Status of Diamond Detectors for Experiments at LHC

Dirk Meier
RD42 04/97
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RD42 Collaboration

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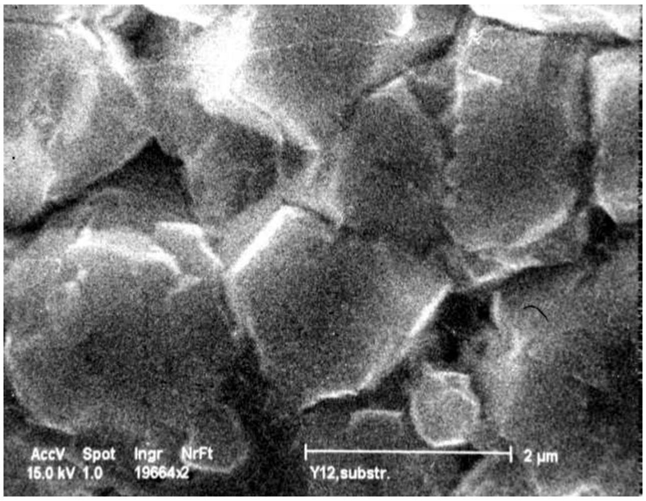
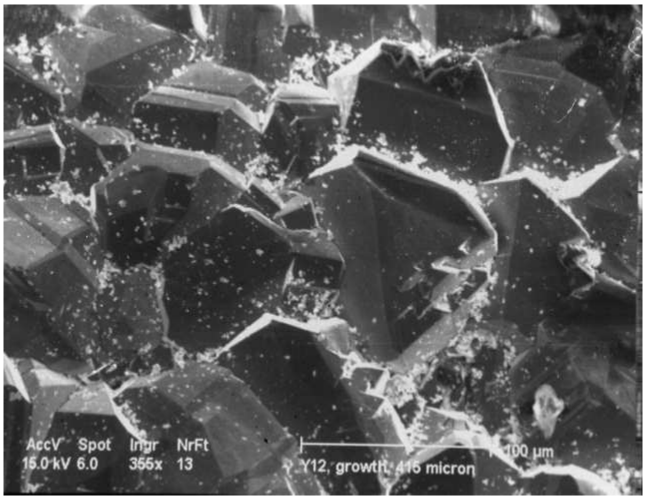
Growth, Substrate of CVD Diamond

Y12, substrate
scale **2 μm**



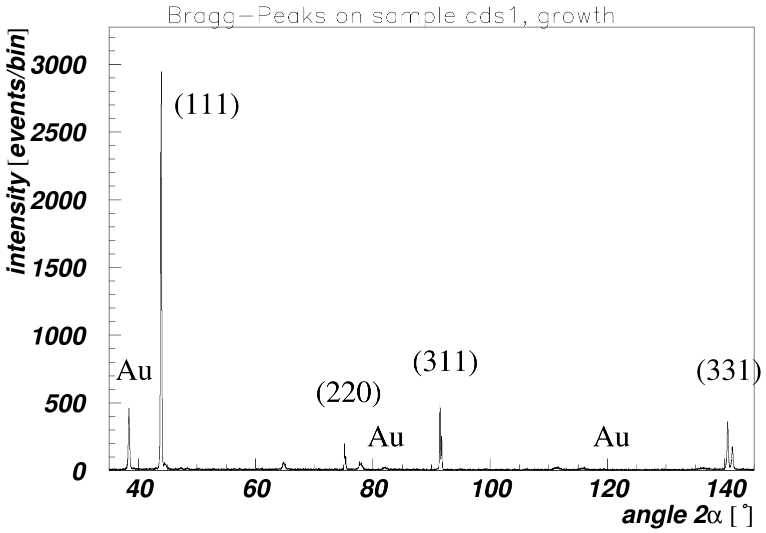
Y12, growth
scale
100 μm



- CVD diamond **columnar** structure
- **grain** size **increases** from substrate to growthside
- charge collection is related to grainsize

Polycrystalline CVD Diamond

X-ray diffraction measure intensity vs. angle 2α.



Identify and determine

- **lattice orientations** hkl
- abundance of **orientations**
- **lattice constant**=3.56 Å @ 25 °C

Samples were metallized with Cr/Au-contacts.
Gold is observed in speactra.

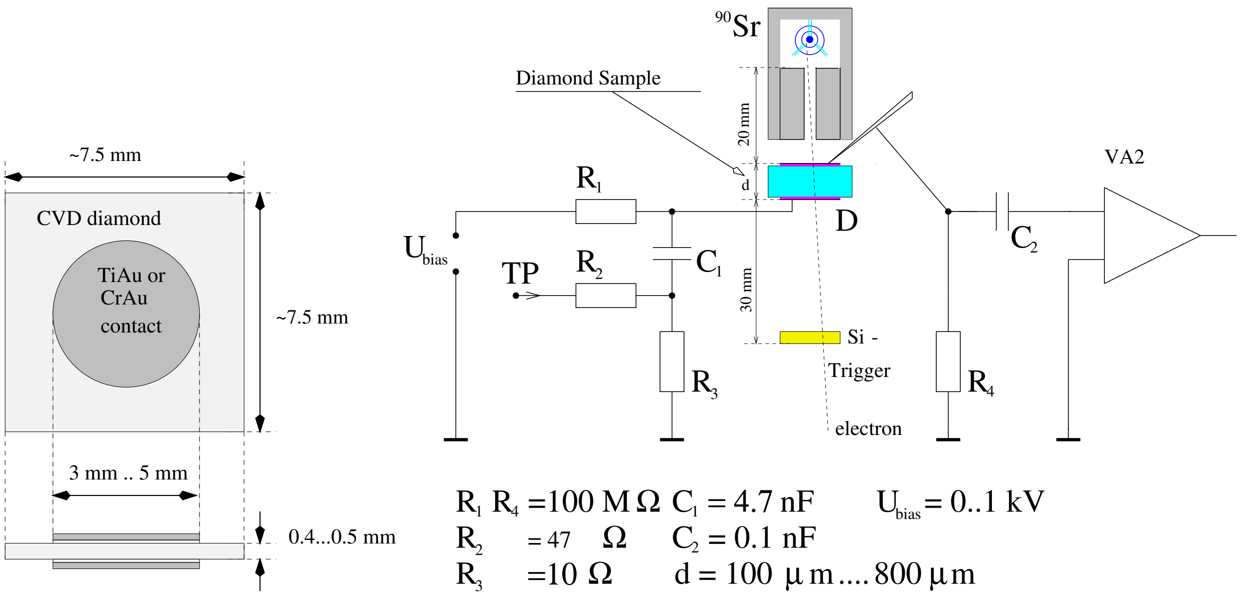
RD42 History

History until April '97

- 1991-1994: DIAMAS collaboration
  R&D for SSC
  diamond tungsten sampling calorimeter
- 1994: DRDC Proposal P56
  approval in Sept.1994, $\rightarrow$ RD42
  increase of charge collection
  demonstration of **radiation hardness** e, γ
  demonstration of **tracking** with low noise electronics
- 1995: CERN/LHCC 95-43, RD42 Status Report to LDRB
  approval spring 1996
  further increase of charge collection
  pion/neutron irradiation $> 1 \times 10^{15}$ /cm^2
  study **pixel tracker** geometry
  test existing **LHC electronics** on diamond
  tracker in **high magnetic field**
- 1996: CERN/LHCC 97-3,P56, RD42 Status Report
  March 13/14, 1997, LHCC agrees to continue RD42 one further year

Charge Collection, Setup

- Diamond connected to HV on i.e. growth side.
- Collimated Sr90 β-source illuminates sample.
- Substrate side of diamond coupled to readout chip.
- Readout: VA2-chip, 128 channels, charge integration and signal shaping of 2 μs, PreAmpNoise=(68+11/pF)e.
- Silicon diode in line with diamond/source triggers readout.



R_1 R_4 =100 MΩ C_1 = 4.7 nF U_{bias} = 0..1 kV
R_2 = 47 Ω C_2 = 0.1 nF
R_3 =10 Ω d = 100 μm .... 800 μm

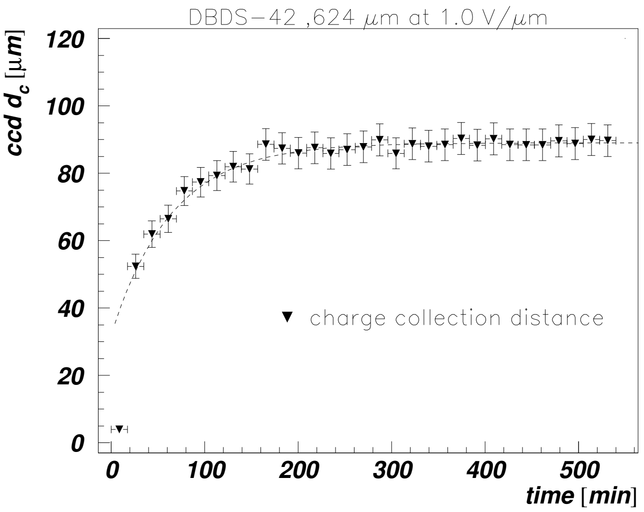
Charge Collection Distance, Pumping

- A *mip* **generates** charge pairs per distance:

$$\boxed{q = 36 \text{ e}/\mu\text{m} = 10800 \; e/300 \; \mu\text{m}} \tag{1}$$

- mean charge $\langle Q_{\text{col}} \rangle$ can be **collected**:

$$\boxed{\langle Q_{\text{col}} \rangle = q \cdot d} \tag{2}$$

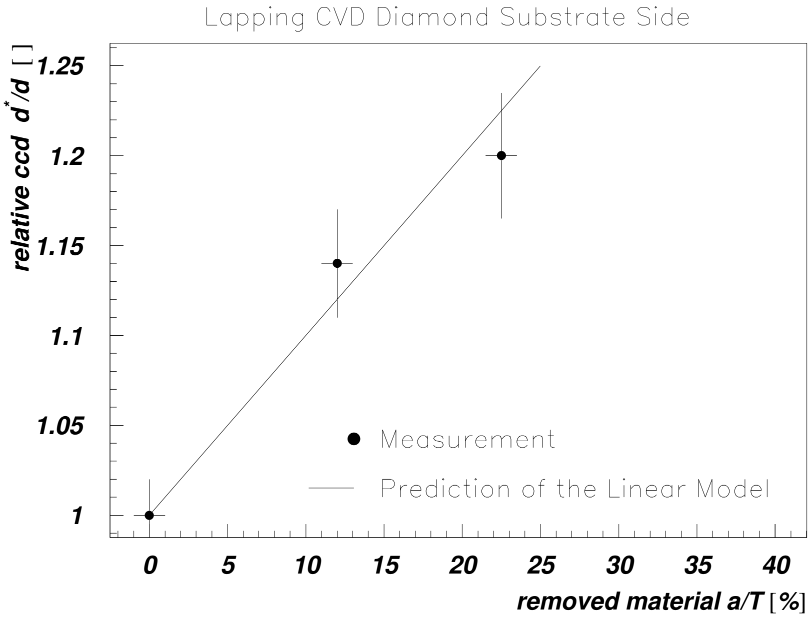


Charge collection distance d ...

- .. increases under irradiation between 1..10 krad, **pumping**
- .. saturates and stays constant above 10 krad, **pumped**
- .. decreases under exposure to fluorescent light, **depumping**

Lapping of Diamond

- d depends on position x, linear model $d(x) = mx + d_0$
- d_0 on substrate side worse than $d(T)$ on growth
- linear model suggest lapping of substrate side

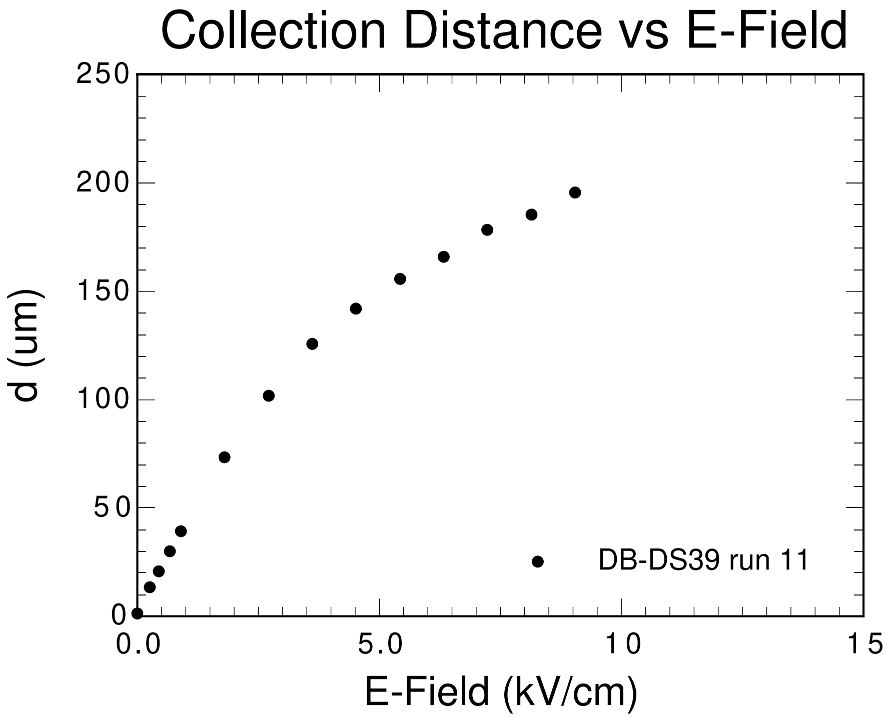


- d increases with material removed from substrate side

Collection vs. Electric Field

- diamond grown to 1600 μm, $d_{\mathrm{pumped},0.5} = 110\ \mu$m
- lapping of 450 μm from substrate down to 1100 μm

after lapping measure charge collection d



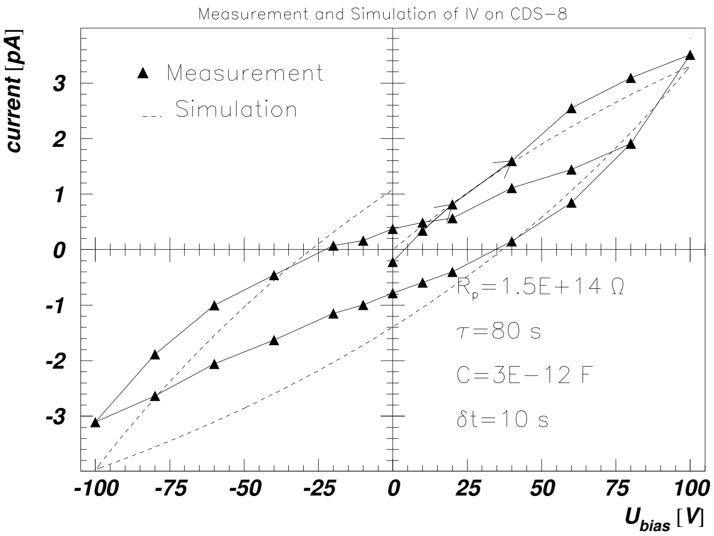
- d^* after lapping bigger than before

  Charge collection distance $d_{\mathrm{pumped},0.5} = 145\ \mu$m

  .. $d^*/d(450/1600) \approx 1.32$
- Charge collection now, Jan. 97, $d_{\mathrm{pumped},1.0} = 200\ \mu$m

Current Voltage Characteristic

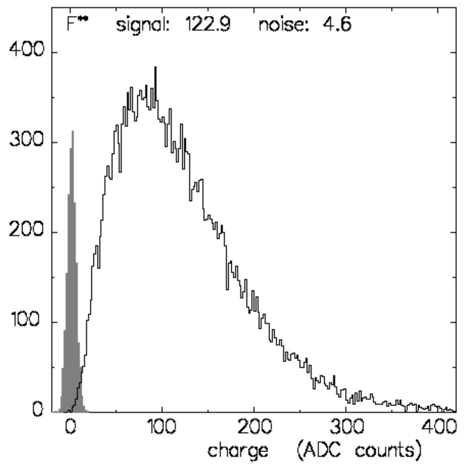
- measuring IV-curve: Apply U_{bias}, wait time δt, take data, change voltage, and so on...
- model diamond with ohmic contacts with 2 resistors and capacitor
- superimpose **measurement and simulation**:

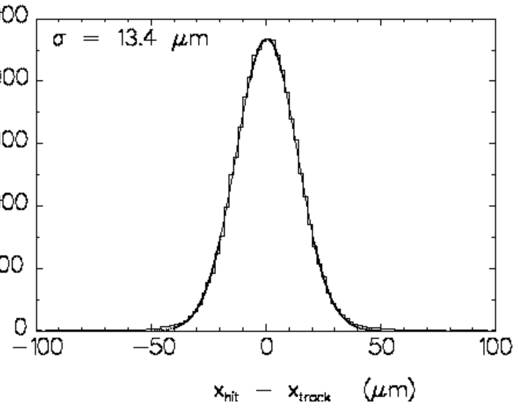


- **current density** $j \approx 0.15$ pA/mm^2 at 100 V.
- **resistivity** $\rho_{\text{diamond}} \approx 1 \times 10^{14}$ Ωcm.
- ... silicon has $\rho_{\text{silicon}} \approx 2.3 \times 10^5$ Ωcm

Norton Strip Detector

- Norton-F strip tracker, 128 strips, pitch 50 μm.
- ... 6.4×6.4 mm^2 active area
- slow readout, VA2, signal peaking time 2 μs.

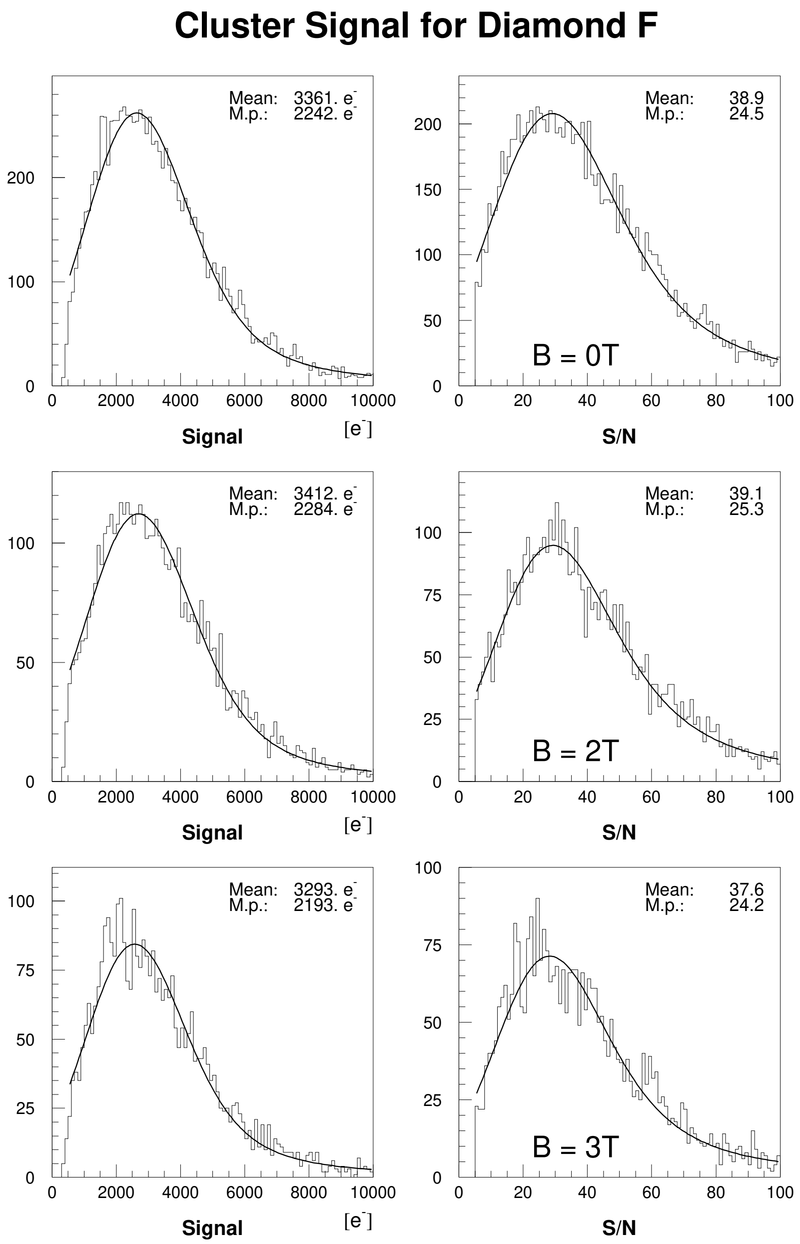




- **average charge** signal 3500 e
- **resolution** 13.4 μm $< 50\ \mu\text{m}/\sqrt{12}$

Magnetic Field, Cluster Signal

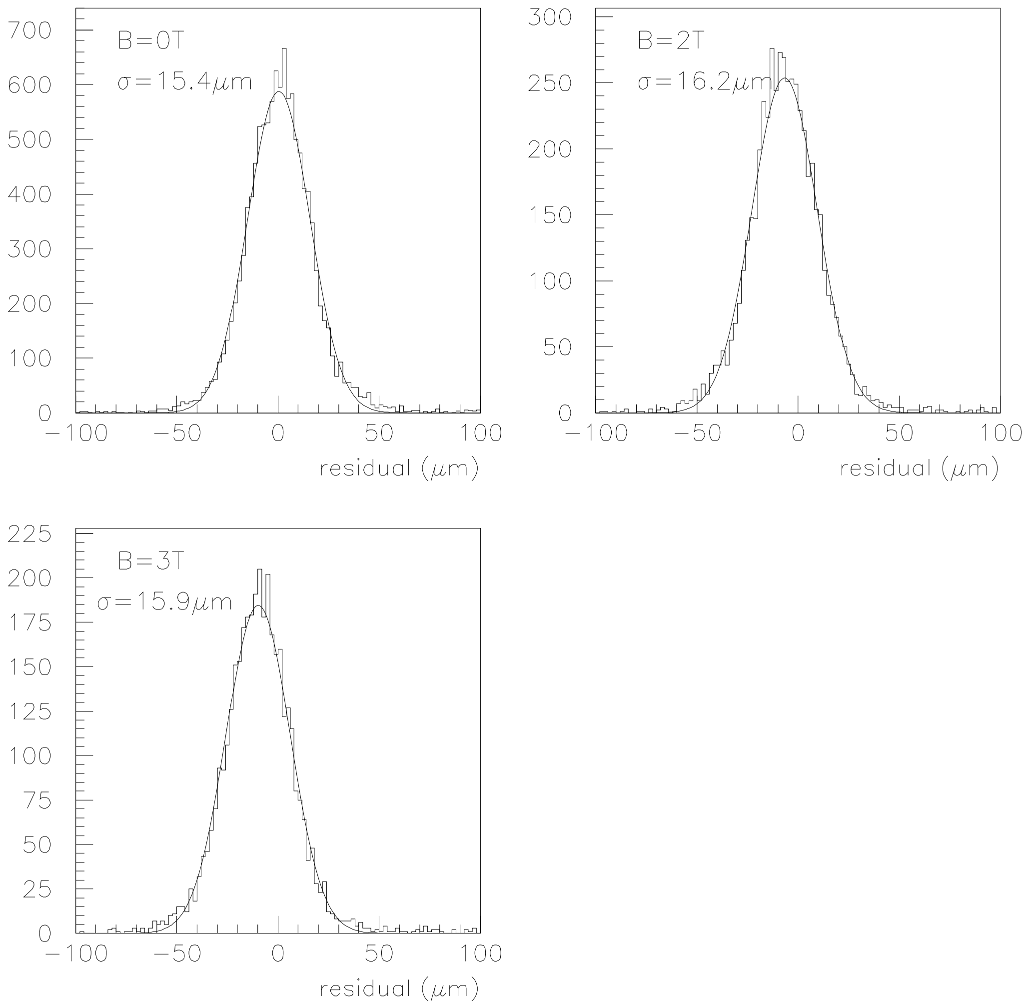
- Norton-F strip tracker in **magnetic field 0 to 3 T**
- signal and signal-to-noise **remains unchanged**



Magnetic Field, Resolution

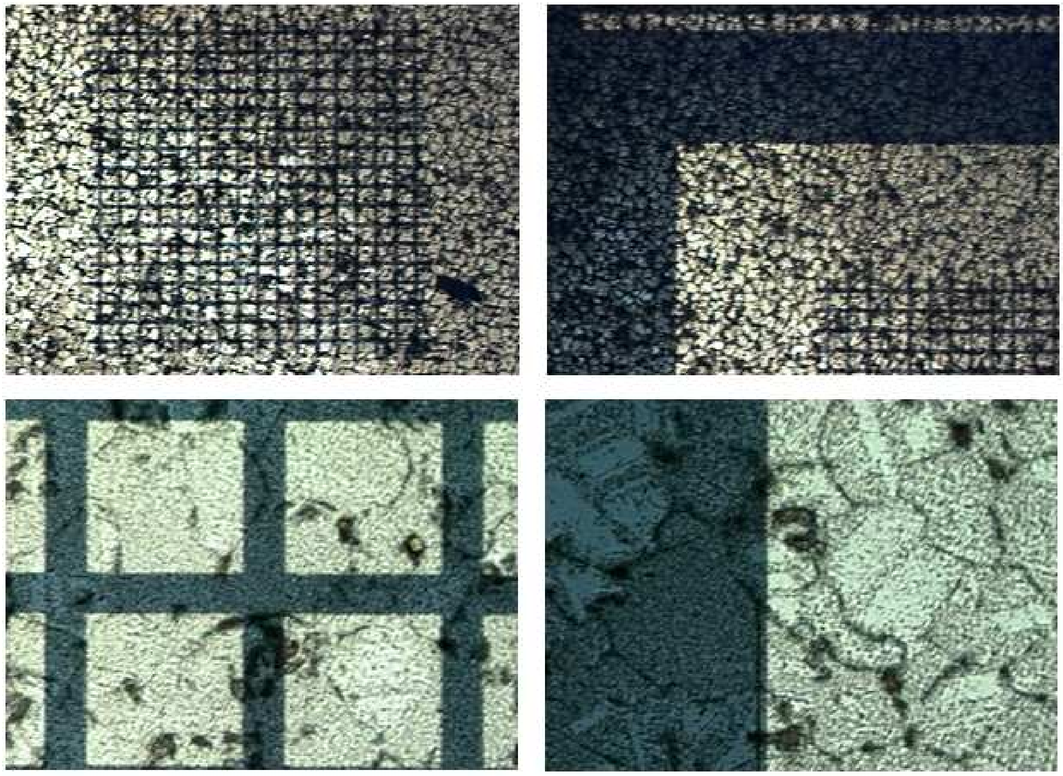
- **resolution unchanged** between 0 to 3 T:

Diamond F



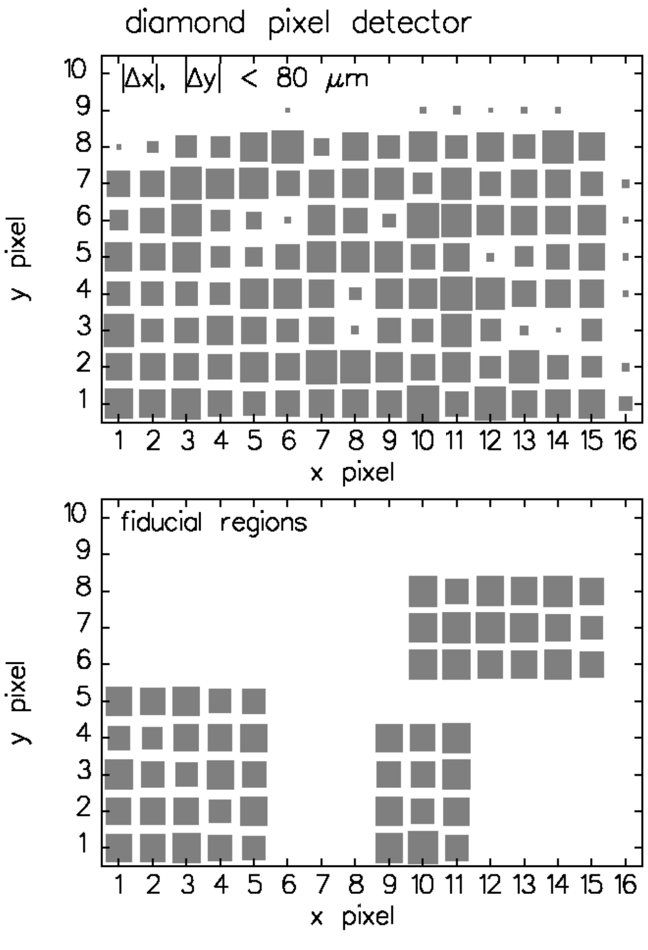
Pixel Detector, Layout

- Norton-B pixel tracker, 16×16 pixel, pitch 150 μm^2
- ... 2.4×2.4 mm^2 active area
- slow readout, VA3, signal peaking time 2 μs.
- glasfanout bonded to pixels with wires, length 60μm.



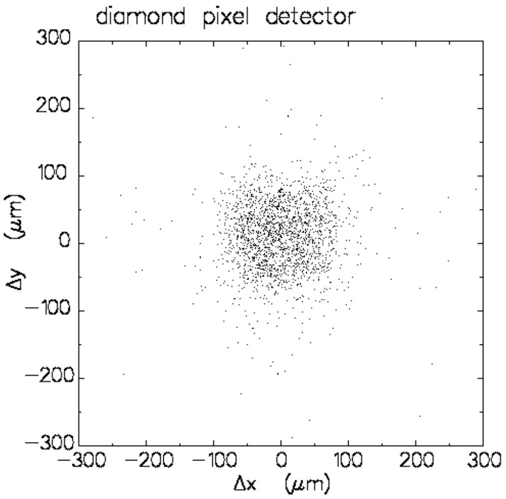
Pixel Detector

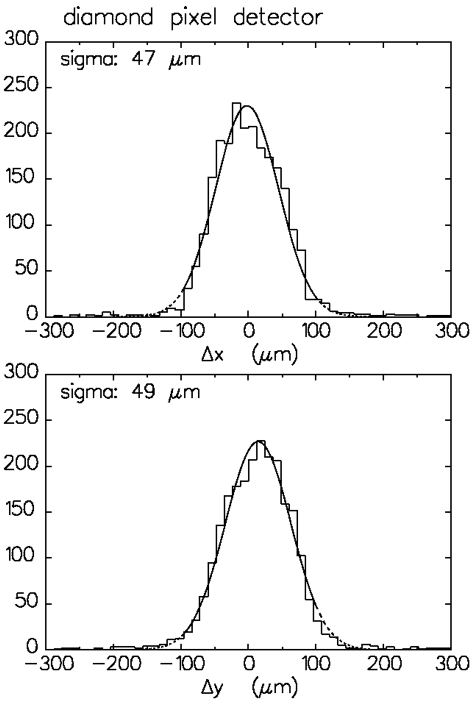
- display number of tracks in pixel, ... within 80 μm from prediction
- determine fiducial region



Pixel Detector, Result

- measure difference between cluster position and track
- gives two dimensional distribution
- and individual resolution σ_x and σ_y





- **resolution** $\sigma_x = \sigma_y \approx 48\ \mu\mathrm{m}$
- **noise** ENC$\approx$ 75 e
- mean **signal-to-noise** 22

LHC Electronics, SCT/DMILL

- first tests with SCT/DMILL chip done
- SCT32A developpement for ATLAS/SCT

  bipolar preamplifier shaper

  signal **peaking time** 25 ns

  analog **pipeline** 112 cells

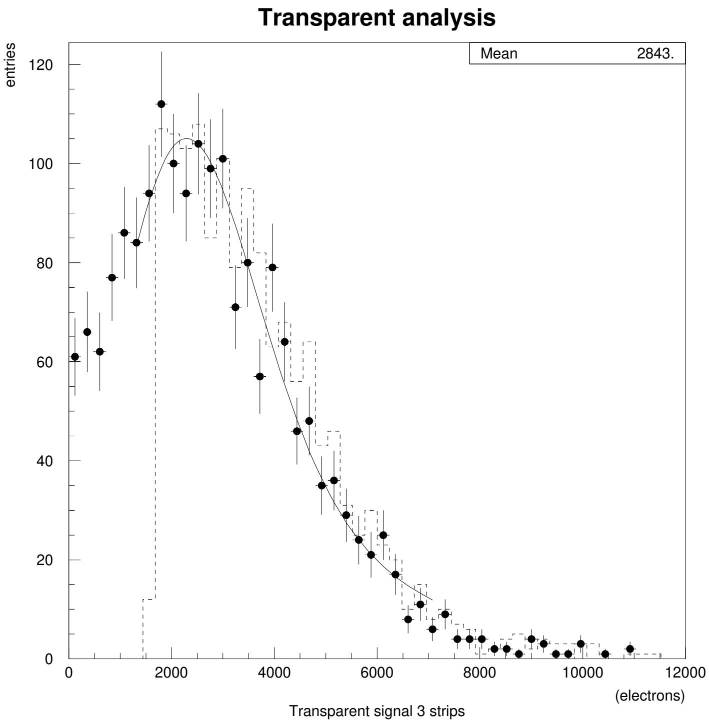
  pipeline **clock** 40 MHz

  multiplexer for 32 channels

  radiation hard DMILL process
- input optimized for silicon, not for diamond!
- on diamond ENC = 550 e+70 e/pF at collector current of 25 μA.

Tracker on SCT/DMILL, Charge Collection

- Norton-F on SCT32A chip
- readout pitch 100 μm

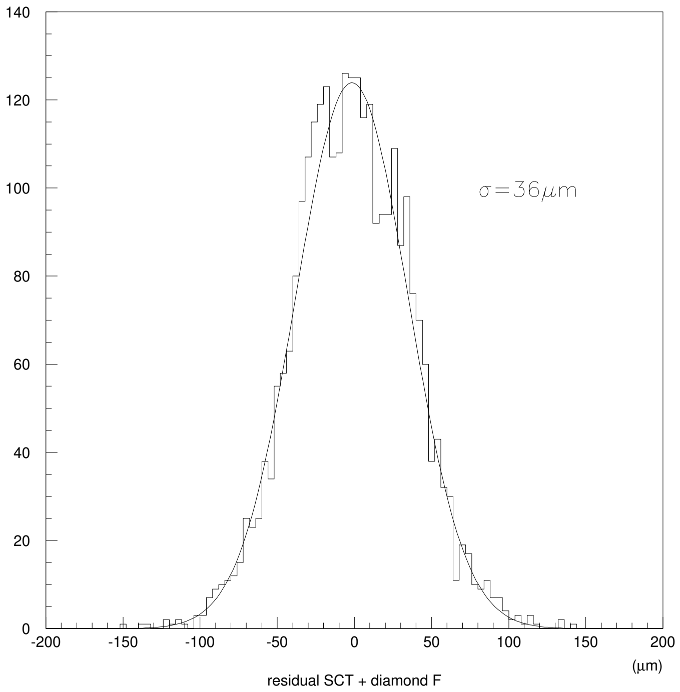


transparent analysis (predict hit and measure deviation)

- mean **signal** charge 2840 e
- mean **signal-to-noise** 4.3

Tracker, SCT/DMILL, Resolution

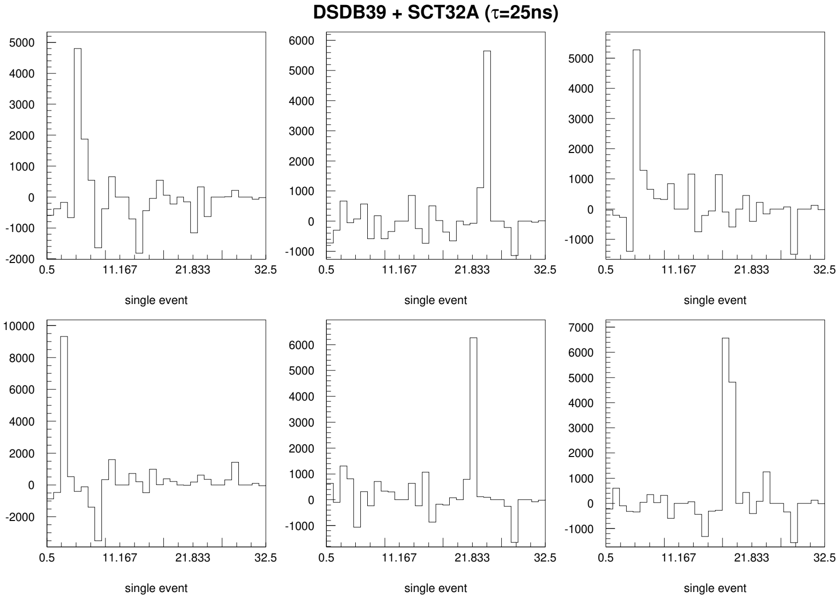
measure spatial resolution σ



$\sigma = 36\ \mu$m

DeBeers Tracker on SCT/DMILL, Hits

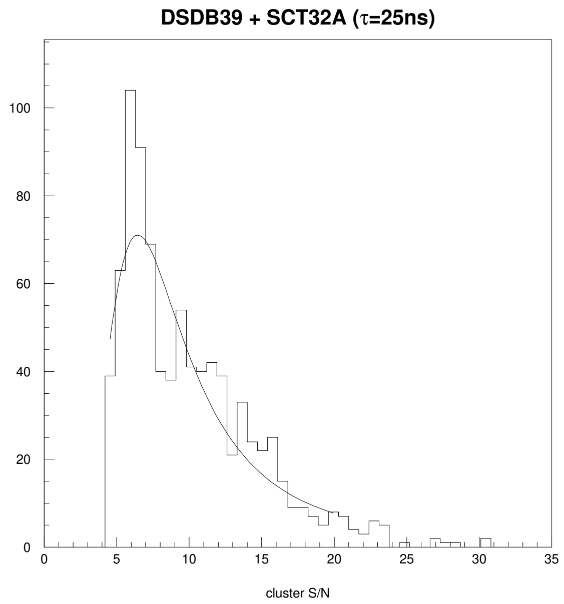
- DeBeers DBDS-39 tracker on SCT32A
- test with Ru109 β-source

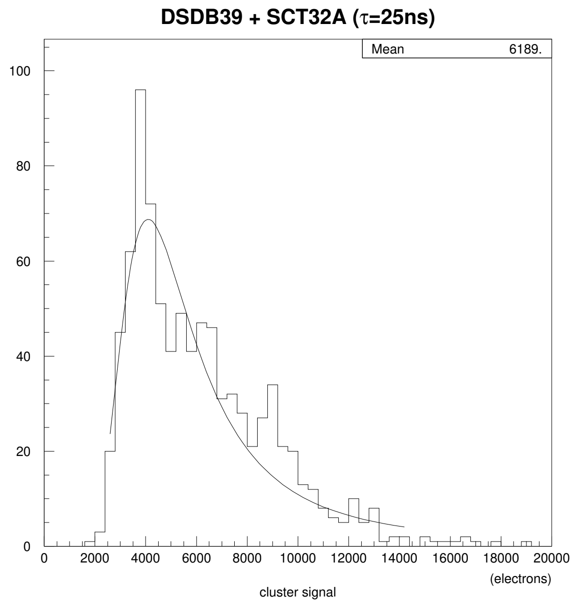


- pulses mean **signal** at 6300 e
- corresponds to $d = 170\ \mu$m

DeBeers Tracker, SCT/DMILL, S/N

cluster analysis

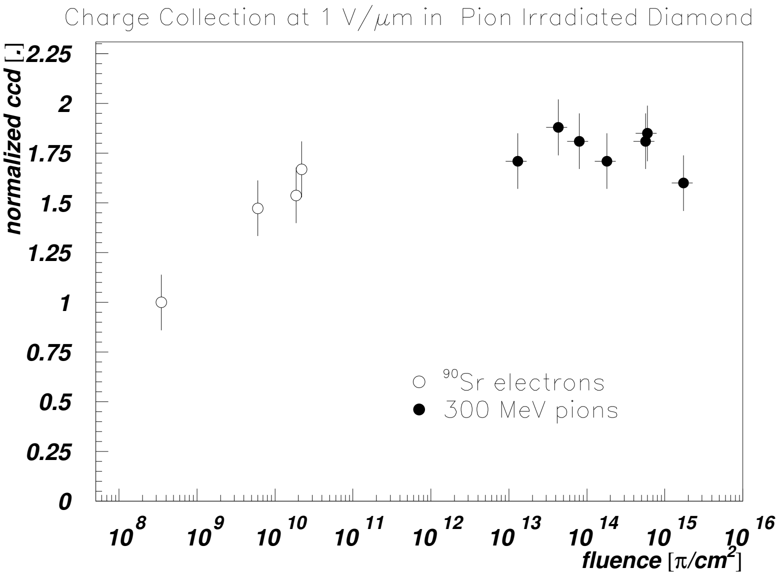




mean **signal-to-noise** is 10-to-1

Pion Irradiation

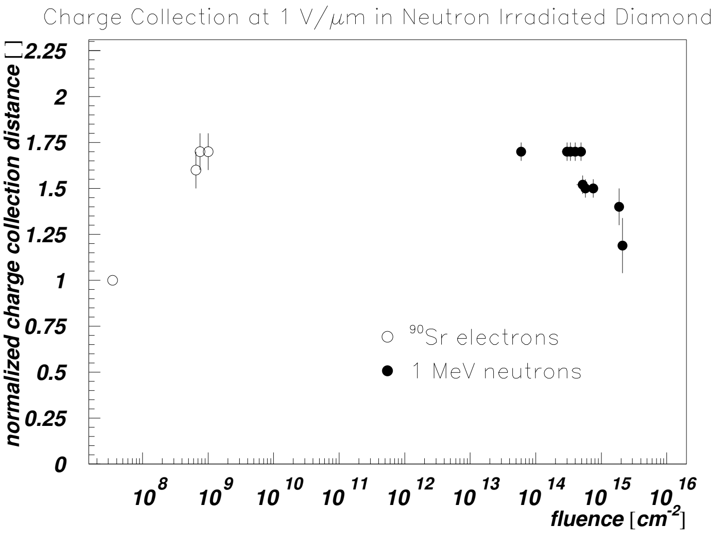
- **pion irradiation** at PSI, Villingen, delivers 300 MeV pions
- irradiation up to **fluence** $1.8 \times 10^{15}\ \pi/\mathrm{cm}^2$,
- room temperature, 100 V applied,
- measure **charge collection**, related to before irradiation:



- signal increased during characterization with Sr90 electrons.
- $6 \times 10^{14}\ \pi/\mathrm{cm}^2$: no decrease in charge collection
- $1.8 \times 10^{15}\ \pi/\mathrm{cm}^2$: indication decrease by 10%

Neutron Irradiation, Charge Collection

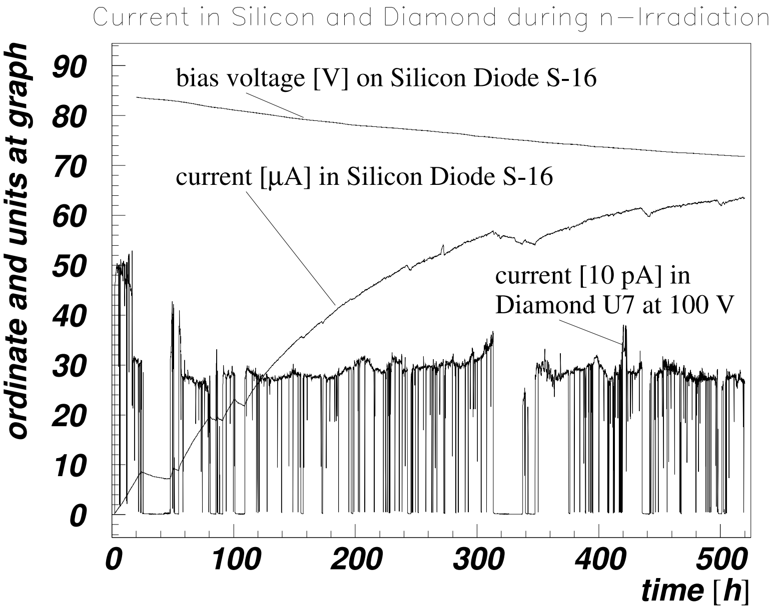
- ISIS **neutron** spallation source at RAL, England
  ... two energy maxima: one below 10 keV and one at 1 MeV.
- irradiation up to **fluence** $1.9 \times 10^{15}\ n/\mathrm{cm}^2$,
- at room temperature, biased 100 V.



- up to $5 \times 10^{14}\ n/\mathrm{cm}^2$ no decrease in charge collection
- $1.9 \times 10^{15}\ n/\mathrm{cm}^2$ d decreases by 15%.

Neutron Irradiation, Current

- current in silicon diode and diamond during n-irradiation
- current in **silicon** is **leakage current**
- current in **diamond** is **particle induced current**



- silicon: increase from few μA to 60 μA in 500 h
- diamond

  induced current follows beam structure

  current constant at 24 pA/mm^2 when beam on

  diamond **monitors** neutron/gamma radiation

Research 1997

- Diamond **growth** and **processing**
  - improvement in chemistry
  - stabilise growthprocess
  - improve post growth processing, lapping
  - large area material 30 cm^2
  - achieve 200 μm collection distance on thin substrates (¡ 1 mm)
- **Irradiation**
  - irradiation studies with best material
  - irradiate tracker
  - proton irradiation at PS/CERN
  - neutron irradiation
- **Electronics**
  - optimise SCT/DMILL readout for diamond
  - build prototype detector module
- **Pixel** Devices
  - continue test with VA2
  - readout with fanout to SCT/DMILL chip
  - CMS readout, collaboration with PSI
  - ATLAS readout, collaboration Marseille/Bonn
- Obtain a **price estimate** from industry

Summary

- Charge collection distance

  $d = 200\ \mu$m (Jan.97) on 1.1 mm sample

  promising results on new material (after Jan.97)

- Irradiation studies approaching 2×10^{15} /cm^2

  no decrease in charge collection up to 5×10^{14} /cm^2

  decrease order 10%..15% above 1×10^{15} /cm^2

- Tracker

  successfull tests of **pixel tracker** geometry

  tracking in high **magnetic field no problem**

  LHC electronics (pipeline 40 MHz, τ_p=25 ns) **S/N$\approx$ 10-to-1**