Brandenburgische Technische Universität Cottbus - Senftenberg

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# Investigation of sapphire detector designed for single particle detection

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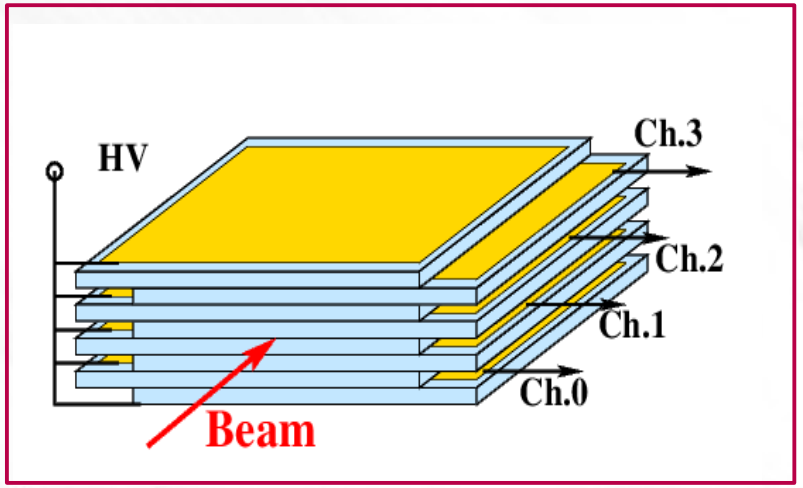
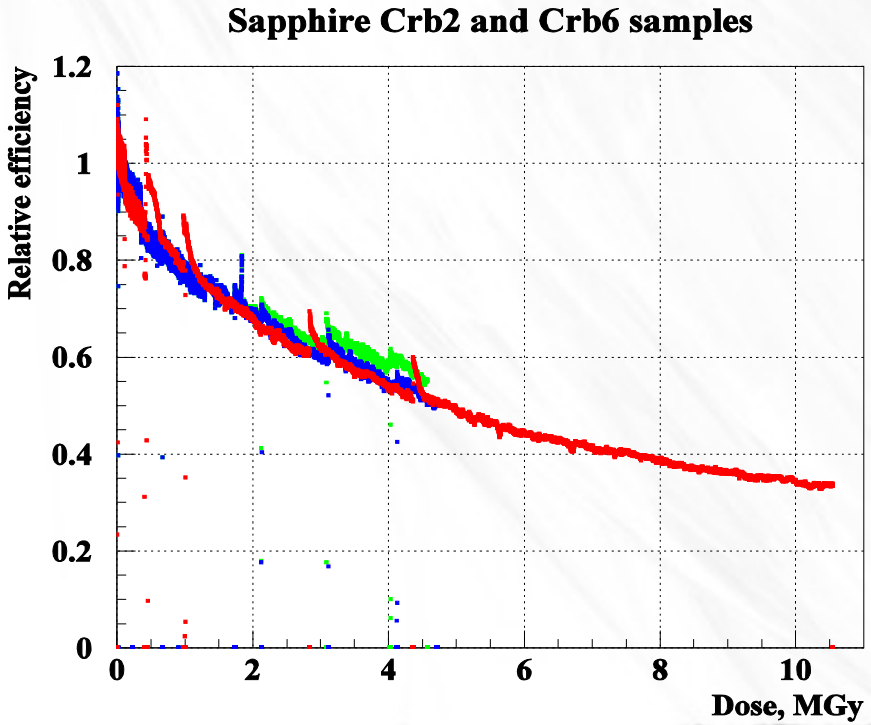


# Sapphire is radiation hard!

→ **promising material for experiments at accelerators beam halo and beam loss monitoring:**

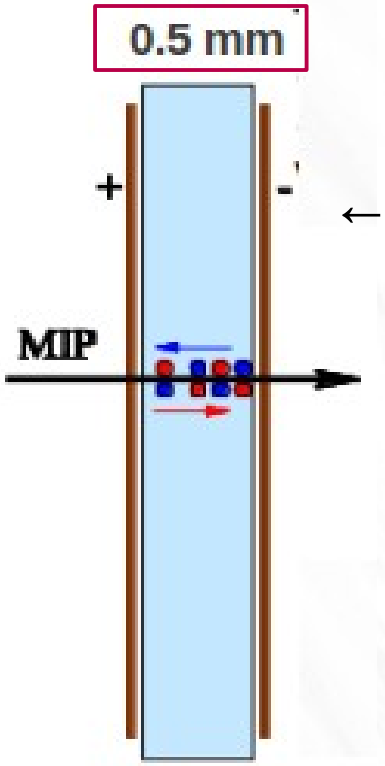
- *it is available in wafer size up to 40 cm, cheap, fast, radiation hard and no cooking required.*
- *currently are used for a Beam Loss Monitor at FLASH.*
- *2 sapphire sensors are installed as a part of CMS BCM2L for test.*




**Test Beam (e-) in Darmstadt :**
**- at least 30% relative efficiency after 10 MGy dose.**
**(After the same dose pcCVD shows 20%, scCVD - 10%.)**
**- leakage current even after irradiation stays in pA range.**

# *From promising material to detector...*

**Assuming 22 $e^-$/h pairs are created per $\mu m^{-1}$ :**

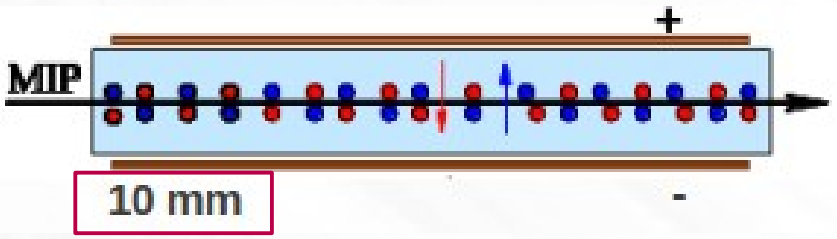



**← ~11K e-/h pairs,**

**for 10% CCE:**

**1100 e- signal,**

**hard to detect.**



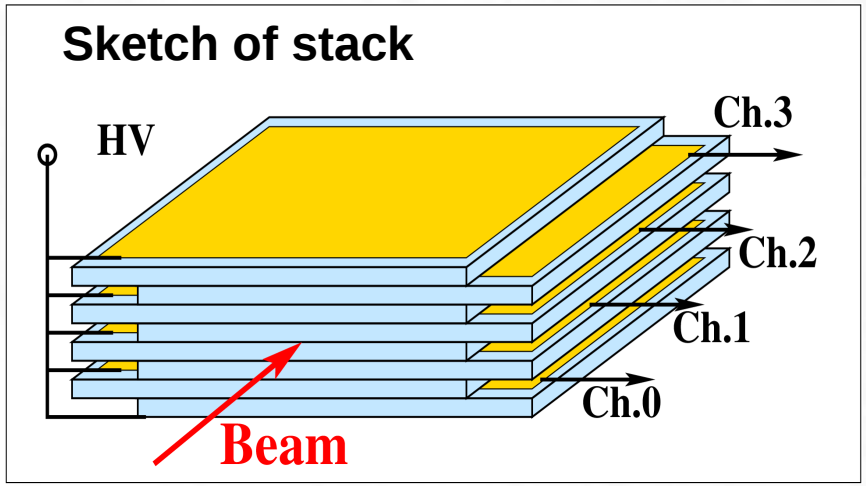

**~220K e-/h pairs,**

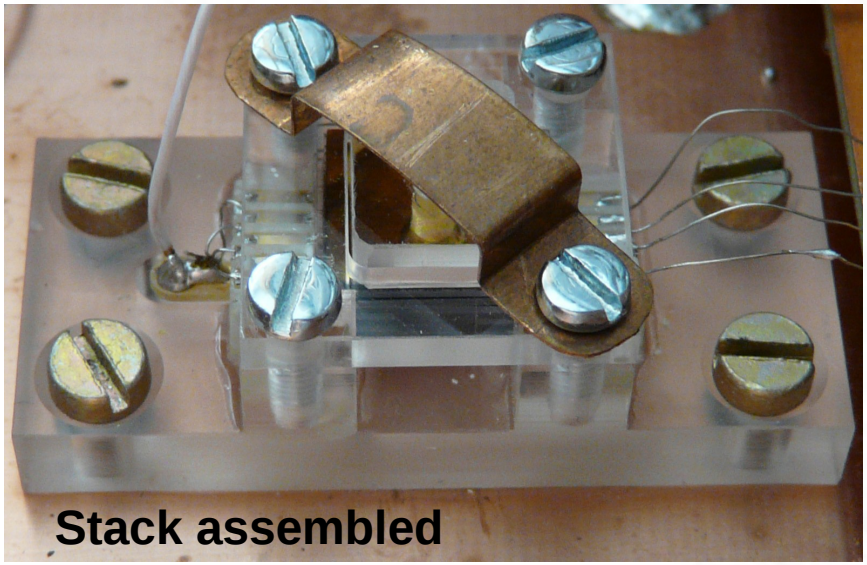
**for 10% CCE: 22K e- signal, big enough to be registered, comparable to 500µm scCVD .**

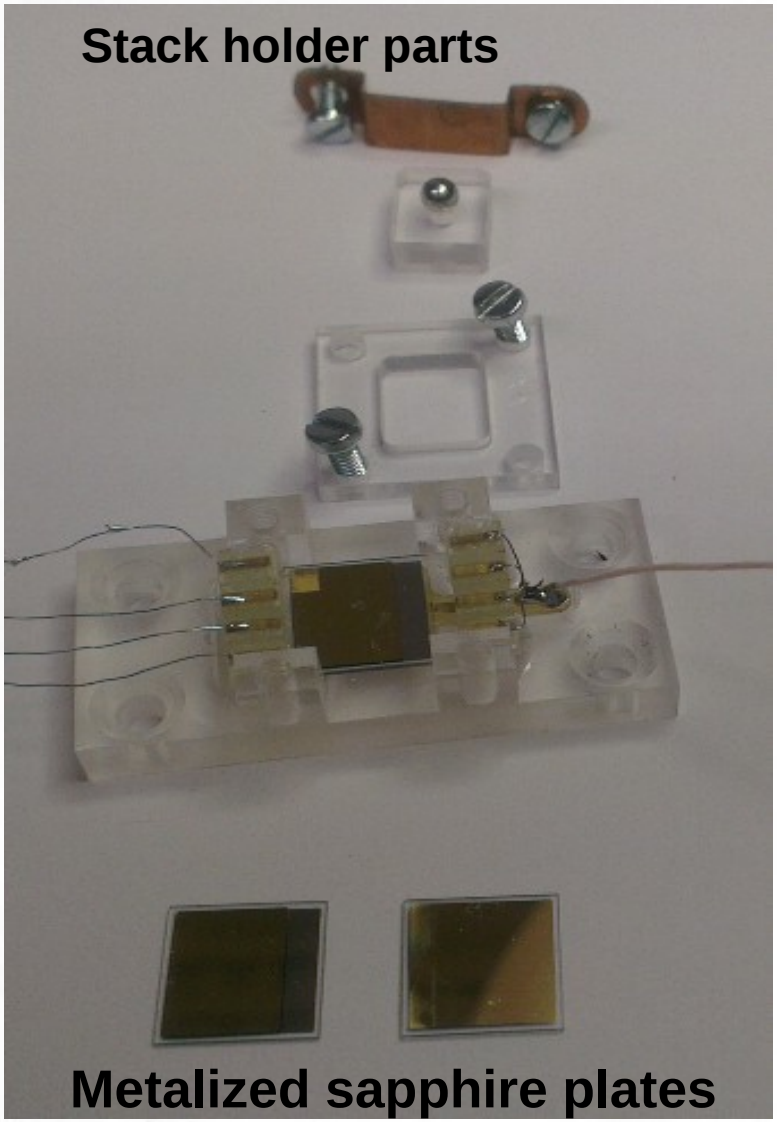
**This design allows strong increase of directional sensitivity!**

# Sapphire stack structure:

- designed for Minimum Ionizing Particle (MIP) detection;
- studied at 5 GeV $e^-$ DESY-II test beam.

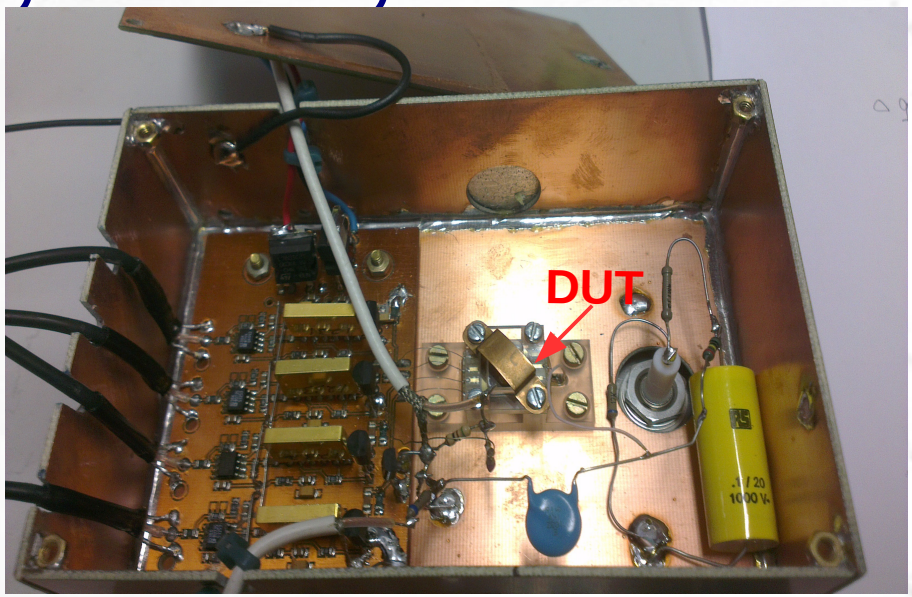


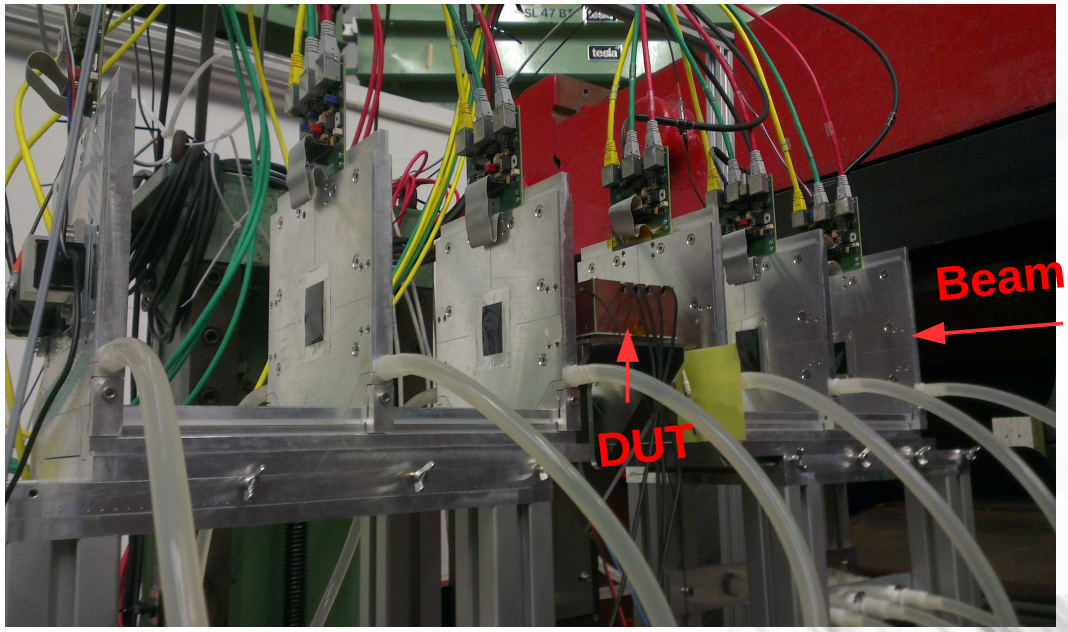



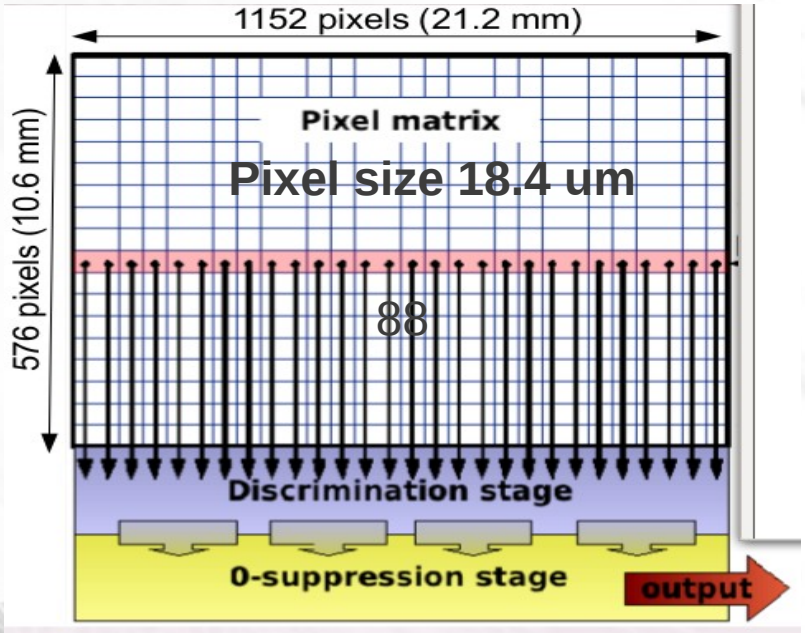



# Test Beam at DESY-II, 5GeV $e^-$, 100 Hz rate

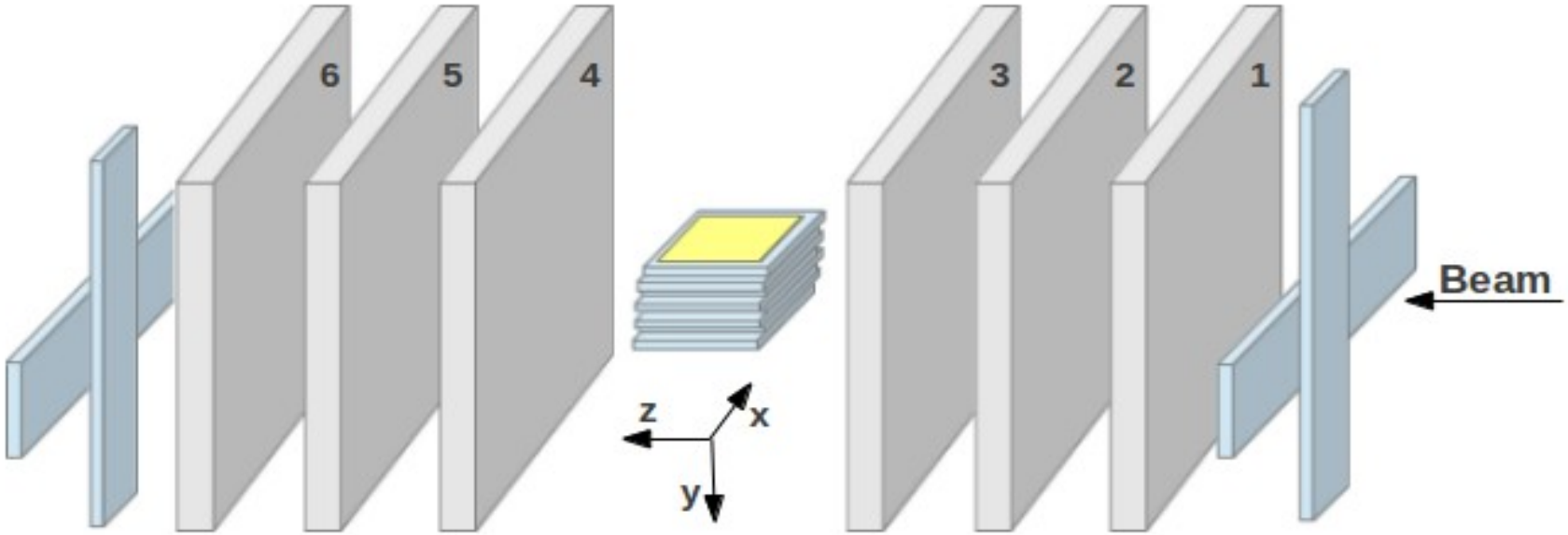
- **Front End:**
  - **Charge sensitive preamplifier A250;**
  - **Shaper with peaking time 100 ns.**
- **Back End:**
  - **Sanpling ADC v1721.**
- **EUDET Telescope:**
  - **6 x Mimosa26 pixel sensors, track pointing resolution ~10 μm.**



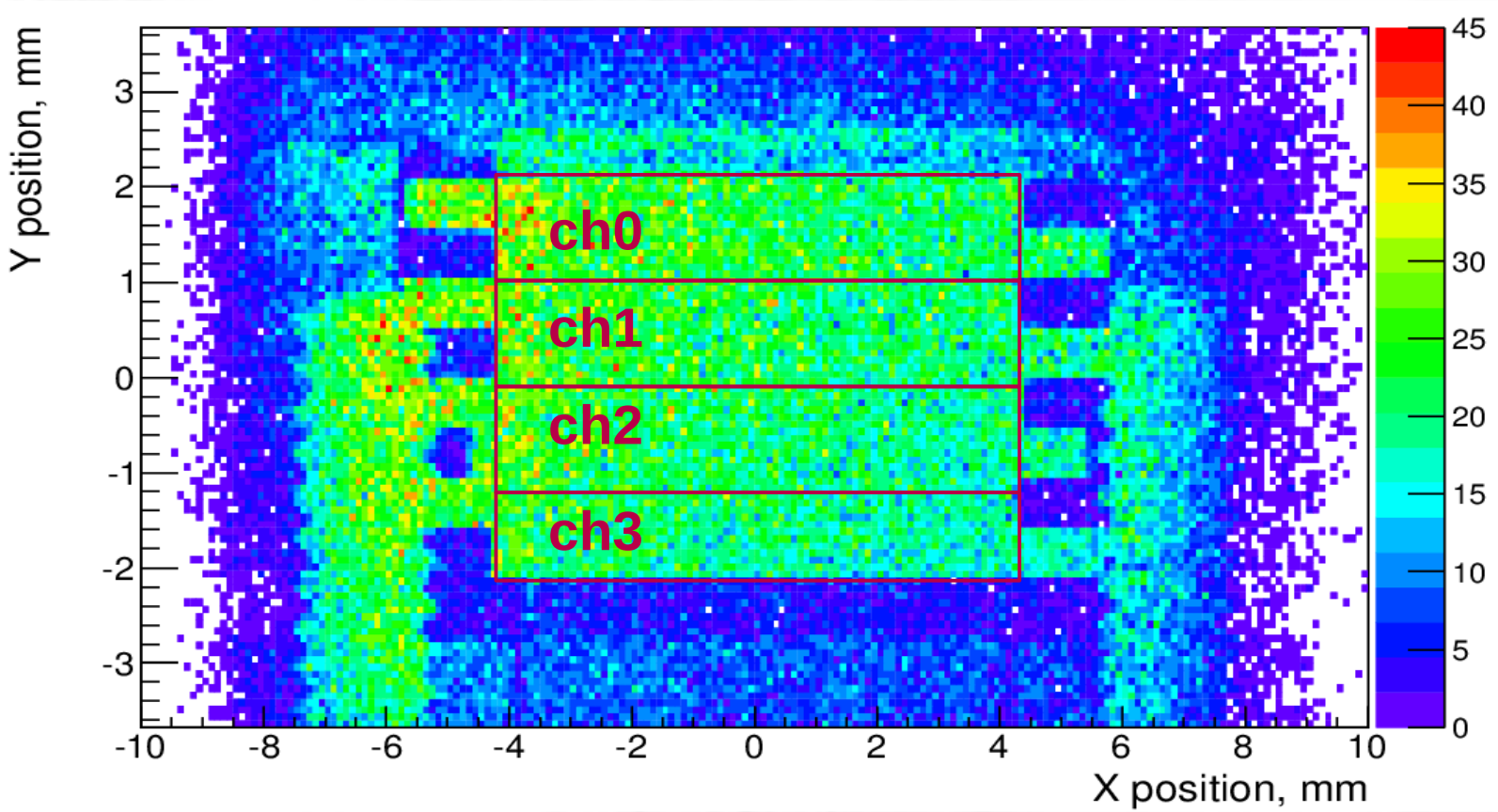
# Track reconstruction




- **EUTelescope includes software for offline analysis: Clustering → Filter → Hitmaker → Alignment → Fitter.**
- **Using hits from Telescope planes, tracks were reconstructed.**
- **Synchronization of Telescope and DUT data was done using independent 15 bits TLU number.**

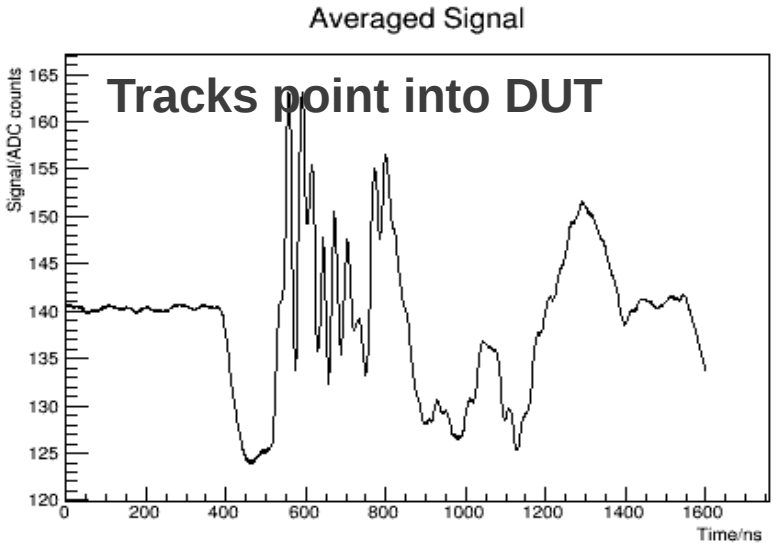
# Reconstructed stack view, XY plane, Z = 0.

- **Events with more than one track in the telescope were rejected.**
- **The track fit was done separately in the three planes upstream and downstream of the stack.**
- **Multiple scattering inside the stack for more than 0.5 mrad was used to determine the precise position of the stack in the beam.**

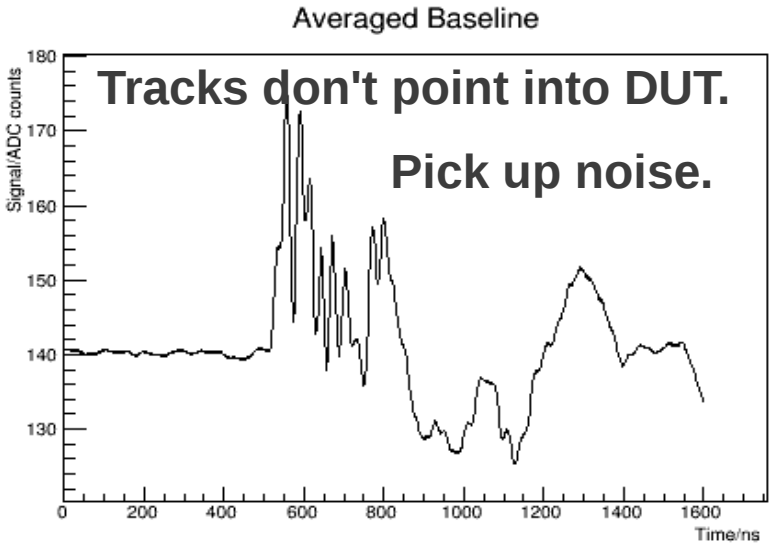


# Signal extraction

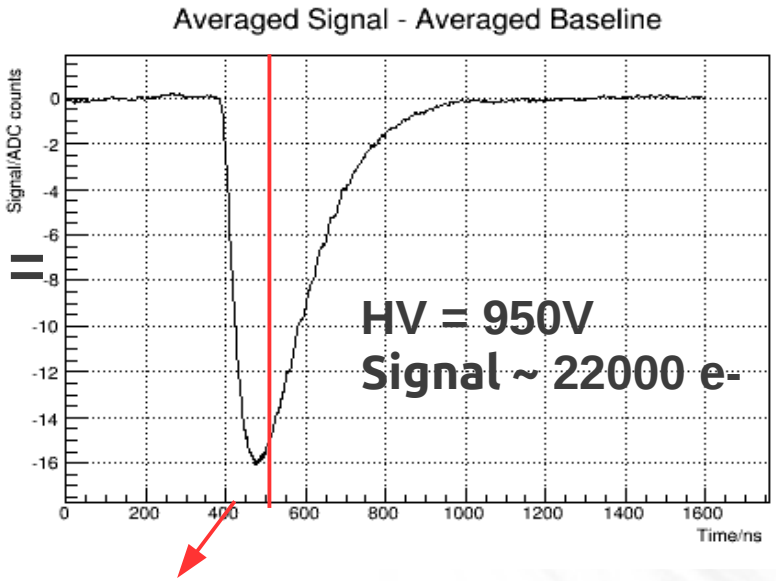
1)

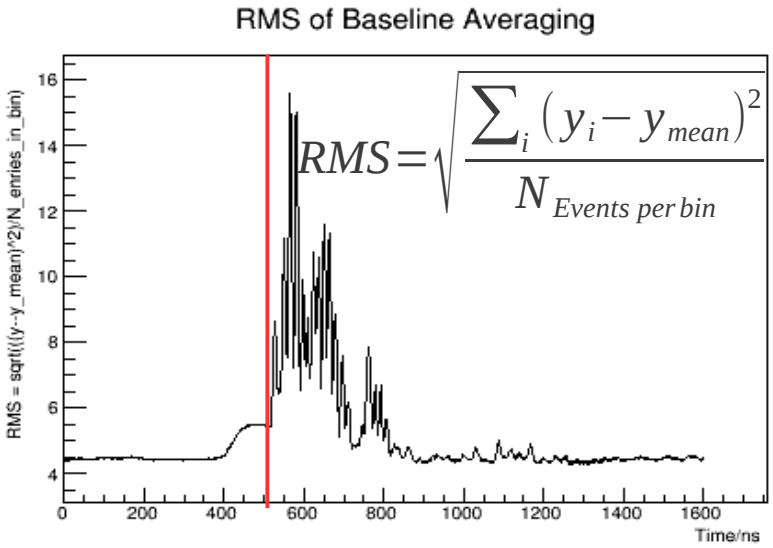



2)




1) - 2) =



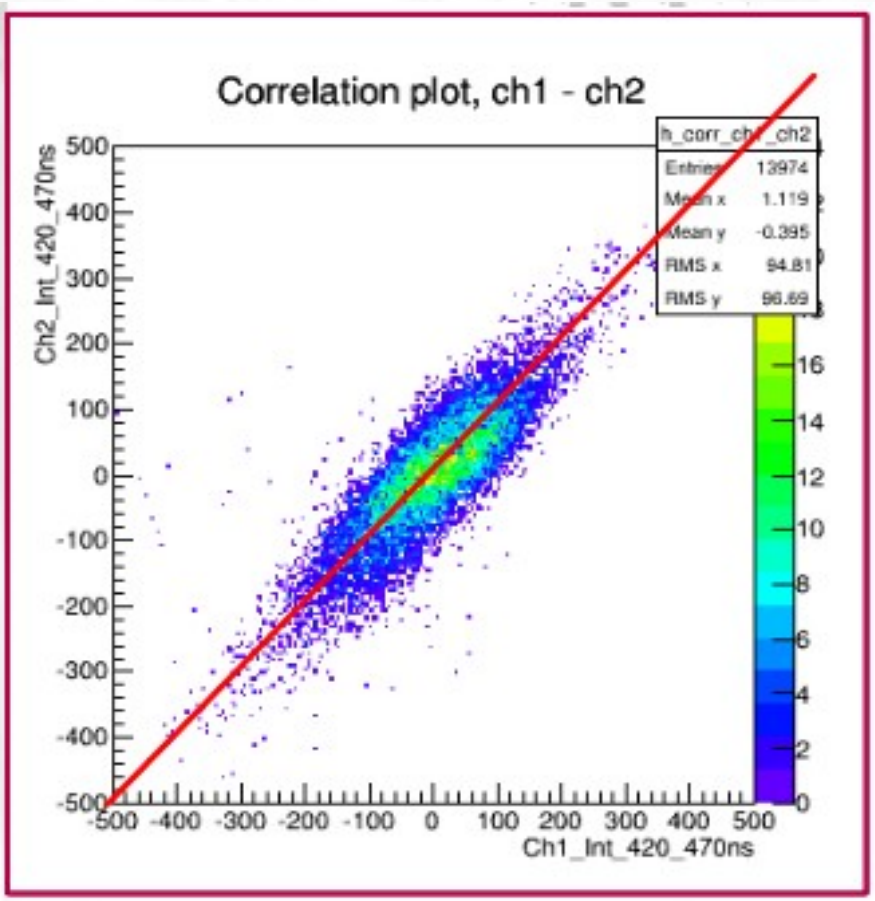



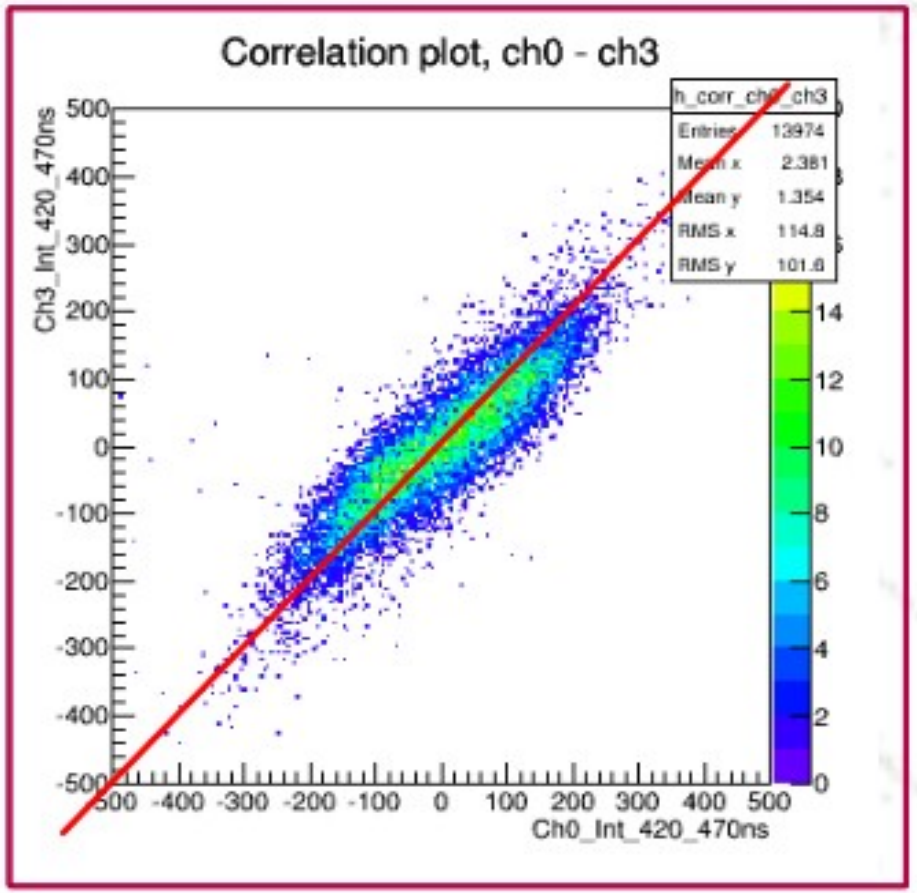

Selected integration window 420-470 ns.

# Common mode noise

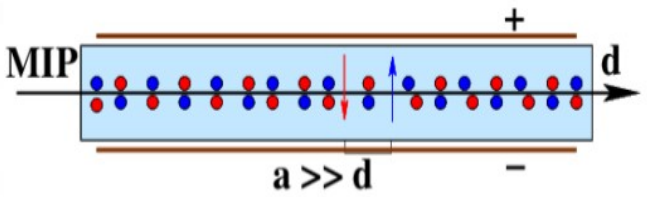
- **Only for tracks not pointing into DUT.**
- **Integral calculated in time window [420; 470] ns for each channel.**

- **Observed linear correlation between pairs: channel 0 - 3, channel 1 - 2.**

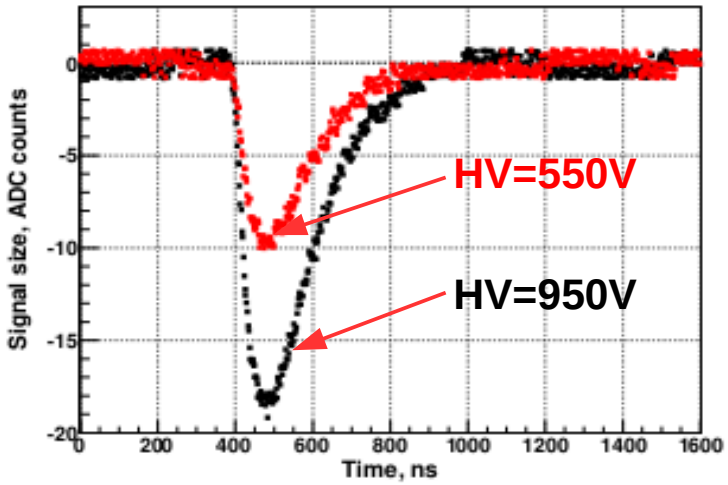


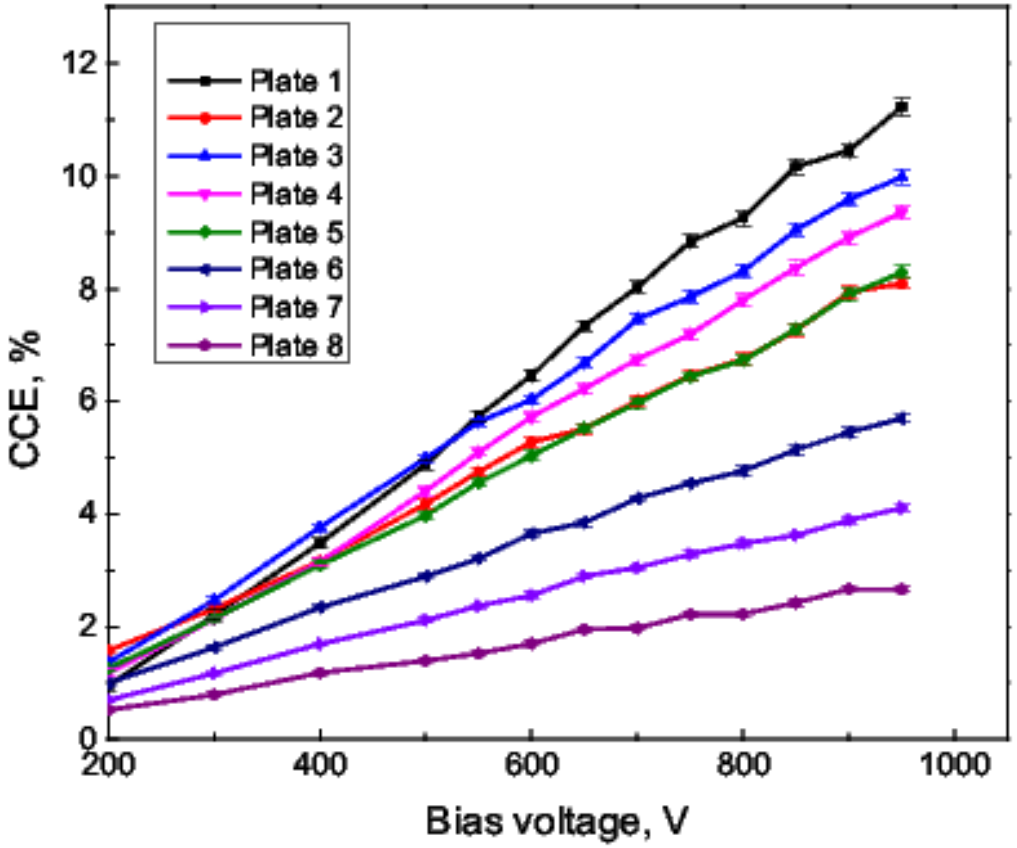



# Charge collection efficiency vs. bias voltage



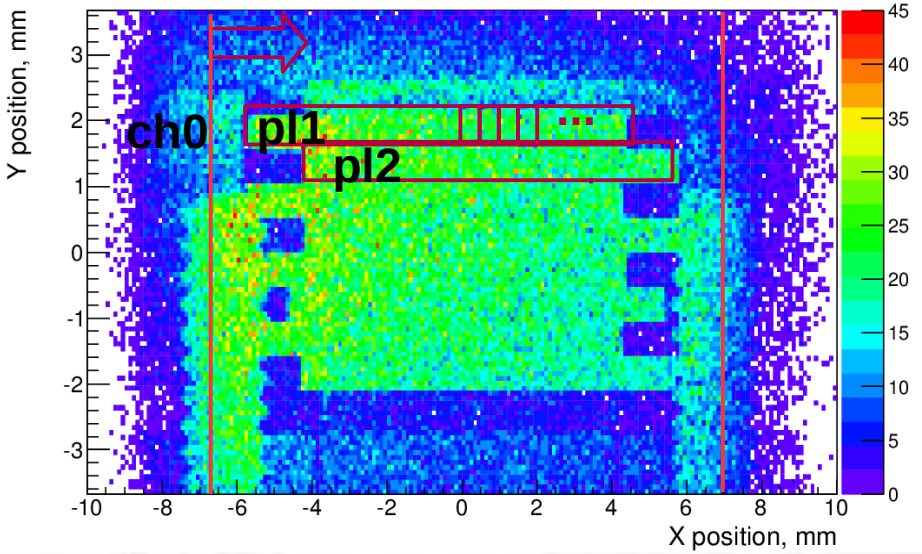

$$CCE = \frac{Q_{coll}}{Q_{ind}} * 100\,\%$$




| Plate number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| CCE, % | 11.2 | 8.1 | 10.0 | 10.3 | 8.3 | 5.7 | 4.1 | 2.7 |
| stat. error | 0.14 | 0.1 | 0.12 | 0.12 | 0.11 | 0.08 | 0.06 | 0.05 |

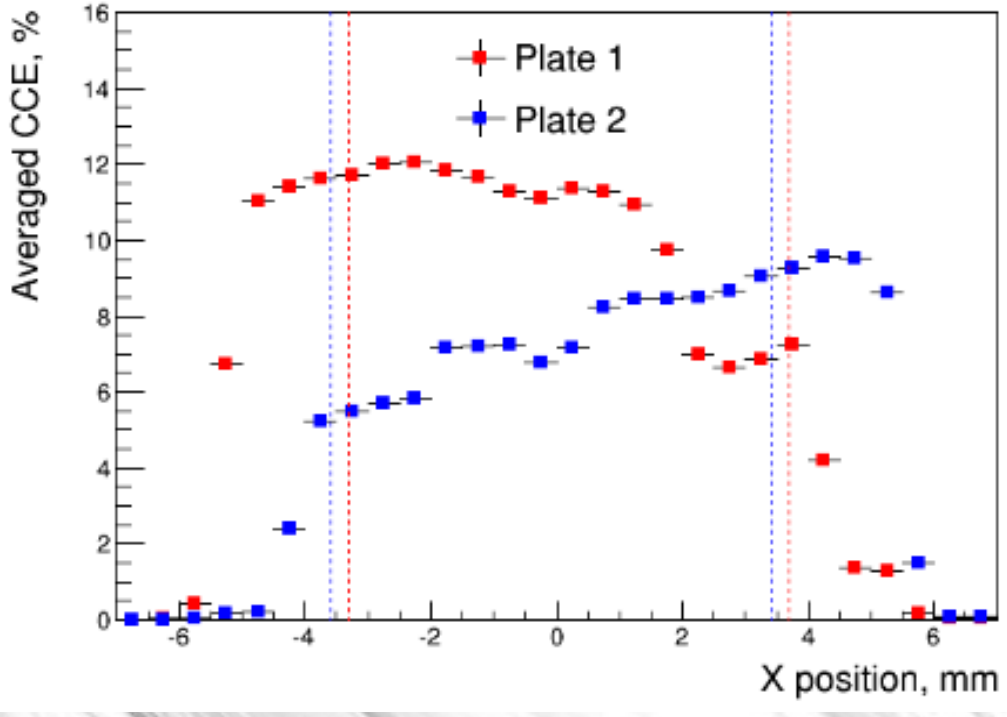
# Homogenity study



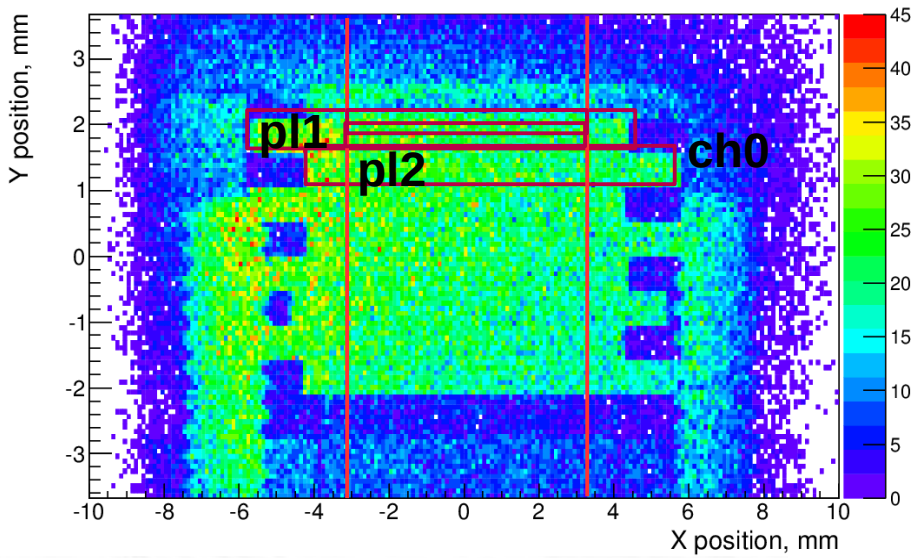

- X [-7; 7] - more than plate length.
- Each plate subdivided into **500μm bins**.
- For tracks pointing into each bin average CCE value was calculated →

- Clearly seen borders of plates.
- Metalized area is marked with dotted line.
- There are variations of calculated CCE →

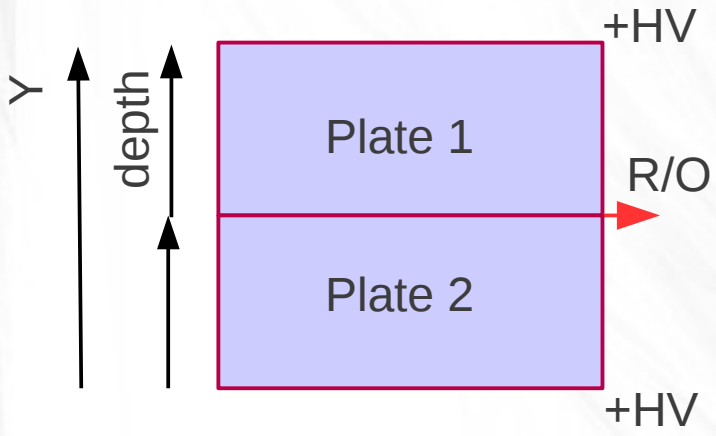
  **plates are not homogeneous.**

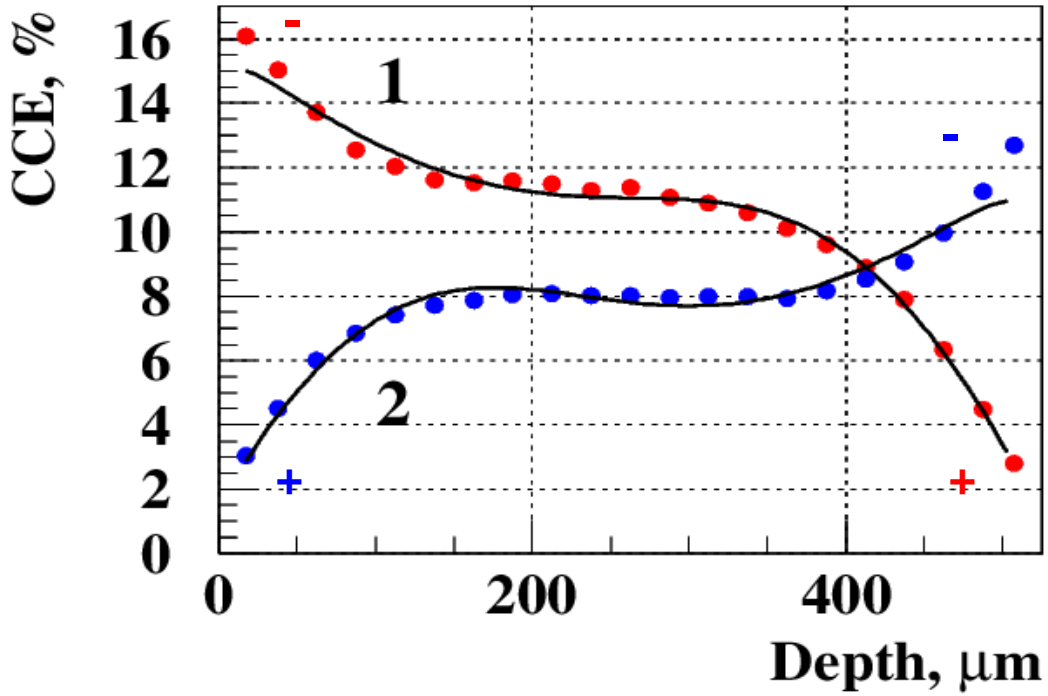


# Vertical scan: CCE vs. depth

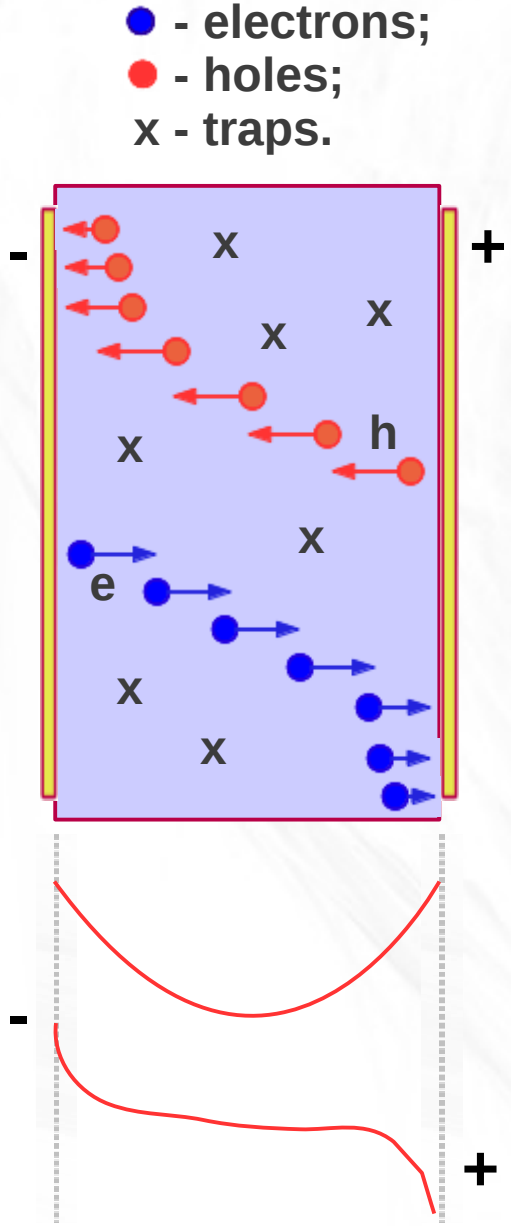



- X [-3; 3] - in metalized area.
- Each plate subdivided into **25µm bands**.
- For tracks pointing into each band average CCE value was calculated →

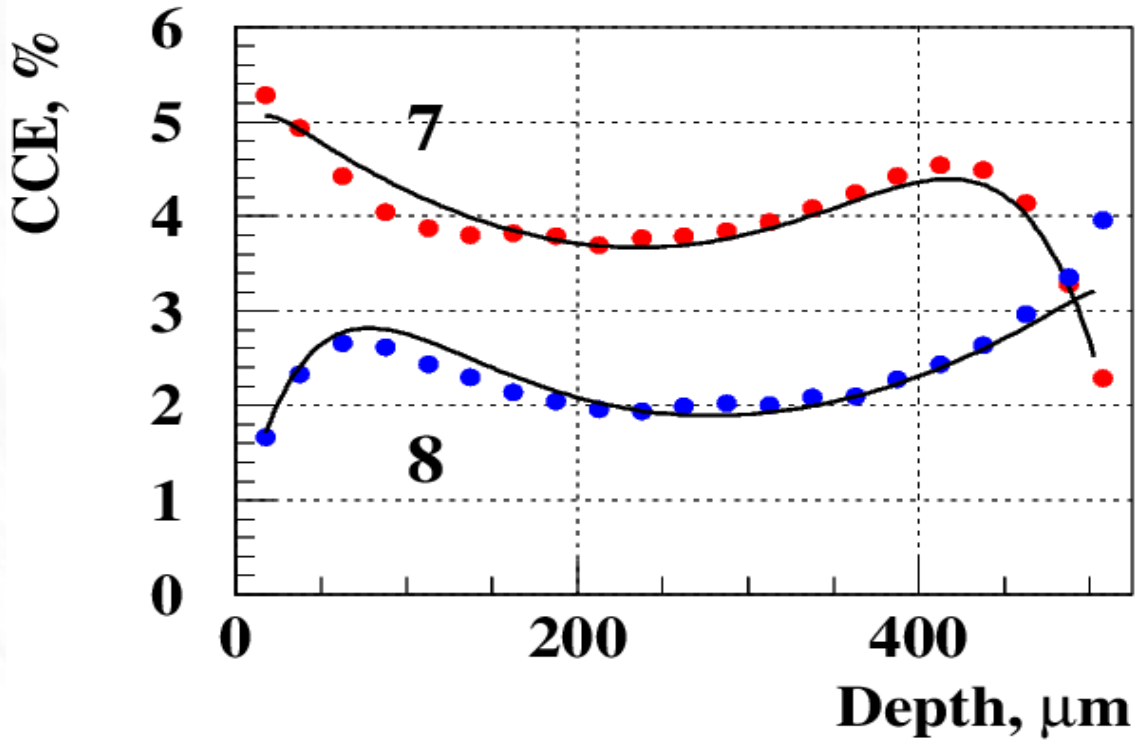


# Results interpretation



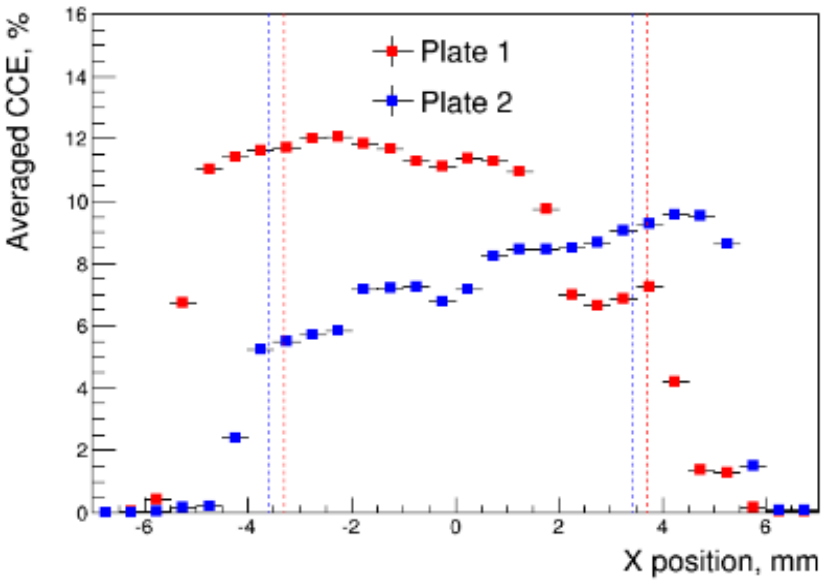

- Signal size is correlated with field direction. It agrees with assumption that charge collection in sapphire is done by only one type of carriers (electrons).
- Maximum near negative (and at ~100 μm from positive) electrode — polarization field!

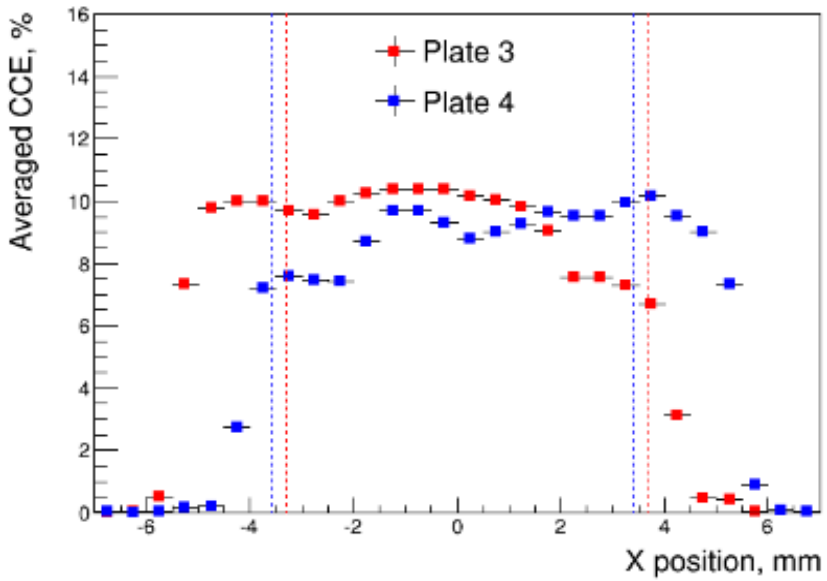


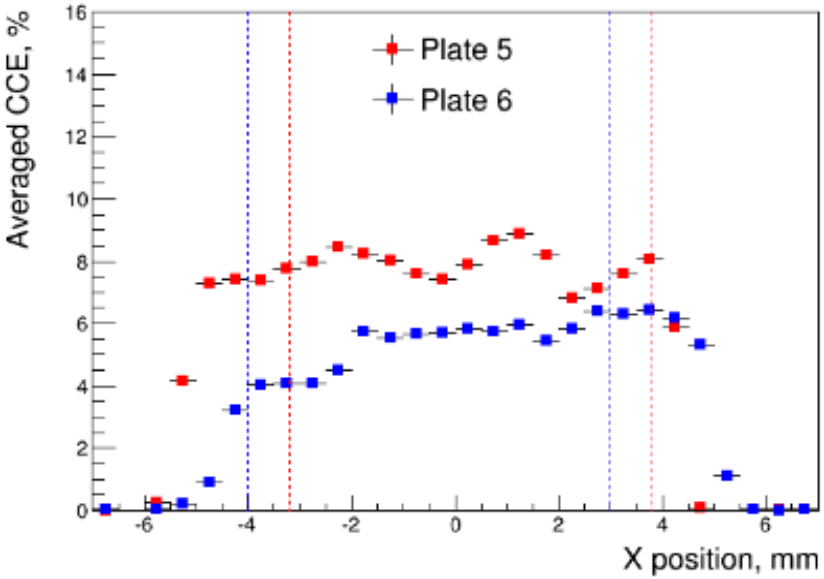
# Conclusions

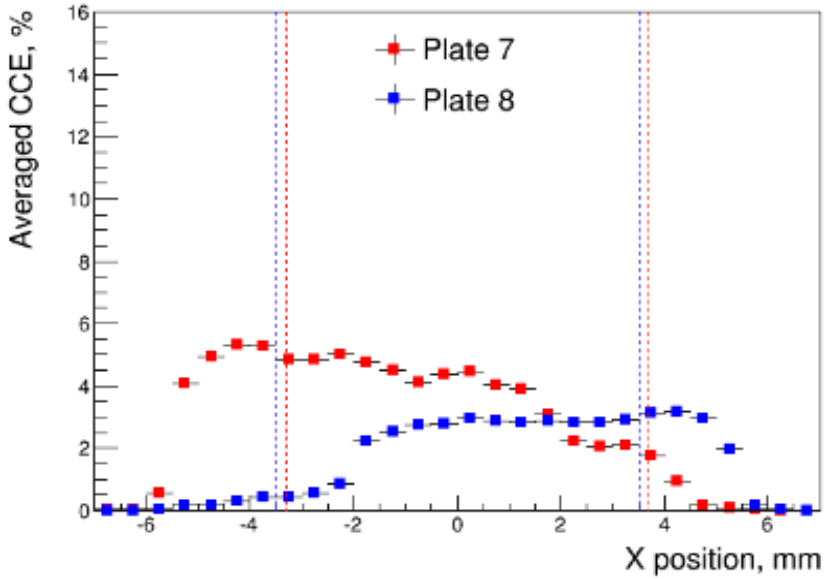
- Single crystal sapphire is a very promising radiation hard material for single particle detection.
- A sapphire direction sensitive detector designed for MIP detection was tested at the DESY II test beam.
  - Averaged CCE is linearly dependent on the bias voltage and approaches 11 % at 950 V.
  - Electrons give the dominant contribution to the signal charge collection.
  - Polarization effect observed.
- TB results are used for design of a next-generation sapphire strip detector for high energy particle tracking.

# Backup: Homogenity study



# Backup: CCE vs. depth