Nuclear Shell Evolution in the Island of Inversion Studied via the $^{28}Mg(t,^{30}Mg)p$ Reaction

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UNIVERSITY of GUELPH

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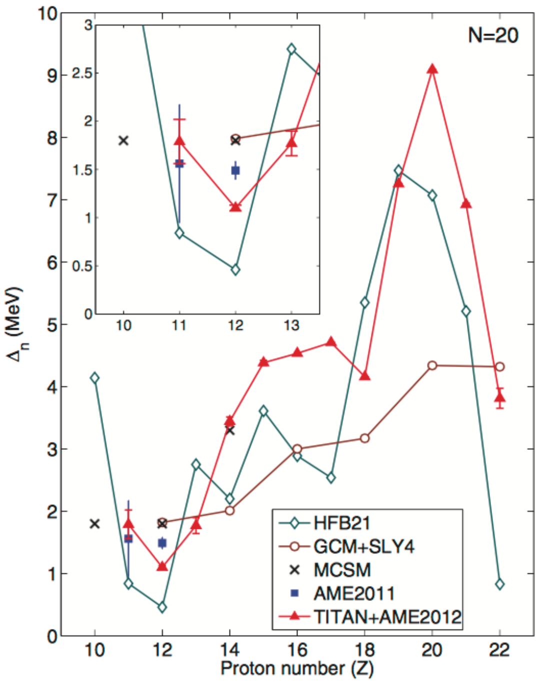
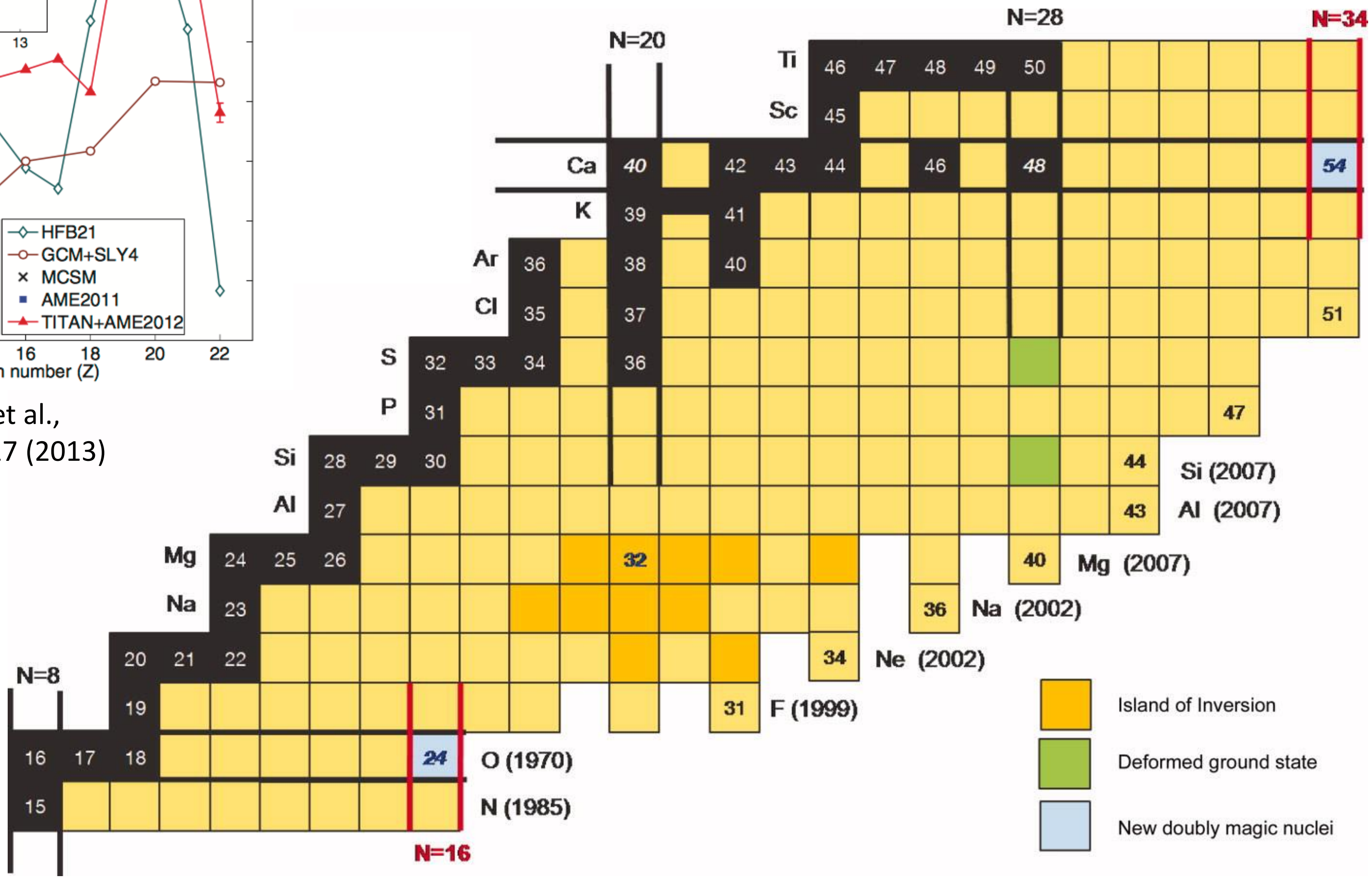
TRIUMF

Introduction: The "Island of Inversion"

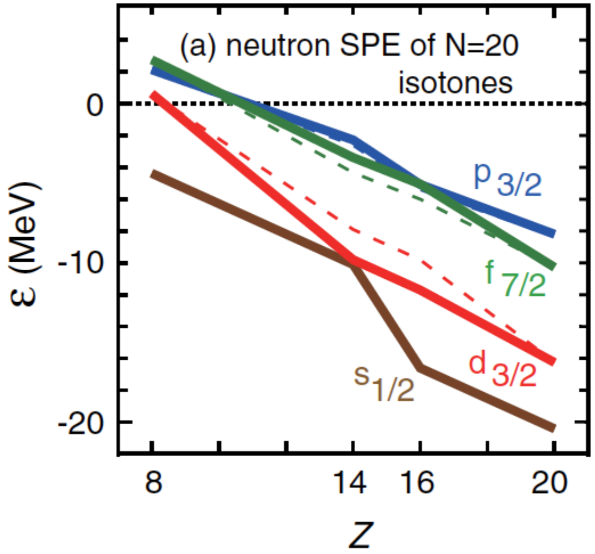


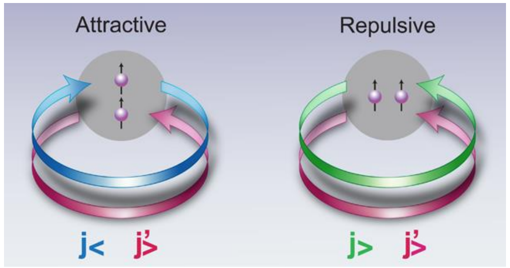
A. Chaudhuri et al.,
PRC **88**, 054317 (2013)

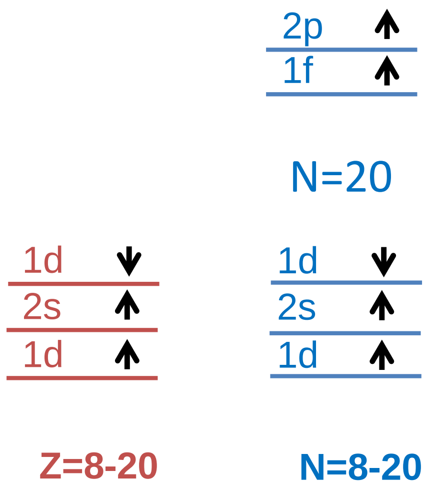


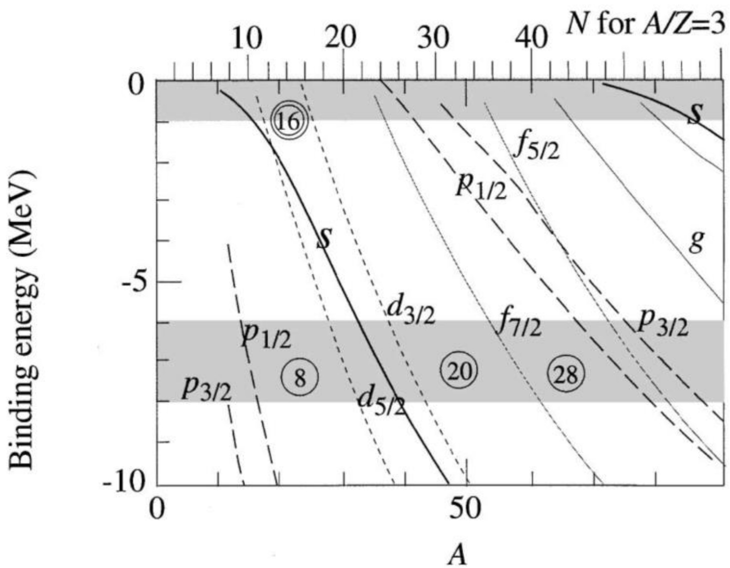
R. Krücken; *Contemporary Physics* **2011,** 52, 101-120.

The origin of shell evolution (in the IOI)







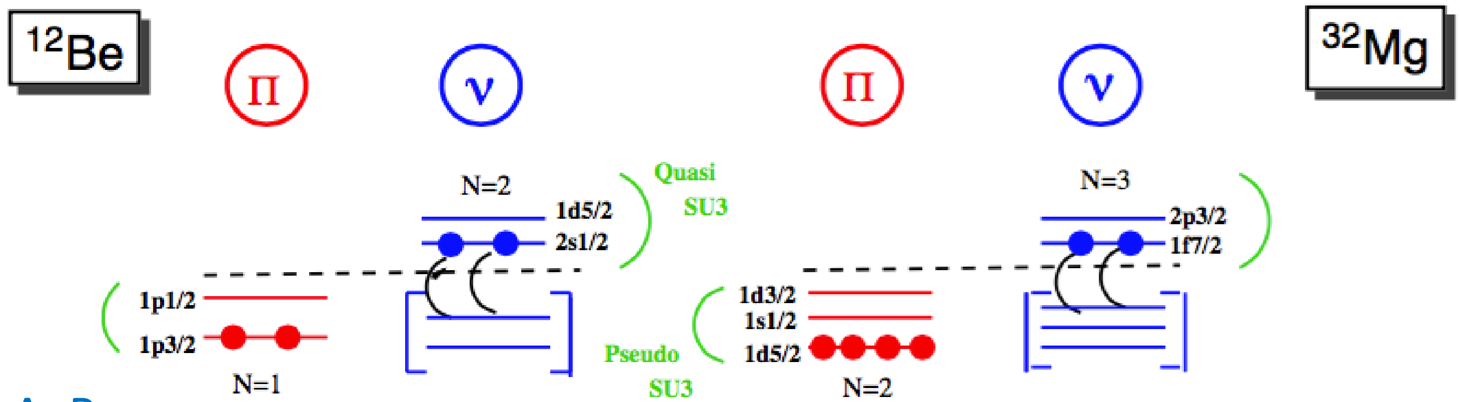


A. Ozawa et al., PRL 84 (2000)

What is the origin of nuclear shell evolution?

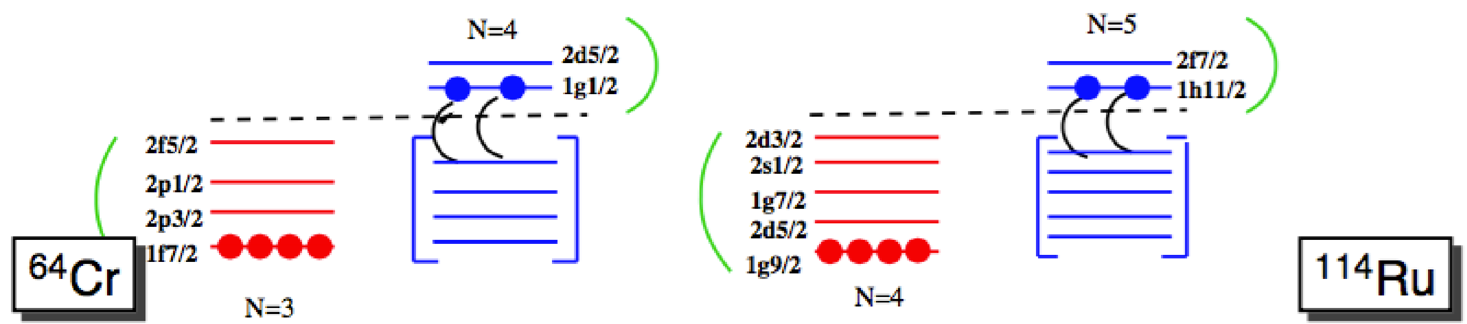
- tensor force: spin-dependent T=0 proton-neutron interaction around N=20 mostly effects neutron $d_{3/2}$ orbital when going neutron-rich
- Neutron halo: low-l orbital gains energy by extending the wavefunction to larger radii

How deformation sets in at N=8, 20, 40, 70. Universality

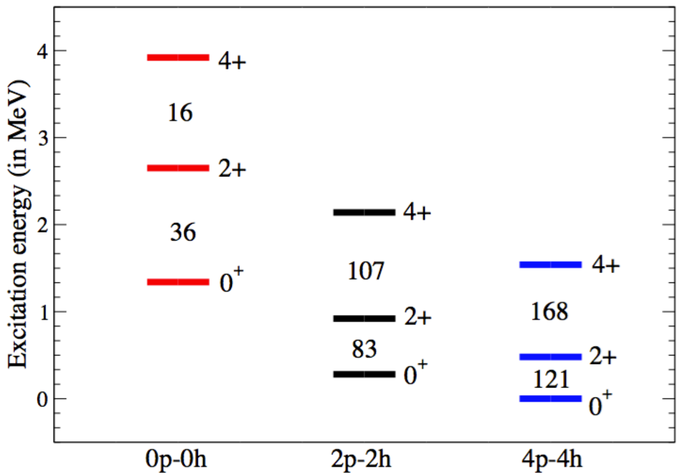


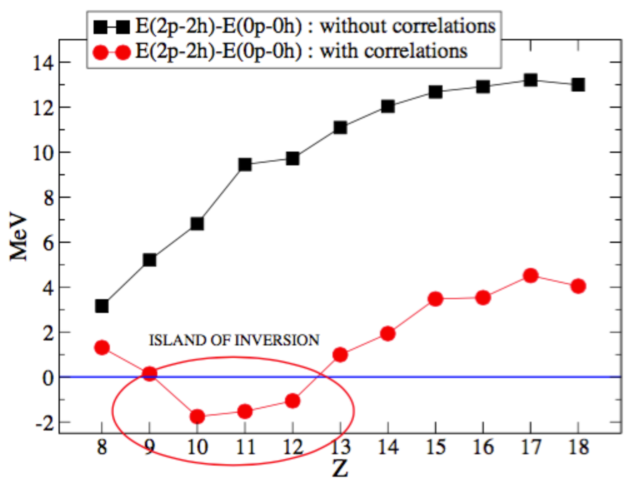
slide from A. Poves:

- **spherical nuclear mean field is close to the HO**
- **dynamical symmetry of the HO SU(3) → quadrupole! (Elliot's model)**



The shell model description of configuration mixing

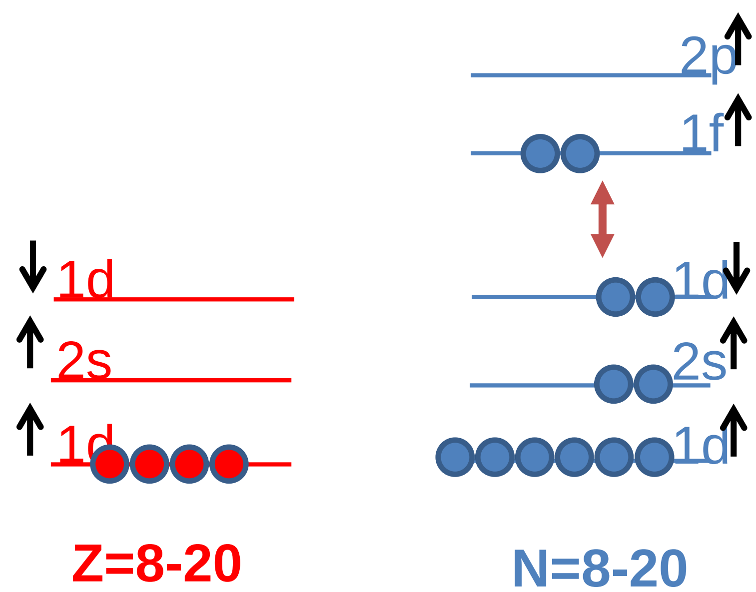




"Shape coexistence is the portal to deformation" (A. Poves)

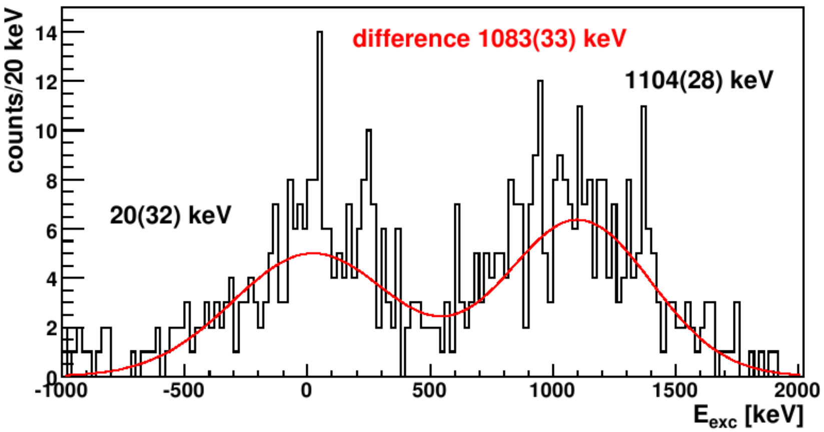
$$|0_1^+\rangle = \alpha\,|0\rangle + \beta\,|\uparrow\downarrow\rangle$$
$$|0_2^+\rangle = -\beta\,|0\rangle + \alpha\,|\uparrow\downarrow\rangle$$

shell model: $\alpha^2 \cong 10\ \%$



SM: E. Caurier F. Nowacki and A. Poves, PRC **90**, 014302 (2014)

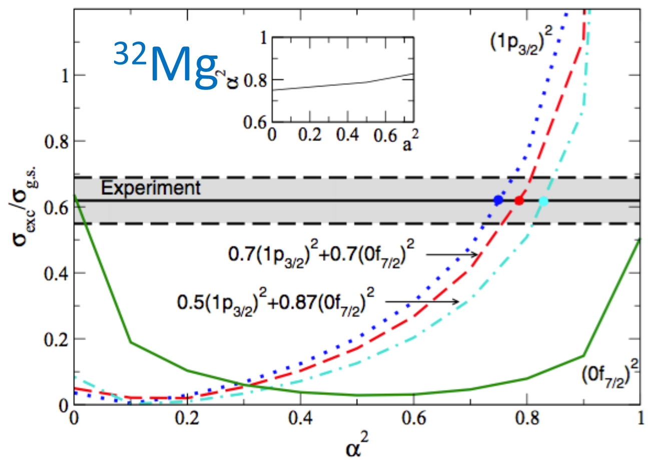
Results from two-neutron transfer into ^{32}Mg at ISOLDE

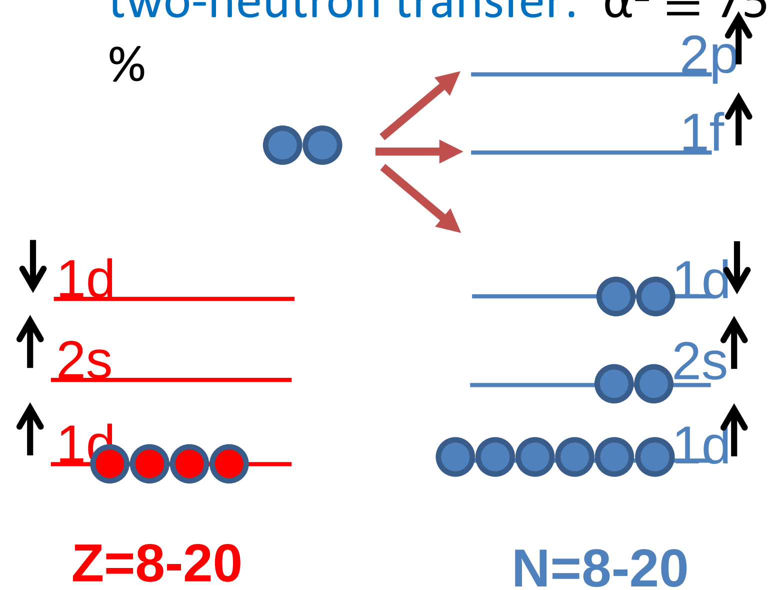


$$|0_1^+\rangle = \alpha\,|0\rangle + \beta\,|\uparrow\downarrow\rangle$$
$$|0_2^+\rangle = -\beta\,|0\rangle + \alpha\,|\uparrow\downarrow\rangle$$

shell model: $\alpha^2 \cong 10\ \%$

two-neutron transfer: $\alpha^2 \cong 75\ \%$

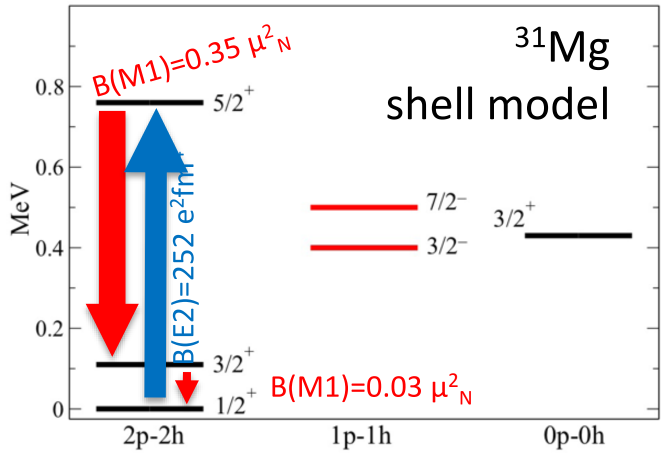




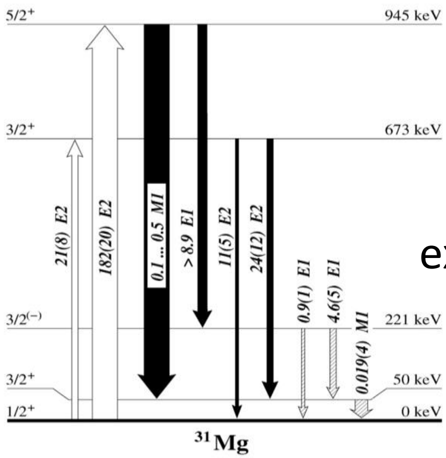
H. T. Fortune, PRC **85**, 064615 (2012)

J. A. Lay et al., PRC **89**, 034618 (2014)

Results from ^{31}Mg Coulex at ISOLDE



SM: E. Caurier F. Nowacki and A. Poves, PRC **90**, 014

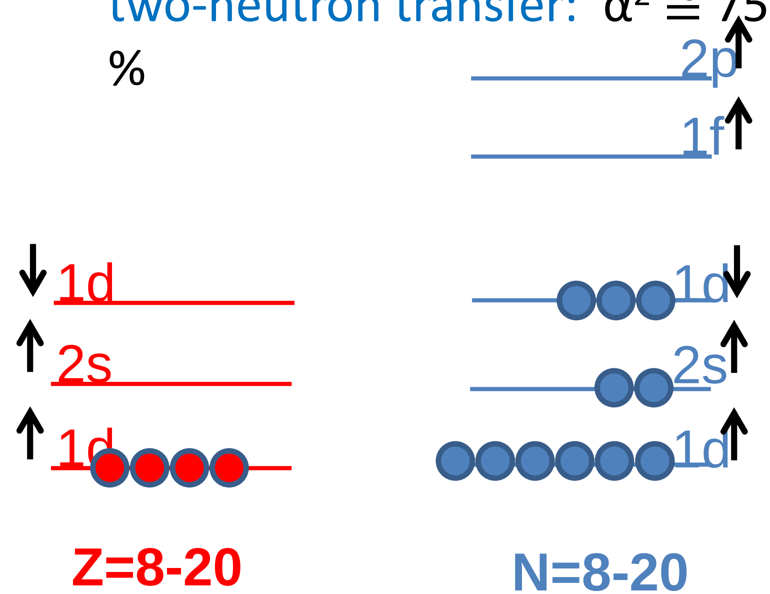


^{31}Mg
exp. data

$$|0_1^+\rangle = \alpha\,|0\rangle + \beta\,|\uparrow\downarrow\rangle$$
$$|0_2^+\rangle = -\beta\,|0\rangle + \alpha\,|\uparrow\downarrow\rangle$$

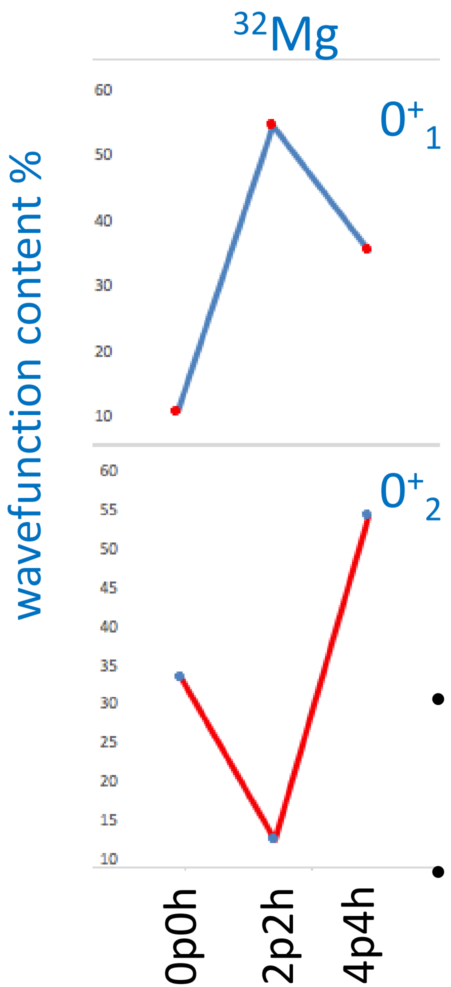
shell model: $\alpha^2 \cong$ 10 %

two-neutron transfer: $\alpha^2 \cong$ 75 %



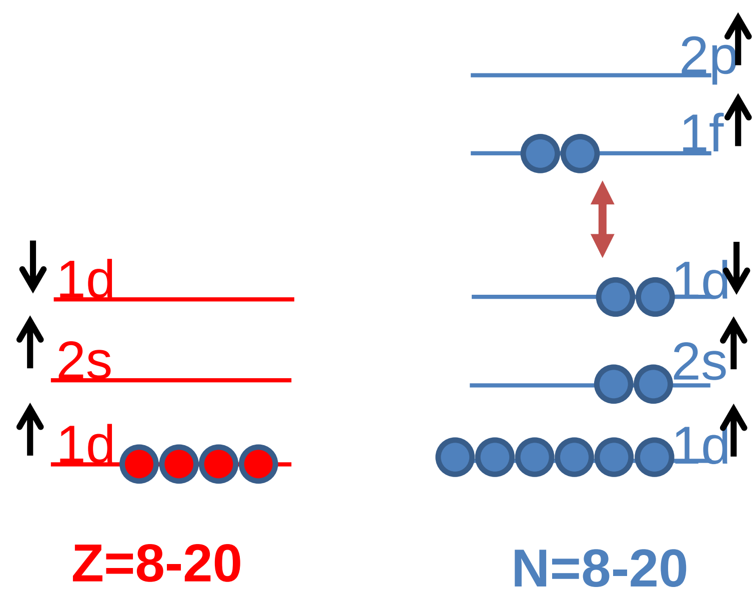
M. Seidlitz, D. Mücher et al. Phys. Lett B 700 (2011) 181-186

Shell model predictions: inconsistencies



$$|0_1^+\rangle = \alpha_1\,|0\rangle + \beta_1\,|2\uparrow\downarrow\rangle + \gamma_1\,|4\uparrow\downarrow\rangle$$
$$|0_2^+\rangle = \alpha_2\,|0\rangle + \beta_2\,|2\uparrow\downarrow\rangle + \gamma_2\,|4\uparrow\downarrow\rangle$$

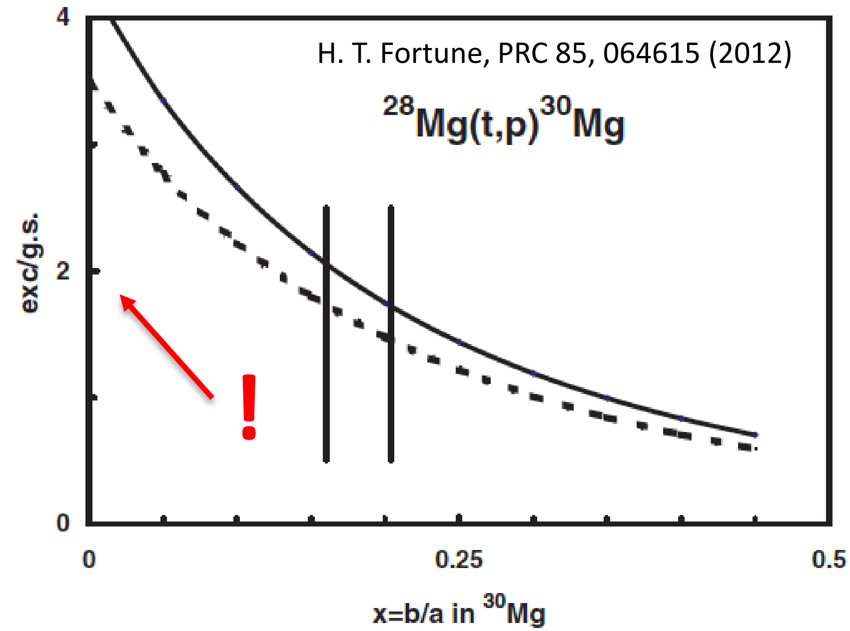
- A. Poves: "entanglement" of nuclear shapes?
- more likely this is an artefact of "glueing" effective interactions which live in separate sd and fp spaces



Two-neutron transfer t(^{28}Mg,p)^{30}Mg

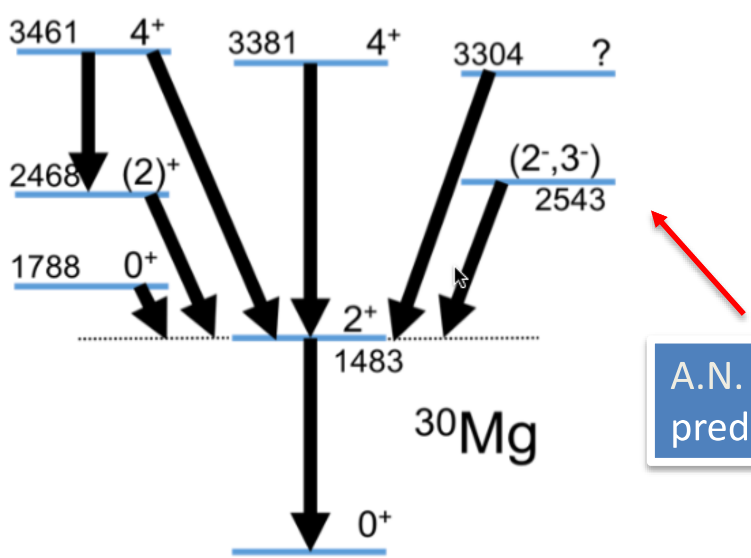
we would like to know:

- do we understand absolute and relative cross sections in the (sd)-(fp) model space ?
  → t(^{28}Mg,p)^{30}Mg:
  Will populate presumed pure (fp) intruder states strongly !
- what is the contribution of $p_{3/2}$ and $f_{7/2}$ in the "deformed" 2p2h (4p4h?) configuration in ^{30}Mg ?
- where is the intruder 2$^+$ state in ^{30}Mg ?
- what is the nature of the (presumed) low-lying negative parity state in ^{30}Mg ?



largest ratio expected for ^{28}Mg(t,p)^{30}Mg:

2n transfer from pure sd shell in ^{28}Mg into pure fp intruder in ^{30}Mg highly favored



A.N. Deacon et al., PRC 82, 034305 (2010): predicted too high in SDPF-M shell model

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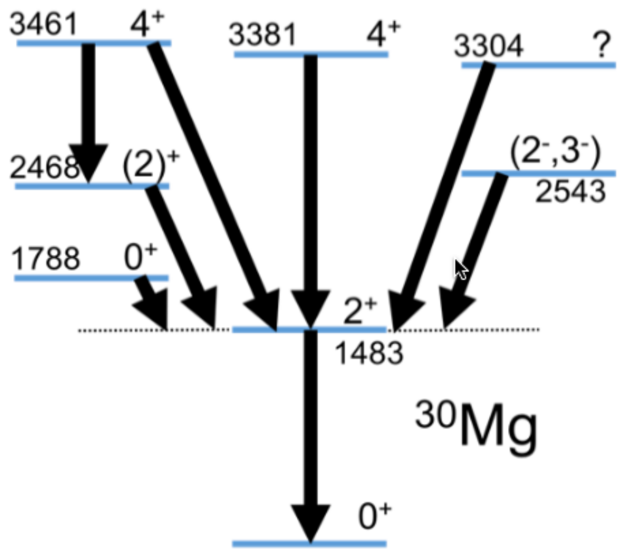

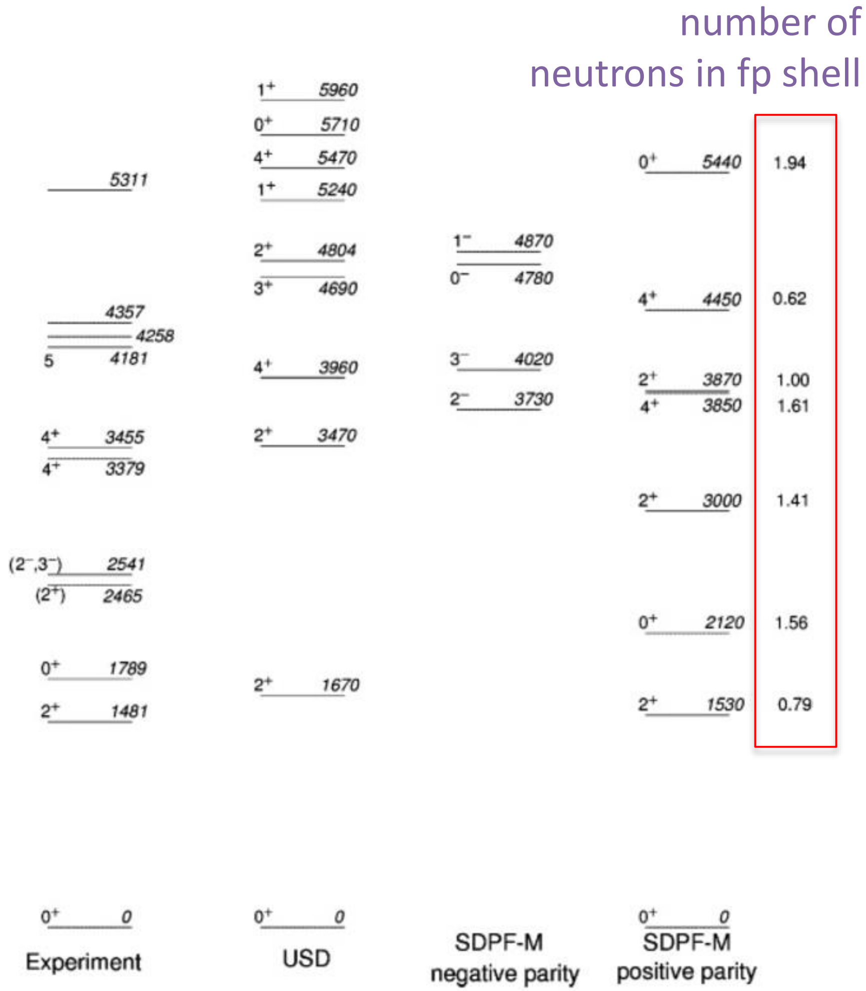

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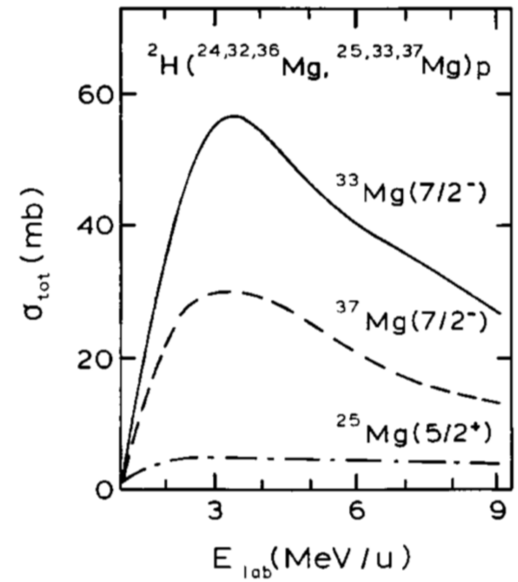
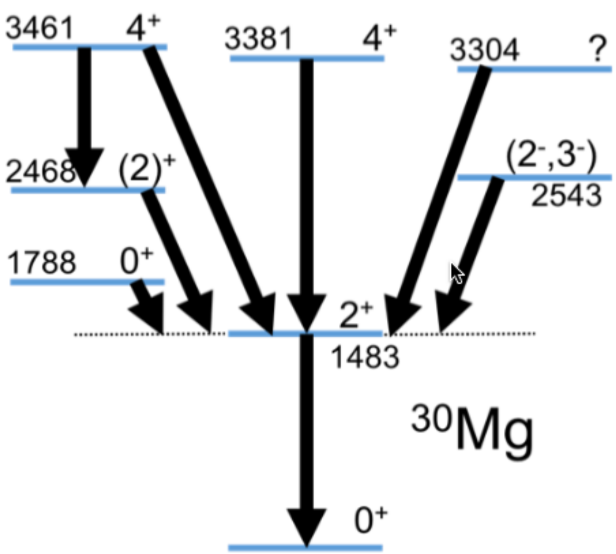


H. Lenske and G. Schrieder, Eur. Phys. J A 2, 41-53 (1998): neutron transfer into sd orbits independent of incident beam energy but cross section into weakly bound orbits strongly depends on beam energy!
--> Measure at 1.8 MeV/u and 4 MeV/u



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experimental details of the proposal

measurement of cross sections:

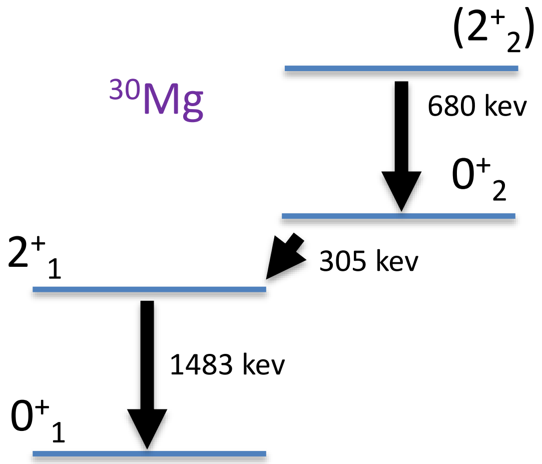
1. using T-REX,only: largest statistics but have to restrict to protons at extreme angles
2. γ-gated on 305 keV: will result in most reliable results, as we learned from our data 44Ar(t,p) and 72Zn(t,p)
3. Energies above and below Coulomb Barrier of Ti layer
   - 1.8 MeV/u: clean spectra and solid comparison to 30Mg(t,p) data
   - 4.5 MeV/u: about 2x more identified protons in forward direction; energy dependence of transfer into weakly bound orbits can be studied--> ratio of f and p intruder orbits
   - fusion evaporation results in protons at similar energies --> in case MINIBALL gate not possible: fusion veto!

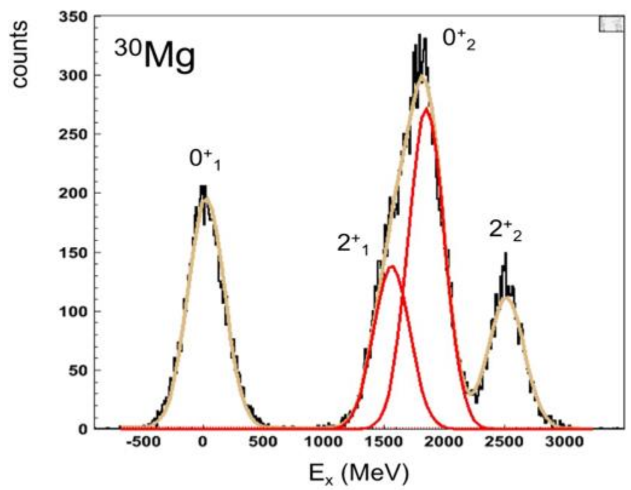
measurement of $\sigma(2^+_2)$:

- we expect $\sigma(2^+_2) / \sigma(0^+_2) \cong 0.2$ (maybe slightly smaller as increase in $f_{7/2}$ likely)

measurement of (2-,3-):

- difficult to predict, but strong population of 3^- octupole in ^{28}Mg after 2n transfer





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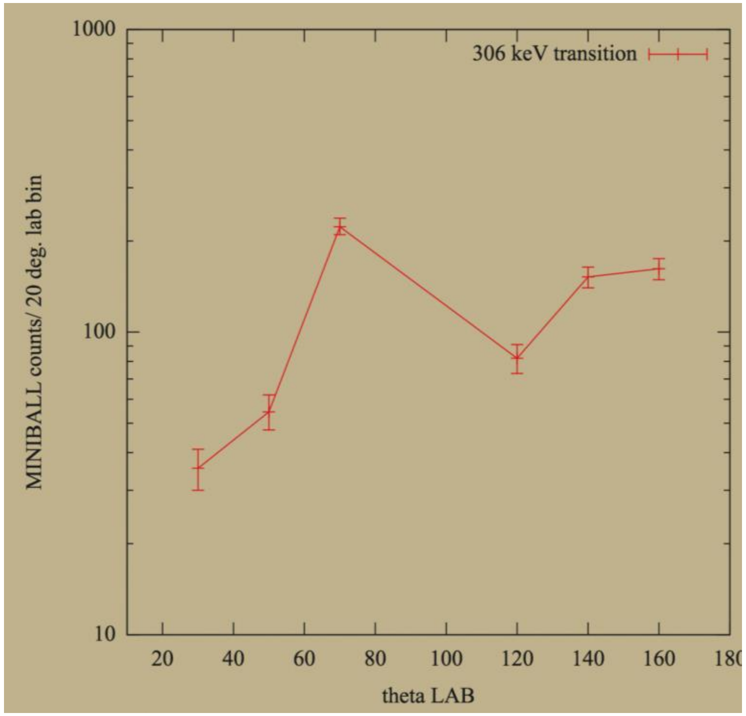
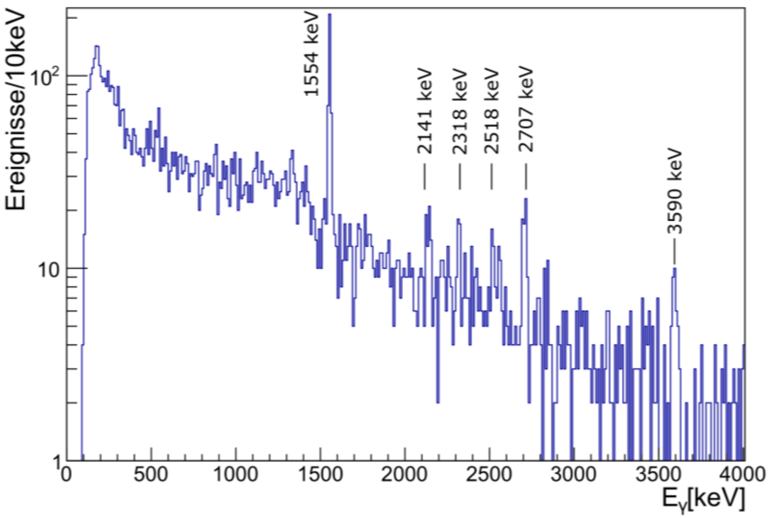




Count rate estimates:

- based on cross sections from DWBA, T-REX angular coverage and MINIBALL efficiency
- Plot shows gamma ray counts after 9 shifts for the 306 keV transition 0^+_2-->2^+_1 with statistical errors
- Cross check: beam intensity 10x higher compared to ^{30}Mg(t,p) experiment cancels out with gamma ray efficiency (13 %) --> similar statistics, but gamma-gated, i.e. improved SNR due to high-res gamma spectra
- Gamma-ray SNR was estimated to be 1:6 for a transfer into a state with a maximum cross section of 1 mb/sr from several experiments using MINIBALL and T-REX, like ^{31}Mg(d,p), ^{46}Ar(t,p), ^{72}Zn(t,p)

experimental details of the proposal

Beam time request:

- 1 shift for the setup of ^{28}Mg beam at 1.8 MeV/u, determination of beam contaminants
- 9 shifts (3 days) 1.8 MeV/u ^{28}Mg on tritium target
- 1 shifts for tuning beam to around 4.5 MeV/u and test fusion veto
- 9 shifts (3 days) 4.5 MeV/u ^{28}Mg on tritium target

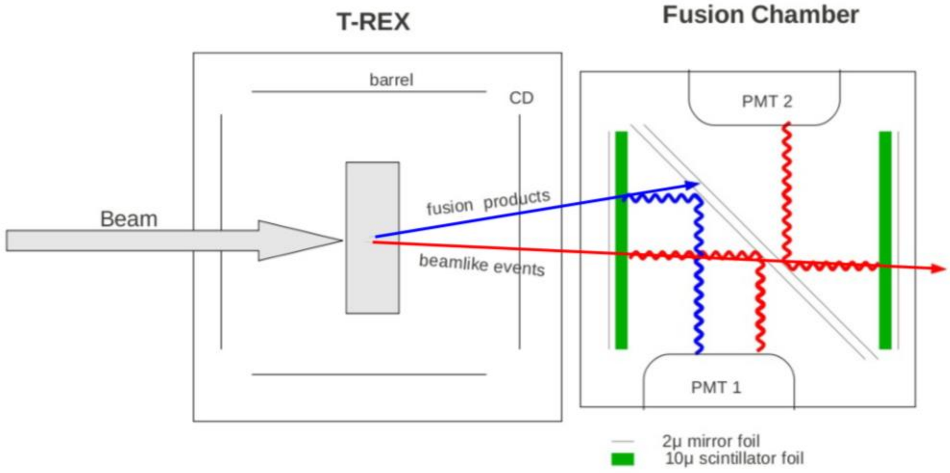
→ 20 shifts total

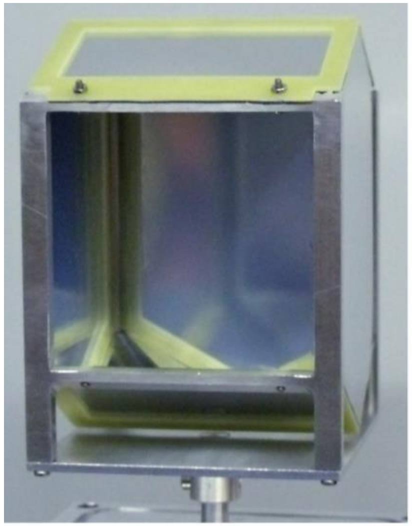
Contribution from University of Guelph:

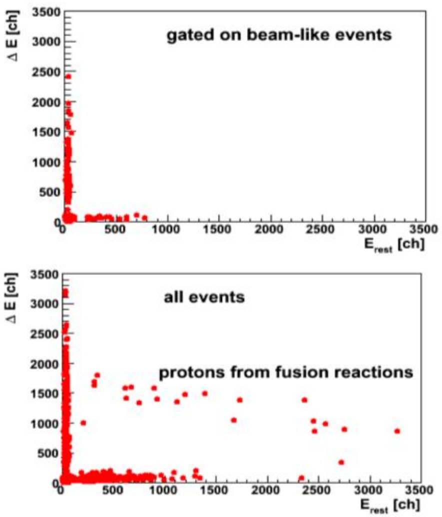
- We provide help setting up C-REX silicon array for 2016 Coulex campaign
- We will participate setting up T-REX for a possible future MINIBALL T-REX campaign
- Development of updated fusion veto together with TU Munich

Thank you for your attention!

Fusion veto







Upgrade of fusion veto for this experiment:

- Instantaneous rate in this experiment: 2x10^7 pps, independent of last proton impact time
- New concept: beam and fusion products pass a degrader foil and are stopped in a fast plastic scintillator detector
- The amplitude in the plastic is much reduced for fusion products due to kinematics, energy loss in degrader and quenching --> software-gate on beam-like events and fusion events
- Mesytec Multihit TDC tested at high rates at TUM: improves selectivity
- Device can be tested and calibrated using stable Mg beam at Munich Tandem accelerator
- Gamma rate due to beta decay under control because of long lifetime of 28Mg beam