Proton-neutron interaction around N=40 studied at ISOLDE

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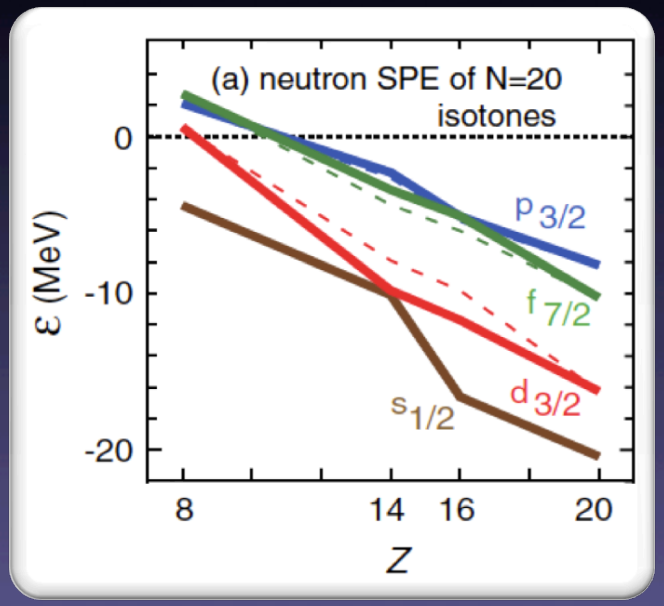
Excellence Cluster Universe

ISOLDE CERN

Technische Universität München

$$V(|\vec{r}_1 - \vec{r}_2|) = \sum_k \nu_k(r_1, r_2) P_k(\cos\theta)$$

MONOPOLE



T. Otsuka et al., Phys. Rev. Lett. 104, 012501 (2010)

matrix element:

$$v_{m,j,j'} = \sum_{k,k'} \langle jkj'k'|V|jkj'k'\rangle$$

linearity: $\Delta\epsilon_j = v_{m;j,j'} n_{j'}$

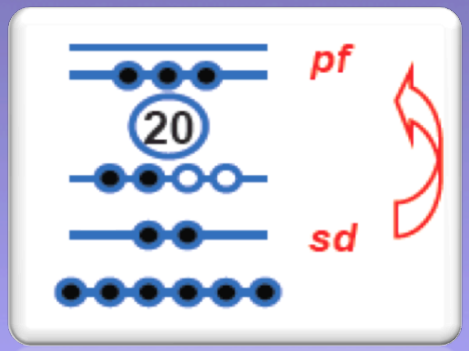
→ evolution of shell closures as a function of T
e.g. ^{24}O vs. ^{28}O

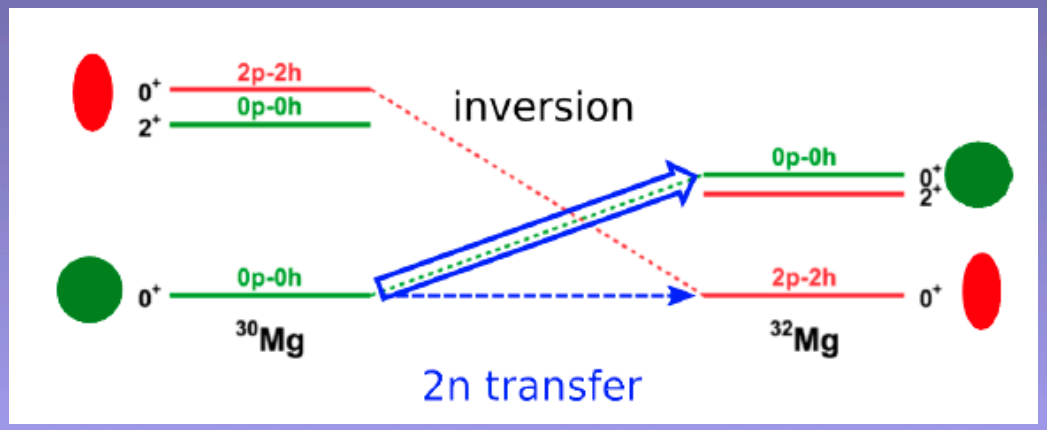
QUADRUPOLE

(+ higher oders)

a few examples:

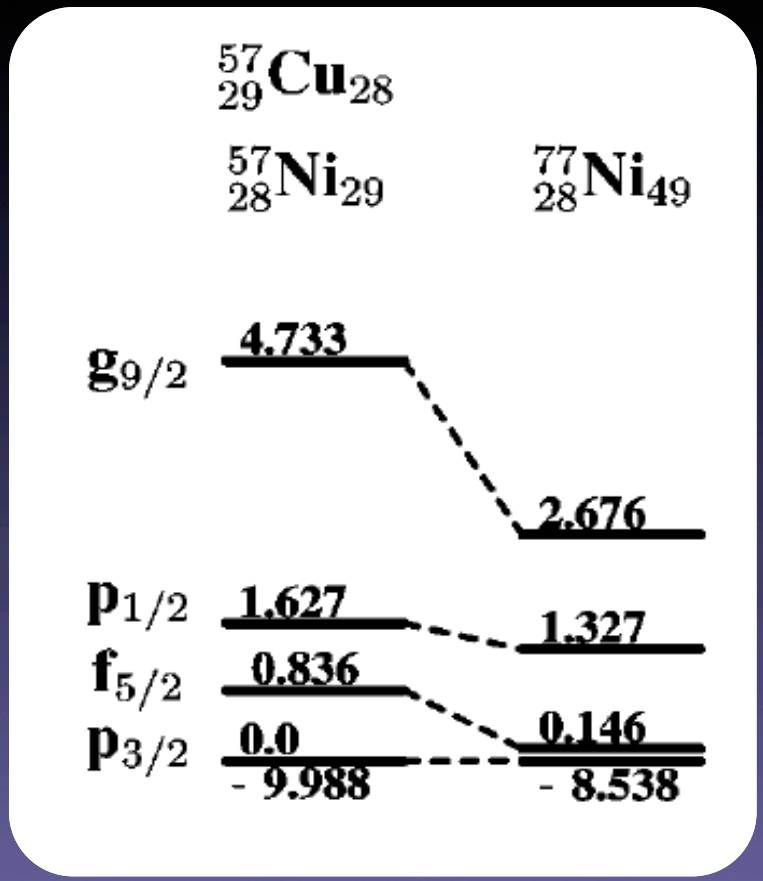
- "sudden" onset of deformation around A=100
- general behaviour of Intruder states: minimal energy at midshell
- island of inversion around ^{32}Mg



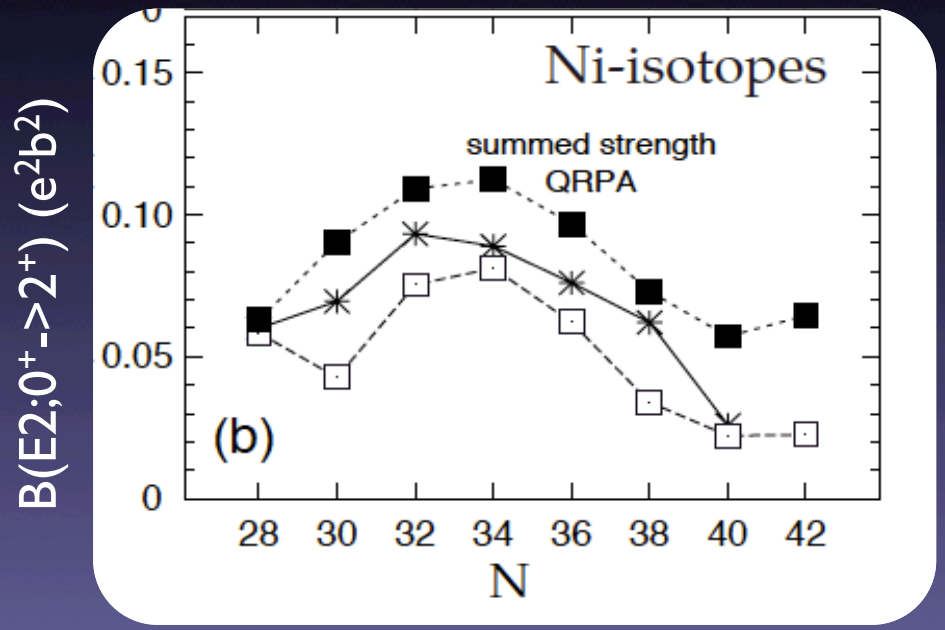


K. Wimmer et al., Phys. Rev. Lett. 105, 252501 (2010)

A. F. Lisetskiy et al., Phys. Rev. C 70, 044314 (2004)

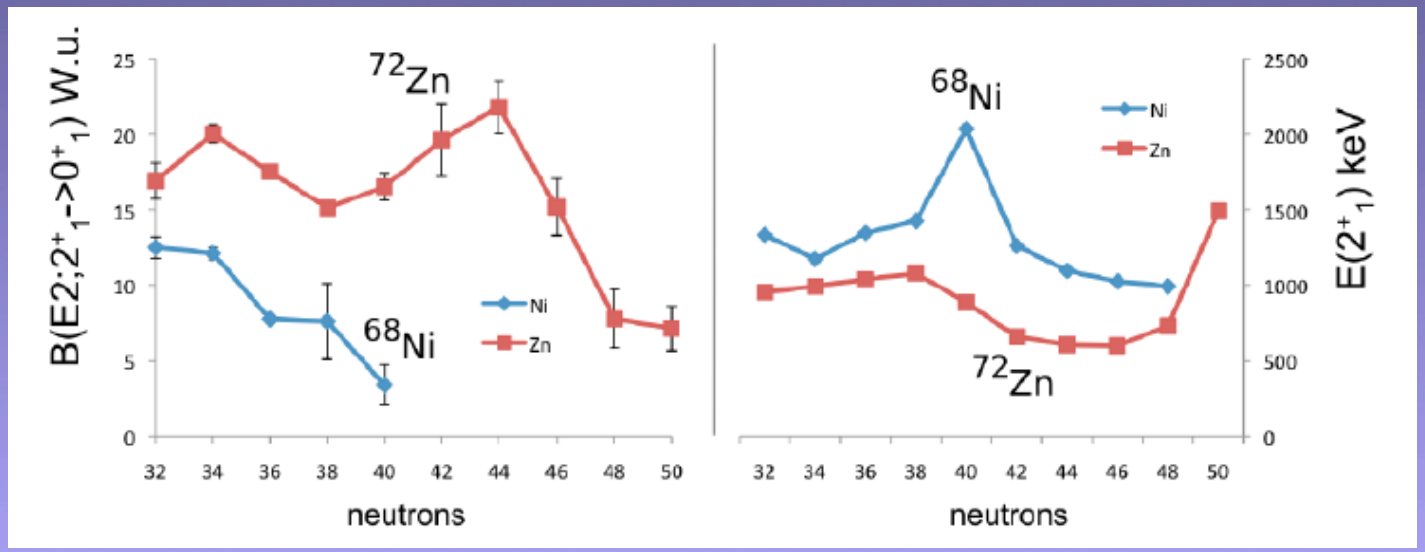


interpretation of N=40: depends on pair scattering between $p_{1/2}$ and $g_{9/2}$ neutron orbitals, thus quadrupole correlations!



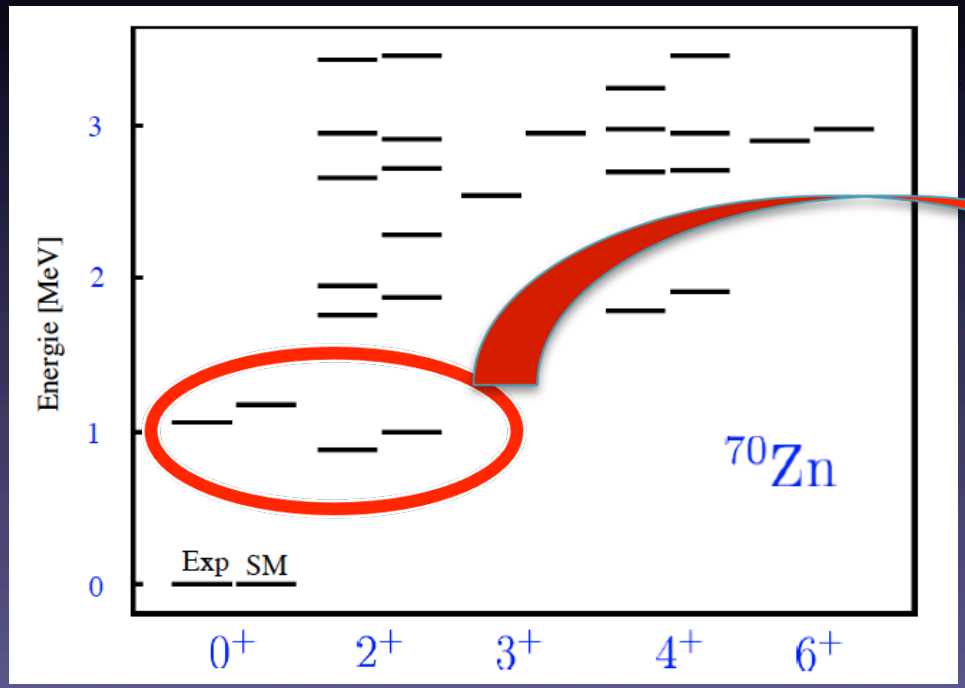
K. Langanke et al., Phys. Rev. C, 67, 044314 (2003)

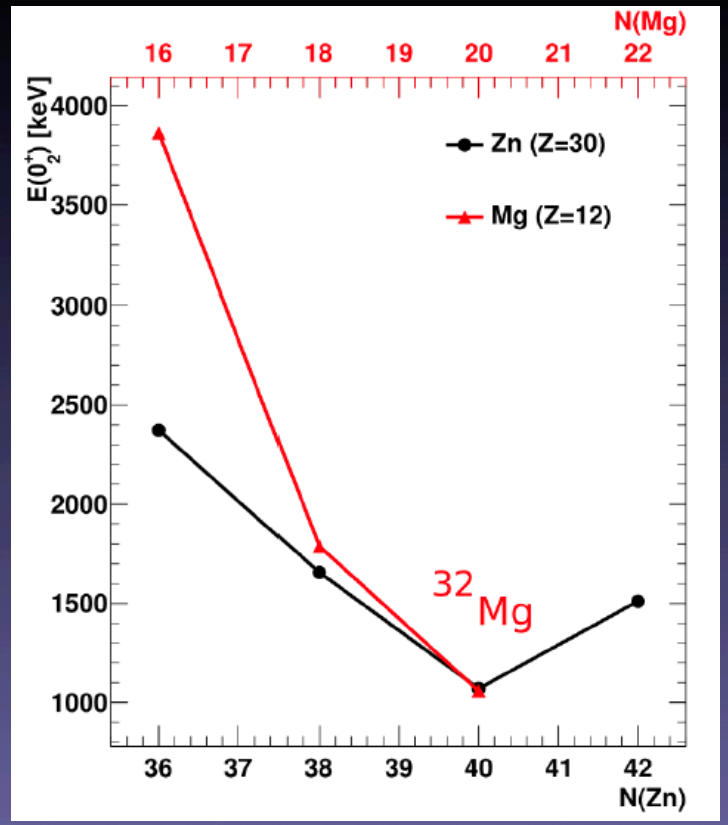
adding two protons gives this:



^{70}Zn: yet another „Island of Inversion“ ?

A. F. Lisetskiy, priv. communication





$f_{5/2}$ $p_{3/2}$ $p_{1/2}$ $g_{9/2}$ for p+n
jj4c interaction (B.A. Brown)

J^π	A	$\pi(f_{5/2})$	$\pi(p_{3/2})$	$\nu(f_{5/2})$	$\nu(p_{3/2})$	$\nu(p_{1/2})$	$\nu(g_{9/2})$
0^+_1	0.146	0	2	4	4	2	2
	0.083	0	2	6	4	2	0
	0.065	2	0	4	4	0	4
	1.0	0.61	1.04	4.35	3.53	1.27	2.85
0^+_2	0.298	0	2	6	4	2	0
	0.076	2	0	4	4	0	4
	0.054	0	2	5	3	2	2
	1.0	0.54	1.17	4.95	3.54	1.44	2.07

if „closed“ configuration on top of 0^+_2: g (2^+) large !
shell model:
$g(2^+_1)$=0.276, configuration „6 4 2 0“ < 10^{-10}
$g(2^+_2)$=0.10, configuration „6 4 2 0“ < 10^{-10}
$g(2^+_3)$=0.88, configuration „6 4 2 0“ largest! (18%)

I_i^π	Exp't.	FPD6 fp	KB3 fp	GXPFA fp	JJ4B $p_{3/2}f_{5/2}p_{1/2}g_{9/2}$
2^+_1	+0.38(2)[a]	+1.52	+1.83	+1.89	+0.276

DM et al, Phys. Rev. C 79, 054310 (2009)

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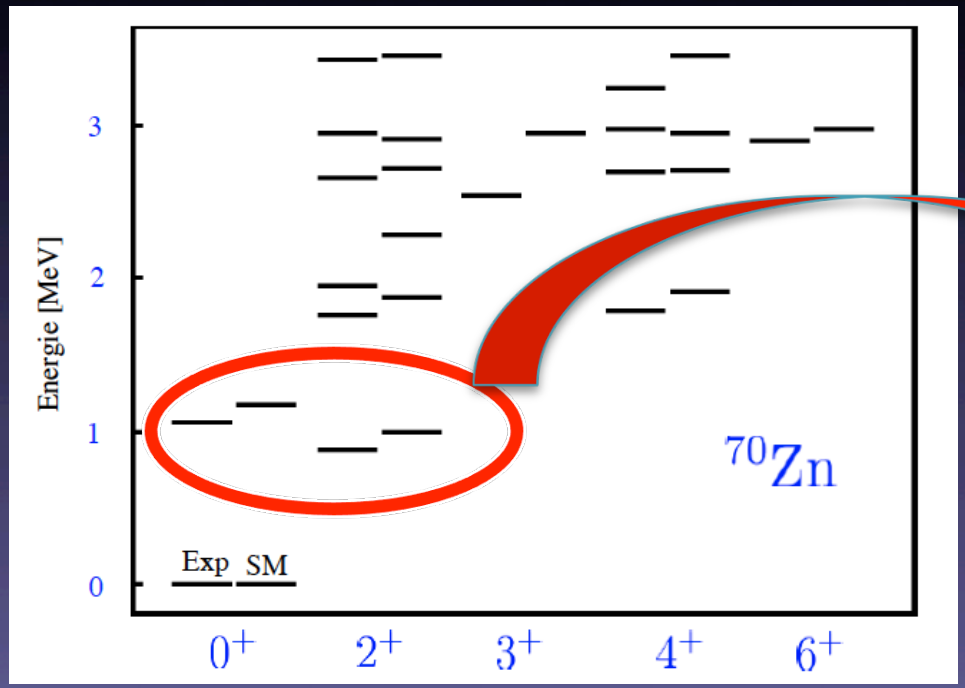
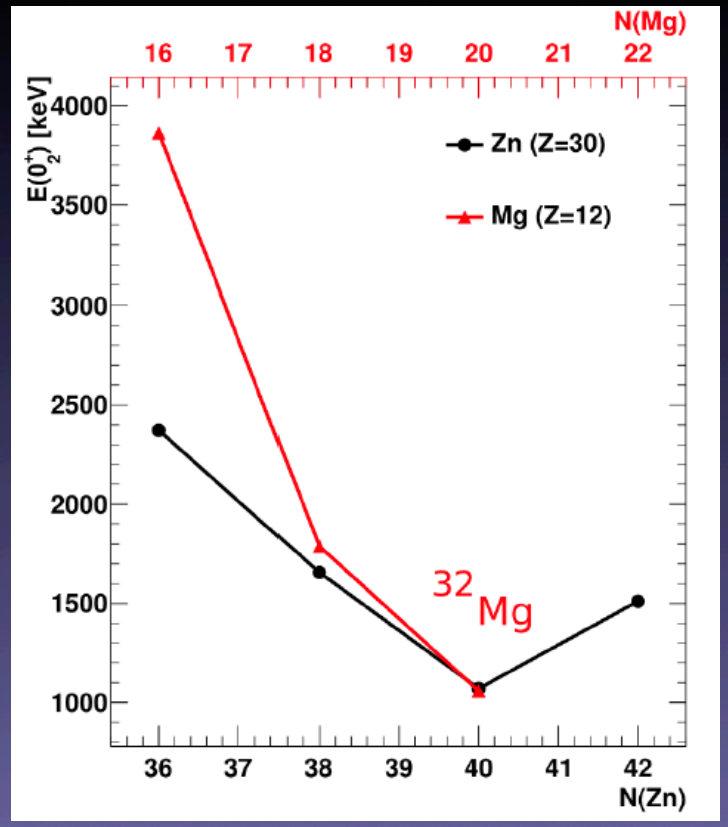
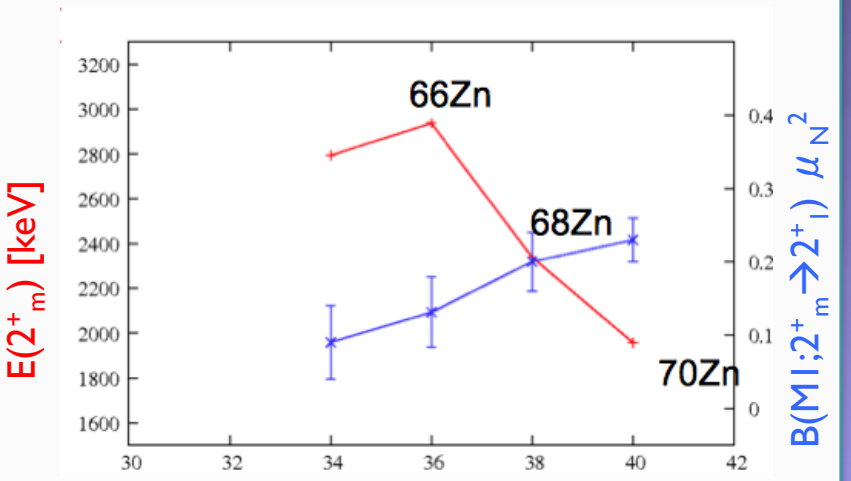




isovector-like M1 transition



shell model: $B(M1;2^+_m \rightarrow 2^+_1) = 0.18\ \mu_N^2$

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K. Heyde, J. Sau, PRC 33, 3 (1986), p. 1050

seniority υ =2 shell-model states, single-j:

$$\left|2_\pi^+\right\rangle = \left|\left[(j_\pi)^{n_\pi}_{\nu=2}\,;2^+\,(j_\nu)^{n_\nu}_{\nu=0}\,;0^+\right]2^+\right\rangle$$

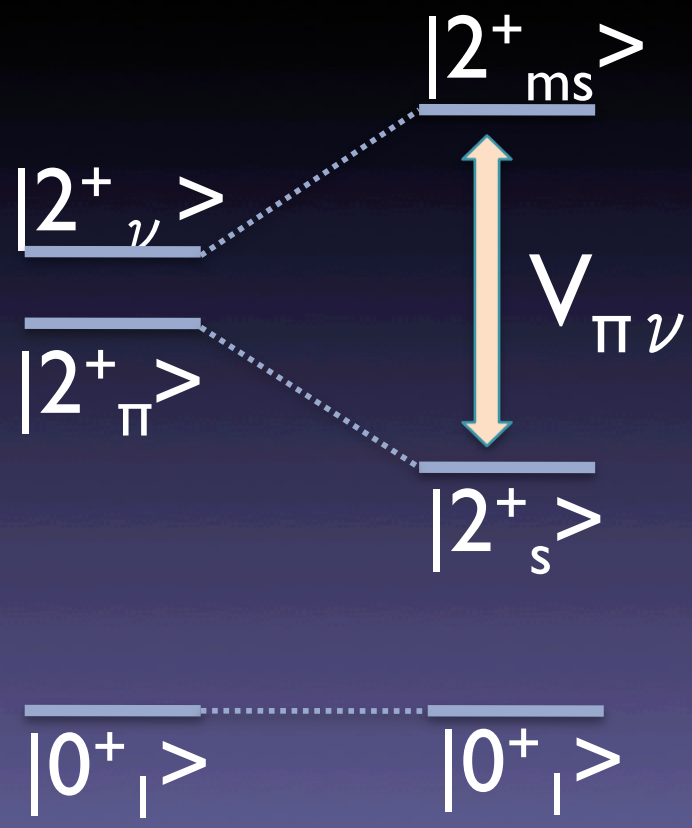
$$\left|2_\nu^+\right\rangle = \left|\left[(j_\pi)^{n_\pi}_{\nu=2}\,;0^+\,(j_\nu)^{n_\nu}_{\nu=0}\,;2^+\right]2^+\right\rangle$$

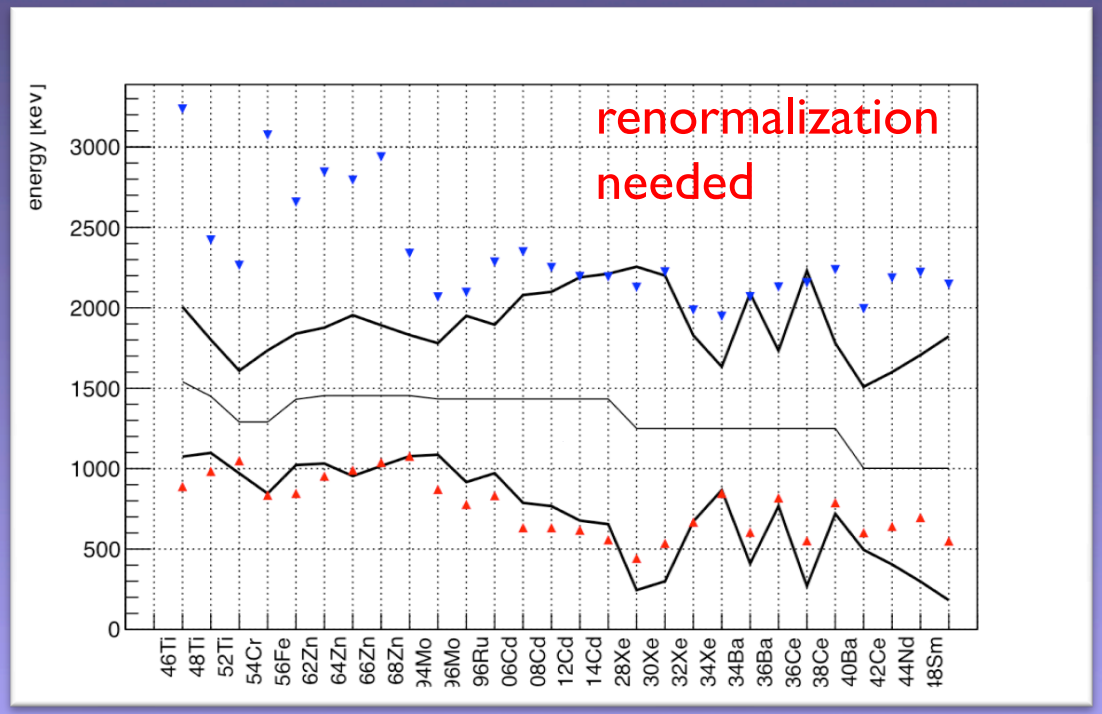
switch on interaction:

$$V_{\pi\nu} = \left\langle 2_\pi^+\left|-\kappa Q_\pi\cdot Q_\nu\right|2_\nu^+\right\rangle$$

$$\left|2_s^+\right\rangle = \frac{1}{\sqrt{2}}\left[\left|2_\pi^+\right\rangle + \left|2_\nu^+\right\rangle\right]$$

$$\left|2_{ms}^+\right\rangle = \frac{1}{\sqrt{2}}\left[\left|2_\pi^+\right\rangle - \left|2_\nu^+\right\rangle\right]$$





M. Zirnbauer, Nucl. Phys. A 419 (1984) p. 241

„The future of the microscopic interacting boson model will very crucially depend on whether a simple and satisfactory solution to the problem of renormalization can be found“

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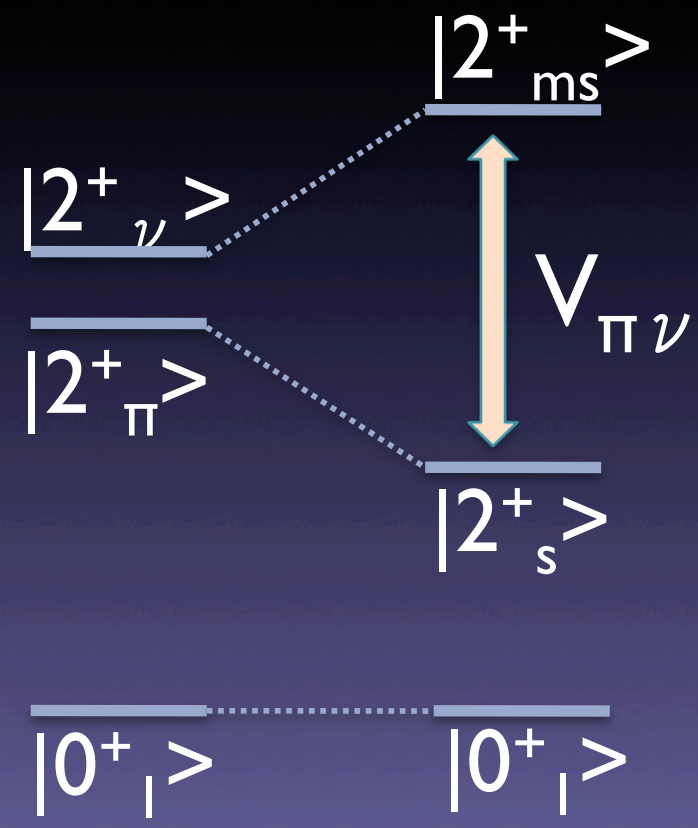

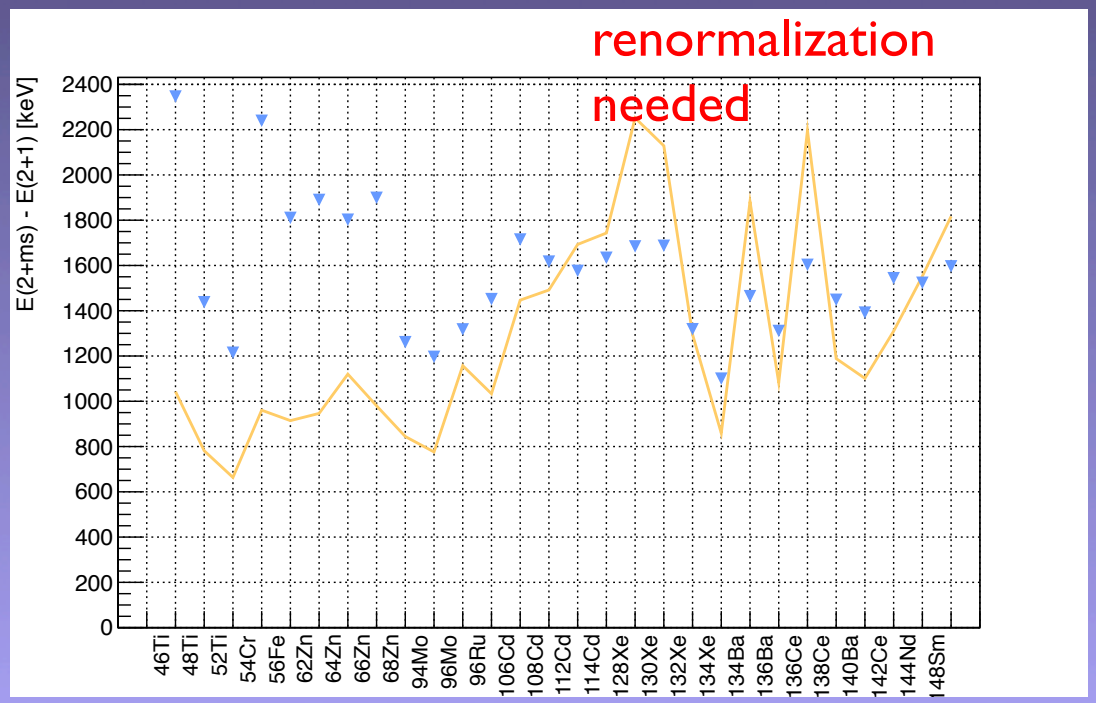

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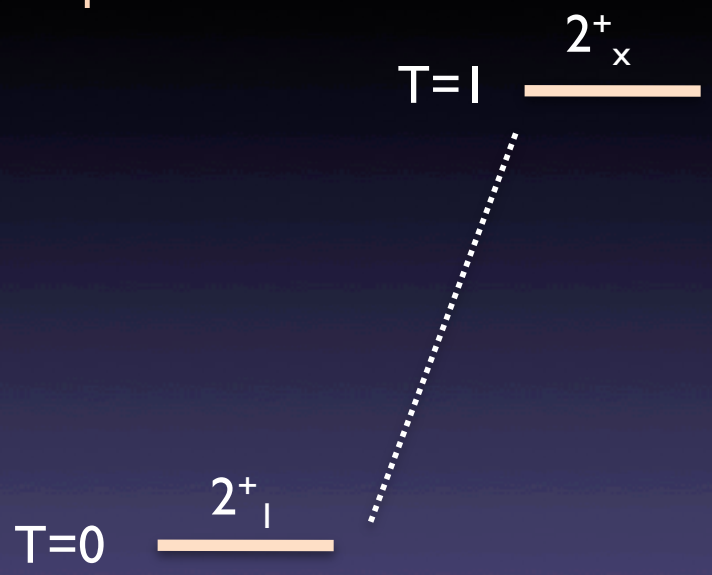
Maybe we can learn from the Isospin formalism ?

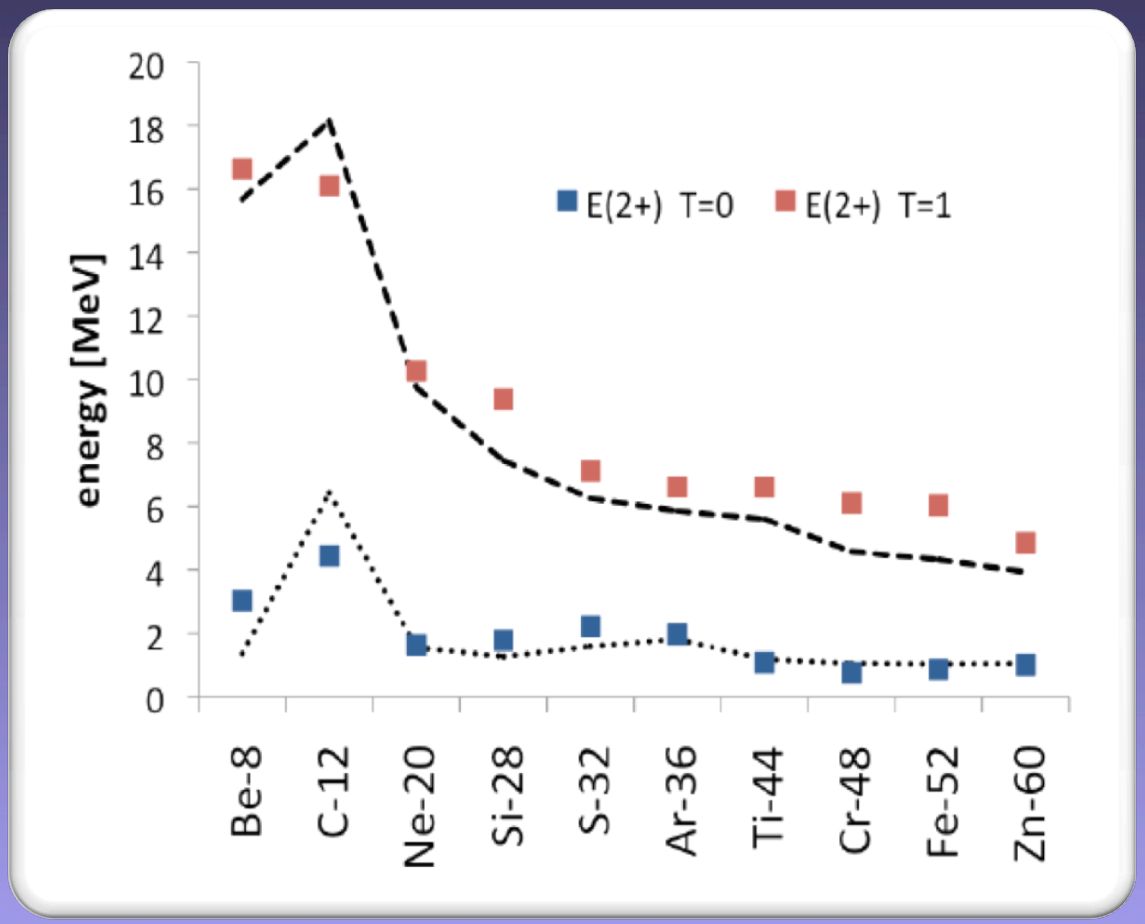
monopole Majorana exchange operator
(Wigner, SU(4) scheme)

$M = \sum_{i<j} P_{ij} \approx T(T+1)$



$\langle J^+_\rho | M_{\rho\rho} | J^+_\rho \rangle = \text{const.} = \varepsilon$

$\langle J^+_\rho | M_{pn} | J^+_{\rho'} \rangle = \text{const.} = \delta$



K. Heyde et al., PRC 49,5, p. 2499 (1994):

seniority scheme: only monopole pn does contribute for groundsate
δ : double difference of binding energies
$\delta = \delta V_{pn}(Z,N)$?

M. Bender, P.-H. Heenen, arXiv: 1102.1903v1, 2011

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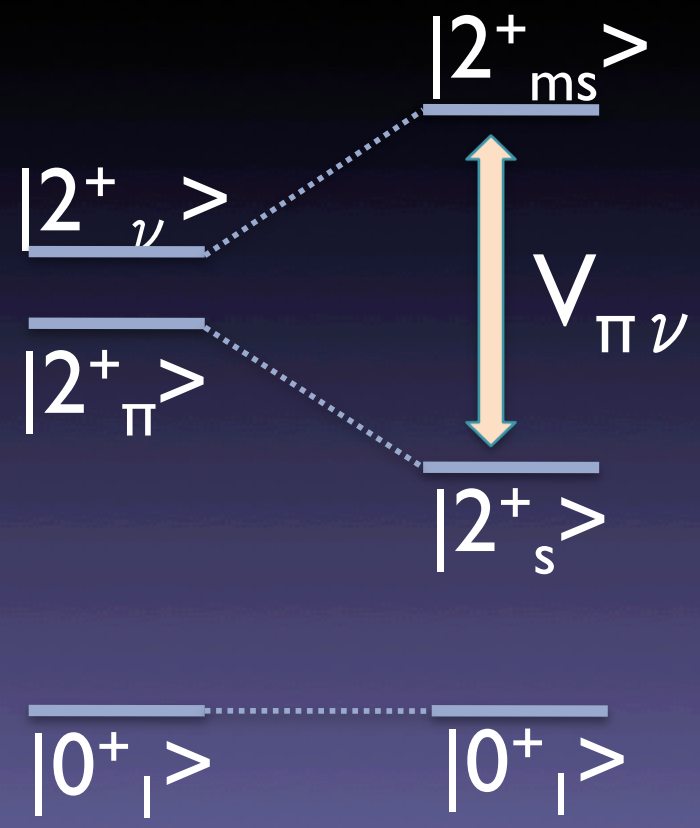

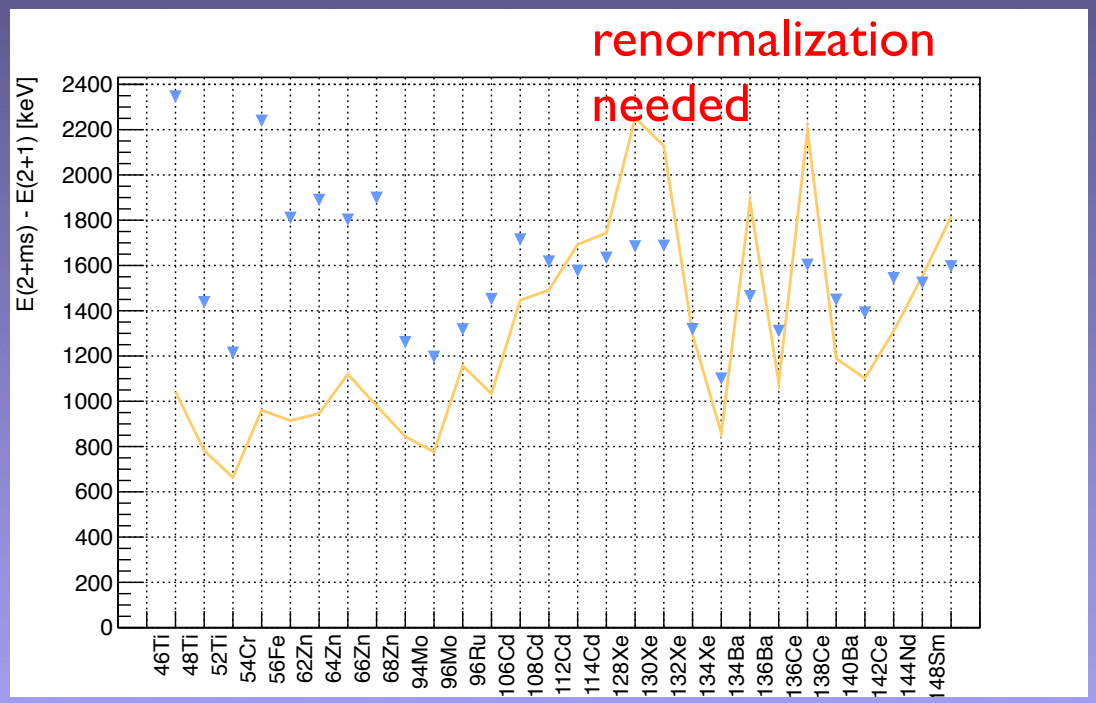

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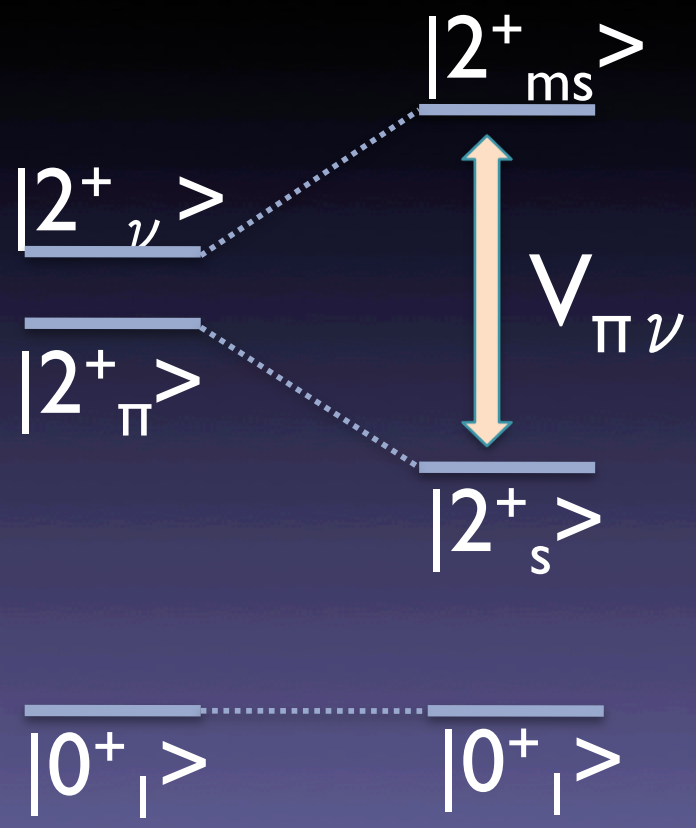
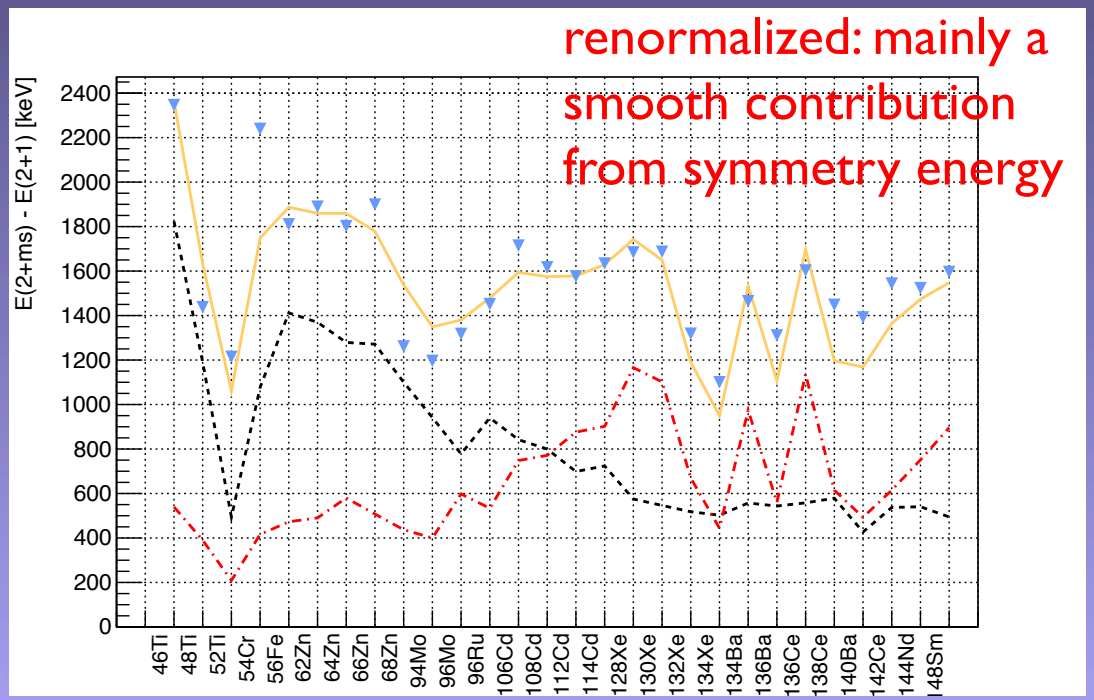
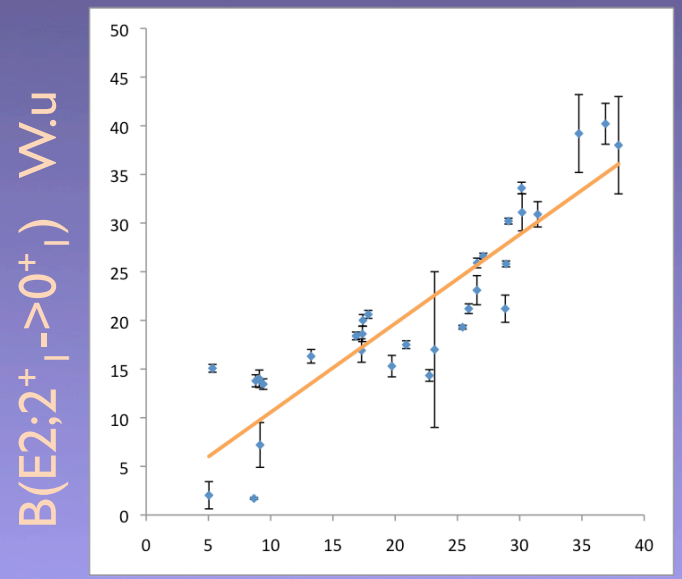
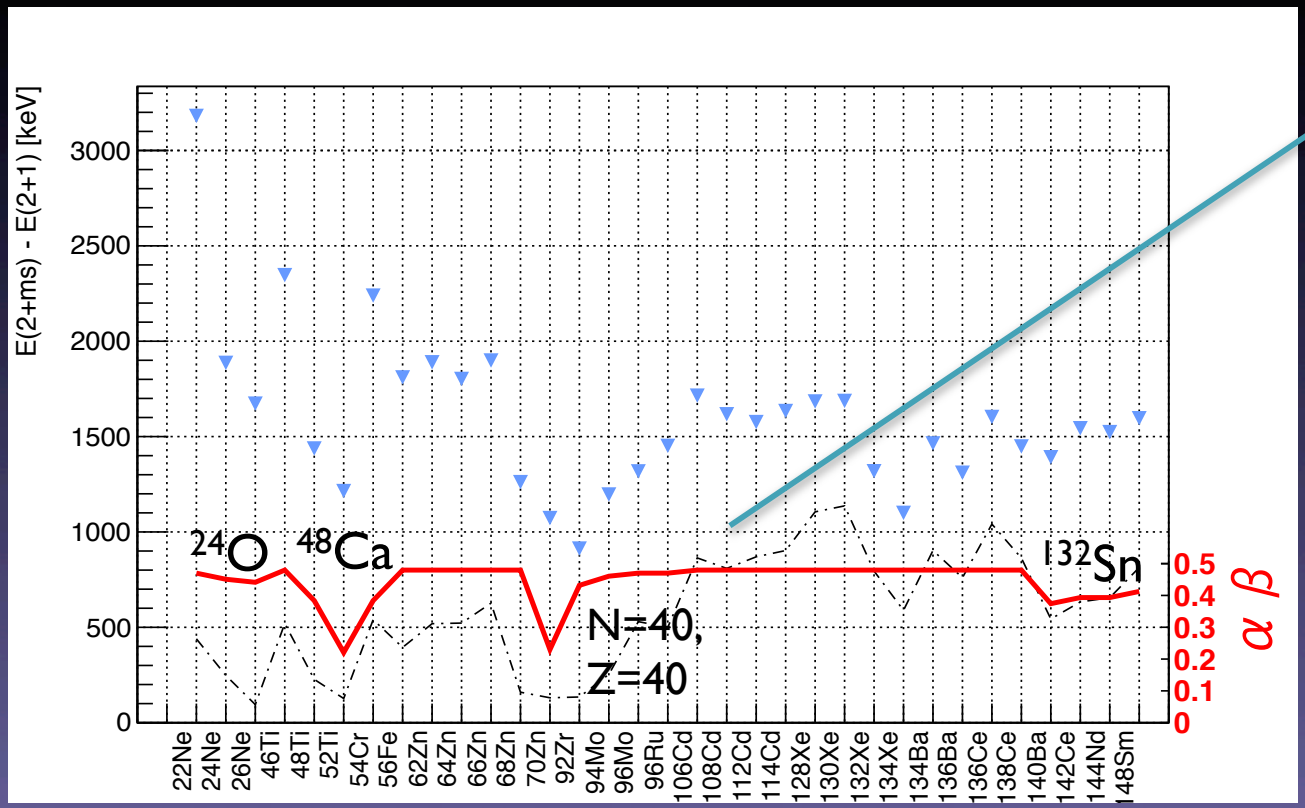






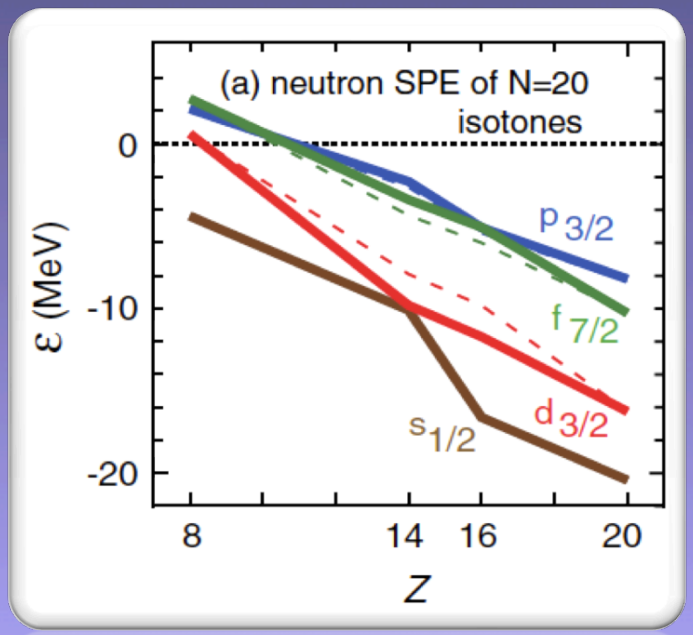
quad. interaction

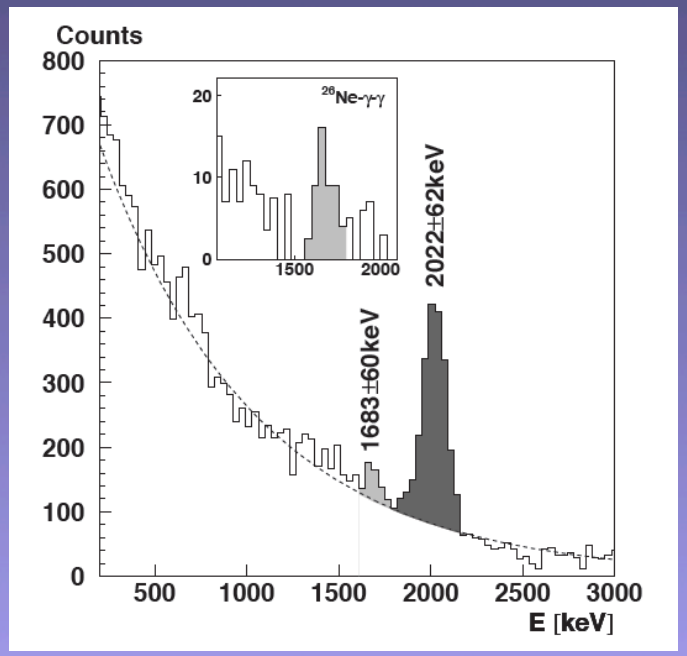
Proton-Neutron polarization deduced from MSS



this curve has NO parameter / normalization

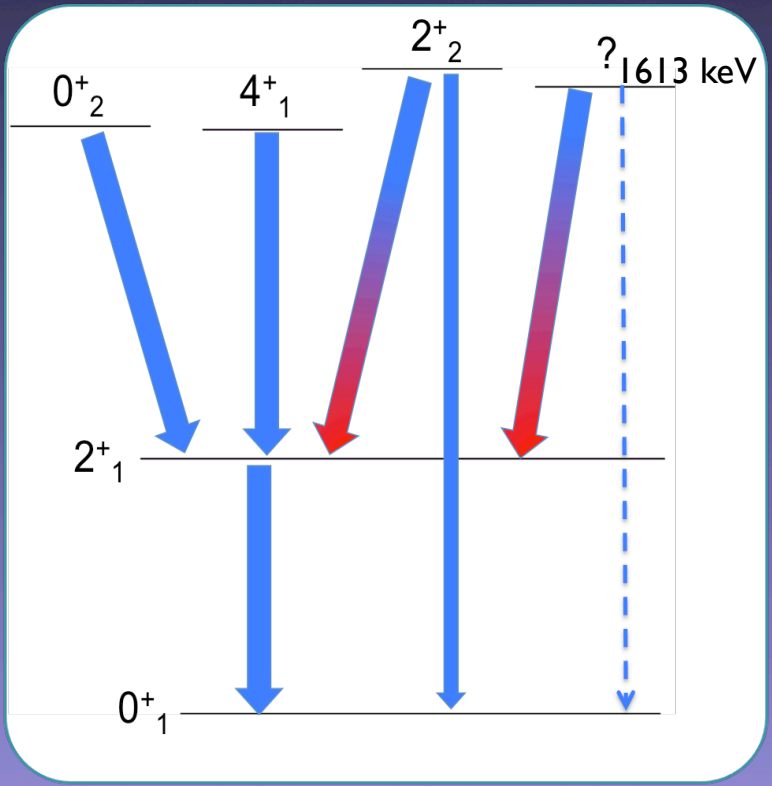
^{26}Ne, Coulomb Excitation @ RIKEN
J. Gibelin et al., PRC 75, 057306 (2007)
shell model: 2^+_2 has isovector character

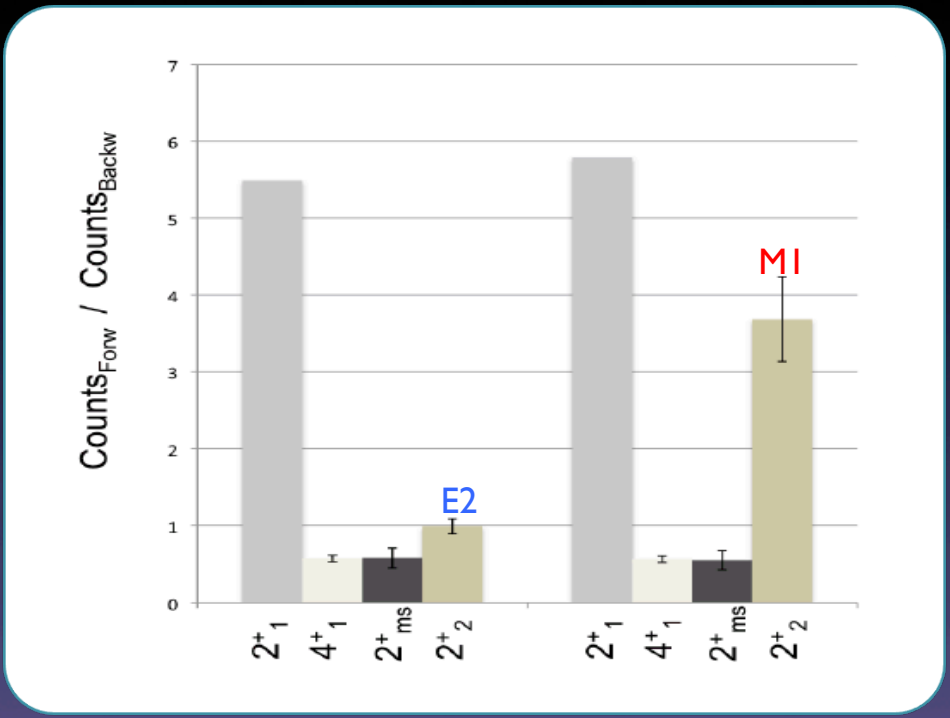


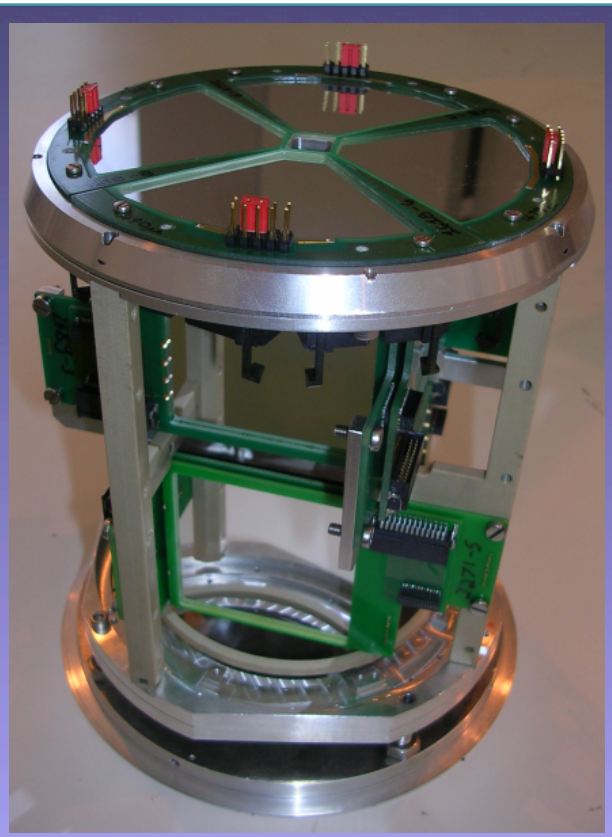


Study of Mixed Symmetry States using RIB experiments: Coulex

up to now: no successful population of MSS using RIB
(88Kr @ ISOLDE + GSI fast beam)







1613 keV state from β -decay:
J.–C. Thomas et al., Phys. Rev. C 74, 054309 (2006)

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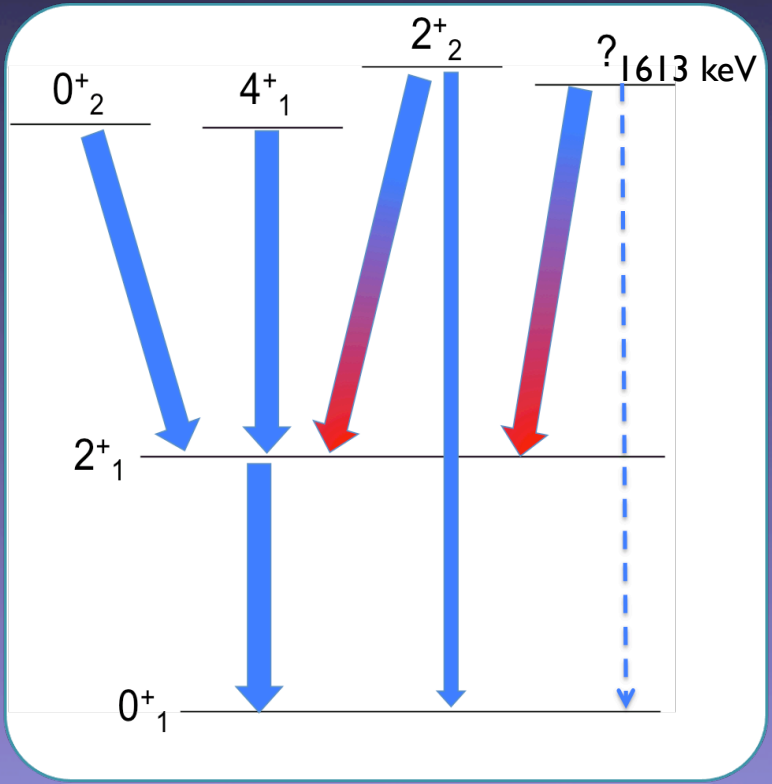

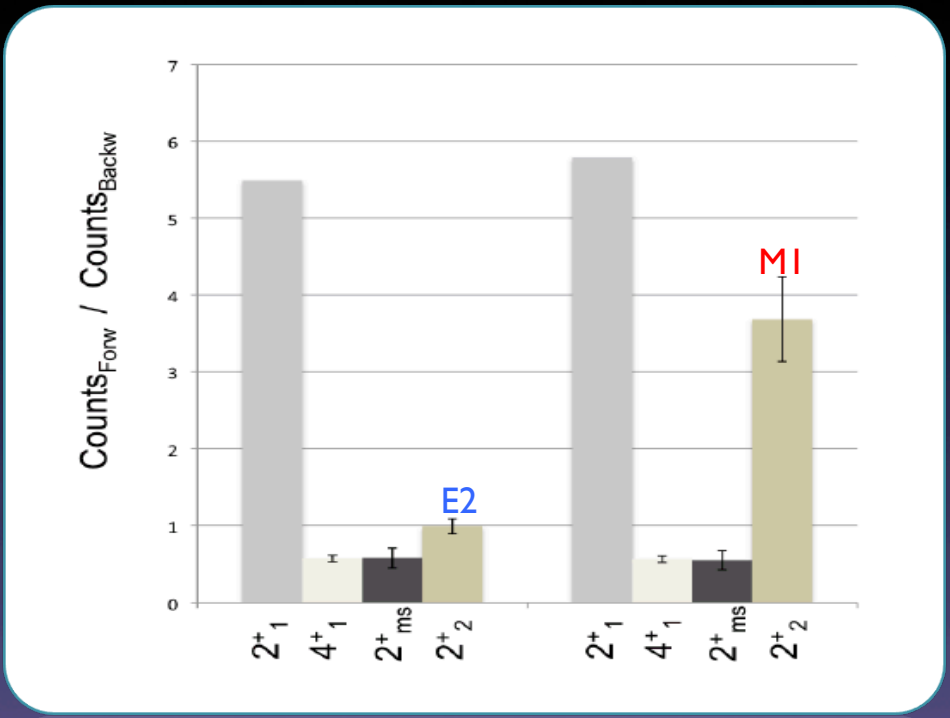

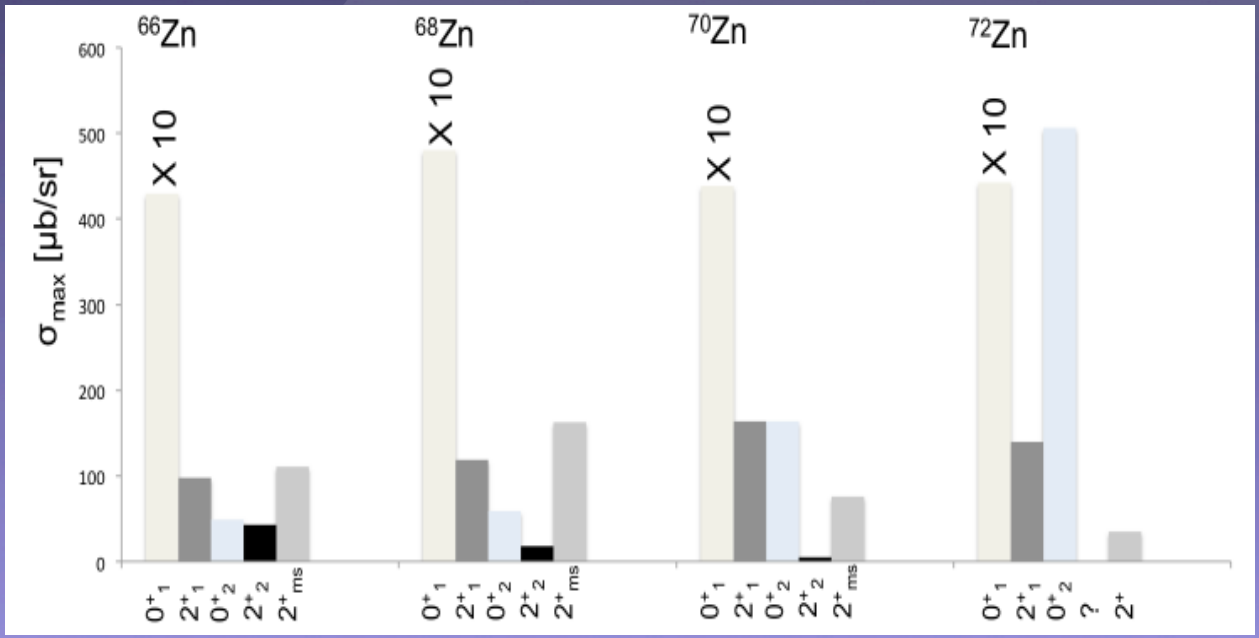

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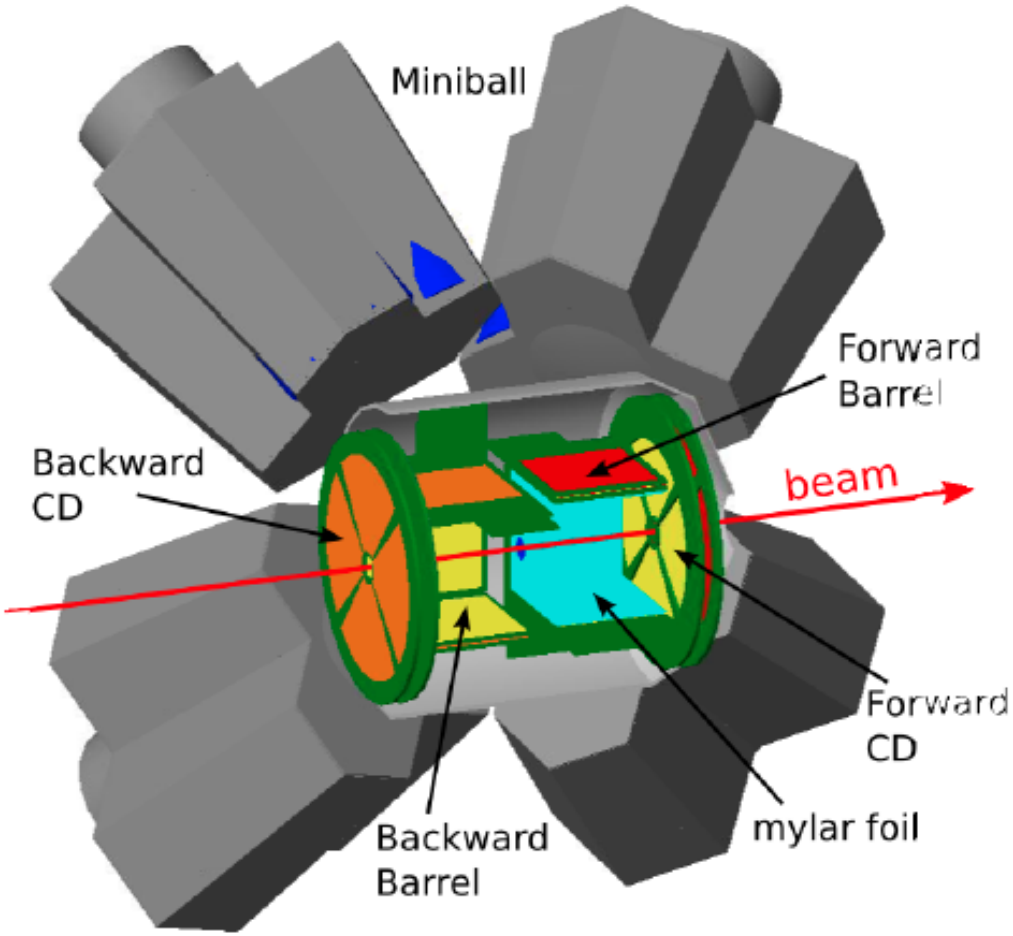
J.–C. Thomas et al., Phys. Rev. C 74, 054309 (2006)

F. R. Hudson et al., Nucl Phys A189 (1972) p. 264

Experimental setup: T-REX + MINIBALL

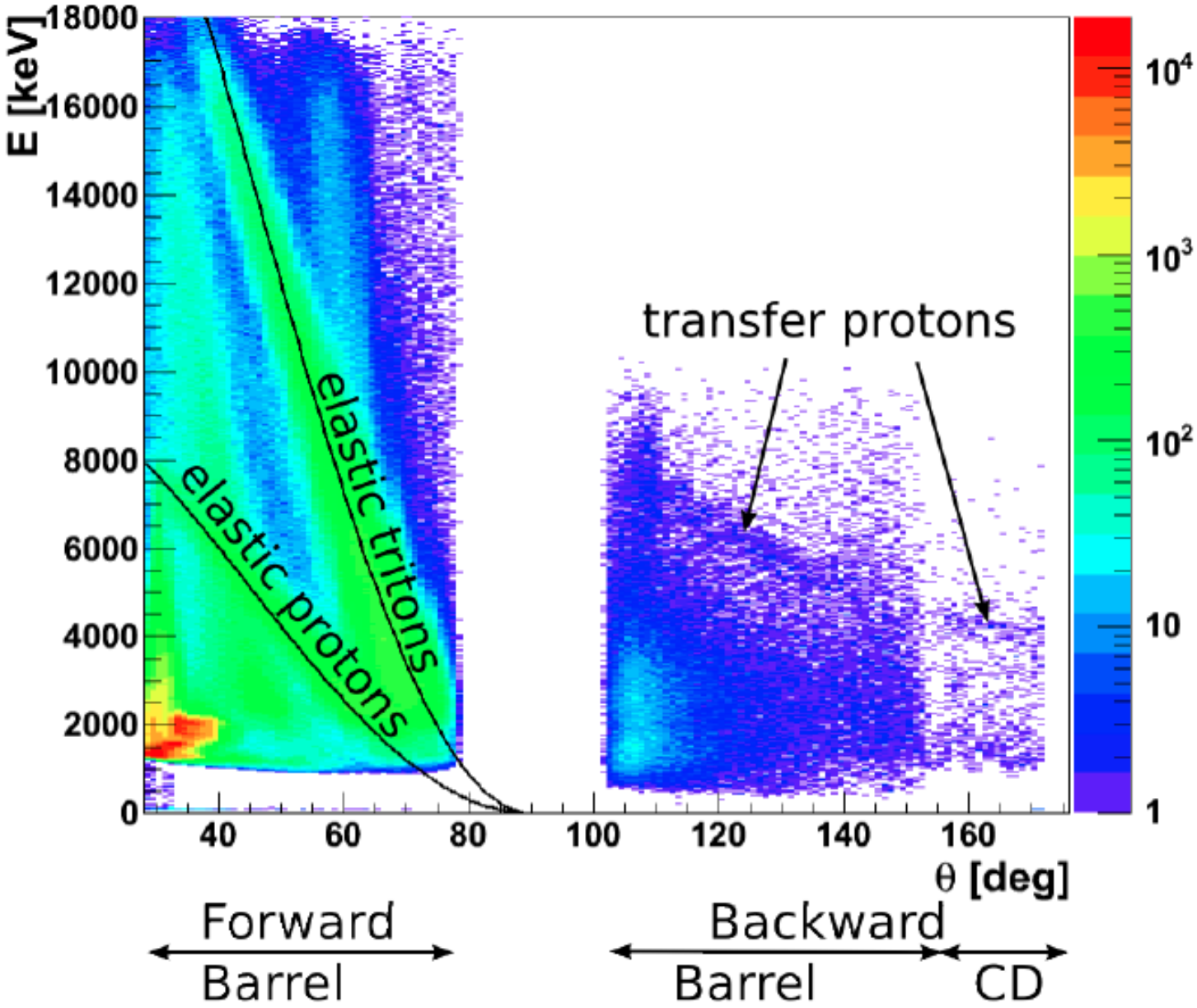
- Target: 40 μg/cm^2 ^{3}H (2n- and 1n-transfer) contained in a 500 μg/cm^2 Ti-foil (Coulex)
- Fully equipped T-REX allows to combine Coulex and transfer experiments.



- Segmented $\Delta E - E$ Si-telescopes for particle identification (p, d, ...)
- 12 μm mylar protection foil in front of Forward Barrel
- Segmented Forward CD for Coulex
- MINIBALL for γ-rays

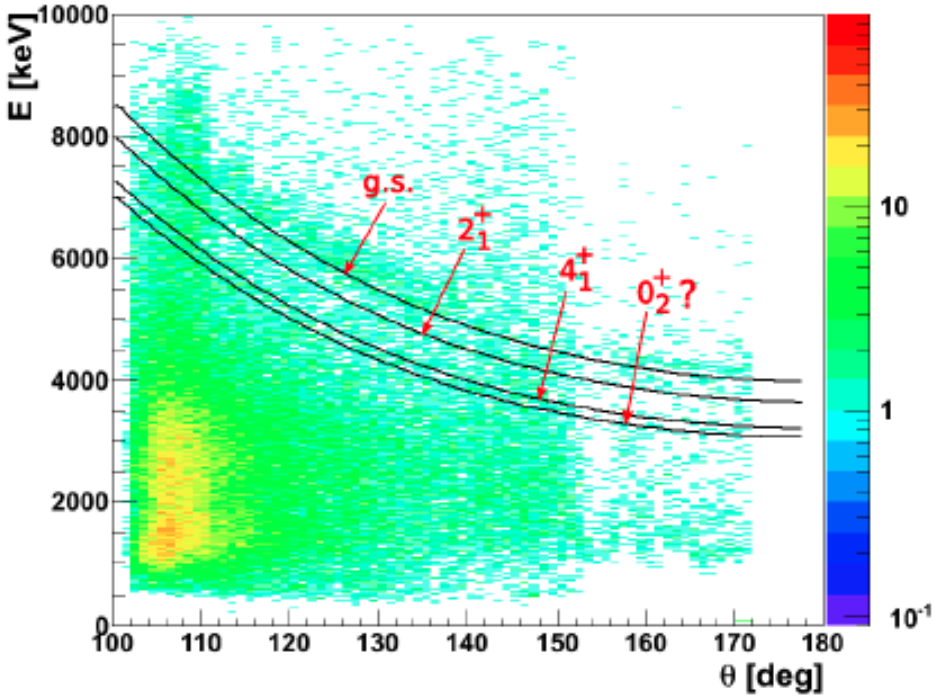
Analysis of IS510 by Stefanie Klupp, E12, TU Munich

2n-Transfer: Reconstructed energy of all particles

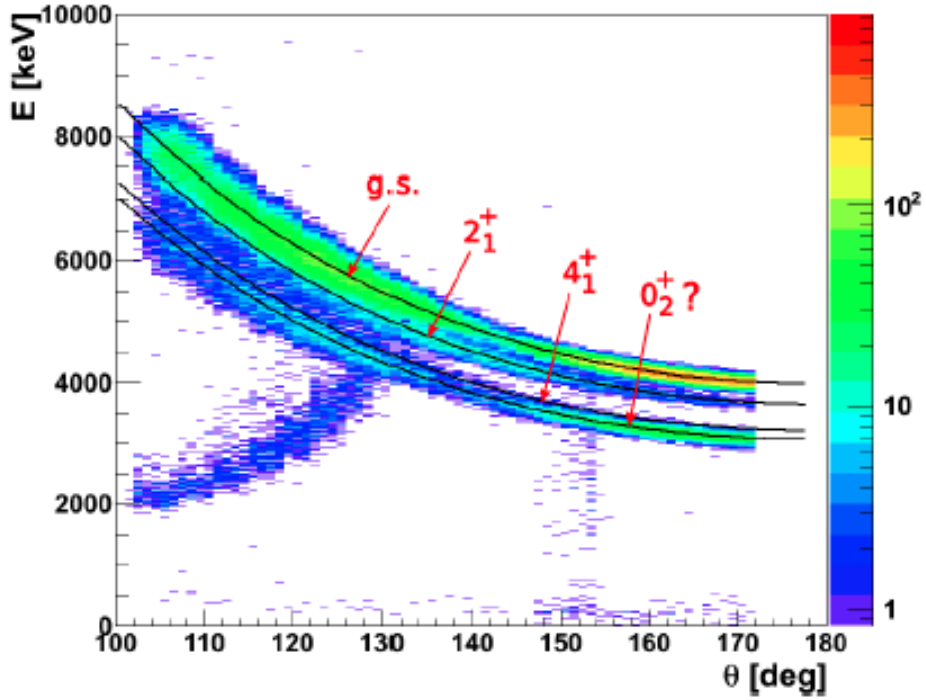


2n-Transfer: Reconstructed energy of the backward detectors

Experiment



Simulation (only transfer p)

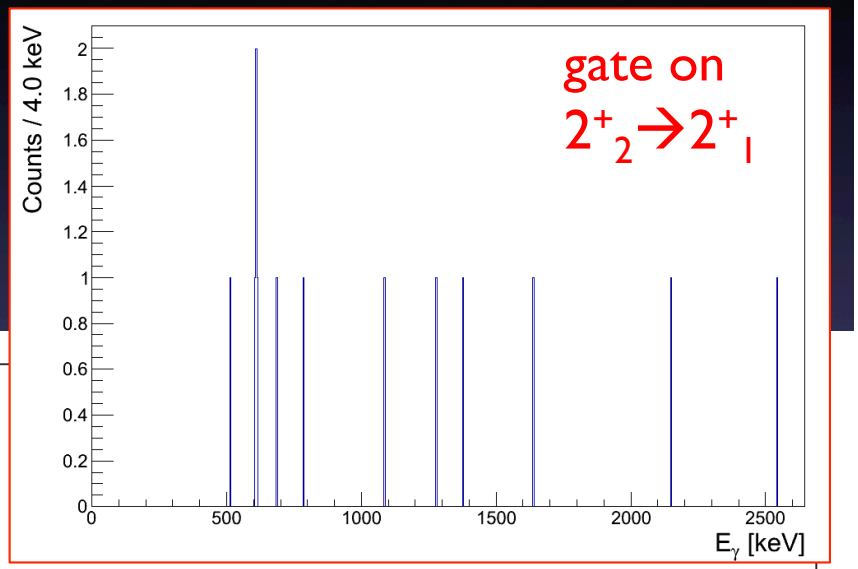


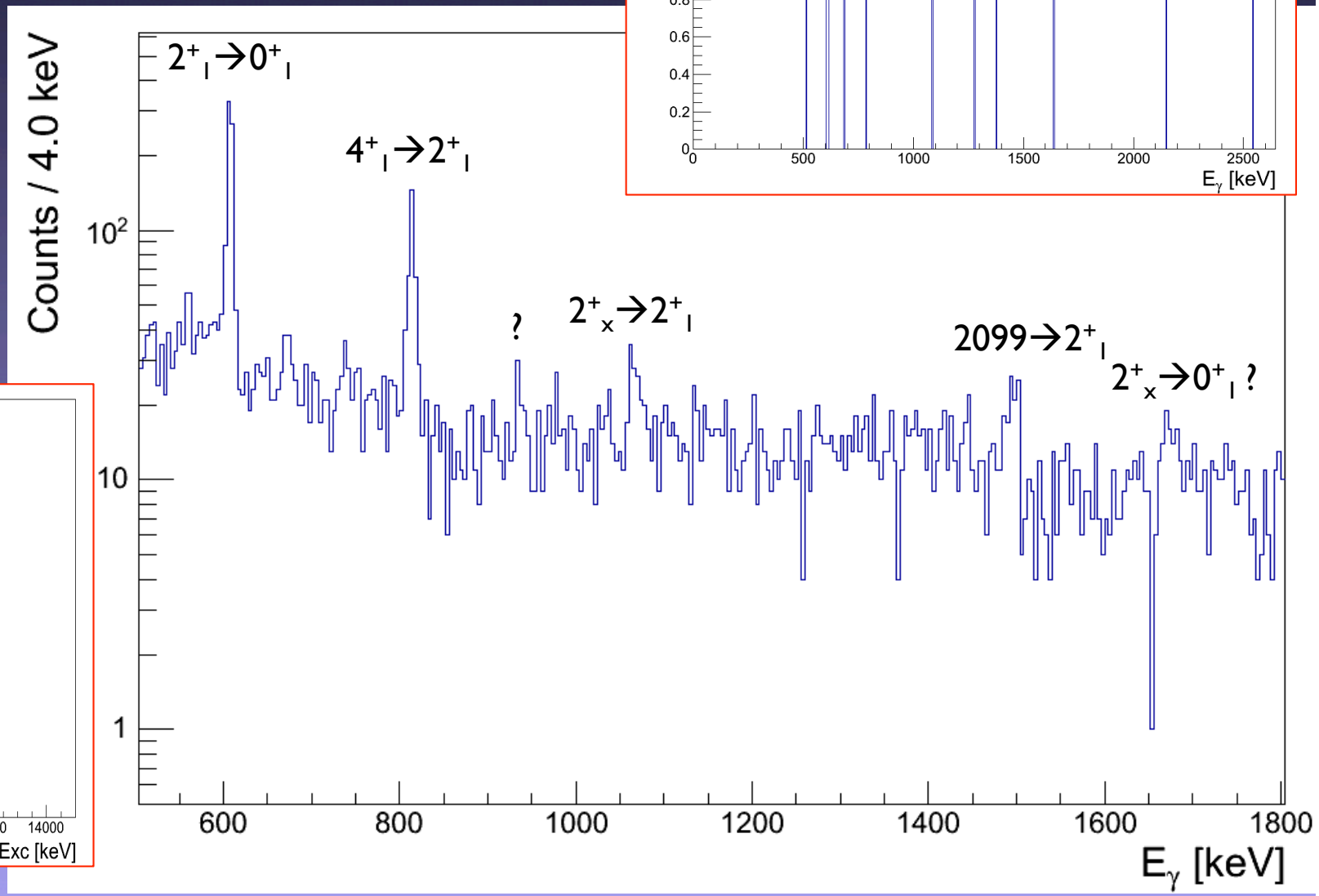
- Ground state visible
- Discrimination between other states challenging in the experiment as well as in the simulation

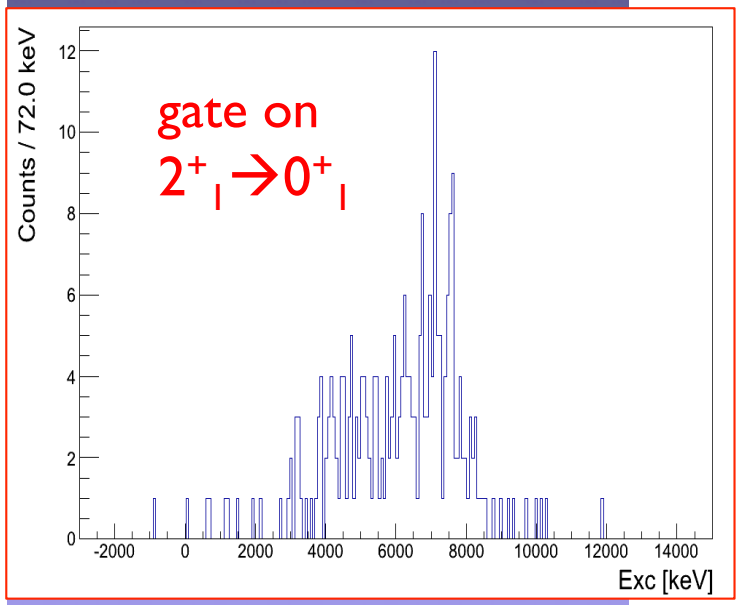
MINIBALL-spectra of ^{74}Zn after 2n transfer, gated on protons

identification of 0^+_2: ongoing, but seems to go up

isovector 2^+: remember: $\sigma(2^+_{ms}) / \sigma(2^+_2) = 15$!



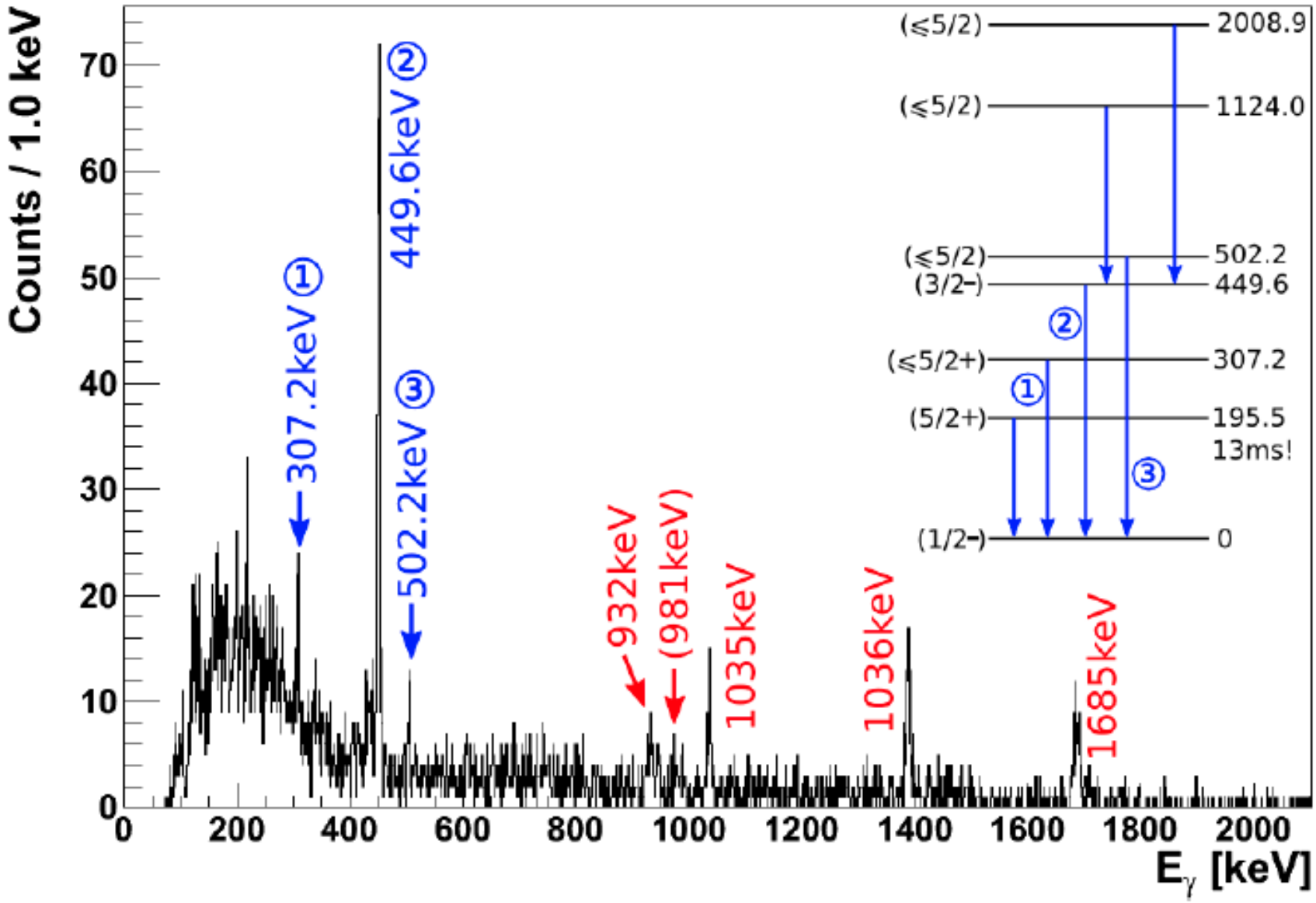




Analysis of IS510 by Stefanie Klupp, E12, TU Munich

1n-Transfer: γ-rays in coincidence with deuterons

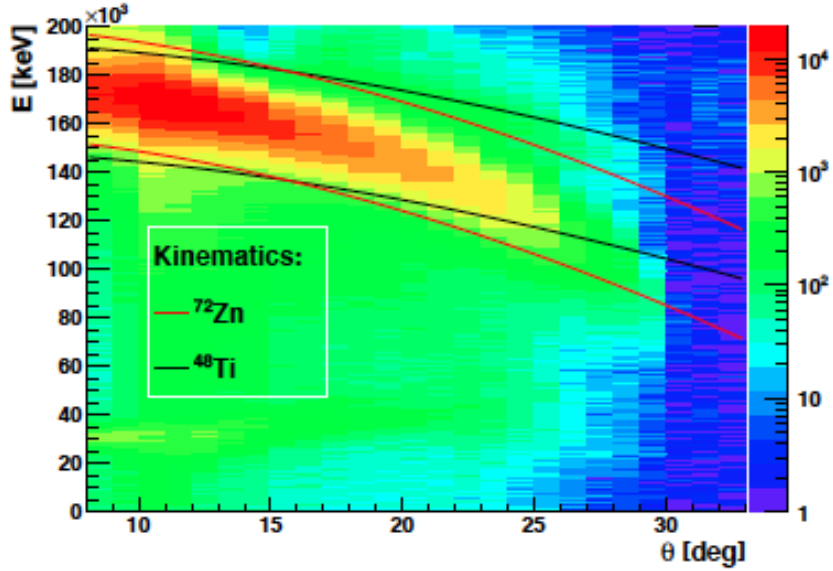
^{73}Zn can be studied with the 1n-transfer reaction t(^{72}Zn,d)^{73}Zn.



Coulex: Modifications for the "real" Coulex experiment

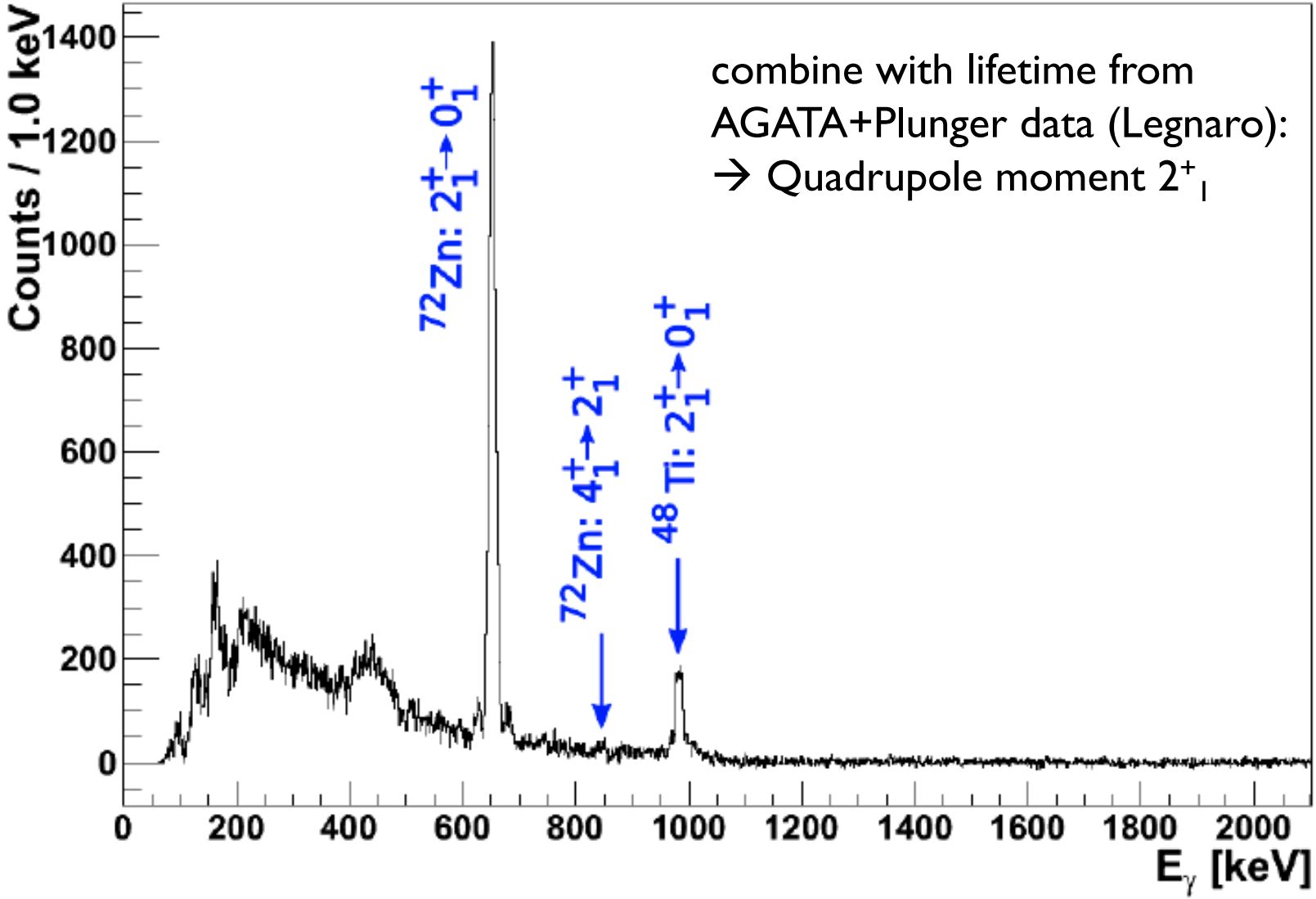
Test experiment 2011: ^{48}Ti as Coulex target was fixed

- 2_1^+ state of ^{48}Ti is close to the $2_2^+ \rightarrow 2_1^+$ transition ($\Delta E \approx 24\,\mathrm{keV}$)
- ^{72}Zn and ^{48}Ti are kinematically strongly overlapping.
  $\Rightarrow$ Identification of ejectile and recoil nearly impossible



$\Rightarrow$ More suitable Coulex target is required for "real" experiment in 2012

Coulex: First results



combine with lifetime from AGATA+Plunger data (Legnaro):
→ Quadrupole moment 2^+_1

$1.95 \cdot 10^4$ counts in the ^{72}Zn($2_1^+ \to 0_1^+$) transition in 72h measurement time!

Summary + Outlook

- evolution of (sub)shells closely related to quadrupole pn interaction (+ higher oders...)
- low-lying M1-strength in even-even nuclei: good probe to characterize the „robustness“ of a core
- 3 in 1 experiment at ISOLDE: coulex + 1n transfer + 2n transfer using tritium target
- population of off-yrast 2^+ state in ^{74}Zn
- exc. 0^+ state in ^{74}Zn seems to go up ?
- rich spectra on ^{73}Zn
- planed 2012: ^{72}Zn coulex, first identification of isovector 2^+ using RIB

during ISOLDE shutdown:

- T-REX upgrade: we nned better resolution !
- measurent of magnetic moments of very short lived states in light nuclei @ MLL Tandem, Munic; MINIBALL cluster detectors needed

Thanks for your attention

IS 510 collaboration

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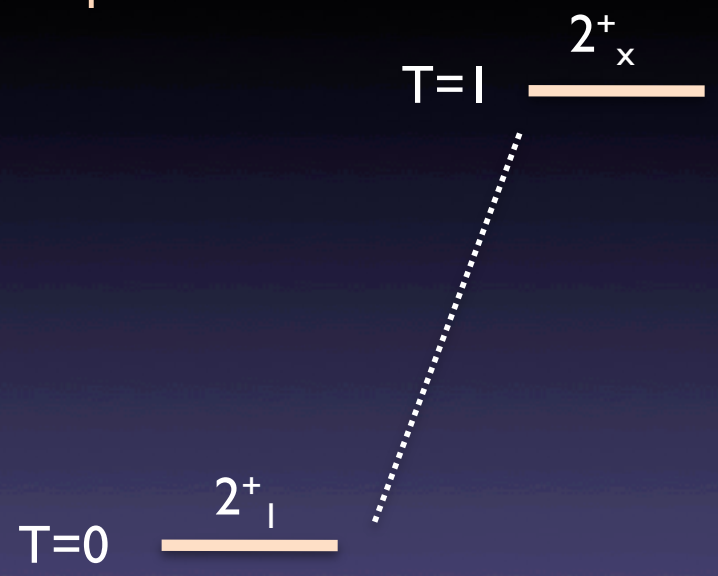
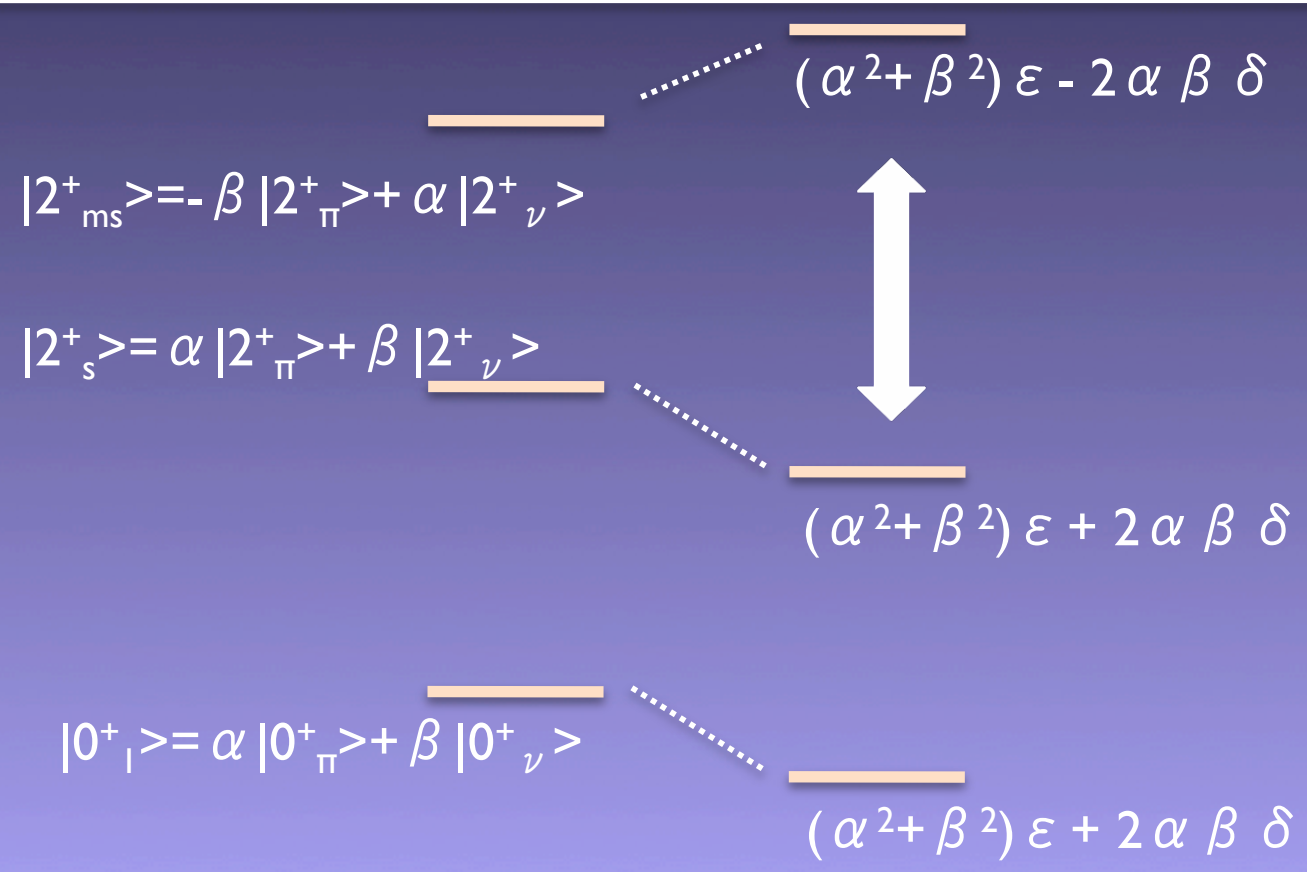
E12: S. Klupp
TU Darmstadt: N. Pietralla+group
Kentucky: S.W.Yates + group

Maybe we can learn from the Isospin formalism ?

monopole Majorana exchange operator
(Wigner, SU(4) scheme)

$M = \sum_{i<j} P_{ij} \approx T(T+1)$





$\langle J^+_\rho \,|\, M_{\rho\rho} \,|\, J^+_\rho \rangle = \text{const.} = \varepsilon$

$\langle J^+_\rho \,|\, M_{pn} \,|\, J^+_{\rho'} \rangle = \text{const.} = \delta$

K. Heyde et al., PRC 49,5, p. 2499 (1994):

seniority scheme: only monopole
pn does contribute for groundsate
δ : double difference of binding energies