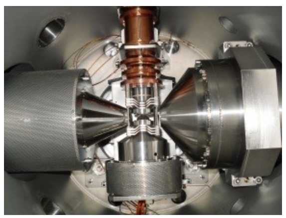
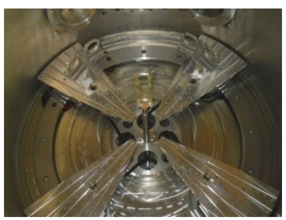
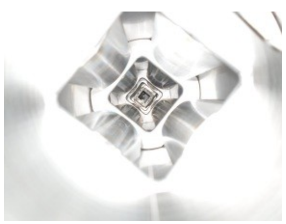



New trends in isotopic identification with telescope detectors

Diego Gruyer (INDRA and FAZIA Collaborations)
LPC Caen , France.

Needs for isotopic identification

EoS and isospin transport

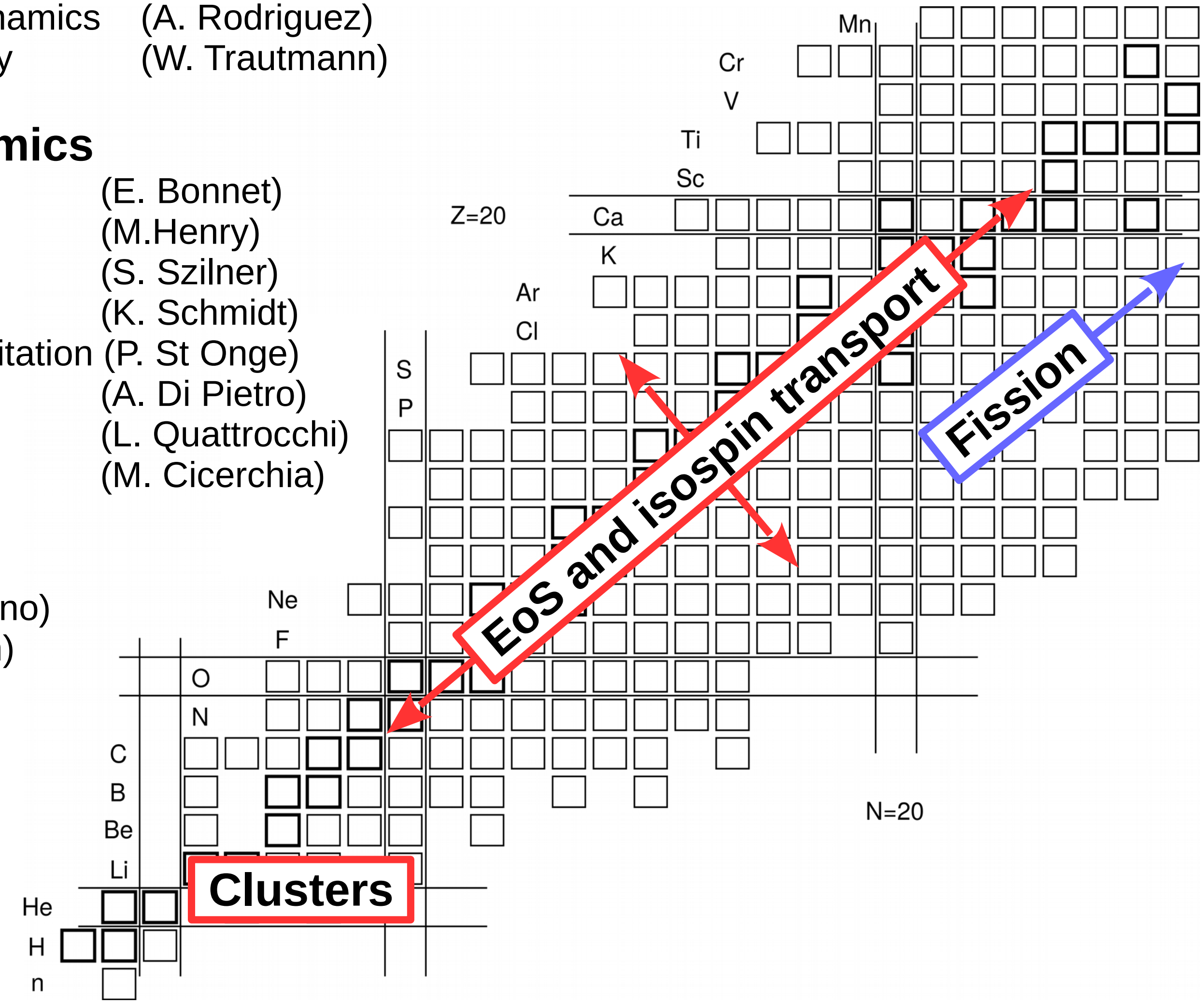
Isospin effects in nuclear reactions (S.Yennello)
Recent results from ISOFAZIA experiment (S.Piantelli)
Study of the N=Z fragment production (A.Camaiani)
Equilibration dynamics and isospin effects (A.S. Umar)
Isospin influence on IMF dynamical emission (B. Gnoffo)
Constrains on the symmetry energy (J. Lukasik)
Equilibration chronometry and reaction dynamics (A. Rodriguez)
Dynamical properties and secondary decay (W. Trautmann)

Clusters in structure and dynamics

Characterization of the nuclear gas phase (E. Bonnet)
Transport properties at Fermi energies (M.Henry)
Probing nucleon-nucleon correlations (S. Szilner)
Temperature and densities of hot ^{40}Ca,^{40}Si (K. Schmidt)
Influence of neutron enrichment on de-excitation (P. St Onge)
Exotic clustering investigation in ^{13}B,^{14}C (A. Di Pietro)
Decay of ^{12}C excited states (L. Quattrocchi)
Study of four reactions forming ^{46}Ti* (M. Cicerchia)

Fission

Fission in inverse kinematics 1 (M. Caamano)
Fission in inverse kinematics 2 (L. Audouin)



1. **ΔE-E identification**

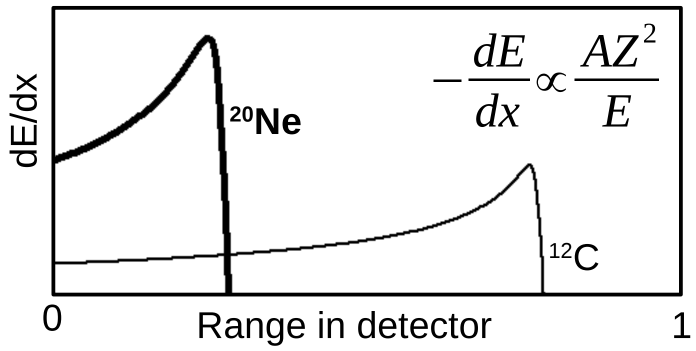
2. **Pulse Shape Analysis identification**

3. **Time of Flight identification**

4. **Data processing**

Isotopic identification with the ΔE-E method

Stopping power
Stopping power depends on the charge (Z), mass (A), and energy (E) of the particle



Isotopic identification with the ΔE-E method

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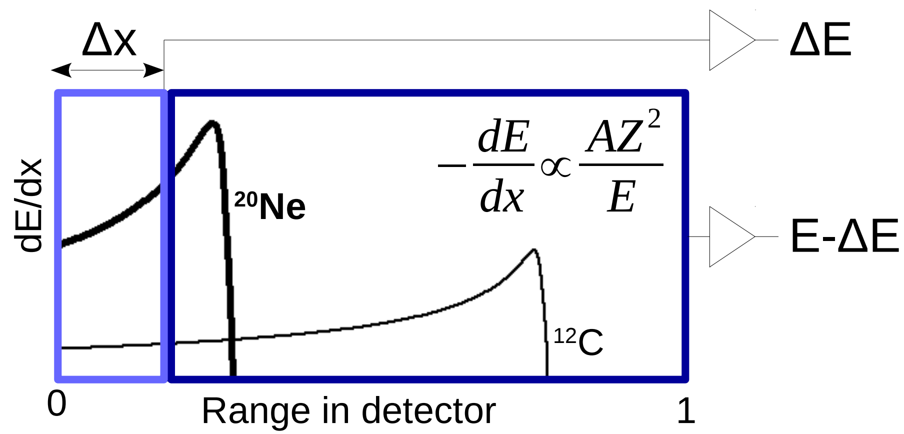

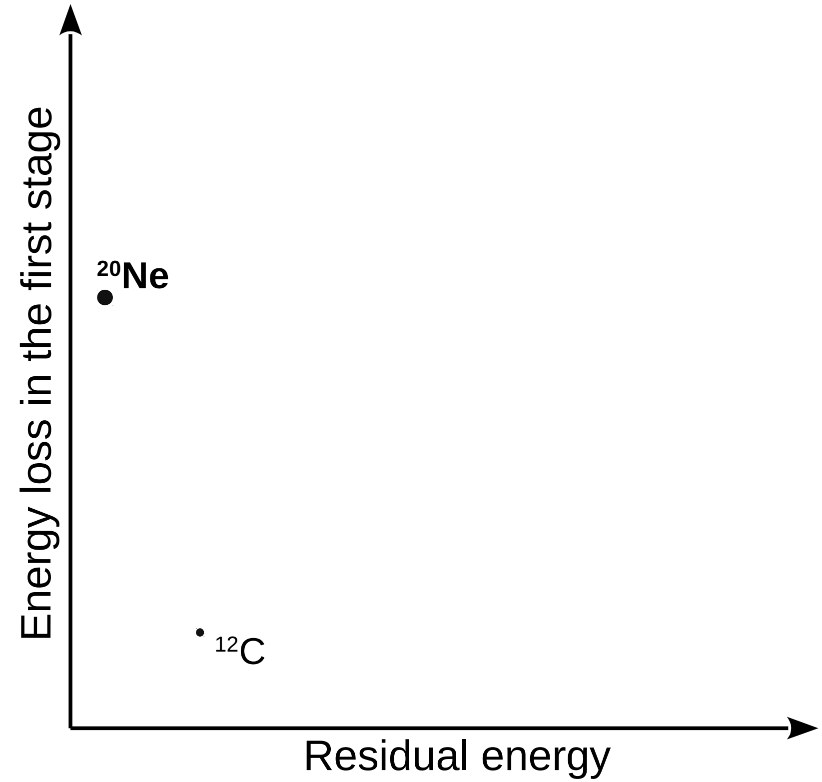

ΔE-E method
Divide the material in ΔE and E layers
In the ΔE-E plot, particles populate lines characteristic of their charge and mass

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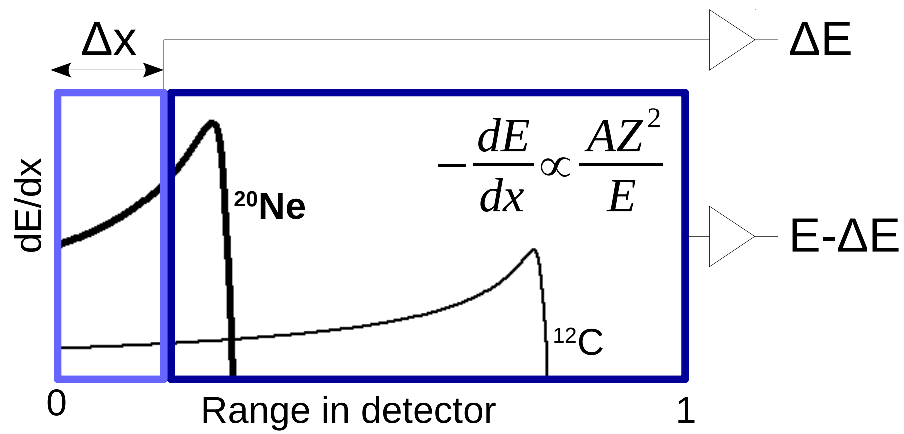

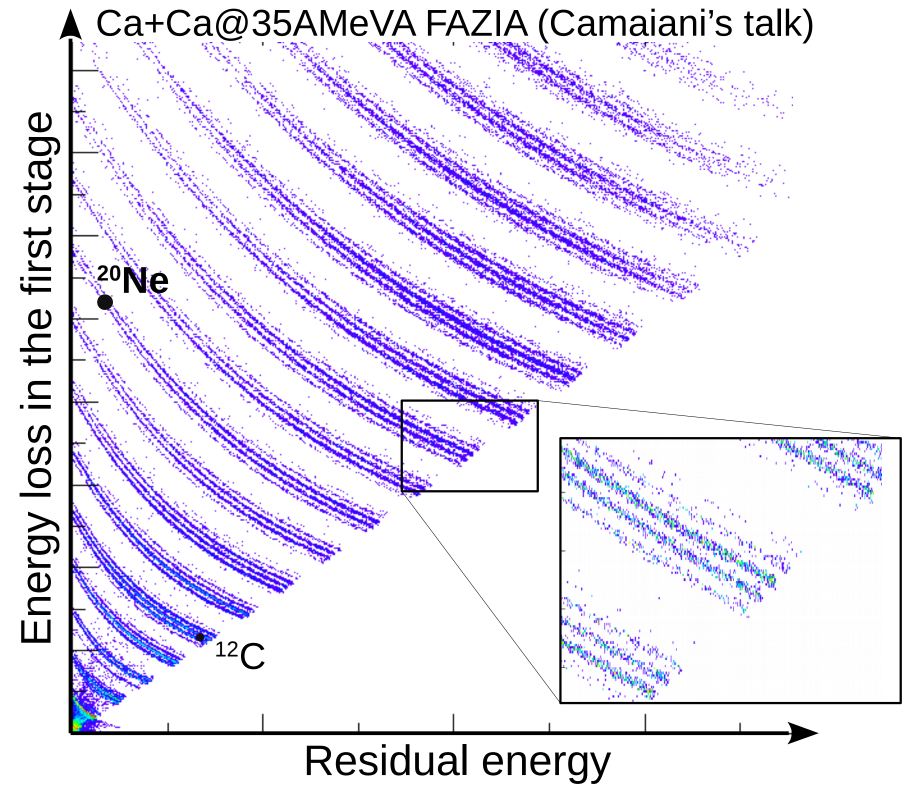

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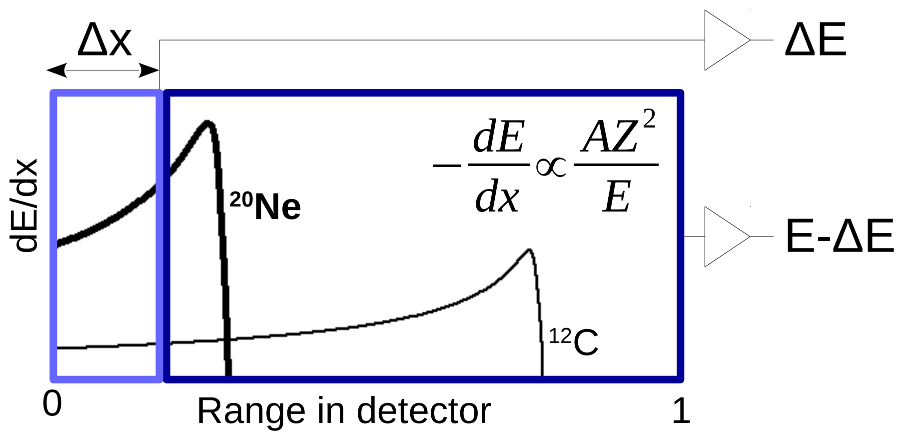
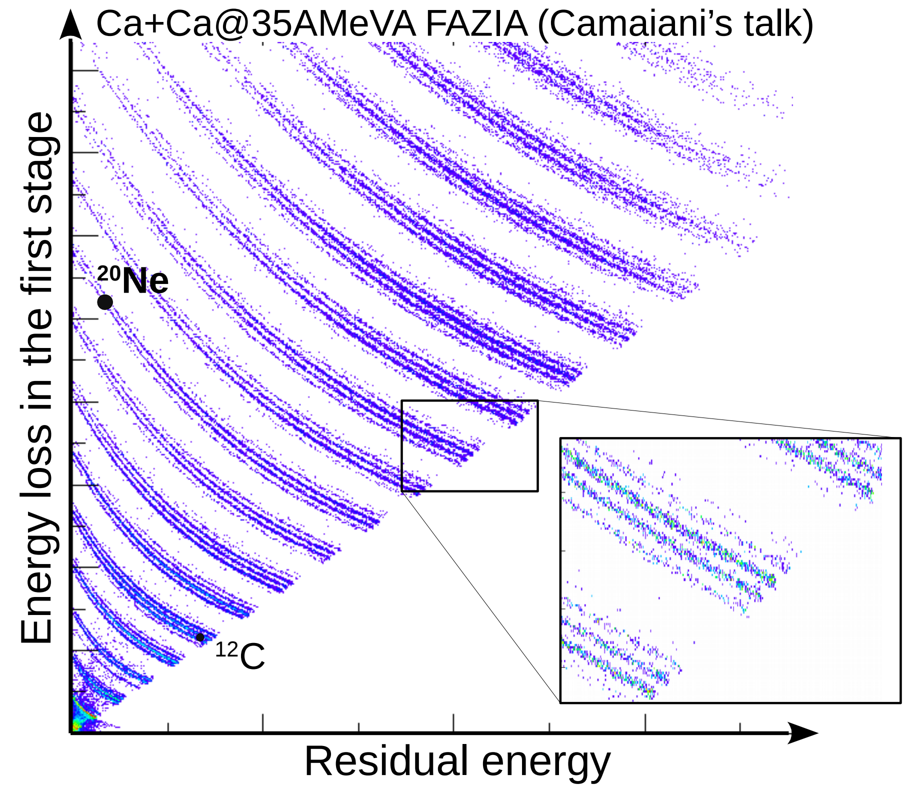


ΔE-E method
Divide the material in ΔE and E layers
In the ΔE-E plot, particles populate lines characteristic of their charge and mass

Performances
No limit in charge ID (up to Z~92)
Energy straggling limits mass ID (Z<25-30)
Limited number of isotopes (~7) per element

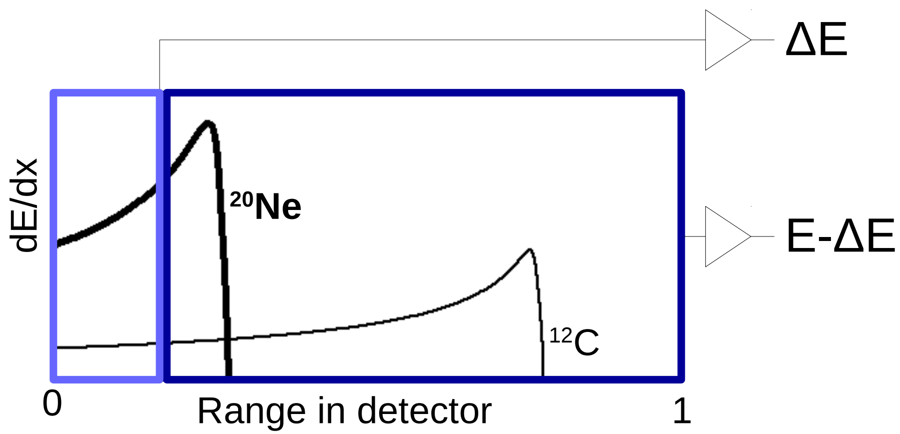


Measure ΔE and E
Electronics and signal processing
Channeling effects in ΔE detector

Keep Δx under control
Detector thickness homogeneity

ΔE-E telescopes

- **Silicon detectors**
  Good energy resolution and fast signals (ToF)
  Good performances for Pulse Shape Analysis
  Can be divided in strips on both side
  Often used as thin ΔE layer (from few µm to few mm)



- **Scintillators**
  Robust and cheap very thick detectors (few cm)
  Mainly CsI(Tl) are used for many years
  Neutron sensitive plastic scintillator (Pagano's talk)

- **Low pressure gas detectors**
  Not suitable for isotopic identification (E resolution)

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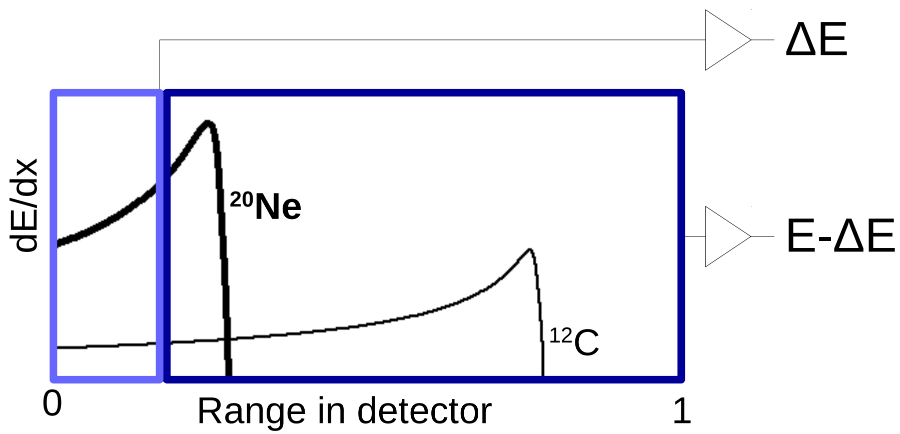

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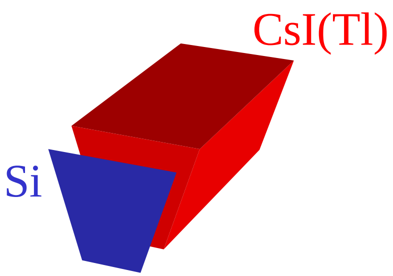
Low pressure gas detectors
- Not suitable for isotopic identification (E resolution)

« Simple » telescopes

CHIMERA	:	Si-CsI
FAZIA	:	Si-Si-CsI
NIMROD	:	Si-Si-CsI

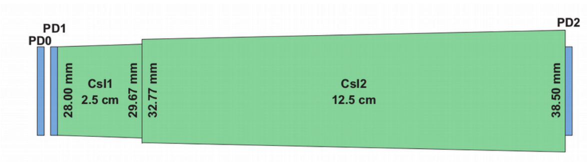


Silicon strip telescopes

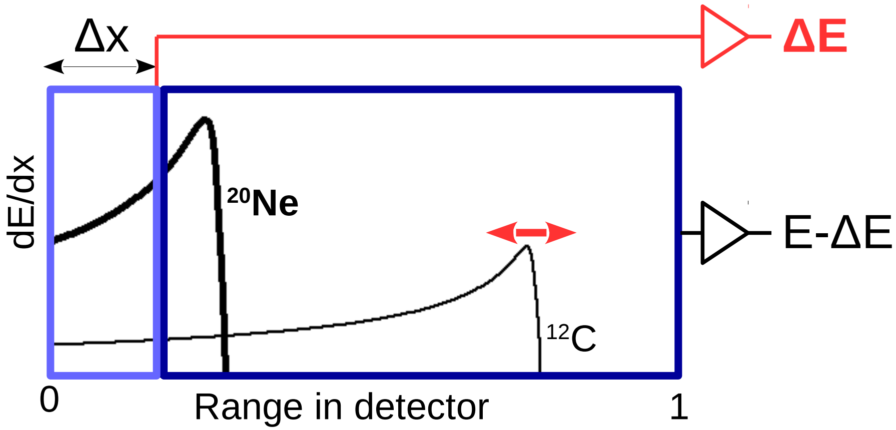
HiRA	:	Si-Si-CsI
OSCAR	:	Si-Si
GASPAR	:	Si-Si-Si
FARCOS	:	Si-Si-CsI

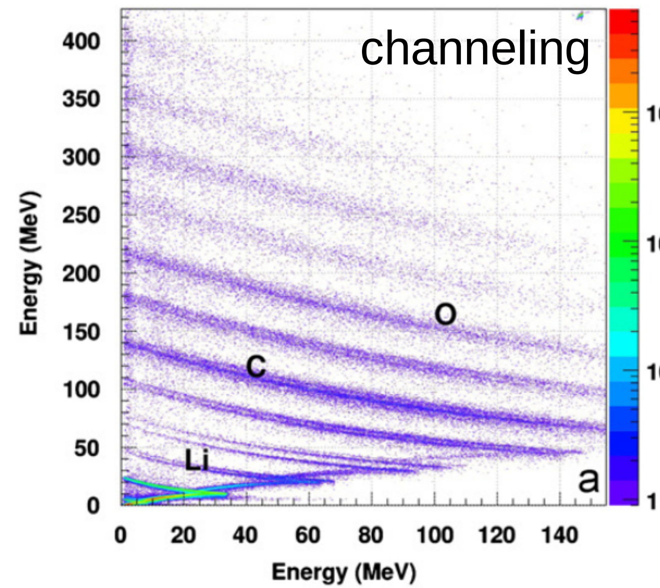
Less simple telescopes

KRATTA : Si-Si-CsI-CsI-Si



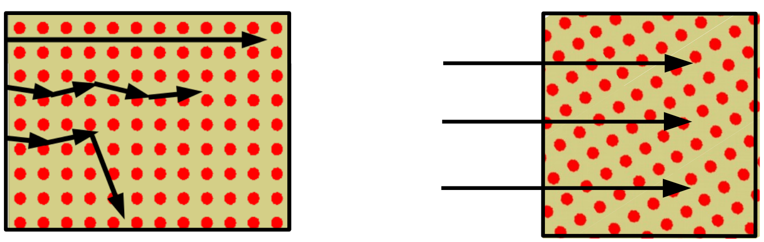
Cristal orientation and channeling

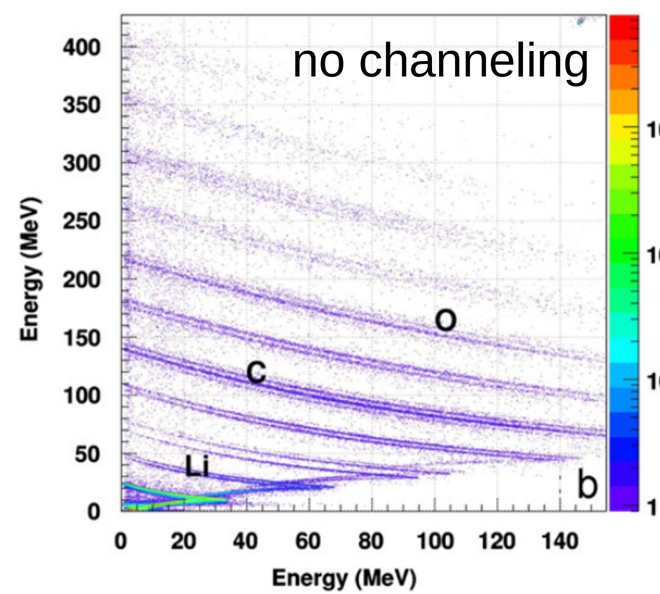




Channeling in silicon

Observed particles goes parallel to the principal axis
Induce a fluctuation on the particle range
Increases the energy straggling in the ΔE silicon



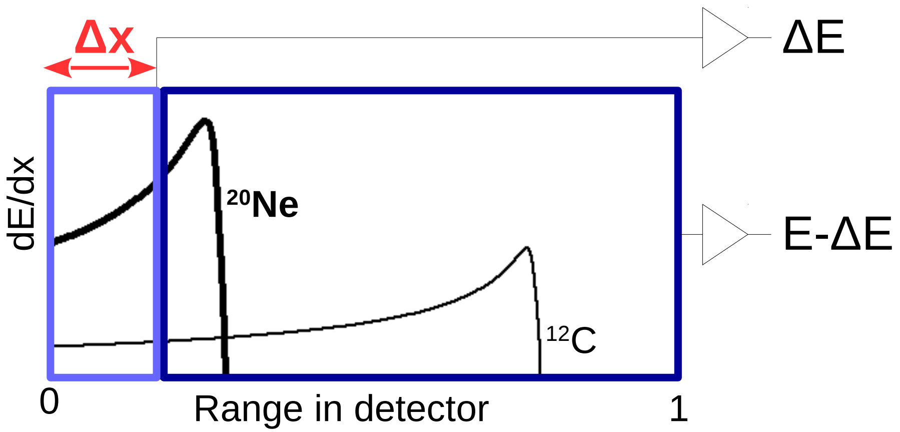


Solution

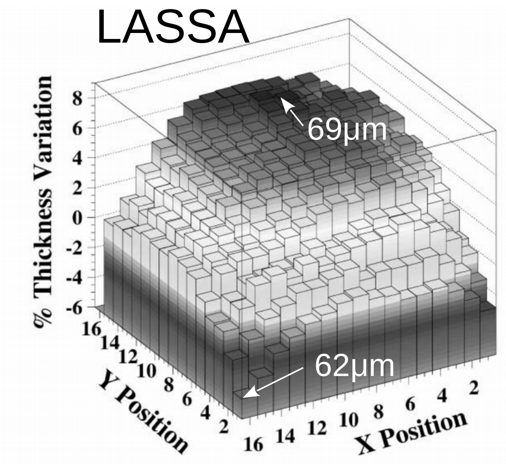
Cutting the cristal at ~7° with respect to the principal axis allows to recover the isotopic resolution

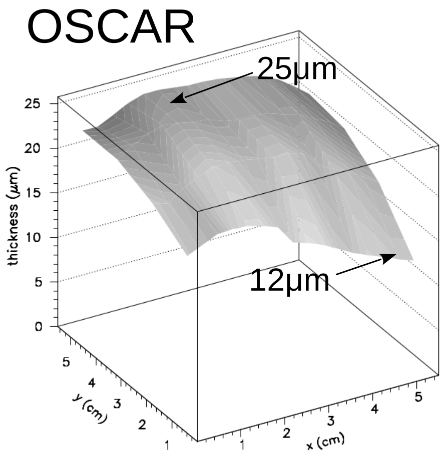
Bardelli, NIMA **654** (2011) 272
Bardelli, NIMA **605** (2009) 353

ΔE detector thickness



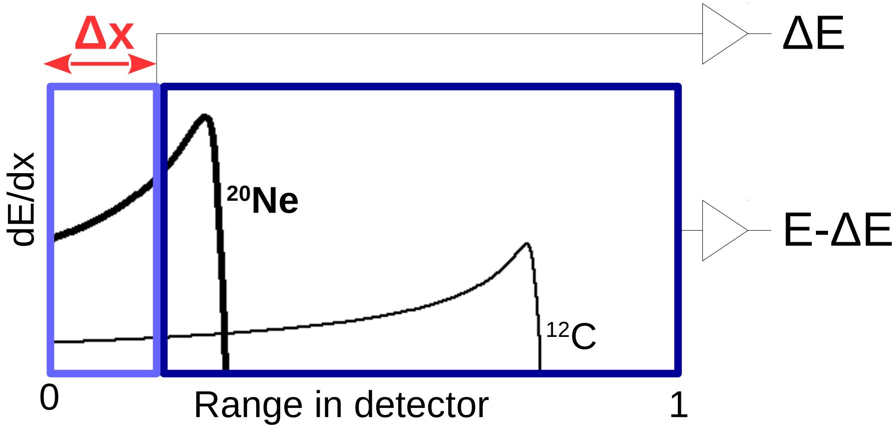
Thickness homogeneity
Detector thickness uniformity of few μm
~1% for 500μm, ~10% for 50μm, ~50% for 20μm





Consequence
No mass ID with large area thin silicon detectors

ΔE detector thickness



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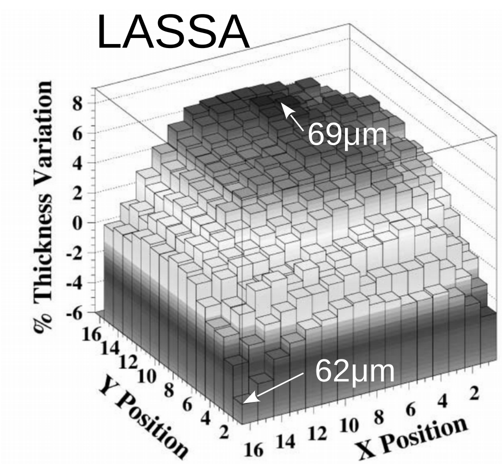
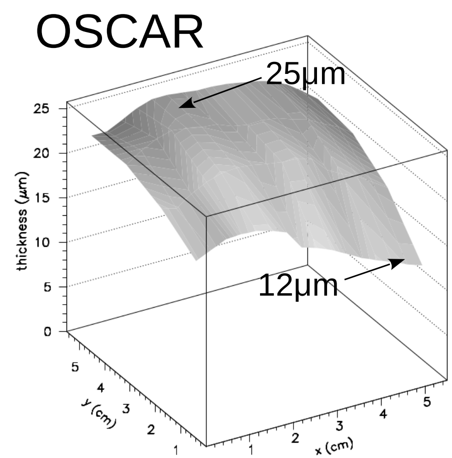
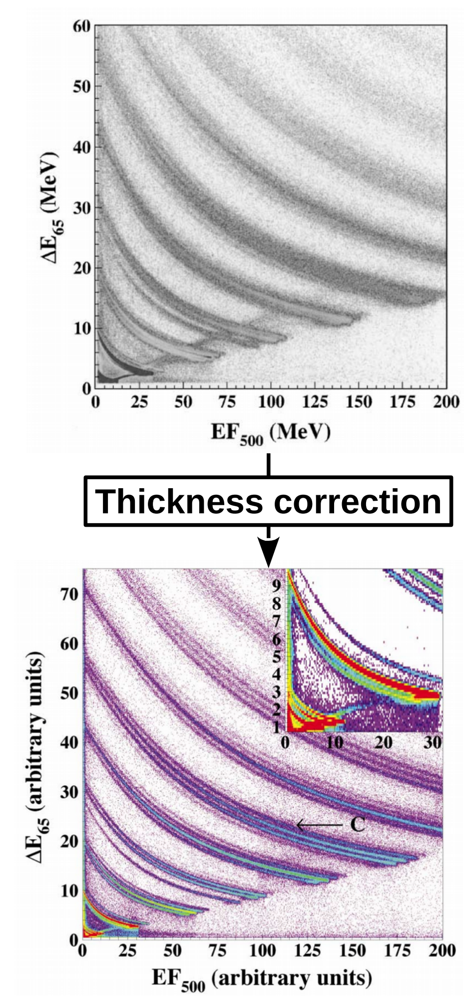




Consequence
No mass ID with large area thin silicon detectors

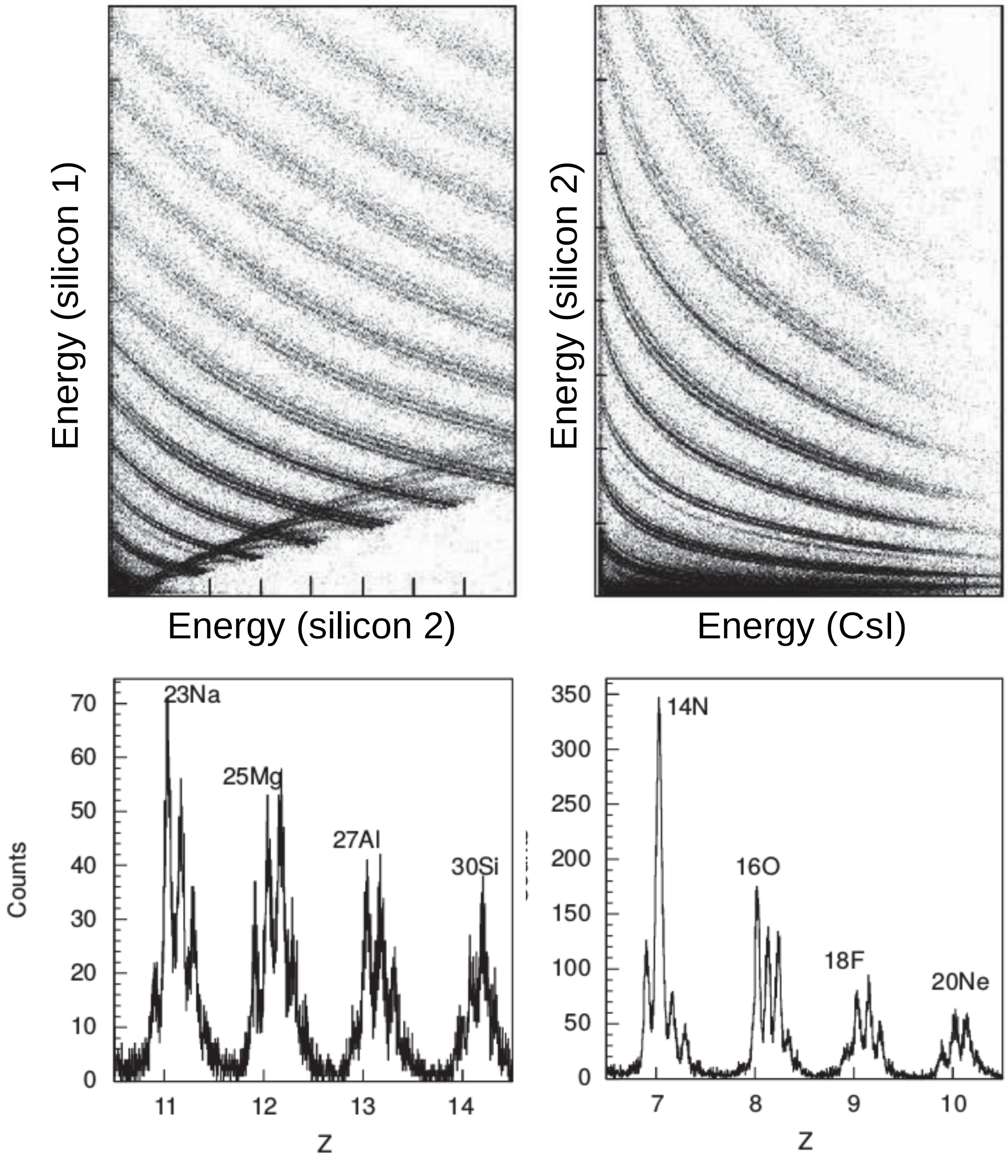
Stripped detectors
Small thickness non-uniformity inside a strip. Can be measured and corrected individually.



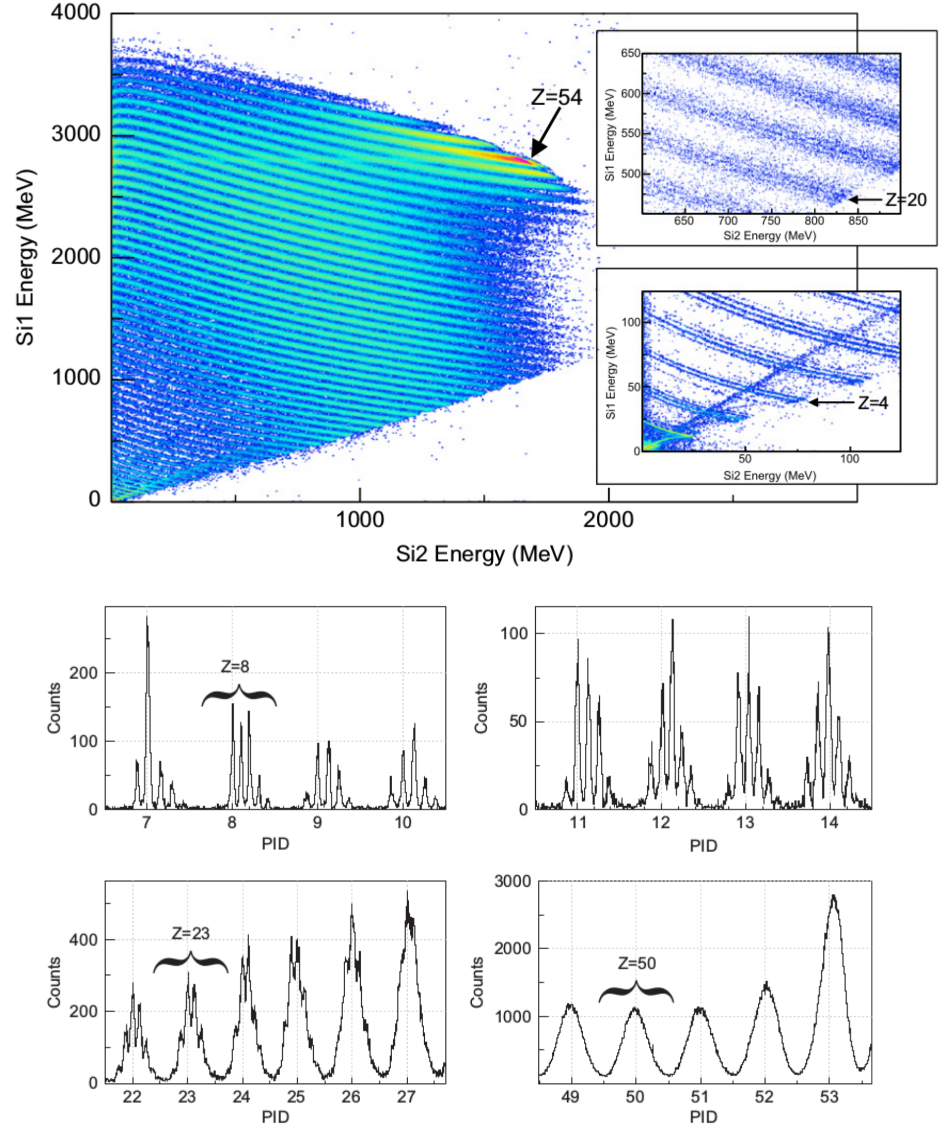
Davin, NIMA **473** (2001) 302
Dell'Aquila, NIMA **877** (2018) 227

ΔE-E identification : two examples

NIMROD



FAZIA



Wuenschel, NIMA **604** (2009) 578

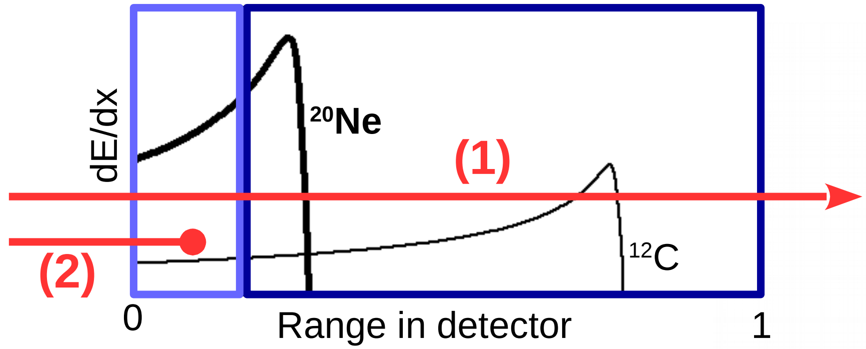
Carboni, NIMA **664** (2012) 251

ΔE-E identification

Basic idea

Divide the material in ΔE and E layers

Z and A lines appear in the ΔE-E correlation



Important points

Precise measurement of ΔE and E

Avoid channeling effects

ΔE detector thickness uniformity

Performances with FAZIA

Full charge identification

Isotopic identification up to Z~25

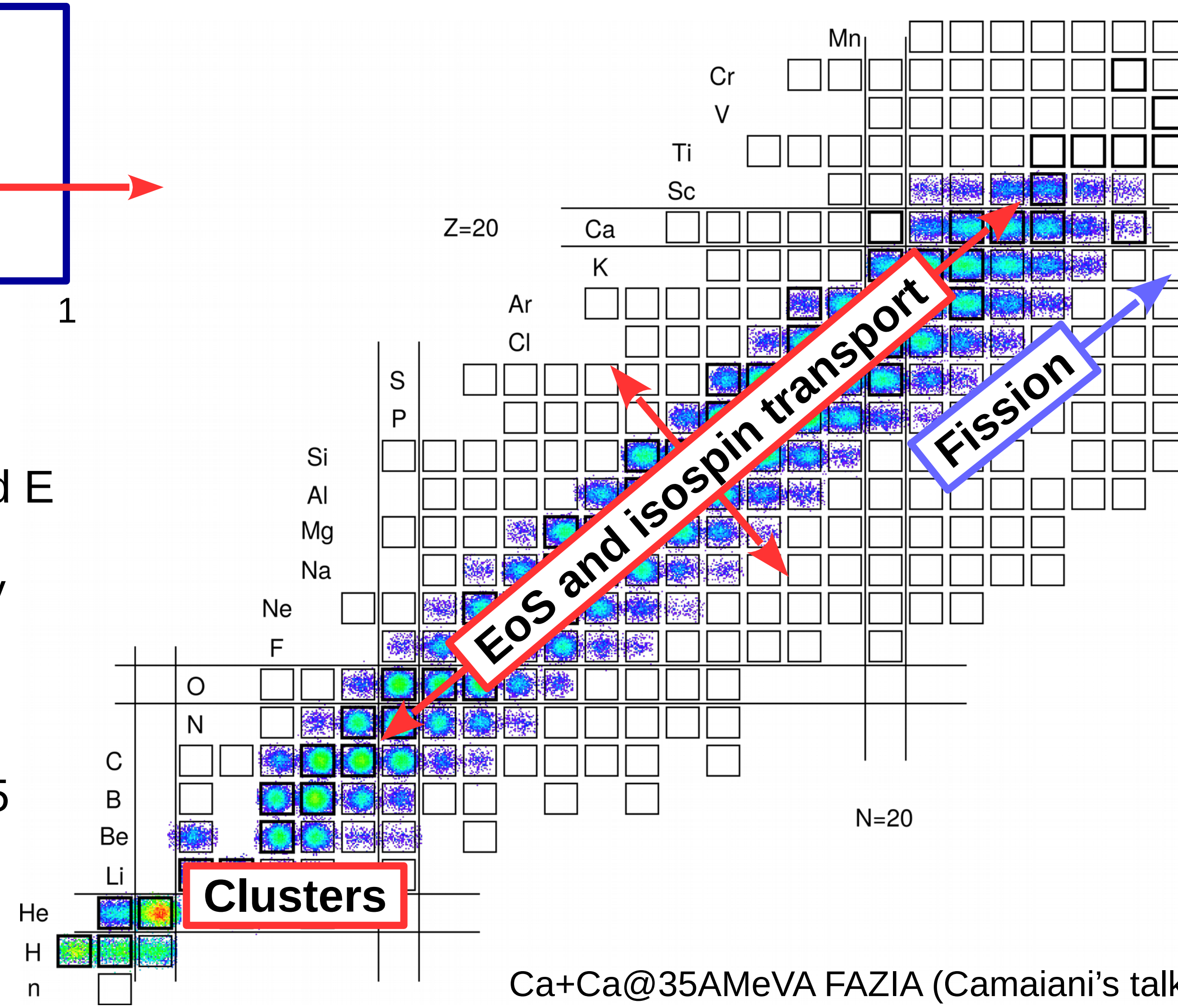
Limitations

Limited number of A per element (~7)

Only particles stopped in the 2nd layer

Solution (1) : add a 3rd layer

Solution (2) : PSA and ToF



Ca+Ca@35AMeVA FAZIA (Camaiani's talk)

1 ΔE-E identification

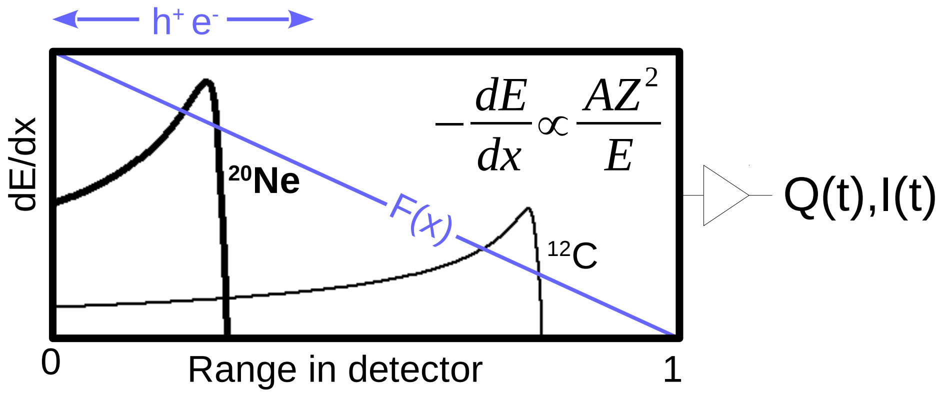
Allows full Z identification and A identification up to Z~25
Limited number of isotopes per element (~7)
Works only for particles punching through the first layer

2 Pulse Shape Analysis identification

3 Time of Flight identification

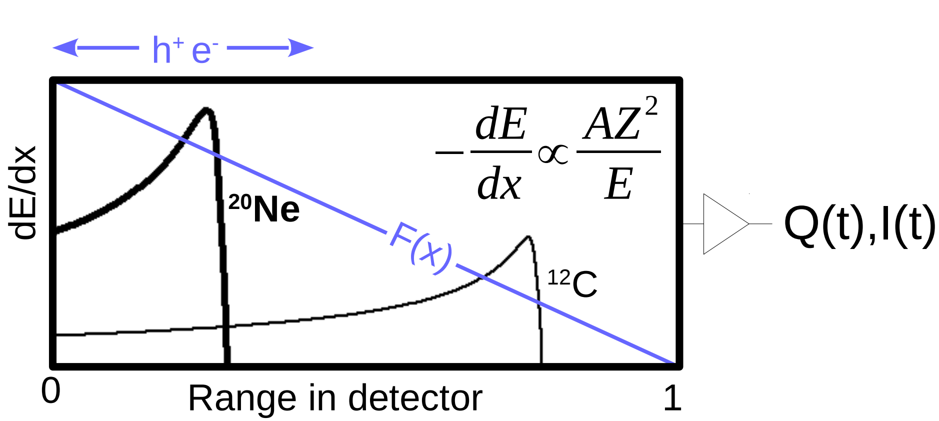
4 Data processing

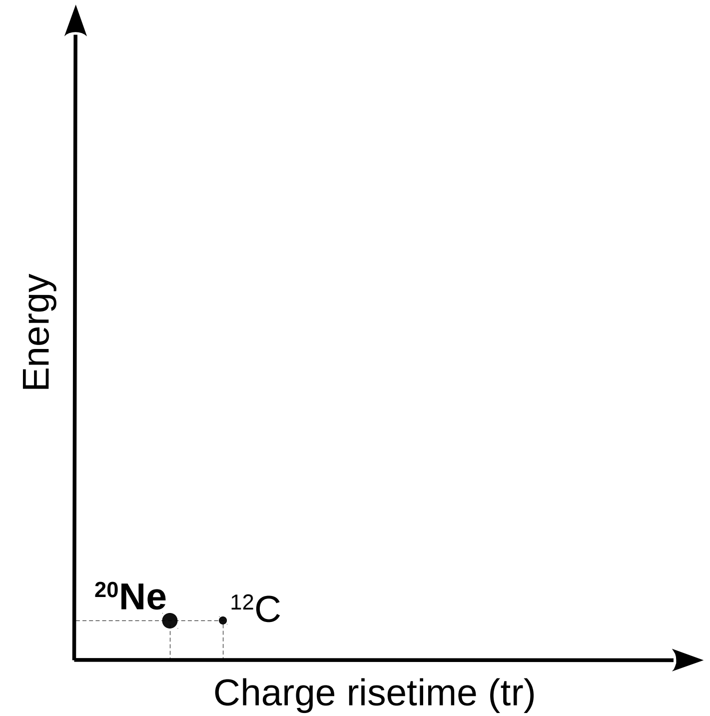
Pulse Shape Analysis in silicon detectors



- **Stopping power (again)**
  Two ions with the same energy but different charge and/or mass have different energy loss profiles

Pulse Shape Analysis in silicon detectors





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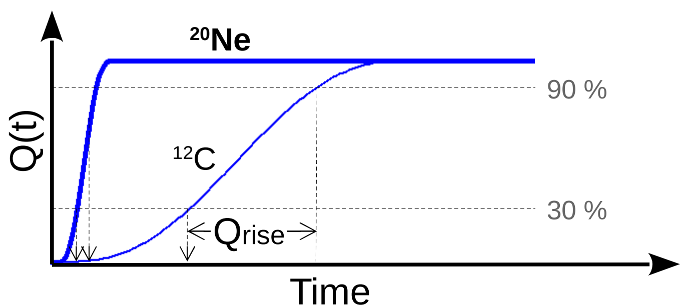
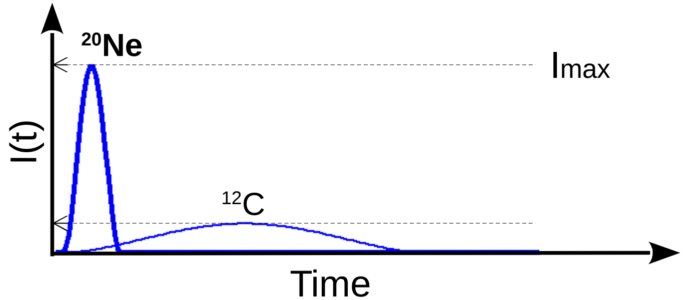
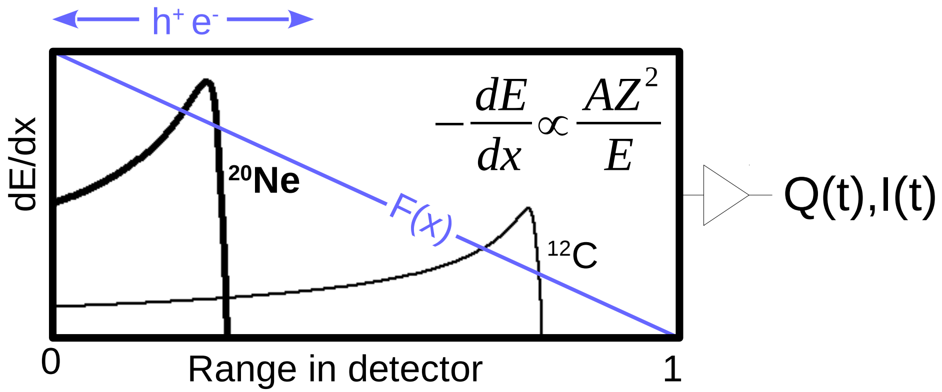
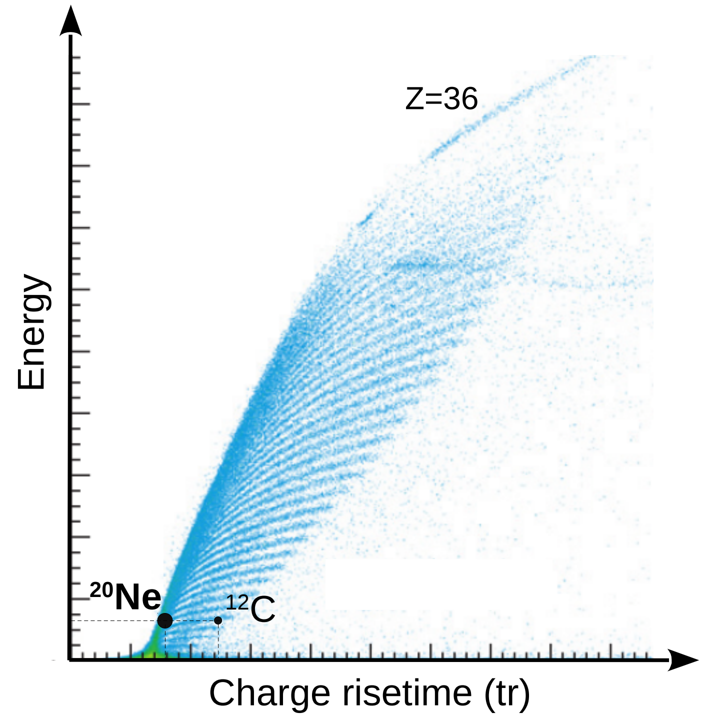




Pulse shape analysis
Use the shape of the signal induced by the charge collection to measure Z (and A)
No clear limit for charge identification

Pulse Shape Analysis in silicon detectors





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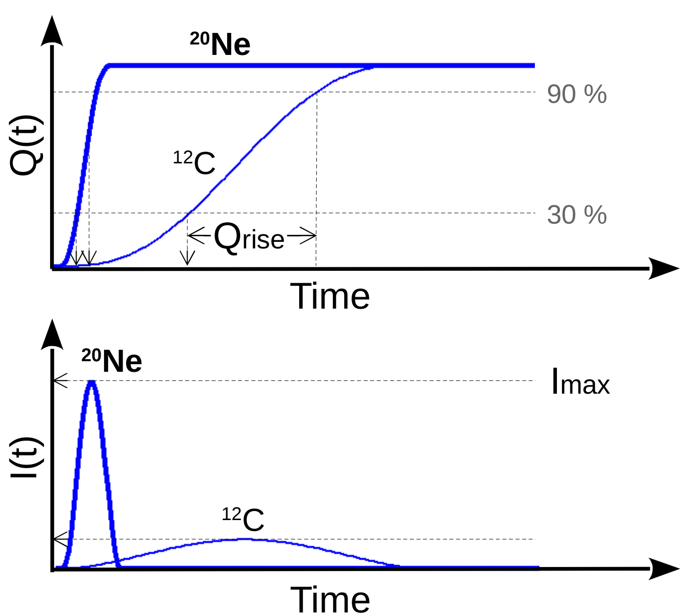
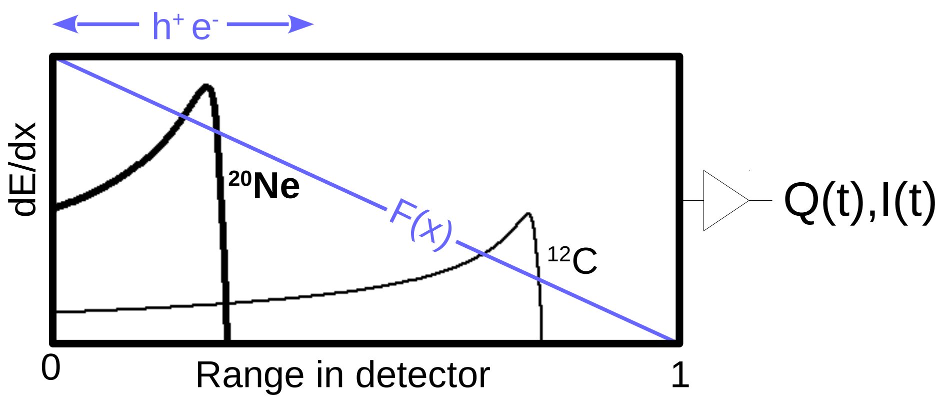
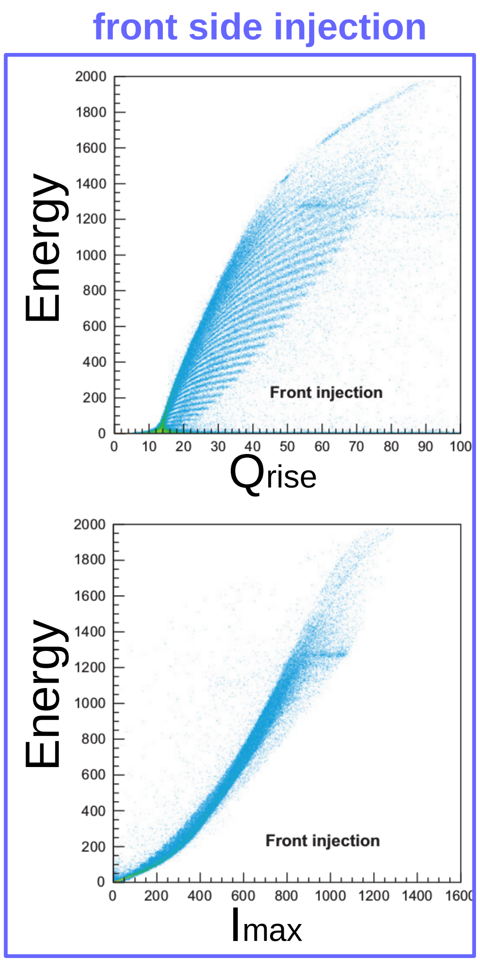


- **Pulse shape analysis**
  Use the shape of the signal induced by the charge collection to measure Z (and A)
  No clear limit for charge identification

- **Important points**
  Precise energy measurement
  Preserve/characterize the signal shape s(t)
  Electric field homogeneity and stability

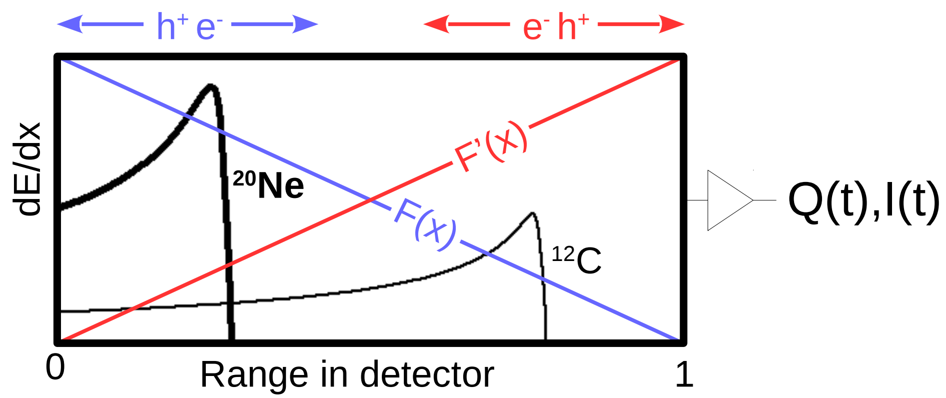
Pulse Shape Analysis : front or rear injection ?

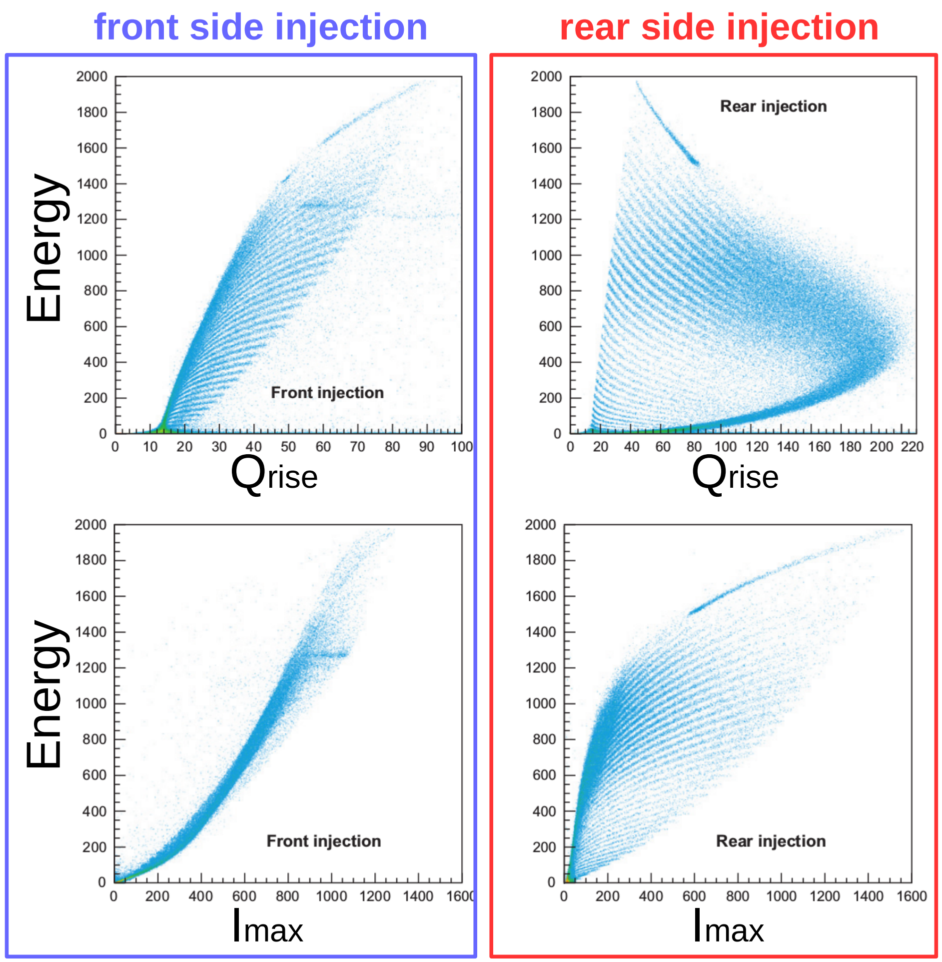




Le Neindre, NIMA **701** (2013) 145

Pulse Shape Analysis : front or rear injection ?

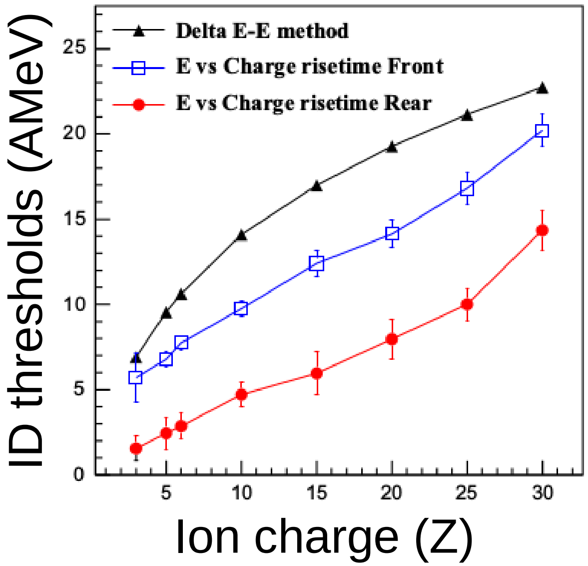




Rear side injection

Particles injected in the low field side

Slower signal for low energy heavy ions



Advantages

Lower identification thresholds in rear injection

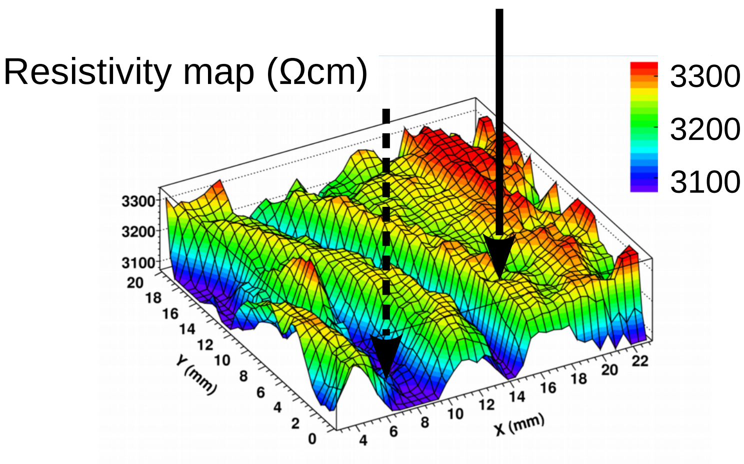
Allows to use Imax which gives better mass ID

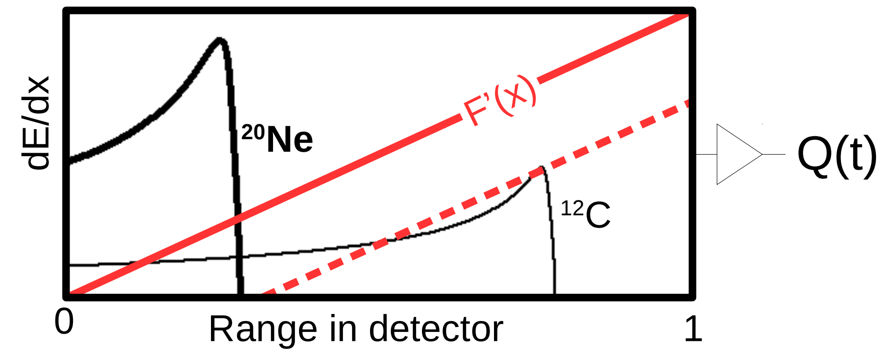
Slower signals are worth for timing (Valdrè's talk)

Le Neindre, NIMA **701** (2013) 145

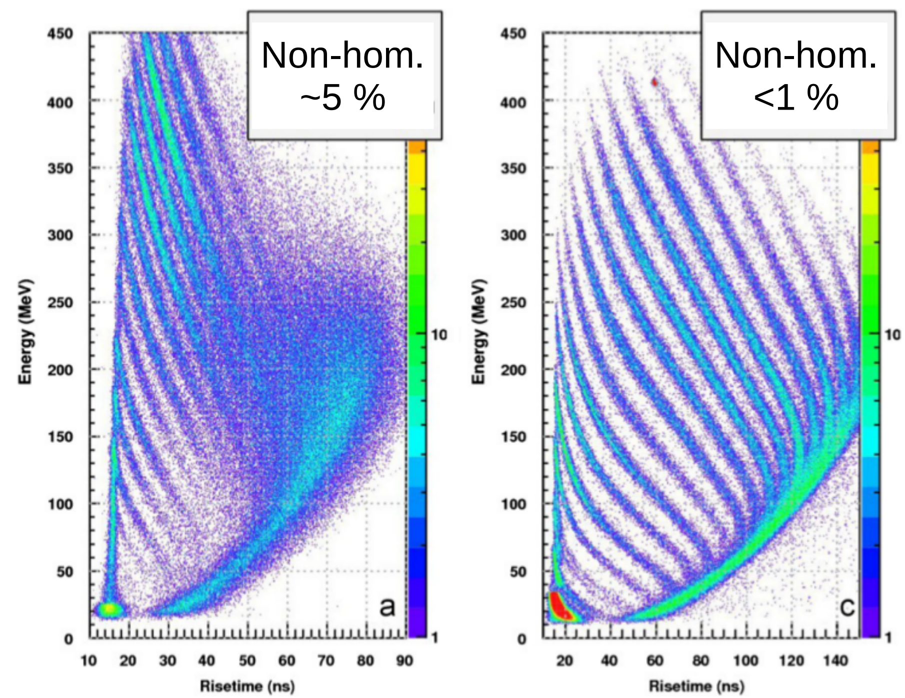
Electric field homogeneity and stability

- **Homogeneity and stability**
  Collection time should be indepedent of impact position or time. Homogeneous resistivity over the detector surface and constant bias voltage.





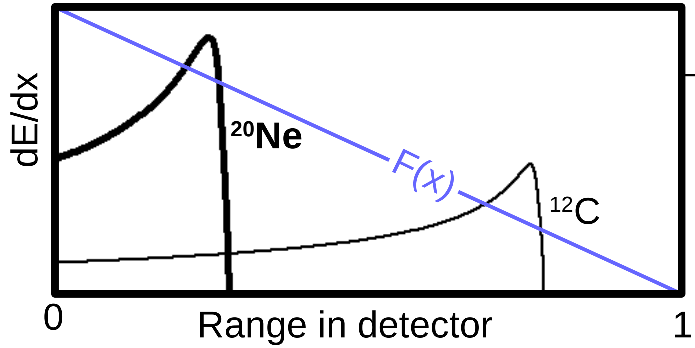
- **Resitivity mapping**
  Non-destructive method for resistivity mapping based on Pulse Shape Analysis. Much better performances with < 1% non-homogeneity.

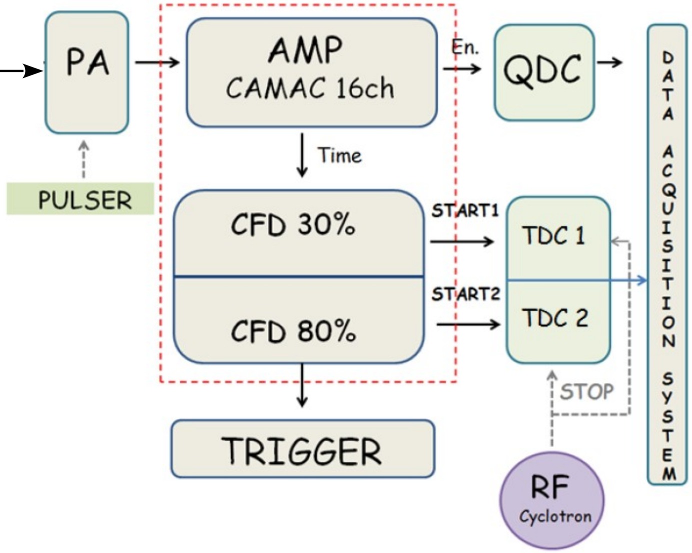


- **Radiation damage**
  Leakage current increases in time due to radiation damage. Bias voltage correction.

Bardelli, NIMA **602** (2009) 501
Bardelli, NIMA **654** (2011) 272

Pulse Shape Analysis in silicon : CHIMERA



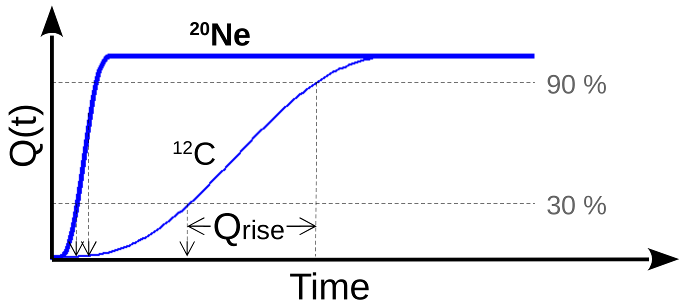


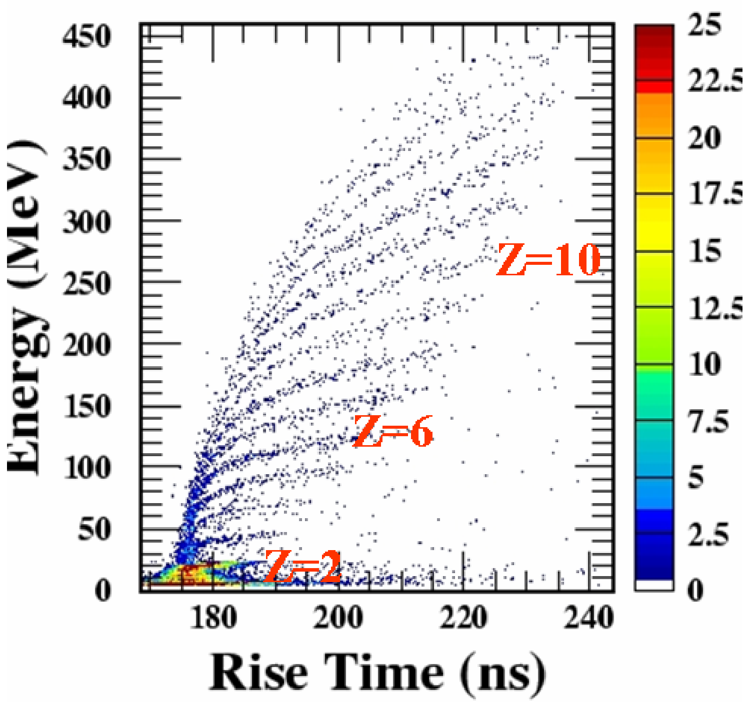
CHIMERA strategy

Front side injection silicons (better for timing)

Two CFD (30 % and 80 %) after amplification

No digitalization of the signal





Performances

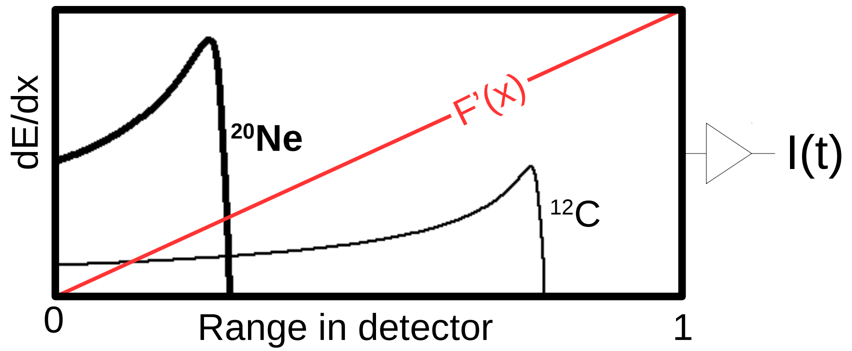
Charge identification

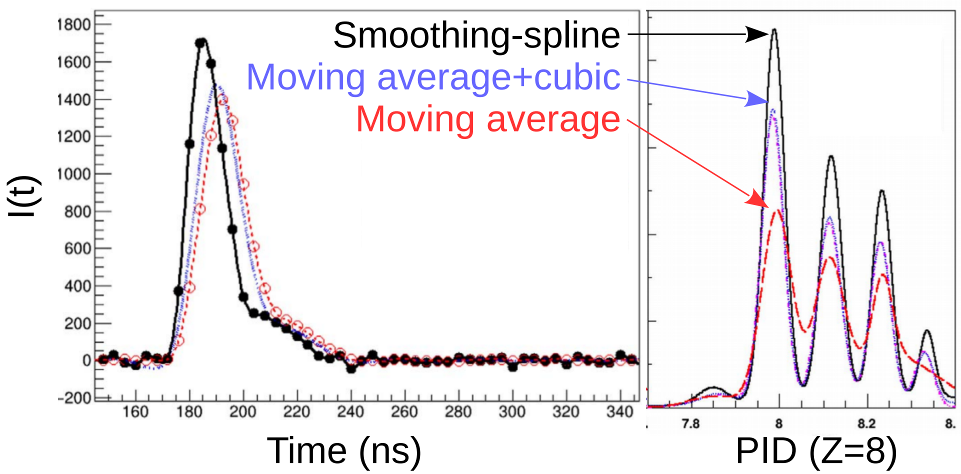
No isotopic identification → time of flight

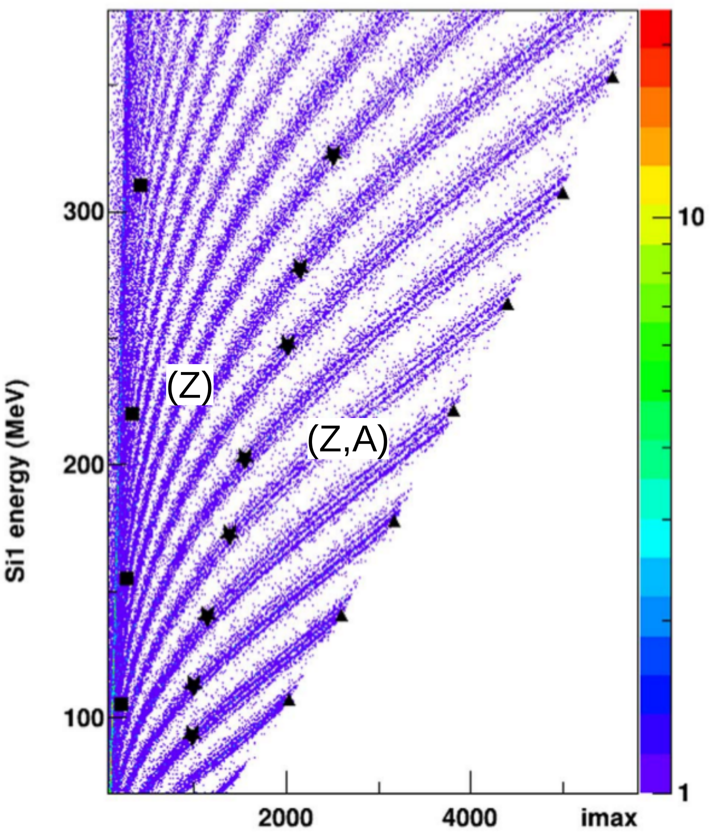
Pagano, NPA **734** (2004) 504

Pulse Shape Analysis in silicon : FAZIA

FAZIA strategy
Reverse mounted nTD silicons (300µm)
I(t) sampled at 250MHz and processed offline
Energy from a trapezoidal shaper in the FPGA
Real-time leackage current auto-correction







Signal processing
Moving average or smoothing (noise reduction) with cubic or spline interpolation

Optimal filter
Smoothing-spline filter on current signal allows for isotopic identification with low thresholds

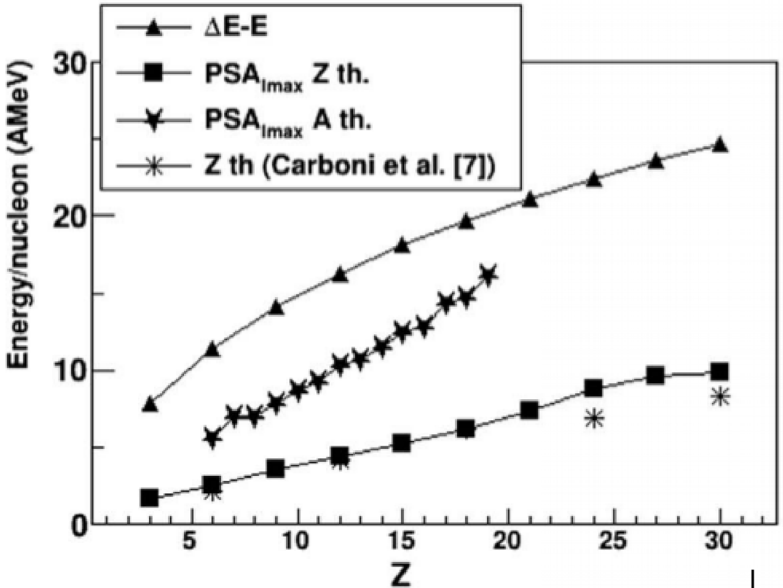
Pastore, NIMA **860** (2017) 42

Pulse Shape Analysis in silicon : FAZIA

Performances

Isotopic identification for 2<Z<20

Z and A identification thresolds reduced

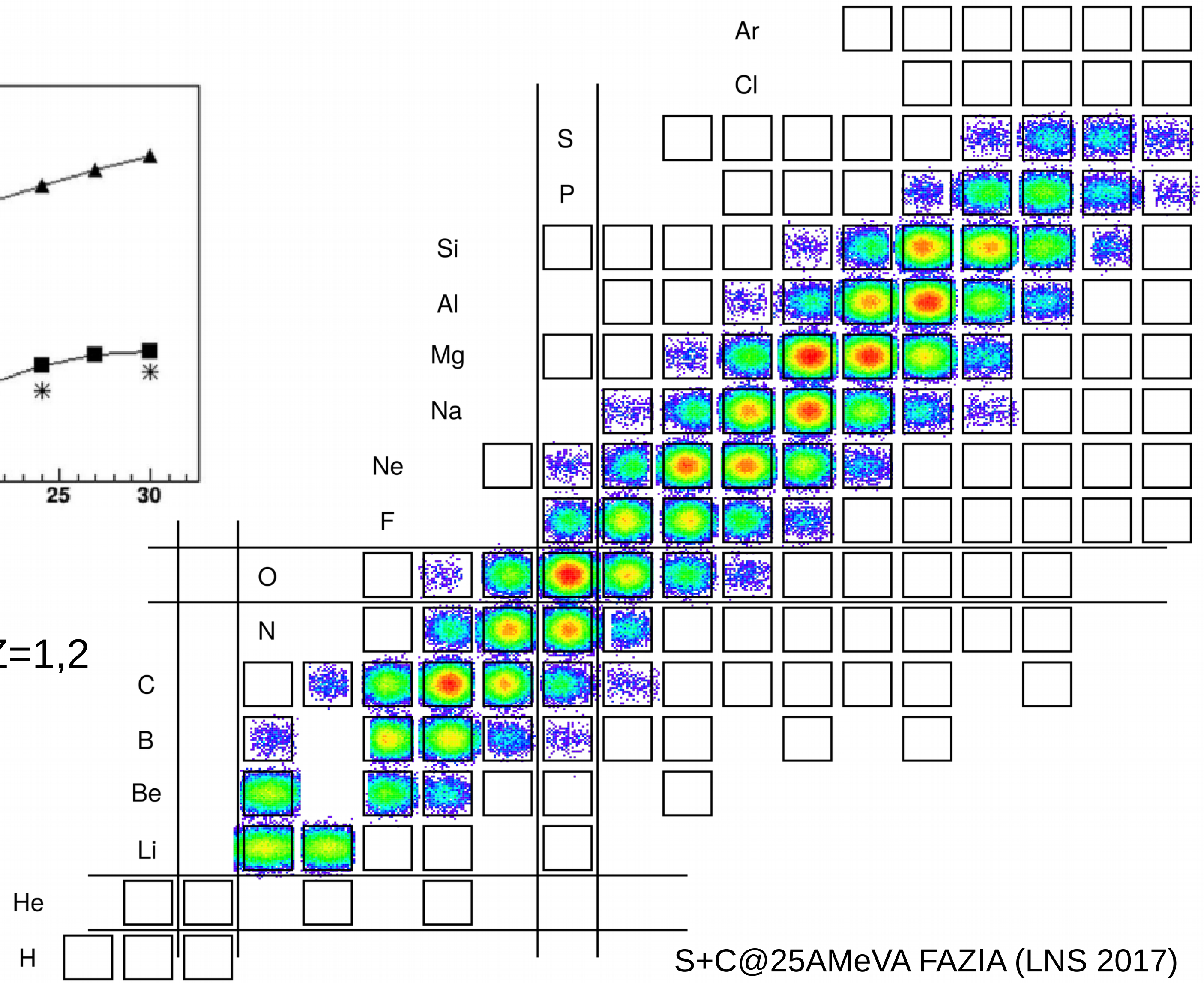


Limitation

No isotopic resolution of Z=1,2

Relative time of flight ?

(see Valdrè’s talk)



S+C@25AMeVA FAZIA (LNS 2017)

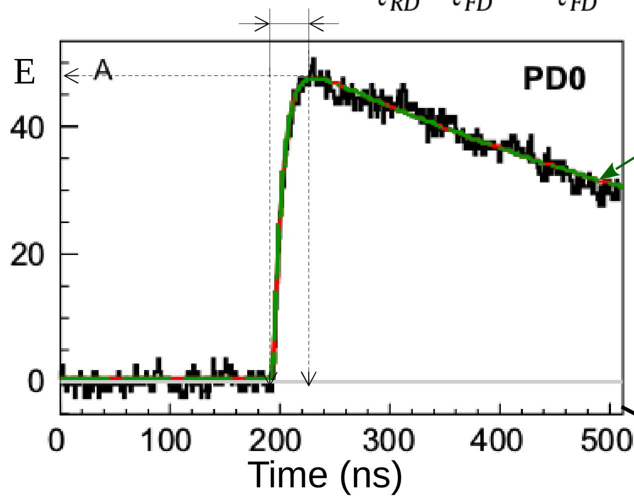
Pulse Shape Analysis in silicon : KRATTA

KRATTA strategy

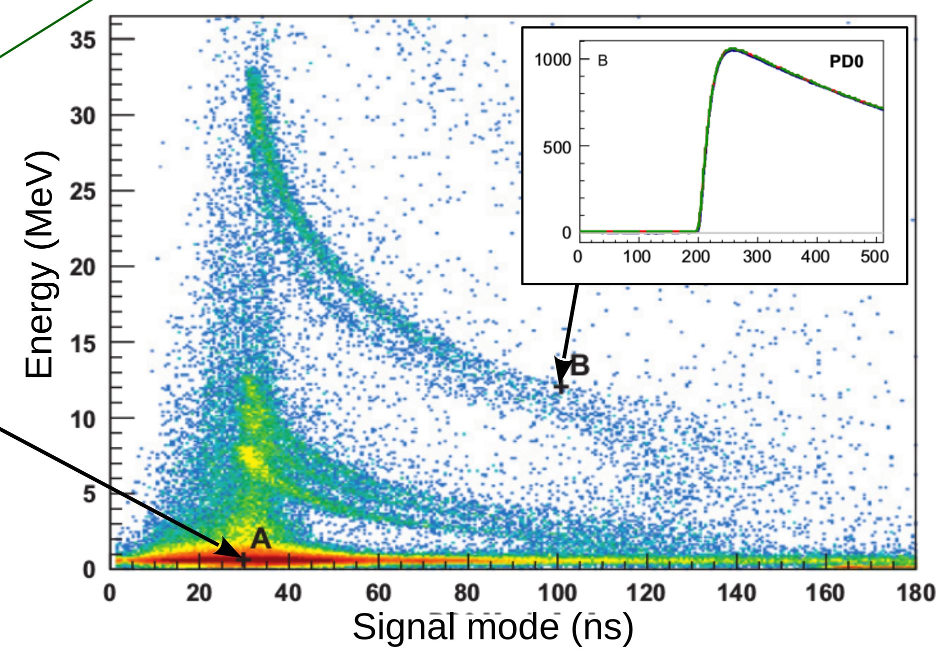
Reverse mounted silicon photodiodes (500µm)

Q(t) sampled at 100MHz and processed offline

$$mode = \frac{\tau_{RD}\tau_{FD}}{\tau_{RD}-\tau_{FD}} \log \frac{\tau_{RD}}{\tau_{FD}}$$



$$V_D(t) = RC\,Q_D\left(\frac{e^{-\Delta t/RC}RC}{(RC-\tau_{RD})(RC-\tau_{FD})} + \frac{e^{-\Delta t/\tau_{RD}}\tau_{RD}}{(\tau_{RD}-RC)(\tau_{RD}-\tau_{FD})} + \frac{e^{-\Delta t/\tau_{FD}}\tau_{FD}}{(\tau_{FD}-\tau_{RD})(\tau_{FD}-RC)}\right)$$



Signal processing

Fit the charge signal with an analitical model

Energy and signal mode extracted from the fit

Performances

Isotopic identification of light clusters

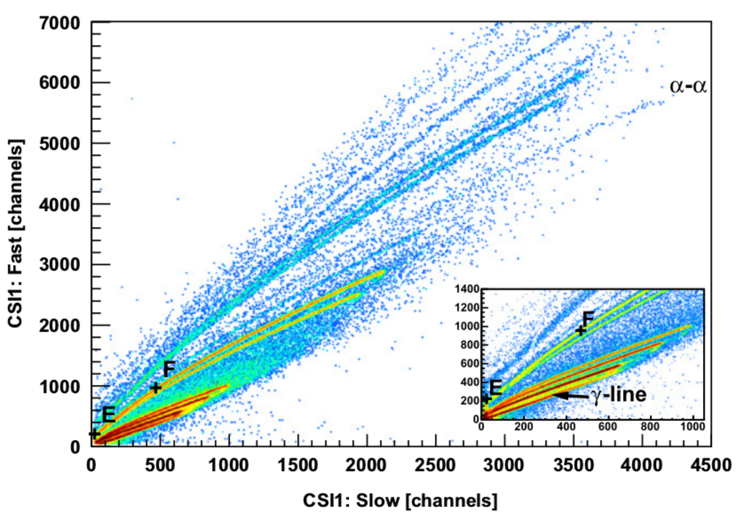
Low identification thresholds

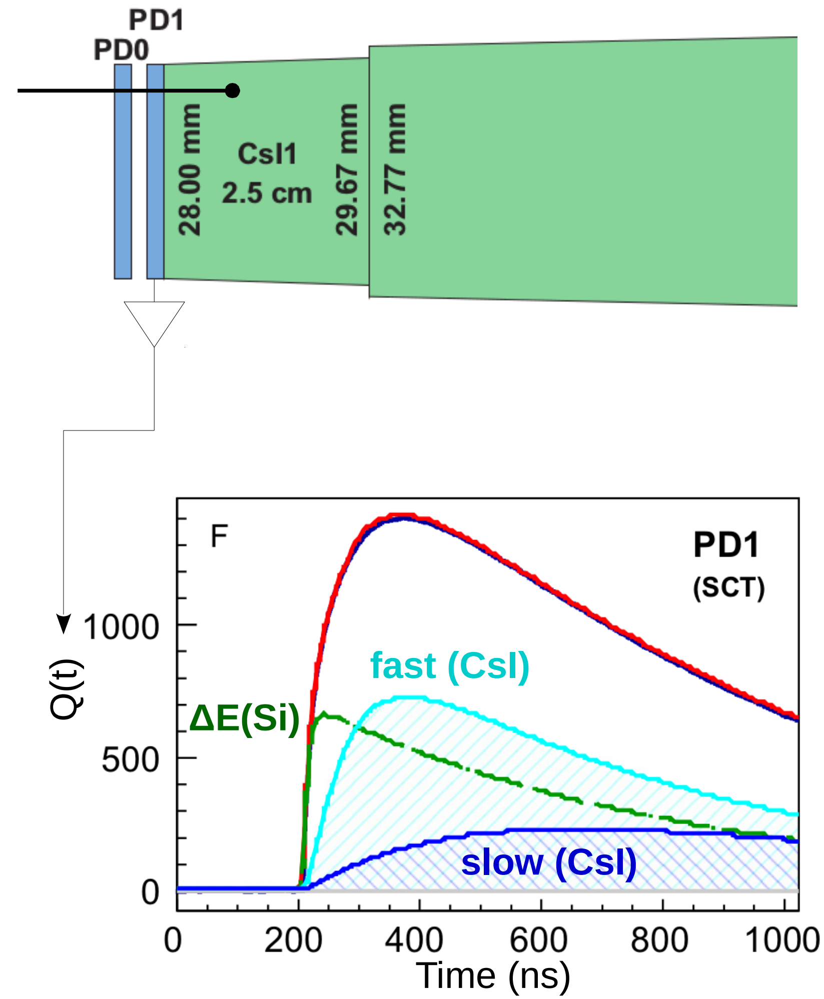
Lukazik, NIMA **709** (2013) 120

Pulse Shape Analysis : single chip telescope

Concept
Use the silicon for ΔE measurement and scintillation light collection. Both ΔE and E are derived from the silicon signal reducing the complexity and the cost of the electronics.

Signal processing
Applying different shapers on Q(t) signal (FAZIA)
Fitting the Q(t) signal with a model (KRATTA)





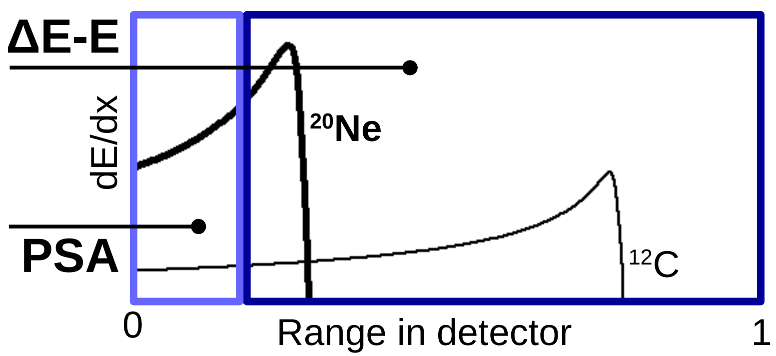
Performances
Both methods give isotopic identification in ΔE-E
The fitting procedure allows to do PSA in the CsI

Pasquali, NIMA **301** (1991) 101
Pasquali, EPJA **48** (2012) 158
Lukazik, NIMA **709** (2013) 120

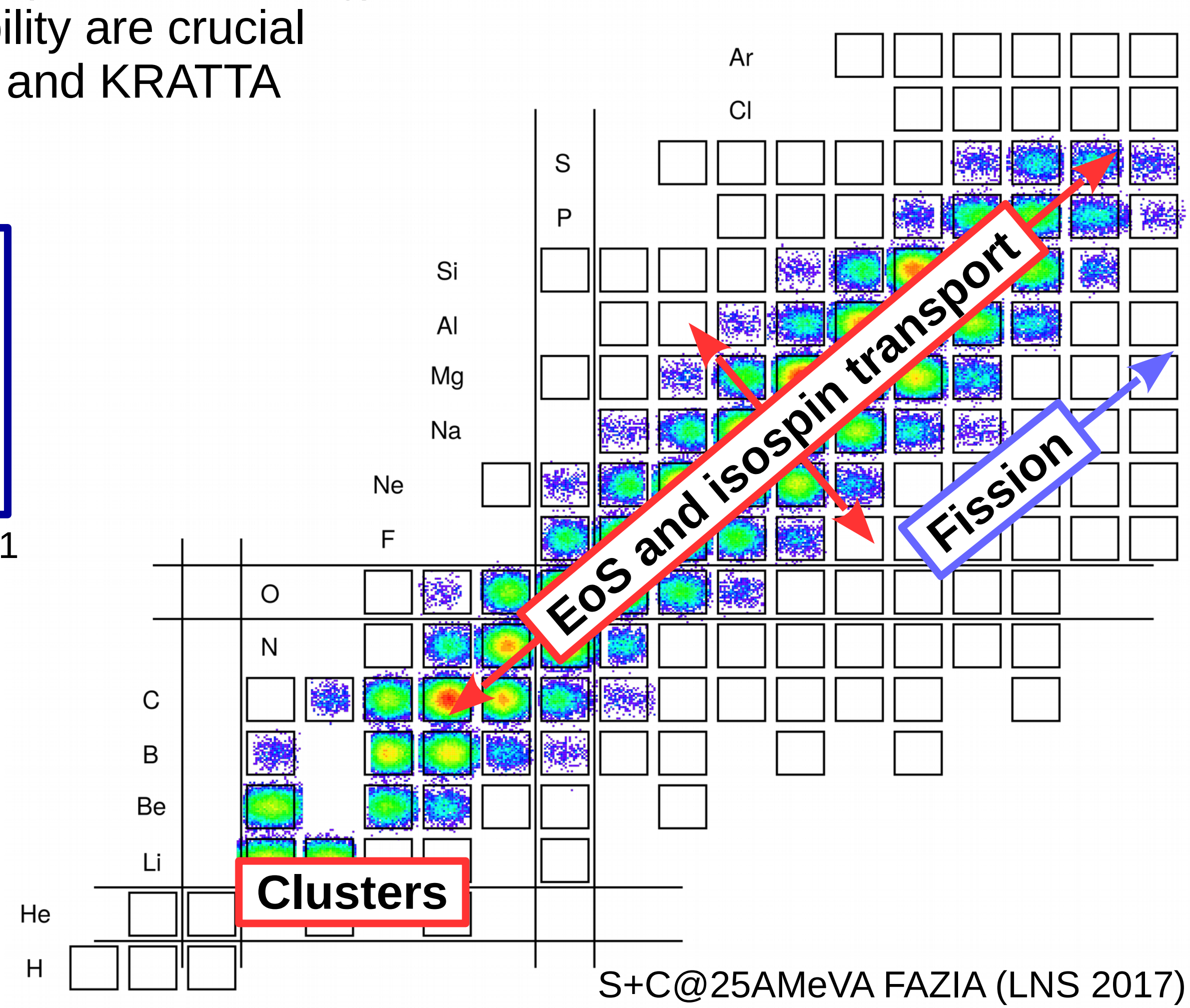
Pulse Shape Analysis identification in silicon

Basic idea
Use the shape of the signal induced by the charge collection to measure Z (and A)

Important points
Better identification in rear injection (worth for timing)
Electric field homogeneity and stability are crucial
Practical uses : CHIMERA, FAZIA, and KRATTA



Performances with FAZIA
Full charge identification
Isotopic identification up to Z~20
Lower identification thresholds



1 ΔE-E identification

Allows full Z identification and A identification up to Z~25
Limited number of isotopes per element (~7)
Works only for particles punching through the first layer

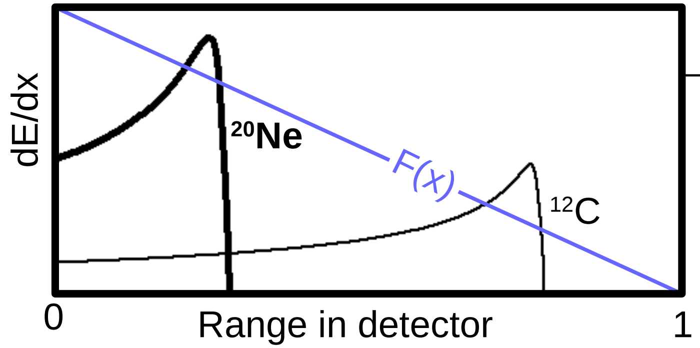
2 Pulse Shape Analysis identification

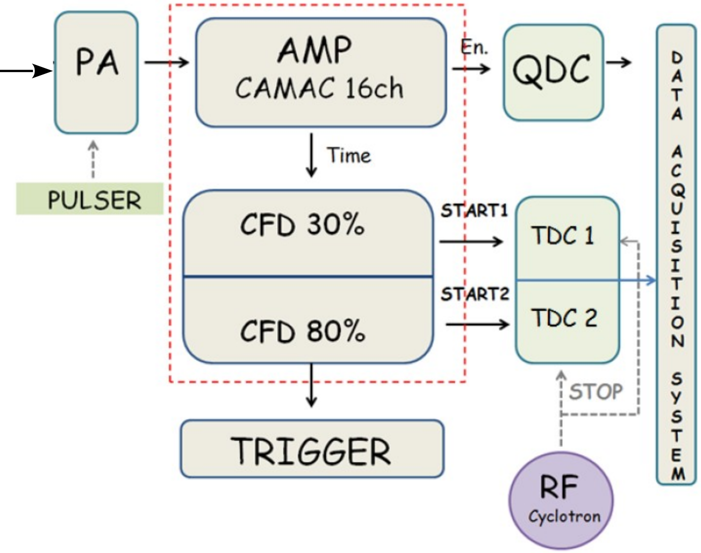
Allows full Z identification and A identification up to Z~20
Low charge and mass identification thresholds
Many different ways to characterize the signal shape

3 Time of Flight identification

4 Data processing

Time of Flight identification : CHIMERA

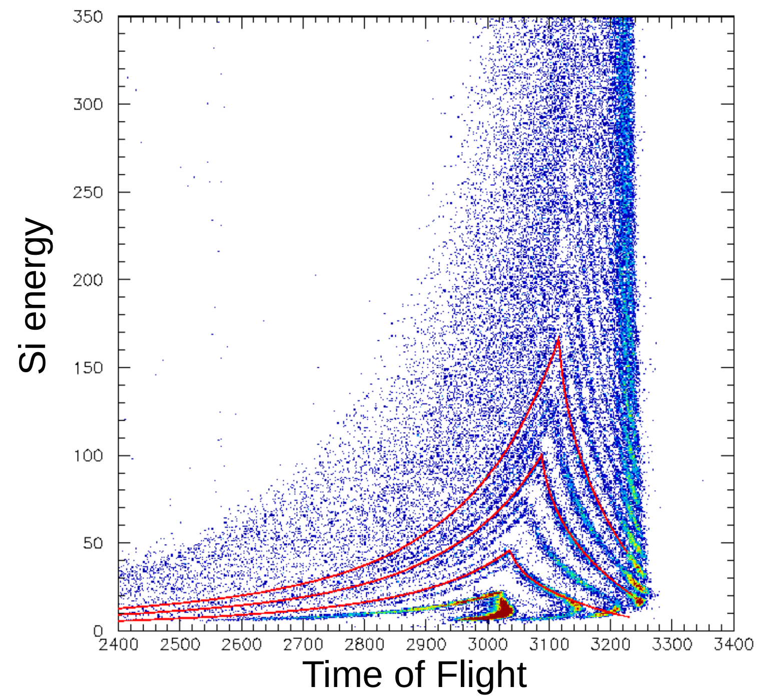




Time of Flight
Deduce the mass from the energy and velocity

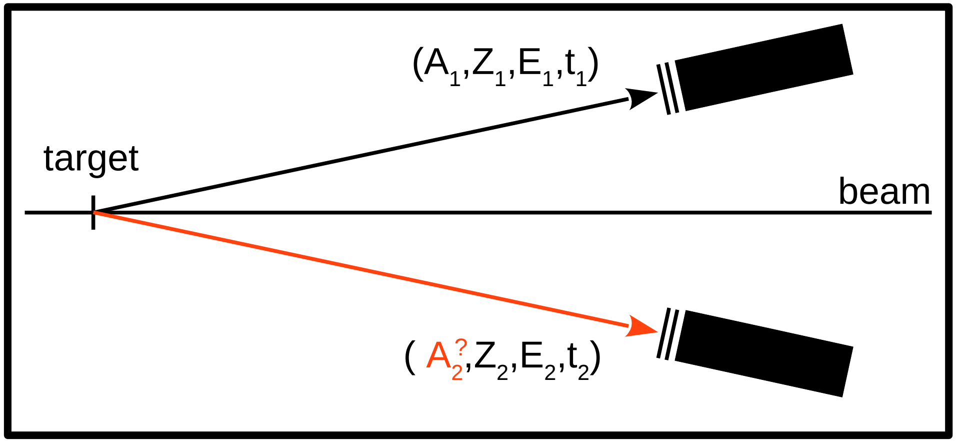
CHIMERA strategy
Front side injection silicons (faster signals)
CFD at 30 % after signal amplification
Reference time from the cyclotron frequency

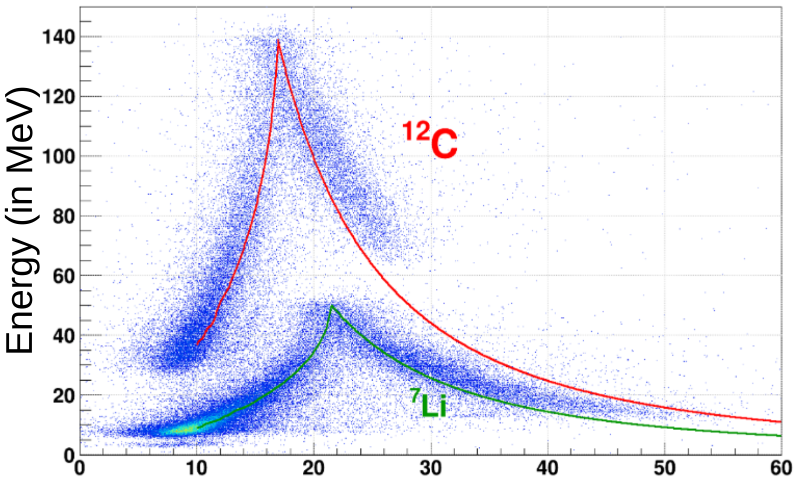
Performances
Mass identification up to A~20
No charge identification → Pulse Shape Analysis

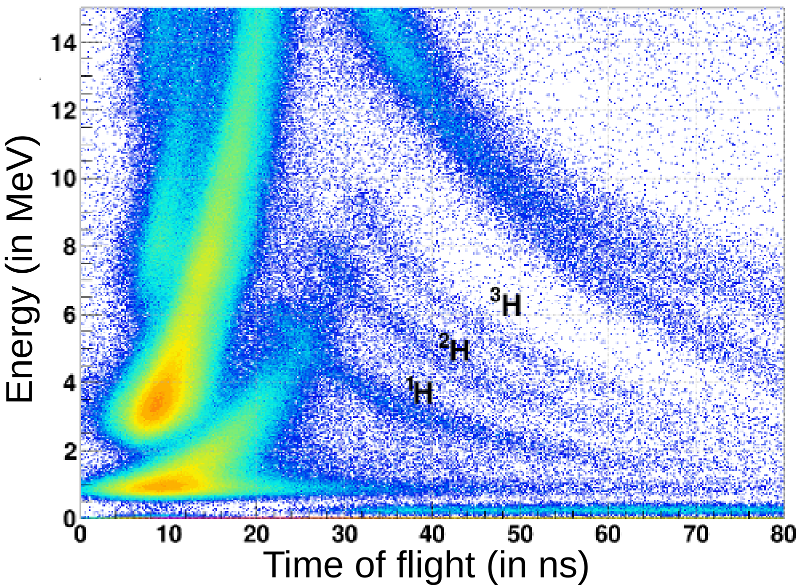


Pagano, NPA **734** (2004) 504

Time of flight identification : FAZIA







- **Relative time**
  Reference time extracted from the time mark of a well identified particle in the same event:

$$ToF_2 = t_2 - t_1 + ToF_1(A_1,E_1)$$

- **Expected performances**
  Hope to recover isotopic identification of Z=1,2 stopped in first silicon (Valdrè's talk)

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2 Pulse Shape Analysis identification

Allows full Z identification and A identification up to Z~20
Low charge and mass identification thresholds
Many different ways to characterize the signal shape

3 Time of Flight identification

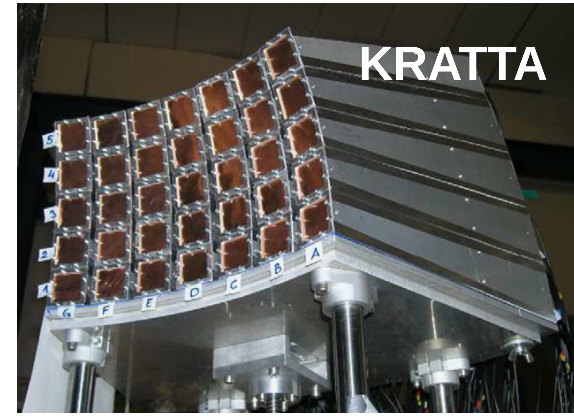
Allows for mass identification only
Can be coupled with Pulse Shape Analysis in silicon

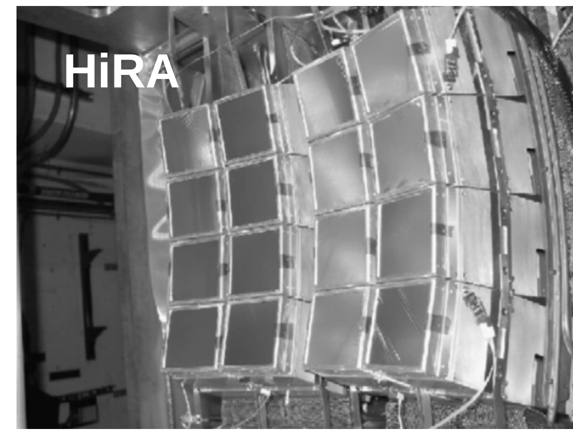
4 Data processing

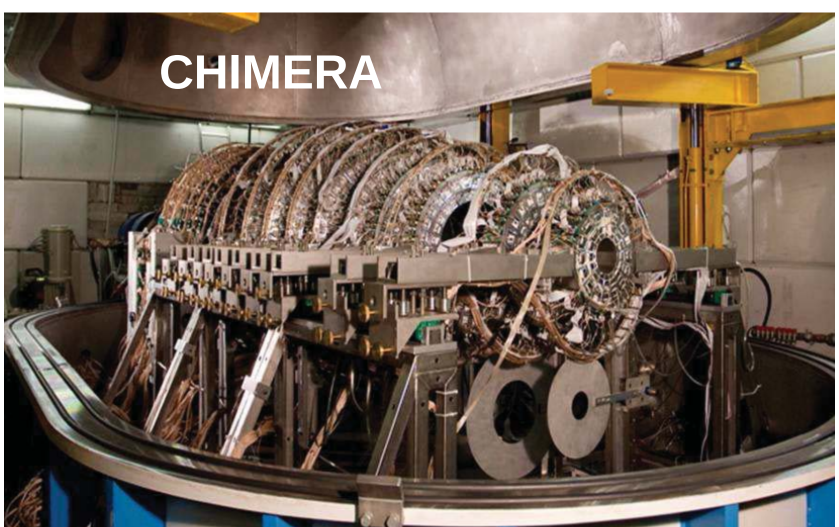
Data processing

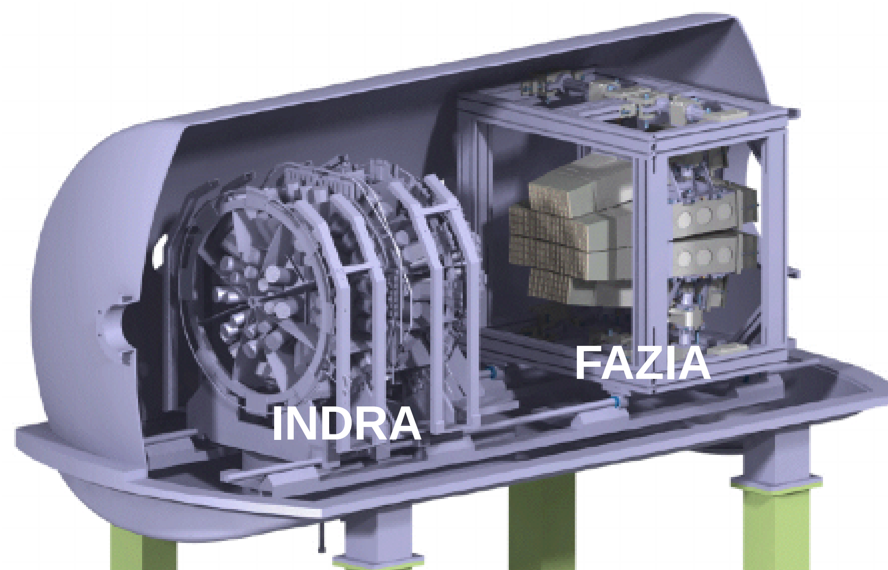
- **Identification matrices**
  Large arrays made of hundreds of telescopes
  Several identification matrices per telescopes
  Matrix complexity increases with increasing isotopic resolution → data reduction more and more difficult and time consuming

- **Automatization**
  Many (semi-)automatic technics : fitting procedures, peak-finding methods, artificial neural netwoks, image processing...







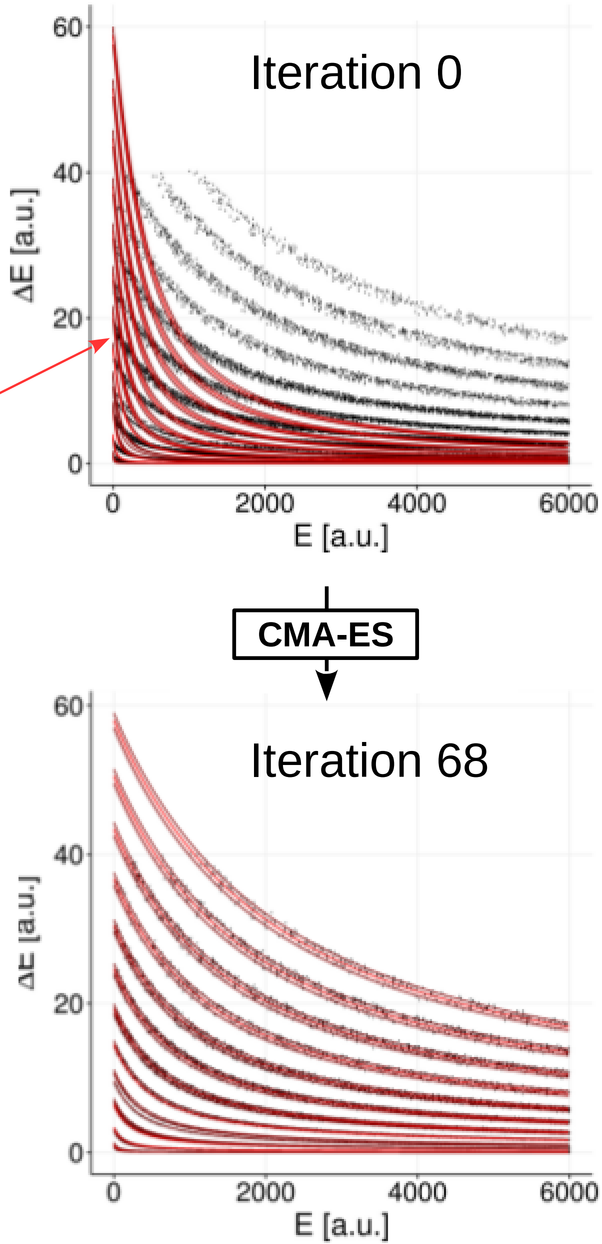


Data processing : evolutionary strategy

Approach
Combines a generative model of ΔE-E relation and a Covariance Matrix Adaptation Evolutionary Strategy (CMA-ES)

Model
Tassan-Got functional (3 free parameters) :

$$\Delta E = \left[(gE)^{\mu+\nu+1} + \left(\lambda Z^{\alpha} A^{\beta}\right)^{\mu+\nu+1} + \xi Z^2 A^{\mu} (gE)^{\nu} \right]^{\frac{1}{\mu+\nu+1}} - gE$$



Minimization
Sum of the distance between each point and the closest line minimized with a CMA-ES method :

$$f(D_{m,2}, g, \mu, \lambda) = \sum_{j=1}^{m} \arg\min_{i \in I} \left(D_{j,1} - t(D_{j,2}, g, \mu, \lambda, A_i, Z_i)\right)^2$$

Performances
Isotopic identification witout any human intervention
Fit result strongly depends on the model quality
Only validated on simulated and labeled data

Schmidt, JINST **12** (2017) P09007

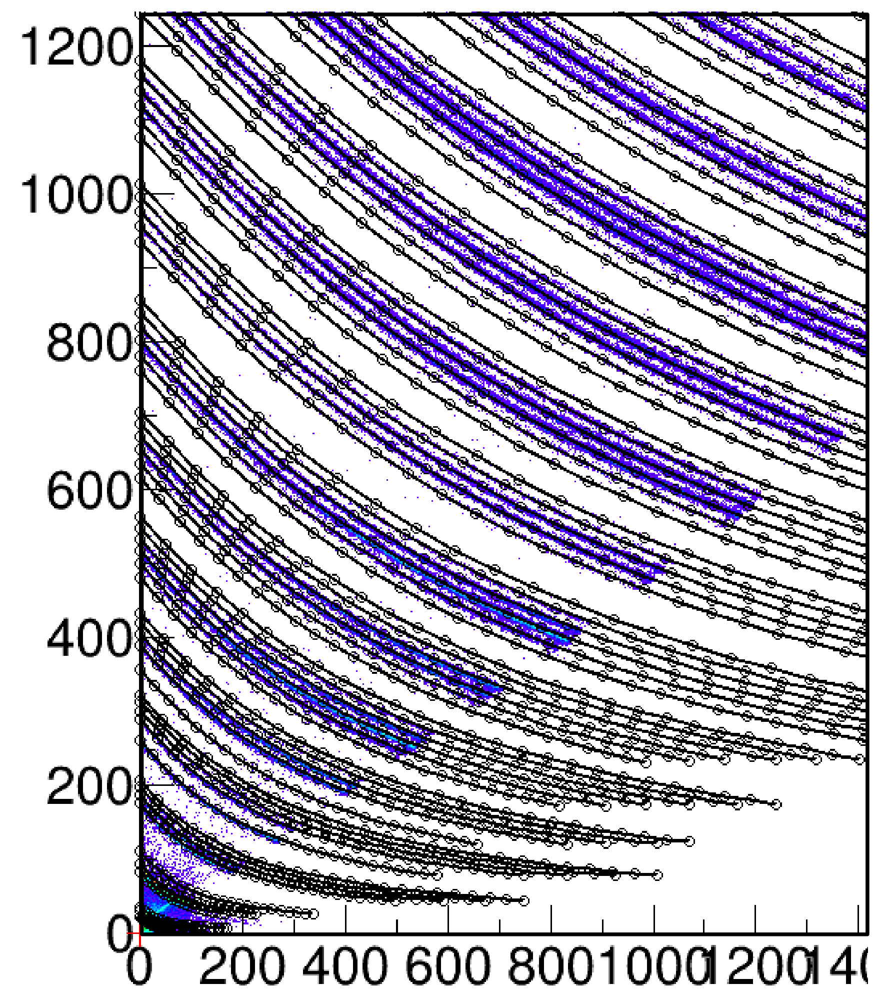
Data processing : from AME to AMI

Approach
Adjust calibration parameters by fitting few clicked (Z,A) lines with the energy loss tables

Originality
Very accurate description of silicon detector response and CsI(Tl) light output :

$$
\begin{aligned}
L(E) = -a_G\{ & \int_0^{E_\delta} \frac{1}{a_R S_e(E)} \ln\left(1 - \frac{a_R S_e(E)}{1 + a_R S_e(E) + a_n S_n(E)}\right) \frac{dE}{1 + S_n(E)/S_e(E)} \\
& + \int_{E_\delta}^{E_0} \frac{1 - F(E)}{y(E) a_R S_e(E)} \ln\left(1 - \frac{y(E) a_R S_e(E)}{1 + a_R S_e(E) + a_n S_n(E)}\right) \frac{dE}{1 + S_n(E)/S_e(E)} \\
& - \int_{E_\delta}^{E_0} \frac{F(E) dE}{1 + S_n(E)/S_e(E)} \}
\end{aligned}
$$

Performances
Isotopic identification with little human intervention (few lines to be clicked)
Successfully applied on FAZIA Si-Si and Si-CsI(Tl) matrices

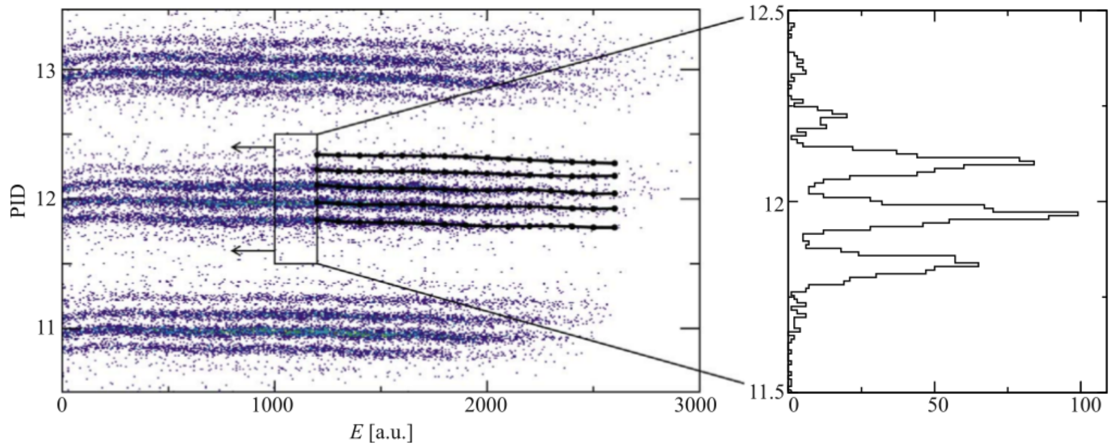


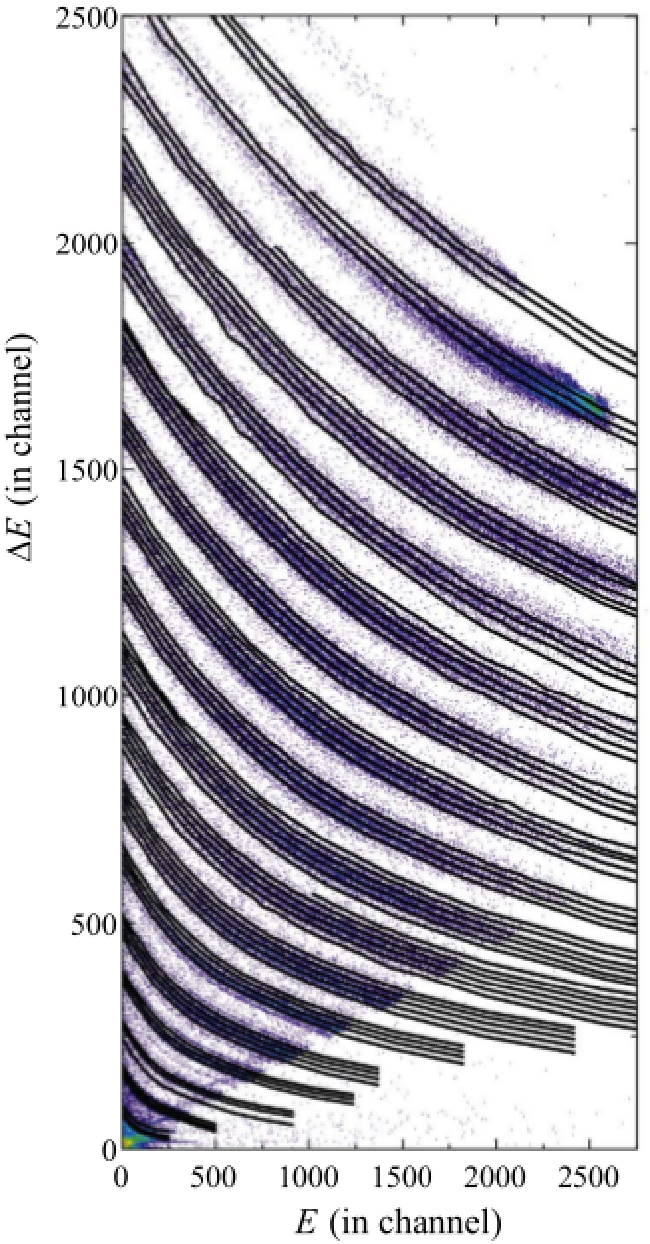
Lopez, NIMA **884** (2018) 140

Data processing : SPIDER identification

- **SPIDER (charge) identification**
  Peak-finding method after projection of the matrix
  No assumption on the underlying physics

- **SPIDER (mass) identification**
  Peak-finding after matrix linearization/projection
  The only input is the Z identification grid





- **Performances**
  Allows for very fast isotopic identification (on-line)
  Little human intervention (two mouse-clicks)
  Works with many matrix types (ΔE-E, PSA)
  Mass ID not precise enough for physics analysis

Gruyer, NIMA **847** (2017) 142

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Can be coupled with Pulse Shape Analysis in silicon

4 Data processing

Matrix complexity increases with increasing performances
New (semi-)automatic methods are welcome

What I forgot...

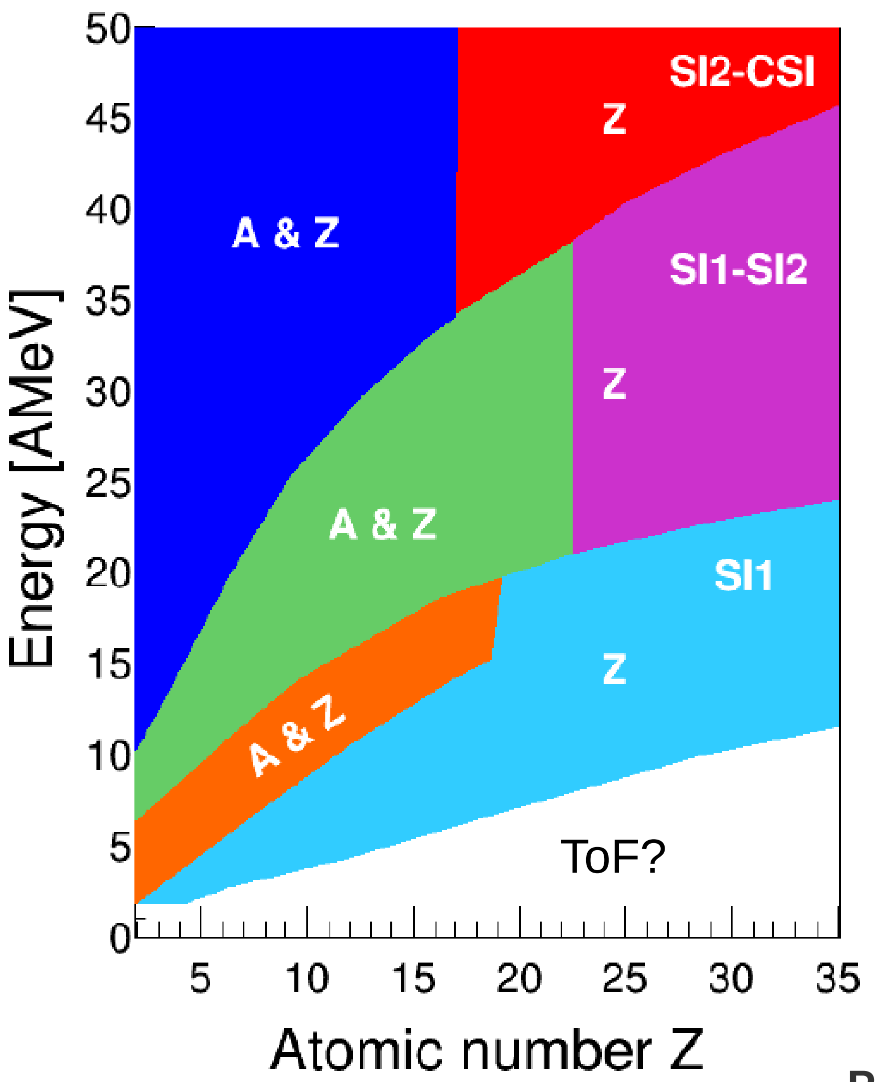
- **Electronics**
  GET electronics (Marchi’s talk, De Filipo’s and Pagano’s talk)
  Multichannel CMOS front ends (Guazzoni’s talk)...
  FAZIA electronics (Valdrè’s talk)

- **Pulse Shape Analysis**
  Artificial neural network approach (Flores, NIMA **830** (2016) 287)
  PSA with stripped detectors (Genolini, NIMA **732** (2013) 87)
  Pulse Shape Analysis in CsI(Tl)

- **High energies**
  Fragmentation in detectors (Morfouace, NIMA **848** (2017) 45)

- **Neutron detection**
  Neutron sensitive solid scintillator (E. Pagano’s talk)
  Neutron-gamma discrimination...

FAZIA block performances



Identification capabilities.
Full charge identification and isotopic identification up to Z=15-25 depending on the ion velocity.

Identification thresholds.
Low identification thresholds thanks to pulse shape analysis in the first silicon stage. Adapted for reaction with beams from 20 MeV/nuc to 150MeV/nuc (GANIL, LNS, GSI). Could be improved with ToF measurements.