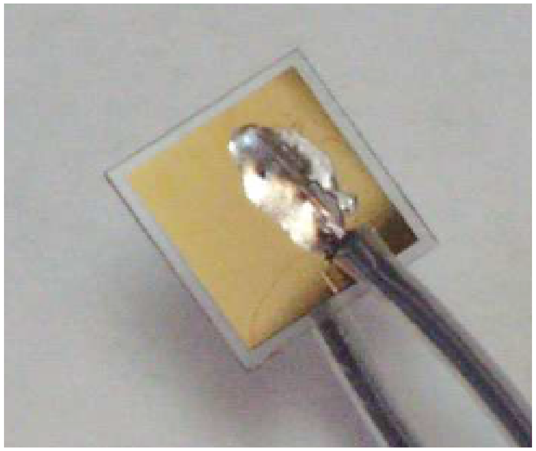


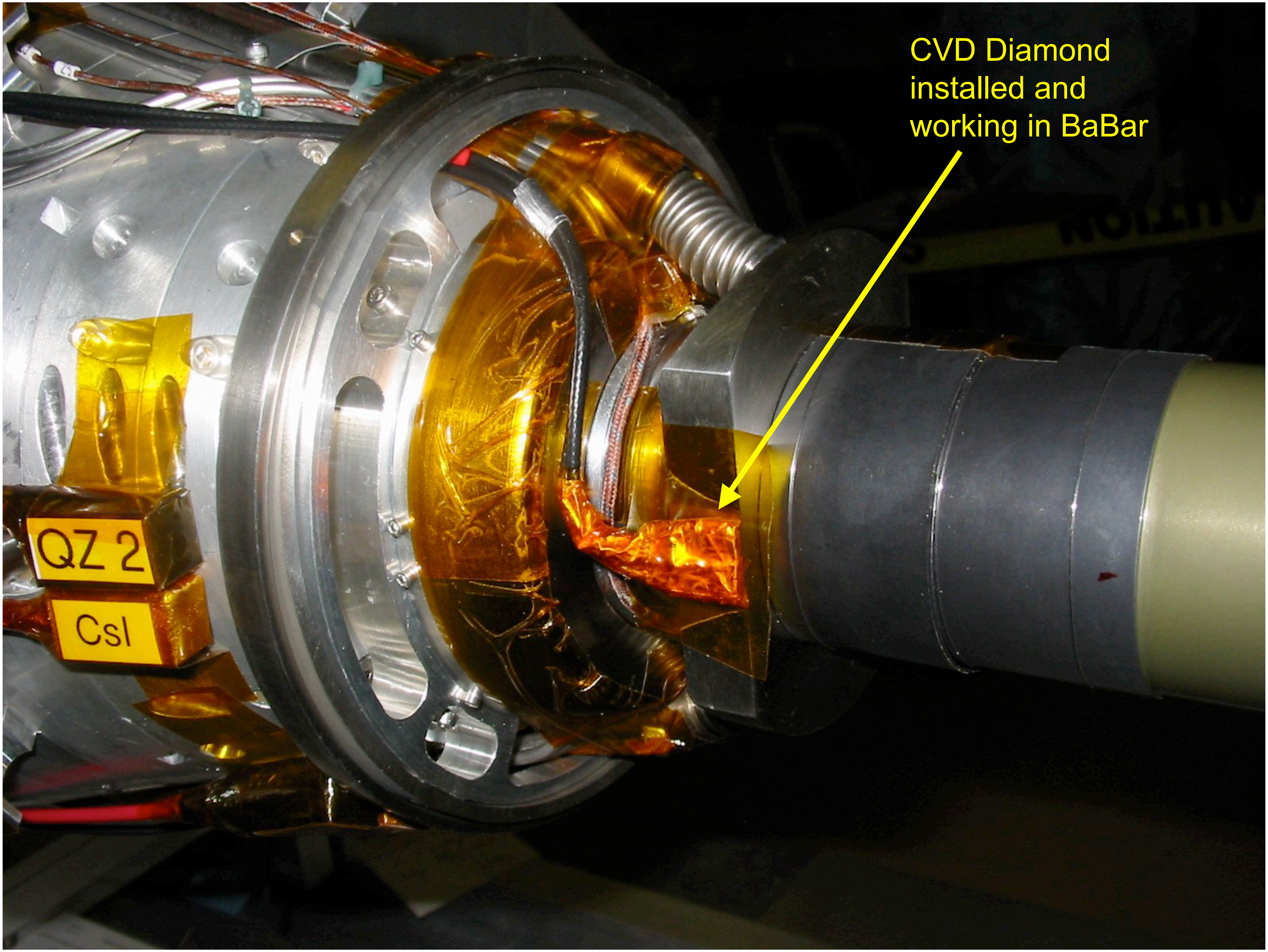


BaBar beam monitor

- For production Si PIN diodes are used.
  - U_{bias} = 50V, I_{leak} increases with 1nA/krad
  - After 100fb^{-1}, noise 50μA, signal 10nA
- Since 4 month CVD diamond beam monitor prototype installed
  - Package must fulfill space constraints
  - Robustness

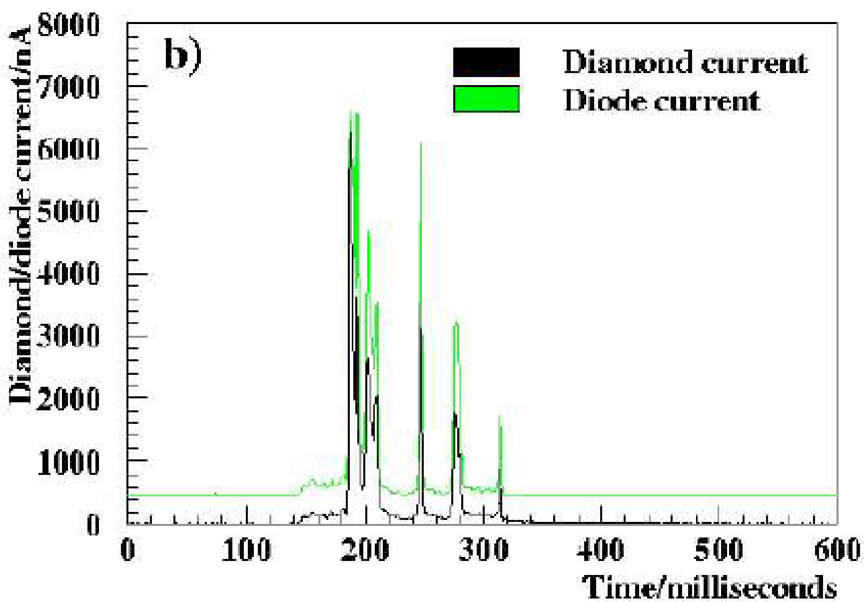


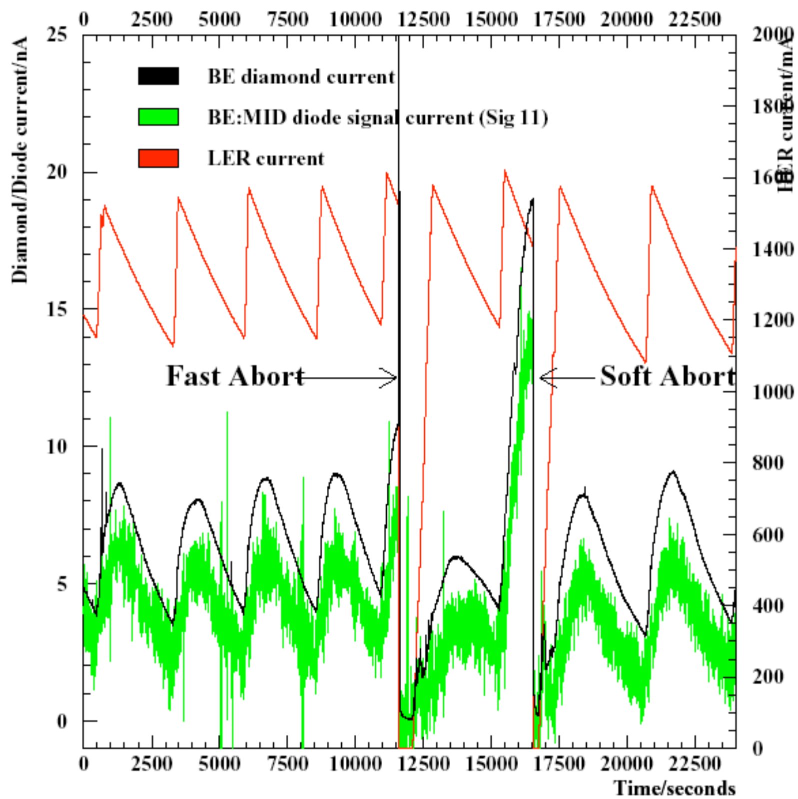



CVD Diamond
installed and
working in BaBar
QZ 2
CsI

BaBar beam monitor

- Promising results!
  - Stable operation
  - Follows closely diode signal

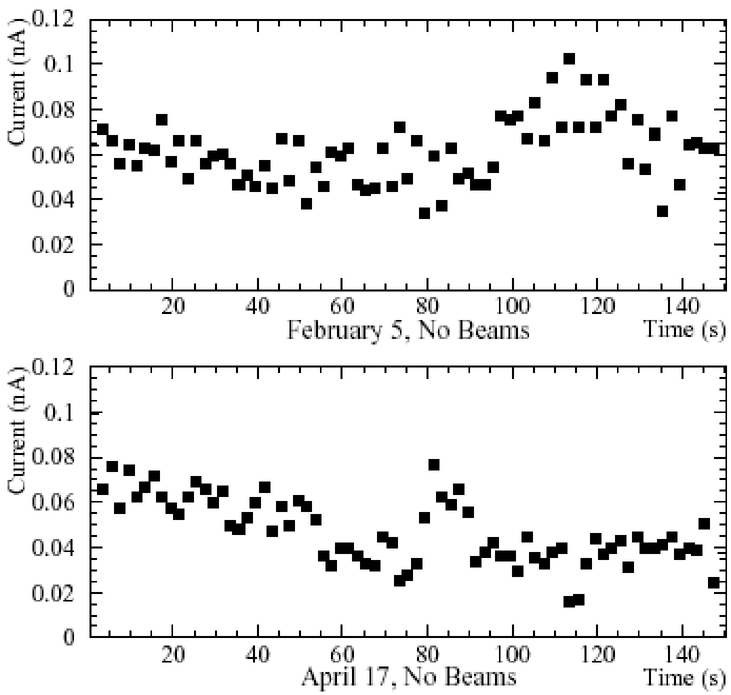




BaBar beam monitor

Leakage Current in BaBar

- Diamonds have received 250kRad ^{60}Co plus 250kRad while installed
- No observed change in leakage current (<0.1nA) or fluctuations (30pA)
- Data directly from BaBar SVTRAD system
- Electronic noise (≈ 0.5nA) substracted off



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Ohio State University
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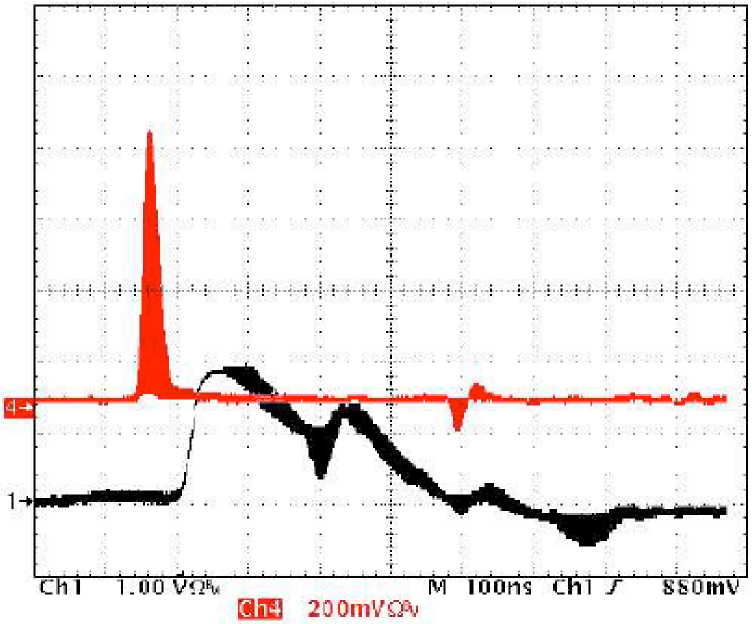
BaBar beam monitor

Very Fast Time Scale (ns) in BaBar

- Use a fast amplifier to look at PIN-diode and diamond signals
- Trigger on the PIN-diode signal
- Look at fast spikes: red = diamond, black = PIN-diode



Diamond is fast enough for Fast Abort

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Summary

- Proto-type Detectors
  - Dots / Strips / Pixel
  - Good resolution and S/N 8:1 obtained with rad-hard electronics
  - Intermediate Strips are tested this July
- Radiation Hardness
  - 50% loss of S/N after 2.9 x 10^{15} pions/cm^2
  - No loss seen for EM radiation up to 10MGy.
  - Will be repeated with newest samples

Summary

- Application in HEP
  - Beam monitoring in BaBar, Belle
  - Option for CMS and ATLAS Beam monitoring
- Future
  - Mono-crystalline CVD diamond
  - Continue research on poly-crystalline diamond to reach 300μm collection distance.