First spectroscopy of the r-process nucleus ^{135}Sn

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MINIBALL HIE-ISOLDE HIC for FAIR Helmholtz International Center

Bundesministerium für Bildung und Forschung

LOEWE – Landes-Offensive zur Entwicklung Wissenschaftlich-ökonomischer Exzellenz

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Region of Interest

Nuclei around doubly-magic shell closure in ^{132}Sn
- Letter of Intent: CERN-INTC-2010-045; INTC-I-111
- Approved Proposals: IS548, IS549, IS551 ... all Coulex (beam time 2016)

Higher energies from HIE-ISOLDE: first nucleon transfer ^{134}Sn(d,p)^{135}Sn

^{135}Sn – r-process nucleus

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- r-process passes region around ^{132}Sn
- abundance pattern depends on both nuclear structure (m, β-$T_{1/2}$, σ(n), etc.) and astrophysical conditions
  ... August 2017: neutron star merger identified as (one) astrophysical site
- (d,p) is surrogate reaction for (n,γ)

Neutron capture rates can change average abundances by up to 43%

^{134}Sn(n,γ) has no impact (^{134}Sb(n,γ) has!!!)
... but transfer to an even-even nucleus is theoretically easier
... contributes to the overall understanding of (d,p) in this region

Z \ N	78	79	80	81	82	83	84	85	86	87
52	^{130}Te	^{131}Te	^{132}Te	^{133}Te	^{134}Te	^{135}Te	^{136}Te	^{137}Te	^{138}Te	^{139}Te
51	^{129}Sb	^{130}Sb	^{131}Sb	^{132}Sb	^{133}Sb	^{134}Sb	^{135}Sb	^{136}Sb	^{137}Sb	^{138}Sb
50	^{128}Sn	^{129}Sn	^{130}Sn	^{131}Sn	^{132}Sn	^{133}Sn	^{134}Sn	^{135}Sn	^{136}Sn	^{137}Sn
49	^{127}In	^{128}In	^{129}In	^{130}In	^{131}In	^{132}In	^{133}In	^{134}In	^{135}In	^{136}In
48	^{126}Cd	^{127}Cd	^{128}Cd	^{129}Cd	^{130}Cd	^{131}Cd	^{132}Cd	^{133}Cd	^{134}Cd	^{135}Cd

R. Surman et al., Phys. Rev. C 79, 045809 (2009)

^{133}Sn … what has been done?

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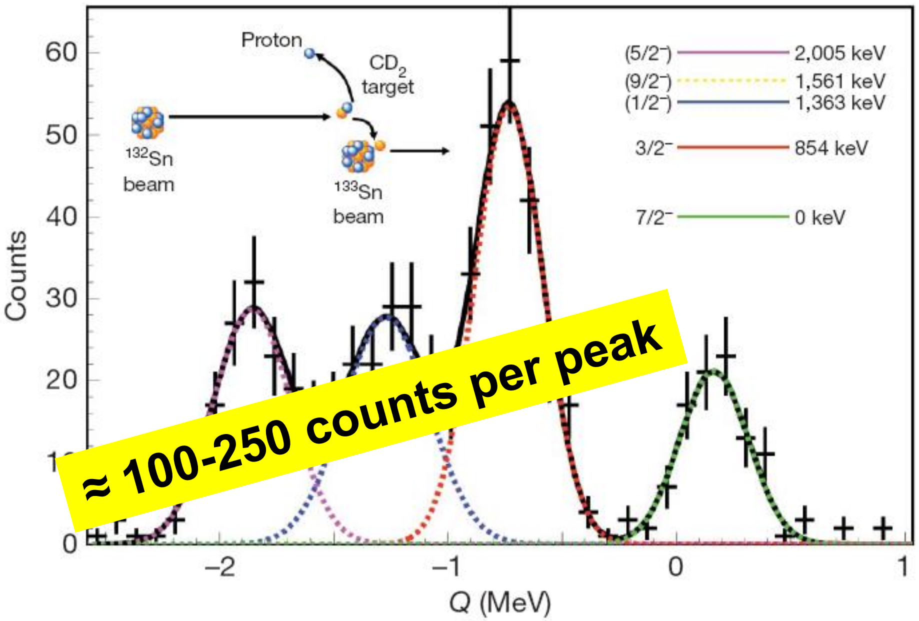
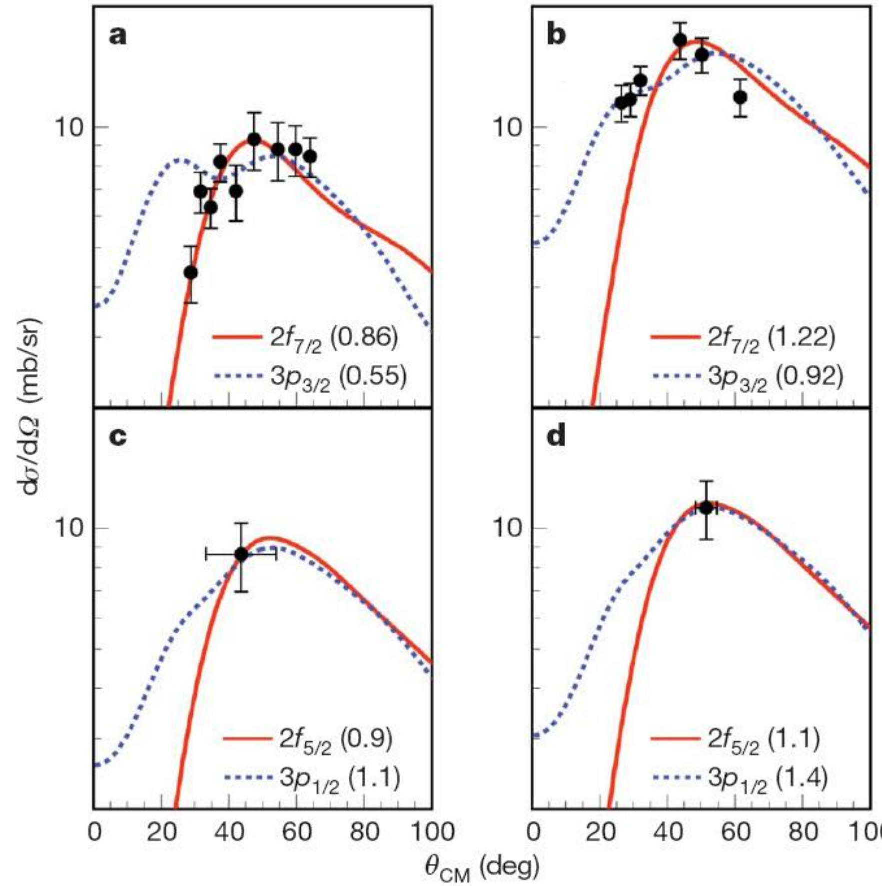


≈ 100-250 counts per peak



^{132}Sn(d,p) @ 4.77 MeV/u

- **particle spectroscopy only**
- **transferred Δℓ determined (angular distributions are quite similar)**
- **SFs extracted**

K. Jones et al., Nature 465, 454 (2010)

^{133}Sn … what has been done?

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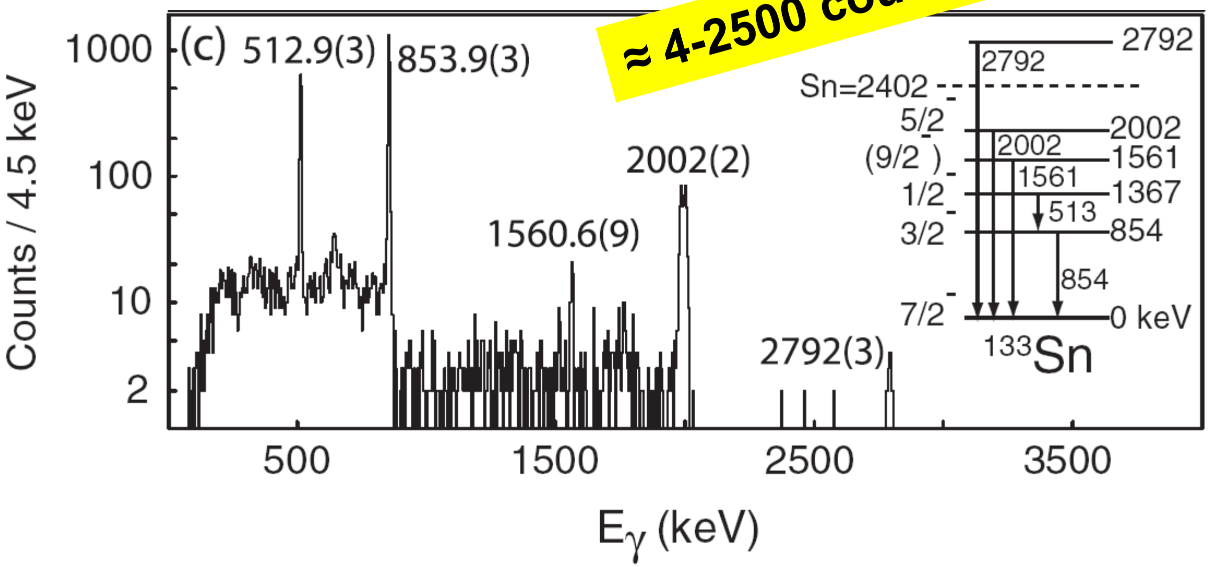
^{132}Sn(^{9}Be,^{8}Be) @ 3 MeV/u

≈ 4-2500 counts per peak

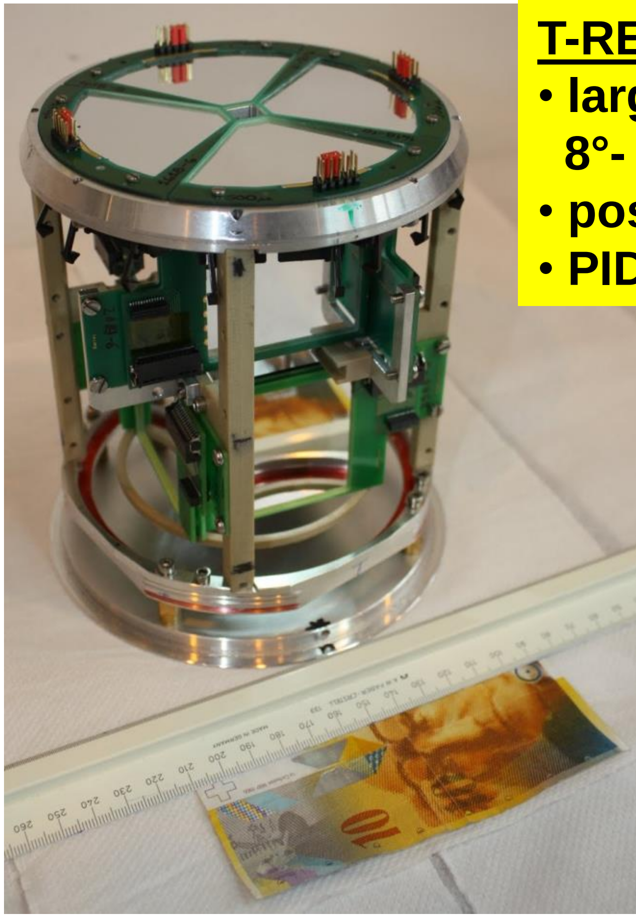


J.M. Allmond et al., Phys. Rev. Lett. 112, 172701 (2014)

- **particle(2α)-γ coincidences**
- **γγ-coincidences, γ-branchings**

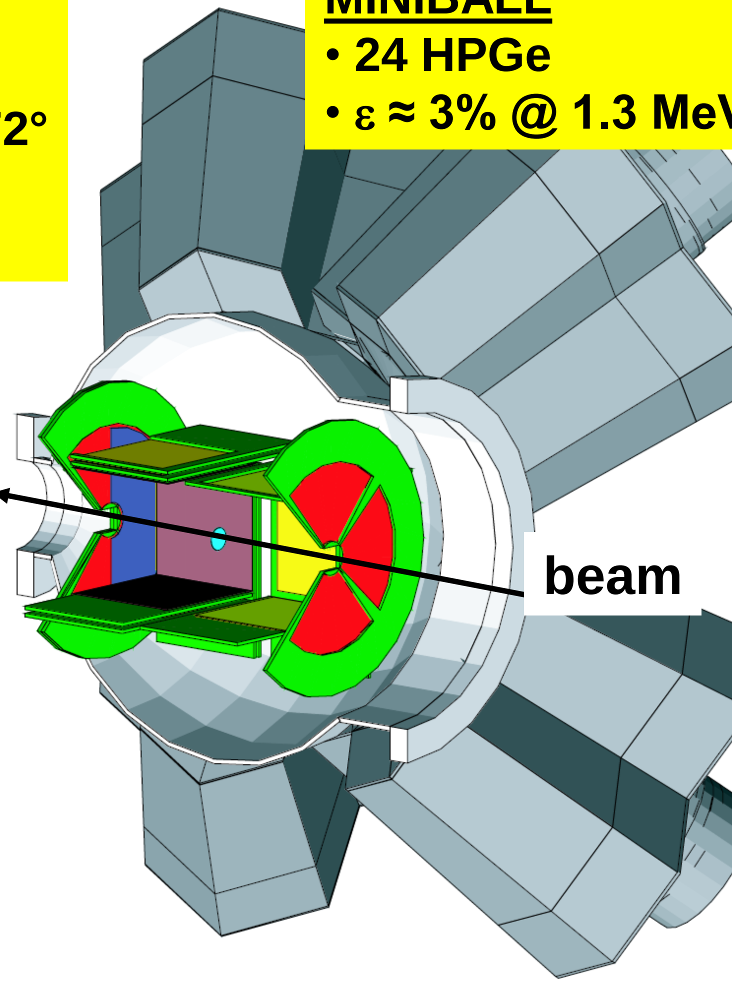
Our approach: combine the best of both light-particle and γ-ray spectroscopy!!!

Set-up: MINIBALL and T-REX



T-REX
- large solid angle
  8°- 78° and 102° - 172°
- position sensitive
- PID (ΔE-E)

MINIBALL
- 24 HPGe
- ε ≈ 3% @ 1.3 MeV



V. Bildstein et al., Eur. Phys. J A 48, 85 (2012)

N. Warr et al., Eur. Phys. J A 49, 40 (2013)

^{135}Sn

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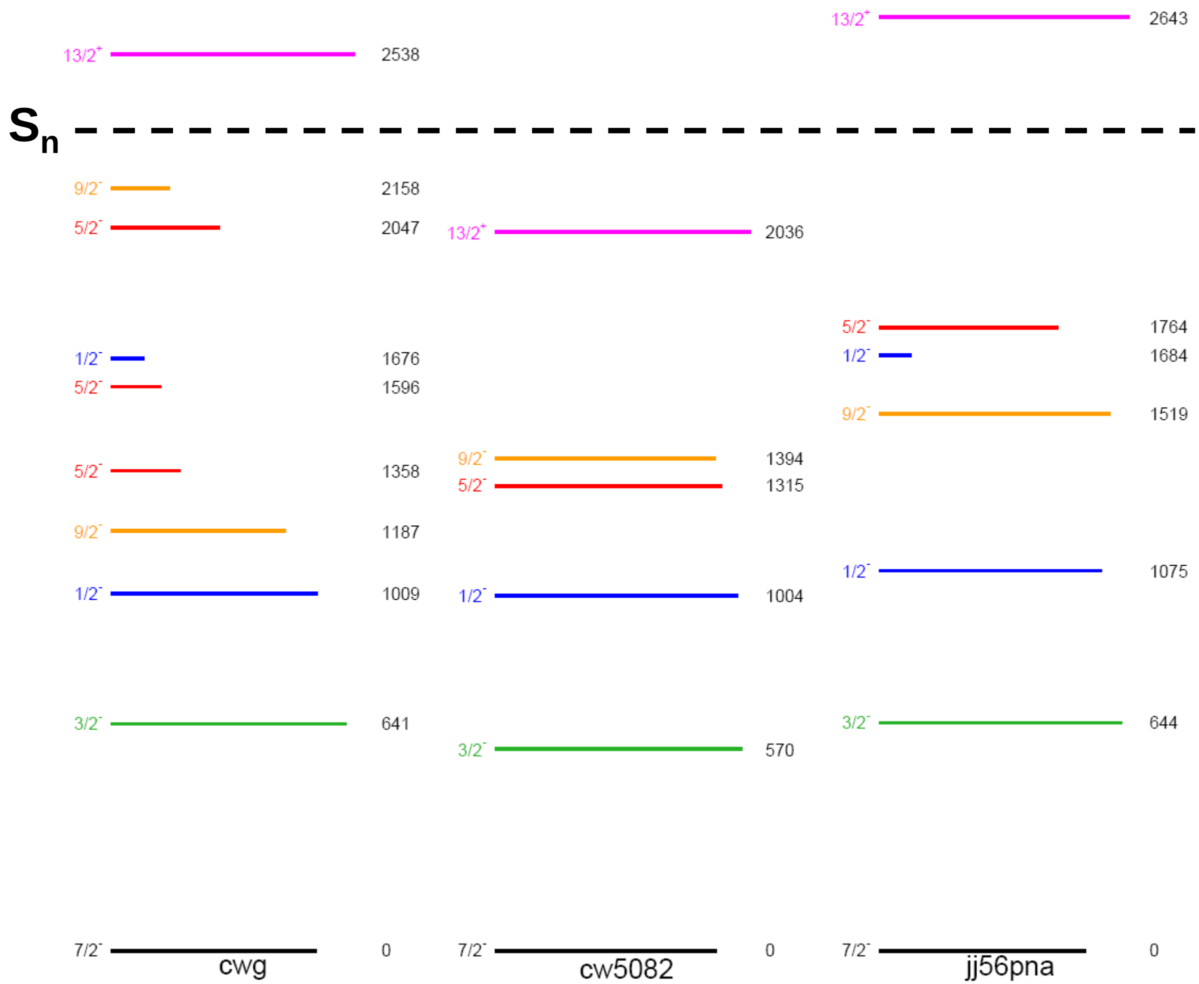
experimental knowledge

?

E(level)	J^{π}	$T_{1/2}$
0	$(7/2^-)$	515 ms 5

Shell model predictions



Comparison 7.5 MeV/u and 10 MeV/u

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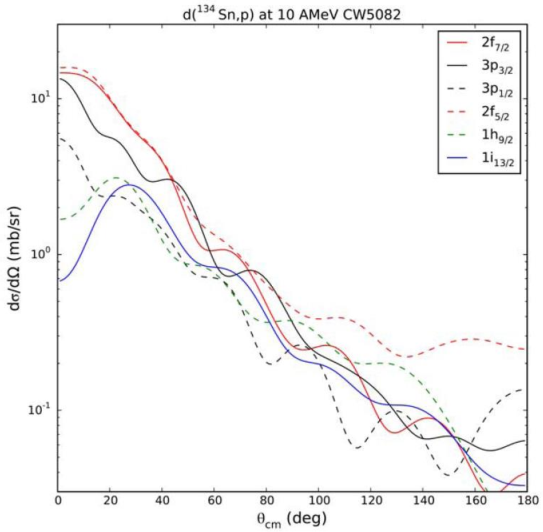
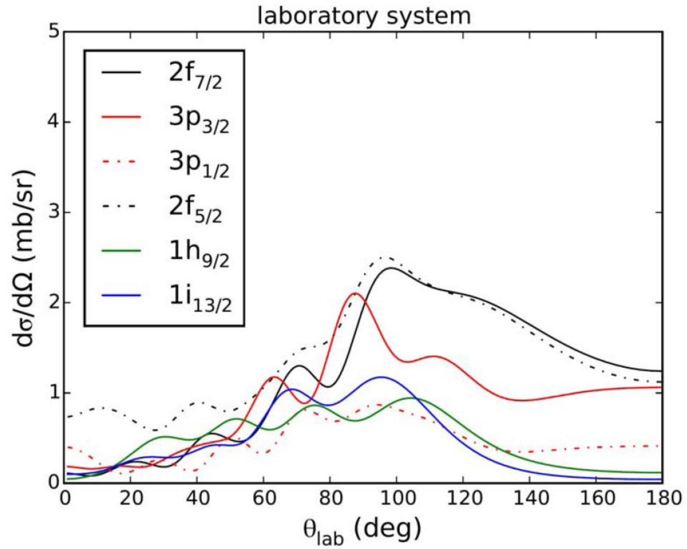
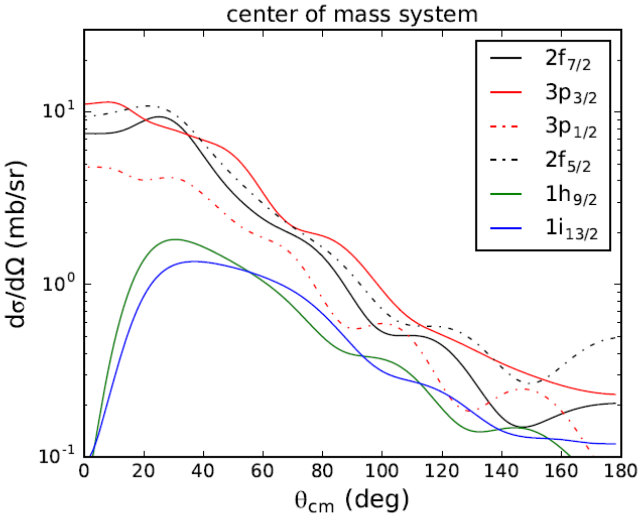
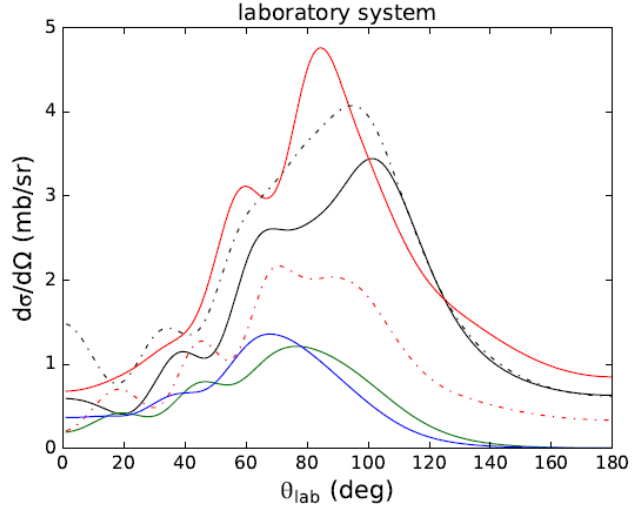




10 MeV/u





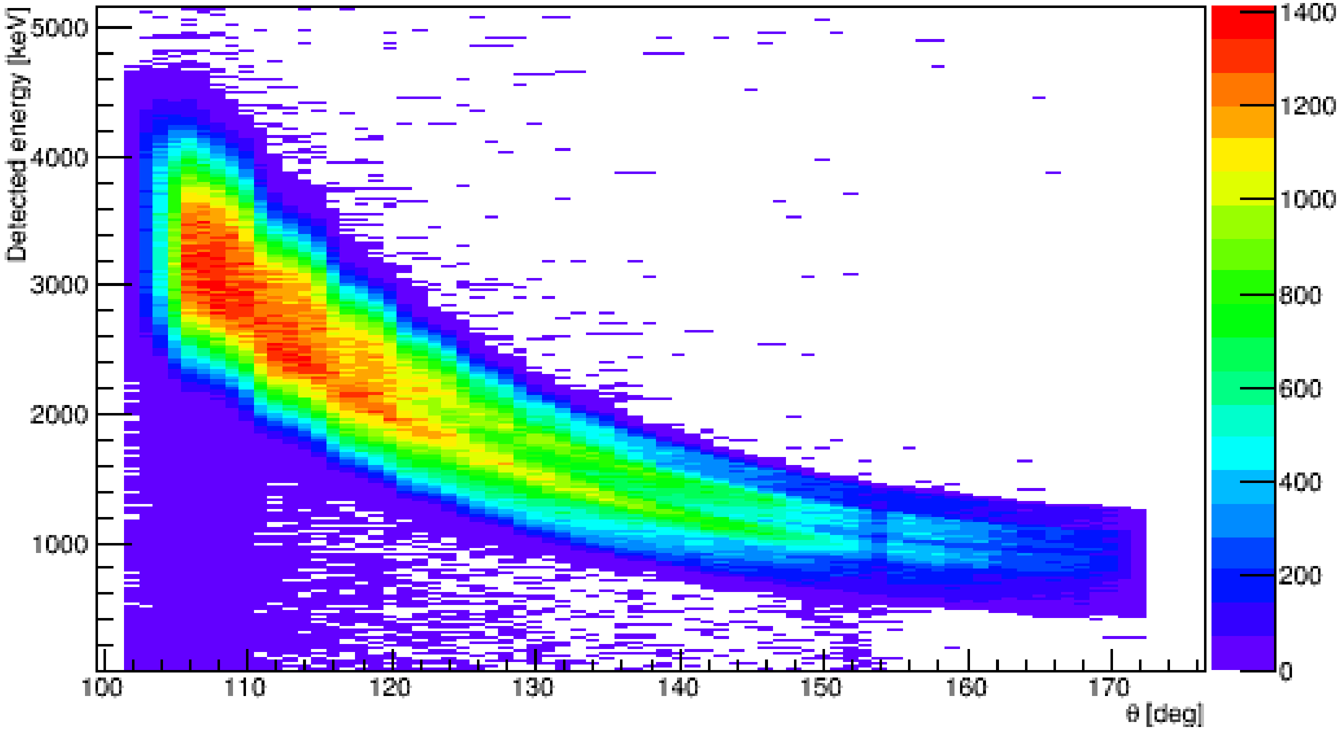
7.5 MeV/u

- **mostly larger cross section**
- **less pronounced angular distributions**
- **smaller energies of protons to be detected**

Simulation (backward direction)

Simulations by Christian Berner (doct. student,TUM)

$^{134}Sn(d,p)$ @ 7.5 MeV/u, 1 mg/cm^2 CD_2 target
Q_0 = 45.2 keV, first 4 levels in ^{135}Sn



- **Energies are well above experimental trigger threshold (≈500 keV @ 3 MeV/u and A=80 ... we have to see at 7.5 or 10 MeV/u and A=140)**
- **Levels are not sufficiently separated .... most likely we need γ-rays!!!**

Physics aims

- Particle spectroscopy, particle-γ(γ) coincidences
  ➔ identify excited states in ^{135}Sn for the first time

- (γ-gated) particle angular distributions
  ➔ determine orbital angular momentum transfer

- γ-decay branching (and guidance by theory)
  ➔ assign (tentatively) total angular momentum

- cross sections
  ➔ extract spectroscopic factors

➔ Comparison with shell model

Note: shell model needs interaction matrix elements AND single-particle energies around ^{132}Sn, i.e. ^{133}Sn and ^{133}Sb
... <u>predictive power can be evaluated only by studying nuclei beyond!!</u>

Beam / rate estimate

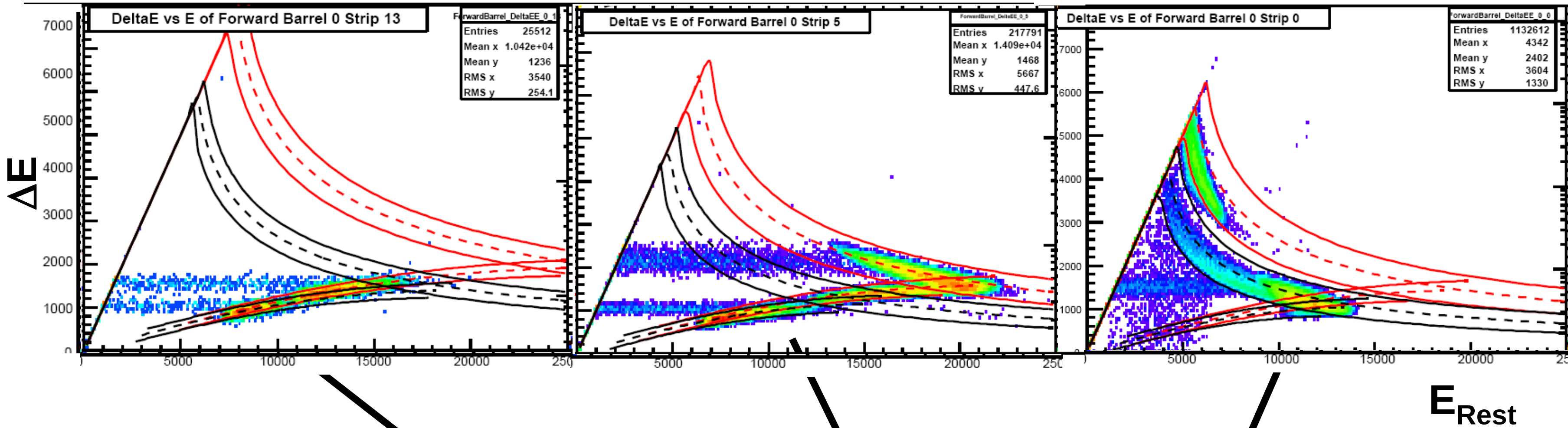
MINIBALL + T-REX (maybe modified configuration in backward direction)

- **Beam**
  - molecular beam $^{134}Sn^{34}S^{+}$ from ISOLDE
  - beam energy from HIE-ISOLDE: 7.8 MeV/u (or whatever is reachable)
  - intensity on target 10^4/s
  - highly contaminated by ^{134}Sb (A=168 contaminations?)

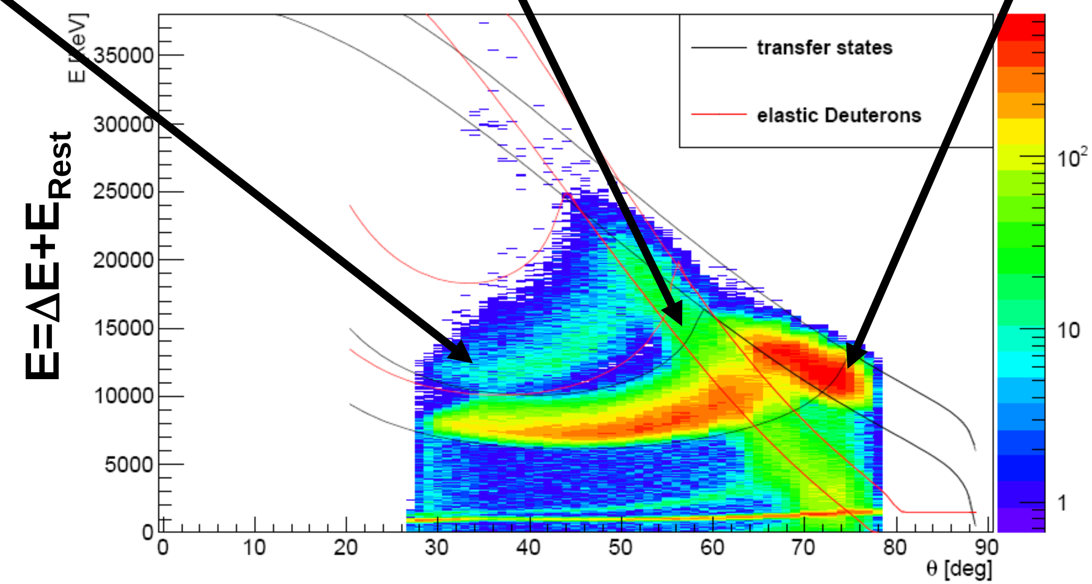
- **Rate (1 mg/cm² CD_2 target)**
  - 650 protons/day (per 1 mb)
  - 2-8 mb per state, 6-10 angular bins ➔ ≈ 300 counts / bin / day
    ➔ 2% statistical error
  - γ-gated: factor 10-30 less ➔ ≈ 150 counts / bin / week
    ➔ 10% statistical error
  - particle-integrated γ-rate per state ➔ ≈ 350 / mb / week
    ➔ the excitation energy can be determined even for very low cross sections

We request 24 shifts (8 days) of beam time

Simulation (forward direction)



Because of high energies many p and d punch through both ΔE and E detectors



Simulation

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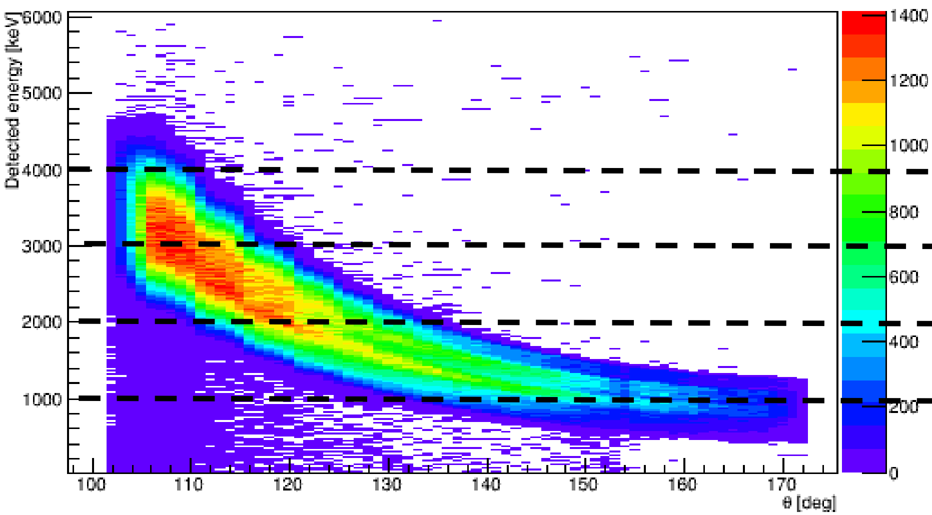
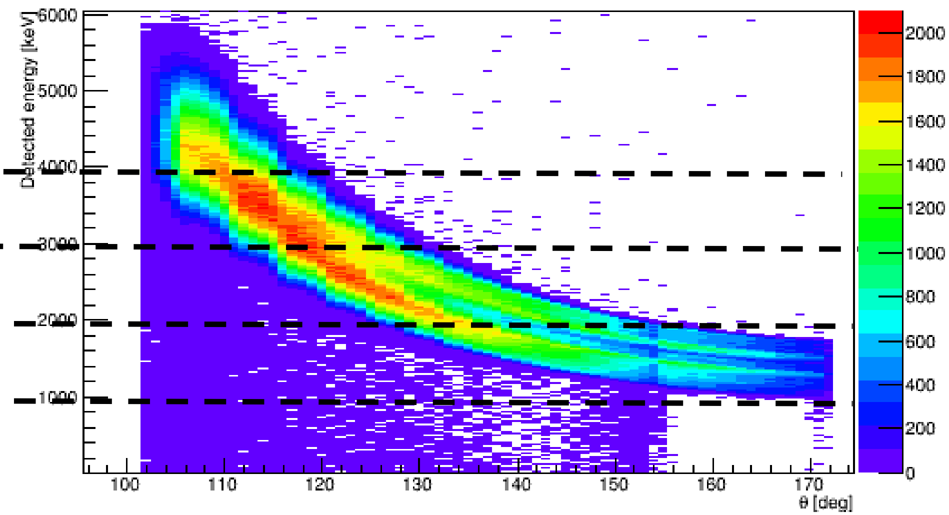
^{134}Sn(d,p) @ 7.5 MeV/u
Q_0 = 45.2 keV



^{134}Sb(d,p) @ 7.5 MeV/u
Q_0 = 1516.5 keV



- **States at high excitation energy in ^{135}Sb* partially overlap with states at low excitation energy in ^{135}Sn**
- **States at higher excitation energy are likely to emit γ-rays in coincidence (which are, of course, not detected with 100% efficiency)!**

*** For simplicity, the same excitation energies as in Sn have been assumed**