GSI

PreSPEC

LYCCA

FAIR NUSTAR

Isospin symmetry in the *sd* shell:
– Coulomb excitation of ^{33}Ar –
and the new 'Lund-York-Cologne-Calorimeter'

PRE HI DE
SPEC for NUSTAR

- Isospin symmetry in the *sd* shell
- The Lund-York-Cologne-Calorimeter
- Analysis of the ^{33}Ar Coulex-experiment
- Results and comparison to SM calculations

NUSTAR Annual Meeting
Darmstadt, 28.02.2013

University of Cologne
Andreas Wendt

Isospin formalism

Proton und neutron: similar mass
and affected in similar way by nuclear interaction

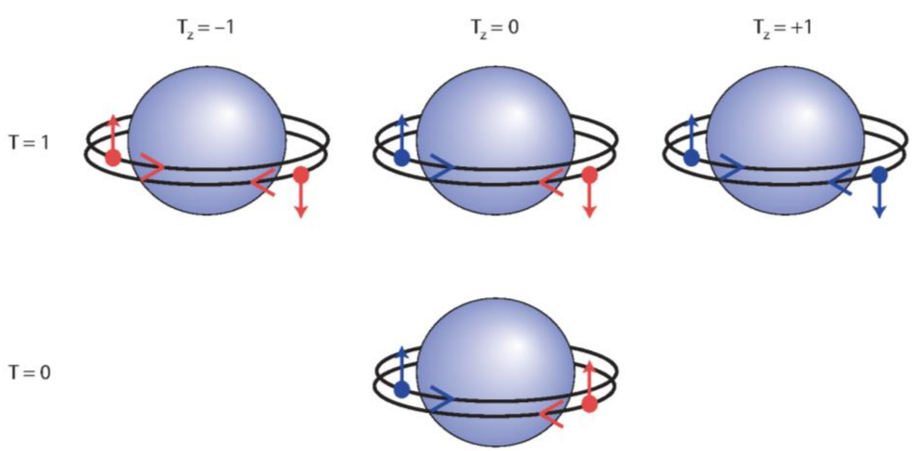
⇒

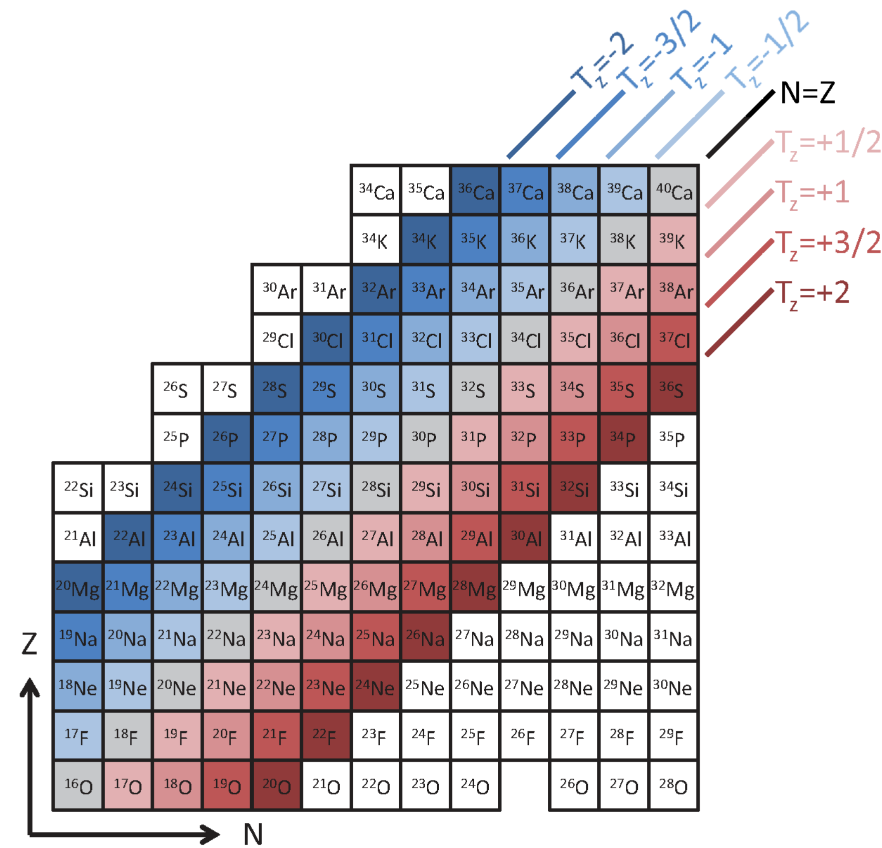
„nucleons“ in different states,
characterised by isospin t = ½.

t_z(proton) = - ½
t_z(neutron) = + ½

$$T_z = (N - Z)/2$$

$$T = t_1 \oplus t_2 \oplus \ldots t_n \Rightarrow \frac{|N-Z|}{2} \le T \le \frac{N+Z}{2}$$





D. D. Warner, M. A. Bentley und P. Van Isacker, Nature Phys. 2, 311 (2006).

Isospin symmetry

Mirror pair:

Nuclei with interchanged proton and neutron numbers e.g.

$${}^{45}_{23}V_{22} \leftrightarrow {}^{45}_{22}Ti_{23}$$

1. Coulomb displacement energy

   (shift of ground state)

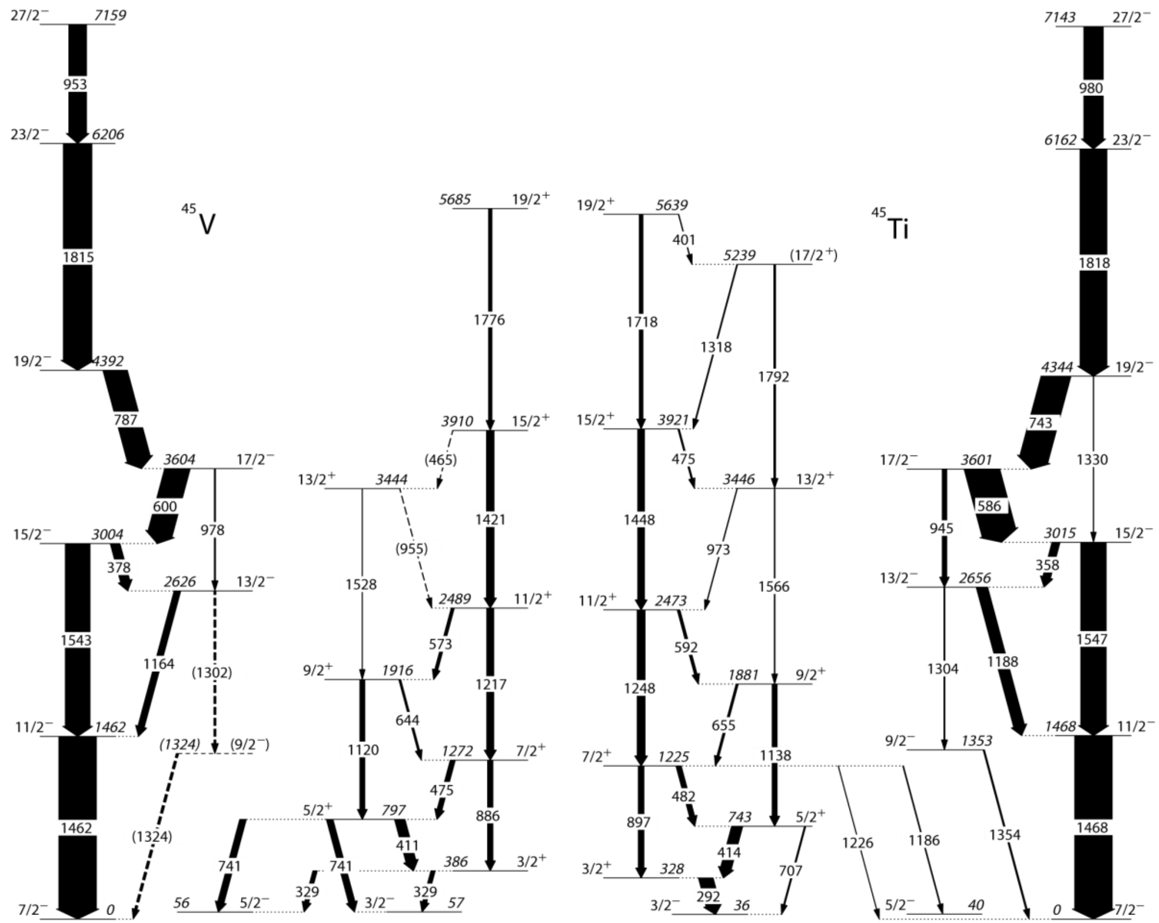
2. Coulomb energy difference

   between analogue exc. states

3. Isospin symmetry breaking (ISB)

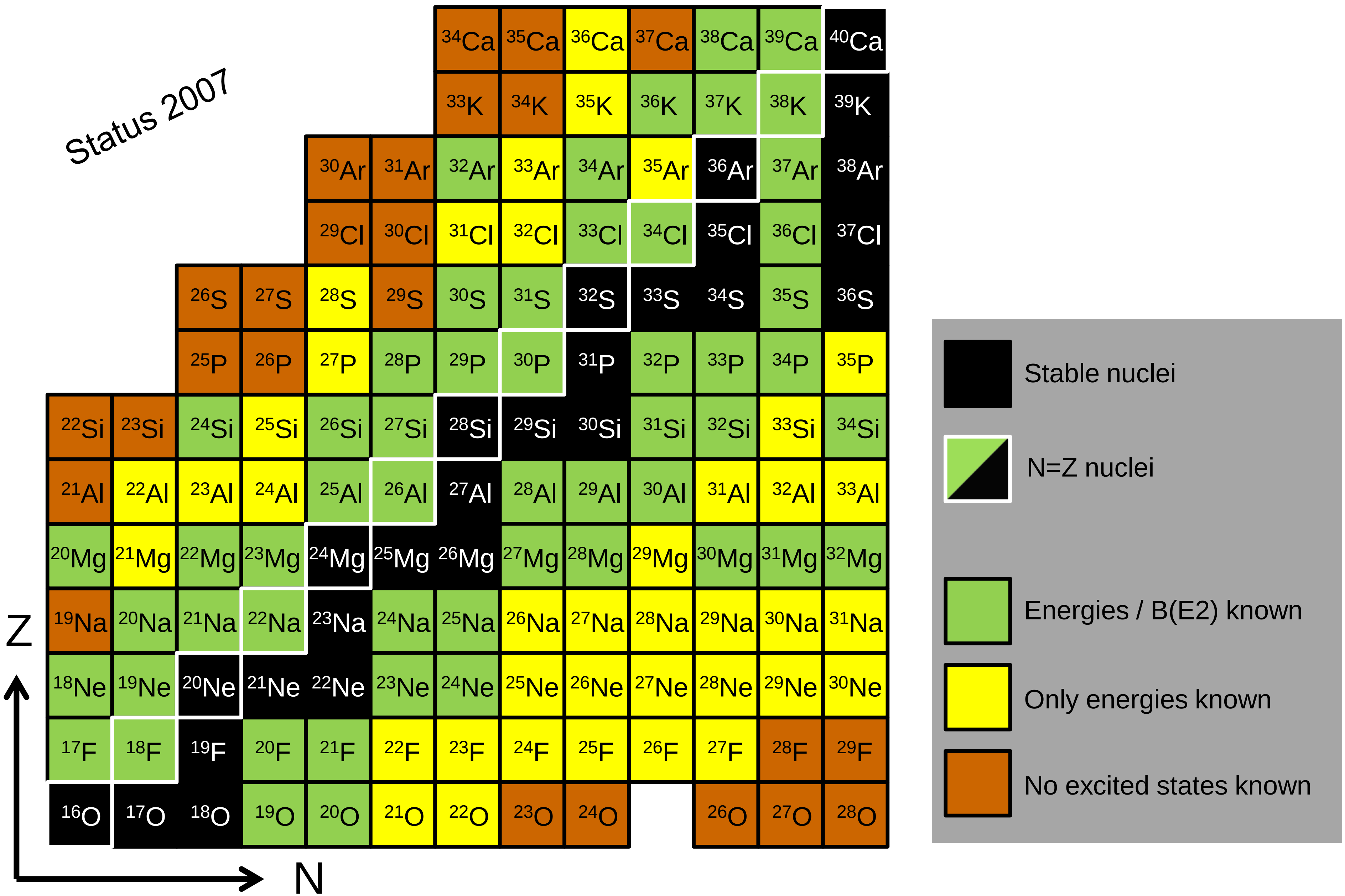
   effects of nucl. interaction

2+3 Mirror Energy Differences

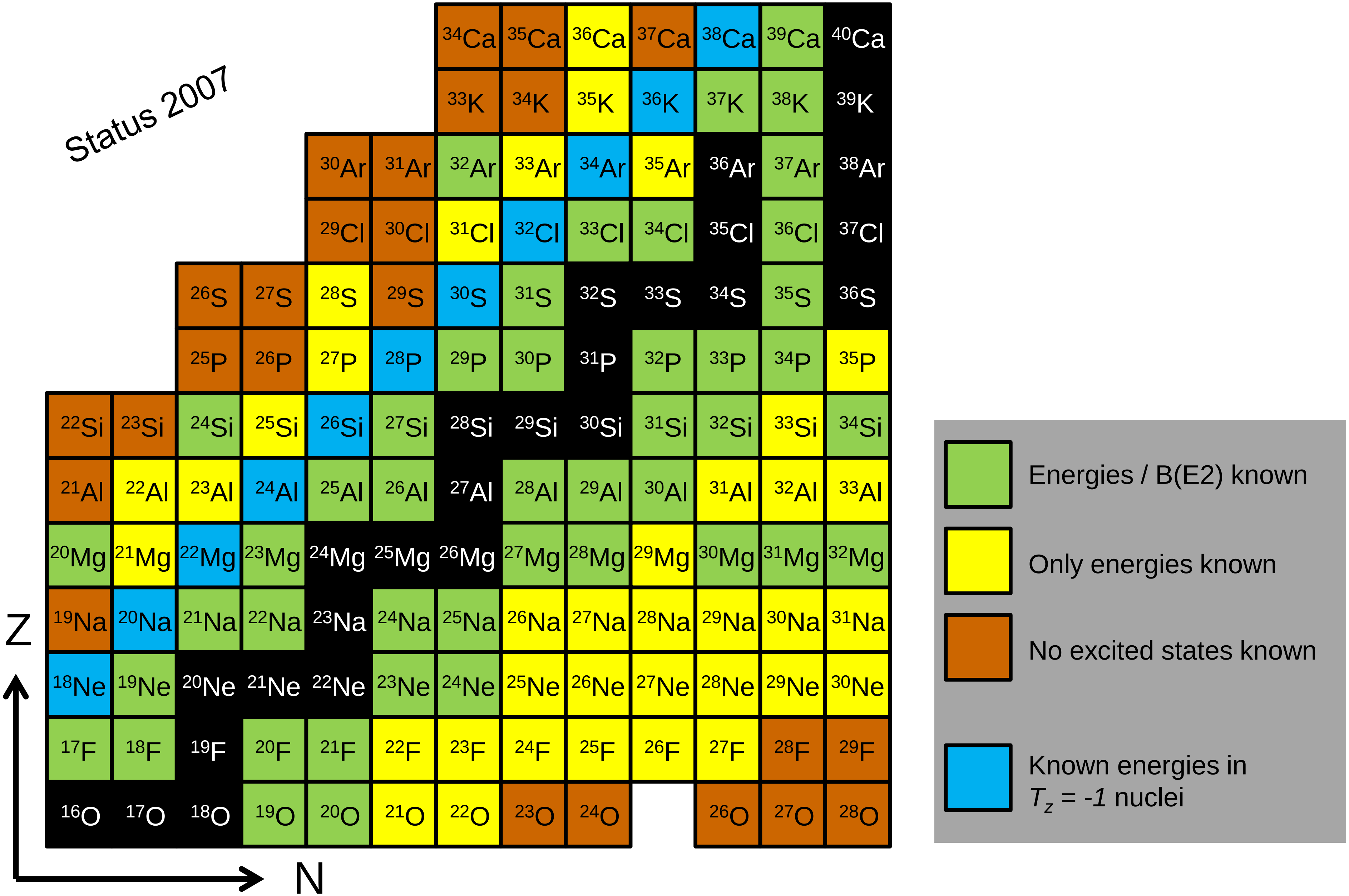


M. A. Bentley et al., PRC 73, 024304 (2006)

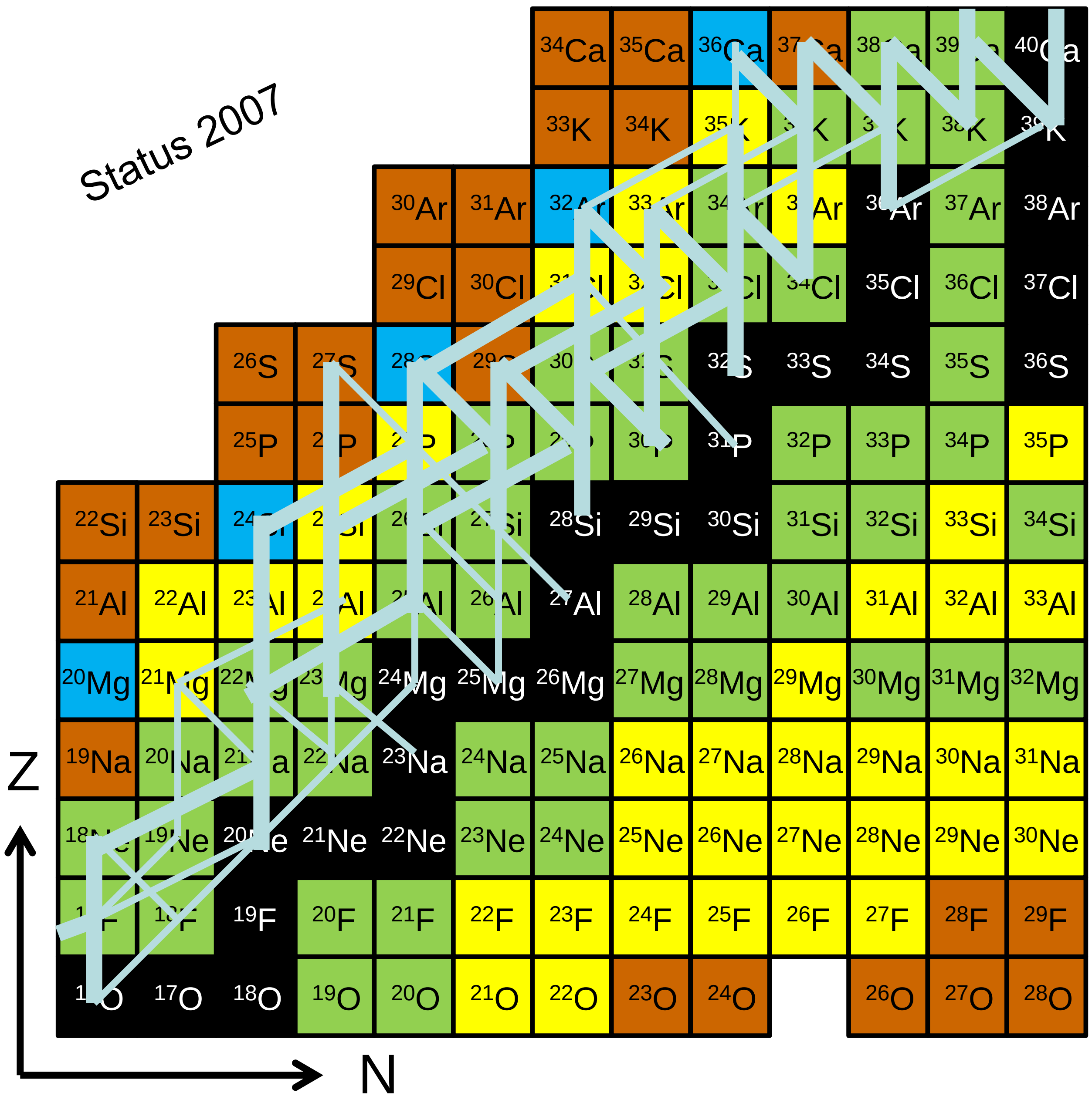
Experimental data for *sd* shell nuclei



Excitation energies of T_z= -1 *sd* shell nuclei



Excitation energies of T_z= -2 *sd* shell nuclei



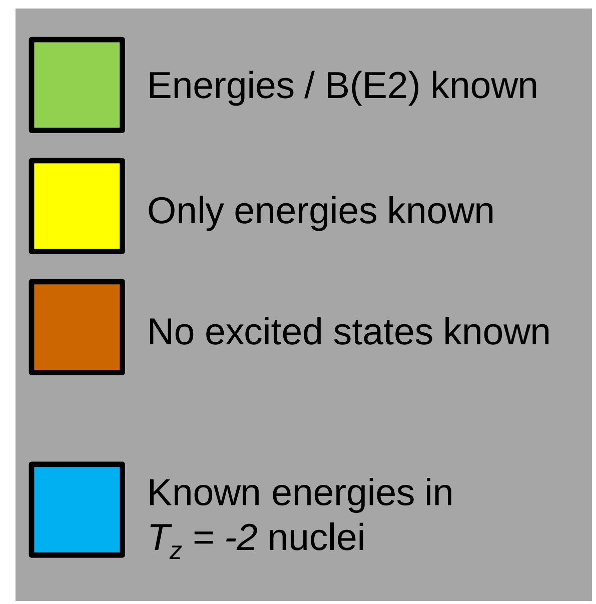
H. Schatz and K. Rehm
Nucl. Phys. A 777, 601 (2006)

^{24}Si: H. Schatz et al., *PRL 79, 203845 (1997)*

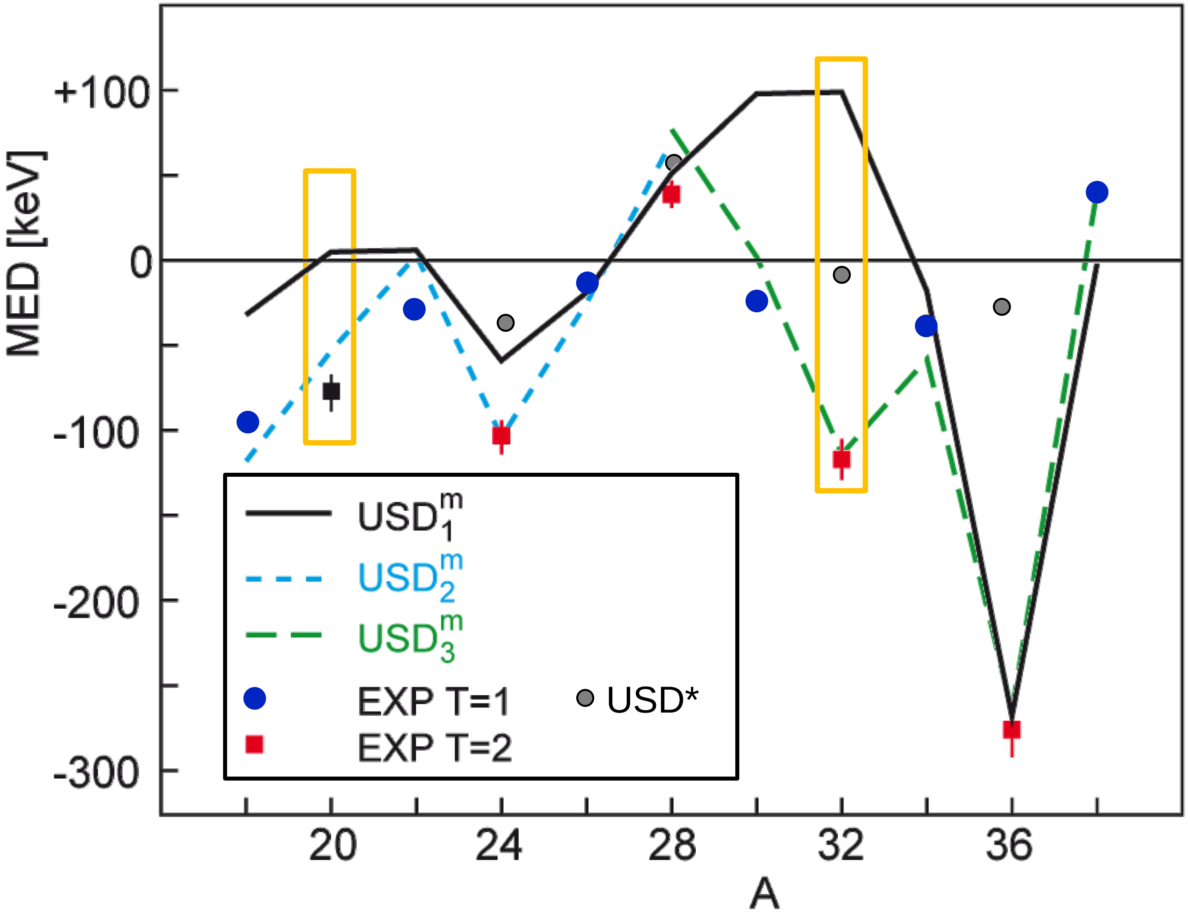
^{28}S, ^{32}Ar: K. Yoneda et al., *PRC 74, 021303 (2006)*

^{36}Ca: P. Doornenbal et al., *PLB 647, 237 (2007)*

^{20}Mg: A. Gade et al., *PRC 76, 024317 (2007)*



MED for $T=1,2$ sd shell nuclei



T-symmetric interaction

USD*: USD + Coulomb WW

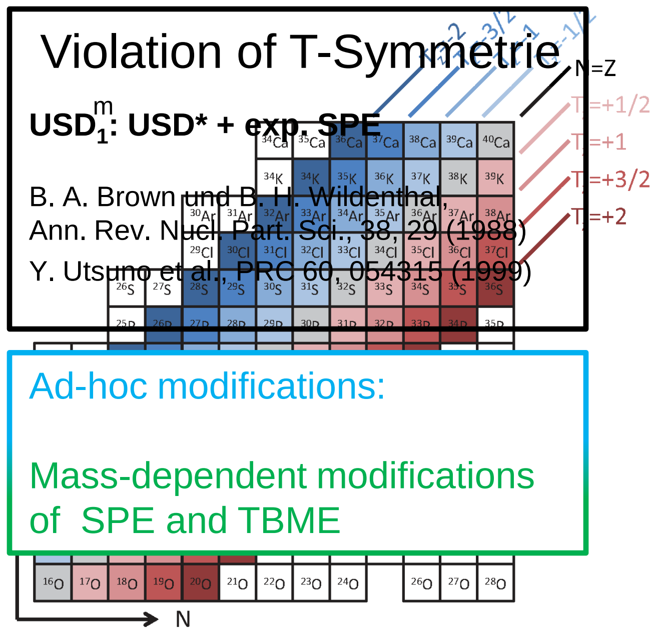
H. Herndl et al., PRC 52, 1078 (1995)

Violation of T-Symmetrie

USD$_1^m$: USD* + exp. SPE

B. A. Brown und B. H. Wildenthal, Ann. Rev. Nucl. Part. Sci., 38, 29 (1988)

Y. Utsuno et al., PRC 60, 054315 (1999)



Ad-hoc modifications:

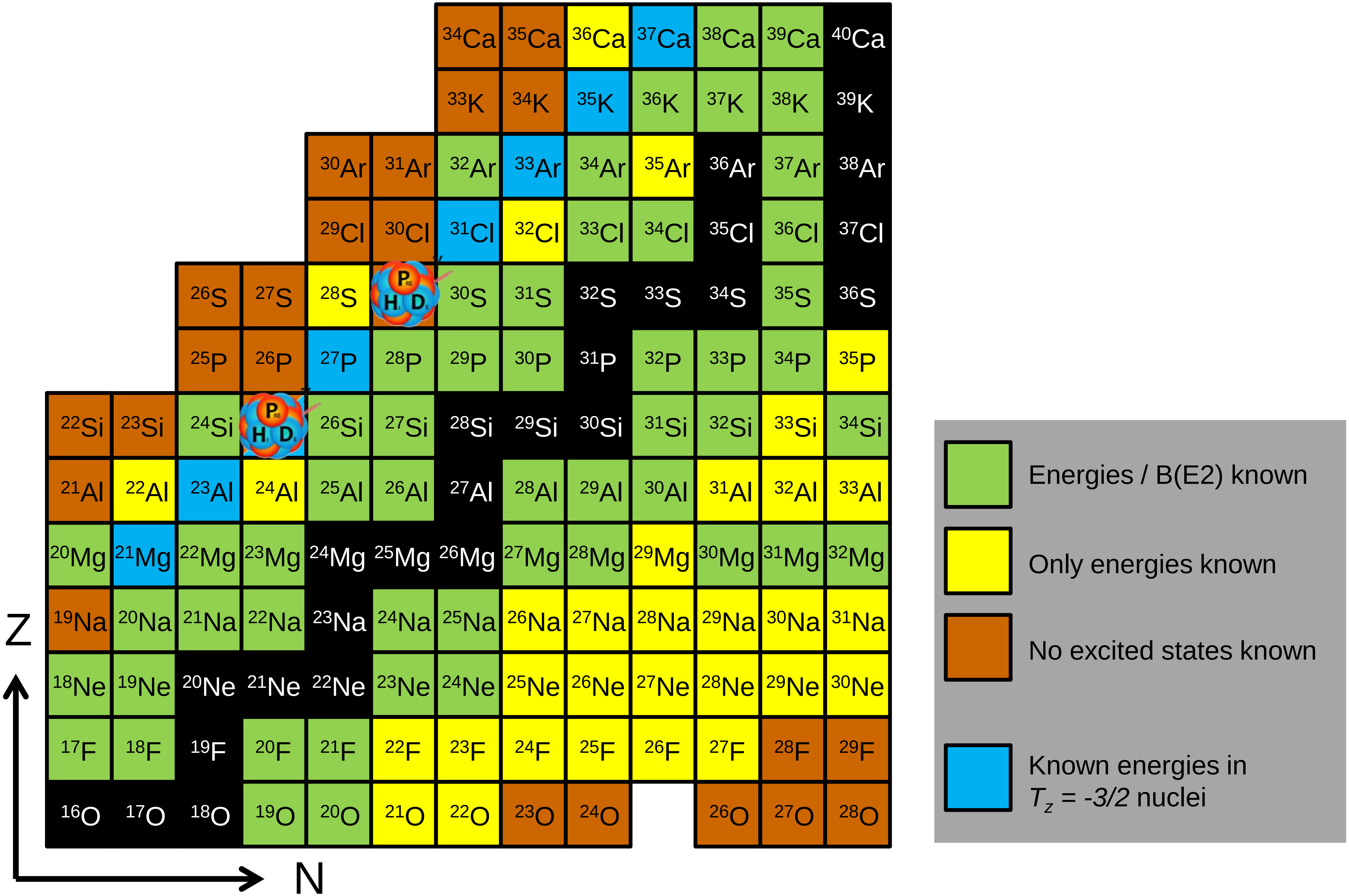
Mass-dependent modifications of SPE and TBME

● *'Proton capture reaction rates in the rp-process', H. Herndl et al., PRC 52, 1078 (1995)*

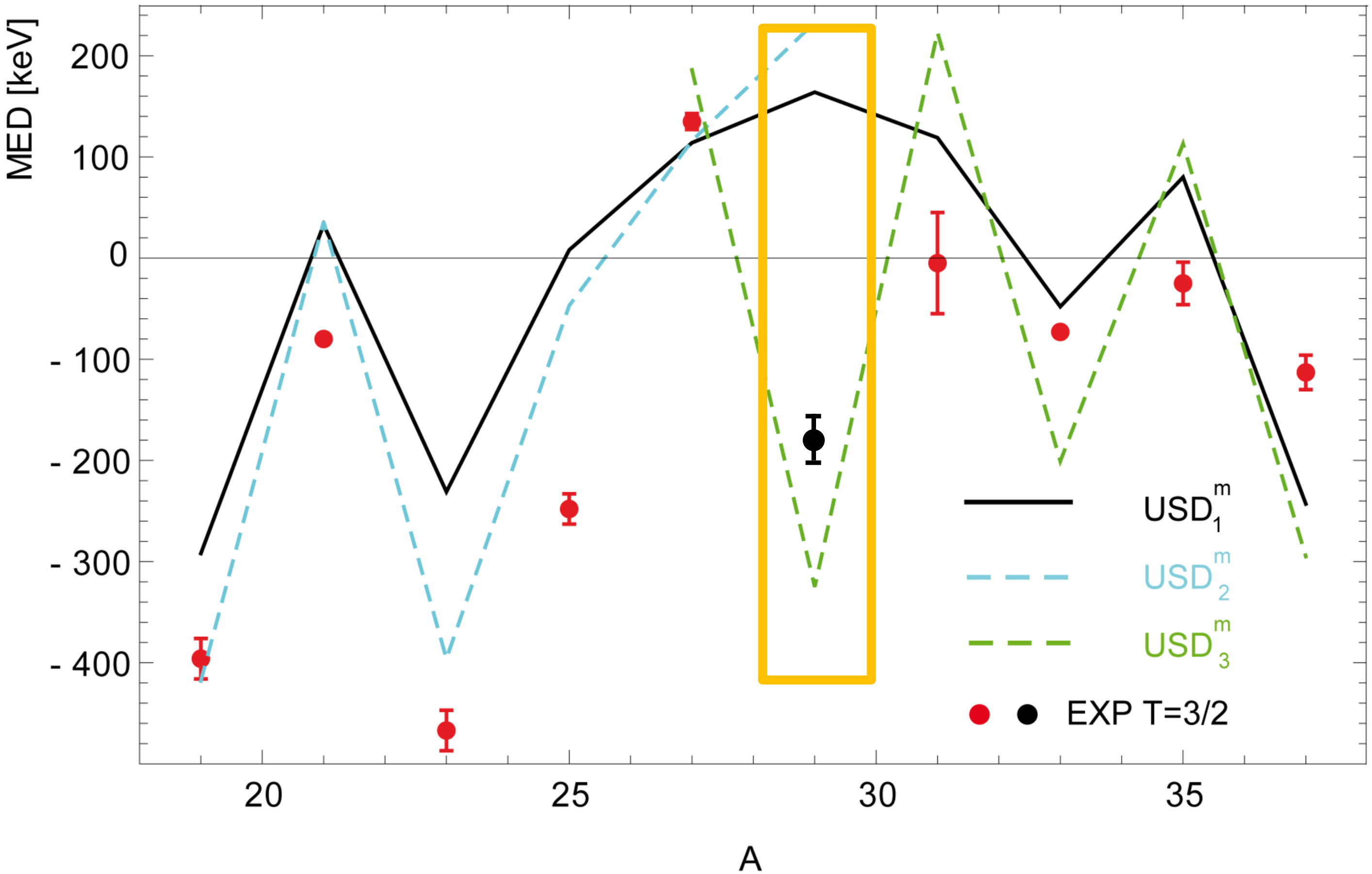
A=20: A. Gade et al., Phys. Rev. C 76, 024317 (2007)
A=24: H. Schatz et al., PRL 79, 3845 (1997)
A=28: K. Yoneda et al., PRC 74, 021303 (2006)
A=32: P. D. Cottle et al., PRL 88, 172502 (2002)
A=36: P. Doornenbal et al., PLB 647, 237 (2007)

Applicable for T=3/2 mirror pairs?

Excitation energies of T_z= -3/2 *sd* shell nuclei



Application on T=3/2 *sd* shell nuclei



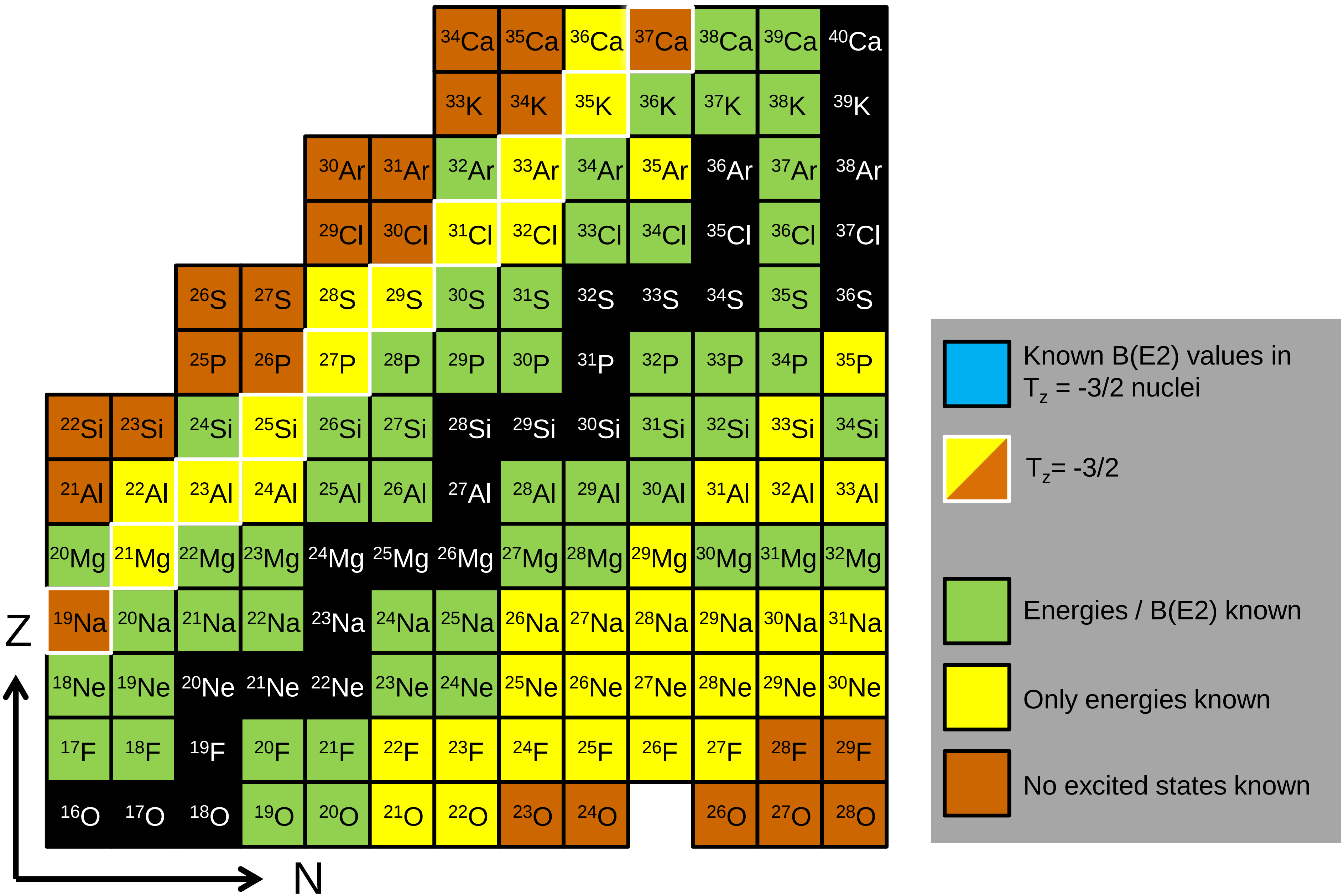
● *R.R. Reynolds et al. Phys. Rev. C 81, 067303(2010)*

Next step: Measurement of ^{29}**S** excitation energies
with two-step-fragmentation: $^{36}Ar \rightarrow {}^{30}S \rightarrow {}^{29}S + \gamma$

PreSpec proposal: Jan. 2009

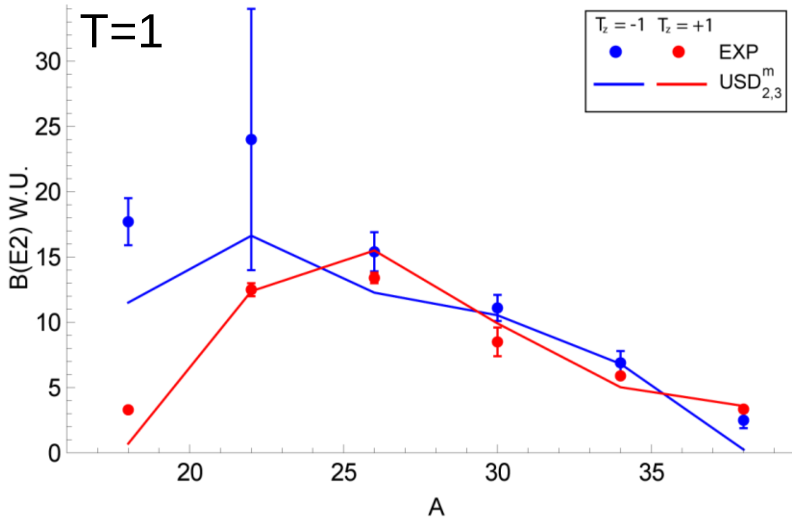
Next step: Investigation of transition strengths

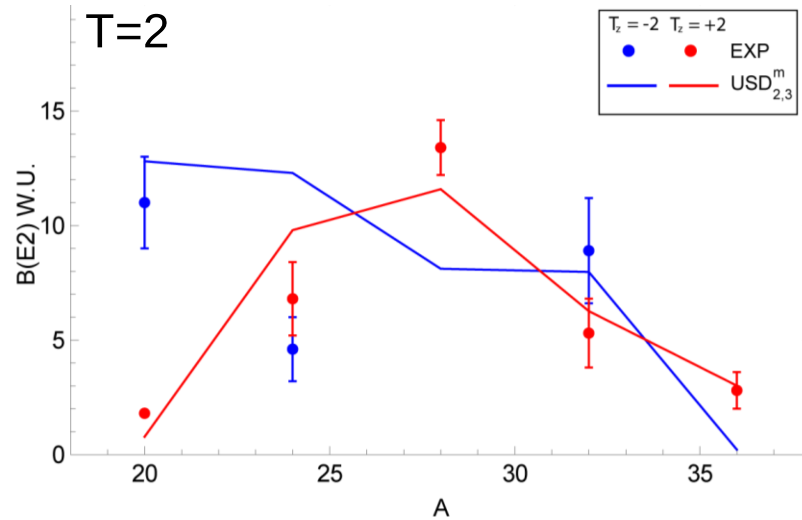
B(E2) values for *sd* shell nuclei



SM calculations for B(E2) values of T=1,2 nuclei

Blue:	p-rich,	T_z = -1, -2
Red:	n-rich,	T_z = +1, +2





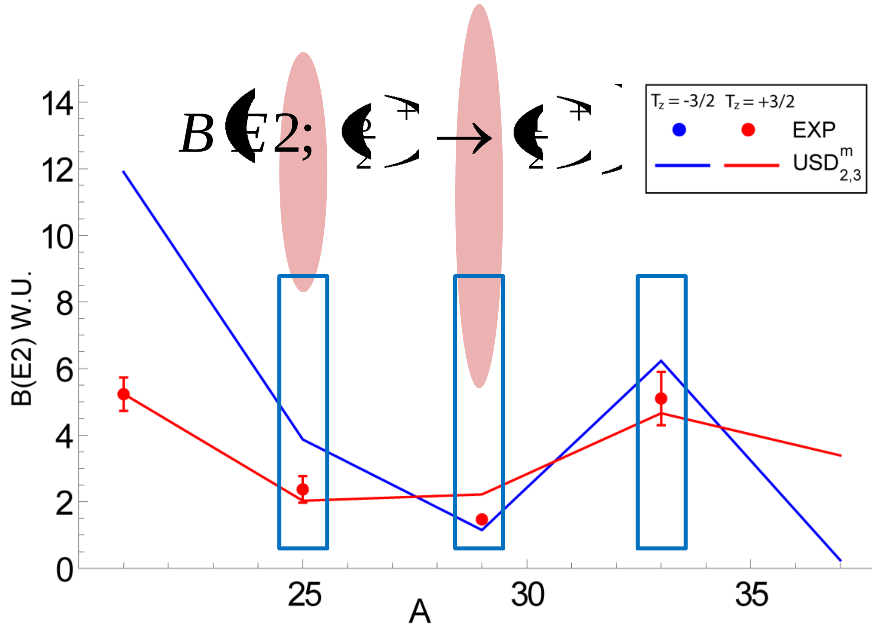
Good agreement of all interactions for n-rich nuclei
p-rich nuclei: limited agreement, exp. very difficult

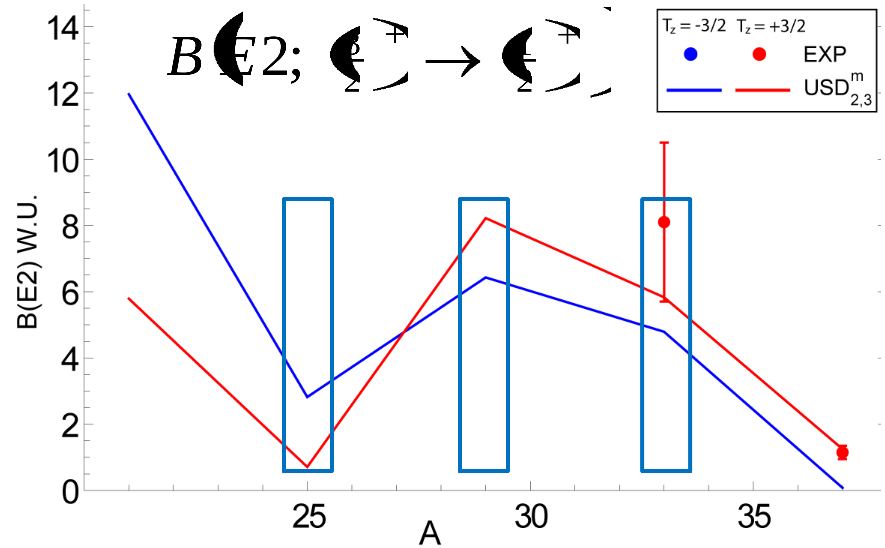
→ Comparison with T=3/2 nuclei

SM calculations for B(E2) values of T=3/2 nuclei

$$T = \frac{3}{2}$$

Blue:	p-rich,	T_z = - 3/2
Red:	n-rich,	T_z = + 3/2





Good agreement for n-rich nuclei

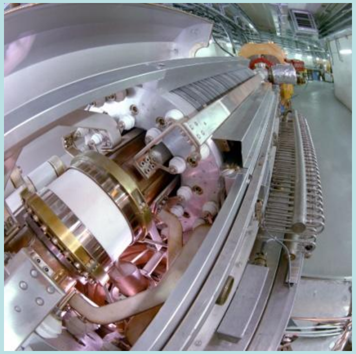
No exp. data for T_z= -3/2 nuclei

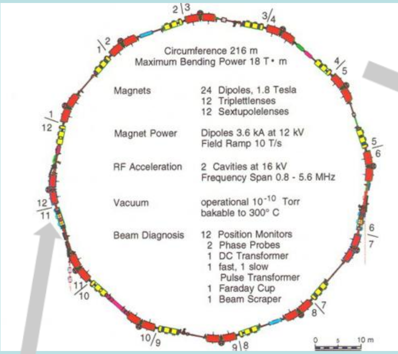
Predictions from kockout differ: R. R. Reynolds et al., PRC 81, 067303 (2010).

→ PreSpec experiment: Coulomb excitation of **^{25}Si**, **^{29}S**, **^{33}Ar**

S377 - Coulomb excitation of ^{33}Ar

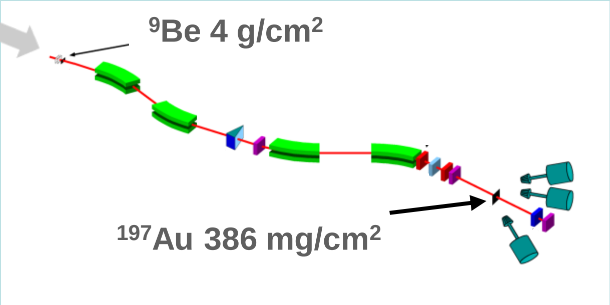
SIS – ^{36}Ar, 450 MeV/u, $2 \cdot 10^{10}$ ppspill





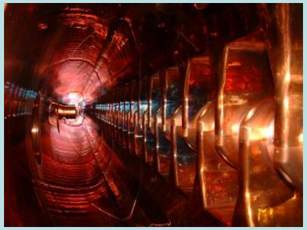
Fragment Separator (FRS)

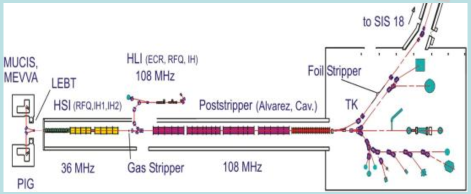
^{33}Ar, 150 MeV/u, 30k ppspill

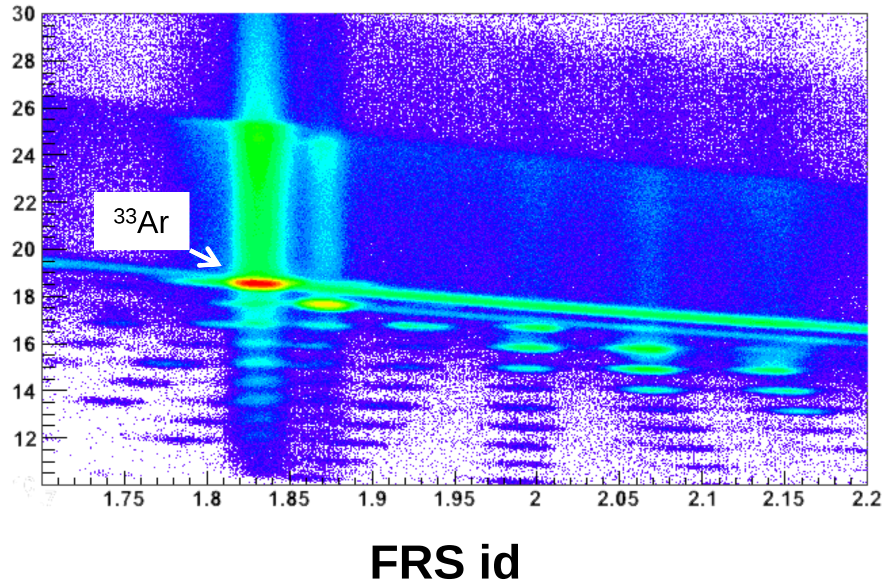


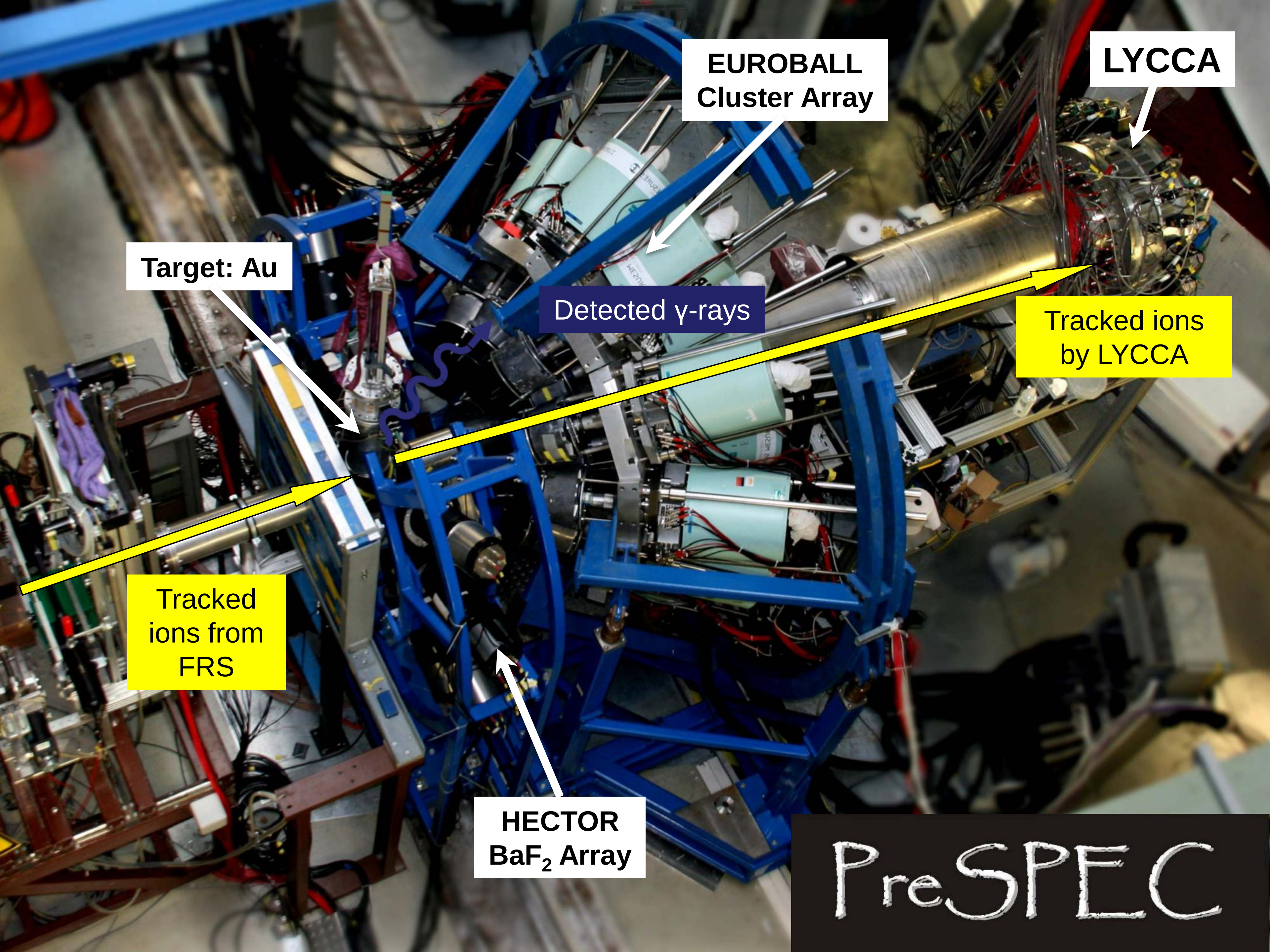
UNILAC

^{36}Ar, 15 MeV/u







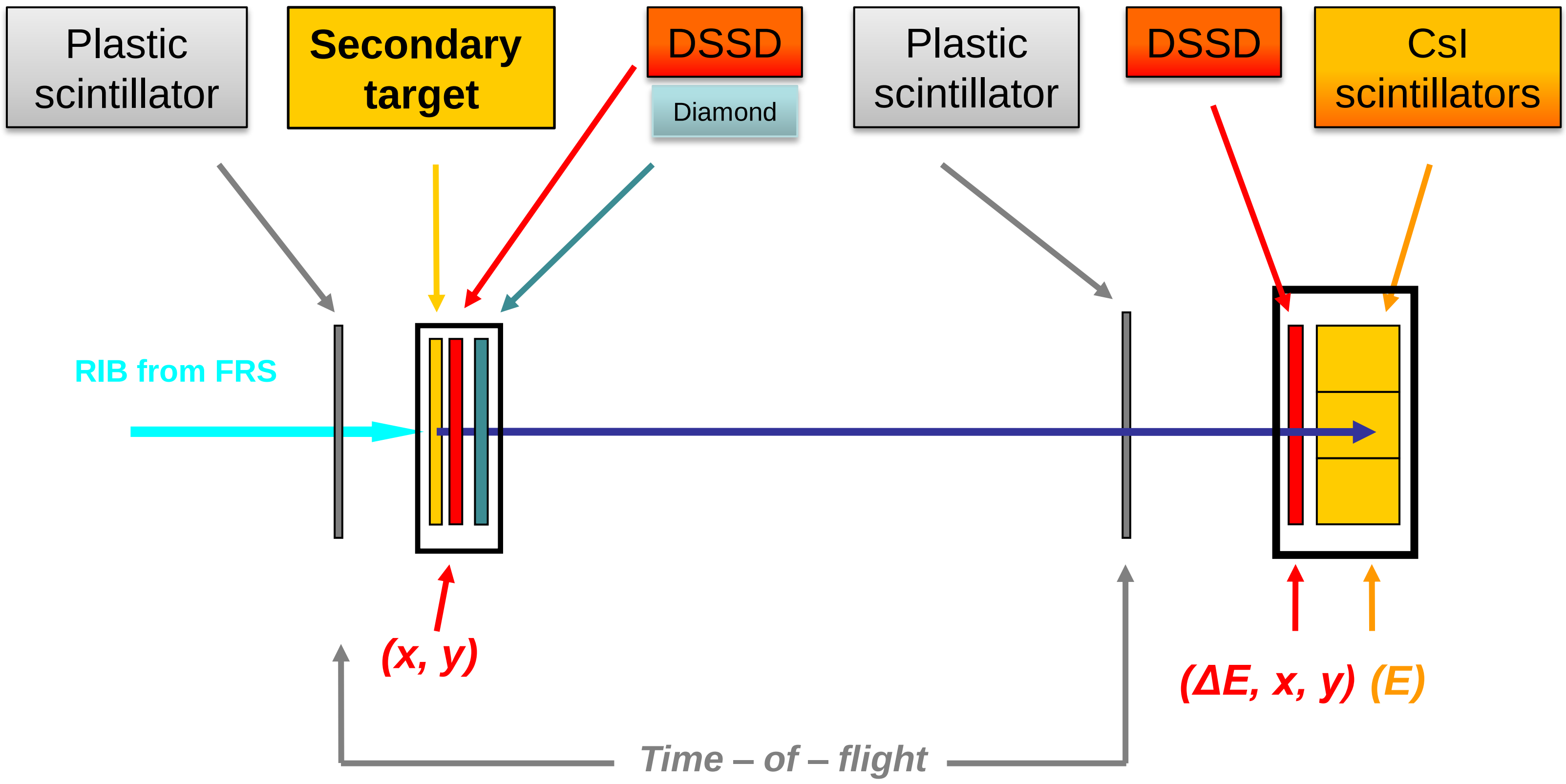


EUROBALL Cluster Array
LYCCA
Target: Au
Detected γ-rays
Tracked ions by LYCCA
Tracked ions from FRS
HECTOR BaF_2 Array
PreSPEC

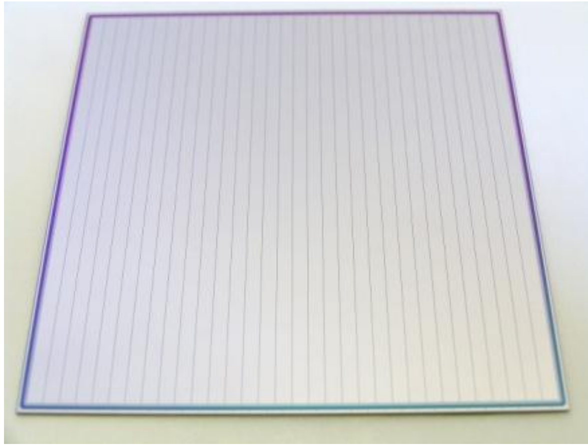
LYCCA – detection principle

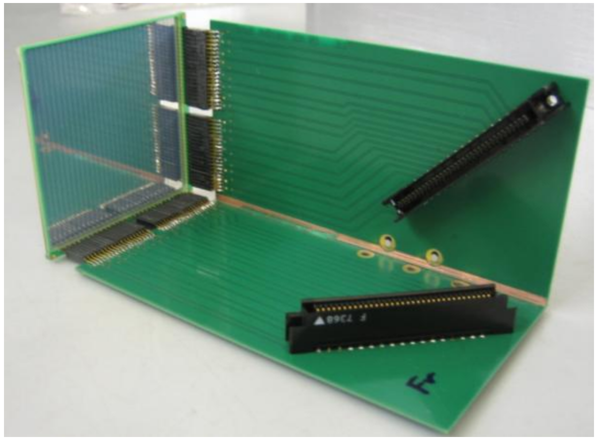
Event-by-event identification by
- Position → Tracking
- ΔE + TKE → Charge Q=Z
- ToF + TKE → Mass A

Needed for
- Doppler correction
- Selection of reaction channel
- Determination of scattering angle

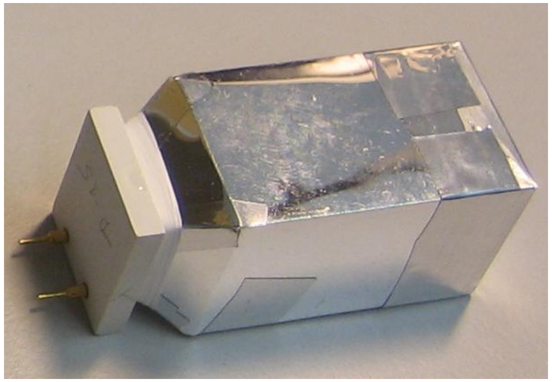


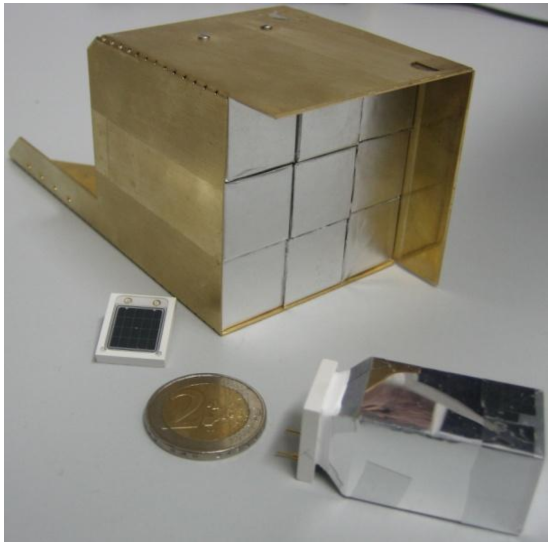
LYCCA – detectors



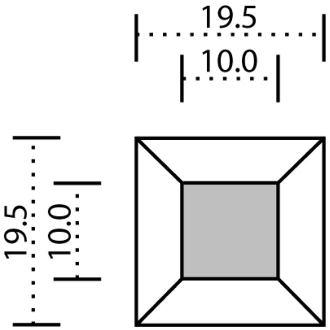


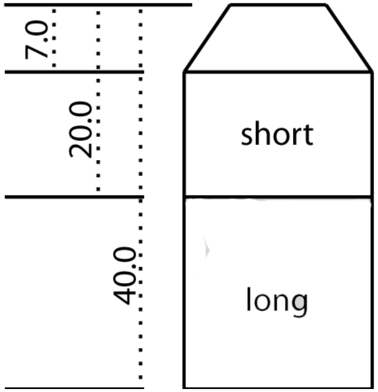
DSSD



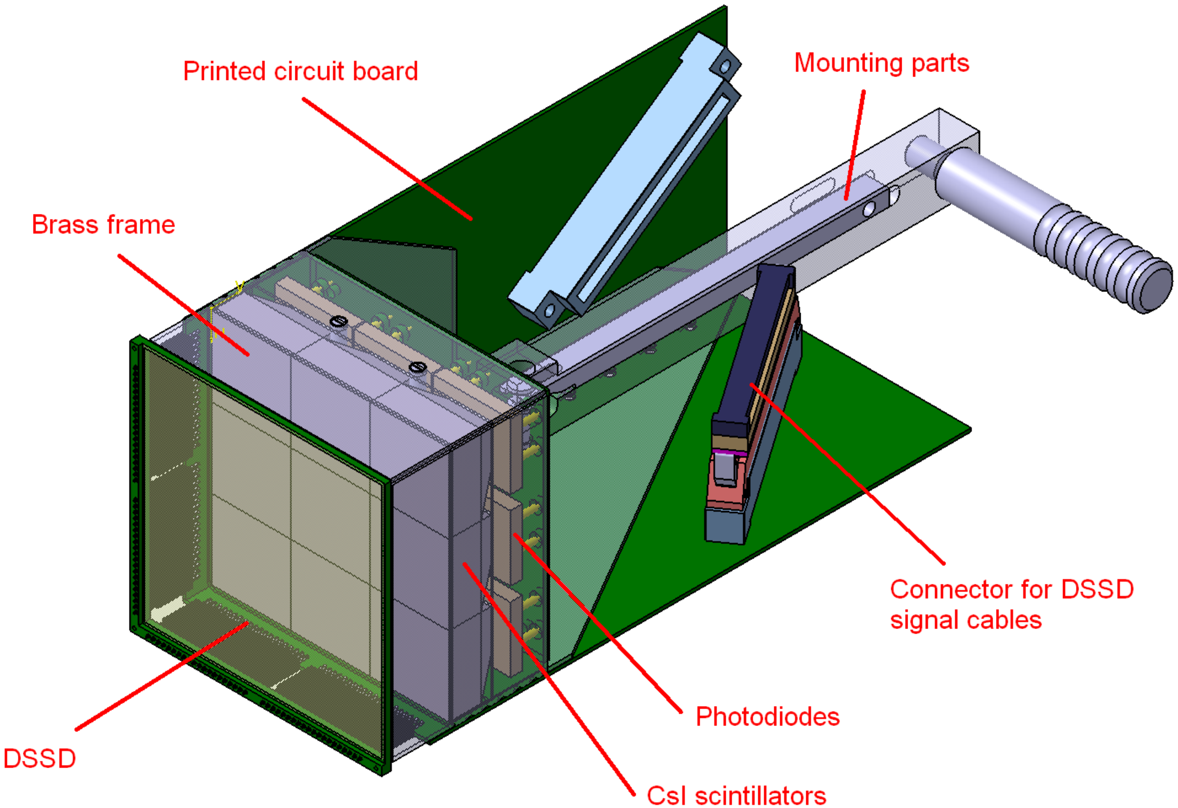


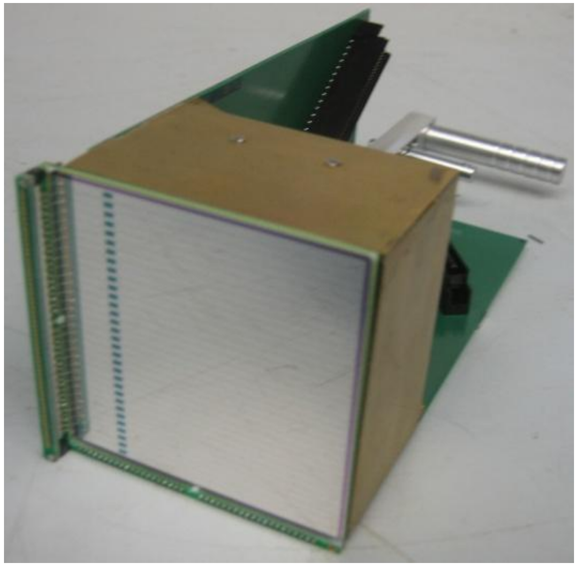
CsI

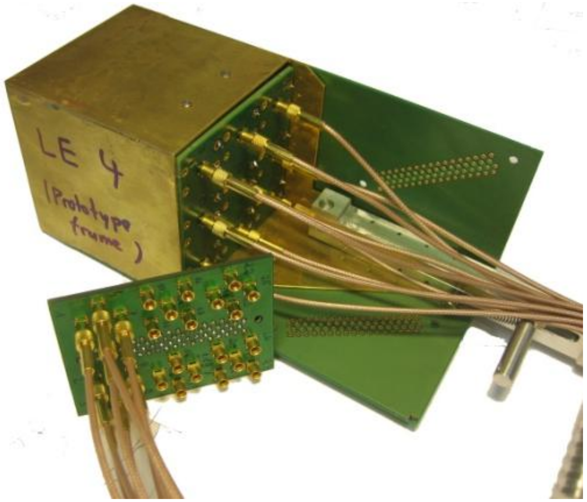




LYCCA – detector module







- Highest solid angle coverage
- Modularity

Observables

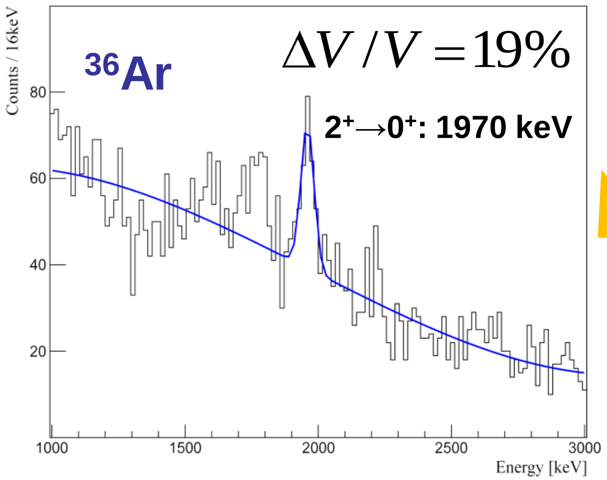
^{33,36}Ar (135-145 AMeV) on 386 mg/cm² Au
→ γ-ray spectrum dominated by background radiation

FRS detectors
- β_{FRS}
- θ_{FRS}, φ_{FRS}
- A/Q
- Z

EUROBALL
- E_γ
- Cluster multiplicity
- Crystal multiplicity
- T_γ
- θ_γ, φ_γ

LYCCA
- ΔE_{tar}
- T_{tar}
- $DSSD_{tar}$ muliplicity
- ΔE_{wall}
- E_{CsI}
- θ_{LYCCA}, φ_{LYCCA}
- β_{LYCCA}

Gates:
FRS A/Q
LYCCA ΔE-E
LYCCA ΔE- ΔE
β_{FRS} - β_{LYCCA}
β_{LYCCA} - E_{CsI}
ΔE_{tar} - T_{tar}
T_γ
Crystal-Multiplicity

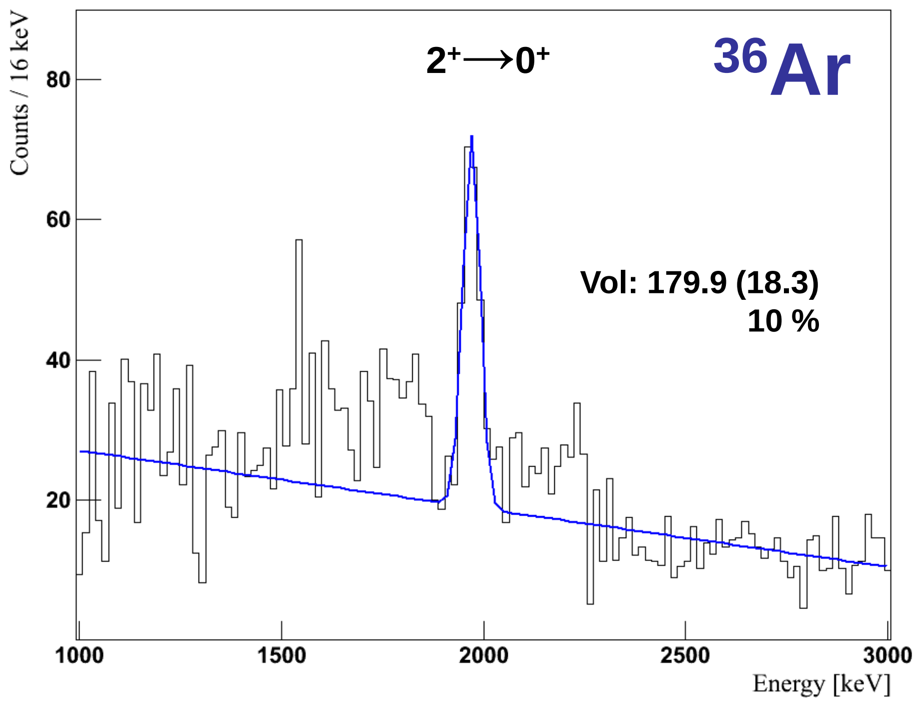


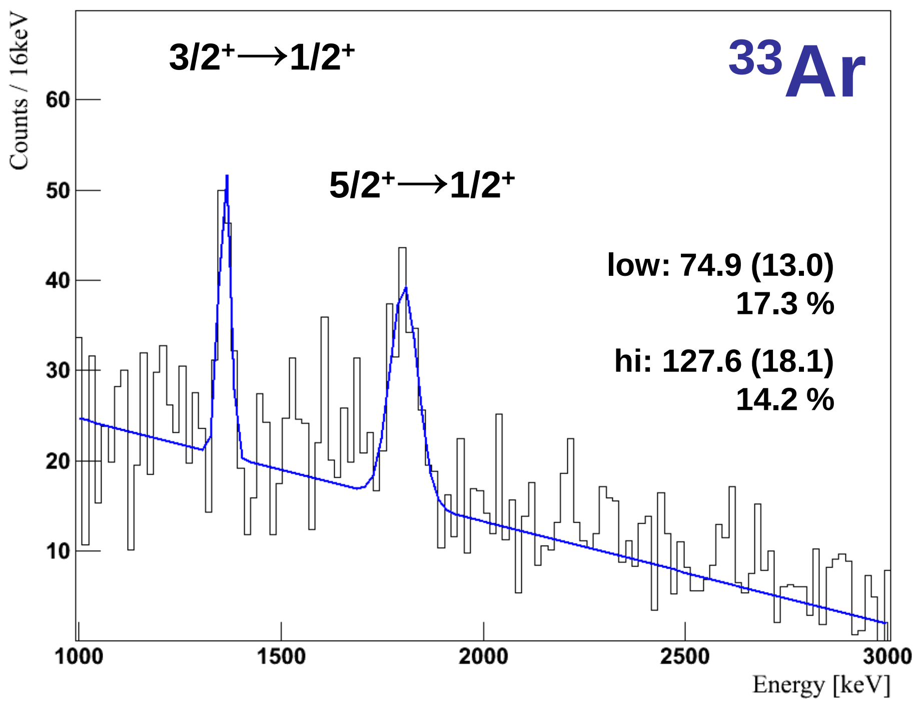
Optimization:
- $DSSD_{tar}$ multiplicity
- Particle gate optimization
- Time gate optimization
- Add back
- Background subtraction

Optimized γ-spectra

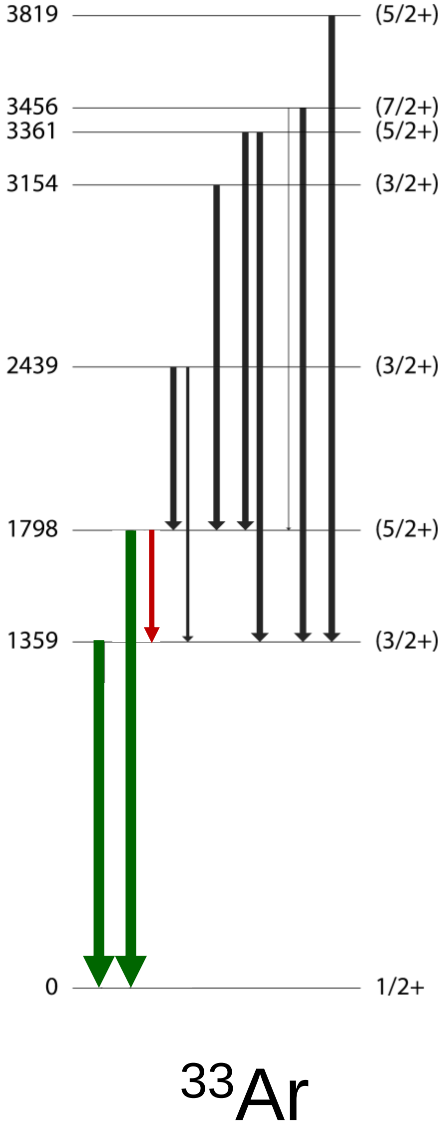
- Optimized particle gates
- Optimized Ge-time gates
- Multiplicity conditions
- Add back
- Background subtraktion

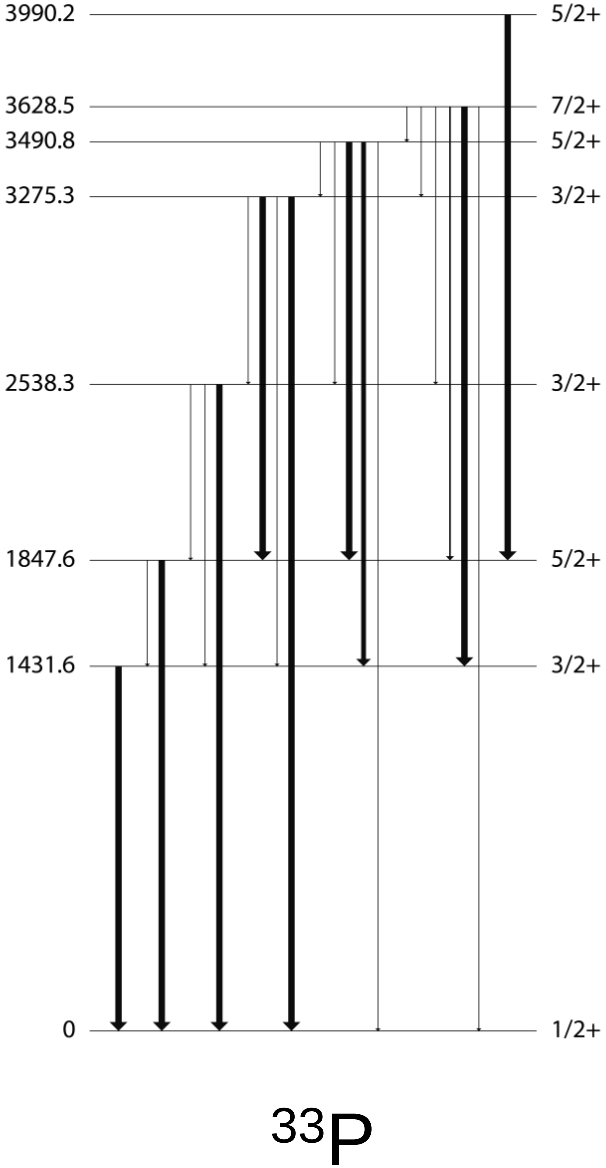
→ Reduction of relative error by approx. 50 %

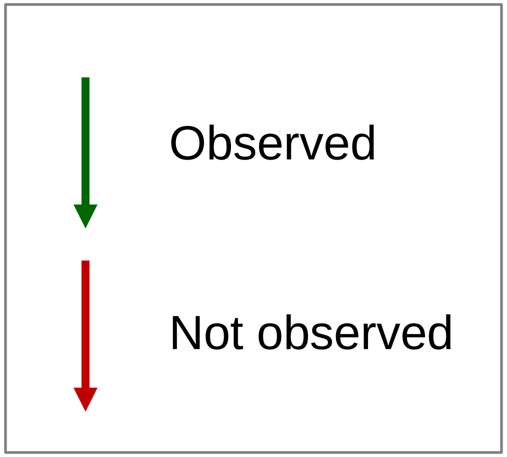




Comparison with mirror nuclei





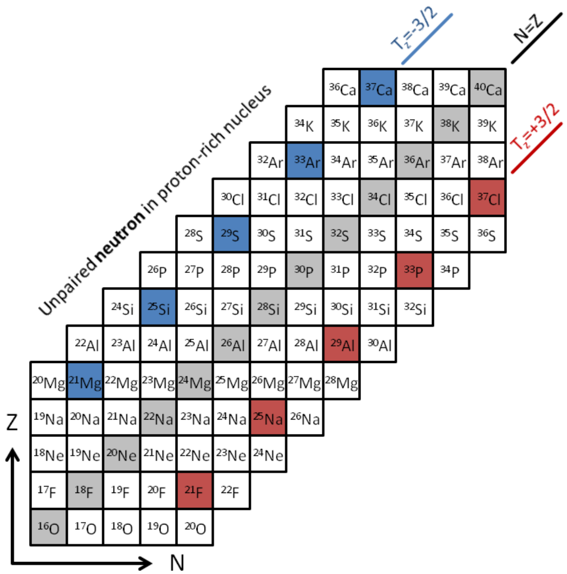


Calculation of B(E2) values

- Efficiency calibration of the PreSpec setup with known transition in ^{36}Ar: $2^+ \rightarrow 0^+$
- Correction for different γ-ray energies
- Correction for different ion velocity (Lorenz boost and scattering angle)
- Application of known ^{33}Ar branching ratio
- Considering of feeding into ^{36}Ar 2^+ state

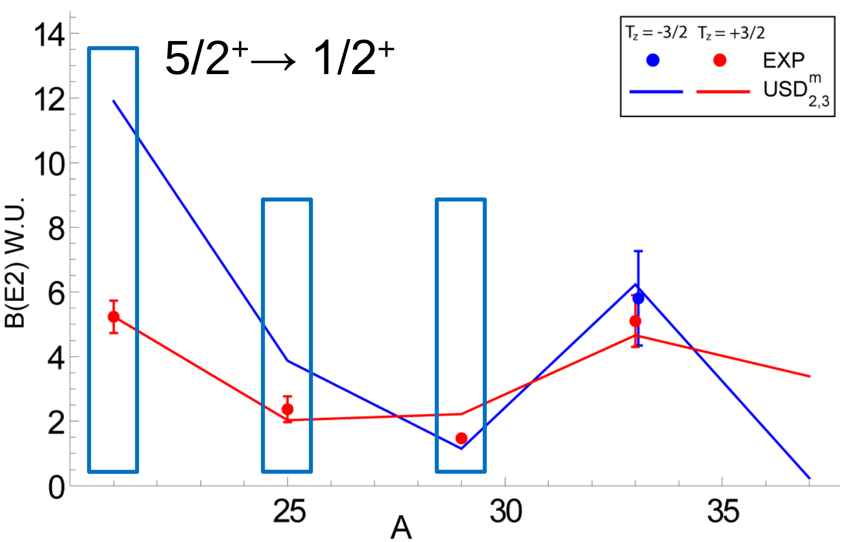
Nucleus	**^{36}Ar**		**^{33}Ar**			
Transition	$2^+ \rightarrow 0^+$		$3/2^+ \rightarrow 1/2^+$		$5/2^+ \rightarrow 1/2^+$	
	Lit.	Exp.	Lit.	Exp.	Lit.	Exp.
Energy [keV]	1970.38(5)	1970(3)	1359(2)	1360(3)	1798(2)	1804(6)
B(E2) [W.U.]	8.5(8)	---	---	6.39(1.49)	---	5.80(1.62)

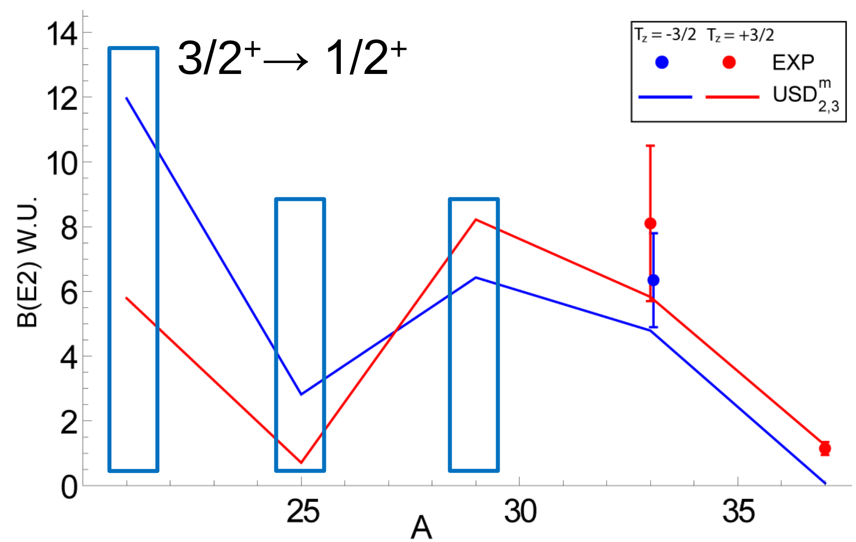
SM calculations for B(E2) values of T=3/2 nuclei



T_z= - 3/2 nuclei with unpaired proton: only weakly bound

- First experimental value in *sd* shell
- Comparison with SM calculation
- Outlook:
  - ➢ Confirmation with further experiments (S377-II and ^{21}Mg)
  - ➢ Extension to *pf* shell (no exp. values)

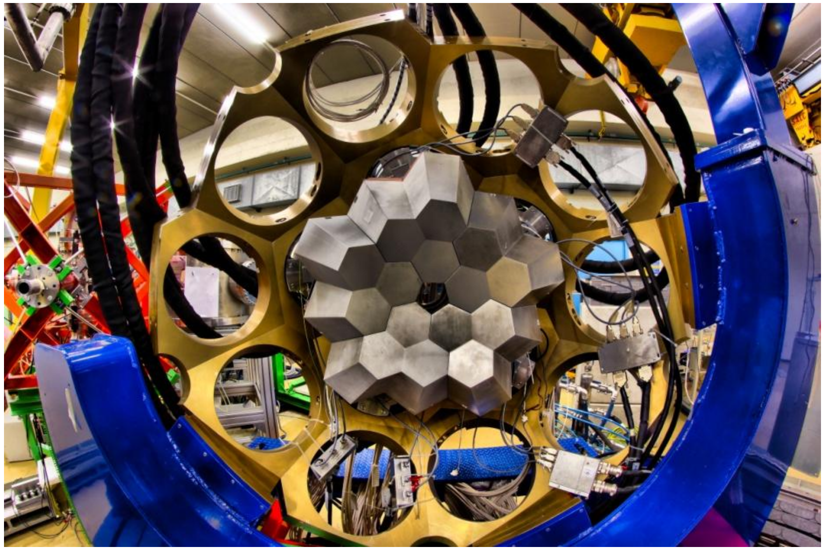


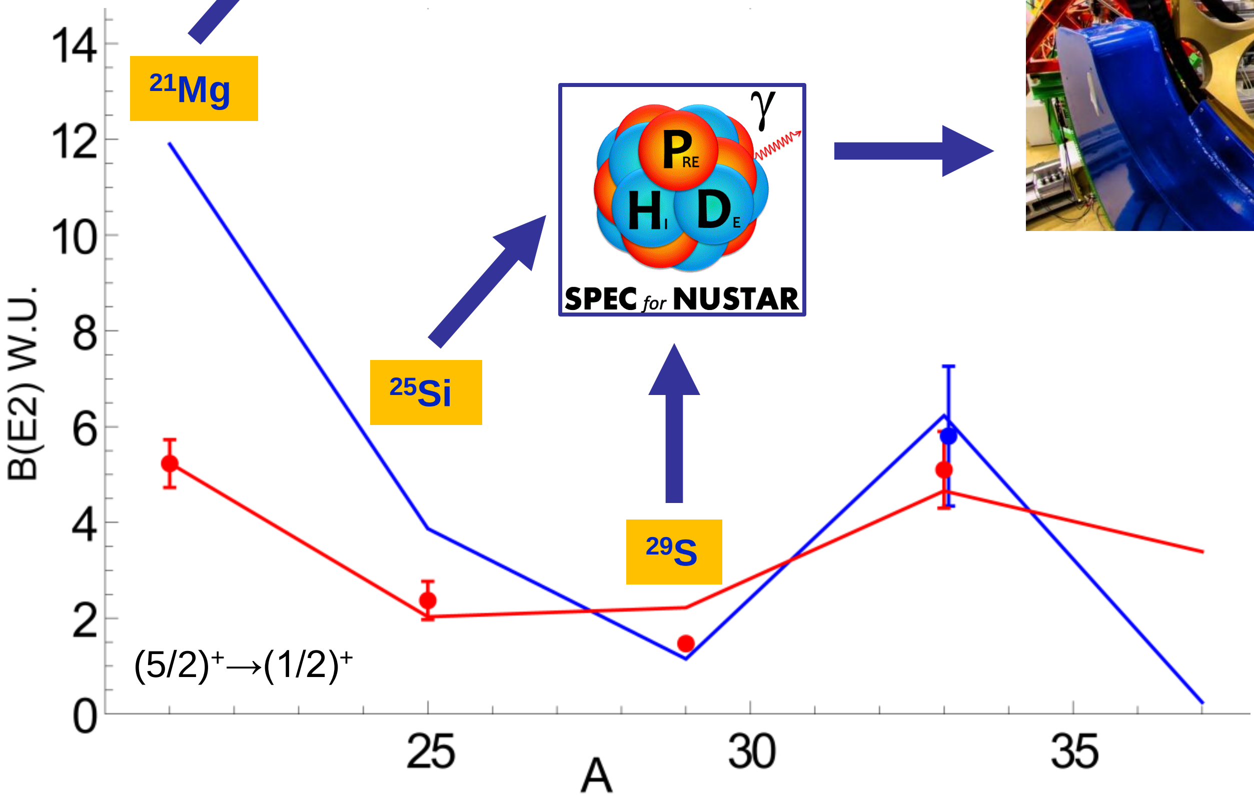


Outlook – further T_z= -3/2 investigations

GANIL spiral2 – laboratoire commun CEA/DSM CNRS/IN2P3

PreSPEC – HiDE – SPEC for NUSTAR





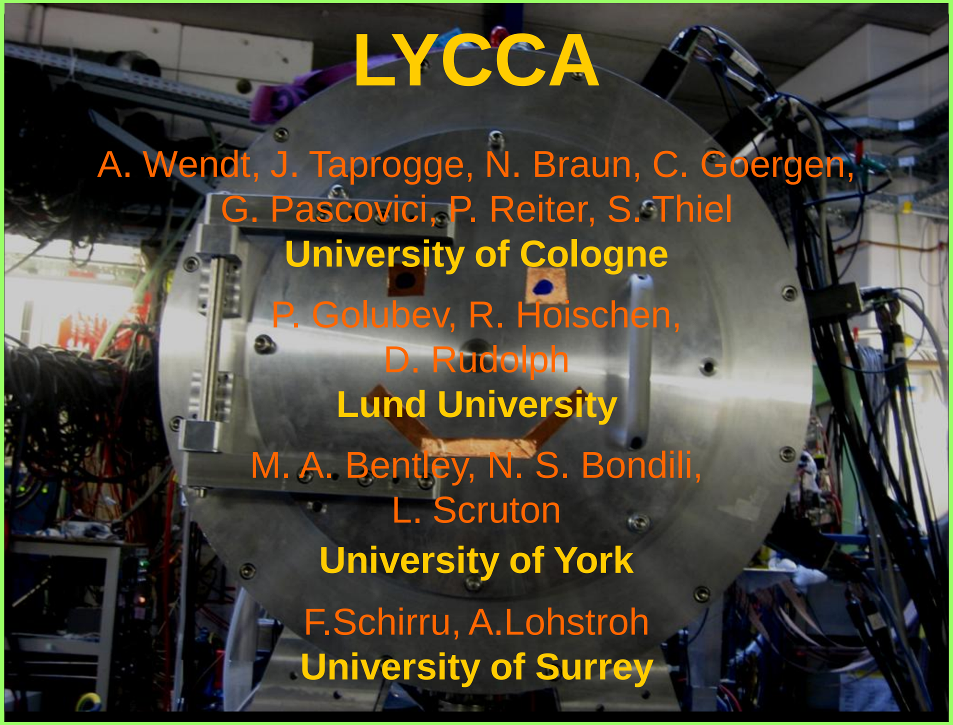
Complementary measurements with stable beams:

- ^{22}Mg (T_z=-1)
- ^{35}Ar (T_z=-1/2)
- ^{33}P (T_z=+3/2)

Summary

- A final PreSpec result
- Transition strengths in ^{33}Ar measured
- Comparison with SM calculation
  - ➢ Further experiments recommended: ^{21}Mg, ^{25}Si, ^{29}S

University of Cologne
Andreas Wendt



S377

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Niklas	Kurz
Henning	Schaffner

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Andrey	Blashev
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PreSpec collaboration &
NUSTAR simulation group

HGS-HIRe for FAIR
Helmholtz Graduate School for Hadron and Ion Research

Bundesministerium
für Bildung
und Forschung

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