Limits on tensor-type weak currents and the beta-neutrino correlation of ^{6}He

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Tensor type currents

Nuclear β decays in the Jackson, Trieman and Wyld 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:

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

Standard Model at low energy:

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

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

Tensor type currents

A new* evaluation of tensor type-weak currents from nuclear and neutron β-decay data was motivated by:

Quark level EFT**

$$\mathcal{L}_{\rm CC} = -\frac{G_F^{(0)} V_{ud}}{\sqrt{2}} (1 + \delta_{RC} + \epsilon_L + \epsilon_R)$$
$$\times \Big[\bar{\ell}\gamma_\mu(1-\gamma_5)\nu_\ell \cdot \bar{u}\gamma^\mu \Big(1 - (1 - 2\,\epsilon_R)\,\gamma_5\Big) d$$
$$+ \epsilon_S \; \bar{\ell}(1-\gamma_5)\nu_\ell \cdot \bar{u} d$$
$$- \epsilon_P \; \bar{\ell}(1-\gamma_5)\nu_\ell \cdot \bar{u}\gamma_5 d$$
$$+ \epsilon_T \; \bar{\ell}\sigma_{\mu\nu}(1-\gamma_5)\nu_\ell \cdot \bar{u}\sigma^{\mu\nu}(1-\gamma_5) d \Big] + \text{h.c.}$$

$$g_S\, \epsilon_S = \frac{C_S + C'_S}{2\, C_V} \qquad g_T\, \epsilon_T = \frac{C_T + C'_T}{8\, C_A}$$
$$g_S\, \tilde{\epsilon}_S = \frac{C_S - C'_S}{2\, C_V} \qquad g_T\, \tilde{\epsilon}_T = \frac{C_T - C'_T}{8\, C_A}$$

$$F_T = \varepsilon_T\, f_T$$

From lattice QCD

New data

*Rev. Mod. Phys. 78, 991–1040 (2006) ** Phys. Rev. D 85, 054512 (2012)

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$$
\begin{aligned}
\mathcal{L}_{\rm CC} &= -\frac{G_F^{(0)} V_{ud}}{\sqrt{2}} \left(1 + \delta_{RC} + \epsilon_L + \epsilon_R\right) \\
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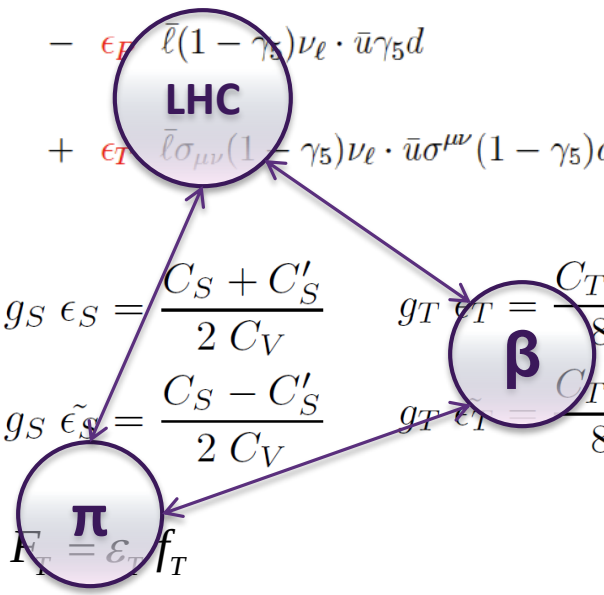
\end{aligned}
$$

$$g_S\,\epsilon_S = \frac{C_S + C'_S}{2\,C_V} \qquad g_T\,\epsilon_T = \frac{C_T + C'_T}{8\,C_A}$$

$$g_S\,\tilde{\epsilon}_S = \frac{C_S - C'_S}{2\,C_V} \qquad g_T\,\tilde{\epsilon}_T = \frac{C_T - C'_T}{8\,C_A}$$

$$F_T = \varepsilon_T f_T$$



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LHC

$$g_S\,\epsilon_S = \frac{C_S + C'_S}{2\,C_V} \qquad g_T\,\epsilon_T = \frac{C_T + C'_T}{8\,C_A}$$

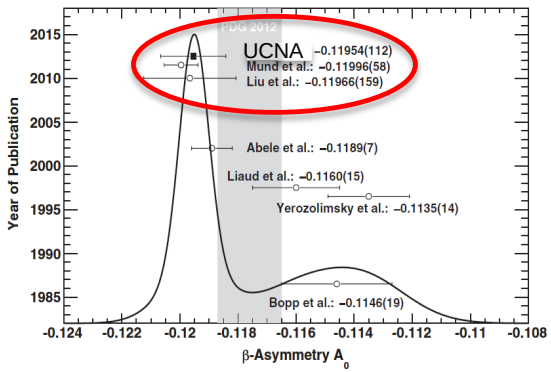
β

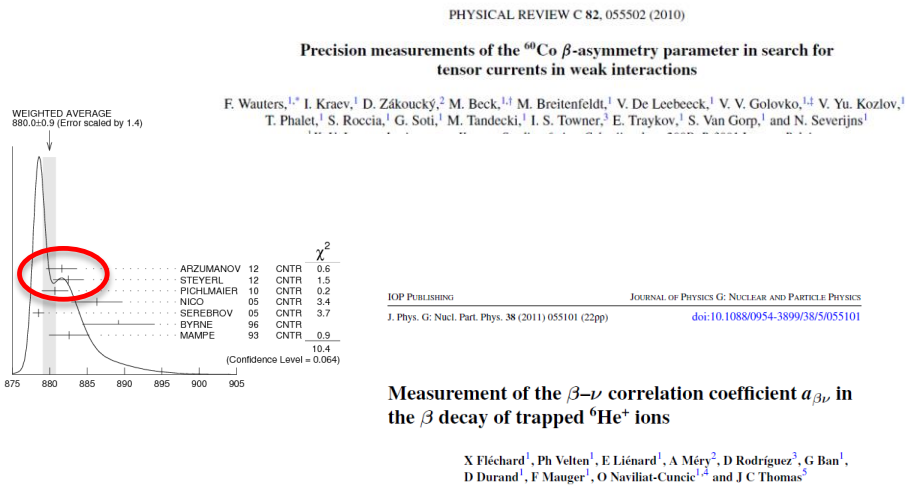
$$g_S\,\tilde{\epsilon}_S = \frac{C_S - C'_S}{2\,C_V} \qquad g_T\,\tilde{\epsilon}_T = \frac{C_T - C'_T}{8\,C_A}$$

π

$$F_T = \varepsilon_T f_T$$

New data




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, I. Kraev, D. Zákoucký, M. Beck, M. Breitenfeldt, V. De Leebeeck, V. V. Golovko, V. Yu. Kozlov, T. Phalet, S. Roccia, G. Soti, M. Tandecki, I. S. Towner, E. Traykov, S. Van Gorp, and N. Severijns

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 ^{6}He$^+$ ions

X Fléchard, Ph Velten, E Liénard, A Méry, D Rodríguez, G Ban, D Durand, F Mauger, O Naviliat-Cuncic and J C Thomas

+ more to come soon!

*Rev. Mod. Phys. 78, 991–1040 (2006) ** Phys. Rev. D 85, 054512 (2012)

Observables

β-decay rate:

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:

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

→ spectrum shape

→ decay rate (life time / ft)

$$a_{\beta\nu} / A_\beta / .. \sim \frac{\left|C_{T(S)}\right|^2 + \left|C'_{T(S)}\right|^2}{C^2_{A(V)}} \longrightarrow \tilde{X} = \frac{X}{1 + \frac{m_e}{E_{tot,\beta}} b_{Fierz}}$$

Data Set

Nuclear:

Selected data set most sensitive to tensor currents
+ ^{32}Ar / ^{38m}K / 0+->0+ to pin down C_S and C'_S

Isotope	Parameter	Decay type	SM value ($q^2 \to 0$)	$\langle \frac{m}{E} \rangle$	Value	Error
^{6}He	a	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	β^+, F	1	0.191	0.9989	0.0065
^{38m}K	a	β^+, F	1	0.133	0.9981	0.0045
^{60}Co	A	β^-, GT	-1	0.704	-1.027	0.022
$0^+ \to 0^+$	b_{Fierz}	β^+, F	0	n/a	-0.0022	0.0026

neutron:

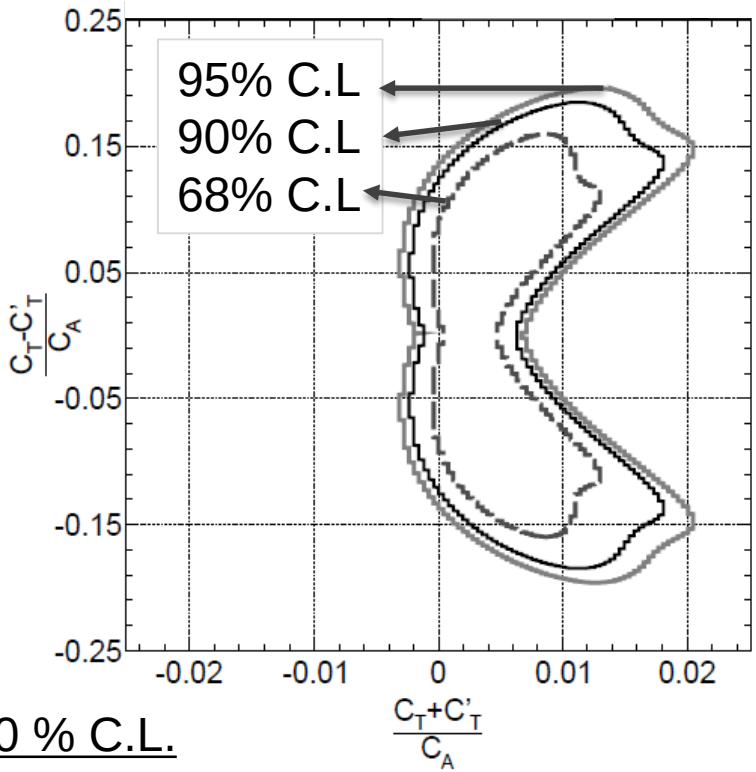
PDG2012 selection for τ_n and A_0

+ recent UCNA and PERKEOII results

Limits

C'_x real,
vector and axial vector
are SM-like
V_{ud}: $0+ \rightarrow 0+$

5 parameter fit (C_A,C_S,C'_S,C_T,C'_T)

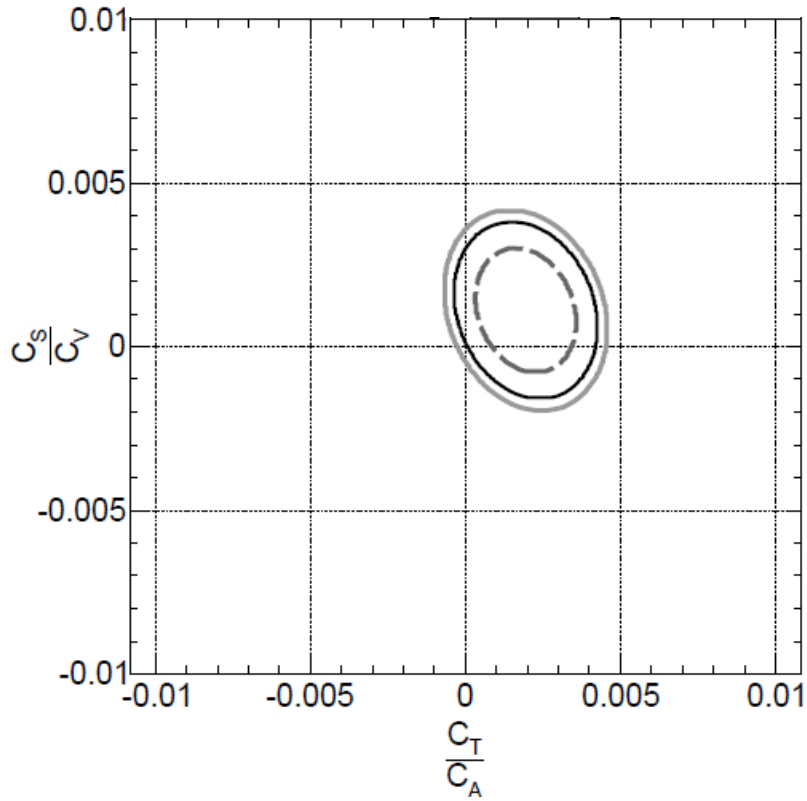


90 % C.L.

$$-0.14 \times 10^{-2} < (C_T + C'_T)/C_A < 1.4 \times 10^{-2}$$

$$-0.16 < (C_T - C'_T)/C_A < 0.16$$

3 parameter fit (C_A,C_S= C'_S,C_T= C'_T)



$$0.0 \times 10^{-2} < C_T/C_A < 0.4 \times 10^{-2}$$

Limits

C'_x real,
vector and axial vector
are SM-like
V_{ud}: $0+ \rightarrow 0+$

5 parameter fit (C_A,C_S,C'_S,C_T,C'_T)

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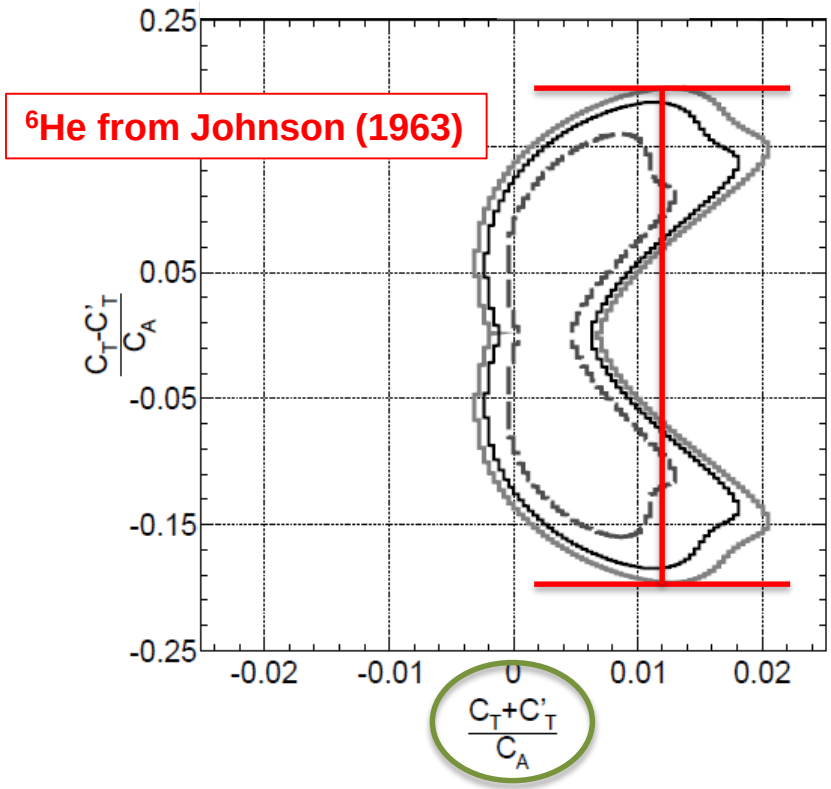
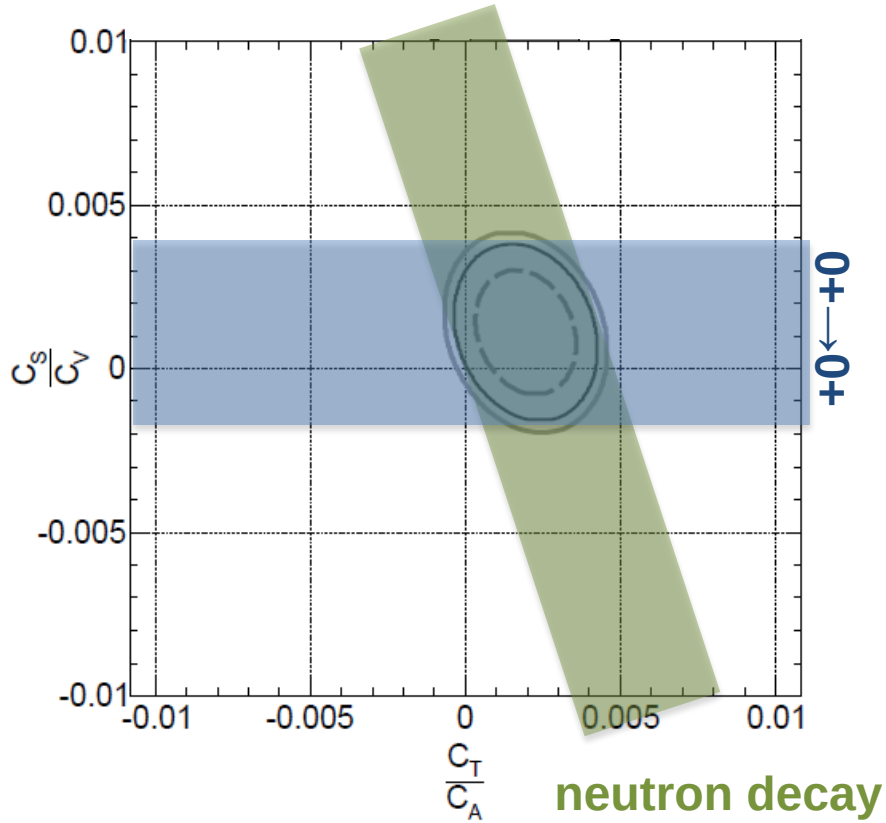
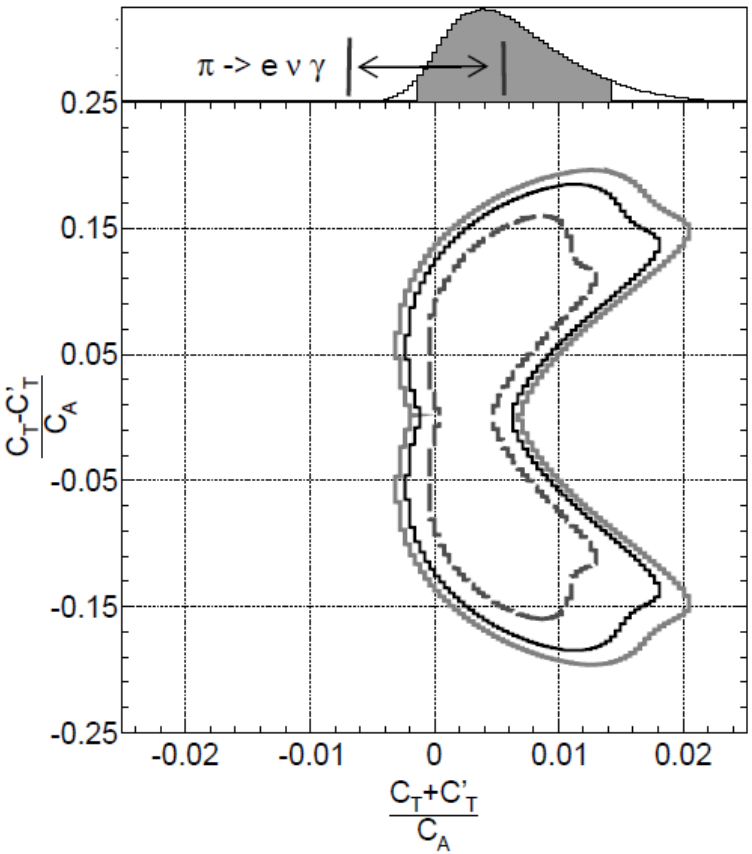
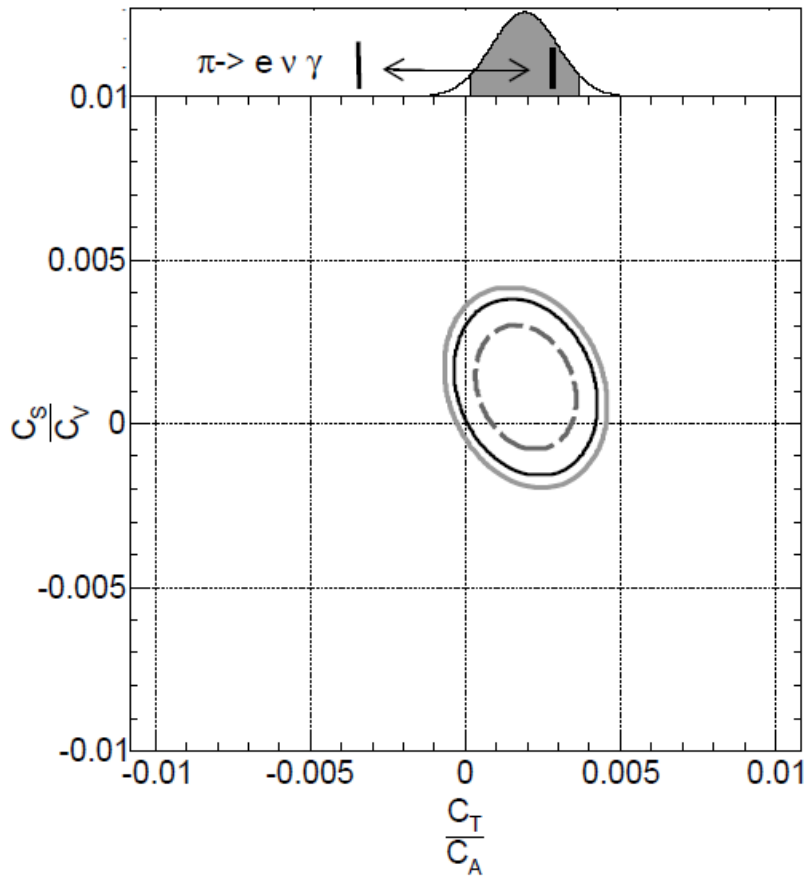




neutron + nuclear (P_F/P_{GT} + F trans. to limit $C^{(\prime)}_S$)

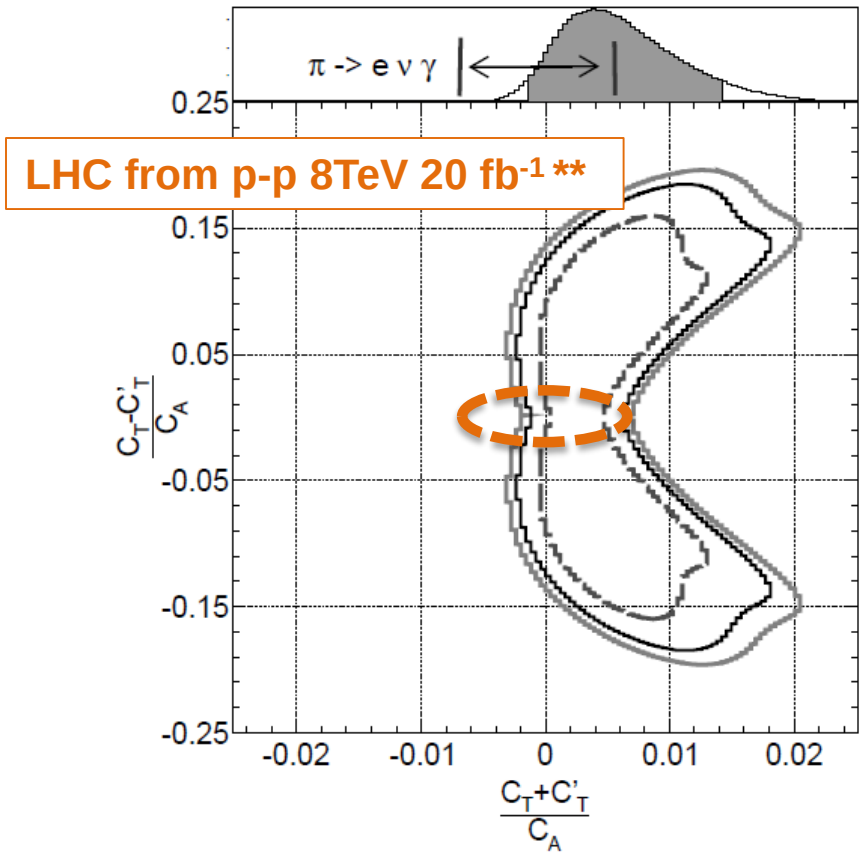
Limits π ↔ β decay*

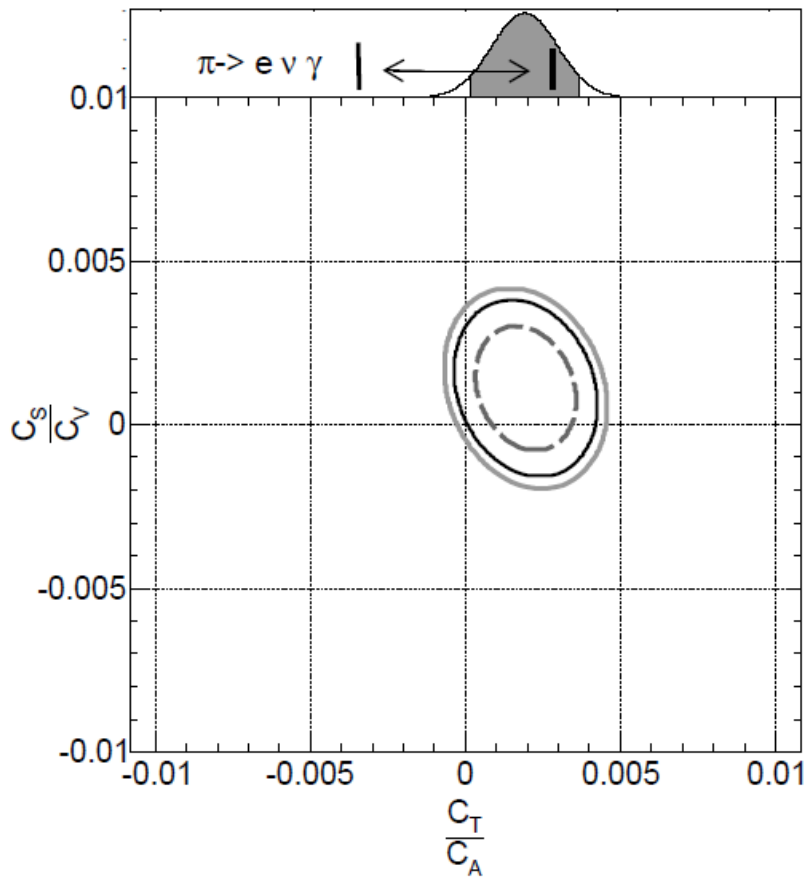




*PIBETA Phys. Rev. Lett. 103, 051802 (2009)

Limits π ↔ β decay* ↔ LHC

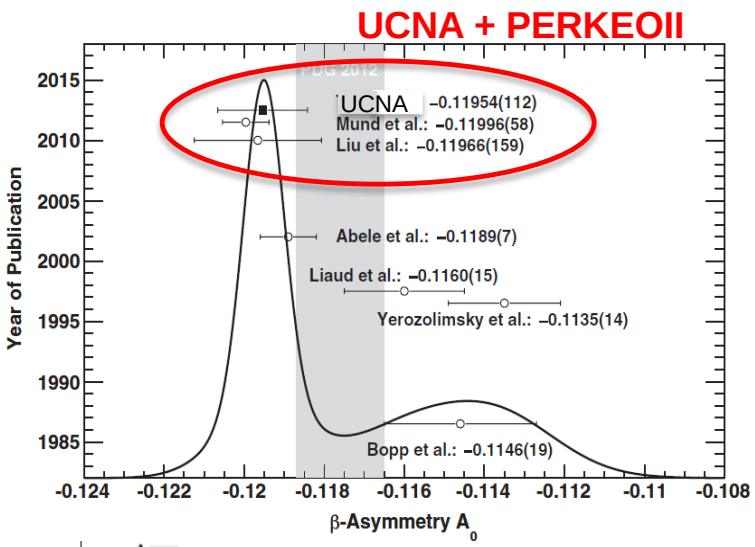


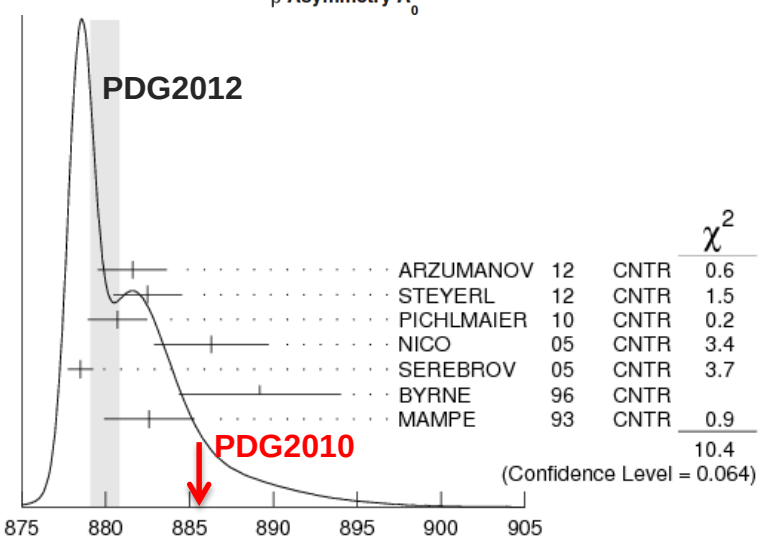


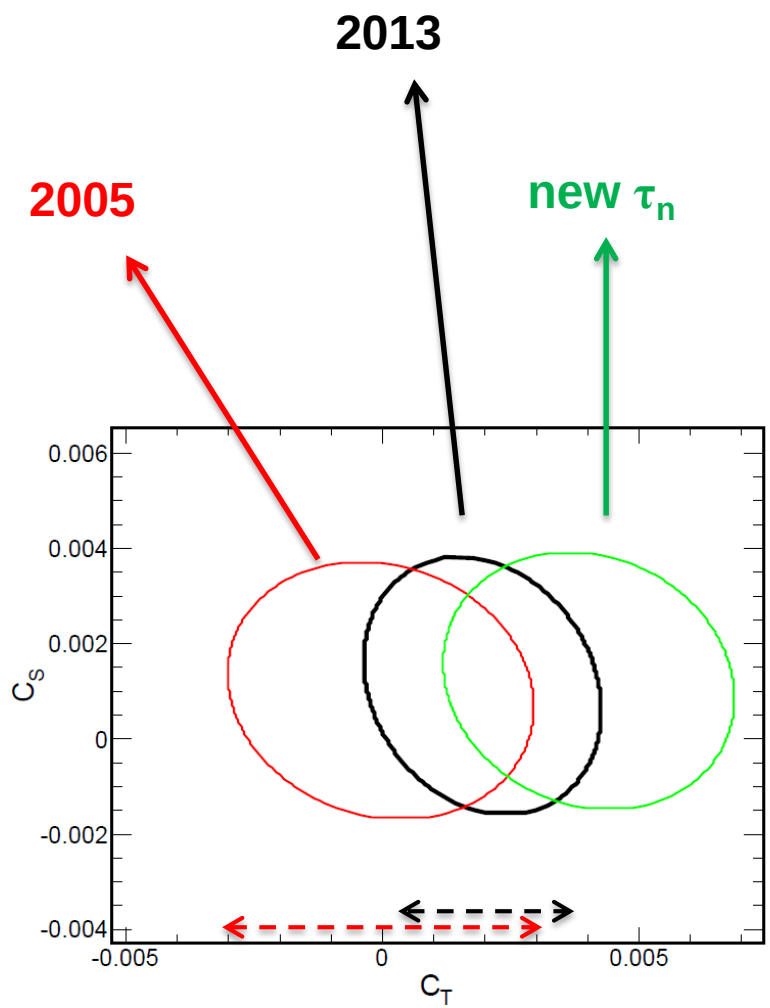
** Cirigliano Journal Of High Energy Physics (2013). *PIBETA Phys. Rev. Lett. 103, 051802 (2009)

Limits ↔ 2005

Big shifts in neutron data







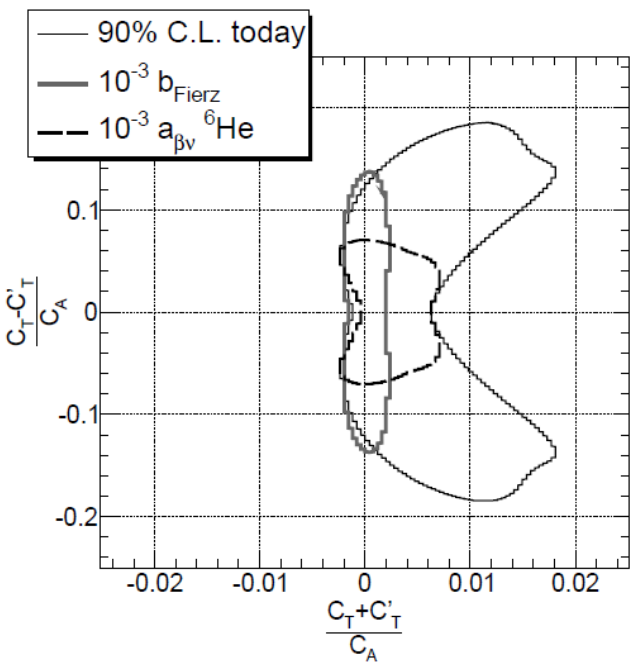
New τn
upcoming PERKEOIII
?

Round up C_T

So …

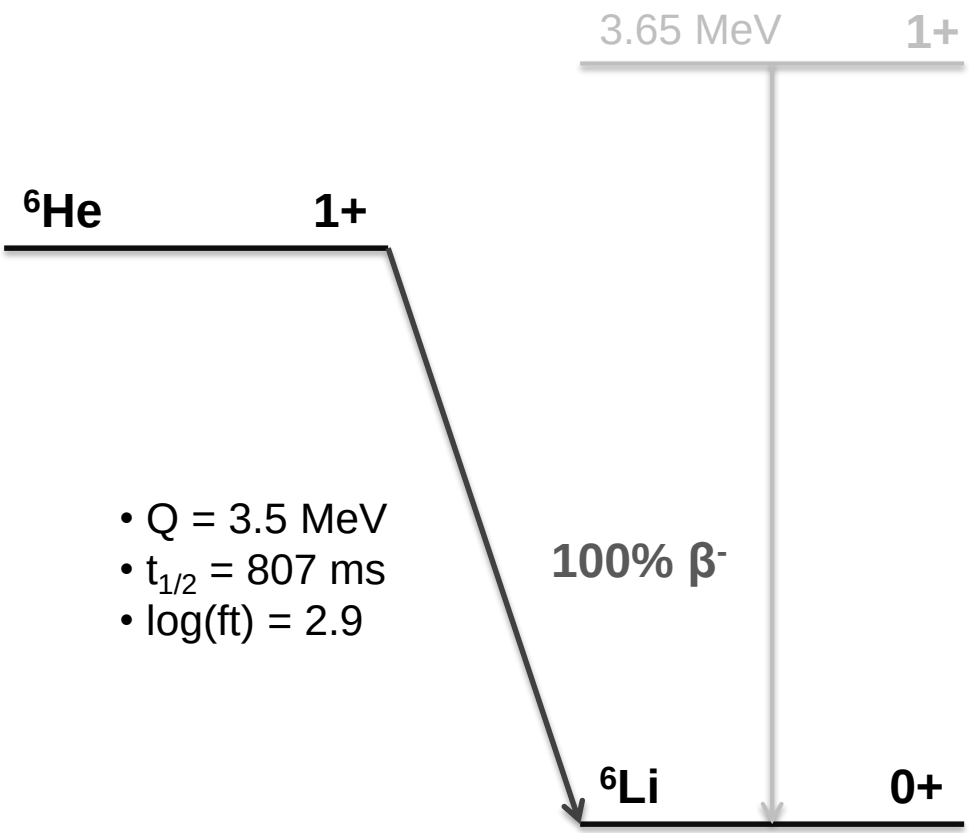
- β decays are a sensitive and competitive probe for tensor currents coupling to **left-handed neutrinos** (it is hard work for the right-handed)
- Current limits are dominated by **τ_n and A_n** + few nuclear β-decay experiments
- Future experiments should aim at **10^{-3} precision**
- Neutron and **light nuclei with fast decays** are preferred to keep theoretical uncertainties under control

b_{Fierz}



Nab … PERKEOIII … PERC … τ_n @ xxx

^{6}He as a probe for C_T



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

✓ Fast 100% GT, ground state to ground state transition→ C'_T

✓ ~1 s lifetime, noble gas + can be produced in large quantities

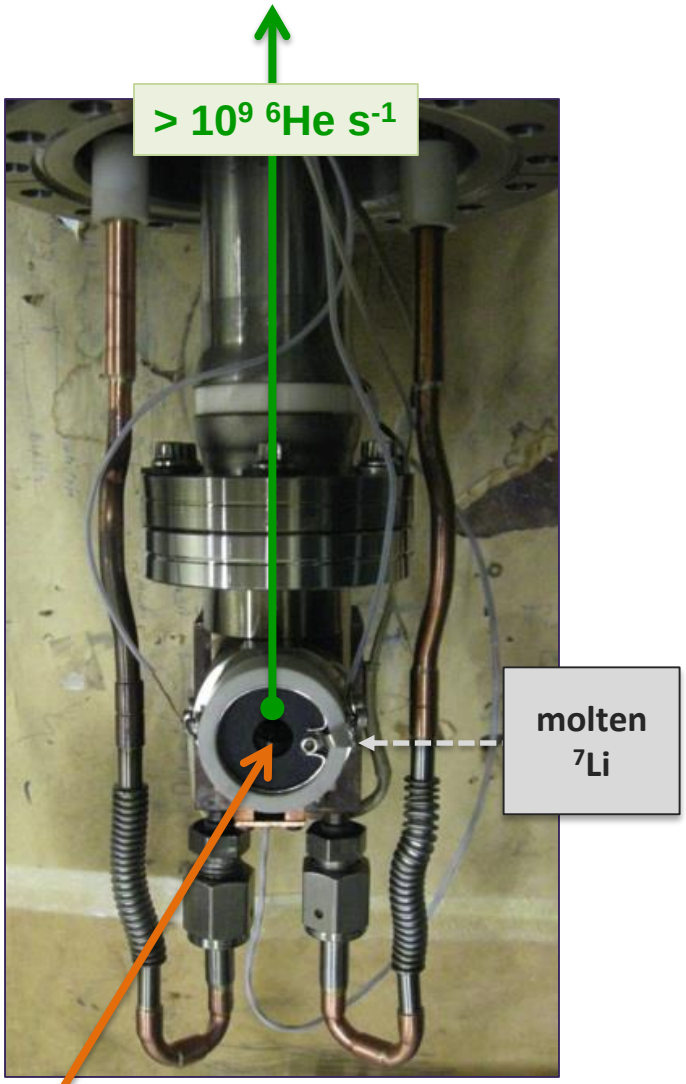
✓ Light nucleus with
- α →F Gluck NPA 628 (1998)
- Weak magnetism from analogue M1 transition in ^{6}Li
- nuclear structure accessible for ab initio /χEFT *

*PHYSICAL REVIEW C **79**, 065501 (2009)

^{6}He at UW

Program

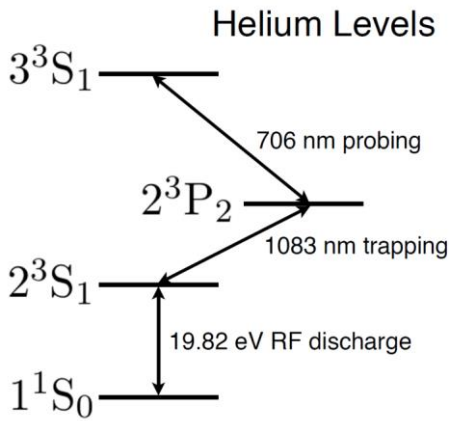
^{6}He half-life	$3 \cdot 10^{-4}$ precision in PRL 108 (2012)
$a_{\beta\upsilon}$ in MOT-MOT aim: 1%	Data taking 2012 - 2013
$a_{\beta\upsilon}$ in MOT-dipole aim: 0.1 %	In preparation
b_{Fierz}	Design phase



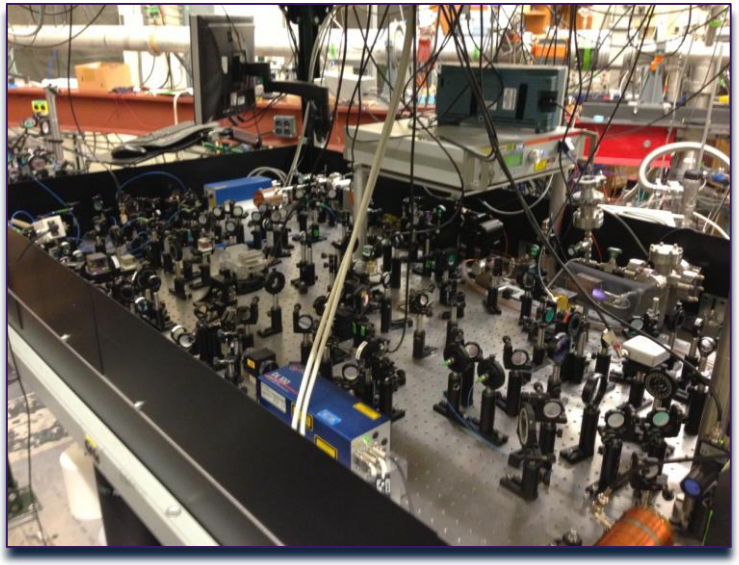
^{2}H (10 uA @ 18 MeV)

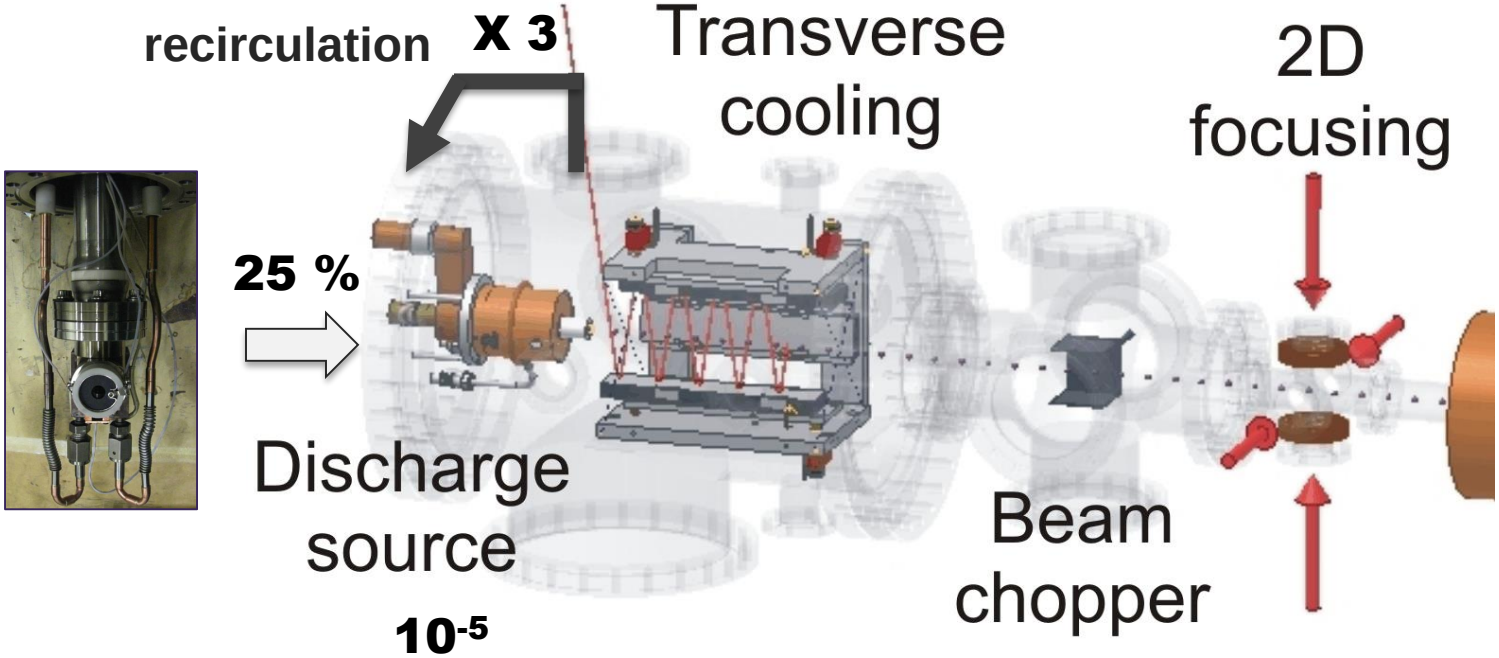
* A. Knecht et al. NIMA 660 (2011)

^{6}He at UW

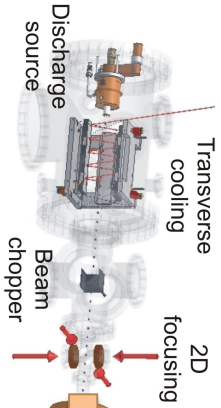


^{6}He atomic beam





Double MOT trap

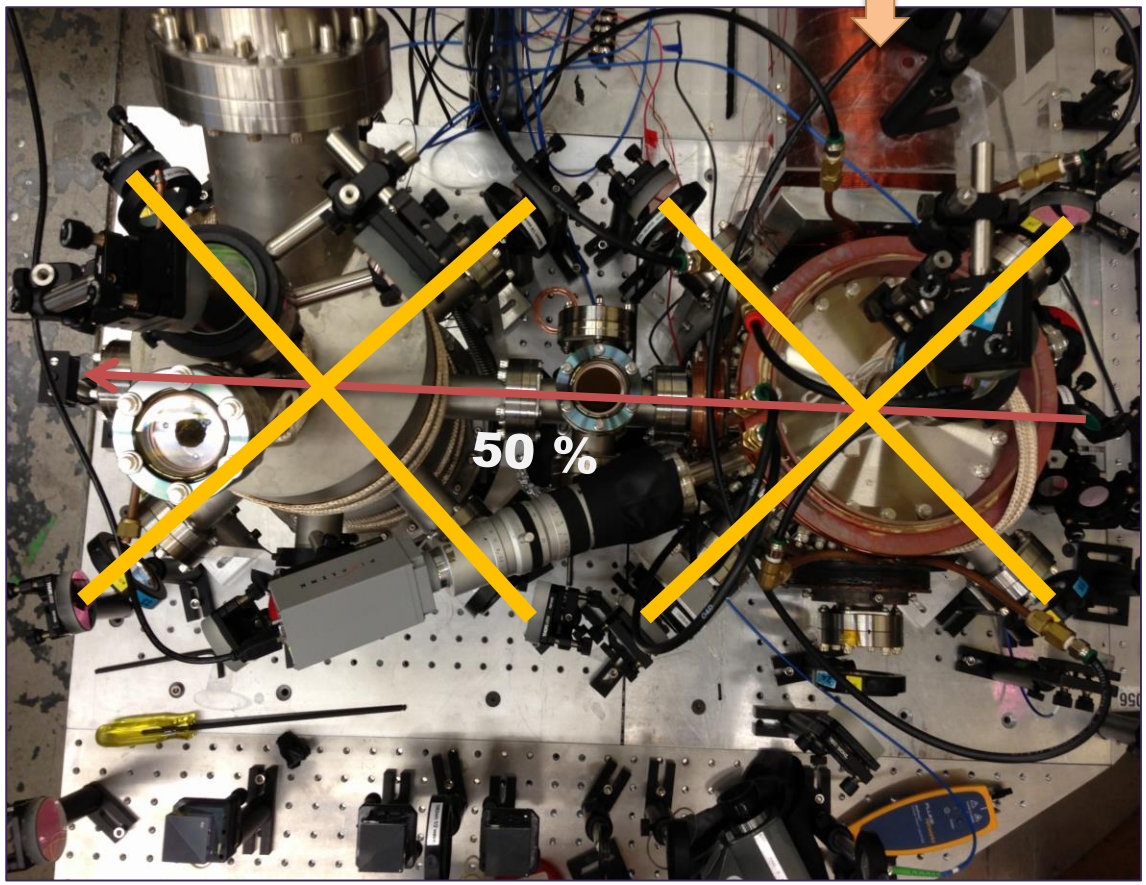


Zeeman slower

~ 3-4 %

Achieved

- ✓ Few hundred trapped 6He in MOT1
- ✓ 50 % MOT1-MOT2 transfer efficiency on ^{4}He
- ✓ β and ion detector systems installed and commissioned

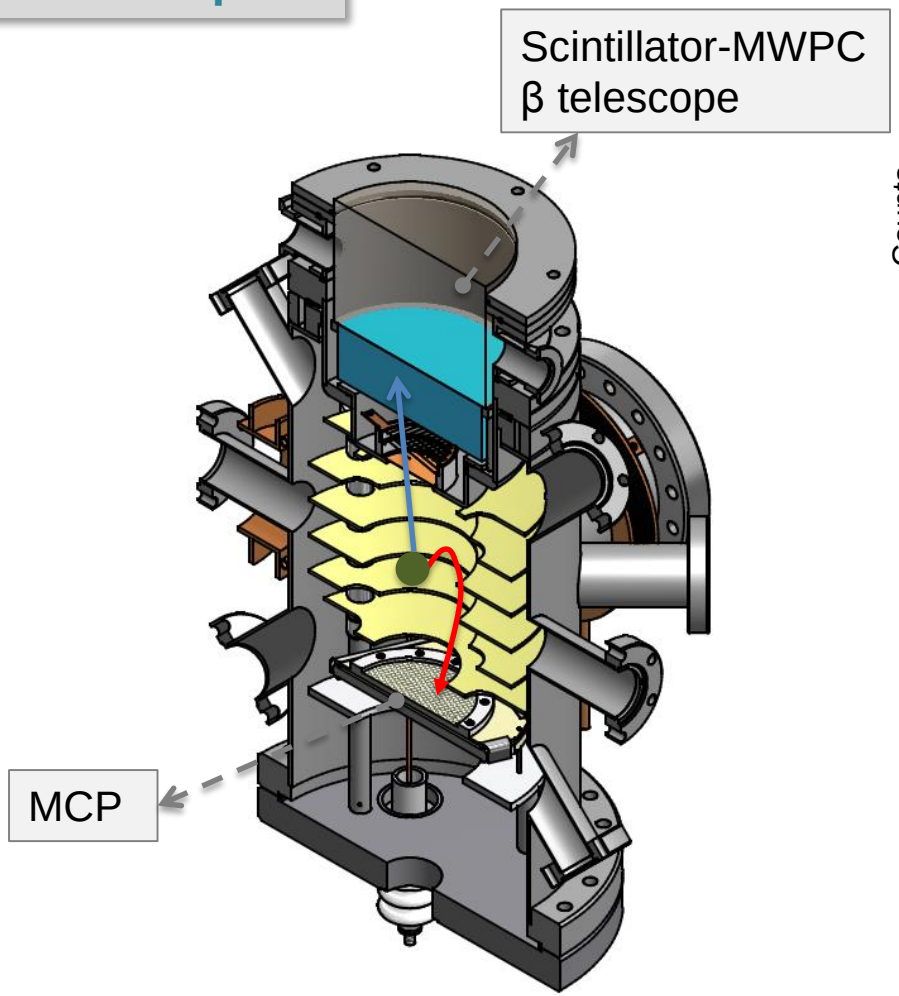


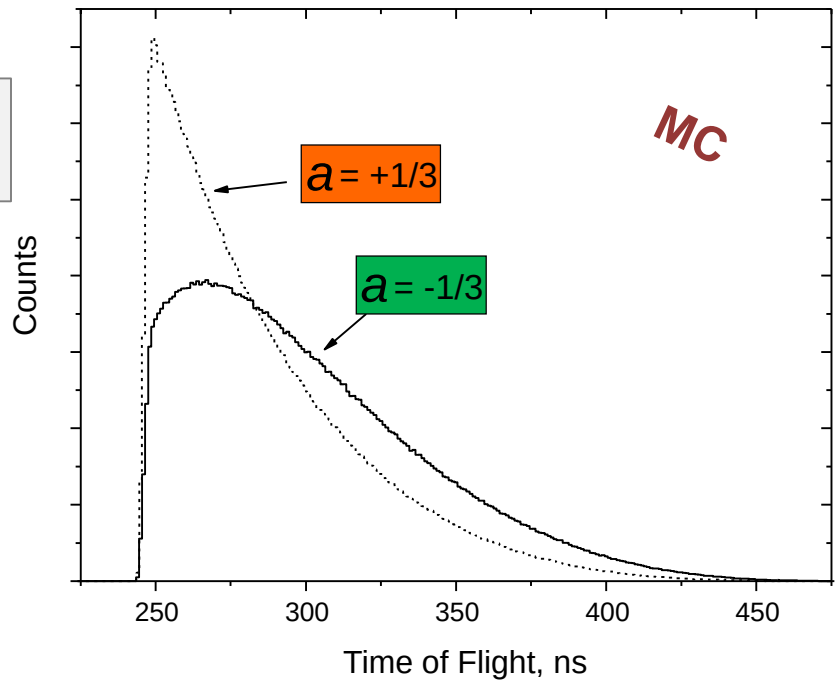
100 trapped 6He in MOT2

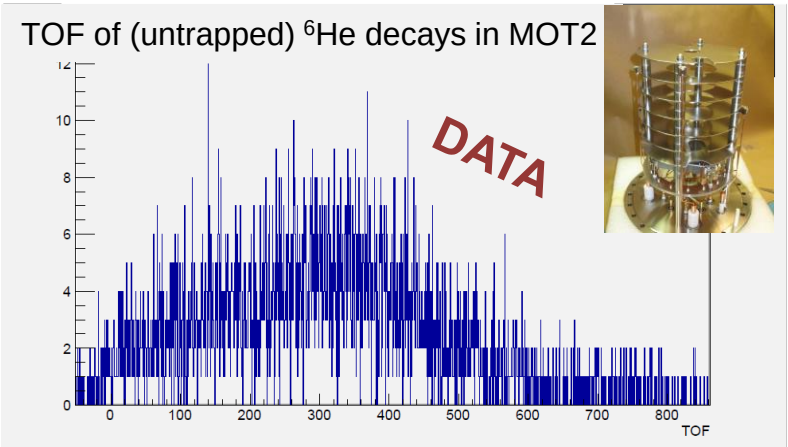
Ready to go

$a_{\beta\upsilon}$ from TOF $^{+}Li_6$

$^{6}He \rightarrow {}^{6}Li + \beta + \upsilon$

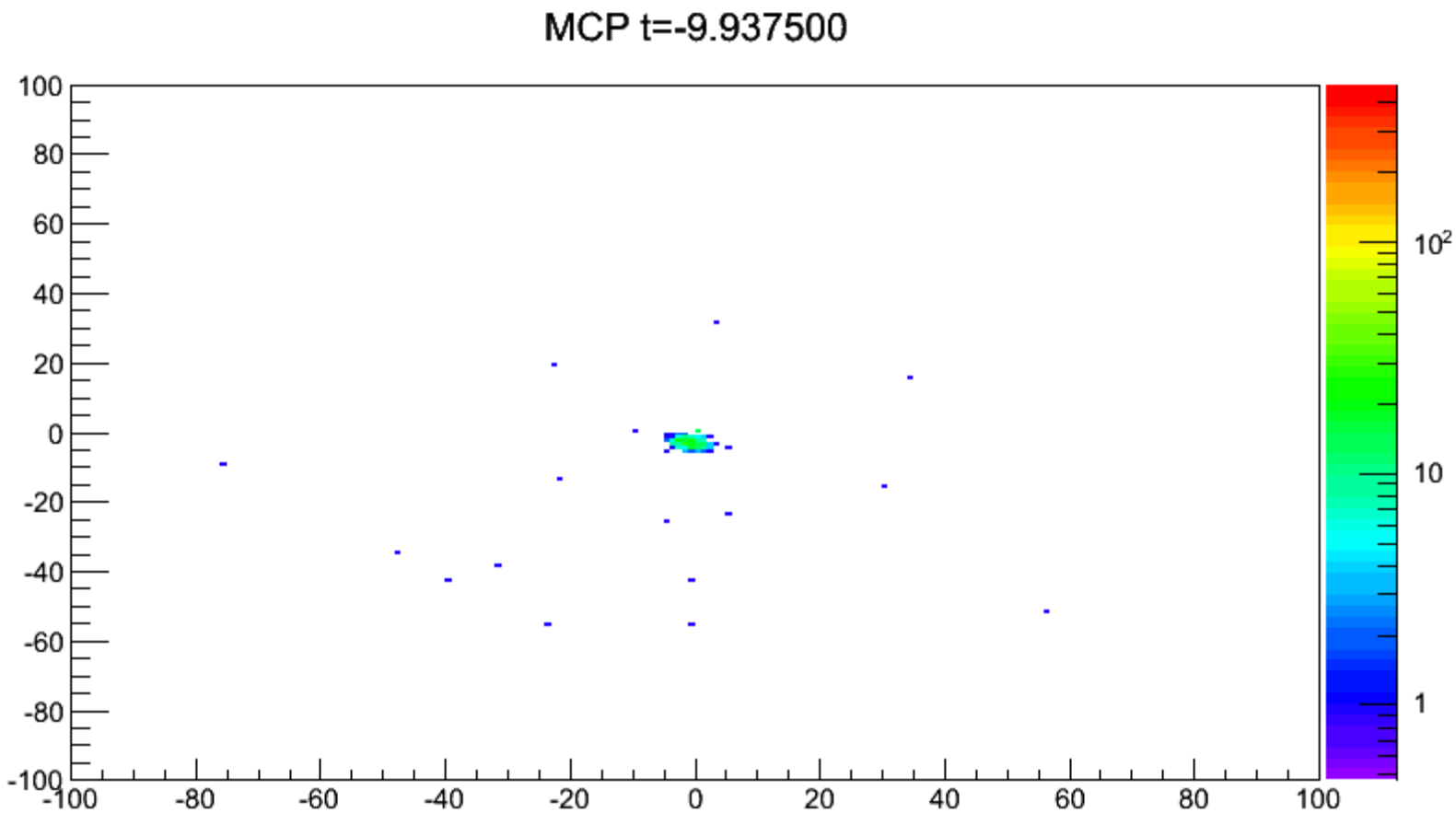






$a_{\beta\upsilon}$ from TOF $^{+}Li_{6}$

He transfer from MOT1 to MOT2 as seen by the MCP



^{6}He collaboration

Yelena Bagdasarova, Alejandro Garcia, **Ran Hong**, Andreas Knecht, Matthew Sternberg, Derek Storm, Erik Swanson, Frederik Wauters, **David Zumwalt**

Peter Müller, Arnoud Leredde

Xavier Fléchard, Etienne Liénard, Gilles Ban

Oscar Naviliat-Cuncic