Transfer reactions at REX-ISOLDE

Vinzenz Bildstein

vinzenz.bildstein@ph.tum.de

Physik-Department E12, TU München

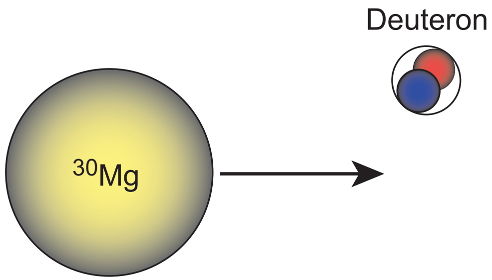
Outline

- Transfer Reactions in inverse Kinematics
- Setup
- Island of Inversion
- Results from d(^{30}Mg, ^{31}Mg)p
- Further Experiments
- Outlook & Summary

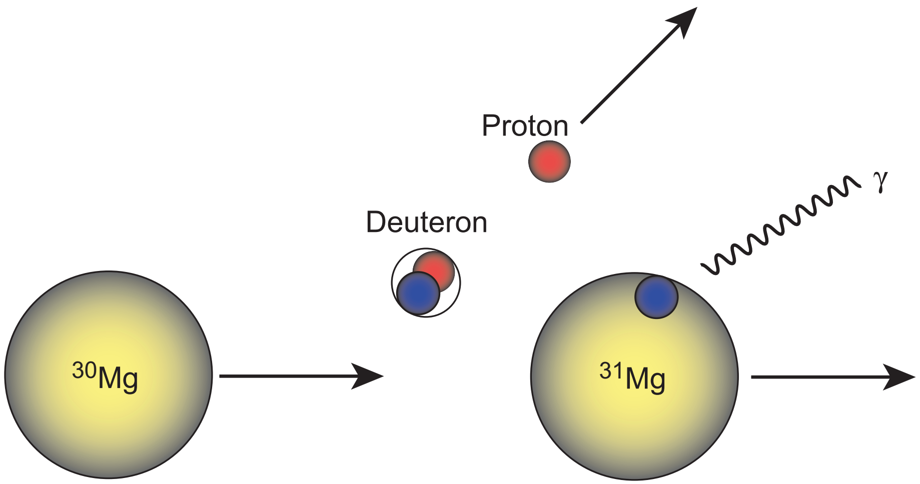
Transfer Experiments with RIBs

TECHNISCHE UNIVERSITÄT MÜNCHEN

radioactive ion beam impinges on target with deuterons (deuterated poly-ethylene)



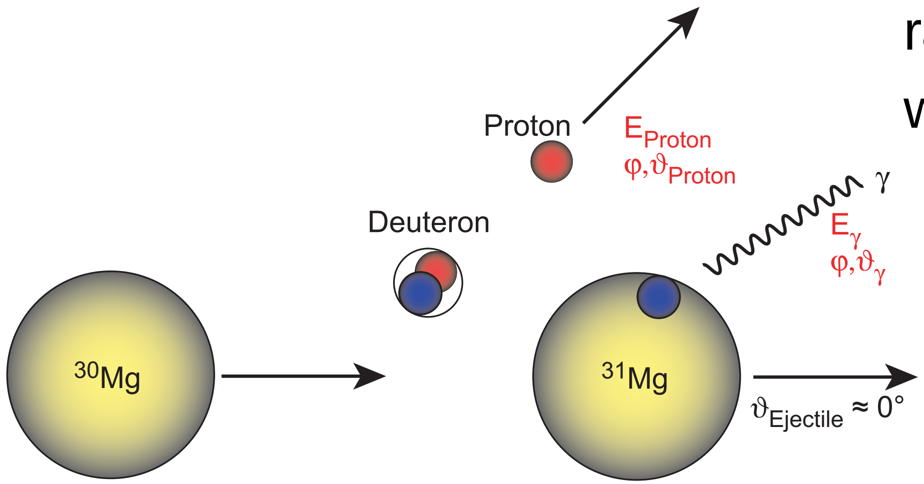
Transfer Experiments with RIBs



radioactive ion beam impinges on target with deuterons (deuterated poly-ethylene)

Transfer Experiments with RIBs

TECHNISCHE UNIVERSITÄT MÜNCHEN



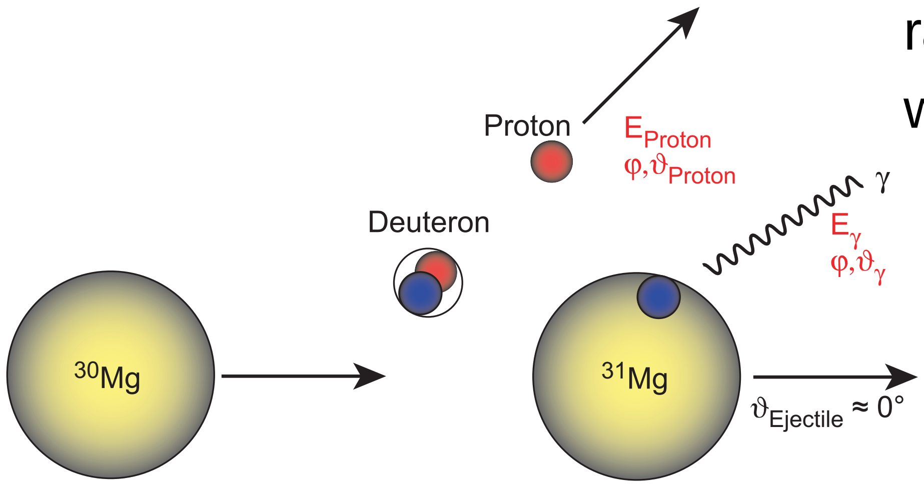
radioactive ion beam impinges on target with deuterons (deuterated poly-ethylene)

Experimental Observables:

- compare measures cross sections with DWBA calculations $\Rightarrow$relative spectroscopic factors S
- particle angular distributions $\Rightarrow$orbital momenta l
- excitation energies $\Rightarrow$single particle energies
- γ angular distributions
- particle-γ-correlations $\Rightarrow$spins I

Transfer Experiments with RIBs

TECHNISCHE UNIVERSITÄT MÜNCHEN



radioactive ion beam impinges on target with deuterons (deuterated poly-ethylene)

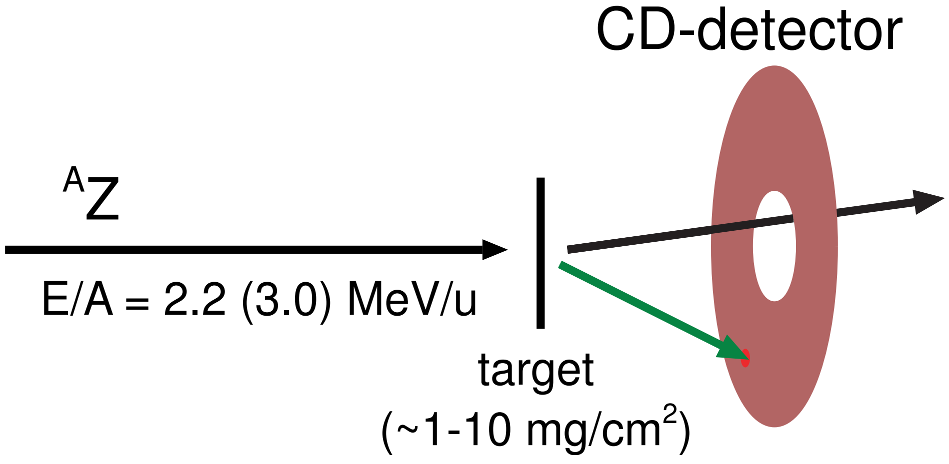
⇒determination of configurations by comparison with shell model calculations

complementary to Coulomb excitation experiments

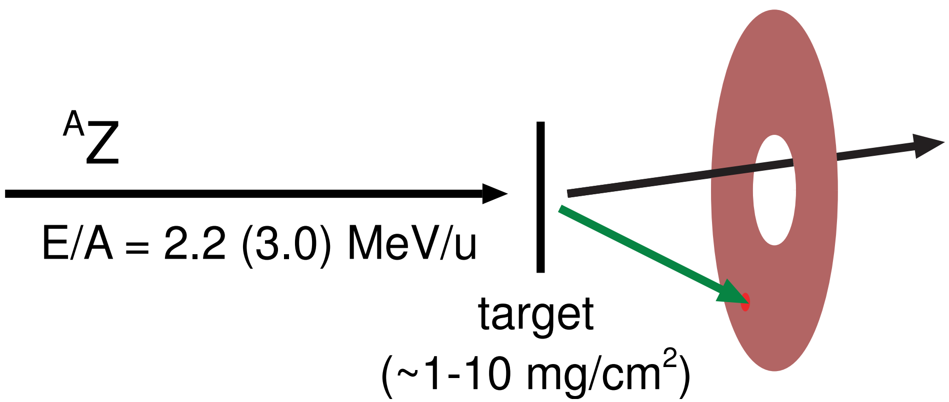
Experimental Observables:

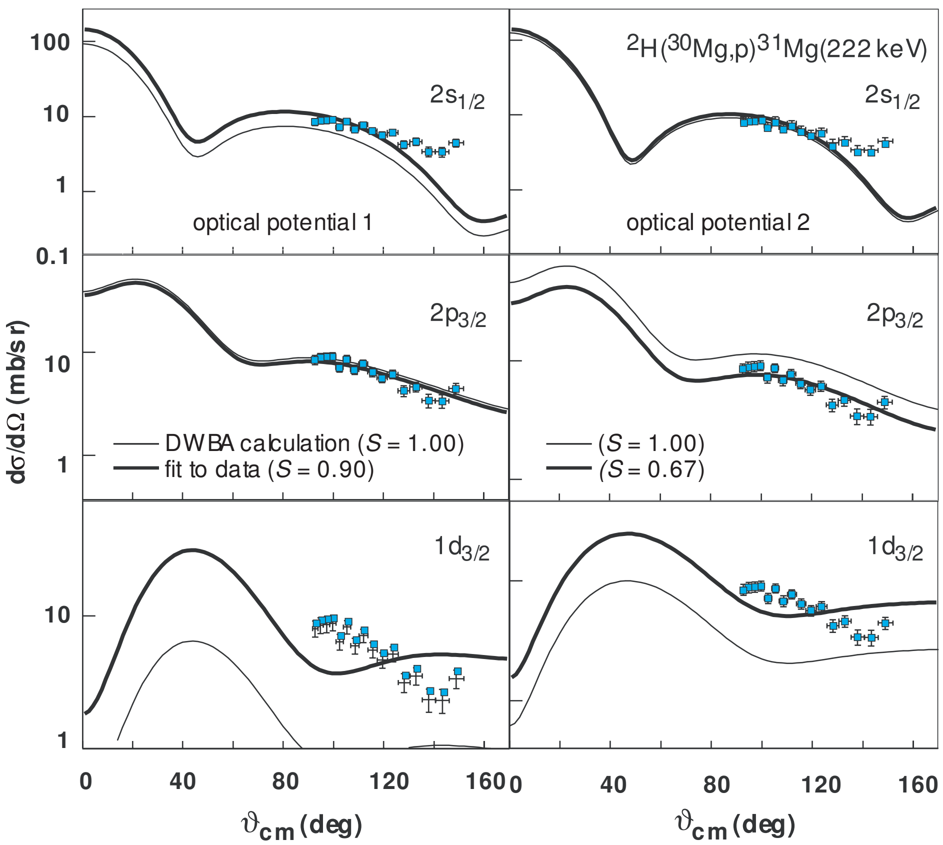
- compare measures cross sections with DWBA calculations ⇒relative spectroscopic factors S
- particle angular distributions ⇒orbital momenta l
- excitation energies ⇒single particle energies
- γ angular distributions
- particle-γ-correlations ⇒spins I

Transfer with Coulex Setup



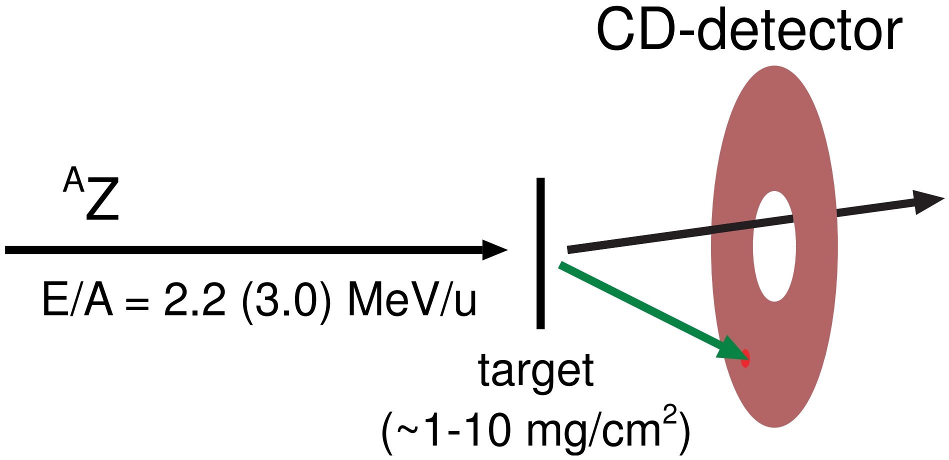
Transfer with Coulex Setup



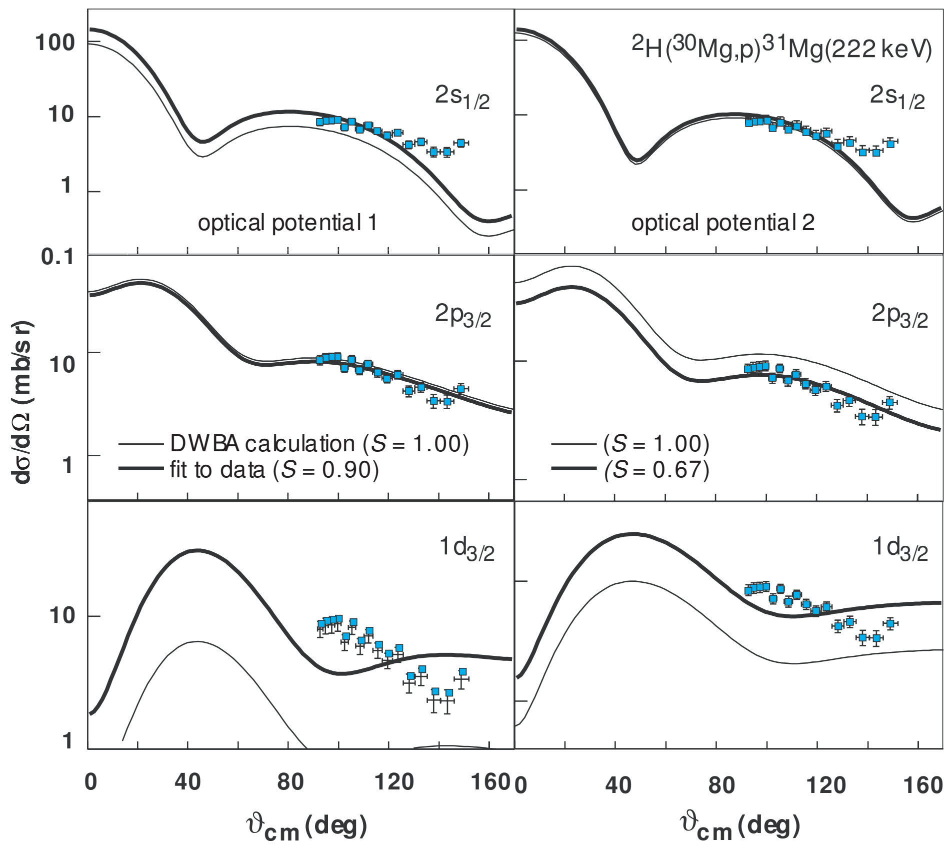


M. Pantea, PhD Thesis (Darmstadt, 2005)
ongoing work: E. Tengborn (Chalmers)

Transfer with Coulex Setup



IS410 @ REX-ISOLDE

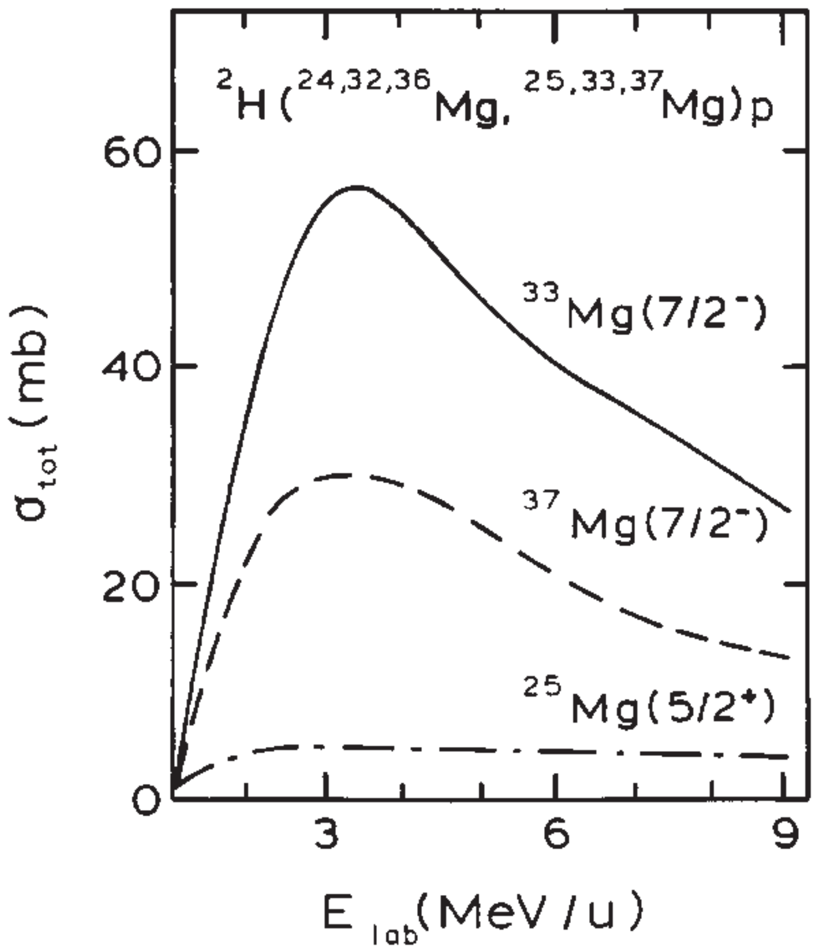


M. Pantea, PhD Thesis (Darmstadt, 2005)
ongoing work: E. Tengborn (Chalmers)

- interesting parts of angular distribution not covered by particle detectors
- E_{cm} is smaller than in normal kinematics ⇒less pronounced angular distributions

Transfer Experiments with RIBs

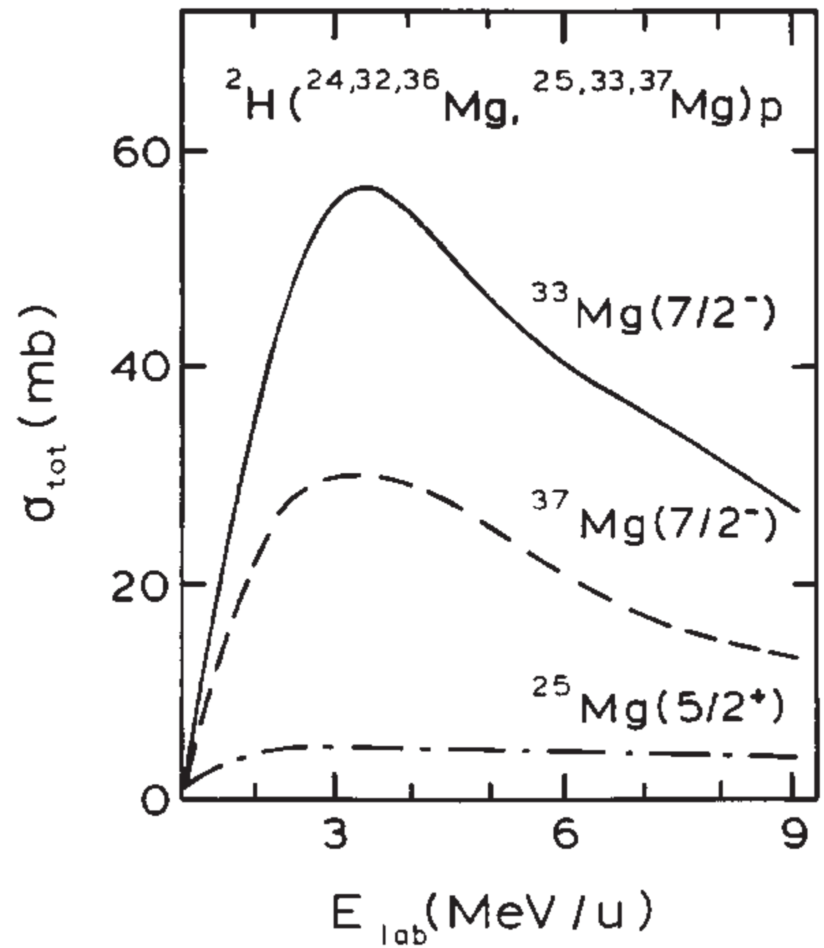
- better momentum matching ⇒higher cross section (optimal around 3 MeV/u)



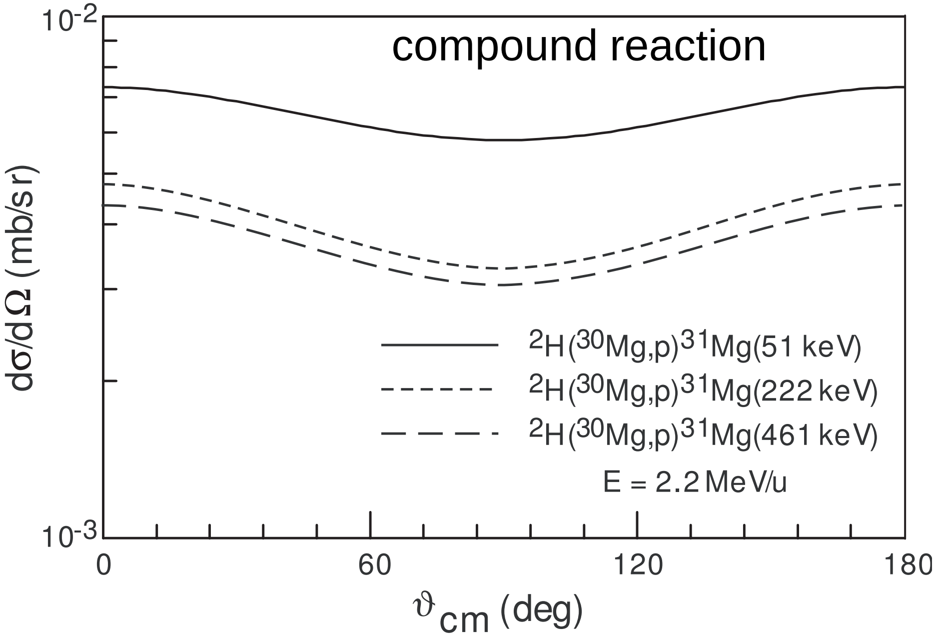
H. Lenske, G. Schrieder, EPJA 2, 41 (1998)

Transfer Experiments with RIBs

- better momentum matching ⇒higher cross section (optimal around 3 MeV/u)
- smaller E_{cm} ⇒higher contribution by compound reactions?



H. Lenske, G. Schrieder, EPJA 2, 41 (1998)

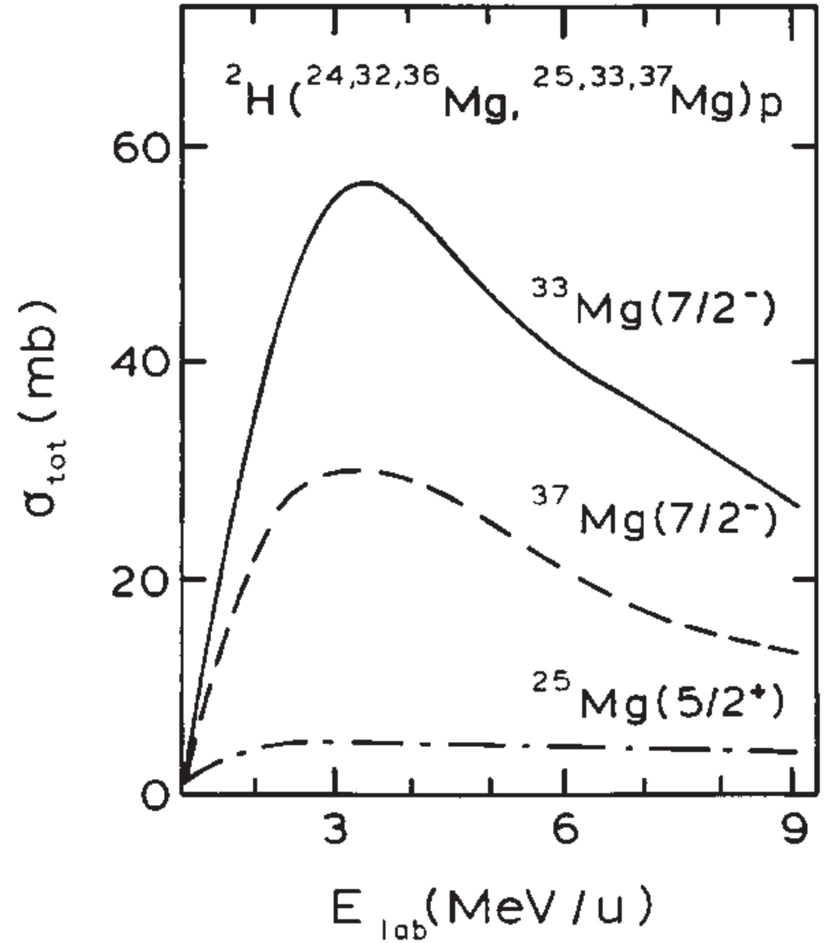


M. Pantea, PhD Thesis (Darmstadt, 2005)

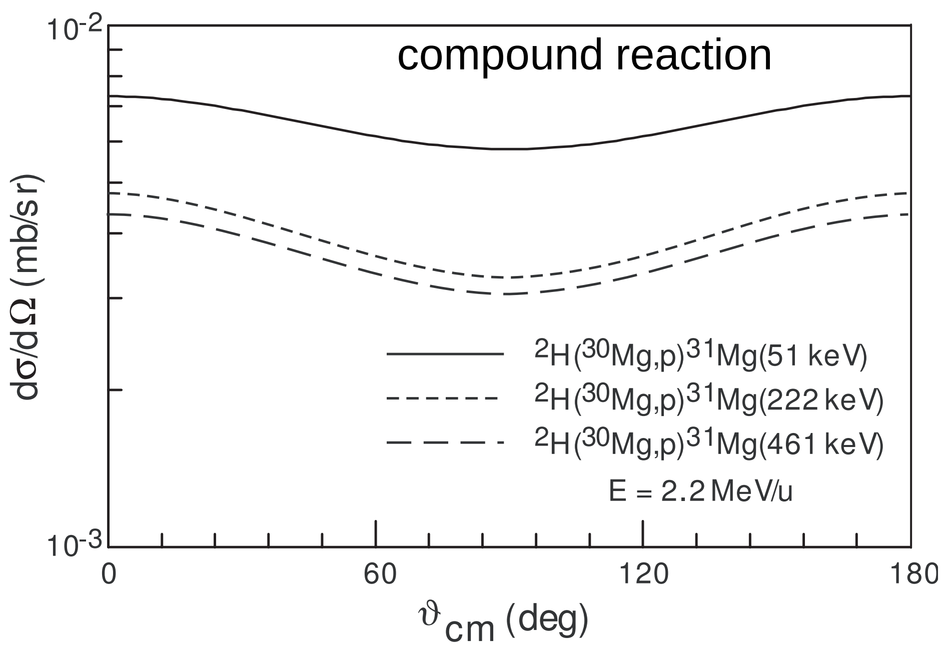
Transfer Experiments with RIBs

- better momentum matching ⇒higher cross section (optimal around 3 MeV/u)
- smaller E_{cm} ⇒higher contribution by compound reactions?

no such protons observed, can be explained by low neutron separation energy which favors *neutron evaporation*

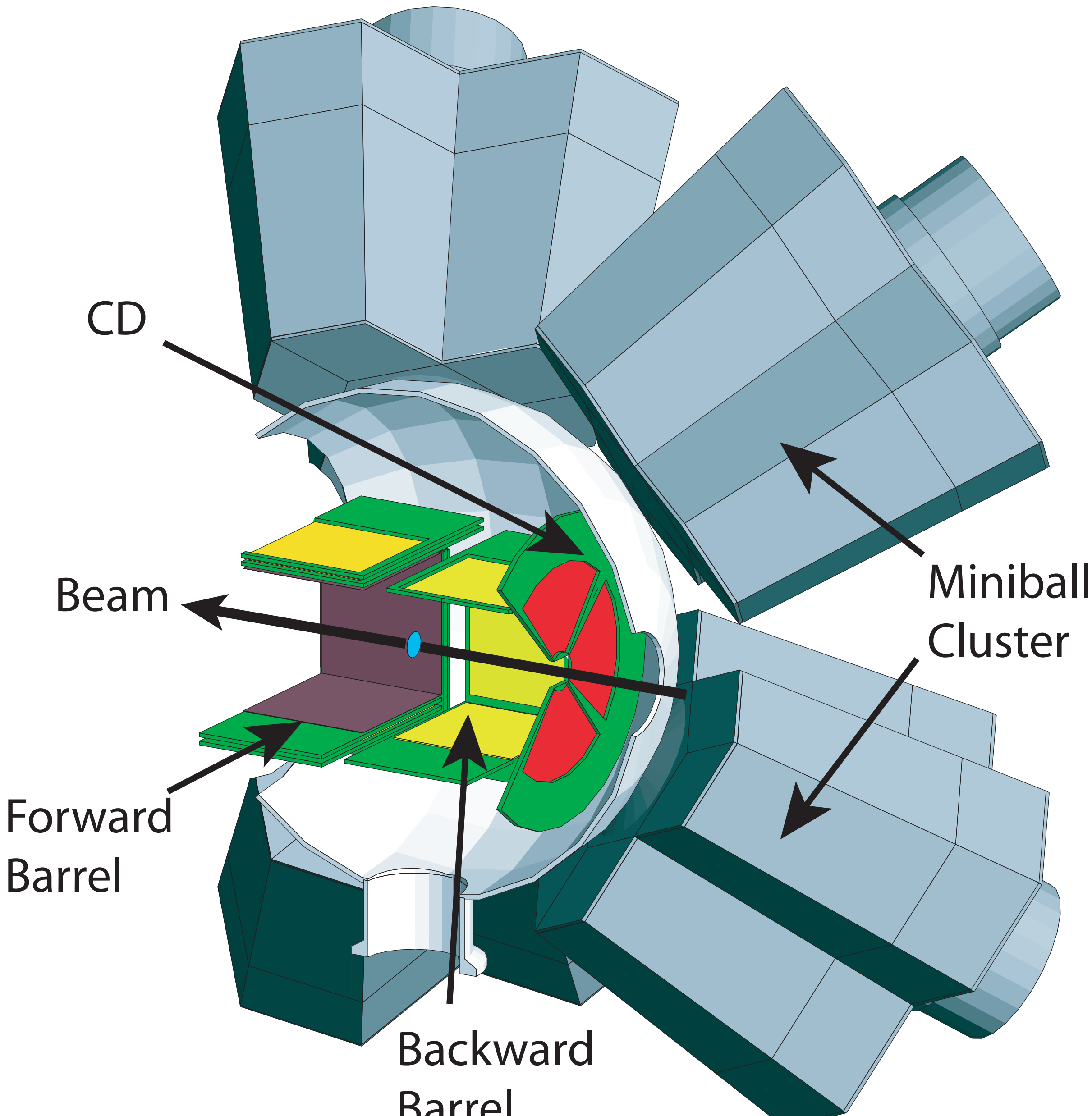


H. Lenske, G. Schrieder, EPJA 2, 41 (1998)



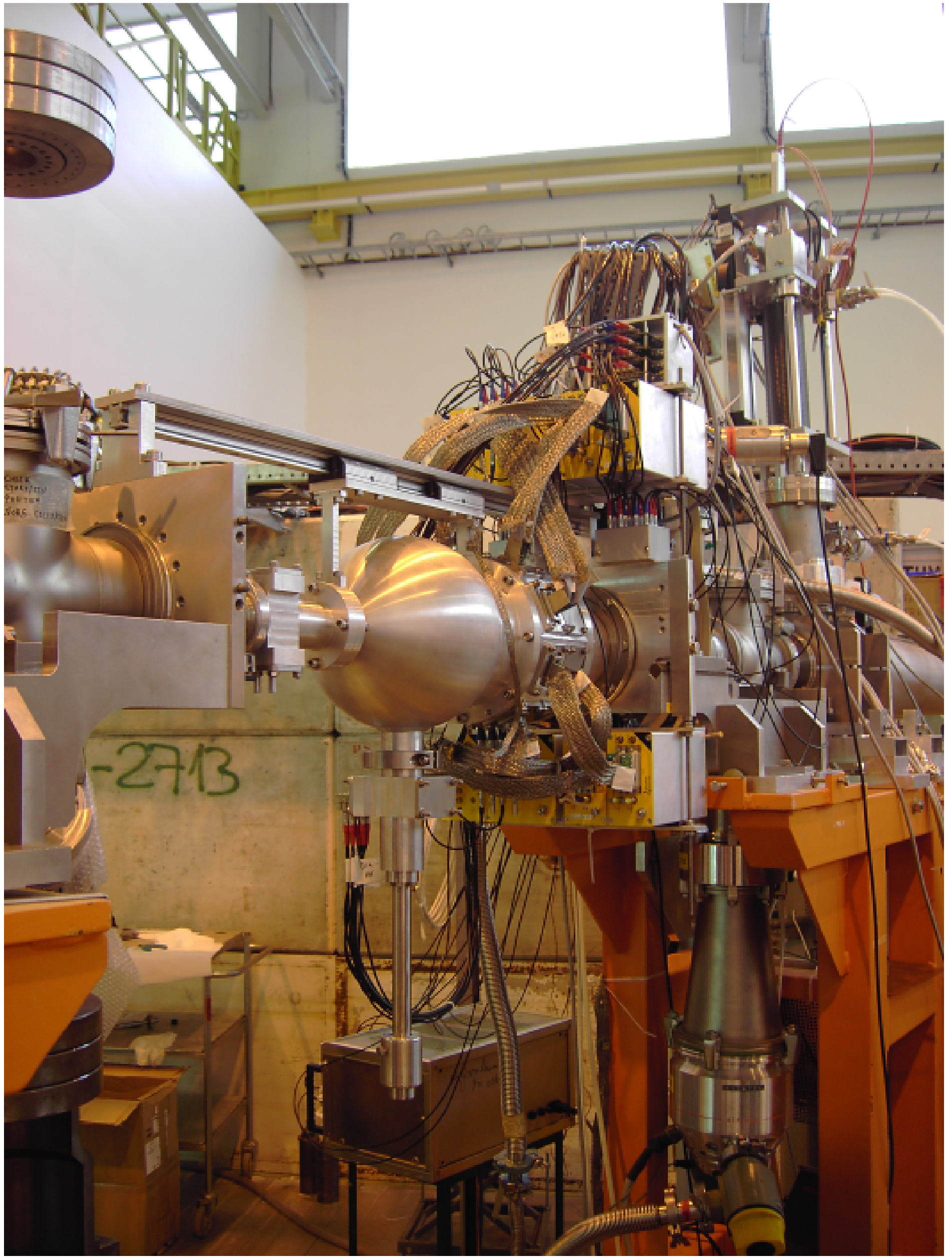
M. Pantea, PhD Thesis (Darmstadt, 2005)

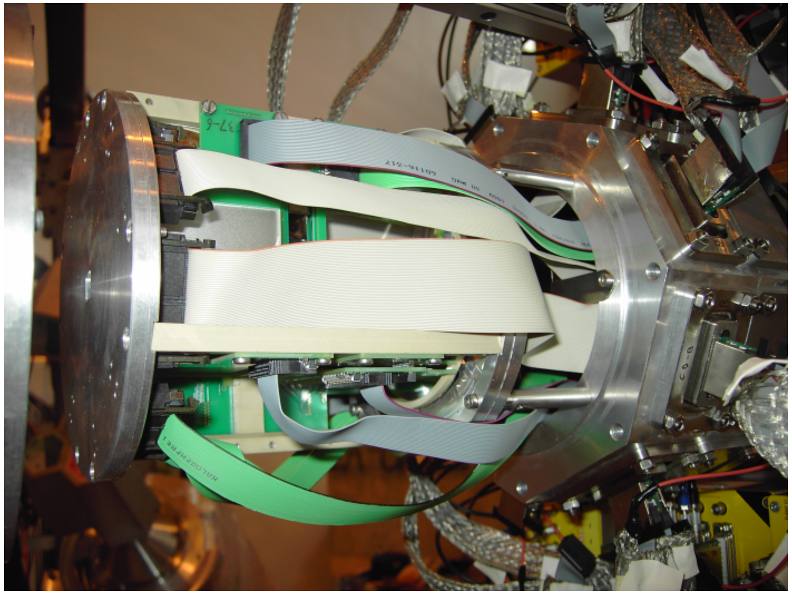
New Setup 2007



- Miniball γ-spectrometer: 24 6-fold segmented HPGe crystals in 8 triple cluster
- forward barrel: 140/1000 μm silicon
- backward barrel/CD: 500 μm silicon
- target: $1\ \mathrm{mg/cm^2}$ deuterated PE

Setup II



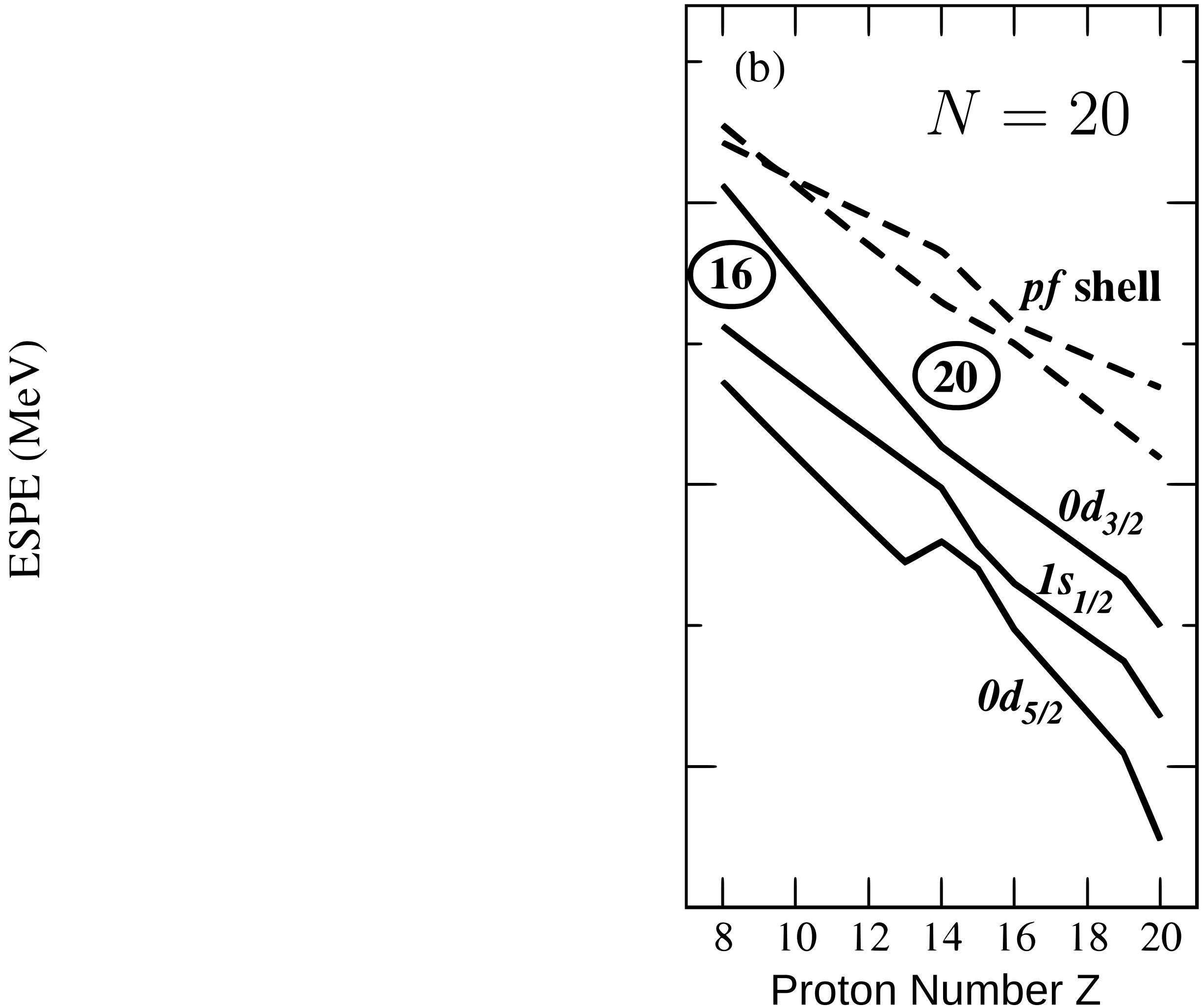


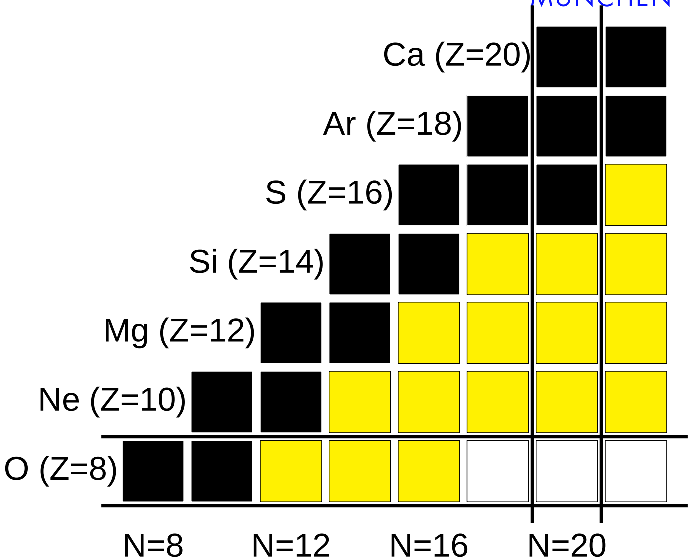
- build and tested in Munich
- detectors and electronics were funded by Leuven, Orsay and Munich
- first experiment with new transfer setup in fall 2007

Island of Inversion

Frontiers and challenges of nuclear shell model

T. Otsuka *et al.*, Euro. Phys. Journal A **15**, 151 (2002)

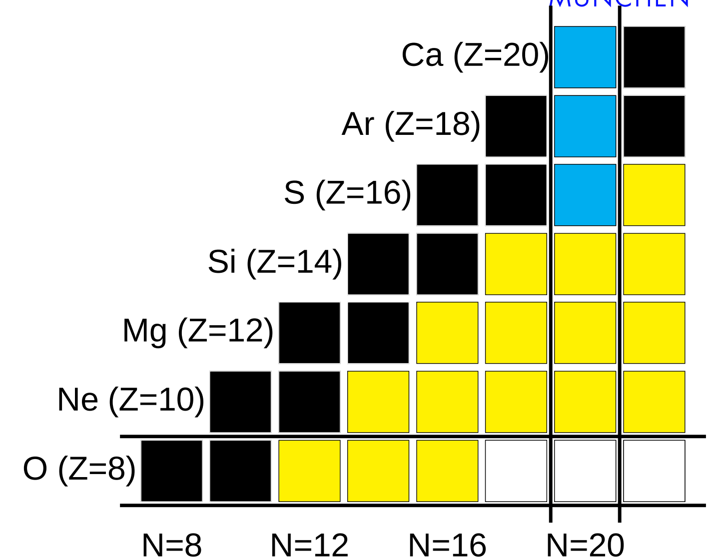


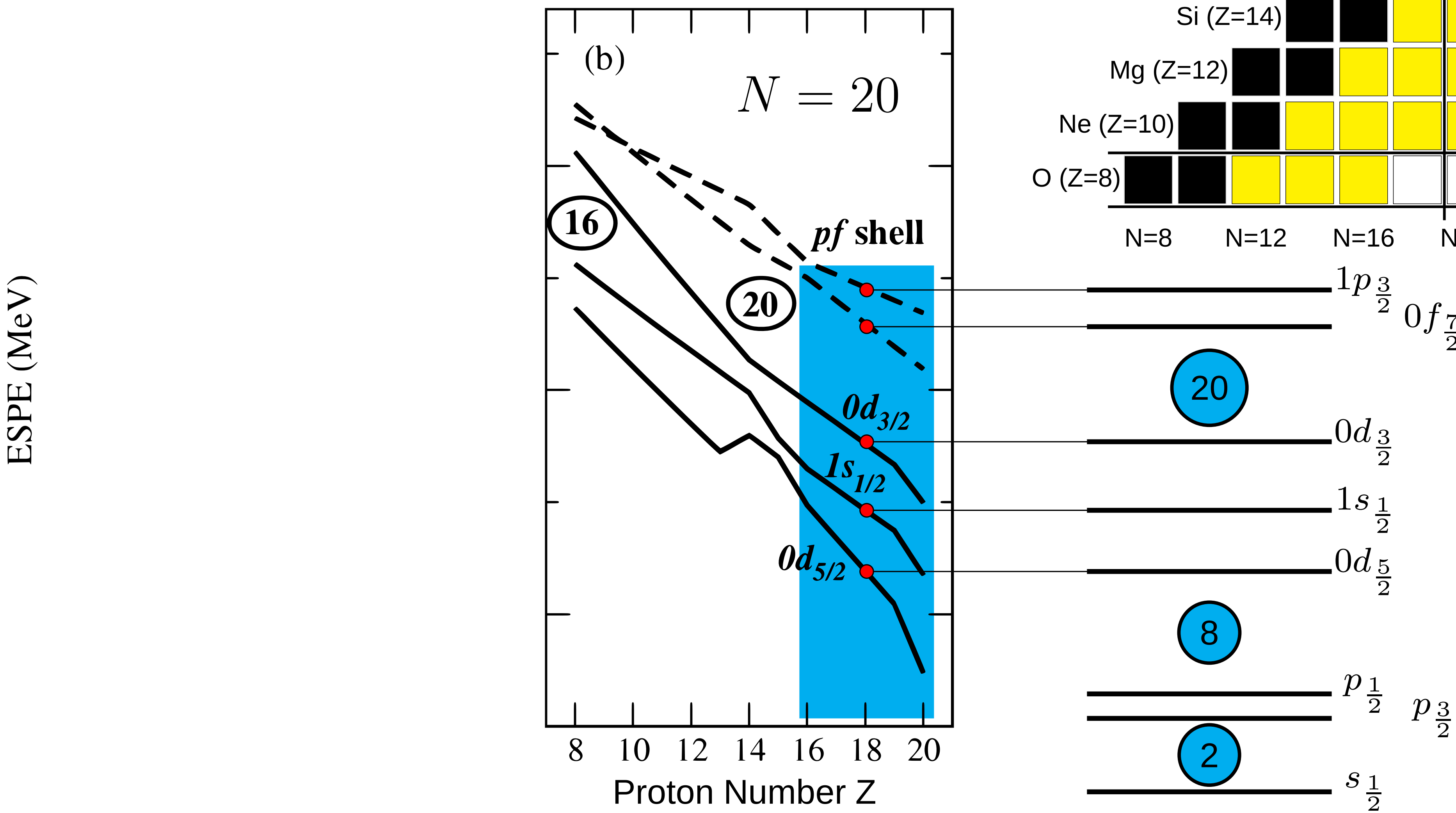


Island of Inversion

Frontiers and challenges of nuclear shell model

T. Otsuka *et al.*, Euro. Phys. Journal A **15**, 151 (2002)

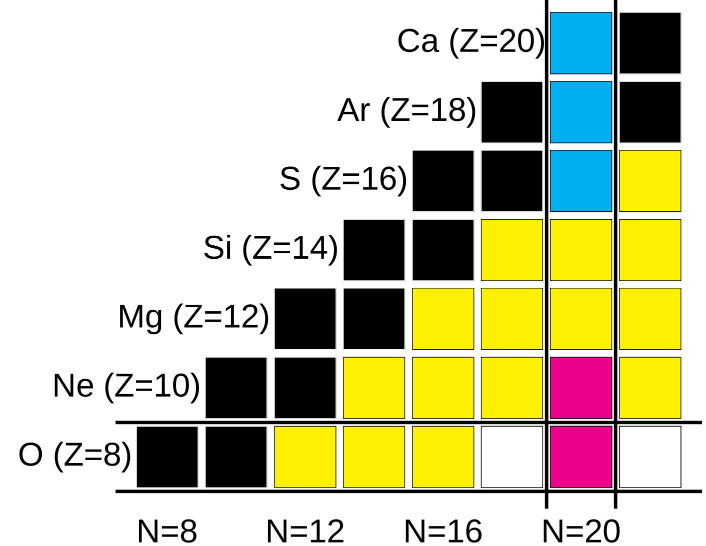


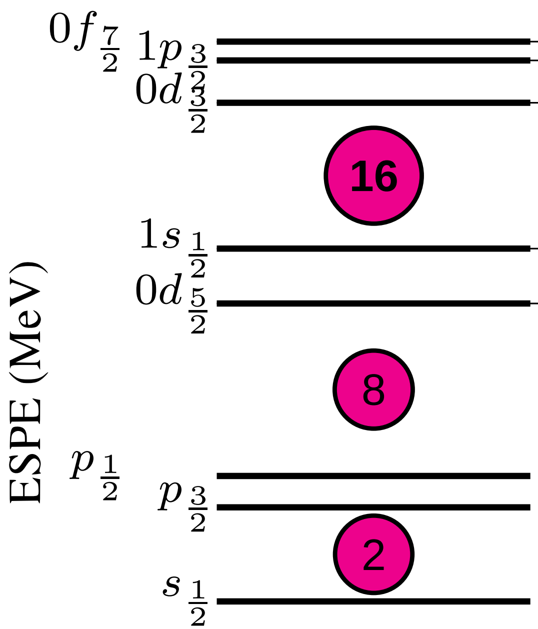


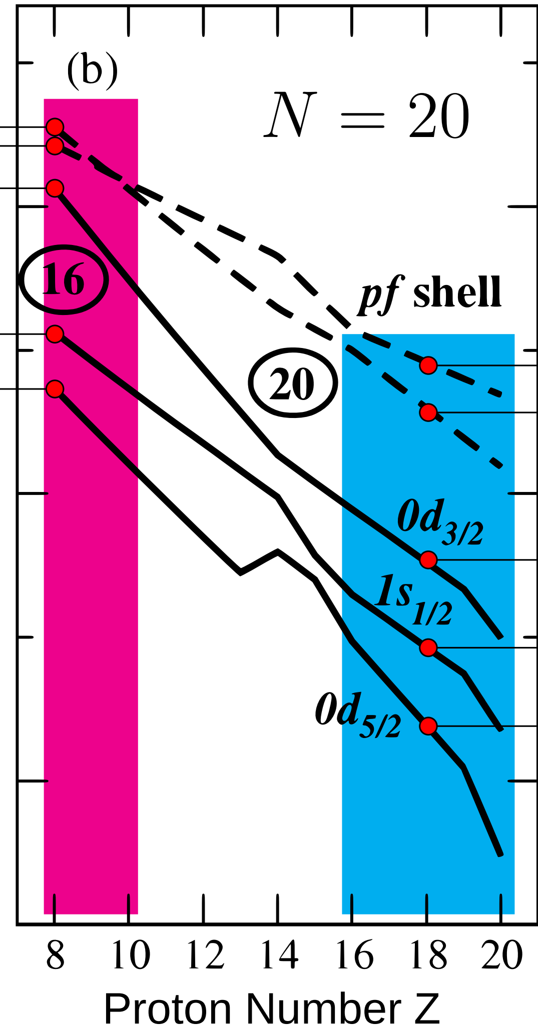
Island of Inversion

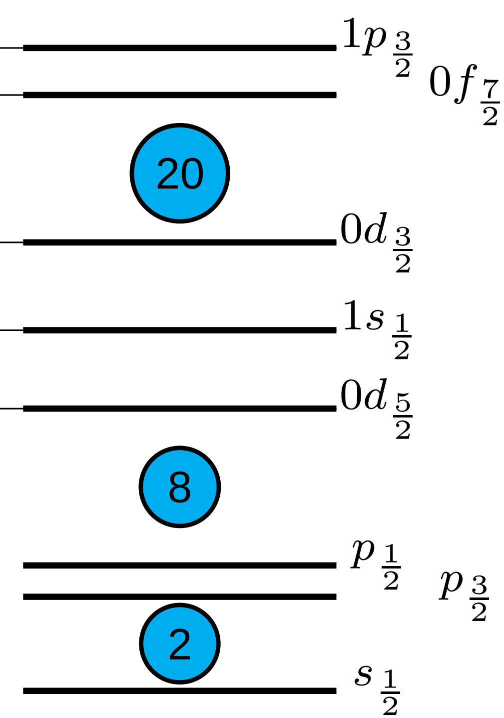
Frontiers and challenges of nuclear shell model

T. Otsuka *et al.*, Euro. Phys. Journal A **15**, 151 (2002)









- completely different shell structure
- **local magic numbers** instead of global magic numbers

Current Status of ^{31}Mg

IS410 @ REX-ISOLDE: "safe" Coulex

^{30}Mg is OUTSIDE
and
^{32}Mg is INSIDE
of the
"Island of Inversion"

many theories explain this, but . . .

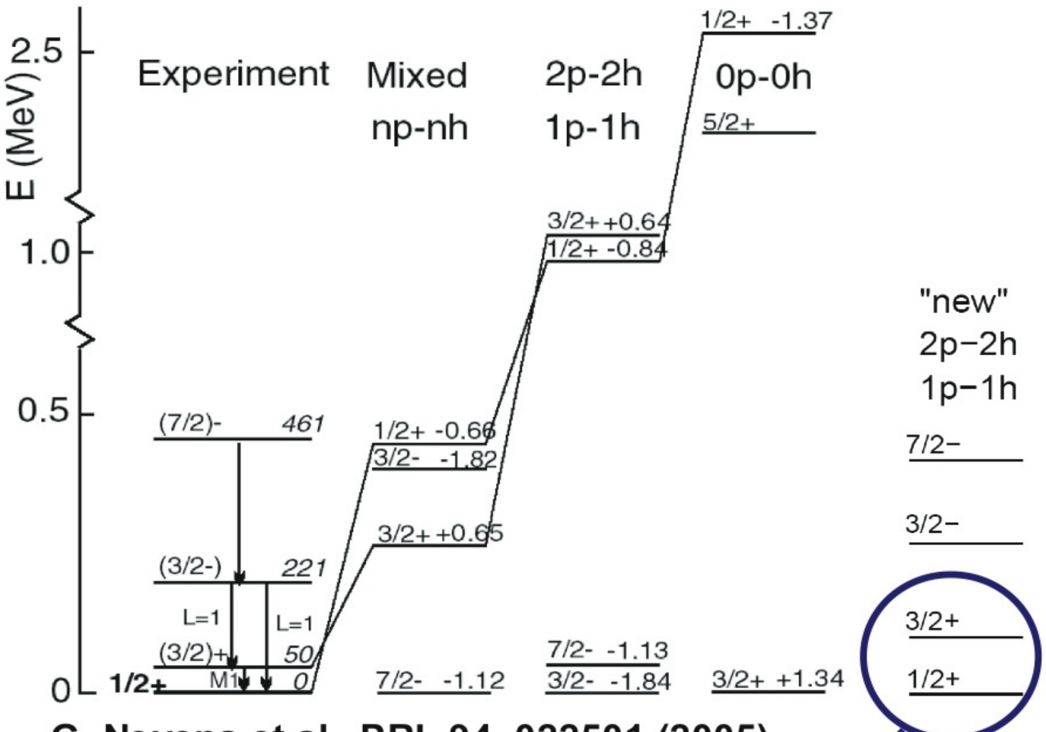
O. Niedermaier et al.,
PRL 94, 172501 (2005);

Current Status of ^{31}Mg

IS410 @ REX-ISOLDE: "safe" Coulex
^{30}Mg is OUTSIDE
and
^{32}Mg is INSIDE
of the
"Island of Inversion"

many theories explain this, but . . .

O. Niedermaier et al., PRL 94, 172501 (2005);



G. Neyens et al., PRL 94, 022501 (2005)
F. Maréchal et al., PRC 72, 044314 (2005)

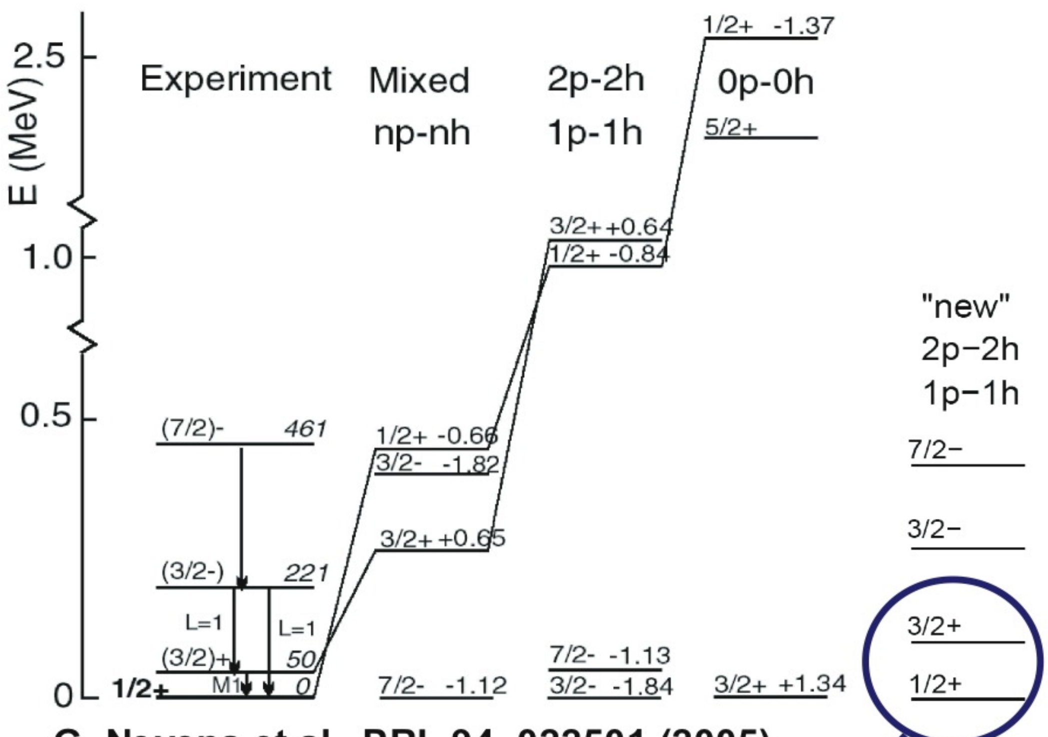
> 90% intruder configuration

Current Status of ^{31}Mg

IS410 @ REX-ISOLDE: "safe" Coulex
^{30}Mg is OUTSIDE
and
^{32}Mg is INSIDE
of the
"Island of Inversion"

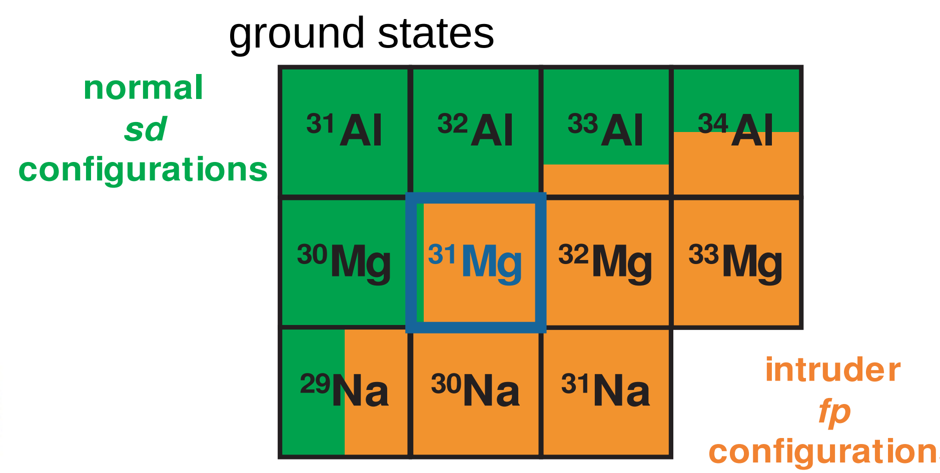
many theories explain this, but . . .

O. Niedermaier et al.,
PRL 94, 172501 (2005);



G. Neyens et al., PRL 94, 022501 (2005)
F. Maréchal et al., PRC 72, 044314 (2005)

> 90% intruder configuration



mostly g-factor measurements

Current Status of ^{31}Mg

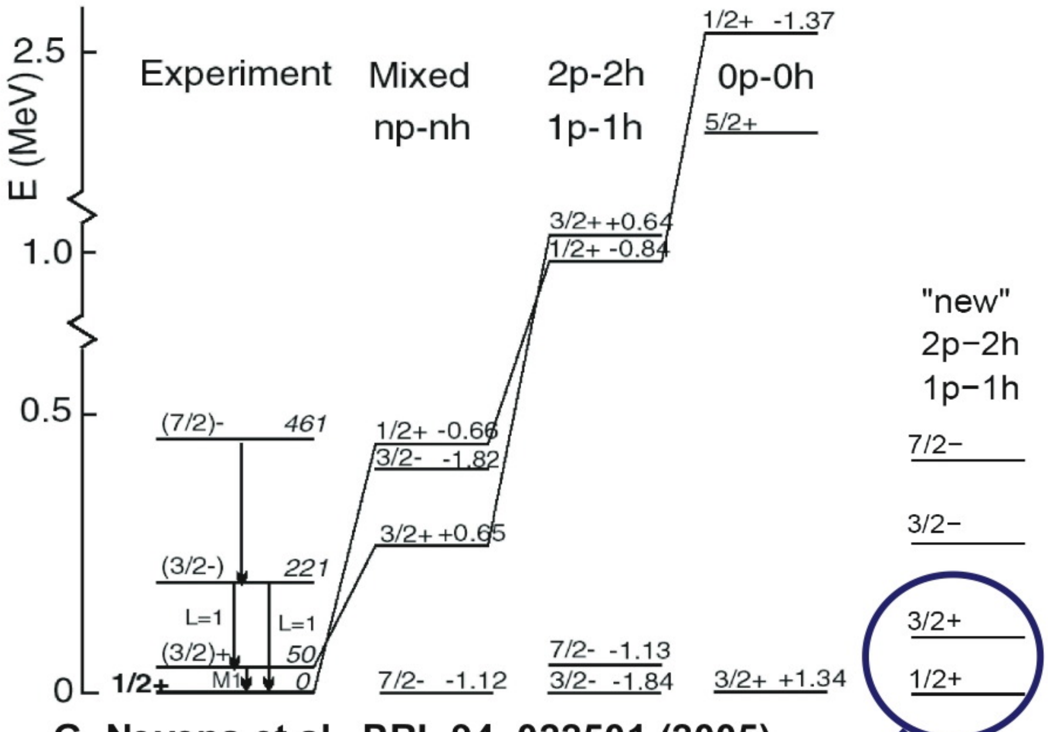
TECHNISCHE UNIVERSITÄT MÜNCHEN

IS410 @ REX-ISOLDE: "safe" Coulex
^{30}Mg is OUTSIDE
and
^{32}Mg is INSIDE
of the
"Island of Inversion"

many theories explain this, but . . .

O. Niedermaier et al., PRL 94, 172501 (2005);

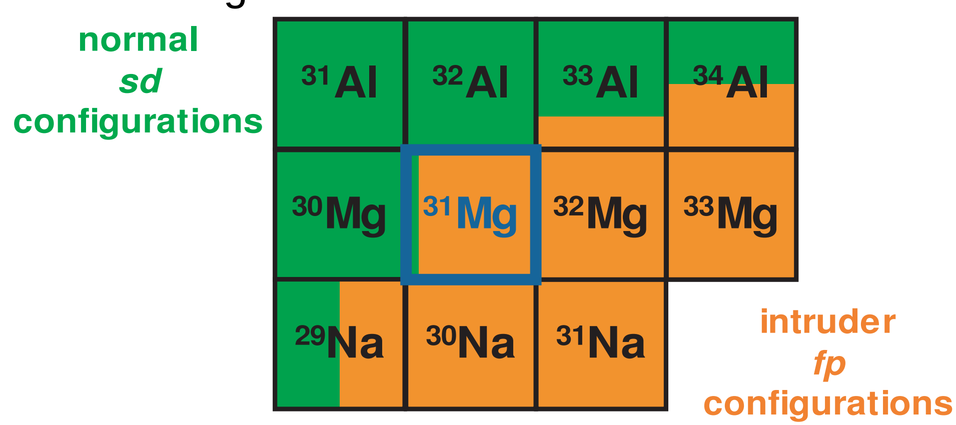
Check the configurations of the *excited* states with (d,p) transfer reaction in inverse kinematic.



G. Neyens et al., PRL 94, 022501 (2005)
F. Maréchal et al., PRC 72, 044314 (2005)

> 90% intruder configuration

ground states

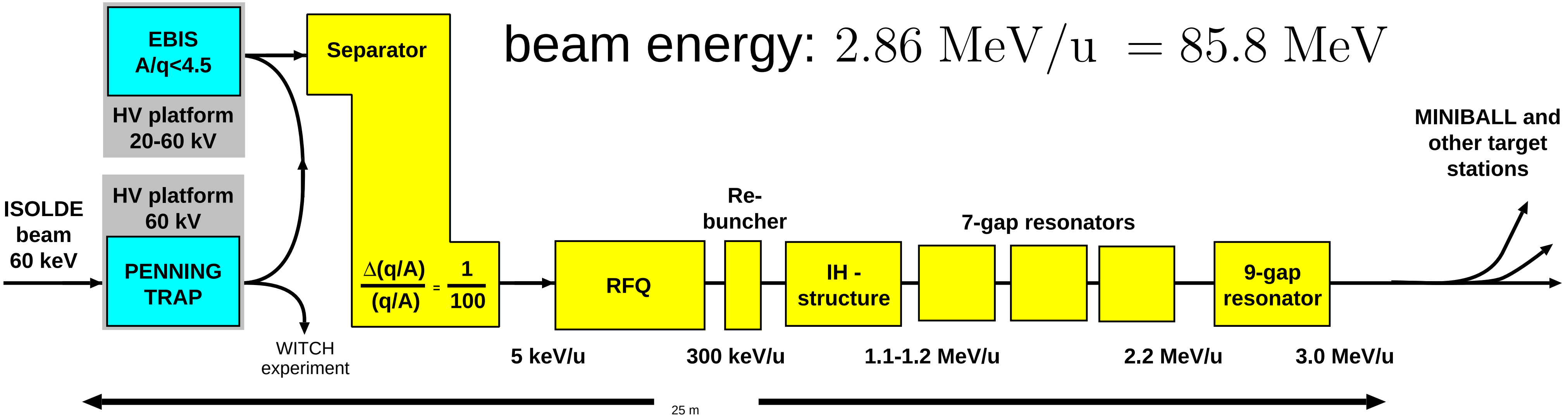


mostly g-factor measurements

REX-ISOLDE

TECHNISCHE UNIVERSITÄT MÜNCHEN

beam energy: $2.86\ \mathrm{MeV/u}\ = 85.8\ \mathrm{MeV}$



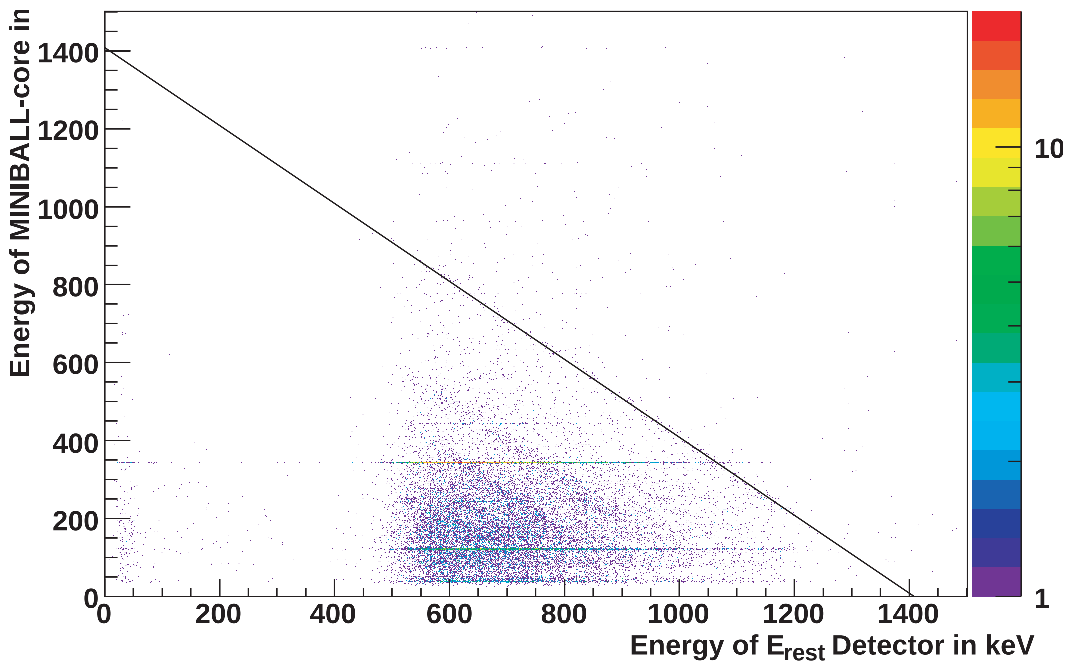
- fragmentation/spallation of UCx-target by 1.4 GeV protons
- ionisation by Resonance Ionization Laser Ion Source (RILIS)
- mass-separation in General Purpose Separator (GPS)

Calibration of E_{rest} Detectors

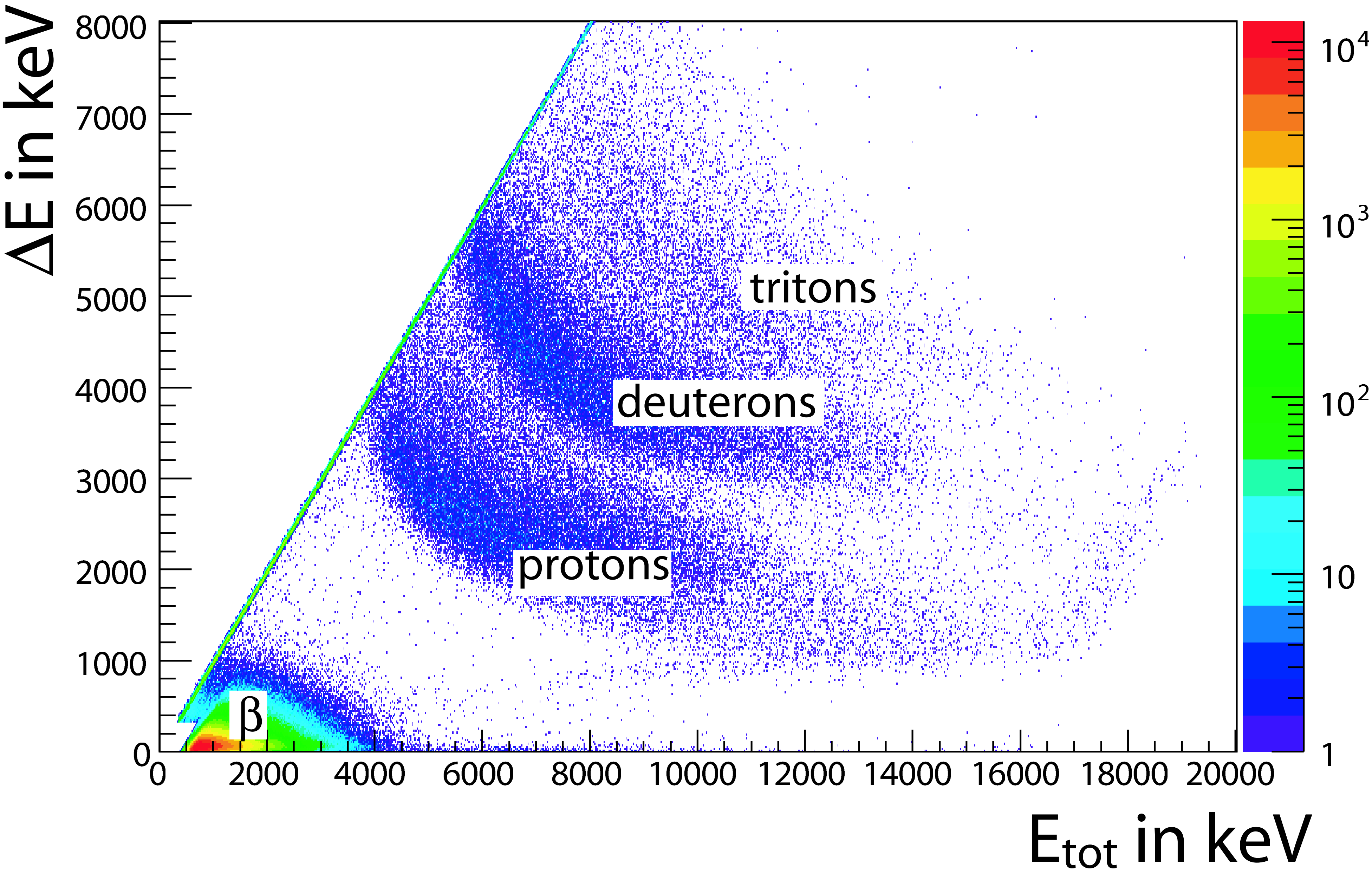
- Barrel detectors in forward direction are ΔE-E_{rest} telescopes: Calibration with α-source not possible for E_{rest} detectors because the ΔE-detectors in front of them stop the α particles.

Calibration of E$_{\mathrm{rest}}$ Detectors

- Barrel detectors in forward direction are ΔE-E$_{\mathrm{rest}}$ telescopes: Calibration with α-source not possible for E$_{\mathrm{rest}}$ detectors because the ΔE-detectors in front of them stop the α particles.
- But detection of γs (e.g. from a ^{152}Eu source), which were Compton-scattered in the E$_{\mathrm{rest}}$ detectors, with the MINIBALL-array allows calibration.

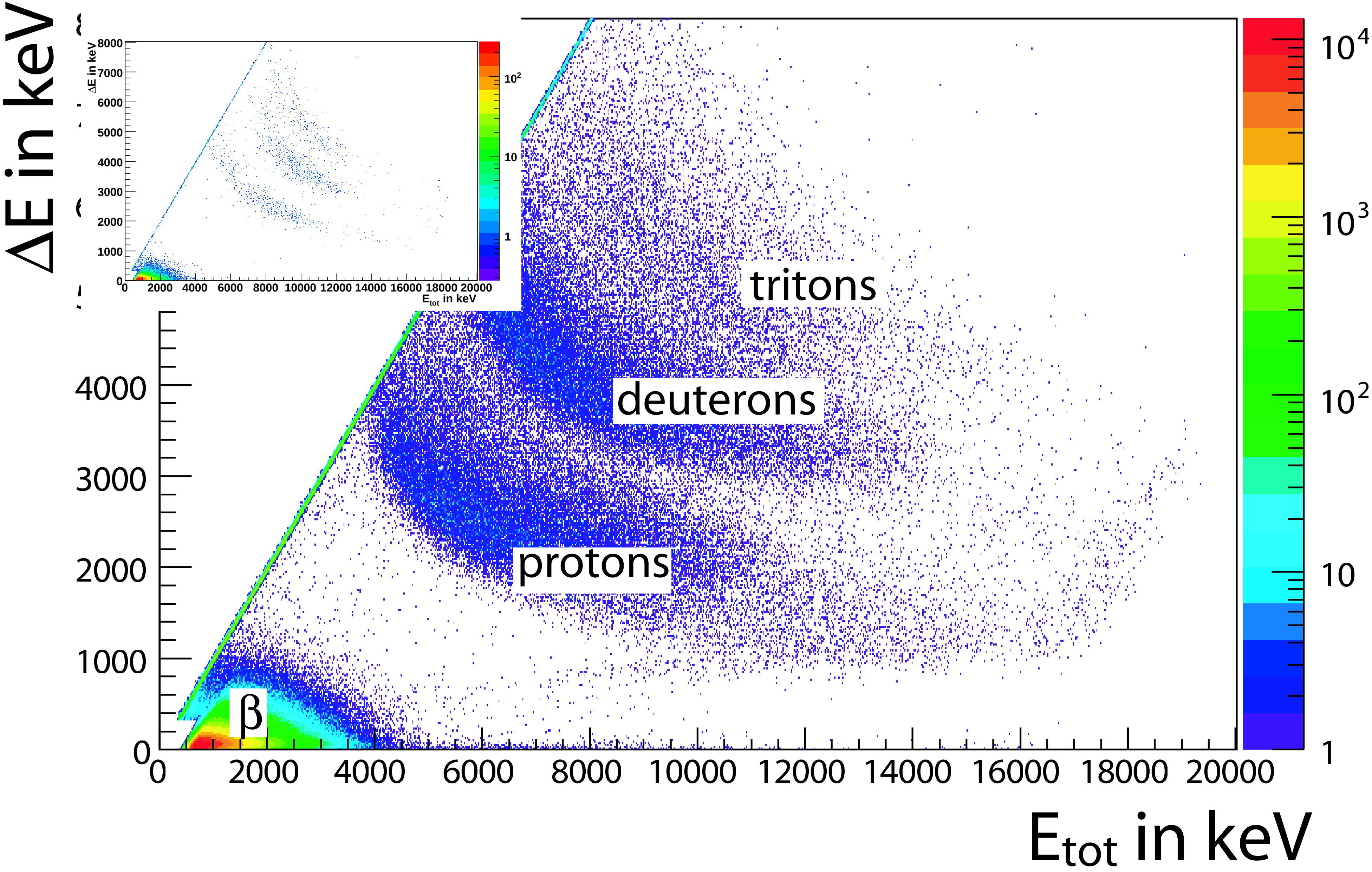


Particle Identification



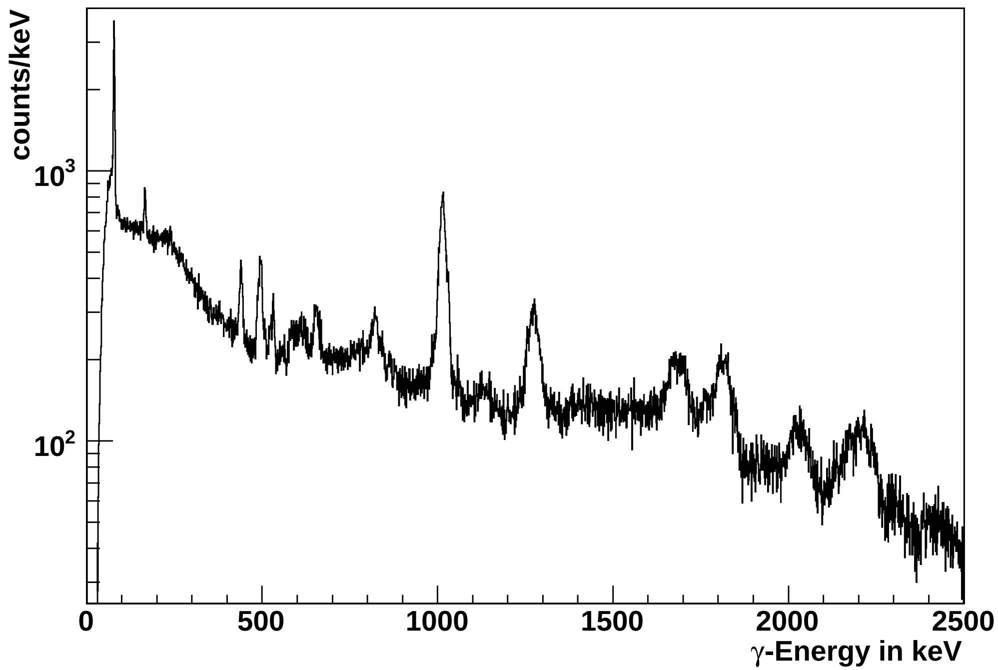
Particle Identification

TECHNISCHE UNIVERSITÄT MÜNCHEN



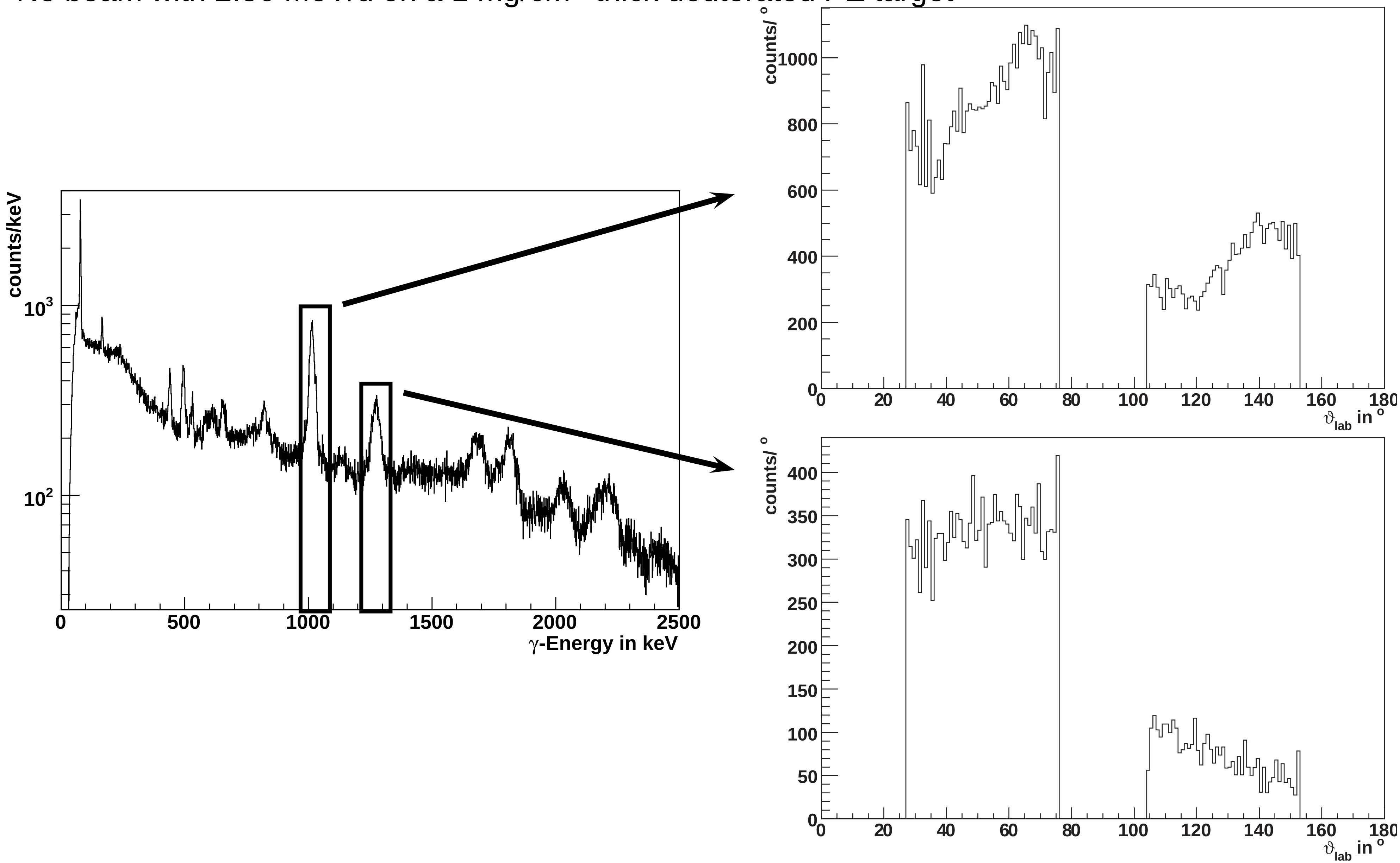
d(^{22}Ne,^{23}Ne)p reaction

^{22}Ne beam with 2.86 MeV/u on a 1 mg/cm^2 thick deuterated PE target

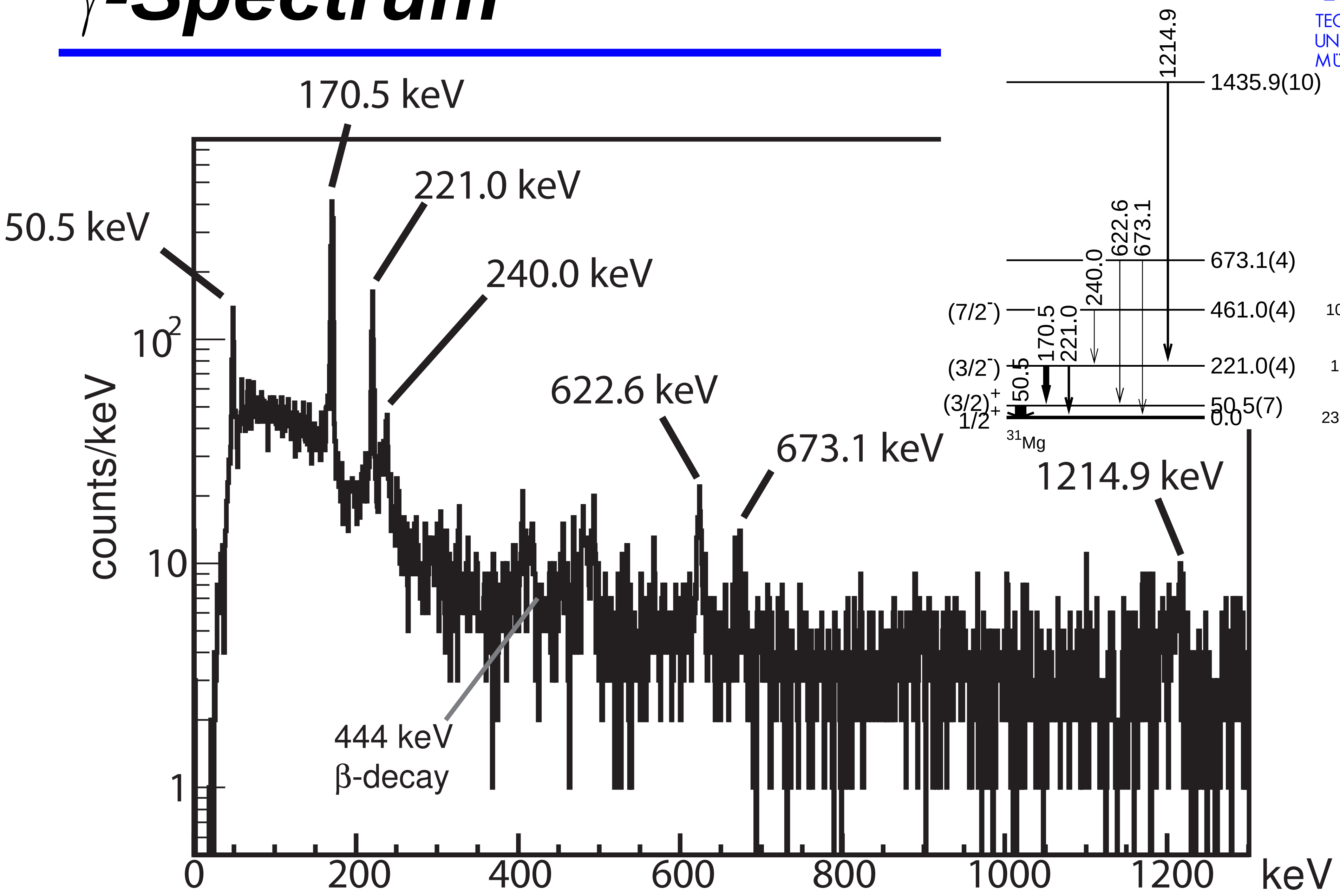


$d(^{22}Ne,^{23}Ne)p$ reaction

^{22}Ne beam with 2.86 MeV/u on a 1 mg/cm^2 thick deuterated PE target



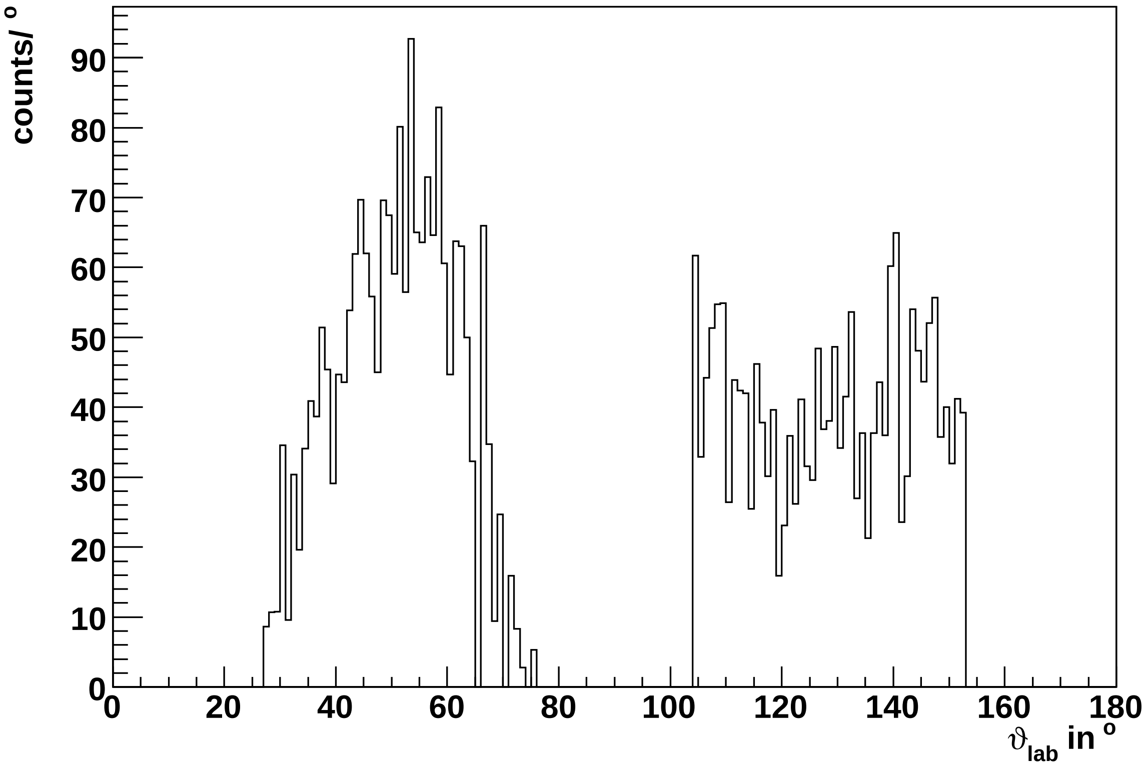
γ-Spectrum



Cut on coincident protons, Doppler corrected with $\vartheta(^{31}\mathrm{Mg}) = 0^\circ$

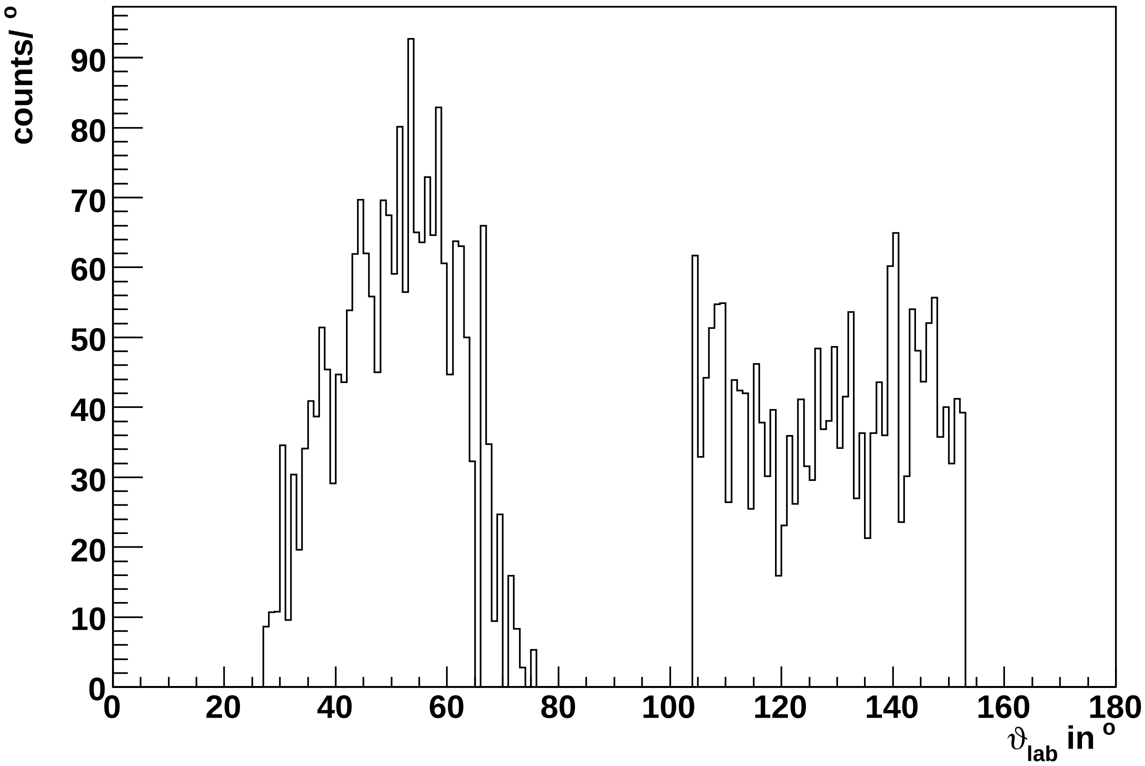
Angular Distributions of ^{31}Mg

cut on 170.5 keV



Angular Distributions of ^{31}Mg

cut on 170.5 keV

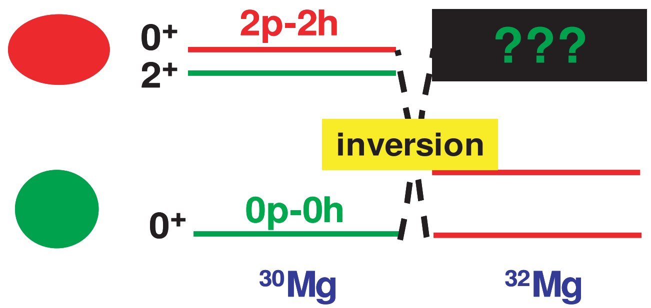


- no correction for background, namely from β-decay
- no correction for feeding from higher states

Two Neutron Transfer

Coexistence of spherical and deformed states

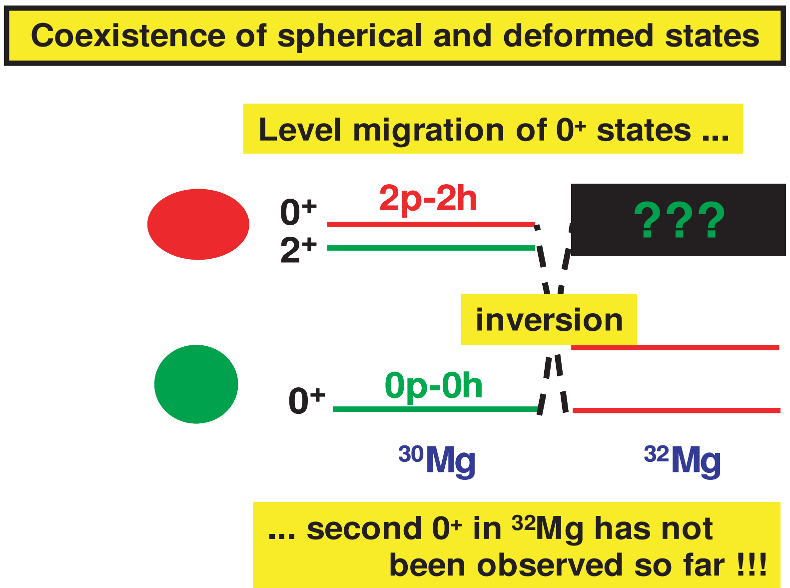
Level migration of 0^+ states ...



... second 0^+ in ^{32}Mg has not been observed so far !!!

Two Neutron Transfer

TECHNISCHE UNIVERSITÄT MÜNCHEN

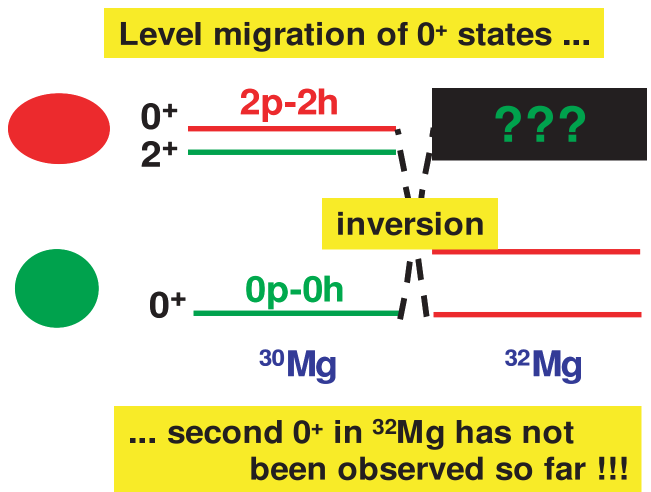


Use the t(^{30}Mg,^{32}Mg)p two neutron transfer reaction to selectively populate states with same particle-hole structure as the ground state of ^{30}Mg.

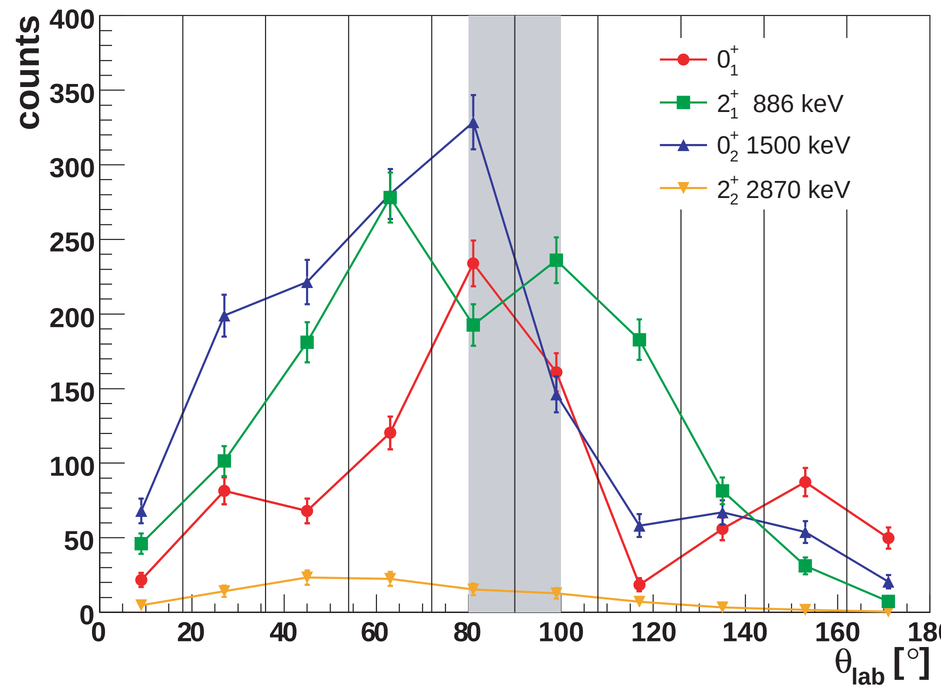
Two Neutron Transfer

TECHNISCHE UNIVERSITÄT MÜNCHEN

Coexistence of spherical and deformed states



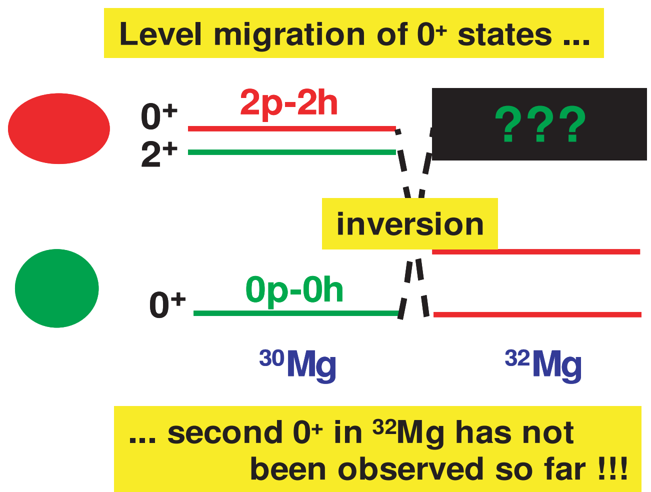
Use the t(^{30}Mg,^{32}Mg)p two neutron transfer reaction to selectively populate states with same particle-hole structure as the ground state of ^{30}Mg.

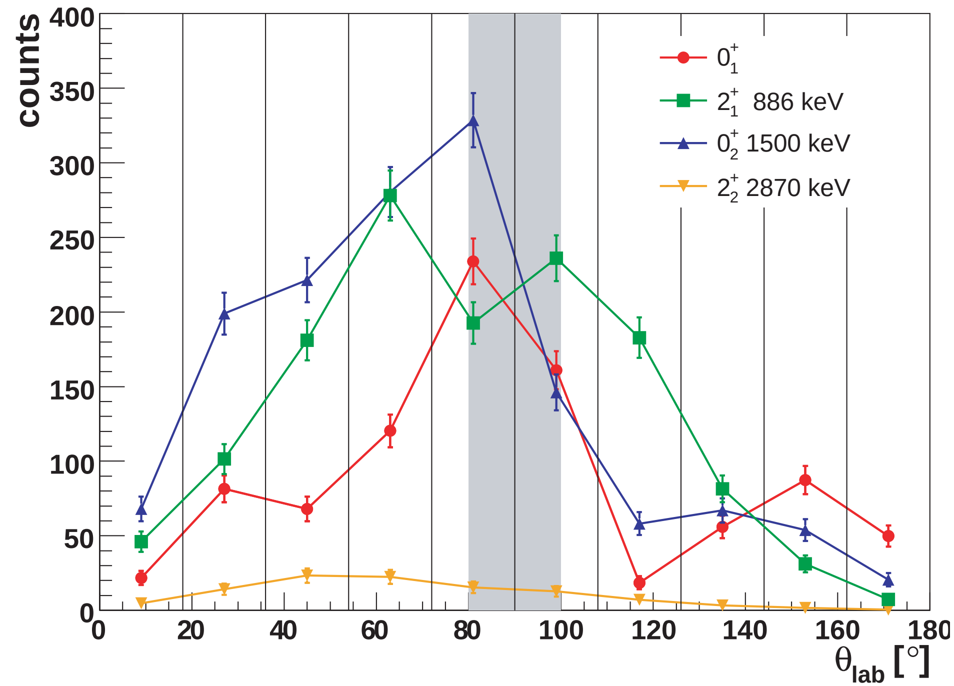


9 days of beam time at 10^5 particle/s

Two Neutron Transfer

Coexistence of spherical and deformed states





Use the t(^{30}Mg,^{32}Mg)p two neutron transfer reaction to selectively populate states with same particle-hole structure as the ground state of ^{30}Mg.

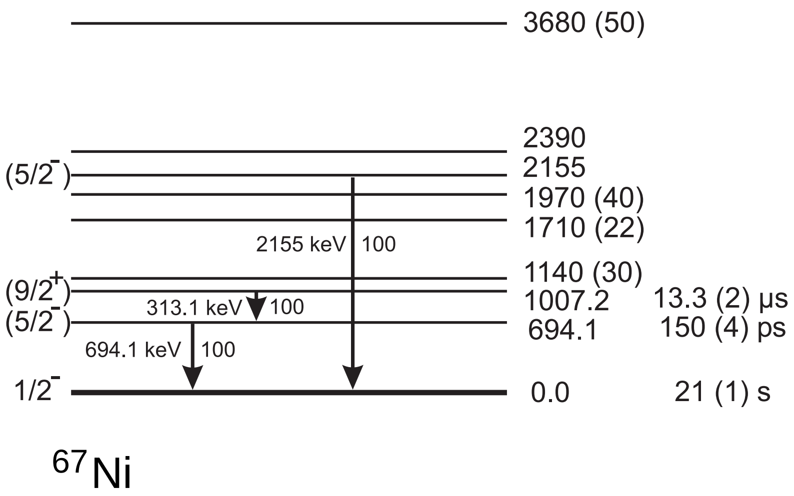
9 days of beam time at 10^5 particle/s

two neutron transfer reactions are more complex than one neutron transfer reactions:

- a correlated pair of neutrons can be transfered
- sequential transfer of two neutron via intermediate states of the nucleus “in between” is also possible, but DWBA calc. show dominant pair transfer (independent of ^{31}Mg structure)
- tritium target: test with stable beam and tritium loaded titanium foil successful

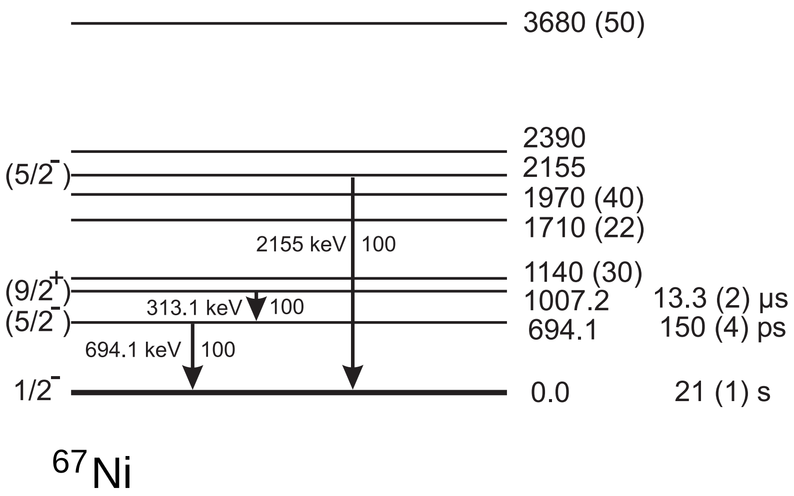
Transfer reactions around ^{68}Ni

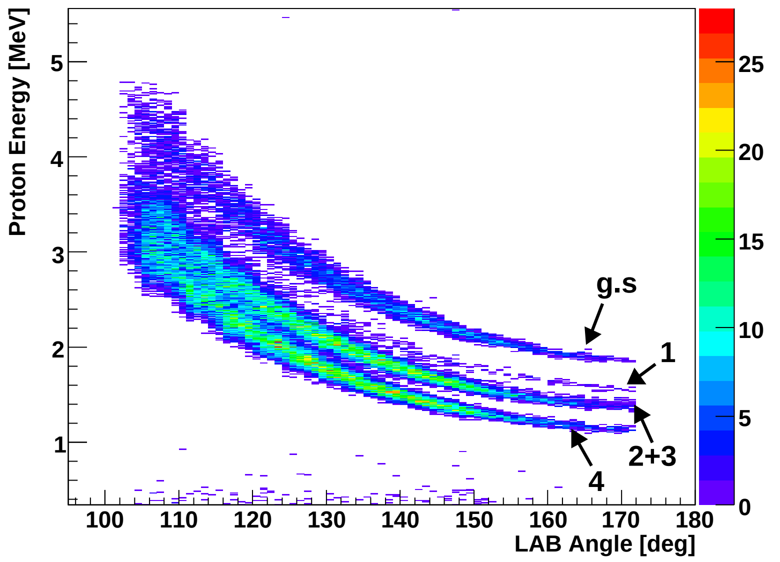
- nature of N=40 shell closure and specific influence of the $1g_{9/2}$ orbital not yet clarified.
- KU Leuven proposed to study the d(^{66}Ni, ^{67}Ni)p reaction
- ^{67}Ni can be considered as a ^{68}Ni core with one neutron hole
- study the single particle character of ground state and first excited states
- fix spin of states
- comparison of relative spectroscopic factors with calculations gives indication whether N=40 is a proper subshell closure



Transfer reactions around ^{68}Ni

- nature of N=40 shell closure and specific influence of the $1g_{9/2}$ orbital not yet clarified.
- KU Leuven proposed to study the d(^{66}Ni, ^{67}Ni)p reaction
- ^{67}Ni can be considered as a ^{68}Ni core with one neutron hole
- study the single particle character of ground state and first excited states
- fix spin of states
- comparison of relative spectroscopic factors with calculations gives indication whether N=40 is a proper subshell closure
- indentifying populated states by prompt γ emission doesn't work for all states
- using a 100 μg/cm^2 thin target allows to distinguish the states w/o prompt γ emission in singles spectrum
- using a 1 mg/cm^2 thick target gives enough statistics to distinguish states by coincident γs





Improvements

TECHNISCHE UNIVERSITÄT MÜNCHEN

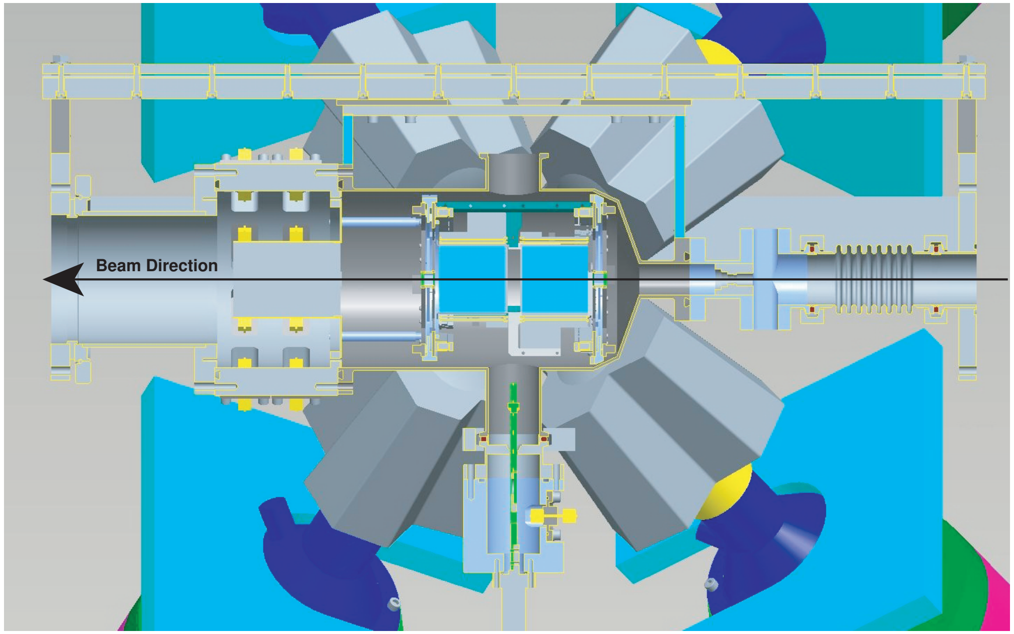
- to reduce background from β-decay backward detectors now also consist of 140 μm strip detectors and 1000 μm pad detectors
  $\Rightarrow \Delta$E-E$_{\mathrm{rest}}$ identification of betas and protons possible

Improvements

- to reduce background from β-decay backward detectors now also consist of 140 μm strip detectors and 1000 μm pad detectors
  $\Rightarrow \Delta$E-$E_{\rm rest}$ identification of betas and protons possible
- new target ladder suitable for tritium target (sealed airtight)
  $\Rightarrow$two neutron transfer reactions possible

Improvements

- to reduce background from β-decay backward detectors now also consist of 140 μm strip detectors and 1000 μm pad detectors
  $\Rightarrow \Delta$E-E$_{\mathrm{rest}}$ identification of betas and protons possible
- new target ladder suitable for tritium target (sealed airtight)
  $\Rightarrow$two neutron transfer reactions possible



Summary & Outlook

- first experiment with the new setup for transfer reactions at REX-ISOLDE

Summary & Outlook

TECHNISCHE UNIVERSITÄT MÜNCHEN

- first experiment with the new setup for transfer reactions at REX-ISOLDE
- first analysis of d(^{30}Mg,^{31}Mg)p experiment shows promise, despite the low statistics

Summary & Outlook

TECHNISCHE UNIVERSITÄT MÜNCHEN

- first experiment with the new setup for transfer reactions at REX-ISOLDE
- first analysis of d(^{30}Mg,^{31}Mg)p experiment shows promise, despite the low statistics
- two further experiments were approved:
    - t(^{30}Mg,^{32}Mg)p - proposed by TU München (scheduled for fall 2008)
    - d(^{66}Ni,^{67}Ni)p - proposed by KU Leuven

Summary & Outlook

- first experiment with the new setup for transfer reactions at REX-ISOLDE
- first analysis of d(^{30}Mg,^{31}Mg)p experiment shows promise, despite the low statistics
- two further experiments were approved:
  - t(^{30}Mg,^{32}Mg)p - proposed by TU München (scheduled for fall 2008)
  - d(^{66}Ni,^{67}Ni)p - proposed by KU Leuven
- upgrade to HIE-ISOLDE:
  - higher beam energies will be available
    $\Rightarrow$transfer reactions with higher masses possible
  - $0°$-spectrometer will allow direct measurement of the ejectiles

Collaboration

TECHNISCHE UNIVERSITÄT MÜNCHEN

Physik-Department E12, Technische Universität München, Garching, Germany
Instituut voor Kern- en Stralingsfysica, Katholieke Universiteit Leuven, Belgium
CERN, Genève, Switzerland
Department of Physics and Astronomy, University of Edinburgh, Scotland, United Kingdom
Fundamental Physics, Chalmers Tekniska Högskola, Göteborg, Sweden
Electronic Engineering and Physics, University of Paisley, Scotland, United Kingdom
Sektion Physik, Ludwig-Maximilians-Universität München, Garching, Germany
Nuclear Physics Group, Department of Physics, University of York, United Kingdom
Nuclear Physics Group, Schuster Laboratory, University of Manchester, United Kingdom
Oliver Lodge Laboratory, University of Liverpool, United Kingdom
Institut für Kernphysik, Universität zu Köln, Germany
Centre de Spectrométrie Nucléaire et de Spectrométrie de Masse, Orsay, France
Institut für Kernphysik, Technische Universität Darmstadt, Germany
INRNE, Bulgarian Academy of Sciences, Sofia, Bulgaria
Dipartimento di Fisica, Università di Camerino, Camerino, Italy
CSIS, IEM Madrid, Madrid, Spain

Collaboration

Physik-Department E12, Technische Universität München, Garching, Germany
Instituut voor Kern- en Stralingsfysica, Katholieke Universiteit Leuven, Belgium
CERN, Genève, Switzerland
Department of Physics and Astronomy, University of Edinburgh, Scotland, United Kingdom
Fundamental Physics, Chalmers Tekniska Högskola, Göteborg, Sweden
Electronic Engineering and Physics, University of Paisley, Scotland, United Kingdom
Sektion Physik, Ludwig-Maximilians-Universität München, Garching, Germany
Nuclear Physics Group, Department of Physics, University of York, United Kingdom
Nuclear Physics Group, Schuster Laboratory, University of Manchester, United Kingdom
Oliver Lodge Laboratory, University of Liverpool, United Kingdom
Institut für Kernphysik, Universität zu Köln, Germany
Centre de Spectrométrie Nucléaire et de Spectrométrie de Masse, Orsay, France
Institut für Kernphysik, Technische Universität Darmstadt, Germany
INRNE, Bulgarian Academy of Sciences, Sofia, Bulgaria
Dipartimento di Fisica, Università di Camerino, Camerino, Italy
CSIS, IEM Madrid, Madrid, Spain

Thanks for your attention!