Recent results of the ISOFAZIA experiment

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ISOFAZIA

- **ISOFAZIA** was the first physics experiment performed by the FAZIA Collaboration after the R&D phase (June 2015, INFN – LNS Catania)
- **Systems:** ^{80}Kr+^{40,48}Ca @ 35AMeV (N/Z_{proj}=1.22 N/Z_{40Ca}=1.00 N/Z_{48Ca}=1.40)

Almost all the presented results concern the n-rich system **^{80}Kr+^{48}Ca**, where the collected statistics is significantly higher and the beam quality was better

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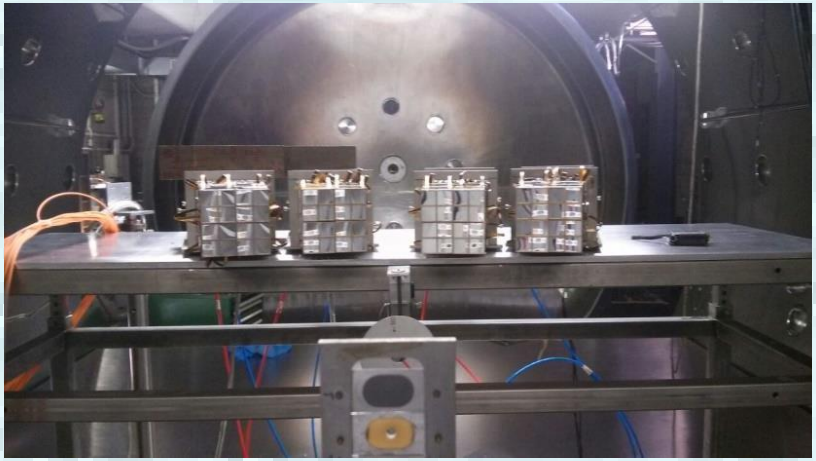
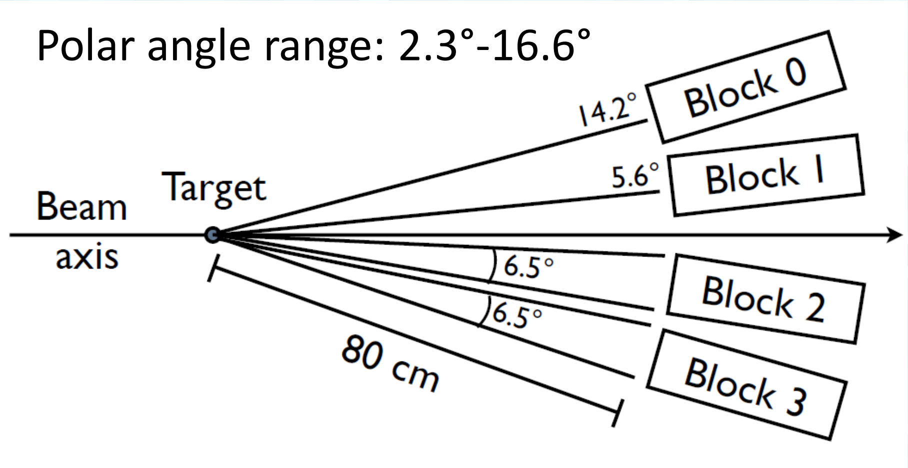
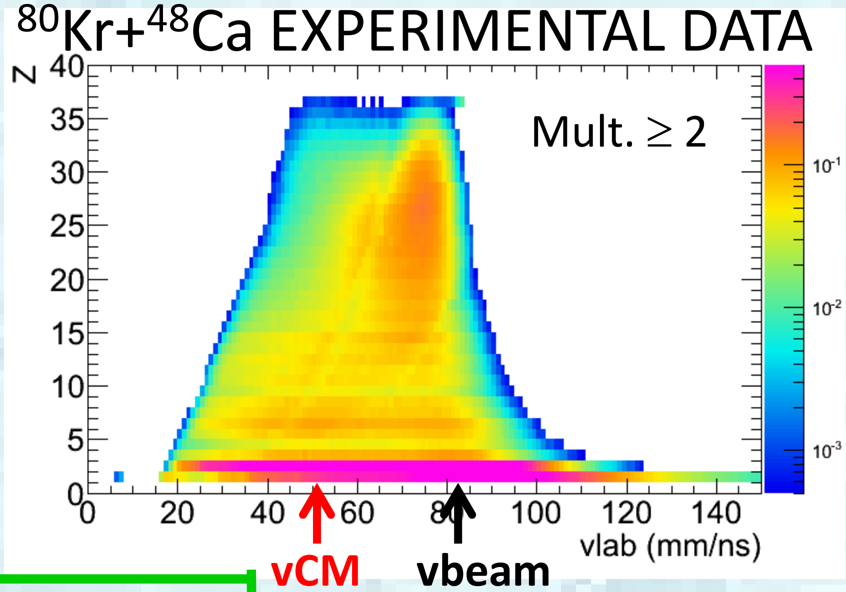
- **Goals:**
  - Study of the isospin transport phenomena and comparison with transport models (in particular AMD by A.Ono) to gain information on the symmetry energy term of the EOS
  - Study of the QP fission (A and Z of both fission fragments) to investigate the time scale of the process
- **Setup:** 4 complete blocks (64 detectors) in belt configuration

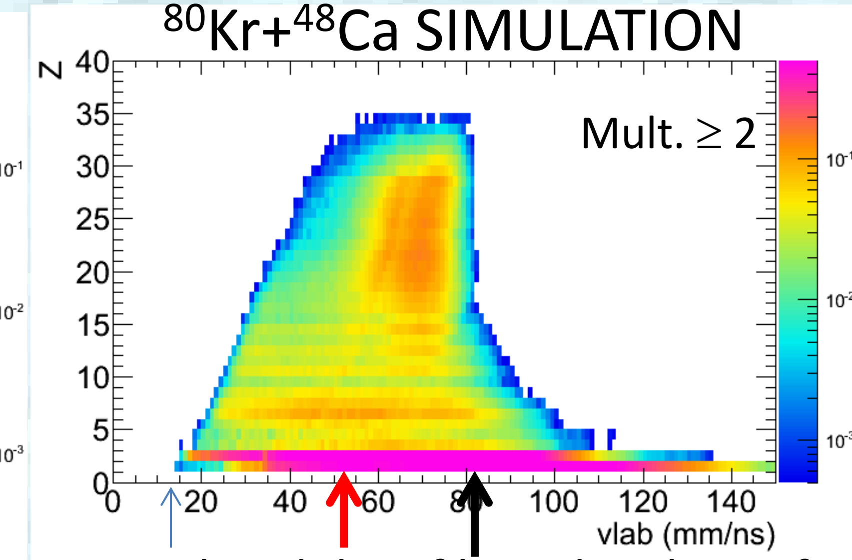




- The data analysis was the subject of the PhD Thesis of G. Pastore (Univ. di Firenze, 2017)

Overview of the events





Simulated data filtered with a software replica of the setup

Simulation:

AMD (Antisymmetrized Molecular Dynamics) A.Ono, PRL 68 (1992) 2898.

Stiff ($E_{sym}(\rho_0)$=32, L=108) and **Soft** ($E_{sym}(\rho_0)$ =32, L=46) parametrizations

in-medium NN cross section $\sigma = y\rho^{-2/3}\tanh(\frac{\sigma_{free}}{y\rho^{-\frac{2}{3}}})$ with y=0.85 Coupland, PRC84(2011)054603

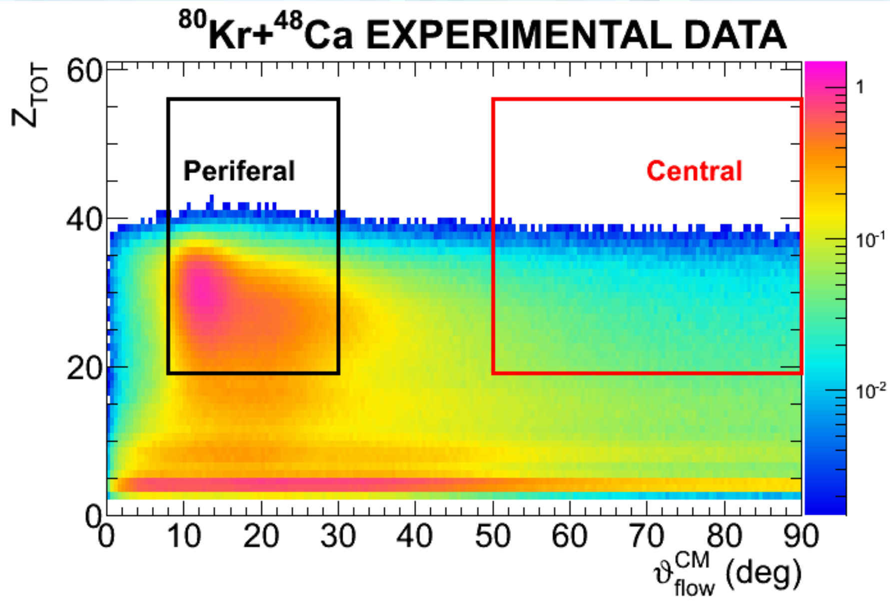
Dynamical calculation stopped at 500fm/c

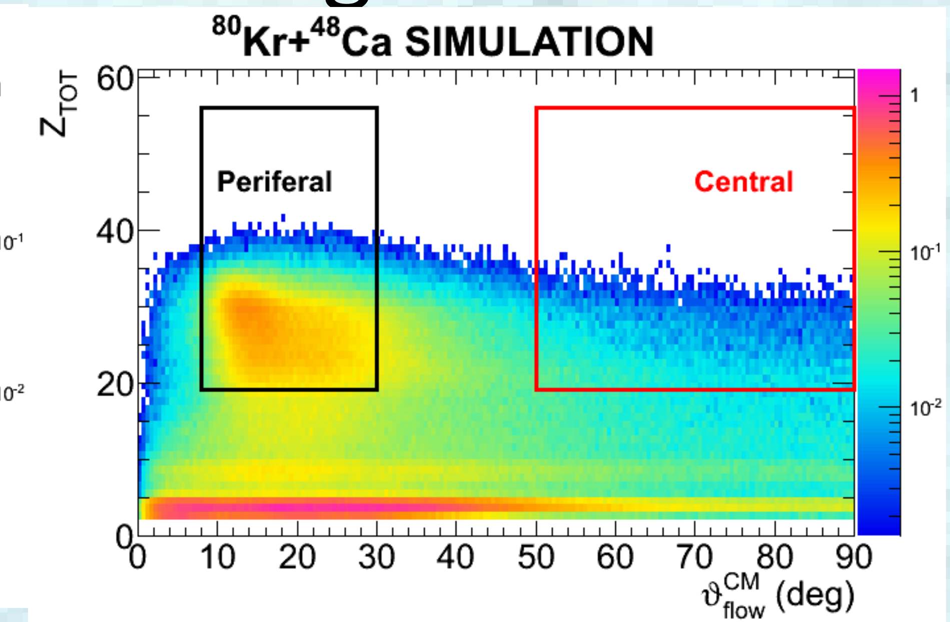
~60000 AMD events in the range 0-$b_{grazing}$

GEMINI++ used as afterburner (1000 secondary events for each primary one)

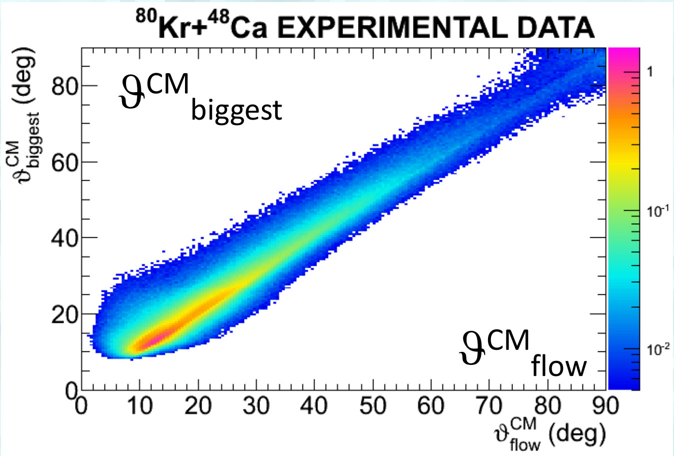
The experimental correlation is qualitatively well reproduced by the simulation

Event sorting





$\vartheta_{flow}{}^{CM}$ built including all the ejectiles



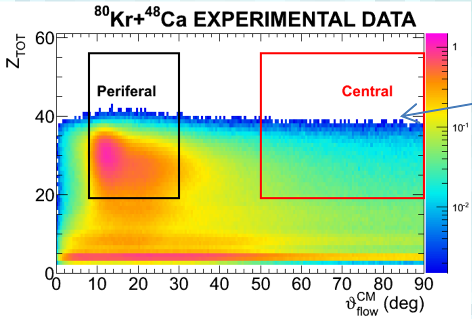
$\vartheta_{flow}{}^{CM} \sim \vartheta_{biggest}{}^{CM}$ due to the low average multiplicity (2.6 for ^{80}Kr+^{48}Ca excluding mult=1) caused by the small angular coverage (10msr for each block)

Two main selections:

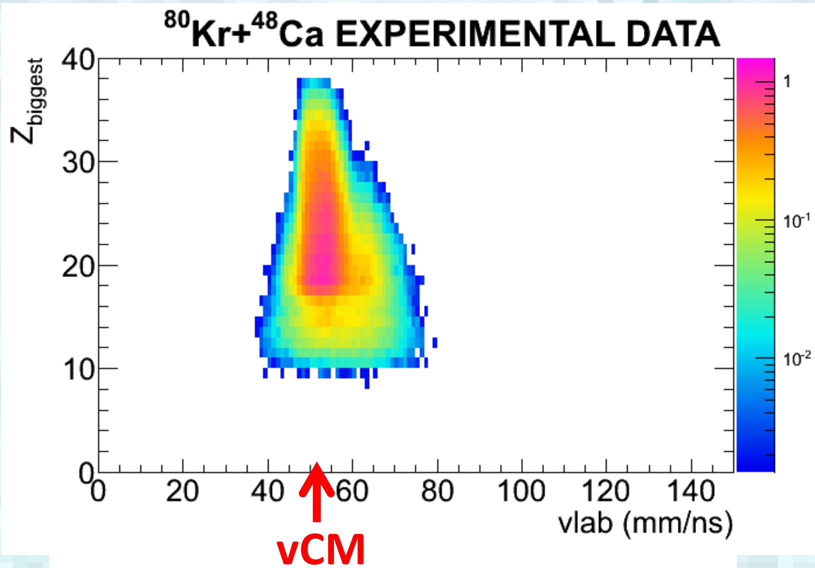
- **"Central" collisions** (multifragmentation or incomplete fusion)
- **Peripheral collisions** (DIC with detection of QP and QT or of the QP only; QP fission)

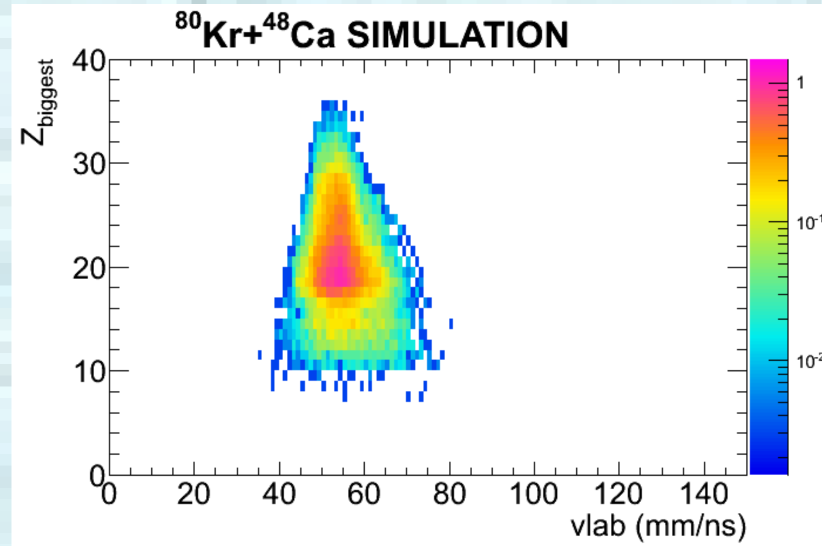
The topology of the events belonging to the two selections has been checked by means of the simulation

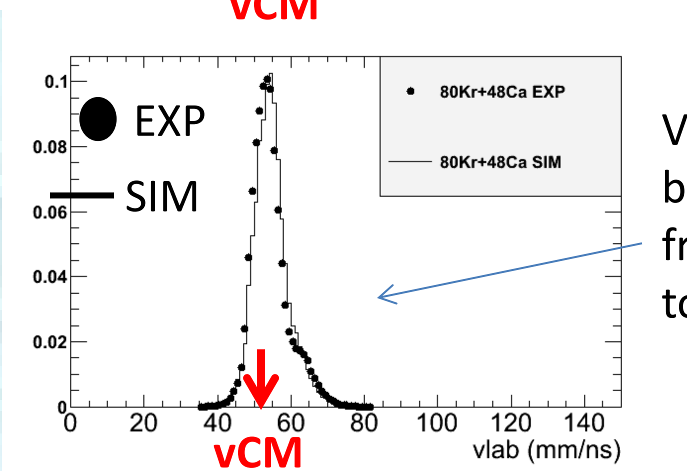
"Central" collisions



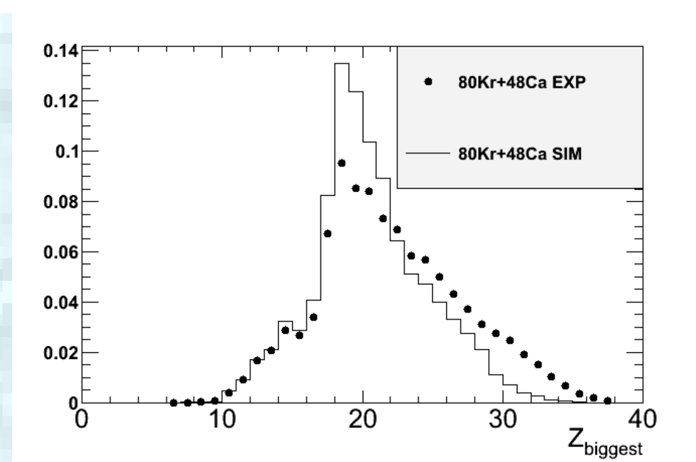
Angular coverage of the setup too small to investigate in a productive way this class of events.
Anyway the simulation reproduces in a reasonable way the observed properties of the biggest fragment





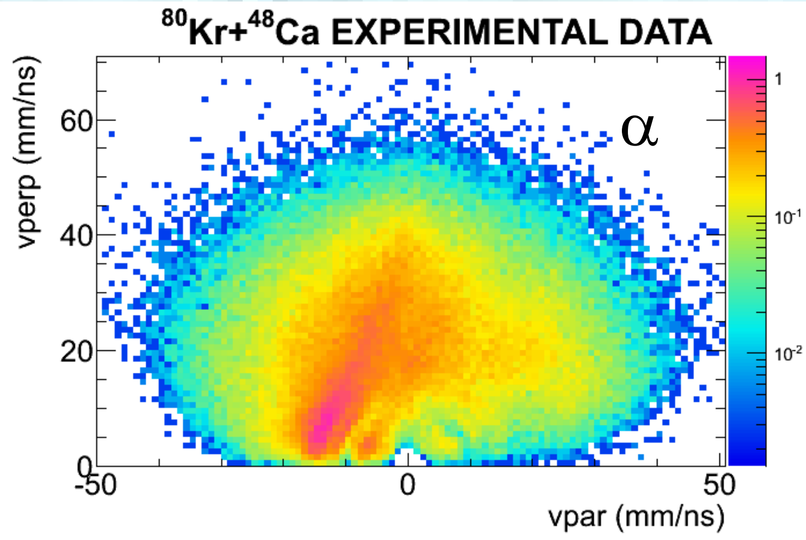


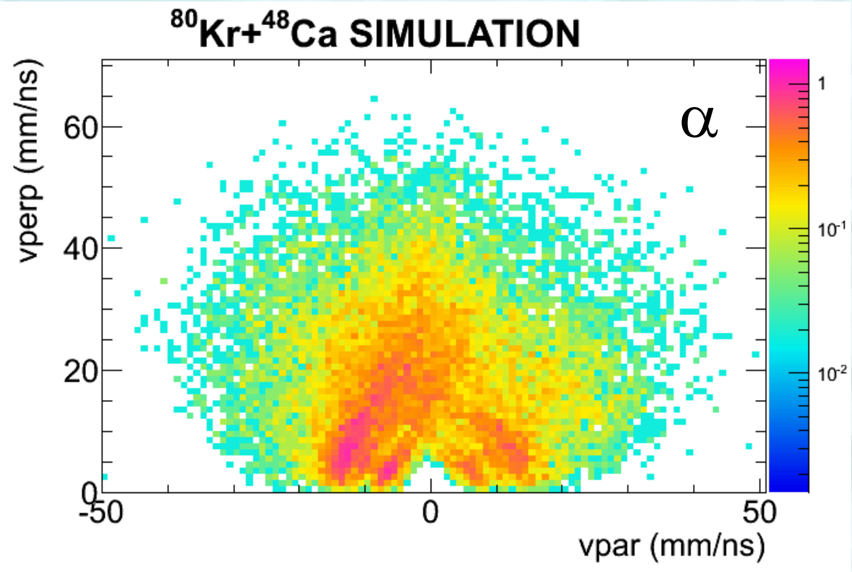
Velocity of the biggest fragment close to the CM



"Central" collisions

The emission pattern of LCP is compatible with a central source





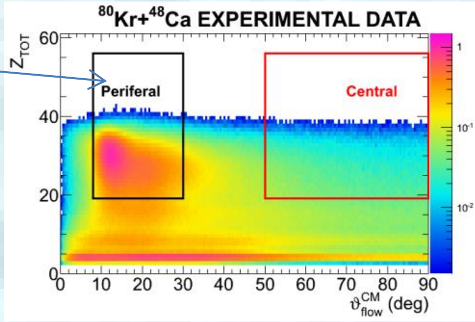
According to the model, these events correspond to

- **Central multifragmentation** events in which only few ejectiles have been detected
- **Incomplete fusion** events with a big deformed fragment at the end of the dynamical phase (see also B.Faure-Ramstein et al., NPA 586(1995) 533 and F.Auger et al., PRC 35 (1987) 190 for evidence of incomplete fusion in similar systems)

The model slightly underestimates the fraction of "central" events with respect to the total detected events for ^{80}Kr+^{48}Ca:
Exp 14%   Sim~12%

From the presented results we can conclude that the model reproduces in a reasonable way this class of events

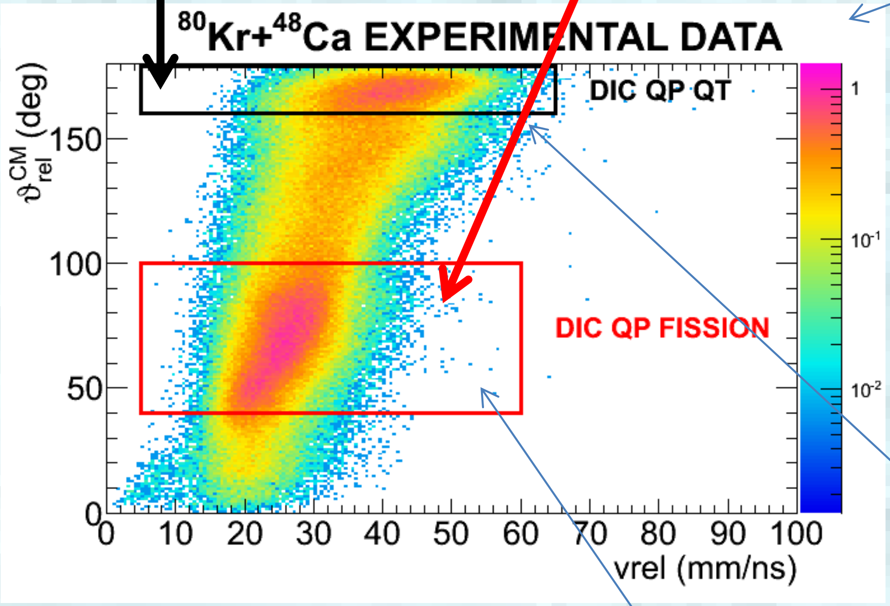
Peripheral collisions

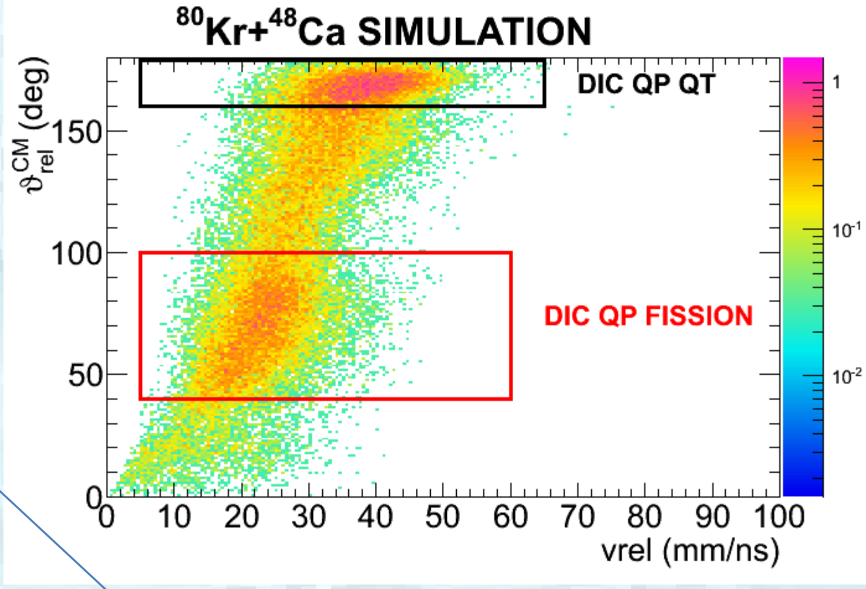


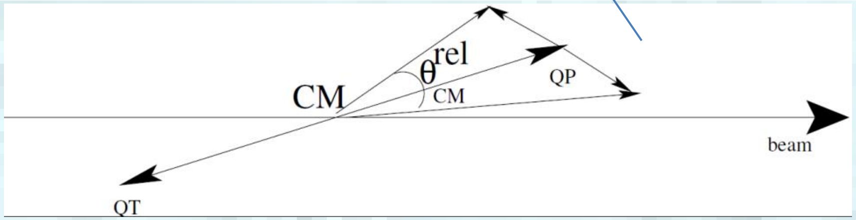
Fragment: $Z \geq 5$

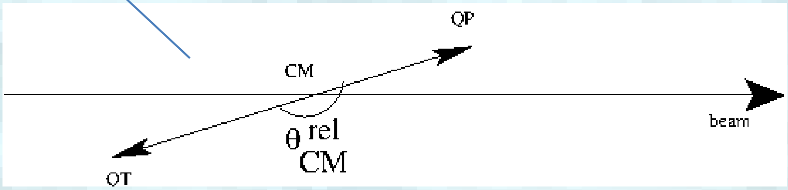
- **DIC with 1 detected fragment :**
  - **QP** (if Z_{frag} >18 && $v_{frag}{}^{CM}{}_z$>0)
- **DIC with 2 detected fragments:**
  - **QP and QT** ($v_{QP}{}^{CM}{}_z$>0 &&Z_{QP}>18)
  - **QP fission fragments** (Z_1 +Z_2>18 &&$v_{cm\text{-}couple}{}^{CM}$>0)

Selection from $\vartheta^{CM}{}_{rel}$ vs. v_{rel}



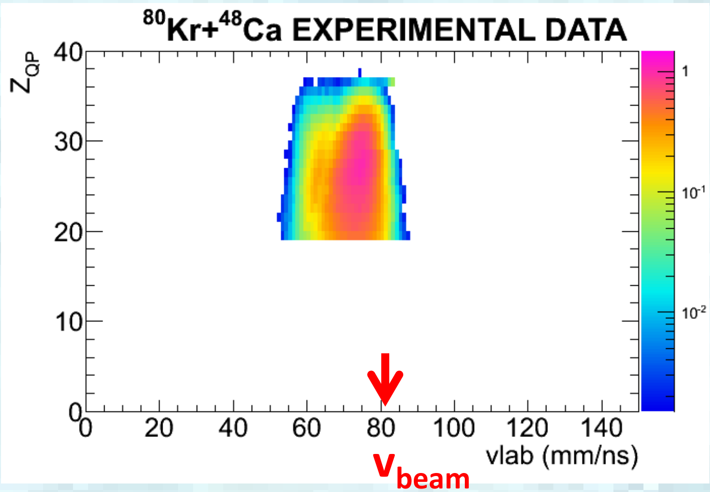


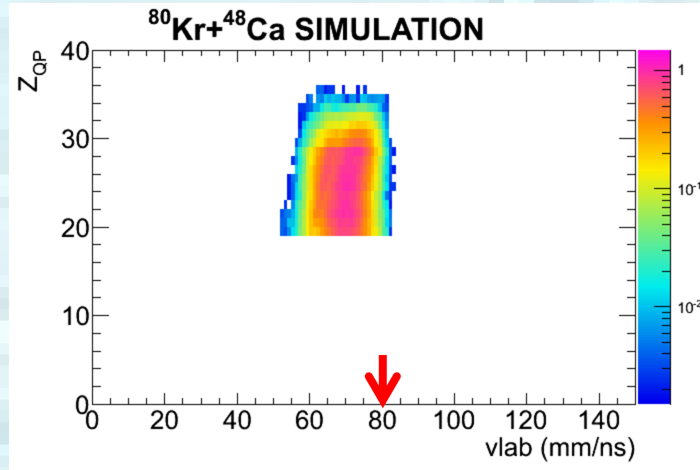


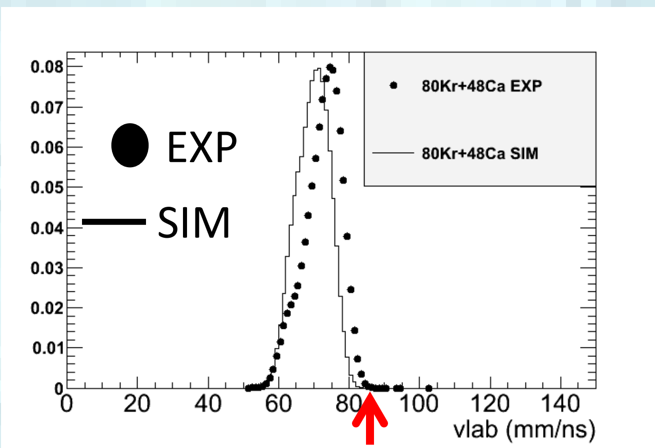


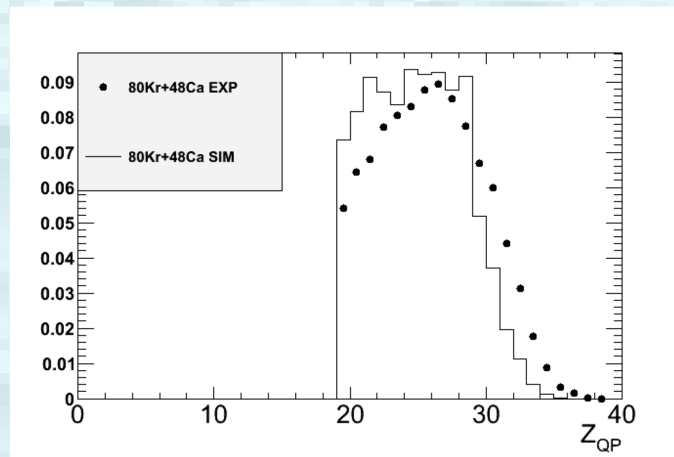
QP

88% of DIC-type events





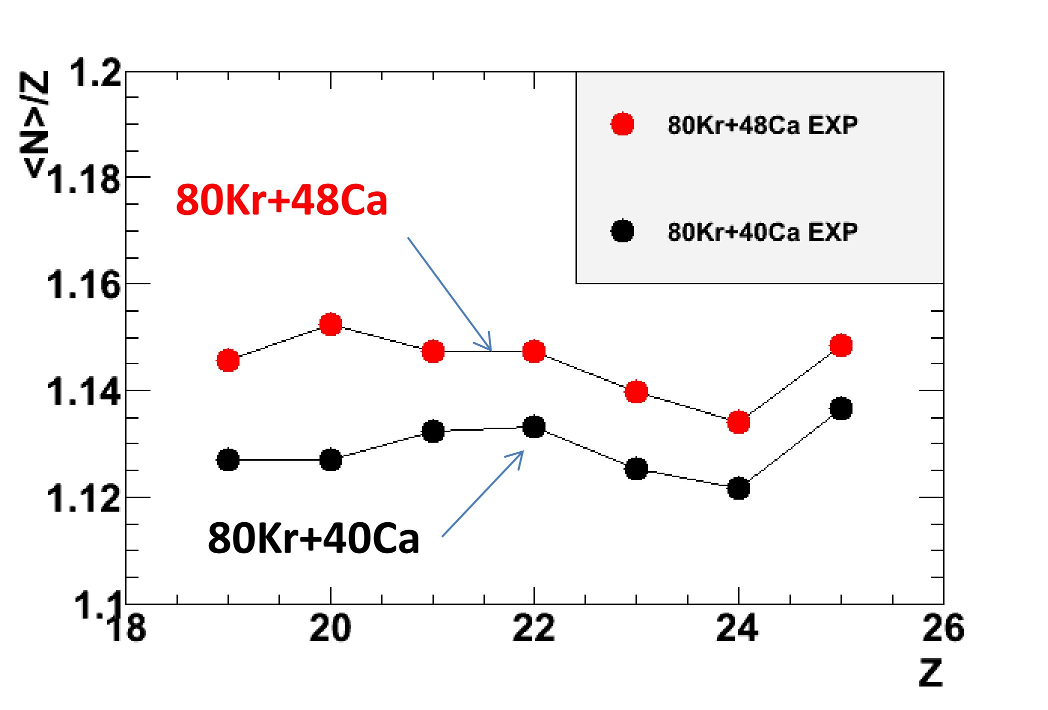




Slight mismatch between data and model for charge and velocity distributions.
Data seem less dissipative than model prediction.
Despite this fact, the agreement between data and model is still reasonable

Evidence of ISOSPIN diffusion

<N>/Z of the QP as a function of its charge (in the region in which there is isotopic resolution, i.e. up to Z=25 thanks to the excellent isotopic resolution of FAZIA) changing the target



<N>/Z of the QP is sistematically higher when the target is the n-rich ^{48}Ca

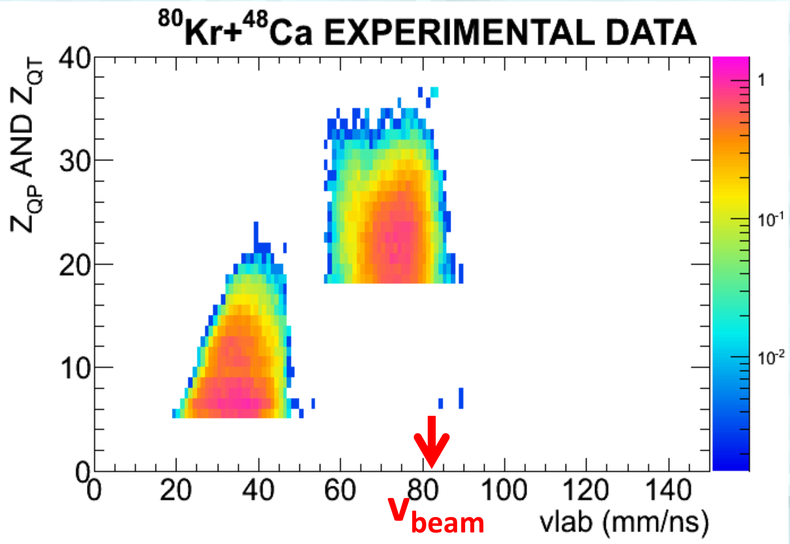
N/Z_{80Kr}=1.22 PROJECTILE

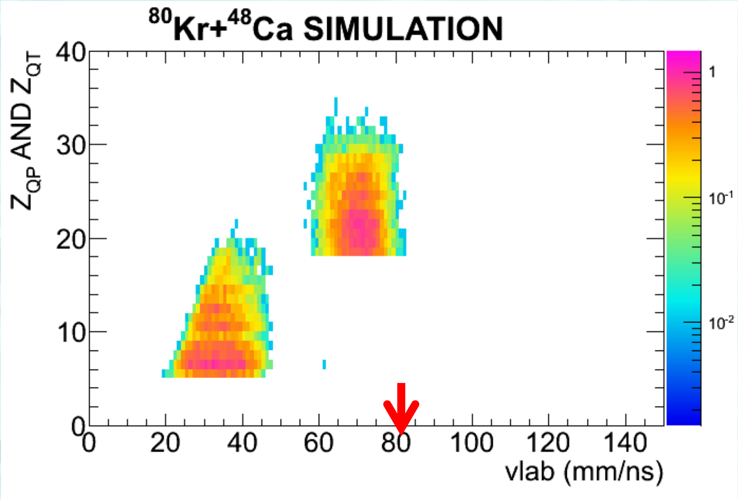
N/Z_{40Ca}=1.00 n-poor TARGET

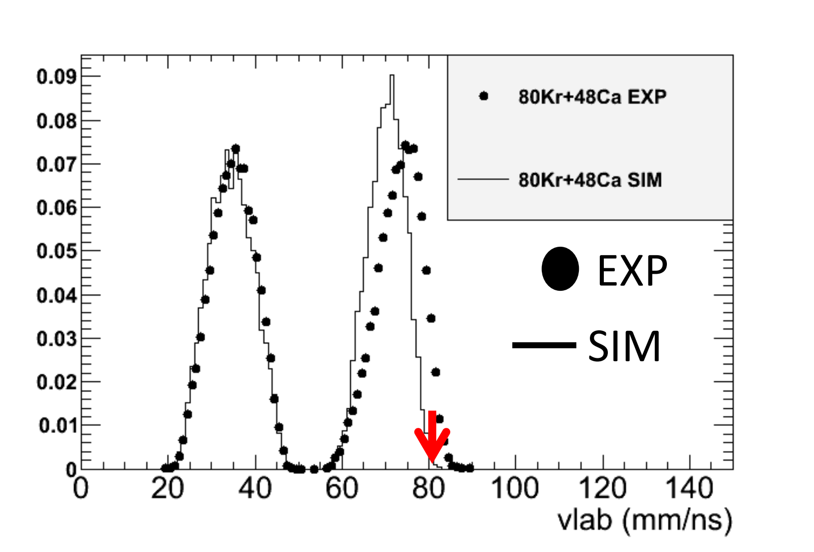
N/Z_{48Ca}=1.40 n-rich TARGET

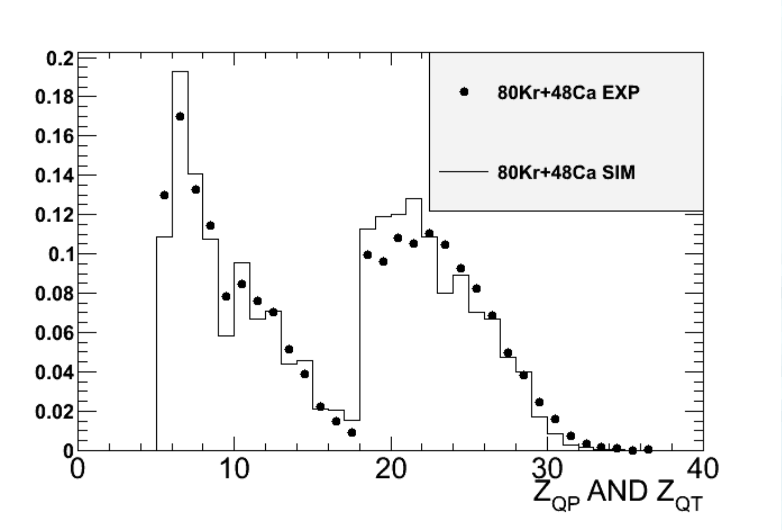
The <N>/Z of the QP depends on the isospin of the target

QP – QT







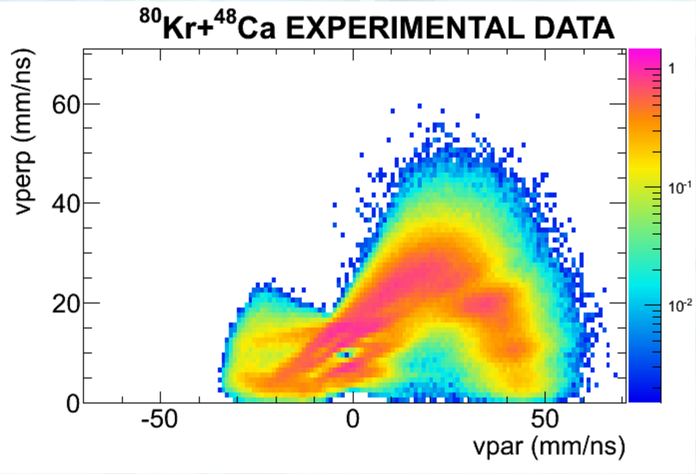


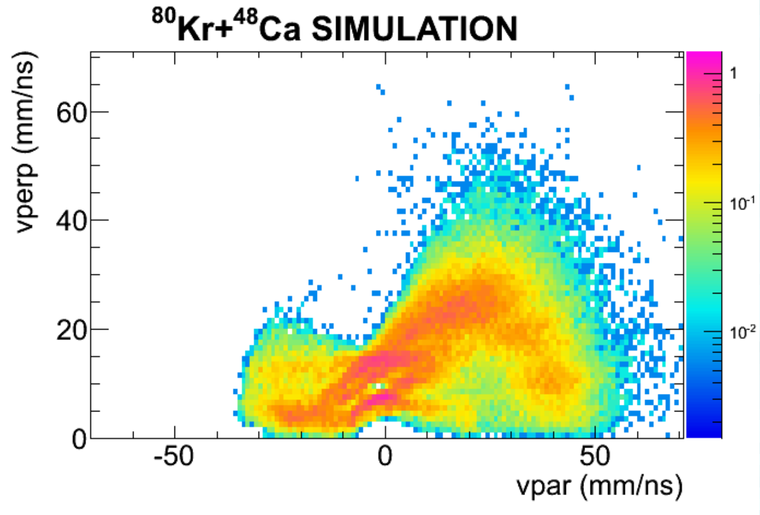
Reasonable reproduction of the data

3% of DIC-type events

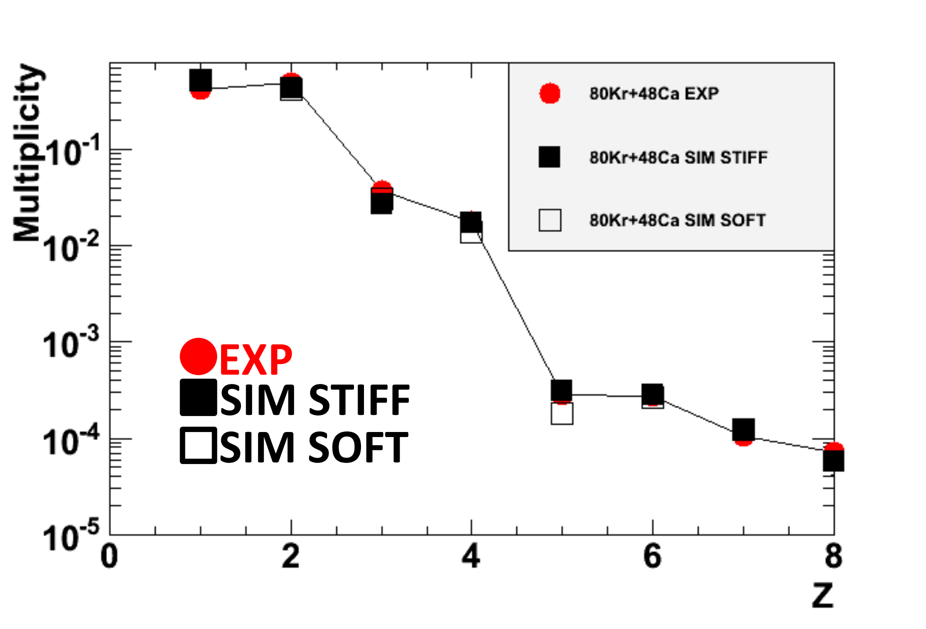
QP && QP-QT

The pattern of the α detected in coincidence is compatible with a two-source emission





LCP and IMF multiplicities are reasonably well reproduced by the model, with the possible exception of Z=1 (slightly overestimated) and Z=2 (slightly underestimated)



Since the simulation is able to reproduce the data in a reasonable way, we can use it to look for possible evidences of stiff or soft symmetry energy on isospin related observables

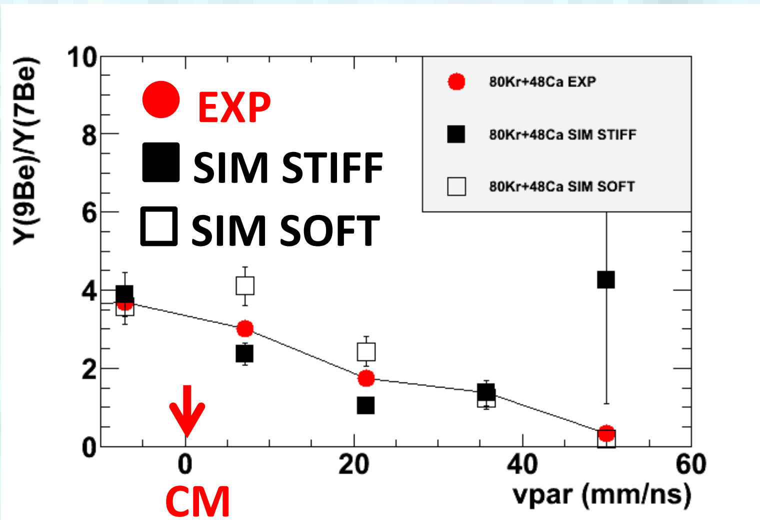
QP and QP+QT may be in coincidence with other light products

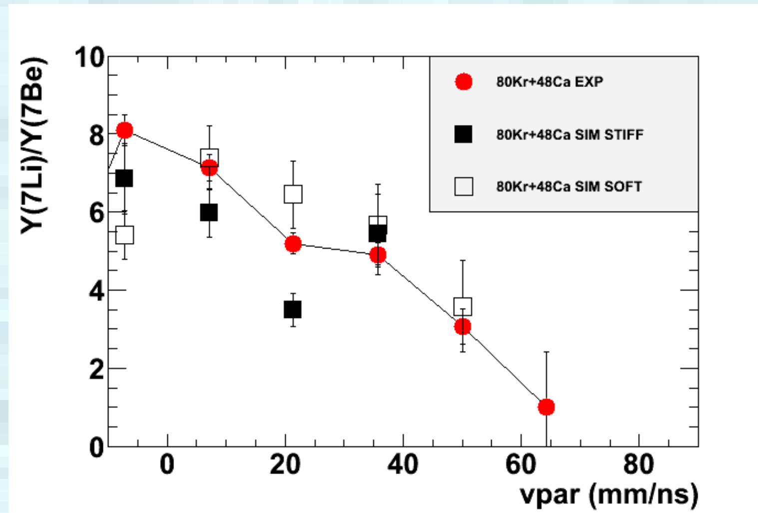
Isotopic and isobaric ratios vs. vpar

LCP's and IMF's in coincidence with QP or QP-QT

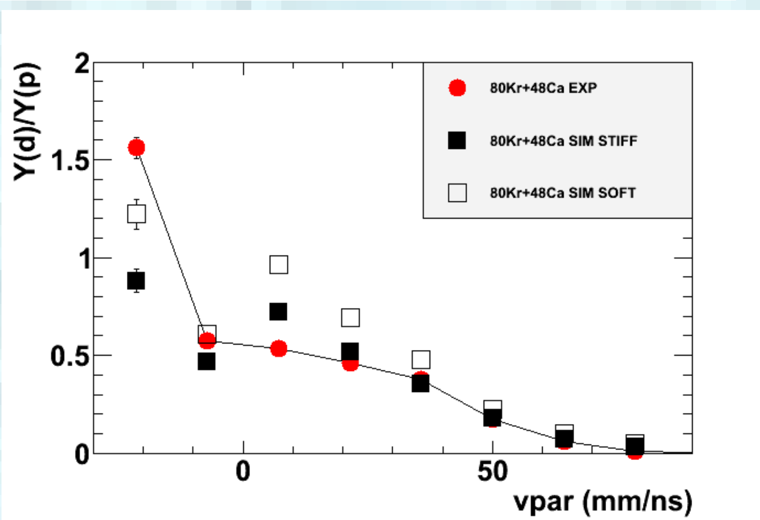
Neutron enrichment moving from the QP towards the neck region

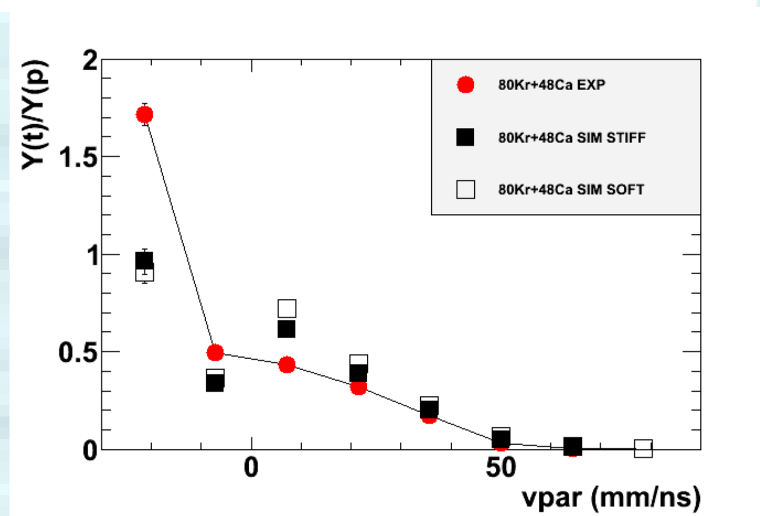
From LCP's weak indication of **stiff symmetry energy**; inconclusive results from IMF's



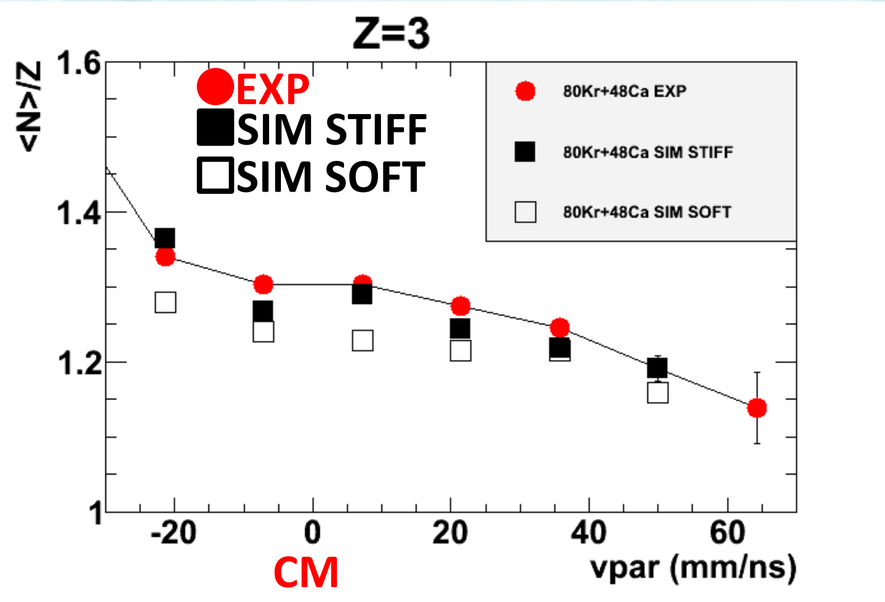


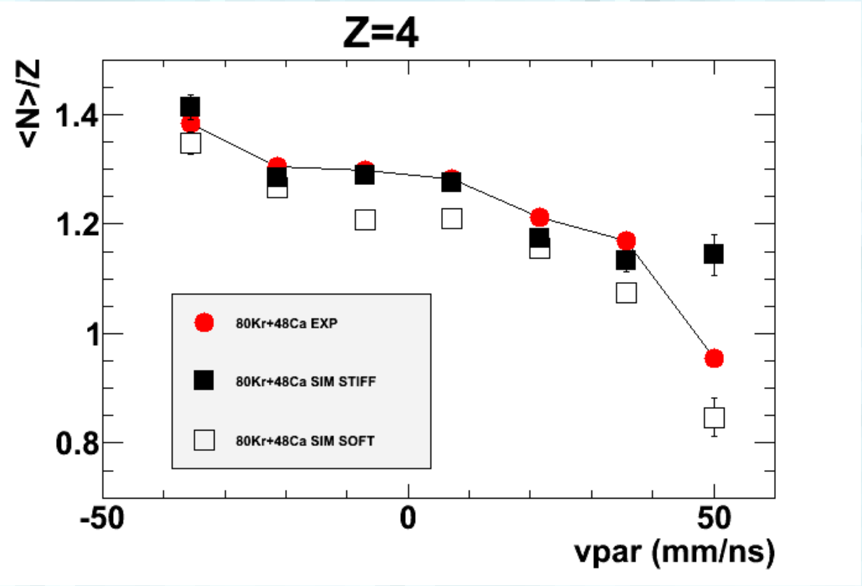
Component calculated with respect to the QP direction



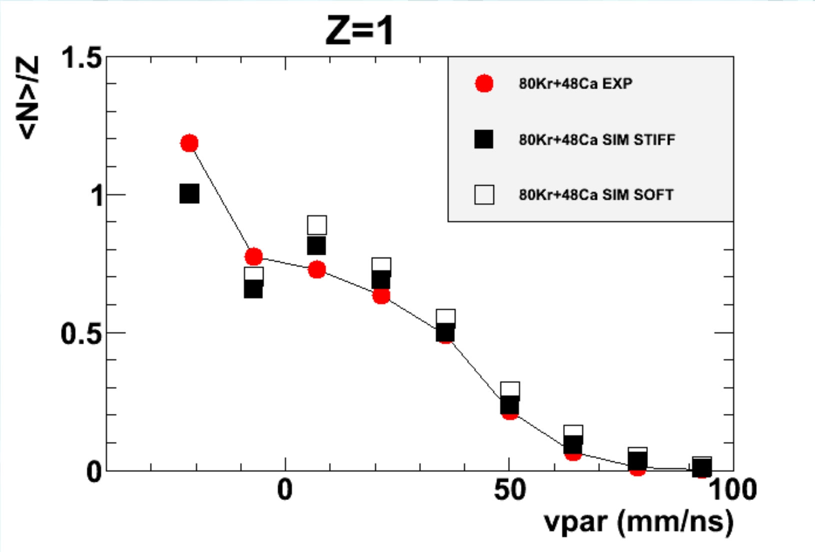


Isospin of LCP's and IMF's vs. vpar





Isospin enrichment in the neck region



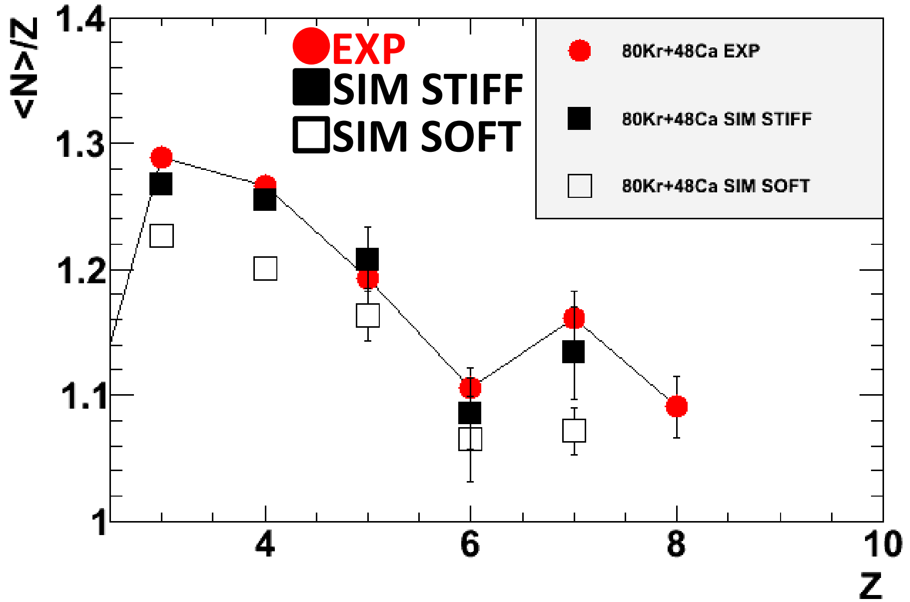
Weak indication of **stiff symmetry energy**

Isospin content of IMF's vs Z

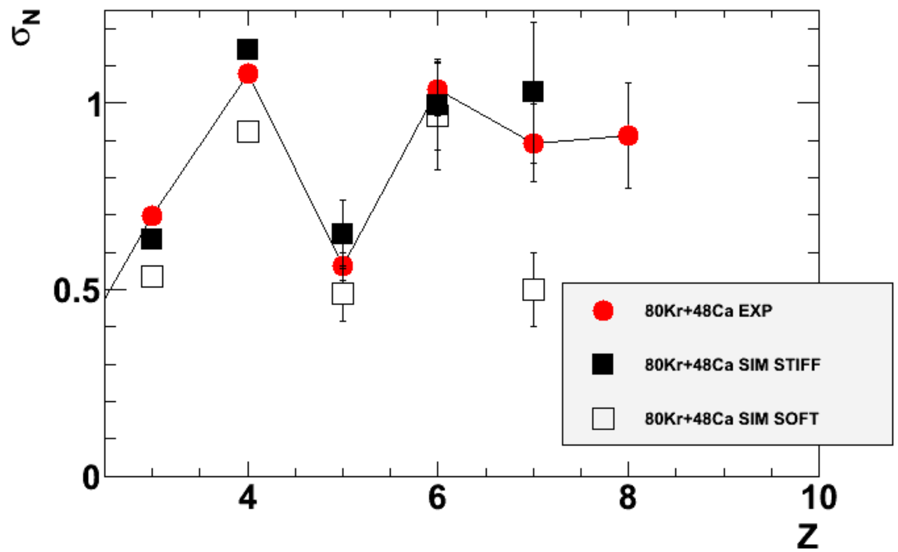
IMF's in coincidence with QP or QP-QT

Weak indication of **stiff symmetry energy**

First moment

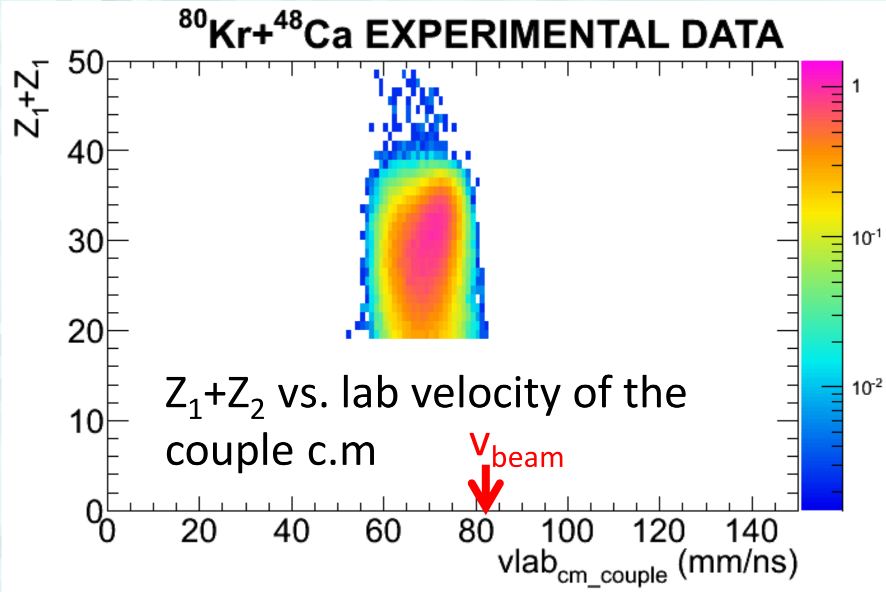


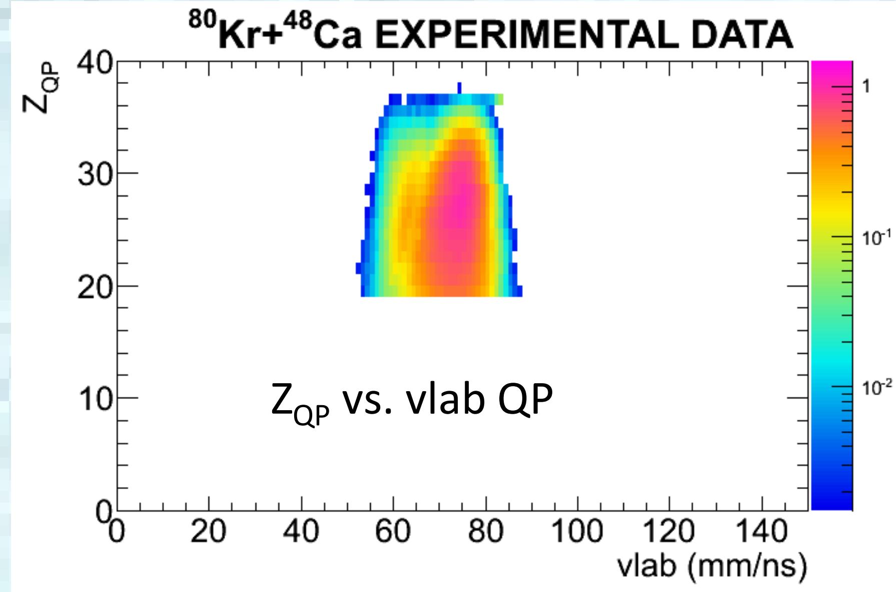
Second moment



See for example E.DeFilippo et al, PRC86(2012)014610 (comparison with SMF +GEMINI)

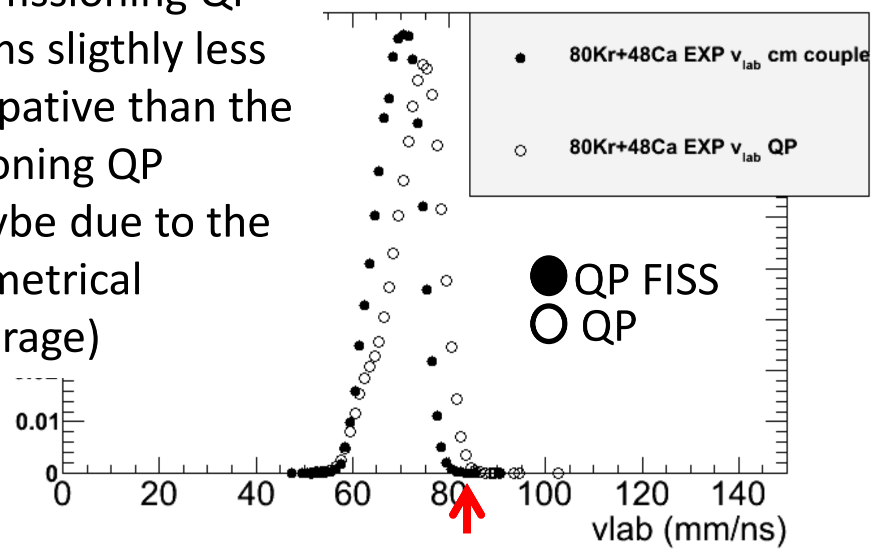
QP fission

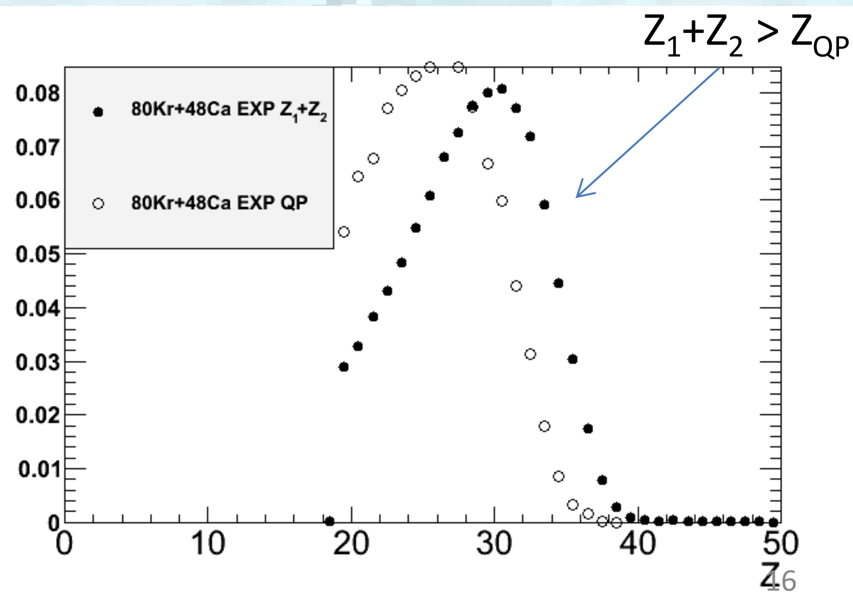




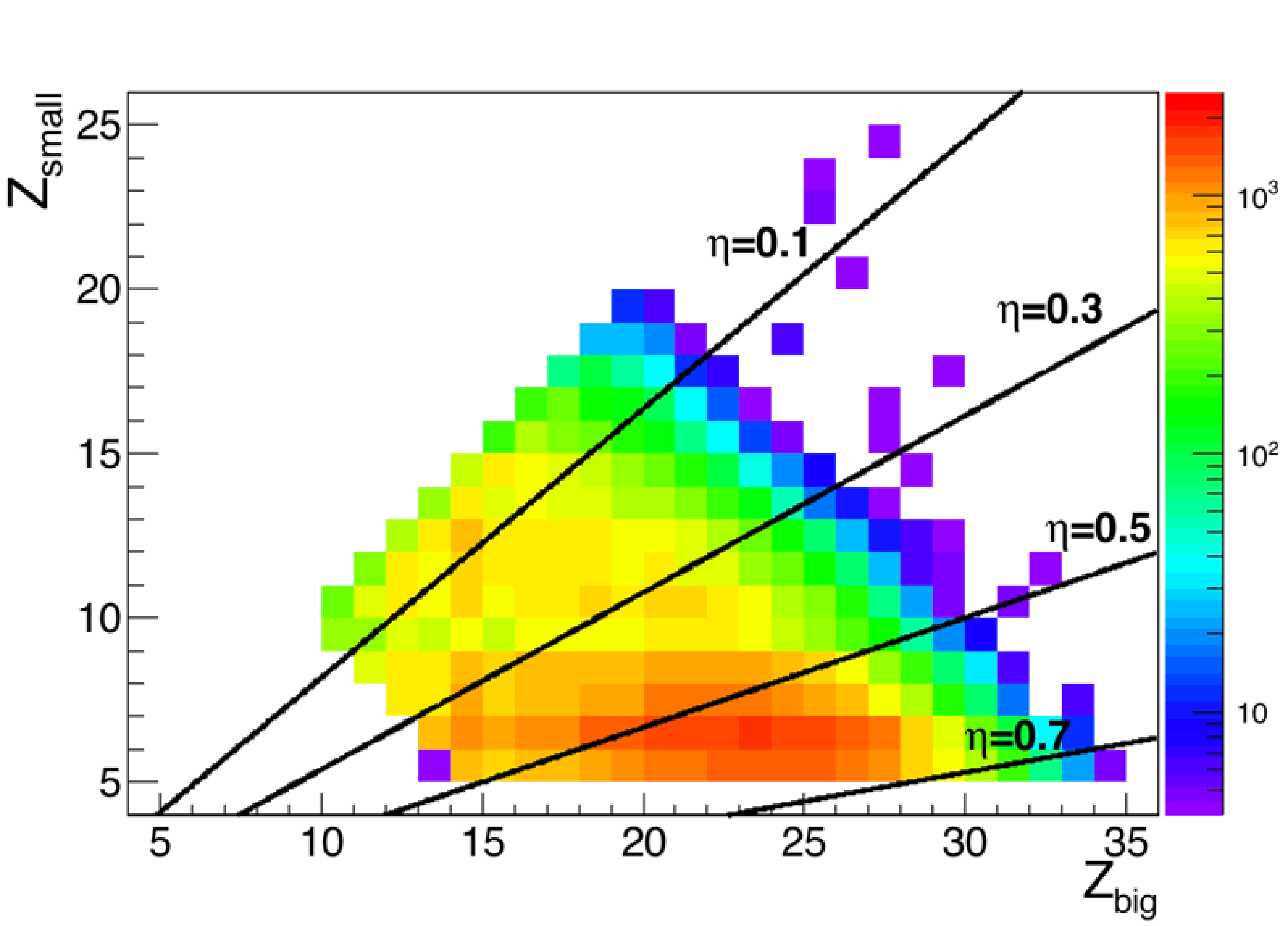
The obtained correlation is compatible with the supposed QP fission mechanism

Non fissioning QP seems sligthly less dissipative than the fissioning QP (maybe due to the geometrical coverage)





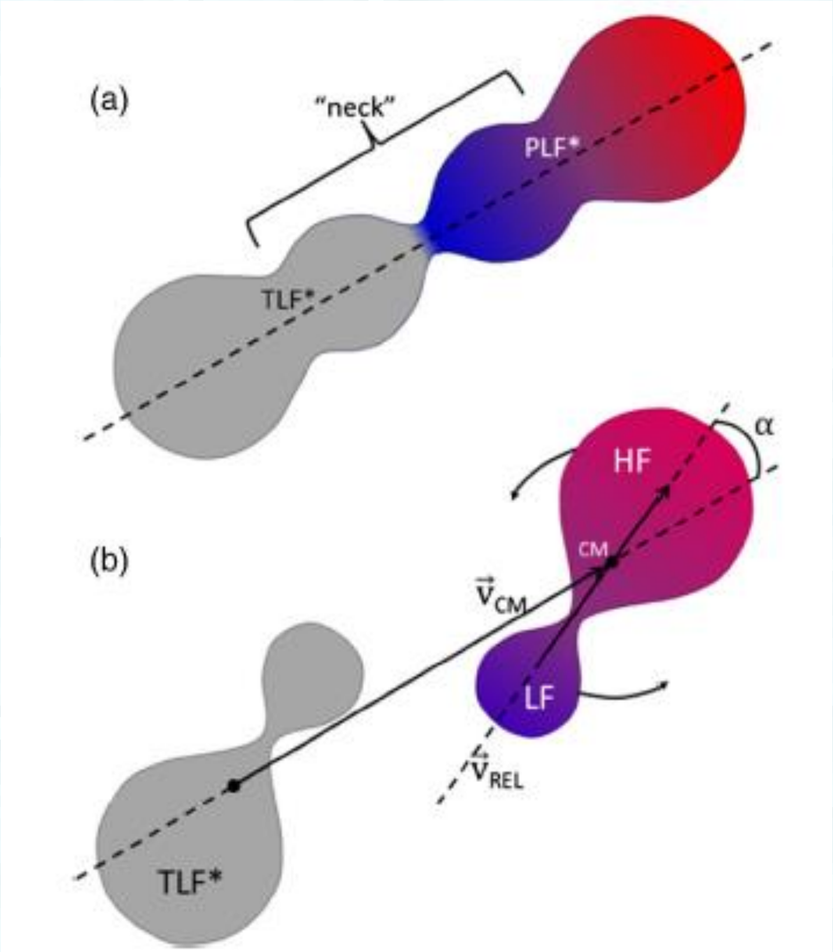
Charge correlation of the fission fragments



$$\eta = \frac{Z_{big} - Z_{small}}{Z_{big} + Z_{smal}}$$

Prevalence of asymmetric fissions in the experimental data set

Emission pattern of fission fragments



A.Jedele et al., PRL118(2017)062501

The smaller the α angle, the more aligned the reaction, with the smaller fragment emitted towards the QT (i.e. in the middle)

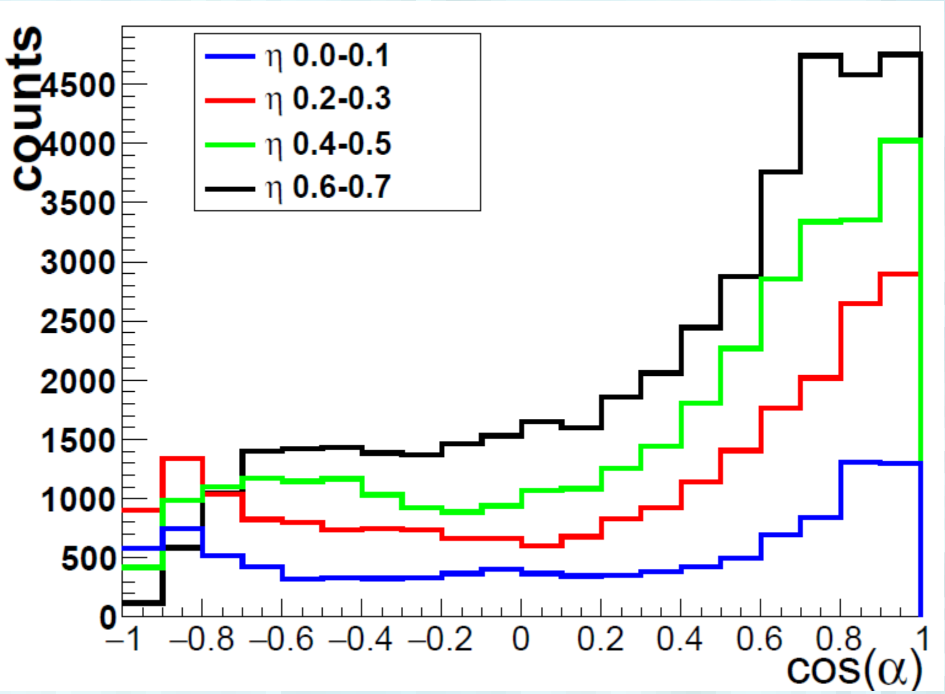
The more aligned the reaction, the faster the splitting (not enough time to have a big rotation of the splitting axis with respect to the QP-QT separation axis)

The smaller the α angle, the faster the splitting

If the splitting is very fast and if there is a n enrichment in the middle (neck region) with respect to the QP region (isospin drift), **the two fission fragments have not enough time to equilibrate the isospin**

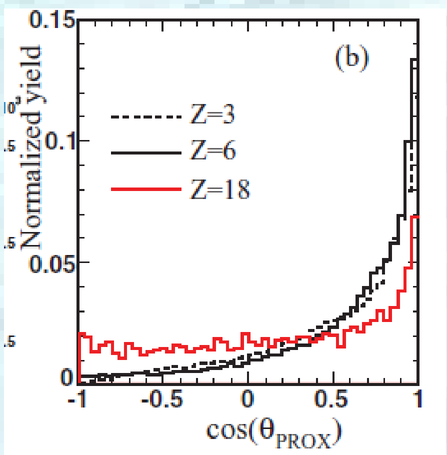
cos α DISTRIBUTION FOR DIFFERENT CHARGE ASYMMETRIES

$^{80}Kr+^{48}Ca$ EXP



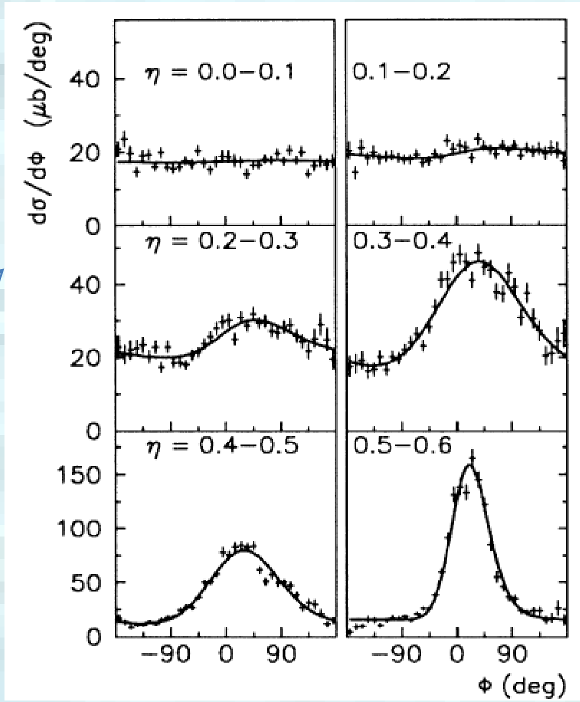
The more asymmetric the fission, the more aligned the emission => **the more asymmetric the fission, the faster the fission process**

See also E.DeFilippo et al., PRC86(2012)014610

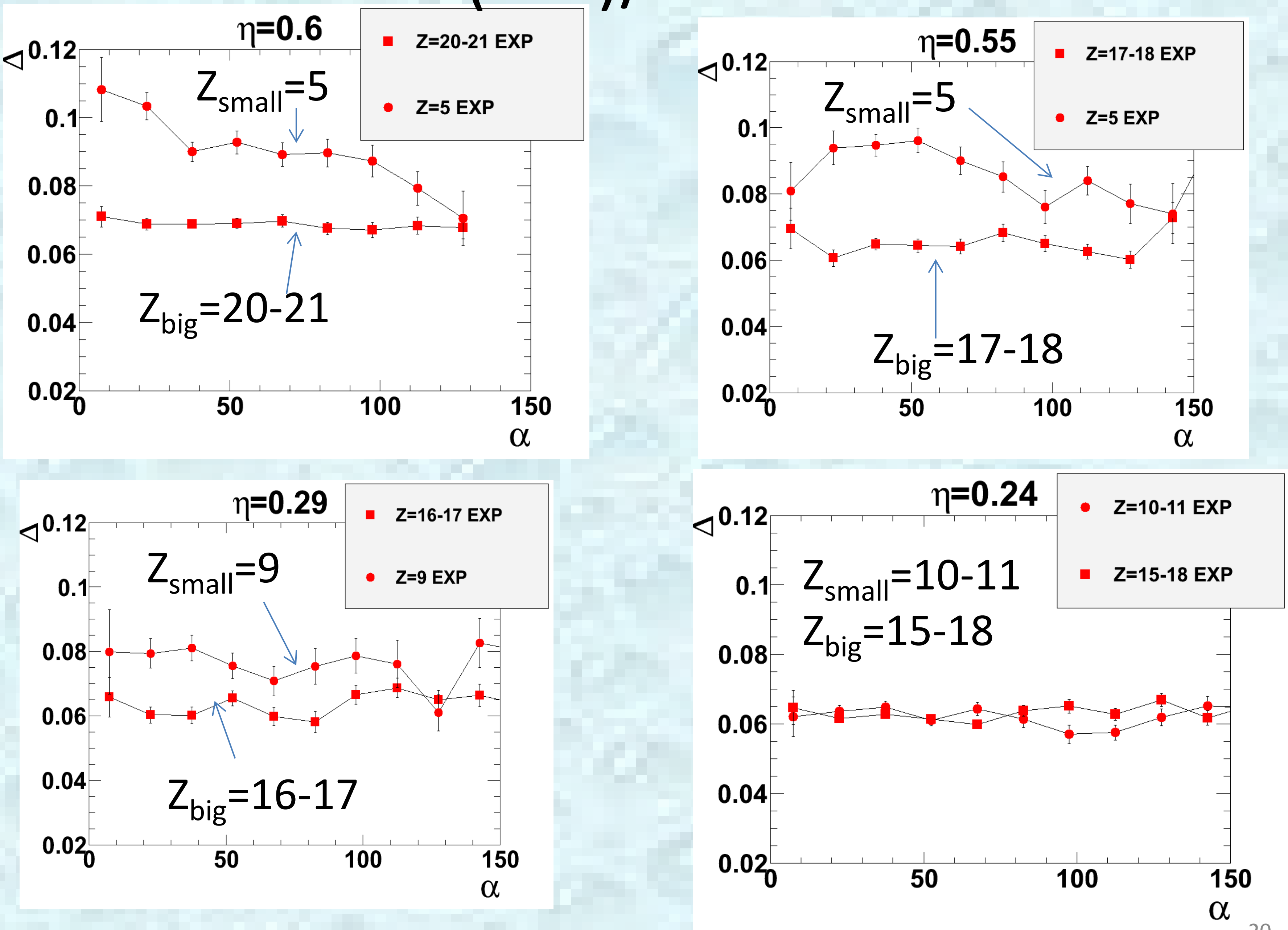


See also Casini et al., PRL71(1993) 2567

In-plane angular distribution for η windows. Flat for symmetric reactions, peaked in the asymmetric case

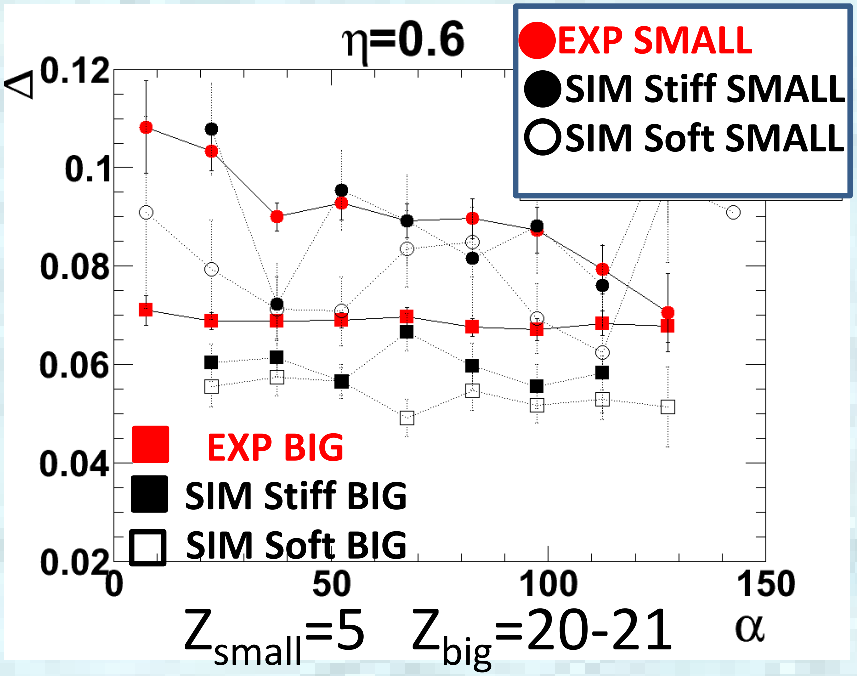


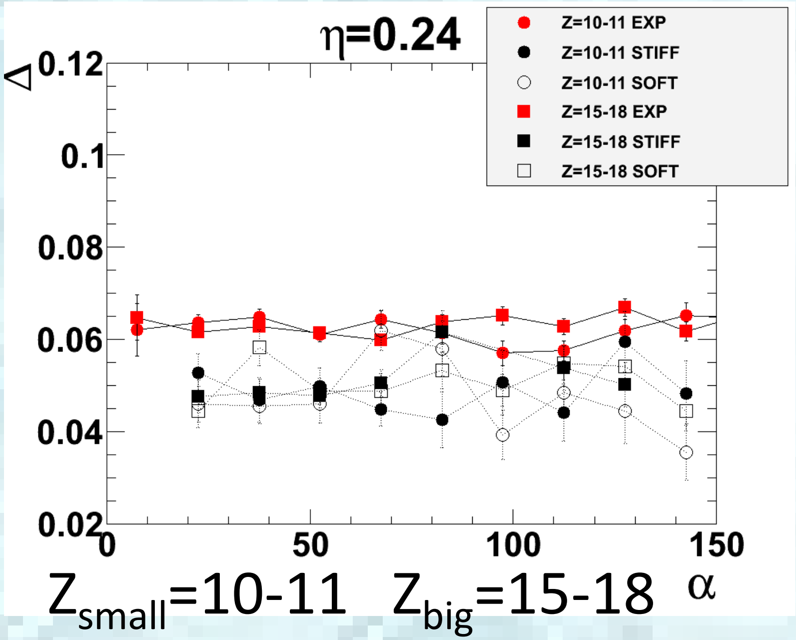
Δ=<(N-Z)/A> vs. α



Evolution as a function of the charge asymmetry

Δ vs. α for the two extreme asymmetries





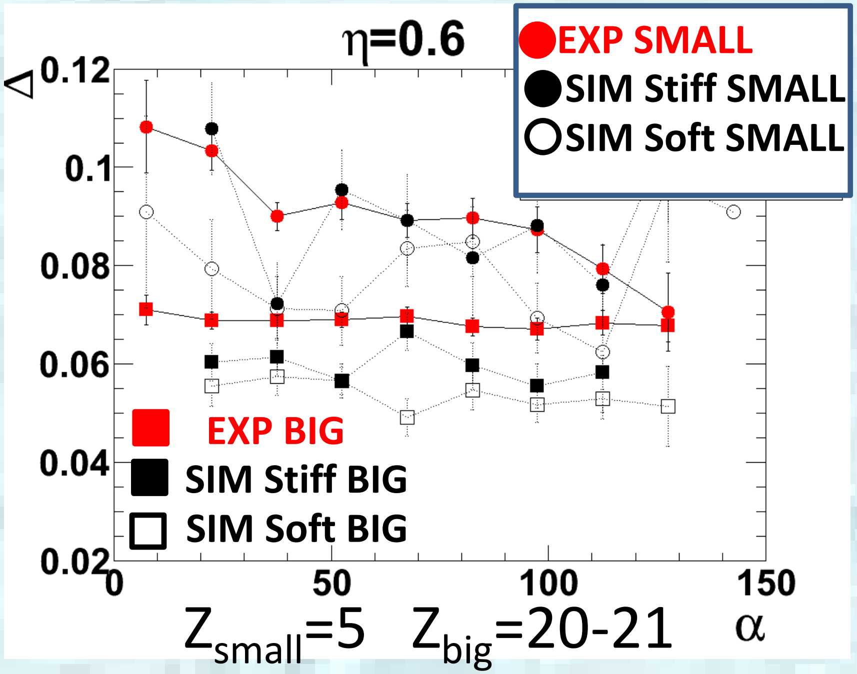
When the splitting is asymmetric, for small α (aligned configuration, fast fission) the light fragment is more n-rich than the heavy one. For large α (slower fission) the isospin equilibration is reached

When the splitting is more symmetric, the isospin is equilibrated for all the α values

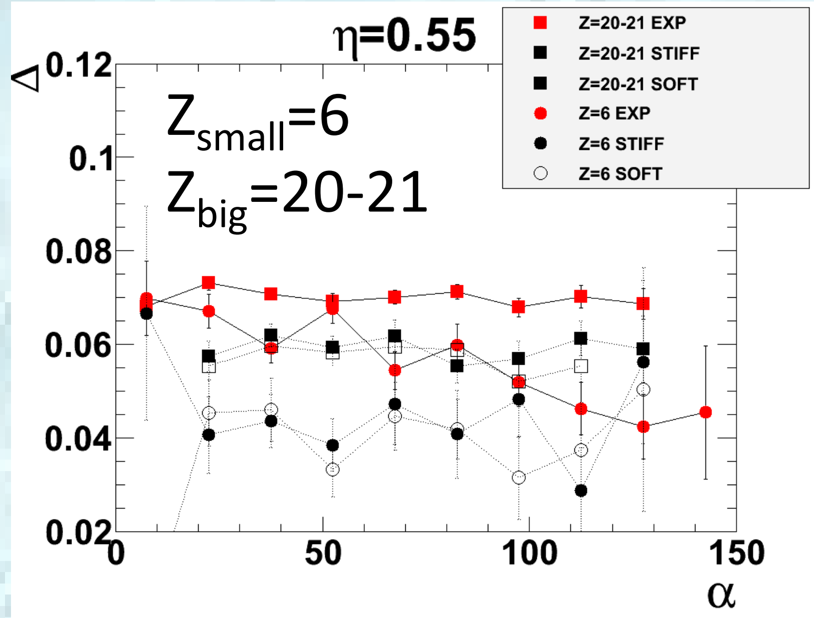
Results in agreement with A.Jedele et al., PRL118(2017)062501
A.Manso et al., PRC95(2018)044604

The observed trend is qualitatively reproduced by the model
From the more asymmetric case there is a **weak indication of stiff symmetry energy**

Some fragments are special: Z=6



Z_{small}=5 Z_{big}=20-21



Although the η is similar, for Z=6 there is an inversion (the lightest fragment is less n rich than the heaviest one) (see also fig. 9 A.Manso et al.,PRC95(2018)044604)

The model qualitatively predicts the observed behaviour

Maybe this fact is due to a structure effect

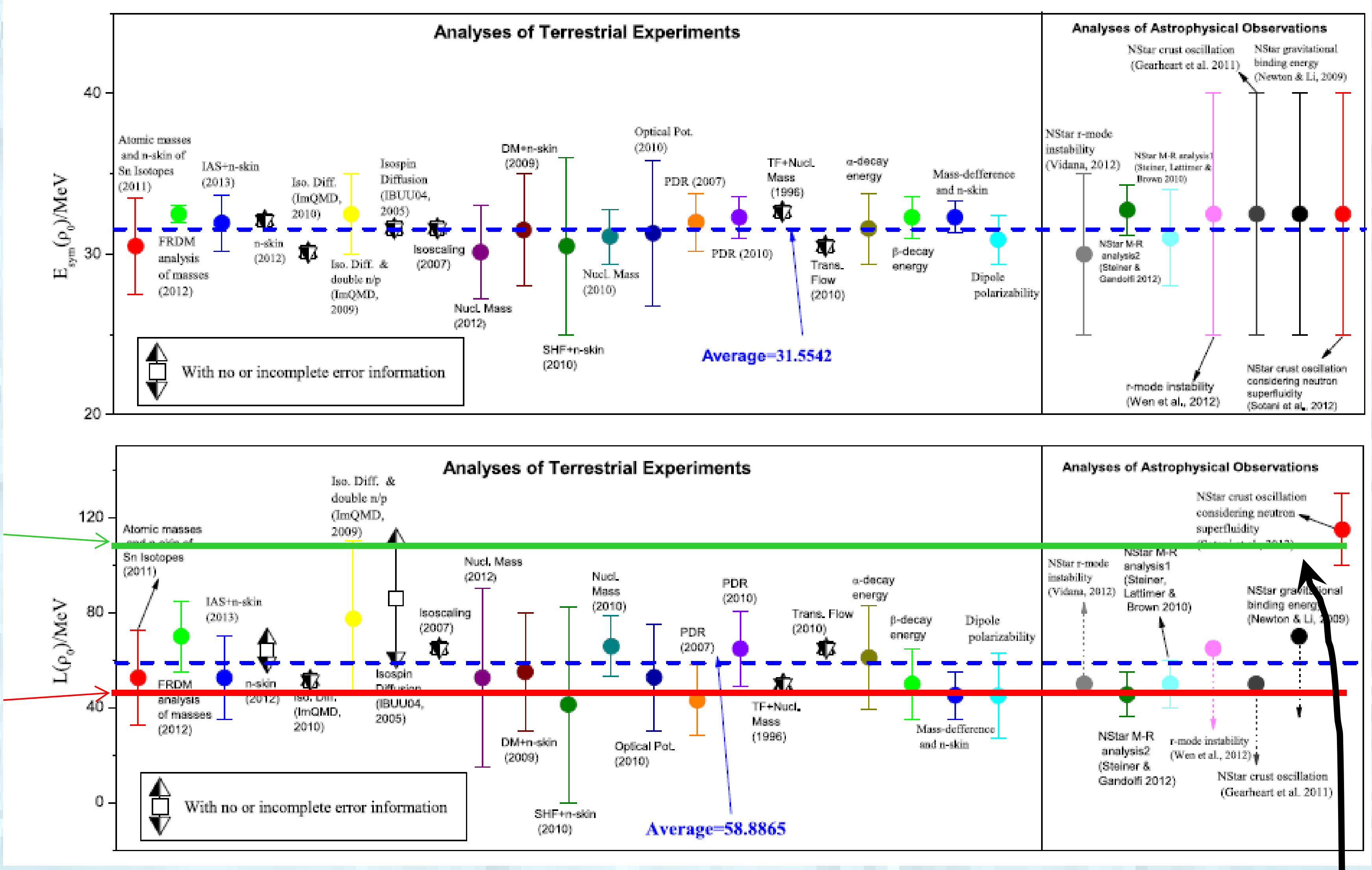
More details in the talk of A.Camaiani

As a conclusion, concerning the symmetry energy….

We have tested:

STIFF

SOFT



B.A.Li et al., PLB 727(2013) 276

$$S(\rho) = E_{sym}(\rho_0) + L(\rho_0)\left(\frac{\rho - \rho_0}{3\rho_0}\right)$$

We have found weak indications of **stiff** symmetry energy, with **L=108**

Conclusions

- Experimental data for the system $^{80}Kr+^{48}Ca$@35AMeV collected by FAZIA in its first physics measurement have been presented
- The main experimental observables have been compared with the prediction of AMD + GEMINI++, finding a reasonable reproduction of the experimental data in all the investigated impact parameter range
- Isospin related observables show a weak indication of stiff symmetry energy
- For QP fission different degree of isospin equilibration as a function of the mass asymmetry and of the alignment of the breaking configuration of the system has been found

Thank you for your attention