Extracting information on E_{sym} by coupling the VAMOS spectrometer and the 4π INDRA detector to reconstruct primary fragments

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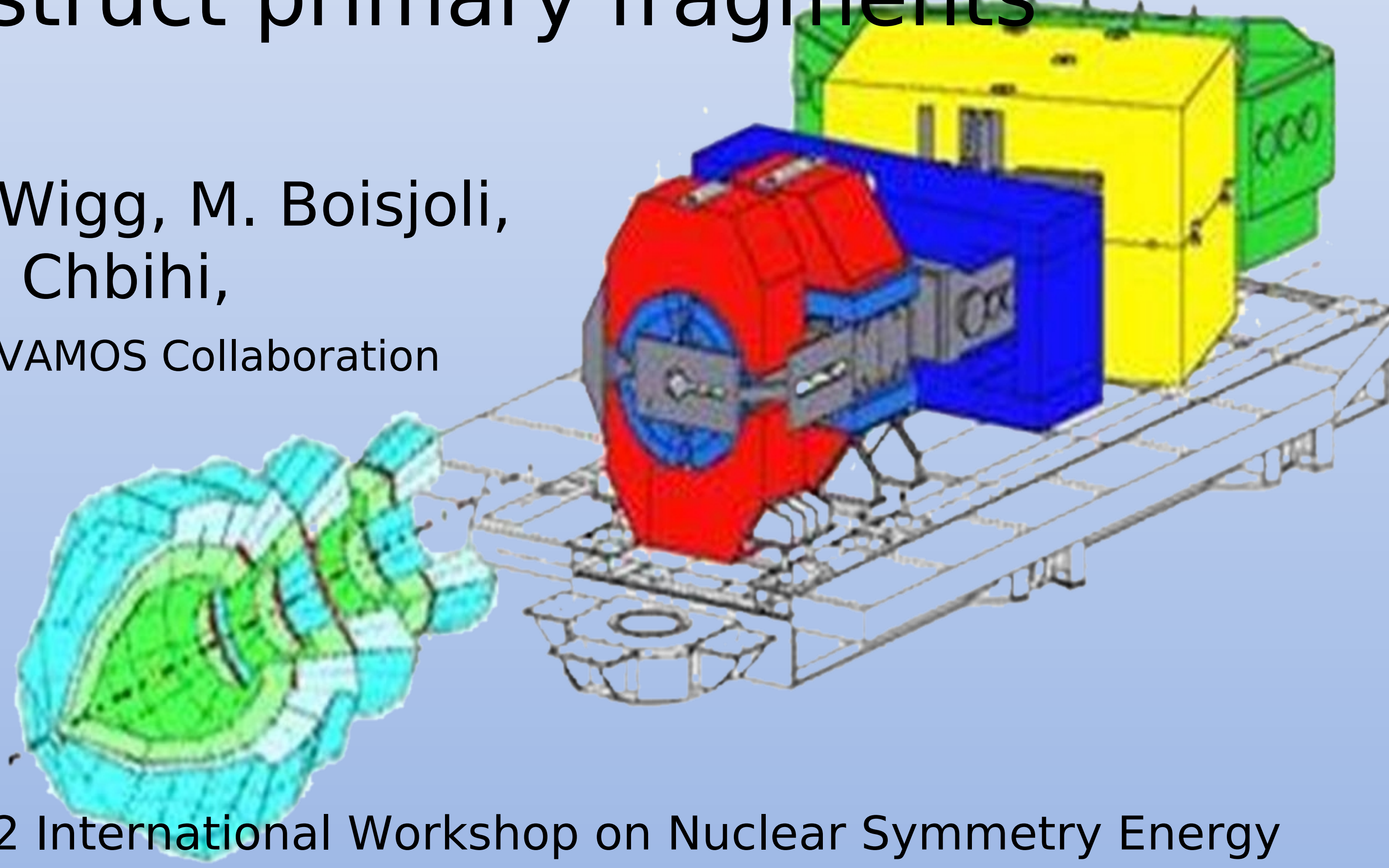


ASY-EOS 2012 International Workshop on Nuclear Symmetry Energy and Reaction Mechanisms - Siracusa 4th – 7nd September 2012

Equation of state of excited exotic nuclei and nuclear matter

$$E(\rho, N\text{-}Z) = \underbrace{E(\rho, N\text{-}Z=0)}_{\text{symmetric}} + \underbrace{E_{sym}(\rho)\frac{(N-Z)^2}{A}}_{\text{asymmetric}}$$

symmetric asymmetric
matter

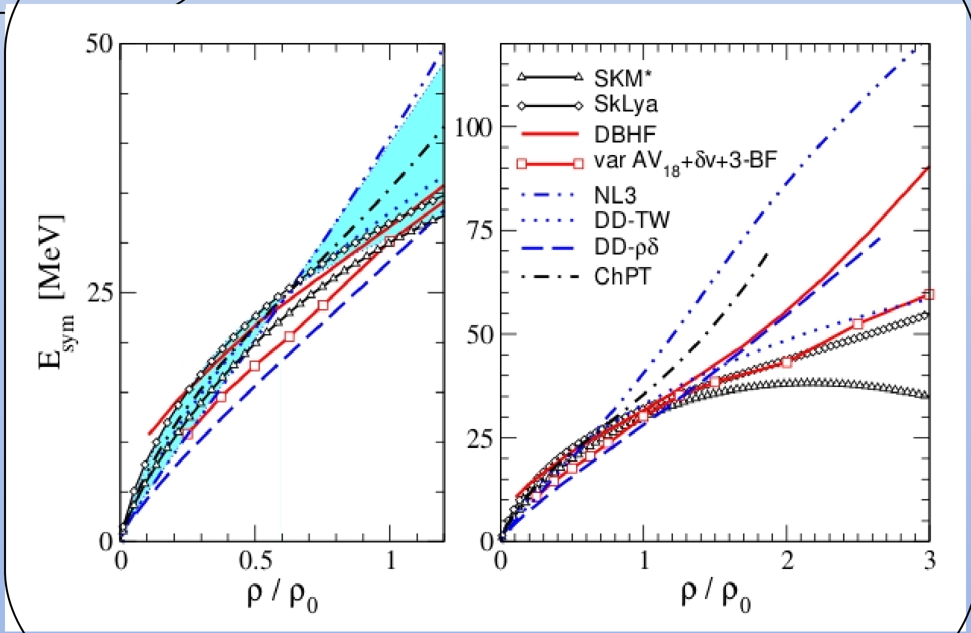
Constraints on the EOS:

- $BE = a_V A - a_s A^{2/3} - a_c \frac{Z(Z-1)}{A^{1/3}} + \delta - a_{sym}\frac{(N-Z)^2}{A}$
- Nuclear incompressibility
- ➡ Rare Ion Beams

Impact of E_{sym} density dependence:

- Nuclear structure of exotic nuclei
  - nuclei properties (n-skin, GDR...)
  - n-drip line (limit of existence of nuclei)
- Heavy ion collisions
  - reaction mechanisms
  - final products composition
- Astrophysics
  - n-star properties (mass, radius, cooling rate...)
  - supernovae evolution

Status of theory



C. Fuchs et al., EPJ A30 (2006) 5

From finite to infinite systems....

Heavy ion collisions
at intermediate energies

⟷

T and densities as in astrophysical
environment

Can we extrapolate from finite to infinite systems?

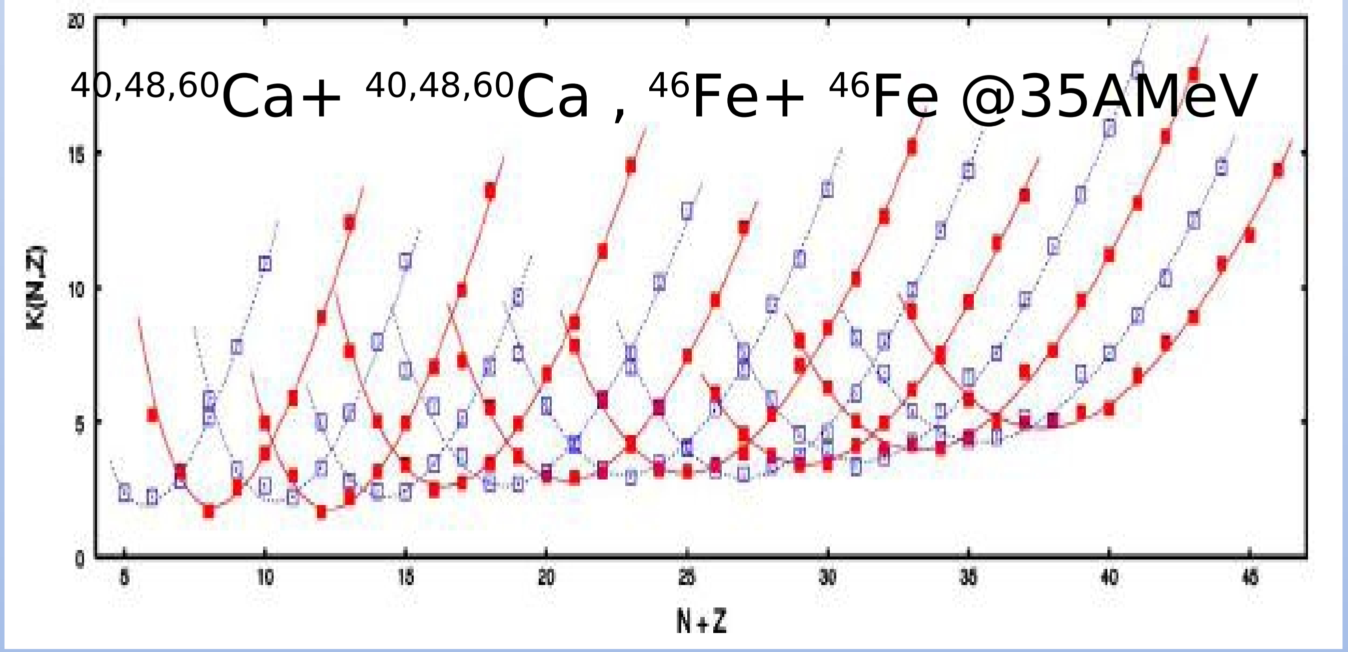
⇩

MEASURABLE
QUANTITY:

Isotopic
distributions of
complex fragments

A. Ono et al., Phys. Rev. C70, 041604(R) (2004)

^{40,48,60}Ca+ ^{40,48,60}Ca , ^{46}Fe+ ^{46}Fe @35AMeV

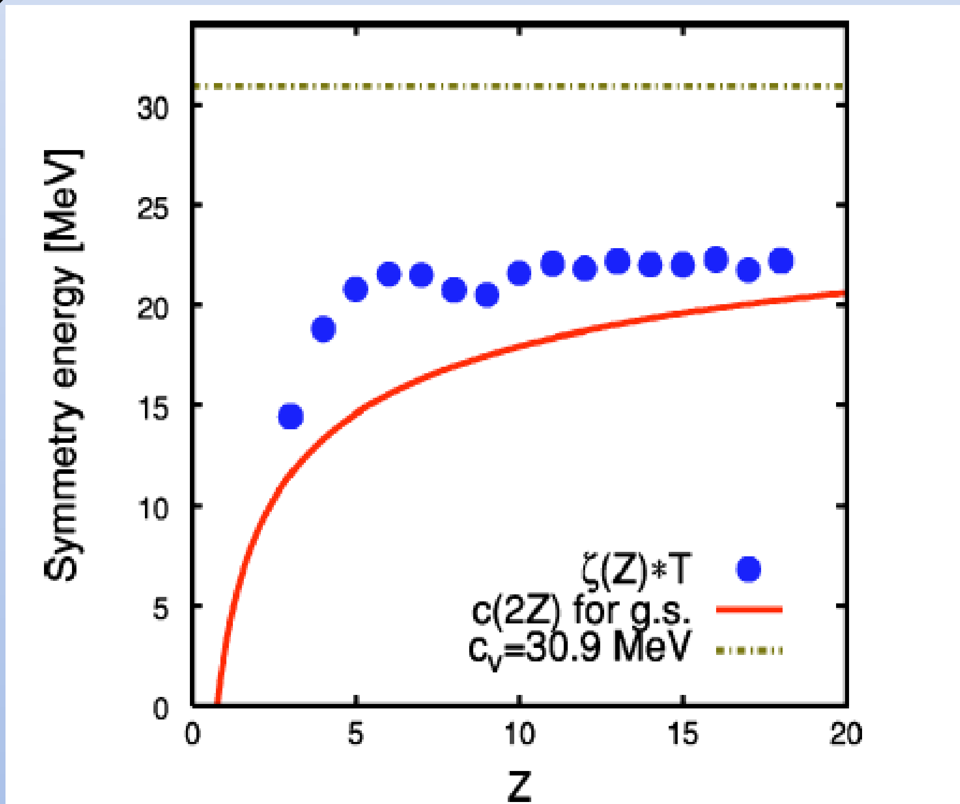


$$K(N,Z) = \varepsilon(Z)N + \eta(Z) + \varsigma(Z)\frac{(N-Z)^2}{(N+Z)}$$

From finite to infinite systems....

$$K(N,Z)=\varepsilon(Z)N+\eta(Z)+\varsigma(Z)\frac{(N-Z)^2}{(N+Z)}$$

Statistical treatment



$$\varsigma=c_{sym}(A(Z))/T$$

$$\varsigma\propto 1-k(2Z)^{-1/3}$$

$$k=-c_s/c_v$$

ζ(Z) independent of Z → negligible surface effects → Symmetry energy of infinite nuclear matter

The INDRA-VAMOS experiment

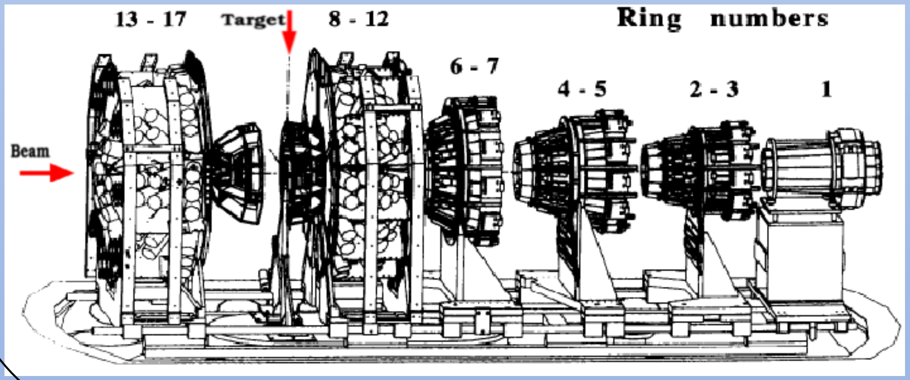
$^{40,48}Ca + ^{40,48}Ca$ @ E/A = 35 MeV GANIL 2007

Goal: experimental verification of AMD predictions on the surface contribution to E_{sym} in multifragmentation reactions

INDRA

- ✓ ≈90% of 4π solid angle
- ✓ high granularity
- ✓ low energy thresholds
- ✓ good energy resolution
- ✓ large dynamic range in E and identification capability

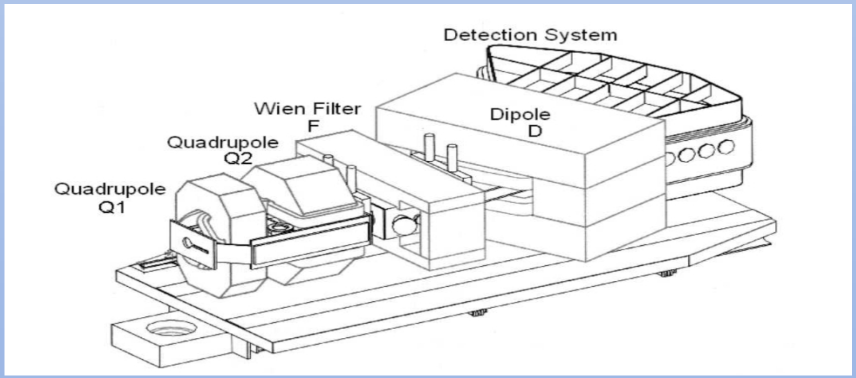
complete reconstruction of kinematics for each event

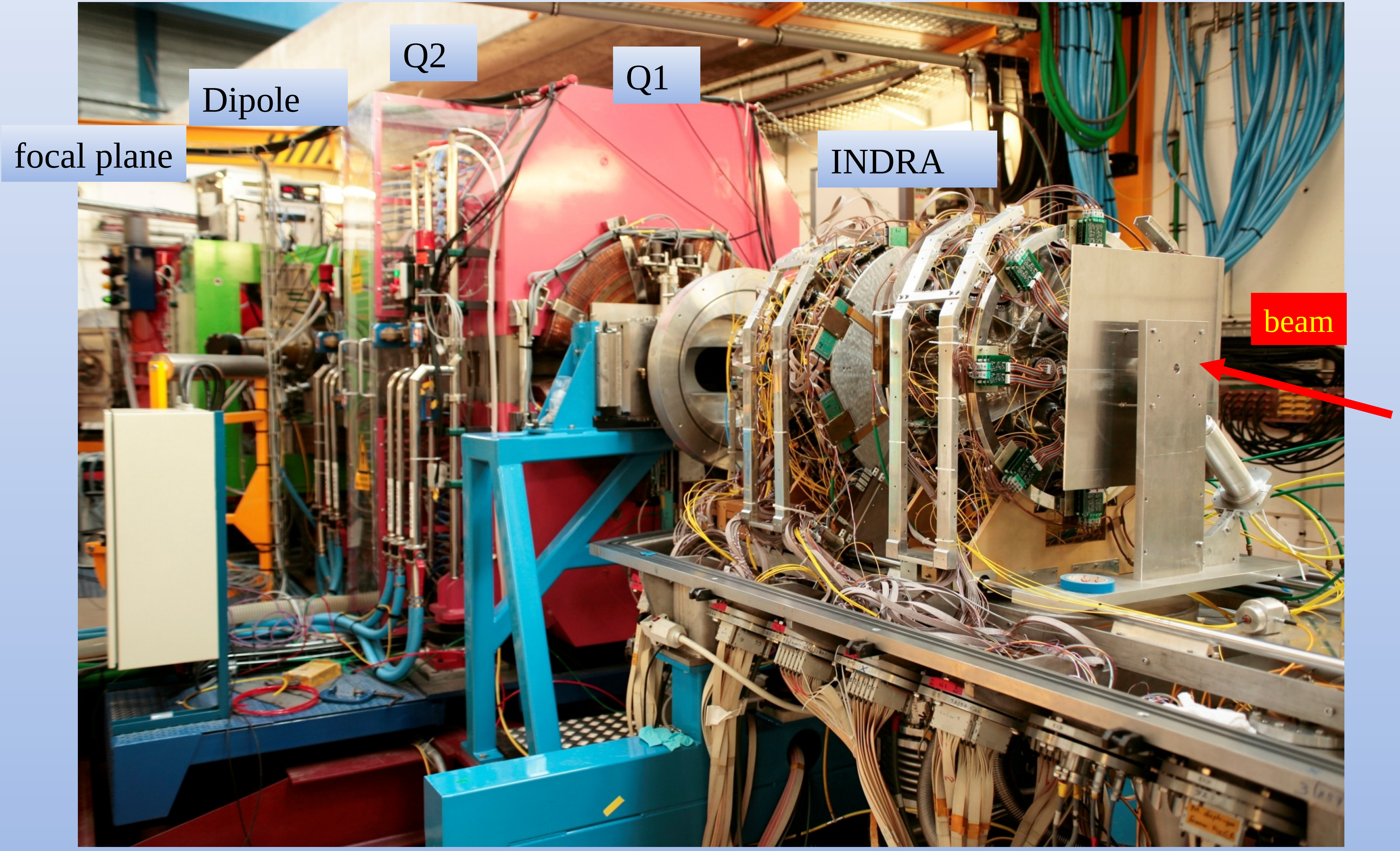


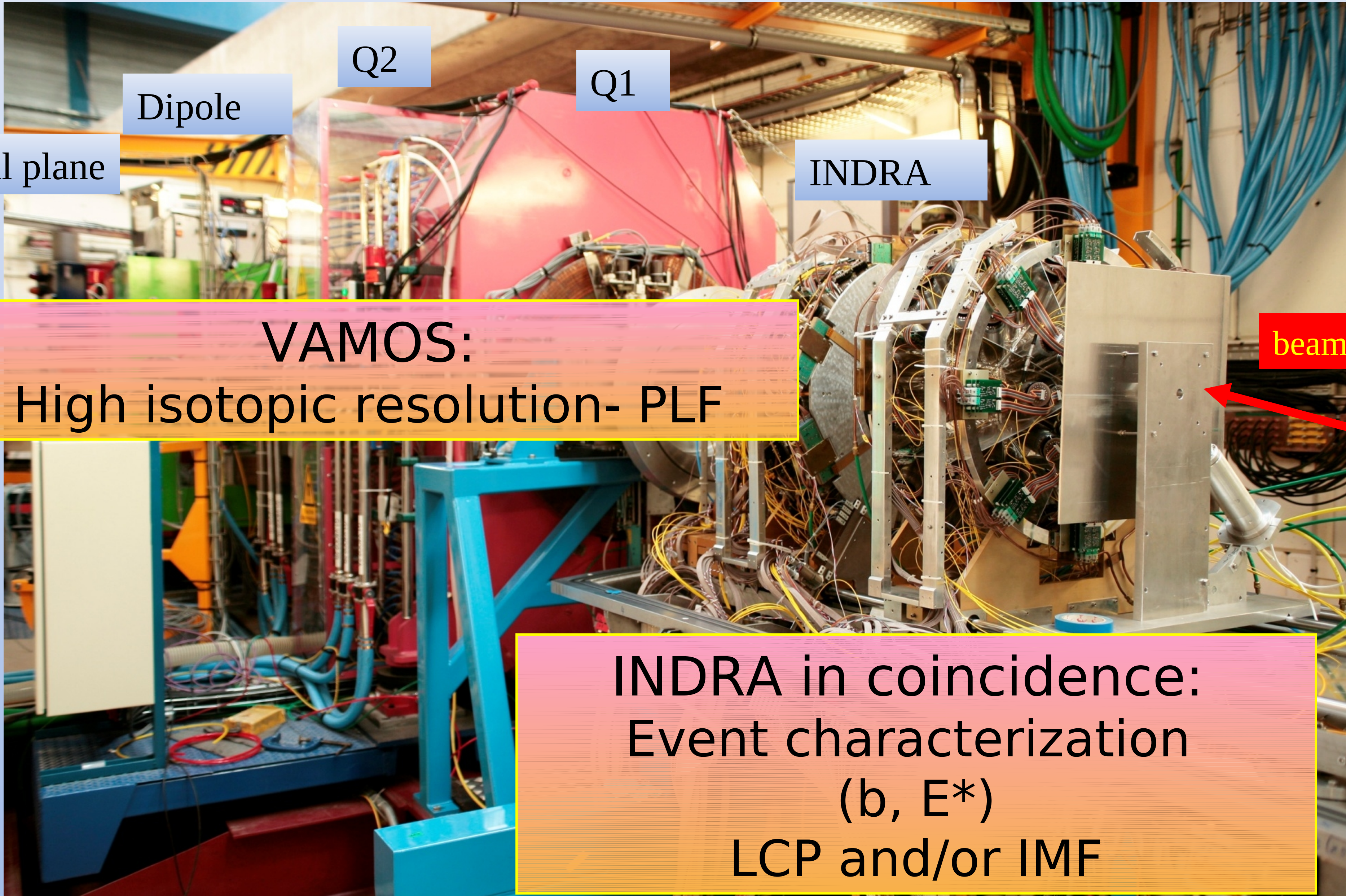
VAMOS

- ✓ large geometrical acceptance
- ✓ momentum acceptance ±10%
- ✓ $B\rho_{max}$=1.6Tm
- ✓ Focal plane detection setting:
  - position sensitive detectors (x,y,t)
  - silicon wall (ΔE)
  - CsI wall (E)

Products selection and high isotopic resolution



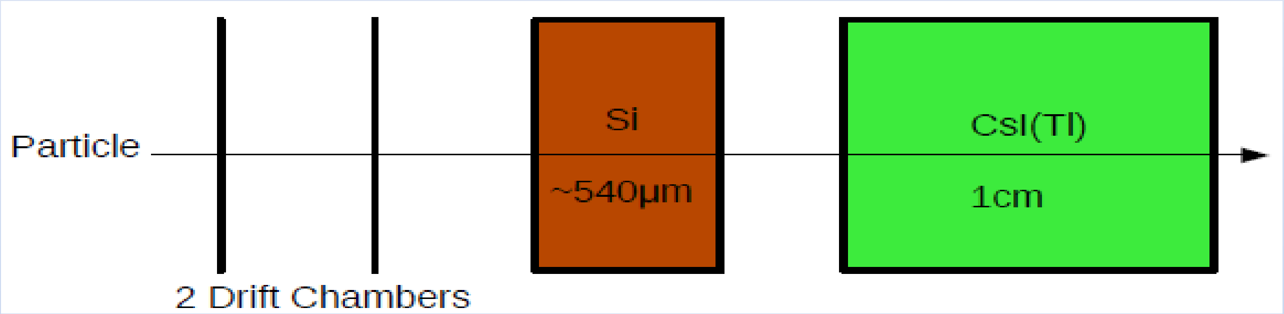

Q2
Q1
Dipole
focal plane
INDRA
beam



VAMOS:
High isotopic resolution- PLF

INDRA in coincidence:
Event characterization
(b, E*)
LCP and/or IMF

How do we get isotopic distributions from VAMOS?
(Peter's and Mark's PhD work)



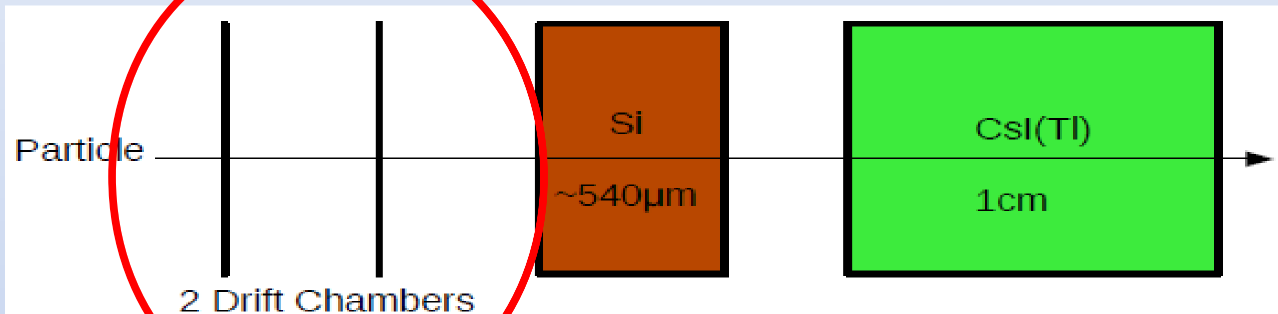
x, y, t — Trajectory reconstruction, A identification

DE, E — Z identification

V
A
M
O
S

- ✓ Trajectory reconstruction
- ✓ Z identification
- ✓ Time of flight calibration
- ✓ A and A/Q corrections
- ✓ Yields normalization

Trajectory reconstruction

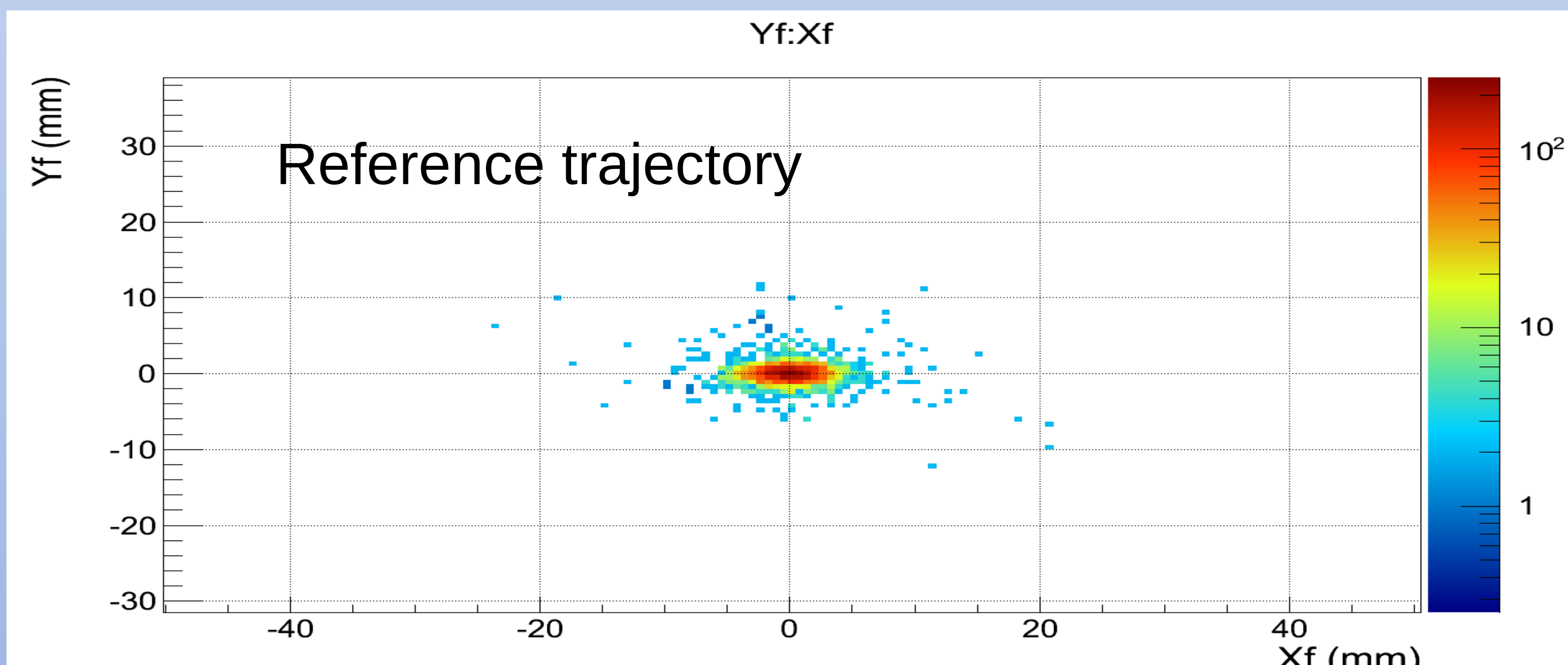


x, y, t   DE   E

Trajectory reconstruction
A identification

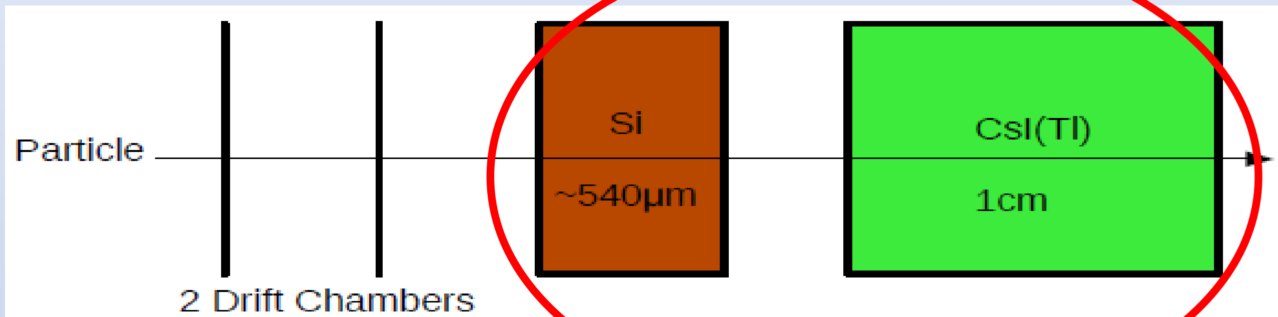
Z identification

V
A
M
O
S



Bρ, θ, ϕ

Z identification



x, y, t

DE

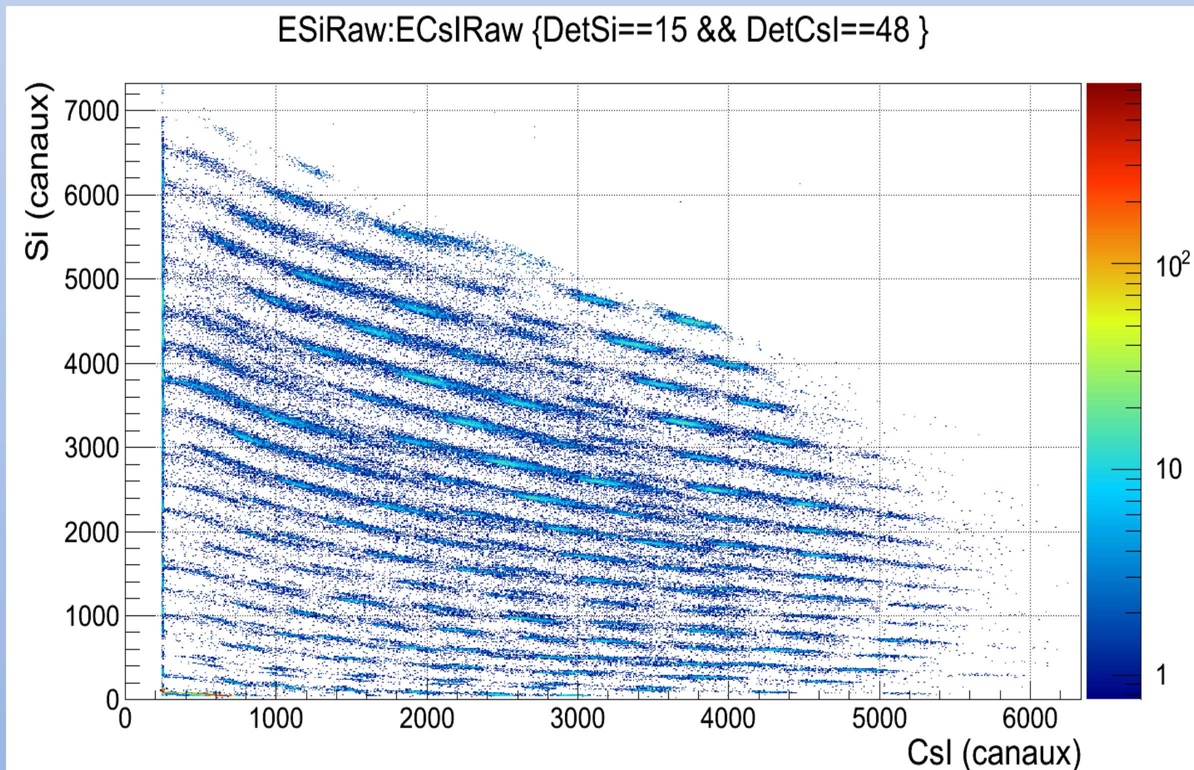
E

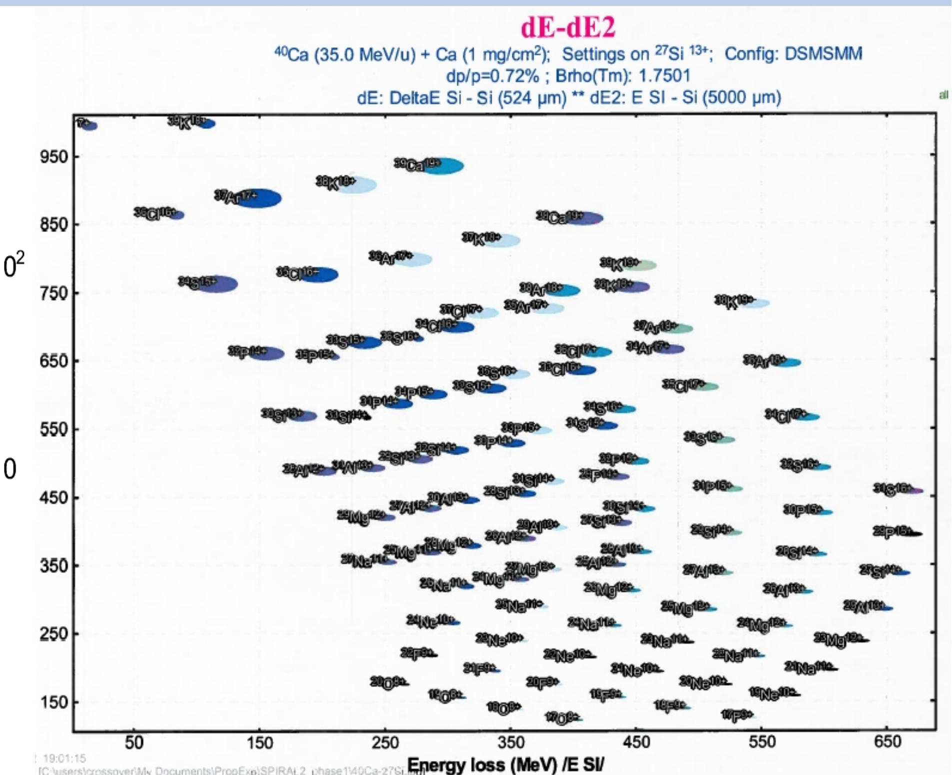
Trajectory reconstruction
A identification

Z identification

Z

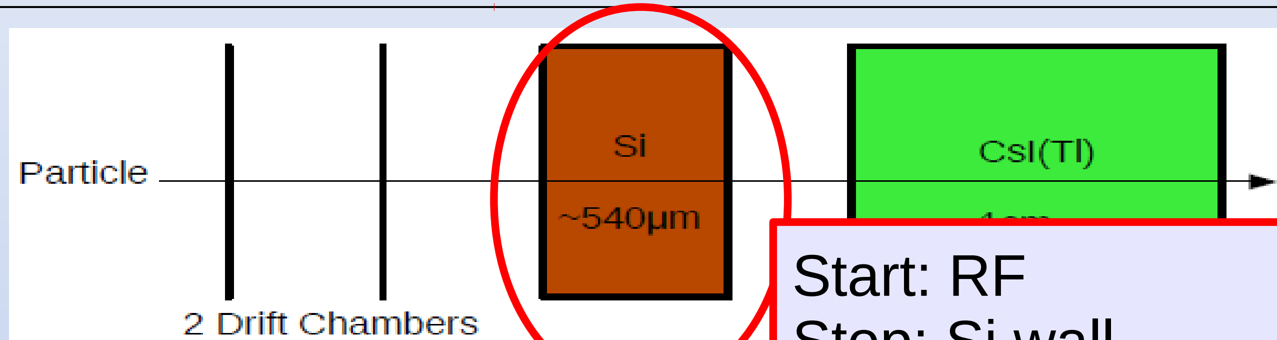
VAMOS





Time of flight calibration

tof



x, y, t

DE

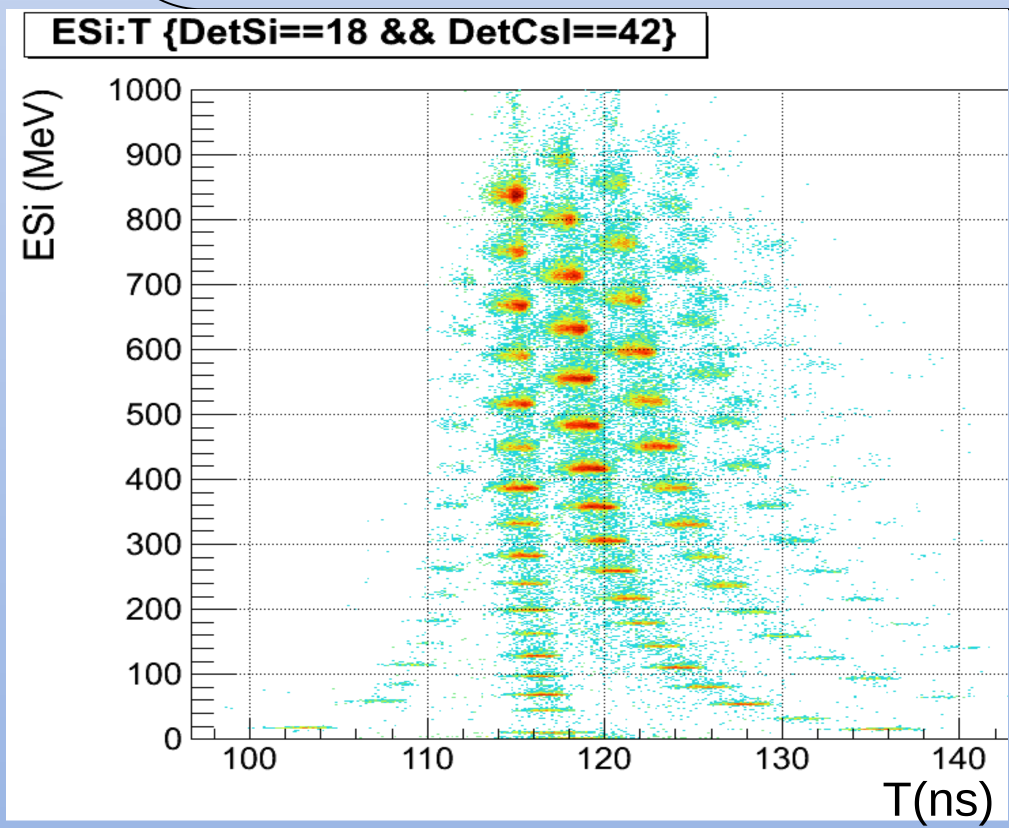
Trajectory reconstruction
A identification

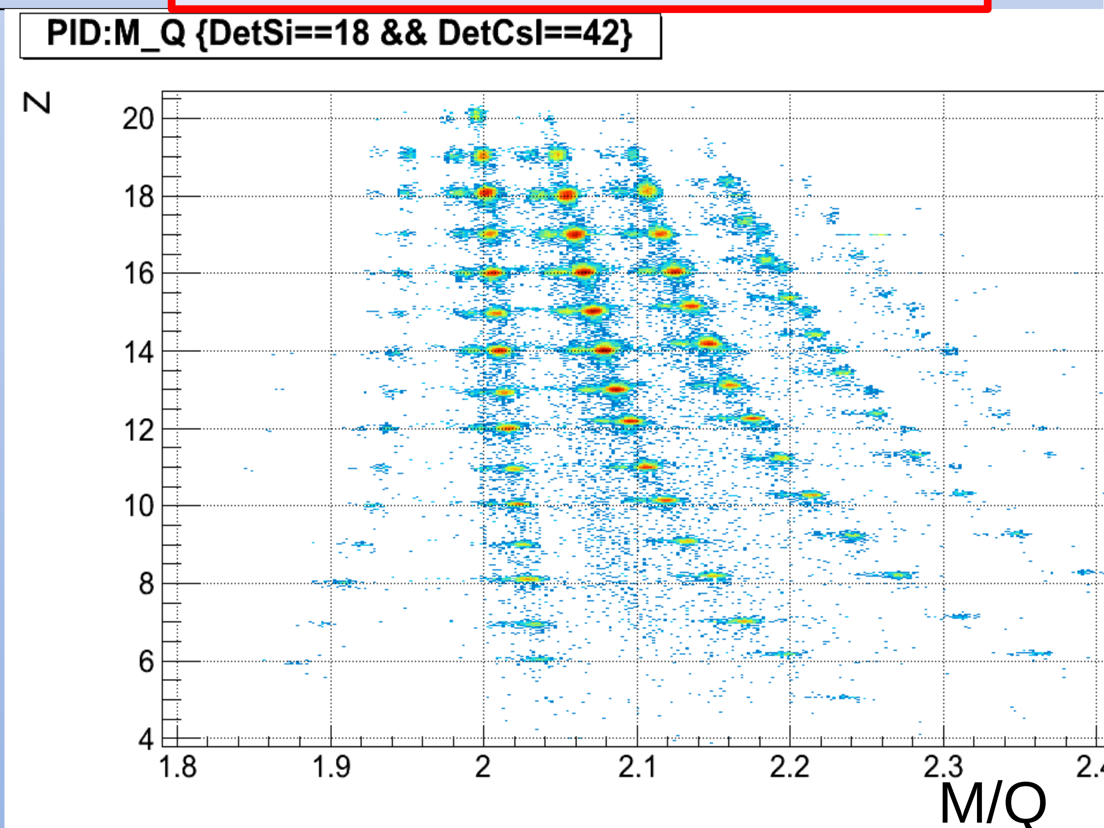
Z ident

Start: RF
Stop: Si wall

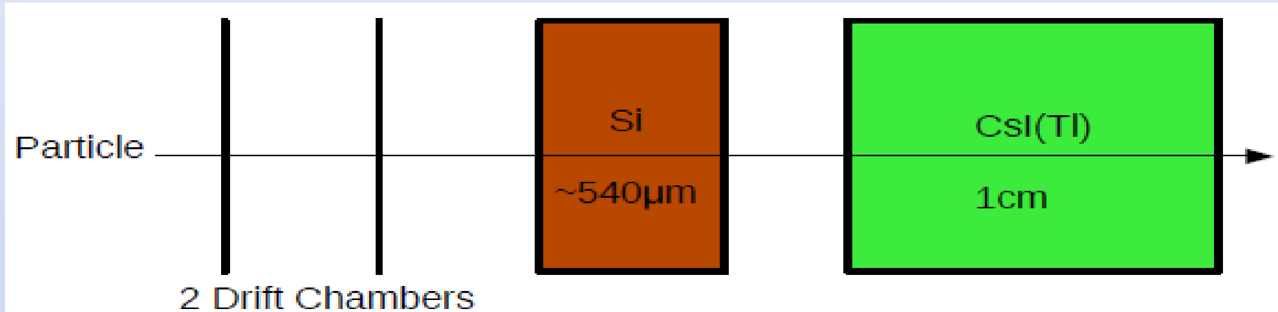
One tof offset for each run to get aligned M/Q distributions

VAMOS





A and A/Q corrections



x, y, t — DE — E

Trajectory reconstruction
A identification

Z identification

VAMOS

Etot, tof, Z, Bρ

$$A = 2\,E_{tot}/v^2$$

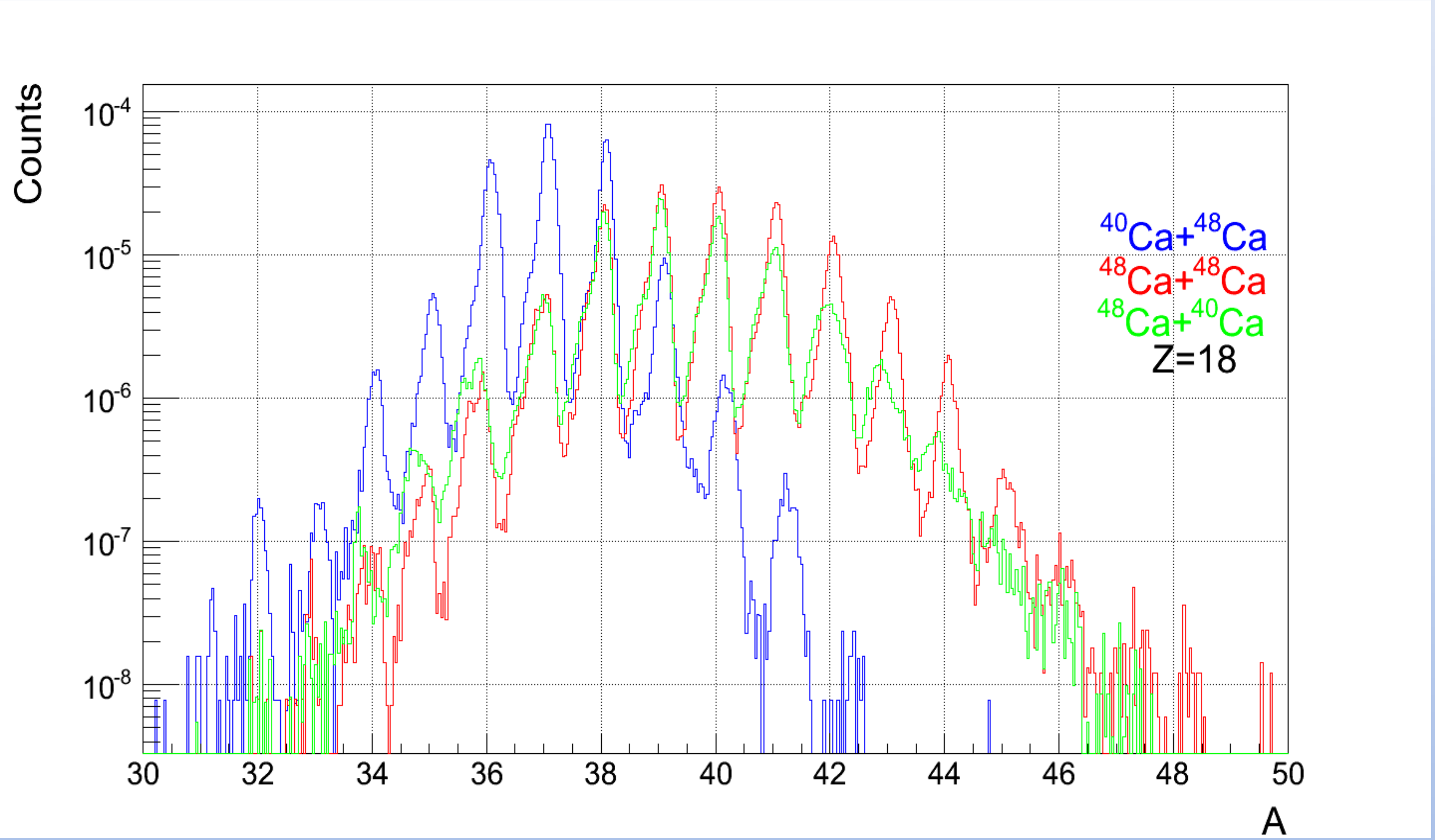
$$A/Q = B\rho/(3.105\,\beta)$$

$$Q = A/(A/Q)$$

Z, A

CsI, Bρ and (Bρ,Q) dependent corrections

Yield normalization



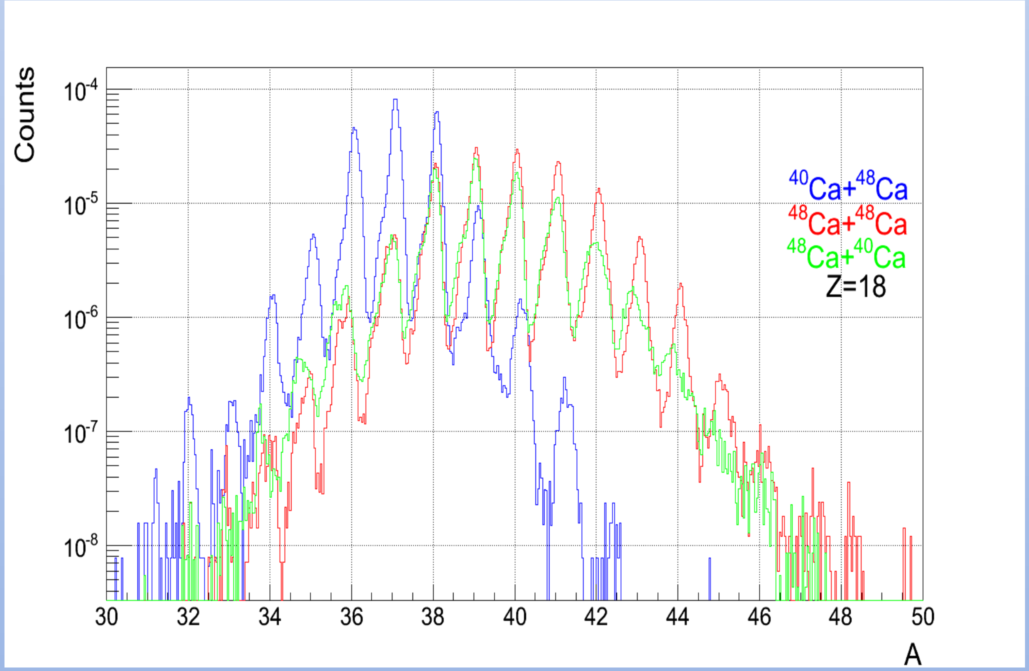
- ✓Beam intensity
- ✓ϕ acceptance for each Bρ
- ✓Account for Bρ overlap

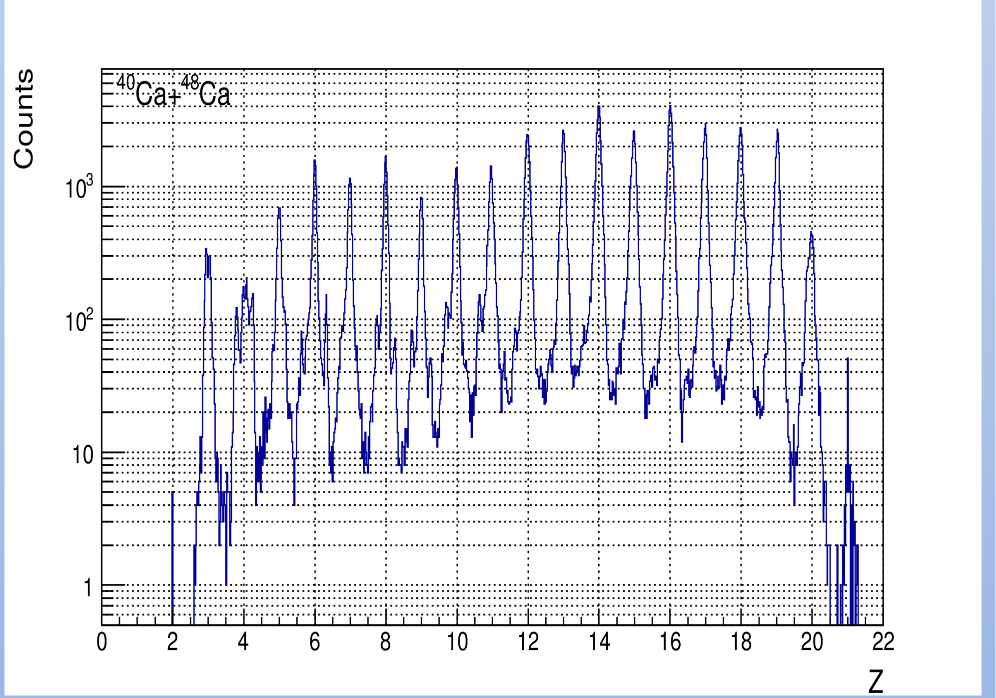
Exploiting the VAMOS isotopic resolution

- ✓Isoscaling and isobaric yield ratio analysis (Mark's thesis)
- ✓Isospin diffusion (Peter's thesis)
- ✓Verification of transport model predictions on the symmetry energy
- ✓.....

Secondary decay

- ✓Primary fragment reconstruction

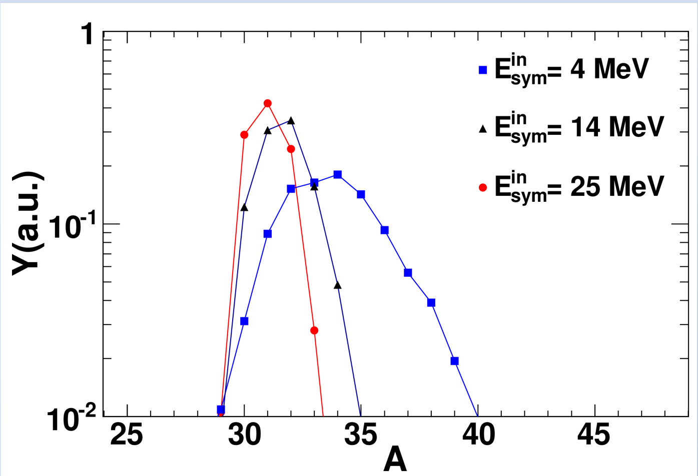




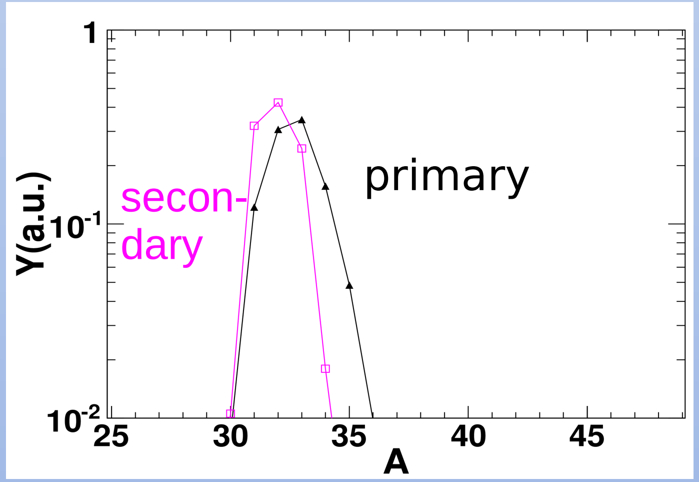
Effects of secondary de-excitation on measured isotopic distributions

Statistical model simulation for Z=15

✓ Fragments production



✓ Secondary de-excitation



Fragment isotopic distributions are:

✘ sensitive to the symmetry energy

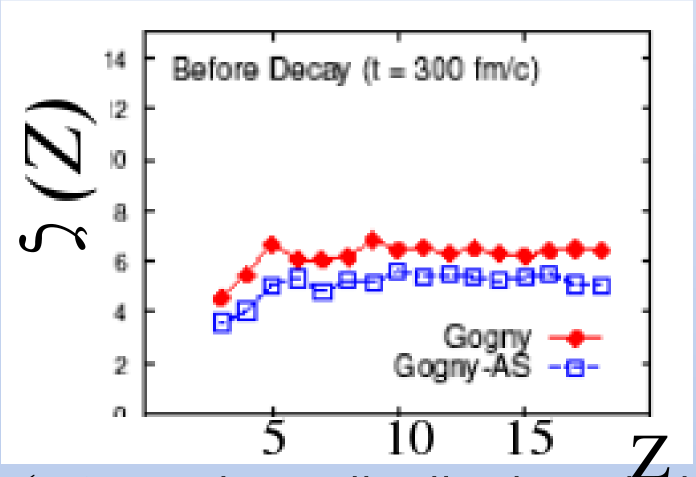
✘distorted by secondary decay

✓ Look for quantities in which the secondary decay effects cancel out

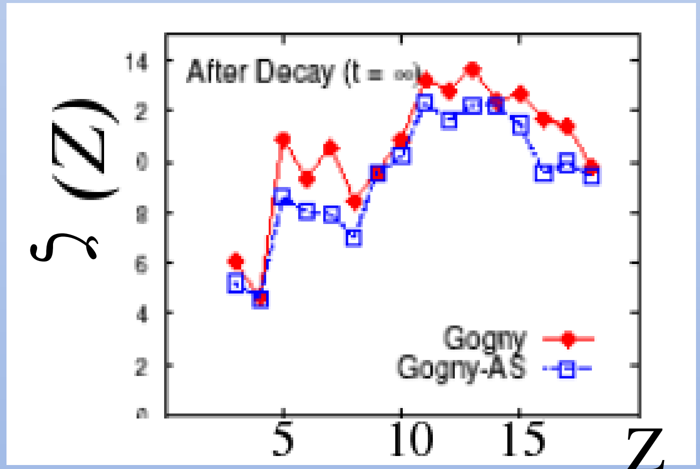
✓ Reconstruct primary fragments

Anti-symmetrized molecular dynamic

✓“Primary” distribution width



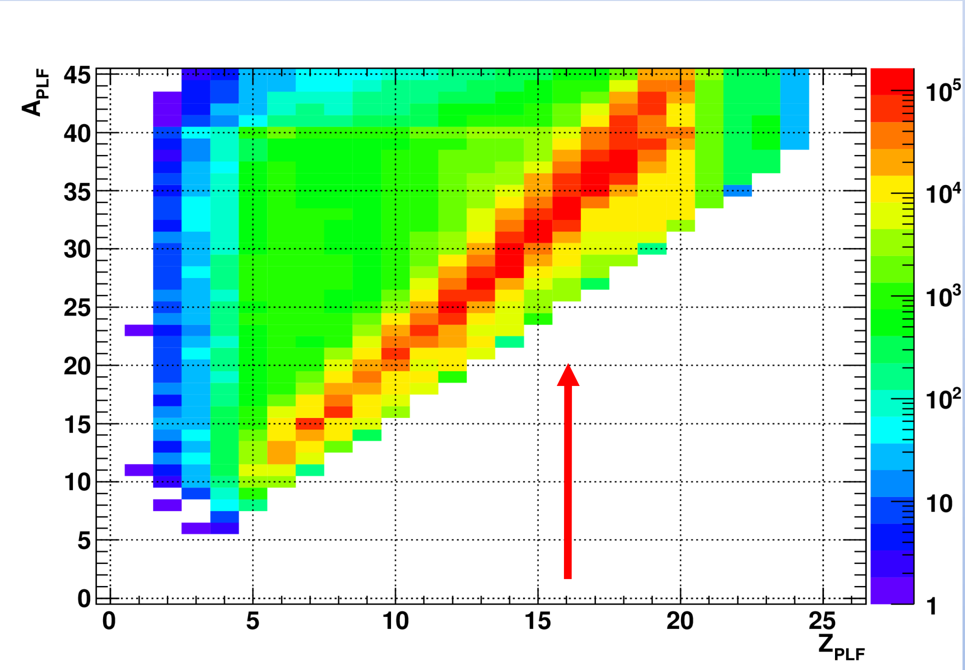
✓ “Secondary” distribution width

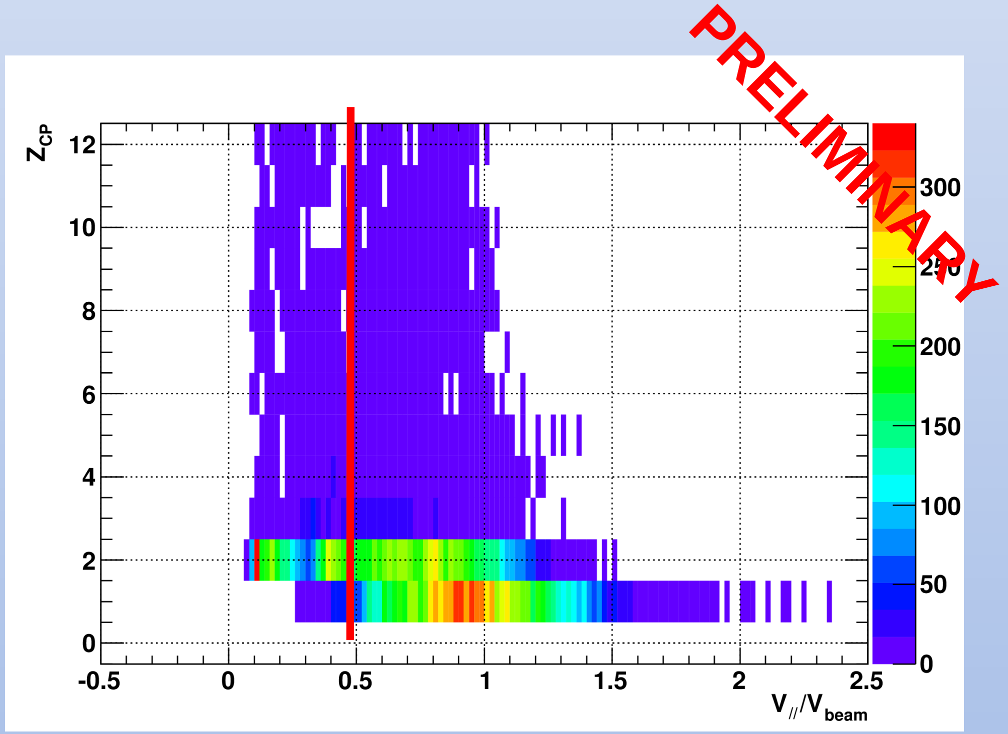


A. Ono et al., PRC 70, 041604(R) 2004

Exploiting the VAMOS isotopic resolution and the INDRA granularity: toward the primary fragment reconstruction

An example of event by event primary fragments reconstruction:
$^{40}Ca + ^{48}Ca$ (peripheral collisions)



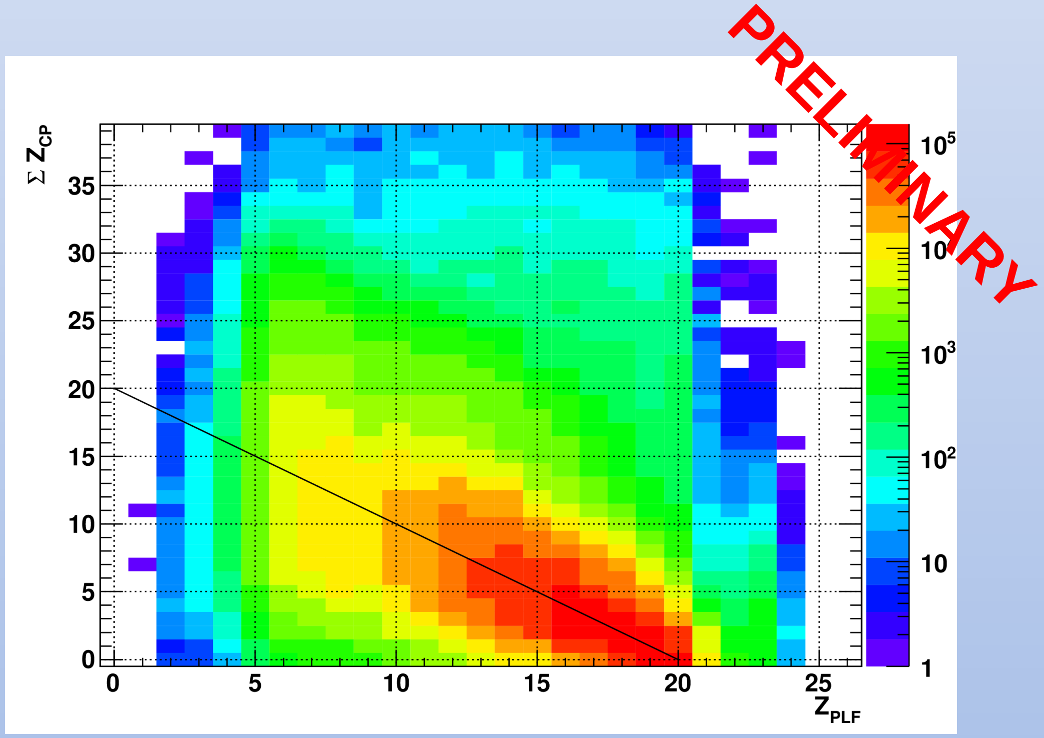


VAMOS isotopic resolution:
precise PLF selection

INDRA energy resolution and identification capability:
CP emitting source selection

Exploiting the VAMOS isotopic resolution and the INDRA granularity: toward the primary fragment reconstruction

An example of event by event primary fragments reconstruction:
$^{40}Ca + ^{48}Ca$ (peripheral collisions)



- $Z_{PLF} = 16$
- Selection of particles emitted from the QP
- Selection of fully detected QP events

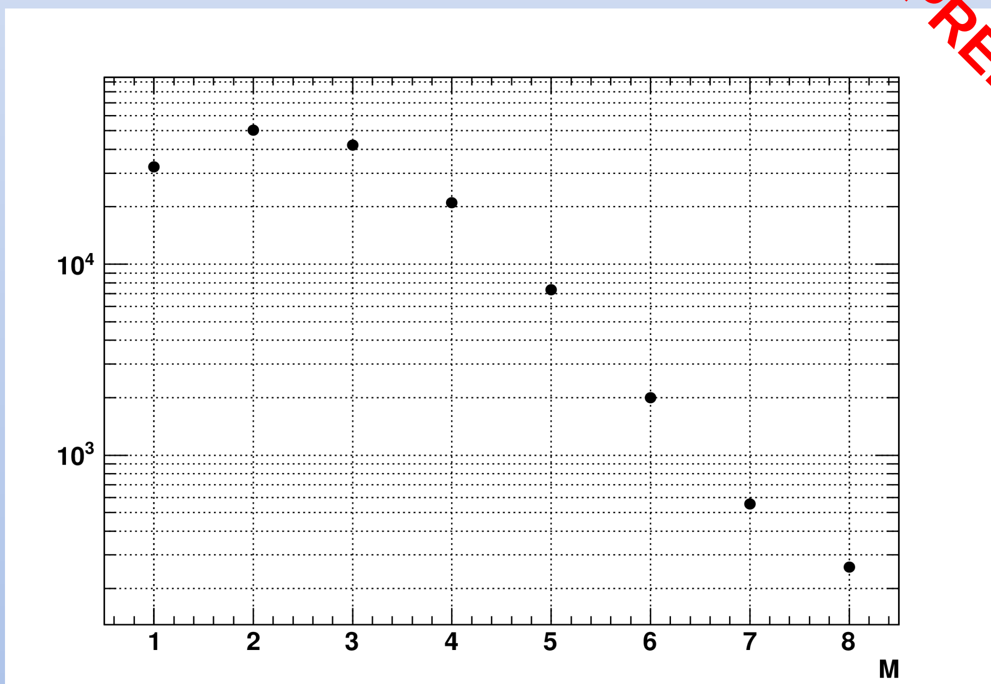
What are the particles emitted in coincidence with the PLF?

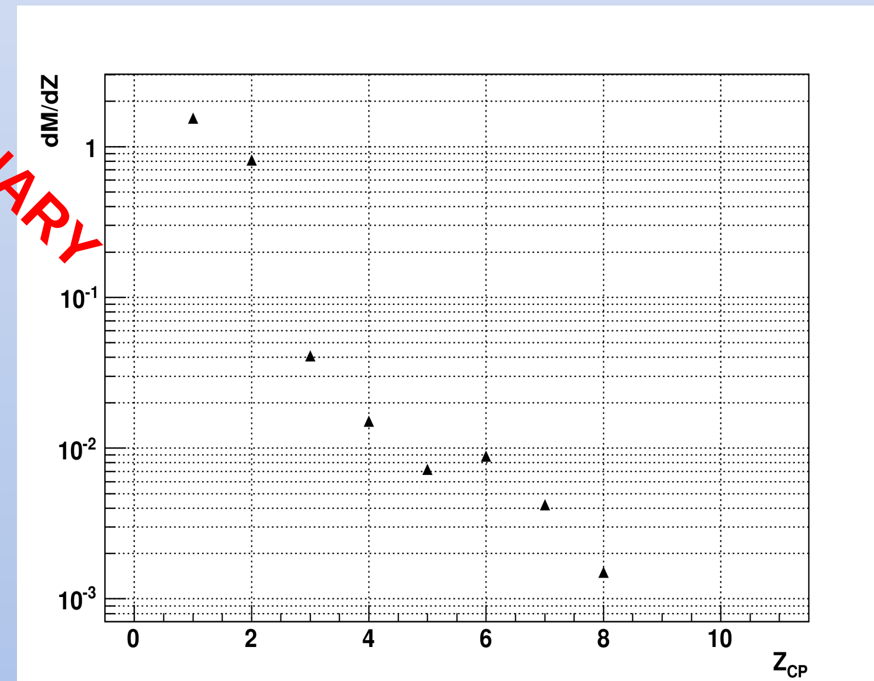
Selection of fully detected QP decay events:
$Z_{total} = 20$

Exploiting the VAMOS isotopic resolution and the INDRA granularity: toward the primary fragment reconstruction

An example of event by event primary fragments reconstruction:
$^{40}Ca + ^{48}Ca$ (peripheral collisions)

PRELIMINARY





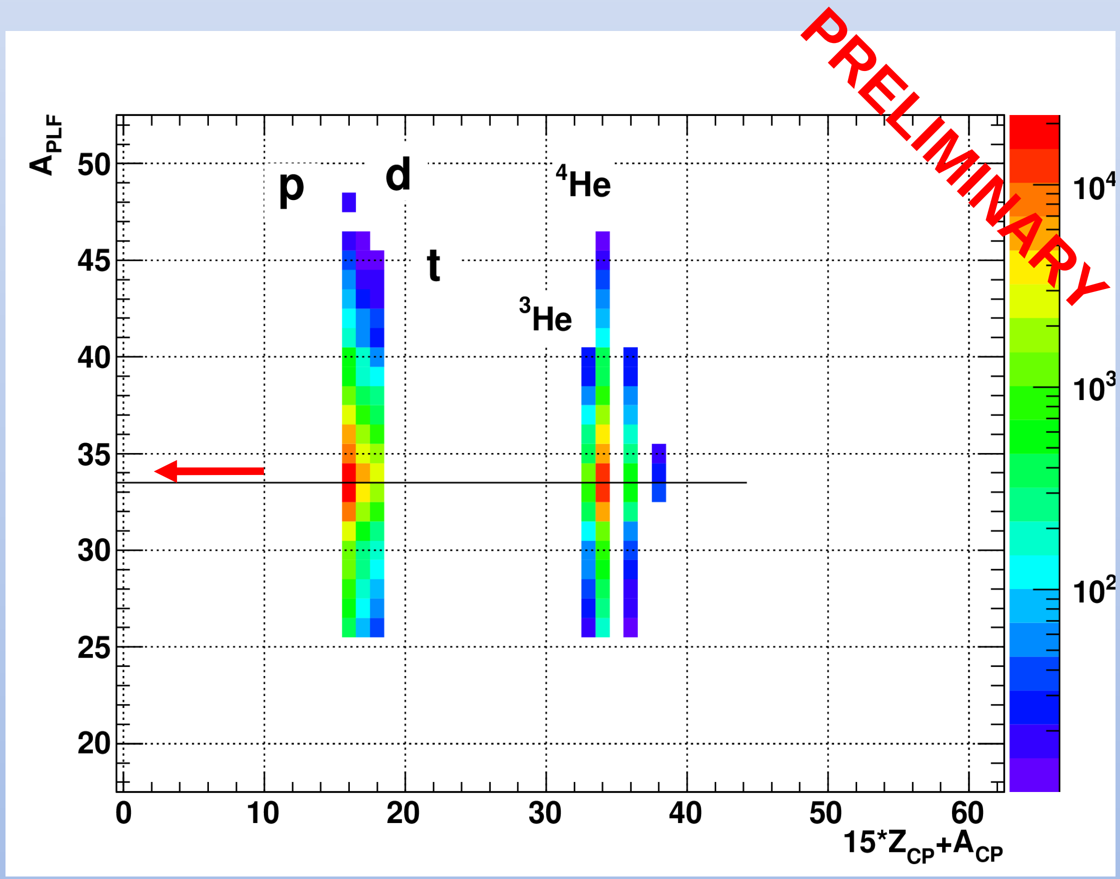
The multiplicity of fragments emitted in coincidence with ZPLF=16 is M=1-3

We select M=3

Fragments emitted in coincidence with ZPLF=16 in events with M=3 are mainly H and He

Exploiting the VAMOS isotopic resolution and the INDRA granularity: toward the primary fragment reconstruction

An example of event by event primary fragments reconstruction:
$^{40}Ca + ^{48}Ca$ (peripheral collisions)



We choose A_{PLF}=34

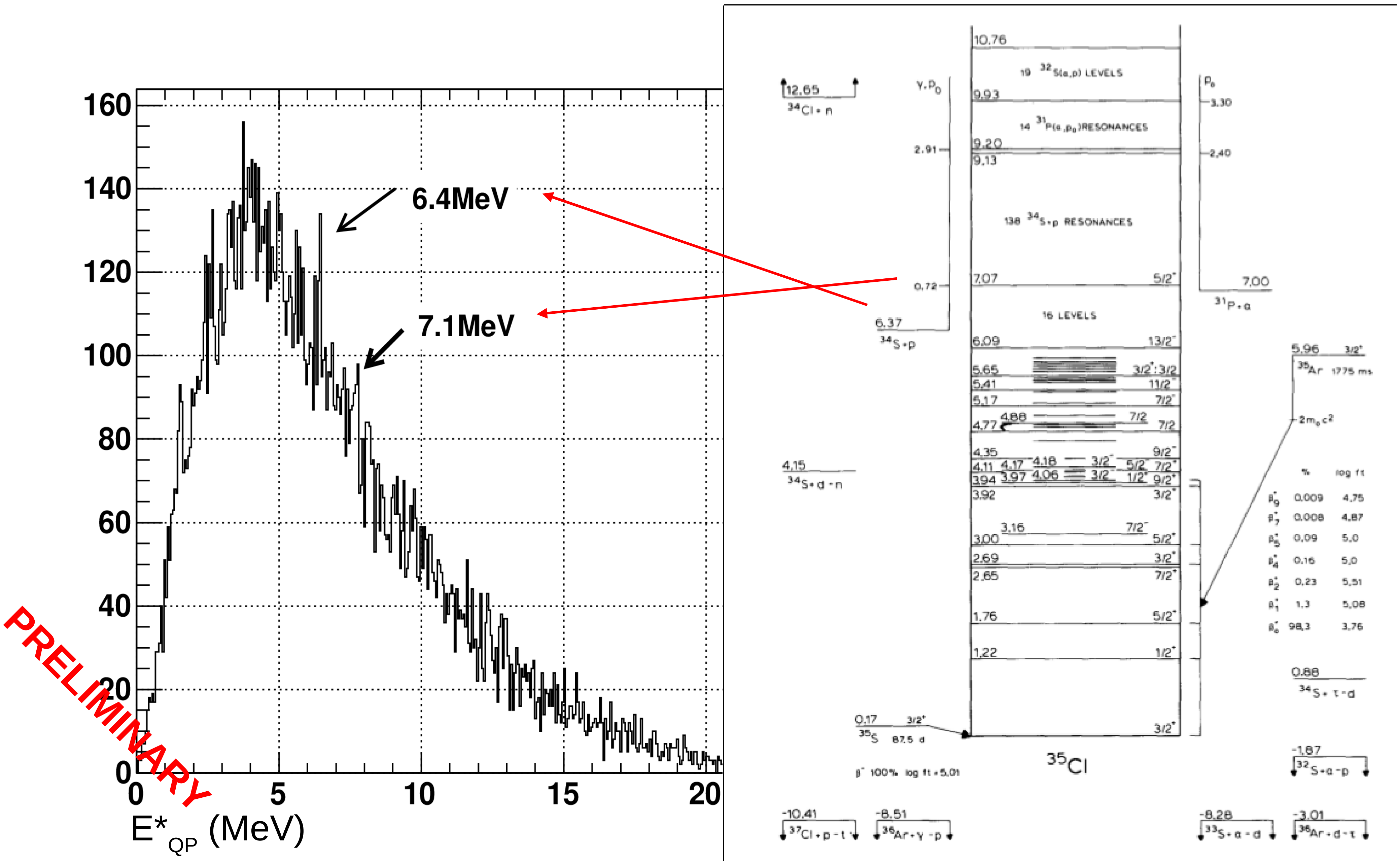
- Z_{PLF} = 16
- Selection of particles emitted from the QP
- Selection of fully detected QP events Z_{total} = 20
- M=3 events
- A_{PLF} = 34

Several possibilities:

- $^{34}S+^{1}H$ (<-^{35}Cl) +^{4}He +^{1}H
- $^{34}S+^{4}He$ (<-^{38}Ar) + $^{1}H+^{1}H$
- $^{34}S+^{1}H+^{4}He$ (<-^{39}K)+^{1}H
- $^{34}S+^{4}He+^{1}H+^{1}H$ (<-^{40}Ca)

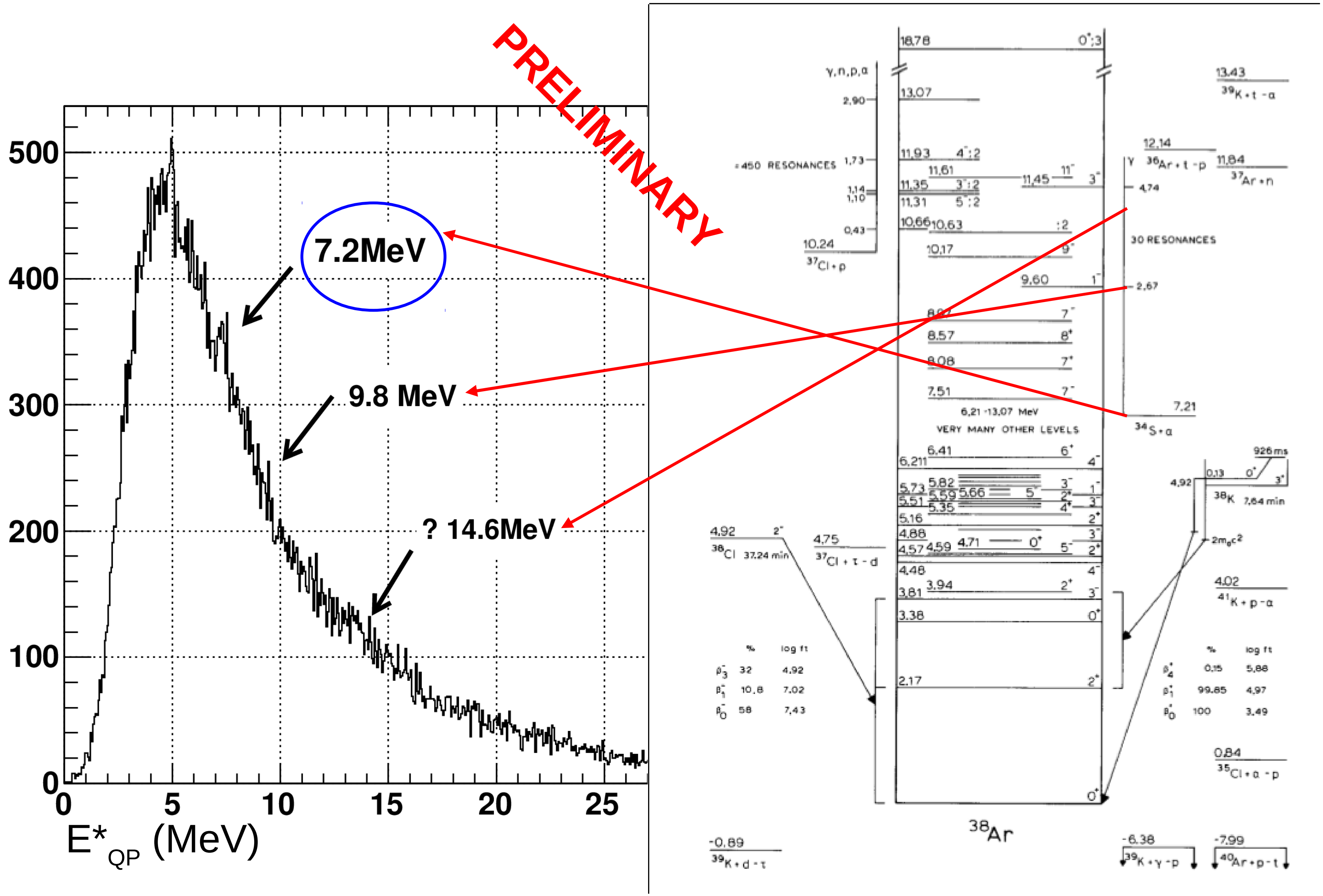
Preliminary results

$^{34}S+^{1}H$ (<-^{35}Cl)



Preliminary results

$^{34}S+^{4}He$ (<-^{38}Ar)



Conclusions:

From finite to infinite systems: heavy ion collisions as a probe of nuclear matter

- Extracting isotopic distributions of complex fragments using the VAMOS spectrometer

Importance of a proper treatment of secondary decay to extract information on the symmetry energy from isotopic yield distributions

- Exploiting the VAMOS isotopic resolution and the INDRA granularity to reconstruct primary fragments

Open the possibility for a new program: CP spectroscopy of exotic nuclei (LoI for SPIRAL2-Day1)

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