Investigation of a direction sensitive sapphire detector stack at the 5 GeV electron beam at DESY-II

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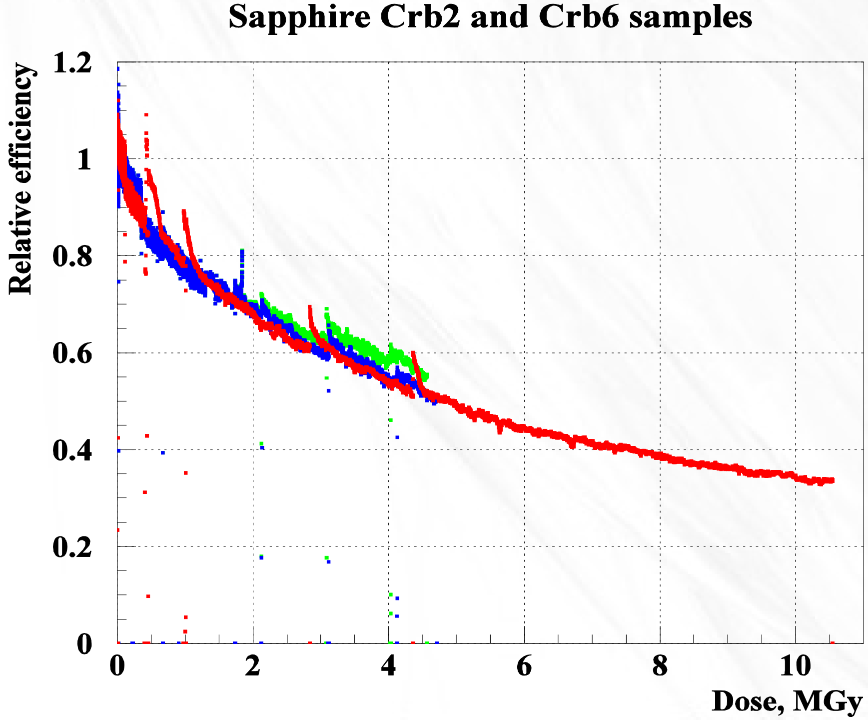
Sapphire detectors

For experiments at accelerators beam halo and beam loss monitoring need very radiation hard detectors.

Single crystal sapphire is promising material:

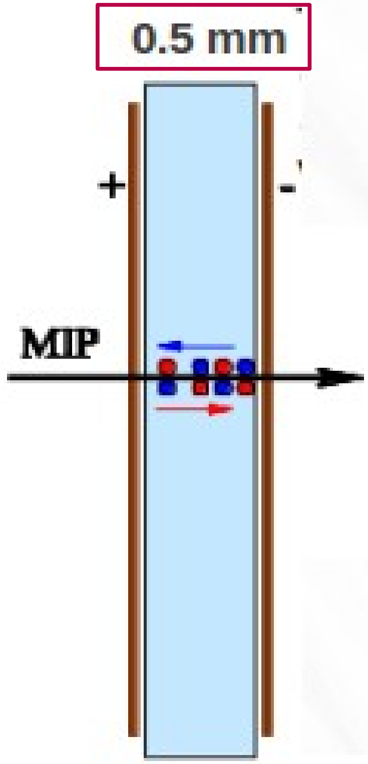
- *it is available in wafer size up to 40 cm, cheaper in comparison to diamond, fast and radiation hard.*
- *currently are used for a beam-loss monitor at FLASH.*



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.**

Sapphire detector prototype for MIP detection had been studied at 5 GeV e^- DESY-II test beam



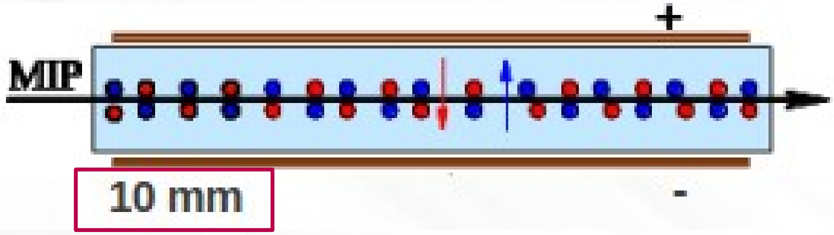
- **22 e-/h um^{-1}**

← ~11K e-/h pairs,

for 10% CCE:

1000 e- signal,

hard to detect.

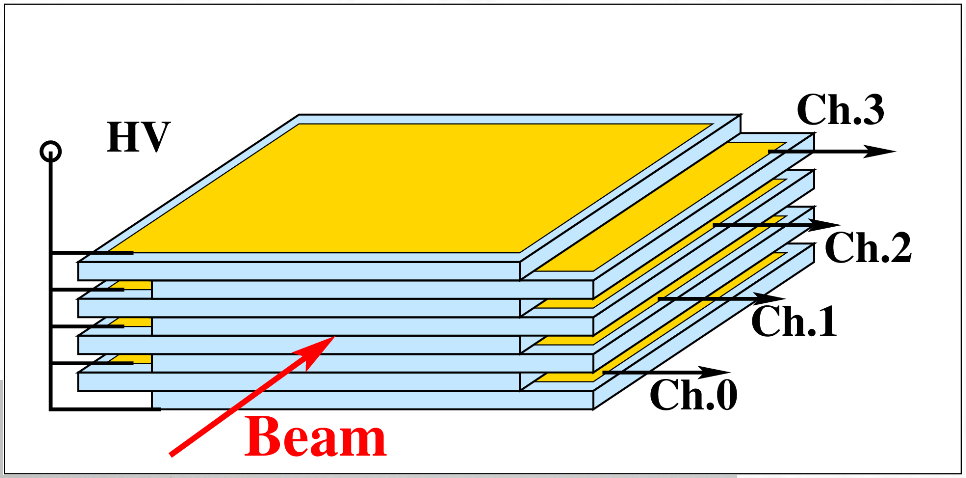


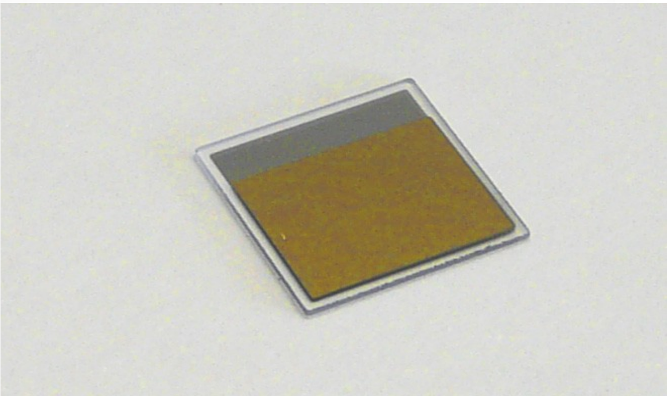
~220K e-/h pairs,

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

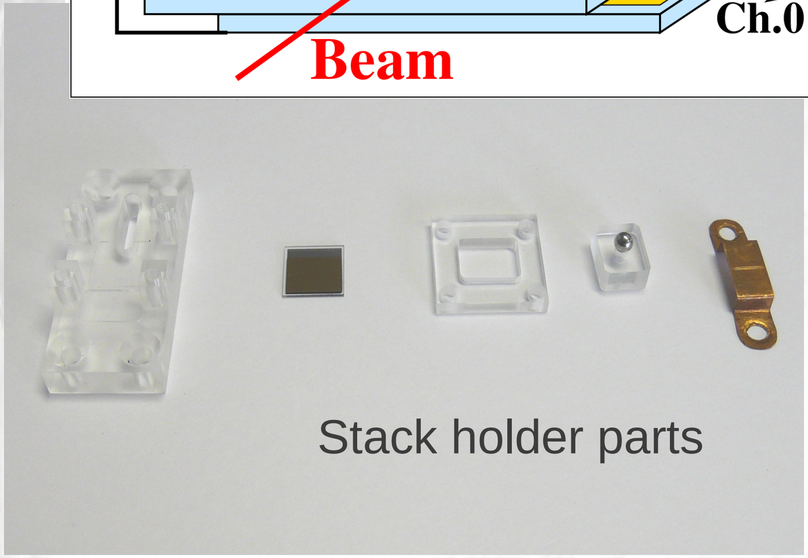
This design allows strong increase of directional sensitivity!

Sapphire stack structure



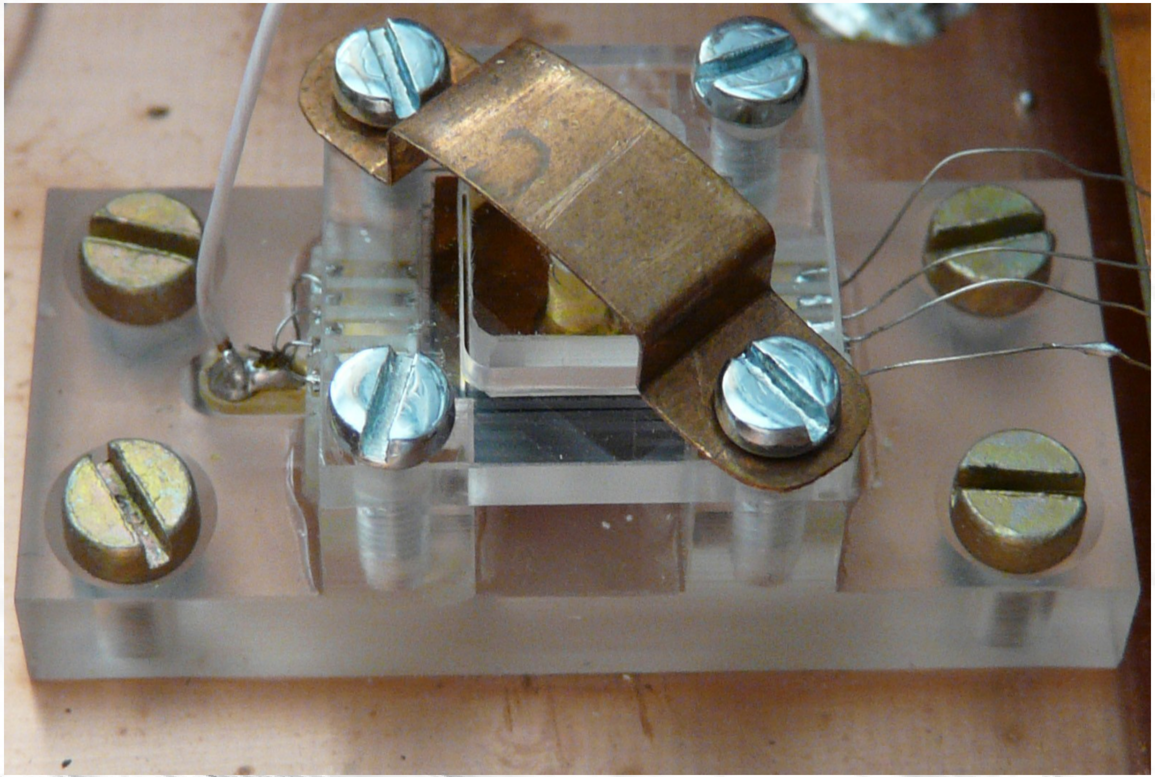


Sapphire plate with metallization

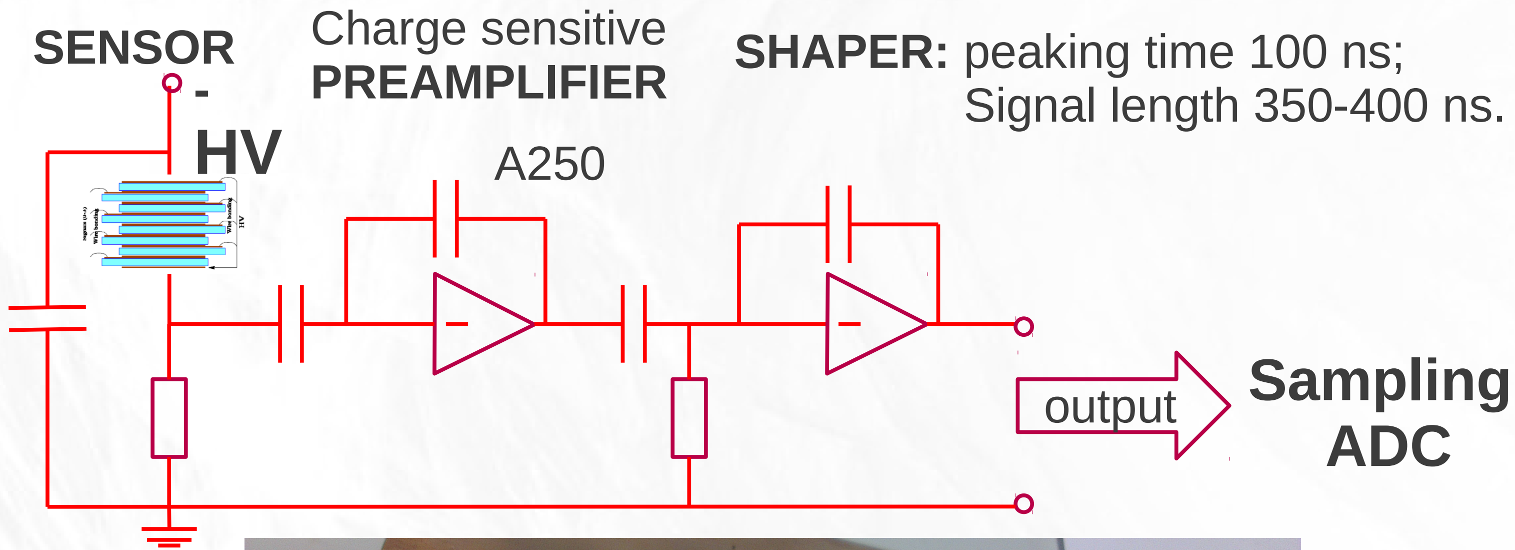


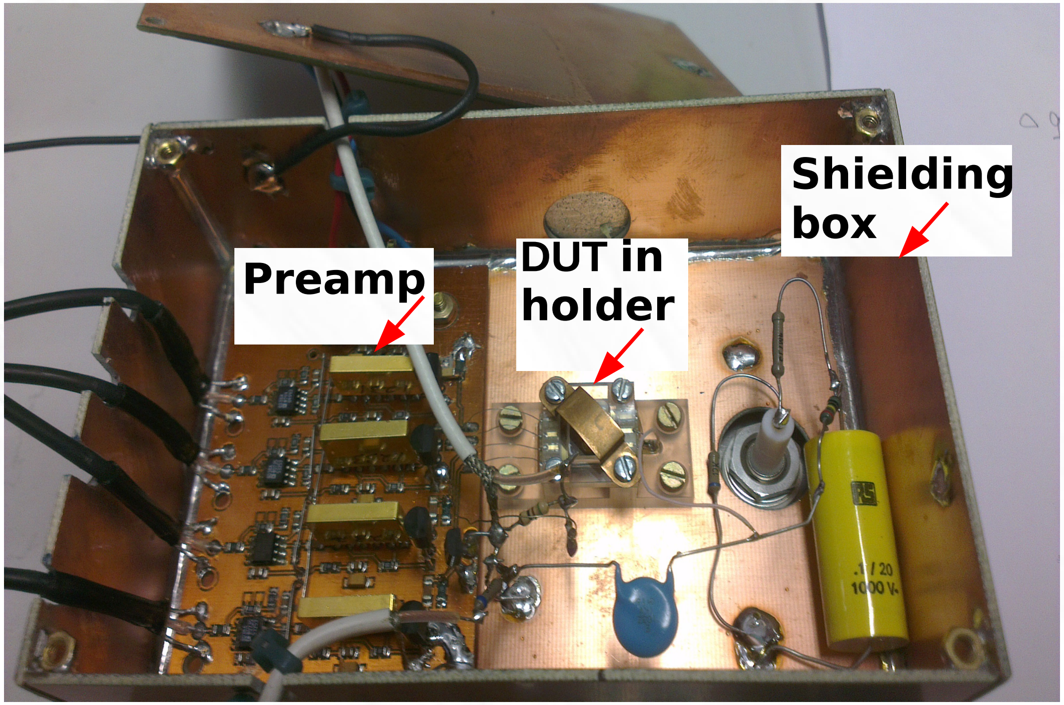
Stack holder parts

Stack assembled



Front-End for DESY II TB

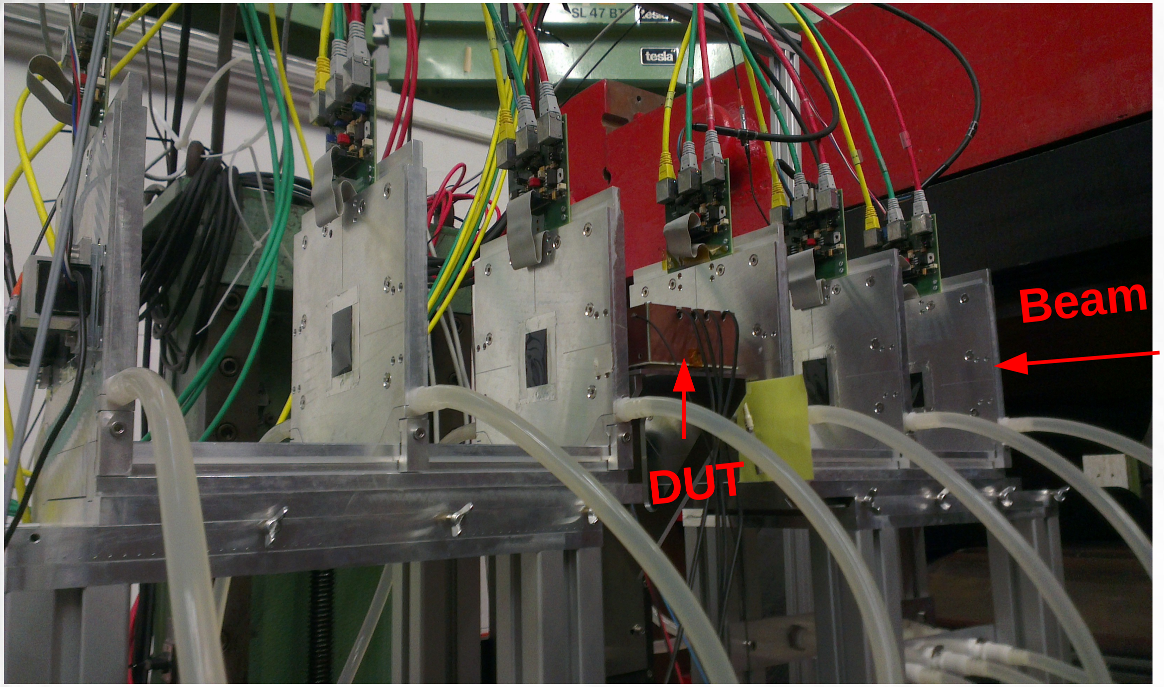


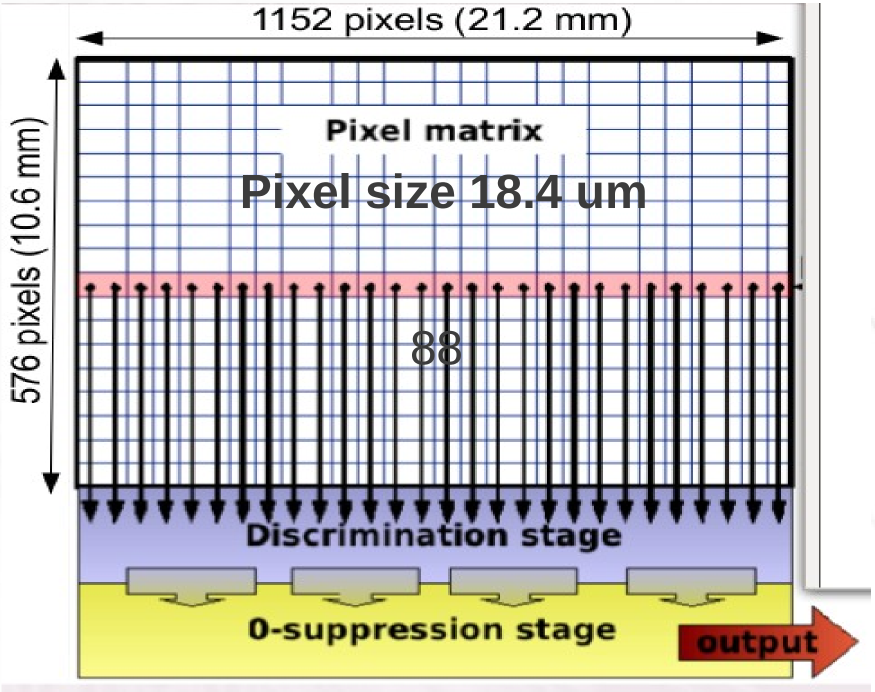


EUDET Telescope -

tracking device designed for detector prototype characterisation at the test beam.

- Active area of the telescope - six Mimosa26 pixel sensors.
- Six space points per track, Track pointing resolution ~10 μm.

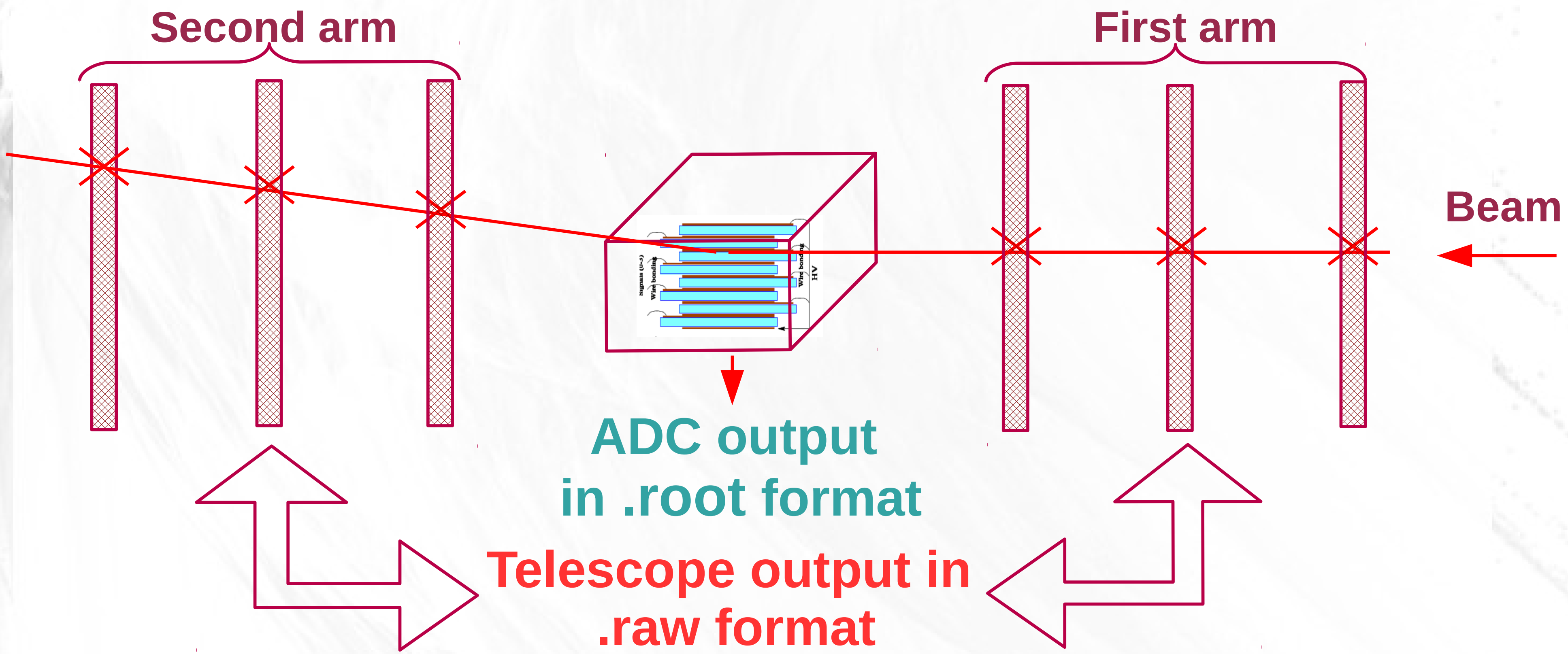




DESY II, TB area 22, 5 GeV electrons, 100 Hz rate.

Track reconstruction

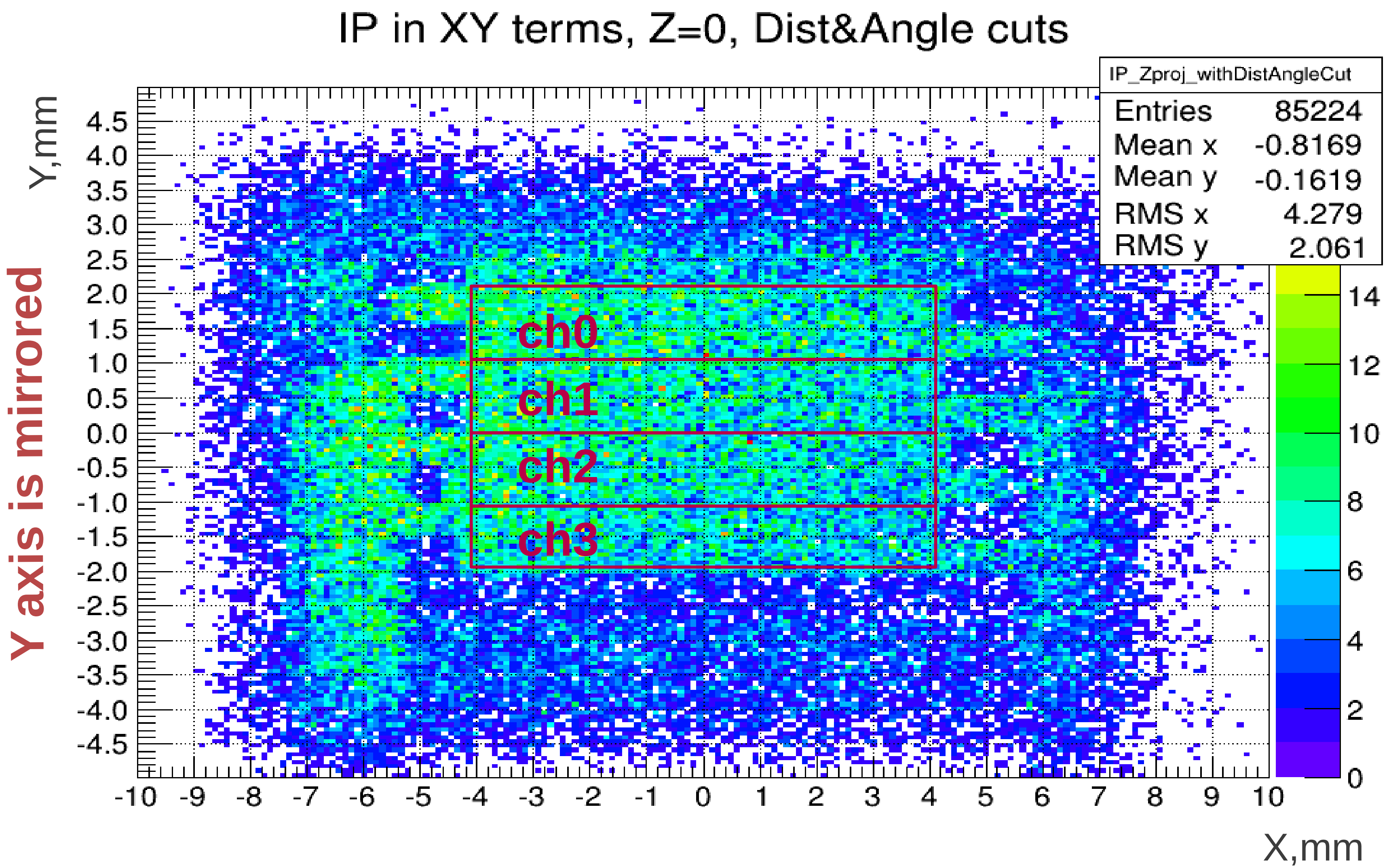
Using hits from Telescope planes, tracks were reconstructed.



Synchronization is done using TLU number.

- **EUTelescope includes software for offline analysis:**
  Clustering → Filter → Hitmaker → Alignment → Fitter → DUT

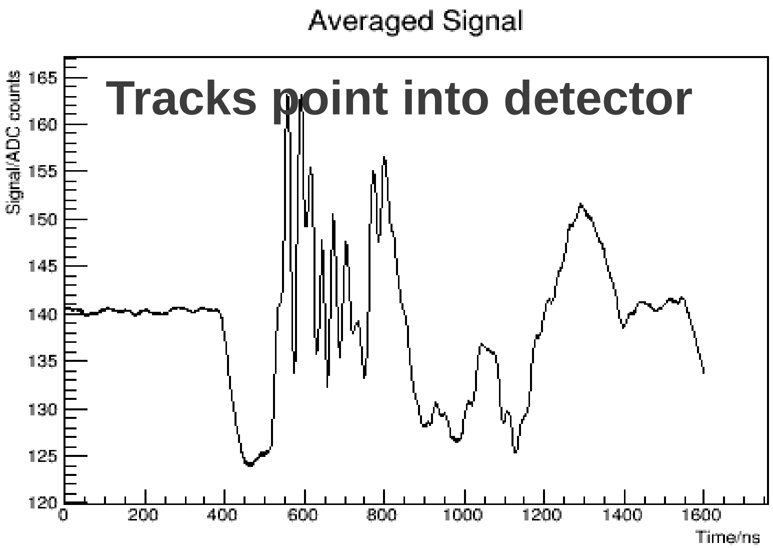
Detector view, reconstructed from tracks scattered in sapphire material



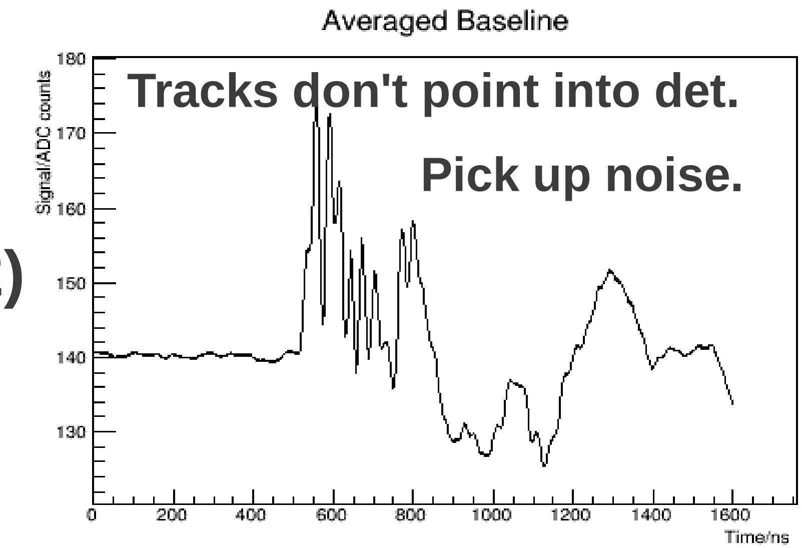
Synchronization of Telescope and ADC is done using Trigger Logic Unit numbers.

Signal extraction

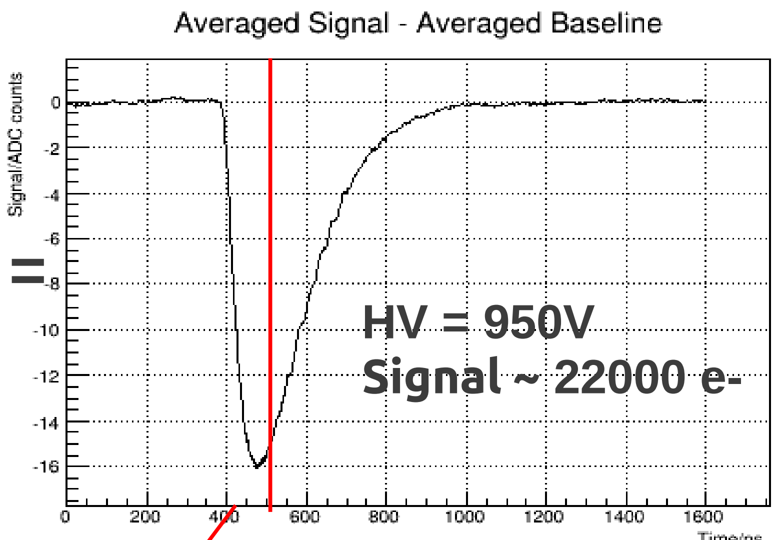
1)

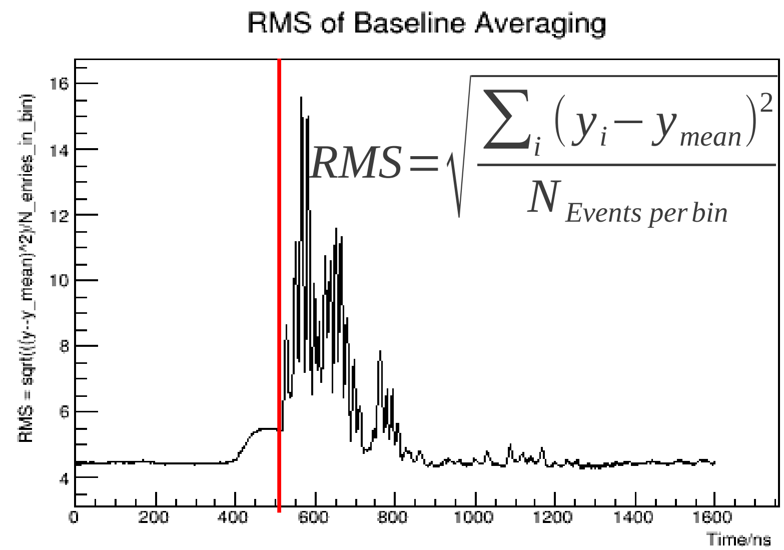


2)



1) - 2) =

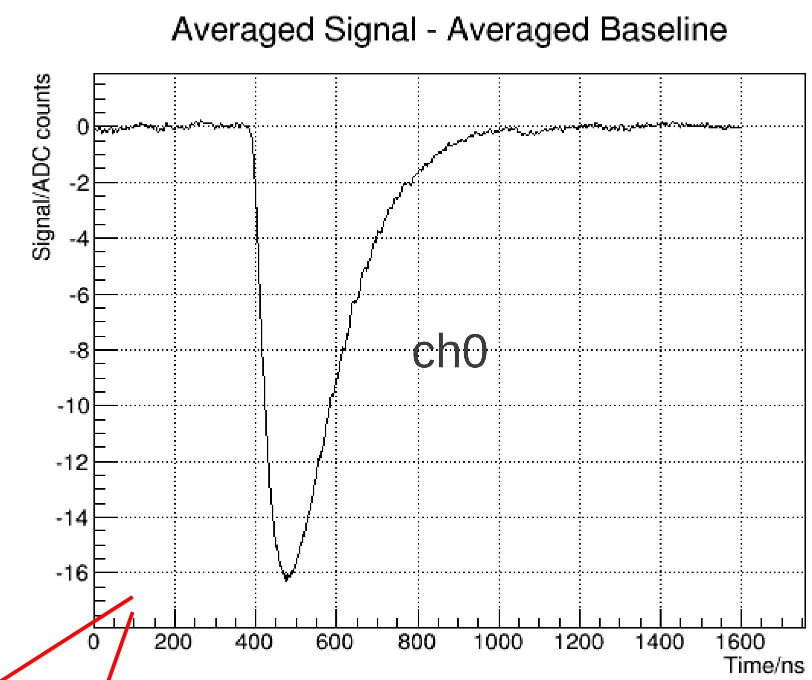


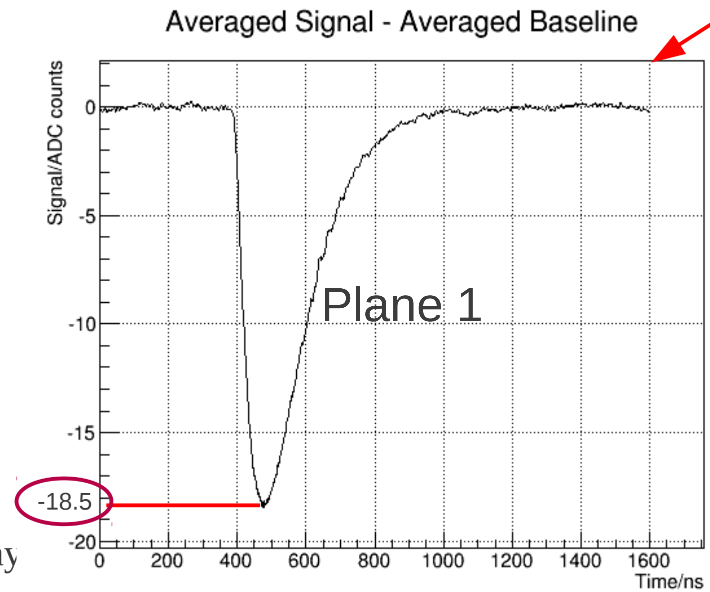


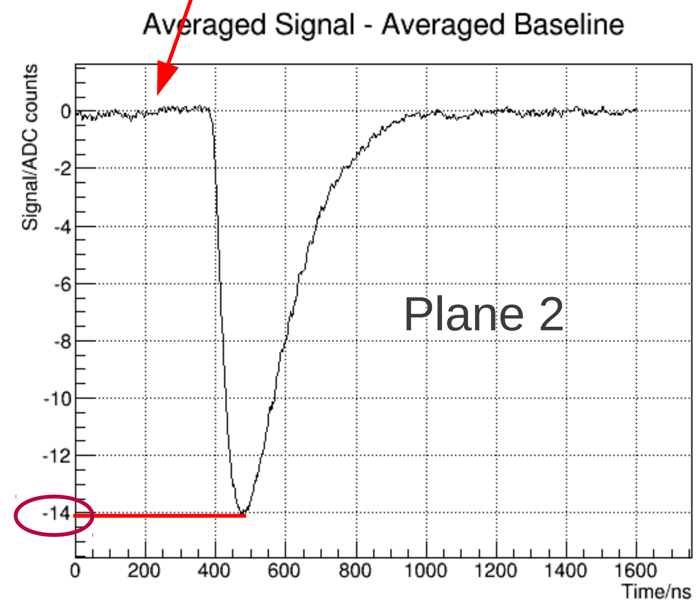
Selected integration window 420-470 ns.

Plate by plate and Ch by Ch Averaged signal

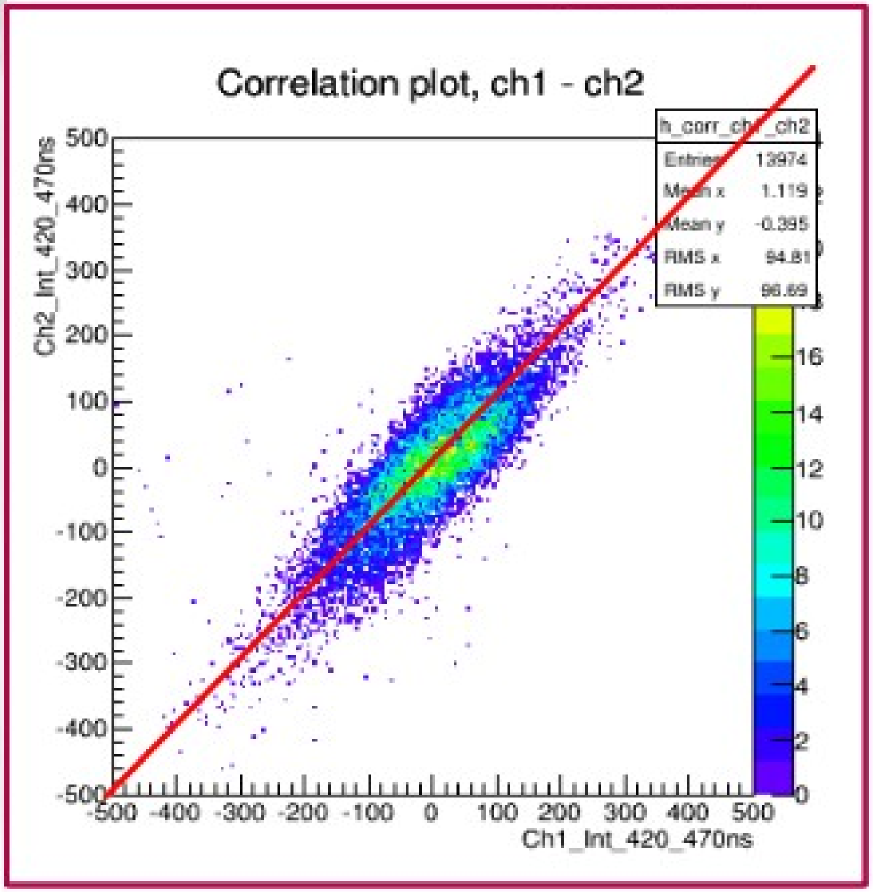
Averaged Signal Amplitude @950V			
Plate 1	18.5	Ch 0	16
Plate 2	14		
Plate 3	15.5	Ch 1	17
Plate 4	18.5		
Plate 5	16	Ch 2	12
Plate 6	10.5		
Plate 7	7.4	Ch 3	6.5
Plate 8	5		

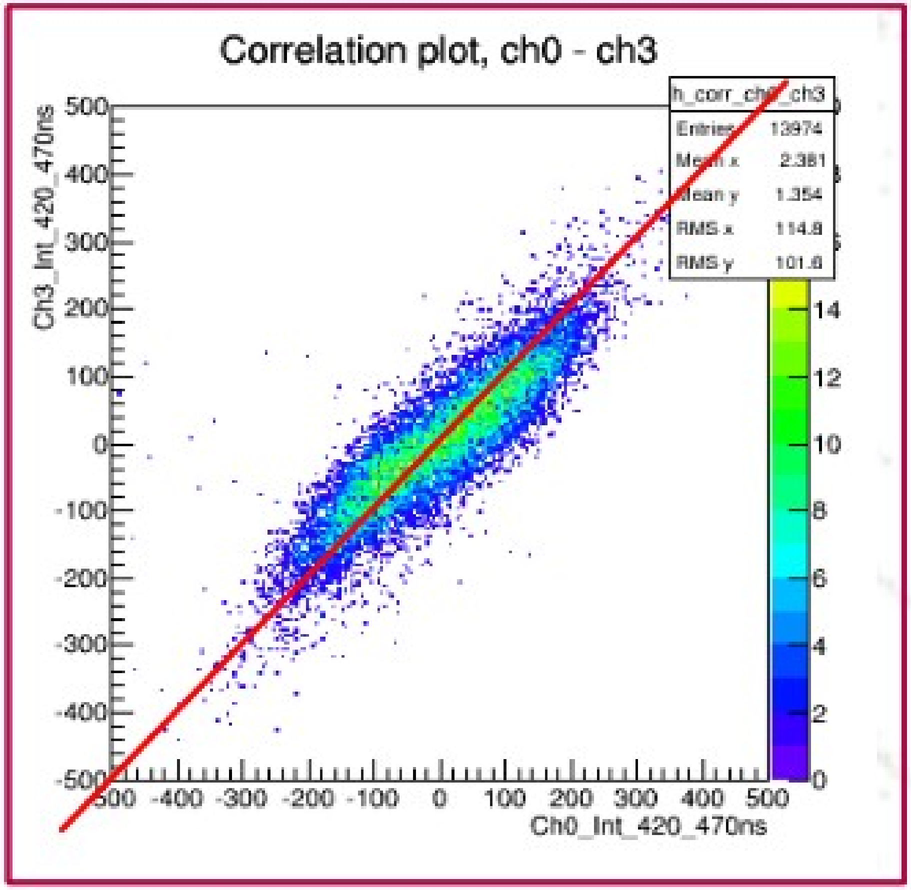




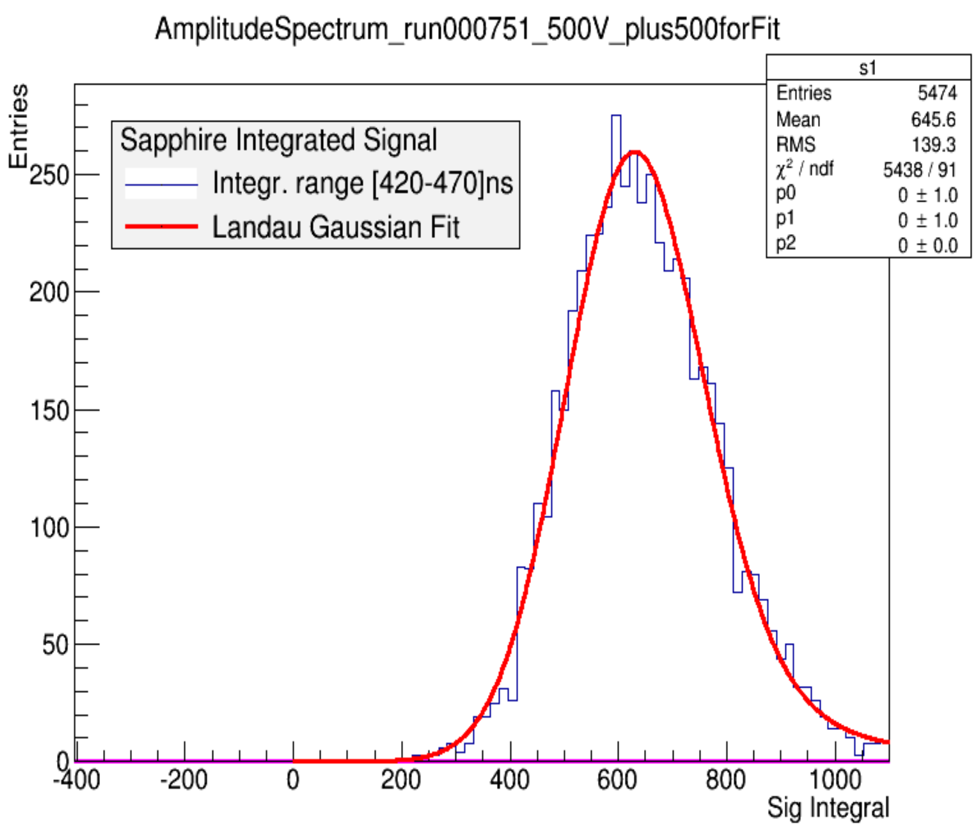


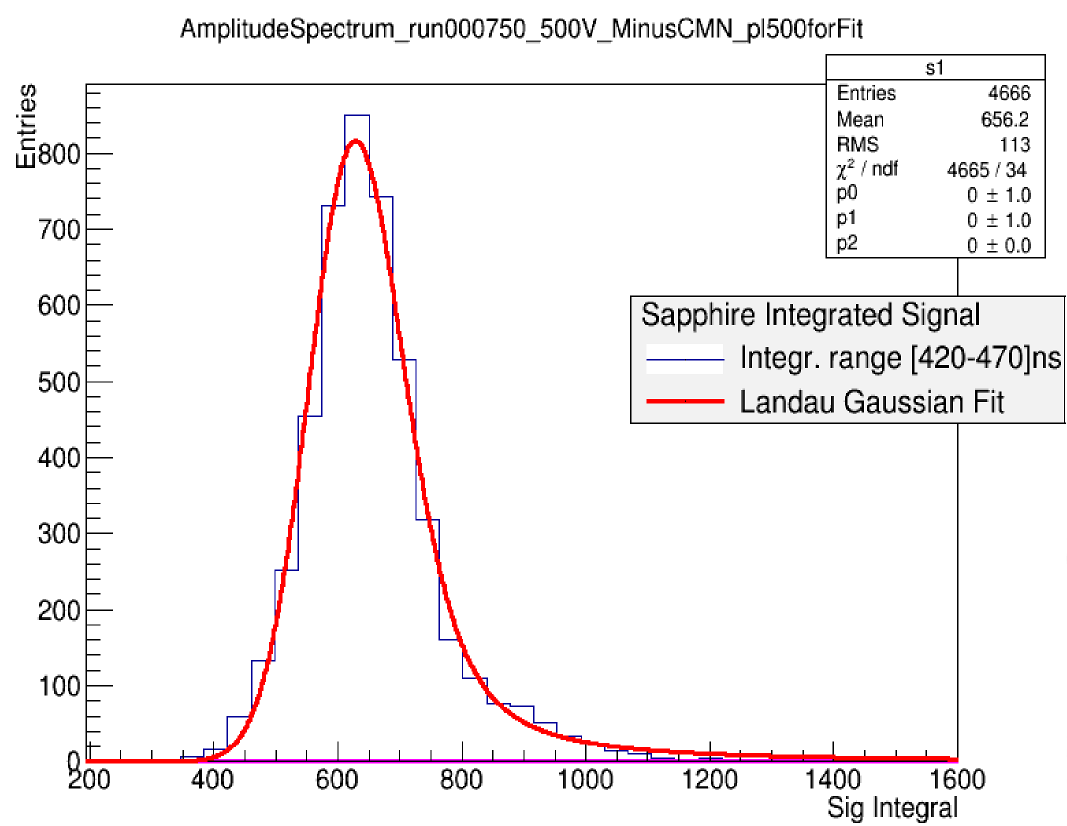
Common mode noise





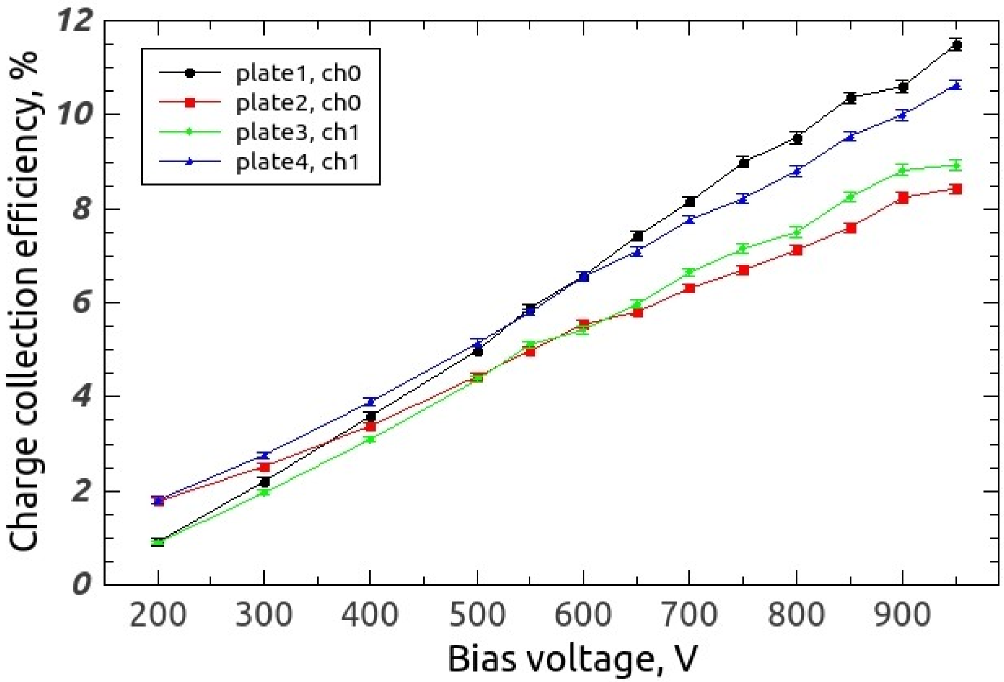
		Before CMN subtraction	After CMN subtraction
@500V	MPV σ Landau	600.6 14.8	604.9 16.3
	Mean σ Gauss	649.2 119.2	656.2 70.2





CMN subtraction reduces the noise, mean value of the signal is practically not affected (~1% change)

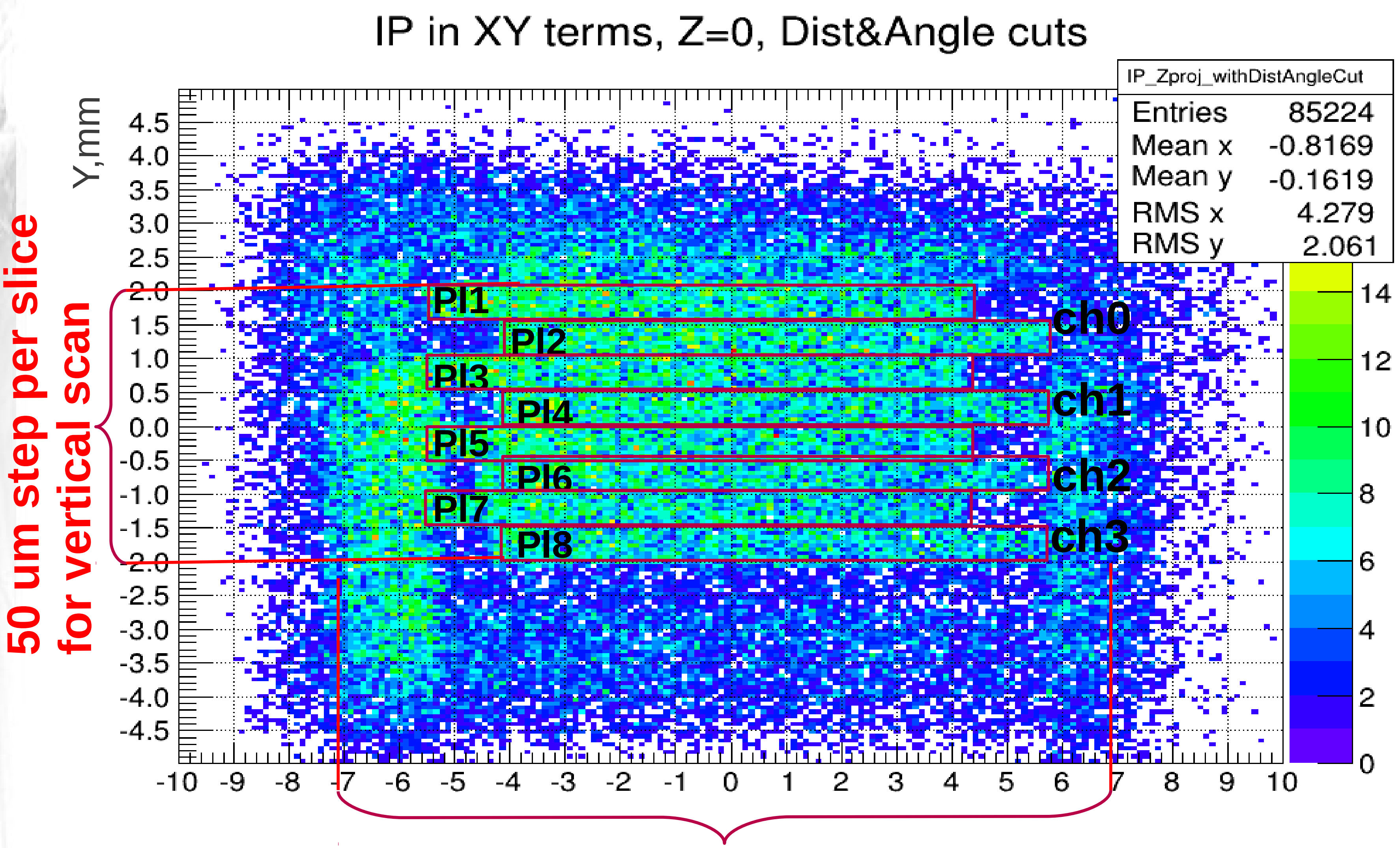
Charge collection efficiency vs. bias voltage



- Sapphire detector CCE linearly depends on the applied voltage.
- For good quality plates it reaches ~10% at 950 V (E ≈ 2 V/μm).

Plate number	1	2	3	4	5	6	7	8
CCE, %	**11.5**	**8.4**	**8.9**	**10.6**	**9.1**	**5.8**	**3.9**	**2.9**
stat. error	0.14	0.1	0.13	0.11	0.11	0.08	0.06	0.06
syst. error	0.6	0.4	0.4	0.5	0.5	0.3	0.2	0.2

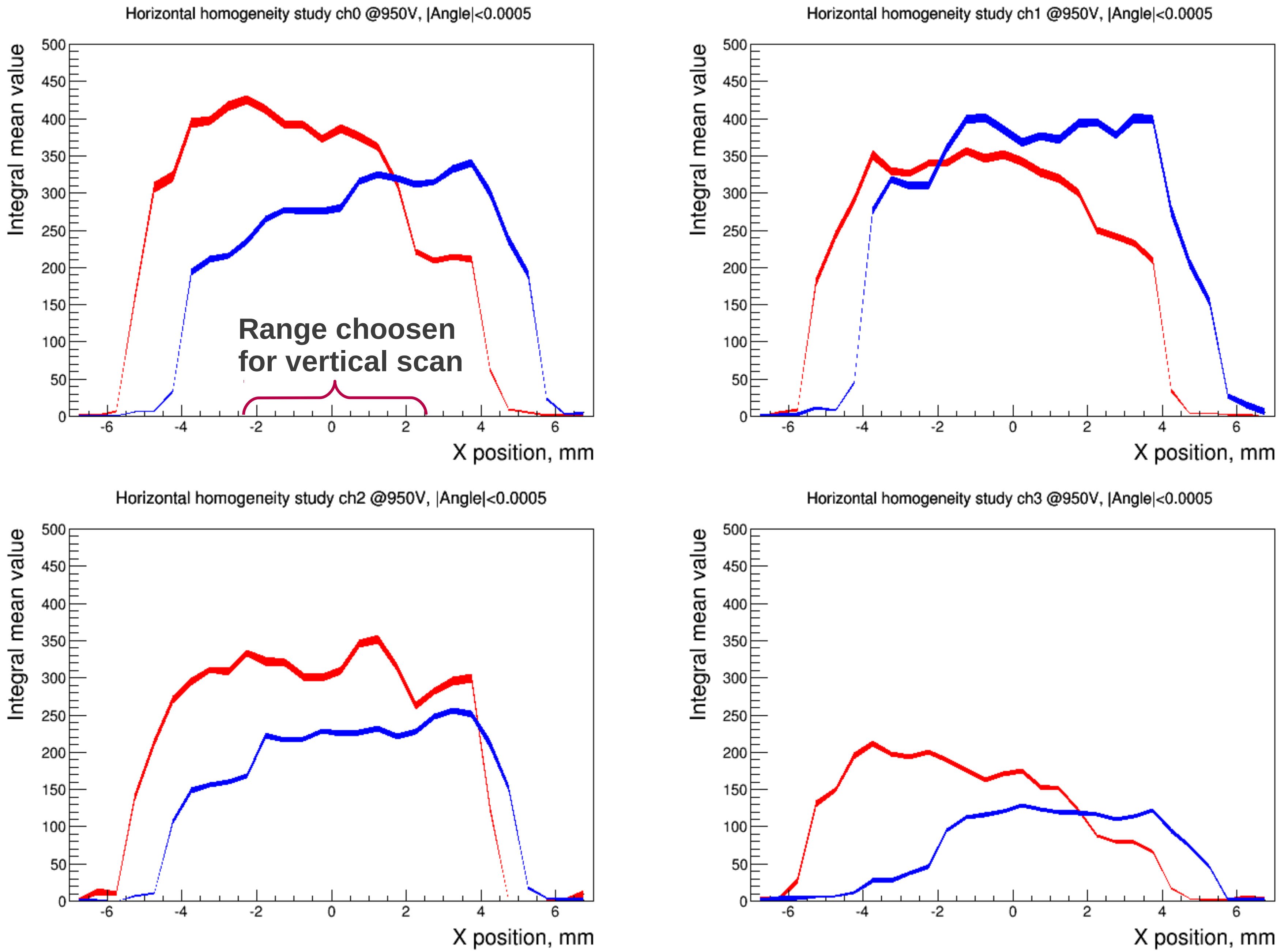
Horizontal and vertical scan



50 um step per slice for vertical scan

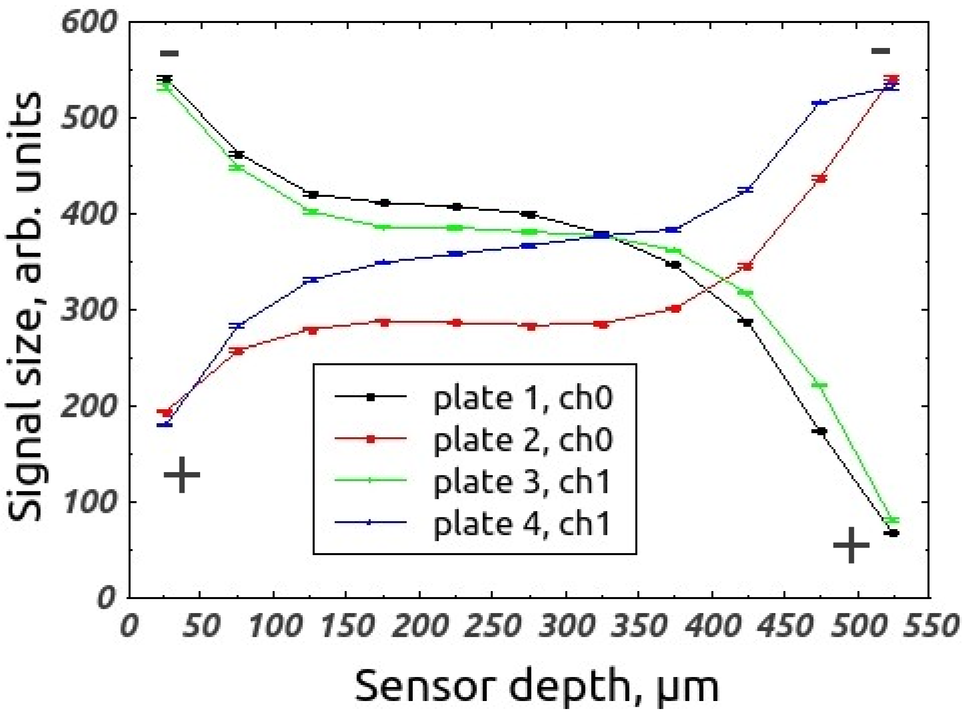
500 um step per slice for horizontal scan

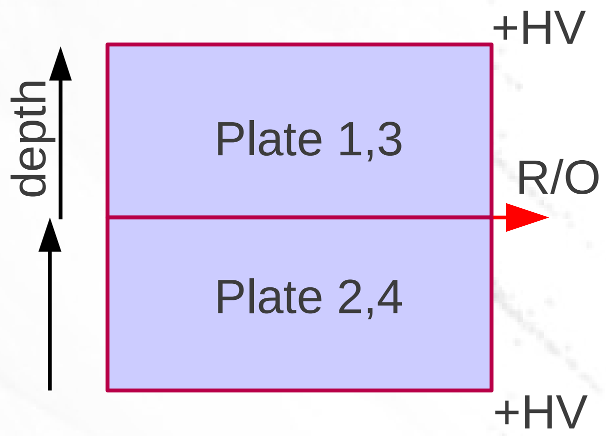
Horizontal scan



Signal size vs. track position between electrodes

Plates with 'high' efficiency



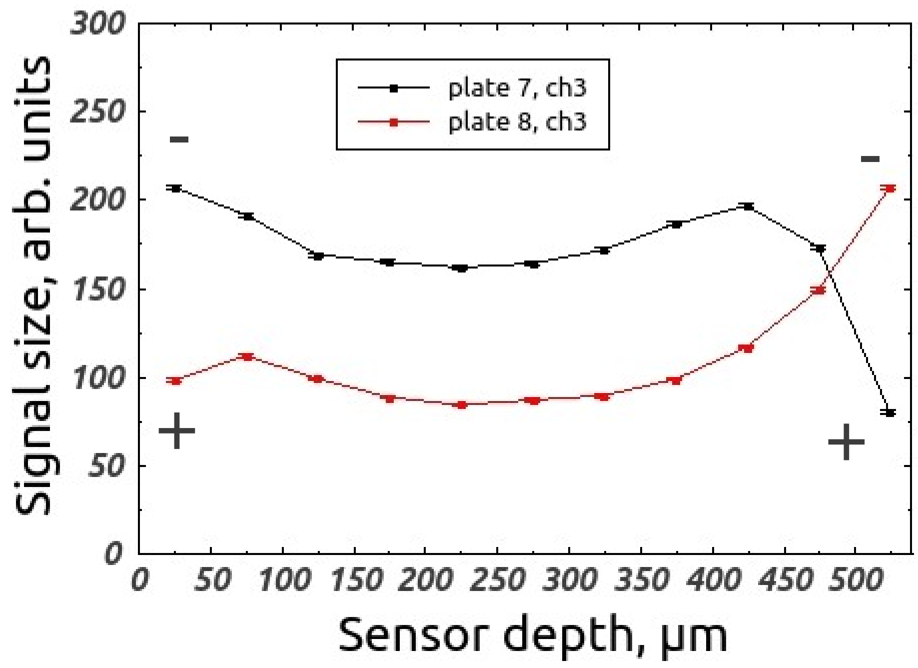


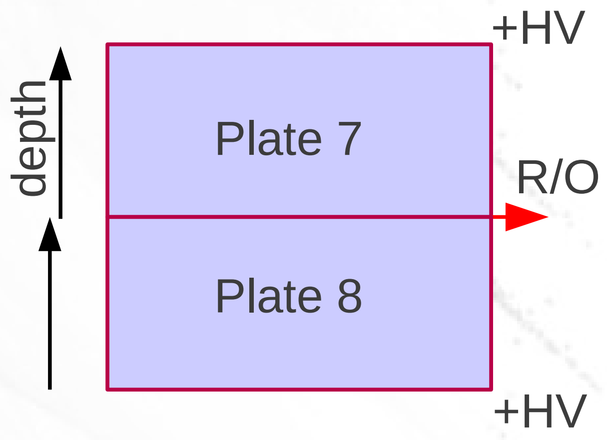
Signal size is correlated with field direction. It agrees with assumption that charge collection in sapphire is done by only one type of carriers (electrons).

Maximum near negative electrode — polarization field!

Signal size vs track position between electrodes - 2

Plates with 'low' efficiency

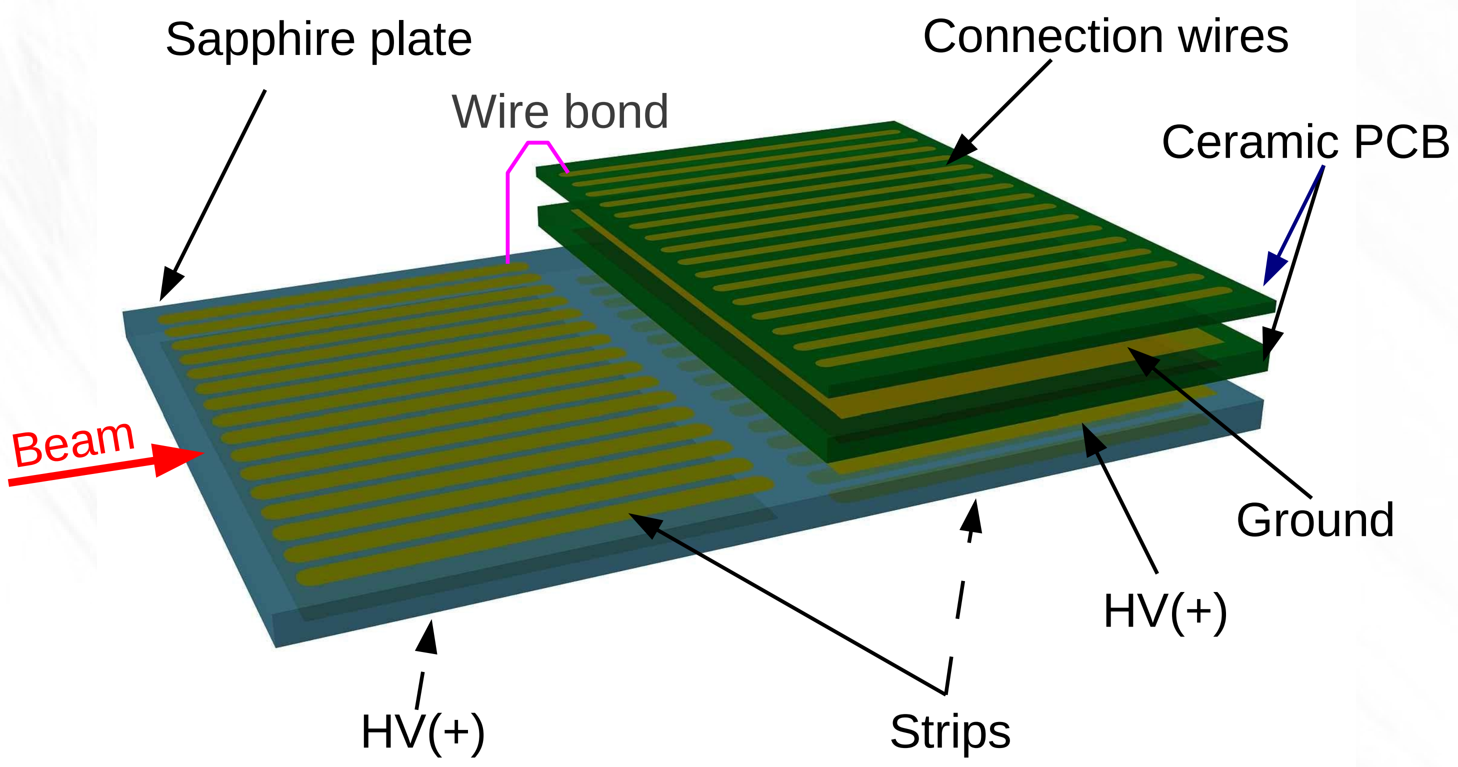




Signal size is correlated with field direction. It agrees with assumption that charge collection in sapphire is done by only one type of carriers (electrons).

Maximum near negative (and at ~100 μm from positive) electrode — polarization field!

Outlook: Next generation sapphire sensor



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.
  - The charge collection efficiency 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.