



TNA04 Highlight:

Recoil β - decay tagging of $N=Z$ nuclei:

First observation of The $A = 66$, $T = 1$ triplet up to 6^+ :
Coulomb and isospin non-conservation effects



THE UNIVERSITY
of EDINBURGH

THE UNIVERSITY
of York

cea

Saclay

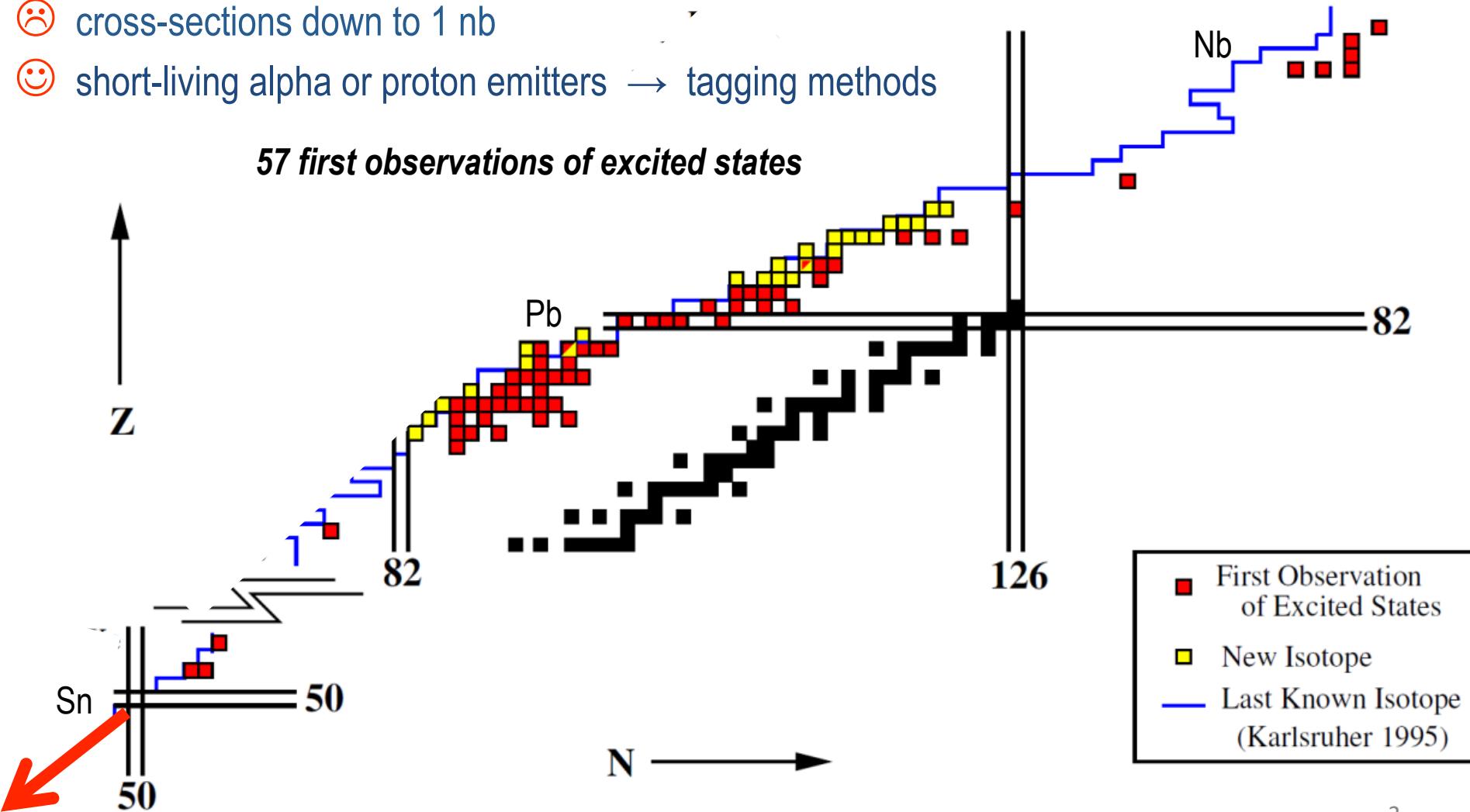


UNIVERSITY OF JYVÄSKYLÄ

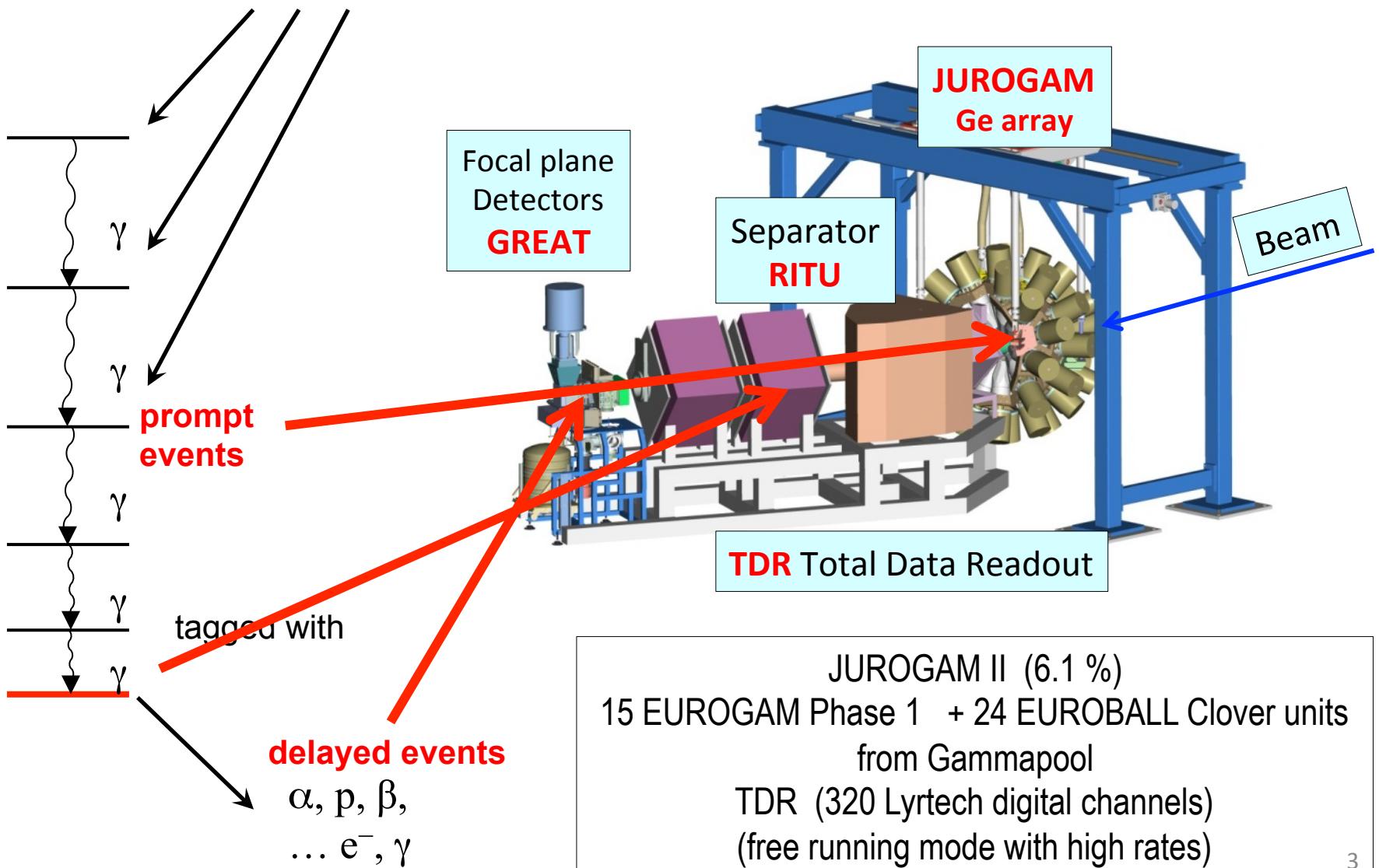
PROBING PROTON-RICH AND HEAVY NUCLEI WITH RECOIL - DECAY - TAGGING (RDT)

very neutron deficient heavy nuclei

- 😊 can be produced via fusion evaporation with stable-ion beams and stable targets
- 😢 cross-sections down to 1 nb
- 😊 short-living alpha or proton emitters → tagging methods



RECOIL - DECAY - TAGGING (RDT) WITH JUROGAM + RITU + GREAT



TOWARDS LIGHTER PROTON-RICH NUCLEI

RECOIL β - DECAY TAGGING

SPECTROSCOPY OF N = Z NUCLEI

Challenge:

- ✓ Large number of fusion-evaporation channels open
→ high rate at the focal plane of the separator
- ✓ No discrete lines from α- nor p- decay for tagging

Methods used so far:

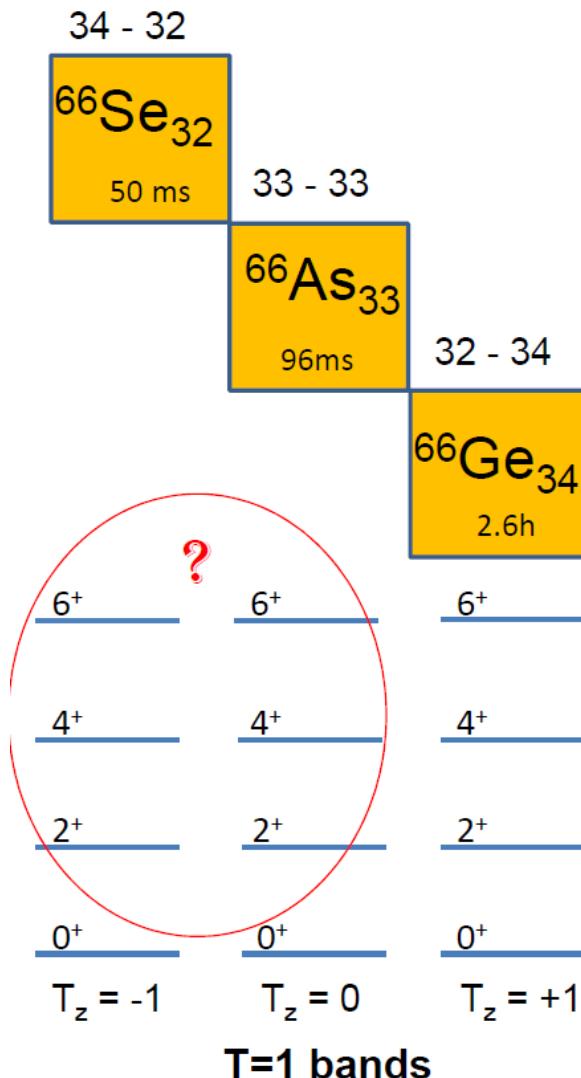
- Channel selection by particle-detector array around the target
- RIB: decay studies or knock-out

	Kr 83.798	Kr 69 32 ms	Kr 70 57 ms	Kr 71 100 ms	Kr 72 17 s	Kr 73 26 s
36	σ 24	β ⁺ βp 4.07	β ⁺	β ⁺ 9.1... γ 198; 207 βp 0.6 - 5.1	β ⁺ 2.8... γ 175; 310; β 63; 577...	β ⁺ 5.6... γ 198; 241; 455... βp 1.5 - 3.0
35	Br 79.904	Br 68 <1.5 μs	Br 69 <24 ns	Br 70 2.2 s 7.1 ms	Br 71 21.4 s	Br 72 10.9 s 1.3 ms
33	Se 78.96 σ 12	Se 64 ? β ⁺ ?	Se 65 <50 ms β ⁺ βp 3.55	Se 66 33 ns β ⁺	Se 67 107 ms β ⁺ γ 352 βp	Se 68 35.5 s β ⁺ 5.6; 5.8... γ 98; 67; 692... βp 1.1; 15; 61; 12... β 1.1; 15; 61; 12...
	As 74.92160 σ 4.0	As 64 40 ms β ⁺	As 65 0.19 s β ⁺	As 65 0.19 s β ⁺	A 67 4.5 s β ⁺ 4.5; 5.0... γ 123; 21; 244...	As 68 2.53 m β ⁺ 4.7; 6.1... γ 1016; 762; 651; 1778... β 1.1; 15; 61; 12...
	Ge 61 40 ms β ⁺ βp 3.10	Ge 62 130 ms β ⁺	Ge 63 95 ms β ⁺	Ge 64 64 s β ⁺ 3.6; 3.3... γ 127; 667; 28...	Ge 65 31 s β ⁺ 4.6; 5.2... γ 650; 62; 809; 191... β 1.28...	Ge 66 5 s ε 0.7; 1.1... γ 382; 44; 109; 273...
	Ga 60 70 ms β ⁺ 8.3; 12.2... γ 1004; 3848... βp βα ?	Ga 61 168 ms β ⁺ 8.2... γ 88; 418; 124; 756...	Ga 62 115.99 ms β ⁺ 8.1... (954...)	Ga 63 31.4 s β ⁺ ~4.5... γ 637; 627; 193; 650...	Ga 64 2.62 m β ⁺ 2.9; 6.1... γ 992; 808; 3366; 1387; 2195...	Ga 65 15 m β ⁺ 2.1; 2.2... γ 115; 61; 153; 752...
	Zn 59 182 ms β ⁺ 8.1... γ 491; 914 βp 1.78; 2.09; 1.82; 1.38...	Zn 60 2.4 m β ⁺ 2.0; 3.1... γ 670; 61; 273; 334...	Zn 61 1.5 m β ⁺ 4.4... γ 475; 1660; 970...	Zn 62 9.13 h ε 0.7	Zn 63 38.1 m β ⁺ 2.3... γ 41; 597; 548; 508...	Zn 64 48.268 σ 0.74
					Zn 65 244.3 d σ _{n, α} 1.1E-5 σ _{n, p} < 1.2E-5	Zn 66 27.975 σ 0.9
						Zn 67 4.102 σ _{n, α} 0.0004

New: Recoil – β – Tagging

RECOIL – β – TAGGING

Application: Energy Differences
between Isobaric Analog States of T=1 bands in A = 66 nuclei



MED = Mirror Energy Differences
TED = Triple Energy Differences



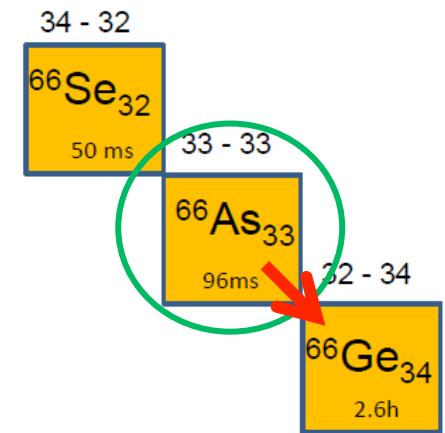
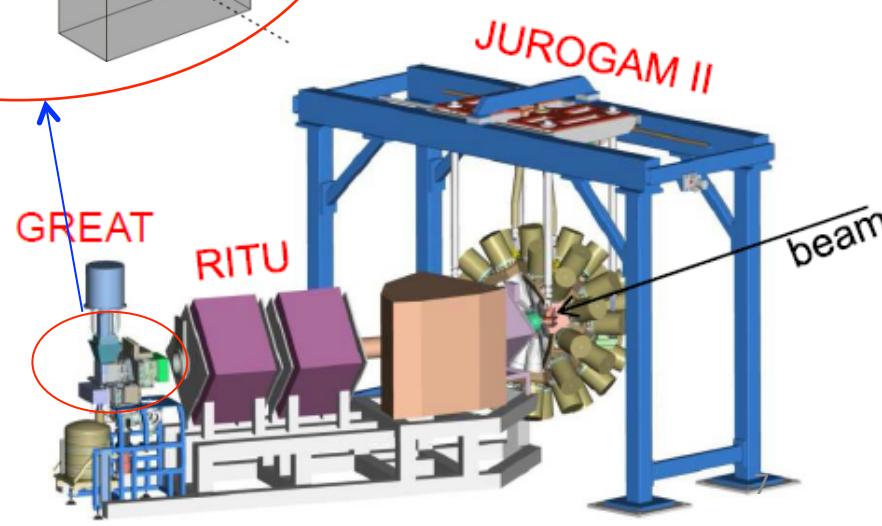
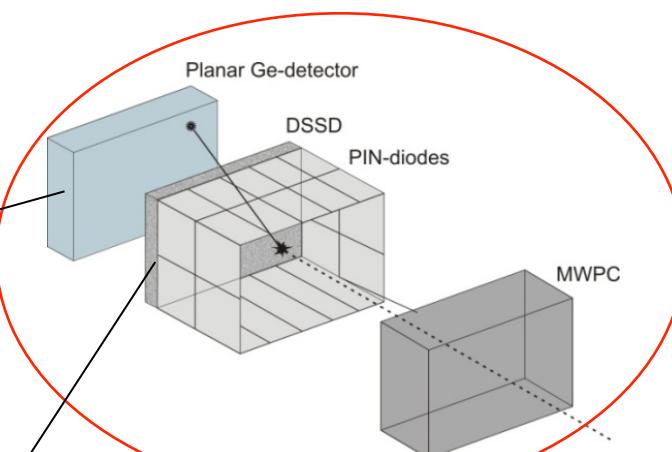
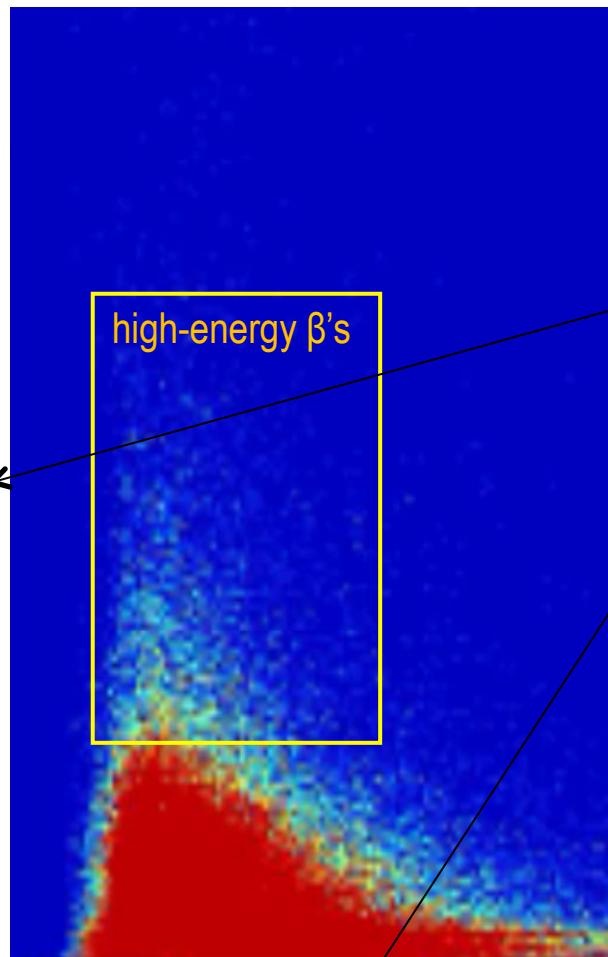
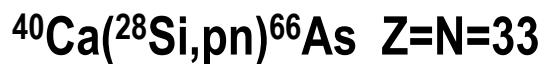
- *High-energy β decays (compared to other reaction products)*
- *Relatively fast super-allowed Fermi β decays:*



- *Continuous β - spectrum overlapping with those from uninteresting evaporation channels*

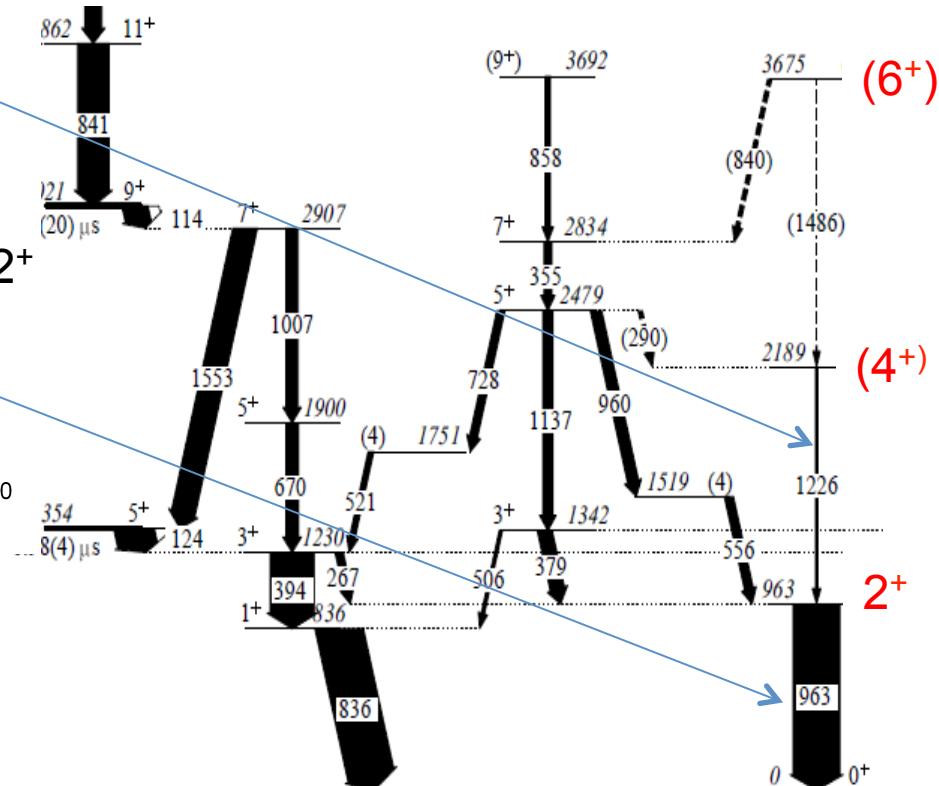
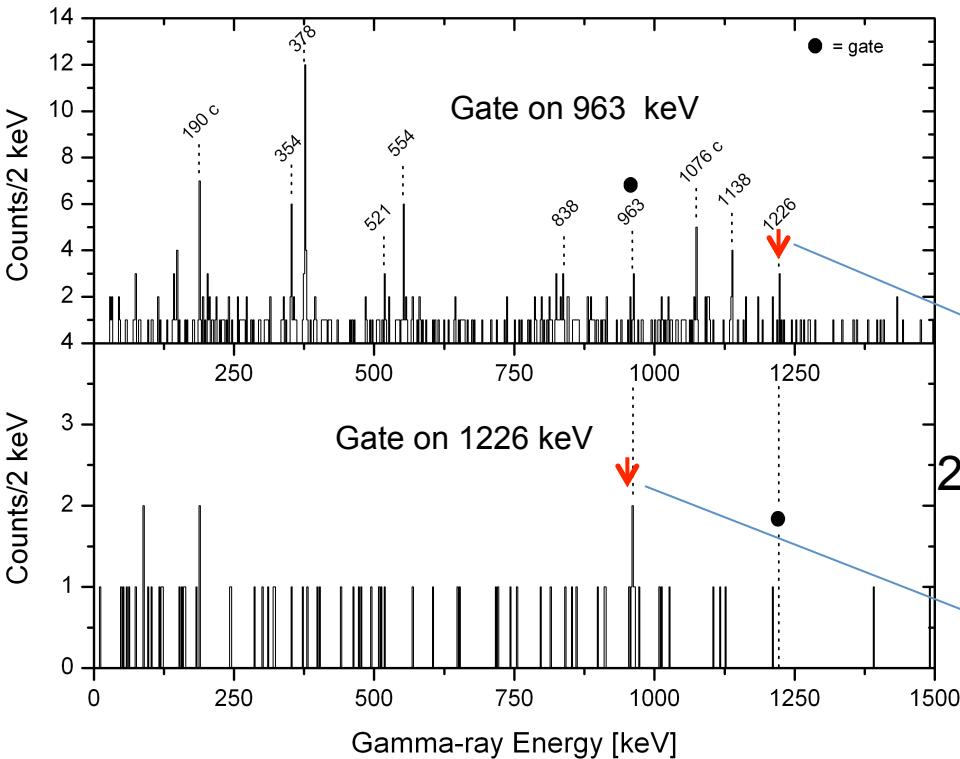
^{66}As ($Z = N = 33$)

γ -rays from $^{66}\text{As}_{33}$ tagged with its 96ms β decay



^{66}As ($Z = N = 33$)

γ -rays from $^{66}\text{As}_{33}$ tagged with its 96ms β decay

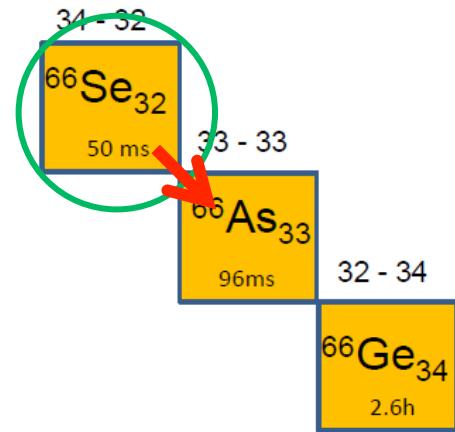


^{66}As is an odd-odd nucleus but still the 0^+ ground state is far below the first excited states, obviously due to the $T=1$ n-p pairing

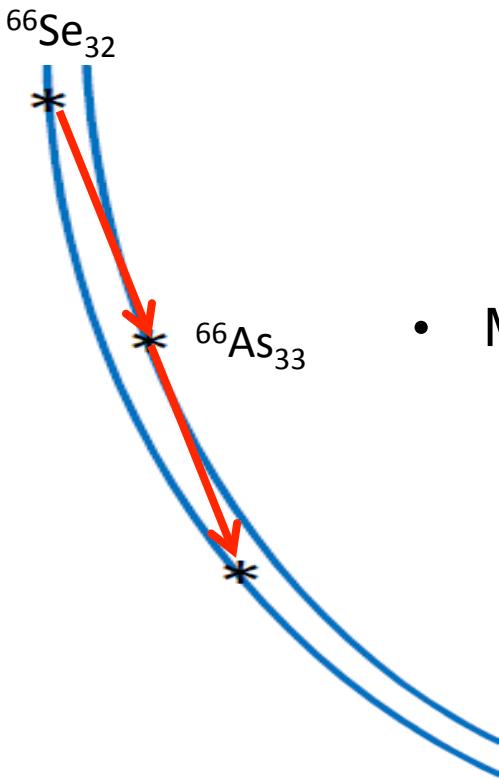
$T = 1$
 $T_z = 0$

^{66}Se (Z = 34, N = 32)

γ -rays from $^{66}\text{Se}_{32}$ tagged with its 50ms β decay



- ^{66}Se is an even-even nucleus
→ the T= 1 band is the yrast band



- Mass parabola → $^{66}\text{Se}_{32}$ and $^{66}\text{As}_{33}$ got similar β - decay energies and lifetimes

^{66}Se (Z = 32, N = 34)

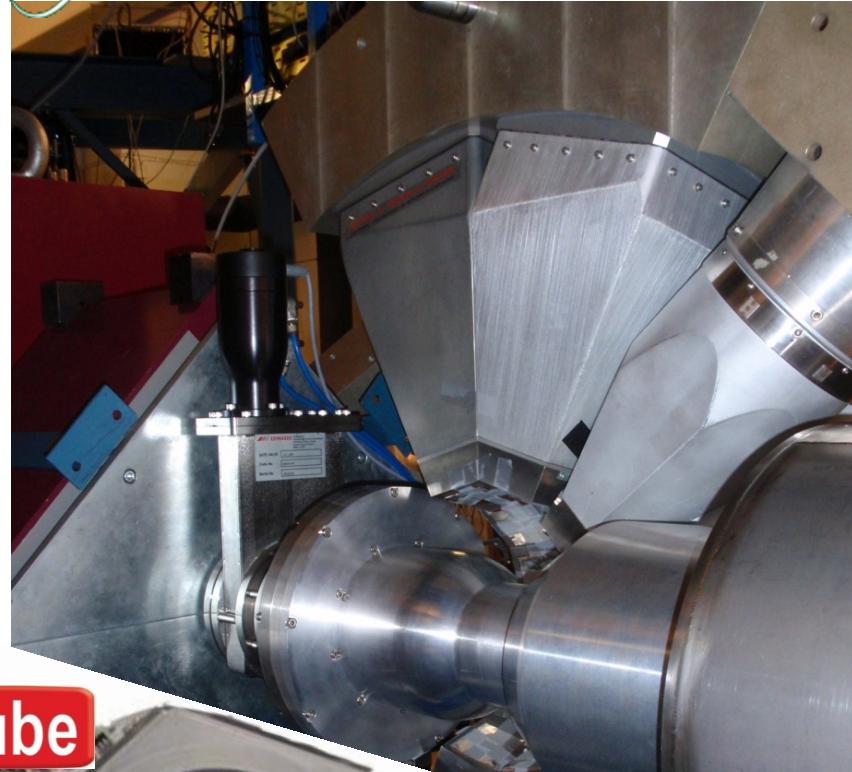


THE UNIVERSITY *of York*

Charged particle veto → efficient suppression
of disturbing proton-evaporation channels

$^{40}\text{Ca}(^{28}\text{Si},2\text{n}) ^{66}\text{Se} \sim 200\text{nb}$

Se 78.96	Se 64 ?	Se 65 <50 ms	Se 66 33 ms	Se 67 107 ms	Se 68 35.5 s	g _{9/2}
$\sigma 12$	$\beta^+ ?$	β^+ βp 3.55	β^+	β^+ γ 352	β^+ γ 3; 26	β^+ γ 3
33	As 74.92160	As 64 40 ms	As 65 0.19 s	As 66 96 ms	As 67 42.5 s	g _{5/2}
	$\sigma 4.0$	β^+	β^+	β^+	$\beta^+ 4.7$; 1... γ 123; 1... 244	β^+ γ 65
Ge 61 40 ms	Ge 62 130 ms	Ge 63 95 ms	Ge 64 64 s	Ge 65 31 s	Ge 66 2.1 s	g _{1/2}
β^+ βp 3.10	β^+	β^+	$\beta^+ 3.0$; 3.3... γ 427; 667; 128...	$\beta^+ 4.6$; 5.2... γ 650; 62; 809; 191... βp 1.28...	ϵ $\beta^+ 0.7$; 1.1... γ 382; 44; 109; 273...	β^+ γ 1
Ga 60 70 ms	Ga 61 168 ms	Ga 62 115.99 ms	Ga 63 31.4 s	Ga 64 2.62 m	Ga 65 15 m	g _{-1/2}



96 20 x 20 mm CsI
crystals

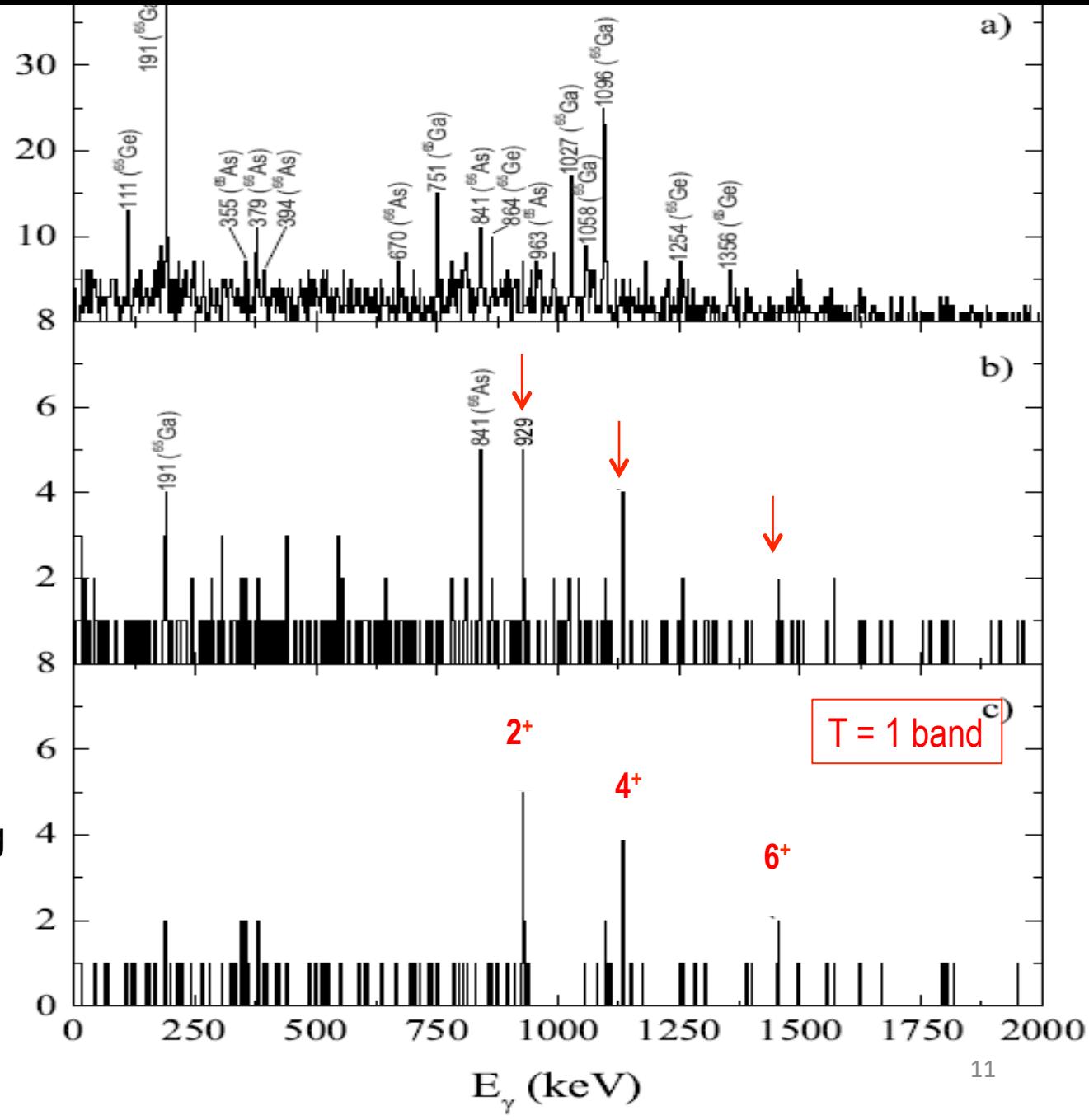


^{66}Se ($Z = 32$, $N = 34$)

γ -rays from $^{66}\text{Se}_{32}$ tagged
with its 50ms β decay

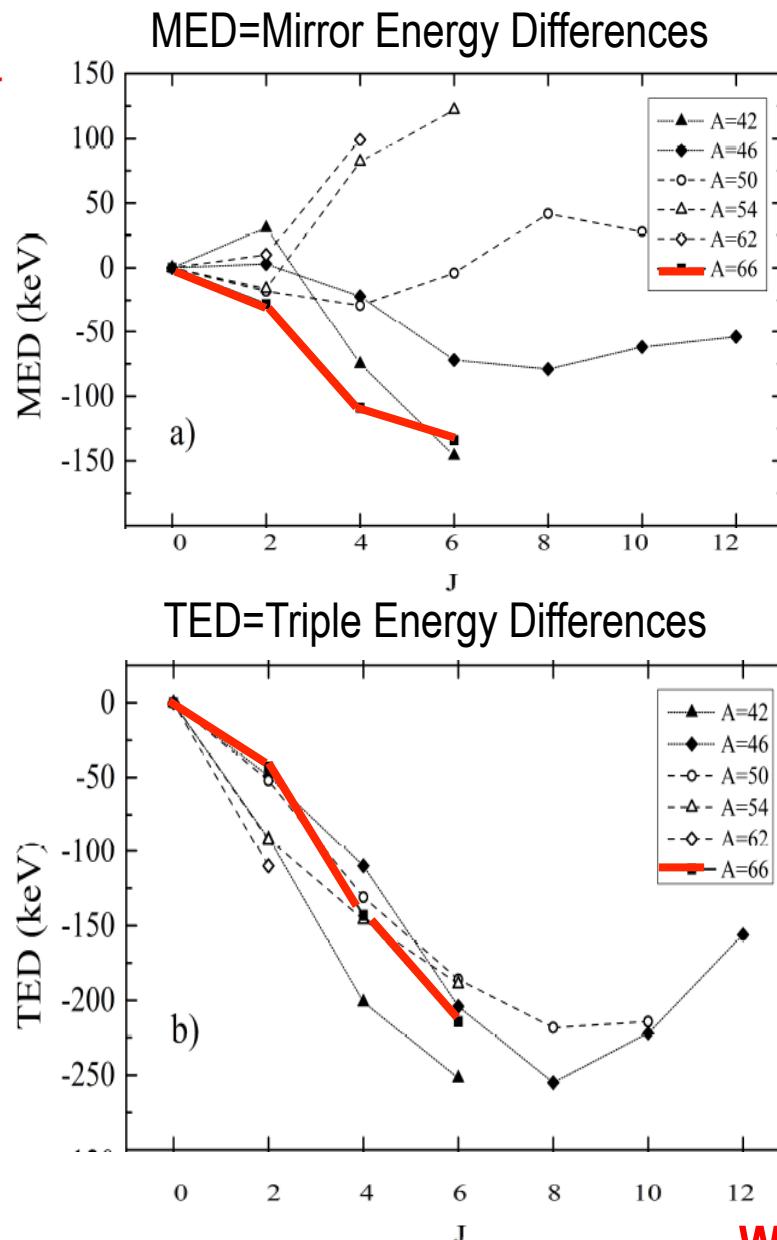
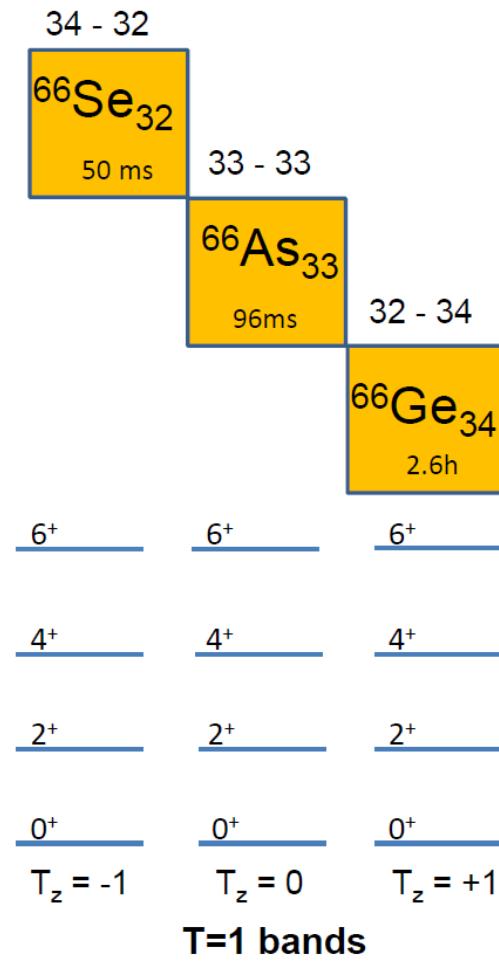
+ UoY **Tube** veto

+ ^{66}As isomer veto-tagging



MED AND TED

A=66 is the heaviest triplet of T = 1 bands up to 6+



$$\text{MED} = E_x(T_z = -1) - E_x(T_z = +1)$$

$$V = V_{pp} - V_{nn}$$

Charge symmetry

$$\text{TED} = E_x(T_z = -1) + E_x(T_z = +1) - 2 E_x(T_z = 0)$$

$$V = V_{pp} + V_{nn} - 2V_{pn}$$

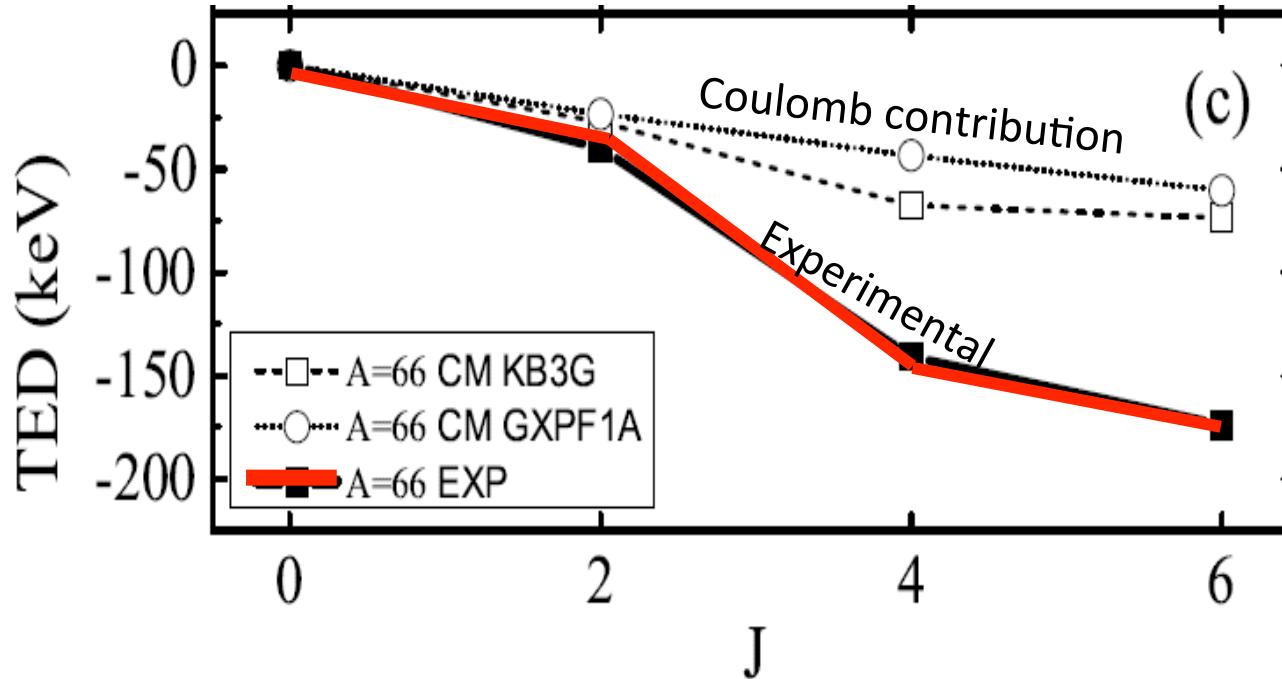
Charge independence

One-body terms cancel out

Why similar TED behaviour ?

TED

TED=Triple Energy Differences
for the A = 66 T=1 triplet

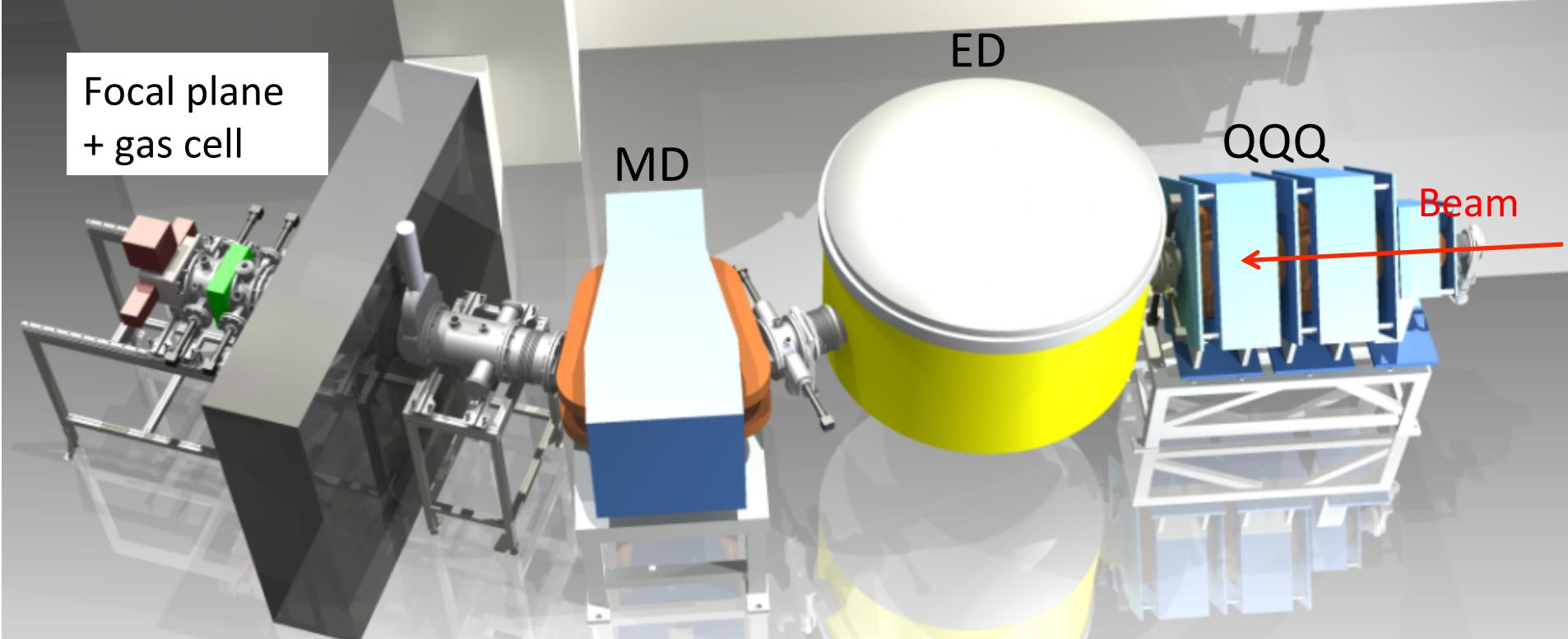


Isospin non-conserving contribution is needed !

$$\begin{aligned}
 \text{TED} &= E_x(T_z = -1) + E_x(T_z = +1) - 2 E_x(T_z = 0) \\
 V &= v_{pp} + v_{nn} - 2v_{pn} \\
 &\text{Charge independence}
 \end{aligned}$$

FUTURE

A new vacuum-mode separator – MARA
→ better mass selection in RDT experiments



- Solid angle acceptance (central m/q and energy) 10 msr
- Typical transmission ~12% per charge state



Thank You

