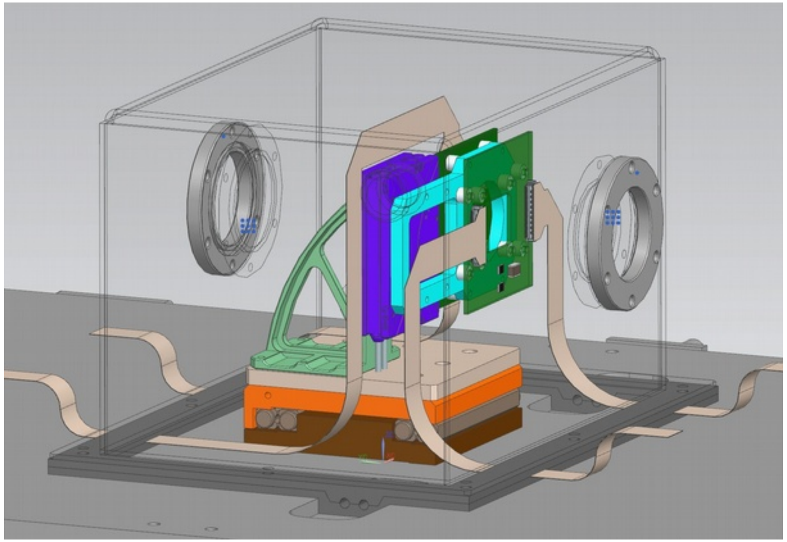
Workshop Contributions



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Istituto Nazionale di Fisica Nucleare
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Wafer / Sensors

- Sapphire wafers:
  - 2", 110 um thick from SITUS Technicals GmbH, Wuppertal
    - 10 shipped from Desy to Padova (6/21)
    - 10 shipped from Desy to Tomsk
  - 2", 150 um thick from University Wafers (US)
    - 20 in total
    - 1 sent to LNGS
  - 60x48 mm, 150 um thick from Monocrystal, Stavropol, Russia
-

Sensors

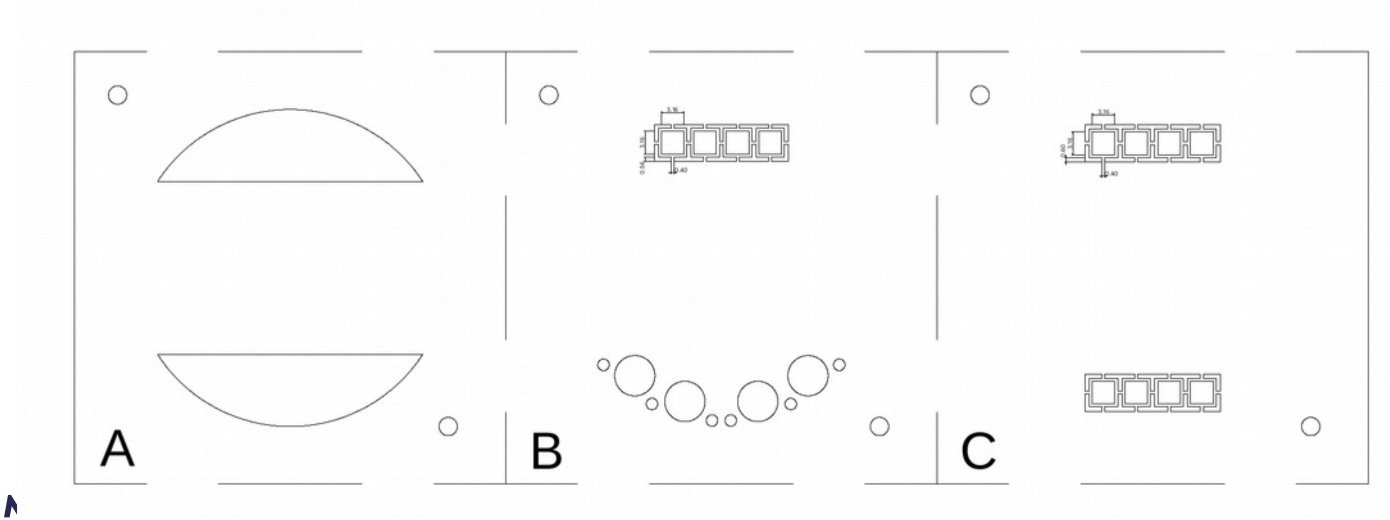
- wafer with pads
  - mainly for CCE measurements
- 4 ch. sensors
  - test readout channels
  - radiation hardness measurements
  - strip signal measurements
  - uniformity measurements
- 200 ch. sensors
  - final prototype for detector validation on beams

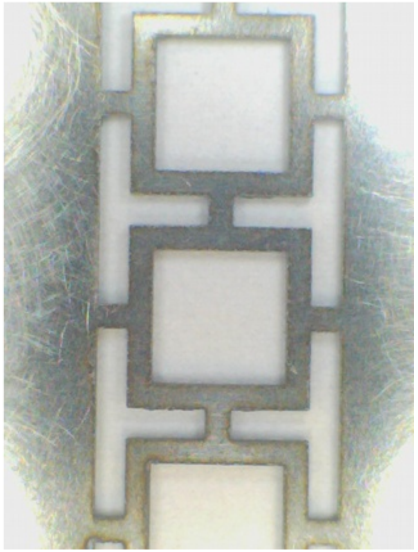
Wafer with pads

- Ag (silver) metallization on 150 um wafer
  - ~100 nm
- adhesion to sapphire not so good
  - bonding possible, but high risk of removing the metal layer
- II attempt: metallization on 110 um wafer:
- two layers:
  - Ti, few nanometers
  - Ag, ~100 nm
- quality of adhesion improved, sufficient for bonding

Wafer with new pads

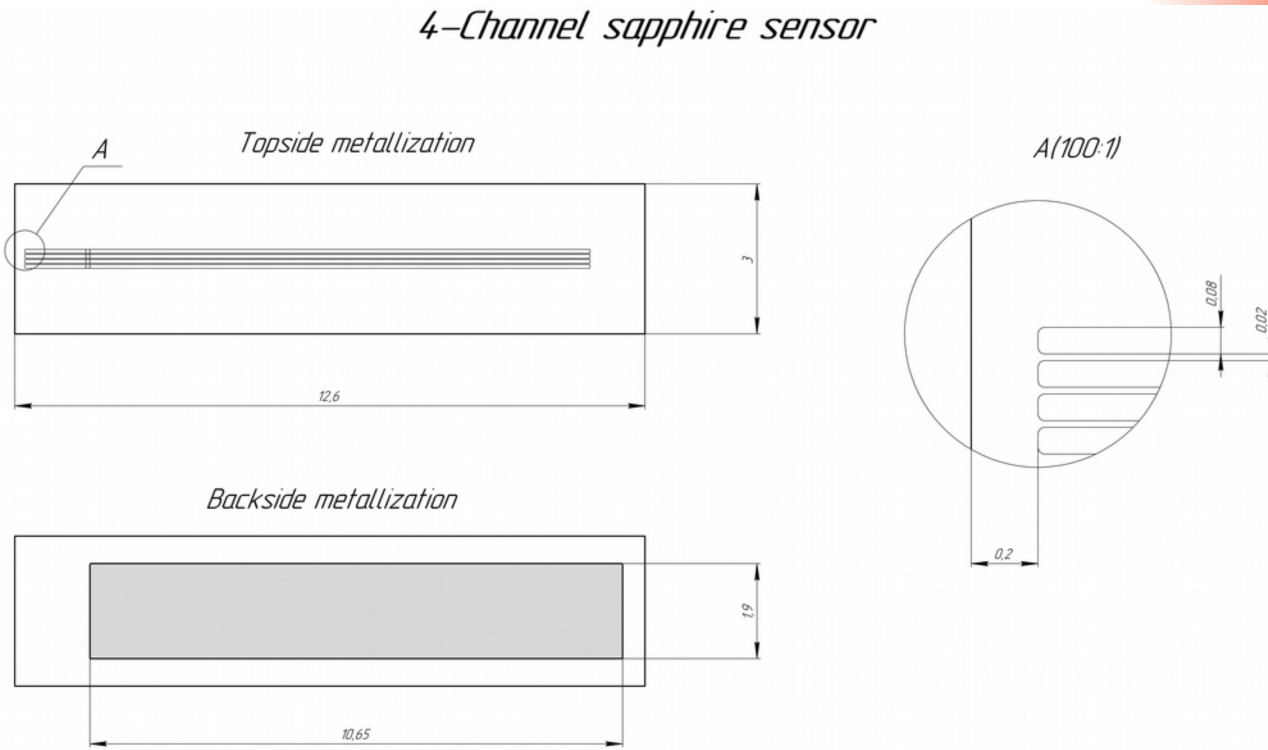
- new masks with circular and rectangular pasds
- guard rings





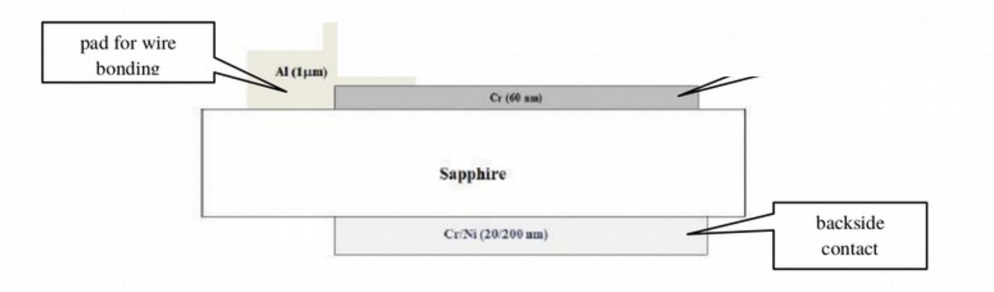
4 ch. sensors

- Designed and produced at Tomsk Univ.



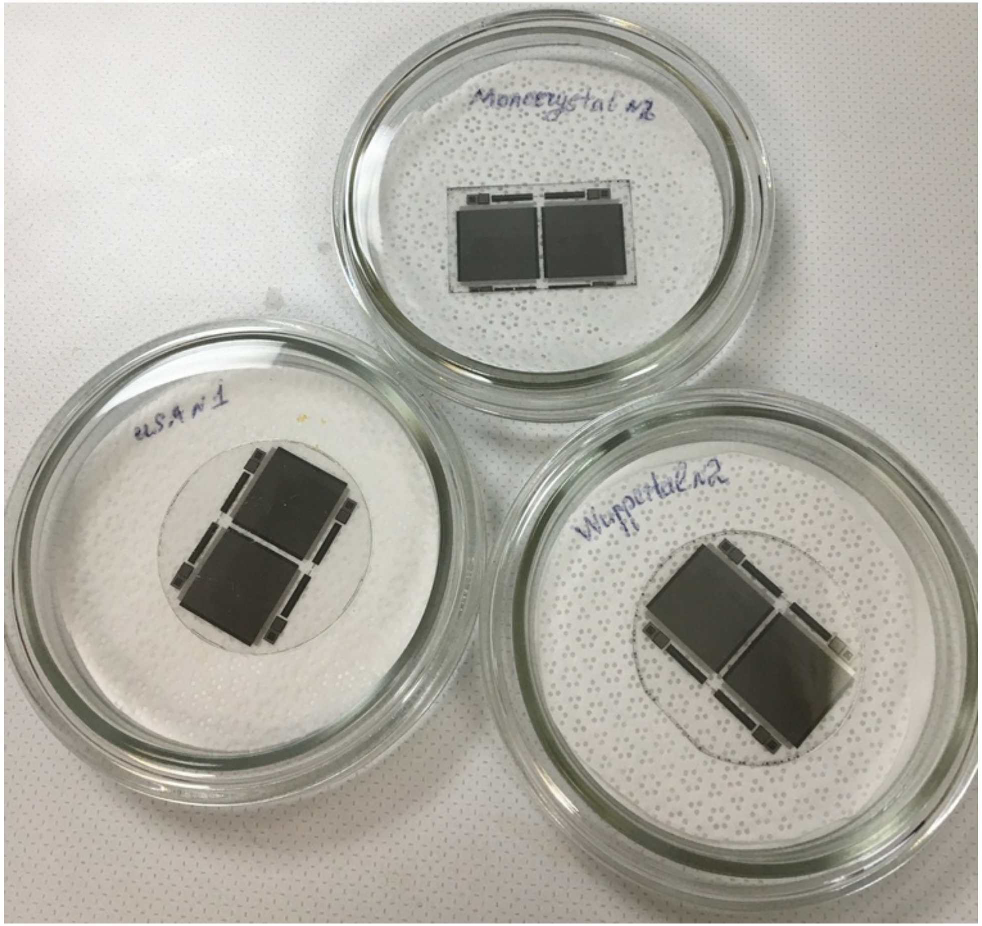
Specification

Sapphire thickness, µm	100-170
Contact type	Al(Si-1%)
Metallization thickness, µm	1.0
Pad size, µm	1200x80
Active strip, mm	10x0,08
Number of strips	4



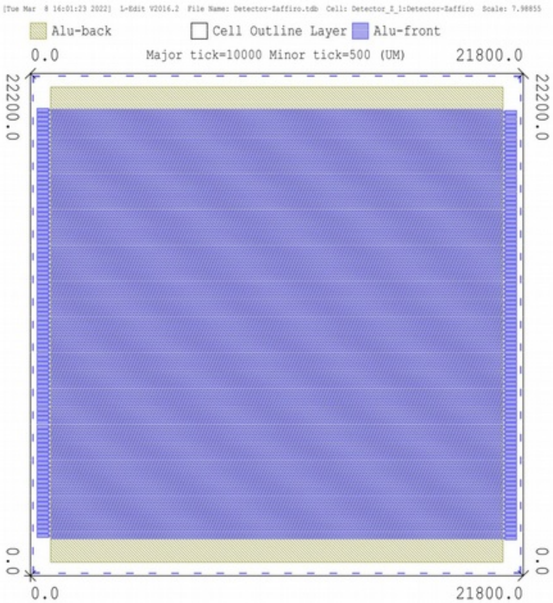
200 strips prototypes

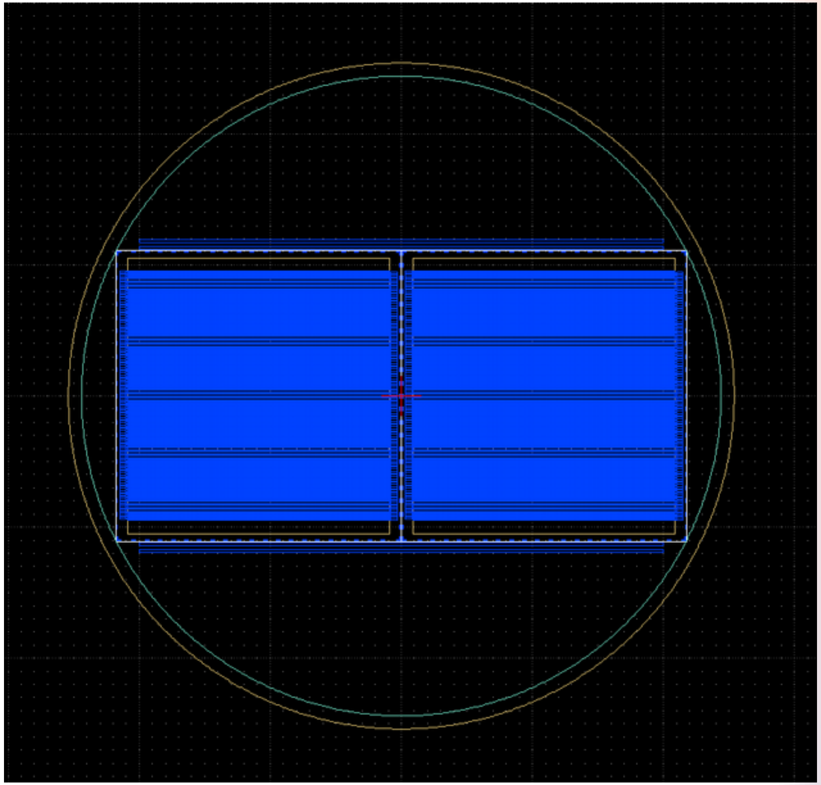
- produced 12/21 at Tomsk

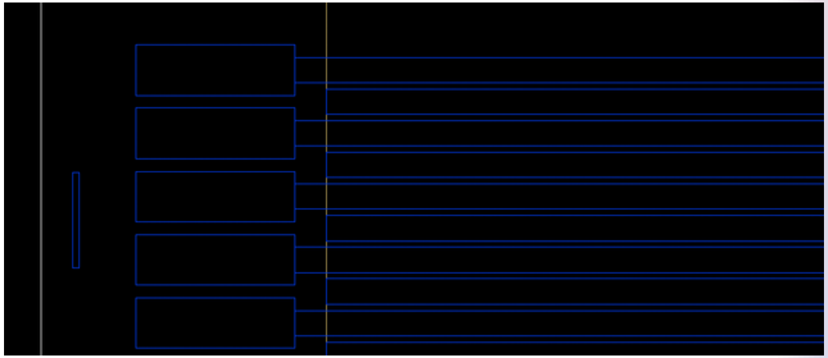


Masks @ FBK

- masks designed to fit two sensors in a 2" wafer (Al deposit foreseen)
- there is still some bureaucracy to be overcome
  - FBK wants to exploit the frame agreement with INFN, but the supervising committee has just been nominated
- of course we still hope we can get the sensors from Tomsk and production at FBK is not needed
- however, from the technical point of view FBK is ready to go
- production takes 4 weeks from green light







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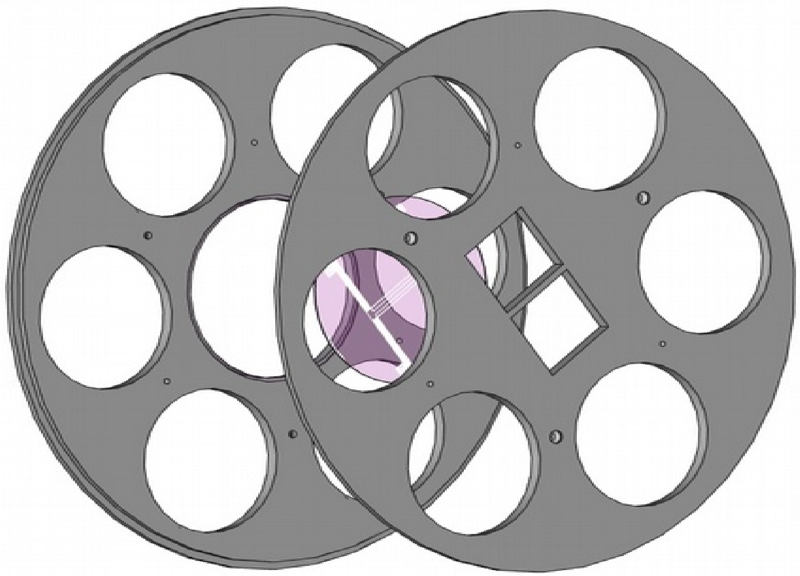
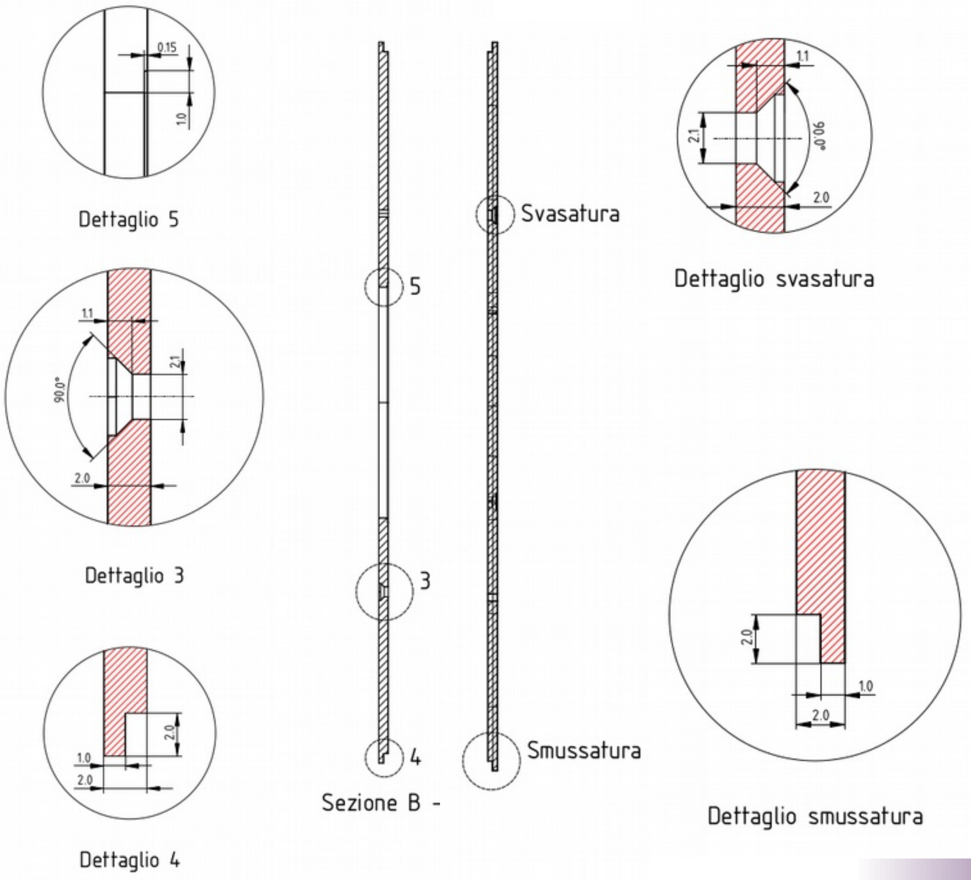
Adapter 2" to 6"

- At FBK equipment is compatible with 6" wafers
- adapter has been designed by Michele G.
- now being produced by the Padova mechanical workshop





- total weight ~98 g
- disks made of Al, 2 mm thickness
- M2 screws with 0.4 mm pitch

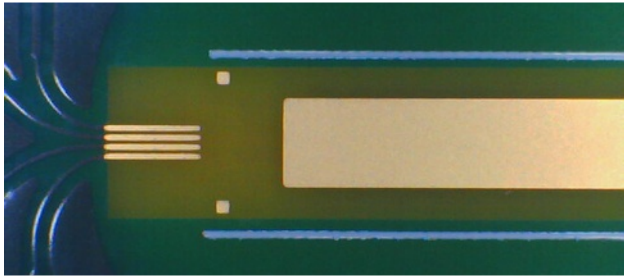
Electronics

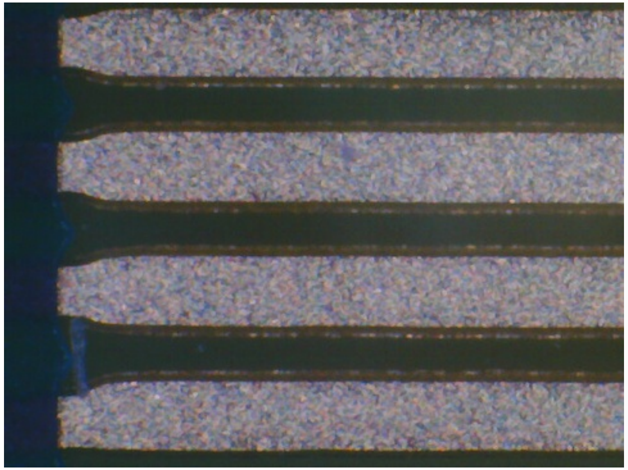
- Charge amplifiers (PD)
  - w/shaper custom design (F. Dal Corso)
    - 245 mV/fC
    - 800 e- noise
    - output on high impedence
  - w/o shaper
    - Cube
    - custom

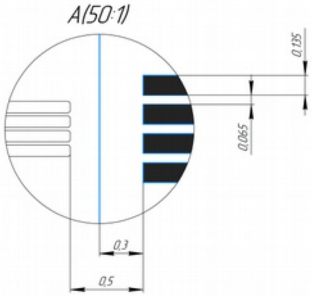
PRE_039

PCB for 4-ch sensors

- Clearance between strips: 65 um
  - compromise between feasibility and costs
  - 40 um possible but thickness of copper also reduced
- Sufficient HV track insulation for 1400V
- Removable connectors for all connections
- Gold plating for good adhesion of bonding wires.
- bonding feasible

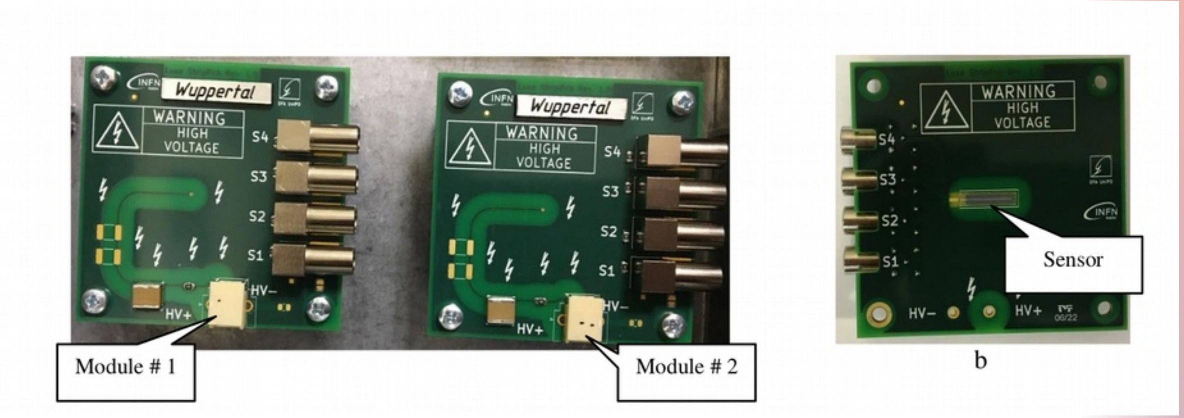






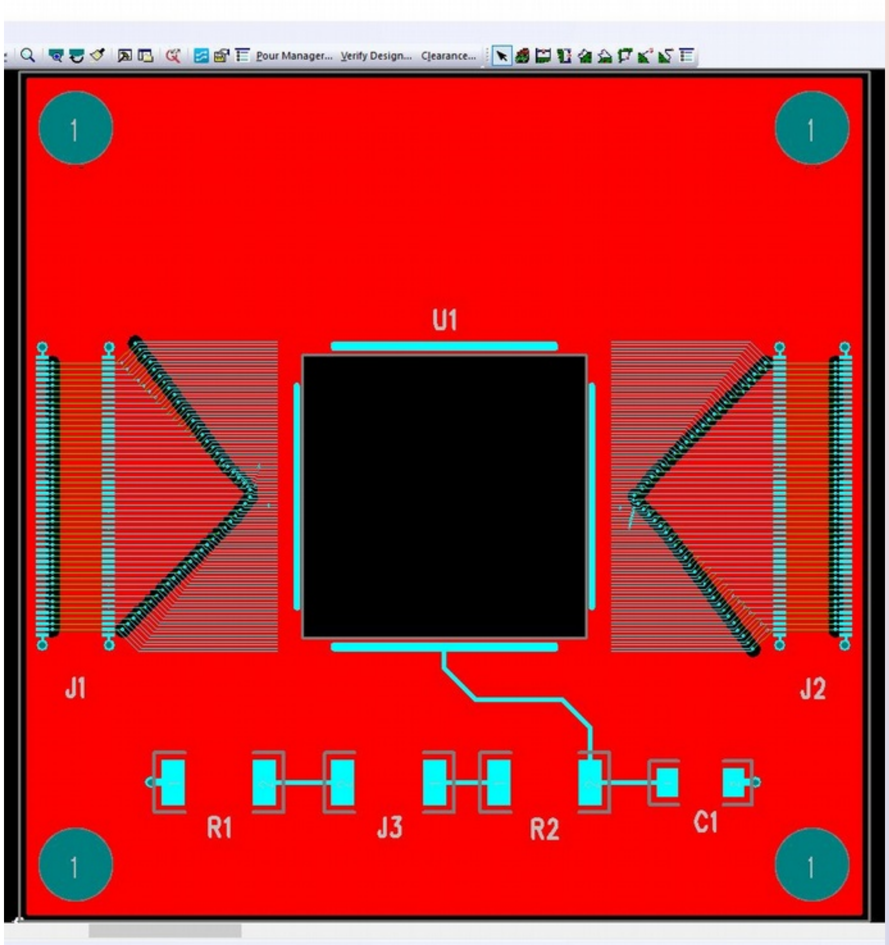
4 ch. detectors at Tomsk

- Assembled and tested on March 2022

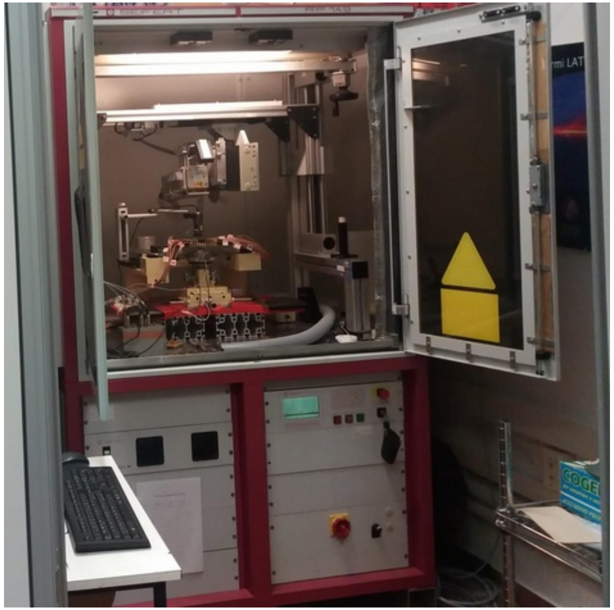


PCB for 200 ch. sensors

- Order submitted to the manuf. company
- should be ready in a few days



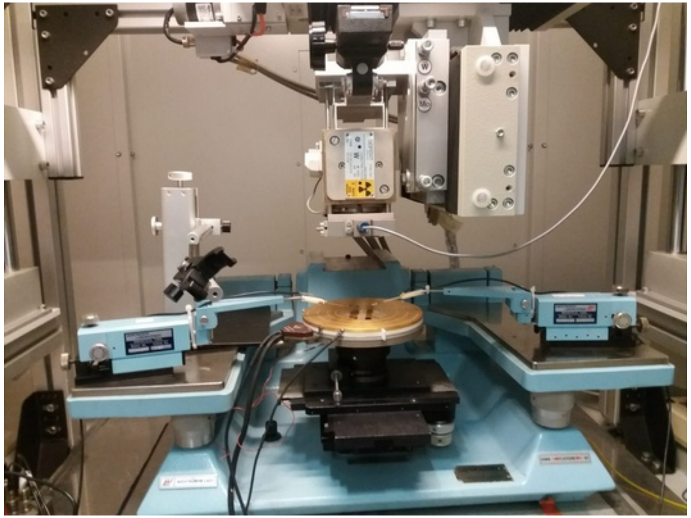
Type of measurements

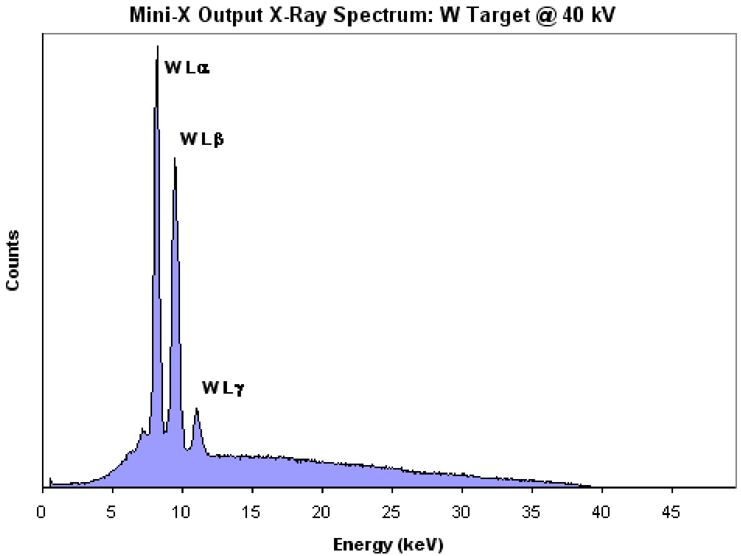


- X-rays
  - Padova
  - Tomsk
- Alfa source
  - Padova
- Electron gun (LNL)
  - huge signals, but very difficult to have control on the quality of the beam on the detector
- Electron beams
  - BTF electron beam @ LNF
  - electron beam @ Elbe

X-ray test station

- SEIFERT X-ray tube type DX-W12X04-S (Long Fine Focus W)
  - Tungsten anode (3 main lines)
  - 150 um Al filter to remove soft component
  - 40 kV, current up to 50 mA (adjustable in 5 mA steps)





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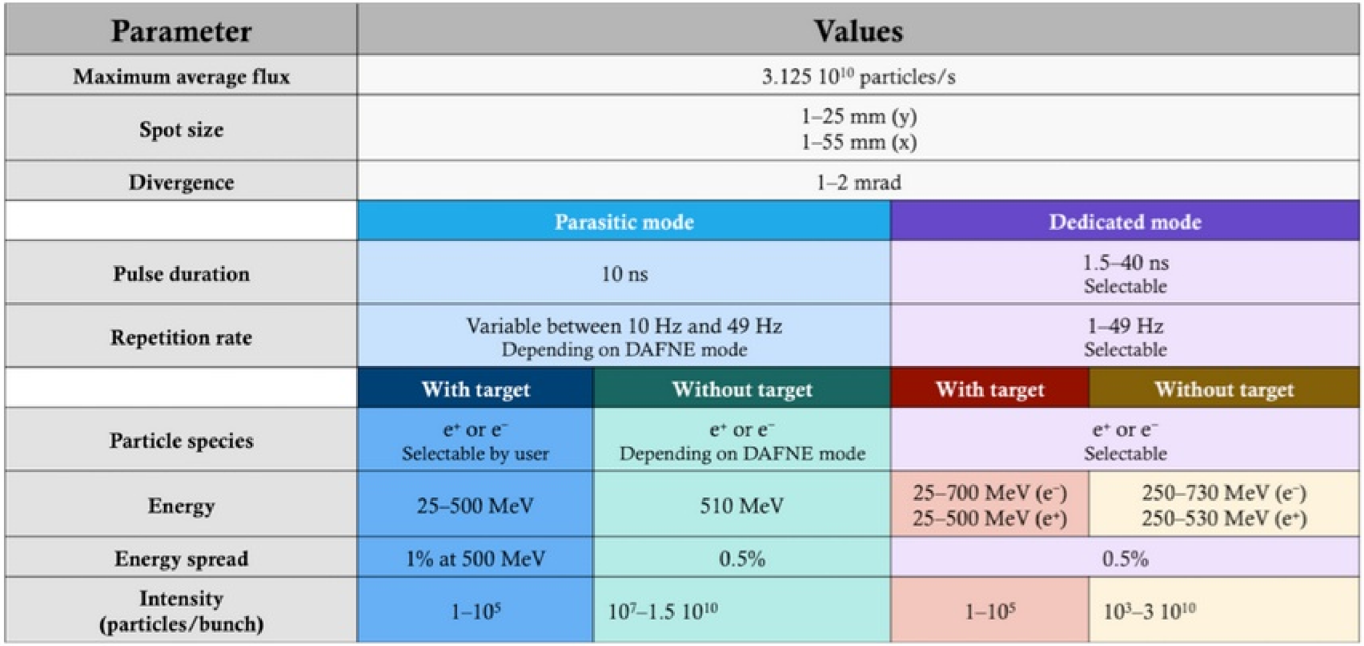
LNF BTF

- current values:
  - multiplicity:
    - 1-10 Hz parasitic mode
    - 1-24 Hz dedicated mode
  - max intensity:
    - 2x10$^{\wedge 6}$ e-/s parasitic mode
    - 1x10$^{\wedge 9}$ e-/s dedicated mode
- energy 300 MeV
- beam center stability: ~1 mm
- beam size σ : 3 mm



Parameter	Values			
Maximum average flux	3.125 10^{10} particles/s			
Spot size	1–25 mm (y) 1–55 mm (x)			
Divergence	1–2 mrad			
	Parasitic mode		Dedicated mode	
Pulse duration	10 ns		1.5–40 ns Selectable	
Repetition rate	Variable between 10 Hz and 49 Hz Depending on DAFNE mode		1–49 Hz Selectable	
	With target	Without target	With target	Without target
Particle species	e^+ or e^- Selectable by user	e^+ or e^- Depending on DAFNE mode	e^+ or e^- Selectable	
Energy	25–500 MeV	510 MeV	25–700 MeV (e^-) 25–500 MeV (e^+)	250–730 MeV (e^-) 250–530 MeV (e^+)
Energy spread	1% at 500 MeV	0.5%	0.5%	
Intensity (particles/bunch)	1–10^5	10^7–1.5 10^{10}	1–10^5	10^3–3 10^{10}

LNF BTF

- max. deposit energy per bunch with pads
  - signal 10-300 times larger than with 5 MeV alpha
  - beam intensity can be reduced down to 1 particle per bunch
  - possible to make measurement with fast pre-amplifiers

			LNF BTF	
			converter	direct LINAC
E		MeV	300	300
Spot size	H	mm	3	2
	V	mm	7	2
Length		ns	10	10
Intensity		e^- / s	2.0E+6	1.0E+9
Bunch		e^- / bx	2.0E+5	1.0E+8
Bunch freq.		Hz	1 -10	1 - 24
e^- in square	5 mm	e^-/bx	3.3E+4	6.2E+7
	1 mm	e^-/bx	1.5E+3	3.9E+6
Dep. Energy	5 mm	MeV	1,495.0	2.8E+6
	1 mm	MeV	67.8	1.8E+5

Sapphire impurity assessment

- one wafer sent to Stefano Nisi (LNGS) to be examined with High Resolution Inductively Coupled Plasma Mass Spectrometer (HR-ICP-MS);
- The analysis starts with a liquid sample so sapphire must be "solubilized"
- Several attempts carried out to make the sapphire soluble with initial poor results
- Some mixture of phosphoric and sulphuric acids eventually succeeded in decomposing the material of the wafer and part of the Al precipitated at the bottom as sulphate
  - this may hinder the measurement if other contaminant precipitate as well
- just yesterday the first results were made available

First very preliminary results

- Procedure of solubilization is the following:
  - 1ml H_2SO_4 and 3ml H_3PO_4 at 250°C in hot-block until complete dissolution of sample
  - 3 ml H_3PO_4 at 160°C for 10h
  - 4ml H_2O at 80°C for 2h
- Sample was diluted 1:10 to perform ICP-MS analysis.
- Further tests will be carried out to reduce the contaminations
- It would help if we could give them a list of contaminants that might be more critical for the performance of the detector

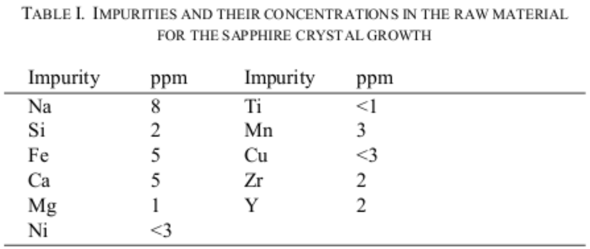


TABLE I. IMPURITIES AND THEIR CONCENTRATIONS IN THE RAW MATERIAL FOR THE SAPPHIRE CRYSTAL GROWTH

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

A. Ignatenko et al. - "Test and First Application of Artificial Sapphire Sensors"
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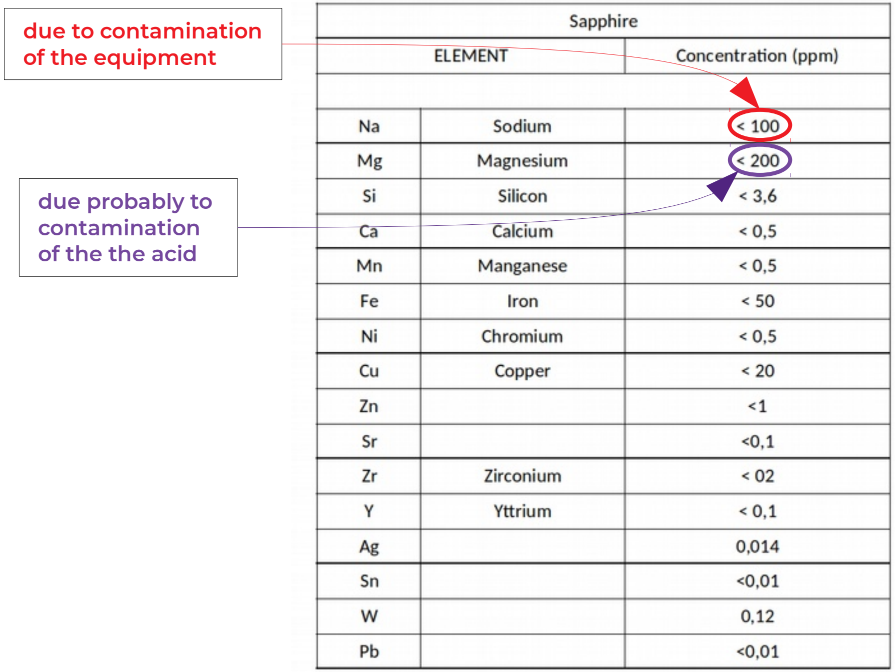


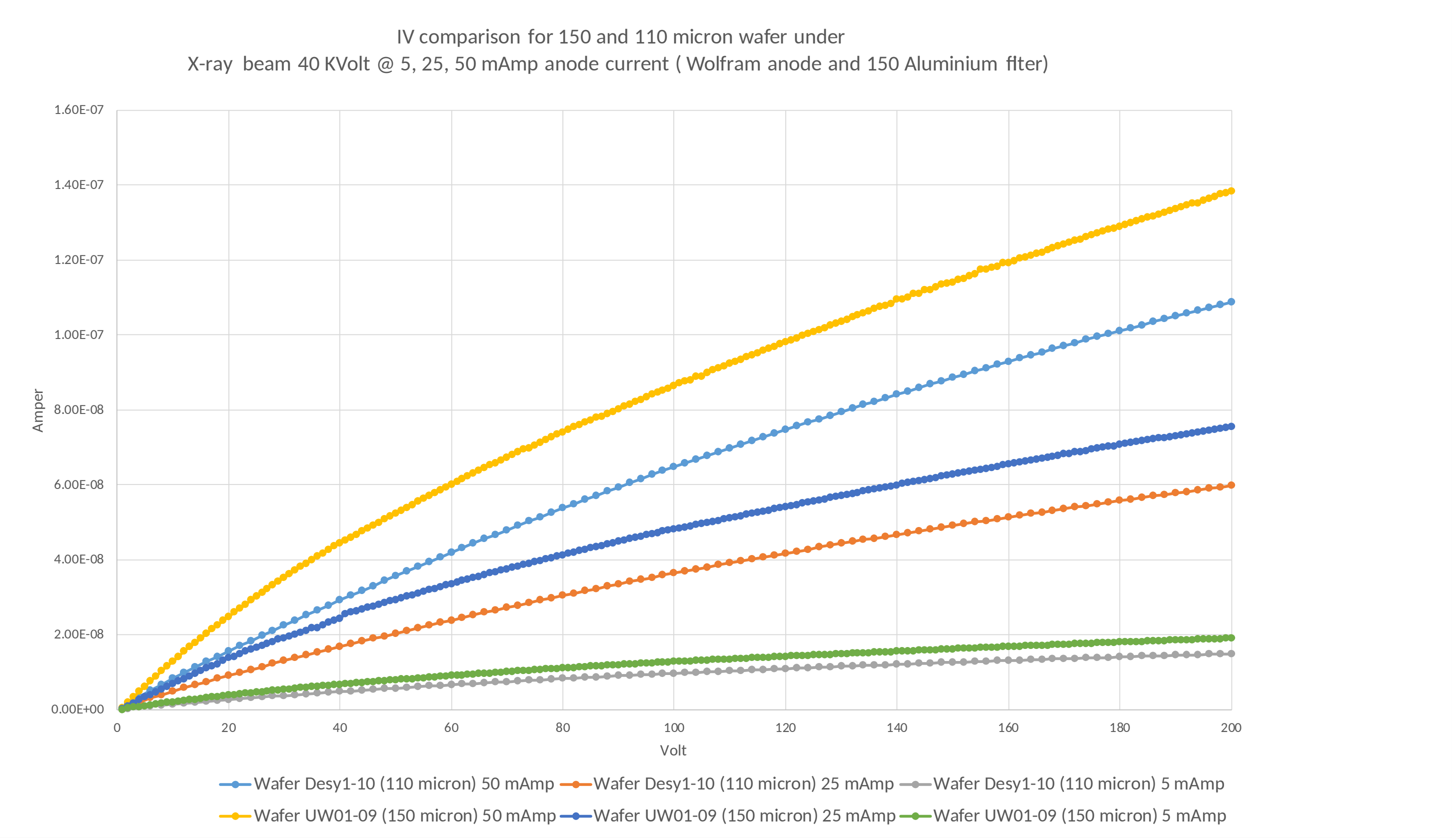
Sapphire		
ELEMENT		Concentration (ppm)
Na	Sodium	< 100
Mg	Magnesium	< 200
Si	Silicon	< 3,6
Ca	Calcium	< 0,5
Mn	Manganese	< 0,5
Fe	Iron	< 50
Ni	Chromium	< 0,5
Cu	Copper	< 20
Zn		<1
Sr		<0,1
Zr	Zirconium	< 02
Y	Yttrium	< 0,1
Ag		0,014
Sn		<0,01
W		0,12
Pb		<0,01

due to contamination of the equipment

due probably to contamination of the the acid

I-V plots under X-rays

- Anode currents:
  - 5, 25, 50 mA
- cont. curves: 150 um wafers
- dotted curves: 110 um wafers



I-V measurements under X-rays

- signal scaling
  - with thickness
  - with X-ray source anode current (except point at lowest current)
  - with V_{bias} applied, but not linearly (no scaling observed with Silicon)
- @ 400 V_{bias} currents are 50 times lower than in Silicon
- first indication

  that CCE is ~ few %

Current on Silicon calibration Diode (25 mm^2, 270 μm thickness)

X-ray anode current	@ 20 Volt V_{bias}
5 mA	0.96 uA
25 mA	4.8 uA
50 mA	9.7 uA

Sapphire 150 micron thick (pad 25 mm^2)

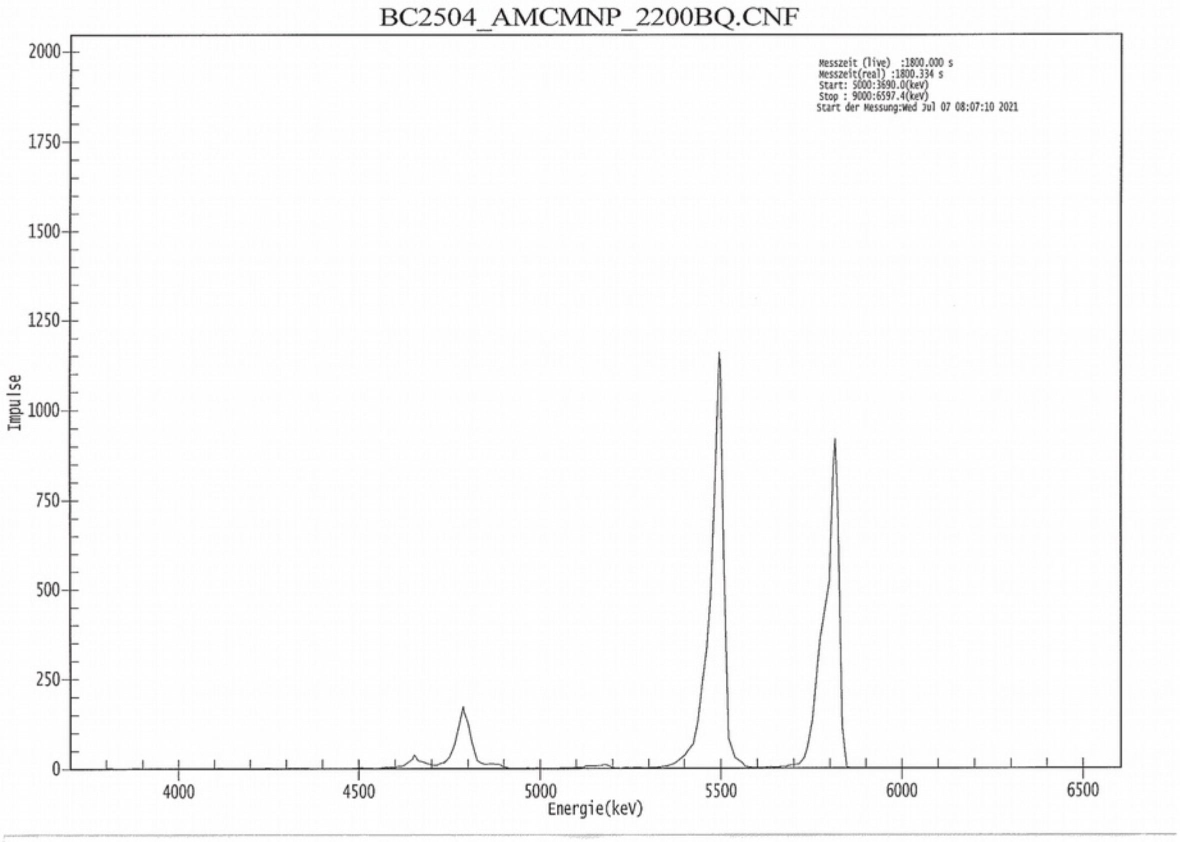
Vbias / X-ray anode current	100 Volt	200 Volt	400 Volt
5 mA	13 nA	19 nA	29 nA
25 mA	48 nA	75 nA	112 nA
50 mA	84 nA	138 nA	211 nA

Sapphire 110 micron thick (pad 25 mm^2)

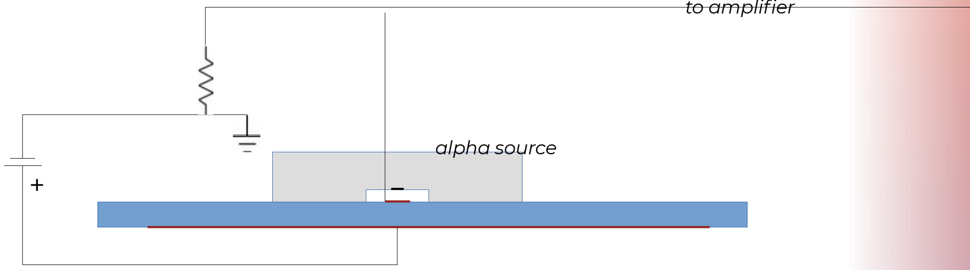
Vbias / X-ray anode current	100 Volt	200 Volt
5 mA	9.8 nA	15 nA
25 mA	37.2 nA	60.6 nA
50 mA	64.9 nA	108.8 nA

Alpha source

- ^{241}Am (1000 Bq)
  - 5.486 MeV (85%)
  - 5.443 MeV (13%)
  - 5.388 MeV (2%)
- ^{244}Cm (1000 Bq)
  - 5.765 MeV (23%)
  - 5.806 MeV (77%)
- ^{237}Np (200 Bq)
  - 4766 MeV (9%)
  - 4771 MeV (23%)
  - 4788 MeV (48%)
- Tolerance on activity: +/- 30%
- Active diameter: 7 mm



Setup



- Sapphire
  - 110 um (Wuppertal)
  - 150 um (US company)

- low noise HV power supply
- new home-made charge amplifier calibrated to 245 mV/fC

RMS noise ~ 12 mV ~ 0.05 fC ~ 780 e-

Working parameters

- HV up to 1200 V
- 6.5 mm nominal air gap from source to sapphire
  7 mm used for calculations to keep into accout also the ~ 100 nm of Ti-Ag deposition
- Estimated Alfa kinetic energy and ionization charge produced

Average inital kinetic energy		*Range in sapphire*	*Charge created*
initial	*at surface*	*direction normal to surface*	
MeV	MeV	um	fC
5.638	4.985	10.900	29.540

Simple model

- In a setup with uniform electric field inside the sapphire, with:

τ	electrons lifetime
μ	electron mobility
d	sapphire thickness
V	electric field potential
v_d	drift velocity
p	average electron drift path
k	fraction of path to thickness

- we have:

$$v_d = \mu E$$
$$p = v_d \tau = \mu \tau E$$
$$k = p/d = \frac{\mu E \tau}{d} = \frac{\mu \tau V}{d^2}$$

CCE is related to k by Hecht equation:

$$CCE = k(1 - \exp(-1/k))$$

and we can fit the data as a function of V for determining $\mu \tau$

How do CCE compare ? Simple model

- For a charge with a lifetime tau

$$\lambda = \frac{\mu \tau V_b}{d} \quad \text{(average drift path)}$$

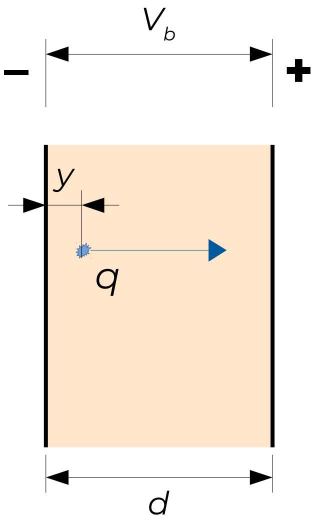
$$CCE = \frac{Q_i}{q_0} = \frac{\lambda}{d}\left(1 - e^{-\frac{d-y}{\lambda}}\right)$$

$$\text{if } \lambda \ll d: \quad CCE \simeq \frac{\lambda}{d} = \frac{\mu \tau V_b}{d}$$

average CCE with sources or beams is the same

$$\text{if } \lambda \gg d > y: \quad CCE \simeq \frac{\lambda}{d}\frac{d-y}{\lambda} = 1 - \frac{y}{d}$$

unform charge deposits -> CCE = 0.5

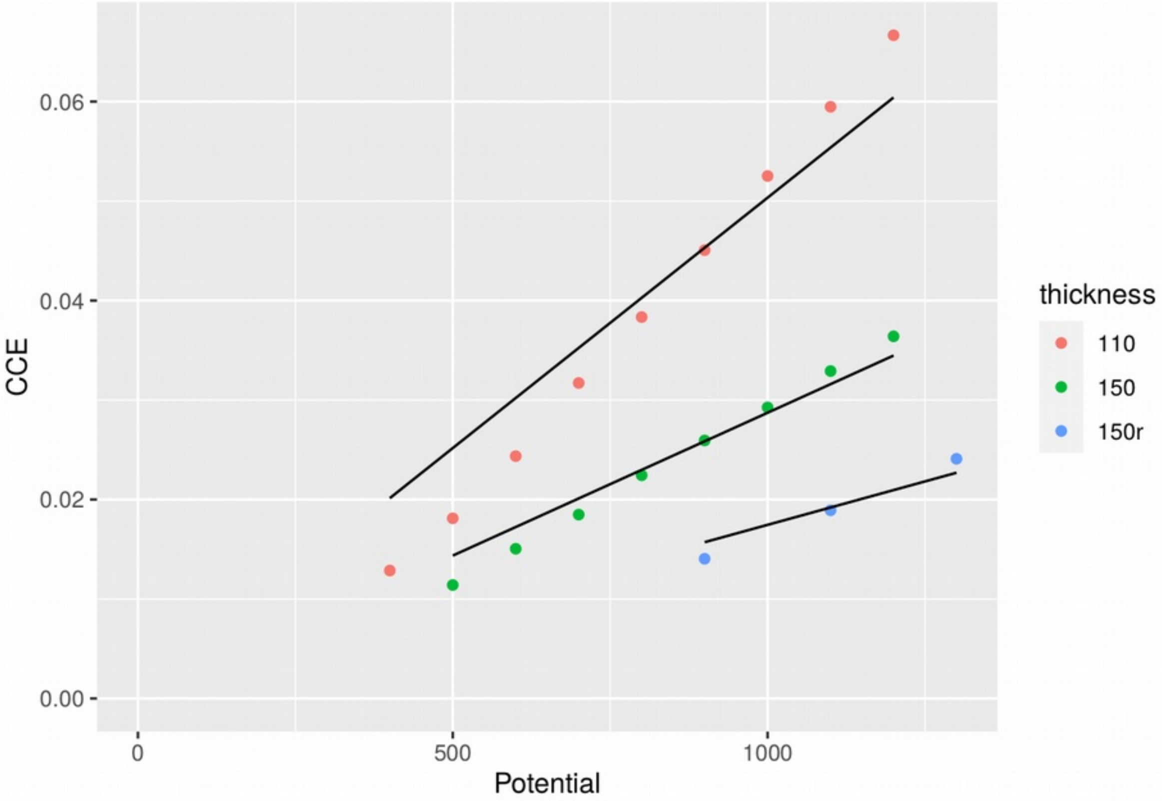


Results: mu x tau

- Points do not align on a straight line from the origin as foreseen by the Hecht equation
- $\mu\tau = 6.09 \, x \, 10^{-9} \ \text{cm}^2/\text{V}$ for 110 um sapphire

  $\mu\tau = 6.46 \, x \, 10^{-9} \ \text{cm}^2/\text{V}$ for 150 um sapphire

  $\mu\tau = 3.93 \, x \, 10^{-9} \ \text{cm}^2/\text{V}$ for 150 um sapphire reversed voltage



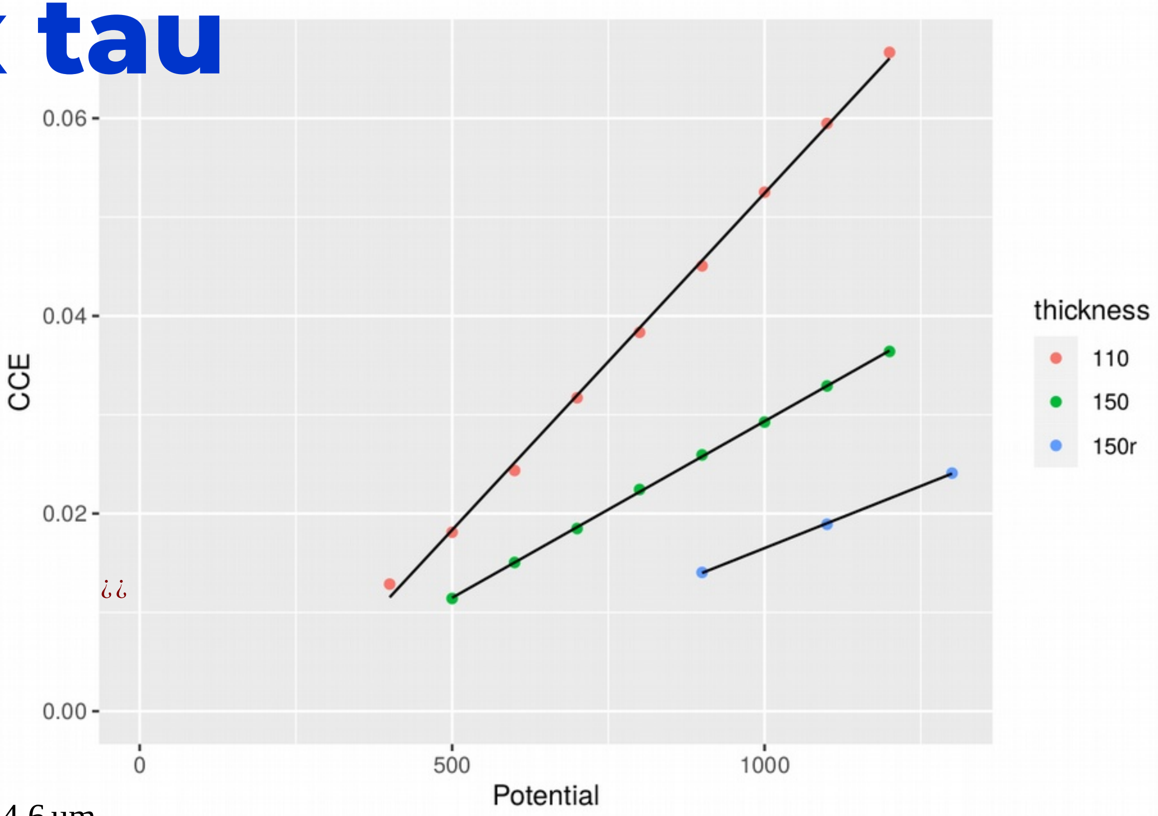
Results: mu x tau

- Fitting for:

$$CCE = CCE_0 + k\left(1-\exp\left(-1/k\right)\right)$$

- one obtains:

$\mu\tau = 8.25\,x\,10^{-9}\ \mathrm{cm}^2/\mathrm{V}$
$CCE_0 = -1.57\,\%$
for 110 um sapphire
$\mu\tau = 8.04\,x\,10^{-9}\ \mathrm{cm}^2/\mathrm{V}$
$CCE_0 = -0.64\,\%$
for 150 um sapphire
$\mu\tau = 5.65\,x\,10^{-9}\ \mathrm{cm}^2/\mathrm{V}$
$CCE_0 = -0.86\,\%$
for 150 um sapphire - reversed bias



- @ $E = 60\,\mathrm{kV/cm}$: $\mu\tau = 8\,x\,10^{-9}\,\mathrm{cm}^2/\mathrm{V}$ ==> $p = 4.6\,\mathrm{um}$
with $\mu \sim 600\ \mathrm{cm}^2/\mathrm{Vs}$: ==> $\tau \sim 13\,\mathrm{ps}$

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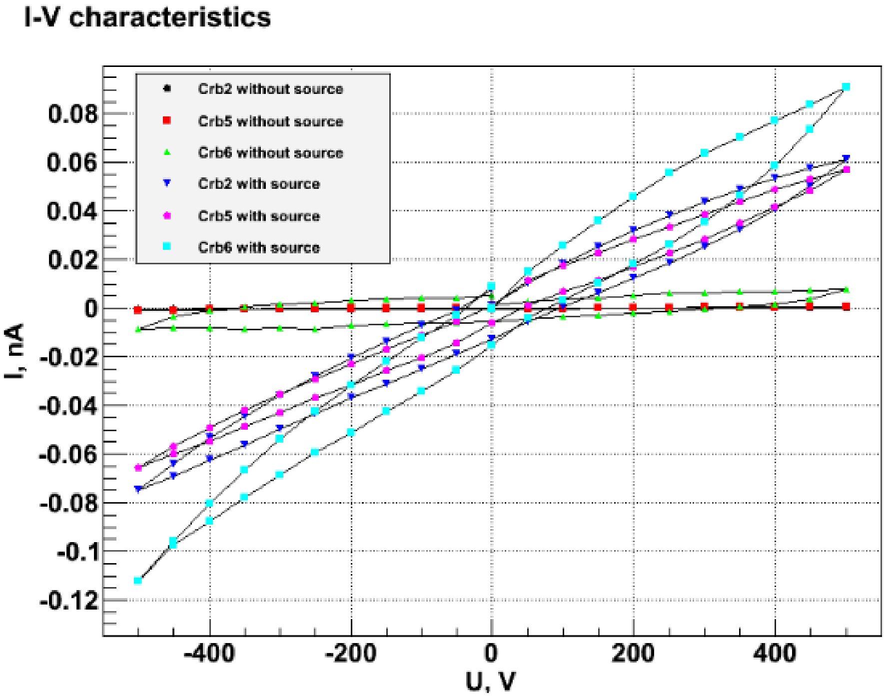
CCE with ^{90}Sr source

- pad 4mm x 4mm
- sapphire thickness: 500 um
- charge amplifier Amptek A250, noise ~500 e-
- leakage current: up to 10 pA
- total current induced by electron flux: up to 60 pA @ 500 V
- current seem to grow linearly with V_{bias}
- estimated CCE: 2-3 %



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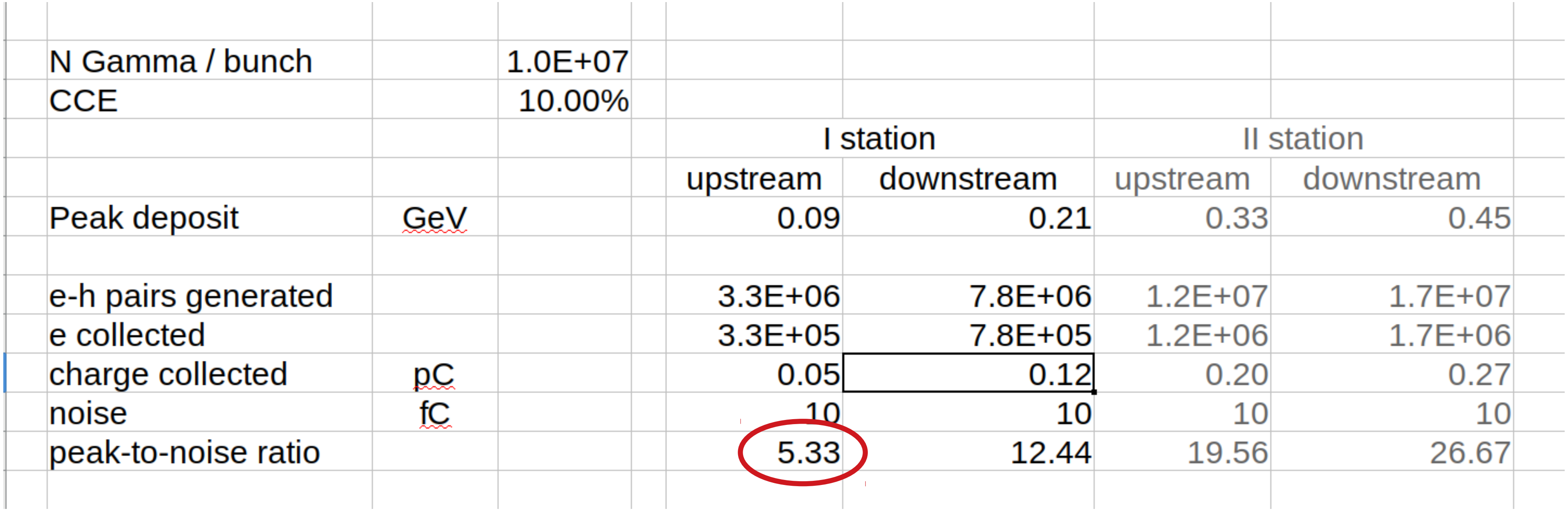
Open questions

- the value of $\mu\tau \sim 0.8\ \mu m^2 / V$

  is 40 times smaller than previously measured
  $f_d \times \mu\tau \sim 30\ \mu m^2 / V$
  - f_d was introduced to represent an immediate recombination of charges (~50%)
- taking into account second order effect (e.g. alpha releases most of the energy at ~ 10 µm, not at the entrance, etc.) disagreement may be reduced a bit
- may the charges produced at high density in the sapphire cause a reduction of the effective electric field ?
  - 18 ke^-/um, compared to ~ 20 e^- /um by m.i.p.
- CCE seems to go to 0 at $V_b \sim 200$ V. As if the effective potential is reduced w.r.t. the nominal one
  - contact potential ?
  - polarization effects as seen in diamond sensors ?
    - we have tried to see if the signal changes in the first minutes after exposure to the source, but no effect seen.

Concern about noise



			I station		II station	
N Gamma / bunch		1.0E+07				
CCE		10.00%				
			upstream	downstream	upstream	downstream
Peak deposit	GeV		0.09	0.21	0.33	0.45
e-h pairs generated			3.3E+06	7.8E+06	1.2E+07	1.7E+07
e collected			3.3E+05	7.8E+05	1.2E+06	1.7E+06
charge collected	pC		0.05	0.12	0.20	0.27
noise	fC		10	10	10	10
peak-to-noise ratio			5.33	12.44	19.56	26.67

Possible measurements at LNF BTF

- Wafers with pads (110 um, 150 um)
  - first set of measurements starting on May 9
  - read-out with an oscilloscope
  - CCE measurements
  - time profile of the signal -> drift time measurement
- 4 strips sensors
  - same read-out
  - CCE measurements
  - uniformity across the strips
- 200 strips channels
  - full sensors and readout chain characterization with final front-end electronics