Transfer reactions with T-REX

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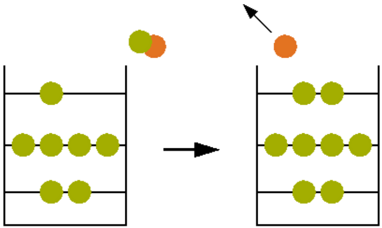
Transfer reactions



- study single particle properties
- complementary to Coulomb excitation

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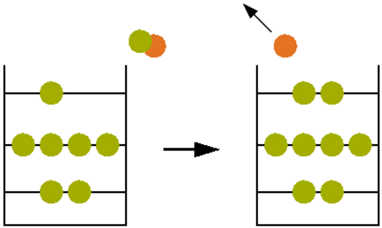

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Observables:

- excitation energy of populated state
- angular distribution
  $\longrightarrow$ angular momentum transfer
- relative population
  $\longrightarrow$ spectroscopic factor
- decay by γ rays

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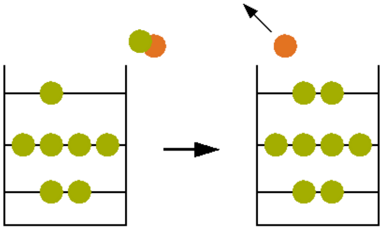

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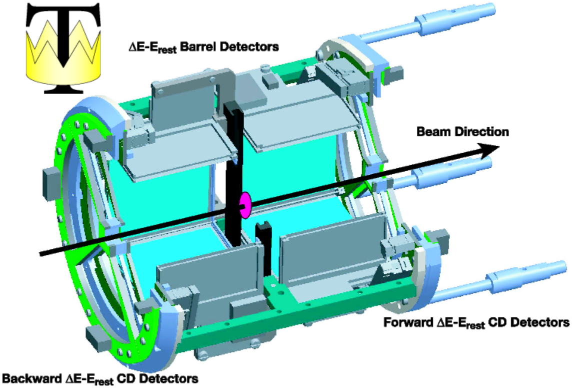
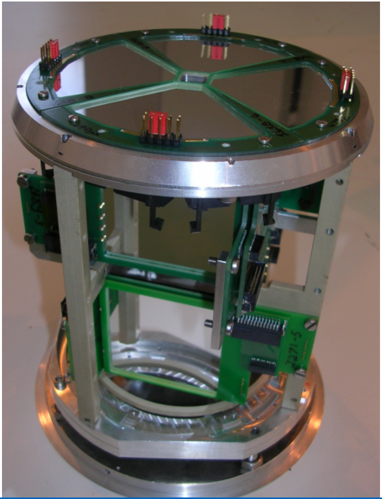
transfer with radioactive beams requires:

- target with deuterons or tritons
- 0° spectrometer for ejectile
  or
- 4π coverage for recoils
- particle identification for α, t ,d ,p
- high efficient Germanium array

The experimental setup T-REX

- 8 $\Delta E - E_{\text{rest}}$ barrel detectors
- 2 $\Delta E - E_{\text{rest}}$ annular CDs
- 60% solid angle coverage





- surrounded by the MINIBALL Ge detector array
- successfully used in IS454 and IS470
- fully implemented into a GEANT4 simulation

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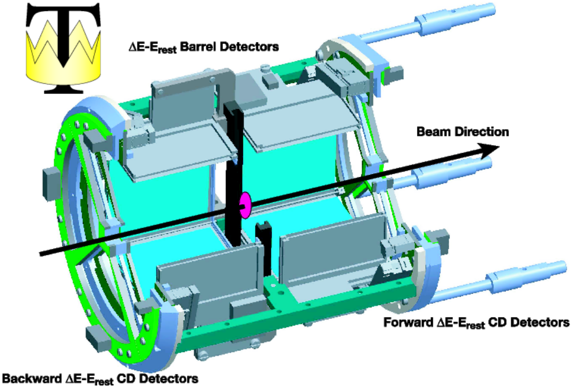

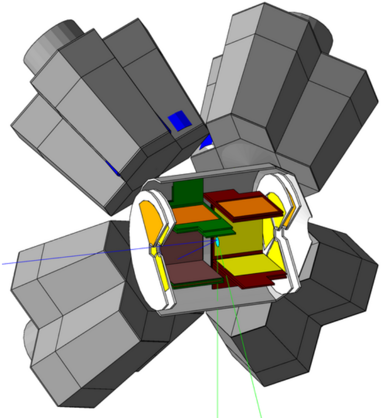

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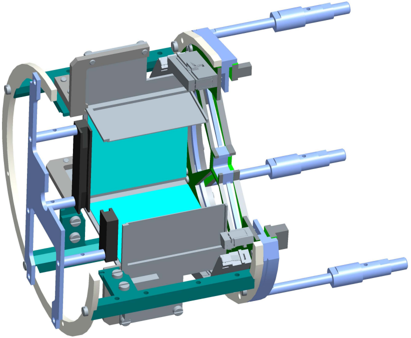
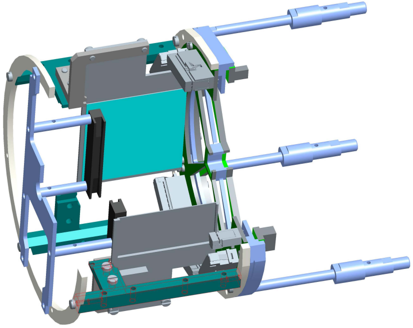
Coulomb excitation with T-REX



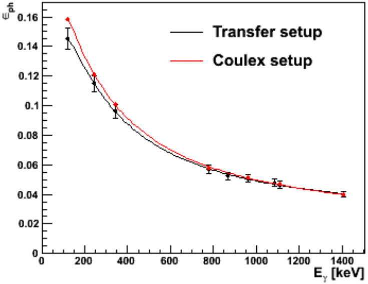


advantages

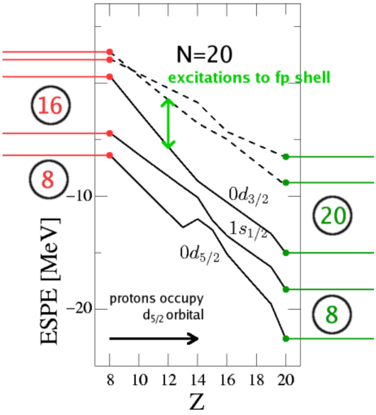
- larger solid angle coverage: detect both particles
- distance target - CD detector adjustable

disadvantage

- reduced γ efficiency especially for energies below 200 keV



The Island of Inversion



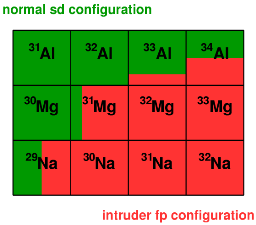
- $N = 20$ shell closure disappears for neutron rich nuclei
- protons in $d_{5/2}$ attract $d_{3/2}$ neutrons
- local magic numbers
- around $Z = 12$ open shells
- excitations to the *fp* shell

deformed *fp* intruder ground states

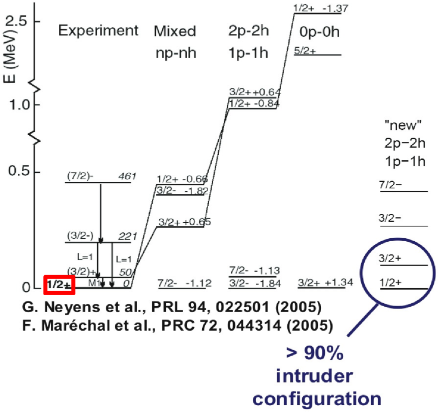
T. Otsuka et al., EPJA **15** (2002) 151

Coulex experiments: ^{30}Mg lies outside the Island of Inversion, ^{32}Mg is inside

O. Niedermaier et al., Phys. Rev. Lett. **94** (2005) 172501



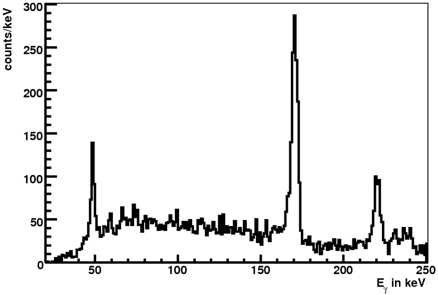
IS454: the $d(^{30}Mg, p)$ reaction

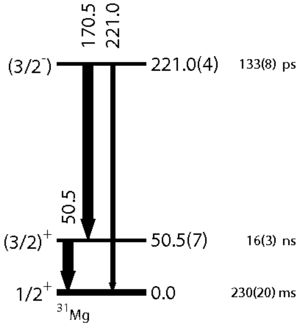


- ground state spin ^{31}Mg $1/2^+$
- what about excited states?
- study single particle properties by one neutron transfer reactions

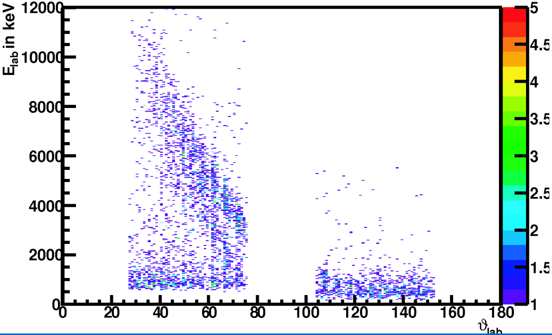
- first experiment with T-REX
- several problems discovered during the beam time
- very low beam intensity, only 10 % of the expected statistics obtained

IS454: the $d(^{30}Mg, p)$ reaction

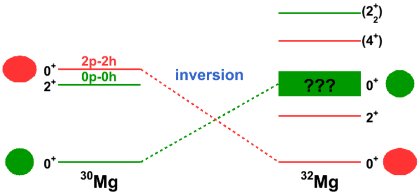




- cut on 170 keV line
- no correction for feeding
- very low Q-value 153 keV
- large background from β decay



IS470: two-neutron transfer to ^{32}Mg

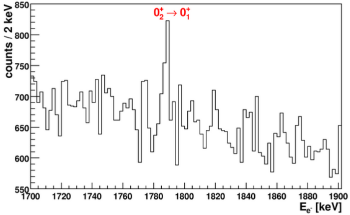


coexistence of spherical and deformed states

- deformed $2p-2h$ configuration becomes ground state in ^{32}Mg
- deformed 0^+ state in ^{30}Mg identified in 2007 by its E0 decay

- electric monopole strength: $\rho^2(\mathrm{E0}; 0_2^+ \rightarrow 0_1^+) = (26.2 \pm 7.5) \cdot 10^{-3}$
- small mixing amplitude $a = 0.18 \pm 0.08$
- sharp transition to the island of inversion

W. Schwerdtfeger et al., Phys. Rev. Lett. 103 (2008) 012501



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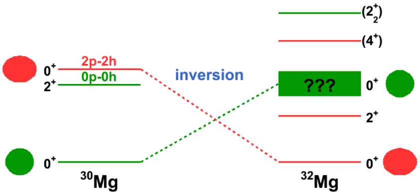

predictions for the 0_2^+ state in ^{32}Mg: between 1.5 and 3 MeV

E. Caurier et al., NPA **693** 374, T. Otsuka, EPJA **20** 69, R. Rodriguez-Guzmán et al., NPA **709** 201

<u>this state has not been observed so far</u>

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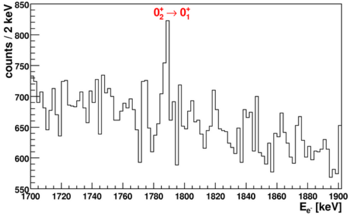

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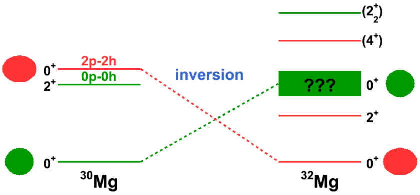

similar particle-hole structure:

- large overlap of wavefunctions
- large spectroscopic factor for transfer

$\rightarrow$ **identify 0^+_2 by its characteristic $\Delta L = 0$ angular distribution**

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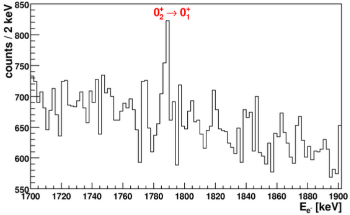
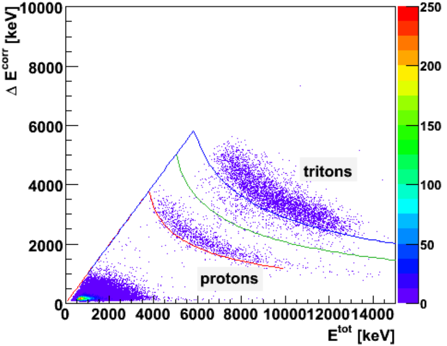


IS470: two-neutron transfer to ^{32}Mg

- performed in October 2008 at REX-ISOLDE
- beam intensity $\approx 4 \cdot 10^4$ /s (determined from elastic scattered tritons)
- about 150 h of data with Tritium target

Identify particles in forward direction by $\Delta E - E_{rest}$:



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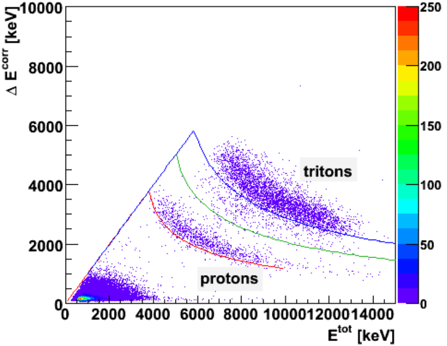
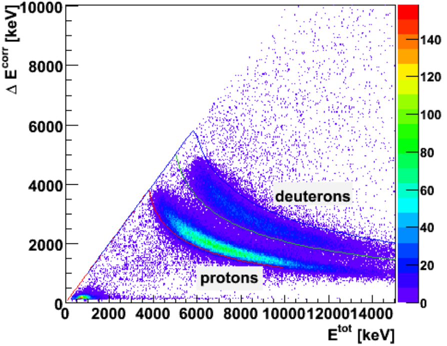


comparison with (d,p) run



no deuterons, (t,d) reaction disfavored by large negative Q-value $= -3.9$ MeV

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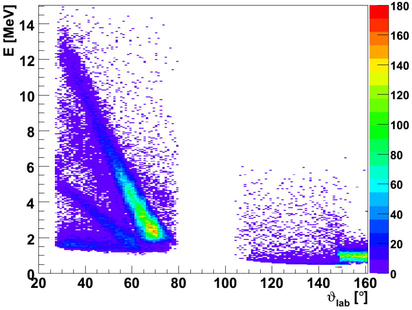

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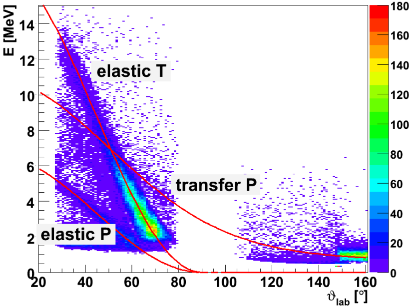

- elastic scattered tritons and protons
- protons from transfer reactions

particle identification:

- forward direction strip by strip $\Delta E - E$
- backward direction protons are stopped in ΔE detector

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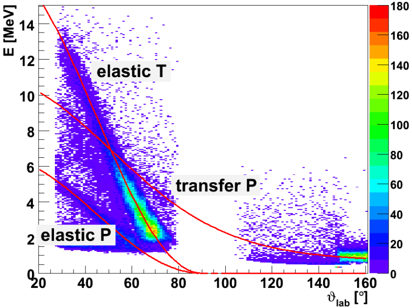

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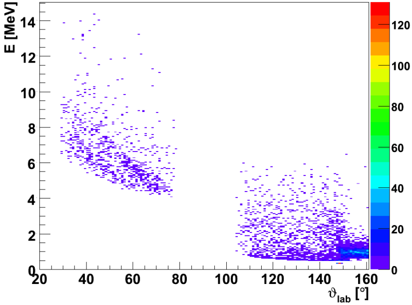

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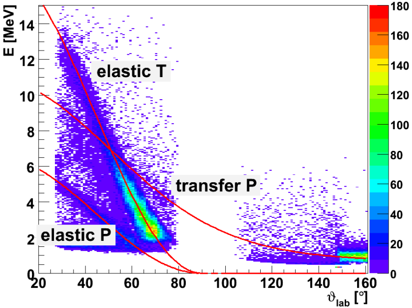

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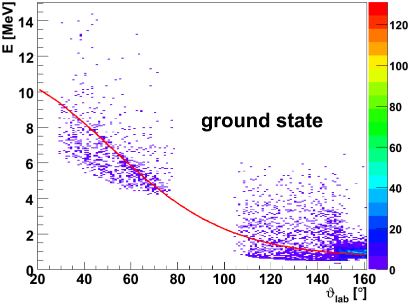

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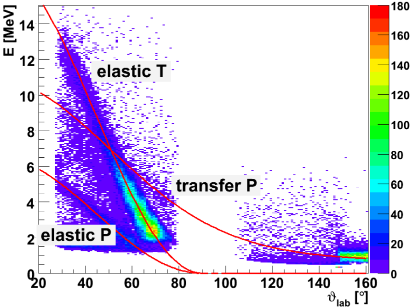

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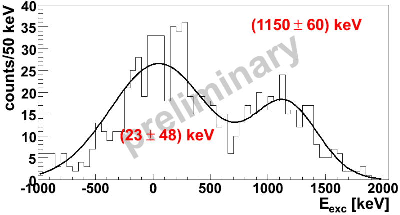
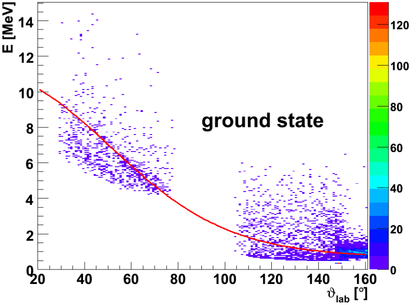
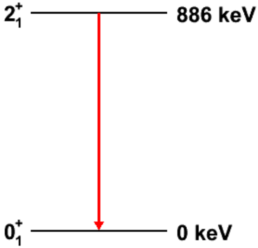
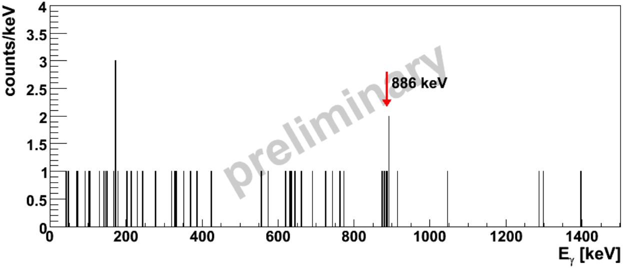




cut on higher lying state coincident γ spectrum

- Doppler corrected with $\vartheta_{^{32}\mathrm{Mg}} = 0^\circ$
- assuming $\varepsilon_{\mathrm{ph}}(886\ \mathrm{keV}) = 5\%$: $\approx$20 counts expected





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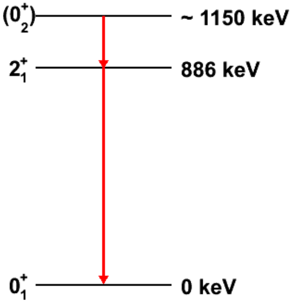
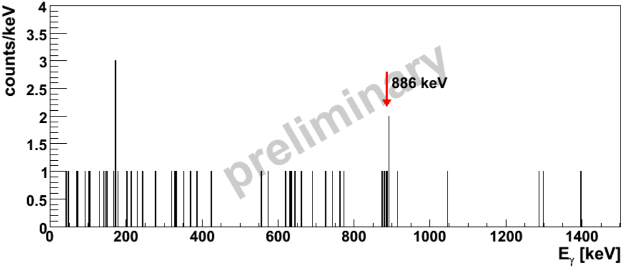
- estimated lifetime of a 0^+ state at 1150 keV:
  $\tau = 12$ ns using $\rho^2(\mathrm{E0})$ and $B(\mathrm{E2})$ from ^{30}Mg
  $\rightarrow$ decays outside of MINIBALL





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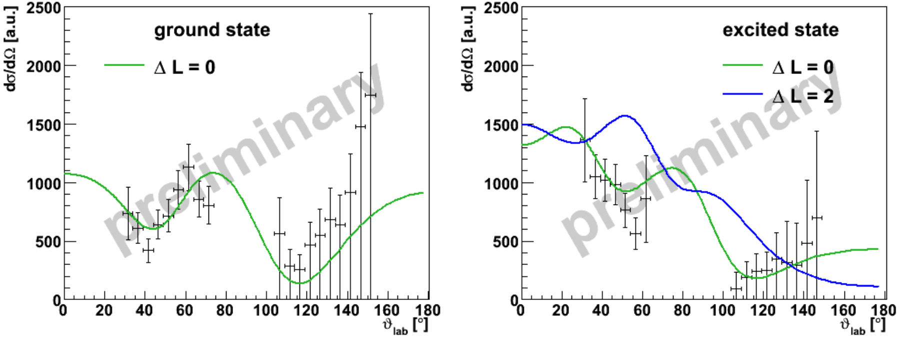

- efficiency and solid angle corrected angular distributions
- no fit, not normalized to elastic scattering

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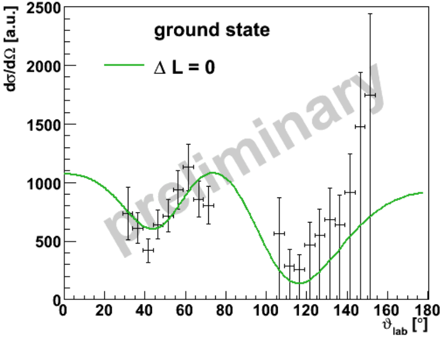

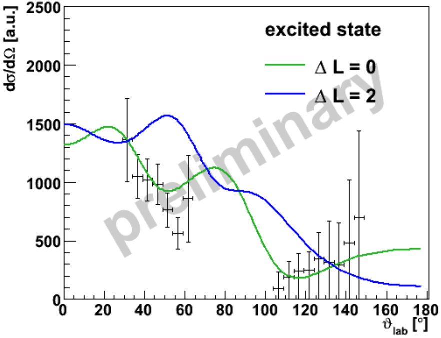

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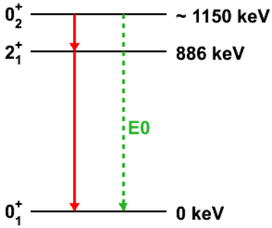
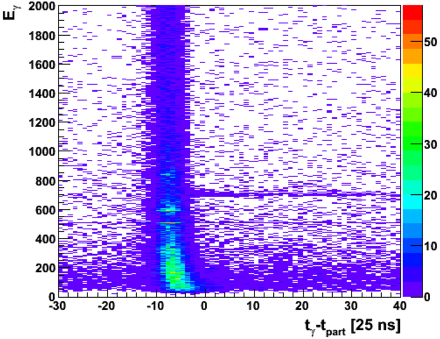


detection of neutrons in coincidence with particles in T-REX



- neutron excites 0_2^+ state at 691 keV in ^{72}Ge
- long halflife (E0 transition) $T_{1/2} = 444.2(8)$ ns

D. Jenkins et al. NIM A 602 (2009) 457

- our fit (exponential + const. background): $T_{1/2} = 442(56)$ ns

2009 campaign: $d(^{11}Be,p)^{12}Be$

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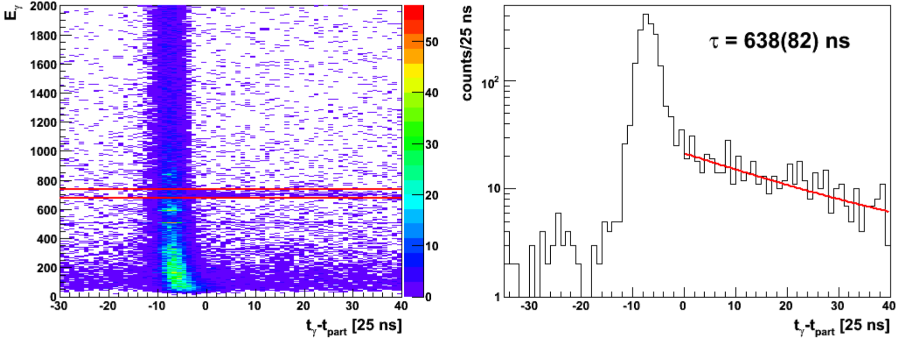

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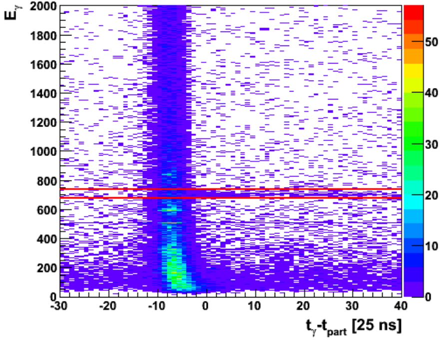

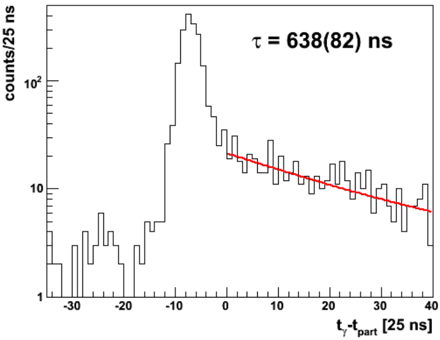

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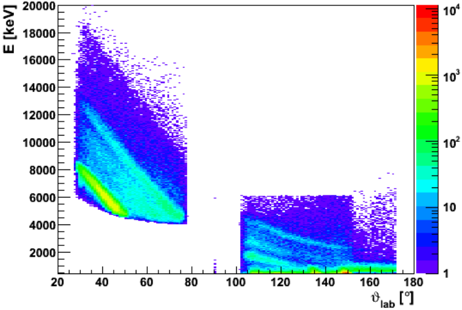
origin of neutrons not clear yet

- deuteron breakup / transfer to unbound states

2009 campaign: d(^{66}Ni,p)^{67}Ni



- several states up to 6 MeV observed
- very good statistics
  proton-γ-γ coincidences possible!

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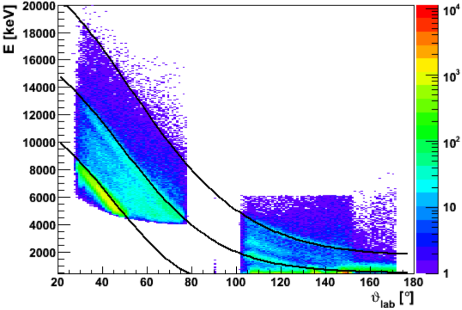

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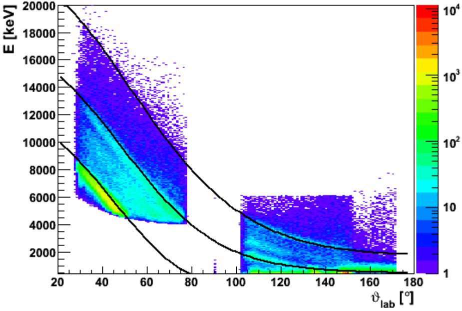

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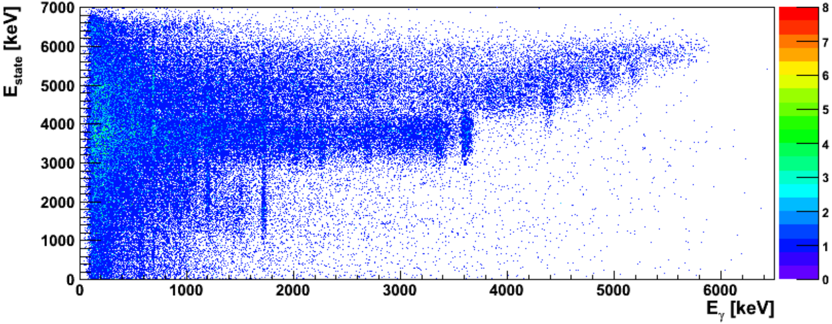

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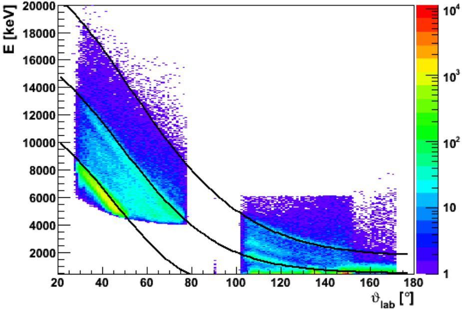

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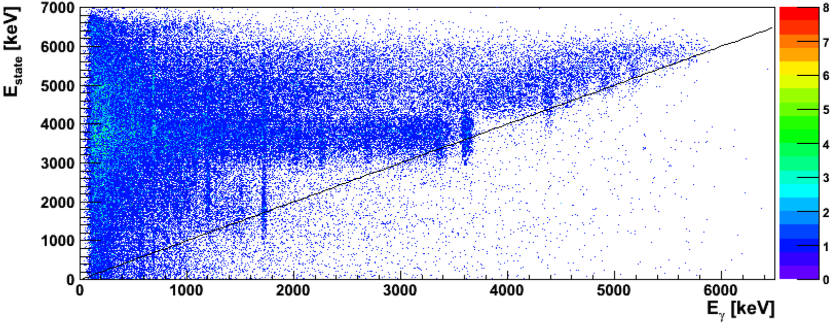
- very good statistics
  proton-γ-γ coincidences possible!



Summary and Outlook

one neutron transfer

- d(^{30}Mg,p)^{31}Mg (V. Bildstein, TU München)
- d(^{11}Be,p)^{12}Be (J. Johansen, University of Aarhus)
- d(^{66}Ni,p)^{67}Ni (J. Diriken, KU Leuven)
- d(^{78}Zn,p)^{79}Zn (R. Orlandi, University of West Scotland)

two neutron transfer reactions with radioactive Tritium target

- two neutron transfer reactions at REX-ISOLDE are possible
- candidate for the 0^+_2 state in ^{32}Mg found
- future plans
  - t(^{44}Ar,p)^{46}Ar (TU München)
  - t(^{66}Ni,p)^{68}Ni (KU Leuven)
- two neutron transfer reactions open a new field for studies of
  - shape coexistence
  - pairing correlations

  in particular at HIE-ISOLDE energies!!

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Thank you