OUTLINE

1/ The Experimental Setup

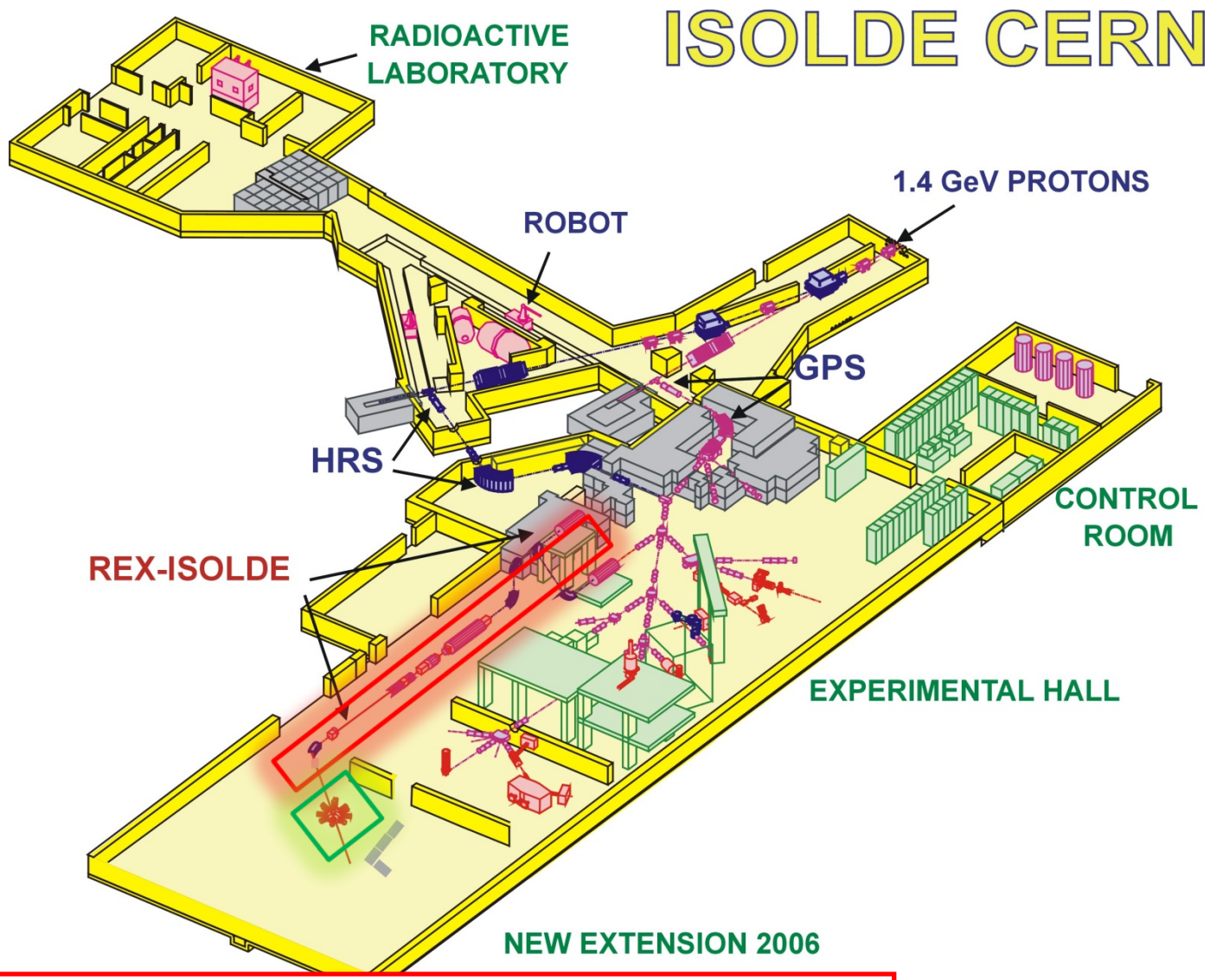
A. (REX-)ISOLDE

B. MINIBALL

2/ Some Physics Cases

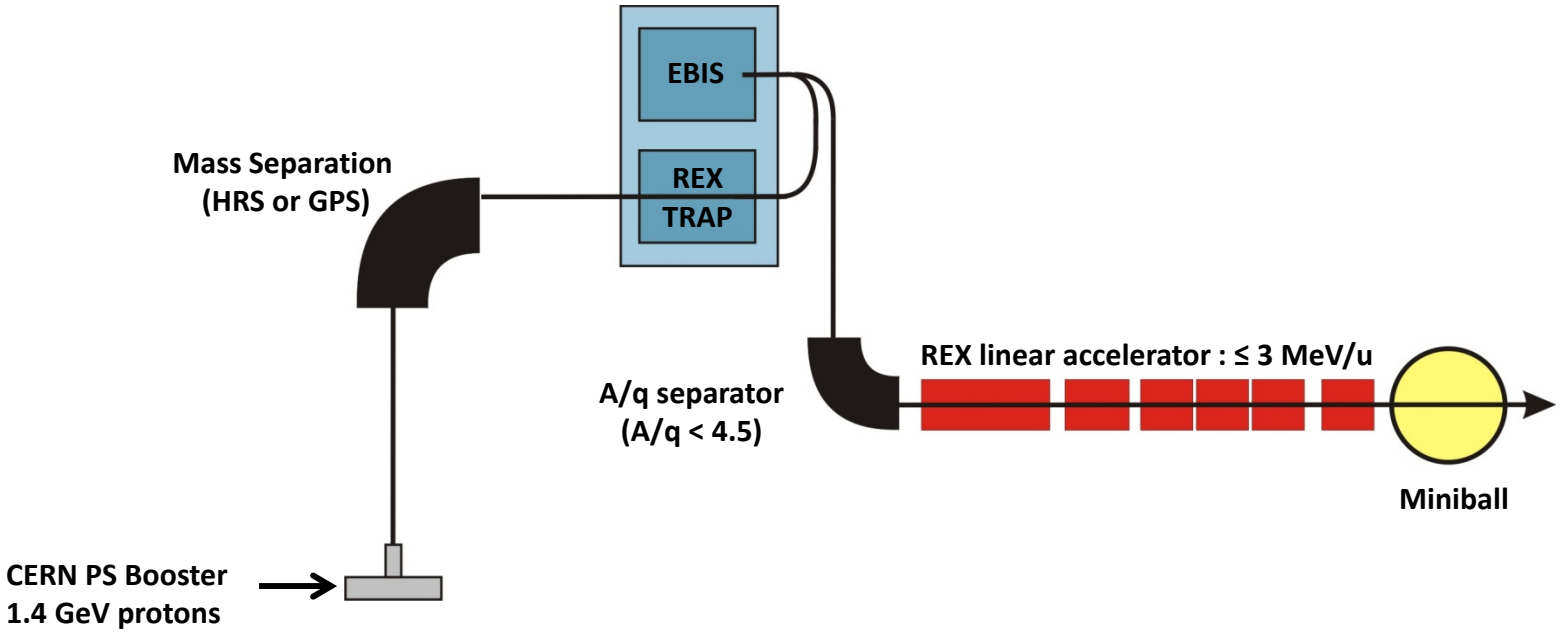
A. Shell Model Interest

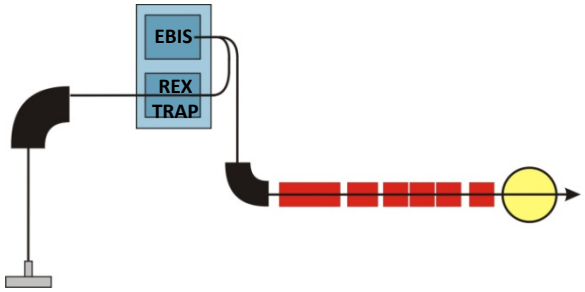
B. Shape Co-existence

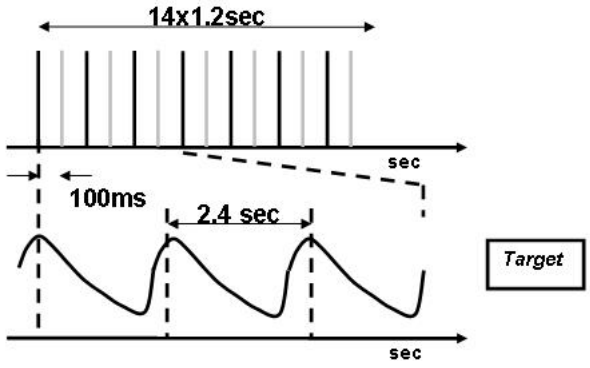


1st post-accelerated beam and Coulomb excitation in 2001

Specific time structure of REX-ISOLDE



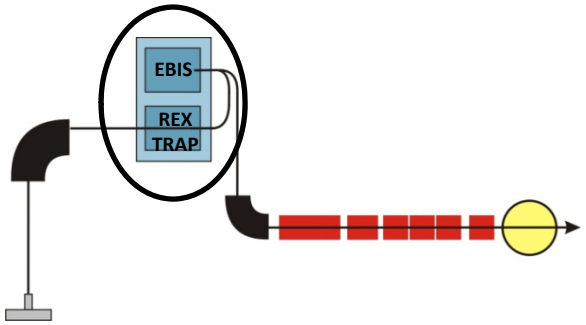


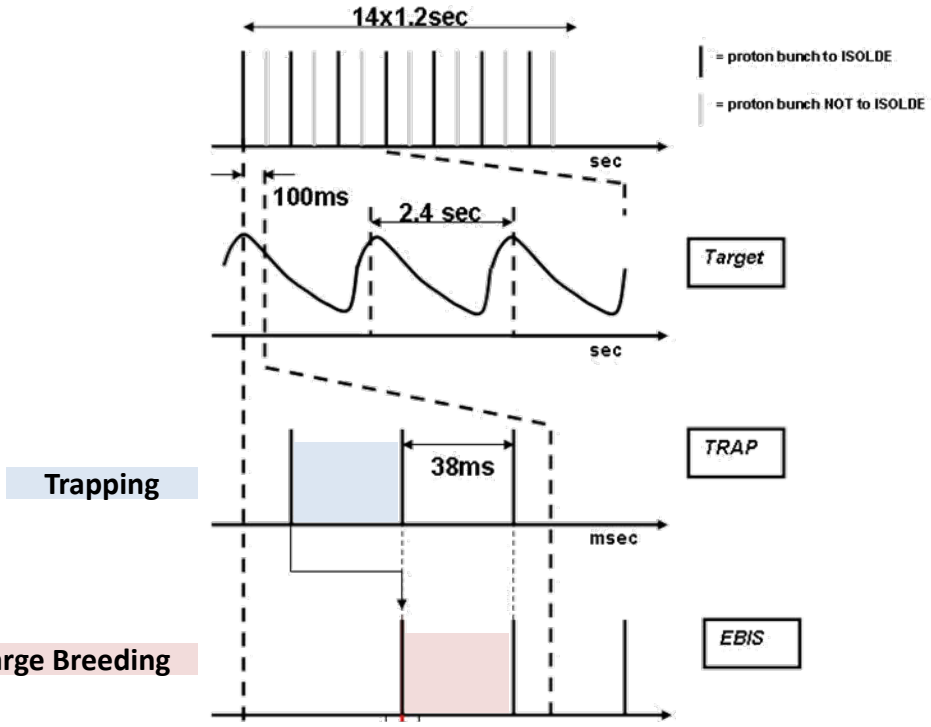


PSB : 1.4 GeV pulsed proton beam

1/ The Experimental Setup : (REX-)ISOLDE

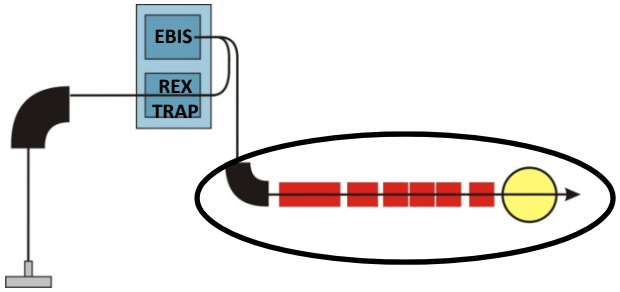
Time Structure



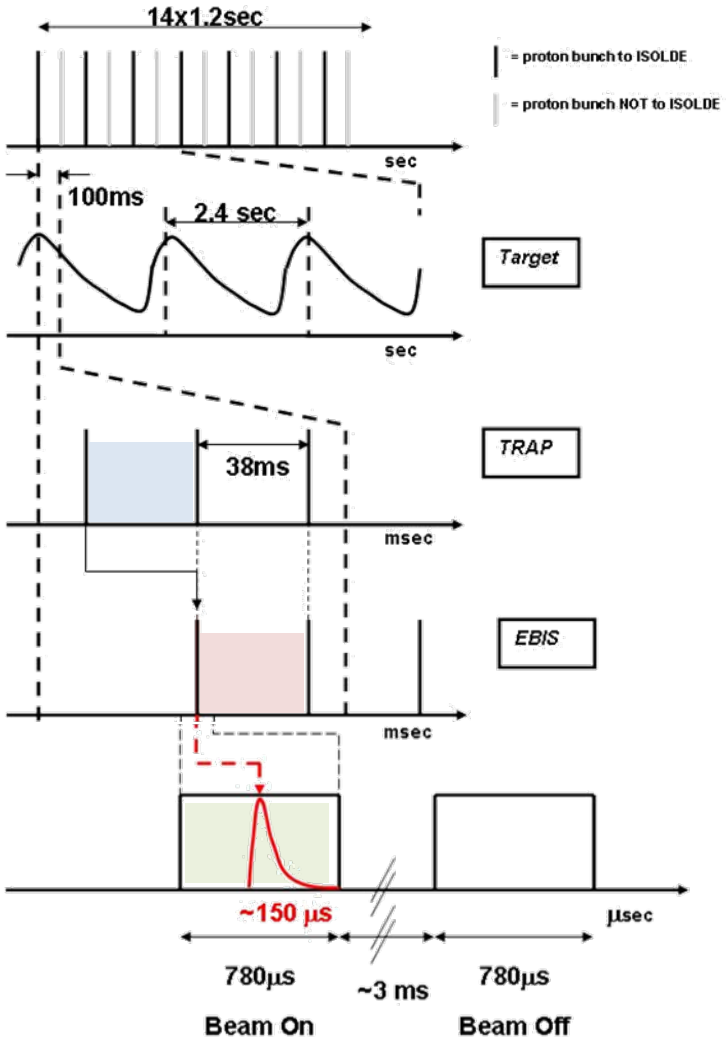


Trapping

Charge Breeding



1 shift at REX
=
19 min actual measuring time



Trapping

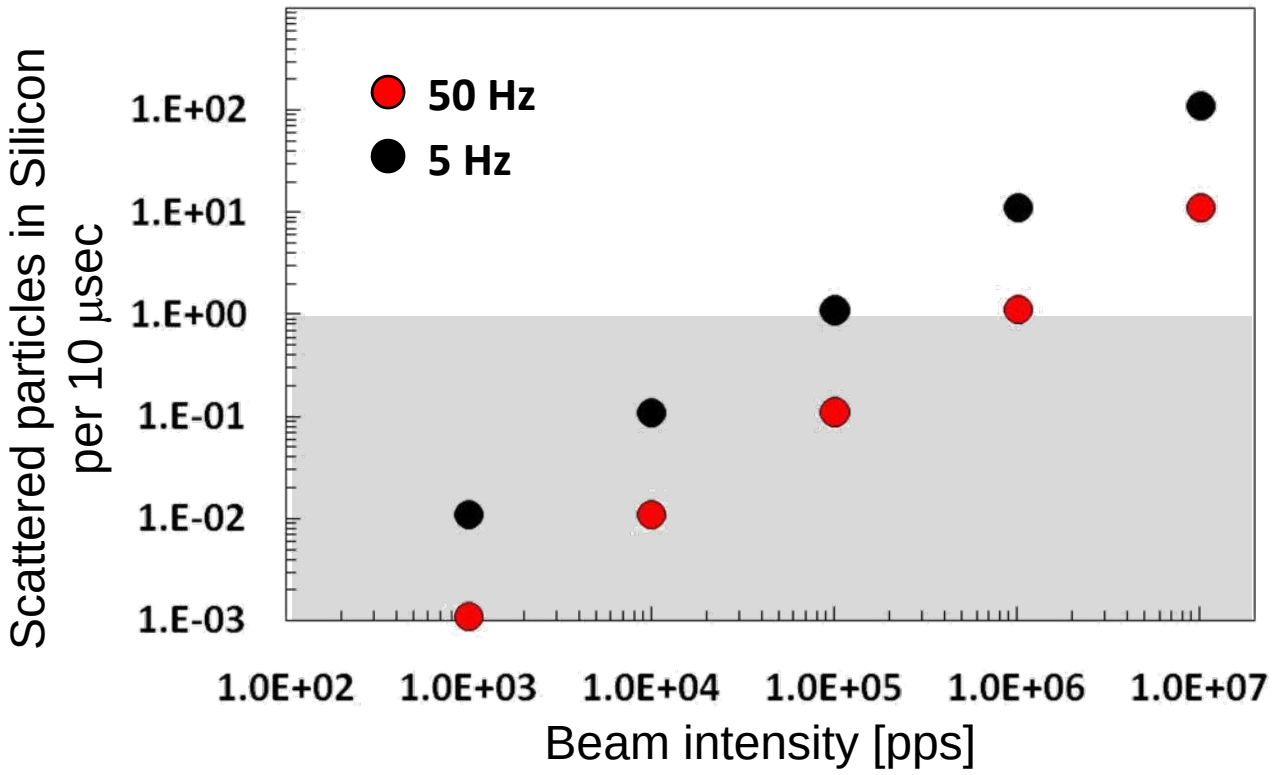
Charge Breeding

Post Acceleration

- ✓ Bunched beam : high instantaneous rate !
  ⇒ deadtime …
- ✓ Good signal/background …

1/ The Experimental Setup : (REX-)ISOLDE

Efficiency and Count Rates



✓ Bunched beam : high instantaneous rate !

⇒ deadtime …

✓ Good signal/background …

REX efficiency = 6-16 %

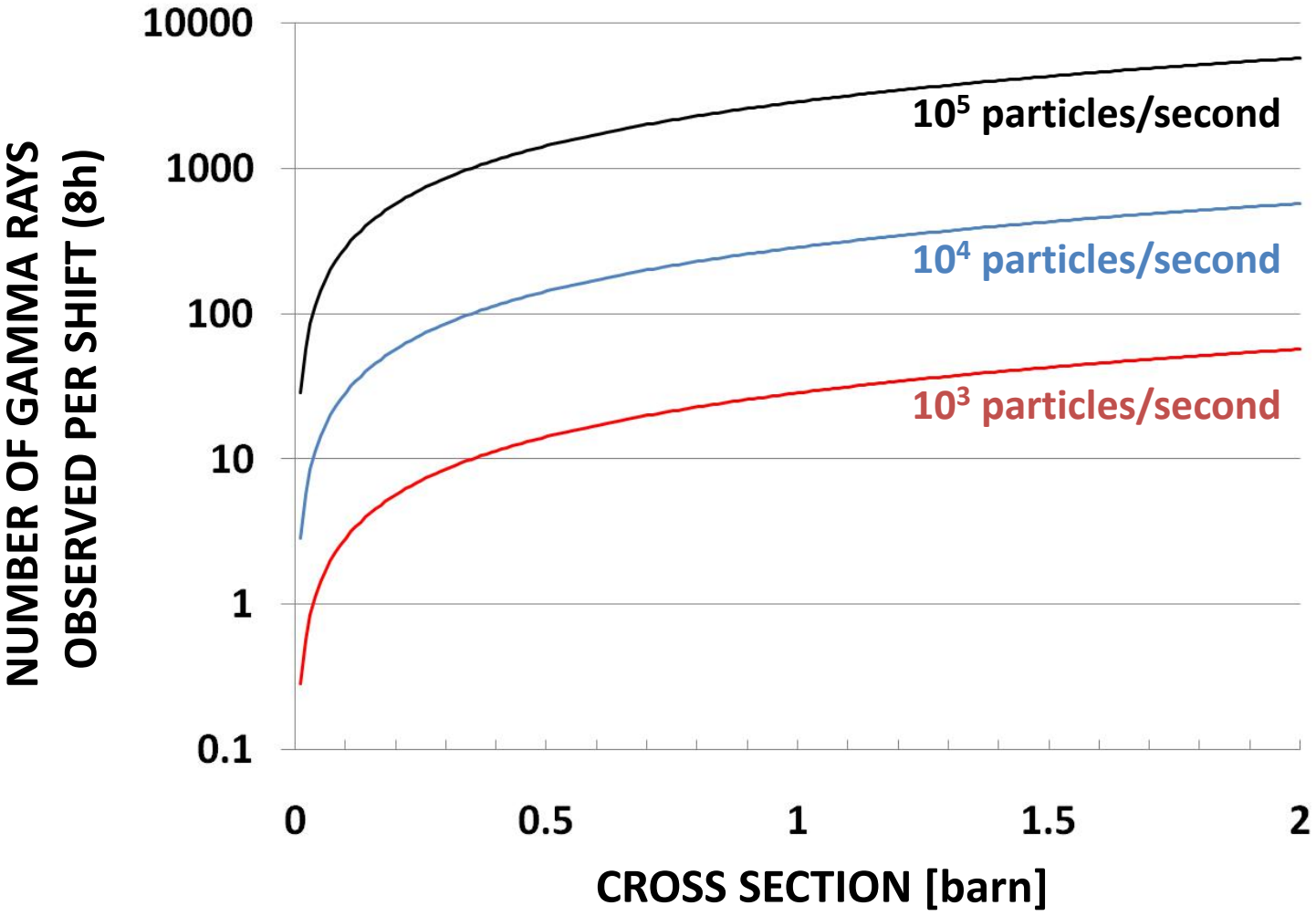
(TRAP+EBIS+A/q = 10-20% Linac transmission = 60-80%)

… depends on mass, A/q, energy … (experience and a bit of luck)

✓ Bunched beam

✓ Good signal/background …

REX efficiency = 1 % (nowadays very conservative)

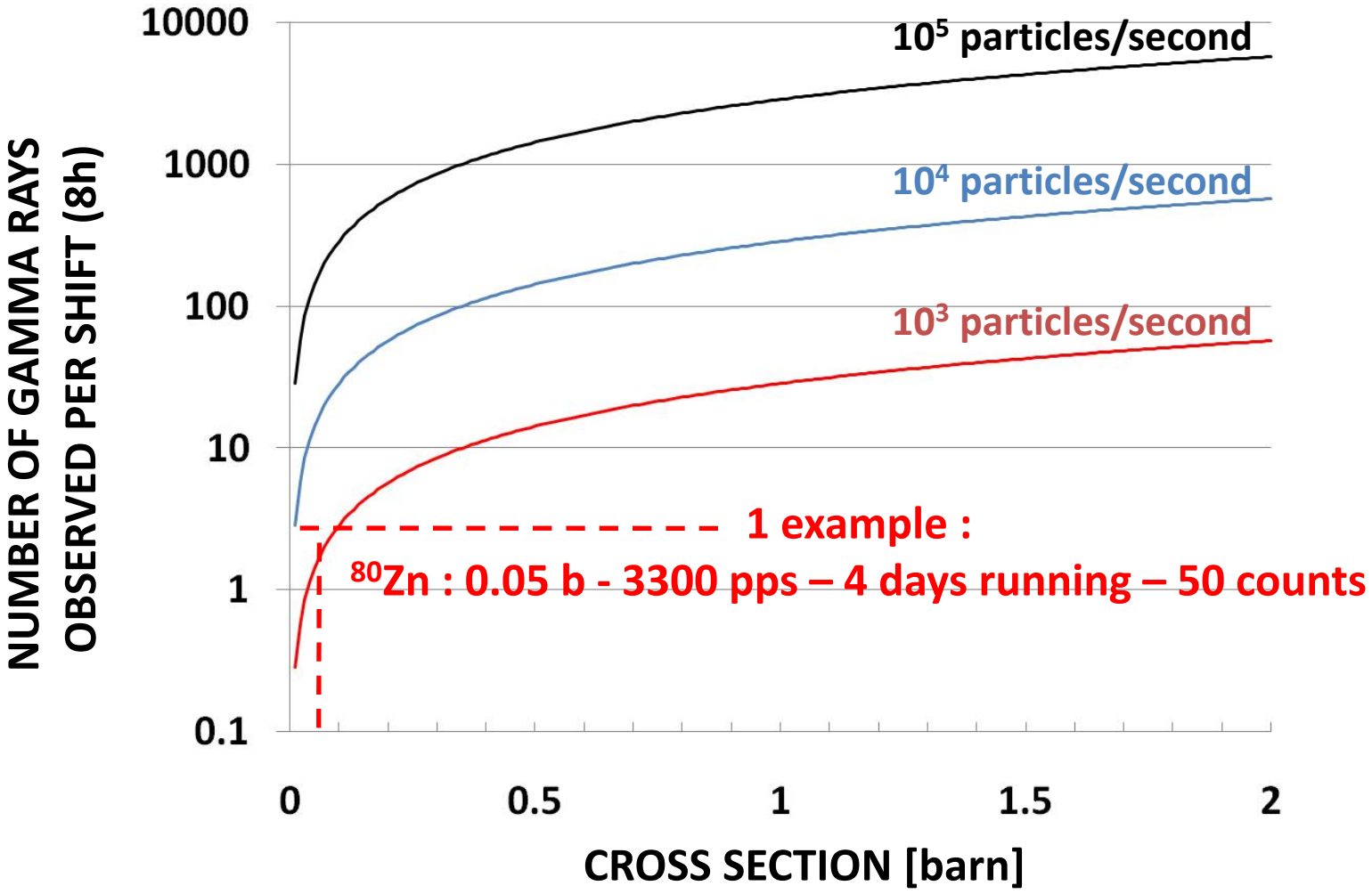


✓ Bunched beam

✓ Good signal/background …

Typically 10% gamma detection efficiency – 2 mg/cm^2 –
A target = 120 – REX efficiency 1%

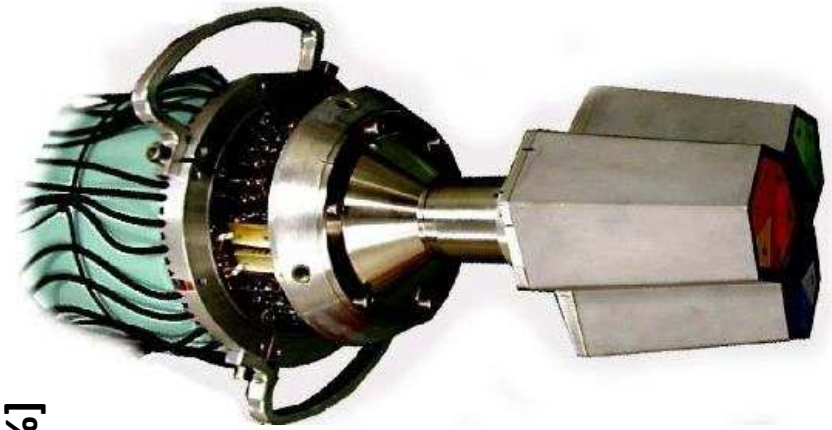
REX efficiency = 1 % (nowadays very conservative)

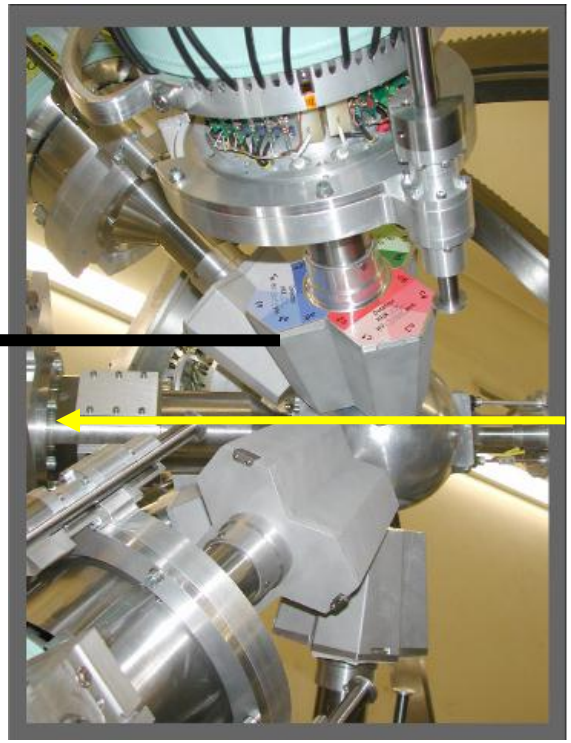


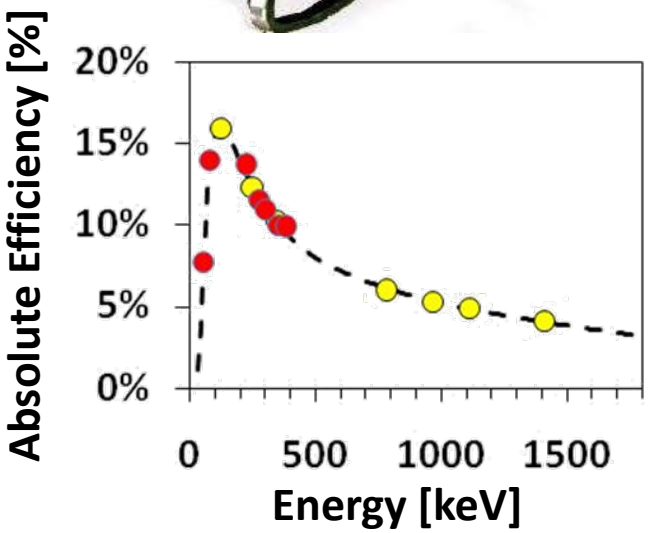
✓ Bunched beam

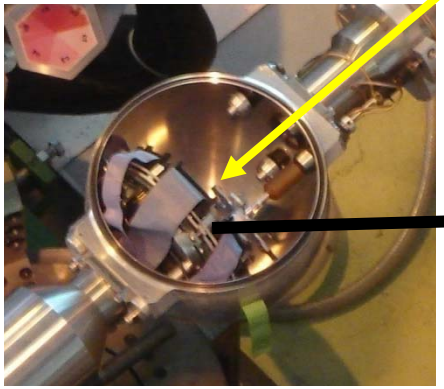
✓ Good signal/background …

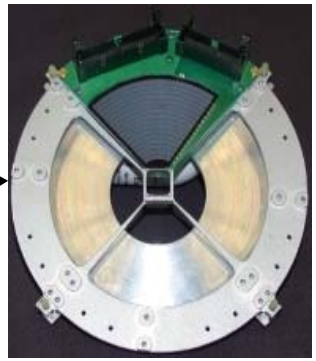
Typically 10% gamma detection efficiency – 2 mg/cm^2 –
A target = 120 – REX efficiency 1%

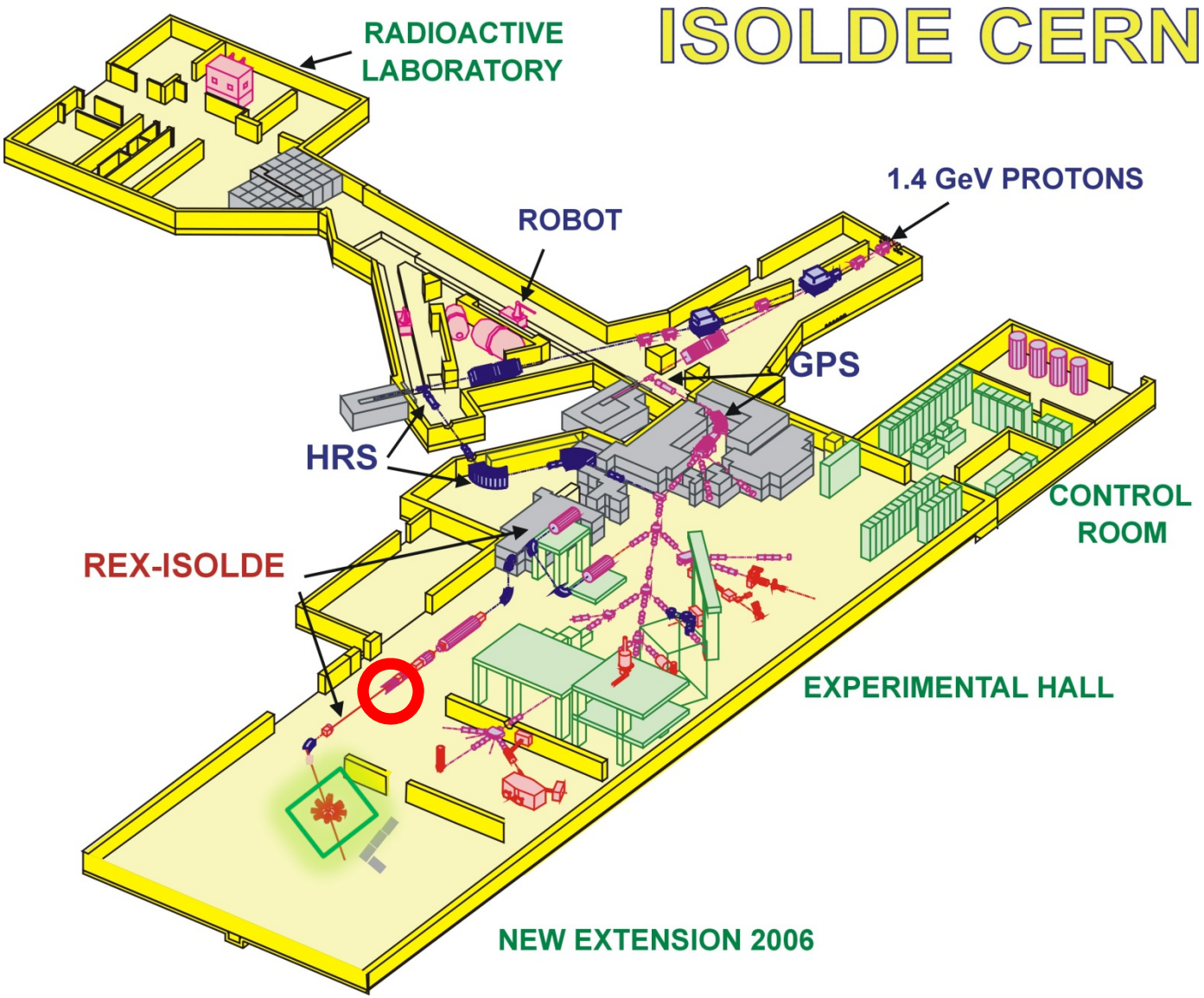


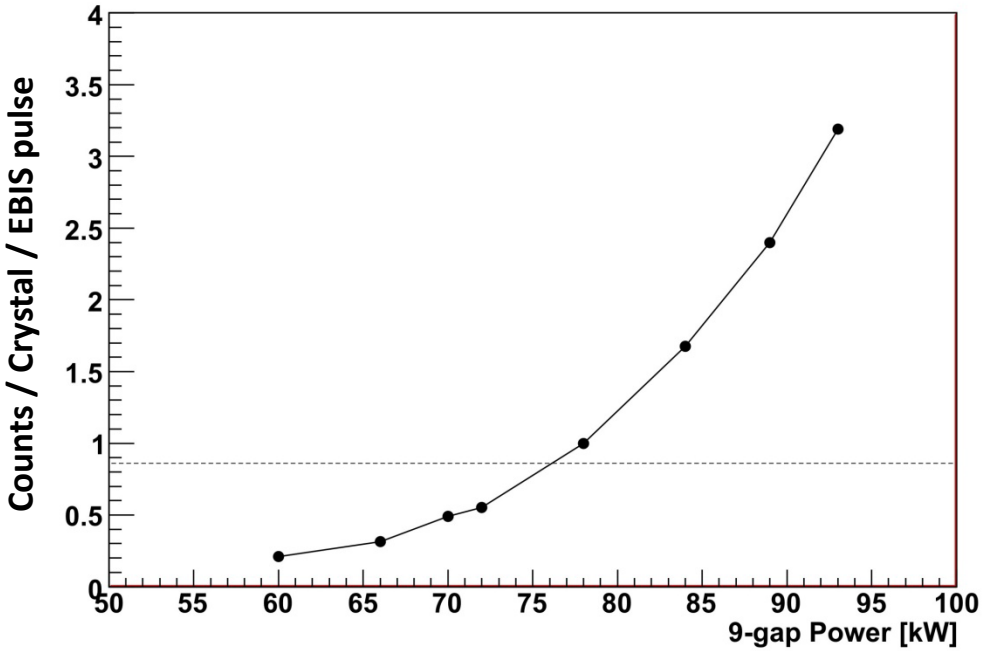


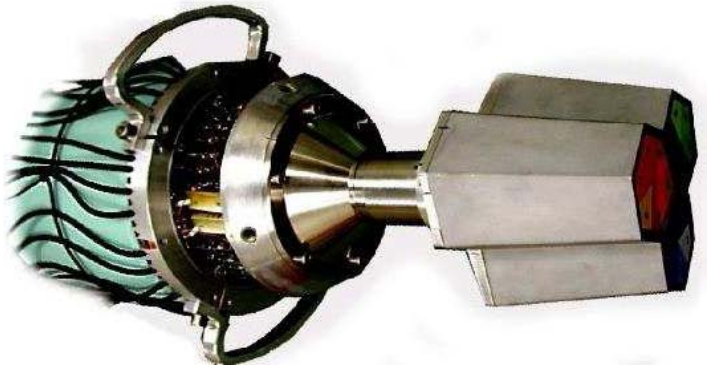

Absolute Efficiency [%]
20%
15%
10%
5%
0%
0
500
1000
1500
Energy [keV]

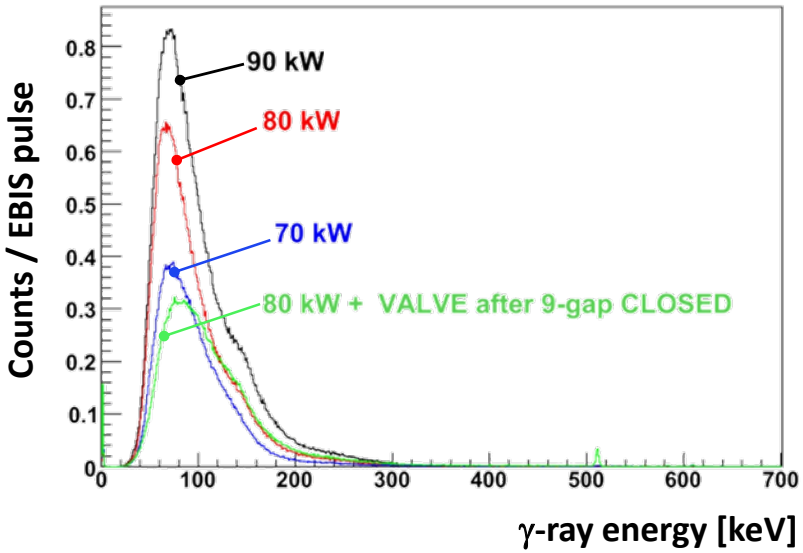





ISOLDE CERN
RADIOACTIVE LABORATORY
1.4 GeV PROTONS
ROBOT
GPS
HRS
CONTROL ROOM
REX-ISOLDE
EXPERIMENTAL HALL
NEW EXTENSION 2006





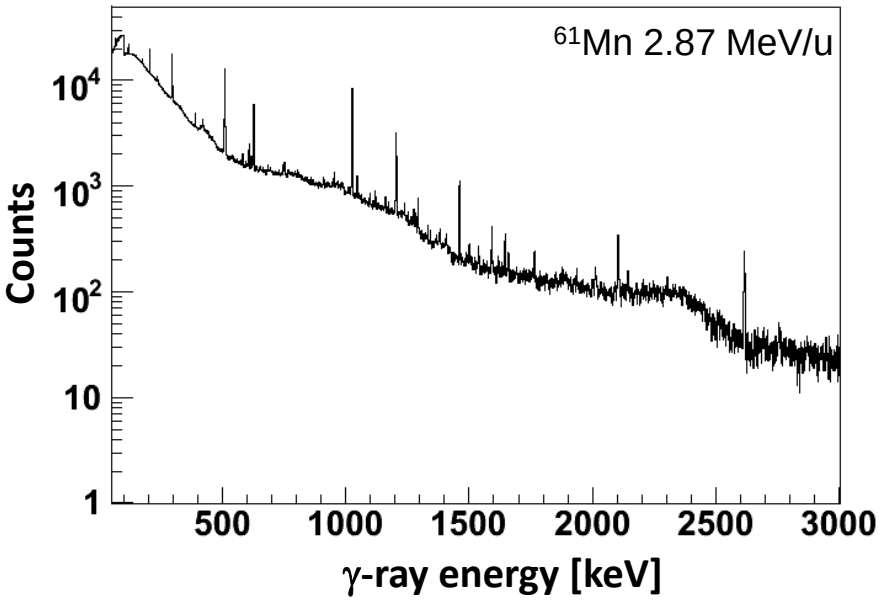


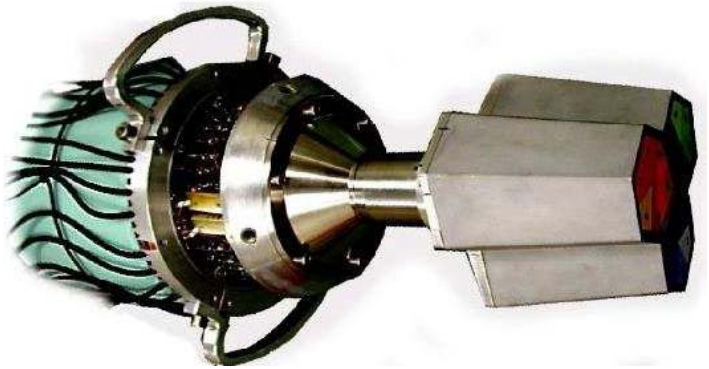
✓ Bunched beam

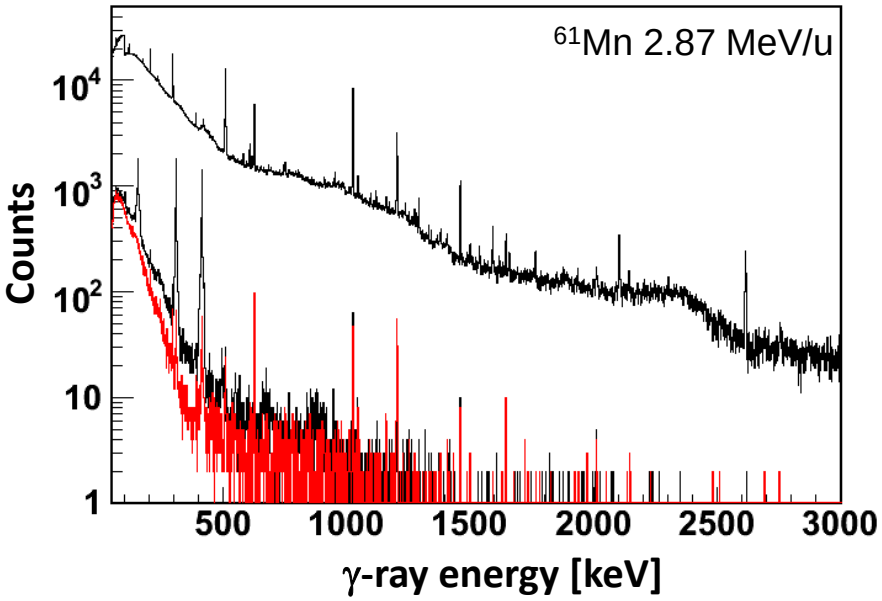
✓ Good signal/background …

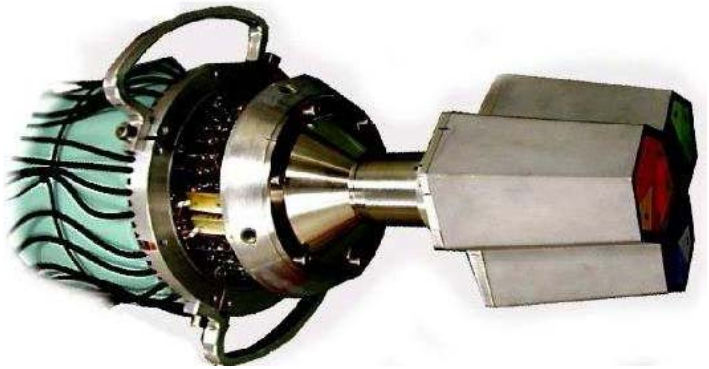
1/ The Experimental Setup : MINIBALL

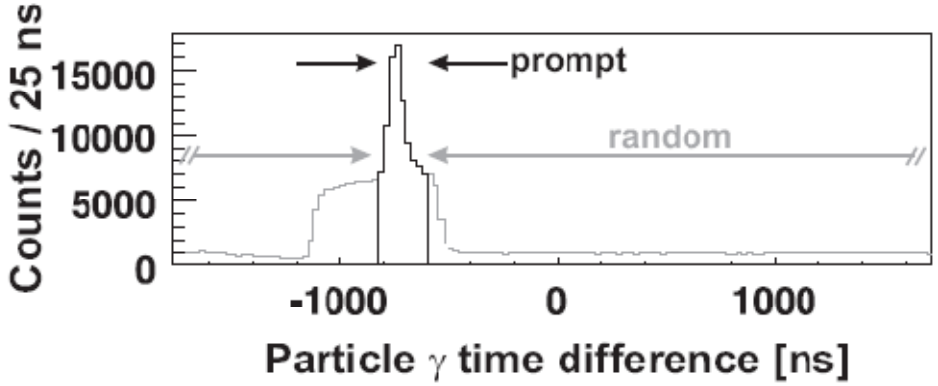
9-gap radiation background

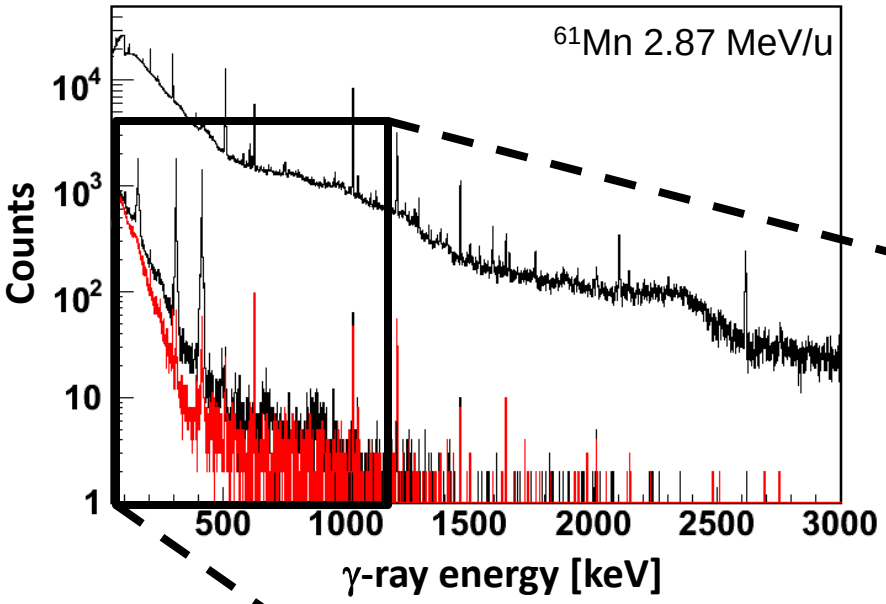


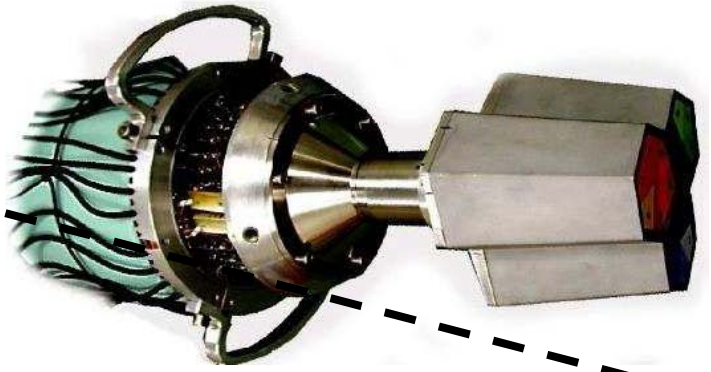


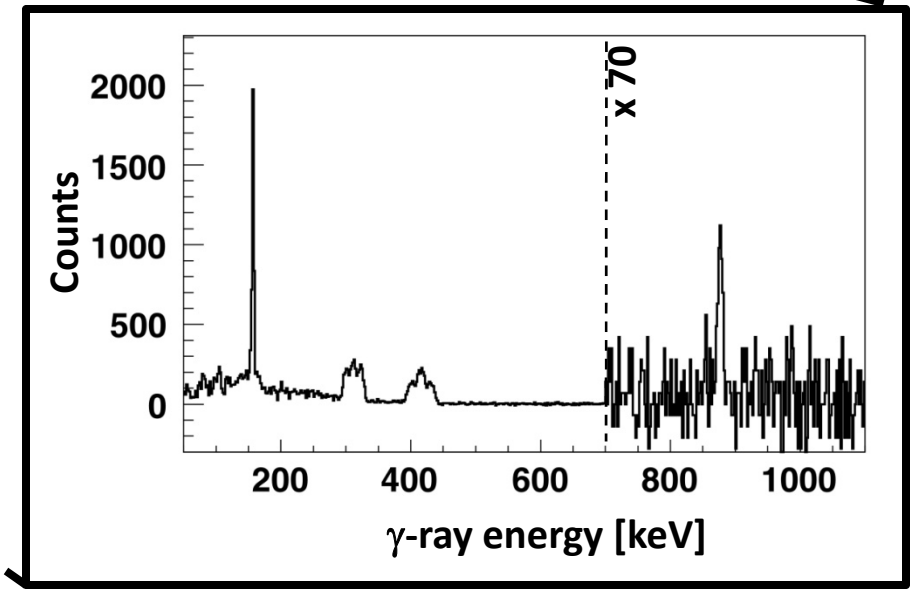

^{61}Mn 2.87 MeV/u
Counts
10^4
10^3
10^2
10
1
500
1000
1500
2000
2500
3000
γ-ray energy [keV]




Counts / 25 ns
15000
10000
5000
0
prompt
random
-1000
0
1000
Particle γ time difference [ns]


^{61}Mn 2.87 MeV/u
Counts
10^4
10^3
10^2
10
1
500
1000
1500
2000
2500
3000
γ-ray energy [keV]

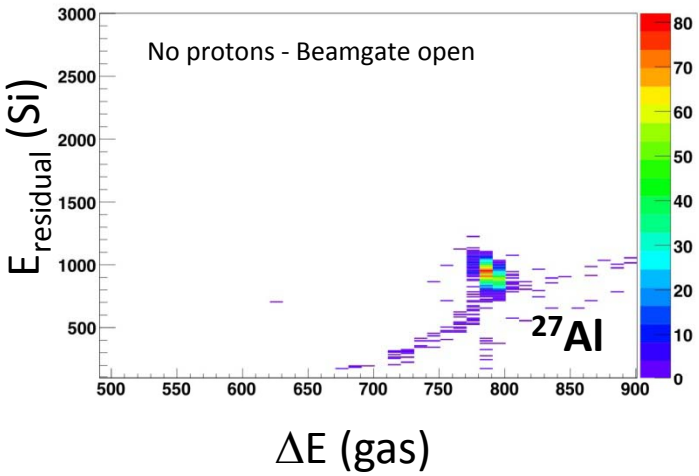


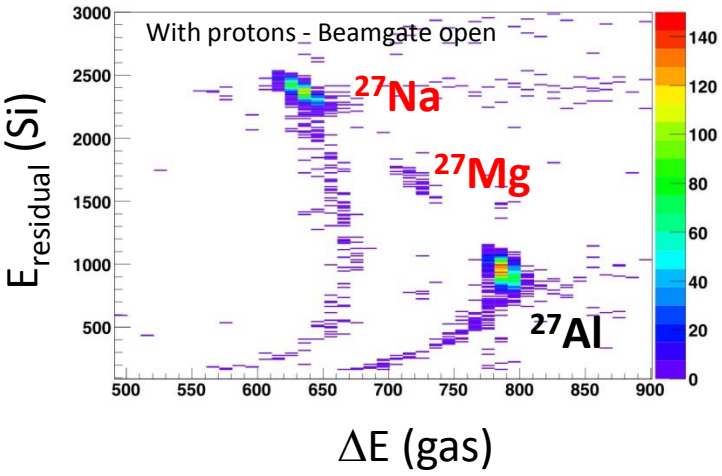

Counts
2000
1500
1000
500
0
x 70
200
400
600
800
1000
γ-ray energy [keV]

1/ The Experimental Setup : MINIBALL

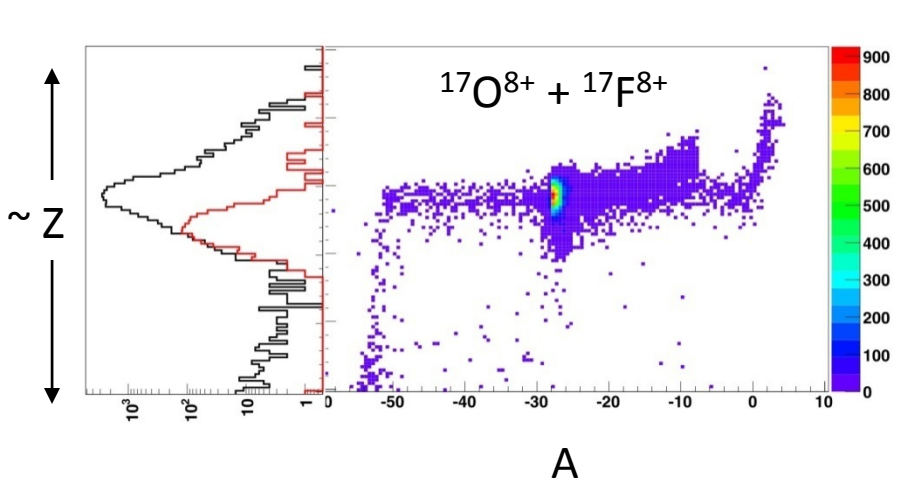
Beam Diagnostics : Z and A determination

1/ ΔE (gas) – E_{rest} (Si) Telescope (35deg beamline)

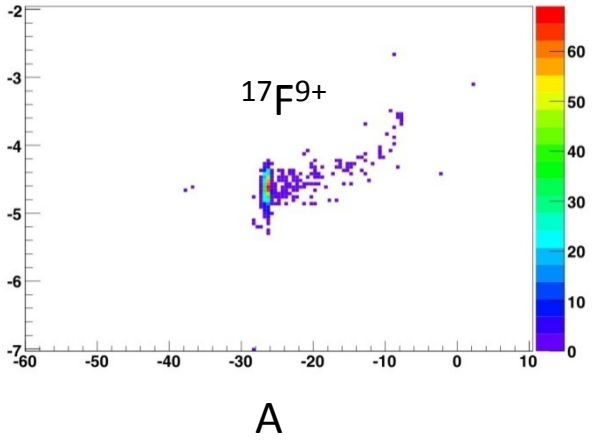


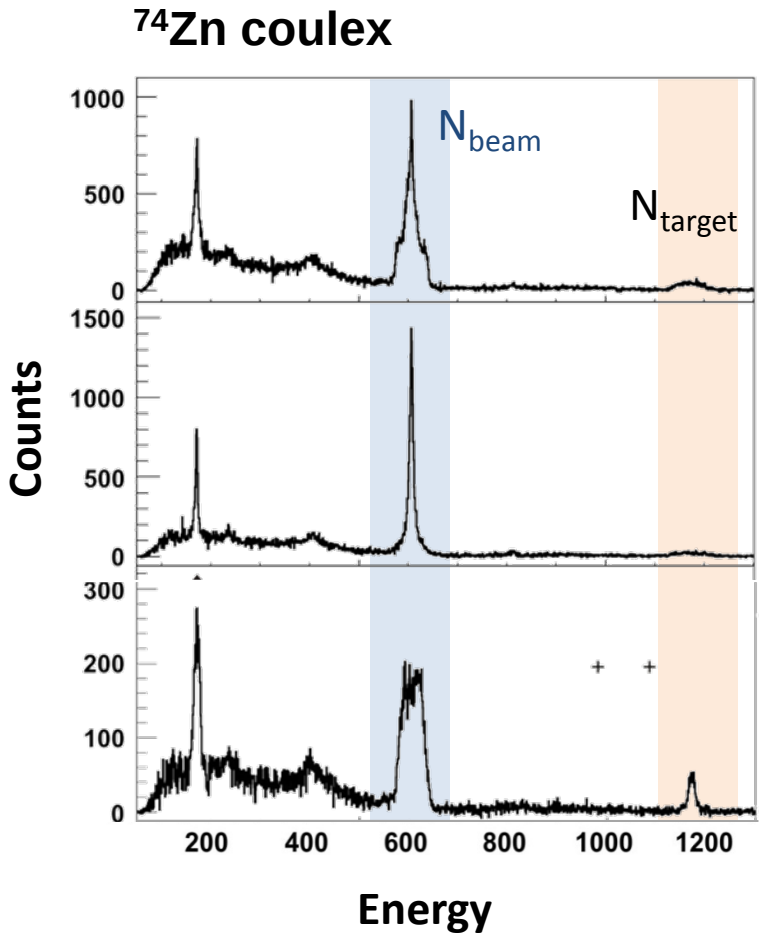


2/ Bragg detector (beamdump Miniball)



with stripper foil after 9-gap



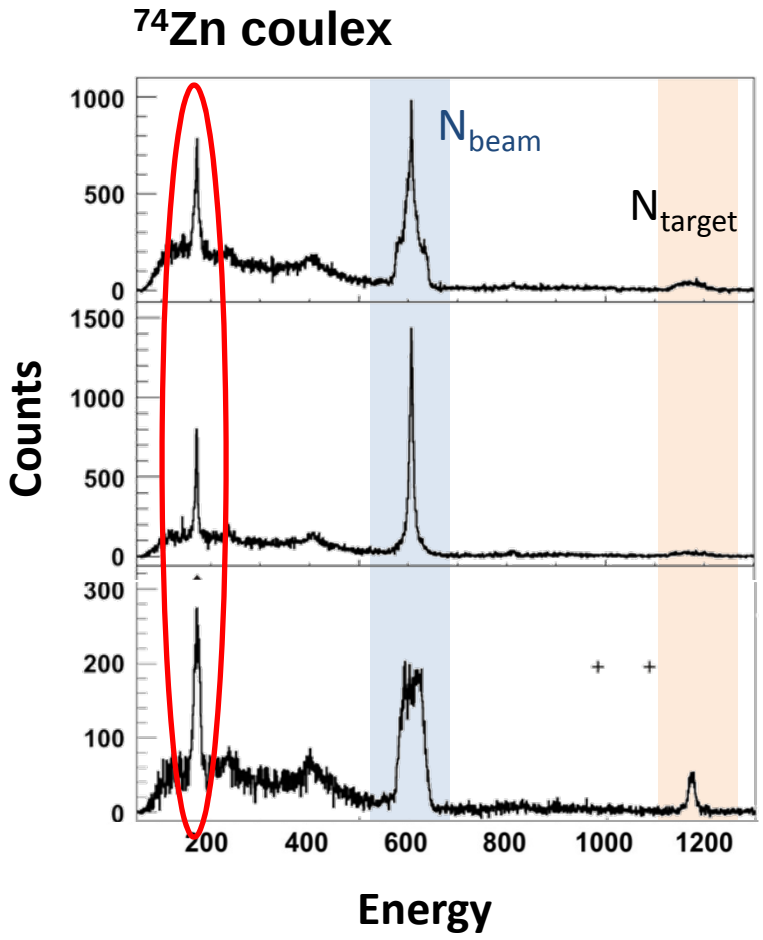


Relative measurement

$N_{beam} \sim \sigma_{beam}(B(E2), Q_{2+}, \ldots)$ unknown

$N_{target} \sim \sigma_{target}(B(E2), \ldots)$ known

J. Van de Walle *et al.*, submitted to Physical Review C (2008) ($^{74\text{-}80}$Zn coulex)



Relative measurement

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$N_{target} \sim \sigma_{target}(B(E2), \ldots)$ known

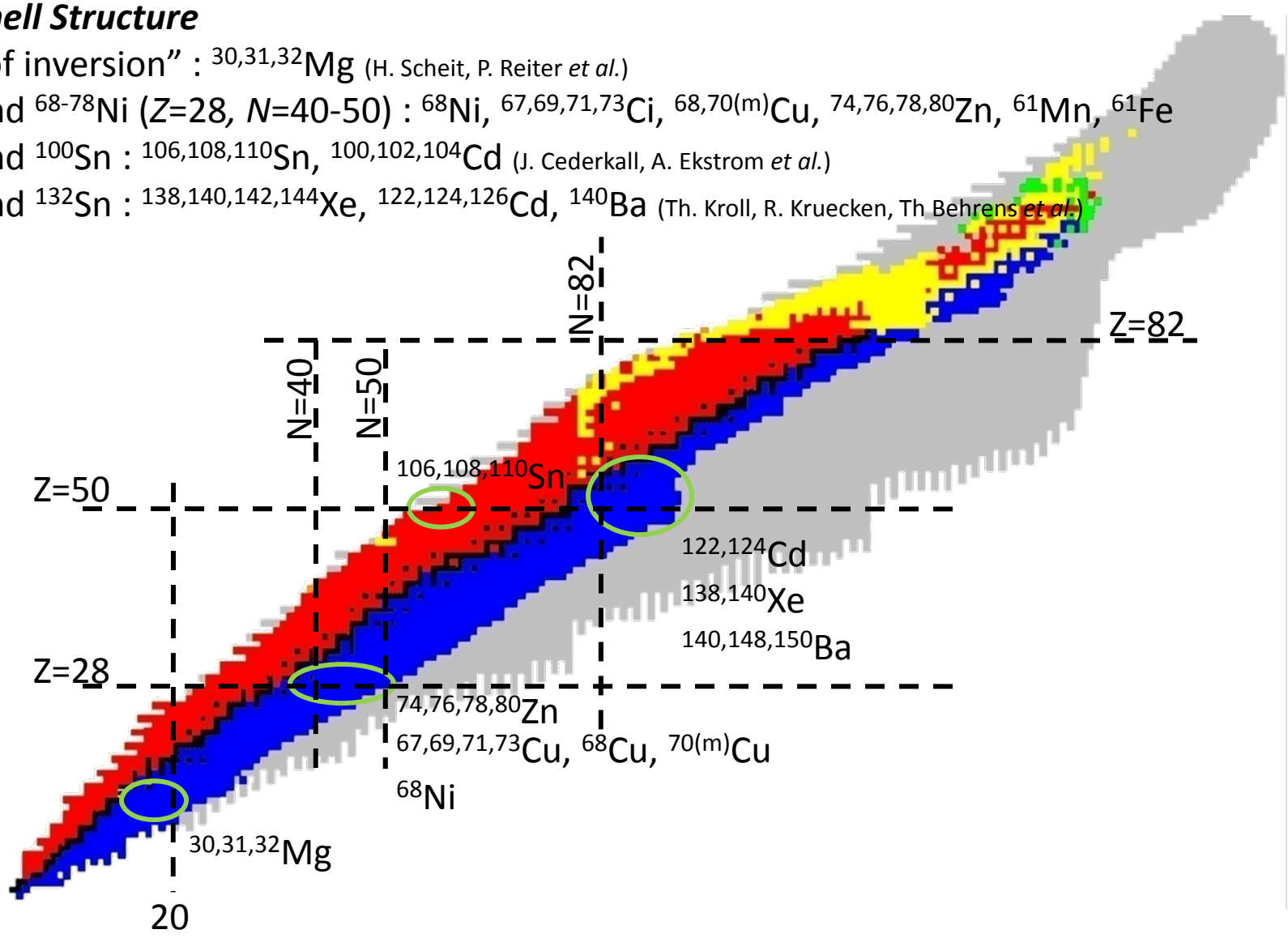
!!! possible beam contamination influences this normalization !!!

J. Van de Walle *et al.*, submitted to Physical Review C (2008) ($^{74\text{-}80}$Zn coulex)

Some physics cases "over the past years" …

Evolution of Shell Structure

- ✓ the "island of inversion" : ^{30,31,32}Mg (H. Scheit, P. Reiter *et al.*)
- ✓ region around $^{68\text{-}78}$Ni (*Z*=28, *N*=40-50) : ^{68}Ni, ^{67,69,71,73}Ci, $^{68,70(m)}$Cu, ^{74,76,78,80}Zn, ^{61}Mn, ^{61}Fe
- ✓ region around ^{100}Sn : ^{106,108,110}Sn, ^{100,102,104}Cd (J. Cederkall, A. Ekstrom *et al.*)
- ✓ region around ^{132}Sn : ^{138,140,142,144}Xe, ^{122,124,126}Cd, ^{140}Ba (Th. Kroll, R. Kruecken, Th Behrens *et al.*)



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- ✓ region around $^{68\text{-}78}$Ni (*Z*=28, *N*=40-50) : ^{68}Ni, ^{67,69,71,73}Ci, $^{68,70(m)}$Cu, ^{74,76,78,80}Zn, ^{61}Mn, ^{61}Fe
- ✓ region around ^{100}Sn : ^{106,108,110}Sn, ^{100,102,104}Cd (J. Cederkall, A. Ekstrom *et al.*)
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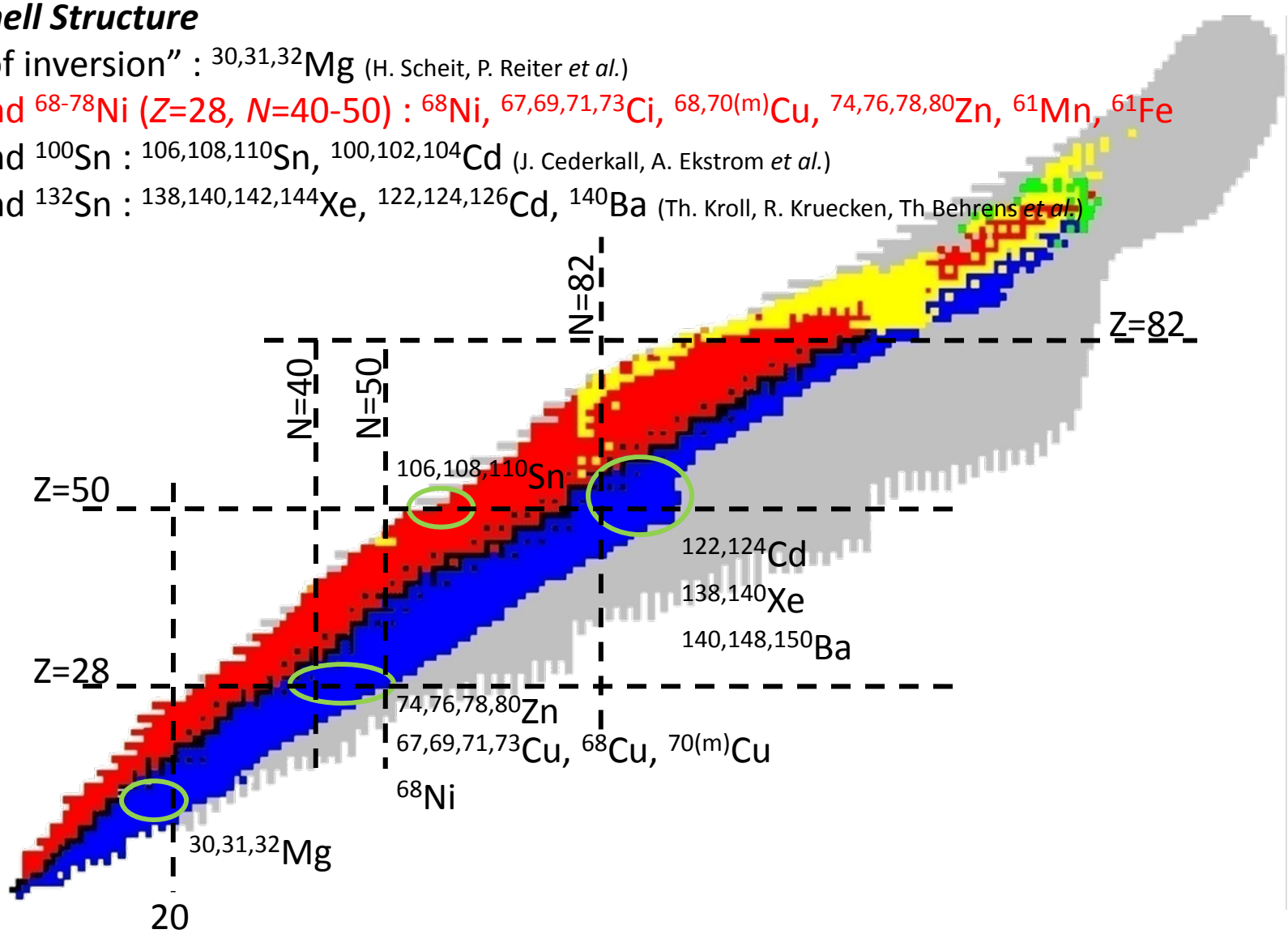
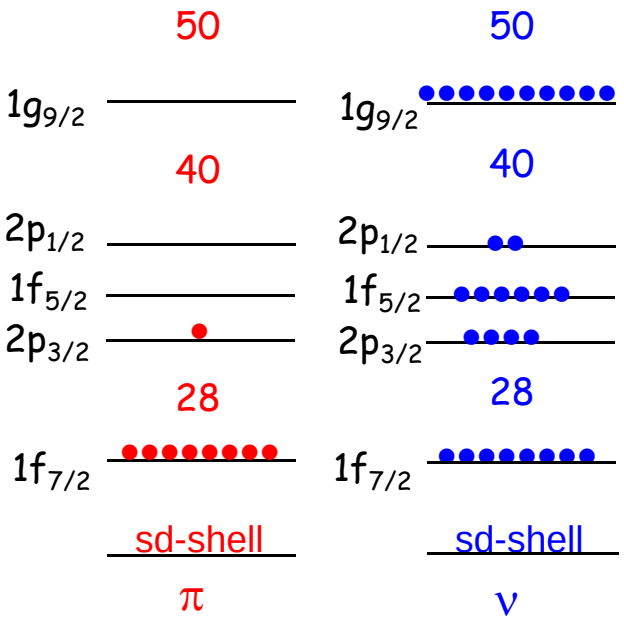


region around $^{68\text{-}78}$Ni (Z=28, N=40-50) : ^{68}Ni, ^{67,69,71,73}Ci, $^{68,70(m)}$Cu, ^{74,76,78,80}Zn, ^{61}Mn, ^{61}Fe

-Single particle properties ($\pi 2p_{3/2}$)
-Collective properties (νg9/2 filling)



J. Van de Walle *et al.*, submitted to Physical Review C (2008) ($^{74\text{-}80}$Zn coulex)
I. Stefanescu *et al.*, Phys. Rev. Lett. 100, 112502 (2008) (^{67,69,71,73}Cu coulex)
N. Bree *et al.*, Phys. Rev. C 78, 047301 (2008) (^{68}Ni coulex)
I. Stefanescu *et al.*, Physical Review Letters 98, 122701 (2007) (^{68,70m}Cu coulex)
J. Van de Walle *et al.*, Physical Review Letters 99, 142501 (2007) ($^{74\text{-}80}$Zn coulex)

-Single particle properties ($2\pi p_{3/2}$)
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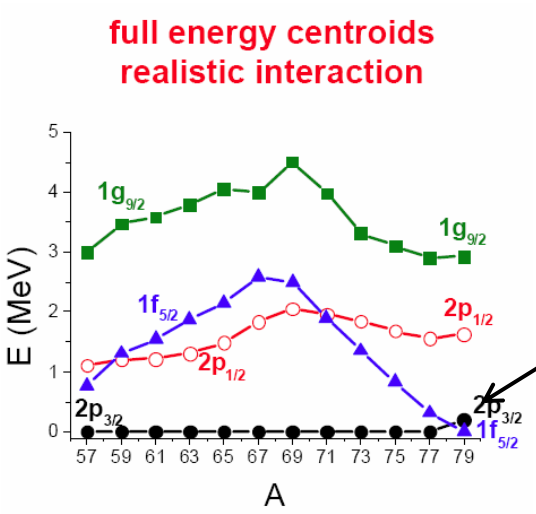
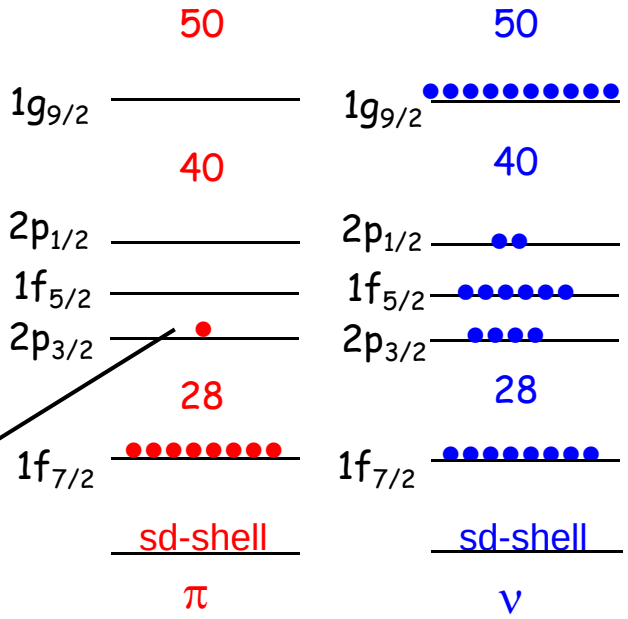
Cu isotopes :





PhD Thesis A. De Maesschalck, University Gent (2005)
N. Smirnova *et al., Phys. Rev. C 69, 044306 (2004).*

-Single particle properties ($2\pi p_{3/2}$)
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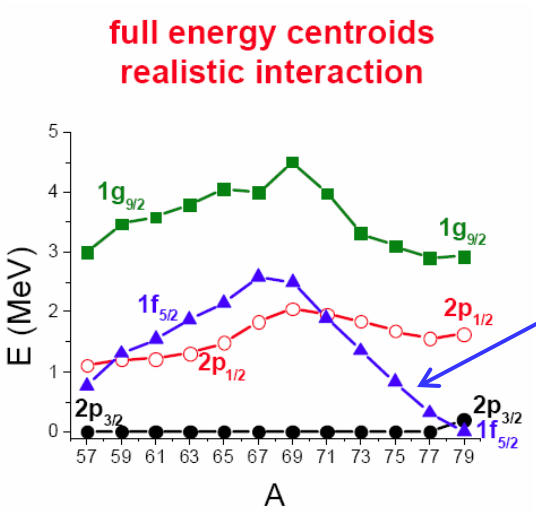
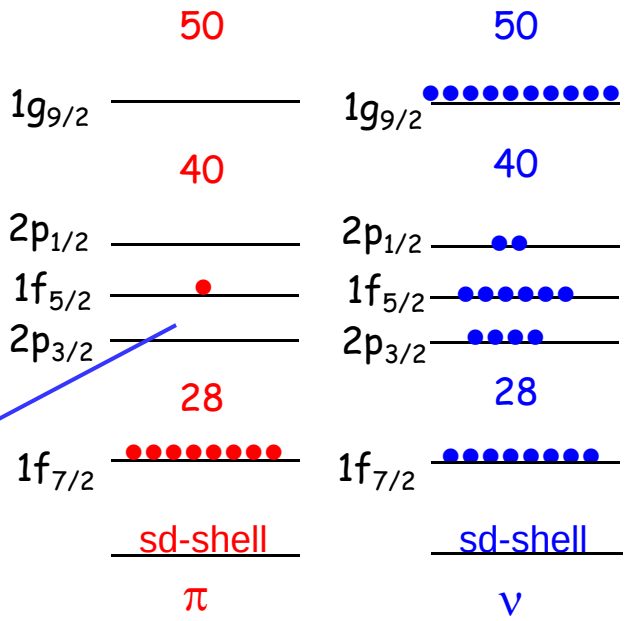
Cu isotopes :





-Single particle properties ($2\pi p_{3/2}$)
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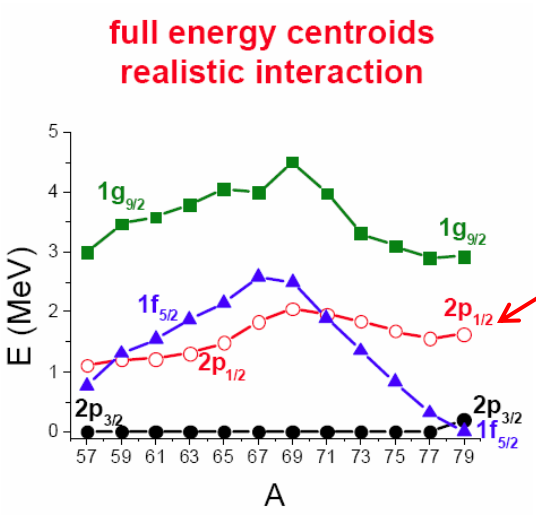
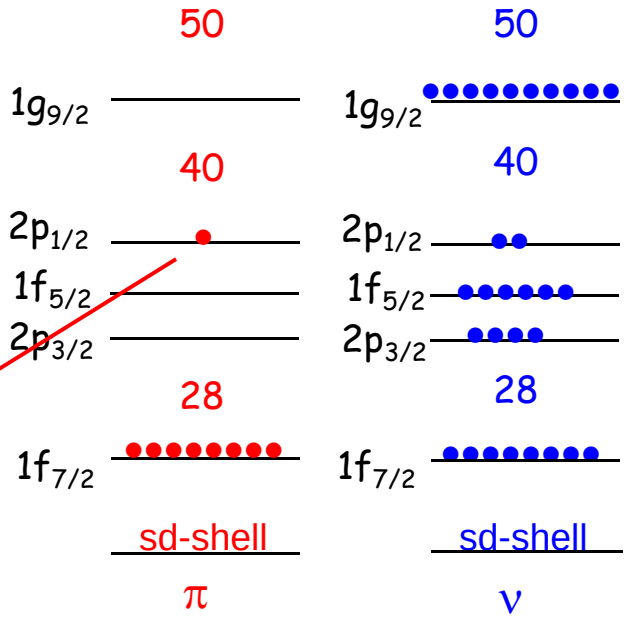
Cu isotopes :





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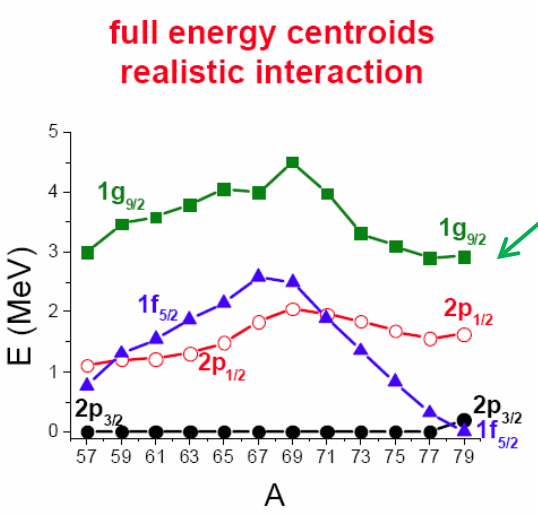
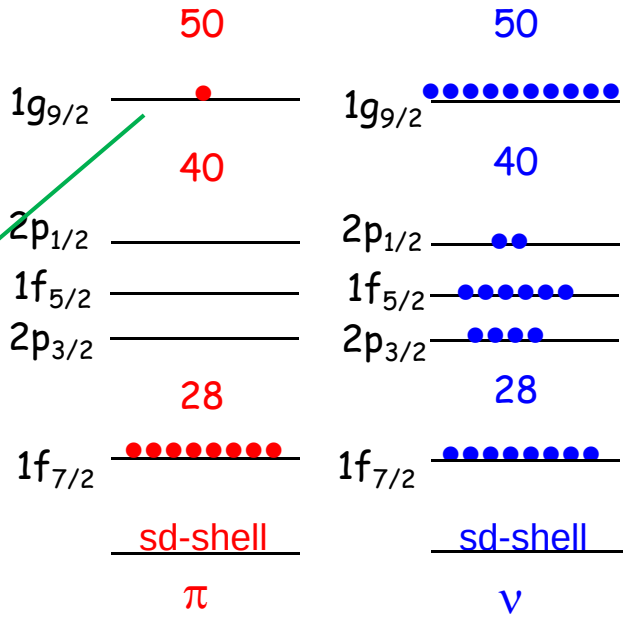
Cu isotopes :





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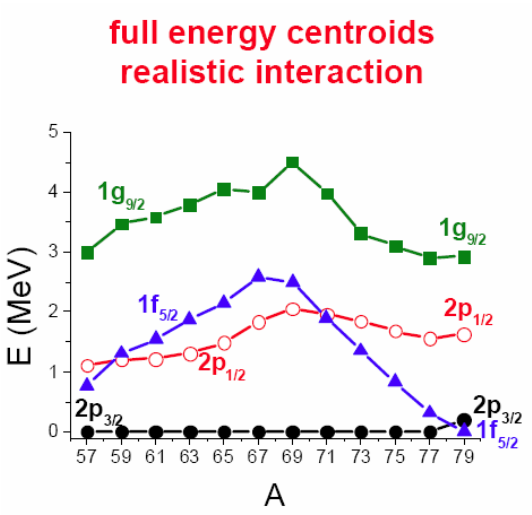
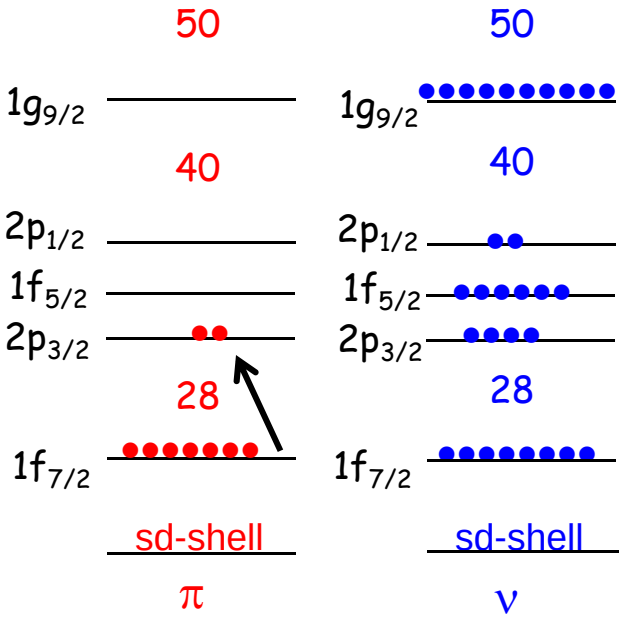
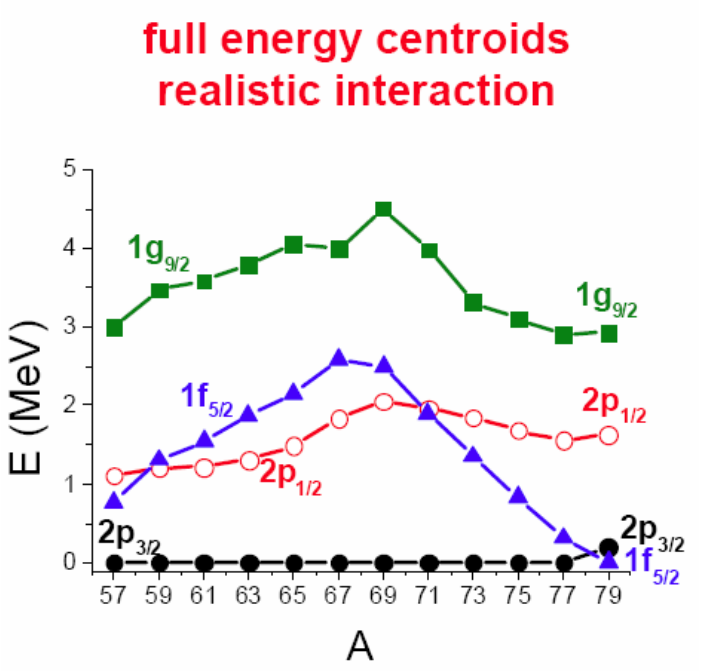
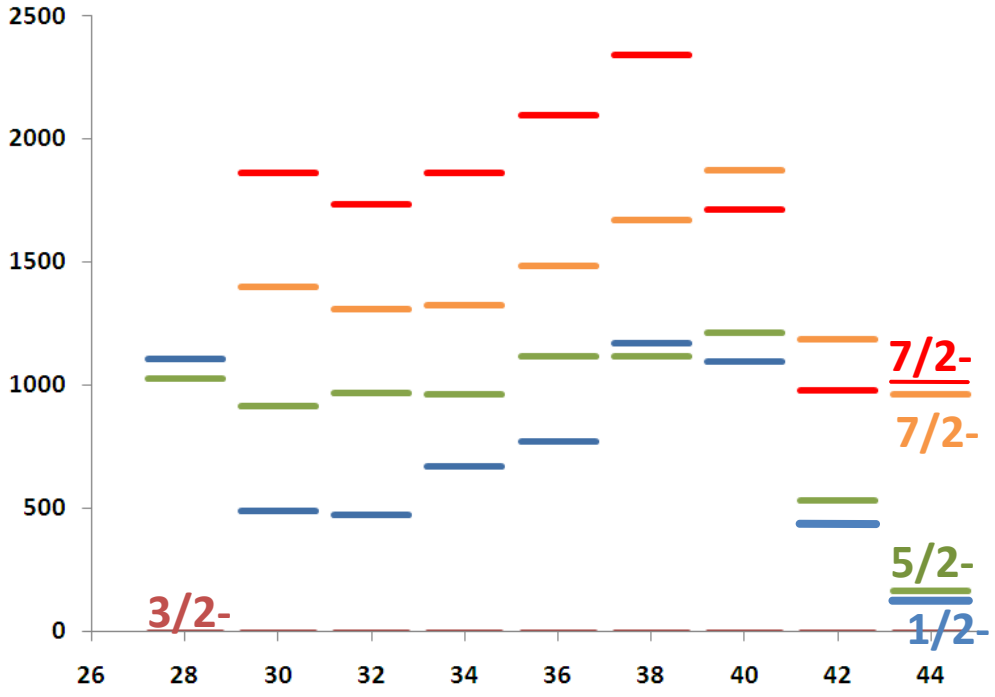


$7/2^-$



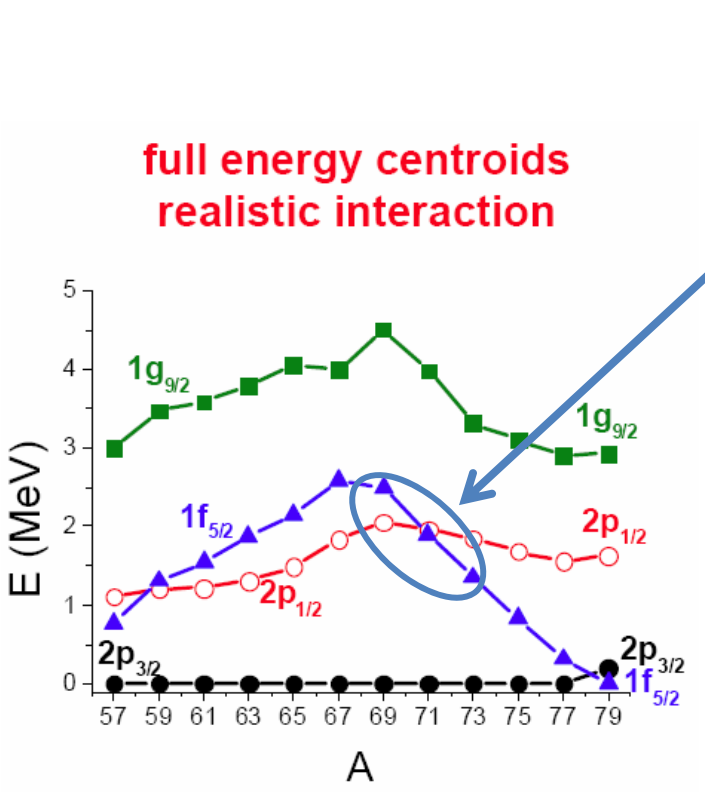


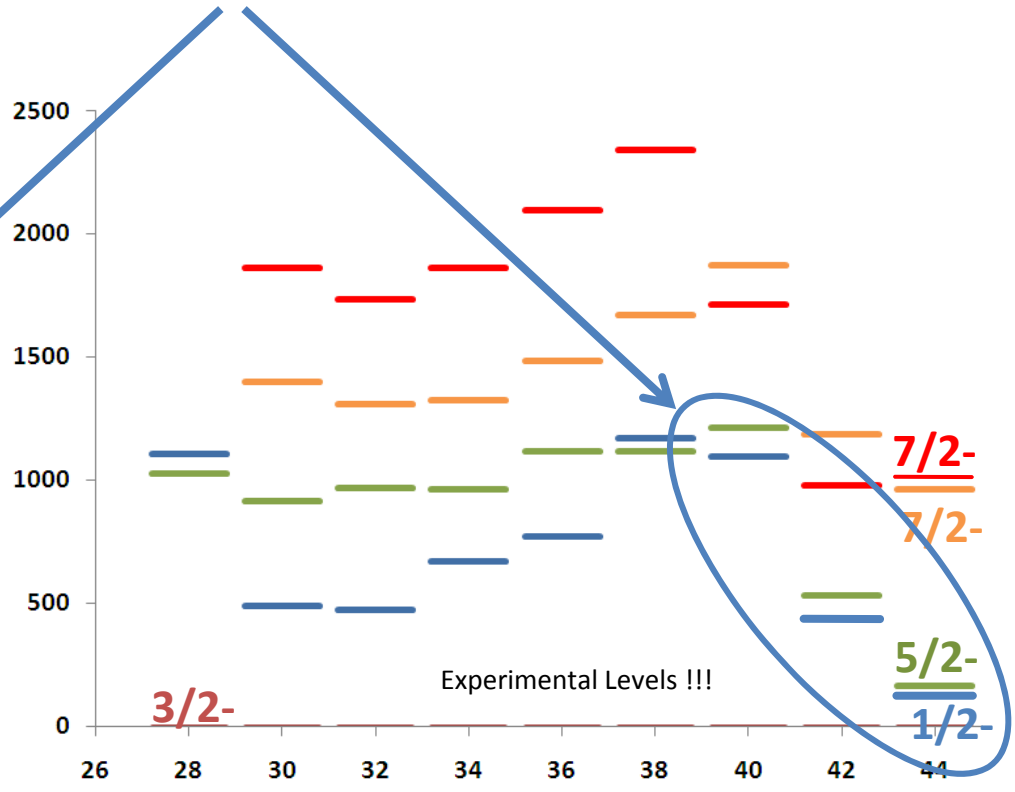


Experimental Levels

I. Stefanescu *et al.,* Phys. Rev. Lett. 100, 112502 (2008) (^{67,69,71,73}Cu coulex)

The observed $1/2^-$ doesn't seem to be behaving as a the theoretical single particle level !





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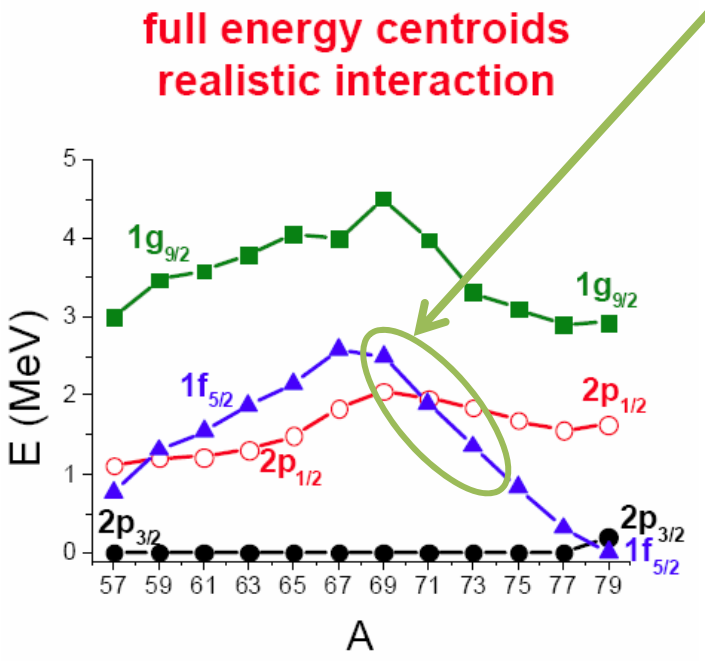
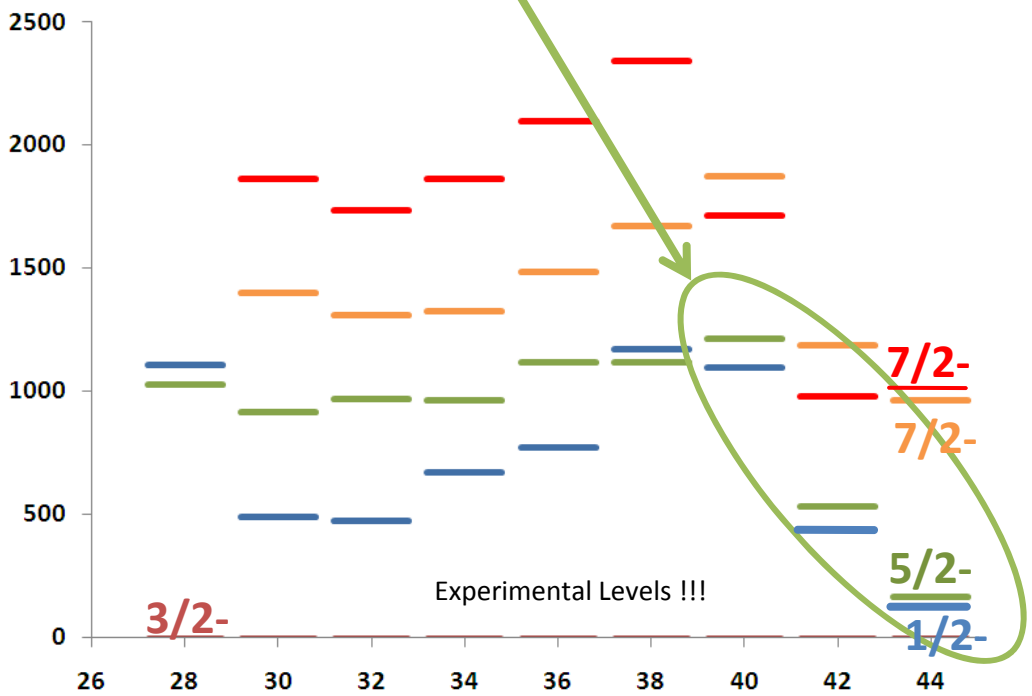
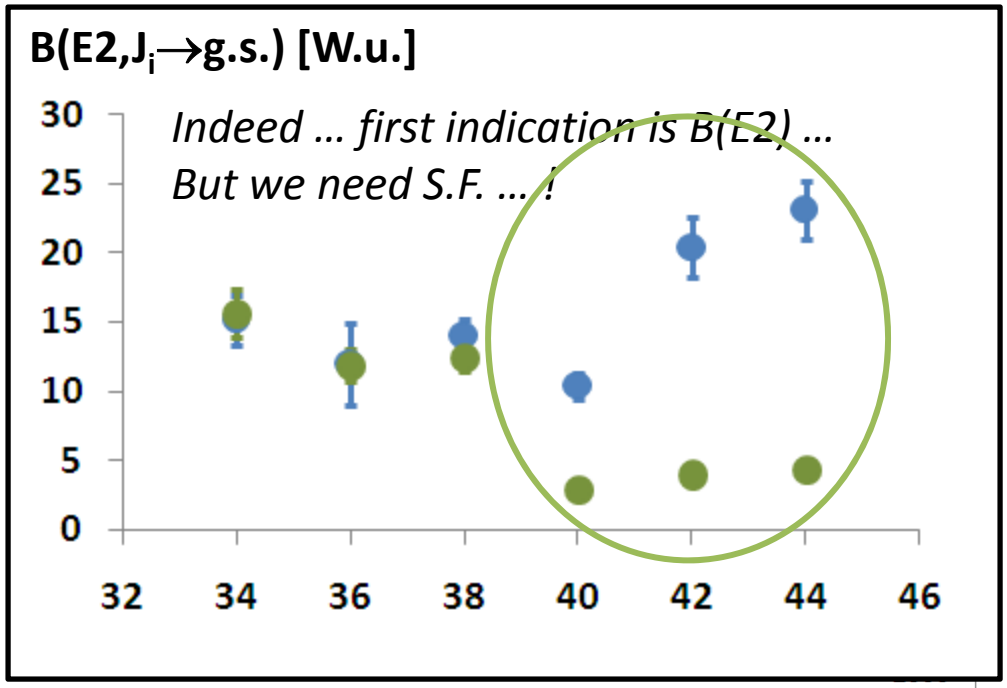
Whereas 5/2- behaves much more "single particle like …"





I. Stefanescu *et al.,* Phys. Rev. Lett. 100, 112502 (2008) (^{67,69,71,73}Cu coulex)



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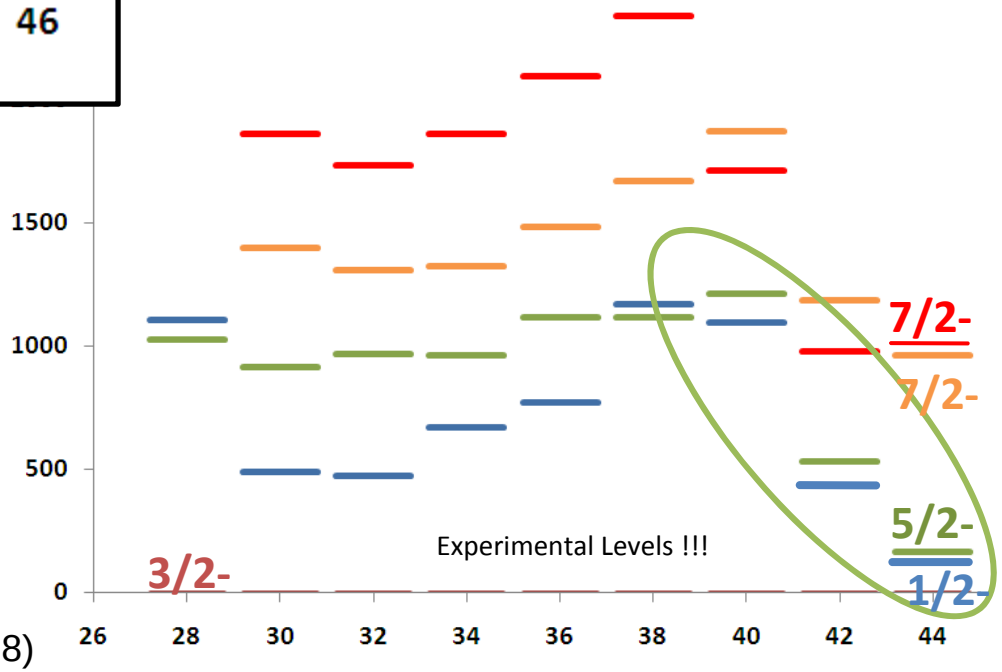
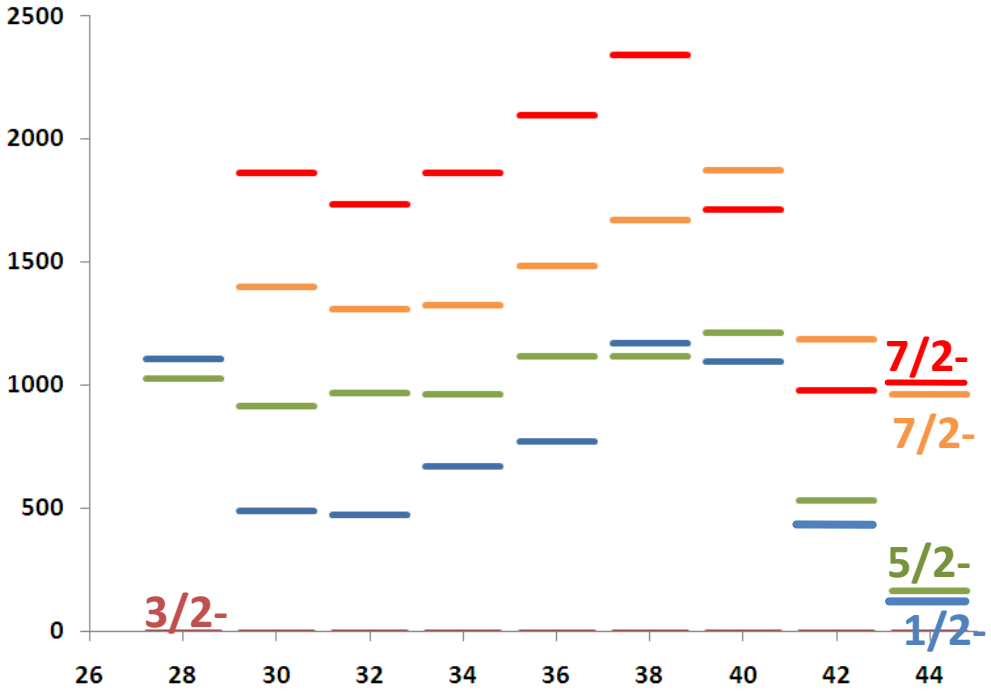
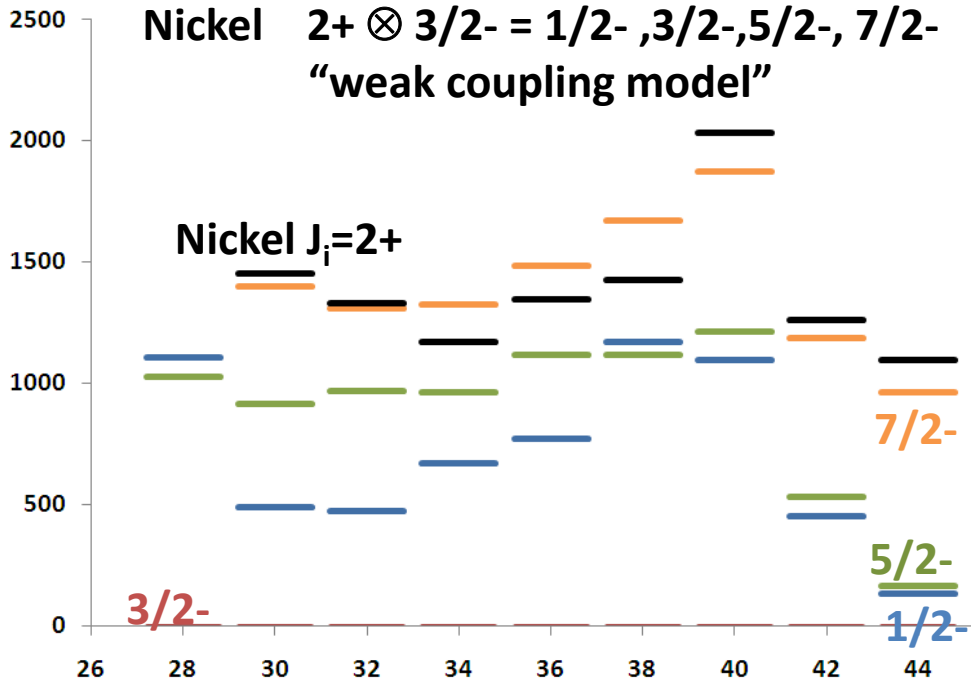


I. Stefanescu *et al.*, Phys. Rev. Lett. 100, 112502 (2008)

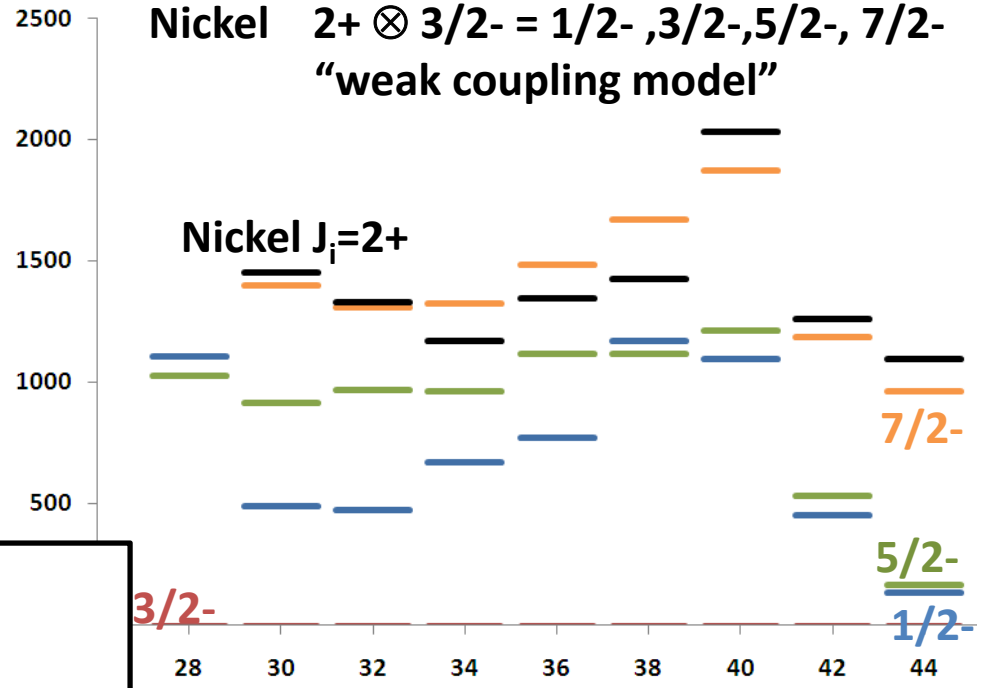
2/ Some Physics Cases : Shell Model Interest
Neutron Rich Cupper isotopes

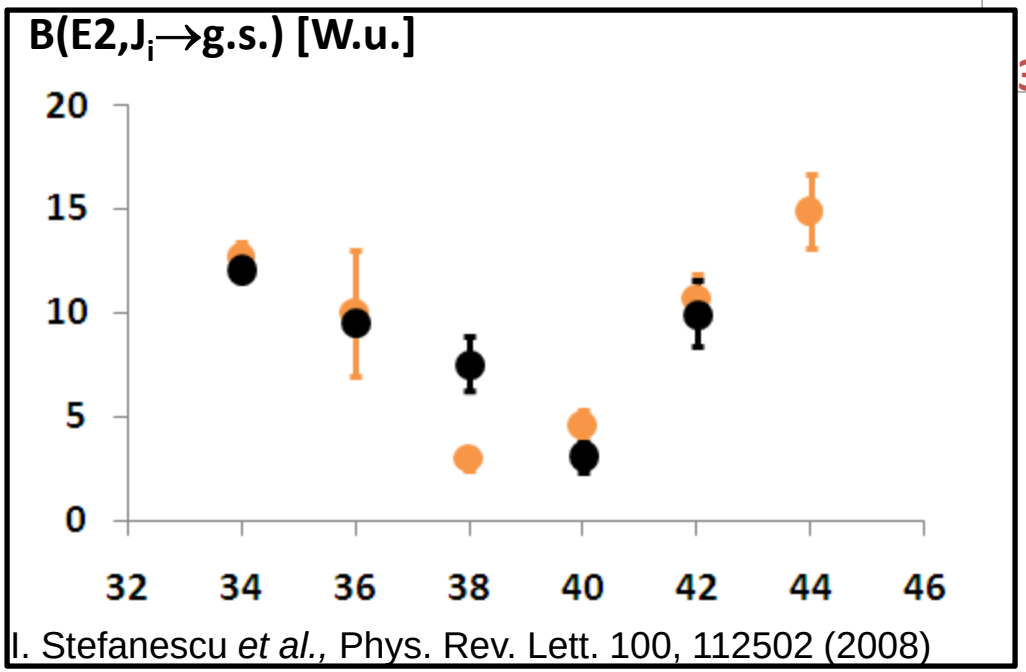


I. Stefanescu *et al.,* Phys. Rev. Lett. 100, 112502 (2008)



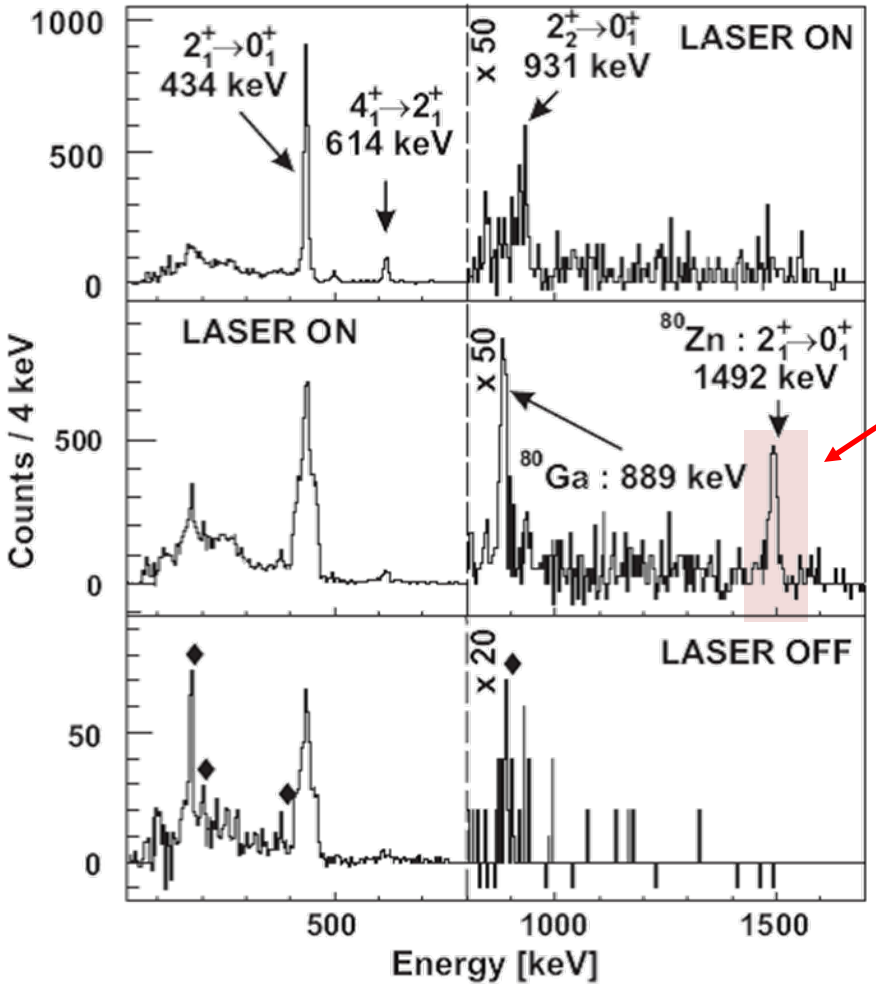
I. Stefanescu *et al.,* Phys. Rev. Lett. 100, 112502 (2008)





I. Stefanescu *et al.*, Phys. Rev. Lett. 100, 112502 (2008)

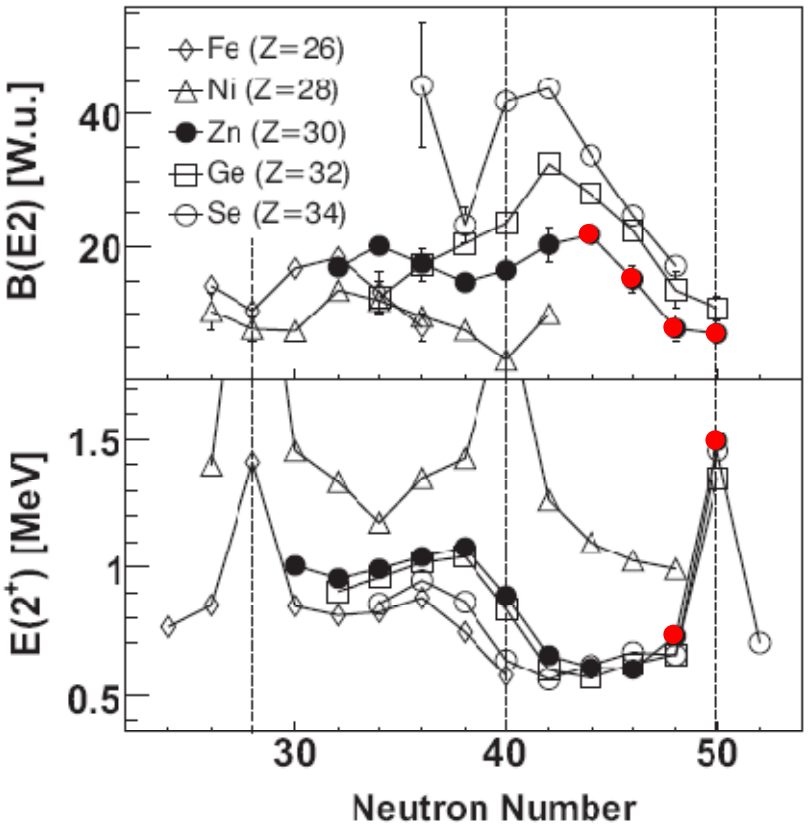
2/ Some Physics Cases : Shell Model Interest
Neutron Rich Zinc isotopes



- UCx + RILIS + quartz line
- 3E3 pps
- 4 days running time
- 2.87 MeV/u on 2.0 mg/cm^2 ^{108}Pd
- Doppler Correction crucial

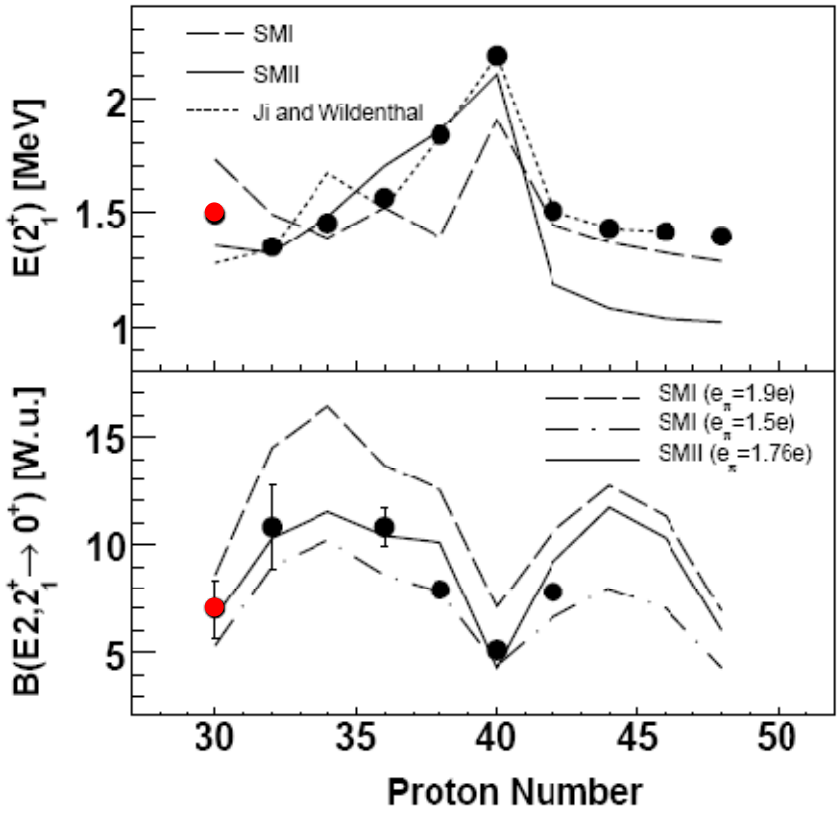
J. Van de Walle *et al.*, submitted to Physical Review C (2008)
J. Van de Walle *et al.*, Physical Review Letters 99, 142501 (2007)

2/ Some Physics Cases : Shell Model Interest

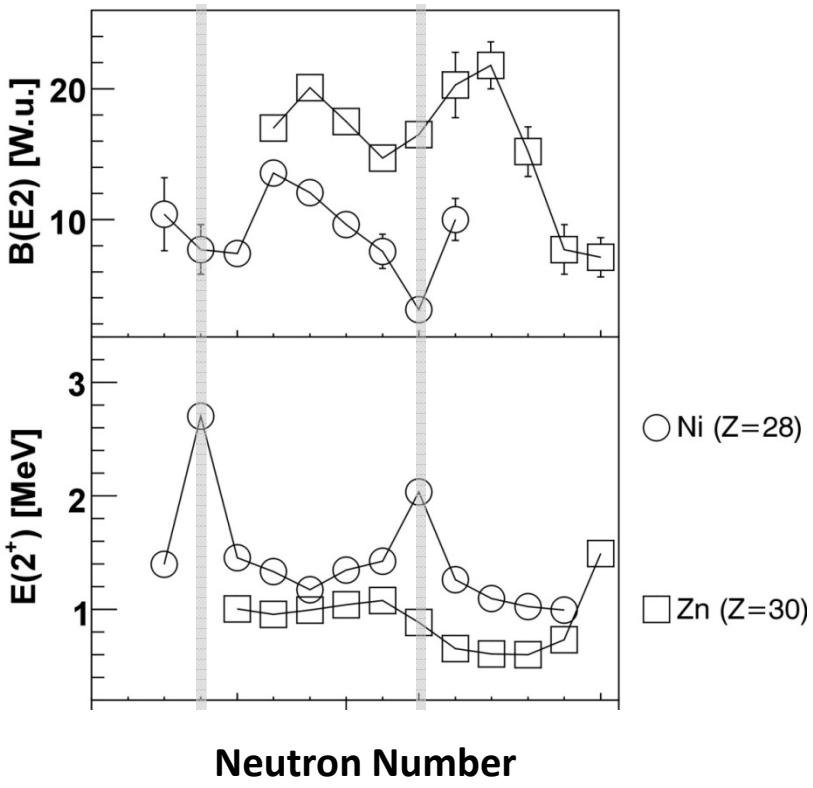


Global systematics : B(E2) and E(2+)

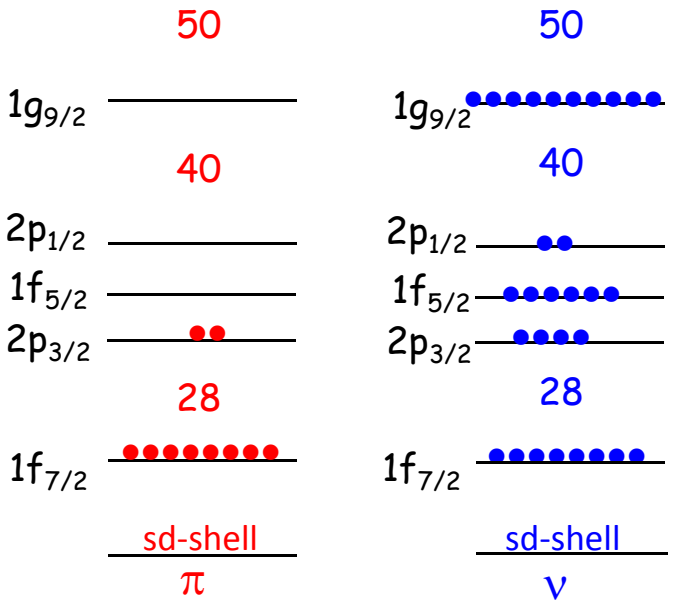
N=50 systematics : B(E2) and E(2+)

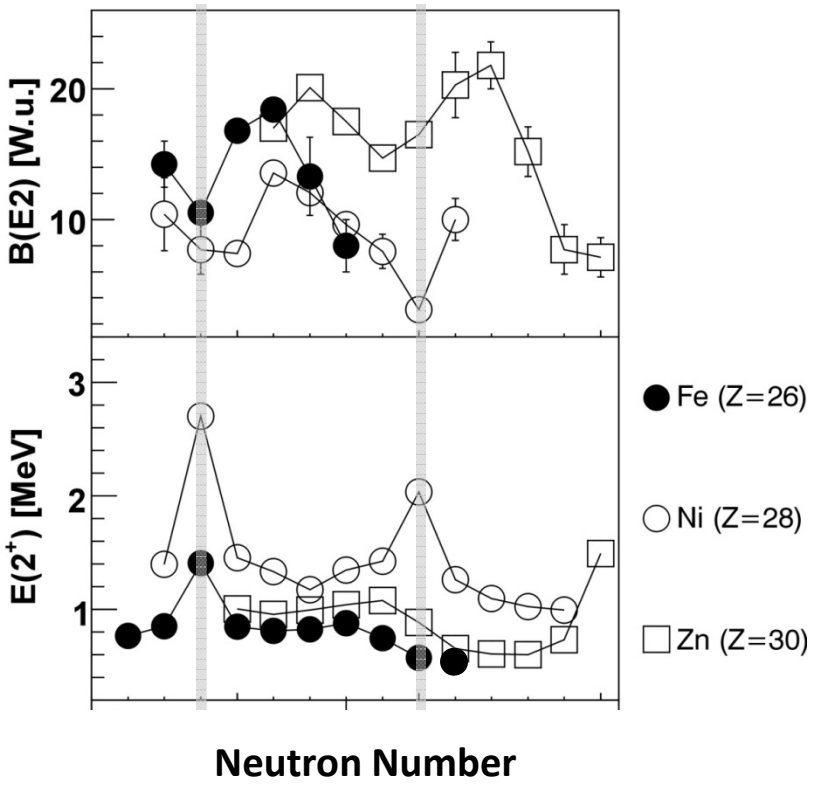


J. Van de Walle *et al.*, submitted to Physical Review C (2008)
J. Van de Walle *et al.*, Physical Review Letters 99, 142501 (2007)



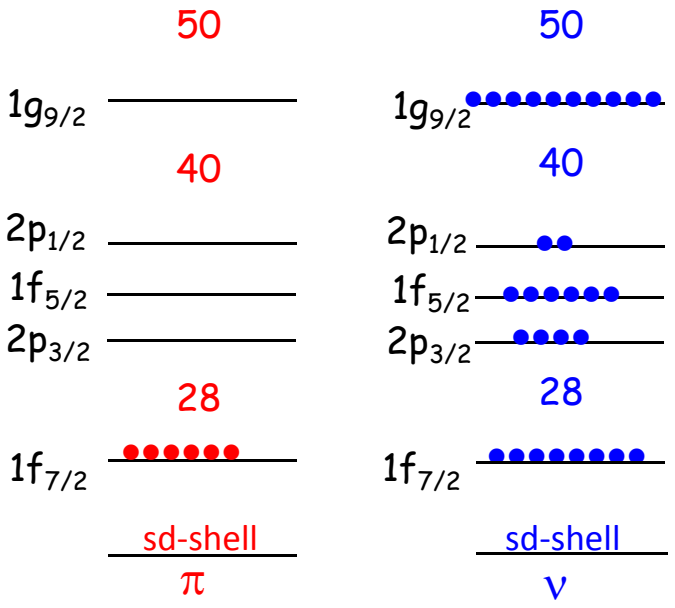
Increased collectivity for Z>28 and 38<N<44

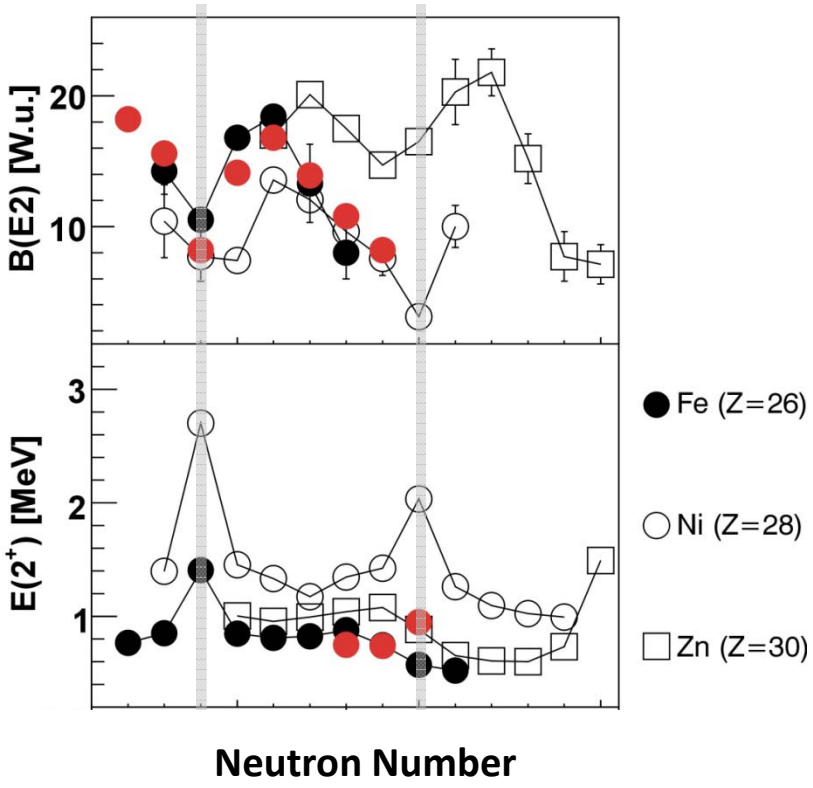




Increased collectivity for Z>28 and 38<N<44

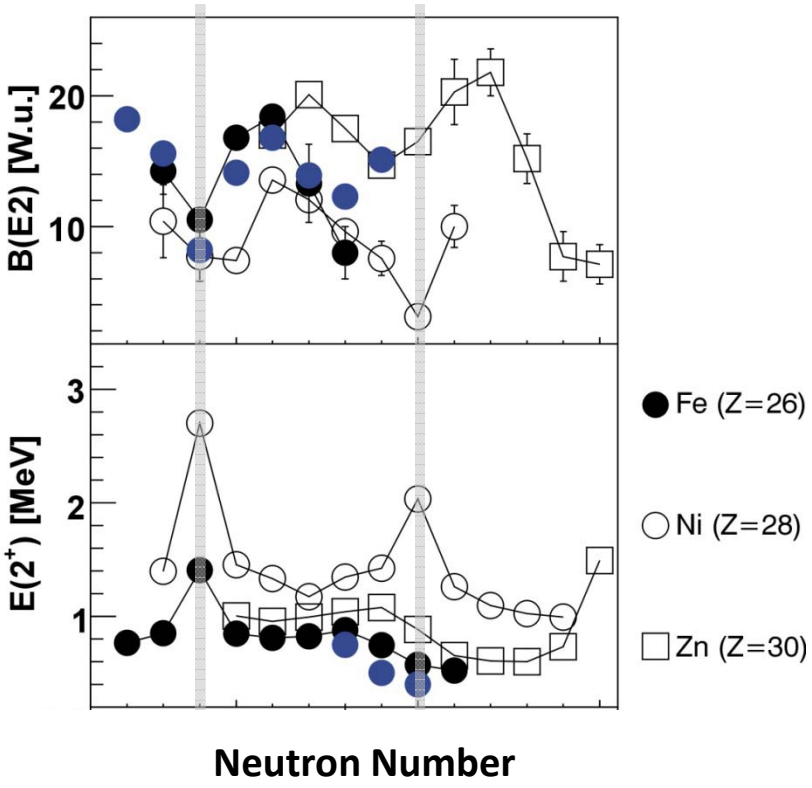
ALSO for Z<28, ex. Z=26 (Iron)
And 36<N< ??





Calculations from Caurier et al.
EPJA, 15, 145-150 (2002)

● pf-shell (KB3G interaction)



Calculations from Caurier et al.
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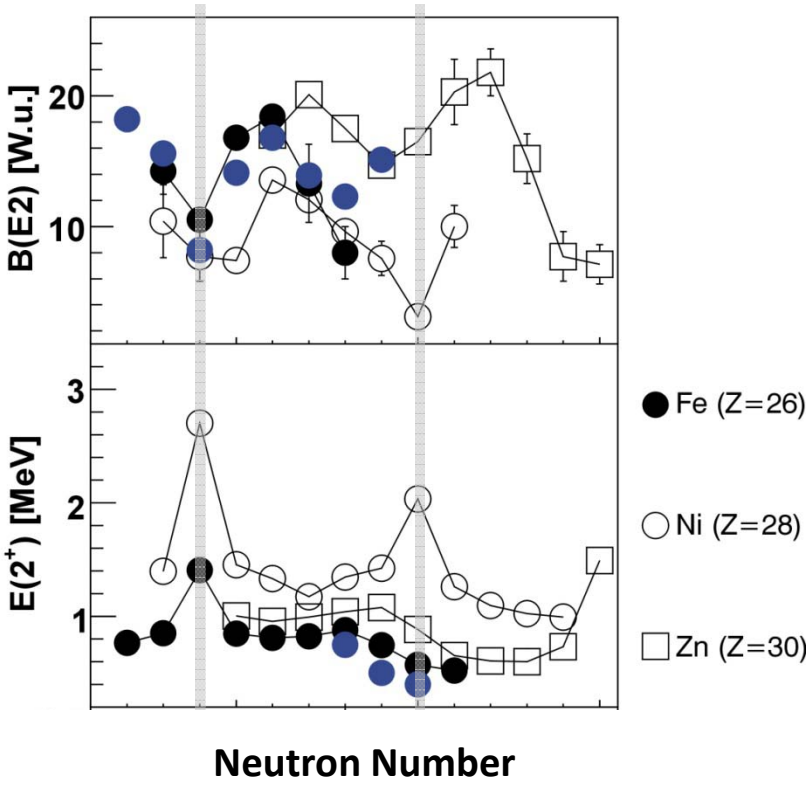
- pf-shell (KB3G interaction)
- pfgd (^{52}Ca core)

How do the $1g_{9/2}$ and possibly $2d_{5/2}$ neutron orbitals influence the quadrupole collectivity below Z=28 ?



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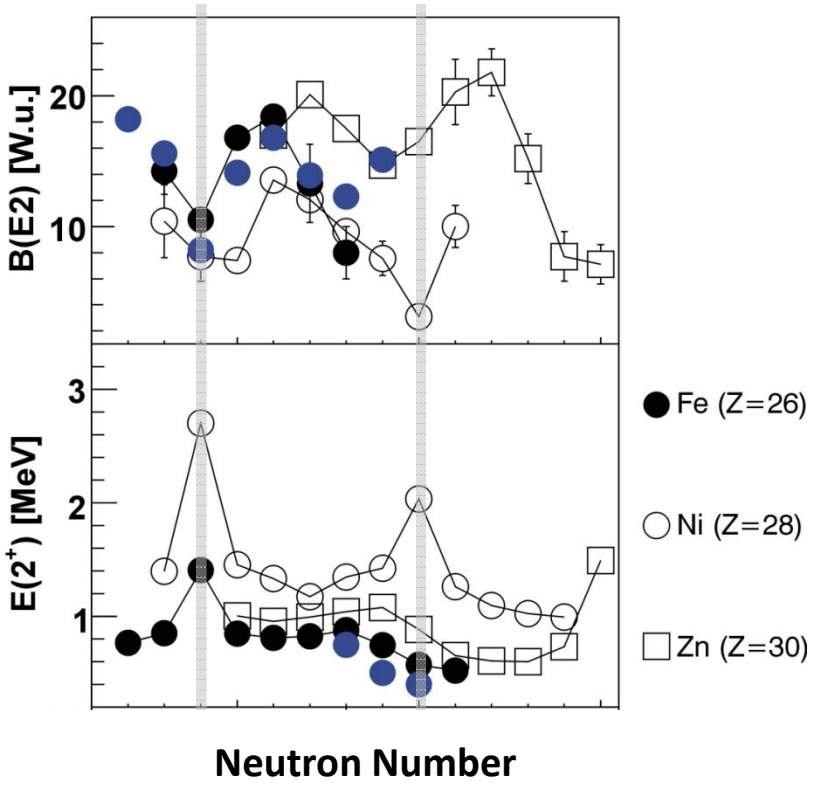
… **BUT**



Calculations from Caurier et al.
EPJA, 15, 145-150 (2002)

- pf-shell (KB3G interaction)
- pfgd (^{52}Ca core)

How do the $1g_{9/2}$ and possibly $2d_{5/2}$ neutron orbitals influence the quadrupole collectivity below Z=28 ?

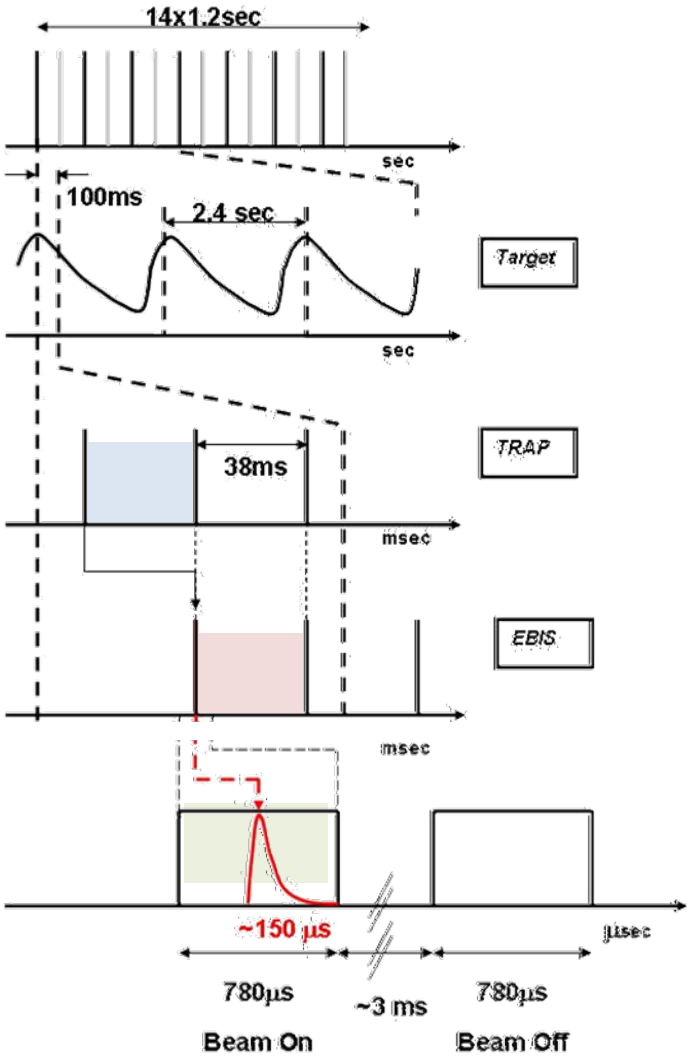
… BUT no Fe beam @ ISOLDE …

First test with ^{61}Mn in-trap decay to ^{61}Fe

Coulomb excitation ^{61}Mn

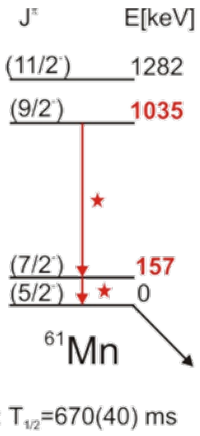
Trapping for 30 ms

Charge Breeding for 28 ms

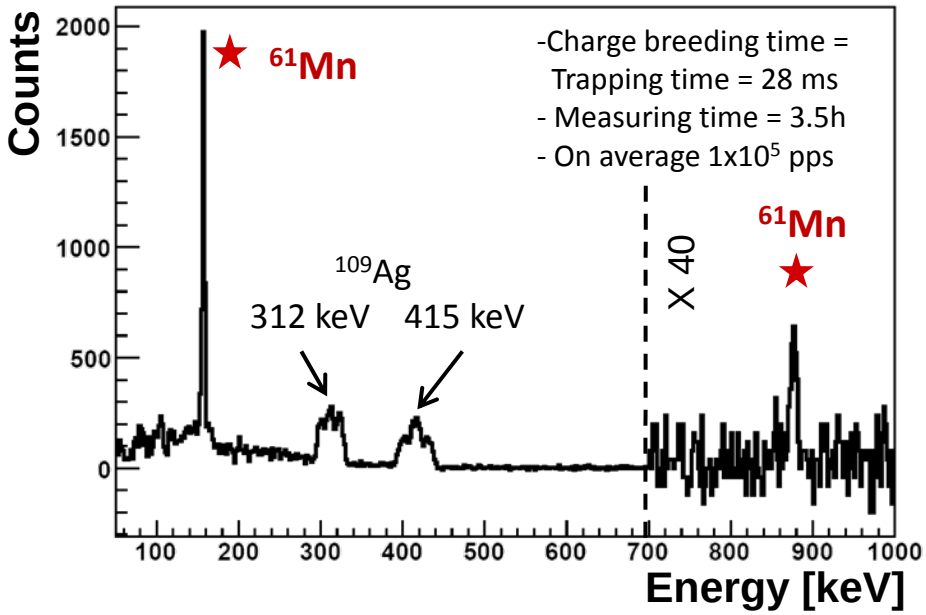


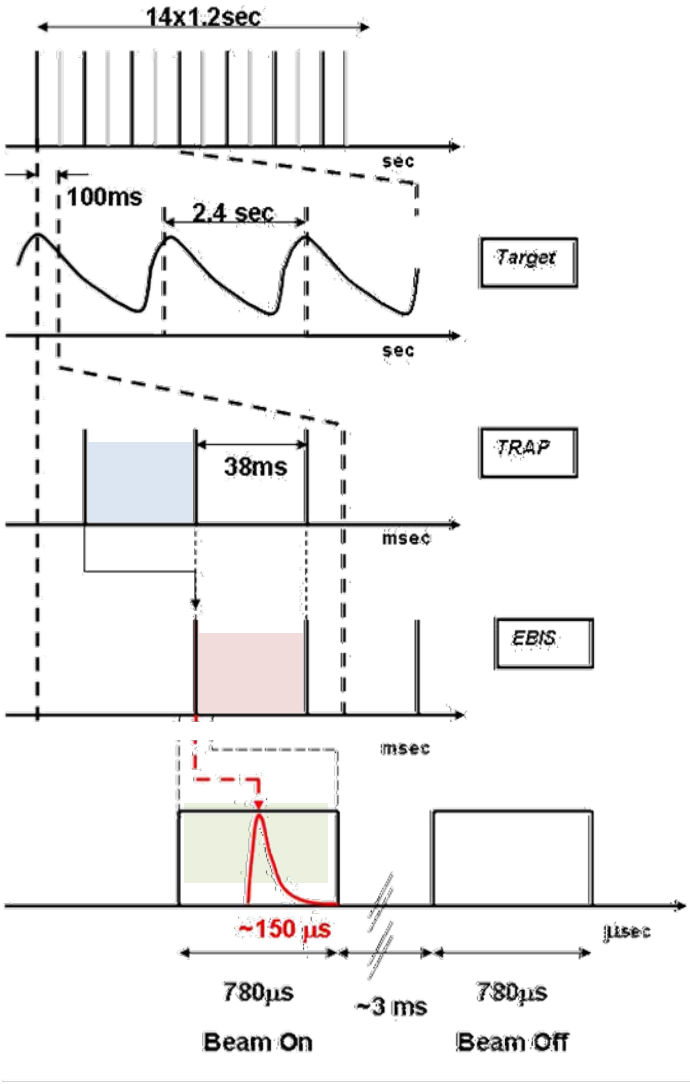
Coulomb excitation ^{61}Mn

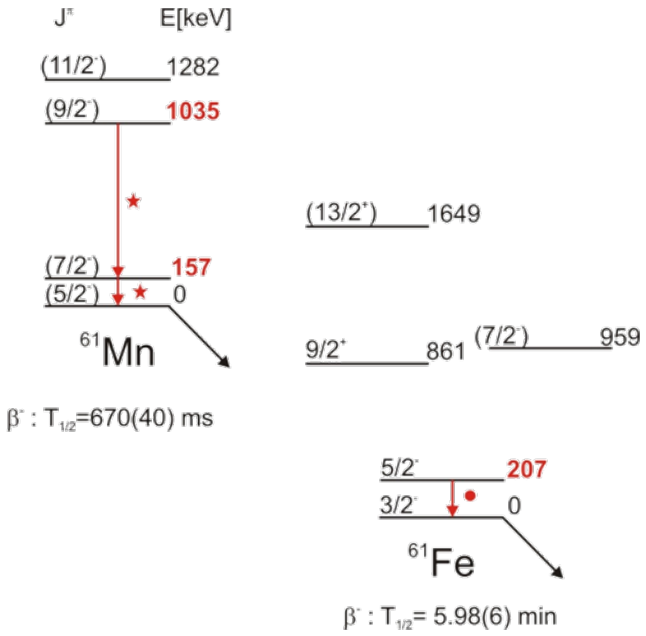
J.J. Valiente-Dobon *et al.*, PRC 78, 024302 (2008)



157 keV : 33(2) W.u. (preliminary)

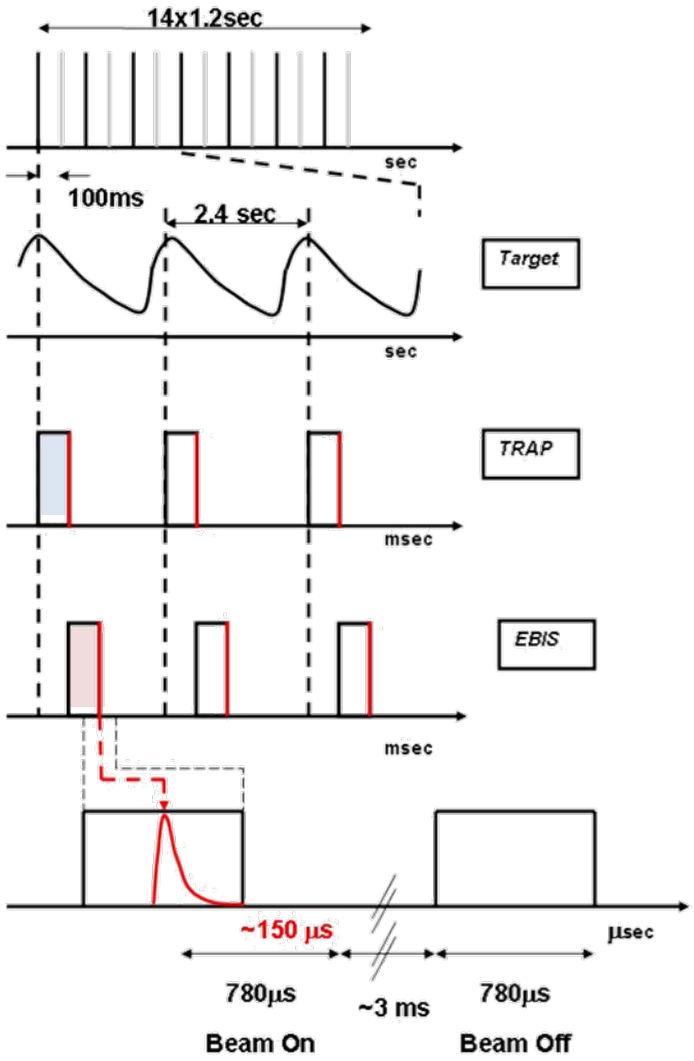




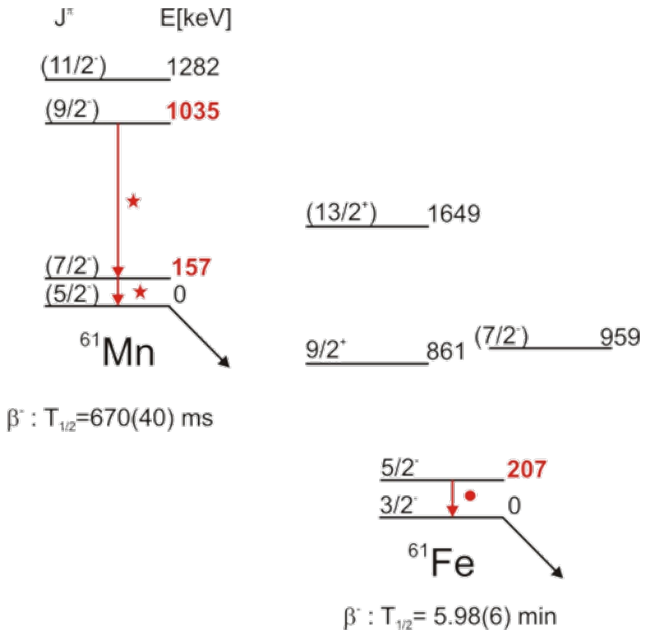


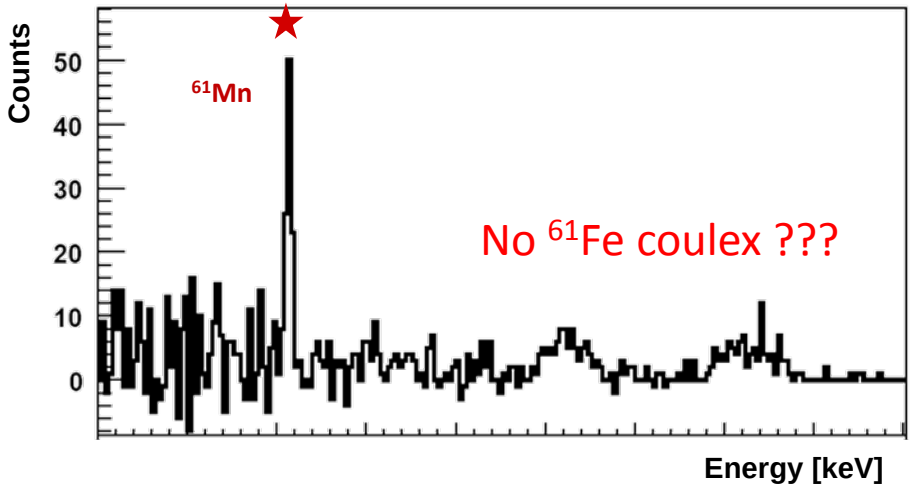
Trapping for 200 ms (up to 900 ms)

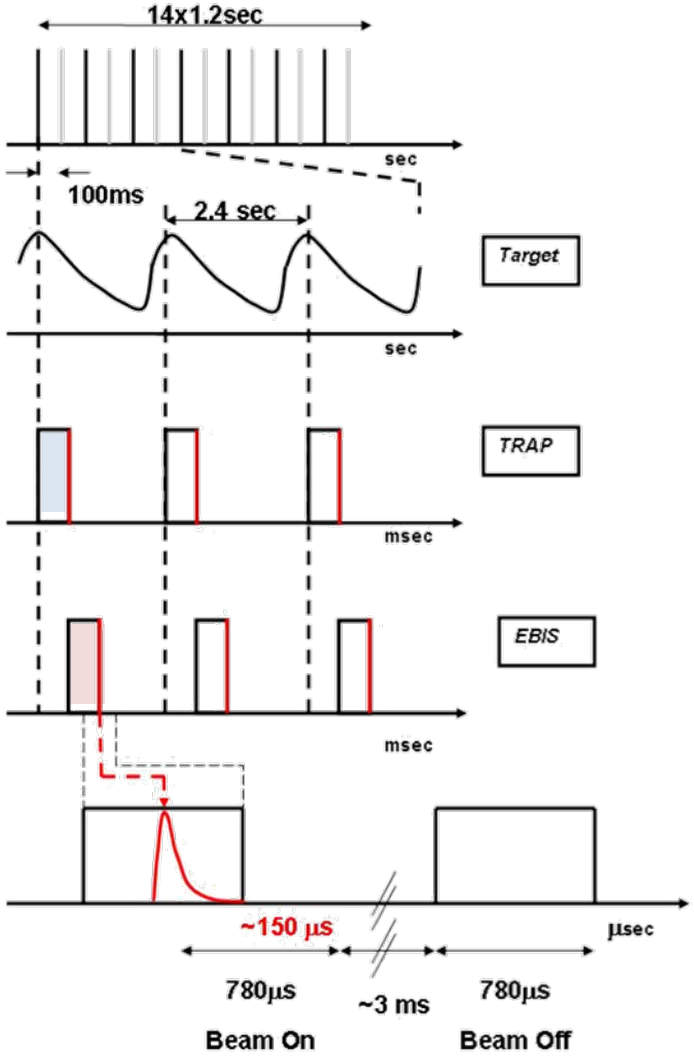
Charge Breeding for 28 ms

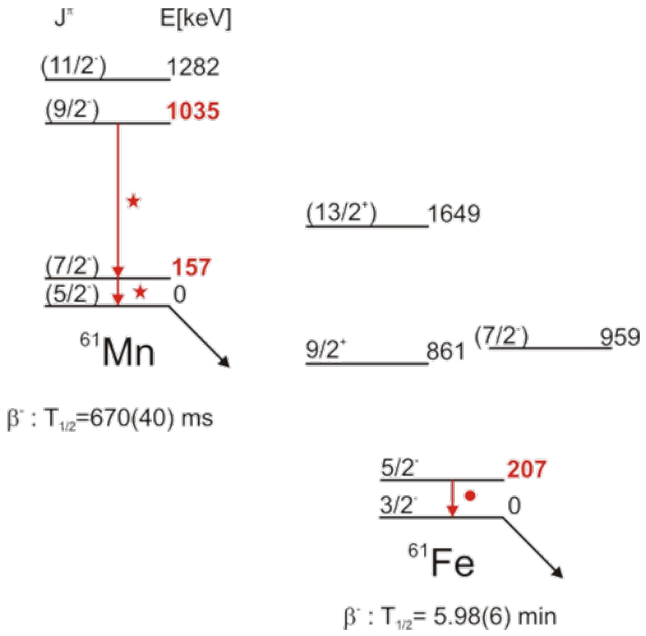


2/ Some Physics Cases : Shell Model Interest



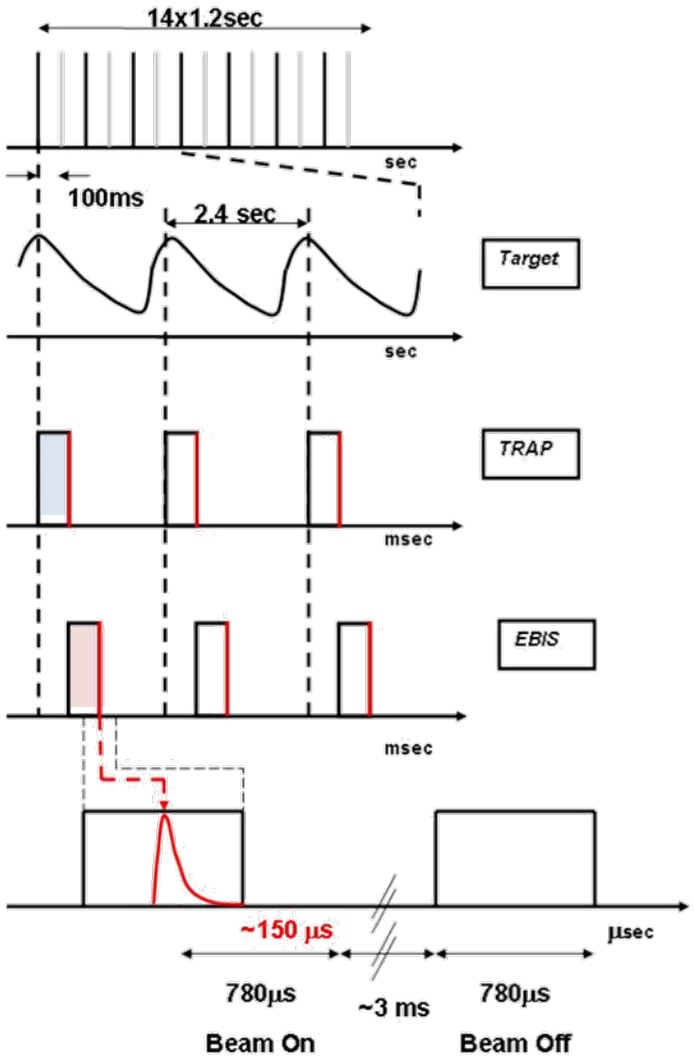






Trapping for 200 ms (up to 900 ms)

Charge Breeding for 298 ms



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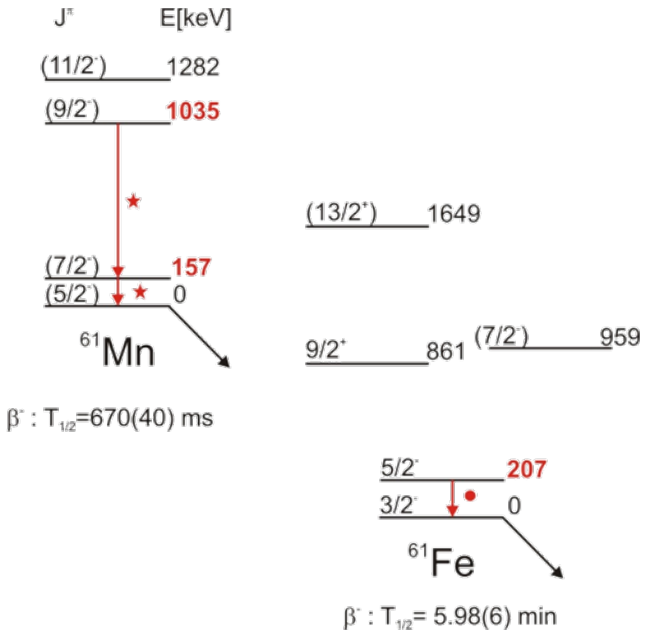
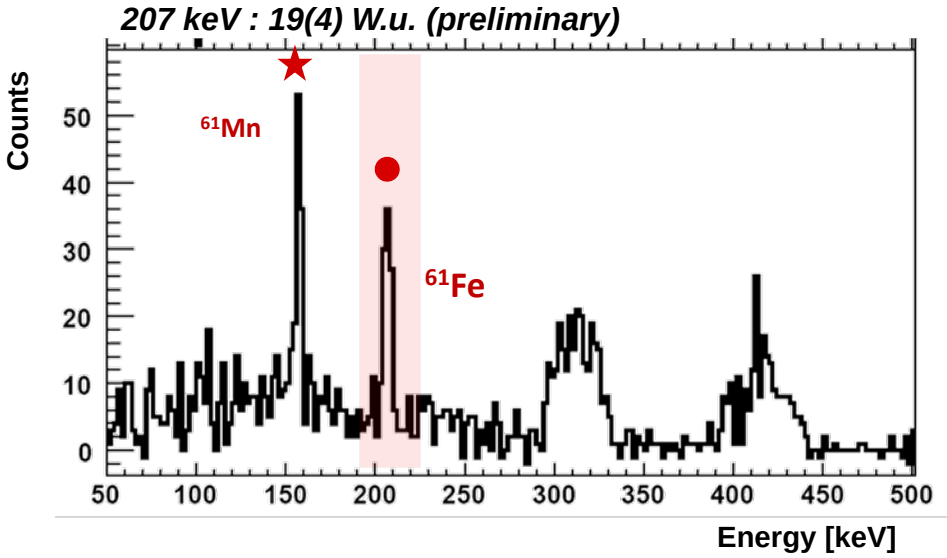
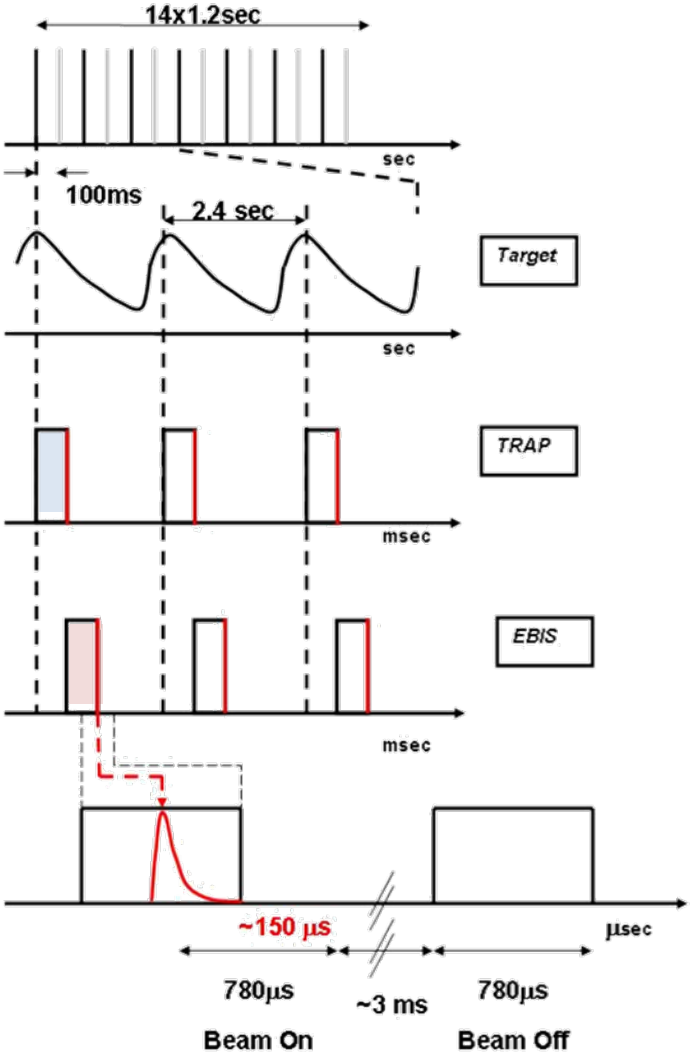


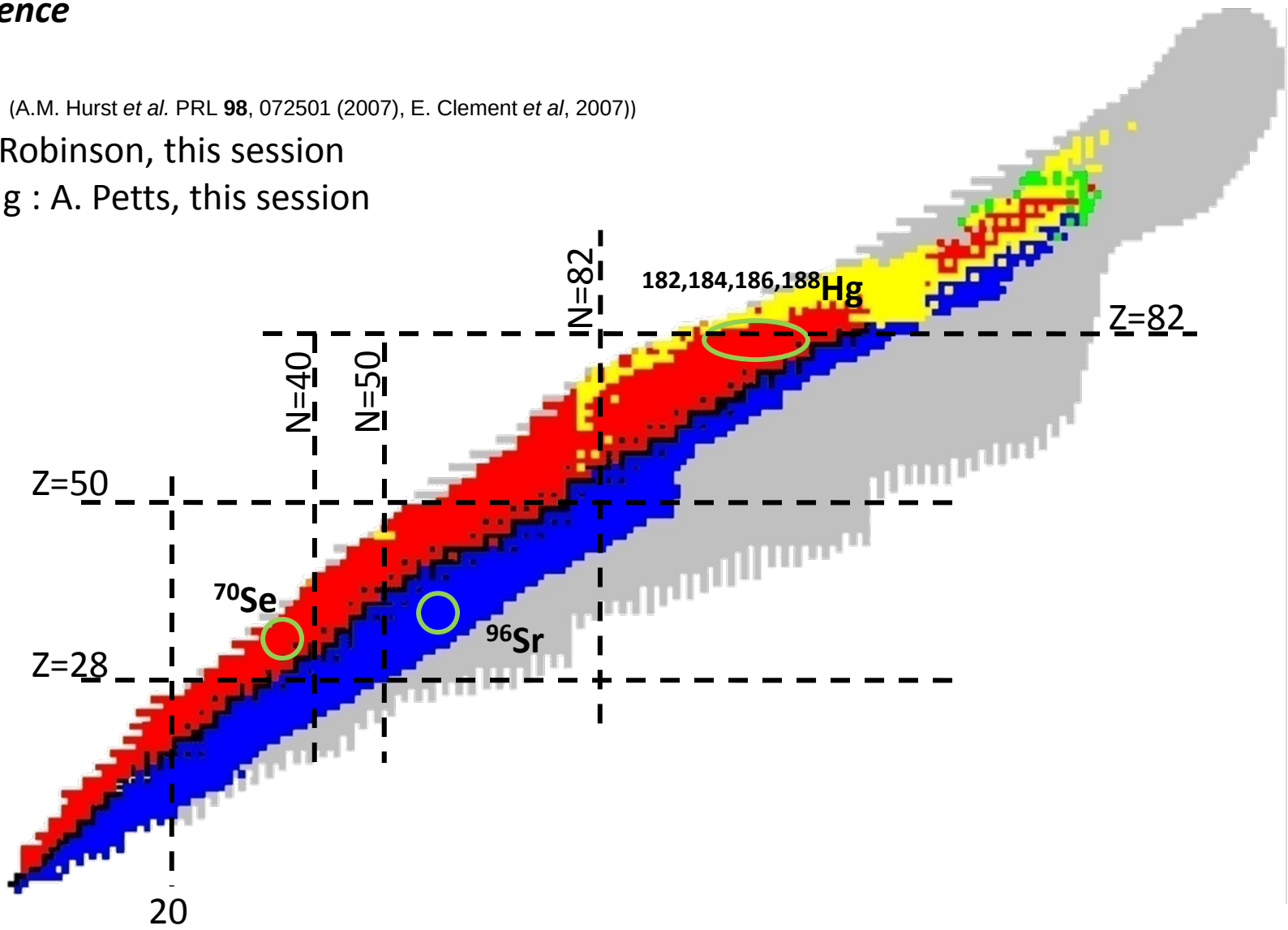




Some physics case "over the past years" …

Shape Co-existence

- ✓ ^{70}Se and ^{96}Sr (A.M. Hurst *et al.* PRL **98**, 072501 (2007), E. Clement *et al*, 2007))
- ✓ ^{202,204}Rn : A. Robinson, this session
- ✓ ^{182,184,186,188}Hg : A. Petts, this session



Determining the sign and magnitude of the spectroscopic Quadrupole Moment … How ?

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- Combining lifetime measurements and Coulomb excitation
  - ☹ Accurate Lifetime measurement needed (non-trivial for rare isotopes)
  - ☺ Low statistics in Coulomb excitation

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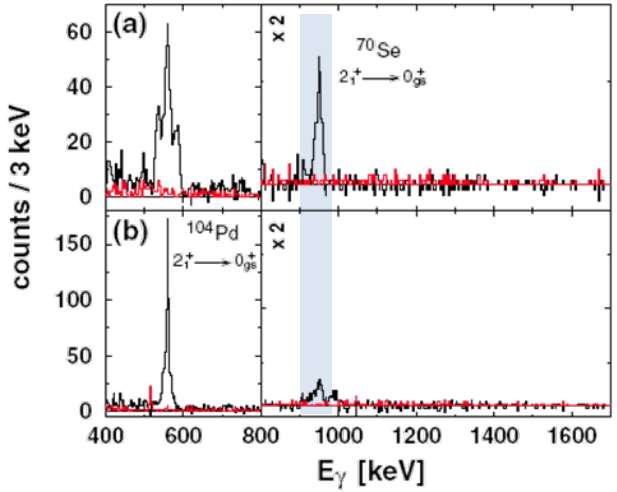
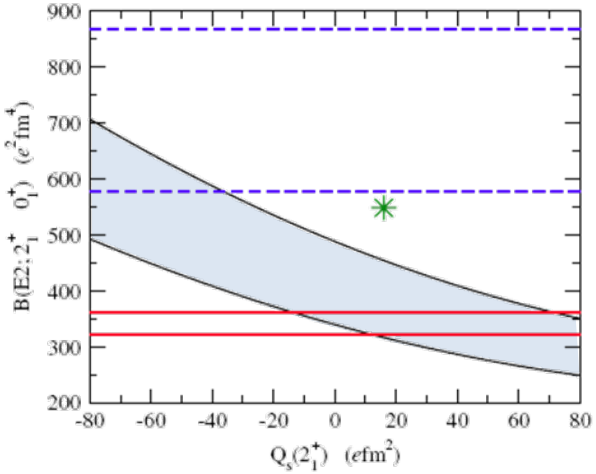
Ex. : the case of ^{70}Se …

A.M. Hurst *et al.* PRL **98**, 072501 (2007)



J. Ljungvall *et al.* PRL 100, 102502 (2008)



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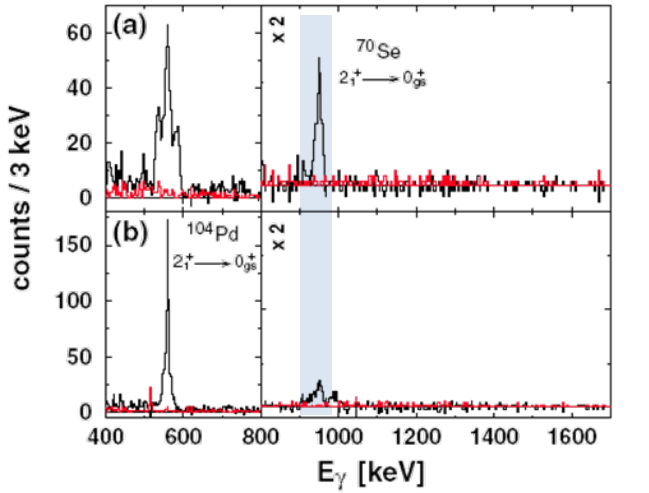
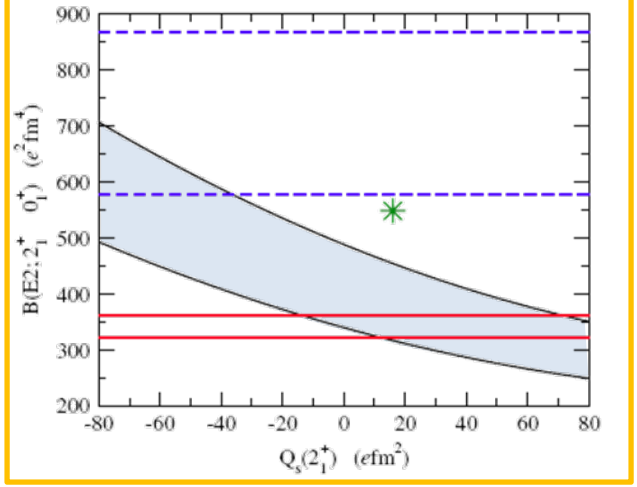
A.M. Hurst *et al.* PRL **98**, 072501 (2007)



J. Ljungvall *et al.* PRL 100, 102502 (2008)



Determining the sign and magnitude of the spectroscopic Quadrupole Moment … How ?

- Combining lifetime measurements and Coulomb excitation
  - ☹ Accurate Lifetime measurement needed (non-trivial for rare isotopes)
  - ☺ Low statistics in Coulomb excitation
- From the sensitivity to diagonal matrix element in Coulex ($\Rightarrow Q_{2^+} = 0.7479 \langle 2^+||M(E2)||2^+\rangle$)
  - ☺ No external input needed
  - ☹ High statistics needed

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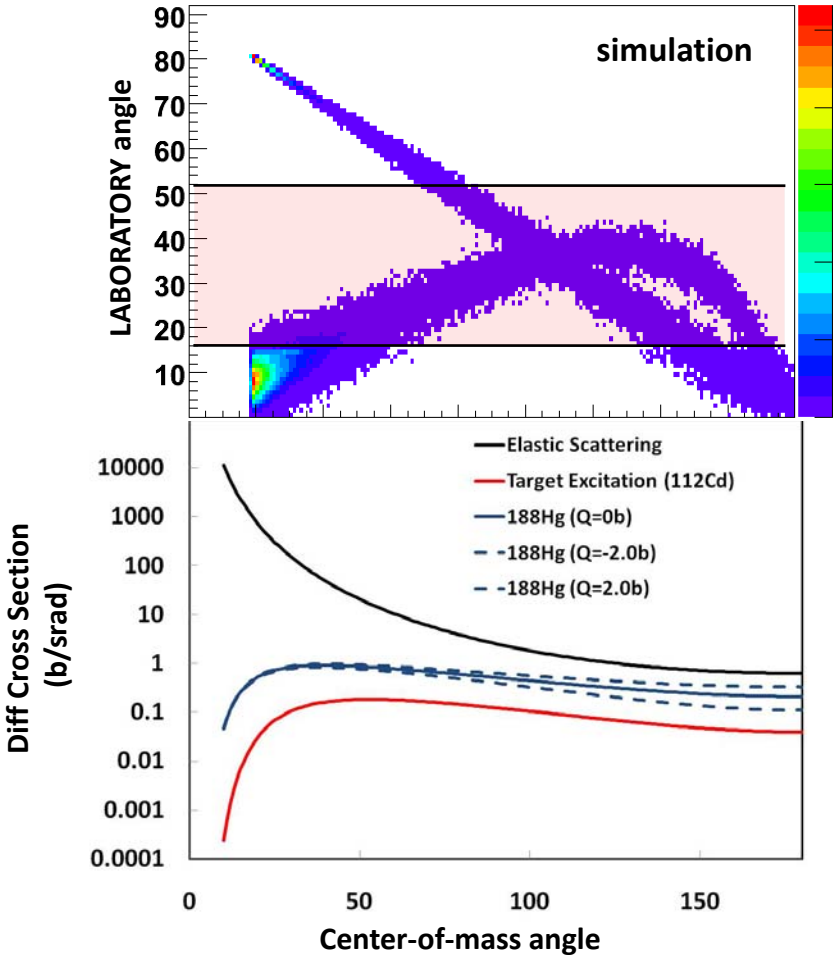

Determining the sign and magnitude of the spectroscopic Quadrupole Moment … How ?

- Combining lifetime measurements and Coulomb excitation
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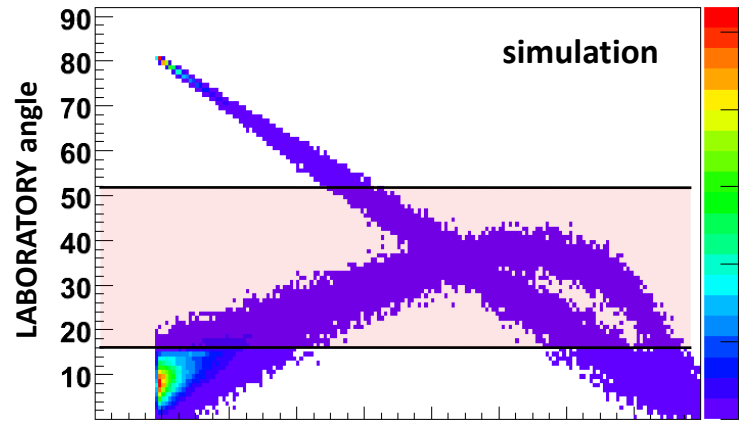
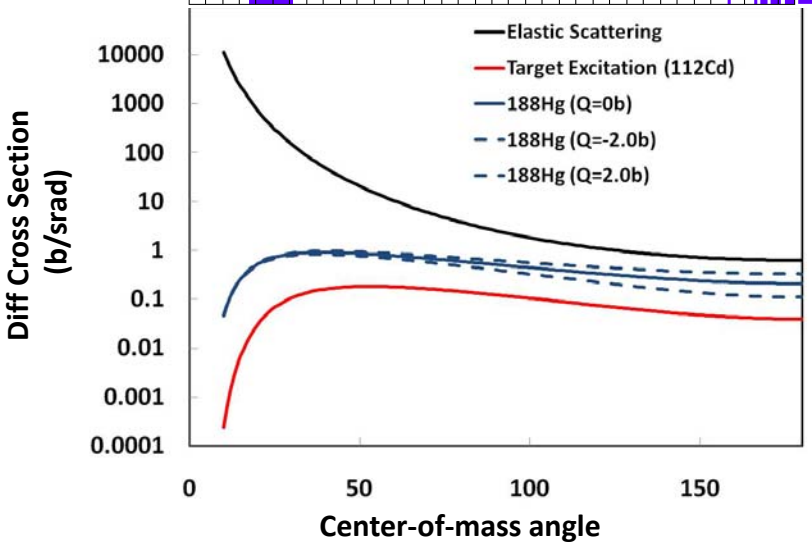
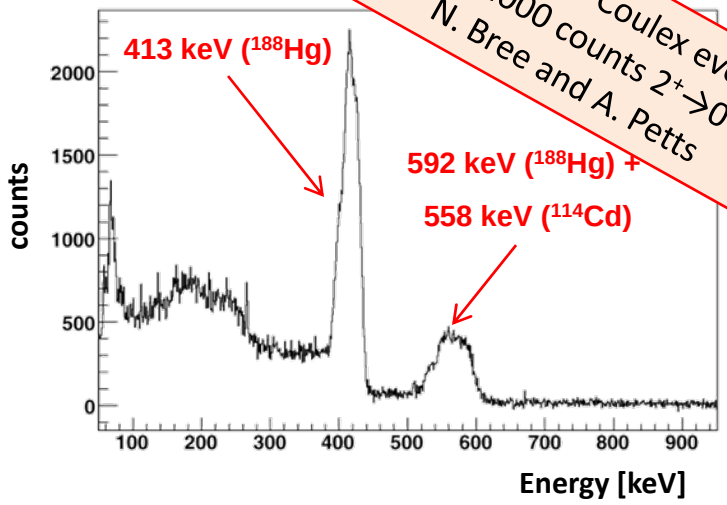
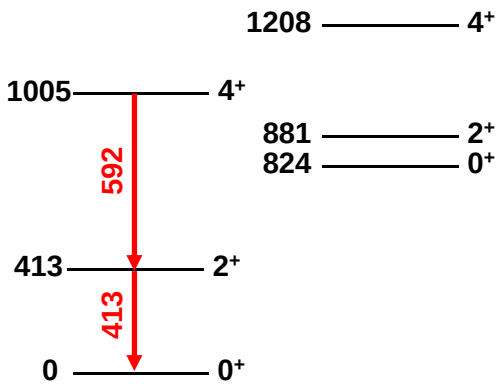
Highest statistics Coulex ever @ REX
(> 60.000 counts $2^+ \rightarrow 0^+$)
N. Bree and A. Petts









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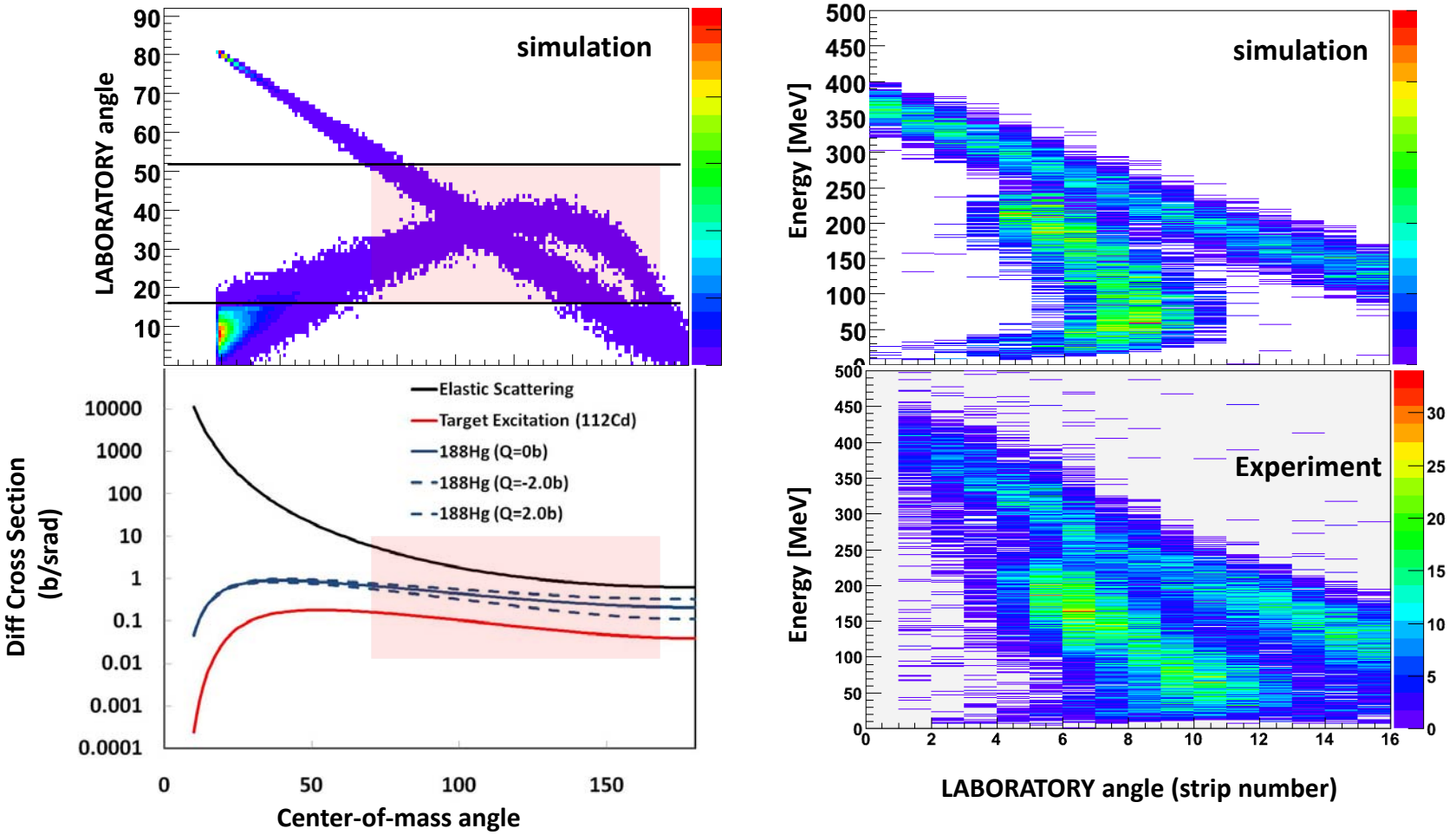
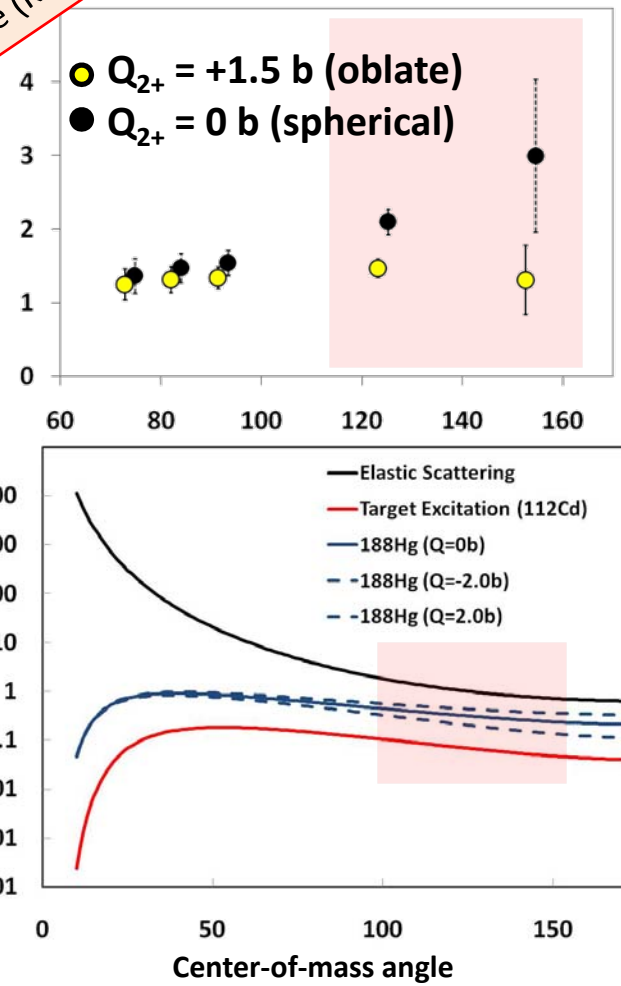
- From the sensitivity to diagonal matrix element in Coulex ($\Rightarrow Q_{2+} = 0.7479 \langle 2^+||M(E2)||2^+\rangle$)

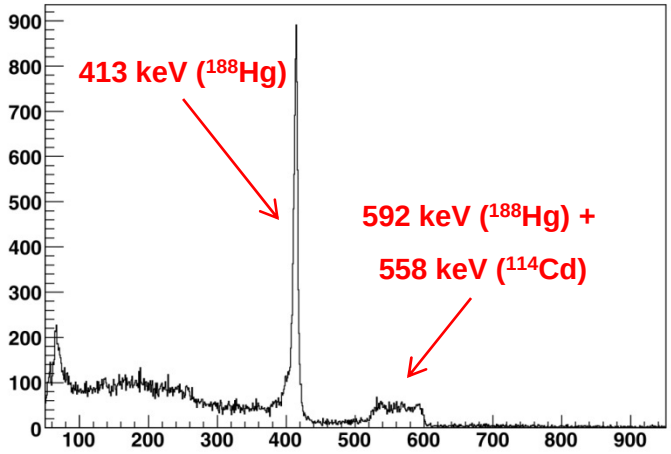


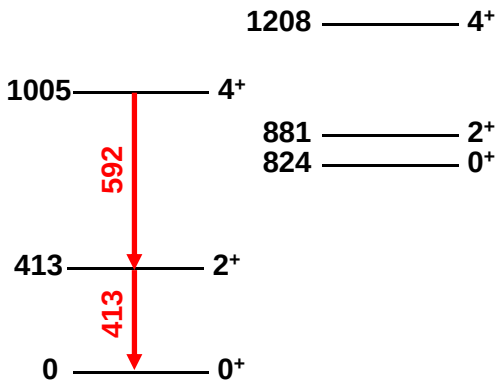
Determining the sign and magnitude of the spectroscopic Quadrupole Moment … How ?

- Combining lifetim[illegible]easurements and Coulomb excitation
- From the sen[illegible]diagonal matrix element in Coulex ($\Rightarrow Q_{2+} = 0.7479 \langle 2^+||M(E2)||2^+\rangle$)

PRELIMINARY
Analysis by N. Bree (KU Leuven)







Determining the sign and magnitude of the spectroscopic Quadrupole Moment … How ?

- Combining lifetime measurements and Coulomb excitation
- From the sensitivity to diagonal matrix element in Coulex ($\Rightarrow Q_{2^+} = 0.7479 \langle 2^+||M(E2)||2^+\rangle$)
- Coulomb excitation on two different targets
  - Choice of targets is difficult
  - Statistics in beam excitation on both targets

Conclusions

- 5 successfull experiments this year.
many more to come next year ...

Conclusions

- 5 successfull coulex experiments this year : Mn, Rn, Hg, Cd, Cu ...
-physics results have been published and are being prepared for publication

(... not necessarily complete !)

Coulomb excitation of neutron-rich beams at REX-ISOLDE
H. Scheit *et al.,* European Physical Journal A 25, 397-402 (2005)
"Safe" Coulomb Excitation of Mg
O. Niedermaier *et al.,* Physical Review Letters 94, 172501 (2005)
The neutron-rich Mg isotopes: first results from MINIBALL at REX-ISOLDE
O. Niedermaier, *et al.,* Nuclear Physics A 752, 273-278 (2005)
First use of post-accelerated isomeric beams for Coulomb excitation studies of odd-odd nuclei around N=40
G. Georgiev *et al.,* International Journal of Modern Physics E 15, 1505 (2006)
Coulomb Excitation of 88Kr and 92Kr in inverse kinematics
D. Mucher *et al.,* Progress in Particle and Nuclear Physics 59, 361-363 (2007)
Measurement of the Sign of the Spectroscopic Quadrupole Moment for the 2+1 State in 70Se : No Evidence for Oblate Shape
A. Hurst *et al.,* Physical Review Letters 98, 072501 (2007)
Coulomb excitation of the odd-odd nuclei 68,70Cu; first use of post-accelerated isomeric beams
I. Stefanescu *et al.,* Physical Review Letters 98, 122701 (2007)
Sub-Barrier Coulomb Excitation of 110Sn and its Implications for the 100Sn Shell Closure
J. Cederkall *et al.,* Physical Review Letters 98, 172501 (2007)
Coulomb Excitation of Neutron Rich Zn isotopes : First Observation of the 2+1 State in 80Zn
J. Van de Walle *et al.*, Physical Review Letters 99, 142501 (2007)
Interplay between single-particle and collective effects in the odd-A Cu isotopes beyond N=40
I. Stefanescu *et al.,* Phys. Rev. Lett. 100, 112502 (2008)
0+gs→2+1 transition strengths in 106Sn and 108Sn
A. Ekström *et al.*, Phys. Rev. Lett. 101, 012502 (2008)
Coulomb excitation of 68Ni40 at “safe” energies
N. Bree *et al.*, Phys. Rev. C 78, 047301 (2008)
Low Energy Coulomb Excitation of Neutron Rich Zinc isotopes
J. Van de Walle *et al.*, submitted to Physical Review C (2008)
In-Trap Decay of 61Mn and Coulomb Excitation of 61Mn and 61Fe
J. Van de Walle *et al.*, in preparation for Eur. Phys. J. A (2008)
...

Conclusions

- 5 successfull experiments this year.
- physics results have been published and are being prepared for publication

- Some online references :
www.miniball.york.ac.uk
isolde.web.cern.ch/ISOLDE

- Tests with stable beams (end nov. or 2009)
- In-trap decay with REXTRAP under investigation
- Transfer reactions using MINIBALL starting now
  (see talk Wednesday, V. Bildstein and K. Wimmer)