Channeling effects and homogeneity measurements in Si detectors for PSA applications

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*for the **FAZIA** collaboration*

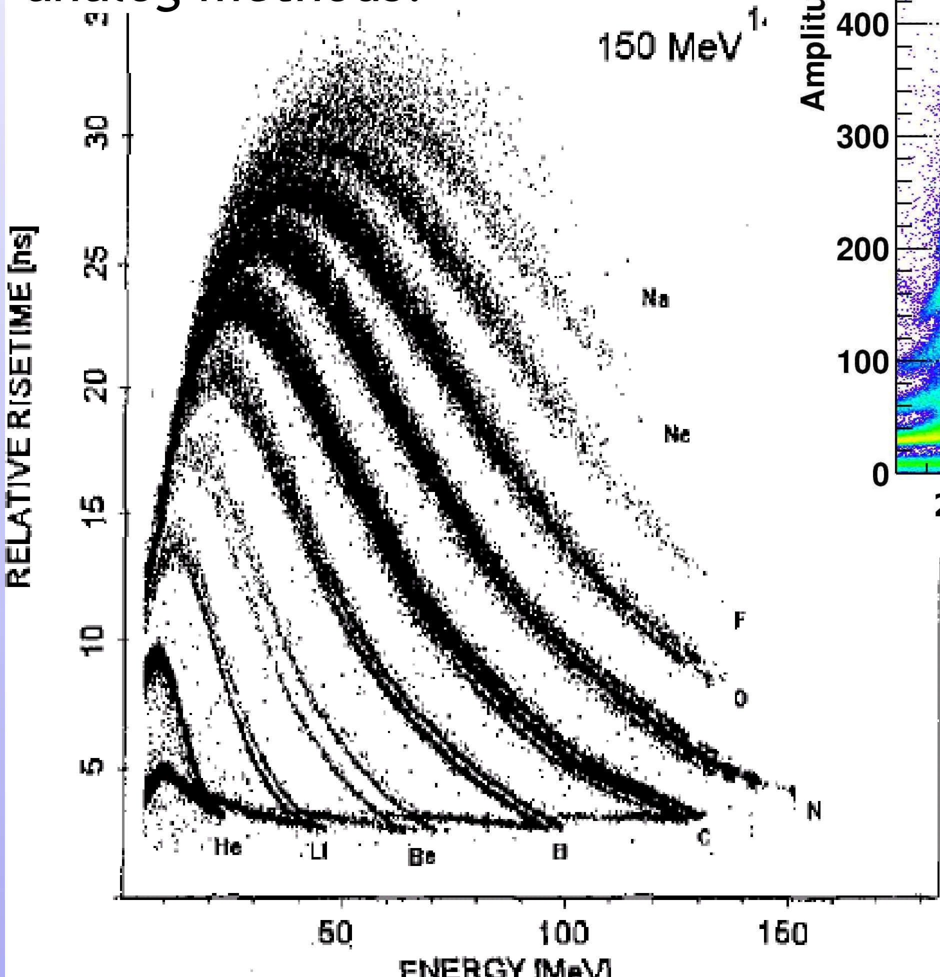
Outline

- Homogeneity:
  - A PSA-based method for resistivity measurements
  - Results
- Channeling:
  - Introduction
  - The silicon crystal structure
  - Experimental results
  - How to “avoid” channeling
- Results from recent FAZIA collaboration PSA tests

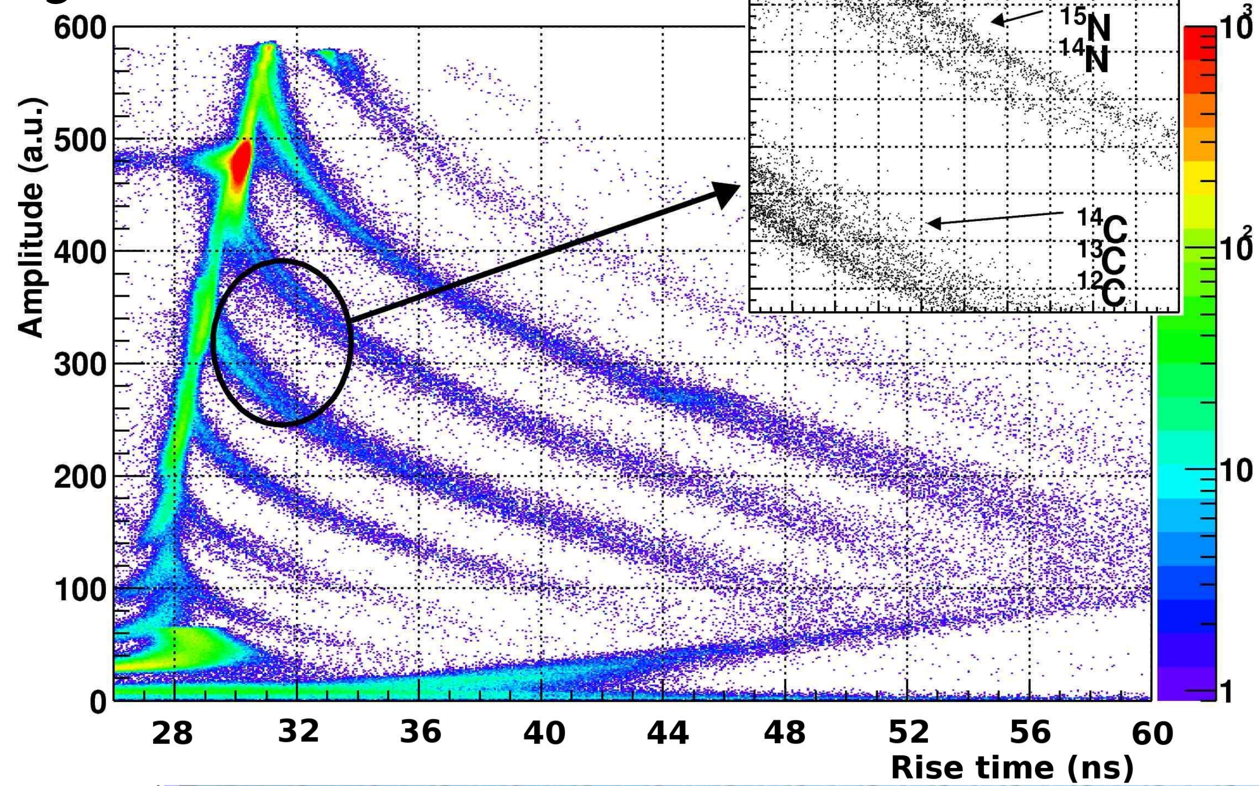
PSA applications

Standard energy vs. "risetime" plots:

analog methods:



digital methods:



L.Bardelli et al, Nucl.Phys.A 746 (2004) 272
(12 bit, 100 MSamples/s digitizer
+ digital signal processing dCFD)

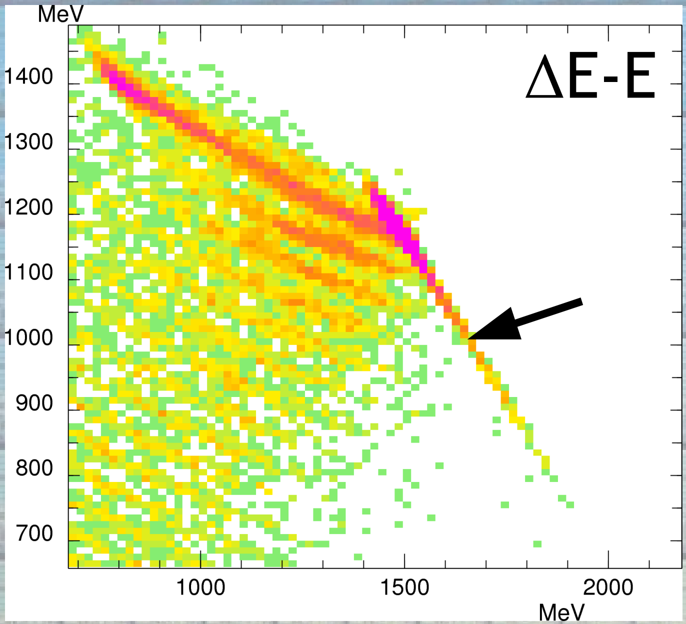
M.Mutterer et al, IEEE Trans. Nucl. Science, vol.47no.3, 2000
(2 ways fast analog shaping + timing)

Detectors

Regardless of the used analysis method (whether analog or digital) the detector properties can play a significant role in the final identification properties:

- resistivity homogeneity
- thickness homogeneity
- dead-layers
- (etc etc)

What about the silicon **crystal structure**, i.e. channeling effects?

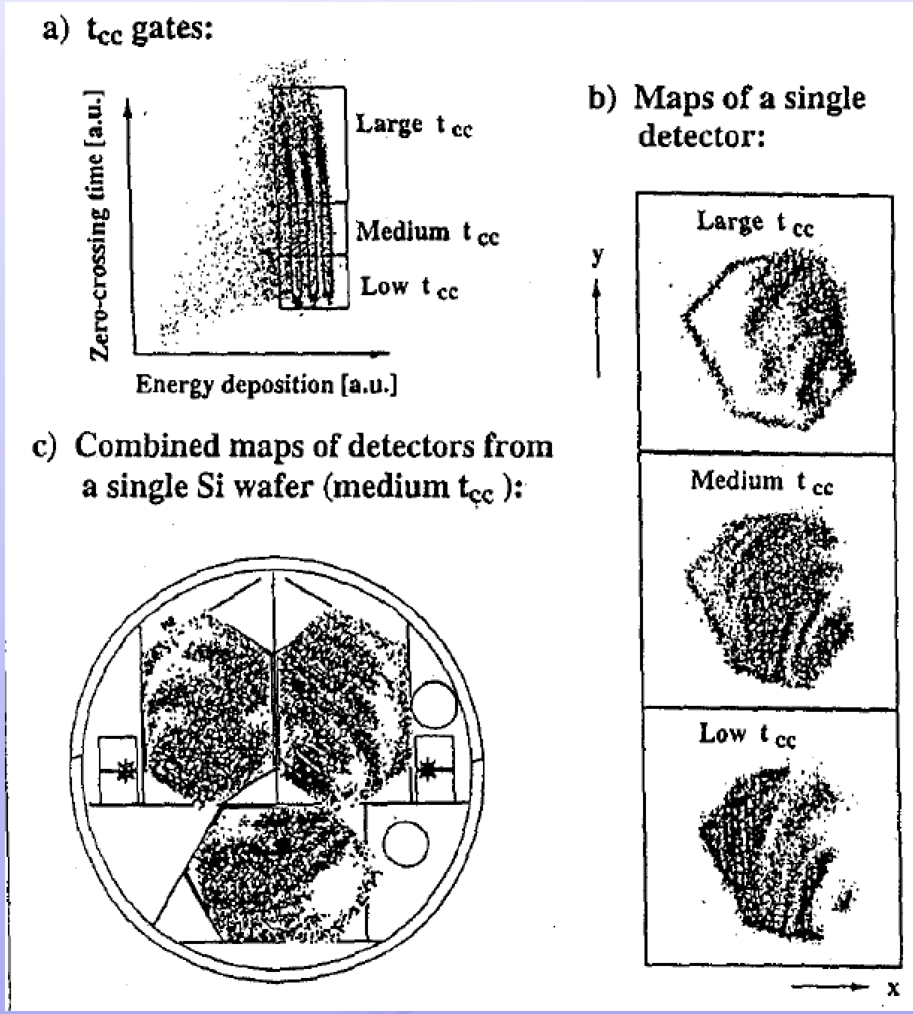


NOTE: channeling is a well known issue in industry for ion impiantation applications (microeletronics), transmission detectors (DE-E) and high energy physics, but it is not (yet) studied for PSA

HOMOGENEITY

Homogeneity

It is well known that any non-homogeneity in the electric field inside the detector may have a severe impact over the PSA discrimination capabilities:



Is it possible to measure the resistivity and/or doping homogeneity of our detectors?

(non destructive is better...........)

G.Paush et al, IEEE NS 44, v3 1997, 1040

Idea

Once the detector thickness is known, the depletion voltage provides a direct measurement of the material resistivity:

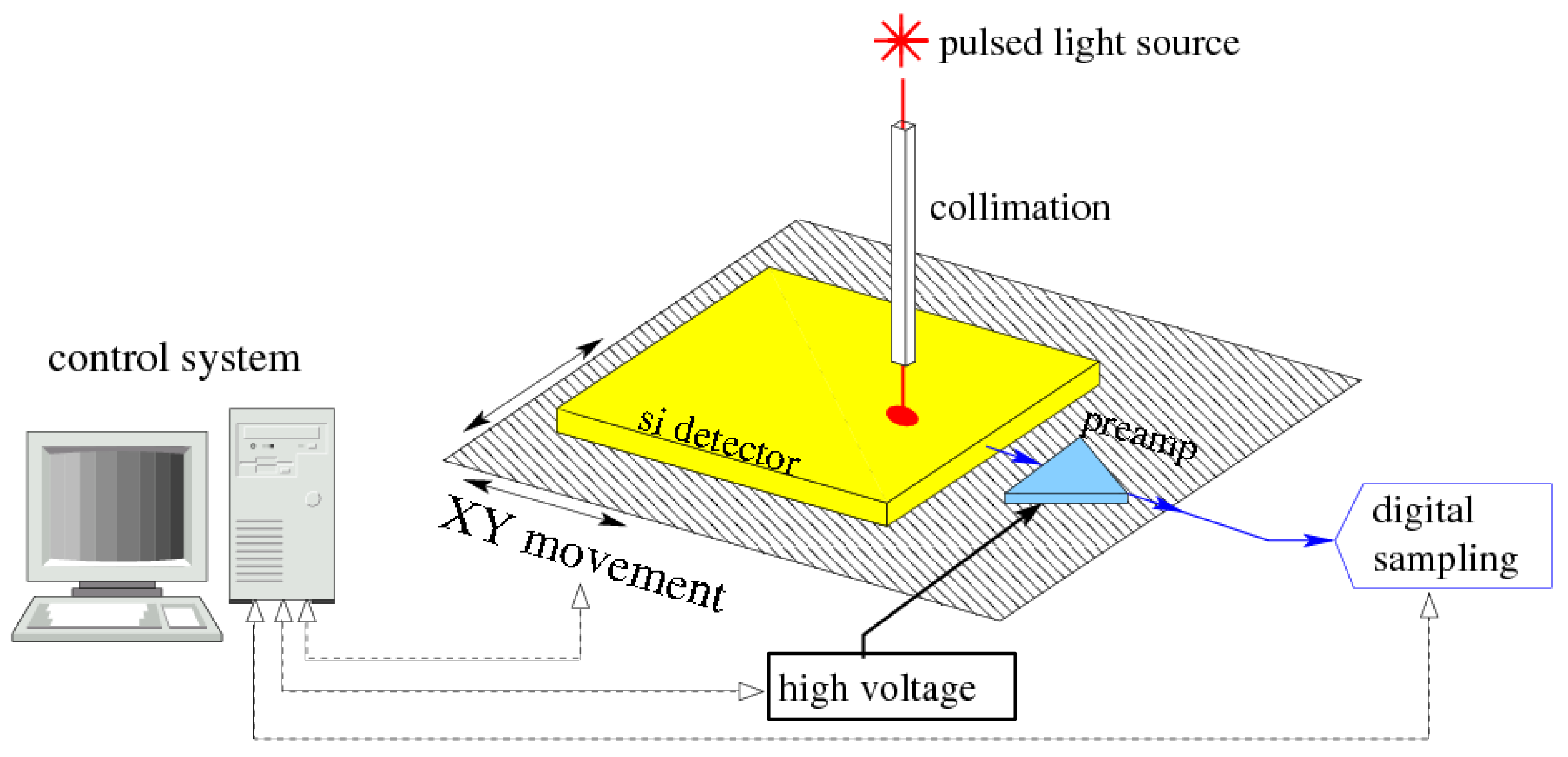
$$\rho = \frac{\mathrm{th}^2}{2\, V_D\, \epsilon_R\, \mu}$$

Depletion voltage measurements are routinely performed with C-V plots.

Can we do something like that as a function of the position on the detector?

(and without the need of particular strip o pixel readout)

The method



L.Bardelli et al, in preparation

The detector is mounted on a XY movement.

Both the XY support and the HV are computer controlled.

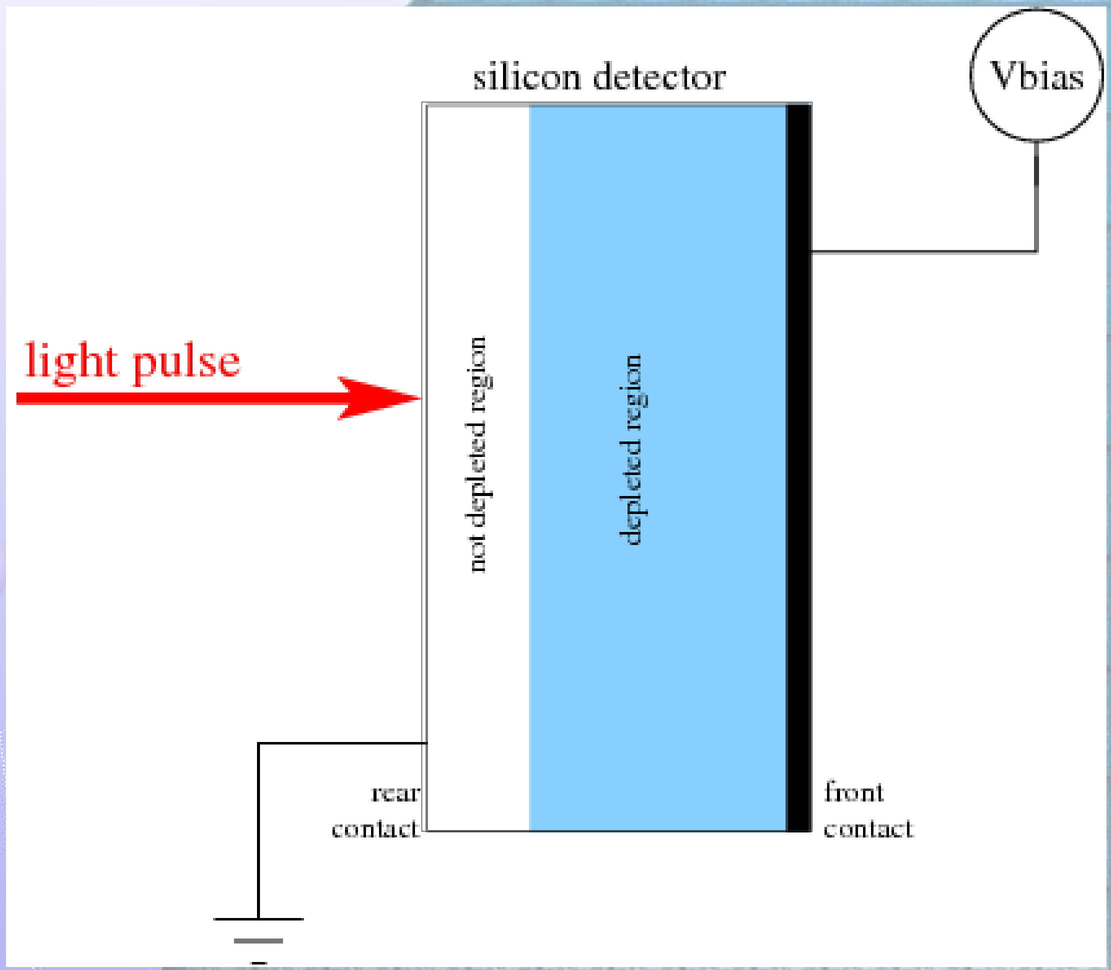
Shapes are collected with a digitizer (Florence DSP card)

The method (2)

The collimated laser pulse enters the detector in the low field zone.

Shapes are collected for various applied voltages and various XY positions.

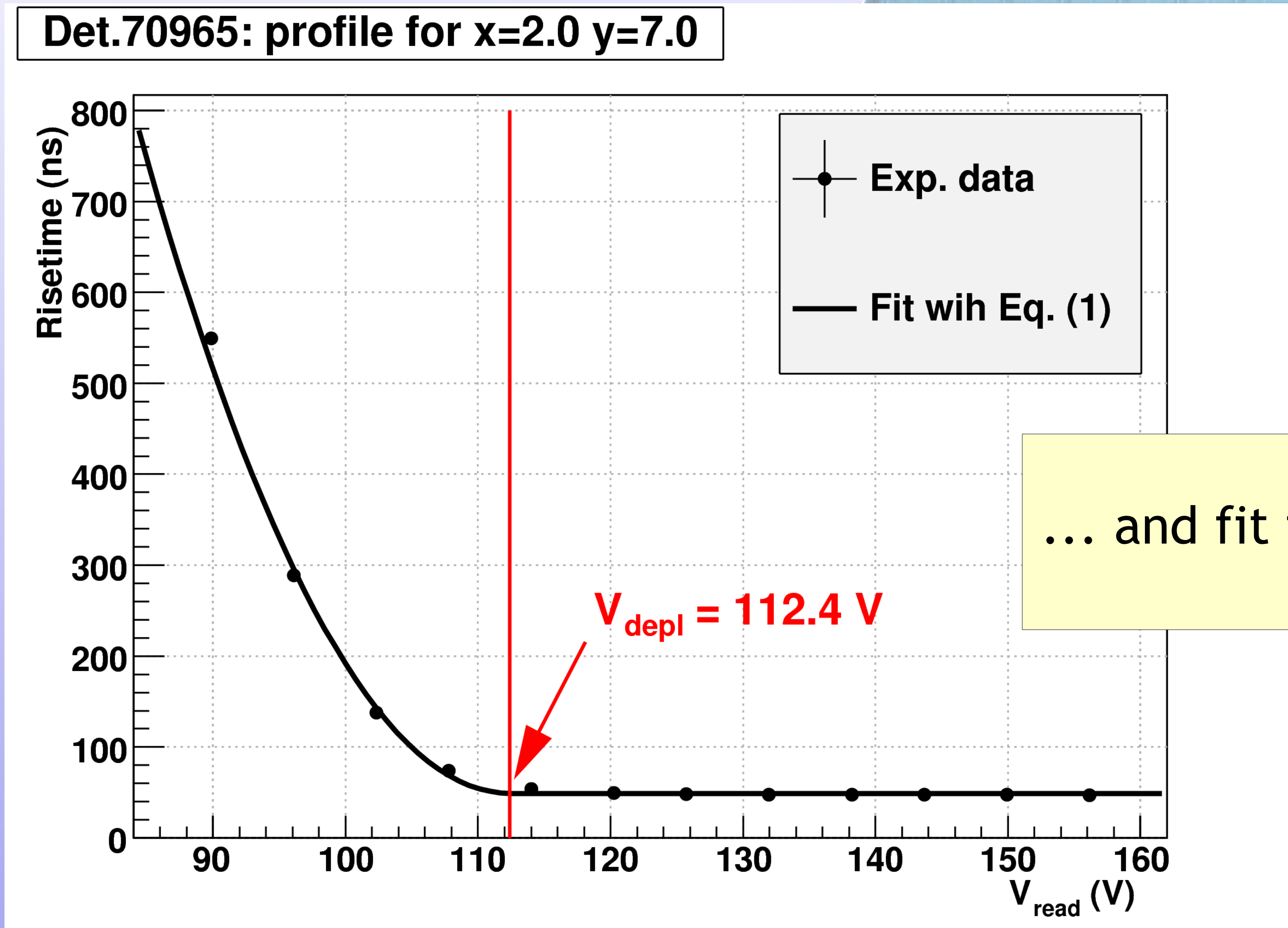
We make a XY and $V_{applied}$ scan of the detector



L.Bardelli et al, in preparation

Local V depletion

For each XY position on the detector we can build an "Average risetime" vs "Vapplied" plot:

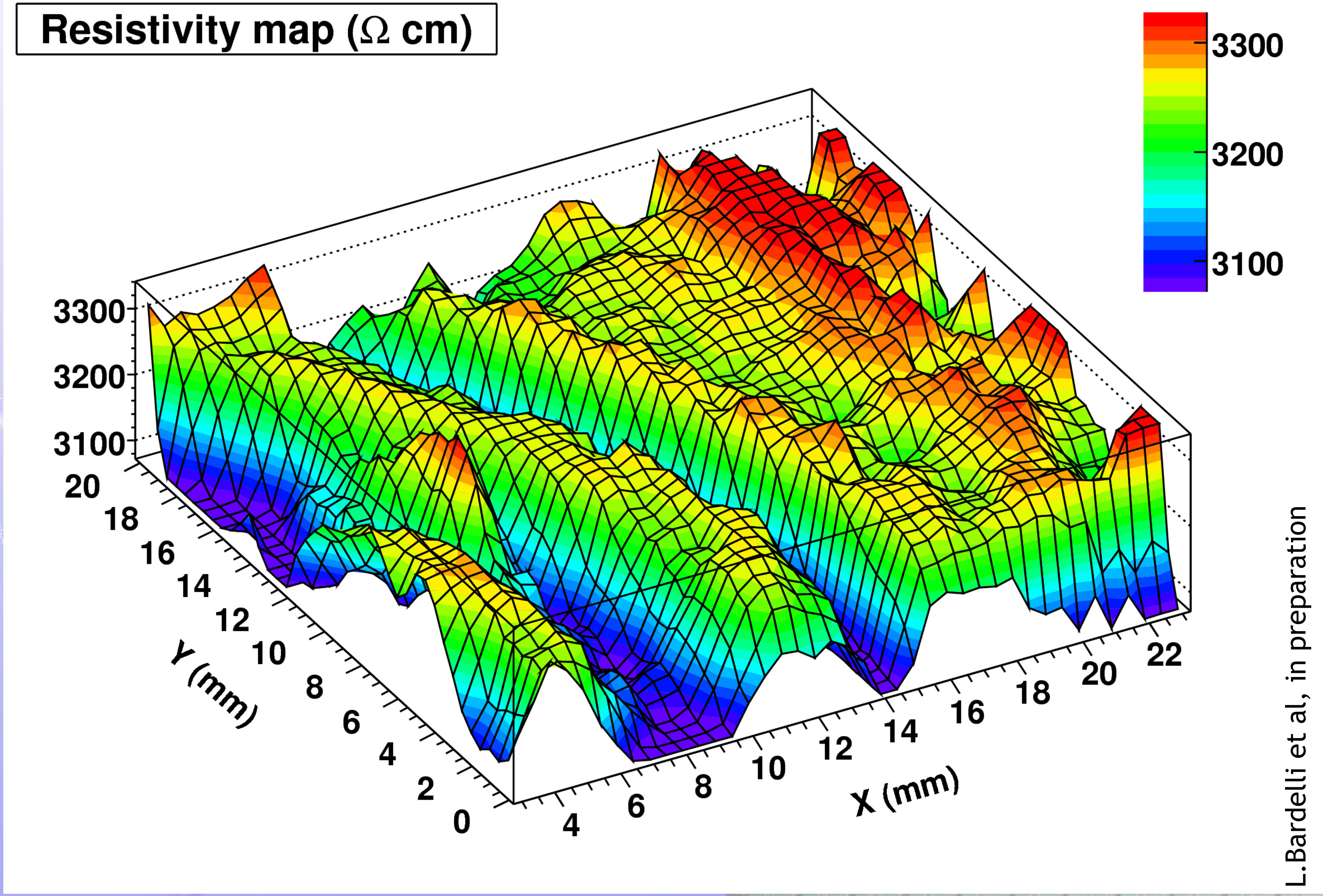


... and fit the LOCAL V_{depl}

L.Bardelli et al, in preparation

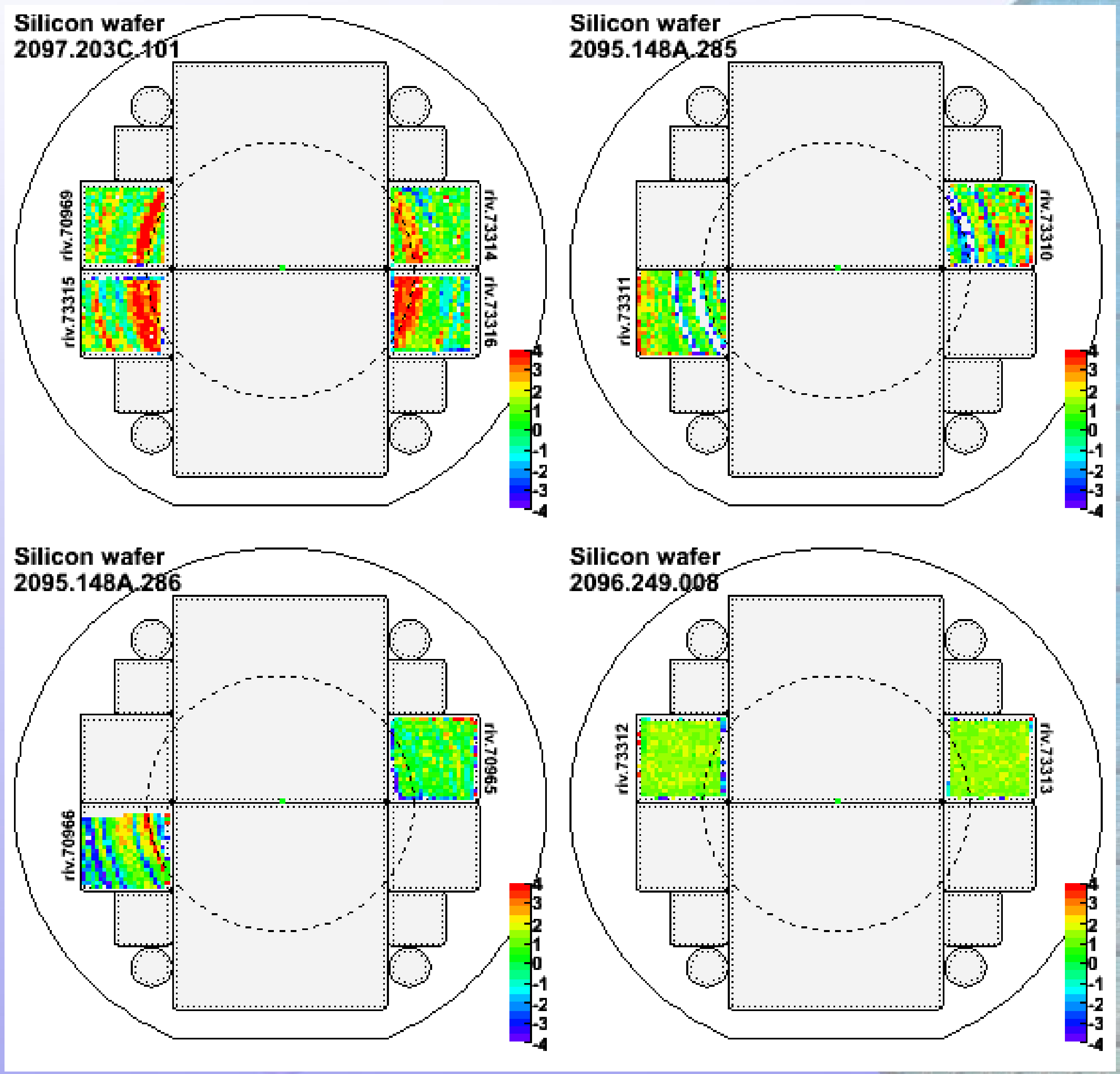
Resistivity plot

... and finally we can build a 2D resistivity plot:



L.Bardelli et al, in preparation

Resistivity plots



We can verify
the dependence on
the geometry
on the initial wafer

clear evidence of
circular "striations"

L.Bardelli et al, in preparation

Resistivity tables

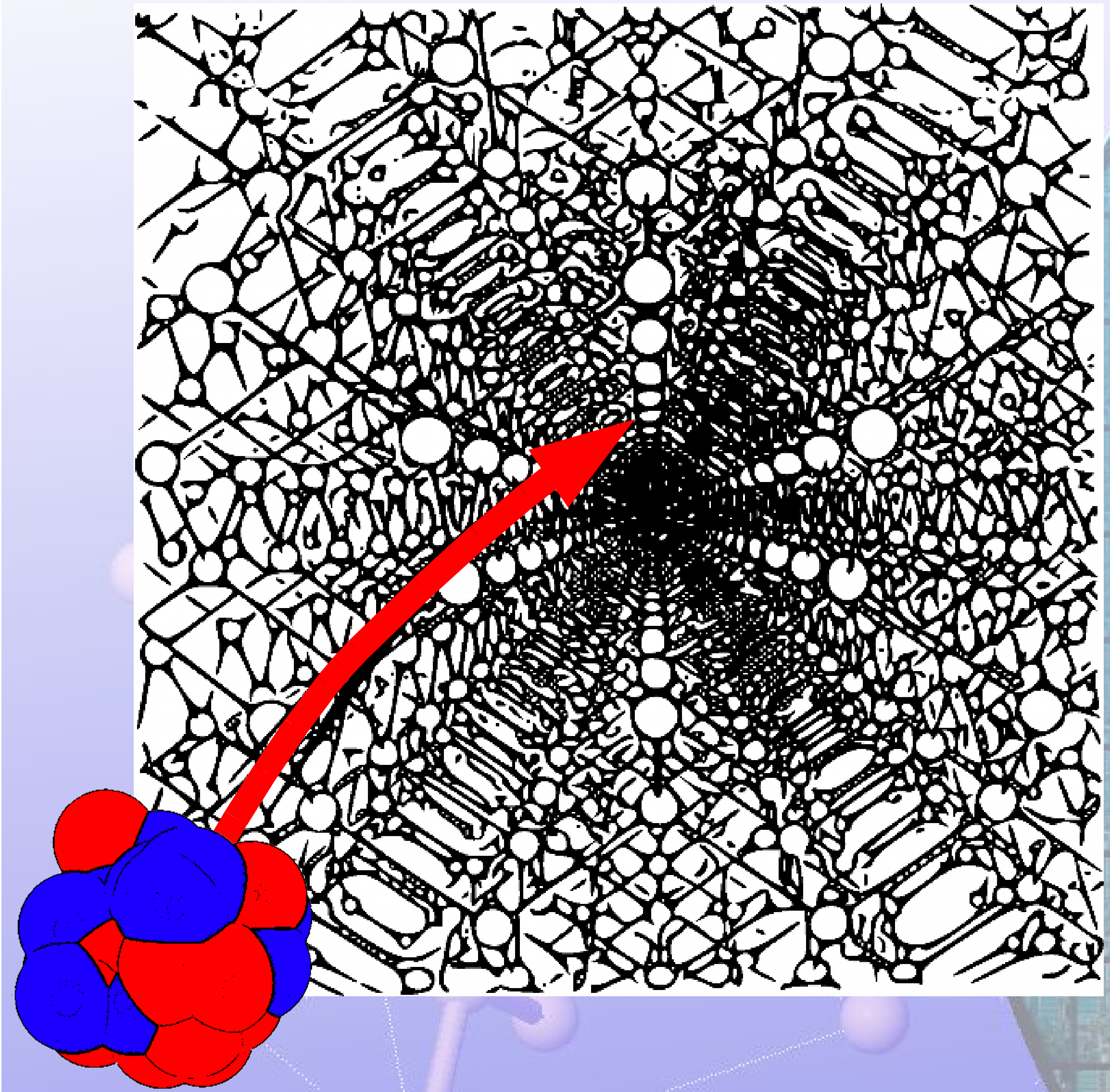
Det. Name	Thickness (um)	Nominal Vdepl (V)	Nominal Resitivity (Ohm cm)	Measured Vdepl (V)	Measured Resistivity (Ohm cm)	Non homogeneity (without border) (max-min, %)
CAN 70964	315	110	3100	120.16	2904	10.3
CAN 70965	315	110	3100	114.55	3046	4.7
CAN 70966	315	110	3100	119.02	2931	11.0
CAN 70967	516	220	4200	226.86	4128	1.7
CAN 70968	516	220	4200	227.59	4115	2.1
CAN 70969	713	150	11900	158.48	11319	7.4
CAN 73311	315	110	3100	109.40	3190	9.4
CAN 73312	516	220	4200	227.26	4124	1.3
CAN 73313	516	220	4200	227.40	4120	1.3
CAN 73314	713	150	11900	161.51	11084	8.0
CAN 73315	713	150	11900	167.95	10677	7.7
CAN 73316	713	150	11900	170.17	10524	37.6

Now we can inspect the measured non-homogeneity and choose the "best" detectors for our PSA applications!

experimental results later ...

CHANNELING

Channeling: introduction



Ions tend to follow the direction between two neighboring **crystalline planes and/or axes**, but at the largest possible distance from each of them

-> they travel in the “channels” present in the material

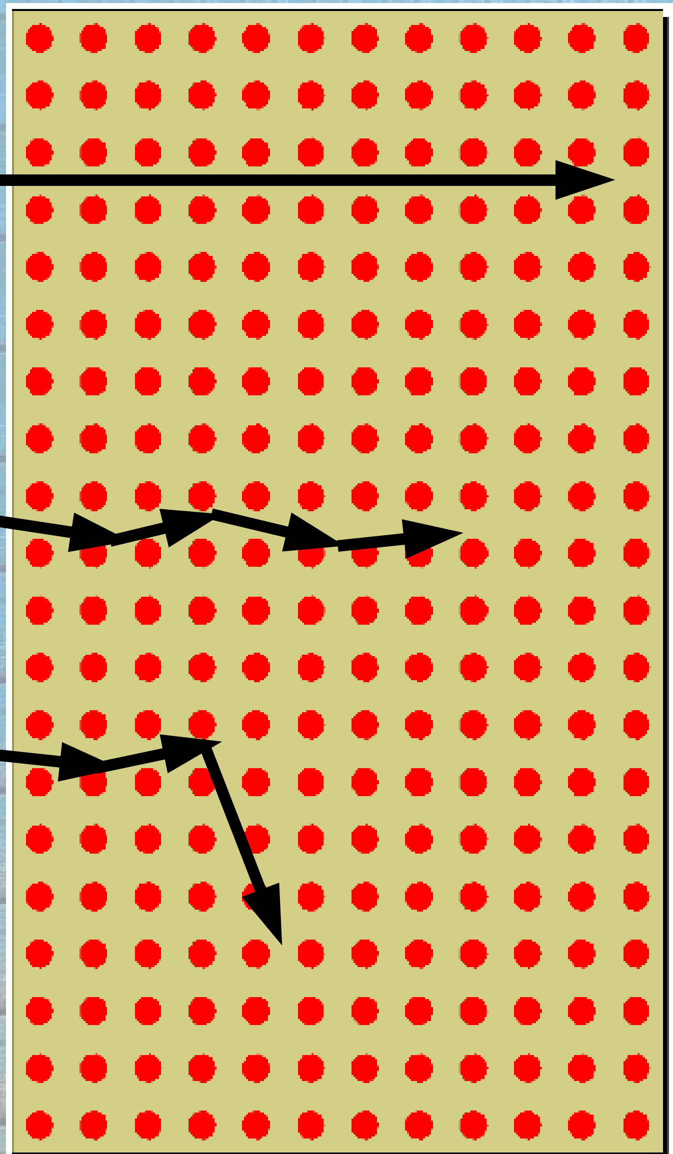
Channeling

Energy loss in an crystal (aligned configuration):

“perfect” channeling
long range, low average dE/dx

shorter range, higher average dE/dx

channeling + de-channeling
even shorter range, higher average dE/dx

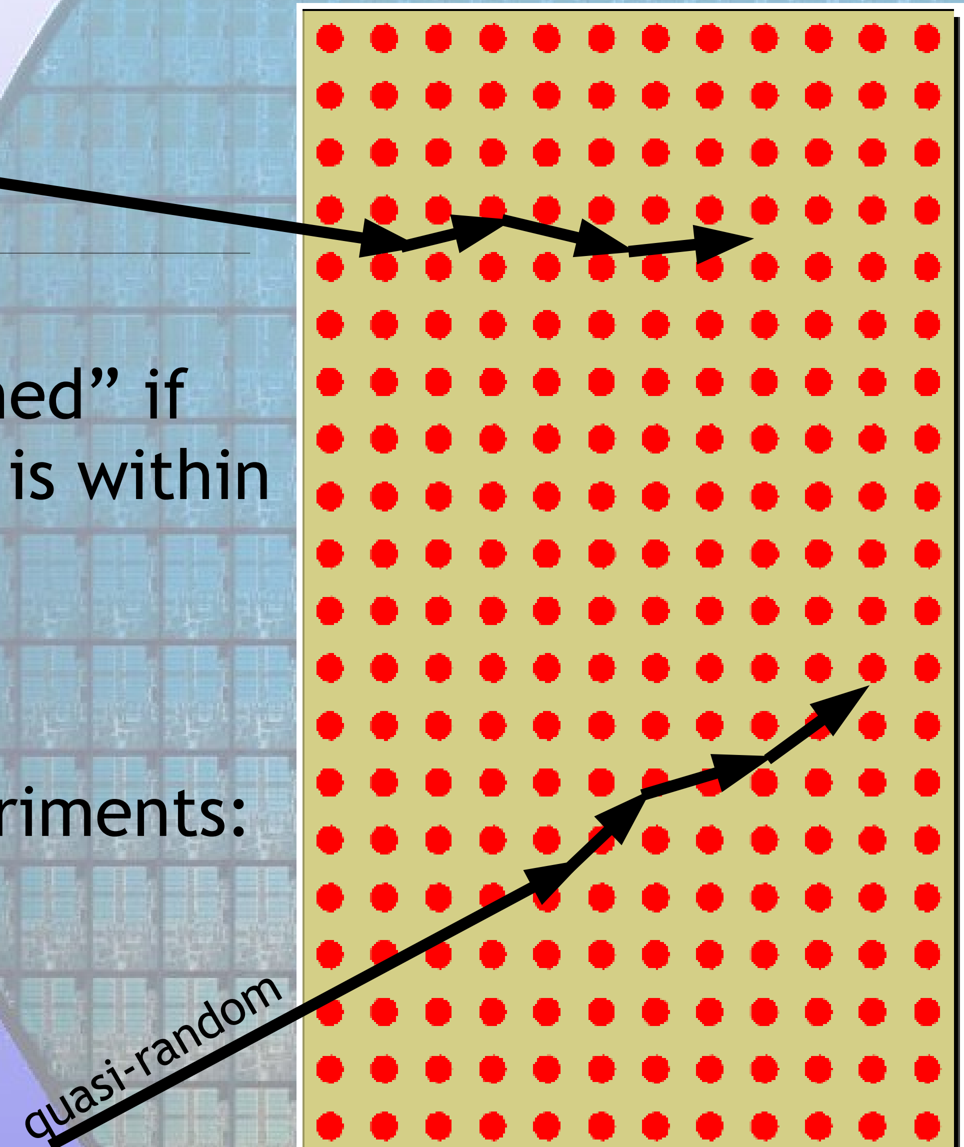


many possible trajectories leading to different ranges and/or average dE/dx

resolution loss!

Angle Ψ½

What is the meaning of "aligned" ?



A detector is considered "aligned" if the incident particle direction is within an angle **Ψ½** from a crystallographics axis.

High energy transmission experiments:

Ψ½ ~ 0.1°

Stopped heavy ions:

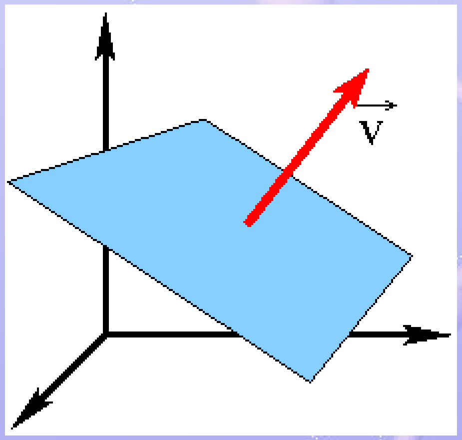
Ψ½ ~ 1° **HUGE!**

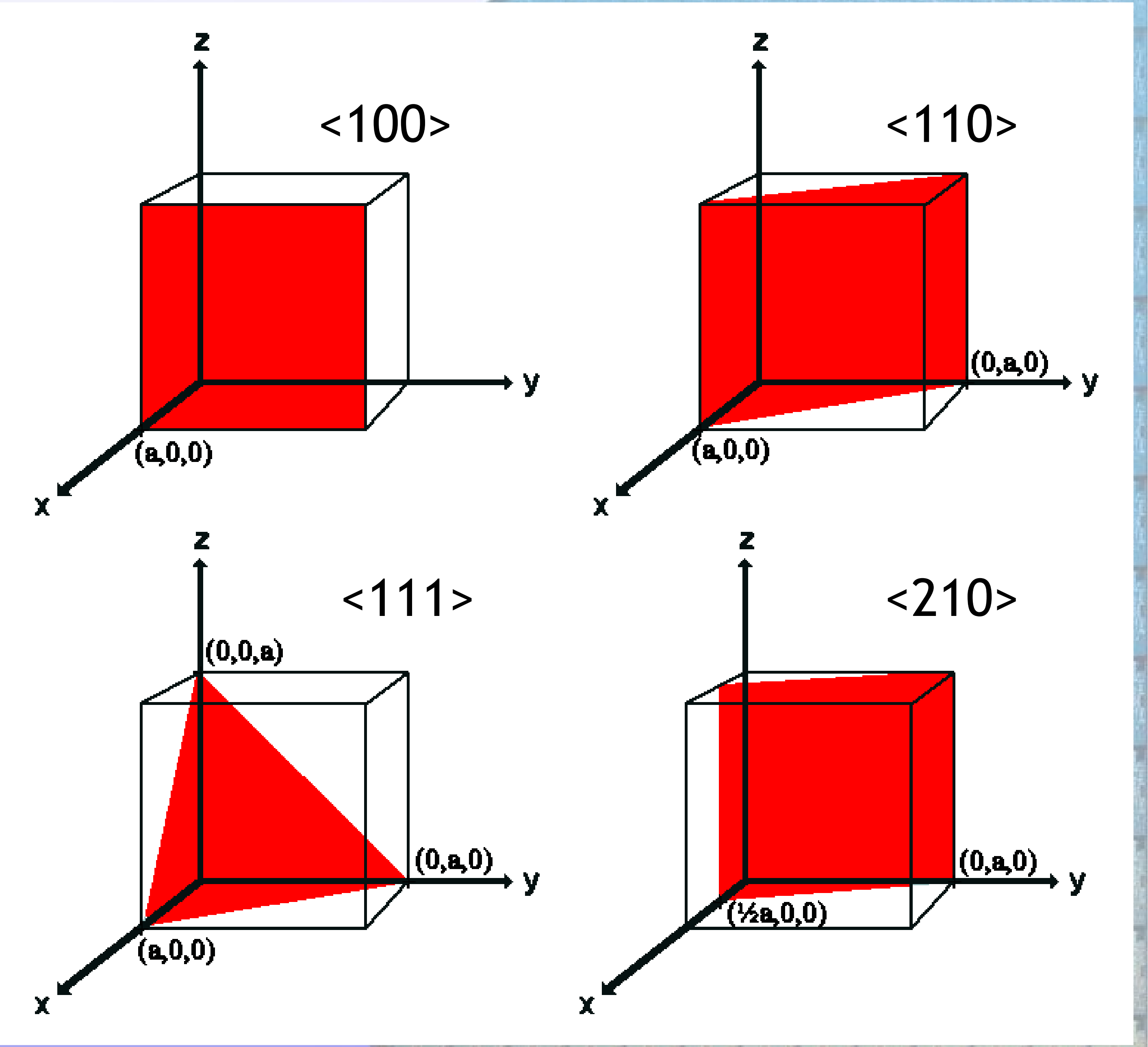
Miller indices

the crystallographics planes are identified with three *integer* numbers <hkl>

The plane is normal to the vector:

$$\vec{v} = (h, k, l)$$

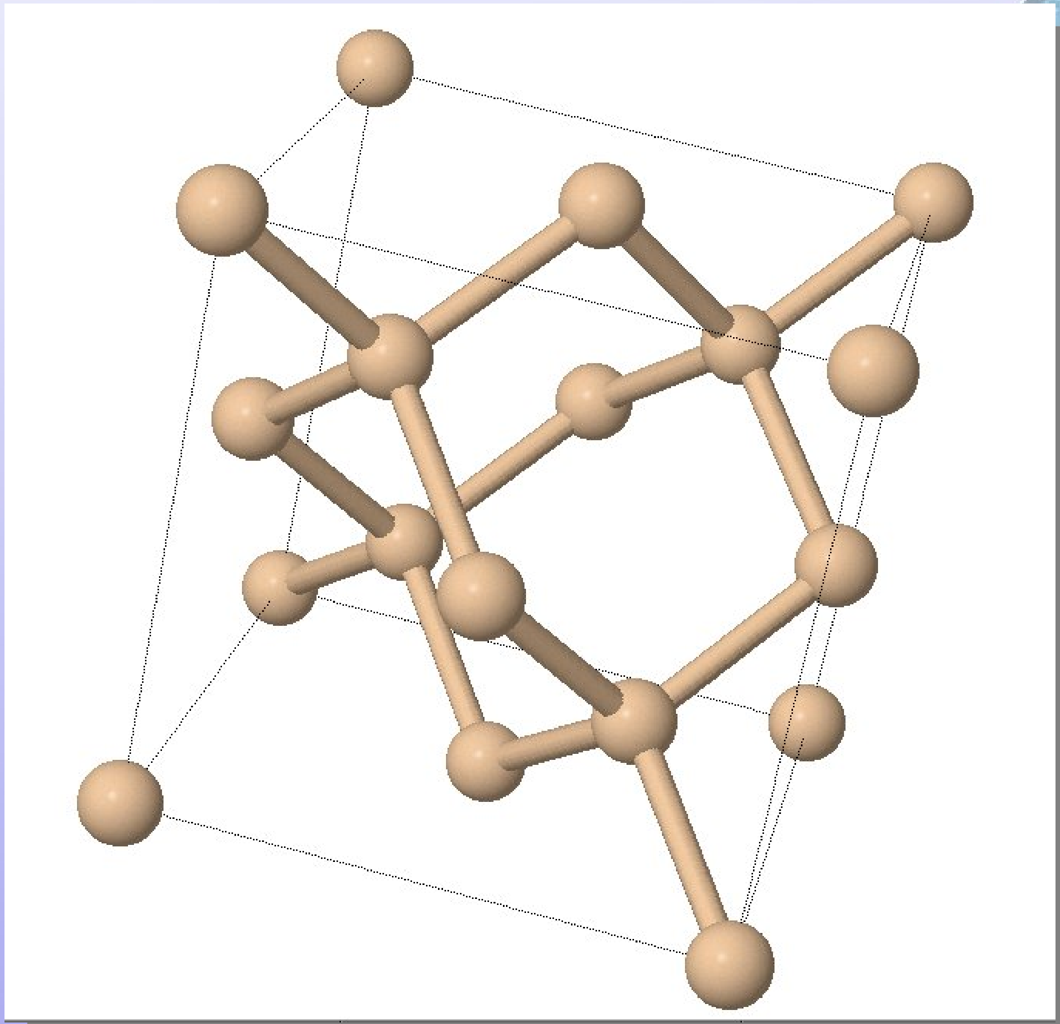




Silicon crystal structure

Face Centered Cubic

(FCC) crystal

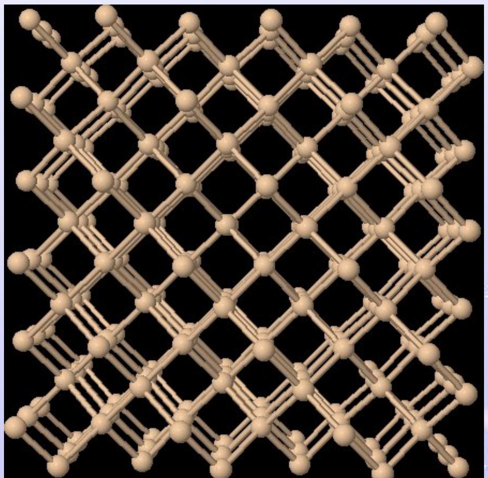


let's look at the silicon crystal structure:

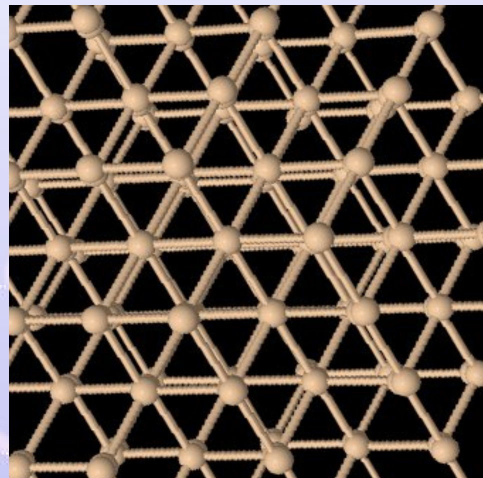
Silicon crystal structure

By rotating the silicon crystal in space, various configurations are accessible:

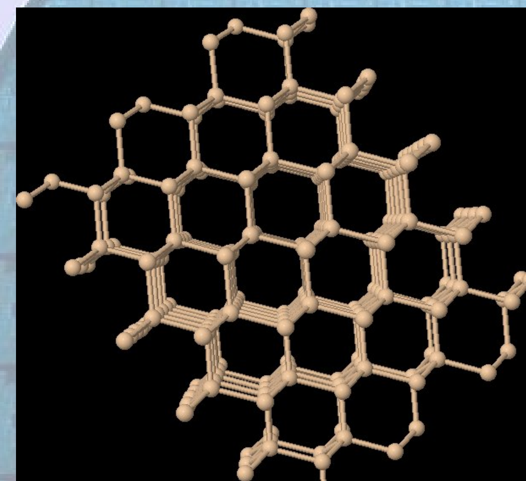
.... some with a clear "structure"......



<100>

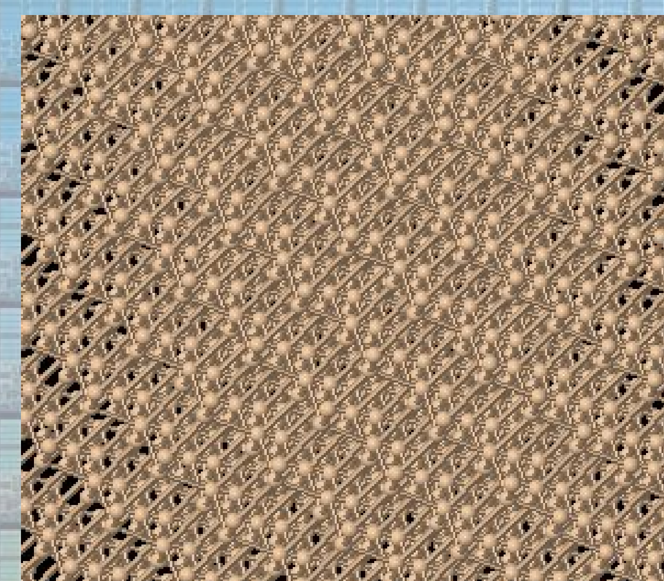


<111>



<110>

... but also some with a nearly-amorphous or "random" structure.



Experiments

The FAZIA collaboration has performed *two* experimental campaigns in order to study the influence of channeling effects in silicon for pulse-shape applications

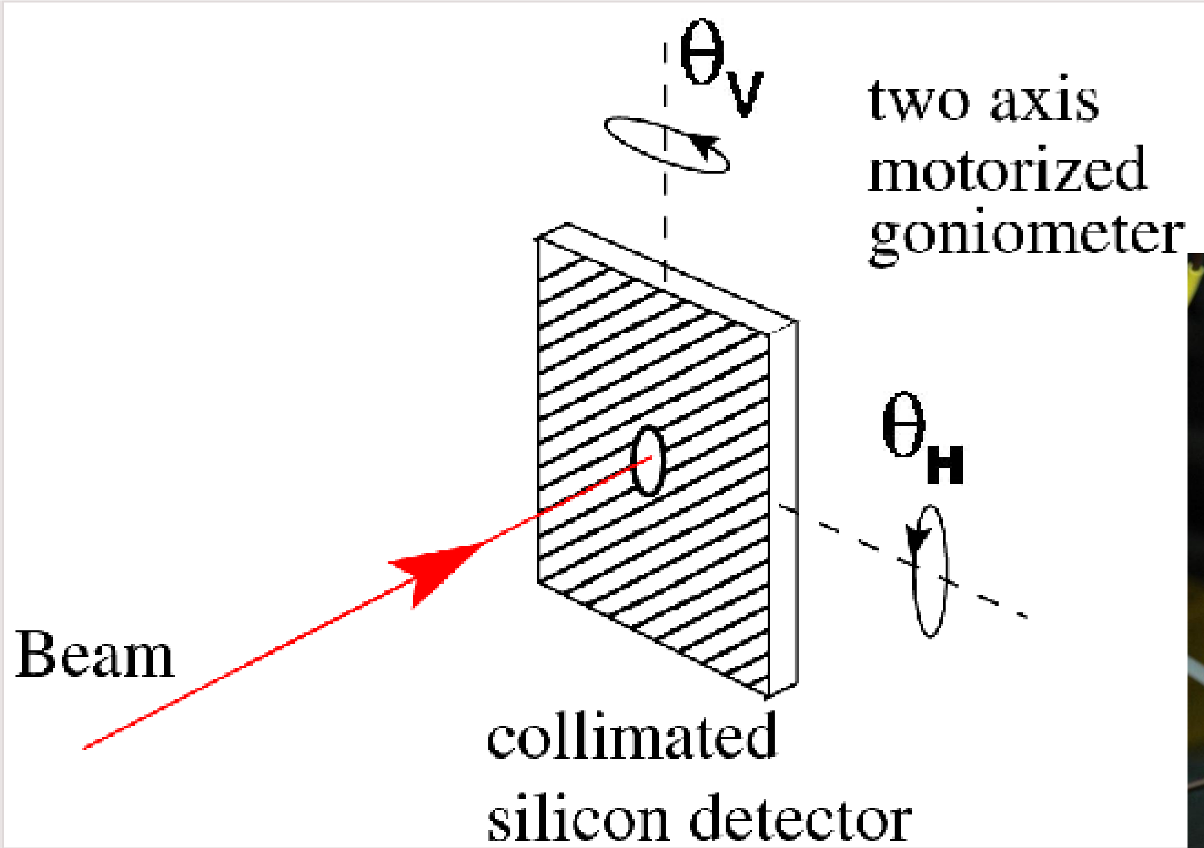
Experimental goals:

1) which is the importance of channeling effects?
   are they able to spoil the experimental "resolution" ?

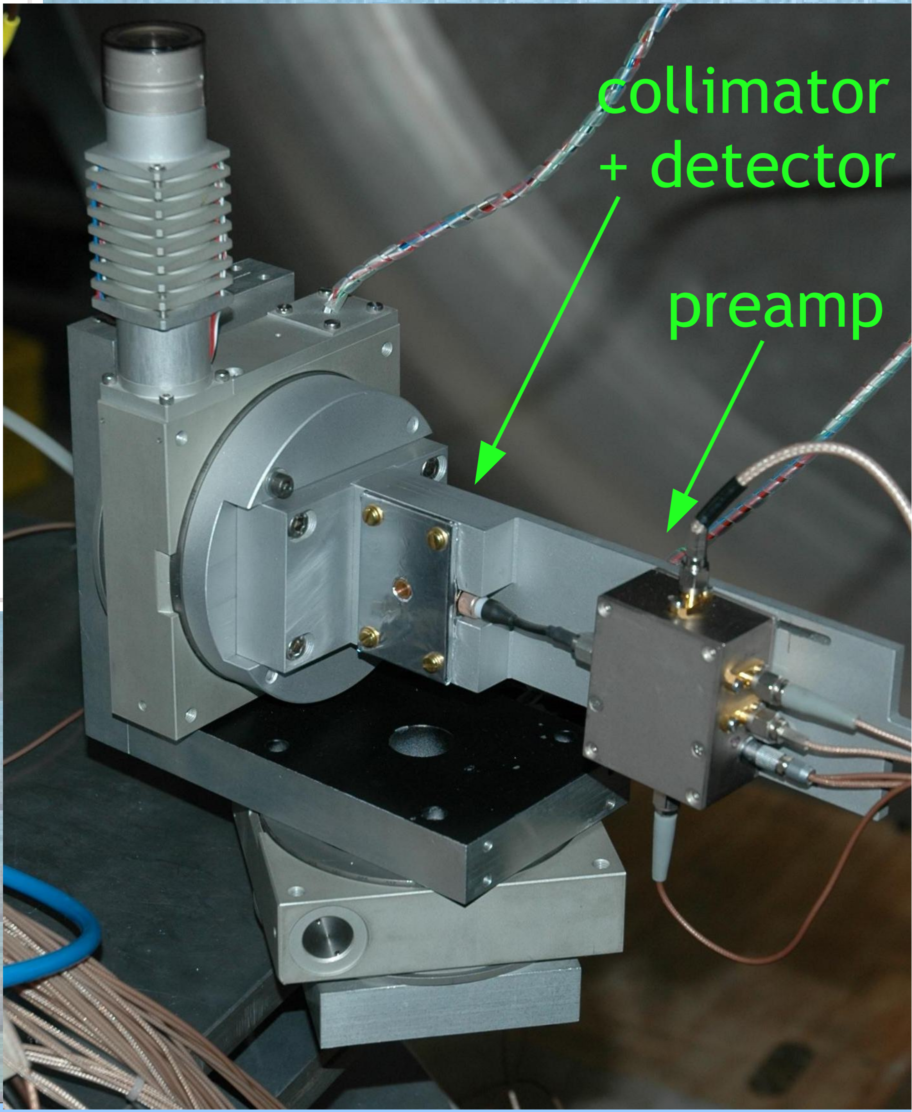
2) if yes, is it possible to avoid these effects? how?

L.Bardelli et al, subm. to NIM

Experimental setup

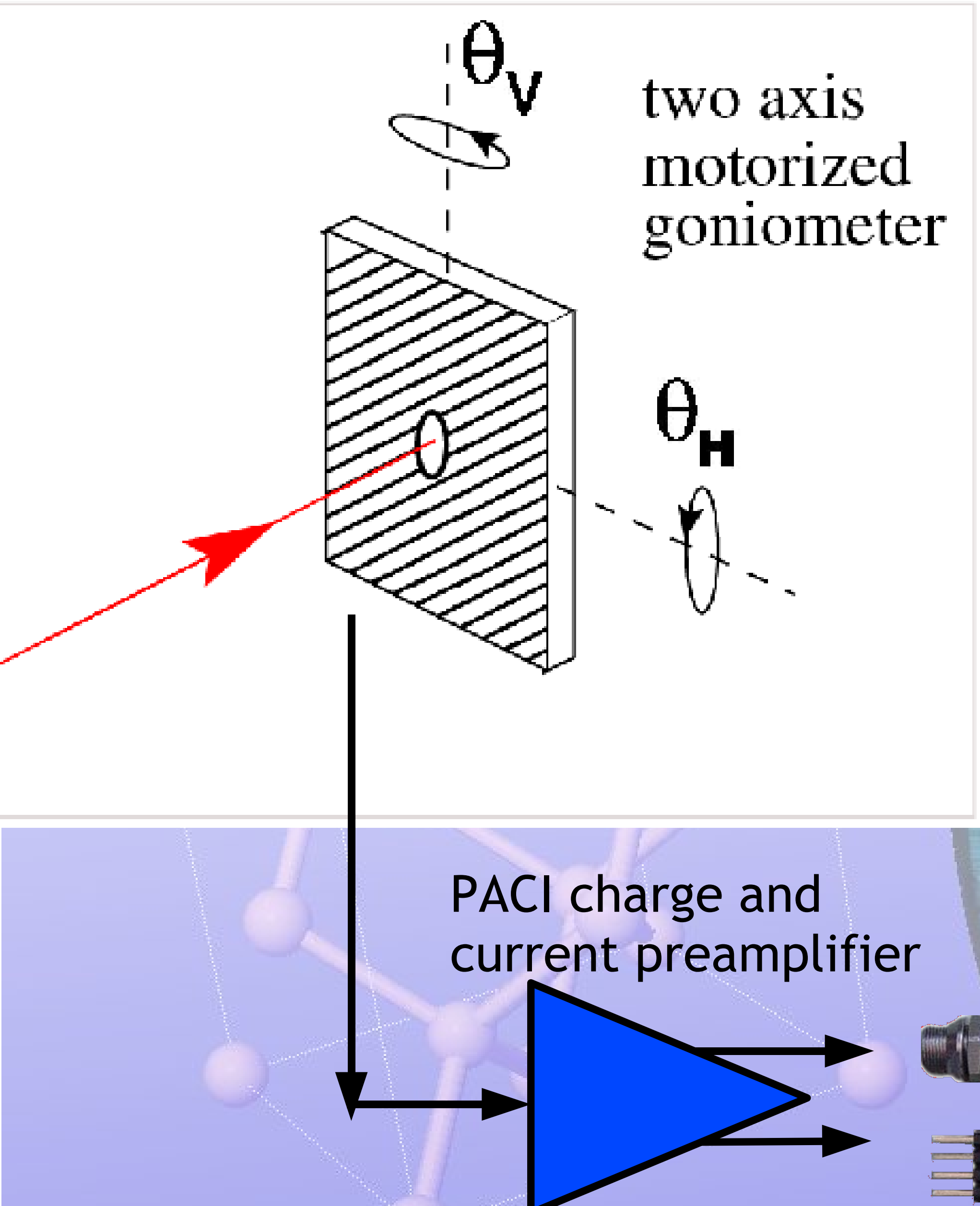


L.Bardelli et al, subm. to NIM



Measure the detector response at various tilt angles by using a motorized support (with remote control)

Experimental setup



Tested ions:

$^{80,\,82}$Se @ 410 MeV

$^{58,\,60}$Ni @ 703 MeV

^{32}S @ 160 MeV

all tests performed at **LNL**

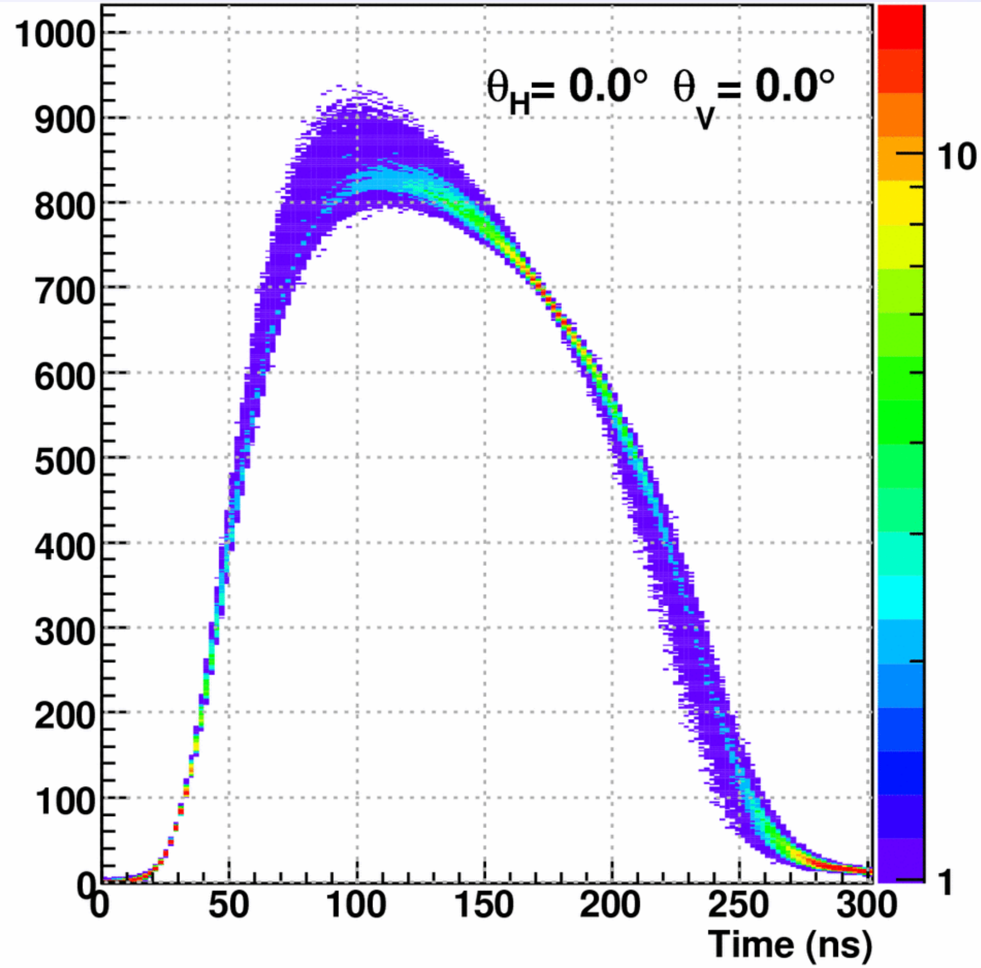
Fast sampling ADCs
12 bit, 125 MS/s

(9 bit, 2 GS/s tested also)

INFN-Fi digitizer: G.Pasquali et al, NIM A 570 (2007)

Signal shapes

Current signals for a ^{80}Se @ 410MeV, <100> detector, 1000 events:



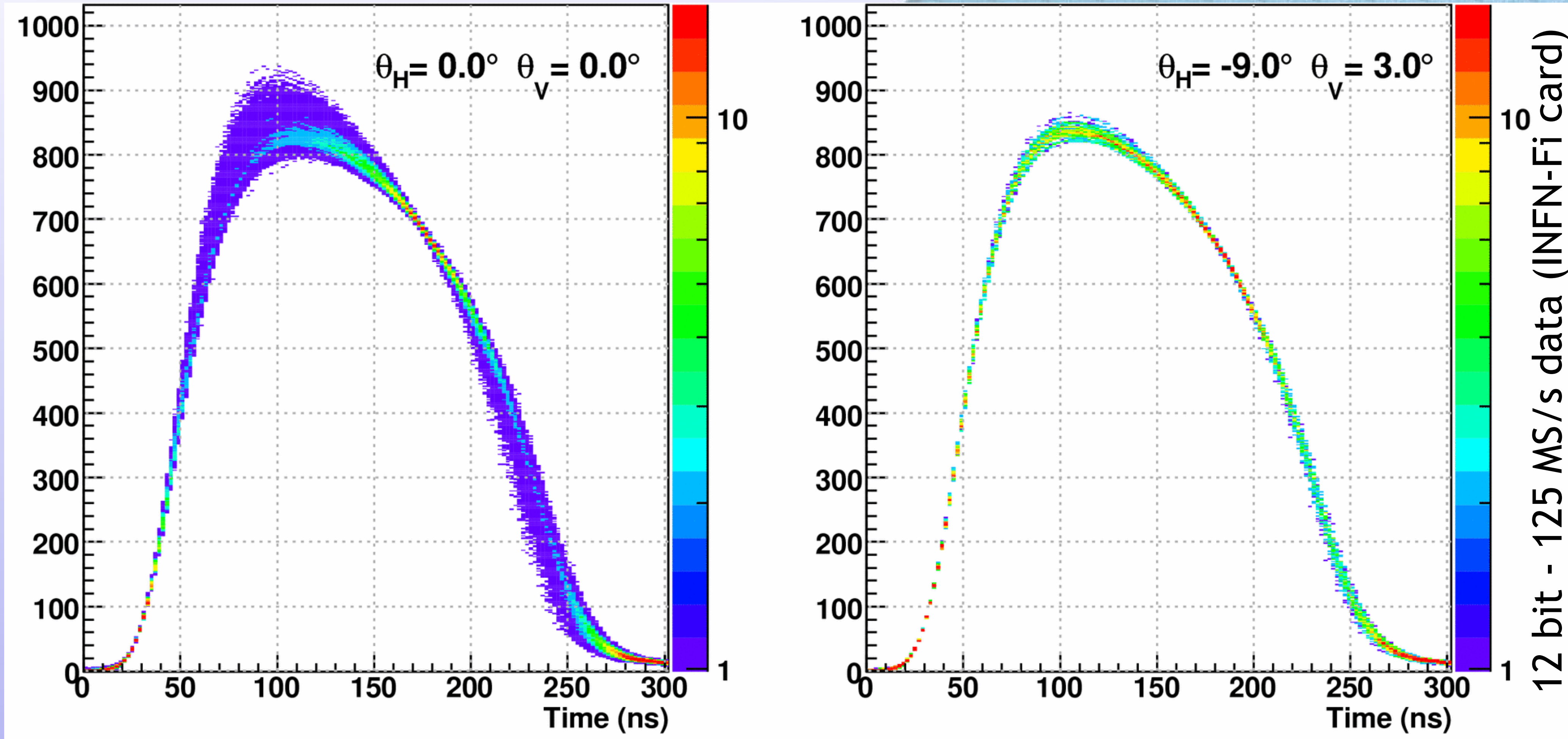
12 bit - 125 MS/s data (INFN-Fi card)

standard detector mounting

(normal to direction of incoming particles)

Signal shapes

Current signals for a ^{80}Se @ 410MeV, <100> detector, 1000 events:



standard detector mounting
(normal to direction of incoming particles)

tilted detector

impressive improvement in signal dispersion!

Data analysis

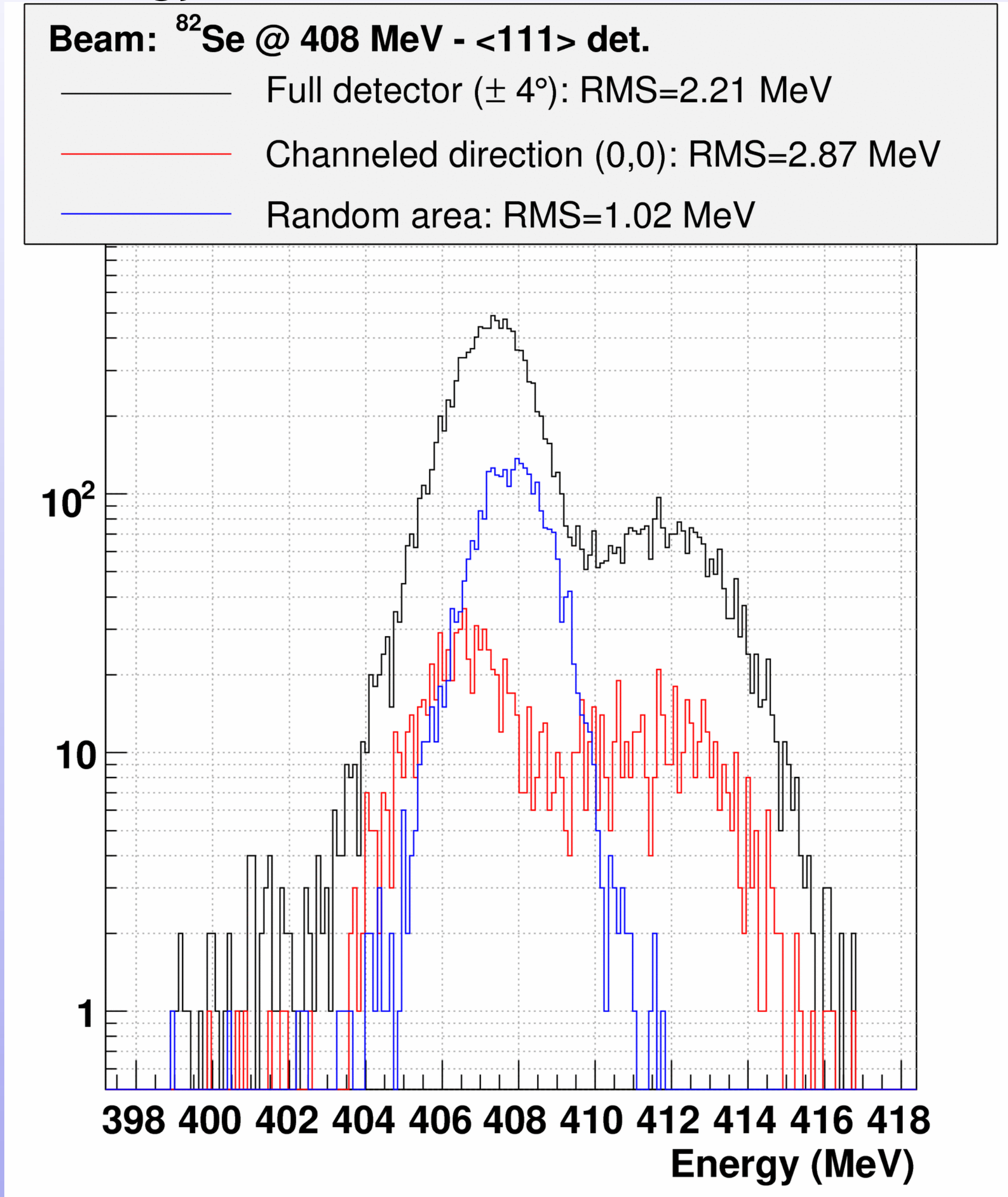
For each event:
- the particle energy is extracted via optimized digital shaping
- the signal risetime (either charge or current) is extracted via a digital CFD algorithm with proper interpolation
  [for details see L.Bardelli et al, NIM **A** 521 (2004)]

For each explored angle pair we can plot:
- energy resolution as a function of the two angles
- risetime resolution as a function of the two angles
- etc etc...

Let's see some examples......

Energy resolution

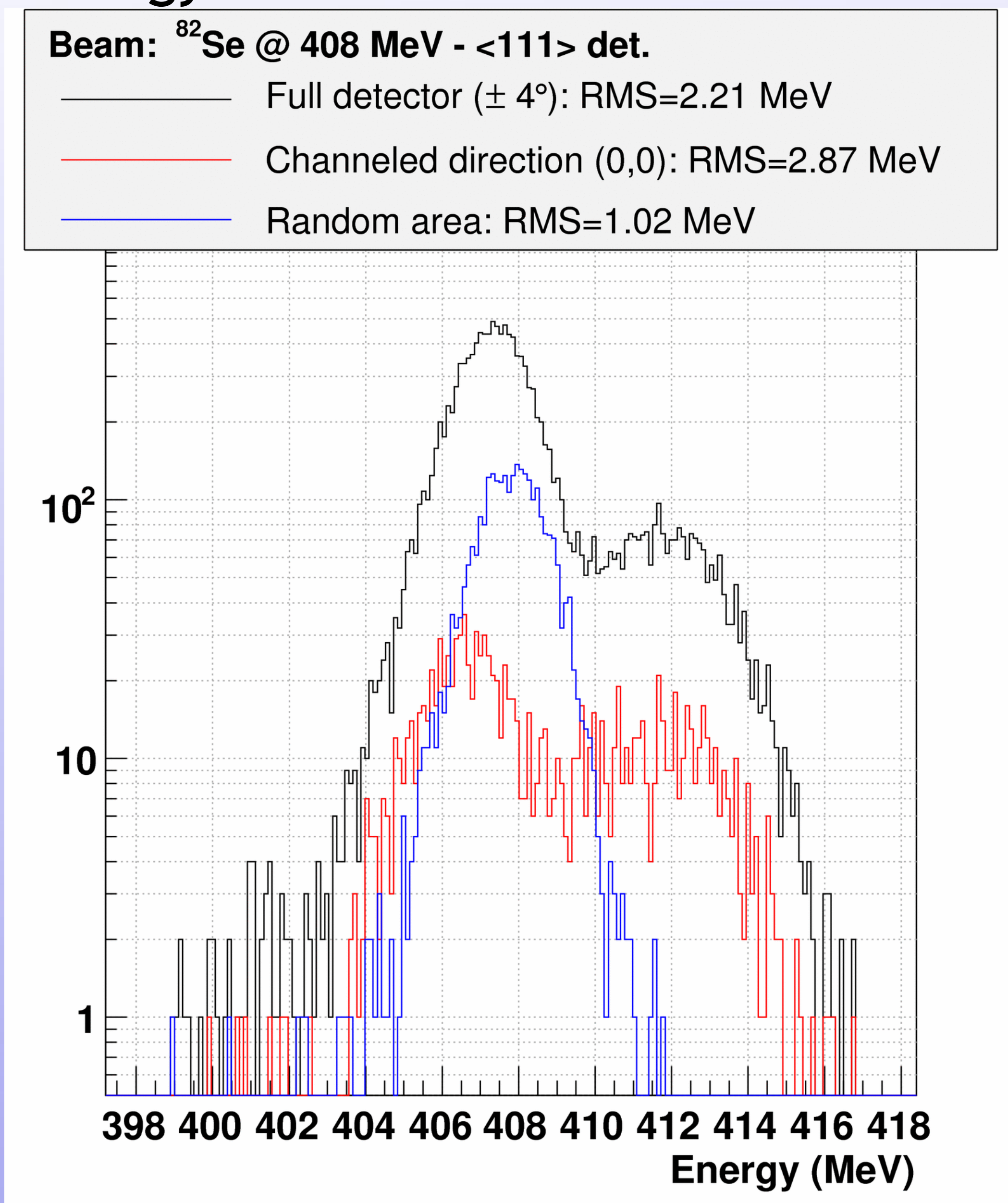
Energy resolution for a <111> detector:

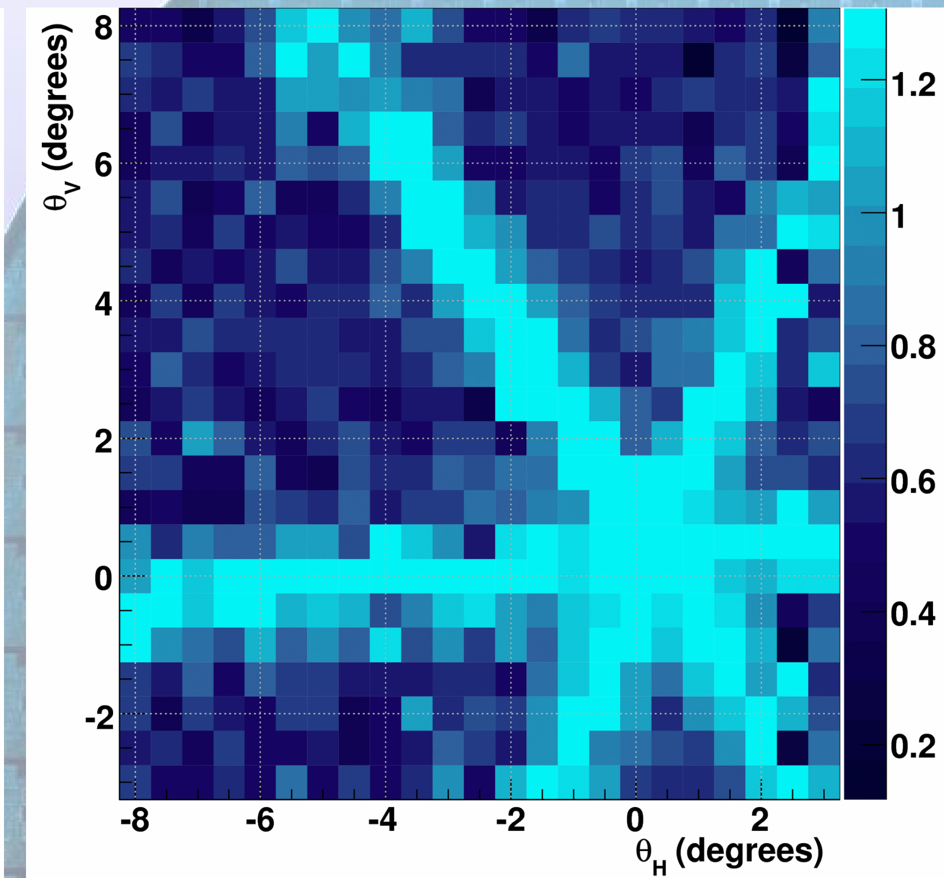


12 bit - 125 MS/s data (INFN-Fi card)

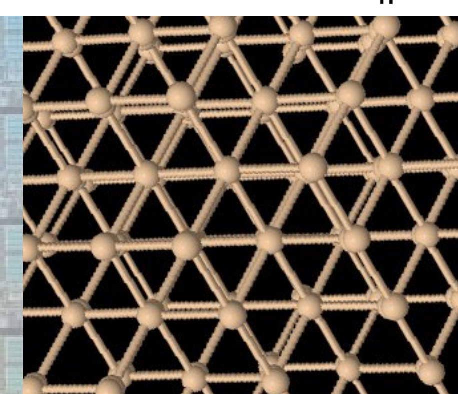
Energy resolution

Energy resolution for a <111> detector:





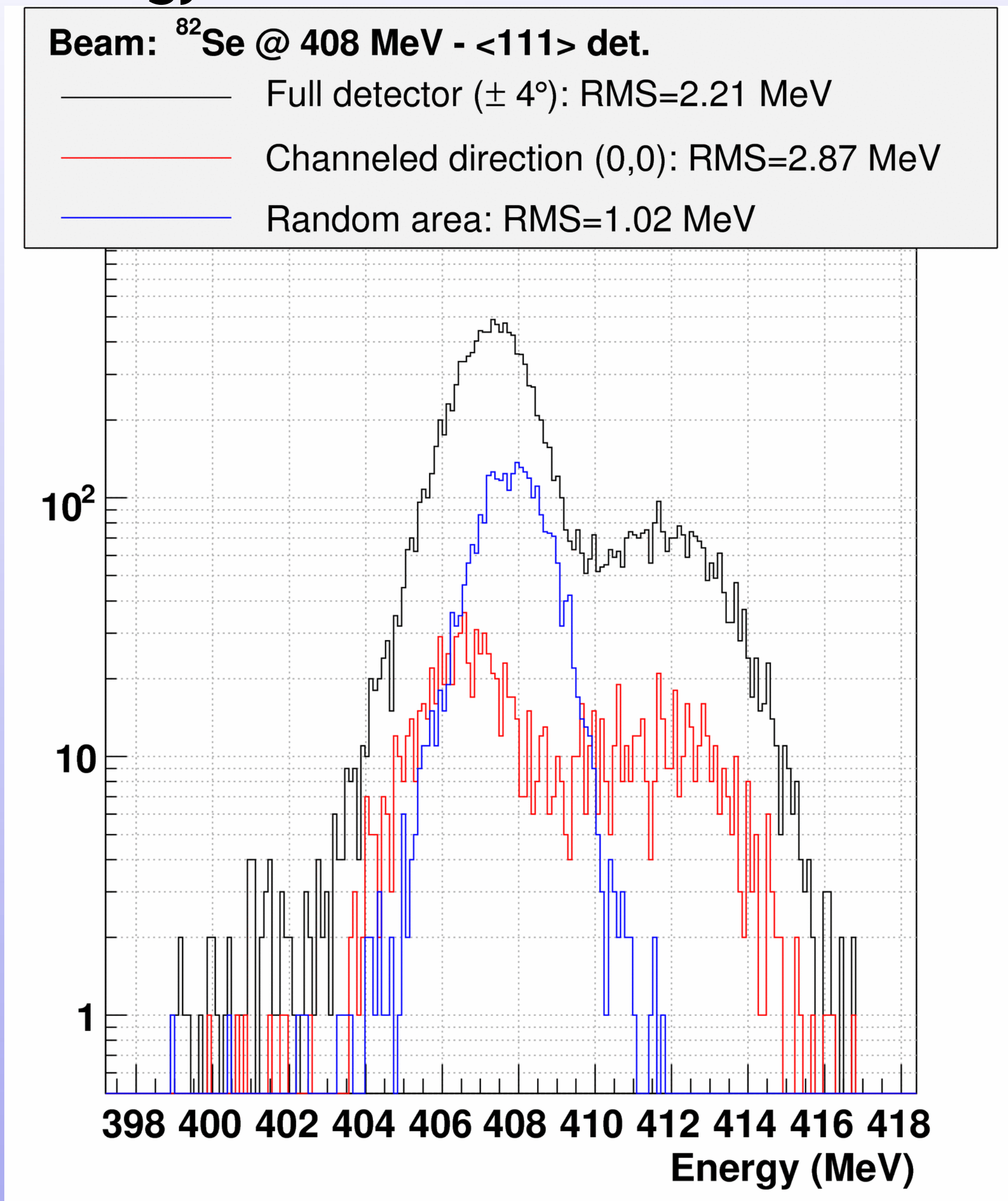
12 bit - 125 MS/s data (INFN-Fi card)

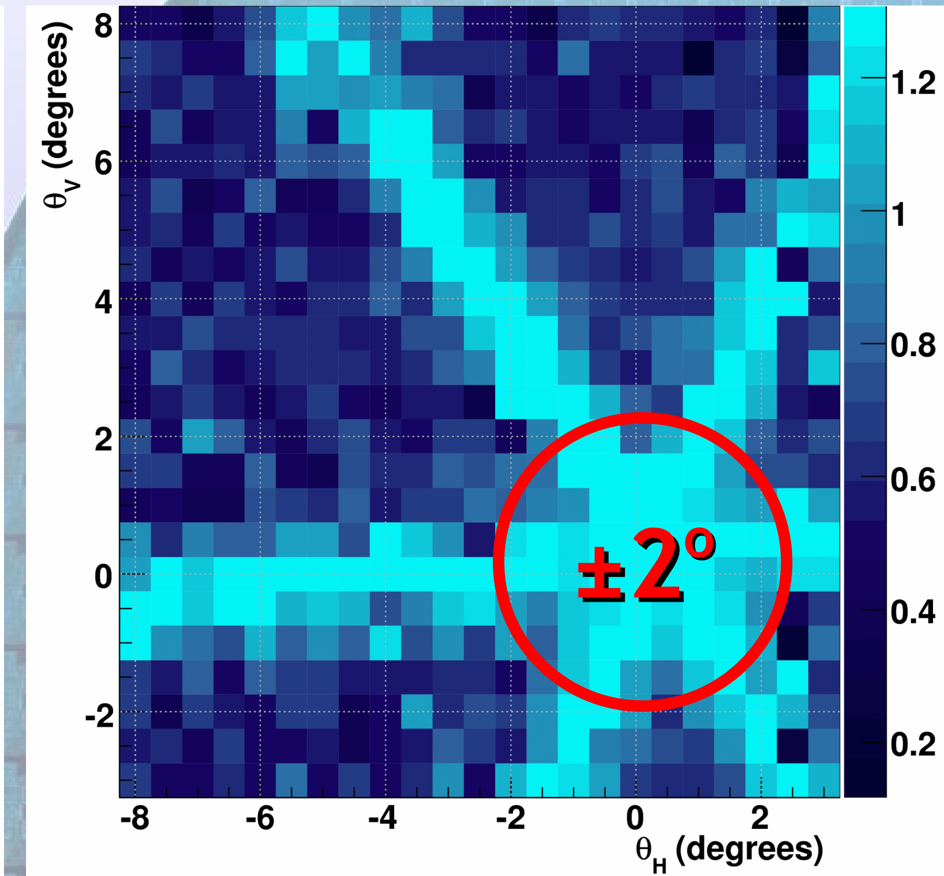


detector structure

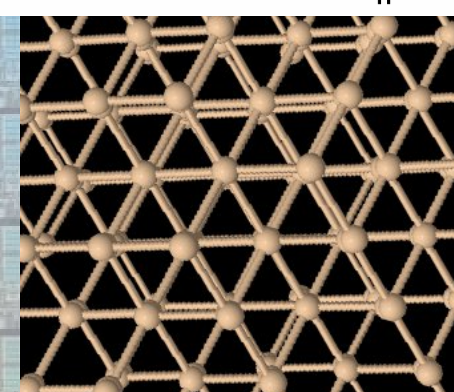
Energy resolution

Energy resolution for a <111> detector:





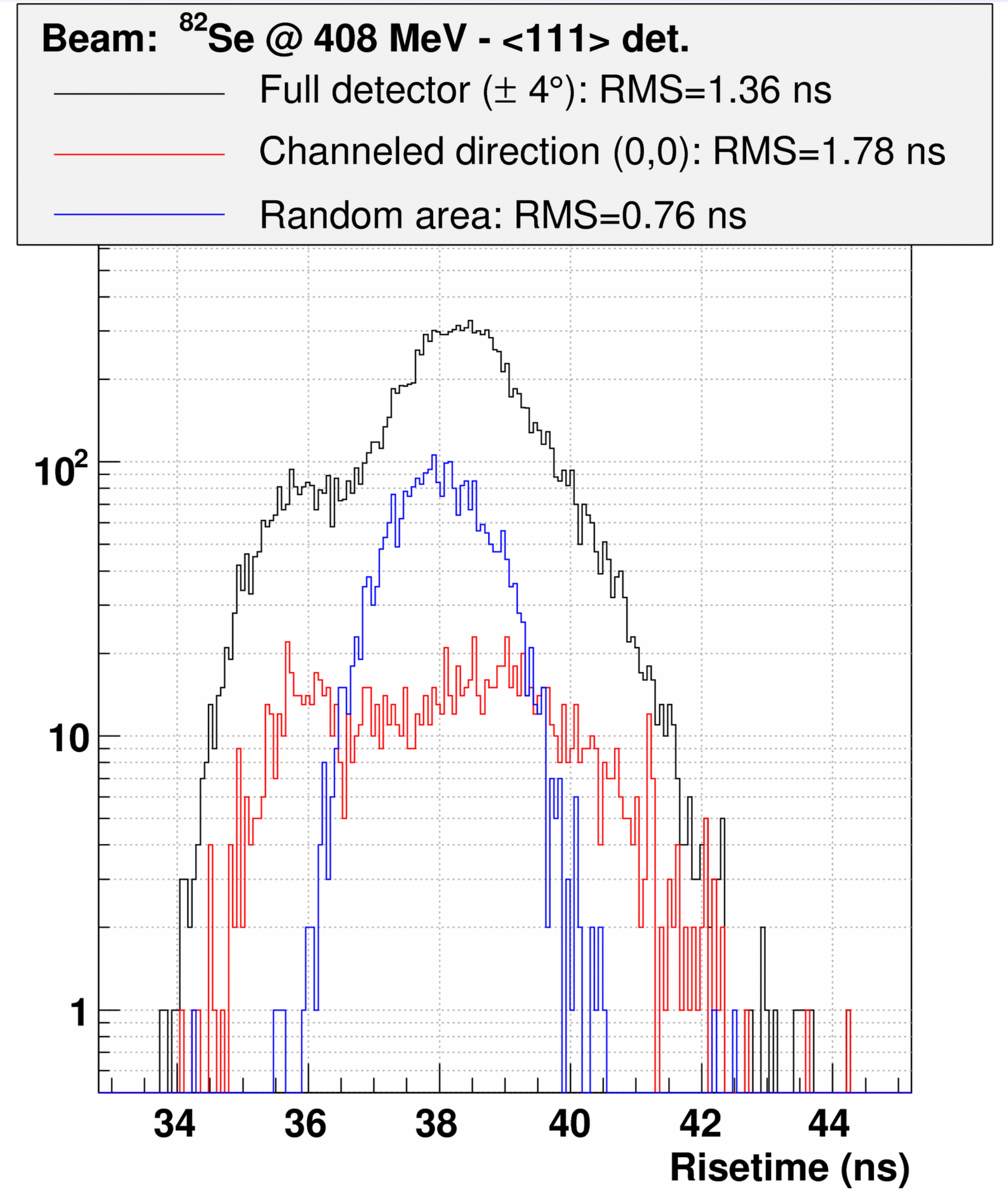
12 bit - 125 MS/s data (INFN-Fi card)

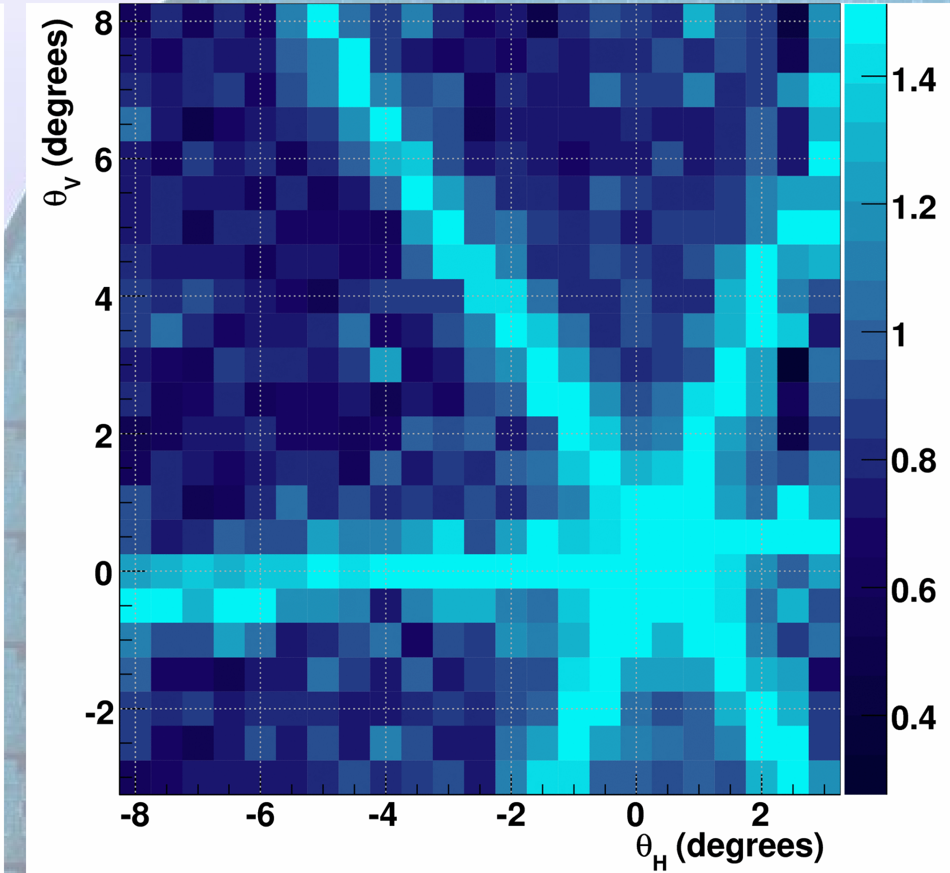


detector structure

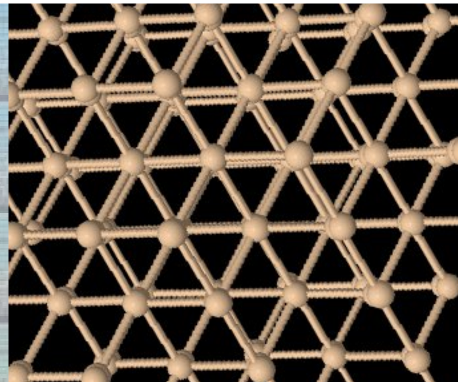
Risetime resolution

Risetime resolution for a <111> detector:





12 bit - 125 MS/s data (INFN-Fi card)

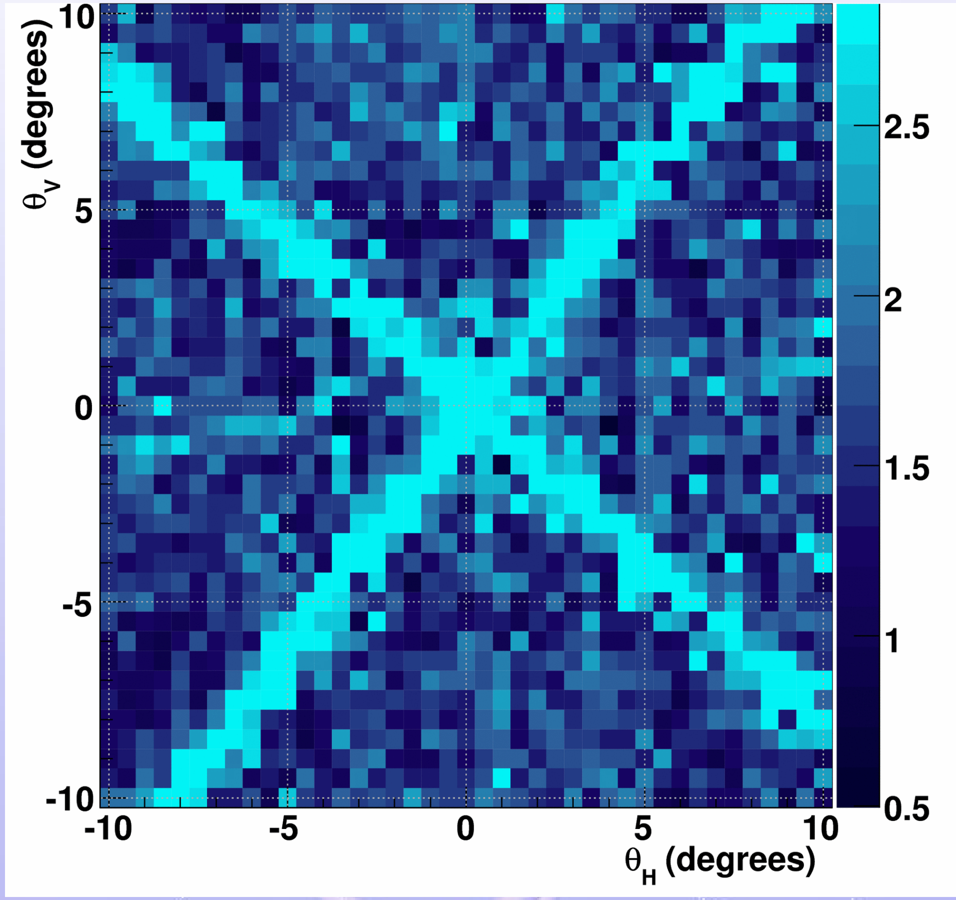


detector structure

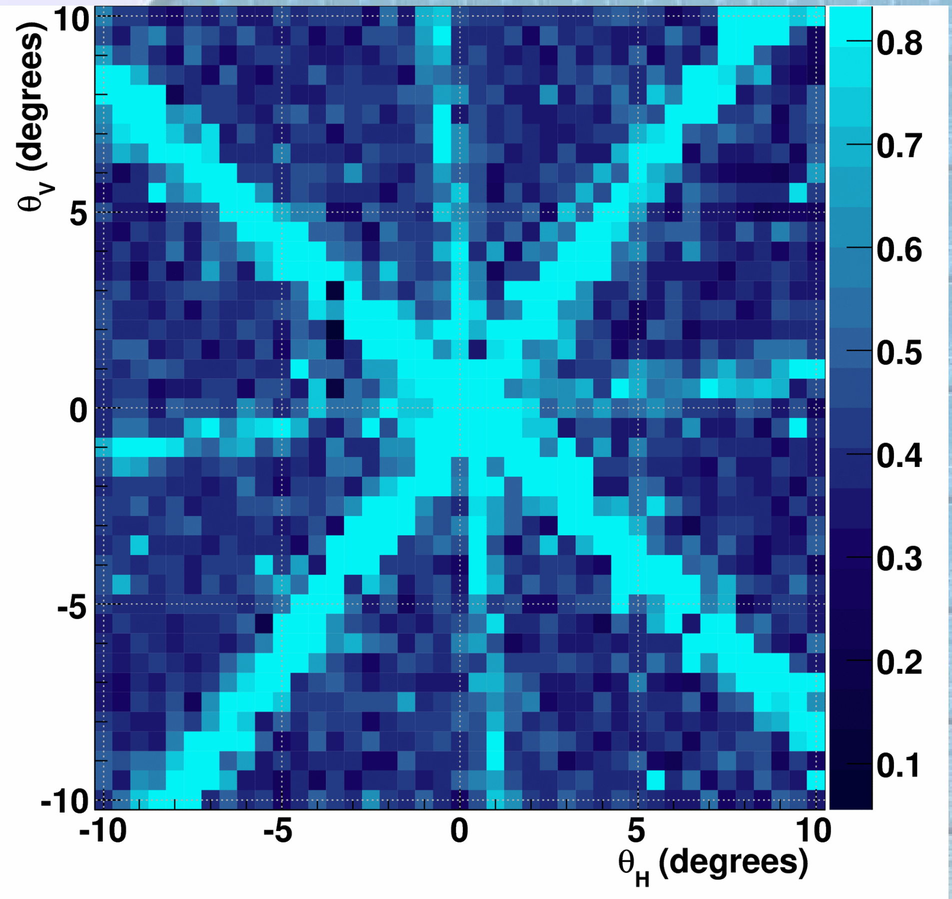
<100> detectors

Same behaviour:

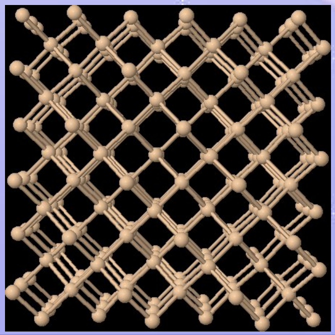
energy resolution



risetime resolution



12 bit - 125 MS/s data (INFN-Fi card)

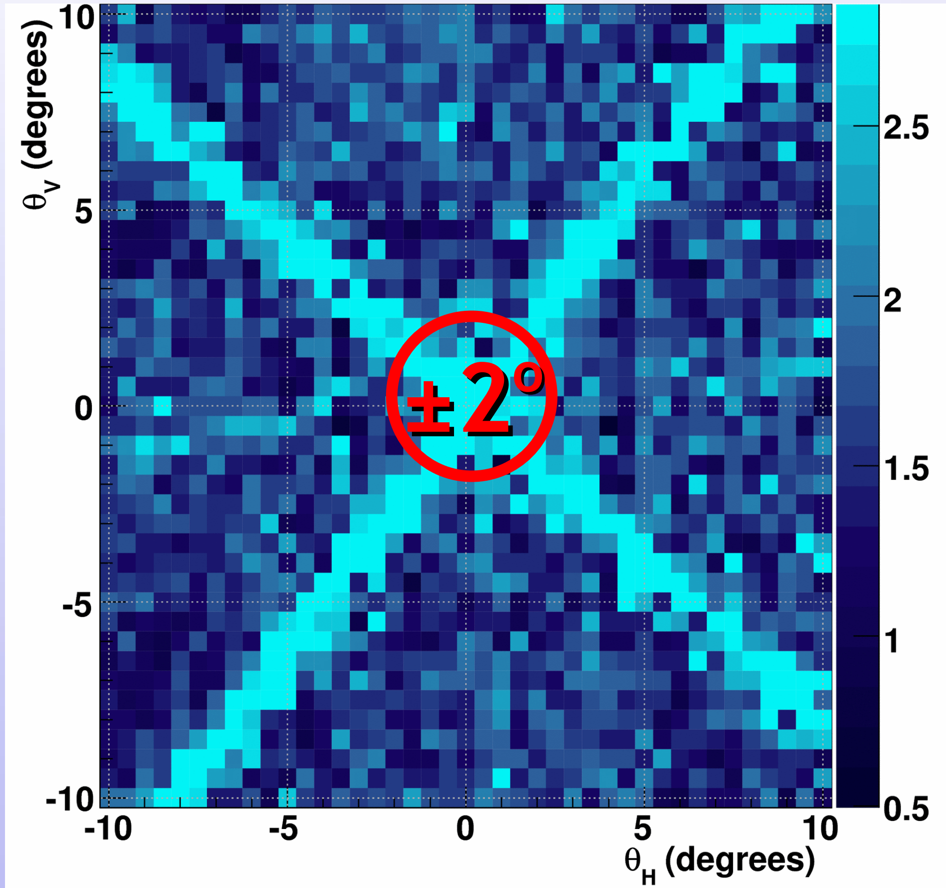


detector structure

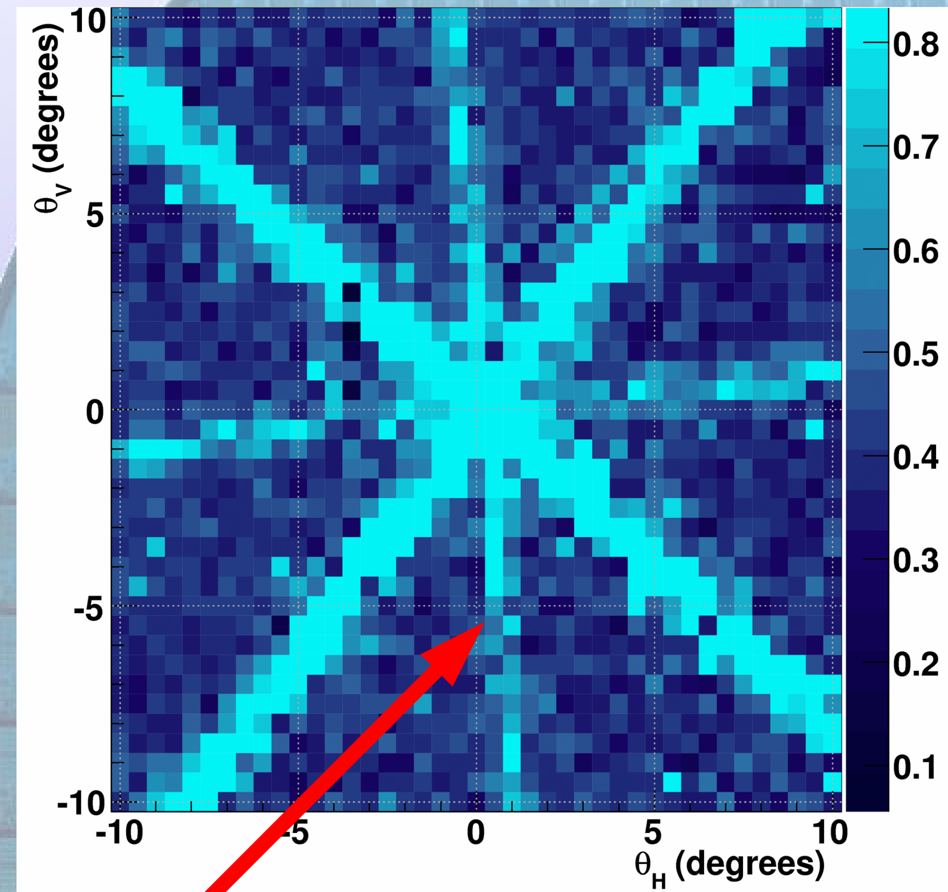
L.Bardelli et al, subm. to NIM

<100> detectors

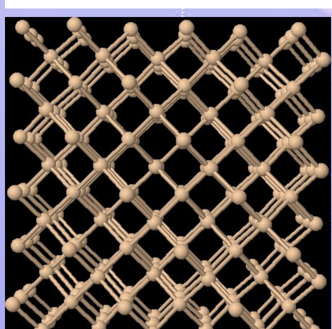
energy resolution



risetime resolution



12 bit - 125 MS/s data (INFN-Fi card)



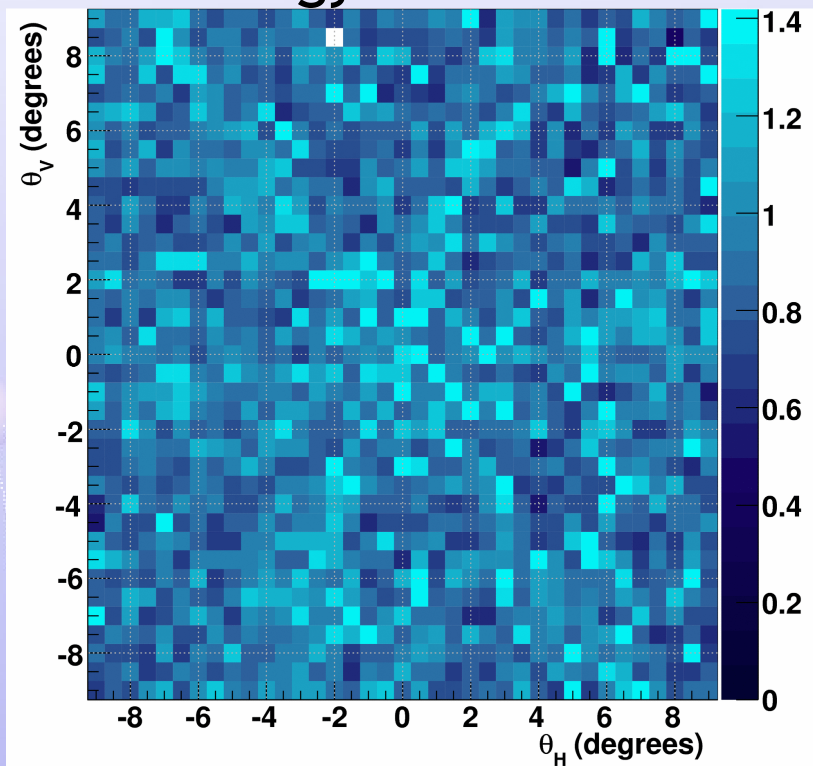
detector structure

risetime can appreciate also higher order crystallographic planes

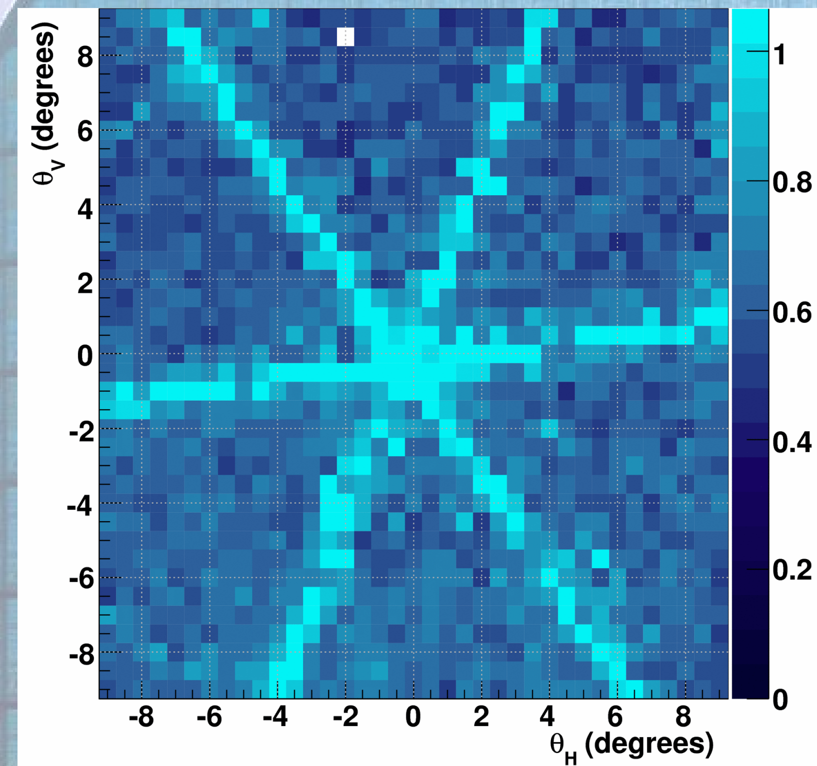
Lighter ions

Experimental data for ^{32}S ions @ 5 AMeV (<111> detector):

energy resolution

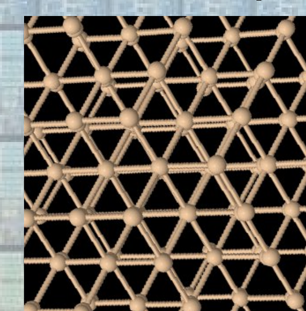


risetime resolution



12 bit - 125 MS/s data (INFN-Fi card)

For these “light” ions where the pulse height defect is small, the energy resolution is not affected by channeling, while the pulse shape is.

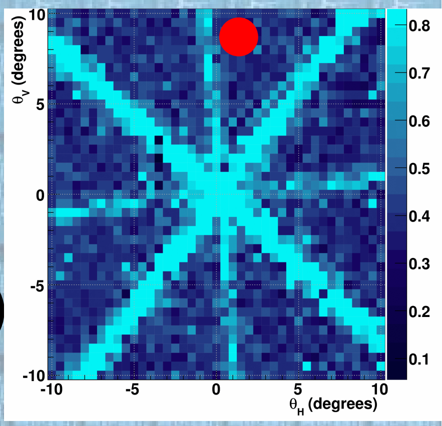


How to “avoid” channeling

We have demonstrated that channeling effects must be avoided in order to obtain good performaces in PSA applications.

How can we avoid these effects??

1) if the detector is cut along a <111> or <100> axis, the only solution is to tilt it (not ok for 4π device...)



2) we can ask manufactures to build detectors from silicon wafers having a special cut

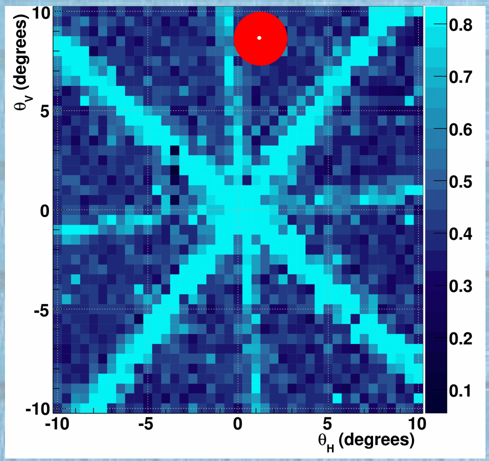
FAZIA is already working in this direction (first detectors in progress)

In both cases the angle covered by the detector must be small (rule of thumb: < ±2°)

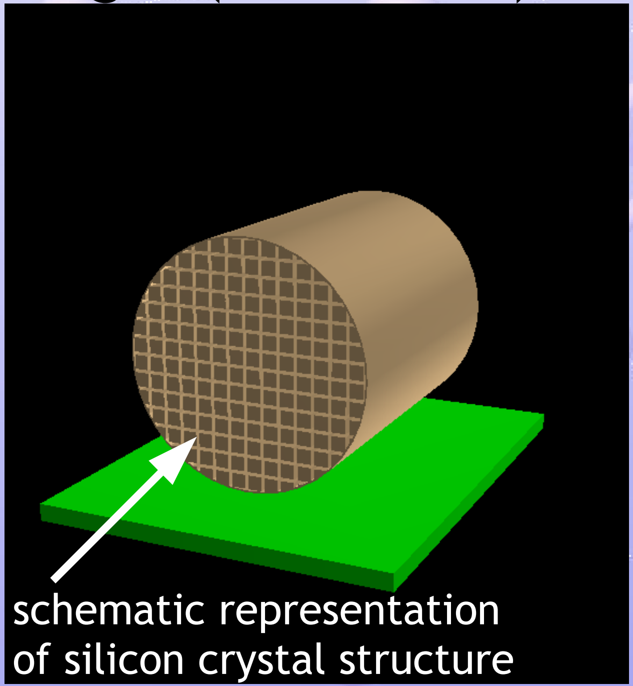
How to “avoid” channeling

Silicon wafers can be cut from silicon ingots with a special cut: in order to recover the “best” experimental configuration, two angles are needed: for <100> θ_{off}=8°, φ=13°

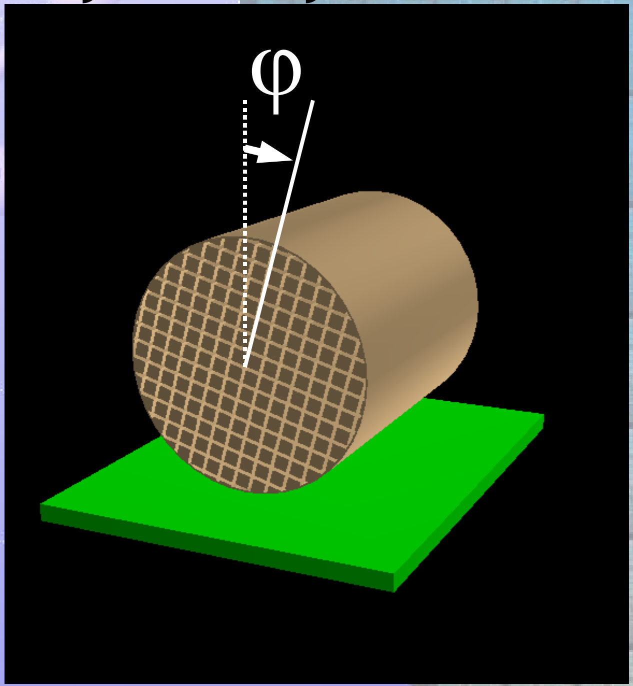
Maximum angular detector coverage: ±2°



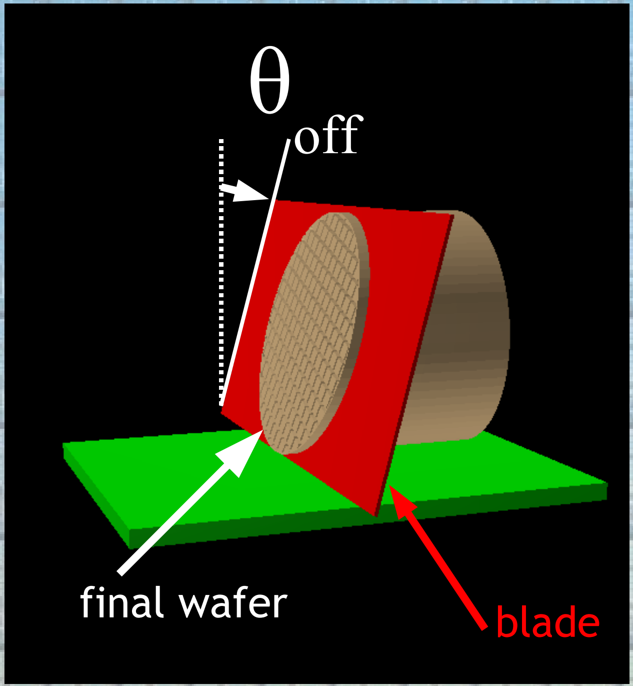
start from a silicon ingot (i.e. <100>)...



...rotate along the symmetry axis...



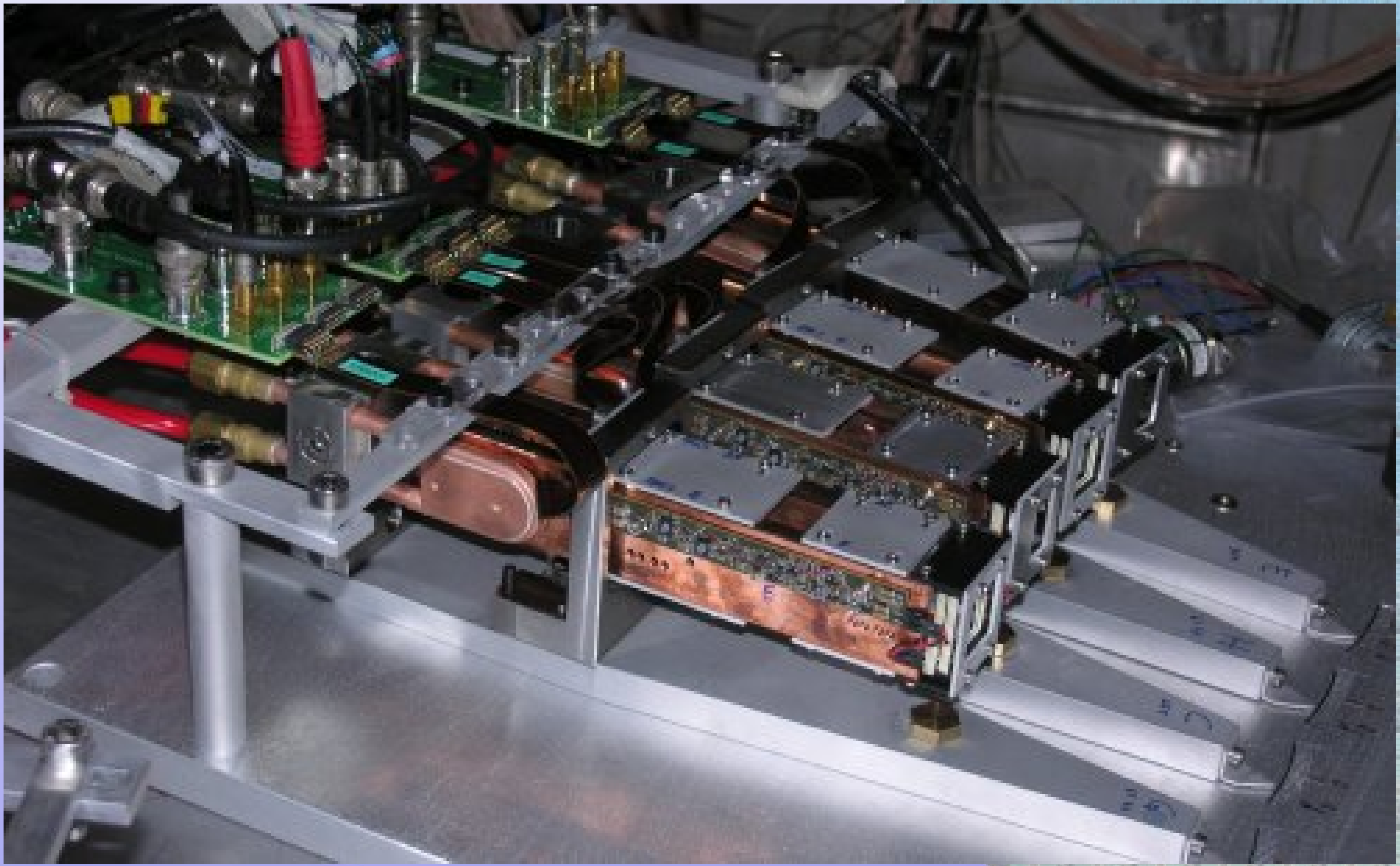
...perform an off-axis wafer cut.



EXPERIMENTS

FAZIA tests

In December 2008, the FAZIA collaboration has performed an experimental test in LNL, in order to test the performances of our detectors and basic idea of our frontend:

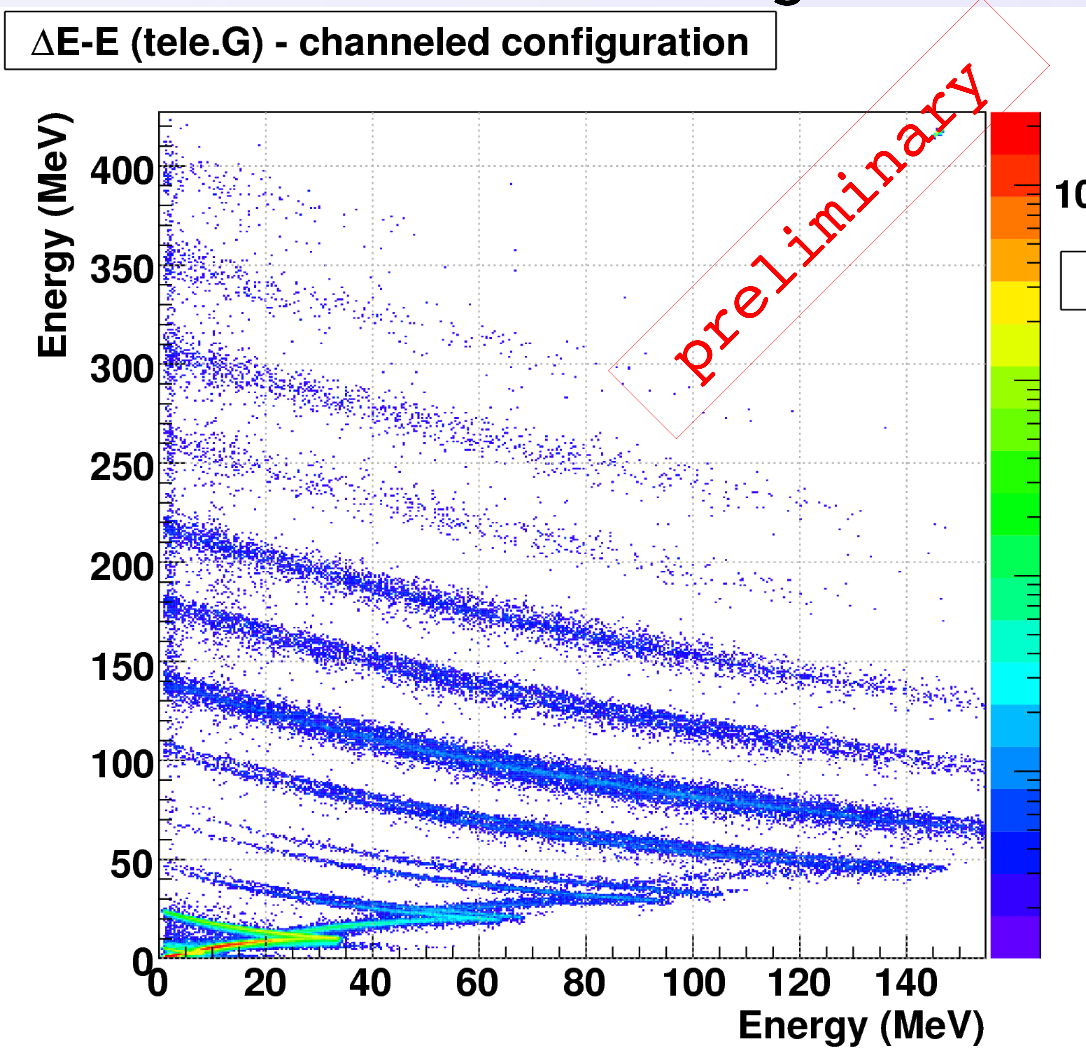


Several Si-Si or Si-CsI telescopes in various configurations and different readouts...

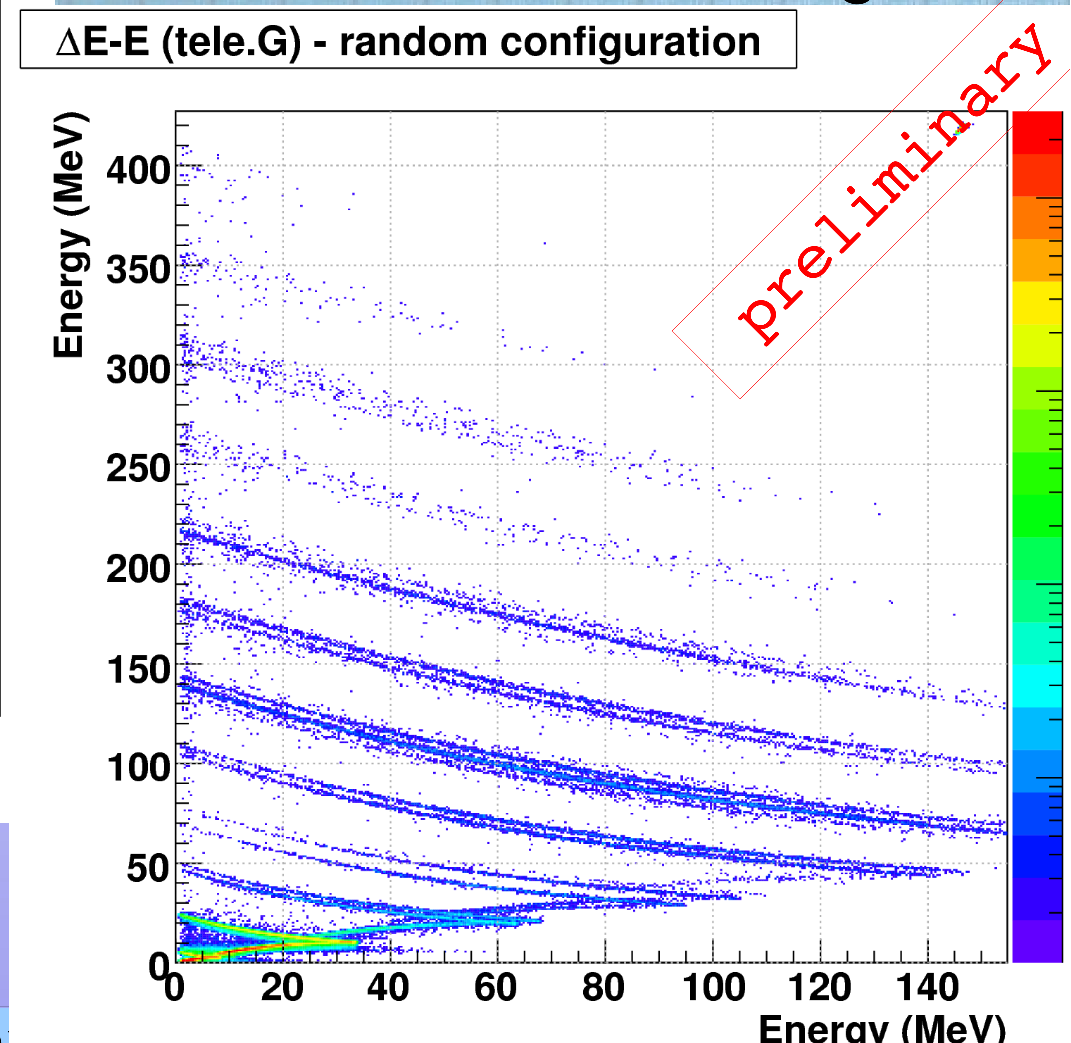
Channeling effects in ΔE-E

14bit, 100 MS/s digitizer
4.2 GeV full range in ΔE

"with" channeling



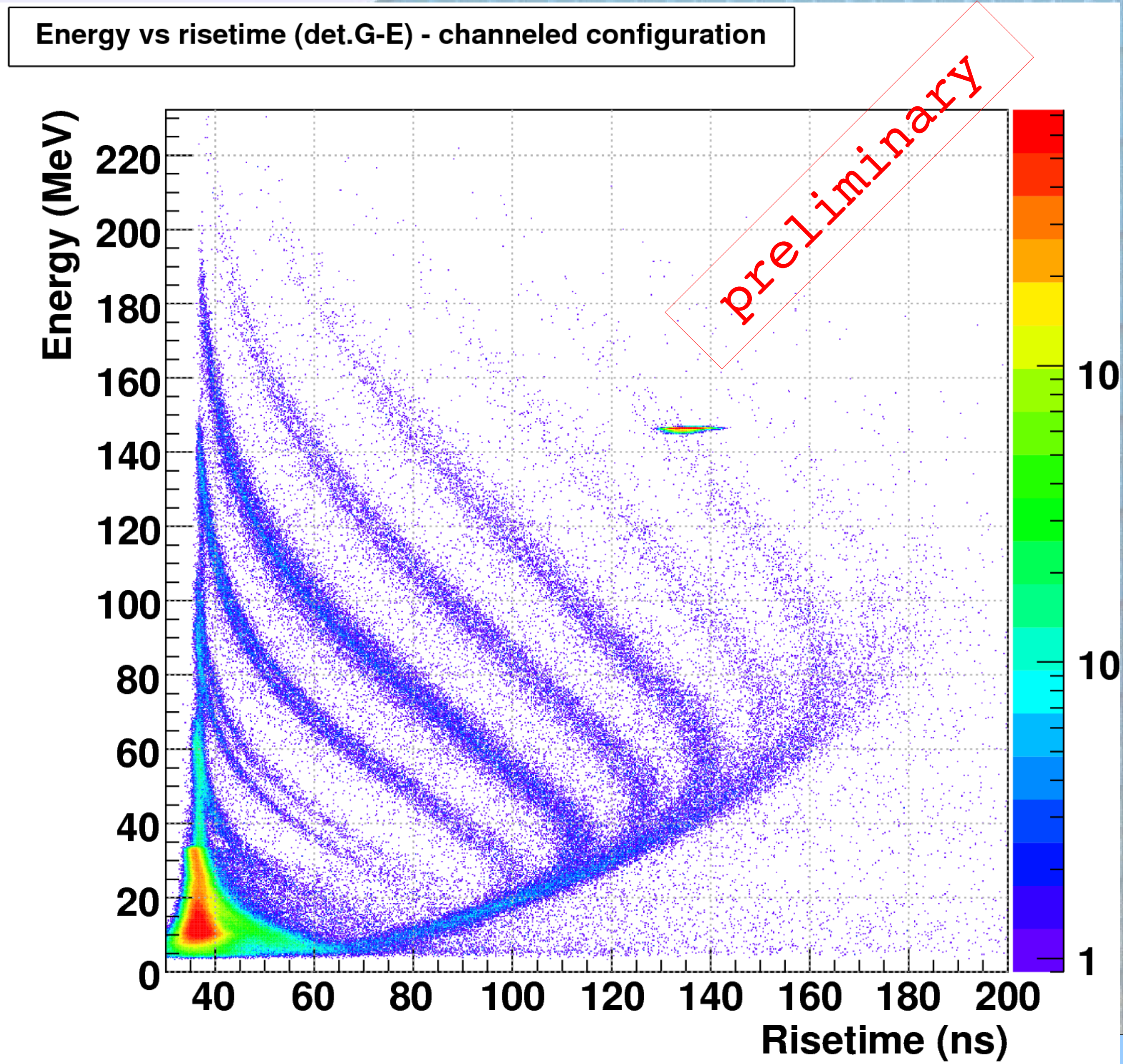
"without" channeling



Control of chann. and hom.

500 um detector
1.5% non-hom. (BEST)

“with” channeling



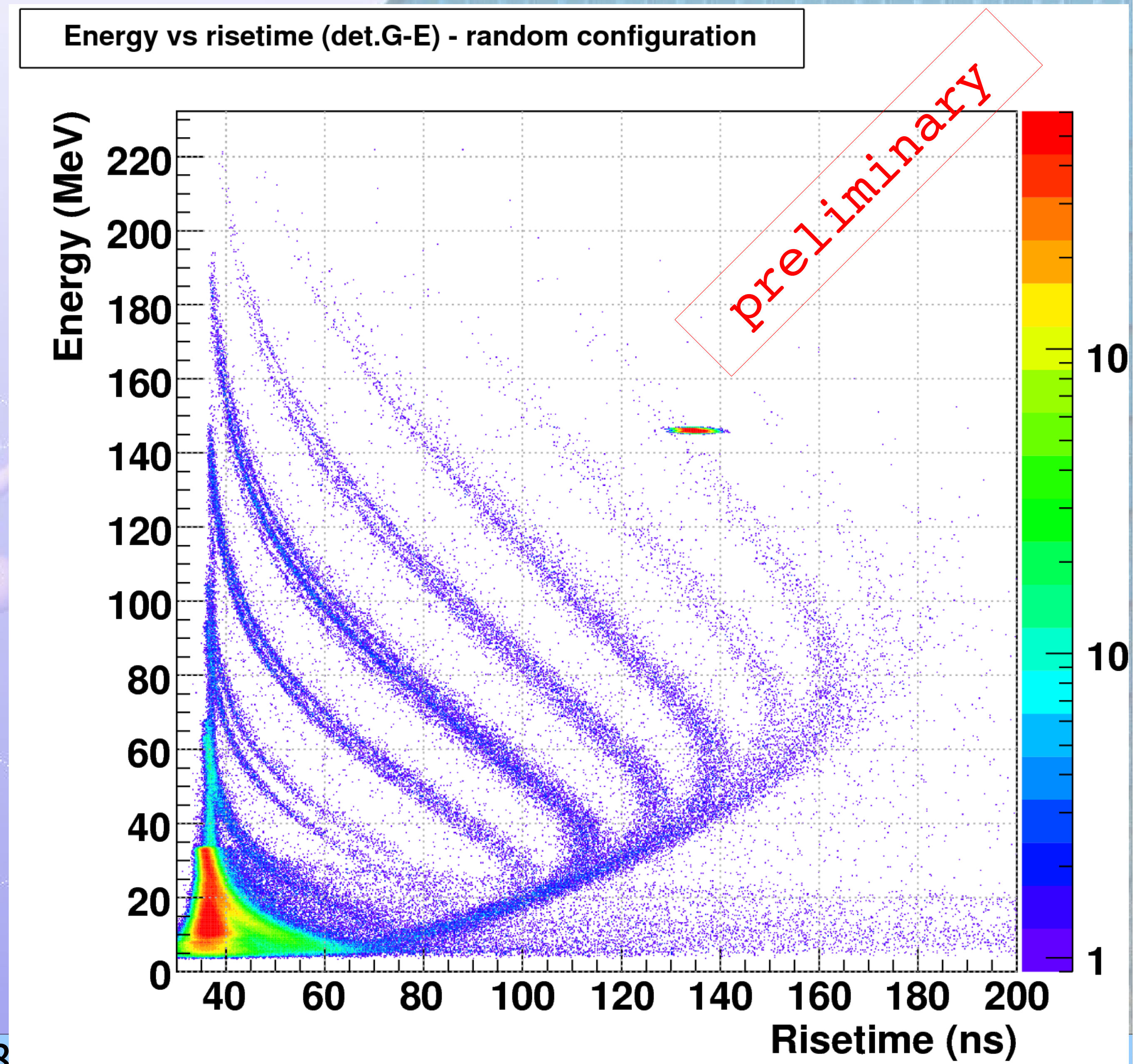
Control of chann. and hom.

500 um detector
1.5% non-hom. (BEST)

“without” channeling
(BEST)

14 bit, 100 MS/s
digitizer

1.3 GeV full range

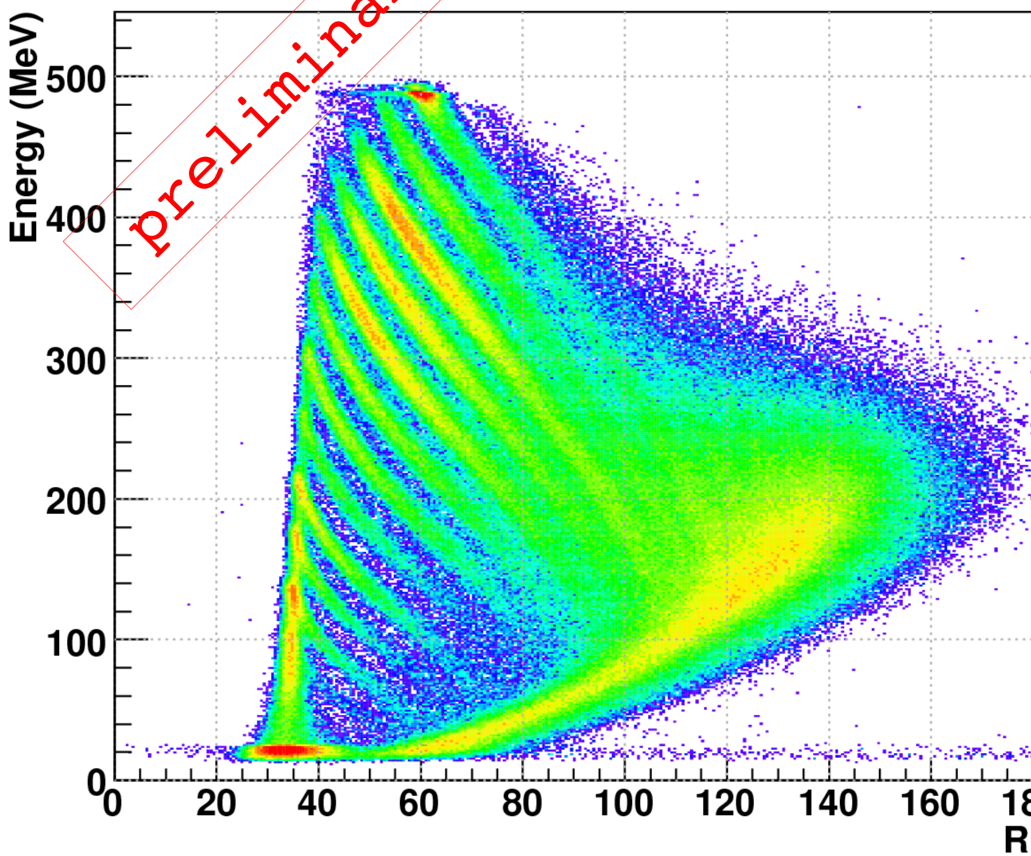


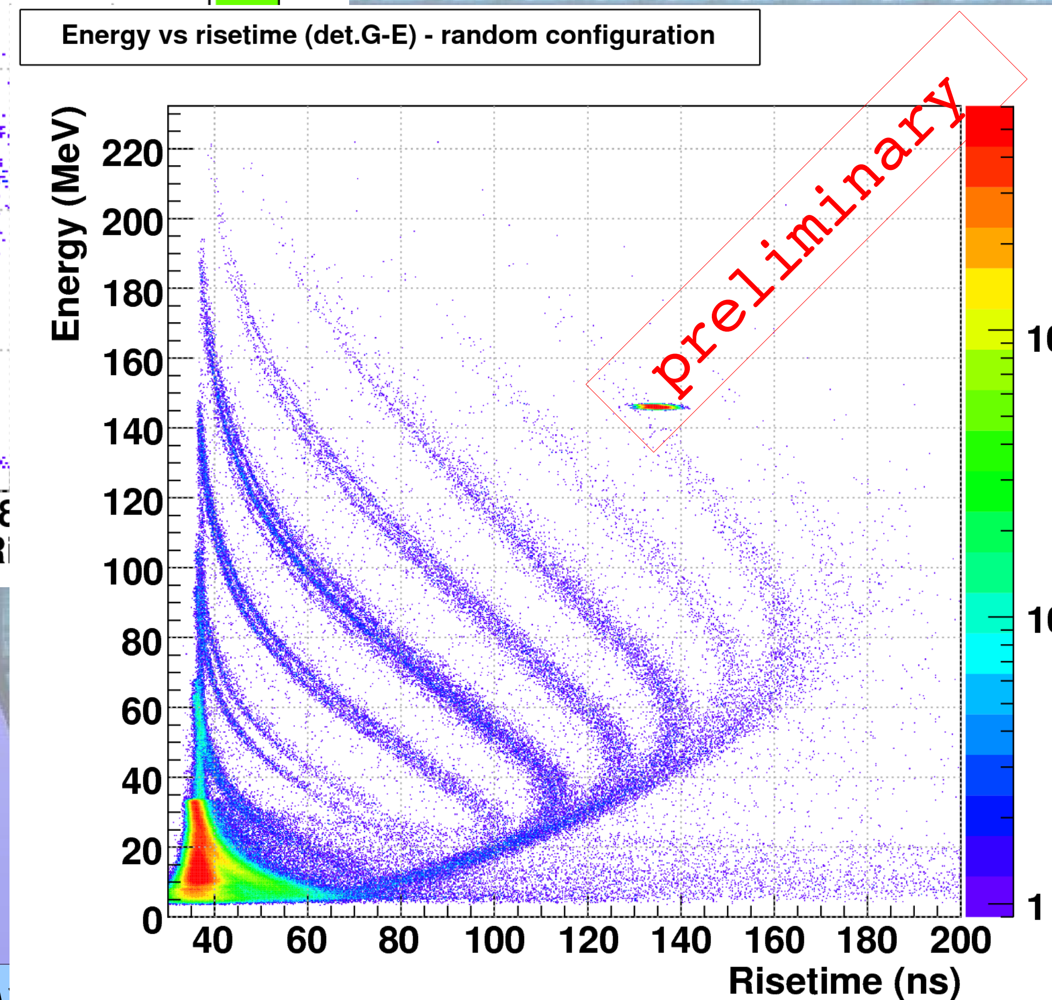
Homogeneity

300 μm, 9.4% non hom.

500 μm, 1.3% non-hom.

PSA in riv.73311



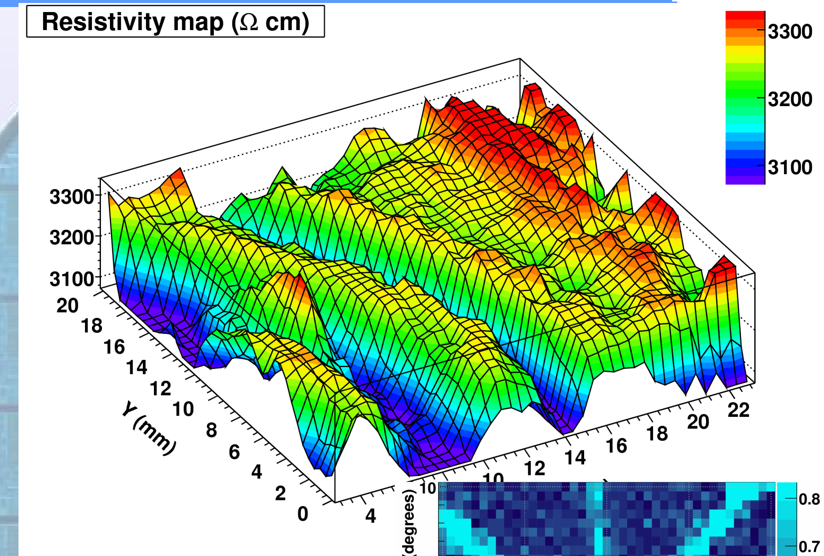


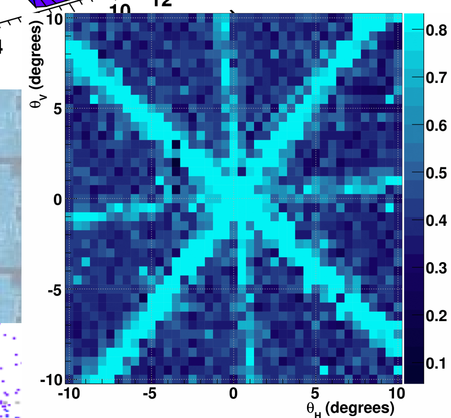
Impressive difference!

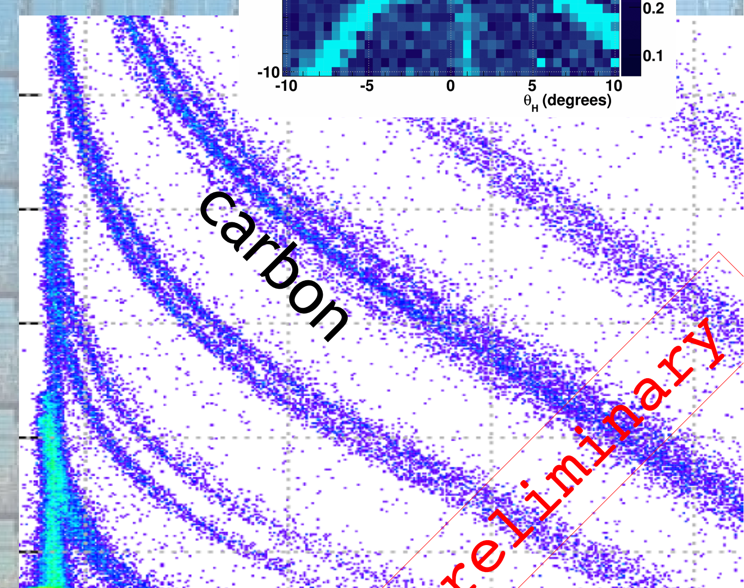
(both using non-channeling configuration,
using as similar as possible overbias)

Conclusions

- A non-destructive method for absolute resistivity measurement in Si detectors has been discussed
- Channeling-related effects are relevant (and must be avoided!!) for both "standard" (like DE-E) and PSA applications.
- Experimental tests have been carried out in order to study channeling and to provide recipes to avoid it
- FAZIA has performed several exp. tests
- Good homogeneity (few %) + no channeling = PSA like ==>







L.Bardelli et al, sub. to NIM A and in prep.