Present Status and Prospects for Radiation Hard CVD Diamond Detectors

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on behalf of the RD42 Collaboration
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Outline of the Talk

- **Introduction**
- **Recent Results on Charge Collection Properties**
- **Recent Radiation Hardness Studies with Trackers**
- **Recent Tracking Studies**
- **Summary**
- **RD42 Future Plans**

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◇ *Spokespersons*

Institutes from **HEP**, **Heavy Ion**, **Solid State Physics**

Introduction

Motivation: Tracking Devices Close to Interaction Region of Experiments

SLHC Issues:

→ Inner tracking layers must survive!

→ Inner tracking layers must provide high precision tracking to tag b, t, Higgs, . . .

→ Annual replacement of inner layers perhaps?

Diamond Properties:

- Radiation hardness
- Low dielectric constant → low capacitance
- Low leakage current → low readout noise
- Room Temperature Operation, Fast signal collection time

Tracking Detector Implementation:

- Based on Chemical Vapor Deposition (CVD) Diamond
- Signal Size and Uniformity?
- Performance of Trackers?
- Pixel Detector Performance?

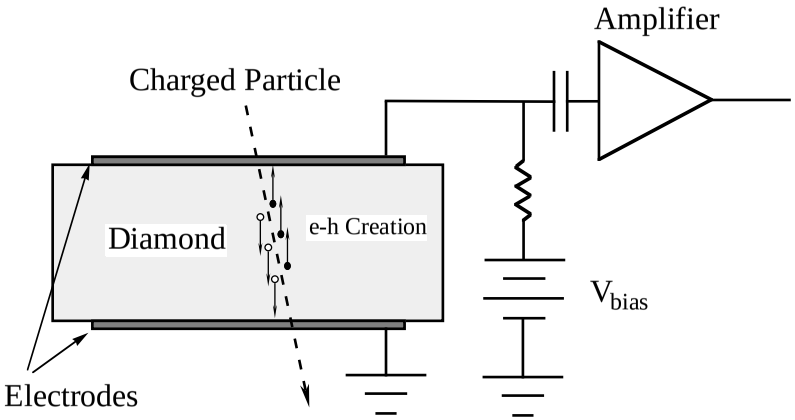
References:

→ CERN/LHCC 2001-002, Status Report RD42

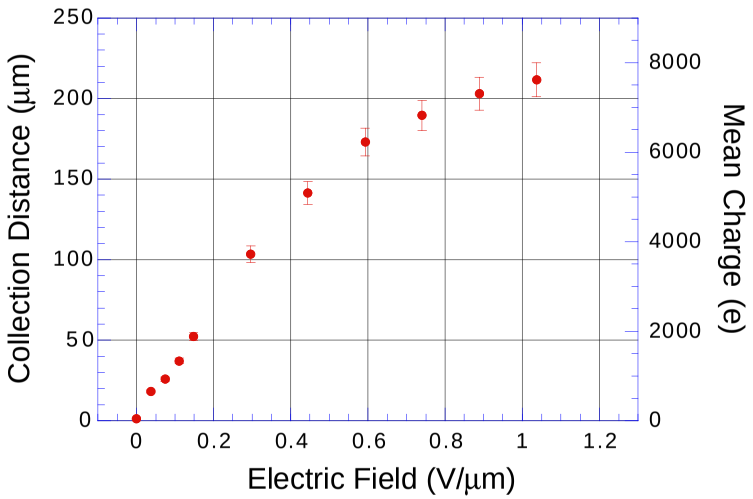
→ http://rd42.web.cern.ch/RD42

Characterization of Diamond:

Signal formation

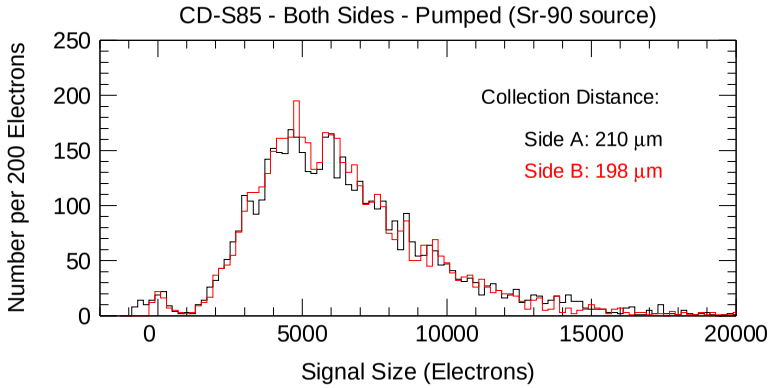


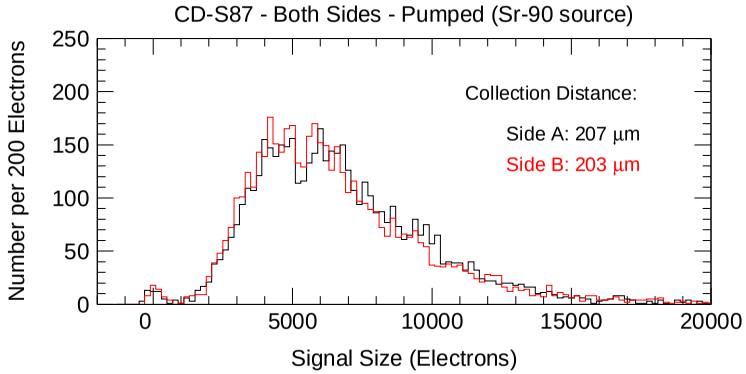
Signal versus applied electric field



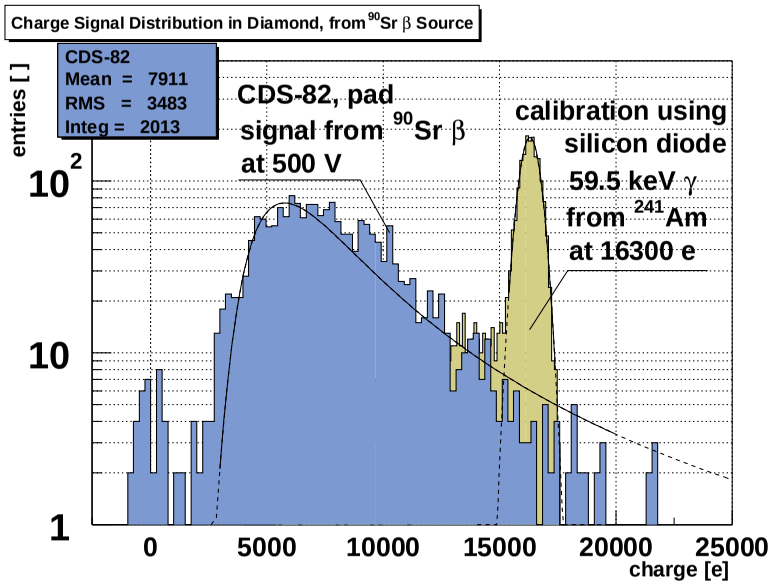
- Metalization is typically Cr/Au or Ti/Au or Ti/W
- Typically operate at 1V/μm
- Mobility saturated

Latest Diamonds Measured with a ^{90}Sr Source:

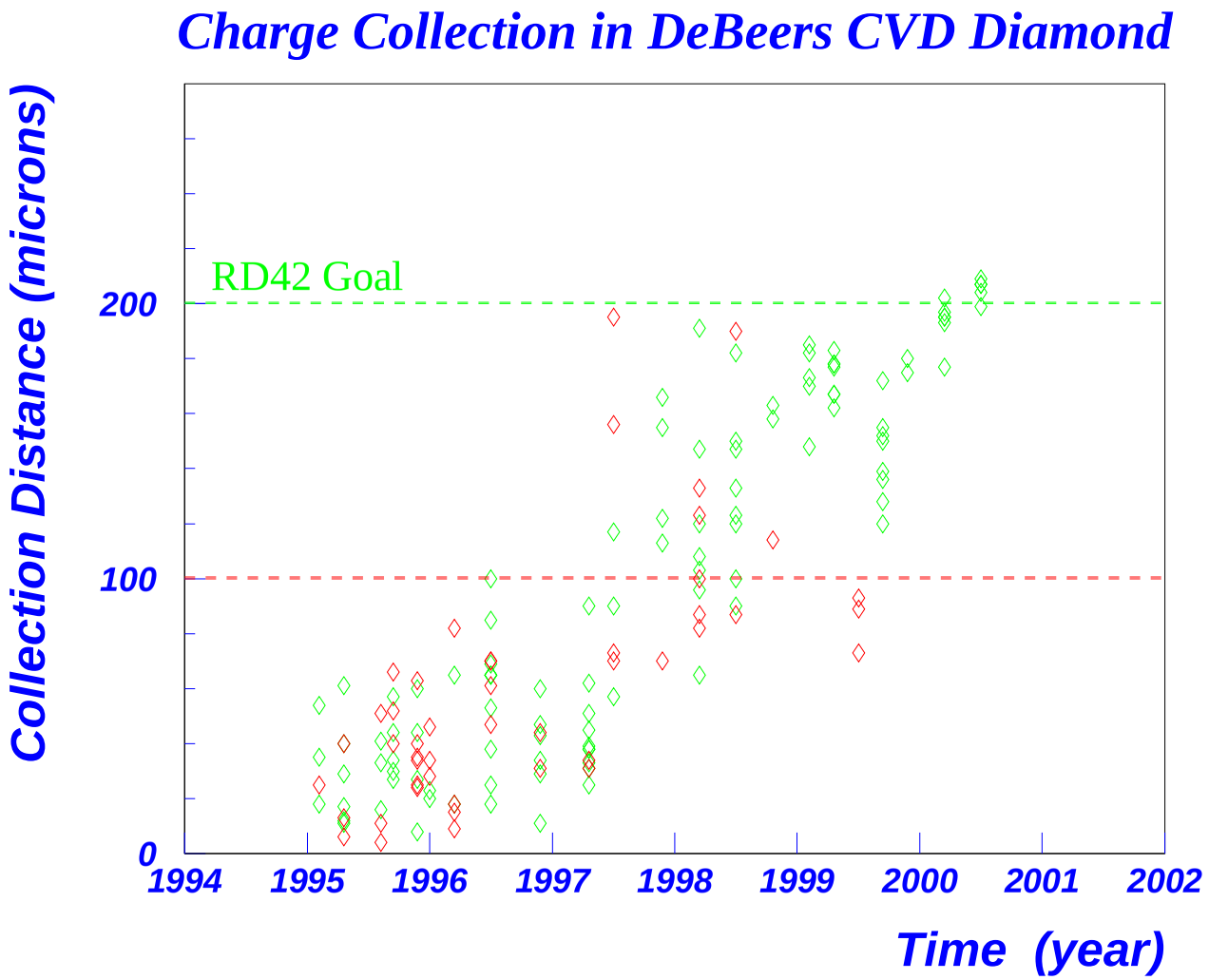




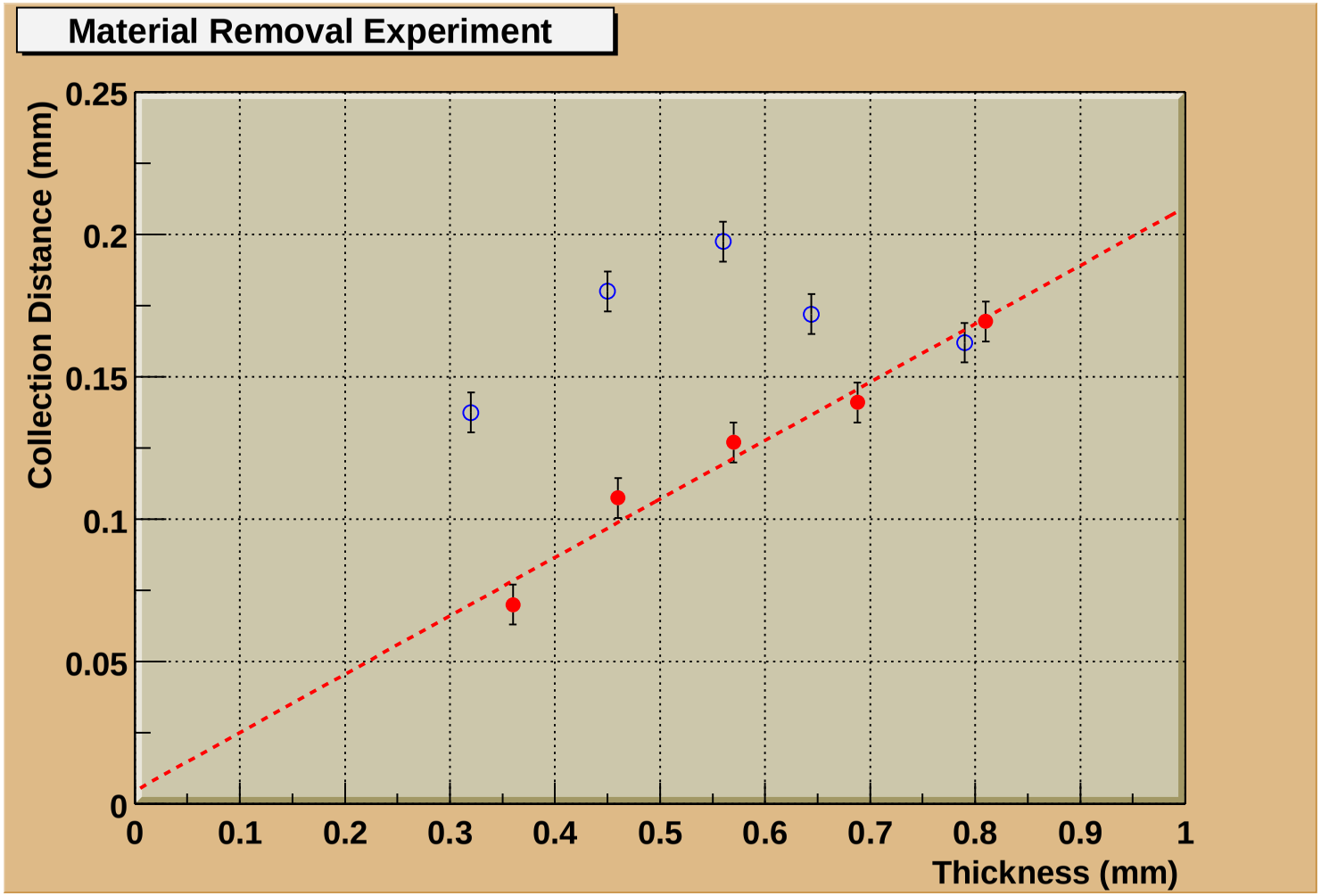
- Test Procedure: dot → strip → pixel
- Source data well separated from 0
- Symmetric charge collection
- Collection Distance routinely 220μm
- Most Probable Charge $\approx 6000e$
- 99% of PH distribution above $2000e$
- FWHM/MP ≈ 0.95 — Si has ≈ 0.5
- This diamond available in 2 x 4 cm^2 sizes



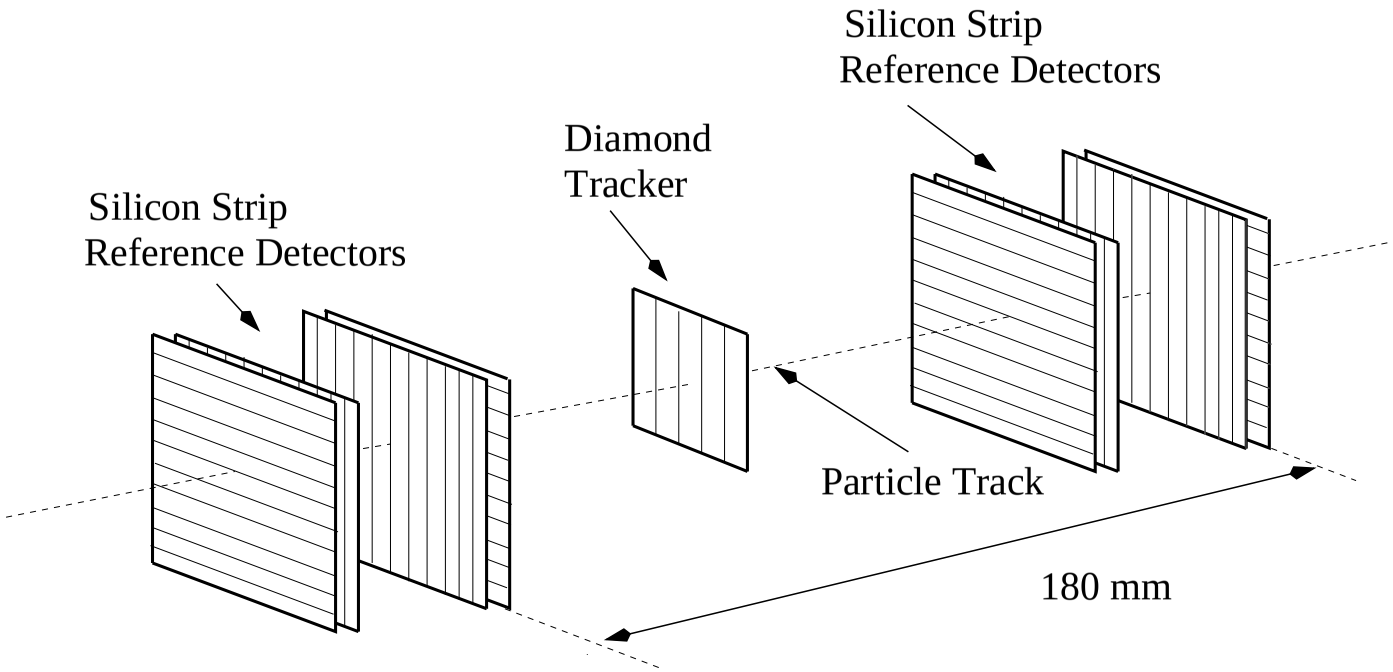
History of Diamond Progress



The Linear Model

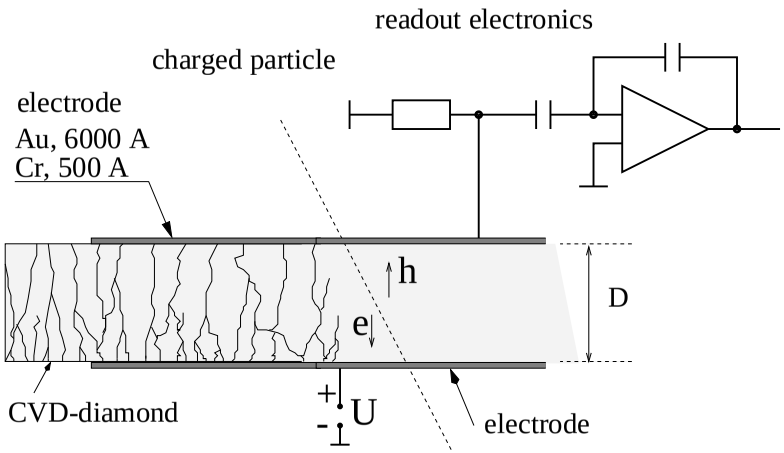


CERN Testbeam Setup:



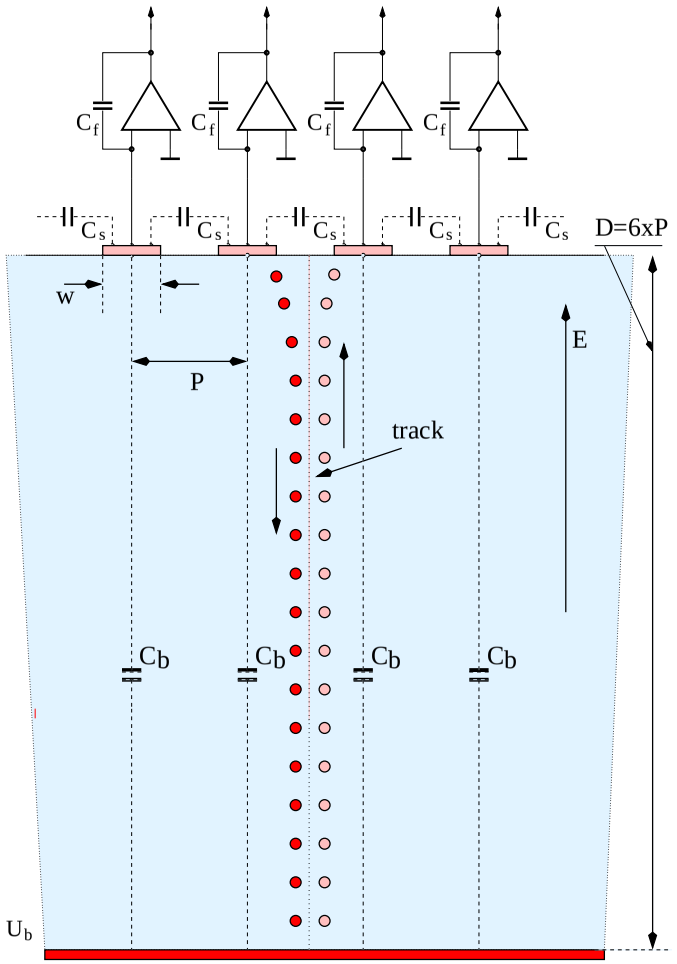
- 100 GeV/c pion beam
- External tracking with "Strassbourg" or "Rutgers" Telescope
- Tracking precision $\approx 2\ \mu$m
- Strip Electronics (2 μsec)
  ENC $\approx 100e + 14e$/pF
- Pixel Electronics (25 nsec)
  Threshold 3500 $\rightarrow$ 1700 e

Principle

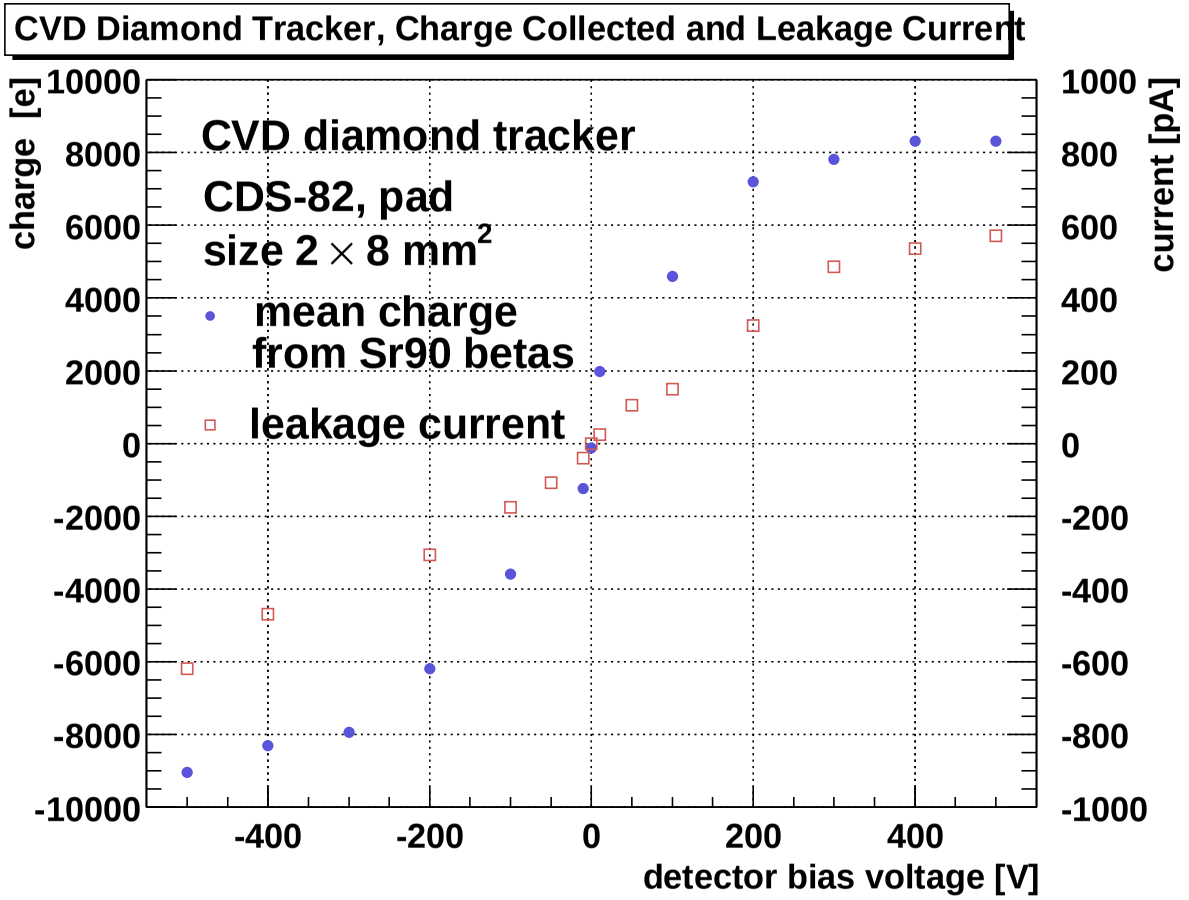


- diamond, contacts on both sides
- apply voltage difference to contacts
- charged particle creates charge carriers
- charge carriers move in elelectric field
- readout using charge sensitive amplifiers

Strips



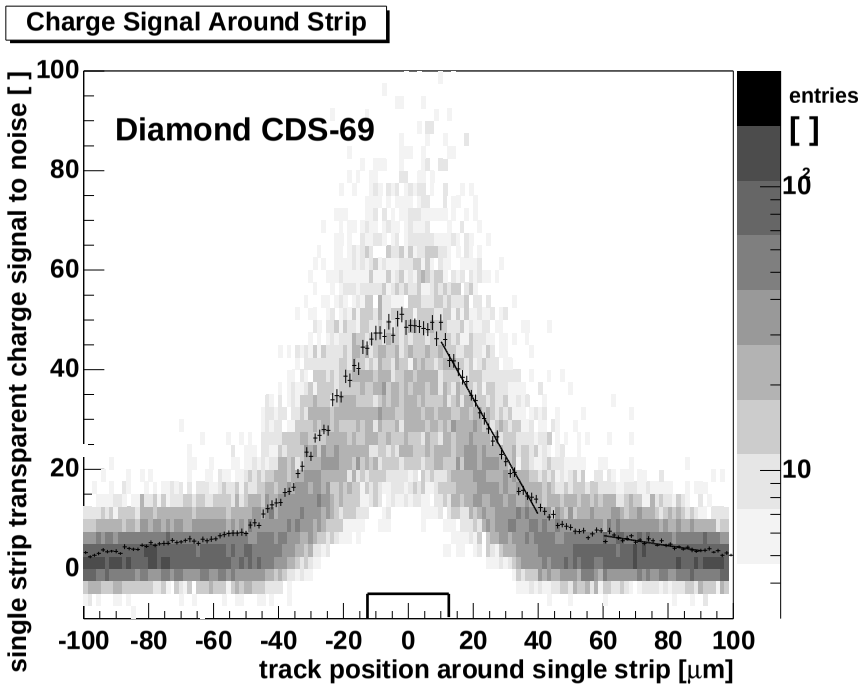
Charge Collection Properties



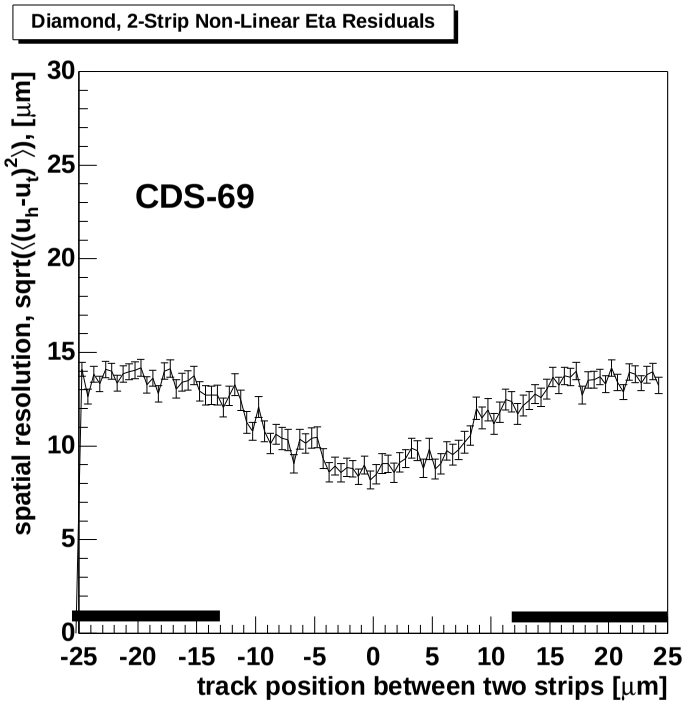
- Charge observed on strips the same as on pads
- Current follows observed charged
- Leakage current small ($< 1\text{pA/mm}^2$)

Tracking Result Details:

Pulse Height vs. Tracking Position



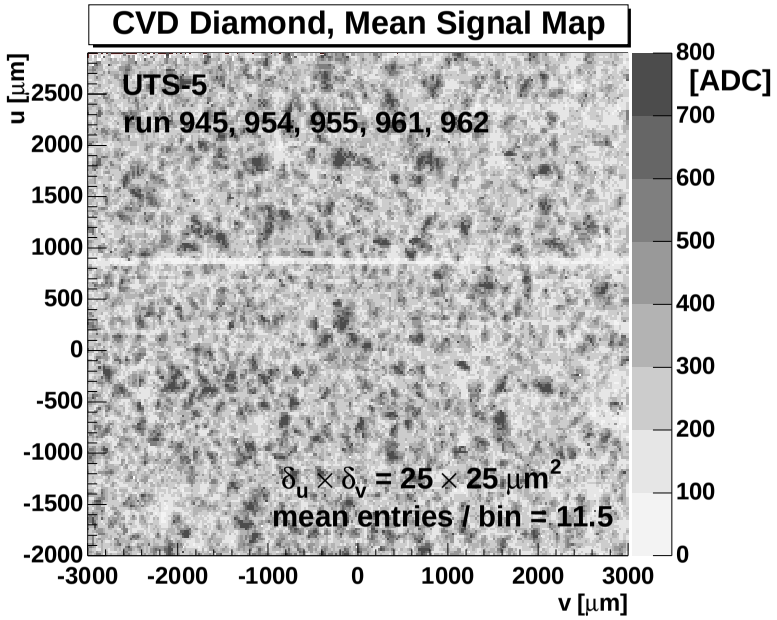
Resolution vs. Tracking Position



- Under strip, little charge sharing $\Longrightarrow$ constant pulse height
- Between strips, linear charge sharing
- Optimize strip width for strip detectors, pixel detectors
- Non-linear η algorithm $\rightarrow$ 7μm resolution between strips

Uniformity:

courtesy of DeBeers Industrial Diamond

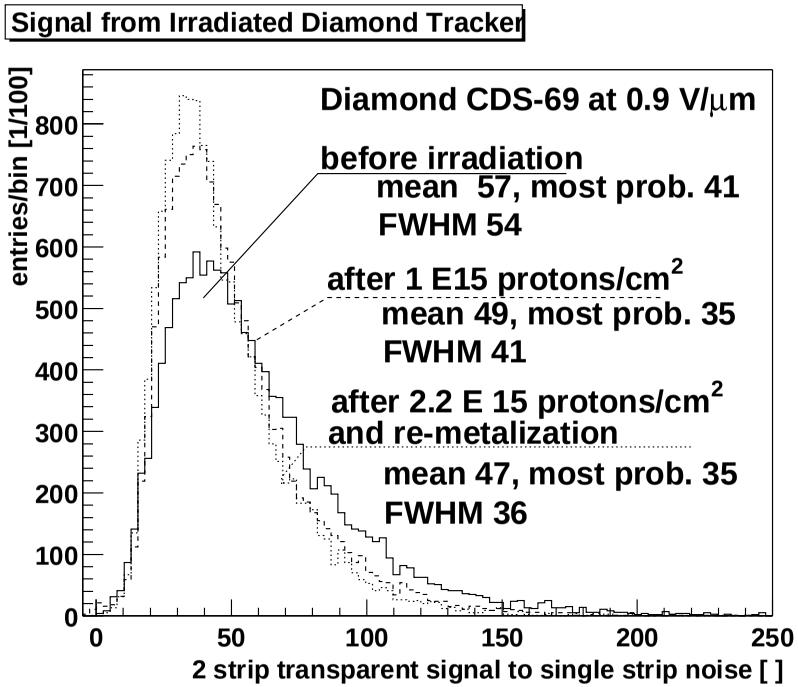


- no visible defects
- wafers diameter larger than 6 inches

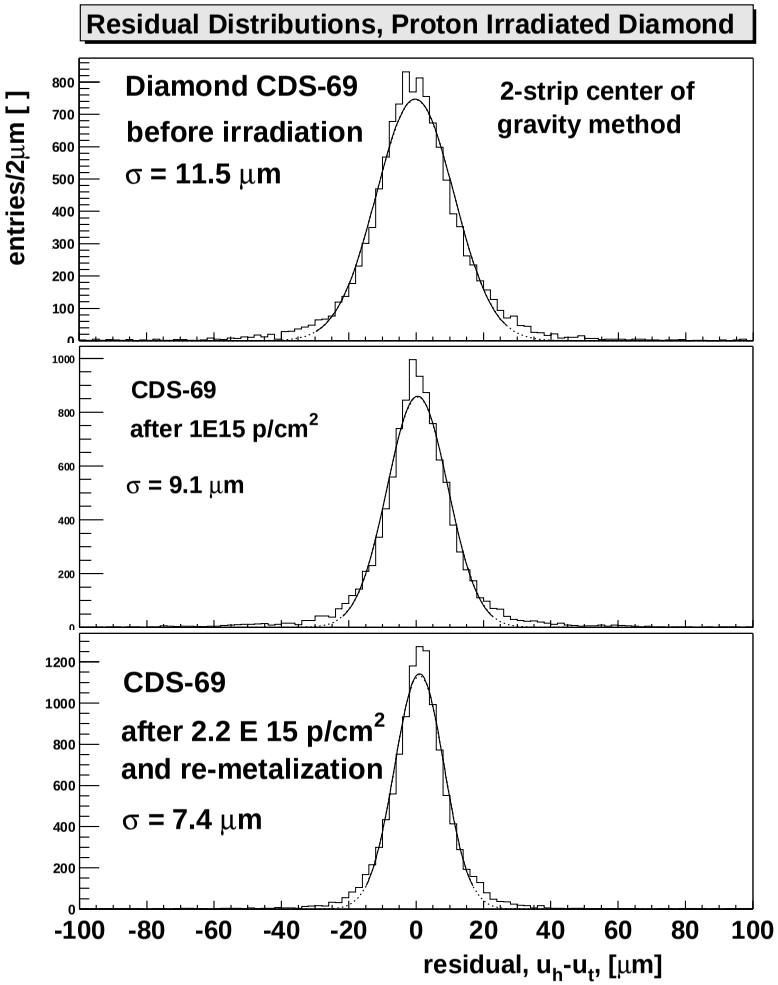
- $25\ \mu\mathrm{m} \times 25\ \mu\mathrm{m}$ bins
- Uniformity (rms/mean) for 11.5 evt/bin
  - Silicon extrapolates $\rightarrow$ 1 %
  - Diamond extrapolates $\rightarrow$ 31 %

Proton Irradiation:

Pulse Height



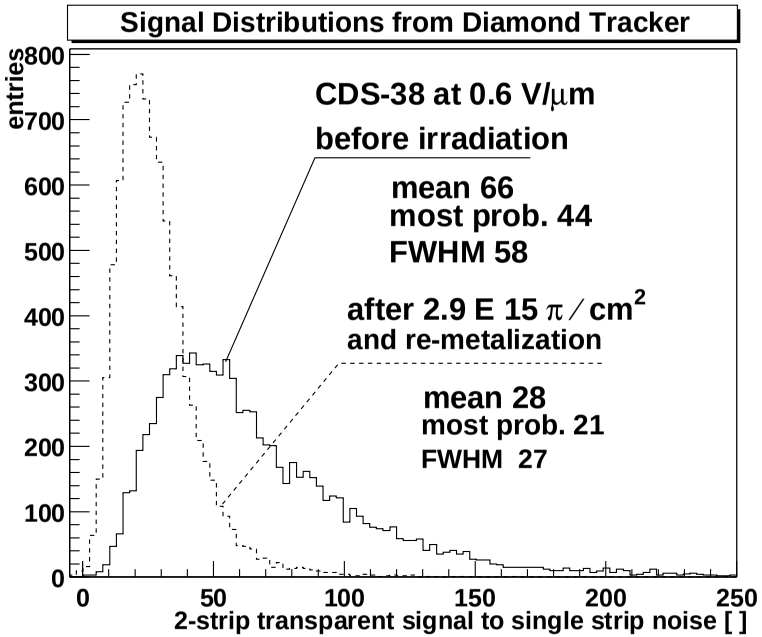
Resolution



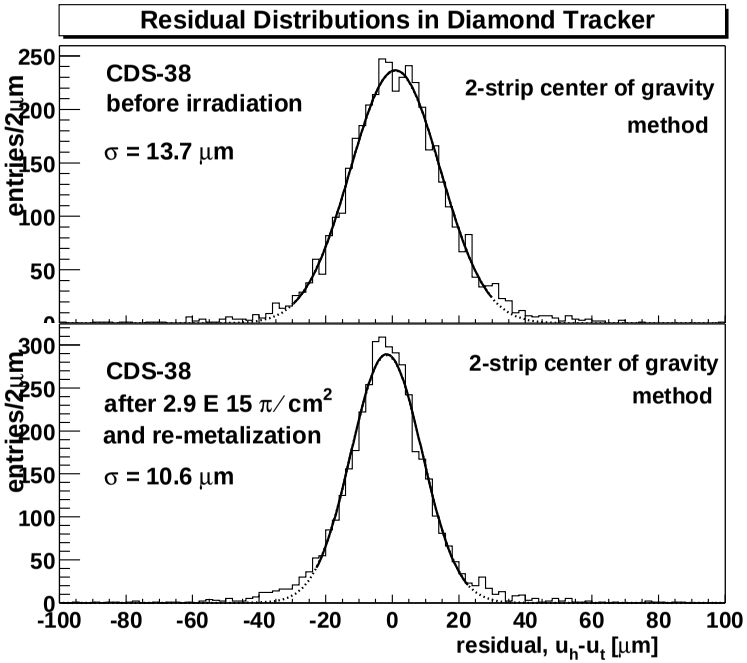
- Data taken over a period of 2 years
- Dark current decreases with fluence
- 15% loss of S/N at $2.2 \times 10^{15}/\mathrm{cm}^2$
- Resolution improves 35% at $2.2 \times 10^{15}/\mathrm{cm}^2$

Pion Irradiation:

Pulse Height

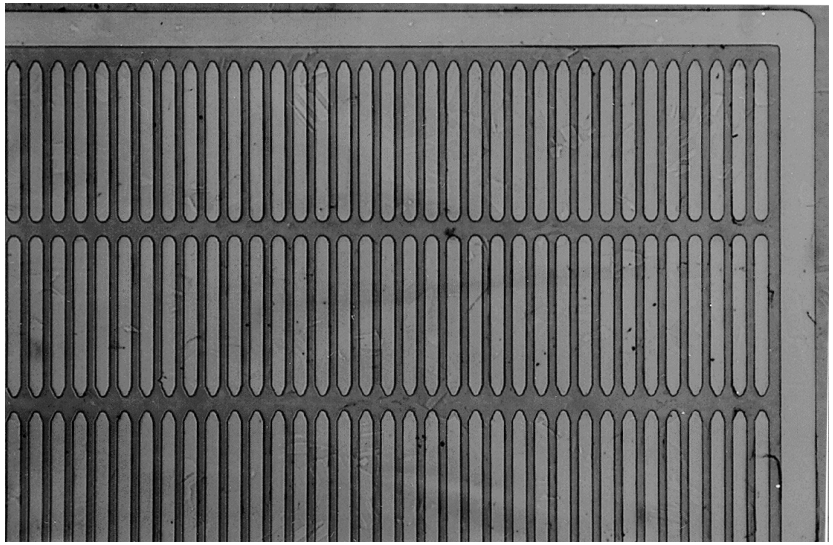


Resolution



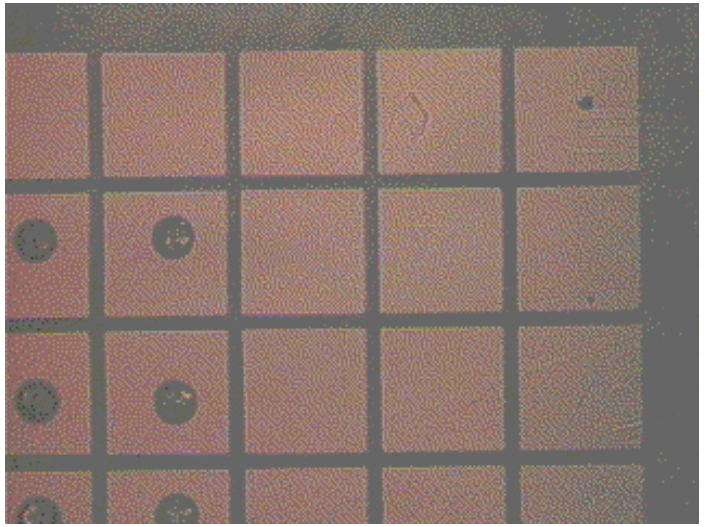
- Data taken over a period of 2 years
- Dark current decreases with fluence
- 55% loss of S/N at $2.9 \times 10^{15}/\mathrm{cm}^2$
- Resolution improves 25% at $2.9 \times 10^{15}/\mathrm{cm}^2$

ATLAS FE/C Pixels (Ti-W)



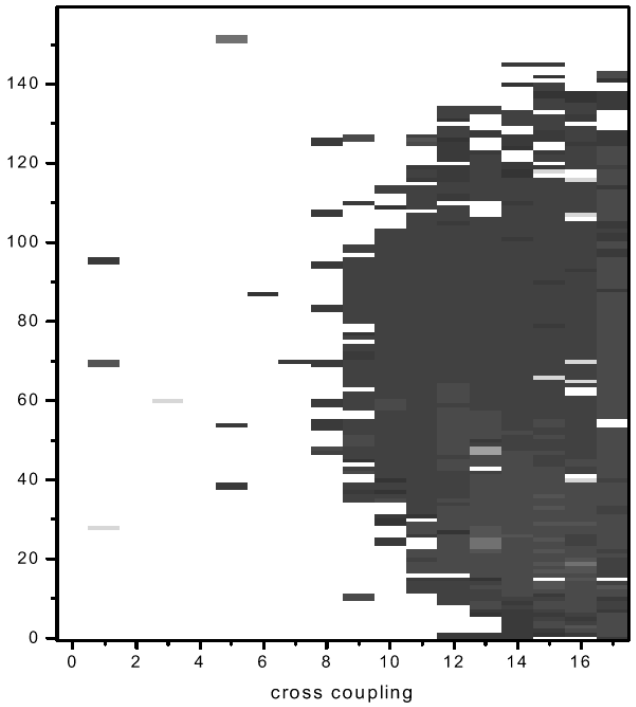
- Atlas pixel pitch 50μm $\times$ 400μm
- Metalization: Ti/W
- Lead-tin solder bumping at IZM in Berlin

CMS Pixels (Ti-W)

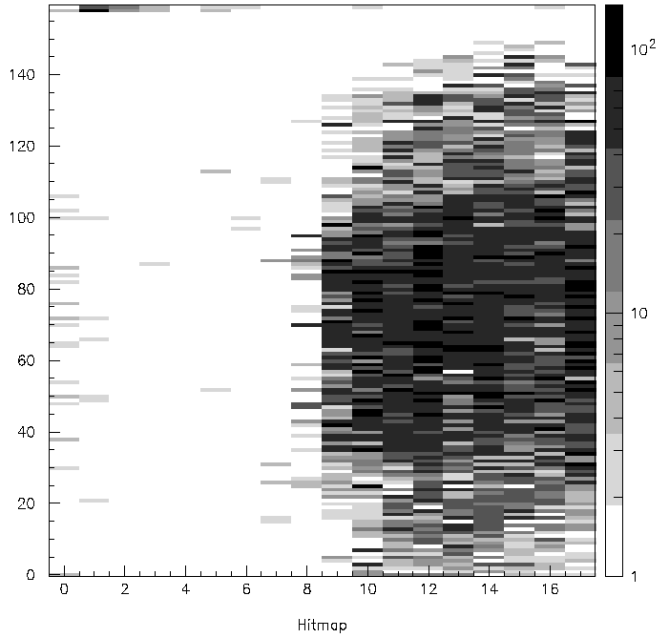


- CMS pixel pitch 125μm $\times$ 125μm
- Metalization: Ti/W
- Indium bumping at UC Davis

Charge Injection Data



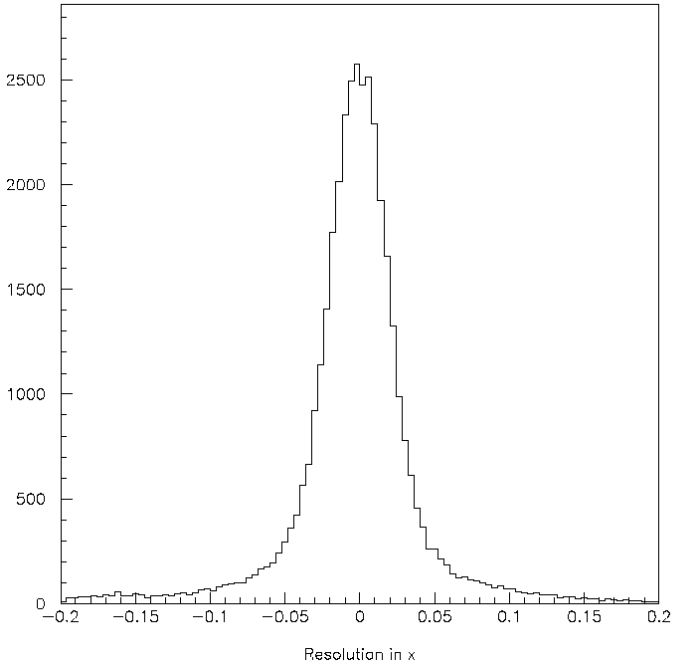
Test Beam Data



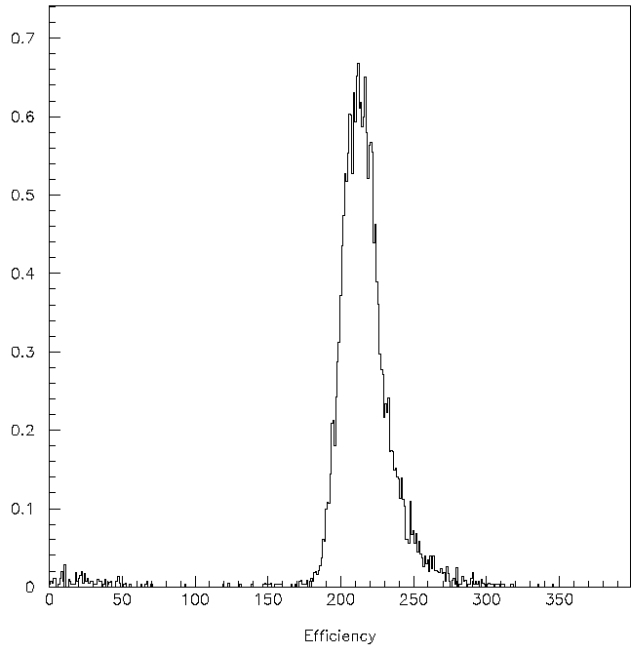
- Detector size 1cm $\times$ 1cm - each detector bump bonded separately
- About 35% of detector bonded

CVD Diamond with ATLAS Pixel Readout

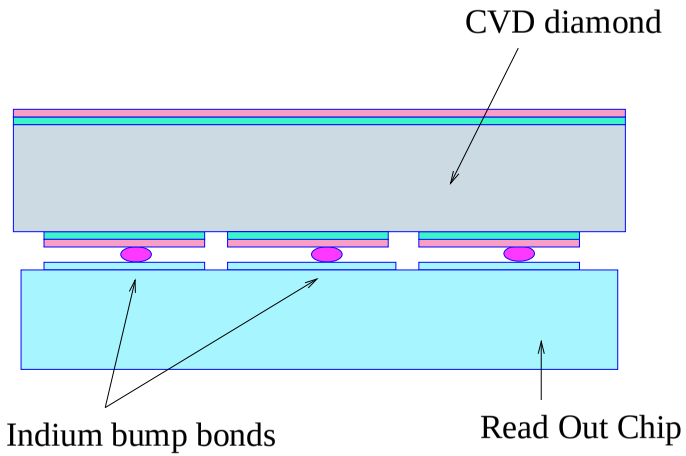
Resolution

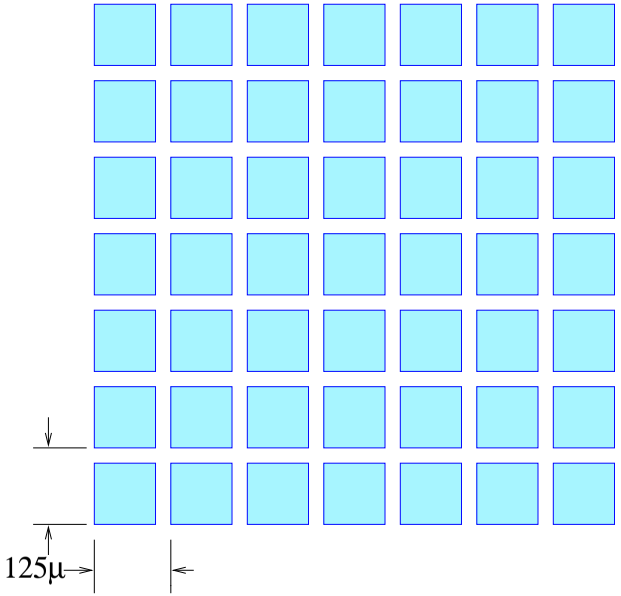


Efficiency in Time

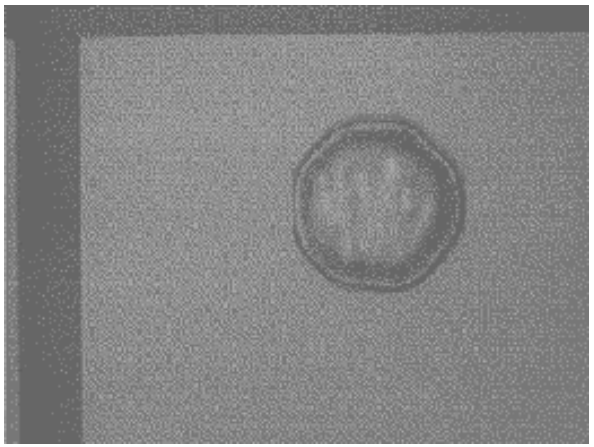


- ATLAS FE-C readout
- FE-C is rad soft $\rightarrow$ diamond was unpumped!
- Digital resolution but timewalk electronic problems??
- New devices ready for test ..... bump bonding much better $\sim 100\%$

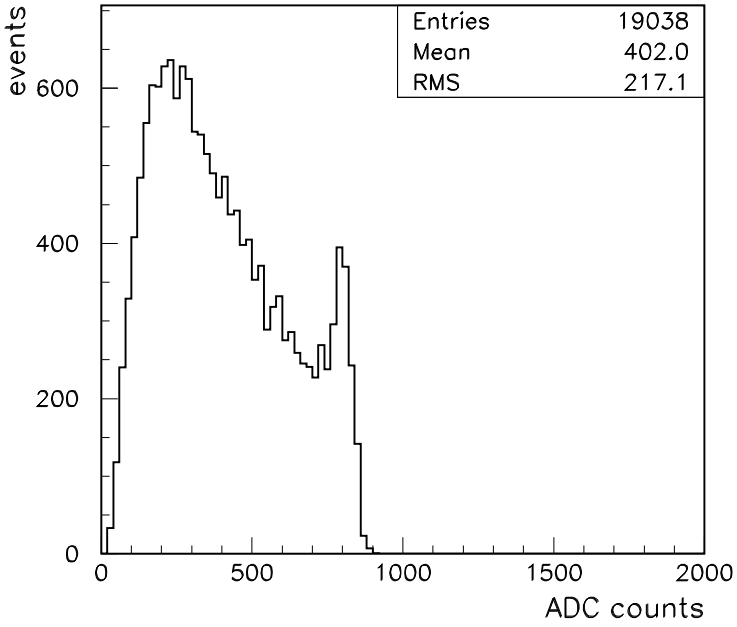


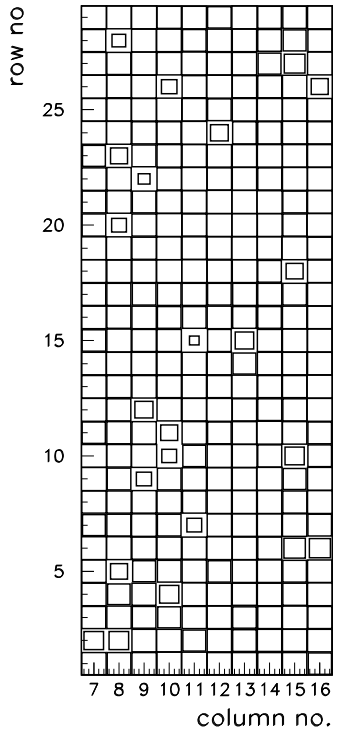


- Active Area: 22 columns x 32 rows
- Diamond Size: 1 cm x 1 cm
- Electronics: PSI30 (Honeywell version)
- Threshold: Adjustable for each pixel



Results from CMS Pixel Detector in CERN beam:

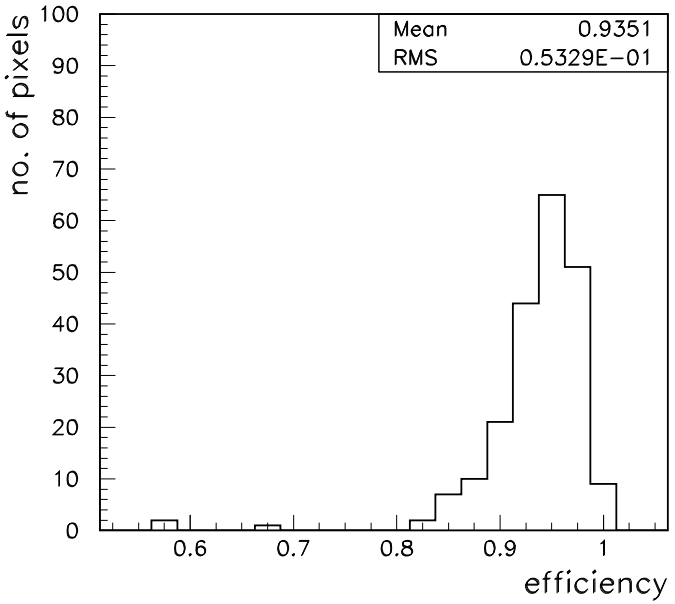




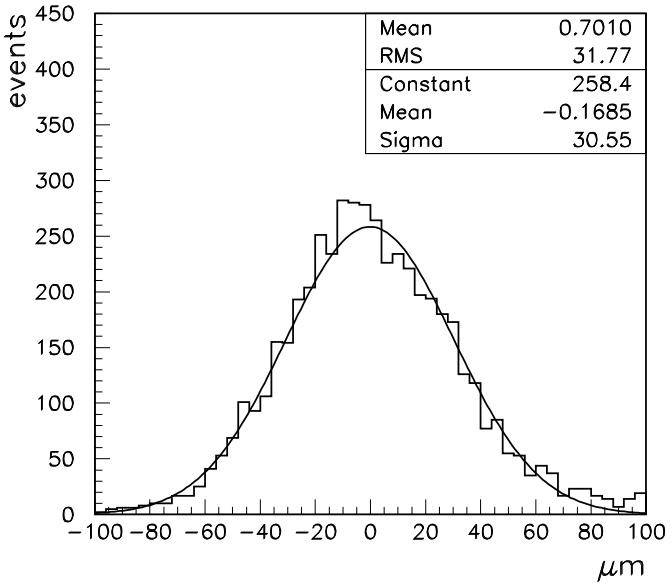
- Bump bonding yield at UC Davis: $\approx$ 100 %
- Thresholds $\approx$ 1500 e
- Noise $\approx$ 750 e (common mode 500 e)
- Excellent track and pixel hit correlation

Results from CMS Pixel Detector in CERN beam:

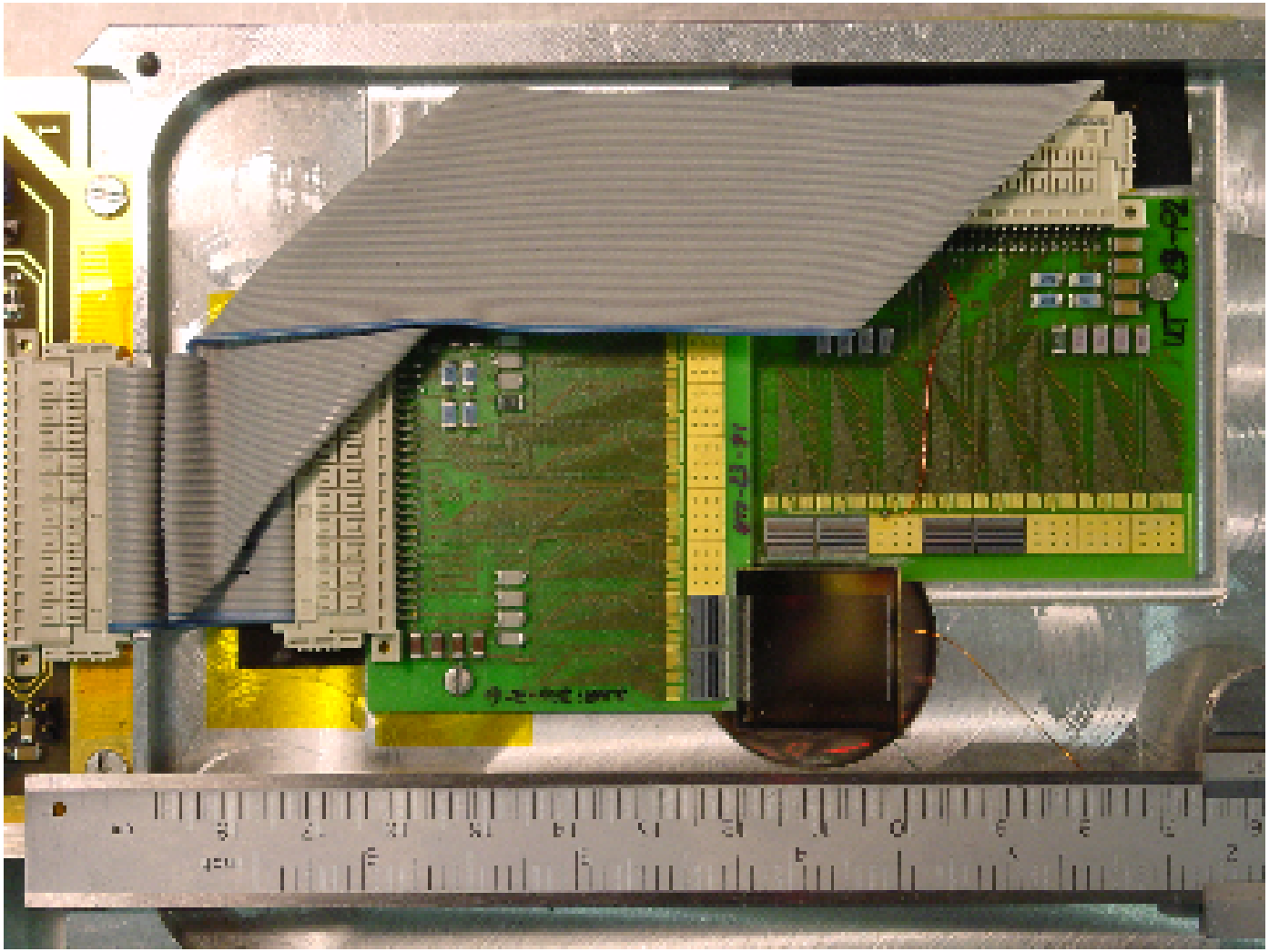
Efficiency



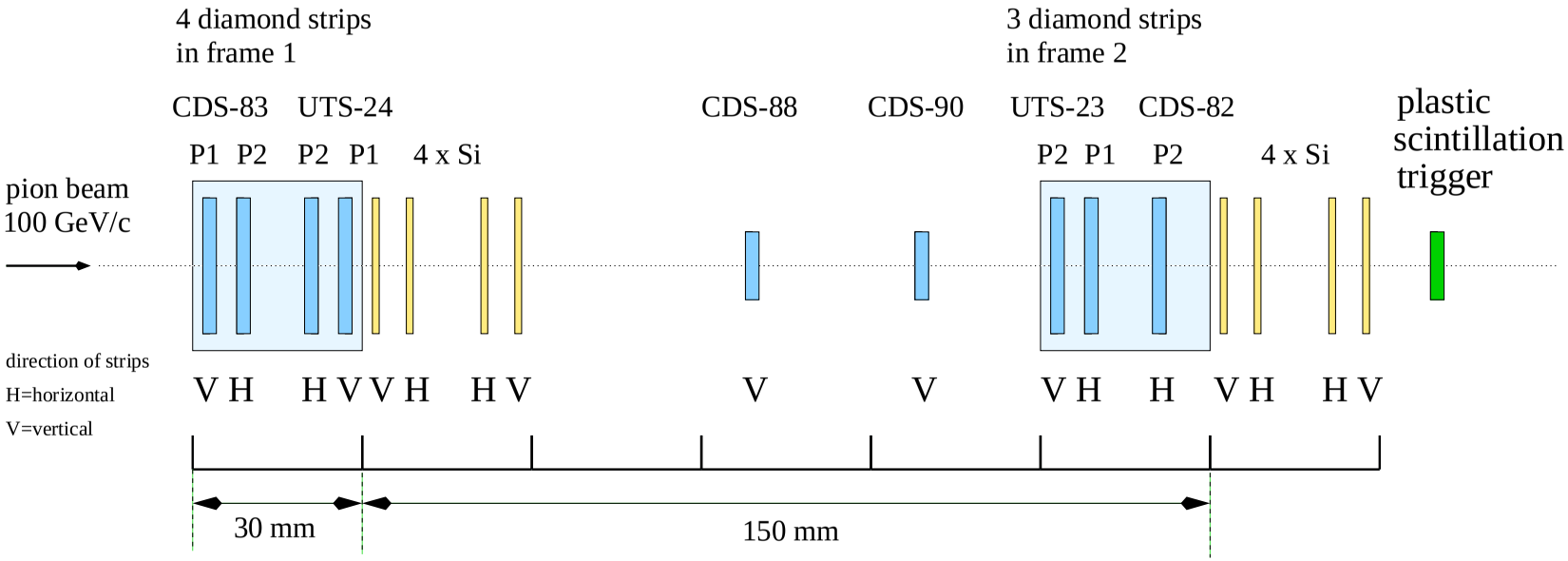
Resolution



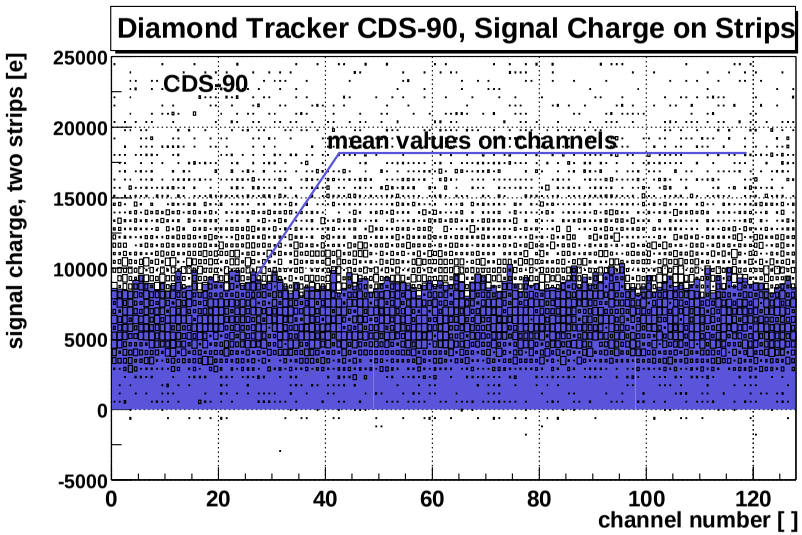
- 18/290 pixel electronics channels not working
- Mean efficiency $\sim$ 94%
- Resolution (COG) $\sim 30\mu$m
- Almost viable of diamond pixel detector

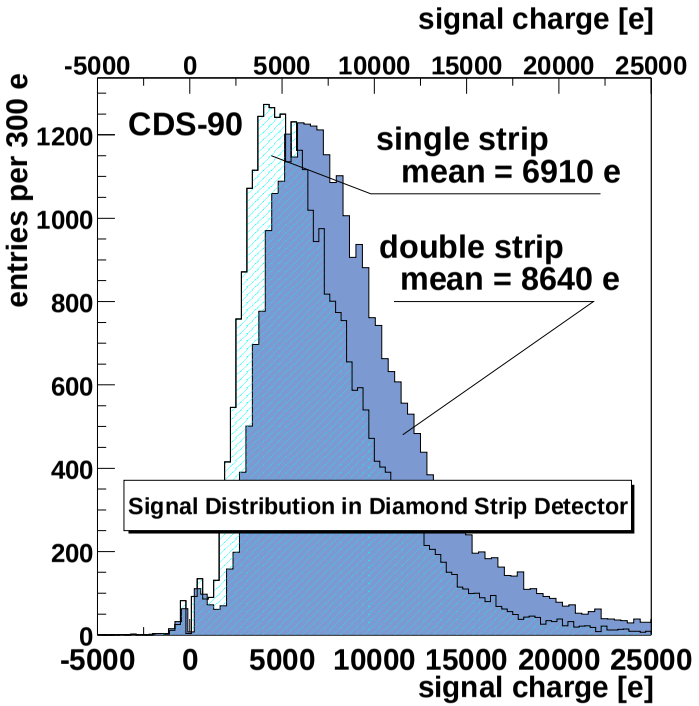


CVD Diamond Beam Telescope



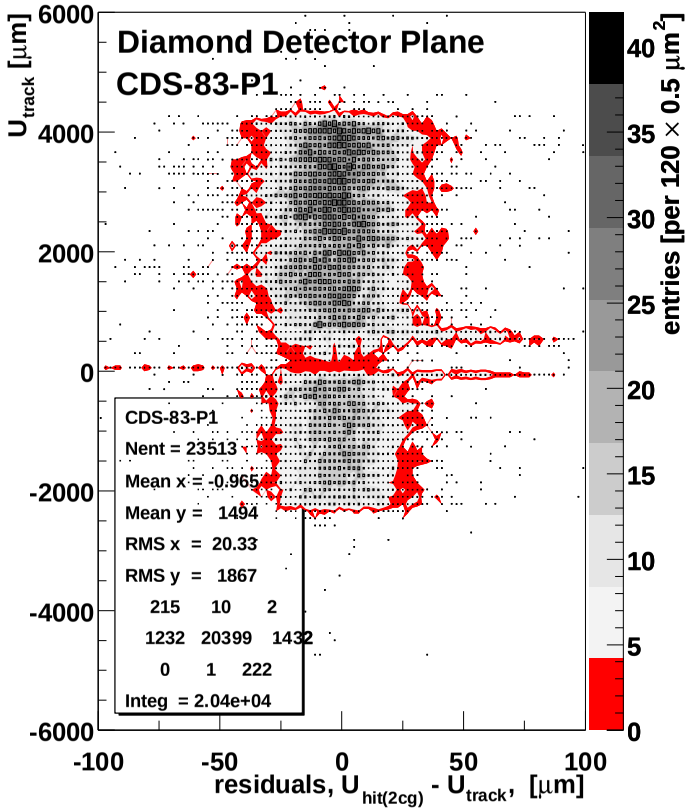
- 100 GeV/c pion/muon beam
- 7 planes of CVD diamond strip sensors each 2cm $\times$ 2cm
- 2 additional diamond strip sensors for test
- several silicon sensors for cross checks



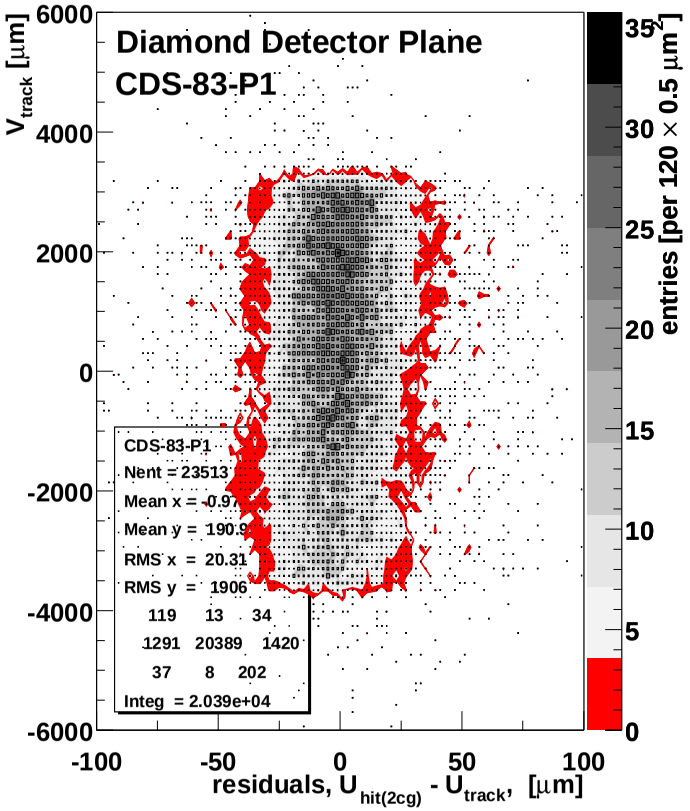


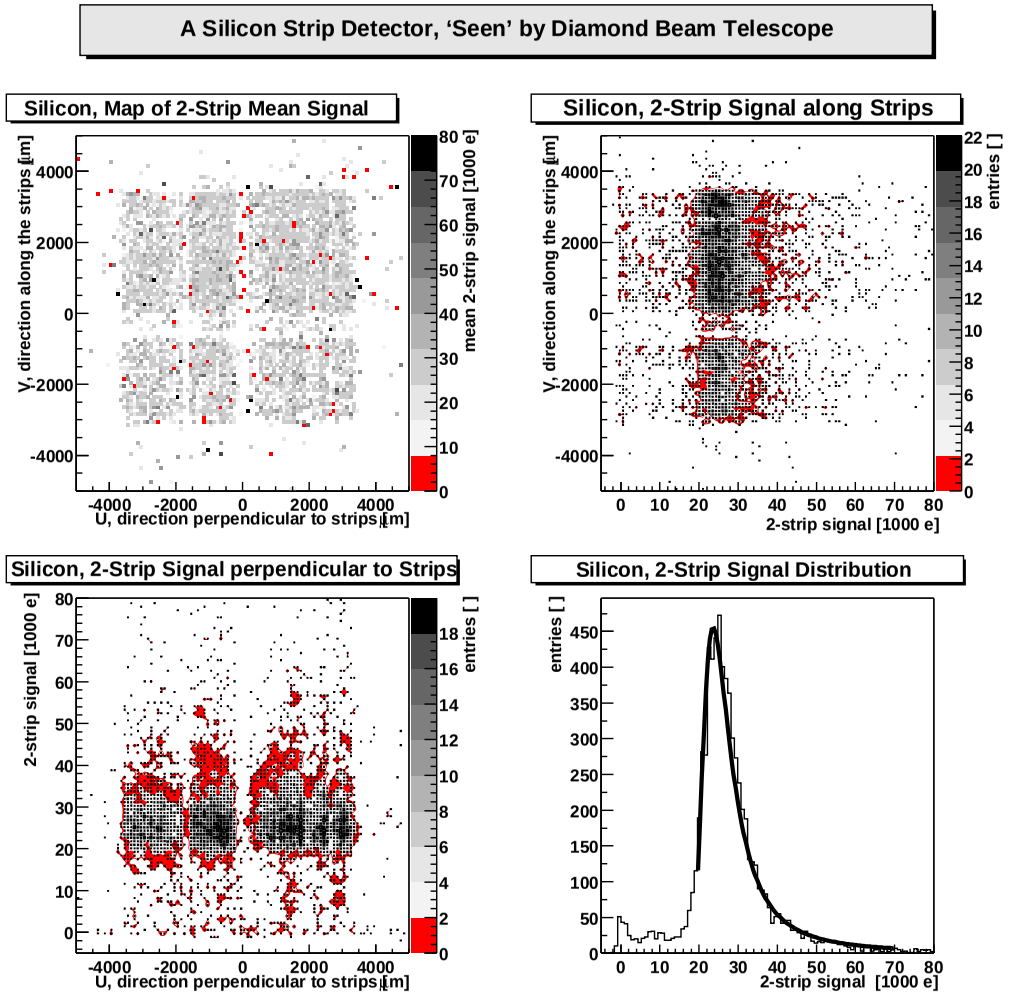
- Uniform signals on all strips
- Pedestal separated from "0" on all strips
- 99% of entries above 2000 e
- Mean signal charge $\sim$ 8640 e
- MP signal charge $\sim$ 6500 e

Residuals perpendicular to Strips



Residuals along Strips





95% of Diamond Telescope tracks are associated with hits in silicon!

Summary

Charge Collection

220 μm collection distance now routine

MP signal $\approx$ 6,500 e

99% of charge distribution above 2000 e

FWHM/MP $\sim$ 0.95 – Working with manufacturers to increase uniformity

This diamond available in almost any size

Strip detectors (50 μm pitch) get $S_{mp}/N = 45/1$

Strip detectors (50 μm pitch) get $\sigma \approx 10$ μm

Radiation Hardness of Diamond Trackers

Using trackers allows a correlation between S/N and Resolution

With Protons:

- Dark current decreases with fluence
- 15% loss of S/N at $2.2 \times 10^{15}/\text{cm}^2$
- Resolution improves 35% at $2.2 \times 10^{15}/\text{cm}^2$

With Pions:

- Dark current decreases with fluence
- 55% loss of S/N at $2.9 \times 10^{15}/\text{cm}^2$
- Resolution improves 25% at $2.9 \times 10^{15}/\text{cm}^2$

All tests will be repeated with more trackers

Summary

- **Diamond Pixel Detectors**
  - Successfully tested ATLAS pixel patterns
    - Bump bonding yield (IZM) was >90 %
    - Excellent correlation between telescope and pixel data
    - Digital spatial resolution for 1500 e threshold
  - Successfully tested CMS pixel patterns
    - Bump bonding yield (UC Davis) was 100 %
    - Excellent correlation between telescope and pixel data
    - Better than digital spatial resolution for 1500 e threshold
- **Diamond Telescope**
  - Successfully operated 7 planes 2cm $\times$ 2cm
  - Works very well for first attempt $\rightarrow$ in progress

Future Plans for RD42

- **Charge Collection**

  Research program to improve material in progress:

  collection distance $\rightarrow$ 300μm ($\bar{Q} = 10,800e$)

  $\rightarrow$ improved uniformity

  $\rightarrow$ identification of trapping centers

- **Radiation Hardness of Diamond Trackers and Pixel Detectors**

  Continue tracker irradiations in the next year, add pixel irradiations

  With Protons:

  $\rightarrow 5 \times 10^{15}/\text{cm}^2$

  With Pions:

  $\rightarrow 5 \times 10^{15}/\text{cm}^2$

- **Develop LHC prototype pixel detectors and strip detectors**