# Neutron-proton exchanges in dissipative collisions

(a letter of intent for SPES)

**G. Casini, G. Verde for the FAZIA collaboration**

**subscribed by 53 members from**

**INFN (Bo, Ct, Fi, LNL, LNS), Italy ;**
**LPC and GANIL, France;**
**Daresbury, United Kingdom;**
**NIPNE, Romania;**
**Institute of Physics, Slovakia;**
**Nevsheir University, Turkey;**
**IFJ PAN Krakow , Jagellonian Univ., Warsaw Univ., Silesian Univ., Poland;**
**Athens University, Greece;**
**Ohio University, USA**

**SPES International WorkShop**
**LNL, 15-17 november 2010**

# Isospin and reaction mechanisms at SPES

Radioactive beams can help in studying not only exotic nuclear structure but also charge-mass transport in nuclear reactions.

**LIMITATIONS**

- moderate SPES bombarding energies: no high excitations; no big variations of nuclear density (light compression-expansion); low emission yields

**ADVANTAGES**

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

N/Z (isovector part of nuclear force) affects:

excitation and deformation of nuclei

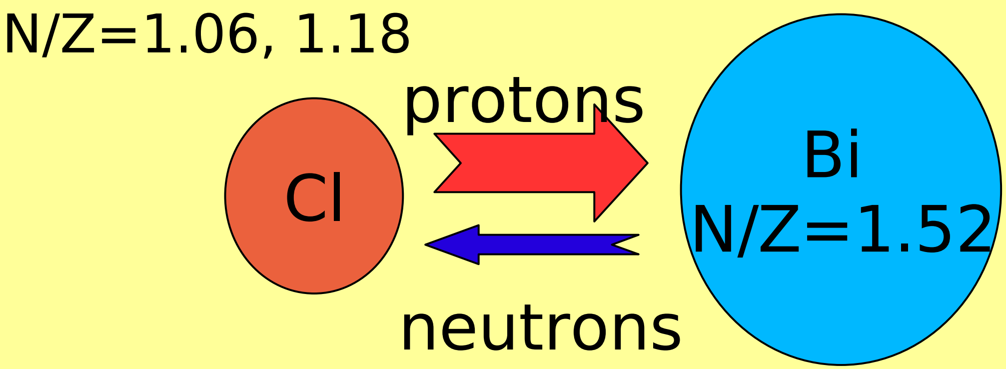
decaying modes

link to the LOI on dynamical dipole resonance

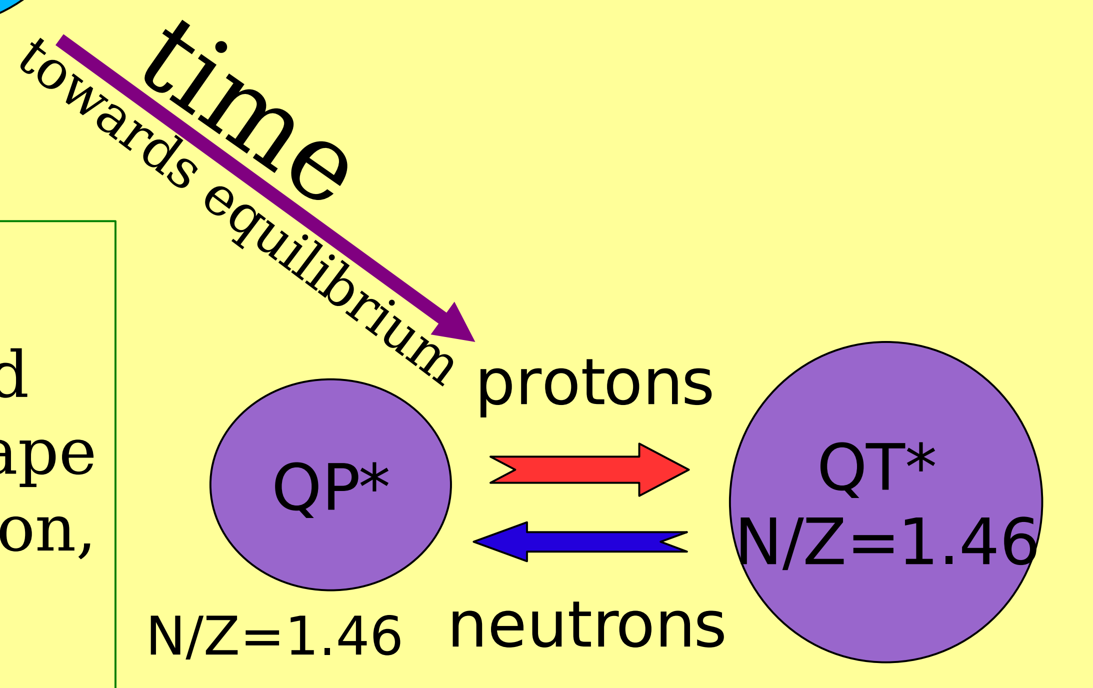
giovanni casini INFN Firenze

# Neutron-proton exchanges in Dissipative Collisions and energy damping

**An Example case: $^{37,35}$Cl+$^{209}$Bi at 7.3,15 AMeV**




Entrance channel

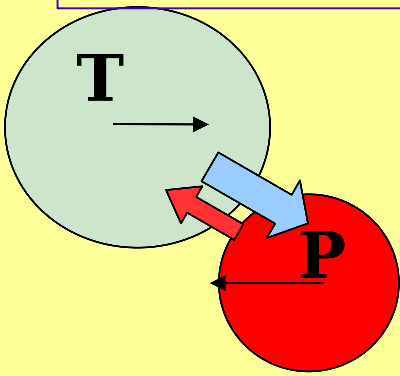



Exit channel:

Energy dissipation, mass and charge distribution, shape deformation, spin excitation, <u>sequential fission of QP/QT</u>

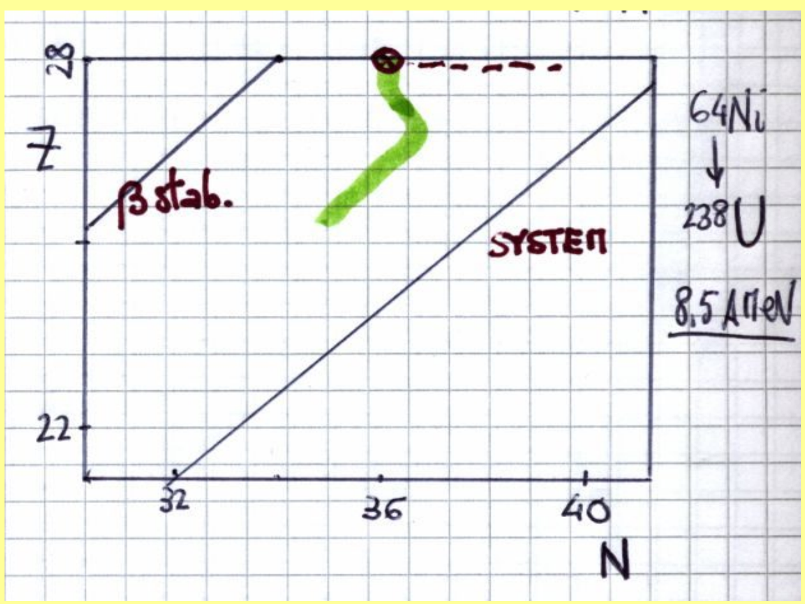
giovanni casini INFN Firenze

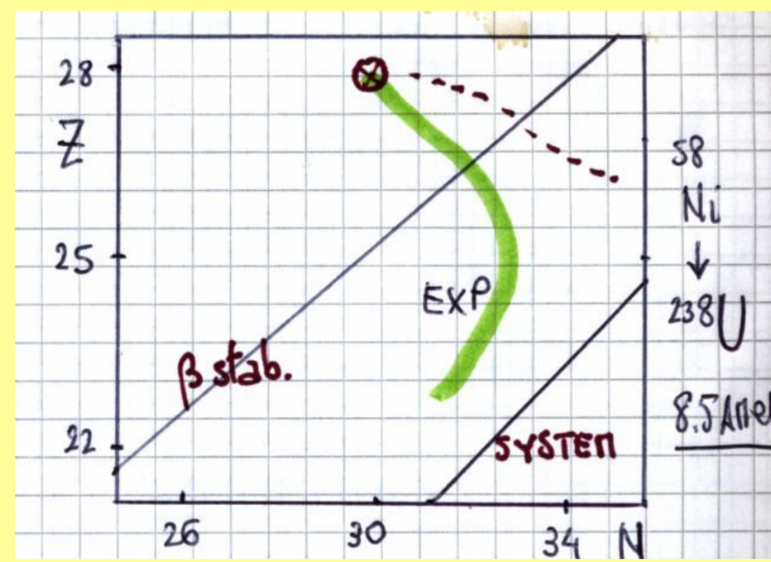
# Isospin dynamics in DIC




First attempts with the **nucleon exchange model** (**NEM)**, were not fully satisfactory:
-the model predicts a strong neutron flow from T to P (N/Z equil and mass symmetry)
-data show a clear proton drift from P to T (N/Z equil and mass asymmetry)

green line: EXP DATA; red dashed: NEM model

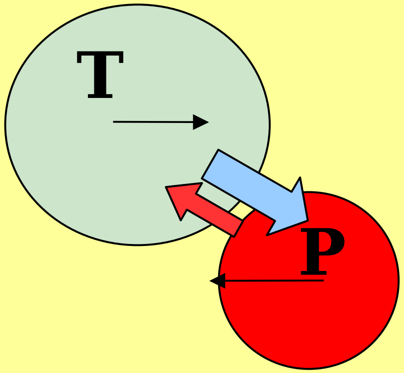



Planeta et al PRC 1988 **$^{58,64}$Ni+$^{238}$U 8.5AMeV**

giovanni casini INFN Firenze

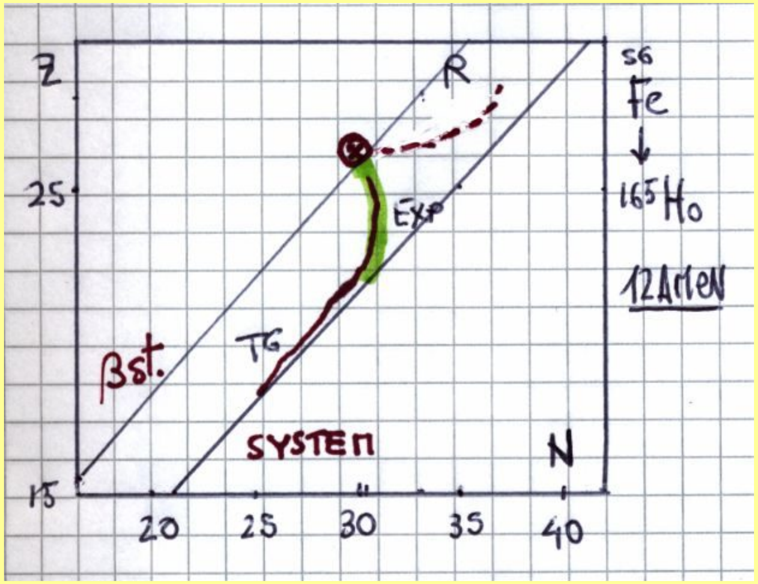
# Isospin dynamics in DIC



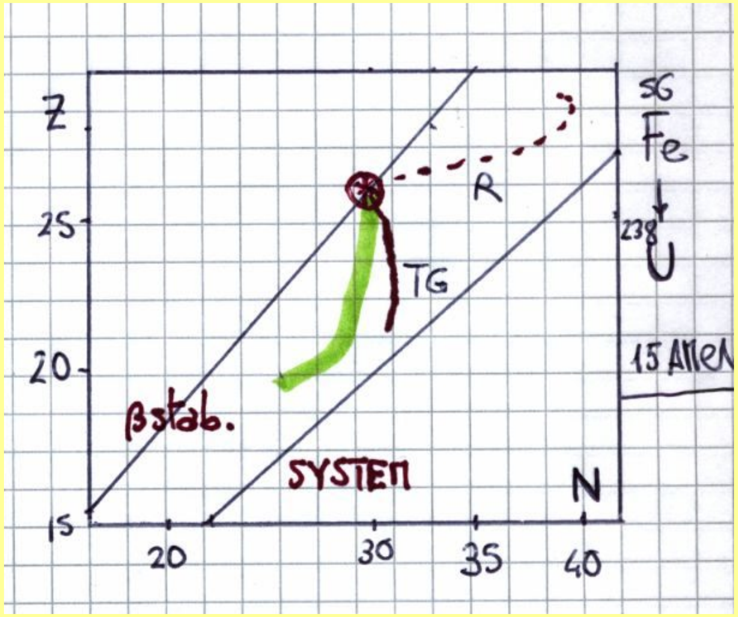

Refined NEM model calculations give a general better agreement, but still:
Discrepancy for mass-asymmetric systems:
- variances of A,Z distributions
-stronger proton transfer in the data

giovanni casini INFN Firenze

red dashed: NEM model (Randrup: one Lagrangian for the whole system )
red contin.: NEM model (Tassan-Got: MC code with two separate nuclei)

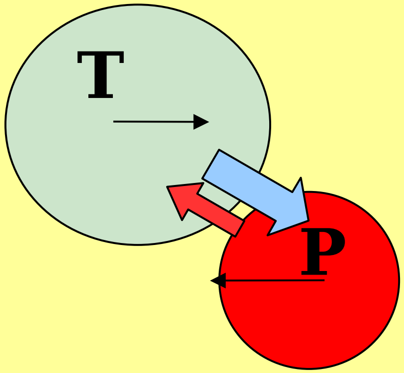



green line:
EXP DATA



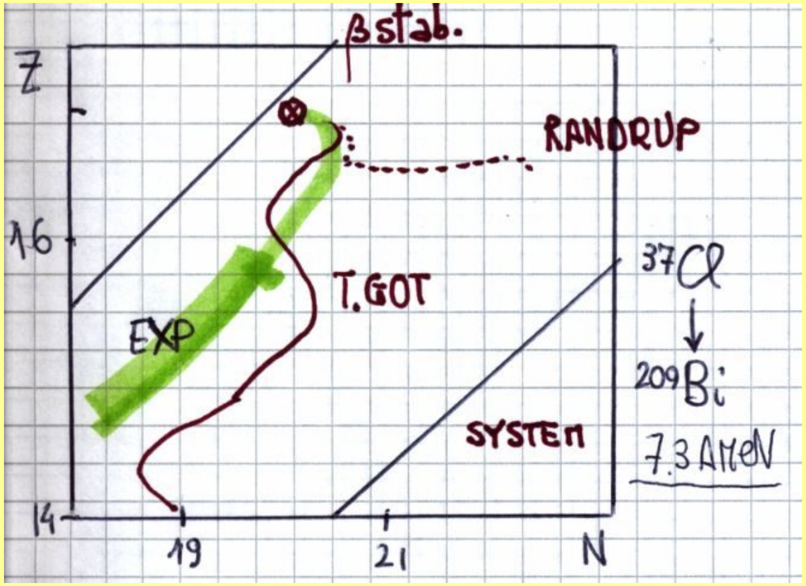

Madani PRC 1995 **$^{56}$Fe+$^{165}$Ho 12AMeV;** **$^{56}$Fe+$^{238}$U 15AMeV**

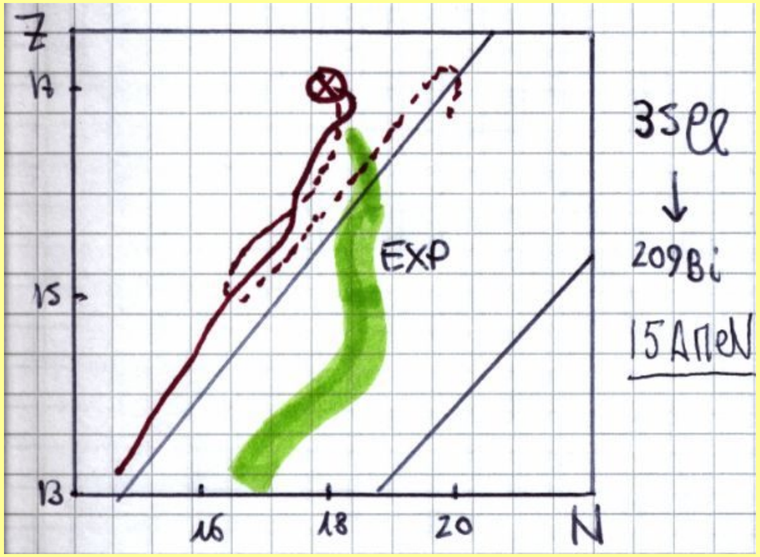
# Isospin dynamics in DIC




Again the NEM (Tassan-Got version) gives a good overall description. BUT
- the N/Z equilibration goes on very slow
- in some cases the model fails at all
- variances of distributions badly reproduced

green line: EXP DATA
red dashed: NEM model (Randrup)
red contin.: NEM model (Tassan-Got)

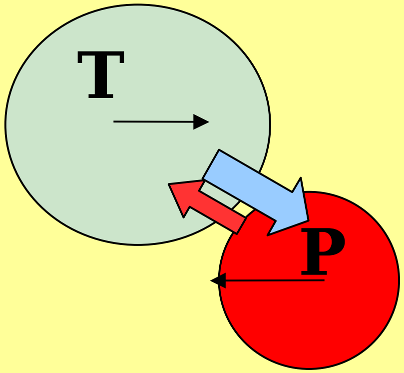



Marchetti PRC 1993 **$^{37}$Cl+$^{209}$Bi 7.3AMeV; $^{35}$Cl+$^{209}$Bi 15AMeV**

giovanni casini INFN Firenze

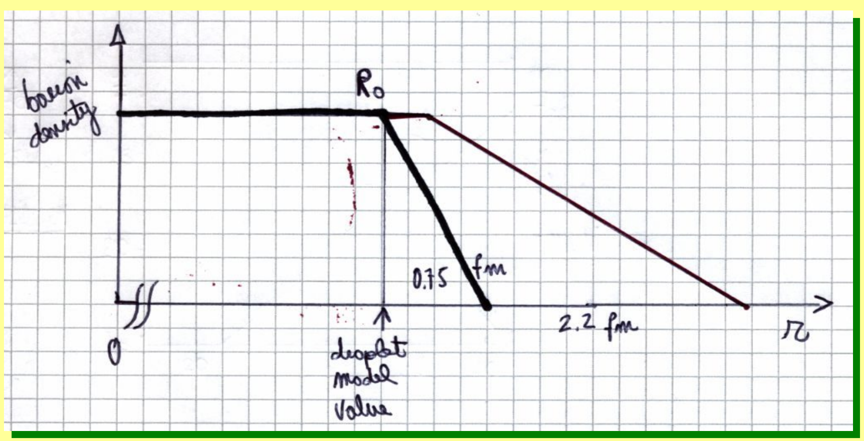
# Isospin dynamics in DIC




Recently the Nucleon Exchange Model has been used with an *extended barion density* to take into account n-skin effects

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

Reanalysis of the QP-mass distributions for several reactions, with NEM




$^{58}$Ni+$^{208}$Pb 5.7AMeV
$^{64}$Ni+$^{208}$Pb 5.5, 25 AMeV
$^{58}$Ni+$^{238}$U 6.1AMeV
$^{22}$Ne+$^{232}$Th 7.9AMeV
$^{22}$Ne+$^{90}$Zr 7.9AMeV

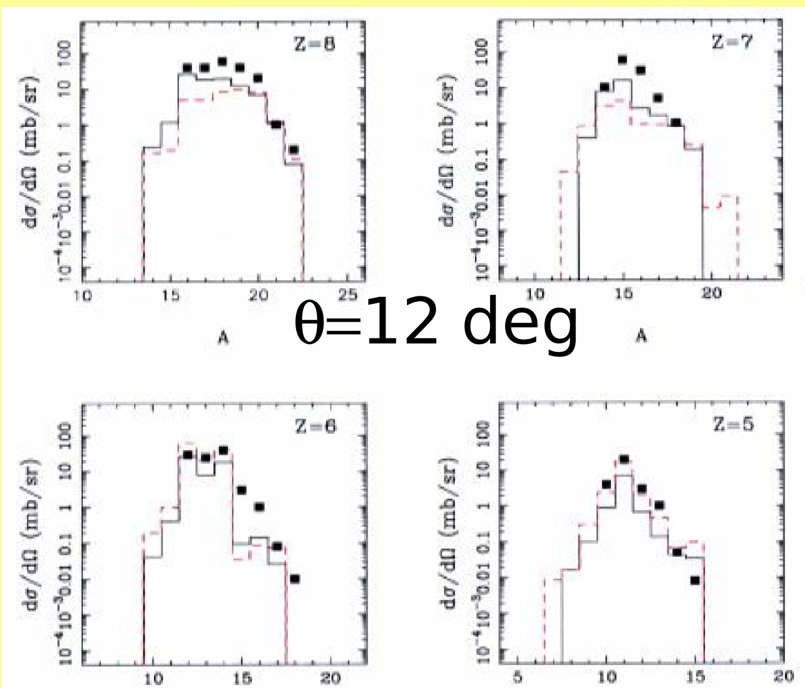
-extension of the window region opened during interaction
-neck region important to control the p,n fluxes
-need of experimental data from 10 to 20 AMeV

# Isospin dynamics in DIC

The modified NEM with larger diffuseness better reproduces isotopic distributions of QP

points: EXP DATA (secondary quantities)
red dashed: NEM (Tassan-Got, standard) + evaporation
Black cont.: NEM (Veselsky, extended) + evaporation

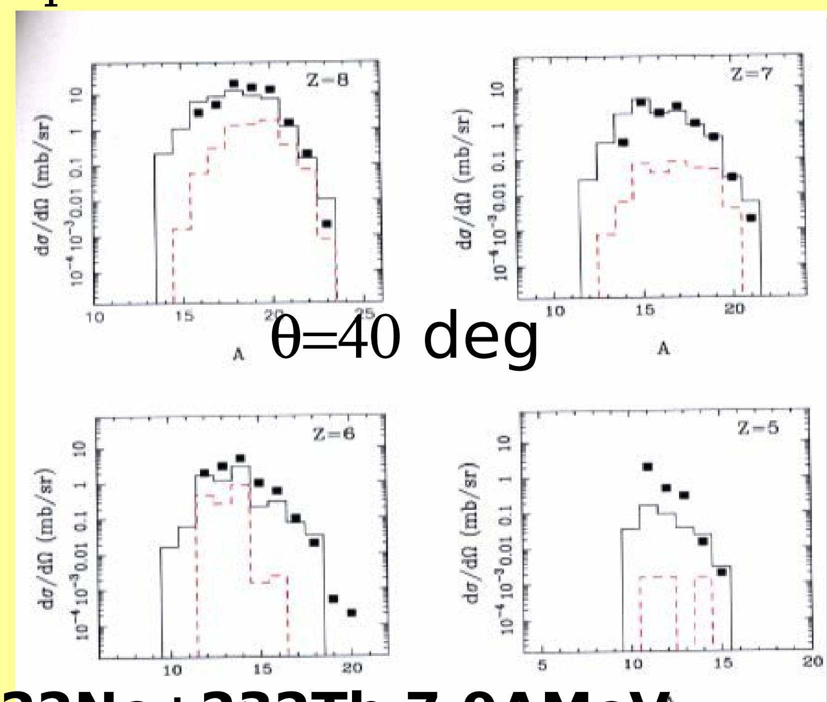
giovanni casini INFN Firenze




**22Ne+90Zr 7.9AMeV**

N/Z=1.2, 1.25

Isospin SYMMETRIC




**22Ne+232Th 7.9AMeV**

N/Z=1.2, 1.58

Isospin ASYMMETRIC

# What's the message?

**A microscopic correction to NEM describes the effect of isospin asymmetry at nuclear periphery**

**This can produce an inversion of the bulk isospin flow due to microscopic structure at nuclear periphery**

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

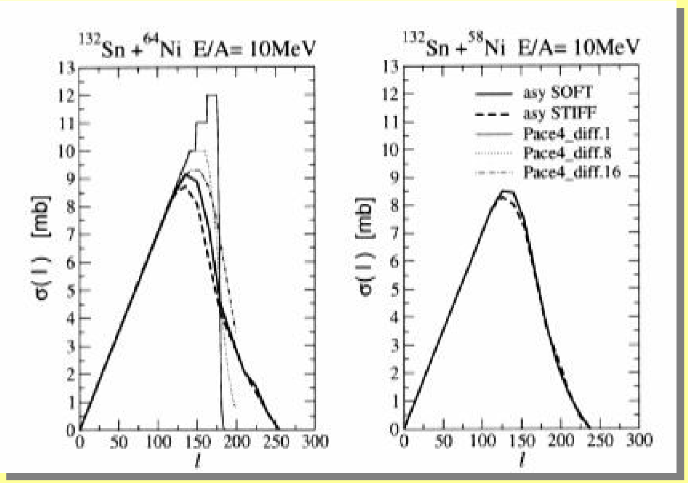
**At SPES energies surface effects can be important in governing the dynamics in semiperipheral collisions**

# Stochastic Mean Field models: EOS, isospin equilibration and reaction mechanisms

*M. Di Toro et al. NP A 787 (2007), 585c*
*C.Rizzo et al. ArXiv nucl-th 2010*
*L.Shvedov et al. PRC 81 2010*

**$^{132}$Sn+$^{64}$Ni at 10 AMeV**
**$^{132}$Sn+$^{58}$Ni at 10 AMeV**

SEE talk of M.Colonna

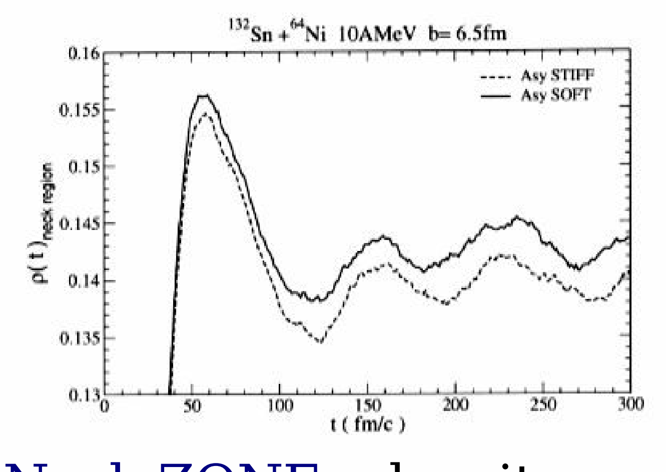



Very large diffuseness in macroscopic fusion models needed to reproduce the SMF fusion cross-section

Stochastic Mean Field model: $E_{sym}$ behavior is modeled as ASYstiff or ASYsoft.

**STIFF** produces a more dissipative neck corresponding to more elongated configurations with larger octupole deformations):
-larger sequential fission yield?
-larger neck emission

**SOFT** less repulsive potential for neutrons over ρ0:
-larger fusion probability
-more compact shapes




Neck ZONE: density behaviour vs. time

# Summarizing, to be done at SPES

- **Mean-field dissipation: role of extended surfaces (n-rich skin) on proton-neutron exchanges**
- **Neck fragments: some neutron-rich emission favoured by extended surfaces?**
- **Surface instabilities vs. sequential fission, competition among reaction channels**
- **Evaporation from exotic nuclei (stringent test for well aknowledged statistical models) --> see LOI S.Pirrone et al.**
- **Possible emission of fast (preequilibrium) neutrons even at moderate energies**

Interesting beams from SPES (with *currents* >$10^7$ pps):
alkalines: Rb, Cs; noble gases: Kr, Xe; halogens: Br
metals: Y,Ag, Sn
-even the maximum Alpi energies are mandatory
-Important and continuous support from theorists !

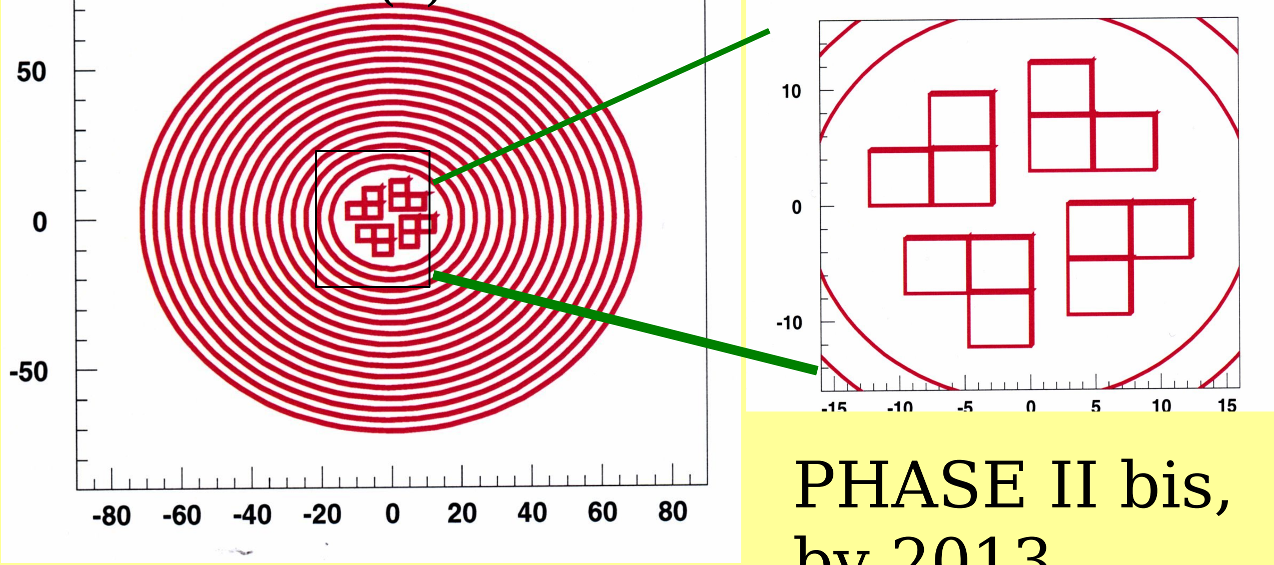
giovanni casini INFN Firenze

# Observables and Detectors

- **Binary (and Ternary) event reconstruction**
- **Isospin-related variables** **(A,Z distribution of as many ejectiles as possible)**
- **Interplay of one-body (Fusion) – binary (DIC) and three body channels**

- **FAZIA** **+ forward special detectors for ER + backward detectors for QT measurement (Tof, position)**
- **Neutron detectors: a recurrent dream?**

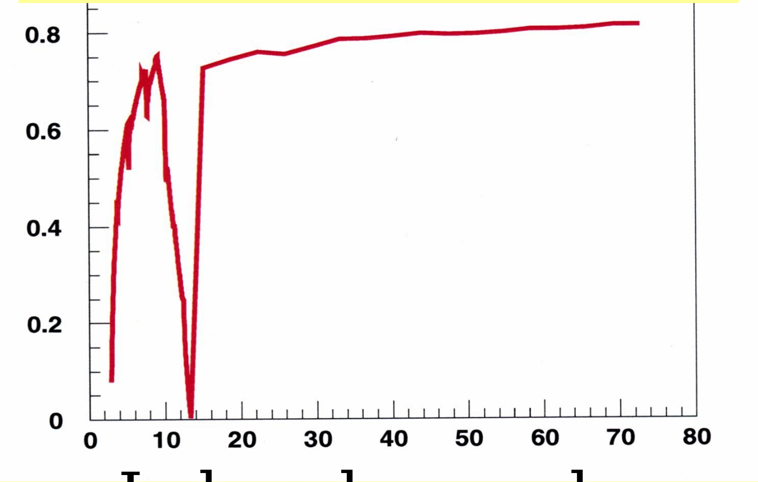
FAZIA 2016 (?): **1180 detectors**




Lab polar projection

PHASE II bis, by 2013
(192 telescopes)

FAZIA
Geometric efficiency

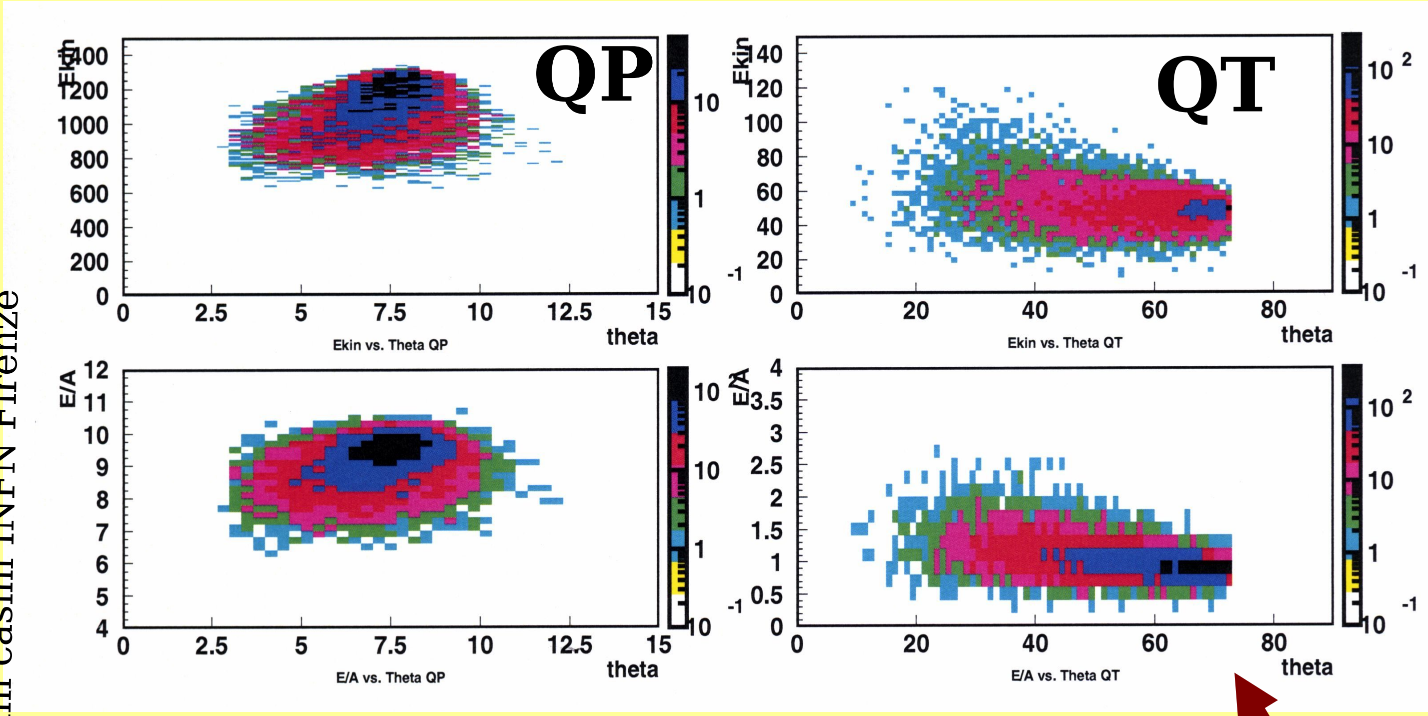



Lab polar angle

giovanni casini INFN Firenze

# Simulated events $^{132}Sn+^{58}Ni$ 10.5AMeV

FAZIA 2016: **1180 detectors (?)**




**Challenge:**

-recostruct at best the QP properties;
-measure the light species, identified in A,Z

preliminary evaluations….

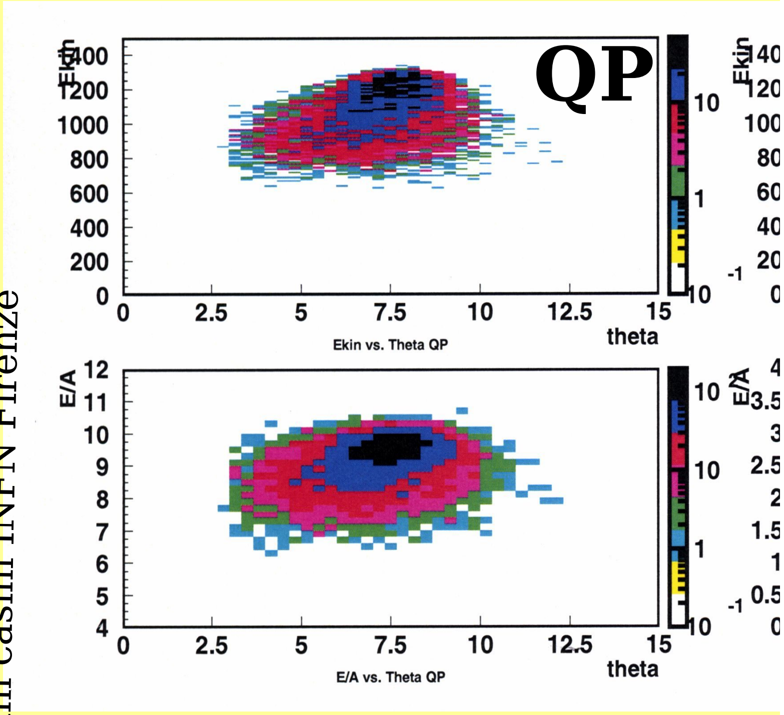
QT detected to constrain the kinematics

giovanni casini INFN Firenze

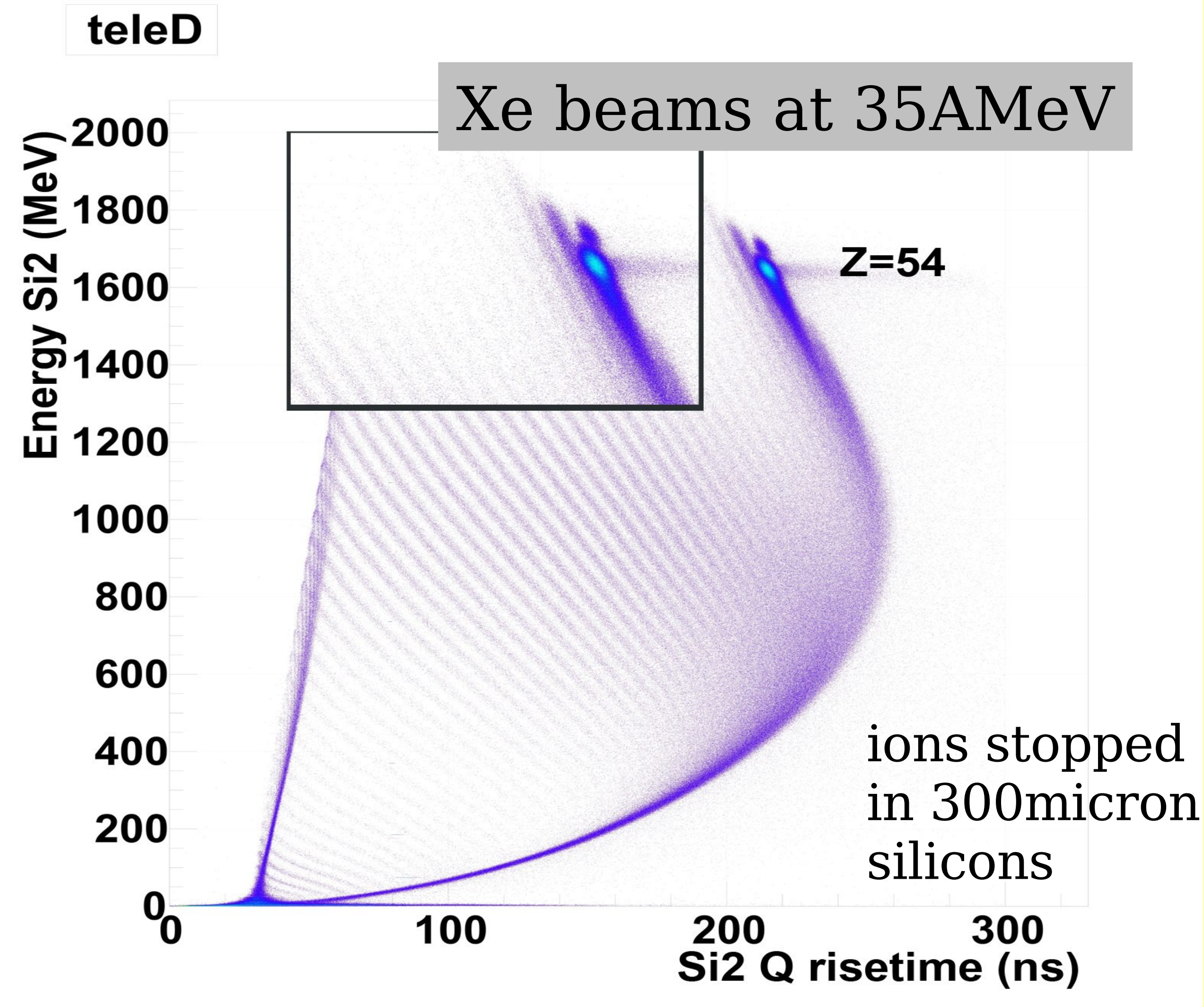
# Simulated events $^{132}Sn+^{58}Ni$ 10.5AMeV

FAZIA 2016

**1180 detectors (?)**




LNS 09




giovanni casini INFN Firenze

we are working to extend the Z,A identification via PSA in Silicons at lower energies

FAZIA Results: talks by Nicolas Le Neindre (review, WS) and by Stefano Carboni (specific, LEA)

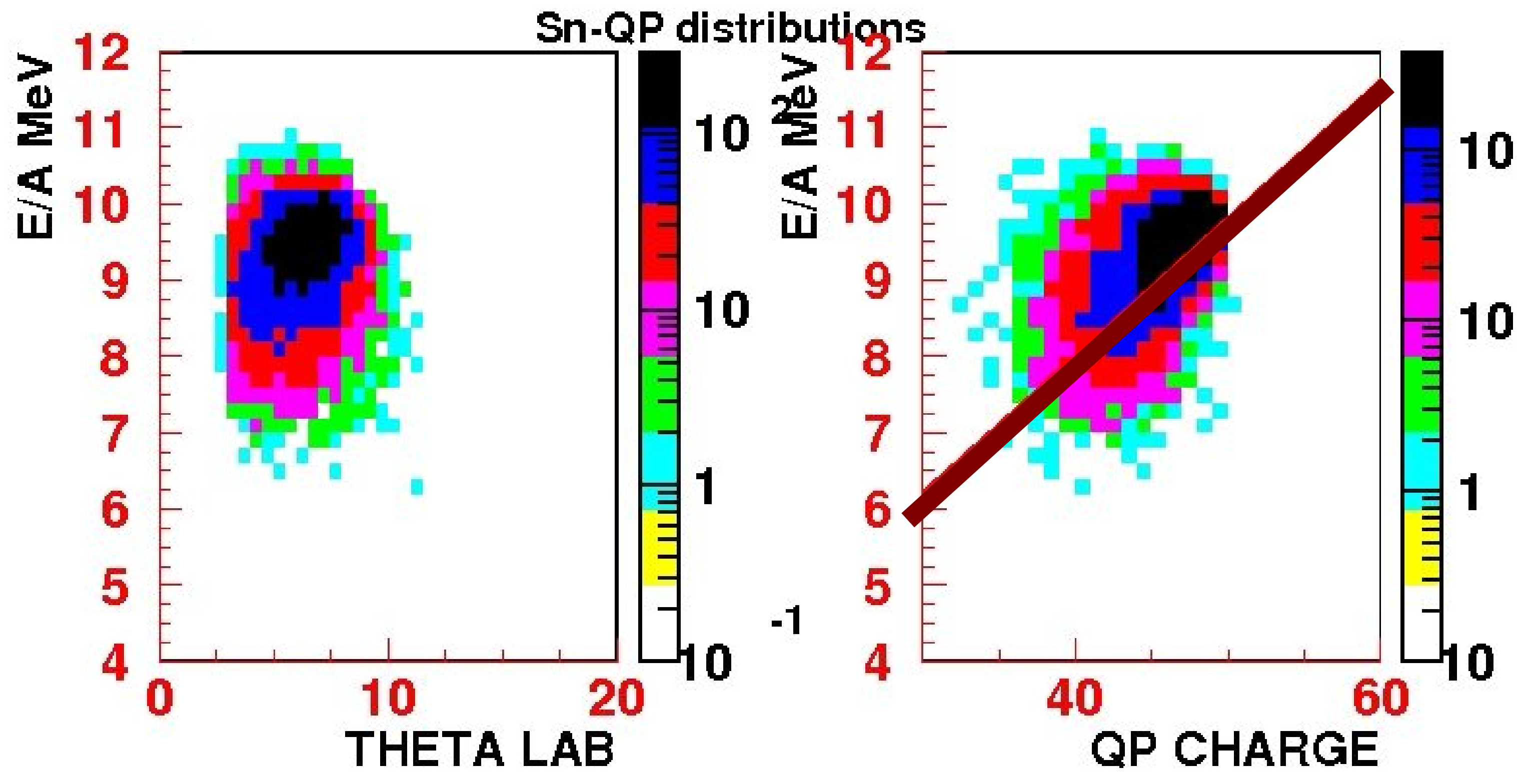
FAZIA plans: talk by Remi Bougault (LEA)

# Simulated events $^{132}Sn+^{58}Ni$ 10.5AMeV

FAZIA 2016; **1180 detectors (?)**

Preliminary simulations of dissipative binary events

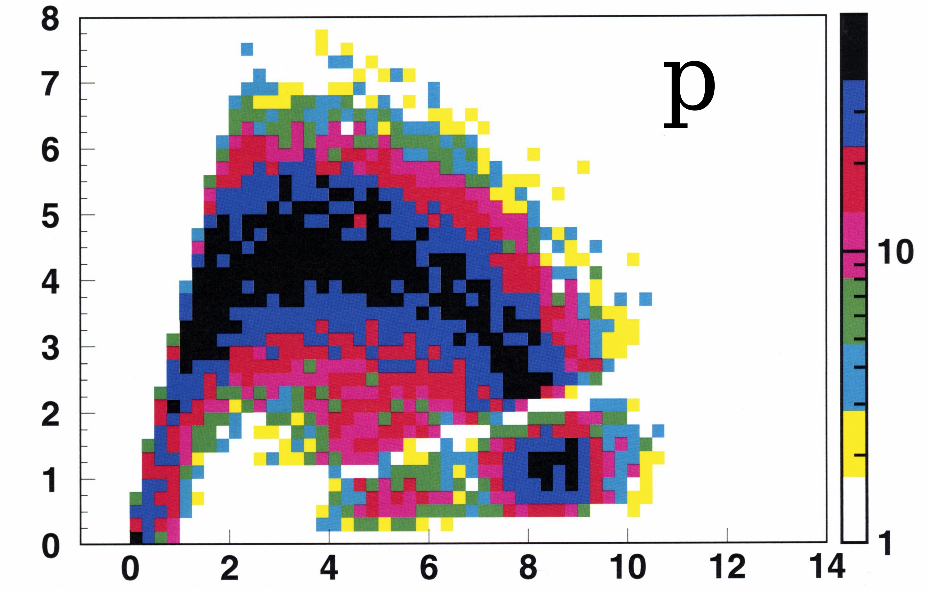
QP correlations ( in geometry)

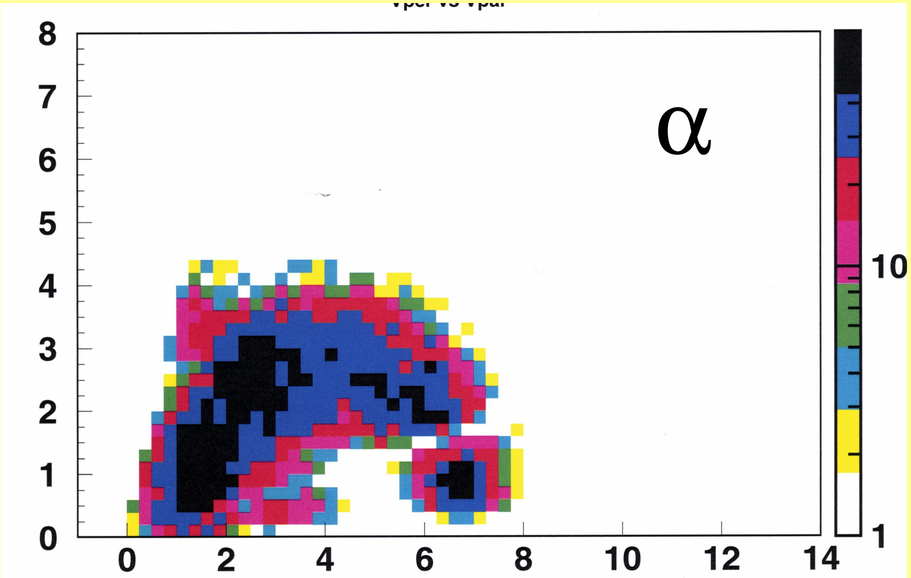



Z-identification thresholds partially affect the detection

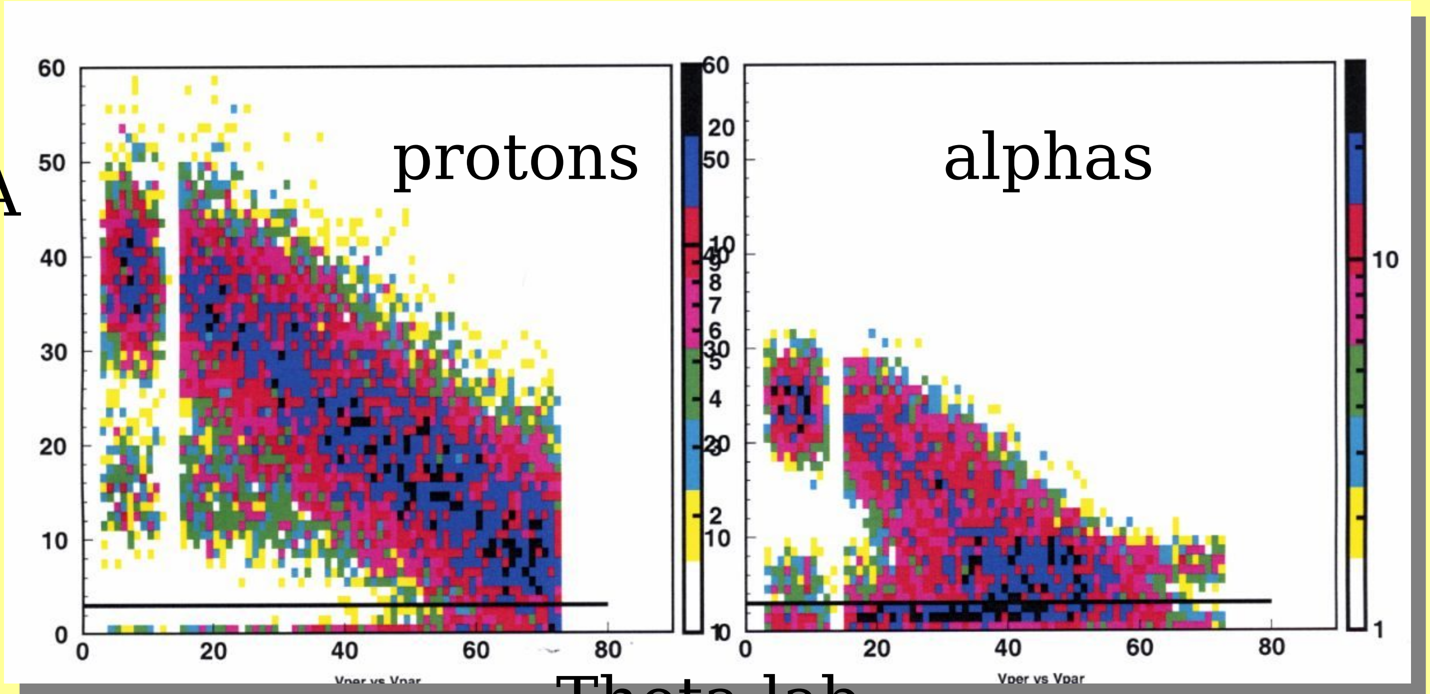
giovanni casini INFN Firenze

# Simulated events $^{132}Sn+^{58}Ni$ 10.5AMeV




E/A




Theta lab

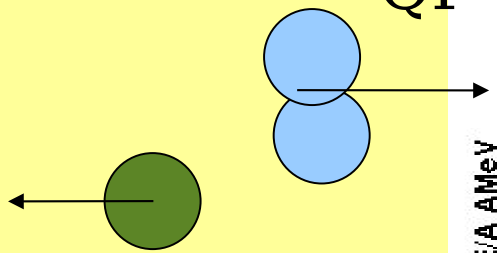
no relevant threshold effects introduced for light particles and fragments

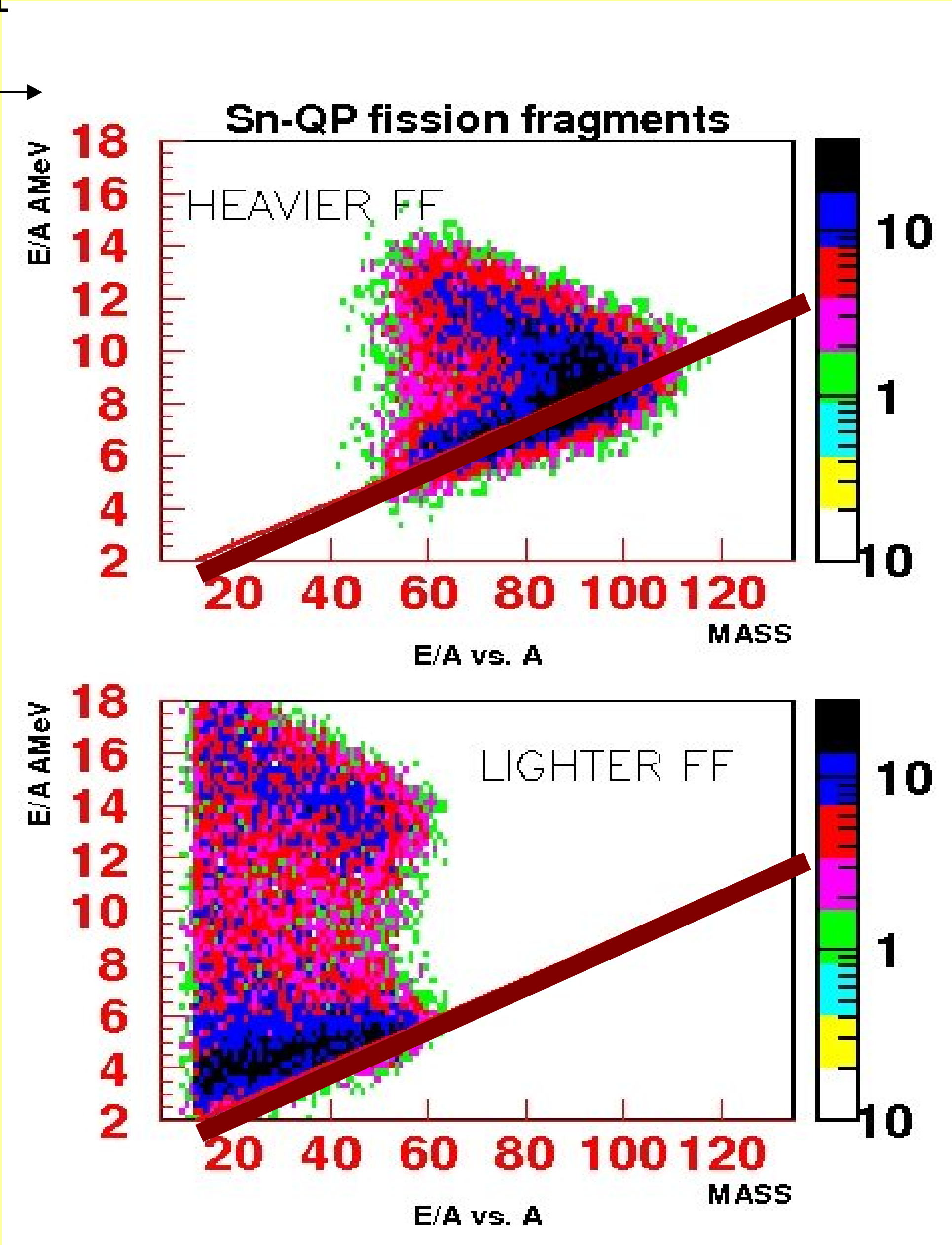
giovanni casini INFN Firenze

# Simulated events $^{132}Sn+^{58}Ni$ 10.5AMeV

SPES-2016 ?
FAZIA config.
**1180 detectors**

QP






## 3-body channel:
## the split of the QP

-uniform angular distribution
-wide mass asymmetry distr.
-Viola systematics for FF rel.velocity
- probability increasing with decreasing imp.parameter

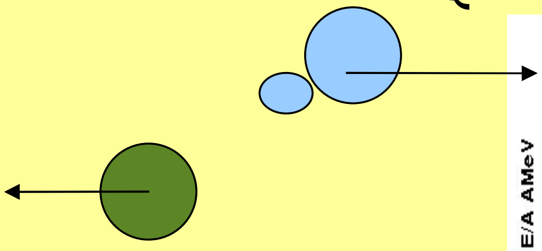
good Z-identification of F.F.

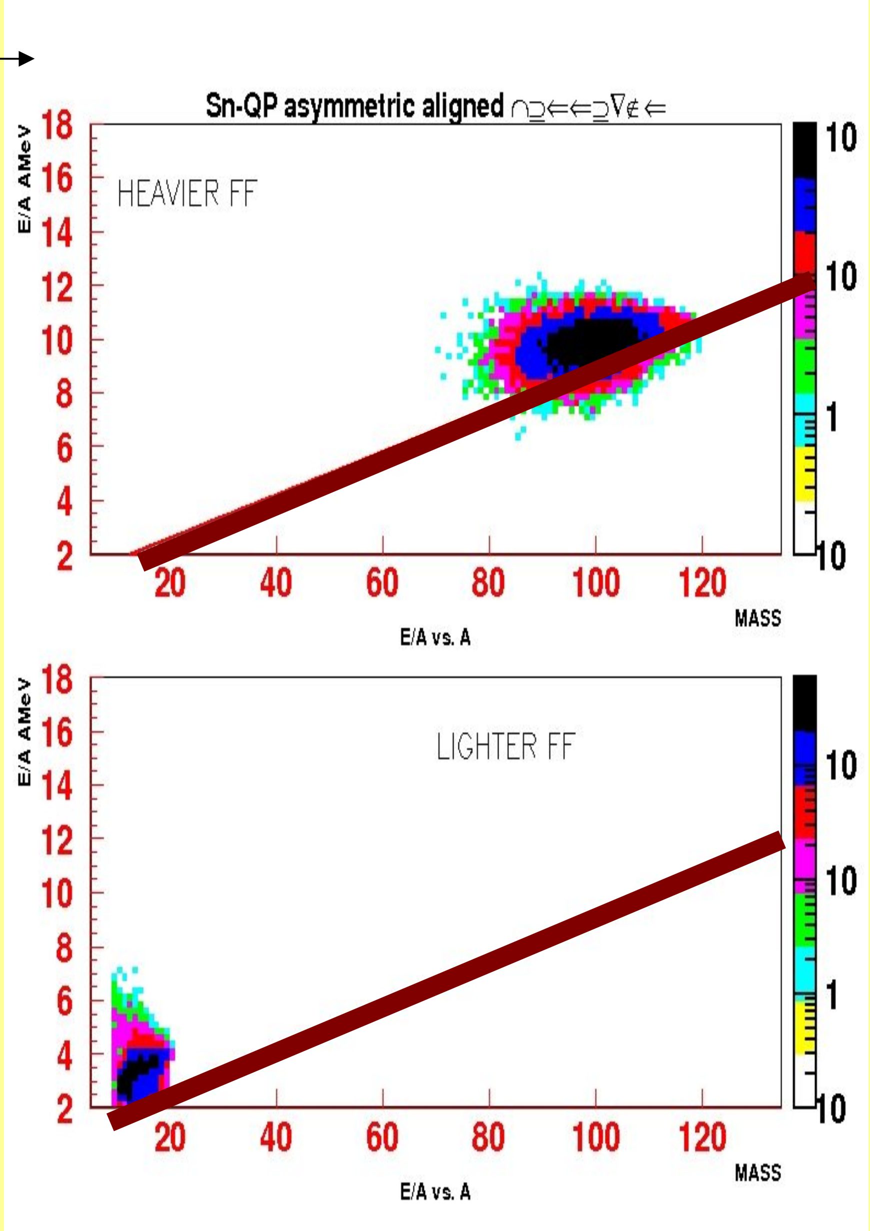
giovanni casini INFN Firenze

# Simulated events $^{132}Sn+^{58}Ni$ 10.5AMeV

QP

SPES-2016 ?
FAZIA config.
**1180 detectors**






**3-body channel: the split of the QP**
-"aligned" angular distribution
-only large mass asymmetry distr.
-Viola systematics for FF rel.velocity
- probability increasing with decreasing imp.parameter

good Z-identification of F.F.

# Estimate of rate and experiment duration (based on $^{132}Sn+^{58}Ni$ 10.5AMeV)

SPES-2016 FAZIA config. **1180 detectors**

**Beam current: $^{132}Sn$ $3*10^7$ pps**
**target thickness: 0.5 mg/cm2**
**Reaction Xsection 3.2 barn; DIC Xsection 2.2 barn**
**DIC total rate: a bout 300 Hz**

## 2-body channel:

**MC estimated eff. for QP & M>=1 LCP: 20-30%**
**Request: $10^7$ dissipative events for the most central impact parameters ($b/b_{gr}<0.5$)**
**Rate for wanted events 15-23Hz --> about 5-8days**
**(this gives 63 million implanted elastic-Sn on the 3deg forward Telescope, 91Hz elastic rate)**

## 3-body channel (the split of the QP)

**MC estimated eff. for (FF1& FF2 & M>=1 LCP): 10%**
**3body probab. assumed to be 20% of DIC**
**Request: the previous $10^7$ binary events**
**Rate for 3-body events 6Hz --> 4 million 3body events in 8 days**

# IT SEEMS FEASIBLE at !

giovanni casini INFN Firenze