EURISOL / Task 10
Physics & Instrumentation

Phase Transitions
Nuclear Reactions & Dynamics

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Concepts for Fundamental Physics

DFT approach to nuclear physics: towards an universal functional

- Study the energy functional for asymmetric nuclear matter
- Constrain the isovector part of the energy (symmetry energy)
- Produce sub- and super-saturation density matter through HI-induced reactions

Nuclear matter phase diagram and finite nuclei phase transitions

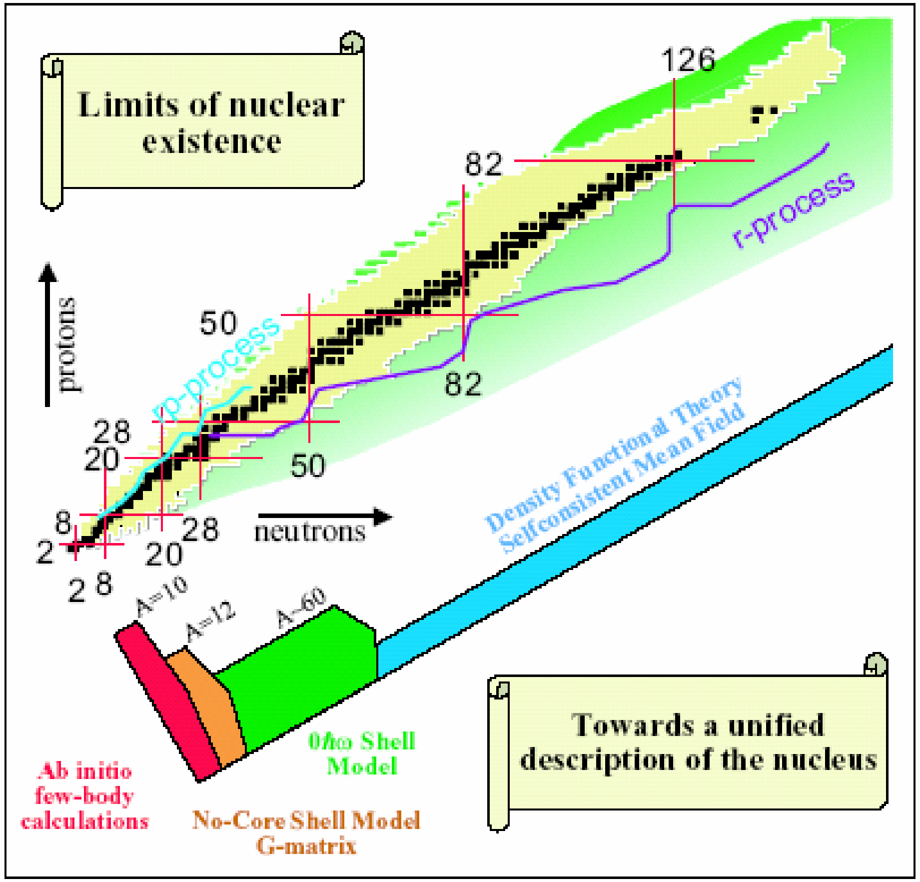
- Scan the low-temperature region of the nuclear matter phase diagram
- Characterize the phase transition (location, order, critical points, …)
- Evidence thermodynamical anomalies in finite systems
- Complementary to the ALICE Physics Program at high energy (QGP)

From finite nuclei to compact star matter

- Constrain MF models for Astrophysics studies
- Study the structures and phase properties of neutrons stars crusts
- Understand the dynamics of supernova explosion (EOS)

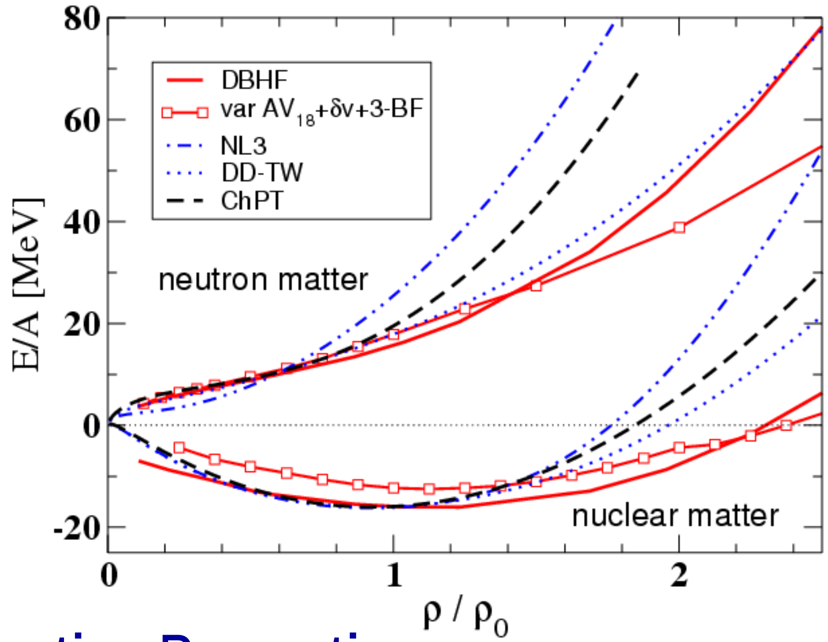
Concepts & Connections (I:DFT)

Self-consistent mean field calculations (and extensions) are probably the only possible framework in order to understand the structure of medium-heavy nuclei.



$$E = \langle \psi \,|\, \mathcal{H} \,|\, \psi \rangle$$

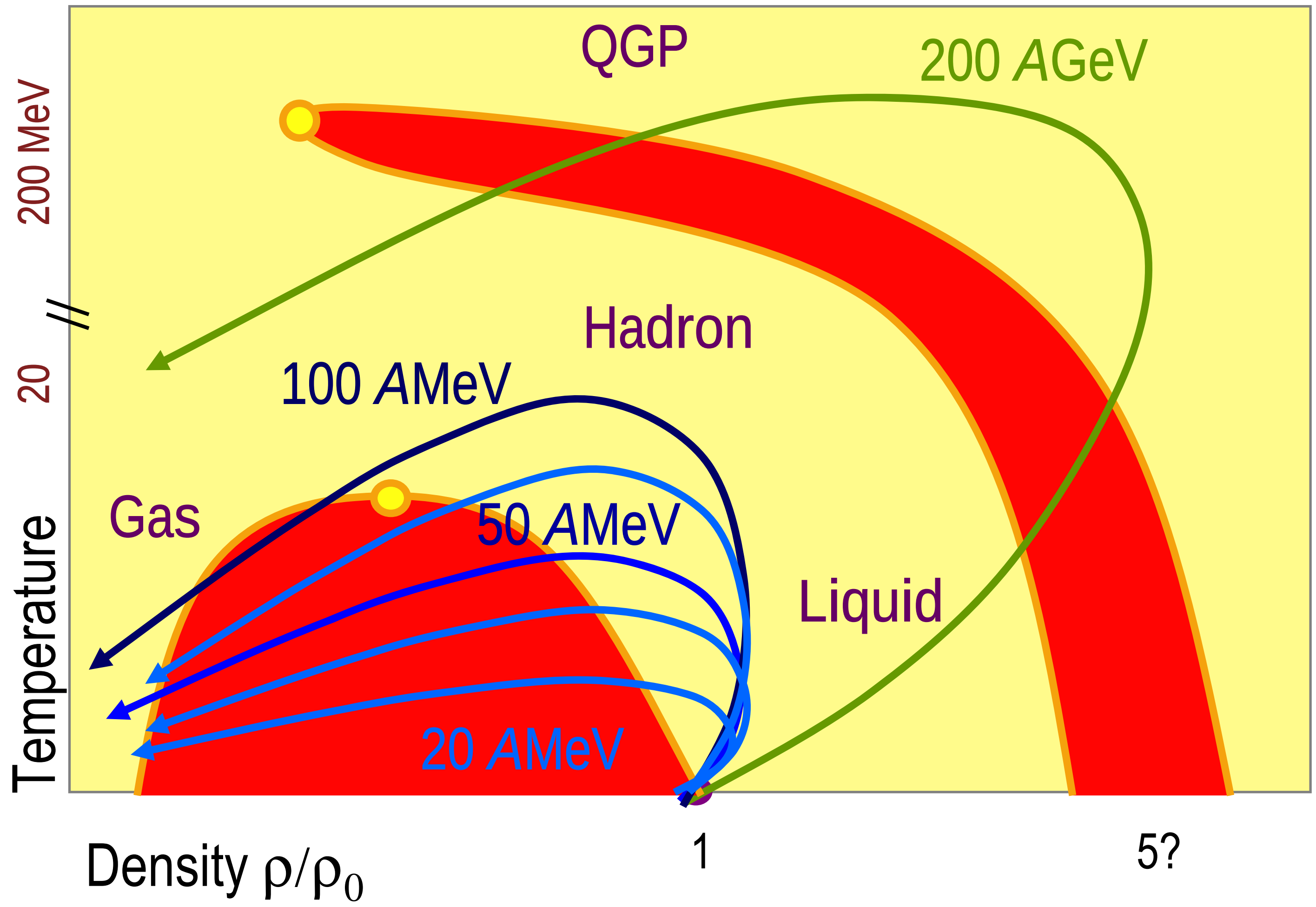
$$\mathcal{H} = \langle \phi \,|\, H_{eff} \,|\, \phi \rangle = E[\rho]$$



Connections: Single Particle and Collective Properties
Ground State Properties

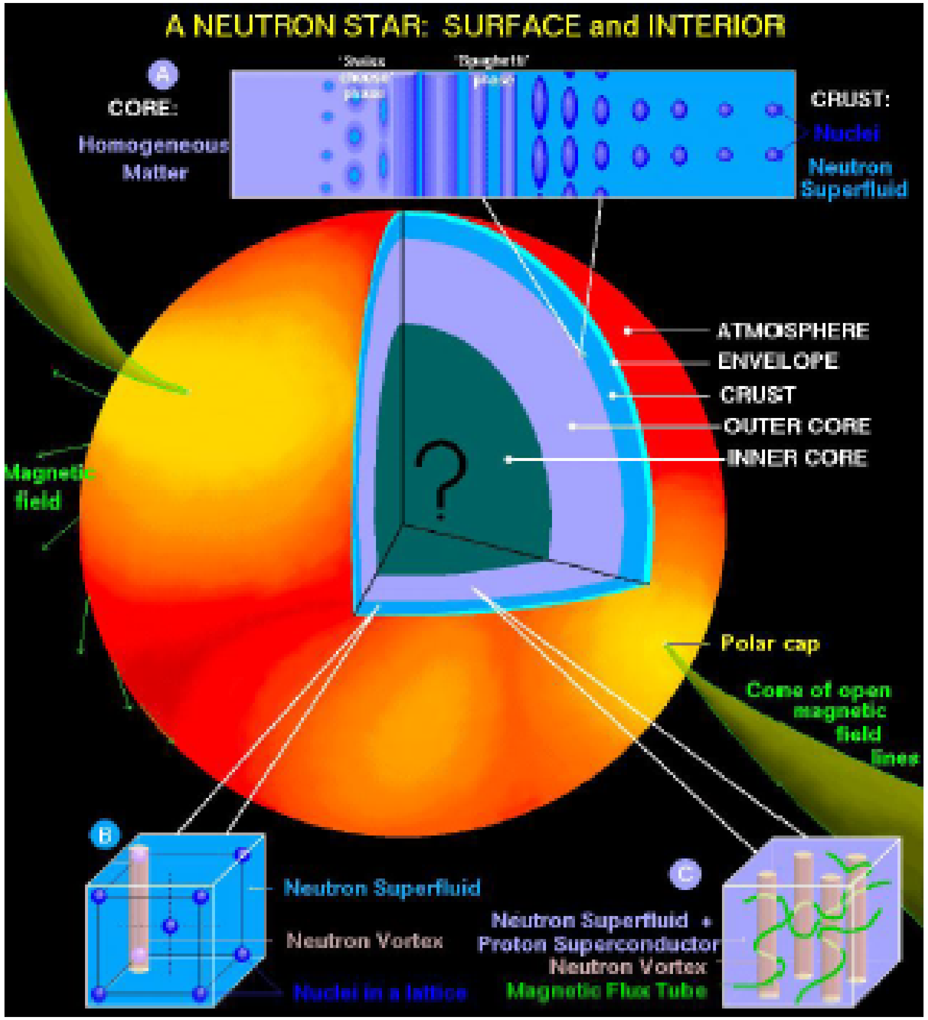
Concepts & Connections (II:ϕtrans)

The phase diagram of nuclear matter

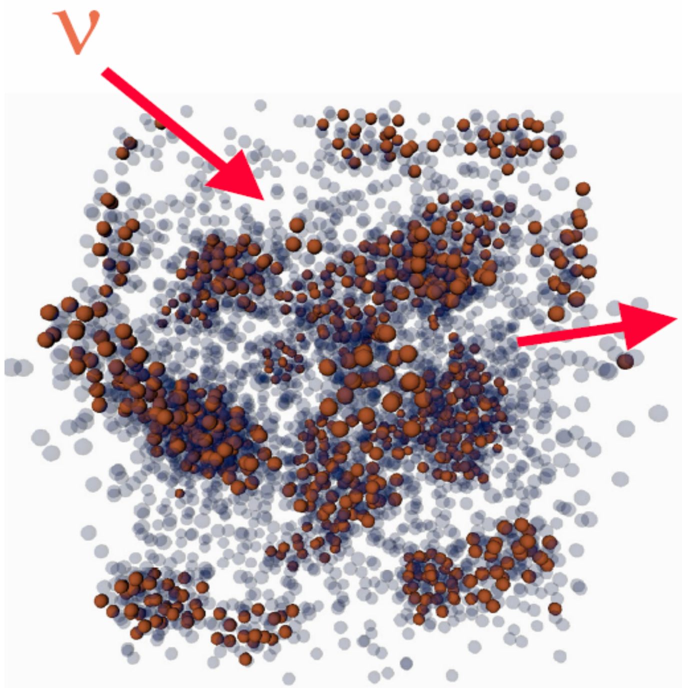


Connections: Limits of stability

Concepts & Connections (III:NS)



(Extended) MF theories with a density functional constraint in a large density domain are a unique tool to understand the structure of neutron stars.



Connections: Astrophysics

Multifragmentation and Phase transition

Key Experiments : what is needed (facility side)

(I) Density dependence of the nuclear symmetry energy (DDSE)

^{56}Ni - ^{74}Ni, ^{106}Sn -^{132}Sn, E/A = 15 – 50 MeV

(II) Neutron-Proton effective mass splitting (NPMS)

^{56}Ni - ^{74}Ni, ^{106}Sn - ^{132}Sn , E/A=50-100 MeV

(III) Isospin-dependent phase transition (IDPT)

^{56}Ni - ^{74}Ni, ^{106}Sn -^{132}Sn, ^{200}Rn - ^{228}Rn, E/A = 30 – 100 MeV

(IV) Isospin fractionation, Isoscaling (IFI)

^{56}Ni - ^{74}Ni, ^{106}Sn -^{132}Sn, ^{200}Rn - ^{228}Rn, E/A = 30 – 100 MeV

Key Points are :

- **large panoply** of beams (light, medium, large A) over the **maximal N/Z extension**
- Beam energy range **around** and **above** the **Fermi** domain (15-100*A*MeV)
- Beam intensity around 10^6-10^8pps, small emittance, **good timing** (<1ns)

Key experiments - summary

E = 15-100 *A*MeV

$$^{106}_{132}Sn + ^{112}_{124}Sn \quad N/Z = 1.12, 1.18, 1.3, 1.44, 1.56, 1.64$$

$$^{106}_{132}Sn + ^{40}_{48}Ca \quad N/Z = 1.08, 1.12, 1.2, 1.46, 1.57, 1.64$$

$$^{56}_{74}Ni + ^{40}_{48}Ca \quad N/Z = 1.0, 1.17, 1.37, 1.54, 1.64$$

$$^{200}_{228}Rn + ^{112}_{124}Sn \quad N/Z = 1.29, 1.32, 1.38, 1.5, 1.59, 1.65$$

- **Aim :** compare systems of **similar size** but **different N/Z**
  - 15 < E/A< 50 MeV ideal for **neck studies** and **deep-inelastic** collisions
  - 50 <E/A < 100 MeV needed for **flow observables**
  - E/A > 30 MeV necessary for **multifragmentation** studies
  - Comparison sym-asym important for **transport properties** : varying N/Z 1-1.7
  - Different sizes essential for **phase transition** : varying A between 50-300

Key Experiments : what is needed (detection side)

(I) density dependence of the nuclear symmetry energy

- 4π and low E threshold, complete A and Z identification for CP (**FAZIA**)
- Large acceptance **spectrometer** for mass identification of QP remnant
- High angular resolution Δθ<0.5 LCP and neutron arrays for correlations

(II) Neutron-Proton effective mass splitting

- 4π and low E threshold, complete A and Z identification for CP (**FAZIA**)
- (1-4)π neutron detector (DeMoN-like, **NEUTROMANIA**)

(III) Isospin-dependent phase transition

- 4π and low E threshold, complete A and Z identification for CP (**FAZIA**)
- 4π neutron detector (DeMon-like, **NEUTROMANIA**)
- High angular resolution Δθ<0.5 LCP and neutron arrays for correlations
- γ-array for hot GDR studies ?

(IV) Isospin fractionation, Isoscaling

- 4π and low E threshold, complete A and Z identification for CP (**FAZIA**)
- (1-4)π neutron detector (**NEUTROMANIA**)
- High angular resolution Δθ<0.5° LCP and neutron arrays for correlations

Detection Requirements

- **Event**-by-**event** information
  - Z,A,E,θ,φ of the heavy residue (QP/QT for peripheral collisions)
  - Z,A,E,θ,φ for fragments(Z<=30) and LCP (low thresholds, high geometrical coverage)
  - Correlations among charged products (and possibly neutrons) $\Delta\theta<0.5°$
- **Average information**
  - Neutron multiplicity & energy
  - Gammas (low/high E) ?
- **Flexible digital electronics** : Pulse Shape Analysis and Timing
- **Easy transportability** and **coupling** : compactness
- **Fast data reduction** : *on-line* calibration!

Instrumentation Summary

	4π LCP	A,Z resolution	High granularity	4π Neutrons	Spectro -meter	γ-array
I/ DDSE	mandatory	mandatory	desirable		mandatory	
II/ NPMS	mandatory	desirable	mandatory	desirable	desirable	
III/ IDPT	mandatory	mandatory	mandatory	mandatory		desirable
IV/ IFI	mandatory	desirable	mandatory	mandatory		

mandatory

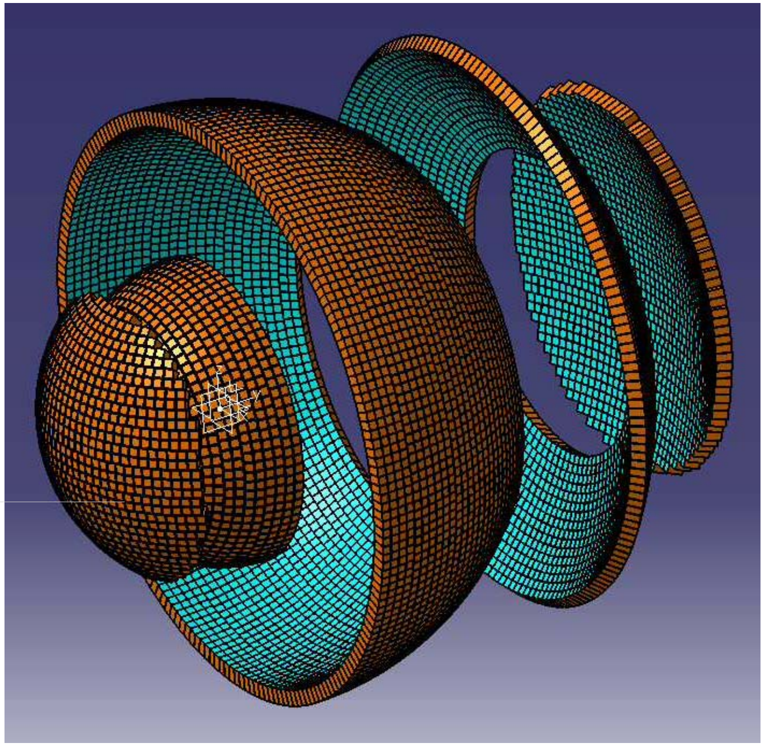
desirable

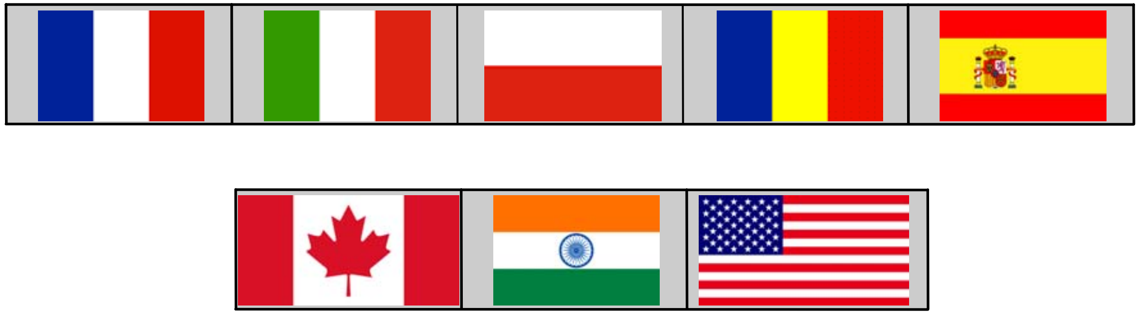
FAZIA project (9/12) 2012-2014

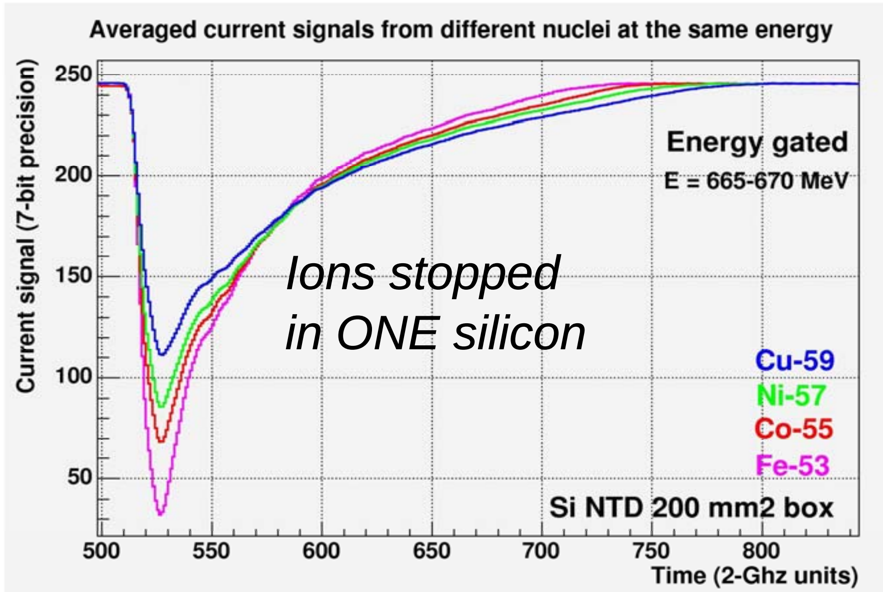
NEUTROMANIA (2/4) 2014

SPIRAL2 (LoI) 2012

FAZIA : Four π A-Z Identification Array







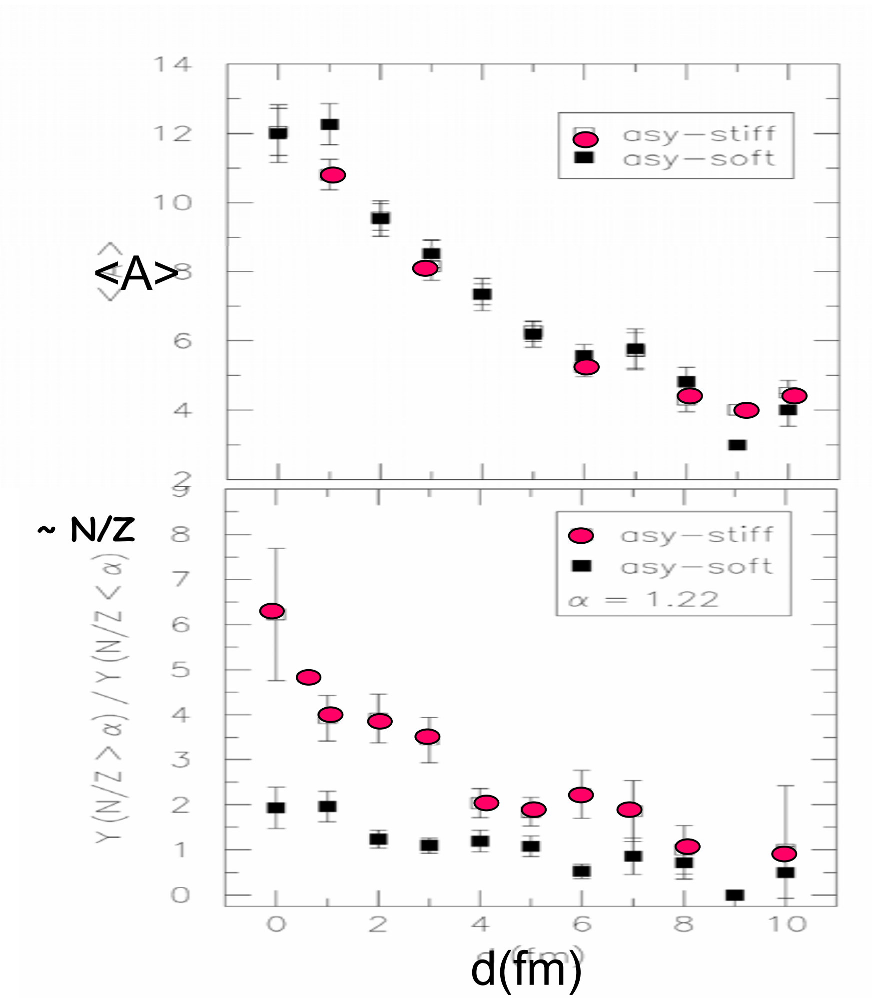
- **Compactness** of the device
- Ebeam from Barrier up to 100 A.MeV
- Telescopes: Si-ntd/Si-ntd/CsI
- **Possibility of coupling** with other detectors
- Aim: **complete Z (~70) and A (~50) id.**
- **Low-energy & identification** threshold
- **Digital electronics** for energy, timing and **pulse-shape id.**

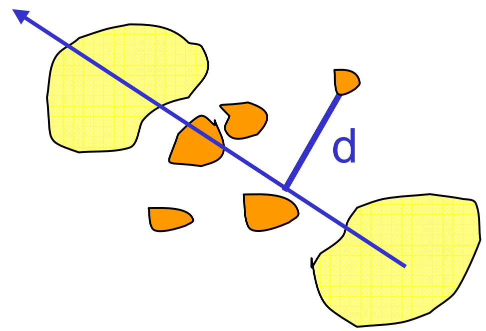
To be continued …

The density dependent symmetry energy

observables sensitive to $E_{sym}(\rho)$

- **Neck composition and isoscaling**





$^{58}Fe + ^{58}Fe$ @ 47 AMeV

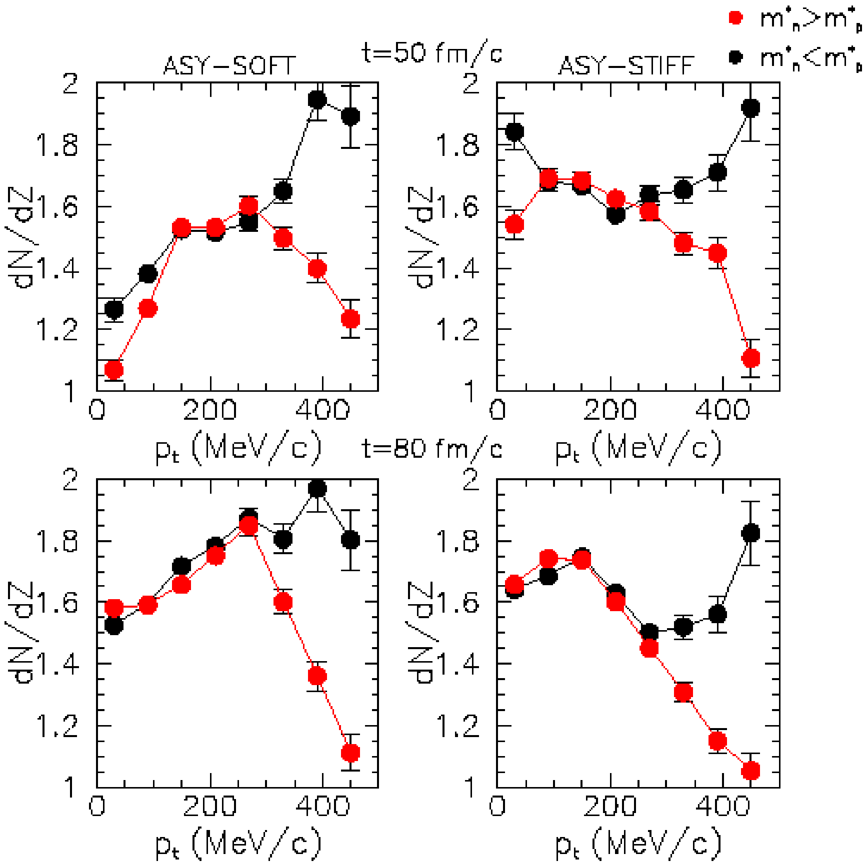
The isotopic content of the neck is sensitive to the asy-stiffness

R.Lionti et al., PLB625 (2005) 33

Neutron-Proton effective mass splitting

observables sensitive to m^*_q

- **P_t distributions in pre-equilibrium emission**



^{132}Sn+^{124}Sn, 100 AMeV, b=2 fm, $y^{(0)} \leq 0.3$

High p_t asymmetry: observable sensitive to the mass splitting and not to the asy-stiffness of the EOS

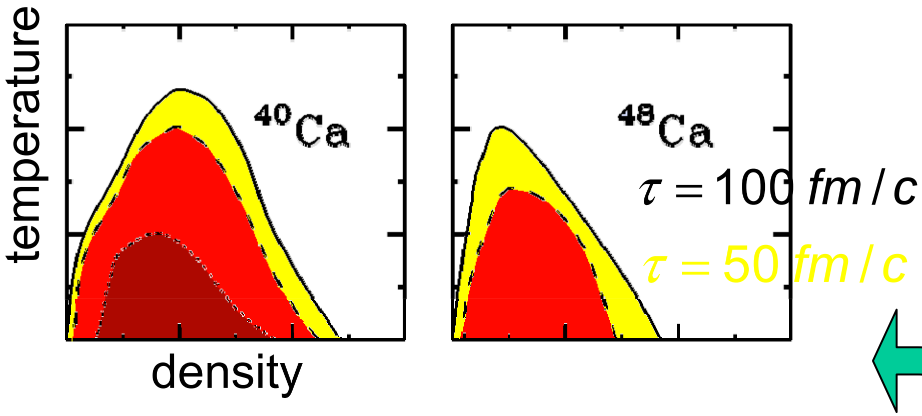
J.Rizzo et al., PRC72(2005)064609

Isospin dependent phase transition

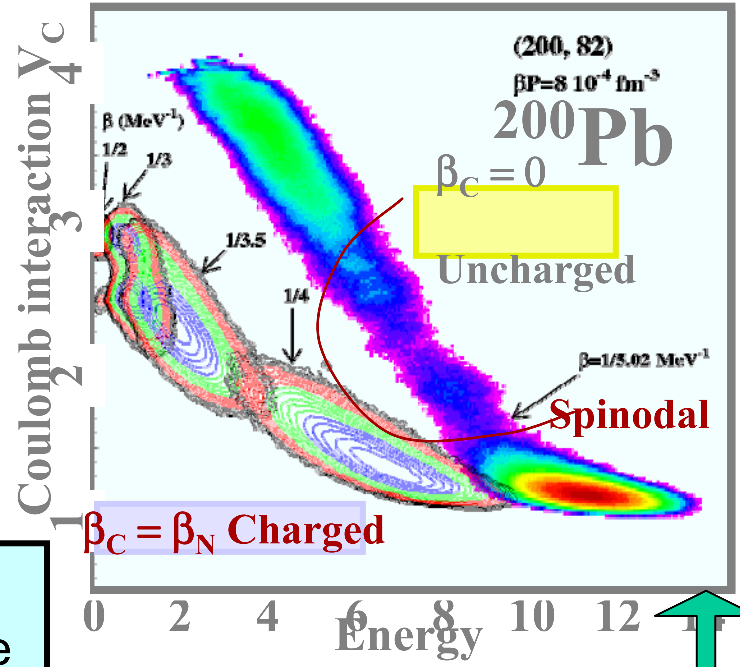
New Physics !

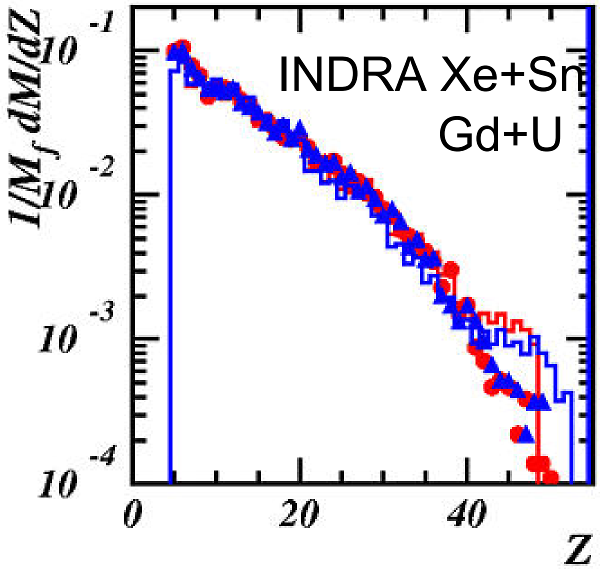
- **Size scalings**

Colonna PRL 2002



Gulminelli PRL 2003





Rivet NPA 2001

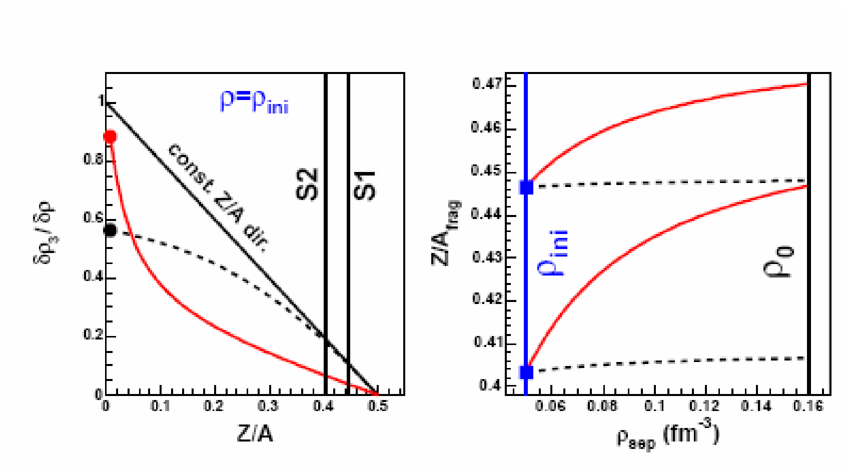
The width of the spinodal zone should depend on isospin

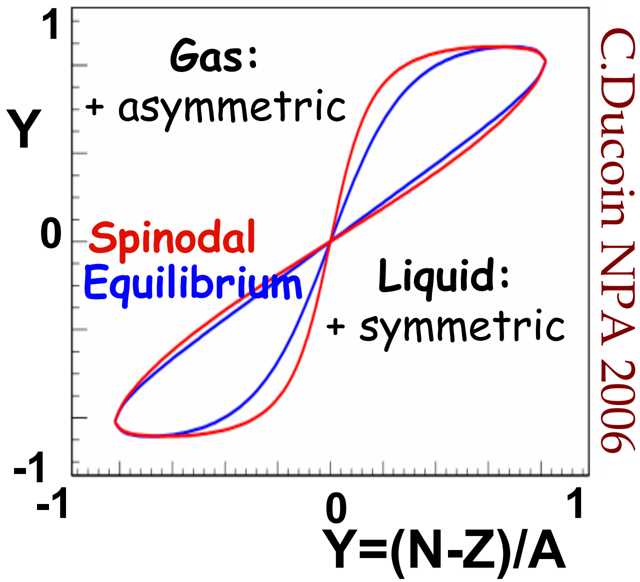
For high Z, the transition should become a cross over

Existing data do not show these effects

Isospin fractionation

- <N>/Z at break up time





Fractionation is a generic feature of phase separation
for multi-component systems; an increased fractionation is expected
If fragmentation occurs out of equilibrium

FAZIA – AZ4π : solutions

Detectors:

1. **Shape analysis of signals from particles stopped in Si (+ time of flight)**
2. **Three steps detection ΔE(Si)-ΔE(Si)-E(CsI), with possibly a new solution for the step ΔE-E and with double strip-Si**

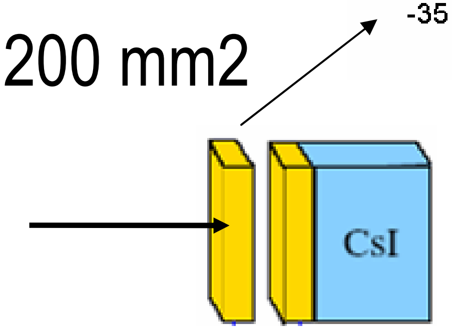
Electronics -> digital:

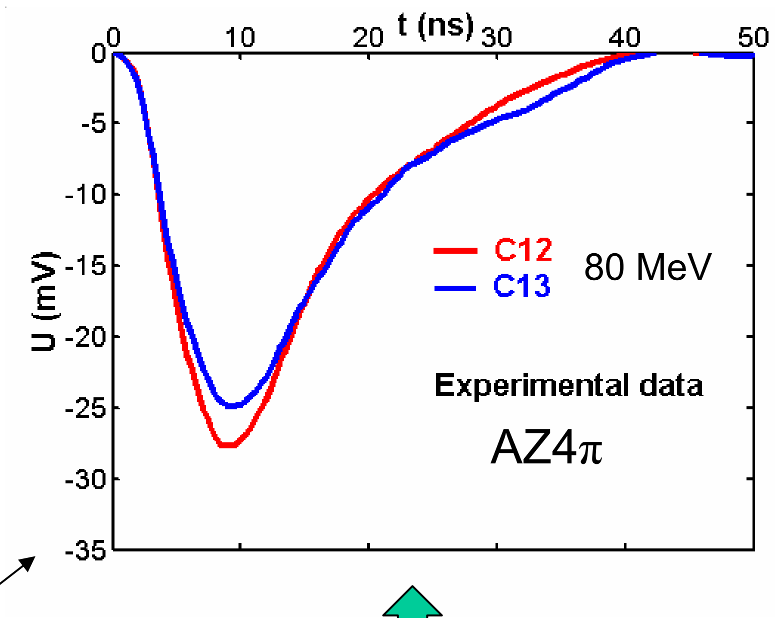
1. **Compact (cost + transport with many thousands of channels)**
2. **Flexibility for signal analysis**
3. **Pulse shaping and TOF**
4. **High dynamical detection range (100 A.MeV Rn to 1 MeV p)**
5. **Possibility of on-line calibration (DSP)**

FAZIA – AZ4π : first results

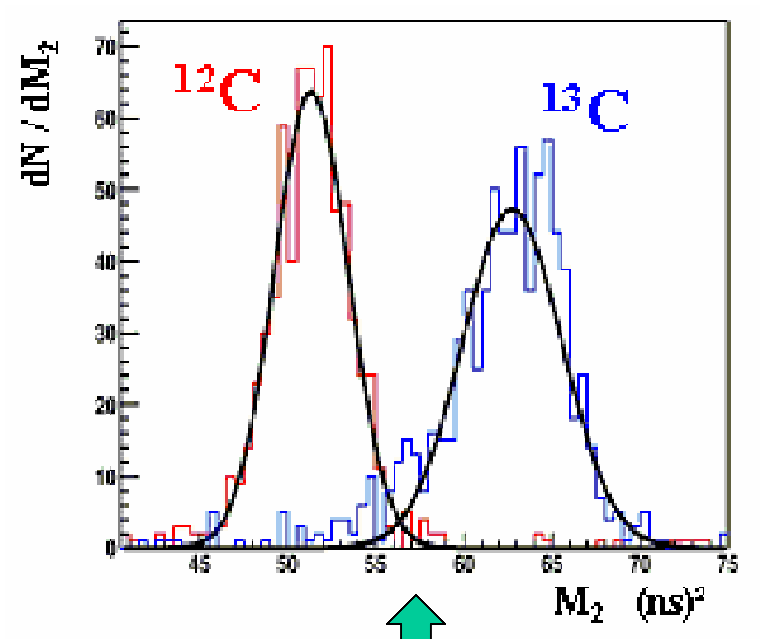
A-Z identification from ions stopped in **one** nTD-Si

nTD-Si
200 mm2





averaged signals



Second moment M_2

H. Hamrita et al. NIMA531 (2004) 607.

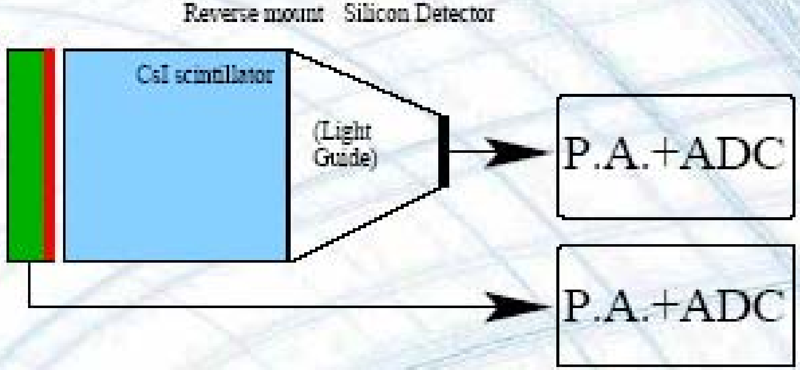
FAZIA – AZ4π : first results

CsI without photodiode/photomultiplier

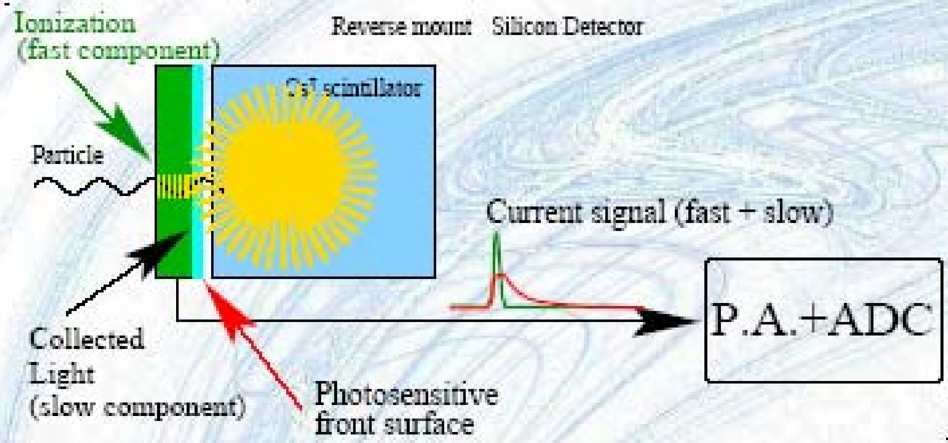
INFN Istituto Nazionale di Fisica Nucleare

The Single Chip Telescope

Standard reverse mount Si-CsI:



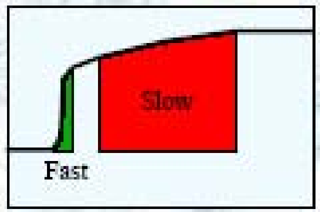
Single Chip Telescope:



This detector was first proposed in G.Pasquali *et al.*, Nucl. Instr. and Meth. A301 (1991)

- **Fast** component from Ionization in Si, **Slow** from scintillation of CsI.
- **Stopped in Silicon**: **identical** to the previous case
- **Stopped in CsI**: **fast-slow discrimination.**

Example of preamplifier output:



Only one digital acquisition channel

International Workshop on Multifragmentation and rel. Topics 2003, GANIL, Caen, France 5th-7th November 2003 **Luigi Bardelli**

FAZIA / AZ4π : strategy

R&D : prototypes realization 2006-2007

nTD Silicon : (DE1=300microns)+Silicon(DE2=700microns)+CsI(4cm)
- DE1 reverse or direct mounted and strip option
- DE2 reverse mounted
- CsI(Tl) with/without photodiode (silicon photosensitive surface)

Preamplifier : 2.5 GeV full energy range (delivers I & Charge (Q) outputs)
- *I-output* to FEE then *vector* to DAQ (pulse shaping)
- *Q-output* to FEE then *scalars* (E,ToF) to DAQ
- *I* : ADC(FEE) 50Mhz 12bits
- *Q*: ADC(FEE) 100Mhz 14bits (>12ENOB)
  ADC(FEE) 100Mhz 12bits (10.8ENOB) is also studied

Minimum ToF base : 50-100cm depending on R&D on detector digital timing

FAZIA Working Groups

Information is available on website : fazia.in2p3.fr

Working Group 1 (WG1) : Modelization of current signals and Pulse Shape Analysis,
contact person : Luigi Bardelli (Univ. of Firenze, Italy)
Perform the modelization of the current signal by using the existing database of these signals and define pulse shape analysis for the best A and Z identification.

Working Group 2 (WG2) : Physics Cases,
contact person : Giuseppe Verde (INFN Catania/GANIL Caen)
*Define the physics cases for FAZIA Physics and the needed performances (Physics cases, **simulations**)*

Working Group 3 (WG3) : Front-End Electronics,
contact person : Pierre Edelbruck (IPN Orsay, France)
Define the characteristics of front-end electronics (inside the vacuum chamber), preamplifier, fast digitalization and processing of current signals

Working Group 4 (WG4) : Acquisition,
contact person : Benjamin Carniol (LPC Caen, France)
Define the characteristics of the 'out-of-vacuum' electronics, link to the acquisition (gigabit ethernet), data flow processing, slow control of detectors

FAZIA Working Groups

Information is available on website : fazia.in2p3.fr

Working Group 5 (WG5) : Semiconductor detectors,
contact person : Laurence Lavergne (IPN Orsay, France)
Characterize the best configuration for detection with silicon detectors (nTD, strip detector, direct .vs. reverse mounting ...)

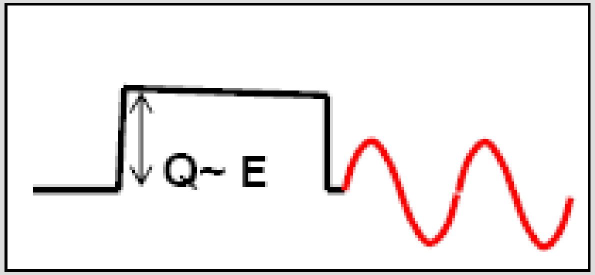
Working Group 6 (WG6) : Cesium Iodide crystals,
contact person : Marian Parlog (INFN Bucarest, Romania)
Define the characteristics of CsI crystals (Thallium doping, thickness, optical readout)

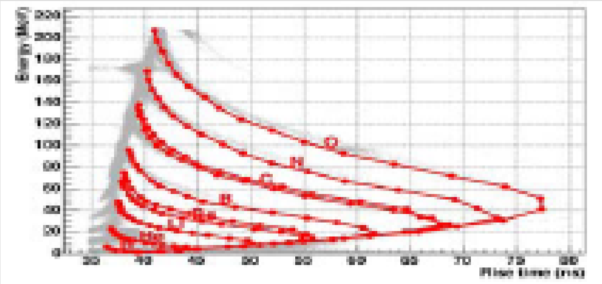
Working Group 7 (WG7) : Single chip detector, contact person :
Giacomo Poggi (INFN Firenze, Italy)
Using a Si-CsI telescope without photomultiplier nor photodiode behind the CsI.

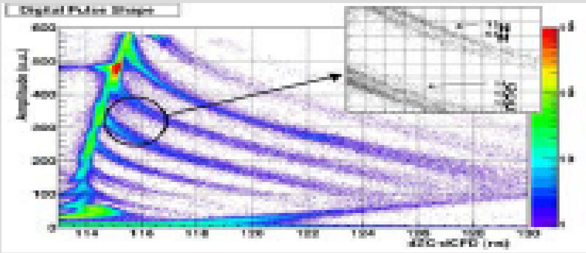
Working Group 8 (WG8) : Design, Detector, Integration and Calibration,
contact persons: R. Bougault (LPC Caen, France), M. Bruno (INFN Bologna)
General implementation of FAZIA setup (mechanical layout, vacuum-related issues,...) as well as needs for online calibration

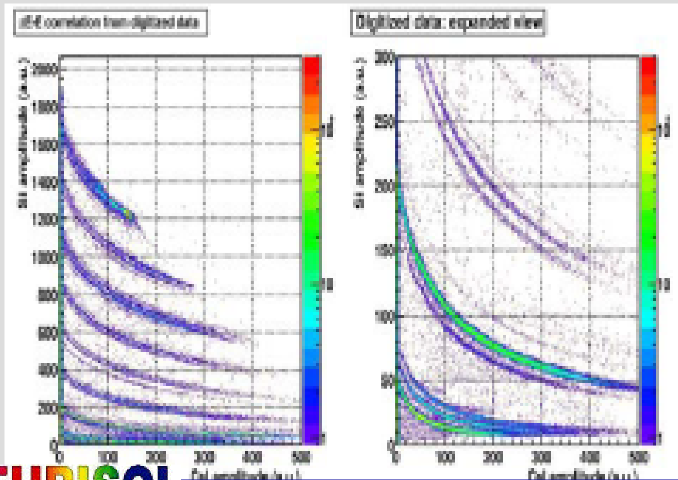
Working Group 9 (WG9) : Web site ,
contact person : Olivier Lopez (LPC Caen, France)
Manage the information access (data, documents) for the collaboration (website, forum)

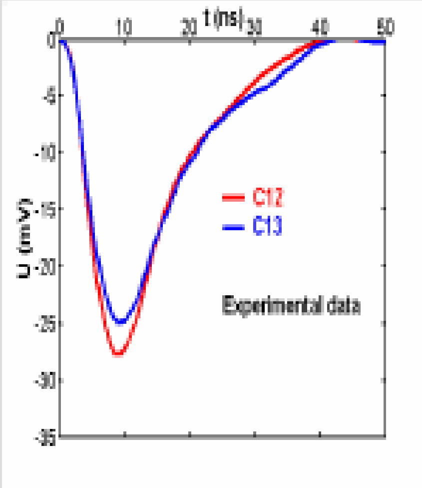
STUDY of a NOVEL 4π DETECTOR ARRAY for NUCLEAR REACTION DYNAMICS and THERMODYNAMICS STUDIES (FAZIA)

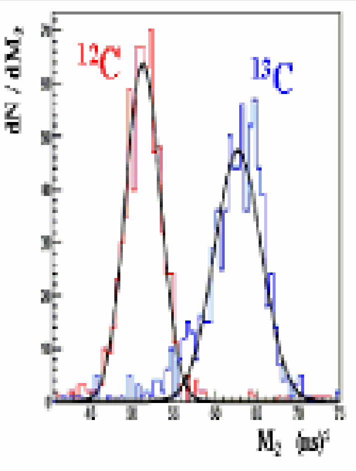


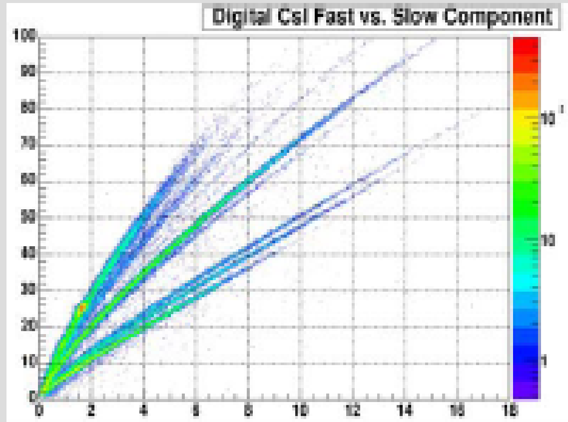


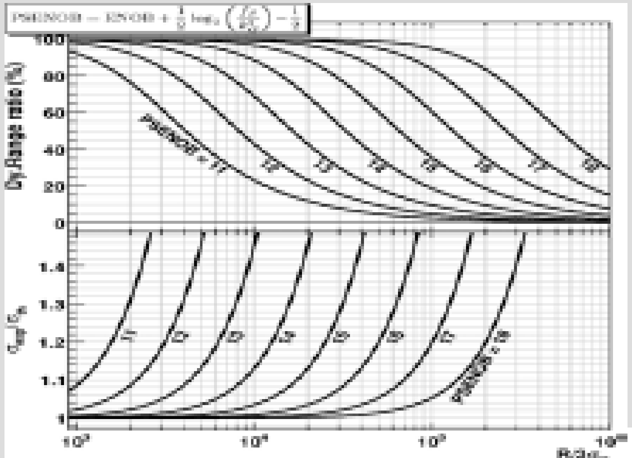


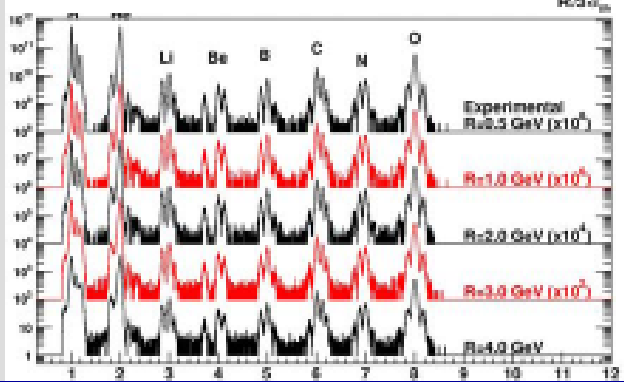


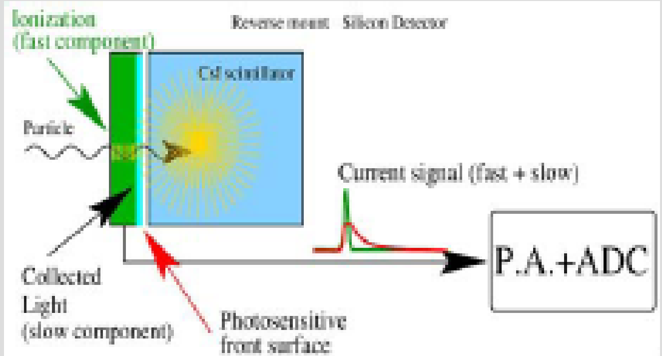


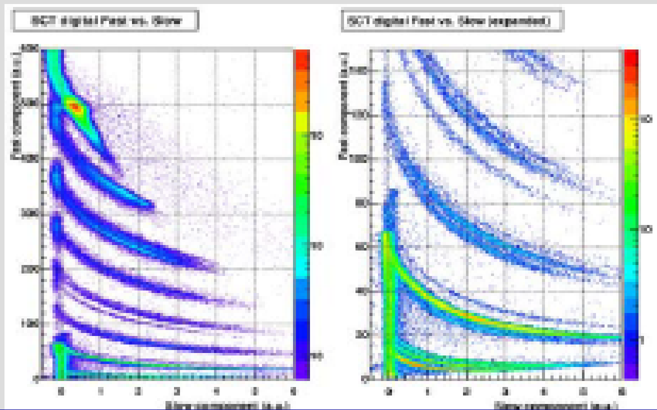




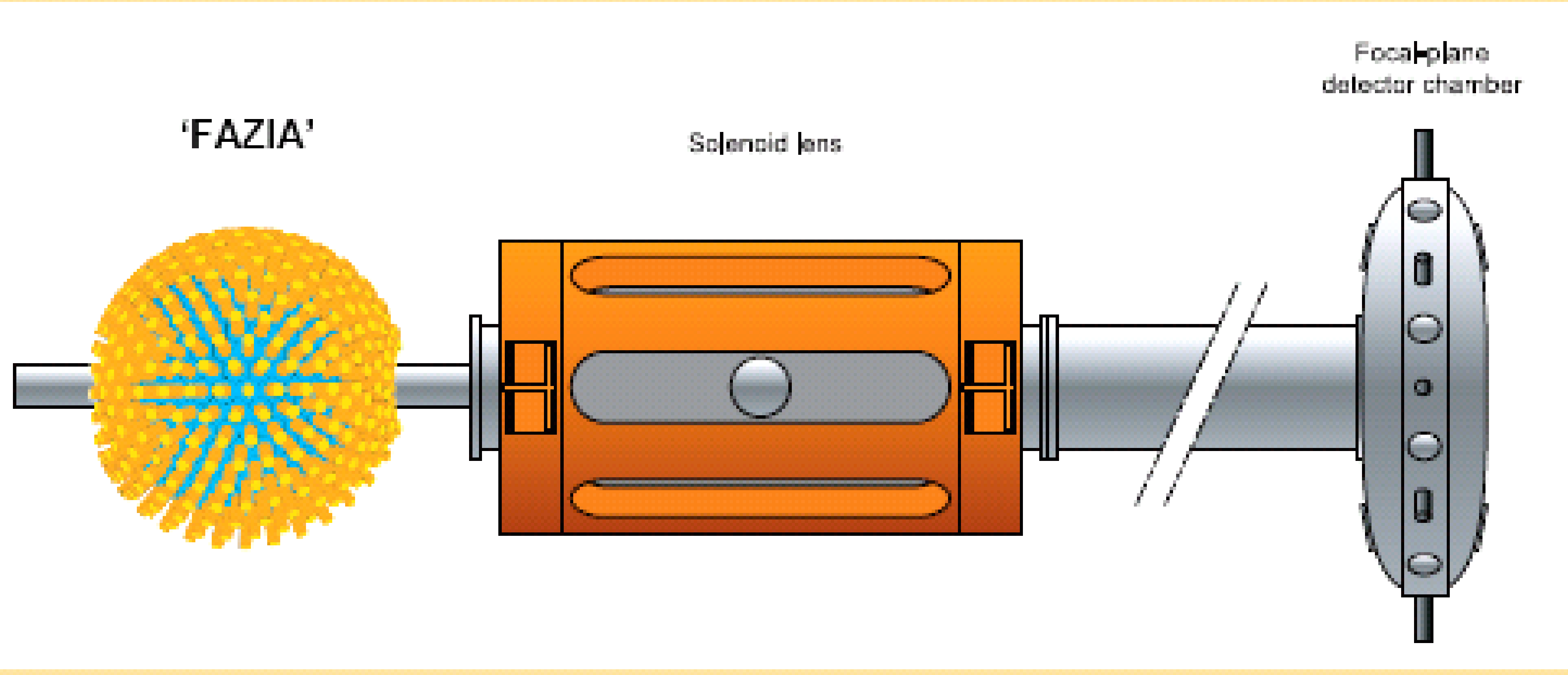








FAZIA: Four π A-Z Indentification Array



4π highly-segmented array
with low E threshold
and Z,A identification

Large acceptance
Magnetic spectrometer
Mass separator for QP remnants

Focal plane detector
High Z,A resolution