R&D on silicon detectors within the FAZIA collaboration: results and perspectives

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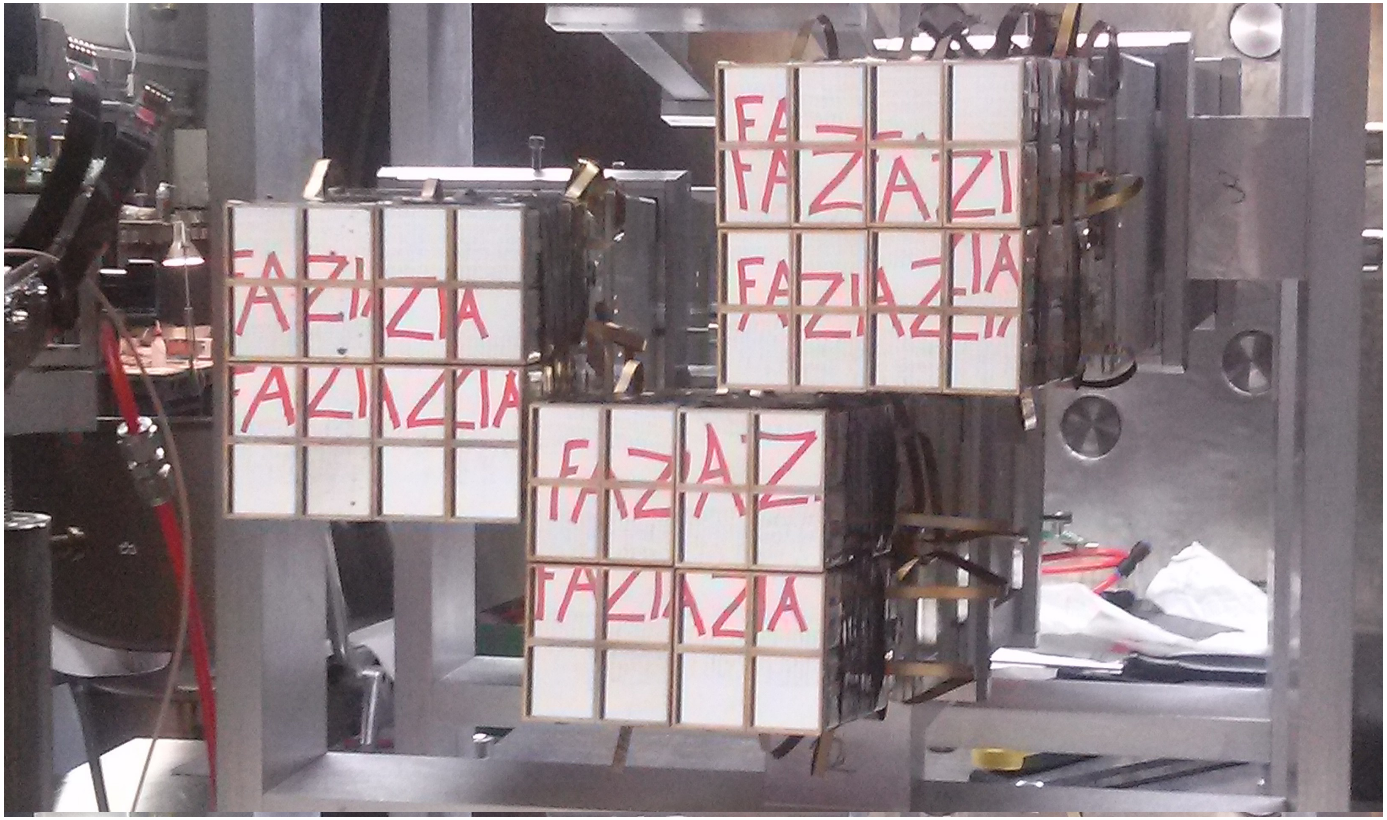
for the SiCilia Florence branch



SiC Workshop- LNS, 7-8 april 2016

Contents

- Physics context of FAZIA
- Improving detectors for fragment identification
- ΔE-E and Pulse Shape Analysis
- Fighting against spoiling effects
    - *Channeling*
    - *Doping homogeneity*
    - *Sheet Resistance*
    - *Radiation damage*
- Results
- A few words on Electronics
- WhatNext on Si for Heavy-ion studies
- A lesson and an expertise useful also for SiC ?

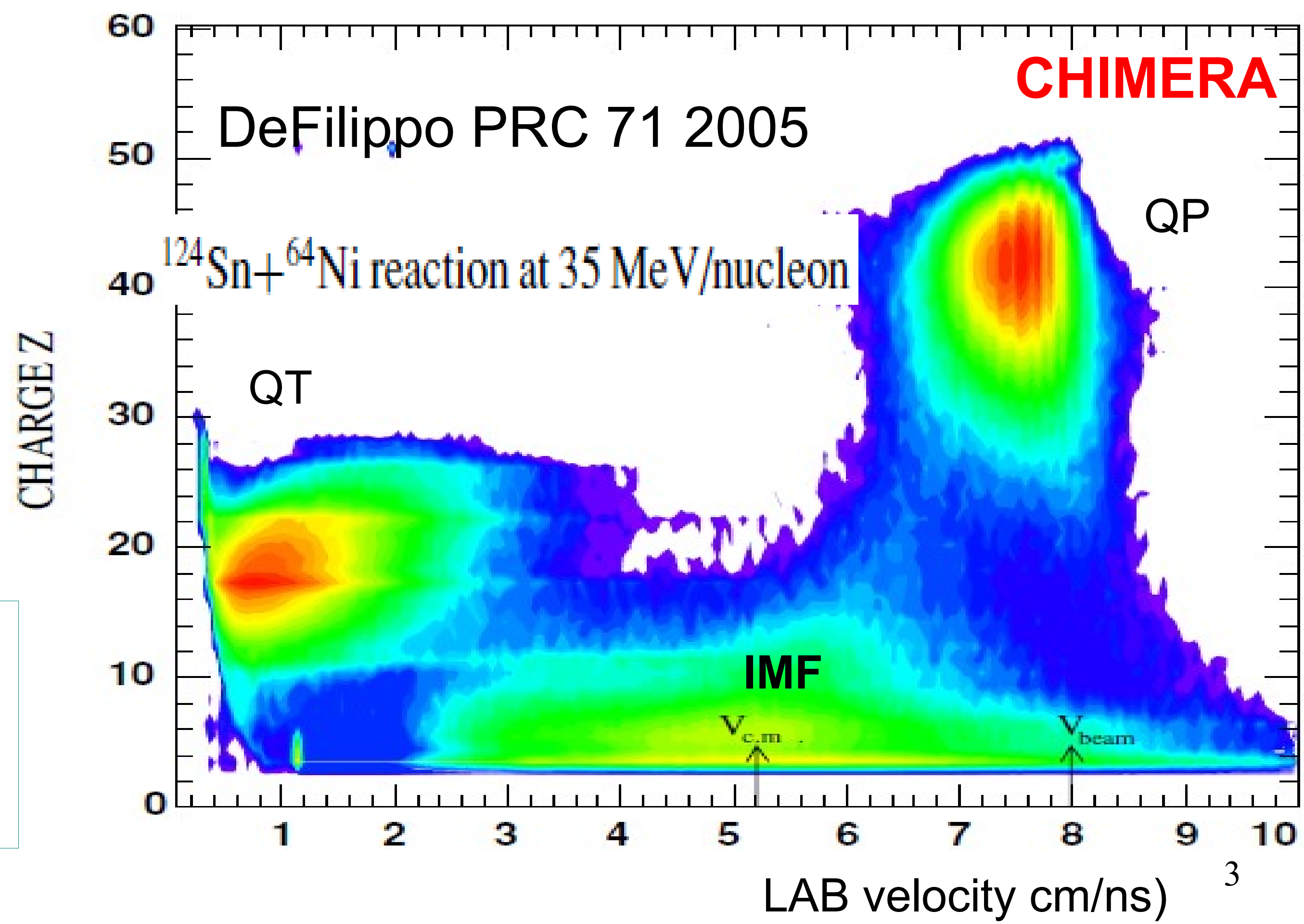
Origin of fragments in nuclear collisions

In nuclear collisions, fragments and clusters can originate together with light particles (n,p,d,t). Their production mechanisms are different, depending on the bombarding energy, the sizes of the nuclei and the impact parameter

Very large variety of species and momenta

A big challenge for detectors/electronics

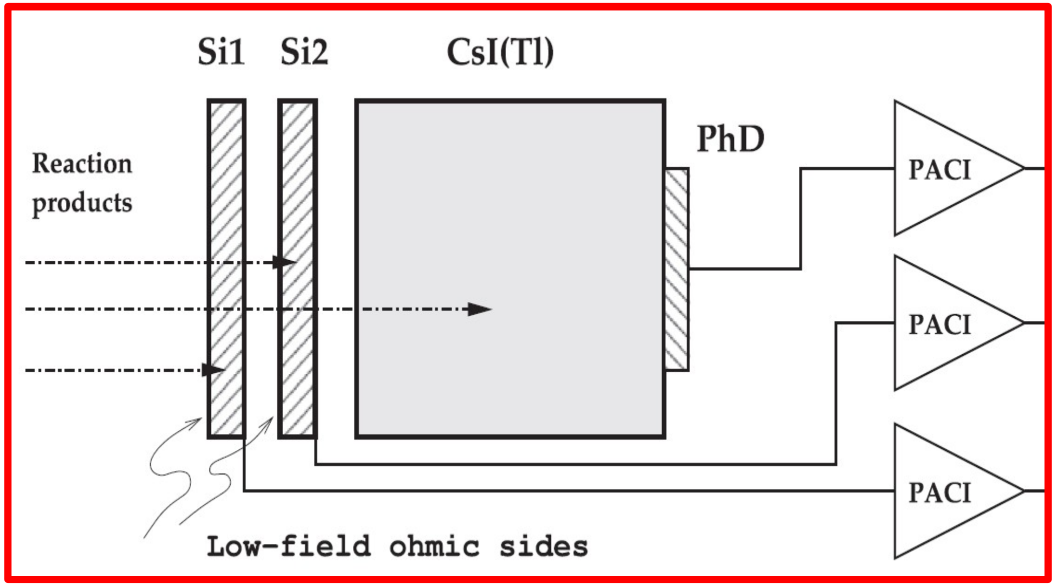
- **From protons to Z>50**
- **Masses of nuclei !**
- **From 1MeV to 5GeV**
- **Large acceptance**



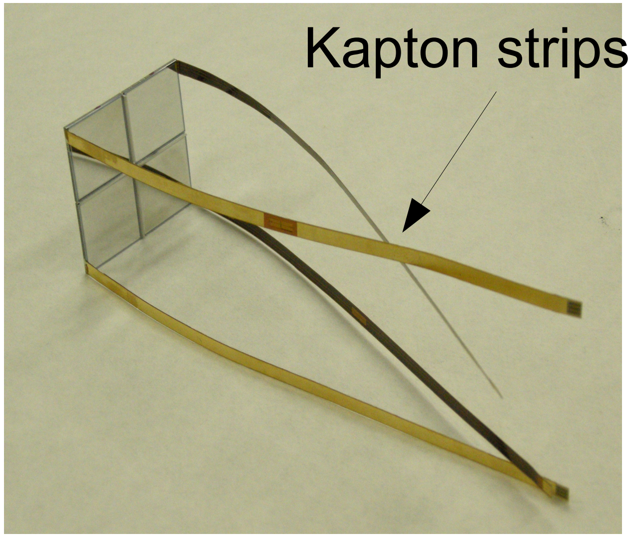
The FAZIA telescope

Valuable work of <u>E.Scarlini</u> on Slii-det (Firenze)

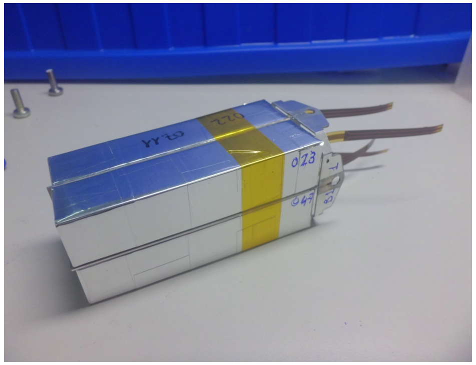
Silicons
20x20mm2
nTD type
ρ~3-4000 ohm*cm
300 and 500 μm
8deg cut off <100>



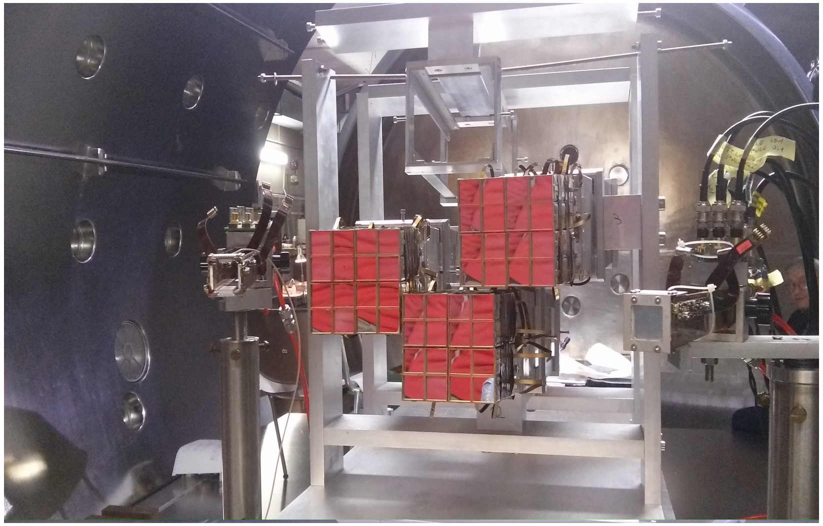
CsI(Tl)
20x20mm2
tapered
1500-2000ppm Tl-doping
Uniform doping
10 cm thick



Quartetto of Si mounted on Al (Ergal) support

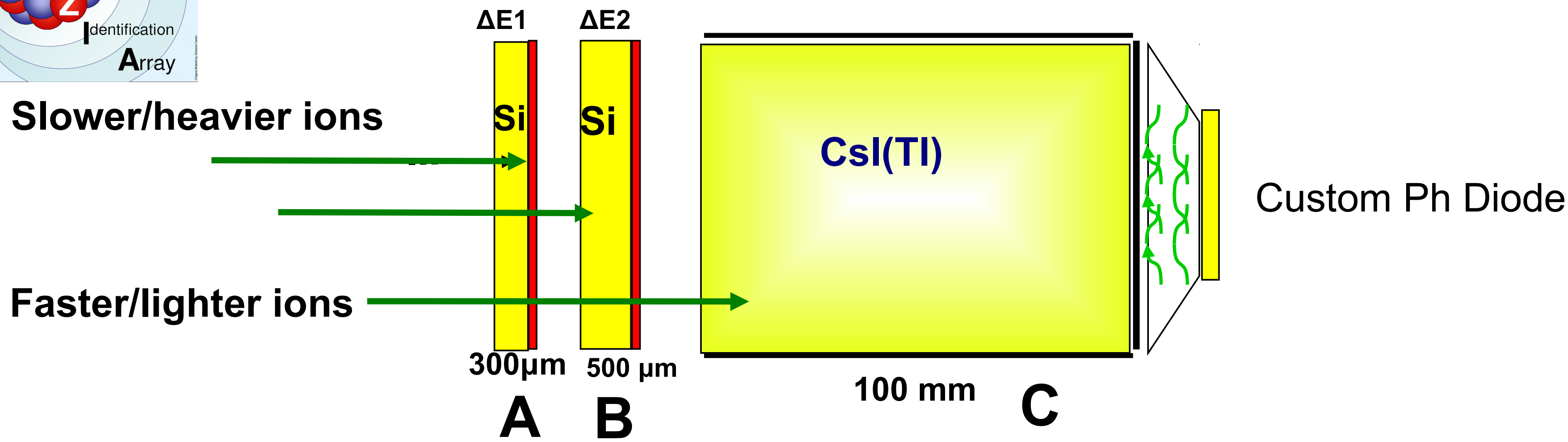


Quartetto of CsI(Tl)



BLOCKS of 16 Telescopes

Identification methods

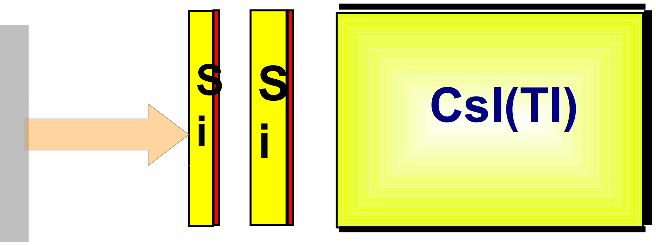


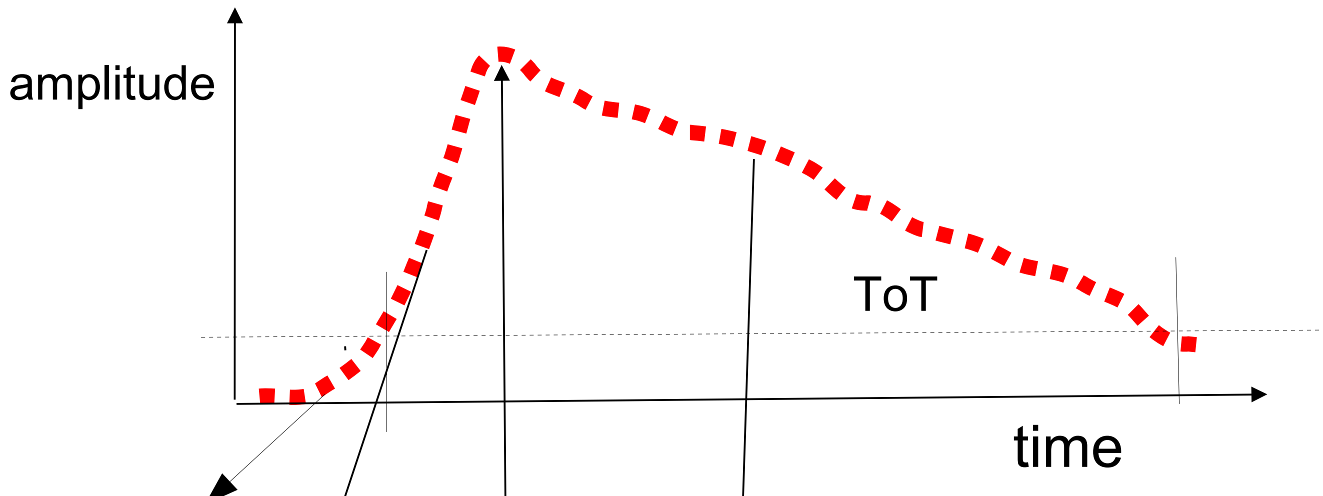
Conventional concept: Si-Si-CsI telescope
special features for detectors and electronics.
silicons used in reverse configuration

		comments
Only A	**Particles are identified through Pulse Shape Analysis**	Lower threshold Delicate technique
A vs. B	**Particles are identified through ΔE-E method**	higher threshold Robust technique
A+B vs. C	**Particles are identified through ΔE-E method**	Optimum for medium mass framents Robust technique
C	**Particles are identified through PSA from scintillation pulses**	Restricted to Z<5 Only for very energetic particles

Fast sampling and Pulse shape analysis (PSA)

Fast digital sampling allows to extract more information on impinging particles





TIMING (time mark to be used as a difference with an other mark) **TOF**

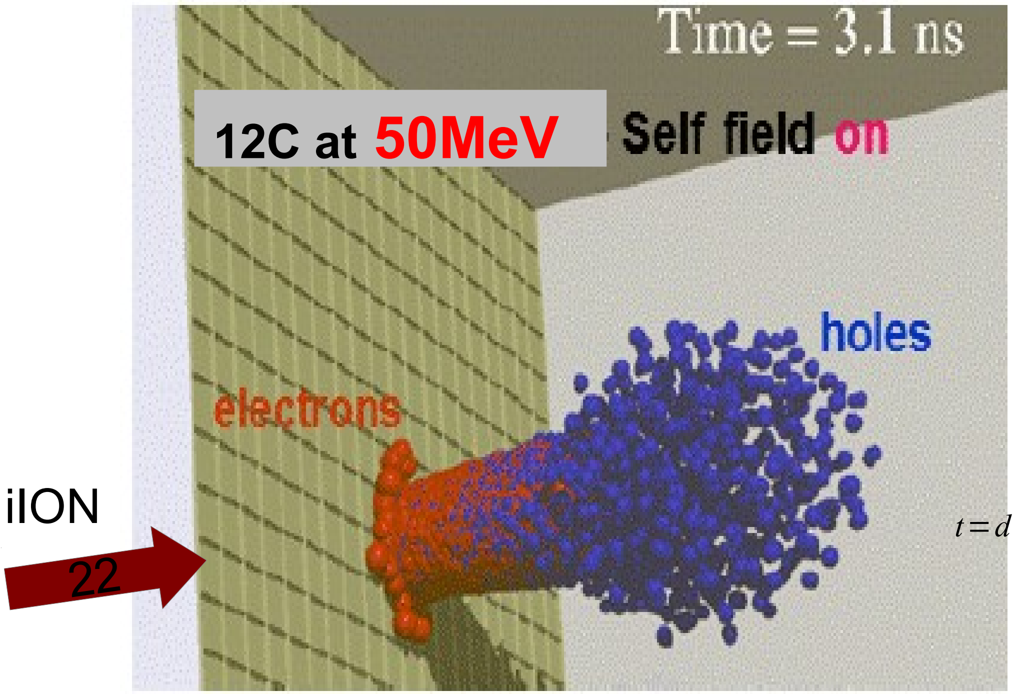
Maximum (directly or after optimum filtering, ie. shaping) **ENERGY**

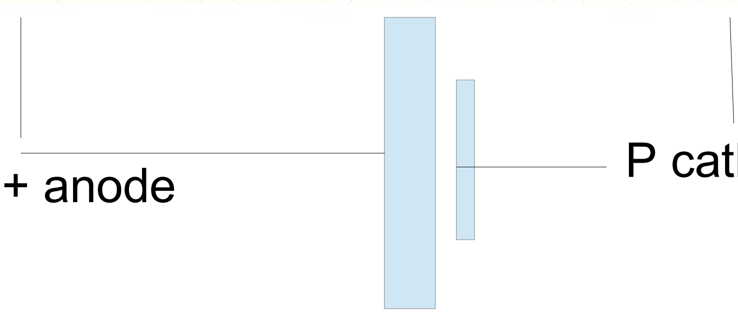
RISETIME (algorithms to evaluate the leading edge duration) **PSA**

Skewness (as a shape parameter) **PSA**

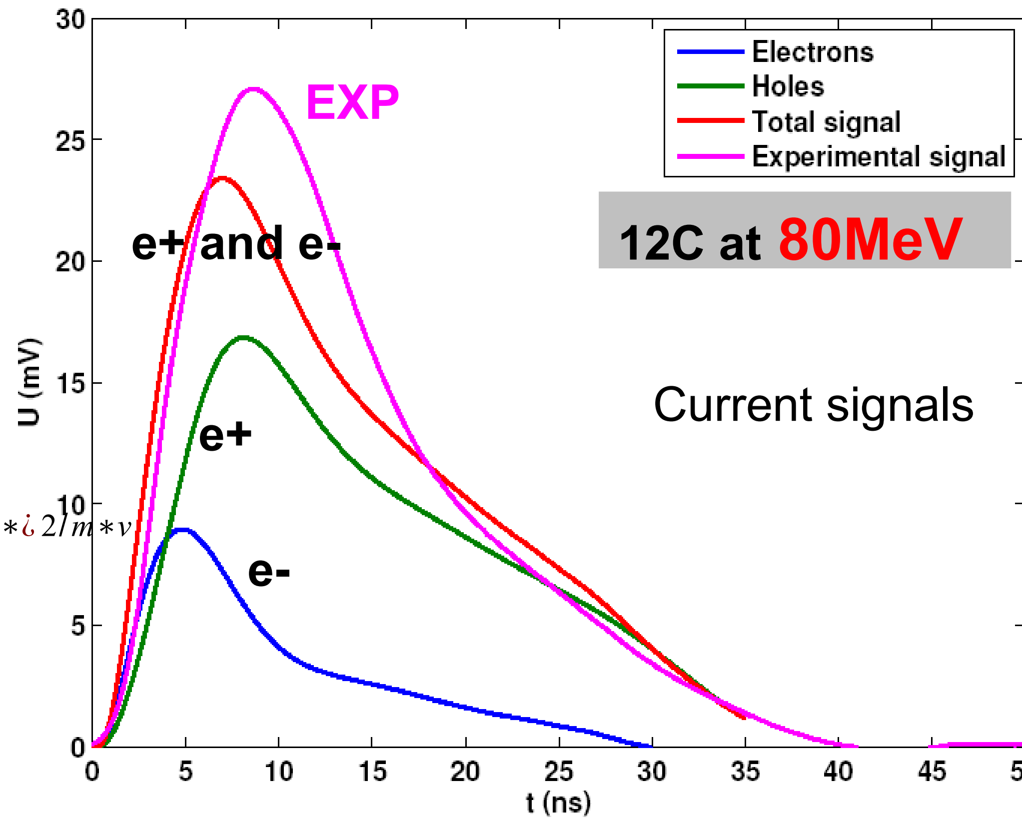
ToT (time over threshold as an overall shape parameter) **PSA**

Charge collection in Si-junctions





t=d*¿2/m*v



Risetimes are of the order of **10 ns** for Carbon ions

Risetime differences for 12C/13C of the same energy are only 200ps: delicate technique!

- Electrons/holes move towards electrodes
- drift time of the order of several **tens ns** in typical Silicon detectors

BUT: on top of "external" E-field there are screening effects generated by the e-h clouds themselves: ***PLASMA TIME***

Ion identification in silicon detectors: critical aspects

Structure and configuration effects

Crystalline nature of Silicon and channeling
Doping inhomogeneities in Silicon bulk
Mounting geometry

And for SiC?

Dynamical effects

Radiation damage

for SiC reasonably better

Electronics and digital treatment

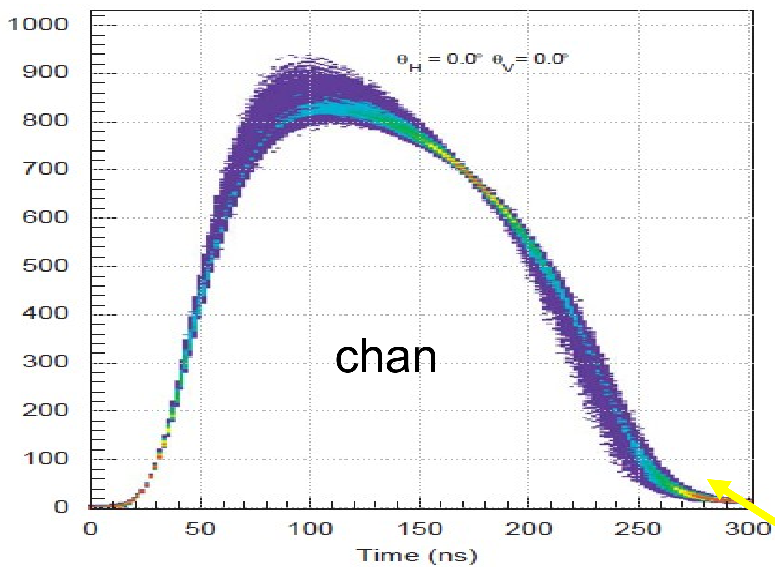
Noise sources and sampling freq limits

Same issues as for Silicon

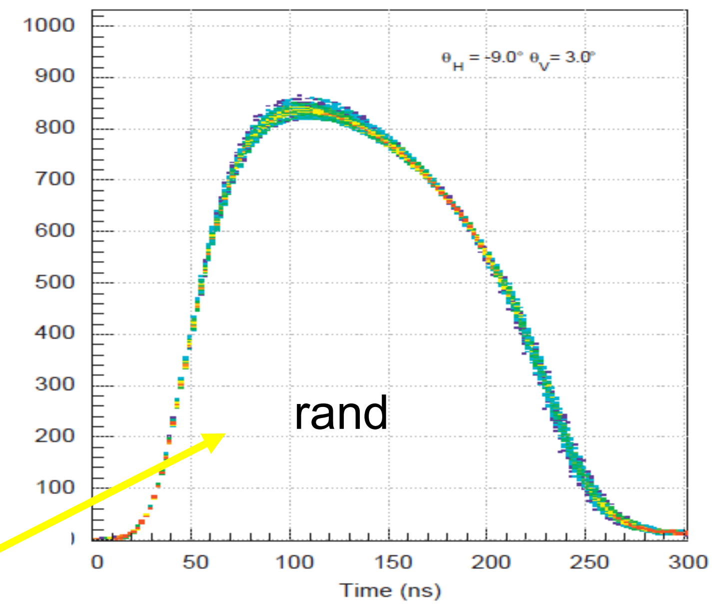
PSA and channeling

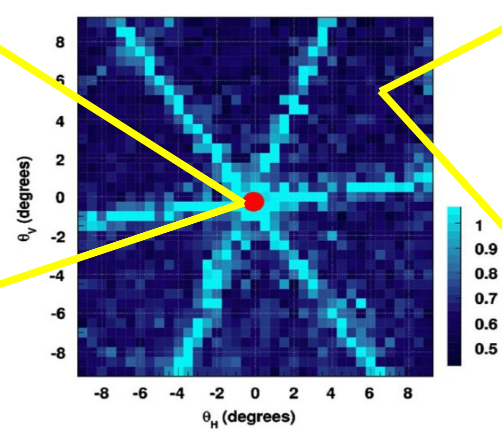
Bardelli et al NIM A 605 2009

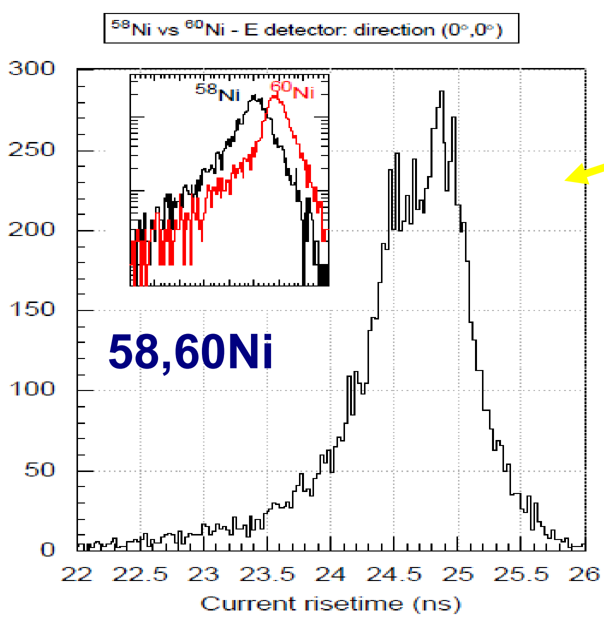
CHANNELING EFFECTS

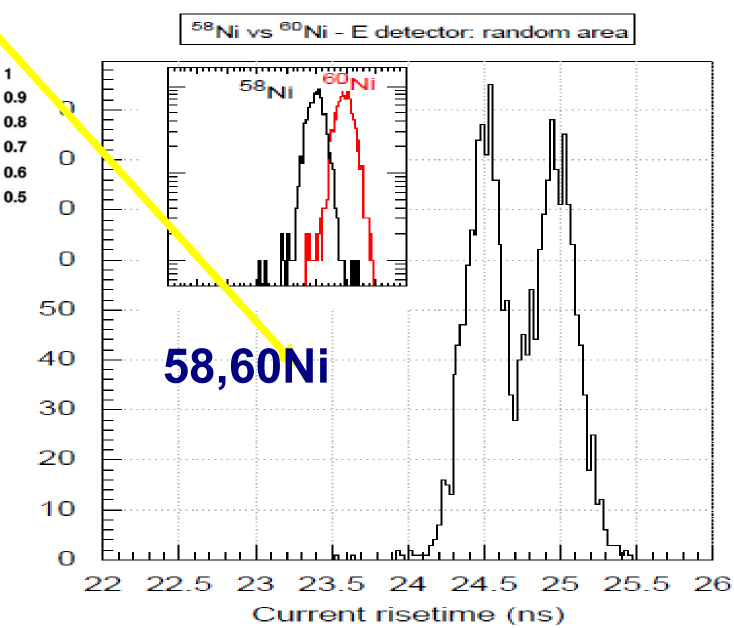


IONS stopped in 58,60Ni 703MeV









For optimum use:

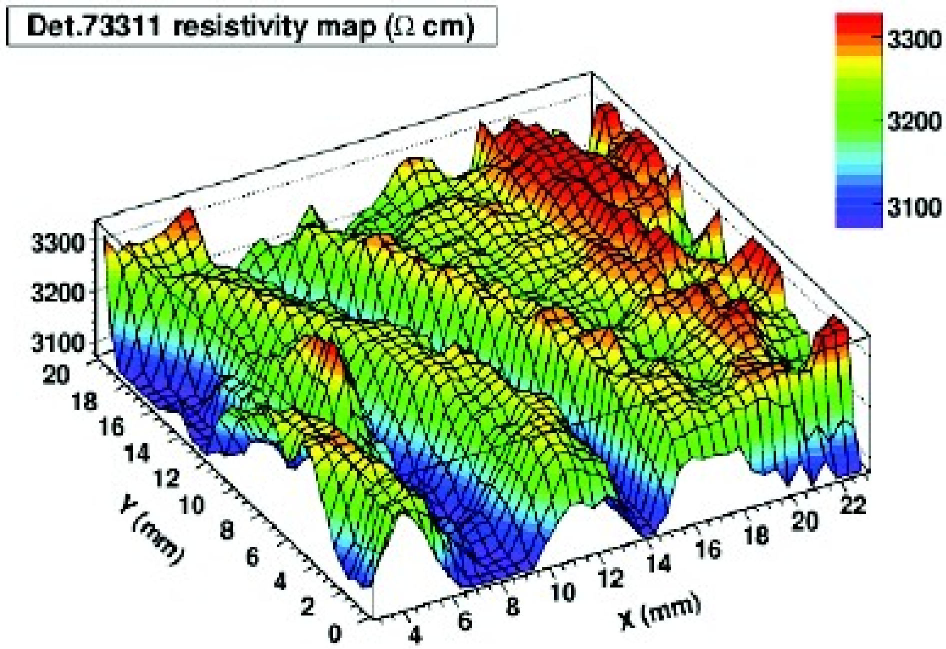
Cut 8.2deg out of <100> plane

PSA and doping homogeneity

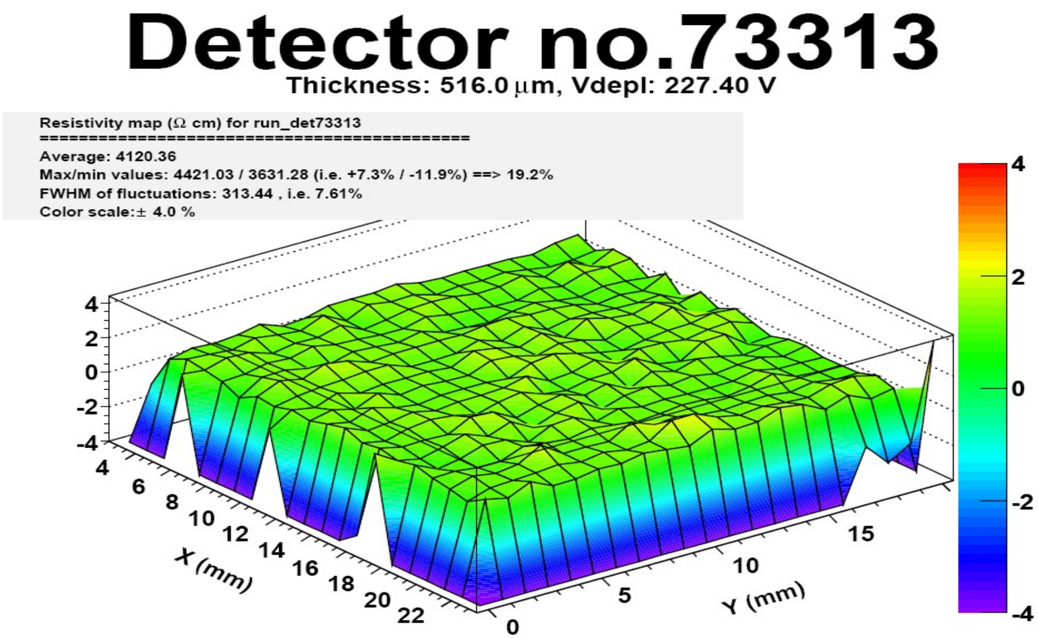
Good PSA needs to reduce spurious E field variations due to doping inhomogeneities

nTD bulk tech appears to be the best chance, so far

d>9 % inhomogeneities



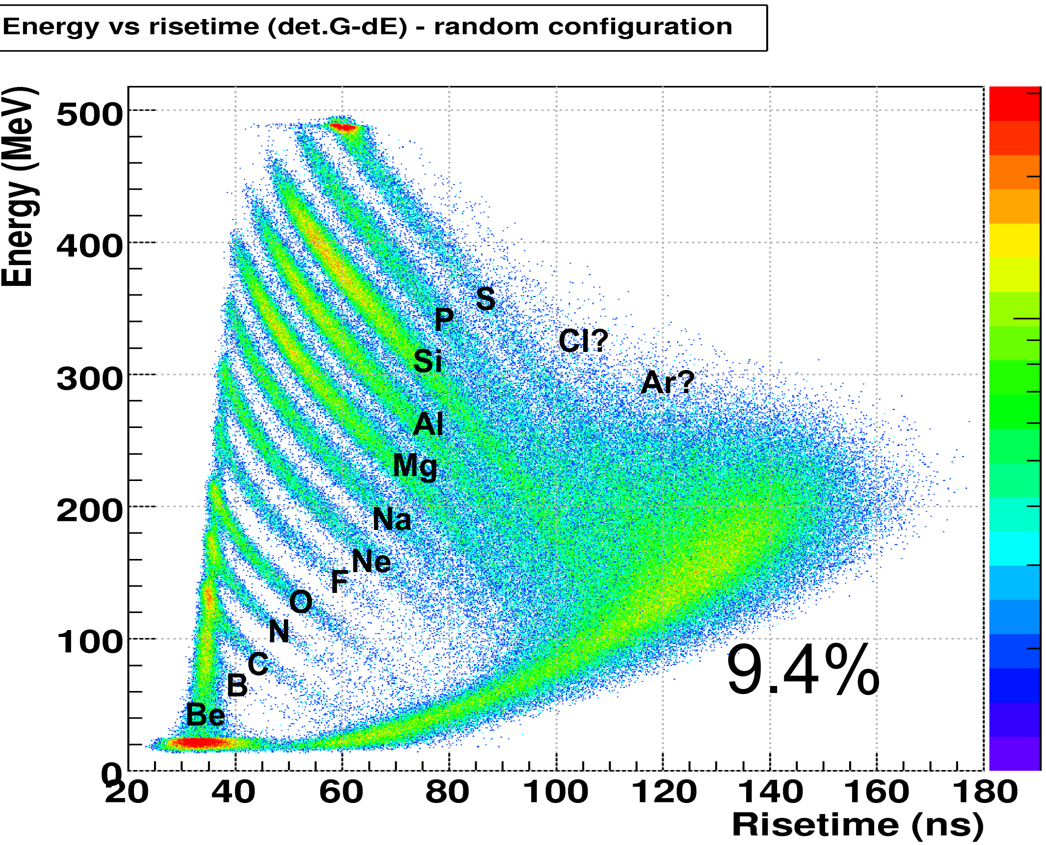
d=1 % dishomogeneities

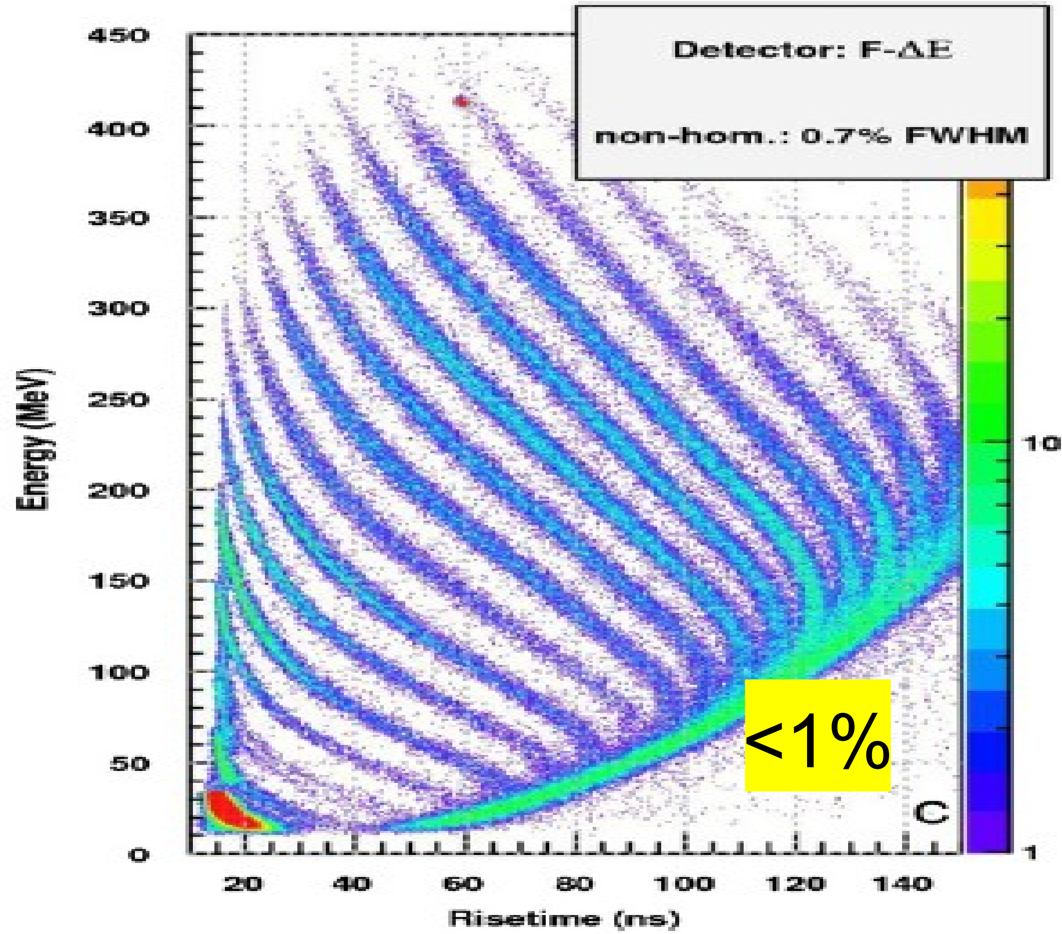


Typical figure of merit for good PSA: d<3%

PSA and doping homogeneity

Bardelli et al NIM A 654 2011





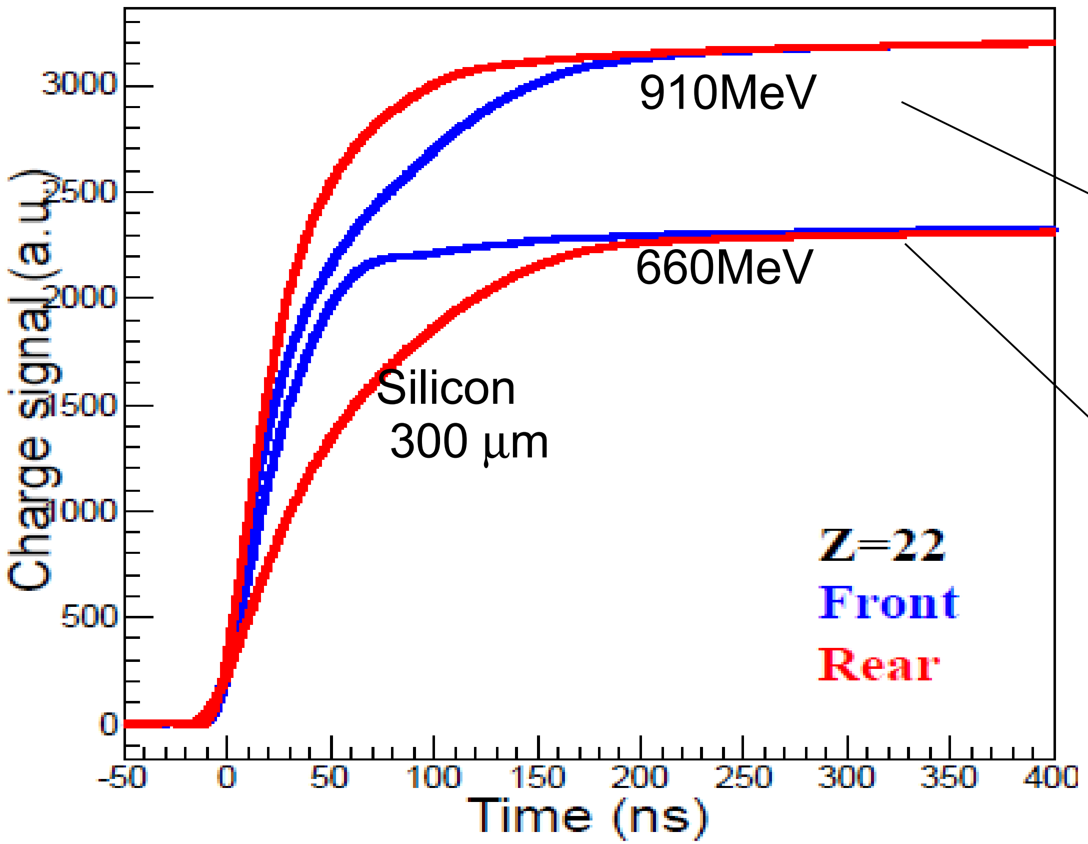
Keep under control channeling effects
Reduce as possible doping inhomogeneities

And for PSA in SiC?
Also relevant, maybe...

Charge collection in Si-junctions

PSA is expected more sensitive in reverse mounting

R.Bougault et al EPJ 50, 2014



Experimental shapes for Titanium ions

Ions stopping just at the end of thickness, 300 micron

Ions stopping at 2/3 f of detector thickness (about 190 micron)

Not only FAZIA., just to mention e.g.

- Lu et al NIM A 2001 (Chimera coll.)
- Prete et al 1999 8plp Silicon
- Pausch et al

PSA and mounting configuration

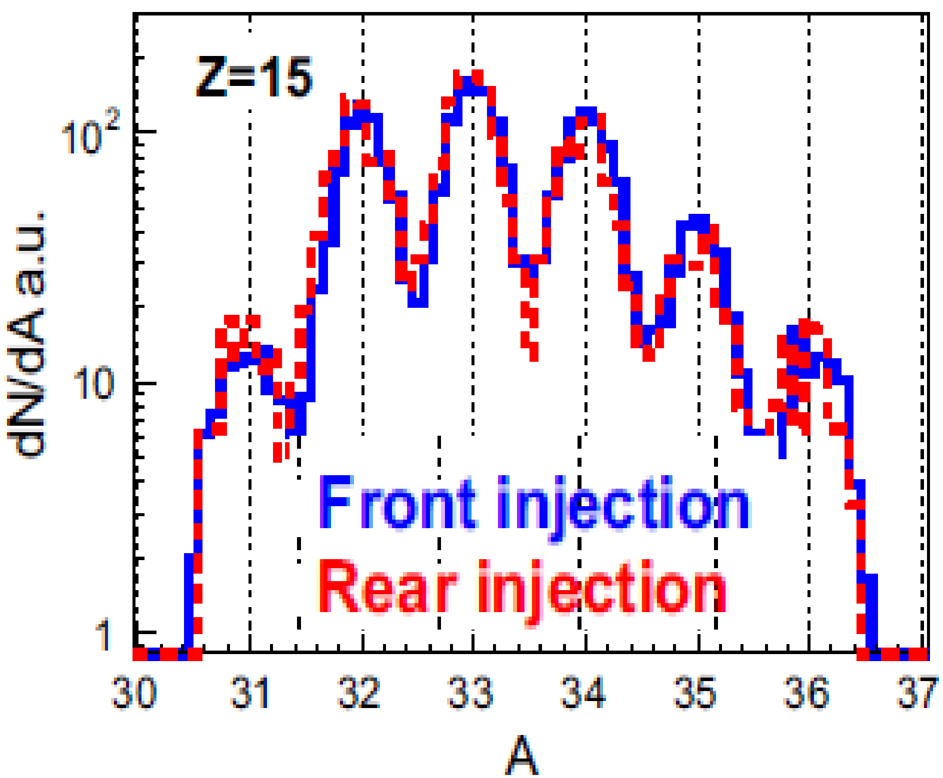
N.LeNeindre NIM A 2013

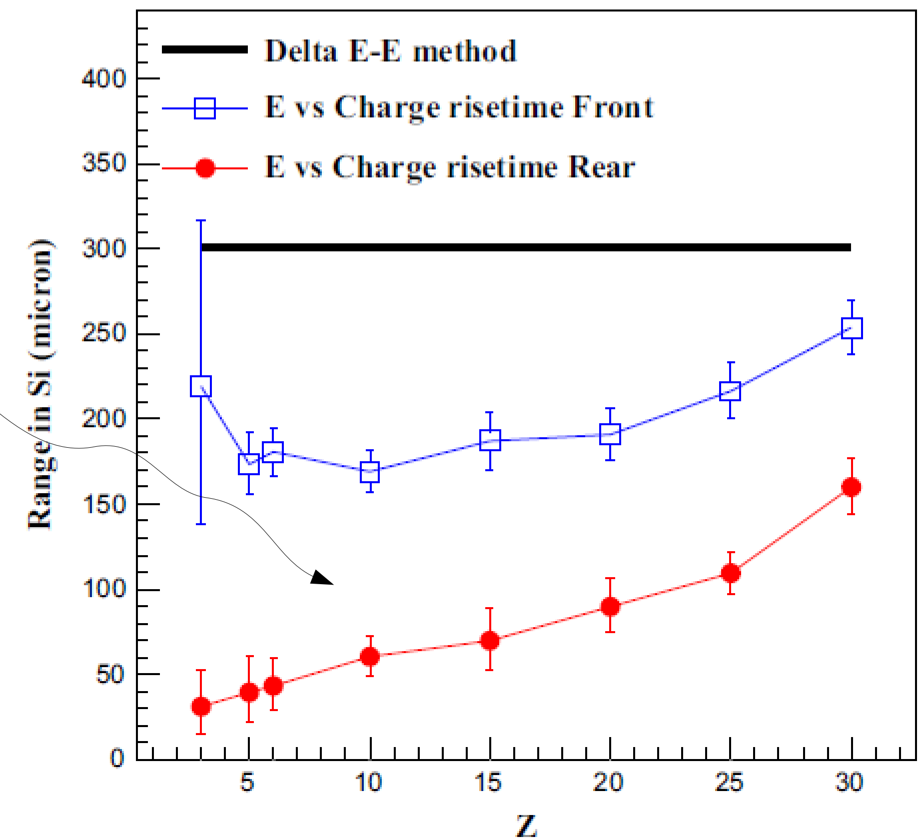
What about ΔE-E and PSA for front injection (junction side) or for rear injection (ohmic side)?

It does matter for PSA!

No effect for DE-E method

$$FoM = \frac{|\overline{PID2} - \overline{PID1}|}{FWHM1 + FWHM2}$$ **> 0.7**



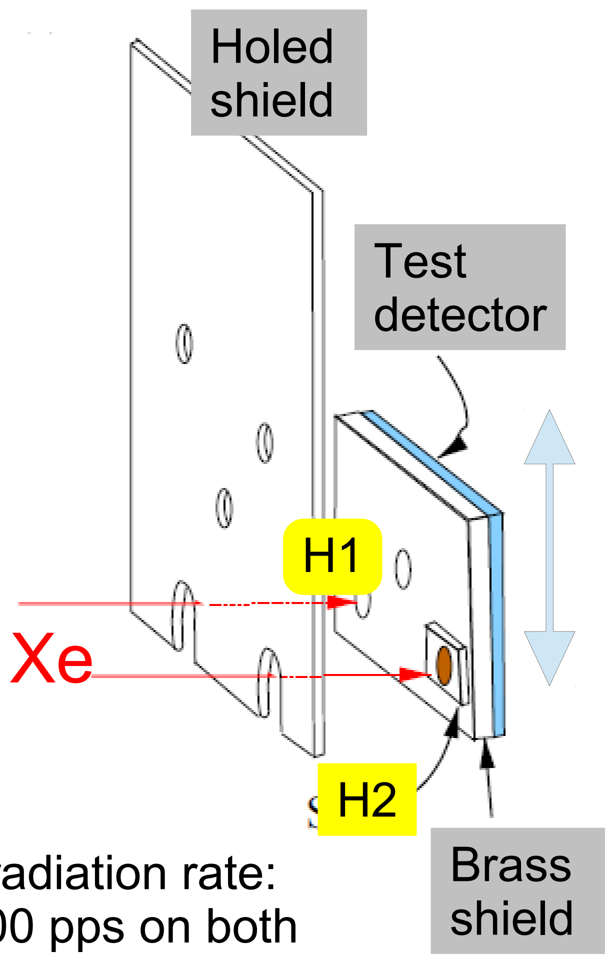


PSA and radiation damage

S.Barlini NIM A 707 2013

- A specific study @LNS using 129Xe ions at 35MeV/u
- Damage induced in Silicons by stopped or trasmitted Xe-ions (monoenergetic)
- Used typical FAZIA 300mic and 500mic detectors, 20x20mm2
- ADC 12bit 125MSs

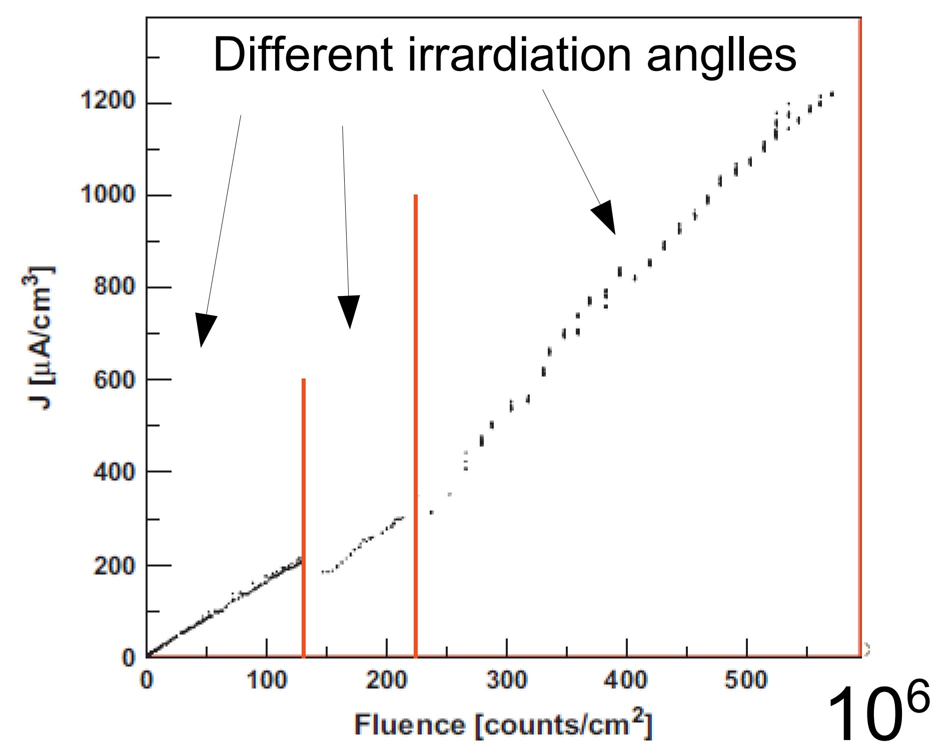
20 × 20 mm
FBK
310 μm
120 V
140 V
n-type
2970 Ωcm
2.3%
301 cm
0.3°/1.4°



Irradiation rate: 700 pps on both holes

Automatic correction to keep applied Voltage constant!

First effect: rev. Current increase



PSA and radiation damage

S.Barlini NIM A 707 2013

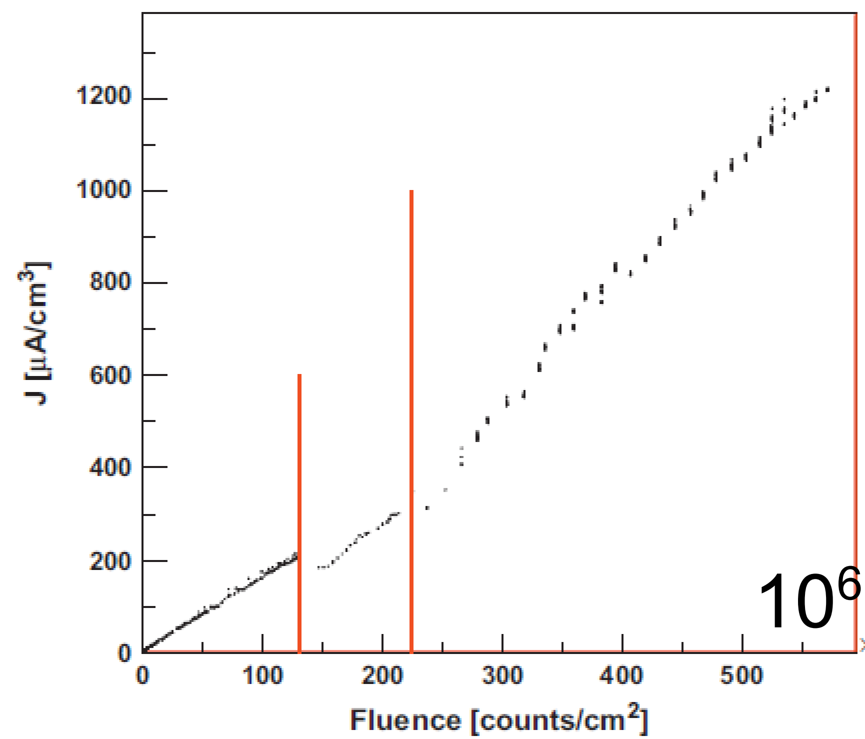
$$D(E) = \frac{A}{N_A} NIEL(E)$$

$$\Phi_{eq} = k\Phi = k \int \phi(E)\, dE = \frac{\int D(E)\phi(E)\, dE}{D(E_n = 1\ \text{MeV})}$$

Evaluation of NIEL for 129Xe from SRIM:
1.37GeV*g/cm2 gives k=700
Xe ion are 700 time more effective to produce damage than neutrons

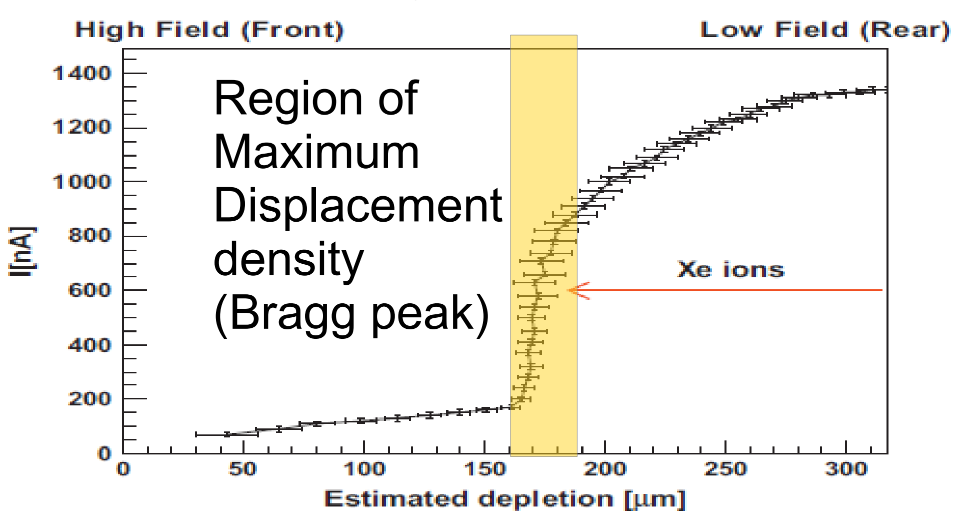
At least 3 orders of magnitudes to have doping inversion in n-type bulk detectors according to proton-neutron HEP test at LHC

First effect: rev. Current increase



0 neutr-equi Fluence 350 10^9

Two years later...



Reverse current vs. Applied Voltage (namely depleted thickness) reveals the wall of maximum damage

PSA and radiation damage

S.Barlini NIM A 707 2013

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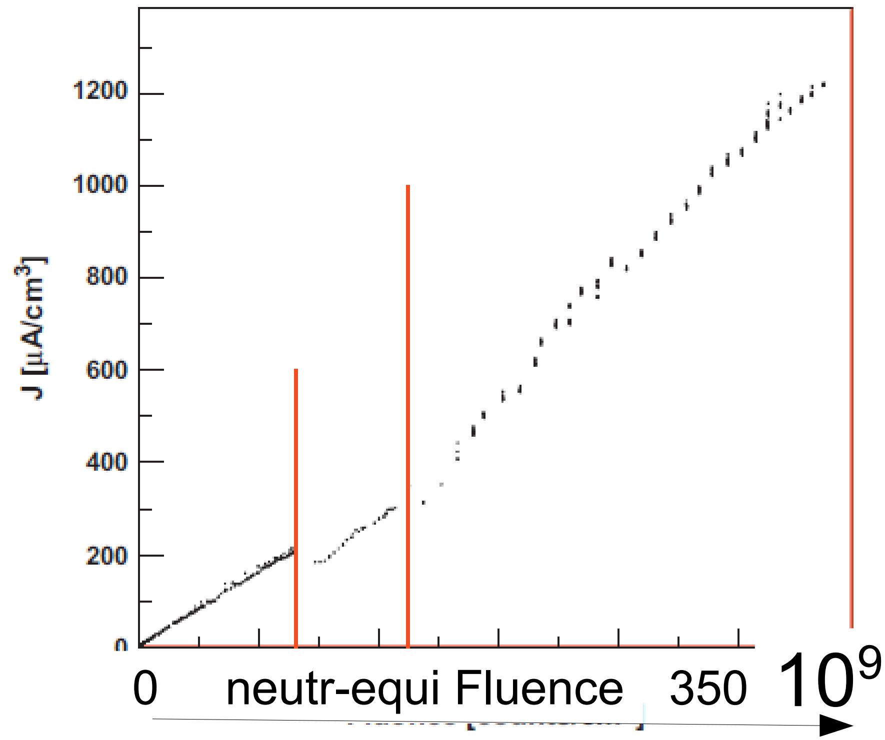
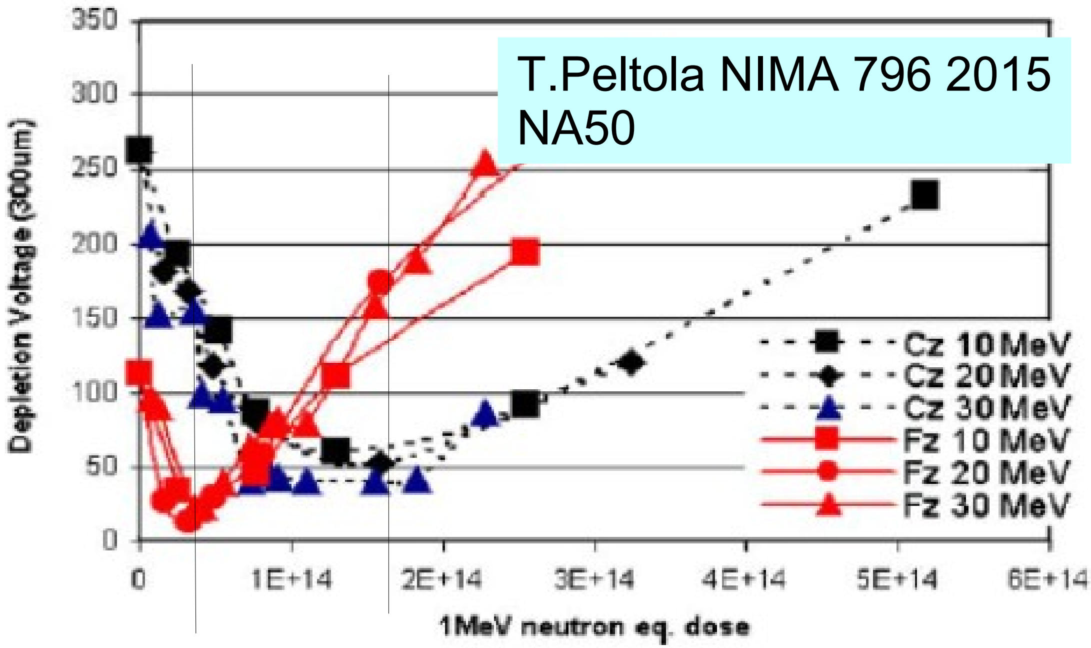




Doping inversion effect for FZ or CZ silicon detectors irradiated with neutrons

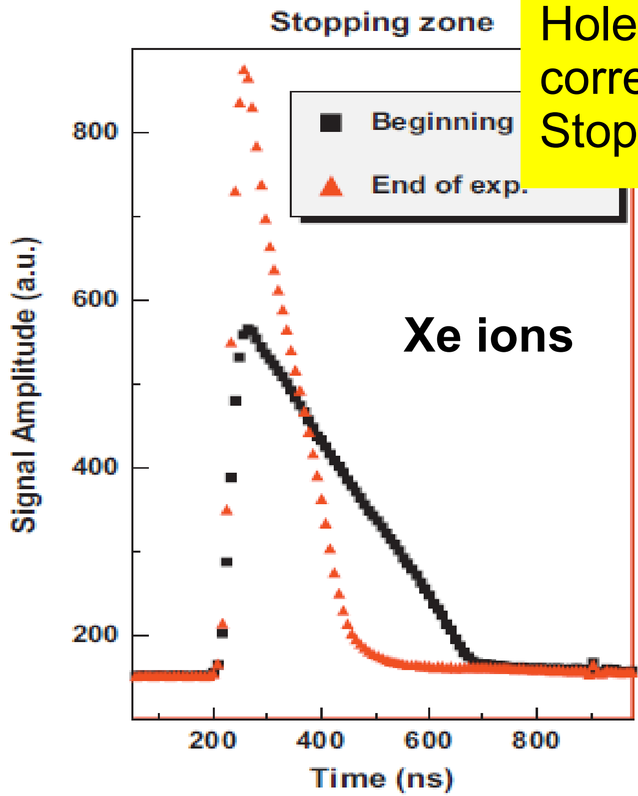
PSA and radiation damage

S.Barlini NIM A 707 2013

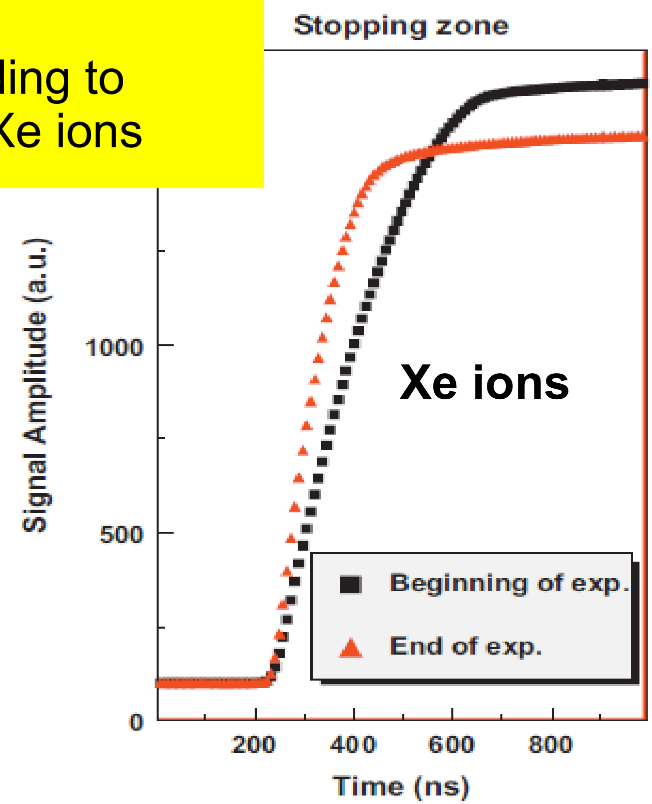
Second Effect: changes in signal evolution

A semi-expected phenomenon: change in pulse shape (ok) but in the unexpected direction: a decrease of collection times

Hole H2 corresponding to Stopping Xe ions



Current signal



Charge signal

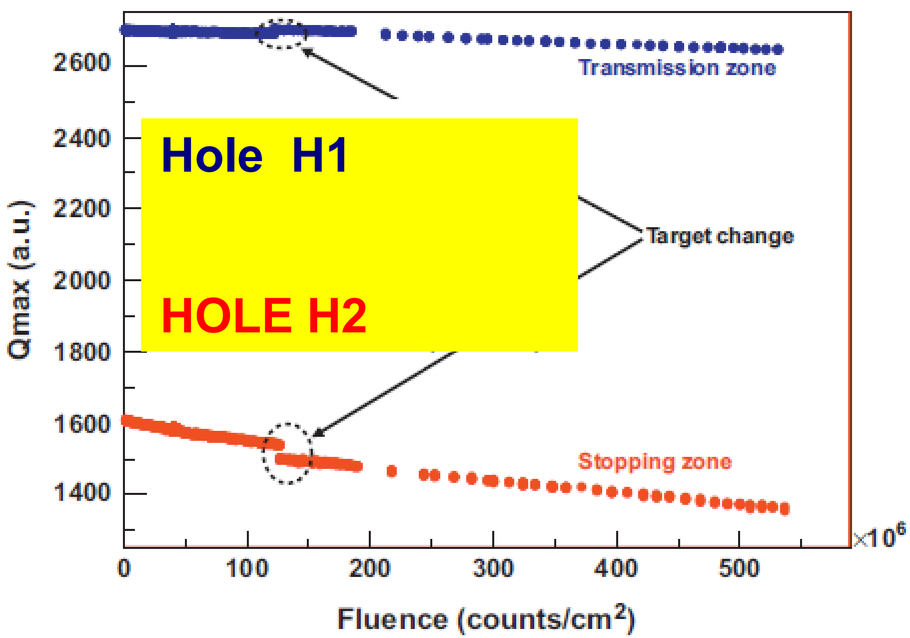
Much less effect for Xe passing in H1, the hole where ions are transmitted

PSA and radiation damage

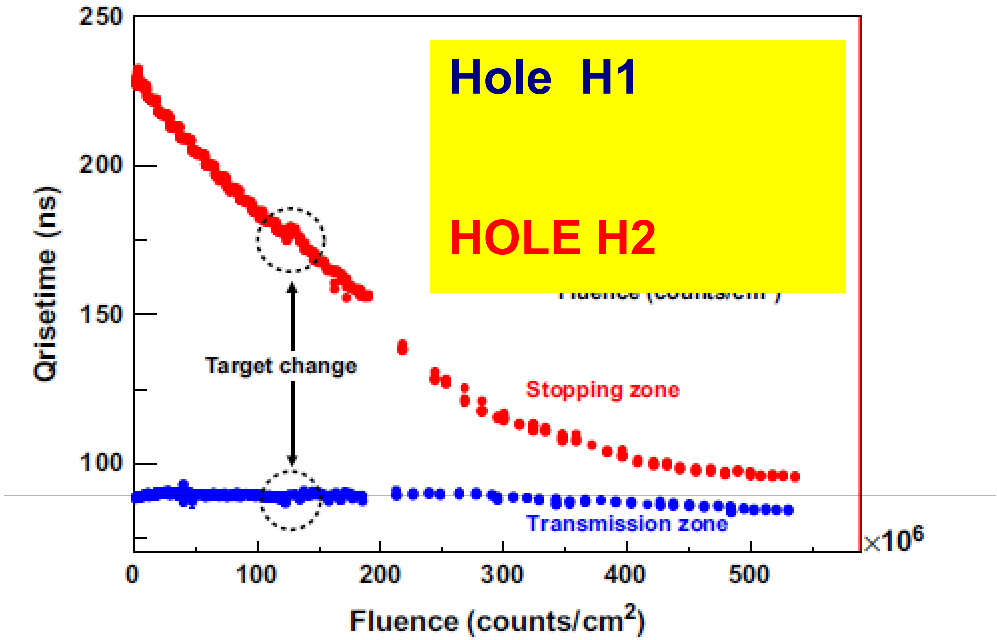
S.Barlini NIM A 707 2013

Second Effect: decrease of CCE and change of shape

For stopped ions: 15% reduction of CCE along time (fluence)
For stopped ions: strong reduction of typical collection times



Charge signal shaped MAX



Charge signal shaped RISETIME

Much less effect for Xe passing in H1, the hole where ions are transmitted

This behaviour deserves more investigation...

PSA and radiation damage

S.Barlini NIM A 707 2013

Second Effect: decrease of CCE and change of shape

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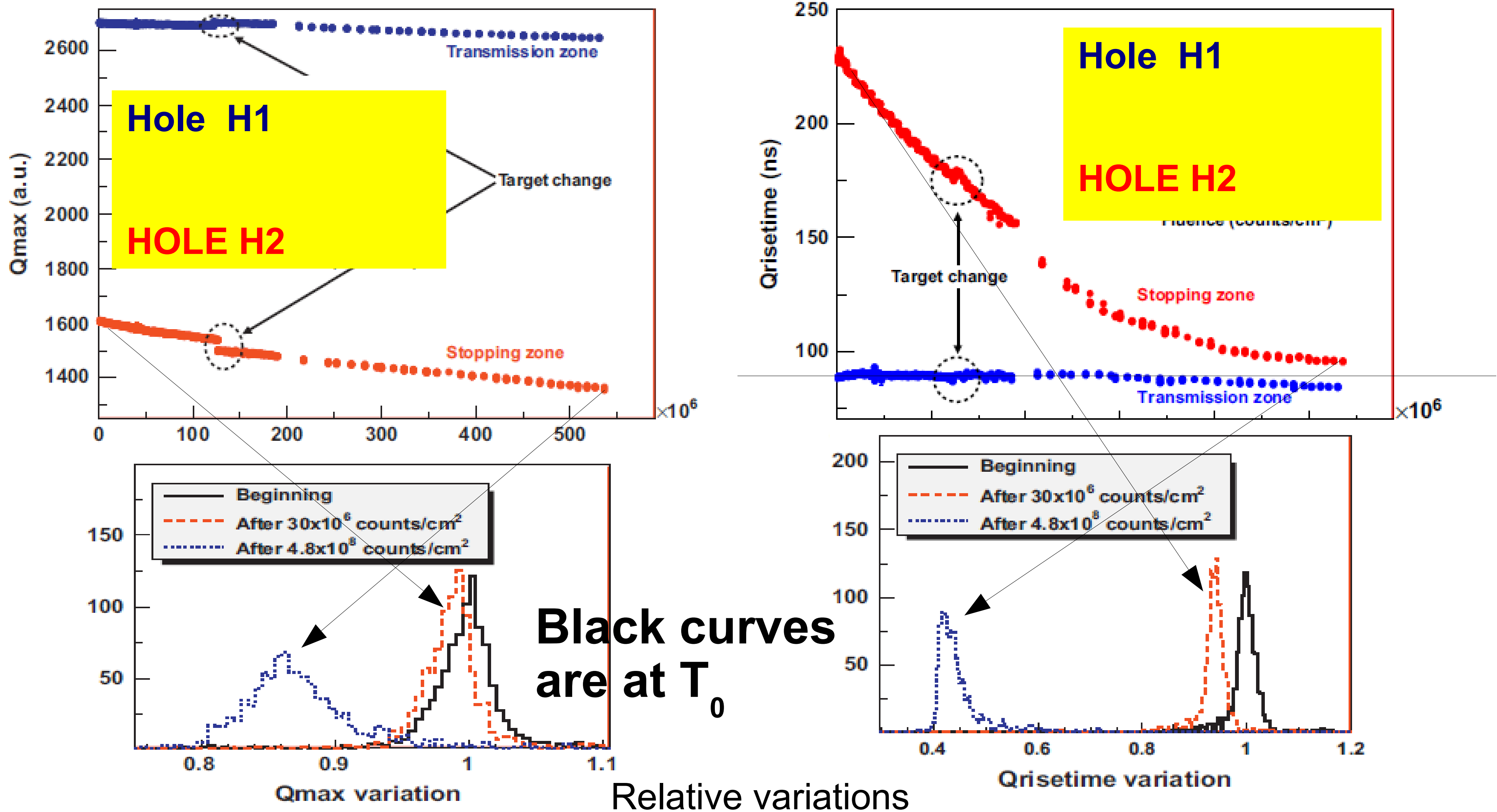
For stopped ions: strong reduction of typical collection times



PSA and radiation damage

In a typical experiment....

Case of **Xe** ions
For a limit of 1% Charge collection and risetime variation we get safe PSA life-limits:

Fluence of 10^7 /cm2 for stopped ions
Fluence of $3*10^8$ /cm2 for punching-through ions

For 200Hz rate on Si pads at 1deg (2x2cm2) this is around
2.5 days for stopped heavy ions and 75 days for trasmission ions.

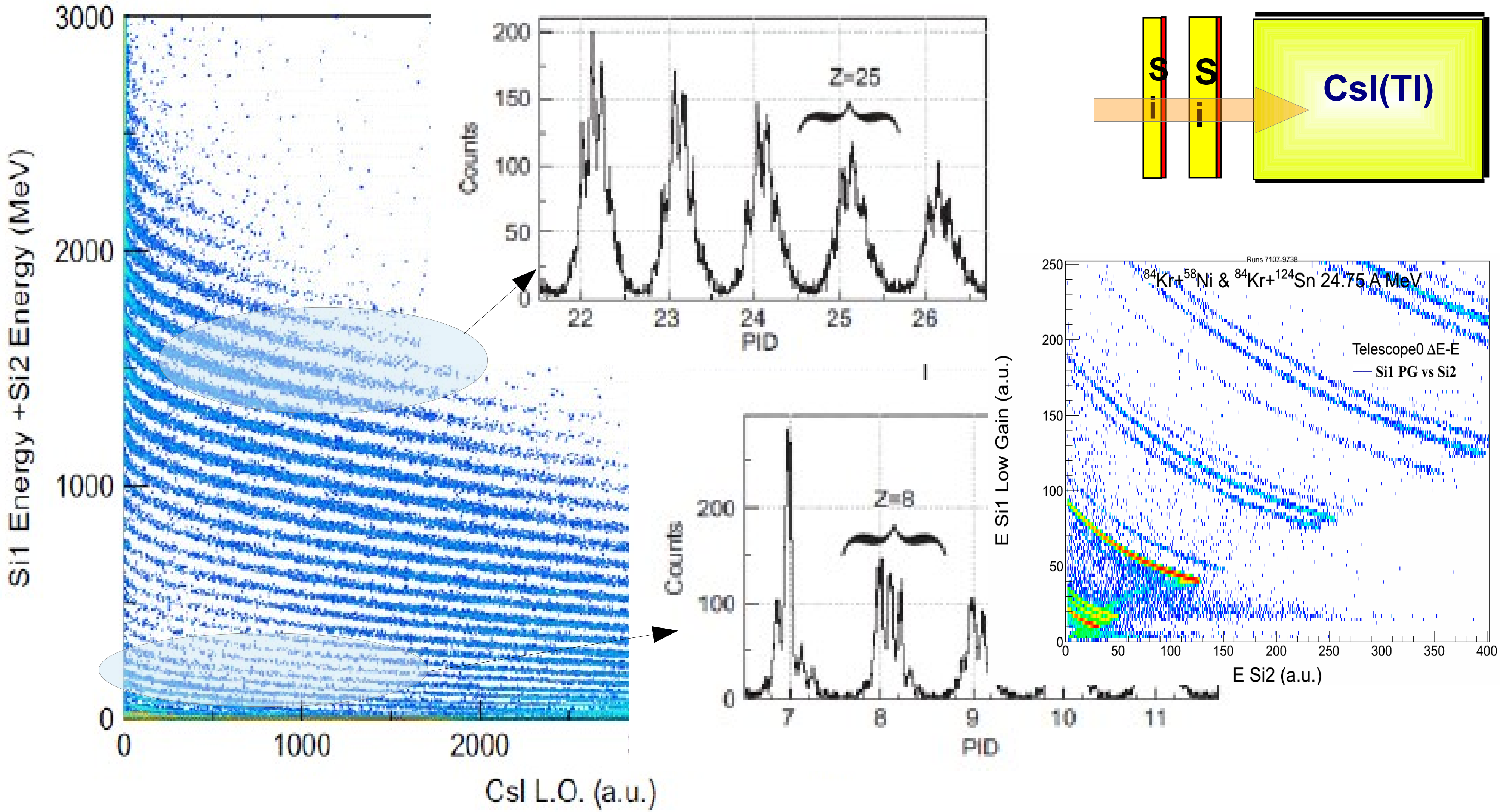
Considering a square Z dependence (*) one can deduce that for lighter ions these limits become

(*) not investigated

Kr 5.6 days for stopped heavy ions and 170 days for trasmission ions.
O 114 days for stopped heavy ions and 3400 days for trasmission ions.

Radiation damage remains an issue

RESULTS: Towards the limits of ΔE-E

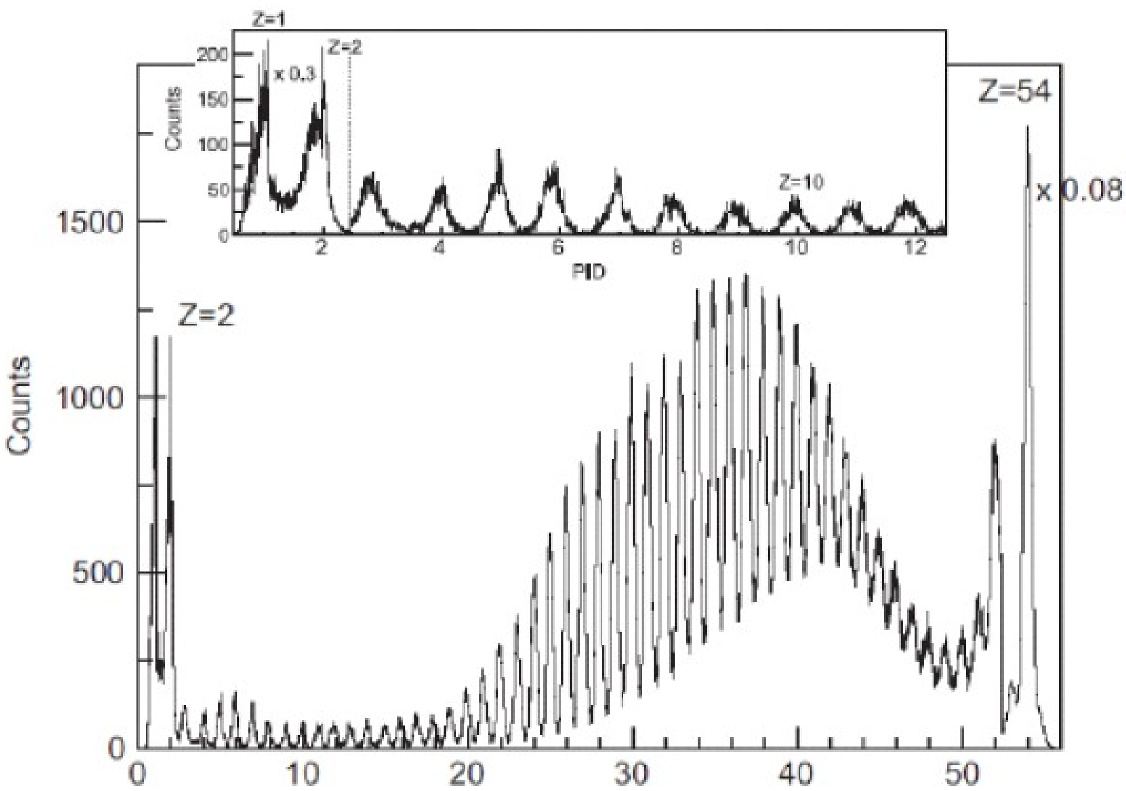


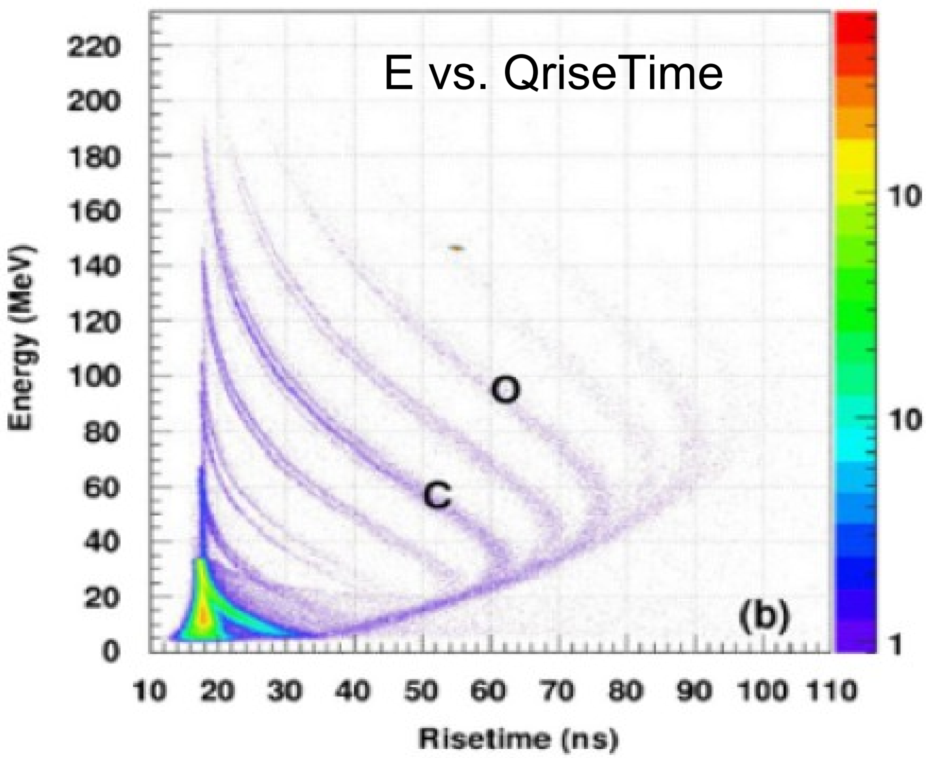
Isotopic separation achieved up to Z=23-25
Charge separation up to Z=54 (it's not a limit)

Results from Phase1 **PSA**

Strong improvement of PSA

IONS STOPPING IN A SINGLE LAYER

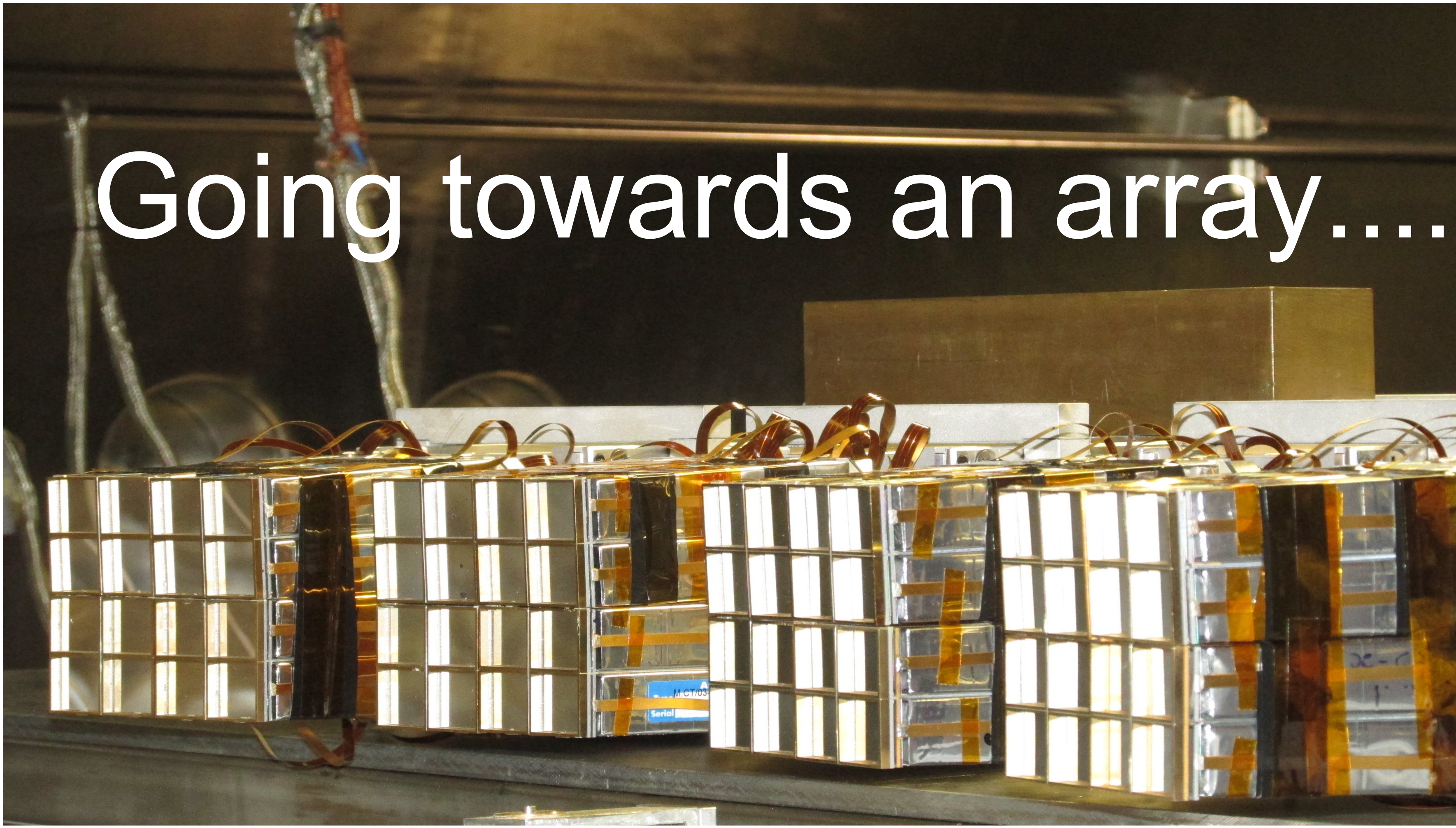




For path in the Silicon detector lower than 30 μm (for a C) to 100 μm (for a Xe), no discrimination is possible using PSA.

- Charge separation is obtained up to Xenon (Z=54)
- Mass separation is more critical; up to Z=14 in best detector-electronics conditions
- Reverse mounting needed
- **IMAX is better that QriseTime as a shape parameter**

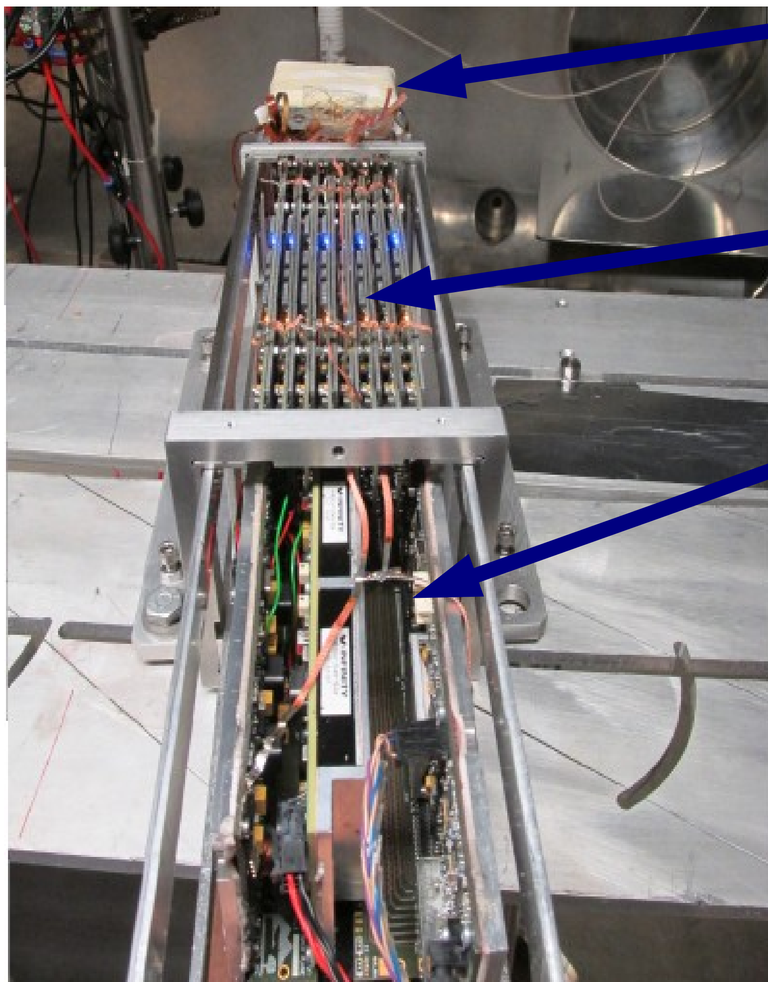
Going towards an array....



NOTE: So far most of these Silicon 20x20mm2 pads were produced by FBK starting from special 4inch nTD wafers from TOPSIL

The basic FAZIA Block

@ LNS



telescopes

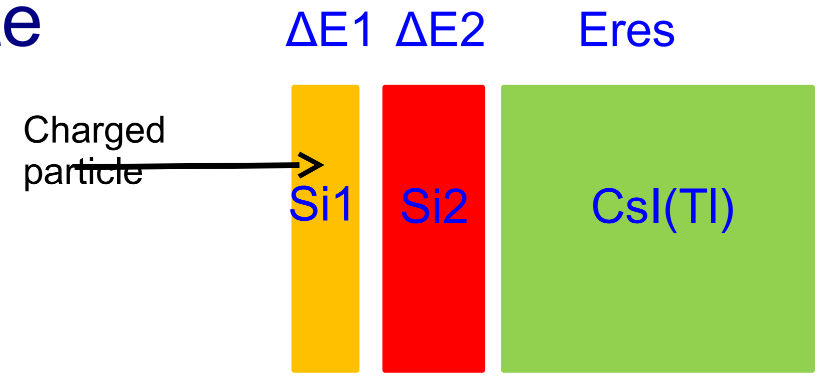
FEE boards, 6x8 channels

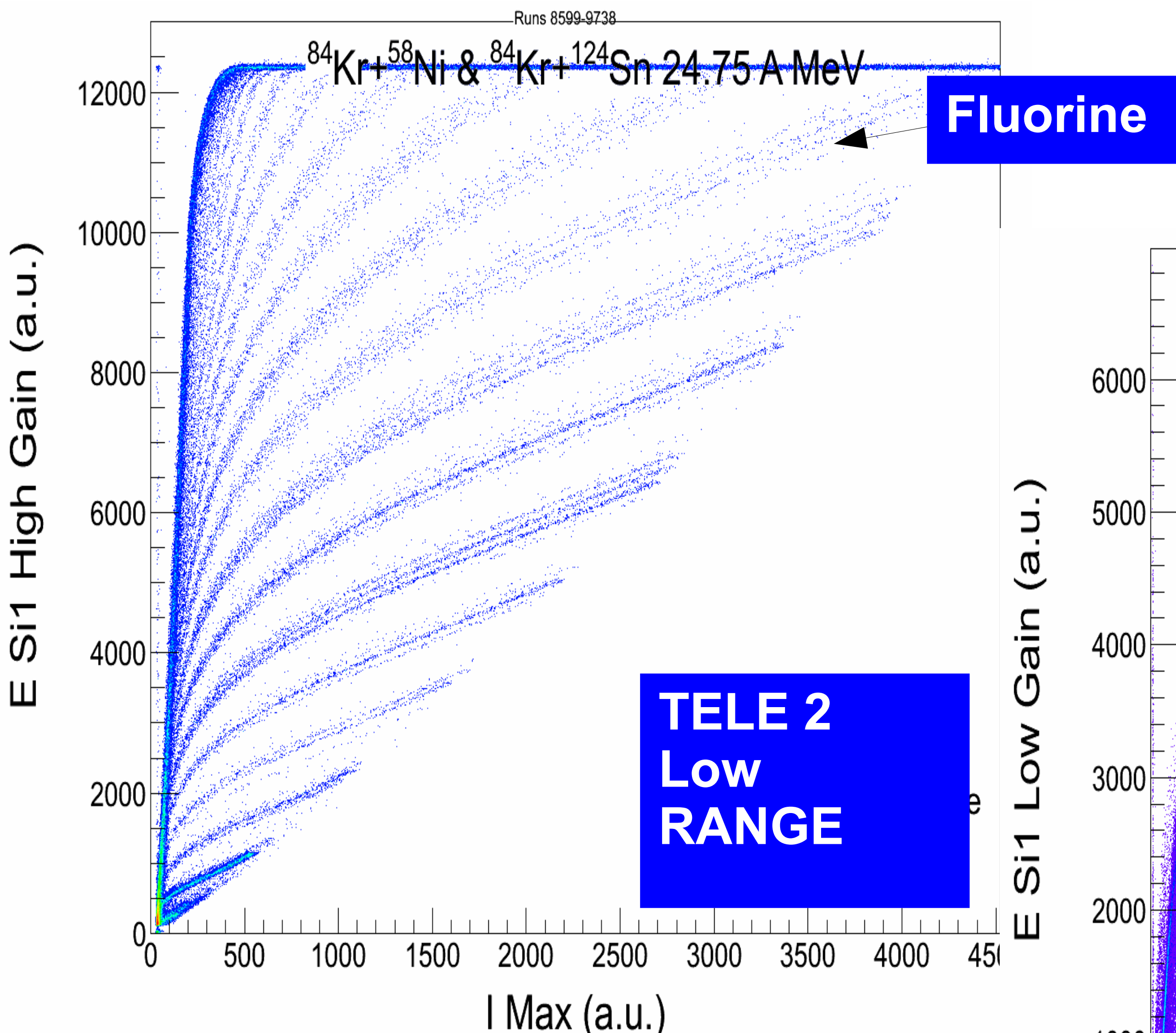
HV stage, Block Card, electro-optical coupling

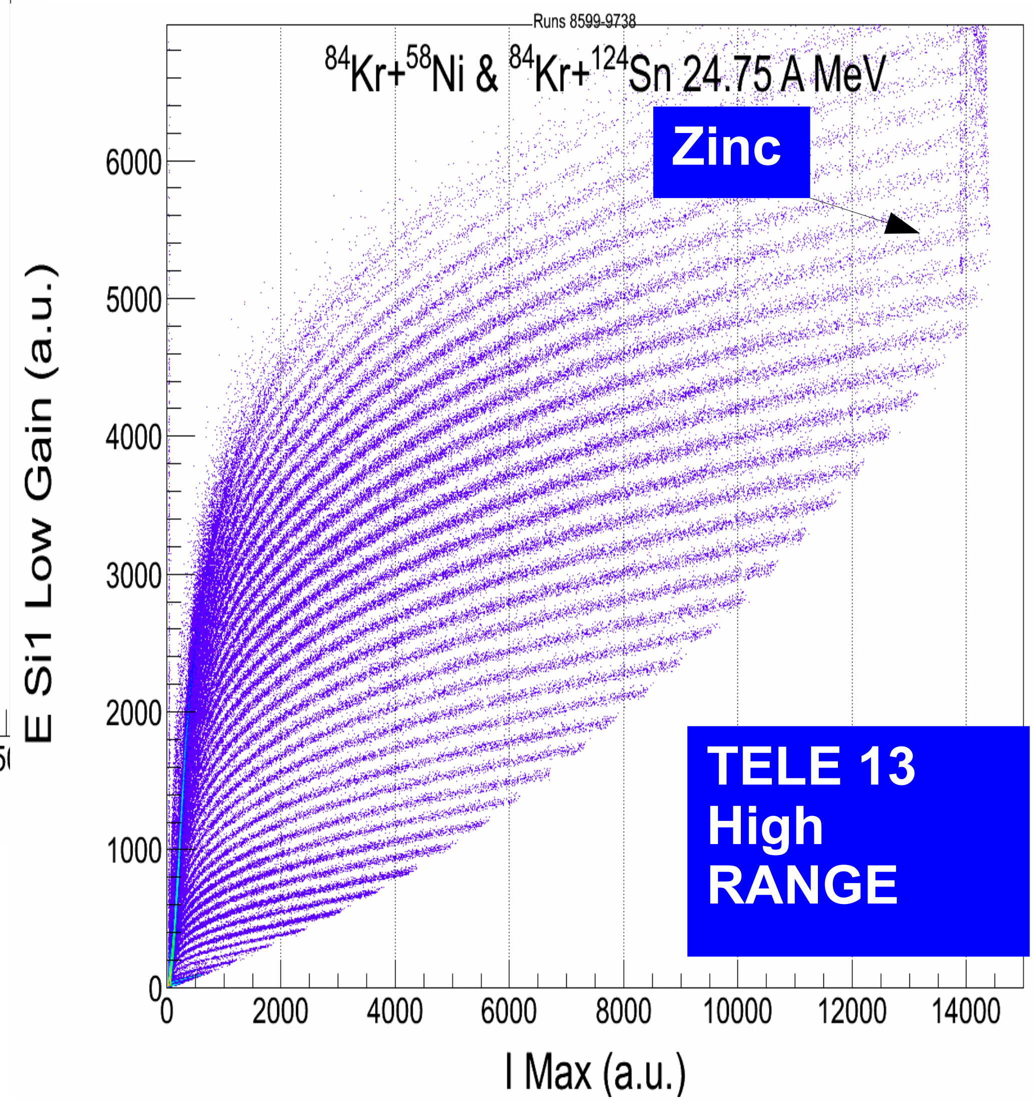
BLOCK: is the stand-alone FAZIA Module

- 16 Si-Si-Telescopes
- 8 FEE Cards wit 48 lines of preamplifiers, ADC and
- FPGA
- Power Generators and regulators. Pulser generation and control

LNS commissioning with a complete BLOCK



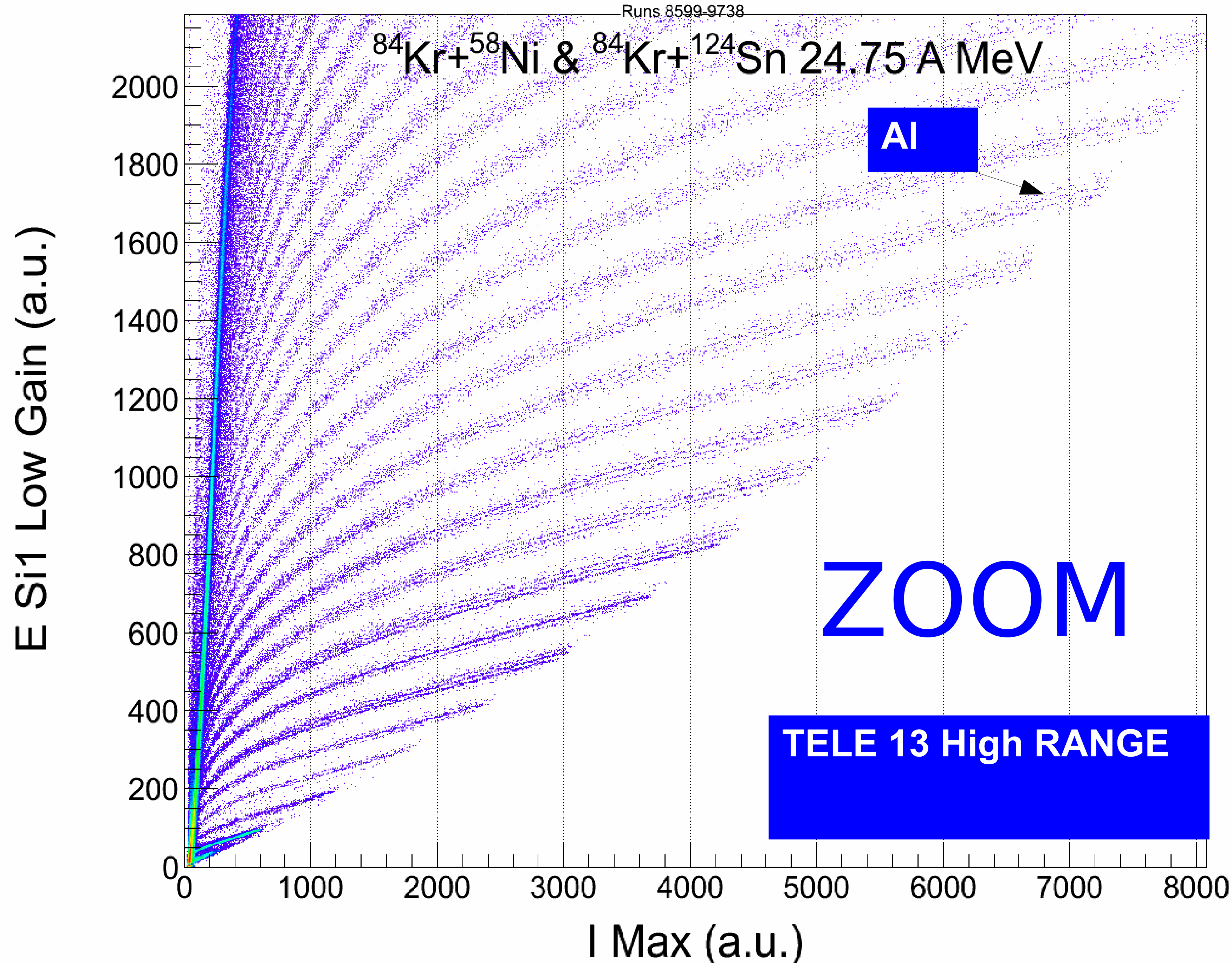




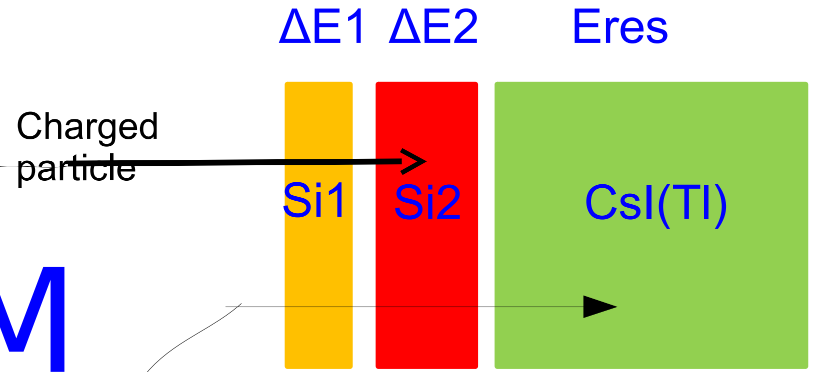
Isotopic separation from PSA up tp
Z=9-13
Full Charge identification

LNS commissioning

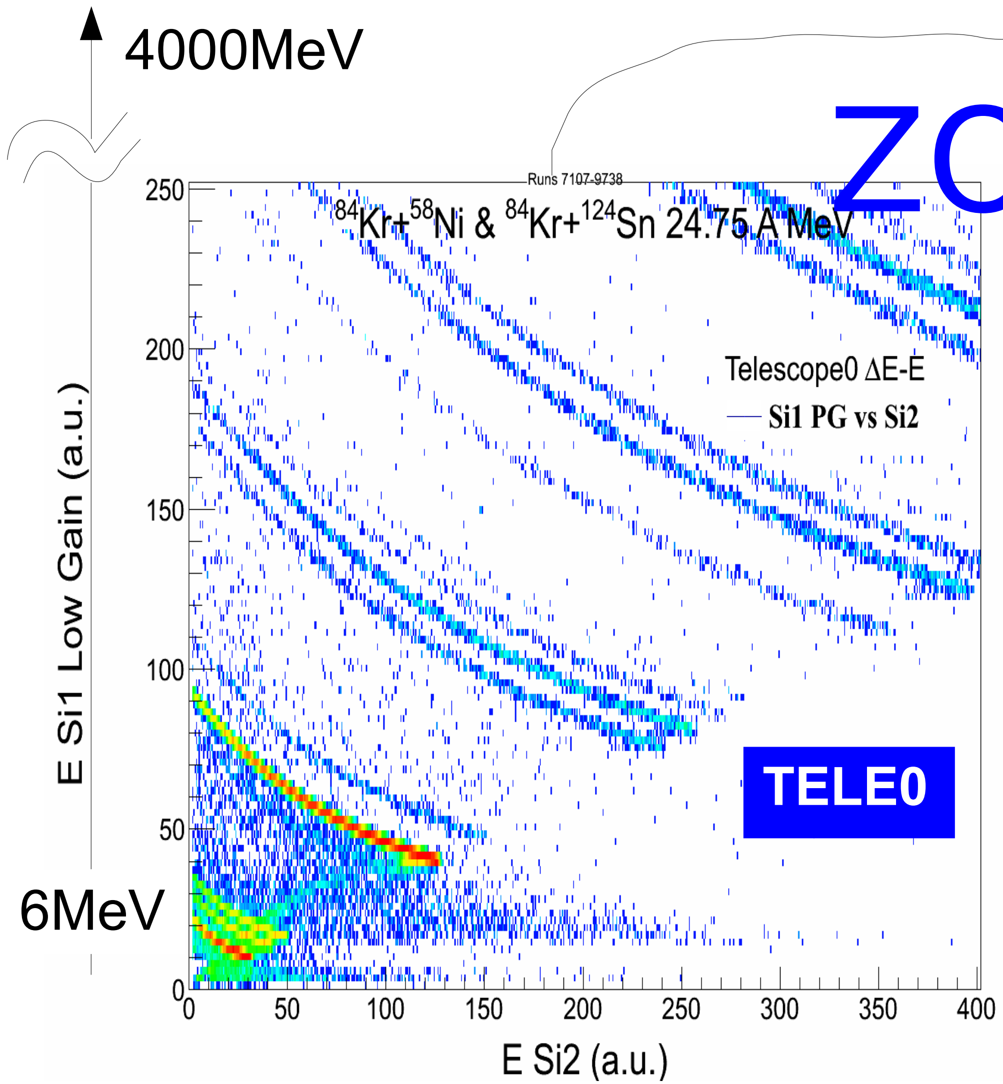
Isotopes for Z at least 14 from PSA

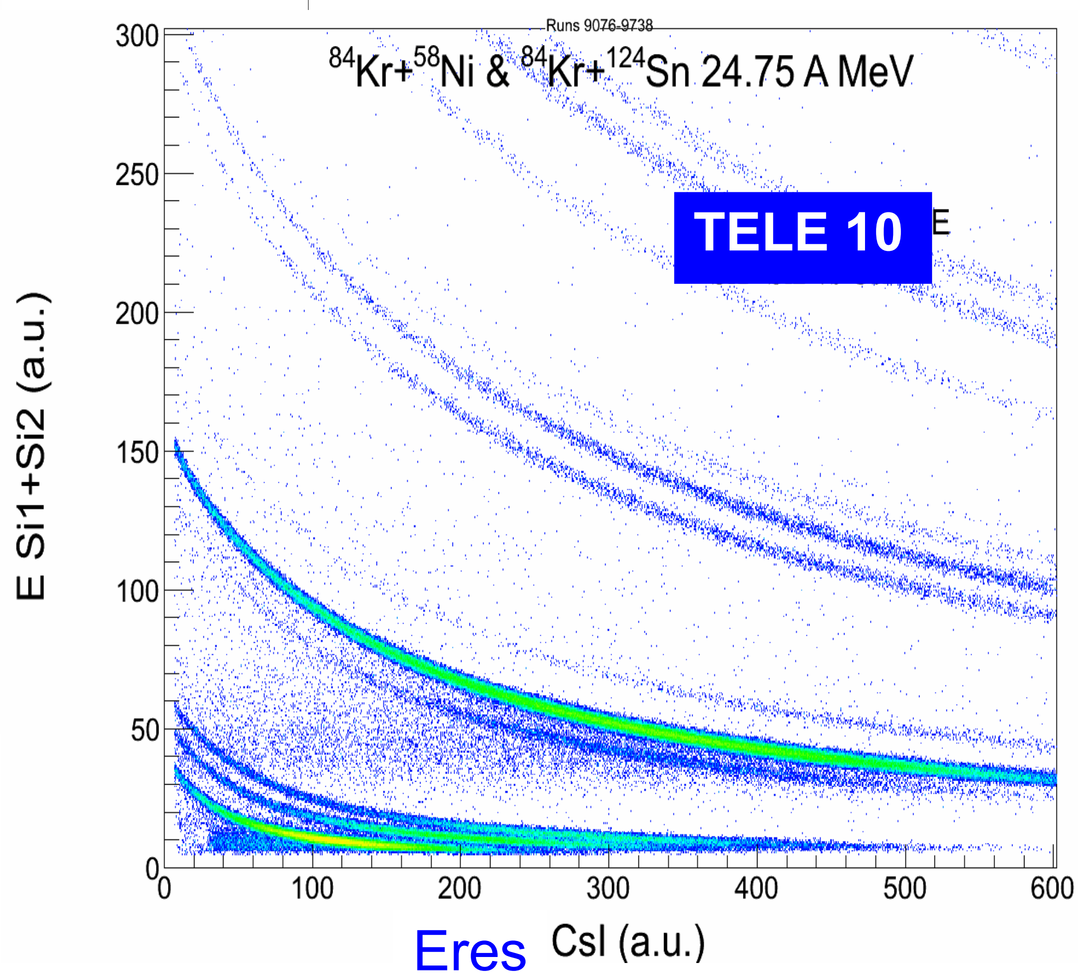


LNS commissioning



ZOOM



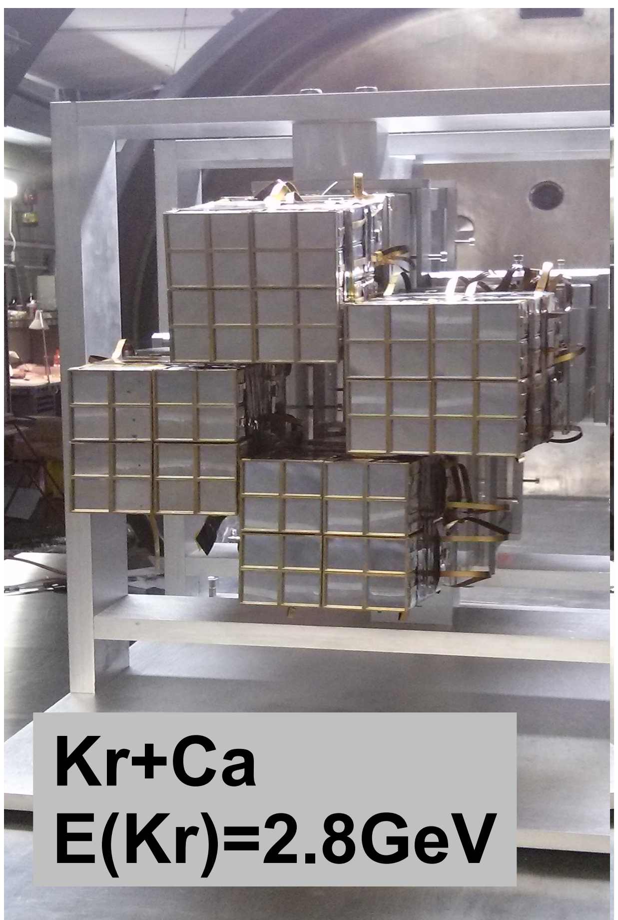


Very good isotopic separation also for light particles even with HighRange channel (ie. 4GeV dynamics!!)

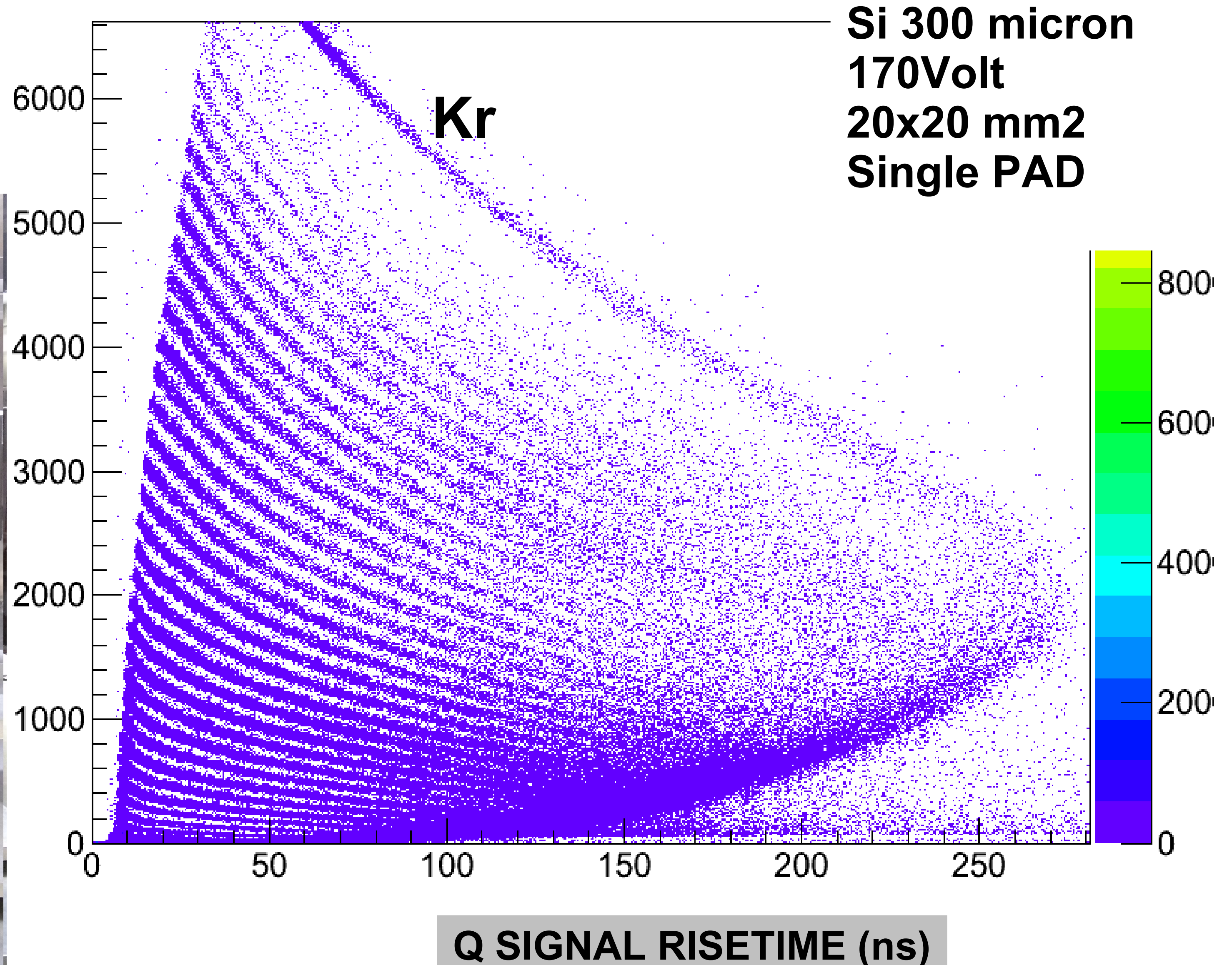
PSA in Silicon over a 'large' scale

The good performance are confirmed in recent (2015) experiments, too

Silicon 20x20 mm2
300micron
Single pad
nTD detector

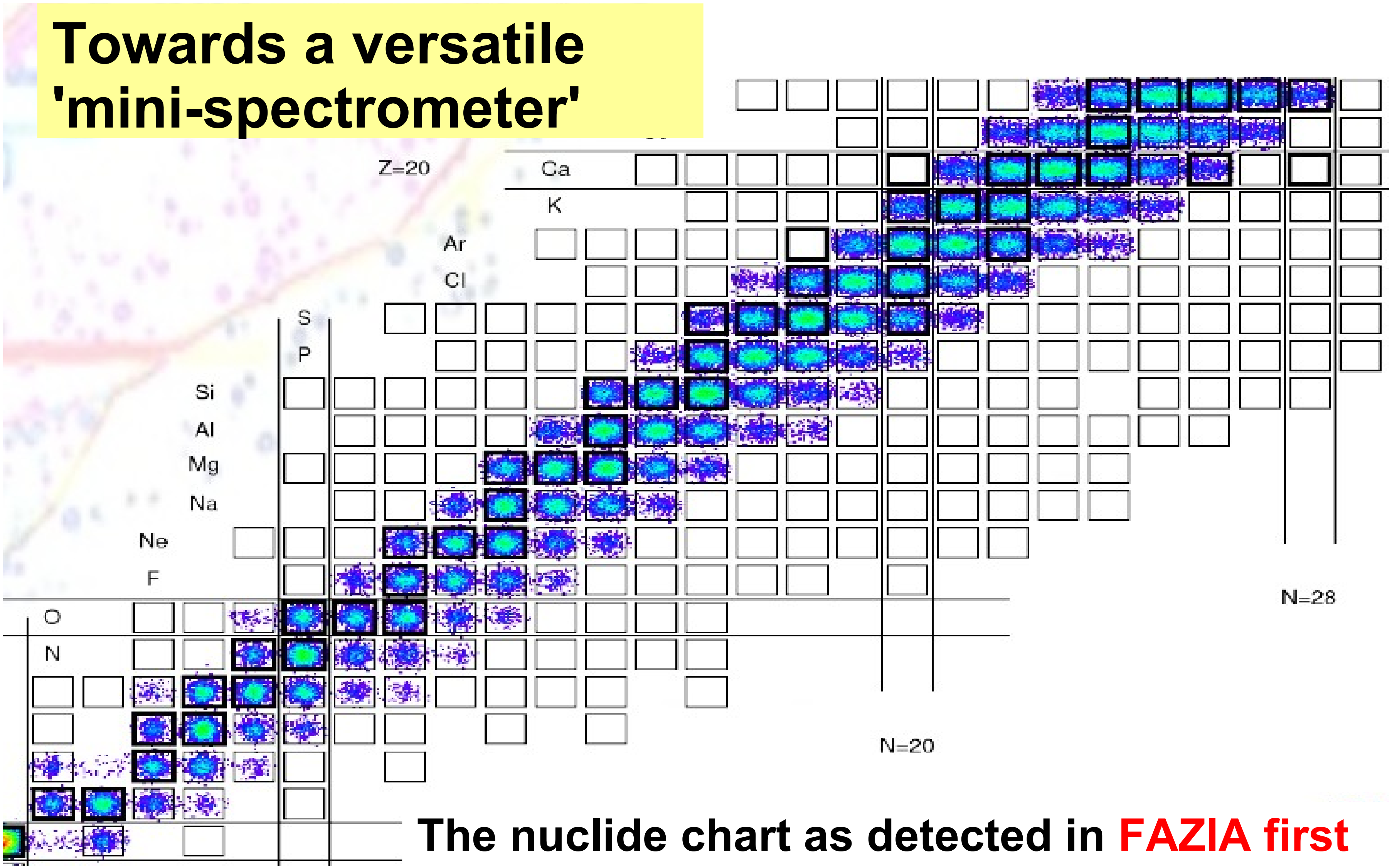


ISOFAZIA experiment LNS 2015



Present identification quality

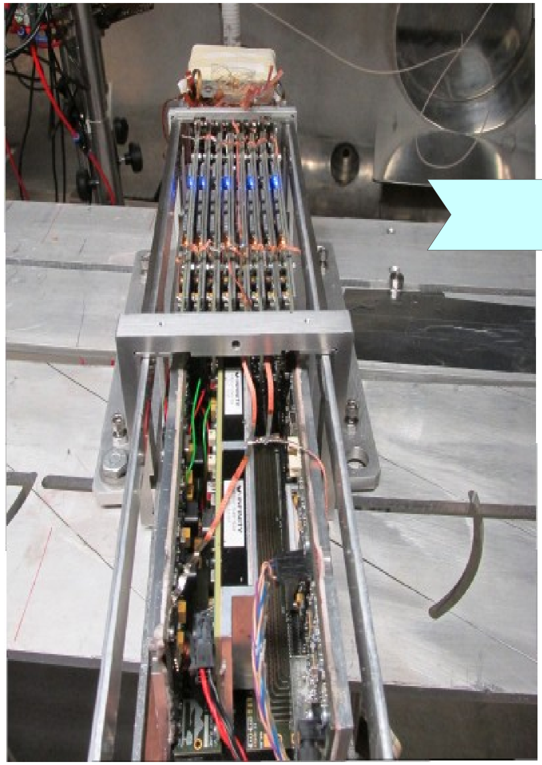
Towards a versatile 'mini-spectrometer'

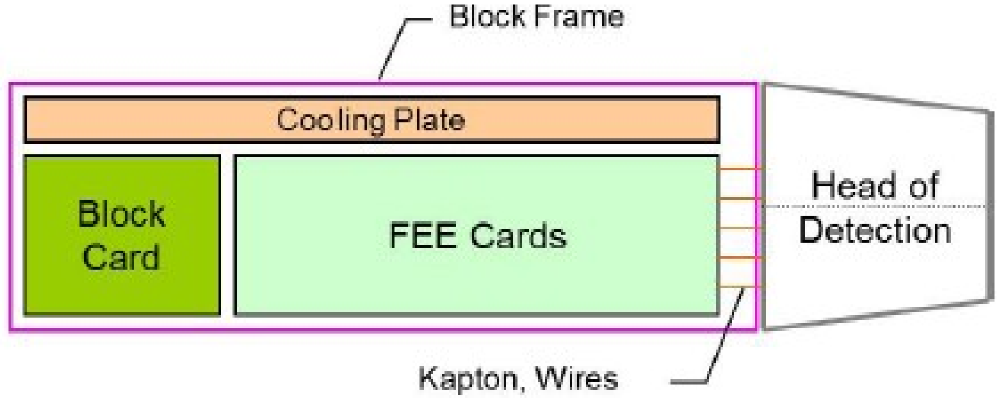


The nuclide chart as detected in FAZIA first experiments
(adapted from J.Frankland, Spiral2 week, 2014)

The basic FAZIA Block: not only detectors...

Charge and current l.n. Preamps; 48 channels on 8 FEE cards. Each FEE contains with 6 channels





Stage 1 (300 μm silicon detector):
- Charge: 250 Ms/s 14 bit (250MeV full scale)
- Charge: 100 Ms/s 14 bit (4 GeV full scale)
- Current: 250 Ms/s 14bit

Stage 2 (500 μm silicon detector):
- Charge: 100 Ms/s 14 bit (4 GeV full scale)
- Current: 250 Ms/s 14bit

Stage 3 (10 cm CsI(Tl) + photo-diode):
- Charge: 100 Ms/s 14 bit (4 GeV silicon-equivalent full scale)

IPN (Orsay)

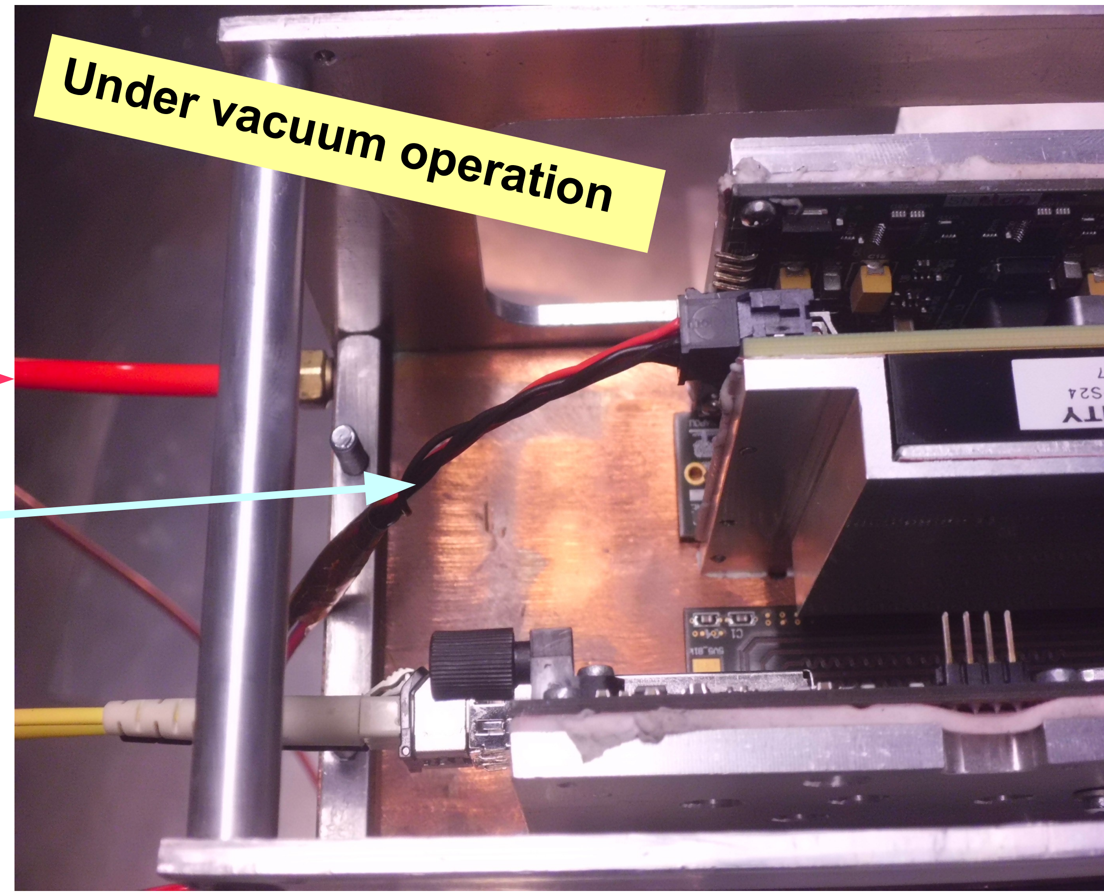
Powerful electronics

High Power, cooling, large data Bandwidth: all on a few cables !

COOLING — Water cooling pipe

POWER — 48V 'parent' Power supply

I/O DATA — 3GB/s optical fibers



MAJOR CONTRIBUTIONS: **IPN (Orsay), INFN Naples and INFN Florence**

Ion identification in silicon detectors: new efforts

Lower identification thresholds

Very thin (large area) detectors for DE-E, but PSA?
Combine PSA with TOF? Timing issue... (see Lu et al.)

Improve identification quality

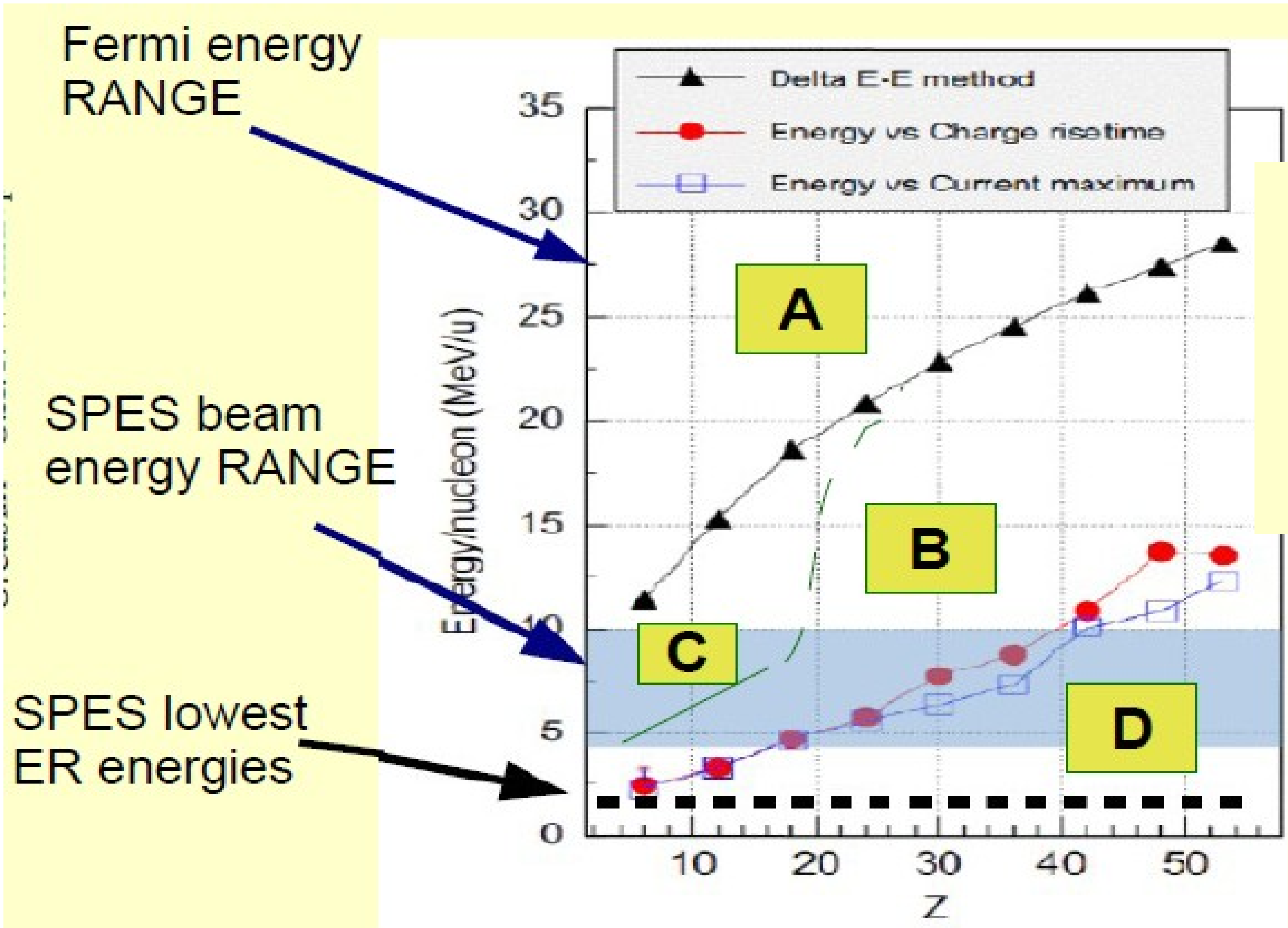
Lowering bias voltage (uncomplete depletion)

More radiation resistent chips

SiC promise... as we're discussing

Long term plans >2020:
FAZIA (12 blocks) @SPES (and Spiral2)

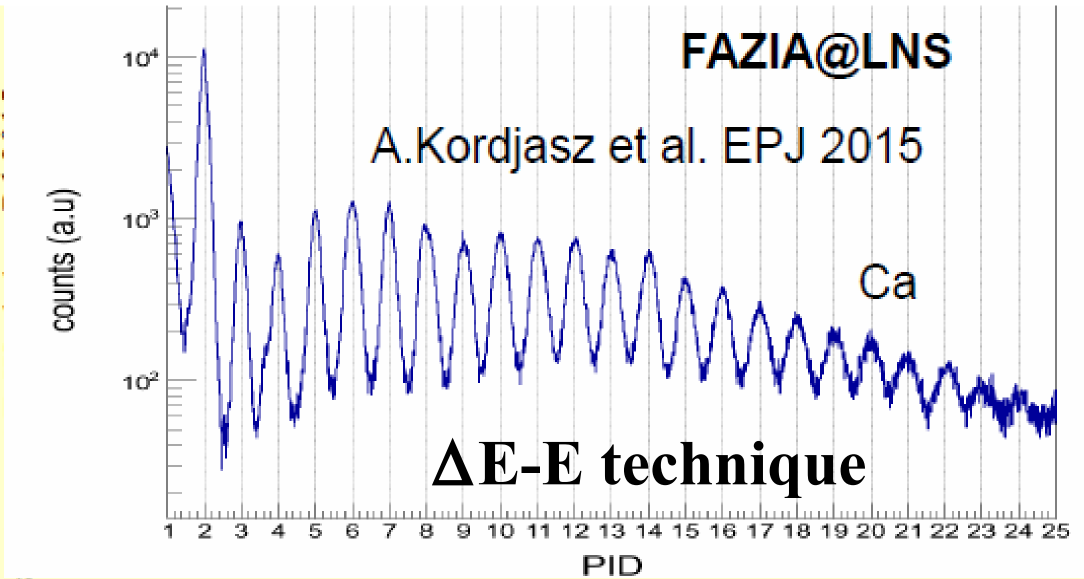
FAZIA very good for Fermi energy domain but what about n-rich ISOL Beams?



A	Unlimited Z A up to Z=23-25
B	Unlimited Z
C	A up to Z=13-14
D	No identification

very thin Epitaxial detectors

Si(20µm)-Si(500µm)

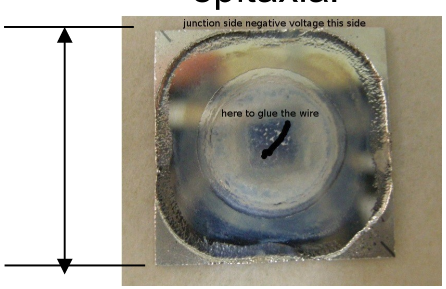


- Use very thin and "large" square FAZIA-custom detectors as a first Silicon stage.
- Recovering ΔE-E method
- Encouraging results

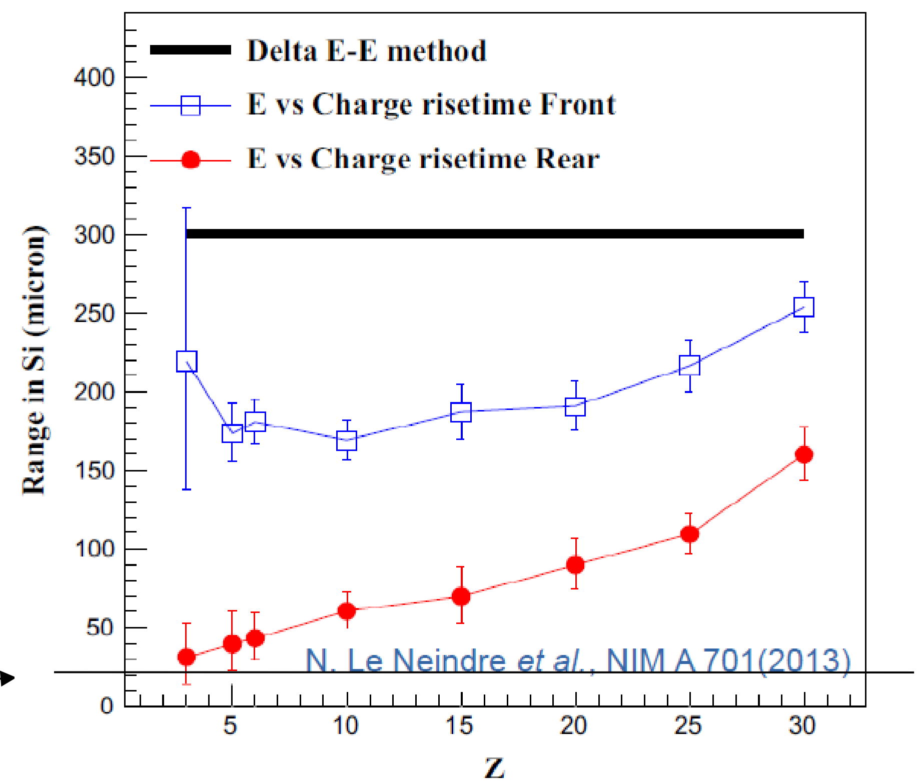
Z-identification with thresholds as low as 1.1MeV for protons and 2MeV/u for Mn ions.

epitaxial

20mm

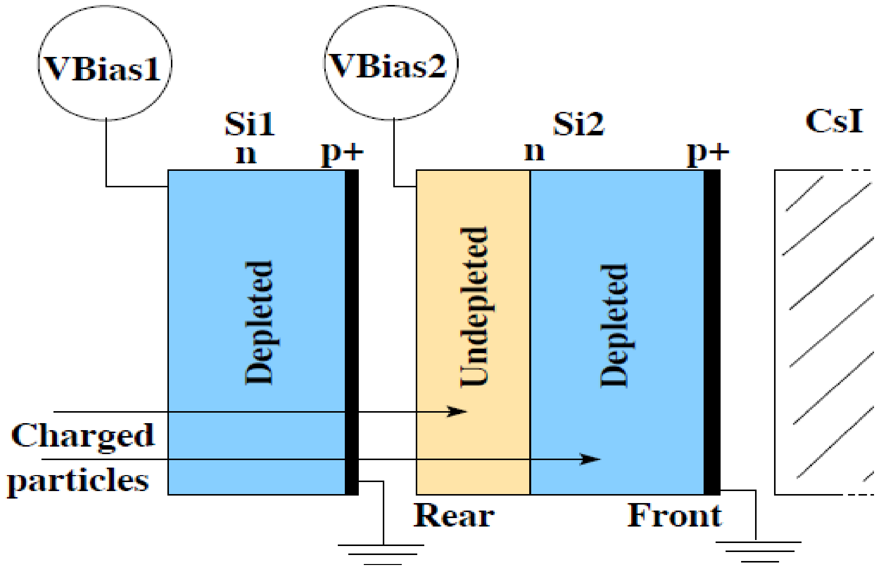


21µm thick



Partially depleted Silicon detectors

Pasquali et al Eur. Phys. J. A (2014) 50: 86



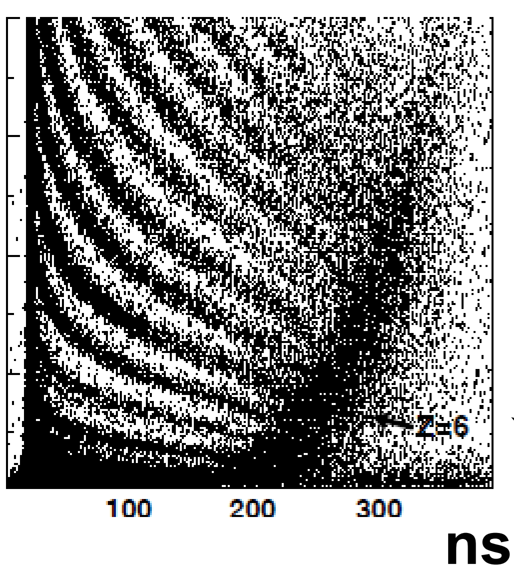
ΔE-E technique

- **What if the E field is decreased within the bulk**
- **Larger PSA sensitivity?**
- **Spoiled Energy resolution?**
- **Thresholds?**

Kr+Sn,Au at 35 MeV/u
FAZIA telescopes

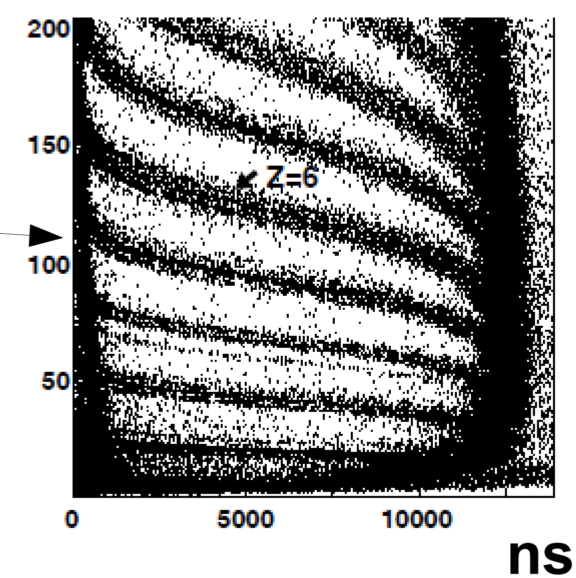
Collection Times strongly increase from 300ns to 13000ns

V=290Volt



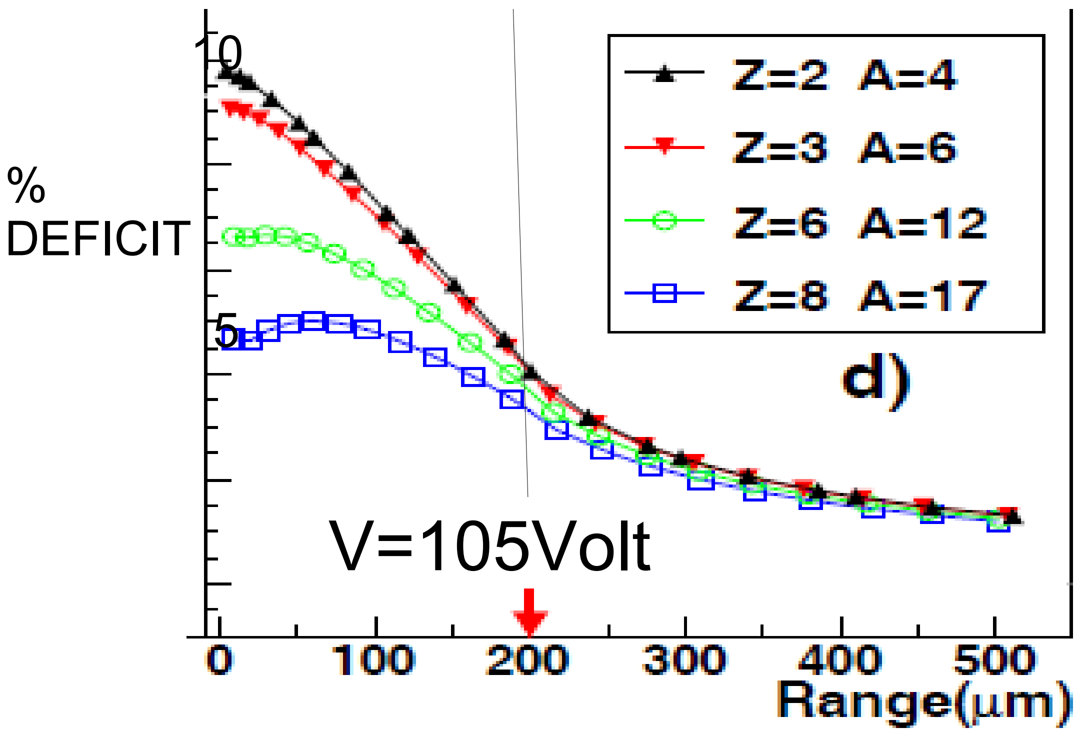
Voltage on Si2 (V)	Depletion depth (μm)	Undepl. layer (μm)	Max. rise-time (20–70%) (μs)
105	310	200	13
130	340	170	10
200	420	90	3.0
235	460	50	1.5
290	510	0	0.45

V=105Volt



Partially depleted Silicon detectors

ΔE-E technique and Energy



Rather surprinsingly

- **Energy calibration only slightly changes from 290 to 105Volt**
- **CCE remains high (only 2% deficit for energetic ions)**
- **CCE is still high (8% deficit) for ions stopping in the E=0 region**

Isotopic separation holds

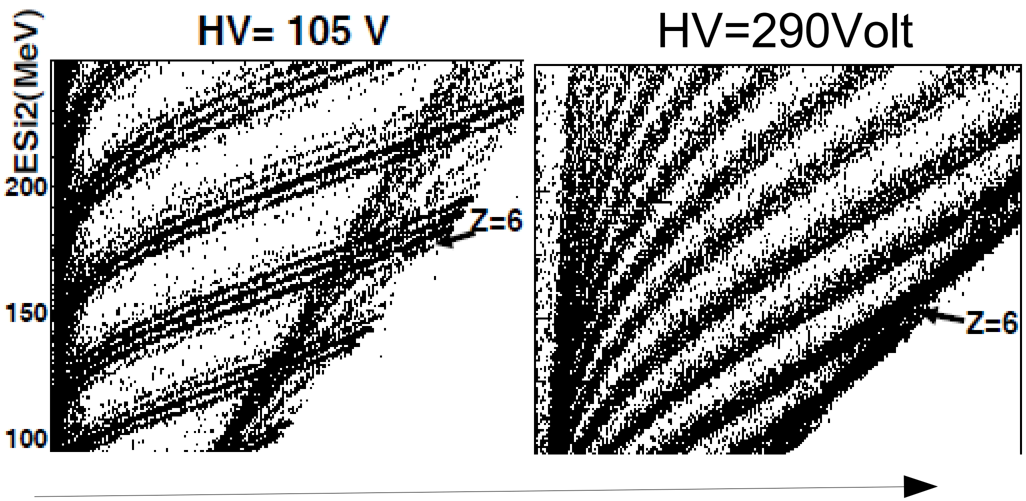
FoM don't change

Energy measurement is preserved (see Table, right) provided that a long shaping time is used

Isotopes	Applied voltage (V)				
	105	130	200	235	290
^{6}Li-^{7}Li	1.51(9)	1.5(2)	1.4(1)	1.5(1)	1.5(1)
^{11}B-^{12}B	1.52(4)	1.50(6)	1.54(6)	1.43(6)	1.42(5)
^{12}C-^{13}C	1.50(5)	1.44(5)	1.50(6)	1.50(5)	1.51(6)
^{21}Ne-^{22}Ne	1.18(9)	1.21(6)	1.20(8)	1.18(3)	1.19(8)

Partially depleted Silicon detectors

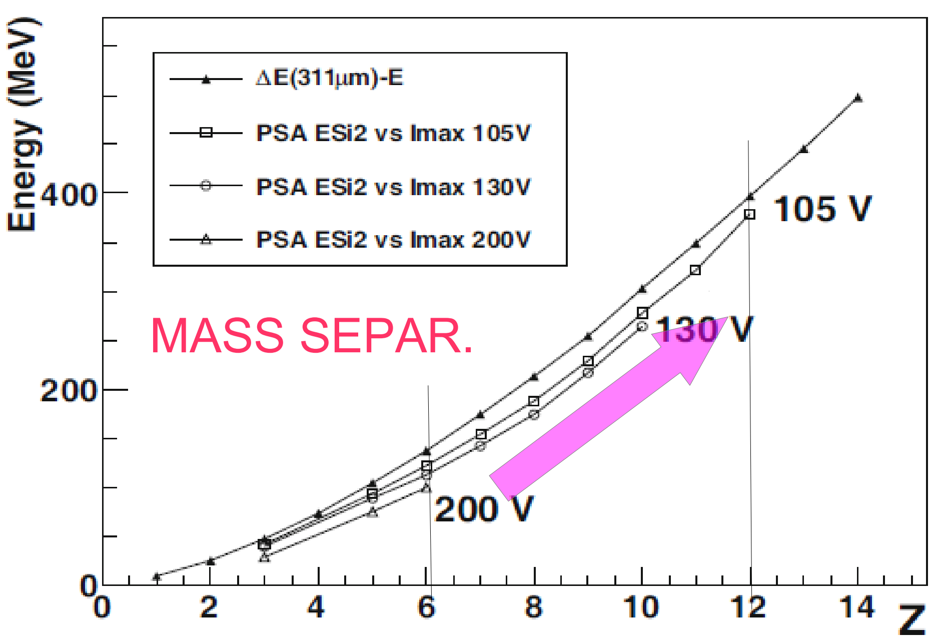
PSA is strongly affected

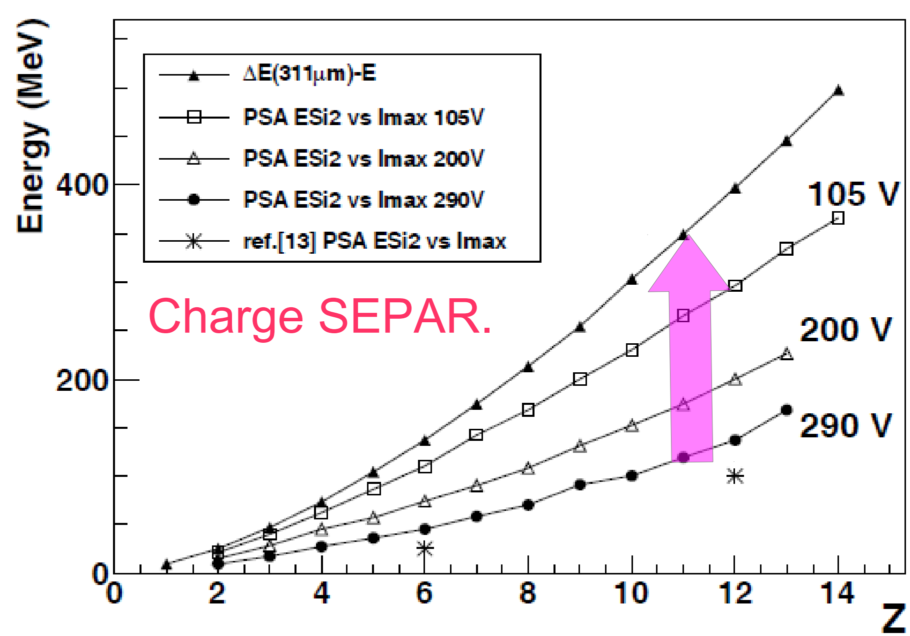


Maximum of the current signal

Rather surprinsingly

- **Identification quality changes from 290 to 105Volt**
- **Isotopes are better separated at low voltages**
- **Charge separation is obtained at higher thresholds for undepleted operation**
-





Conclusions

Many aspects related to an optimum use of Si detectors for heavy ion spectroscopy have been evidenced during the FAZIA activity

Parameters to be kept under control for PSA and DE-E

Orientation of processing and mounting
Homogeneity of the doping
Metalization of surfaces
Radiation Damage

Other subjects

Going to thin detectors
Underbiasing and PSA
Charge collction in Zero Field regions
Best filters (analysis of samples)
Timing

This is an expertise than can be useful for SiC developments in the HIC field