Unique forbidden β-decays at zero momentum transfer

Chien-Yeah Seng, Ayala Glick-Magid, **Vincenzo Cirigliano**

Phys. Rev. Lett. ***134****, 081805*

UNIVERSITY of WASHINGTON

INSTITUTE for NUCLEAR THEORY

FRIB

U.S. DEPARTMENT OF ENERGY | Office of Science

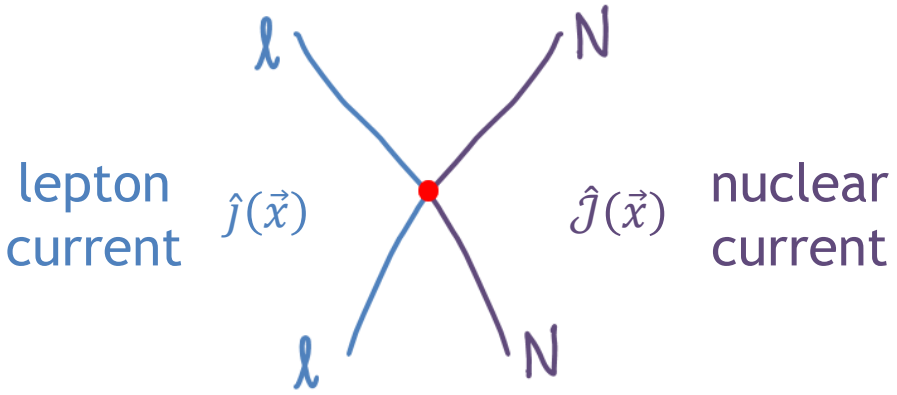
Nuclear Theory for New Physics Topical Collaboration

CIPANP 2025

- Introduction: β-decays for exotic weak interactions
- **Forbidden** β-decays (tree level)
- Experimental Surge
- Radiative Effects (loop level)
- $\Longrightarrow$ ~~**Forbidden**~~ (and other opportunities)
- Summary & Outlook

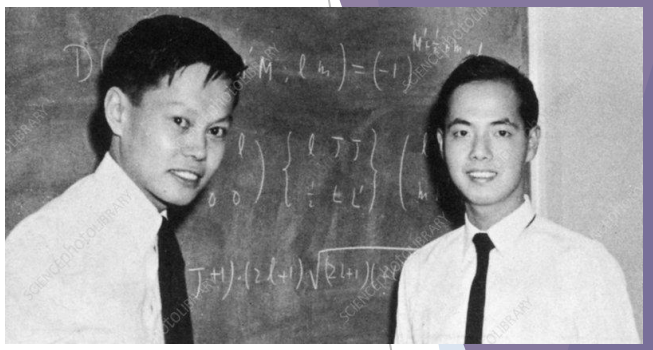
Weak interaction

Low energy reaction of leptons with nucleons



$$\hat{\mathcal{H}}_W \sim C\, \hat{\jmath}(\vec{x}) \cdot \hat{\mathcal{J}}(\vec{x})$$

A-priori:
- Scalar (C_S)
- PseudoScalar (C_P)
- Vector (C_V)
- Axial vector (C_A)
- Tensor (C_T)



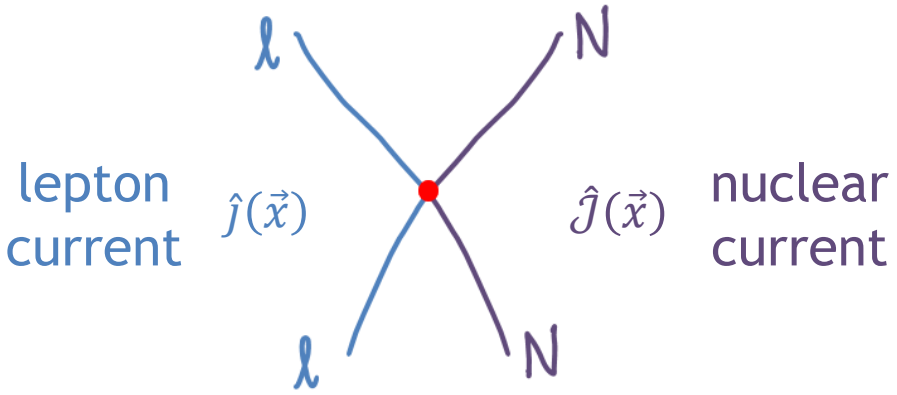
Theory: C.N. Yang and T.D. Lee (Nobel 1957)

Experiment: C.S. Wu:
Parity violation in ***nuclear β-decays***

⇒ **Weak SM structure: "$V - A$"**

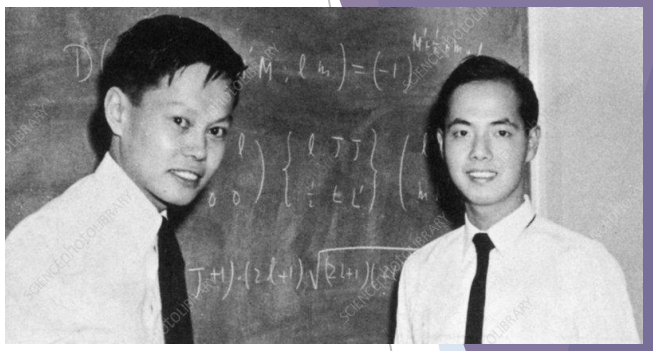
Weak interaction

Low energy reaction of leptons with nucleons



$$\hat{\mathcal{H}}_W \sim C\, \hat{\jmath}(\vec{x}) \cdot \hat{\mathcal{J}}(\vec{x})$$

A-priori:
- Scalar (C_S)
- PseudoScalar (C_P)
- Vector (C_V)
- Axial vector (C_A)
- Tensor (C_T)



Theory: C.N. Yang and T.D. Lee (Nobel 1957)

Experiment: C.S. Wu:
Parity violation in ***nuclear β-decays***

⇒ **Weak SM structure: "$V - A$"**

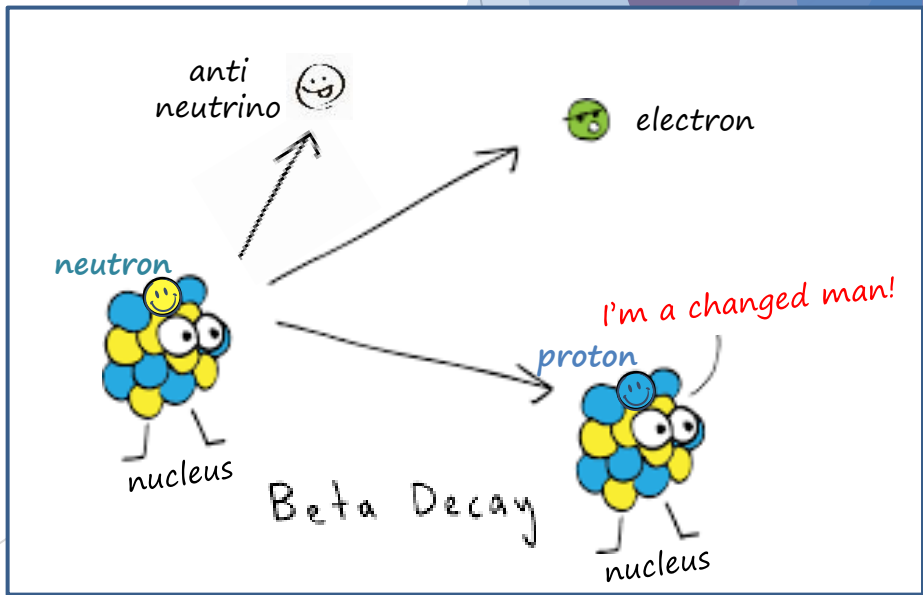
The SM is incomplete

>> Ongoing searches for C_S, C_P, C_T in precision ***nuclear β-decay*** experiments

Nuclear β-decay

Low momentum transfer: $q \sim 0 - 10\ \mathrm{MeV/c}$

Beta decay, Khan Academy, cdn.kastatic.org/ka-perseus-images/8d978444f15f9bbc3bcadb0549816bc7e264b977.svg



Nuclear β-decay

Low momentum transfer: $q \sim 0 - 10\ \mathrm{MeV/c}$

angular momentum

parity

Transitions $J^{\Delta\pi}$:

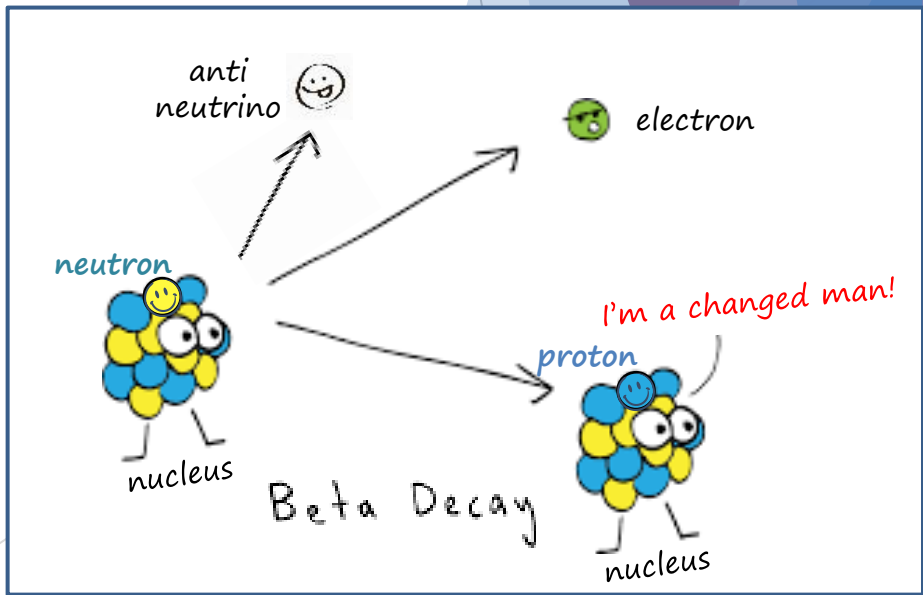
"Allowed" (when $q \to 0$)

- Fermi (0^+)
- Gamow-Teller (1^+)

"Forbidden" (vanish for $q \to 0$)

- All the rest $(J^{\Delta\pi})$

Beta decay, Khan Academy, cdn.kastatic.org/ka-perseus-images/8d978444f15f9bbc3bcadb0549816bc7e264b977.svg

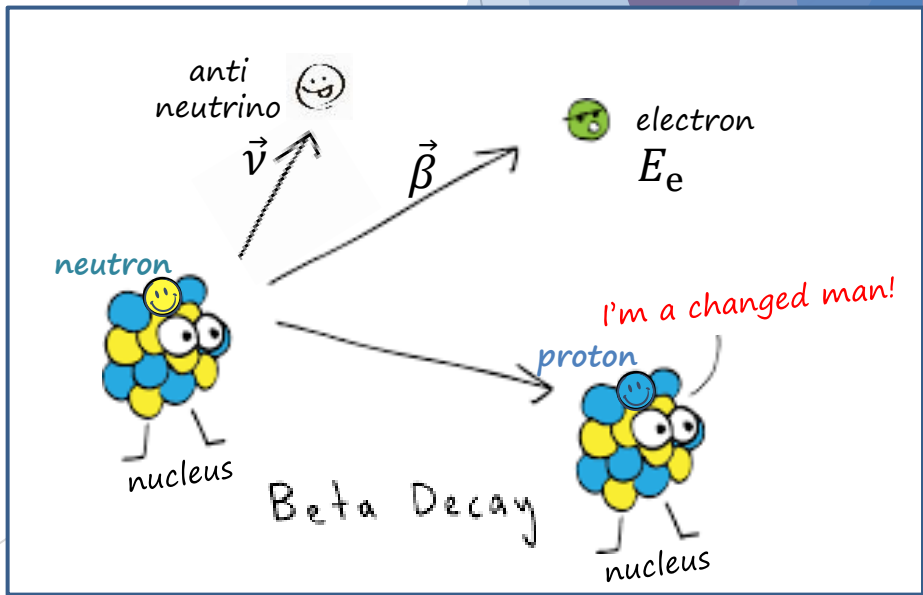


Allowed decays

$$d\Gamma \propto \left|\langle \psi_f \| \hat{H}_W \| \psi_i \rangle\right|^2 \propto 1 + \boldsymbol{b}\frac{m_e}{E_e} + \boldsymbol{a}\,\vec{\beta}\cdot\hat{\nu}$$

1) Energy spectrum: Fierz term $\boldsymbol{b} = \overset{\text{SM}}{0} \pm \overset{\text{BSM}}{\frac{C_T^+}{C_A}}$
   - **Linear** in C_T^+
2) Angular correlation: $\boldsymbol{a} = -\frac{1}{3}\left(1 - \frac{\overset{\text{BSM}}{\left|C_T^+\right|^2 + \left|C_T^-\right|^2}}{4\left|C_A\right|^2}\right)$ (SM)
   - Sensitive to **right-handed** neutrinos C_T^-

Beta decay, Khan Academy, cdn.kastatic.org/ka-perseus-images/8d978444f15f9bbc3bcadb0549816bc7e264b977.svg



Unique forbidden decays

$$d\Gamma \propto \left|\langle \psi_f \| \hat{H}_W \| \psi_i \rangle\right|^2 \propto 1 + \boldsymbol{b}\frac{m_e}{E_e} + \boldsymbol{a}\,\vec{\beta}\cdot\hat{\nu} + \boldsymbol{a_2}\left[\beta^2 - \left(\hat{\beta}\cdot\hat{\nu}\right)^2\right]$$

AGM & Gazit, PRD 2023

4:30 PM @ Nuclear Structure for Neutrino & Astro:
Novel Simplification of tensor interactions
On the technique behind this result & applications to β-decay, neutrinos, DM & $\mu \to e$

1) Energy spectrum: Fierz term $\boldsymbol{b} = \overset{\text{SM}}{0} \pm \overset{\text{BSM}}{\frac{C_T^+}{C_A}}$
   - **Linear** in C_T^+
2) Angular correlation: $\boldsymbol{a} = \overset{\text{SM}}{-\frac{1}{5}}\left(1 - \overset{\text{BSM}}{\frac{\left|C_T^+\right|^2 + \left|C_T^-\right|^2}{4\left|C_A\right|^2}}\right)$
   - Sensitive to **right-handed** neutrinos C_T^-
3) Angular squared correlation: $\boldsymbol{a_2} = \overset{\text{SM}}{\frac{1}{5}}\left(1 - \overset{\text{BSM}}{\frac{\left|C_T^+\right|^2 + \left|C_T^-\right|^2}{4\left|C_A\right|^2}}\right)$
   - Sensitive to **right-handed** neutrinos C_T^-

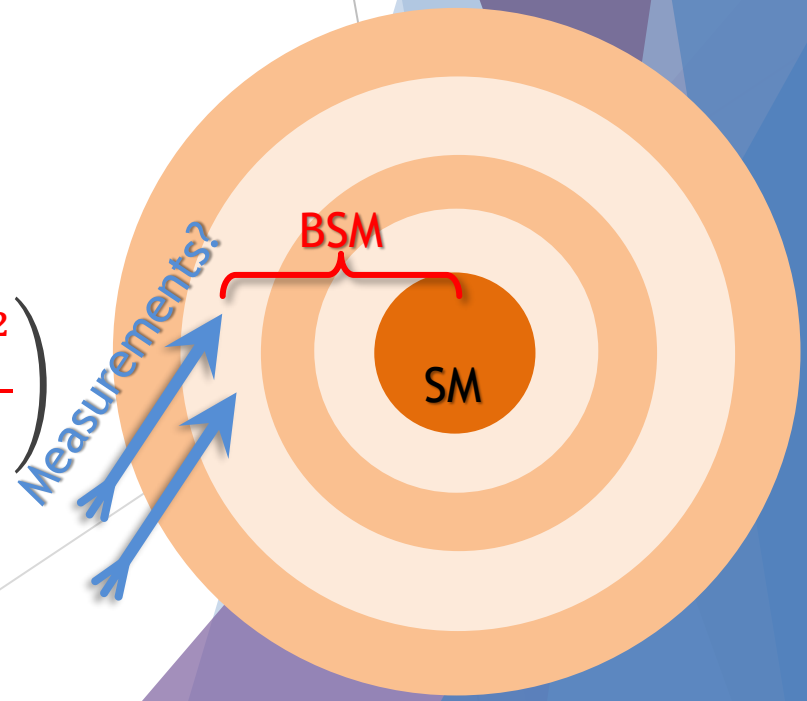
Unique forbidden decays

$$d\Gamma \propto \left|\langle \psi_f \| \hat{H}_W \| \psi_i \rangle\right|^2 \propto 1 + \boldsymbol{b}\frac{m_e}{E_e} + \boldsymbol{a}\,\vec{\beta}\cdot\hat{\nu} + \boldsymbol{a_2}\left[\beta^2 - \left(\hat{\beta}\cdot\hat{\nu}\right)^2\right]$$

AGM & Gazit, PRD 2023

4:30 PM @ Nuclear Structure for Neutrino & Astro:
Novel Simplification of tensor interactions
On the technique behind this result & applications to β-decay, neutrinos, DM & $\mu \to e$

1) Energy spectrum: Fierz term $\boldsymbol{b} = 0 \pm \frac{C_T^+}{C_A}$ (SM: 0; BSM: $\frac{C_T^+}{C_A}$)
   - **Linear** in C_T^+
2) Angular correlation: $\boldsymbol{a} = -\frac{1}{5}\left(1 - \frac{|C_T^+|^2 + |C_T^-|^2}{4|C_A|^2}\right)$ (SM: $-\frac{1}{5}$; BSM: $\frac{|C_T^+|^2 + |C_T^-|^2}{4|C_A|^2}$)
   - Sensitive to **right-handed** neutrinos C_T^-
3) Angular squared correlation: $\boldsymbol{a_2} = \frac{1}{5}\left(1 - \frac{|C_T^+|^2 + |C_T^-|^2}{4|C_A|^2}\right)$ (SM: $\frac{1}{5}$; BSM: $\frac{|C_T^+|^2 + |C_T^-|^2}{4|C_A|^2}$)
   - Sensitive to **right-handed** neutrinos C_T^-



Unique 1st-forbidden

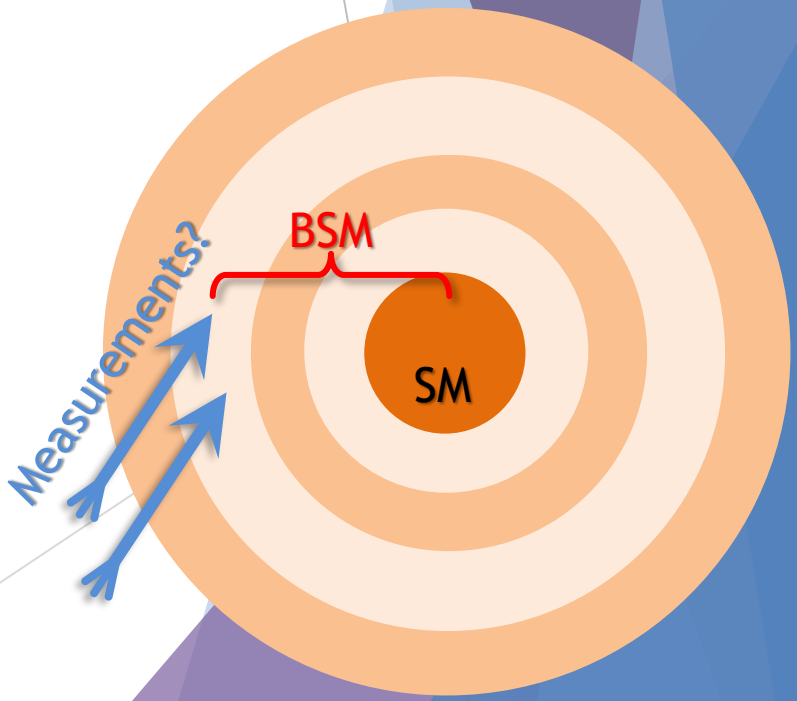
$$d\Gamma \propto \left|\langle \psi_f \| \hat{H}_W \| \psi_i \rangle\right|^2 \propto 1 + \boldsymbol{b}\frac{m_e}{E_e} + \boldsymbol{a}\,\vec{\beta}\cdot\hat{\nu} + \boldsymbol{a_2}\left[\beta^2 - \left(\hat{\beta}\cdot\hat{\nu}\right)^2\right]$$

AGM & Gazit, PRD 2023

4:30 PM @ Nuclear Structure for Neutrino & Astro:
Novel Simplification of tensor interactions
On the technique behind this result &
applications to β-decay, neutrinos, DM & $\mu \to e$

> **Experiments:**

Searches for deviations from the SM "V-A" structure



Unique 1st-forbidden

$$d\Gamma \propto \left|\langle \psi_f \| \hat{H}_W \| \psi_i \rangle\right|^2 \propto 1 + \boldsymbol{b}\frac{m_e}{E_e} + \boldsymbol{a}\,\vec{\beta}\cdot\hat{\nu} + \boldsymbol{a_2}\left[\beta^2 - \left(\hat{\beta}\cdot\hat{\nu}\right)^2\right]$$

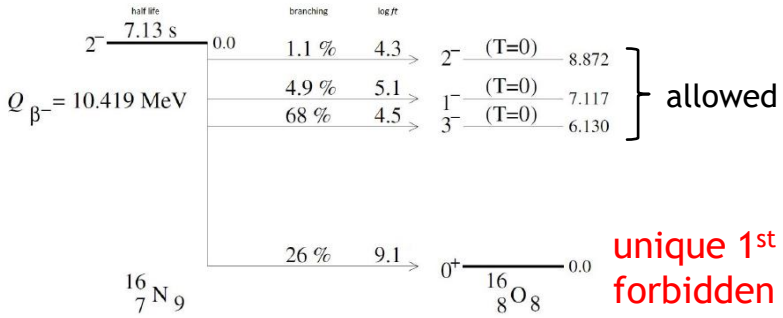
AGM & Gazit, PRD 2023

4:30 PM @ Nuclear Structure for Neutrino & Astro:
Novel Simplification of tensor interactions
On the technique behind this result & applications to β-decay, neutrinos, DM & $\mu \to e$

> Experiments:

Searches for deviations from the SM "V-A" structure

^{16}N: Large energy separation between forbidden and allowed branches

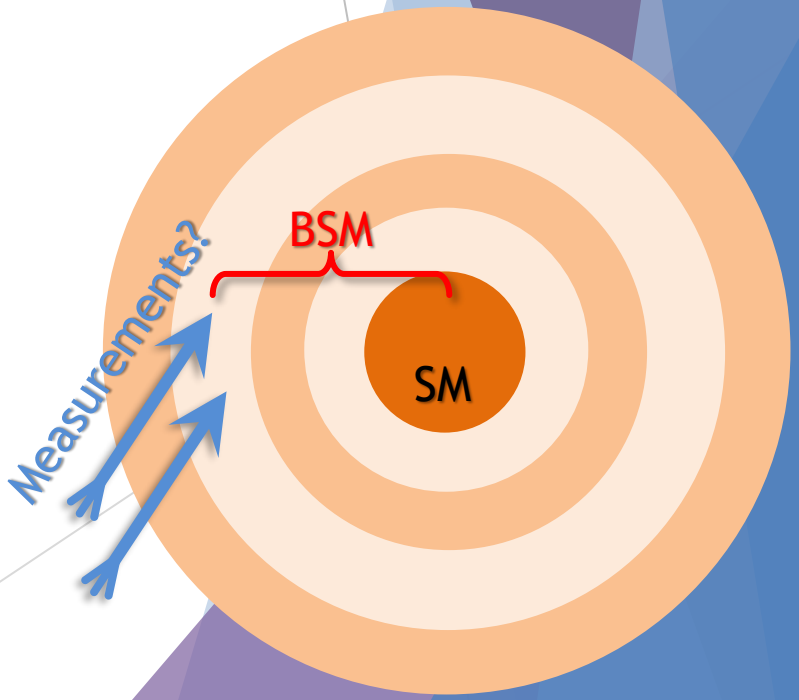


unique 1st forbidden

Ohayon, Chocron, Hirsh, AGM, *et al.*, Hyp.Int.2018

THE HEBREW UNIVERSITY OF JERUSALEM

SOREQ Soreq Nuclear Research Center



Unique 1st-forbidden

$$d\Gamma \propto \left|\langle \psi_f \| \hat{H}_W \| \psi_i \rangle\right|^2 \propto 1 + \boldsymbol{b}\frac{m_e}{E_e} + \boldsymbol{a}\,\vec{\beta}\cdot\hat{\nu} + \boldsymbol{a_2}\left[\beta^2 - \left(\hat{\beta}\cdot\hat{\nu}\right)^2\right]$$

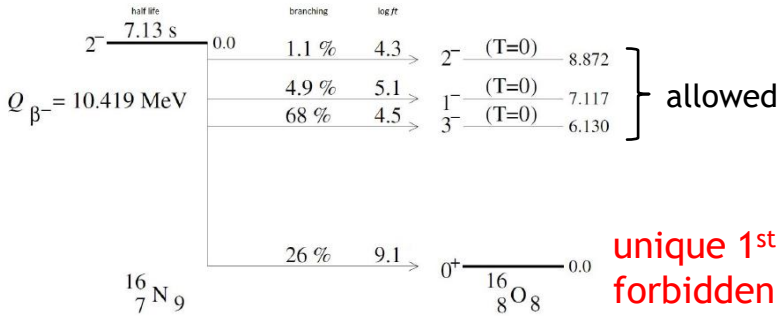
AGM & Gazit, PRD 2023

4:30 PM @ Nuclear Structure for Neutrino & Astro:
Novel Simplification of tensor interactions
On the technique behind this result & applications to β-decay, neutrinos, DM & $\mu \to e$

> Experiments:

Searches for deviations from the SM "V-A" structure

^{16}N: Large energy separation between forbidden and allowed branches

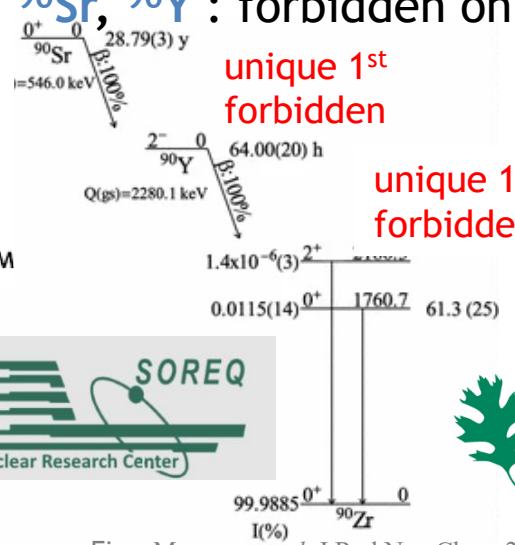


unique 1st forbidden

Ohayon, Chocron, Hirsh, AGM, *et al.*, Hyp.Int.2018

THE HEBREW UNIVERSITY OF JERUSALEM

^{90}Sr, ^{90}Y : forbidden only



unique 1st forbidden

unique 1st forbidden

Soreq Nuclear Research Center

OAK RIDGE National Laboratory

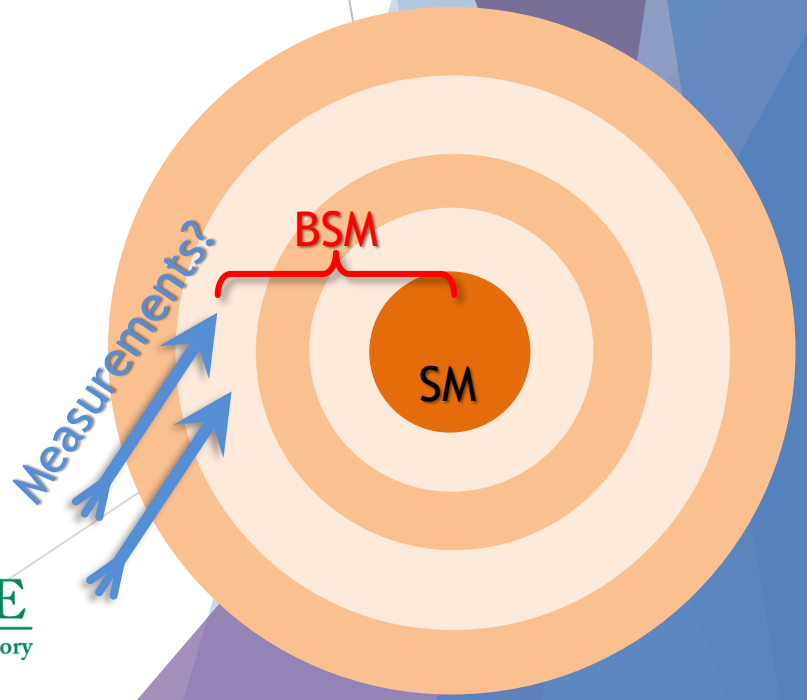


Fig.: Morozov *et al.* J.Rad.Nuc.Chem.2010

Unique 1st-forbidden

$$d\Gamma \propto \left|\langle \psi_f \| \hat{H}_W \| \psi_i \rangle\right|^2 \propto 1 + \boldsymbol{b}\frac{m_e}{E_e} + \boldsymbol{a}\,\vec{\beta}\cdot\hat{\nu} + \boldsymbol{a_2}\left[\beta^2 - \left(\hat{\beta}\cdot\hat{\nu}\right)^2\right]$$

AGM & Gazit, PRD 2023

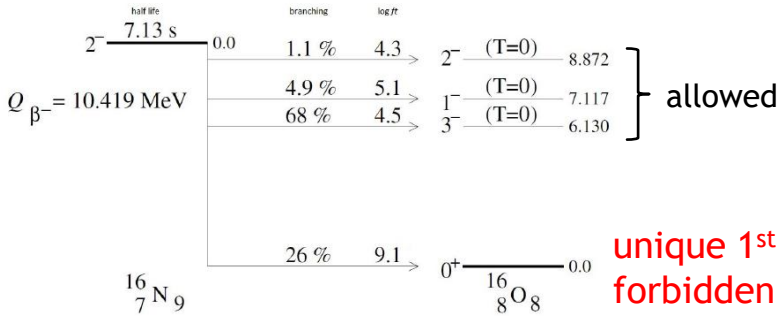
> Experiments:

Searches for deviations from the SM "V-A" structure

⇒ Development of **MTAS @ ORNL** Modular Total Absorption Spectrometer to *distinguish between decay transitions*

Shuai, Rasco, *et al.*, PRD 2022

^{16}N: Large energy separation between forbidden and allowed branches

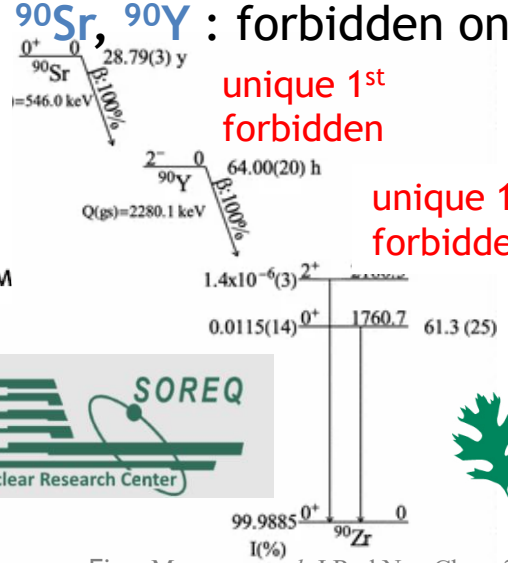


unique 1st forbidden

Ohayon, Chocron, Hirsh, AGM, *et al.*, Hyp.Int.2018

THE HEBREW UNIVERSITY OF JERUSALEM

^{90}Sr, ^{90}Y : forbidden only



unique 1st forbidden

unique 1st forbidden

SOREQ Soreq Nuclear Research Center

OAK RIDGE National Laboratory

Fig.: Morozov *et al.* J.Rad.Nuc.Chem.2010

^{144}Pr: Mixed

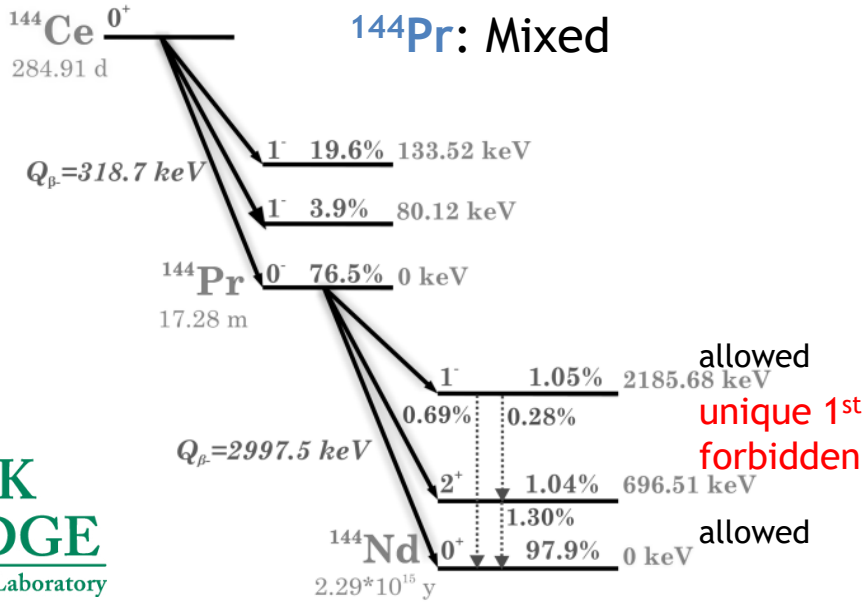


Fig.: Journal of Physics: Conference Series 1390 (2019) 012117

Unique 1st-forbidden

$$d\Gamma \propto \left|\langle \psi_f \| \hat{H}_W \| \psi_i \rangle\right|^2 \propto 1 + \boldsymbol{b}\frac{m_e}{E_e} + \boldsymbol{a}\,\vec{\beta}\cdot\hat{\nu} + \boldsymbol{a_2}\left[\beta^2 - \left(\hat{\beta}\cdot\hat{\nu}\right)^2\right]$$

AGM & Gazit, PRD 2023

> Experiments:

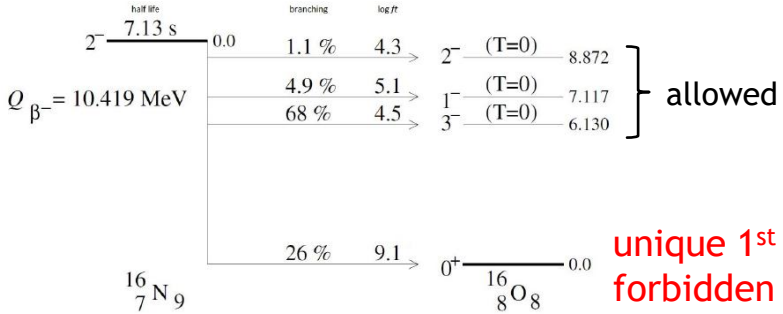
Searches for deviations from the SM "V-A" structure

⇒ Development of **MTAS @ ORNL**
Modular **T**otal **A**bsorption **S**pectrometer
to *distinguish between decay transitions*

Shuai, Rasco, *et al.*, PRD 2022

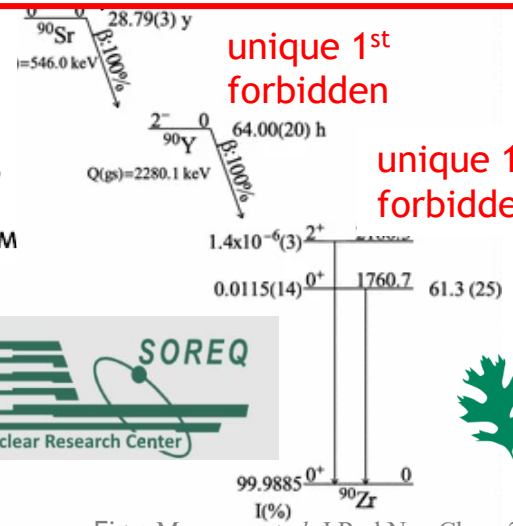
>> More accurate theory is needed

^{16}N: forbidden and allowed branches



Ohayon, Chocron, Hirsh, AGM, *et al.*, Hyp.Int.2018

THE HEBREW UNIVERSITY OF JERUSALEM



unique 1st forbidden

unique 1st forbidden

unique 1st forbidden

SOREQ Soreq Nuclear Research Center

OAK RIDGE National Laboratory

Fig.: Morozov *et al.* J.Rad.Nuc.Chem.2010

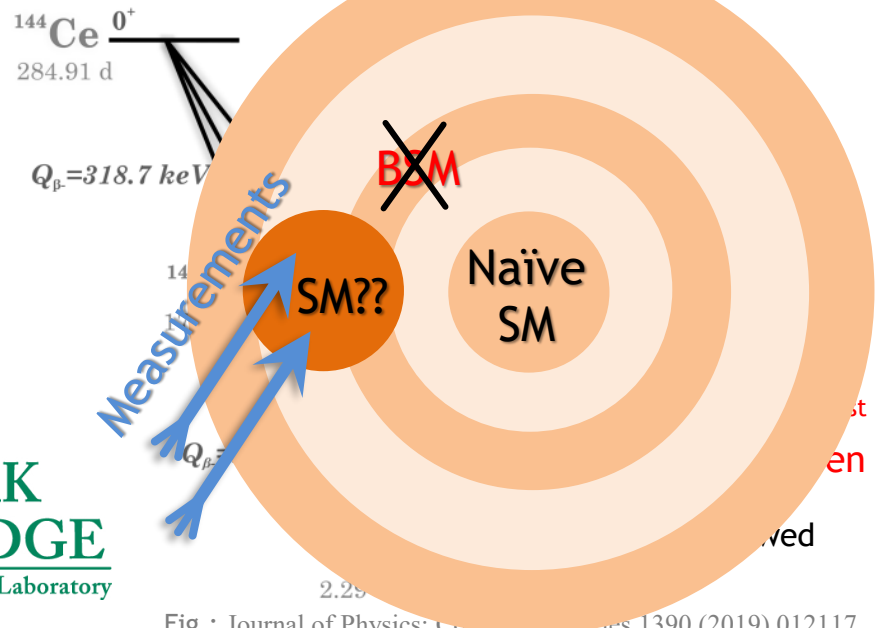
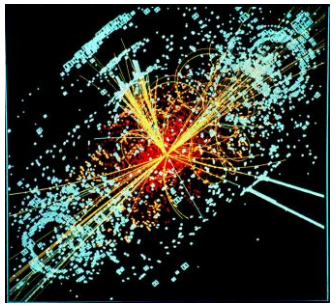


Fig.: Journal of Physics: Co... ...eries 1390 (2019) 012117

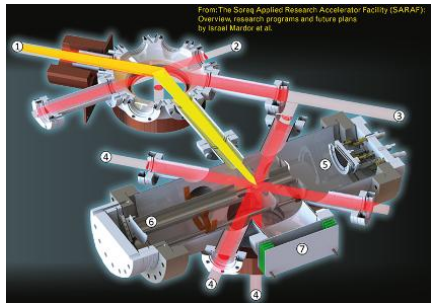
High energy frontier



Lucas Taylor / CERN - http://cdsweb.cern.ch/record/628469

Searches for BSM physics

Precision frontier



Mardor *et al.*, Eur. Phys. J. A 54, 91 (2018)

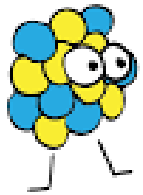
LHC
TeV scale

$C_T^+ (C_T^-)$ Tensor left (right) coupling constants

Nuclear phenomena
10^{-3} precision level

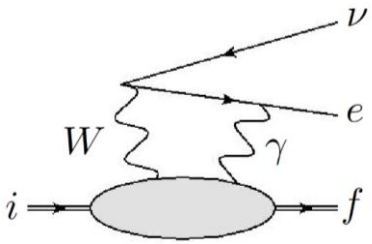
new experiments

Requires Precision Theory – two challenges:



➢ *Nuclear-structure many-body problem*

➥ *4:30 PM @ Nuclear Structure for Neutrino & Astro:*
Novel Simplification of tensor interactions
On the technique behind forbidden's rate & applications to β-decay, neutrinos, DM & $\mu \to e$

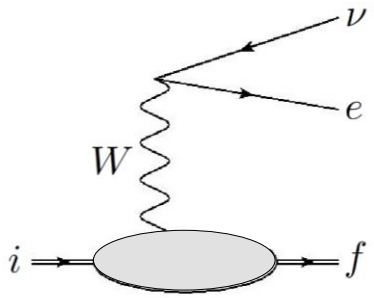


➢ ***High-order radiative effects***

➥ **Now**

Unique 1st-forbidden

$$d\Gamma \propto \left|\langle 0^+ \| \hat{H}_W \| 2^- \rangle\right|^2 \propto \; 1 + \boldsymbol{b}\frac{m_e}{E_e} + \boldsymbol{a}\,\vec{\beta}\cdot\hat{\nu} + \boldsymbol{a_2}\left[\beta^2 - \left(\hat{\beta}\cdot\hat{\nu}\right)^2\right]$$



"Forbidden" (vanish for $q \to 0$)

- All the rest ($J^{\Delta\pi}$)

angular momentum

parity

$$J_i^{\pi_i} \to J_f^{\pi_f}$$

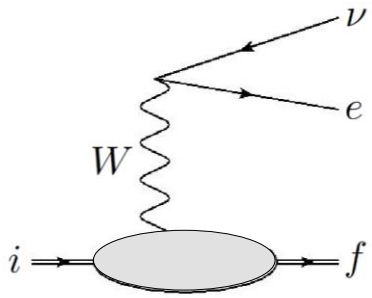
$$|J_i - J_f| \le J \le J_i + J_f$$

$$\Delta\pi = \pi_i \cdot \pi_f$$

Unique 1st-forbidden

$$d\Gamma \propto \left|\langle 0^+ \| \hat{H}_W \| 2^- \rangle\right|^2 \propto \left\{1 + \boldsymbol{b}\frac{m_e}{E_e} + \boldsymbol{a}\,\vec{\beta}\cdot\hat{\nu} + \boldsymbol{a_2}\left[\beta^2 - \left(\hat{\beta}\cdot\hat{\nu}\right)^2\right]\right\}\left|\langle 0^+ \| \hat{O}_J \| 2^- \rangle\right|^2$$

$$\propto q^{J-1}$$



"Forbidden" (vanish for $q \to 0$)

- All the rest ($J^{\Delta\pi}$)

angular momentum

parity

$$J_i^{\pi_i} \to J_f^{\pi_f}$$

$$|J_i - J_f| \le J \le J_i + J_f$$

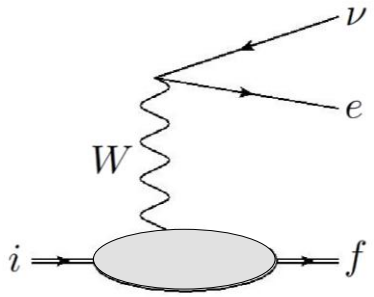
$$\Delta\pi = \pi_i \cdot \pi_f$$

Unique 1st-forbidden

$$d\Gamma \propto \left|\langle 0^+ \| \hat{H}_W \| 2^- \rangle\right|^2 \propto \left\{1 + \boldsymbol{b}\frac{m_e}{E_e} + \boldsymbol{a}\,\vec{\beta}\cdot\hat{\nu} + \boldsymbol{a_2}\left[\beta^2 - \left(\hat{\beta}\cdot\hat{\nu}\right)^2\right]\right\}\left|\langle 0^+ \| \hat{O}_J \| 2^- \rangle\right|^2$$

$$\propto q^{J-1} \underset{q\to 0}{\longrightarrow} 0$$

Forbidden!



"Forbidden" (vanish for $q \to 0$)

- All the rest ($J^{\Delta\pi}$)

angular momentum

parity

$$J_i^{\pi_i} \to J_f^{\pi_f}$$

$$|2-0| \le J \le 2+0$$

$$\Delta\pi = -$$

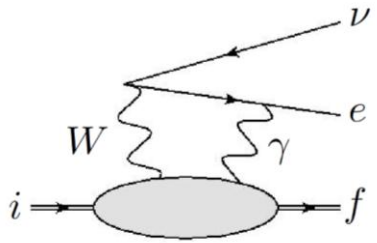
Unique 1st-forbidden

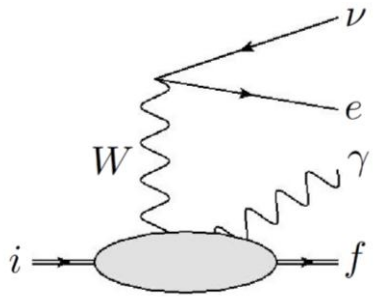
$$d\Gamma \propto \left|\langle 0^+ \| \hat{H}_W \| 2^- \rangle\right|^2 \propto \left\{1 + \boldsymbol{b}\frac{m_e}{E_e} + \boldsymbol{a}\,\vec{\beta}\cdot\hat{\nu} + \boldsymbol{a_2}\left[\beta^2 - \left(\hat{\beta}\cdot\hat{\nu}\right)^2\right]\right\}\left|\langle 0^+ \| \hat{O}_J \| 2^- \rangle\right|^2$$

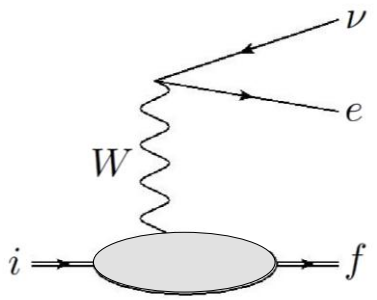
$$\propto q^{J-1} \underset{q\to 0}{\longrightarrow} 0$$

Forbidden!

Radiative Corrections:







$$\langle 0^+ \| \hat{O}_J^W \hat{Q}_{J'}^{EM} \| 2^- \rangle$$

"Forbidden" (vanish for $q \to 0$)

- All the rest ($J^{\Delta\pi}$)

angular momentum

parity

$$J_i^{\pi_i} \to J_f^{\pi_f}$$

$$|2 - 0| \le J \le 2 + 0$$

$$\Delta\pi = -$$

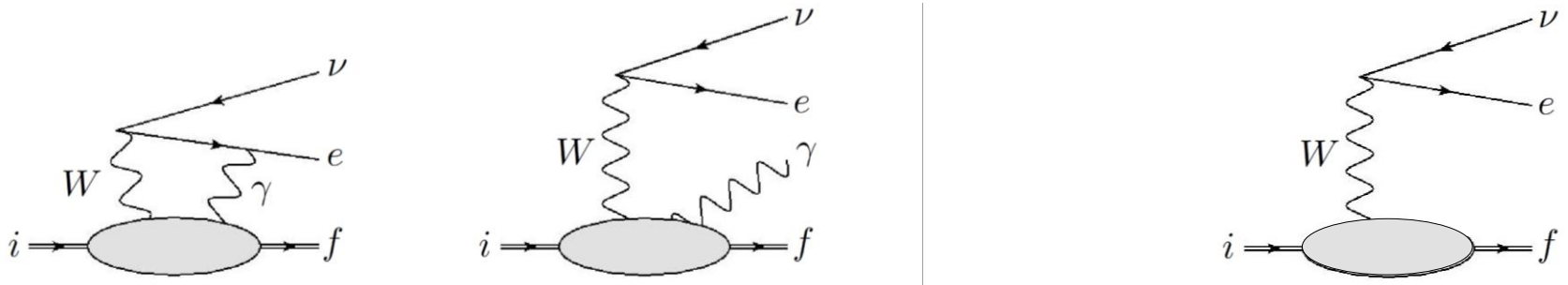
Unique 1st-forbidden

$$d\Gamma \propto \left|\langle 0^+ \| \hat{H}_W \| 2^- \rangle\right|^2 \propto \left\{1 + \boldsymbol{b}\frac{m_e}{E_e} + \boldsymbol{a}\,\vec{\beta}\cdot\hat{\nu} + \boldsymbol{a_2}\left[\beta^2 - \left(\hat{\beta}\cdot\hat{\nu}\right)^2\right]\right\}\left|\langle 0^+ \| \hat{O}_J \| 2^- \rangle\right|^2$$

$$\propto q^{J-1} \xrightarrow[q\to 0]{} 0$$

Forbidden!

Radiative Corrections:



$$\langle 0^+ \| \hat{O}_J^W \hat{Q}_{J'}^{EM} \| 2^- \rangle = \sum_X \langle 0^+ \| \hat{O}_J^W \| \psi_X \rangle \langle \psi_X \| \hat{Q}_{J'}^{EM} \| 2^- \rangle$$

"Forbidden" (vanish for $q \to 0$)

- All the rest ($J^{\Delta\pi}$)

angular momentum

parity

$$J_i^{\pi_i} \to J_f^{\pi_f}$$

$$|2 - 0| \le J \le 2 + 0$$

$$\Delta\pi = -$$

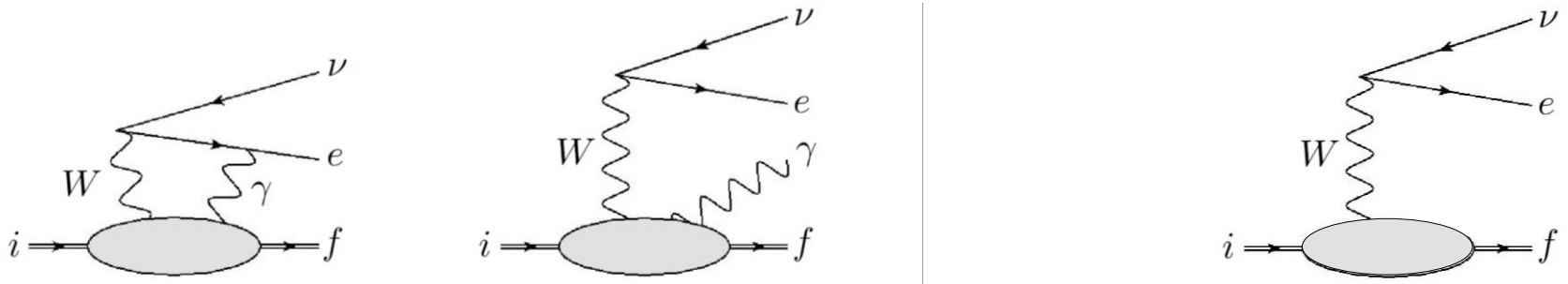
Unique 1st-forbidden

$$d\Gamma \propto \left|\langle 0^+ \| \hat{H}_W \| 2^- \rangle\right|^2 \propto \left\{1 + \boldsymbol{b}\frac{m_e}{E_e} + \boldsymbol{a}\,\vec{\beta}\cdot\hat{\nu} + \boldsymbol{a_2}\left[\beta^2 - \left(\hat{\beta}\cdot\hat{\nu}\right)^2\right]\right\}\left|\langle 0^+ \| \hat{O}_J \| 2^- \rangle\right|^2$$

$$\propto q^{J-1} \underset{q\to 0}{\longrightarrow} 0$$

Forbidden!

Radiative Corrections:



$$\langle 0^+ \| \hat{O}_J^W \hat{Q}_{J'}^{EM} \| 2^- \rangle = \sum_X \langle 0^+ \| \hat{O}_J^W \| \psi_X \rangle \langle \psi_X \| \hat{Q}_{J'}^{EM} \| 2^- \rangle$$

No longer limited to $J = 2$ operators to satisfy the selection rule!

$$|J_X - 0| \le J \le J_X + 0$$
$$|2 - J_X| \le J' \le 2 + J_X$$

angular momentum

parity

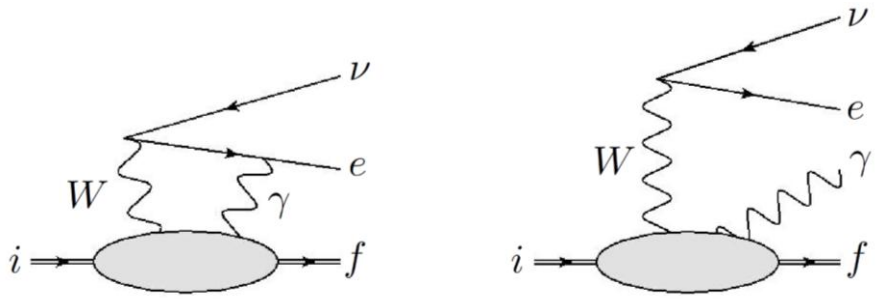
$$J_i^{\pi_i} \to J_f^{\pi_f}$$
$$|2 - 0| \le J \le 2 + 0$$
$$\Delta\pi = -$$

Unique 1st-forbidden

$$d\Gamma \propto \left|\langle 0^+ \| \hat{H}_W \| 2^- \rangle\right|^2 \propto \left\{1 + \boldsymbol{b}\frac{m_e}{E_e} + \boldsymbol{a}\,\vec{\beta}\cdot\right.$$

	$\Delta\pi$	transition	multipoles
$J=0$	$+$	Fermi	$\hat{C}_0^V \sim 1$
	$-$	1^{st} forbidden	$\hat{L}_0^A \sim qR$ $\hat{C}_0^A \sim p_f/m_N$
$J>0$	$(-)^J$	J^{th} forbidden	$\hat{C}_J^V \sim (qR)^J$ $\widehat{M}_J^A \sim (qR)^J$
	$(-)^{J-1}$	Gamow Teller ($J=1$) unique $(J-1)^{\text{th}}$ forbidden	$\hat{L}_J^A \sim (qR)^{J-1}$ $\hat{C}_J^A \sim p_f/m_N (qR)^J$ $\widehat{M}_J^V \sim p_f/m_N (qR)^J$

Radiative Corrections:



AGM & Gazit, J.Phys.G 2022

$$\langle 0^+ \| \hat{O}_J^W \hat{Q}_{J'}^{EM} \| 2^- \rangle = \sum_X \langle 0^+ \| \hat{O}_J^W \| \psi_X \rangle \langle \psi_X \| \hat{Q}_{J'}^{EM} \| 2^- \rangle$$

➢ ***Choose wisely the intermediate states and operators:***

No longer limited to $J=2$ operators to satisfy the selection rule!

$$|J_X - 0| \le J \le J_X + 0$$
$$|2 - J_X| \le J' \le 2 + J_X$$

Decay process	Intermediate states	Multipole operators
$i(2^-) \to f(0^+)$	$i(2_g^-), f(0_g^+)$	$C_0^{\text{em}}, L_2^A, E_2^A$
	$i(1_X^+), f(1_X^-)$	$C_1^{\text{em}}, L_1^{\text{em}}, E_1^{\text{em}}, L_1^A, E_1^A$
$i(0^+) \to f(2^-)$	$i(0_g^+), f(2_g^-)$	$C_0^{\text{em}}, L_2^A, E_2^A$
	$i(1_X^-), f(1_X^+)$	$C_1^{\text{em}}, L_1^{\text{em}}, E_1^{\text{em}}, L_1^A, E_1^A$

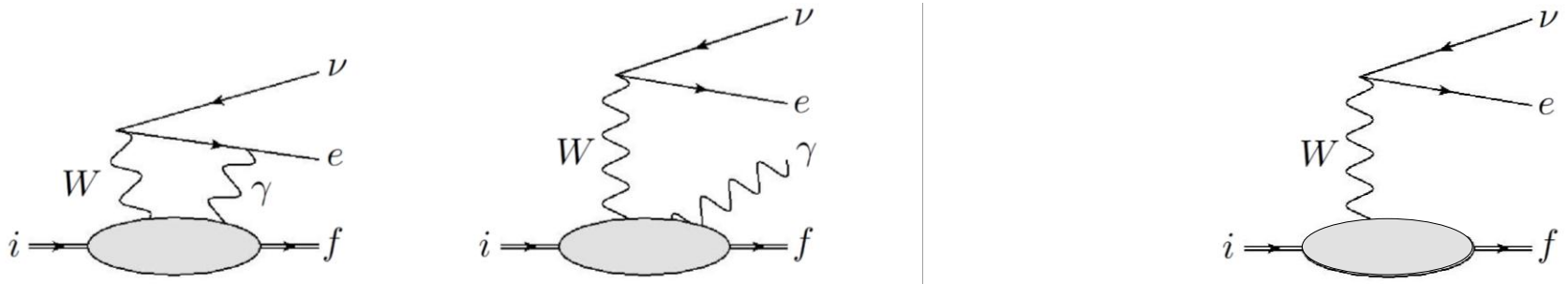
Unique 1st-forbidden

$$d\Gamma \propto \left|\langle 0^+ \| \hat{H}_W \| 2^- \rangle\right|^2 \propto \left\{1 + \boldsymbol{b}\frac{m_e}{E_e} + \boldsymbol{a}\,\vec{\beta}\cdot\hat{\nu} + \boldsymbol{a_2}\left[\beta^2 - \left(\hat{\beta}\cdot\hat{\nu}\right)^2\right]\right\}\left|\langle 0^+ \| \hat{O}_J \| 2^- \rangle\right|^2$$

$$\propto q^{J-1} \xrightarrow[q\to 0]{} 0$$

Forbidden!

Radiative Corrections:



$$\langle 0^+ \| \hat{O}_J^W \hat{Q}_{J'}^{EM} \| 2^- \rangle = \sum_X \langle 0^+ \| \hat{O}_J^W \| \psi_X \rangle \langle \psi_X \| \hat{Q}_{J'}^{EM} \| 2^- \rangle$$

No longer limited to $J = 2$ operators to satisfy the selection rule!

$$d\Gamma \propto f_0 q^0 + f_1 q^1 + f_2 q^2$$

interference

angular momentum

parity

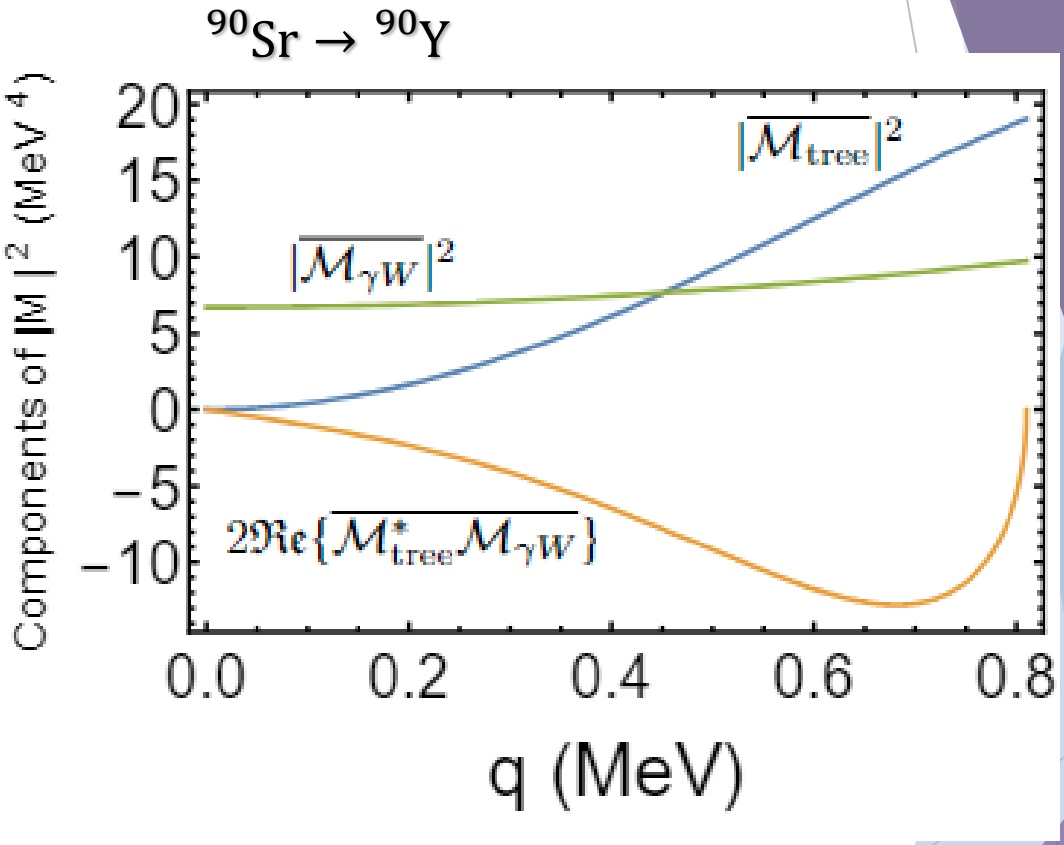
$$J_i^{\pi_i} \to J_f^{\pi_f}$$

$$|J_i - J_f| \le J \le J_i + J_f$$

$$\Delta\pi = \pi_i \cdot \pi_f$$

Unique Forbidden decays

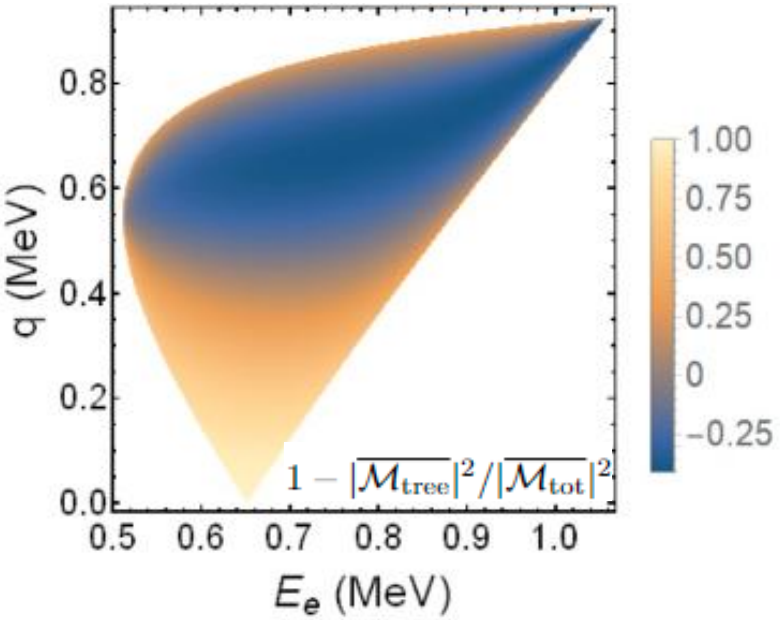
~~No~~ decay @ $q \to 0$

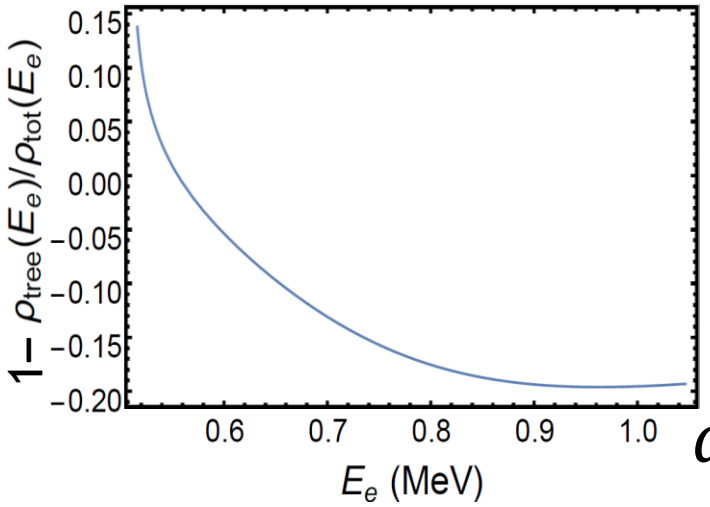


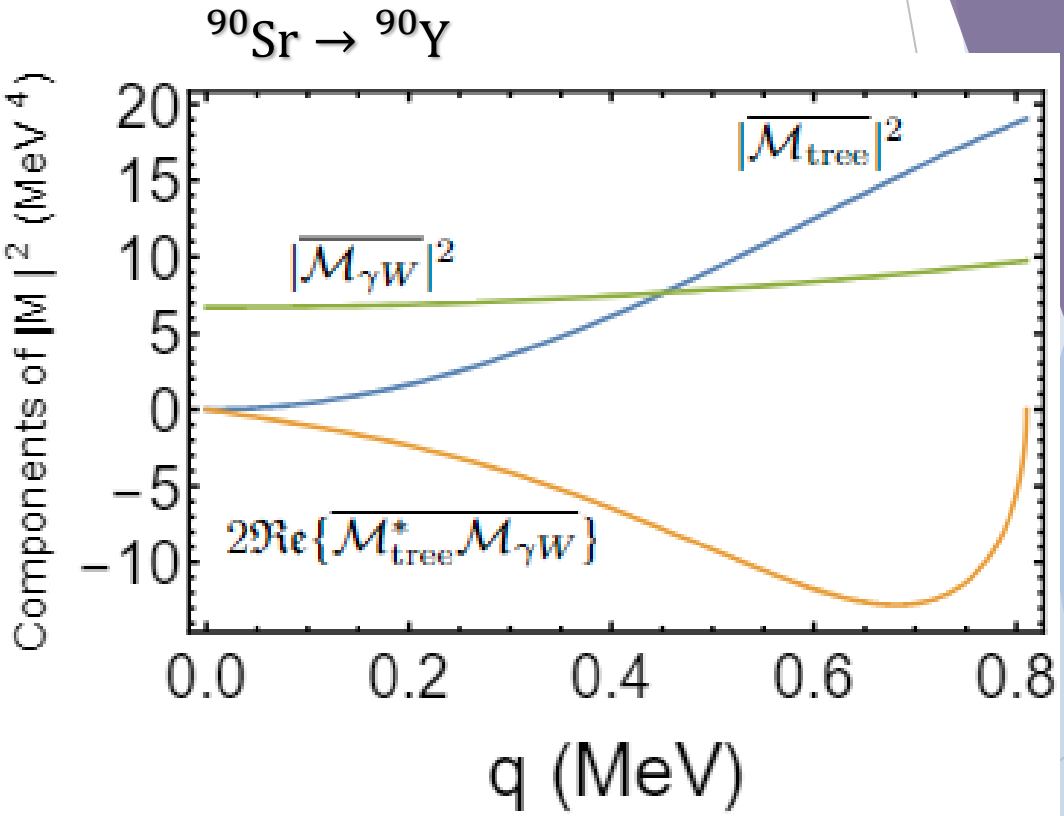
$$d\Gamma \propto \underbrace{f_0 q^0}_{|\overline{\mathcal{M}_{\gamma W}}|^2} + f_1 q^1 + \underbrace{f_2 q^2}_{|\overline{\mathcal{M}_{\mathrm{tree}}}|^2}$$

$2\Re\mathrm{e}\{\overline{\mathcal{M}^*_{\mathrm{tree}}\mathcal{M}_{\gamma W}}\}$

Unique Forbidden decays



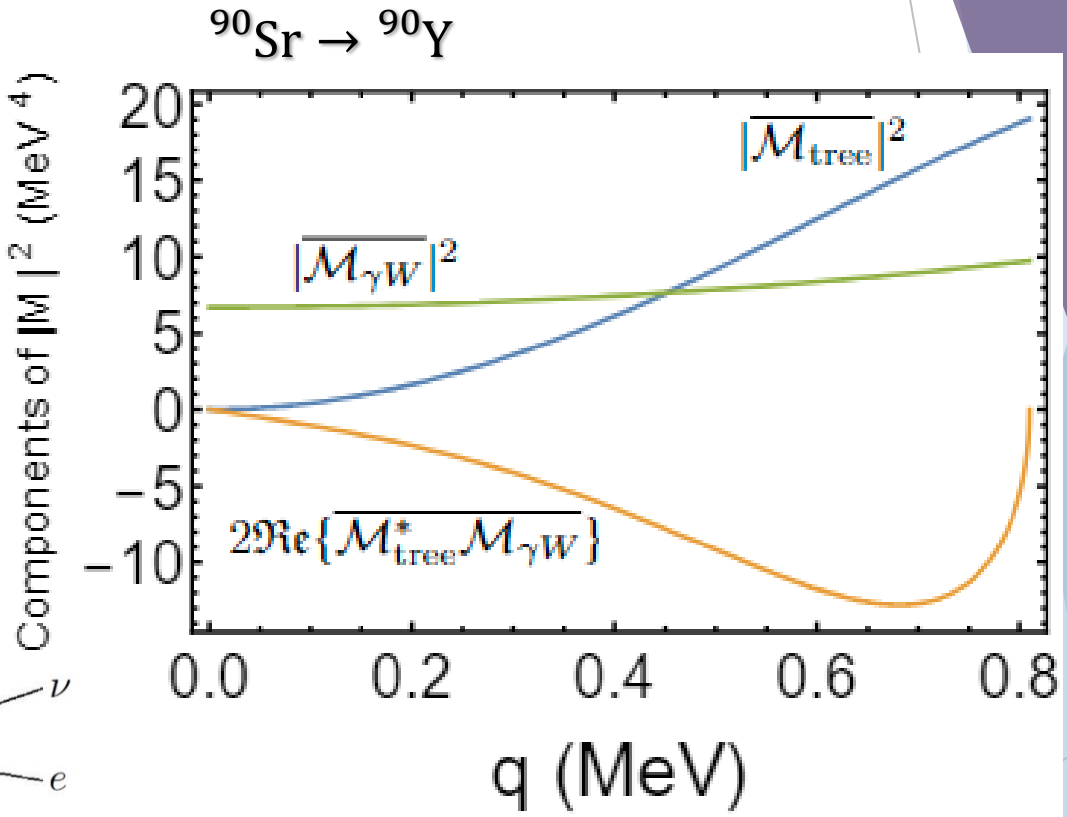




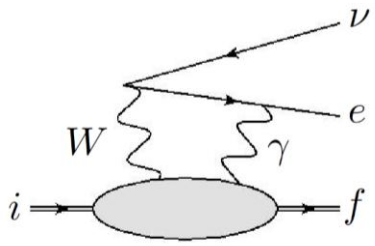
$$d\Gamma \propto \underbrace{f_0 q^0}_{|\overline{\mathcal{M}_{\gamma W}}|^2} + \underbrace{f_1 q^1}_{2\Re e\{\overline{\mathcal{M}^*_{\rm tree}\mathcal{M}_{\gamma W}}\}} + \underbrace{f_2 q^2}_{|\overline{\mathcal{M}_{\rm tree}}|^2}$$

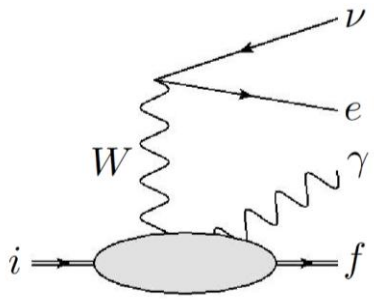
Unique Forbidden decays

~~No~~ decay @ $q \to 0$



Light New Physics





$$d\Gamma \propto f_0 q^0 + f_1 q^1 + f_2 q^2$$

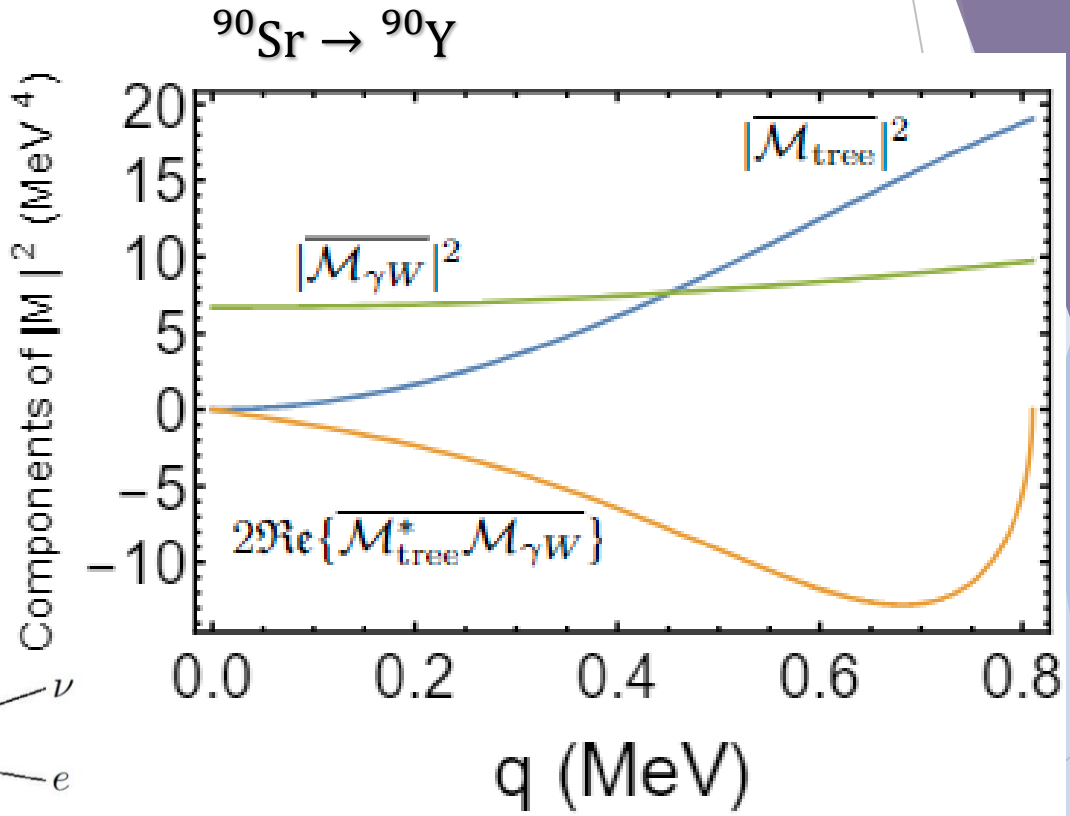
Unique Forbidden decays: Summary

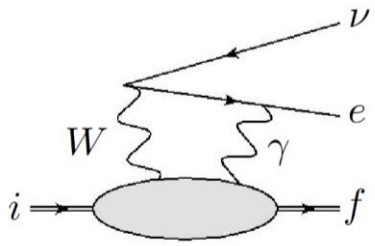
~~No~~ decay @ $q \to 0$

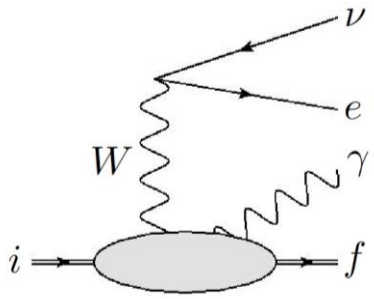
Experiments
@ ORNL, HUJI, SOREQ (FRIB?)

Spectrum is sensitive to:

- Exotic Weak Interactions
- Light New Physics







$$d\Gamma \propto f_0 q^0 + f_1 q^1 + f_2 q^2$$

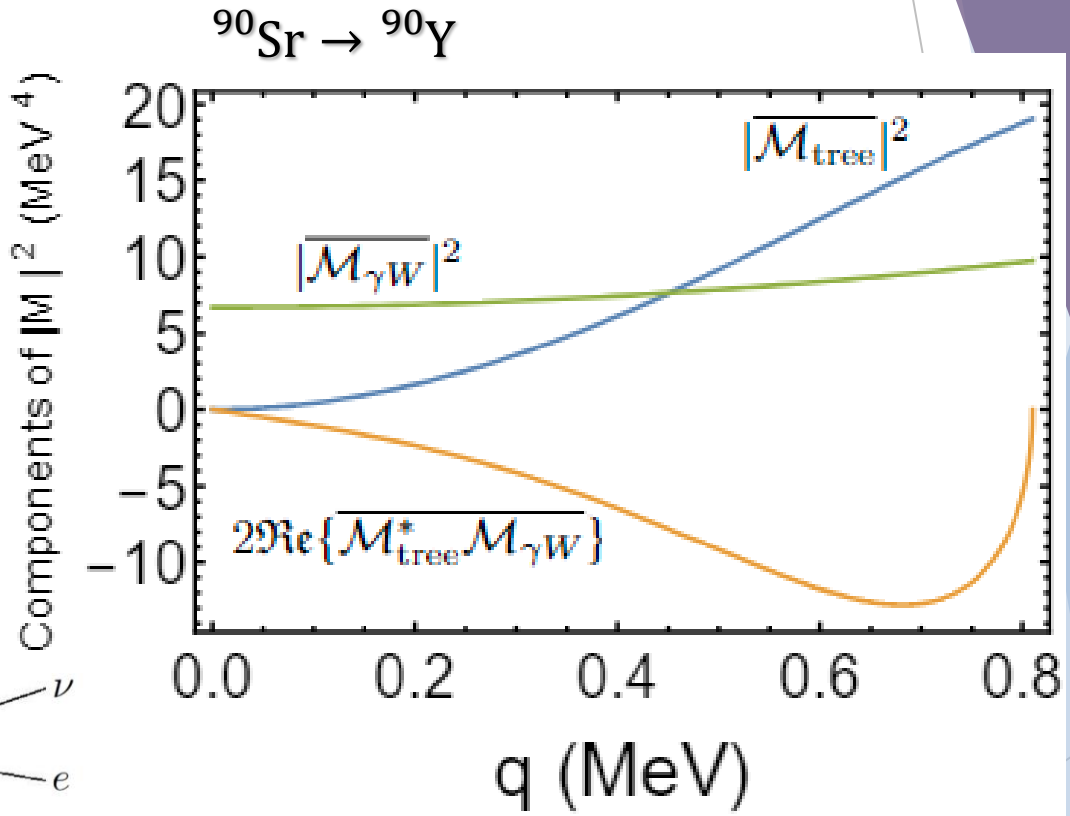
Unique Forbidden decays: Summary & Outlook

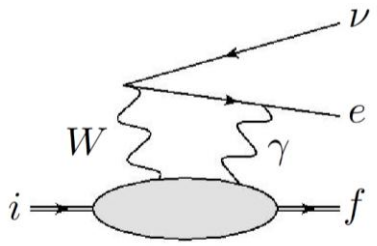
~~No~~ decay @ $q \to 0$

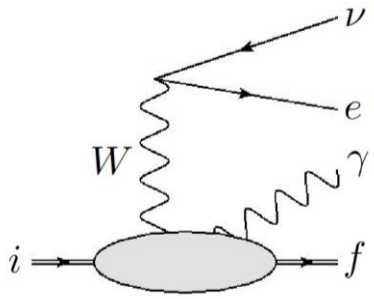
Experiments
@ ORNL, HUJI, SOREQ (FRIB?)

Spectrum is sensitive to:

- Exotic Weak Interactions
- Light New Physics







$$d\Gamma \propto f_0 q^0 + f_1 q^1 + f_2 q^2$$

The new radiative regime:
→ Beyond $q \to 0$ power counting
→ With nuclear matrix elements
→ Light new physics possibilities

Thanks!

Oscar Naviliat-Cuncic
FRIB & LPC Caen

Mikhail Gorchtein
Mainz U.

Leendert Hayen
LPC Caen

Charlie Rasco
ORNL

Guy Ron
Hebrew U.

DOE Topical Collaboration "Nuclear Theory for New Physics"

FRIB Theory Alliance

U.S. DOE Office of Science, Office of Nuclear Physics

U.S. DEPARTMENT OF ENERGY | Office of Science

Nuclear Theory for New Physics

UW/INT
Vincenzo Cirigliano
Wouter Dekens
Chien-Yeah Seng
Ayala Glick-Magid
Maria Dawid

FNAL
Noemi Rocco

ANL
Alessandro Lovato
Anna McCoy
Robert Wiringa

MSU (& FRIB)
Scott Bogner
Heiko Hergert

Notre Dame
Ragnar Stroberg

Carnegie Mellon University
Colin Morningstar
Sarah Skinner

UC Berkeley/LBNL
Wick Haxton
André Walker-Loud
Andrea Shindler
Lukáš Gráf
Zack Hall

UMass Amherst
Michael Ramsey-Musolf
Leon Friedrich

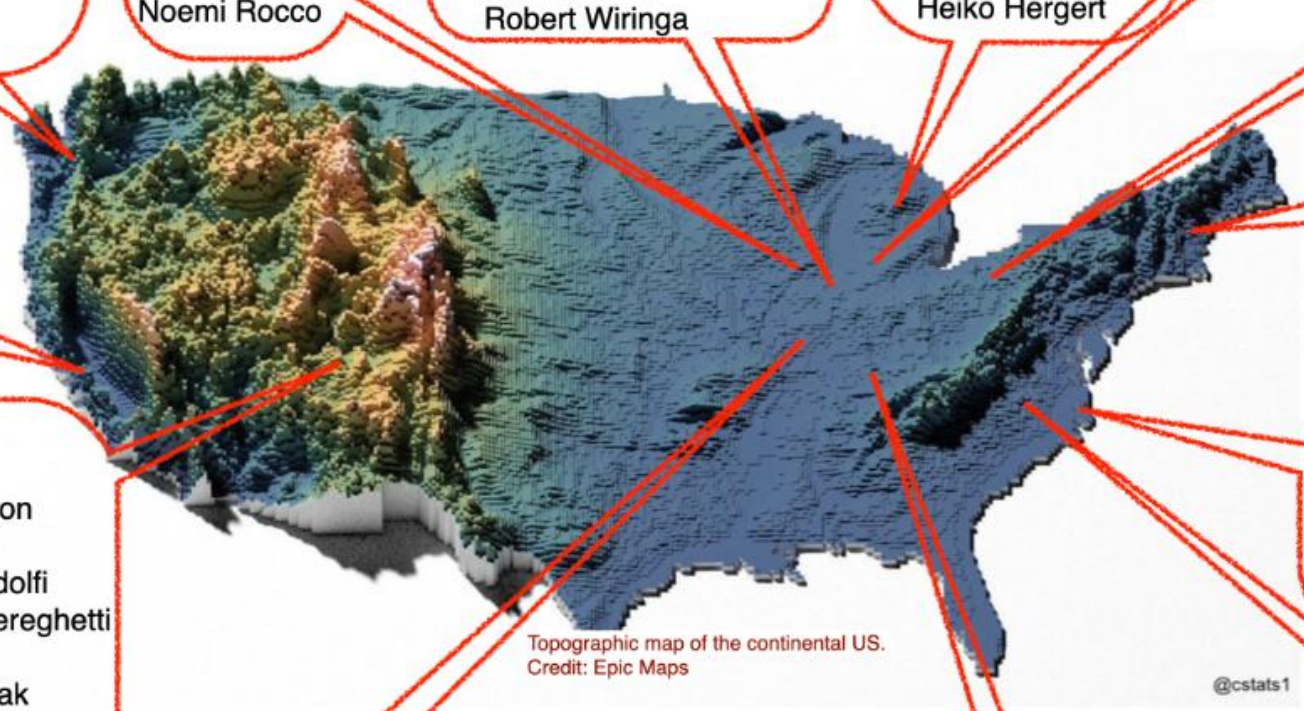
LANL
Joseph Carlson
Kaori Fuyuto
Stefano Gandolfi
Emanuele Mereghetti
Ingo Tews
Sasha Tomalak
Jacky Kumar

ODU/JLab
Alex Gnech
Rocco Schiavilla
Lorenzo Andreoli

Wash. U. St Louis
Bhupal Dev
Saori Pastore
Maria Piarulli
Anna McCoy
Abe Flores
Sam Novario
Jason Bub
Garrett King
Graham Chambers-Wall

ORNL / University of Tennessee
Gaute Hagen
Thomas Papenbrock
Lucas Platter
Evan Combes

UNC Chapel Hill
Jon Engel
Amy Nicholson
Zack Hall
Joeseph Moscoso



Topographic map of the continental US.
Credit: Epic Maps