FAZIA: Recent results

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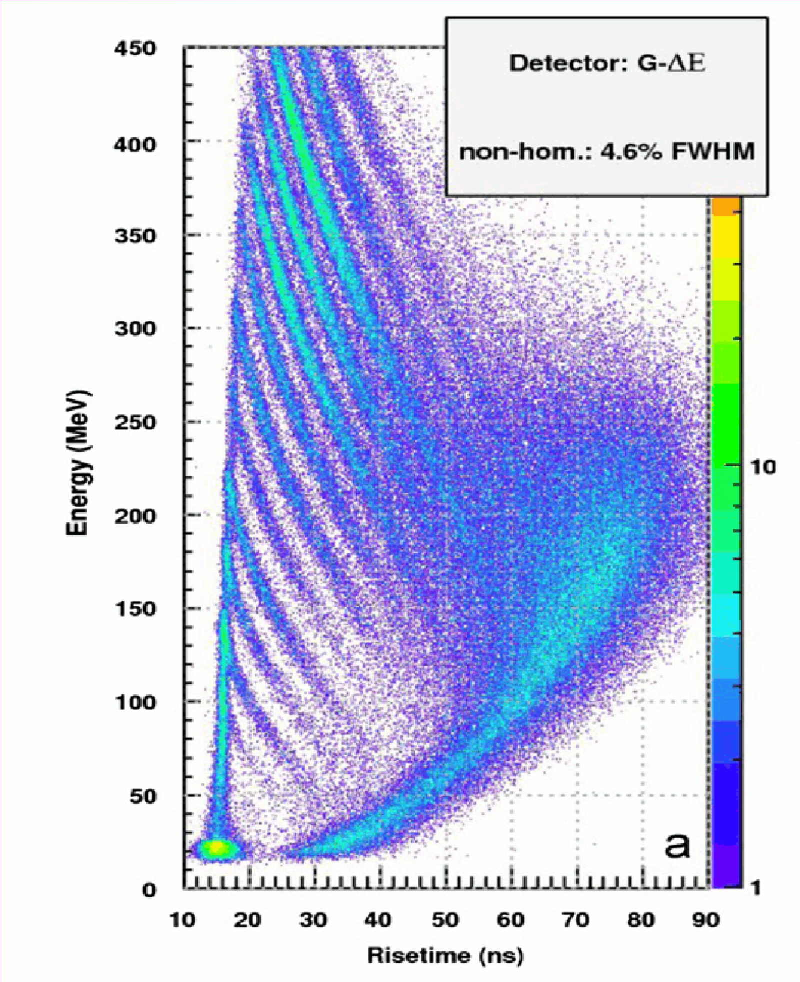
Outlook

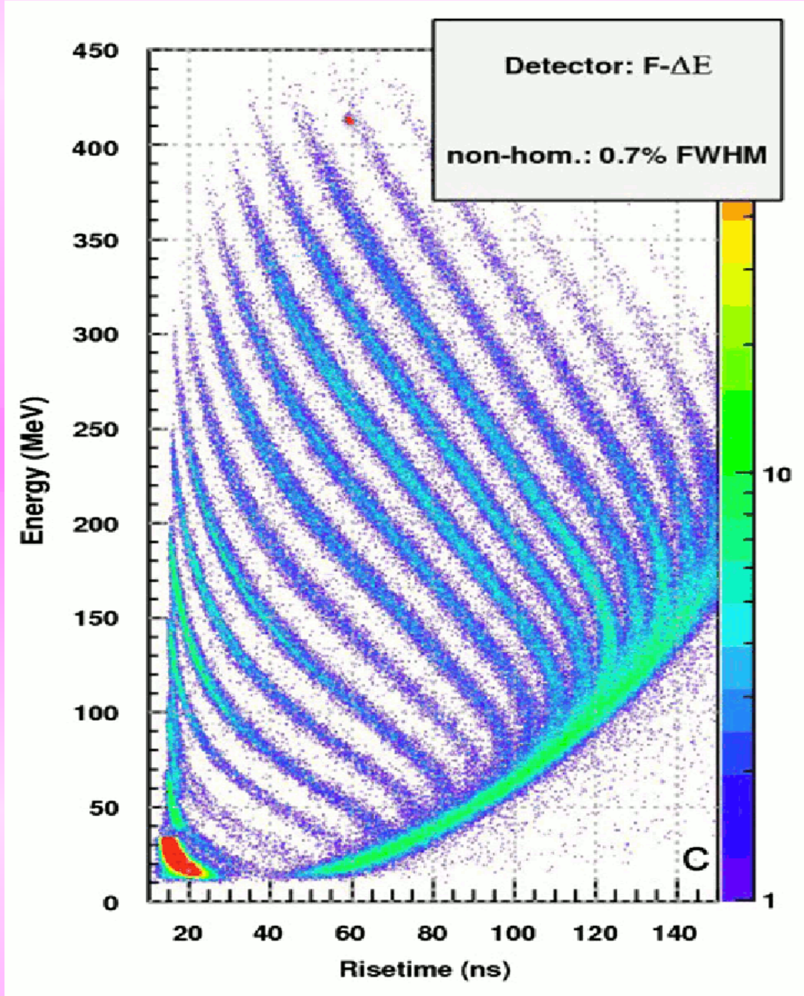
- The FAZIA recipe
- Some physics results with a prototype telescope
- ISOFAZIA: the first physics experiment (June 6-15 2015).
- Very preliminary results from ISOFAZIA
- Conlusions and perspectives

The FAZIA recipe in a nutshell….

- **n-TD Si detectors with good doping uniformity (<3% FWHM), important for PSA**

Doping uniformity: effects on PSA (particles stopped in the first Si)





L.Bardelli et al., NIMA 654 (2011) 272

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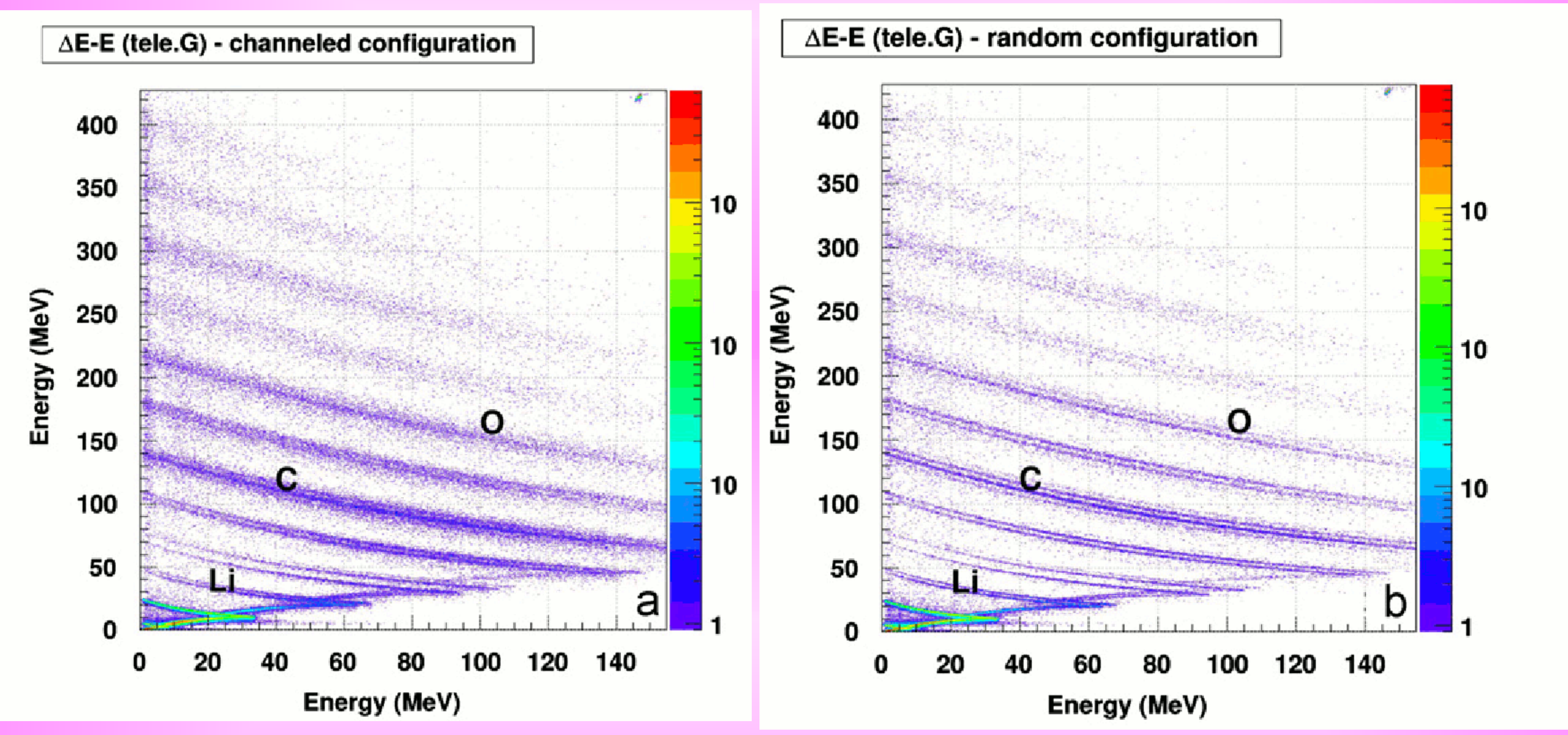
Channeling: effects on ΔE-E



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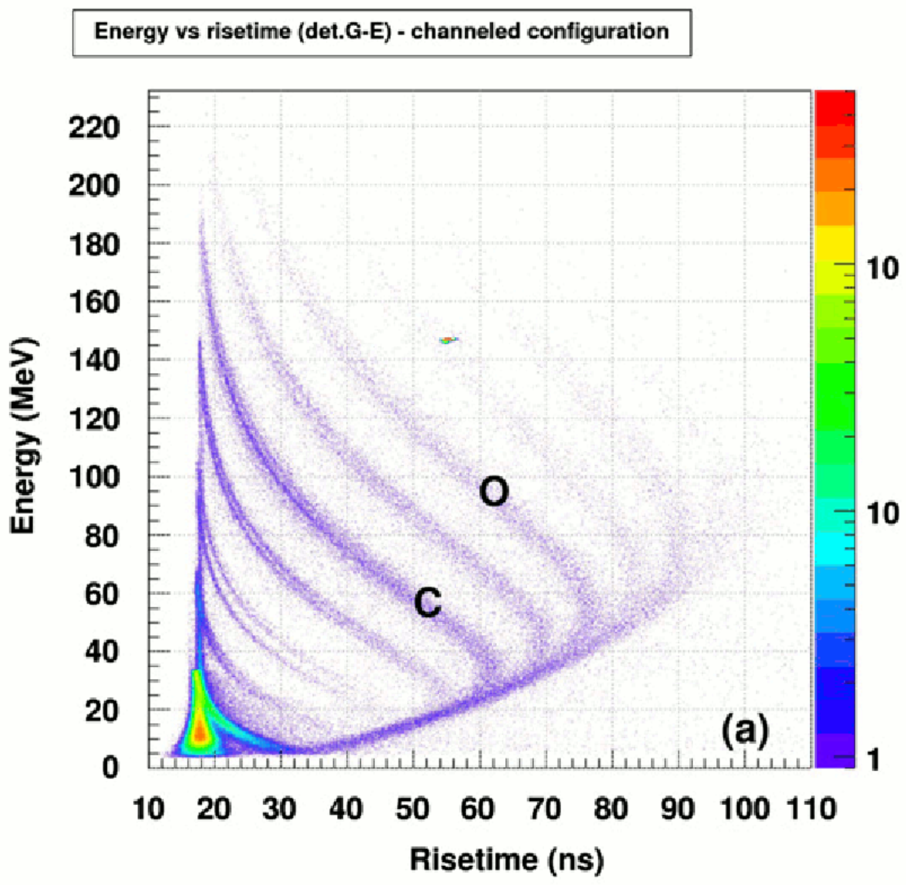
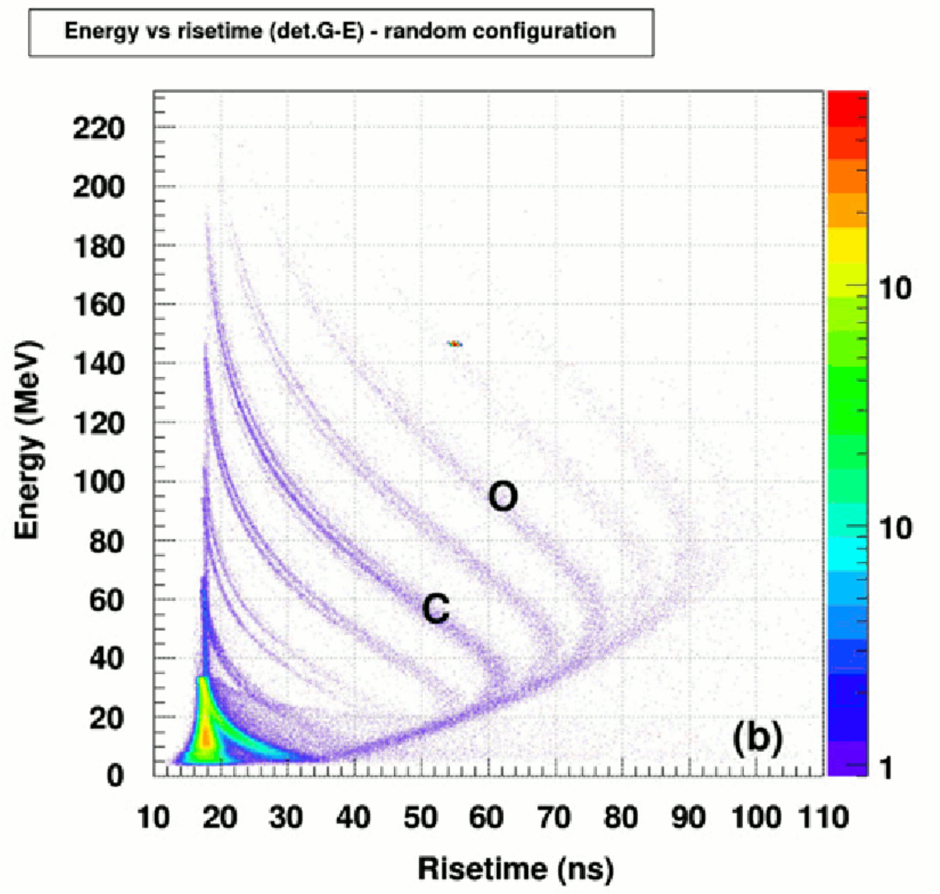
Channeling: effects on PSA





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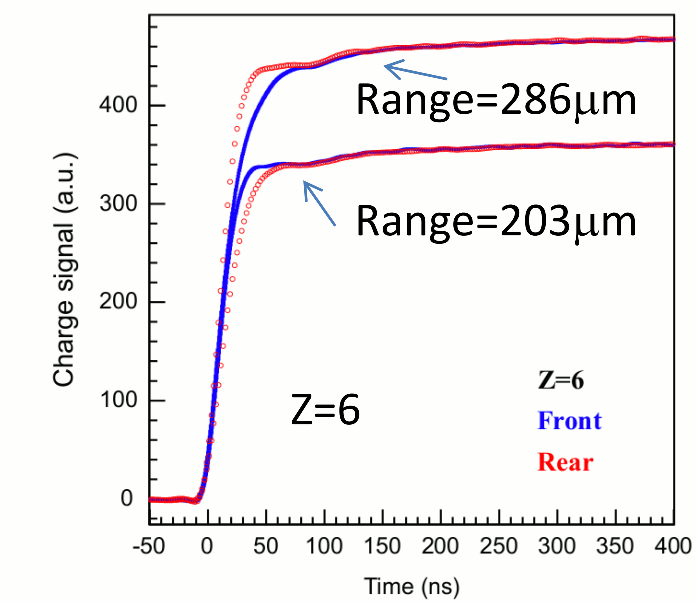
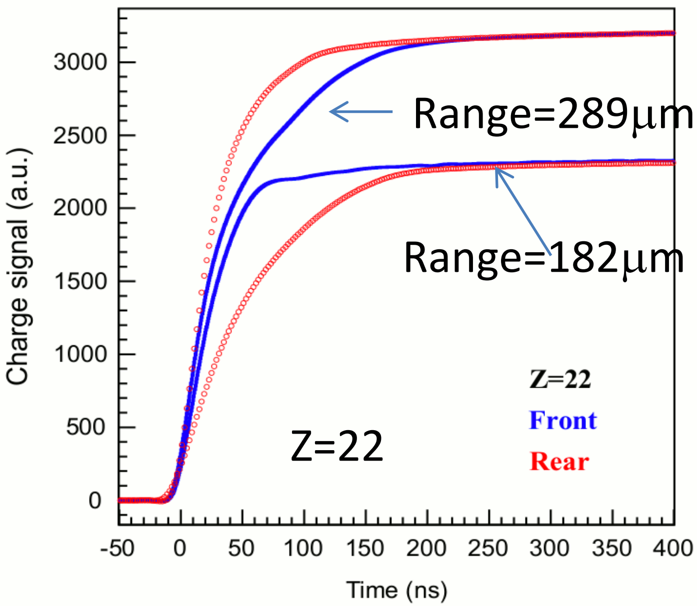
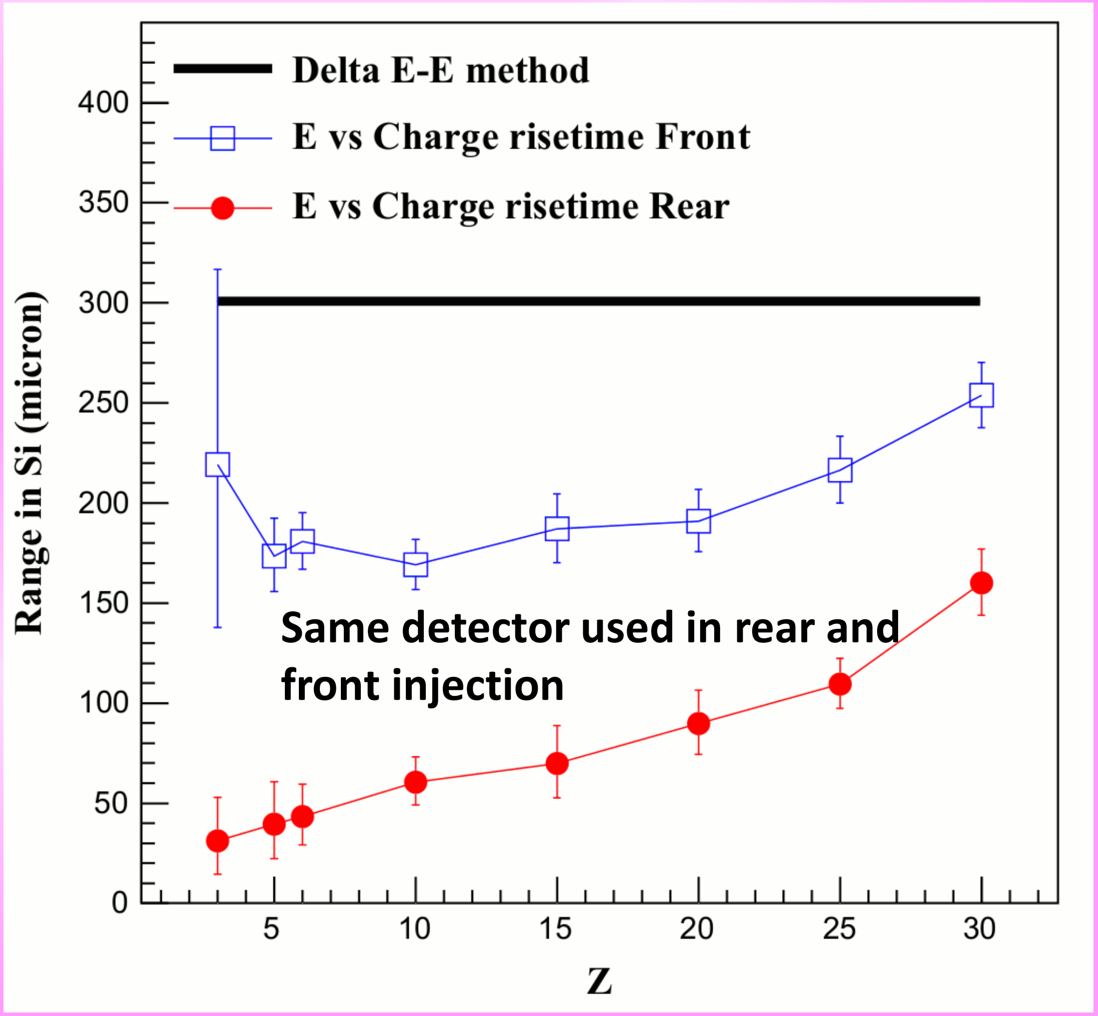
Front vs. Rear Injection



Shape difference between light and heavy ions maximized for rear injection (entrance from low electric field side)



Identification thresholds



N.LeNeindre et al., NIMA 701(2013)145

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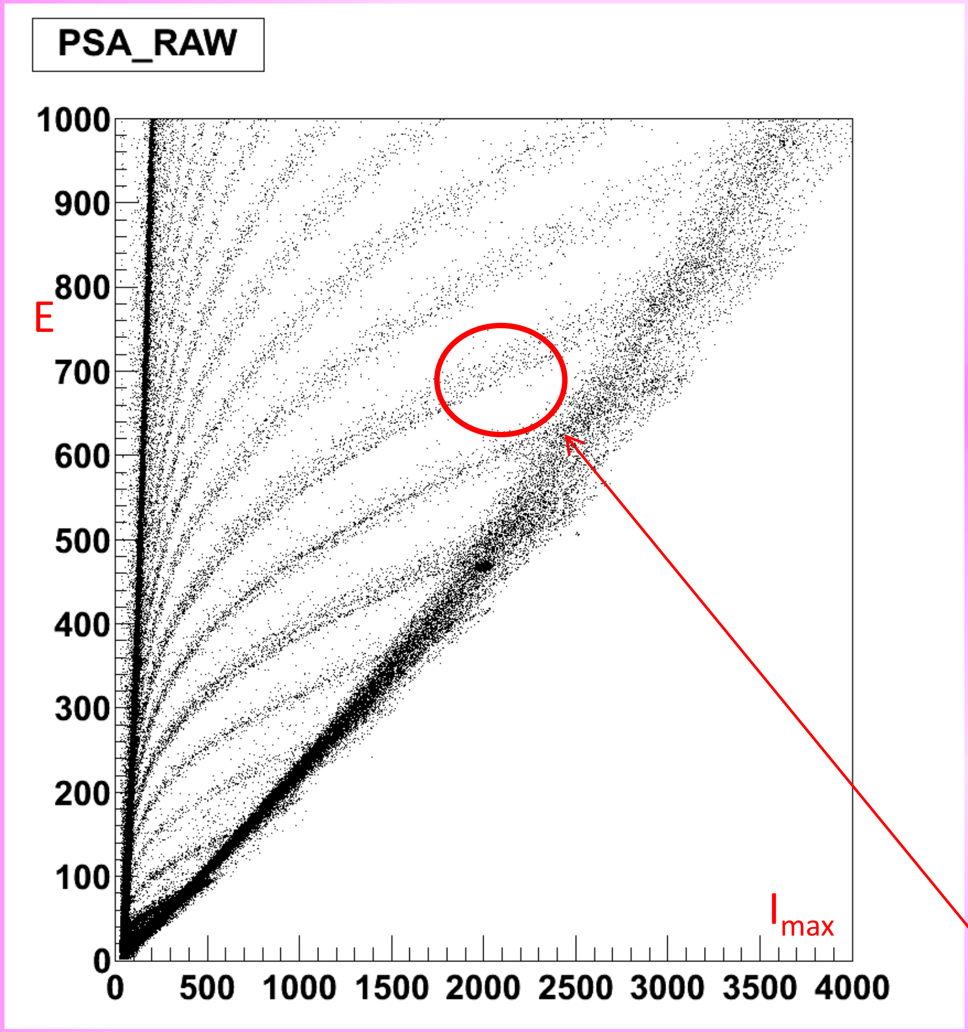
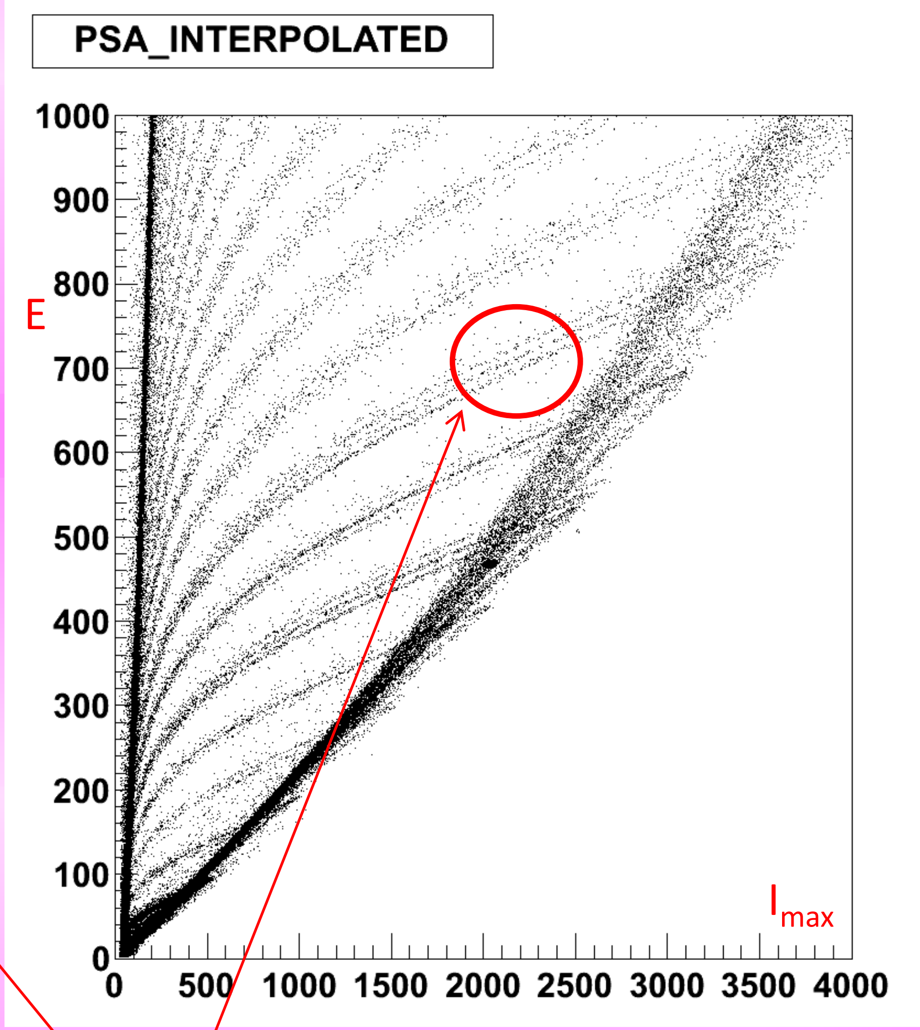
Development of proper algorithm: PSA from Energy vs. Imax

Search for the maximum of the current signal **without interpolation** among the acquired samples



Search for the maximum of the current signal **with cubic interpolation on 4 consecutive samples**



Better mass resolution

The FAZIA recipe in a nutshell….

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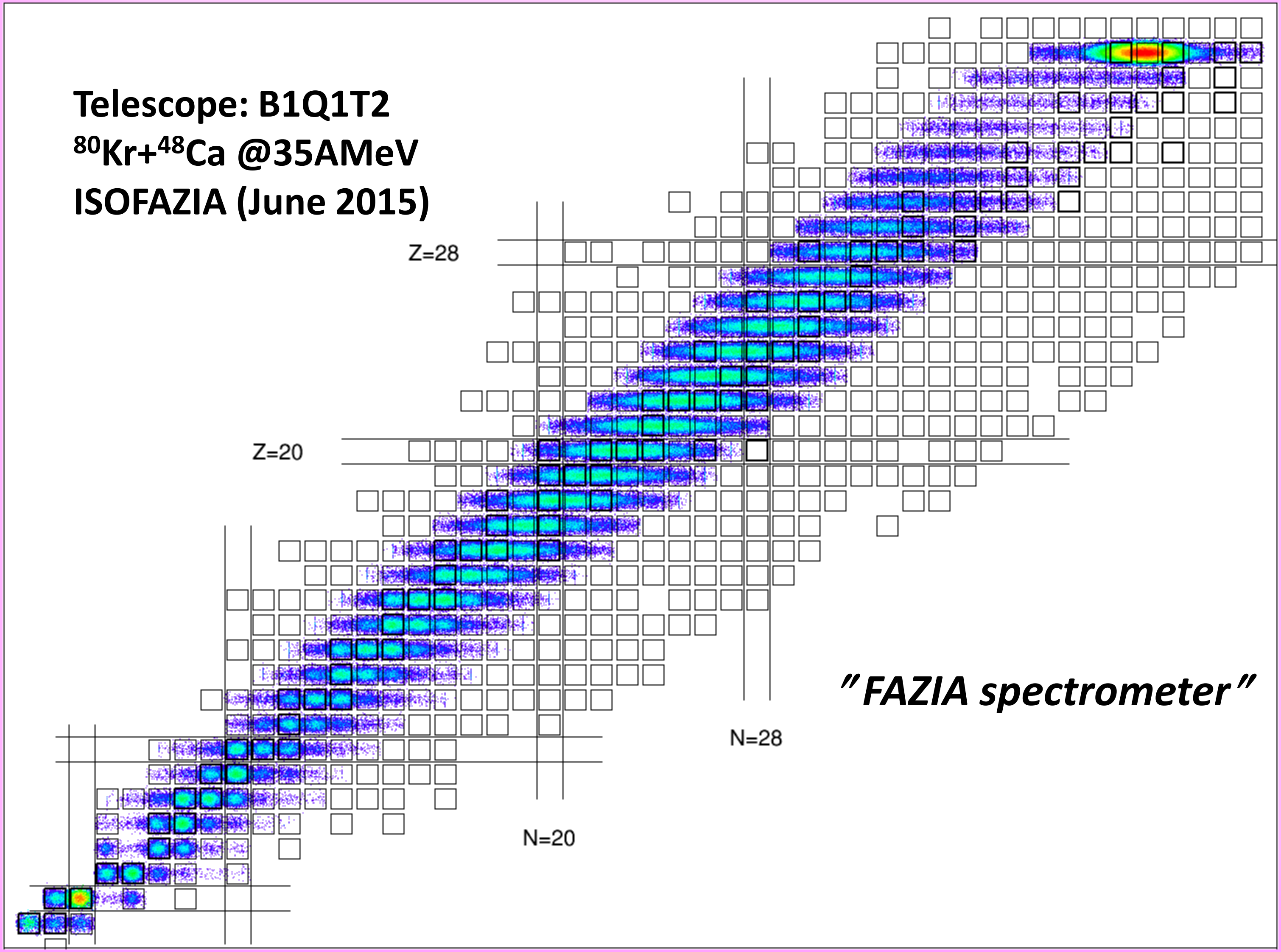
- Si detectors obtained from wafers cut at 7° off the <100> axis, to minimize channeling (important both for PSA and ΔE-E)
- Reverse mounting of the Si detectors (essential for PSA)
- 30nm thick Al layer on both sides of the Si in order to reduce sheet resistance to few Ω (good timing properties, useful for rise time measurement in PSA)
- Purposely developed Front End Electronics and preamp located inside the vacuum chamber (to reduce noise)
- Proper algorithms for digital signal shaping have been developped (e.g. trapezoidal shaping of the digitized signal form)
- Applied voltage across the detector kept constant (on line monitoring of the reverse current)

This recipe allowed us to obtain extremely good results in terms of isotopic identification…..



Fazia Applications

Fazia shows very good performances in terms of Z and A identification, with low thresholds.

Which physics can be done with FAZIA exploiting at best its capabilities?

We can investigated phenomena related to the isospin of the ejectiles

Why measuring the isospin of the ejectiles is important?

- Because it can give information on isospin transport phenomena
- Isospin transport phenomena depend on the **symmetry energy S(ρ)** term of the nuclear equation of state; S(ρ) is not well known far from normal conditions

$$\frac{E(\rho,I)}{A} = \frac{E(\rho)}{A} + S(\rho)\, I^2 \qquad I = \frac{N-Z}{A}$$

EOS for symmetric matter

$S(\rho_0)$~30MeV from Weiszacker mass formula

Studying isospin transport phenomena we can get information on the symmetry energy term

Why measuring the isospin of the ejectiles is important?

- Because it can give information on isospin transport phenomena
- Isospin transport phenomena depend on the **symmetry energy S(ρ)** term of the nuclear equation of state; S(ρ) is not well known far from normal conditions
- Isospin transport arises because n and p are subject to different forces

$$j_n - j_p \propto S(\rho)\nabla I + \frac{\partial S(\rho)}{\partial \rho} I \nabla \rho$$

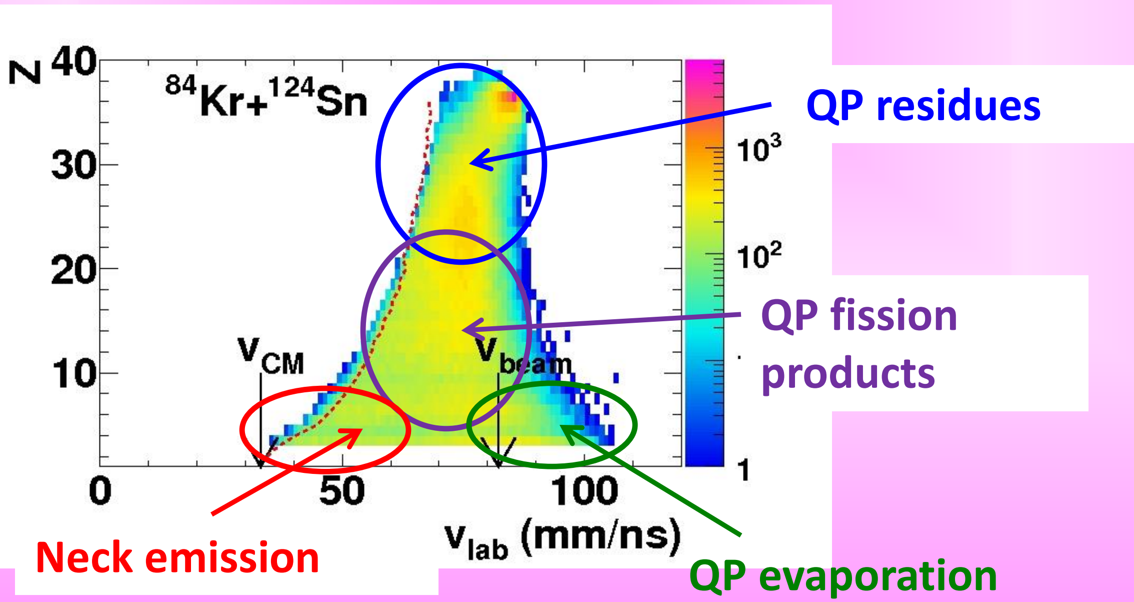
Difference between the neutron and proton currents

V.Baran et al., Phys. Rep. 410 (2005) 335
M.DiToro et al., J.Phys.G 37 (2010) 083101

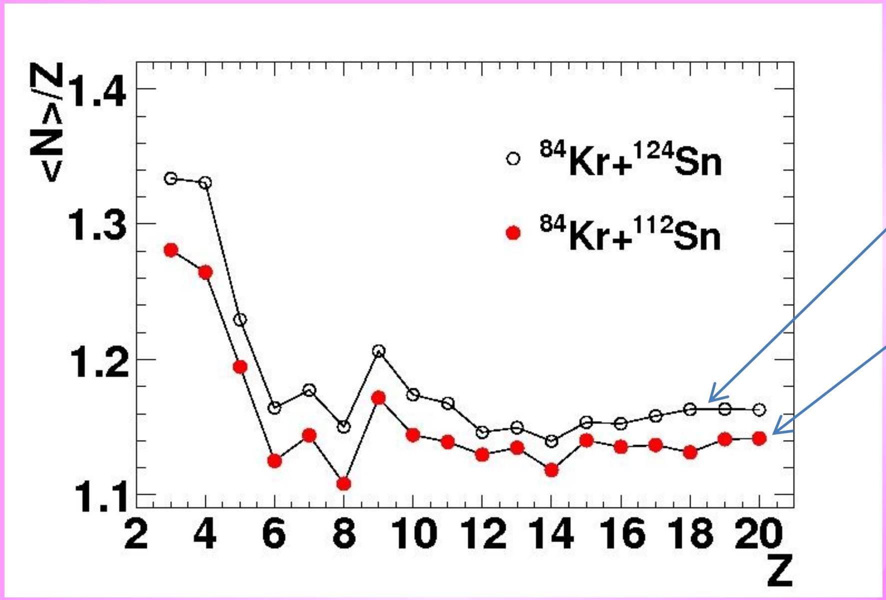
- **The isospin gradient ∇I between target and projectile (in isospin asymmetric reactions) is responsible of the isospin diffusion process, sensitive to S(ρ)**
- **The density gradient ∇ρ between the QP/QT region (at normal density) and the more diluted neck zone (both in symmetric and asymmetric reactions), is responsible of the isospin drift, sensitive to ∂S/∂ρ**

Some experimental results on isospin transport effects with 1 FAZIA telescope:

- Test experiment done in 2011 at LNS-INFN
- $^{84}Kr+^{112,124}Sn$ at 35AMeV
- $N/Z_{projectile}$= 1.33; N/Z_{112Sn}=1.24; N/Z_{124Sn}=1.48
- Only inclusive measurements
- Angular coverage: 4°-6° (just beyond the grazing angle)
- Only products coming from QP phase space are accessible

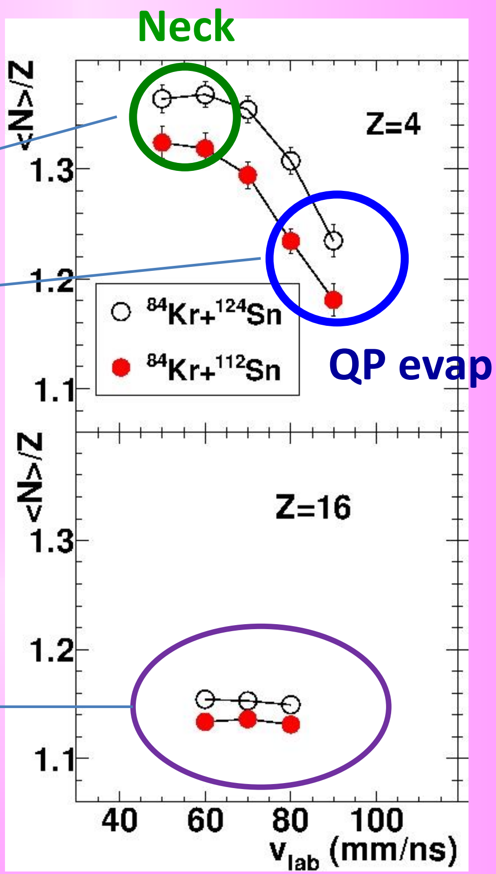


Isospin diffusion

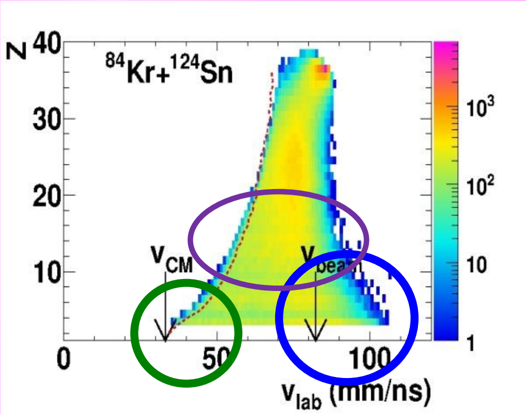


<N>/Z of QP phase space products systematically higher when the target is nrich

Isospin drift



<N>/Z of neck emitted fragments higher than <N>/Z of QP evaporated fragments



No dependence on lab velocity for QP fission fragments

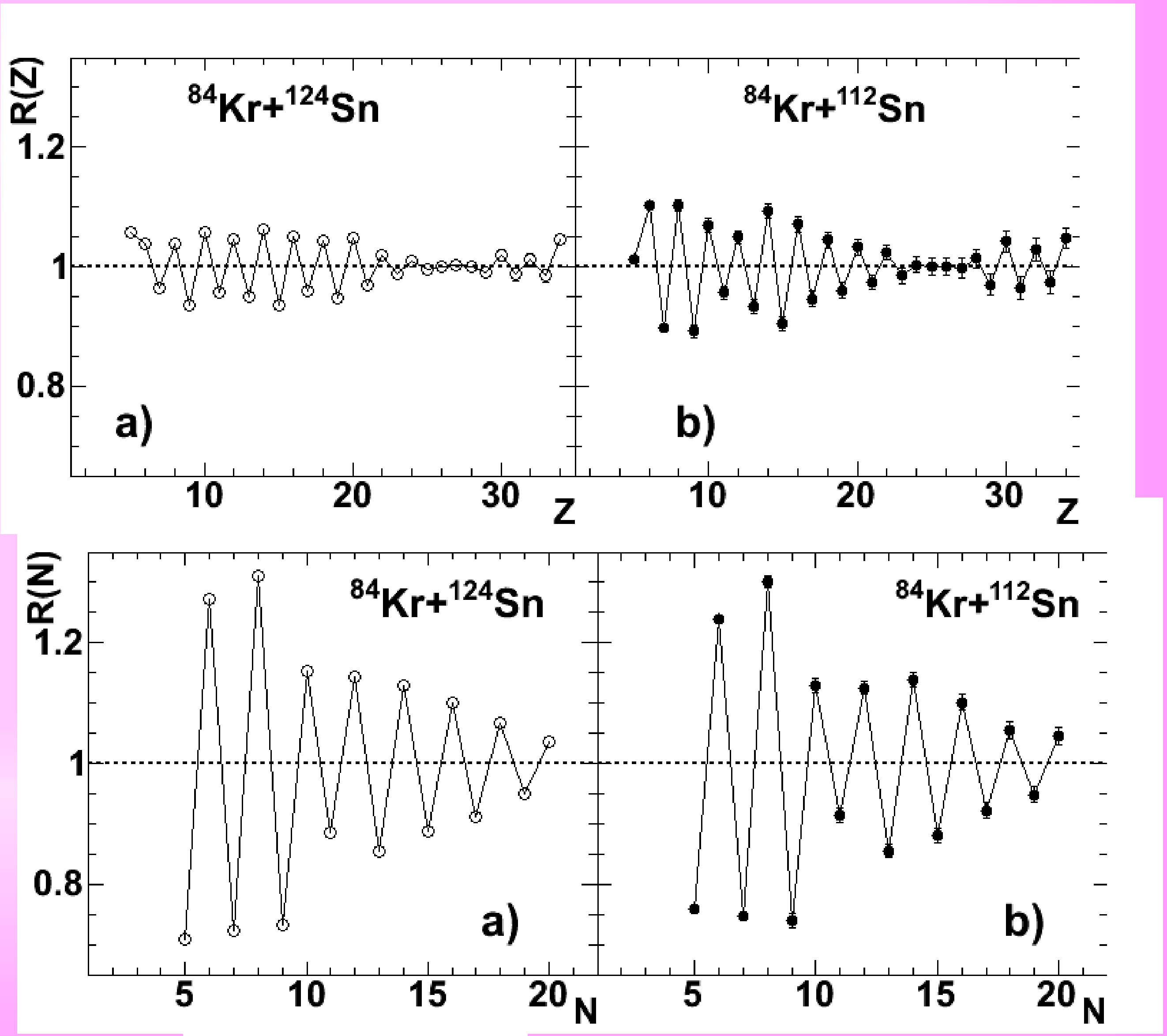
S.Barlini et al., PRC87(2013)054607

We have found evidence of isospin drift and diffusion. But…

- In order to extract information on the EOS it is necessary **to compare experimental data with the predictions of transport models, including also the de-excitation stage** by means of afterburner codes.
- As a consequence, **it is important to investigate all the aspects which could affect the decay of hot primary products** and which might be not completely included in statistical decay codes, such as **Z and N staggering**

Z and N staggering

Ratio among experimental yields and a smoothing curve



- N staggering greater than Z staggering for our systems
- Z staggering greater for n-poor system
- N staggering more similar for both systems
- The staggering decreases when the size of the fragments increases

S.Piantelli et al., PRC88 (2013)064607

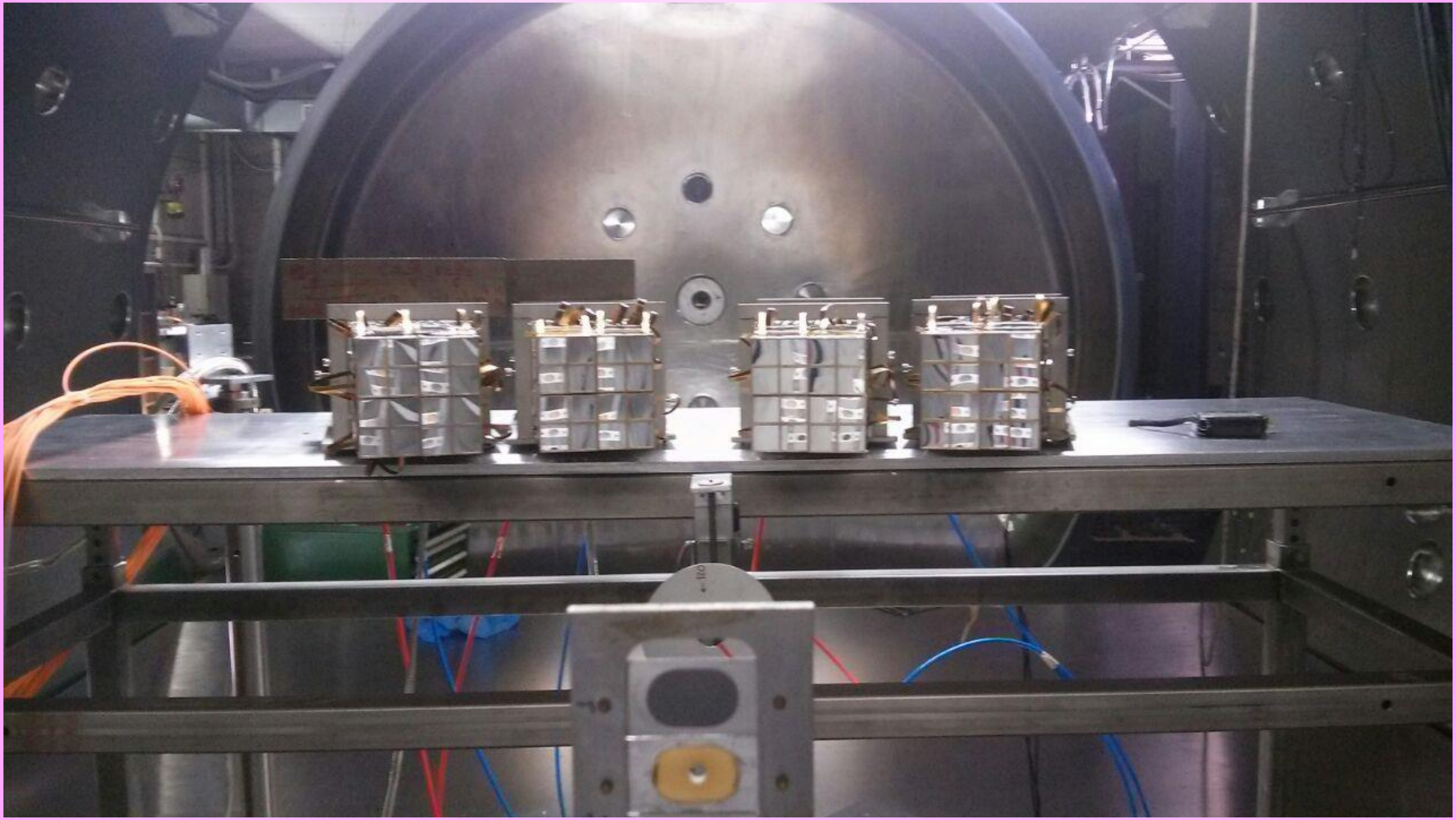
Wide range in N

These results have been obtained with a prototype telescope during a test experiment

The most recent experiment (June 6-15 2015): the first physics measurement

- First use of 4 complete blocks
- Belt configuration from 3.6° to 17.8°

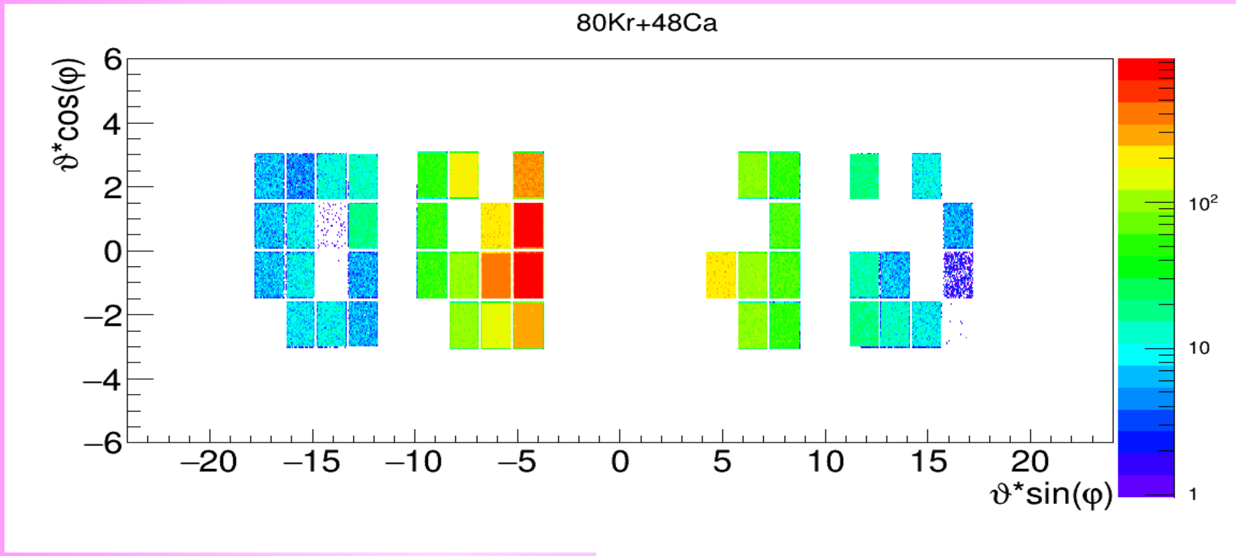
Ciclope scattering chamber (INFN-LNS)
June 2015
4 complete blocks



The most recent experiment (June 6-15 2015): the first physics measurement

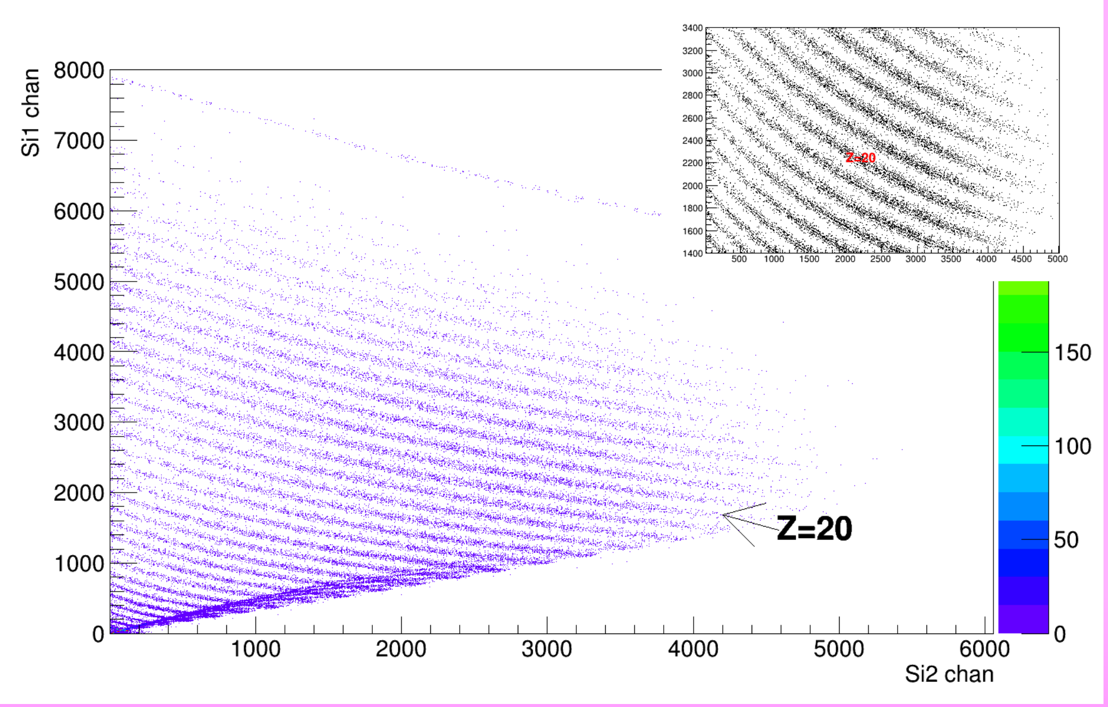
- First use of 4 complete blocks
- Belt configuration from 3.6° to 17.8°
- **$^{80}Kr+^{40,48}Ca$ at 35AMeV**
- $N/Z_{projectile}=1.22$
- $N/Z_{40Ca}=1.0$ $N/Z_{48Ca}=1.40$
- **Goals:** Extension of the analysis concerning the isospin transport process performed in the test experiment of 2011 (**measuring** particles and fragments **in coincidence**) in terms of
  - Centrality selection by means of the $Z_{biggest}$ - v_{lab} correlation
  - Identifying light fragments coming from the neck
  - Identifying QP fission fragments detected in coincidence
  - Measuring the isotopic composition of both fission fragments
  - Comparison with transport models (e.g. SMF V.Baran et al., NPA 730 (2004) 329, AMD A.Ono, PRC 59 (1999) 853, BLOB P.Napolitani and M.Colonna)

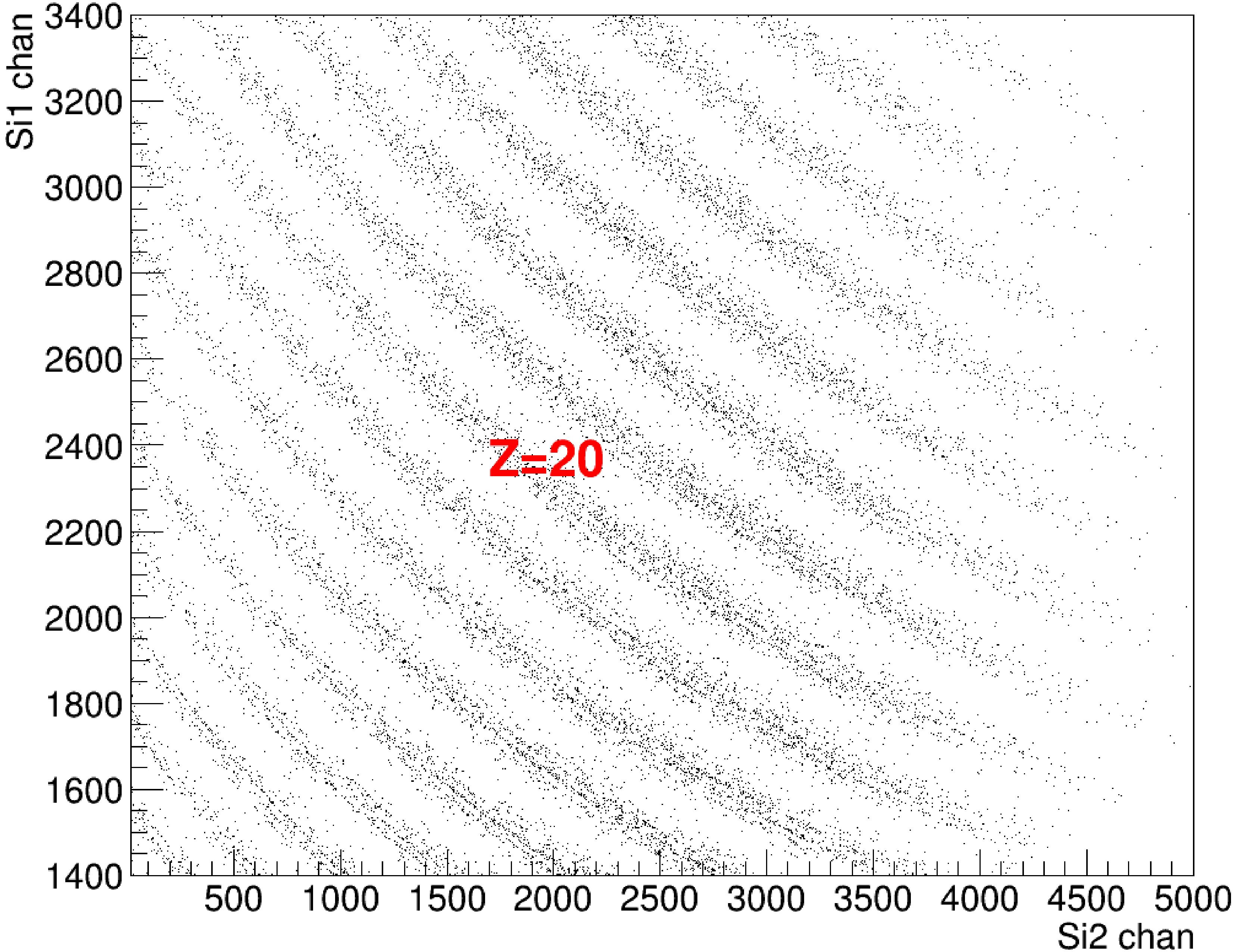
All the blocks worked:



Polar representation

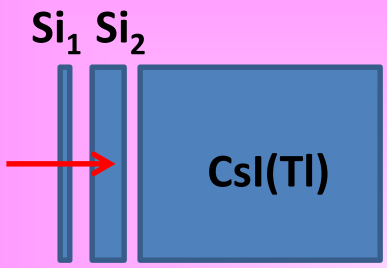
The quality of the identification is equal to the results obtained during the R&D phase with the prototype telescopes





Si1 chan
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Si2 chan
Z=20

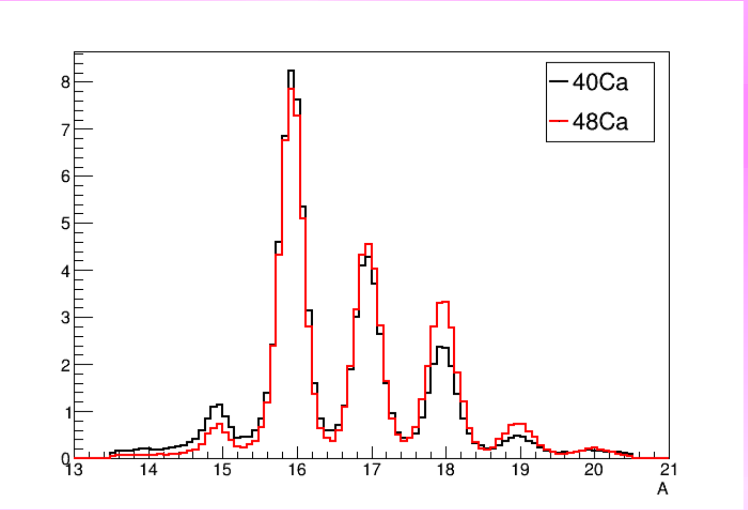
Preliminary analysis



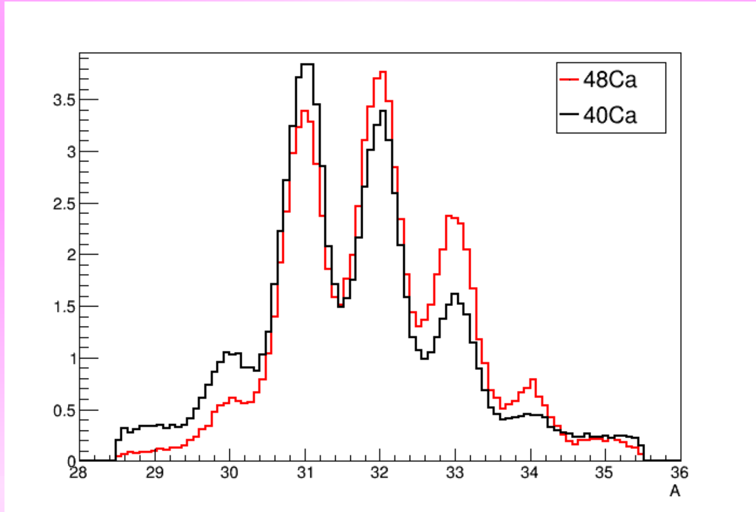
Only fragments stopped in Si_2 are included (ΔE-E only)

Inclusive data

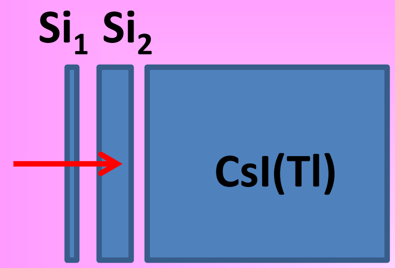
Z=8



Z=15



A difference in the isotopic distribution of the elements is observed when the two systems are compared.



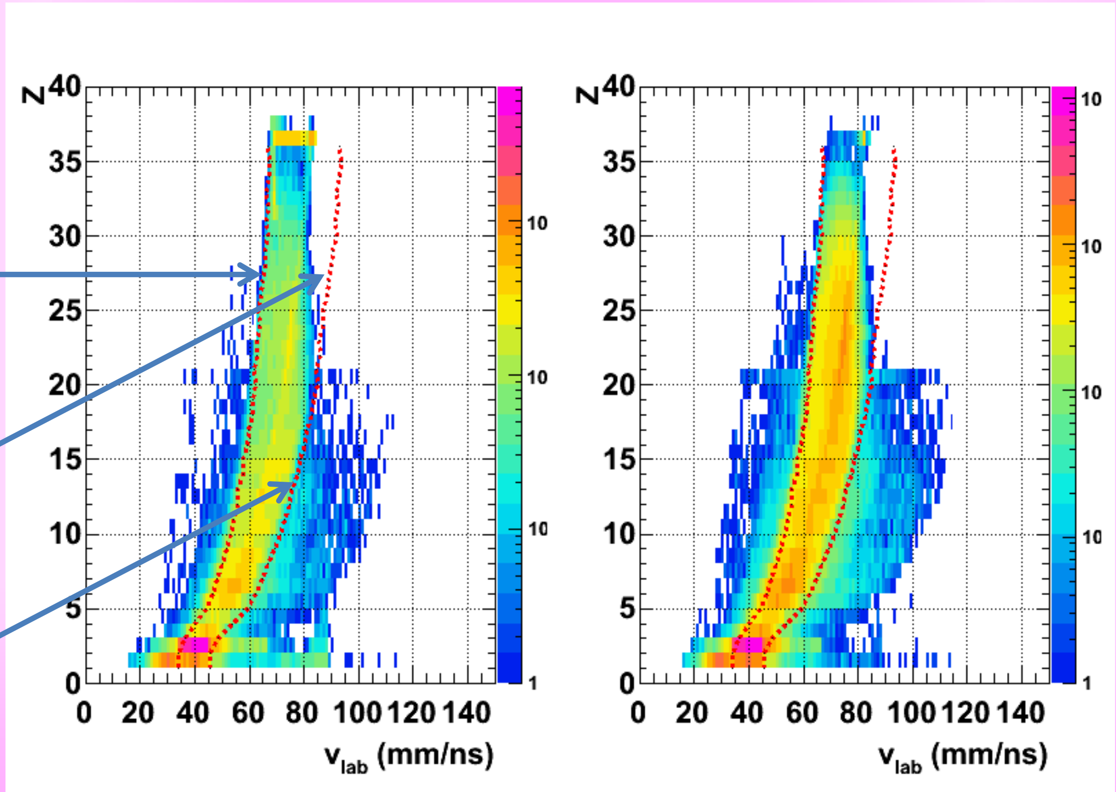
Preliminary analysis

Z – v_{lab} correlation for all the detected particles

Only fragments stopped in Si_2 are included (ΔE-E only)

^{12}C contribution (backing of both targets) not removed

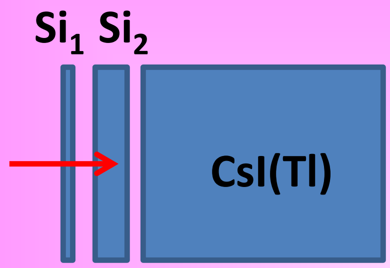
$^{80}Kr+^{40}Ca$ $^{80}Kr+^{48}Ca$



Punch-through of Si_1

Punch-through of Si_2

^{40}Ar beam contamination (mainly for ^{40}Ca)



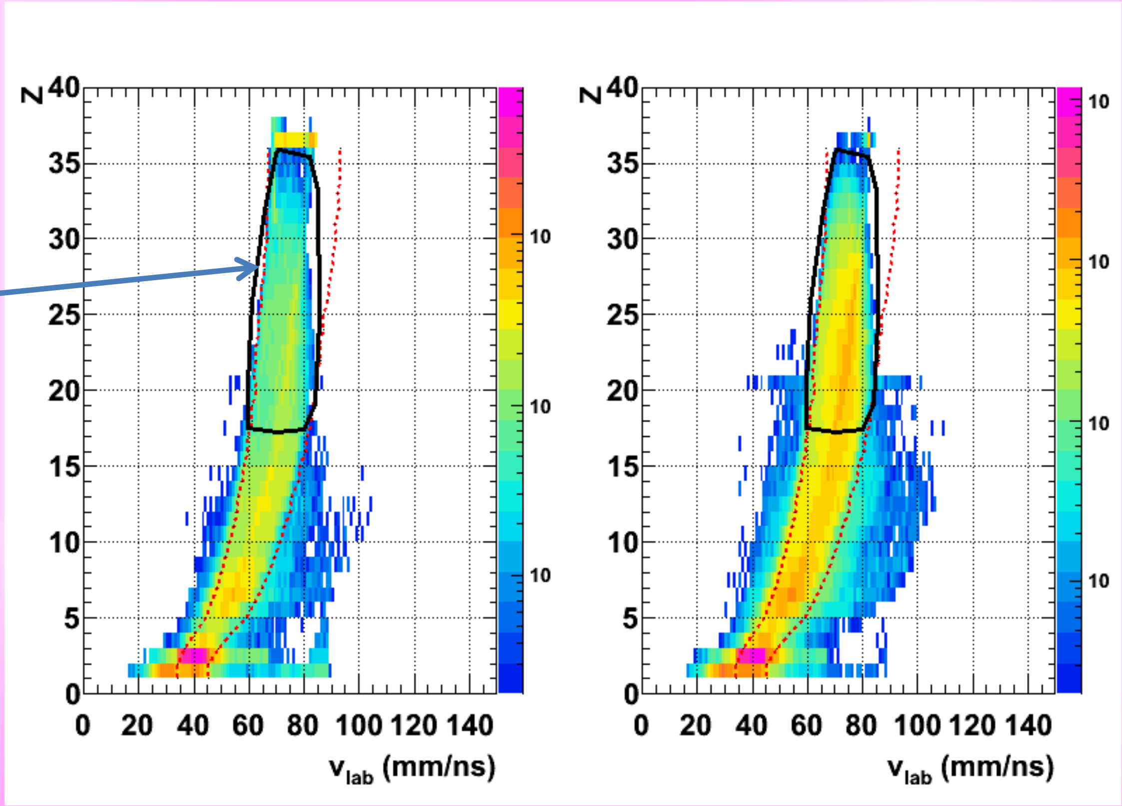
Preliminary analysis

^{12}C contribution (backing of both targets) not removed

Only fragments stopped in Si_2 are included (ΔE-E only)

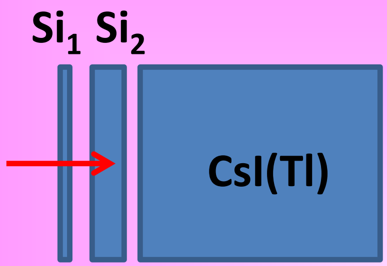
$^{80}Kr+^{40}Ca$ **$^{80}Kr+^{48}Ca$**

QP selection



Asking a fragment inside the areal gate removes the ^{40}Ar contamination

Preliminary analysis



Only fragments stopped in Si_2 are included (ΔE-E only)

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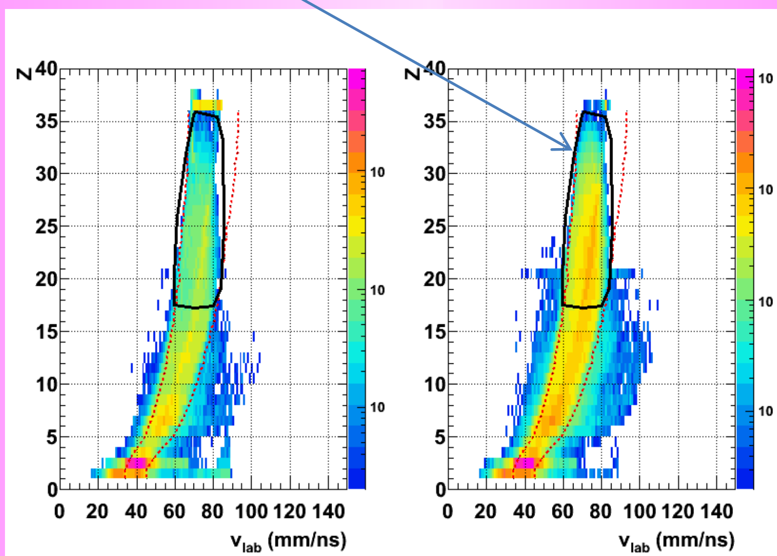
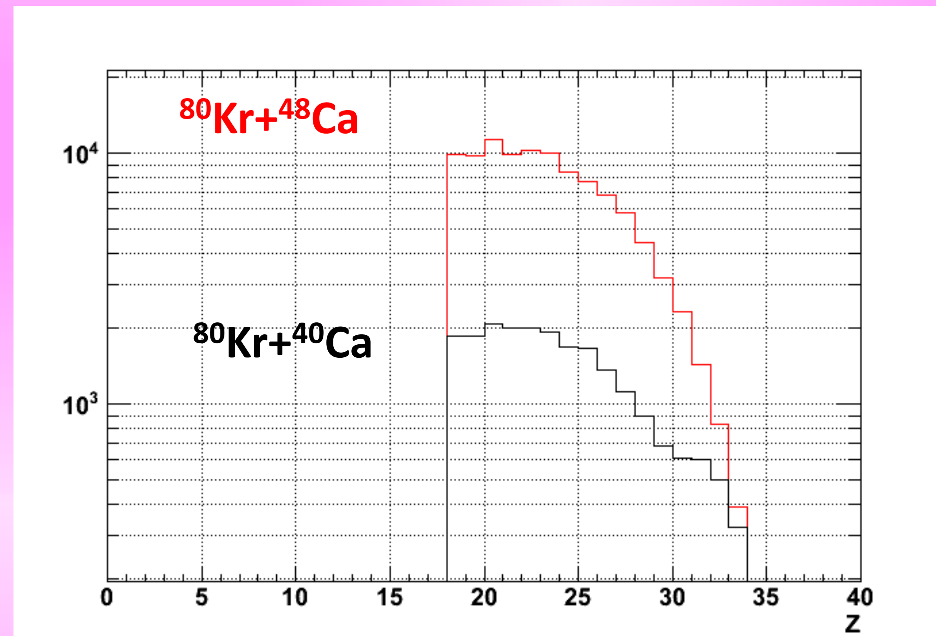
QP charge distribution

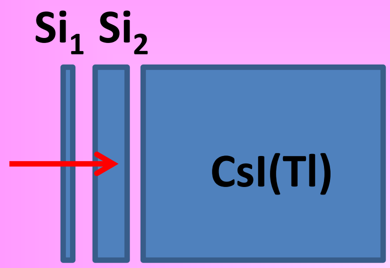
QP selection



$^{80}Kr+^{40}Ca$ **$^{80}Kr+^{48}Ca$**



Preliminary analysis



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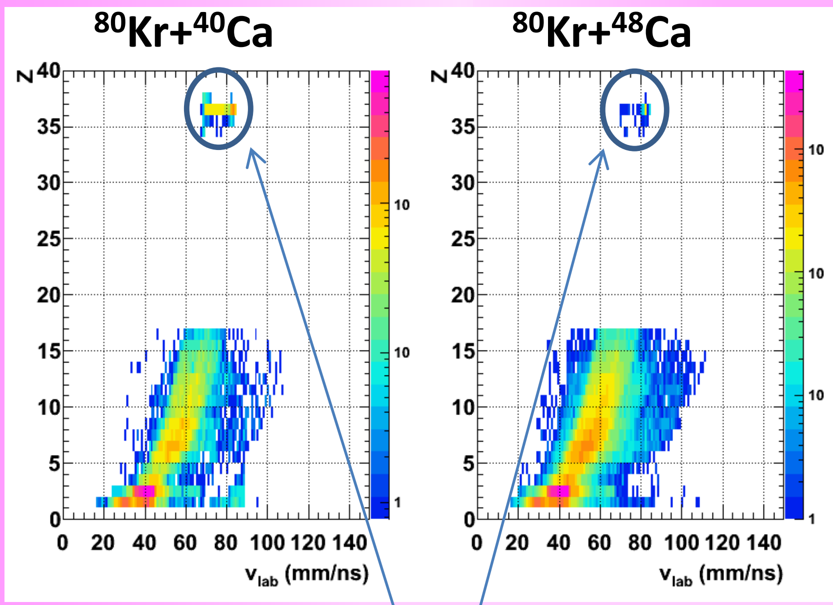
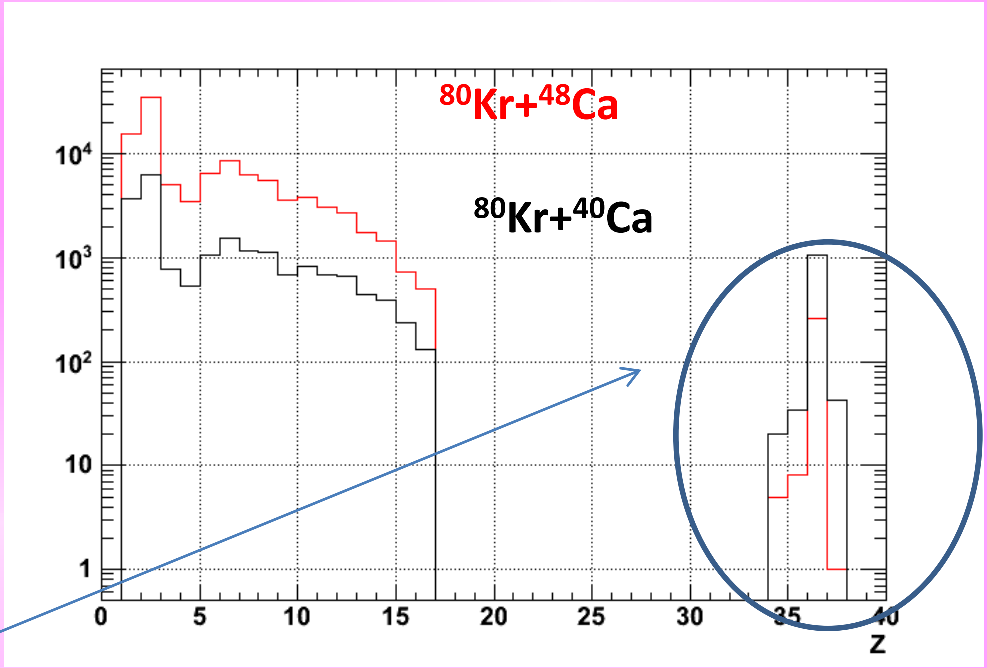
^{12}C contribution (backing of both targets) not removed

Fragments detected in coincidence with the QP



Charge distribution



Spurious coincidences

Preliminary analysis

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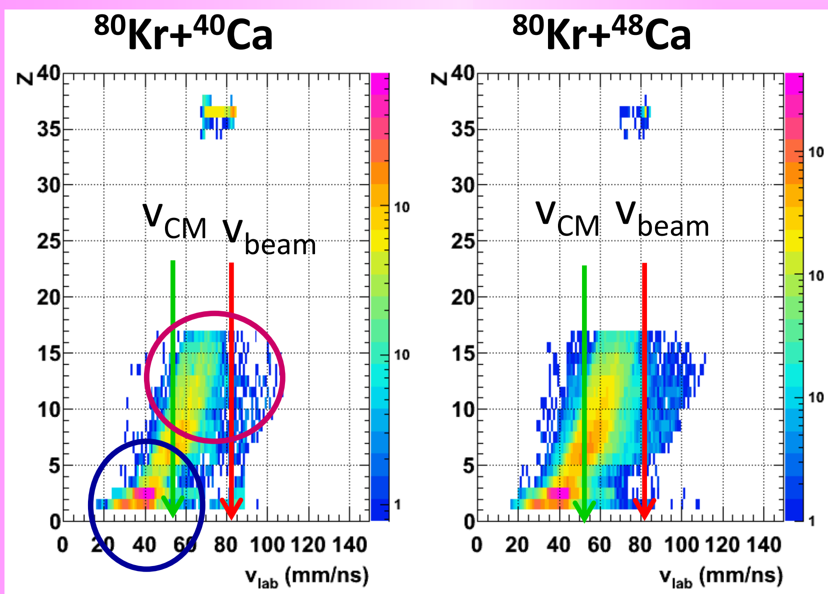
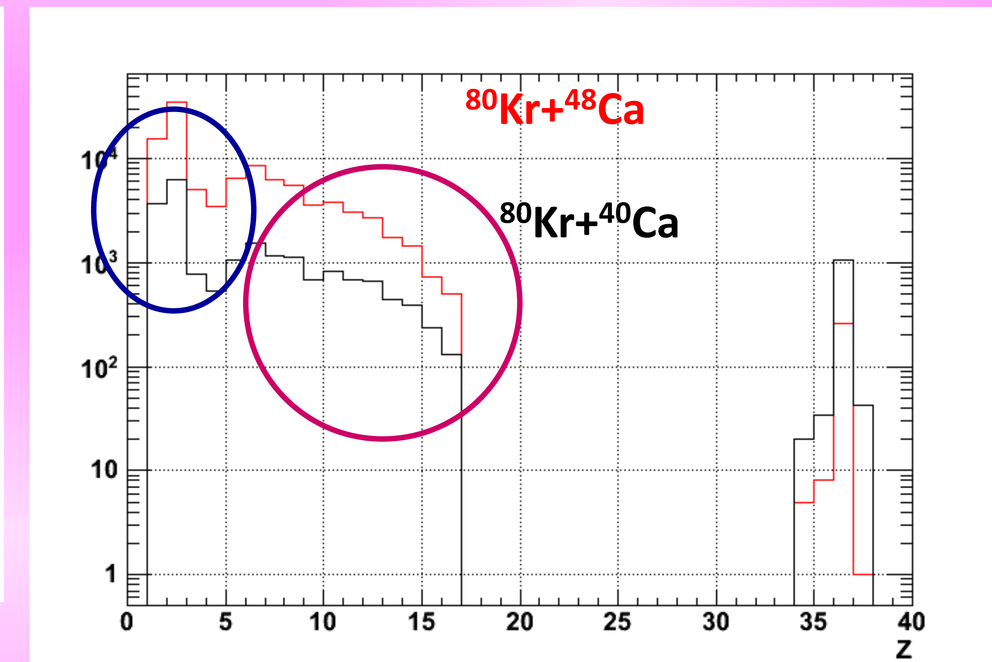
Fragments detected in coincidence with the QP

Z-v_{lab}



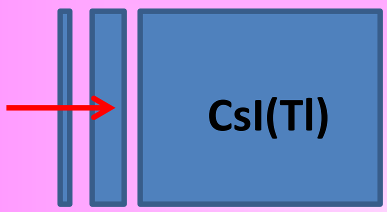
Charge distribution



Light fragments are mainly backward emitted with respect to CM

Similar charge distribution for both reactions

Heavier fragments mainly forward emitted



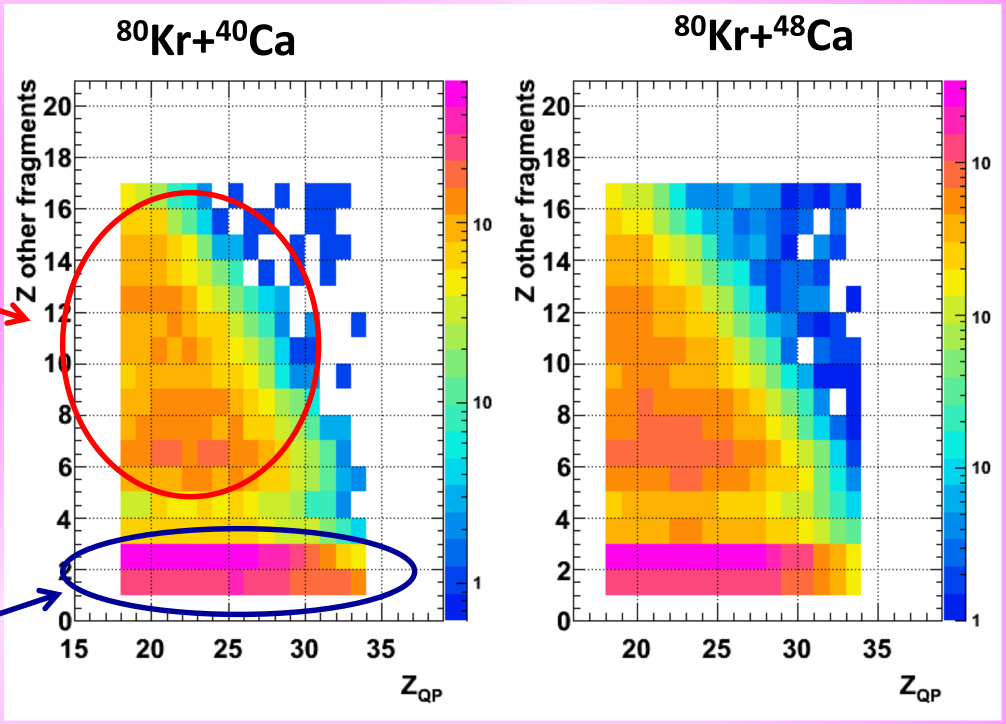
Preliminary analysis

[12]C contribution (backing of both targets) not removed

Fragments detected in coincidence with the QP

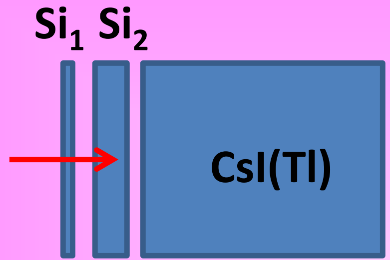
Only fragments stopped in Si_2 are included (ΔE-E only)

Z_{QP}-$Z_{other\ frag}$

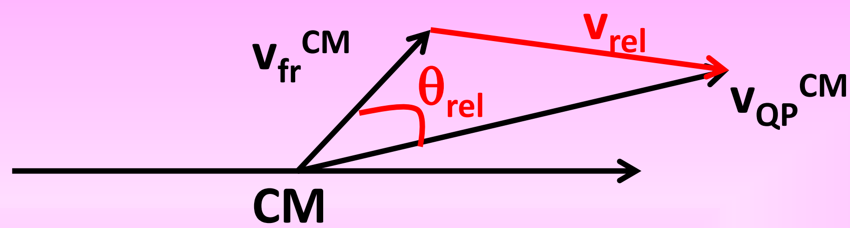


Heavier fragments anticorrelated with the size of the QP => QP fission? In this hypothesis, the "QP" is the biggest fission fragment

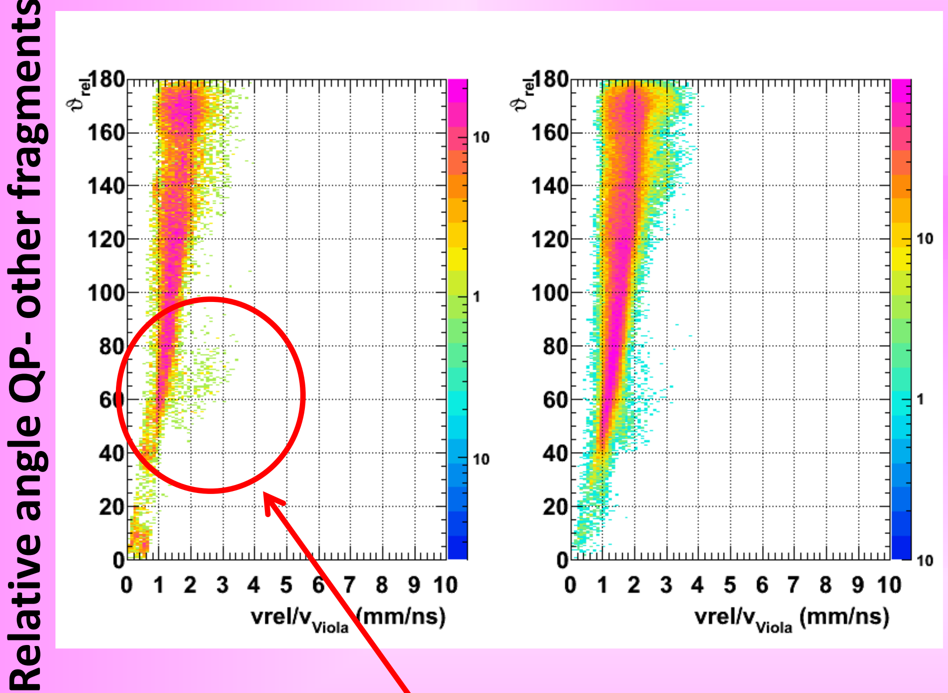
Light fragments emitted in coincidence with QP of every size => possible neck emission (QT contribution cannot be excluded)



Preliminary analysis

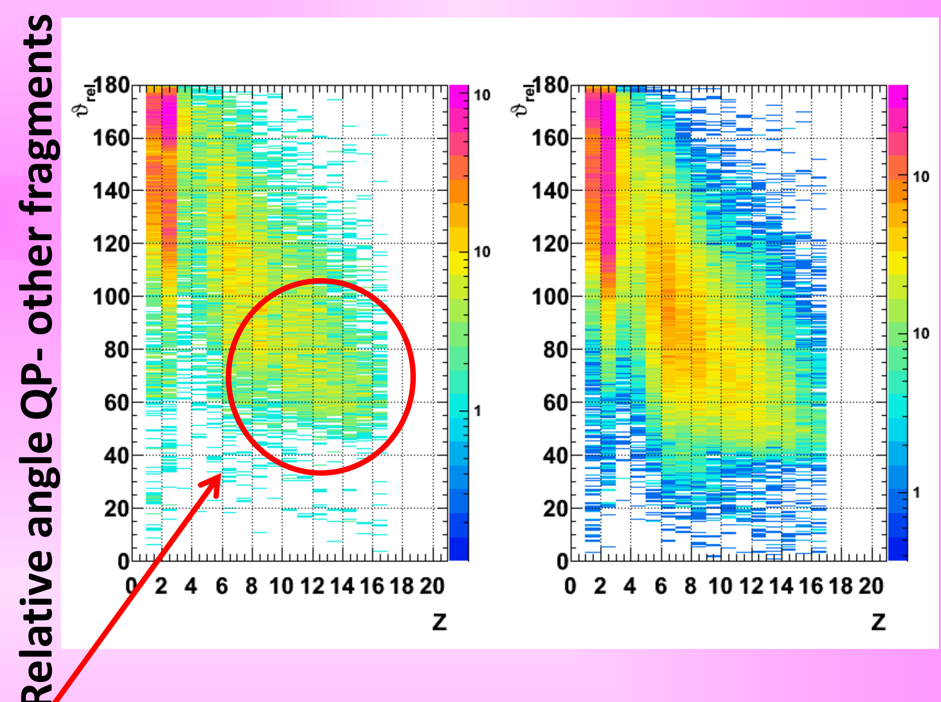


^{80}Kr+^{40}Ca ^{80}Kr+^{48}Ca



Relative velocity QP- other frag./v_{Viola}

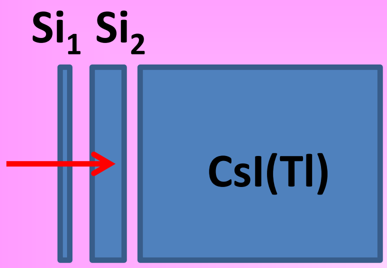
^{80}Kr+^{40}Ca ^{80}Kr+^{48}Ca



Z frag. detected in coinc. with the QP

Relative velocity of heavier fragments compatible with Viola velocity => fission hypothesis supported

Preliminary analysis

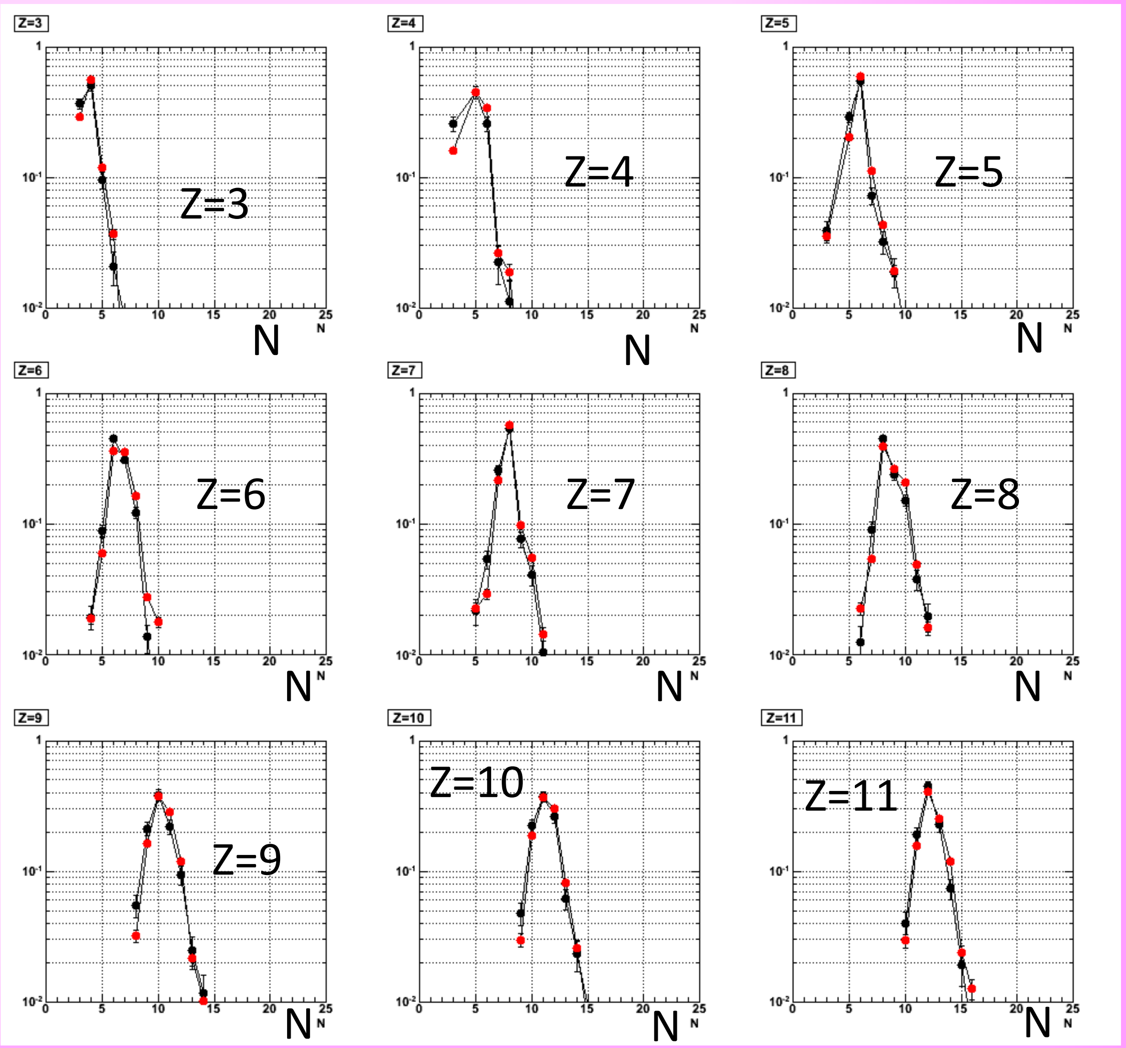


Only fragments stopped in Si_2 are included (ΔE-E only)

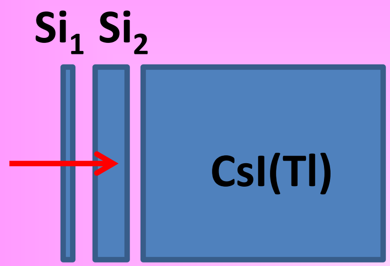
$^{80}Kr+^{48}Ca$

$^{80}Kr+^{40}Ca$

Isotopic distribution for different elements (fragments detected in coincidence with QP)



Isotopic distribution shifted towards the n-rich side for ^{48}Ca



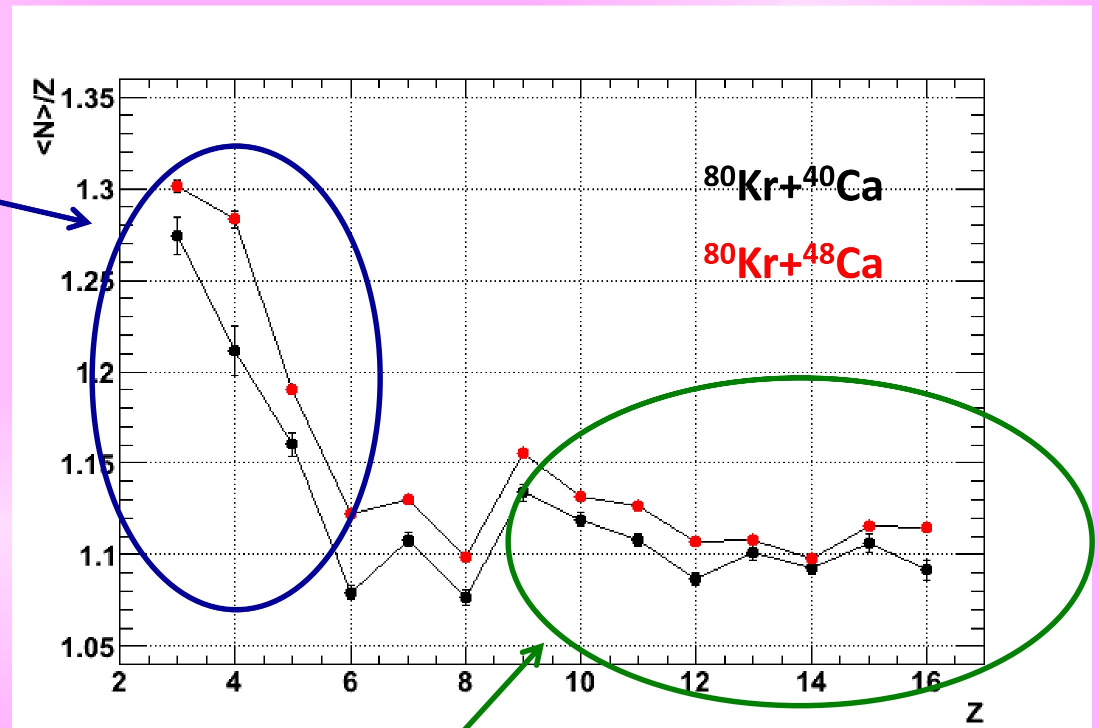
Preliminary analysis

^{12}C contribution (backing of both targets) not removed
It can reduce the difference in <N>/Z between the two systems

Only fragments stopped in Si_2 are included (ΔE-E only)

Average isospin of fragments detected in coincidence with the QP

Neck (although a QT contribution cannot be excluded)



Fragments detected in n-rich reaction show a bigger <N>/Z

Substantial agreement with the results obtained with the prototype telescope

QP fission?

Conclusions and perspectives

- <N>/Z higher for fragments detected in coincidence with QP when the target is the n-rich ^{48}Ca
- **Next steps:**
  - add to the analysis the fragments stopped in Si_1 (PSA) and fragments stopped in CsI(Tl) (ΔE-E in Si_2-CsI(Tl) and PSA in CsI(Tl))
  - Separation of the QT contribution => clearer neck identification
  - Centrality selection (e.g. from $Z_{biggest}$ vs. v)
  - When possible, N/Z event by event for the two fission fragments of the QP
  - Comparison with the prediction of the models (e.g. SMF, AMD) in order to extract information on the symmetry energy term

Thank you for your attention