Unique Forbidden β-decays for Precision New Physics Searches

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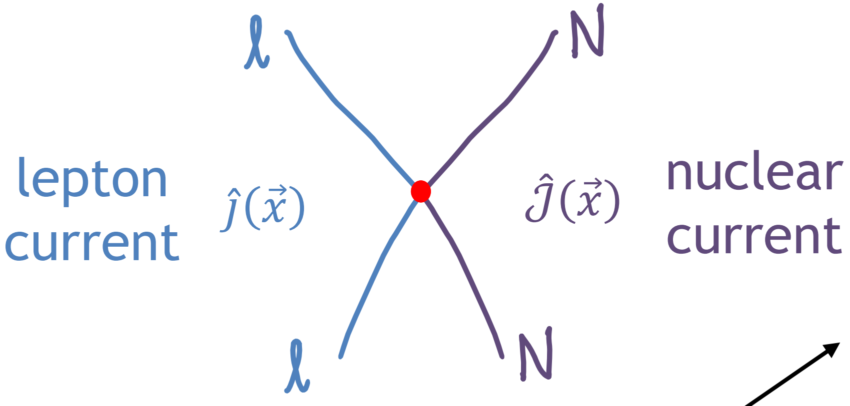
→

TEL AVIV UNIVERSITY

Hirschegg
Jan. 2026

- Introduction: BSM Searches & Forbidden β-decays
- Radiative Effects
  - $\Longrightarrow$ **~~Forbidden~~**
- Nuclear-structure Corrections
  - $\Longrightarrow$ **New observable: SPAM**
- ✓ Summary

Weak interaction



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

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

Experiments with ***nuclear β-decays***

Weak SM structure:

“$V - A$”

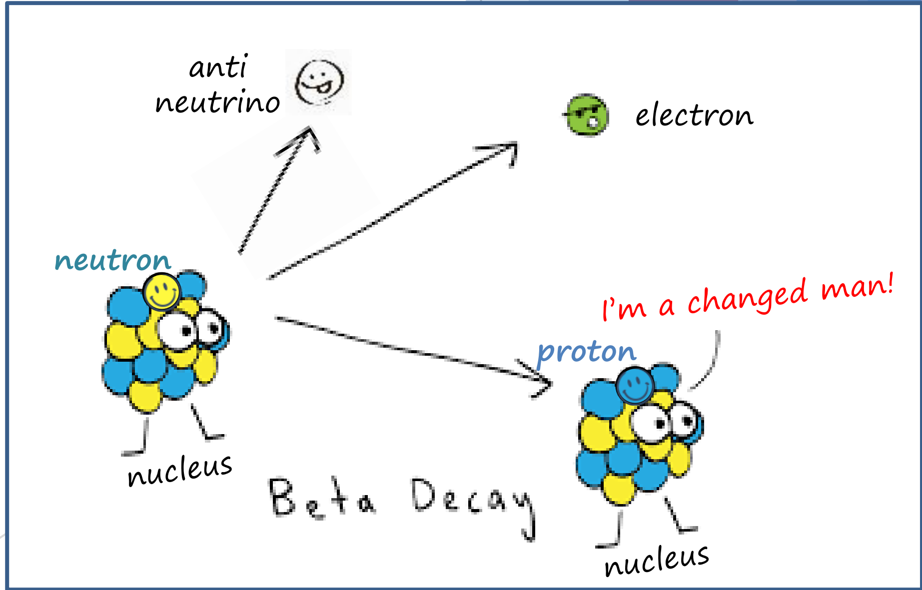
The SM is incomplete

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

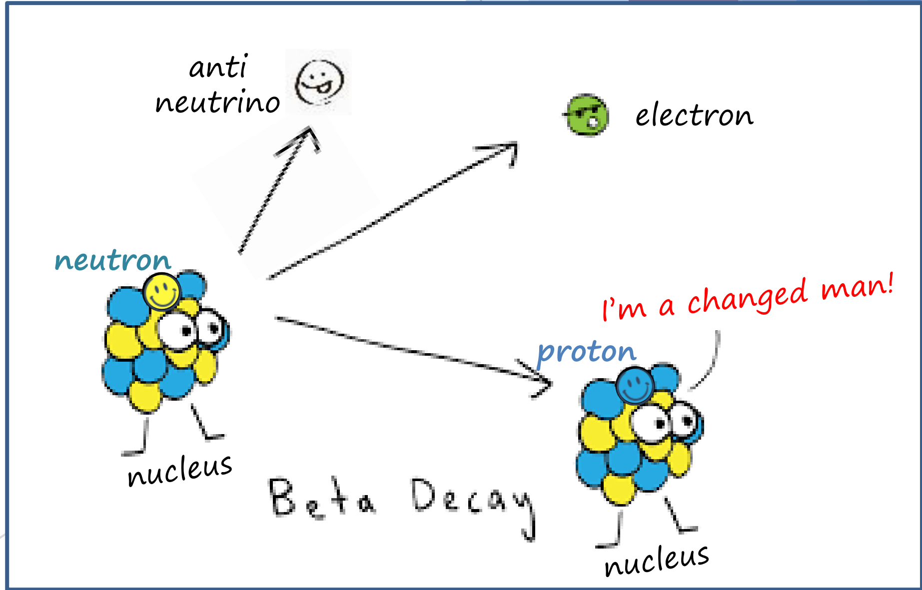
“Allowed” (when $q \to 0$)

- 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



Forbidden

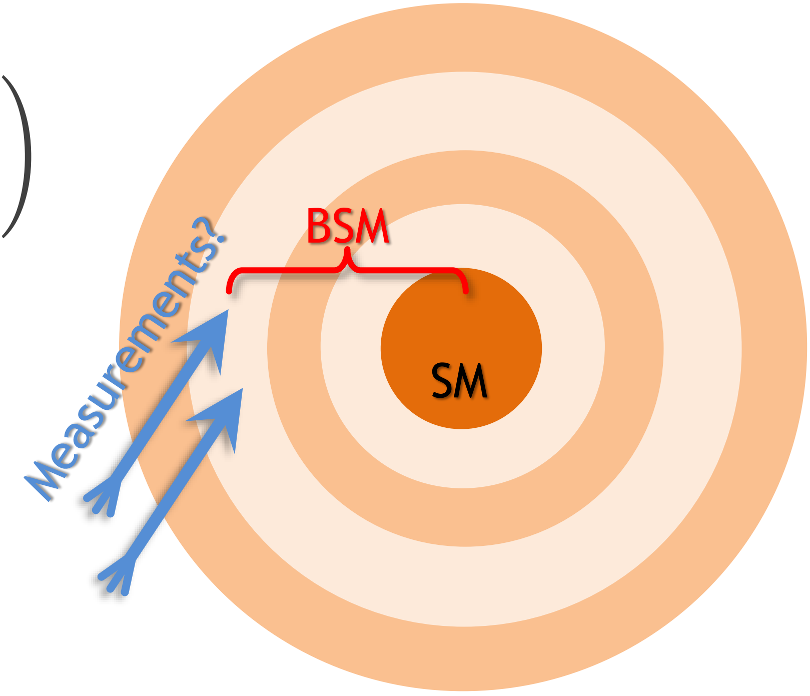
Allowed decays

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

$$1)\quad \boldsymbol{b} = \overset{\text{SM}}{0} \pm \overset{\text{BSM}}{\frac{C_T^+}{C_A}}$$

$$2)\quad \boldsymbol{a} = -\frac{1}{5}\left(1 - \frac{|C_T^+|^2 + |C_T^-|^2}{4|C_A|^2}\right)$$

(E.g., Gamow-Teller)



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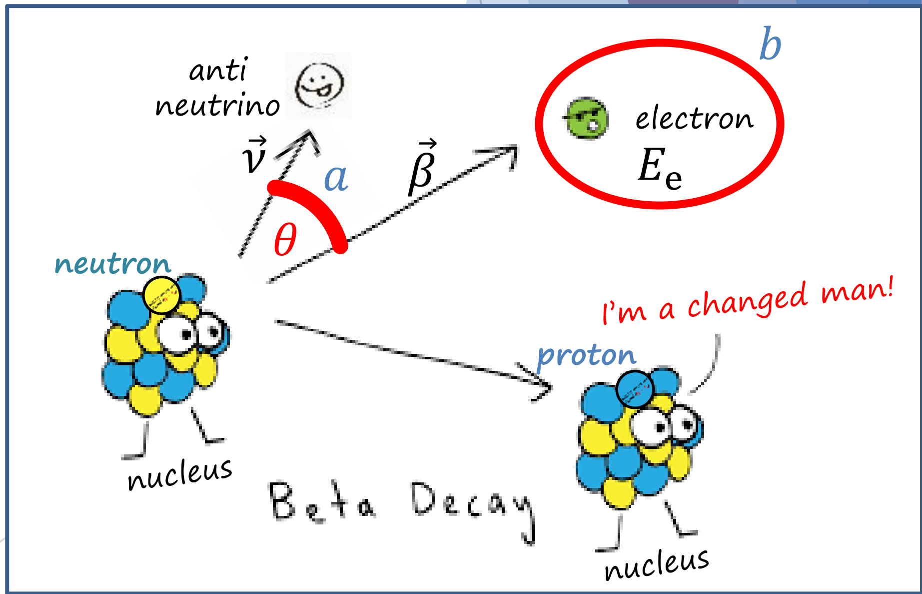


$C_A = 1.27$ Axial vector coupling constant (SM)

$C_T^+\,(C_T^-) \lesssim 10^{-3}$ Tensor left (right) coupling constants (BSM), unknown

Unique forbidden decays

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

AGM & Gazit, PRD 2023

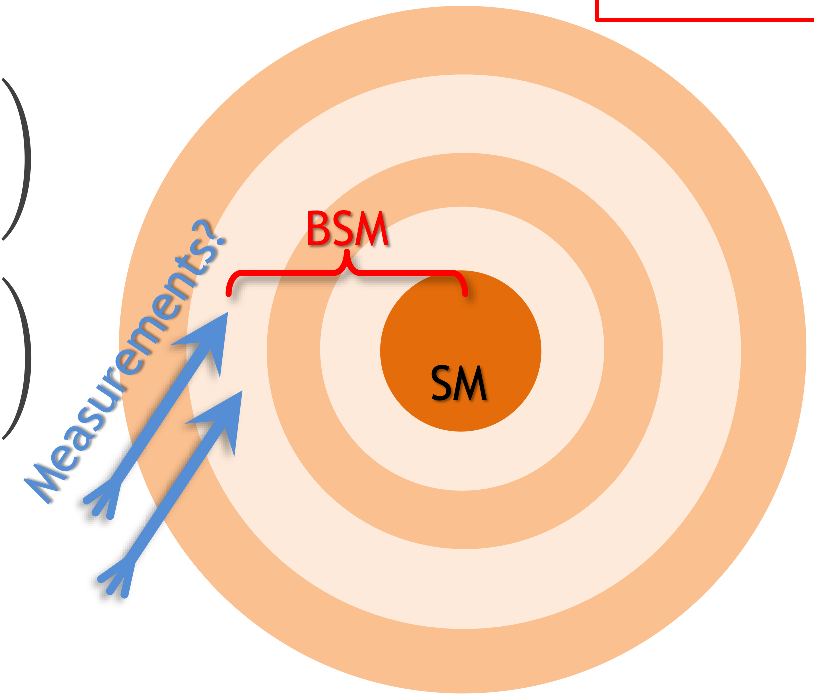
SM BSM

1) $\boldsymbol{b} = 0 \pm \frac{C_T^+}{C_A}$

2) $\boldsymbol{a} = -\frac{1}{5}\left(1 - \frac{|C_T^+|^2+|C_T^-|^2}{4|C_A|^2}\right)$

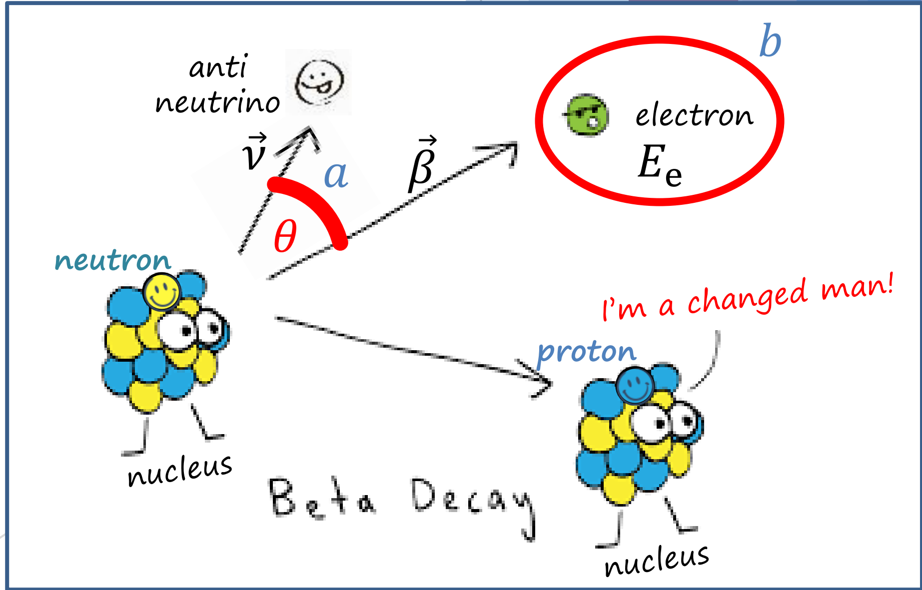
3) $\boldsymbol{a_2} = \frac{1}{5}\left(1 - \frac{|C_T^+|^2+|C_T^-|^2}{4|C_A|^2}\right)$

(E.g., Unique 1st-forbidden)



BSM Predictions & Observables for all forbidden decays

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



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AGM & Gazit, PRD 2023

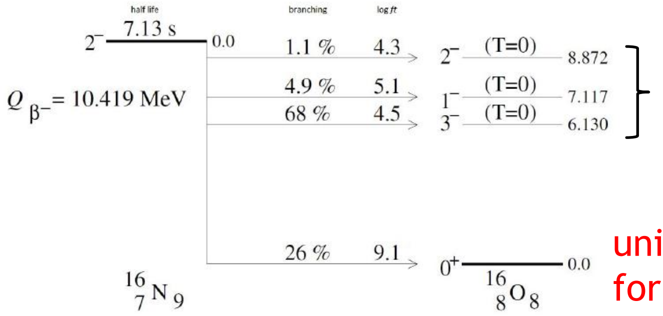
> **Experiments:**

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

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

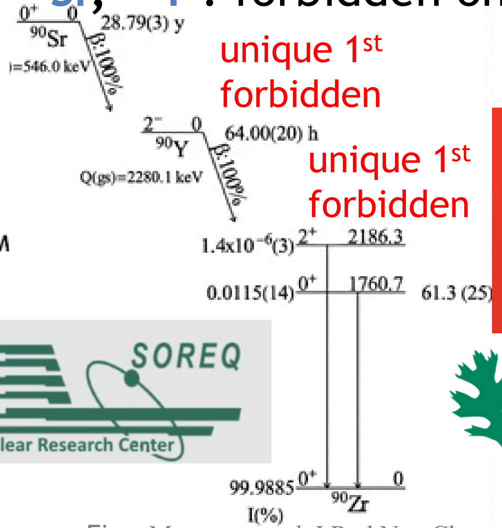


allowed

unique 1st forbidden

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

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

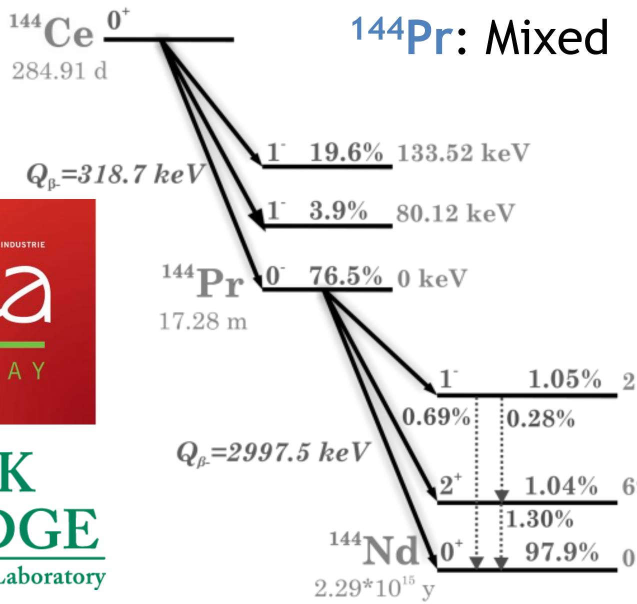


unique 1st forbidden

unique 1st forbidden

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

^{144}Pr: Mixed



allowed

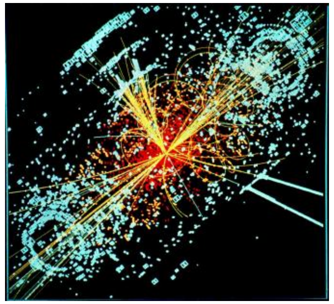
unique 1st forbidden

allowed

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

Searches for BSM physics

High energy frontier



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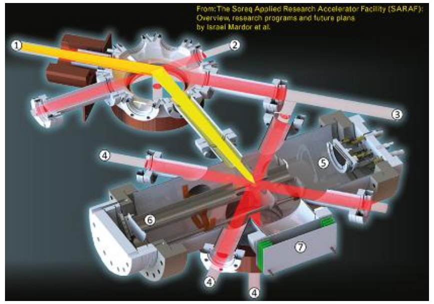
LHC
TeV scale

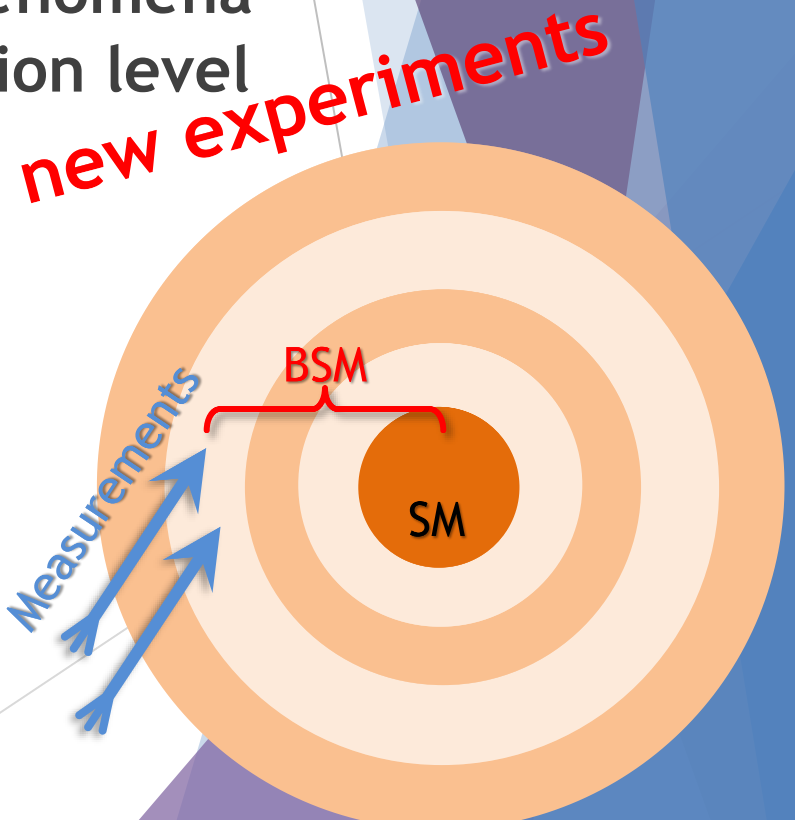
$C_T^+ (C_T^-)$ Tensor left (right) coupling constants

Precision frontier

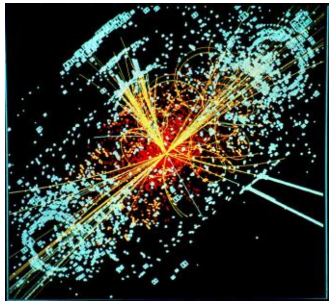


Mardor *et al.*, [Eur. Phys. J. A 54, 91](#) (2018)

Nuclear phenomena
10^{-3} precision level



High energy frontier



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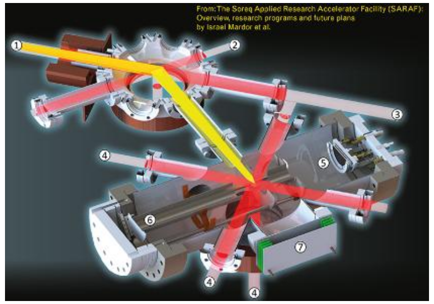
Precision frontier



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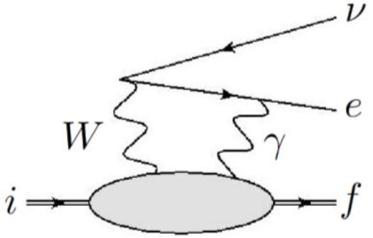
LHC
TeV scale

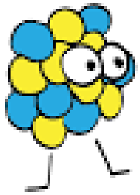
$C_T^+ (C_T^-)$ Tensor left (right) coupling constants

Nuclear phenomena
10^{-3} precision level

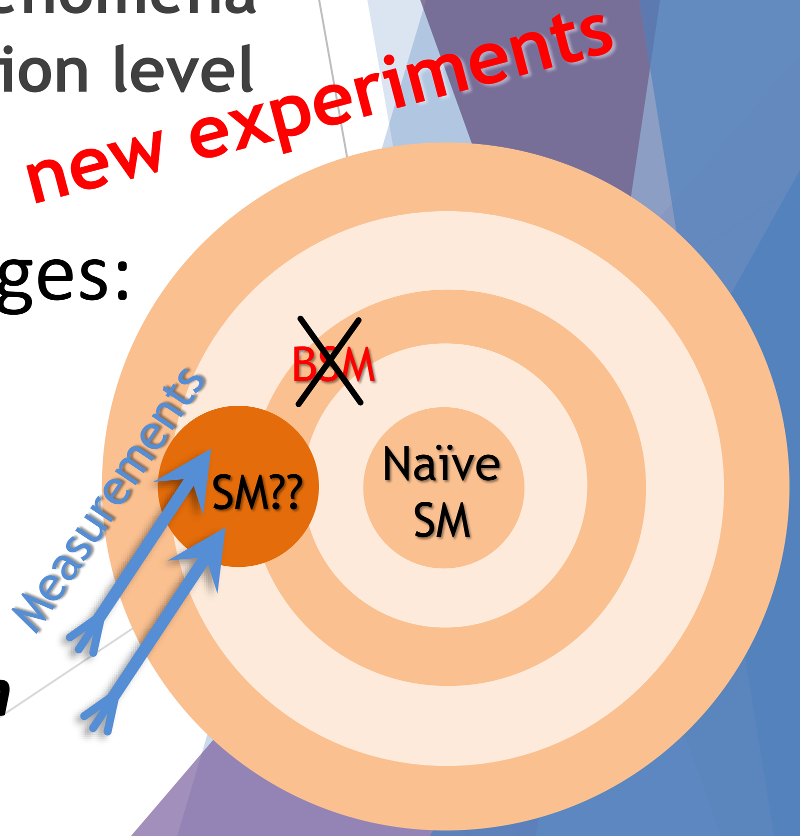
Requires Precision Theory – two challenges:



- ➢ ***High-order radiative effects***



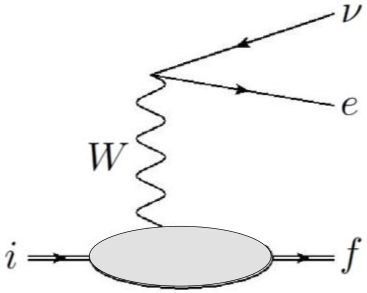
- ➢ ***Nuclear-structure many-body problem***



Radiative Effects

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 ($J^{\Delta\pi}$)

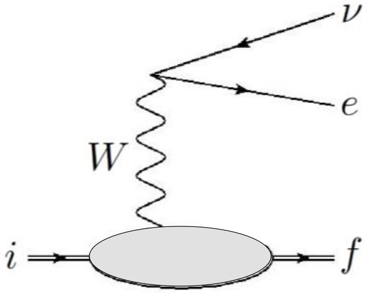
angular momentum

parity

$$J_i^{\pi_i} \to J_f^{\pi_f}$$
$$\left|J_i - J_f\right| \leq J \leq J_i + J_f$$
$$\Delta\pi = \pi_i \cdot \pi_f$$

Unique 1st-forbidden

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



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$2^- \to 0^+$

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

$\Delta\pi = -$

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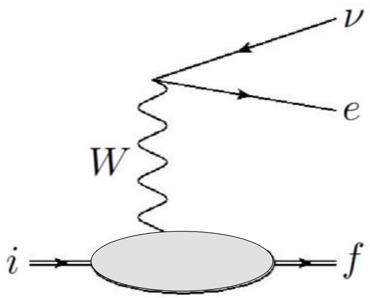
$$\propto q^{J-1} \xrightarrow[q\to 0]{} 0$$

Forbidden!



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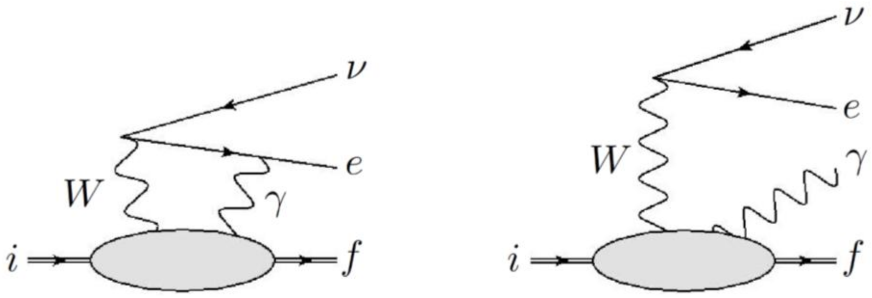
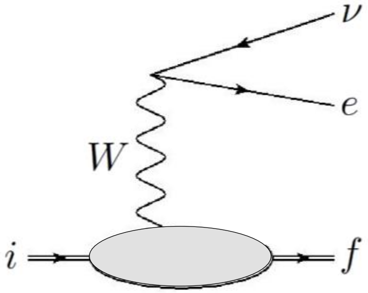
$$\propto q^{J-1} \xrightarrow[q\to 0]{} 0$$

Forbidden!

Radiative Corrections:





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

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angular momentum

parity

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Seng, AGM, Cirigliano, PRL 2025

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

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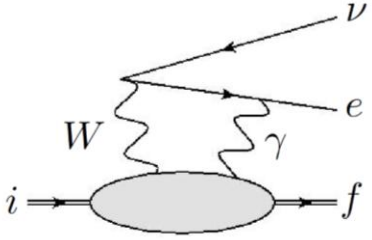

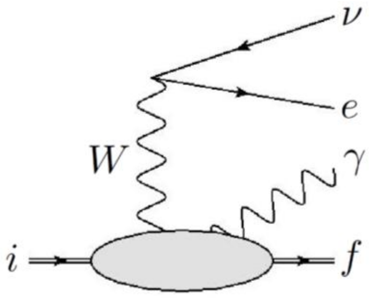

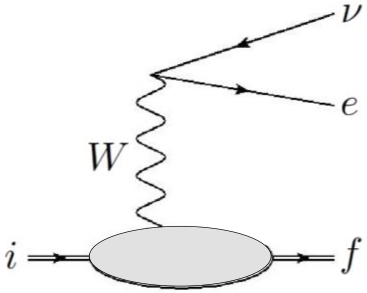

$$\langle 0^+\|\hat{O}^W_J\,\hat{Q}^{EM}_{J'}\|2^-\rangle = \sum_X \langle 0^+\|\hat{O}^W_J\|\psi_X\rangle\,\langle\psi_X\|\hat{Q}^{EM}_{J'}\|2^-\rangle$$

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$$2^- \to 0^+$$
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Seng, AGM, Cirigliano, PRL 2025

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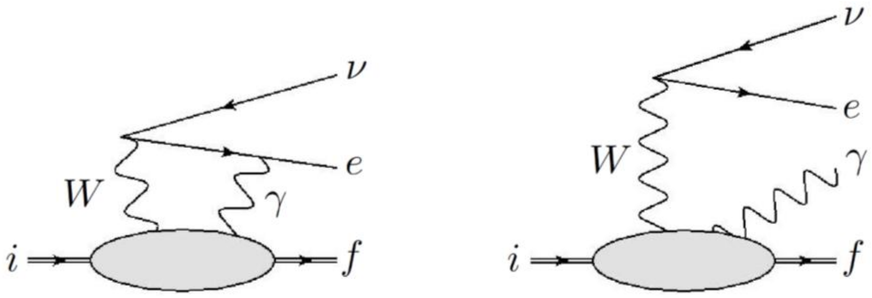
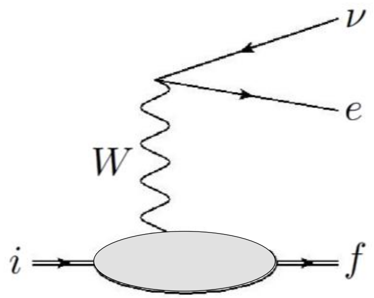
Forbidden!

Radiative Corrections:





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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

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$$|2-0| \le J \le 2+0$$
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Seng, AGM, Cirigliano, PRL 2025

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Forbidden!

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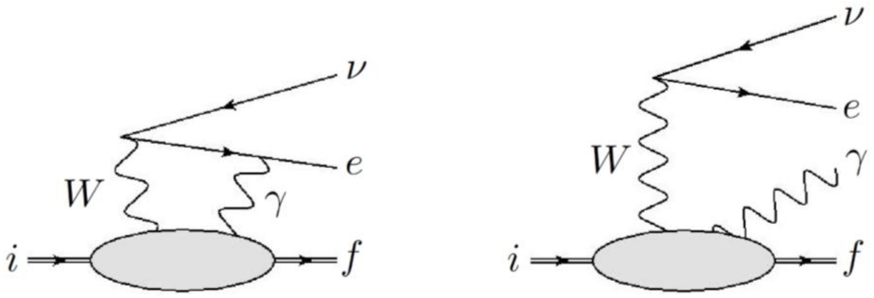
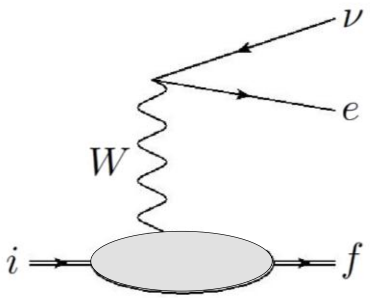




$$\langle 0^+\|\hat{O}^W_J\,\hat{Q}^{EM}_{J'}\|2^-\rangle = \sum_X \langle 0^+\|\hat{O}^W_J\|\psi_X\rangle\,\langle \psi_X\|\hat{Q}^{EM}_{J'}\|2^-\rangle$$

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

$$d\Gamma \propto f_0 q^0 + \underbrace{f_1 q^1}_{\text{interference}} + f_2 q^2$$

angular momentum

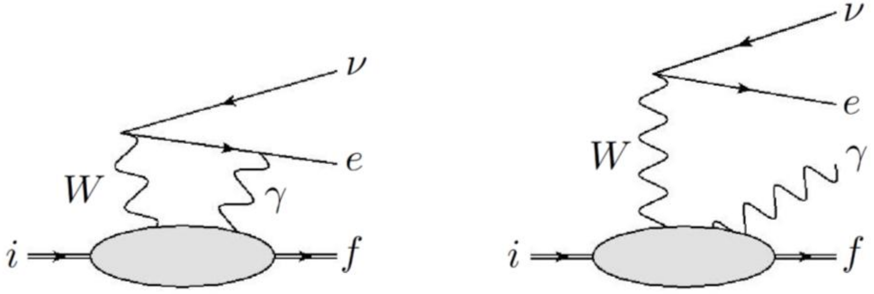
parity

$$2^- \to 0^+$$
$$|2-0| \le J \le 2+0$$
$$\Delta\pi = -$$

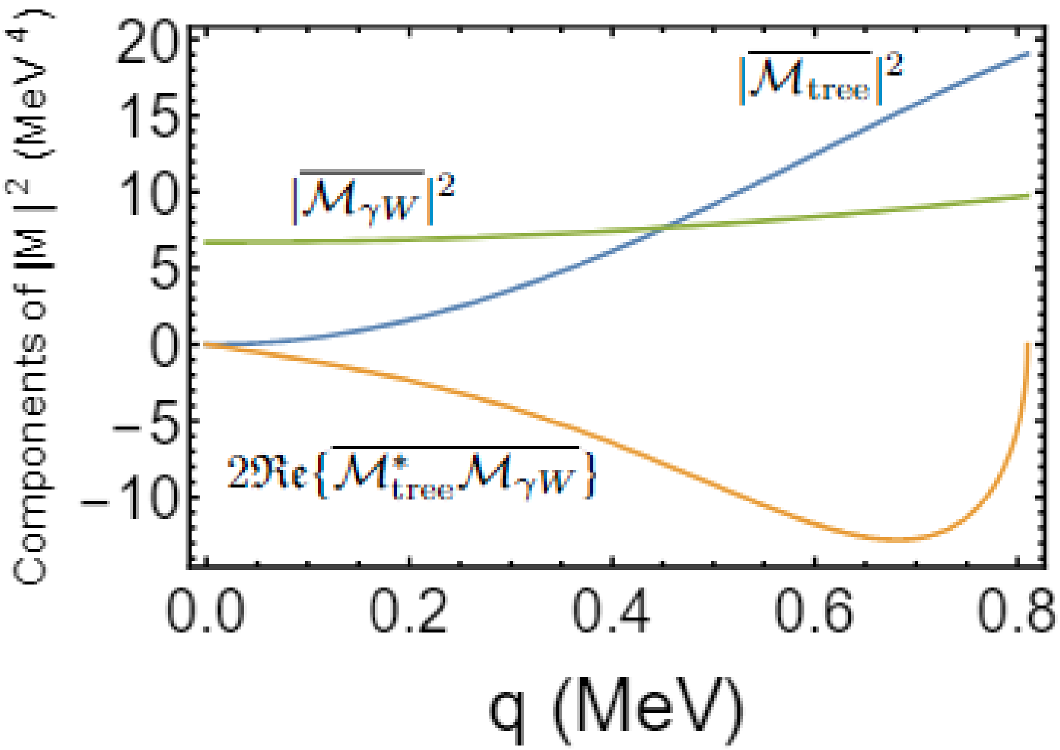
Seng, AGM, Cirigliano, PRL 2025

Unique Forbidden decays

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



$^{90}\mathrm{Sr} \to {}^{90}\mathrm{Y}$

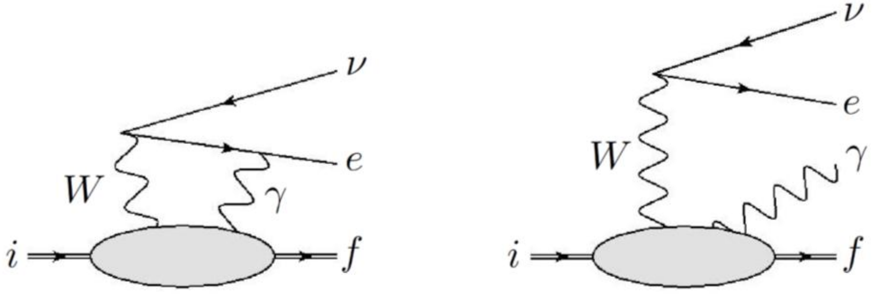


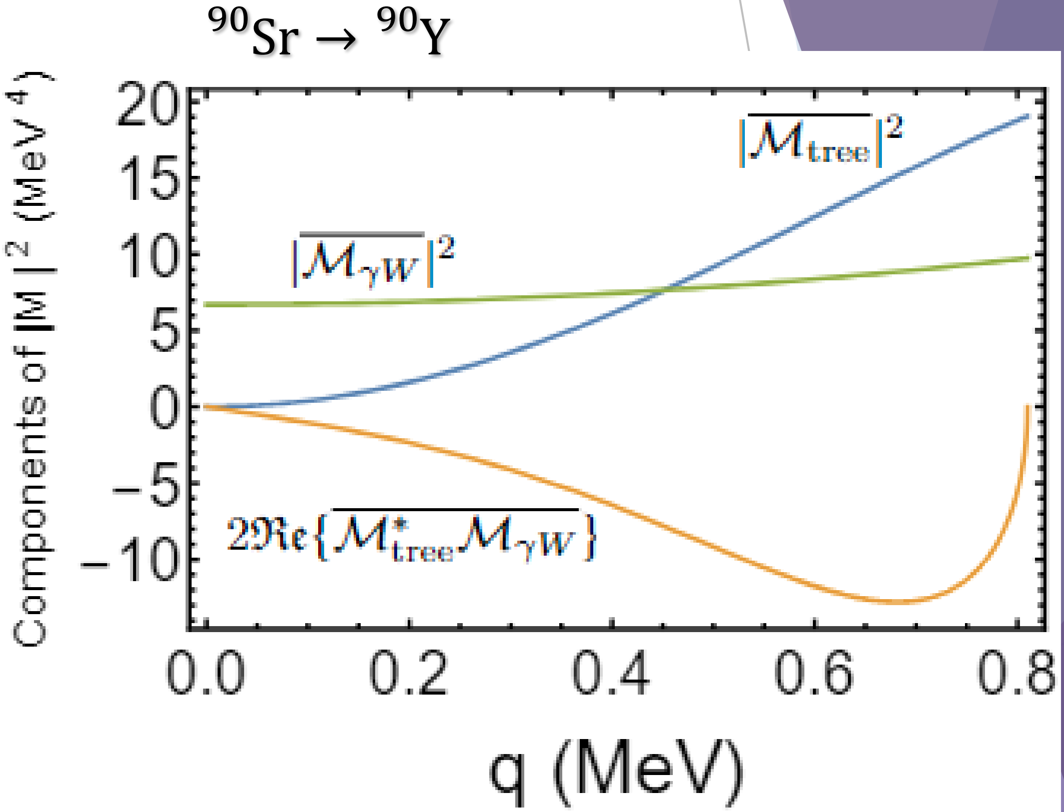
$$d\Gamma \propto \overset{|\overline{\mathcal{M}_{\gamma W}}|^2}{f_0 q^0} + \underset{2\Re\mathfrak{e}\{\overline{\mathcal{M}^*_{\mathrm{tree}}\mathcal{M}_{\gamma W}}\}}{f_1 q^1} + \overset{|\overline{\mathcal{M}_{\mathrm{tree}}}|^2}{f_2 q^2}$$

Seng, AGM, Cirigliano, PRL 2025

Unique Forbidden decays

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





Light New Physics

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

Seng, AGM, Cirigliano, PRL 2025

Unique Forbidden decays: Summary & Outlook

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

Experiments

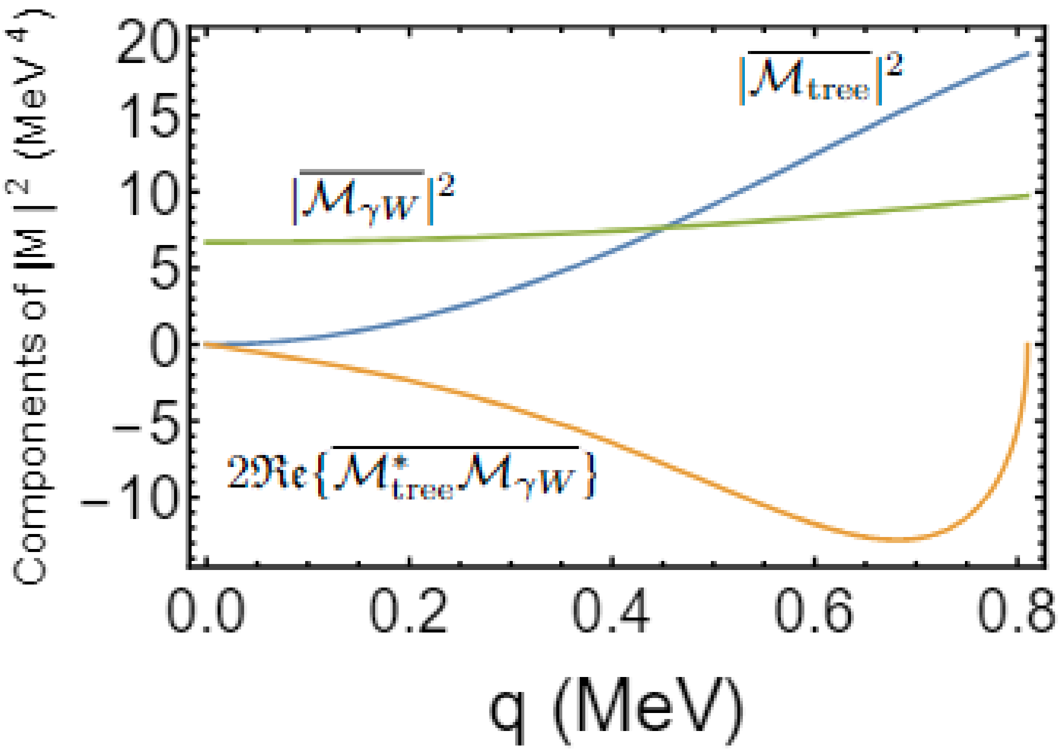
@ ORNL, CEA Saclay, HUJI, SOREQ

- New possibilities with MTAS @ORNL

Spectrum is sensitive to:

- Exotic Weak Interactions
- *Light New Physics*

$^{90}\mathrm{Sr} \to {}^{90}\mathrm{Y}$



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

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

[Seng, AGM, Cirigliano, PRL 2025](#)

➢ *High-order radiative effects*

Unique Forbidden decays:

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

Experiments

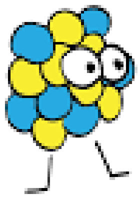
@ ORNL, CEA Saclay, HUJI, SOREQ

- New possibilities with MTAS @ORNL

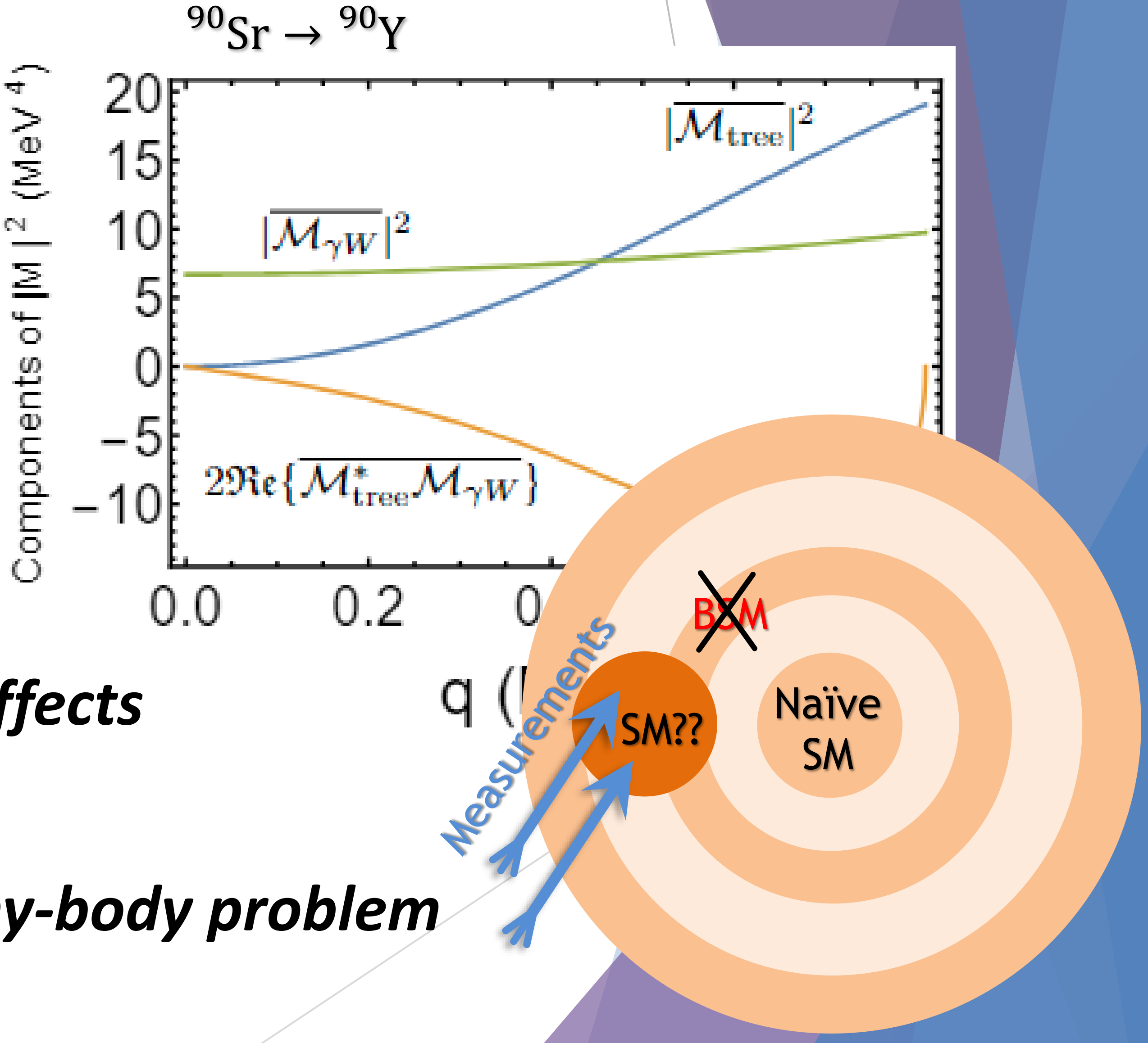
Spectrum is sensitive to:

- Exotic Weak Interactions
- *Light New Physics*

✓ ➢ ***High-order radiative effects***



➢ ***Nuclear-structure many-body problem***



Nuclear Structure Corrections

➢ ***Nuclear-structure many-body problem***

Accuracy: Nuclear structure corrections

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

SM SM correction

$1 + \delta_1$

SM SM correction

$0 + \delta_b$

SM SM correction

$-\frac{1}{5}(1+\delta_a)$

SM SM correction

$\frac{1}{5}(1+\delta_{a_2})$

Multipole operator's matrix elements between the nuclear states

- $$\delta = f\left(\underbrace{\frac{\langle\psi_f\|\widehat{M}_J^V\|\psi_i\rangle}{\langle\psi_f\|\widehat{L}_J^A\|\psi_i\rangle}, \frac{\langle\psi_f\|\hat{C}_J^A\|\psi_i\rangle}{\langle\psi_f\|\widehat{L}_J^A\|\psi_i\rangle}}_{\sim\, \epsilon_{\mathrm{NR}}\epsilon_{qr}\, \sim 10^{-2}}\right) + \mathcal{O}\Big(\underbrace{\epsilon_{qr}^2, \epsilon_c^2}_{\sim\, 10^{-4}}\Big)$$

Identifying Small Parameters

$\epsilon_{\mathrm{NR}} \sim \frac{p_{\mathrm{fermi}}}{m_N} \approx 2\cdot10^{-1}$

$\epsilon_{\mathrm{EFT}} \sim 1\cdot10^{-1}$

$\epsilon_{qr} \sim qR \approx 5\cdot10^{-2}$

$\epsilon_c \sim \alpha Z_f \approx 2\cdot10^{-2}$

$\epsilon_{\mathrm{recoil}} \sim \frac{q}{m_N} \approx 4\cdot10^{-3}$

Multipole Expansion

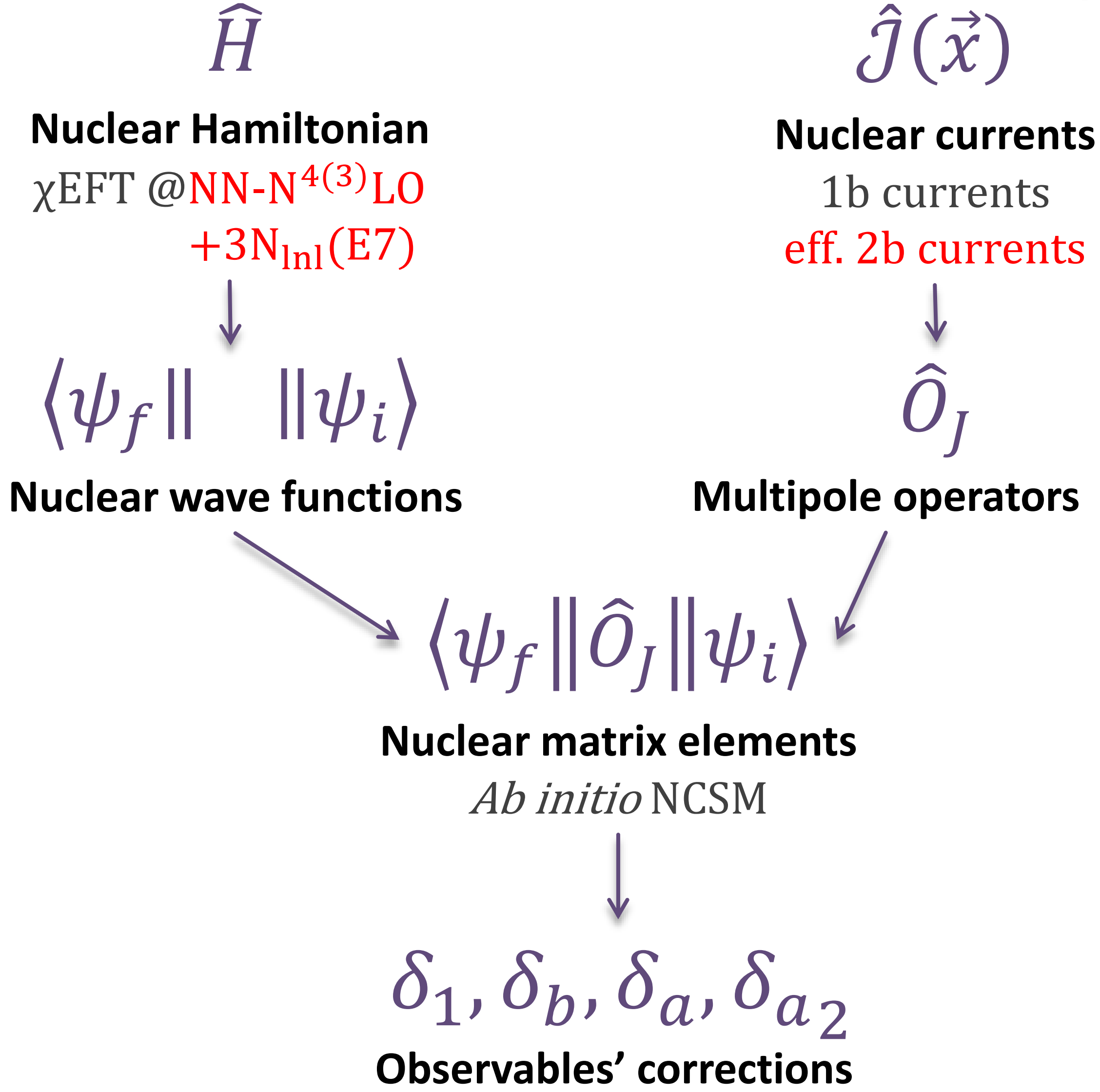
General Theory – for any transition & nucleus

Uncertainty Quantification

AGM & Gazit, J.Phys.G 2022

$^{16}\mathrm{N} \xrightarrow{\beta^-} {}^{16}\mathrm{O}$ forbidden decay

- ➢ ***Nuclear-structure many-body problem***



$\hat{H}$

Nuclear Hamiltonian

χEFT @NN-N$^{4(3)}$LO +3N$_{\mathrm{lnl}}$(E7)

$\hat{J}(\vec{x})$

Nuclear currents

1b currents

eff. 2b currents

$\langle \psi_f \| \quad \| \psi_i \rangle$

Nuclear wave functions

$\hat{O}_J$

Multipole operators

$\langle \psi_f \| \hat{O}_J \| \psi_i \rangle$

Nuclear matrix elements

Ab initio NCSM

$\delta_1, \delta_b, \delta_a, \delta_{a_2}$

Observables' corrections

In prep. with:

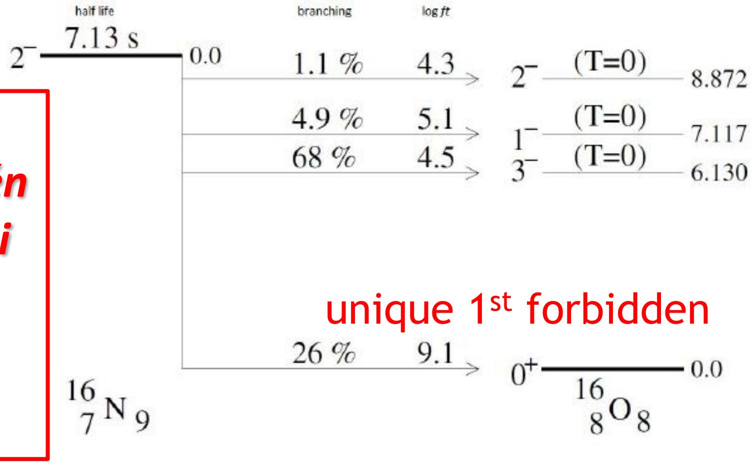
Christian Forssén

Lotta Jokiniemi

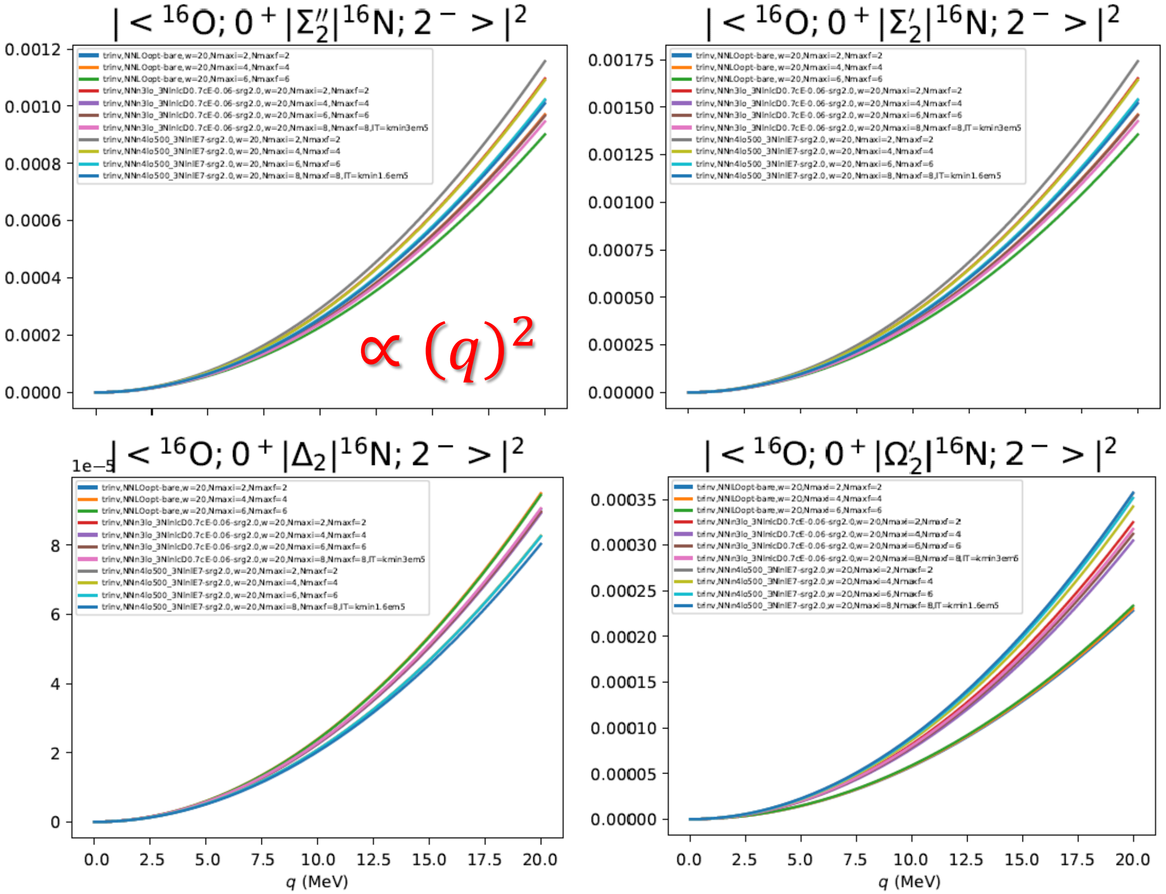
Petr Navrátil

Daniel Gazda

Doron Gazit



unique 1$^{\mathrm{st}}$ forbidden



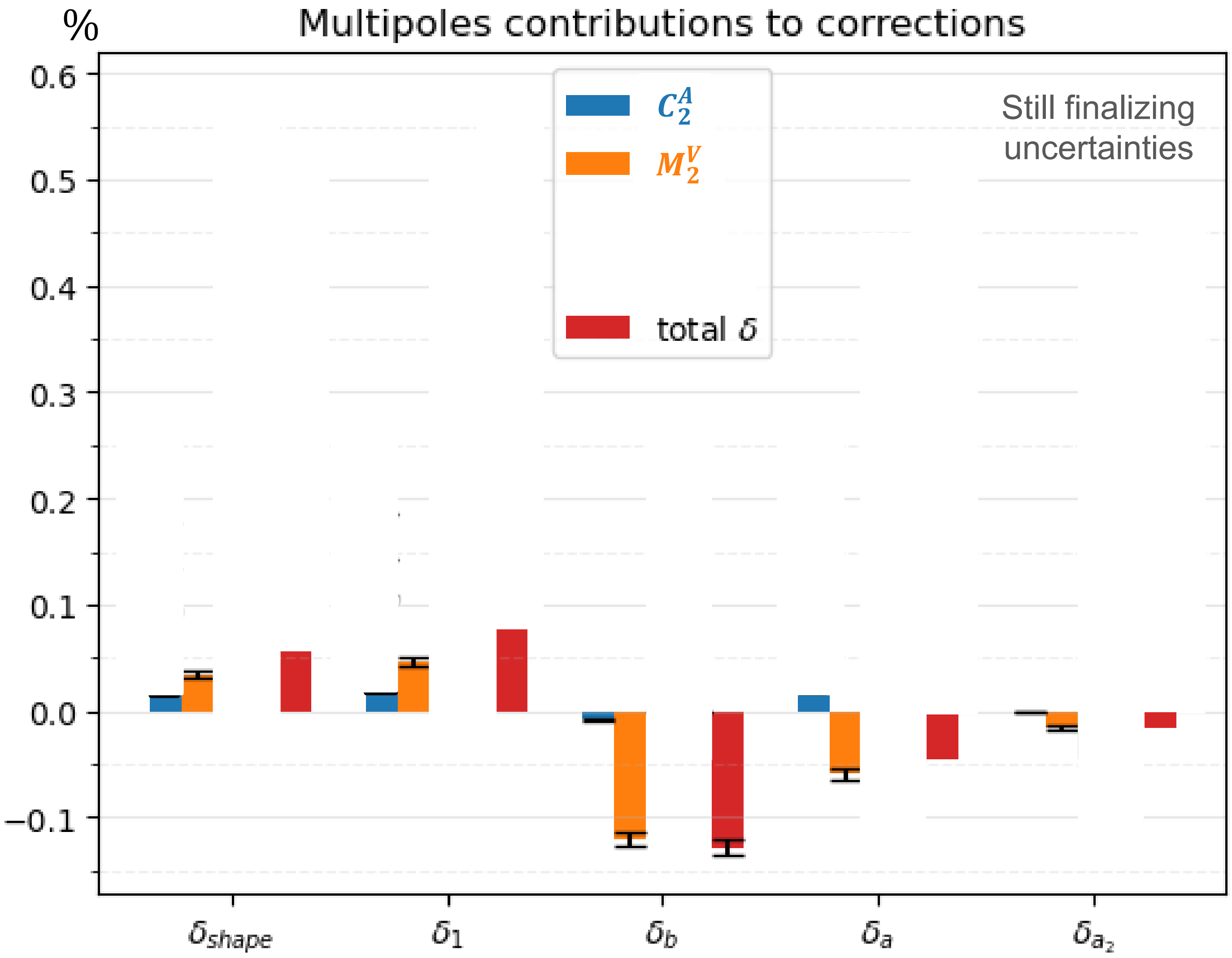
➢ ***Nuclear-structure many-body problem***

$^{16}\mathrm{N} \rightarrow {}^{16}\mathrm{O}$ forbidden spectrum

Leading Order: $L_2^{A(0)}$ (~ Holstein's *c*)

The known corrections:

- Weak Magnetism M_2^V (~ Holstein's *b*)
- Induced Tensor C_2^A (~ Holstein's *d*)



Still finalizing uncertainties

$^{16}\mathrm{N} \to {}^{16}\mathrm{O}$ forbidden spectrum

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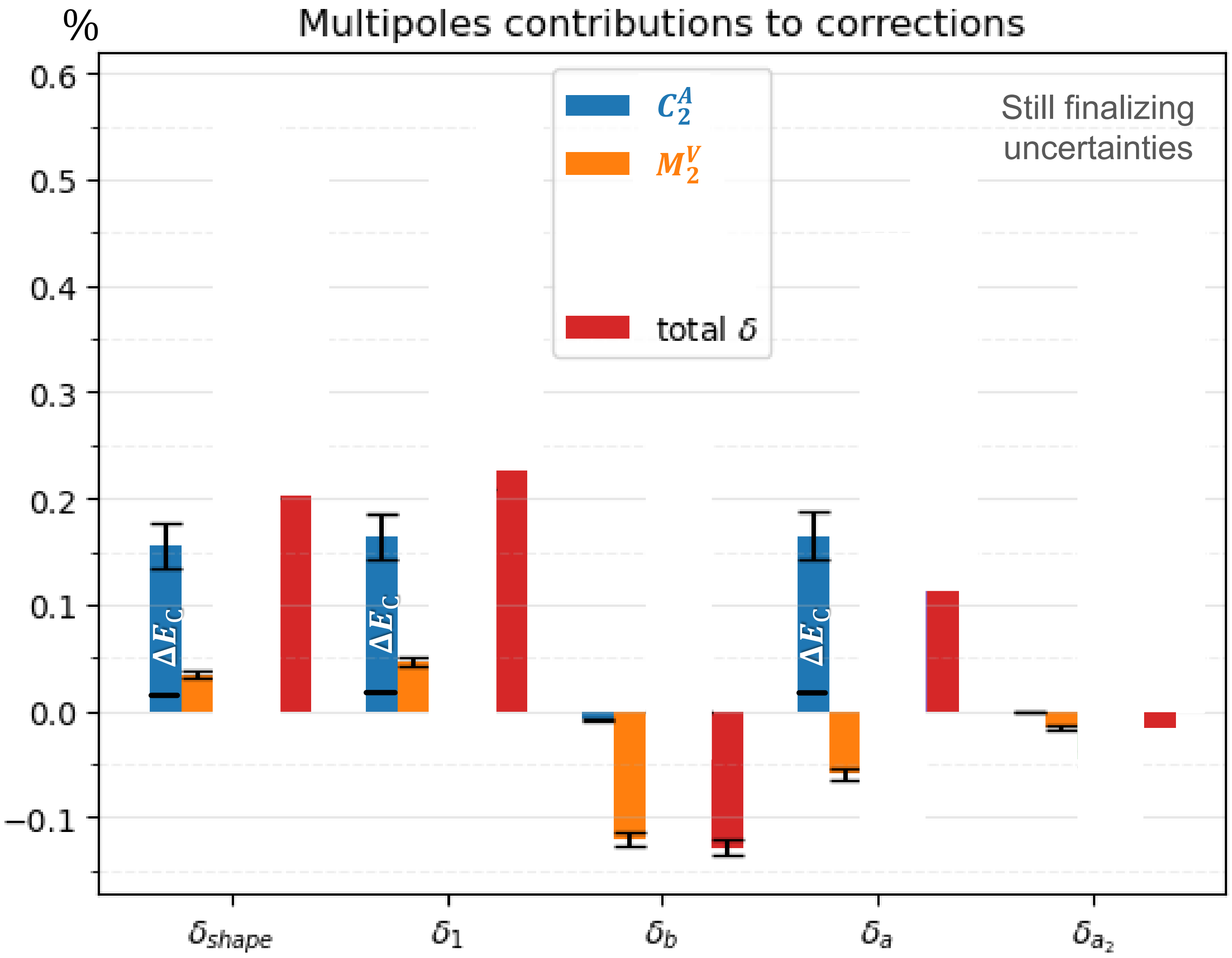
- $C_2^A \propto E_0 + \Delta E_c$

  Coulomb Displacement Energy!



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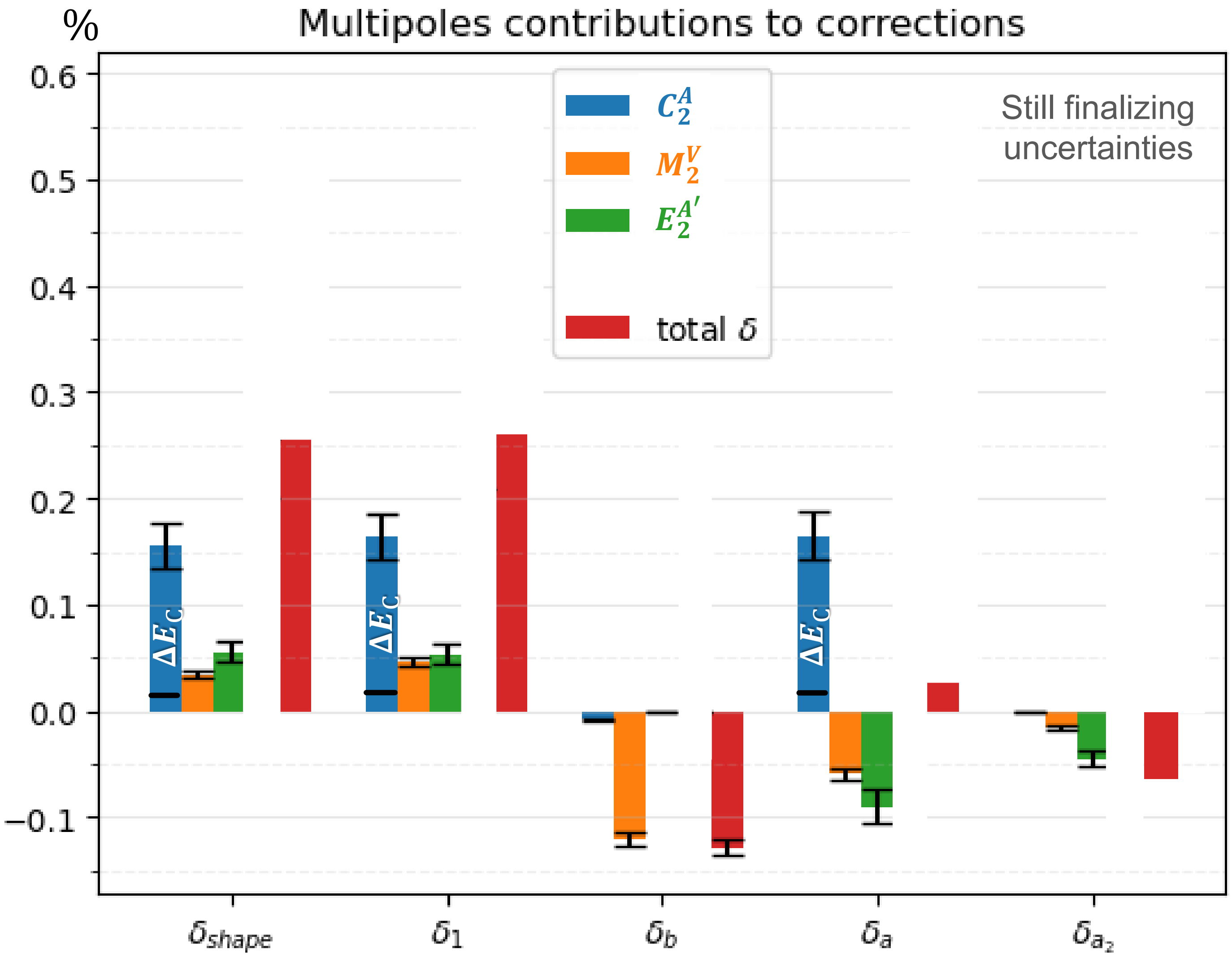
  Coulomb Displacement Energy!

- $$E_2^A \propto L_2^A + \underbrace{\mathcal{O}\left(\epsilon_{qr}^2\right)}_{E_2^{A'} \sim 10^{-3}}$$



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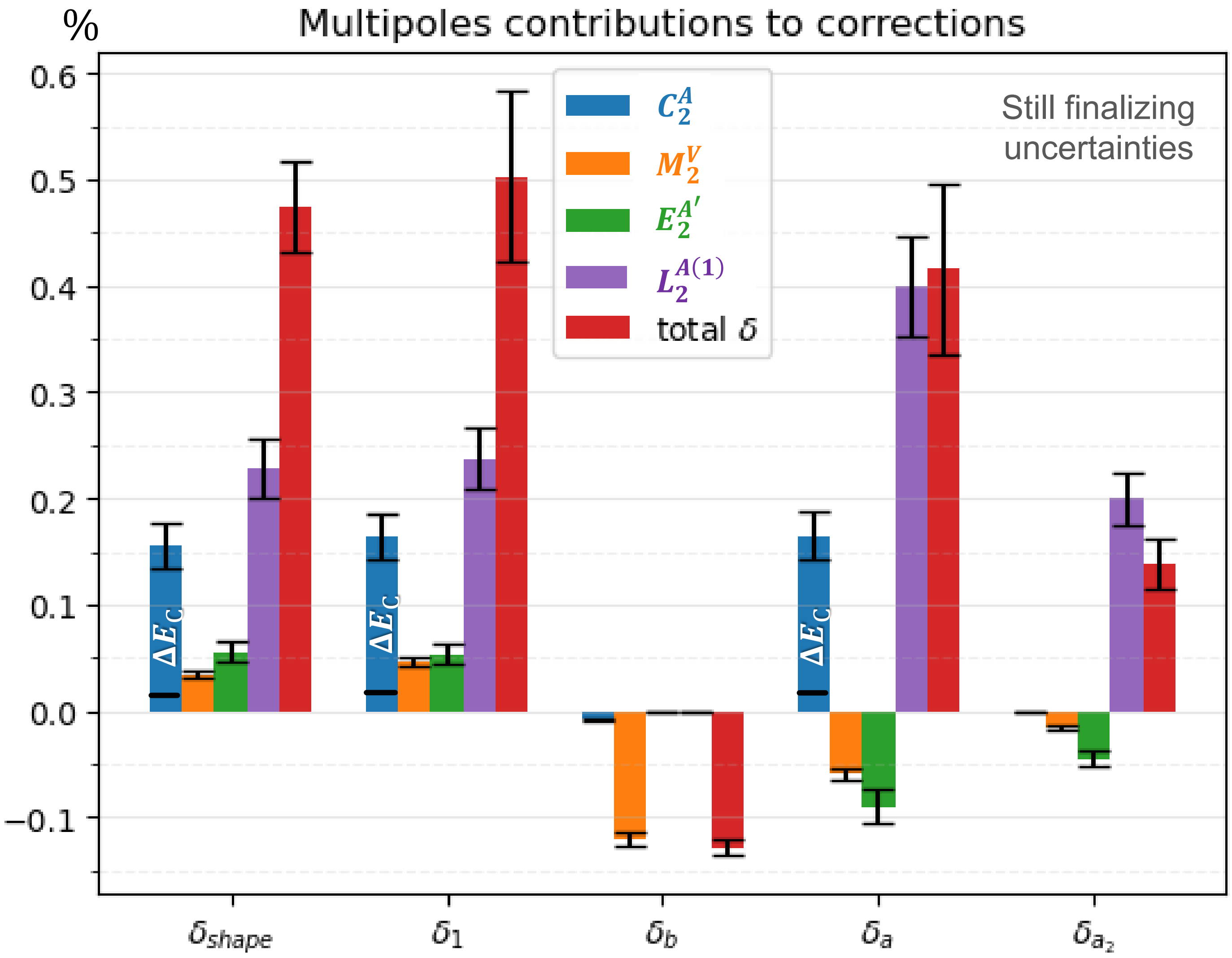
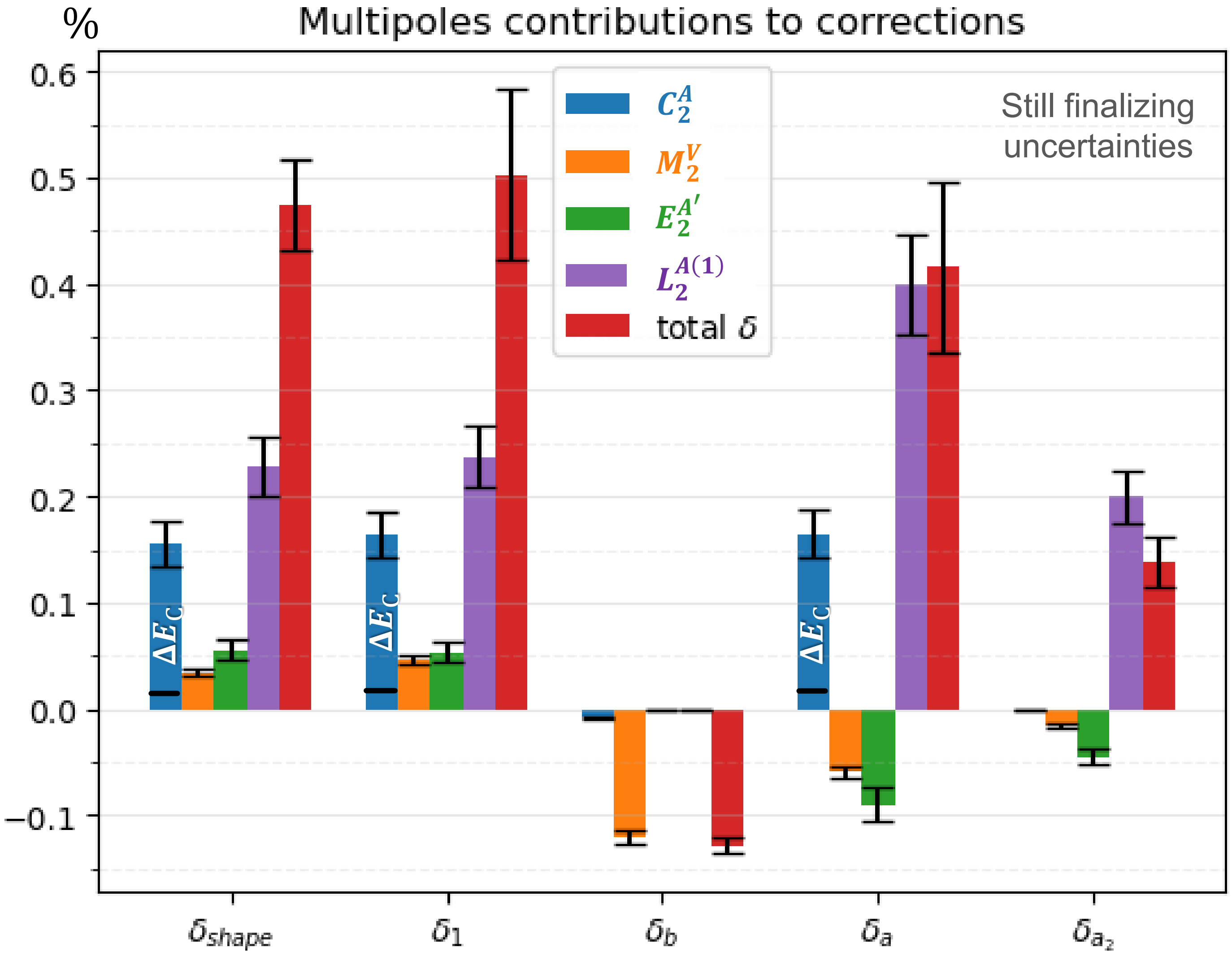
  Coulomb Displacement Energy!
- $E_2^A \propto L_2^A + \underbrace{\mathcal{O}\left(\epsilon_{qr}^2\right)}_{E_2^{A'} \sim 10^{-3}}$
- $L_2^A \propto L_2^{A(0)} + L_2^{A(1)} + \mathcal{O}\left(\epsilon_{qr}^4\right)$



$^{16}\mathrm{N} \rightarrow {}^{16}\mathrm{O}$ forbidden spectrum

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

- Well-known WM $\boldsymbol{M_2^V}$ & $\boldsymbol{C_2^A}$ are relatively small
- Dominant Coulomb correction $\boldsymbol{\Delta E_c}$
- Higher-order axial corrections $\boldsymbol{E_2^{A'}}$ & $\boldsymbol{L_2^{A(1)}}$ are the dominant



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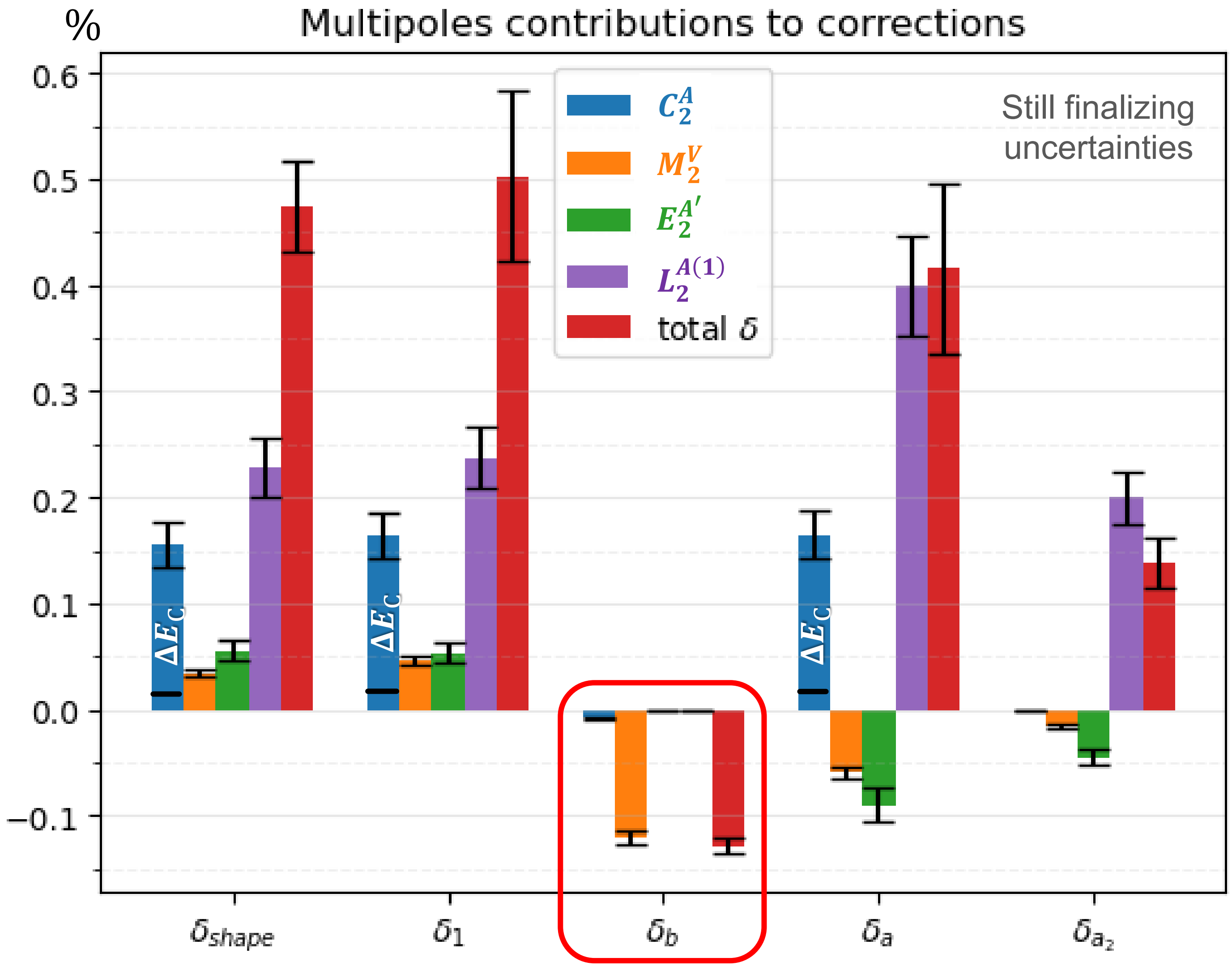
- Well-known WM M_2^V & C_2^A are relatively small
- Dominant Coulomb correction ΔE_c
- Higher-order axial corrections $E_2^{A'}$ & $L_2^{A(1)}$ are the dominant

- $\boldsymbol{b}$'s structure corrections are different:
  - Not affected by the dominant higher-order axial contributions $E_2^{A'}$ & $L_2^{A(1)}$
  - Suppressed Coulomb correction C_2^A
  - leaving only the weak magnetism M_2^V



Multipoles contributions to corrections

Still finalizing uncertainties

^{16}N → ^{16}O forbidden spectrum

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

- Well-known WM M_2^V & C_2^A are relatively small
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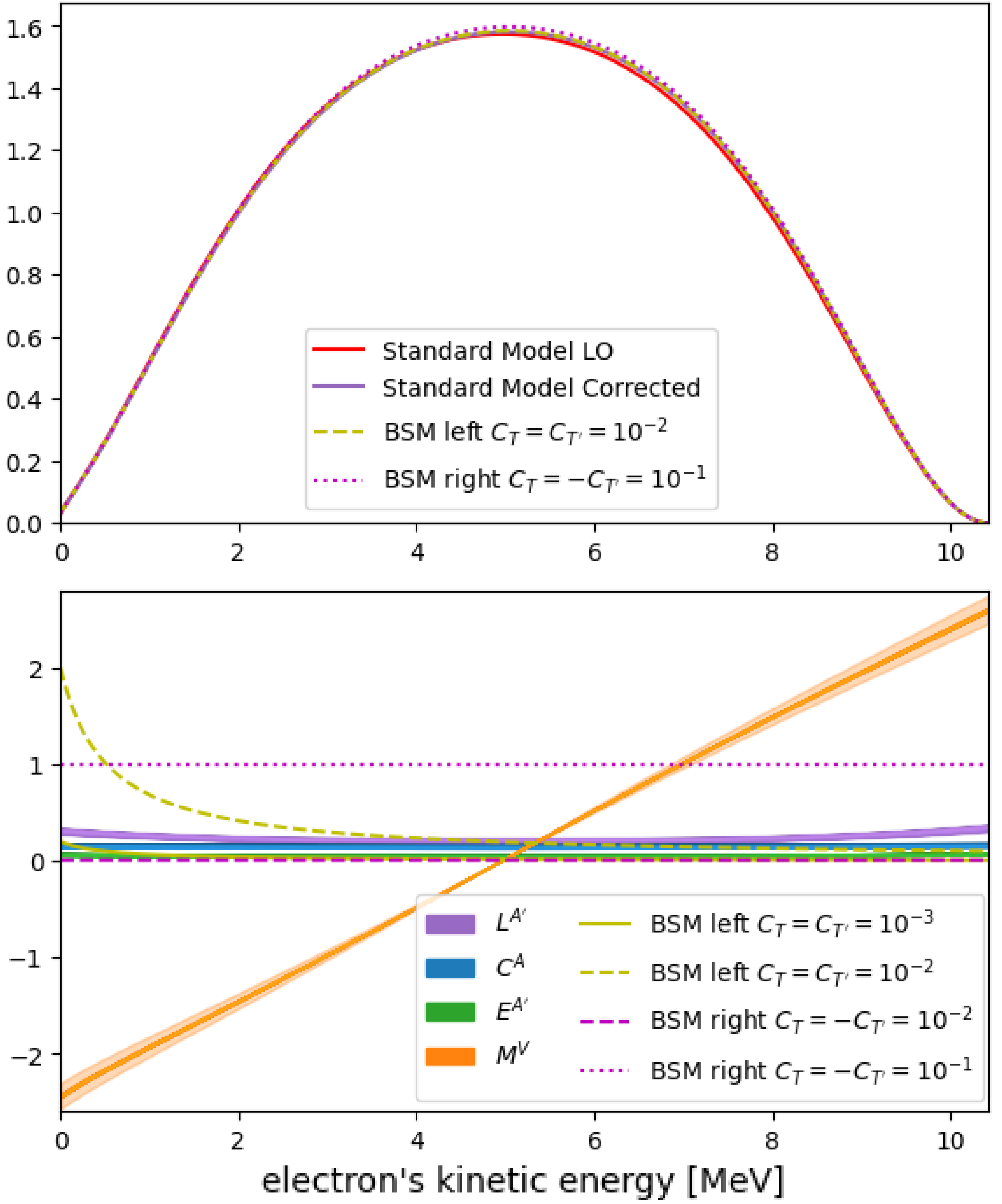
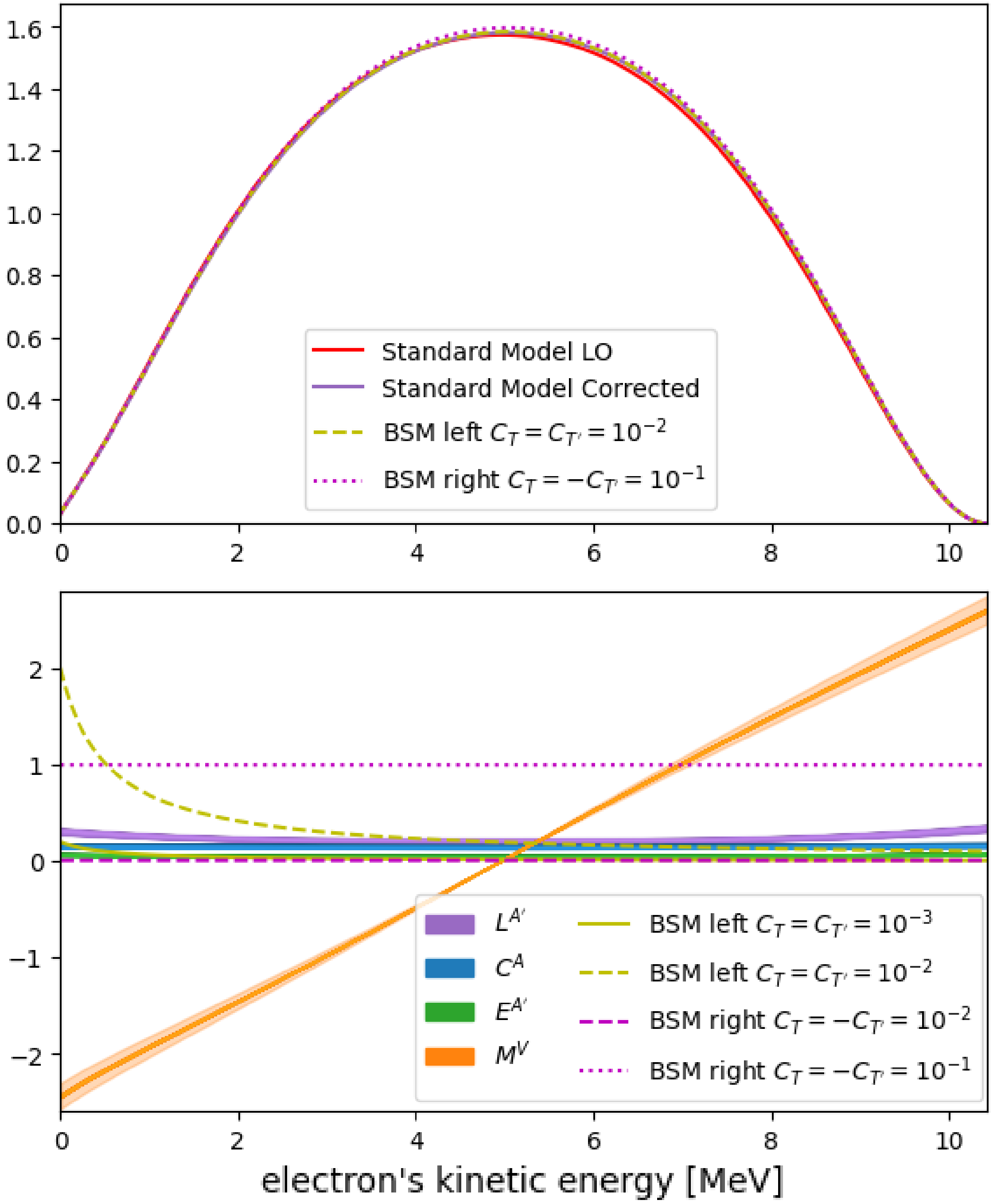


$^{16}\mathrm{N} \rightarrow {}^{16}\mathrm{O}$ forbidden spectrum

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

- Corrections are smaller near the spectral maximum ("peak")
- LO spectrum is symmetric around the peak
- **BSM b** produces an energy distortion $\propto \frac{m_e}{E_e}$
- Corrections (but M_2^V) are independent of E_e



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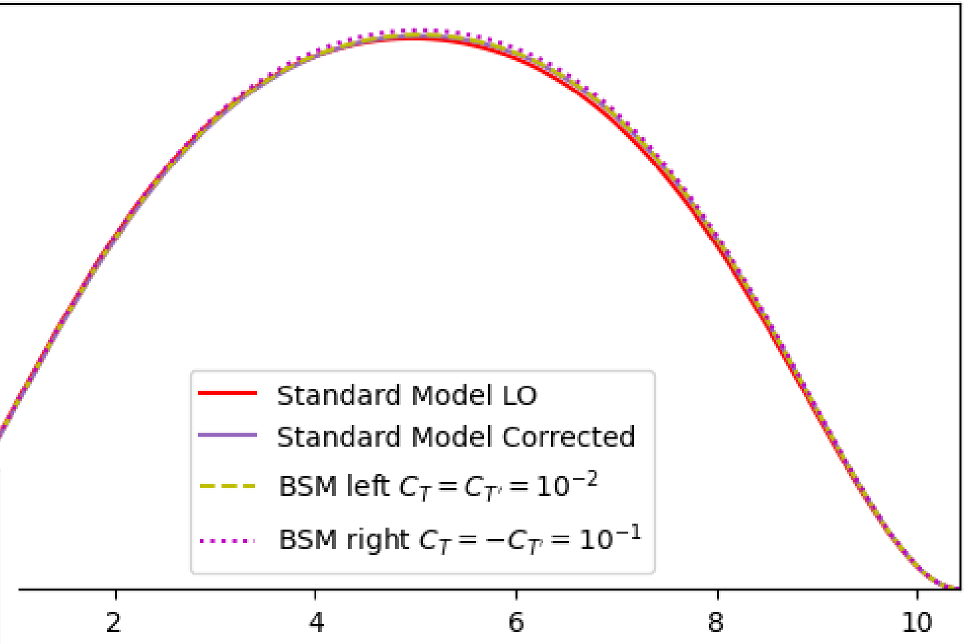
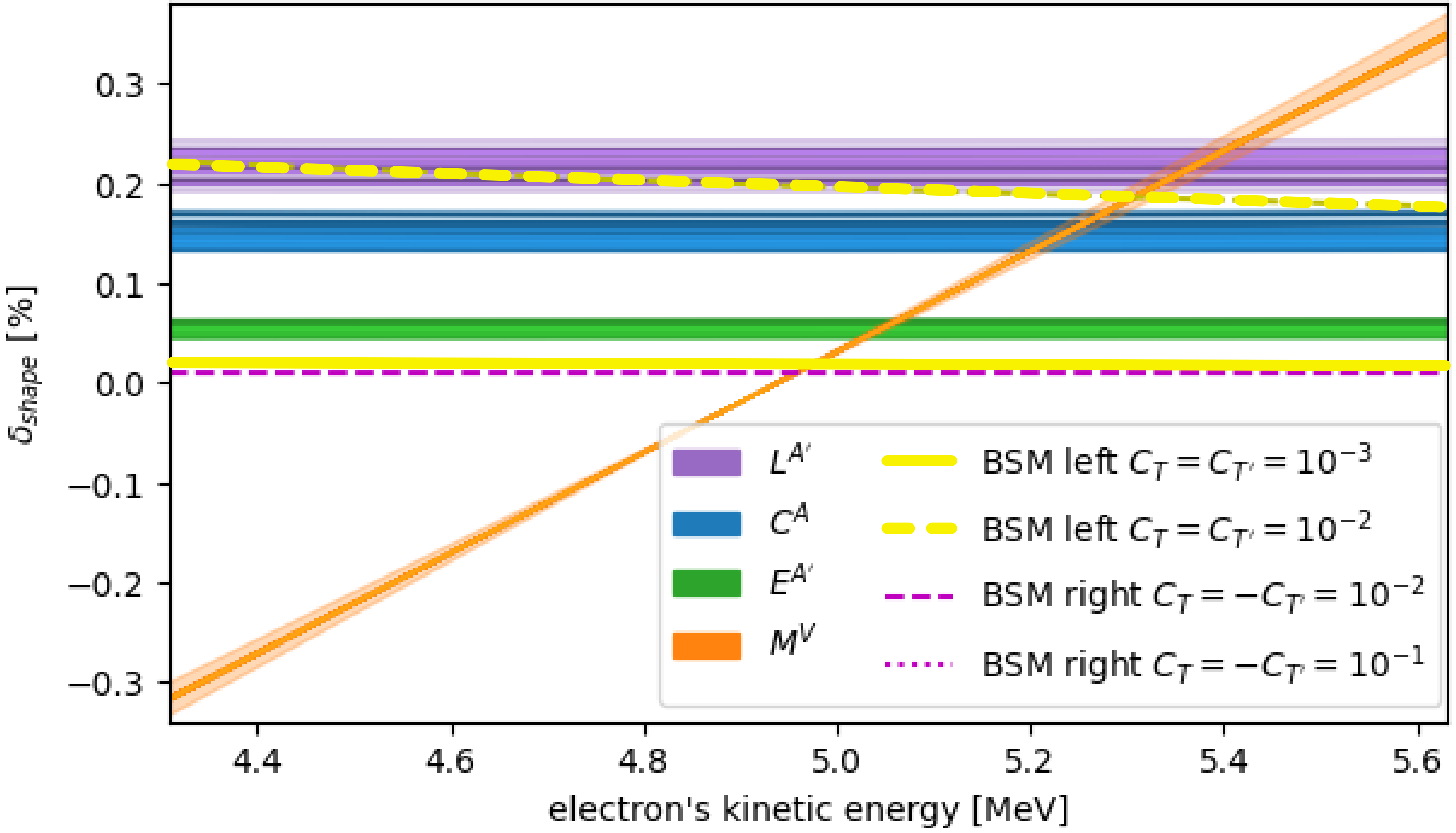
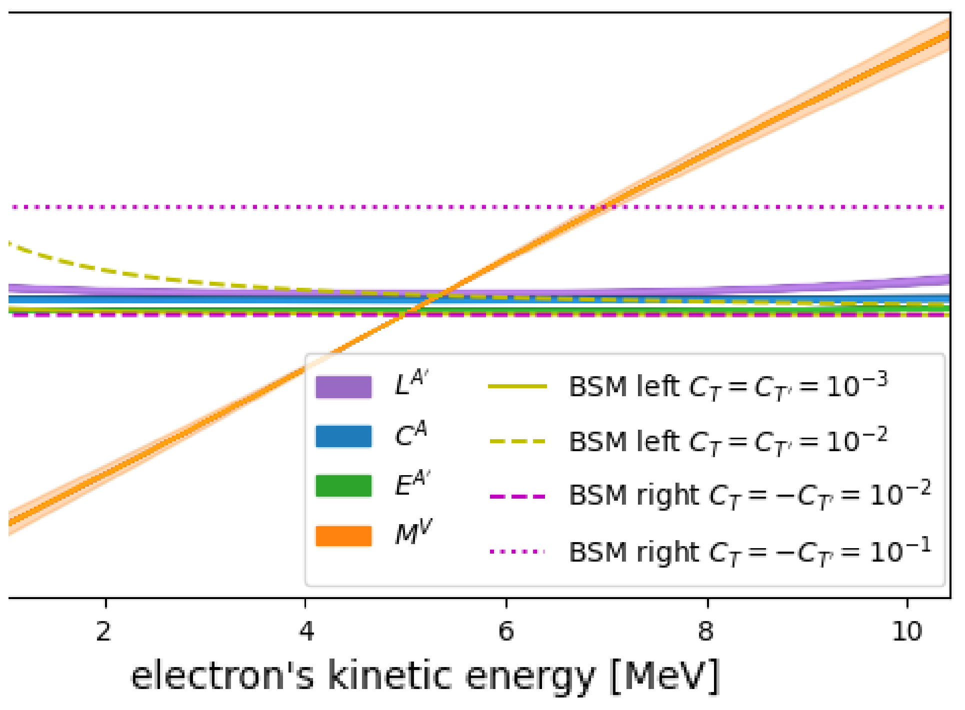
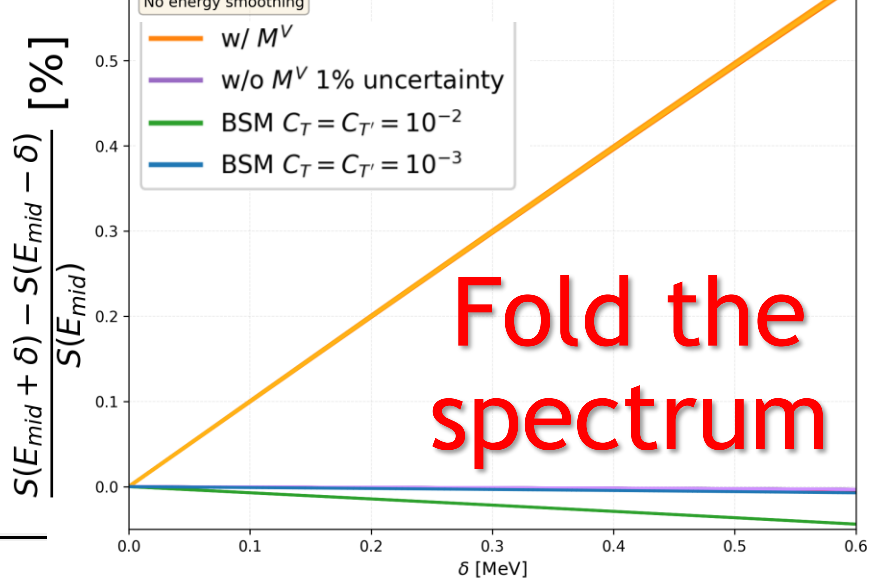
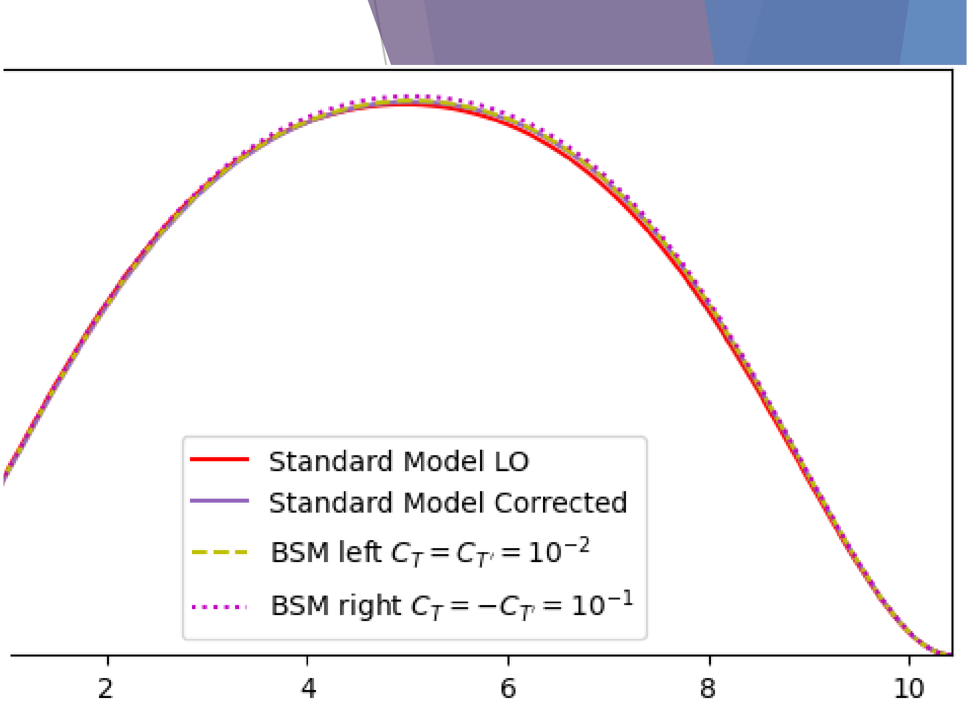


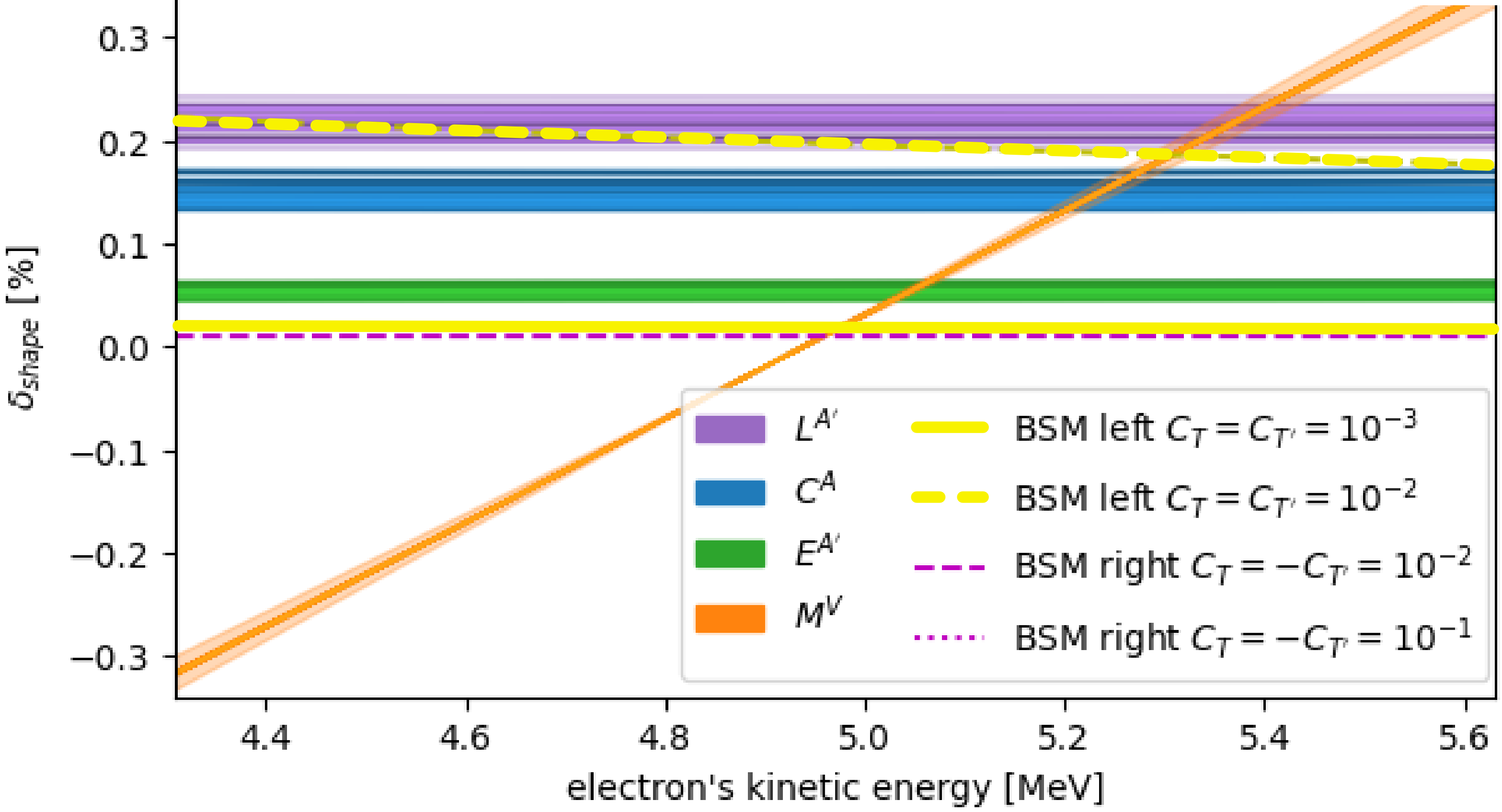


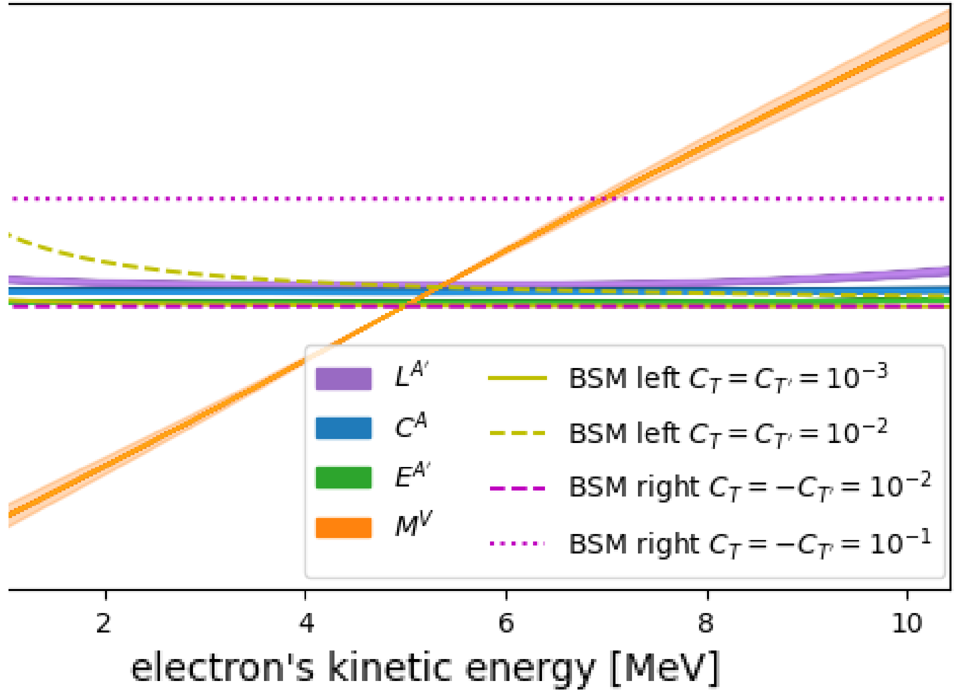


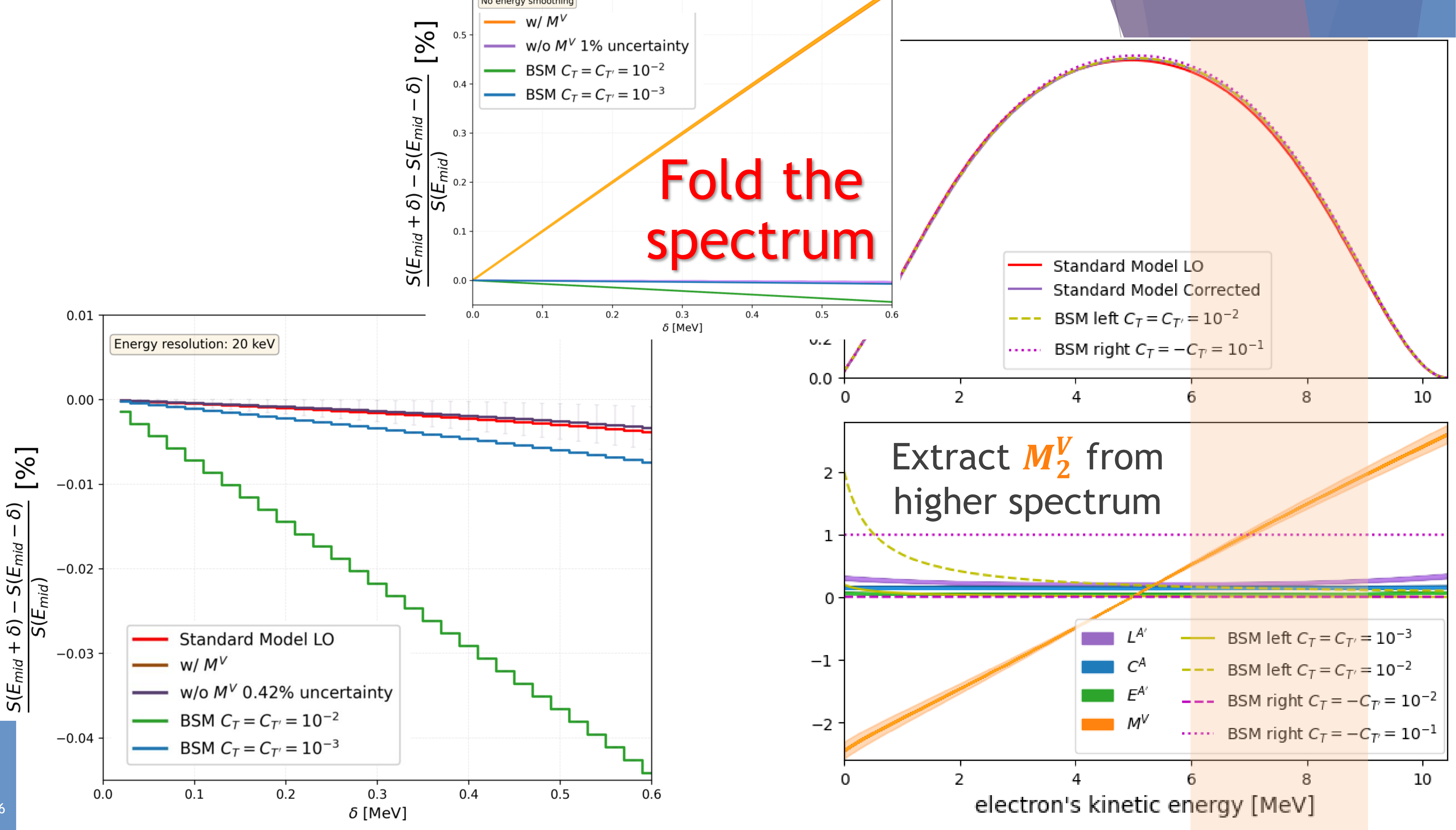


Fold the spectrum





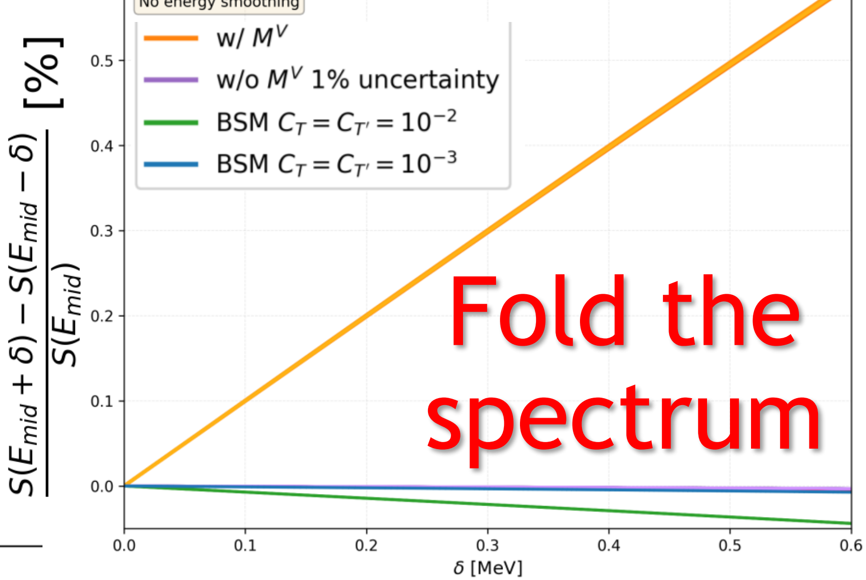




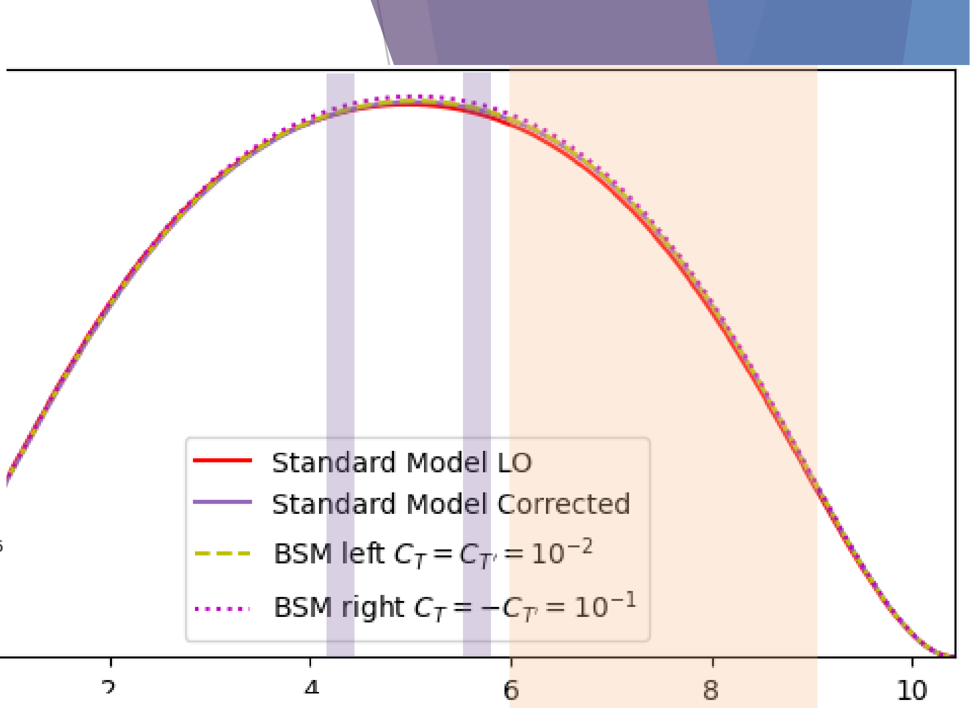
Fold the spectrum

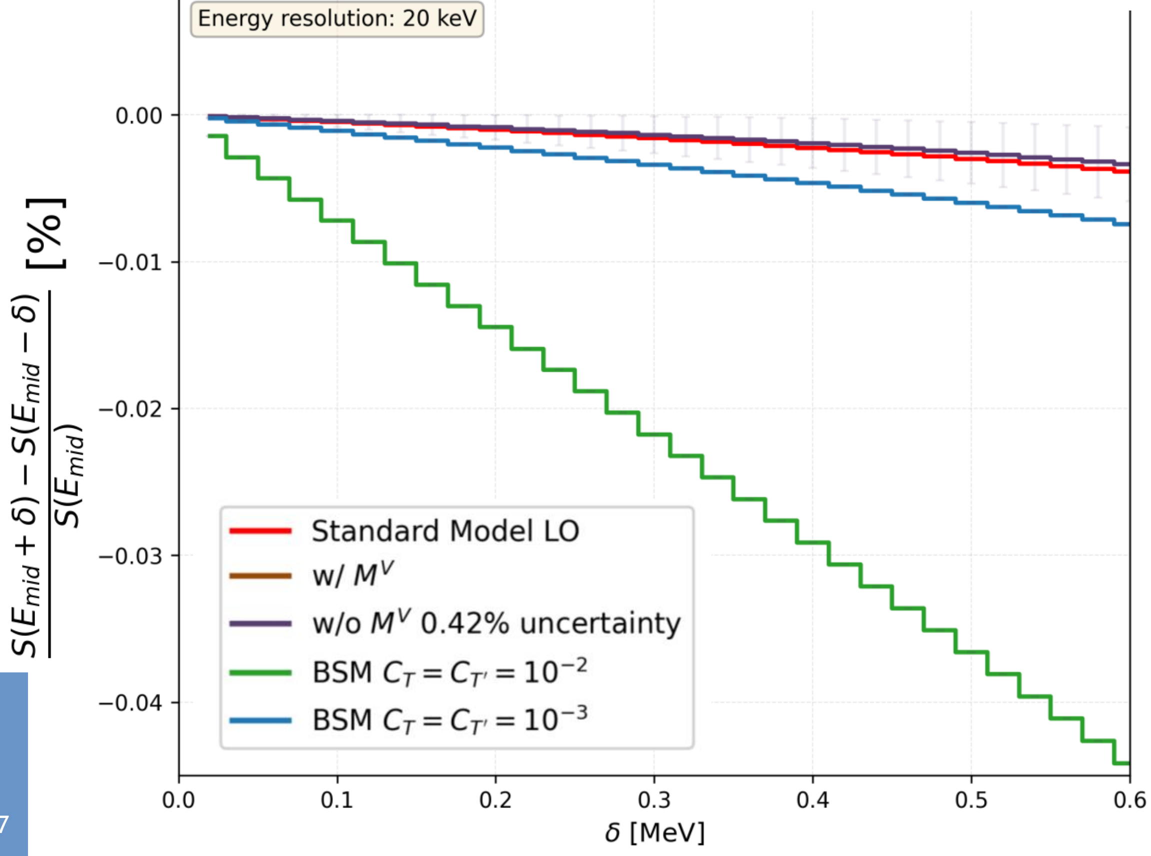
Extract M_2^V from higher spectrum

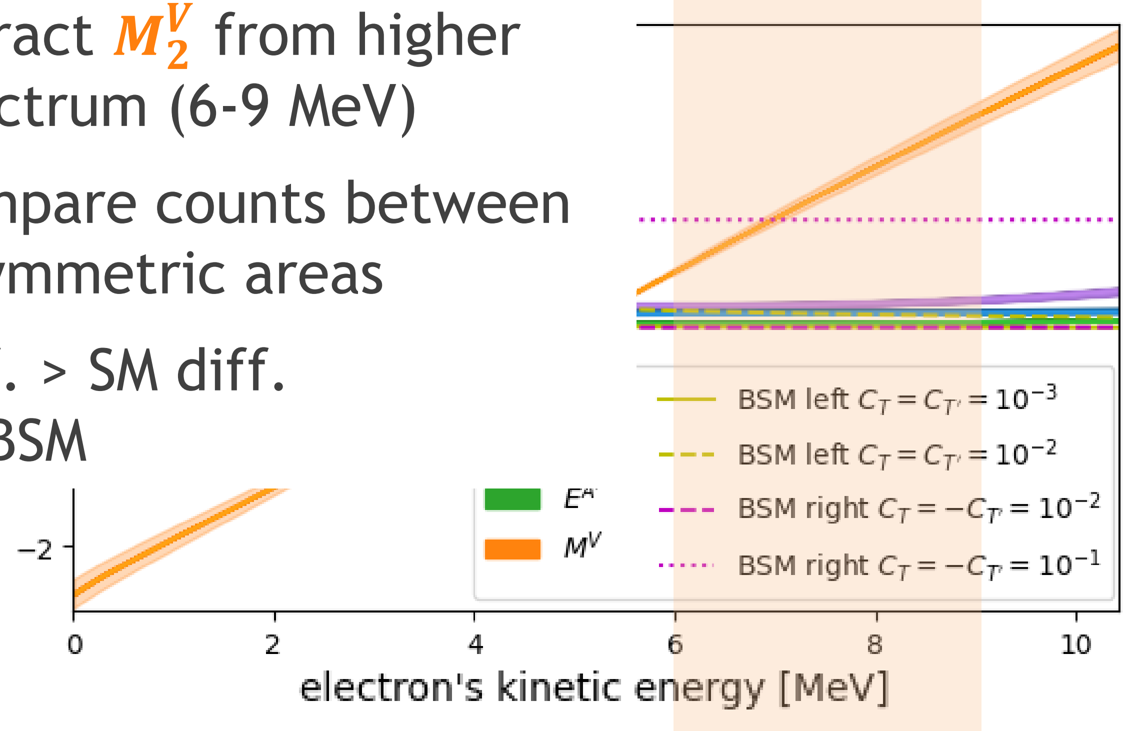
Spectrum Peak Asymmetry Method (SPAM)



Fold the spectrum

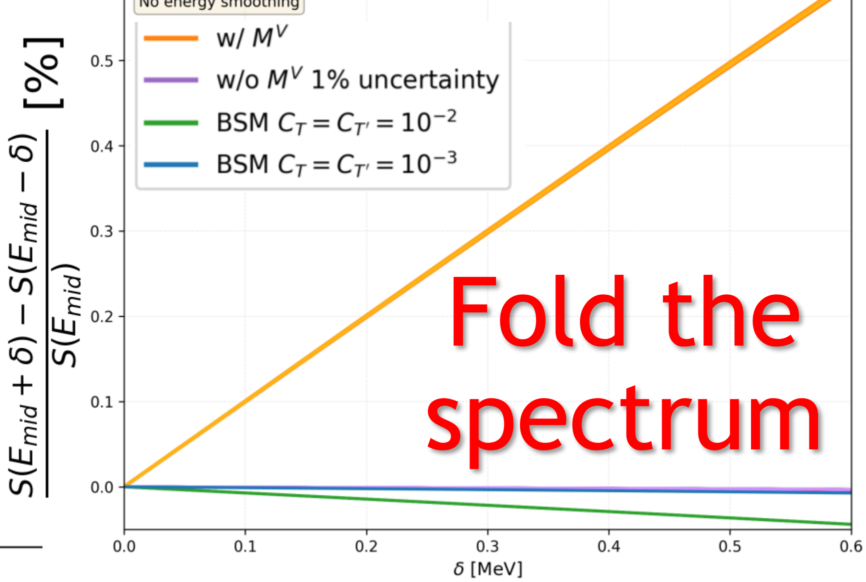




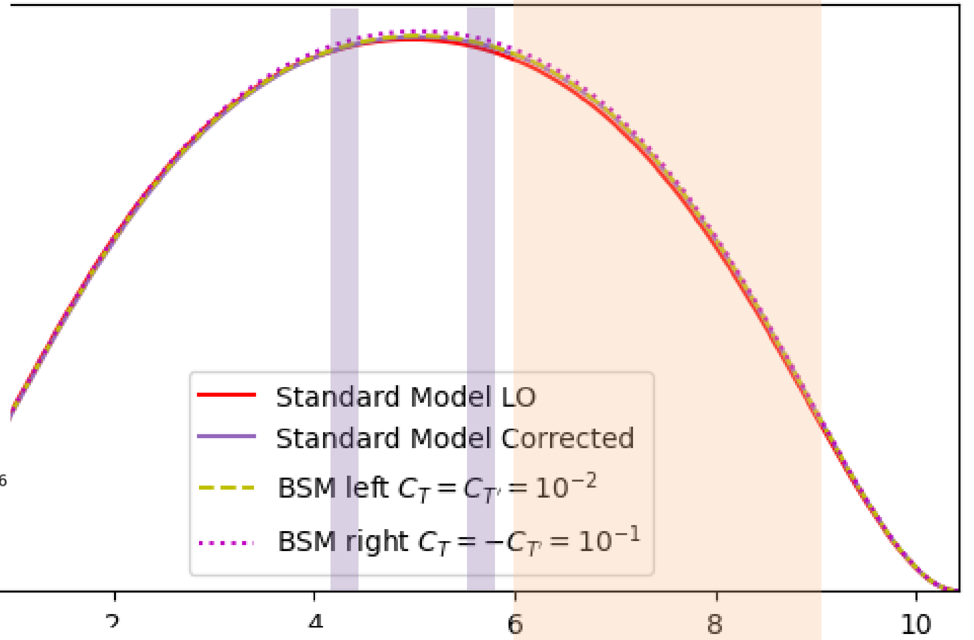


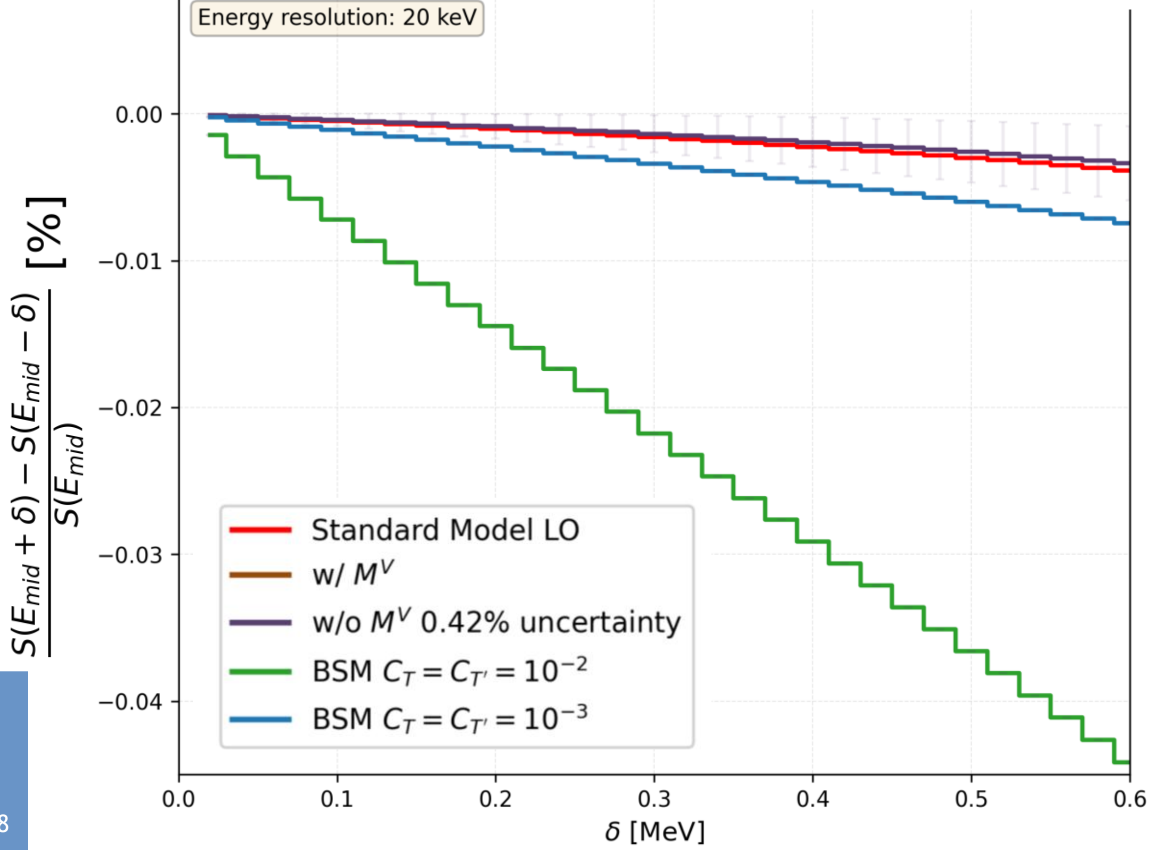
- Extract M_2^V from higher spectrum (6-9 MeV)
- Compare counts between 2 symmetric areas
- Diff. > SM diff.
=> BSM

Spectrum Peak Asymmetry Method (SPAM)

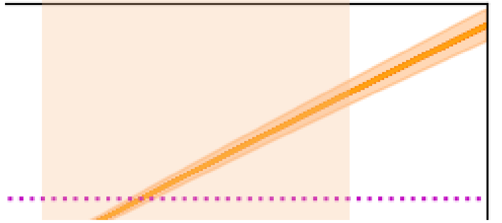


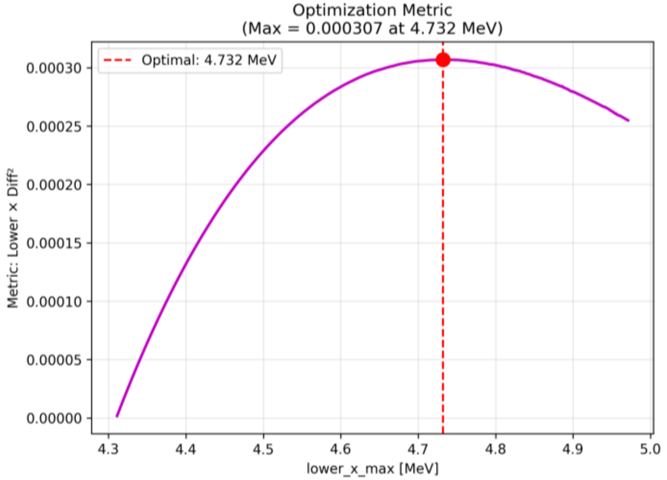
Fold the spectrum



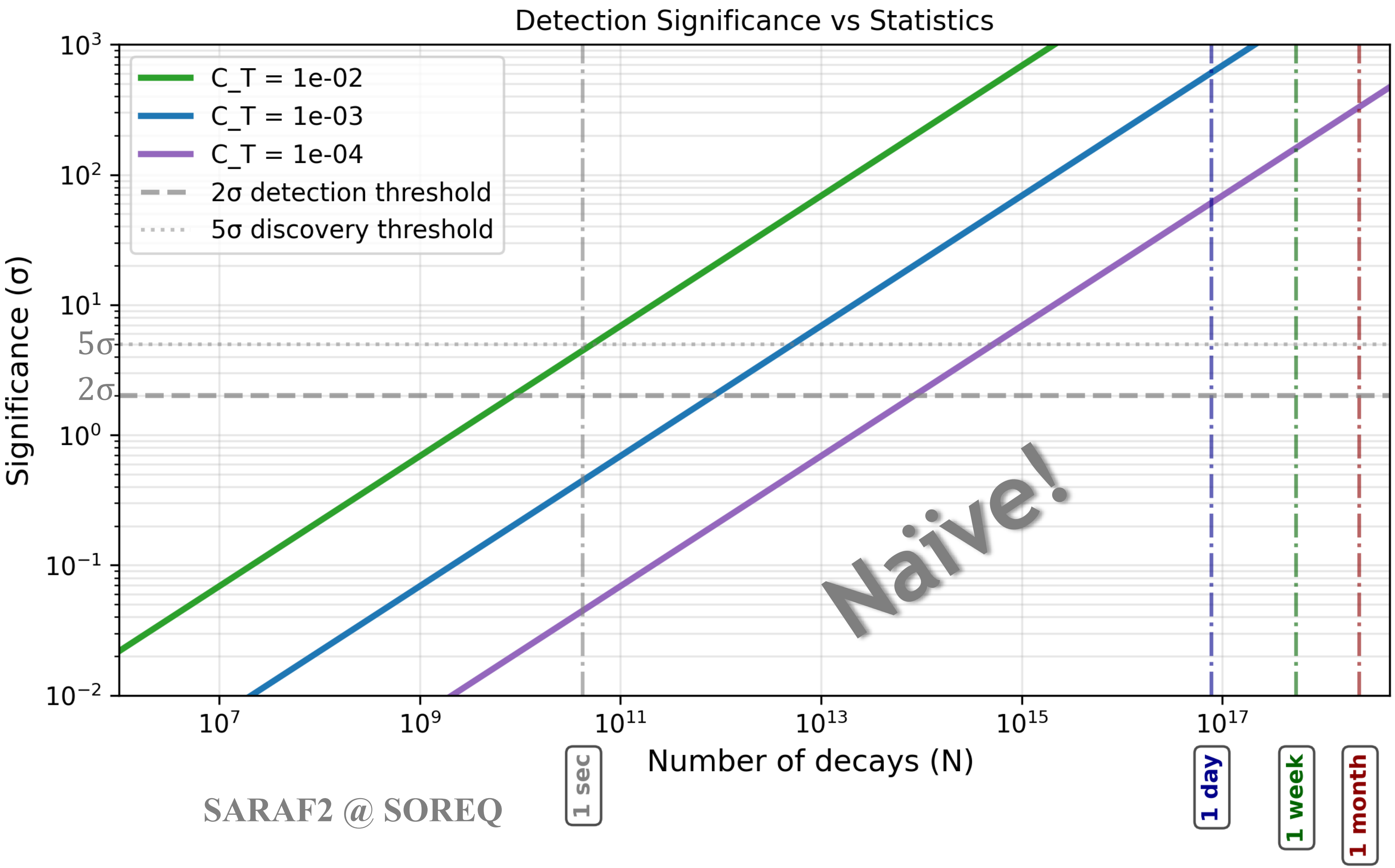


- Extract M_2^V from higher spectrum (6-9 MeV)
- Compare counts between 2 symmetric areas
- Diff. > SM diff. => BSM
- Optimize the areas for effect vs. noise





Spectrum Peak Asymmetry Method (SPAM)



SARAF2 @ SOREQ

Summary:
Unique Forbidden β-decays

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

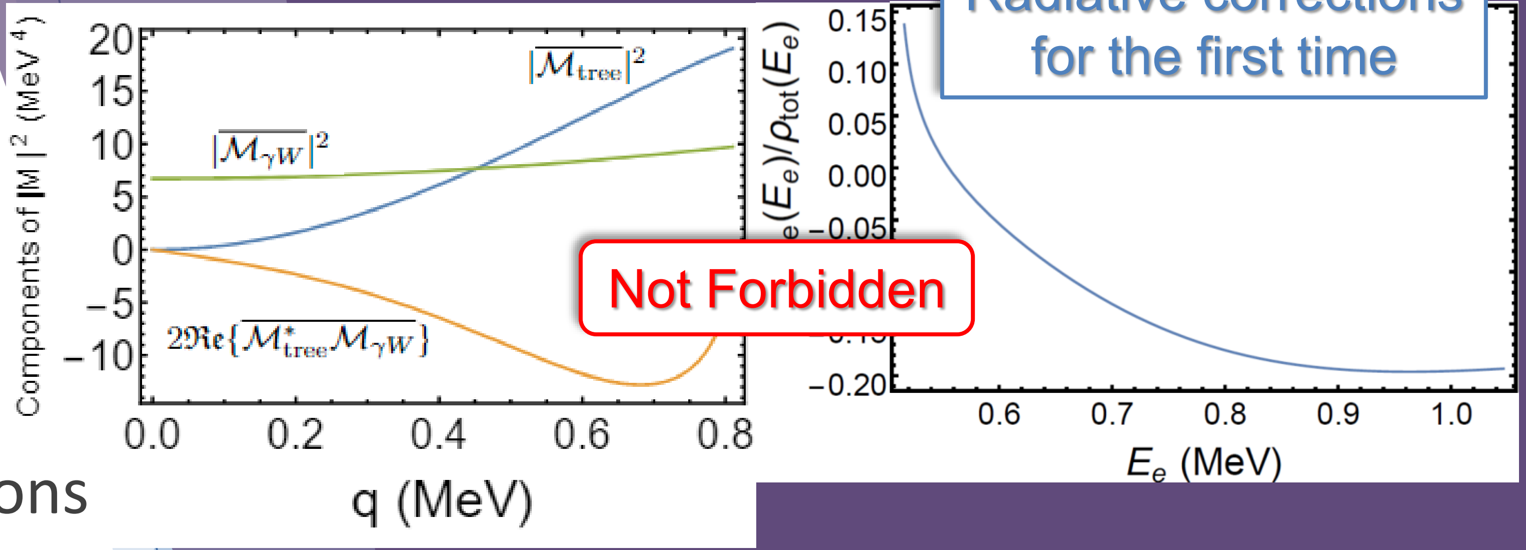
Spectrum is sensitive to:
- *Light New Physics*
- *SPAM* for Tensor Weak Interactions

Experiments

@ ORNL, CEA Saclay, HUJI, SOREQ
- ▶ New possibilities with MTAS @ORNL

Precision theory – 2 challenges:
- ➢ *High-order quantum effects*
- ➢ *Nuclear-structure corrections*
- ➢ *Outlook: Combining!*

➢ *High-order quantum effects:*

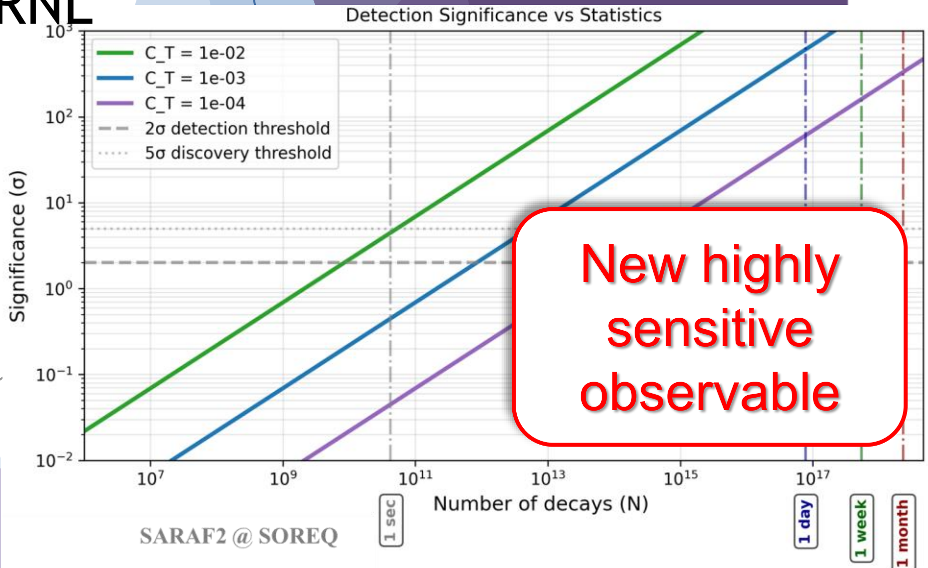


Radiative corrections for the first time

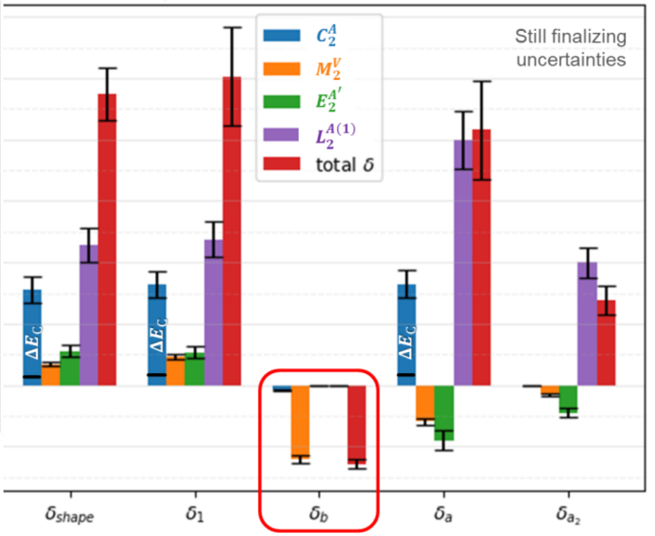
Not Forbidden

➢ *Nuclear-structure corrections:*

Observables vs. (new) corrections



New highly sensitive observable



Thanks!

Chalmers U.
Christian Forssén

TU Darmstadt
Lotta Jokiniemi

TRIUMF
Petr Navrátil

ÚJF Rez
Daniel Gazda

Hebrew U.
Doron Gazit
Daniel Ben Atar
Guy Ron

SOREQ
Sergey Vaintraub

INT
Vincenzo Cirigliano

UTK
Chien-Yeah Seng

ORNL
Charlie Rasco

Caen U. & FRIB
Oscar Naviliat-Cuncic

LPC Caen
Leendert Hayen

Mainz U.
Mikhail Gorchtein

LLNL
Kostas Kravvaris

Some Details

$\hat{\mathcal{H}}_W \sim C_{\text{sym}}\; \hat{j}(\vec{x}) \cdot \hat{J}(\vec{x})$

Lepton current

Nuclear current

Required accuracy

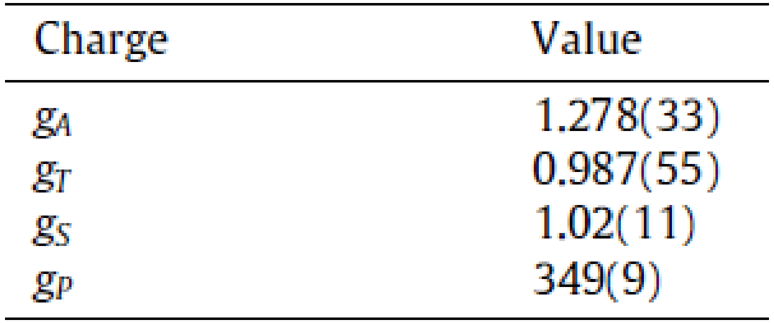
$C_{\text{sym}} \sim g_{\text{sym}}\; \epsilon_{\text{sym}}$

Nuclear charges
Nuclear currents:

$$\langle p \| \bar{u} \sigma^{\mu\nu} d \| n \rangle \approx g_T\; \bar{u}_p \sigma^{\mu\nu} u_n$$

Similar terms for the other sym

$g_V = 1$



Charge	Value
g_A	1.278(33)
g_T	0.987(55)
g_S	1.02(11)
g_P	349(9)

M. Gonzalez-Alonso *et al.*, PPNP 104 165-223 (2019)

> Same nuclear charges for SM & BSM

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

Lepton current

Nuclear current

Required accuracy

$$C_{\text{sym}} \sim g_{\text{sym}}\, \epsilon_{\text{sym}}$$

Nuclear charges
(Nuclear currents)

Effective theory’s coefficients
(Weak interaction)

Low energy effective Lagrangian:

$$\mathcal{L}^{\text{eff}}_{udev} = \epsilon_T\, \bar{e}\sigma_{\mu\nu}\nu_e \cdot \bar{u}\sigma^{\mu\nu}d + \cdots$$

Similar terms for the other sym

$$\boxed{M_W \approx 80\ \text{GeV}}$$

$$\epsilon_{\text{sym}} \propto \left(\frac{M_W}{\Lambda}\right)^n$$

$n = 0$ for sym in SM
$n \geq 2$ for sym $\neq$ SM

The effective theory’s cutoff
↔ New physics scale

$$\hat{\mathcal{H}}_W \sim C_{\text{sym}}\, \hat{j}(\vec{x}) \cdot \hat{J}(\vec{x})$$

Lepton current

Nuclear current

Required accuracy

$$C_{\text{sym}} \sim g_{\text{sym}}\, \epsilon_{\text{sym}}$$

Nuclear charges
(Nuclear currents)

Effective theory’s coefficients
(Weak interaction)

Low energy effective Lagrangian:

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Similar terms for the other sym

$$\boxed{M_W \approx 80\ \text{GeV}}$$

$$\epsilon_{\text{sym}} \propto \left(\frac{M_W}{\Lambda}\right)^n$$

$$\boxed{\begin{array}{l} n = 0 \ \text{ for } \ \text{sym in SM} \\ n \geq 2 \ \text{ for } \ \text{sym} \neq \text{SM} \end{array}}$$

The effective theory’s cutoff
↔ New physics scale

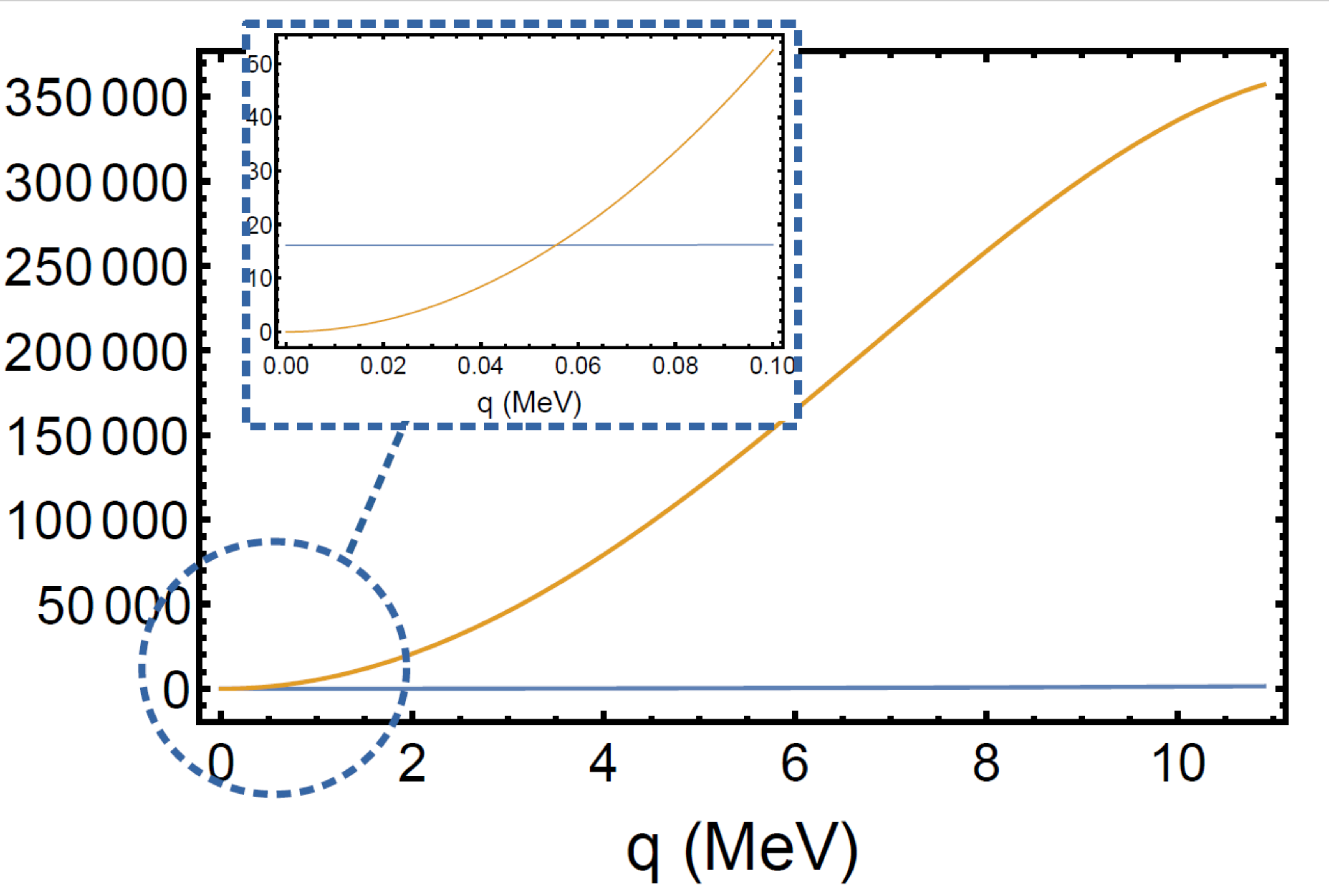
For the simplest BSM operator ($n = 2$): TeV ↔ $C_{\text{sym}} \sim \epsilon_{\text{sym}} \sim 10^{-3}$

New experiments will have a 10^{-3} level of precision

- ▶ Sensitive to new physics at the TeV scale

➢ ***High-order radiative effects***

16N



Seng, AGM, Cirigliano, PRL 2025