The role of the isospin in the formation and decay of excited nuclei

G. Casini for the FAZIA Collaboration

INFN Florence

and

M. Chartier, R. Lemmon , M. Veselsky, S.Ayik, C.Simenel, B. Yilmaz, K.Washiyama, M.Degerlier, S.Dogan, M. Colonna , M. Di Toro , C. Rizzo , V. Baran, D.Lacroix, A.Raduta, F. Gulminelli, R.K. Gupta

Spiral2, SAC meeting

LoI for Spiral2 1day EXP

Memorial de Caen, 27 january 2011

Isospin effects at SPIRAL2

Physics case: dynamics and decay of exotic systems, exploring the interplay between nuclear structure and reactions

LIMITATIONS: moderate Spiral2 bombarding energies (from CIME)
no multifragment modes, no big sub-systems far from saturation densities (small compression-expansion); low emission yields

ADVANTAGES:

- **neutron richness: more exotic nuclear structure (n-skin, more extended surfaces) affects more the dynamics**
- **fragments formed in collisions are not very hot: they better keep memory of their original 'isospin' content (with respect to decay)**

N/Z (isovector part of nuclear force) affects

- **Dynamics and reaction mechanisms** DIC
- **deformation of nuclei, decaying modes, clustering** FUS

R.Lemmon LOI Sp2-41 and this LOI

Isospin eq. in DIC by G.C 2 LOIs at SPES Fazia Coll. October 2010

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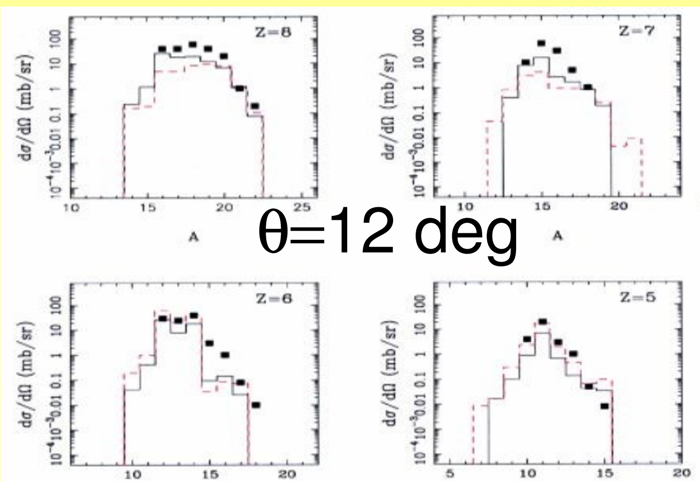
Isospin dynamics in deep inelastic scattering, DIC

Transport models (e.g. the **nucleon exchange model, NEM)** to describe evolution of (n-poor)+(n-rich) reactions**.**

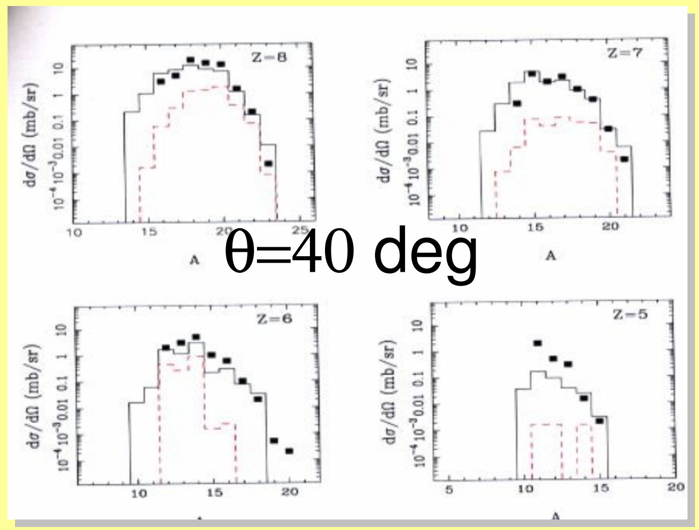
M.Veselsky and G. Souliotis NP A 765 2006; and submitted to EPJ 2010

Betak and Veselsky ECT* Tn 2006



22Ne+90Zr 7.9AMeV

Isospin symmetric



22Ne+232Th 7.9AMeV

Isospin asymmetric

Reanalysis of various systems and also:
^{22}Ne+^{232}Th 7.9AMeV
^{22}Ne+^{90}Zr 7.9AMeV

an ***extended barion density*** to take into account n-skin effects

The new MESSAGE from this study:
-extension of the window region opened during interaction
-neck region important to control the p,n fluxes (large diffuseness)
-need of experimental data from 10 to 20 AMeV

Isospin dynamics in DIC: recent issues

In exotic systems nuclear periphery (neck, surfaces) affects the proton-neutron flows during the nuclear interaction (NEM, Transport + Friction Model, Stochastic Mean Field)

Recent efforts to better include fluctuations in quantum models start giving promising results at low energies where quantal effects are supposed to be important (TDHF family)

The details of the EOS (about Esym) affect the fusion channel (compression in central collisions) and the DIC channel (neck-like structure in semiperipheral collisions) (SMF)

C.Rizzo et al. PRC 83 2011 Shvedov et al PRC81 2010 Takigawa et al NPA588 1995
C.Simenel arXiv 1011.2293 2010

Veselsky and Souliotis NPA 2010 Betak and Veselsky ECT* Tn 2006

Spiral2
TheoreticalGroup
D.Lacroix

At Spiral2 energies surface and/or structure effects can be important in governing the reaction dynamics

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Isospin content and fusion reactions

N/Z (isospin content) affects the way how the two nuclear potentials (P+T) merge and how the coupling between intrinsic and collective modes occurs

Many ingredients scarcely known for exotic systems:

- Coupling of intrinsic & collective d.o.f: viscosity and dissipation (in transport equation models and/or in TDHF calculations)
- Fission barriers vs. Trasmission Coefficients
- Level density parameter and its A,Z,T dependence
- Potential Energy surfaces and complex phase-space configurations for iso-asymmetric and deformed systems

Many modes and phenomena for experiments:

- Fast processes such as dynamical dipole and early particle emissions
- Fusion-fission channels
- Complex fragment emission, odd-even staggering
- Correlations of emitted particles and clustering

A modern open research field

Experiments (among the others..)

E.Bonnet et al. Int J. M.Ph E17(2008) Ba isotopes decay
M.Ciemala et al. Zakopane proc.(2010) search for Jacobi trans. in 88Mo
S.Barlini et al. Zakopane proc.(2010) Fission modes in 88Mo
J.P. Wieleczko et al. Ac.Ph.Pol.B40 (2009) Ba isotopes decay
G.Ademard et al. EPJ web conf. 2 (2010) Ba isotopes decay
J.P.Wieleczko EXP ISODEC at LNS (2010) Ba isotopes decay
A.Corsi at al. Phys. Lett B (2009) dynamical dipole radiation

A very incomplete list!

Models (among the others..)

Washiyama and Lacroix arXiv0811.3907 (2008) dissipative-dynamics TDHF
R.K.Kumar et al. Dic 2010 dynamical cluster m.
G.Royer at al NPA (2002) generalized LDM with proximity
R.Charity PRC 82 (2010) a,b statistical model Gemini, focus on evap. And fission
C. Simenel arXiv 1011.2293 (2010) TDHF and the right fluctuation description
Ch. Schmitt et al. Ac.Phys.Pol B34(2003) 2-dim Langevin fusion-fission m.
C.Rizzo et al. PRC 83 (2011) DDR, Iso-stifness and fusion-DIC competition
L.Shvedov et al PRC 81 (2010) shape fluctuations and fusion-DIC channels
Y.Iwata et al NPA 836 (2010) TDHF and a "geometric" N-Z-plane catalogue

Even at low-moderate energies there is room for good physics on reaction mechanisms and nuclear decay modes

How does Isospin affect the decay of excited nuclei ?

Comparison: ^{94}Kr + ^{48}Ca at 8AMeV ^{80}Kr + ^{40}Ca at 10.2AMeV

Four-π A Z Identification Array

Fast n emission ?

towards fusion

time

A 22 neutron number difference!

CN*
N/Z=1.54?

CN*
N/Z=1.14

How do these decay modes or effects change when going towards n-drip line?

Fusion and Fusion Fission Exit channels:

Preequilibrium effects, shape deformation, cluster preformation, spin excitation, interplay structure-dynamics, dynamical shape transiotions (Jacobi)

Why choosing unstable Kr ions as a first SP2 beams?

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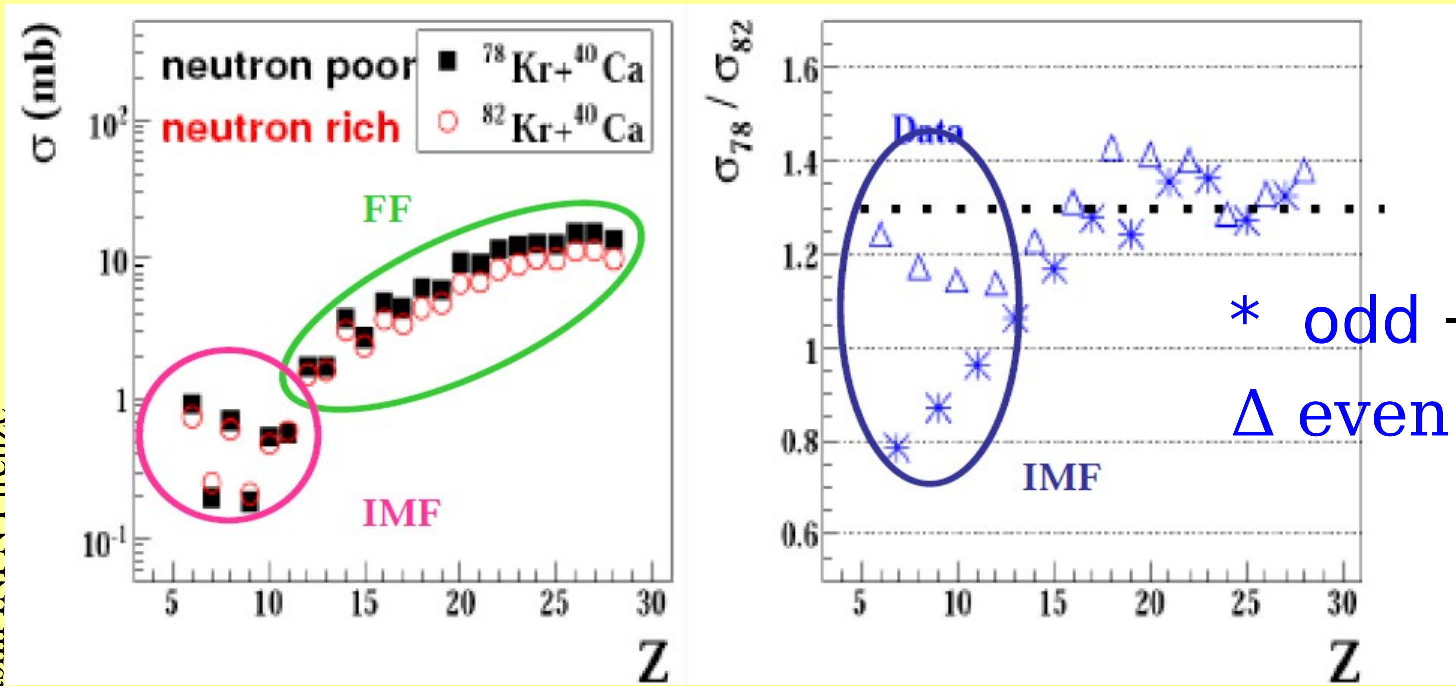
Results from previous works on 118,122Ba at E*=100MeV

Data by E.Bonnet et al. 2008 Exp E475s with INDRA, 5.5AMeV

INDRA at GANIL



* odd ->More in n-deficient

Δ even ->More in n-rich

Symmetric fission 30% larger for n-deficient 118Ba

Strong even-odd staggering for IMF (larger for 118Ba)

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NOTE:

An other experiment, 'Isodec', done in 2010 at LNS

J.P.Wieleczko et al with CHIMERA collaboration

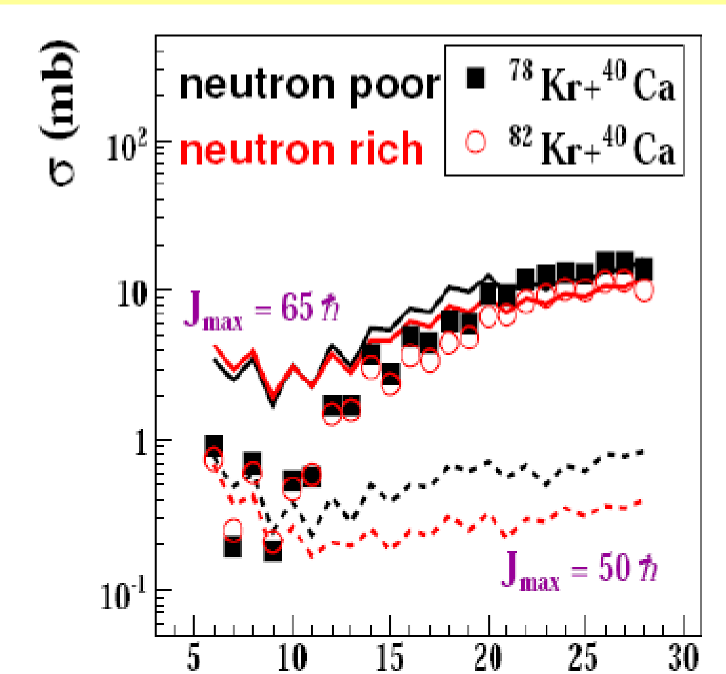
$^{78,86}Kr + ^{40,48}Ca \longrightarrow ^{118,134}Ba^*$

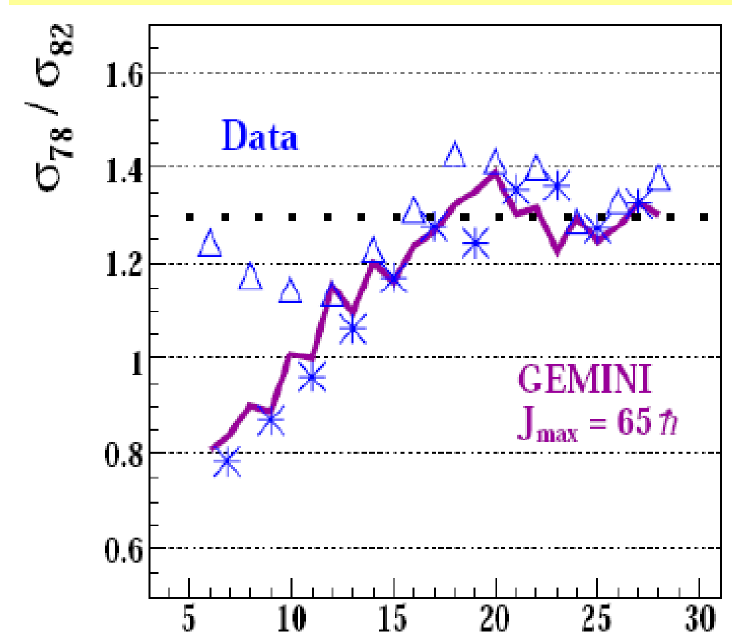
$E_{Lab} = 10\ AMeV \quad E^* \approx 250\ MeV$

Results from previous works on 118,122Ba at E*=100MeV

Data by E.Bonnet et al. 2008, JP Wieleczko et al. AP Pol B40 2009)

An attempt with **GEMINI** (transition state model) by Charity





Possible Refinements

- -Barriers
- -high spin treatment
- -isospin dependence

Symmetric fission 30% larger for n-deficient 118Ba

Strong even-odd staggering for IMF (larger for 118Ba)

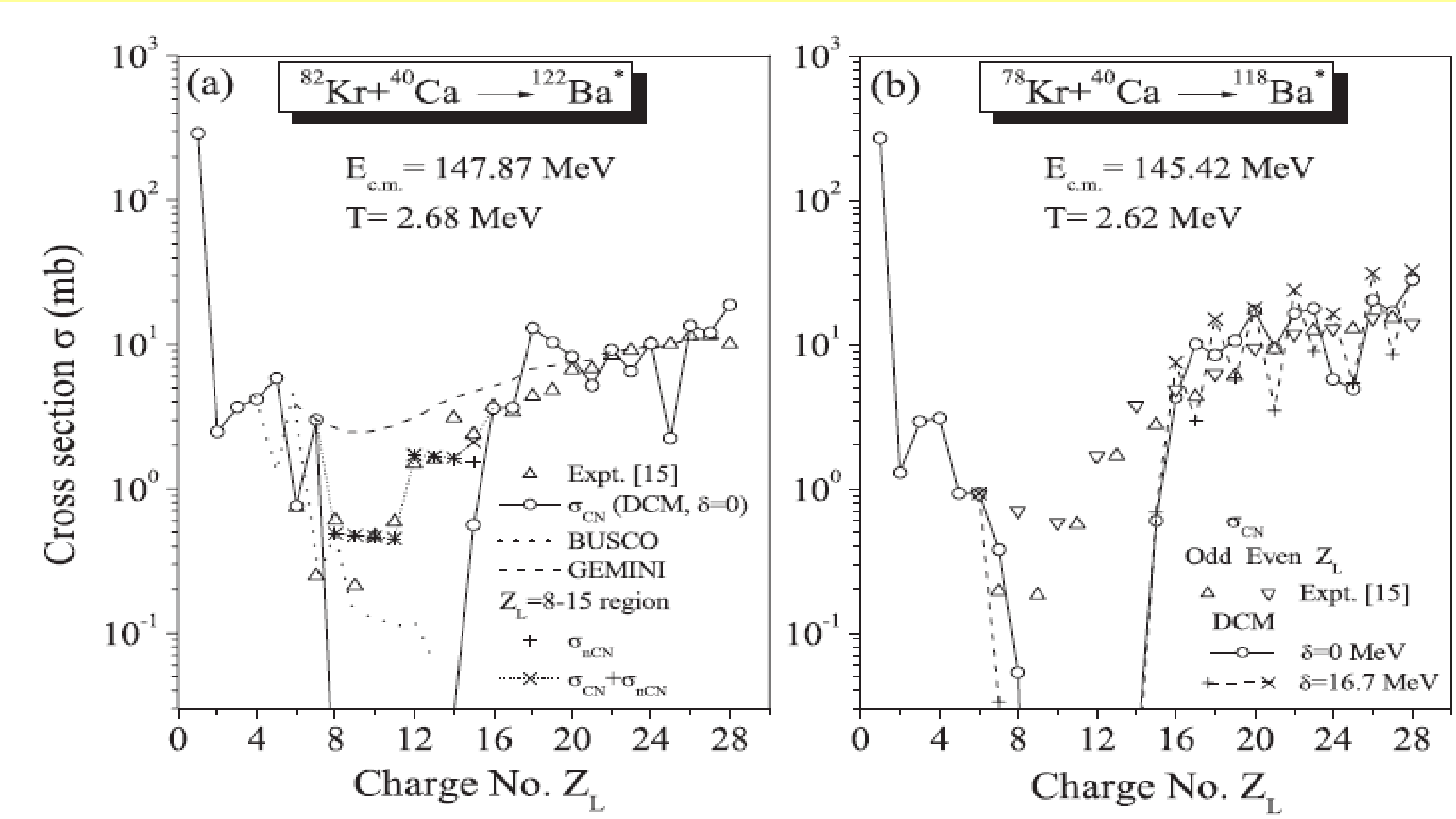
giovanni ca

Reasonable agreement for symmetric fission

Bad results for IMF concerning staggering and N/Z dependencies

Preformed clusters: the Dynamical Cluster Model, DCM

Exp Data by E.Bonnet et al. 2008, JP Wieleczko et al. AP Pol B40 2009



R.Kumar
R.K.Gupta
PRC 79 2009

Collective coordinates
-Z,A asymmetries (preformation)
-R-motion (barrier penetration)

Reasonable agreement for symmetric fission and for Z<8
Critical region for all models 8<Z<15. Contribution of Quasi-fission?
Pairing even at 'high' Temperature to get odd-even staggering?

Extending this investigation to SP2 beams (in red)

^{94}Kr+^{48}Ca=^{142}Ba 6-8AMeV N/Z=1.54 up to E*=230 n-rich CN

^{92}Kr+^{48}Ca=^{140}Ba 6-8AMeV N/Z=1.5 *CN: neutron close shell N=64!*

^{80}Kr+^{40}Ca=^{120}Ba 6-15AMeV N/Z=1.14 n-deficient

^{94}Kr+^{13}C=^{107}Mo 6-8AMeV N/Z= 1.55 up tp E*=110 n-rich

^{80}Kr+^{12}C=^{92}Mo 8-15AMeV N/Z=1.19 n-deficient

Isospin and Decay (FUSION channel)

^{92,94}Kr+^{40}Ca 8AMeV n-rich on n-deficient

^{80}Kr+^{48}Ca 8-10AMeV n-deficient on n-rich

Isospin transport (DIC channel)

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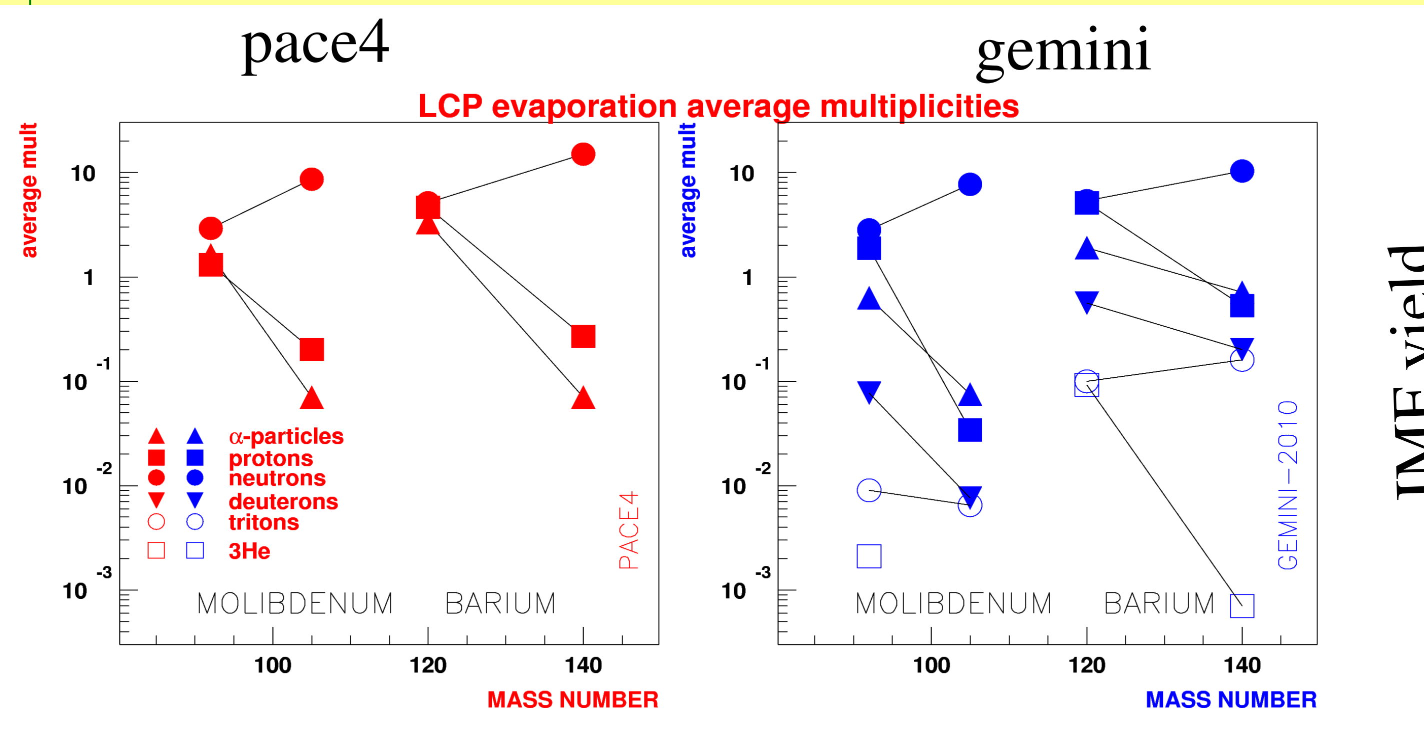
First DAY EXPERIMENT BEAMS

92,94Kr exotic beams (with *currents* >10^7 pps)

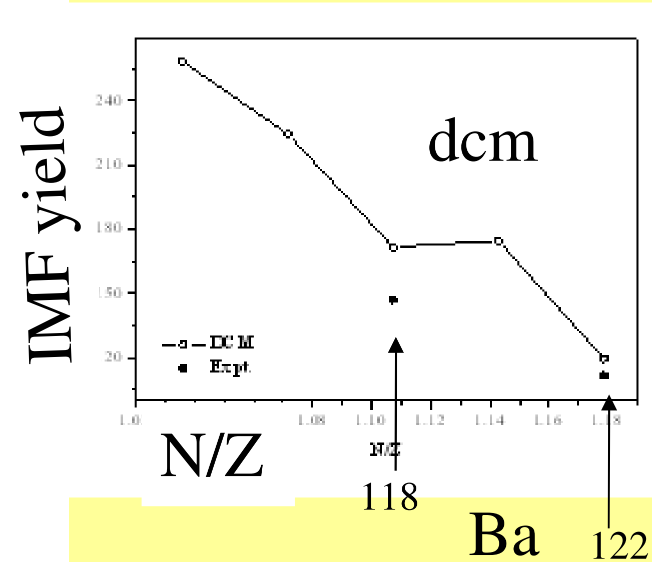
(80Kr standard stable beams)

Maximum CIME energies (till 8-9 AMeV for exotic species)

Some Model predictions for CN decay



DCM R.Gupta priv.comm.



Experimental data to contrain models far from stability

- Strong increase of neutron yield (to be indirectly checked)
- Strong dccrease of p,alpha (but differences in models!) and IMF yields
- Reduction of n-poor species (e.g. 3He in Gemini)
- Reduction of the fission channel (fission yield)
- Surface effects → prodroms of neck-like structures at low energies (n-rich light fragments?)
- Dependence of *little a* on neutron richness (slope of LCP energy spectra)

Observables and Detectors

- CN emitted particles and fragments (fusion evaporation)
- CN fission fragments and particles (fusion fission)
- QP-QT event detection and reconstruction (DIC)
- Isospin-related variables (A,Z,E distribution of as many ejectiles as possible)
- Interplay of one-body (Fusion) – binary (DIC)

FAZIA and/or specific forward detectors for ER (VAMOS?) + and/or other specific detectors for QT measurement (for DIC studies)

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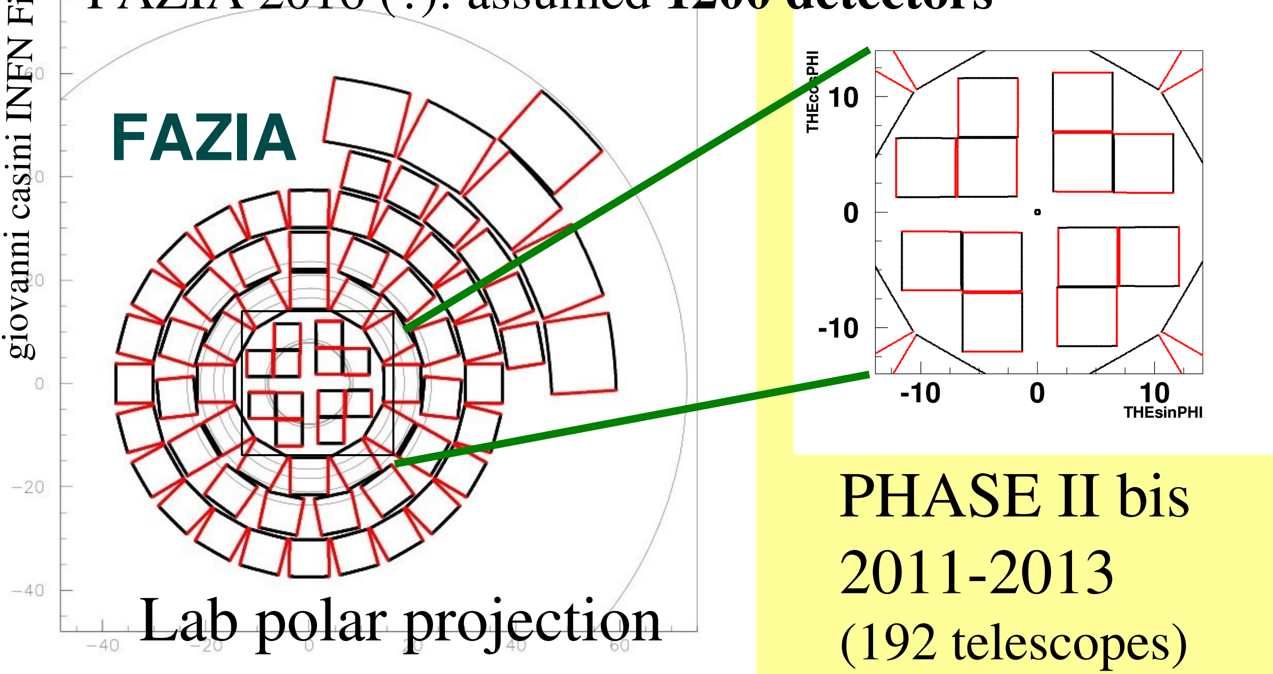
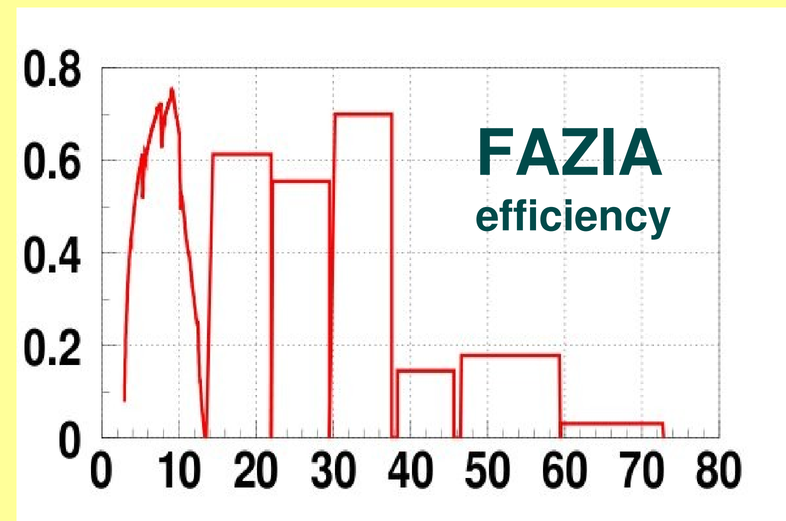
FAZIA 2016 (?): assumed **1200 detectors**



Lab polar projection

PHASE II bis
2011-2013
(192 telescopes)

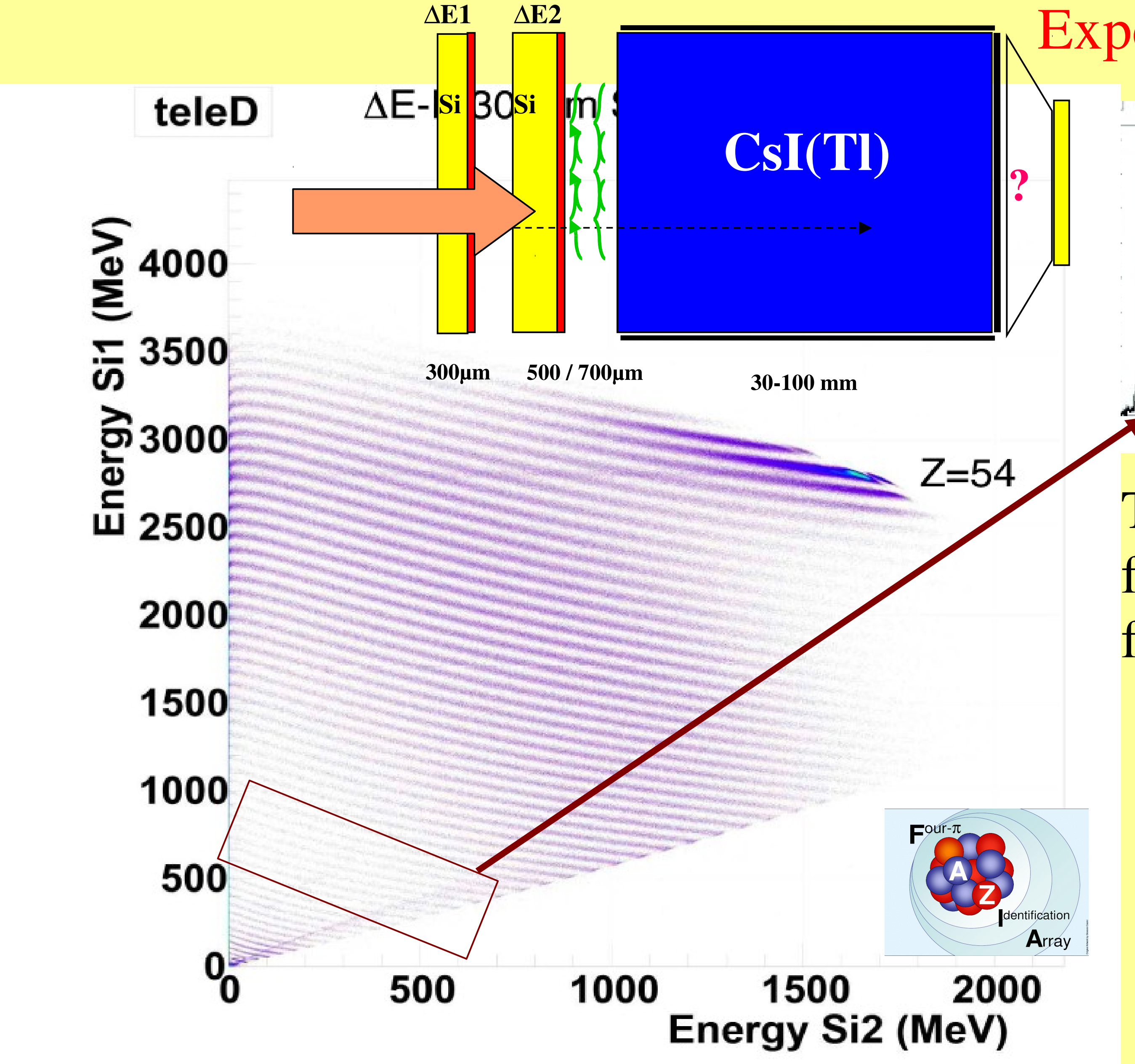


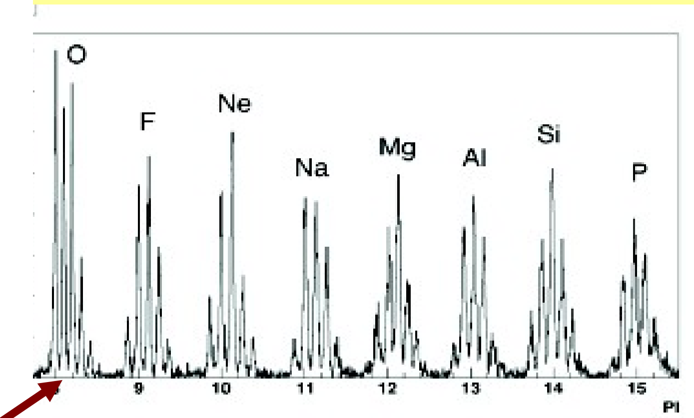
LAB Polar angle

Geometric efficiency vs. θ

Fazia performances…fast ions

Experimental tests LNS





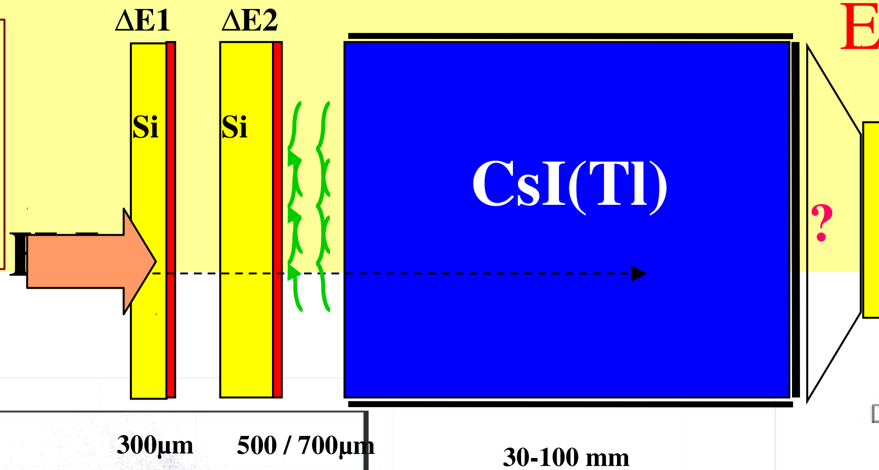
This is for ΔE-E technique, for ions passing-throu the first 300micron Si-layer

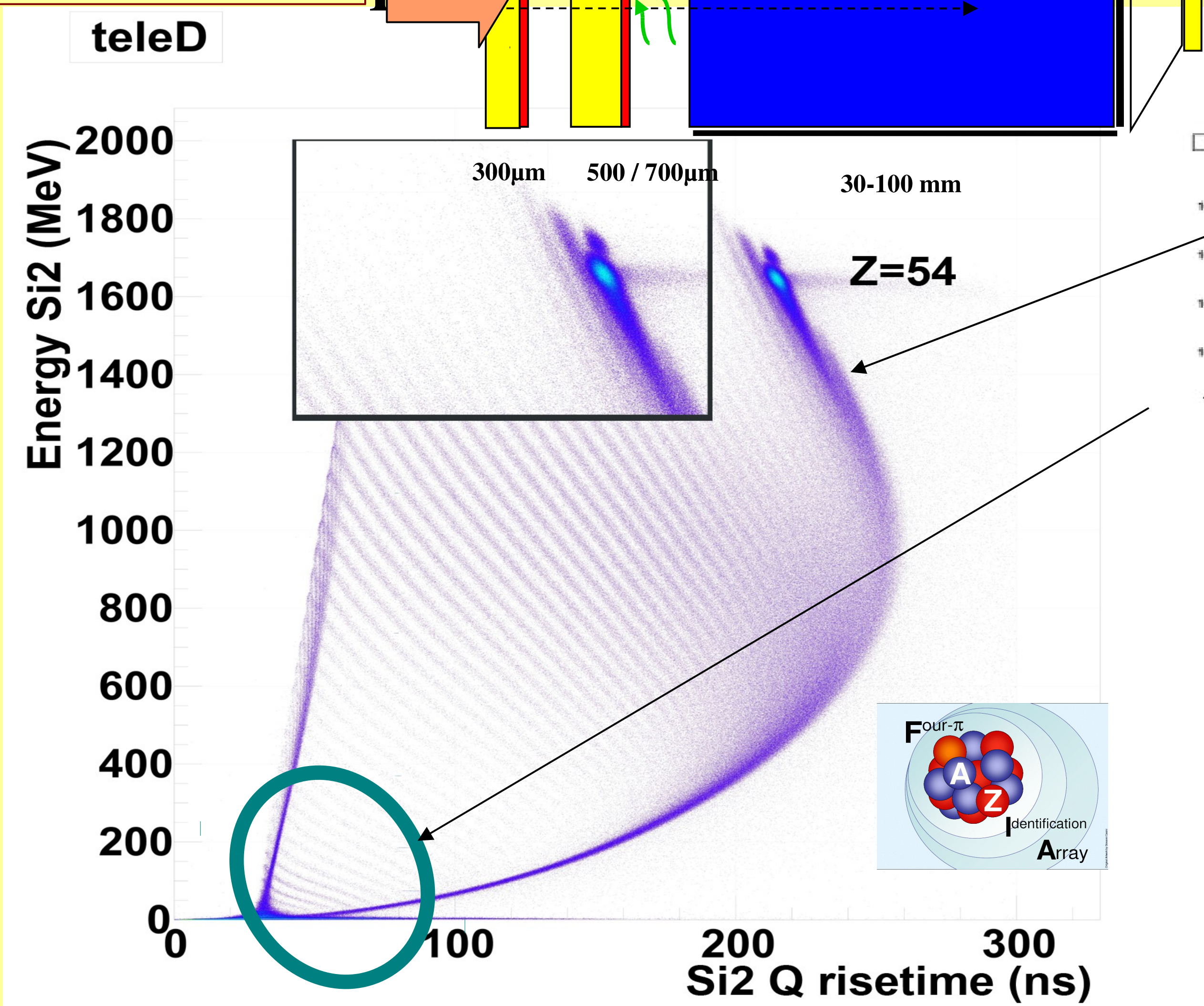
WONDERFUL for Intermediate energy experiments!

Fazia performances...slow ions

more severe thresholds at low energies

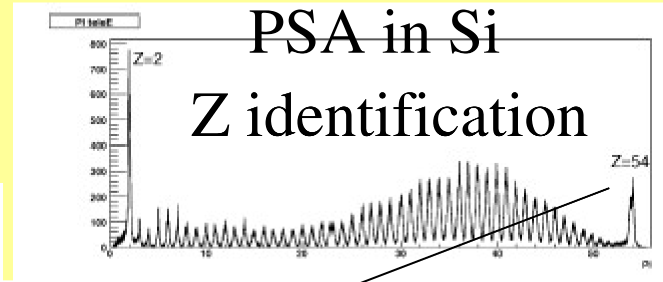
Experimental tests LNS



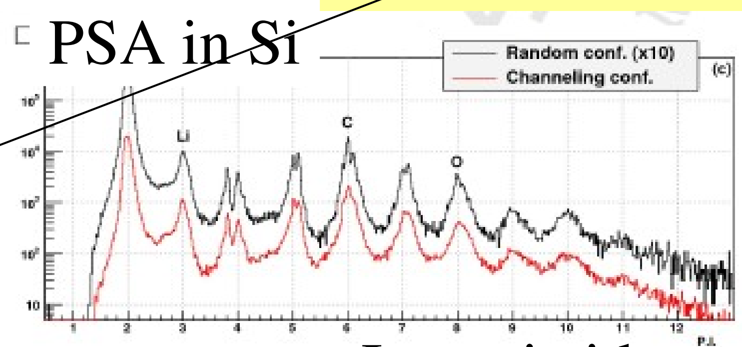


PSA in Si

Z identification



PSA in Si



Isotopic ident.

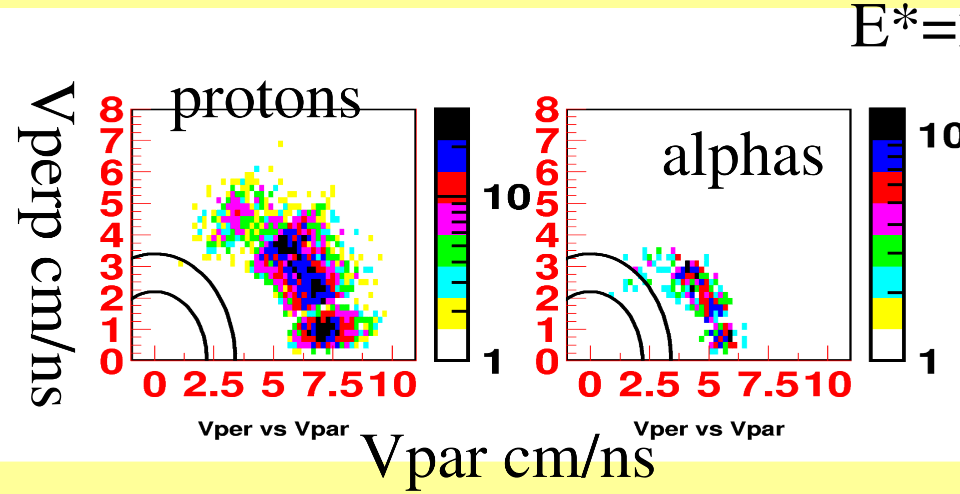
FoM ^{12}C-^{13}C @ 100 MeV	Threshold C-N	Threshold ^{12}C-^{13}C
0.7	33 MeV (2.5 AMeV)	110 MeV (8.5 AMeV)
1.0	32 MeV (2.5 AMeV)	64 MeV (4.9 AMeV)
0.7	36 MeV (2.8 AMeV)	108 MeV (8.3 AMeV)
1.1	35 MeV (2.7 AMeV)	65 MeV (5.0 AMeV)

ENERGY THRESHOLDS

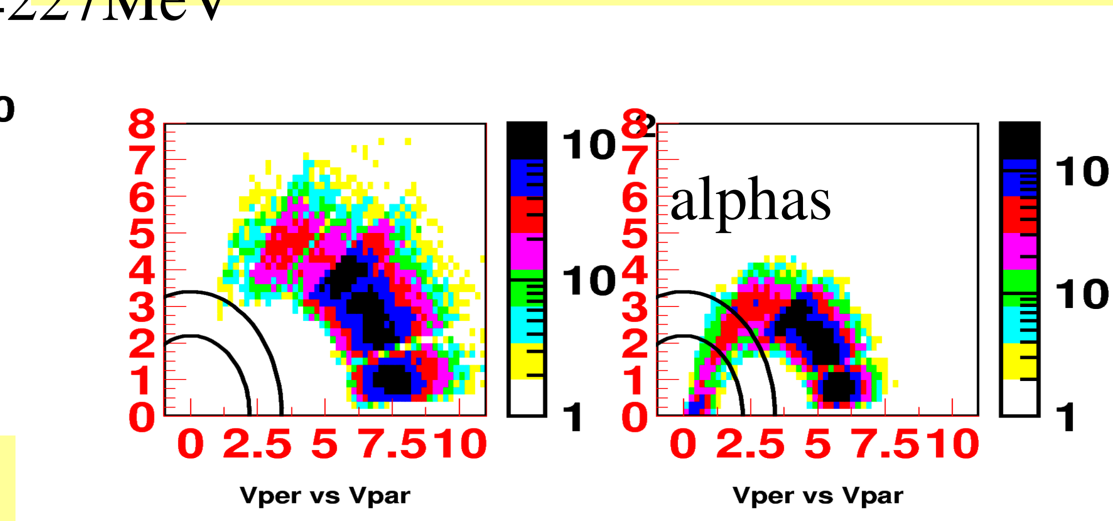
L.Bardelli et al. To be submitted to NIM

Simulated FUSION events

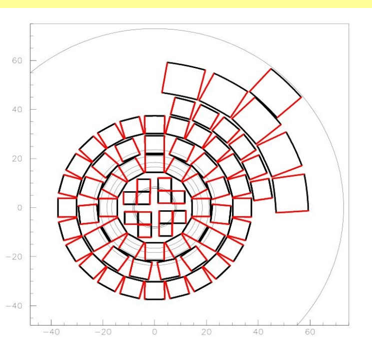
E*=227MeV



^{94}Kr+^{48}Ca 8.0AMeV

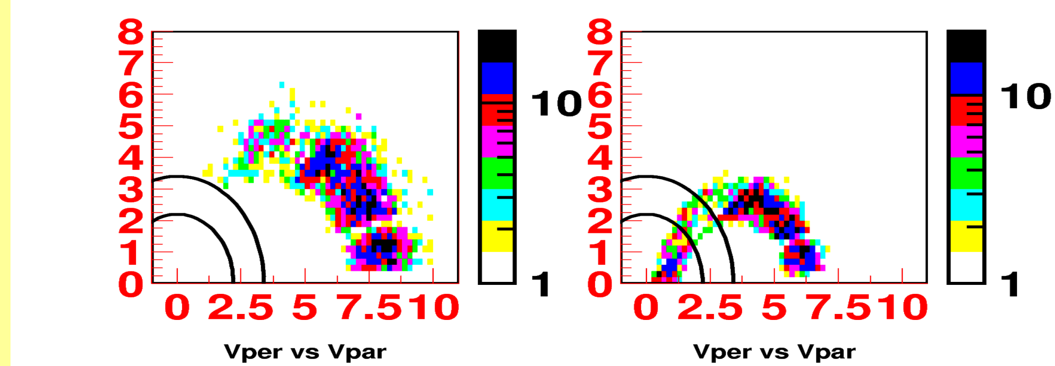


^{80}Kr+^{40}Ca 10.2AMeV



FAZIA 2016: **1200 detectors**

E*=106MeV



^{94}Kr+^{13}C 8AMeV

Most LCP will be
Identified in charge and mass
(sufficient energies) with PSA
and ΔE-E

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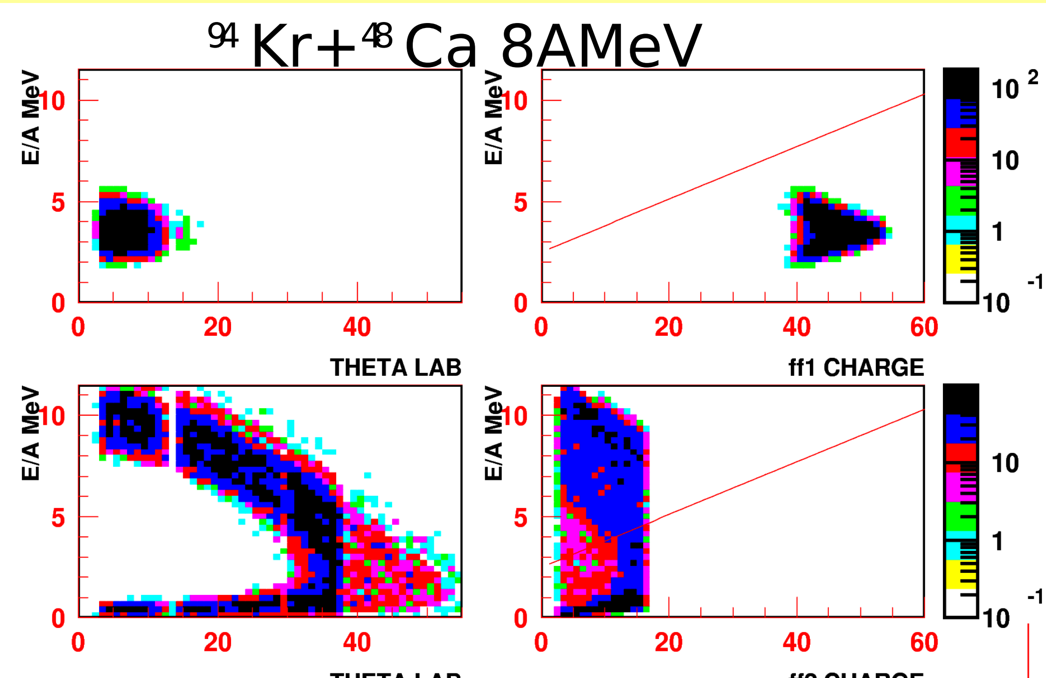
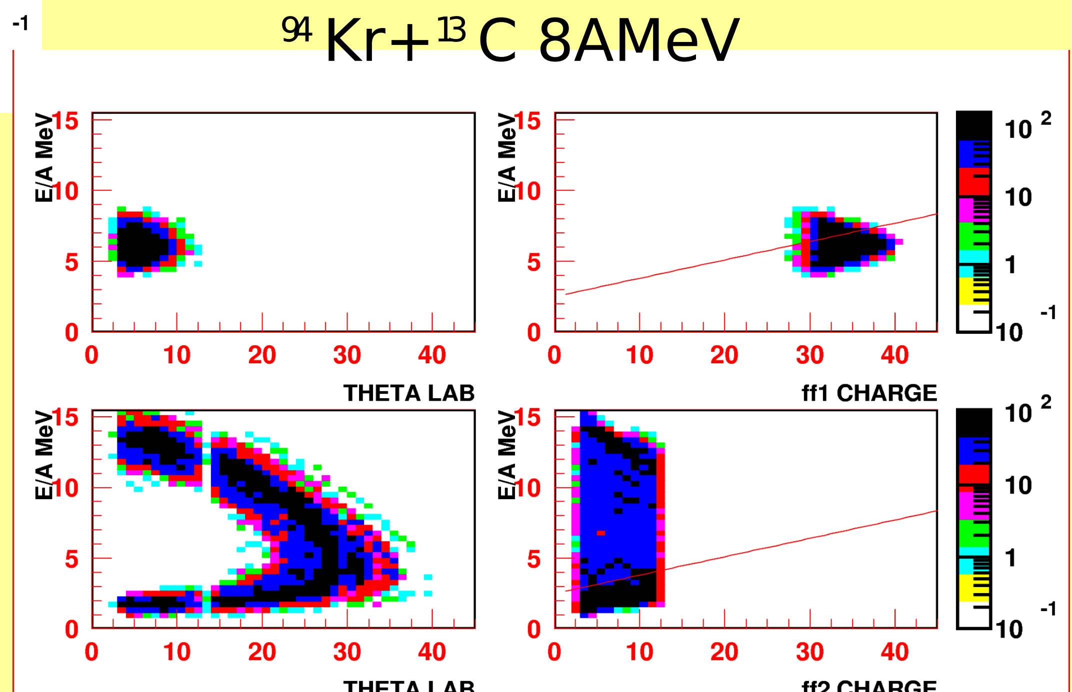
Simulated FUS-FISS events

FAZIA 2016: **1200 detectors**



Asymmetric fission, equilibrium T ansatz

Z identification impossible for the big fragment but accesible for FF2 (the IMF)



Thanks to the strongly reverse kinematics Z identification possible even for part of the bigger FF

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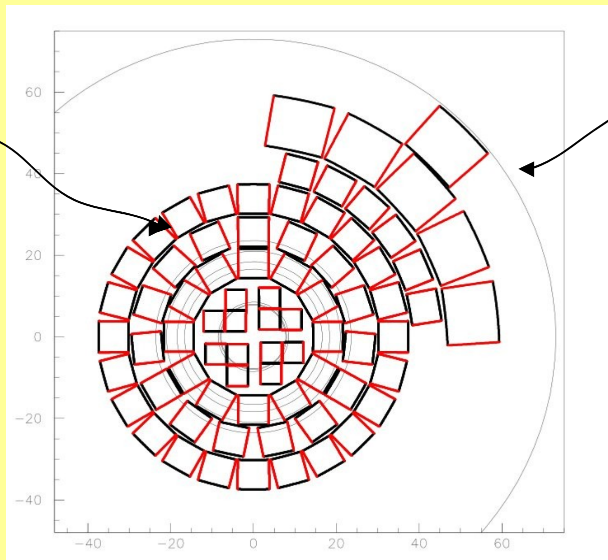
Experiments with SP2 beams

PRELIMINARY
Estimation for fusion

Geometric efficiency 57% in the polar range 2.2-38 deg

Geometric efficiency 24% in the polar range 2.2-72 deg



FUSION + evaporation

Prob. Detection m_{LCP} ≥1: 16-17%

Prob. Detection (m_{LCP} ≥*1* LCP & 1ER): 1%

FUSION + **fission** (all asymmetries)

Prob. Detection m_{LCP} ≥1: 4-6%

Prob. Detection ((FF1*U*FF2)&m_{LCP} ≥*1*): 3-4%

HYPOTHESES (close to the ISODEC experiment in LNS, CT, i.e. realistic!!)

Intensity= 10^7pps; Target thickness: 300µg/cm2

Reaction cross Section: 2.7barn (Ba) and 2barn (Mo)

Fusion from 1 to1.8 barn (20% fission) → 35-100 cps

Detection: fusion-evap rate 0.3-1 cps (ER&LCP)

Fusion-fission rate 0.2-0.8cps ((FF1*U*FF2)&LCP)

About 10 days to have some 10^5 coincidence events