



# Nuclear moments of neutron-rich Al at the border of the island of inversion

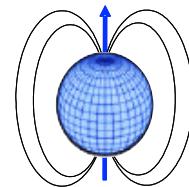


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SSNET, 8 November 2016



# Introduction

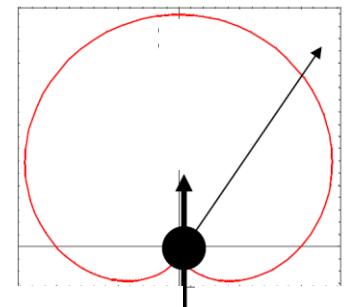
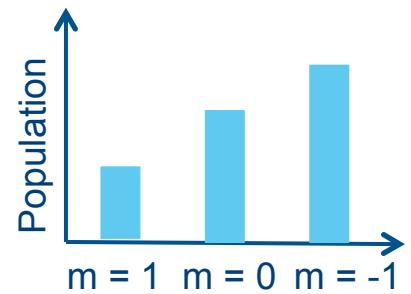
- Magnetic dipole moment  $\mu$ 
  - g-factor =  $\mu/I$
  - Orbital occupation of unpaired valence nucleons  
→ **Wave function composition**
- Electric quadrupole moment  $Q_s$ 
  - Deviation from sphericity → **Deformation**
- Measure moments to study nuclear structure at the border of the island of inversion around  $N = 20$ 
  - $\beta$ -NMR/NQR at GANIL





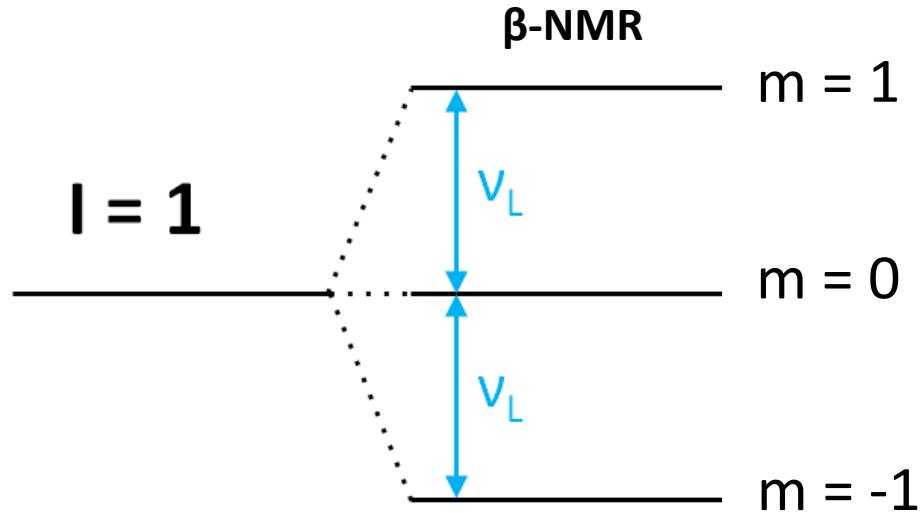
# $\beta$ -detected Nuclear Magnetic Resonance Quadrupole

- Spin-polarized beams in projectile-fragmentation/pick-up reactions at LISE-GANIL
  - ms – s half-lives
  - Minimum a few 100 ions/s
- Spin-polarization
  - Unequal population of m-states
  - $\beta$  – decay is anisotropic in space ( $N_{\text{up}} \neq N_{\text{down}}$ )  
$$\text{Asymmetry} = (N_{\text{up}} - N_{\text{down}})/(N_{\text{up}} + N_{\text{down}})$$
  
$$\propto \text{degree of polarization}$$





# $\beta$ -NMR/NQR



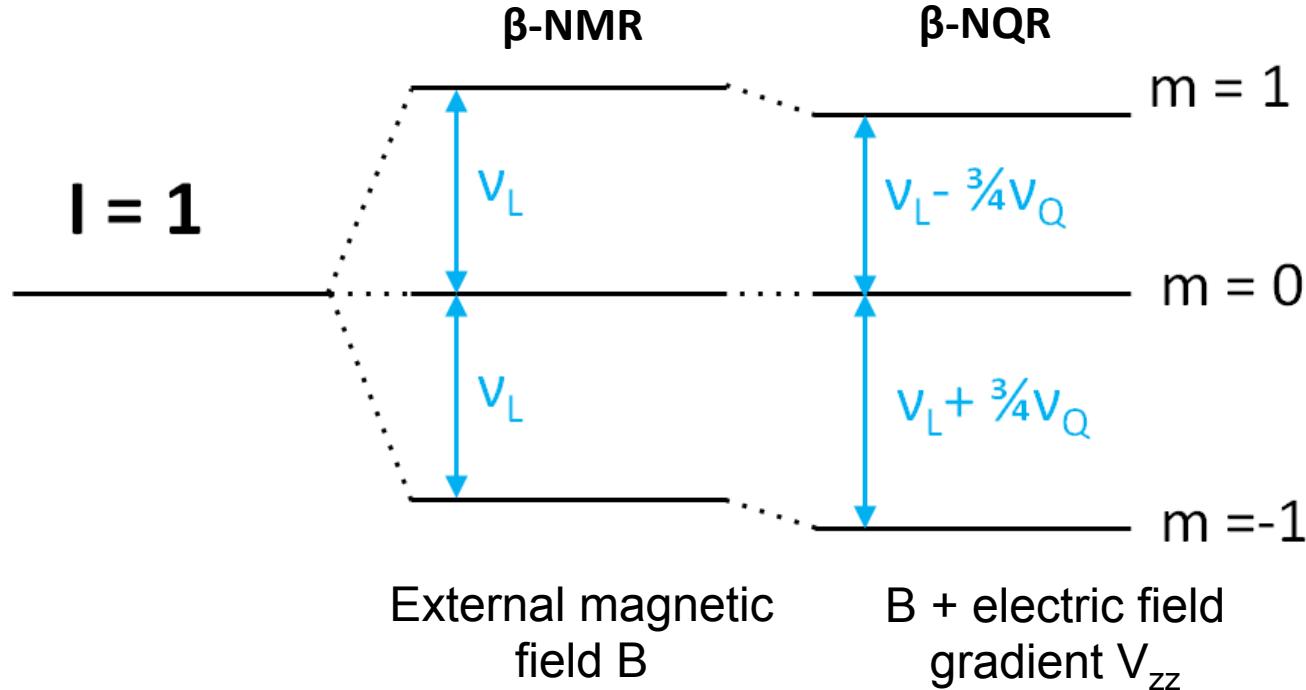
External magnetic  
field  $B$

- Hyperfine interaction in implantation crystal

$$v_L \propto |g| \cdot B$$



# $\beta$ -NMR/NQR



- Hyperfine interaction in implantation crystal

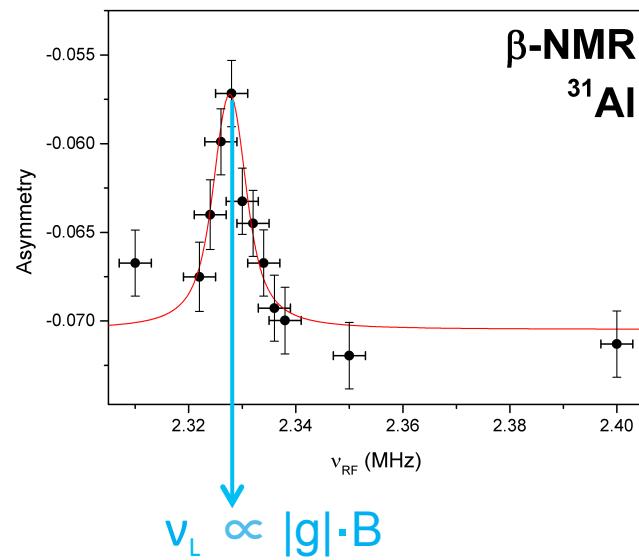
$$v_L \propto |g| \cdot B$$

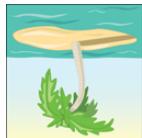
$$v_Q \propto |Q_s| \cdot V_{zz}$$



# $\beta$ -NMR/NQR

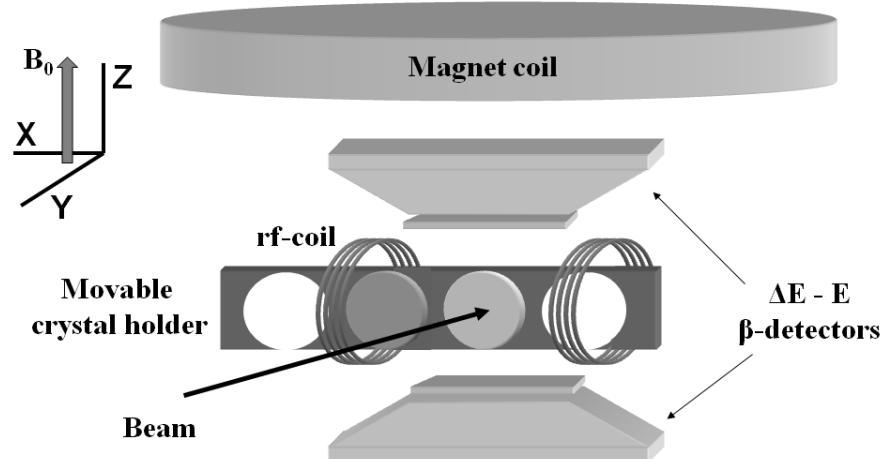
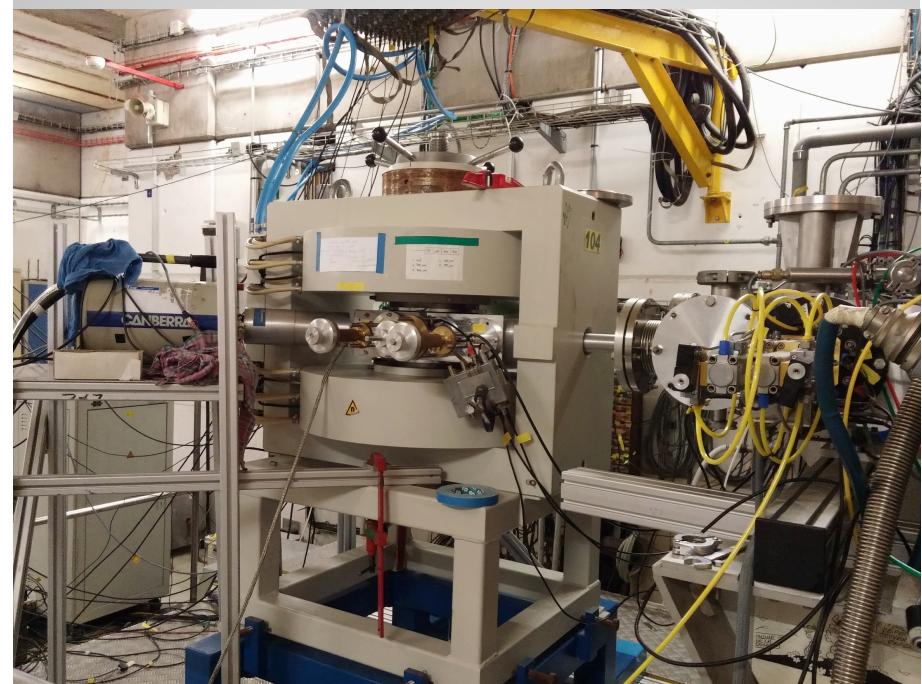
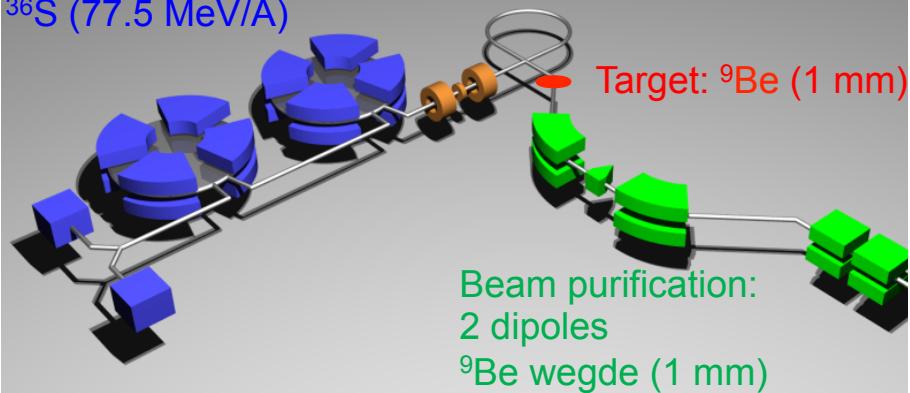
- $\beta$ -NMR
  - RF magnetic field at frequency  $v_{RF}$
  - $v_{RF} = v_L$      $\rightarrow$  Equalize m-state populations  
 $\rightarrow$  Polarization = 0
- Detect change in  $\beta$ -asymmetry when polarization is resonantly destroyed
- $\beta$ -NQR
  - Non-equidistant splitting
  - 2I RF-frequencies simultaneously





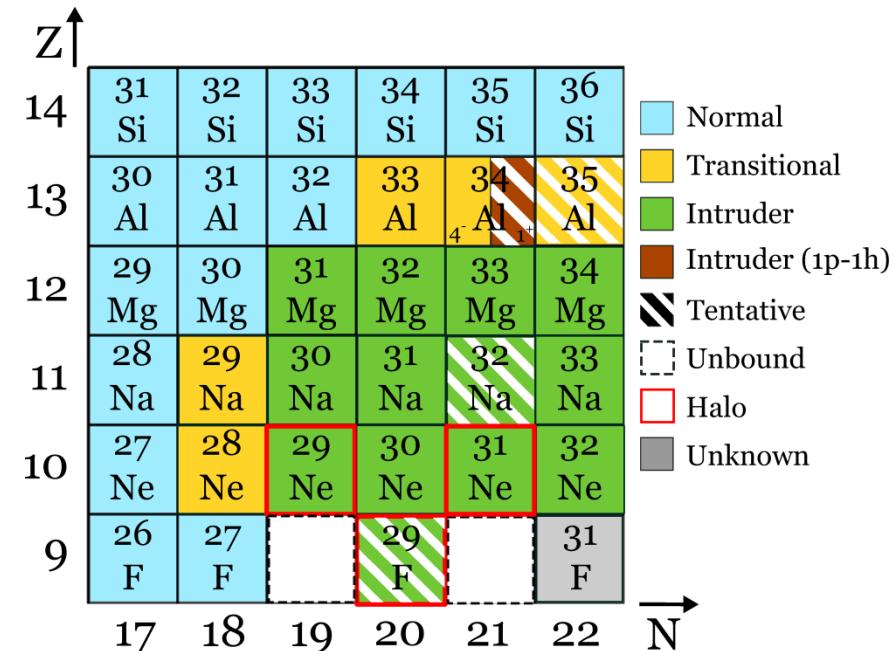
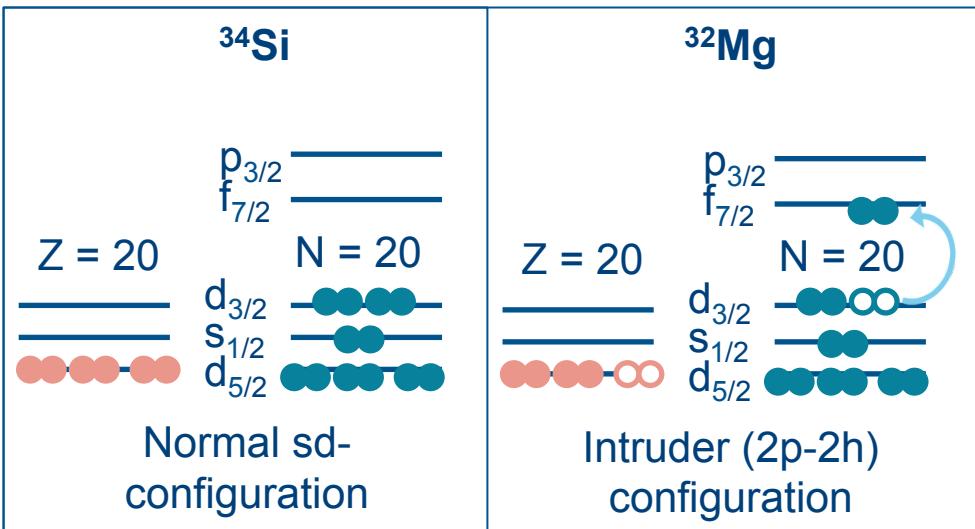
# $\beta$ -NMR/NQR set-up @ LISE-GANIL

Primary beam accelerated in 2 cyclotrons  
 $^{36}\text{S}$  (77.5 MeV/A)





# Island of inversion around N = 20



## Region of deformation near classical $N = 20$ magic number

- $np-nh$  intruder configurations become gs below normal  $sd$ -configurations
- Subtle balance
  - Shell gaps
  - Quadrupole correlations between protons and neutrons



34
Si
33
Al
32
Mg

# Island of inversion – $^{33}\text{Al}_{20}$

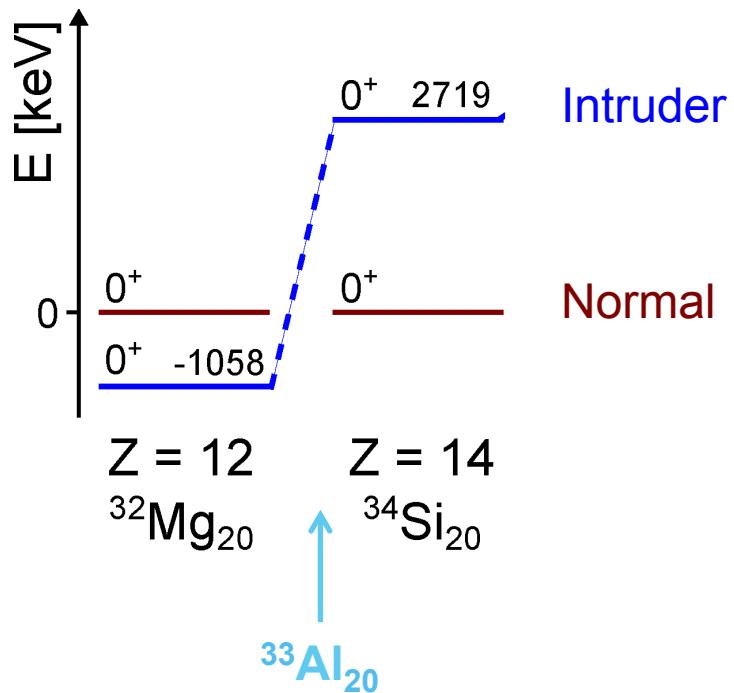
## Neutron-rich Al ( $Z = 13$ )

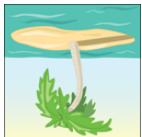
- Border of island of inversion

## $N = 20$ isotones

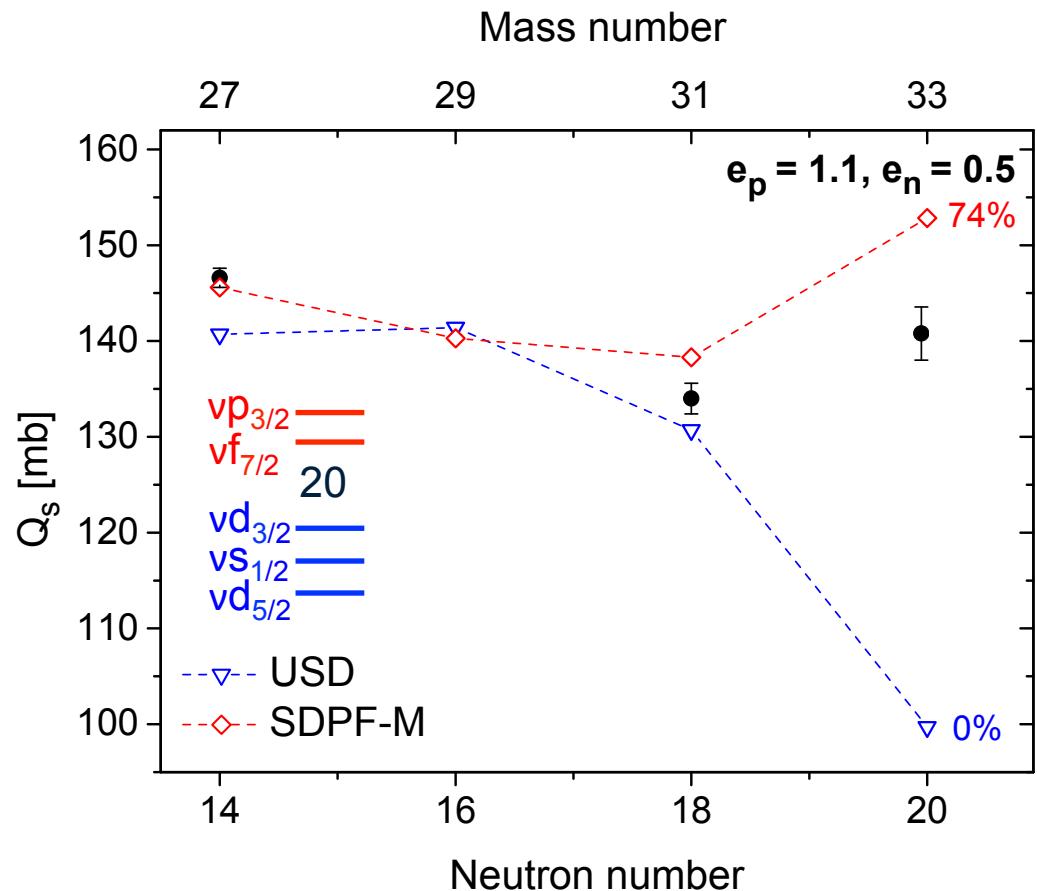
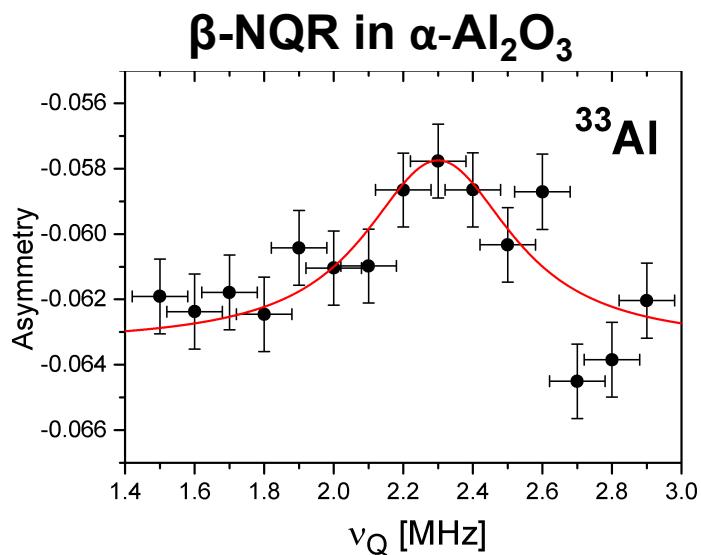
- Rapid transition into island
- Intruder admixtures in  $^{33}\text{Al}_{20}$  gs?
  - Masses No
  - $\beta$ -decay No/Yes
  - g-factor Yes
  - Low-precision Q Yes but ...

→ High-precision Q of  $^{33}\text{Al}_{20}$

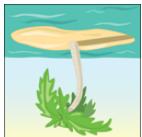




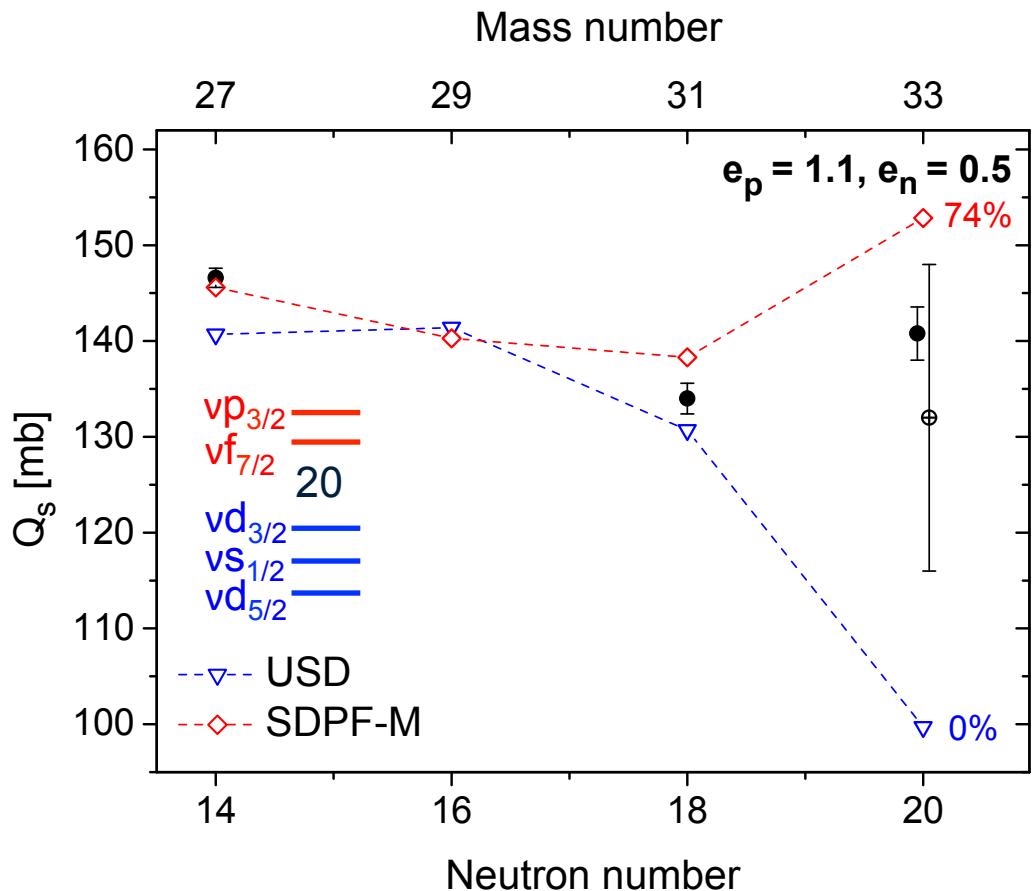
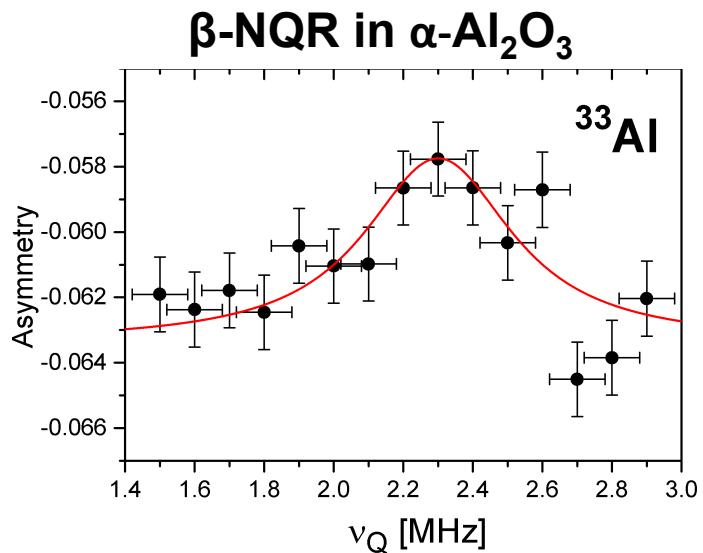
# High-precision quadrupole moment of $^{33}\text{Al}$



→ Significant intruder component in gs wave function of  $^{33}\text{Al}$



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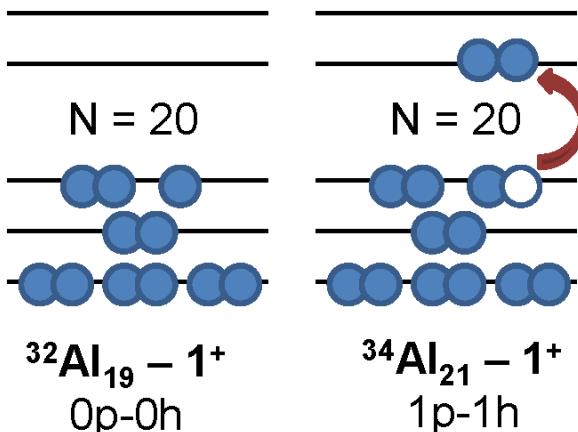
→ Significant intruder component in gs wave function of  $^{33}\text{Al}$



# Island of inversion – $^{34}\text{Al}_{21}$

## Unique nature of $1^+$ state in $^{34}\text{Al}_{21}$

- Proposed 1p-1h configuration: unique in island of inversion
- g-factor and quadrupole moment compared to  $^{32}\text{Al}$ 
  - Verify configuration
  - Investigate increase in deformation due to 1p-1h intruder



		Exp.	SDPF-M	SDPF-U-MIX
g-factor	$^{32}\text{Al}$	1.9516(22)	1.83	1.80
	$^{34m}\text{Al}$	?	1.73	1.76
$Q_s$ (mb)	$^{32}\text{Al}$	24(2)	30	27
	$^{34m}\text{Al}$	?	43	44

g-factor: Himpe, PLB 643, 257 (2006);

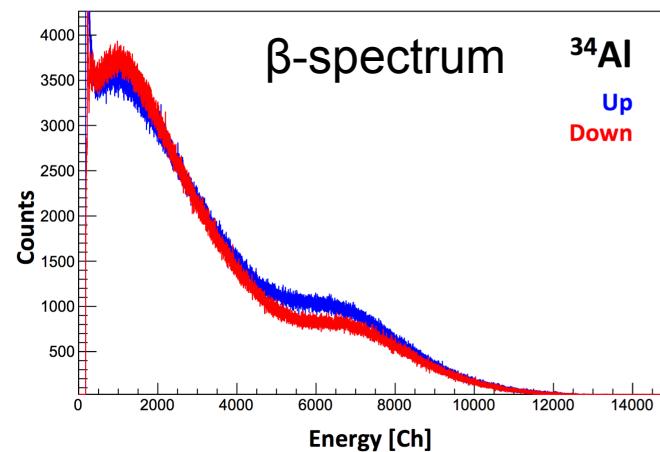
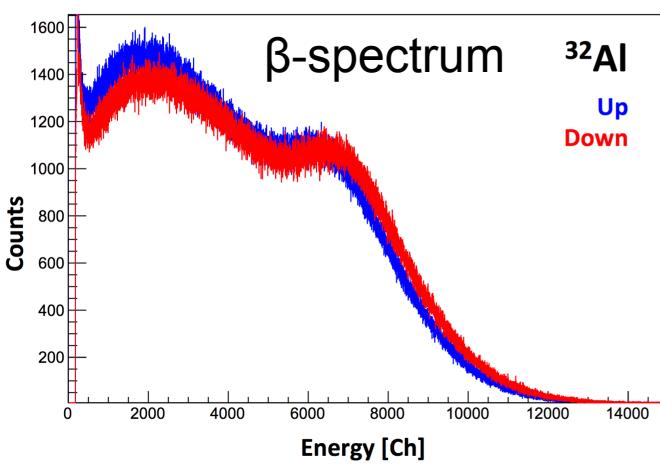
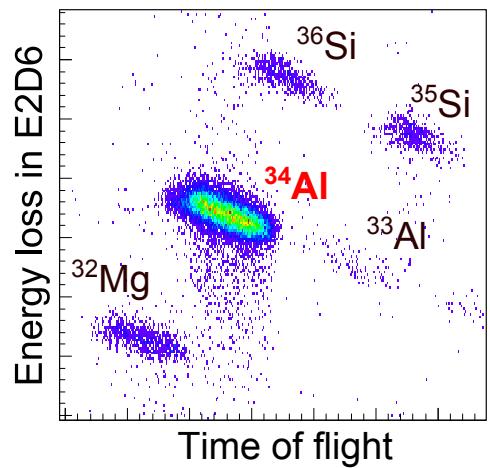
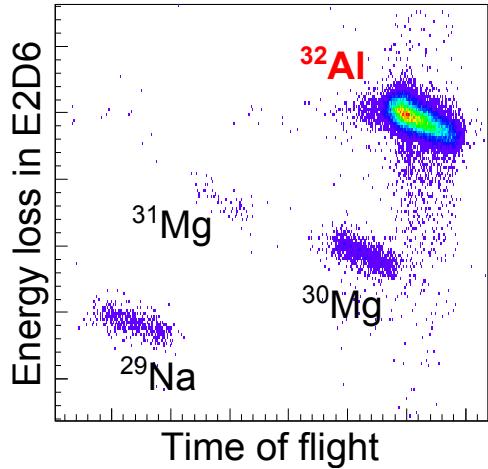
$Q_s$ : Kameda., PLB 647, 93 (2007);

SDPF-M (Tokyo): PRC 60, 054315 (1999)

SDPF-U-MIX (Strasbourg): PRC 90, 014302 (2014)



# The very exotic $^{34}\text{Al}_{21}$

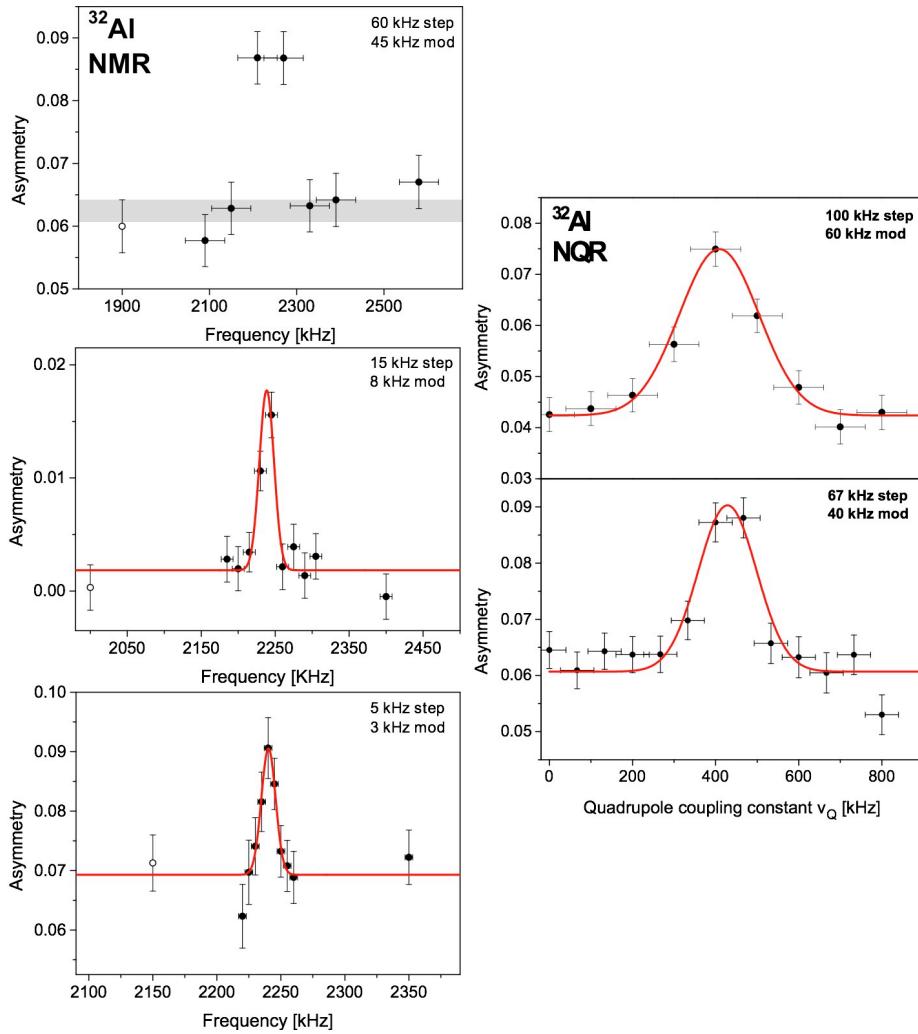


## Challenges

- 450  $^{34}\text{Al}/\text{s}$ 
  - Only  $\sim 30\% 1^+$
- Large background of daughter  $\beta$ s +  $^{34}\text{gAl}$ 
  - Reduction of asymmetry by factor of  $\sim 9$



# Optimisation with $^{32}\text{Al}$



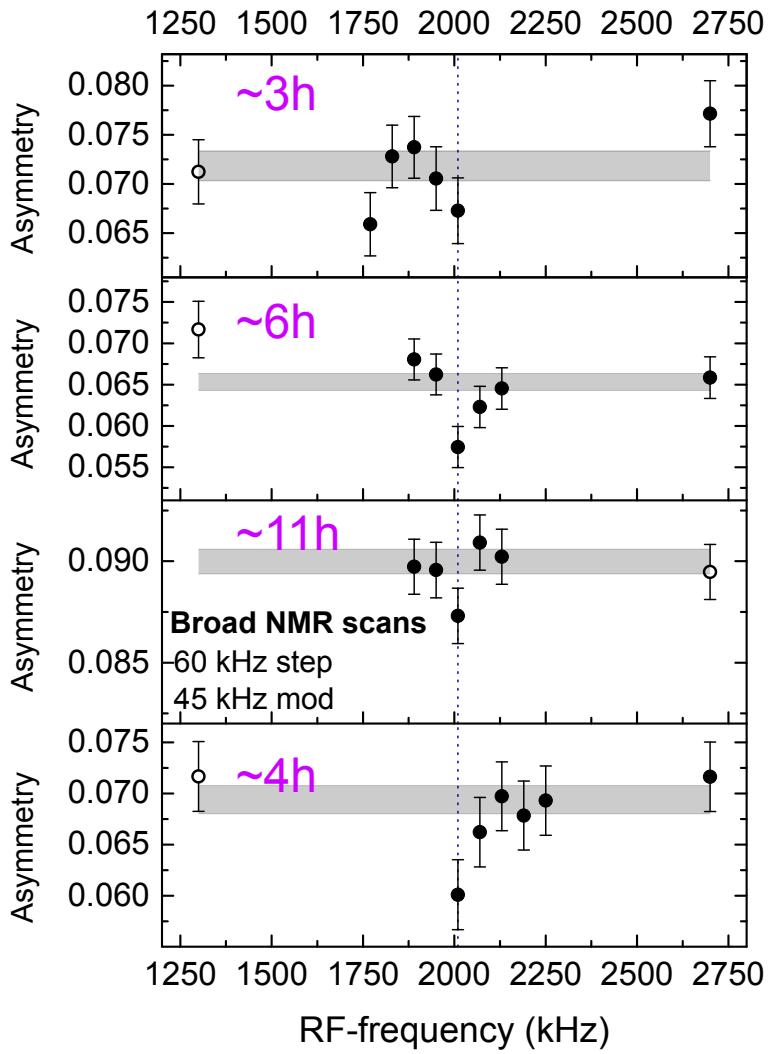
	This work	Lit.
g-factor	1.957(4)	1.952(2)
$Q_s$ [mb]	24.9(6)	25(2)

Preliminary results

Improved precision



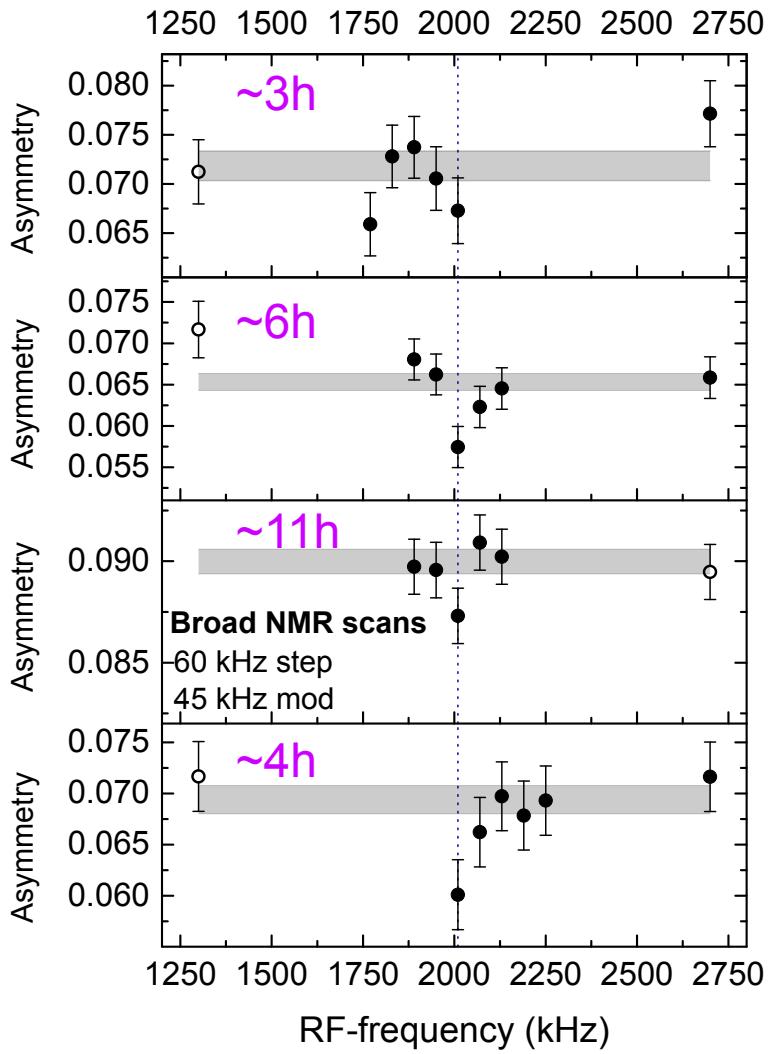
# The search for the $1^+$ NMR resonance



- Large step size + modulation  
→ 1 point in resonance  
→ “Dip” instead of peak
- Point at **2010(45)** kHz goes down in 4 independent scans regions ...  
BUT statistical significance?
- Work in progress ...
  - Add spectra with different baselines?
  - Bootstrapping
  - No resonance in fine scans?



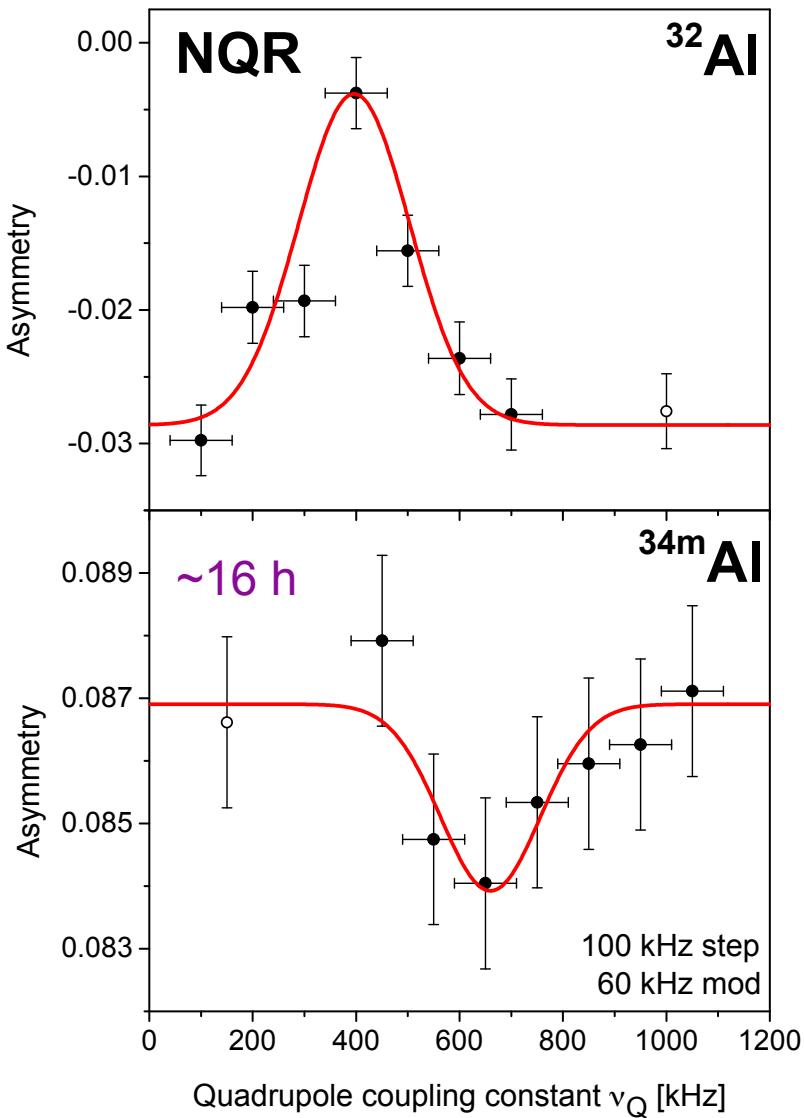
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- Work in progress ...
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  - Bootstrapping
  - No resonance in fine scans?
- If true resonance:  
 $g(^{34m}\text{Al})/g(^{32}\text{Al}) \sim 0.9$



# The search for the $1^+$ NQR resonance



- Similar FWHM as  $^{32}\text{Al}$
- IF true resonance:  
 $Q(^{34\text{m}}\text{Al})/Q(^{32}\text{Al}) \sim 1.6$



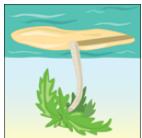
# Conclusion

- High-precision quadrupole moment reveals significant intruder component in  $^{33}\text{Al}$  gs
- Analysis of  $^{34}\text{Al} - 1^+$  state underway

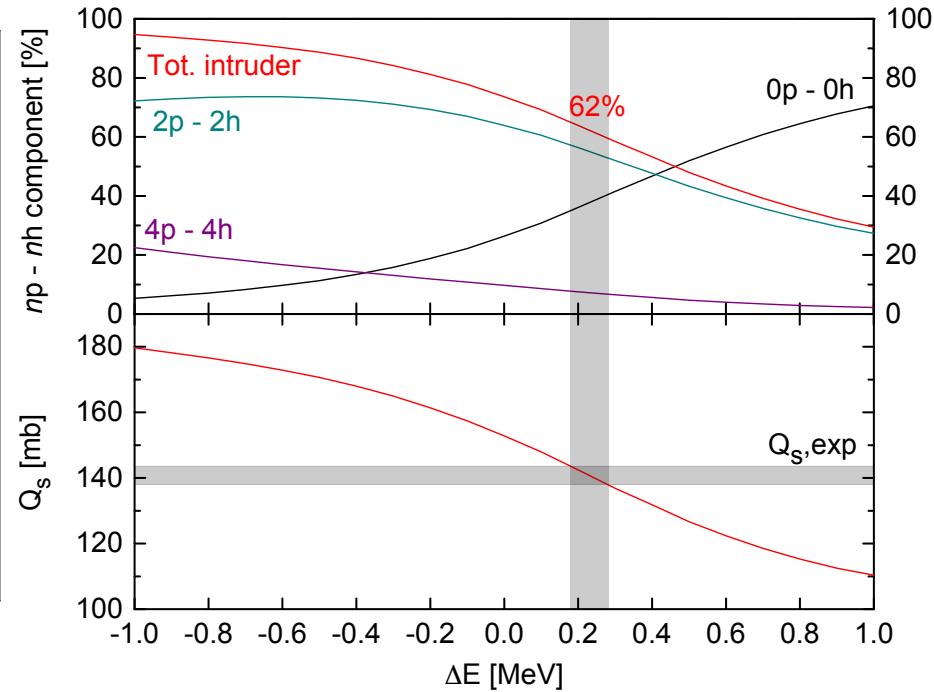
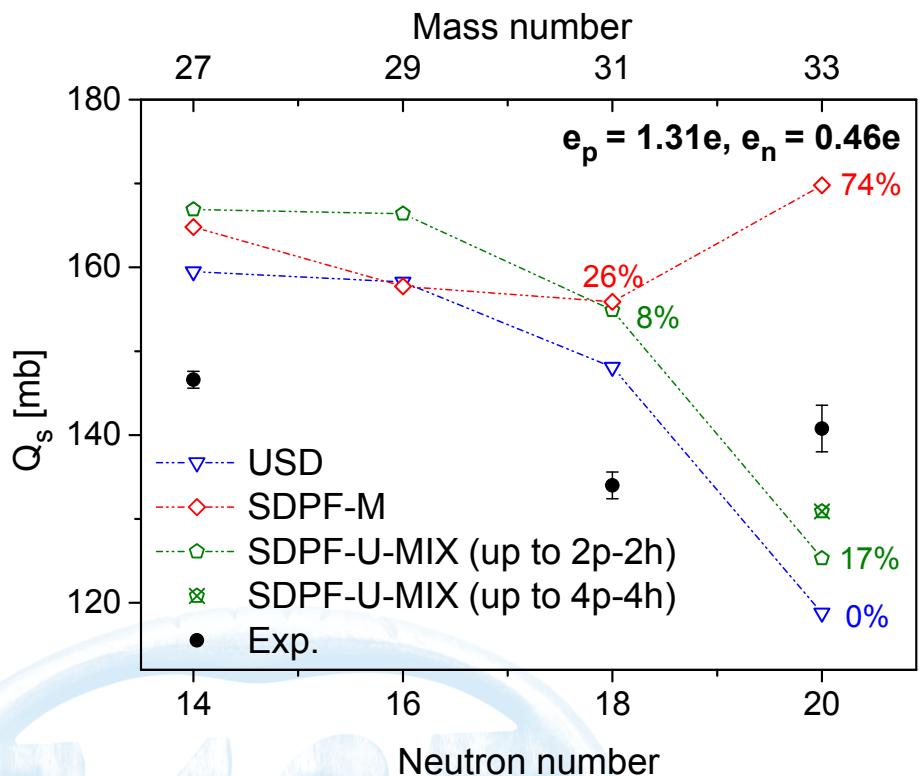


**Collaboration**  
KU Leuven  
GANIL  
RIKEN  
Tokyo Tech  
University of Tokyo  
University of Athens  
CEA/DAM/DIF

**Questions?**

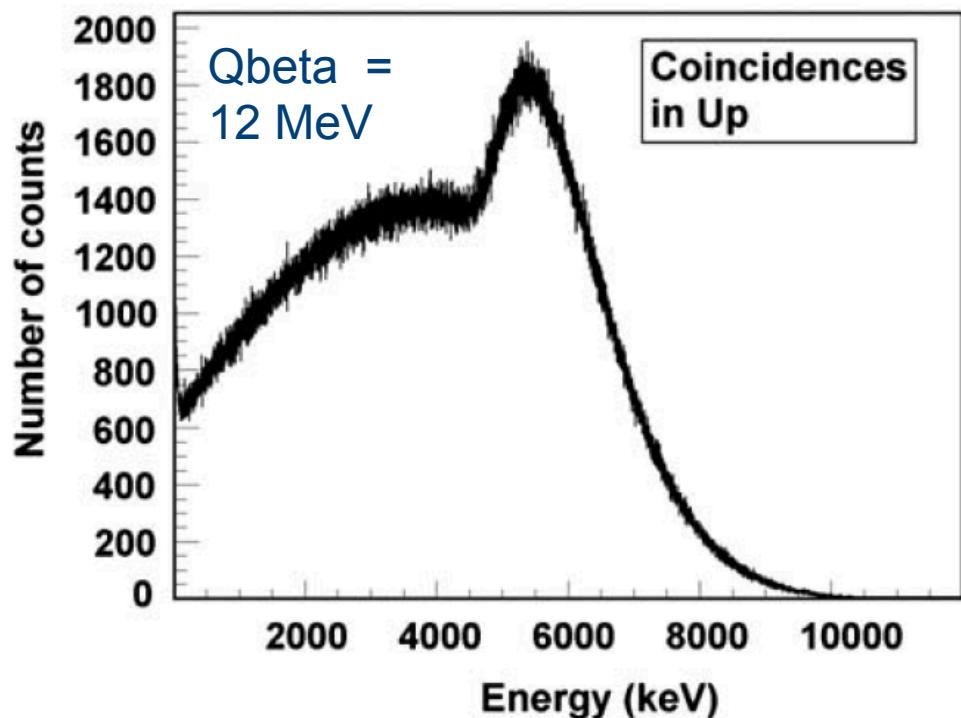


# High-precision quadrupole moment of $^{33}\text{Al}$



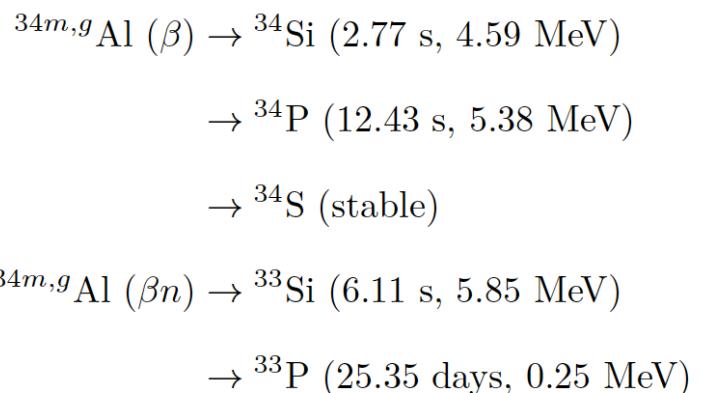


# Geant4 simulations



$\Delta E$  peak around 5.5 MeV

- This high energetic electrons which pass through both detectors.
- 7000 Ch ~ 5.5 MeV -> 3500 Ch ~ 2.25 MeV





# Strategy

Finish analysis → Analysis report

- Normalization
- → Try with entire baseline
- NQR 34AI
  - After break → Energy cuts
  - 1 file which doesn't contribute
- Systematic analysis of 32AI
  - Influence of energy cuts on extracted parameters
- Magnet calibration
- Gamma spectra → TAC triggered vs gamma singles
- Bootstrapping of 34AI
  - Randomly pick events, Add trees together
- Compare <3500 asymmetry → Different sign → Way to normalise? Compare if ratio remains the same?
- Publications