TREDI 2015

10th “Trento” Workshop on Advanced Silicon Radiation Detectors (3D and p-type)

17 - 19 February 2015

Identification of nuclear fragments using digitized signals from a partially depleted Si detector

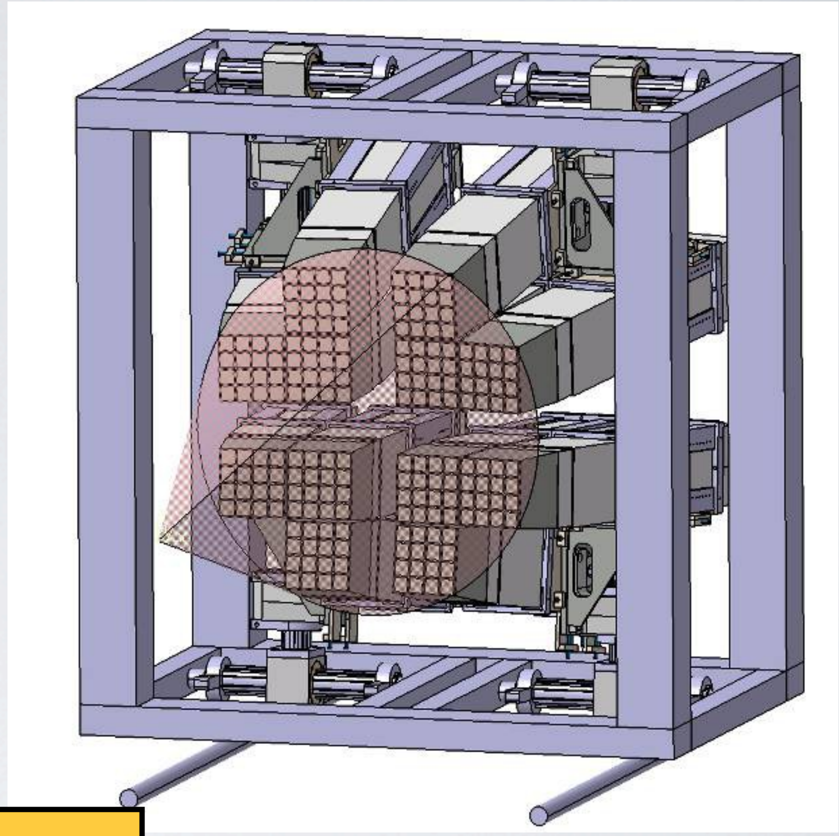
Giuseppe Pastore: *PhD student at University of Florence*
(for the FAZIA Collaboration)

FAZIA

This work was part of the FAZIA (Four-π A Z Identification Array) Collaboration R&D:
http://fazia2.in2p3.fr

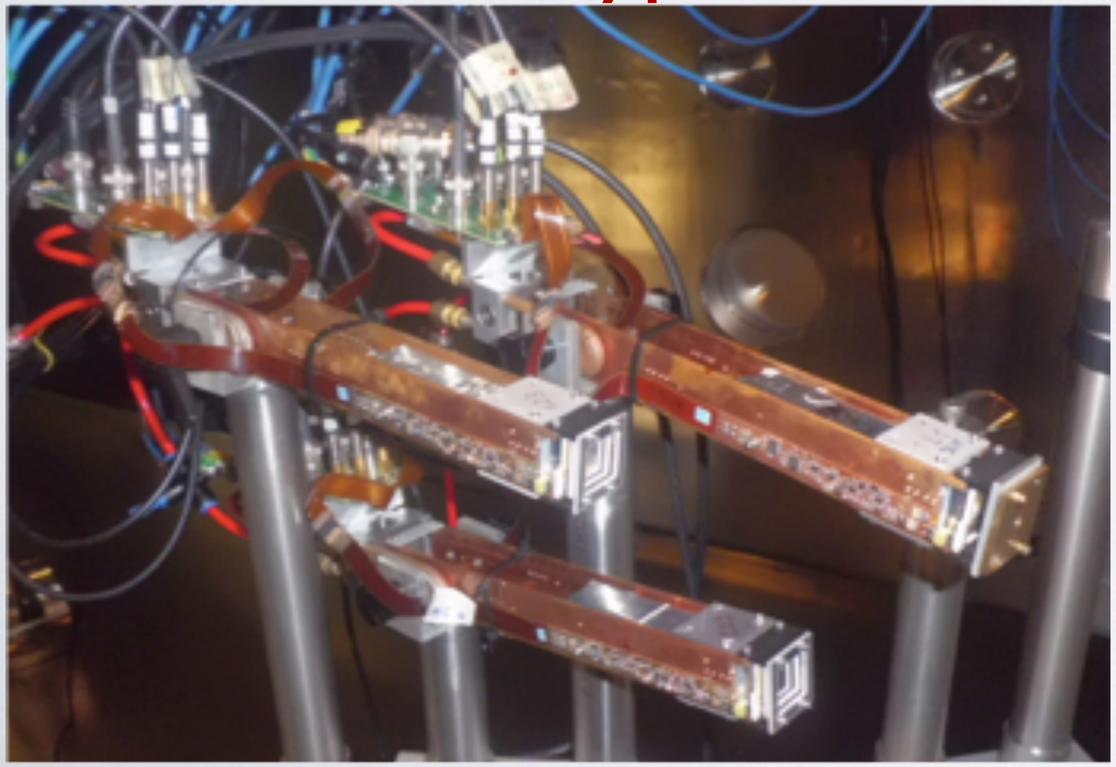
FAZIA Collaboration is dedicated to develop a state-of-the-art 4π multi-detector for detection and identification of fragments in heavy ion nuclear reactions

Demonstrator: 12 blocks

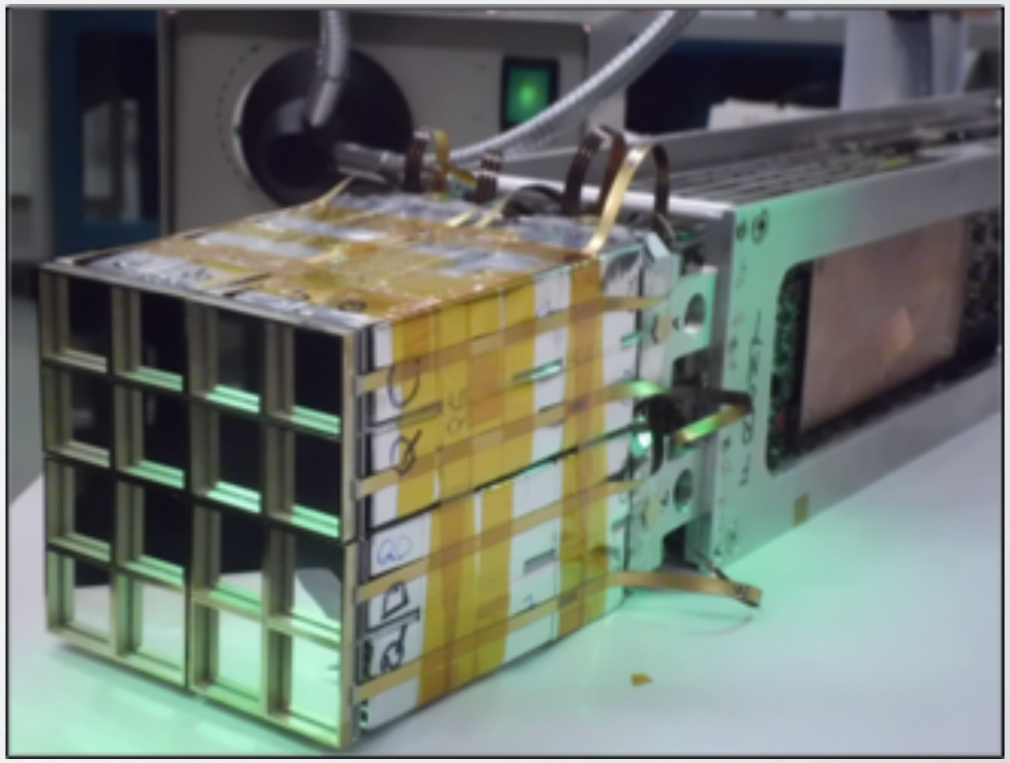


The FAZIA project in Europe: R&D phase⋆, R. Bougault et al, Eur. Phys. J. A 50, 47 (2014)

Prototypes



Final block of 16 telescopes

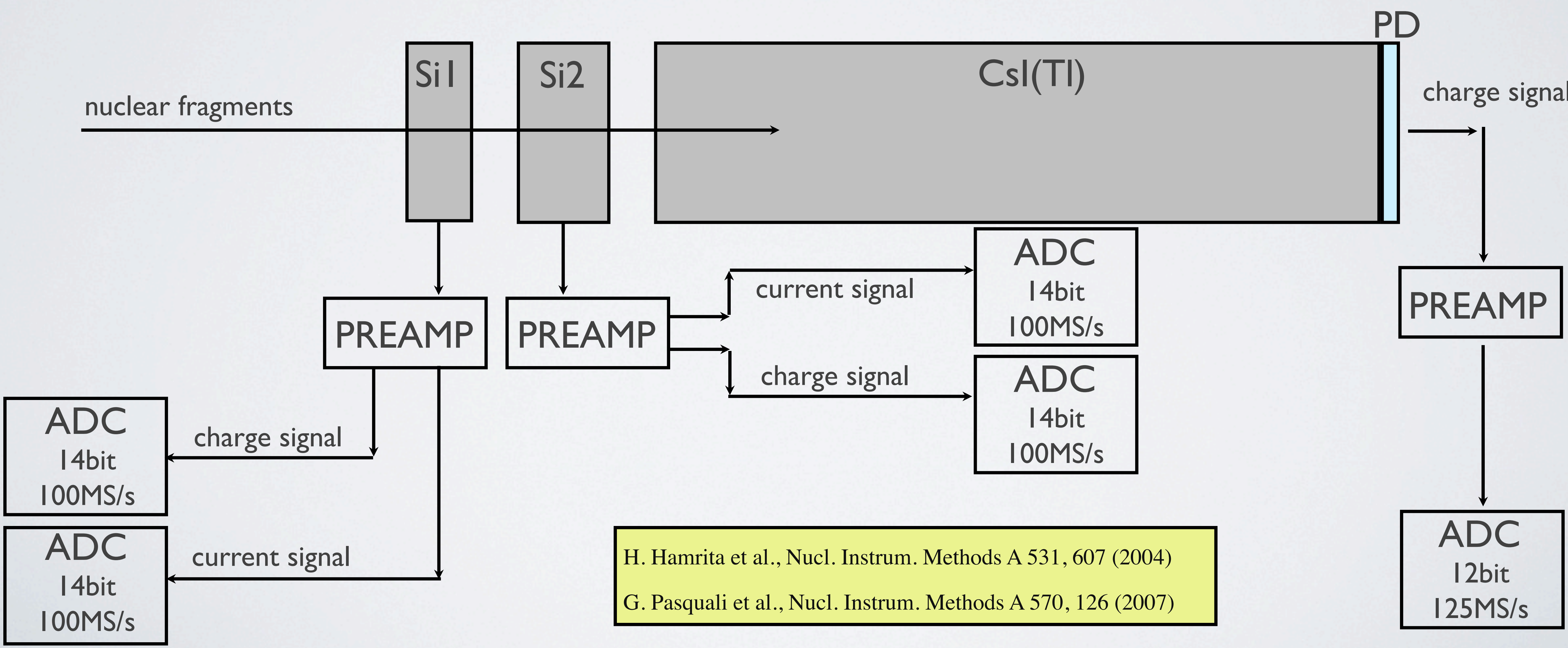


FAZIA telescope prototype

- First stage Si1: Si detector (20x20mm^2 active area, 300 μm thickness) by FBK;
- Second stage Si2: Si detector (20x20mm^2 active area, 500 μm thickness) by FBK;
- Third stage CsI: Scintillator detector of CsI(Tl) (20x20mm^2 active area, 10cm lenght).

We use PACI preamplifiers with separated charge and current outputs

Signals are digitized immediately after preamplifier stage



H. Hamrita et al., Nucl. Instrum. Methods A 531, 607 (2004)

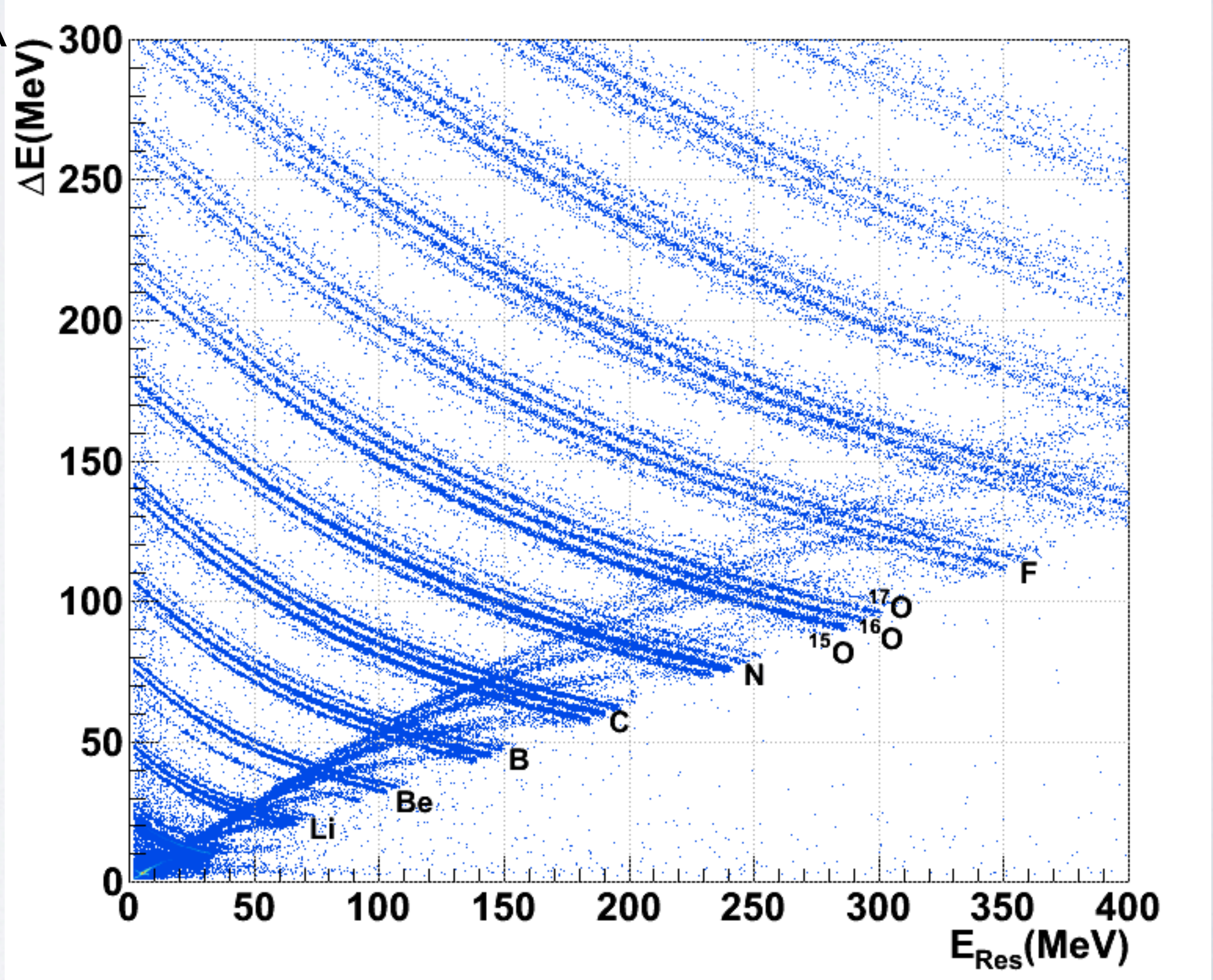
G. Pasquali et al., Nucl. Instrum. Methods A 570, 126 (2007)

ΔE-E technique

- Charge produced in Si $\longrightarrow$ energy information
- ΔE: energy lost in Si1
- E_{res}: energy lost in Si2
- Bethe-Block formula $\longrightarrow$ Stopping Power $\left|\frac{\mathrm{d}E}{\mathrm{d}x}(x)\right|$ depends on Z, A, E
- Correlating ΔE vs E_{Res} we identify Z and A

Only fragments punching through Si1 are identified

For good isotopic resolution (mainly depend on ΔE informations) we need good thickness uniformity and no channeling effect



PSA (Pulse Shape Analysis)

PSA technique will be used to identify fragments stopped inside Si1 (no ΔE-E identification)

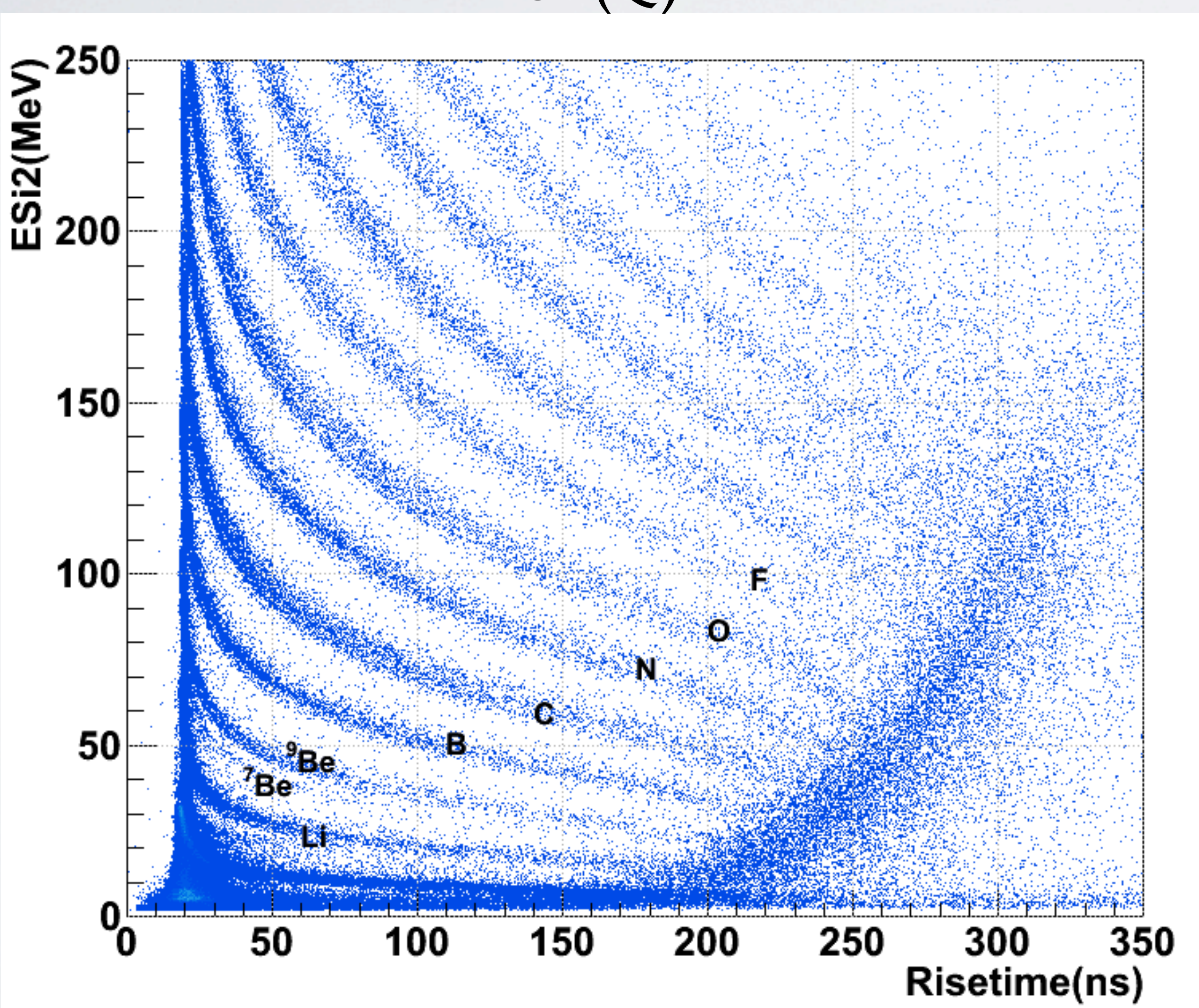
Signal shape depends on Z, A, E

Differences in shape enhanced for rear (ohmic side) injection

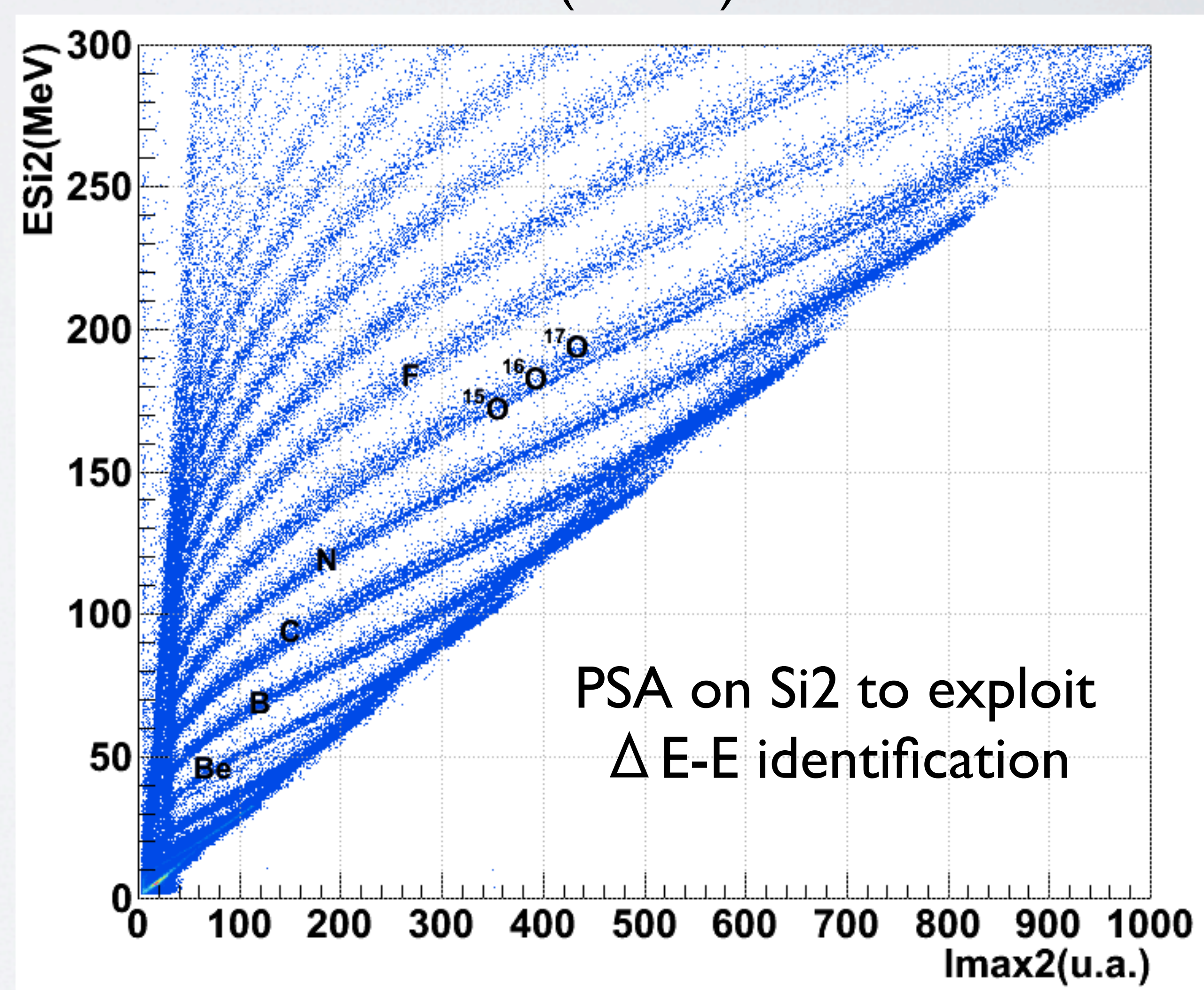
Identification from the following correlations:

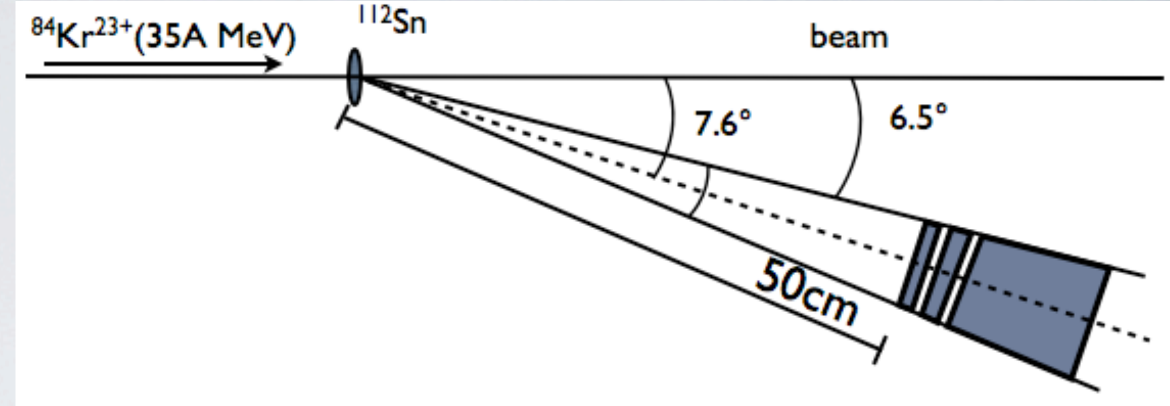
1) E vs Risetime of charge signal OR 2) E vs Maximum of current signal

PSA(Q)



PSA(IMAX)



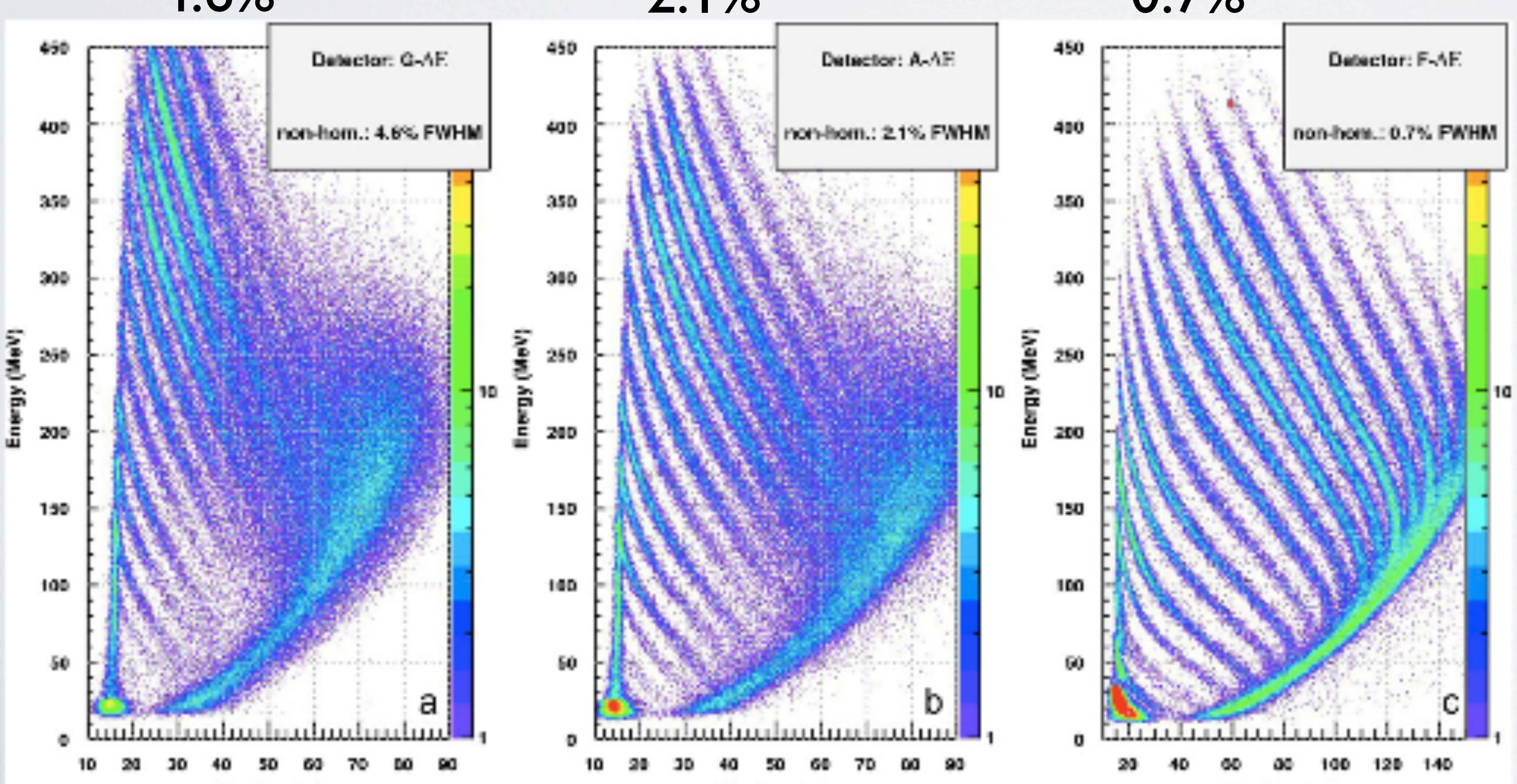


Experimental setup

- Beam of $^{84}Kr^{23+}$ on a target of ^{112}Sn at energy of 35A MeV
- Si detectors rear mounted
- Wafer cut at ~8° respect to <100> direction to avoid channeling
- Doping uniformity of Si detectors was ~3% FWHM (nTD doping)

For isotopic identification about 1% uniformity FWHM needed

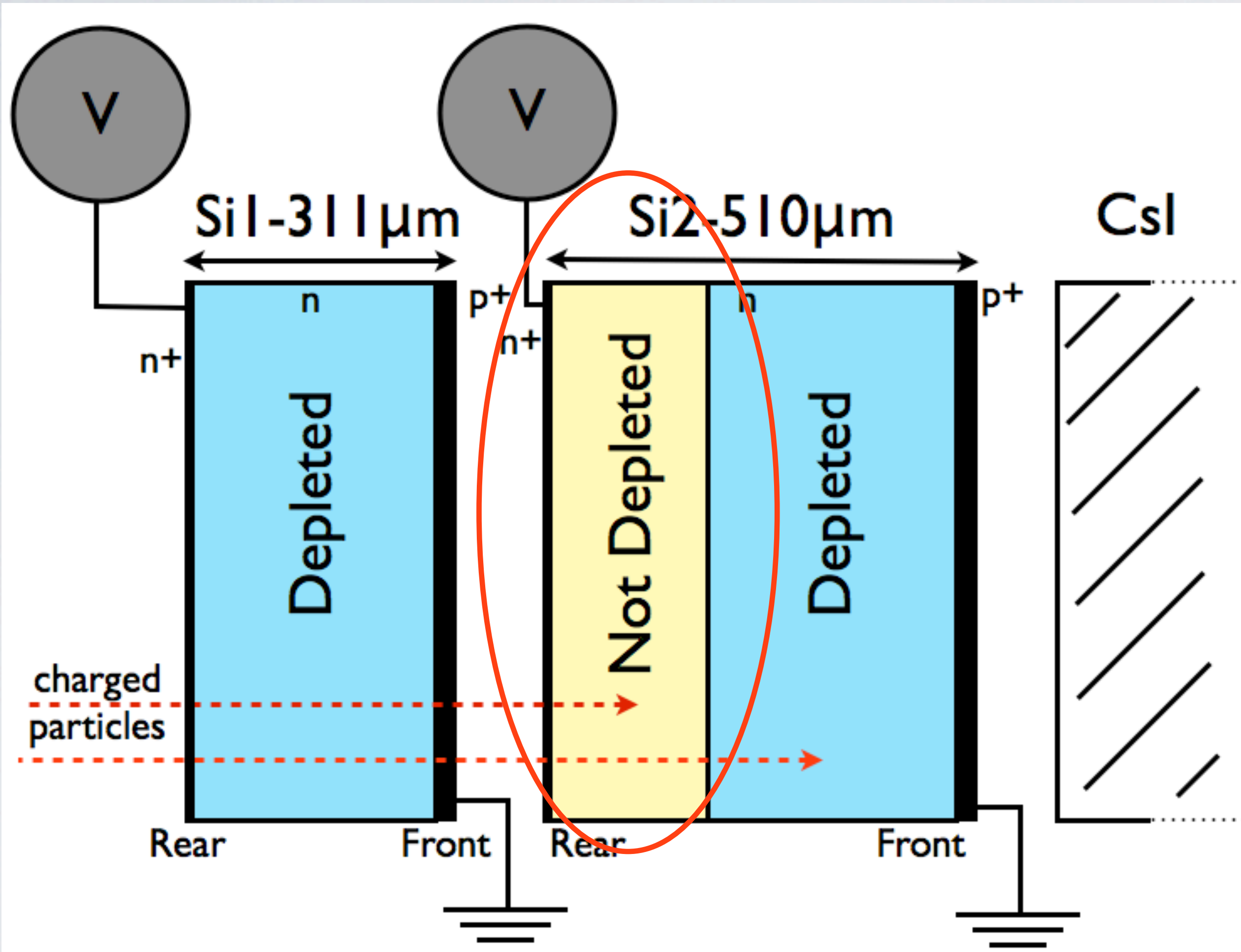
4.6% 2.1% 0.7%



N. Le Neindre *et al*, Nucl. Instrum. Methods A 701, 145 (2013)

L. Bardelli *et al*, Nucl. Instrum. Methods A 654, 272 (2011)

Partially depleted detector



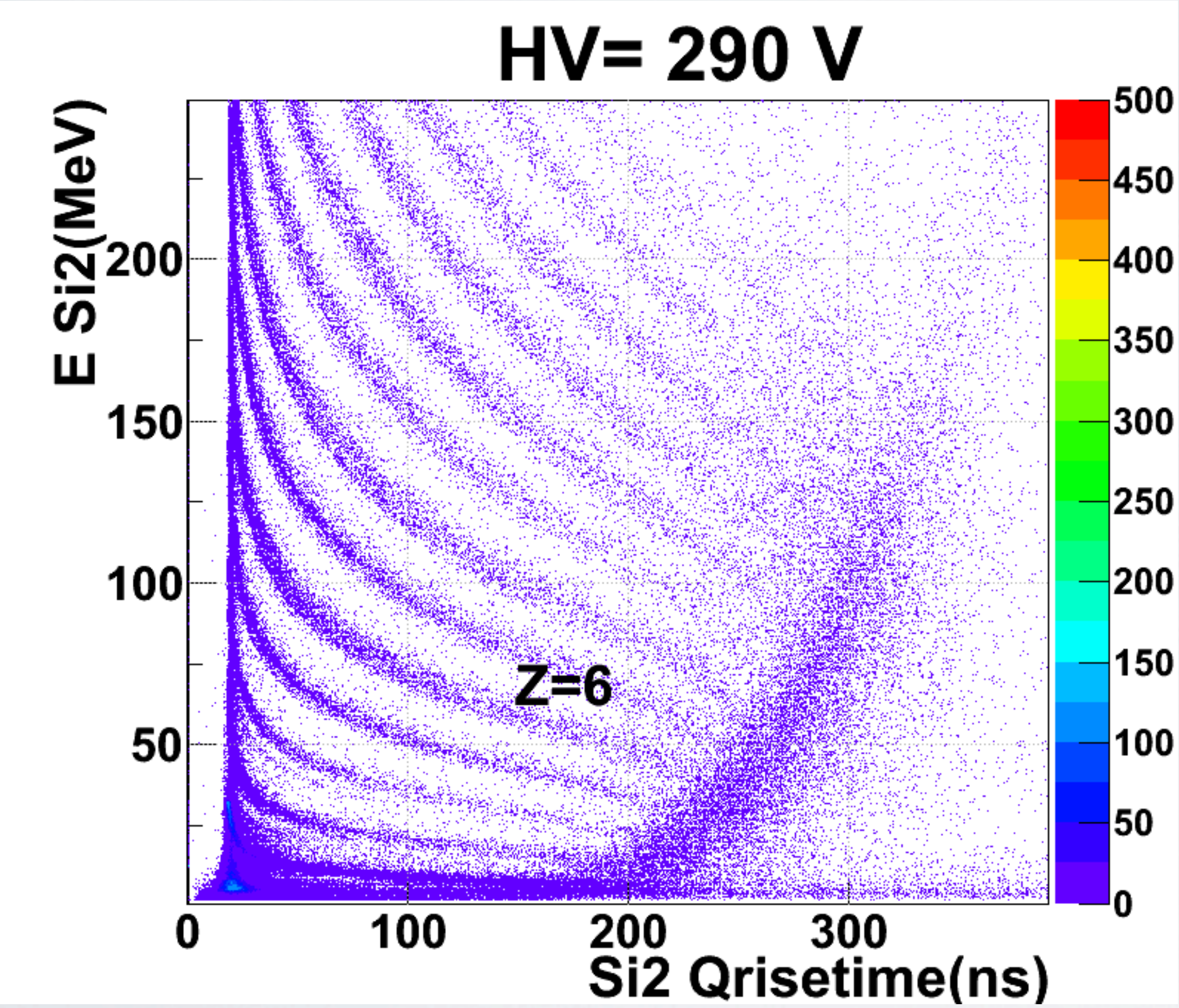
- Depletion Voltage Si1 = 140V
- Thickness Si1 = 311 μm
- Depletion Voltage Si2 = 290V
- Thickness Si2 = 510 μm

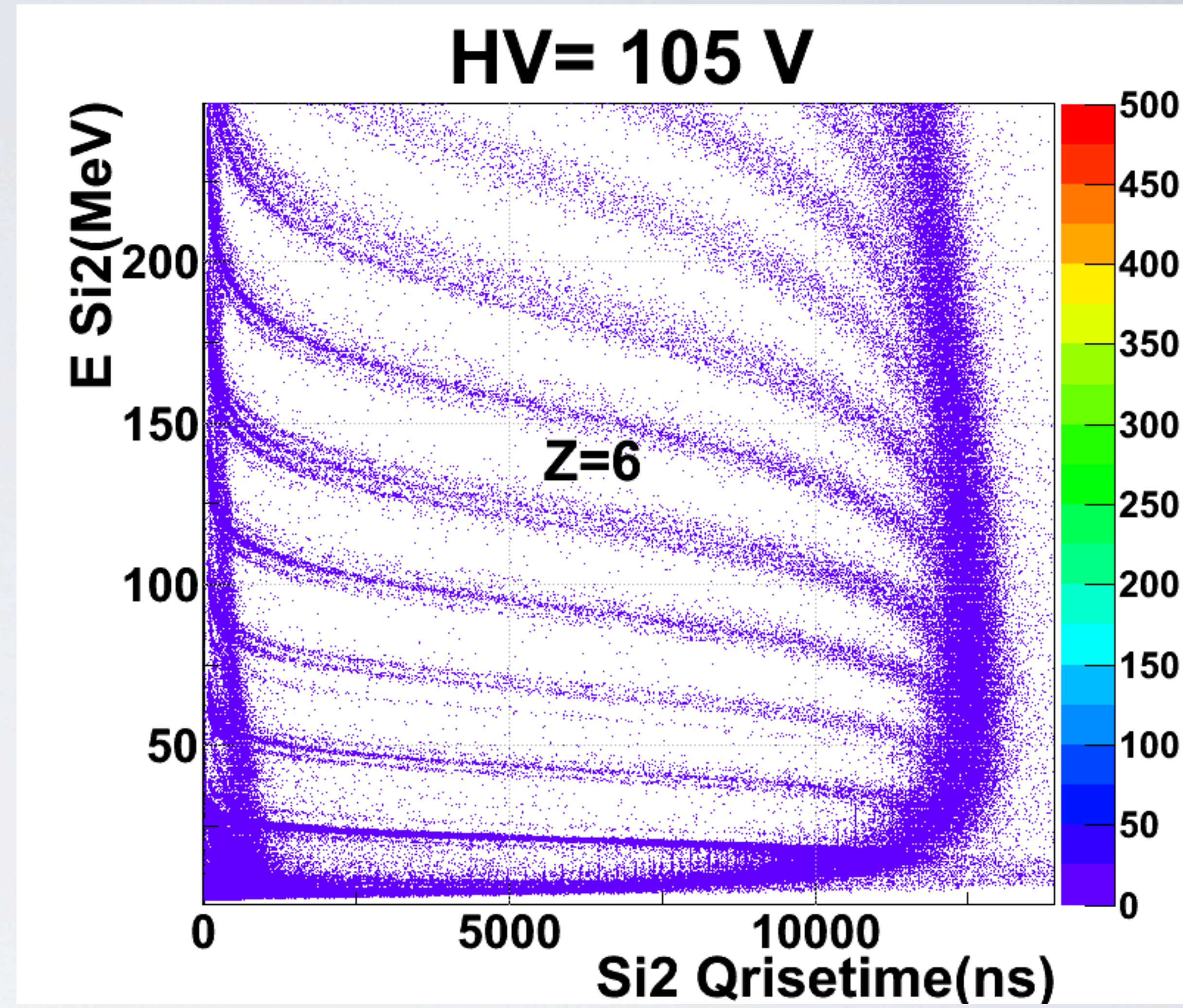
Voltage applied on Si1 kept constant slightly overdepletion.
Data acquired for different voltage applied on Si2

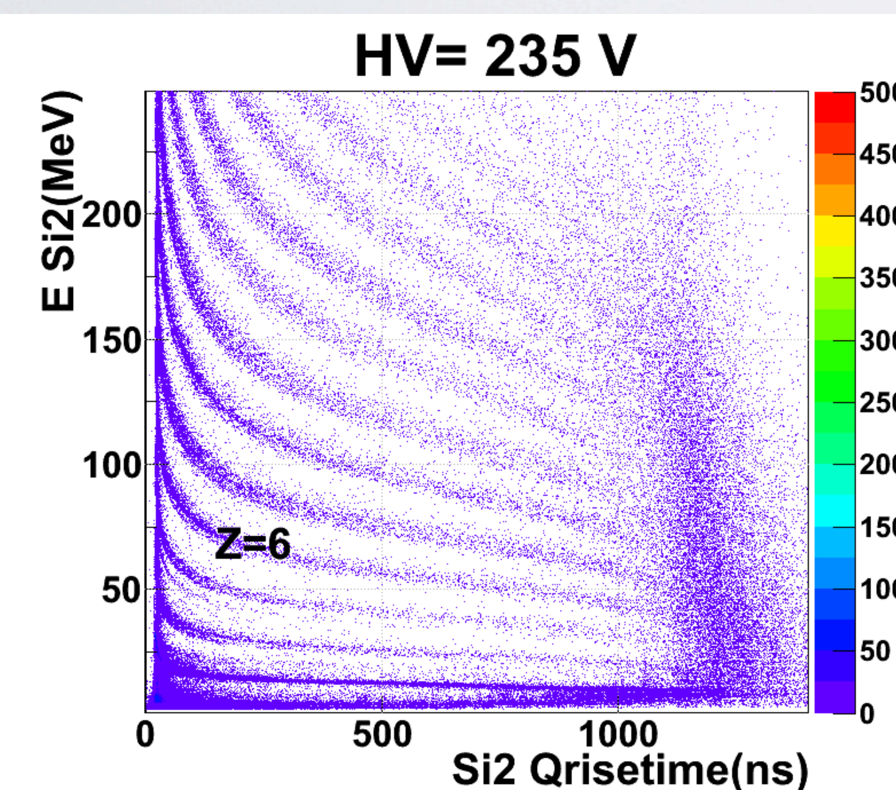
Almost 40% of detector thickness not depleted!

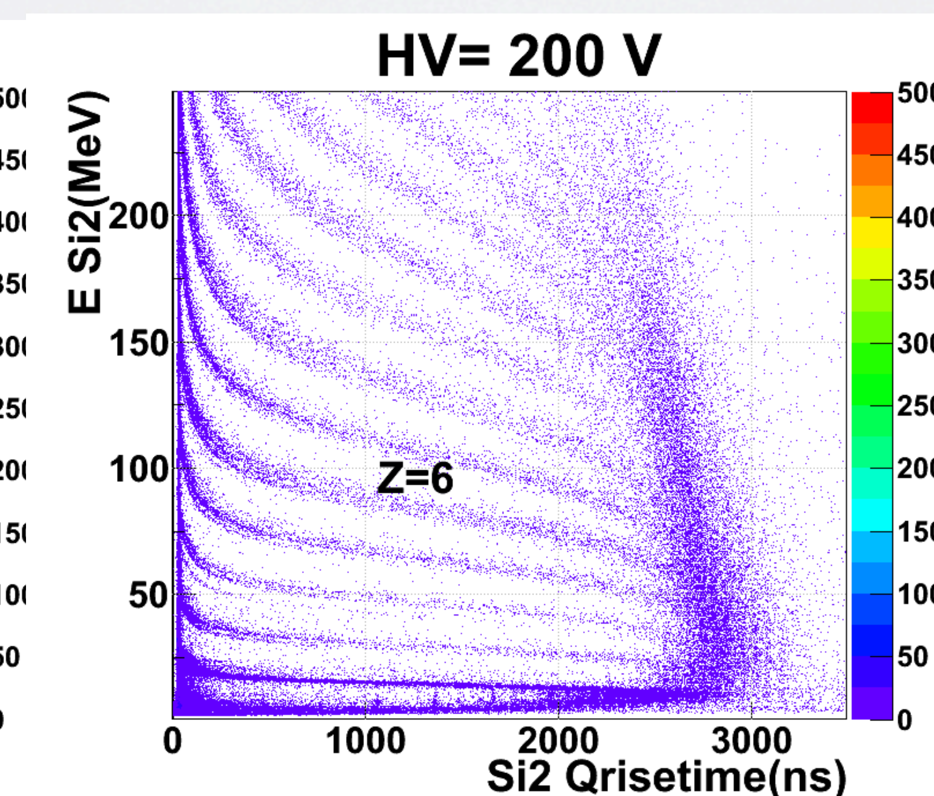
Voltage applied on Si2 (V)	Depletion depth (μm)	Not depleted depth (μm)	Not depleted depth (%)
105 V	310	200	40
130 V	340	170	30
200 V	420	90	20
235 V	460	50	10
290 V	510	0	0

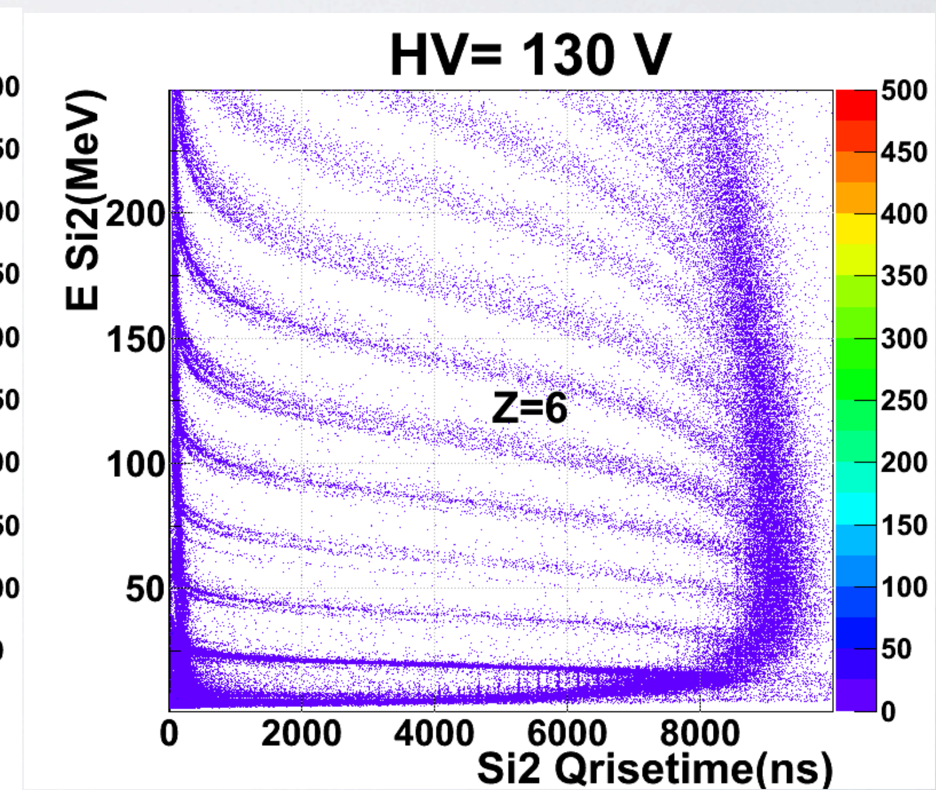
PSA(Q)


HV= 290 V
E Si2(MeV)
Si2 Qrisetime(ns)
Z=6
0
100
200
300
50
150
250
350
400
450
500

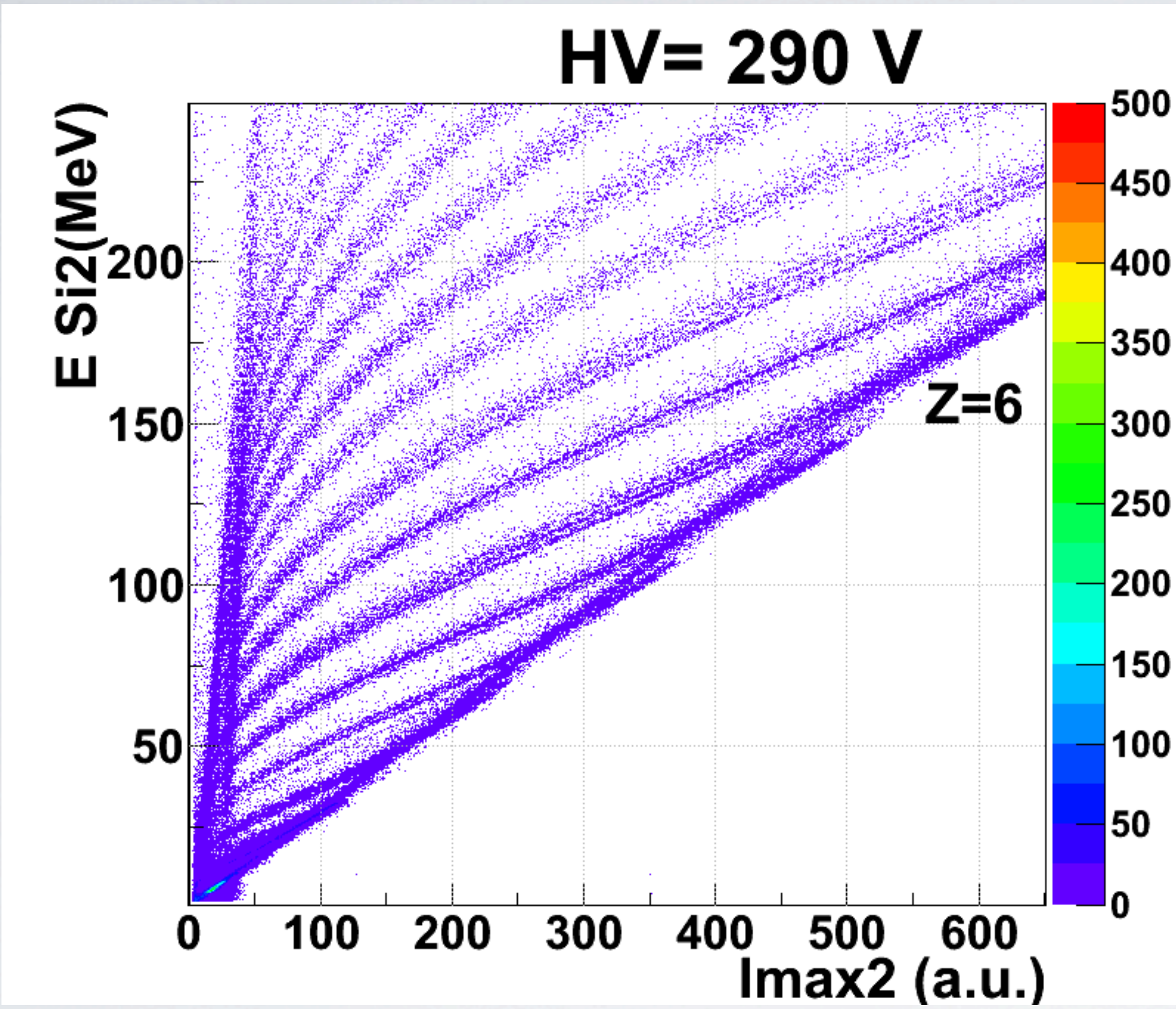

HV= 105 V
E Si2(MeV)
Si2 Qrisetime(ns)
Z=6
0
5000
10000
50
100
150
200
250
300
350
400
450
500

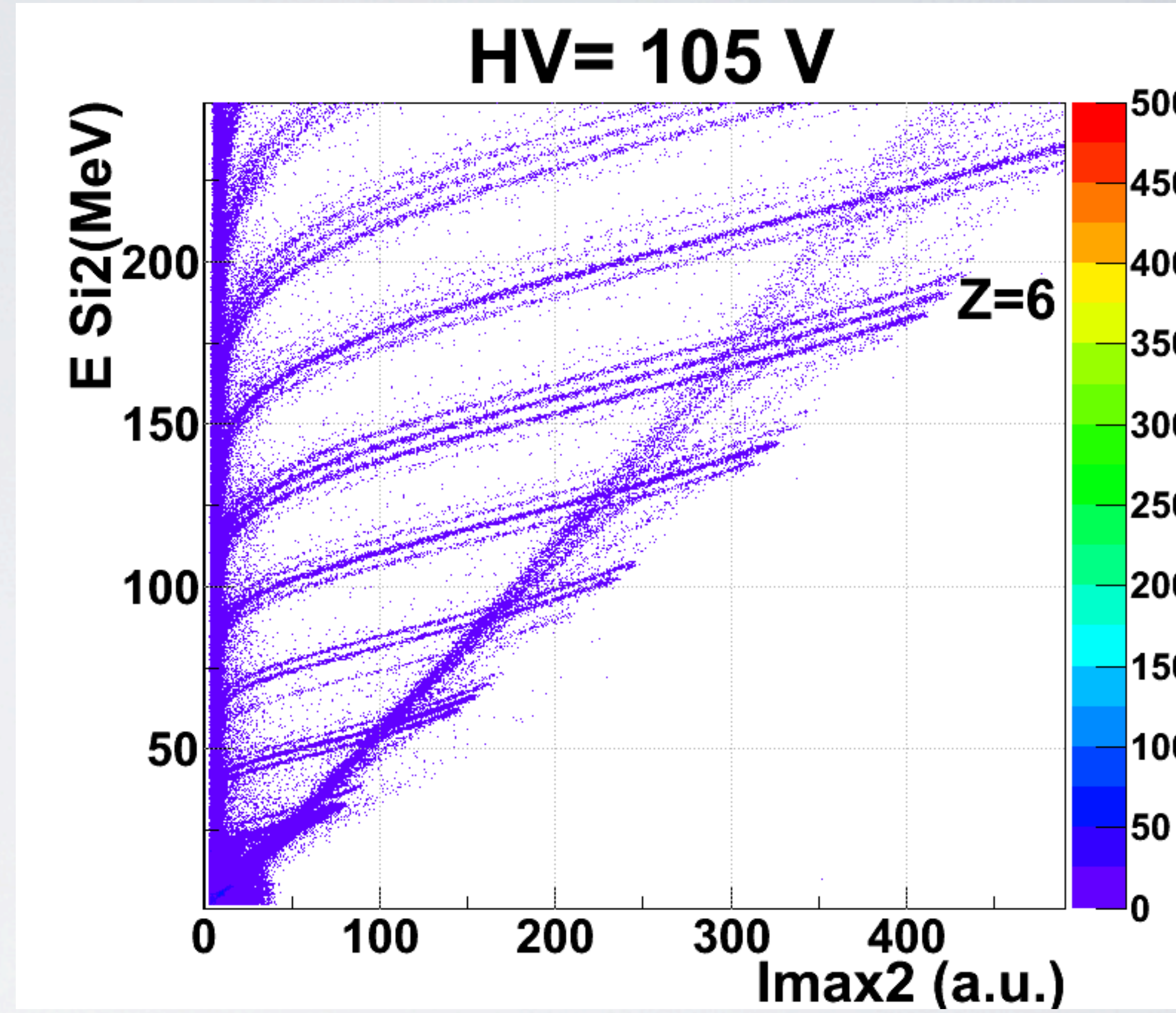

HV= 235 V
E Si2(MeV)
Si2 Qrisetime(ns)
Z=6
0
500
1000
50
100
150
200

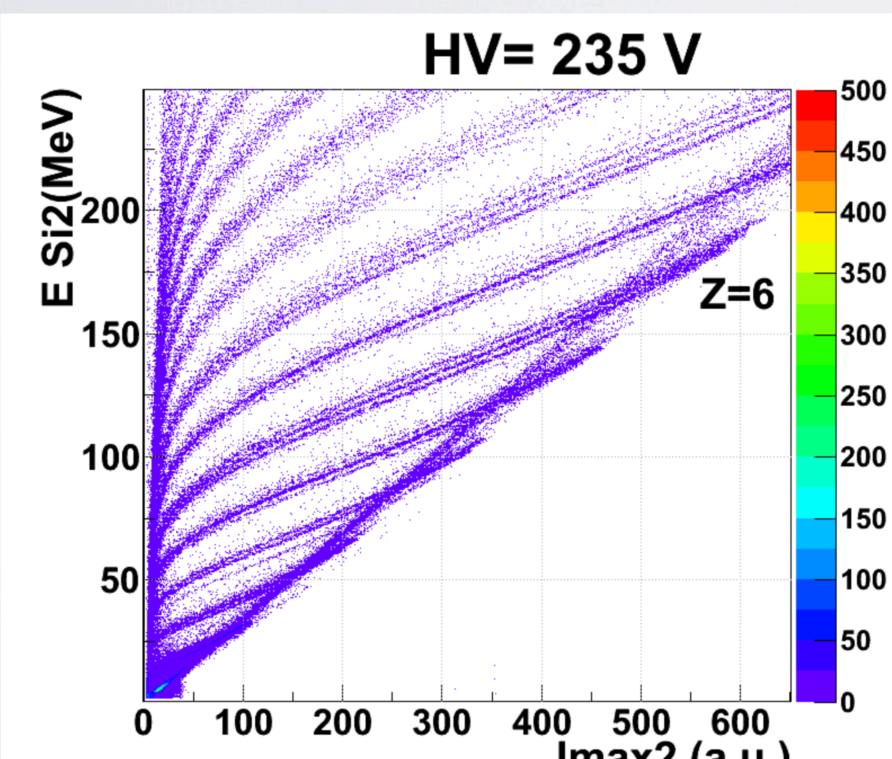

HV= 200 V
E Si2(MeV)
Si2 Qrisetime(ns)
Z=6
0
1000
2000
3000
50
100
150
200
250
300
350
400
450
500

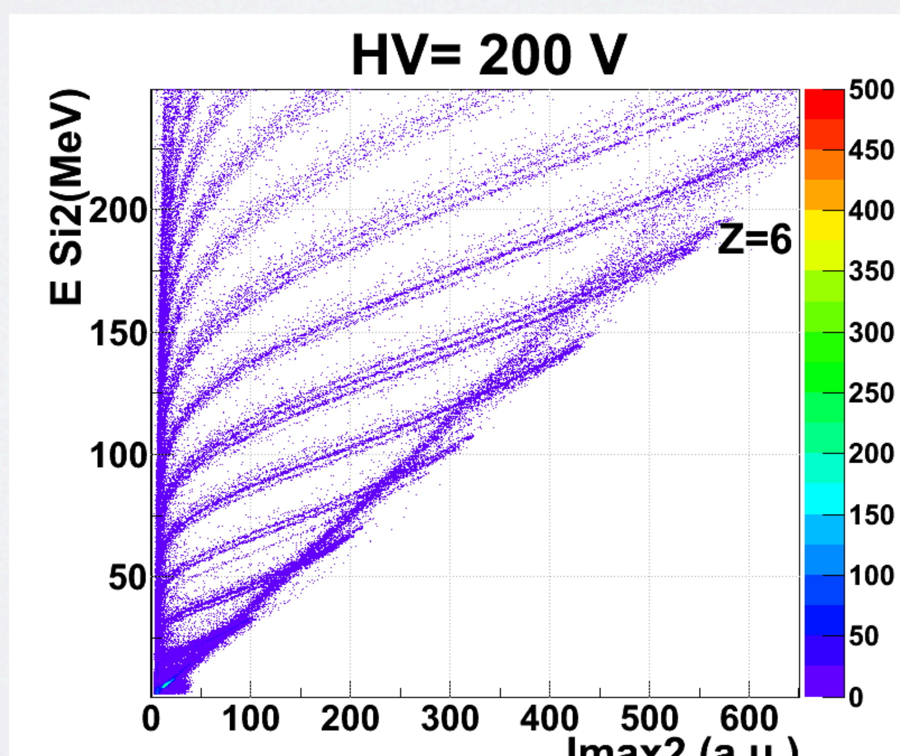

HV= 130 V
E Si2(MeV)
Si2 Qrisetime(ns)
Z=6
0
2000
4000
6000
8000
50
100
150
200
250
300
350
400
450
500

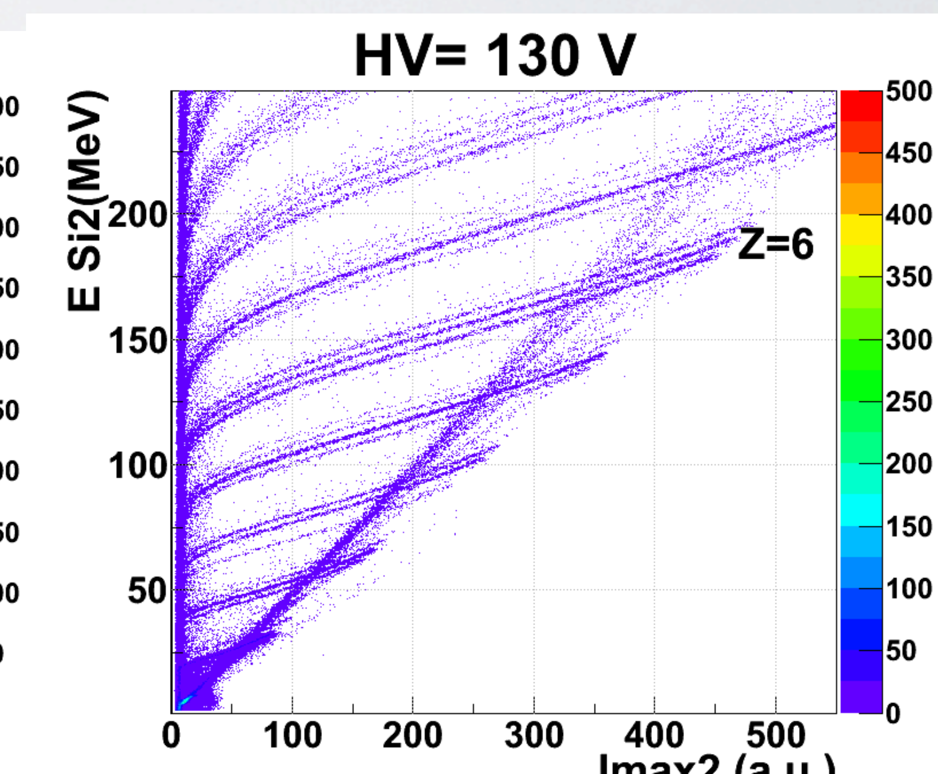
PSA(IMAX)


HV= 290 V
E Si2(MeV)
Imax2 (a.u.)
Z=6


HV= 105 V
E Si2(MeV)
Imax2 (a.u.)
Z=6


HV= 235 V
E Si2(MeV)
Imax2 (a.u.)
Z=6

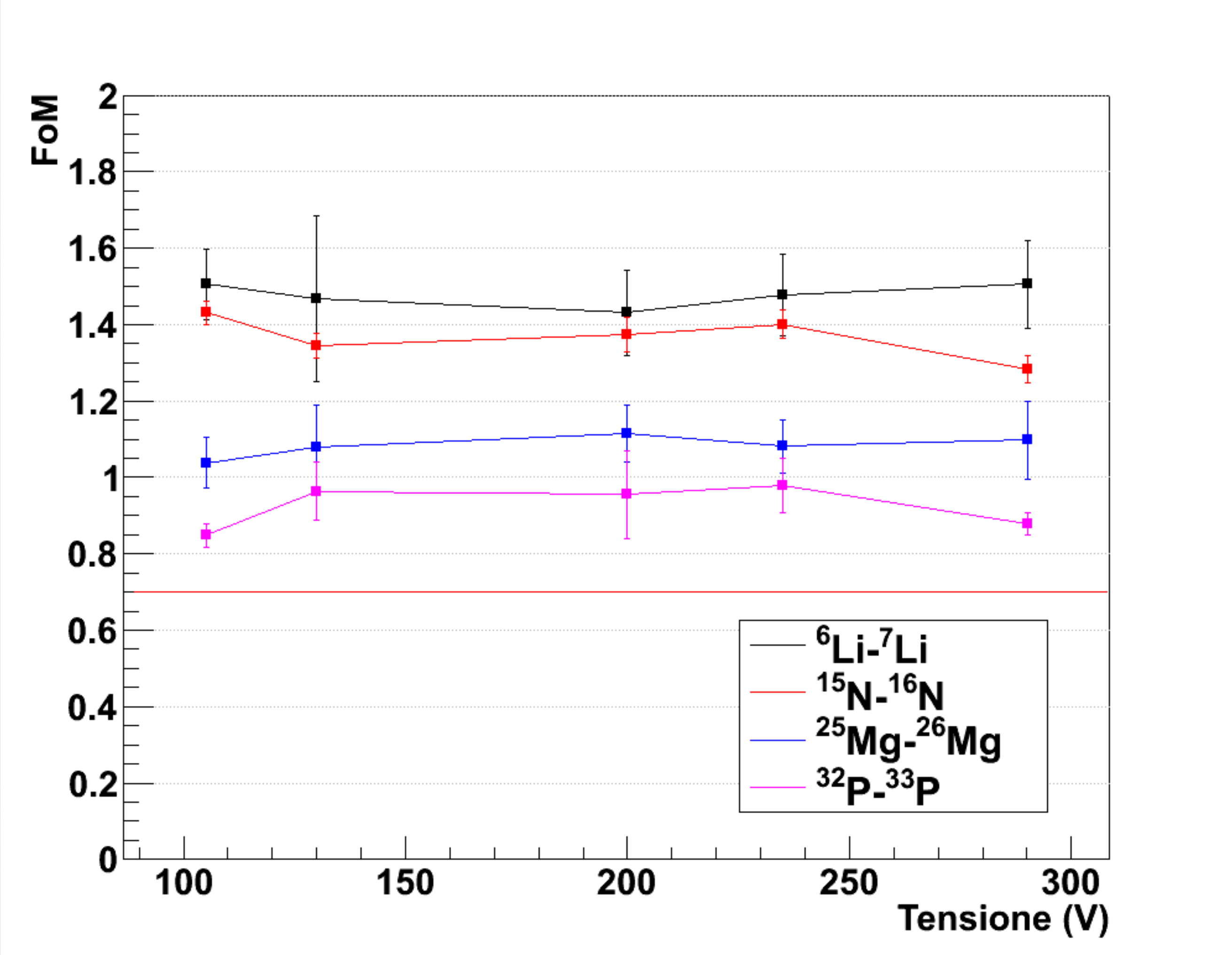

HV= 200 V
E Si2(MeV)
Imax2 (a.u.)
Z=6

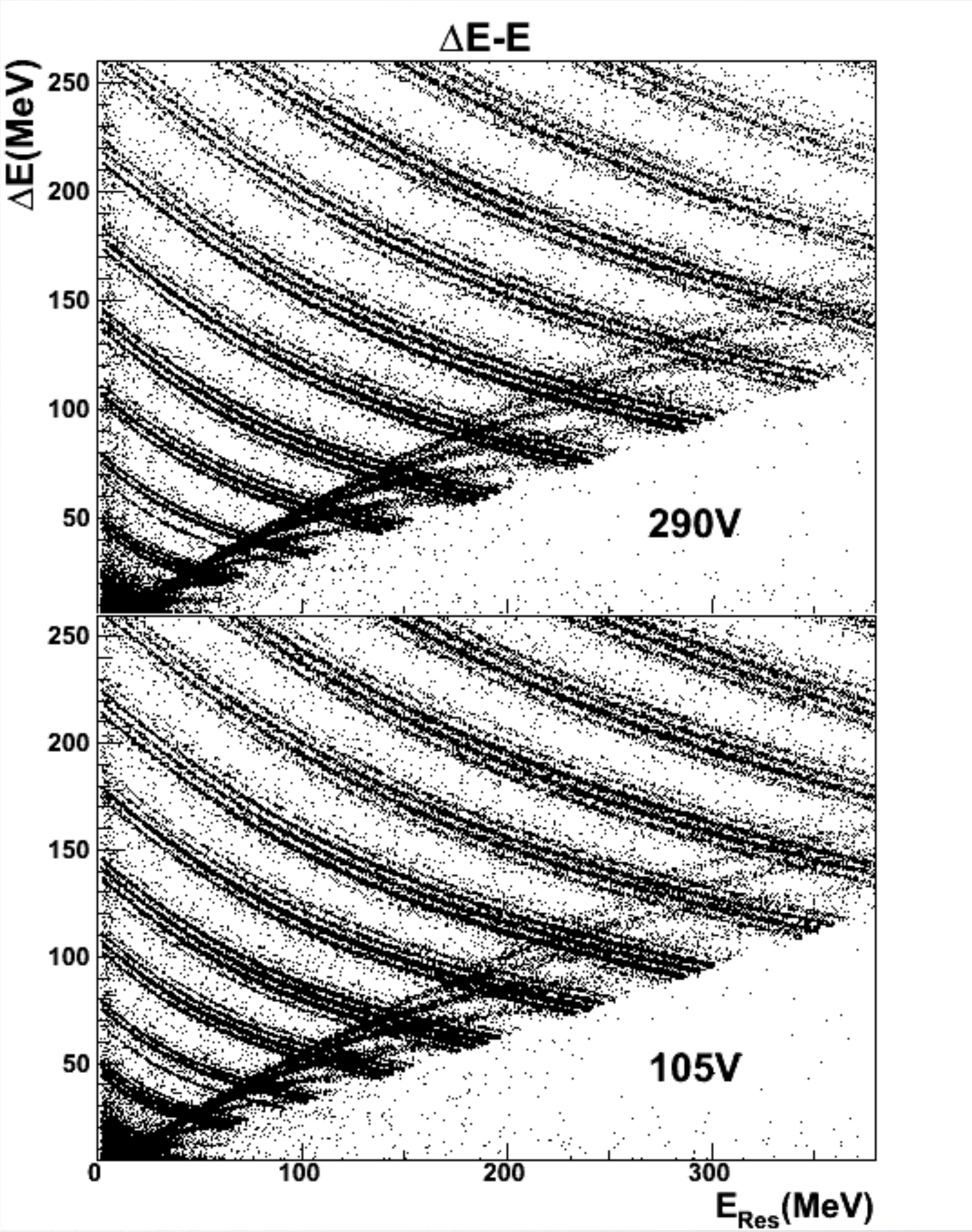

HV= 130 V
E Si2(MeV)
Imax2 (a.u.)
Z=6

Δ E-E identification

Do Δ E-E plot chnge with underbias?

Isotopic resolution doesn't change by underbiasing the detector even at 105 V





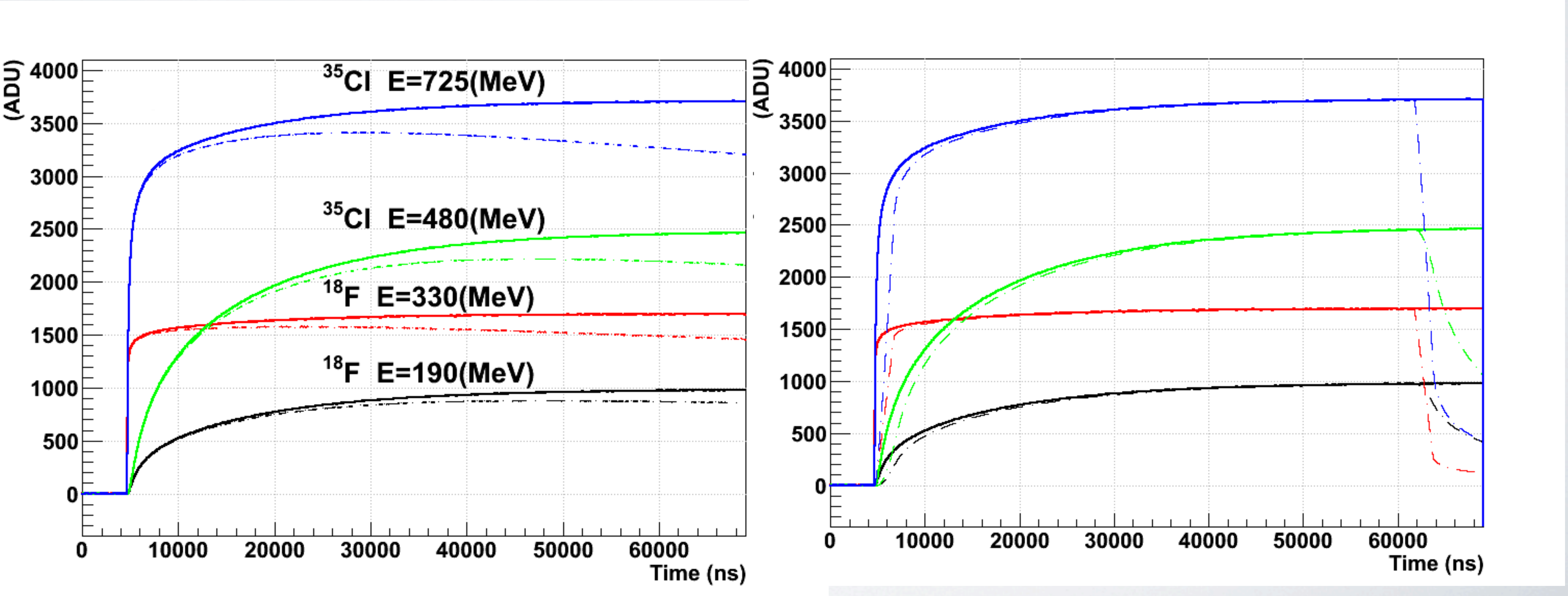
Signals shape

Underbias + rear injection = signals very long (signals with length ~70 μ s are acquired)

We need pole-zero cancellation to correct ballistic deficit at preamplifier output

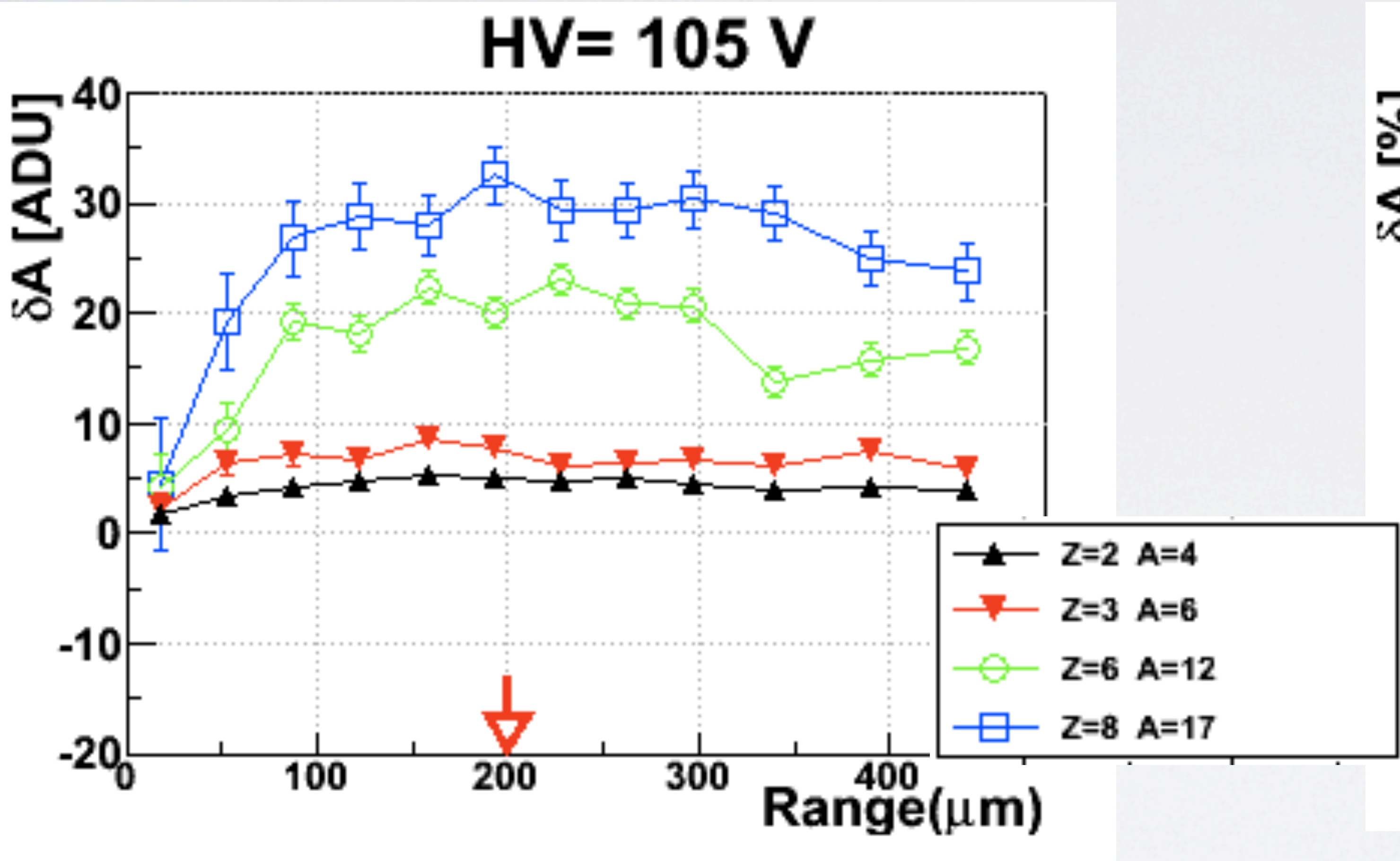
We use a very long trapezoidal shaper (>50 μ s of flat-top)

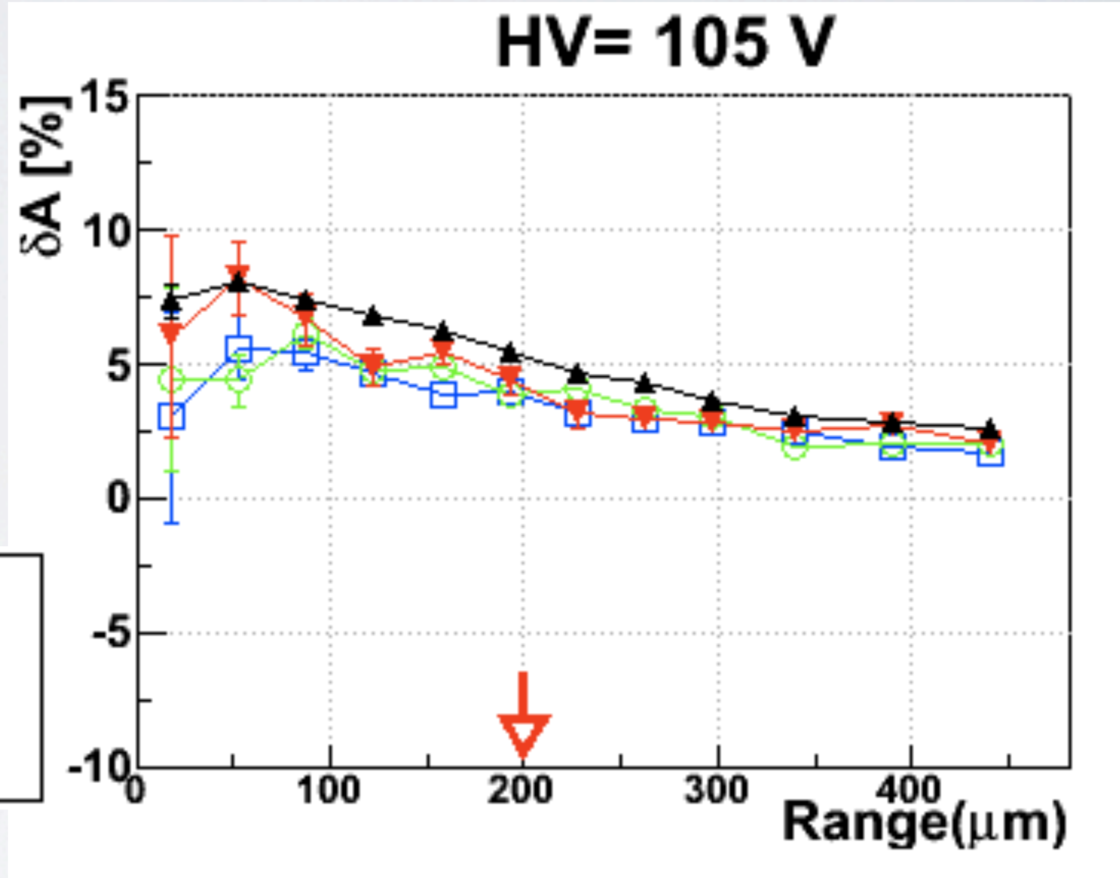
Big differences in risetime for isotopes stopped in not depleted region with respect to that stopped in the depleted area



Charge collection efficiency

- Using ΔE-E we identify Z and A of fragments
- We use charge collection efficiency at 290V (full depletion) as reference
- From a given Z, A and ΔE we obtain fragment range in Si2
- For a given Z,A we compare signal amplitude of partial depleted detector to that at 290V





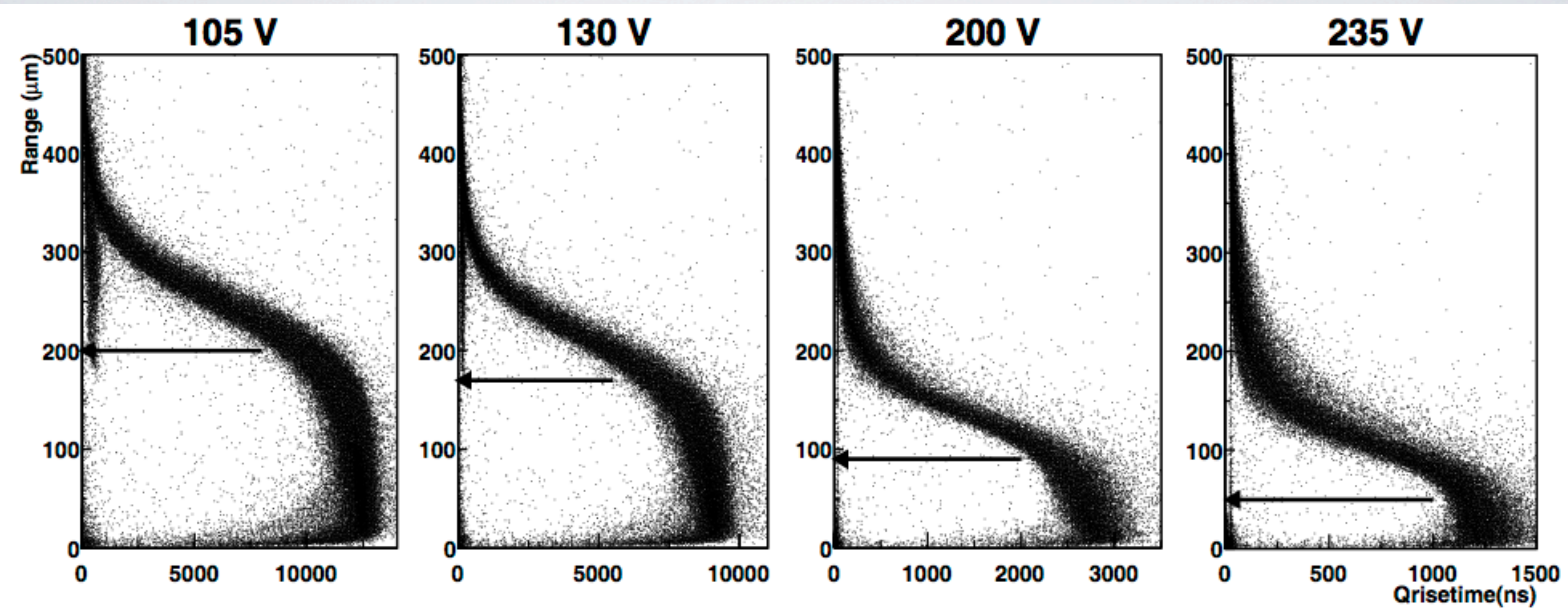
- Absolute amplitude differences <u>increase</u> with range
- Relative amplitude differences <u>decrease</u> with range
- Relative differences for particles range equal to detector thickness are less than 2%

Charge collection from undepleted region unexpectedly high

Funneling?

The “funneling” effect:

- occurs along the high ionized track when track extend in depleted region
- It seems due to an extention of the electric field into the undepleted region along the track
- It could produce a faster charge collection



All fragments have an almost constant risetime in the undepleted region

Risetime rapidly decreases as soon as fragments get close to the depleted region

Summary

Goals of this work:

- To study nuclear fragment identification both using ΔE-E and PSA technique with partially depleted silicon detectors

- To study charge collection efficiency in partially depletion

Results:

- Isotopic identification improves with underbias (identification not even possible at full depletion due to doping non uniformity of about 3%)

- Performance of ΔE-E technique doesn't change

- Collection charge efficiency is only few % less than at full depletion

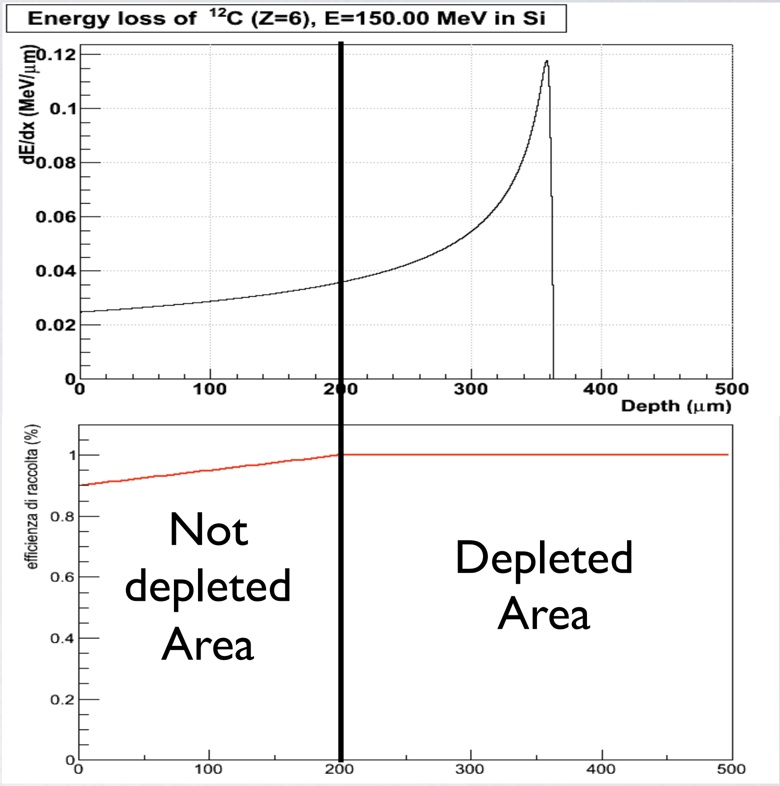
- The use of this technique require to acquire and process very long signals (~70μs with a shaping time~50μs) → digitization is mandatory

G. Pasquali, G.Pastore *et al,* Eur. Phys. J. A (2014) 50: 86

Add Material

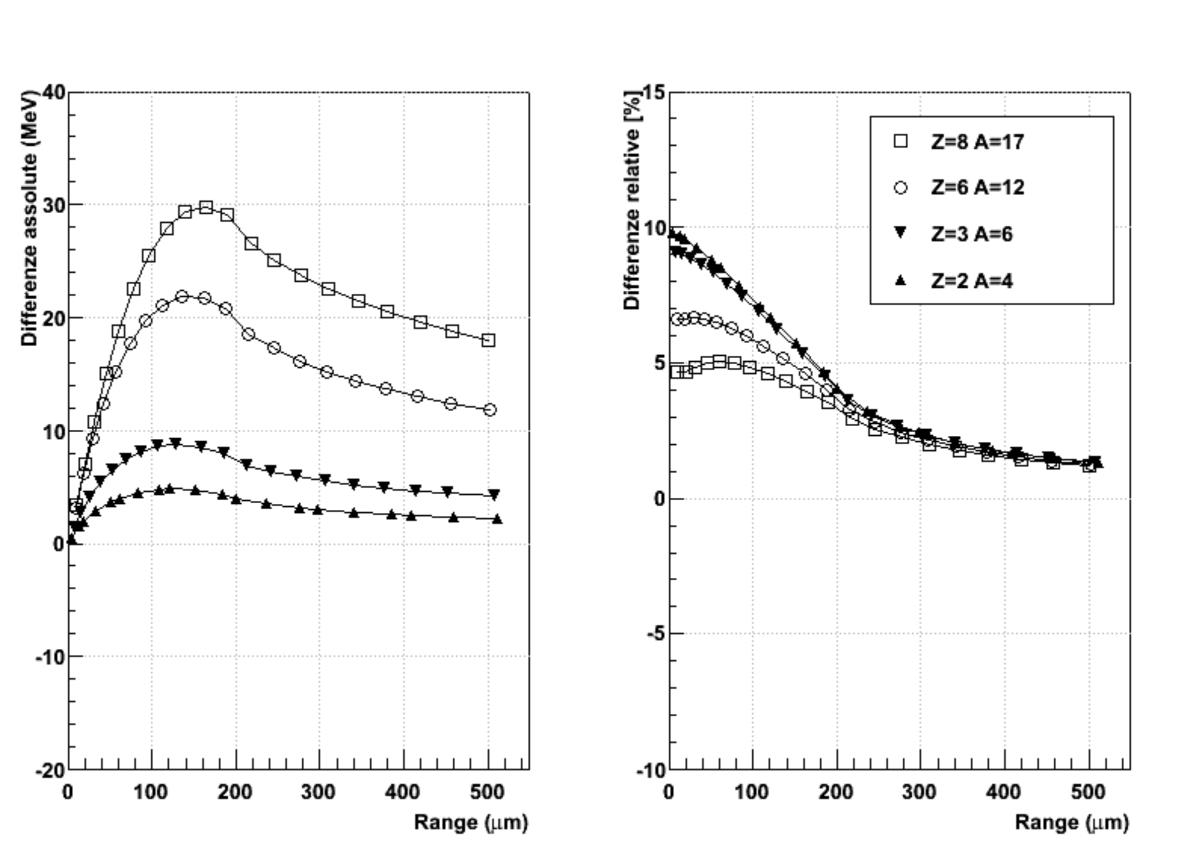
Fenomenological model

- We integer the Bragg curve of a particular isotope to obtain the energy loss inside detector
- Divide the detector into 2 zone: the depleted one with 100% of efficiency, the not depleted one with a linear behaviour
- We introduce a linear dependence with concentration of charge carrier to enhance the dependence of the isotope
- We could change the starting value of the efficiency at 0 μm



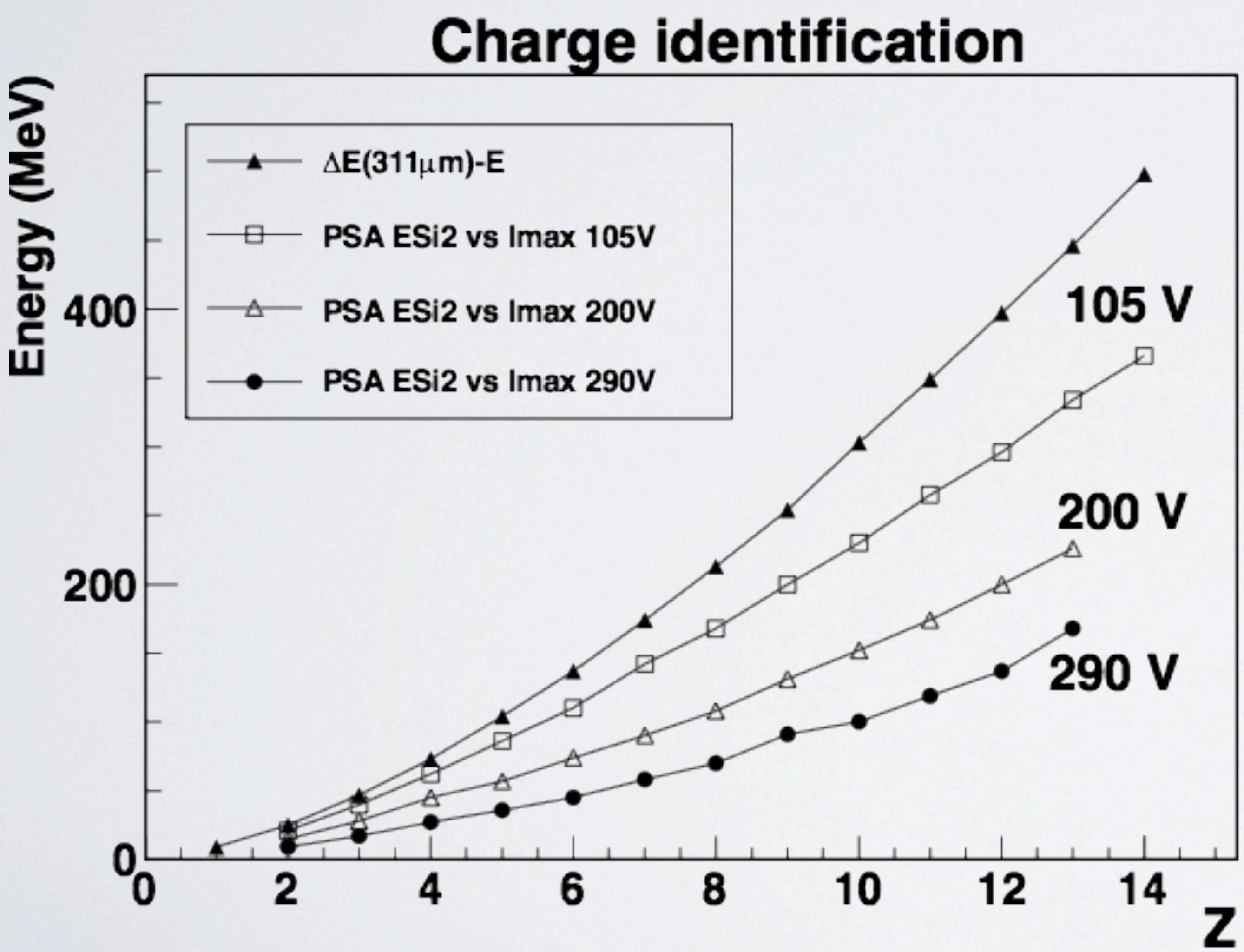
$$\eta(x) = \begin{cases} \eta(0) + (1-\eta(0))\dfrac{x}{d} + \alpha \left| \dfrac{dE}{dx}(x) \right| \dfrac{d-x}{d}, & \text{if } x < d \\ 1, & \text{if } x \geq d \end{cases}$$

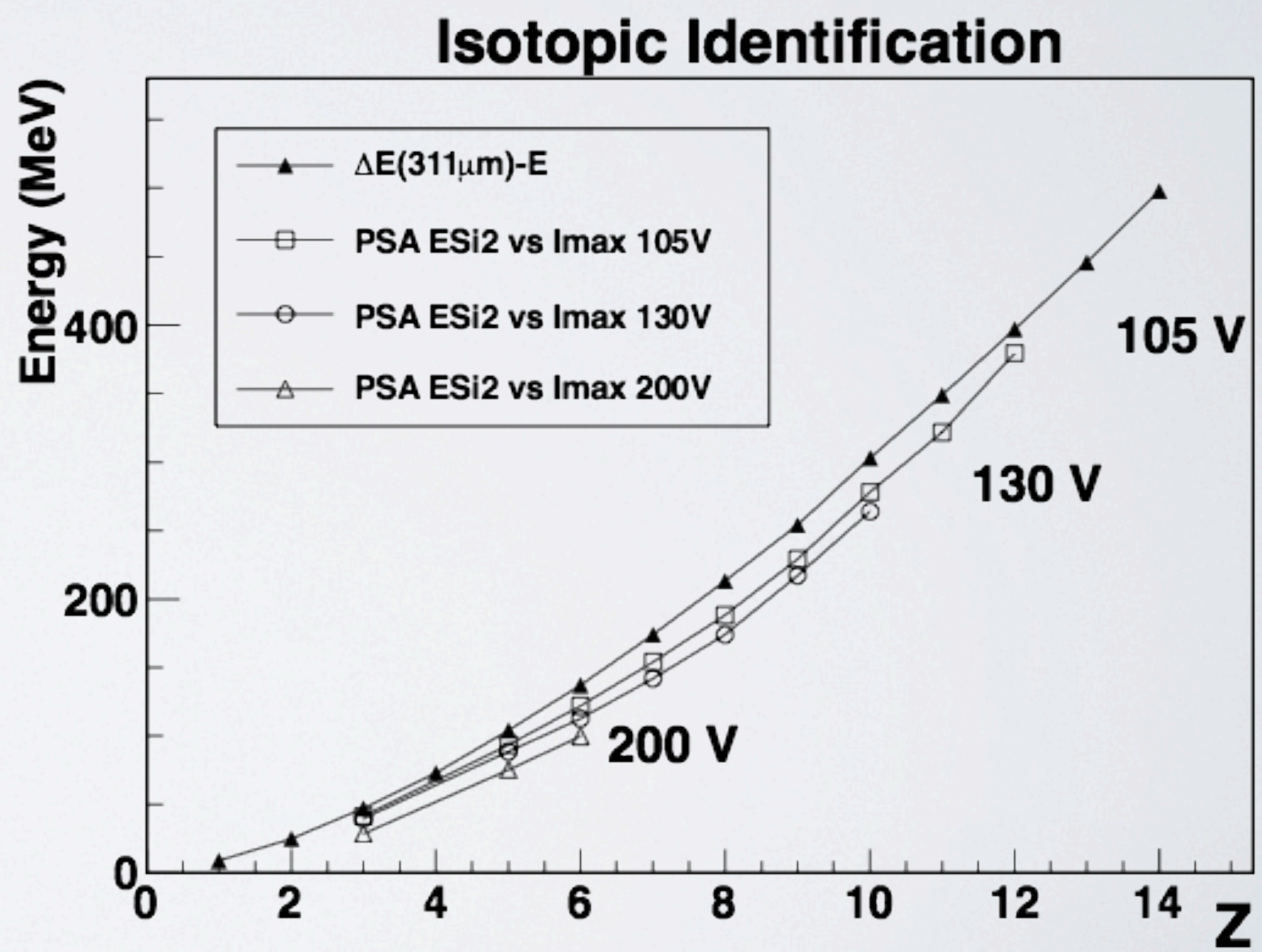
Starting value of efficiency = 90%!



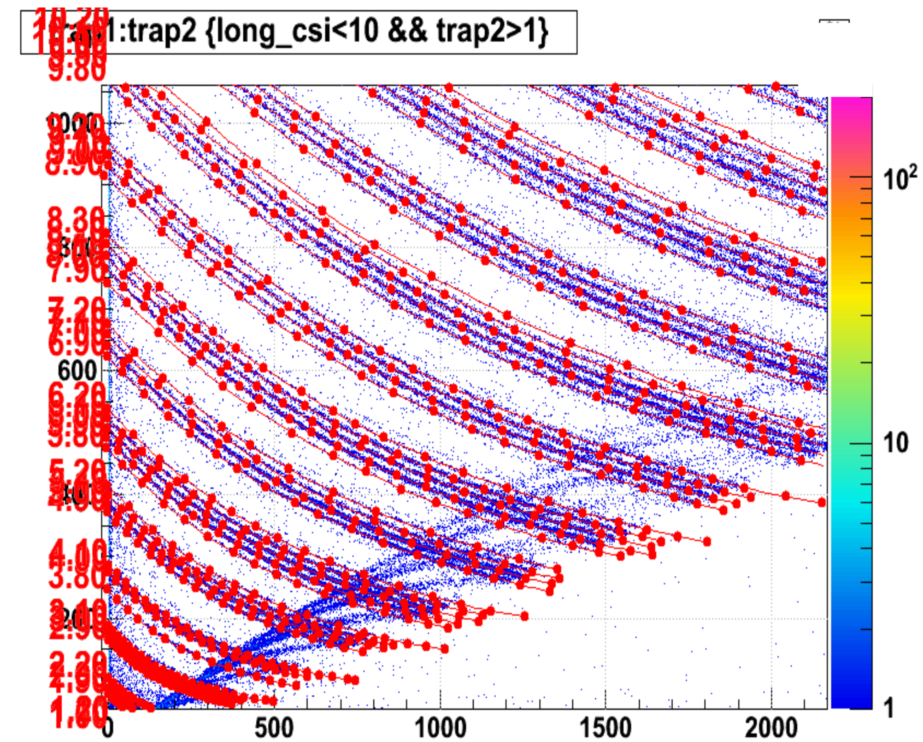
Energy thresholds

- The lower the bias voltage, the higher the energy threshold for identification for a give Z
- The lower the applied voltage, the larger the maximum Z for which isotopic identification is achieved

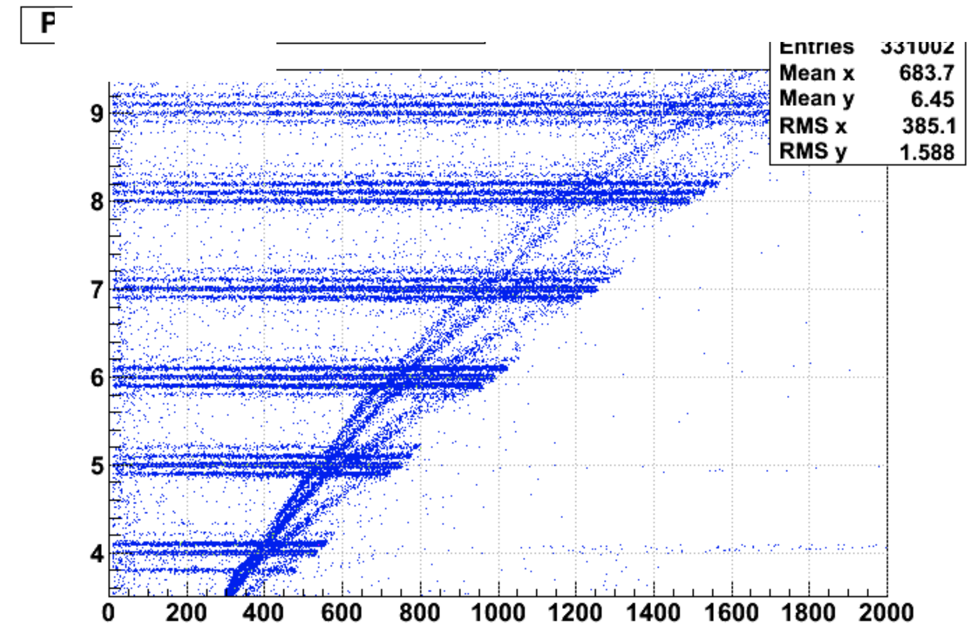




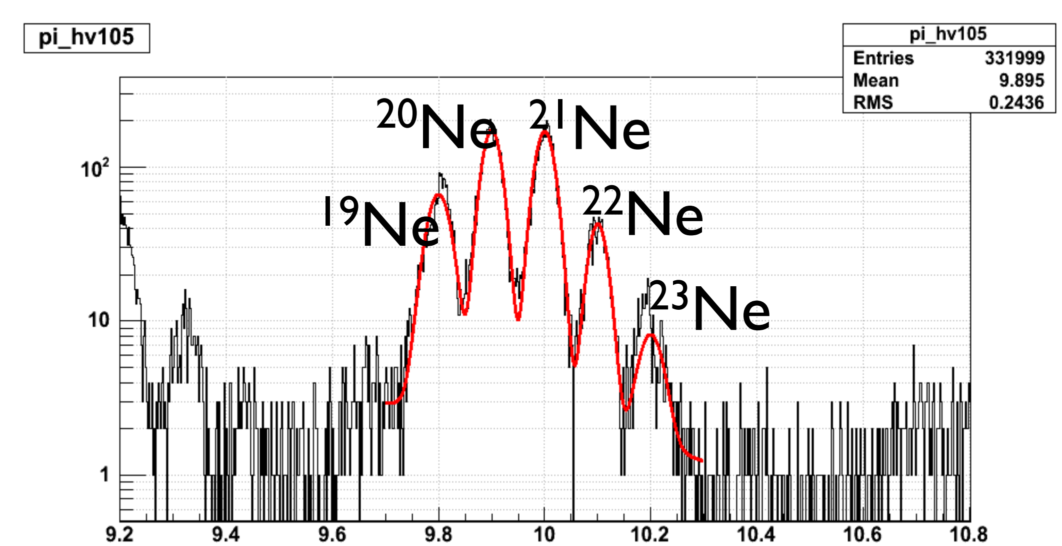
FoM (Figure of Merit)



- Build “refer curve”
- Assign a PID (Particle IDentification) to every refer curve
- Linearize using interpolation for assign to every isotope the right PID
- Build the histogramme of PID
- Multigaussian fit on histogramme

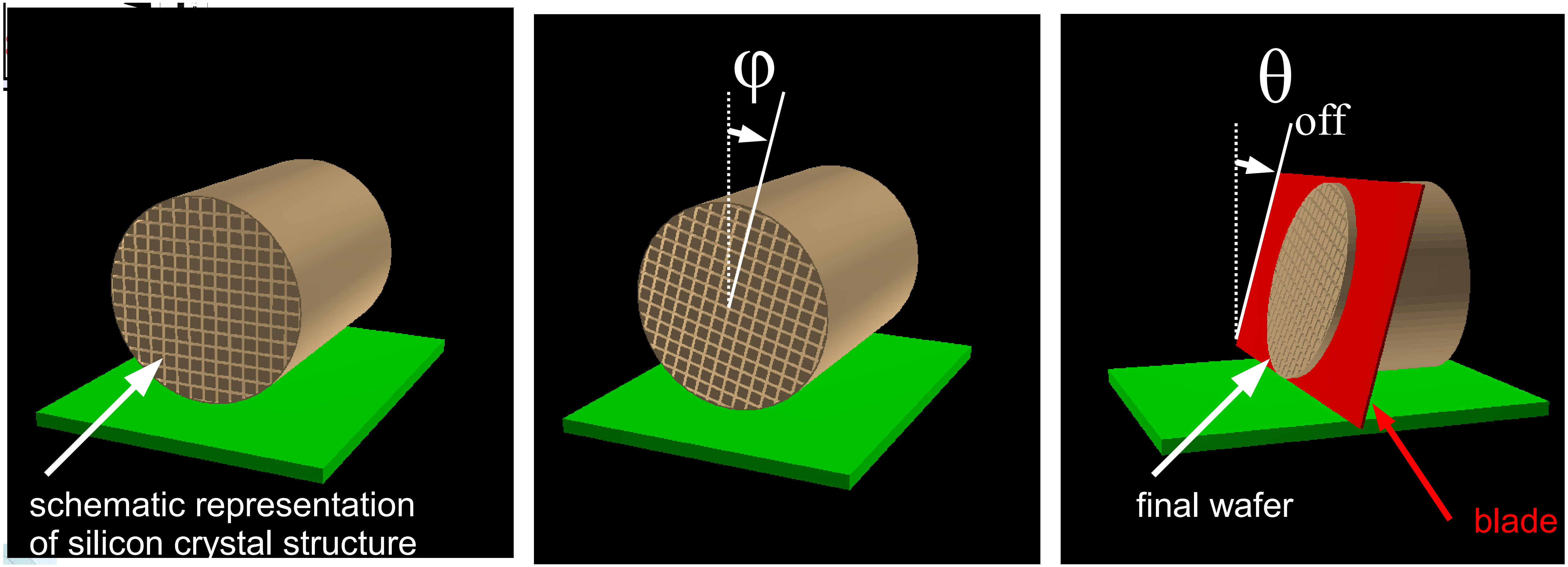


$$FoM = \frac{|\overline{PID_2} - \overline{PID_1}|}{FWHM_1 + FWHM_2}$$



<u>Isotopes are risolved if FoM>0.7</u>

Wafer cut


schematic representation
of silicon crystal structure
φ
θ
off
final wafer
blade