**N-SI-128**

# Investigation of high spin structures in $^{44}$Ti and $^{42}$Ca via discrete and continuum gamma spectroscopy using NuBall2, PARIS, and Warsaw DSSD

Scientific Workshop on Nu-Ball2 2024
Reports from the last campaign and prospects for future experiments

Magdalena Matejska-Minda (IFJ PAN)

3 – 5 July 2024, University of Milan

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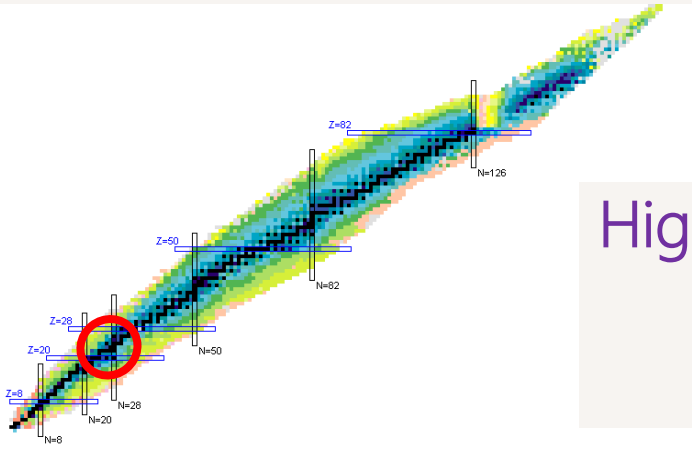
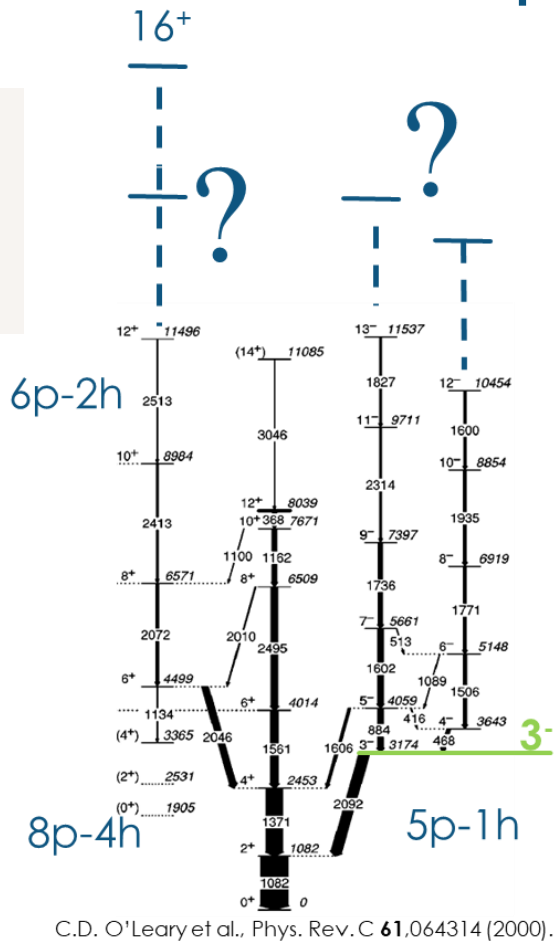



## High-spin spectroscopy of A~40

$^{44}$Ti




C.D. O'Leary et al., Phys. Rev. C **61**,064314 (2000).

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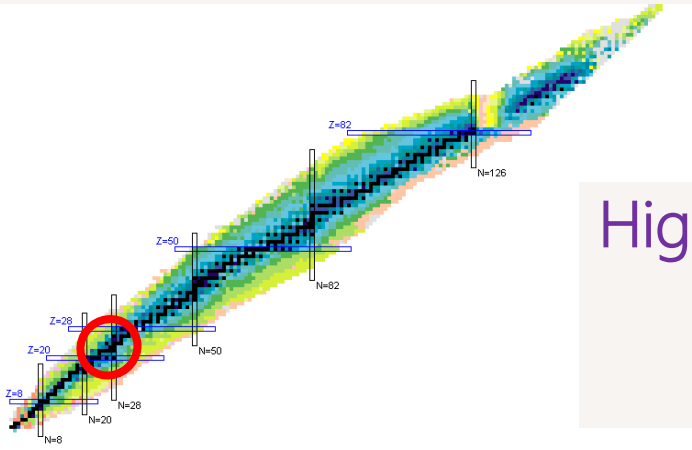


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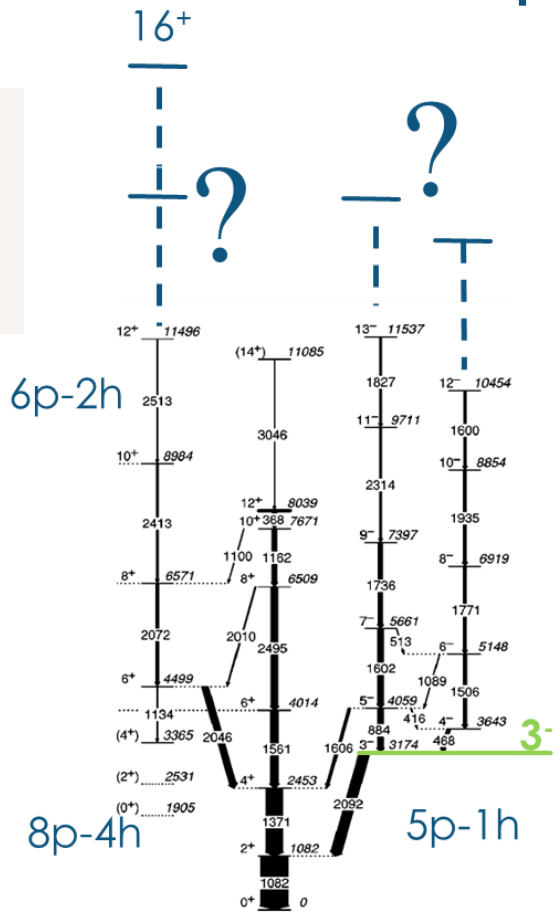


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- Negative parity states form two rotational bands with a band-head at spin $J^\pi = 3^-$. Are interpreted as 5p-1h excitation and should arrive at the maximum aligned spin of $J_{max} = 15^-$ - **not yet observed**

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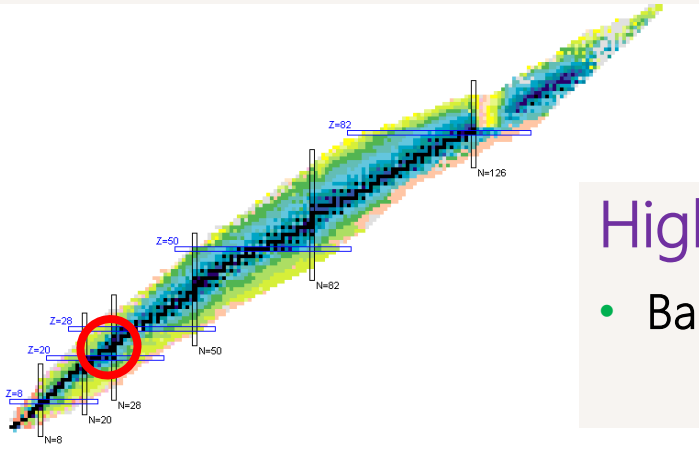
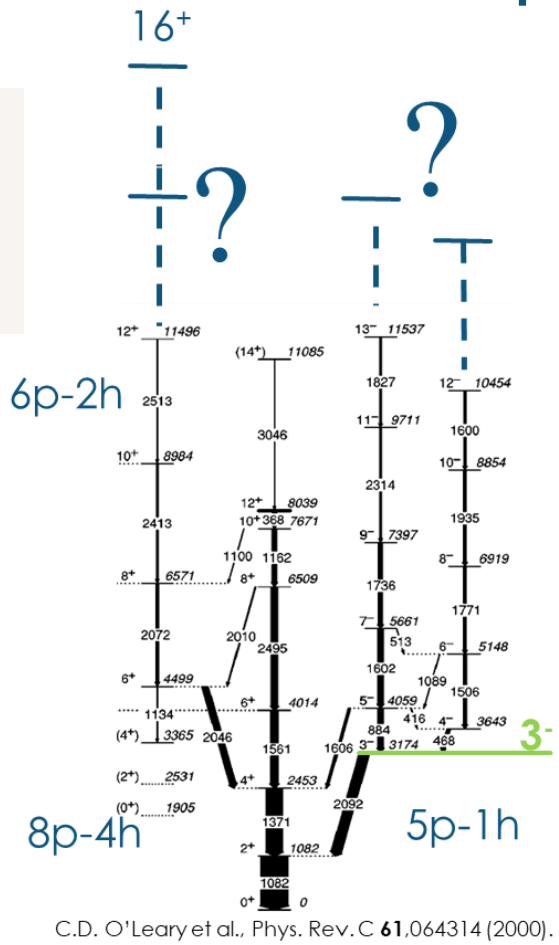



## High-spin spectroscopy of A~40

- **Band termination** – beyond **Shell Model** spin limit

$^{44}$Ti

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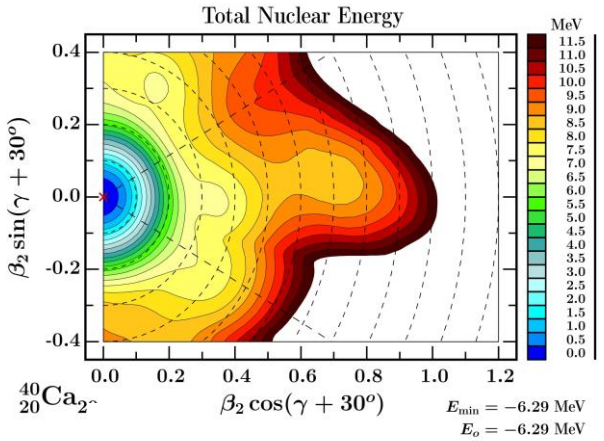


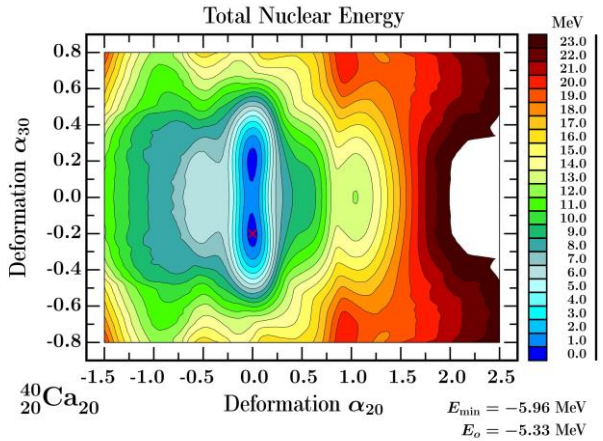


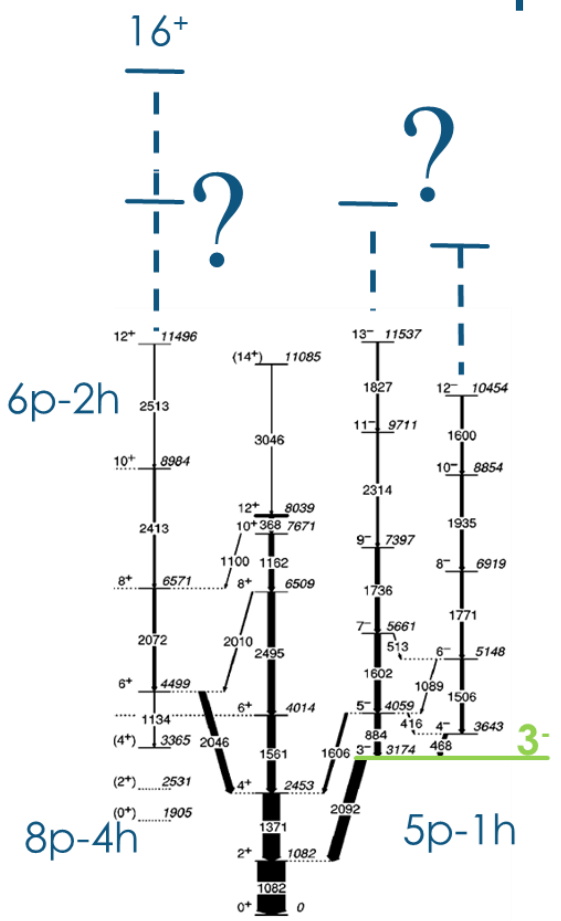


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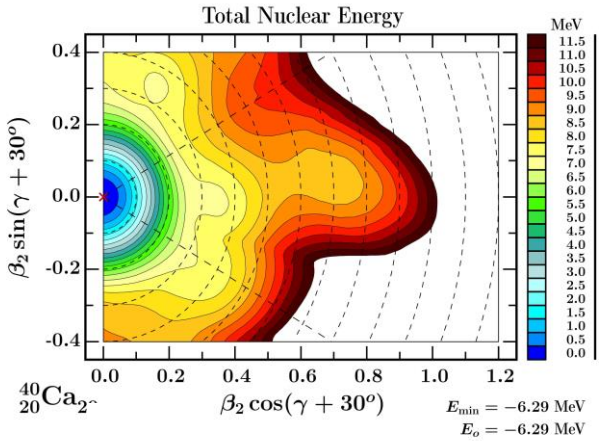
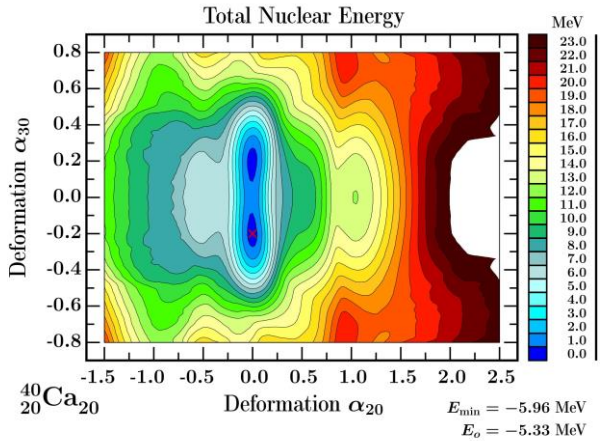
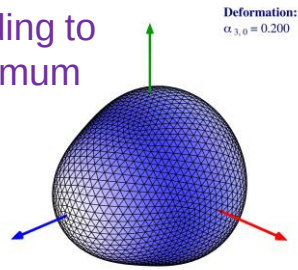
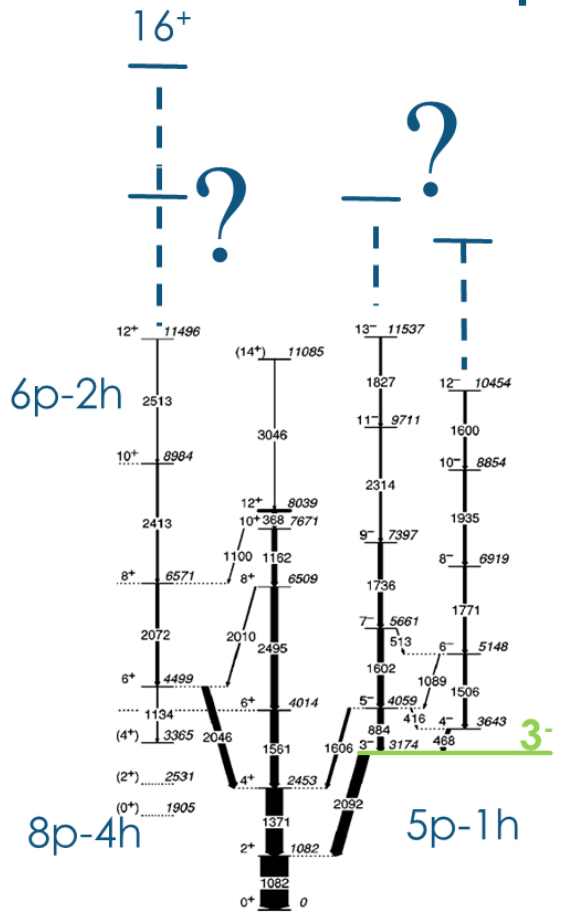



Shape corresponding to the octupole minimum




## $^{44}$Ti

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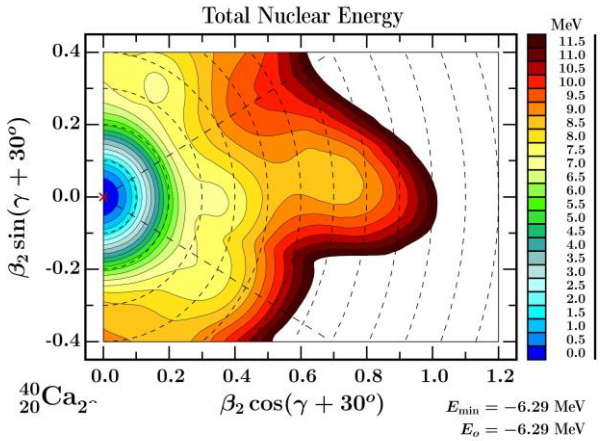
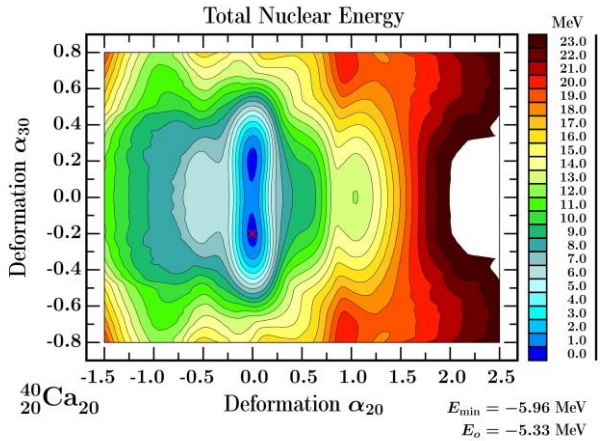
- Such deformed ground state configuration could be a foundation for the excited negative parity structures, bulit on top of the 3$^-$ state, in $^{44}$Ti

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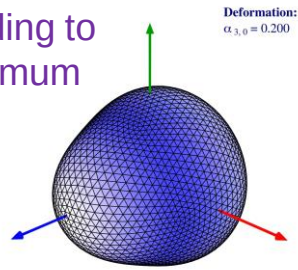


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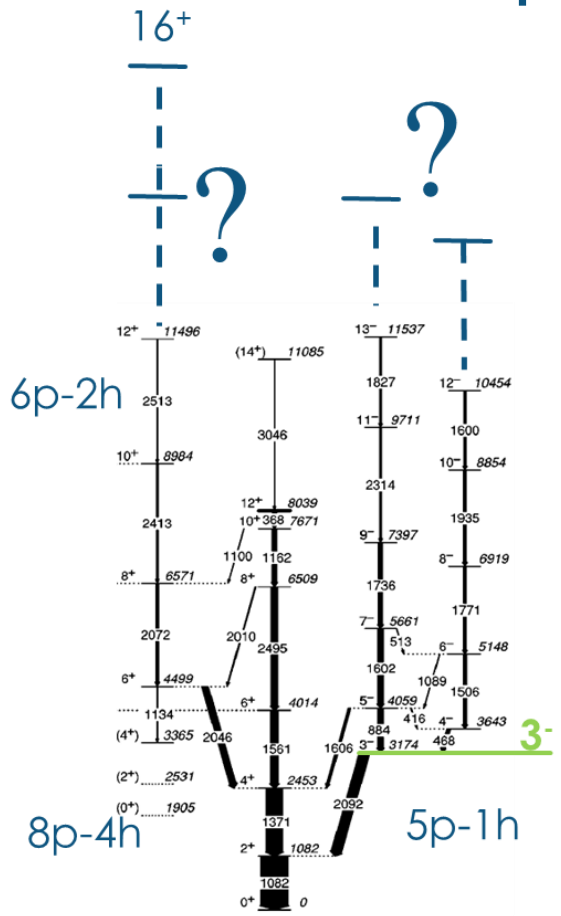


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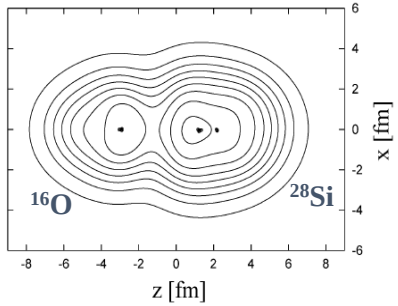
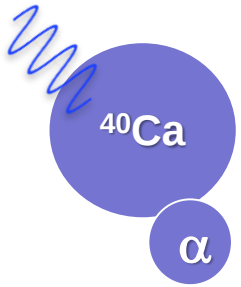
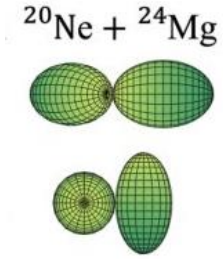
## Cluster configurations for $^{44}$Ti

### predicted at high E*




M.Kimura, H.Horiuchi NPA 767 58 (2006)

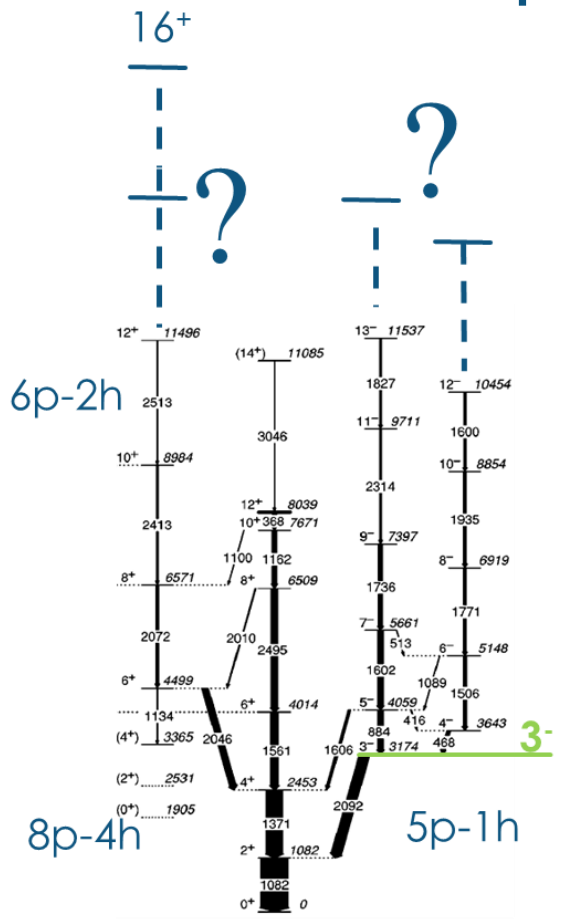



P. Dang, et al., Phys. Rev. C 107, 044315 (2023)

- deformed „cluster states" favored at high spin
  - shape isomers
- no experimental information on the remaining high-spin structures

## $^{44}$Ti

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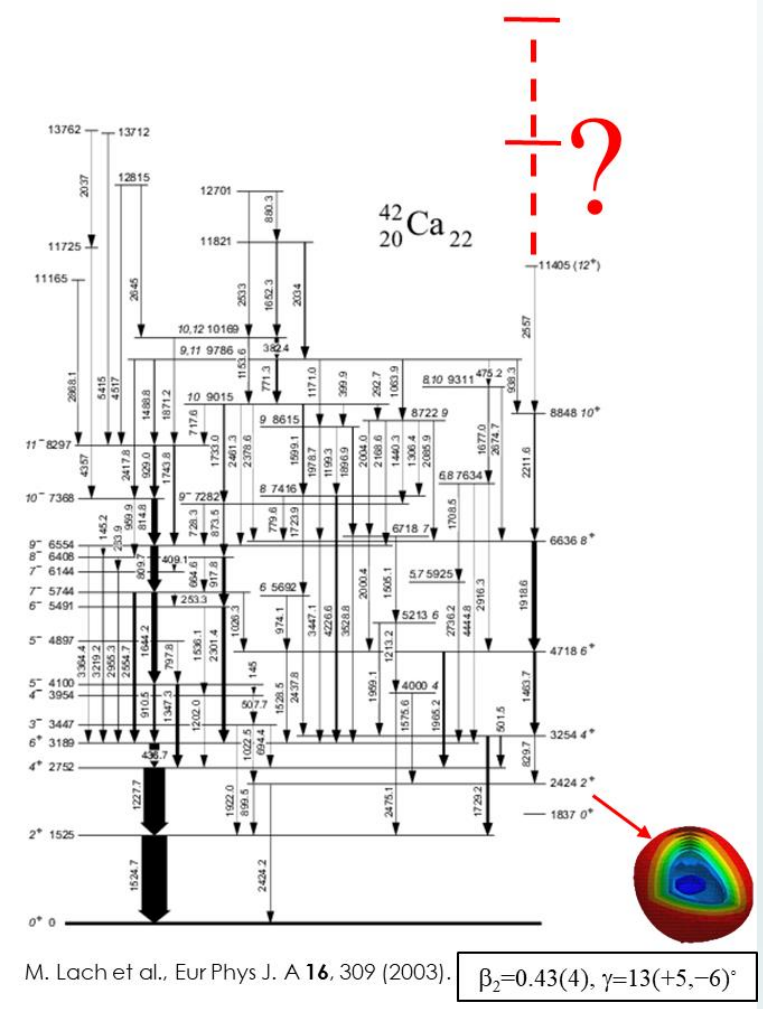


- ✓ Previous measurements of our group indicated **high deformation** associated with the positive parity excited band, which is known up to spin $12^+$

  (M. Lach et al., Eur Phys J. A 16, 309 (2003))

- ✓ From the Coulomb-excitation experiment - triaxial shape of the band head ($2^+_2$ state) was determined: beta = 0.43(2) and gamma = 13(+5, -6). In the Shell Model interpreted as a 6p-4h excitation.

  (K. Hadyńska-Klęk et al, Phys. Rev. Lett. 117, 062501 (2016)

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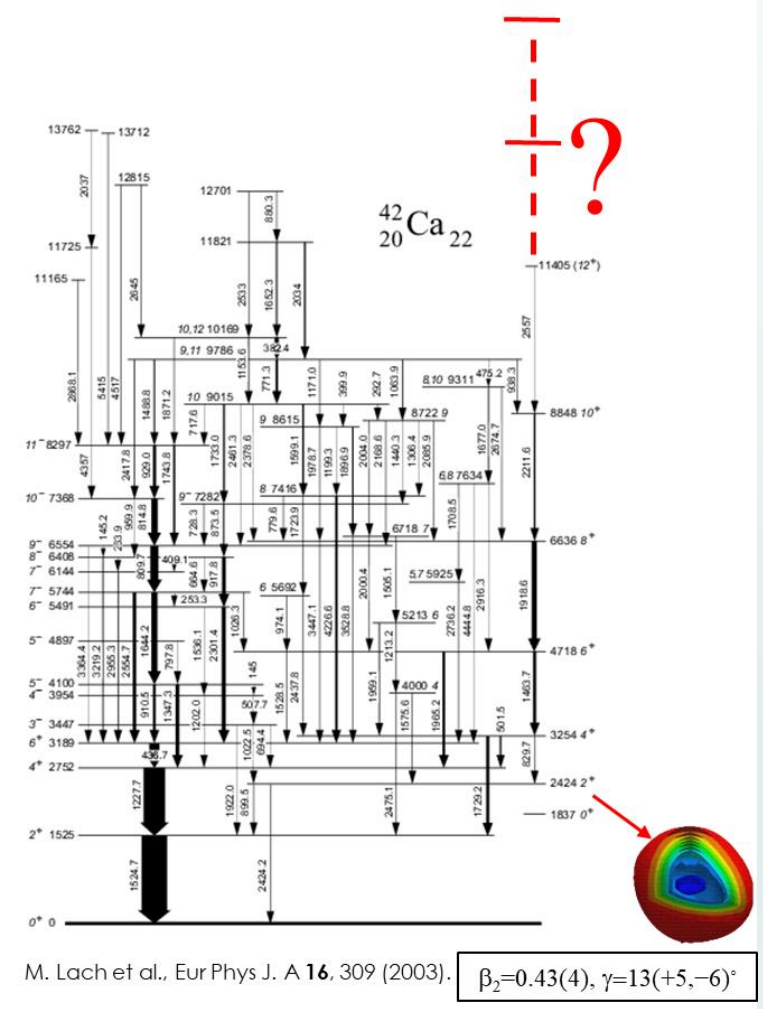


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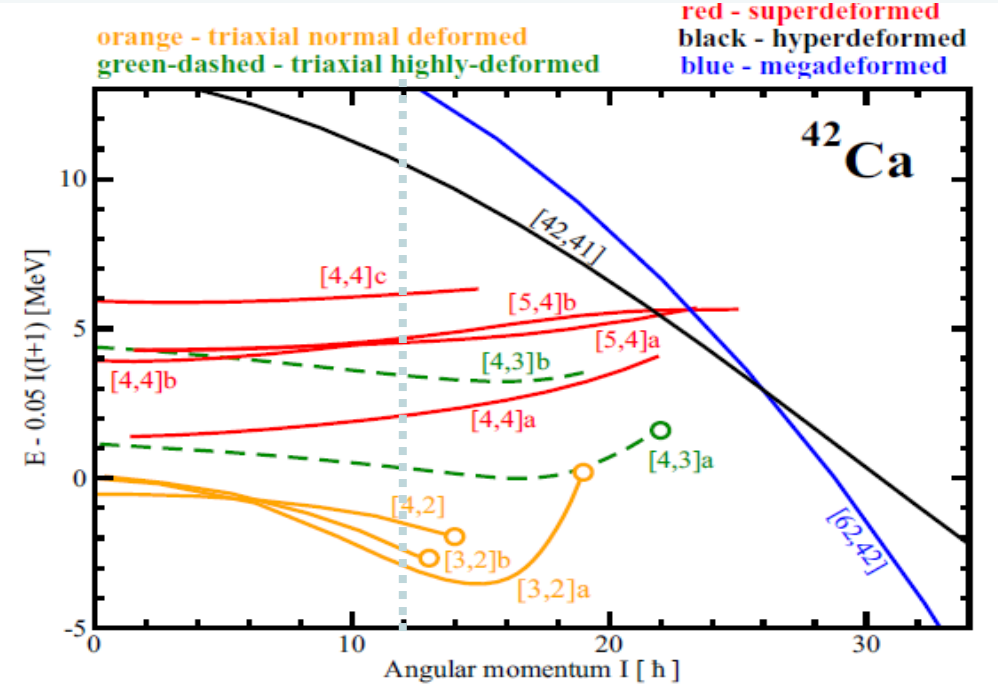
Covariant density functional theory(CDFT) calculations, energies of the calculated configurations relative to liquid drop reference.




D. Ray and A.V.Afanasjev Phys. Rev. C 94, 014310 (2016)

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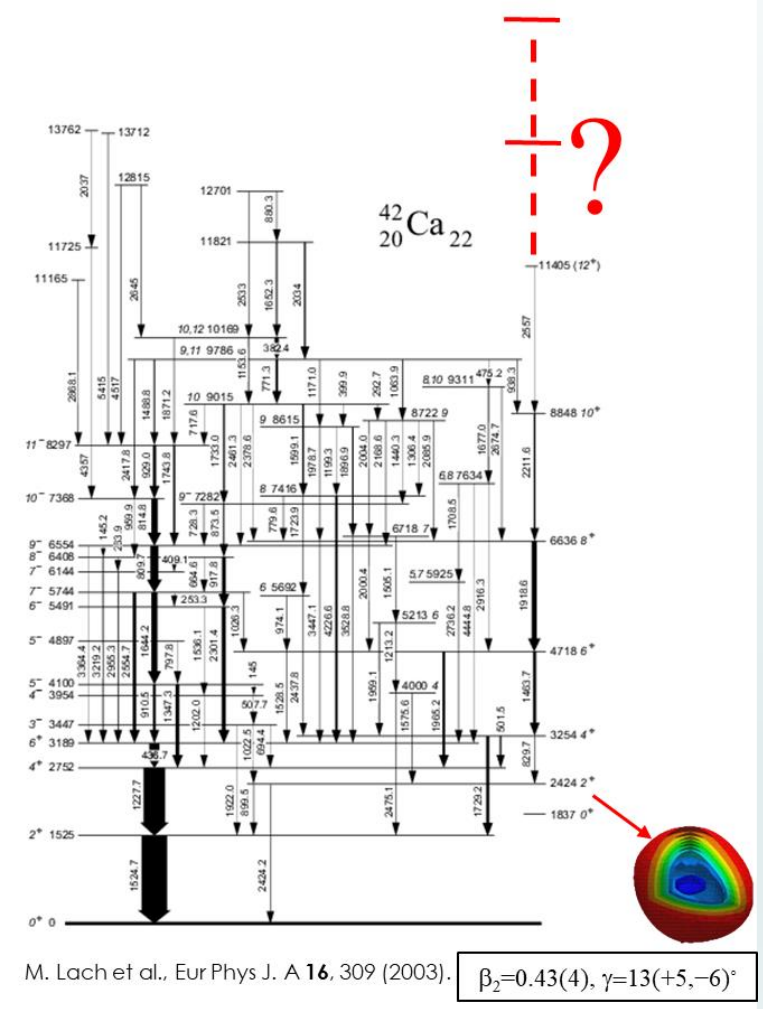


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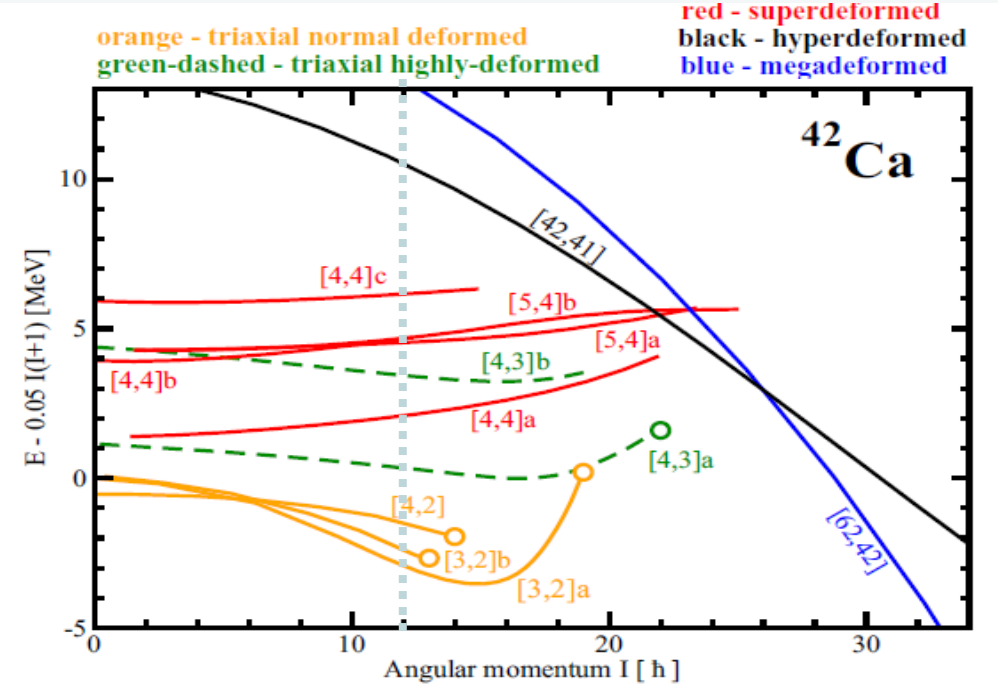


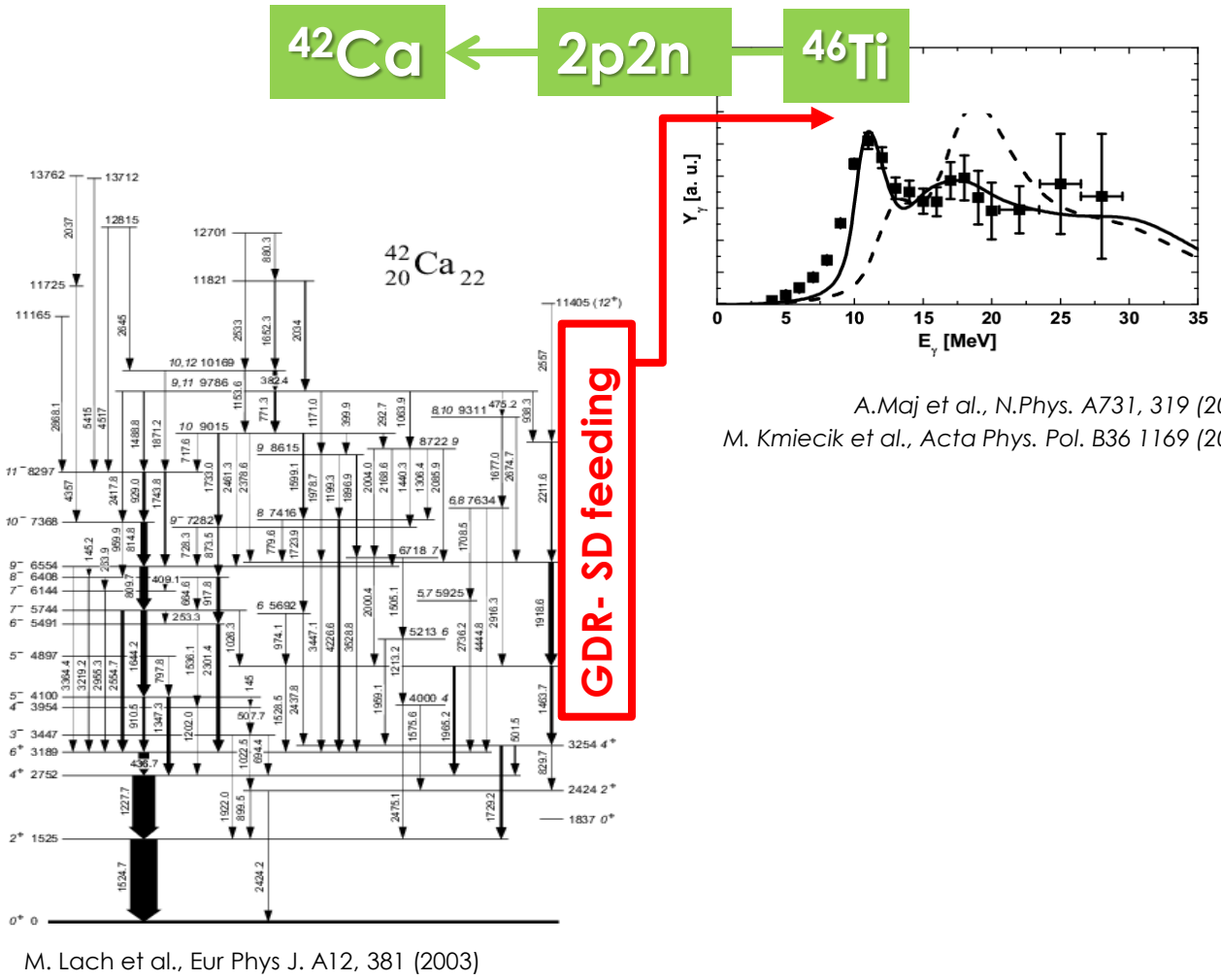

D. Ray and A.V.Afanasjev Phys. Rev. C 94, 014310 (2016)

- Investigate $^{42}$Ca at high spins, to experimentally check if such a band **continues beyond the SM spin limit** (as SD should behave) or terminates.

# Investigation of high spin structures in $^{44}$Ti and $^{42}$Ca via discrete and continuum gamma spectroscopy using NuBall2, PARIS, and Warsaw DSSD

## Survival of large deformation

- The low energy GDR component ~10MeV seems to **feed preferentially** the highly-deformed band in $^{42}$Ca
- This suggests that the very deformed shape of hot CN **persists in the entire** evaporation process
- Investigating discrete and high energy gamma rays – a link between deformed states (resonances) in a hot CN and yrast SD in a cold **ER by coincident measurement of continuum and discrete gamma rays**




*A.Maj et al., N.Phys. A731, 319 (2004)*
*M. Kmiecik et al., Acta Phys. Pol. B36 1169 (2005)*

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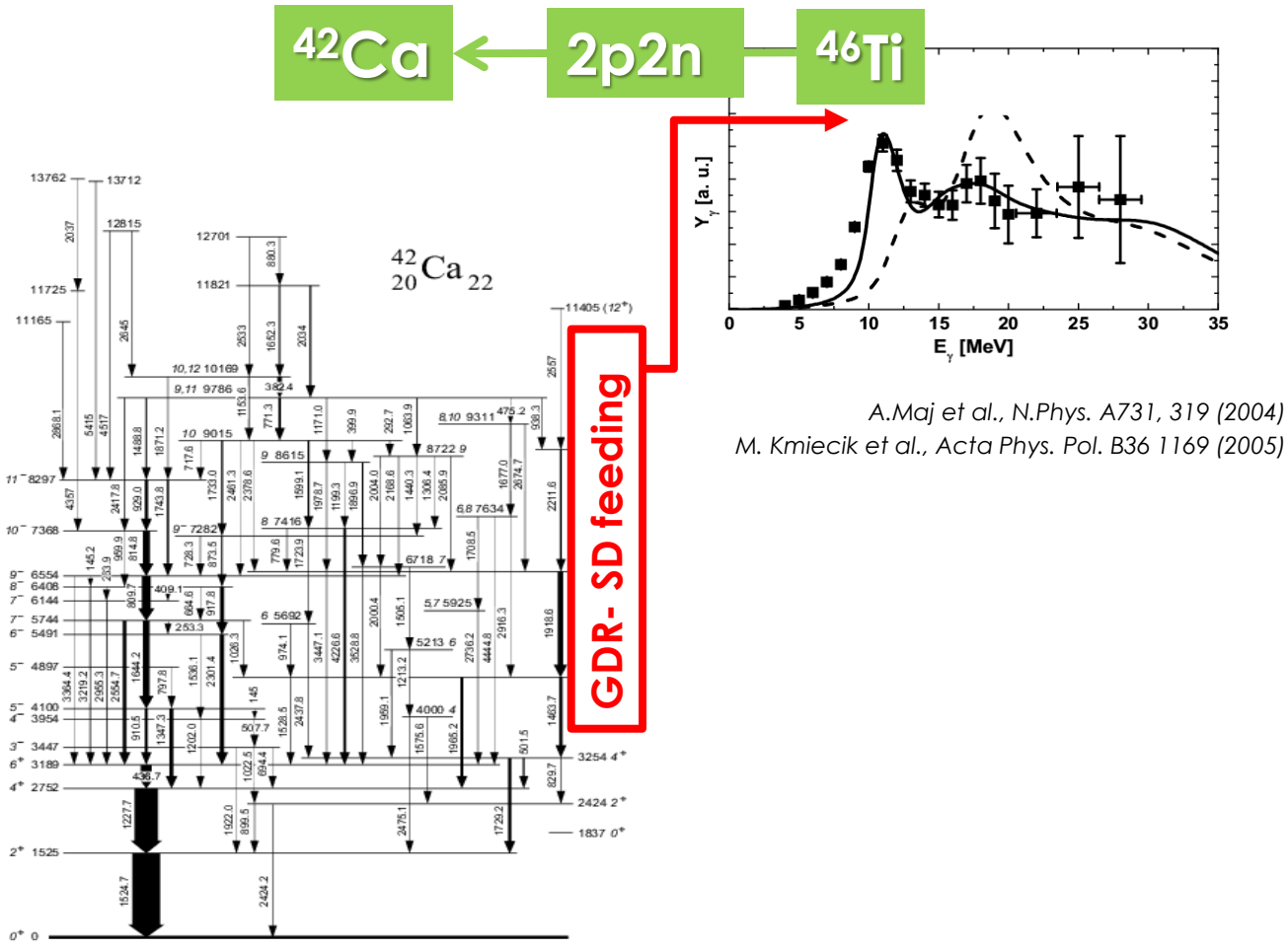
Simultaneously probe the resonance modes and discrete excited states

To explore these different regimes of excitation energies

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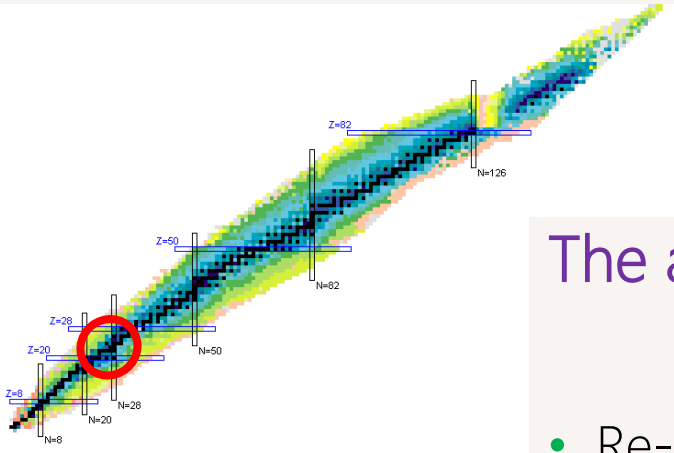



## The aim of the measurement:

### High-spin spectroscopy of A~40

- Re-examine at high spins $^{42}$Ca and $^{44}$Ti, to **extend the known and unknown structures** up to or beyond the terminating states
- **Evaluation of nuclear theories**, as well as testing the hypotheses of the new types of octupolarities predicted in these mass region (**exotic shapes, cluster models**- a new approach to describe the nuclear matter)
- Link between the structures at high and low temperatures – combination of NuBall2 and PARIS is a unique system

# Experimental setup

**Fusion-evaporation reaction: 110 MeV $^{24}$Mg+ 1mg/cm$^2$ $^{24}$Mg**

Gamma rays in coincidence with charged particles

**Nu-Ball2**: extension/termination of rotational bands

discrete γ-rays

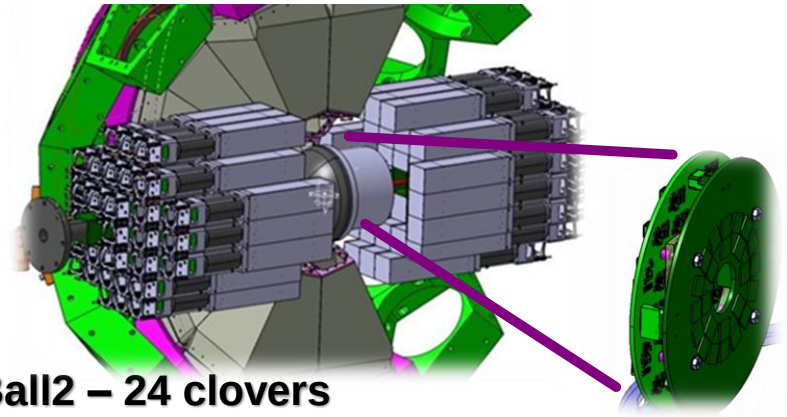
**PARIS:** SD band feeding by high energy γ-rays (>5MeV)

(E1, GDR)

**OPSA**: charged particle detector (α,p...)

- reaction channel selection
- γ–α correlations

**Set-up: Nu-Ball2 + PARIS + OPSA**



- **Nu-Ball2 – 24 clovers**
- **PARIS – 72 phoswithes**
- **OPSA – 24 scintillators**

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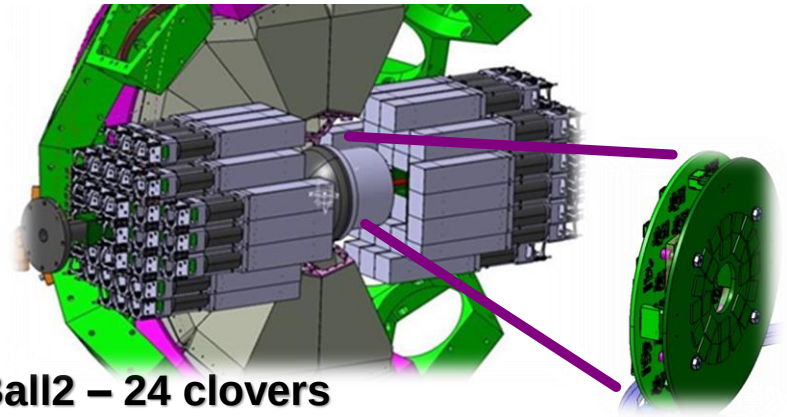

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Gamma rays in coincidence with charged particles

**Performed June 2023**

## Set-up: Nu-Ball2 + PARIS + DSSD

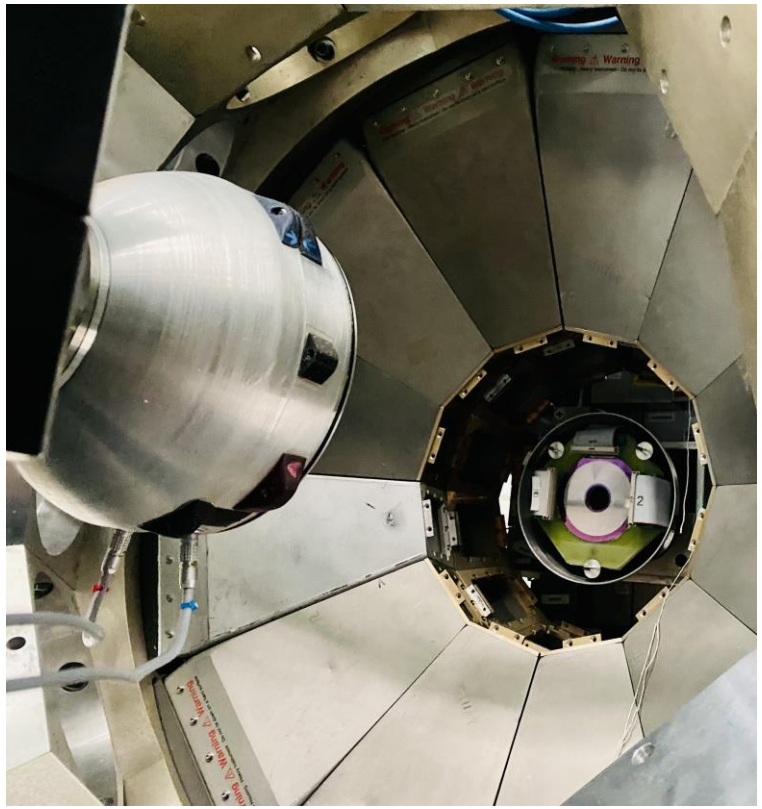
**Nu-Ball2**: extension/termination of rotational bands

discrete γ-rays

**PARIS:** SD band feeding by high energy γ-rays (>5MeV)

(E1, GDR)

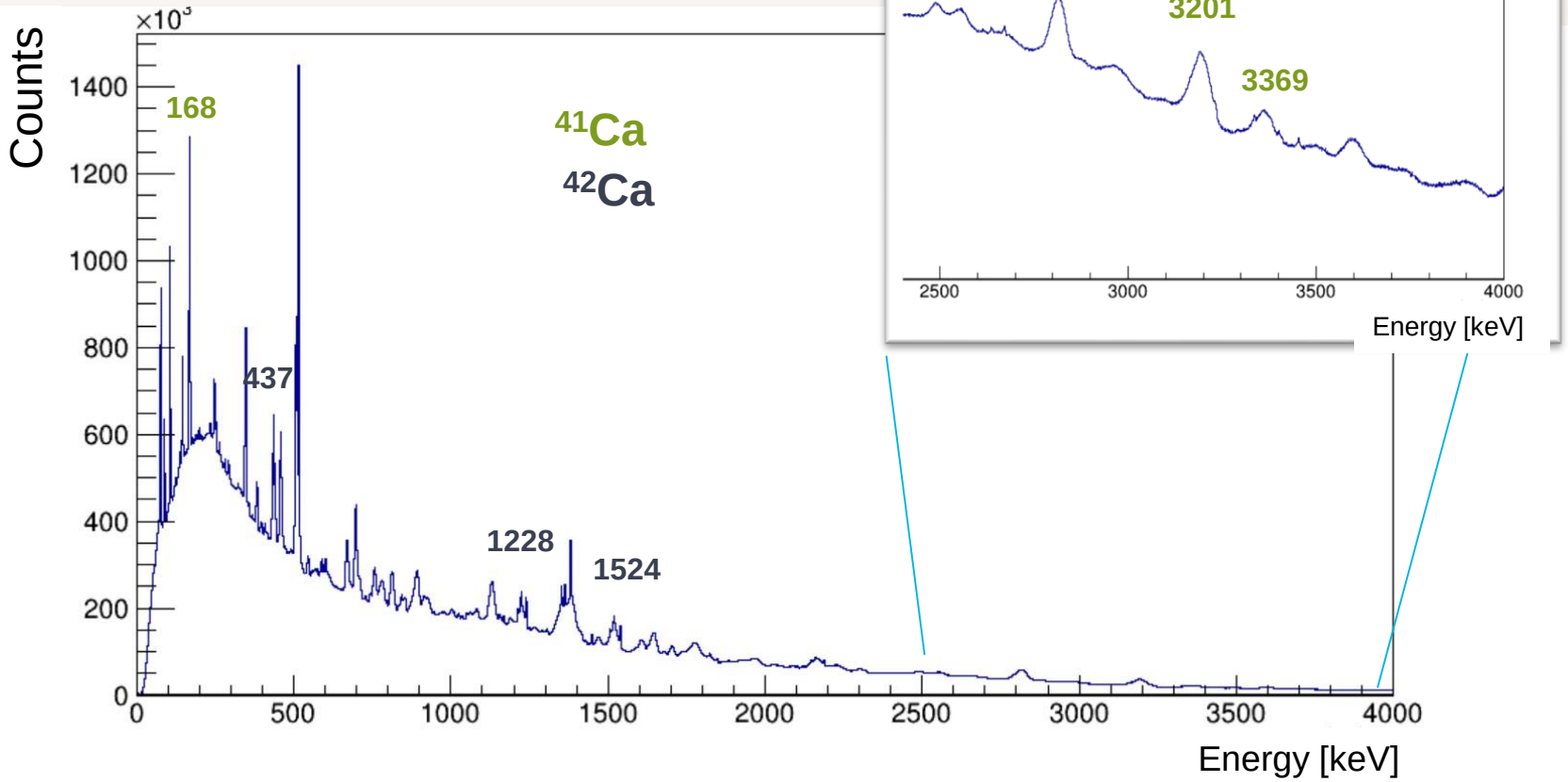
**Warsaw DSSD**: charged particle detector



## Collected data

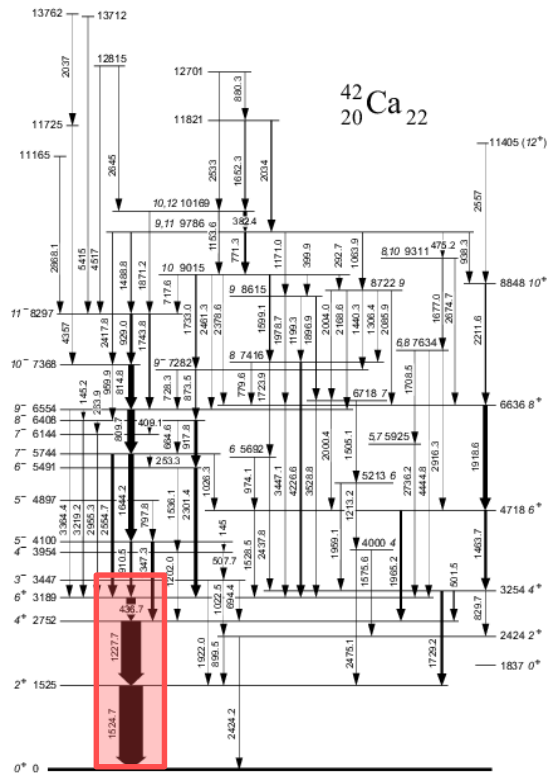
- ✓ $^{24}$Mg is a very difficult beam
- ✓ Scheduled: **11 days** $^{24}$Mg **24 enA**
- ✓ Collected: ~**3 days**, with much lower intensity

# NuBall2 - Doppler corrected spectrum









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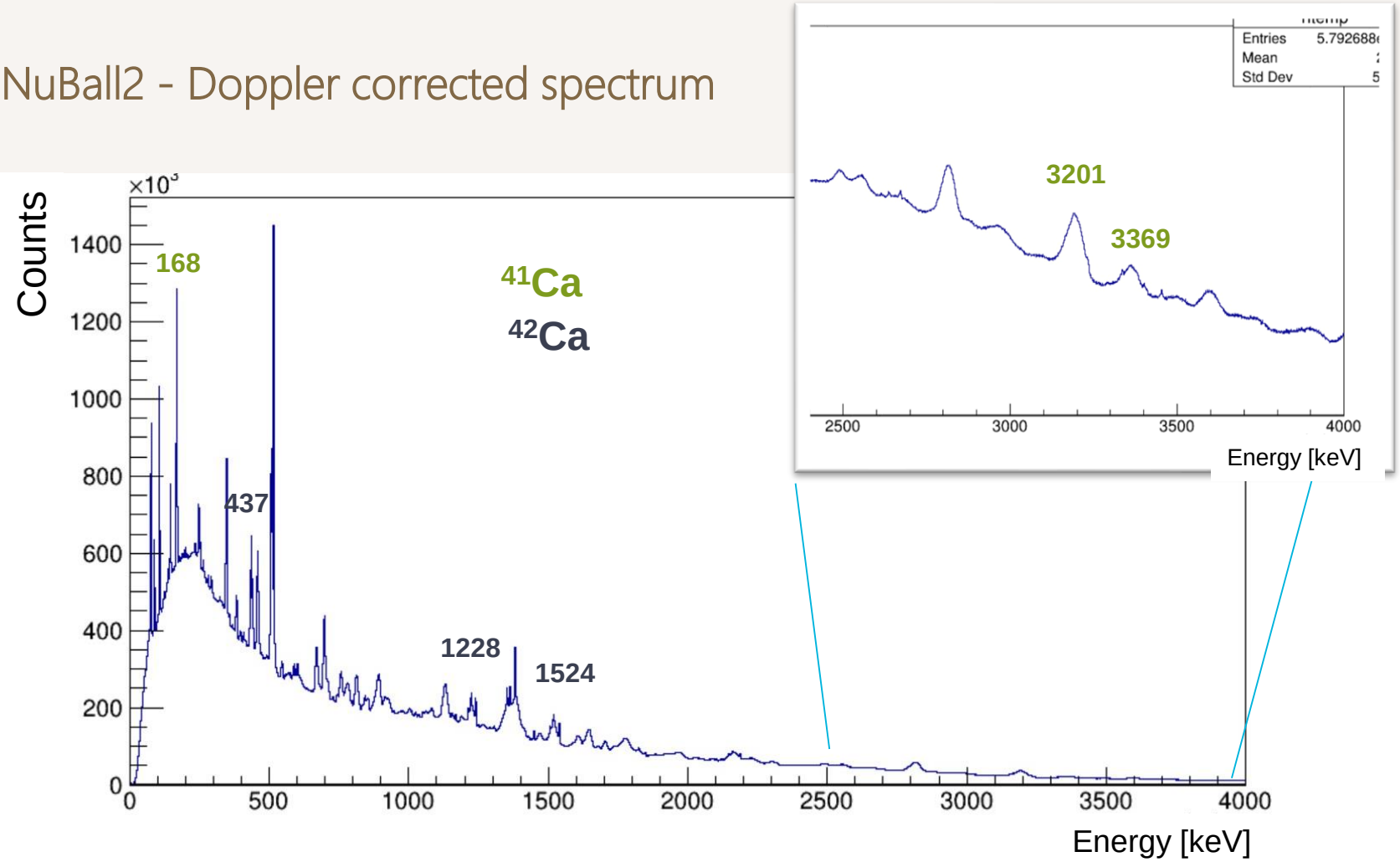
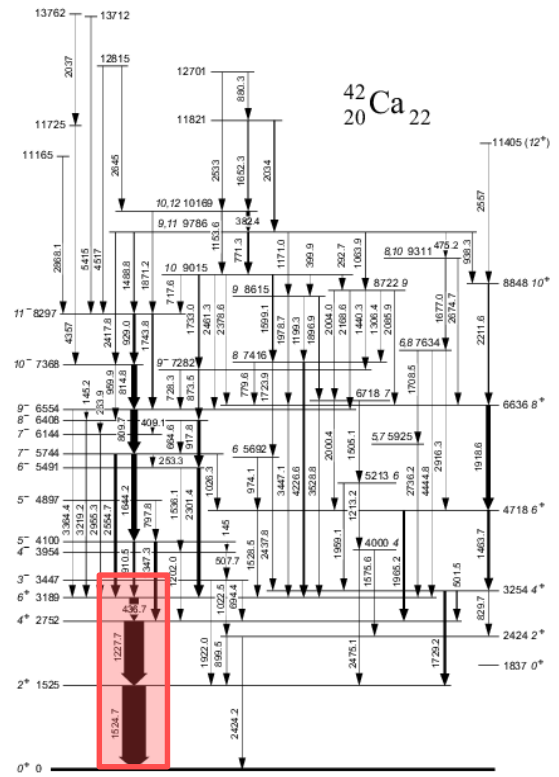
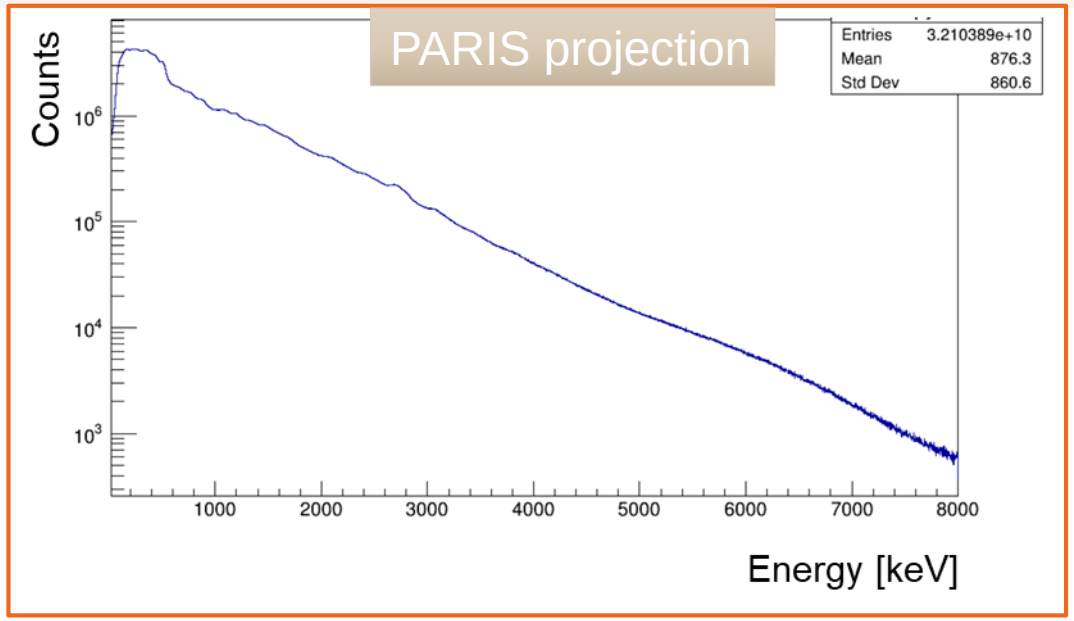



- 437 keV, 1228 keV, 1524 keV from $^{42}$Ca (3% of of $\sigma_{fus}$ cross-section)
- In higher energies lines from $^{41}$Ca – the strongest reaction channel
- Unshifted: 1014 keV from $^{27}$Al, 6128 keV - $^{16}$O, 1368 keV from $^{24}$Mg – Coulex
- For more gamma-gamma -> optimized DC-> NuBall2 angles

# PARIS-NuBall2



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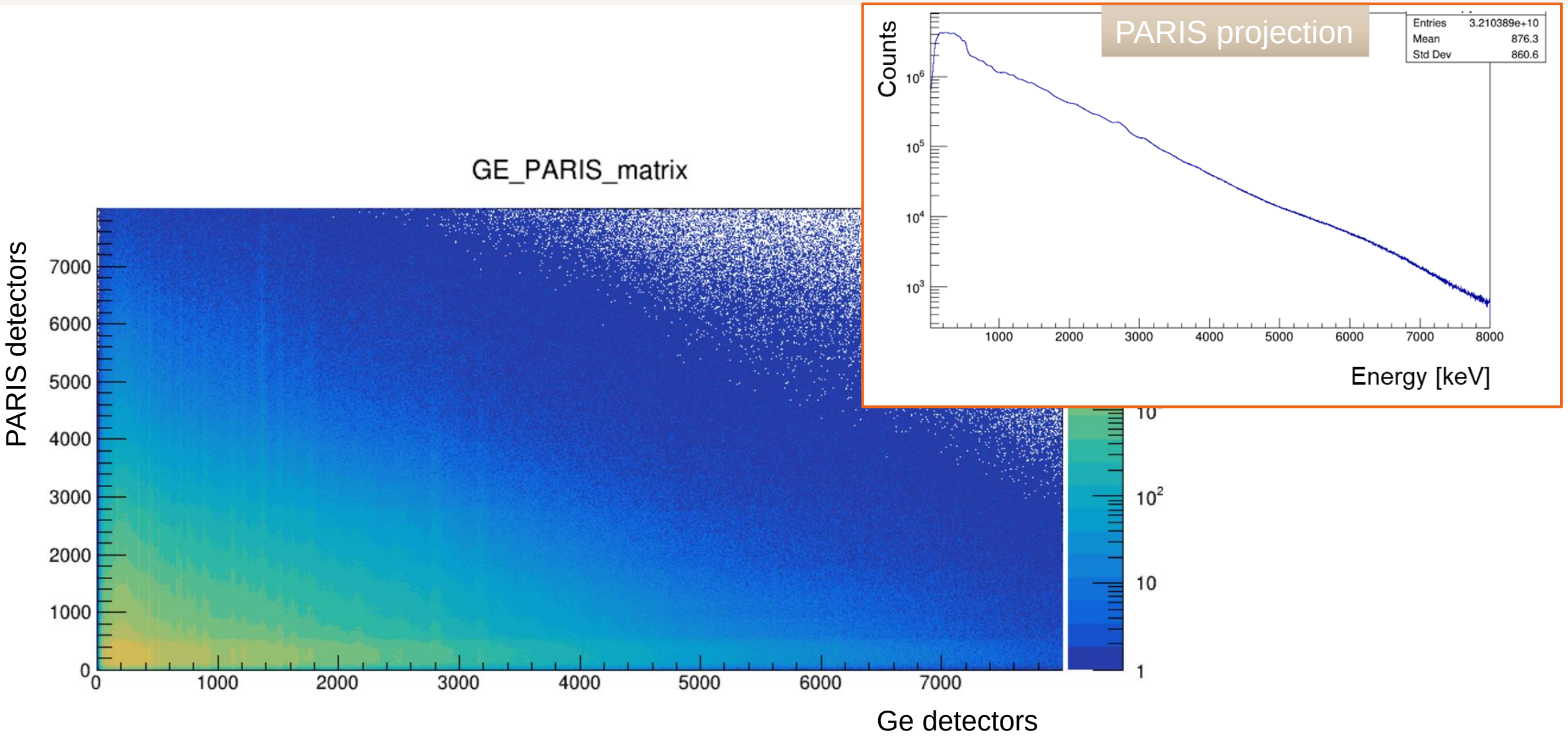
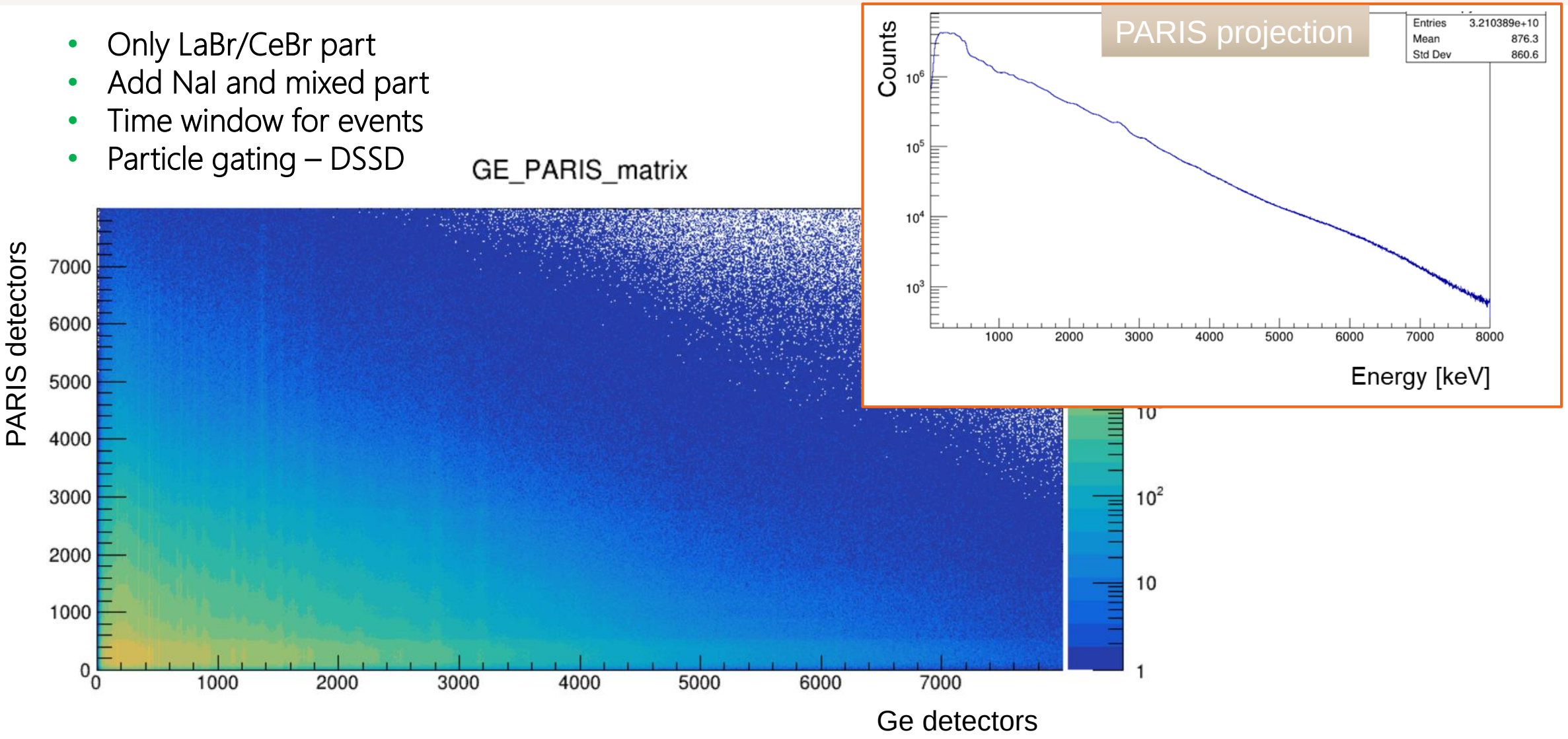


# PARIS-NuBall2

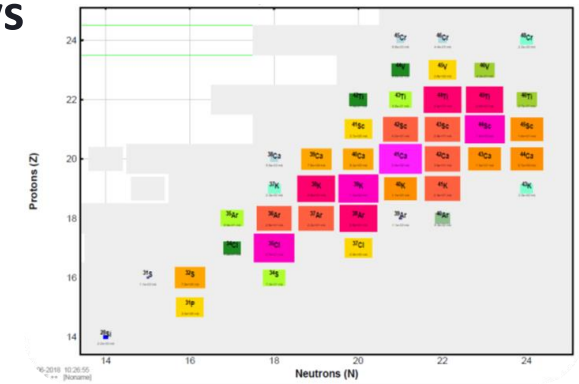
- Only LaBr/CeBr part
- Add NaI and mixed part
- Time window for events
- Particle gating – DSSD



# Summary

- **N-SI-128** “Investigation of  high spin structures in $^{44}$Ti and $^{42}$Ca via discrete and continuum gamma spectroscopy using NuBall2, PARIS, and Warsaw DSSD” was performed in June 2023 @ ALTO
- It was very challenging experiment due to the **very difficult beam** $^{24}$Mg and **different setup that originally planed** – DSSD instead of OPSA
- Collected statistic: the beam time useful for the obtaining physics results is **~3 days** with low intensity (of 11 days)
- Statistic most probably is not sufficient to obtain all the proposed experimental goals
- For the strongest reaction channel like $^{41}$Ca one can hope to obtain new results
- Analysis is ongoing

| Nucleus | Channel | σ [mb] |
|---|---|---|
| $^{45}$Ti | 2p1n | 55 |
| $^{44}$Ti | 2p2n | 60 |
| $^{44}$Sc | 3p1n | 140 |
| $^{42}$Ca | α2p | 36 |
| $^{41}$Ca | α2pn | 240 |
| $^{39}$K | 2αp | 110 |
| $^{38}$K | 2αpn | 58 |
| $^{38}$Ar | 2α2p | 68 |
| $^{35}$Cl | 3αp | 96 |



# Collaboration

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