IRP COPIGAL project No. 6

MAGNETIC MOMENTS OF SHORT-LIVED STATES USING TDRV TECHNIQUE

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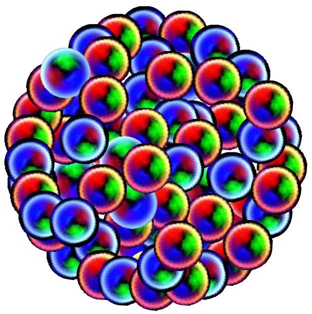
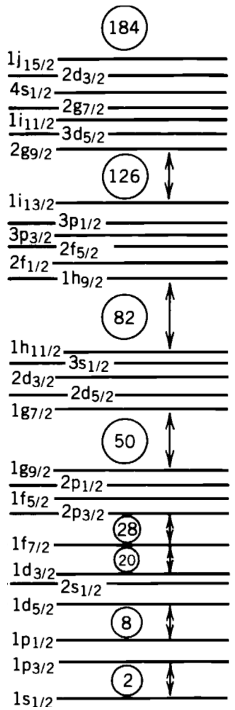
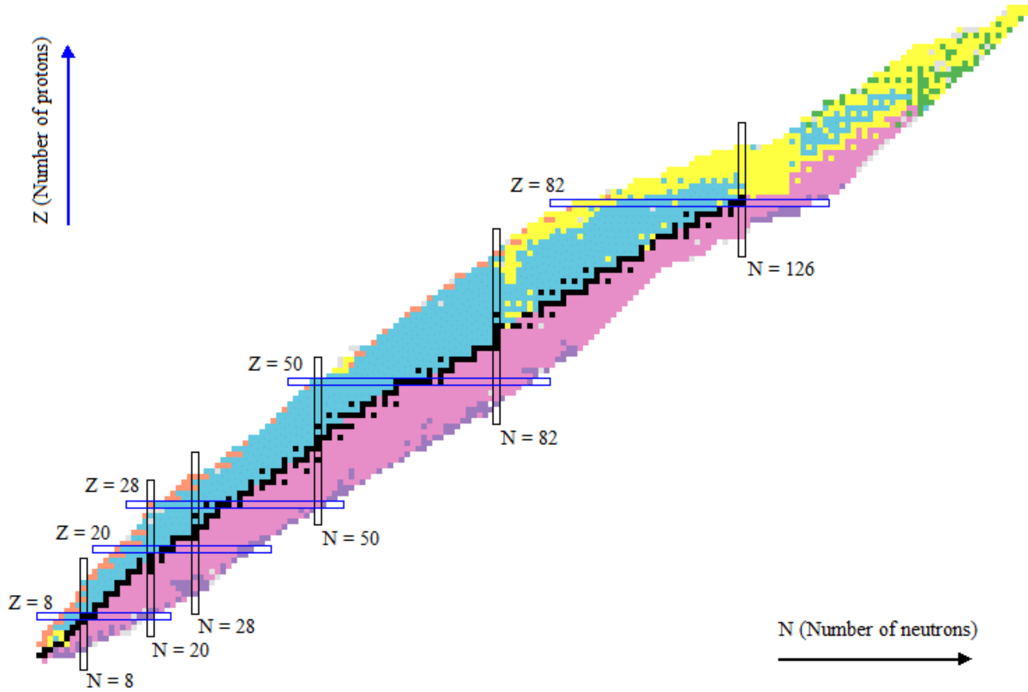
Shell-model of atomic nucleus







The nuclear magnetic dipole moment is sensitive to the single-particle structure!

Magnetic dipole moment

The **magnetic moment** is a property of a magnet that interacts with an externally applied magnetic field to generate a mechanical moment. Spinning charge generates the magnetic field, so spinning protons act like small magnets.

MAGNETIC DIPOLE MOMENT OF A NUCLEAR STATE

$$\vec{\mu} = g\vec{I}\mu_N$$

g factor
nuclear gyromagnetic ratio

spin of
nuclear state

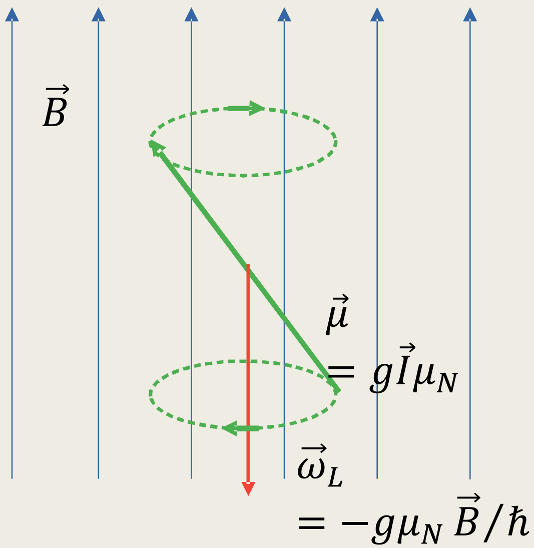
$\mu_N = e\hbar/2m_p$
nuclear magneton
unit of nuclear magnetic moment

Generated by:	Sensitive to:
• orbital motion of protons • intrinsic spins of all nucleons	• single-particle configurations of a nuclear state • single-particle energies of the orbitals

*In particular, the **g factor** reveals which single particle orbits are occupied by the valence nucleons and can be used as a rigorous probe for the proton-neutron character of the nuclear states.*

Measurement of magnetic moments of excited states

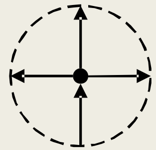
Nuclear spin gives rise to nuclear magnetic moment which leads to magnetic interaction with environment.



Larmor frequency

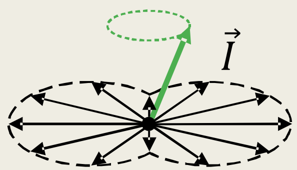
1) Excited nuclear states de-excite through **gamma-ray emission**

- Randomly oriented nuclear spins:



) = const

- **Spin-aligned nuclear ensemble:**



ω_L ←)

2) Half-lives of excited states span multiple orders of magnitude

- Period of precession must be similar to the half-life of the state of interest

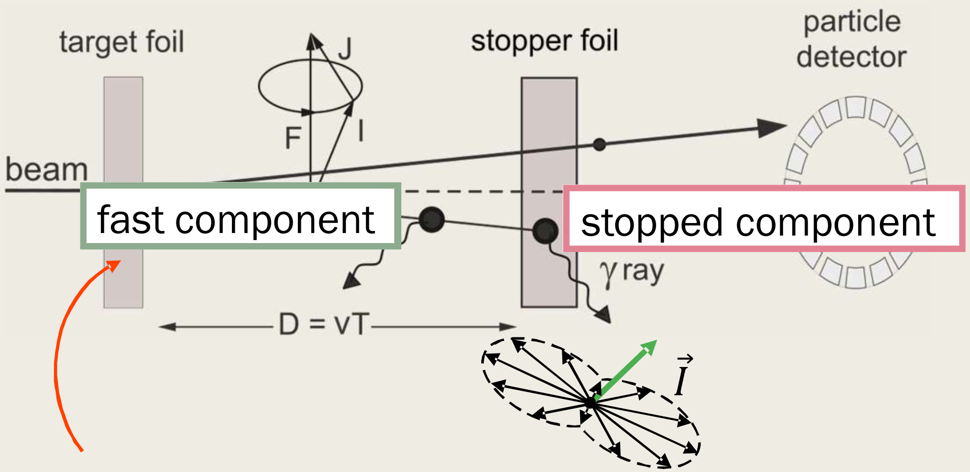
↓

Select *B*

$T_{1/2} \approx$ ns, μs $B \approx$ [T] **Electromagnets**

$T_{1/2} \approx$ ps $B \approx$ [kT] **Hyperfine fields**

Time-Differential Recoil-In-Vacuum technique



Spin-oriented nuclear states
populated in nuclear reaction

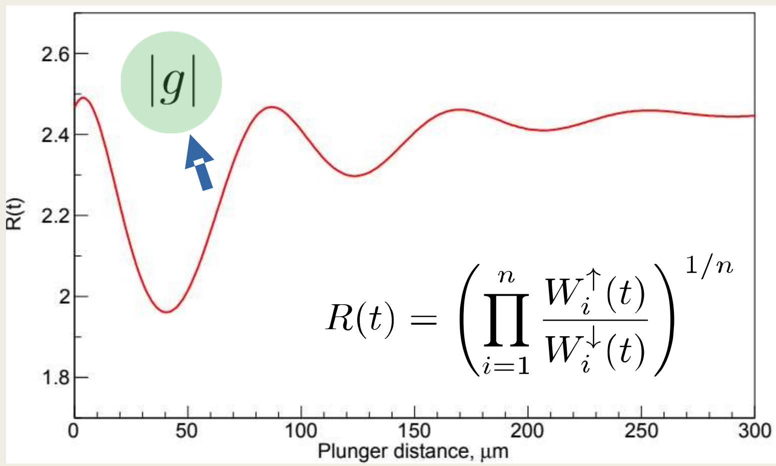
Particle-gamma angular correlations

$$W(\theta_p, \theta_\gamma, \Delta\phi, t) \propto cos(\omega_{FF}, t)$$

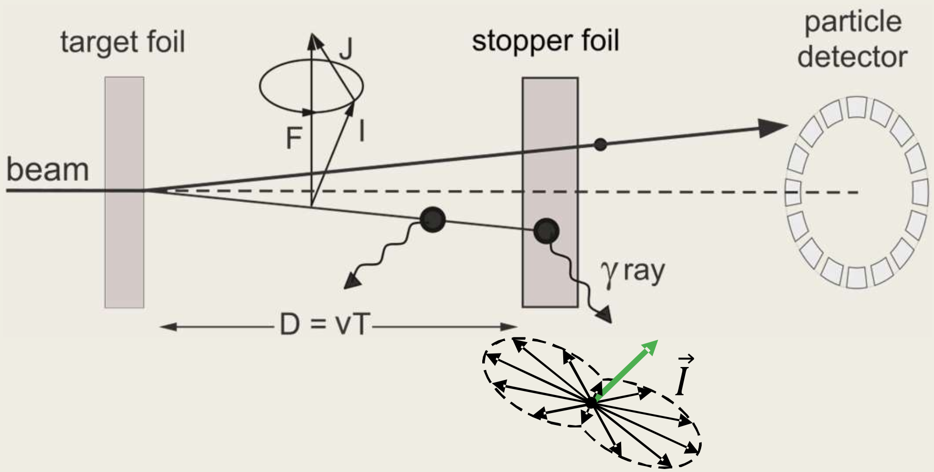
fast component

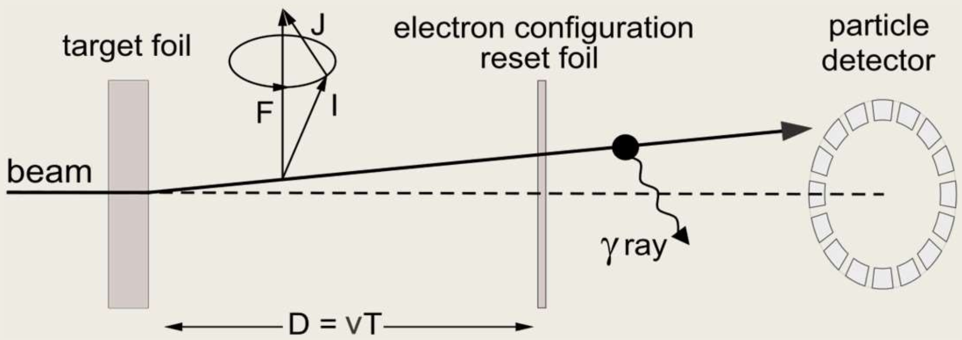
stopped component

→ $R(t)$ → g factor



TDRIV on Radioactive Ion Beams





A.E.Stuchbery *et al.*, PRC71, 047302 (2005).

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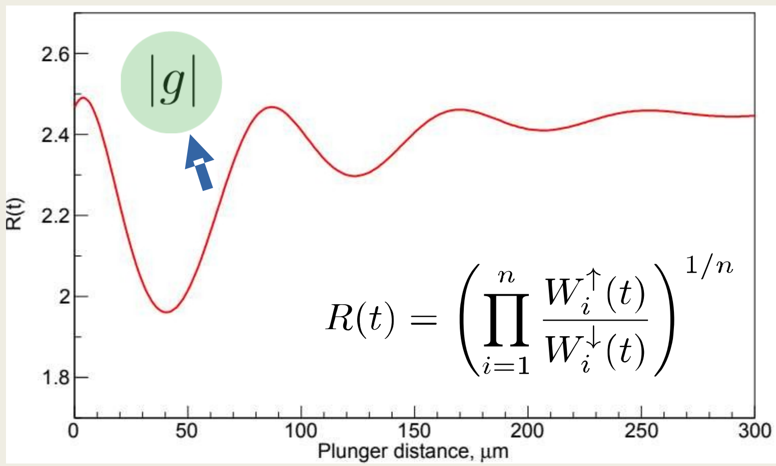
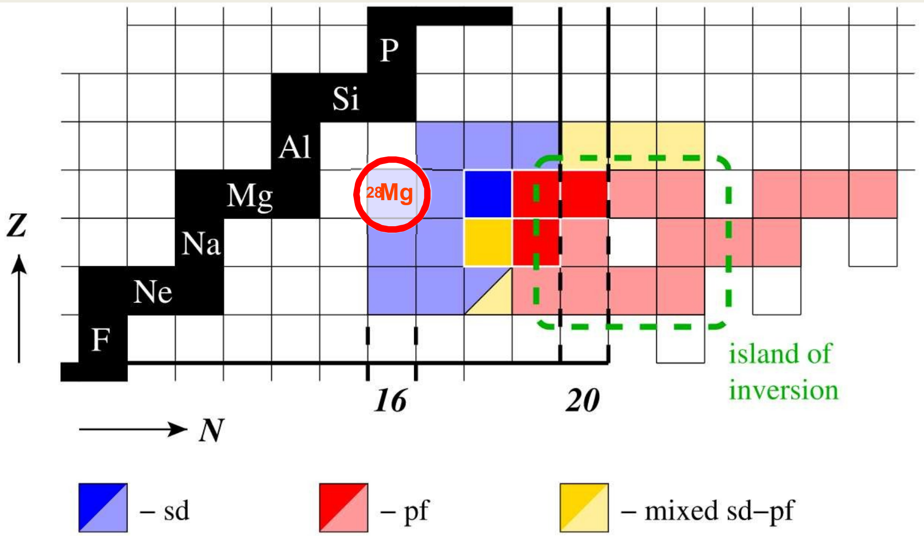


TDRIV on RIB: N=20 Island of Inversion

The aim of that measurement was to reveal possible *fp* admixtures in the Mg isotopes when approaching the Island of Inversion around ^{32}Mg.

P.A. Butler *et al.*, 2017 J. Phys. G: Nucl. Part. Phys.44 044012

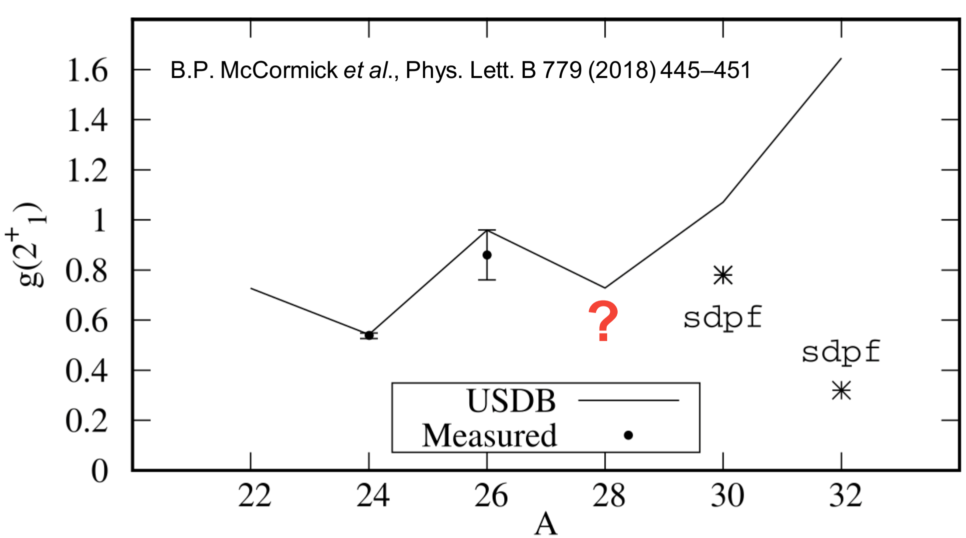


Where does the Island of Inversion for the Mg isotopes begin → ^{31}Mg?

Recent calculations predict *fp* admixtures in the ground state of ^{30}Mg and even in the ground state of ^{28}Mg

(*N. Tsunoda, et al., Phys. Rev. C 95 021304(R) (2017)*)

TDRIV on RIB: *N*=20 island of inversion



Comparison of USDB shell model calculations and experiment for Mg isotopes g-factor values. The theoretical g factors for ^{30}Mg and ^{32}Mg in a more realistic sdpf model space are shown by the stars.

TDRIV measurement of $g(2_1^+, {}^{28}\mathrm{Mg})$ with H-like ions:

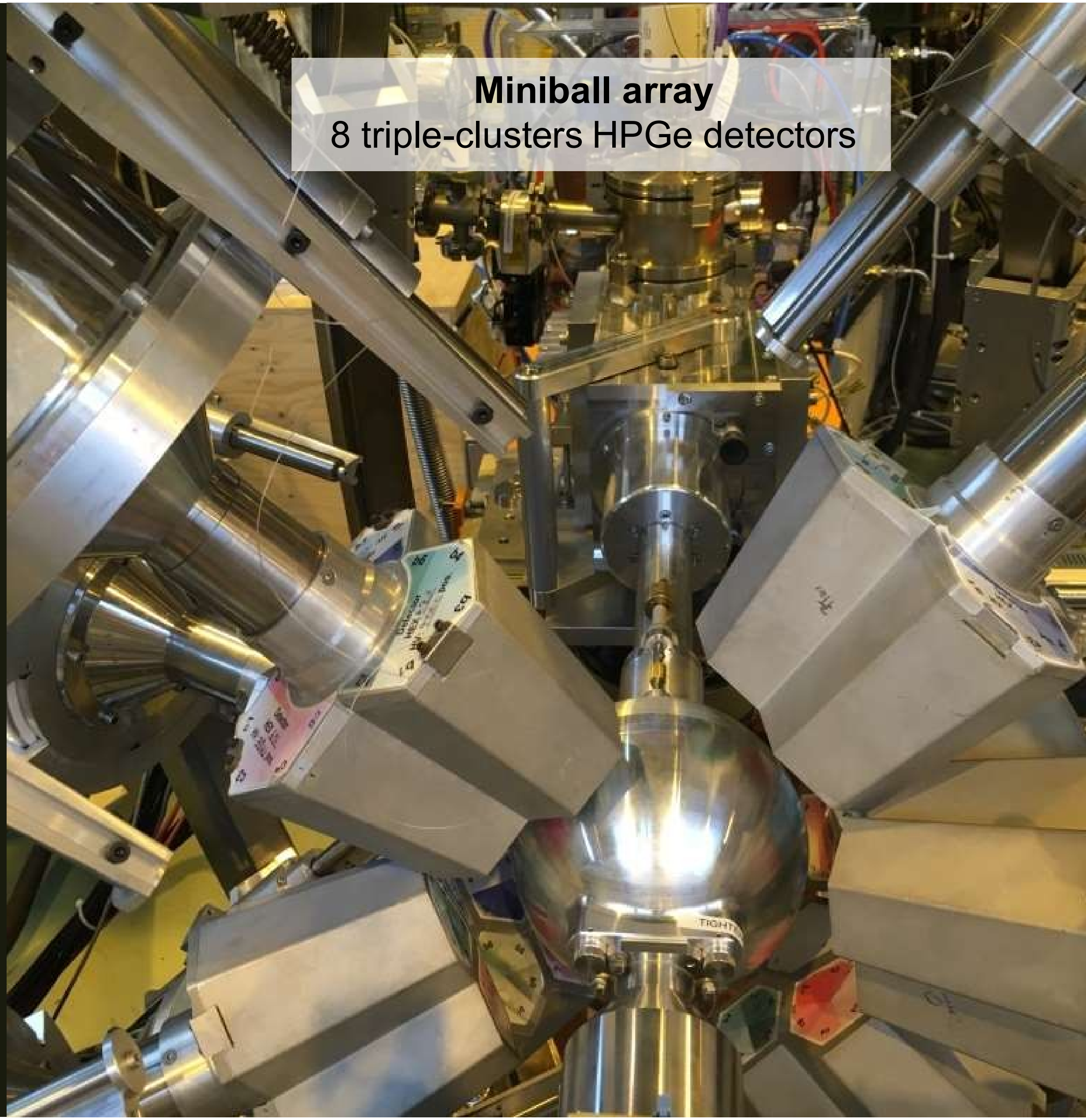
- ❑ Test the feasibility of the TDRIV method on a RIB
- ❑ A sensitive tool to study the composition of the excitations at N=16 and, thus, probe the boundaries of the Island of Inversion

Miniball setup

CD DSSSD particle detector

Miniball plunger

Target: 3.9 mg/cm^2 ^{93}Nb
Degrader: 1.1 mg/cm^2 ^{181}Ta



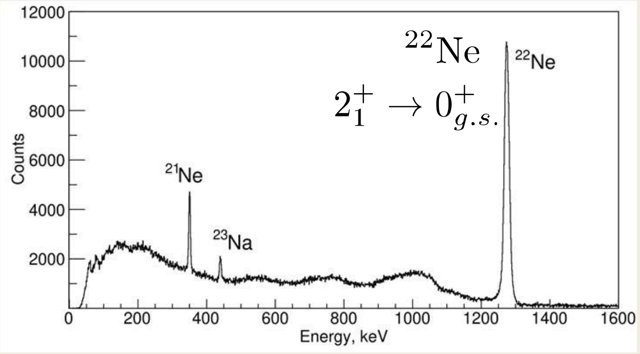
Miniball array
8 triple-clusters HPGe detectors

Experiment IS628

1) A test measurement (calibration) with **^{22}Ne beam** of 121 MeV (5.5 MeV/A, ~10^7 pps)

- reaction - beam Coulex
- 25 plunger distances
- testing the setup with a well known case (g=0.326(12))
- **plunger's zero offset** – important to determine on known case for TDRIV technique

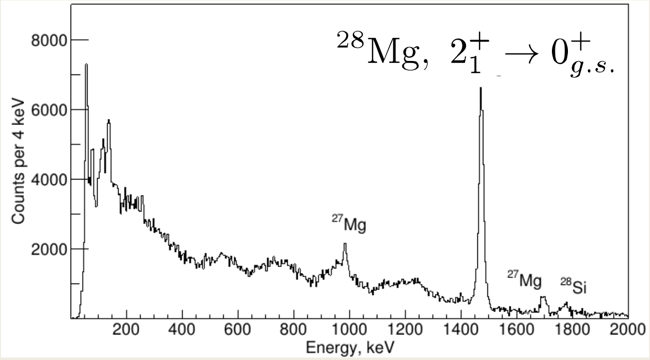
$T_{1/2}$ = 3.60(5) ps



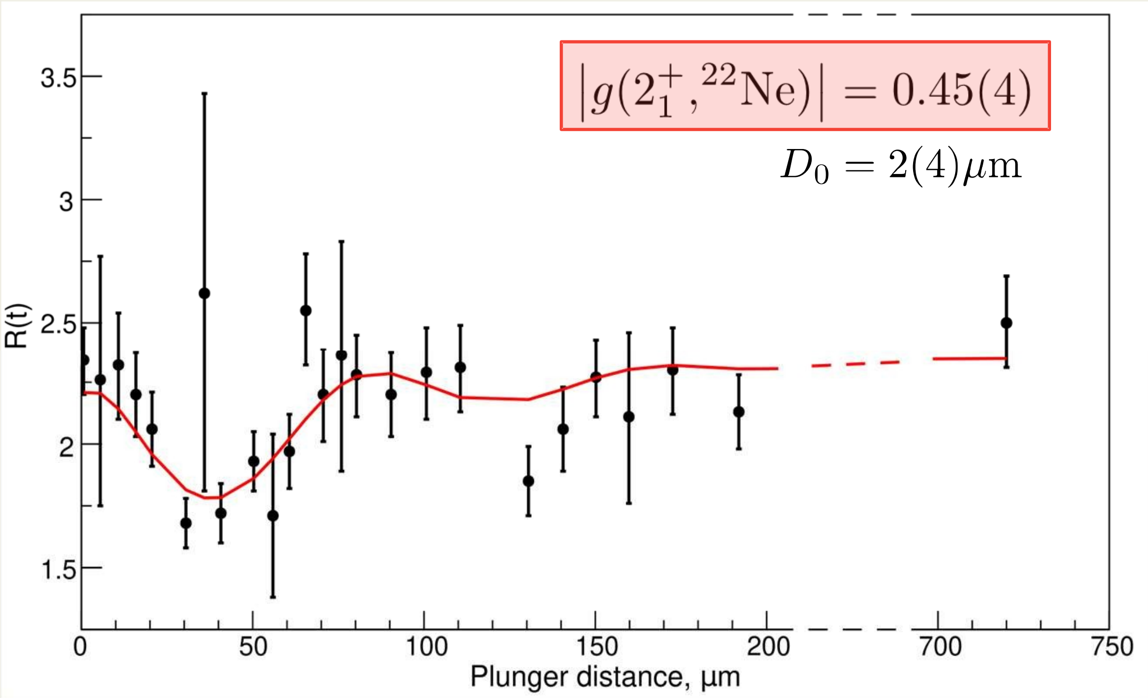
1) **^{28}Mg** (5.5 MeV/A, ~10^6 pps)

- high HPGe rates from β decay
- beam contamination ^{28}Si (~40%)
- determining the oscillation frequency – plunger's zero offset is a free parameter (to be determined from ^{22}Ne)
- 10 plunger distances

$T_{1/2}$ = 1.2(1) ps

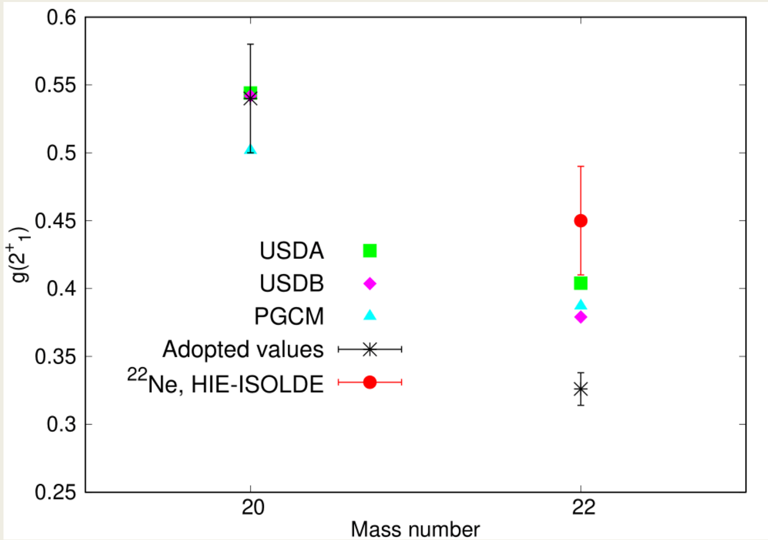


^{22}Ne results



$\left|g(2_1^+, {}^{22}\mathrm{Ne})\right| = 0.326(12)$

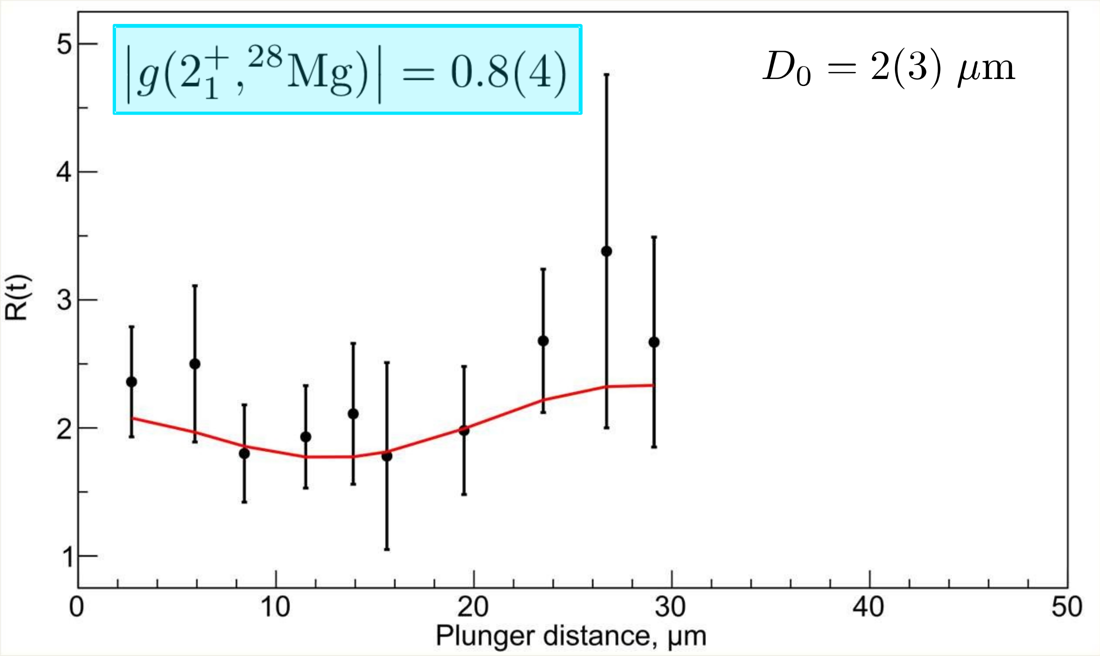
R.E. Horstman *et al.*, NP A 275 (1977), 237



Such a big discrepancy shows that the literature value cannot be used in the analysis of our ^{28}Mg data.

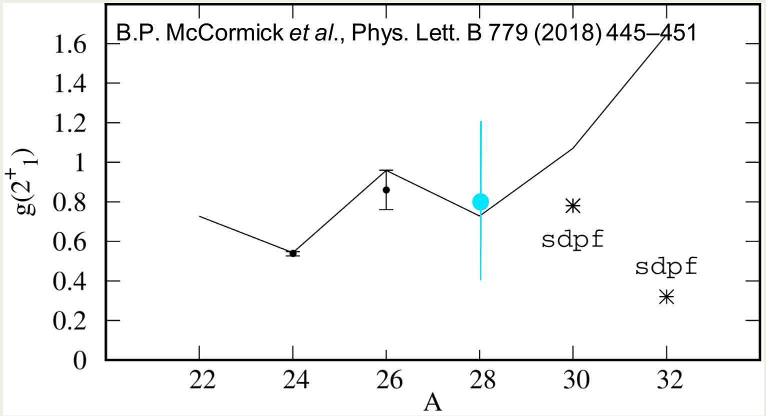
A new, high precision measurement was needed!

^{28}Mg results



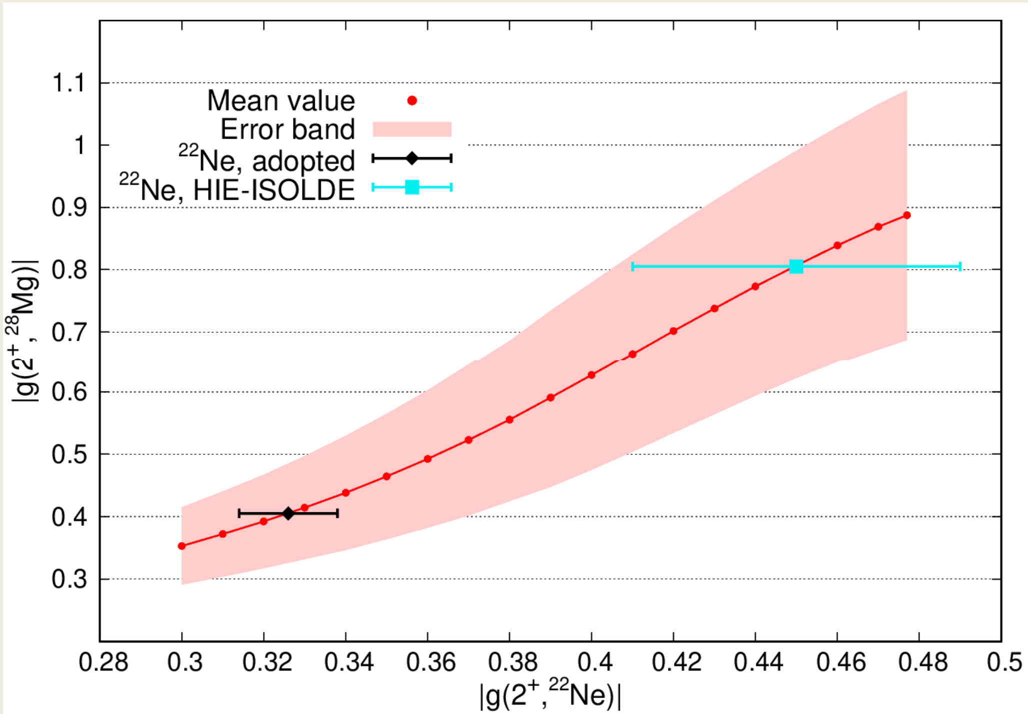
Initial goals of IS628:

- ✓ Test the feasibility of the TDRIV method on a RIB
- ✗ Probe the boundaries of the island of inversion

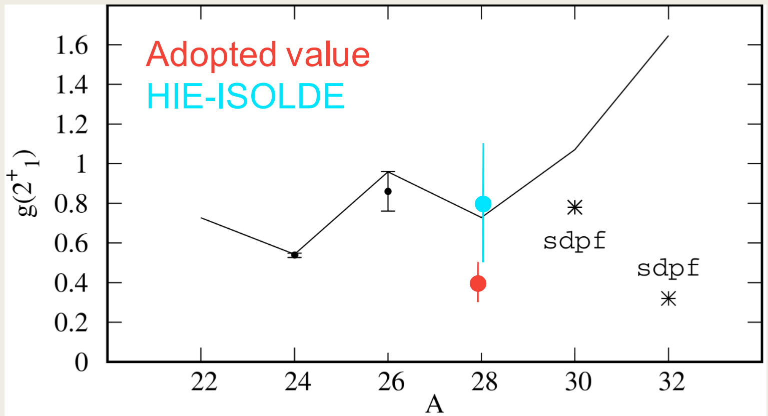


Correlation curve

The maximum that is presently achievable
is a correlation between the g factor values of ^{22}Ne and ^{28}Mg



1) Fix ^{22}Ne g-factor value
2) Fit ^{22}Ne data for the zero-offset distance
3) Fit ^{28}Mg data with fixed zero-offset distance



Courtesy of K. Stoychev

^{22}Ne TDRIV at GANIL (September 2024)

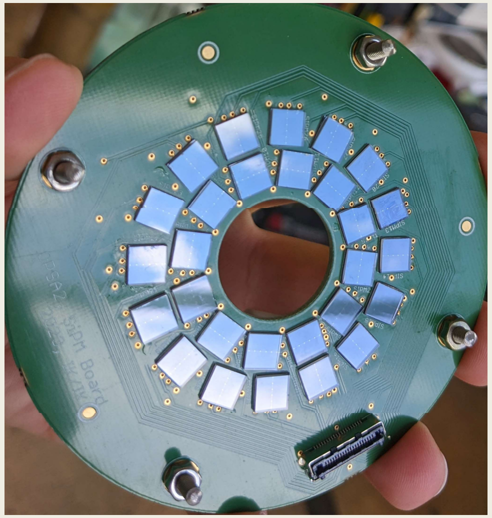
Beam: **^{22}Ne** @ 5.5 MeV/A
Intensity: **~10^9 pps (~0.2 pnA)**
Target: 3.4 mg/cm^2 ^{93}Nb
Reset foil: 1.9 mg/cm^2 ^{181}Ta + 20μg/cm^2 ^{12}C

Aim: obtain a high-accuracy value (~2%) for the g factor of ^{22}Ne that would:
1) Allow for a reliable comparison with the theory
2) Provide a sufficiently accurate value for the g factor of ^{28}Mg

Experimental setup

- 12+ EXOGAM Clover detectors
  - ~12 % efficiency
  - more sensitive angular positions
- **Orsay Particle Scintillator Array (OPSA)**
  - two rings of LYSO+SiPM
  - good granularity and high acceptable rate
- Orsay Universal Plunger System (OUPS)

OPSA particle detector



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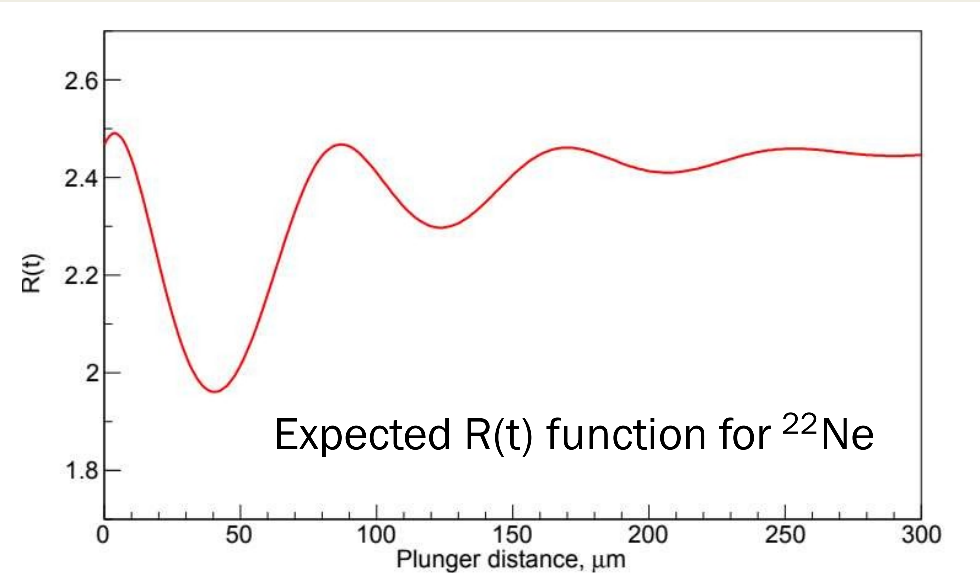

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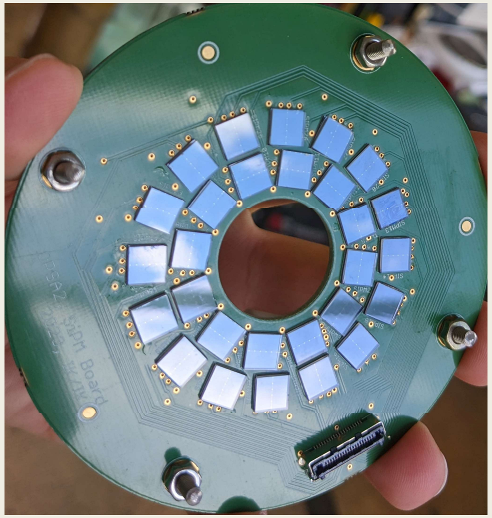

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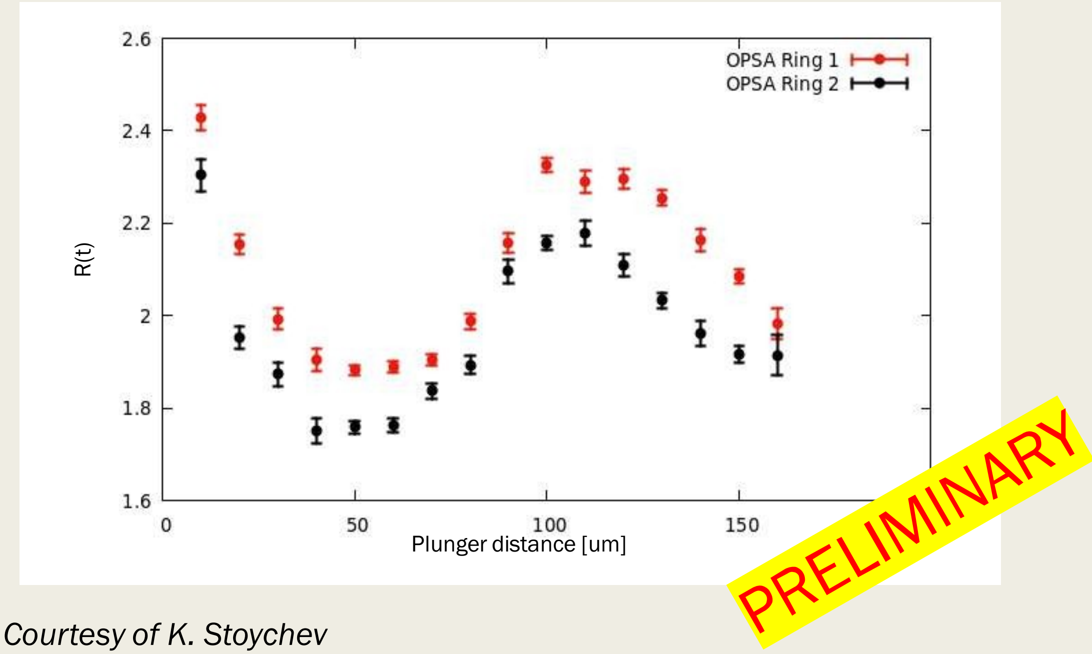

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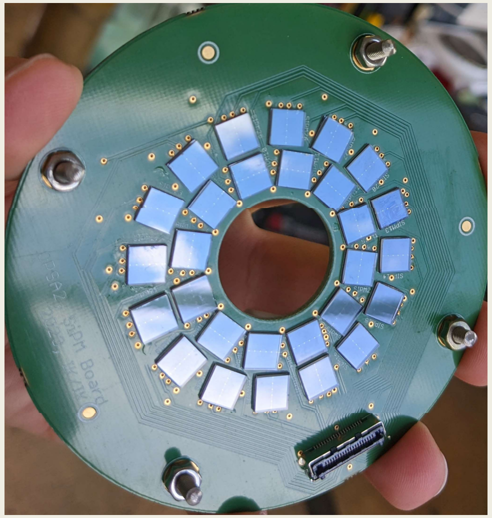
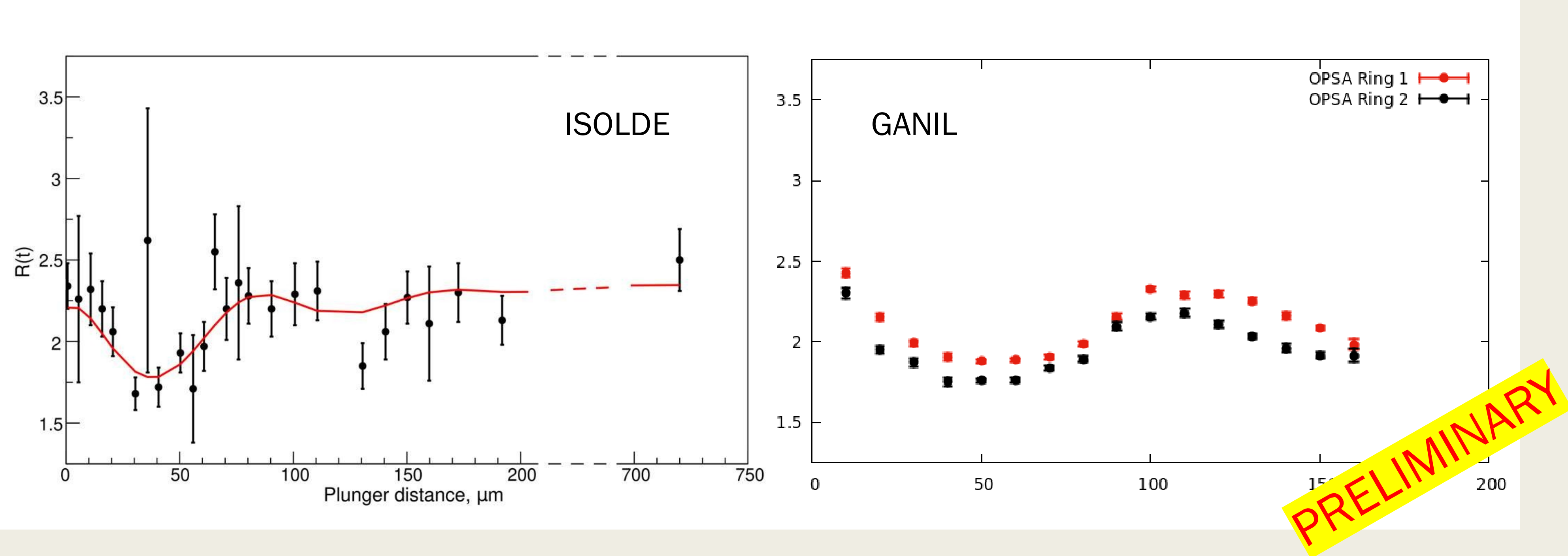


Courtesy of K. Stoychev

More precise value of g factor for ^{22}Ne should be obtained!



Courtesy of K. Stoychev

TDRIV on RIBs at the presently available beam intensities require test measurements with stable beams with well defined g factors.

It appears that not all old high-precision values are not accurate enough and my need to be revisited.

✓ ***First TDRIV experiment on a RIB*** *at* ***ISOLDE***

✗ **g(2^+, ^{22}Ne)** discrepancy with literature value

✓ *A repeat TDRIV measurement of* ***g(2^+, ^{22}Ne)*** *at* ***GANIL*** *(2024) - may solve the puzzle both on the experimental and theoretical sides*

- Analysis of the collected data
- Re-visit ISOLDE data to extract **g(2^+, ^{28}Mg)** from correlation curve
- Return to **GANIL** or **ISOLDE** for future TDRIV measurements on RIBs

Thank you for your attention!