Performance of Proton Irradiated Diamond Detectors

The RD42 Collaboration
presented by
D.Meier

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Contents

CVD Diamond Detectors

RD42 Collaboration

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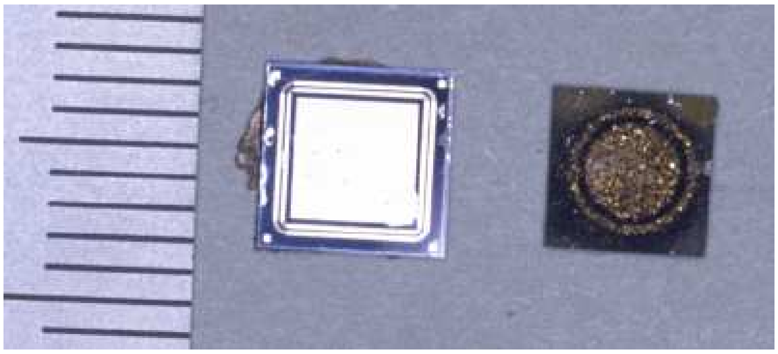
Application in High Energy Physics

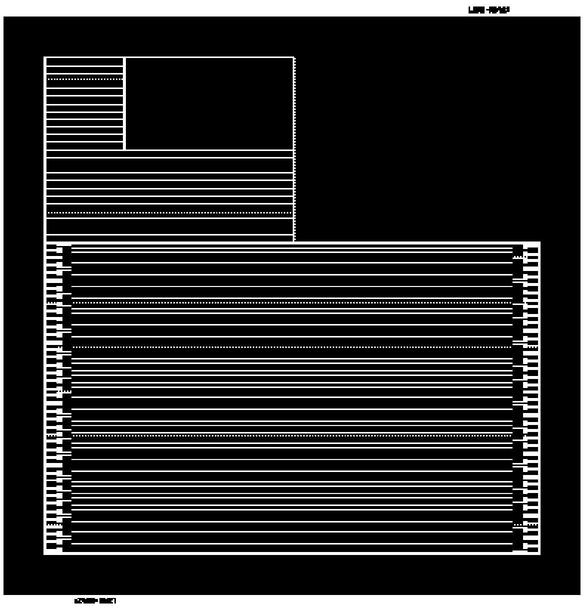
- **C**hemical **V**apour **D**eposition diamond detector substrate
- thickness between about 100 μm to 2.6 mm possible
- disk sizes 4 inch diameter
- **Particle Tracking** using
  Strips on diamond substrate
  (e.g. 50 μm pitch, length order(cm)), or
  Pixel patterns (e.g. ATLAS or CMS geometries)
- Important Parameters
  Charge signal, charge collection distance (now $\approx$ 250 μm)
  spatial track **resolution**, about digital resolution
  Detection **efficiency**, normaly $\geq$ 95 % on tested strip detectors
  noise, low leakage **current**, low **capacitance**
- **Radiation Resistance** of diamond
  electrons up to 100 MRad, γ up to 10 MRad
  300 MeV/c pions, 1 MeV neutrons (work in progress)
  protons in this report

Diamond Detector Samples

- Irradiated diamond samples with dot contacts on both sides
- thickness $\approx 700~\mu$m, size 5×5 mm^2



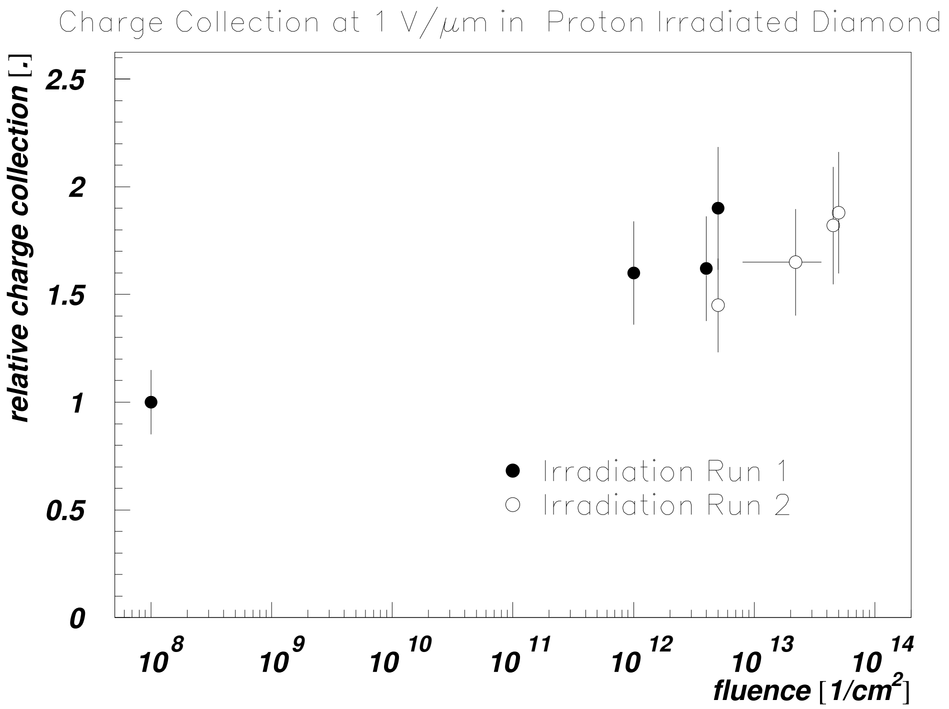
Strip mask of irradiated diamond detector, thickness 470 μm, size 1×1 cm^2, with 50 μm and 100 μm pitch strips, rectangular dot and guard ring.



Charge Collection

CVD diamond proton irradiation before 1997

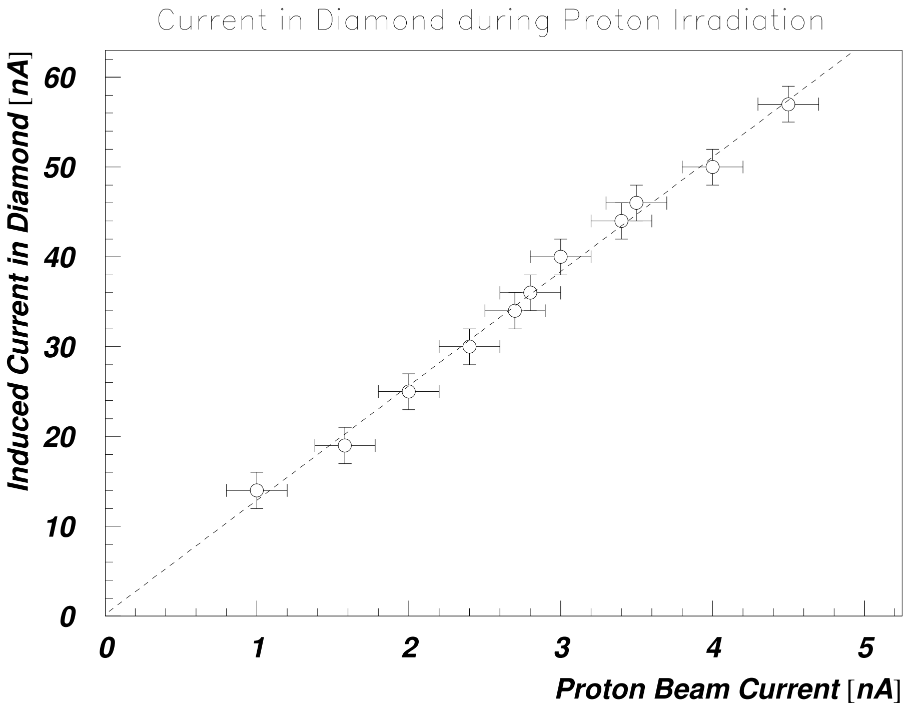
- Proton irradiation at TRIUMF, 1994 and 1995
- **Proton fluence:** $\approx 8 \times 10^{13}\ p/\mathrm{cm}^2$
- **Proton flux:** $\approx 8 \times 10^{8}\ p/\mathrm{cm}^2/\mathrm{s}$
- **Proton momentum:** 500 MeV/c



- no decrease in charge collection

Induced Current

- **Proton flux:** $\approx 8 \times 10^8\ p/\mathrm{cm}^2/\mathrm{s}$

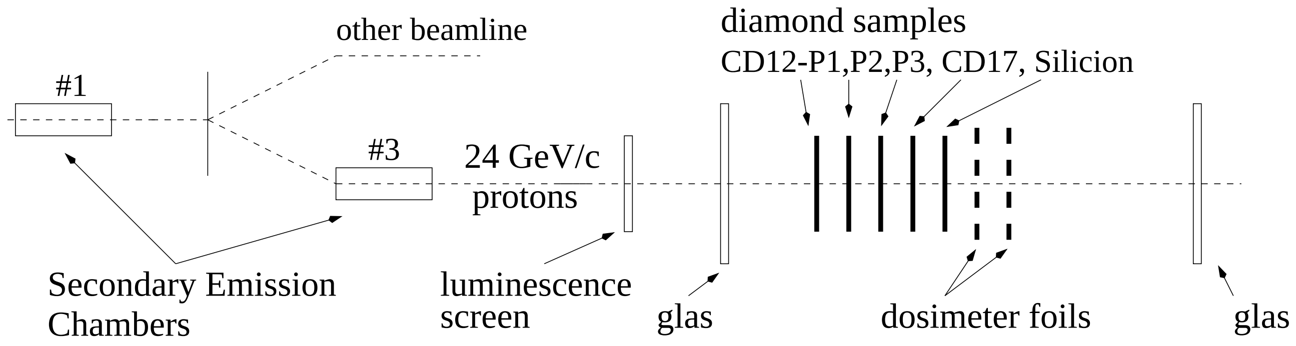


- induced current is proportional to proton flux

Proton Irradiation, CERN, 1997

- RD42 in ATLAS/SCT proton irradiation
- **Date:** two weeks in June 1997
- **Location:** CERN, Proton Synchrotron, beamline T7

  Irradiation setup

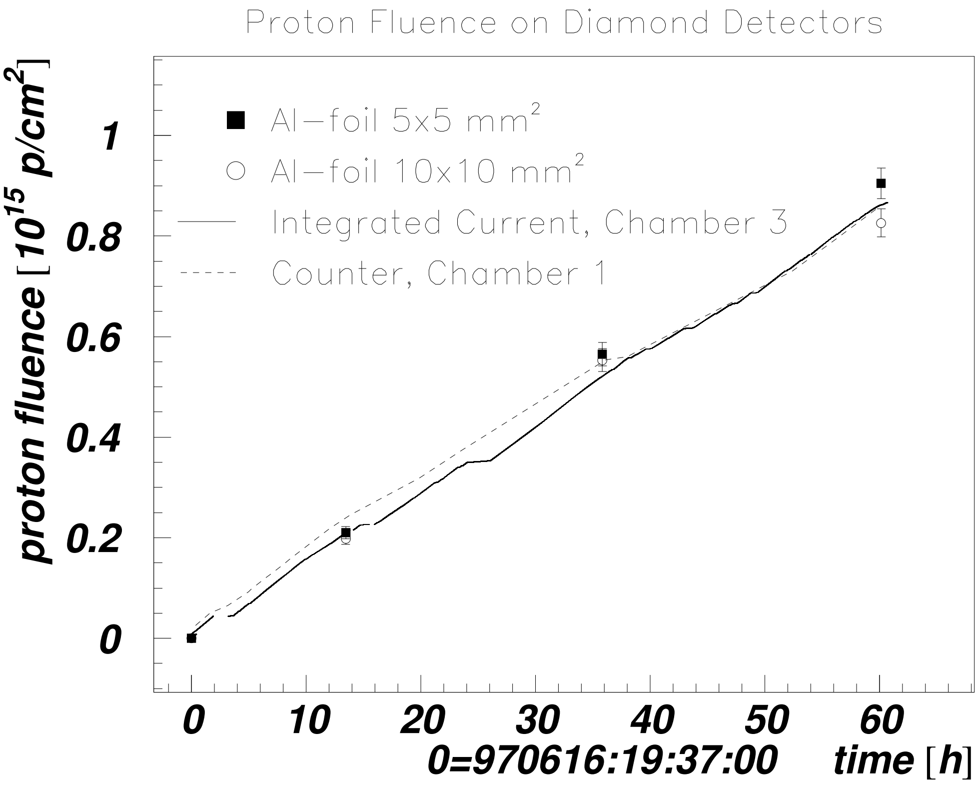


- **Proton fluence:** 0 to 5×10^{15} p/cm^2
- **Proton flux:** up to 2.9×10^{10} p/cm^2/spill,

  one spill of 300 ms, twice or three times in 14 s
- **Proton momentum:** 24.2 GeV/c

Dosimetry

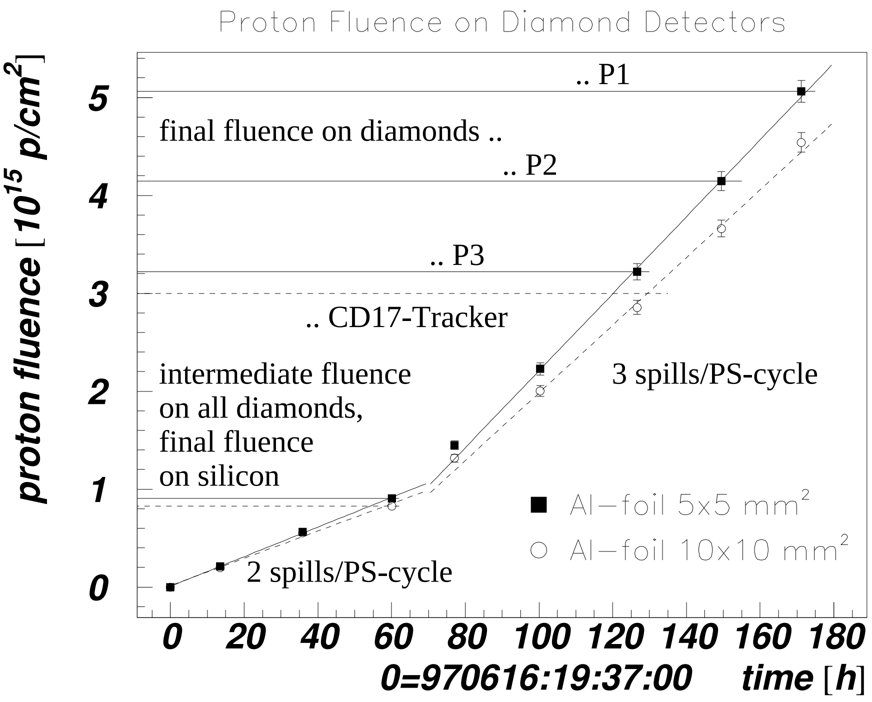
- Dosimetry
  1. Al-foils and ^{24}Na activation
  2. Counting clock from emission chamber (SEC1)
  3. Summing current from emission chamber (SEC3)



- Values from both emission chambers interpolate foil dosimetry

Samples and Final Fluences

- Three diamond samples, same wafer
- One diamond tracker, similar quality like other three samples
- One silicon diode (p-on-n, 350 μm) for comparison
- Irradiation at room temperature



- After 70 h irradiation increase from 2 spills to 3-spill extraction
- Final fluence $5 \times 10^{15}\ p/\mathrm{cm}^2$

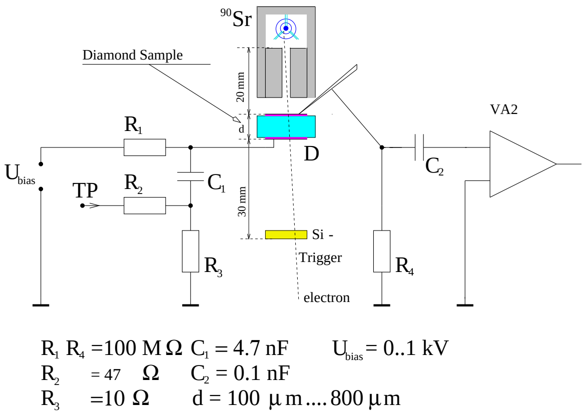
Charge Collection, Setup and Signal

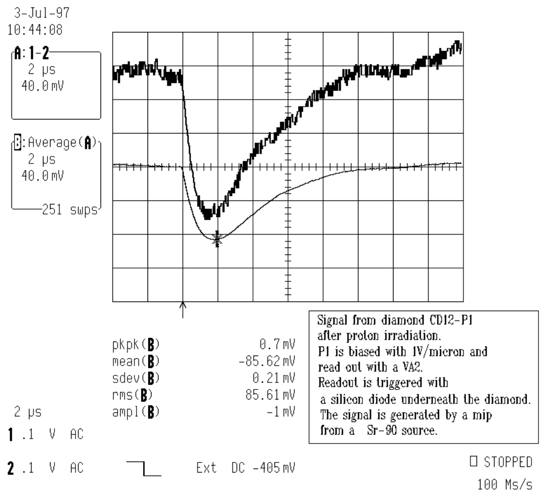
- Diamond connected to high voltage on e.g. growth side
- Collimated ^{90}Sr β-source illuminates sample
- Substrate side of diamond is coupled to readout chip
- Readout:

  VA2-chip, 128 channels,

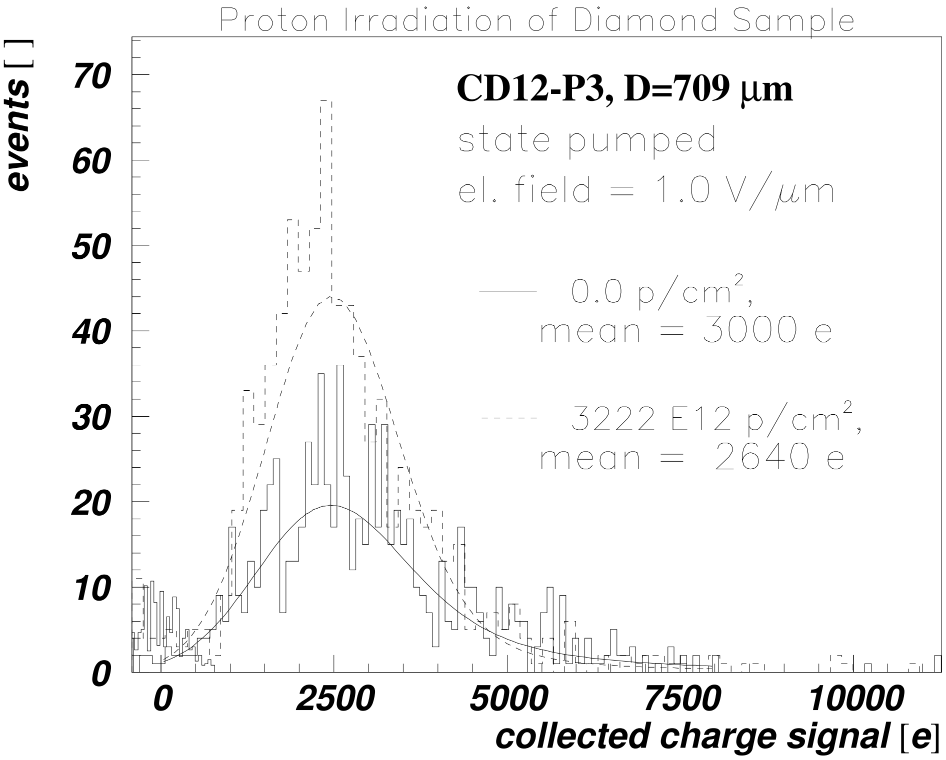
  charge integration, signal shaping of 2 μs.

  Low noise of 80 e^- ENC on 20 mm^2 sample.
- Silicon diode in line with diamond and source triggers readout



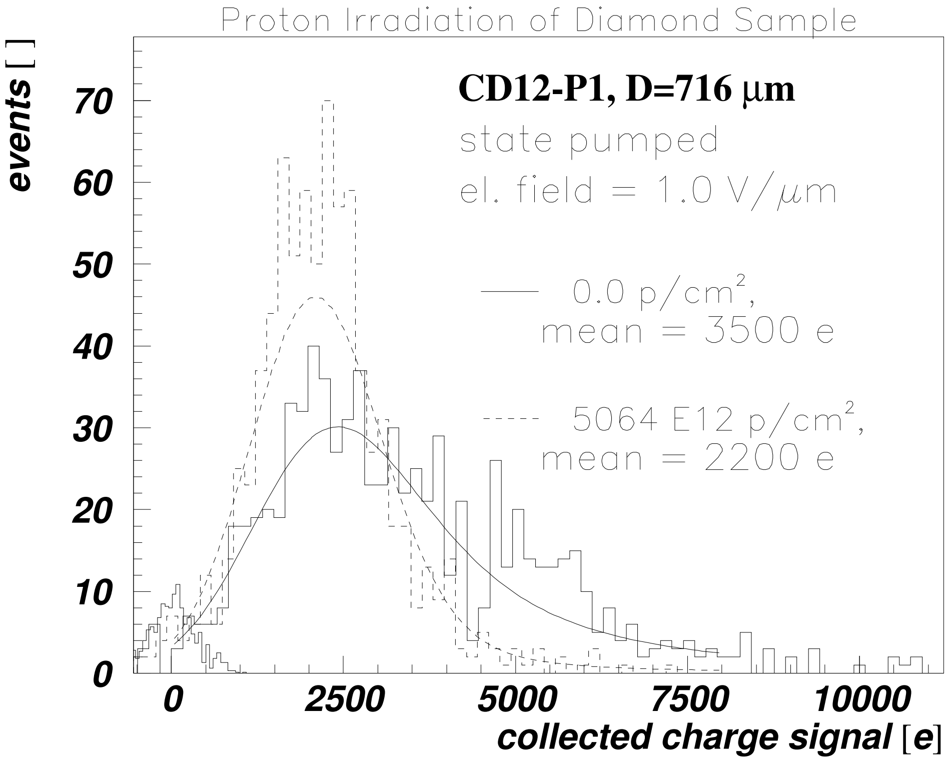


Charge Collection, Histogram



- **Landau-Gauss-convolution** fits charge signal distribution
- About 12% decrease observed at 3×10^{15} p/cm^2
- Most probable value shows no decrease after irradiation

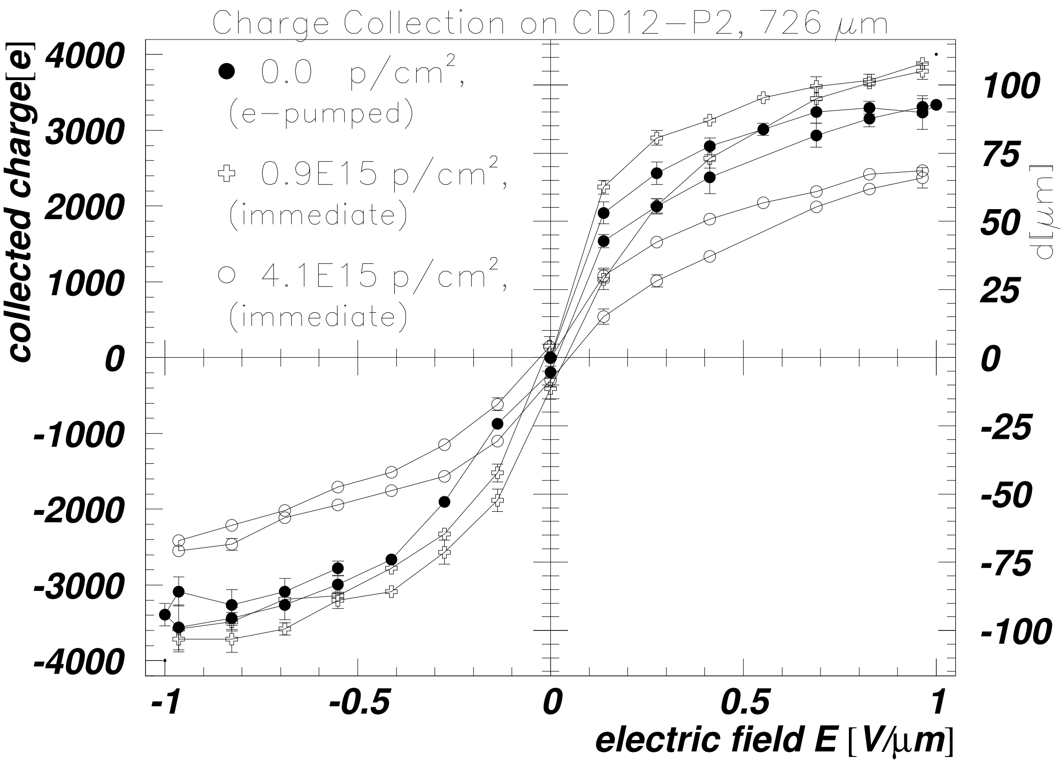
Charge Collection, Histogram



- **most probable** signal constant up $5 \times 10^{15}\ p/\mathrm{cm}^2$
- **mean value** decreases by ≈40% due to less events in Landau tail

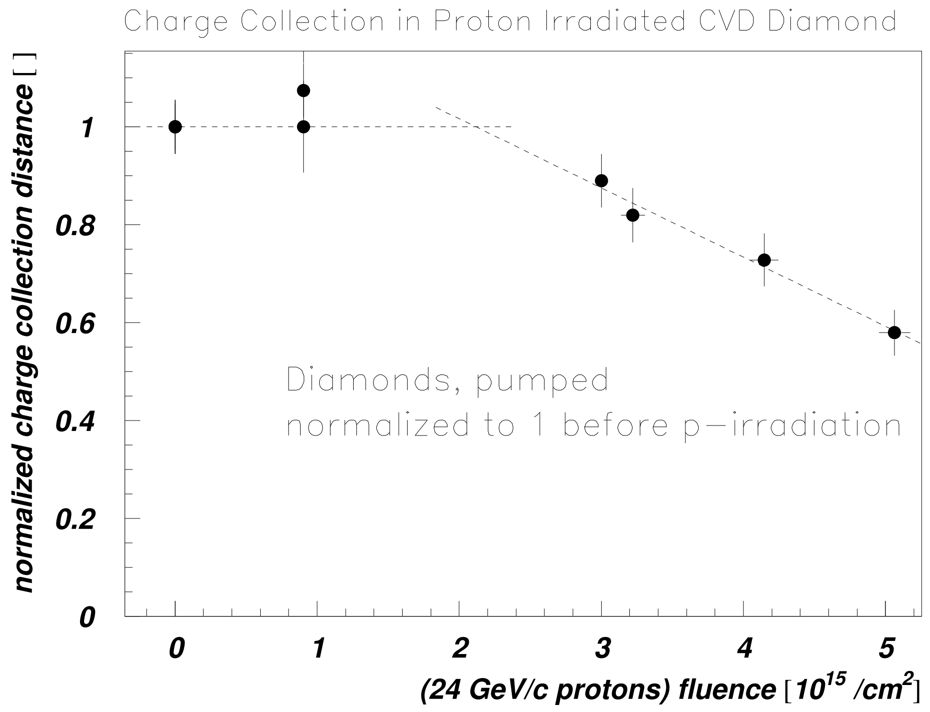
Charge Collection vs Voltage

- charge collection vs voltage (example)



Pumped Charge Collection vs Fluence

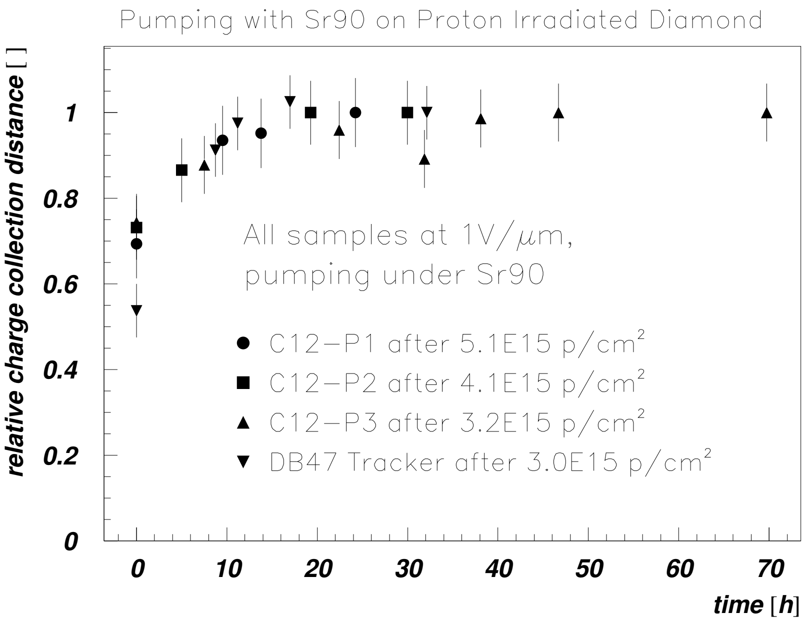
- Charge collection distance after irradiation



- Charge collection distance measured
  constant up to $1 \times 10^{15}\ p/\mathrm{cm}^2$
  decrease between $(3 \times 10^{15} ... 5 \times 10^{15})\ p/\mathrm{cm}^2$
  slope $-14\ \%/10^{15}\ p/\mathrm{cm}^2$
  fits intersect at $2 \times 10^{15}\ p/\mathrm{cm}^2$
- **Conclusion**: decrease in ccd sets in at $2 \times 10^{15}\ p/\mathrm{cm}^2$

Pumping Charge Collection

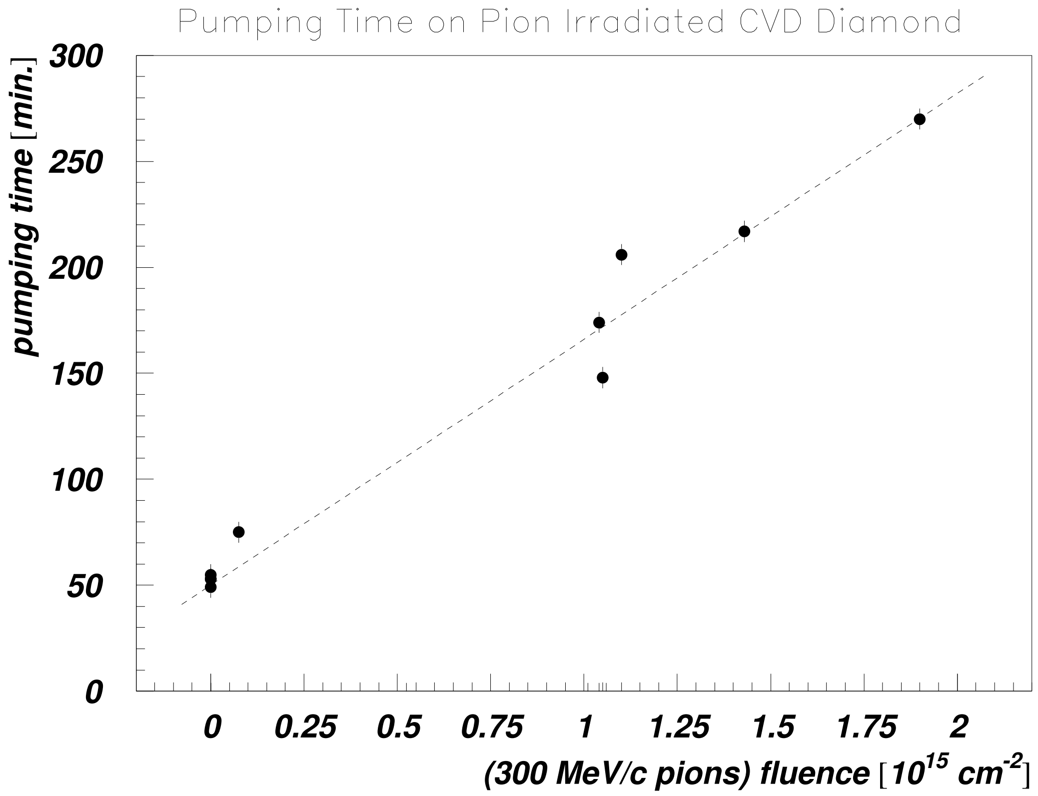
- Exposure to e.g. ^{90}Sr pumps diamond and ccd increases
- Illumination with fluorescent light releases traps, ccd decreases
- Measure charge collection during exposure to ^{90}Sr



- Samples are pumped after proton irradiation
- Fluorescent light decreases ccd, but ^{90}Sr pumping of ccd in 10 h possible
- Here 10 h under ^{90}Sr correspond to 10 krad

Pumping Charge Collection

- Comparison with **Pion irradiated** samples



- Observation:

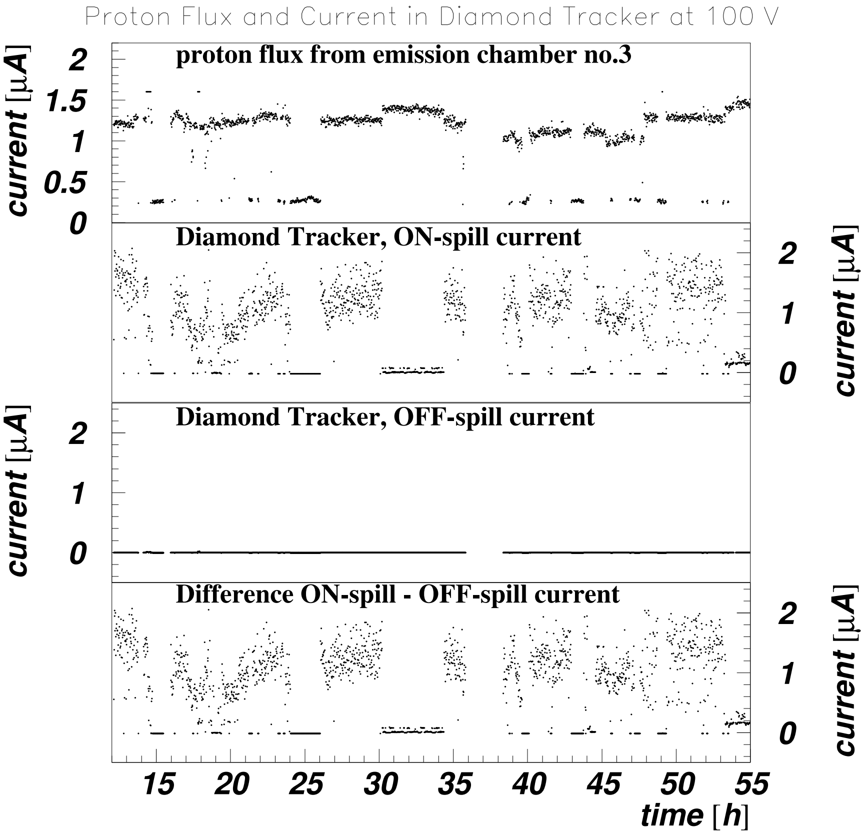
  ccd pumping is exponential with time

  slope of exponential pumping is proportional to fluence

  ... this measurement is planed on proton irradiated samples

Induced Currents during Irradiation

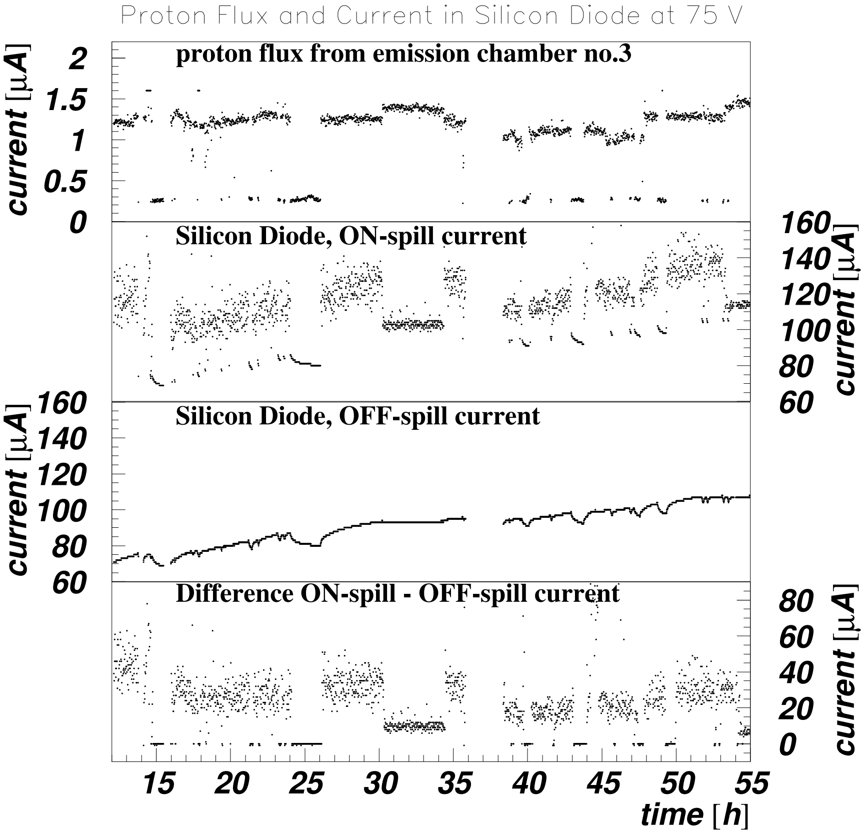
- Measure current in diamond during irradiation
- **On-spill** is $\approx$ 300 ms protons passing sample
- **Off-spill**, no protons, 'most' of the time in 14 s PS cycle



- On-spill currents correlate with proton flux
- Off-spill current **diamond: constant** (nA) up to $1 \times 10^{15}\ p/\mathrm{cm}^2$

Induced Current in Silicon

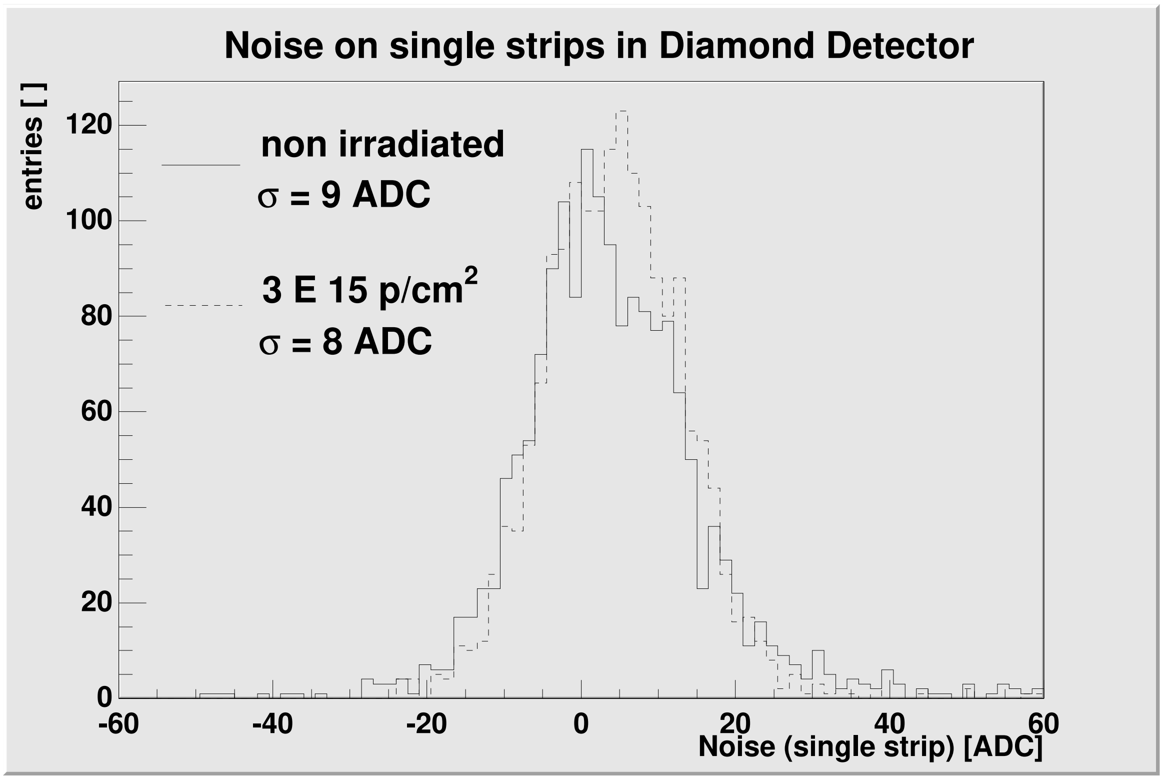
- .. and silicon for comparison



- On-spill currents correlate with proton flux
- Off-spill current **silicon: increase** (μA)

Noise

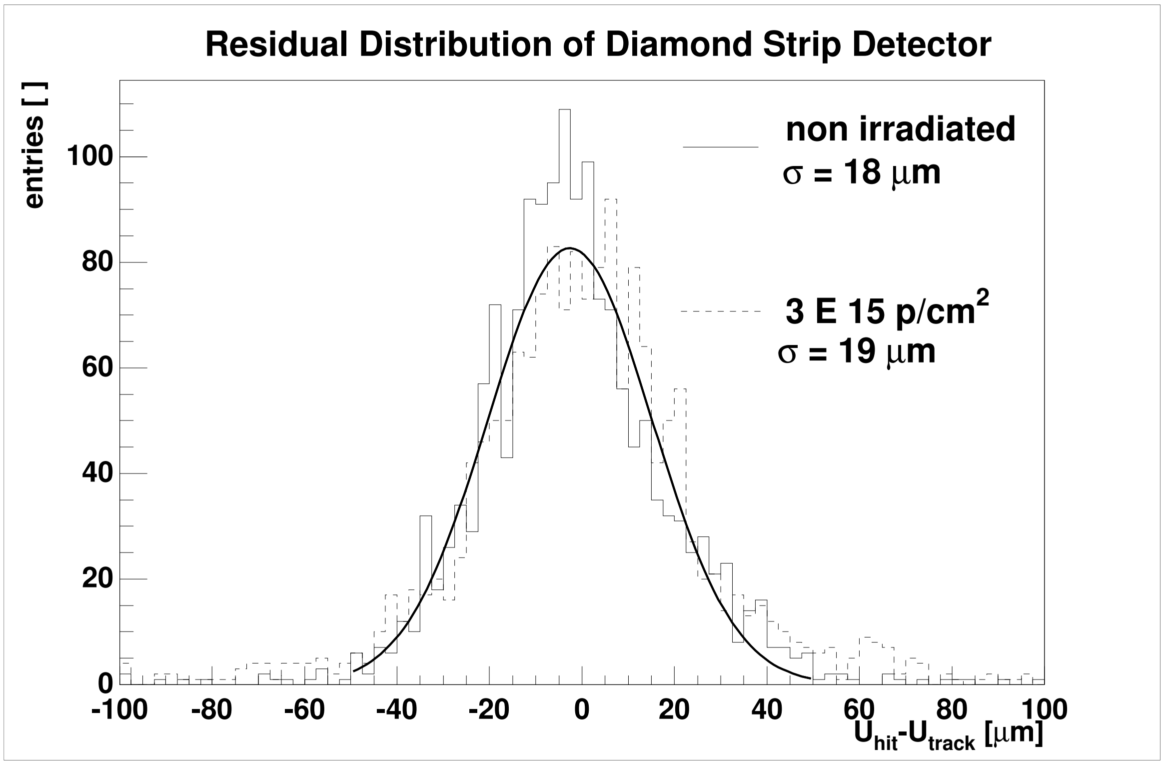
- Signal distribution on strips which had no hit give noise
- Noise is determined by front end amplifier,
- ... here 130 e..150 e per strip



- Noise about unchanged after irradiation

Spatial Resolution

- Difference between measured hit and predicted track position
- ... gives nearly Gaussian residual distribution
- here **center of gravity method**



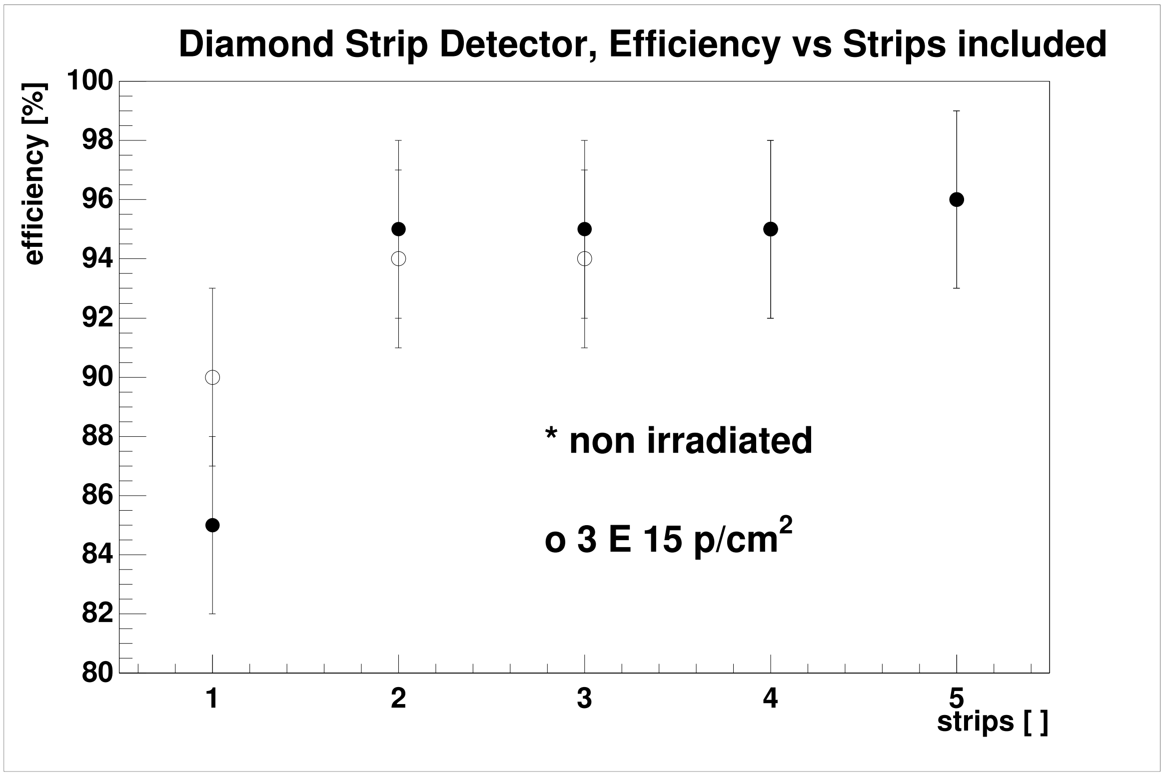
- Standard deviation is spatial resolution about 18 μm
- Resolution is unchanged to before irradiation

Efficiency (PRELIMINARY)

- Definition of **efficiency**

$$\text{efficiency} = \frac{\text{number of events above signal threshold}}{\text{all events}}$$

- Here with threshold ca. $4\times$ noise charge



- Efficiency unchanged to before irradiation

Conclusion

- CVD diamond samples irradiated with 24 GeV/c protons
- **charge collection distance**
  - **constant** up 1×10^{15} p/cm^2
  - **linear decrease** between $(3 \times 10^{15} ... 5 \times 10^{15})$ p/cm^2
  - slope -14 %/10^{15} p/cm^2
  - fits intersect at 2×10^{15} p/cm^2
  - decrease in ccd sets in at 2×10^{15} p/cm^2
- **particle induced on-spill current** in diamond
  - correlates with proton flux
  - mean current (several μA) does not change with fluence
- **Diamod strip tracker**
  - efficiency unchanged
  - spatial resolution unchanged after 3×10^{15} p/cm^2
- **off-spill current** remains constant
- leakage current after irradiation few pico Ampere