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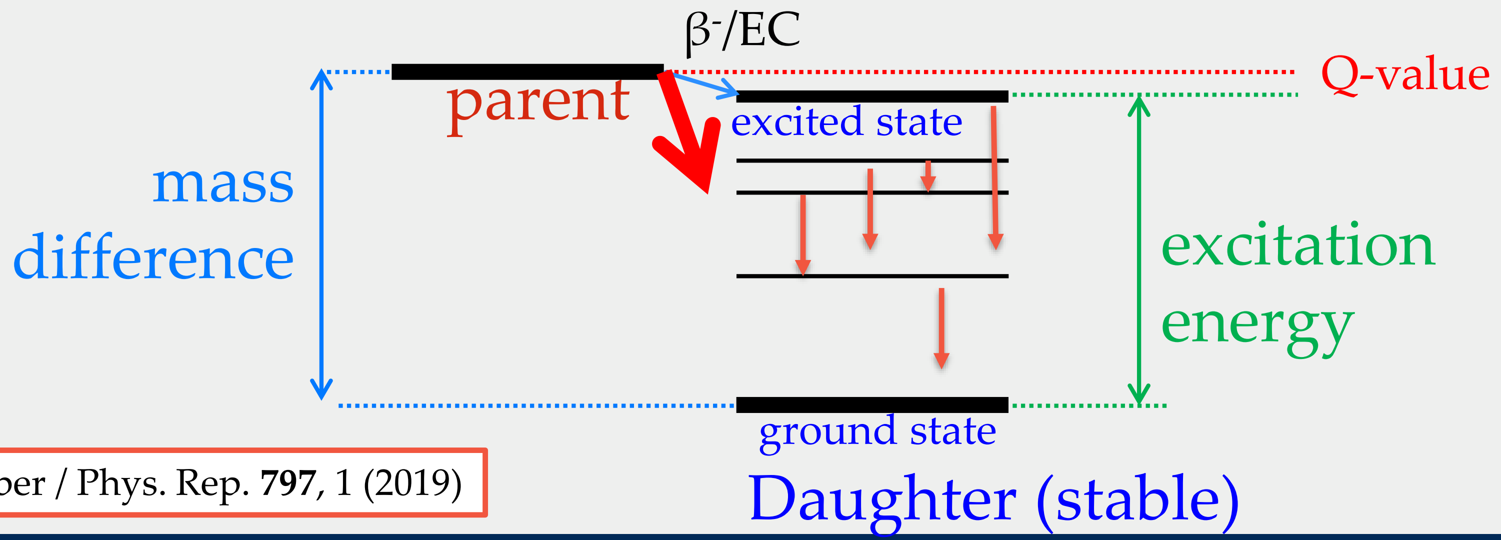
Q-value measurements of rare weak beta decays with JYFLTRAP

^{135}Cs

Tommi Eronen

Rare weak decays with ultralow Q-value

- Single β^- and EC capture decays
- Decay with a very low Q-value to an excited state
  - Search for ”slightly positive” Q-value
- Big change in angular momentum



H. Ejiri, J. Suhonen and K. Zuber / Phys. Rep. **797**, 1 (2019)

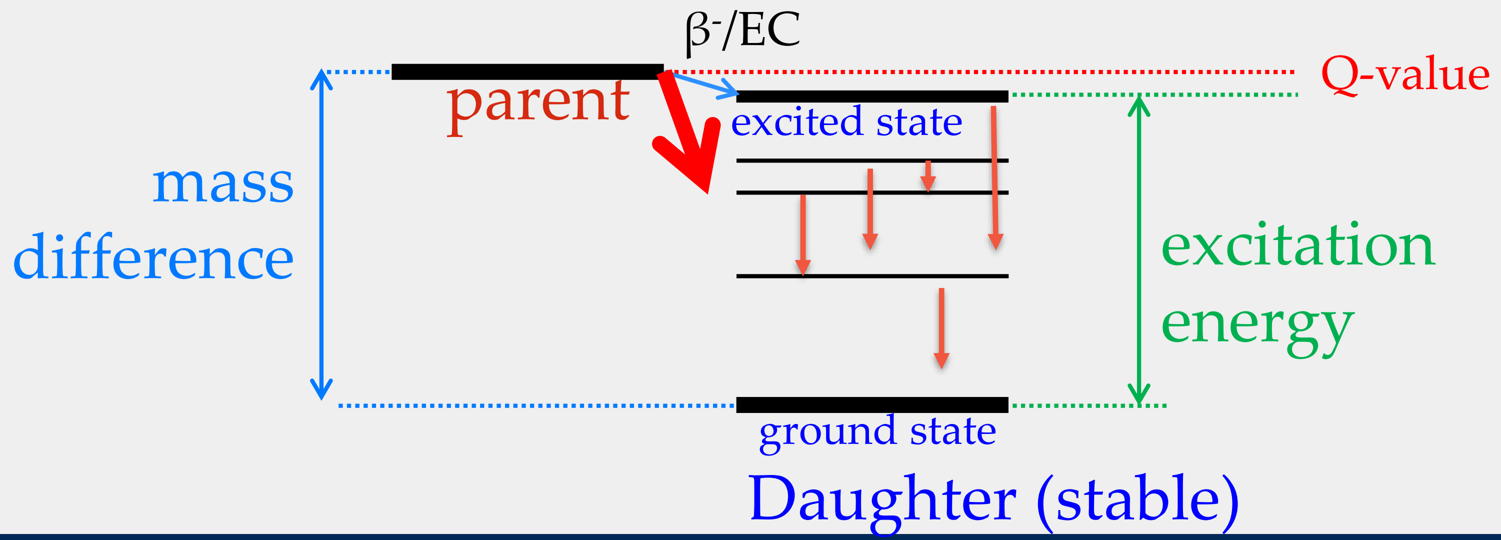
Are the decays feasible for neutrino mass determination?

Feasibility?

- Is the Q-value positive?
- Expected half-live and branching ratio?
- Transition for gating?

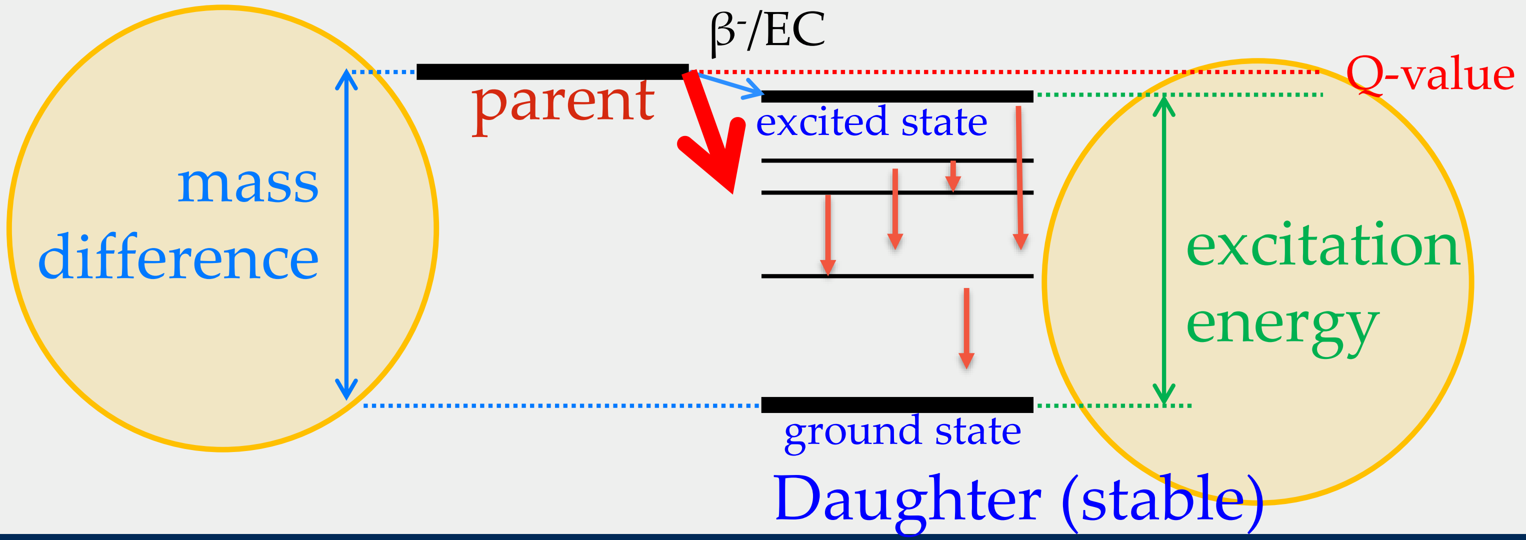
Challenges

- The branch will be small
  - Dominated by more allowed decays
- Short half-lives, need on-line production



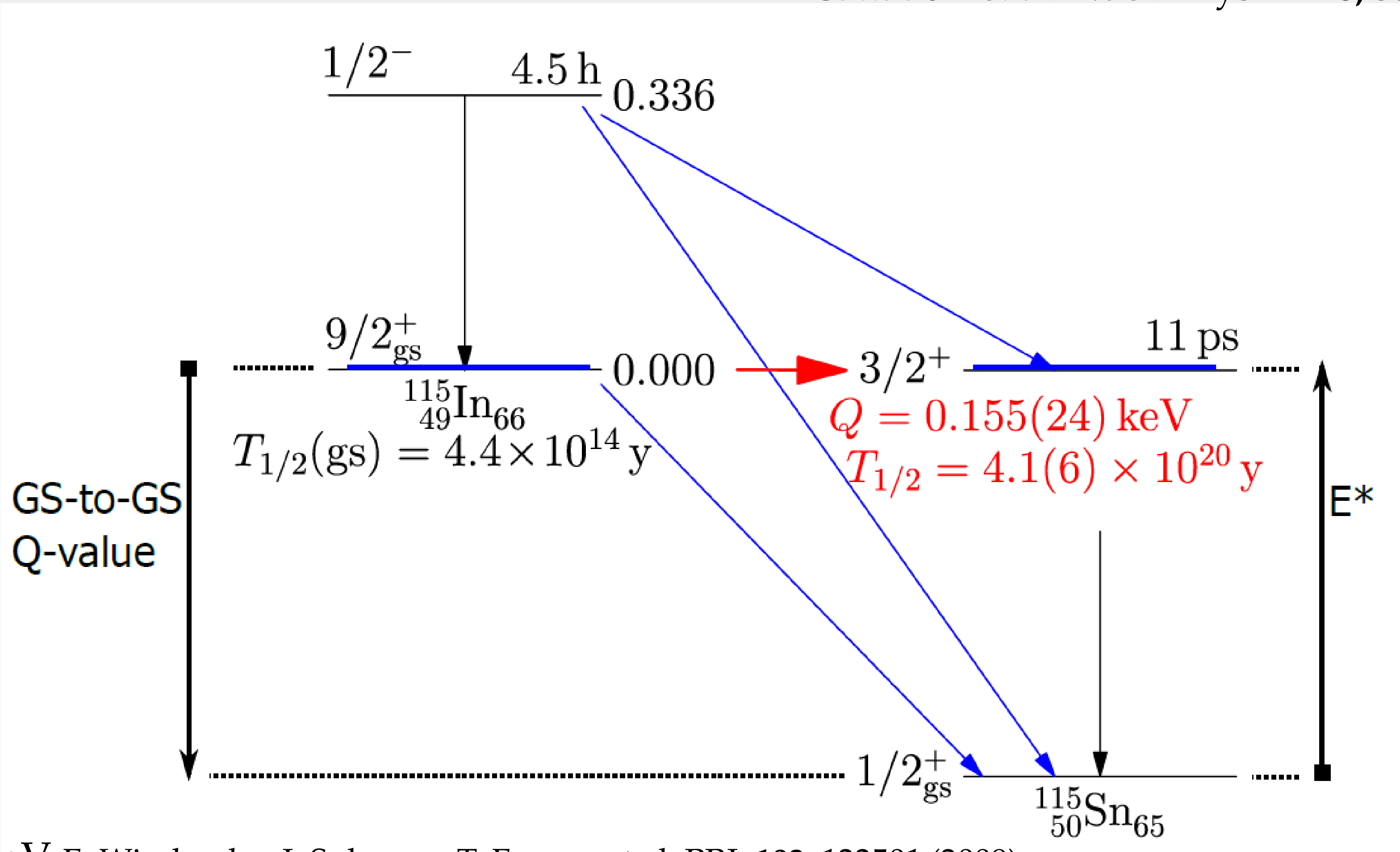
Search for ultralow Q-values

- Parent-daughter decay Q-value – mass difference
  - From mass spectroscopy
- Daughter excited state excitation energy



^{115}In decay – lowest β decay Q-value

Cattadori et al. Nucl. Phys A **748,** 333 (2005)



Scheme by J. Suhonen

Q-values:

JYFLTRAP 350(170) eV E. Wieslander, J. Suhonen, T. Eronen et al. PRL **103**, 122501 (2009)

FSU-TRAP 155(24) eV B.J. Mount, M. Redshaw, E.G. Myers, PRL **103**, 122502 (2009)

Some candidates

Immediate improvement
With precise
Mass difference
measurement

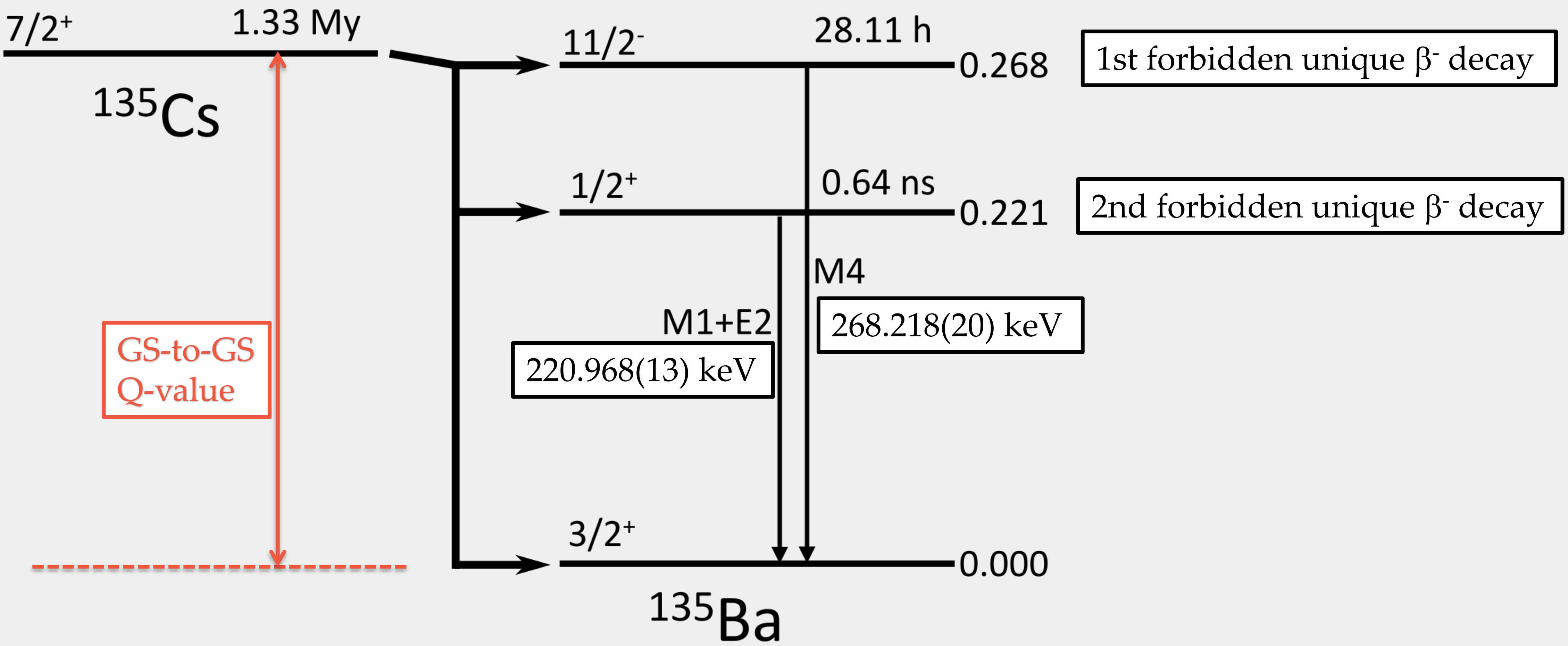
Transition	E^* (keV)	decay type	Q (keV)	
$^{77}As \to ^{77}Se$	680.1046(16)	β^-	2.8±1.8	•
$^{111}In \to ^{111}Cd$	864.8(3)	EC	-2.8±5.0	
$^{111}In \to ^{111}Cd$	866.60(6)	EC	-4.6±5.0	•
$^{131}I \to ^{131}Xe$	971.22(13)	β^-	-0.4±0.7	
$^{146}Pm \to ^{146}Nd$	1470.59(6)	EC	1.4±4.0	•
$^{149}Gd \to ^{149}Eu$	1312(4)	EC	1±6	
$^{155}Eu \to ^{155}Gd$	251.7056(10)	β^-	1.0±1.2	•
$^{159}Dy \to ^{159}Tb$	363.5449(14)	EC	2.1±1.2	•
$^{161}Ho \to ^{161}Dy$	857.502(7)	EC	1.4±2.7	•
$^{161}Ho \to ^{161}Dy$	858.7919(18)	EC	0.1±2.7	•
$^{188}W \to ^{188}Re$	346.580(7)	β^-(?)	2.4±3.0	•
$^{189}Ir \to ^{189}Os$	531.54(3)	EC	0±13	•

See comprehensive review:

N.D. Gamage et al.,
Hyp. Int. **240**, 43 (2019)

J. Suhonen, Phys. Scr. 89, 054032 (2014).

^{135}Cs ground state (7/2$^+$) decay



N. Sugarman et al.
Phys. Rev. **75** 1473 (1949)

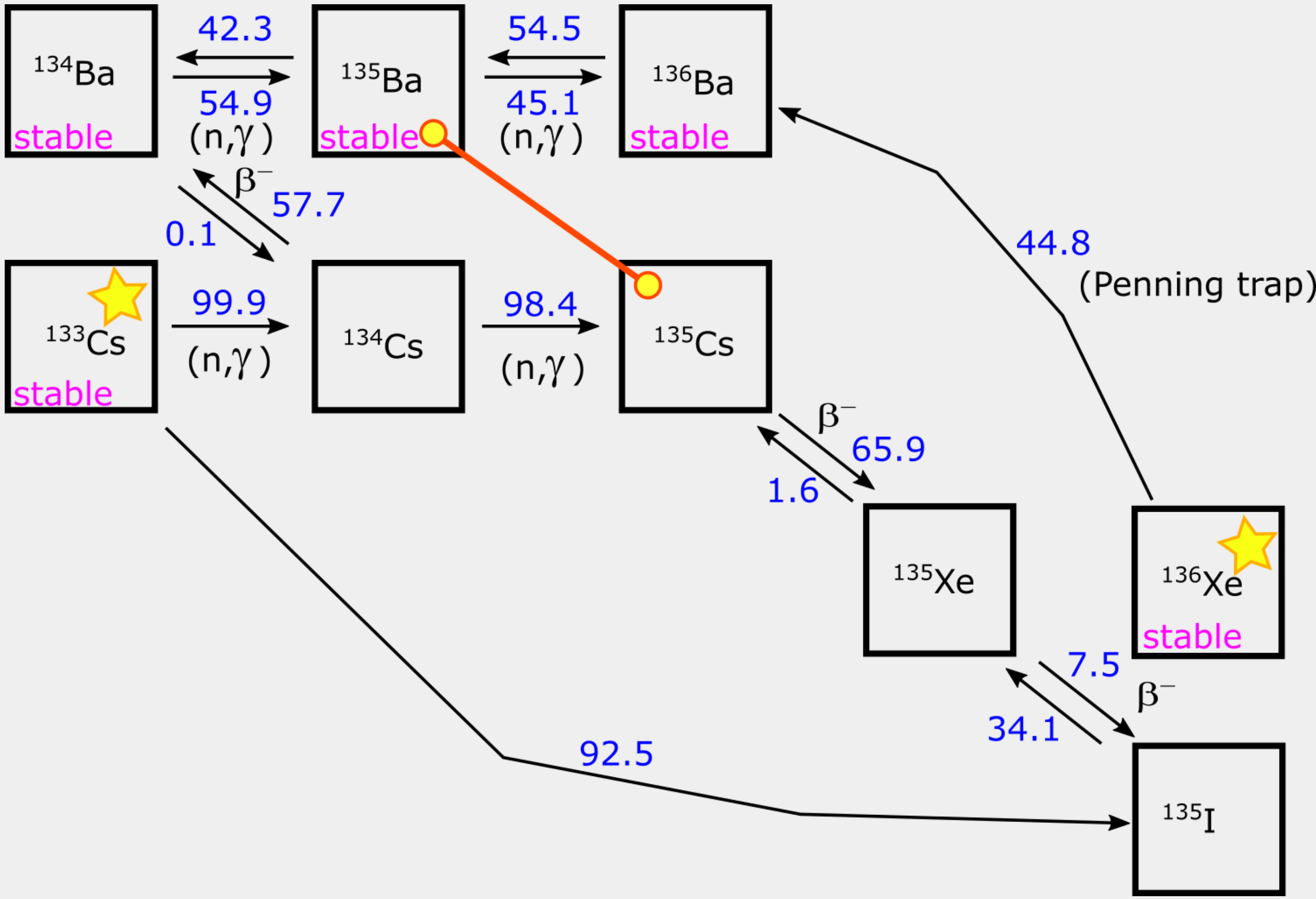
GS-to-GS Q-value 1/2: Beta decay endpoint measurement

- Precursor ^{135}Xe (10^{12} Bq)
  - ($T_{1/2}$ ~ 9 hours)
- Aluminum absorbers of various thicknesses
- GS-to-GS Q-value
  - (210 ± 10) keV
  - Too small to allow either

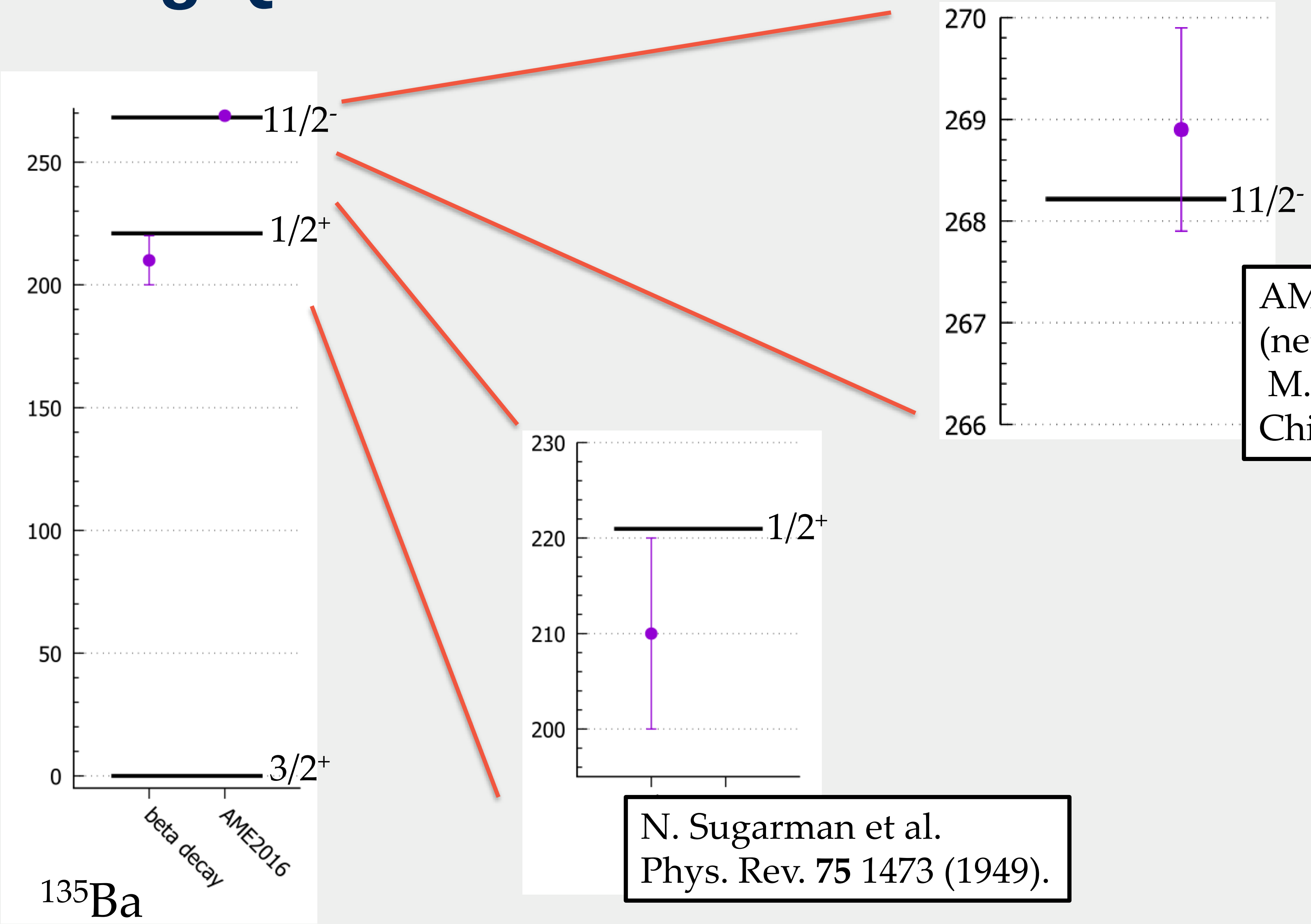
^{135}Ce β+	^{136}Ce Stable	^{137}Ce β+	^{138}Ce Stable	^{139}Ce e- capture	^{140}Ce Stable	^{141}Ce β-	^{142}Ce Stable
^{134}La β+	^{135}La β+	^{136}La β+	^{137}La e- capture	^{138}La Stable	^{139}La Stable	^{140}La β-	^{141}La β-
^{133}Ba e- capture	^{134}Ba Stable	^{135}Ba Stable	^{136}Ba Stable	^{137}Ba Stable	^{138}Ba Stable	^{139}Ba β-	^{140}Ba β-
^{132}Cs β+	^{133}Cs Stable	^{134}Cs β-	^{135}Cs β-	^{136}Cs β-	^{137}Cs β-	^{138}Cs β-	^{139}Cs β-
^{131}Xe Stable	^{132}Xe Stable	^{133}Xe β-	^{134}Xe Stable	^{135}Xe β-	^{136}Xe Stable	^{137}Xe β-	^{138}Xe β-
^{130}I β-	^{131}I β-	^{132}I β-	^{133}I β-	^{134}I β-	^{135}I β-	^{136}I β-	^{137}I β-
^{129}Te β-	^{130}Te Stable	^{131}Te β-	^{132}Te β-	^{133}Te β-	^{134}Te β-	^{135}Te β-	^{136}Te β-

GS-to-GS Q-value 2/2: based on AME2016

- **Atomic mass evaluation**
  - network of mass links
  - GS-to-GS
    - → (268.9 ± 1.0) keV
  - Ultralow $7/2^+ \rightarrow 11/2^-$
    - → **(0.7 ± 1.0) keV**
    - → Inconclusive!
- 59(10) keV discrepant to beta endpoint



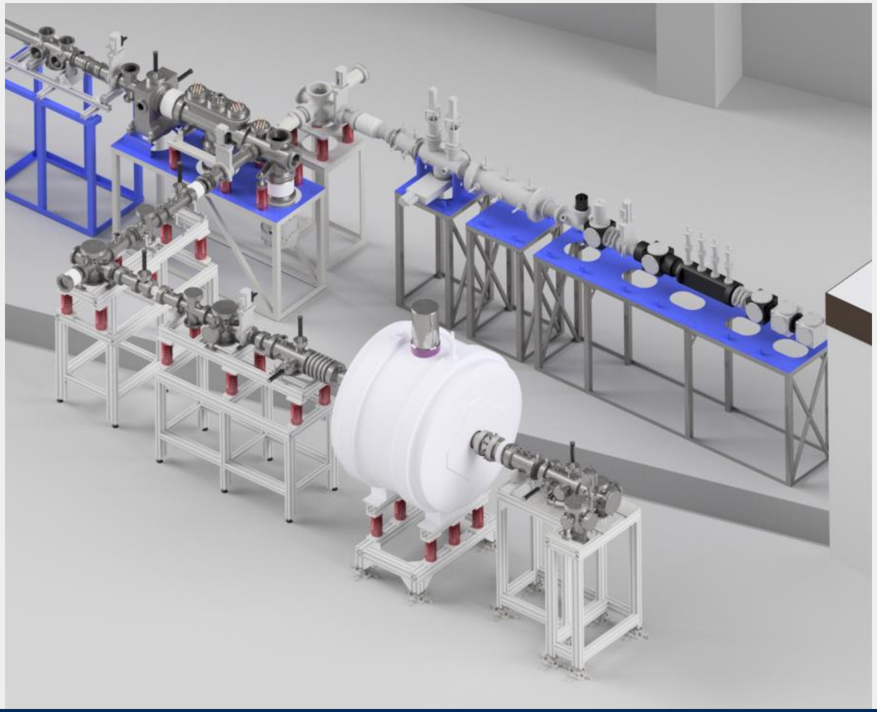
Existing Q-values

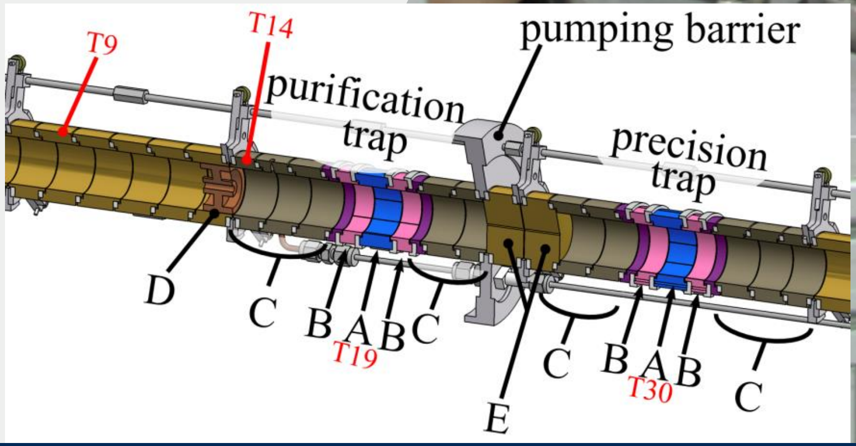


AME2016
(network of masses)
M. Wang et al.,
Chin. Phys. C 41, 030003 (2017).

N. Sugarman et al.
Phys. Rev. **75** 1473 (1949).

JYFLTRAP Penning trap

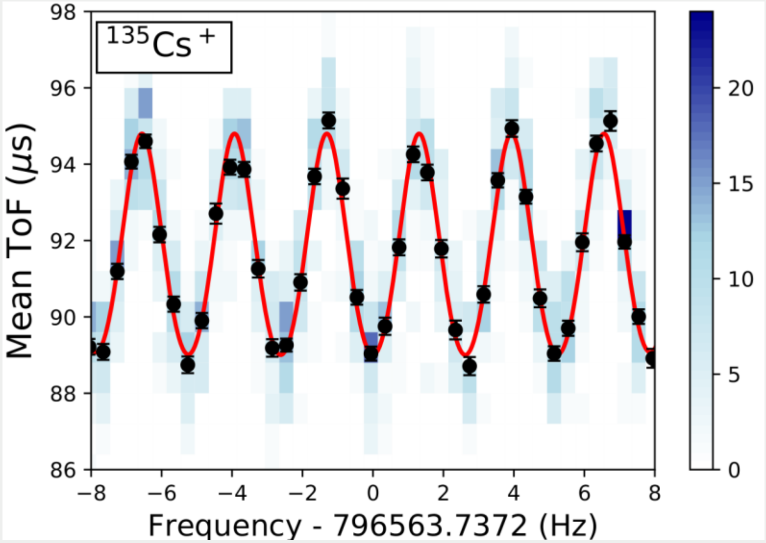




$$\nu_c = \frac{1}{2\pi}\frac{q}{m}B$$

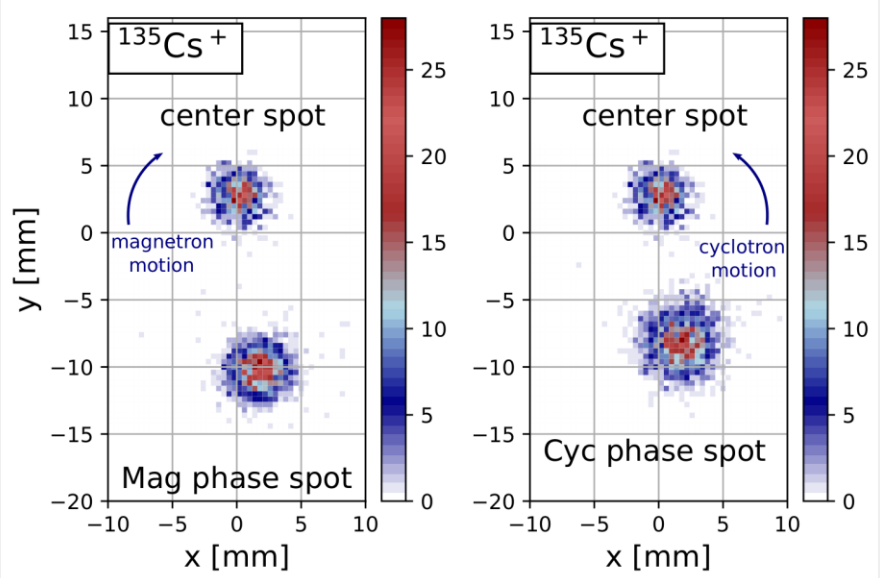
Two mass measurement techniques used

- Time-of-flight ion cyclotron resonance (TOF-ICR)
  - M. König et al., IJMS **142**, 95 (1995)
- Ramsey's method



- Phase-imaging cyclotron resonance (PI-ICR)
  - S. Eliseev et al., PRL **110**, 082501 (2013)

5x precision



From frequencies to Q-value

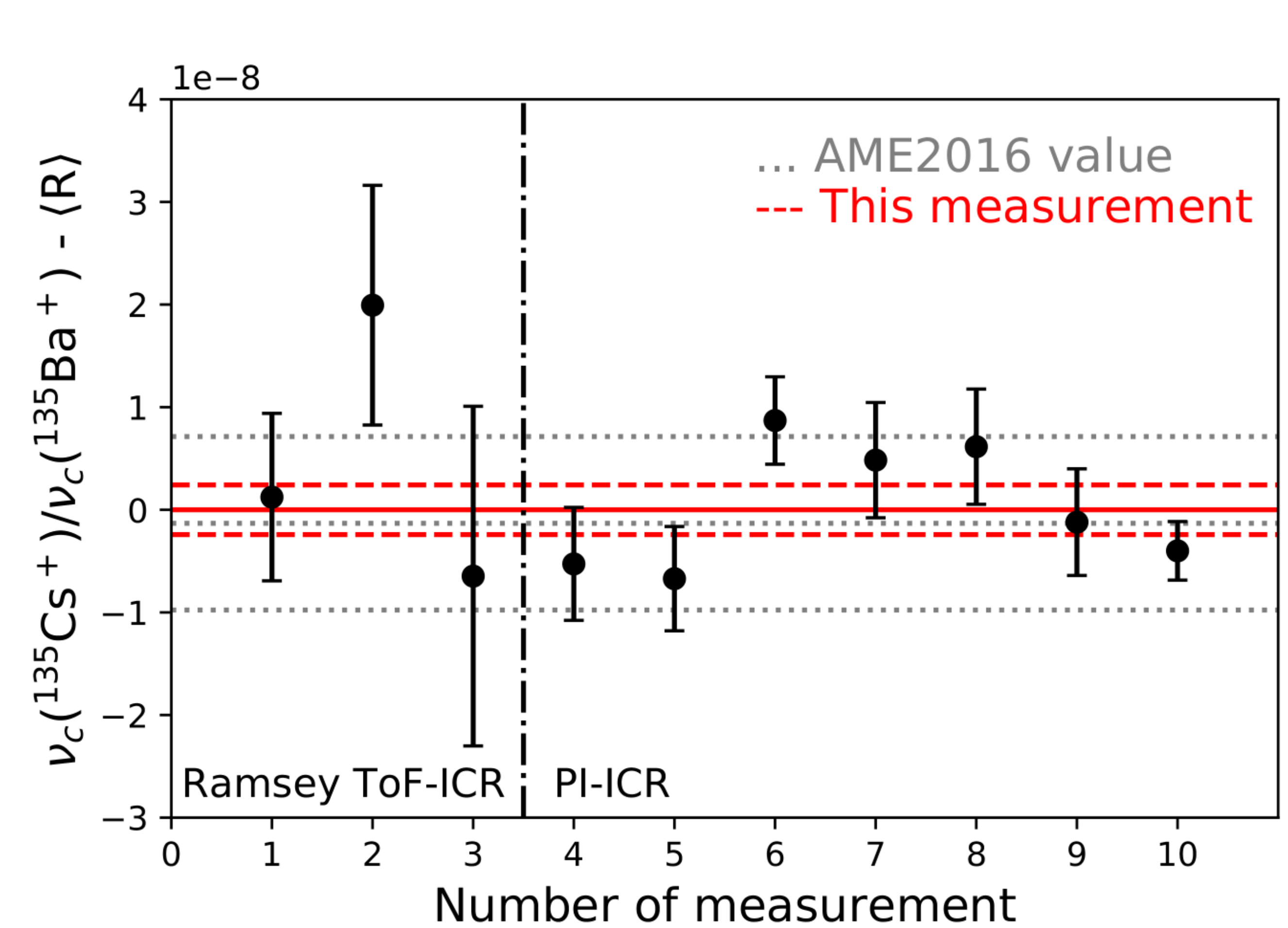
- Parent-daughter frequency ratio $r = \frac{\nu_{daughter}}{\nu_{parent}}$

parent daughter

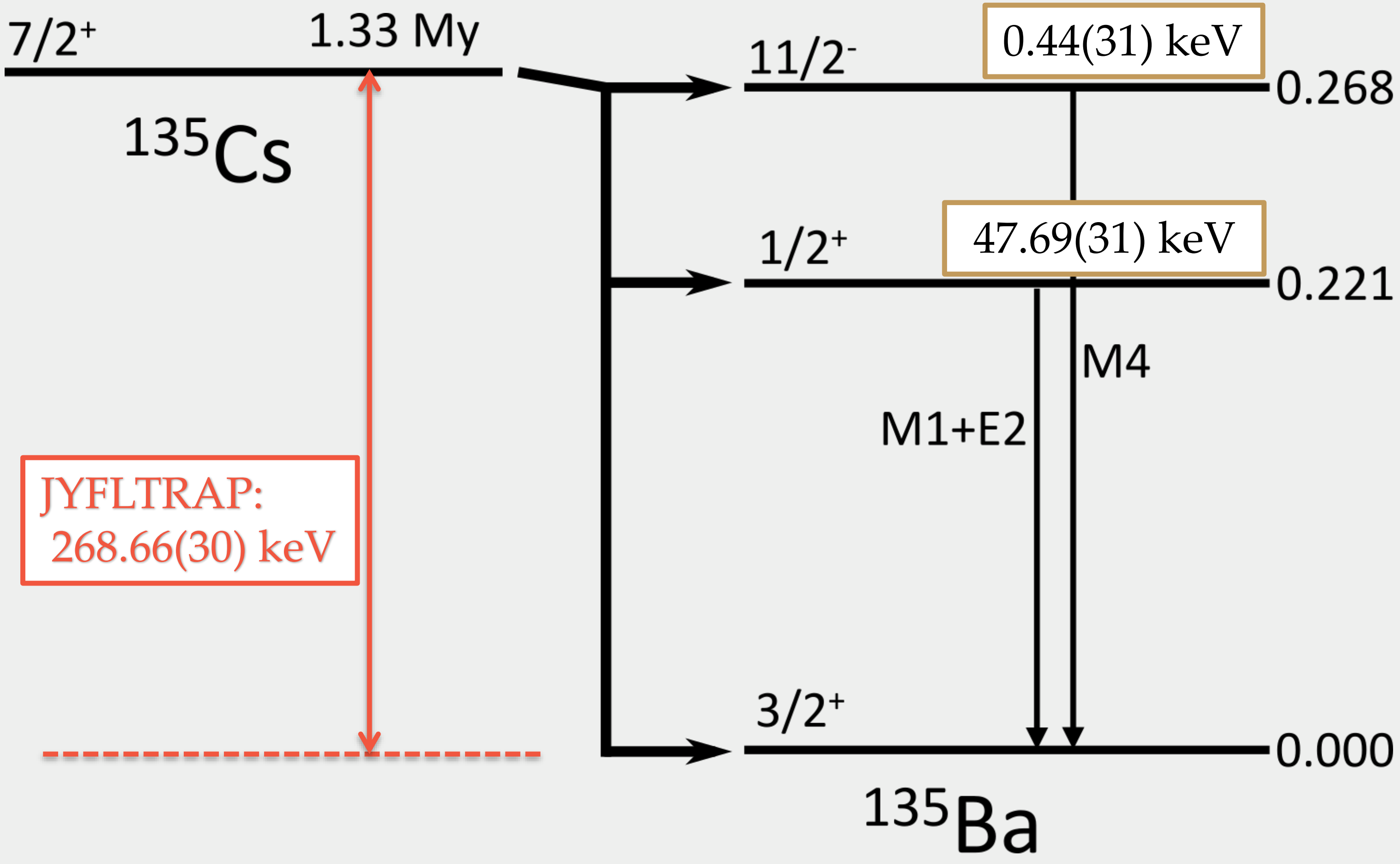
$$Q = (M_2 - M_1)c^2 = (r-1)\,(M_1 - m_e)\,c^2 + m_e c^2$$

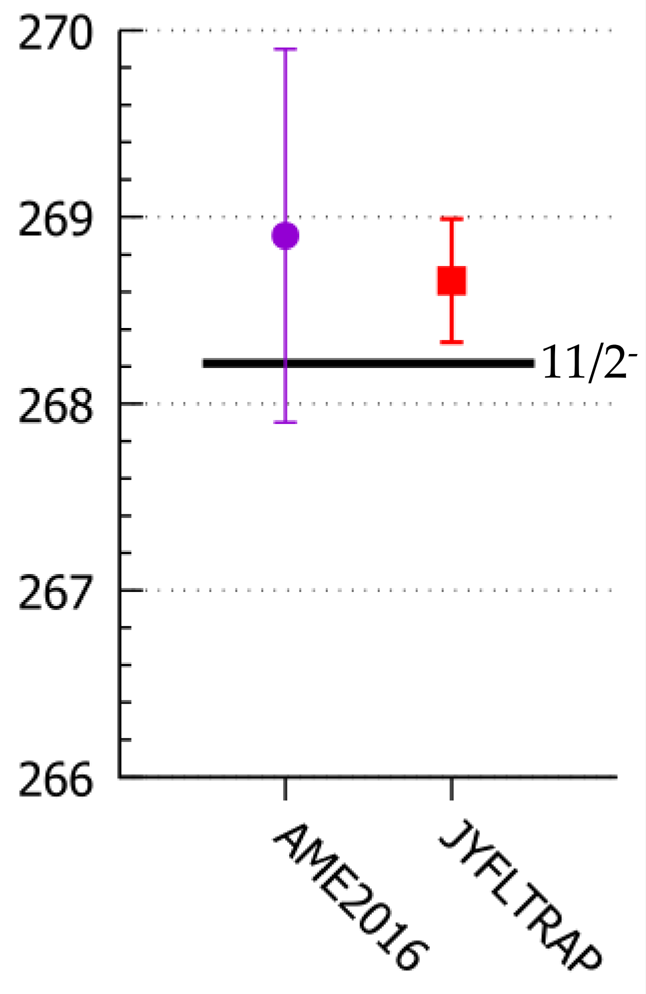
JYFLTRAP ^{135}Cs Q-value

- GS-to-GS
  - 268.66(30) keV



^{135}Cs ground state decay

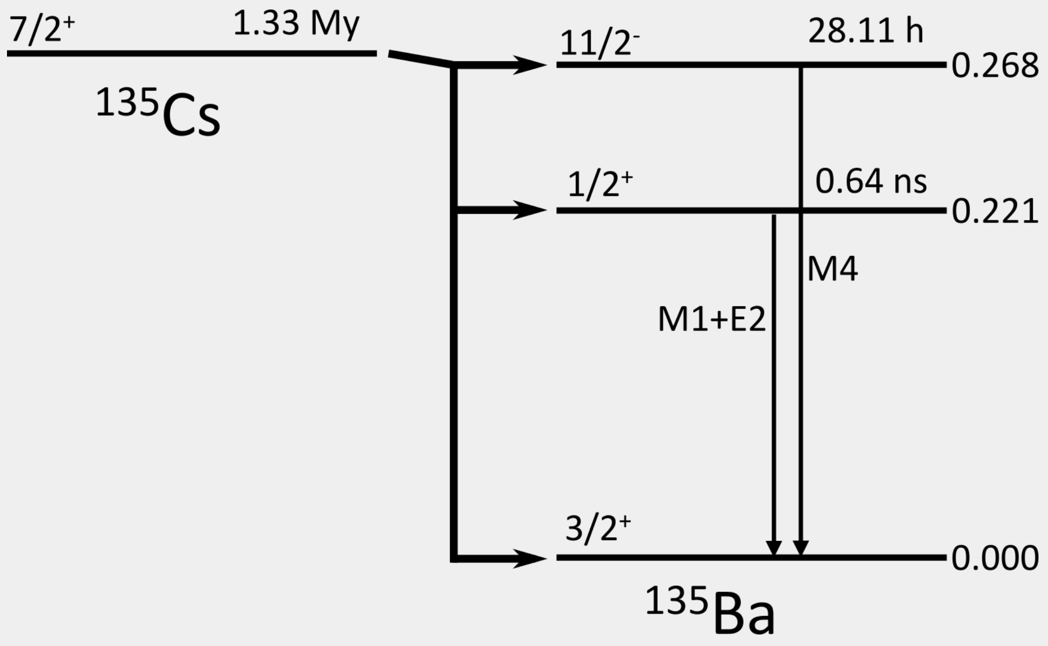




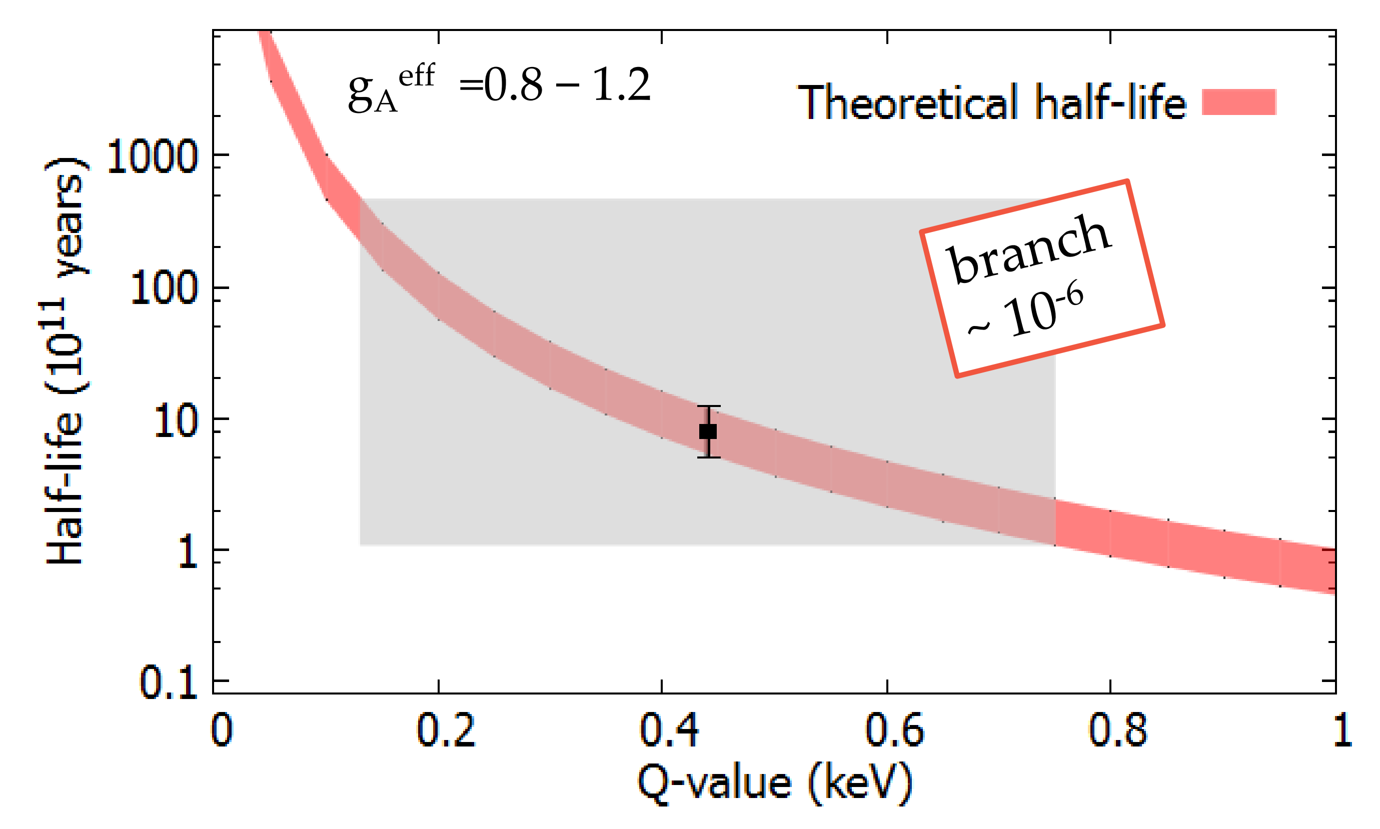
A. de Roubin, J. Kostensalo, T.E., J. Suhonen et al., arXiv:2002.08282 [nucl-ex]

Partial half-lives

- NuShellX@MSU (J. Kostensalo)



7/2+ → 11/2-



Conclusions

- ^{135}Cs Q-value improved by x3
  - It is positive and small
- Expected rare branch ~ 10^{-6}
  - Feasible to detect
- Simple, unique electron spectrum shape

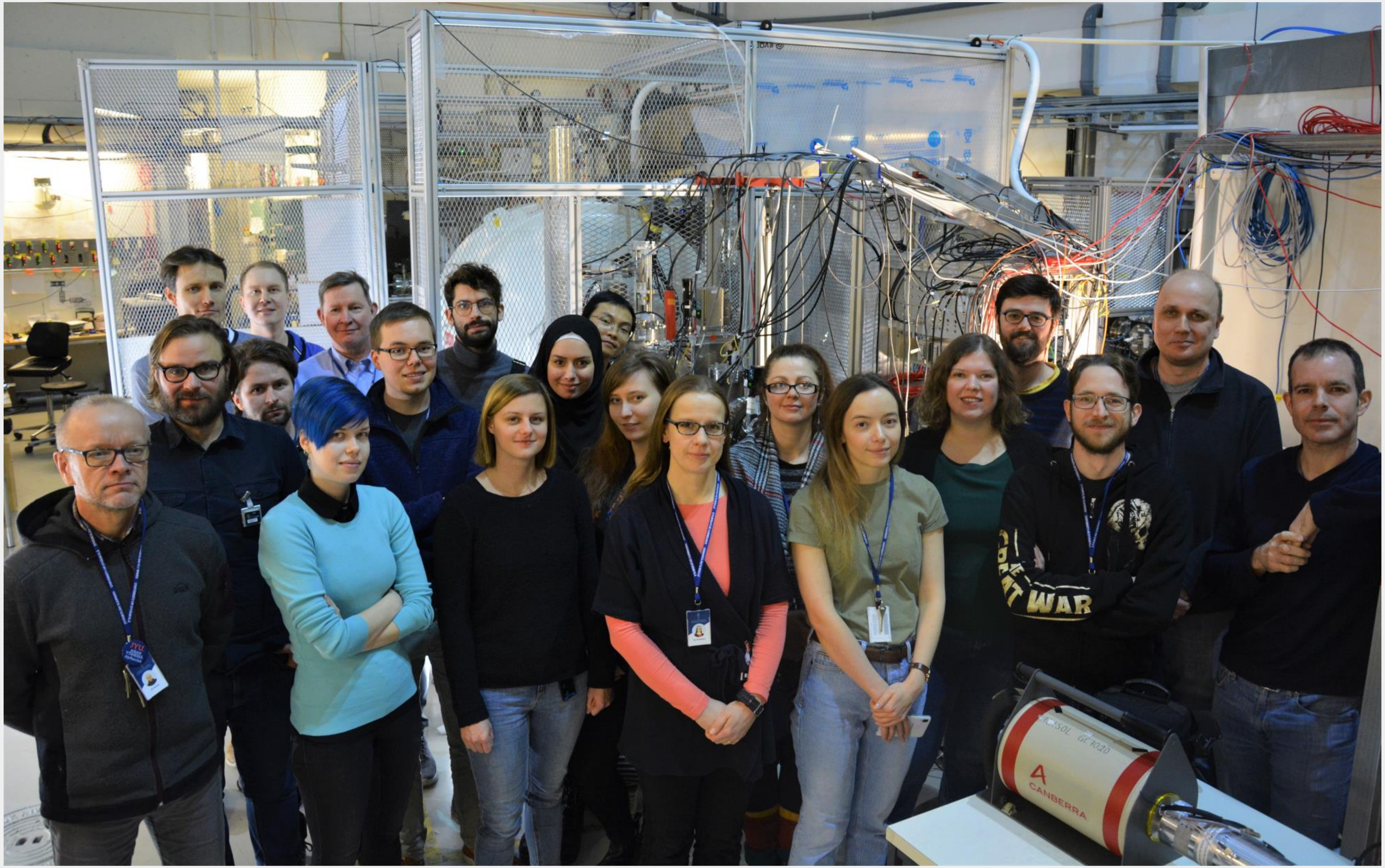
- Compare to ^{115}In

	^{115}In	^{135}Cs
GS-to-GS $T_{1/2}$	10^{14} y	10^{6} y
Rare branch	~ 10^{20} y	~10^{11} y
Detected?	yes	**no**

^{135}Cs beta decay could be used as a neutrino mass probe.

Thank you for listening!

Jyväskylä, November 2018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