

# Körte alakú atommagok

Sveiczzer András, MSc 2. év

ELTE TTK

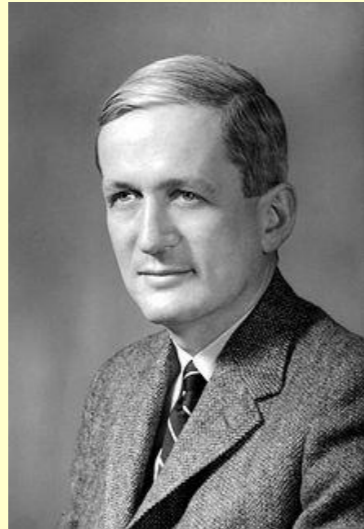
Magfizika szeminárium  
2018 őszi félév

# Körte alak és EDM

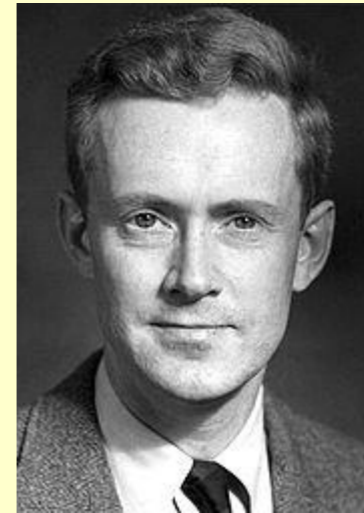
- A végcélunk alapállapotú objektumok EDM-jének mérése
- A Standard Modell tesztelése, és QCD CP-sértés keresése, antianyag kérdés magyarázata (Sakharov-feltételek)
- Semleges objektumok EDM mérése könnyű
- Az elektronfelhő viszont leárnyékolja szinte teljesen
- A megmaradó EDM körte alakú atommagok esetén sokkal jelentősebb

# Neutron and Atomic EDM moment

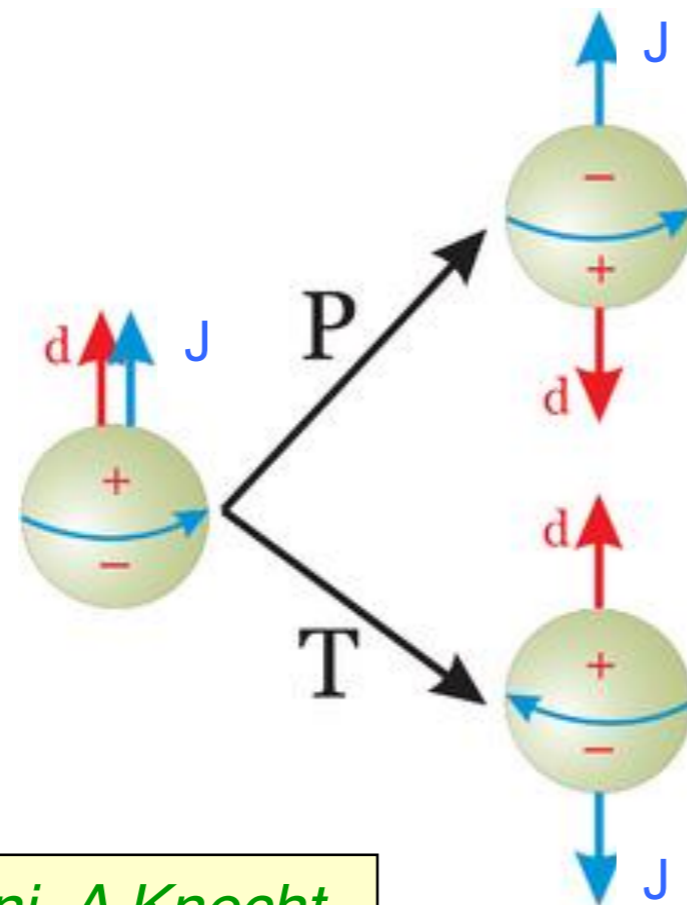
Static Electric Dipole Moment implies CP-violation



*N. Ramsey*



*E. Purcell*

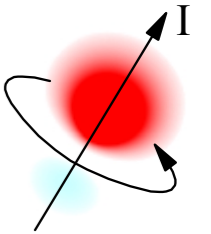


Parity violation

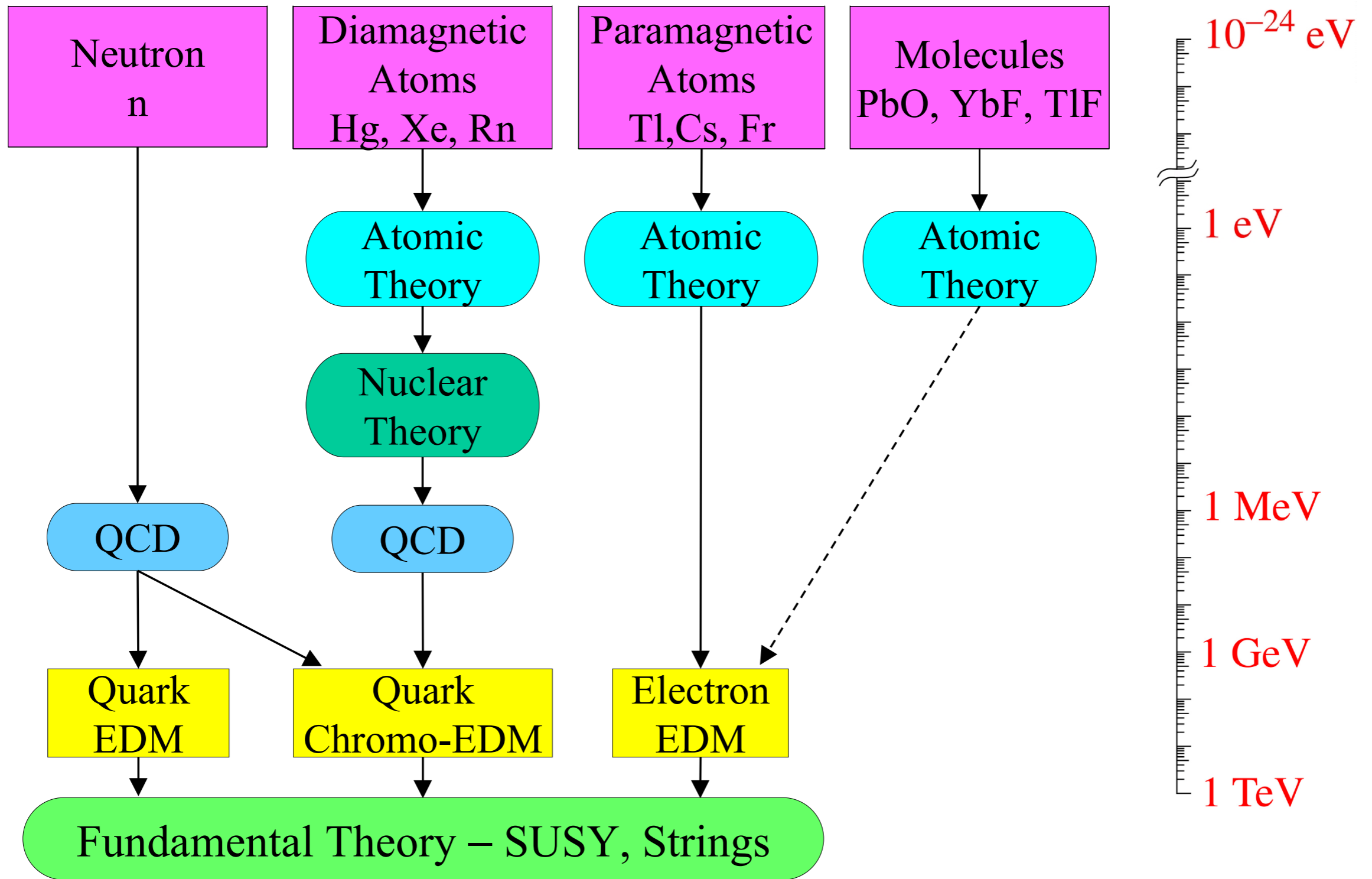
Time reversal invariance violation → CP violation

*See also talk by M Viviani, A Knecht*

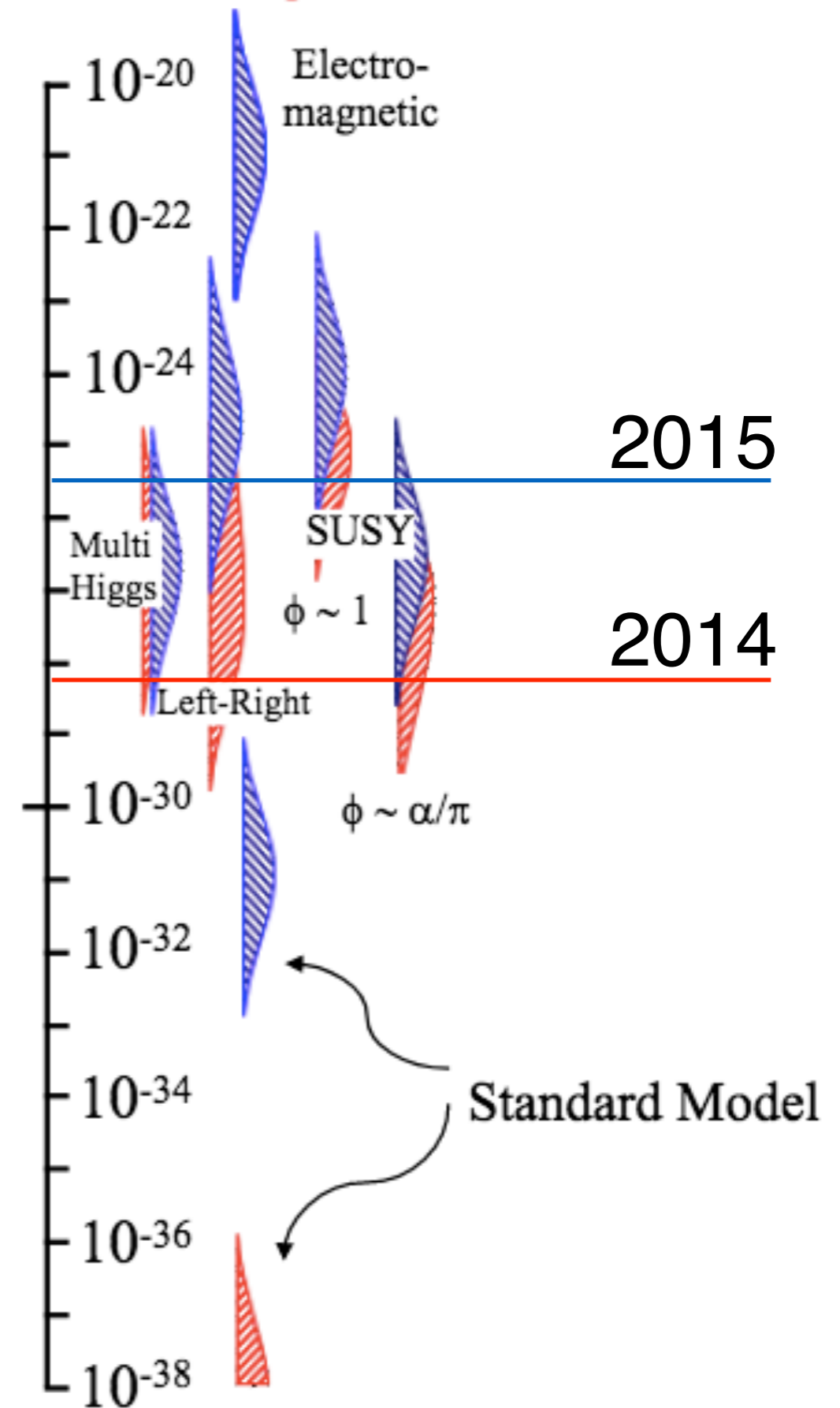
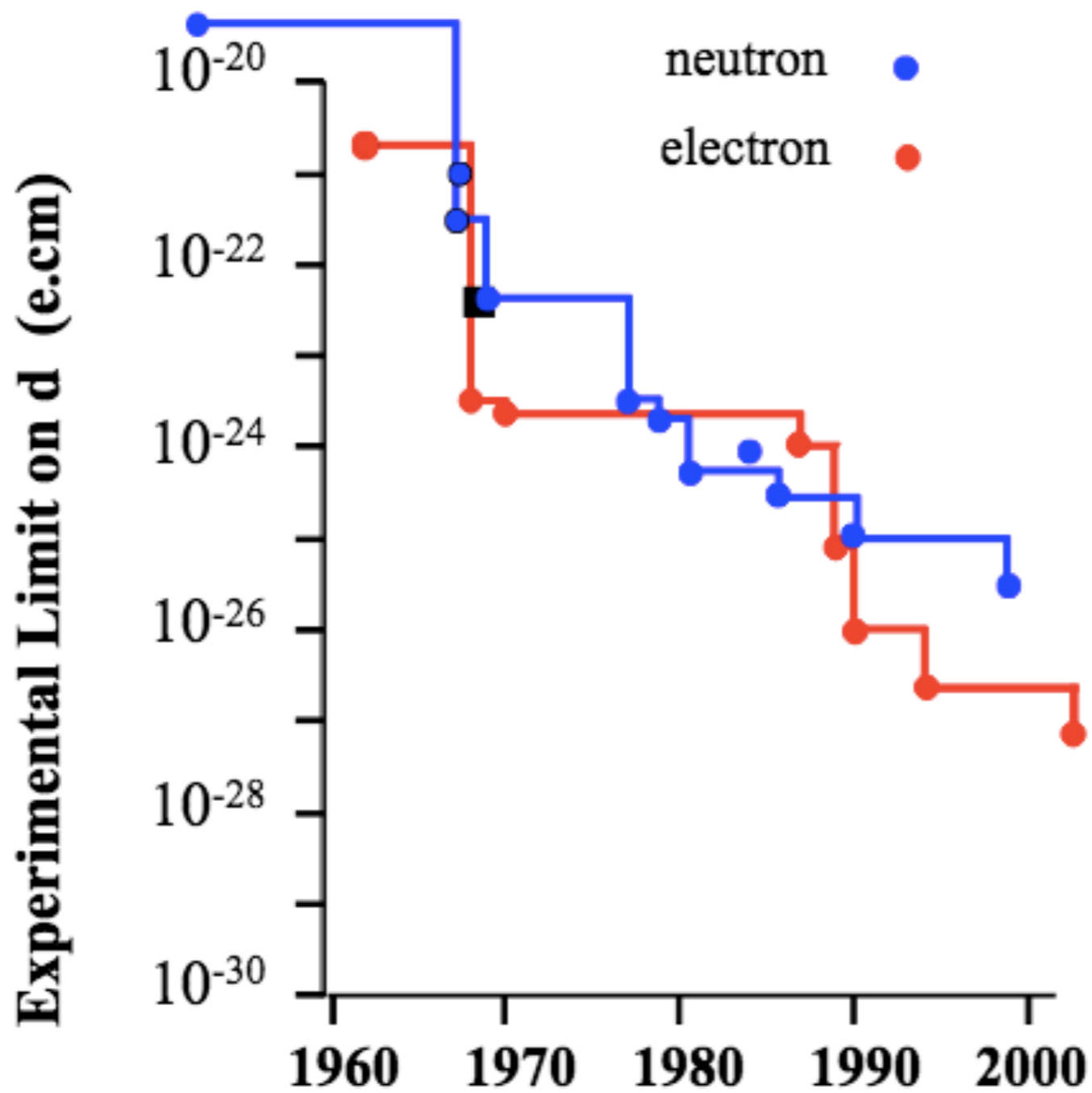
# EDM Searches



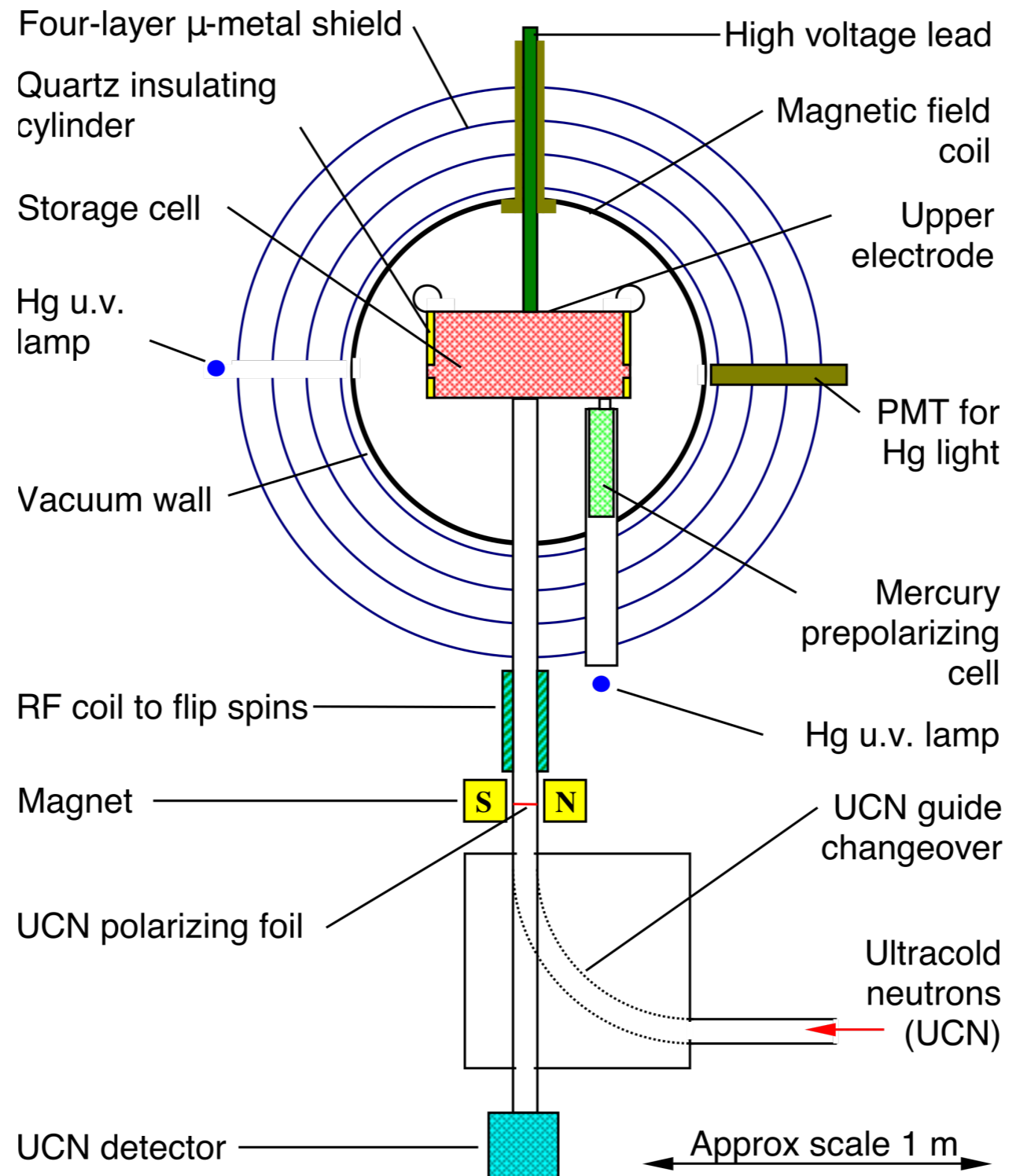
*Nuclear Physics*      *Atomic Physics*      *Molecular Physics*



# A Bit of History



# n(eutron)EDM mérése



# Probing the electron EDM

System	Group	Limit	C.L.	Value	Year
$^{205}\text{Tl}$	Berkeley	$1.6 \times 10^{-27}$	90%	$6.9(7.4) \times 10^{-28}$	2002
YbF	Imperial	$10.5 \times 10^{-28}$	90	$-2.4(5.7)(1.5) \times 10^{-28}$	2011
ThO	ACME	$8.7 \times 10^{-29}$	90	$-2.1(3.7)(2.5) \times 10^{-29}$	2014

- Schiff's theorem overcome by relativity (electric and magnetic fields mix)

$$d_A(d_e) = K_A d_e \quad K_A \propto Z^3 \alpha_{em}^2$$

- So for light systems large suppression
- But for heavy systems we can even enhance the EDM !

Paramágneses anyagok, vagyis nyílt elektronhéj!

# Octupole enhanced atomic EDM moment

körte alak!

Semleges atom EDMje  $\propto$

$$S = -2 \frac{J}{J+1} \frac{\langle \hat{S}_z \rangle \langle \hat{V}_{PT} \rangle}{\Delta E}$$

related to  $Q_3$  P,T-violating n-n interaction, etc

energy splitting of parity doublet

erős CP és CT sértés?

See, e.g.  
 WC Haxton & EM Henley  
 PRL **51** (1983) 1937  
 VV Flaumbaum & VG Zelevinsky  
 PRC **68** (2003) 035502  
 J Dobaczewski & J Engel  
 PRL **94** (2005) 232502  
 J Ellis, JS Lee & A Pilaftsis  
 JHEP **02** (2011) 045

Measured in  $^{220}\text{Rn}$ ,  
 $^{224,226}\text{Ra}$   
*(but not odd-A nuclei)*

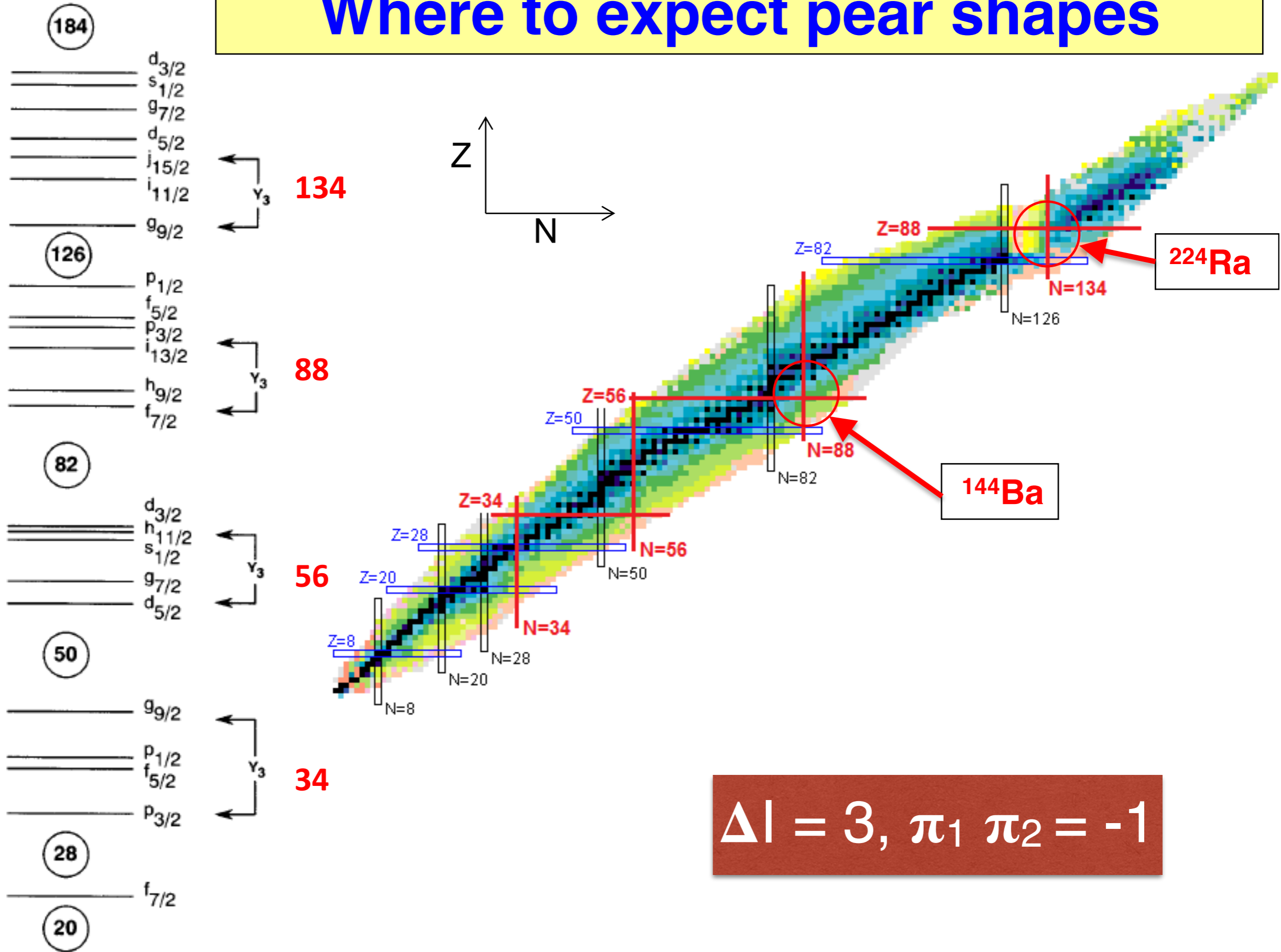
Measured in  $^{223,225}\text{Ra}$   
*(but not odd-A Rn)*

Schiff moment enhanced by  $\sim 3$  orders of magnitude in pear-shaped nuclei

Diamágneses anyagok, vagyis zárt elektrónhéj!



# Where to expect pear shapes



# Q<sub>n</sub> meghatározása

- Az átmeneti mátrix elemei mérhető mennyiségek, meghatározzák a különböző gamma-átmenetek valószínűségét -> ezeket kell kísérletileg megmérni a Q<sub>n</sub>-ek meghatározásához

**Table 1 | Values of matrix elements measured in the present experiment**

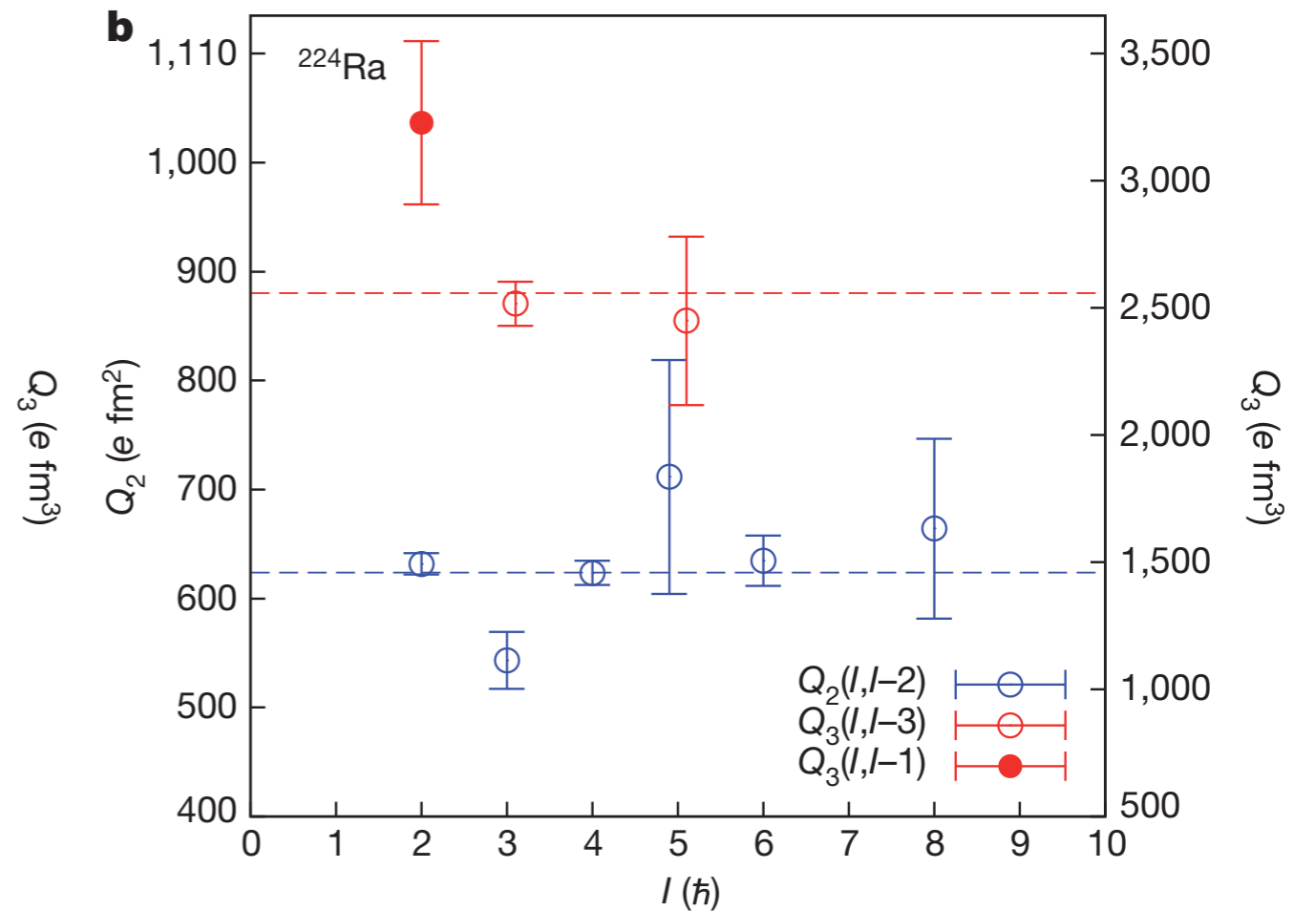
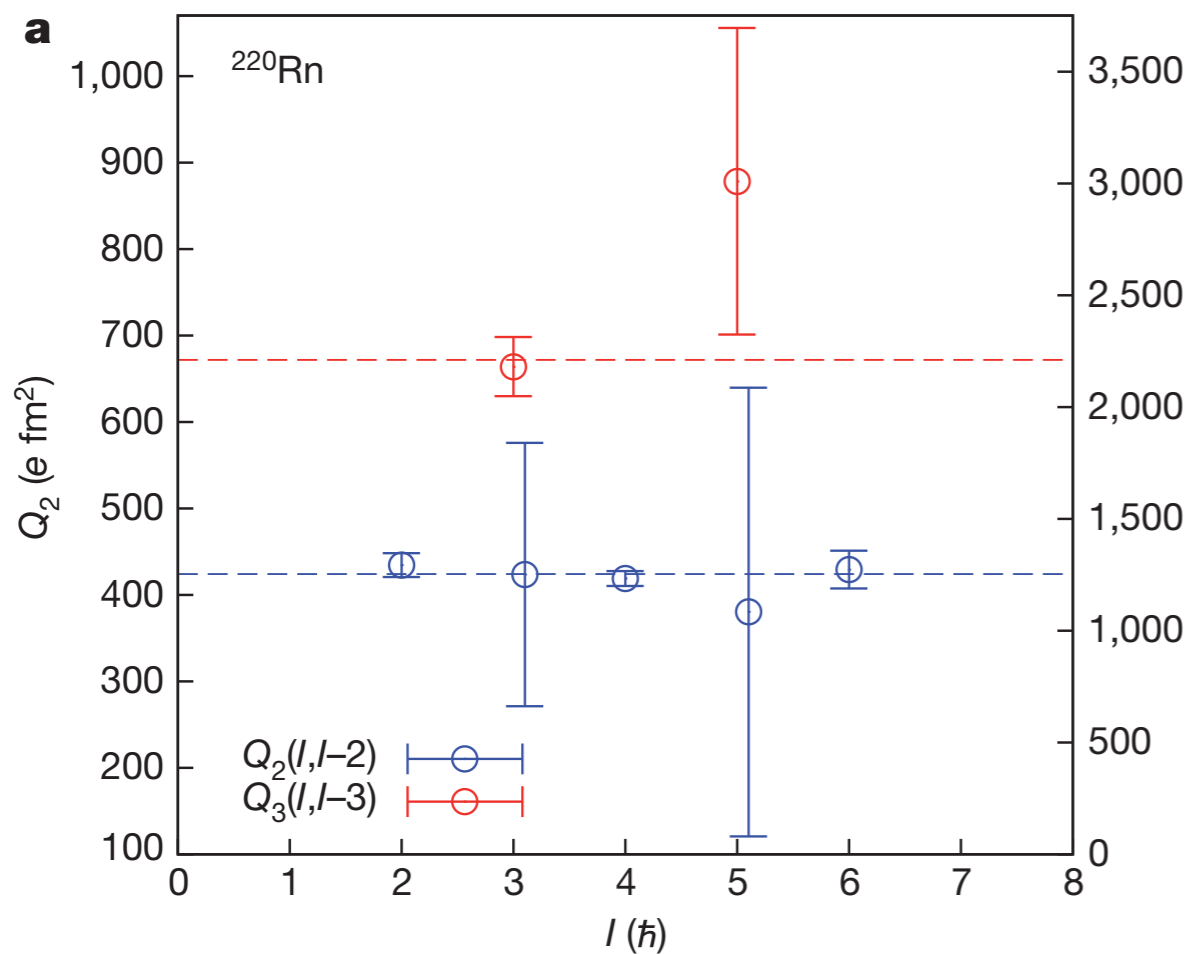
Matrix element $\langle I'    E\lambda    I \rangle$	<sup>220</sup> Rn		<sup>224</sup> Ra	
	m.e.   (efm <sup>2</sup> )	B(Eλ)↓ (WU)	m.e.   (efm <sup>2</sup> )	B(Eλ)↓ (WU)
$\langle 0^+    E1    1^- \rangle$	<0.10	$<1.5 \times 10^{-3}$	<0.018	$<5 \times 10^{-5}$
$\langle 2^+    E1    1^- \rangle$	<0.13	$<3 \times 10^{-3}$	<0.03	$<1.3 \times 10^{-4}$
$\langle 2^+    E1    3^- \rangle$	<0.18	$<2 \times 10^{-3}$	$0.026 \pm 0.005$	$3.9_{-1.4}^{+1.7} \times 10^{-5}$
$\langle 4^+    E1    5^- \rangle$	$0.028 \pm 0.009$	$3.0_{-1.6}^{+2} \times 10^{-5}$	$0.030 \pm 0.010$	$4_{-2}^{+3} \times 10^{-5}$
$\langle 6^+    E1    7^- \rangle$	<1.3	<0.5	<0.10	$<3 \times 10^{-4}$
$\langle 0^+    E2    2^+ \rangle$	$137 \pm 4$	$48 \pm 3$	$199 \pm 3$	$98 \pm 3$
$\langle 1^-    E2    3^- \rangle$	$180 \pm 60$	$60_{-30}^{+50}$	$230 \pm 11$	$93 \pm 9$
$\langle 2^+    E2    4^+ \rangle$	$212 \pm 4$	$63 \pm 3$	$315 \pm 6$	$137 \pm 5$
$\langle 3^-    E2    5^- \rangle$	$220 \pm 150$	$60_{-50}^{+100}$	$410 \pm 60$	$190 \pm 60$
$\langle 4^+    E2    6^+ \rangle$	$274 \pm 14$	$73 \pm 8$	$405 \pm 15$	$156 \pm 12$
$\langle 6^+    E2    8^+ \rangle$			$500 \pm 60$	$180 \pm 60$
$\langle 0^+    E2    2^+_{\gamma} \rangle$	$32 \pm 7$	$2.6 \pm 1.1$	$23 \pm 4$	$1.3 \pm 0.5$
$\langle 0^+    E3    3^- \rangle$	$810 \pm 50$	$33 \pm 4$	$940 \pm 30$	$42 \pm 3$
$\langle 2^+    E3    1^- \rangle$	<2,600	<760	$1,370 \pm 140$	$210 \pm 40$
$\langle 2^+    E3    3^- \rangle$	<5,300	<1,400	<4,000	<600
$\langle 2^+    E3    5^- \rangle$	$1,700 \pm 400$	$90 \pm 50$	$1,410 \pm 190$	$61 \pm 17$

The experimental measurements for the absolute values of the matrix elements, |m.e. |, and the reduced transition probabilities, B(Eλ), are given here. The values of B(Eλ) for electromagnetic decay (↓) are derived from the matrix elements and are given in single particle units (Weisskopf units, WU). The uncertainties include the 1σ statistical error from the fit (χ<sup>2</sup> + 1 type) and systematic contributions—beam energy and target thickness uncertainties, deorientation, beam spot effects, and so on. The upper limits correspond to 3σ.

$$\langle I' || E\lambda || I \rangle = \sqrt{(2I' + 1)(2\lambda + 1) / 16\pi (I' 0 \lambda 0 | I 0)} Q_{\lambda}$$

# $Q_n$ meghatározása

- Az átmeneti mátrix elemei mérhető mennyiségek, meghatározzák a különböző gamma-átmenetek valószínűségét -> ezeket kell kísérletileg megmérni a  $Q_n$ -ek meghatározásához



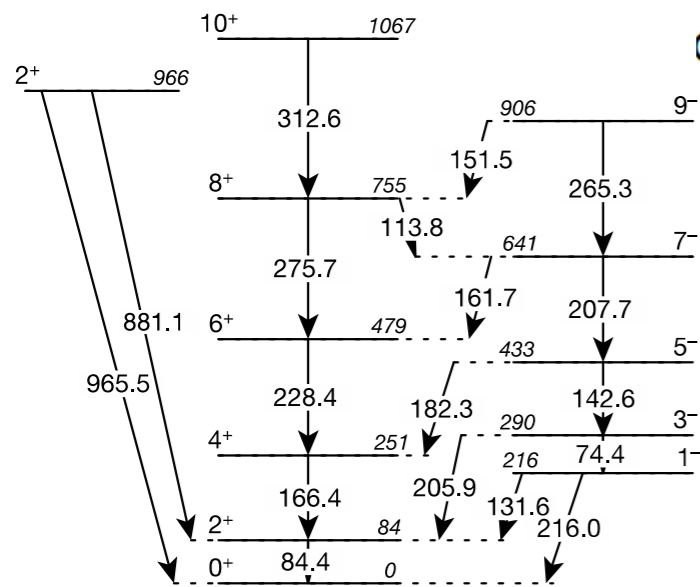
$$\langle I' || E\lambda || I \rangle = \sqrt{(2I' + 1)(2\lambda + 1) / 16\pi (I' 0 \lambda 0 | I 0)} Q_\lambda$$

# A kísérleti módszer

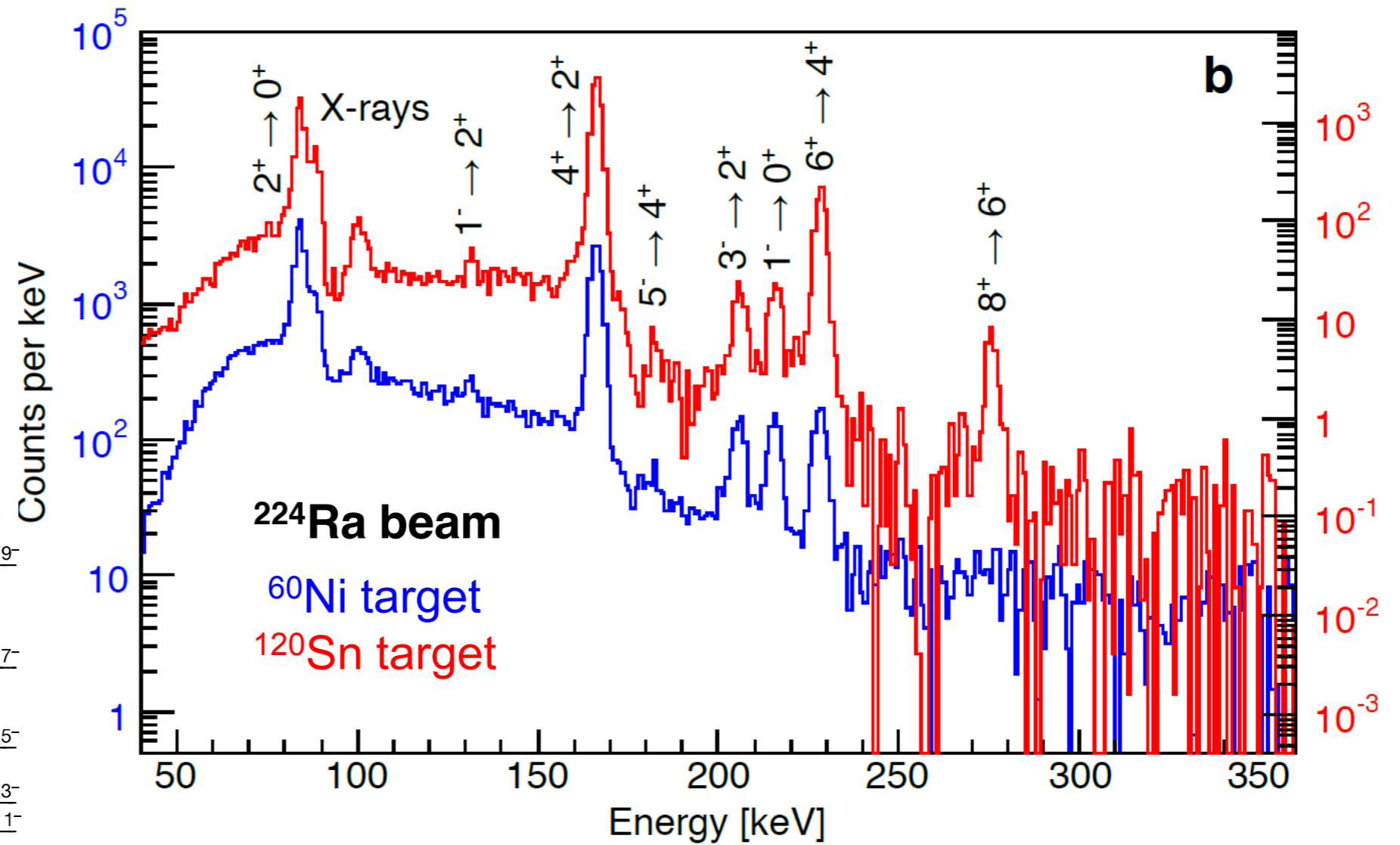
- Radioaktív ionnyalábot hoznak létre, viszonylag alacsony energián (néhány MeV/nukleon)
- Nehézelem fix céltárgyon gerjesztik az atommagokat  
(Coulomb-gerjesztés,  $n(\text{virtuális foton}) \propto Z^2$ )
- Az alapállapotba való visszatéréskor az átmeneteknek megfelelő fotonokat bocsájt ki az izotóp

# Coulomb excitation of $^{224}\text{Ra}$ beam

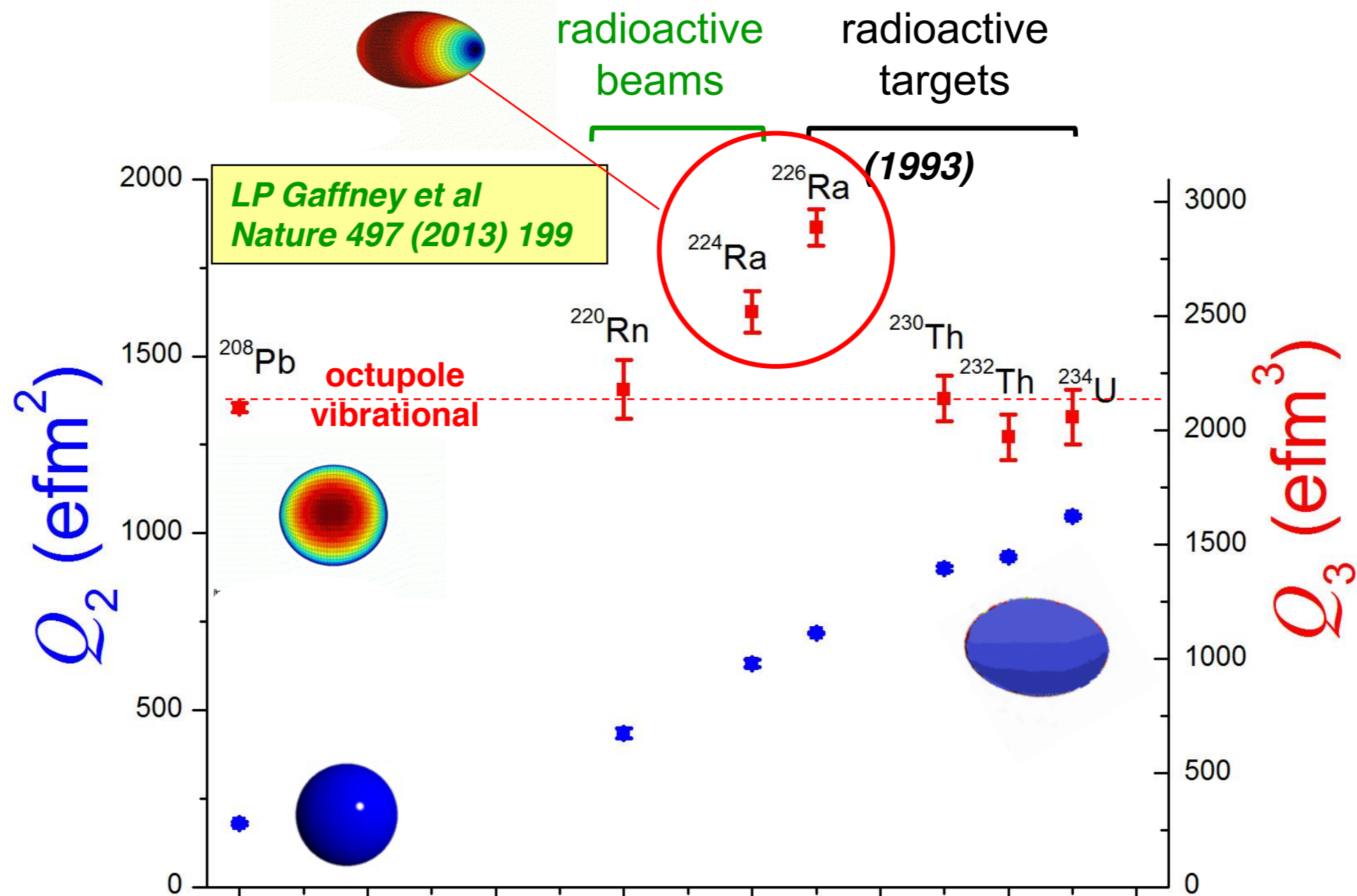
*$\gamma$ -ray spectrum taken  
with MINIBALL & REX-ISOLDE*



$^{224}\text{Ra}$



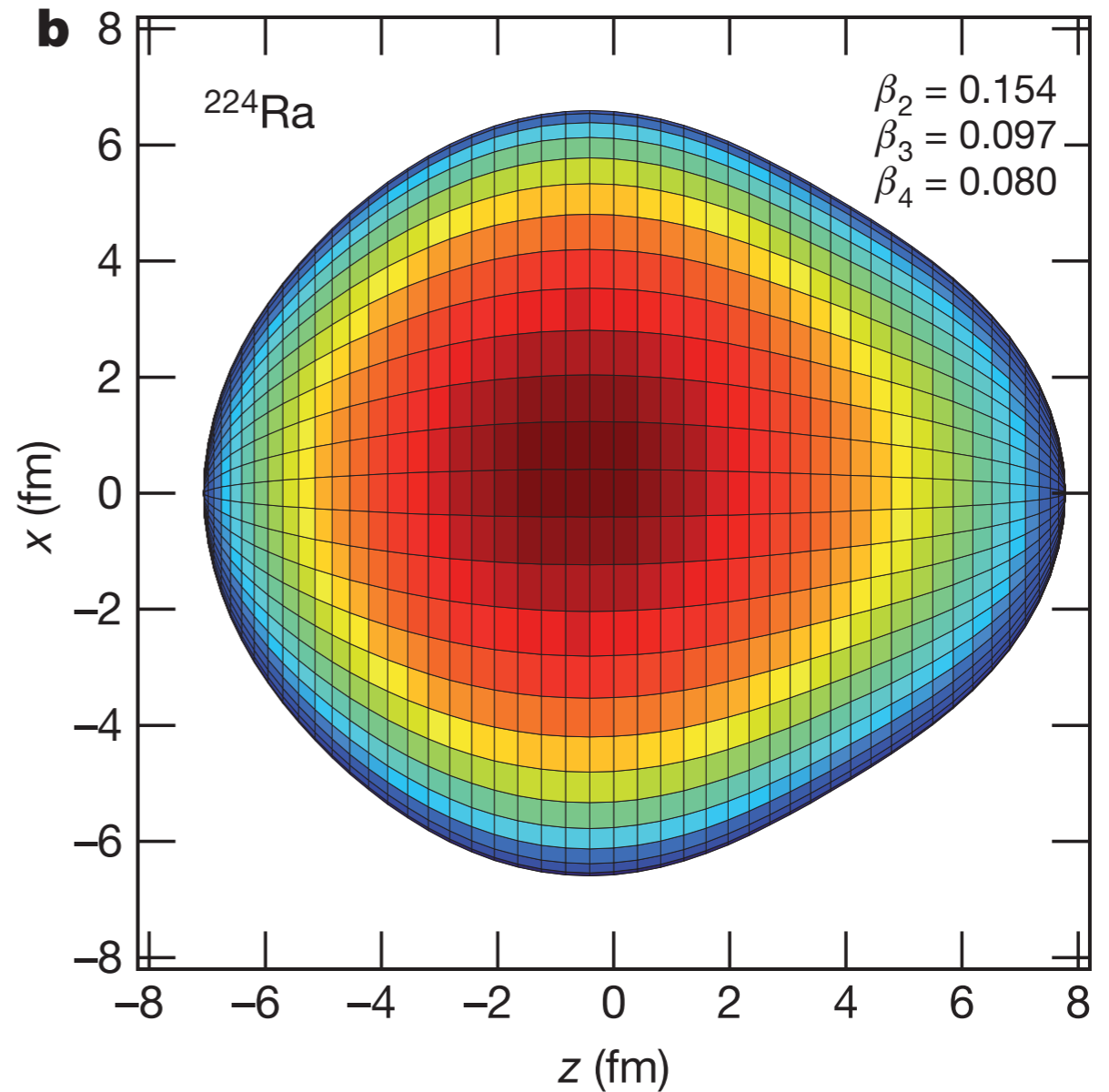
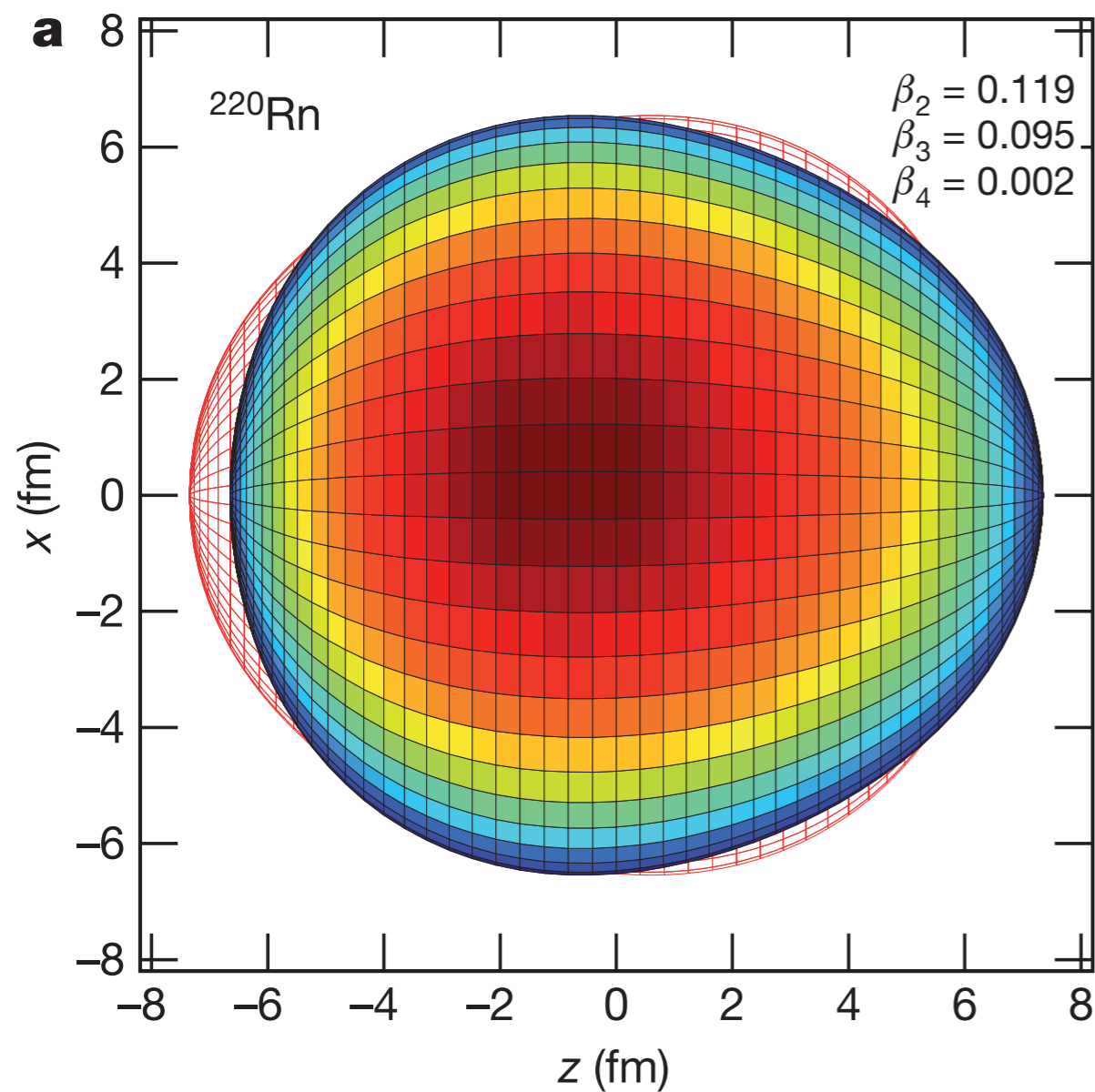
# E2 and E3 moments for heavy nuclei



## NewStatesman

*The Higgs boson was small beer. Exploring the properties of the fruit-shaped nucleus could finally reveal the reason for our existence.*

# Magok töltéseloszlása



# Octupole enhanced atomic EDM moment

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See also talk by F Recchia



# 2016 EDM Limits

Prog. Part. Nuc. Phys. 71 (2013) 21; PHYSICAL REVIEW C 94, 025501 (2016) , Phys. Rev. Lett. 116, 161601 (2016)

System	Best Limit ( $2\sigma$ ) $10^{-28} e^* cm$	SM estimate $10^{-28} e^* cm$	Method (Location)
Electron	0.9	$\sim 10^{-10}$	cold ThO beam (Harvard / Yale)
Neutron	300	$\sim 10^{-4}$	UCN in bottle (ILL)
Nuclear	0.074	$\sim 10^{-7}$	Hg atoms in vapor cell (Washington-Seattle)

Nuclear	Best Limit ( $2\sigma$ ) $10^{-28} e^* cm$	Long Term Goal	Goal on "Hg scale"	Method (Location)
Hg-199	0.074	0.010	0.010	Hg atoms in vapor cell (Washington-Seattle)
Xe-129	66	0.001	0.010	Xe/He gas mixture cell (Michigan)
Ra-225	140000	1.000	0.001	Ra atoms in a laser trap (Argonne)

*JD Singh  
Mazurian Lakes, Piaski, Sept 2017*

# Hogyan tovább?

- Körte alakú magú atomok EDM mérése, neutron és elektron EDM mérések nagyobb precizitással
- Nem zérus EDM következményei
  1. kísérleti bizonyíték BSM-re nagy eséllyel!
  2. nem paritás sajátállapotban van az alapállapota egy részecskének!

*Köszönöm a figyelmet!*