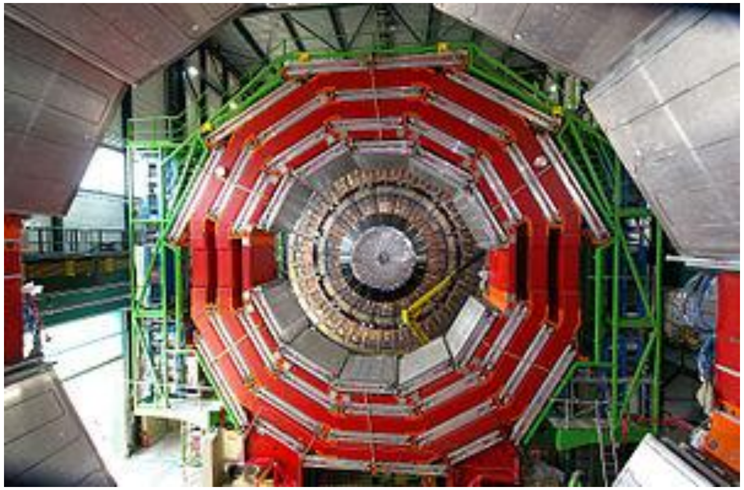
Sapphire Detectors

Sergej Schuwalow, Uni Hamburg /DESY Zeuthen



Contents

Sapphire properties (Diamond)

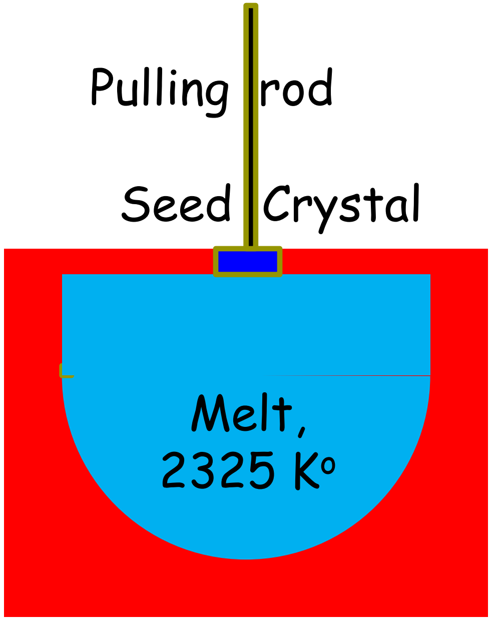
	Sapphire	(Diamond)
• Density	3.98 g cm^{-3}	3.52 g cm^{-3}
• Dielectric constant	9.3 – 11.5	5.7
• Breakdown field	~10^6 V cm^{-1} *	10^7 V cm^{-1}
• Resistivity	>10^{14} Ω cm	>10^{11} Ω cm
• Band gap	9.9 eV	5.45 eV
• Electron mobility	~600 (20°C) **	1800 cm^2 V^{-1} s^{-1}
• Hole mobility	30000 (40°K) **	1200 cm^2 V^{-1} s^{-1}
• Average signal created	22 eh μm^{-1}	36 eh μm^{-1}

* Typical operation field ~10^4 V cm^{-1}

**Optical-Pump/THz-Probe Spectroscopy

Synthesis of sapphire (Al_2O_3)

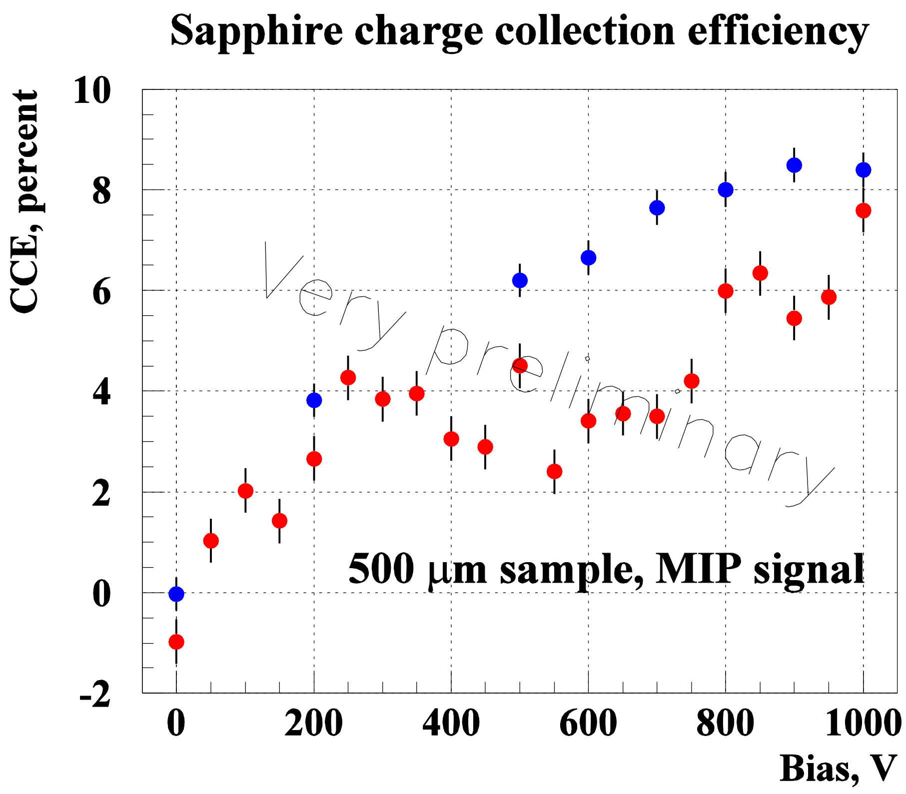
- Single crystals are grown by Czochralski process
- Growing speed ~100 mm/hour
- Up to 440 mm diameter crystals
- Crystal weight up to ~500 Kg
- World annual production >250 tons
- Used in chemistry, electronics, semiconductor industry, lasers, etc.



Impurity	Na	Si	Fe	Ca	Mg	Ni	Ti	Mn	Cu	Zr	Y
ppm	8	2	5	5	1	<3	<1	3	<3	2	2

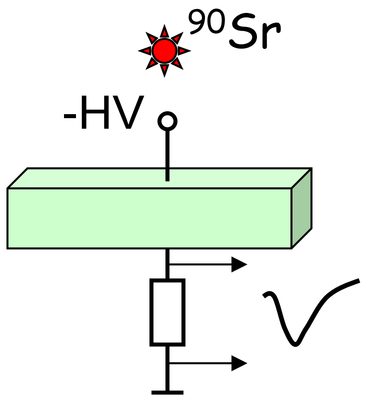
Sapphire charge collection efficiency

Measured at ^{90}Sr setup



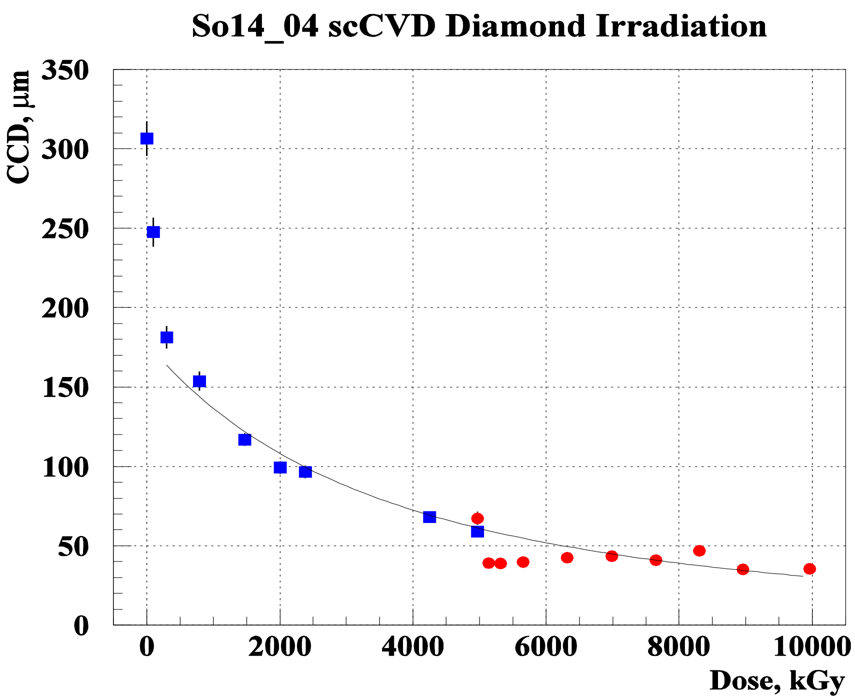
Signal ~ 600 e^-

SC Sapphire
$10 \times 10 \times 0.5\ mm^3$
Metallization
Al+Ti+Au

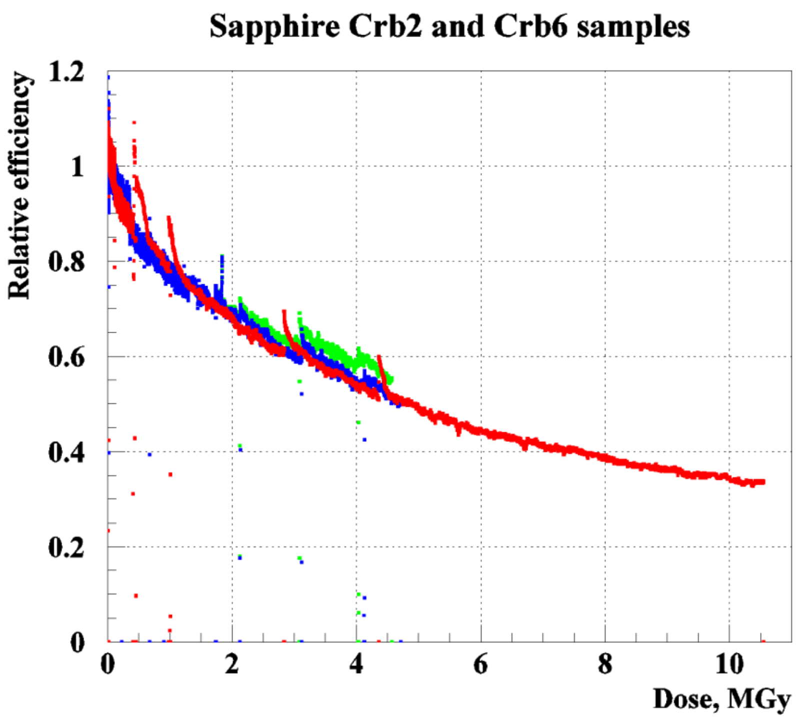


Irradiation of sapphire and diamond sensors at 10 MeV electron beam

Single crystal CVD diamond



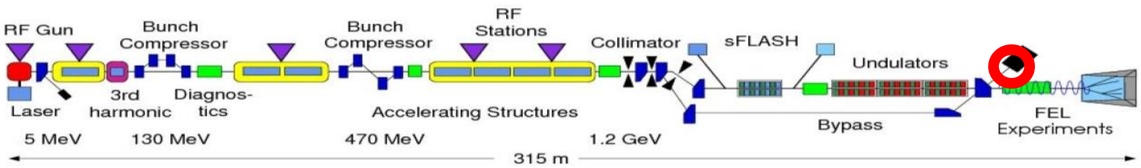
Single crystal sapphire



Leakage current after irradiation is still at few pA level

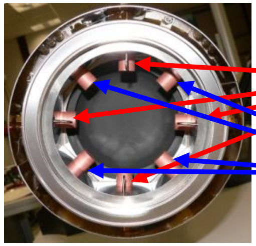
10 MGy ~ $5{\cdot}10^{16}$ MIPs ~ $2.5{\cdot}10^{15}$ [1 MeV neq] (NIEL, G.P.Summers)

BHM at FLASH



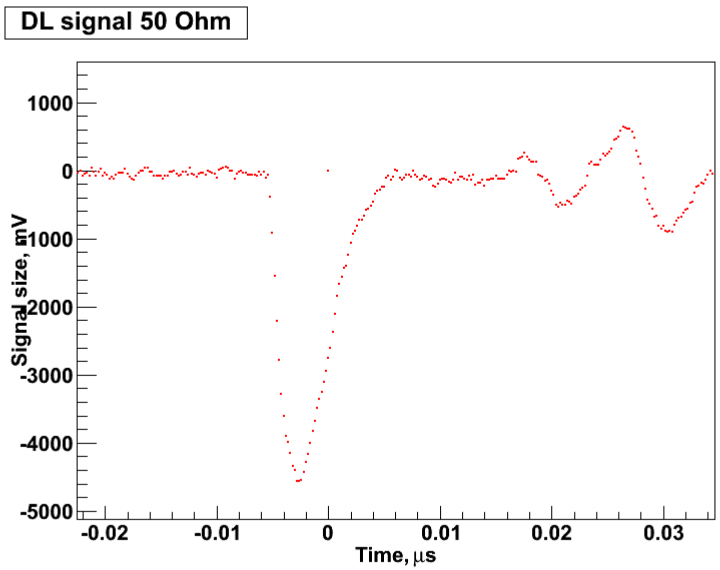
4 artificial sapphire sensors

4pCVD diamond sensors

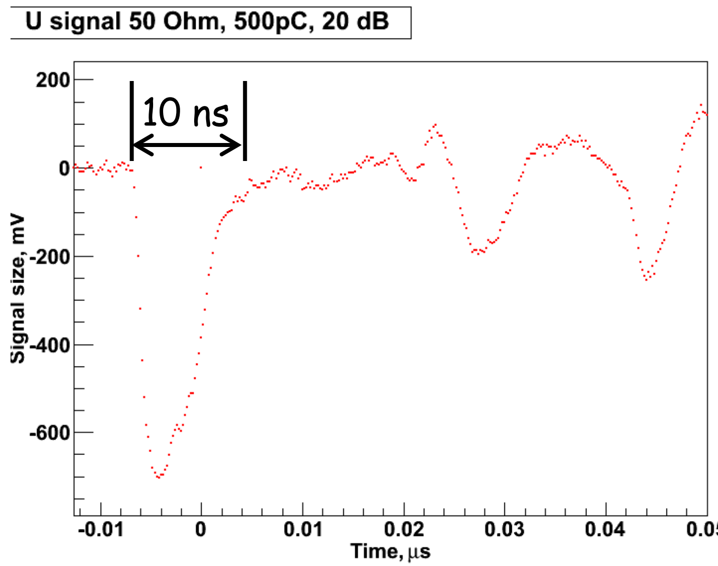


Sapphire sensors

Diamond sensors



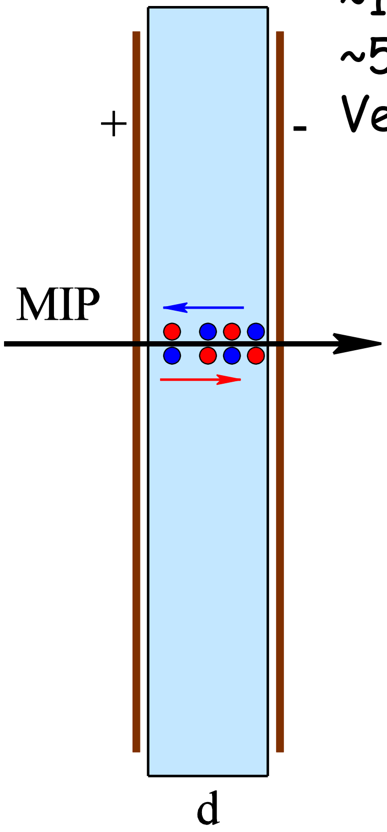
Analog signal from diamond sensor



Analog signal from sapphire sensor

Courtesy of A.Ignatenko, DESY-HH

Detection of MIPs



Typical thickness ~0.5 mm
~11K e-h pairs created
~5% CCE -> 550 e signal
Very hard to detect

Detection of MIPs - 1

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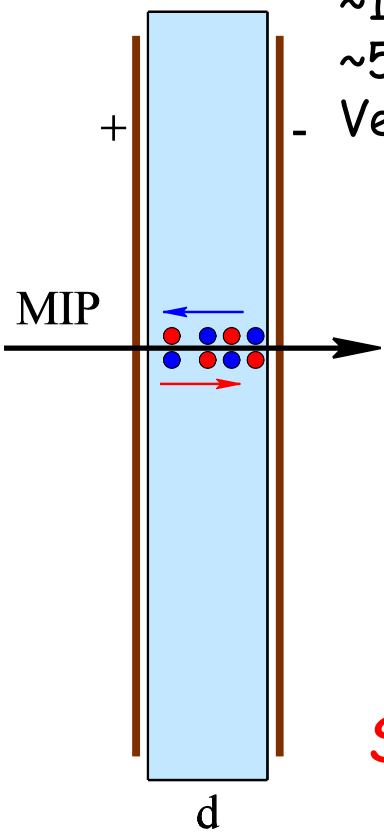
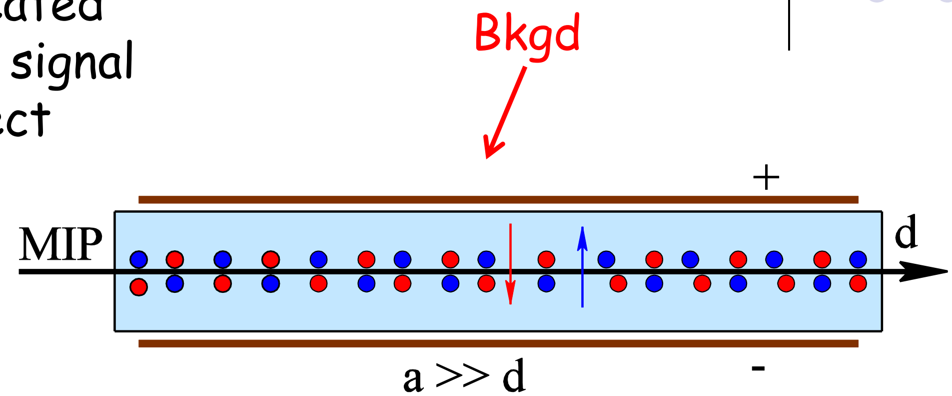
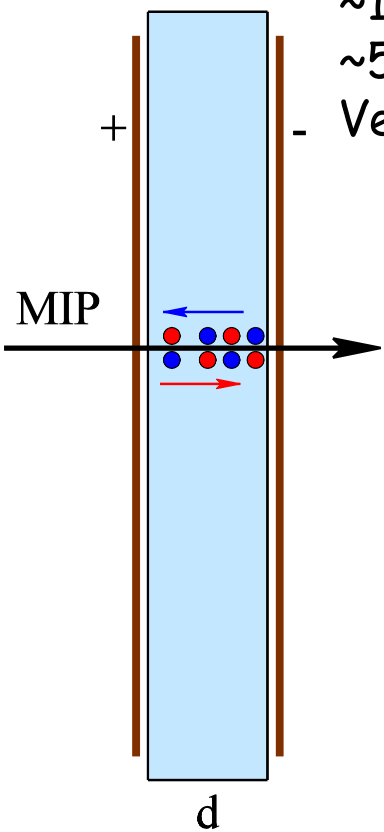




a=10 mm => 220K e-h pairs produced
~5% CCE -> ~11000 e signal, similar to scCVD diamond detectors.

Strongly reduced sensitivity to background!

Detection of MIPs - 2



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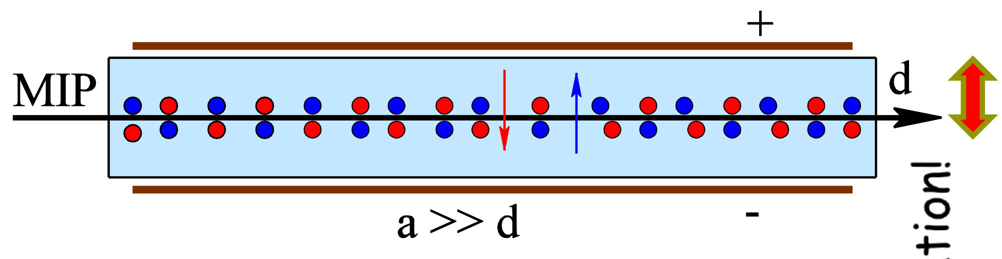

10 nm deviation!

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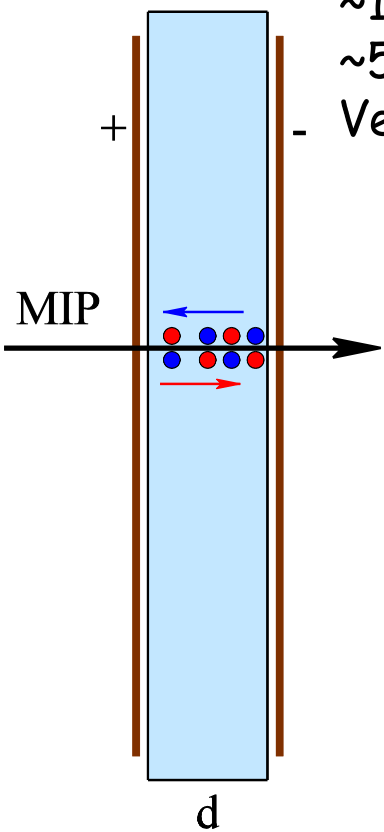
Rad. Length: x/Xo = 0.142

Multiple scattering:

Energy	5 Gev	24GeV	500 GeV	7 TeV
θ_o	$9.5\ 10^{-4}$	$1.98\ 10^{-4}$	$9.5\ 10^{-6}$	$6.8\ 10^{-7}$

Detection of MIPs - 3



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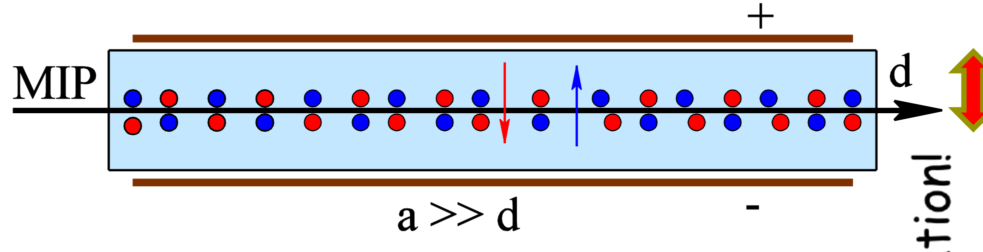

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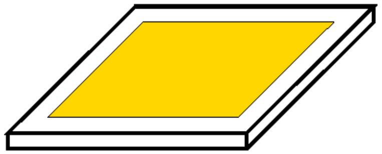
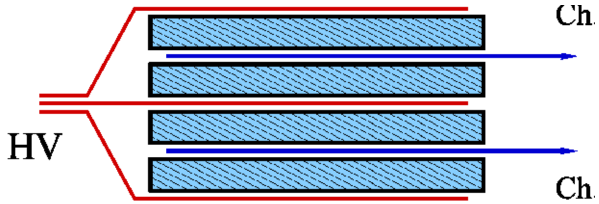
DESY test beam

Possible sensor configurations

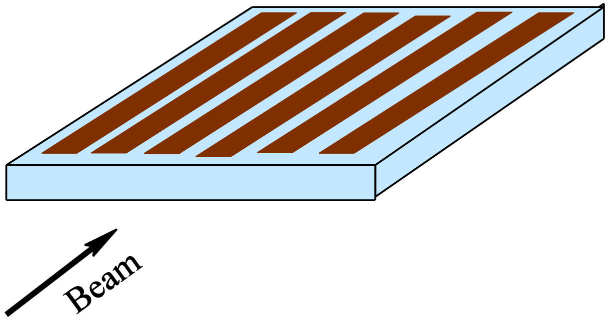
Pad sensor



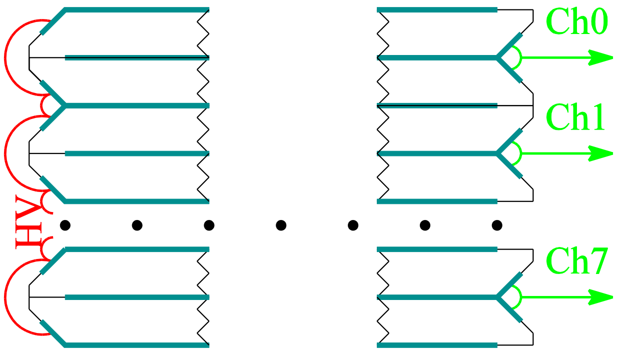
Stack



Segmented sensor
("pixel row")



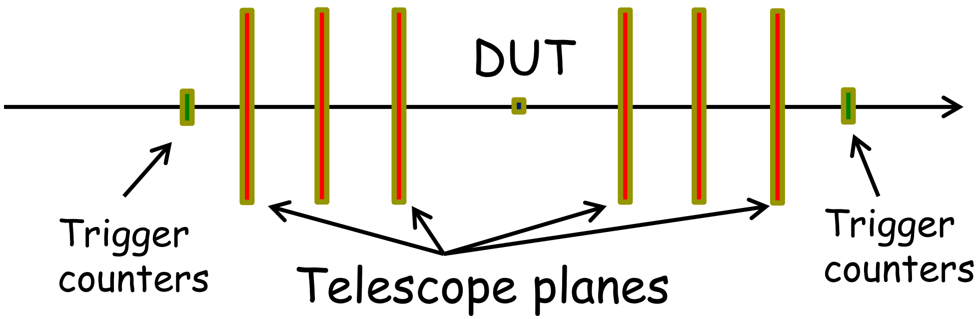
"No dead space" stack



And much more ….

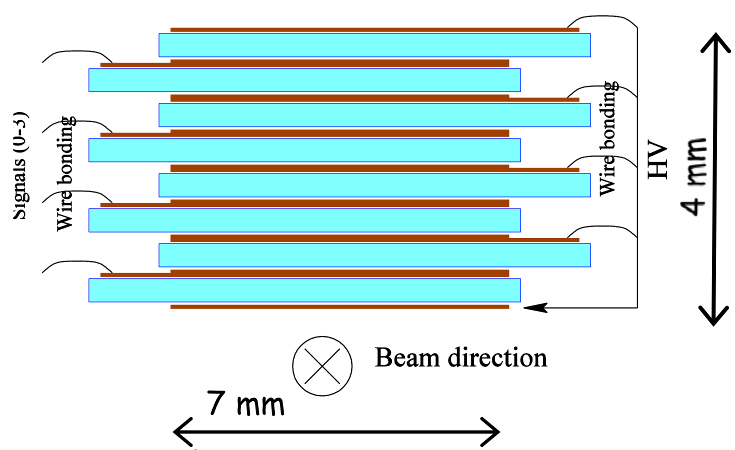
Test beam at DESY 08.2013

- 5 GeV electrons + pixel telescope

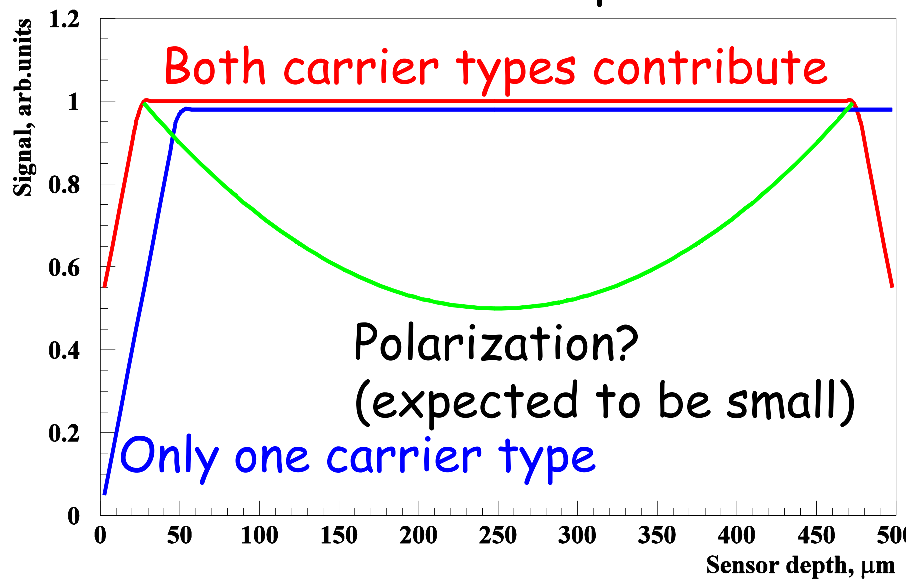


~50% efficiency expected
(hits in all trigger counters)
(MC GEANT)

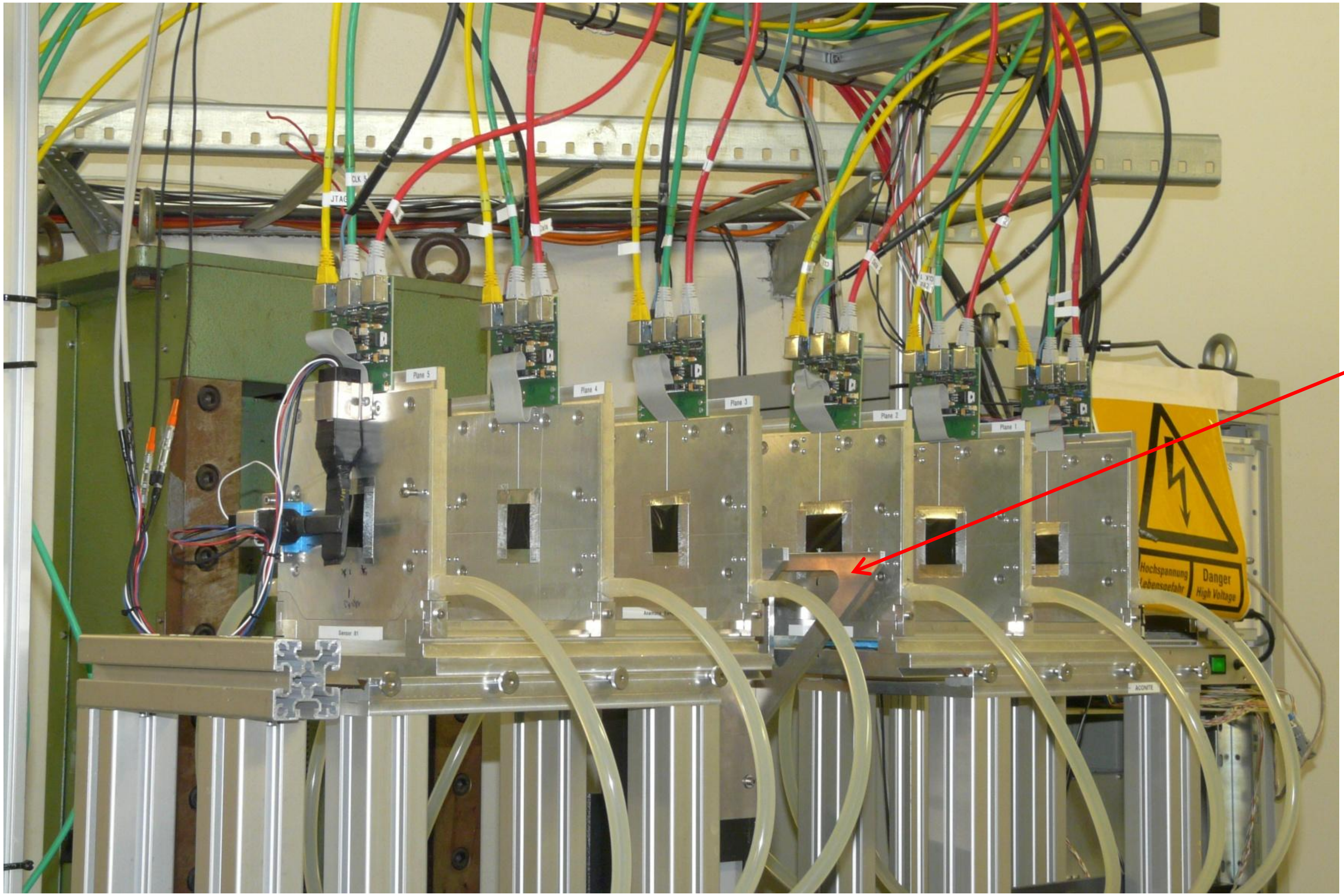
Detector – 8 sensors,
4 readout channels



What we expect to see:

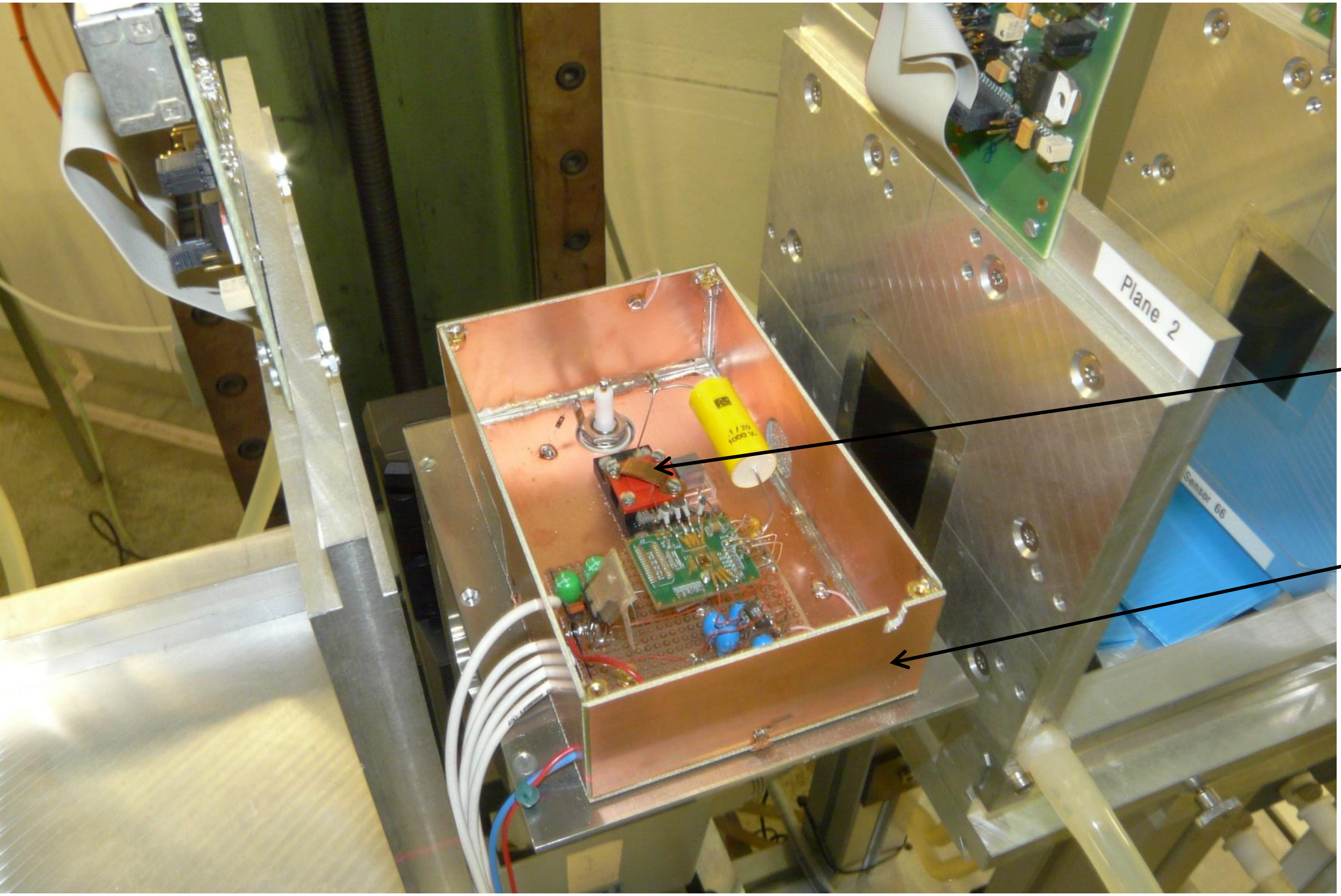


Test beam at DESY. EUDET telescope

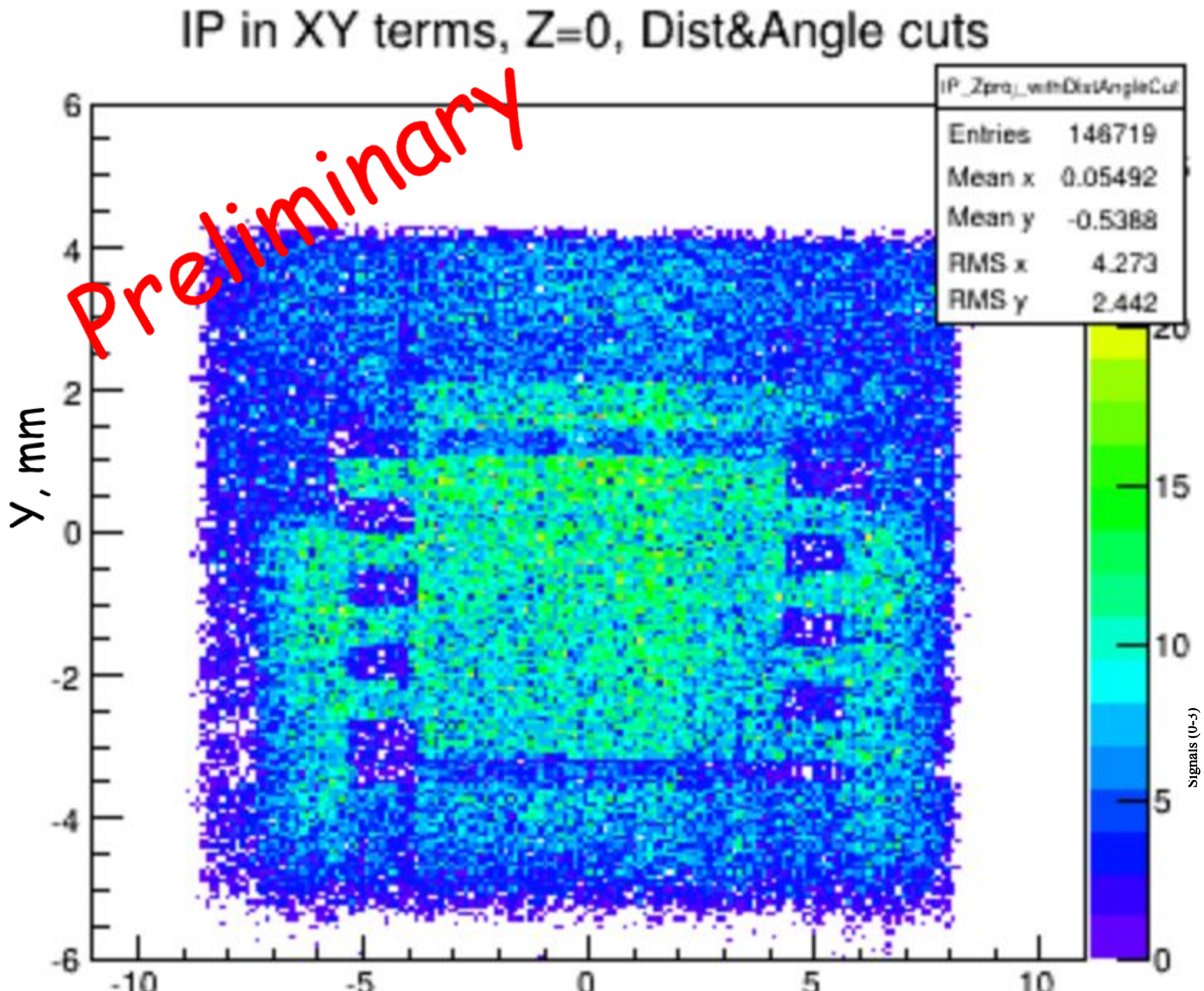


Detector
support
platform
at XY-table

Test beam at DESY. Detector installed



Telescope information only, XY of vertices



Work is going on (PhD student at DESY Zeuthen)

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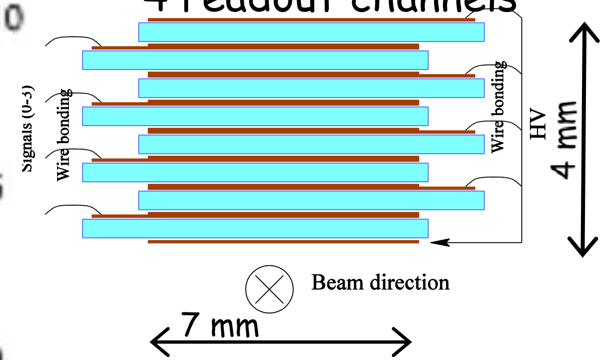
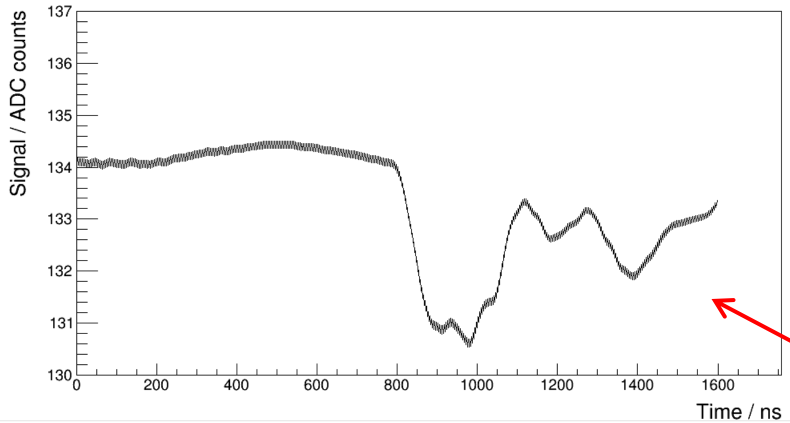


Sapphire detector signal, 500 V bias
DUT information only



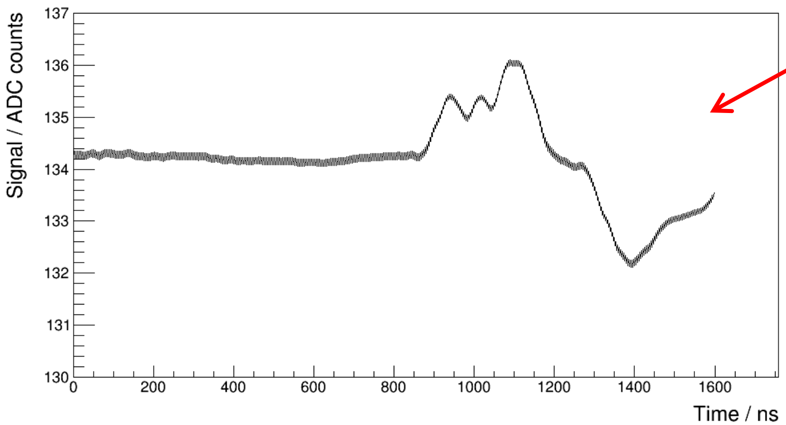
Large pick-up of telescope trigger logical signals

Average of signals **above** the threshold

–

Average of signals **below** the threshold

=



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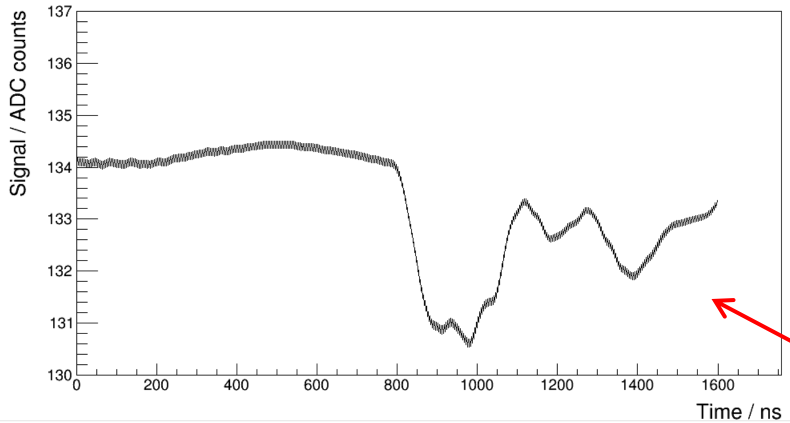

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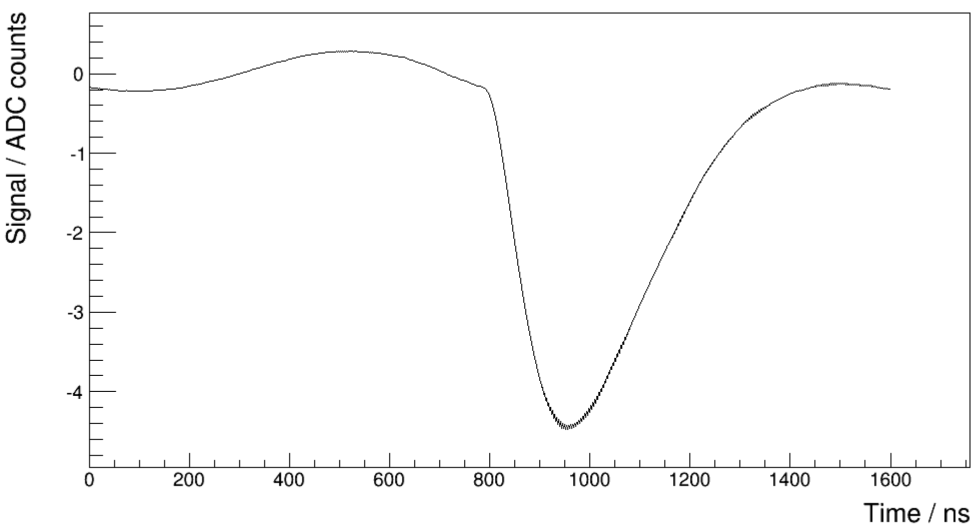
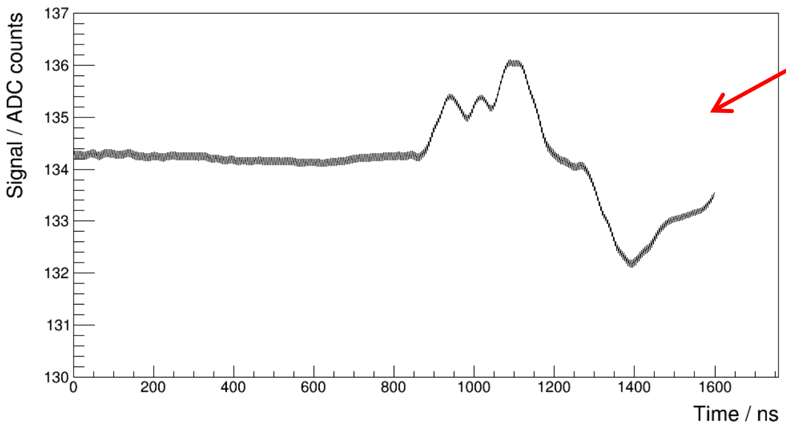
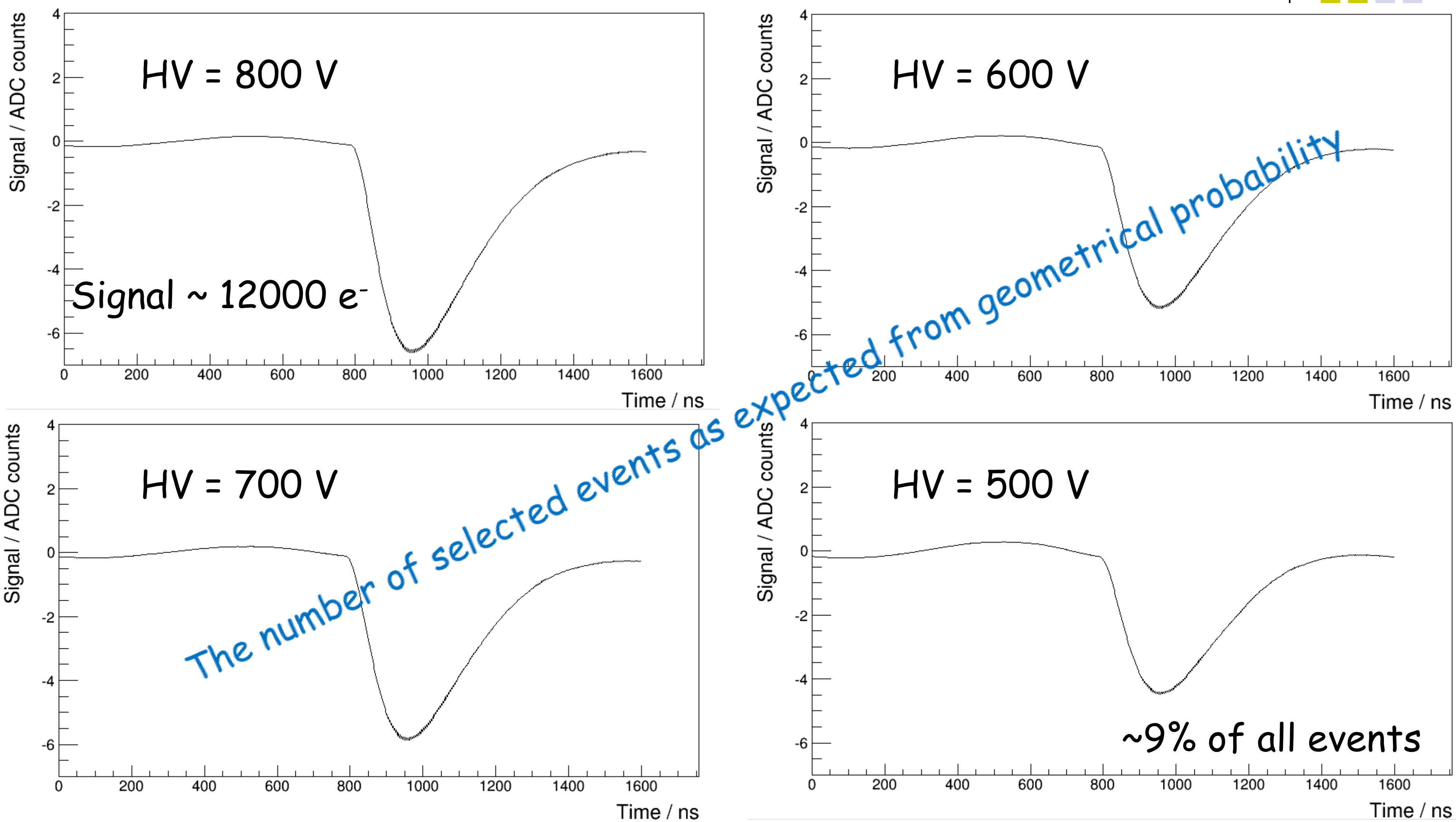
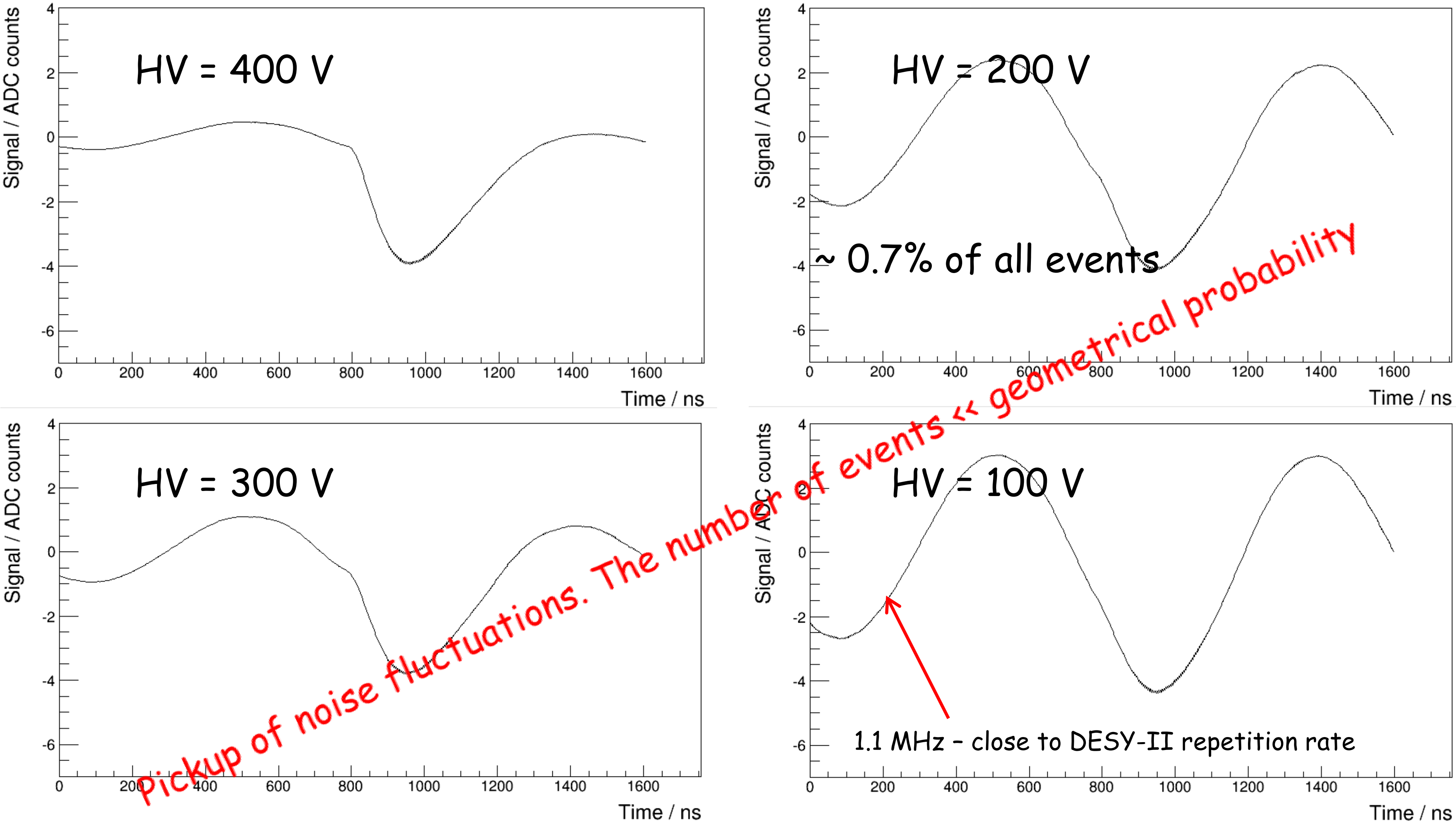




Sapphire detector signal vs bias voltage

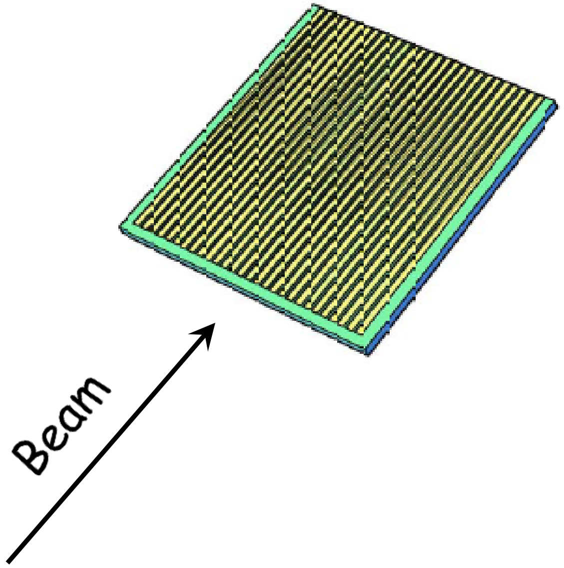


Sapphire detector signal vs bias voltage - 1



Sensor configurations

(i.e. Very Forward Tracking at LHC)



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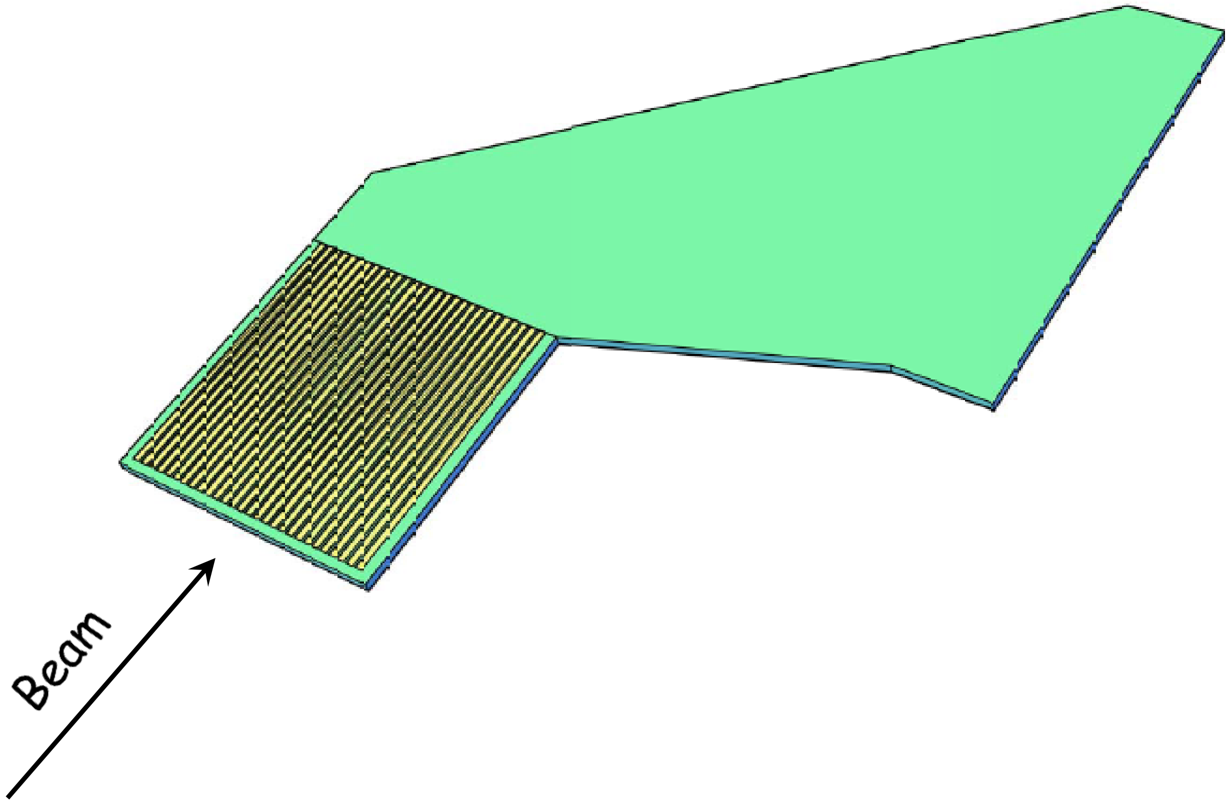

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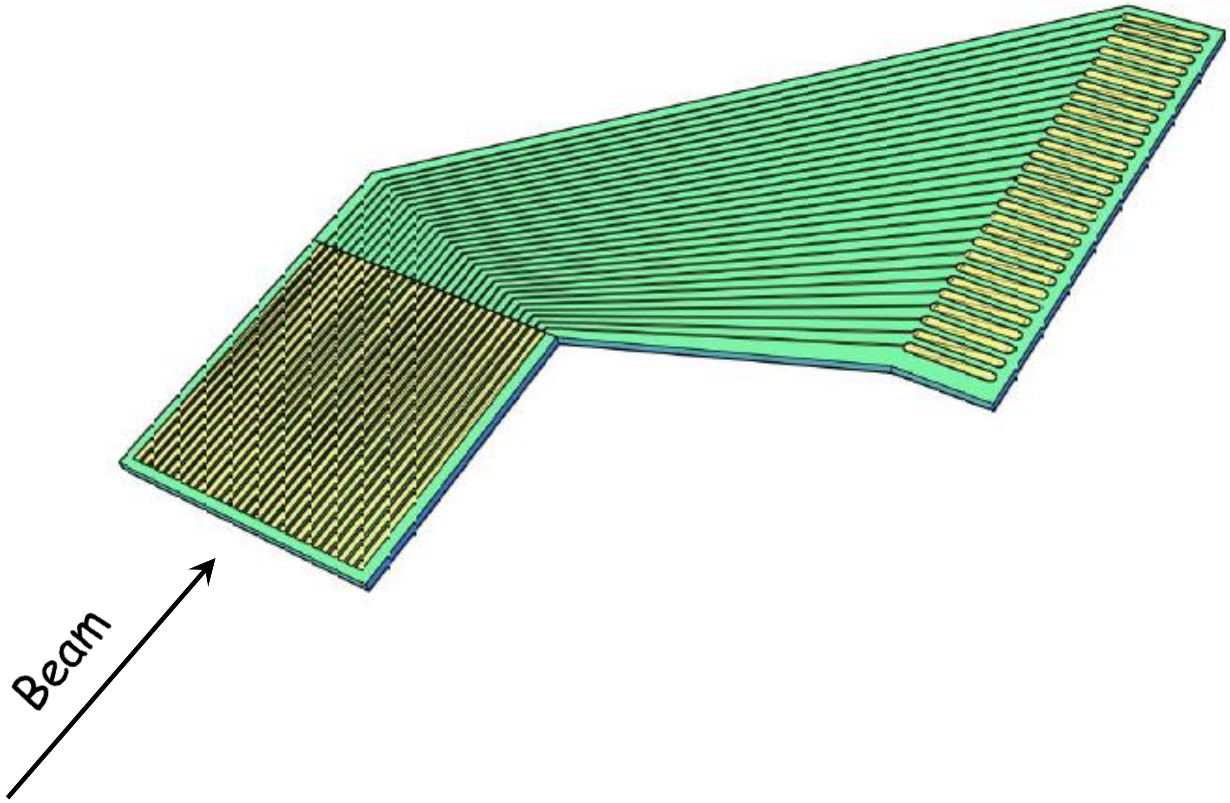

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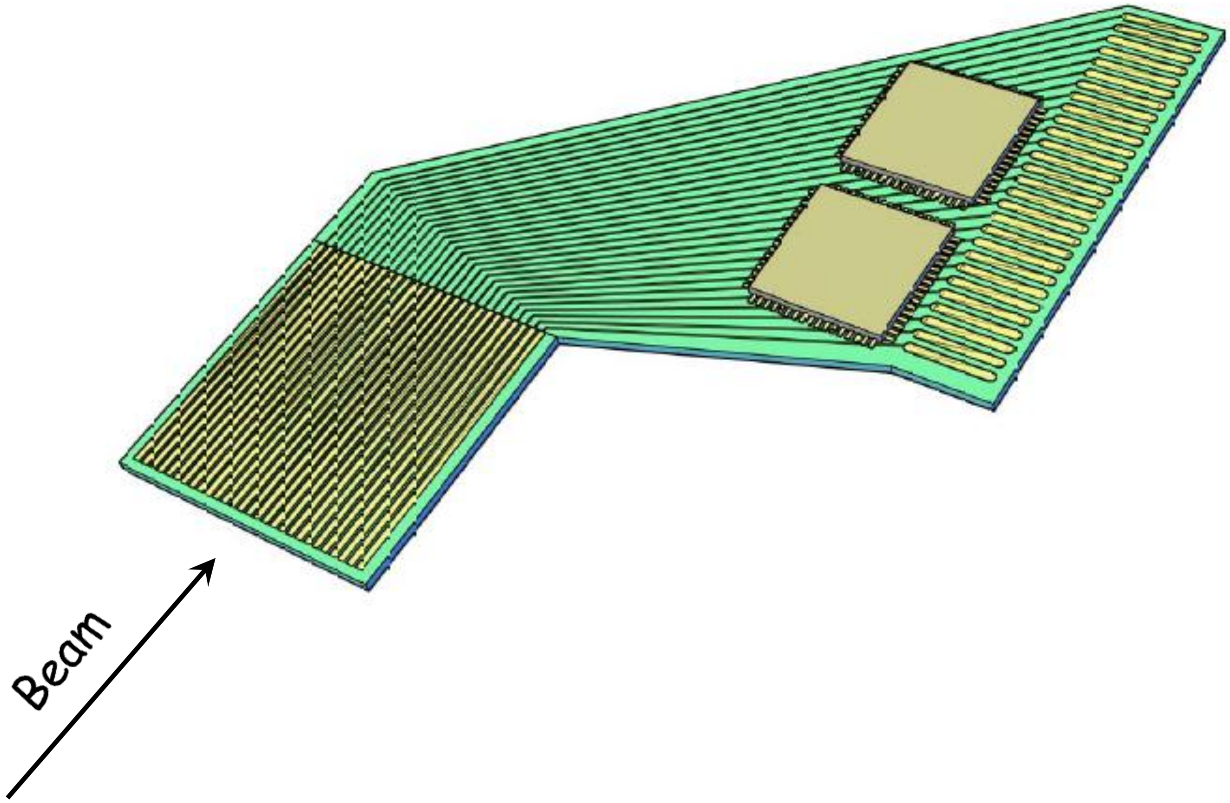


Conclusions and outlook

- Sapphire (single crystal Al_2O_3) is a very promising wide-bandgap material for HEP applications
- Produced in large quantities for industrial purposes, large size wafers are available (~25 cm, up to 40 cm diameter is possible), not expensive
- Perfect electrical properties, excellent radiation hardness, but presently low charge collection efficiency (~ 5%, probably due to high level of impurities)
- For many applications, where radiation hardness is an issue (large particle fluxes), sapphire could be used as it is, i.e. leakage current sensors, detection of particle bunches, calorimetry etc
- Sapphire sensors are successfully operating at FLASH, are to be installed at FLASH-2 and XFEL
- Sapphire sensors could be used for MIP detection in cases where tracker material budget is not critical (beam diagnostics, very forward tracking)
- Sapphire detector designed for MIP detection was tested at the DESY test beam. Preliminary results show expected performance.
- Further developments will follow.

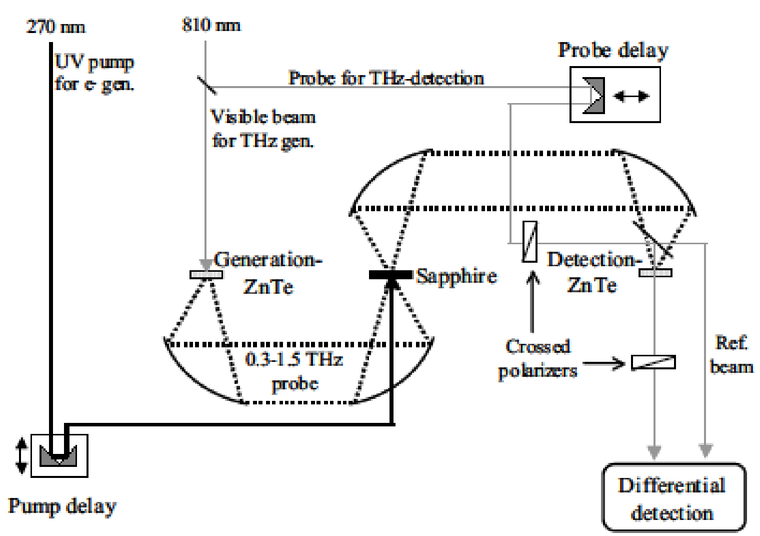
Thank you!

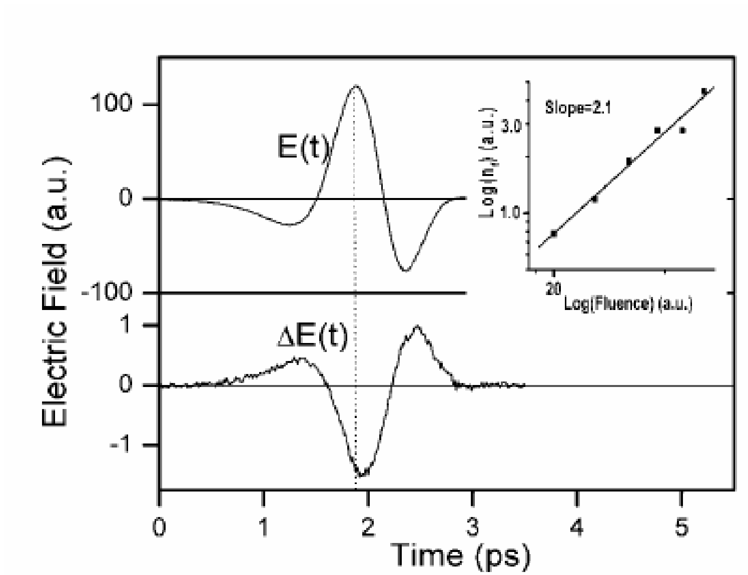
Optical-pump/THz-Probe Spectroscopy

40 – 350 K⁰

F.Wang et.al., 2004

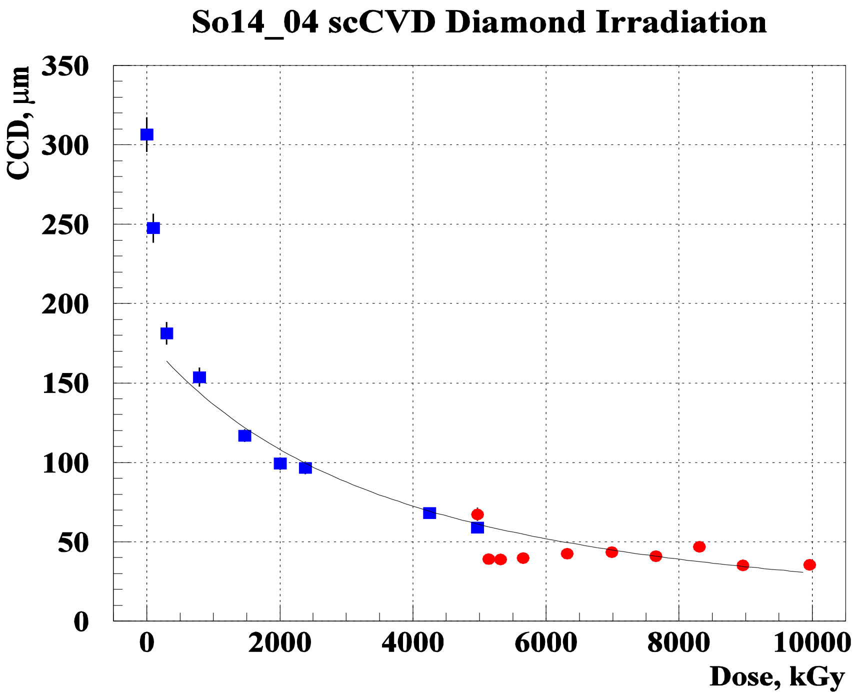
Ultrafast photo-excitation + THz time-domain spectroscopy



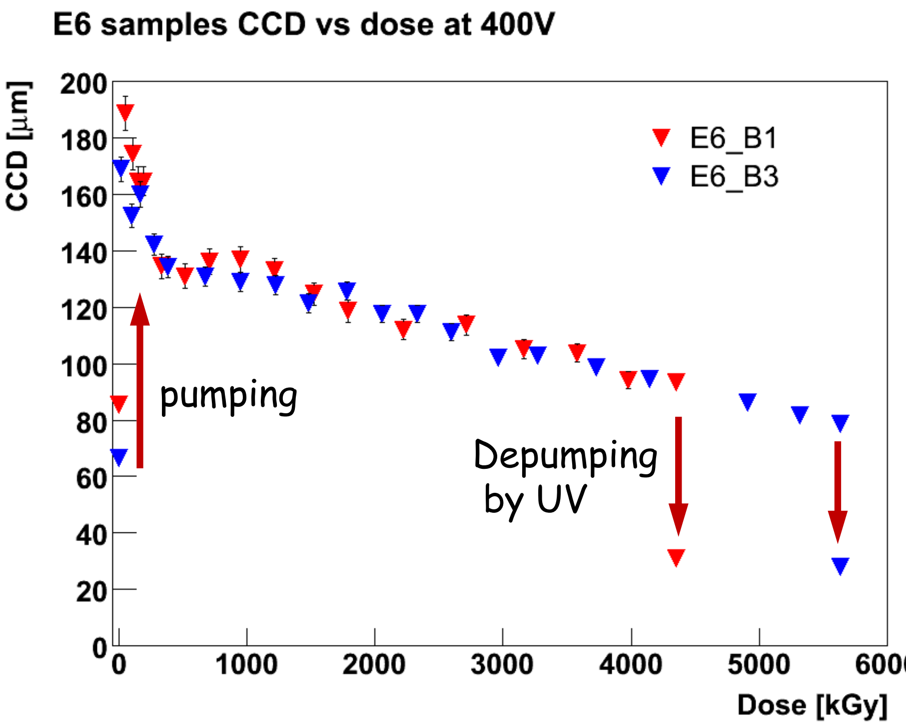


Irradiation of sapphire and diamond sensors at 10 MeV electron beam

Single crystal CVD diamond

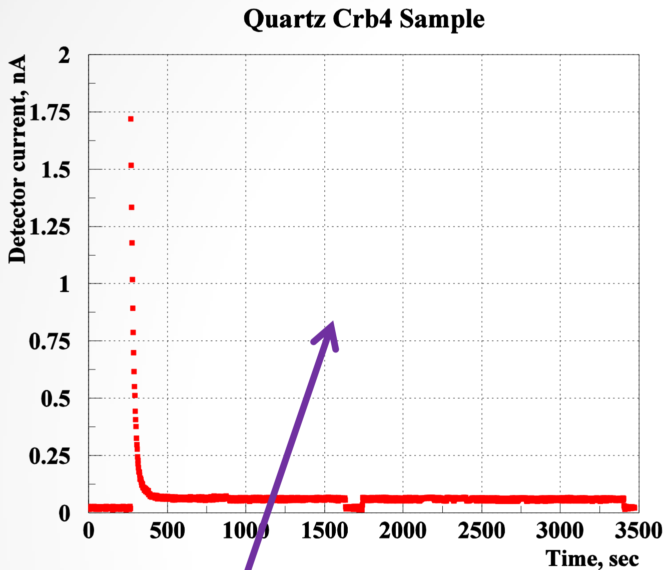


Polycrystalline CVD diamond

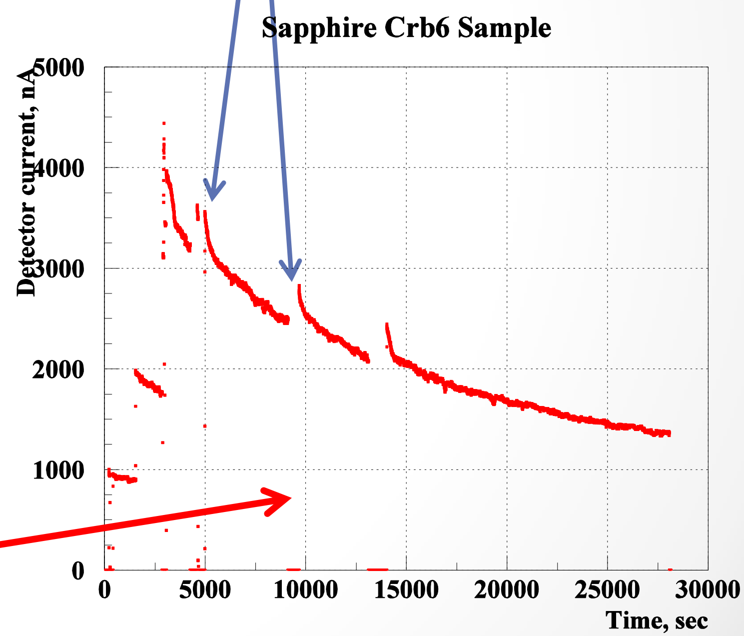


Leakage current after irradiation is still at few pA level

Test of sapphire and quartz sensors at the 10 MeV electron beam



Other two samples. Some recovery effect for sapphire during beam interruptions.



Silicon oxide

Aluminum oxide