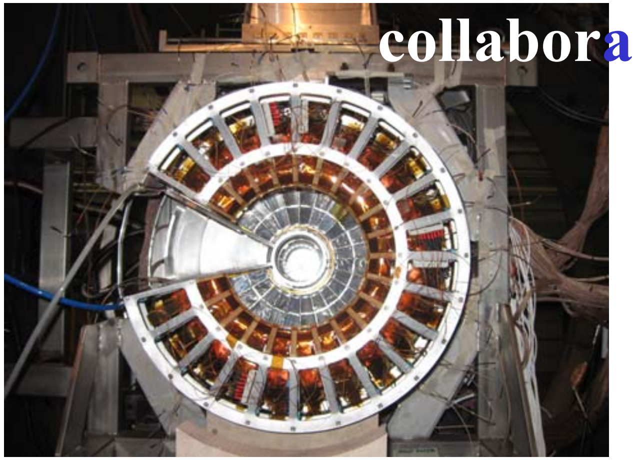
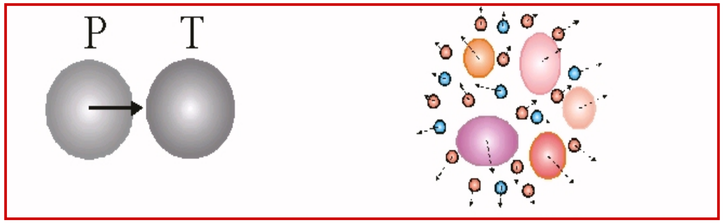
Signal Shapes of Silicon and Scintillation Detectors via Digital Sampling Electronics

G. Casini for the Nucl-Ex and FAZIA collaborations



1. The collaboration and the program
2. Motivation for these test measurements
3. Beam Request

A new detector for the physics with radioactive beams



Laboratories

GARFIELD + PIAVE-ALPI beams
INDRA (GANIL) + GANIL beams
Warsaw laboratory

The new Heavy-Ion Physics with radioactive beams requires a 4π Detector with high granularity, capable of determining the energy, atomic and mass number of all emitted fragments → detailed energy, charge and mass balance for determining the (equilibrium and non-equilibrium) thermodynamics of the excited nuclear matter

***FAZIA (Four Pi Z and A Identification Array)*: a growing number of physicists from France, Italy, Poland, Spain, Rumania and outside Europe (Canada, India and US) are co-operating for studying and testing new solutions aiming at making a step beyond the presently available arrays.**

(previous work done in the *AZ4π Franco-Italian initiative*)

GOAL: a unique detector array for low energy (SPIRAL2 / SPES) and higher energy (GANIL / LNS / FAIR / EURISOL) studies with exotic and stable beams.

Main characteristics of the 4π-detector array

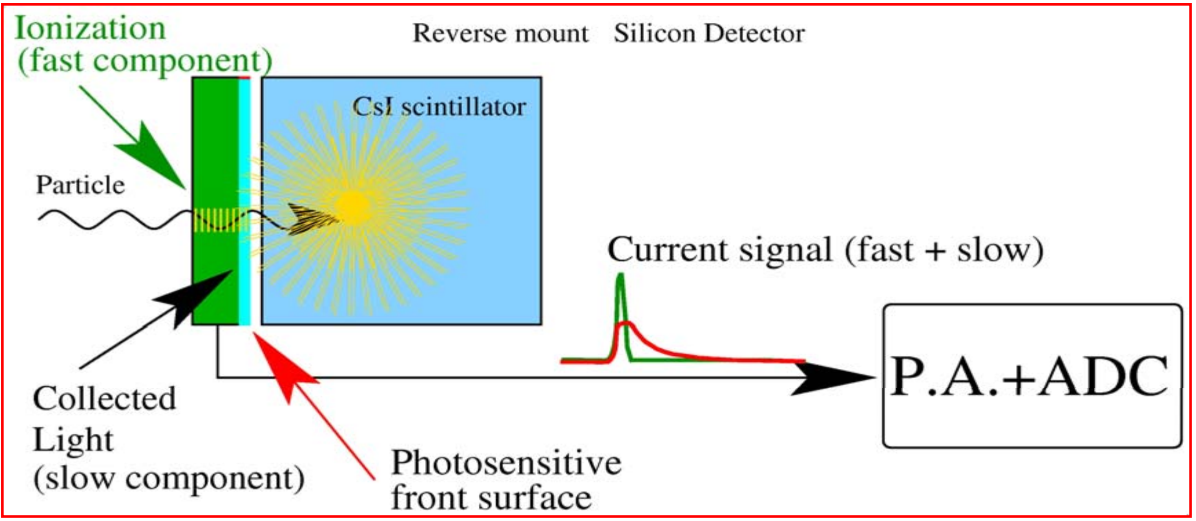
- High granularity, Z (~60) and A (~40?) identification, low energy detection-identification thresholds, good timing, compactness, modern digital electronics

Detector: Two (or three) stage ΔE-E Si-(Si)-CsI telescope, with a novel solution for Si-CsI stage.
Single Chip Telescope: very first prototype implemented with digital electronics already working -- meant to be the basic detection module of the Array

SINGLE CHIP TELESCOPE

G.Pasquali et al.

NIM A301 (1991) 101



Identification technique:

ions stopped in silicon: Pulse Shape Analysis (PSA) to extract Z and A, also exploiting ToF

Ions stopped in CsI: PSA for light-particles + standard ΔE-E identification

Front End Electronics: Full digital signal acquisition and processing

Pulse Shape in Silicon: channeling problems?

- The PSA in Silicon is based on the possibility to identify ions with different charge thanks to the different shapes produced in the crystals

- Best results when ions enter the crystal at the low electric field side (reverse mounting; see e.g. Pausch et al. NIMA365(1995)176) because shape differences are amplified

- Recent tests on reverse mounted silicons irradiated with medium-charge ions at Tandem energies (French-Fazia group), show that, for a given ion-energy combination, in some percent of cases the signal shapes strongly differ from the average. This can limit a satisfactory use of PSA for ions in the interesting charge range (up to about Z=30)

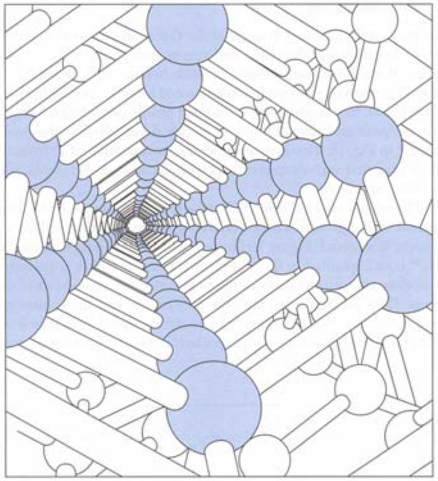
Hypothesis: atypical shapes correspond to *channeled* ions which, by travelling on average far from the atoms, differently interact with electrons (e.g. they have a smaller Pulse Height Defect since they produce less dense electron-hole clouds)

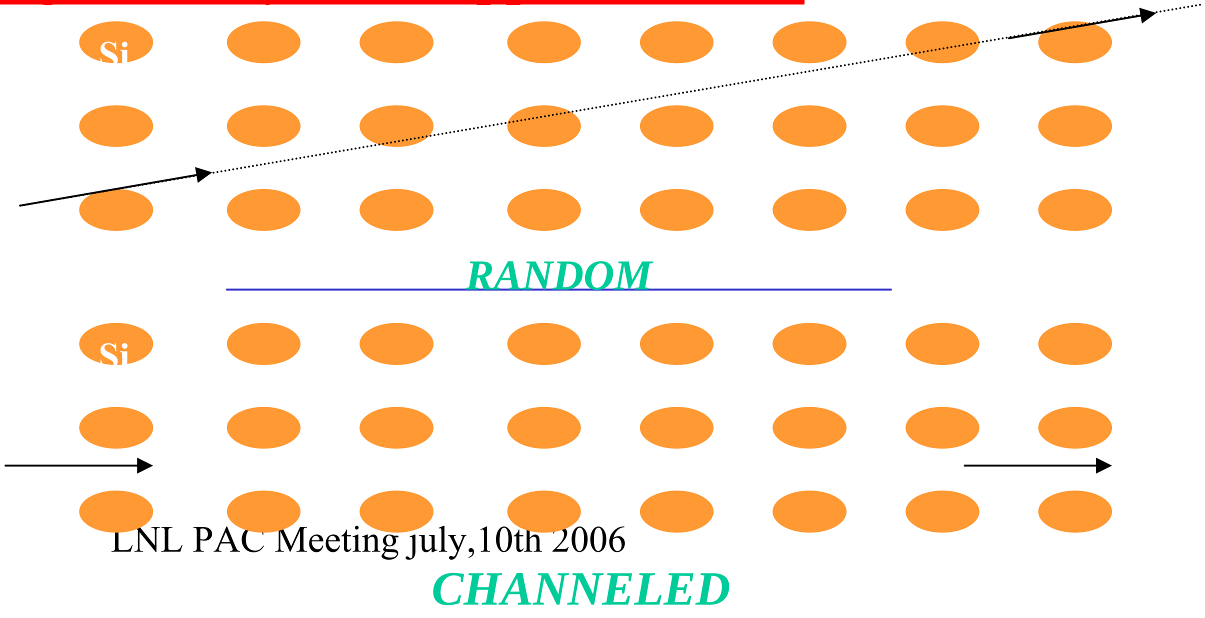
CHANNELING

Channeling is a well known set of effects which occur in detectors made of monocrystals (like Si). They are connected to the orientation of the incident radiation with respects to crystallographic planes and axes of the detector.

Channeling has been studied mainly in trasmission experiments (very thin crystals). Concerning HEP, the literature presents many results on channeling for leptons at very high energies while for NP few data are available. They mainly deal with channeled (not stopped ions) at low energy (≤ 1 AMeV). **see for example: Cohen and Dauveregne NIMB 225(2004),40**

As far as we know, no data exist on the relationship between signal-shape and channeling for energetic heavy-ions stopped in silicon

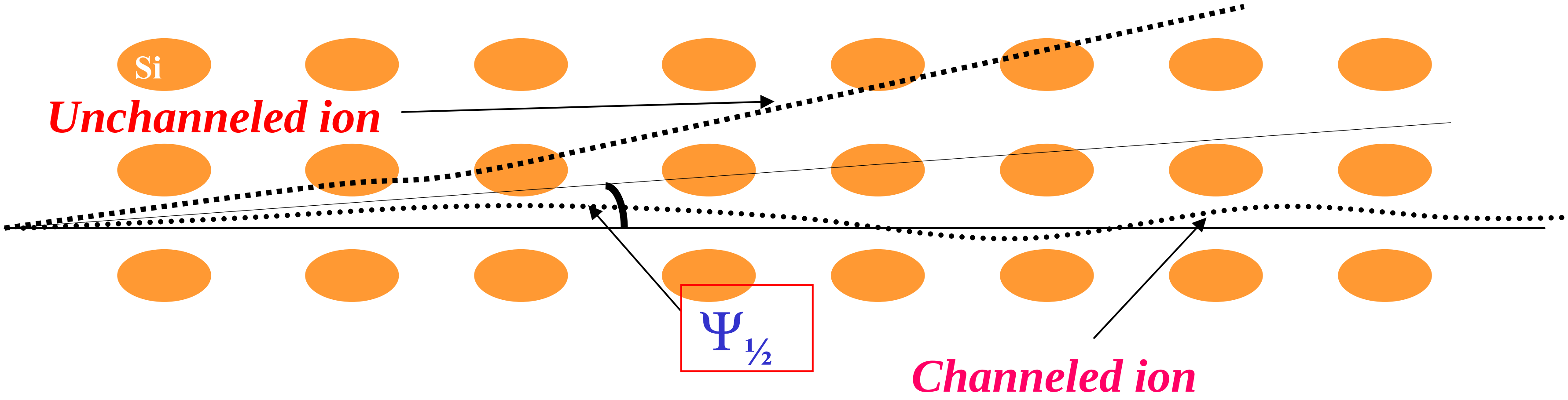




CHANNELING effects for heavy ions

Critical angle Ψ½

Several quantities G (e.g. the Pulse Height of the signals or their dispersion) can vary in passing from random to channeled directions. For a given ion kinetic energy E_c , the *half width at half maximum* of G as a function of the angle between the ion velocity and a selected crystallographic direction represents the critical angle usually called $\Psi_{1/2}$



For a given ion and for a given crystallographic direction (e.g. <111>) the critical angle $\Psi_{1/2}$(<111>) depends on the kinetic energy as $(E_c)^{-1/2}$

Hogg et al App.Phys Lett 80(2002),4363; Cohen et al NIM B225(2004)40

Critical angle for Heavy Ion CHANNELING

Calculated values of critical angle for channeling (in silicon) are small:

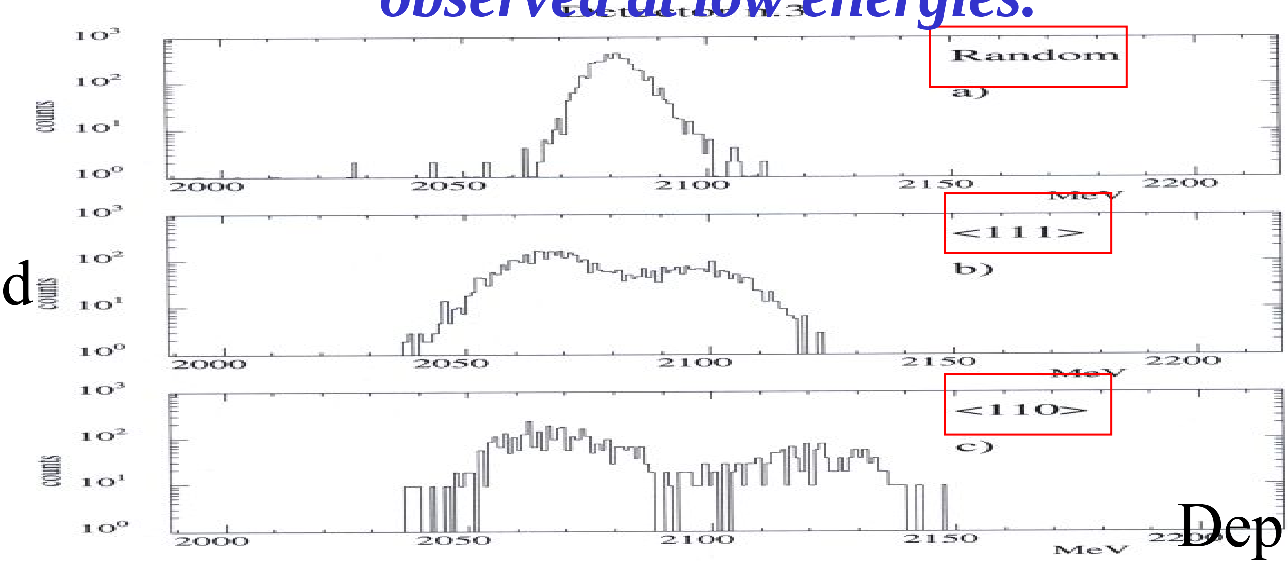
^{100}Mo @ 15 AMeV: axis <111> $\Psi_{1/2}$<111>= 0.07°

^{197}Au @ 11 AMeV : axis <111> $\Psi_{1/2}$<111>= 0.07° ; plane {110} $\Psi_{1/2}${110} = 0.04°

HOWEVER

Our previous experience on these effects and a dedicated experiment with Au ions at 11AMeV ***stopped*** in silicon performed at GSI (**G.Poggi et al. *NIM B 119 (1996) 375***) show that channeling can occur for incident angles much larger than Ψ½ .

The channeling probability is <u>quite larger</u> than what expected and observed at low energies.



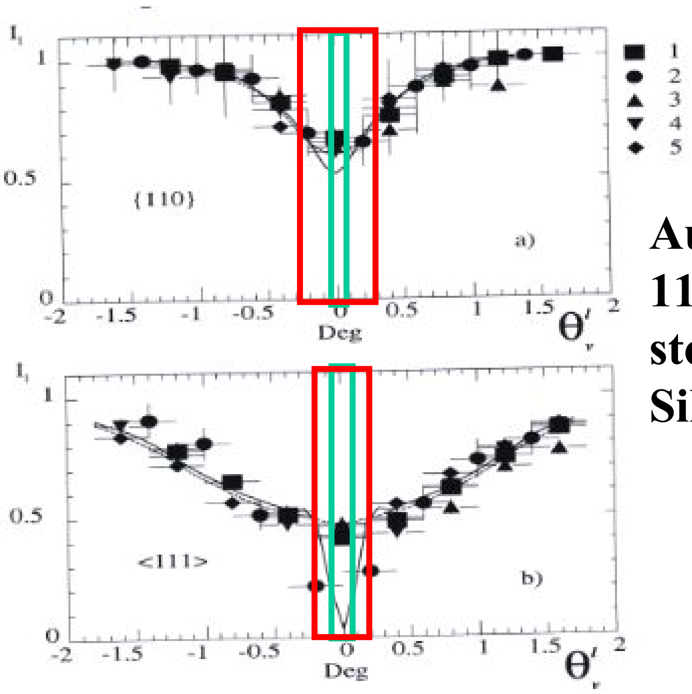
Yield

Dep. Energy

Critical angle for Heavy Ion CHANNELING

The channeling probability results <u>quite larger</u> than what expected and observed at low ion energies (<1 MeV/amu).

The observed critical angle (red) is larger than the predicted one (green)

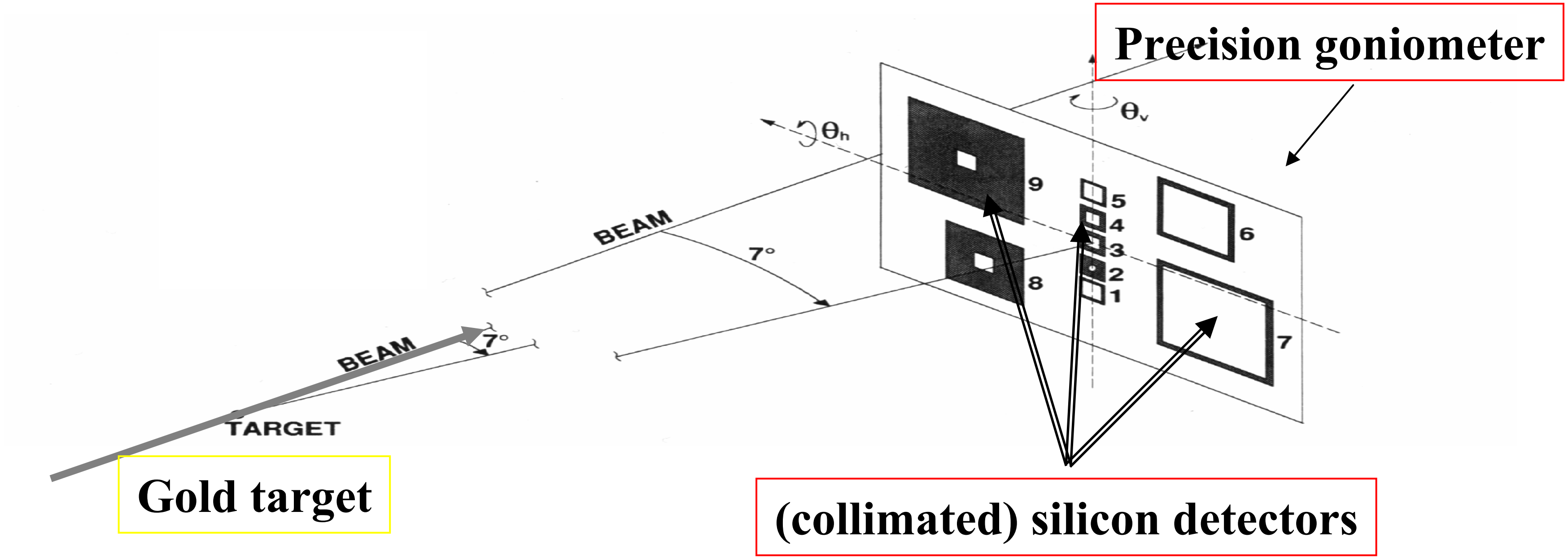


Au ions 11MeV/amu stopped in Silicon

This has been explained with the process of multiple scattering which allows the unchanneled ion to continue travelling nearby crystallographic directions until they are captured by the channel.

Channeling and Pulse Shape Analysis: an old-idea + the new digital electronics

We plan to use a set-up very similar to the old GSI experiment



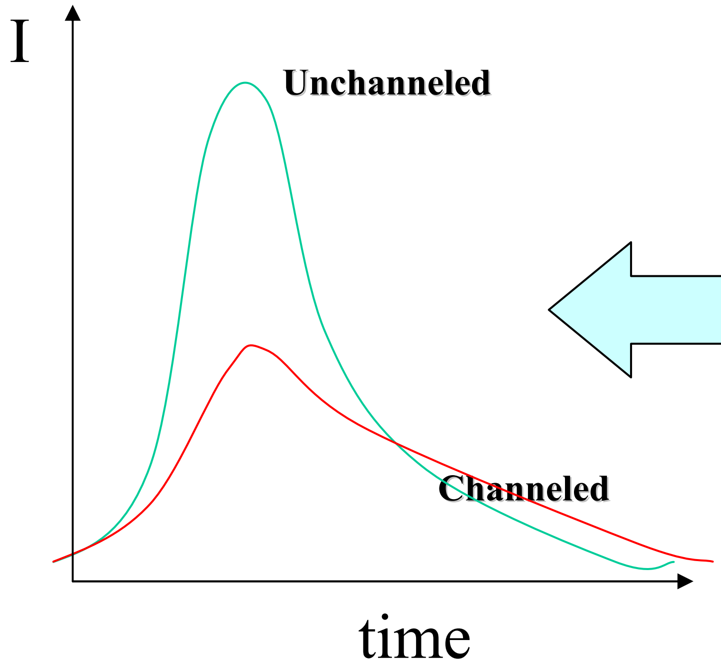
Precision goniometer

Gold target

(collimated) silicon detectors

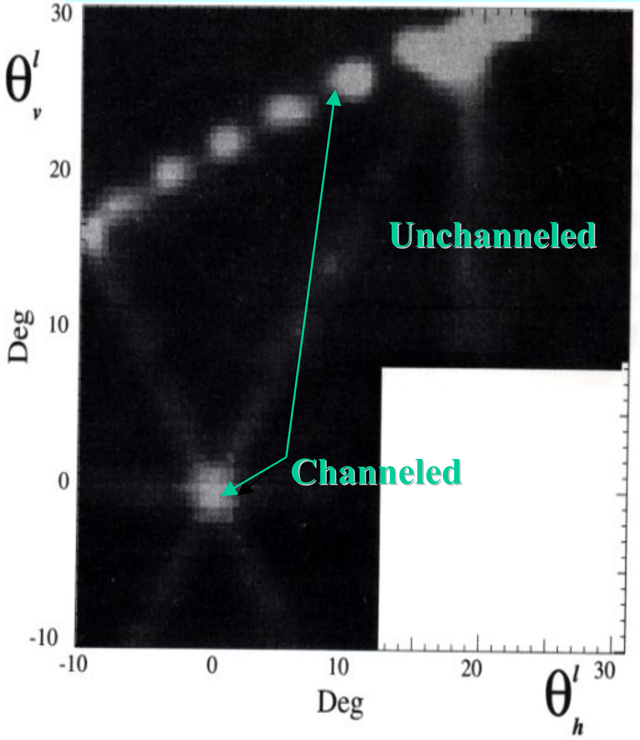
- **We will use ions scattered from a thin gold target at known angles**
- **We plan to use several different silicon detectors produced by different companies.**
- **They will be reverse mounted on a double-angle precision goniometer *(resolution 0.01º)* and many angles will be scanned**
- **A good geometry is needed to precisely define the relative angles (long path in the HuygensVat chamber HALL-III)**

Digital Pulse Shape and Blocking picture: what we expect



?

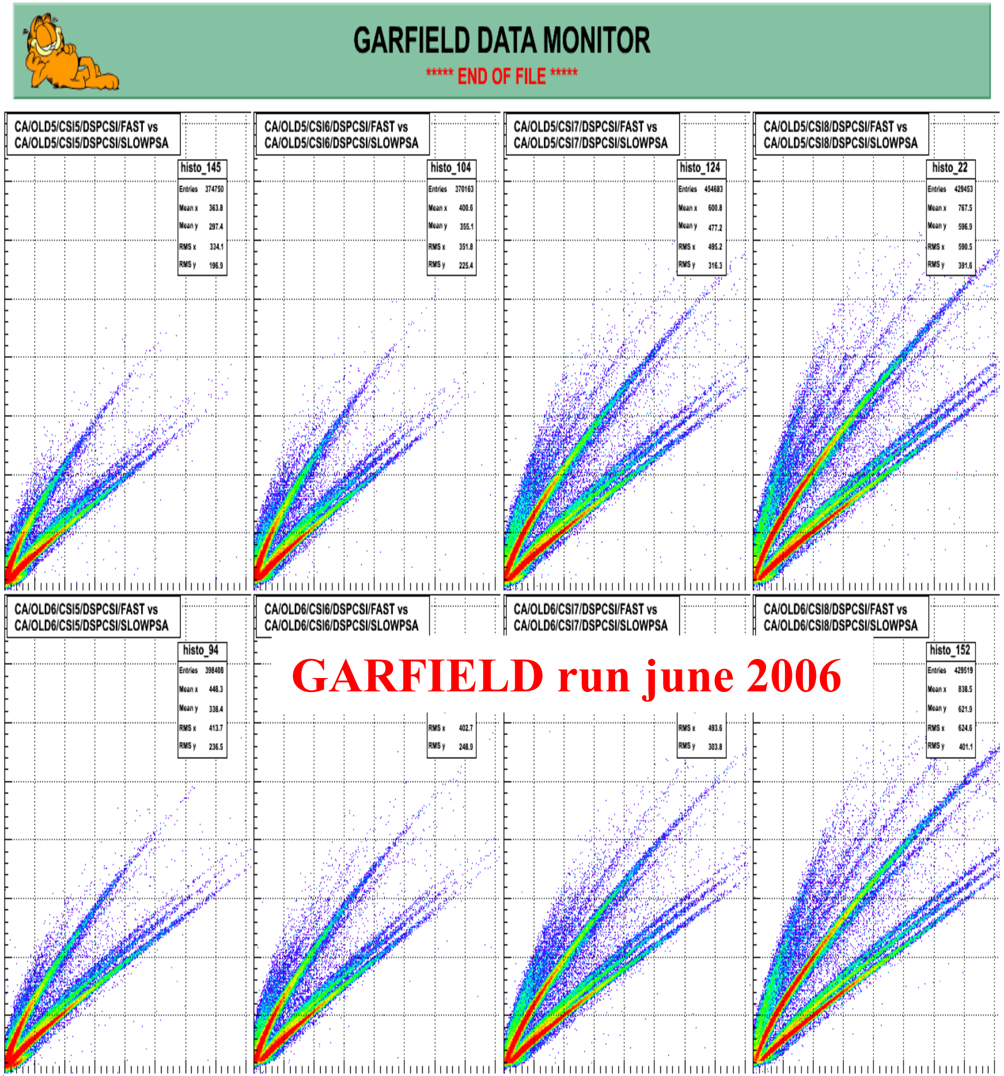
G.Poggi et al NIMB119(1996),375



Digital Pulse Shape and Blocking picture: we are able to try this task!

Since years our group develops and uses ADC-DSP boards. With this new electronics many encouraging results have been obtained.

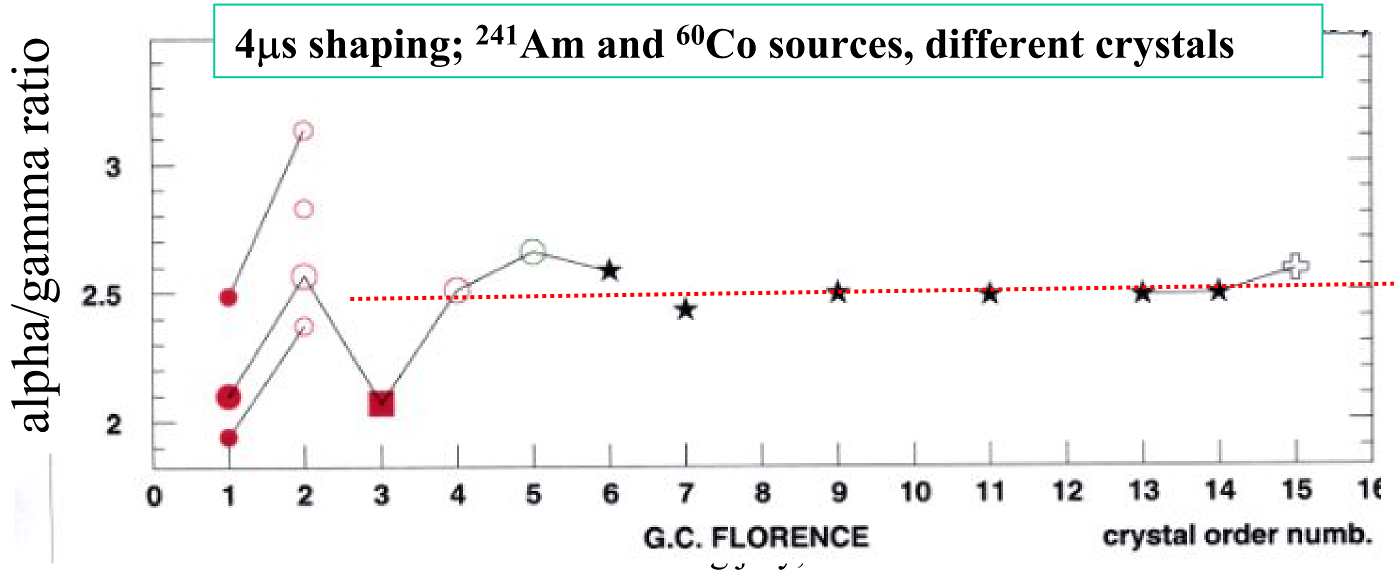
Here is an example with CsI-fast-slow isotopic separation for hydrogen and helium ions.



GARFIELD run june 2006

CsI(Tl): optimizing performances for heavy-ions

CsI scintillators will be the final stage of the FAZIA telescope. The usual Tl doping concentration is around 1000-1200ppm as at these values the light output ratio between alpha and gamma reachs some kind of saturation (see Kudin et al NIM A537(2005)105)



4μs shaping; ^{241}Am and ^{60}Co sources, different crystals

CsI(Tl): optimizing performances for heavy-ions

There are recent indications for a possible increase of the light production for heavy-ions at higher Tl concentrations. We plan to investigate this subject via standard and digital electronics by using different crystals with the dimensions of the FAZIA module (20x20x40mm^3)

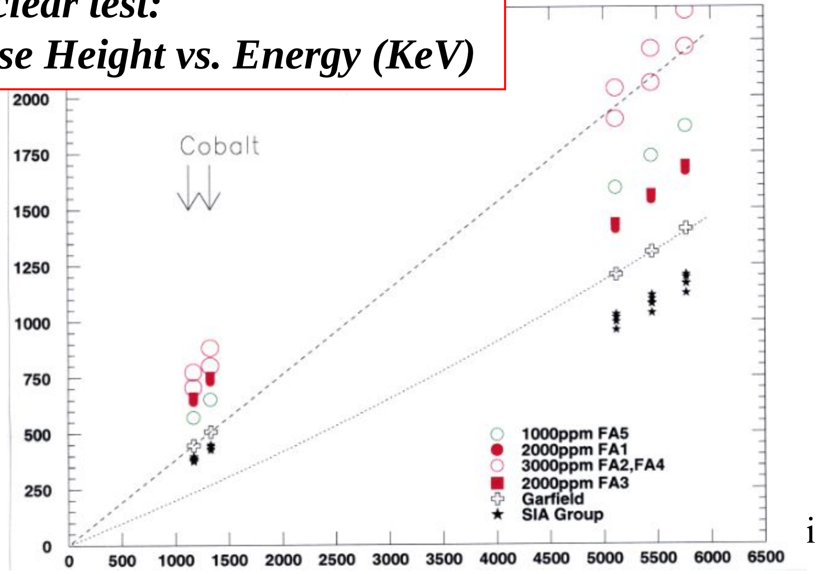
In the framework of FAZIA we planned different approaches.

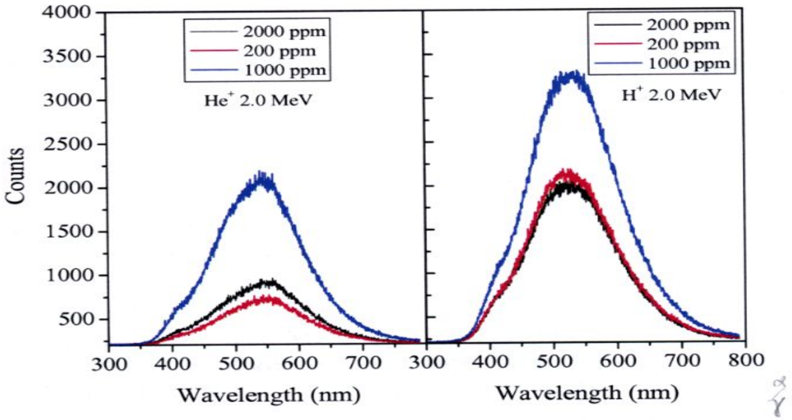
- **Beam tests with heavy ions (*nuclear physics approach*)**
- **Ion Beam Induced Luminescence (IBIL) measurements to study the light emission spectrum -and its ageing- vs. Tl doping (*matter physics approach → see proposal by A.Quaranta*)**
- **PIXE measurements to confirm and check the declared concentration values (*→ test at the LABEC Tandertron, Florence*)**

CsI(Tl): optimizing performances for heavy-ions

We want to measure the light output (and signal shape) for elastically scattered ions using the same beams of the previous subject and mounting the crystals inside the Garfield scattering chamber
The nominal doping concentration till now available are 200, 500, 700, 1000, 2000, 2500, 3000ppm produced by four different companies.

Nuclear test:
Pulse Height vs. Energy (KeV)





IBIL test:
Light Yield vs. Wavelenght (nm)

Requested ALPI and XTU Beams

	Energy (MeV/amu)	Time (days)	Range in Si (μm)	Approx. count rate cps at 9^{o}	Grid scanning points (approx)
^{58}Ni	5	0.5	46	32	20
^{58}Ni	13	1	137	5	20
^{56}Fe	13	1	147	5	20
^{32}S	15	1	220	34	20
^{32}S	5	0.5	50	51	20

current 1 nAe; target 0.2 $\mathrm{mg/cm^2}$; distance 100cm, active area 4 $\mathrm{mm^2}$