The problem of sub-barrier transfer reactions in Coulomb excitation studies

Kasia Hadyńska-Klęk

3rd GOSIA Workshop
Heavy Ion Laboratory
University of Warsaw
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Outline

1. Coulex of ^{42}Ca (INFN LNL)
   - Motivation
   - Experiment
2. Verification of the level scheme of ^{42}Ca
   - Experiment
   - Results
3. 1n transfer – case of ^{42}Ca
4. Coulex of ^{94}Zr at INFN LNL – 1n transfer?

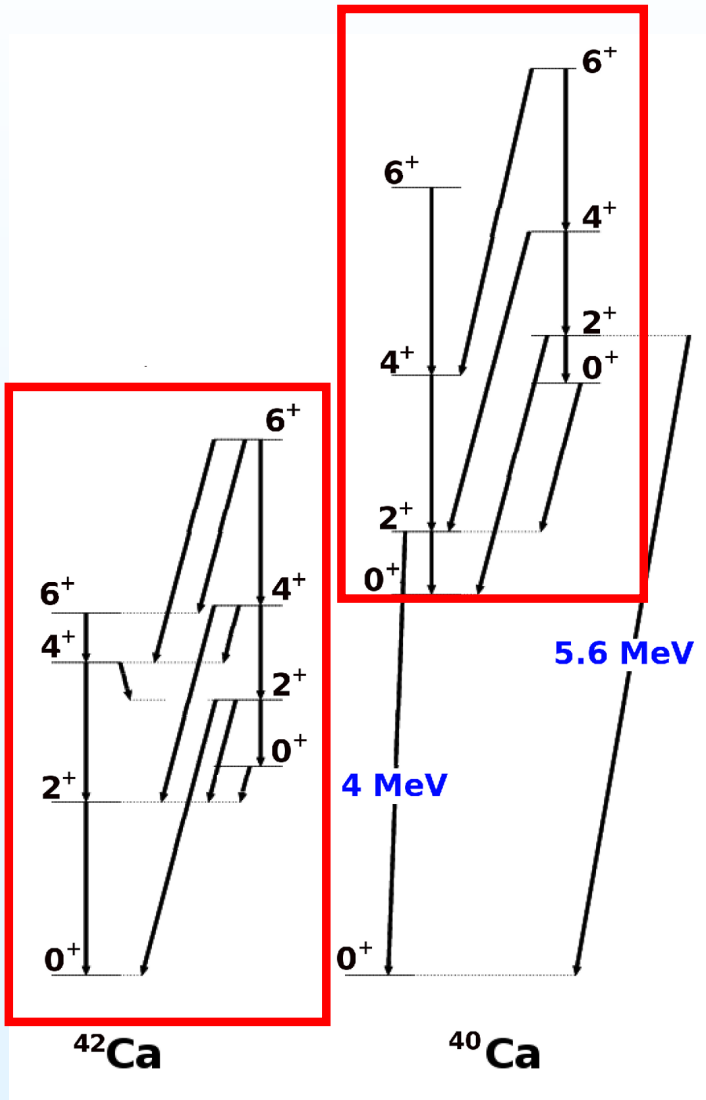
Why ^{42}Ca? – A=40 region

Superdeformed band in ^{40}Ca:

- B(E2) $[4_2^+ \rightarrow 2_2^+]$ = 170 W.u. (DSAM)
- deformation in the side band β_2=0.6
  E.Ideguchi et al., PRL 87 (2001) 222501
  C.J.Chiara et al., PRC 67 (2003) 041303(R)

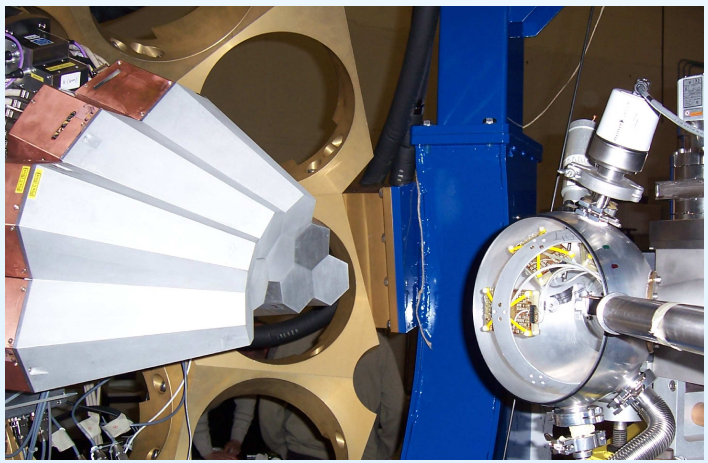
Superdeformation in other isotopes:

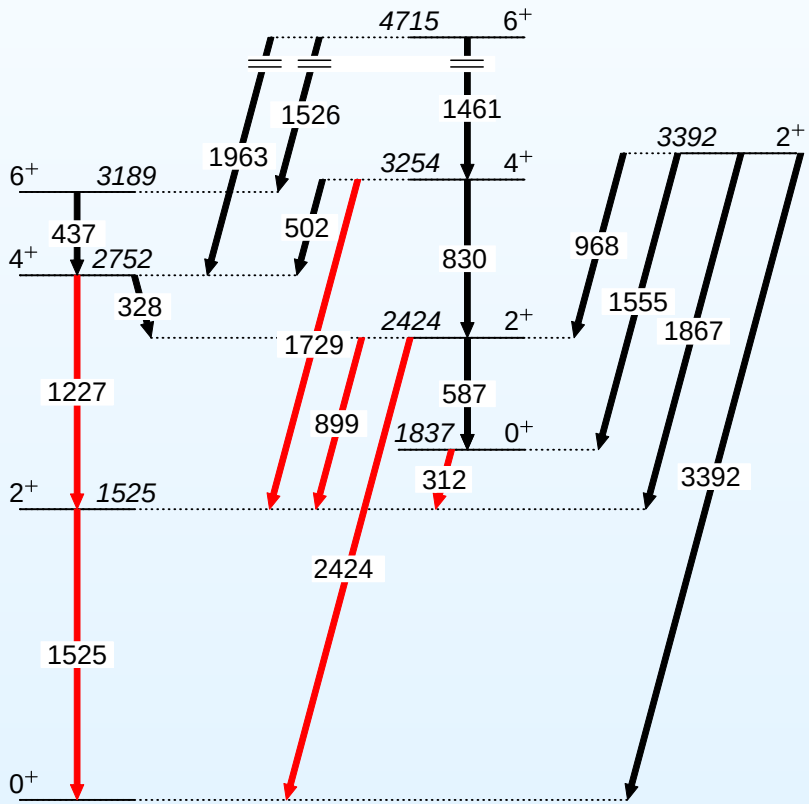
- ^{36}Ar:
  C.E.Svensson et al., PRL85 (2000) 2693
- ^{38}Ar:
  D.Rudolph et al., PRC65 (2002) 034305
- ^{40}Ar:
  E.Ideguchi et al., PLB686 (2010) 18
- ^{44}Ti:
  D.C.O'Leary et al., PRC61 (2000) 064314



Coulomb excitation of ^{42}Ca – INFN LNL, Italy

- Beamtime:
  Feb.2010, INFN LNL
- Beam:
  ^{42}Ca, E=170 MeV
- Targets:
  ^{208}Pb, 1 mg/cm^2
  ^{197}Au, 1 mg/cm^2
- AGATA: 3 triple clusters,
  143.8 mm from the target
- DANTE: 3 MCP detectors,
  θ range from 100°-144°





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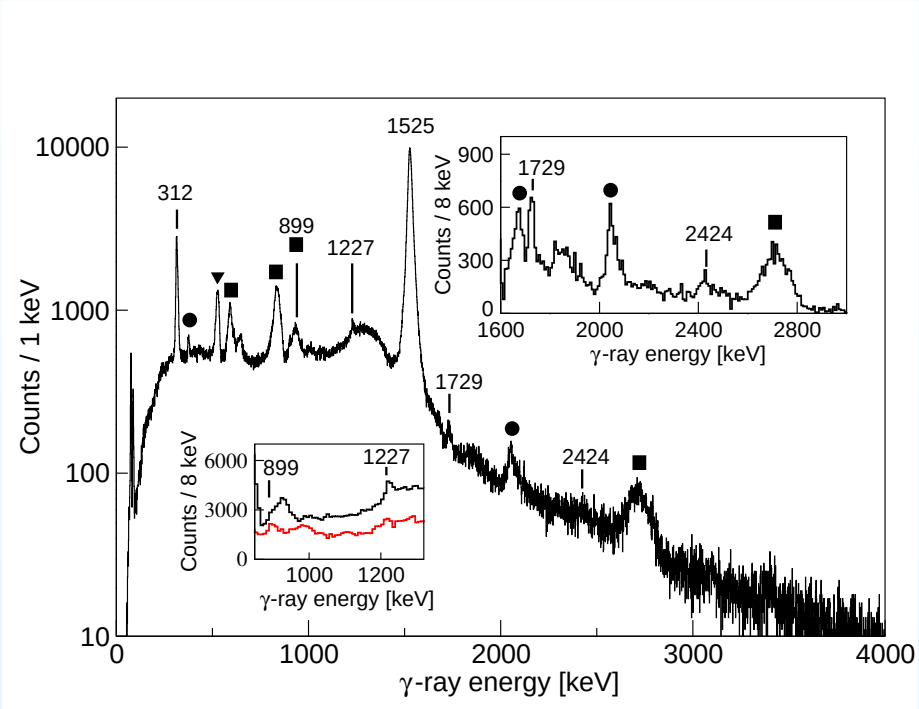
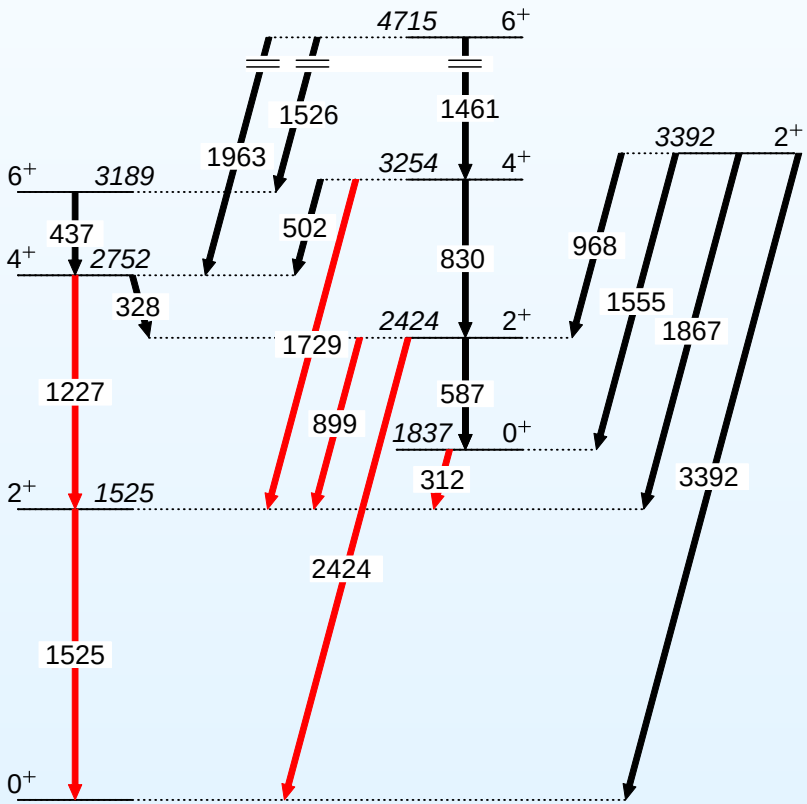
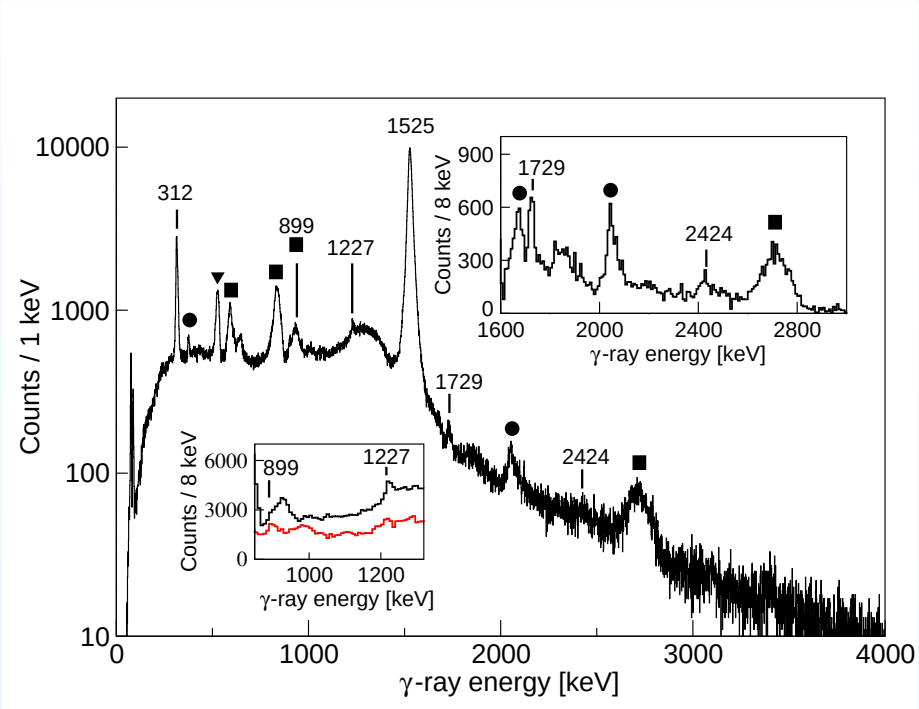
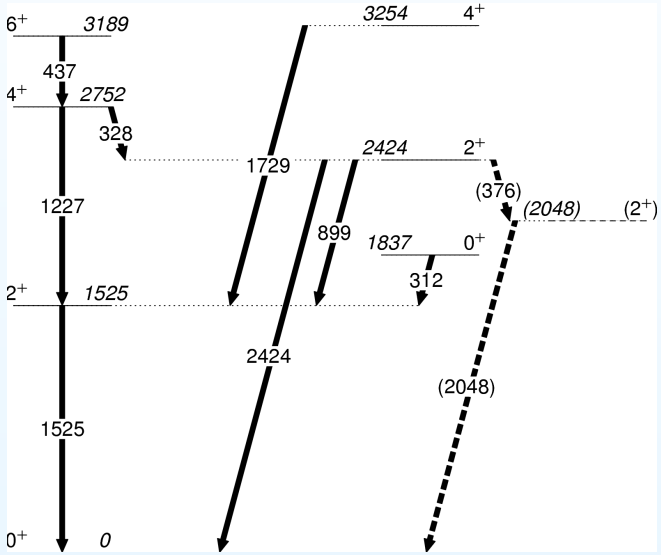


- lead isotopes (^{204,206,207,208}Pb),
- ▼ 511 keV,
- ● **376, 2048 and 1676 keV – ?**



Coulomb excitation of ^{42}Ca – new lines?





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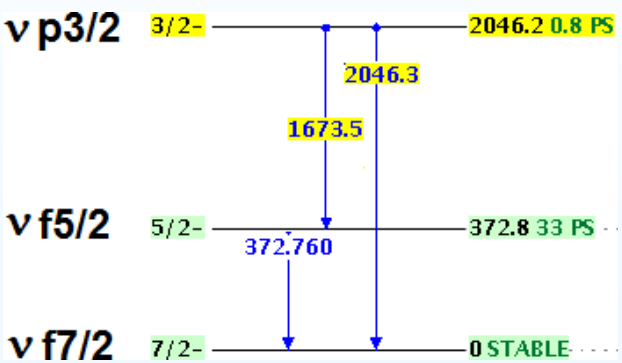
Sub-barrier transfer reaction analysis – ^{43}Ca



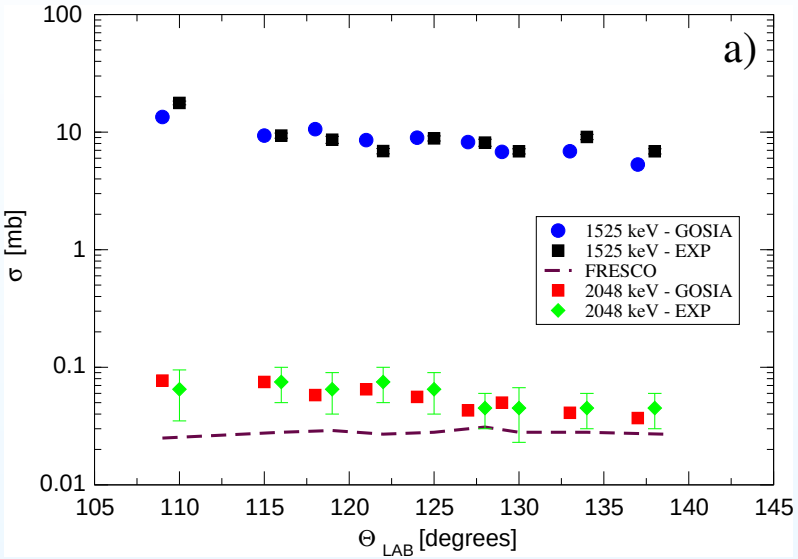
Level	dσ/dω (mb/sr) (max)
0	2.85
373	0.06
593	1.36
990	0.29
1393	0.03
1676	0.03
1899	0.05
1928	0.02
1954	2.79
2041	28.2
2096	0.04
2219	0.02
2246	0.06
2269	0.06

Selective population of the 2 MeV state:
Brown et.al., Nucl. Phys. A225 (1974) 267-299
(^{42}Ca(d,p)^{43}Ca reaction investigated)

Sub-barrier transfer reaction analysis

^{208}Pb+^{42}Ca, 85% of the Coulomb barrier
Comparison of distributions (9 bins):

- 2048 keV (assumed $2^+ \rightarrow 0_1^+$) and 1525 keV (known $2_1^+ \rightarrow 0_1^+$ in ^{42}Ca) – GOSIA
- ^{208}Pb(^{42}Ca,^{43}Ca)^{207}Pb transfer to populate the $p_{3/2}$ state in ^{43}Ca – FRESCO
- Intensity ratio of 2048 and 376 keV lines: 30%, same as the ratio of 2046 and 373 keV transitions in ^{43}Ca
- Q(^{208}Pb(^{42}Ca,^{43}Ca)^{207}Pb) = 565 keV



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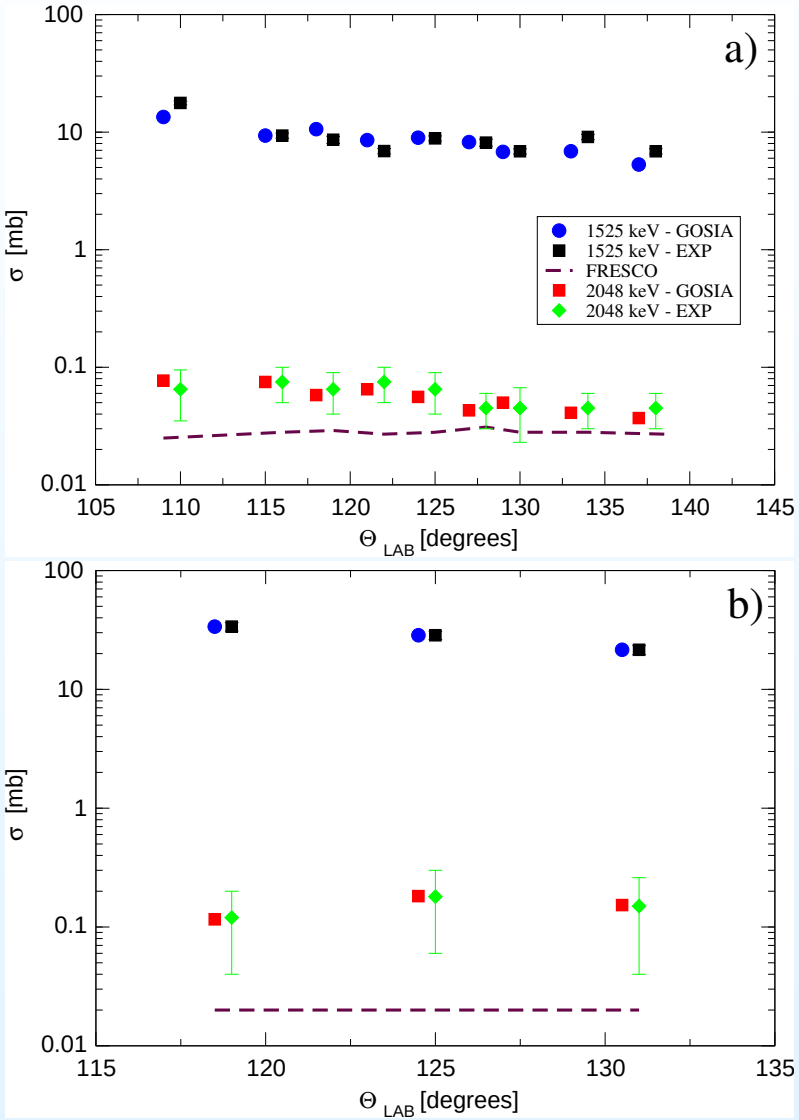
^{197}Au+^{42}Ca COULEX data (87% Coulomb barrier)
Comparison of distributions (3 bins):

- ^{197}Au(^{42}Ca,^{43}Ca)^{196}Au transfer
- Q(^{197}Au(^{42}Ca,^{43}Ca)^{196}Au) = -140 keV
- one order of magnitude difference



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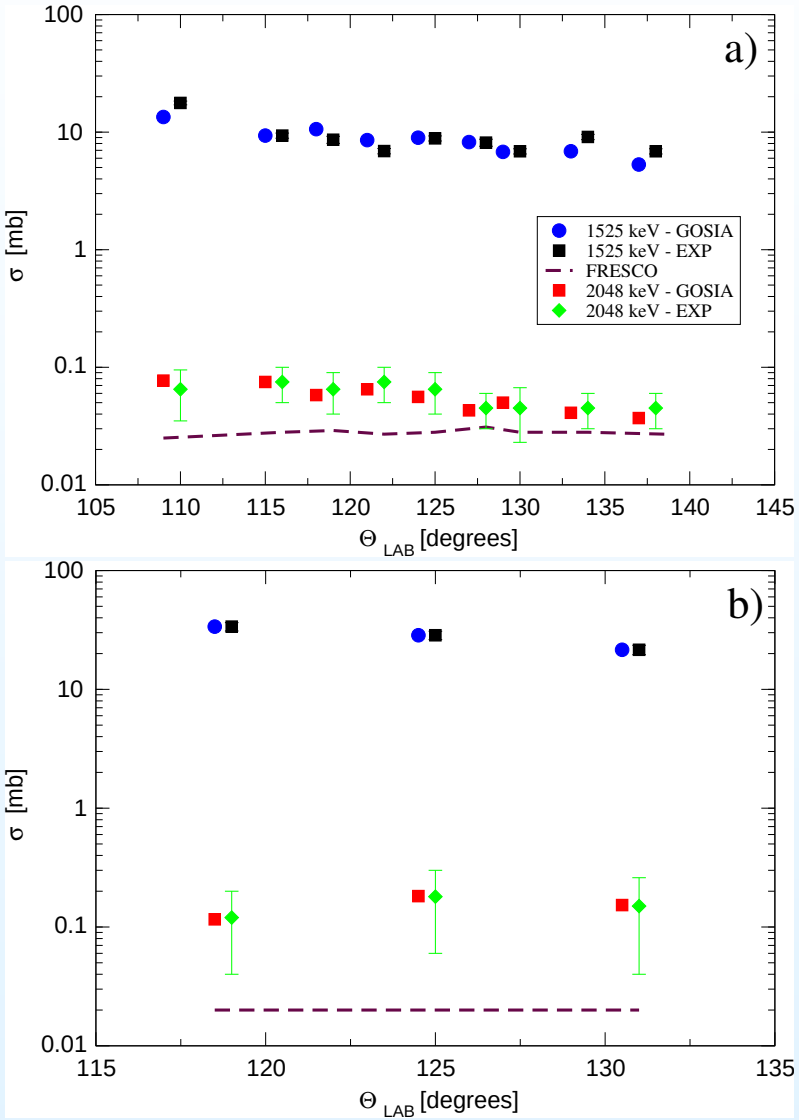
FRESCO:

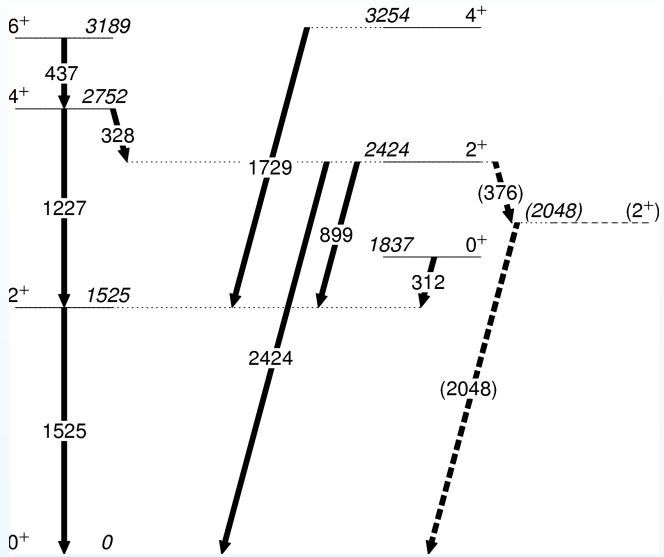
1. the optical model potentials in the entrance and exit channels were taken from the global parametrization (R. A. Broglia and A. Winther, Heavy Ion Reactions (Benjamin/Cummings, Reading, MA, 1981), Vol. 1.)
2. the spectroscopic factors for the target nucleus and the ejectile were set to unity

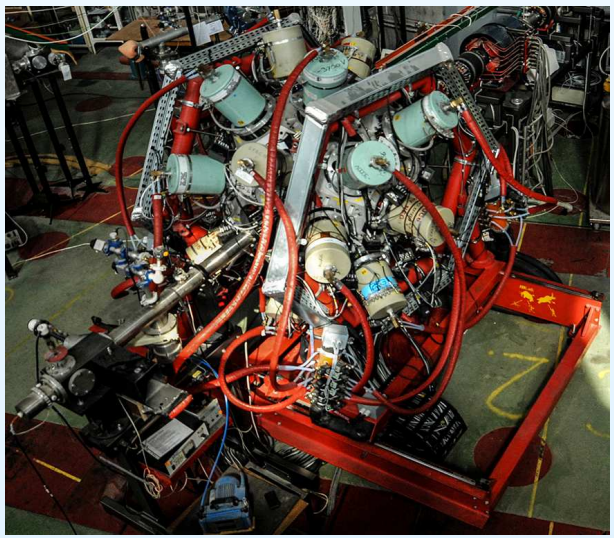


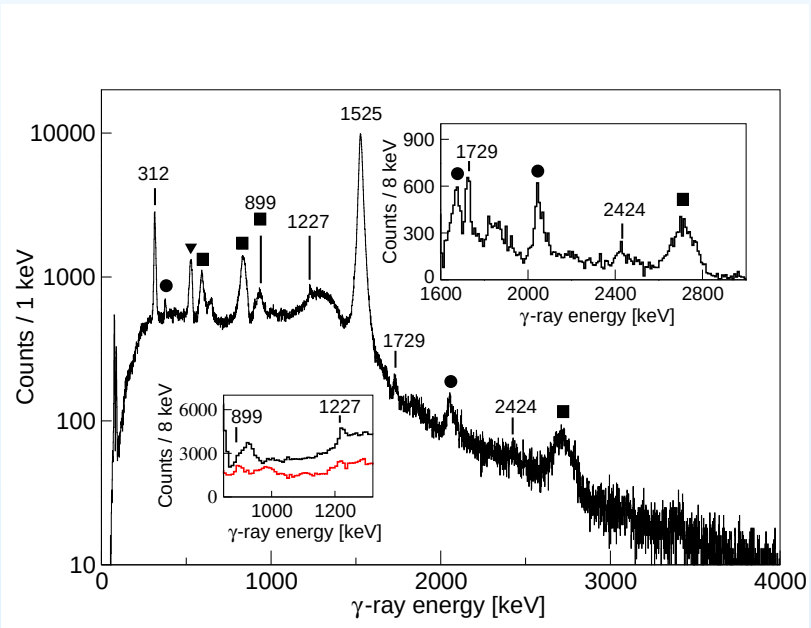
Verification of the level scheme of ^{42}Ca

- **Motivation:** observation of two additional lines in the γ-ray spectra from Coulex of ^{42}Ca
- **Aim:** to confirm the medium and low spin region in ^{42}Ca

1. Experiment at HIL, 2011
2. ^{12}C(^{32}S,2p)^{42}Ca, E_{beam}= 76 MeV
3. EAGLE: 15 HPGe in ACS







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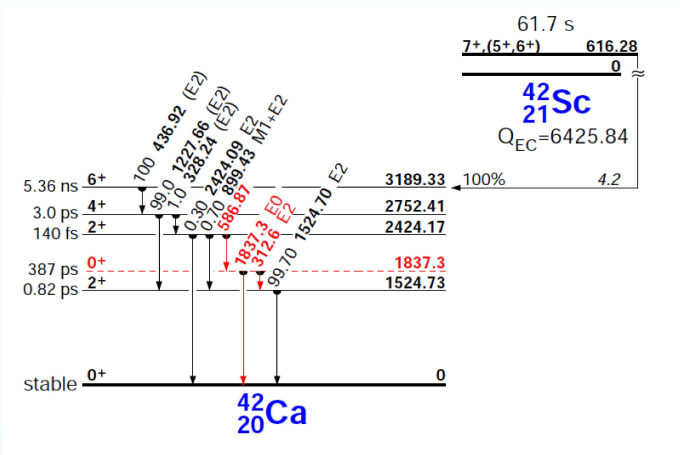

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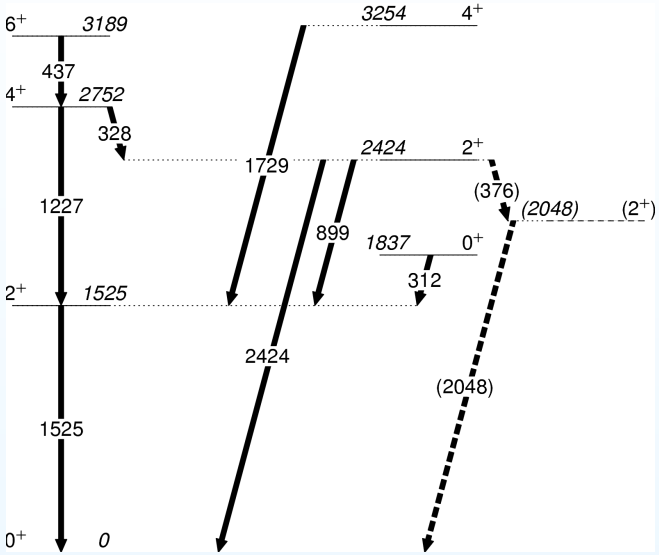

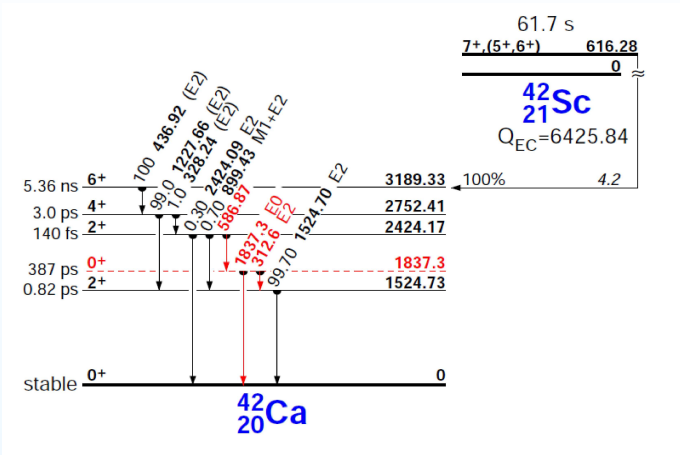

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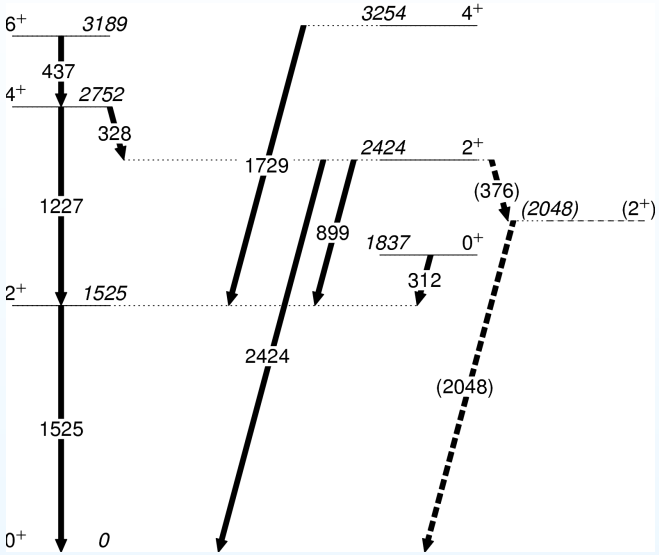

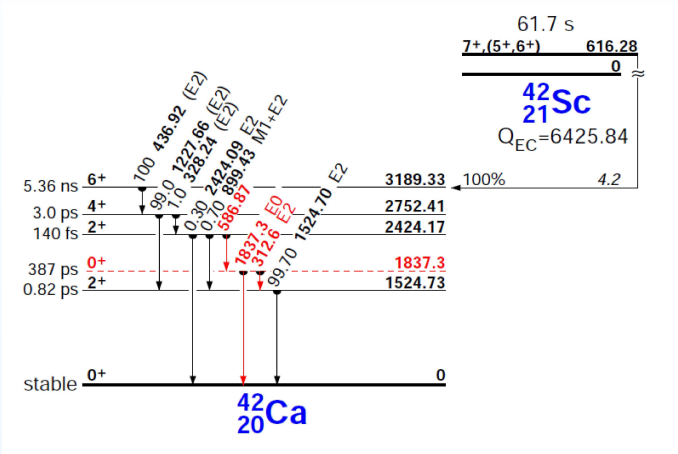

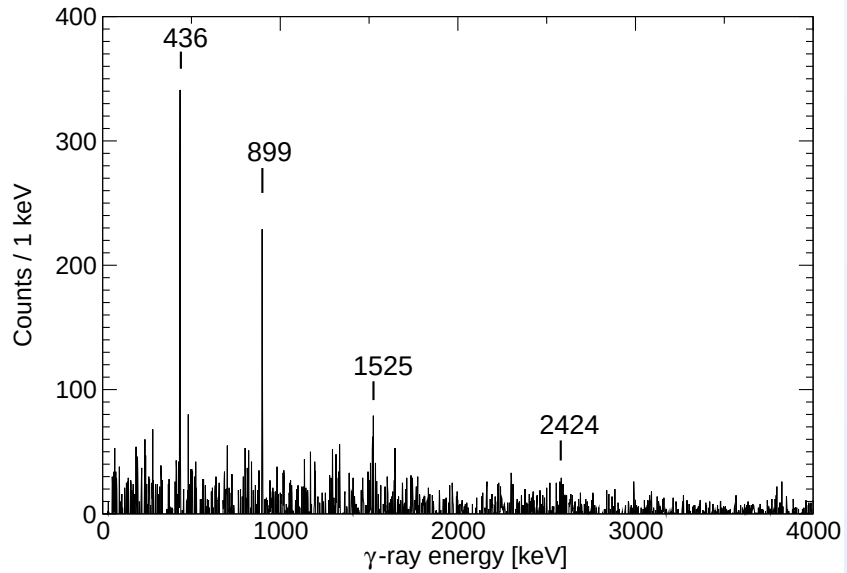

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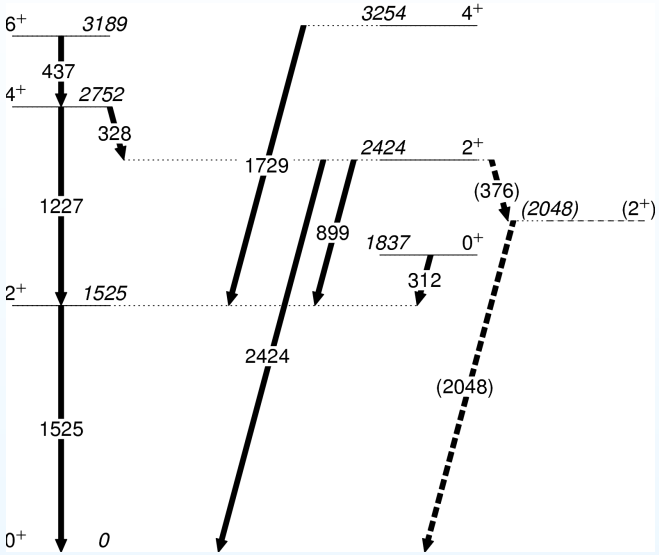
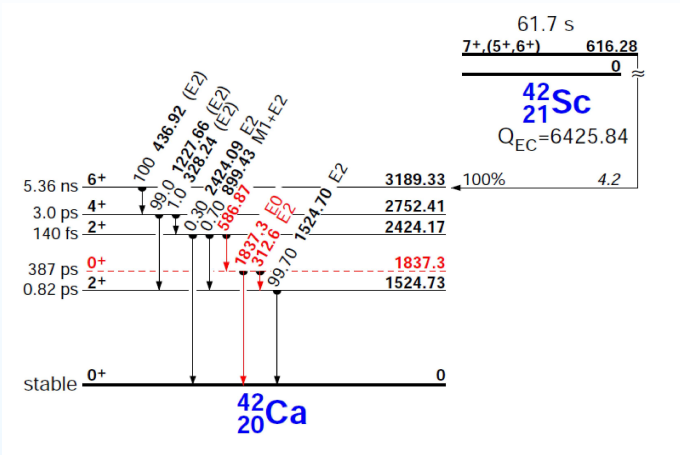
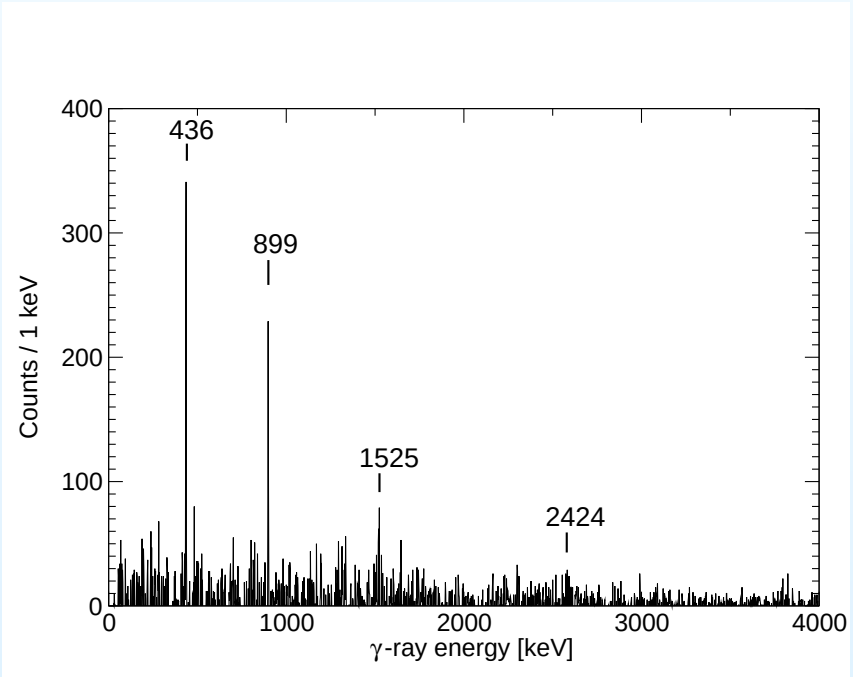




- ^{42}Sc→^{42}Ca, off-beam decay to 6_1^+ state (62 s)
- Coincidence gate: 328 keV (2_2^+ feeding)
- No indication of both 376 keV and 2048 keV



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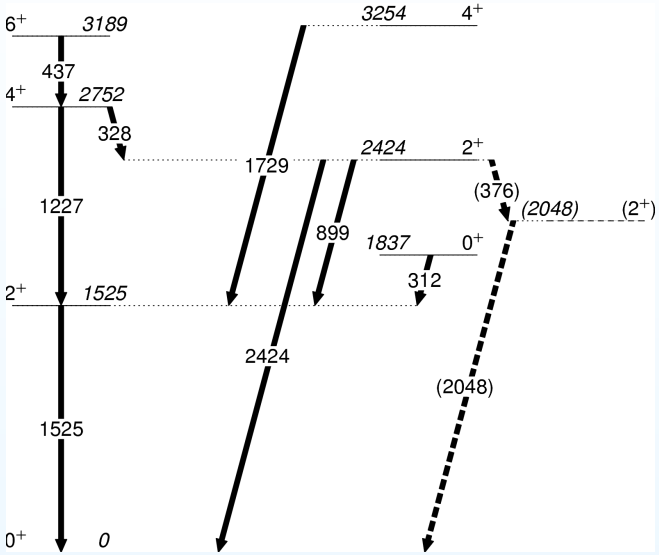

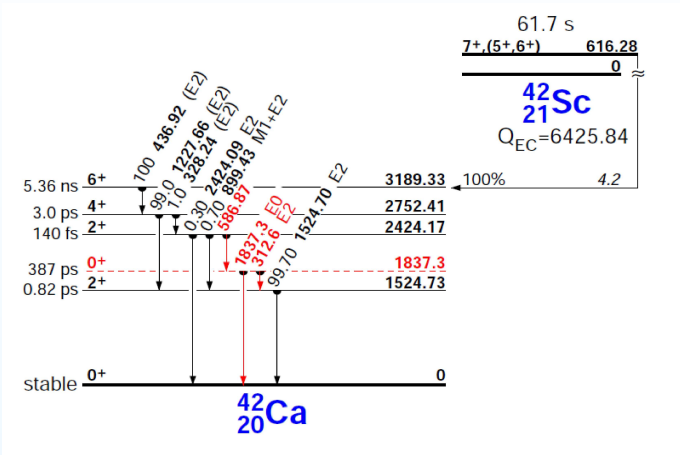

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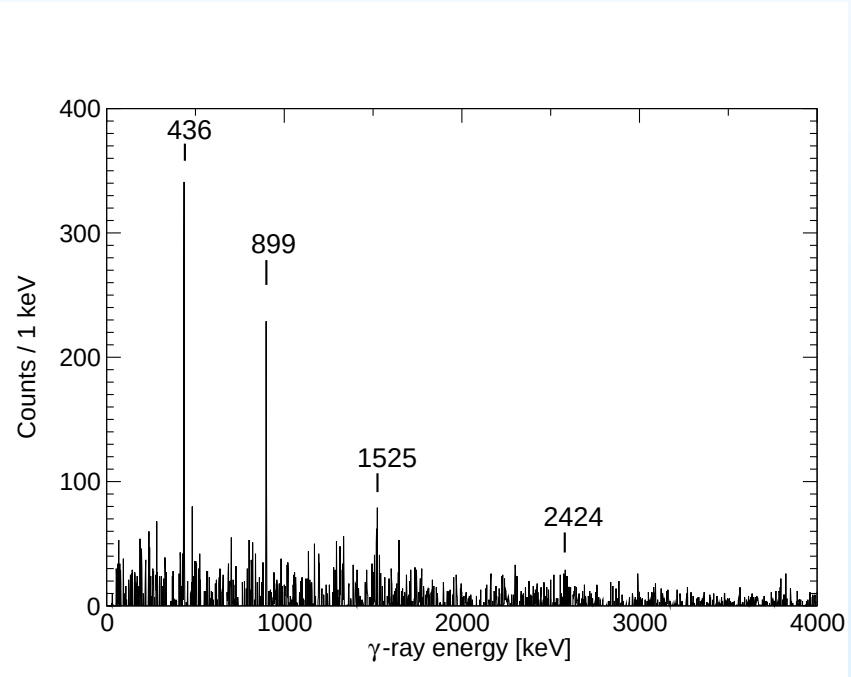
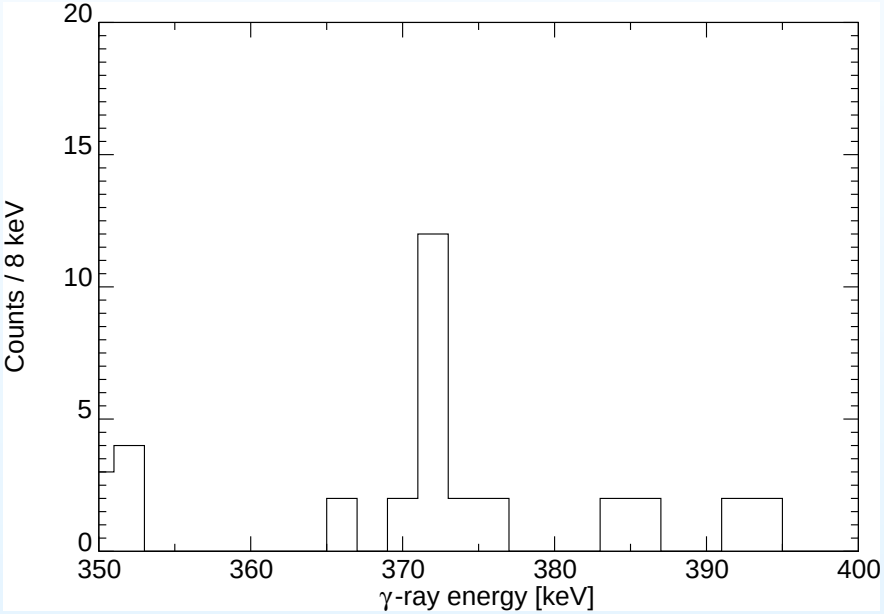
- **CONCLUSION: no additional structure in ^{42}Ca: a sub-barrier transfer reaction hypothesis verified**



COULEX of ^{42}Ca – γ – γ analysis

- γ rays Doppler corrected for the projectile velocity on one axis,
- γ rays Doppler corrected for the recoil velocity on the other axis
- Coincidence gate: 570-keV γ-ray line – first excited state in ^{207}Pb
- 373-keV γ-ray line in ^{43}Ca visible



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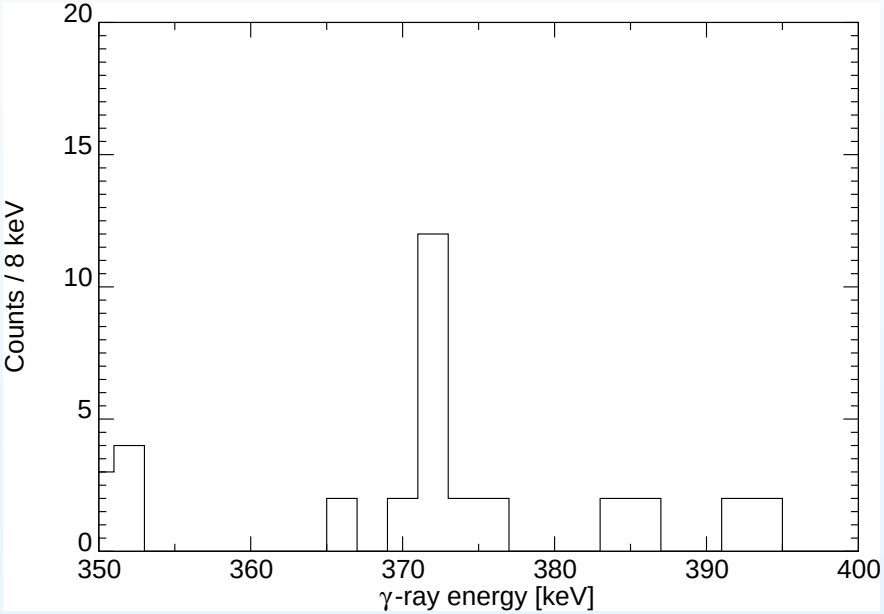


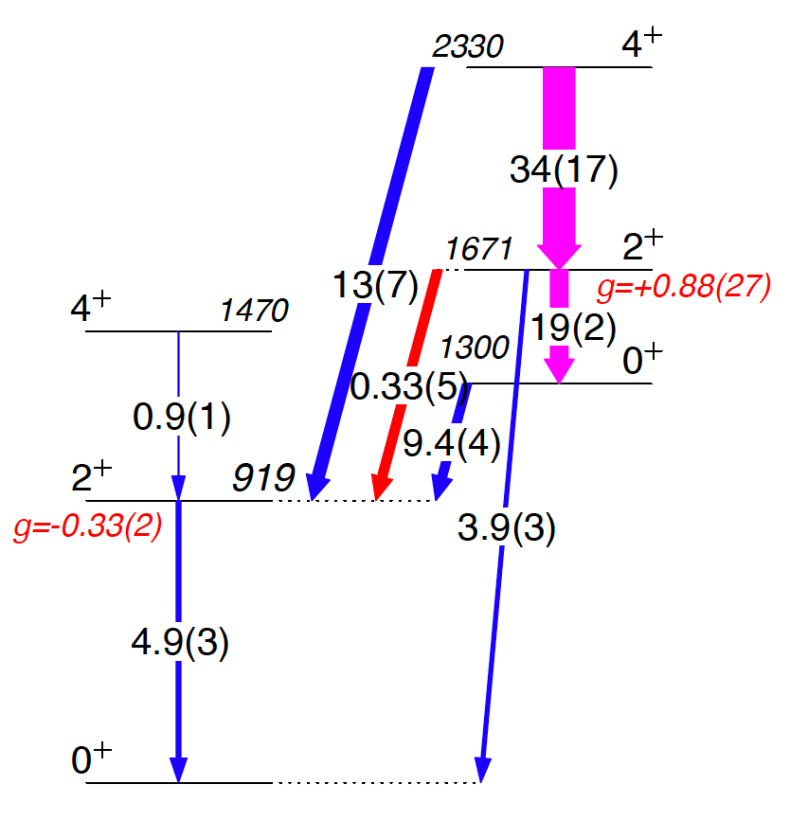
a strong evidence for the one-neutron transfer reaction

"Probing collectivity and configuration coexistence in ^{94}Zr with low-energy Coulomb excitation"

D.T. Doherty, M. Zielińska, M. Rocchini

Questions we want to answer:

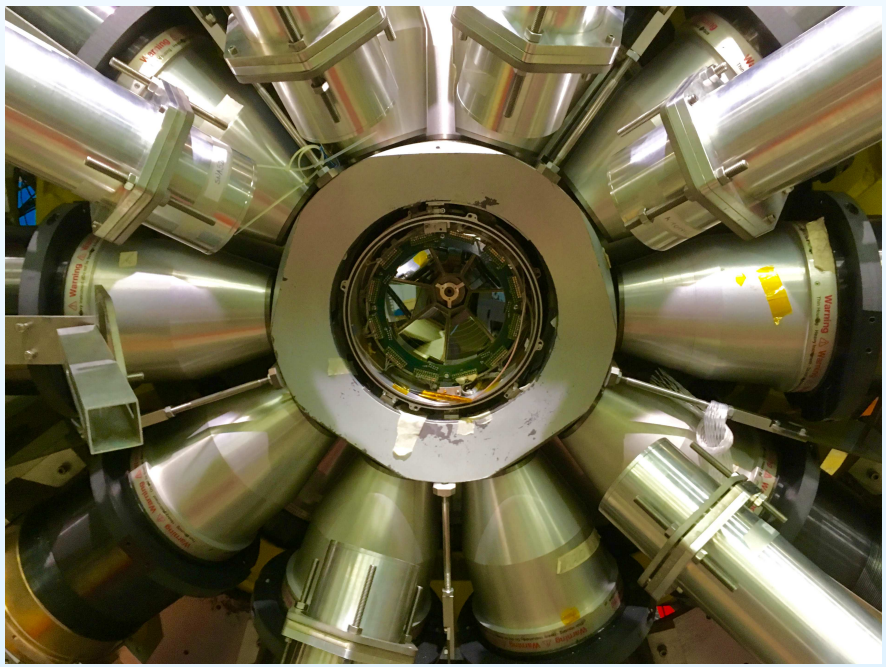
- What is the shape of ^{94}Zr in $2^+_{1,2}$ states?
  - measurement of quadrupole moments of $2^+_{1,2}$ states – verification of the spherical-deformed (oblate?) scenario
  - is mixing between the coexisting structures small, like in ^{96}Zr and ^{98}Sr?
- Is 2^+_2 a mixed-symmetry state?
  - are quadrupole moments of $2^+_{1,2}$ states similar?
  - γ-ray angular distributions yielded two possible values of δ: 0.02(2) and 2.2(5) – which one is correct?
- (bonus) How important are octupole correlations in ^{94}Zr?
  - 3^- excitation cross section is related to B(E3; $3^- \rightarrow 0^+$)



Courtesy: M. Zielińska
LNL PAC, February 13, 2017

COULEX of ^{94}Zr at INFN LNL

- ^{94}Zr beam, E=370 MeV, 1-2 pnA (TANDEM+ALPI)
- ^{208}Pb target, 1mg/cm^2
- safe energy (180°): 379 MeV
- SPIDER – 7 segmented particle detector (*see talk: M. Rocchini*)
- GALILEO – 25 HPGe detectors in ACS
- 6 large volume $LaBr_3$:Ce detectors from INFN Milano
- 4 days of data taking in March 2018



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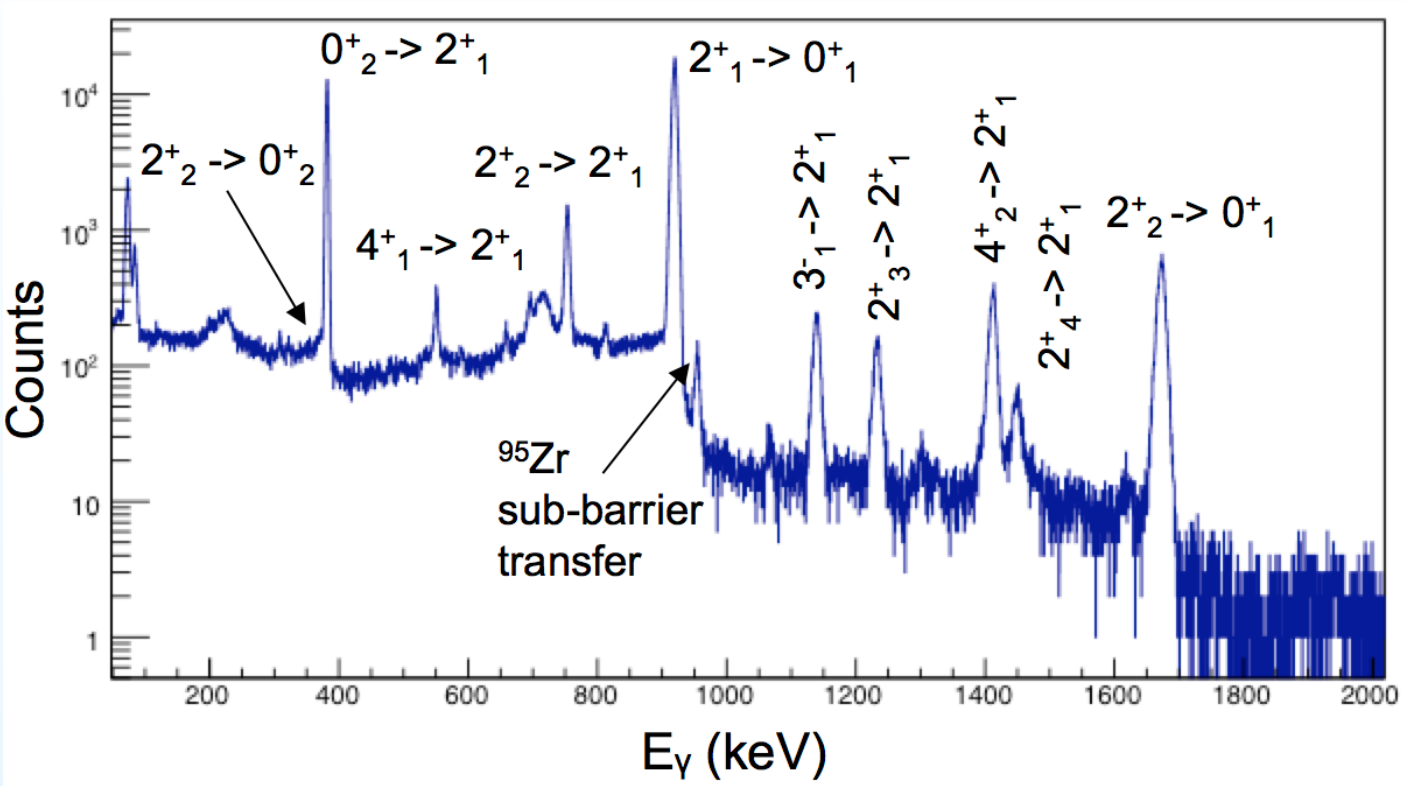

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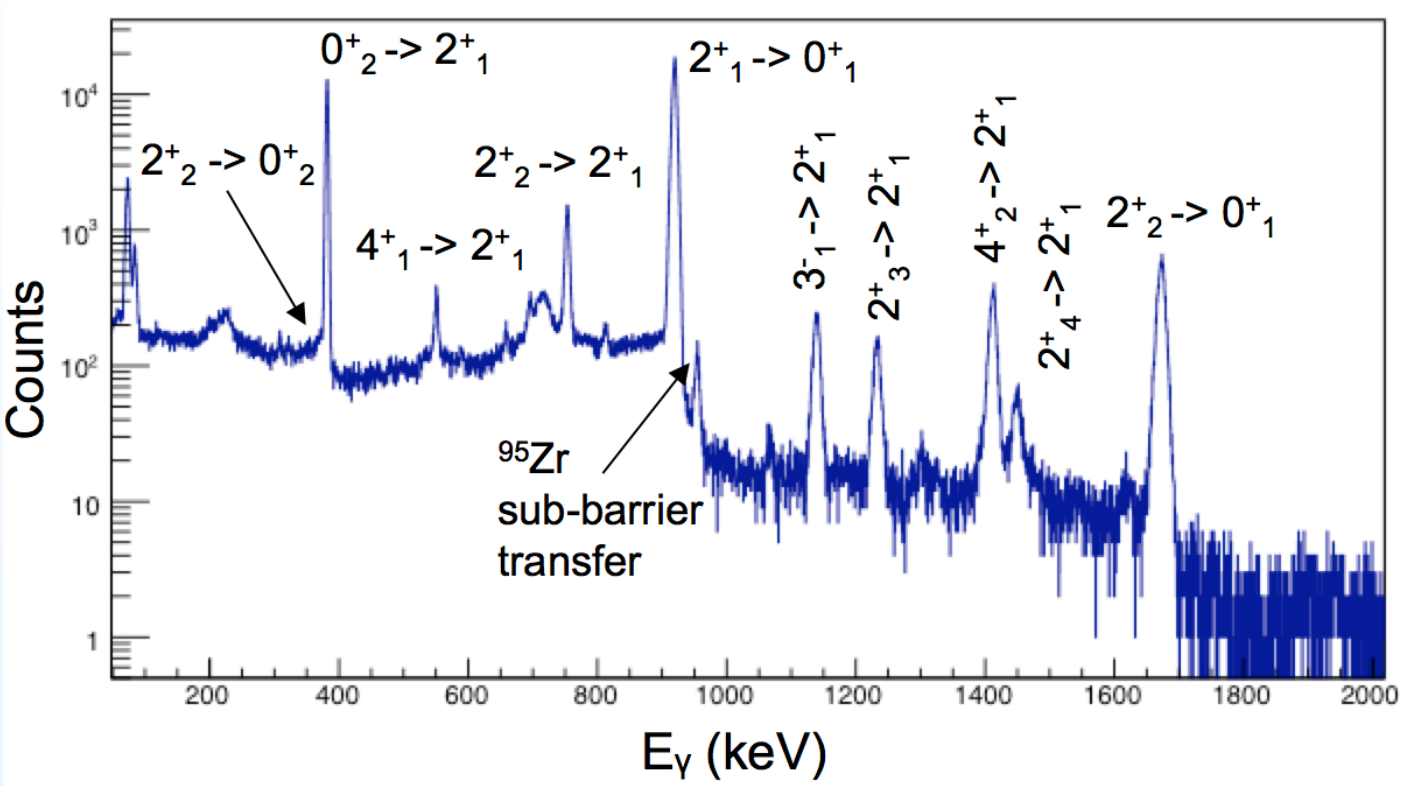

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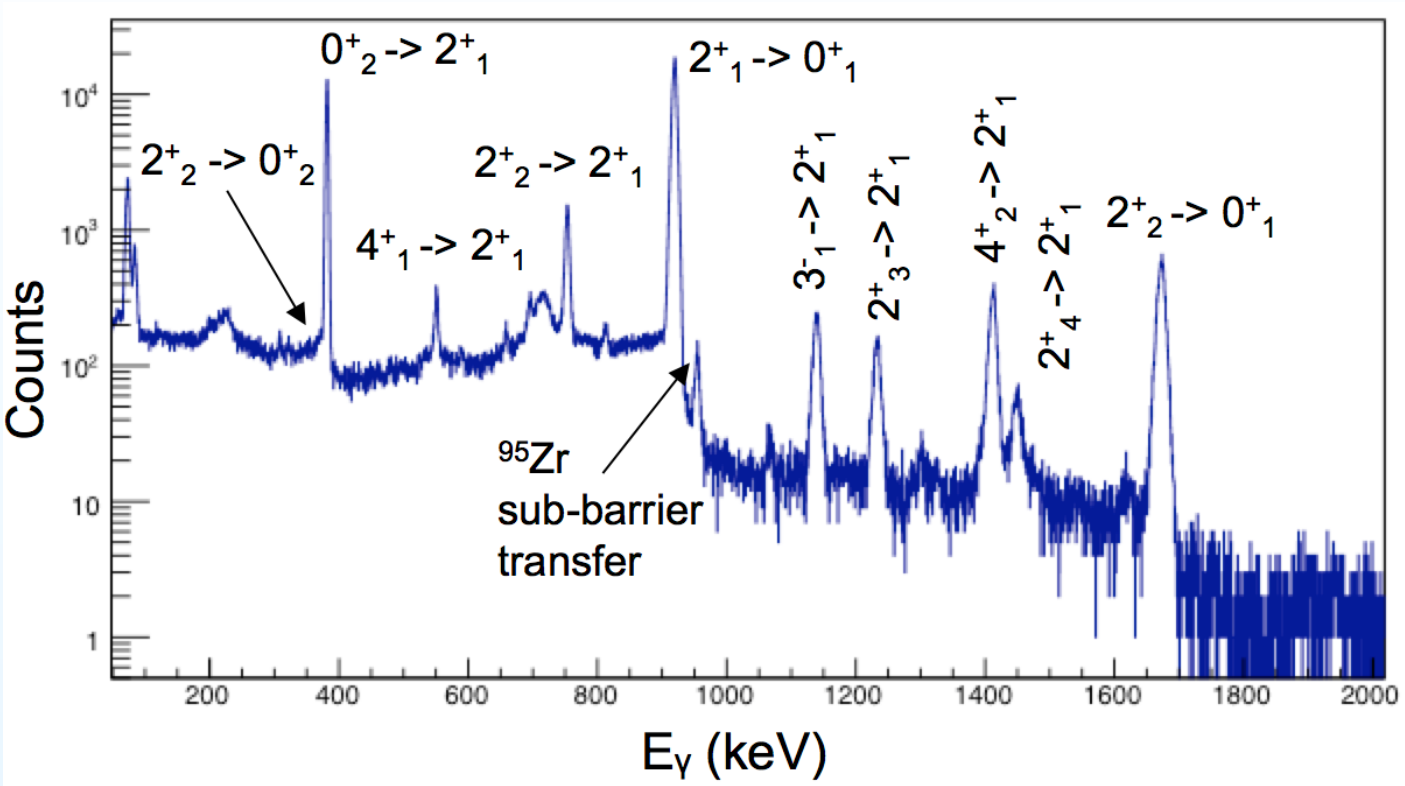

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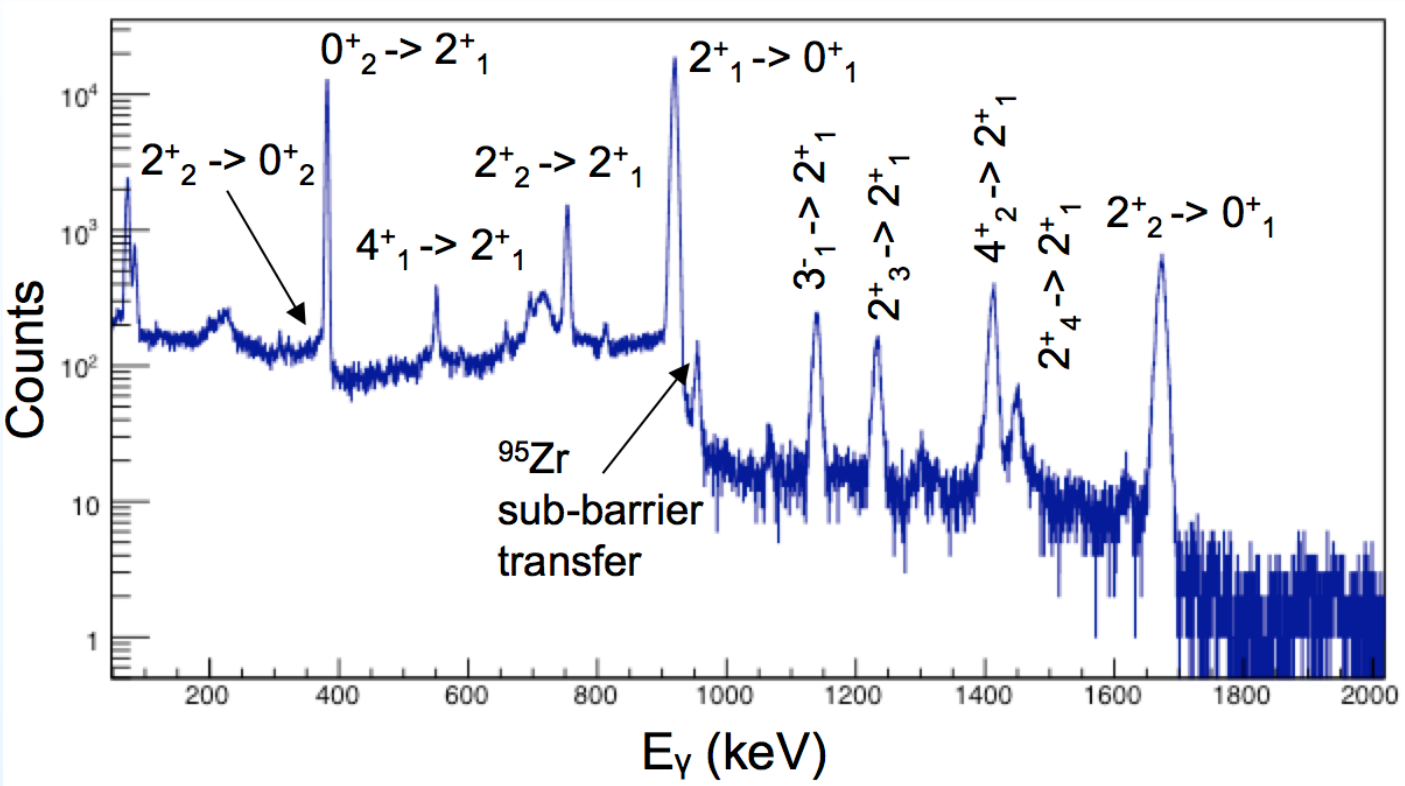

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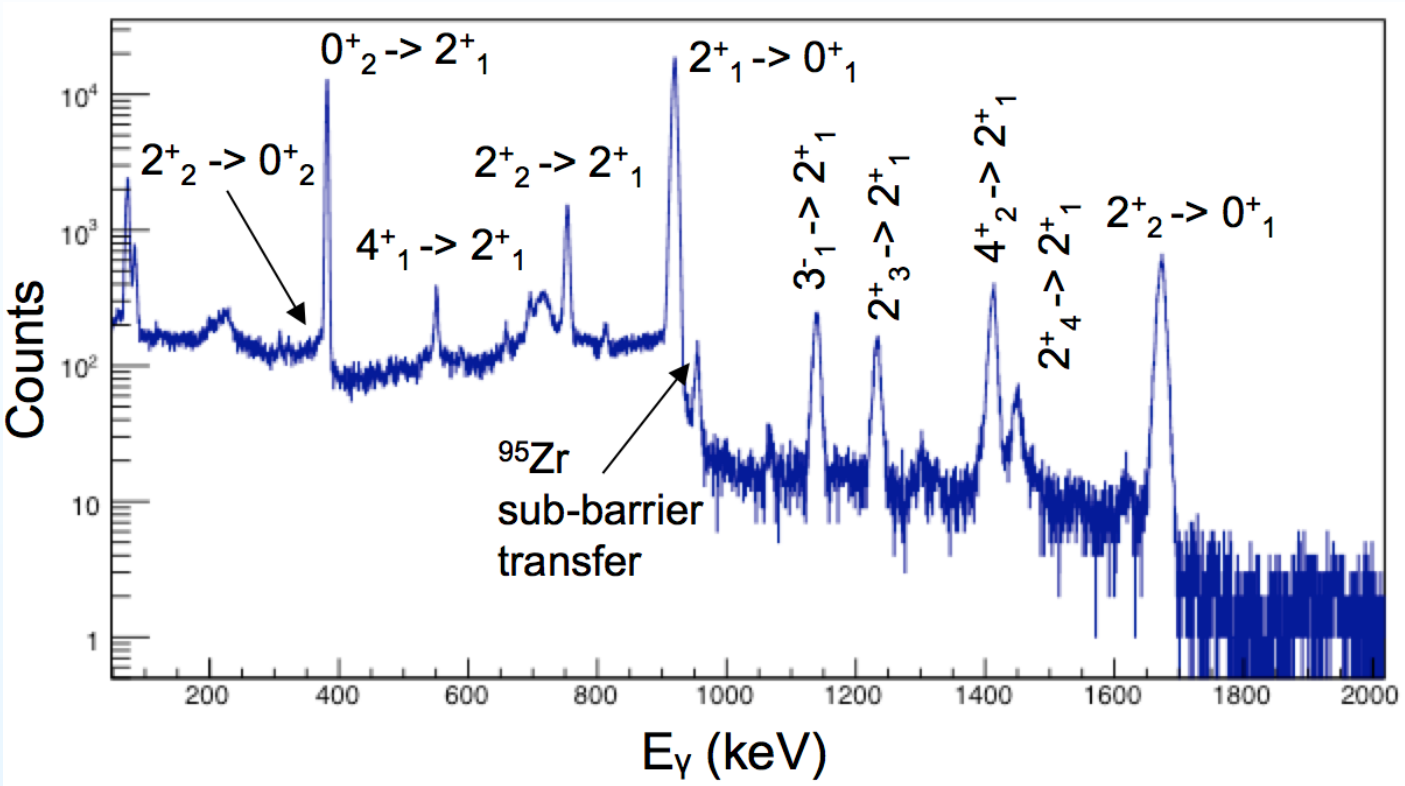

- excited states in ^{94}Zr: up to 2^+_4!
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- another case of subbarier transfer from ^{208}Pb? - to be solved

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Thank you for listening