Recent results from VAMOS

In this presentation:

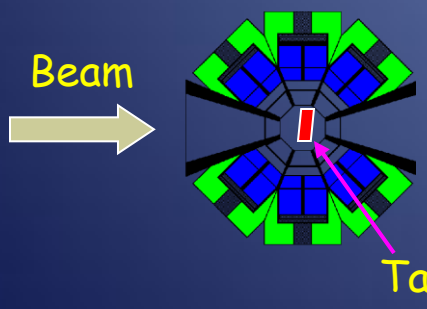
- VAMOS
- recent results using:
  - Low intensity radioactive beams
  - High intensity stable beams

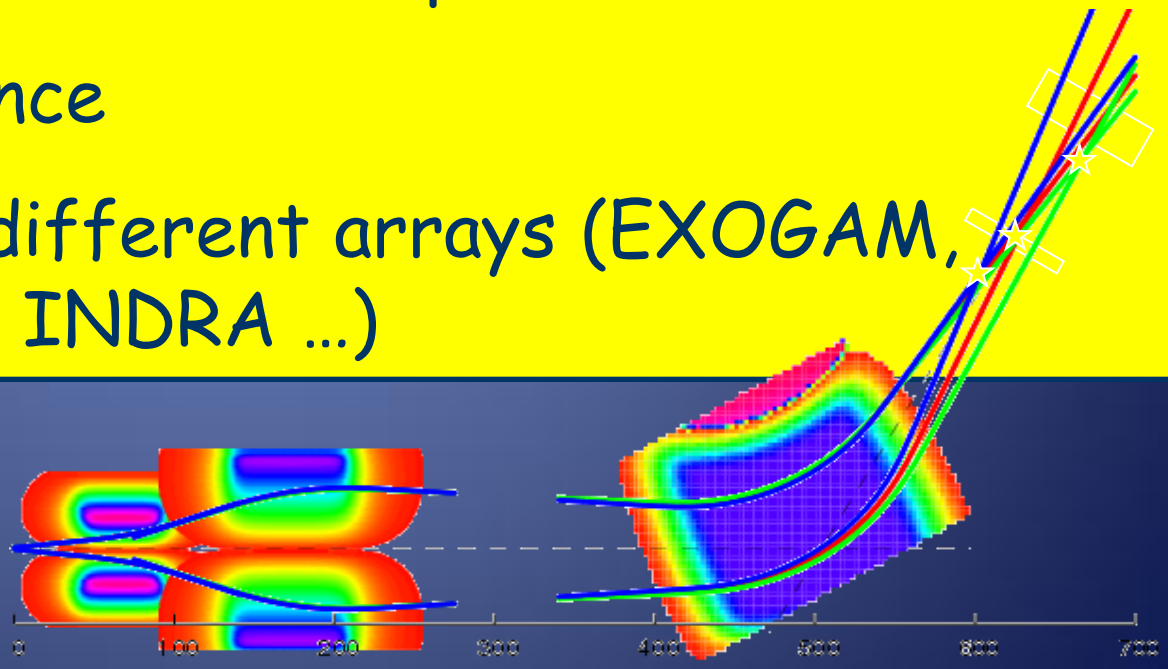
VAMOS++

VARIABLE MODE SPECTROMETER

Essential for nuclear structure and reaction studies

- ✓ Identification of reaction products
- ✓ Large acceptance
- ✓ Coupling with different arrays (EXOGAM, MUST2, TIARA, INDRA …)





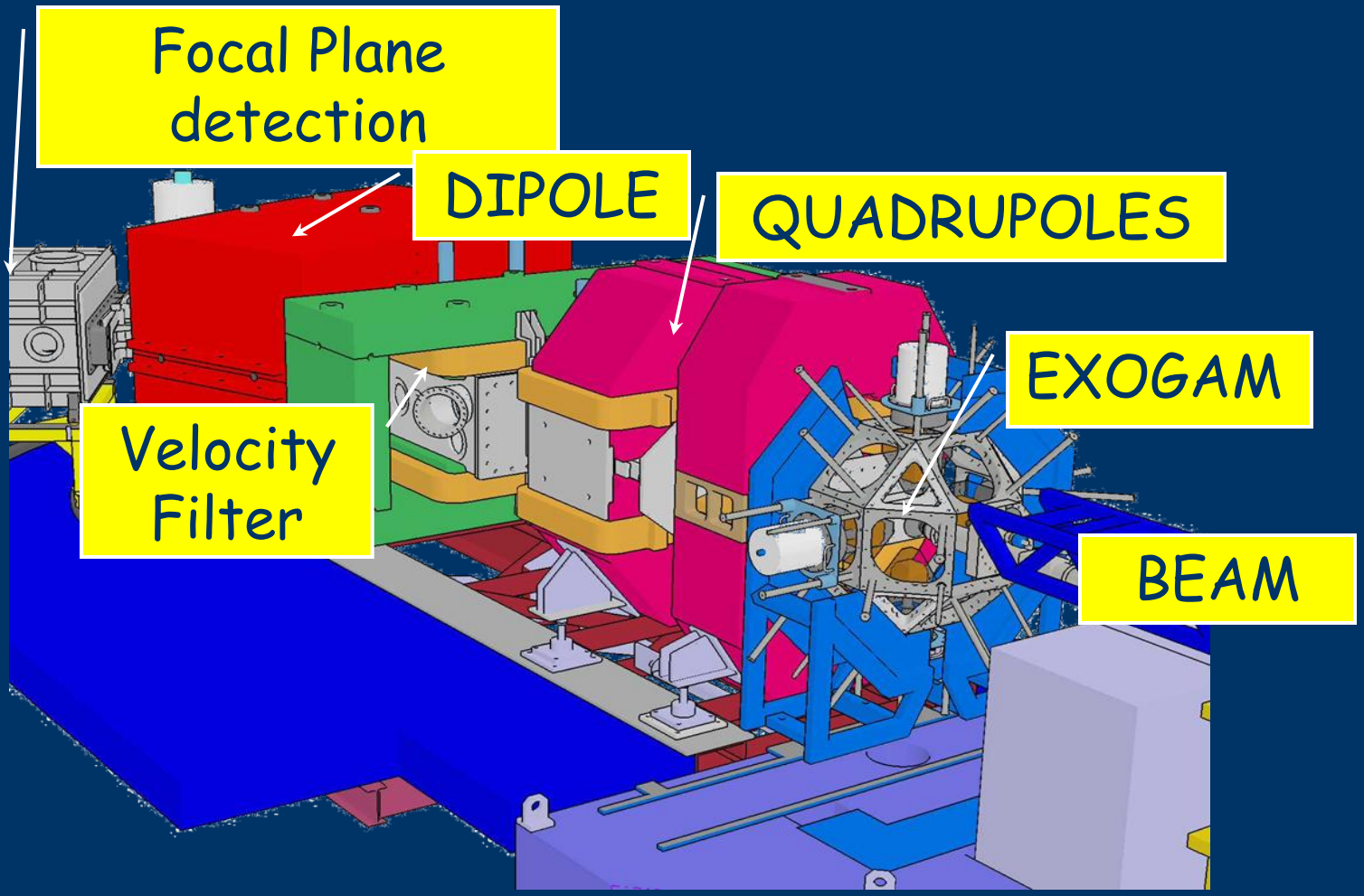
Variable Mode Operation

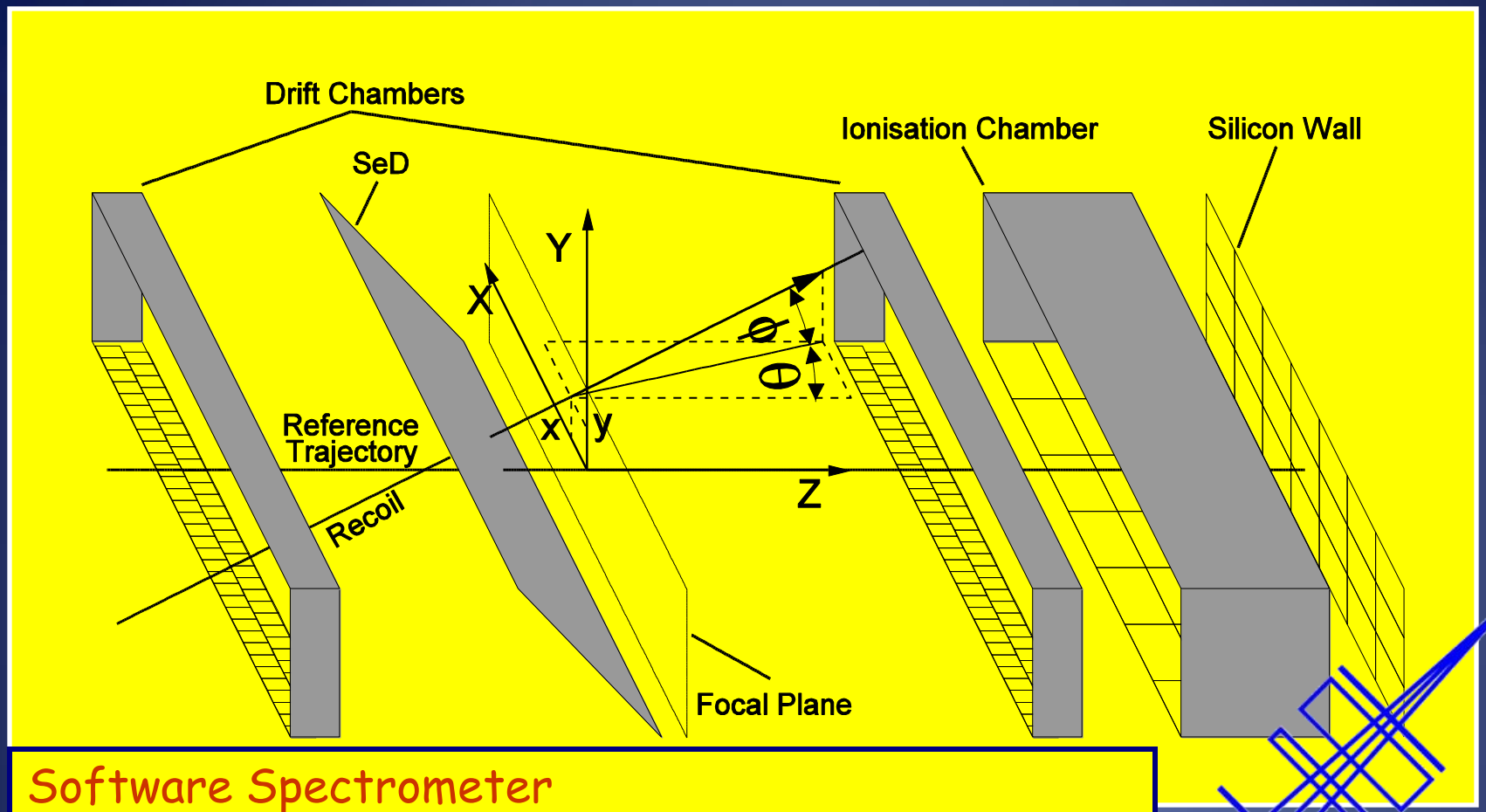
- ✓ QQ – Focusing Mode
- ✓ QQD – Spectrometer
  - ➢ Variable Dispersion
- ✓ Recoil Separator
  - ▪ QQF(D)
  - ▪ QQD (Gas filled)

S. Pullanhiotan et al, NIMA 593 (2008) 343

C. Schmitt et al, NIM A 621 (2010) 558

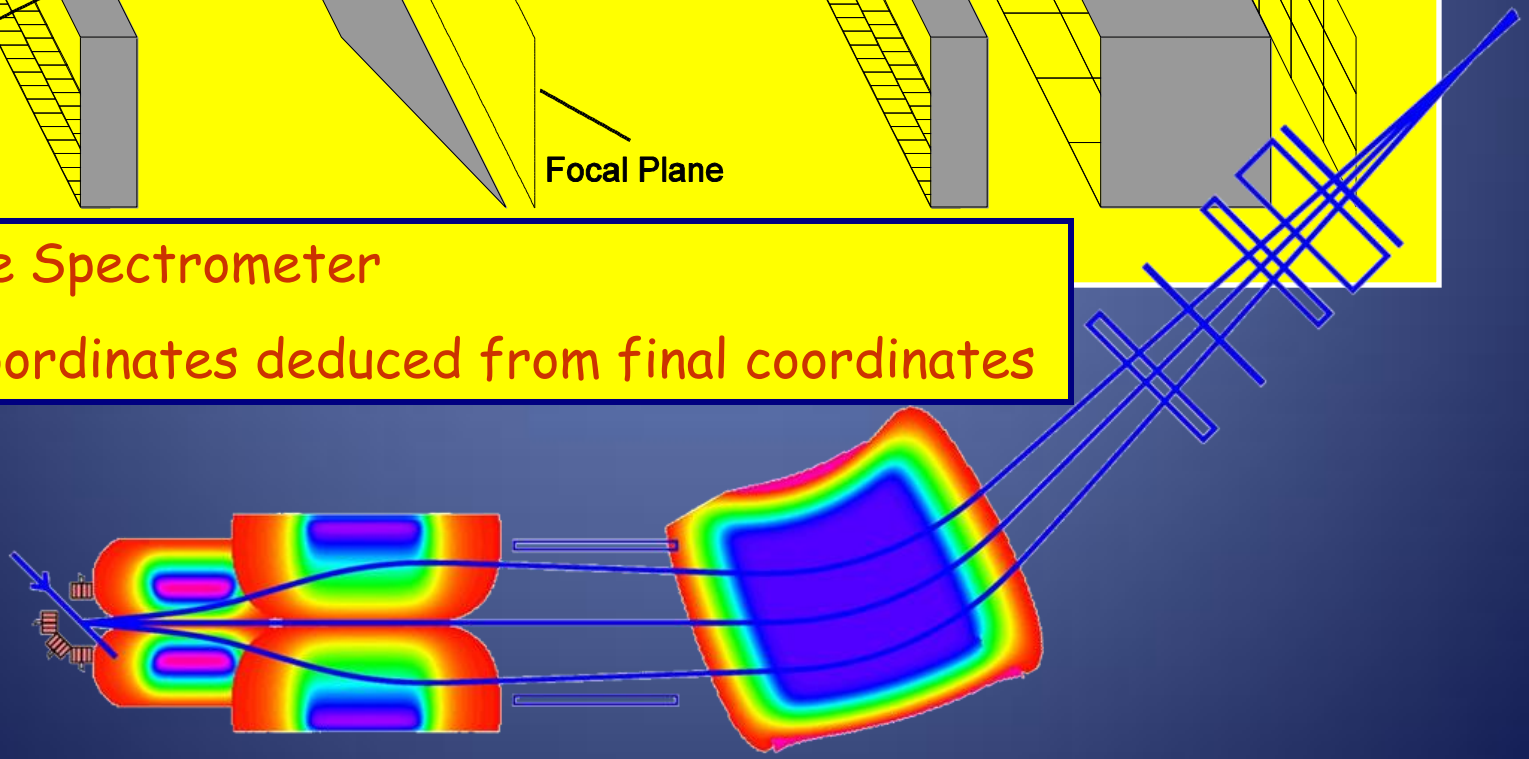
VAMOS Spectrometer Schematic View



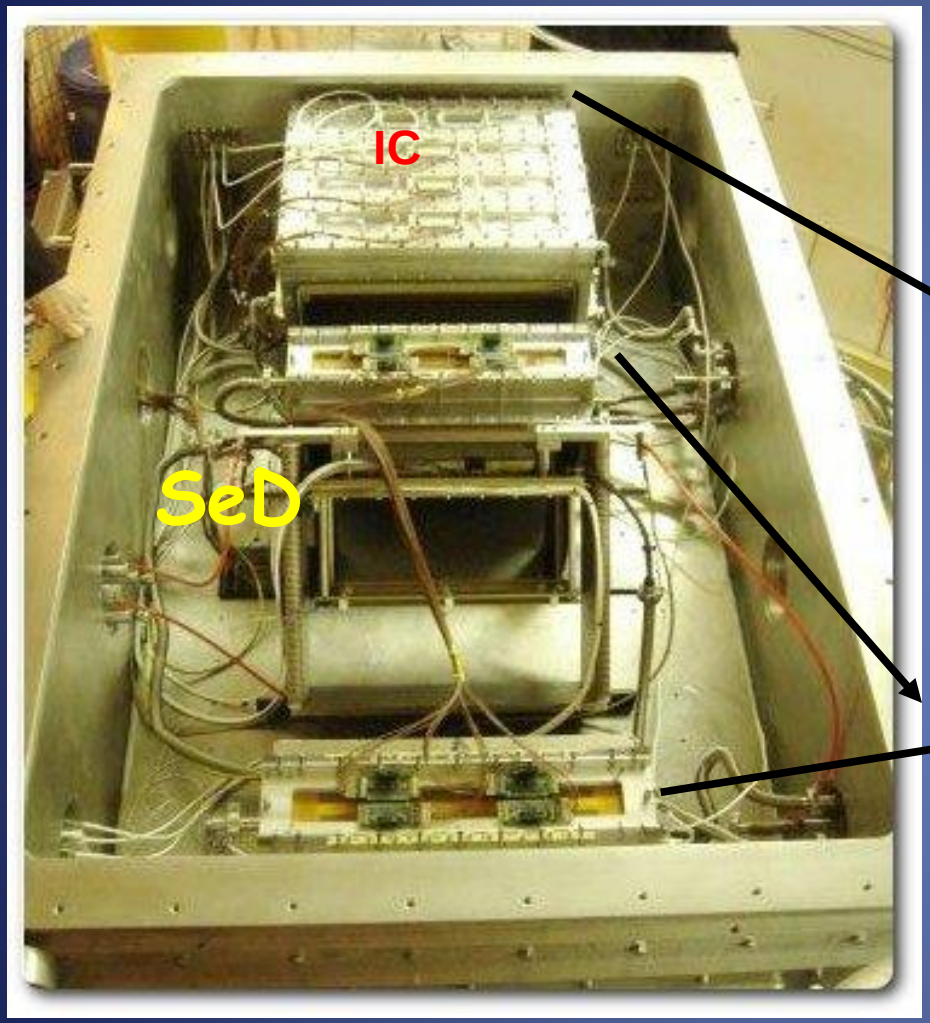


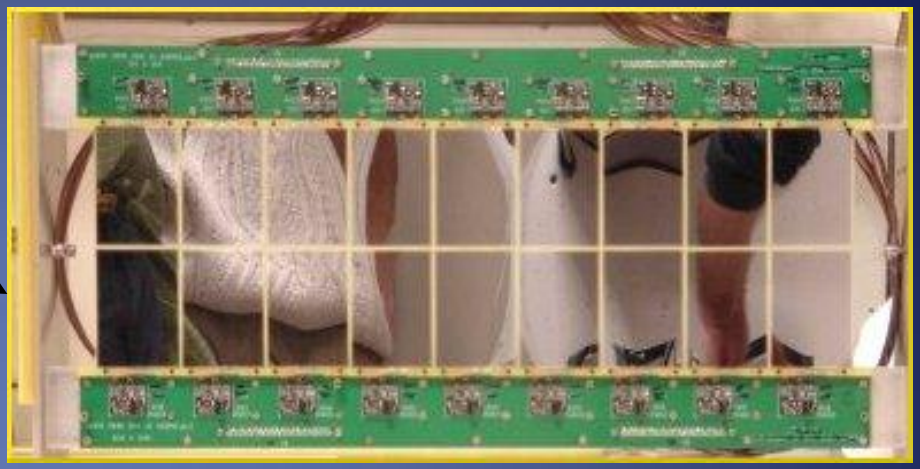
Software Spectrometer

Initial coordinates deduced from final coordinates

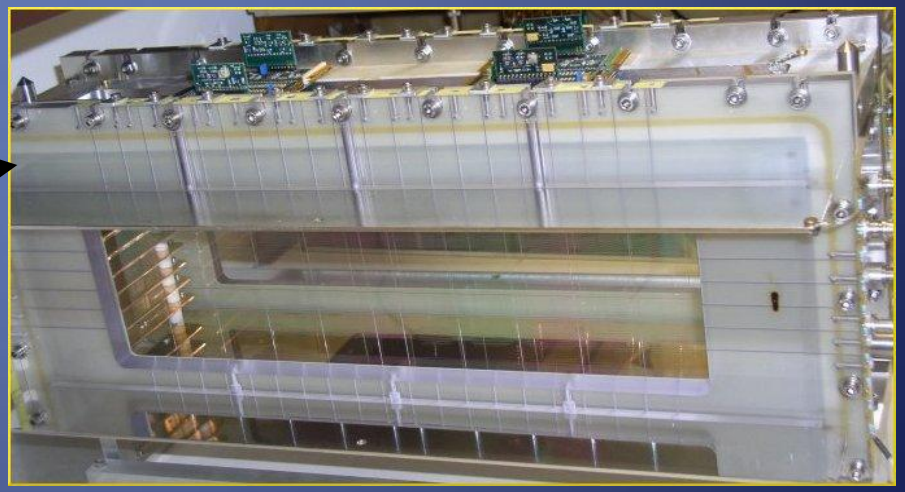


Focal Plane Setup





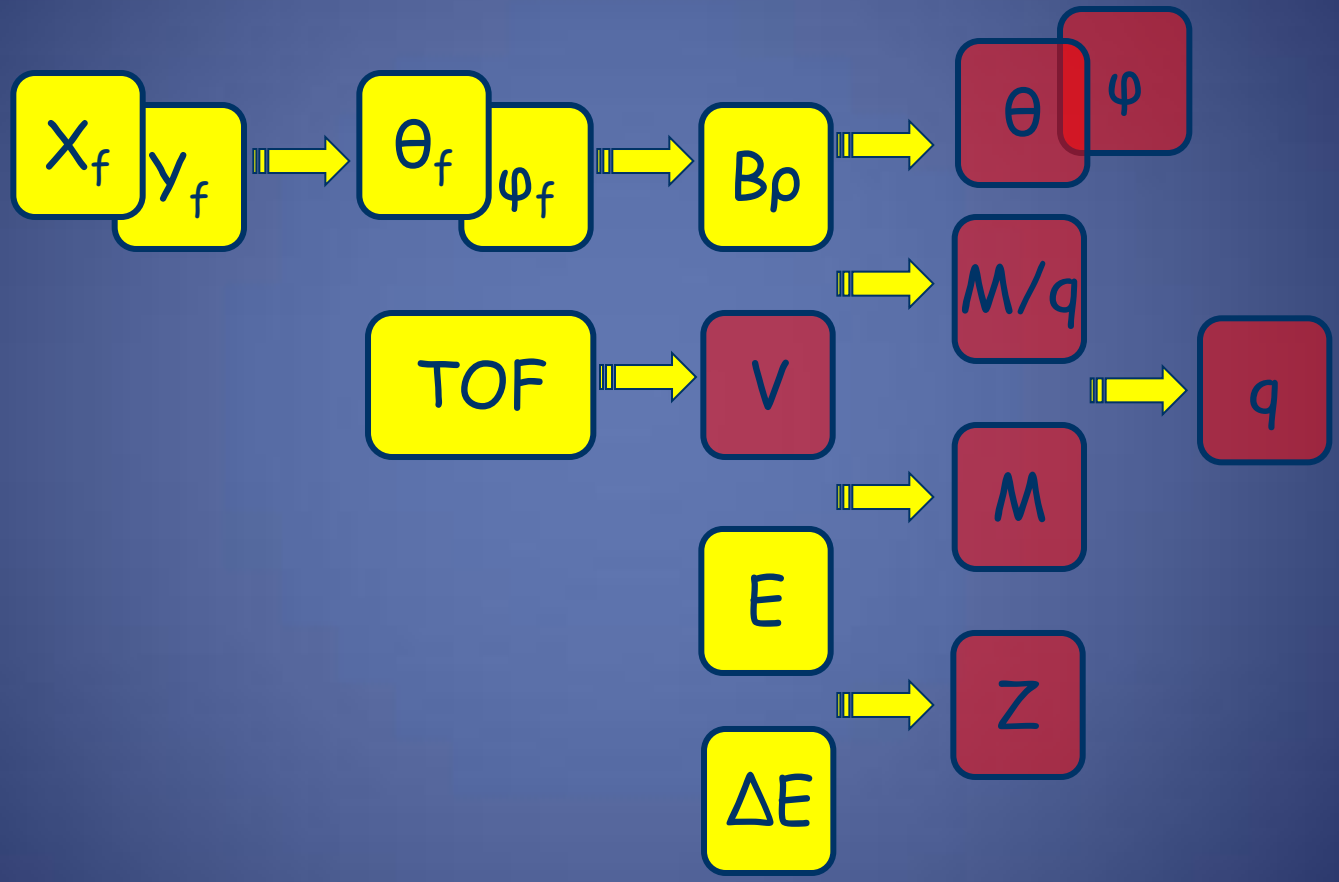
Si Wall



Drift Chamber

beam

VAMOS Measurement (Software Spectrometer)

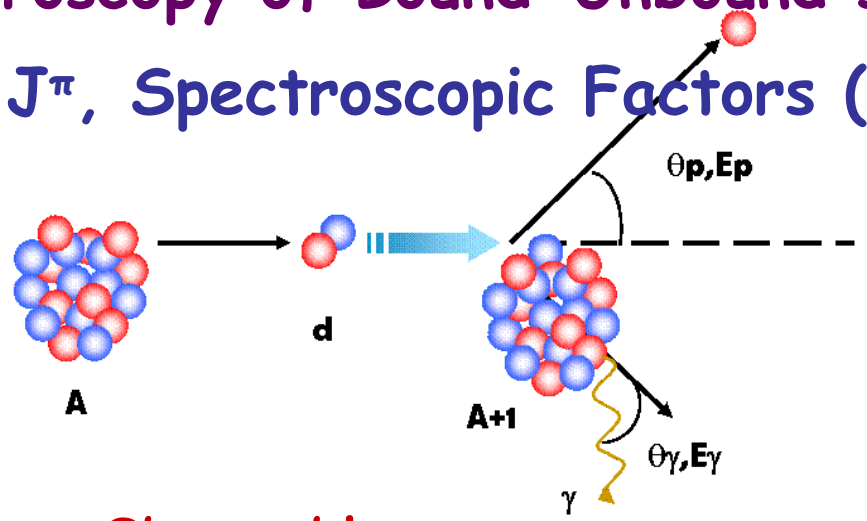


Experimental approach

-transfer reactions in inverse kinematics

Spectroscopy of Bound-Unbound states

Ex, J^{π}, Spectroscopic Factors (SF)



Measurements -> Observables

Ep and/or Eγ ->Ex

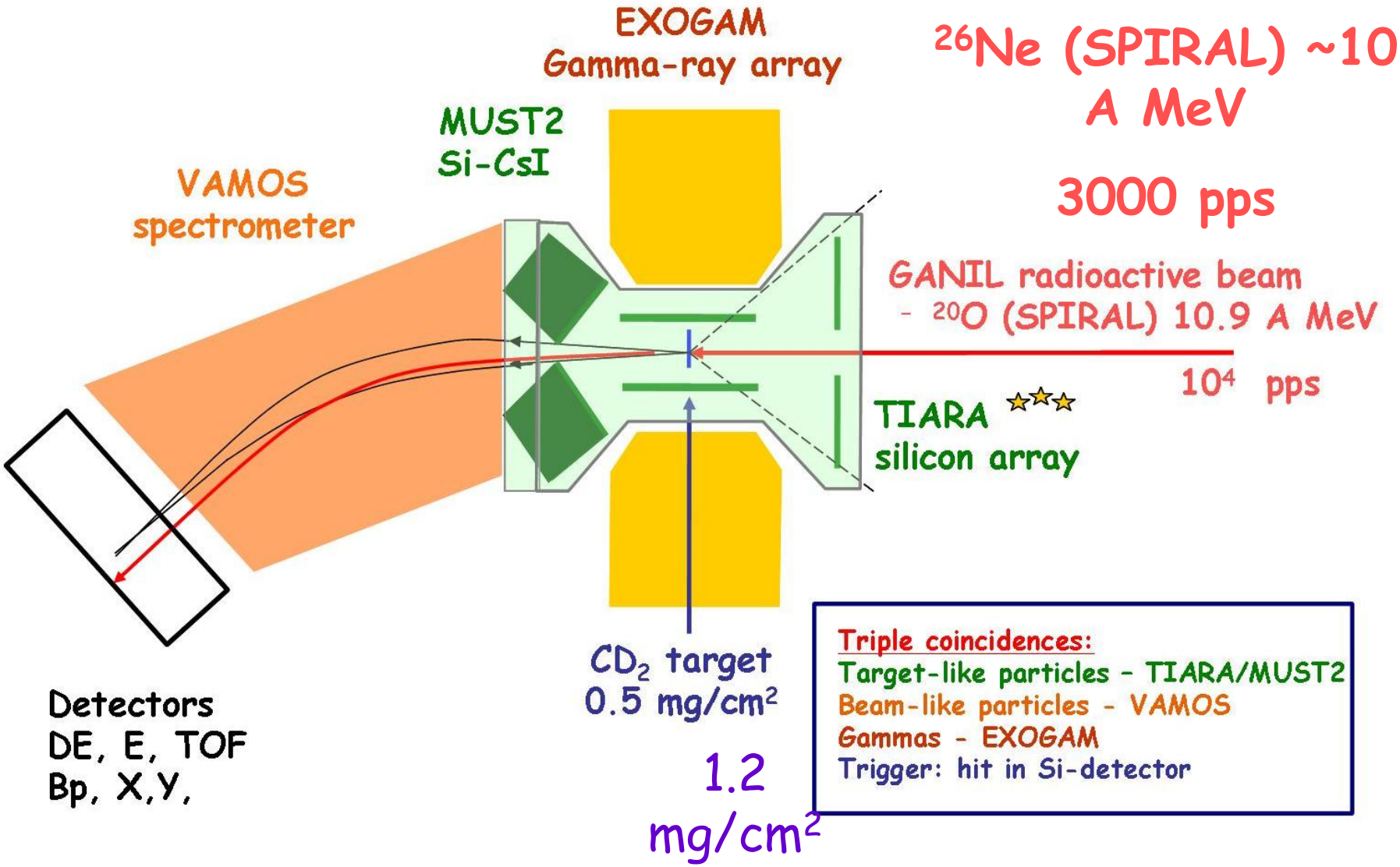
θp -> dσ/dΩ -> (ℓ , SF)

Inverse kinematics->(d,p),(d,t),(d,^{3}He),(d,d')

B. Fernandez-Dominguez et al, PRC 84, (2011), 011301

Experimental Set-Up

TIARA+MUST2+VAMOS+EXOGAM @ GANIL

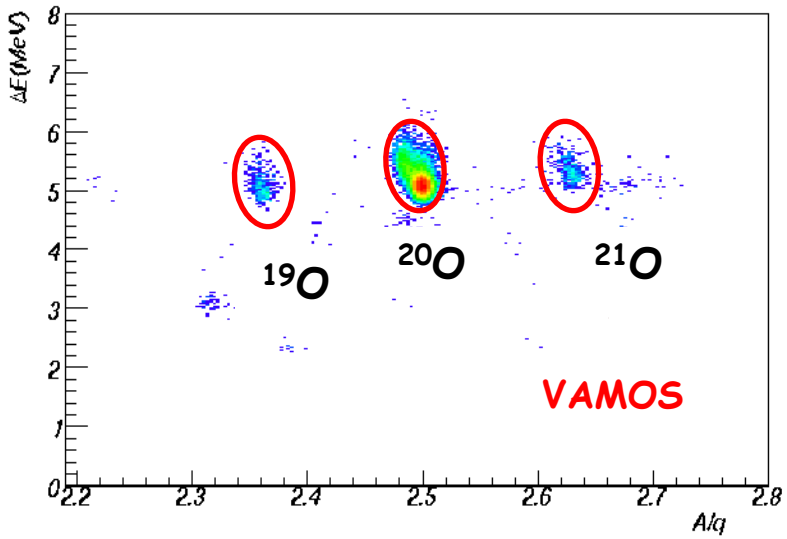


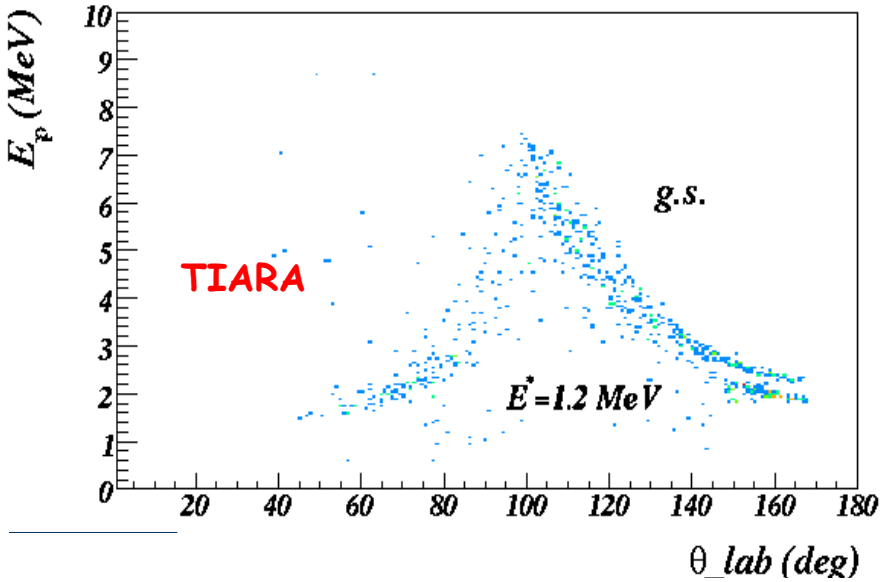
^{26}Ne (SPIRAL) ~10 A MeV

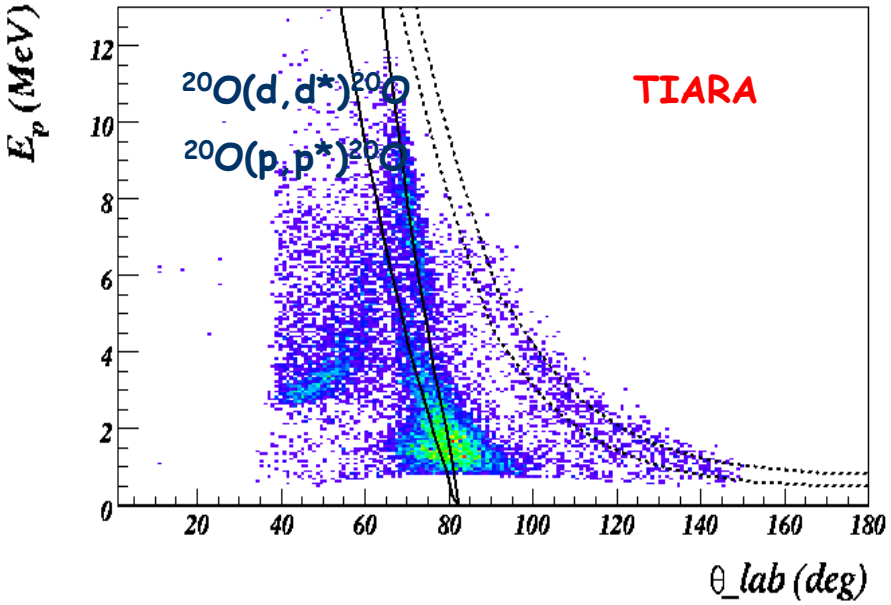
3000 pps

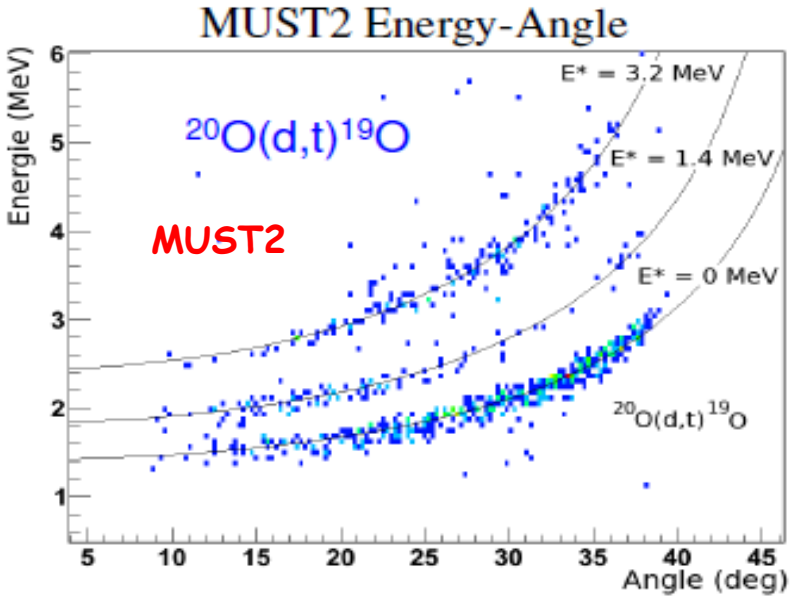
Triple coincidences:
Target-like particles - TIARA/MUST2
Beam-like particles - VAMOS
Gammas - EXOGAM
Trigger: hit in Si-detector

ANALYSIS : Example $d(^{20}O,p)^{21}O$

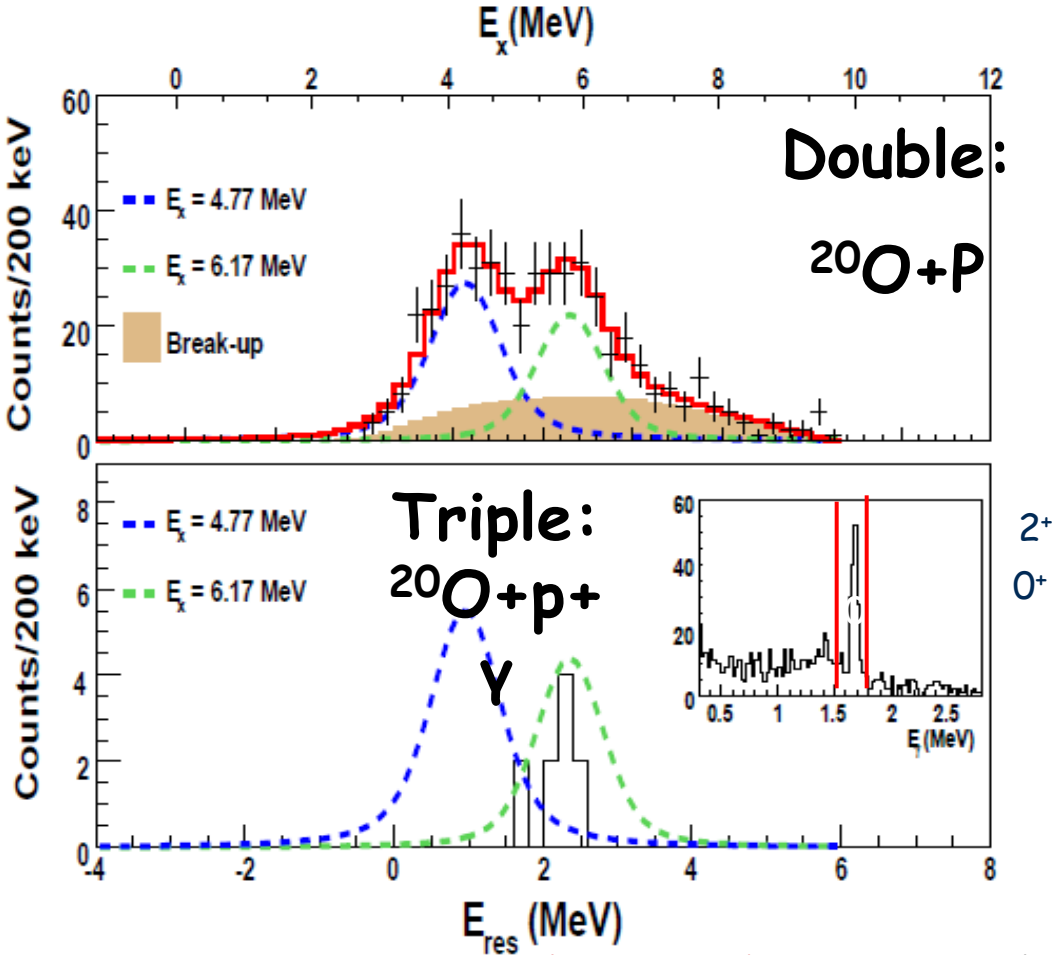


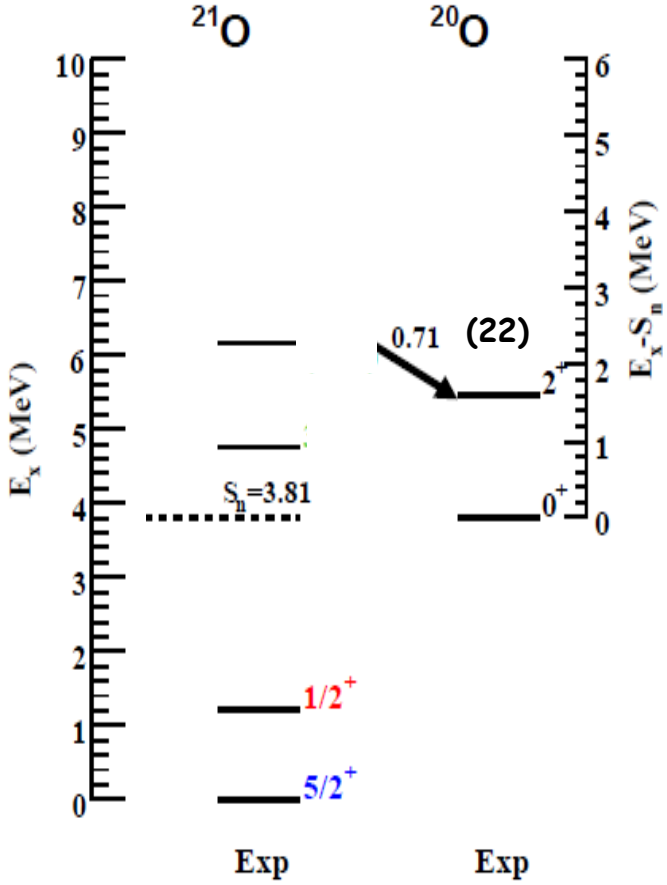






UNBOUND STATES: $d(^{20}O,p)^{21}O \rightarrow {}^{20}O + n$ (stripping)



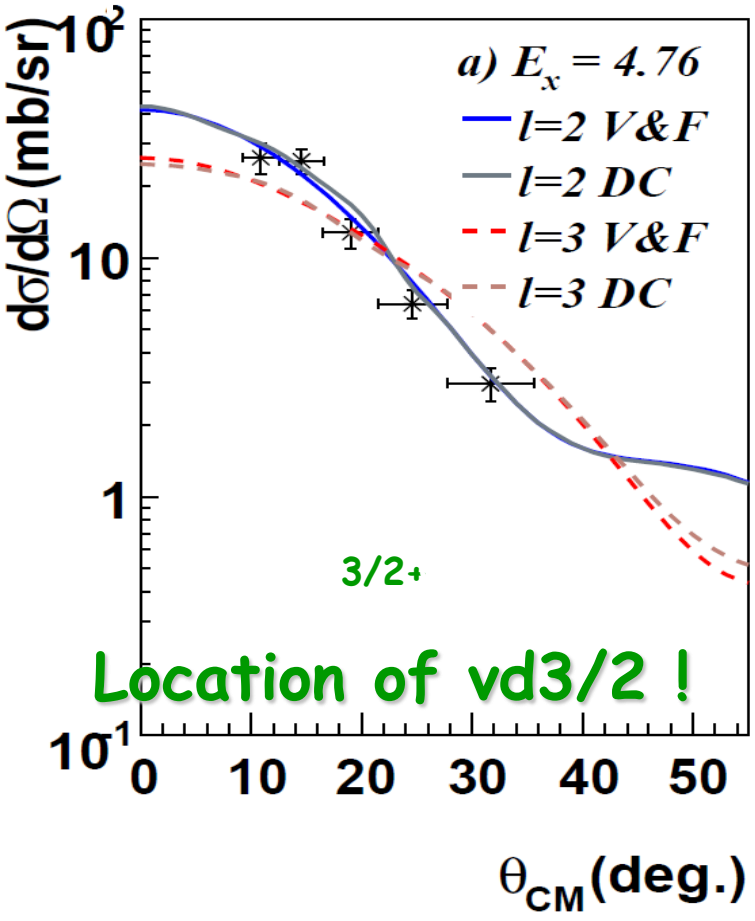


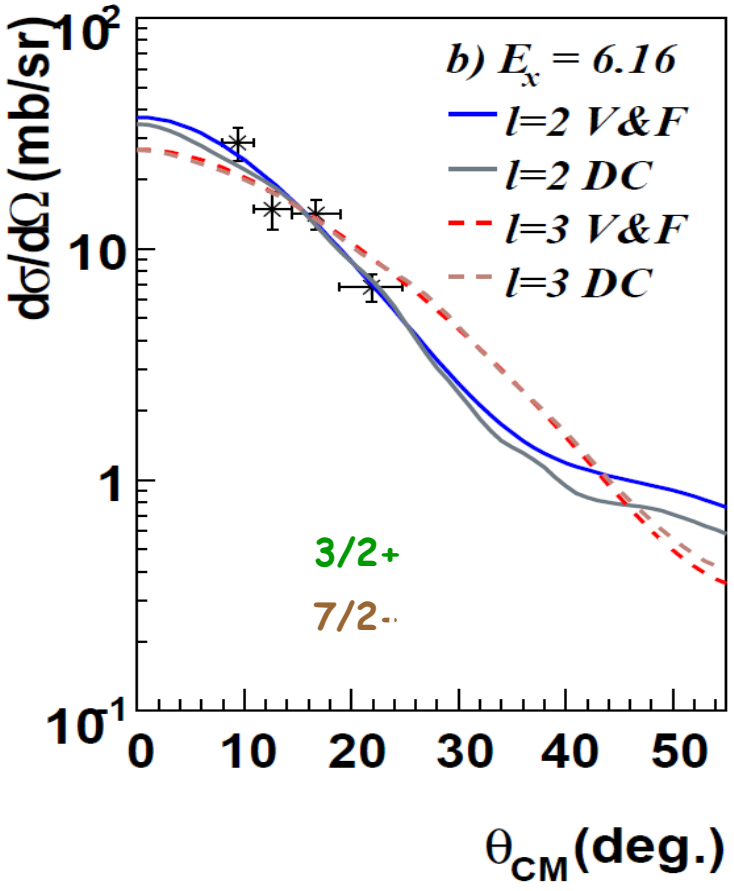
Triple coincidence: particle+γ+recoil

Measurement of core-excitations in unbound nuclei through its decay:

$\Psi(^{21}O \text{ @ } 6.2 \text{ MeV}) = a\,|n \times {}^{20}O(0^+)\rangle + b\,|n \times {}^{20}O(2^+)\rangle$

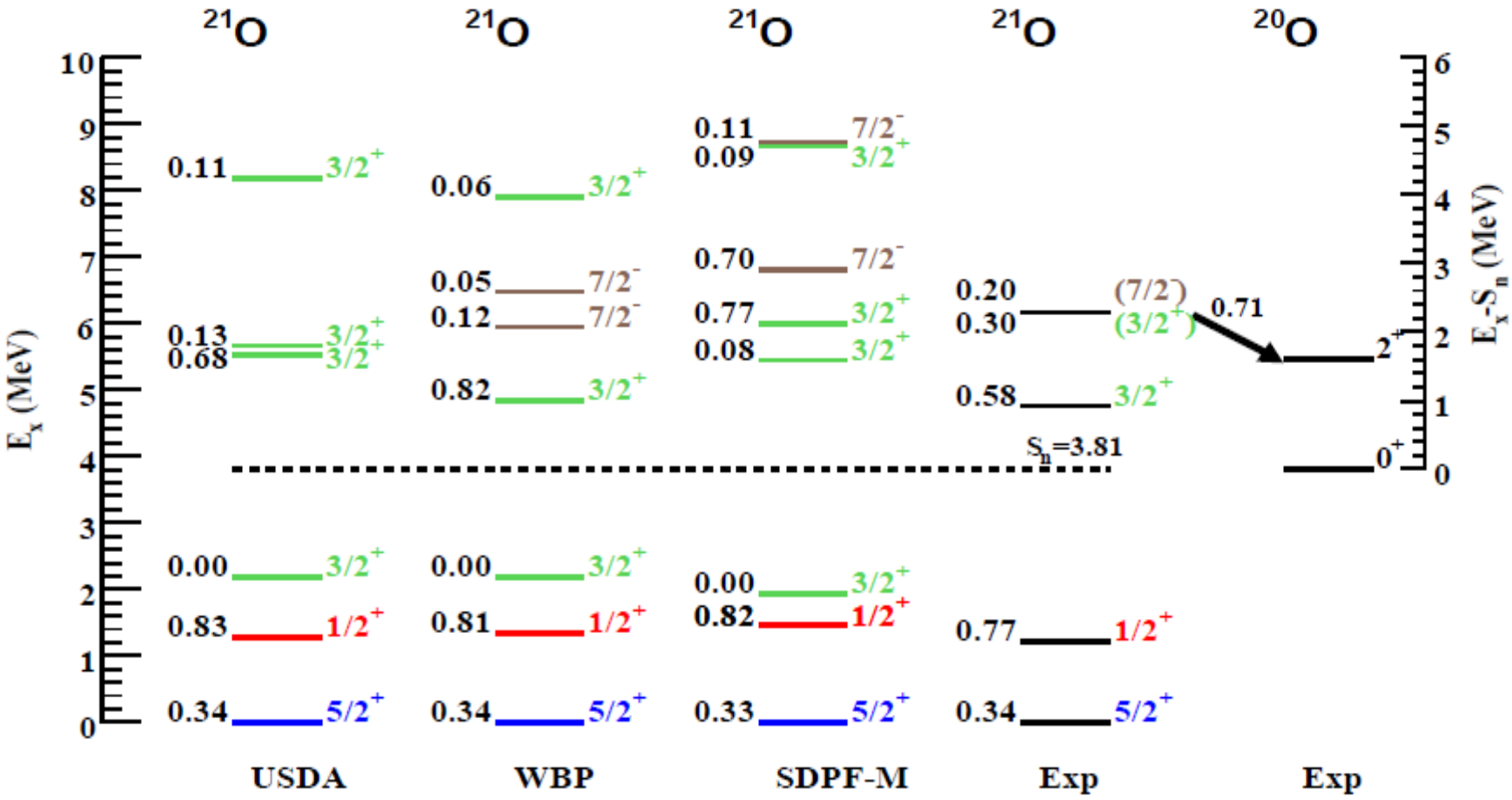
UNBOUND STATES: $d(^{20}O,p)^{21}O \rightarrow {}^{20}O + n$ (stripping)





First 3/2+ state corresponds to the sought vd3/2

UNBOUND STATES: $d(^{20}O,p)^{21}O \rightarrow {}^{20}O + n$ (stripping)

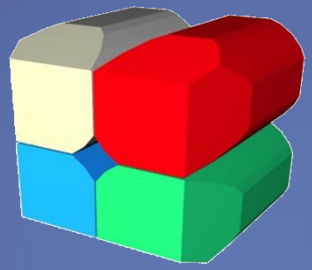


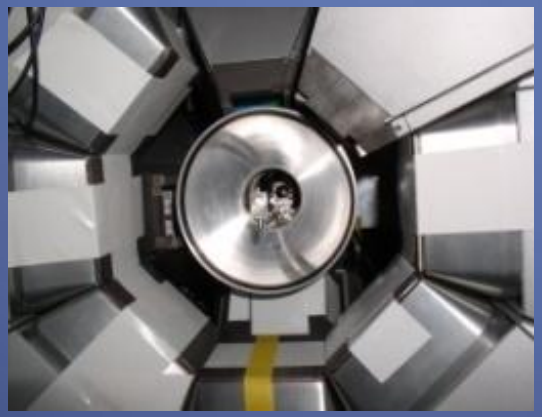
Difficult to interpret unbound states with the standard Shell Model:

Relying on spectrocopic factors the 3/2+ state seems to favour USDA which predicts ^{26}O unbound

Multinucleon and Deep Inelastic Transfer Reactions

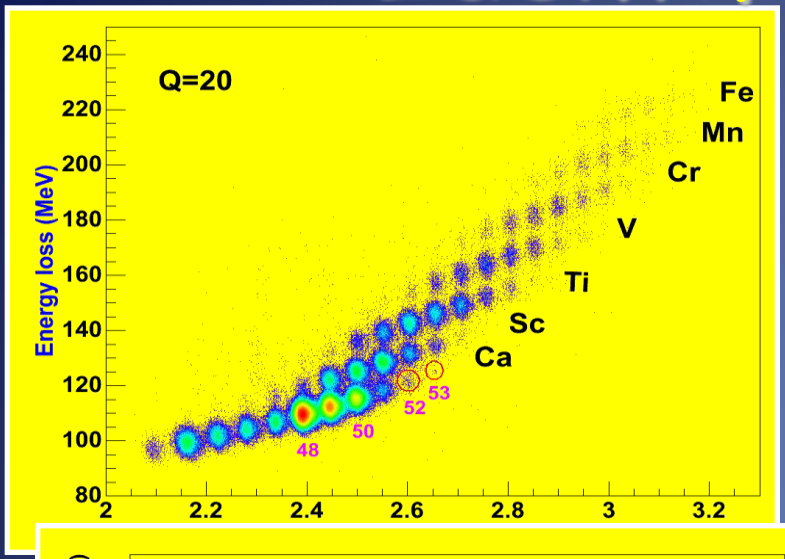
- Beam:
  - ^{238}U
  - 5.5 MeV/u
  - 2pnA
- Target
  - ^{48}Ca
  - 1 mg/cm^2

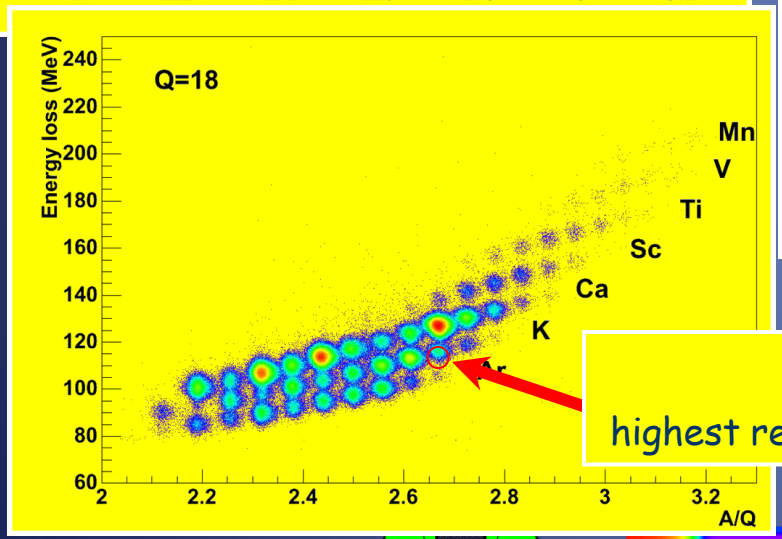


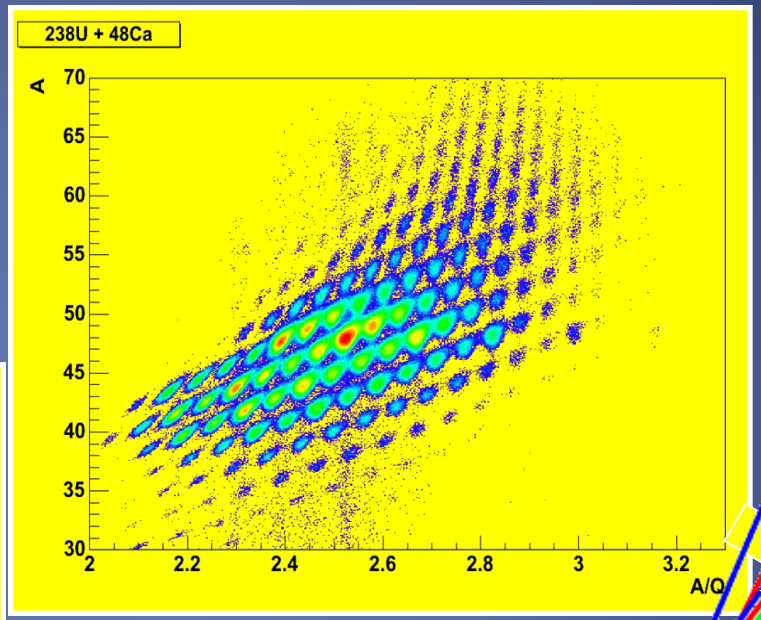


NIMA 593, 343 (2008)

Identification spectra







Target-like

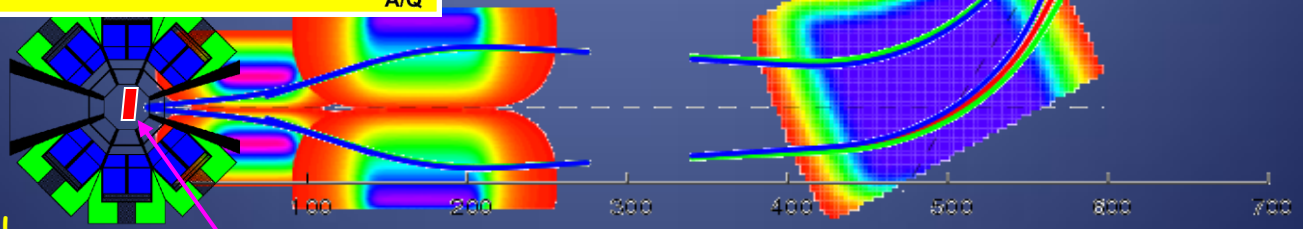
^{48}Ar N/Z=1.67

highest reached in this kind of reaction

Beam

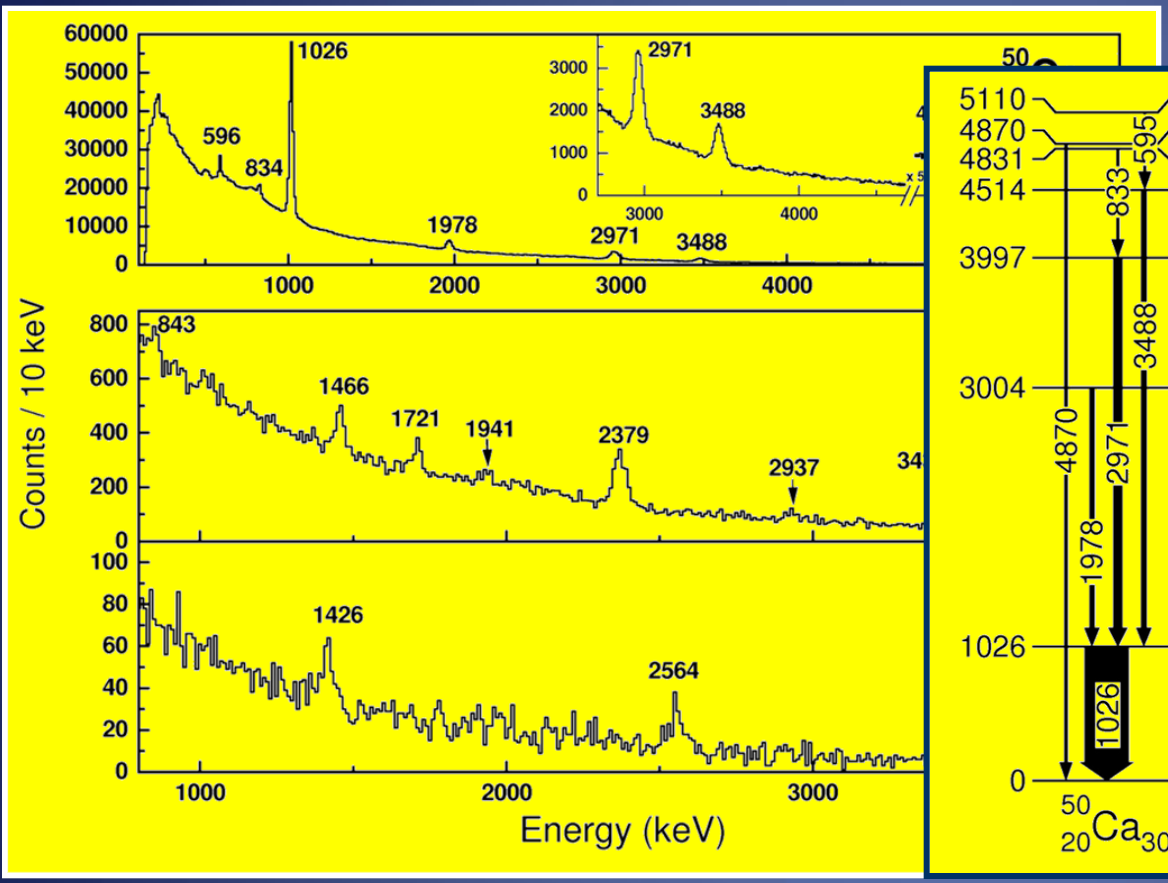
^{238}U

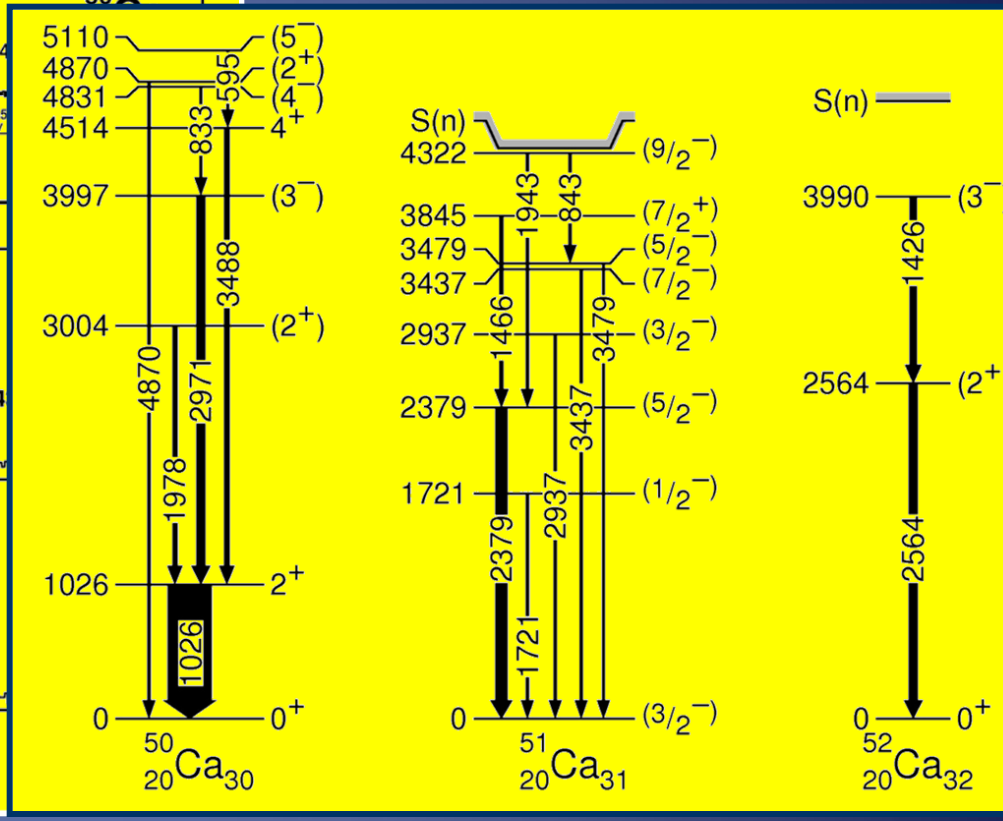
5.5 MeV/u



Target : ^{48}Ca

Neutron rich isotopes of Calcium

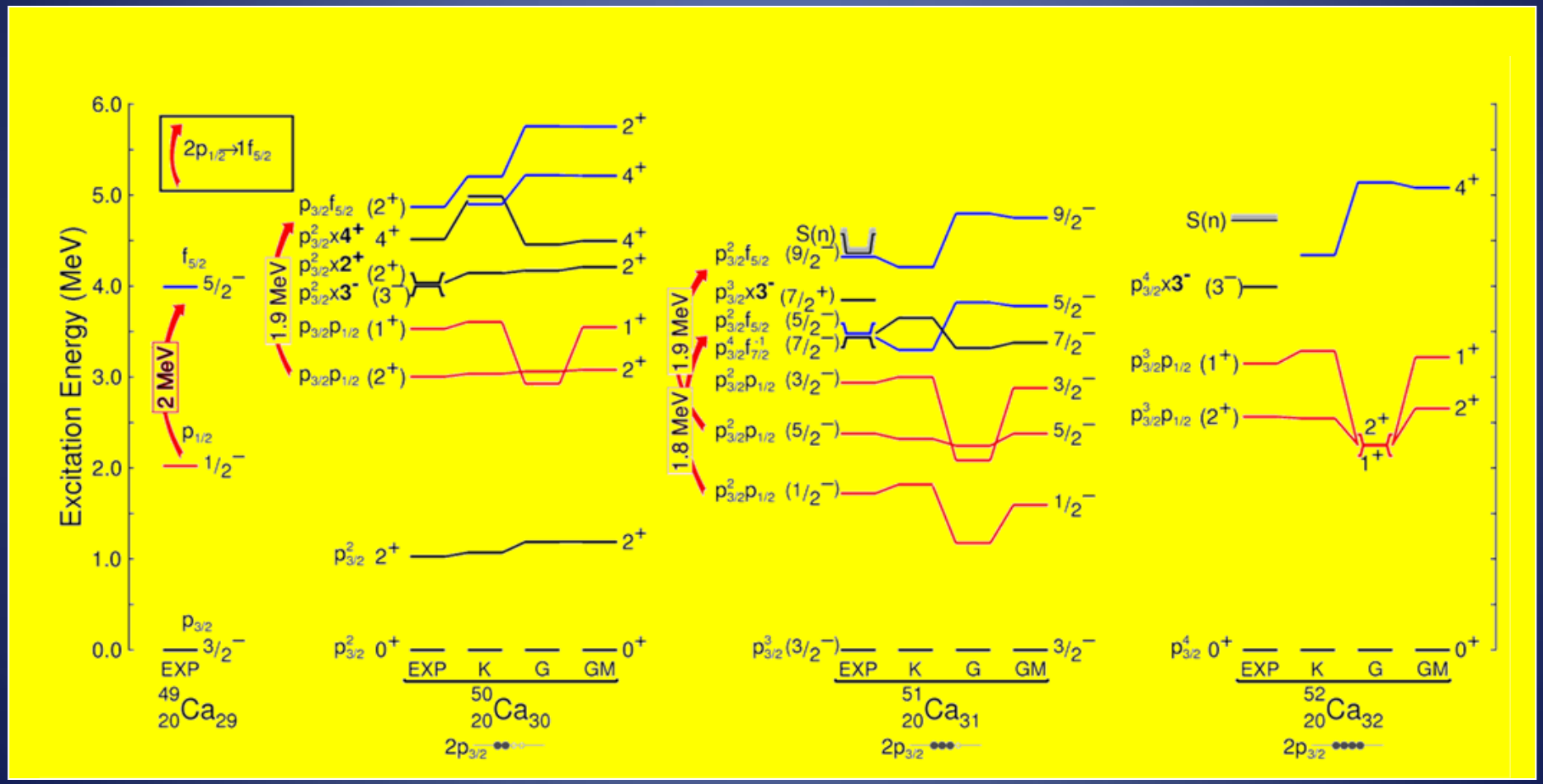




Doppler corrected using V from VAMOS

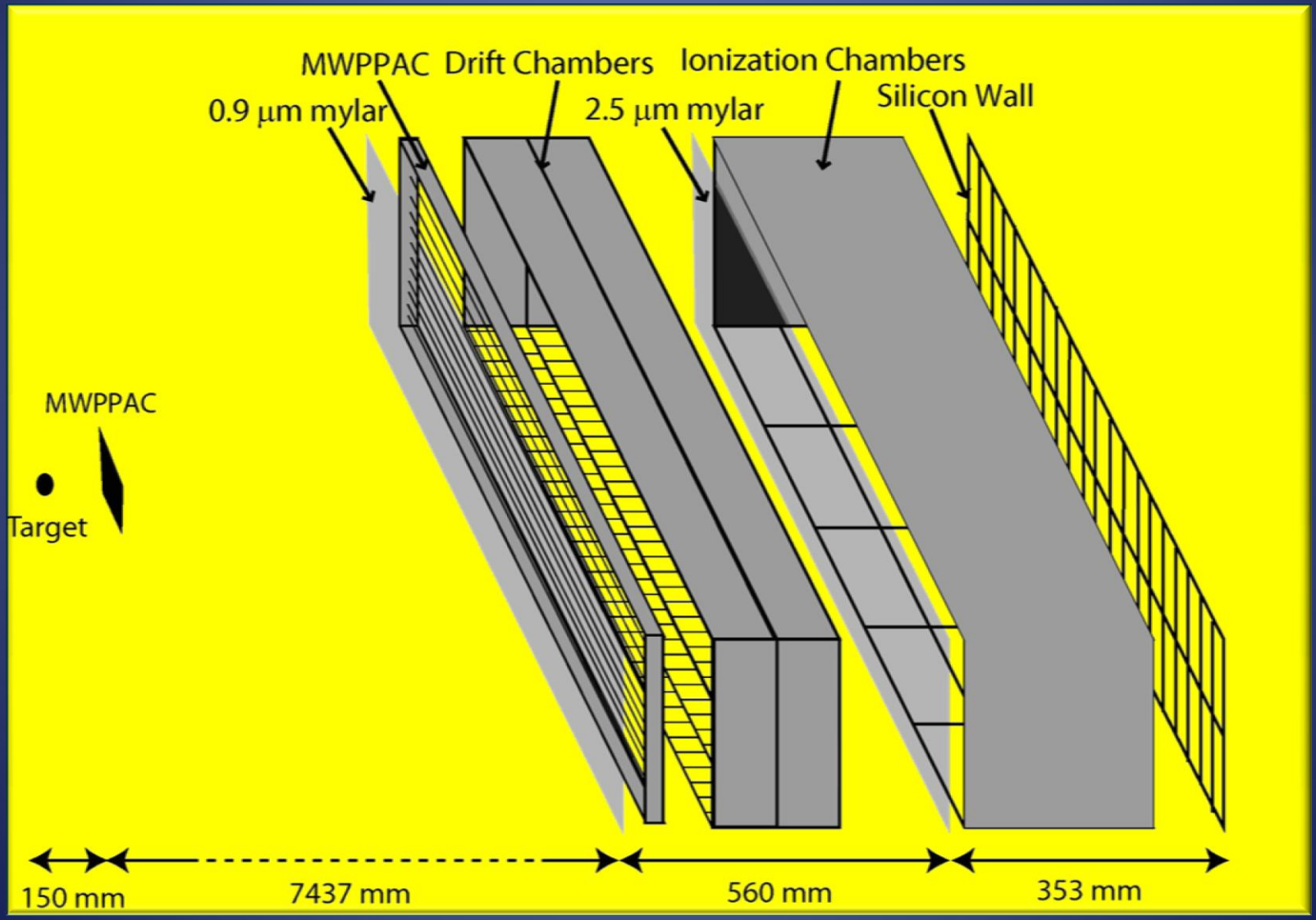
^{238}U (5.5 MeV/u) + ^{48}Ca

No new shell gap at N=34 in Calcium



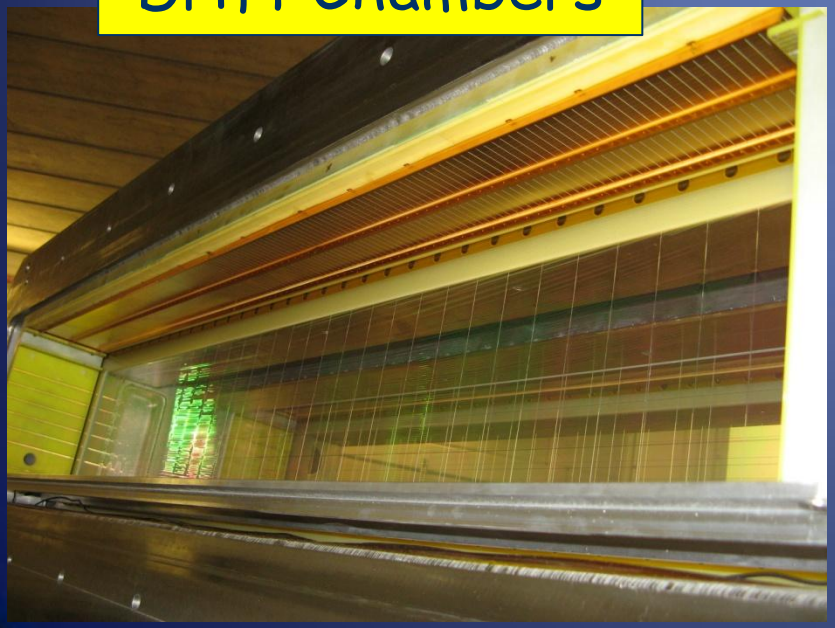
M. Rejmund et al. PRC 76, 021304(R) (2007)

VAMOS++
New Detection System

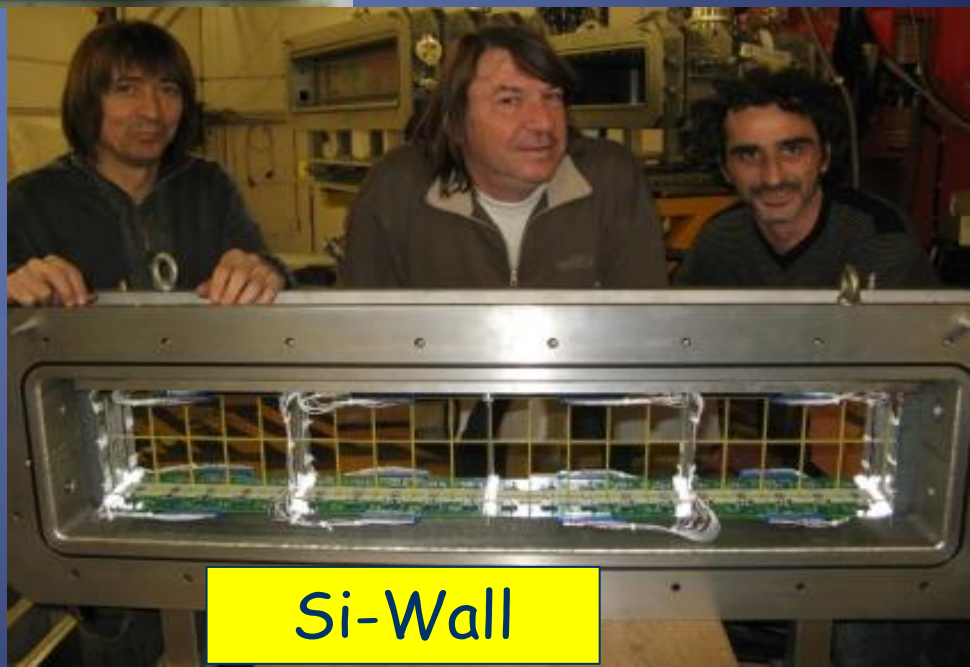


Detectors

Drift Chambers

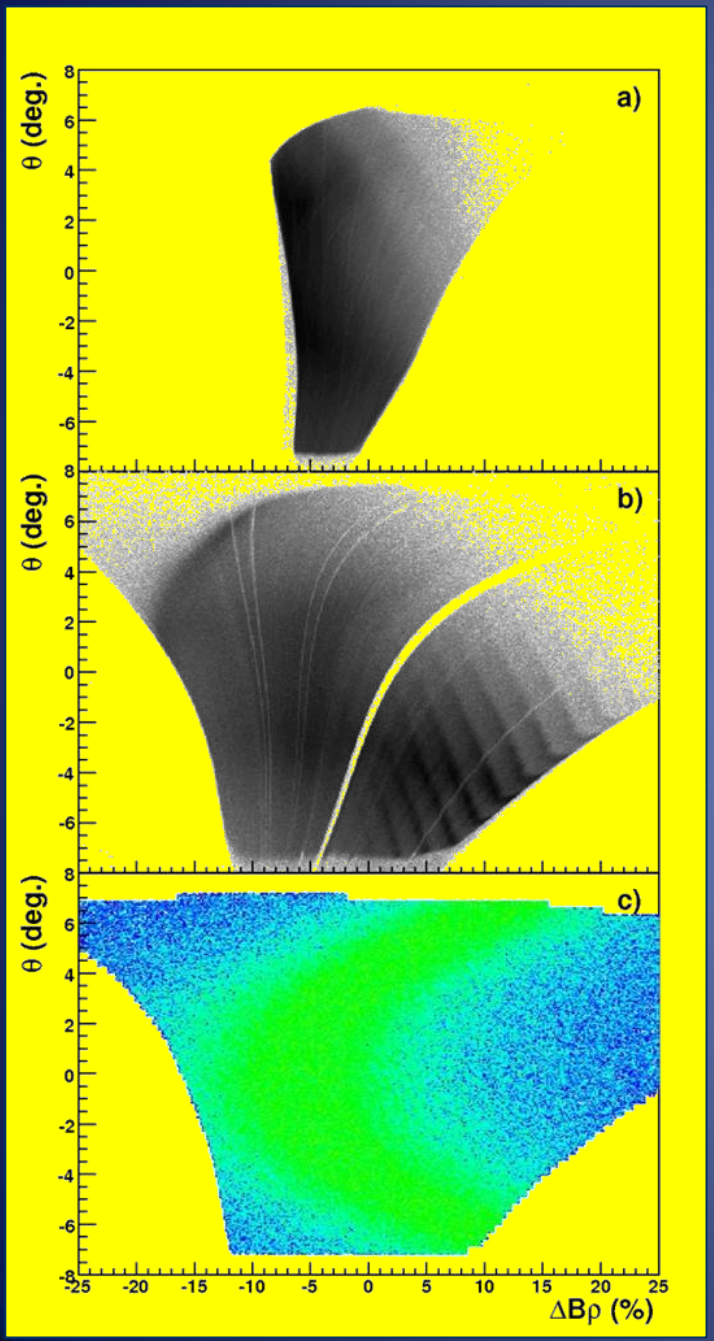


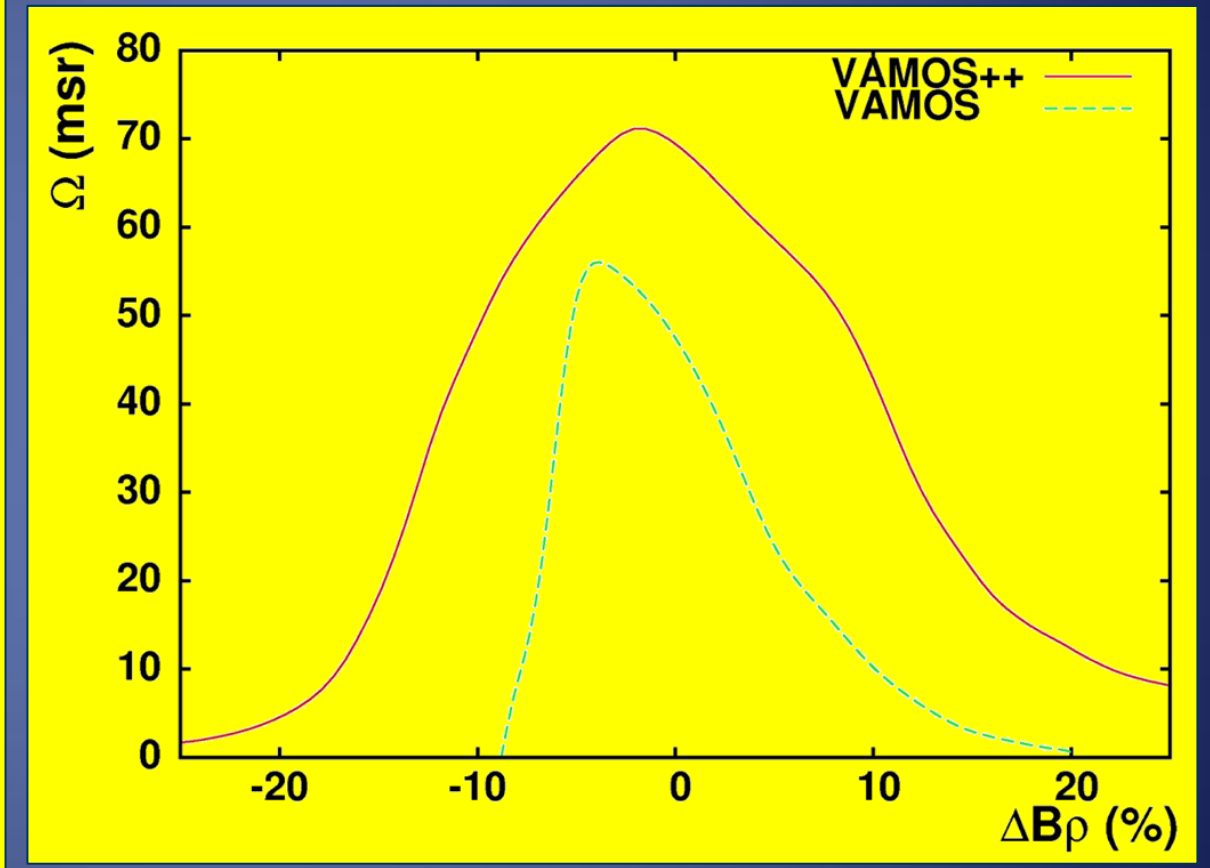
MWPPACs



Si-Wall

Acceptance



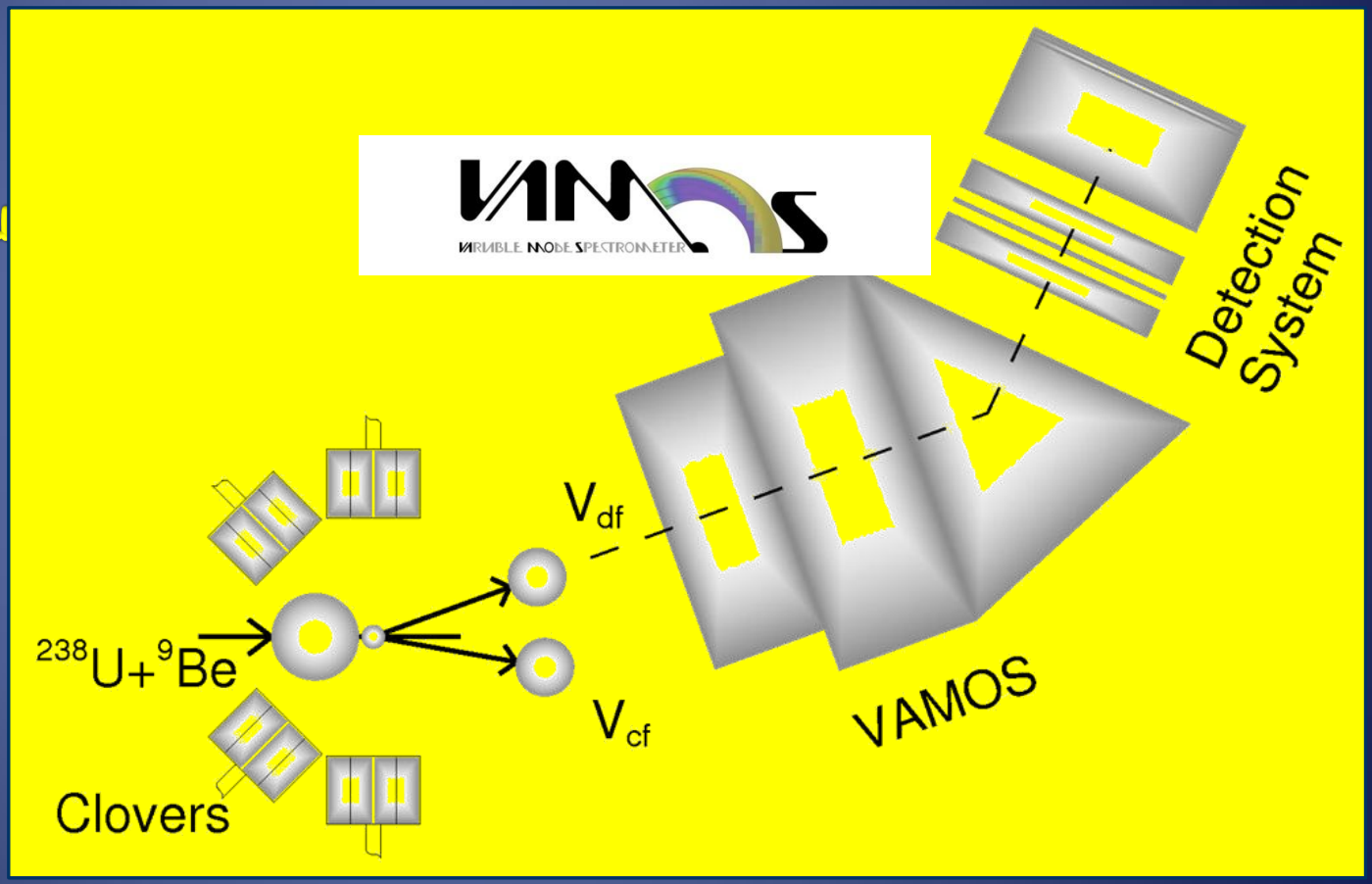


M. Rejmund et al,

NIM A 646 (2011) 184

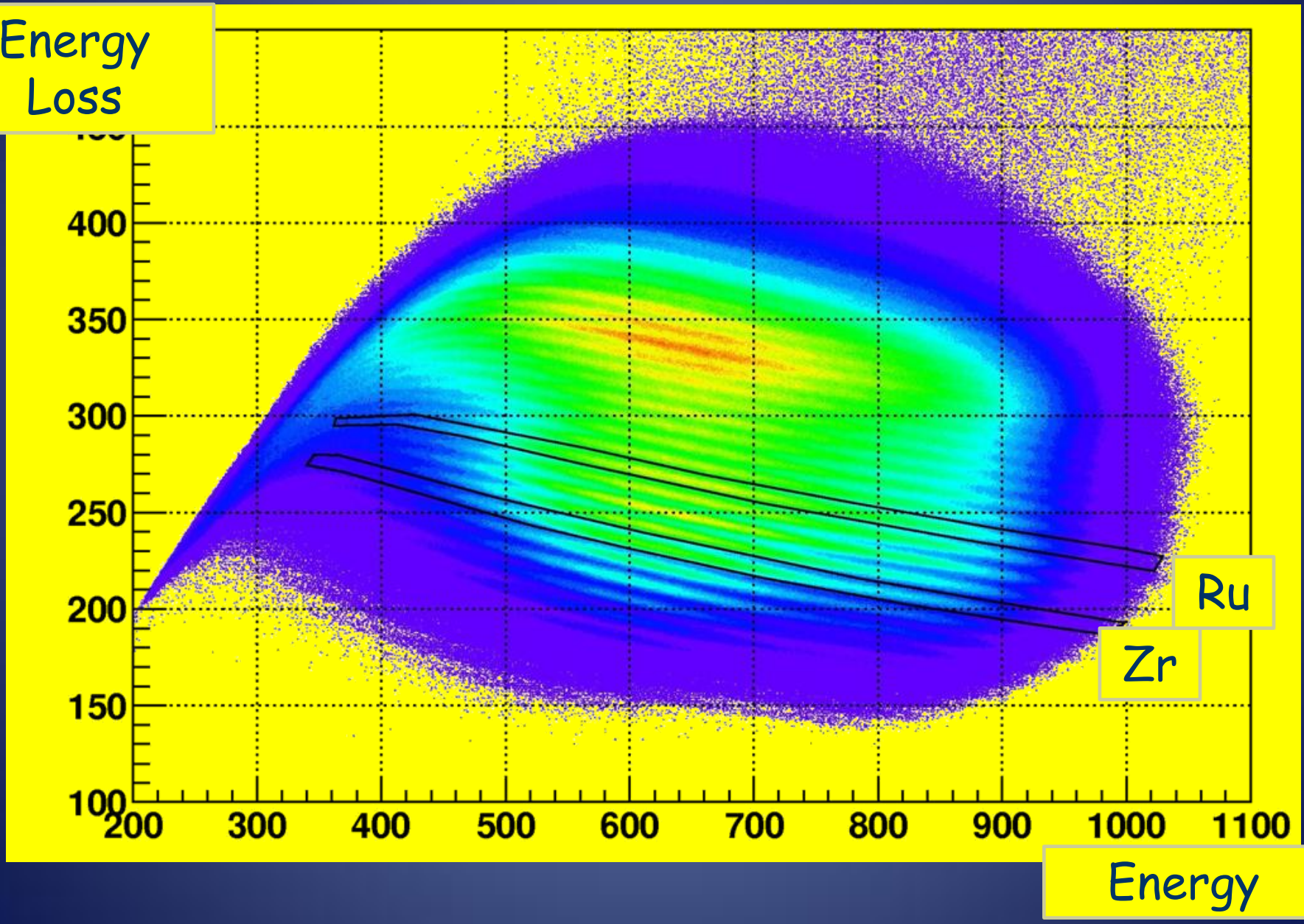
Prompt Gamma Spectroscopy of Fission Fragments

- Beam:
  - ^{238}U
  - 6.2 MeV/u
- Target
  - ^{9}Be
  - 2 mg/cm^2



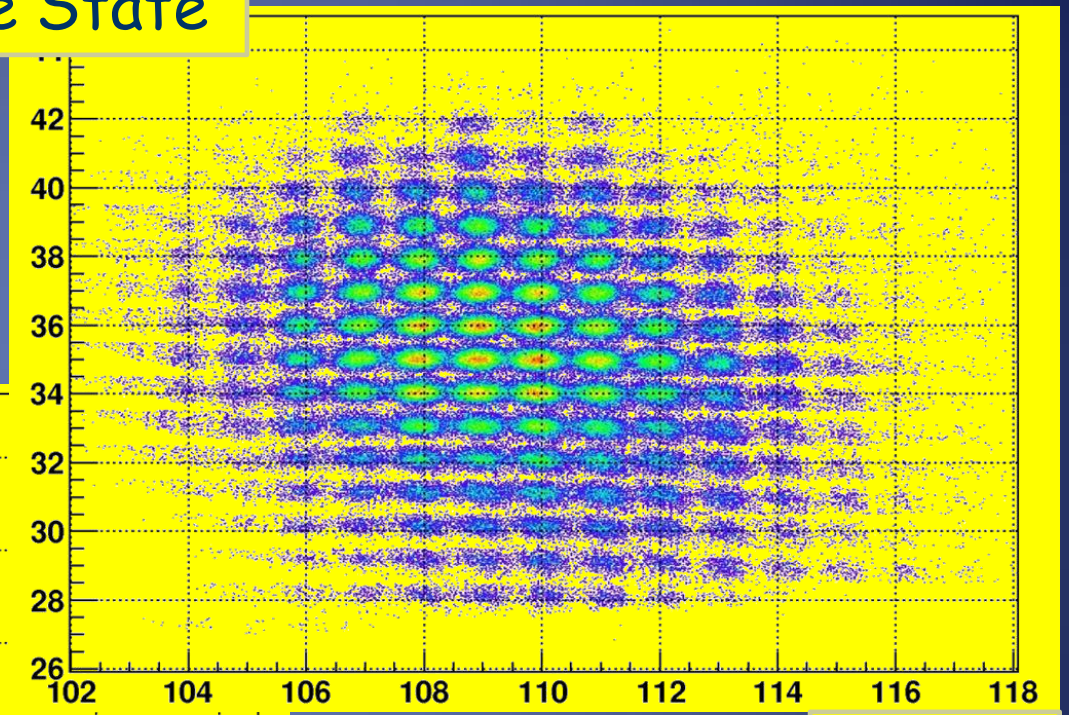
Preliminary Results Only

Identification of the Element



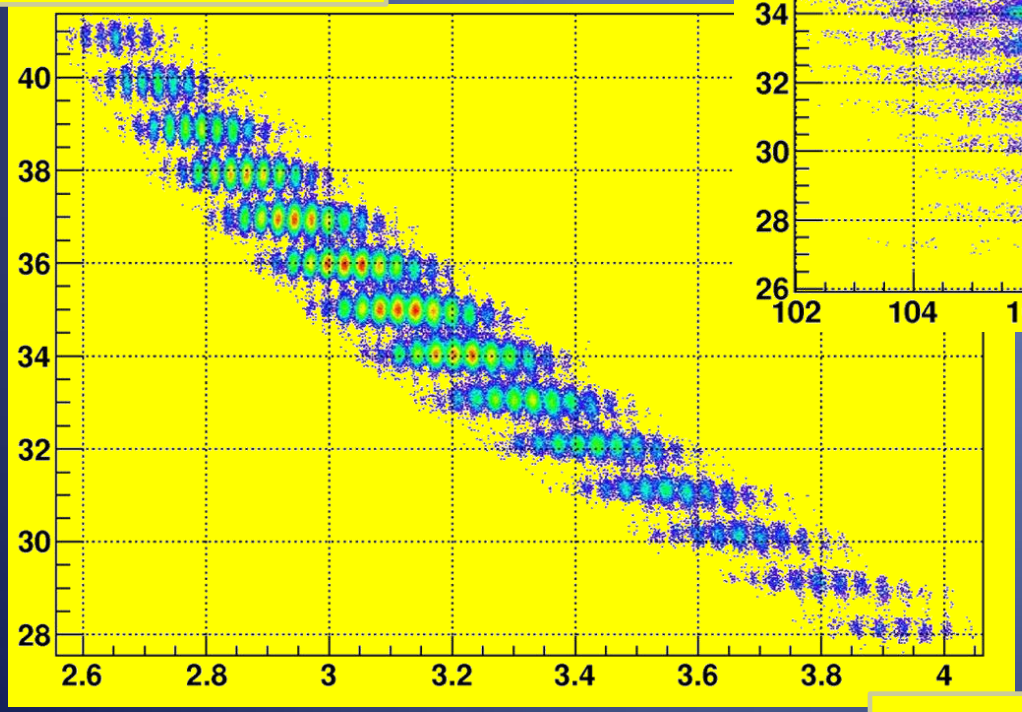
Identification of the Isotope

Charge State



Mass

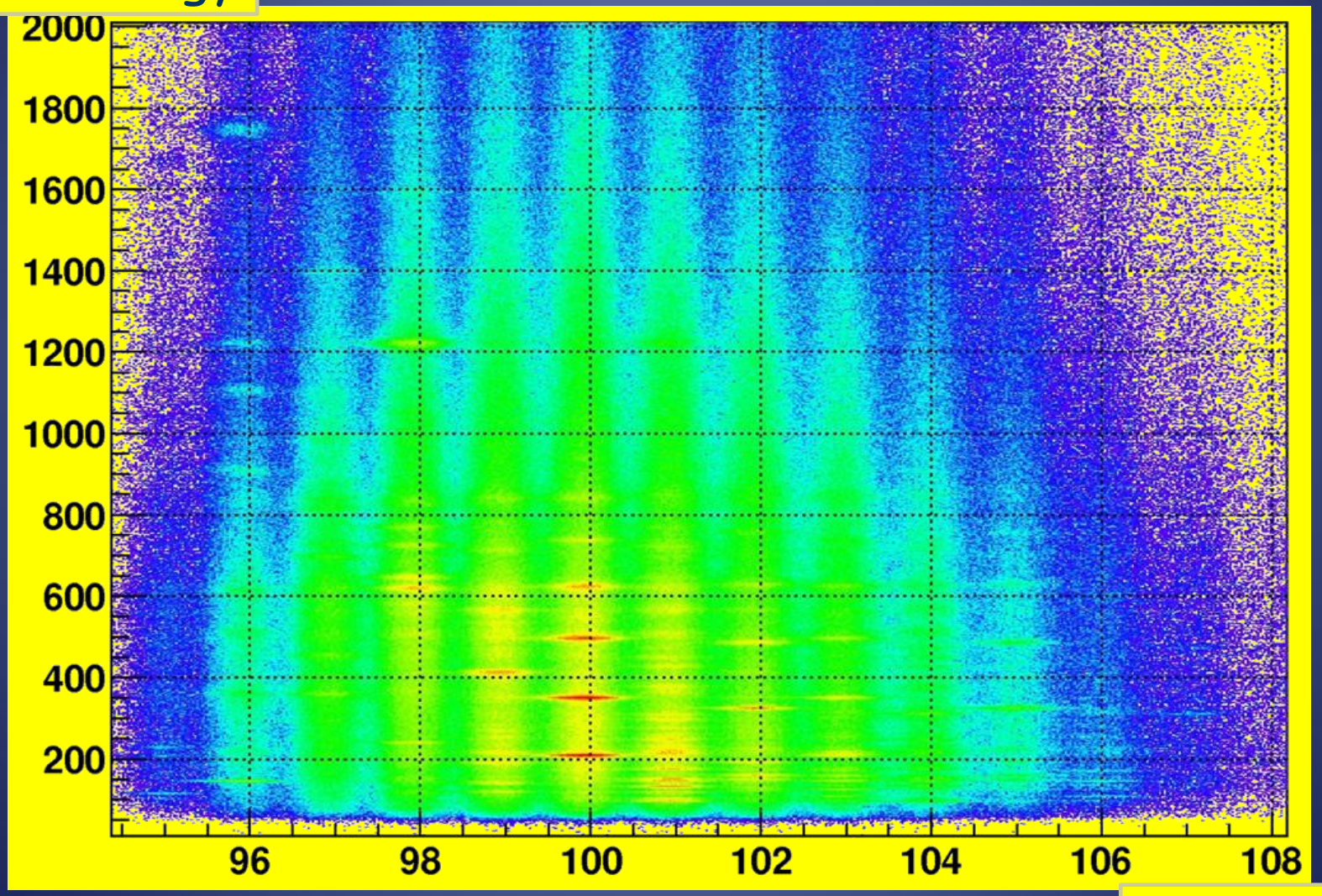
Charge State



Mass over Charge

Eγ vs A for Zr Z=40

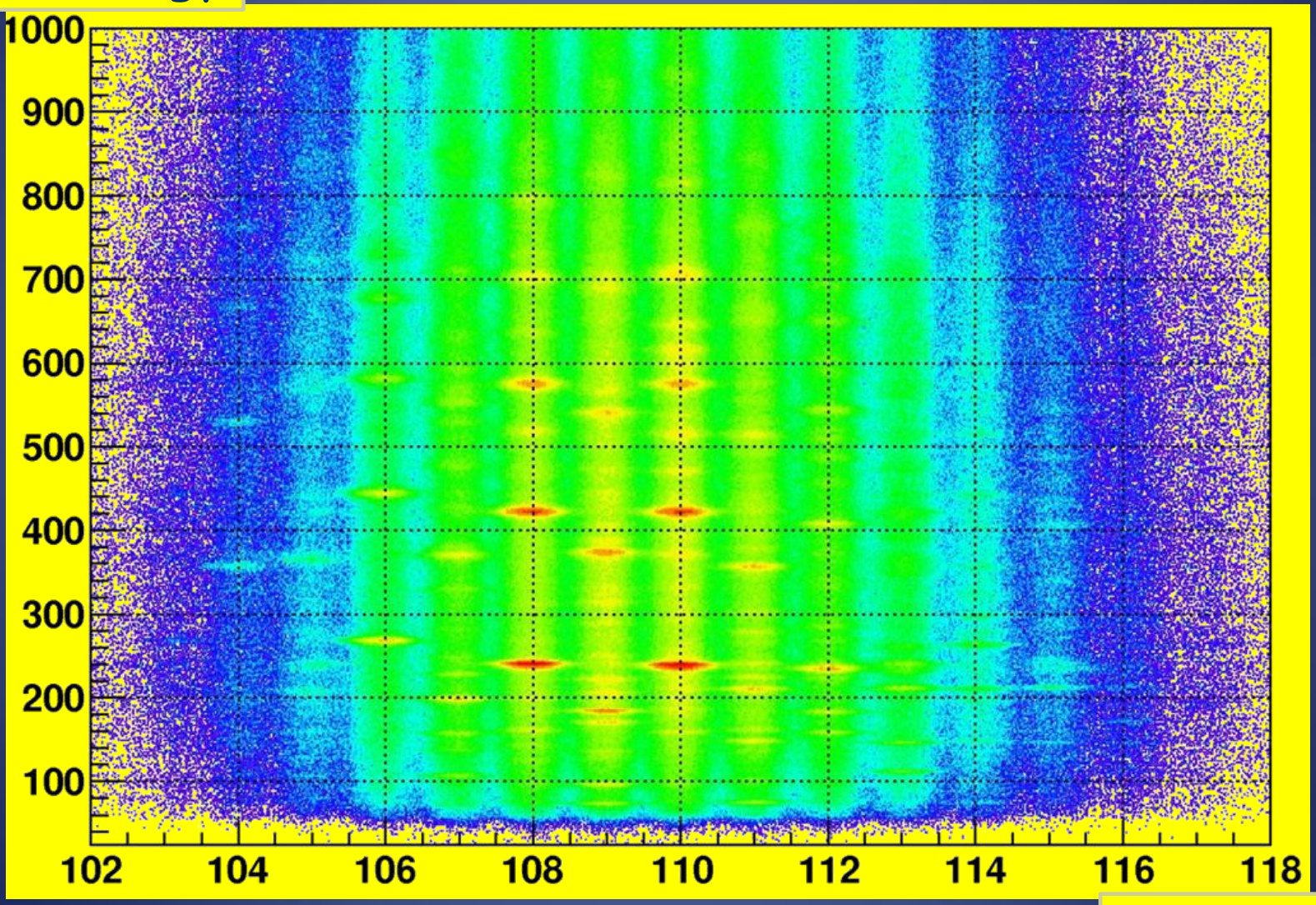
Gamma Energy



Mass

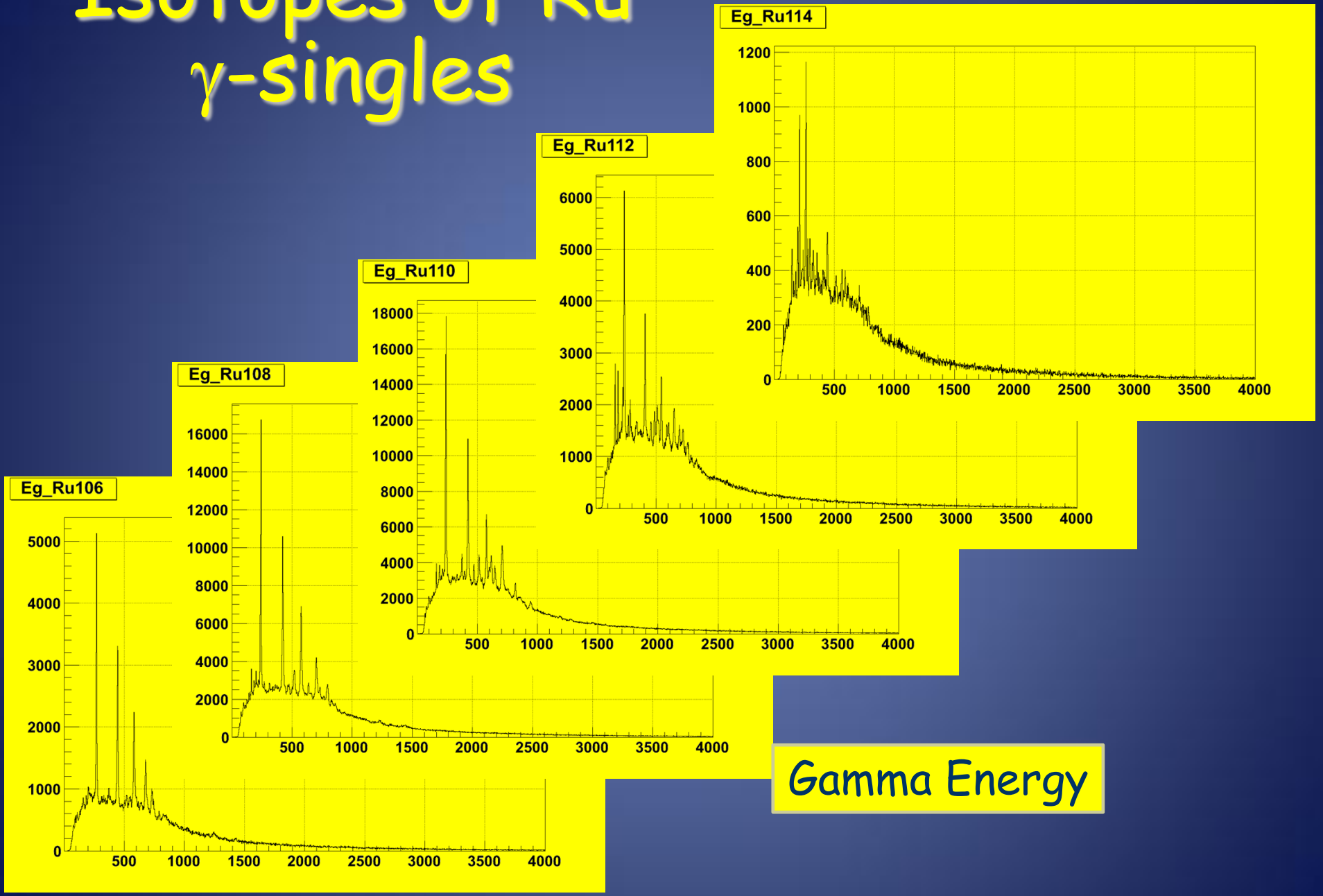
Eγ vs A for Ru Z=44

Gamma Energy

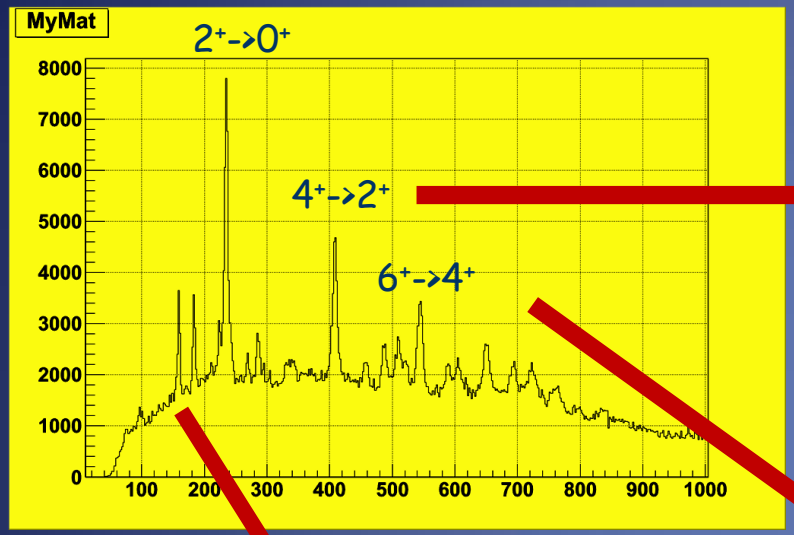


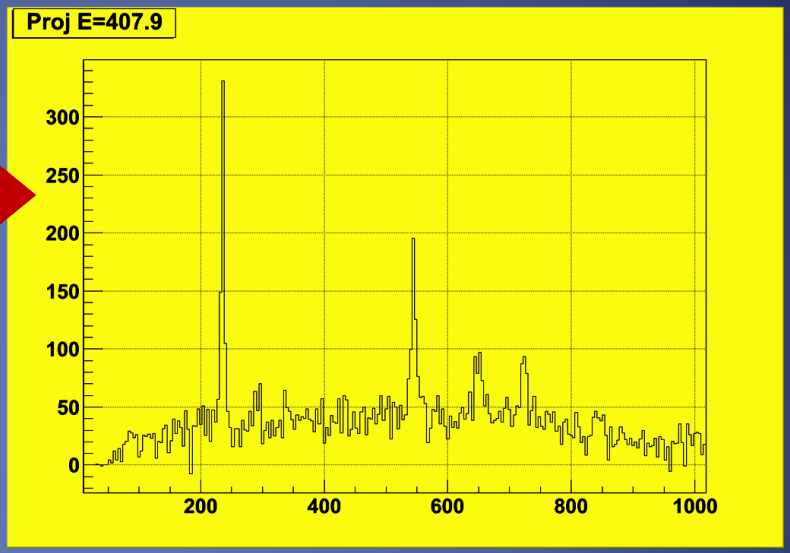
Mass

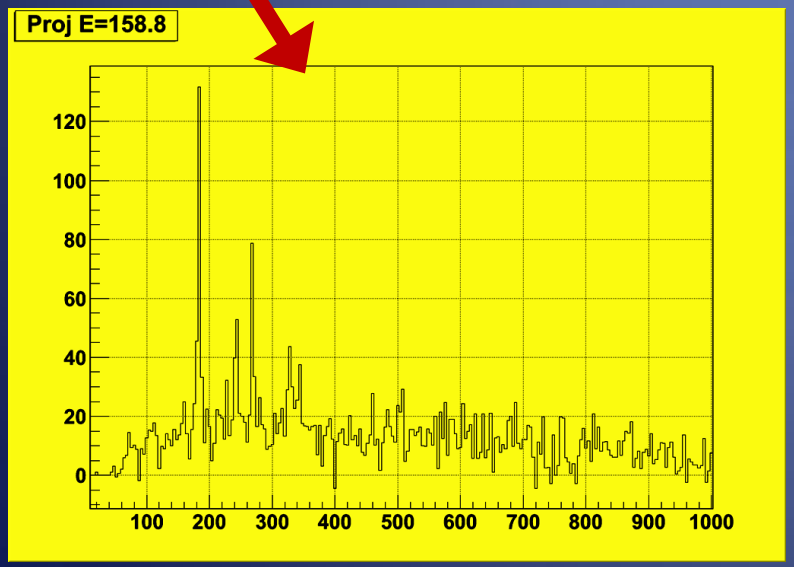
Isotopes of Ru
γ-singles

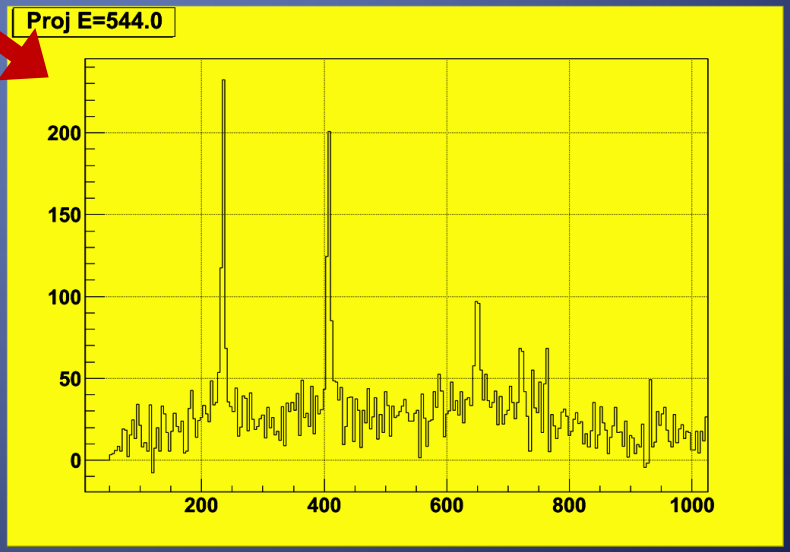


^{112}Ru
γ-γ coincidences





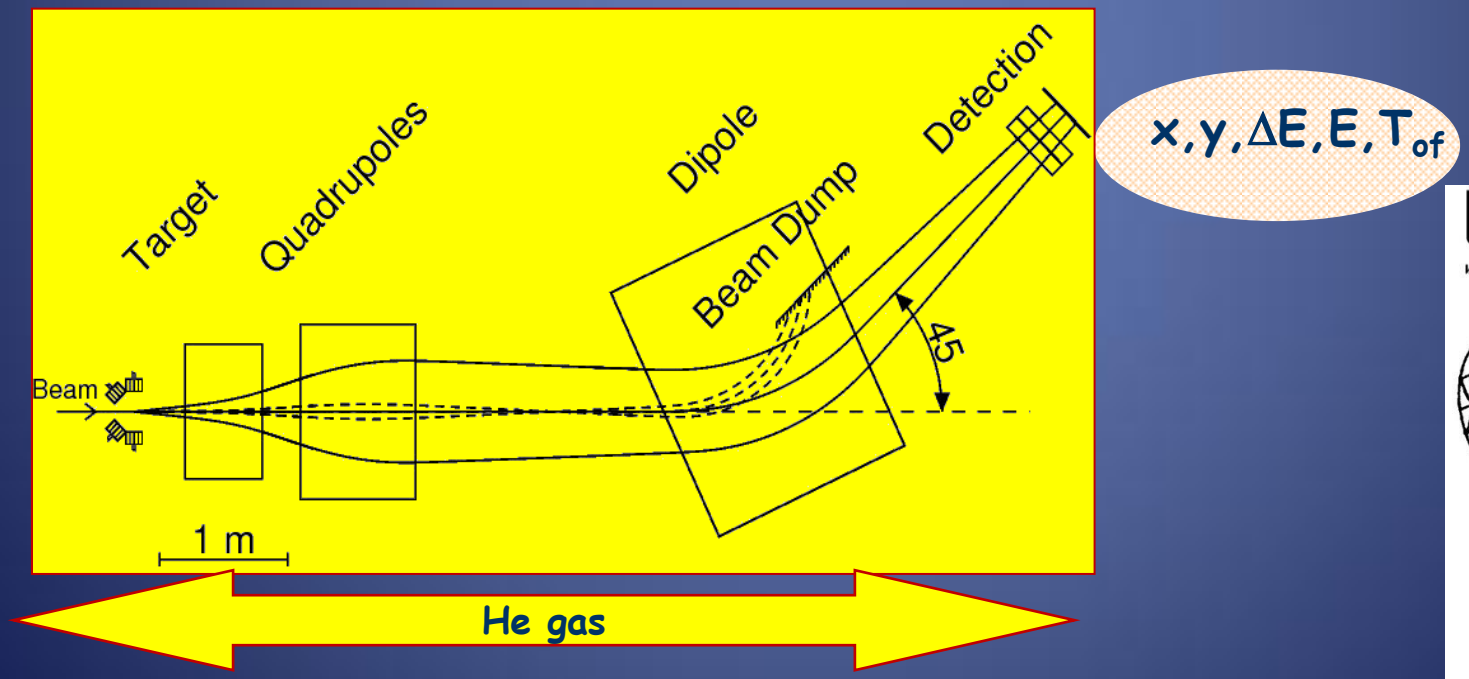




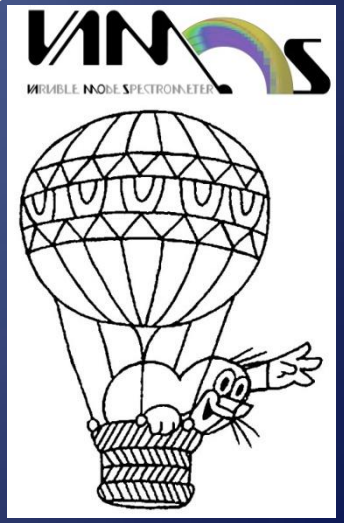
VAMOS Gas Filled

- ✓ C foil before the target for vacuum/gas separation
- ✓ He gas-filling ~(0.2–1.3) mbar
- ✓ beam dump (Ta plate)

^{40}Ca (196 MeV) + $^{150}Sm \rightarrow {}^{190}Pb^*$ (σ_{ER} ~ 50mb)

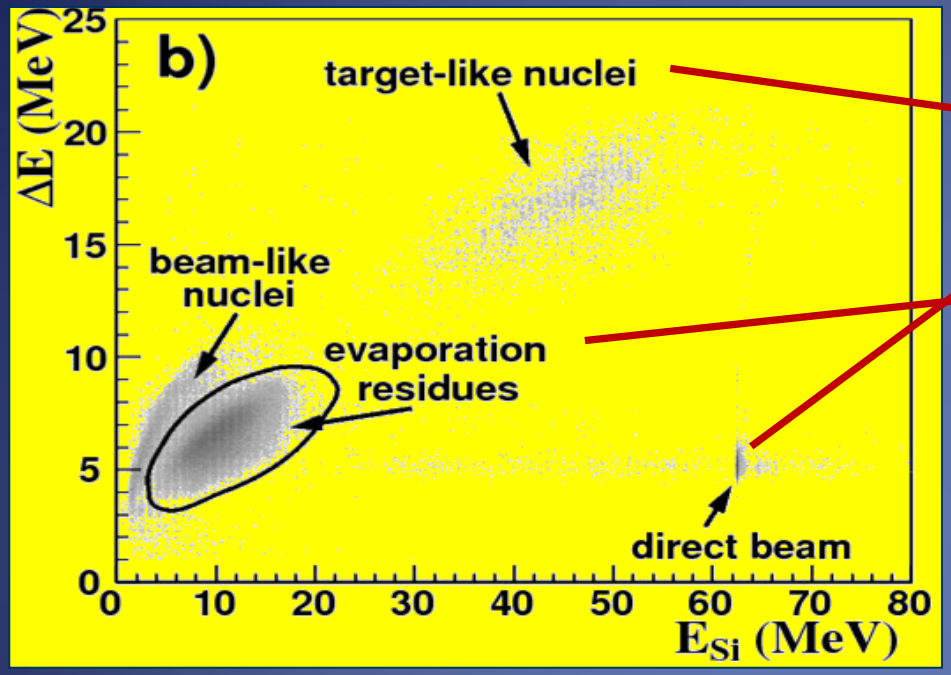


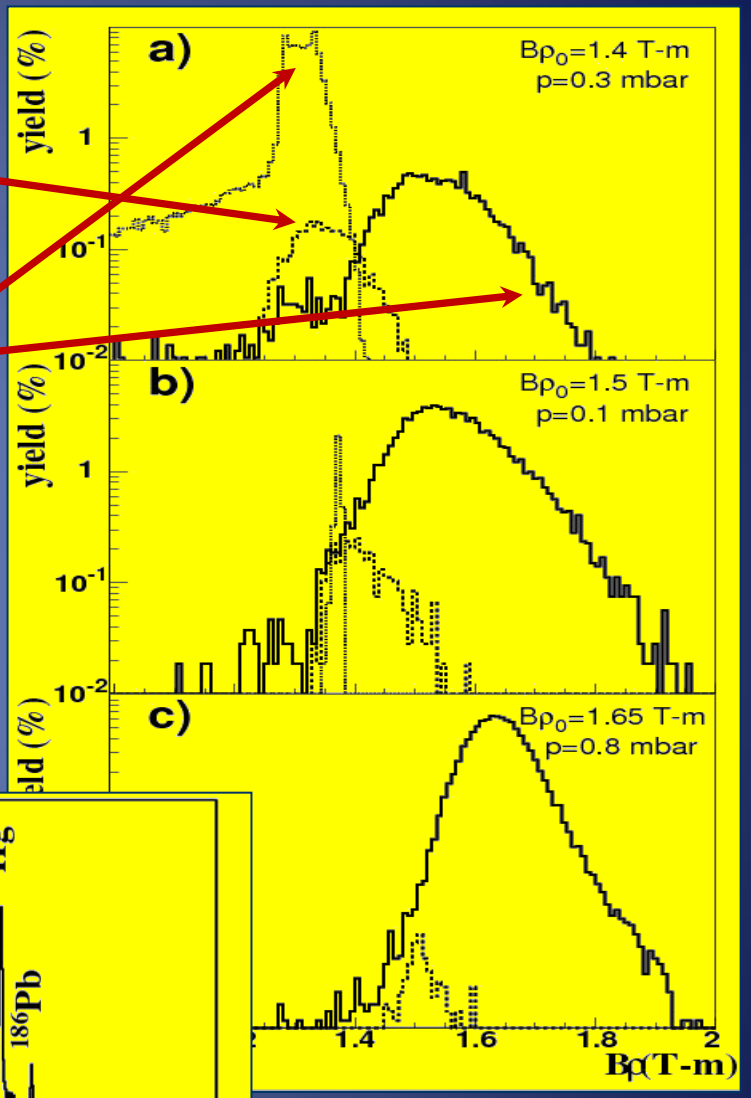
x, y, ΔE, E, T_{of}

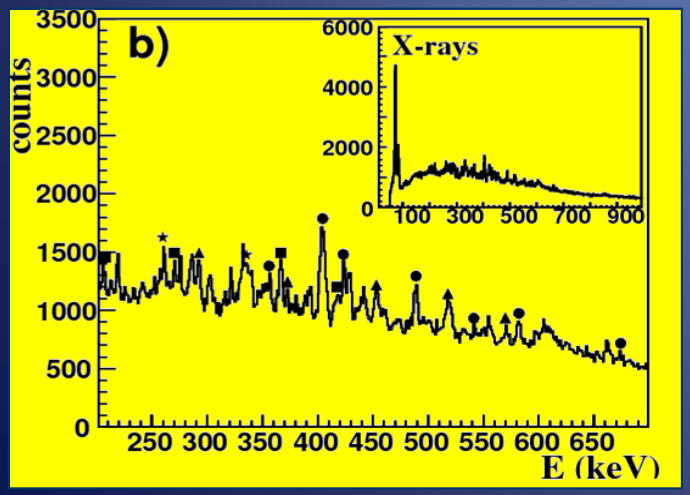


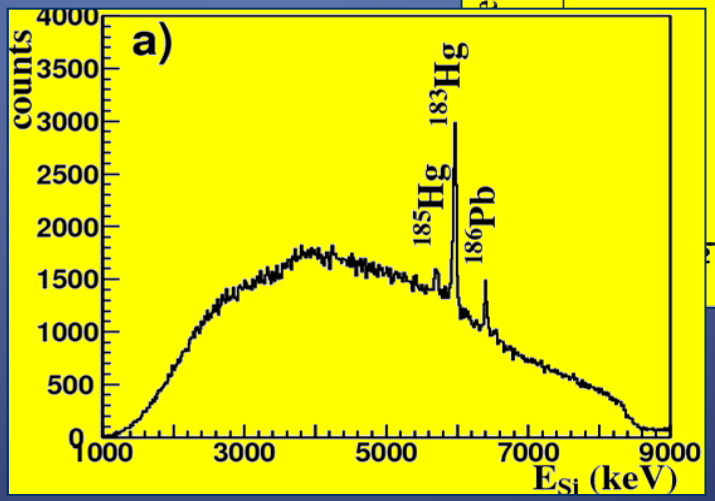
Ch.Schmitt et al., NIMA621(2010)558

Spectra


b)
target-like nuclei
beam-like nuclei
evaporation residues
direct beam
ΔE (MeV)
E_Si (MeV)


a)
Bρ0=1.4 T-m
p=0.3 mbar
b)
Bρ0=1.5 T-m
p=0.1 mbar
c)
Bρ0=1.65 T-m
p=0.8 mbar
yield (%)
Bρ(T-m)


b)
X-rays
counts
E (keV)


a)
183Hg
185Hg
186Pb
counts
E_Si (keV)

Performances

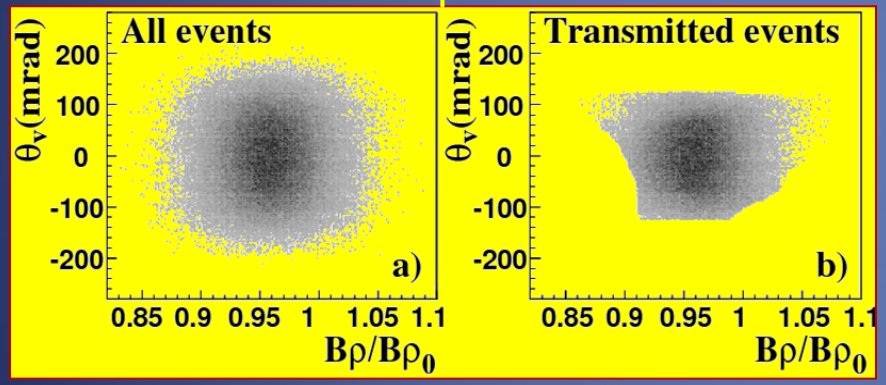
Optimal conditions : $B\rho_0$=1.65Tm and p ~ 1mbar (with present simple set-up

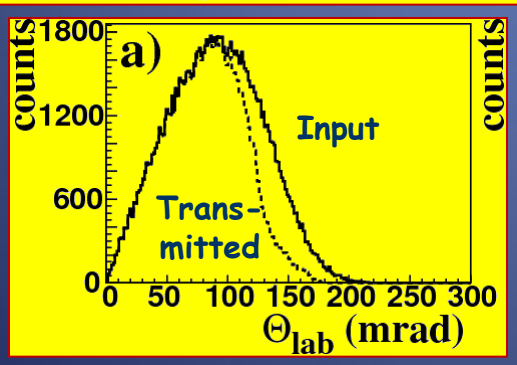
Beam rejection factor > 10^{10}

No direct beam on the detectors for $1{\cdot}2{\cdot}10^{10}$ ^{40}Ca per sec sent in VAMOS

Transmission (from ion-optical calculations)

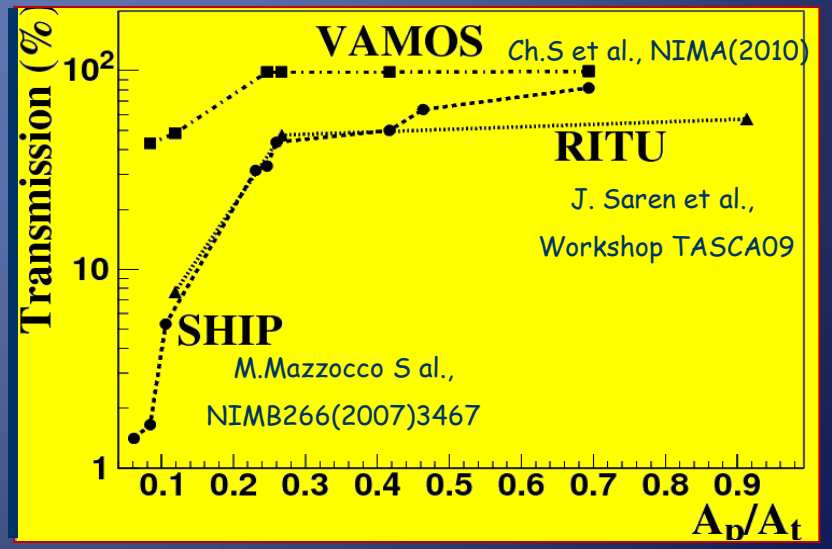
α3n evaporation channel





Large ϑ aperture

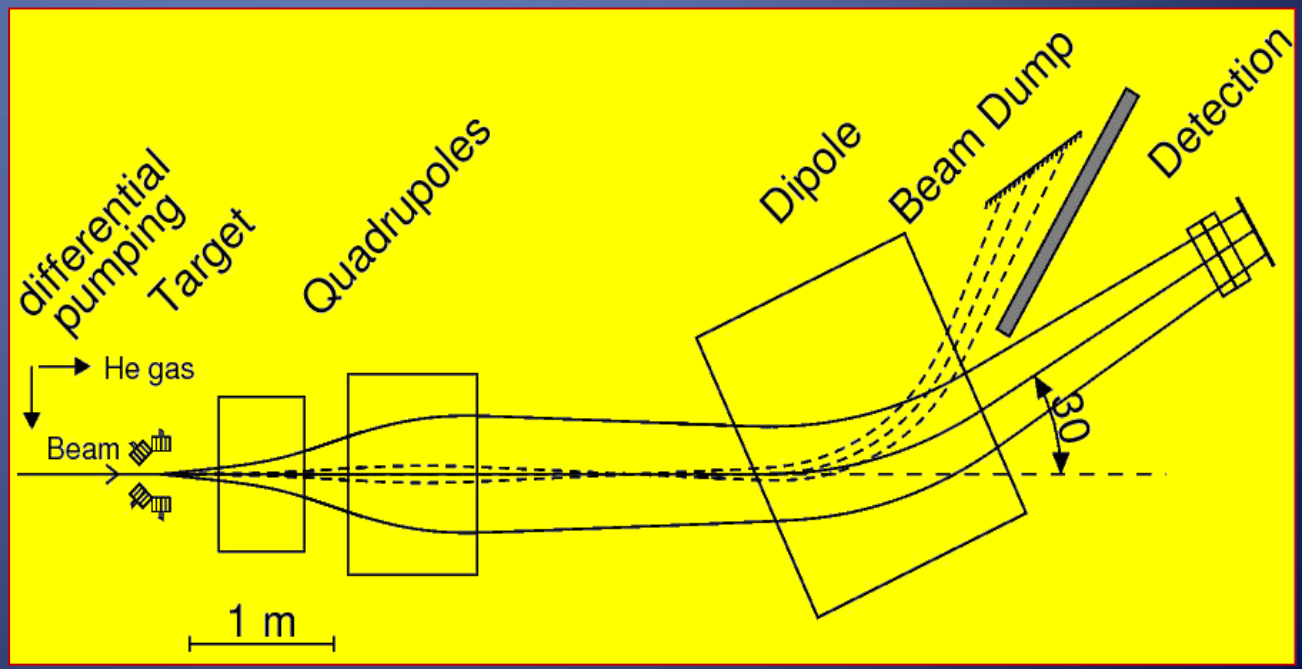
Big detectors



Improvements towards physics experiments

- ✓ **Beam dump behind VAMOS and shielded** (↓ scattering from there)
- ✓ **Differential pumping system** (↓ γ-background)
- ✓ **Recoil Decay Tagging with MUSETT** (ER-decay correlation)

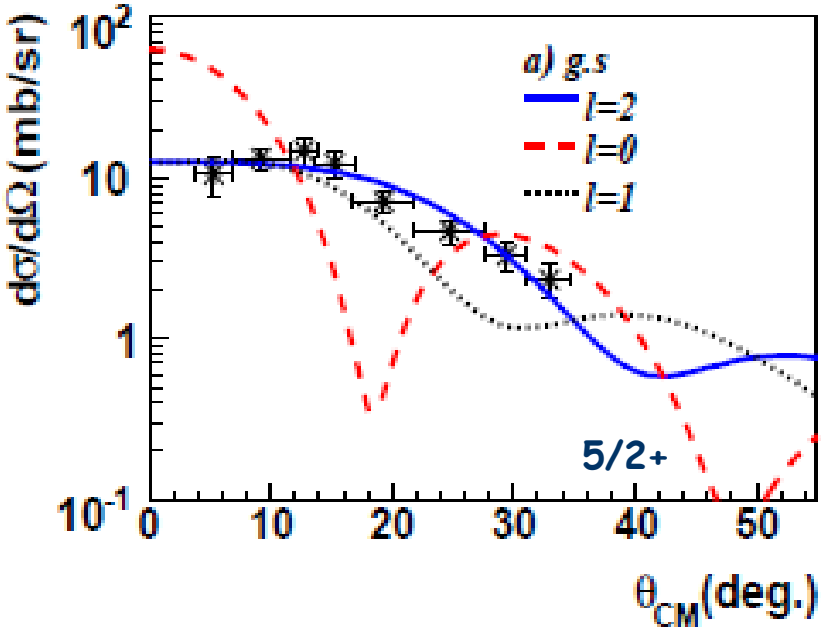
Larger beam rejection and transmission

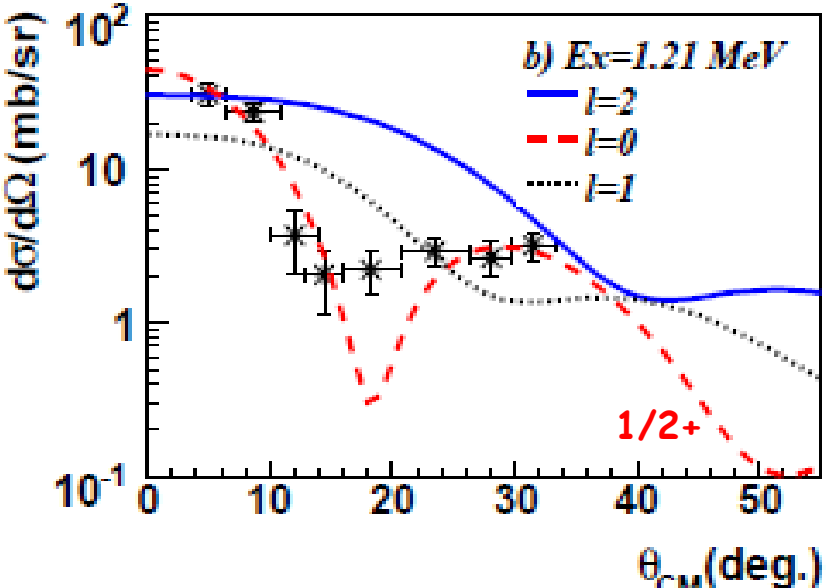


Tomorrow and the day after

- Old mechanisms with modern tools provide unique insights to the physics of nuclei towards drip line
  - Gamma spectroscopy of neutron rich exotic nuclei
    - Transfer Reactions
    - Fission
  - Gamma spectroscopy of heavy nuclei
    - Fusion
- Ensures fruitful endeavors with SPIRAL2

BOUND STATES: $d(^{20}O,p)^{21}O$ (stripping)





ADWA Calculations

The 5/2+ and 1/2+ states carry most of the available strength of the $\nu 0d_{5/2}$, $\nu 1s_{1/2}$

$0d_{5/2}$ $1s_{1/2}$

	Exp	USD	USDA	SDPF-M
$\varepsilon d_{5/2}$	-6.47(171)	-6.05	-6.06	-5.67
$\varepsilon s_{1/2}$	-4.18(100)	-3.54	-3.44	-2.67

CONCLUSIONS

TIARA/MUST2+VAMOS+EXOGAM:Poweful set-up to study the transfer to bound and unbound states with full channel identification.

$^{20}O(d,p)^{21}O$:

-First unbound 3/2+ state corresponds to the s.p. $vd_{3/2}$ with ~ 60% of the strength favours the USDA interaction that predicts the ^{26}O unbound.

-Second unbound state is consistent with a (3/2+, 7/2-) state and has a branching ratio of 0.71(22) to the 2^+_1 in ^{20}O, which indicates a significant component of core-excitations.

-Information on the $\varepsilon d_{5/2}$, $\varepsilon s_{1/2}$ has also been obtained.

Description of data need models that contain explicitily the continuum