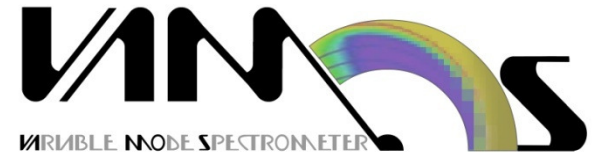


VAMOS

Spectrometer for Binary Reaction Products

Focus on

- gamma spectroscopy
- isotopic identification
- neutron rich nuclei
- binary reactions

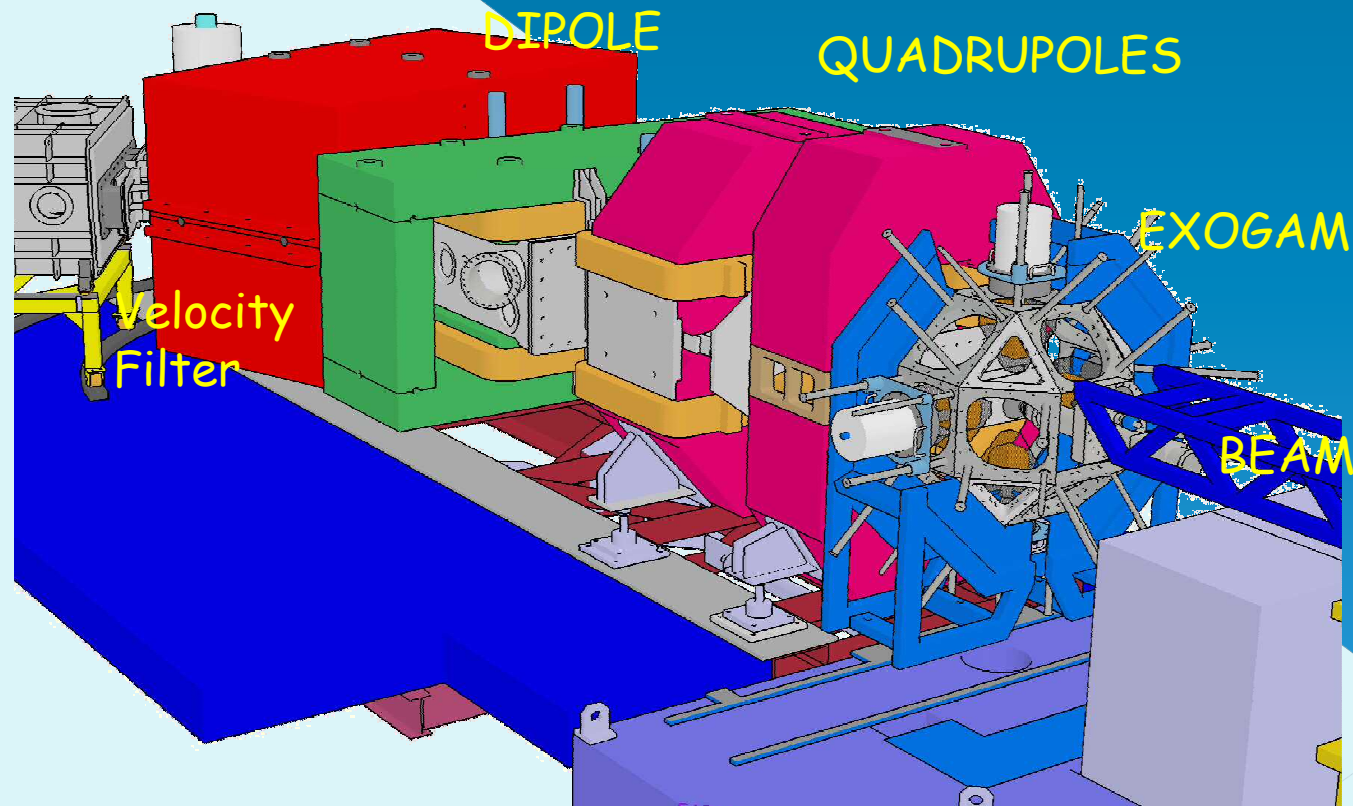


- ◉ VAMOS Spectrometer
- ◉ Detection Systems
- ◉ Methods
- ◉ Applications for Binary Reactions
 - > Multinucleon Transfer Reactions
 - > Fission

VAMOS

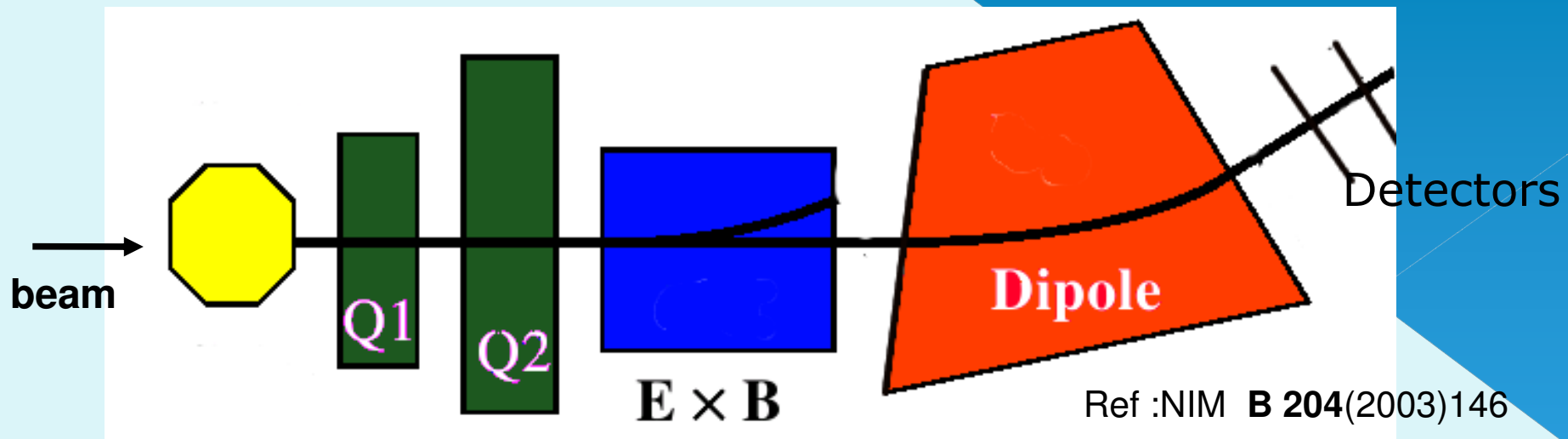
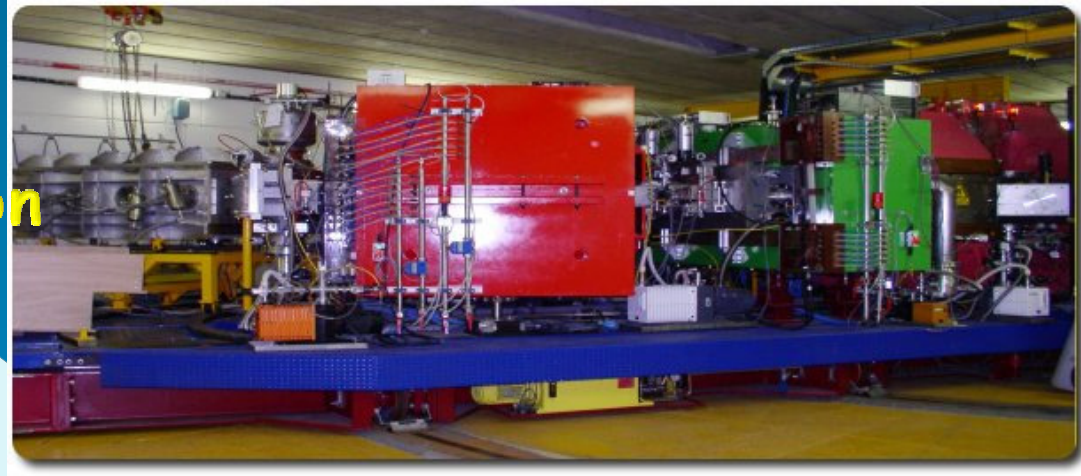
Schematic View

Focal Plane detection

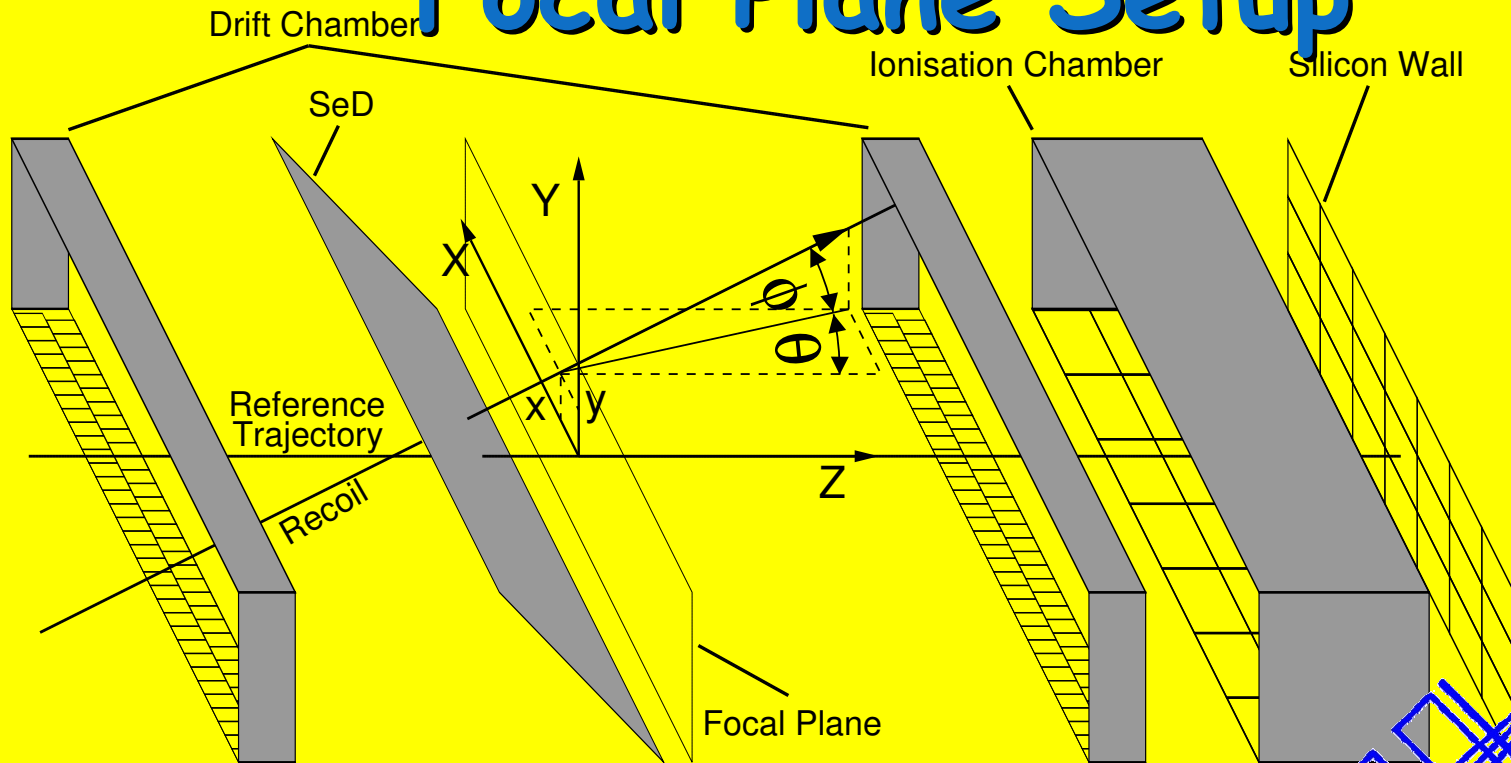


Variable Mode Operation

- ✓ QQ - Focusing Mode
- ✓ QQD - Spectrometer
 - Variable Dispersion
- ✓ Recoil Separator
 - QQF(D)
 - QQD (Gas filled)

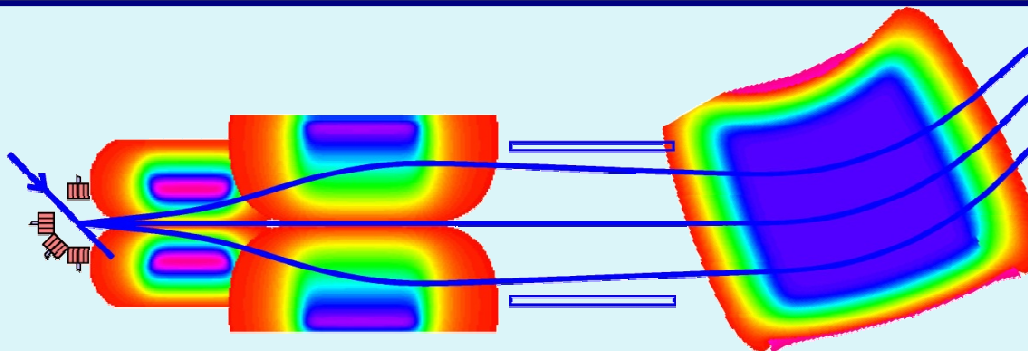


Focal Plane Setup

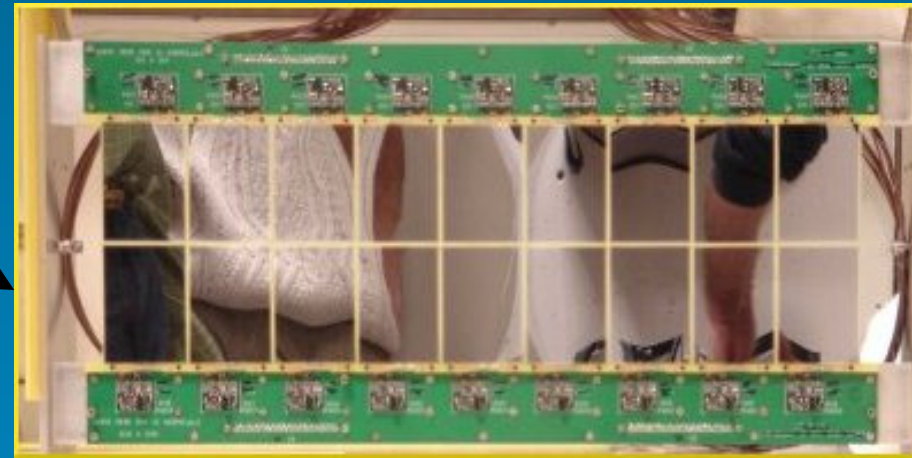
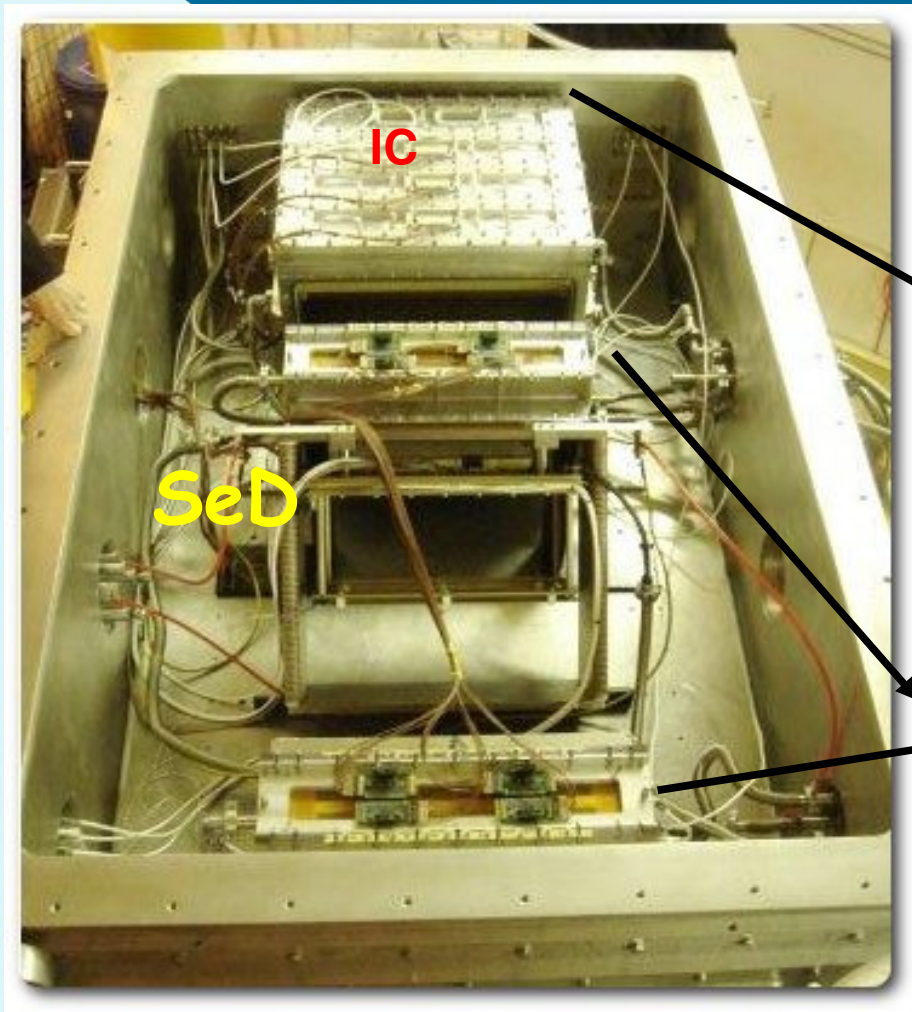


Software Spectrometer

Initial coordinates deduced from final coordinates



Focal Plane Setup



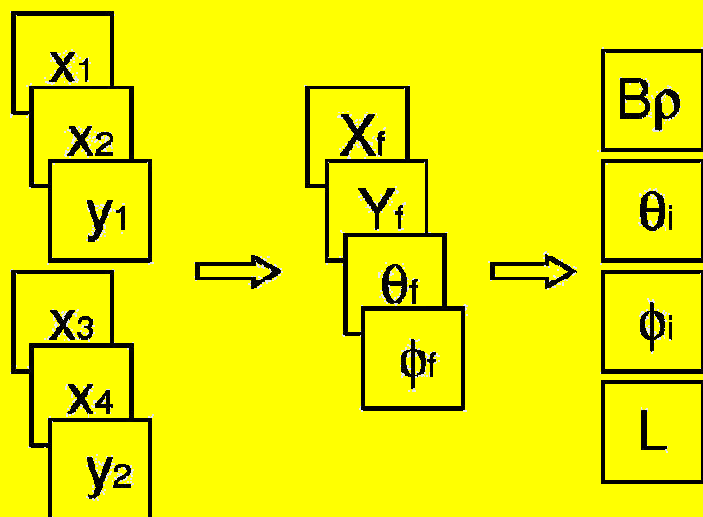
Si Wall



Drift Chamber

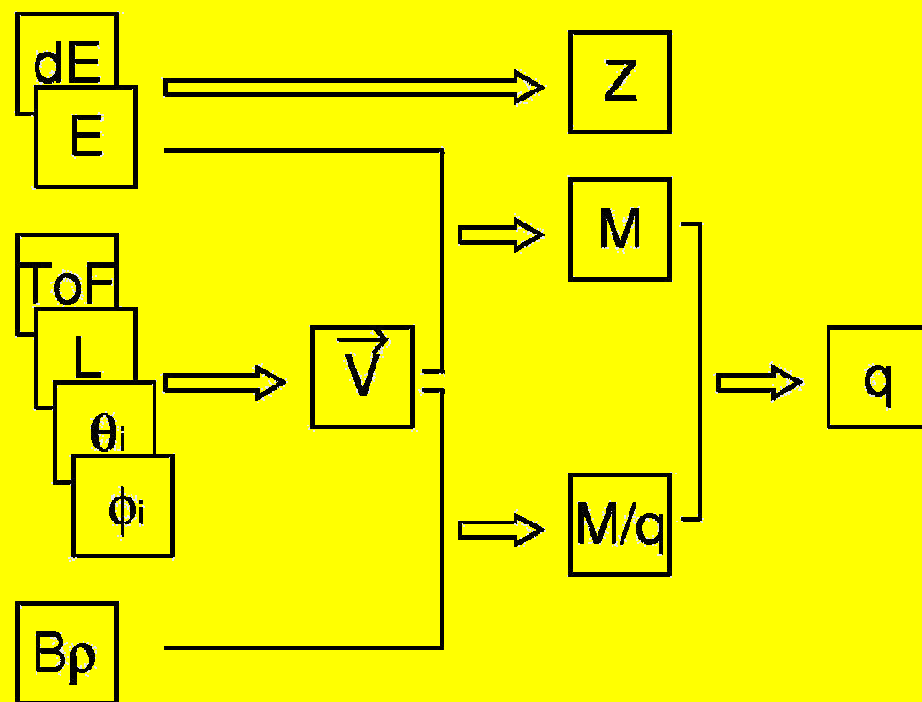
Software Reconstruction

a)



$$\begin{aligned}\delta &= F_1(x_f, \theta_f, y_f, \phi_f) \\ \theta_i &= F_2(x_f, \theta_f, y_f, \phi_f) \\ \phi_i &= F_3(x_f, \theta_f, y_f, \phi_f) \\ L &= F_4(x_f, \theta_f, y_f, \phi_f)\end{aligned}$$

b)



$$B\rho = B\rho_{ref} \times \delta$$

$$\delta = \sum_{i,j,k,l=0}^{i+j+k+l=10} C_{ijkl} x_f^i \theta_f^j y_f^k \phi_f^l$$

10-th order reconstruction

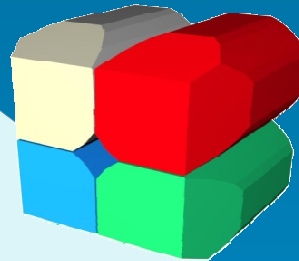
Multinucleon and Deep Inelastic Transfer Reactions

◎ Beam:

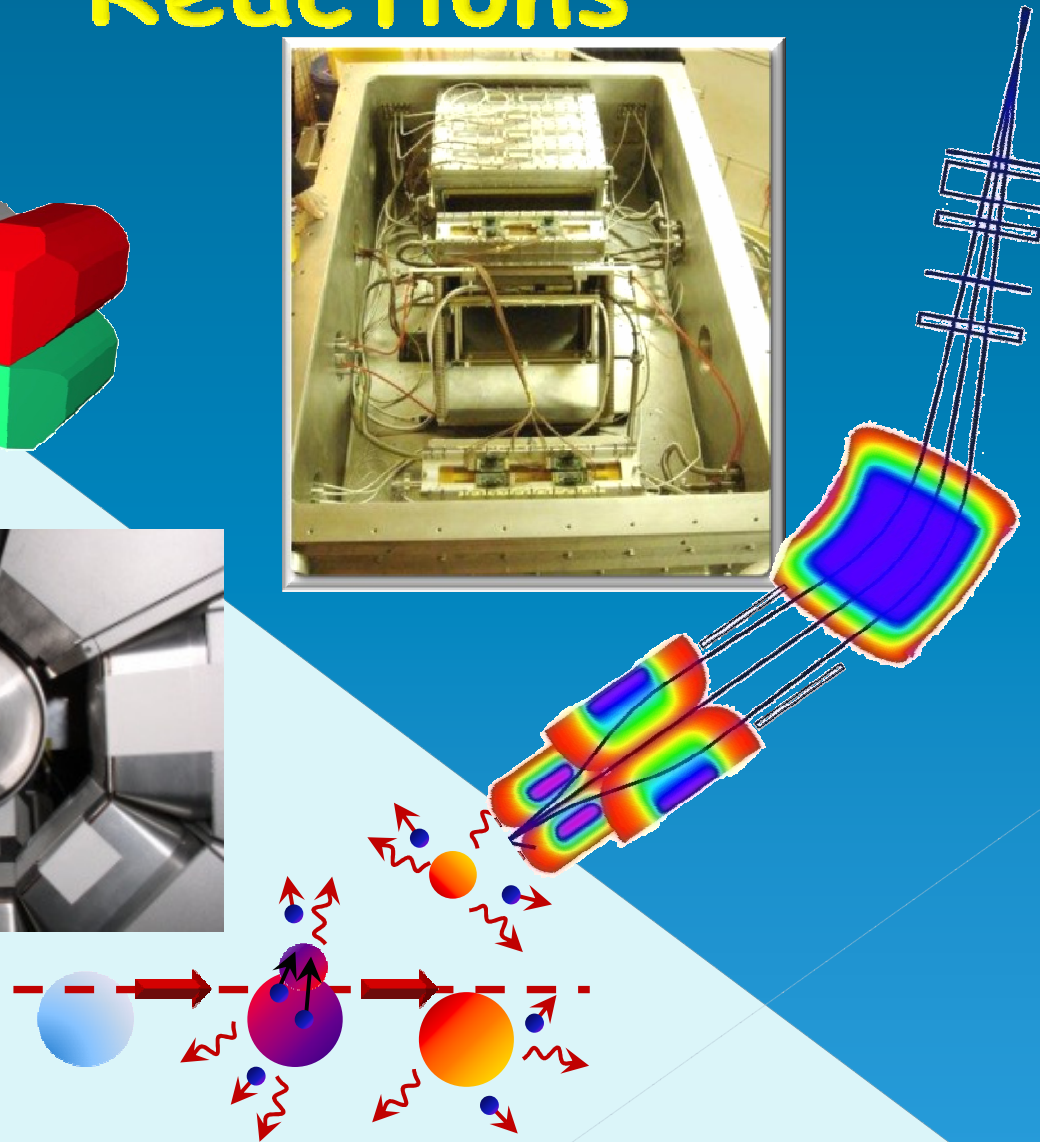
- > ^{238}U
- > 5.5 MeV/u
- > 2 pnA

◎ Target

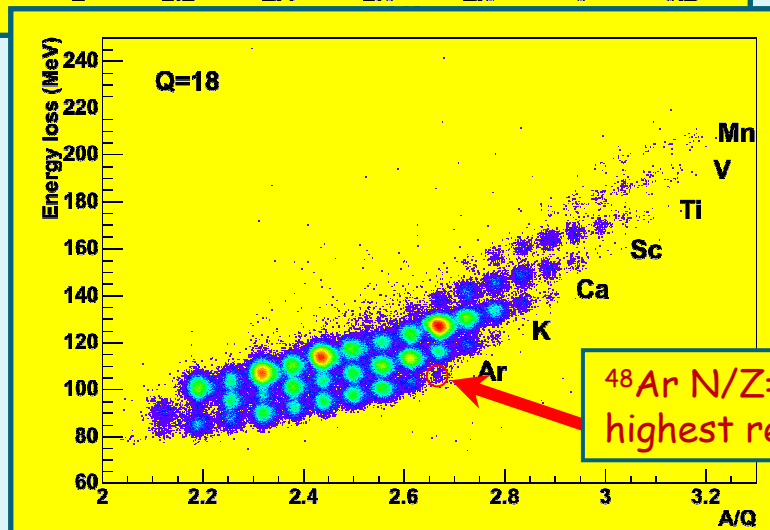
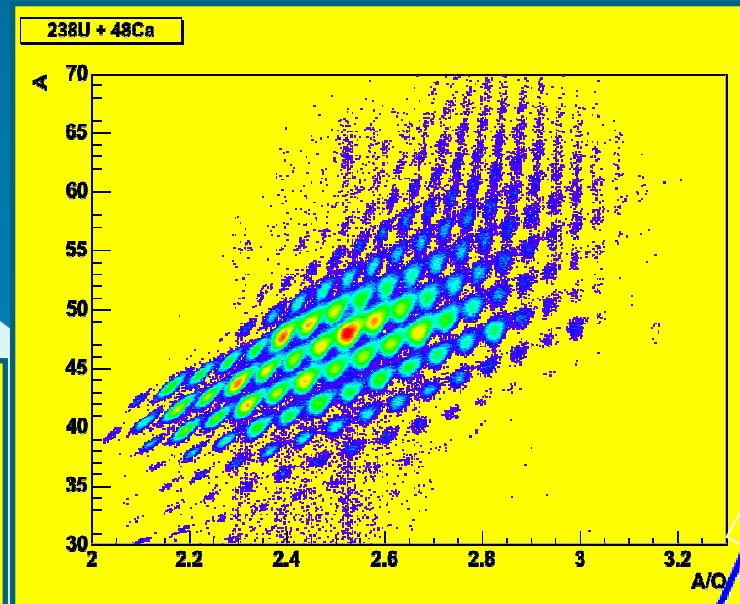
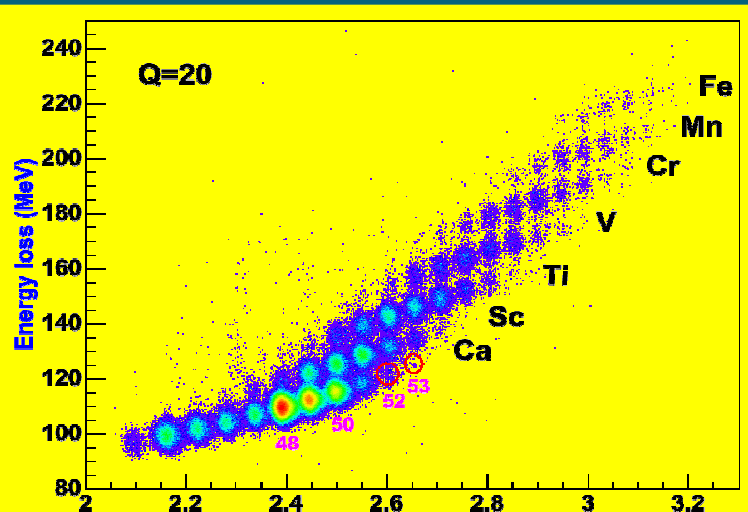
- > ^{48}Ca
- > 1 mg/cm²



Inverse kinematics

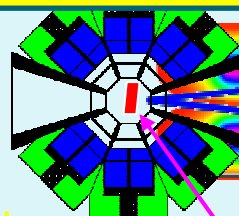


Identification spectra

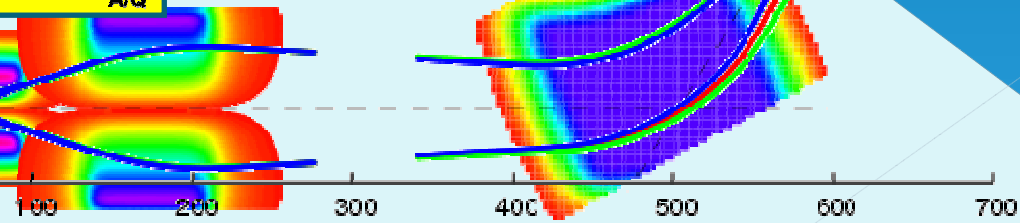


^{48}Ar $N/Z=1.67$
highest reached in this kind of reaction

Beam
→
 ^{238}U
5.5 MeV/u

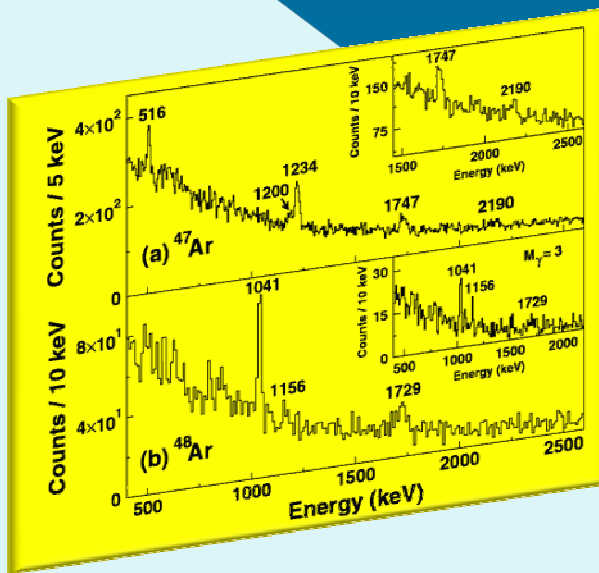


Target : ^{48}Ca



Target-like

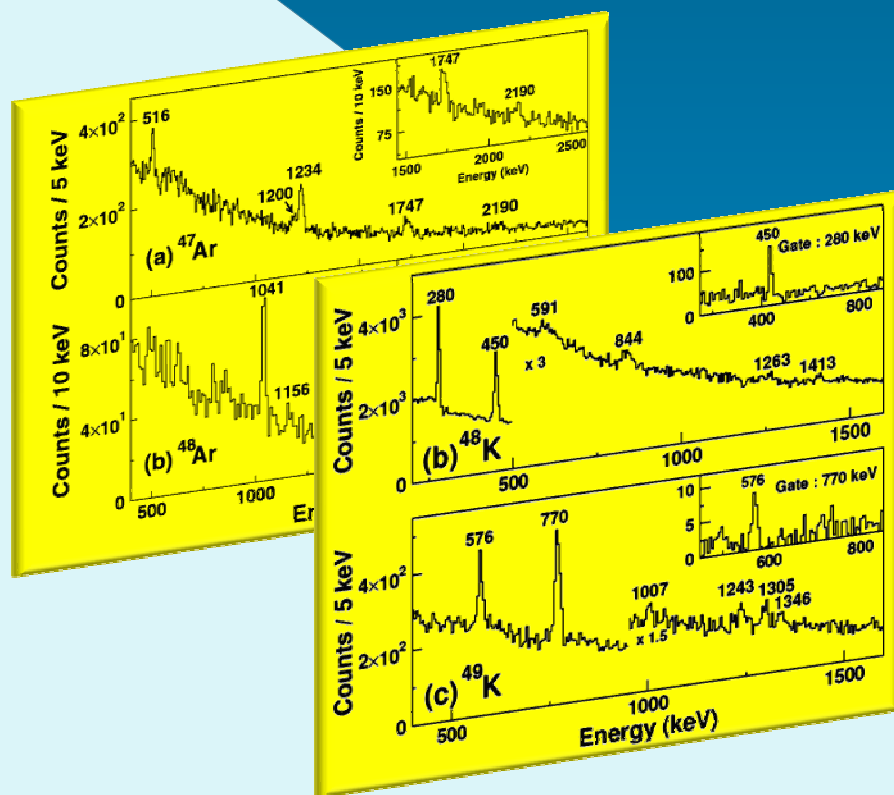
"Almost as good as beta decay"



References

- M. Rejmund et al., PRC 76,021304 (2007)
- S. Bhattacharyya et al., PRL 101,032501, (2008)
- S. Bhattacharyya et al., PRC 79,014313, (2009)

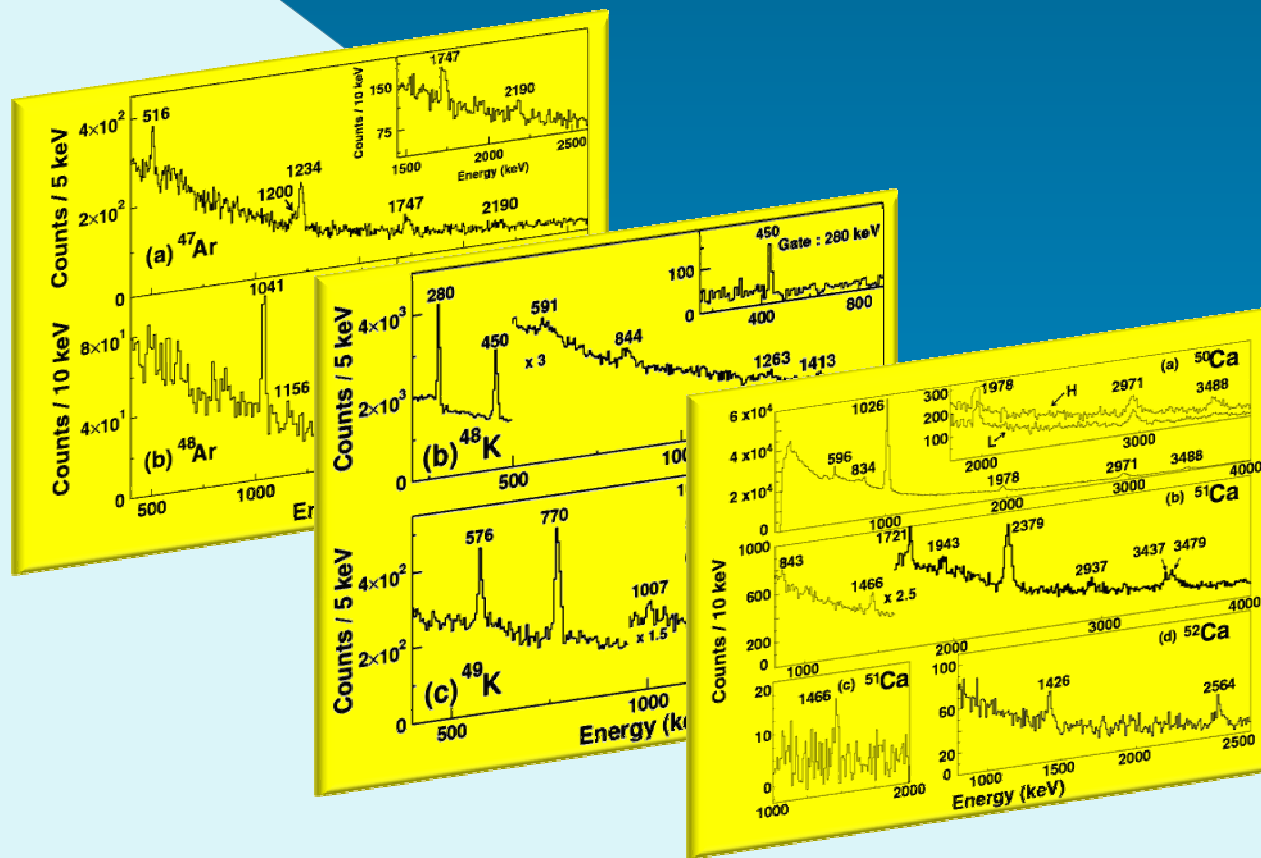
"Almost as good as beta decay"



References

- M. Rejmund et al., PRC 76,021304 (2007)
- S. Bhattacharyya et al., PRL 101,032501, (2008)
- S. Bhattacharyya et al., PRC 79,014313, (2009)

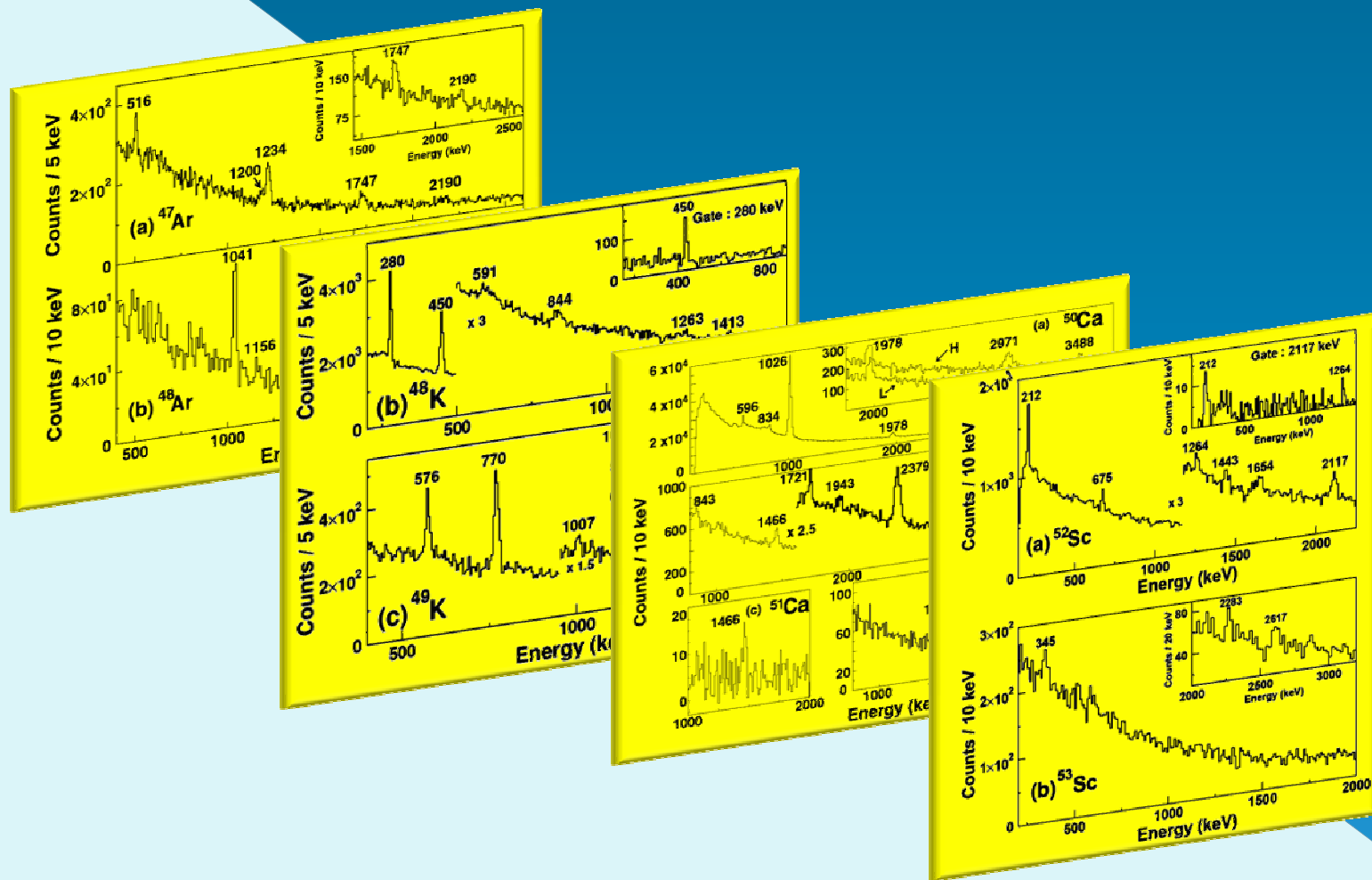
"Almost as good as beta decay"



References

- M. Rejmund et al., PRC 76,021304 (2007)
- S. Bhattacharyya et al., PRL 101,032501, (2008)
- S. Bhattacharyya et al., PRC 79,014313, (2009)

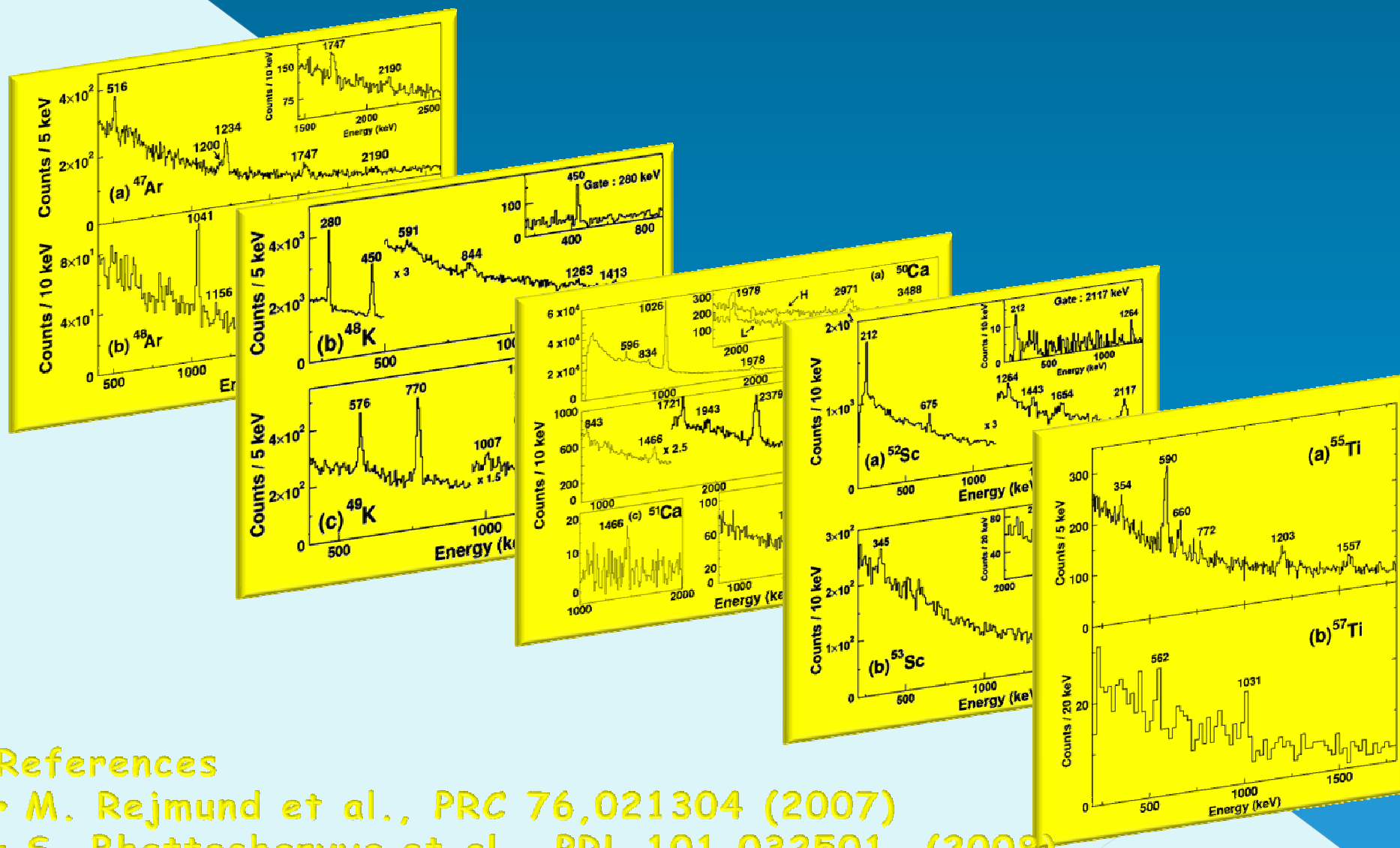
"Almost as good as beta decay"



References

- M. Rejmund et al., PRC 76,021304 (2007)
- S. Bhattacharyya et al., PRL 101,032501, (2008)
- S. Bhattacharyya et al., PRC 79,014313, (2009)

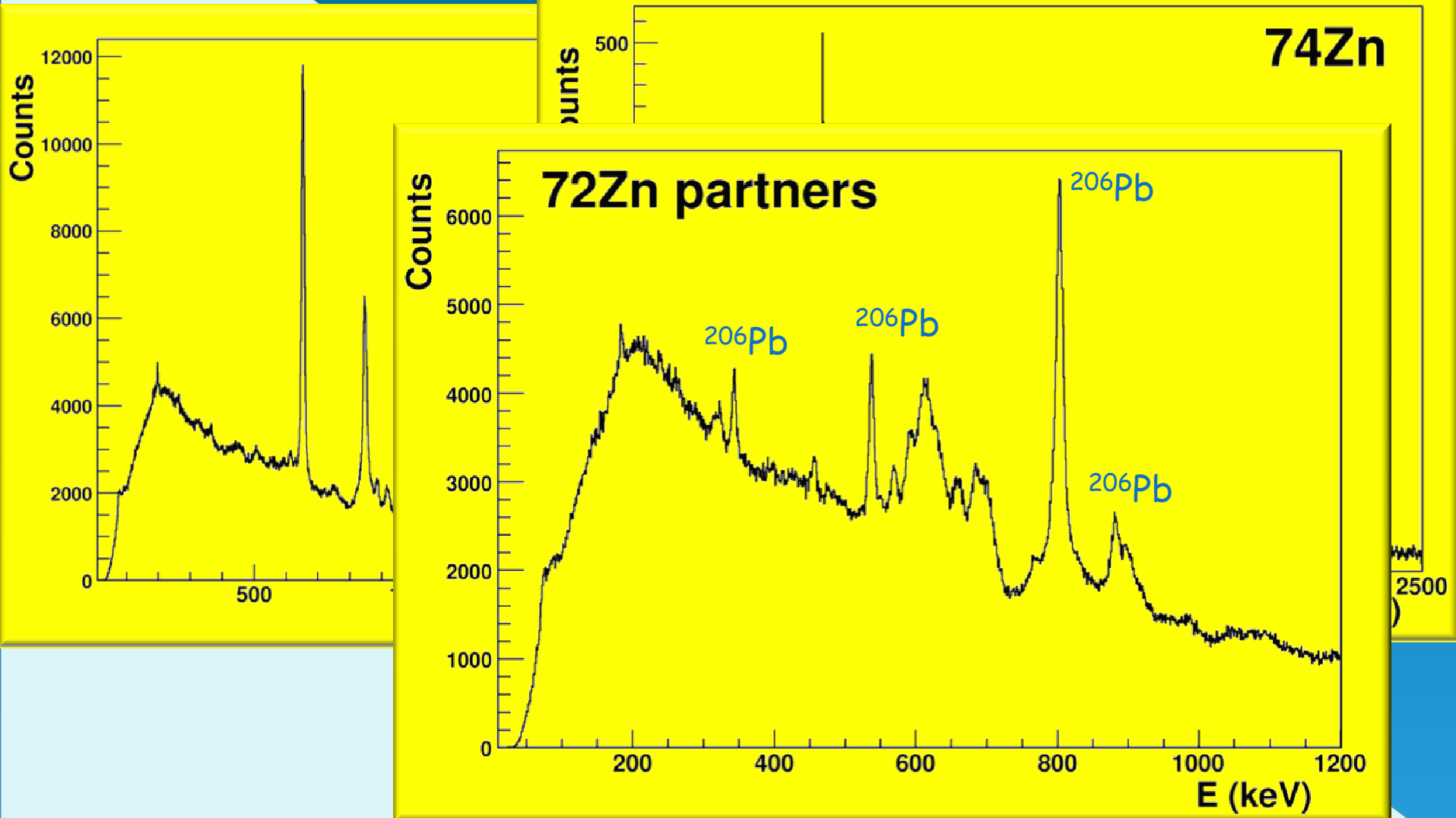
"Almost as good as beta decay"



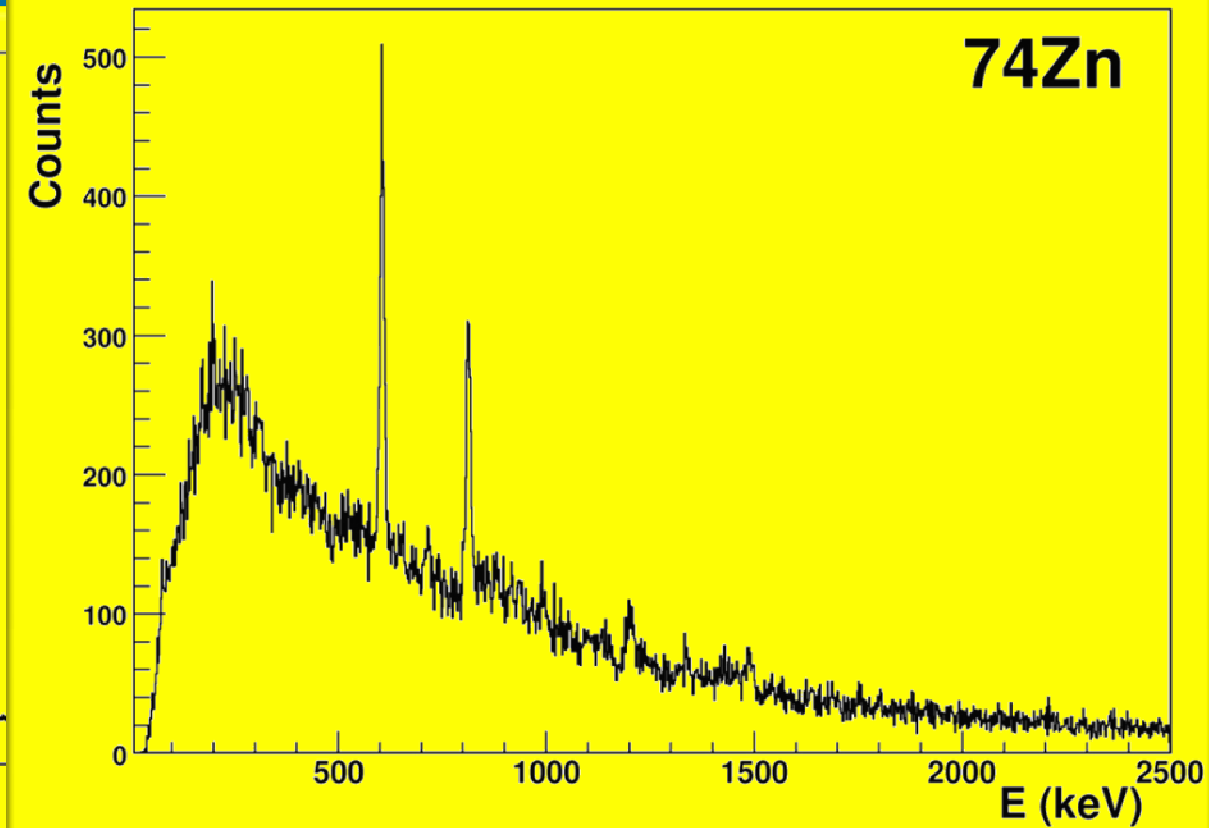
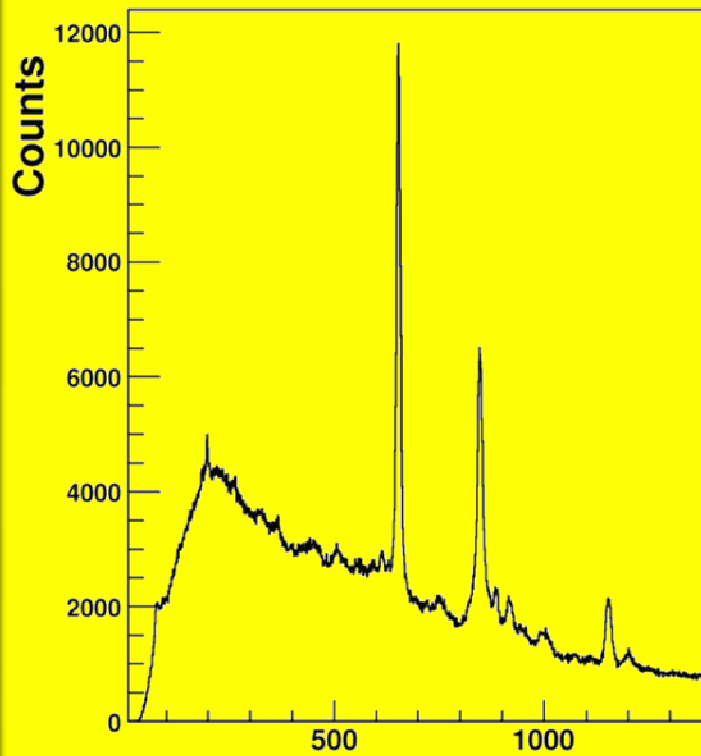
References

- M. Rejmund et al., PRC 76,021304 (2007)
- S. Bhattacharyya et al., PRL 101,032501, (2008)
- S. Bhattacharyya et al., PRC 79,014313, (2009)

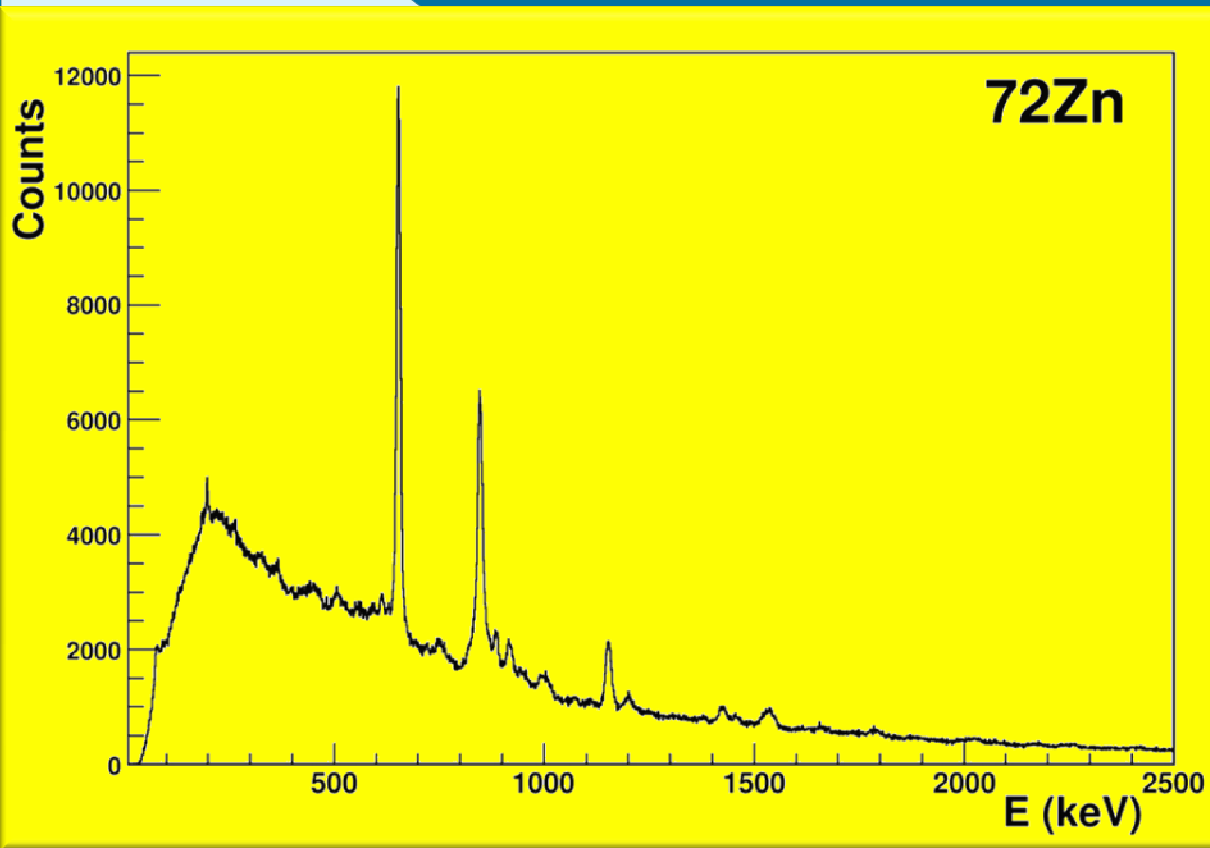
^{208}Pb (6.2 MeV/u) + ^{70}Zn VAMOS@45°



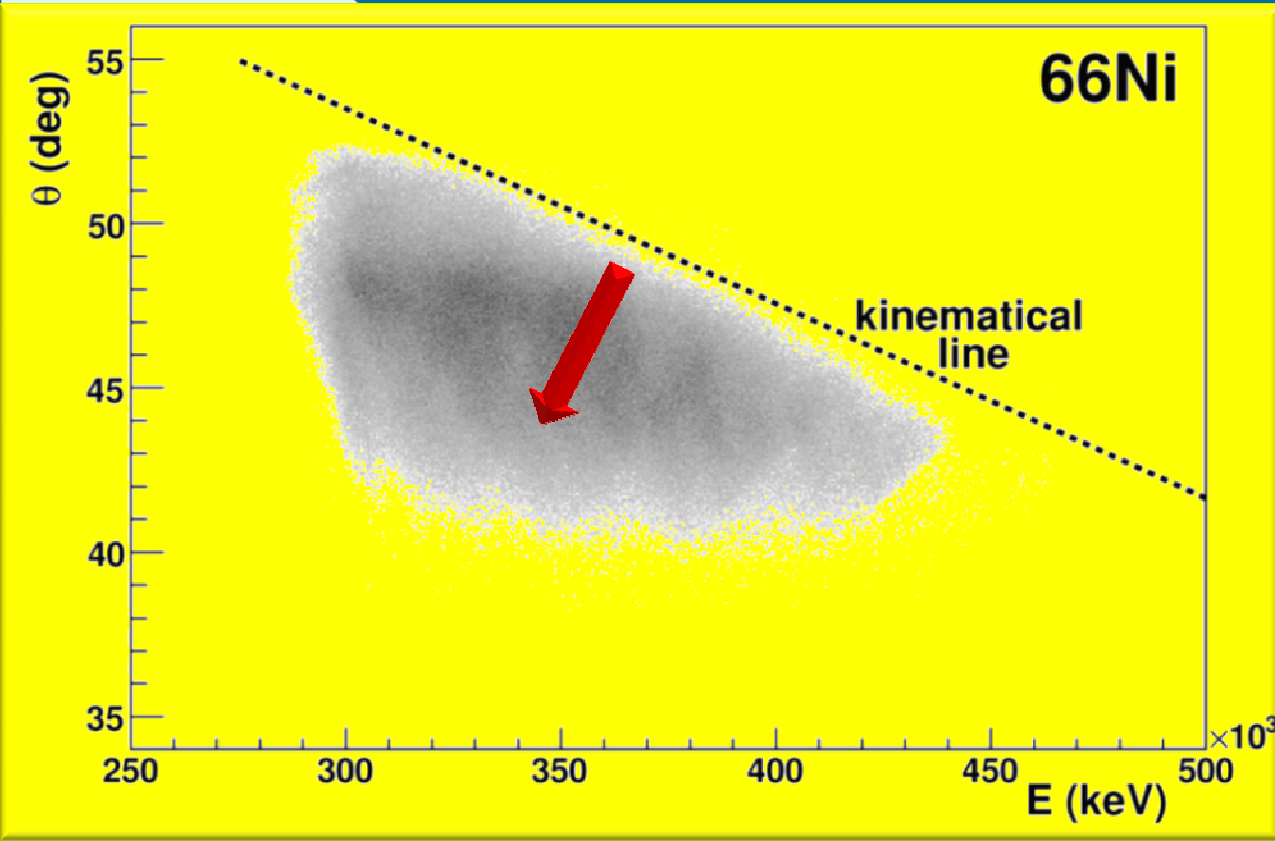
^{208}Pb (6.2 MeV/u) + ^{70}Zn VAMOS@45°



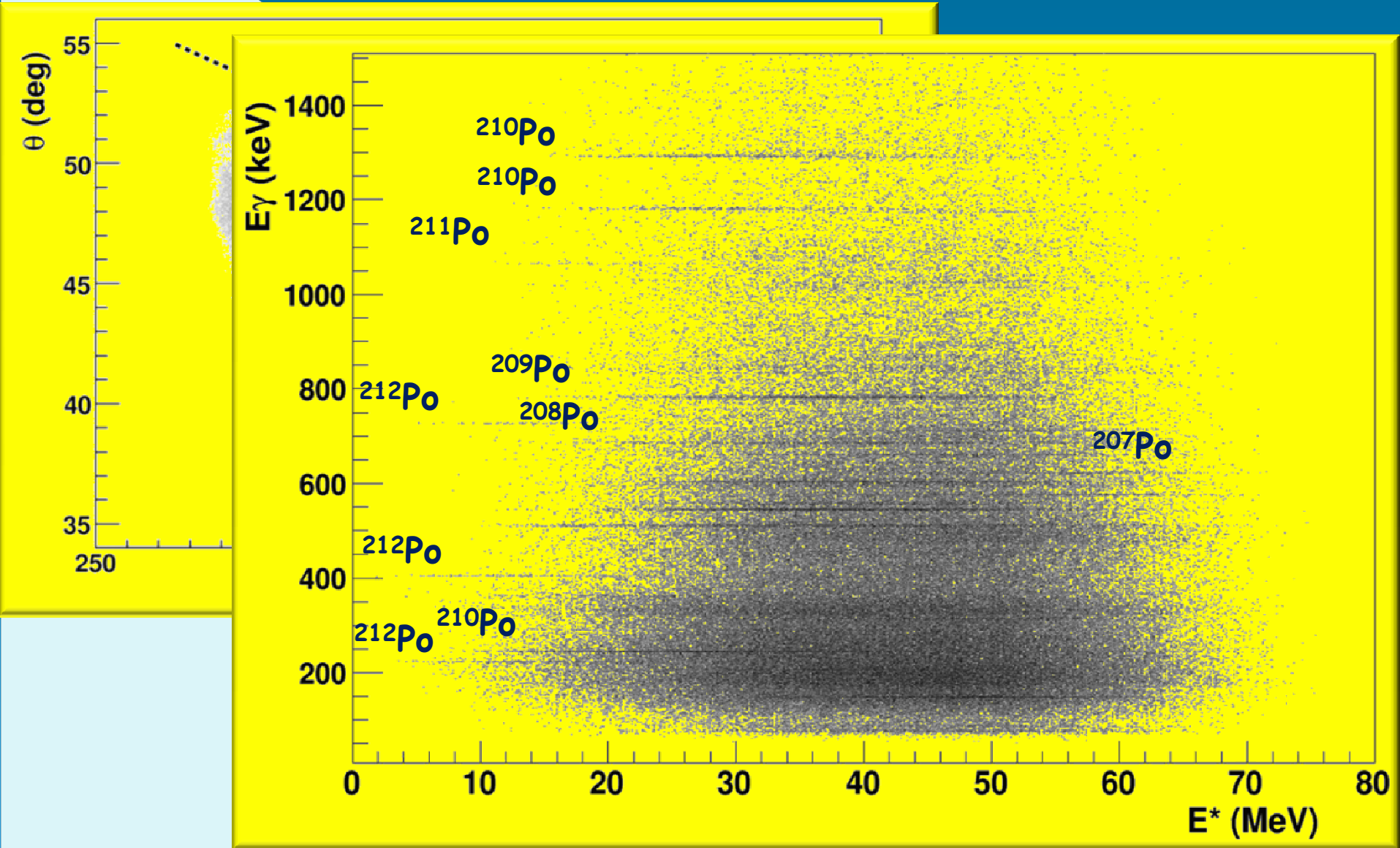
^{208}Pb (6.2 MeV/u) + ^{70}Zn VAMOS@45°



Excitation energy and neutron evaporation



Excitation energy and neutron evaporation



Isotopic Yields of Fission Fragments

◎ Beam:

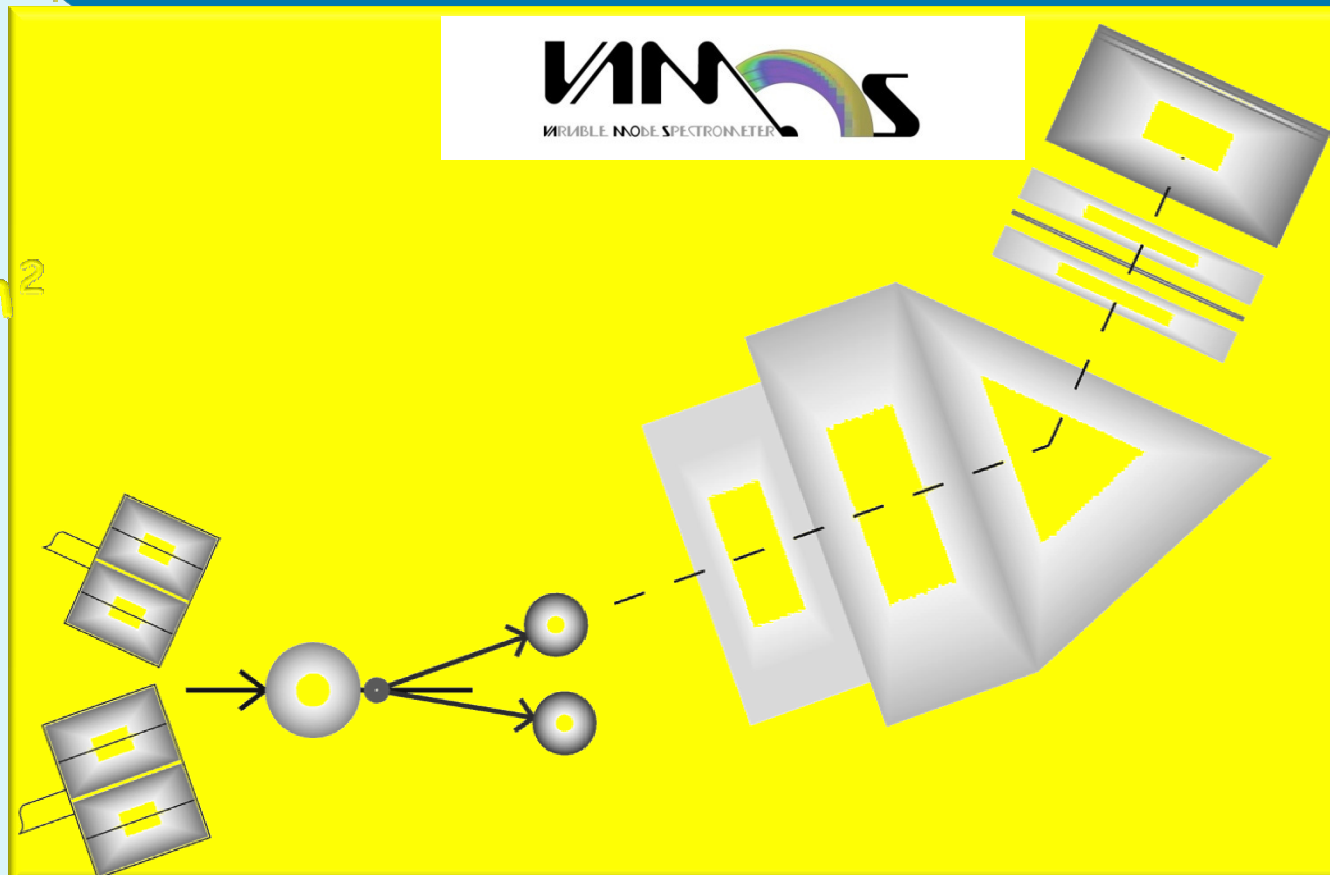
> ^{238}U

> 6.15 MeV/u

◎ Target

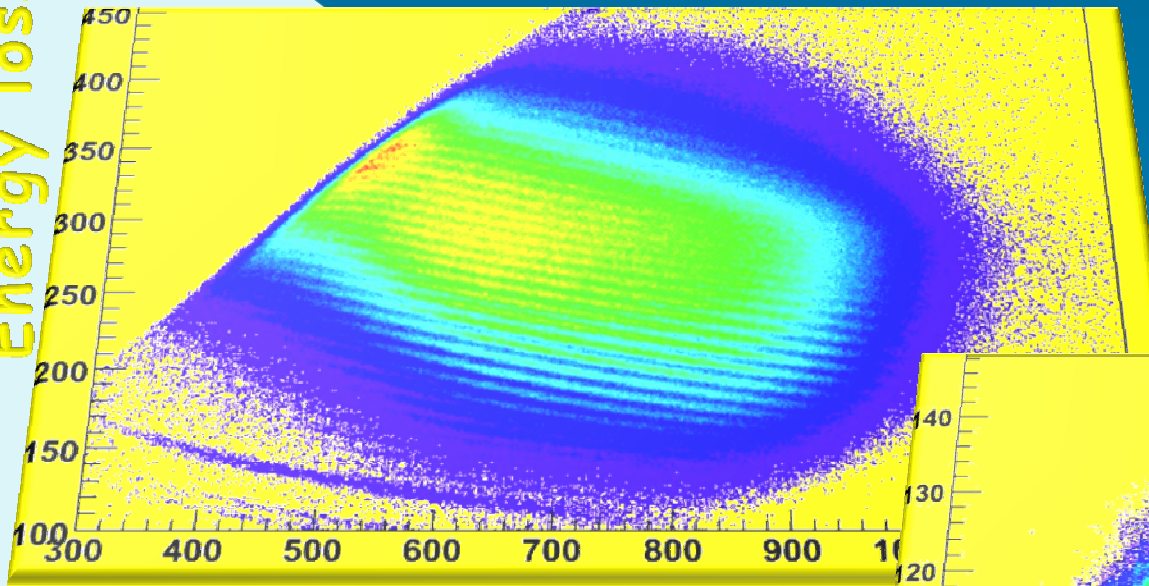
> ^{12}C

> 100 $\mu\text{g}/\text{cm}^2$

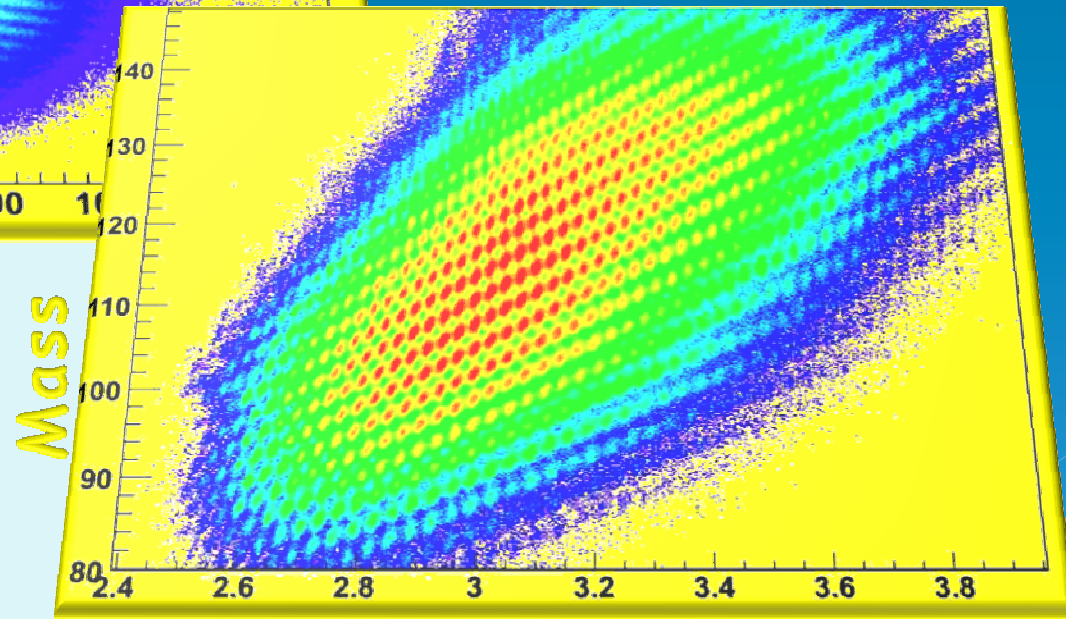


Identification

Energy loss

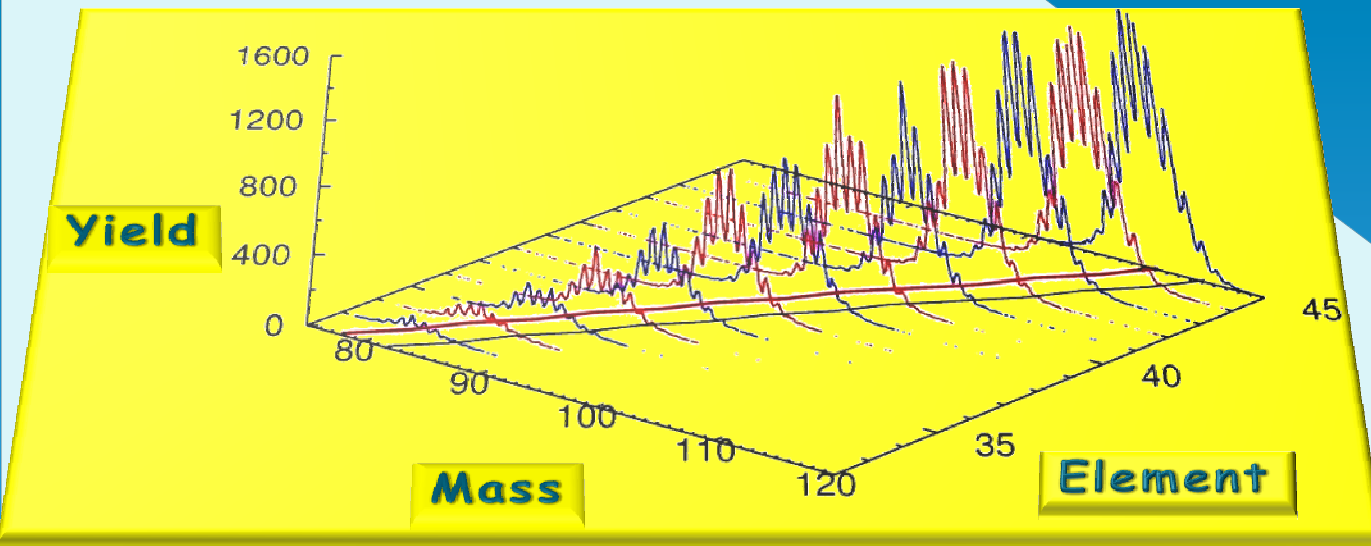
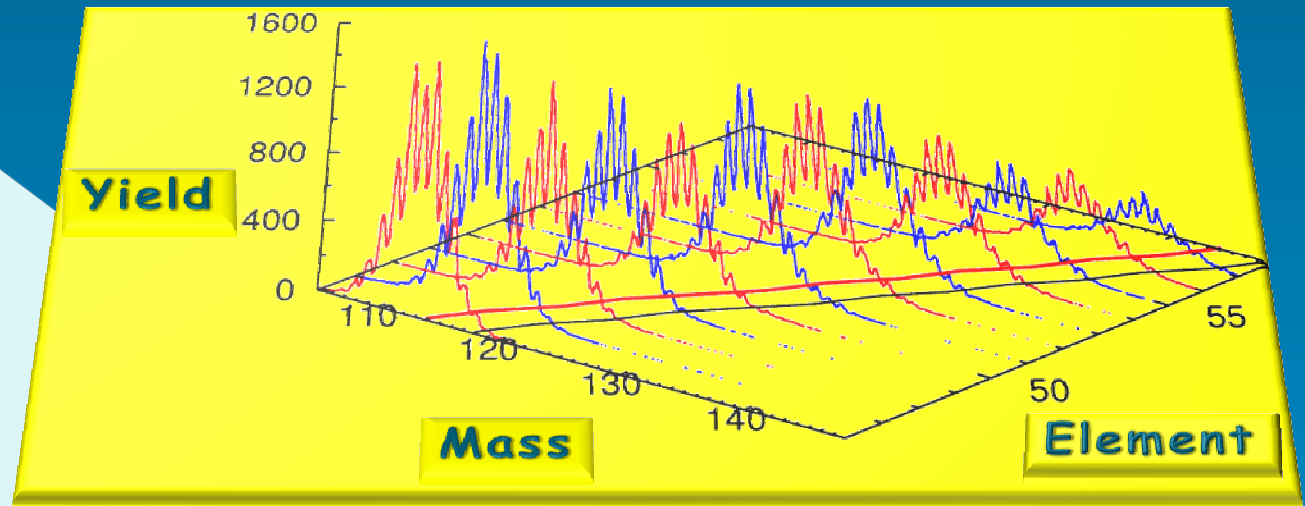


Energy

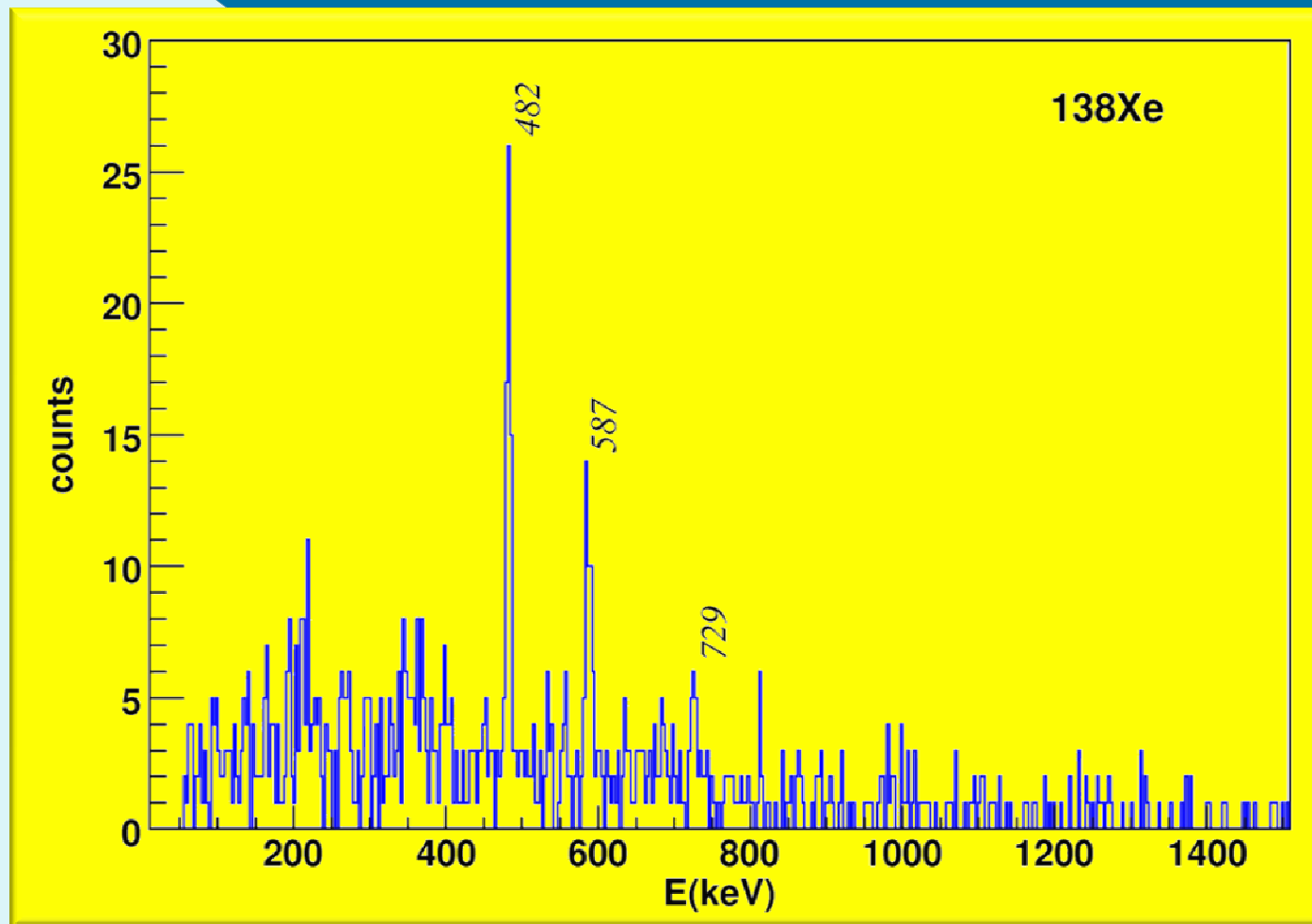


Mass / Charge

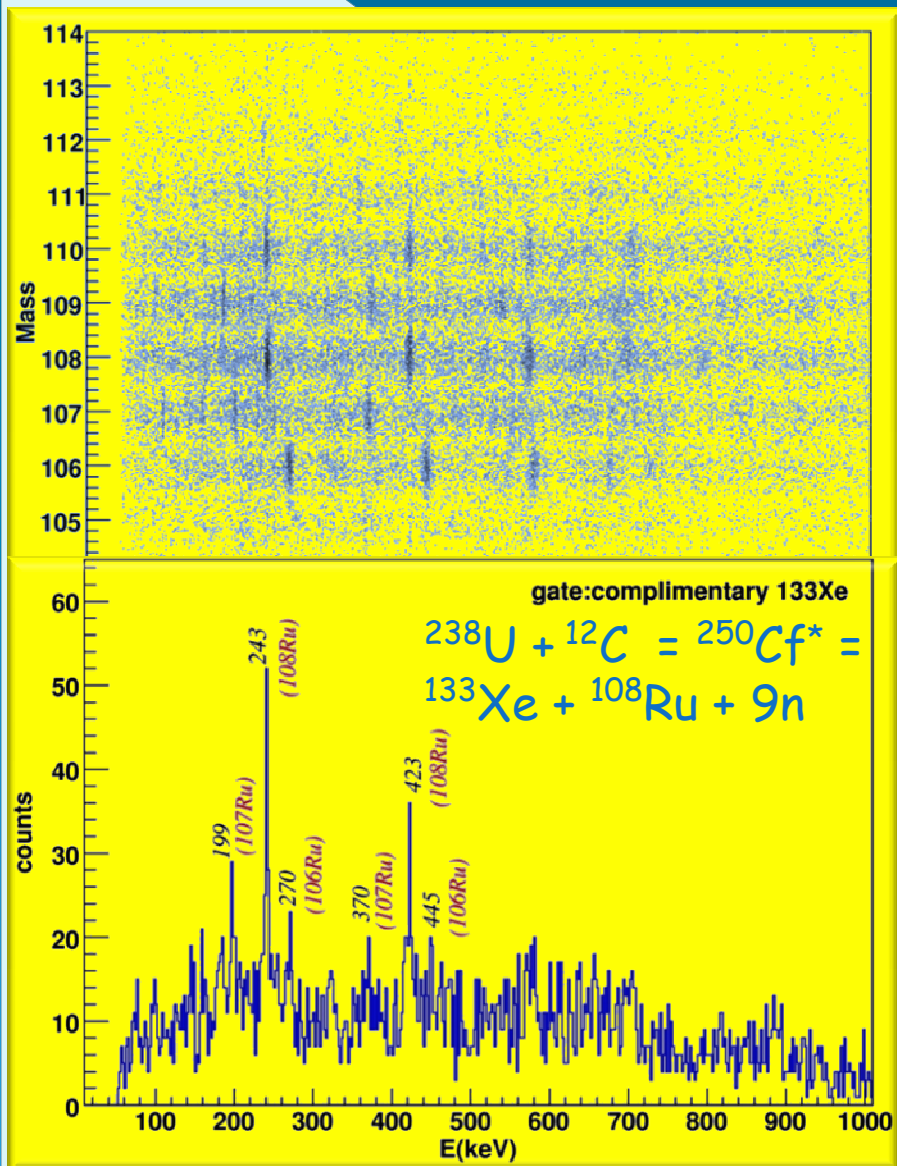
Mass Distributions



Isotopically identified fragments ^{138}Xe



Light Fission Fragment



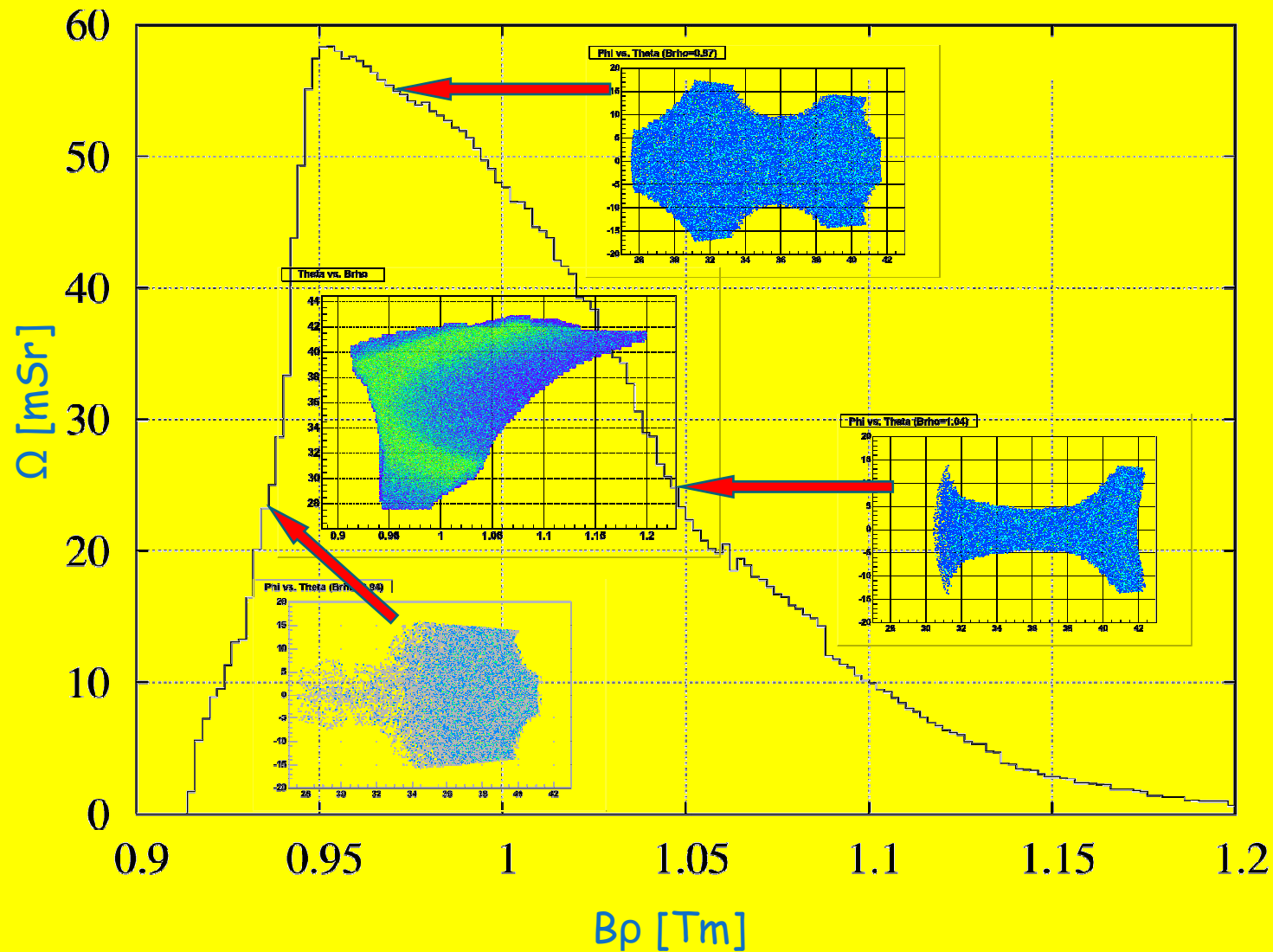
◎ dE-E gate on Ru
(Z=44)

- > Measured Mass
- > Measured Energy of γ -ray
- > Doppler correction using measured V

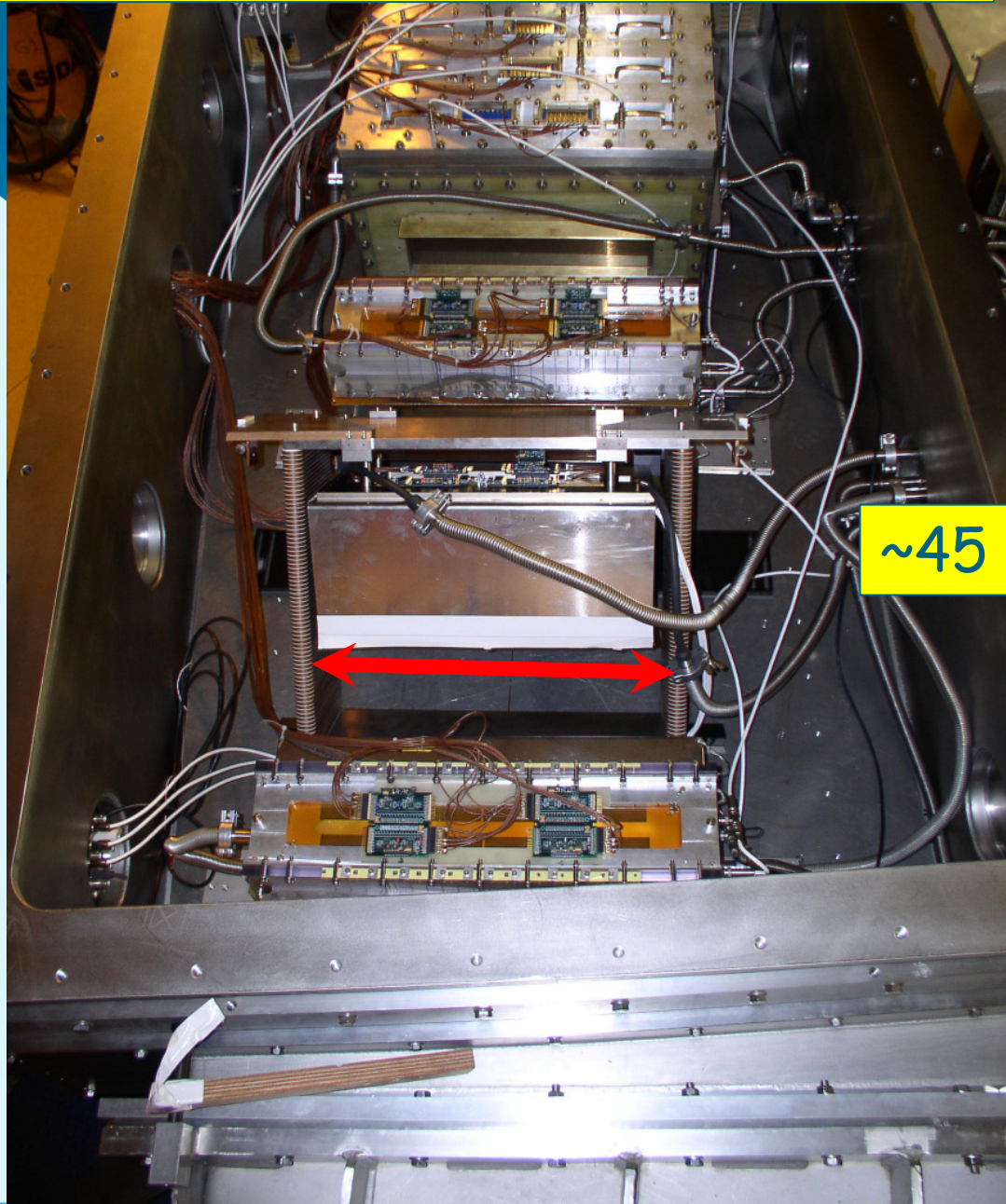
◎ Gate on ^{133}Xe
(Z=54)

- > Measured Energy of γ -ray
- > Doppler correction using V deduced for the partner

Acceptance of VAMOS



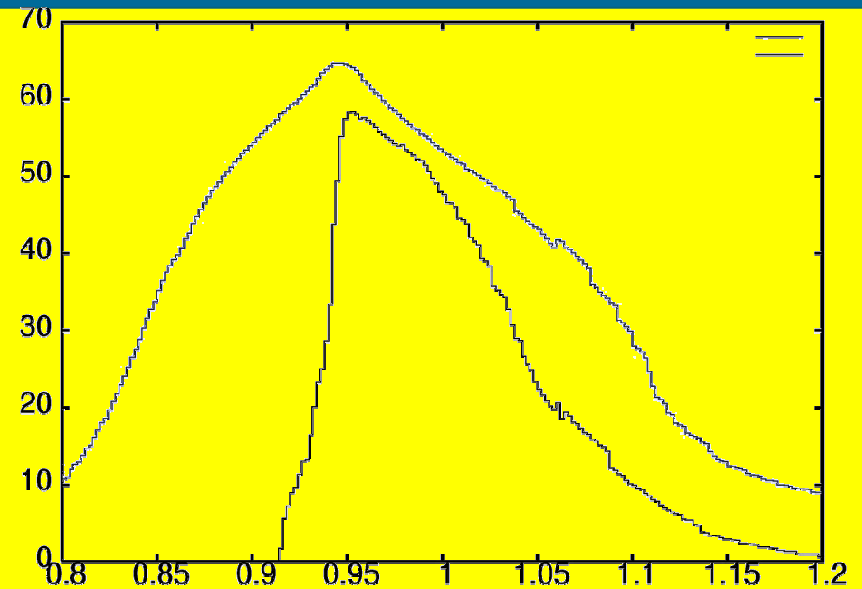
Acceptance is determined by a detector size !



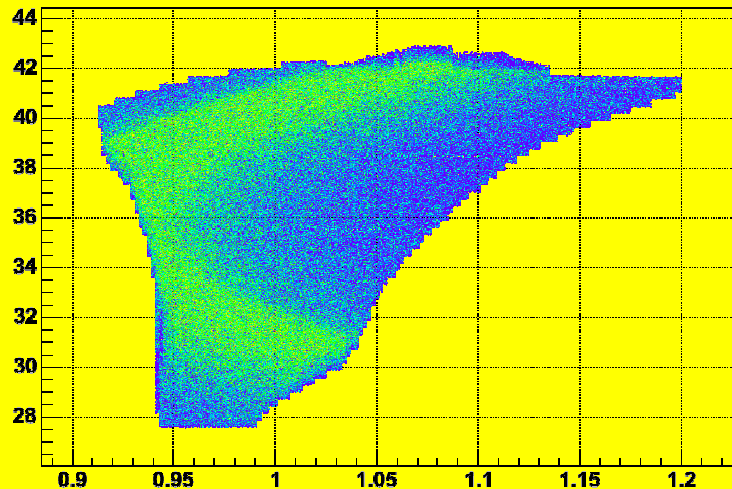
~45 cm

Ongoing Improvement

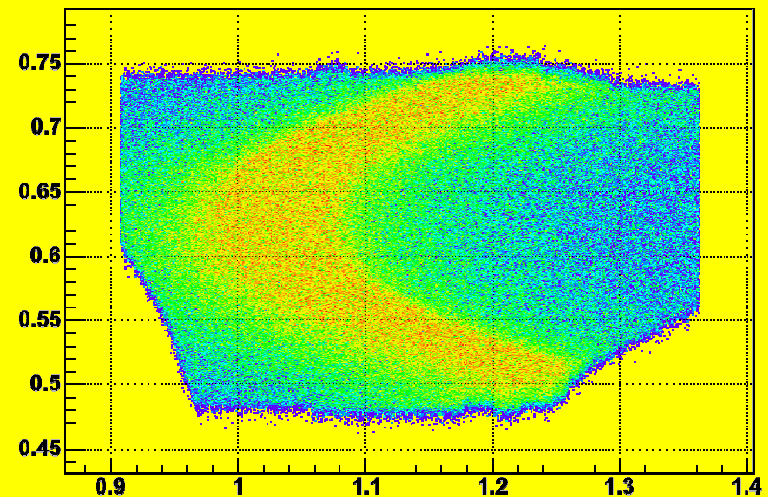
By doubling of size of the focal plane detection



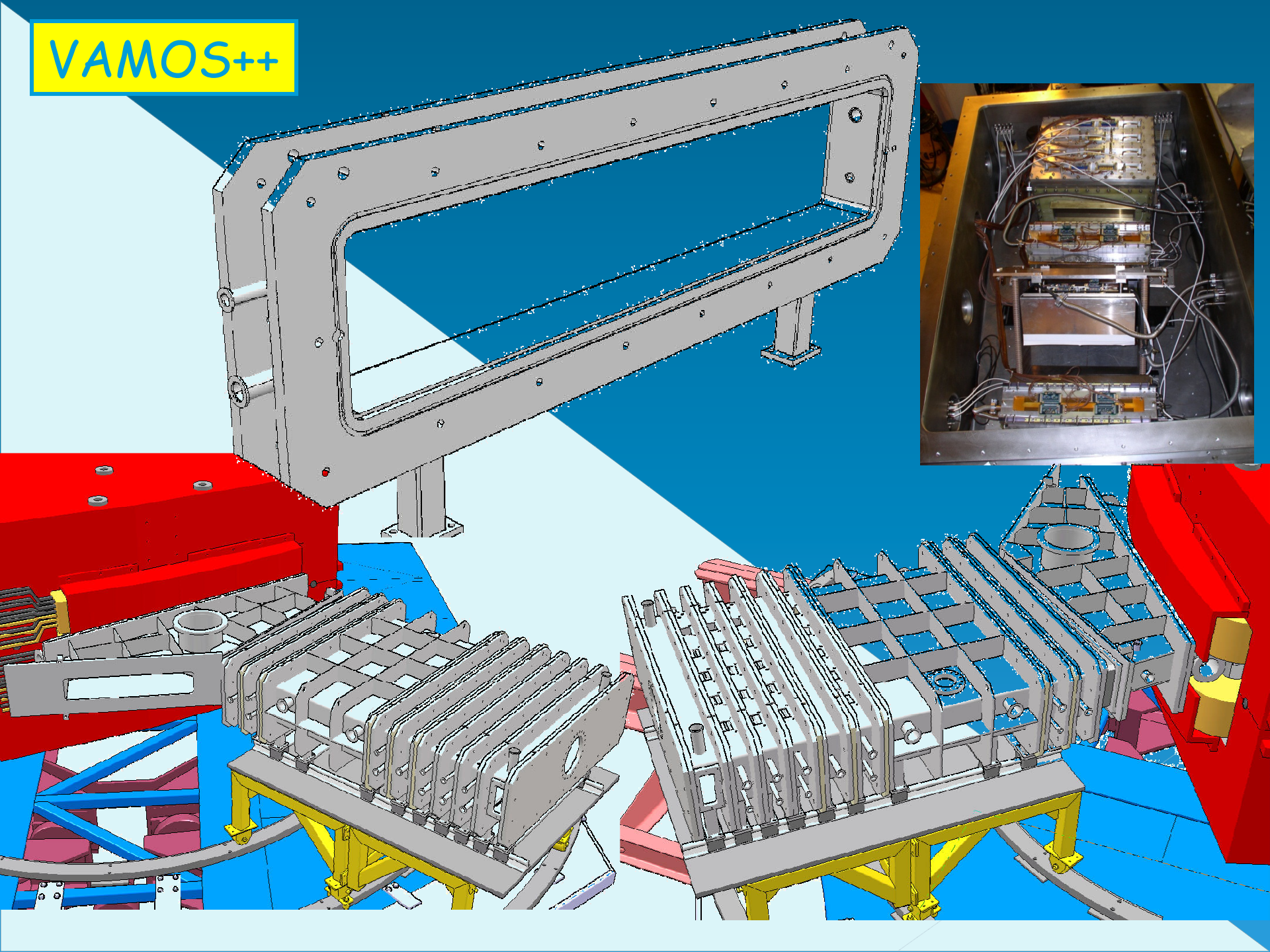
Theta vs. Brho



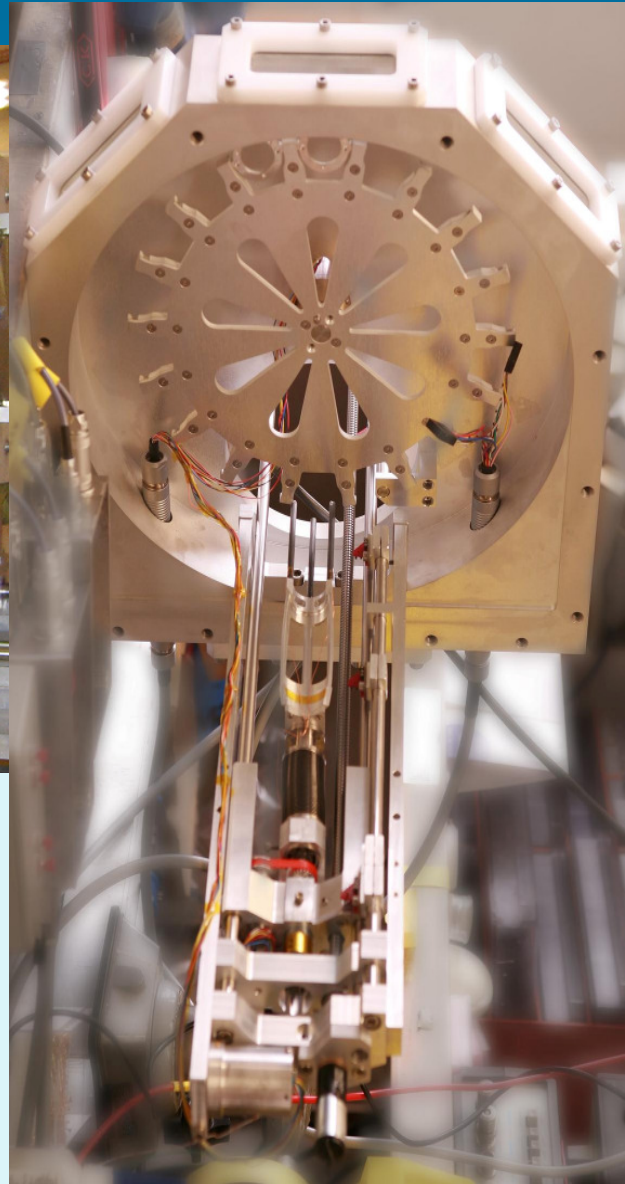
ThetaL:Brho



VAMOS++



New stuff



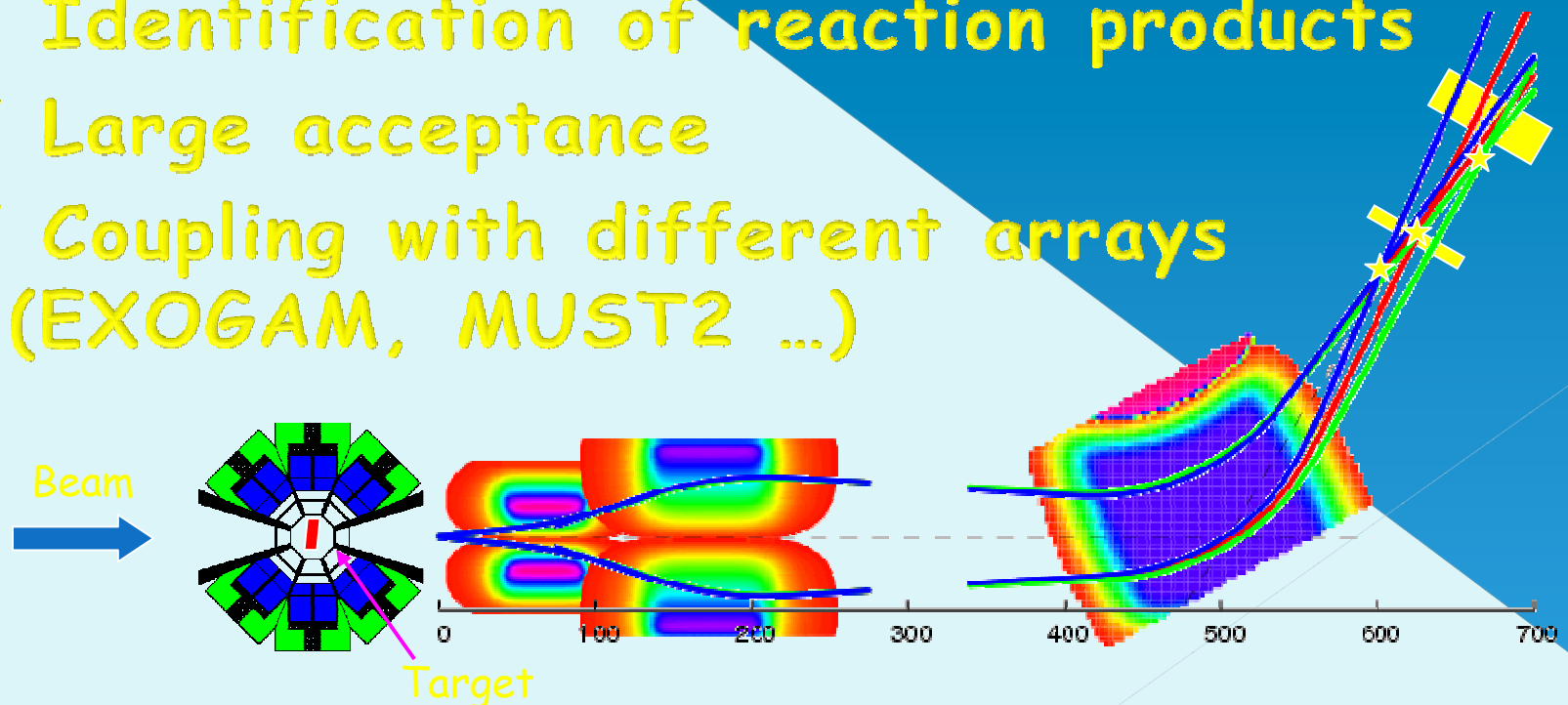
Tomorrow and the day after

- ◎ Old mechanisms with modern tools provide unique insights to the physics of nuclei towards drip line
 - > Gamma spectroscopy of neutron rich nuclei at the limits
 - Deep Inelastic Transfer
 - Fission
- ◎ Ensures fruitful endeavors with SPIRAL2

VAMOS

Unique Spectrometer

- ◎ Essential for nuclear structure and reaction studies
 - ✓ Identification of reaction products
 - ✓ Large acceptance
 - ✓ Coupling with different arrays (EXOAM, MUST2 ...)

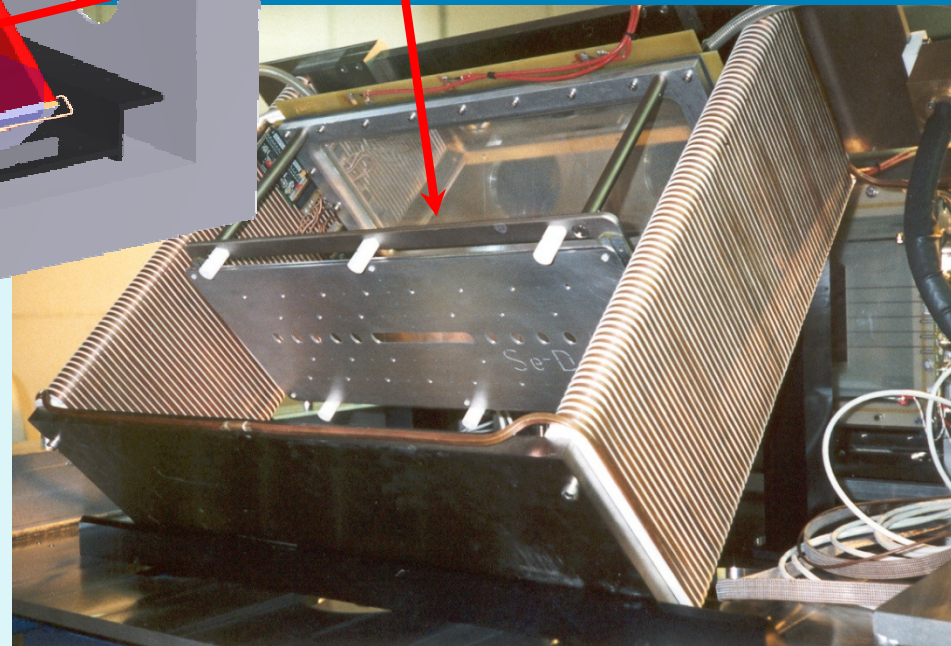


Heavy/Slow Ion Detection

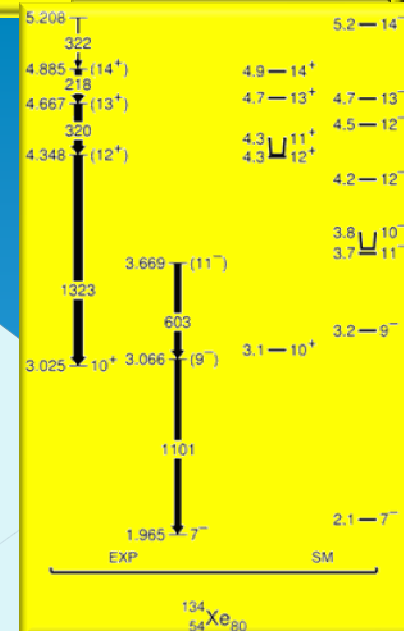
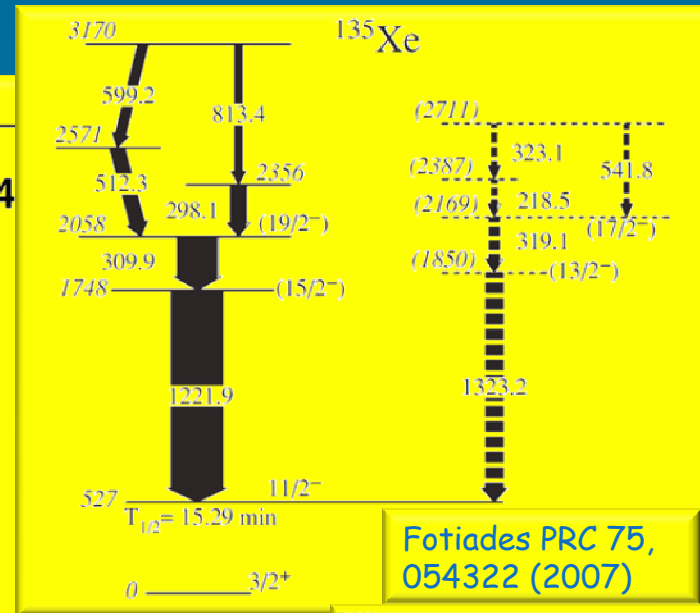
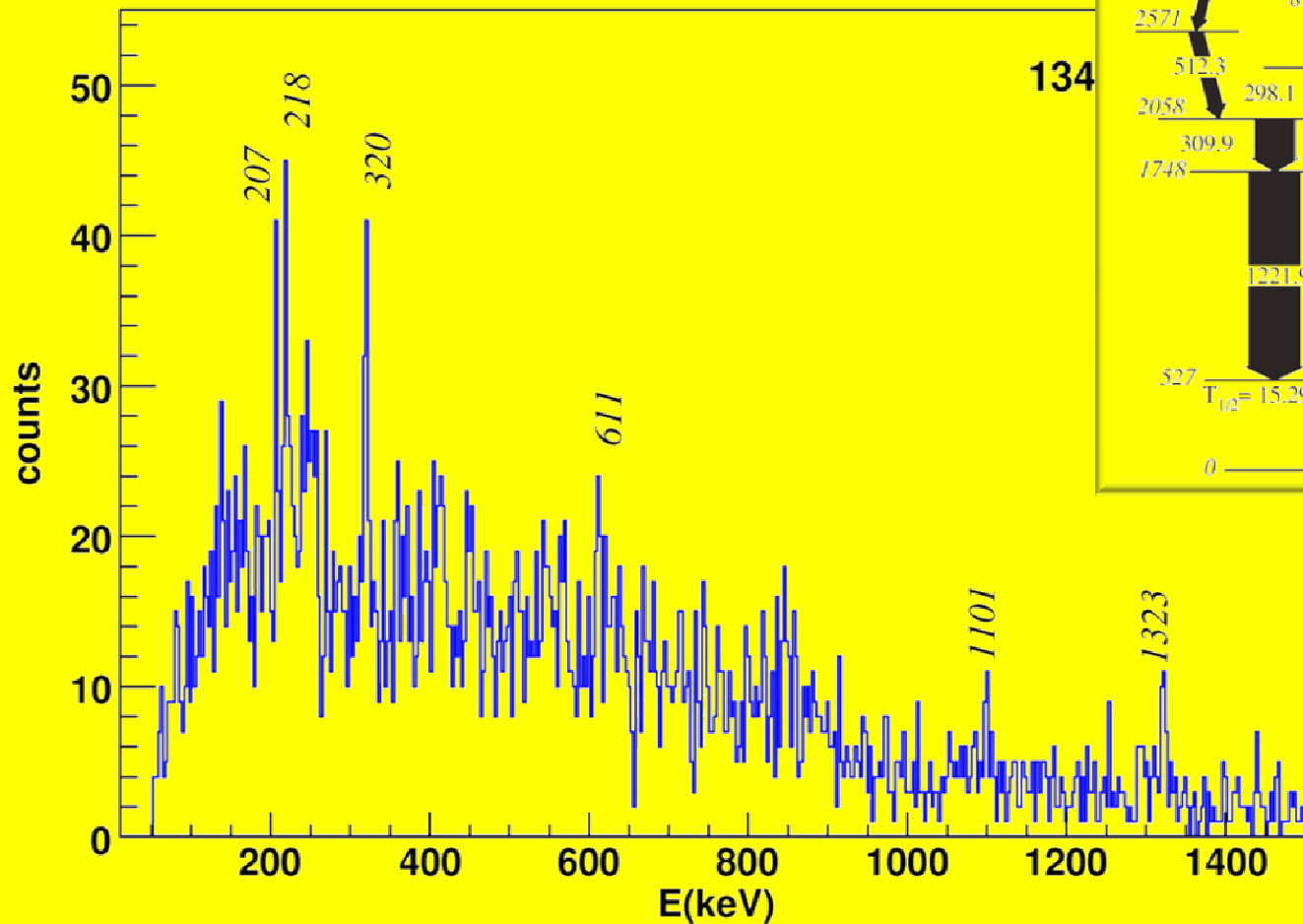
Ionisation Chamber

Secondary electron Detector

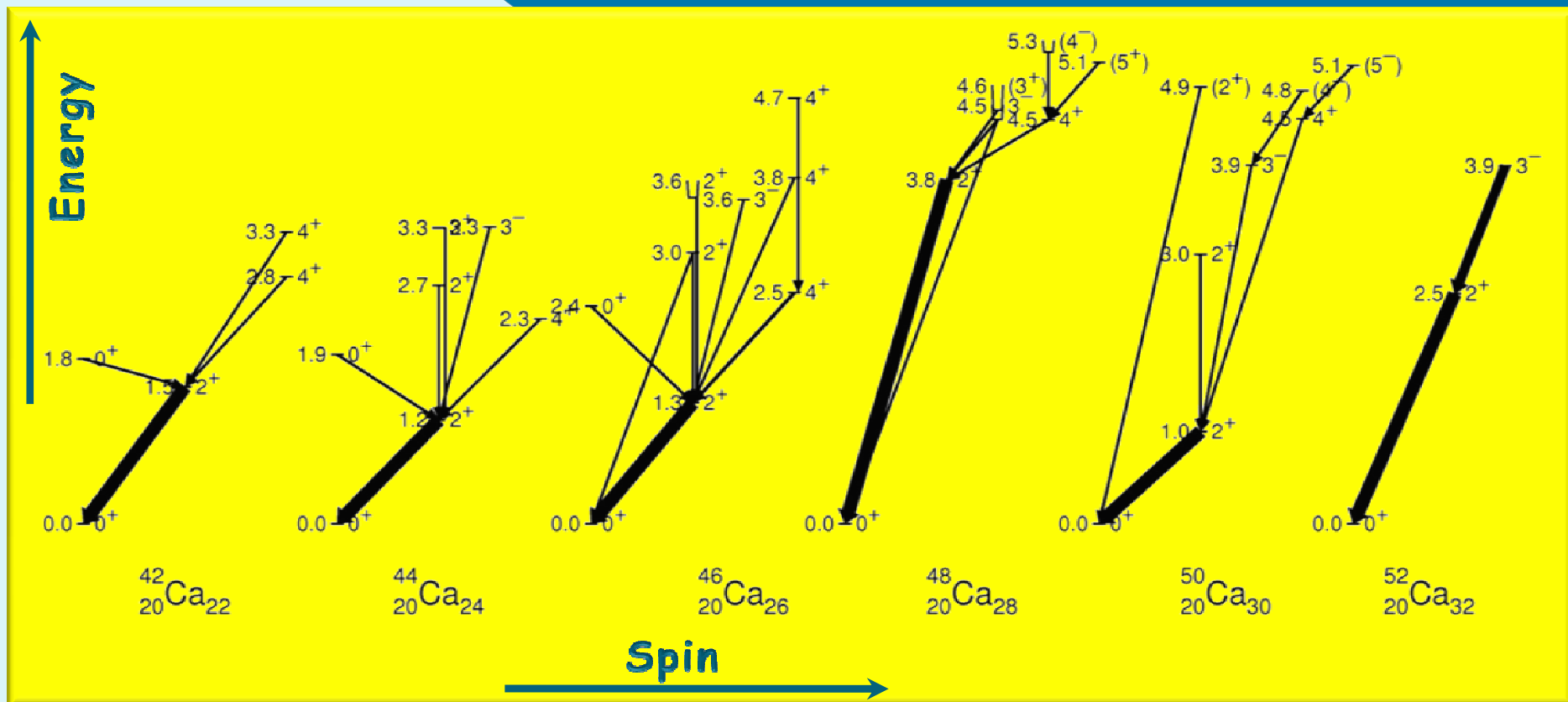
Mylar emissive foil



The spectrum of ^{134}Xe



Yrast and nonyrast states



Reactions near the Barrier

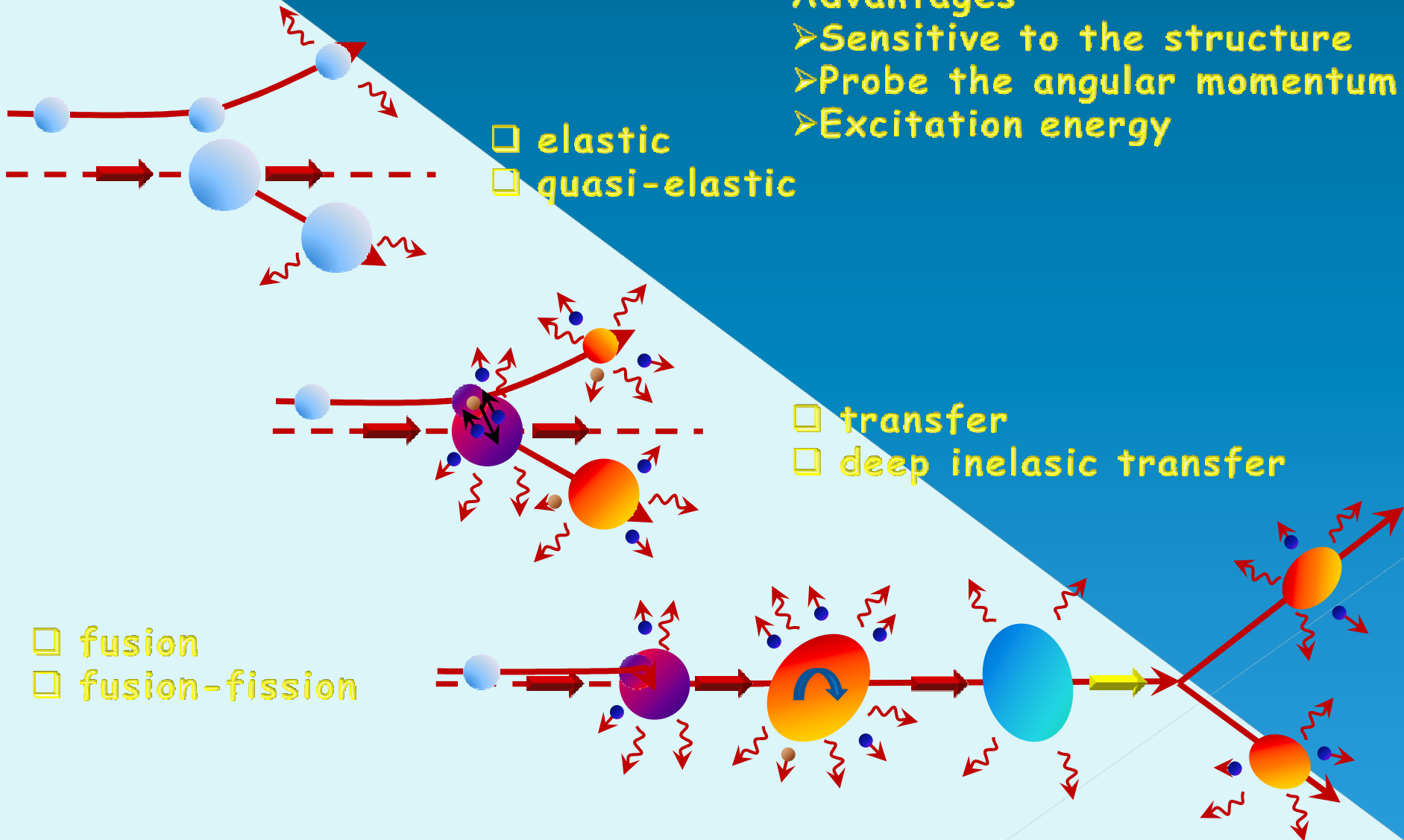
Advantages

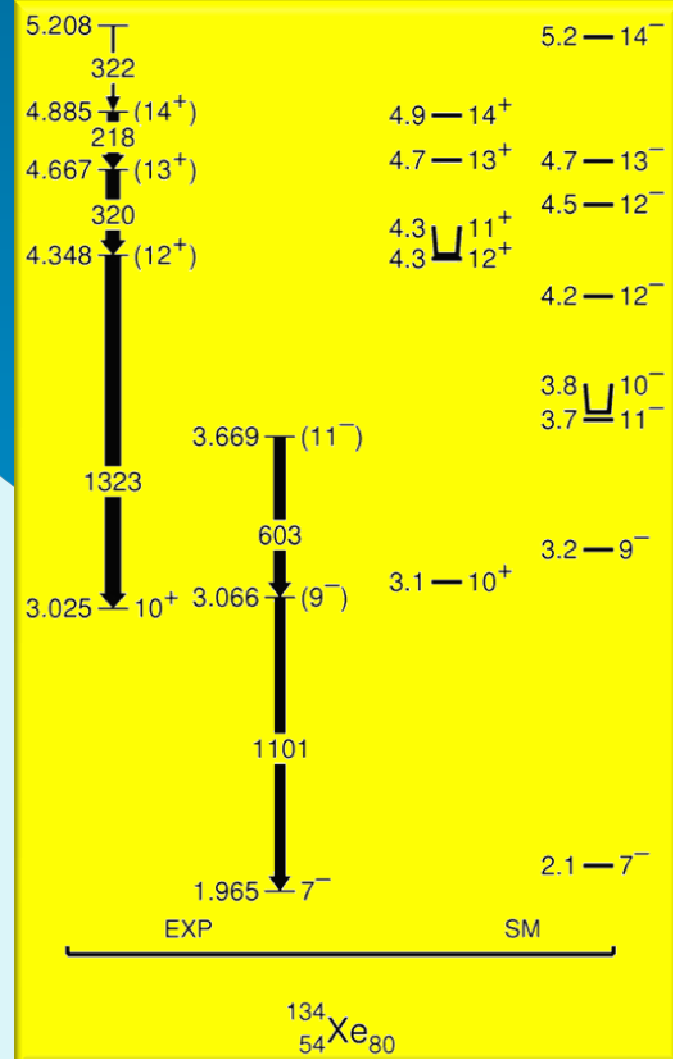
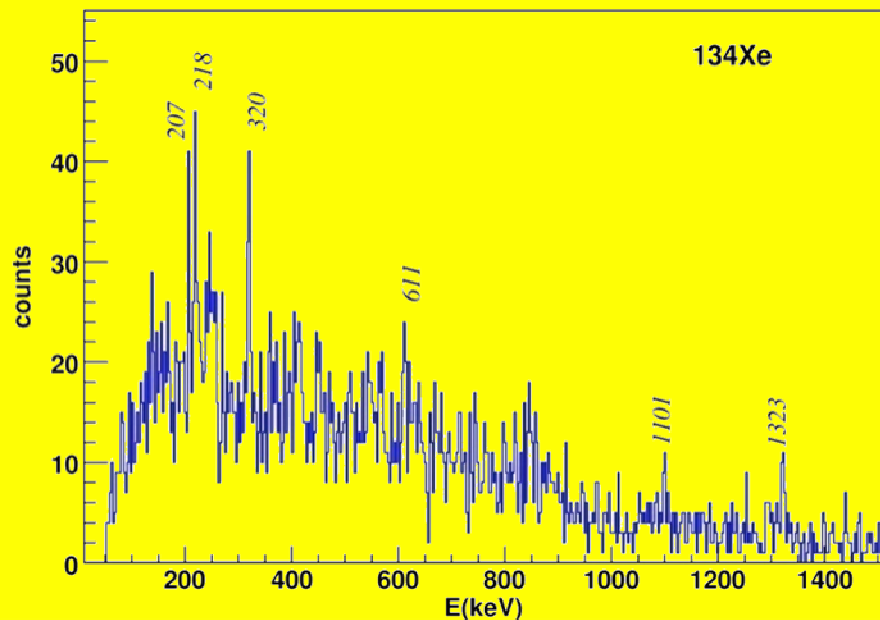
- Sensitive to the structure
- Probe the angular momentum
- Excitation energy

- elastic
- quasi-elastic

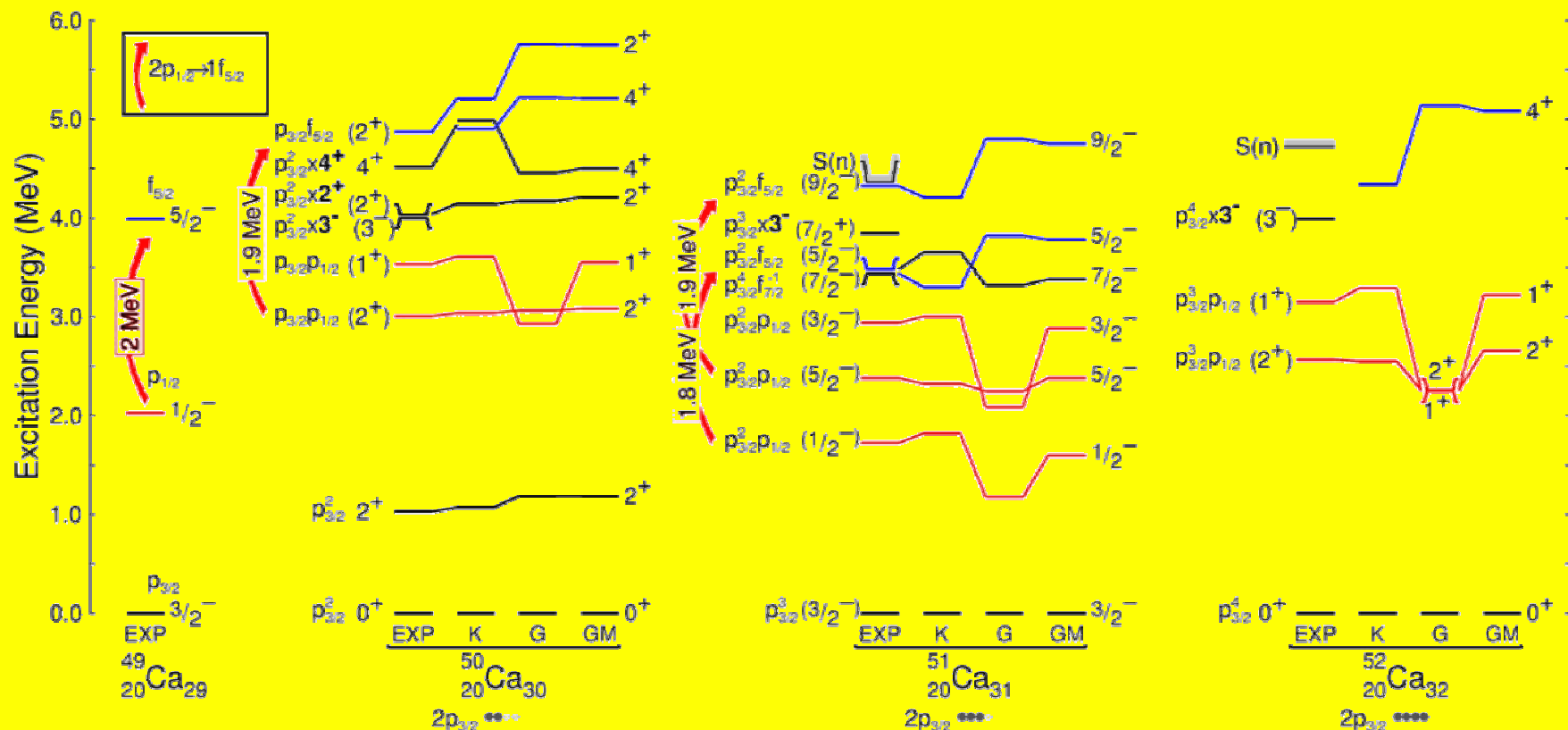
- transfer
- deep inelastic transfer

- fusion
- fusion-fission



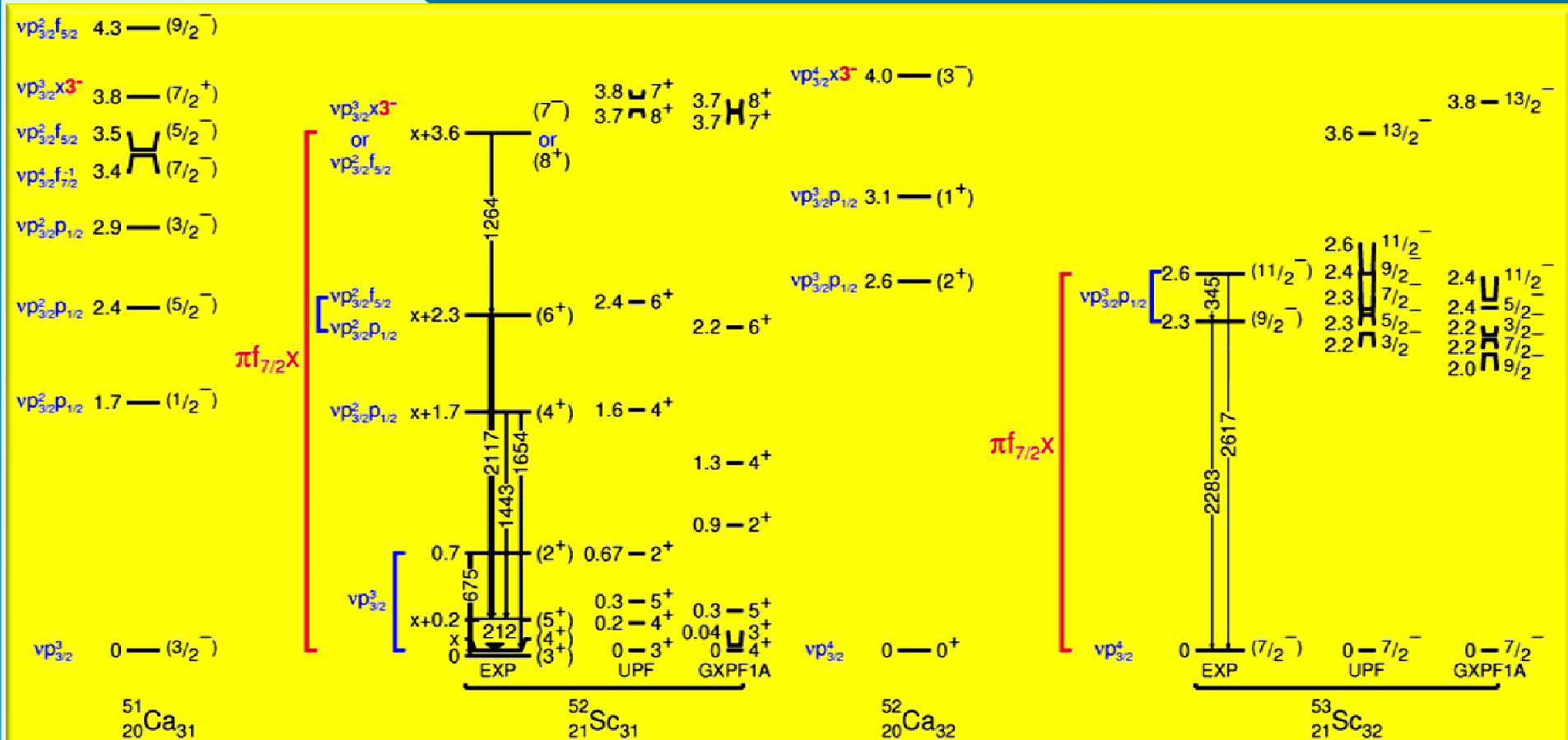


Shell gap at N=34?

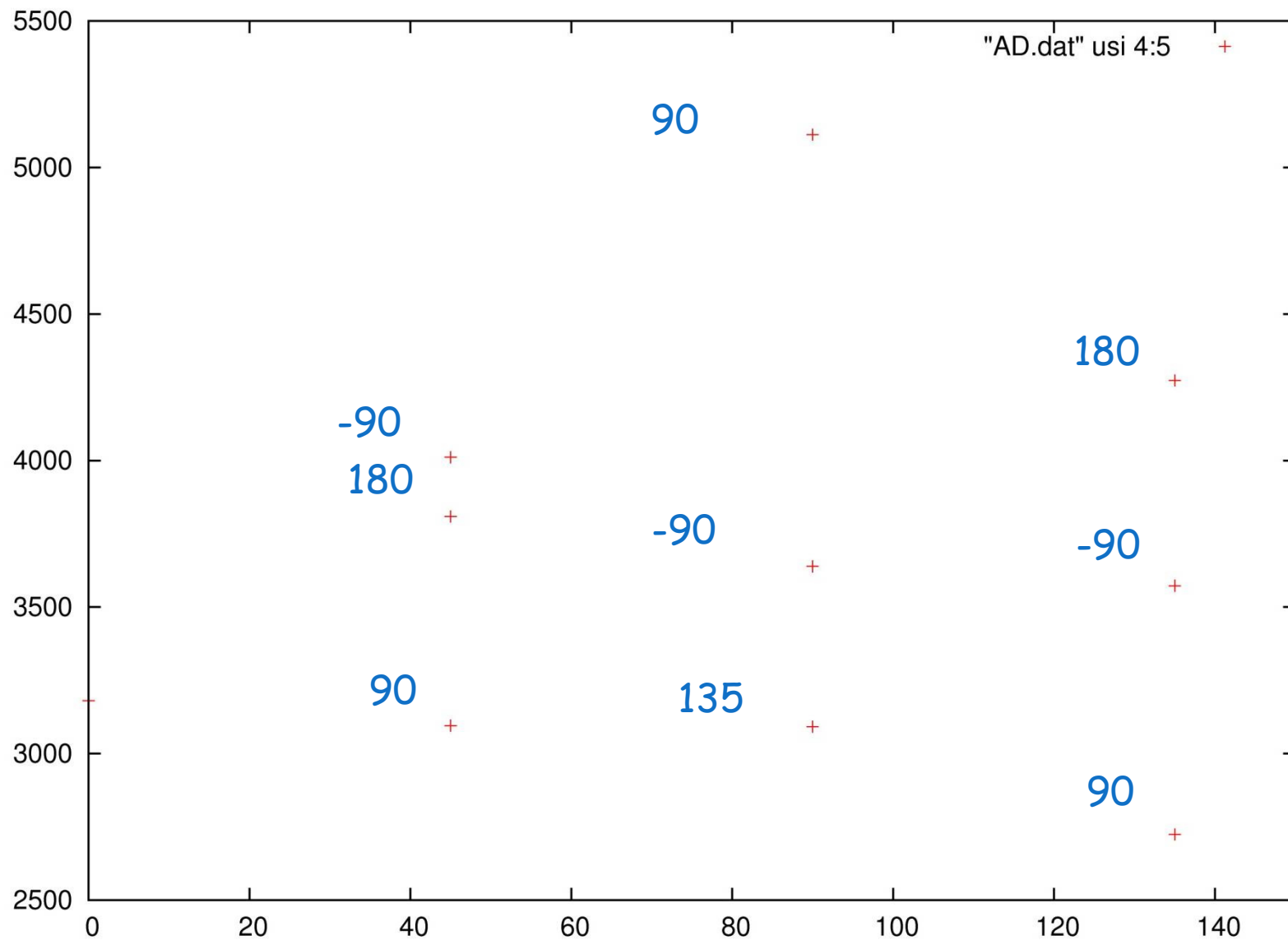


No new shell gap at N=34

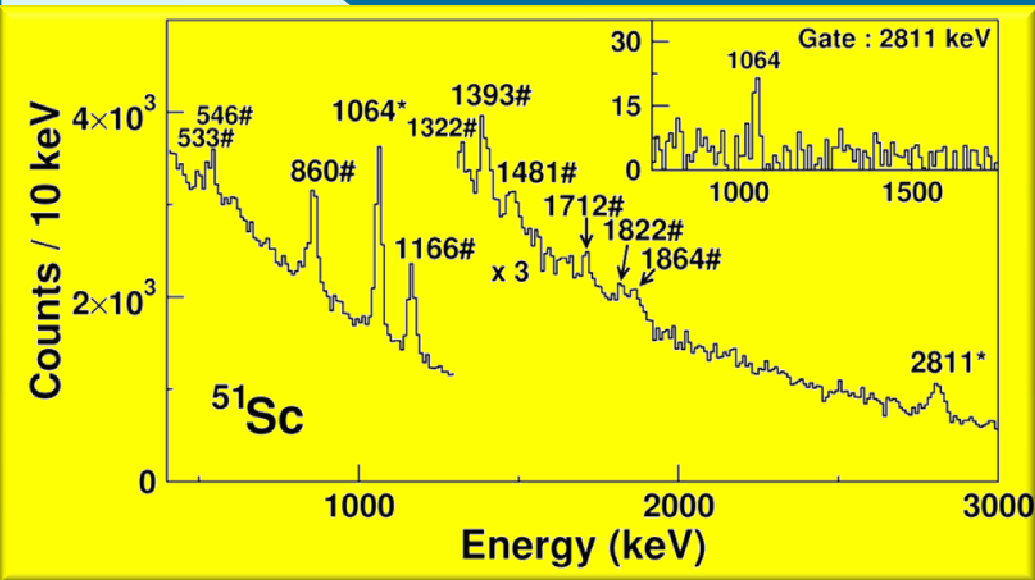
M. Rejmund et al.
PRC 76, 021304(R) (2007)



S. Bhattacharyya et al.
PRC 79, 014313 (2009)



Yrast and nonyrast states



yrast states

3875 $(15/2^-)$

1064 $11/2^-$

0 $7/2^-$

2811

1064

nonyrast states

3193 $(3/2^-, 5/2^-)$

3034 $(5/2^-)$

1712

1393 $(3/2^-, 5/2^-)$

1166 $(3/2^-, 5/2^-, 7/2^-)$

860 $(3/2^-)$

0 $7/2^-$

1322

533

1712

1166

546

1481

$^{51}_{21}\text{Sc}_{30}$

S. Bhattacharyya et al.
PRC 79, 014313 (2009)

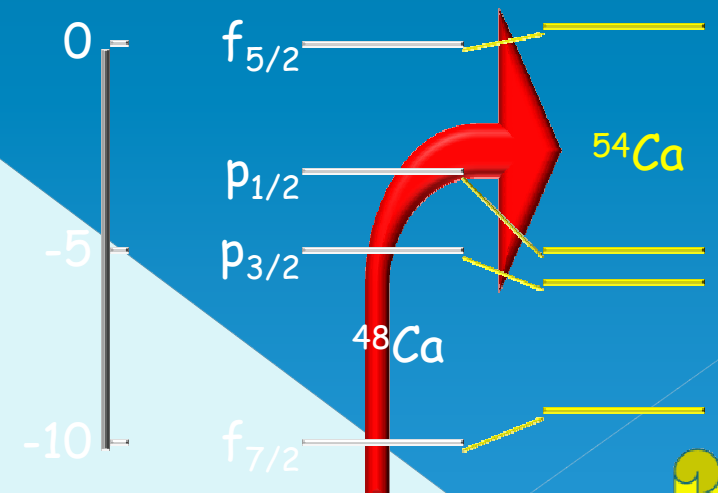
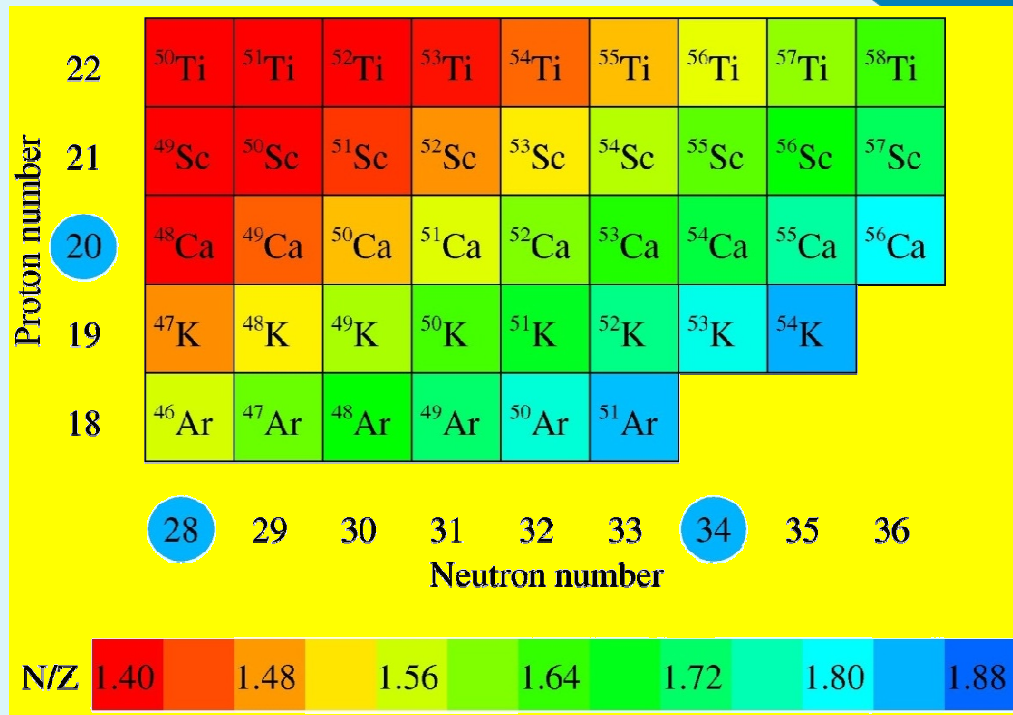
Exotic nuclei and highly intense stable beams around the barrier

○ Shell structure evolution away from stability

- > Magic numbers?
- > Shapes and collectivity?

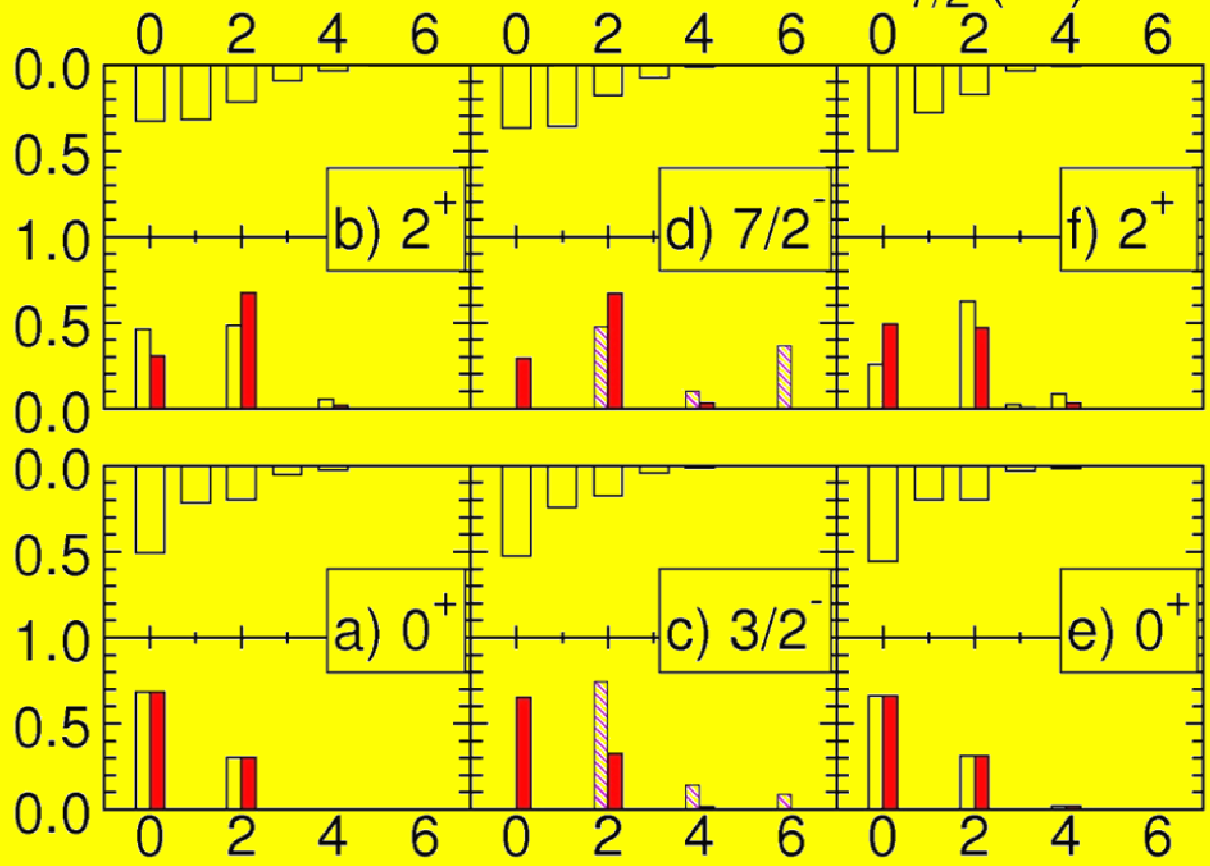
○ Recent prediction

- > New Magic gap at $N=34$ in ^{54}Ca



Pronounced shell gap in ^{54}Ca ?

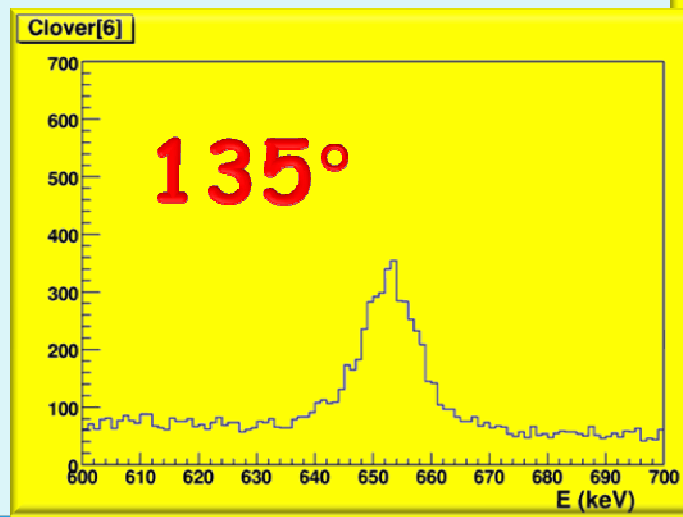
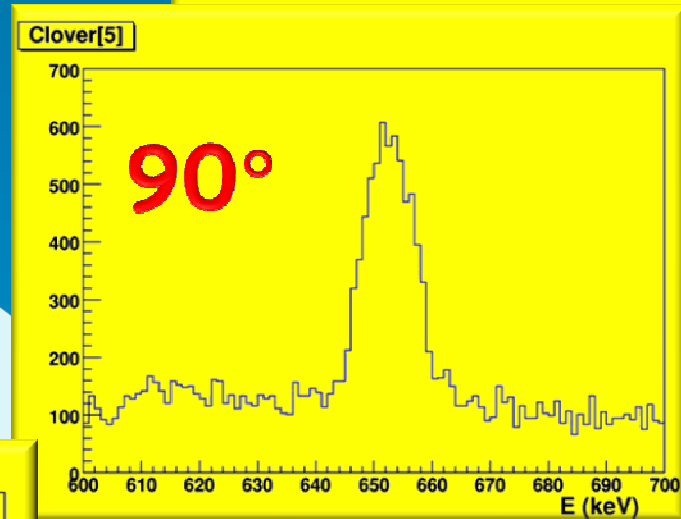
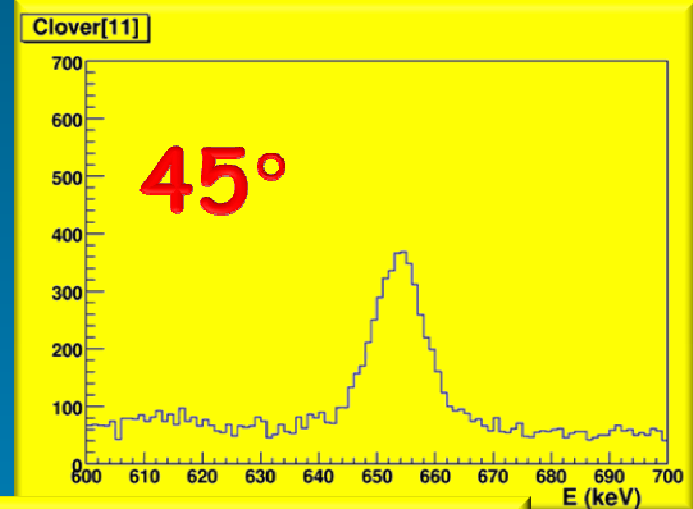
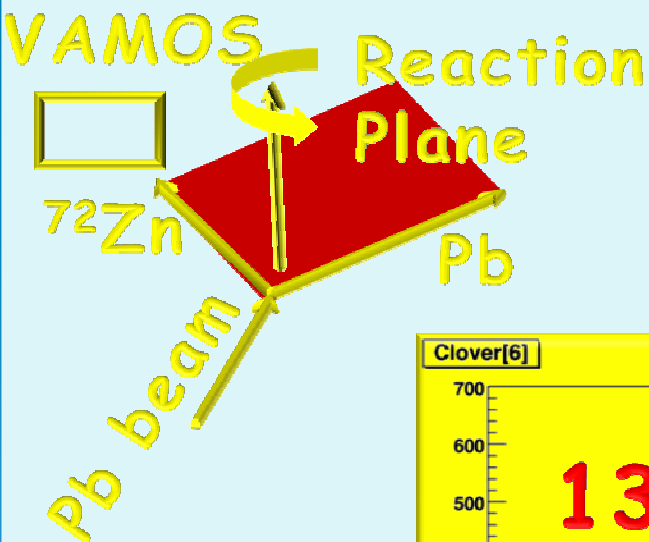
^{46}Ar ^{47}Ar ^{48}Ar
 Number of neutron holes in $f_{7/2}$ (□)



Angular momentum J_v (□), $2 \cdot J_v - 1$ (▨) and J_π (■)

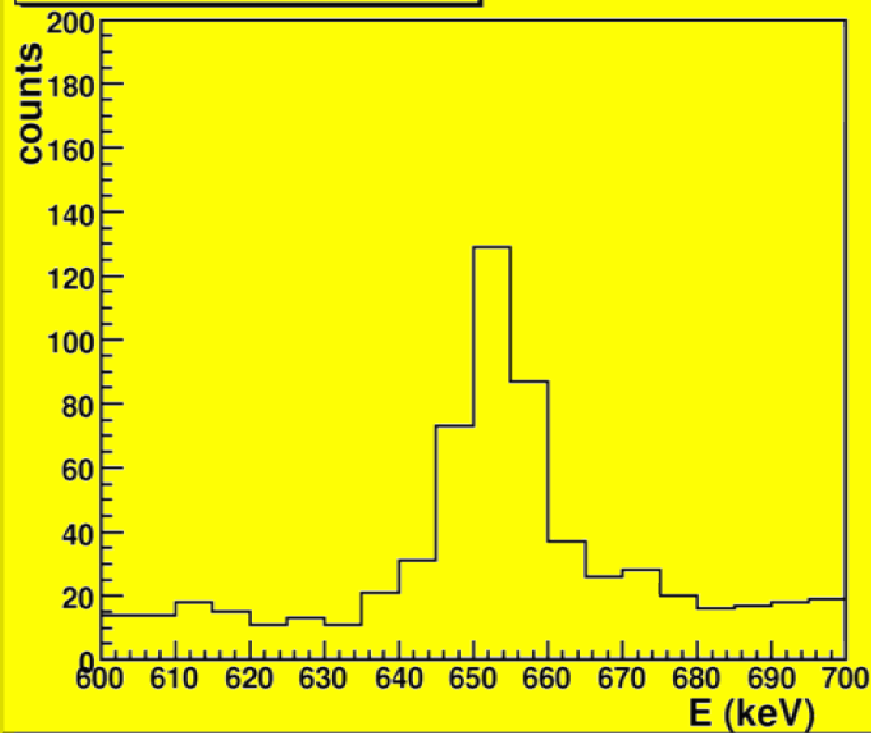
Nuclear alignment

- ^{72}Zn
- $2^+ \rightarrow 0^+$
- Different Clover angles



Linear polarization of gamma rays from Compton scattering

Parallel



Perpendicular

