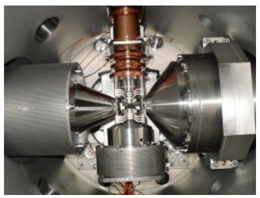
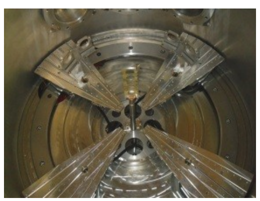




Isospin transport in nuclear collisions studied by multidetectors INDRA-FAZIA

Quicray Joël

Supervisors E. Vient & N. Le Neindre

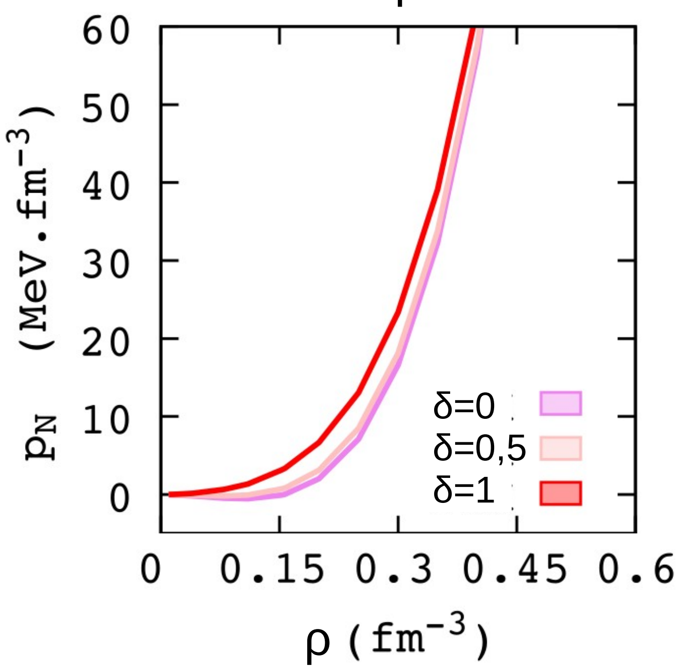
Introduction : theoretical context

Theoretical context : Equation of State

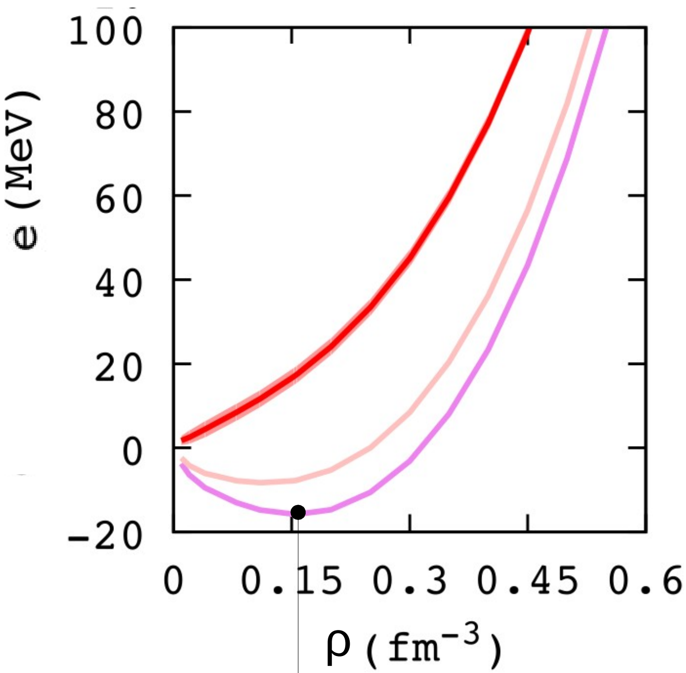
Def. Equation of State (EoS) : Pressure = f(Temperature, Density).
A well-known one is the perfect gas equation **P=ρRT**

In nuclear physic : **EoS of nuclear matter** P(T, ρ, δ) , with ρ density of nuclear matter
More often written Energy(T, ρ, δ)

P vs ρ



E vs ρ



ρ_0 saturation density

Margueron et al. Physical Review C 97, 025805 (2018)

for ∞ nuclear matter

$$\delta = \frac{\rho_n - \rho_p}{\rho}$$

for a nucleus

$$\delta = \frac{N - Z}{A}$$

Theoretical context

To get EoS's parameters we use a limited expansion

expanded in power of δ

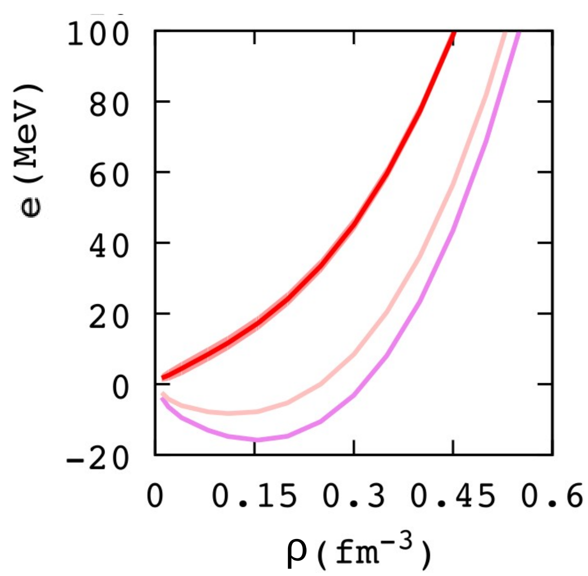
$$e(\rho,\delta) = e_{is}(\rho) + e_{iv}(\rho)\delta^2 + O(\delta^4)$$

expanded in power of $x=(\rho-\rho_0)/(3\rho_0)$ around saturation density $\rho=\rho_0$

$$e_{is}(x) = E_{sat}+\frac{1}{2}K_{sat}x^2+O(x^4)$$ well-known at first orders

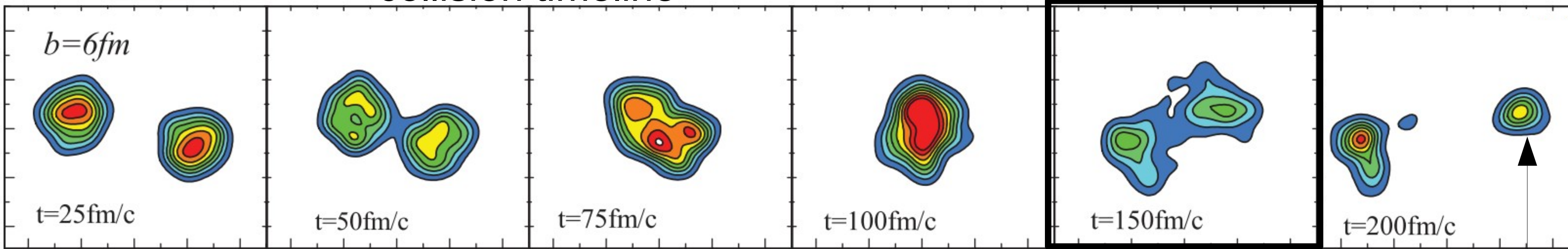
$$e_{iv}(x) = E_{sym}+L_{sym}x+\frac{1}{2}K_{sym}x^2+O(x^4)$$

Parameter	Relative uncertainty
E_{sym}	5 %
L_{sym}	30 %
K_{sym}	100 %



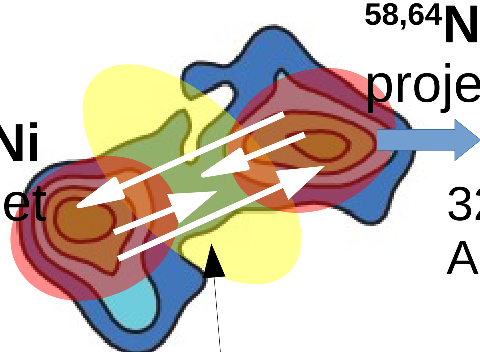
Experimental way to constrain these parameters

collision timeline



Yingxun Zhang, et al. Physical Review C, 85(2)

Quasi-Projectile



^{58,64}Ni projectile

^{58,64}Ni target

32,52 AMeV

isospin transport :
redistribution of neutrons & protons between projectile/target & neck during reaction time (10^{-22}-10^{-20} sec.)

Requirements :
impact parameter b, deduced from fragments multiplicity
reaction time, deduced from b and E(projectile)

Isospin and collisions

neutrons stream and protons stream difference $|\vec{j}_n - \vec{j}_p|$,

deduced from $\left(\frac{N}{Z}\right)_{ini} - \left(\frac{N}{Z}\right)_{final}$

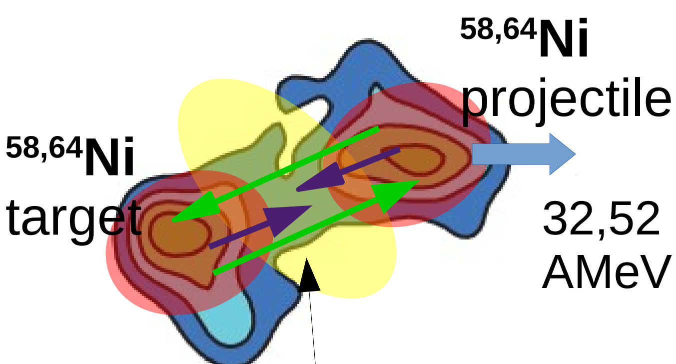
$$|\vec{j}_n - \vec{j}_p| \propto \underbrace{L_{sym} \vec{\nabla} \rho}_{\text{migration}} - \underbrace{e_{iv}(\rho) \vec{\nabla} \delta}_{\text{diffusion}}$$

migration: neutrons enrichment of the neck

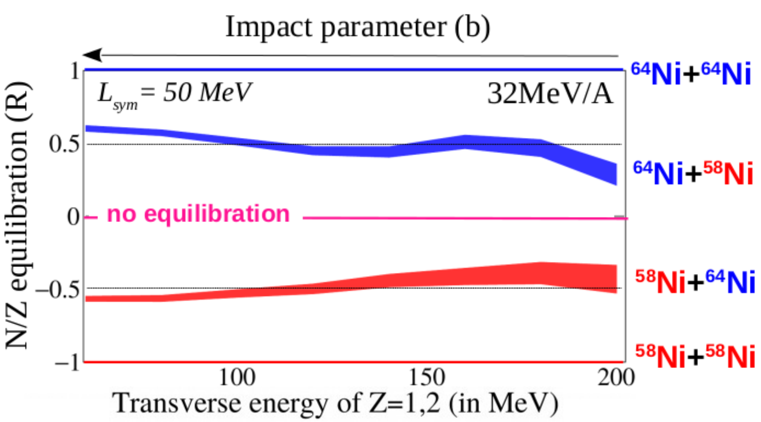
change with the couple chosen target/projectile couple

diffusion: equilibration isotopic

Change with the collision enregy

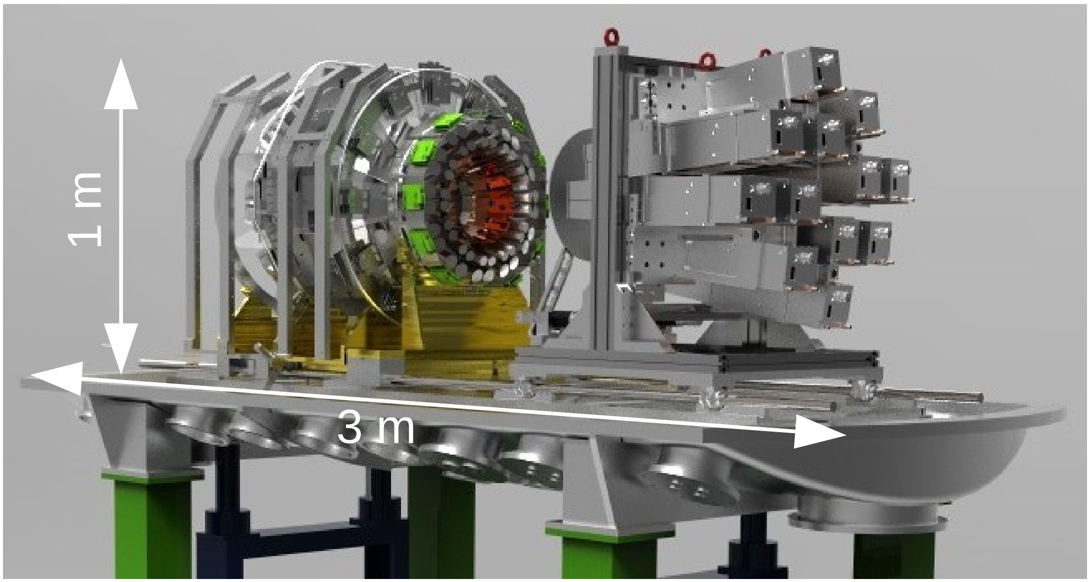


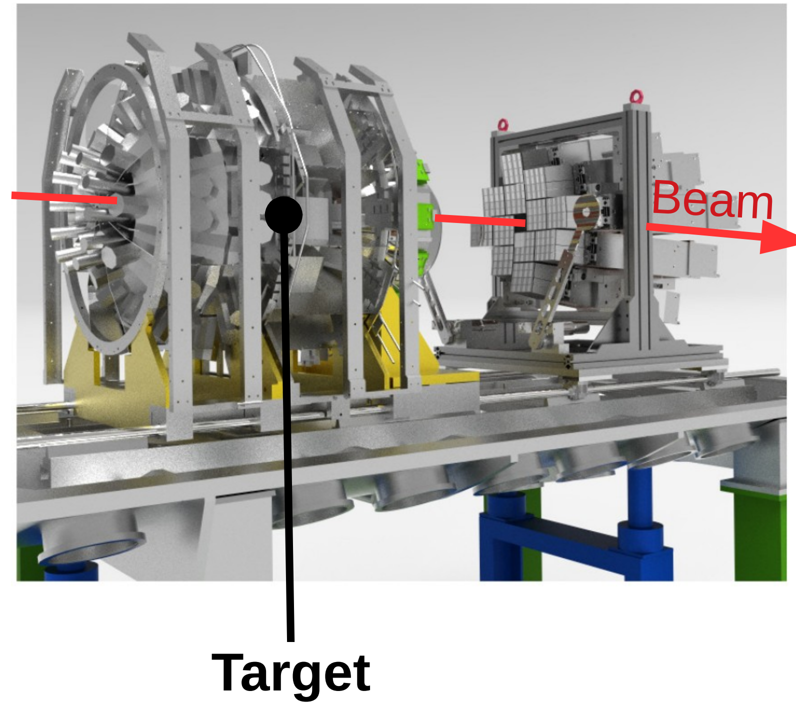
isospin transport :
redistribution of neutrons & protons between projectile/target & neck during reaction time (10^{-22}-10^{-20} sec.)

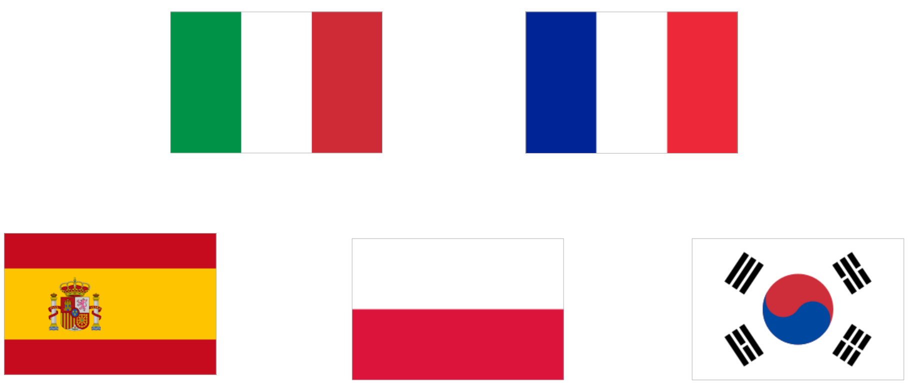


Lopez and Piantelli, E789 proposal

The multidetector : INDRA-FAZIA





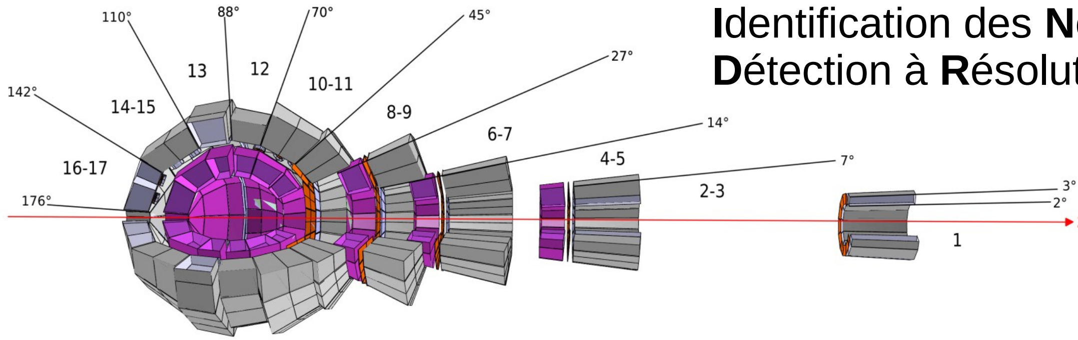


almost 4 π angular coverage

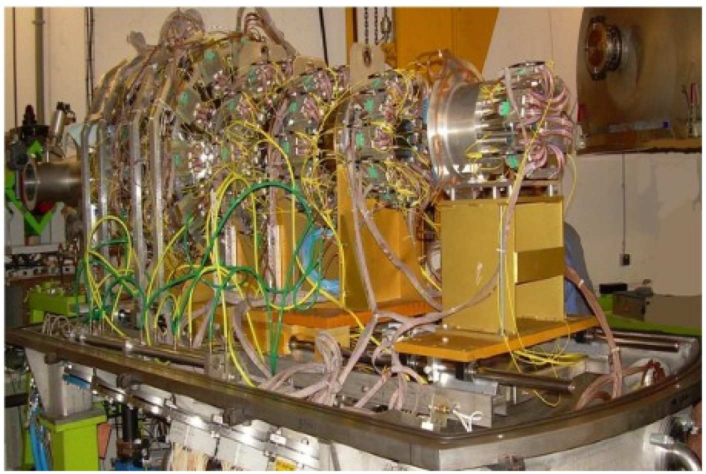
A & Z Quasi-Projectile well-measured

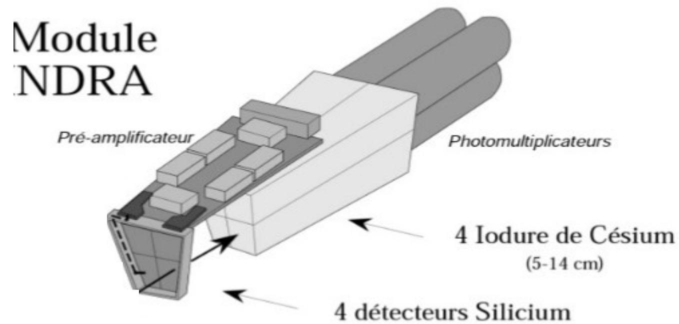
The multidetectors : INDRA

Identification des **N**oyaux et
Détection à **R**ésolution **A**ccrue



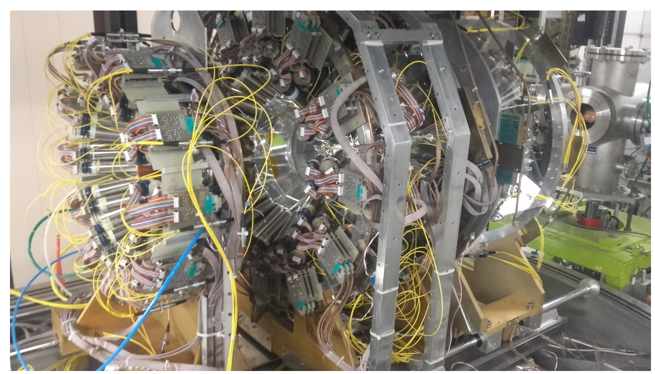
25 years
analogic electronic





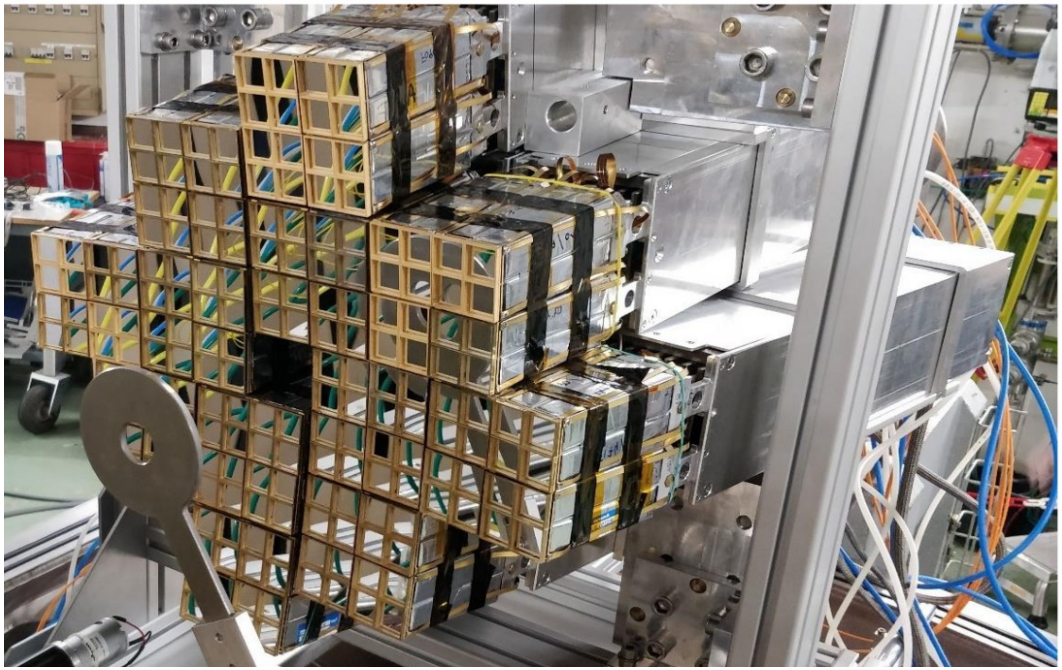
12 rings left = 240 telescopes
Angular coverage 14° to 176°

Z identification up to Z = 92
Isotopic identification up to Z = 6



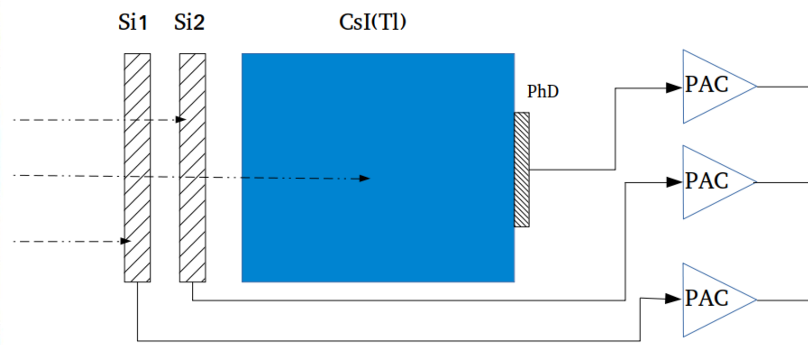
The multidetectors : FAZIA

Forward **A** and **Z** **I**dentification **A**rray



12 blocks x 16 telescopes =
192 telescopes = 576 detectors

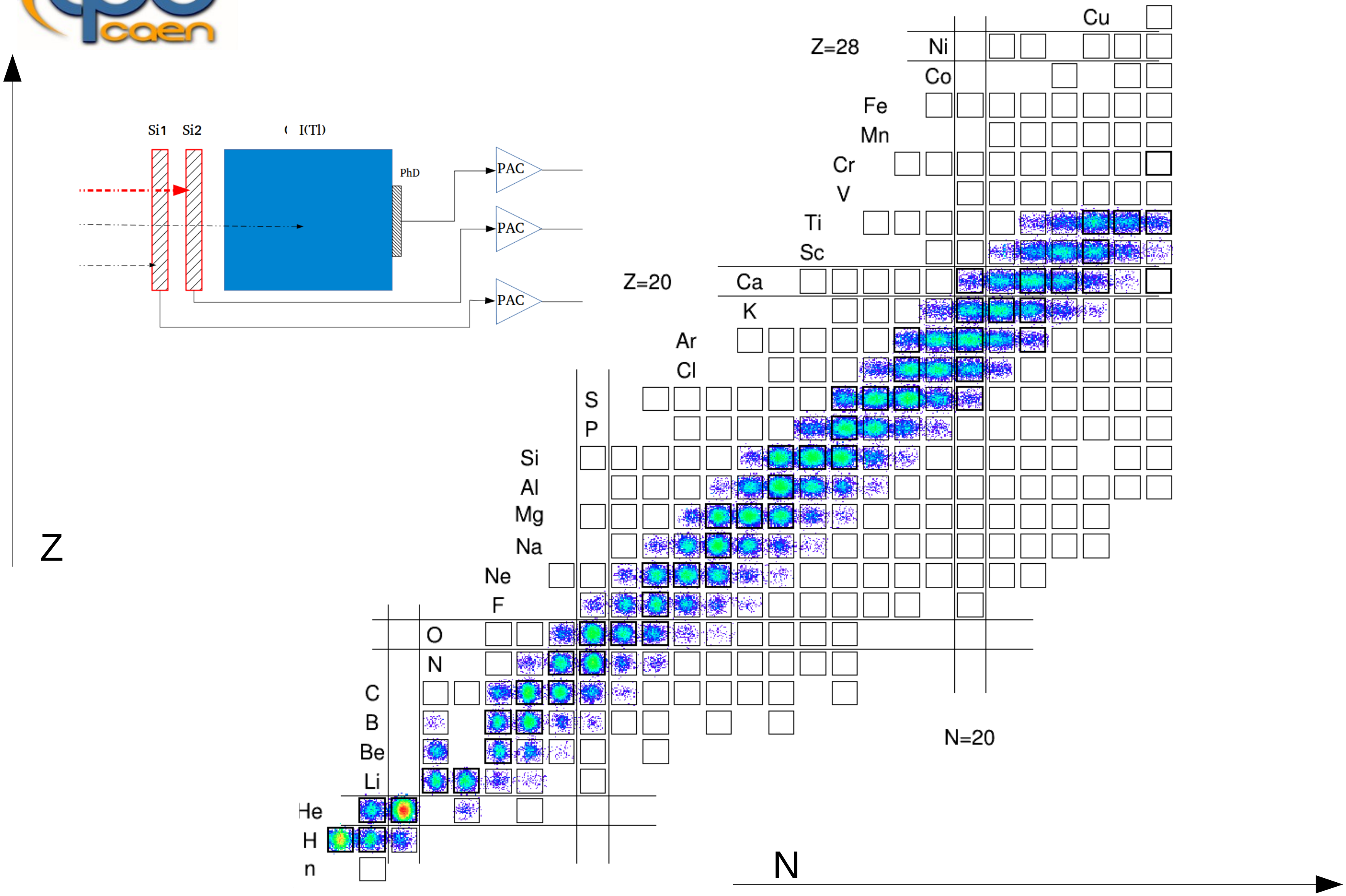
Angular coverage from 1,5° to 14°



- numeric electronic = better signal treatment
- Si new generation optimized for mass detection (homogeneity)
- Good angular resolution (small size of telescopes)

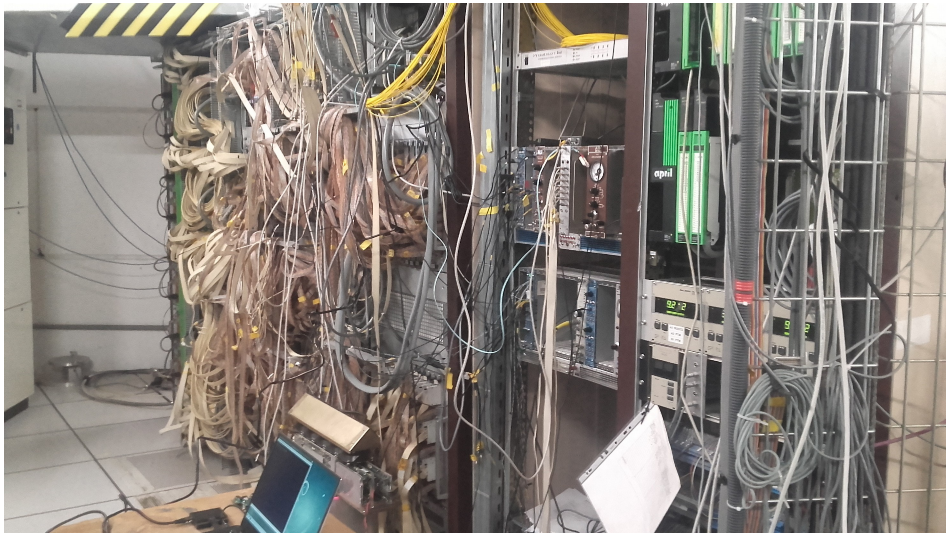
Z identification up to Z = 92
Isotopic identification up to Z = 25 !

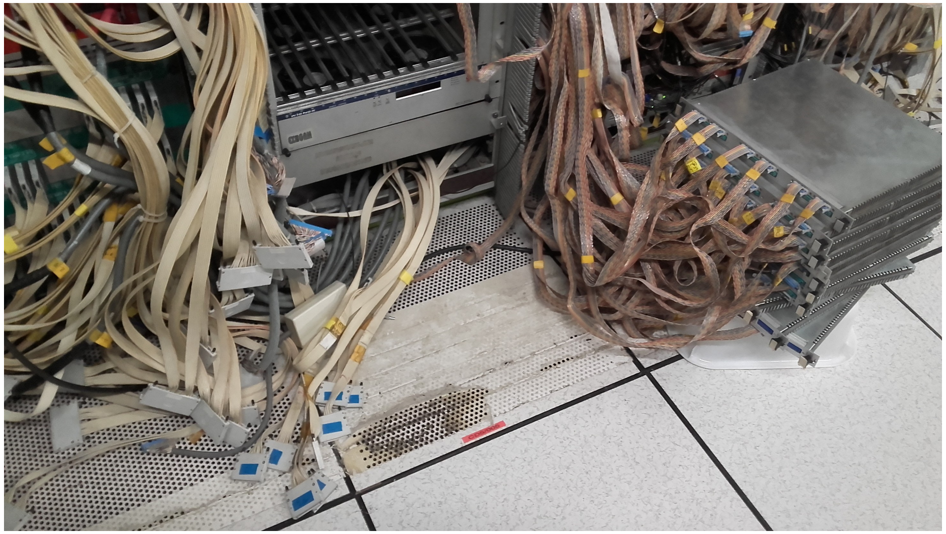
The multidetectors : FAZIA



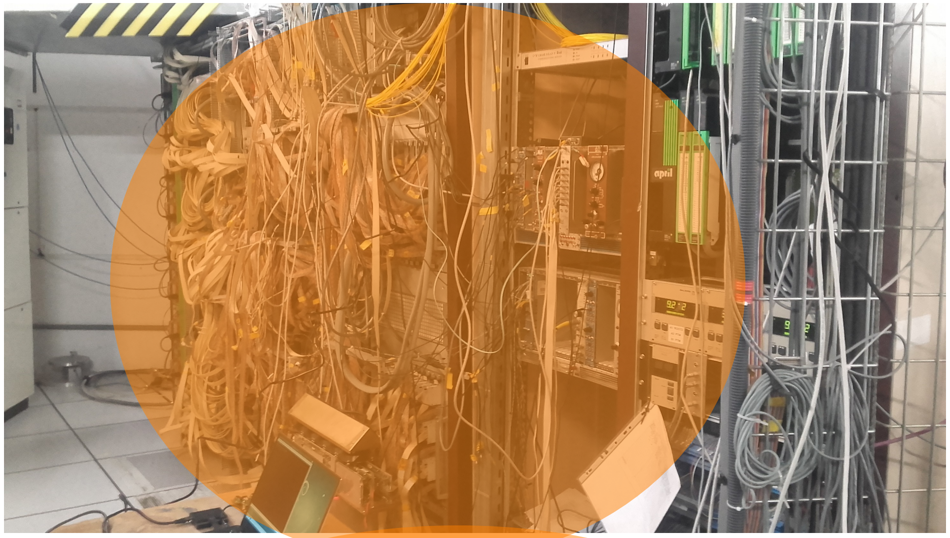
Identification map

The multidetectors : comparison



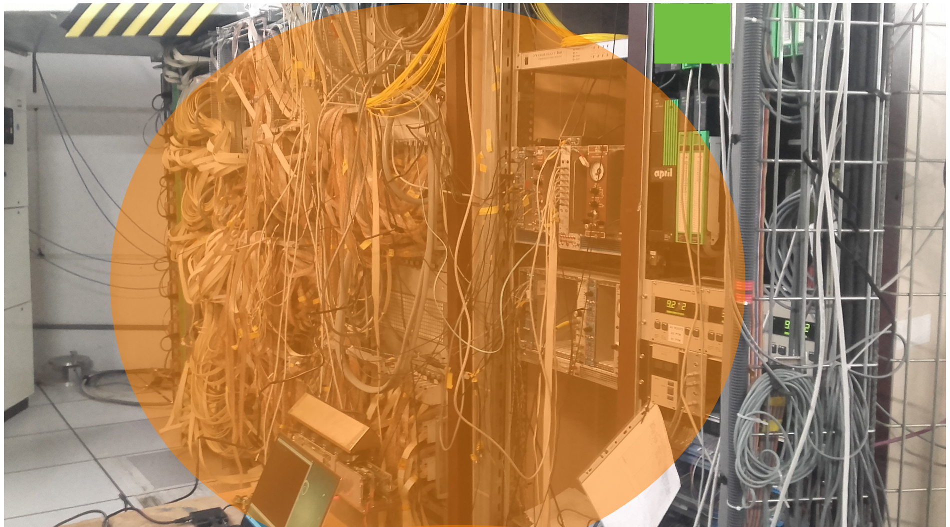


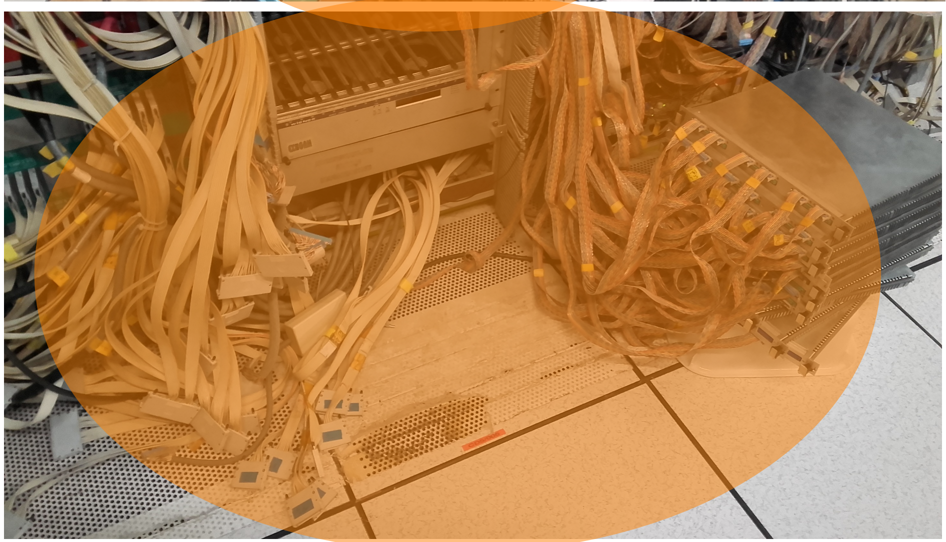
The multidetectors : comparison



INDRA

The multidetectors : comparison

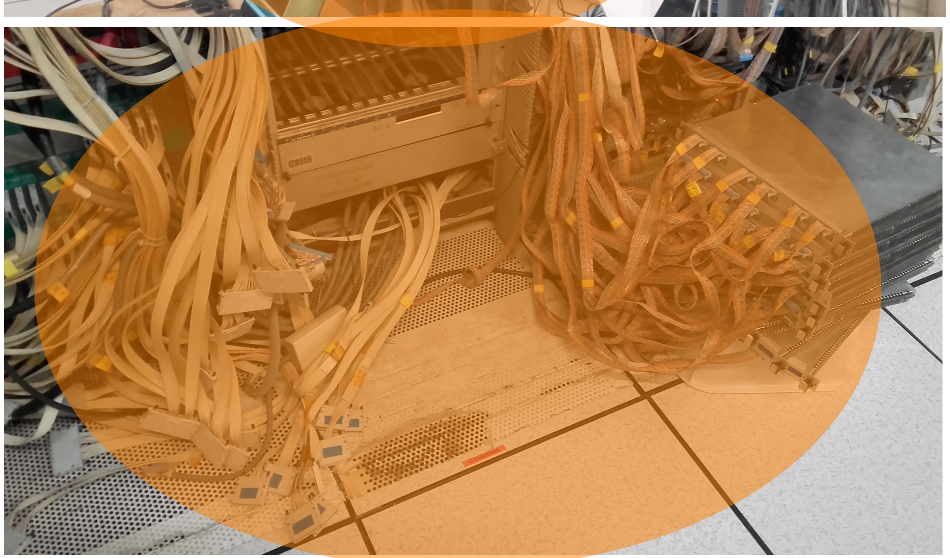




FAZIA

INDRA

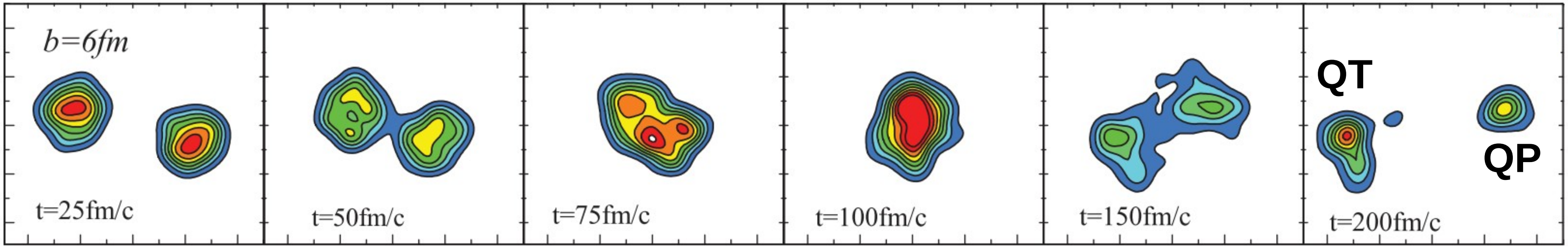
The multidetectors : comparison



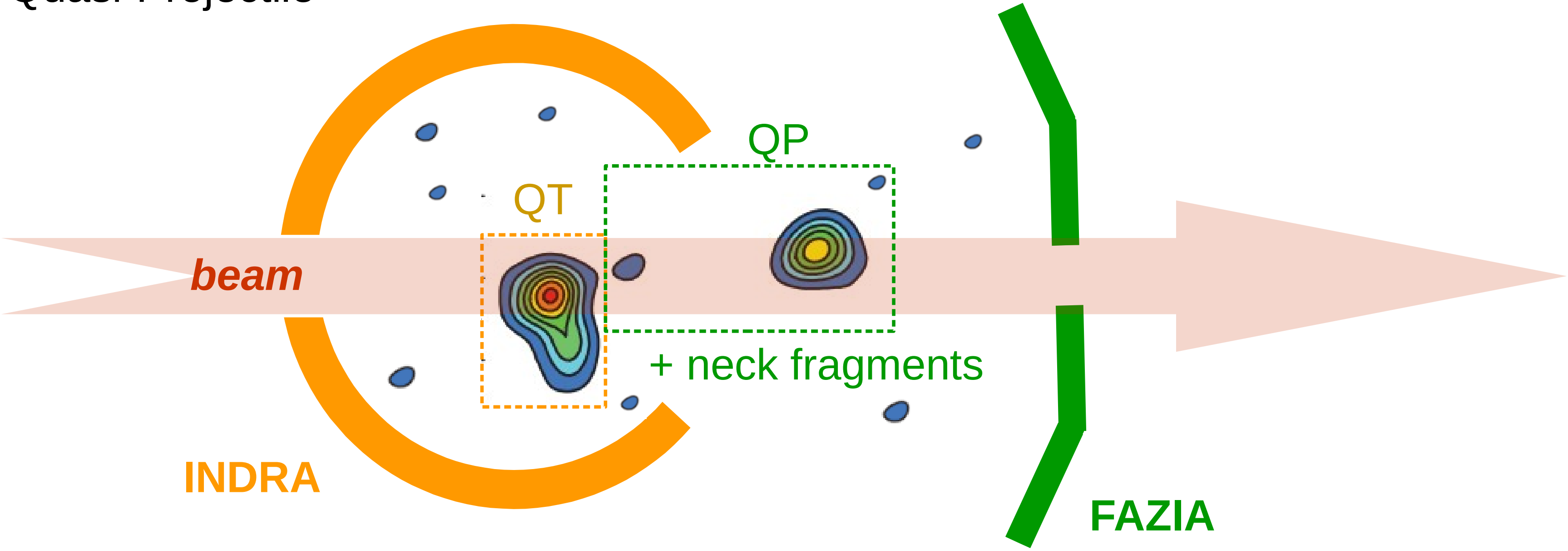
FAZIA

INDRA

The multidetectors : FAZIA



QT : Quasi-Target
QP : Quasi-Projectile

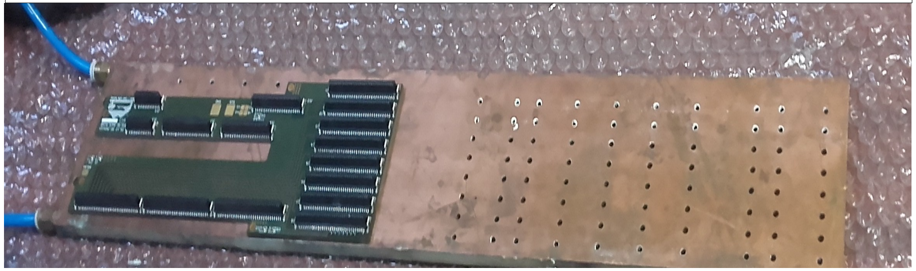


Mounting E789 INDRA-FAZIA (december 2018 – march 2019)

Mounting E789 : Mounting FAZIA

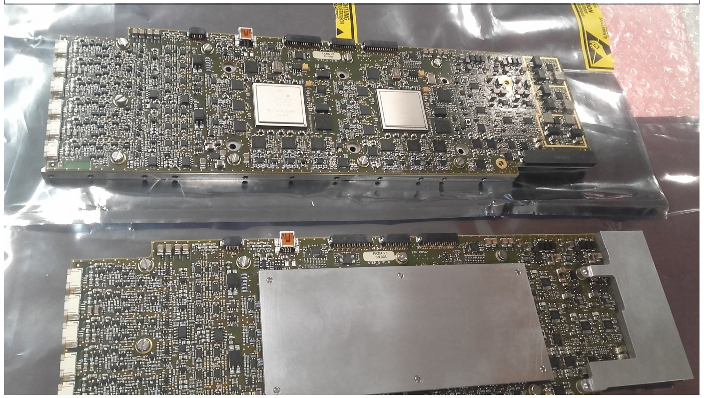
Block's electronic

Cooling plate



Working in vacuum (6h de pumping)

Telescopes electronic cards

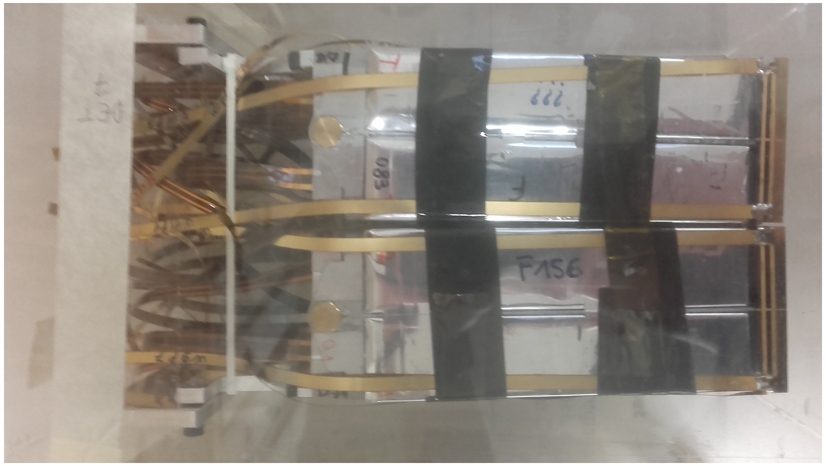


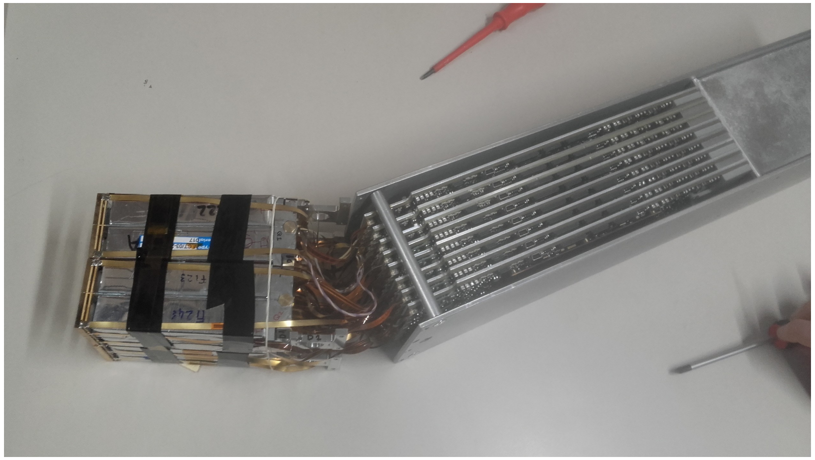
PS card, Half Bridge, Block card

All mounted in the shelter

Mounting E789 : Mounting FAZIA

Detection's head

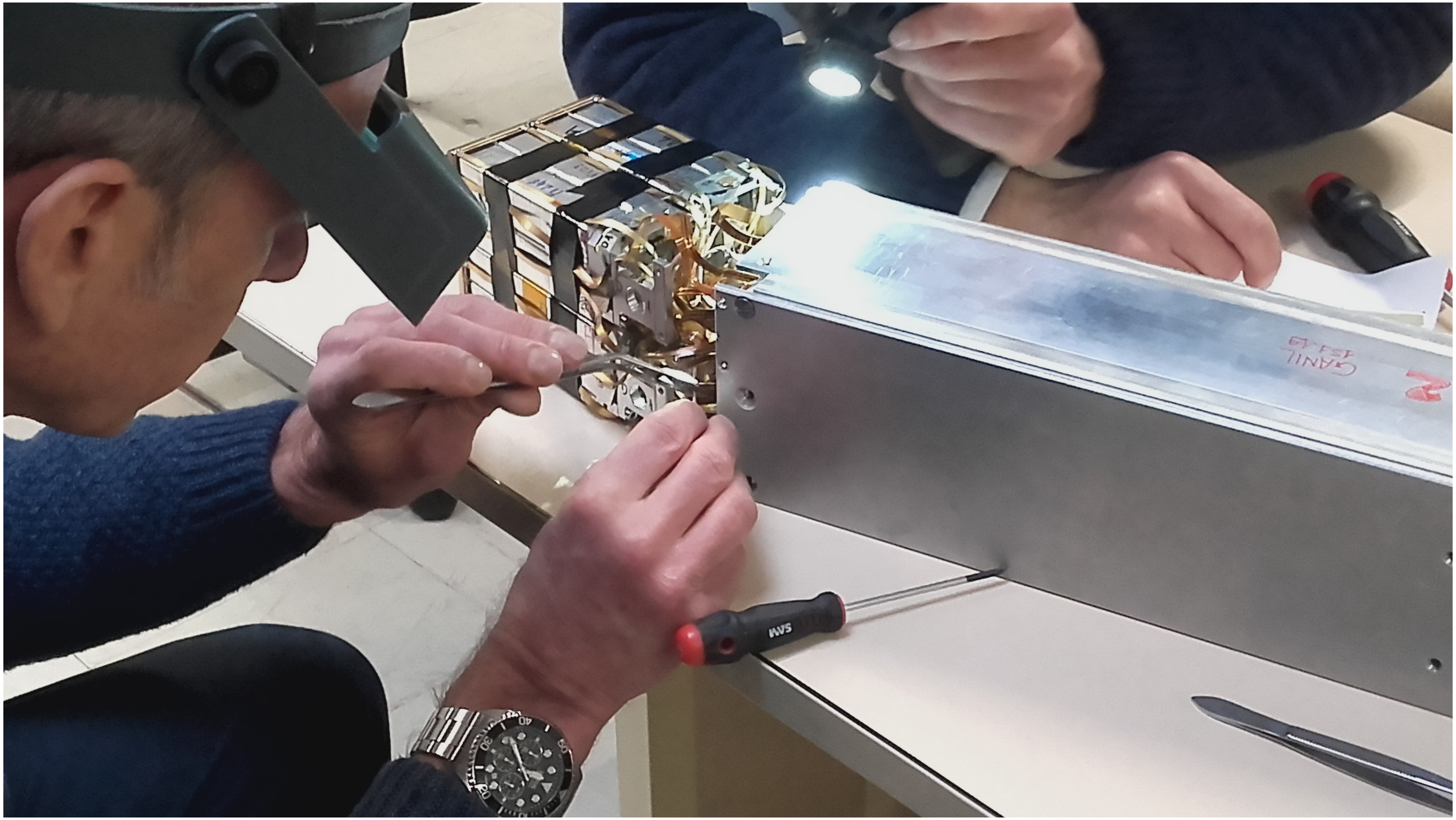




1 cable Kapton by detector = 48 cables by head of detection

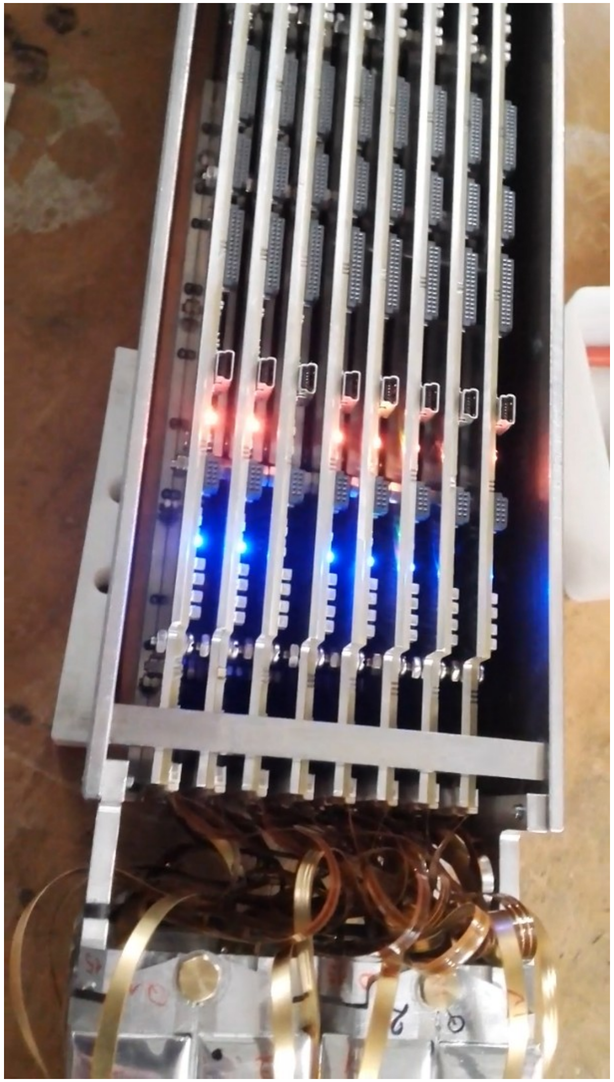
Mounting E789 : Mounting FAZIA

Detector's head



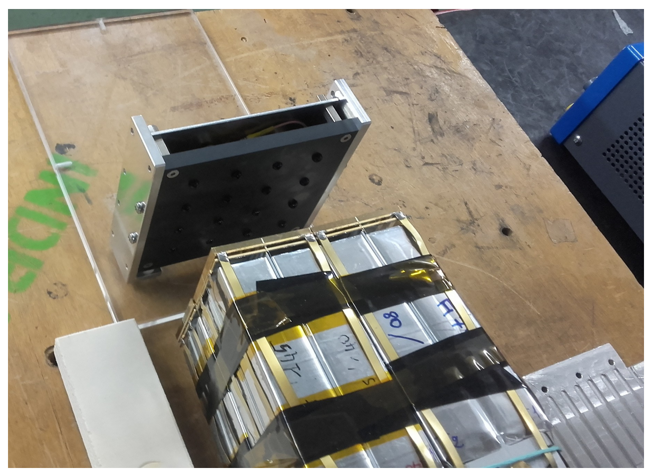
Giovanni Casini connecting the detector's head to the electronic cards

Mounting E789 : Mounting FAZIA



Electronic tests
Pulser tests
Infrared LED tests
Cosmics/alphas tests

Each block is tested alone before mounting in the vacuum chamber



THE EXPERIMENT E789 INDRA-FAZIA

- Good beam intensity
- Stable detectors
- **240 millions events** saved

The experiment : the beam

2 projectiles X 2 targets X 2 energies = **8 systems**

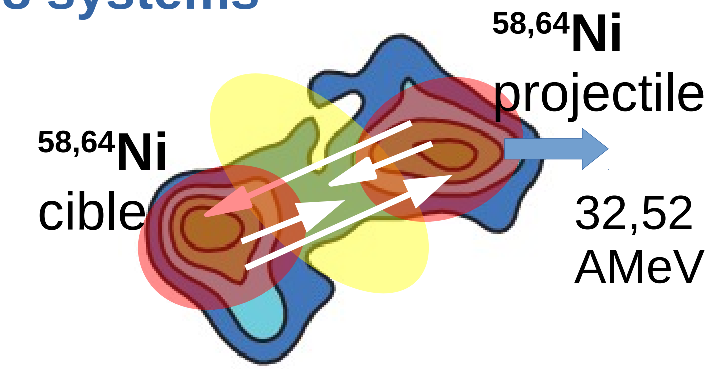
$\left\{ {}^{58}Ni, {}^{64}Ni \right\}$ + $\left\{ {}^{58}Ni, {}^{64}Ni \right\}$ @ $\left\{ 32\ MeV/A, 50\ MeV/A \right\}$

isospin gradient

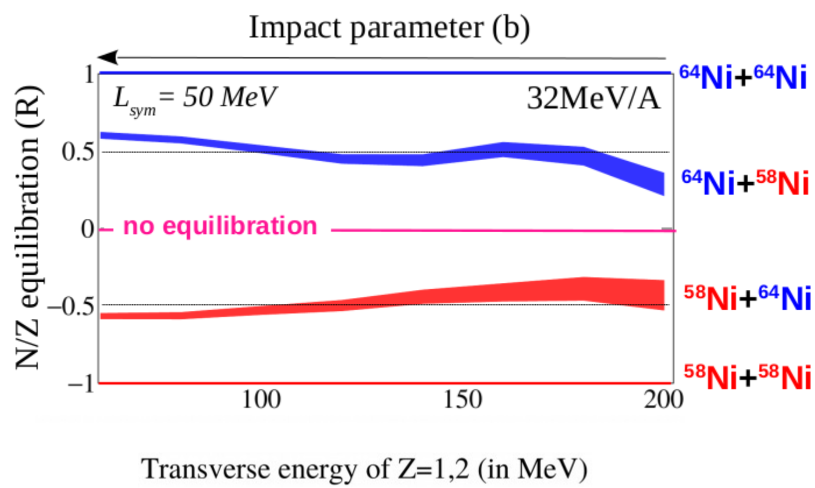
density gradient
interaction time

diffusion

migration



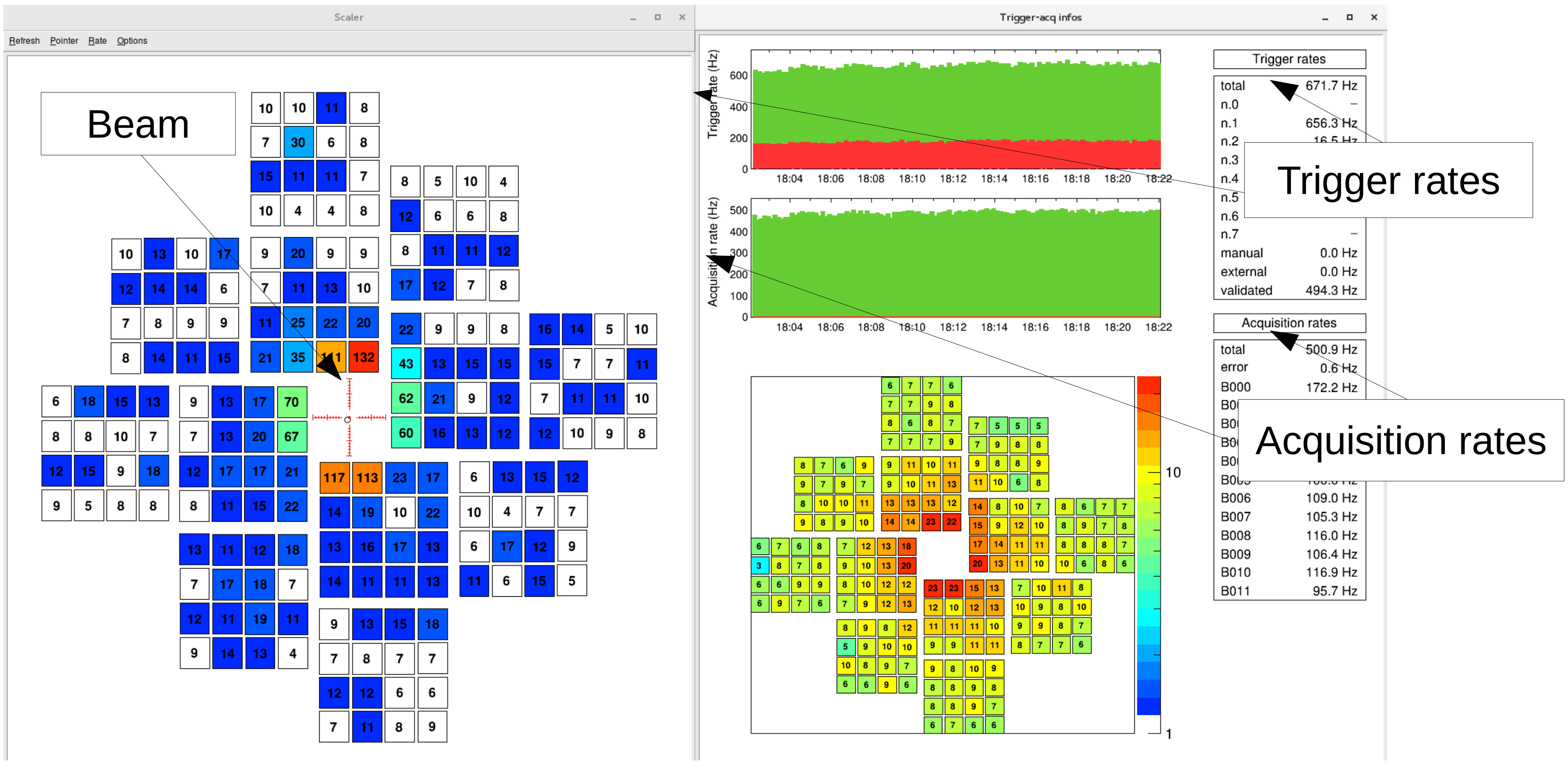
Study symmetric systems avoid experimental influence



The experiment: monitoring

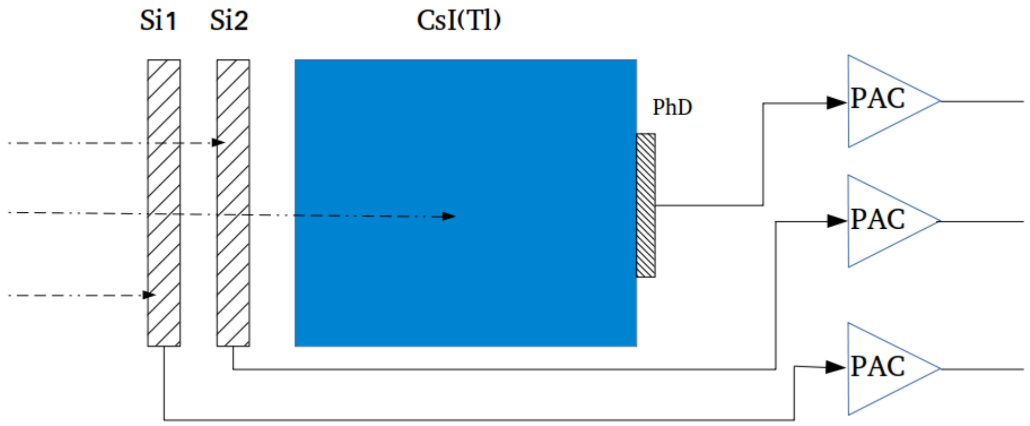
Temperature of FAZIA cards
Temperature of INDRA electronic
Vacuum quality Electronic stability

Beam intensity
Beam focus
Telescopes counting rate



DATA REDUCTION

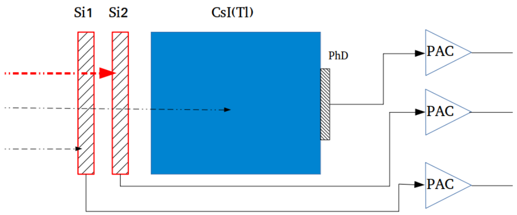
Data reduction : identification methods



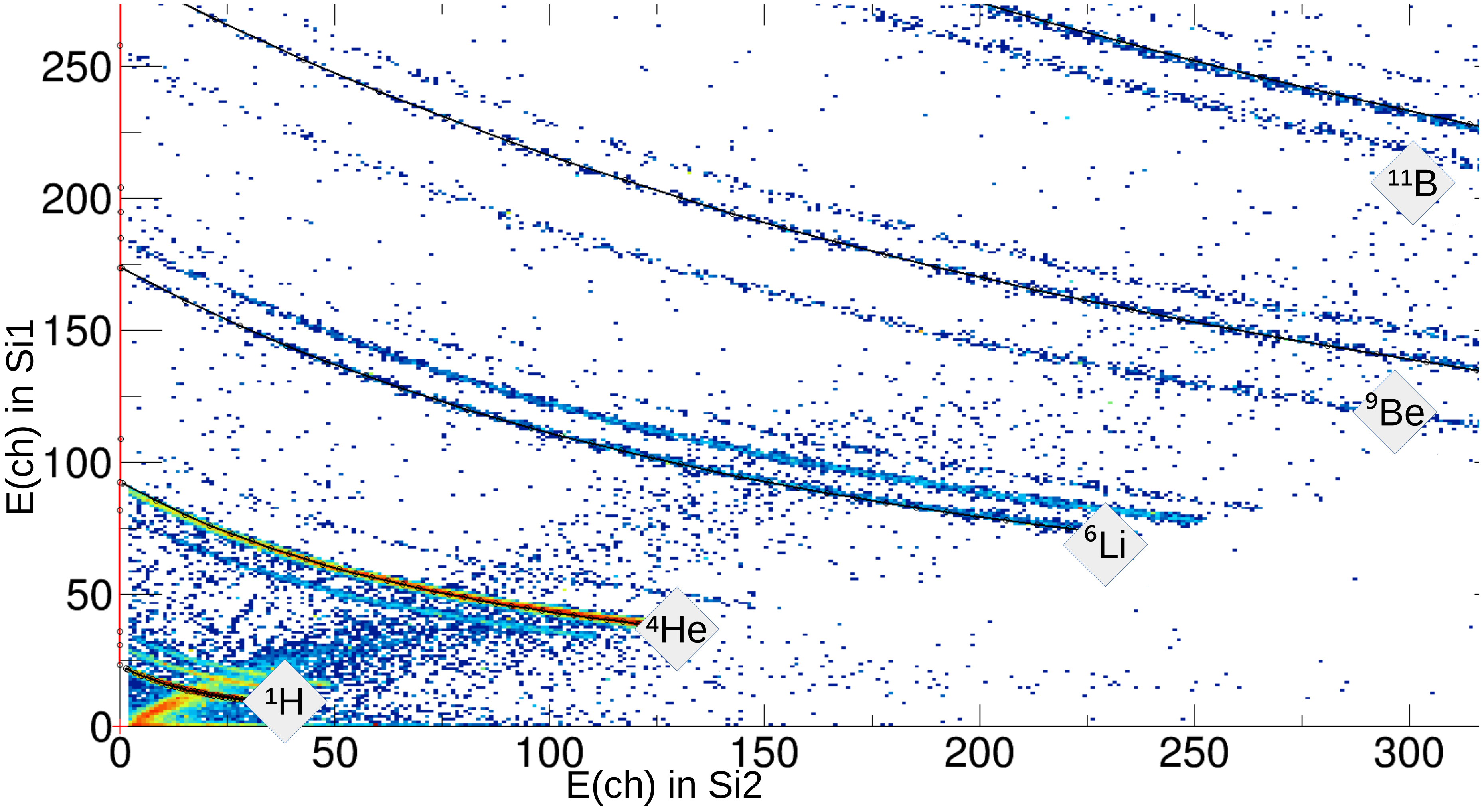
- The **Pulse Shape Analysis** (PSA) method in the first, second silicon or cesium iodure scintillator (Si1, Si2, CsI(Tl))

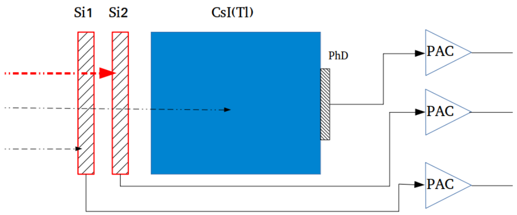
- The **ΔE - E** method between the first and the second silicon (Si1 - Si2) but also between the second silicon and the CsI (Tl) (Si2 – CsI)

$$Bethe-Bloch \quad \Delta E \propto \frac{AZ^2}{E}$$

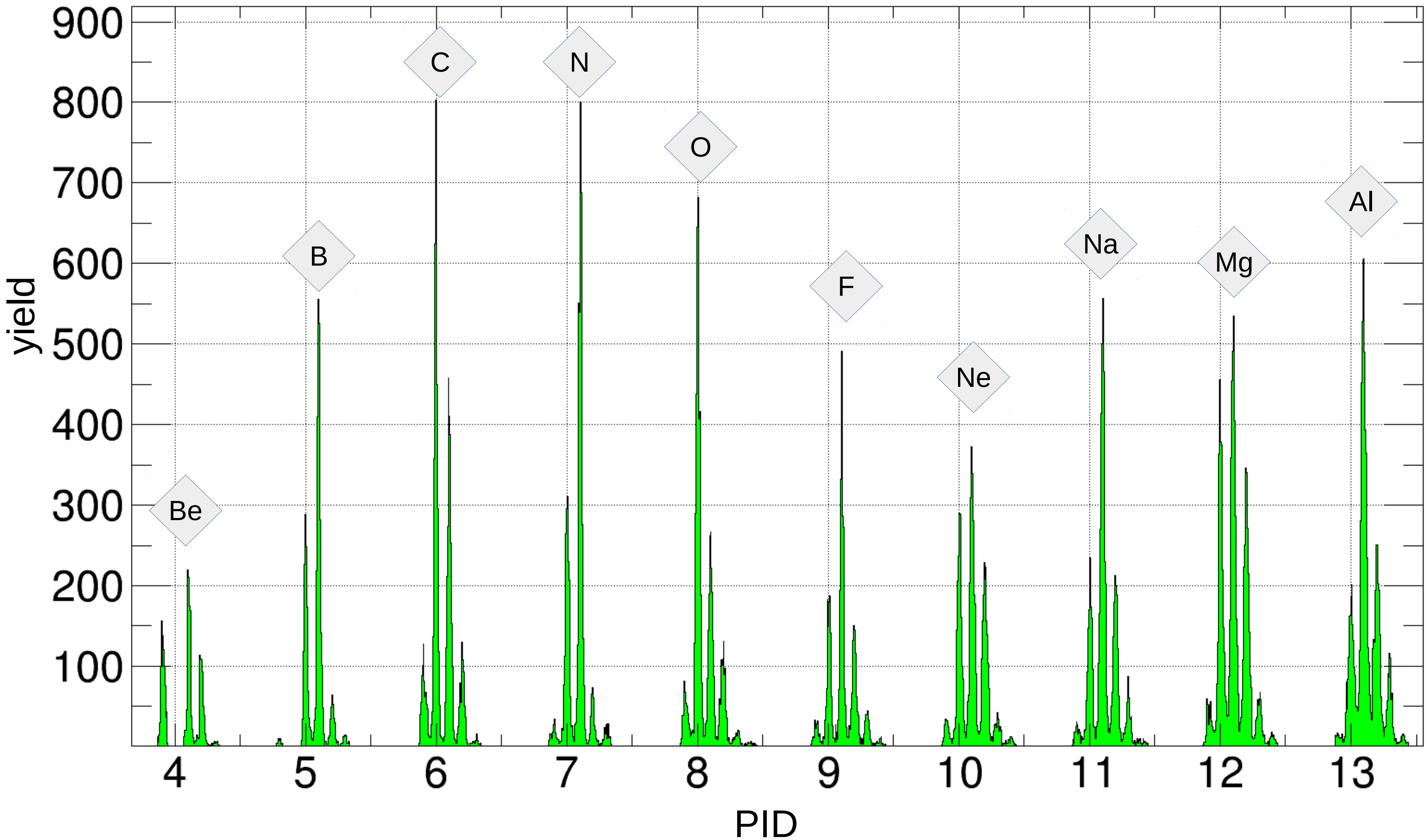


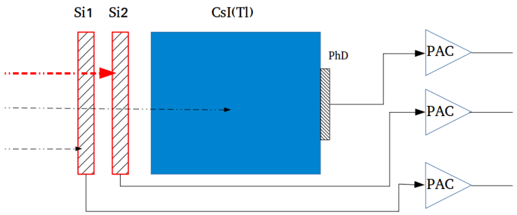
Data reduction : Identification Si1-Si2





Data reduction : Identification Si1-Si2





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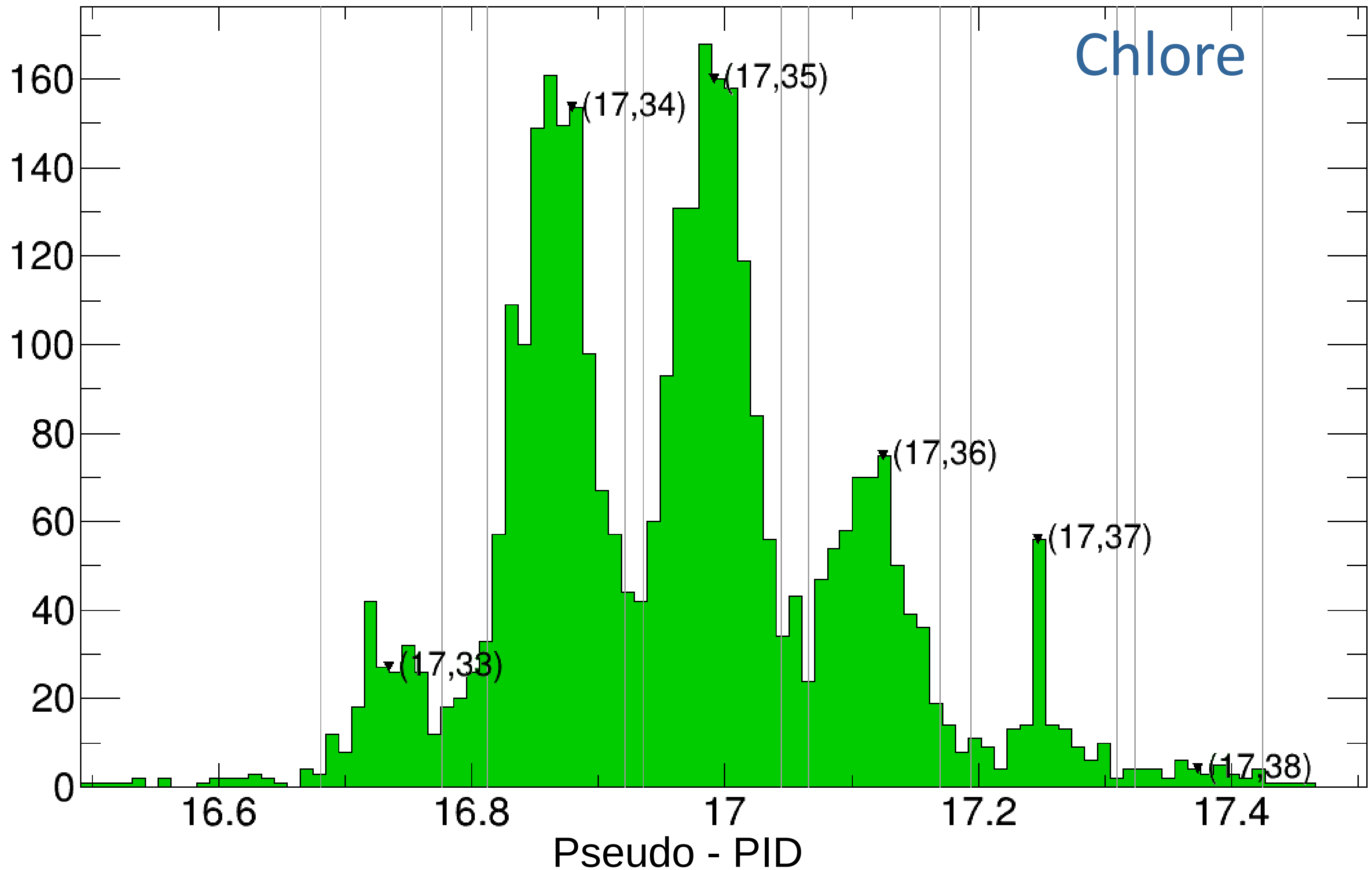
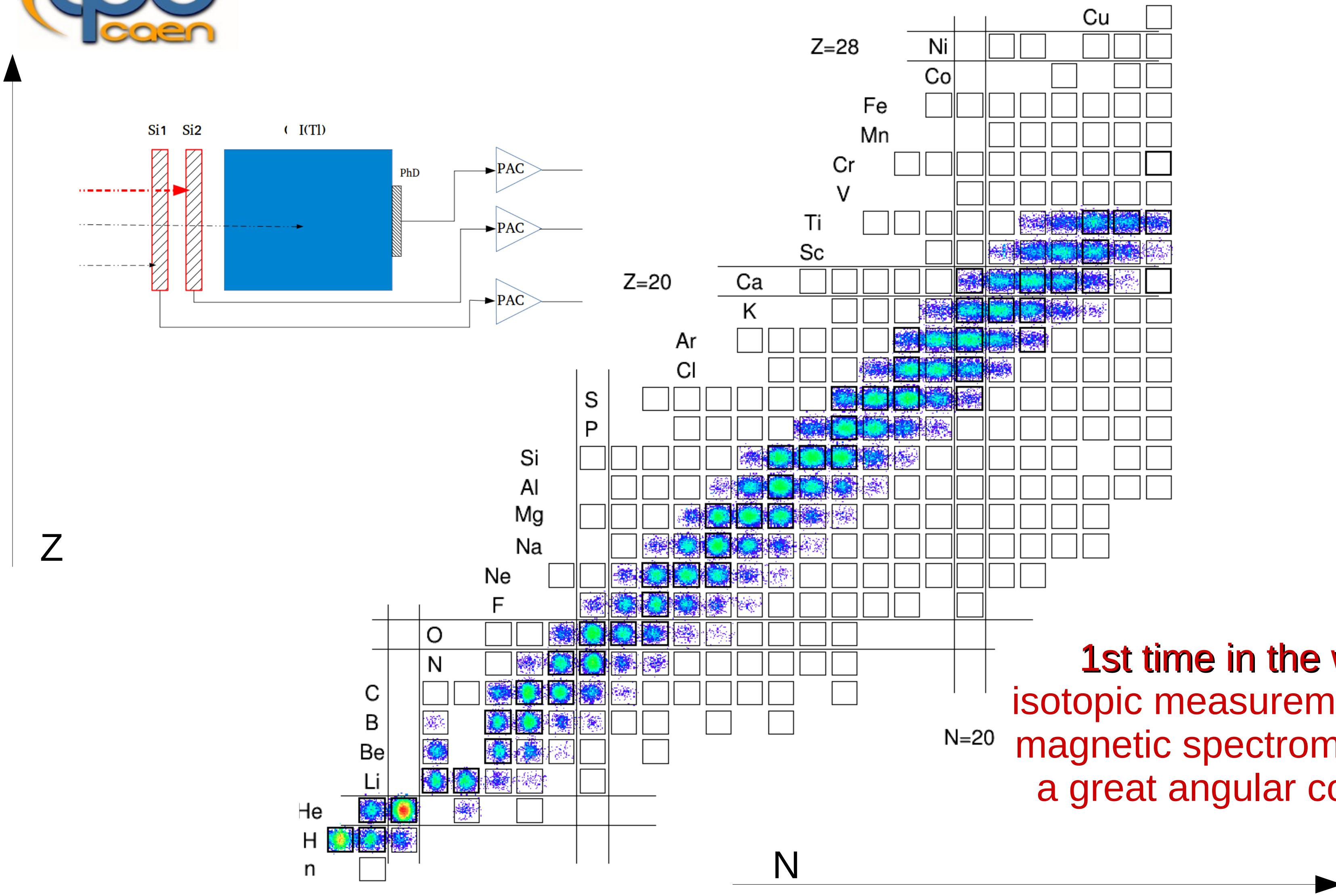
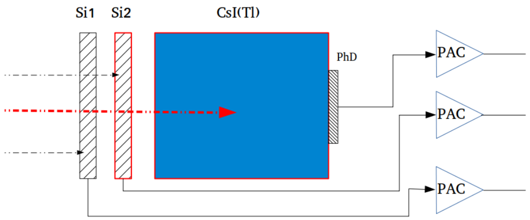


Data reduction : Identification Si1-Si2

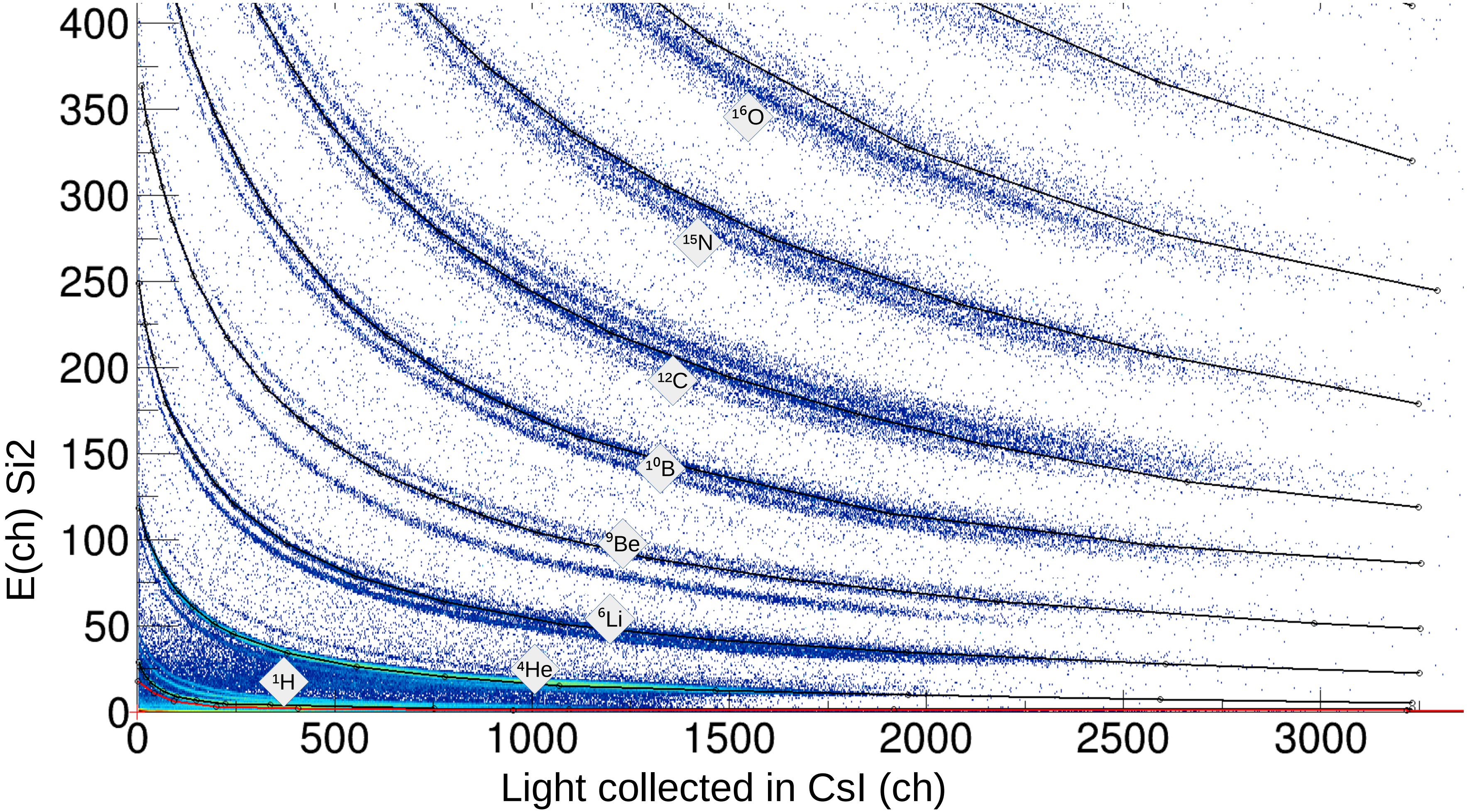


Identification map

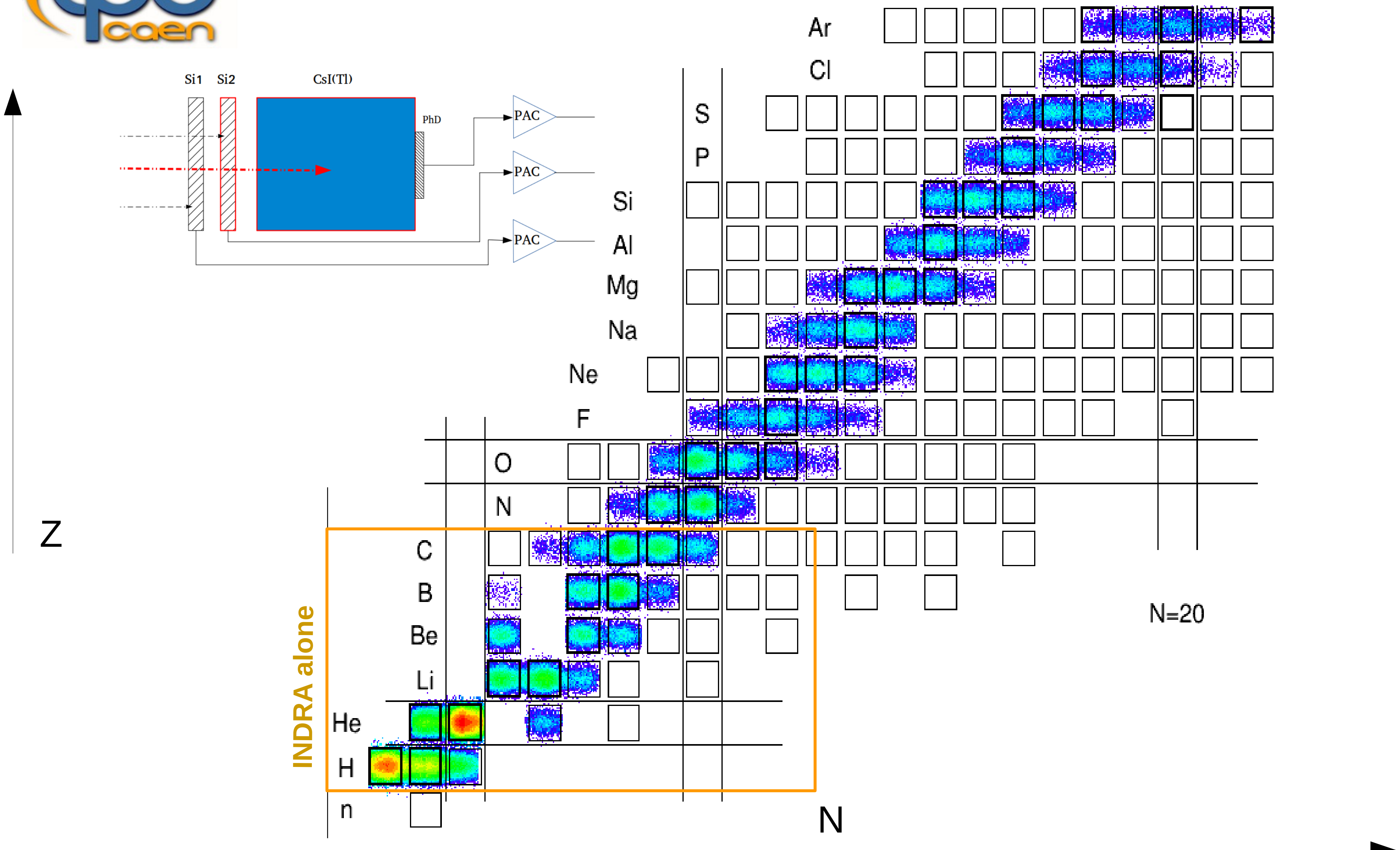
1st time in the world
isotopic measurement like a magnetic spectrometer with a great angular coverage



Data reduction: Identification Si2-CsI

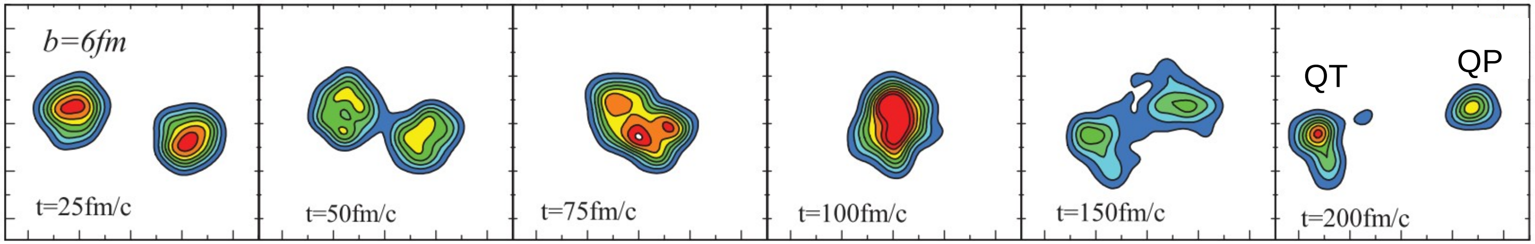


Data reduction : Identification Si2-CsI



Identification map, Z vs N

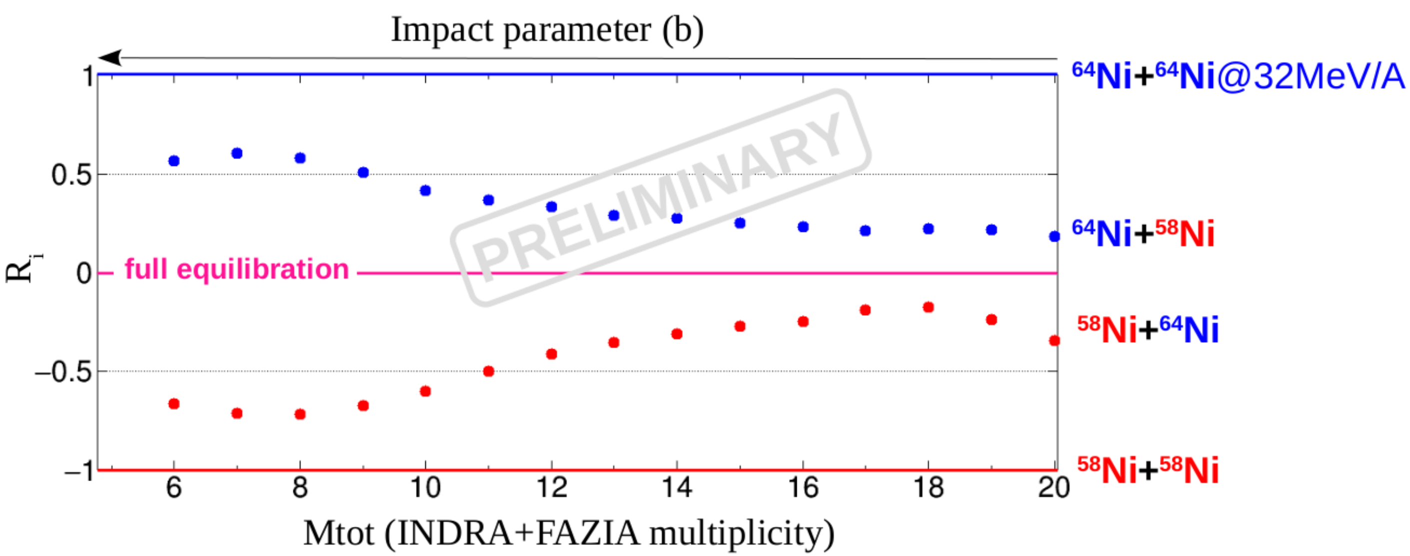
Preliminary results : isospin equilibration



$$R_i = \left\langle \frac{N}{Z} \right\rangle_{QP}$$

R_i = +1 (-1) : no N/Z equilibration

R_i = 0 : full N/Z equilibration



Smaller b

↓

Nuclei more mixed

↓

N/Z équilibration

Questions ?

BACKUP

Theoretical context

B-W

$$E_L(N,Z) = \underbrace{-a_V \cdot A}_{\text{Volume}} + \underbrace{a_S \cdot A^{2/3}}_{\text{Surface}} + \underbrace{\left(a_V^{sym} A + a_S^{sym} A^{2/3}\right)\delta^2}_{\text{Symétrie}} + \underbrace{a_C \cdot \frac{Z(Z-1)}{A^{1/3}}}_{\text{Coulomb}}$$

- Historical formula of Bethe-Weizsacker, good starting point
- System at **T = 0** and **without ρ dependence**
- System more realistic = function of protons and neutrons density :

$$e(\rho, \delta)$$

density → ρ

isospin → δ

Les collisions et l'isospin

$\vec{j}_n = D_n^{\rho}\vec{\nabla}\rho - D_n^{\delta}\vec{\nabla}\delta$: *courant de neutrons*

$\vec{j}_p = D_p^{\rho}\vec{\nabla}\rho - D_p^{\delta}\vec{\nabla}\delta$: *courant de protons*

D^{ρ} : *coefficient de transport en densité*

D^{δ} : *coefficient de transport en isospin*

migration — diffusion

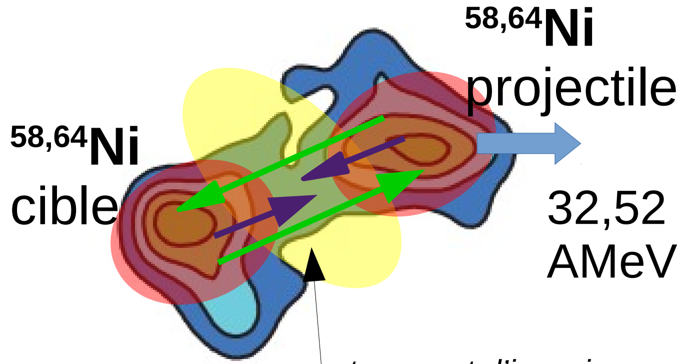
$$|\vec{j}_n - \vec{j}_p| = \underbrace{(D_n^{\rho} - D_p^{\rho})\vec{\nabla}\rho}_{\text{migration}} - \underbrace{(D_n^{\delta} - D_p^{\delta})\vec{\nabla}\delta}_{\text{diffusion}}$$

$$(D_n^{\rho} - D_p^{\rho}) \propto 4\delta\frac{\partial e_{iv}}{\partial\rho} \qquad (D_n^{\delta} - D_p^{\delta}) \propto 4\rho e_{iv}(\rho=\rho_0)$$

$\vec{\nabla}\rho$: *gradient d'isospin* $\qquad$ $\vec{\nabla}\delta$: *gradient de densité*

Varie avec le couple cible/projectile choisi

Varie avec l'énergie de collision



transport d'isospin :
redistribution de neutrons & protons
entre projectile/cible & col
pendant le temps de réaction (10^{-22}-10^{-20} sec.)

J. Frankland (GANIL, cnrs)

Rapport de Rami

rapport isobarique ou isotopique des particules détectées pout le système riche en neutrons

rapport isobarique ou isotopique des particules détectées pout le système riche en protons

rapport isobarique ou isotopique des particules détectées

Rapport de Rami

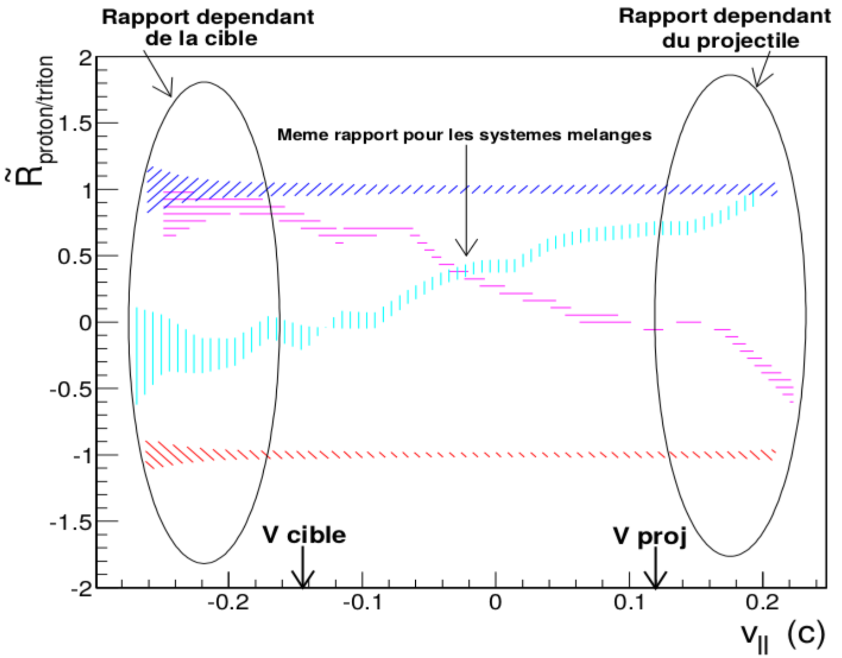
$$\tilde{R}_{p/n} = \frac{2R_{p/n} - {R^N}_{p/n} - {R^P}_{p/n}}{{R^N}_{p/n} - {R^P}_{p/n}}$$

- Marqueur d’isospin : Une fois normalisé, on retrouve l’isospin du QP ou de la QT à l’avant du centre de masse ou non
- Elimine le biais expérimental

Rapport de Rami

Pour la détermination du rapport de Rami, il faut se normaliser par rapport aux deux systèmes les plus extrêmes étudiés

- 1 pour système très riche en neutrons (correspondant à l'exposant N)
- -1 pour système très riche en protons (exposant P)



E.Legouée, Ph.D Thesis, Université de Caen-Basse Normandie (2013)

Interprétation : le modèle thermique

<u>Hypothèses</u> : Source de 10B à l'équilibre thermodynamique à une température donnée

Energie d'excitation

Constante de normalisation

Moment angulaire total du niveau i

Largeur intrinsèque du niveau i

$$\left[\frac{dN}{dE}\right]_\alpha = A \times \exp\left(-\frac{E}{\langle T \rangle}\right) \sum_i (2J_i + 1) \times \frac{\Gamma_i / 2\pi}{(E - E_i)^2 + \Gamma_i^2/4} \frac{\Gamma_{\alpha,i}}{\Gamma_i}$$

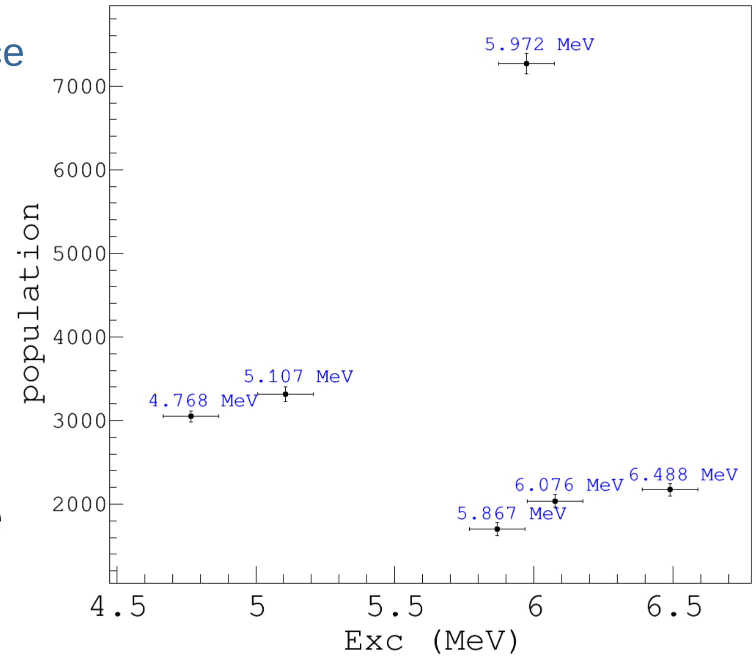
Proportion de décroissance α du niveau ≈ 1

Nombre de décroissances α

Température moyenne du système

Terme de résonance

- Normalisation par (2J+1) de la population de chaque niveau
- Décroissance exponentielle non-observée, modèle thermique non-valide ici
- Noyaux produits dans différentes conditions de **température** car il n'y a pas eu de sélection selon le paramètre d'impact ou la température



Les simulations, quelques ingrédients

AMD-QMD

Antisymetrized **M**olecular **D**ynamic – **Q**uantum **M**olecular **D**ynamic

- Paquets d'onde gaussiens
- Potentiel local de Skyrme (dépend de la densité locale)
- Potentiel de Yukawa décrivant la surface
- Potentiel dépendant des vitesses
- Algorithme stochastique de collisions à deux corps
- Principe de Pauli plus ou moins bien traité

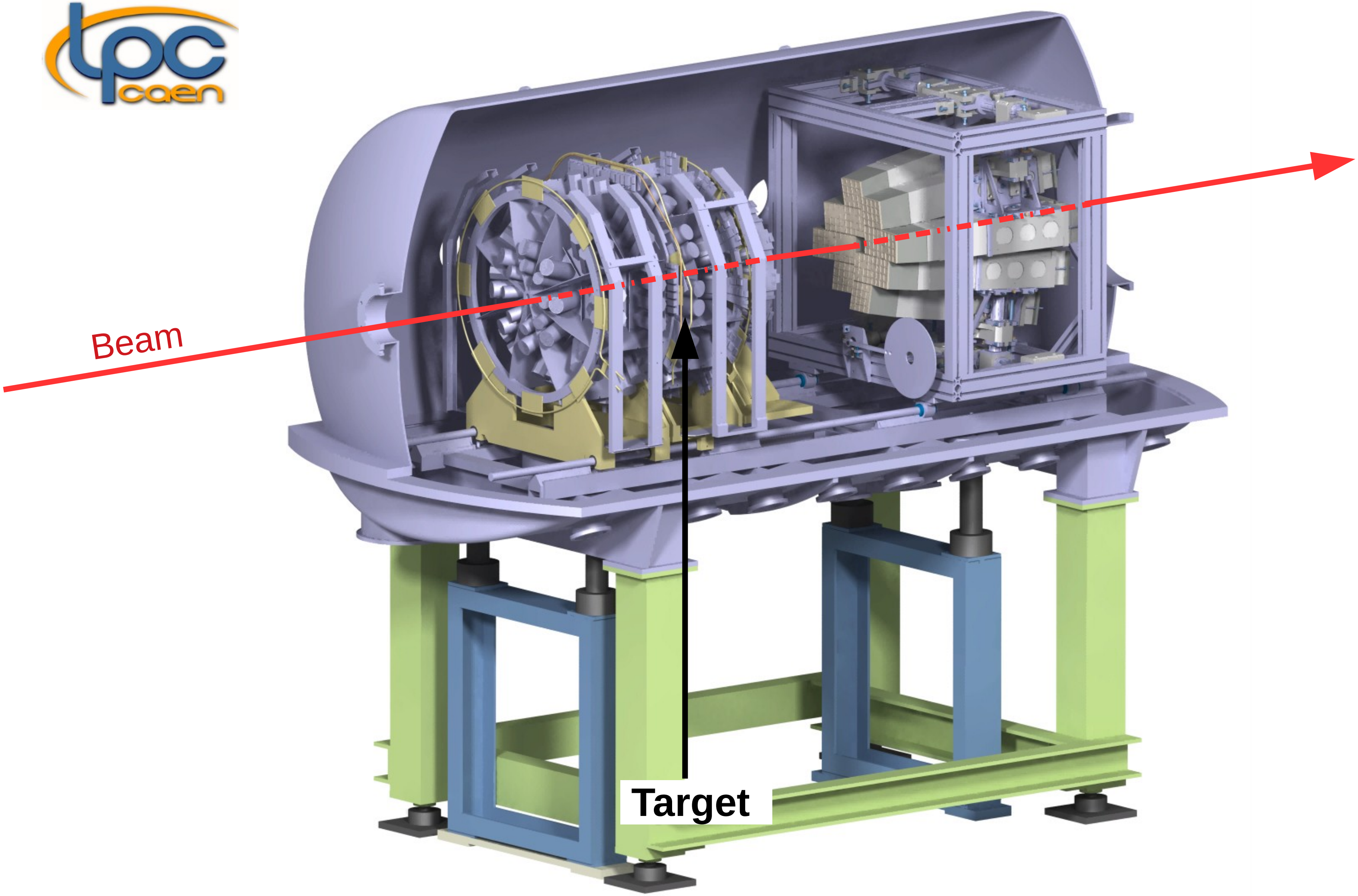
Mouvement de toutes les particules du système sous l'action de leurs interactions mutuelles

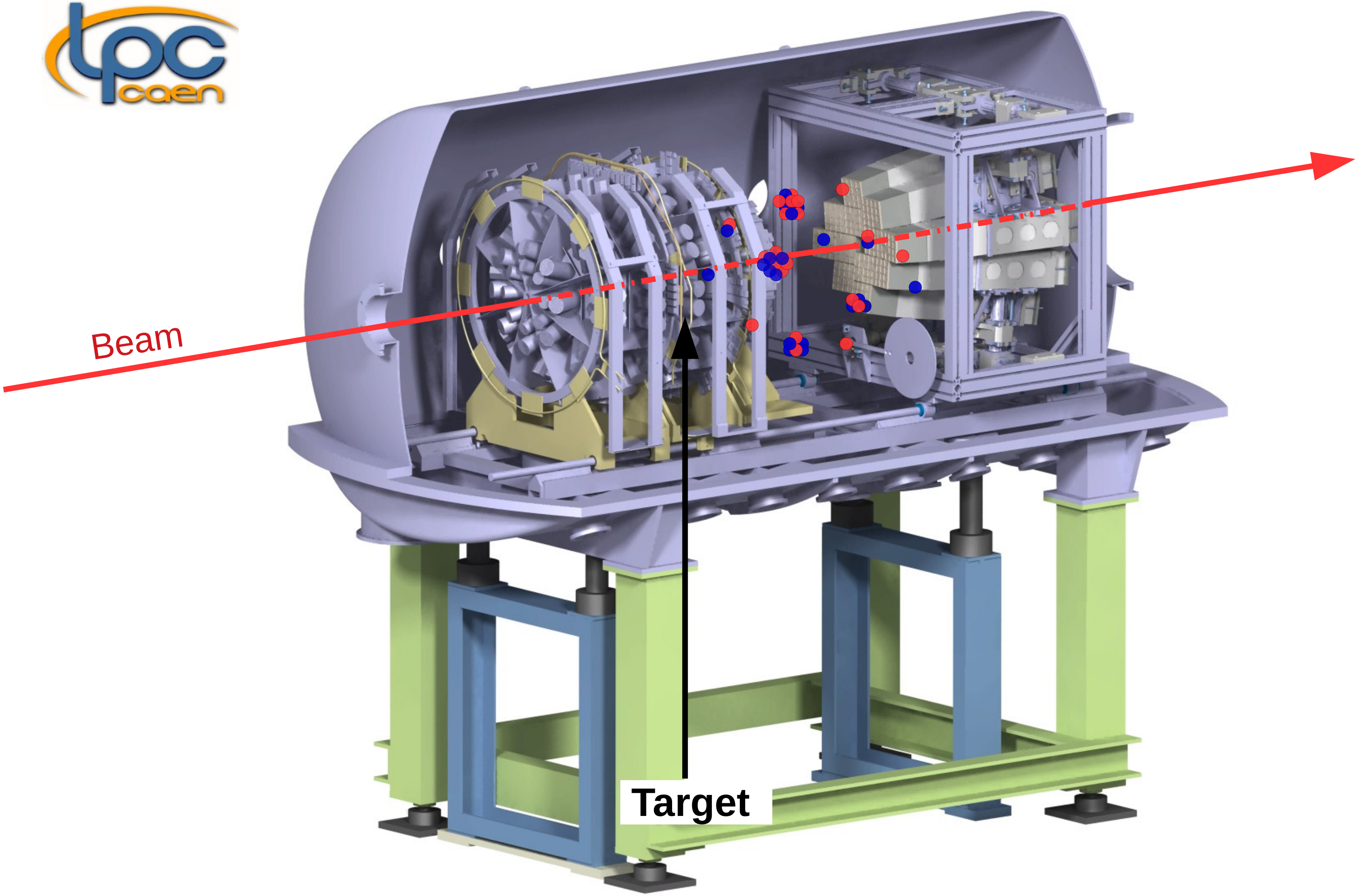
HIPSE

Heavy-**I**on **P**hase **S**pace **E**xploration

- Phase d'approche de la collision basée sur l'équation du mouvement à deux corps
- Réarrangement des nucléons en plusieurs clusters de particules légères selon le paramètre d'impact de la réaction. Suit les lois de coalescence dans l'espace des impulsions et des positions
- After-burner, la partition est propagée en prenant en compte les effets de reaggreagation dus aux intéractions nucléaires fortes et coulombiennes
- Les décroissances secondaires sont prises en compte à l'aide d'un code d'évaporation

Très phénoménologique
Intéraction de Skyrme simplifiée
Approximation soudaine


Beam
Target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