Electromagnetic properties of ^{45}Sc studied by low-energy Coulomb excitation

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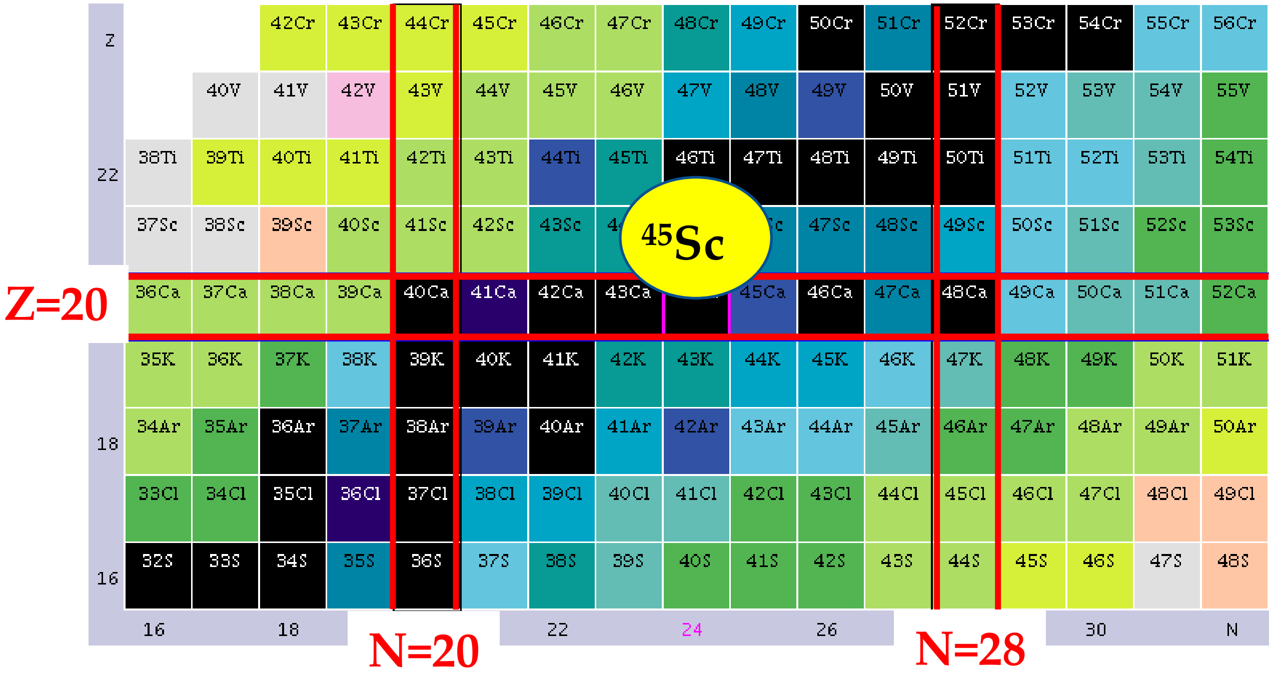
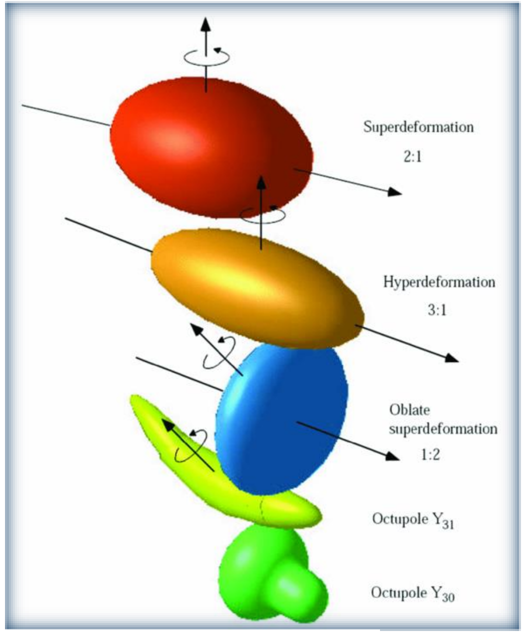
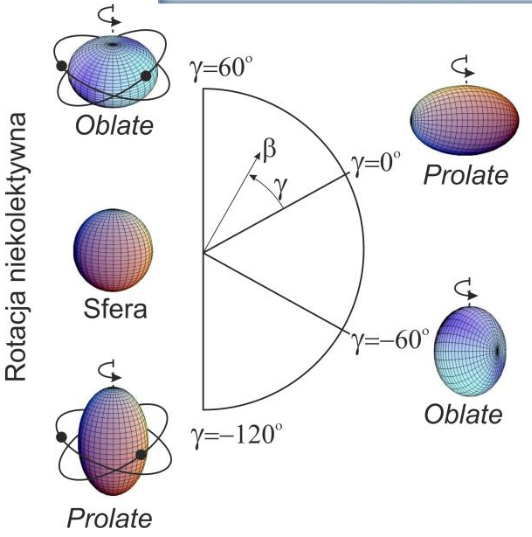
AGENDA

- Why ^{45}Sc? Overview
- Experimental setup
- Gosia analysis
- Results
- Summarize and next steps

Why ^{45}Sc?







^{45}Sc: odd-even nucleus, 1p4n beyond N=Z=20
GS structure – spherical SM
p-h excitations results in SD

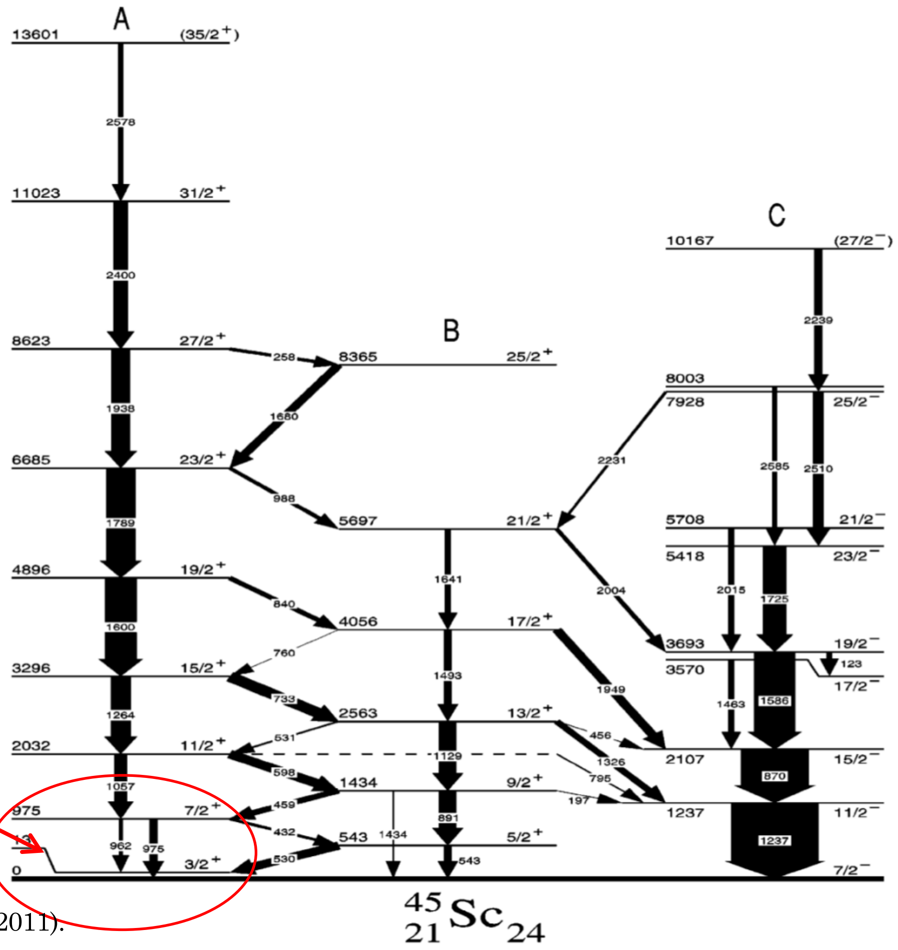
^{45}Sc - overview

- Negative parity g.s. spherical
- Positive parity well deformed rotational-like band is formed upon the isomer
- Low-lying positive parity states: promotion of an s-d shell particle to the $f_{7/2}$ shell
- proton 2p1h excitation

Izomeric 3/2+ state,
12.4 keV, $T_{1/2}$=318 ms

Qs=0.28(5) b, prolate def. β~0.3

M. Avgoulea, et al., J. Phys. G: Nucl. Part. Phys. **38**, 025104 (2011).



^{45}Sc level scheme, taken from P. Bednarczyk, et al., Eur. Phys. J. A 2, 157 (1998).

- Isomeric states are common in the vicinity of doubly magic nuclei,
- hence they probe the nuclear interaction used to describe these fix points of the shell model
- at the same time as they provide severe constraints on the respective parameter set
- In particular they probe
  - excitation energies,
  - Electromagnetic decay properties

Previous ^{45}Sc Coulex measurements

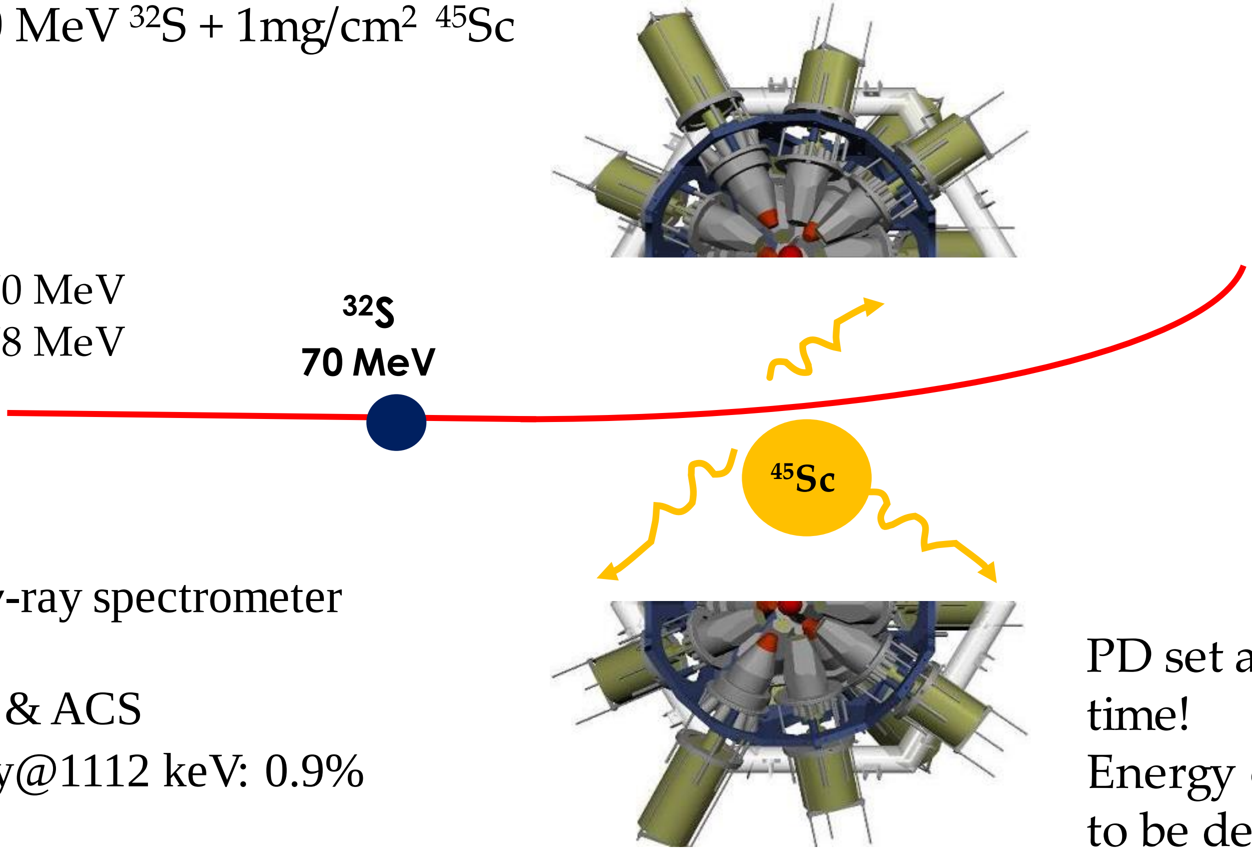
- Beam of 2-4 MeV protons - D.C. Tayal et.al., Phys. Rev. C 34, 1262 (**1986**).
- ^{4}He, and protons - V.U. Patila and R.G. Kulkarni Can. J. Phys..57. 1196(**1979**).
- ^{16}O - A.E. Blaugrund et al., Phys. Rev. Vol. 159, no. 4, 926 (**1967**).
- ^{37}Cl - M.D. Goldberg and B.W. Hooton, Nuclear Physics A132, 369 (**1969**).

- B(E2), B(E1) – for the few lowest states
- Upper limit for B(E3, $7/2^{-}_{g.s.} \rightarrow 3/2^{+}$) $\leq$ 2.7 W.u.
- No other E3 transition strenght to higher lying states
- No quadrupole moments for any state

Experimental setup @HIL UW

70 MeV ^{32}S + 1mg/cm^2 ^{45}Sc

Emax(69°) = 70 MeV
Emax(49°) = 78 MeV



EAGLE γ-ray spectrometer

16 HPGe & ACS
Efficiency@1112 keV: 0.9%

γ-rays in coincidence with scattered ions

Particle detector

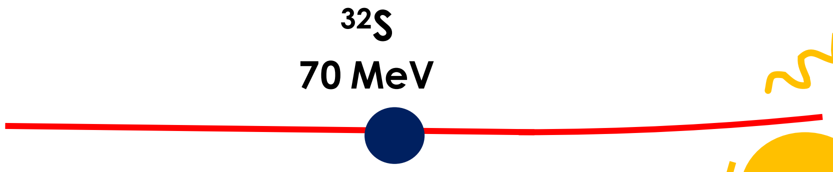
48 PiN-Diode HI Detectors

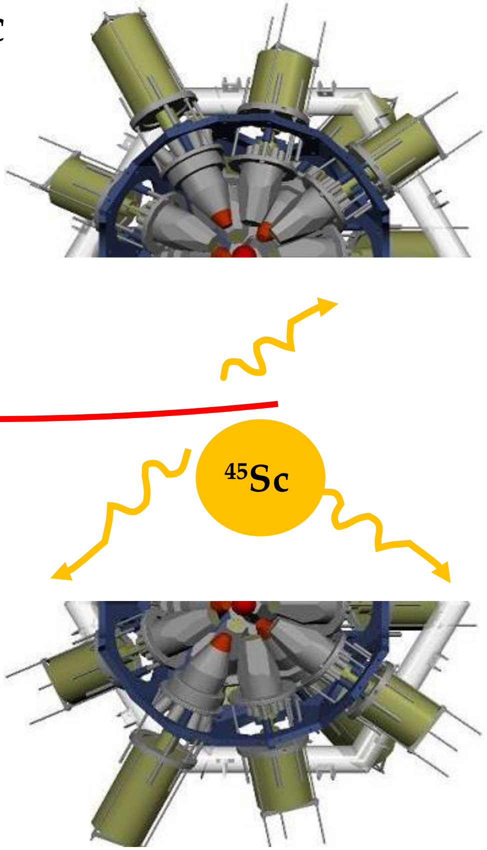
θ_{LAB}: 49÷69 deg
θ_{CM}: 38÷111 deg

PD set at forward angles for the very first time!
Energy of back-scattered ions is too small to be detected in PIN diodes.
Radiation damage appeared - only 16h was possible – change the concept

Experimental setup @HIL UW part2

70 MeV ^{32}S + **15** mg/cm^2 ^{45}Sc





EAGLE γ-ray spectrometer

16 HPGe & ACS
Efficiency@1112 keV: 0.9%

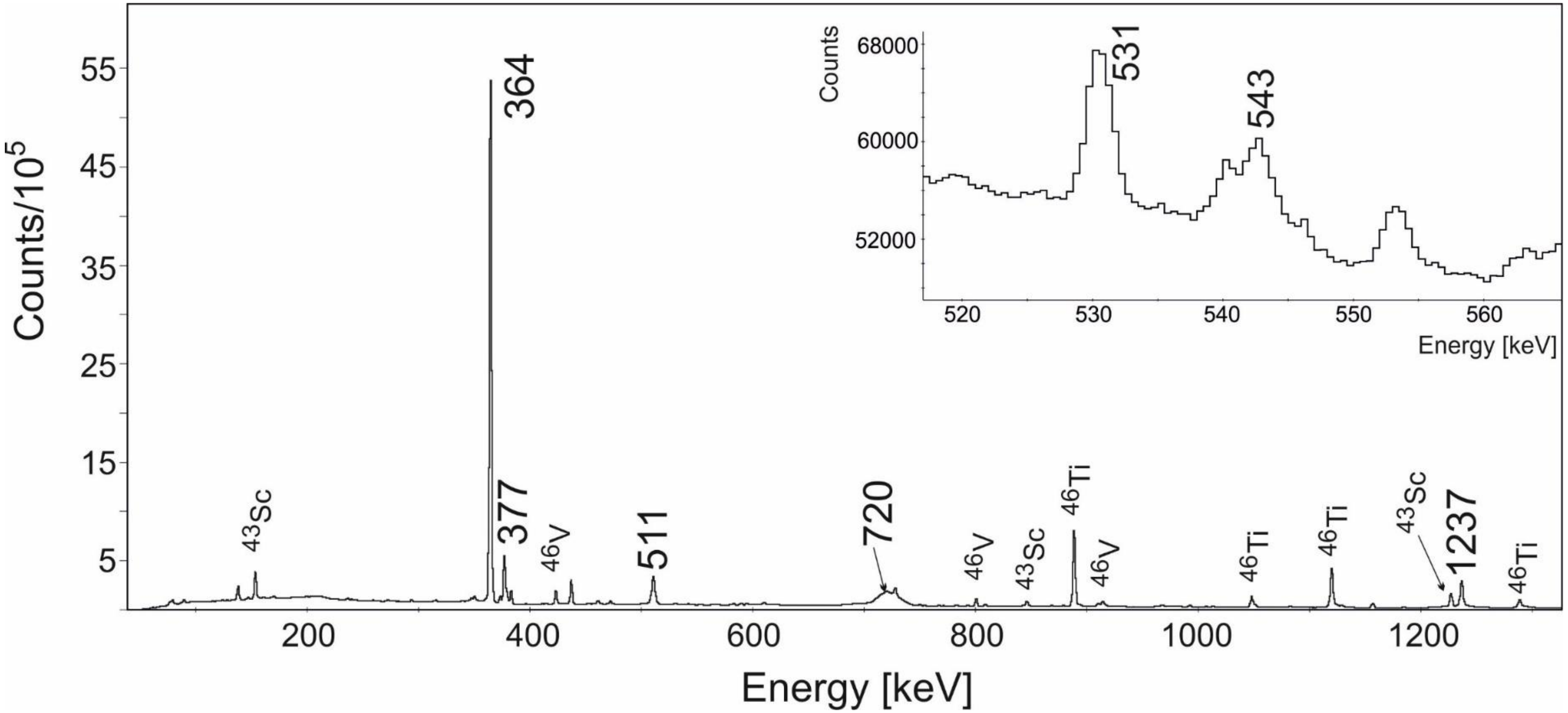
Integral measurement:

θ_{CM}: 0÷180 deg

While previously:
θ_{LAB}: 49÷69 deg
θ_{CM}: 38÷111 deg

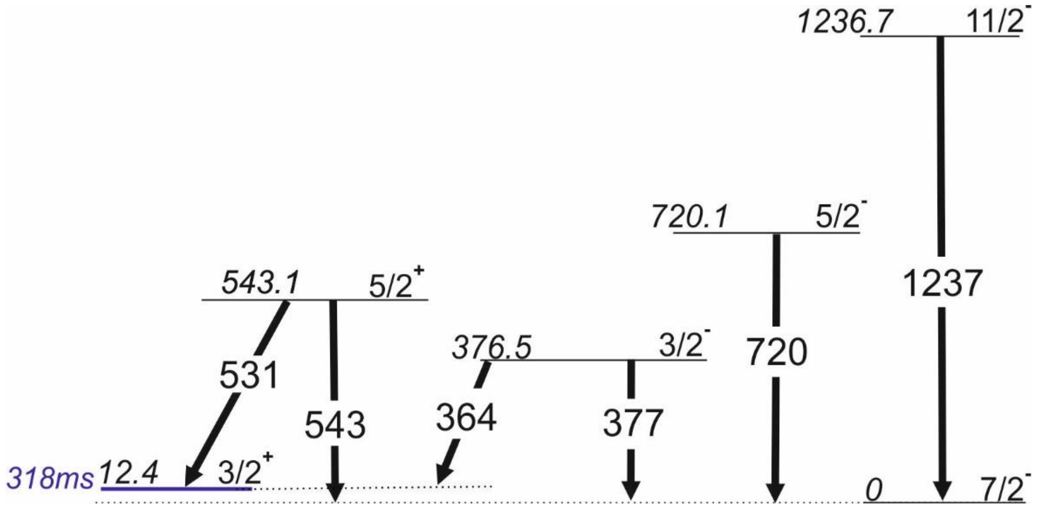
- Due to the Rutherford scattering cross sections the very forward scattering angles are favorized

Collected γ-ray energy spectrum



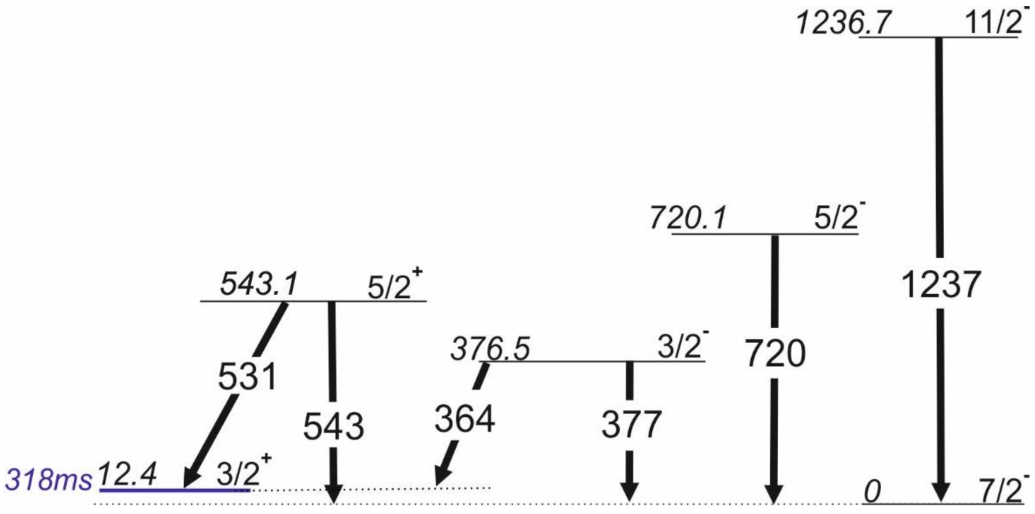
- 70 MeV ^{32}S beam + thick 15 mg/cm2 ^{45}Sc target
- Sum over 16 detectors
- Lines originating from the reaction products on the target oxidation are marked; i.e. ^{46}Ti, ^{46}V, ^{43}Sc

^{45}Sc level scheme



- Observation of the 531 and 543 keV confirmed that the positive parity band was populated, and BR confirms identification

GOSIA caclulations

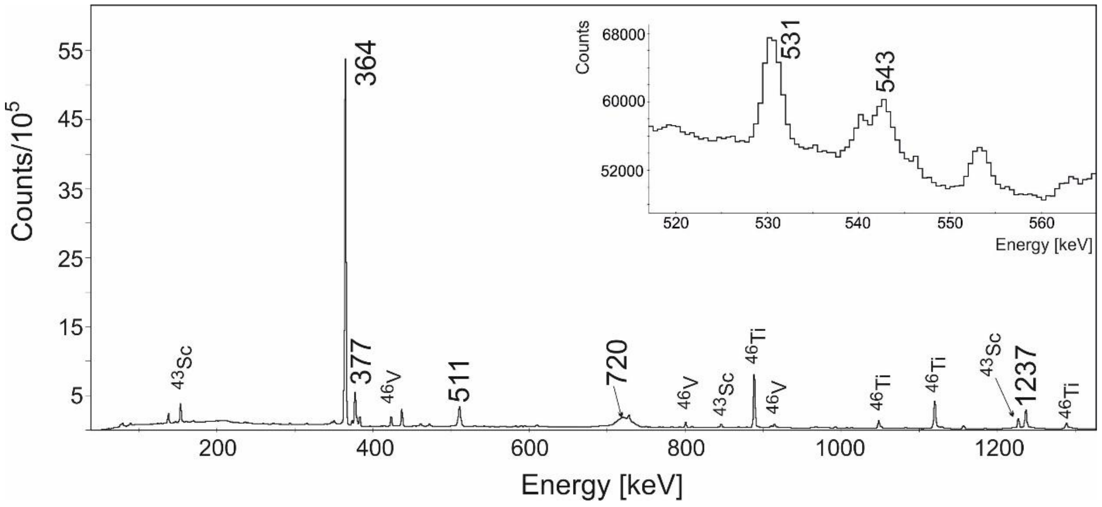


- Observed line intensities
- Additional constrains:

  level lifetimes (4)

  BR (2)

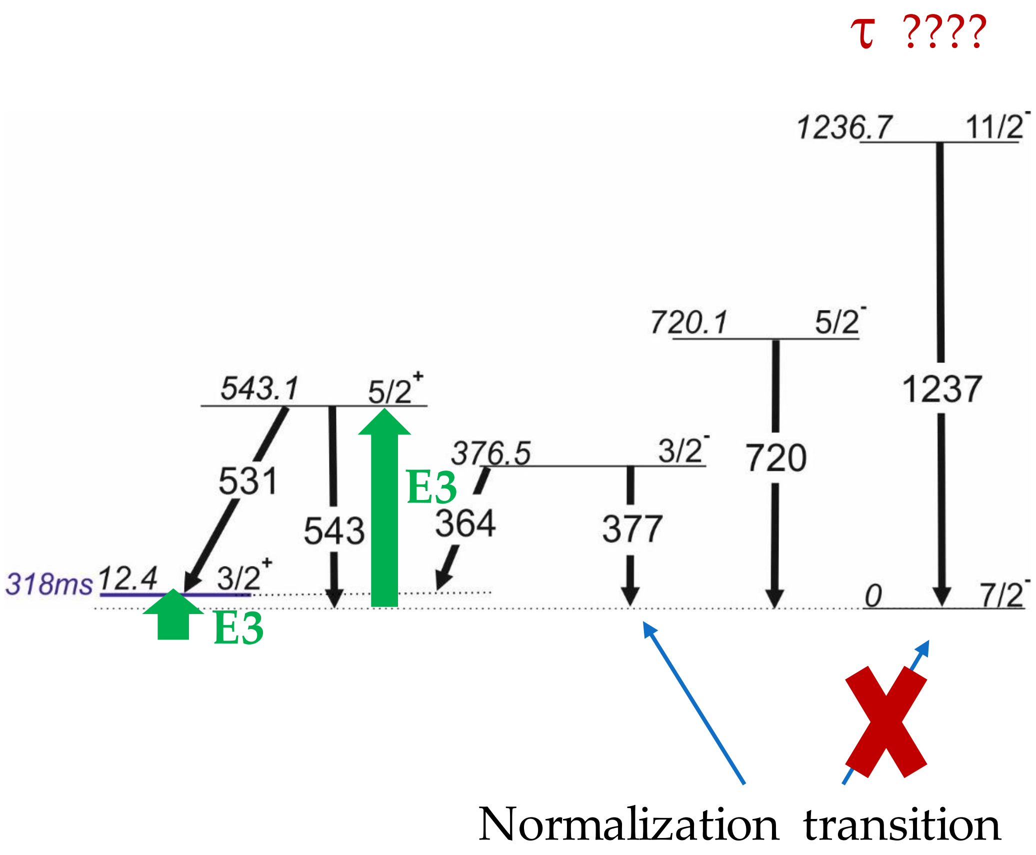
  δ(E2/M1) Mixing ratios (2)



Uncertainties included into Gosia calculations:

- Observed intensities of ^{45}Sc lines were compared with to the population of the ^{46}Ti states;
- And taking into account calculated (PACE4) cross sections for ^{46}Ti (214 mb) and ^{45}Sc (0.205 mb)
- Up to 5% of registered intensity may originate from the reaction on the oxygen;

GOSIA caclulations cd.



Upper limit from the
$B(E3, 7/2^-_{g.s.} \rightarrow 3/2^+) \leq 105\ e^2fm^6$

$B(E3, 7/2^-_{g.s.} \rightarrow 5/2^+)$ was unknown

Initial results:

$B(E3, 7/2^-_{g.s.} \rightarrow 3/2^+) \leq 1.20\ e^2fm^6$

$B(E3, 5/2^+ \rightarrow 7/2^-_{g.s.}) = 1.44 * 10^{-5}\ e^2b^3$

$= 0.12(3)$ W.u

SUMMARIZE

- Positive parity isomeric band can be populated via Coulomb excitation in the present projectile-target combination (70 MeV ^{32}S + 1mg/cm^2 ^{45}Sc),
- From the collected data we obtain set of matrix elements for populated states,
- We were able to extract B(E3, $5/2^+ \rightarrow 7/2^-_{g.s.}$) = 0.12(3) W.u, and confirm the limit for the B(E3, $7/2^-_{g.s.} \rightarrow 3/2^+$) $\leq$ 1.20 e^2fm^6
- This result pave the way for further studies
- We can now define the excitation probability of the isomeric band
- Experiment is scheduled for the end of this year in New Delhi, India (PPAC, and 4 clover det.)
- We are interested in the deformation of the band formed upon the isomer (quadrupole moments)

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COLLABORATION

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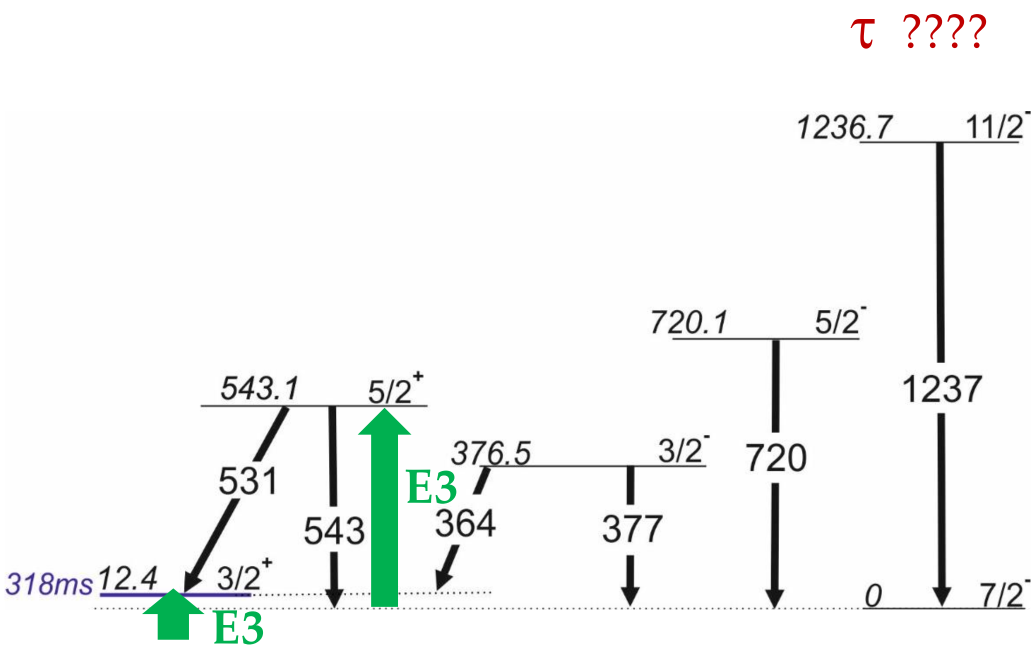
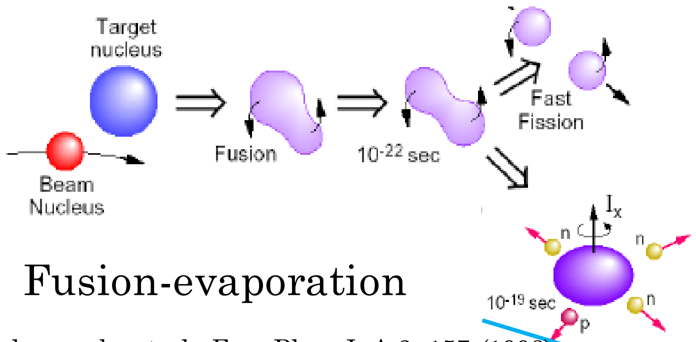
ADDITIONAL SLIDES

Further investigation



2.4 ps +10−6 from (alpha,pγ)

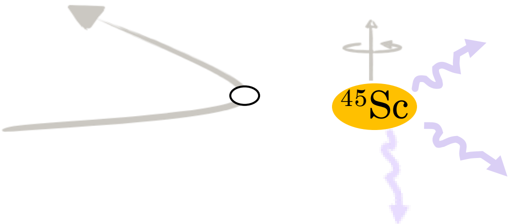
0.12 ps 8 (DSAM)



Fusion-evaporation

P. Bednarczyk, et al., Eur. Phys.J. A 2, 157 (1998).

Coulomb excitation



Izomeric 3/2+ state, 12.4 keV, $T_{1/2}$=318 ms, Laser spectroscopy measurement

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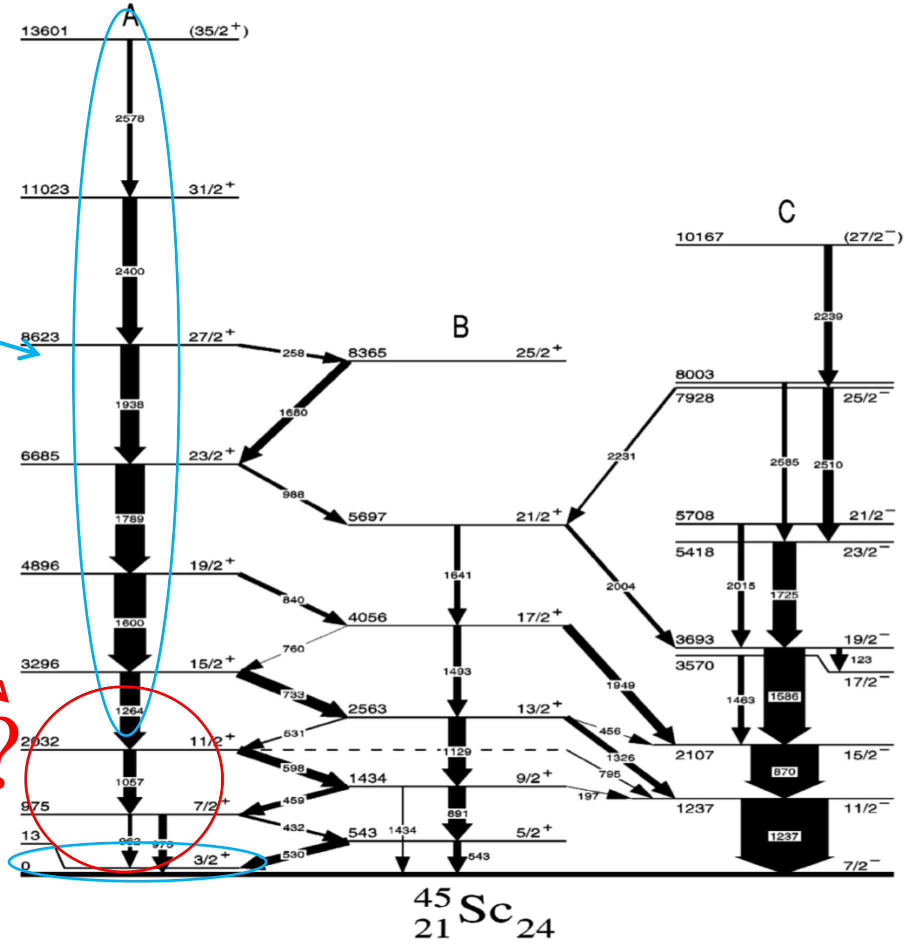
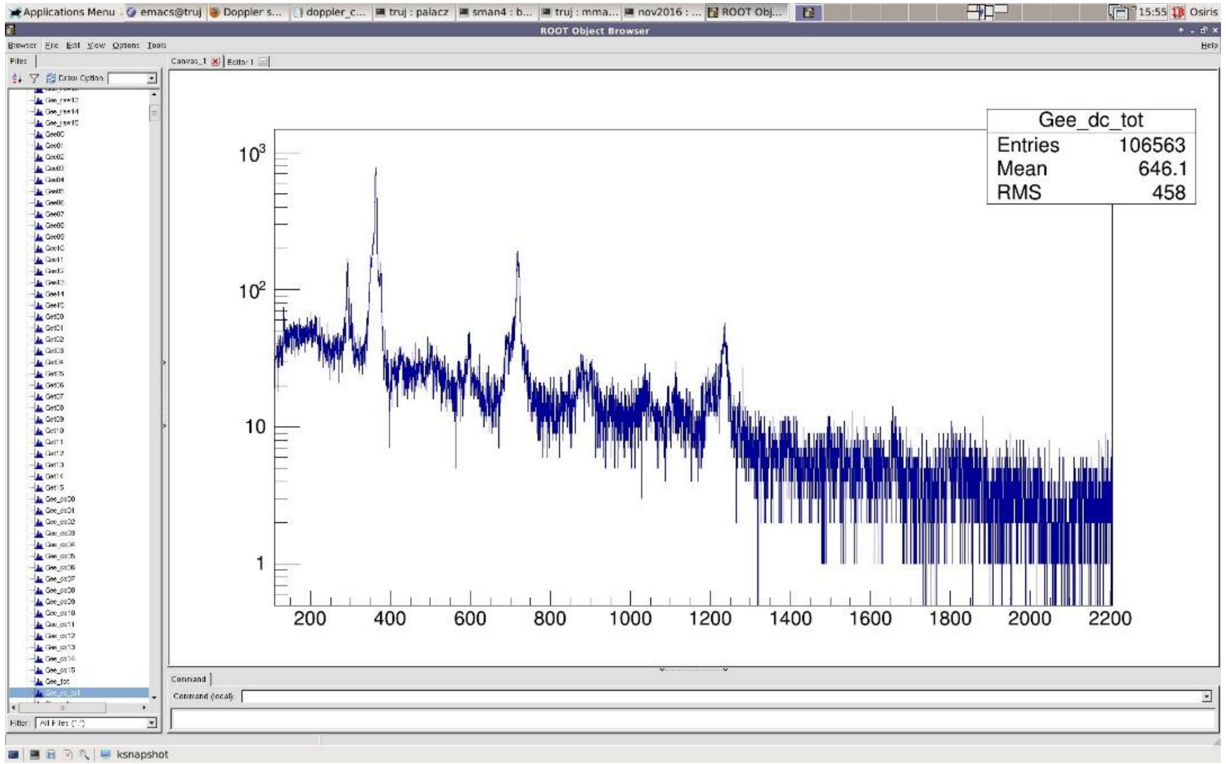


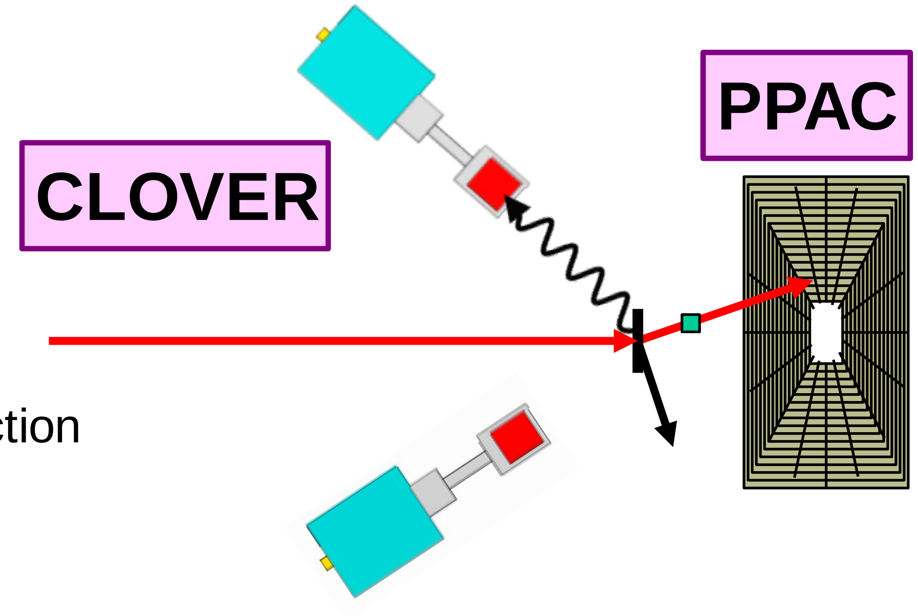
^{45}Sc level scheme, taken from P. Bednarczyk, et al., Eur. Phys.J. A 2, 157 (1998).

P-γ coincidence online spectra

- Very promising ....



Experimental Setup @ IUAC New Delhi, India



4 clover detectors in backward direction

PPAC parallel-plate avalanche counters can be operated stably at high counting rates without significant radiation damage.