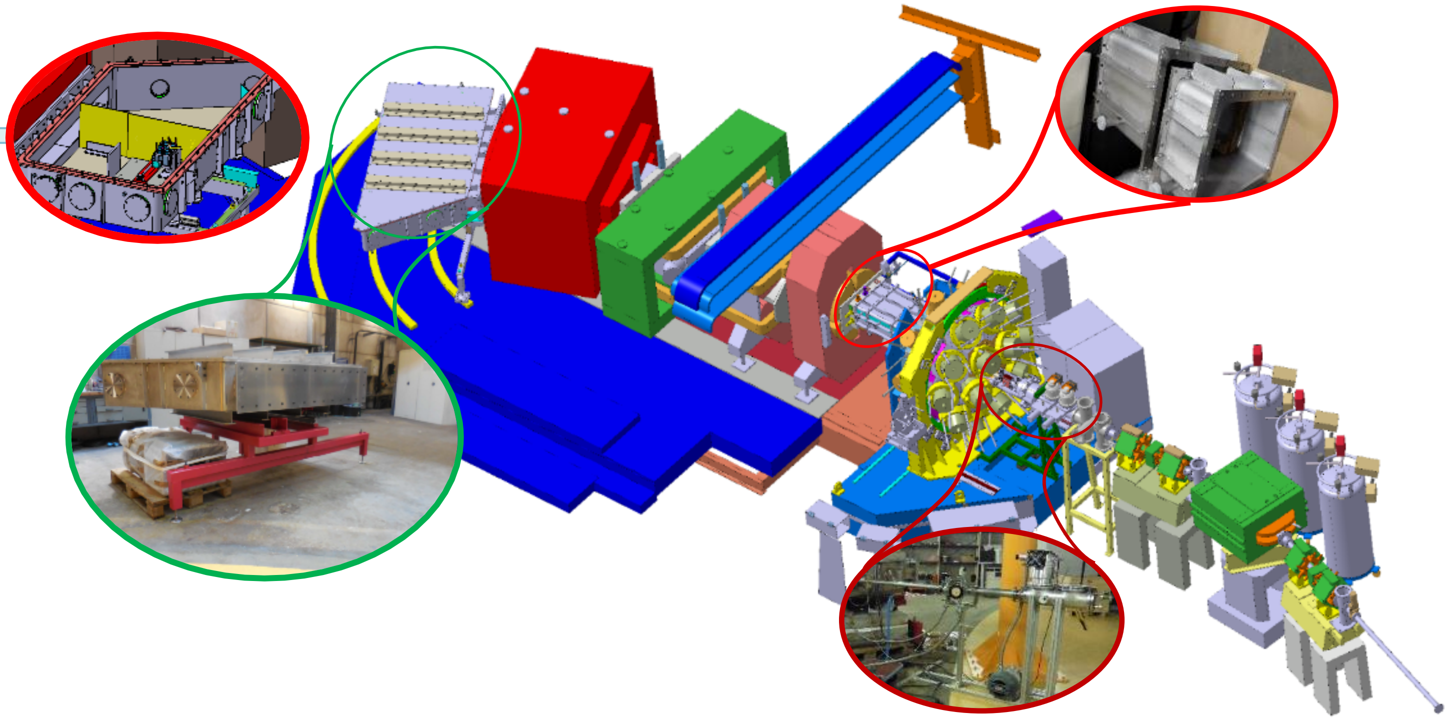


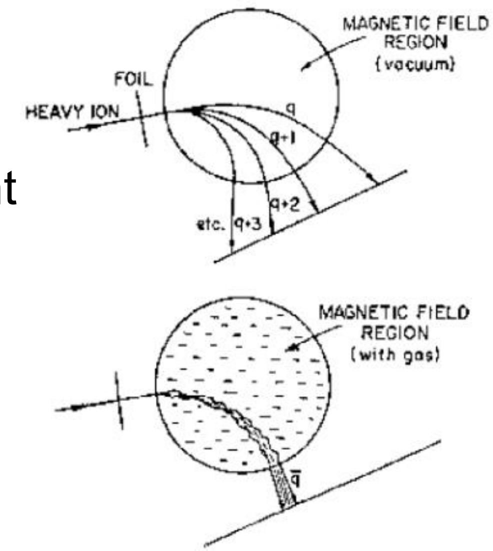
VAMOS in gas-filled mode and MUSETT

M.Z. for the VAMOS-GFS Collaboration

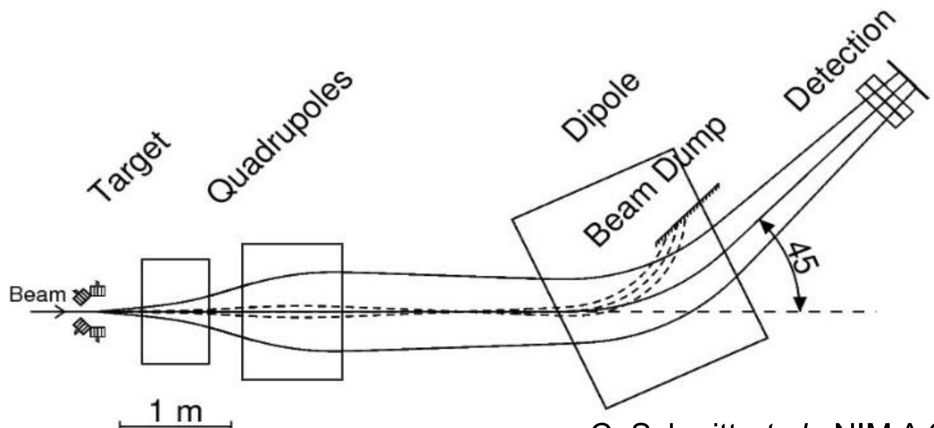
CEA IRFU DPhN/DIS/DEDIP - GANIL

18th AGATA Week – September 2017

VAMOS-GFS test 2009



Proof of principle established in 2009: test experiment
^{40}Ca (196MeV) + ^{150}Sm → ^{190}Pb* (σ_{ER} ~ 50mb)

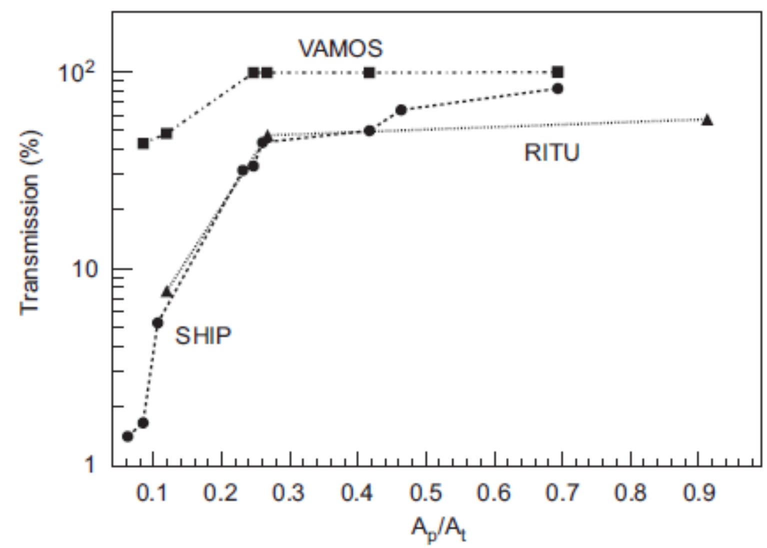


C. Schmitt *et al.*, NIM A 621 (2010) 558

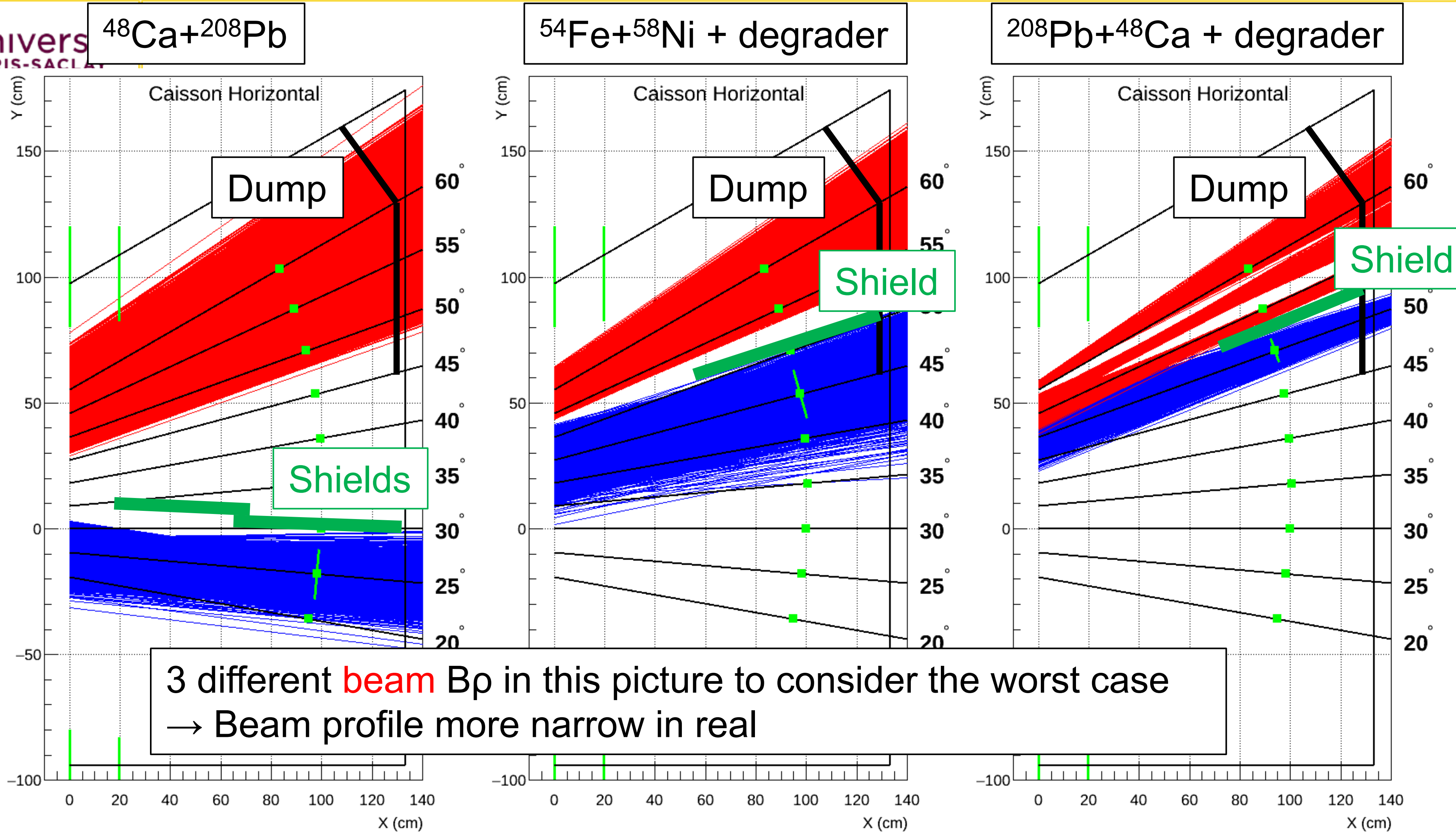
Transmission :
- 95 % for *xn* channels
- 80% for α, p channels

Rejection > 10^{10}

- Up to Bρ = 2.1 - 2 .2 Tm if VAMOS pushed back



VAMOS-GFS : a versatile device

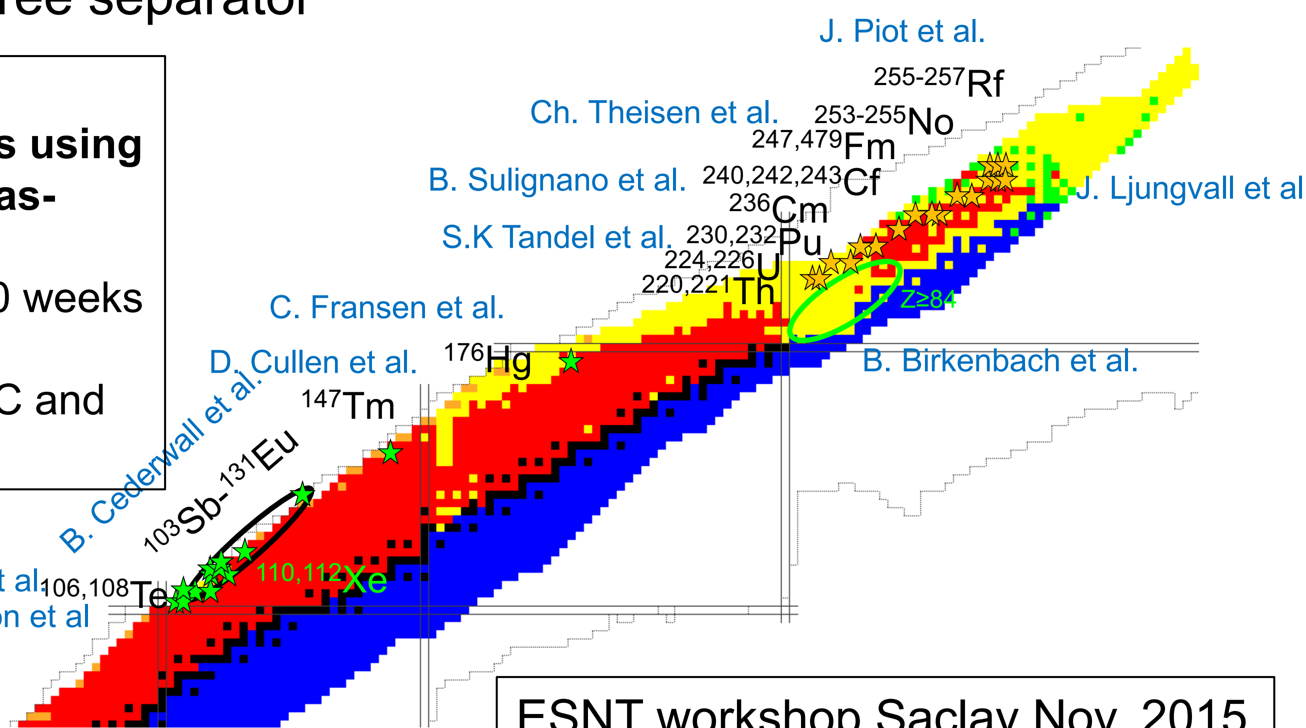


3 different beam Bρ in this picture to consider the worst case
→ Beam profile more narrow in real

What for ?

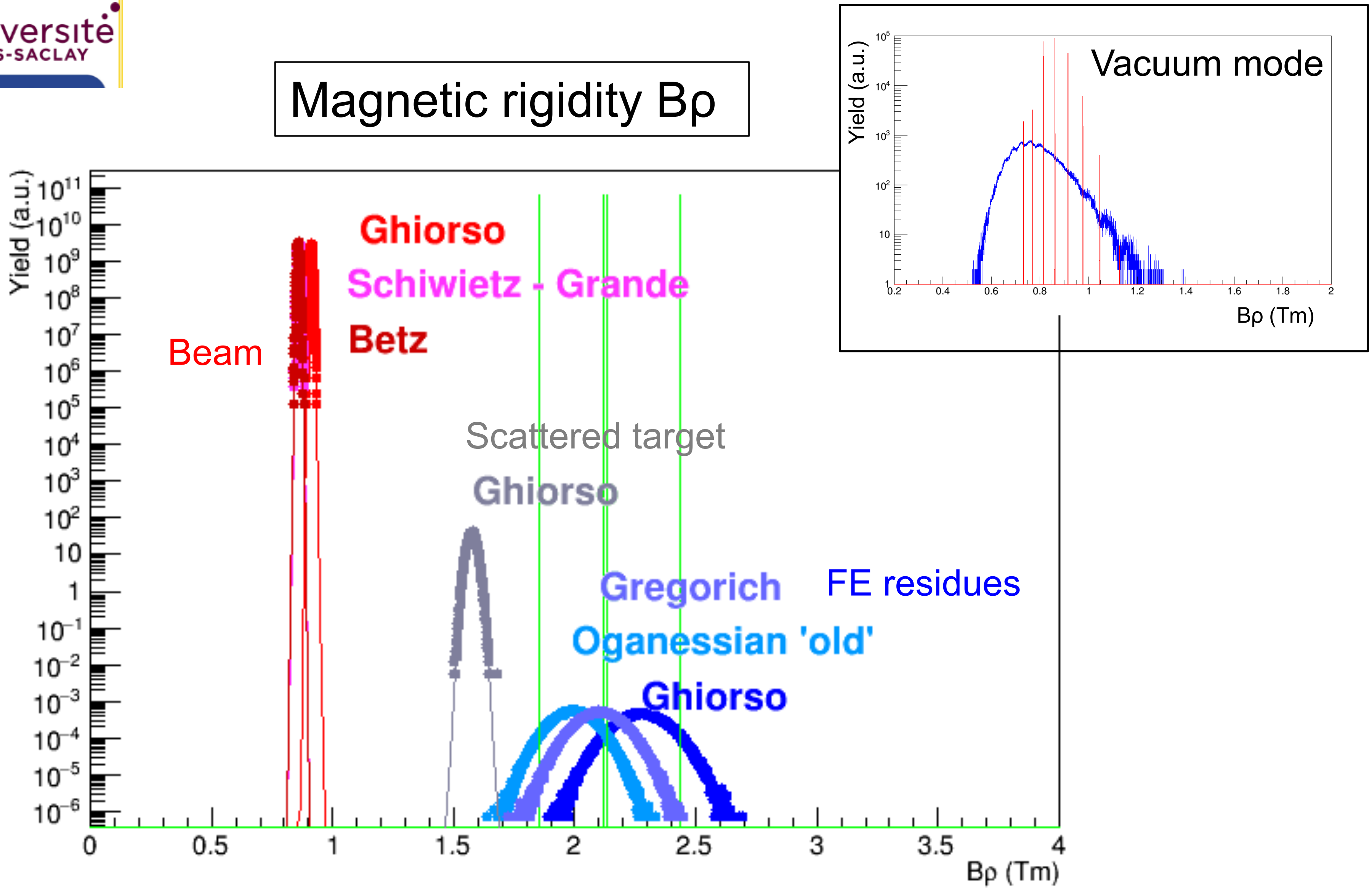
- Fusion-evaporation reactions
- Low cross sections → separator + tagging techniques
- Regions of interest : VHE/SHE, ^{100}Sn region, proton drip line, neutron-deficient Pb
- Note: no other place foreseen for the coupling of AGATA with a zero-degree separator

PAC GANIL LoI June 2016
“Spectroscopy at the limits using AGATA and the VAMOS Gas-Filled Separator”
31 labs, 180 signatories, ~50 weeks of beam time
Proposals to follow: next PAC and in 2018

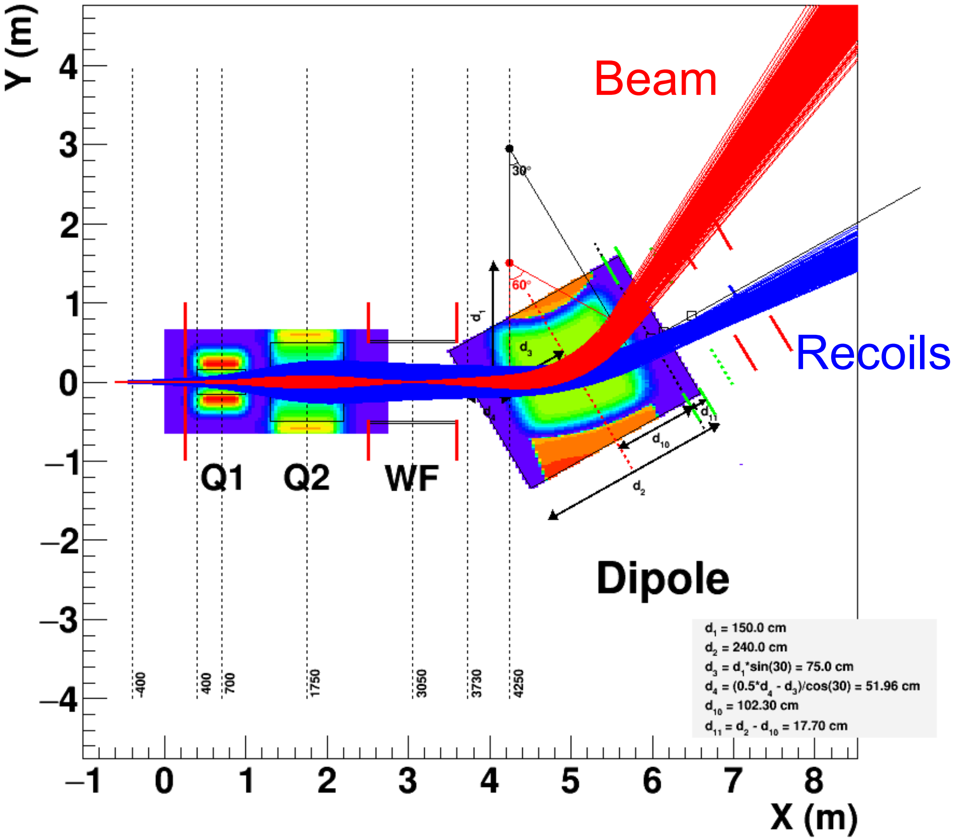


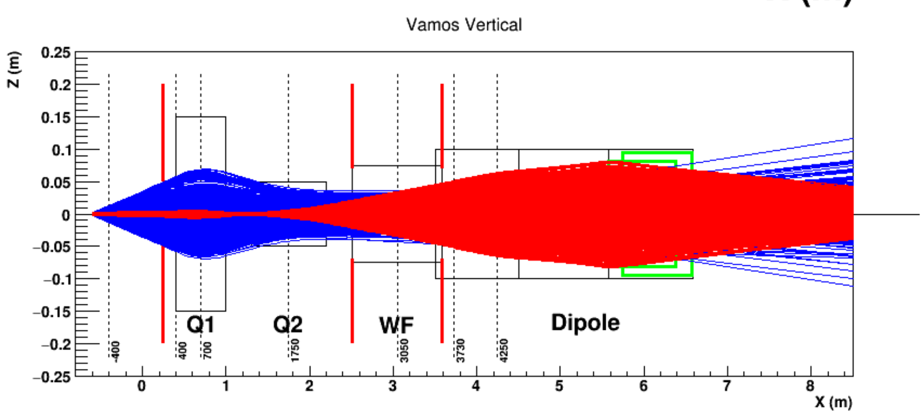
ESNT workshop Saclay Nov. 2015
http://esnt.cea.fr/Phocea/Page/index.php?id=52

^{48}Ca + ^{208}Pb → ^{254}No + 2n



$^{48}Ca + ^{208}Pb \rightarrow ^{254}No + 2n$



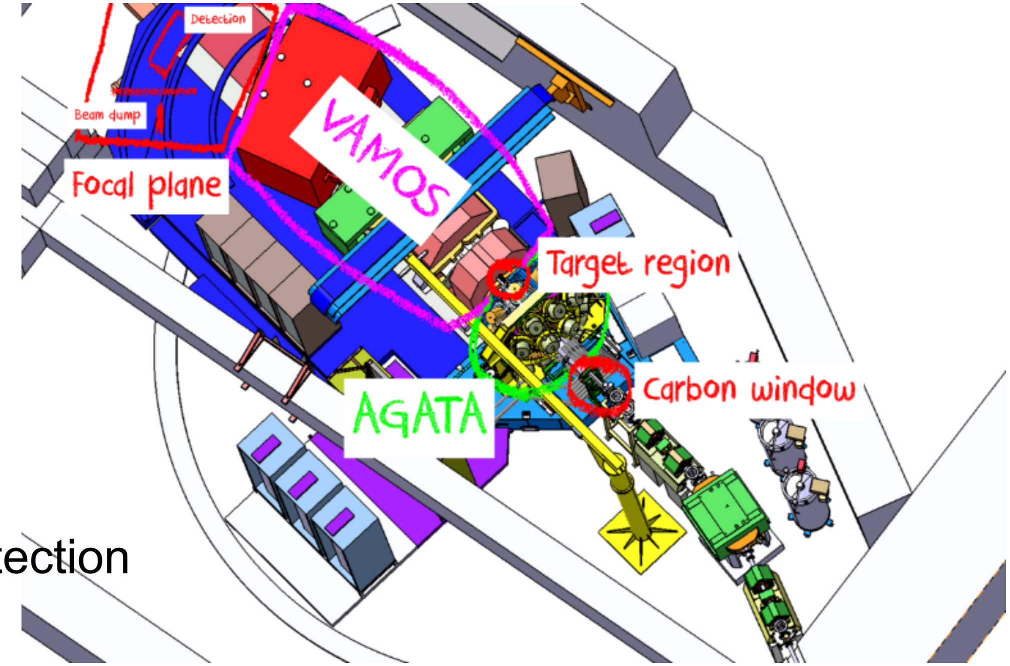


Detection 25°
Vamos -60 cm
Foc recoils at 9m

Transmission
recoils : > 60 %

The VAMOS-GFS upgrade

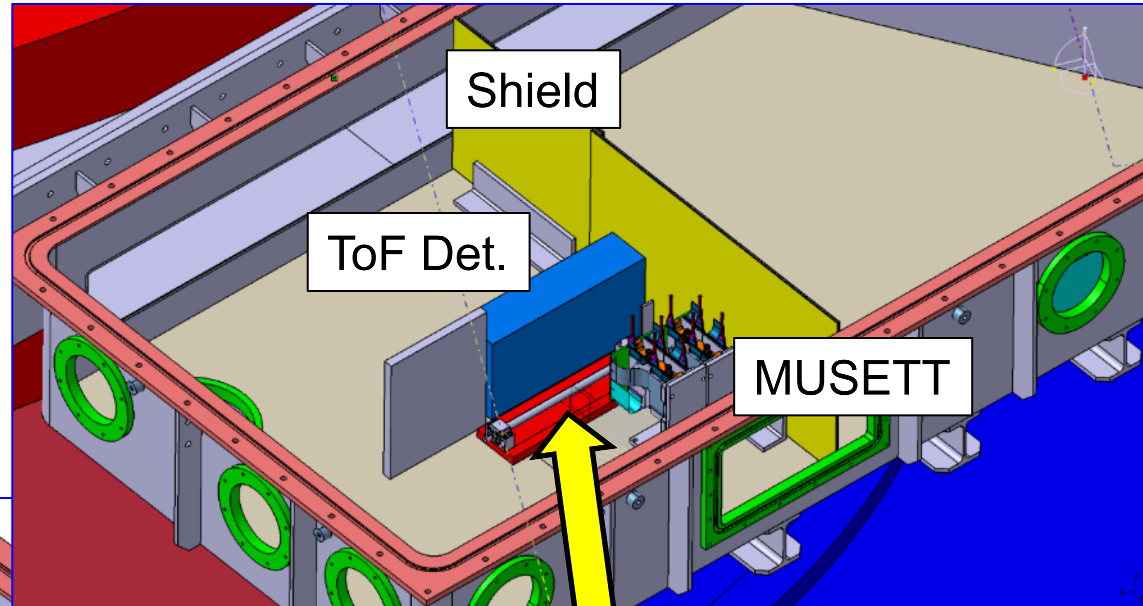
Improvements needed to run routinely and achieve the best performance compared to the 2009 test

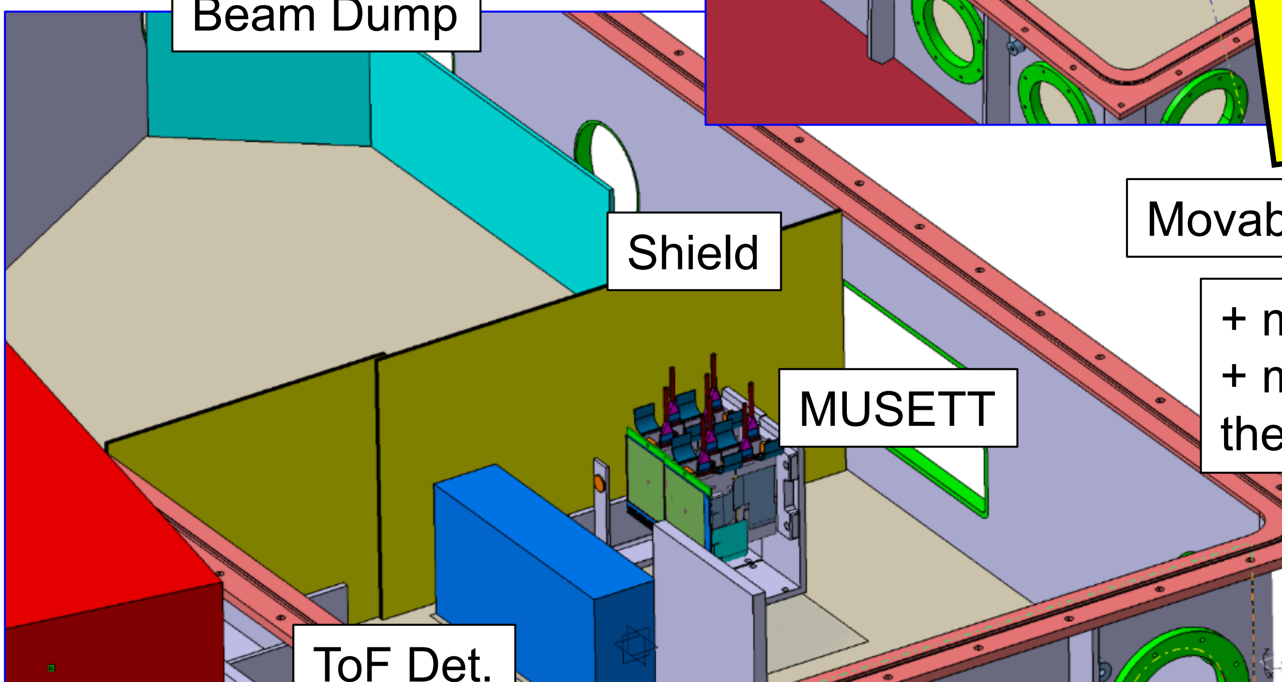


1. Focal plane
   - Beam dump
   - MUSETT & ToF detection
   - Detection shielding

   → New focal plane chamber
2. Low pressure regulation
3. Transition He - vacuum
   - C Window
4. Adaptation of AGATA target chamber

Focal plane





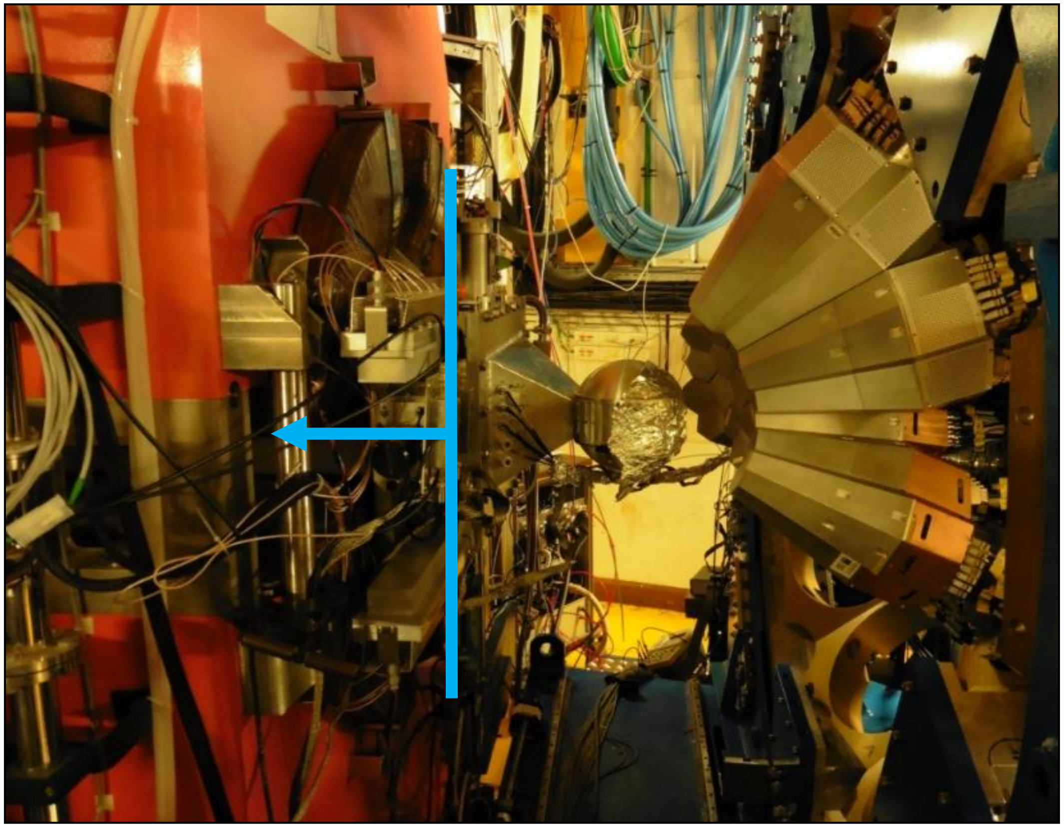
+ movable mask after dipole
+ movable mask in front of the gas detector

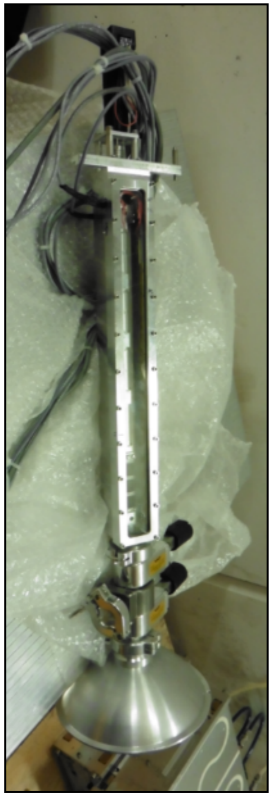
Status : focal plane caisson

Target chamber

→ AGATA

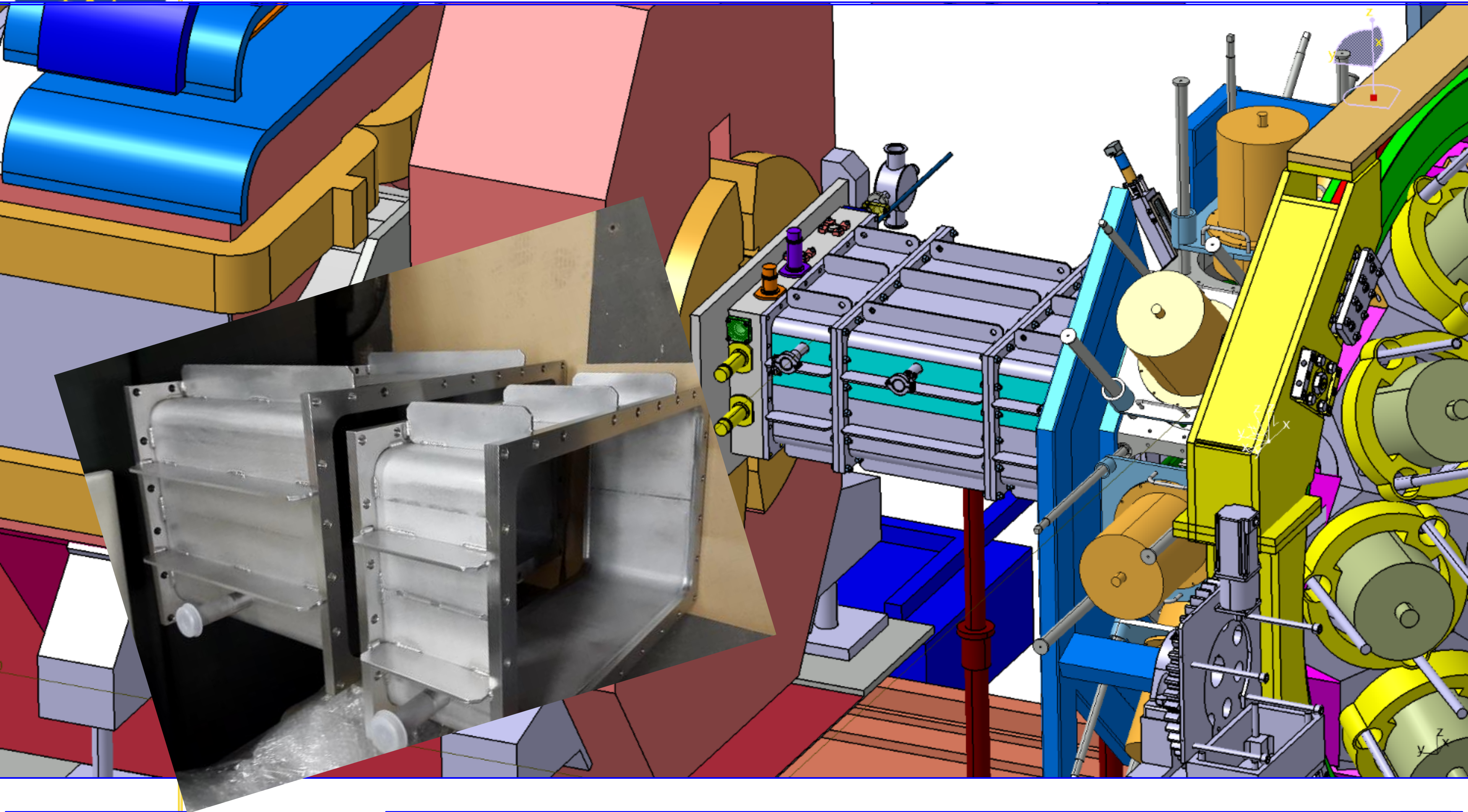
→ Need adaptation to push VAMOS back 20-100 cm to fit with highest Bρ (Q2 current limitation; also helps to reduce beam scattering).





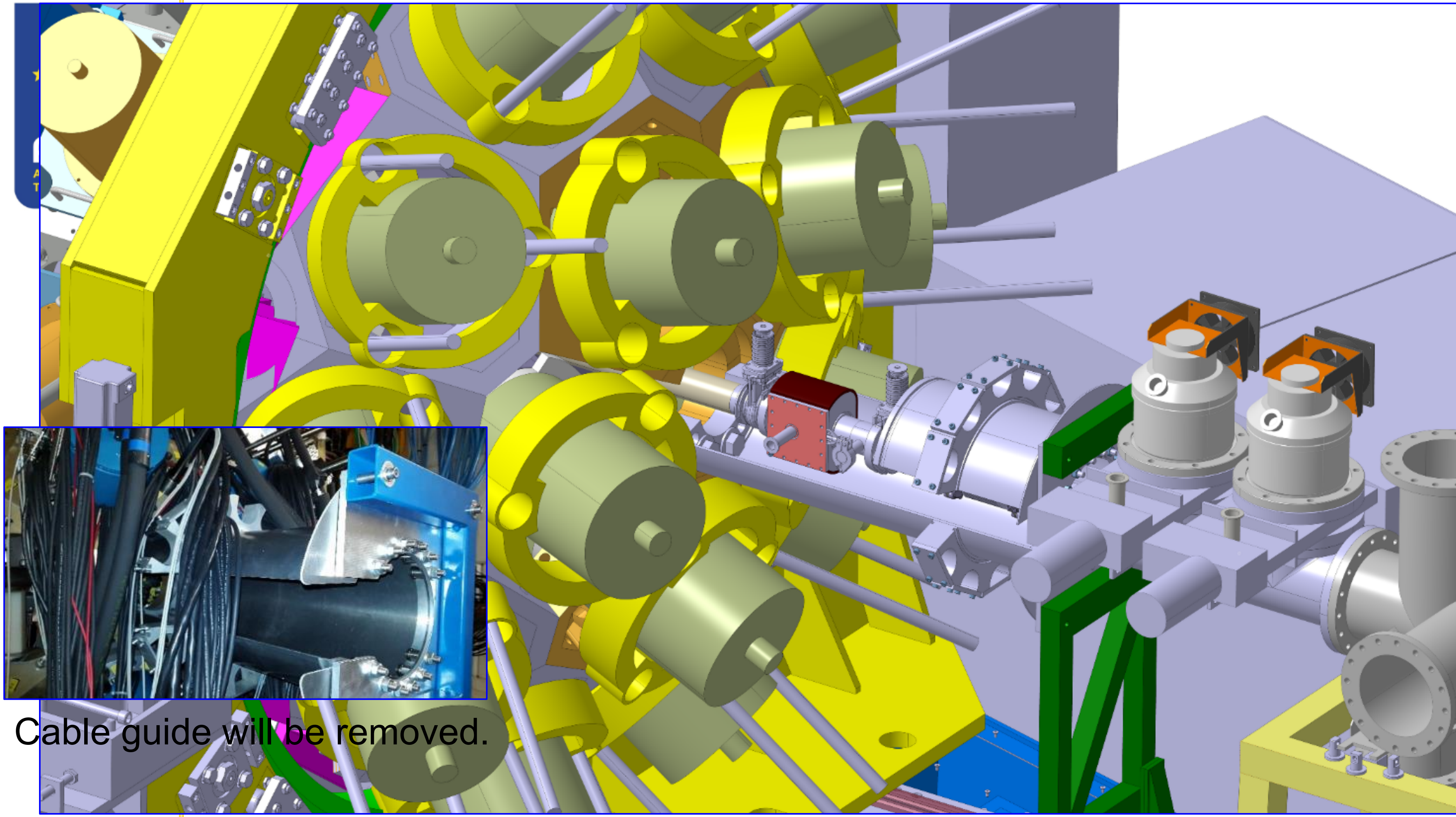
Extensions

1000 mm



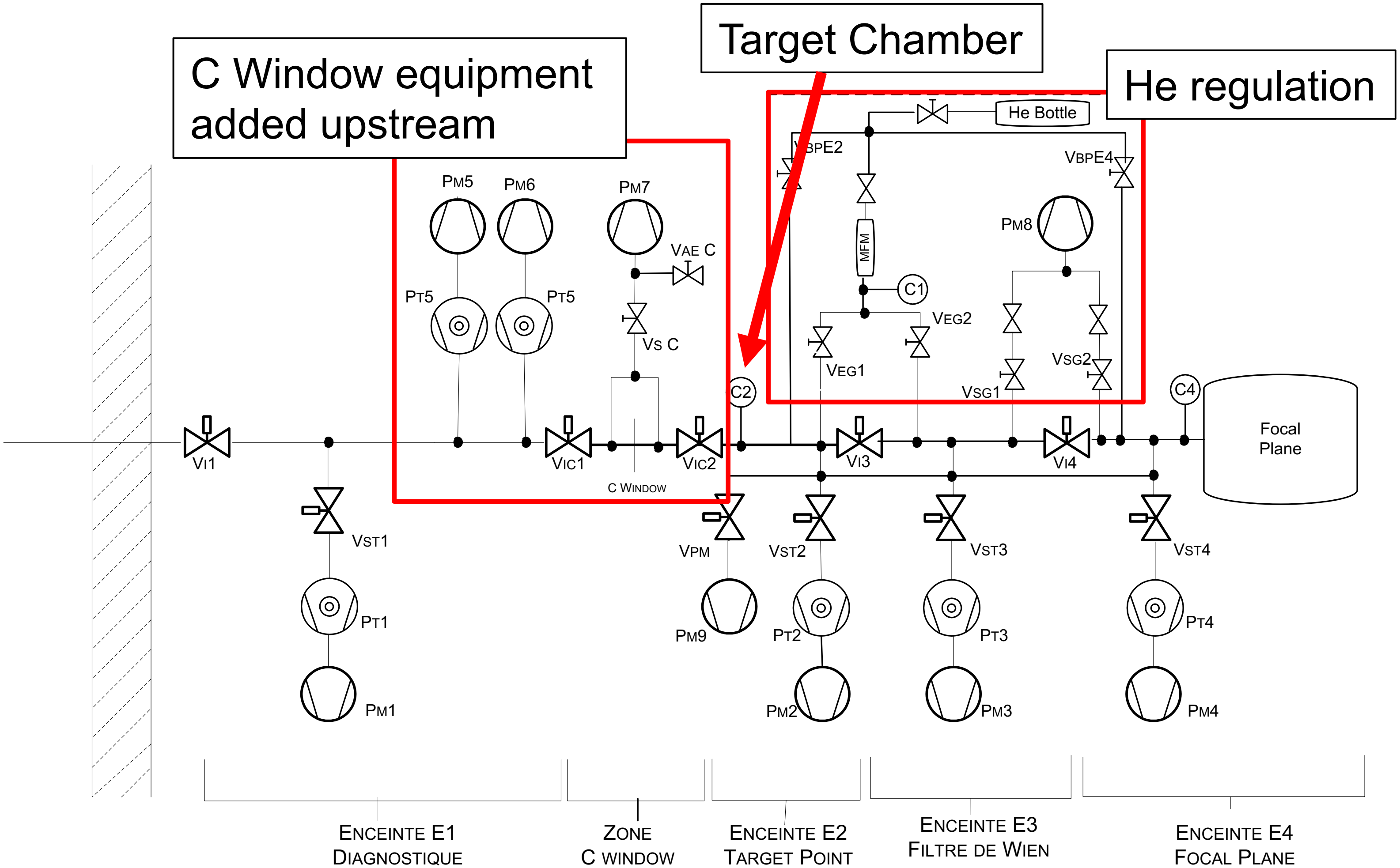
Status : C window line

Inspired by 2009 test & RITU@JYFL



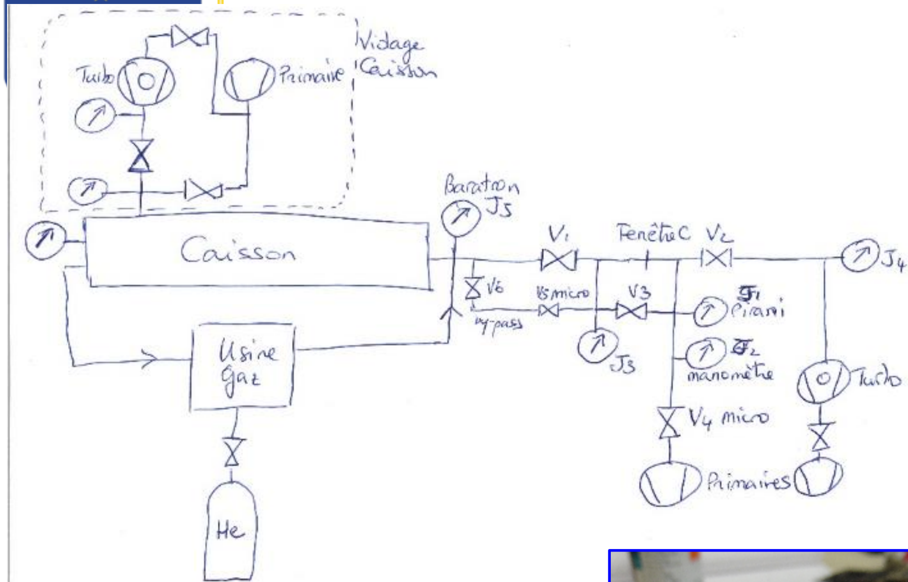
Cable guide will be removed.

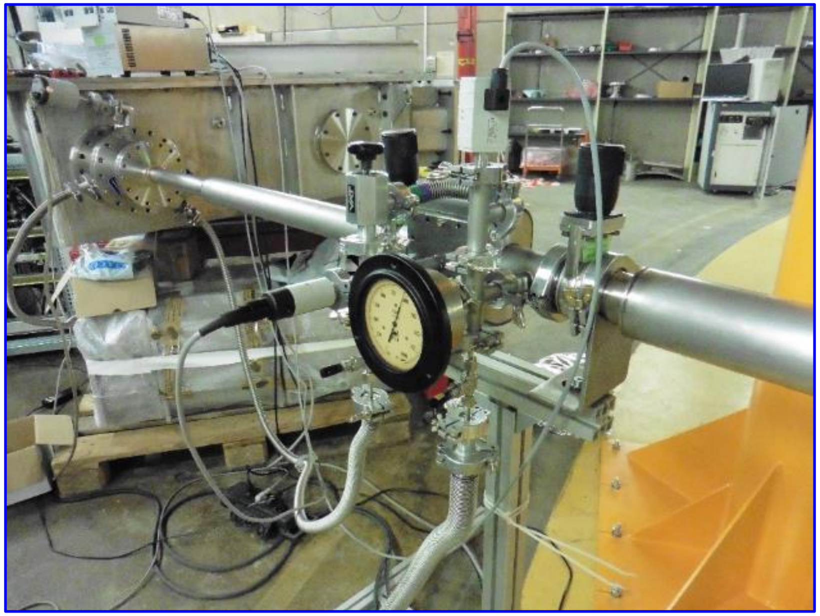
Vacuum / He regulation



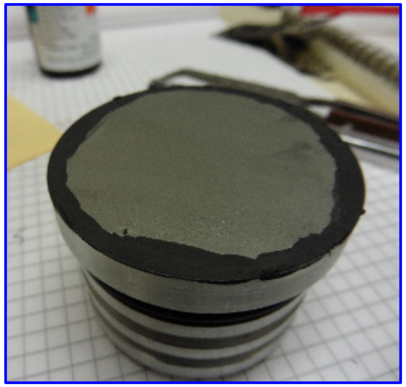
C-Window beam line tests in G3

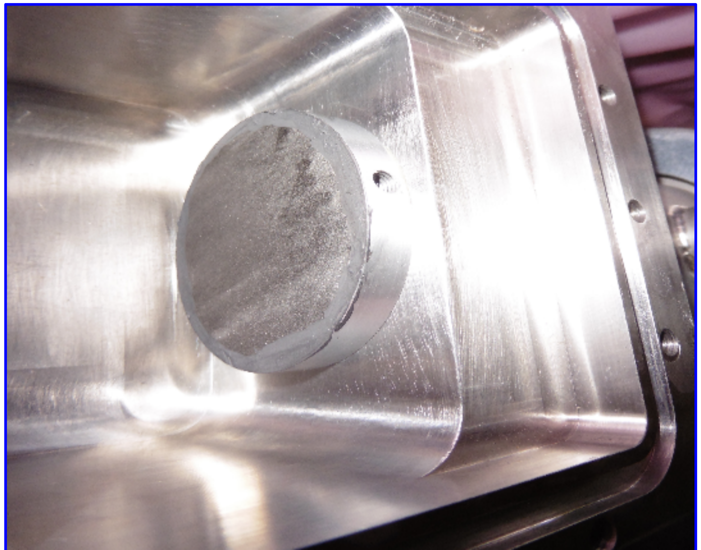
C-Window beam line connected to the focal-plane caisson to simulate the VAMOS volume.





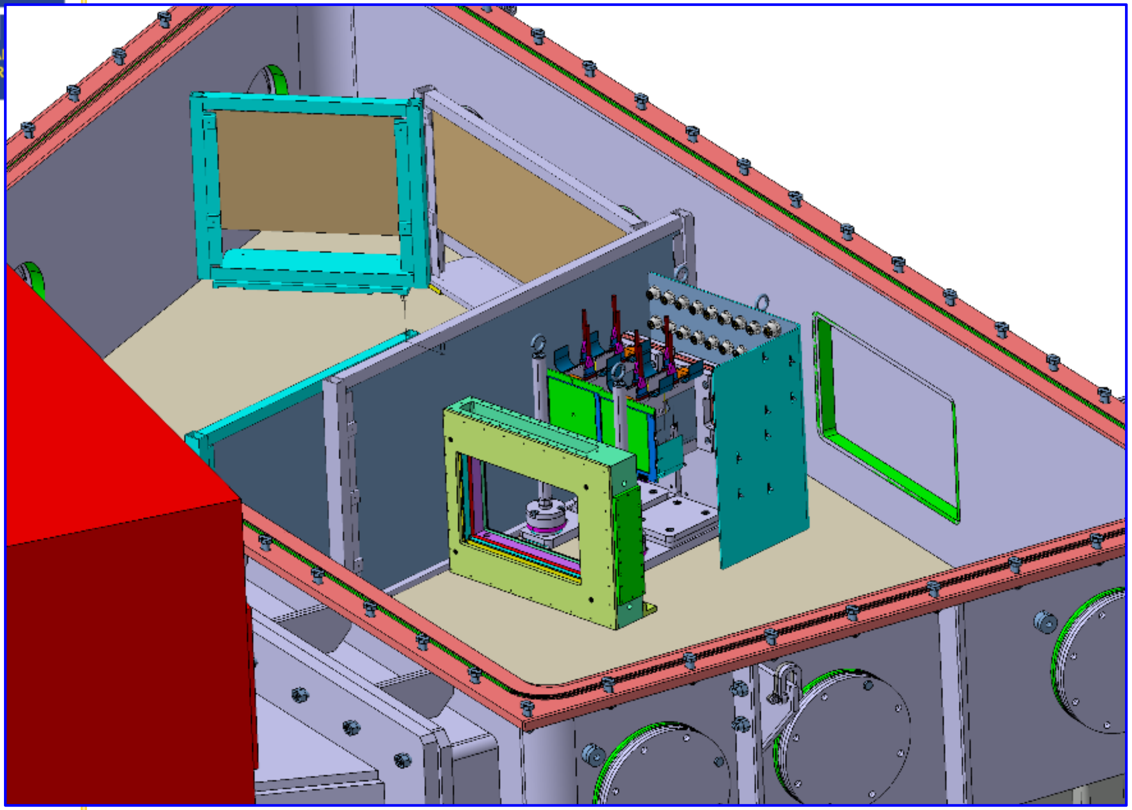
Test: fine up to more than 2 mbar.

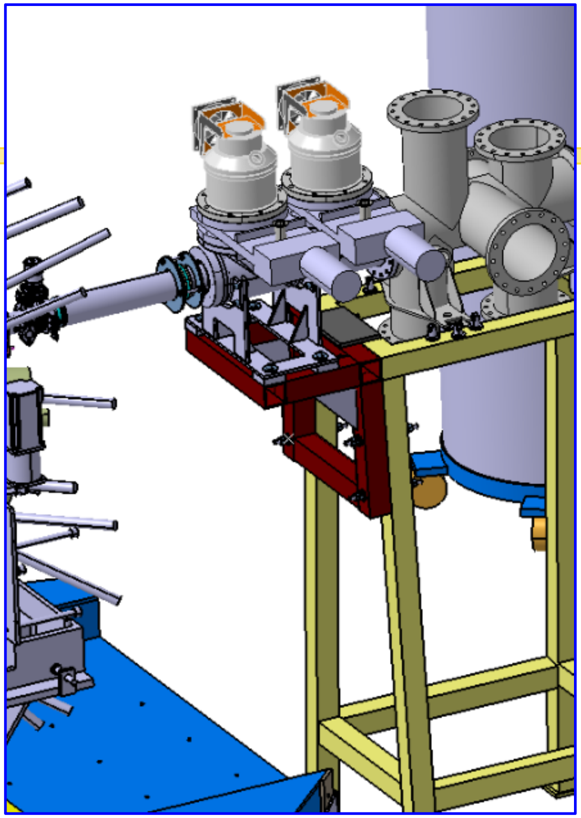


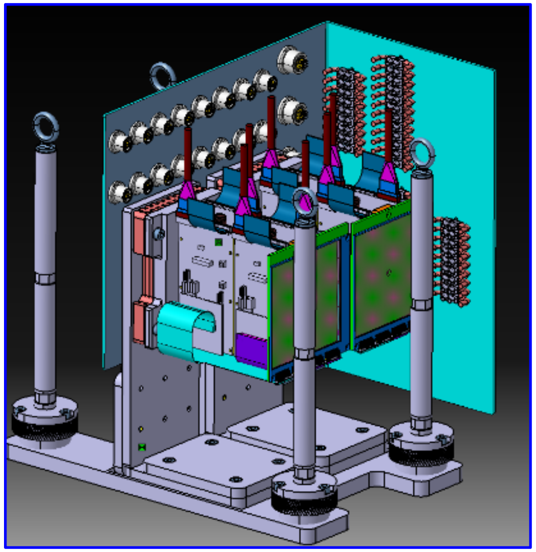


To Do

- Finalize upstream turbo pumps frame
- Finalize beam dump and shield
- Finalize ToF detector







- Finalize new MUSETT mechanics

C&C Electronics and DAQ

- Control&Command: minor updates needed

- VXI MUVI electronics + DAQ at Saclay since Jan. 2016
- Cables + MUSETT feedthroughs (a lot) OK
- ToF detector = same electronics as VAMOS++
  - → coupling with AGAVA
  - → no problems foreseen but need to check

VAMOS-GFS Team

MECHANICS: P. Girardot, A. Raut, Ph. Daniel-Thomas, P.Gangnant, P. Contrepois, P. Graffin et al.

MUSETT : E. Monmarthe, B. Sulignano et al.

MUSETT EDAQ : C. Houarner, L. Legeard, C. Maugeais, F.Saillant et al.

GAS Detector : G. Frémont et al.

C foils : G. Frémont

VAMOS : J. Goupil, A. Lemasson et al.

AGATA : E. Clément, L. Menager, J. Ropert, et al.

SIMULATIONS & OPTICS : Ch.T, J. Sarén (JYFL), B. Jacquot, Ch. Schmitt

PLC : J. Cacitti

+ JYFL RITU team for help and advices

FIN

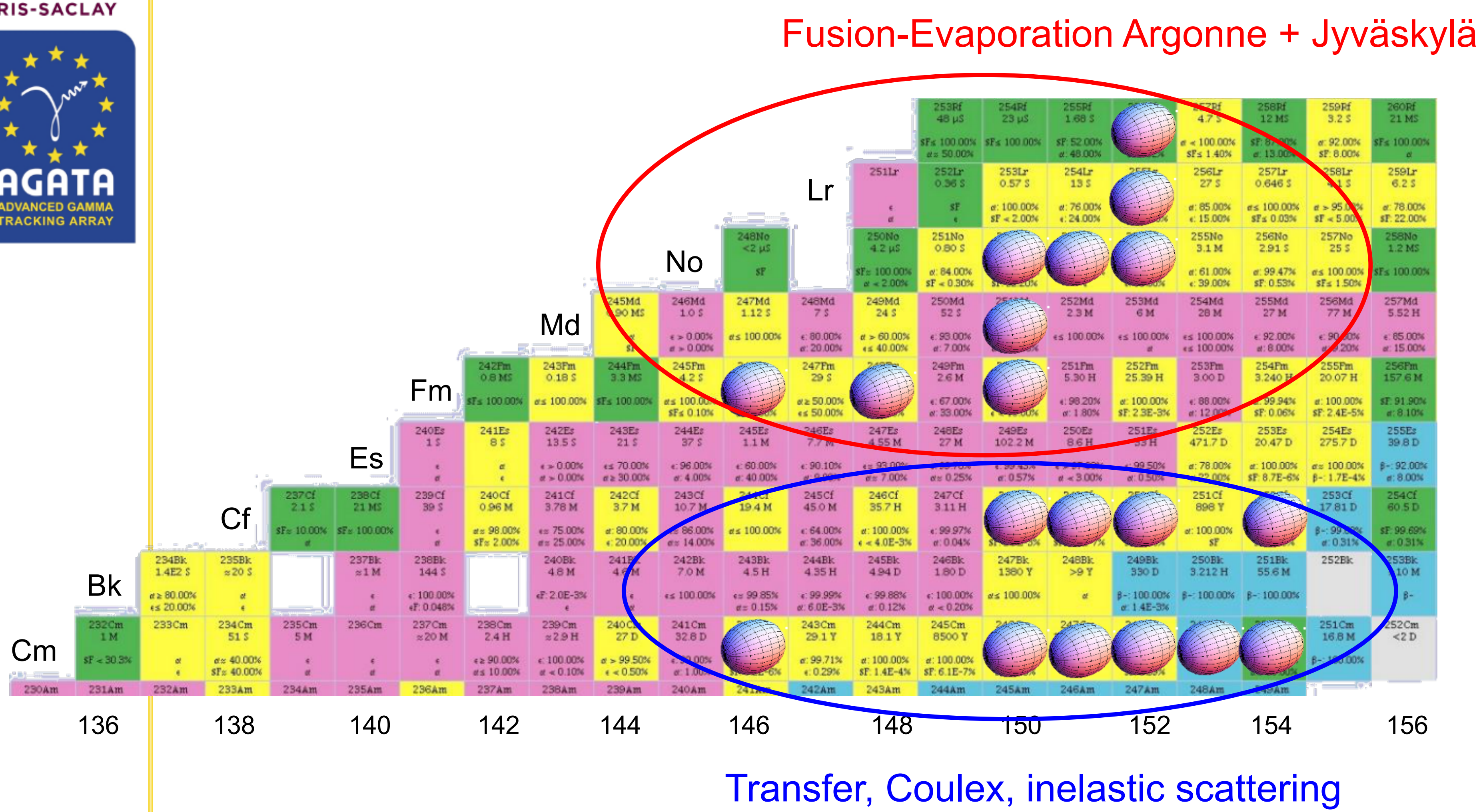
SHE with VAMOS-GFS

Motivations

- Basic questions on VHE/SHE:
  - Limits of stability
  - Island of stability, spherical/deformed magic shells gap ?
  - Lifetimes (fission barriers)
  - Reactions mechanism
  - Predictive power of models
  - …

- Experimental techniques:
  - Synthesis
  - Ground state properties (masses, laser spectroscopy).
  - Decay spectroscopy (mostly s.p. excitations)
  - Prompts spectroscopy (mostly collective properties)
  - Combination decay + prompt (isomers, …)

Status prompt spectroscopy

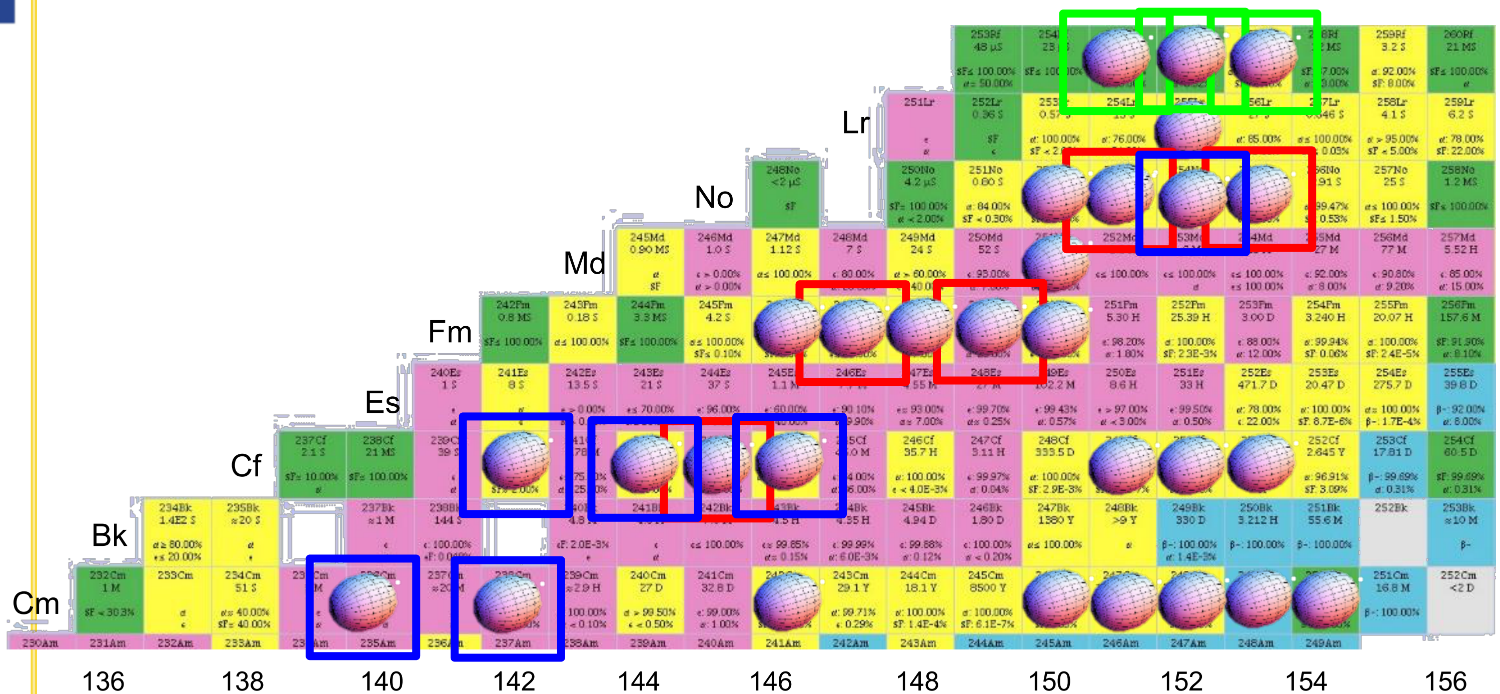


VHN/SHN with VAMOS-GFS and AGATA

K-isomers in even-even actinide nuclei.

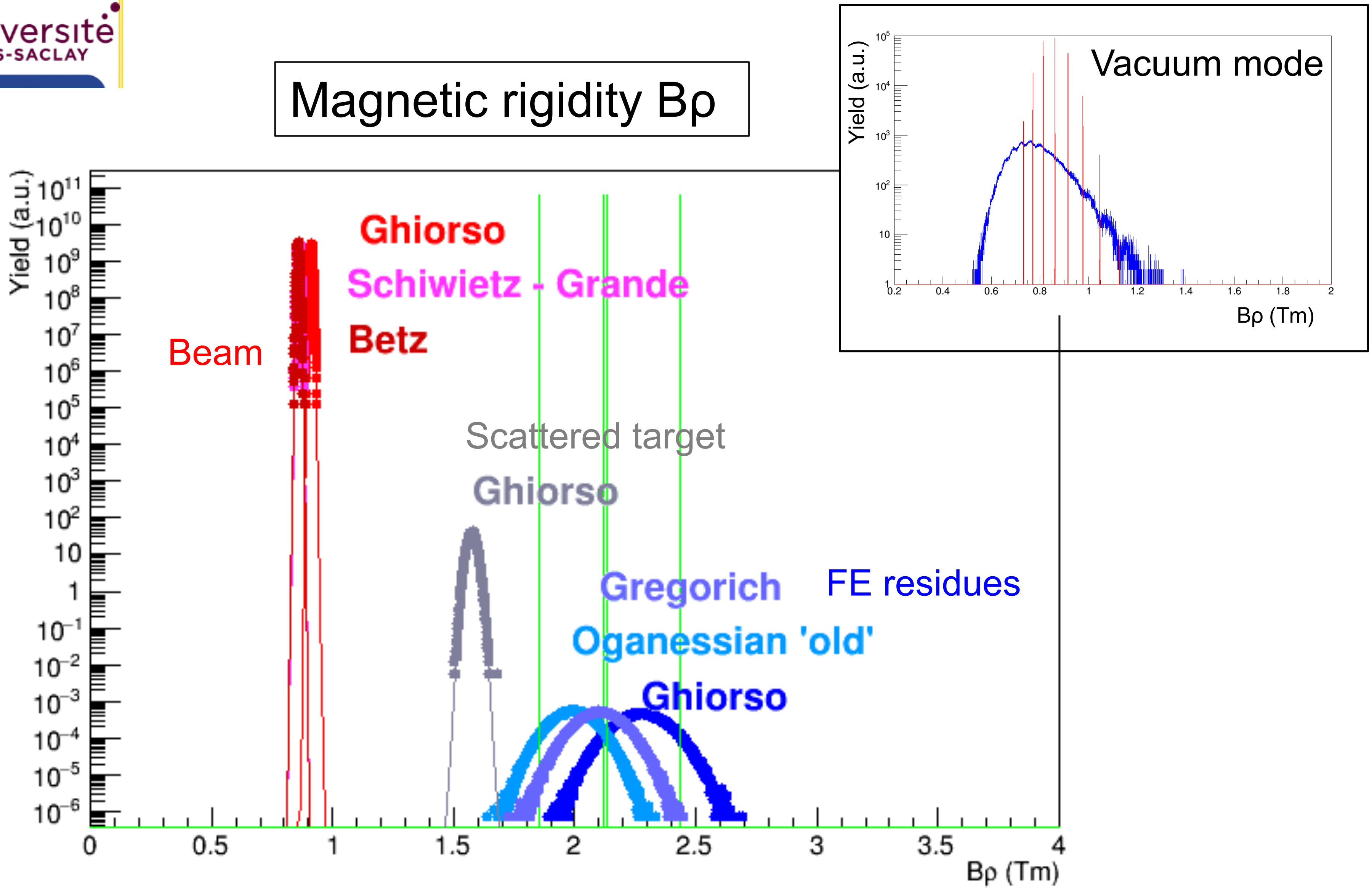
Spectroscopy of the heaviest odd actinides.

Prompt spectroscopy of superheavy elements using AGATA @ VAMOS.

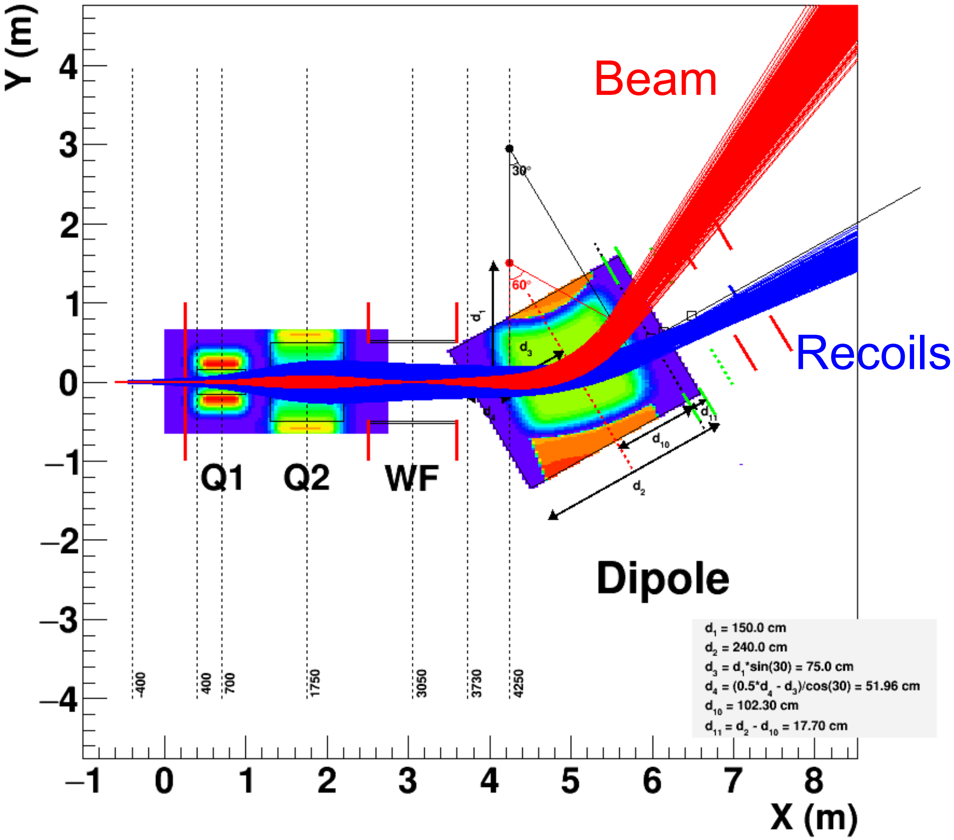


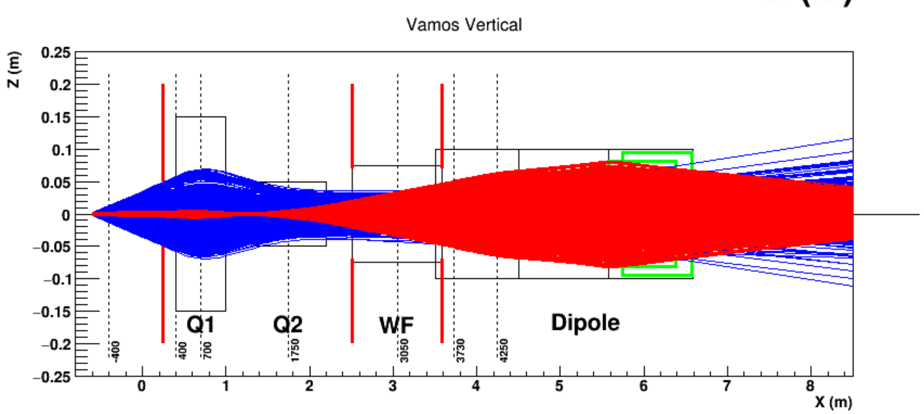
$^{224,226}U + ^{228,230,232}Pu$

$^{48}Ca + ^{208}Pb \rightarrow ^{254}No + 2n$



$^{48}Ca + ^{208}Pb \rightarrow ^{254}No + 2n$

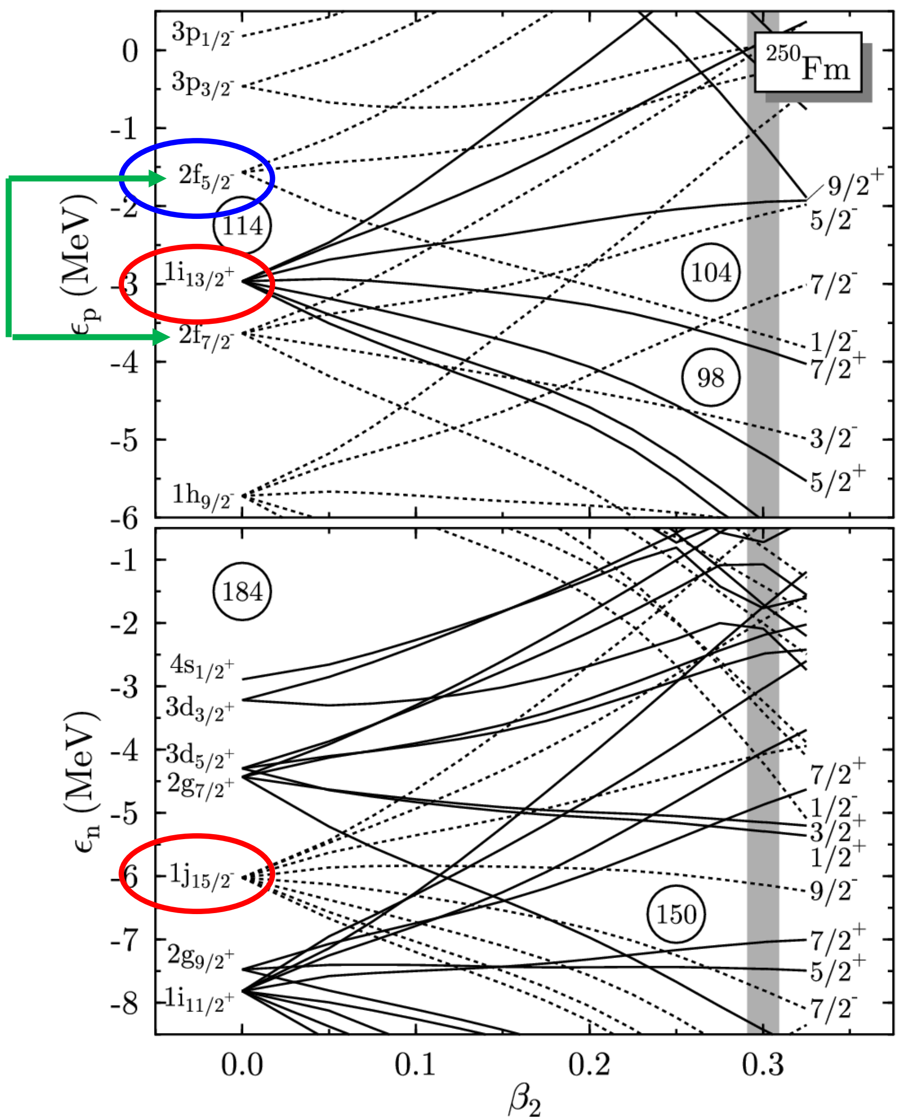




Detection 25°
Vamos -60 cm
Foc recoils at 9m

Transmission
recoils : > 60 %

Structure of VHE/SHE : open problems



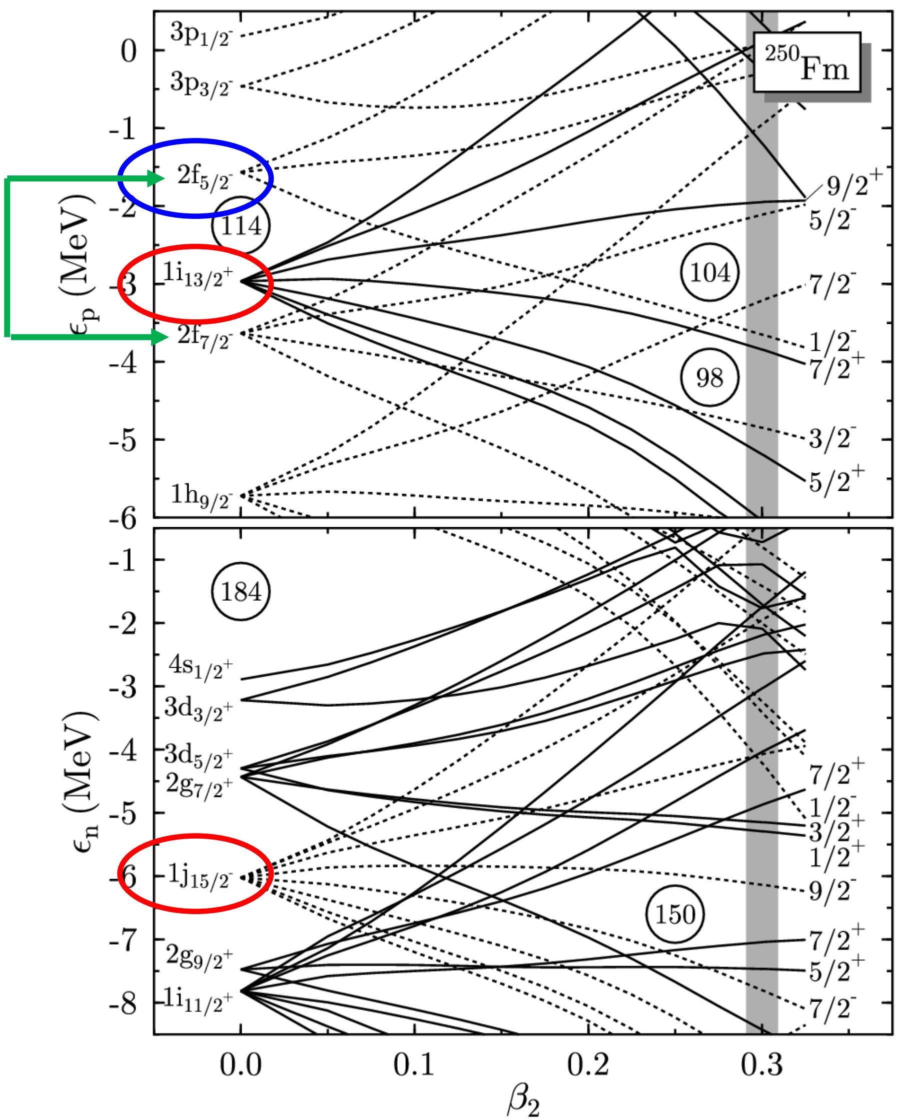
→ Position of deformed shell gaps (problem with N=152, Z=100 using DFT)

→ Position of spherical shell gaps

- High *j* orbitals
- Down-sloping orbitals
  e.g. $\pi 2f_{5/2}$
- Spin-orbit splitting
  e.g. $\pi 2f_{7/2}$-$2f_{5/2}$

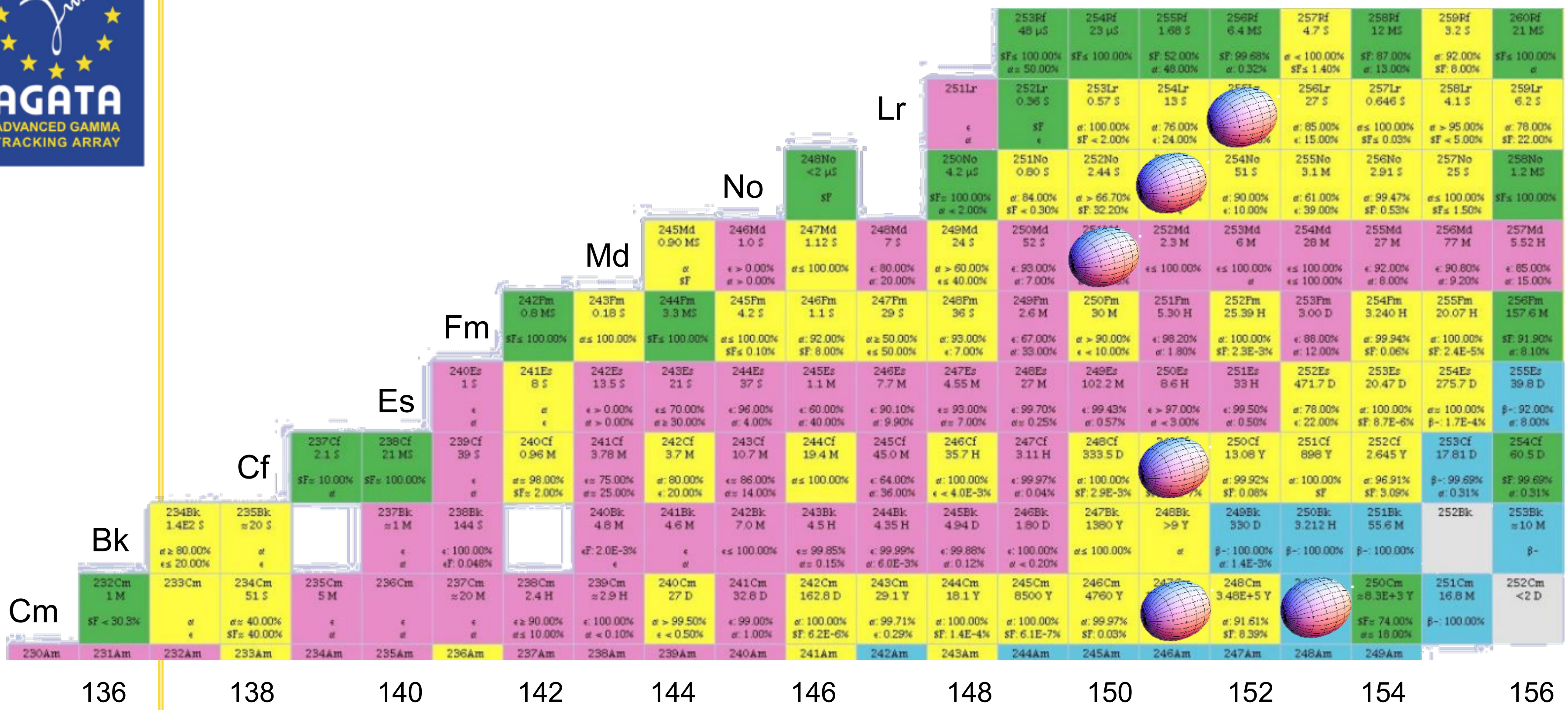
→ Spectroscopy of odd nuclei, 2qp high-K isomeric states

Odd nuclei



- Clear signature of single particle states
- Behaviour as function of rotation sensitive to s.p. orbital properties
  - → Moment of inertia
  - → Alignment (blocking of specific orbital allows/forbids alignment)
  - → Magnetic moment
  - → Signature splitting
  - → …

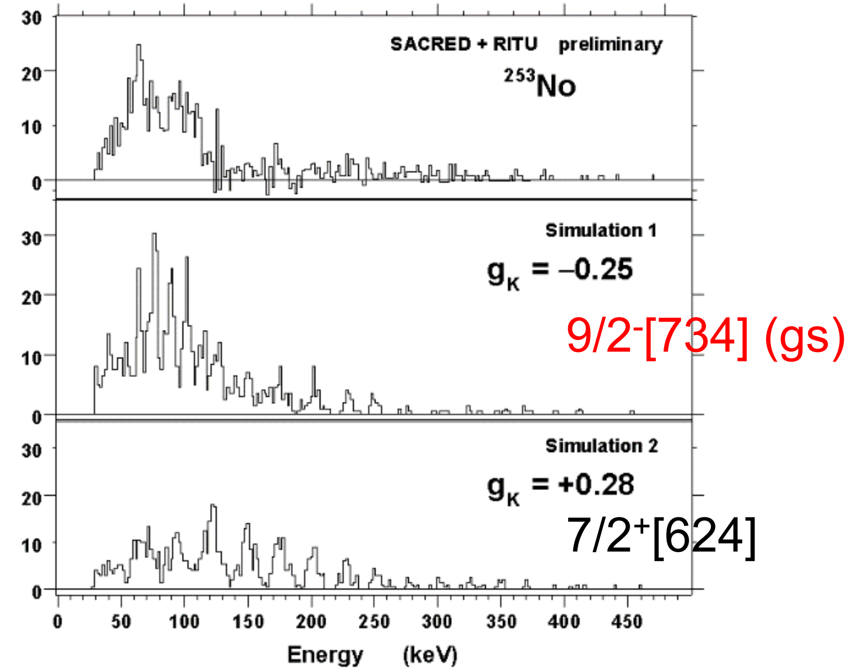
Prompt spectroscopy status: odd nuclei

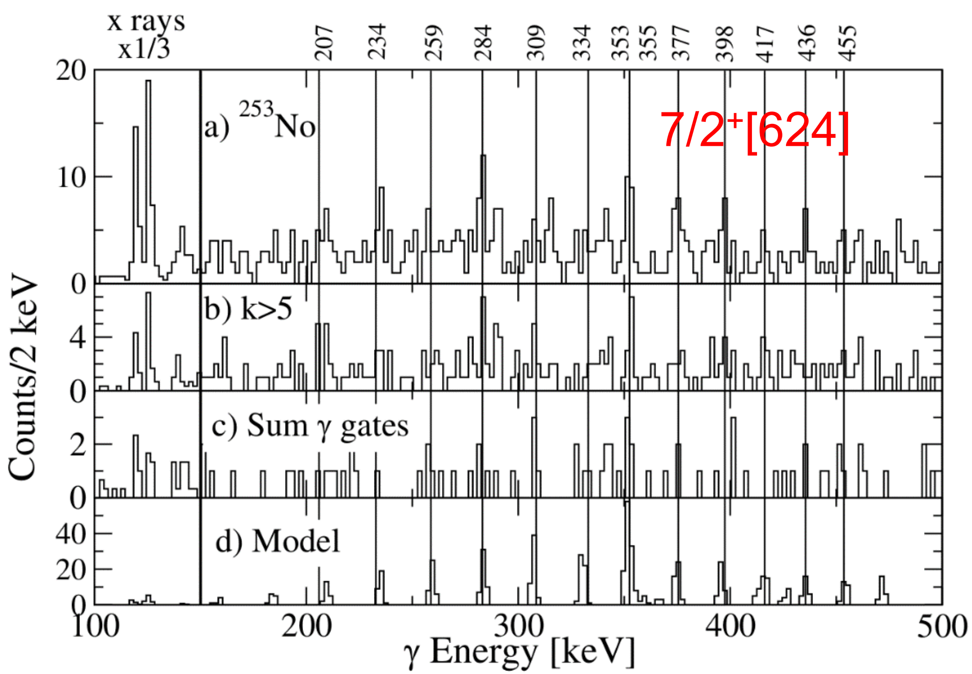


Why is it difficult : the ^{253}No example

- Electron spectroscopy.

R.-D. Herzberg, et al.,
Eur. Phys. J. A 15 (2002) 205.





- Gamma spectroscopy.

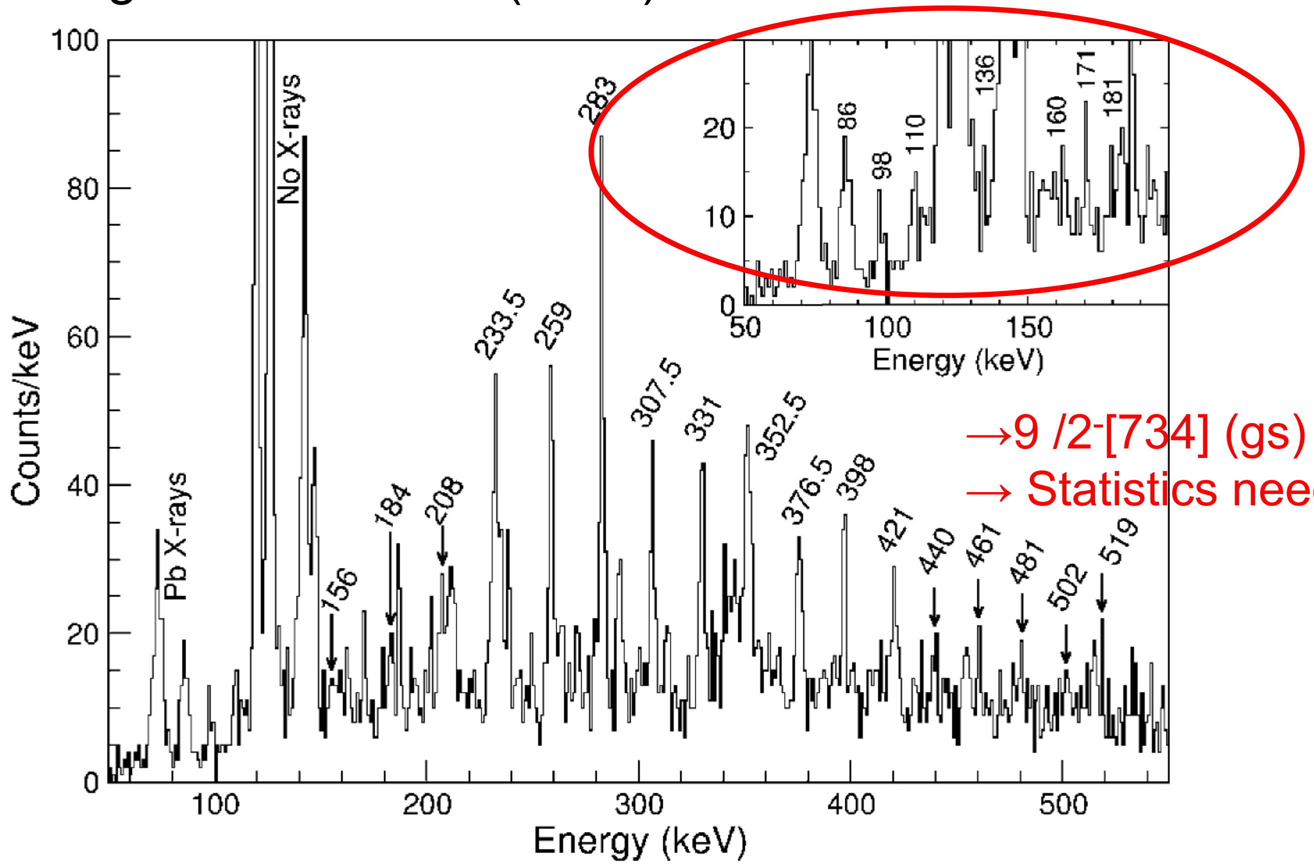
P. Reiter et al. PRL 95 (2005) 032501

^{253}No

- Gamma spectroscopy.

Herzberg et al. EPJA 42 (2009) 333

M1 transitions



→9 /2$^-$[734] (gs)

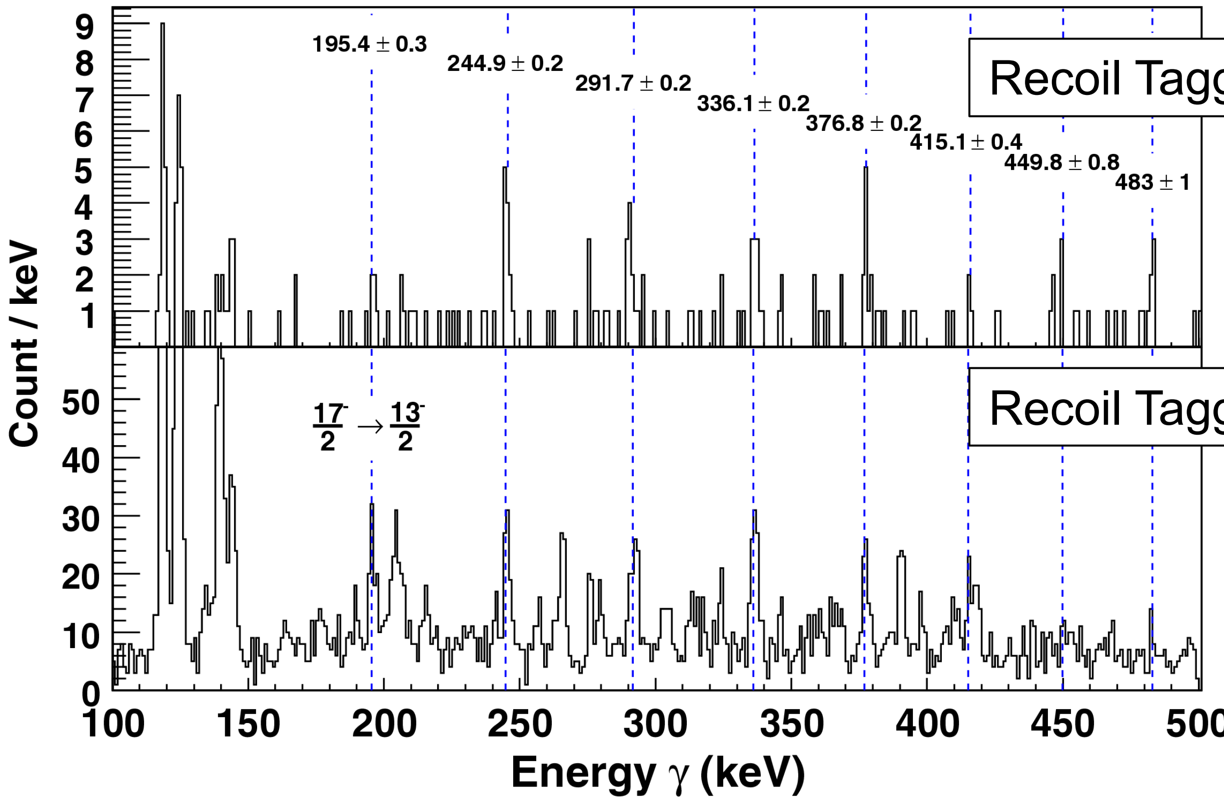
→ Statistics needed !

$$B(M1)/B(E2) \propto K^2(g_K-g_R)^2/Q_0^2$$

$$g_K \sim 1/K(g_s\Sigma + g_l\Lambda)$$

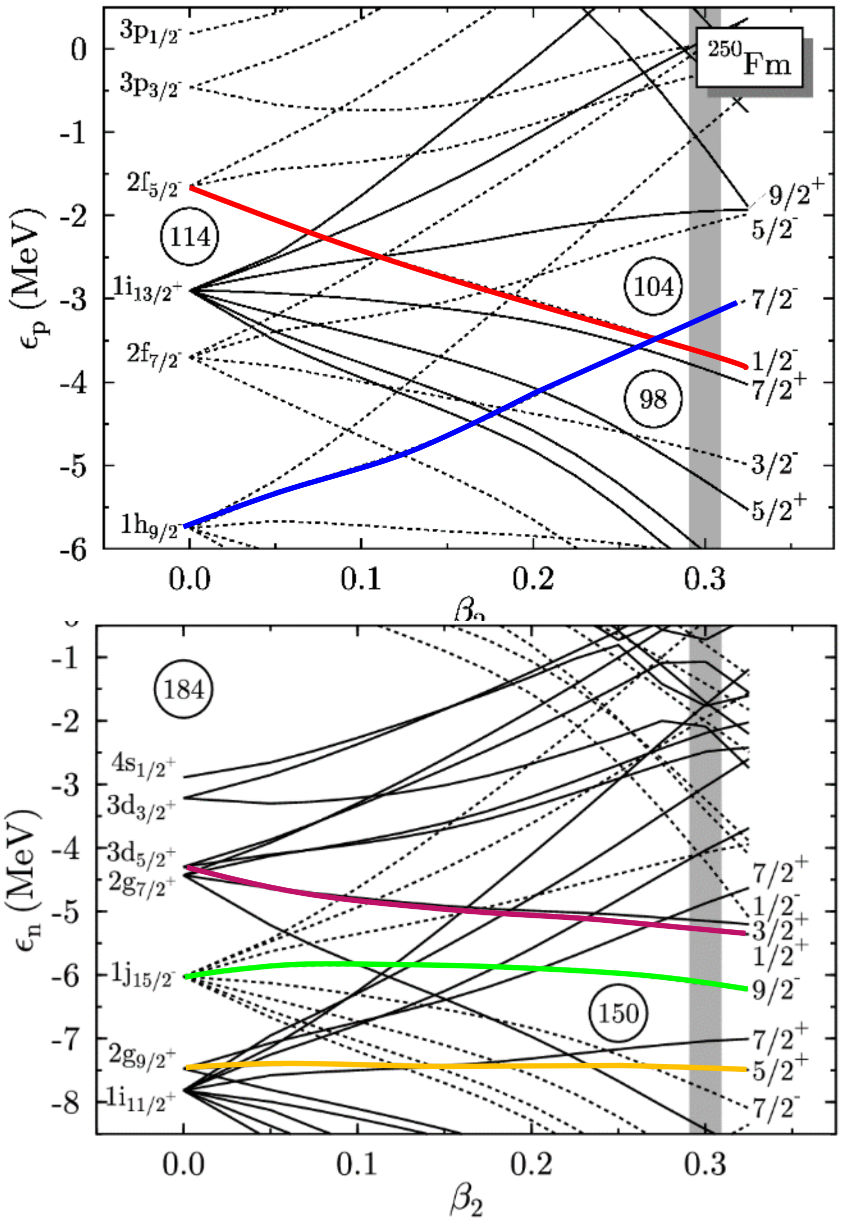
Example 2 : ^{251}Md

E. Chatillon et al. PRL 98 (2007) 132503



- Complex spectrum → fragmented de-excitation in odd isotopes → γγ needed
- No signature partner → K=1/2 → [521]1/2- → excited s.p.state
- $2f_{5/2}$ orbital closing the (presumed) spherical Z=114 shell
- Where is the gs band ?

Odd nuclei : what has been done in ~20 years



^{251}Md, ^{255}Lr

^{255}Lr

^{249}Cm

^{247}Cm, ^{249}Cf, ^{253}No

^{247}Cm, ^{249}Cf

Alignment

Hota PL 739B (2014) 13

VOLUME 51, NUMBER 17 PHYSICAL REVIEW LETTERS 24 OCTOBER 1983

First Observation of Backbending in an Actinide Nucleus

W. Spreng, F. Azgui, H. Emling, E. Grosse, R. Kulessa,[a] Ch. Michel, D. Schwalm,[b] R. S. Simon, and H. J. Wollersheim
Gesellschaft für Schwerionenforschung, D-6100 Darmstadt, Germany

and

M. Mutterer and J. P. Theobald
Institut für Kernphysik, Technische Hochschule Darmstadt, D-6100 Darmstadt, Germany

and

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Los Alamos Scientific Laboratory, Los Alamos, New Mexico 87544

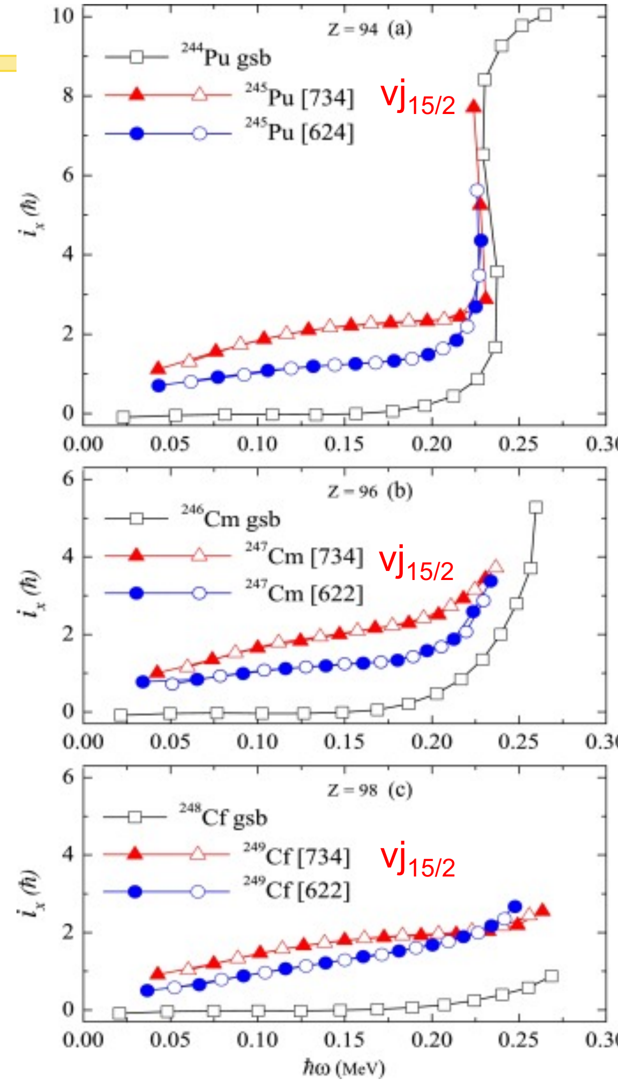
and

N. Trautmann
Institut für Kernchemie, Universität Mainz, D-6500 Mainz, Germany

and

J. L. Egido[c] and P. Ring
Physikalisches Institut, Technische Universität München, D-8046 Garching, Germany

(Received 18 August 1983)

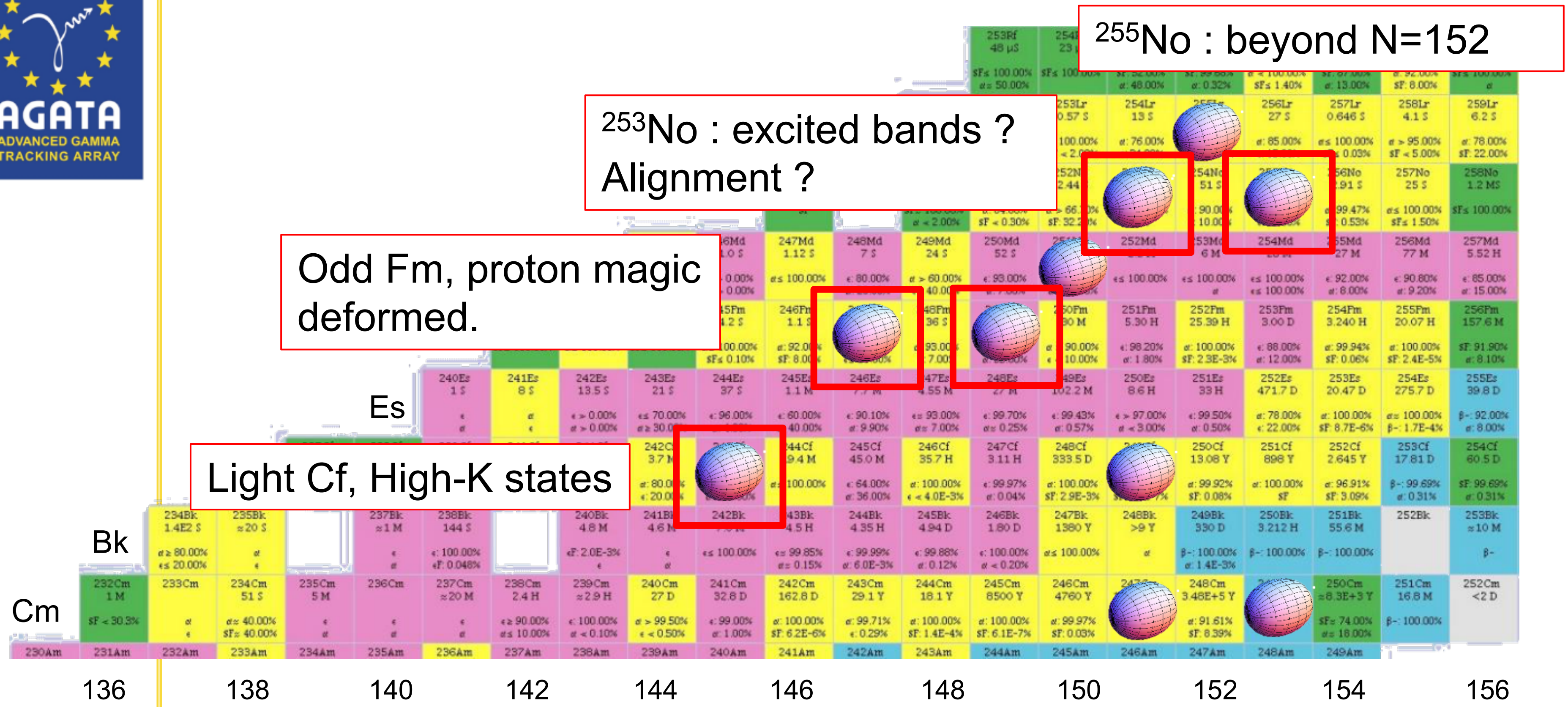


Alignement due to $\pi i_{13/2}$ or $\nu j_{15/2}$?

Alignment in ^{245}Pu du to $\pi i_{13/2}$

"However, the experimental elusiveness of predicted $\nu j_{15/2}$ alignments needs further investigation"

Selected Proposed investigations



Odd-Z nuclei difficult !

END OF SHE with VAMOS-GFS

The benefits of VAMOS-GFS + AGATA

$M\gamma=10$	SAGE+RITU	AGATA 30+VGF	AGATA 45+VGF
γ- Efficiency @ 300 keV	~ 8 %	~ 10 %	~ 15 %
$N\gamma$/evt	0,22	0,83	1,28
$N\gamma\gamma$/evt	0,08	0,37	0,82
$N\gamma\gamma\gamma$/evt	0,02	0,10	0,31

VAMOS-GFS transmission ~ 70 % for ~^{48}Ca + ~^{208}Pb

$\gamma\gamma$ are essential in odd isotopes

Physics generator : some details

- Beam and ER energy loss in target and degraders
  - Ziegler, as implemented in TERS v2.0 code. Phys. Comm. 180 (2009) 2392.
  - Northcliffe-Schilling and Hubert-Bimbot-Gauvin : « range » code http://www.calel.org/range.html
- Straggling due to target & degraders
  - Energy : Bohr with Lindhard-Scharff corrections : Bohr, Dan. Mat. Phys. Medd. 18 (1948) 8. Lindhard & Scharff Dan, Mat. Phys. Medd. 27 (1953) Vol. 15
  - Angle : Amsel et al, NIM B 201 (2003) 325, Szilagyi et al., NIM B 100 (1995) 103
  - See also Dahlinger et al, for energy and angular dispersion ; NIM 219 (1984) 513
- Particle evaporation
- Charge state in gas
  - Ghiorso et al. NIM A 269 (1988) 192, Compilation 36<Z<102 and 1.5<v/v0<4.5
  - Oganessian et al. PRC 64 (2001) 064309. Compilation 89<Z<116 V <~ 0.5 cm/ns
  - Oganessian et al. ZPD 21 (1991) S357. Nuclei from Sm to Fm. Works quite well for VHE, SHE
  - Gregorich et al, PRC 72 (2005) 014605. Compilation Z > 45.
    - See also NIM A 711 (2013) 47 for details for GFS simulations
  - Schiwietz and Grande NIM B 475 (2001) 125. Compilation 552 data with 1<Zp<92, 1<Zgaz<54
  - Betz. In Applied atomic collisions, Vol, 4. Academic press, 1983
  - Ziegler. Handbook of stopping cross-sections for energetic ions in all elements. Pergamon press, 1980,

Effect of gas

- Angular straggling in the gas (Amsel + Szilagyi)
- Influence of charge exchange on Bρ dispersion (1)
  - Ambruster et al. NIM 91 (1971) 499
- Influence of small angular scattering on Bρ dispersion
  - Leino NIM B 126 (1997) 320
- Influence of initial velocity dispersion on Bρ dispersion
  - Ambruster et al, NIM 91 (1971) 499

This provides final dispersions.

.. However we inject initial trajectories in zgoubi.

What we do is add the predicted final dispersion at the input (not very elegant).

For (1) : charge state dispersion after target needed

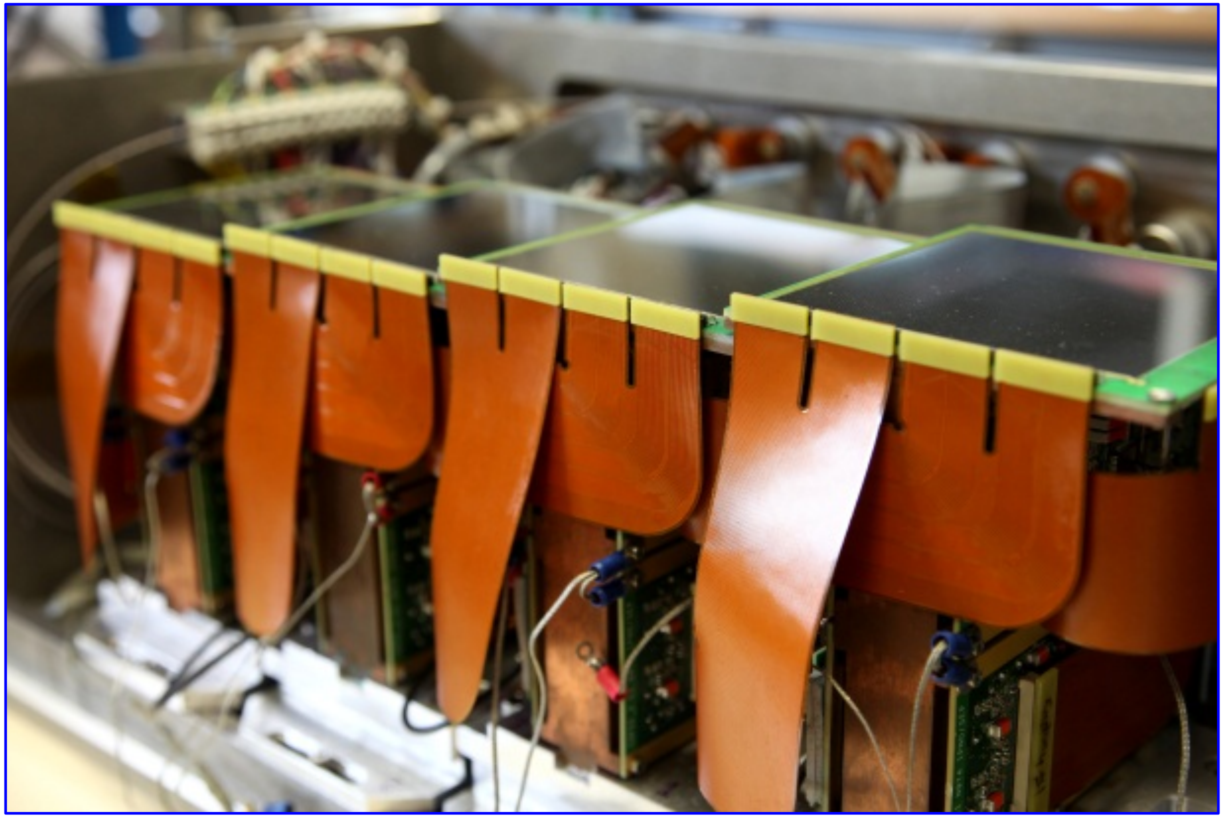
Several Charge states parameterization in solid implemented :

- Nikolaev and Dimitriev, PLA 28 (1968) 277
- Shima et al NIM 200 (1982) 605. Projectiles Z>8, targets 4<Z<79, Energies < 6 MeV/A
- Sagaidak and Yeremin, NIM B 93 (1994) 103, Z>=53 through C foil, 0.001<E/A< 10 MeV
- Baron et al. NIM A 328 (1993) 177. Ar to U through C foil. 3.8 <E/A < 10.6
- Schiwietz and Grande, NIM B 175 (2001) 125, Compilation of 850 data

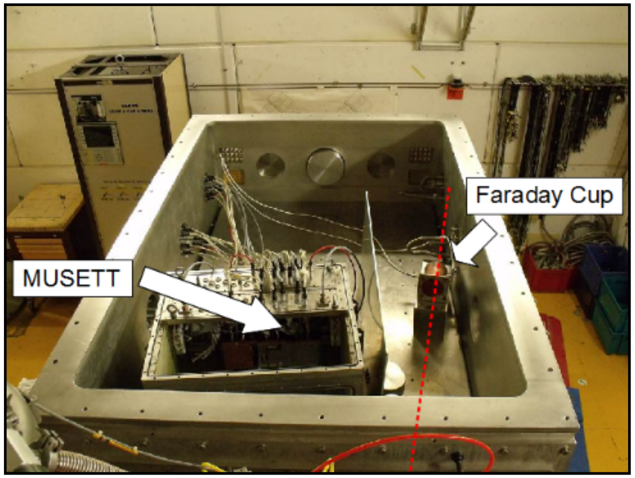
Focal plane detection : MUSETT

Highly segmented Si wall for RDT at VAMOS

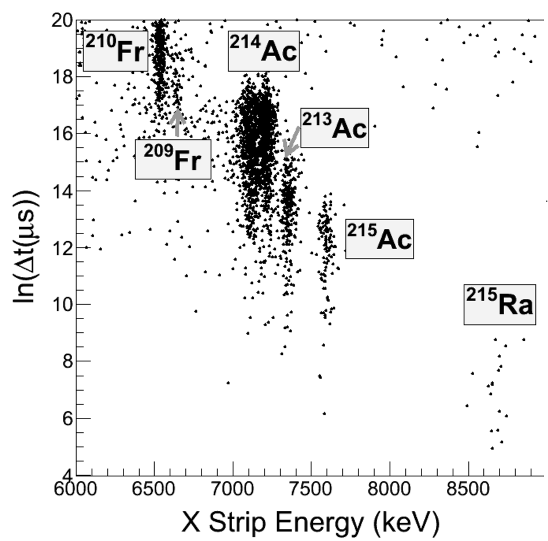
(*MUr de Silicium pour l'Etude des Transfermiens par Tagging*)

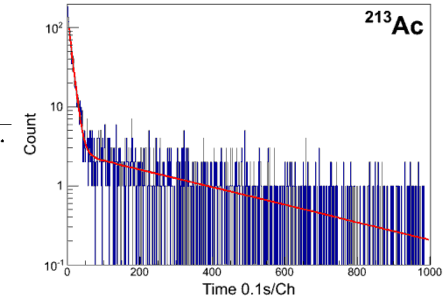


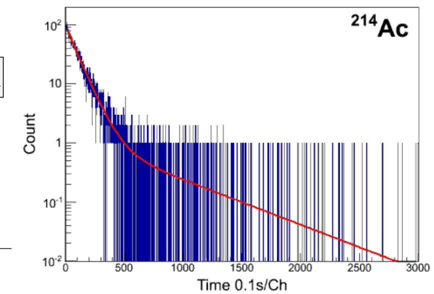
MUSETT commissioning 2010 (WF mode)

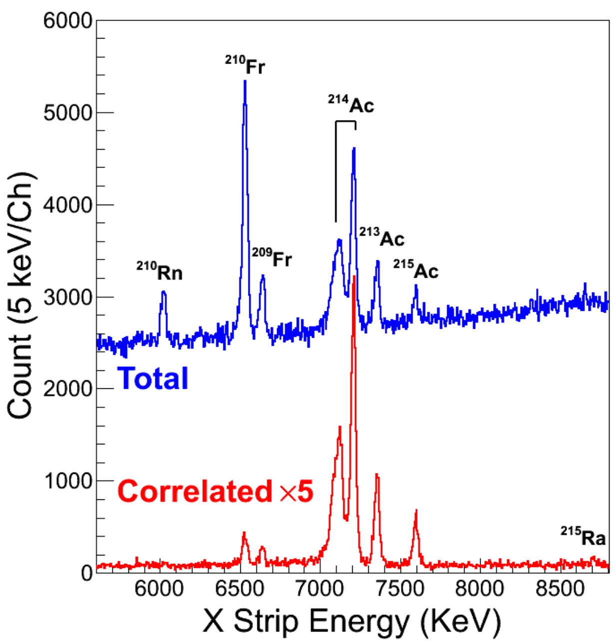


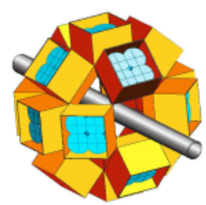
$^{22}Ne + ^{197}Au \rightarrow ^{213-215}Ac$

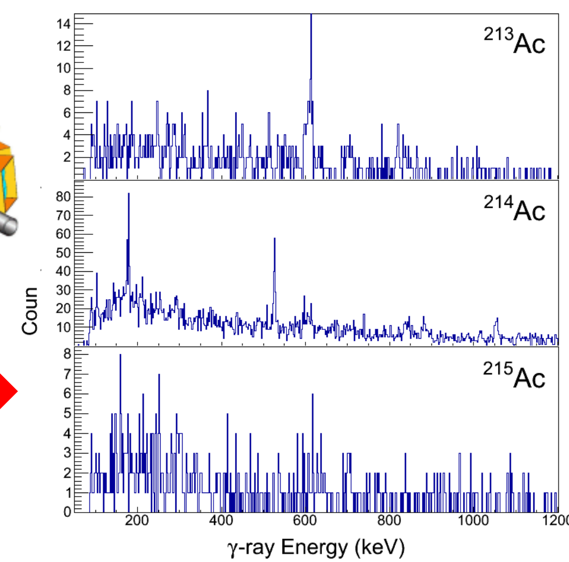






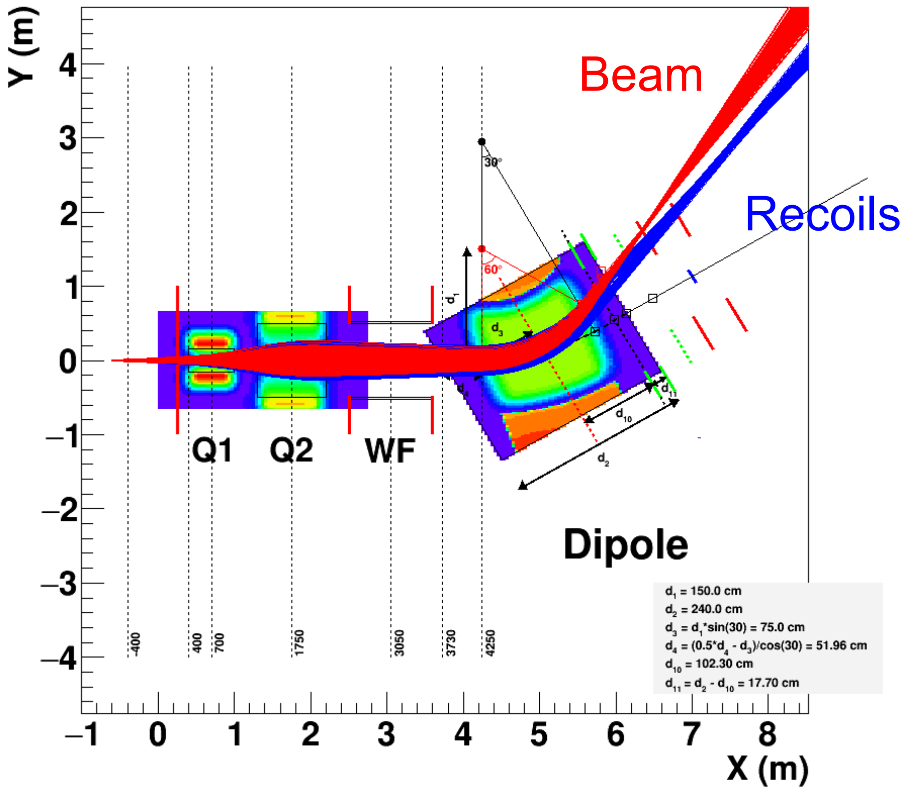


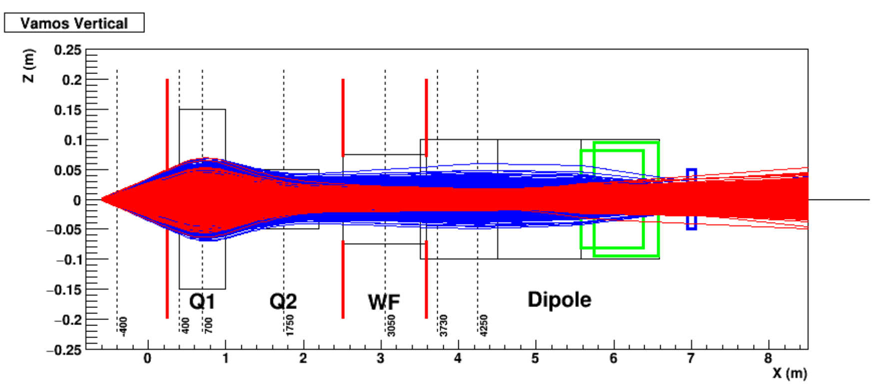




Ch. T *et al.* NIMA 747 (2014) 69

$^{208}Pb + ^{48}Ca \rightarrow ^{254}No + 2n$ with degrader





Target =
2 mg/cm^2 ^{197}Au
0.5 mg/cm^2 ^{48}Ca +
0.5 mg/cm^2 ^{197}Au +
Degrader = 5 mg/cm^2 Au

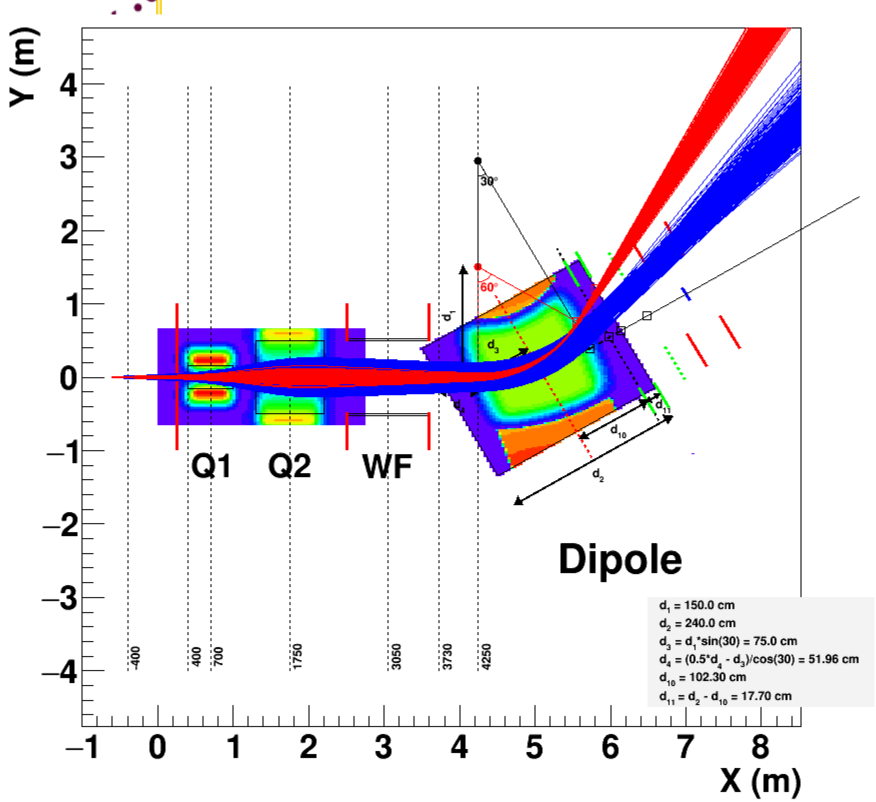
Detection 50°
Vamos -60 cm
Foc recoils at 9m

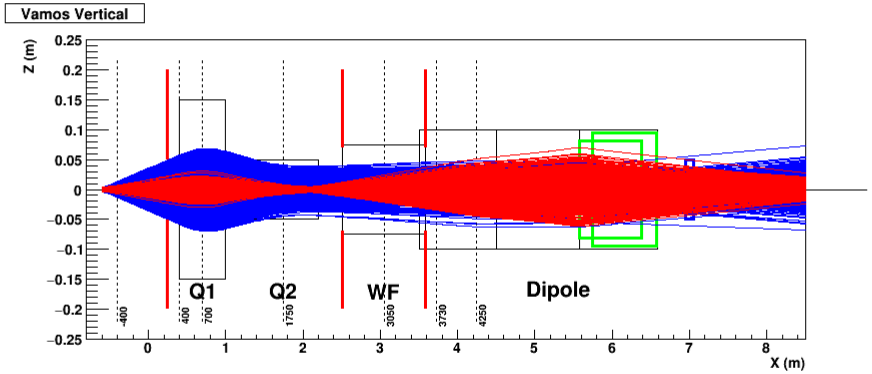
Transmission Recoils ~80 %

Mg degrader better than Au

- Angular straggling
- Bρ(Au) ~ Bρ(residues)

$^{54}Fe + ^{58}Ni \rightarrow ^{110}Xe + 2n$ with degrader





Target =
1 mg/cm² ^{58}Ni
Degrader =
1 mg/cm² Mg

Detection 45°
Vamos -60 cm
Foc recoils at 9m

Transmission
2n channel : 72 %
4p channel : 57 %
α2p channel : 29 %

$^{136}Xe+^{207}Pb \rightarrow$ MNT at 0 degree (target like)