# Proton-neutron balance of quadrupole-collective states of even-even n-rich Isotopes

TECHNISCHE UNIVERSITÄT DARMSTADT

**N. Pietralla, V. Werner, G. Martinez-Pinedo**
**(TU Darmstadt)**
**G. Rainovski, M. Danchev, K. Gladnishki**
**(U. Sofia)**
**N. Lo Iudice, G. De Gregorio**
**(U. Napoli Frederico II)**
**F. Nowacki, K. Sieja**
**(U. Strasbourg, CNRS)**

**Volker Werner**
**Senior Researcher, AG Pietralla / TU Darmstadt**
**Adjunct Professor / Yale University**

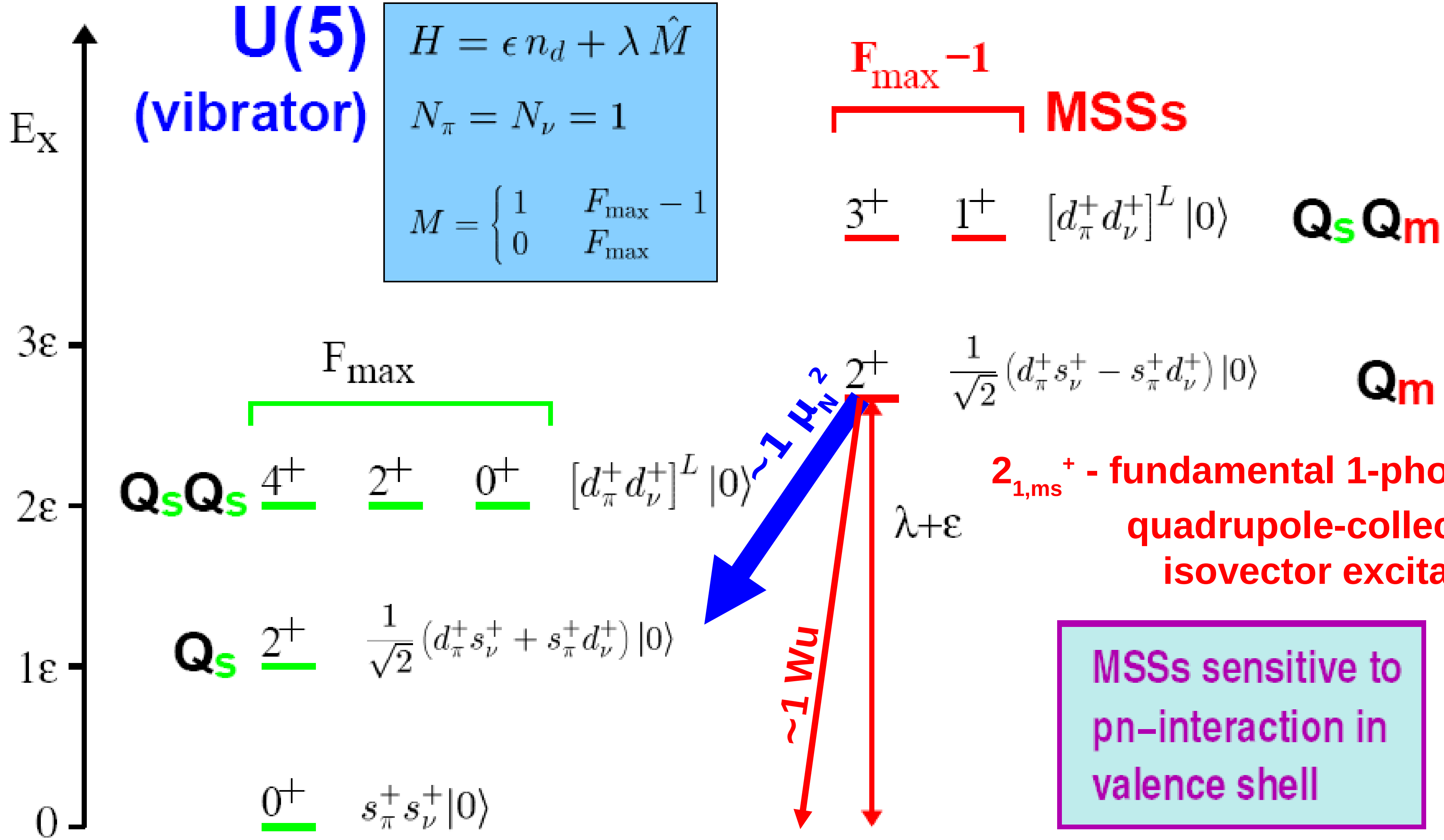


Yale

# What are Mixed-Symmetry States

TECHNISCHE UNIVERSITÄT DARMSTADT

**Simple Example: Harmonic Oscillator, N=2**




**$2^+_{1,ms}$ - fundamental 1-phonon quadrupole-collective isovector excitation**

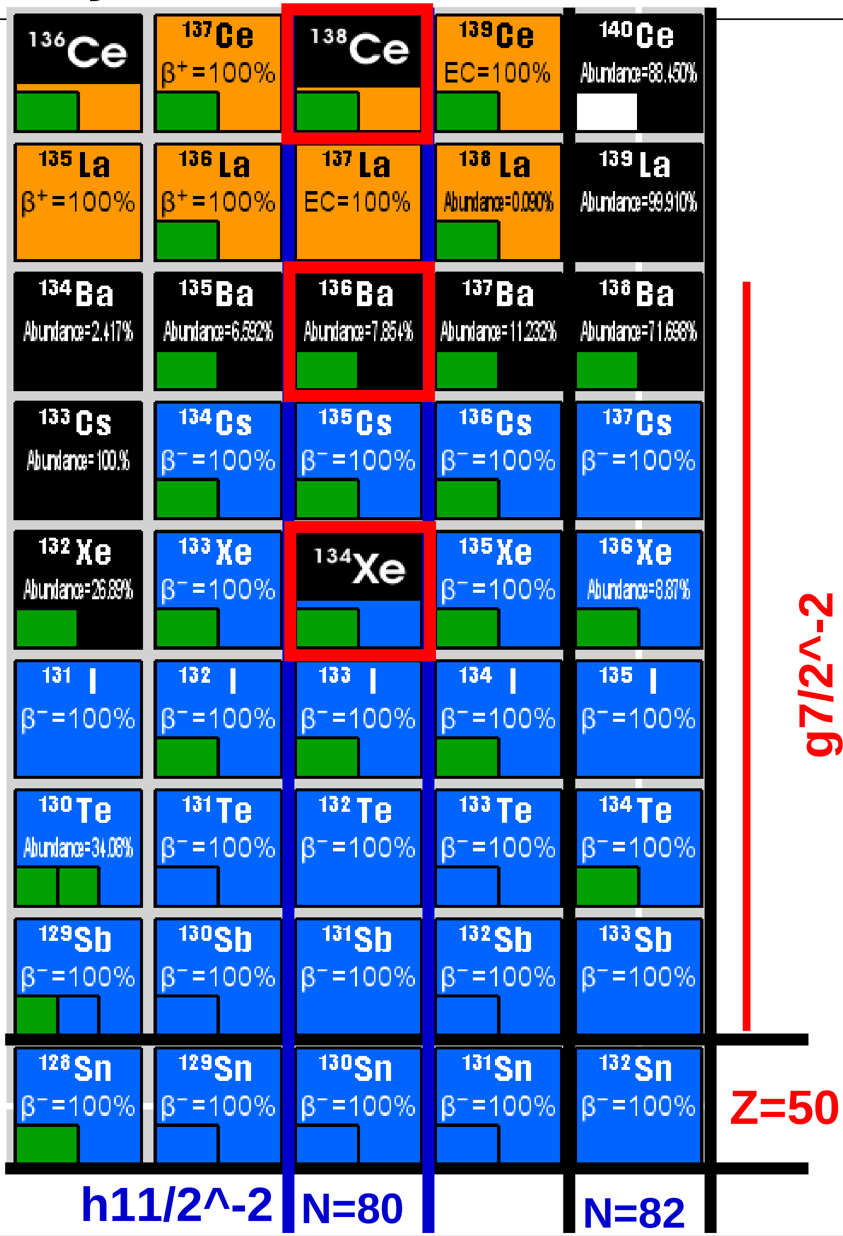
MSSs sensitive to pn–interaction in valence shell

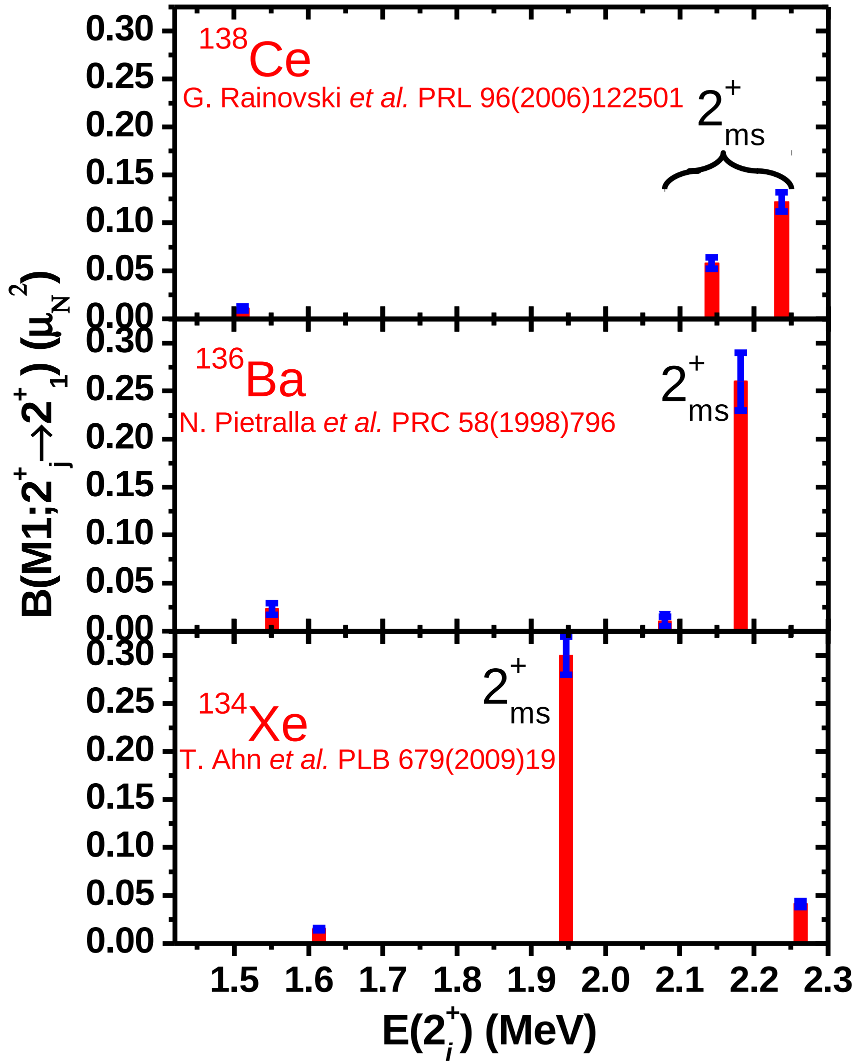
**IBM-2 A. Arima, F. Iachello**

# MSSs in the N=80 isotones

## Projectile CoulEx at ANL, stable beams, G-Sphere

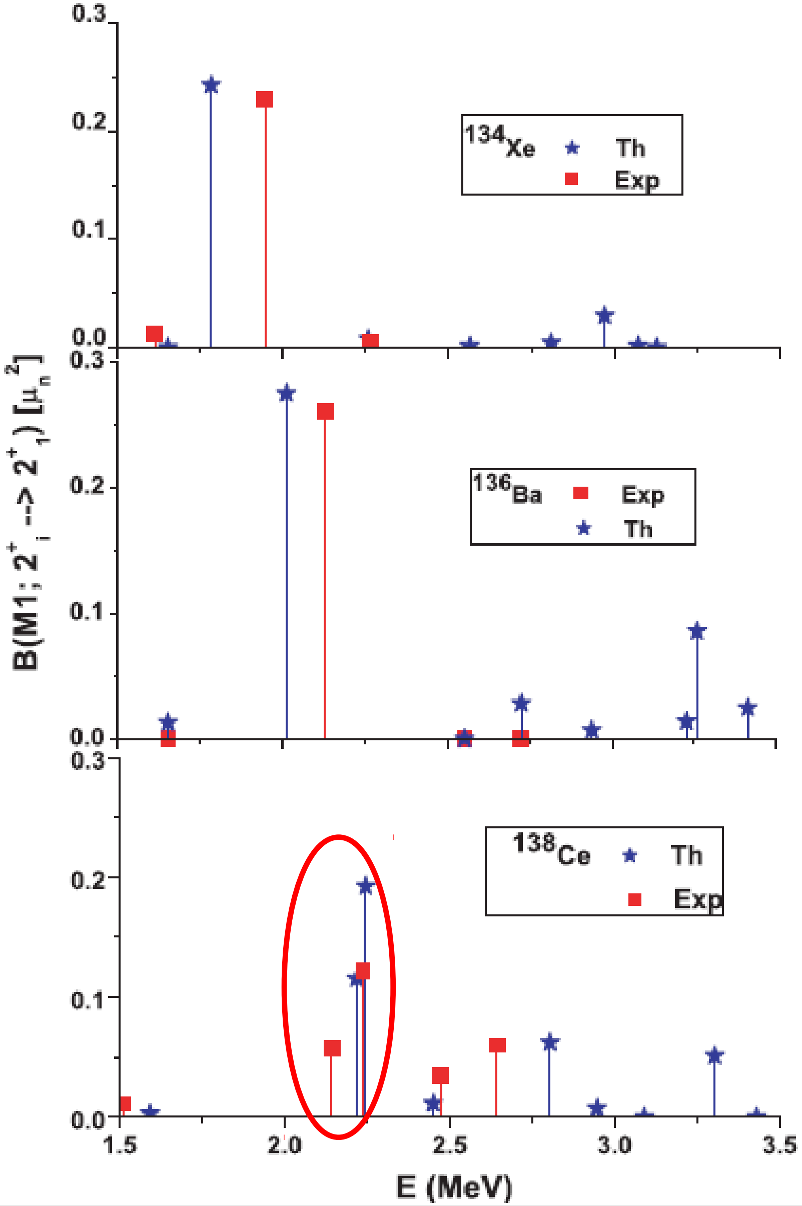
TECHNISCHE UNIVERSITÄT DARMSTADT




The properties of MSSs are sensitive to the sub-shell structure

# Microscopic Theory: QPM




Consistent description of the MSSs of 134Xe, 136Ba and 138Ce, including the fragmentation in latter one, can be achieved by a slight (~300 keV) increase of the energy gap between πg7/2 and πd5/2 orbitals ⇒

weaken the paring correlations

The splitting of the M1 strength in 138Ce is a genuine shell effect caused by the specific shell structure and the pairing correlations!

**-> Shell Stabilization**

**N. Lo Iudice, Ch. Stoyanov, D. Tarpanov, PRC 77 ('08) 044310**

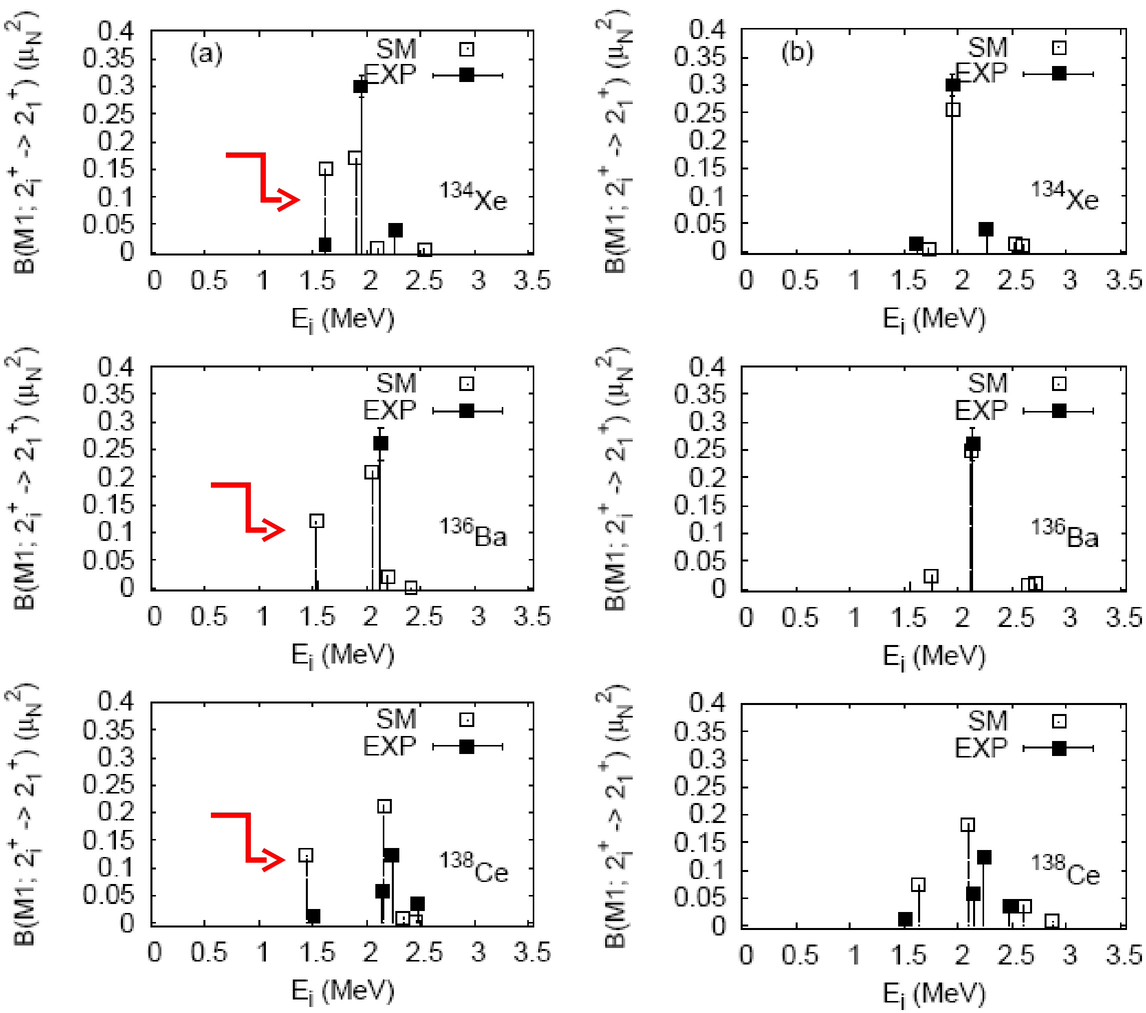
# Microscopic Theory: Shell-Model

TECHNISCHE UNIVERSITÄT DARMSTADT

GCN5082 – realistic Bonn-C potential + empirical correction to the monopole part

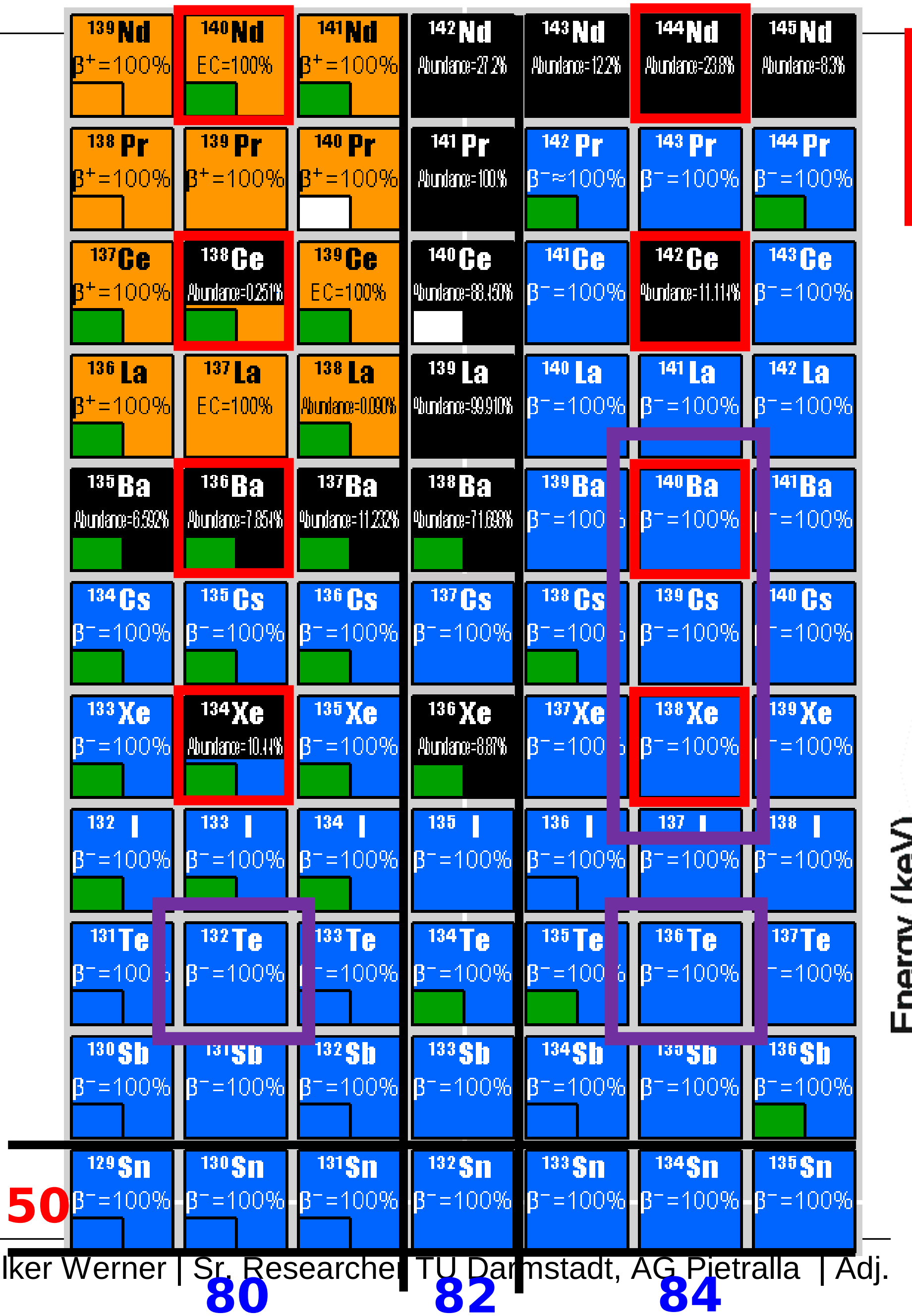
**K. Sieja, G. Martínez-Pinedo, L. Coquard, N. Pietralla, PRC80, 054311 ('09)**

Original interaction | Modified pairing




- realistic SM calculations reproduce energy spacing between 2+1 and 2+1,mss in known cases ⇒ prediction for neighboring isotones.
- information on MSSs provides a tool to determine pairing matrix elements of realistic interactions as they depend very sensitively on the treatment of core polarization corrections.
- **experimental information on MSSs of 132Te and 140Nd needed!**

# Is Shell Stabilization generic?

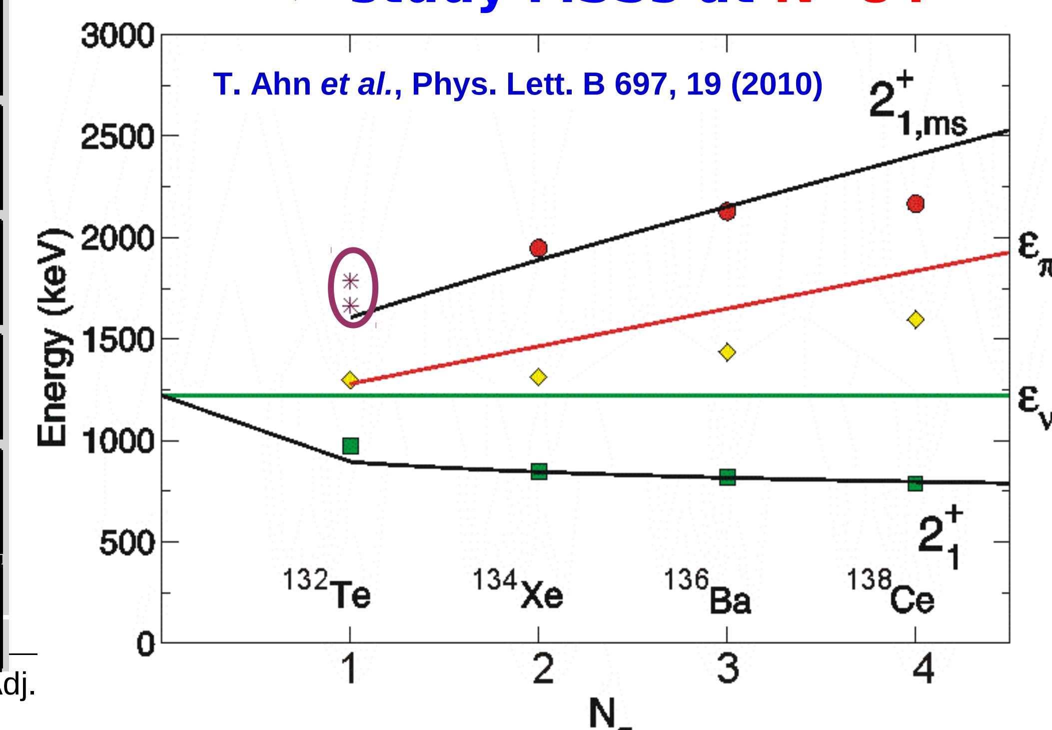



- Is shell stabilization present in different proton sub-shell? πd5/2

**-> MSSs in 140Nd and 142Sm**

- How does shell stabilization depend on relative proton and neutron contributions to the collective wave function?

**-> study MSSs at N=84**



# ORNL – $2_1^+$ g factor Experiment

**Experimental details:**

- **inverse kinematic reaction 132Te on a C target (0.83 mg/cm2);**
- **beam energy 3 MeV/u (80% CB);**
- **beam intensity 3 x 10^7 pps, run time 64 hours;**

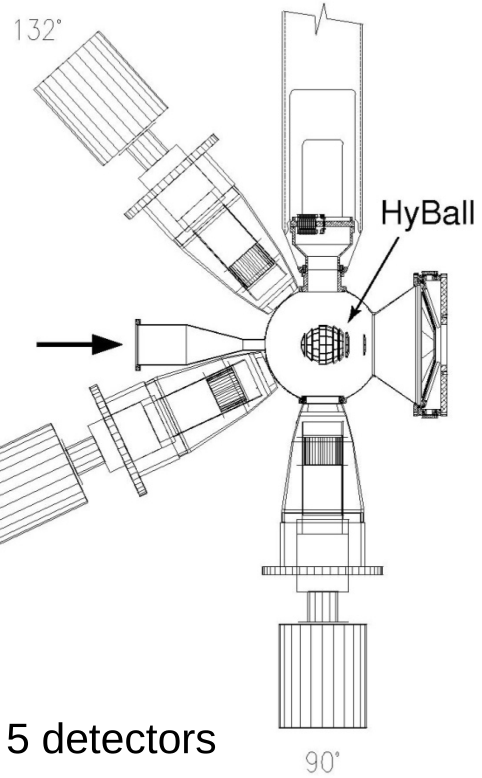
**Clarion array – 11 clovers**

4 detectors

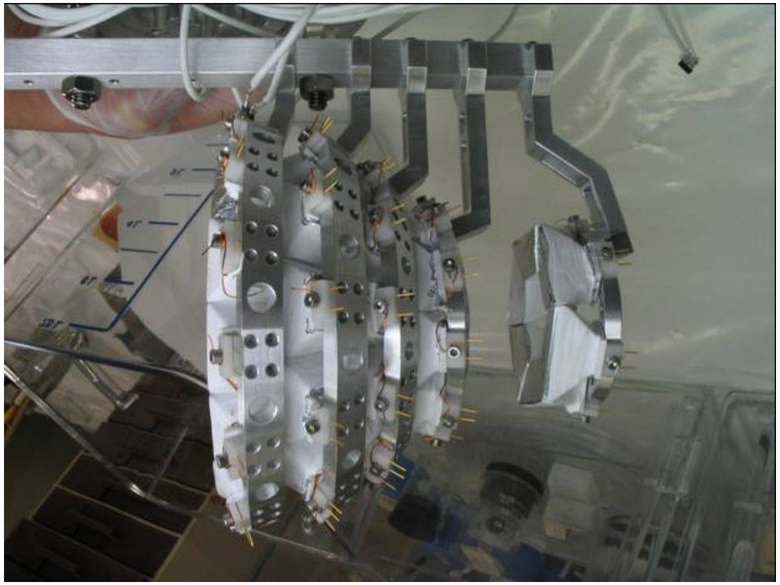
Bea
m

2 detectors

5 detectors




**HyBall array**

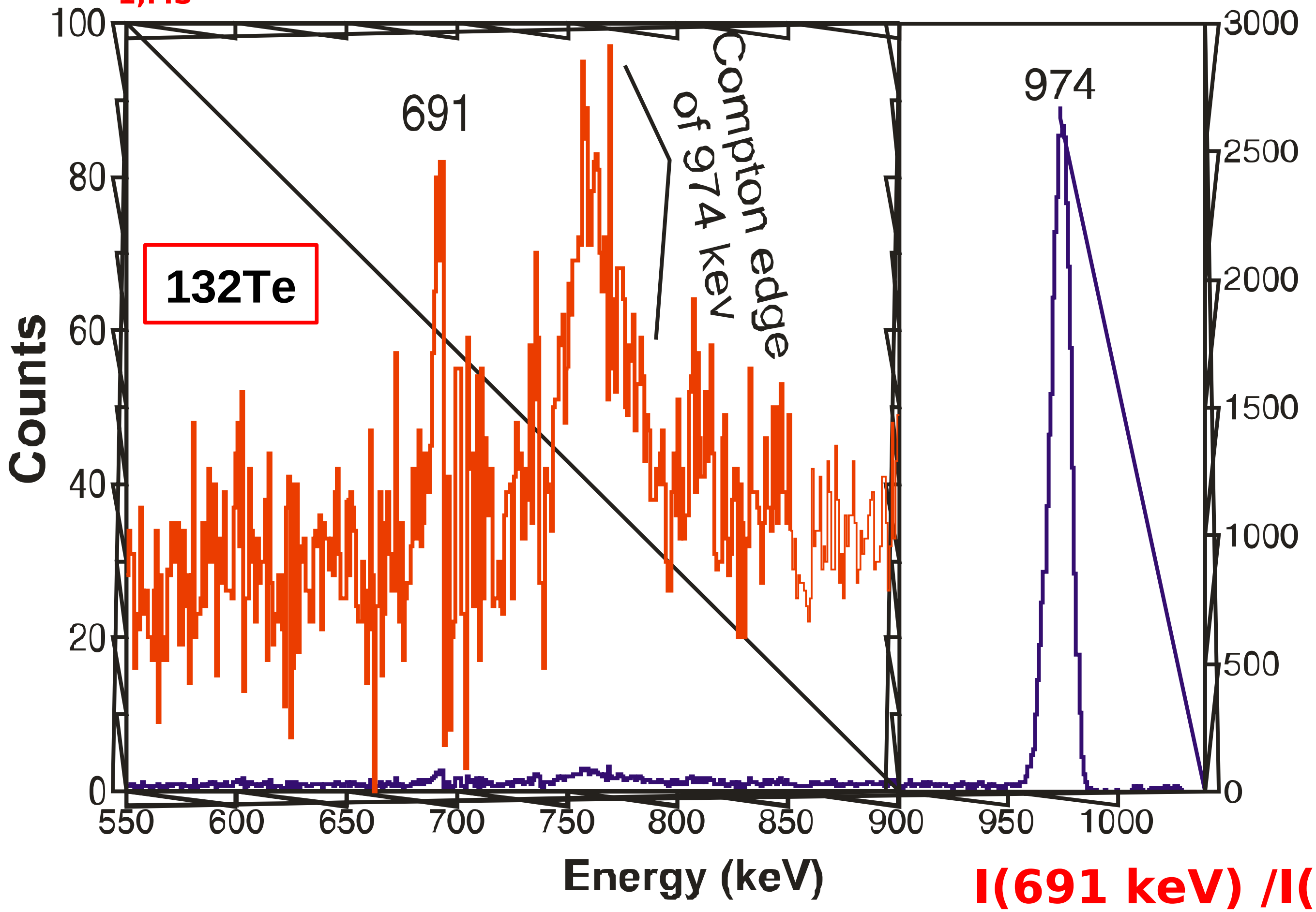


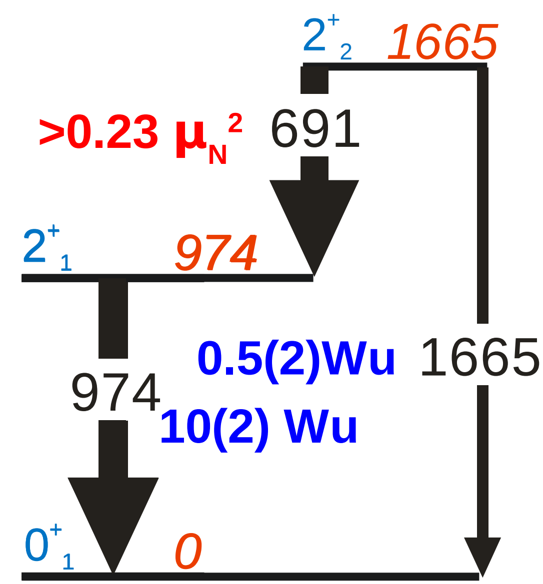
**CsI charged particle detectors:**

**Ring 1 – 6 detectors 7° - 14°**
**Ring 2 – 10 detectors 14° - 28°**
**Ring 3 - 12 detectors 28° - 44°**

# First MS observation with RIB

**$2_{1,MS}^{+}$ observed in coincidence with 12C recoils detected in HyBall.**




**M. Danchev *et al.*, PRC84 ('11) 061306(R)**

**I(691 keV) /I(1665 keV) = 100 (52)**

$$^{132}\mathrm{Te}: \frac{I_\gamma(691\mathrm{keV})}{I_\gamma(974\mathrm{keV})} = 1.01(28)\%$$

$$\frac{Y(2_2^+)}{Y(2_1^+)} = \frac{\sigma(0_1^+ \rightarrow 2_2^+)}{\sigma(0_1^+ \rightarrow 2_1^+)} \propto \frac{B(E2;0_1^+ \rightarrow 2_2^+)}{B(E2;0_1^+ \rightarrow 2_1^+)}$$

# Configurational Isospin Polarization (CIP)

TECHNISCHE UNIVERSITÄT DARMSTADT

$$2^+_{sym} = a_1 \cdot 2^+_n + b_1 2^+_p$$

$$2^+_{ms} = a_2 \cdot 2^+_n - b_2 2^+_p$$

**protons and neutrons contribute about equally: good F-spin**

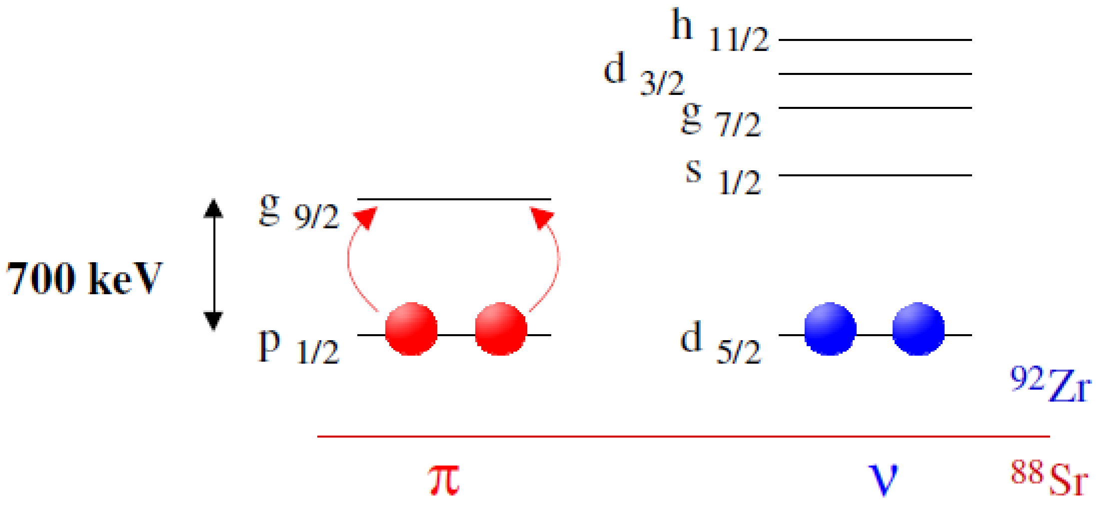
$$|a_i| \approx |b_i|$$

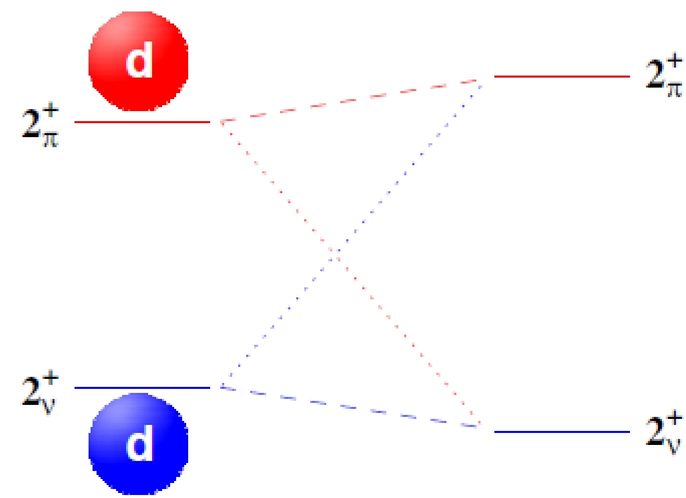
**imbalance in proton and neutron contributions: broken F-spin**

$$|a_i| \neq |b_i|$$

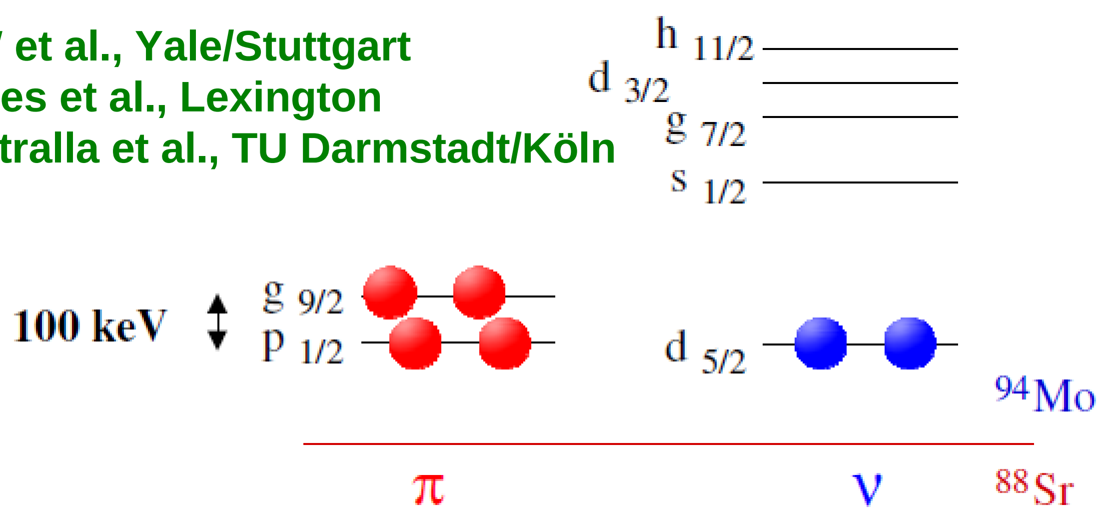
**need observable which is sensitive to p/n content: magnetic moment !**

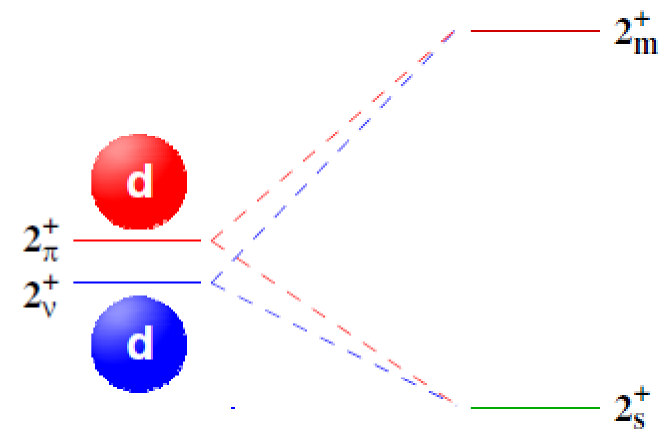
# First CIP found at N=52 Zr



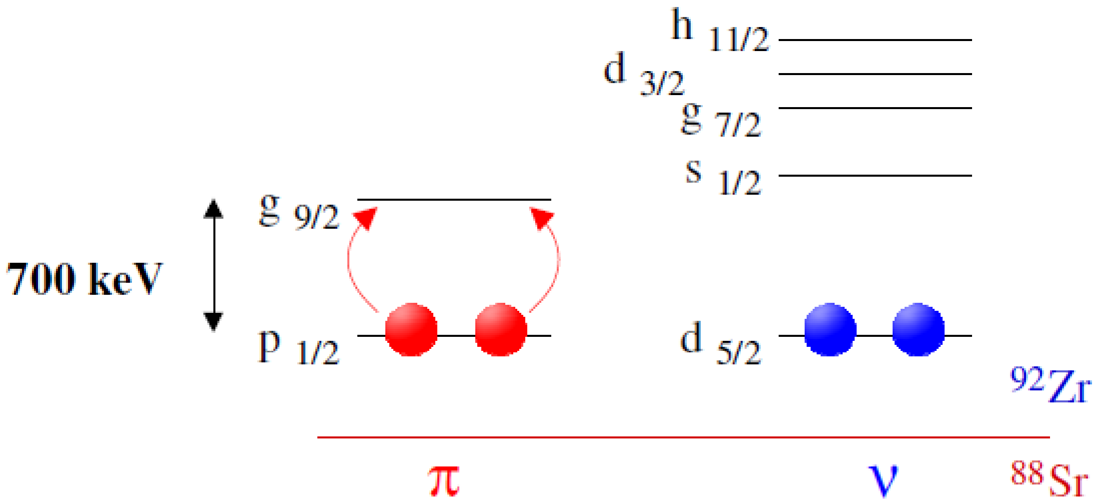



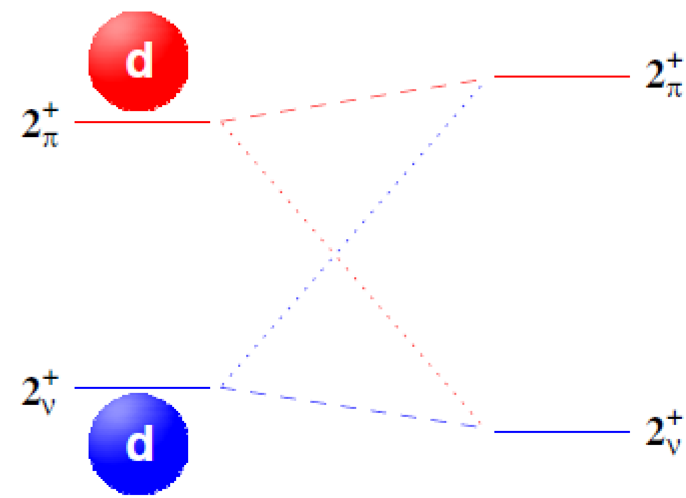

**VW et al., Yale/Stuttgart**
**Yates et al., Lexington**
**Pietralla et al., TU Darmstadt/Köln**



# First CIP found at N=52 Zr

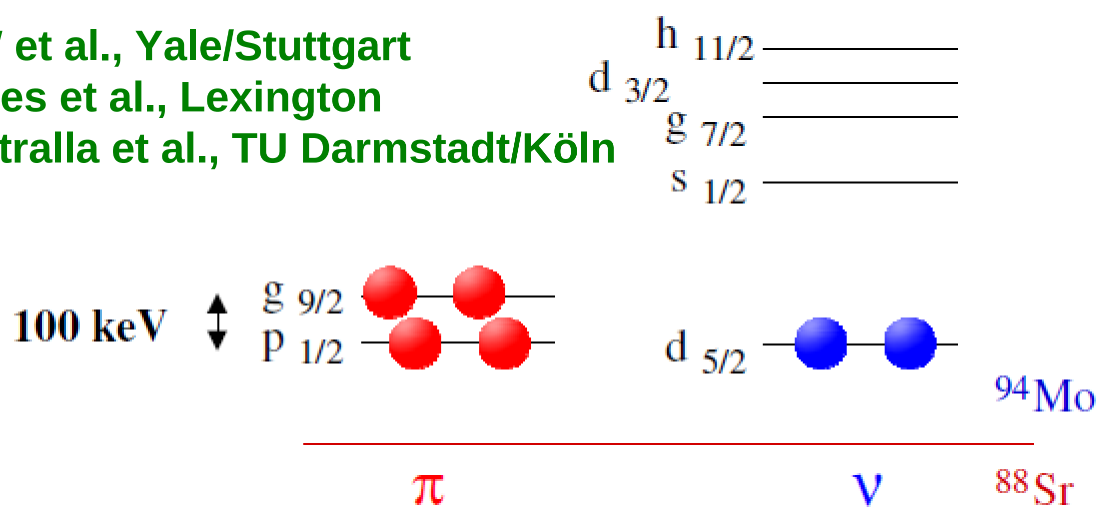


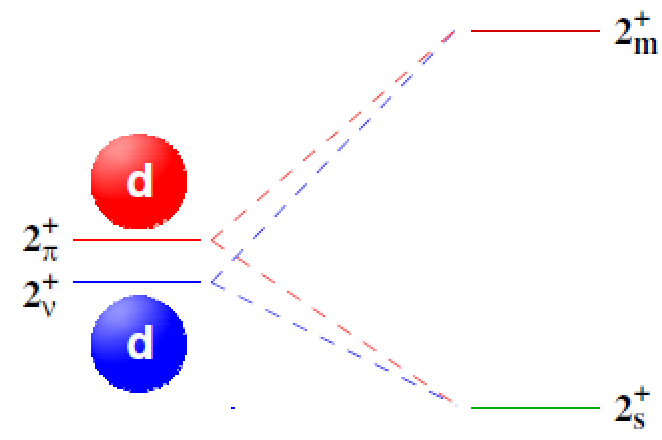




**p/n content measured through g factors, lifetimes from NRF, Coulex, (n,n'g)**

**At SPES we can test n-unstable 90Sr !**

**VW et al., Yale/Stuttgart**
**Yates et al., Lexington**
**Pietralla et al., TU Darmstadt/Köln**



# New CIP case predicted: 136Te

2+1 and 2+2 have significant E2 -> 1-phonon states

Strong M1 between them -> 2+2 = 2+1,MS

| | $\lambda_i^\pi = 2_i^+$ | Energy (MeV) | | Structure | $B(E2; 0_{gs}^+ \to 2_i^+)$ ($e^2 fm^4$) | | $B(E2; 2_i^+ \to 2_1^+)$ ($e^2 fm^4$) | | $B(M1; 2_i^+ \to 2_1^+)$ ($\mu_N^2$) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Expt. | Theory | | Expt. | Theory | Expt. | Theory | Expt. | Theory |
| $^{136}$Te | $2_1^+$ | 0.606 | 0.92 | $97\%[2_1^+]_{QRPA}$ | 1030±150 | 1120 | | | | |
| | $2_2^+$ | 1.568 | 2.01 | $94\%[2_2^+]_{QRPA}$ | | 740 | | 20 | | 0.51 |

QPM: A. Severyukhin *et al.*, submitted to PRC

# New CIP case predicted: 136Te

TECHNISCHE UNIVERSITÄT DARMSTADT

2+1 and 2+2 have significant E2 -> 1-phonon states

Strong M1 between them -> 2+2 = 2+1,MS

2+1 neutron dominated, 2+2 large proton amplitudes

-> CoulEx at SPES !

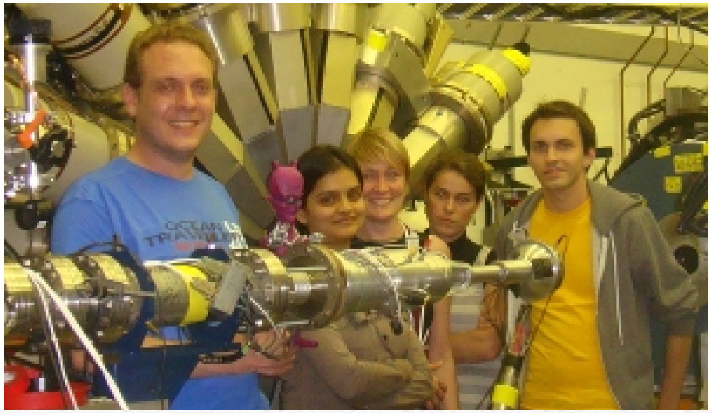
| | $\lambda_i^\pi = 2_i^+$ | Energy (MeV) Expt. | Energy (MeV) Theory | Structure | $B(E2; 0_{gs}^+ \to 2_i^+)$ ($e^2fm^4$) Expt. | $B(E2; 0_{gs}^+ \to 2_i^+)$ ($e^2fm^4$) Theory | $B(E2; 2_i^+ \to 2_1^+)$ ($e^2fm^4$) Expt. | $B(E2; 2_i^+ \to 2_1^+)$ ($e^2fm^4$) Theory | $B(M1; 2_i^+ \to 2_1^+)$ ($\mu_N^2$) Expt. | $B(M1; 2_i^+ \to 2_1^+)$ ($\mu_N^2$) Theory |
|---|---|---|---|---|---|---|---|---|---|---|
| $^{136}$Te | $2_1^+$ | 0.606 | 0.92 | $97\%[2_1^+]_{QRPA}$ | 1030±150 | 1120 | | | | |
| | $2_2^+$ | 1.568 | 2.01 | $94\%[2_2^+]_{QRPA}$ | | 740 | | 20 | | 0.51 |

| | State | Energy (MeV) | $B(M1; 2_i^+ \to 2_1^+)$ ($\mu_N^2$) | $B(E2; 0_{gs}^+ \to 2_i^+)$ ($e^2fm^4$) | $\{n_1l_1j_1, n_2l_2j_2\}_\tau$ | X | Y | % |
|---|---|---|---|---|---|---|---|---|
| $^{136}$Te | $[2_1^+]_{QRPA}$ | 1.05 | | 1010 | $\{2f_{7/2}, 2f_{7/2}\}_\nu$ | 1.32 | 0.14 | 86 |
| | | | | | $\{2d_{5/2}, 2d_{5/2}\}_\pi$ | 0.32 | 0.13 | 4 |
| | | | | | $\{1g_{7/2}, 1g_{7/2}\}_\pi$ | 0.30 | 0.12 | 4 |
| | $[2_2^+]_{QRPA}$ | 2.20 | 0.44 | 920 | $\{2f_{7/2}, 2f_{7/2}\}_\nu$ | -0.52 | 0.13 | 13 |
| | | | | | $\{2d_{5/2}, 2d_{5/2}\}_\pi$ | 0.82 | 0.04 | 34 |
| | | | | | $\{1g_{7/2}, 1g_{7/2}\}_\pi$ | 0.83 | 0.04 | 34 |

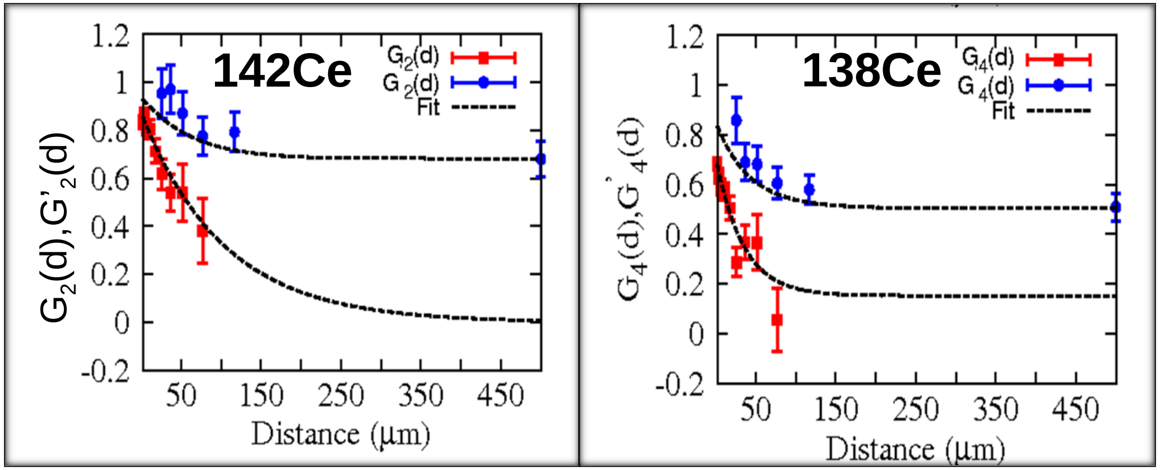
QPM: A. Severyukhin *et al.*, submitted to PRC

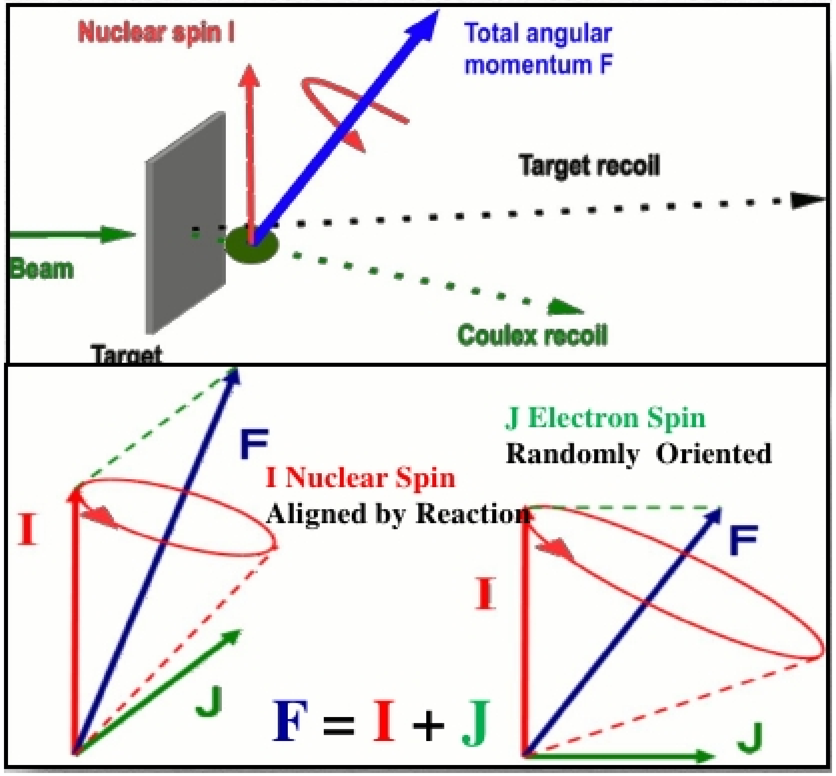
# Plunger: Time-Differential Recoil-Into-Vacuum (TDRIV)

TECHNISCHE UNIVERSITÄT DARMSTADT

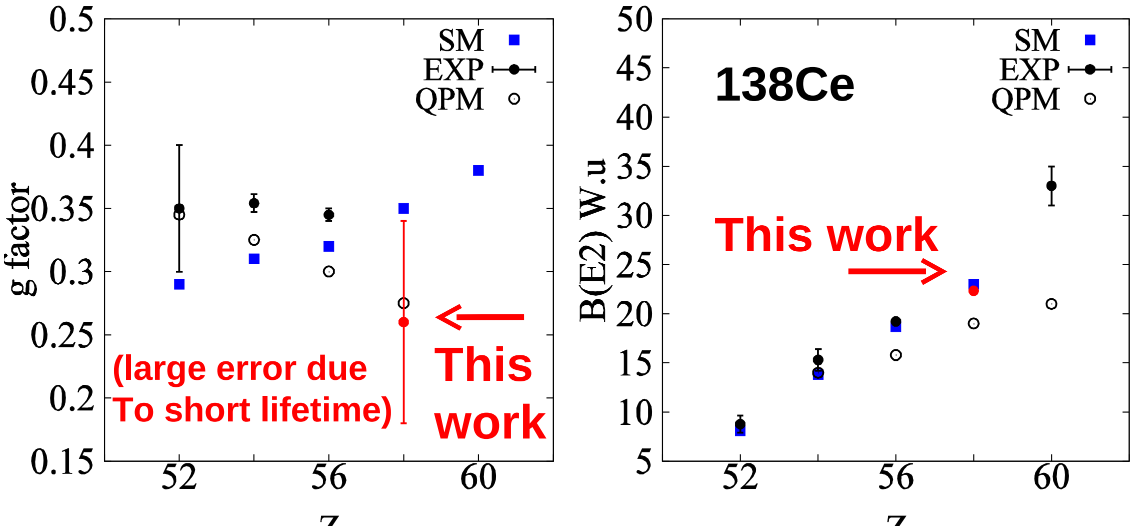


**Obtain lifetime and g factor simultaneously – inv. Coulex (+Q-Mom.)**



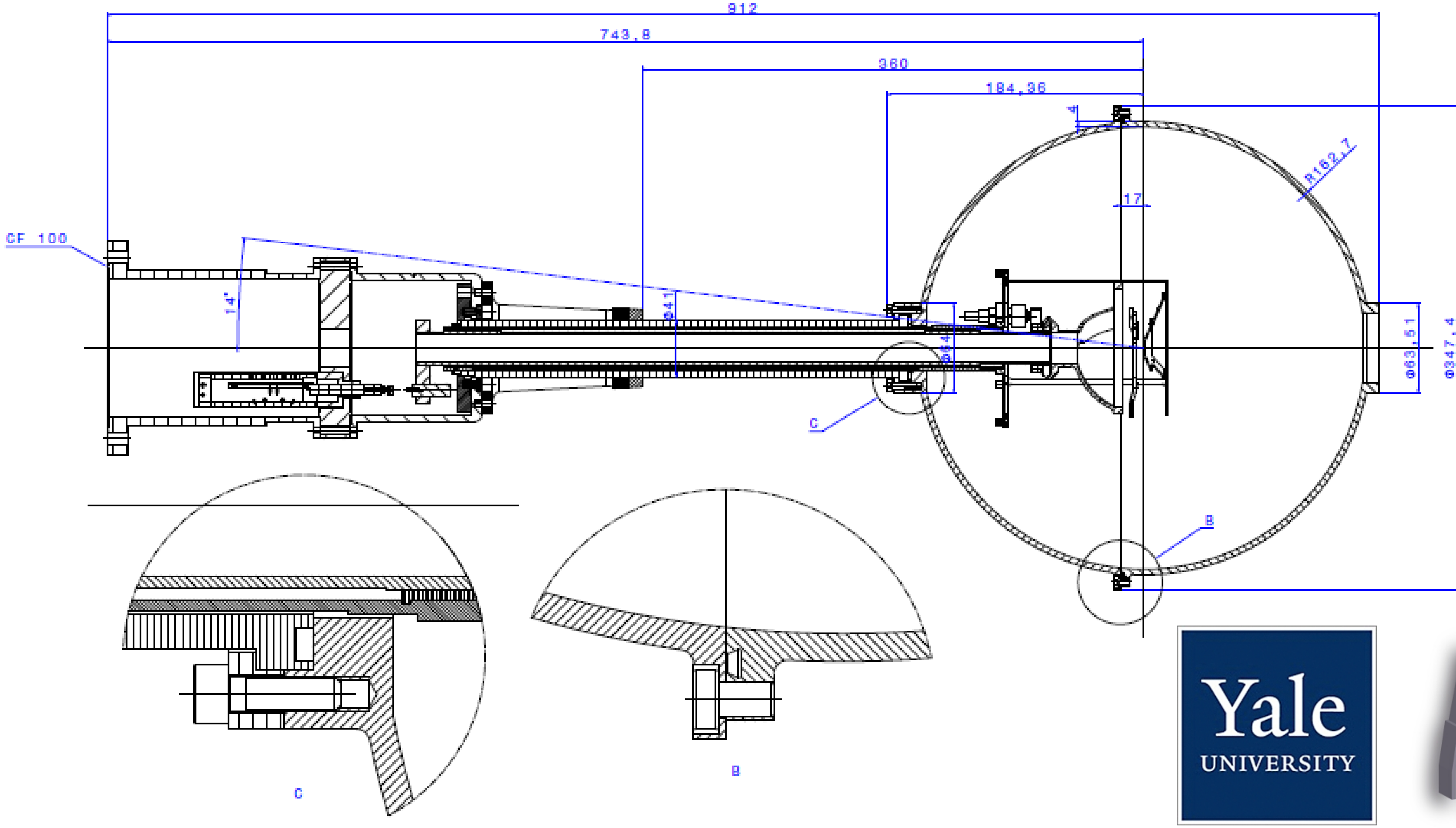

**F. Naqvi, V. Werner, *et al.*, PLB 728, 303 (2014)**



# New Reaccelerated RIB Plunger Underway

TECHNISCHE UNIVERSITÄT DARMSTADT

**Developed by Yale (VW) and Cologne, Si Disk to be purchased by TU Darmstadt**




Yale UNIVERSITY

IKP

**Will fit into GammaSphere, GRETINA, MiniBall, AGATA, GALILEO ...**
**Will be able to couple to other auxiliaries like CHICO2, PhoSwitch Wall**

# New Reaccelerated RIB Plunger Underway

**Developed by Yale (VW) and Cologne, Si Disk to be purchased by TU Darmstadt**


**Will fit into GammaSphere, GRETINA, MiniBall, AGATA, GALILEO ...**
**Will be able to couple to other auxiliaries like CHICO2, PhoSwitch Wall**

# Conclusion

TECHNISCHE UNIVERSITÄT DARMSTADT

Identification of one-phonon 2+1,ms of radioactive nuclei *is* possible in Coulomb excitation on a light (carbon) target with beam energy ~85 % CB

⇒ 3.8 ÷ 4.5 MeV/u at ~10^6÷10^7 pps

⇒ **SPES offers optimum conditions!**

Pending first results – move to simultaneous CoulEx/Plunger

**Beams of interest**:

138Xe, 140Ba, 132Te, 136Te

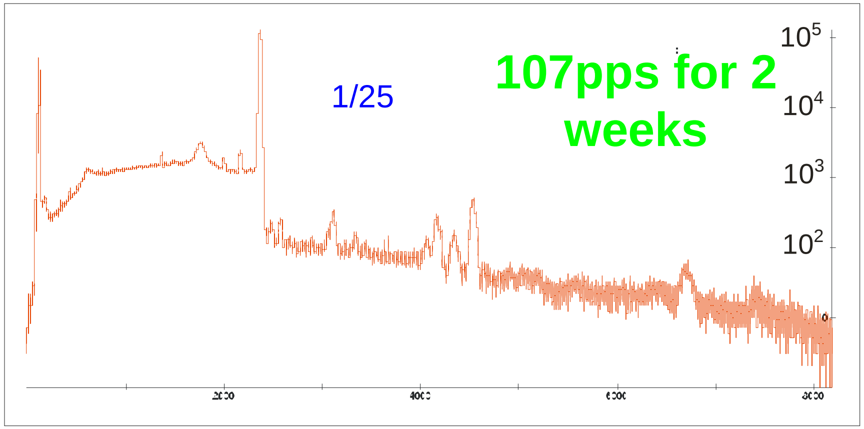
Later extend to:

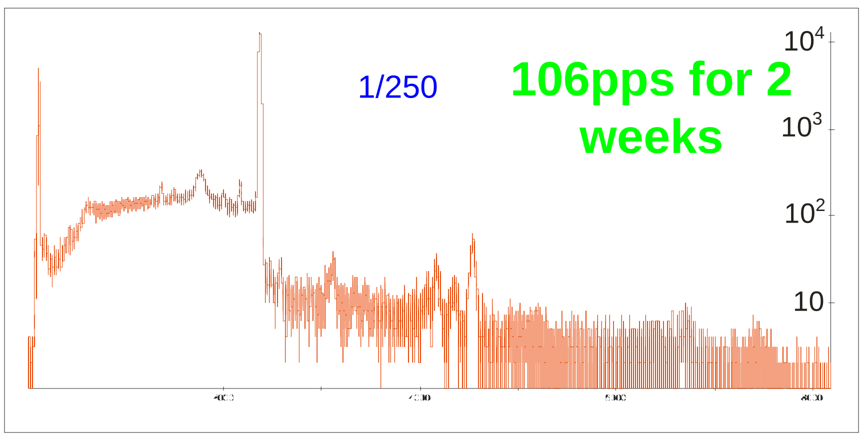
90Sr

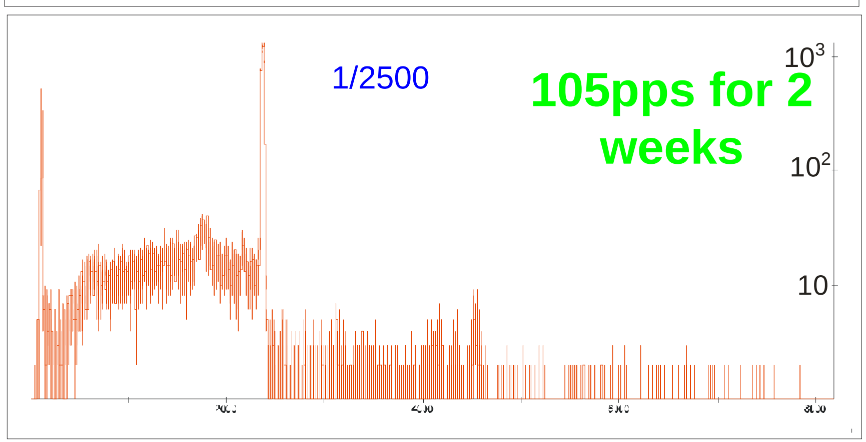
# Experimental approach

<u>Coulomb excitations in inverse kinematics on C target</u>

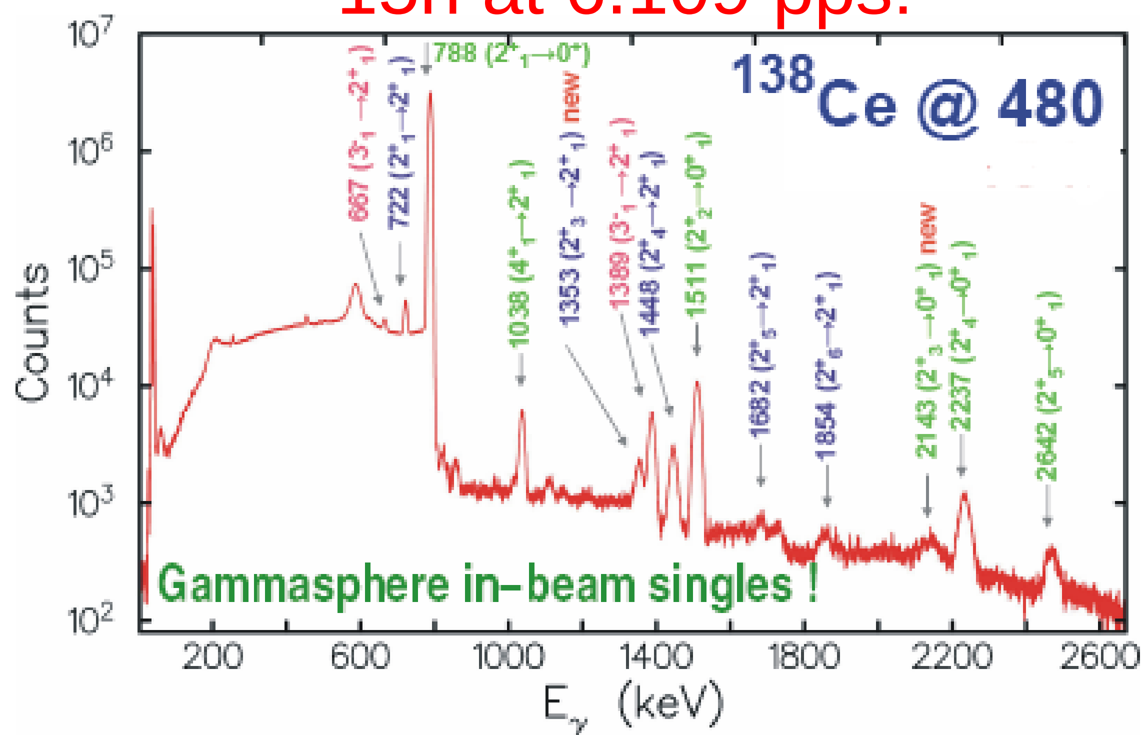
predominantly one-step processes and clean γ-spectrum (no target excitations)




15h at 6.109 pps!




**To identify excited 2+ states (beyond the 2+1) in vibrational nucleus (B(E2)~1Wu) with a 10% array for 2 weeks beam time we need 105pps. For complete spectroscopy 106-107 pps will be needed!**

Feasible, but requires beam energy ~85% CB (3.5-4 MeV/n)

**well within the capability of SPES**