UNIVERSITY of WASHINGTON

Limits on tensor-type weak currents from neutron and nuclear β decays

(and some scalar currents)

Frederik Wauters

Tensor currents

JTW formalism

For the vector and axial vector currents:

$$H_{int} = \sum_{i=V,A} (\bar{\psi}_p O^i \psi_n) \left((C_i + C_i') \, \bar{\psi}_e^L O_i \psi_\nu^L + (C_i - C_i') \, \bar{\psi}_e^R O_i \psi_\nu^R \right)$$

while for the scalar and tensor currents:

$$H_{int} = \sum_{i=S,T} (\bar{\psi}_p O^i \psi_n) \left((C_i + C_i') \, \bar{\psi}_e^R O_i \psi_\nu^L + (C_i - C_i') \, \bar{\psi}_e^L O_i \psi_\nu^R \right)$$

In the SM

$$C_i = C_i' \qquad C_S = C_T = 0$$

$$C_V = \frac{G_F V_{ud}}{\sqrt{2}} \qquad \frac{C_A}{C_V} = 1.27 \text{ (from exp.)}$$

Tensor currents

JTW formalism

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In the SM

$$C_i = C_i'$$

? β decays

$$C_S = C_T = 0$$

$$C_V = \frac{G_F V_{ud}}{\sqrt{2}} \qquad \frac{C_A}{C_V} = 1.27 \text{ (from exp.)}$$

Tensor currents

Why a new evaluation?

Tests of the standard electroweak model in nuclear beta decay
Rev. Mod. Phys. **78**, 991 – Published 29 September 2006

Nathal Severijns, Marcus Beck, and Oscar Naviliat-Cuncic

Tensor currents

Why a new evaluation?

- Progress in EFT and lattice QCD

González Alonso

Gupta

$$
\begin{aligned}
\mathcal{L}_{\rm CC} = & -\frac{G_F^{(0)} V_{ud}}{\sqrt{2}} \Big[\Big(1+\epsilon_L\Big)\ \bar{e}\gamma_\mu(1-\gamma_5)\nu_\ell \cdot \bar{u}\gamma^\mu(1-\gamma_5)d \\
& + \tilde{\epsilon}_L\ \ \bar{e}\gamma_\mu(1+\gamma_5)\nu_\ell \cdot \bar{u}\gamma^\mu(1-\gamma_5)d \\
& + \epsilon_R\ \ \bar{e}\gamma_\mu(1-\gamma_5)\nu_\ell \cdot \bar{u}\gamma^\mu(1+\gamma_5)d \ + \ \tilde{\epsilon}_R\ \ \bar{e}\gamma_\mu(1+\gamma_5)\nu_\ell \cdot \bar{u}\gamma^\mu(1+\gamma_5)d \\
& + \epsilon_S\ \ \bar{e}(1-\gamma_5)\nu_\ell \cdot \bar{u}d \ + \ \tilde{\epsilon}_S\ \ \bar{e}(1+\gamma_5)\nu_\ell \cdot \bar{u}d \\
& - \epsilon_P\ \ \bar{e}(1-\gamma_5)\nu_\ell \cdot \bar{u}\gamma_5 d \ - \ \tilde{\epsilon}_P\ \ \bar{e}(1+\gamma_5)\nu_\ell \cdot \bar{u}\gamma_5 d \\
& + \epsilon_T\ \bar{e}\sigma_{\mu\nu}(1-\gamma_5)\nu_\ell \cdot \bar{u}\sigma^{\mu\nu}(1-\gamma_5)d \ + \ \tilde{\epsilon}_T\ \bar{e}\sigma_{\mu\nu}(1+\gamma_5)\nu_\ell \cdot \bar{u}\sigma^{\mu\nu}(1+\gamma_5)d
\end{aligned}
$$

V. Cirigliano, M. Gonzalez-Alonso, and M. L. Graesser, Journal Of High Energy Physics **1302**.

nuclear ⟷ mesons ⟷ HEP

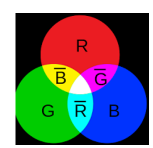
$$g_S\ \epsilon_S = \frac{C_S + C_S'}{2\,C_V}$$

$$g_S\ \tilde{\epsilon}_S = \frac{C_S - C_S'}{2\,C_V}$$

$$g_T\ \epsilon_T = \frac{C_T + C_T'}{8\,C_A}$$

$$g_T\ \tilde{\epsilon}_T = \frac{C_T - C_T'}{8\,C_A}$$

$$F_T = \varepsilon_T\, f_T$$

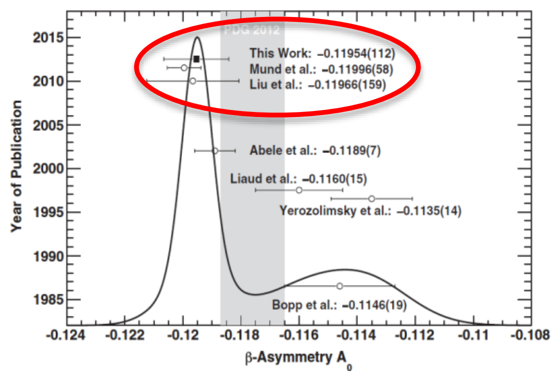


Tensor currents

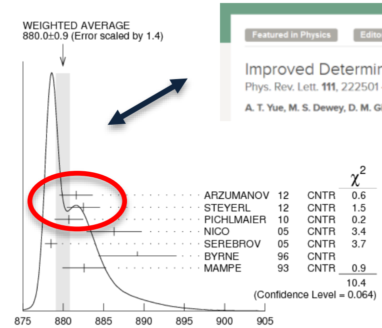
Why a new evaluation?

- Progress in EFT and lattice QCD
- New (neutron) data

A_β



T_n



Featured in Physics | Editors' Suggestion

Improved Determination of the Neutron Lifetime

Phys. Rev. Lett. **111**, 222501 – Published 27 November 2013

A. T. Yue, M. S. Dewey, D. M. Gilliam, G. L. Greene, A. B. Laptev, J. S. Nico, W. M. Snow, and F. E. Wietfeldt

PHYSICAL REVIEW C **82**, 055502 (2010)

Precision measurements of the ^{60}Co β-asymmetry parameter in search for tensor currents in weak interactions

F. Wauters,[1,*] I. Kraev,[1] D. Zákoucký,[2] M. Beck,[1,†] M. Breitenfeldt,[1] V. De Leebeeck,[1] V. V. Golovko,[1,‡] V. Yu. Kozlov,[1] T. Phalet,[1] S. Roccia,[1] G. Soti,[1] M. Tandecki,[1] I. S. Towner,[3] E. Traykov,[1] S. Van Gorp,[1] and N. Severijns[1]

Z>0

IOP Publishing | Journal of Physics G: Nuclear and Particle Physics

J. Phys. G: Nucl. Part. Phys. **38** (2011) 055101 (22pp) | doi:10.1088/0954-3899/38/5/055101

Measurement of the β–ν correlation coefficient $a_{\beta\nu}$ in the β decay of trapped $^6He^+$ ions

X Fléchard[1], Ph Velten[1], E Liénard[1], A Méry[2], D Rodríguez[3], G Ban[1], D Durand[1], F Mauger[1], O Naviliat-Cuncic[1,4] and J C Thomas[5]

Measurement of the Half-Life of the $T = \frac{1}{2}$ Mirror Decay of ^{19}Ne and its Implication on Physics Beyond the Standard Model

Phys. Rev. Lett. **112**, 212301 – Published 27 May 2014

L. J. Broussard, H. O. Back, M. S. Boswell, A. S. Crowell, P. Dendooven, G. S. Giri, C. R. Howell, M. F. Kidd, K. Jungmann, W. L. Kruithof, A. Mol, C. J. G. Onderwater, R. W. Pattie, Jr., P. D. Shidling, M. Sohani, D. J. van der Hoek, A. Rogachevskiy, E. Traykov, O. O. Versolato, L. Willmann, H. W. Wilschut, and A. R. Young

Tensor currents

Why a new evaluation?

- Progress in EFT and lattice QCD
- New (neutron) data
- What are the most sensitive (future) experiments

Observables

β decay beyond SM

Fermi: (C_S, C'_S) **Gamov Teller:** (C_T, C'_T)

Mixed: $(C_A, C_S, C'_S, C_T, C'_T)$

$$W \propto \left[1 + \frac{m_e}{E_e} b_{Fierz} + A \frac{\boldsymbol{p}_e}{E_e} \cdot \frac{\boldsymbol{J}}{J} + a \frac{\boldsymbol{p}_e}{E_e} \cdot \frac{\boldsymbol{p}_\nu}{E_\nu} + \cdots \right]$$

Correlation coefficients

Naviliat-Cuncic

$$b_F \sim \frac{C_{T(S)} + C'_{T(S)}}{C_{A(V)}} \longrightarrow$$

- Spectrum shape
- $e^{-(+)}$ polarization (e.g. Carnoy et al.)
- Normalization or energy dependence of other observable

Limits on tensor coupling from neutron β decay
Phys. Rev. C **88**, 048501 – Published 16 October 2013
R. W. Pattie, Jr., K. P. Hickerson, and A. R. Young

$$\alpha_{\beta\nu}, A_\beta, \ldots \sim \frac{|C_{T(S)}|^2 + |C'_{T(S)}|^2}{|C_{A(V)}|^2} \longrightarrow \tilde{X} \equiv \frac{X}{1 + \frac{m_e}{E} b_F}$$

Dataset

Selected dataset (limited selection)

Isotope	Parameter	Decay type	SM value ($q^2 \to 0$)	$\langle \frac{m}{E} \rangle$	Value	Error
^{6}He	$a_{\beta\nu}$	β^-, GT	$-\frac{1}{3}$	0.286	−0.3308	0.003
^{14}O ^{10}C	P_F/P_{GT}	β^+, F/GT	1	0.292	0.9996	0.0037
^{26m}Al ^{30}P	P_F/P_{GT}	β^+, F/GT	1	0.216	1.003	0.0184
^{32}Ar	$a_{\beta\nu}$	β^+, F	1	0.191	0.9989	0.0065
^{38m}K	$a_{\beta\nu}$	β^+, F	1	0.133	0.9981	0.0045
^{60}Co	A_β	β^-, GT	−1	0.704	−1.027	0.022
$0^+ \to 0^+$	b_{Fierz}	β^+, F	0	n/a	−0.0022	0.0026
n	A_0	β^-, F/GT	$A_{0,SM}$	0.560	−0.11952	0.00110
n	A_0	β^-, F/GT	$A_{0,SM}$	0.539	−0.11926	0.00050
n	A_0	β^-, F/GT	$A_{0,SM}$	0.582	−0.1160	0.0015
n	A_0	β^-, F/GT	$A_{0,SM}$	0.558	−0.1135	0.0014
n	A_0	β^-, F/GT	$A_{0,SM}$	0.551	−0.1146	0.0019
n	τ	β^-, F/GT		0.653	881.6	2.1
n	τ	β^-, F/GT		0.653	880.7	1.8
n	τ	β^-, F/GT		0.653	887.7	2.2
n	τ	β^-, F/GT		0.653	878.5	0.76
n	τ	β^-, F/GT		0.653	889.2	4.8
n	τ	β^-, F/GT		0.653	882.6	2.7
n	τ	β^-, F/GT		0.653	887.6	3.0

PDG 2012
+ UCNA
+ PERKEO II

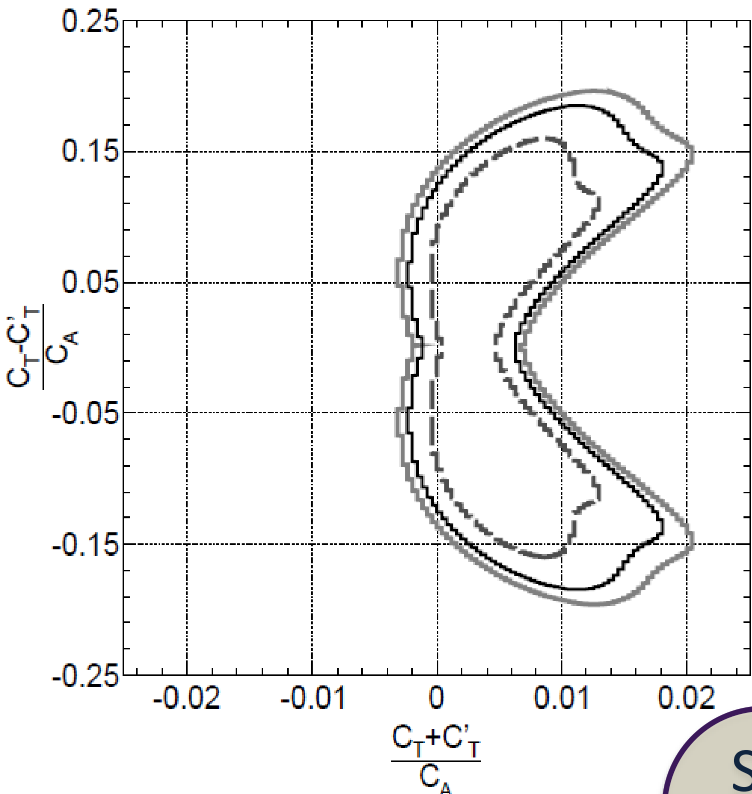
PDG 2012
+ Yue

Limits on $C^{(\prime)}_T$

68%, 90%, 95% C.L. shown

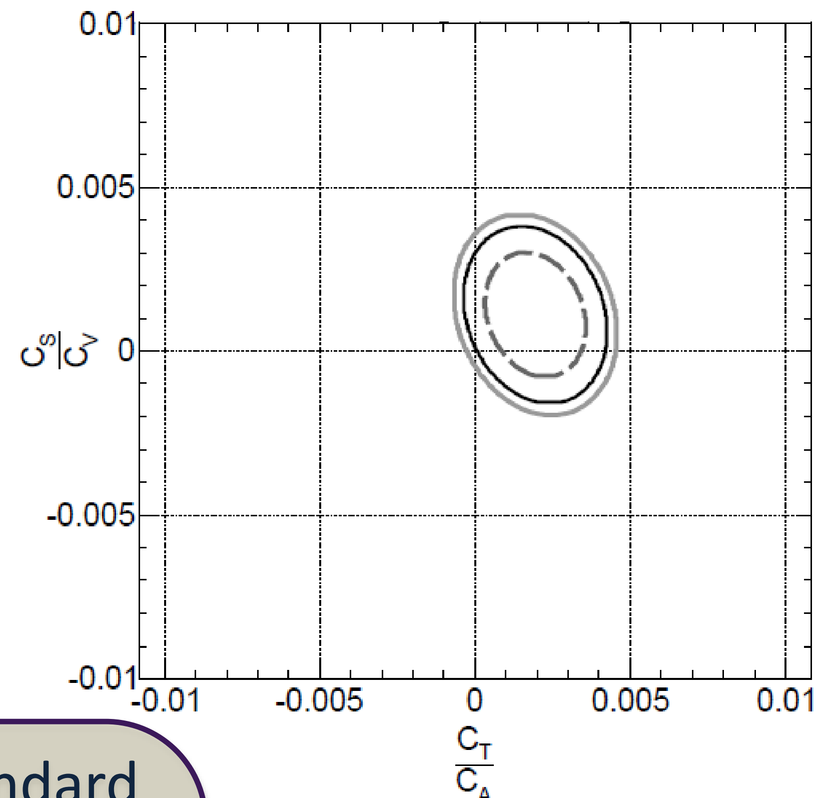
5 parameter fit

- $(C_T, C'_T, C_S, C'_S, C_A)$
- All real, $C_{V,A} = C'_{V,A}$



3 parameter fit

- (C_T, C_S, C_A)
- All real, $C_{V,A,S,T} = C'_{V,A,S,T}$



Standard Model OK

Limits on $C^{(\prime)}_T$

68%, 90%, 95% C.L. shown

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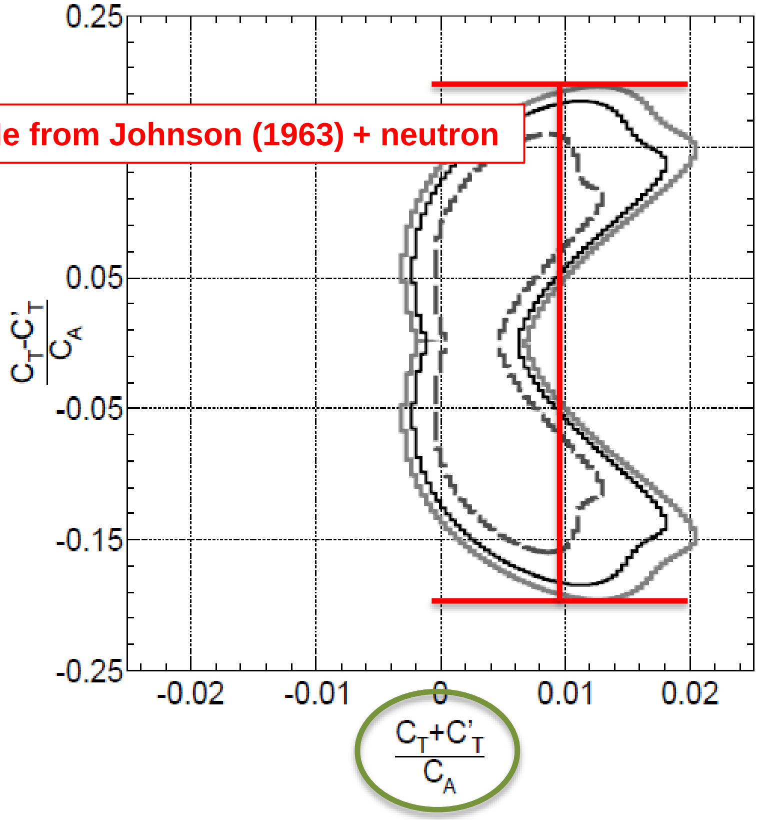
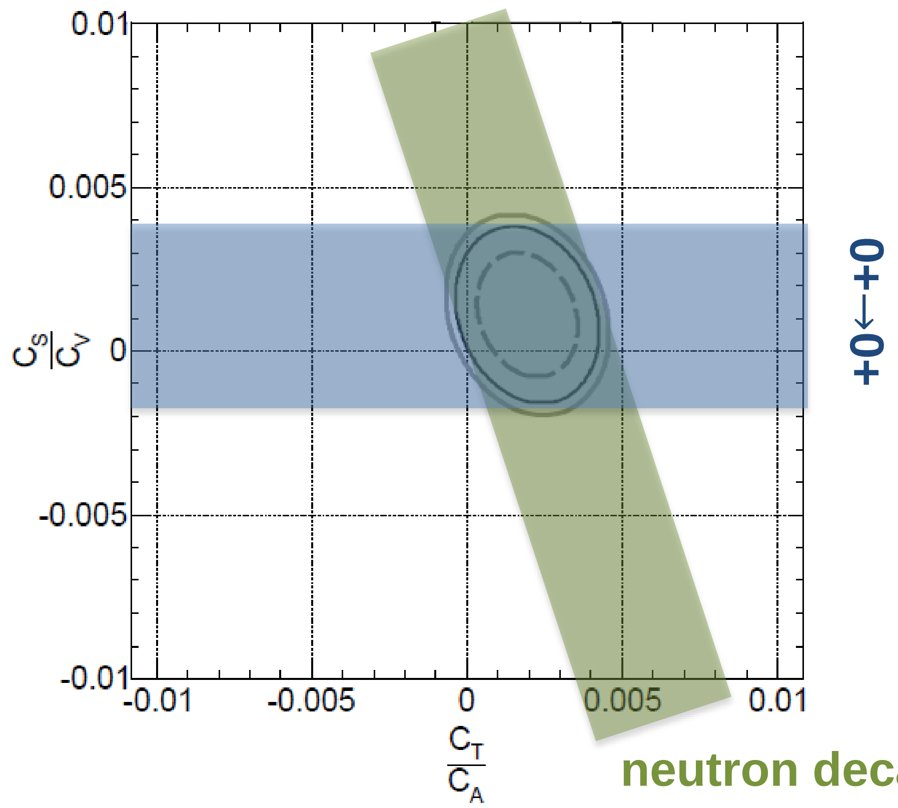


neutron + nuclear (P_F/P_{GT} + F trans. to limit $C^{(\prime)}_S$)

3 parameter fit

- (C_T, C_S, C_A)
- All real, $C_{V,A,S,T} = C'_{V,A,S,T}$

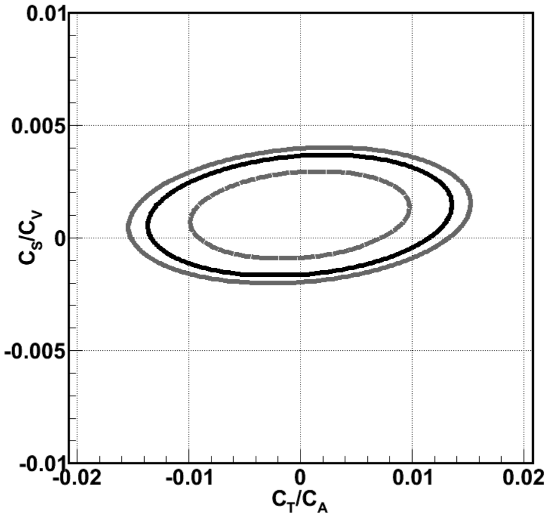


Limits on tensor coupling from neutron β decay
Phys. Rev. C **88**, 048501 – Published 16 October 2013
R. W. Pattie, Jr., K. P. Hickerson, and A. R. Young

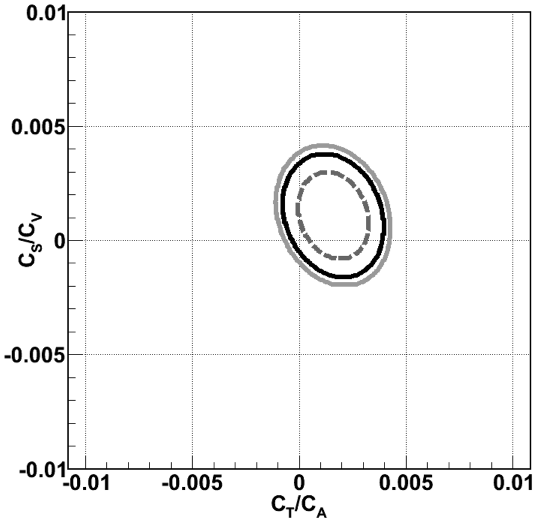
Limits on $C^{(\prime)}_T$

neutron dominates

Nuclear only

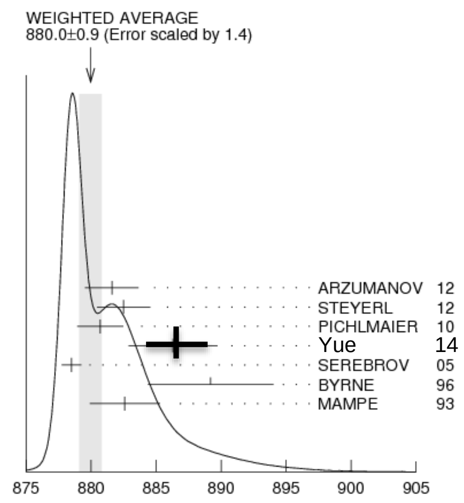


+ neutron



Limits on $C^{(')}_T$

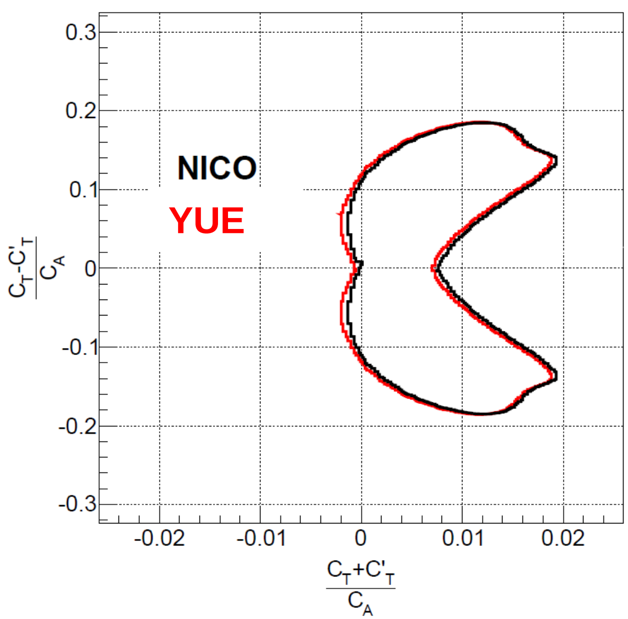
neutron dominates **But**

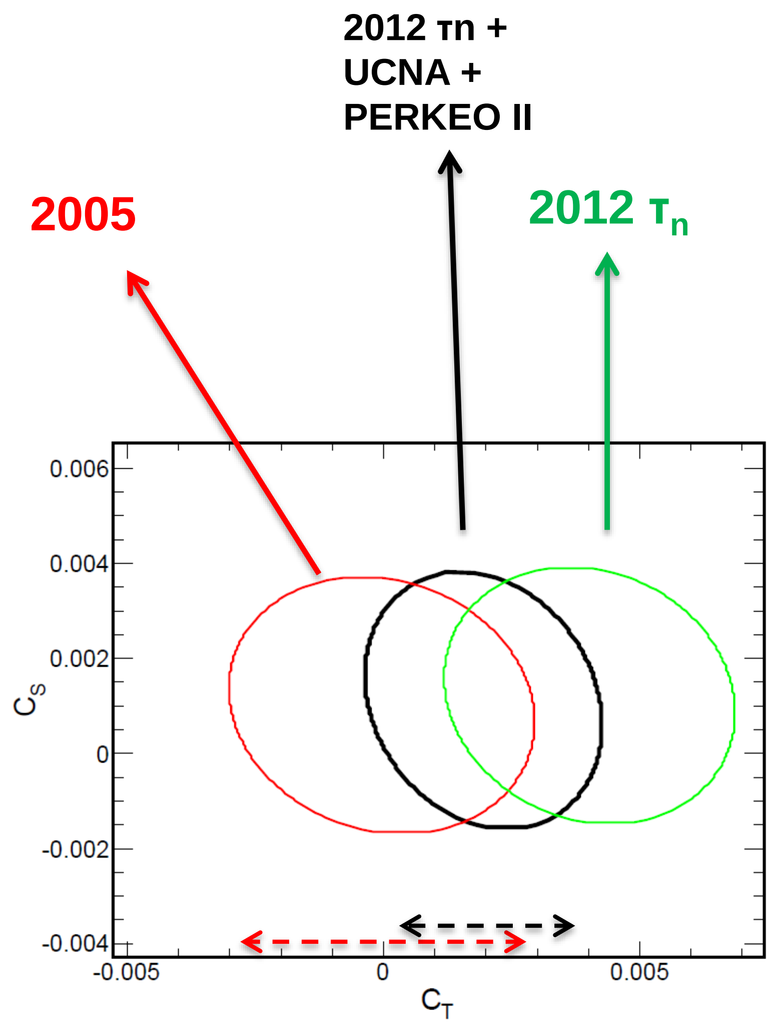


Limits on $C^{(\prime)}_T$

neutron dominates **But**

tension

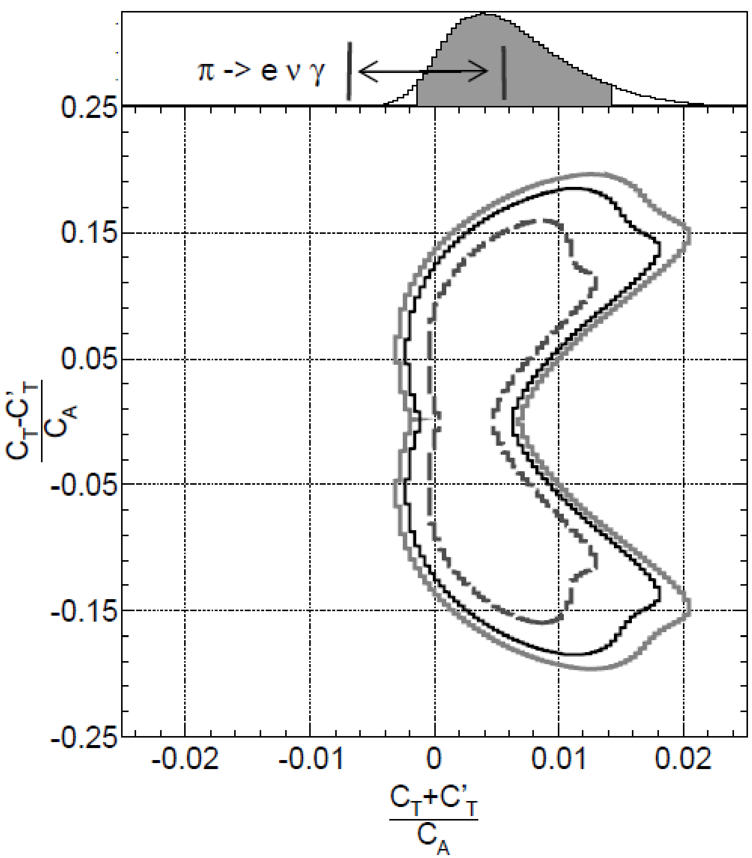


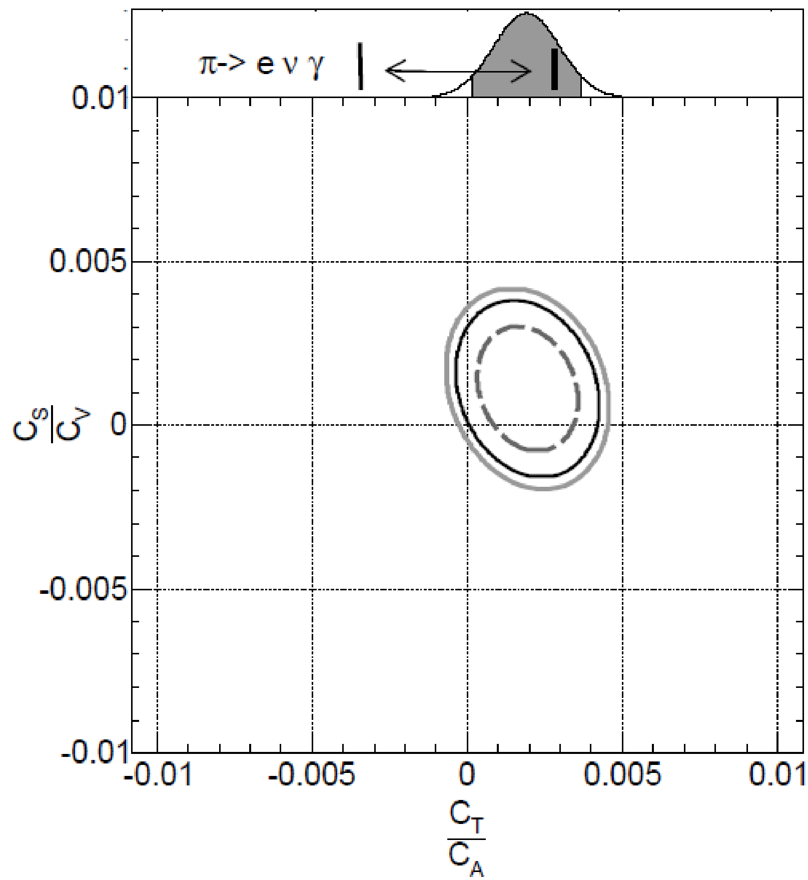


Limits on $C^{(')}_T$

β decay ↔ π decay

New Precise Measurement of the Pion Weak Form Factors in $\pi^+ \to e^+ \nu \gamma$ Decay
Phys. Rev. Lett. **103**, 051802 – Published 30 July 2009
M. Bychkov et al.





Limits on $C^{(\prime)}_T$

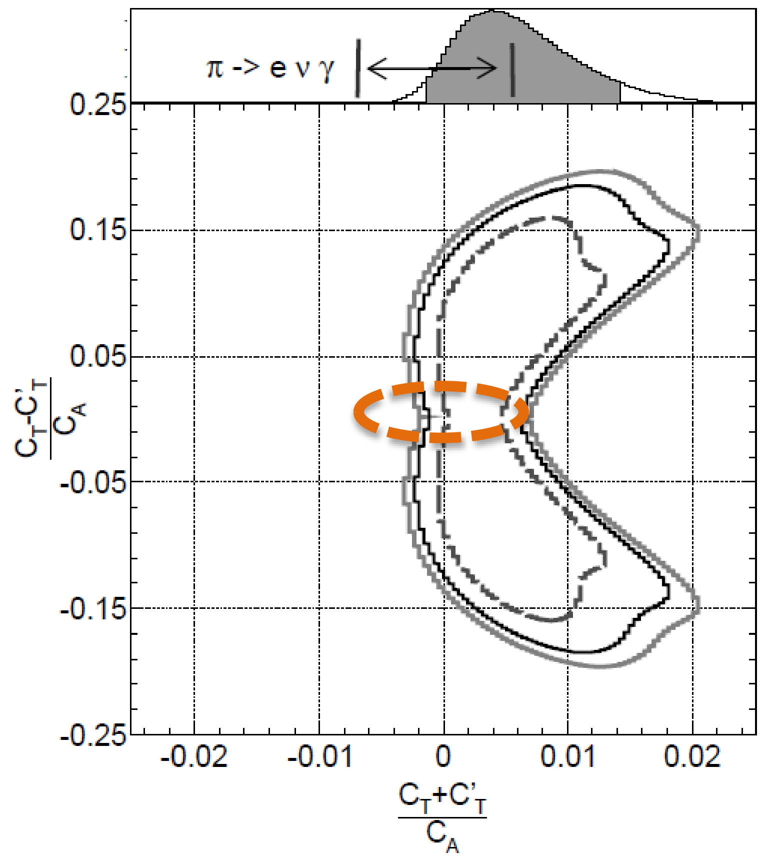
Journal of High Energy Physics
February 2013, 2013:46

Date: 08 Feb 2013

Non-standard charged current interactions: beta decays versus the LHC

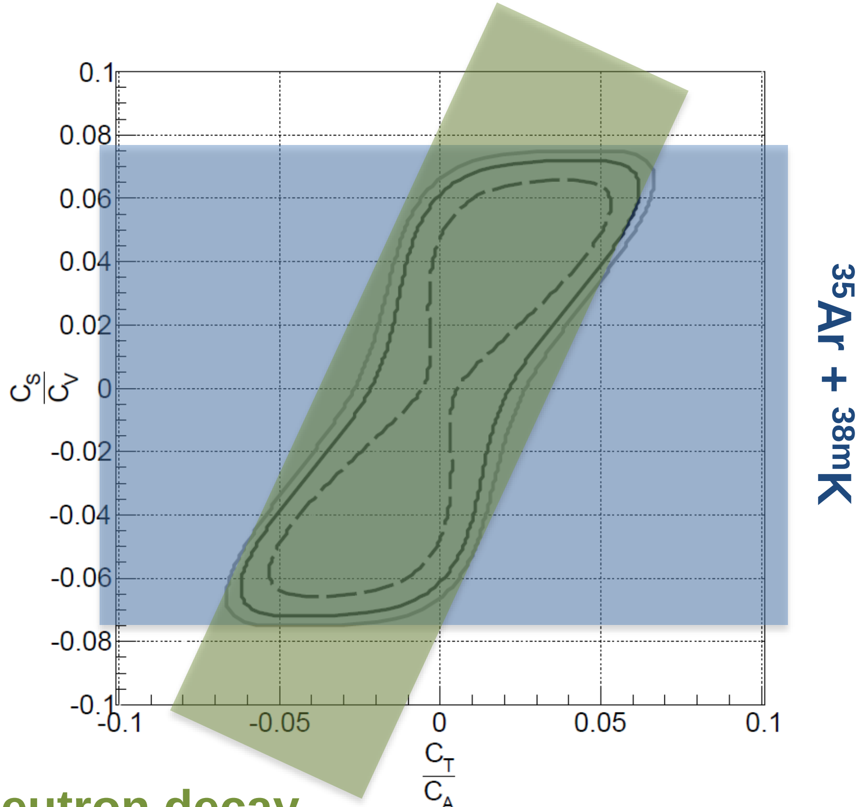
Vincenzo Cirigliano, Martín González-Alonso, Michael L. Graesser

β decay ↔ LHC



Limits on $C^{(\prime)}_T$

Coupling to right-handed neutrinos



neutron decay
(+ ^{6}He and ^{8}Li)

C_T, C'_T: The numbers

1-D 90% C.L. x 100

5 parameter fit

- $\frac{C_T + C'_T}{C_A} \rightarrow [-0.21; 1.4]$
- $\frac{C_T - C'_T}{C_A} \rightarrow [-16; 16]$

3 parameter fit ν_L

- $\frac{C_T}{C_A} \rightarrow [-0.01; 0.34]$
- $\frac{C_S}{C_V} \rightarrow [-0.27; 0.48]$

3 parameter fit ν_R

- $\frac{C_T}{C_A} \rightarrow [-4.5; 4.5]$
- $\frac{C_S}{C_V} \rightarrow [-6.7; 6.7]$

C_T, C'_T: The numbers

1-D 90% C.L. x 100

5 parameter fit

- $\frac{C_T + C'_T}{C_A} \rightarrow [-0.21; 1.4]$ **1 %**
- $\frac{C_T - C'_T}{C_A} \rightarrow [-16; 16]$ 10 %

3 parameter fit ν_L

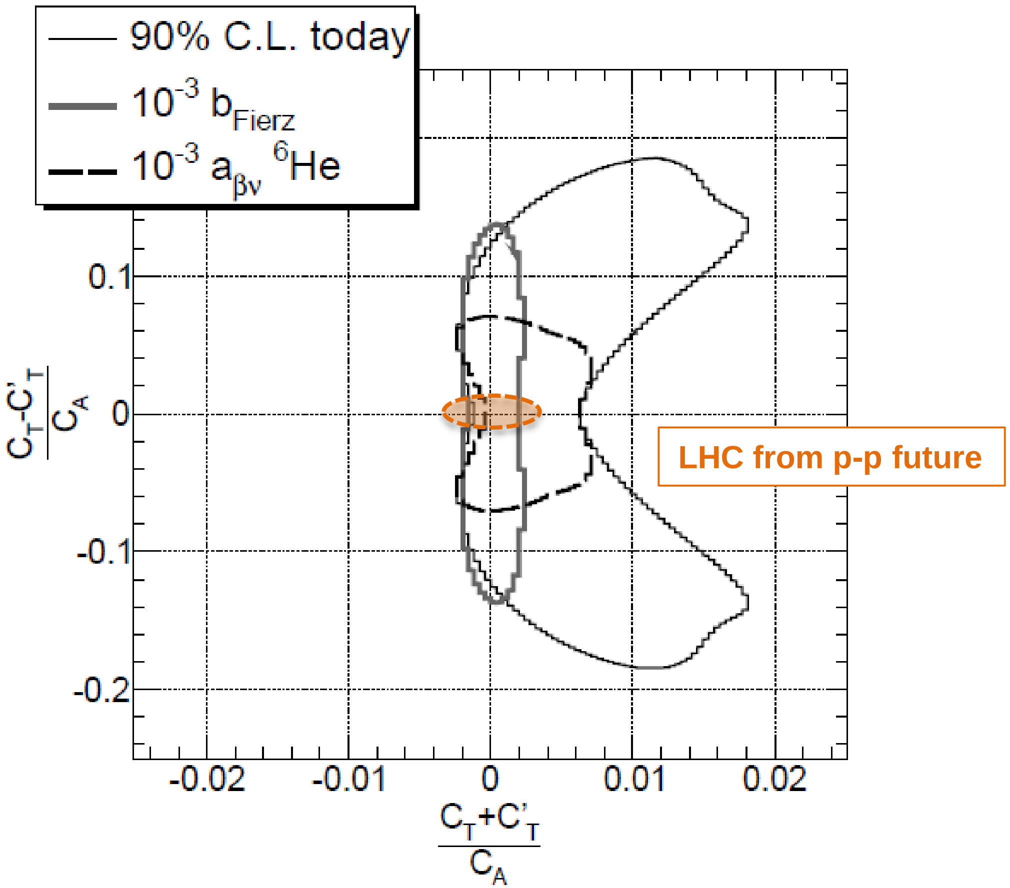
- $\frac{C_T}{C_A} \rightarrow [-0.01; 0.34]$ **< 1 %**
- $\frac{C_S}{C_V} \rightarrow [-0.27; 0.48]$ **< 1 %**

Limits on tensor coupling from neutron β decay
Phys. Rev. C **88**, 048501 – Published 16 October 2013
R. W. Pattie, Jr., K. P. Hickerson, and A. R. Young

3 parameter fit ν_R

- $\frac{C_T}{C_A} \rightarrow [-4.5; 4.5]$ 5 %
- $\frac{C_S}{C_V} \rightarrow [-6.7; 6.7]$ 5 %

Limits on $C^{(\prime)}_T$



PERKEO III $\rightarrow < 10^{-3}$ $on\ \tilde{A} = \frac{A_0}{1+\frac{m}{E}b_F}$

Conclusions


PHYSICAL REVIEW C
nuclear physics
Highlights Recent Accepted Authors Referees Search About

Limits on tensor-type weak currents from nuclear and neutron β decays
Phys. Rev. C **89**, 025501 – Published 28 February 2014
F. Wauters, A. García, and R. Hong

- For ν_L couplings, β decay is and will be competitive
- $< 10^{-3}$ is needed for beyond SM sensitivity

- Neutron experiments are one step ahead on the nuclear β decays
- Pions?

- For ν_R couplings, life is hard

Did not discuss:
- Radiative corrections
- Nuclear corrections

Conclusions


PHYSICAL REVIEW C
nuclear physics
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Limits on tensor-type weak currents from nuclear and neutron β decays
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- For ν_L couplings, β decay is and will be competitive
- < 10^{-3} is needed for beyond SM sensitivity

- Neutron experiments are one step ahead on the nuclear β decays
- Pions?

b_{Fierz}

- For ν_R couplings, life is hard

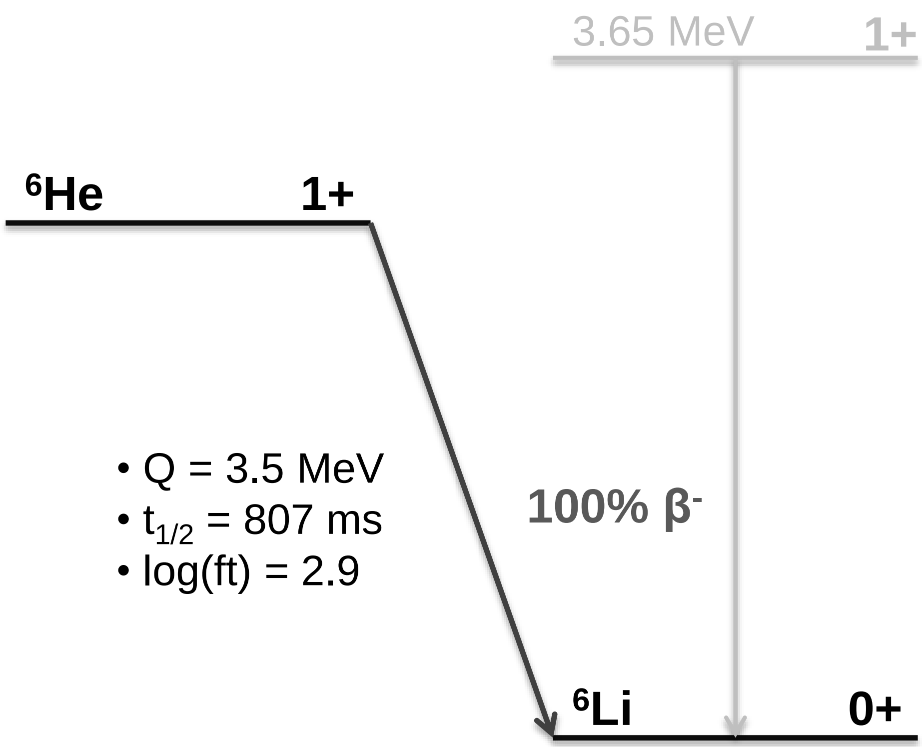
Did not discuss:
- Radiative corrections
- Nuclear corrections (Z>1)

(this talk is not over)

^6He at UW

An alternative to the neutron

- 10^{10} s-1 at CENPA (UW)
- 10^3 trapped atoms: $a_{\beta\nu}$ Mueller

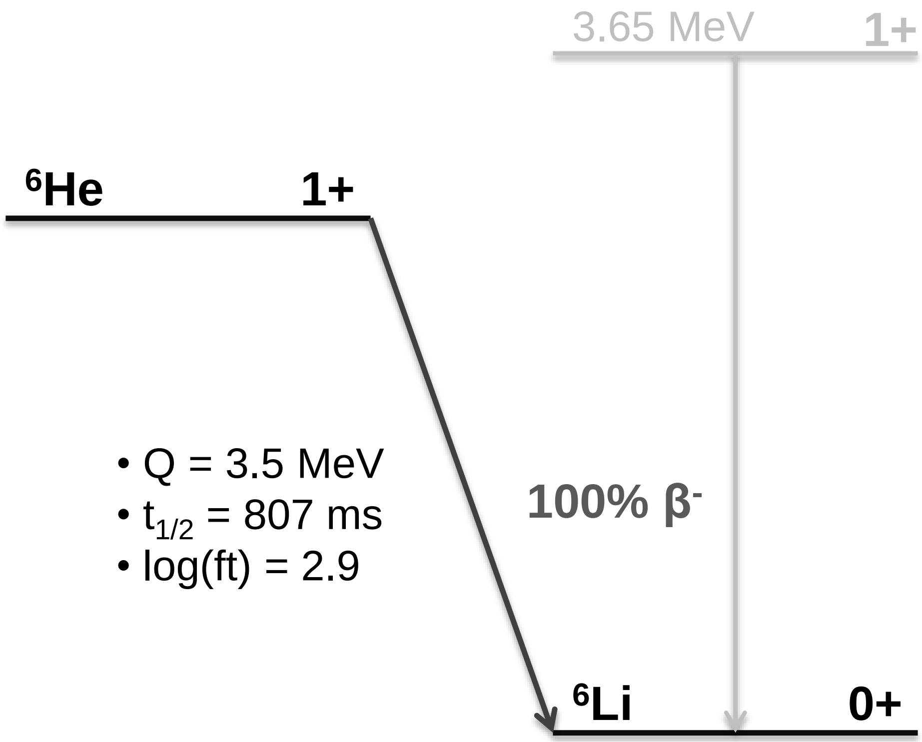


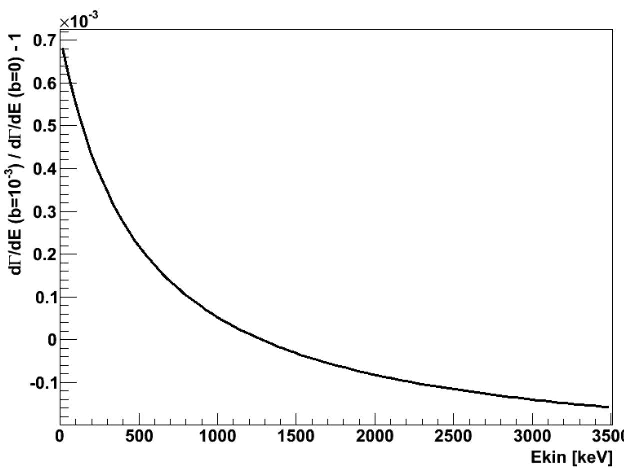
- Q = 3.5 MeV
- $t_{1/2}$ = 807 ms
- log(ft) = 2.9

lil' b ^{6}He at UW

An alternative to the neutron

- 10^{10} s-1 at CENPA (UW)
- 10^3 trapped atoms: $a_{\beta\nu}$ Mueller
- 10^6 trapped ions
- $\sigma_{bFierz} \cong \frac{10}{\sqrt{N}} \rightarrow 10^{10}\ for\ 10^{-4}$

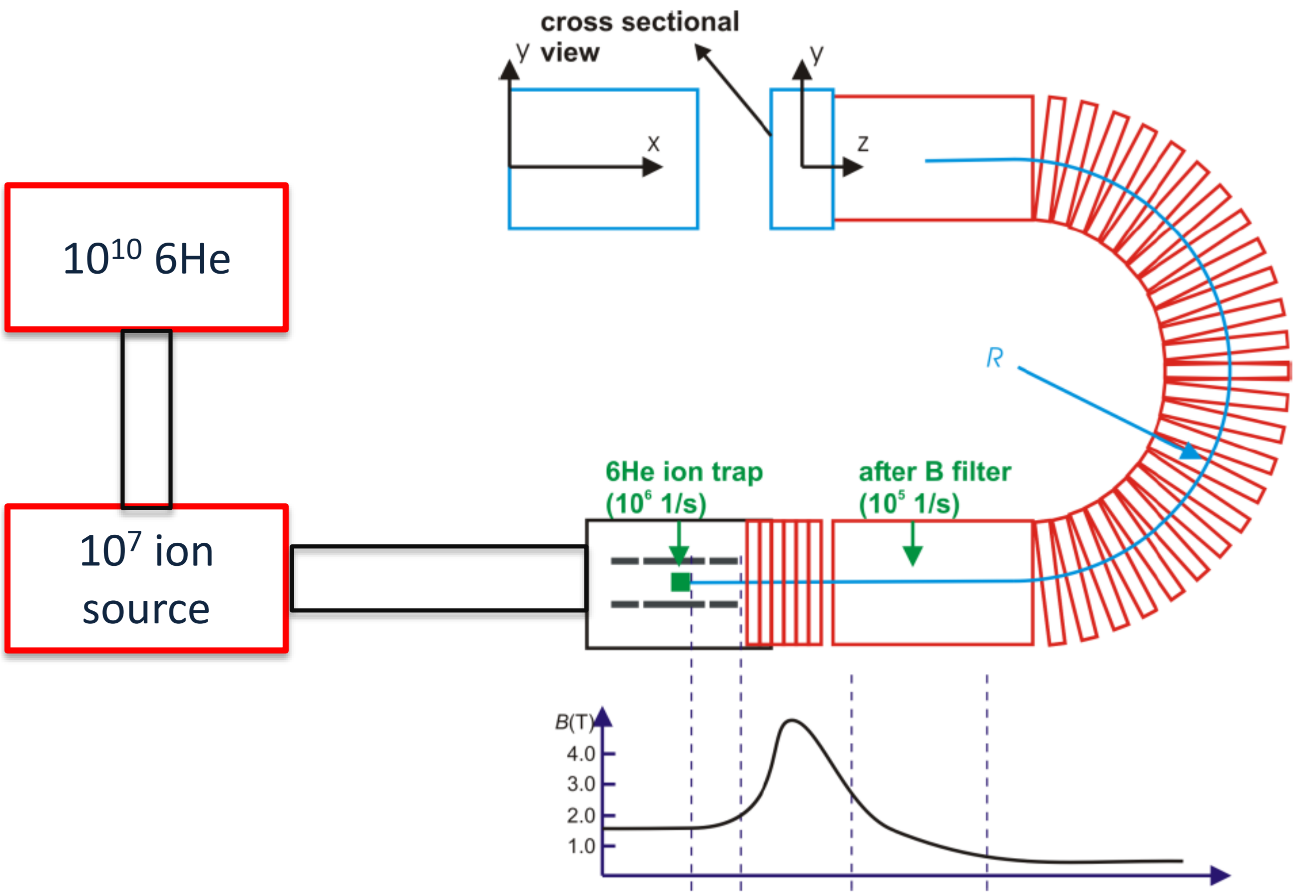




lil‘ b ^{6}He at UW: idea 1

perc like RxB spectrometer

- Scale B fields and R to 3.4 MeV



A. Garcia
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lil' b ^{6}He at UW: idea 2

Single electron cyclotron emission spectroscopy

arXiv.org > physics > arXiv:1408.5362

Search or Artic

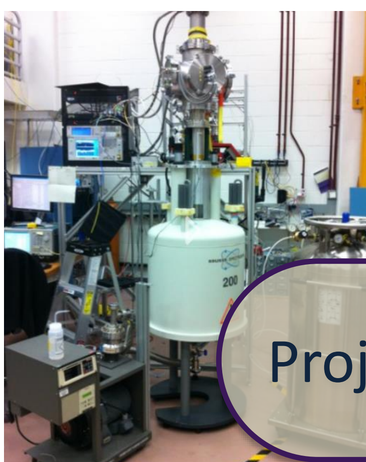
Physics > Instrumentation and Detectors

Single electron detection and spectroscopy via relativistic cyclotron radiation

D.M. Asner, R.F. Bradley, L. de Viveiros, P.J. Doe, J.L. Fernandes, M. Fertl, E.C. Finn, J. A. Formaggio, D. Furse, A. M. Jones, J. N. Kofron, B. H. LaRoque, M. Leber, E. L. McBride, M. L. Miller, P. Mohanmurthy, B. Monreal, N. S. Oblath, R. G. H. Robertson, L. J Rosenberg, G. Rybka, D. Rysewyk, M. G. Sternberg, J. R. Tedeschi, T. Thummler, B. A. VanDevender, N. L. Woods

(Submitted on 22 Aug 2014)

It has been understood since 1897 that accelerating charges must emit electromagnetic radiation. Cyclotron radiation, the particular form of radiation emitted by an electron orbiting in a magnetic field, was first derived in 1904. Despite the simplicity of this concept, and the enormous utility of electron spectroscopy in nuclear and particle physics, single-electron cyclotron radiation has never been observed directly. Here we demonstrate single-electron detection in a novel radiofrequency spec- trometer. We observe the cyclotron radiation emitted by individual magnetically-trapped electrons that are produced with mildly-relativistic energies by a gaseous radioactive source. The relativistic shift in the cyclotron frequency permits a precise electron energy measurement. Precise beta elec- tron spectroscopy from gaseous radiation sources is a key technique in modern efforts to measure the neutrino mass via the tritium decay endpoint, and this work demonstrates a fundamentally new approach to precision beta spectroscopy for future neutrino mass experiments.



Project 8 @ UW

$$P(\gamma,\theta) = \frac{1}{4\pi\epsilon_0}\frac{2}{3}\frac{e^4}{m_e^2 c}B^2\left(\gamma^2-1\right)\sin^2\theta$$

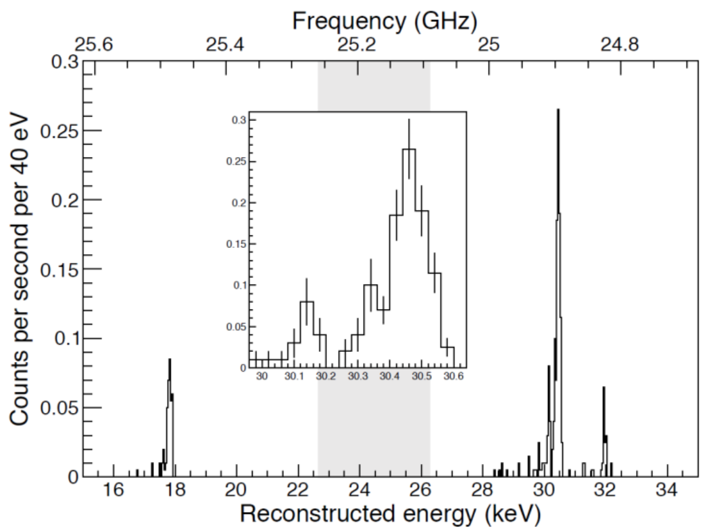
$$\gamma = \left(1 + K/m_e c^2\right)$$

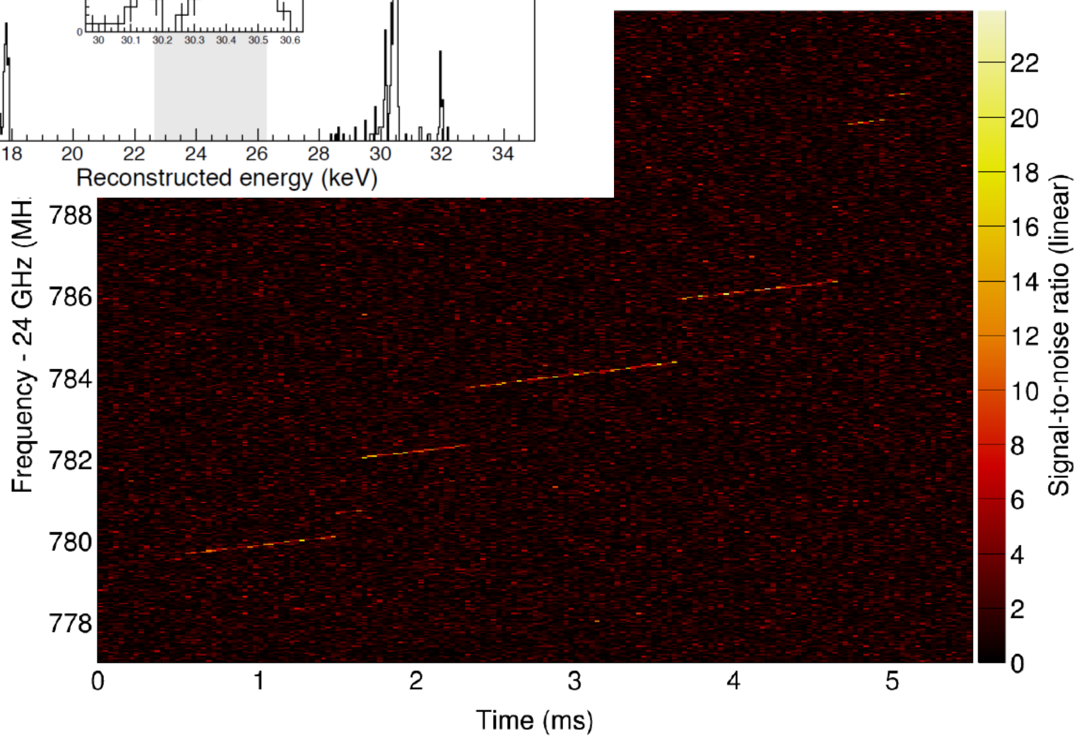
$$f_\gamma \equiv \frac{f_c}{\gamma} = \frac{eB}{2\pi\gamma m_e}$$

http://www.project8.org/

lil' b ^{6}He at UW: idea 2

Single electron cyclotron emission spectroscopy





- ? ^{6}He ?
- non-destructive
- frequency measurement

M. Sternberg
mgrants@uw.edu

Extra's

Comparison of neutron to 6He shape measurement with $R \times B$ spectrometer

Parameter		Neutron	6He
K_{eMax}(MeV)		0.97	3.5
B3 (Tesla)		0.15	0.15
Effective decay rate (1/s)		10^6	10^5
Trappable		No	Yes
Image size at $p \approx 0$		1×1 cm2	0.3×0.3 cm2
Backgrounds		?	?

Extra's

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Tests of the standard electroweak model in nuclear beta decay

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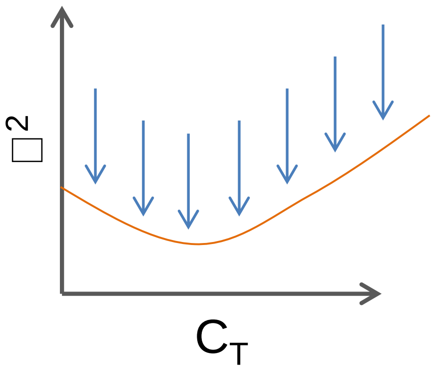
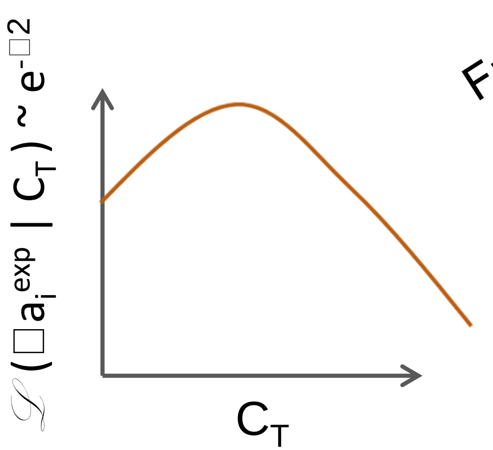
Isotope	Z	J	J'	Type	Parameter	Value	Error	$\langle W^{-1}\rangle$	Reference
^{6}He	3	0	1	GT/β^-	a	−0.33000	0.01000	0.286	Johnson *et al.* (1961)
						−0.33080[a]	0.00300	0.286	Johnson *et al.* (1963)
						−0.31900	0.02800	0.199	Vise and Rustad (1963)
^{8}Li	4	2	2	GT/β^-	R	0.00090	0.00220	0.062	Huber *et al.* (2003)
^{12}B	6	1	0	GT/β^-	G	−0.98000	0.06000	0.055	Lipnik *et al.* (1962)
^{12}N	6	1	0	GT/β^+	P^-/P^+	1.00060	0.00340	0.079	Thomas *et al.* (2001)
^{14}O	7	0	0	F/β^+	G	0.97000	0.19000	0.338	Hopkins *et al.* (1961)
^{14}O/^{10}C	7/5			$F-$GT/β^+	P_F/P_{GT}	0.99960	0.00370	0.292	Carnoy *et al.* (1991)
^{18}Ne	9	0	0	F/β^+	a	1.06000	0.09500	0.289	Egorov *et al.* (1997)
^{23}Ne	11	2.5	1.5	GT/β^-	a	−0.37000	0.04000	0.243	Allen *et al.* (1959)
						−0.33000	0.03000	0.243	Carlson (1963)
^{26}Al/^{30}P	12/14			$F-$GT/β^+	P_F/P_{GT}	1.00300	0.00400	0.189	Wichers *et al.* (1987)
^{32}Ar	17	0	0	F/β^+	a	0.99890	0.00650	0.210	Adelberger *et al.* (1999)
^{38}K^m	18	0	0	F/β^+	a	0.99810	0.00480	0.161	Gorelov *et al.* (2005)
^{68}Ga	30	1	0	GT/β^+	G	0.99000	0.09000	0.307	Ullman *et al.* (1961)
^{107}In	48	4.5	3.5	GT/β^+	P^-/P^+	0.92600	0.04100	0.311	Severijns *et al.* (1993)
					P^-/P^0	0.98980	0.00820	0.311	Camps (1997)
^{114}In	50	1	0	GT/β^-	b	0.05000	0.02000	0.399	Daniel and Panussi (1961)
						0.00500	0.02200	0.399	Daniel *et al.* (1964)
					A	−1.01300	0.02400	0.662	Severijns (1989)
					G	−0.96900	0.03700	0.449	van Klinken (1966)
^{127}Te	53	1.5	2.5	GT/β^-	A	0.56900	0.05100	0.721	Vanneste (1986)
^{129}Te	53	1.5	2.5	GT/β^-	A	0.64500	0.05900	0.528	Vanneste (1986)
^{133}Xe	55	1.5	2.5	GT/β^-	A	0.59800	0.07300	0.818	Vanneste (1986)
Several		0	0	F/β^+	b_F	0.0001	0.0026		Hardy and Towner (2005a)

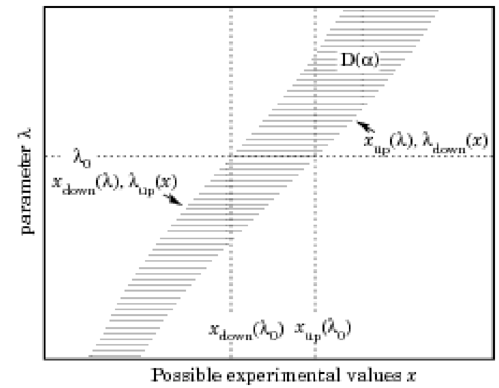
Extra's



Walk through C_T space for each point
calculate $□^2_{min}(C_S)$ for a_i^{exp} □ $a_i(C_T)$



Frequentist



- know □
- large data limit
  □ parabolic log($\mathscr{L}$)

$(1-\alpha)$ (%)	$m=1$	$m=2$	$m=3$
68.27	1.00	2.30	3.53
90.	2.71	4.61	6.25
95.	3.84	5.99	7.82
95.45	4.00	6.18	8.03
99.	6.63	9.21	11.34
99.73	9.00	11.83	14.16

Bayesians

$$C.I.(C_T \mid \sum a_i^{exp}) \sim \int_{C_T^{low}}^{C_T^{high}} \mathscr{L}(\sum a_i^{exp} \mid C_T) □ prior(C_T) dC$$

comments

- bFierz, +?
- ? Right handed currents, formulate as a question ?
- Measure bFierz:
  - A/B in neutron:
  - Quote CT evalution Young
  - 6He at CENPA -> 10^10
    - 10^3 in a MOT
    - Ion (penning) trap 10^6: RxB need 10^5
      - Bigger magnet
      - Cloud + <-> perc
      - Background+
    - Project 8 measurement (Matt), quote arXiv paper
    - 10/sqrt(N), 10-4 -> N10e10. 10 kHz->10days
  - Slides?
    - RxB : Elog 174. loos order magnitude between source and filter