Neutrinoless double beta decay in effective field theory

Wouter Dekens

with

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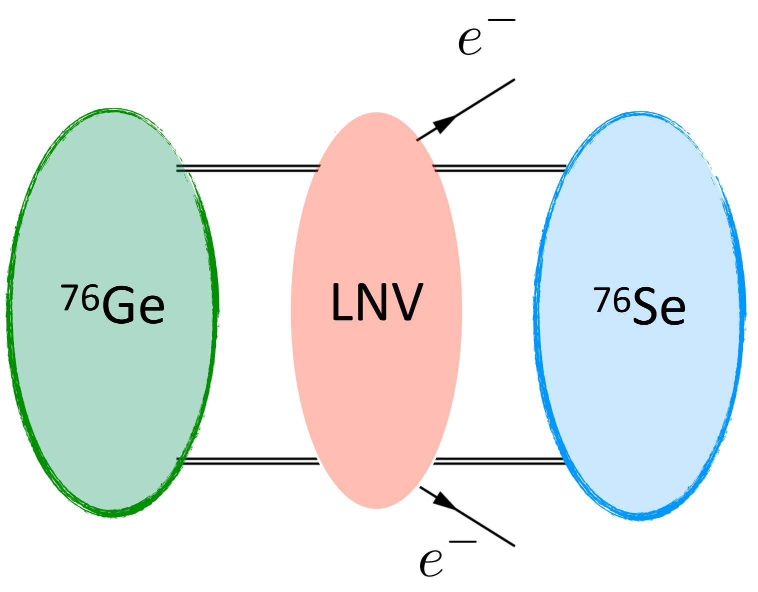
UC San Diego

Introduction

0νββ



- Violates lepton number, ΔL=2

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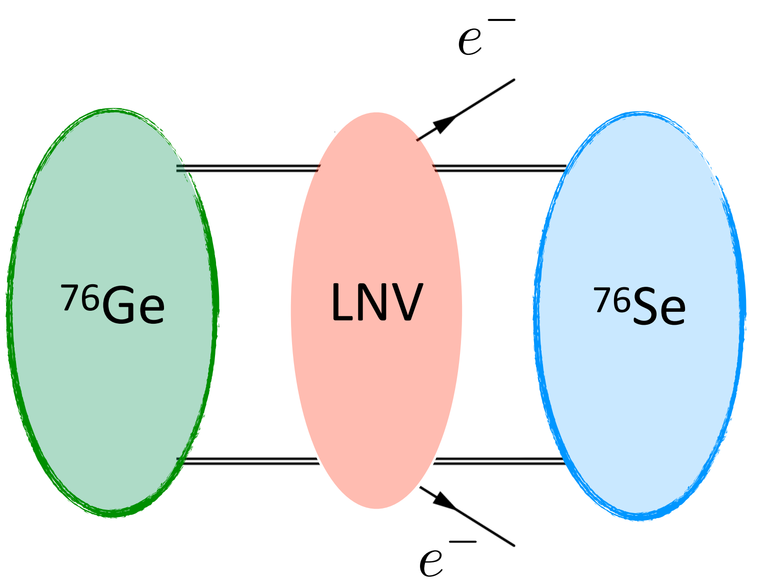

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- Stringently constrained experimentally
  - To be improved by 1-2 orders

$T^{0\nu}_{1/2}(^{76}\mathrm{Ge})$ Gerda	$T^{0\nu}_{1/2}(^{130}\mathrm{Te})$ Cuore	$T^{0\nu}_{1/2}(^{136}\mathrm{Xe})$ KamLAND-zen
$> 9 \cdot 10^{25}\,\mathrm{yr}$	$> 3.2 \cdot 10^{25}\,\mathrm{yr}$	$> 1.1 \cdot 10^{26}\,\mathrm{yr}$

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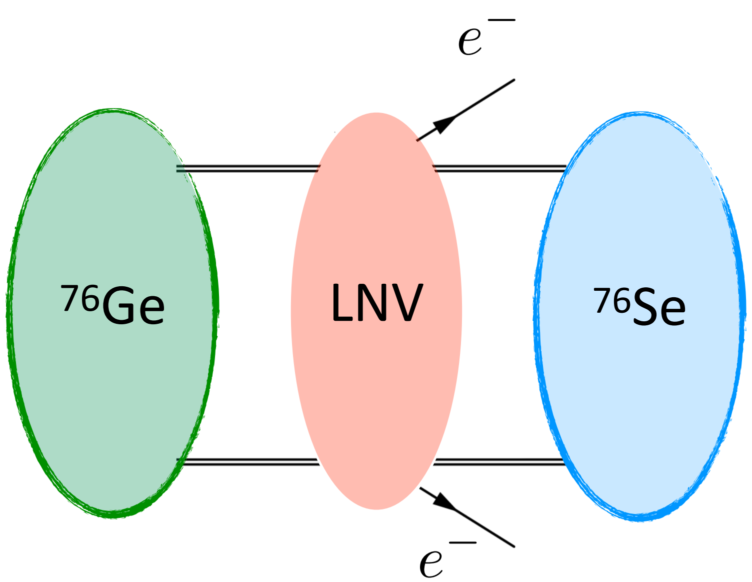

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- Would imply that
  - Neutrino's are Majorana particles
  - Physics beyond the SM

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Schechter, Valle, `82

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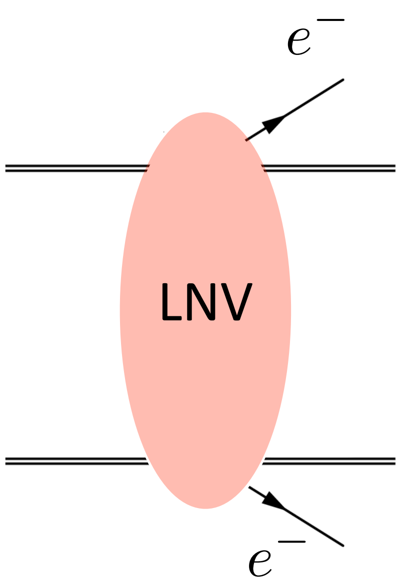

= **BSM physics**

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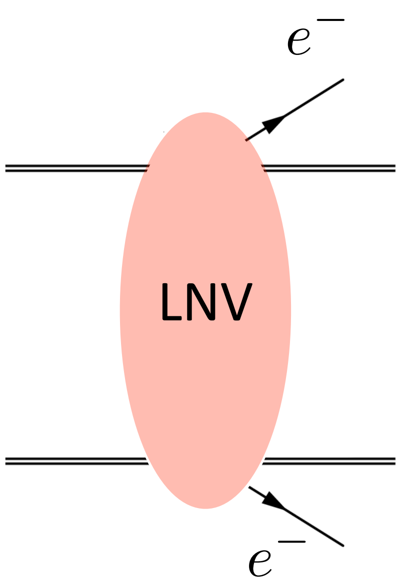

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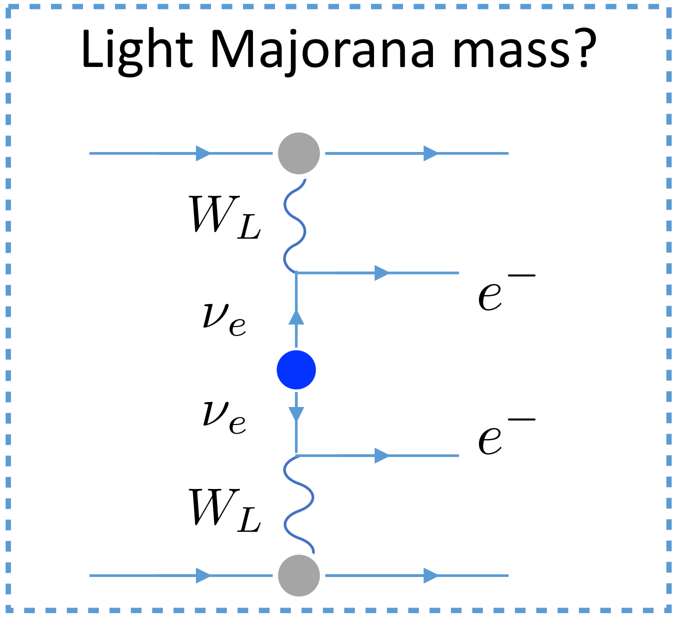
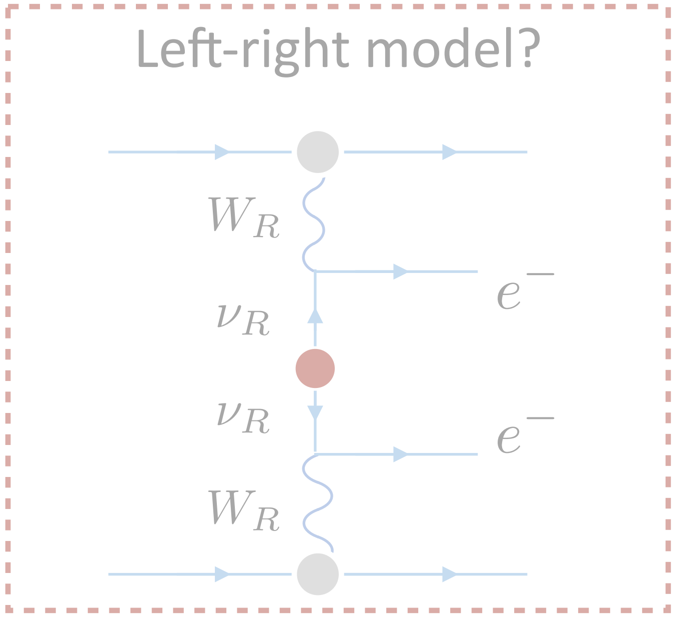
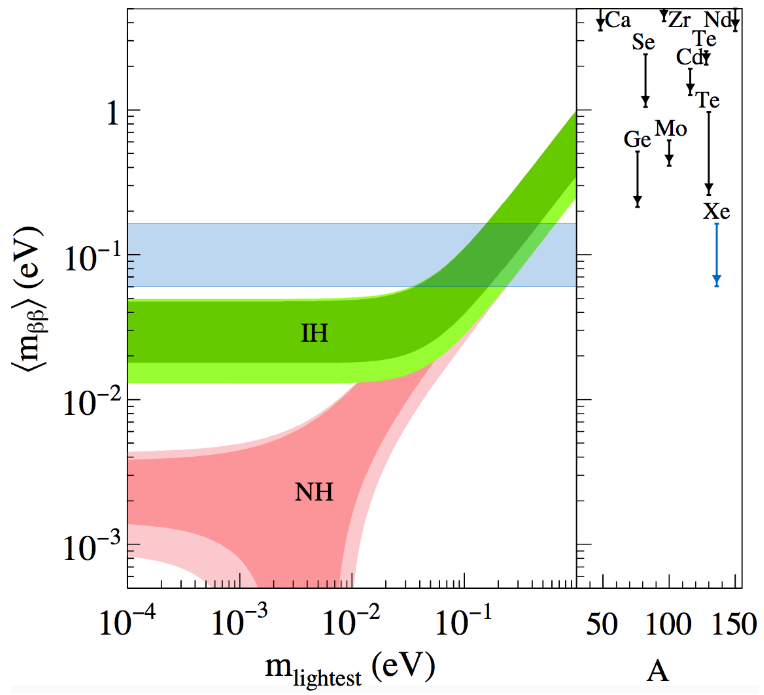




+ ??

Well-known Majorana mass mechanism



- Implications for the mass hierarchy

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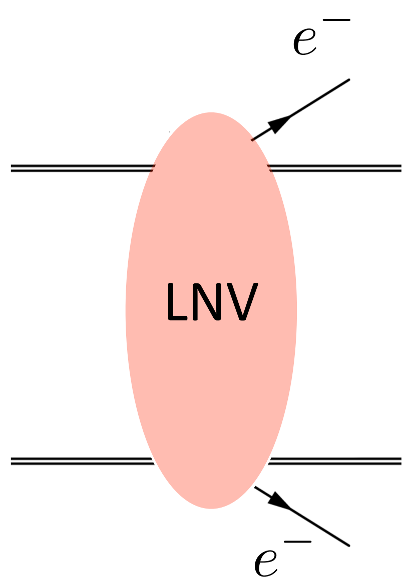
0νββ



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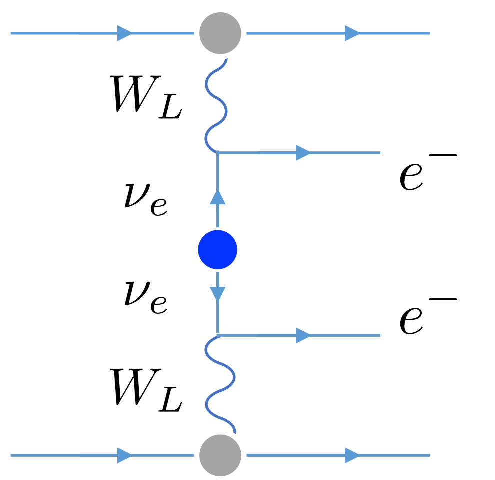

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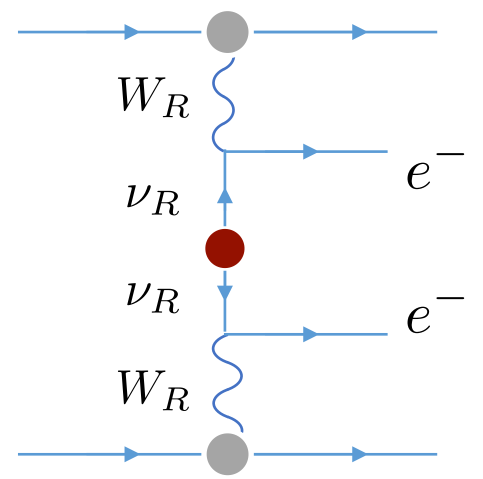

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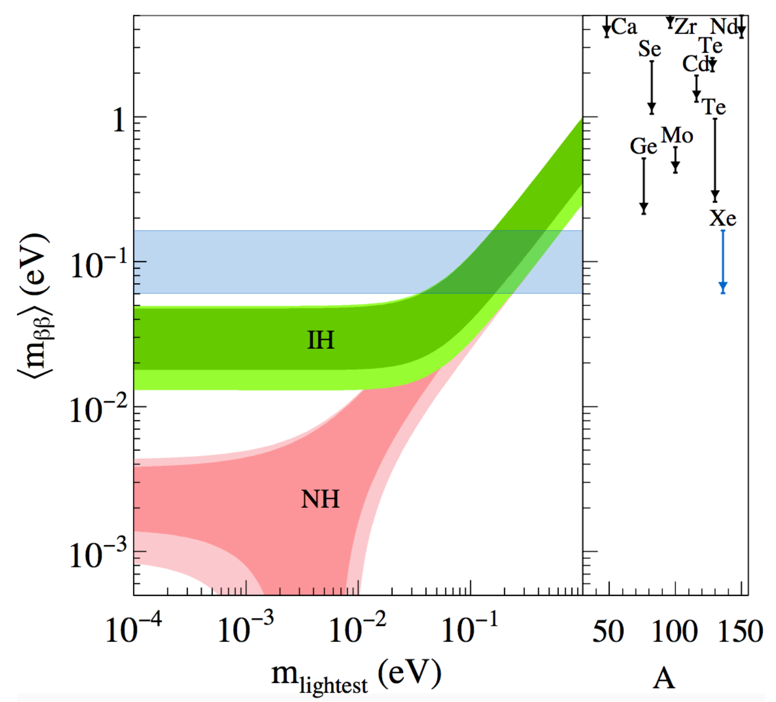

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Heavy BSM mechanisms

- Many possible scenarios
  - Left-right model,
  - R-parity violating SUSY
  - Leptoquarks…

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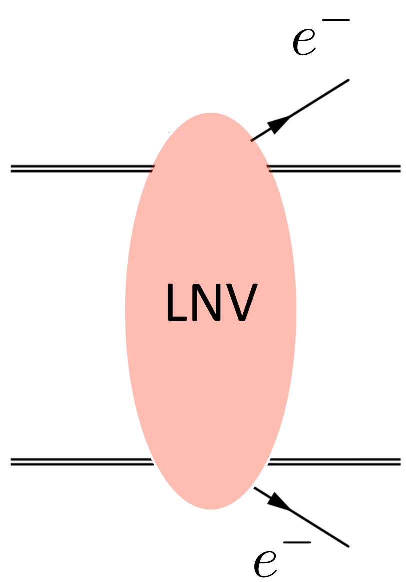

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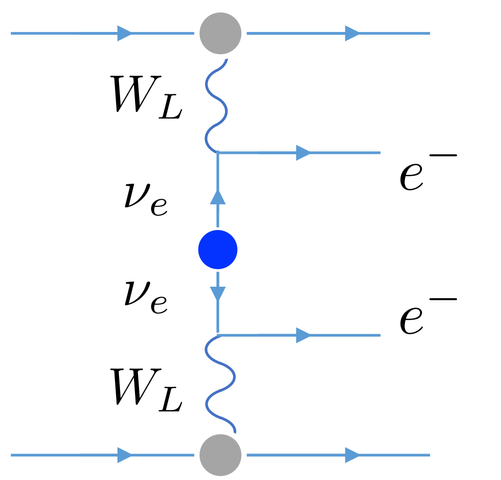

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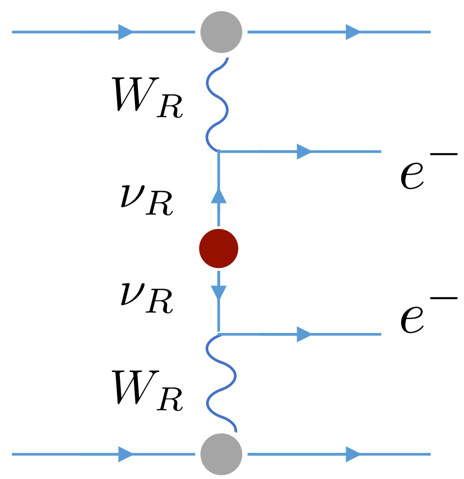

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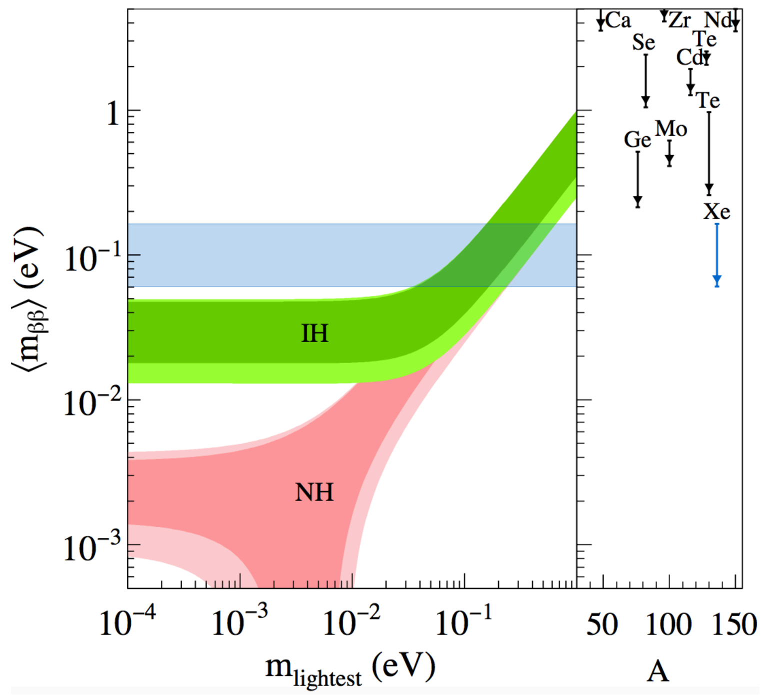

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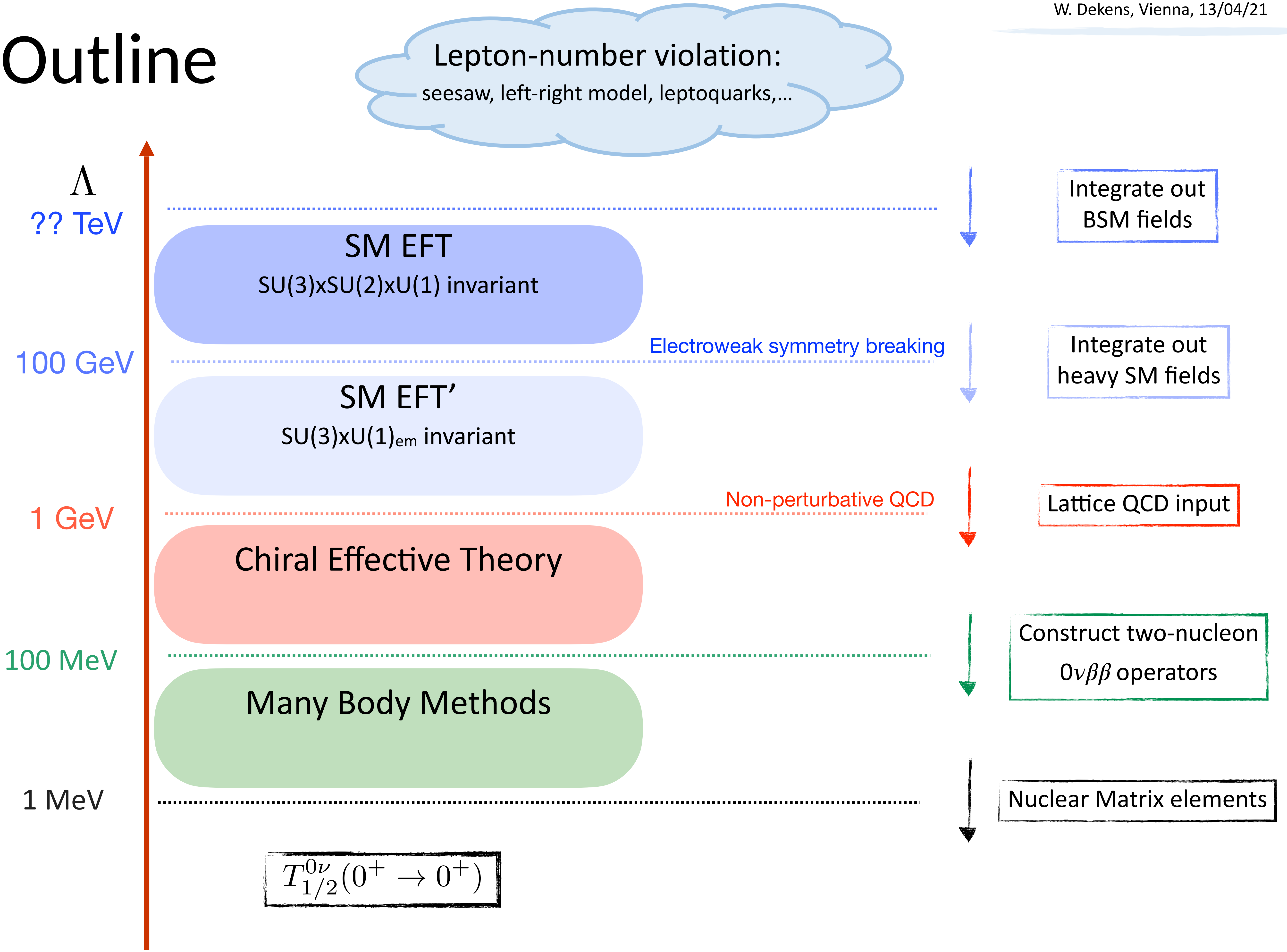
  - Left-right model,
  - R-parity violating SUSY
  - Leptoquarks…
- How to describe all LNV sources systematically?

Outline



Lepton-number violation:
seesaw, left-right model, leptoquarks,…
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?? TeV
100 GeV
1 GeV
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SM EFT
SU(3)xSU(2)xU(1) invariant
Electroweak symmetry breaking
SM EFT'
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Non-perturbative QCD
Chiral Effective Theory
Many Body Methods
$T^{0\nu}_{1/2}(0^+ \to 0^+)$
Integrate out BSM fields
Integrate out heavy SM fields
Lattice QCD input
Construct two-nucleon $0\nu\beta\beta$ operators
Nuclear Matrix elements

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Effective Field Theory

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \frac{c_i^{(5)}}{\Lambda} O_i^{(5)} + \frac{c_i^{(7)}}{\Lambda^3} O_i^{(7)} + \frac{c_i^{(9)}}{\Lambda^5} O_i^{(9)} + \dots$$

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$$\mathcal{L}_5 = \frac{c_5}{\Lambda}(L^T C \tilde{H})(\tilde{H}^T L)$$

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- 12 ΔL=2 operators

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- Consider subset of operators

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Naive scaling of Dimension 5, 7, 9 operators

$$\mathcal{A}_{0\nu\beta\beta} \sim \frac{c_5}{\Lambda}\left[1 + \left(\frac{v}{\Lambda}\right)^2 \frac{c_7}{c_5} + \left(\frac{v}{\Lambda}\right)^4 \frac{c_9}{c_5}\right]$$

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$m_\nu \sim c_5 v^2/\Lambda$ Allows for relative enhancement:

- $c_5 \ll O(1), \qquad \Lambda = \mathcal{O}(1-100)\text{TeV}$
  - Relative enhancement of higher-dimensional terms due to $c_{7,9}/c_5 \gg 1$
- Happens, for example, in the left-right model

Effective Field Theory

Naive scaling of Dimension 5, 7, 9 operators

$$\mathcal{A}_{0\nu\beta\beta} \sim \frac{c_5}{\Lambda}\left[1 + \left(\frac{v}{\Lambda}\right)^2 \frac{c_7}{c_5} + \left(\frac{v}{\Lambda}\right)^4 \frac{c_9}{c_5}\right]$$

- $v/\Lambda \ll 1$ So why keep dimension 7 & 9?

$m_\nu \sim c_5 v^2/\Lambda$ Allows for relative enhancement:

- $c_5 \ll O(1), \qquad \Lambda = \mathcal{O}(1-100)\mathrm{TeV}$
  - Relative enhancement of higher-dimensional terms due to $c_{7,9}/c_5 \gg 1$
- Happens, for example, in the left-right model

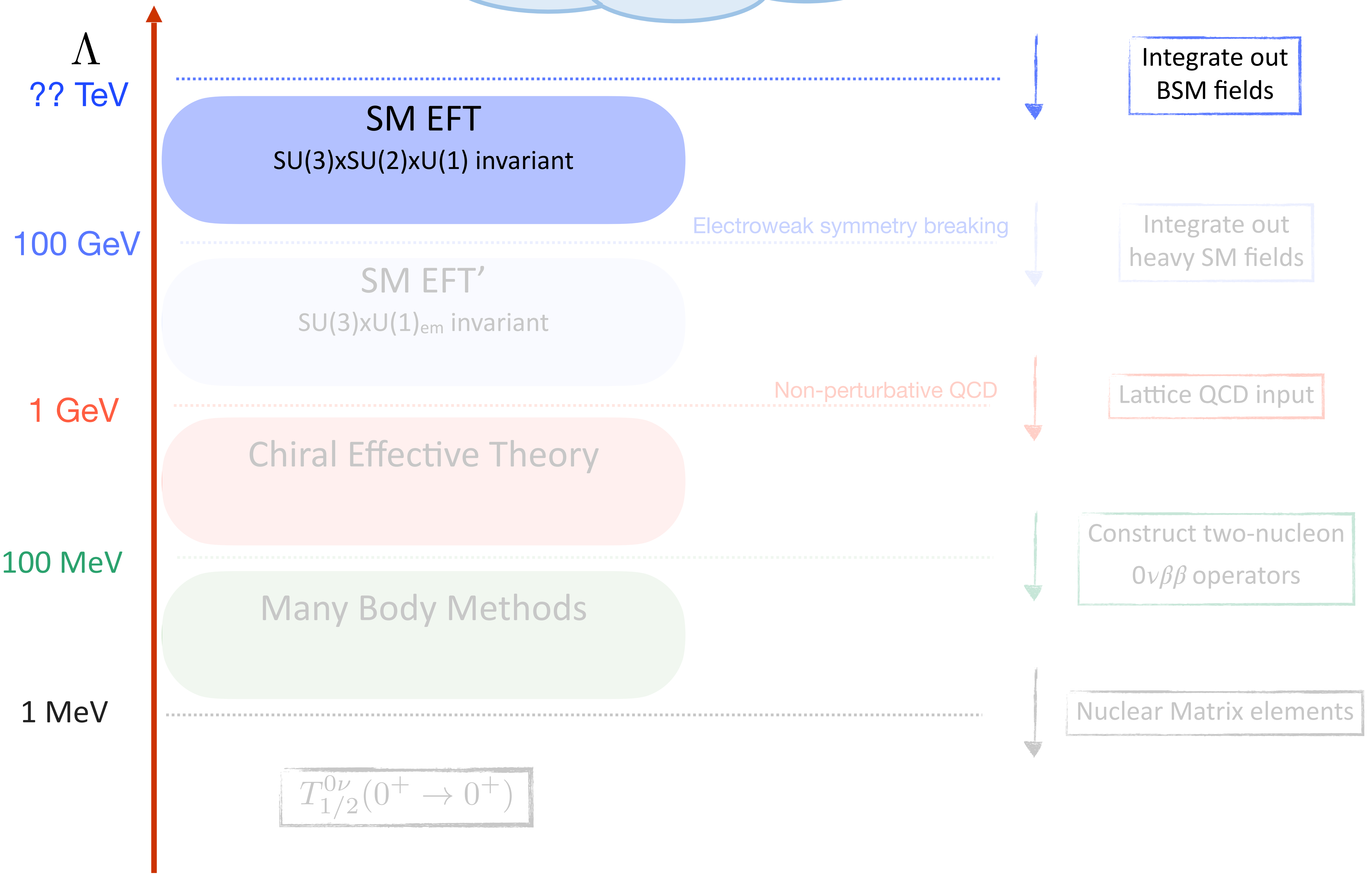
- However, if $c_5 = \mathcal{O}(1), \qquad \Lambda = 10^{15}\,\mathrm{GeV}$
  - dimension-7, -9 irrelevant in this case

W. Dekens, Vienna, 13/04/21

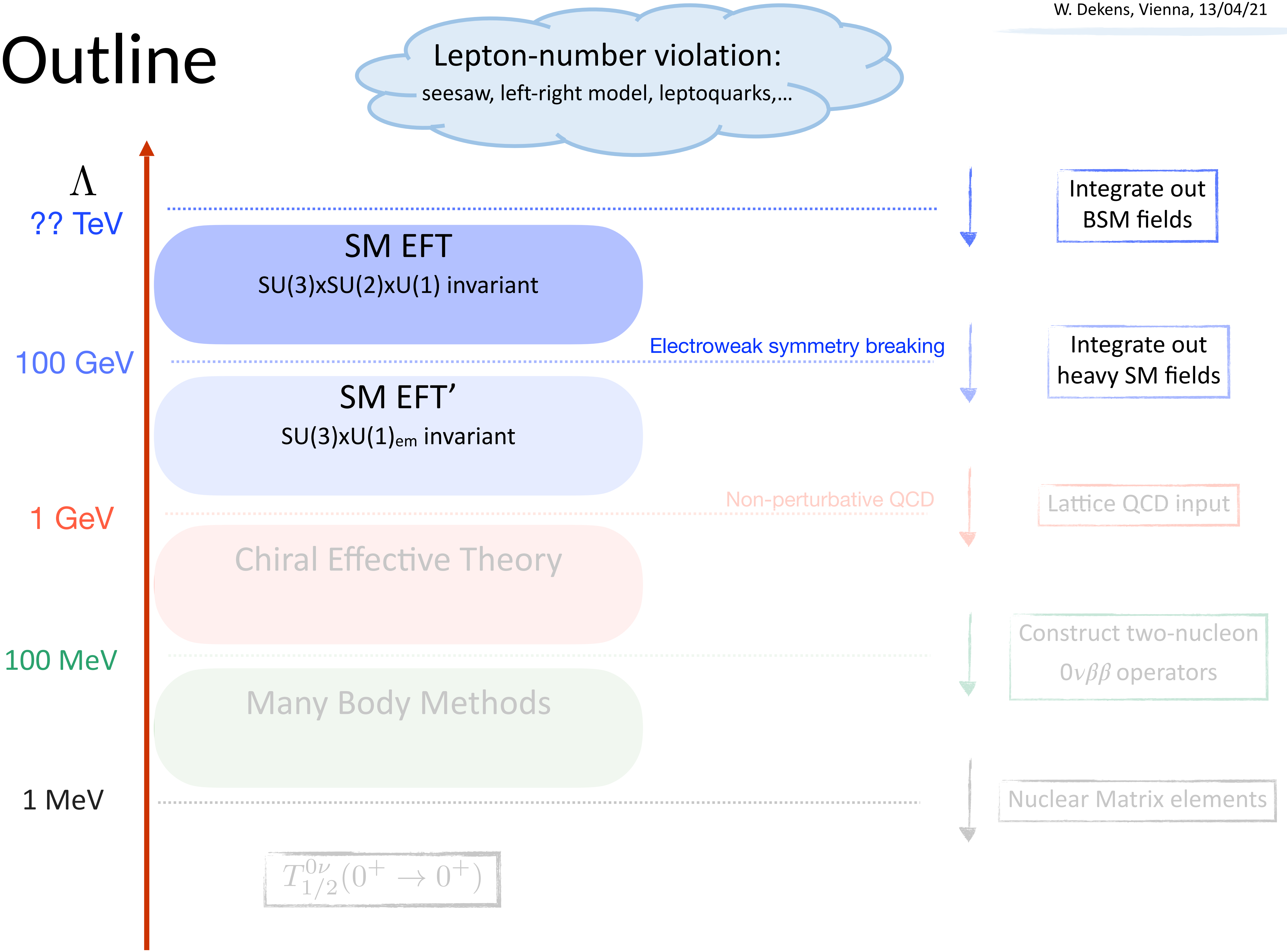
Outline

Lepton-number violation:

seesaw, left-right model, leptoquarks,...



Outline


Lepton-number violation:
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Λ
?? TeV
100 GeV
1 GeV
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SM EFT
SU(3)xSU(2)xU(1) invariant
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Integrate out BSM fields
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Lattice QCD input
Construct two-nucleon $0\nu\beta\beta$ operators
Nuclear Matrix elements

Running/matching at the weak scale

SM EFT

SU(3)xSU(2)xU(1) invariant

$$\mathcal{L} = \frac{c_i^{(5)}}{\Lambda} O_i^{(5)} + \frac{c_i^{(7)}}{\Lambda^3} O_i^{(7)} + \frac{c_i^{(9)}}{\Lambda^5} O_i^{(9)}$$

M_{EW}

100 GeV

Electroweak symmetry breaking

SM EFT’

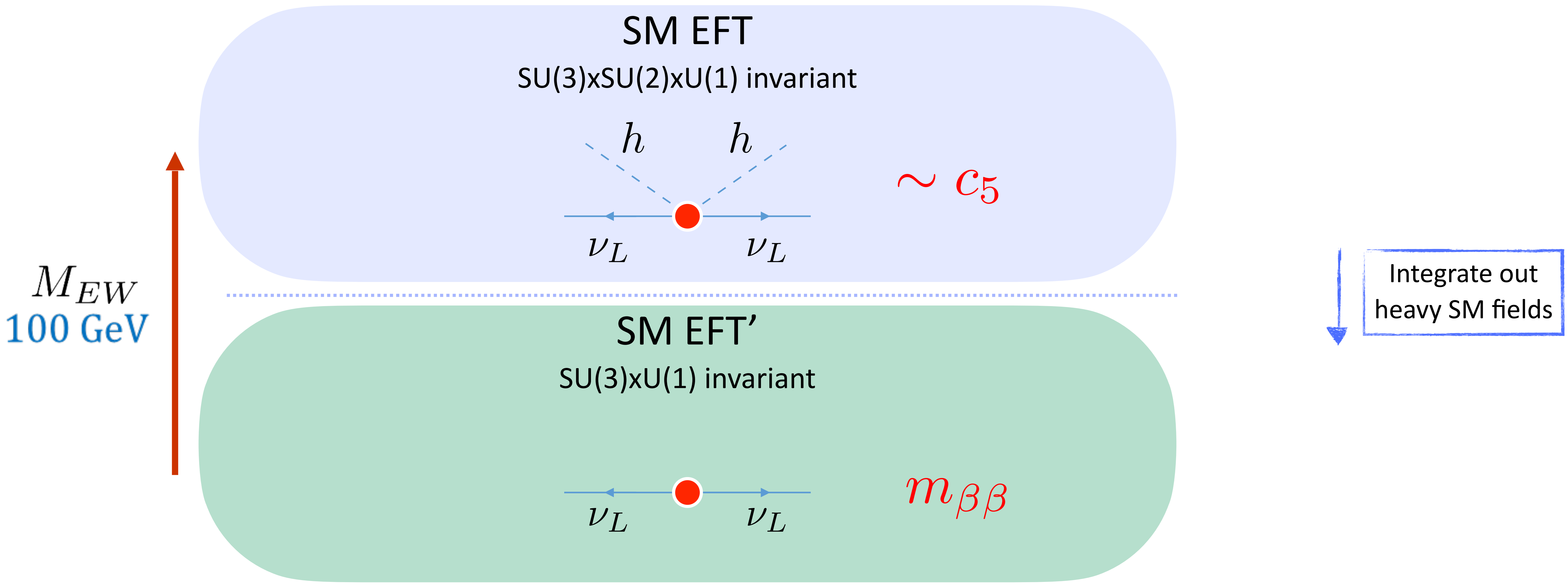
SU(3)xU(1) invariant

$$\mathcal{L} = \frac{c_i^{(3)}}{\Lambda} O_i^{(3)} + \frac{c_i^{(6)}}{\Lambda^3} O_i^{(6)} + \frac{c_i^{(7)}}{\Lambda^3} O_i^{(7)} + \frac{c_i^{(9)}}{\Lambda^5} O_i^{(9)}$$

- Mismatch in dimensions due to insertions of the Higgs vacuum expectation value

Low-energy operators

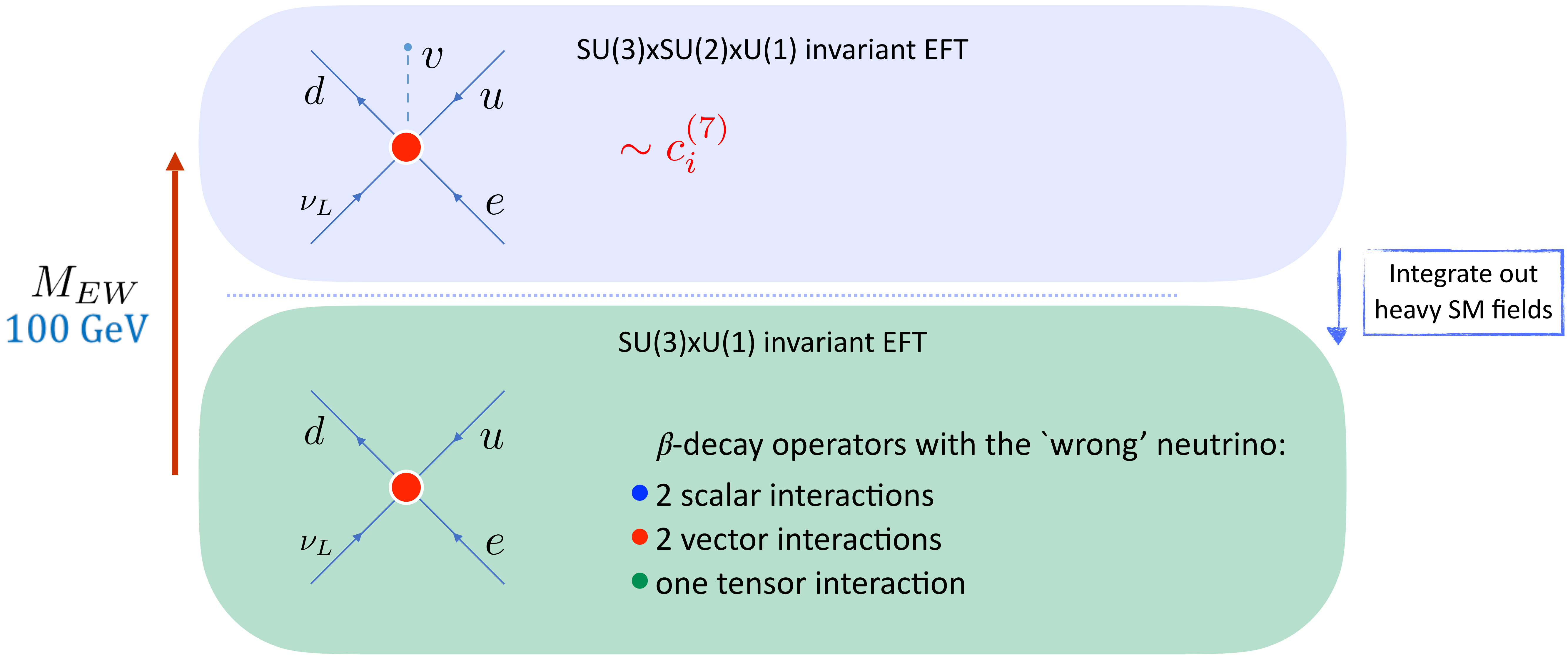
Dimension-3



Induced by dimension-5 SU(2)-invariant operator

$$m_{\beta\beta} \sim v^2/\Lambda$$

Low-energy operators
Dimension-6



$$\mathcal{L}^{(6)}_{\Delta L=2} = \frac{2G_F}{\sqrt{2}}\Big\{ C^{(6)}_{\mathrm{VL},ij}\,\bar u_L\gamma^\mu d_L\,\bar e_{R,i}\,\gamma_\mu\, C\bar\nu^T_{L,j} + C^{(6)}_{\mathrm{VR},ij}\,\bar u_R\gamma^\mu d_R\,\bar e_{R,i}\,\gamma_\mu\, C\bar\nu^T_{L,j}$$

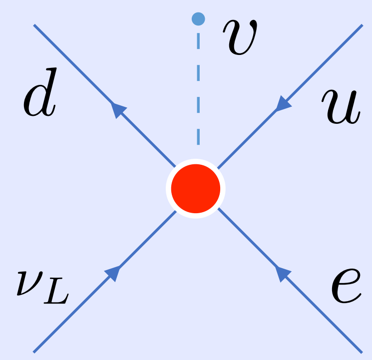
$$+ C^{(6)}_{\mathrm{SR},ij}\,\bar u_L d_R\,\bar e_{L,i}\, C\bar\nu^T_{L,j} + C^{(6)}_{\mathrm{SL},ij}\,\bar u_R d_L\,\bar e_{L,i}\, C\bar\nu^T_{L,j} + C^{(6)}_{\mathrm{T},ij}\,\bar u_L\sigma^{\mu\nu} d_R\,\bar e_{L,i}\sigma_{\mu\nu}\, C\bar\nu^T_{L,j}\Big\}$$

Low-energy operators

Dimension-6

M_{EW}
100 GeV

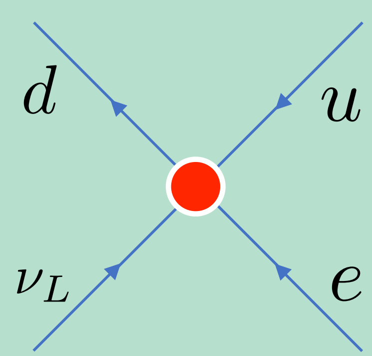
SU(3)xSU(2)xU(1) invariant EFT



$\sim c_i^{(7)}$

Integrate out heavy SM fields

SU(3)xU(1) invariant EFT



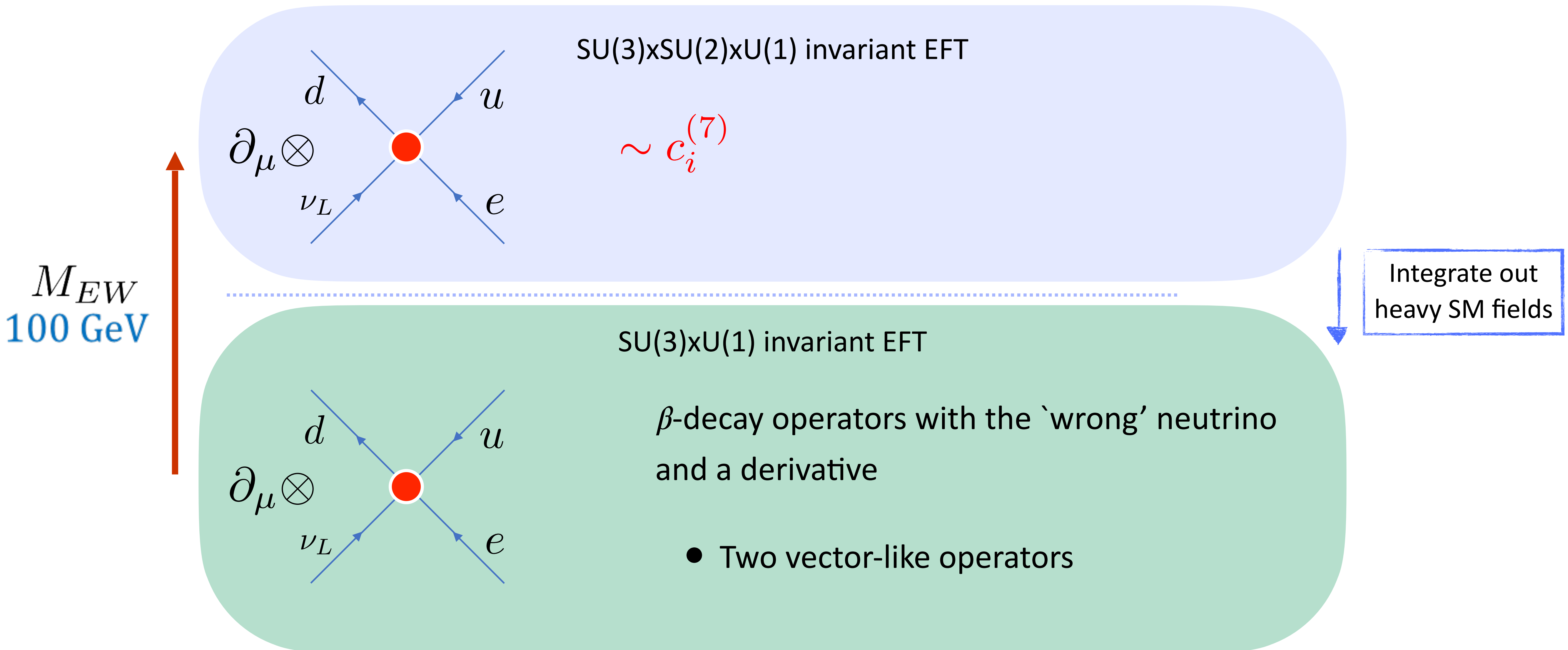
β-decay operators with the `wrong' neutrino:

- 2 scalar interactions
- 2 vector interactions
- one tensor interaction

Induced by dimension-7 SU(2)-invariant operators

$$C_i^{(6)} \sim v^3/\Lambda^3$$

Low-energy operators
Dimension-7

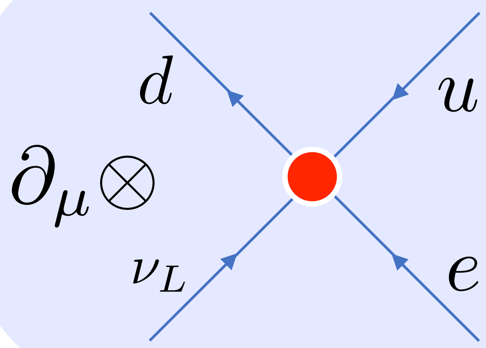


$$\mathcal{L}^{(7)}_{\Delta L=2} = \frac{2G_F}{\sqrt{2}v}\left\{ C^{(7)}_{\mathrm{VL},ij}\,\bar u_L\gamma^\mu d_L\,\bar e_{L,i}\,C\,i\overleftrightarrow{\partial}_\mu\bar\nu^T_{L,j} + C^{(7)}_{\mathrm{VR},ij}\,\bar u_R\gamma^\mu d_R\,\bar e_{L,i}\,Ci\overleftrightarrow{\partial}_\mu\bar\nu^T_{L,j}\right\} + \mathrm{h.c.}$$

Low-energy operators

Dimension-7

SU(3)xSU(2)xU(1) invariant EFT



$\sim c_i^{(7)}$

M_{EW}

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Integrate out heavy SM fields

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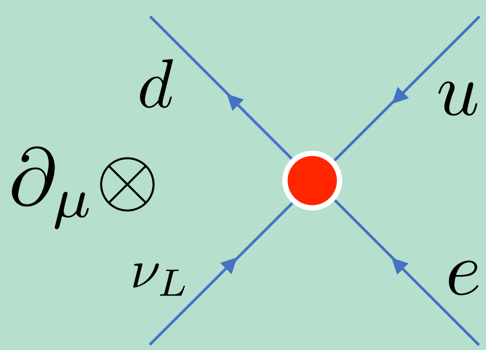


β-decay operators with the `wrong' neutrino and a derivative

- Two vector-like operators

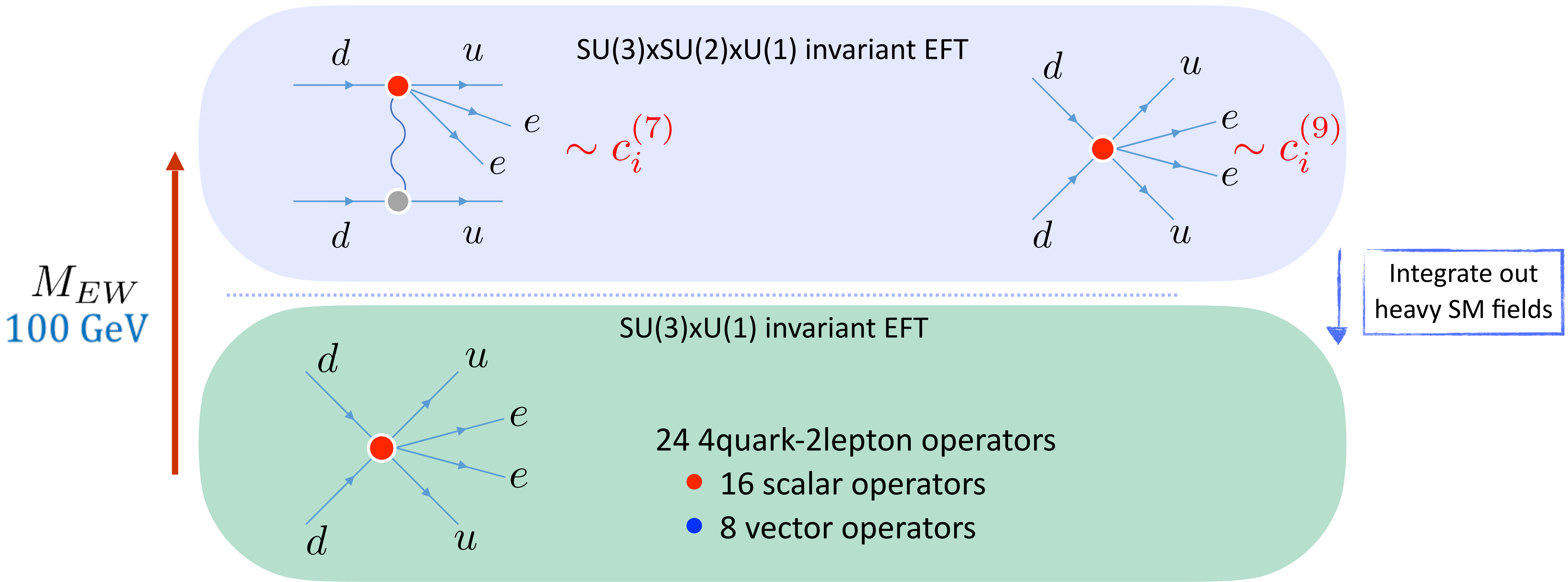
$\mathcal{L}^{(7)}_{\Delta L=2} =$ … $\overleftrightarrow{\partial}_\mu \bar{\nu}^T_{L,j} \Big\} + \text{h.c.}$

Induced by dimension-7 SU(2)-invariant operators

$$C_i^{(7)} \sim v^3/\Lambda^3$$

Low-energy operators

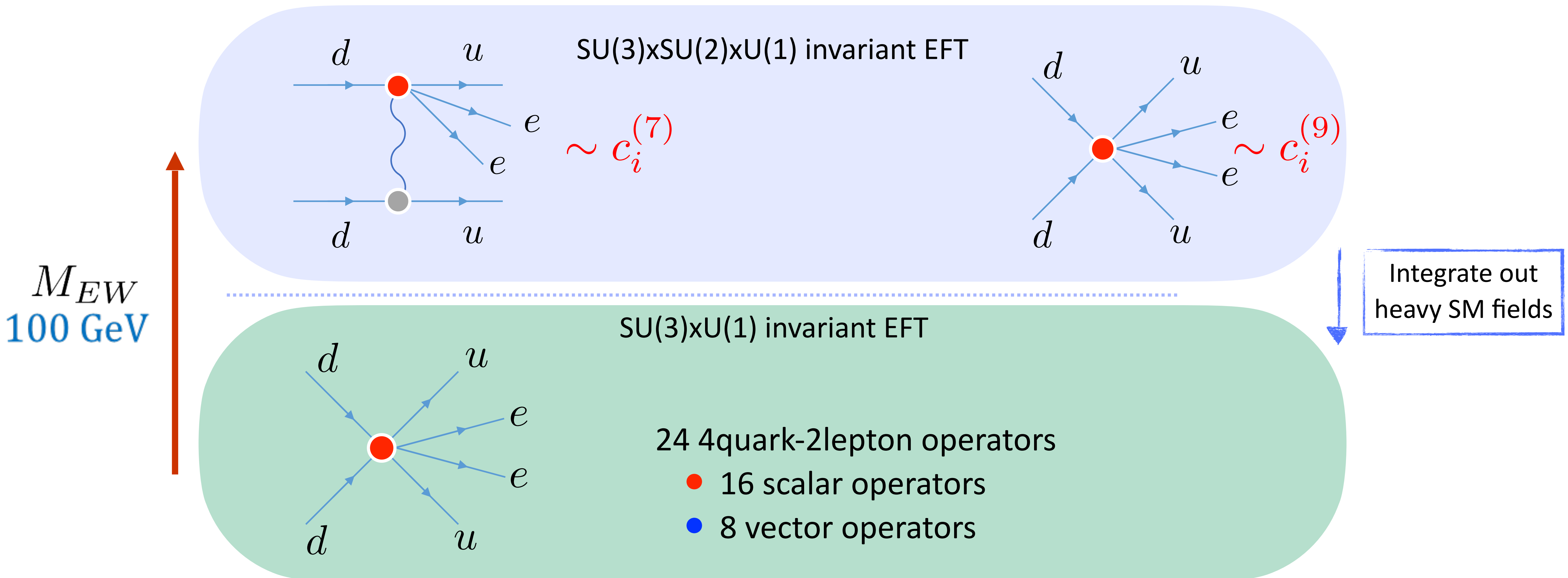
Dimension-9



$$\mathcal{L}^{(9)}_{\Delta L=2} = \frac{1}{v^5}\sum_i \left[\left(C^{(9)}_{i\,\mathrm{R}}\, \bar e_R C \bar e_R^T + C^{(9)}_{i\,\mathrm{L}}\, \bar e_L C \bar e_L^T \right) O_i + C^{(9)}_i \bar e \gamma_\mu \gamma_5 C \bar e^T O_i^\mu \right],$$

Low-energy operators

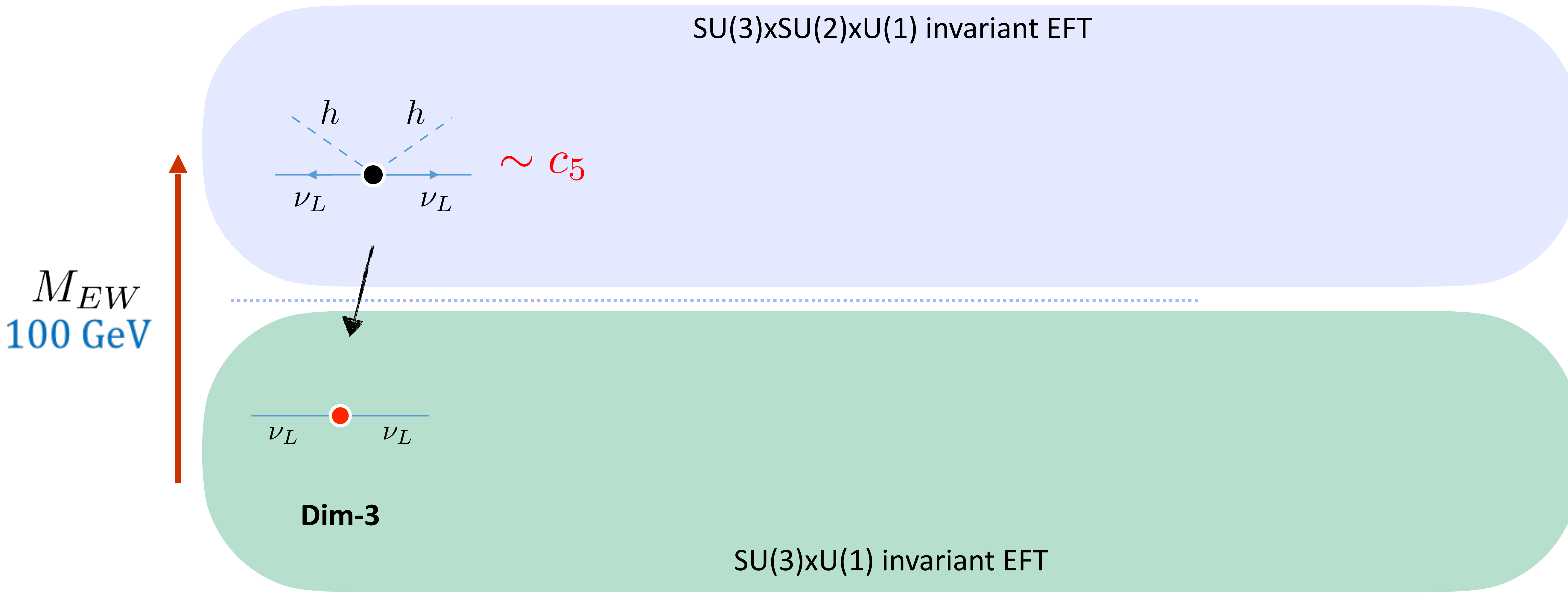
Dimension-9



- 3 can be induced by dimension-7 operators $C_i^{(9)} \sim v^3/\Lambda^3$
- 19 can be induced by dimension-9 operators $C_i^{(9)} \sim v^5/\Lambda^5$

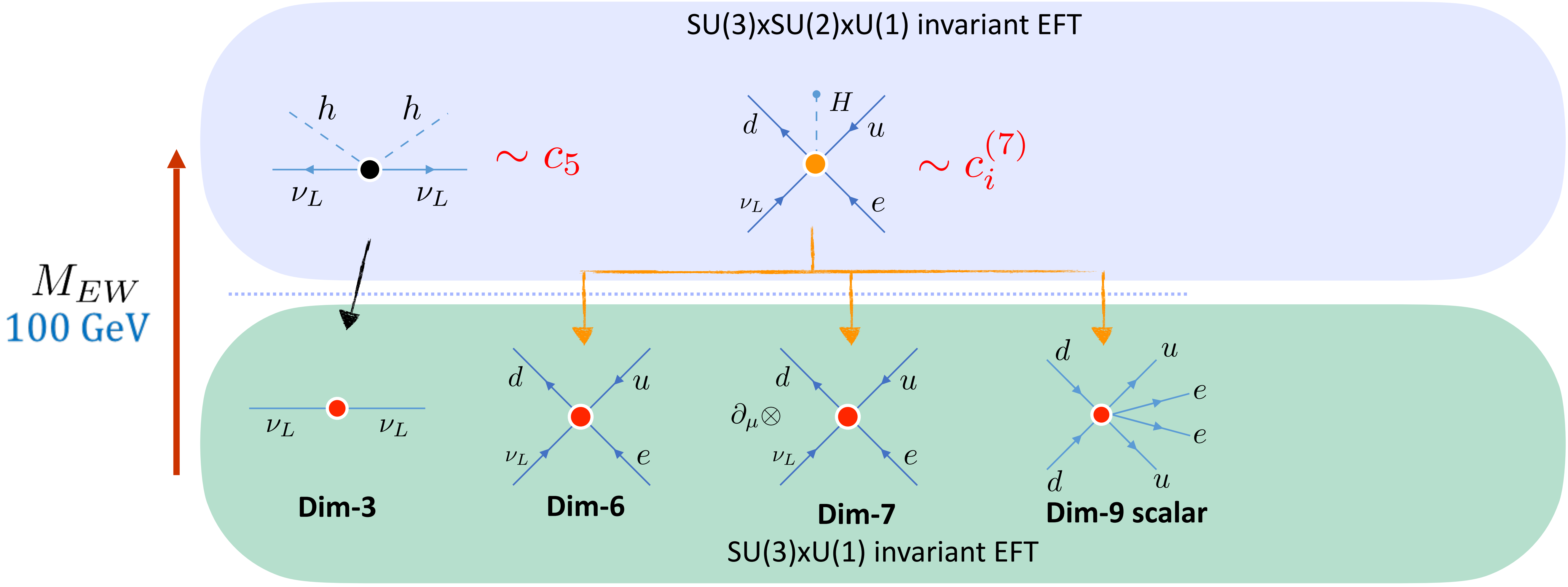
Low-energy operators

Summary

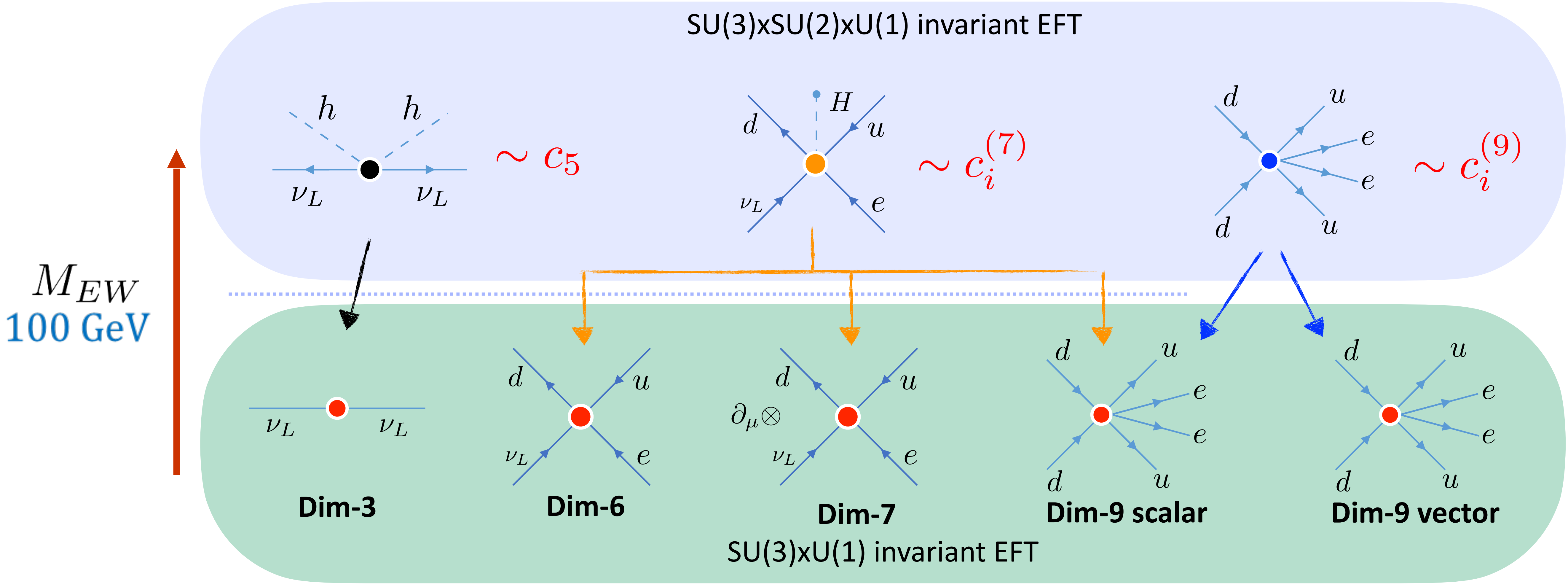


Low-energy operators

Summary



Low-energy operators
Summary



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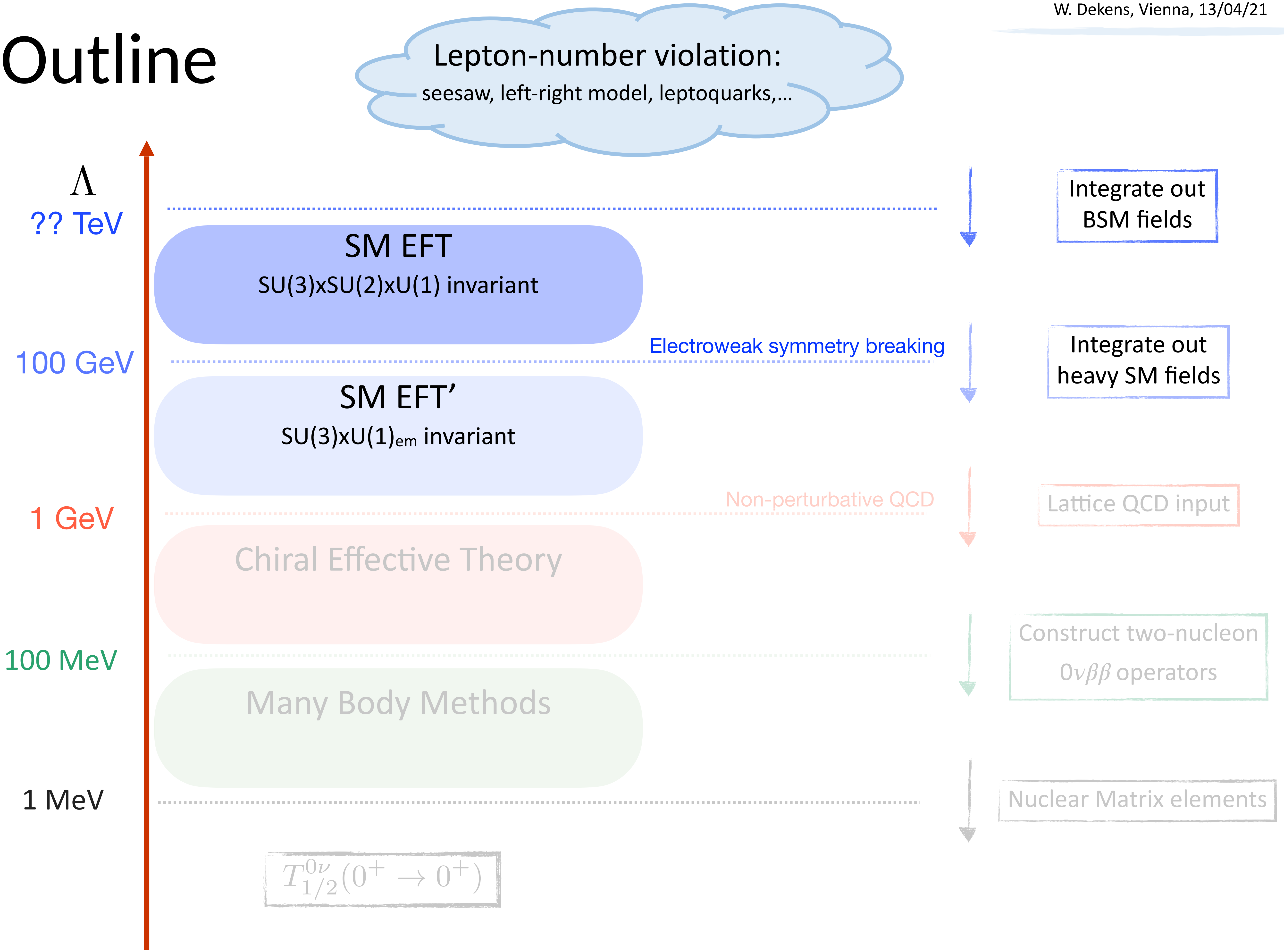
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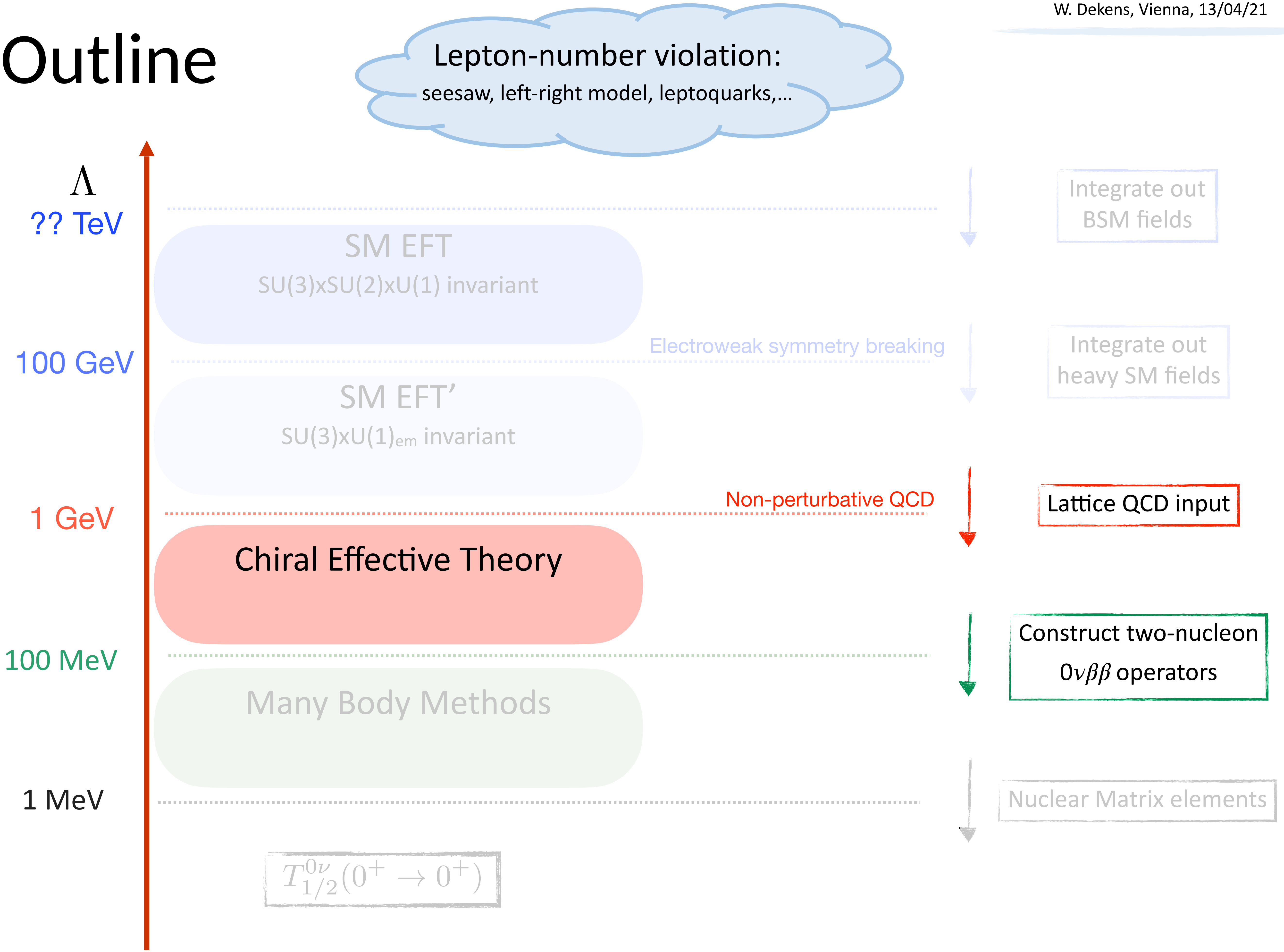
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Matching to Chiral EFT

M_{QCD}
1 GeV

SM EFT'

$SU(3)xU(1)_{em}$ invariant

In terms of quarks, gluons, leptons $\mathcal{L}(u, d, g, \nu, e)$

Chiral Effective Theory

In terms of nucleons, pions, leptons $\mathcal{L}_{\chi PT}(N, \pi, \nu, e)$

Form of operators determined by chiral symmetry

The operators come with unknown constants (LECs)

Need a power-counting scheme

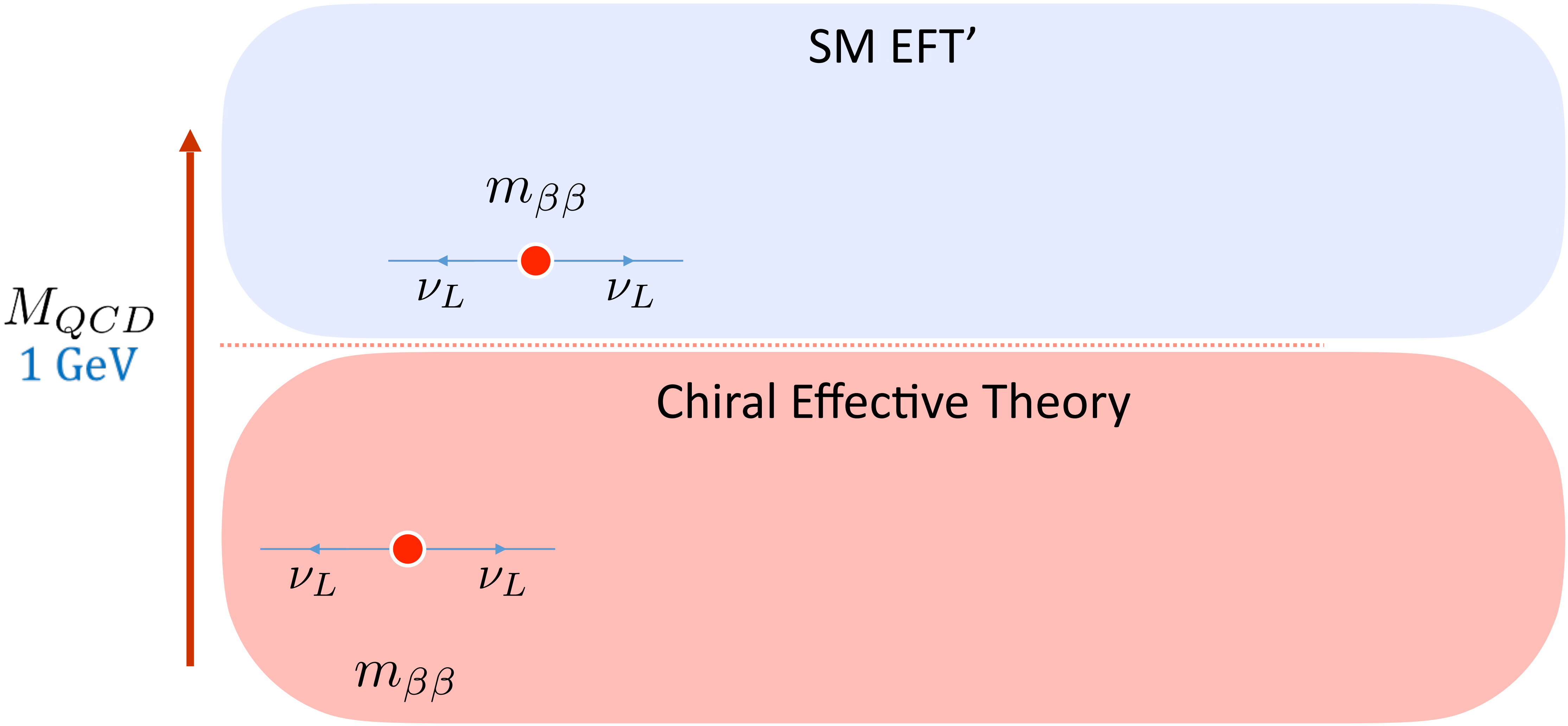
- Start by assuming Naive dimensional analysis (NDA)
- Will come back to whether it breaks down

Manohar, Georgi, \`84; Weinberg, \`90, \`91

Matching to Chiral EFT

Dimension-3

Warning: Based on NDA



Matching to Chiral EFT

Dimension-3

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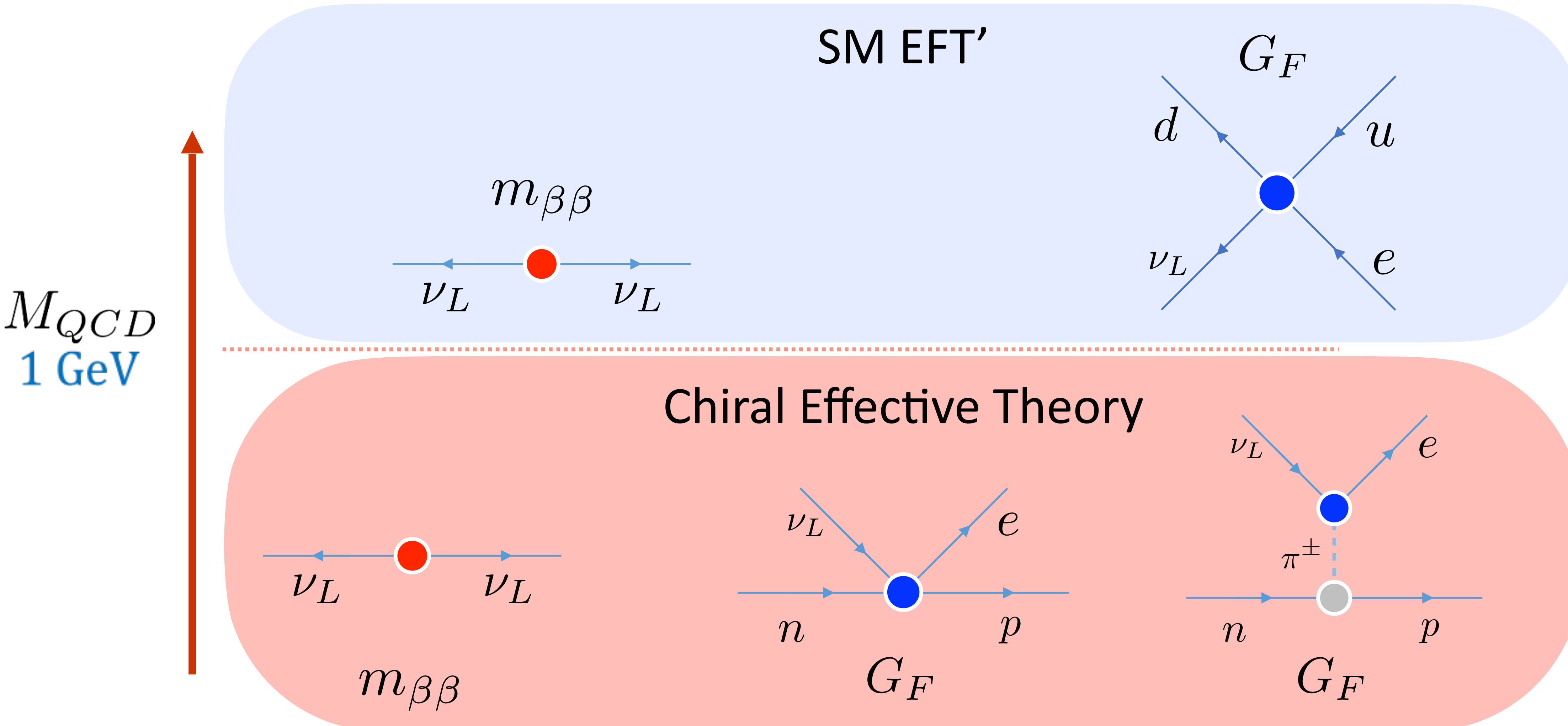

Matching to Chiral EFT

Dimension-3

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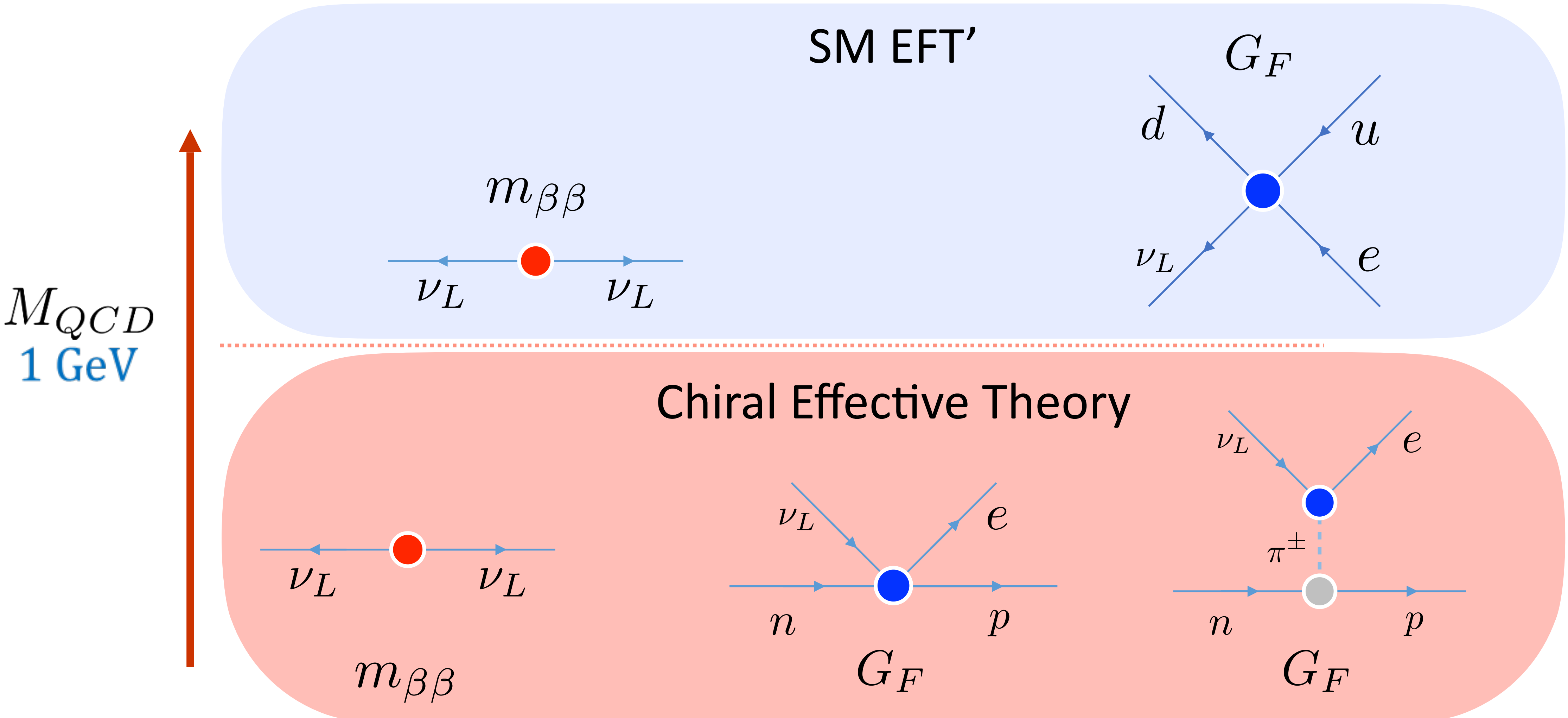
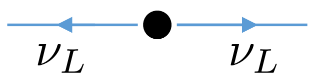


- At LO in Weinberg counting, only need the nucleon one-body currents
- Needed low-energy constants are known from experiment / Lattice QCD

Chiral EFT

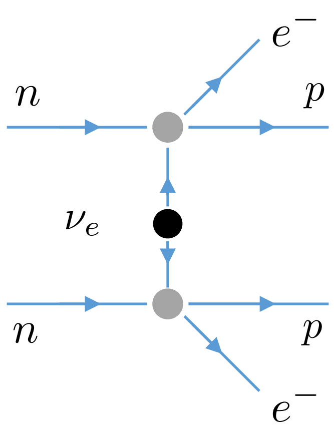
Dim 3

$m_{\beta\beta}$

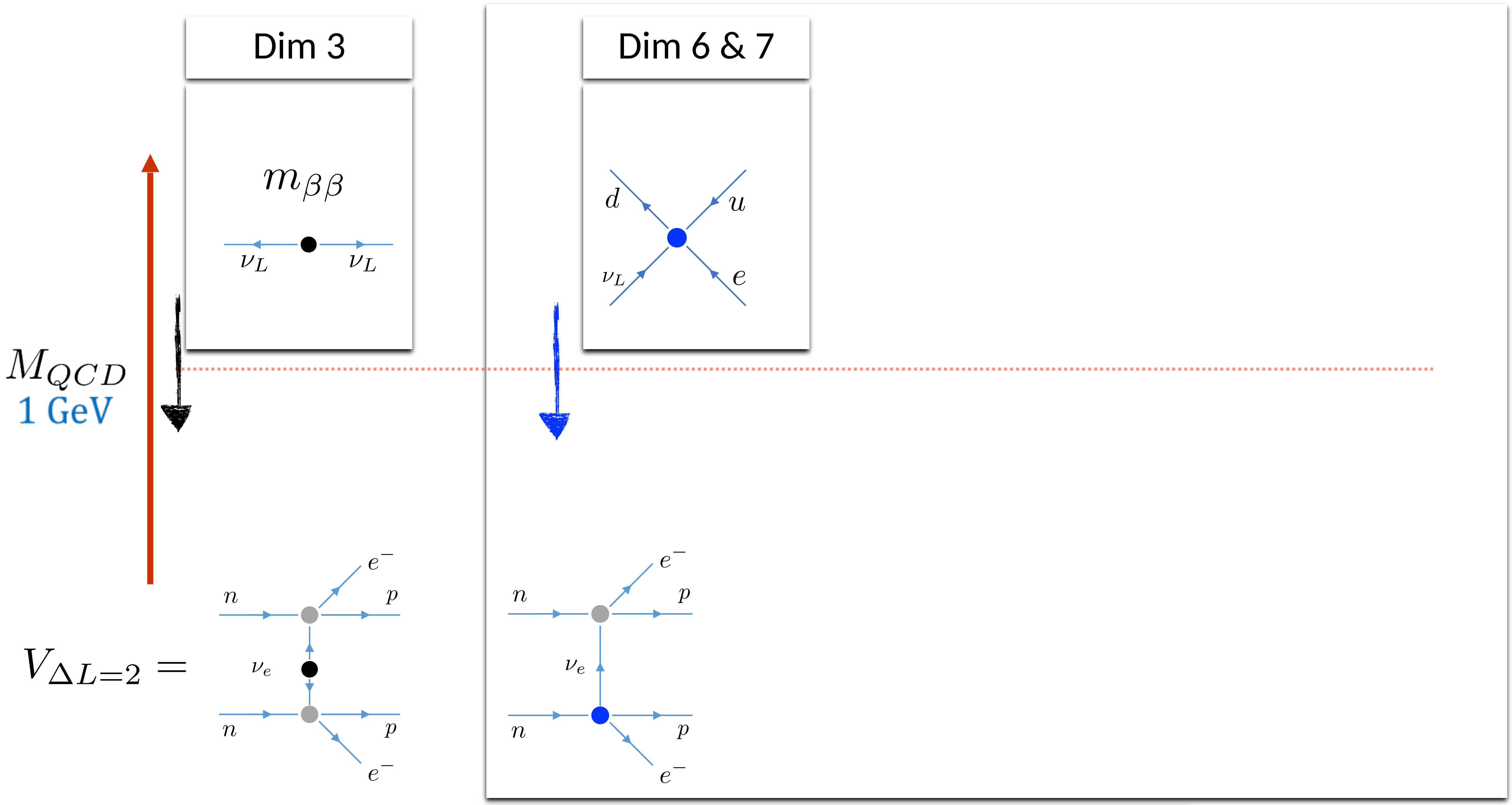


M_{QCD}
1 GeV

$V_{\Delta L=2} =$



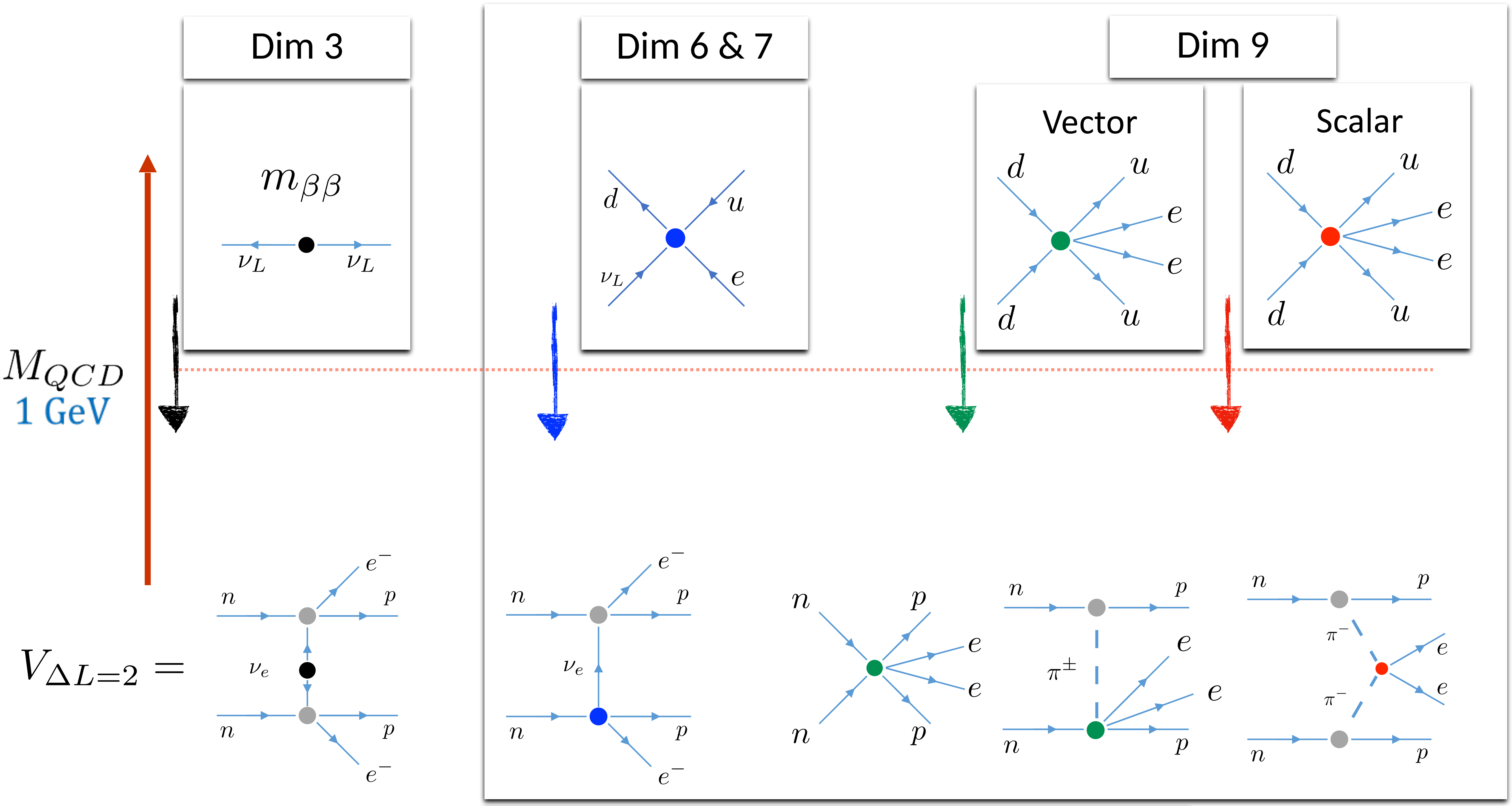
Chiral EFT



Matching similar for higher-dimensional operators:

- Additional $\pi\pi$, πN, NN interactions
- New Low-energy constants

Chiral EFT



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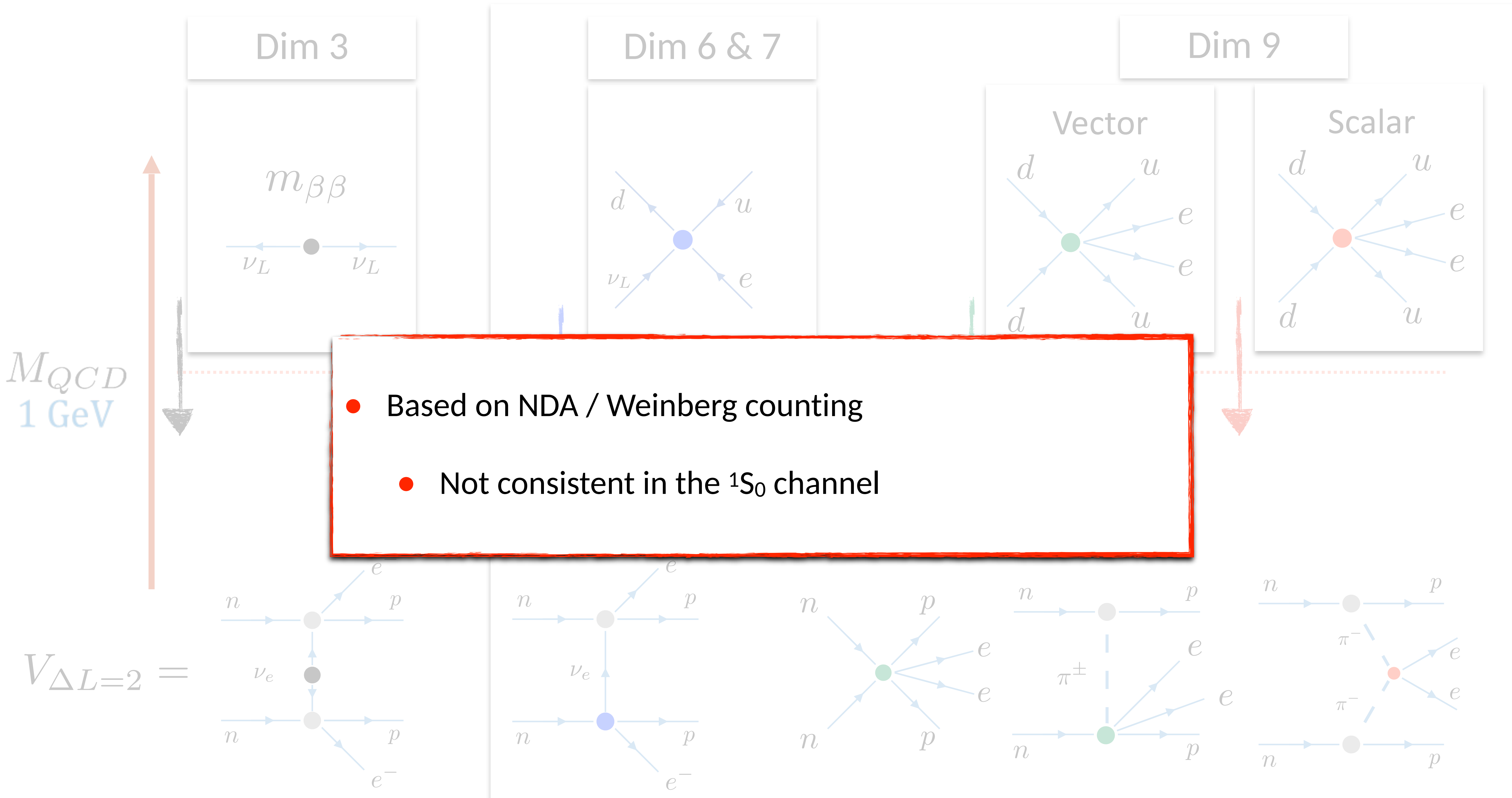
Chiral EFT



- Based on NDA / Weinberg counting
  - Not consistent in the ${}^1S_0$ channel

Matching similar for higher-dimensional operators:

- Additional $\pi\pi, \pi N, NN$ interactions
- New Low-energy constants

Kaplan, Savage, Wise, '96; Beane, Bedaque, Savage, van Kolck, '03, Nogga, Timmermans, van Kolck, '05, Long, Yang, '12;

Checking the power counting

Dimension-3

Check that $\mathcal{A}(nn \to ppee)$ is finite

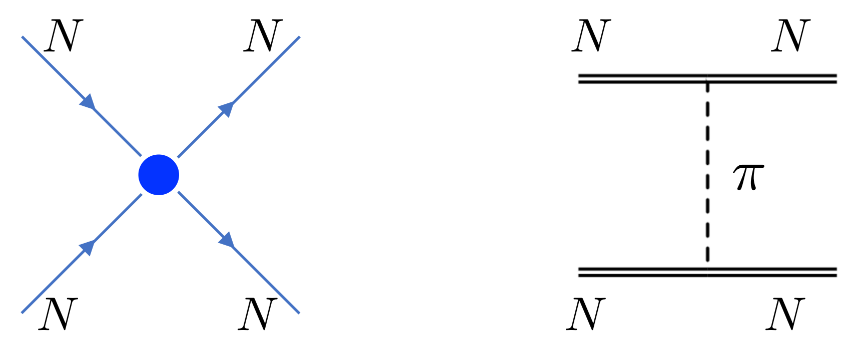
Checking the power counting

Dimension-3

Check that $\mathcal{A}(nn \to ppee)$ is finite

- Requires inclusion of the strong interaction

$$\mathcal{L}_\chi = C \left(N^T P_{^1S_0} N\right)^\dagger N^T P_{^1S_0} N - \frac{g_A}{2F_\pi} \nabla\pi \cdot \bar{N} \tau \boldsymbol{\sigma} N$$



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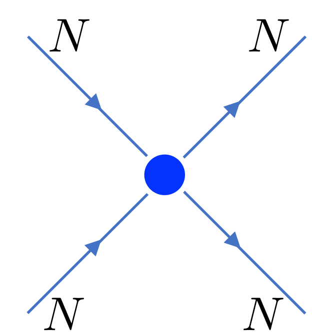
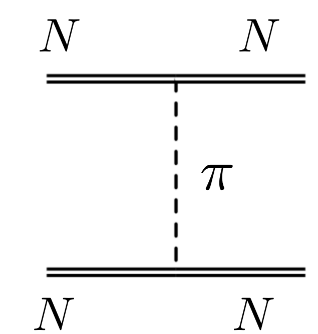
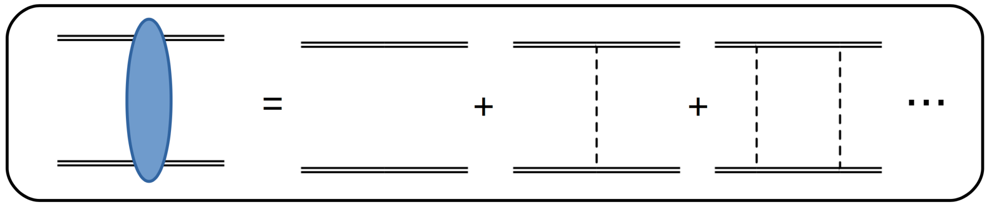
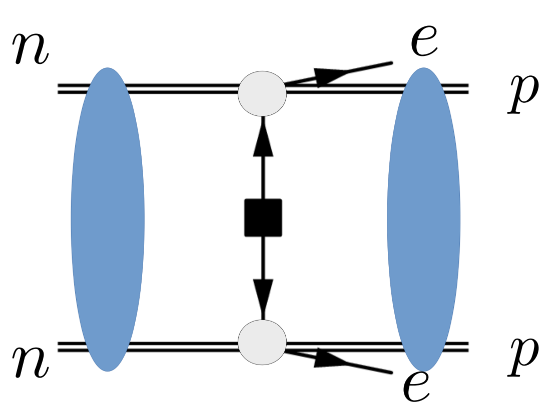




Dress the ΔL=2 potential with (renormalized) strong interactions:





✓ finite

Checking the power counting

Dimension-3

Check that $\mathcal{A}(nn \to ppee)$ is finite

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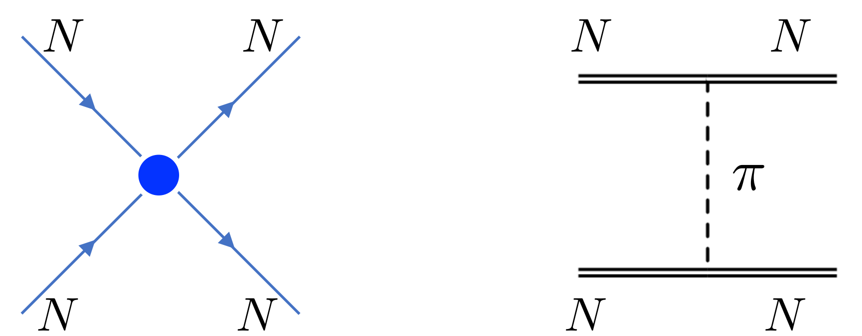
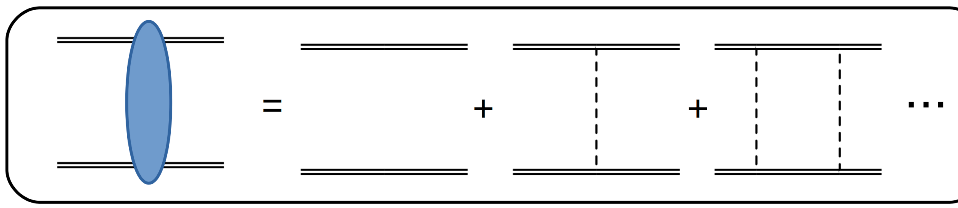
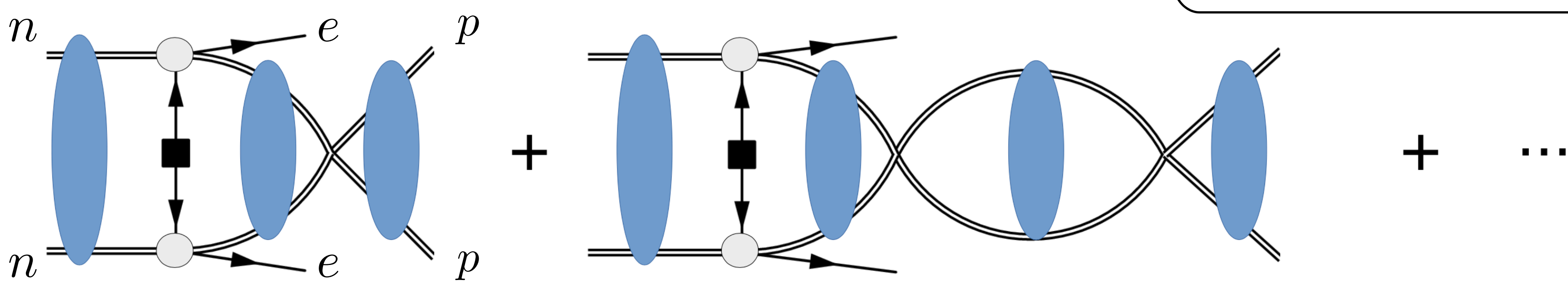


Dress the ΔL=2 potential with (renormalized) strong interactions:





✓ finite

Checking the power counting

Dimension-3

Check that $\mathcal{A}(nn \to ppee)$ is finite

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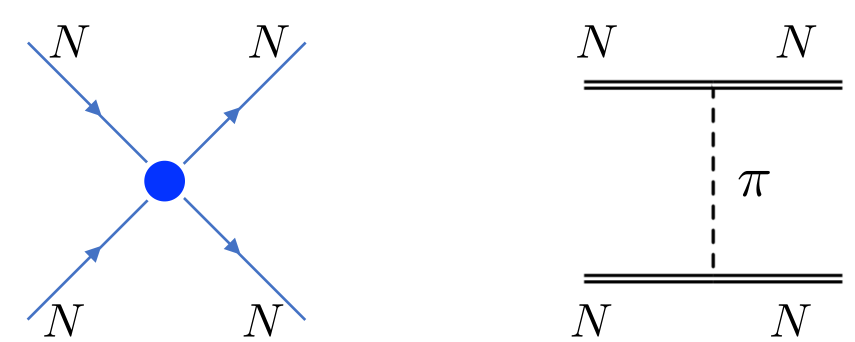
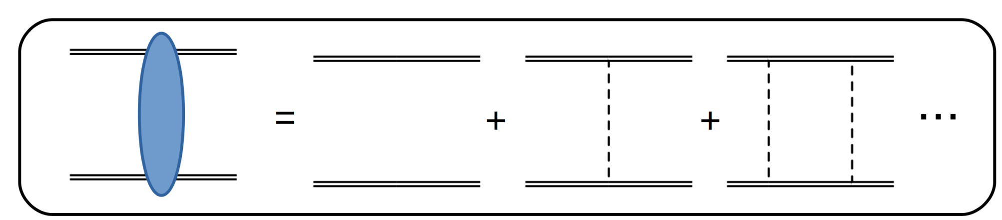
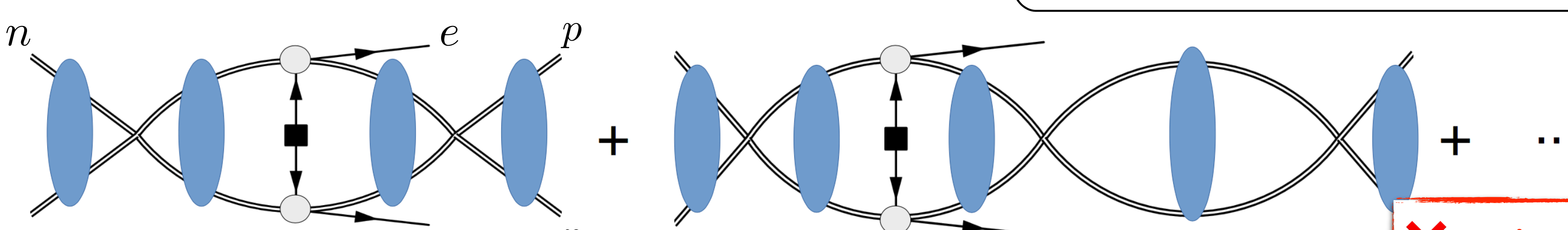
$$\mathcal{L}_\chi = C\,\left(N^T P_{^1S_0} N\right)^\dagger N^T P_{^1S_0} N - \frac{g_A}{2F_\pi}\nabla\pi \cdot \bar{N}\tau\boldsymbol{\sigma}N$$



Dress the ΔL=2 potential with (renormalized) strong interactions:





❌ Divergent

Checking the power counting

Dimension-3

Check that $\mathcal{A}(nn \to ppee)$ is finite

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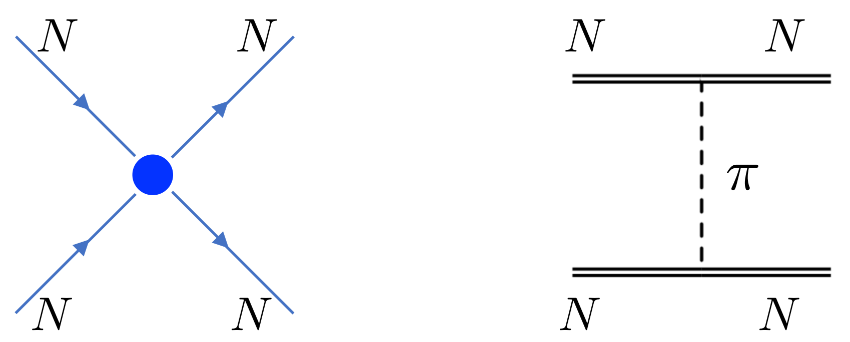
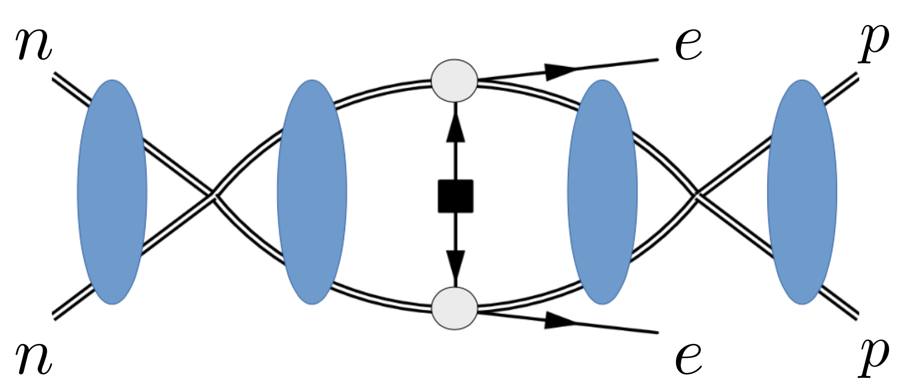


Dress the ΔL=2 potential with (renormalized) strong interactions:

In MS-bar:

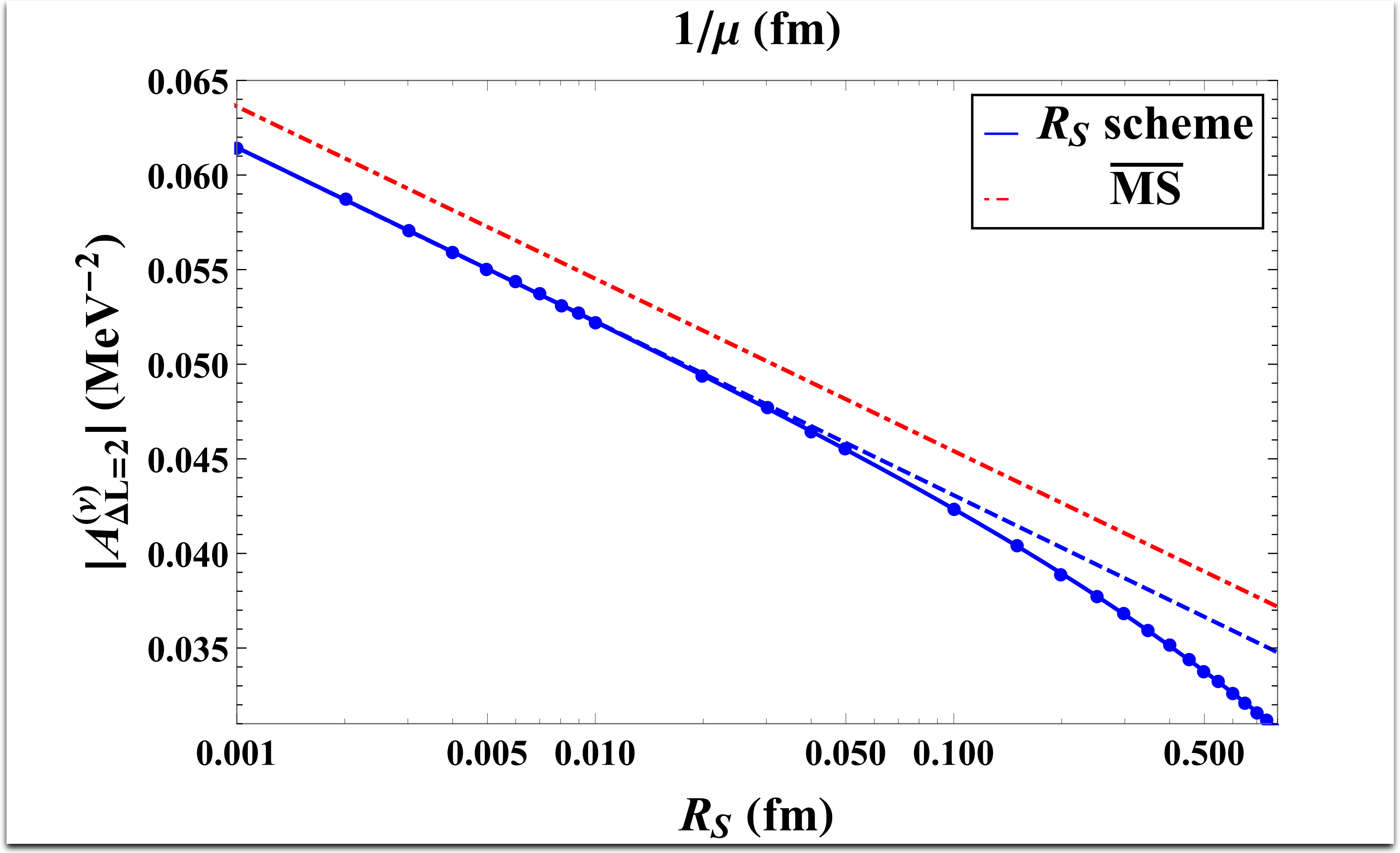


$$= -\left(\frac{m_N}{4\pi}\right)^2 (1+2g_A^2)\frac{1}{2}\left(\log\frac{\mu^2}{-(|\mathbf{p}|+|\mathbf{p}'|)^2+i0^+}+1\right)$$

$+\text{finite}$

Regulator dependent

Numerical results



- Amplitudes obtained using
  - MS-bar
  - Coordinate-space cut-off

$$\tilde{C}\,\delta^{(3)}(\mathbf{r}) \rightarrow \frac{\tilde{C}(R_S)}{(\sqrt{\pi}R_S)^3}\exp\left(-\frac{r^2}{R_S^2}\right)$$

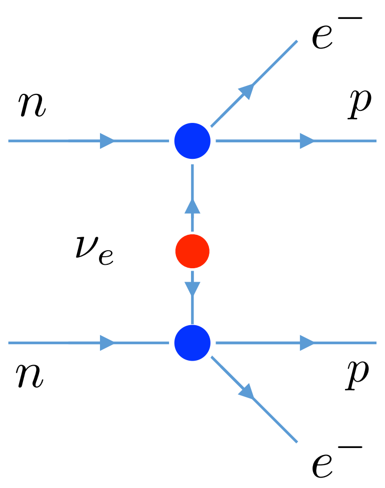
- Clear μ or R_S dependence

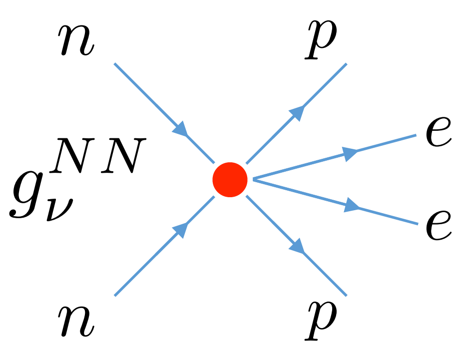
Need for a counter term

- Need a new contact interaction at leading order to get physical amplitudes:

$$\mathcal{L}_{CT} = 2G_F^2 V_{ud}^2 m_{\beta\beta}\, g_\nu^{NN}\, \bar{p}n\, \bar{p}n\, \bar{e}_L C \bar{e}_L^T$$

$$V_{\Delta L=2} = V_\nu + V_{\nu,CT} =$$





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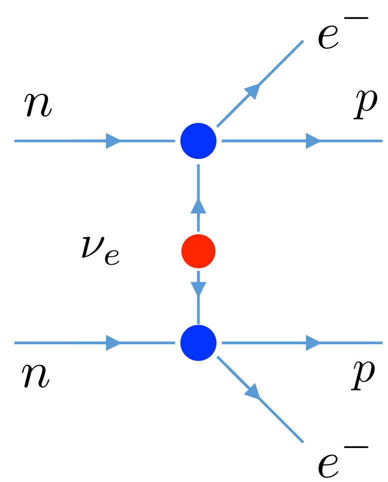

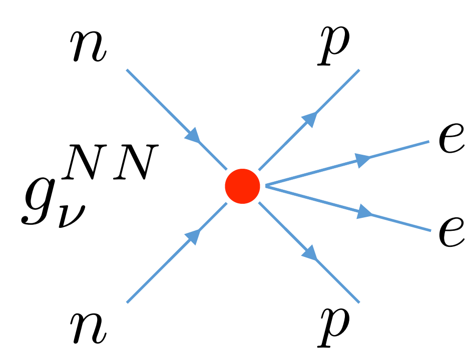

- Finite part of g_ν^{NN} is currently unknown, hard to estimate its impact

- Could be determined from a lattice calculation of $\mathcal{A}(nn \to ppe^-e^-)$
  - Area of active research

Davoudi and Kadam, '20; Feng et al, '20

- Estimate from relation to EM (back-up slides)
  - ~10-30% contribution in $\mathcal{A}(nn \to ppe^-e^-)$
  - ~60% in light nuclei, $^{12}Be \to {}^{12}C e^- e^-$

Determination of the counterterm

- Analogy to the Cottingham approach for pion/nucleon mass differences

$$\mathcal{A}_\nu \propto \int \frac{d^4k}{(2\pi)^4} \frac{g_{\mu\nu}}{k^2 + i\epsilon} \int d^4x \, e^{ik\cdot x} \langle pp | T\{ j^\mu_{\rm w}(x) j^\nu_{\rm w}(0) \} | nn \rangle$$

- Compute the $0\nu\beta\beta$ amplitude by constraining the correlator

Cirigliano et al, '20, '21

W. Cottingham '63; H. Harari, '66

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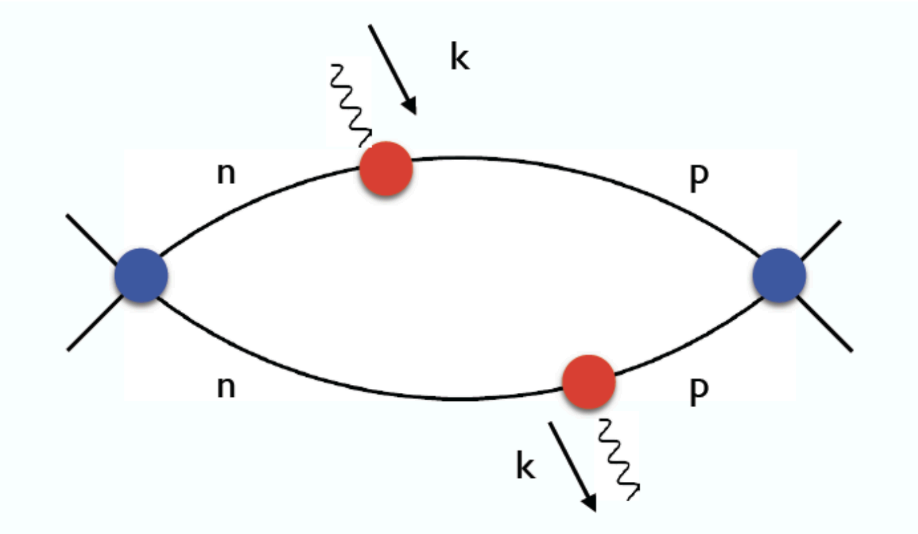

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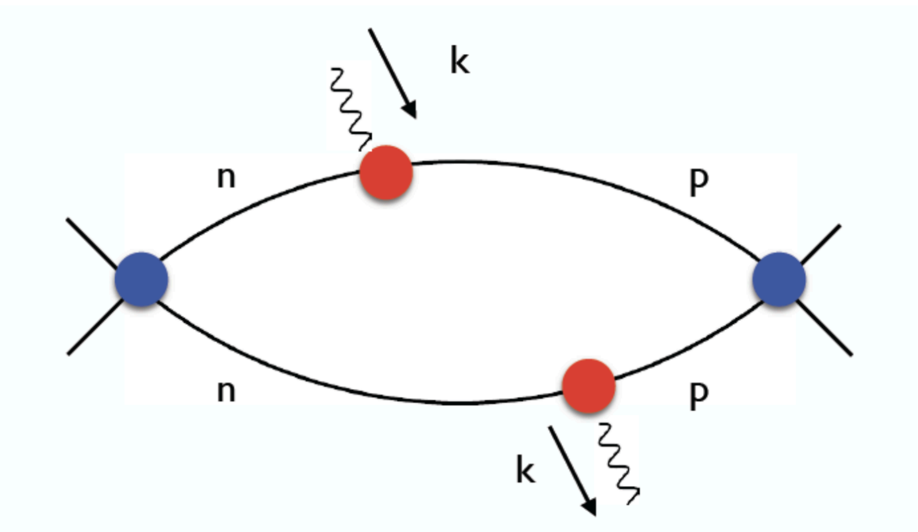

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- Model intermediate region using:
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- Gives $\tilde{g}_\nu^{NN}(\mu = m_\pi) = 1.3(6)$ in $\overline{\mathrm{MS}}$
  - Estimated 30% uncertainty
  - Validated with isospin-breaking contact terms, $j_W^\mu \to j_{\mathrm{EM}}^\mu$ (see backup)
- A_ν can then be used to fit $\tilde{g}_\nu^{NN}$ in *ab-initio* many-body calculations

Consistent with large-Nc
Richardson et al, '21

W. Cottingham '63; H. Harari, '66

Checking the Weinberg counting

Any effect for the dim-6,7,9 terms?

- In the Majorana-mass case, the LNV potential leads to a divergence
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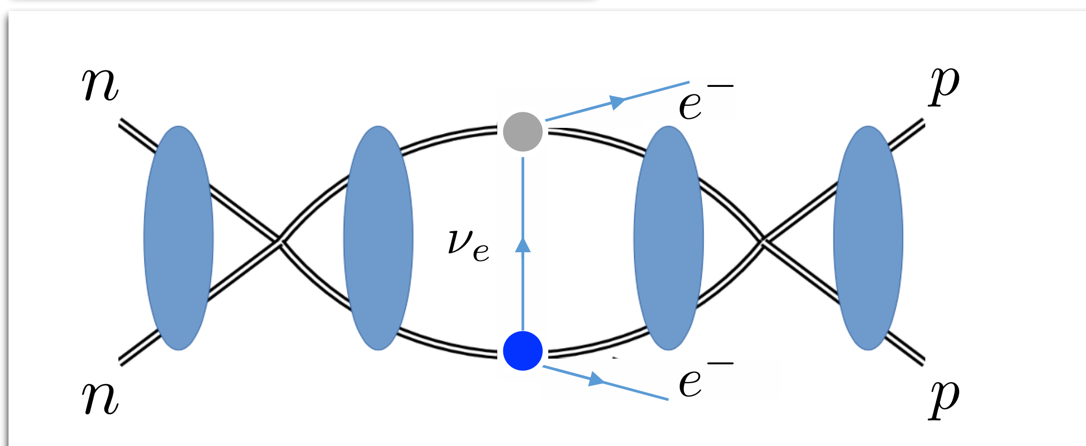
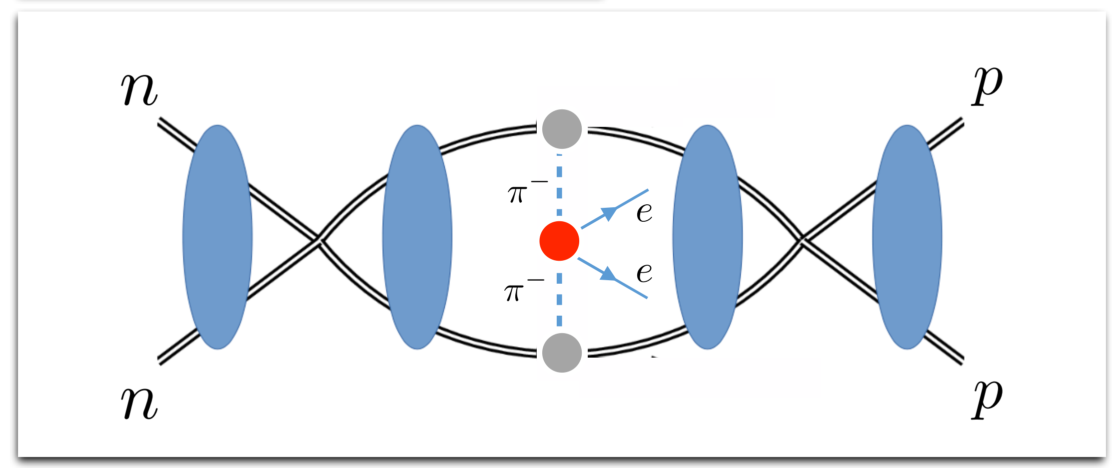


Dim-9: $C^{(9)}_{1-9}$



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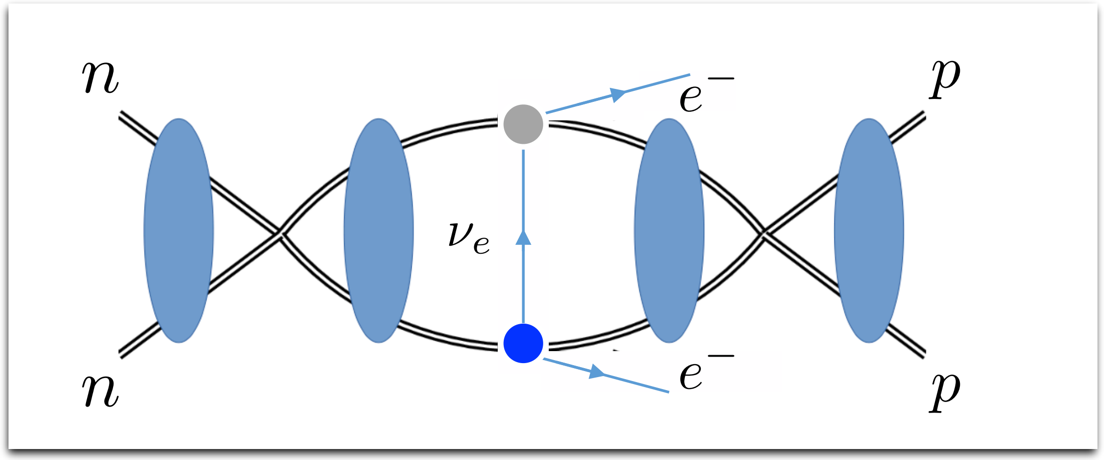

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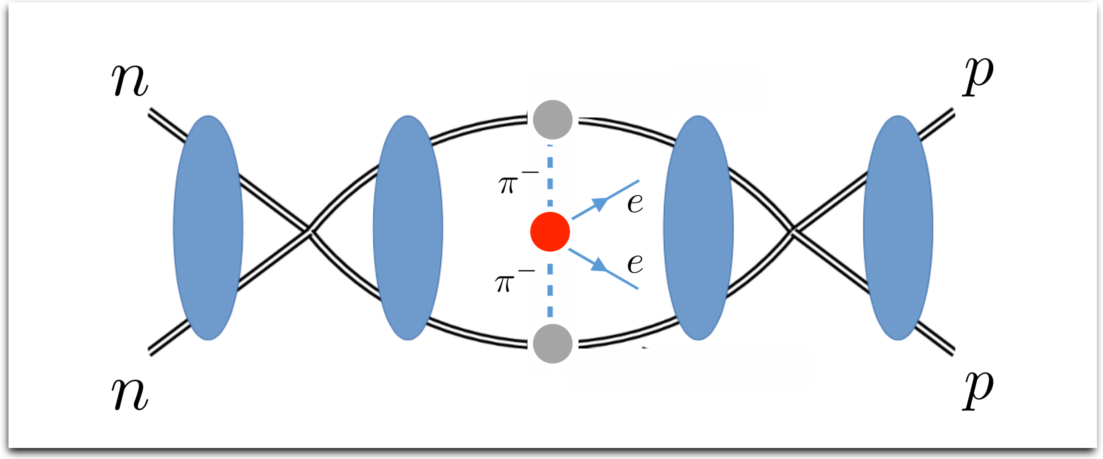
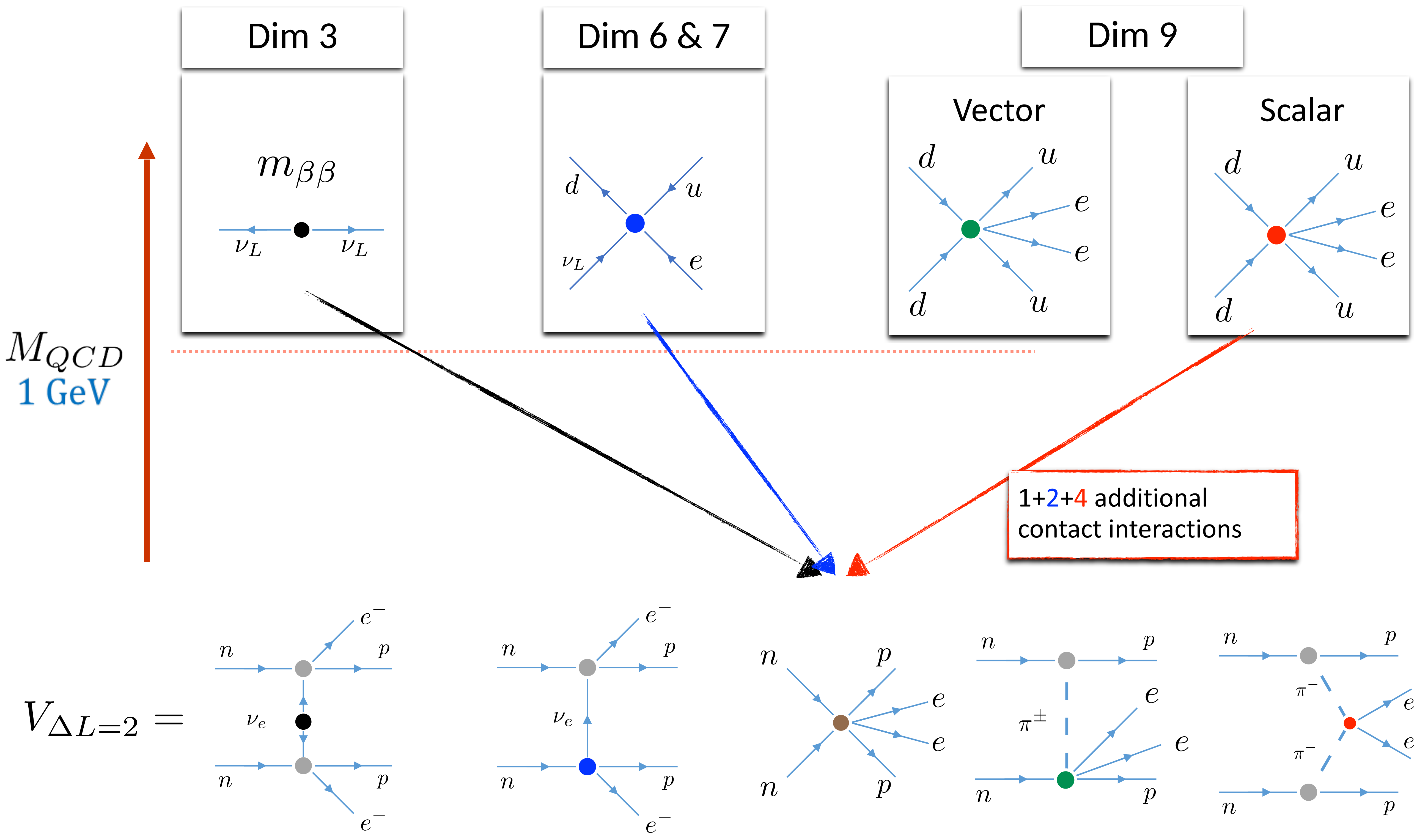


- Need to include contact interactions at LO in these cases
  - Often disagrees with the Weinberg / NDA counting

Chiral EFT

Beyond NDA / Weinberg



Outline

Lepton-number violation:
seesaw, left-right model, leptoquarks,...

Λ

?? TeV

SM EFT
SU(3)xSU(2)xU(1) invariant

Integrate out BSM fields

Electroweak symmetry breaking

100 GeV

SM EFT'
SU(3)xU(1)$_{em}$ invariant

Integrate out heavy SM fields

Non-perturbative QCD

1 GeV

Lattice QCD input

Chiral Effective Theory

100 MeV

Construct two-nucleon $0\nu\beta\beta$ operators

Many Body Methods

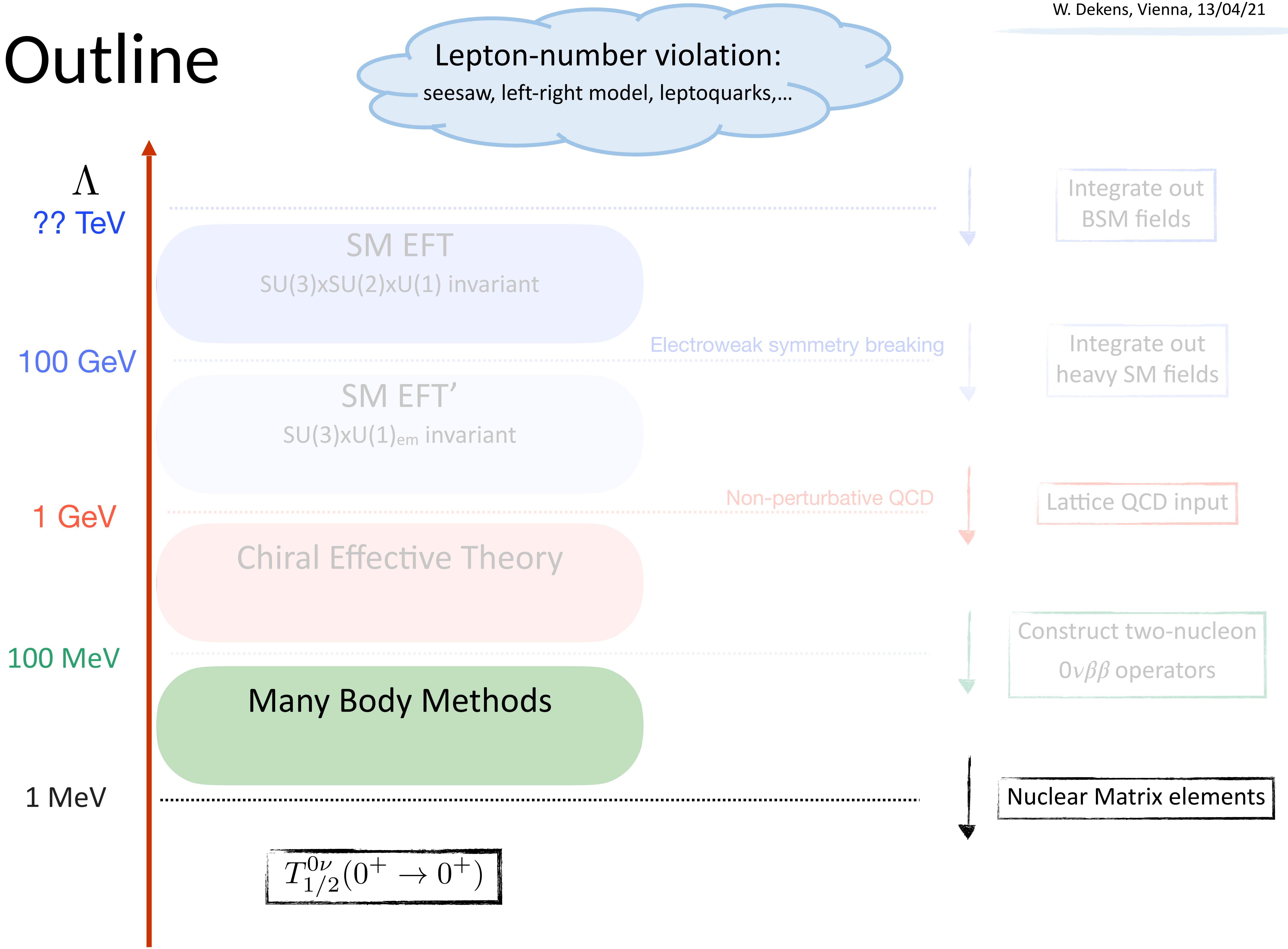
1 MeV

Nuclear Matrix elements

$T_{1/2}^{0\nu}(0^+ \to 0^+)$

Outline

W. Dekens, Vienna, 13/04/21



The $0\nu\beta\beta$ half-life

$$\Gamma^{0\nu}(0^+ \to 0^+) \sim \left| \langle 0^+ | \sum_{\text{nucleons}} \int \frac{d^3\boldsymbol{q}}{(2\pi)^3} e^{i\boldsymbol{q}\cdot\boldsymbol{r}}\, V(\boldsymbol{q}^2)\, |0^+\rangle \right|^2 = \sum_{i,j} G_{i,j} M_i M_j g_i g_j C_i C_j^*$$

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Nuclear matrix elements

- All NMEs can be obtained from those of light/heavy neutrino exchange
  - 9 long-distance & 6 short-distance
  - Have been determined in literature

NMEs	^{76}Ge			
	[74]	[31]	[81]	[82, 83]
M_F	-1.74	-0.67	-0.59	-0.68
M_{GT}^{AA}	5.48	3.50	3.15	5.06
M_{GT}^{AP}	-2.02	-0.25	-0.94	
M_{GT}^{PP}	0.66	0.33	0.30	
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$M_{F,\,sd}$	-3.46	-1.55	-1.46	-1.1
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$M_{GT,\,sd}^{PP}$	1.99	0.85	0.82	0.42
$M_{T,\,sd}^{AP}$	-0.85	0.01	-0.05	-0.97
$M_{T,\,sd}^{PP}$	0.32	0.00	0.02	0.38

- Follow ChiPT expectations fairly well
  - E.g. all $O(1)$ and

$$M_{GT,sd}^{PP} = -\frac{1}{2}M_{GT,sd}^{AP} - M_{GT}^{PP}\,, \qquad M_{T,sd}^{PP} = -\frac{1}{2}M_{T,sd}^{AP} - M_{T}^{PP}\,,$$

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Barea et al. '15; Hyvarinen et al, '15; Horoi et al. '17, Menendez et al, '18

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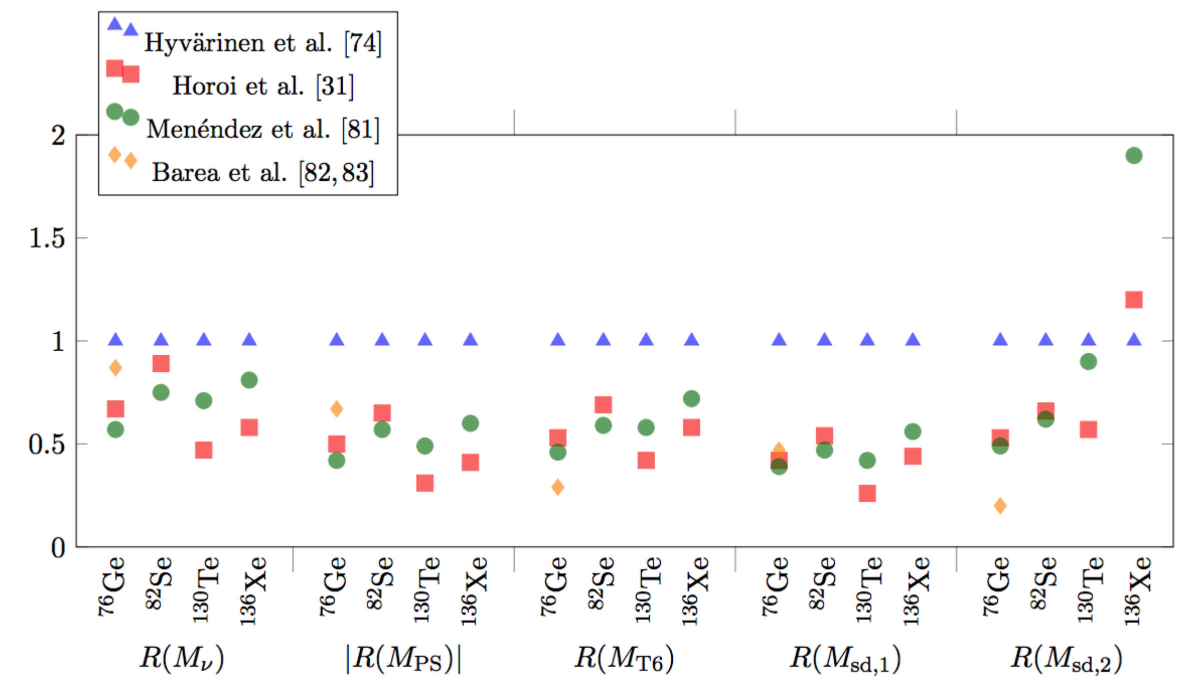
- The NMEs differ by a factor 2-3 between methods
  - For Majorana-mass term & other LNV sources



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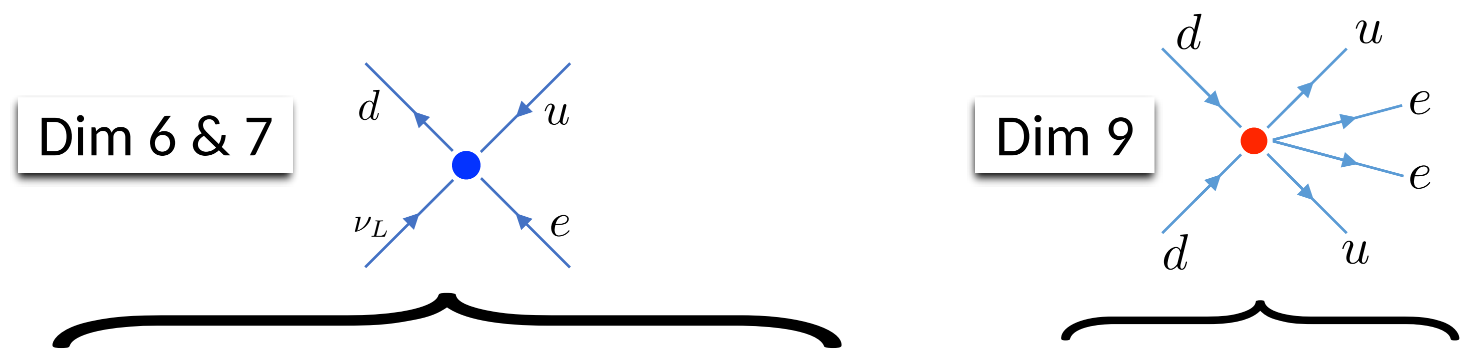
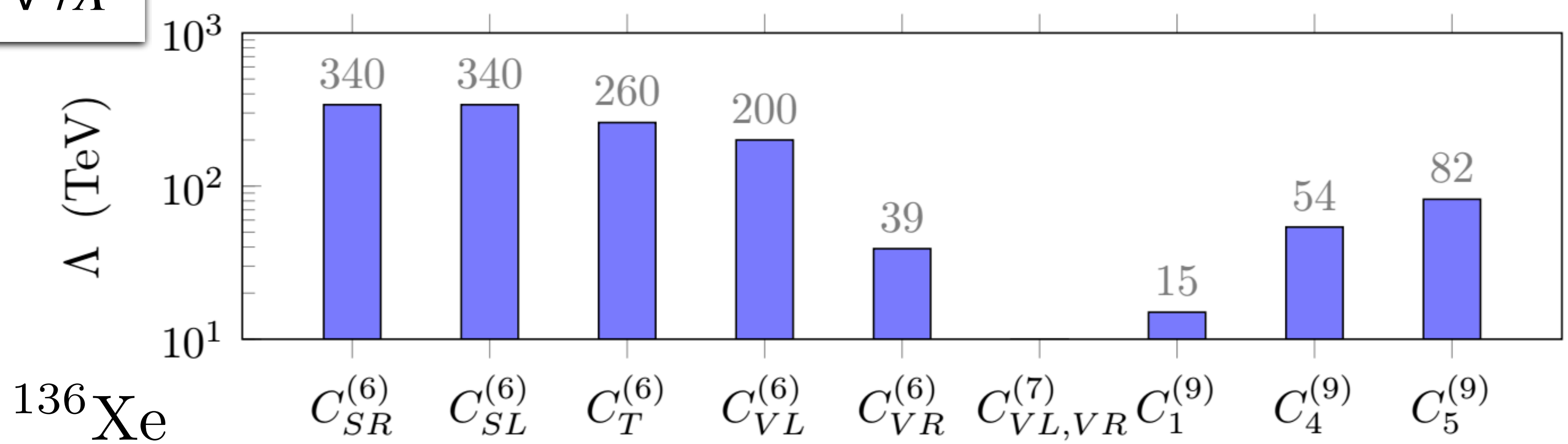
Phenomenology

Current limits

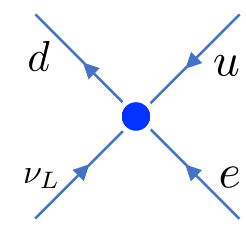
- Couplings with $C_i \sim v^3/\Lambda^3$



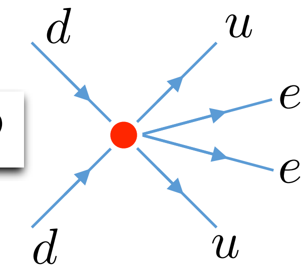


Current limits

Dim 6 & 7



Dim 9



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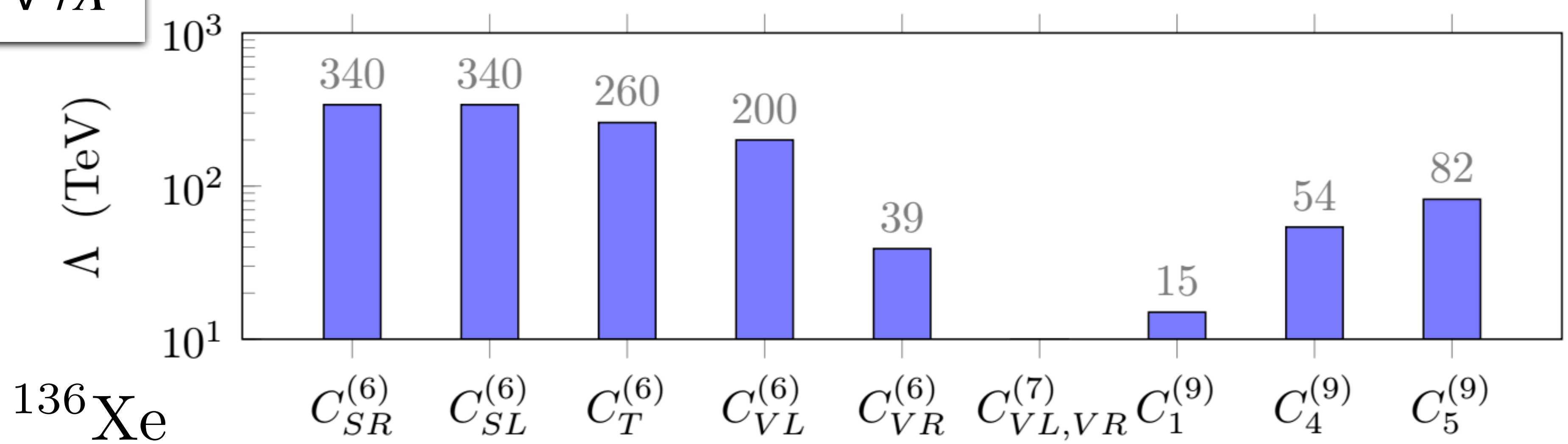

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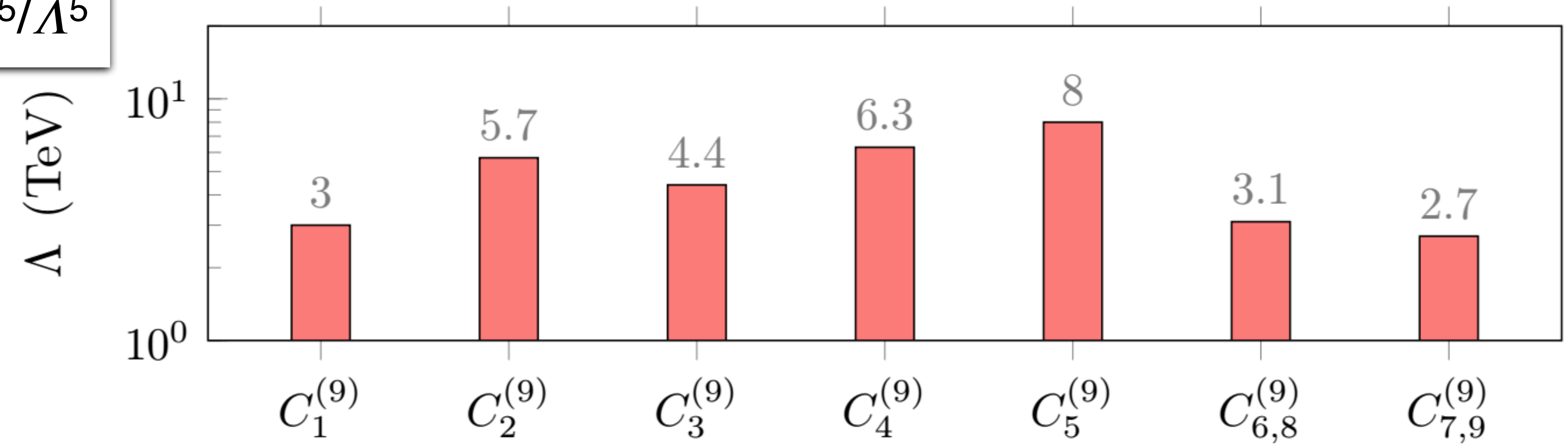

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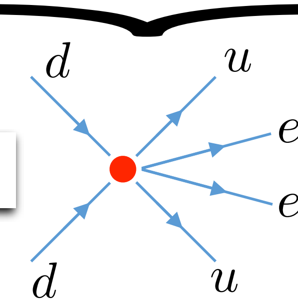
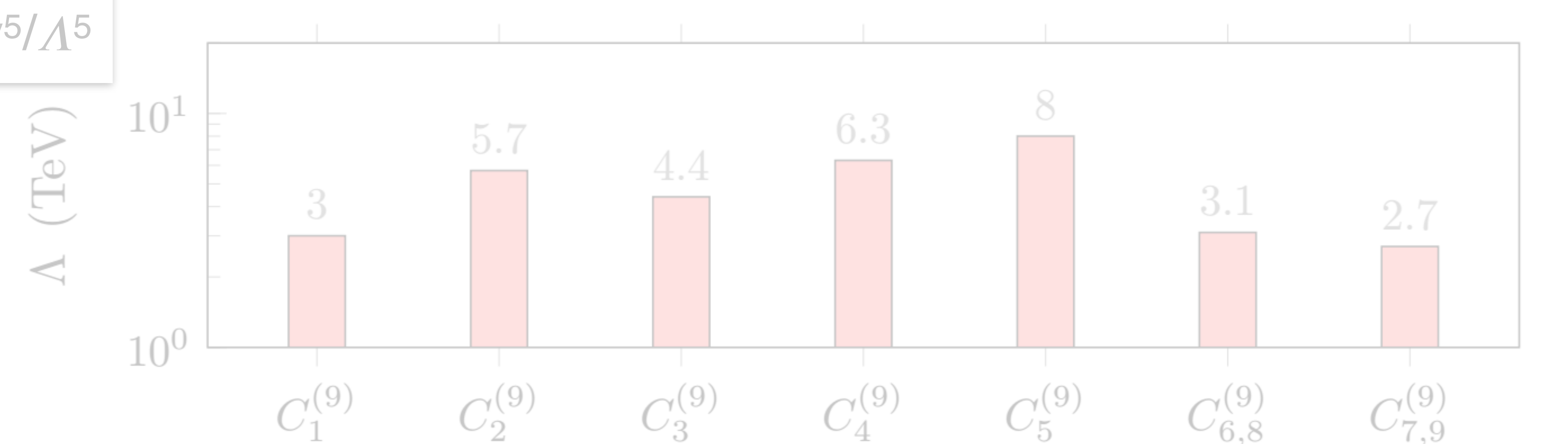


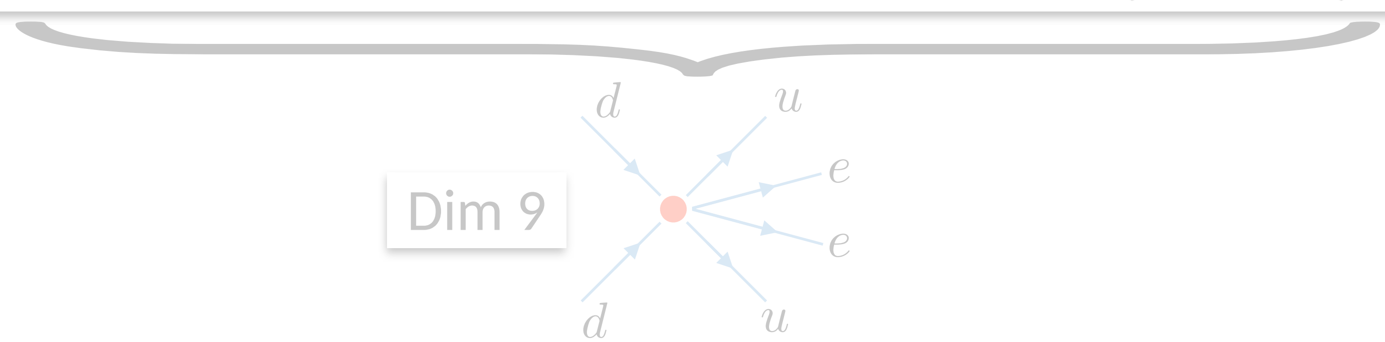
Current limits

- Couplings with $C_i \sim v^3/\Lambda^3$

- O(1) uncertainties:
  - Unknown LECs
  - Nuclear Matrix elements

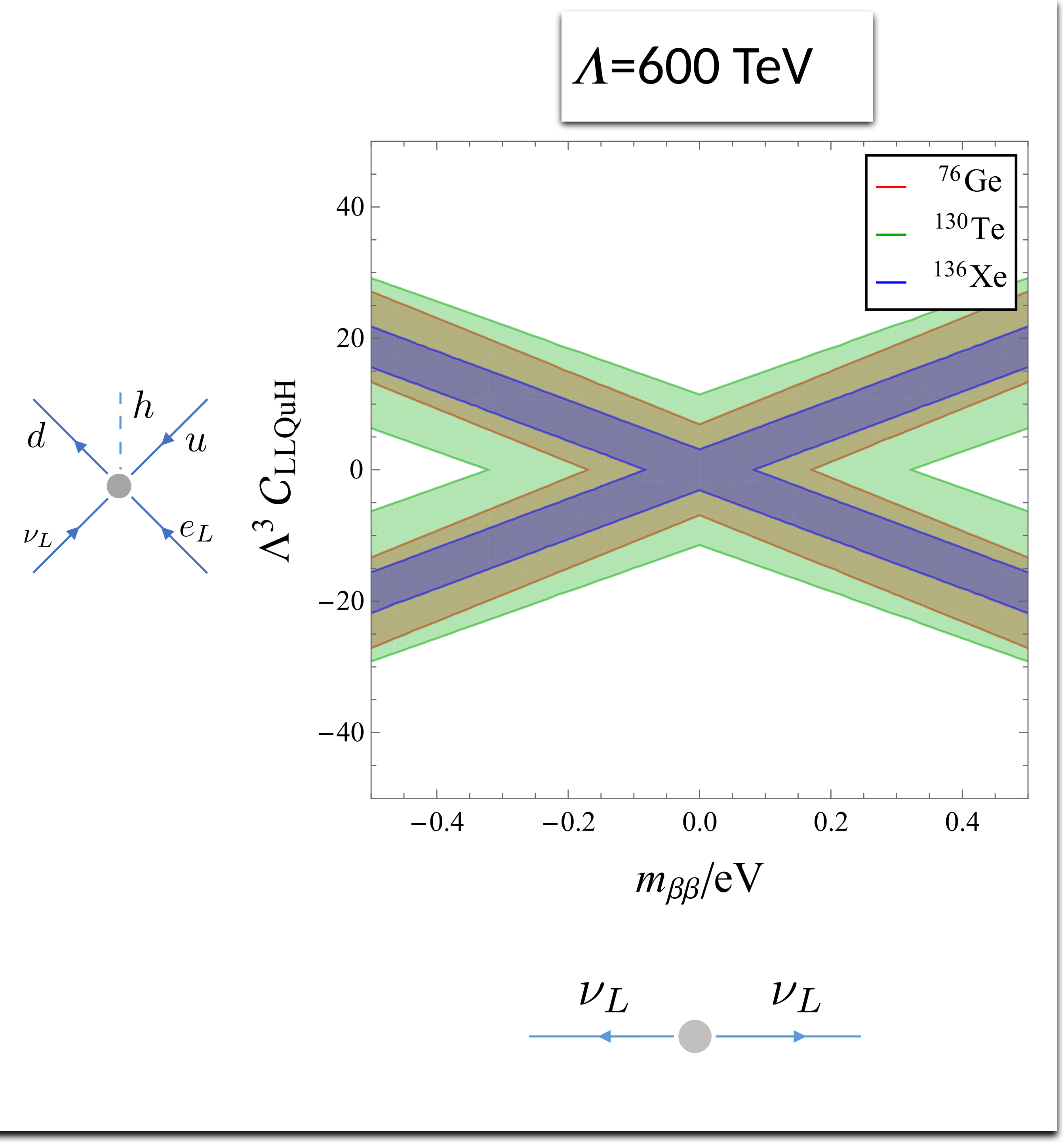
- Couplings with $C_i \sim v^5/\Lambda^5$

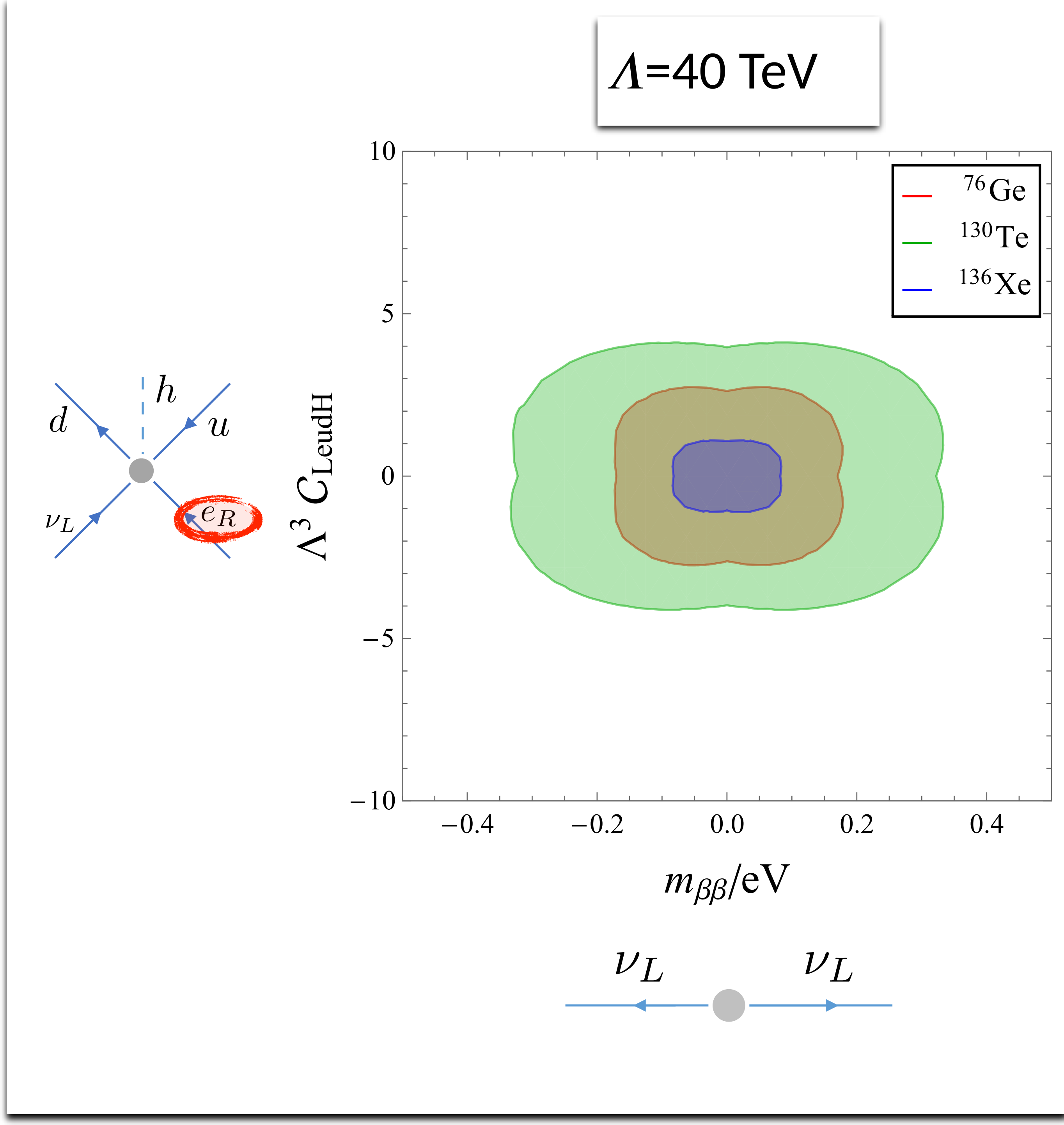




Current limits

Two-coupling analysis





Light (almost) sterile neutrinos

Based on arXiv:2002.07182

G. Zhou, K. Fuyuto, J. de Vries, E. Mereghetti, WD

Sterile neutrinos

- Could play a role in leptogenesis Canetti et al. '13
- Provides a dark matter candidate Boyarski et al. '19
- Appear in Left-Right models / Leptoquark scenarios / Grand Unified Theories
- Have been suggested as a solution to neutrino oscillation experiments Böser et al. '19

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- Add sterile effects by including:

$$\mathcal{L}_{\nu_R} = i\bar{\nu}_R \partial\!\!\!/ \nu_R - \frac{1}{2}\bar{\nu}_R^c M_R \nu_R - \bar{L}\tilde{H} Y_D \nu_R + \mathcal{L}_{\nu_R}^{(6)} + \mathcal{L}_{\nu_R}^{(7)}$$

see also Blennow et al, ’10; Barea et al, ’15; Giunti et al, ’15; Bolton et al, ’19;

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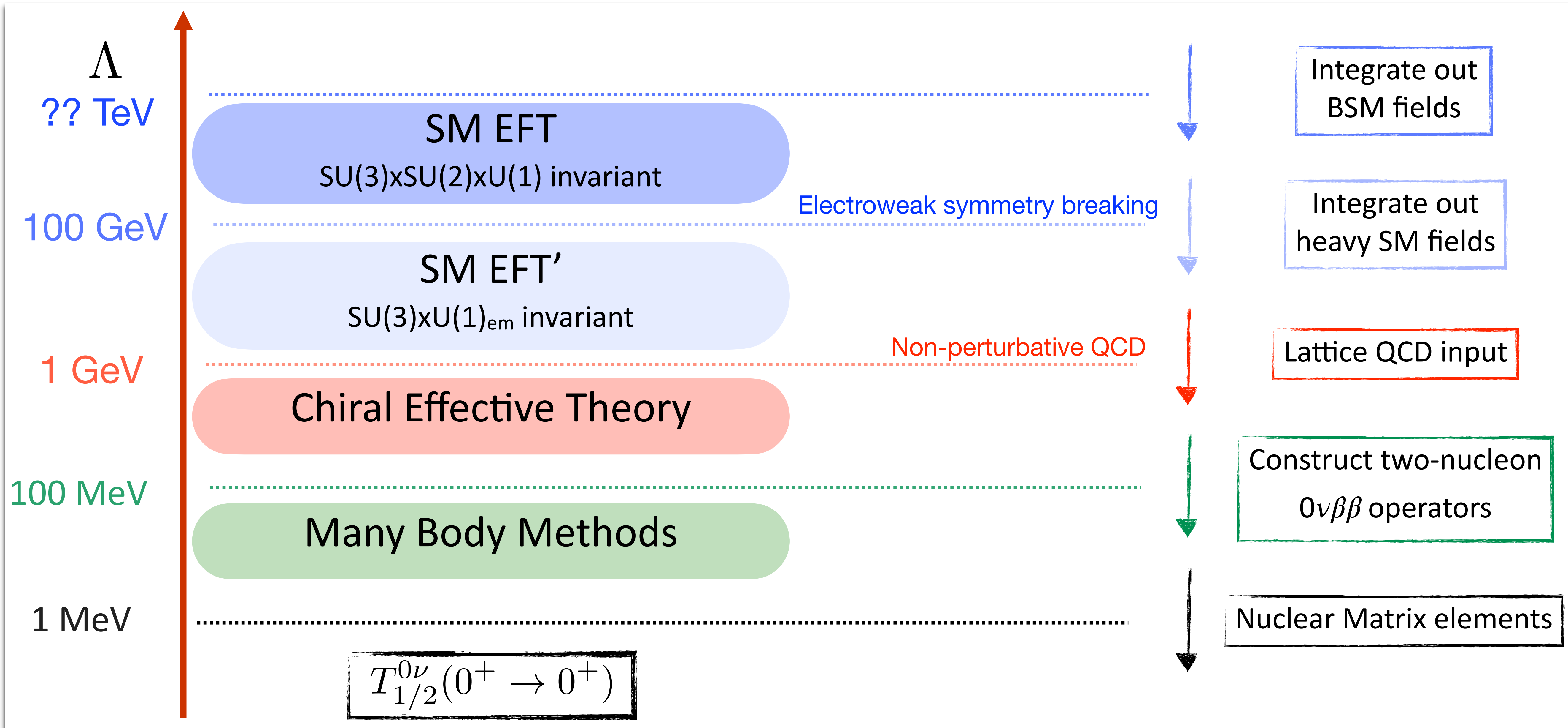
- Majorana mass (L violating)
- Dirac mass (L conserving)

- Dimension-6 (L-conserving)
- Dimension-7 operators (L-violating)
- Induced by heavy BSM physics

see also Blennow et al, ’10; Barea et al, ’15; Giunti et al, ’15; Bolton et al, ’19;

Sterile neutrinos

Can now go through the same steps as before:



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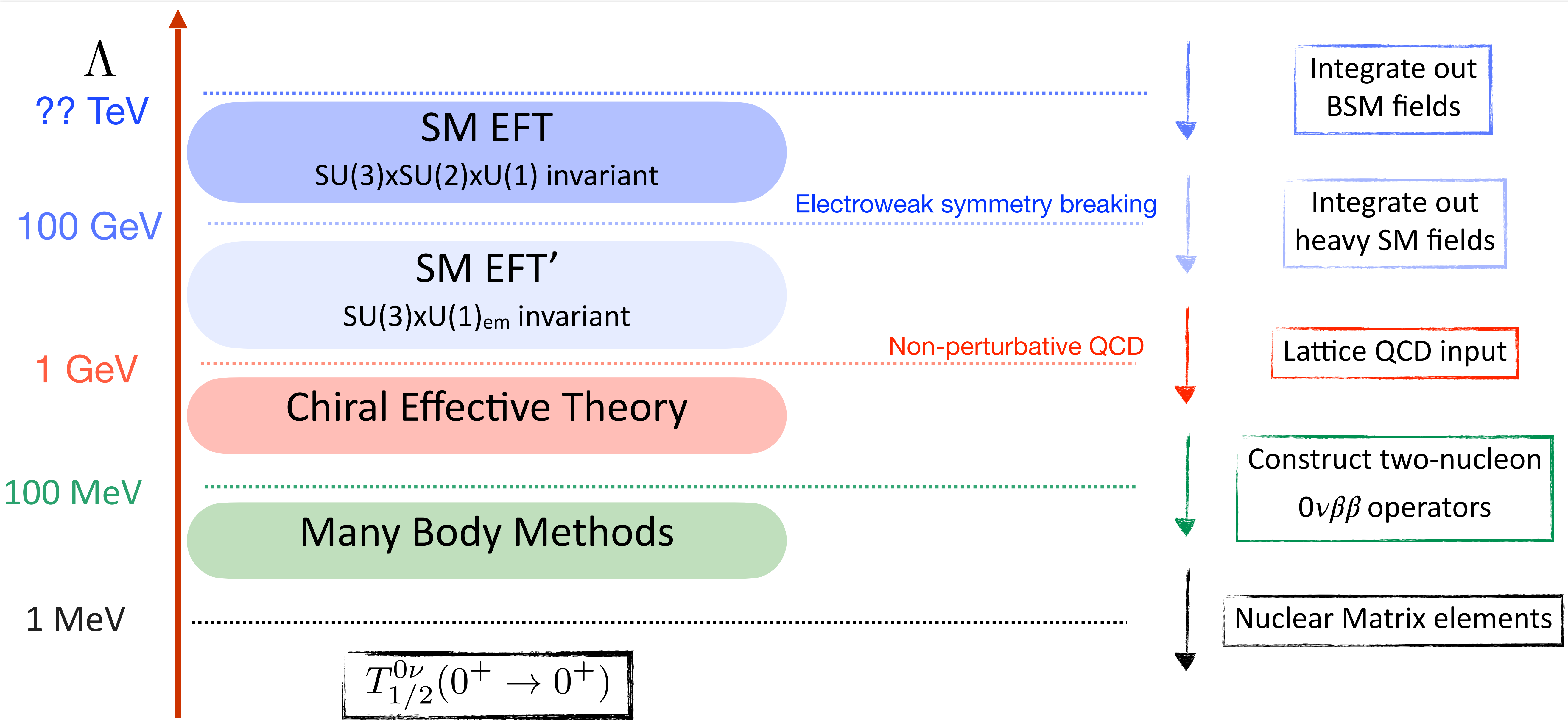
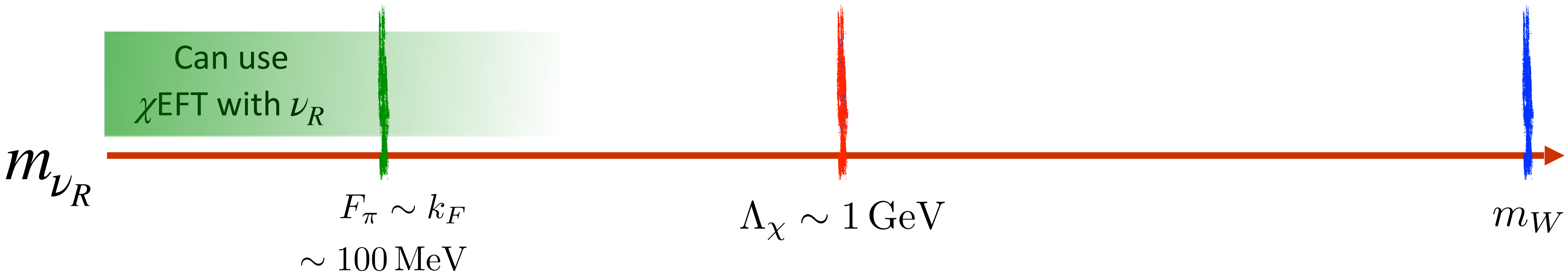


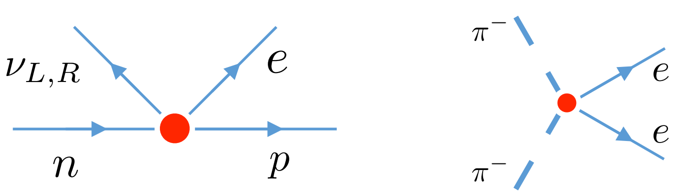
- EFT now includes ν_R as explicit degrees of freedom
- LECs and NMEs now depend on m_{ν_R}
- When/if ν_R can be integrated out depends on m_{ν_R}

Sterile neutrinos

Complication: m_{ν_R} dependence



- Chiral EFT involving ν_R



$$A \propto m_{\nu_R}$$

Sterile neutrinos

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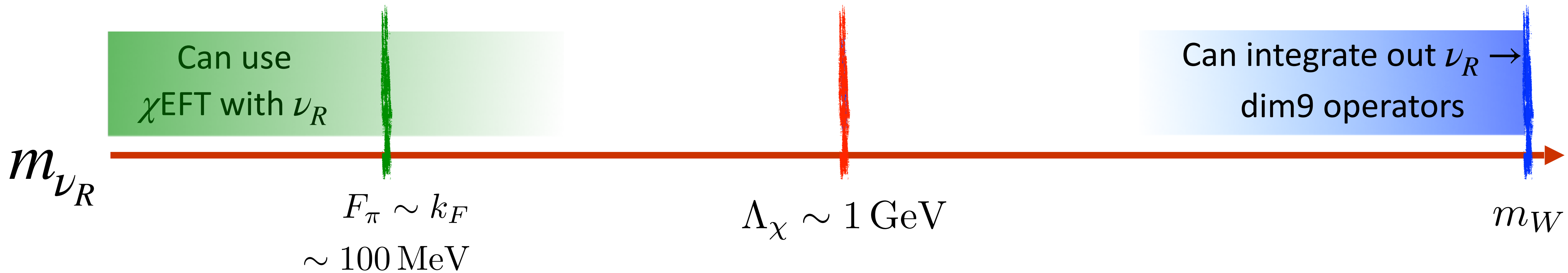

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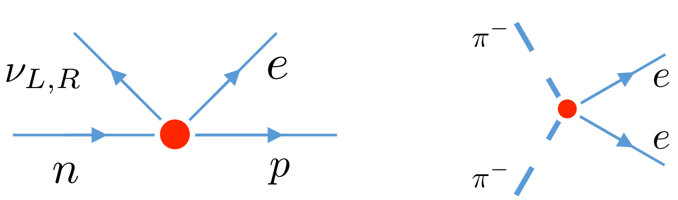
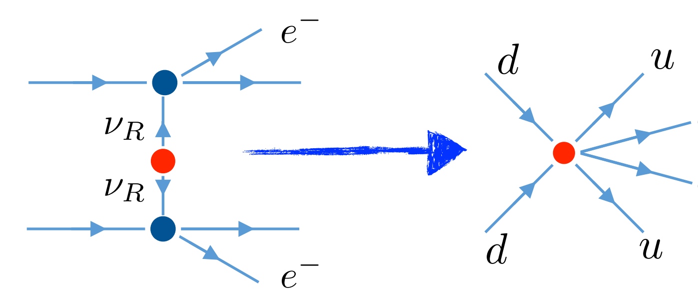


- Integrate out ν_R



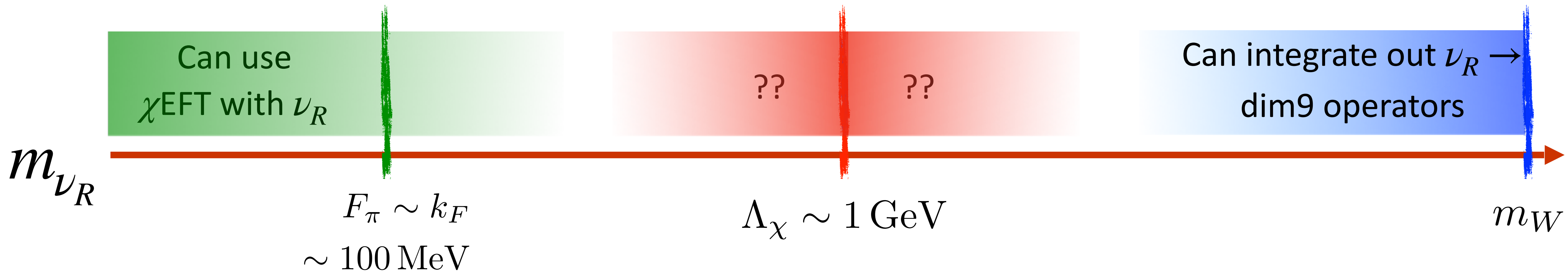
$\rightarrow$ Chiral EFT without ν_R

$A \propto m_{\nu_R}$

$A \propto m_{\nu_R}^{-1}$

Sterile neutrinos

Complication: m_{ν_R} dependence



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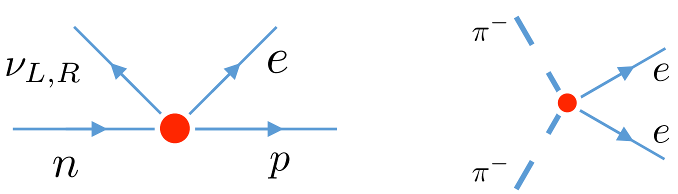
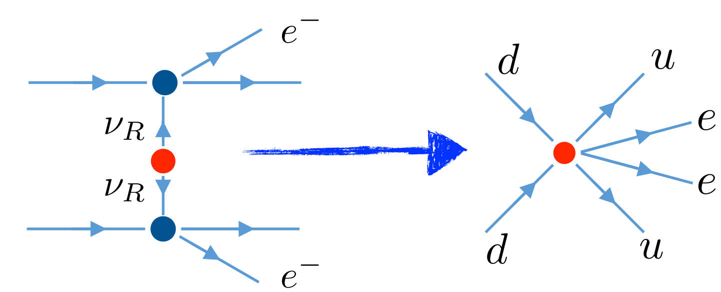


- Neither EFT works well here
  - Missing operators ~ Λ_χ / m_{ν_R}
  - Loop corrections ~ m_{ν_R} / Λ_χ

- Integrate out ν_R



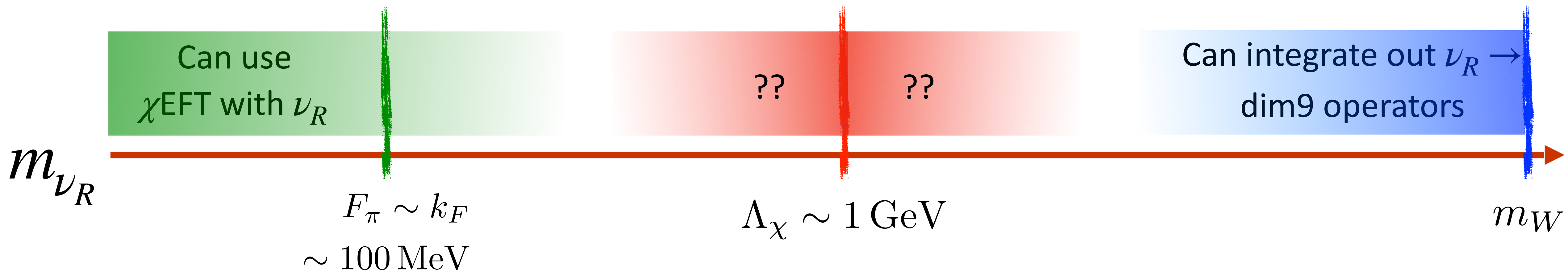
→ Chiral EFT without ν_R

$A \propto m_{\nu_R}$

$A \propto m_{\nu_R}^{-1}$

Sterile neutrinos

Complication: m_{ν_R} dependence



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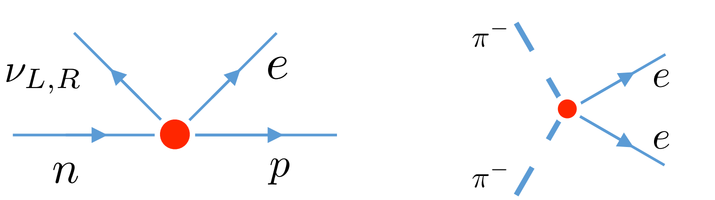

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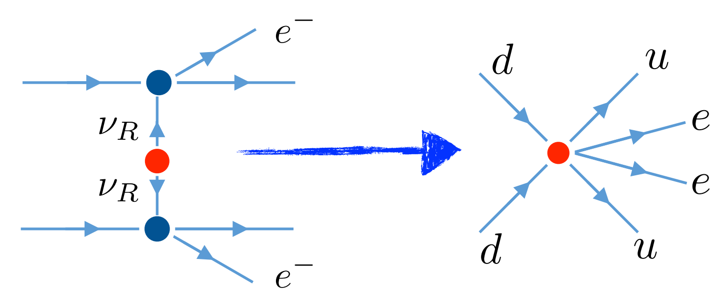

$\rightarrow$ Chiral EFT without ν_R

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Interpolate

$A \propto m_{\nu_R}^{-1}$

Sterile neutrinos

Toymodel

- SM + a sterile neutrino + a leptoquark

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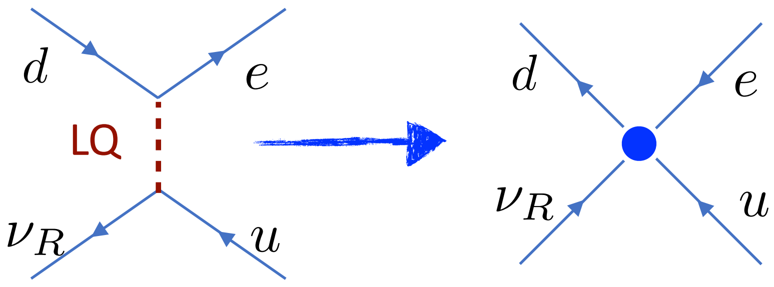

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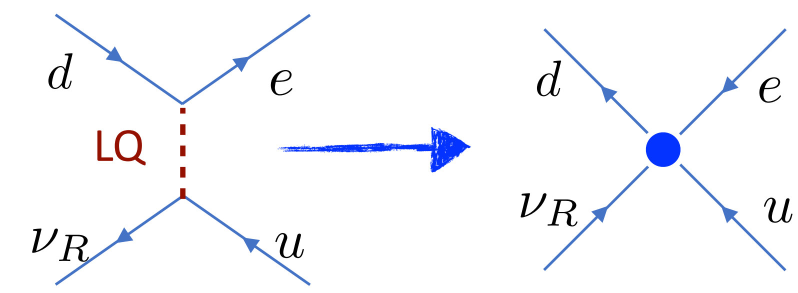

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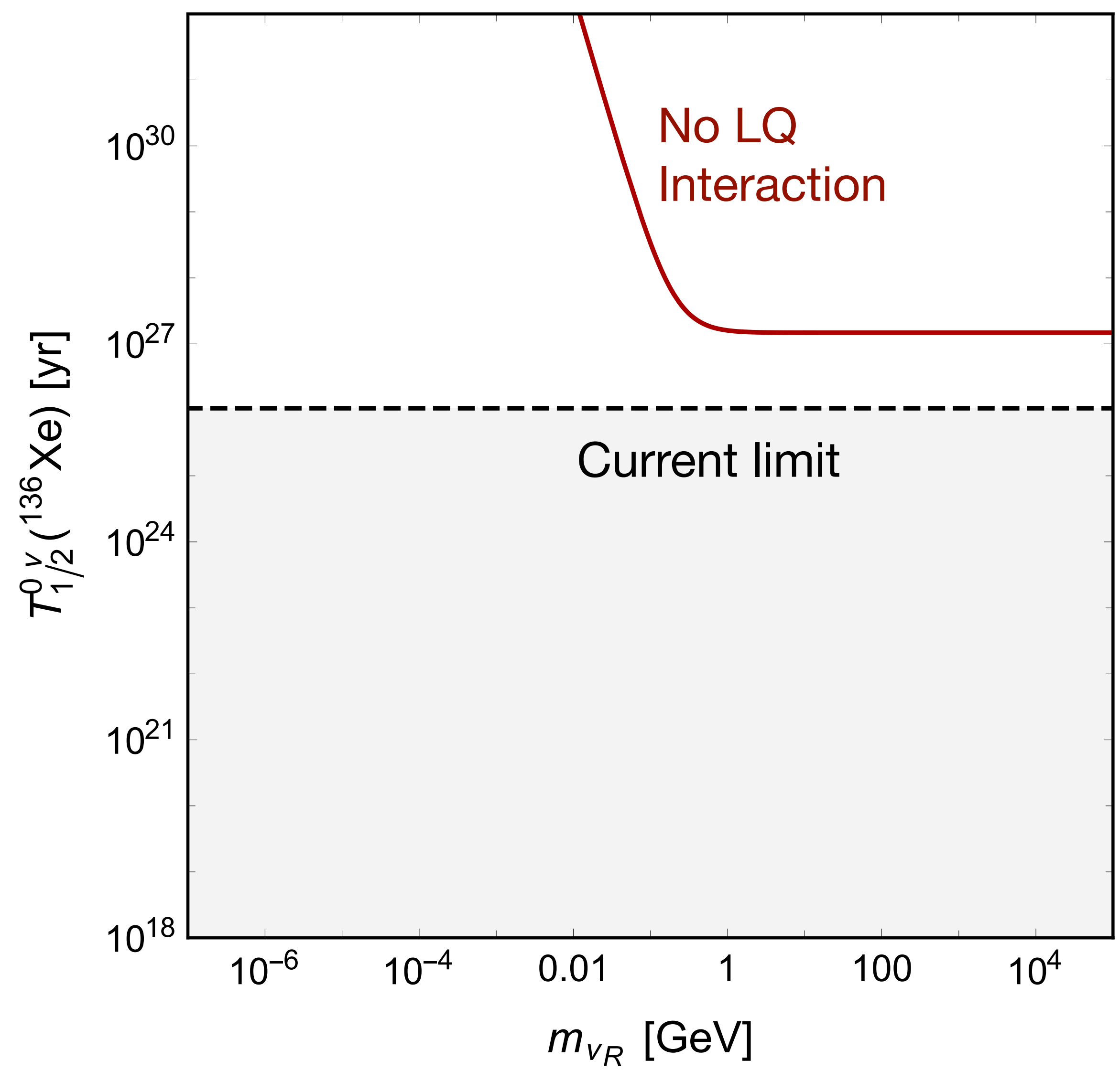

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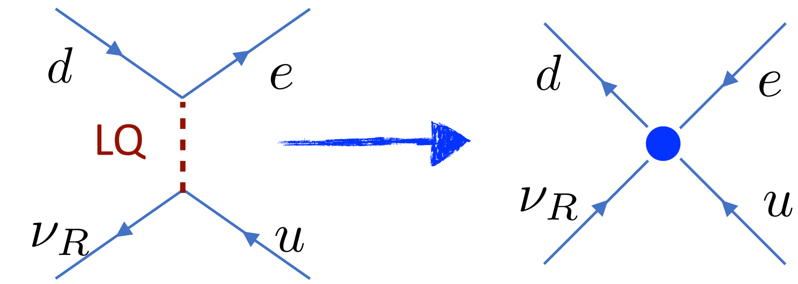
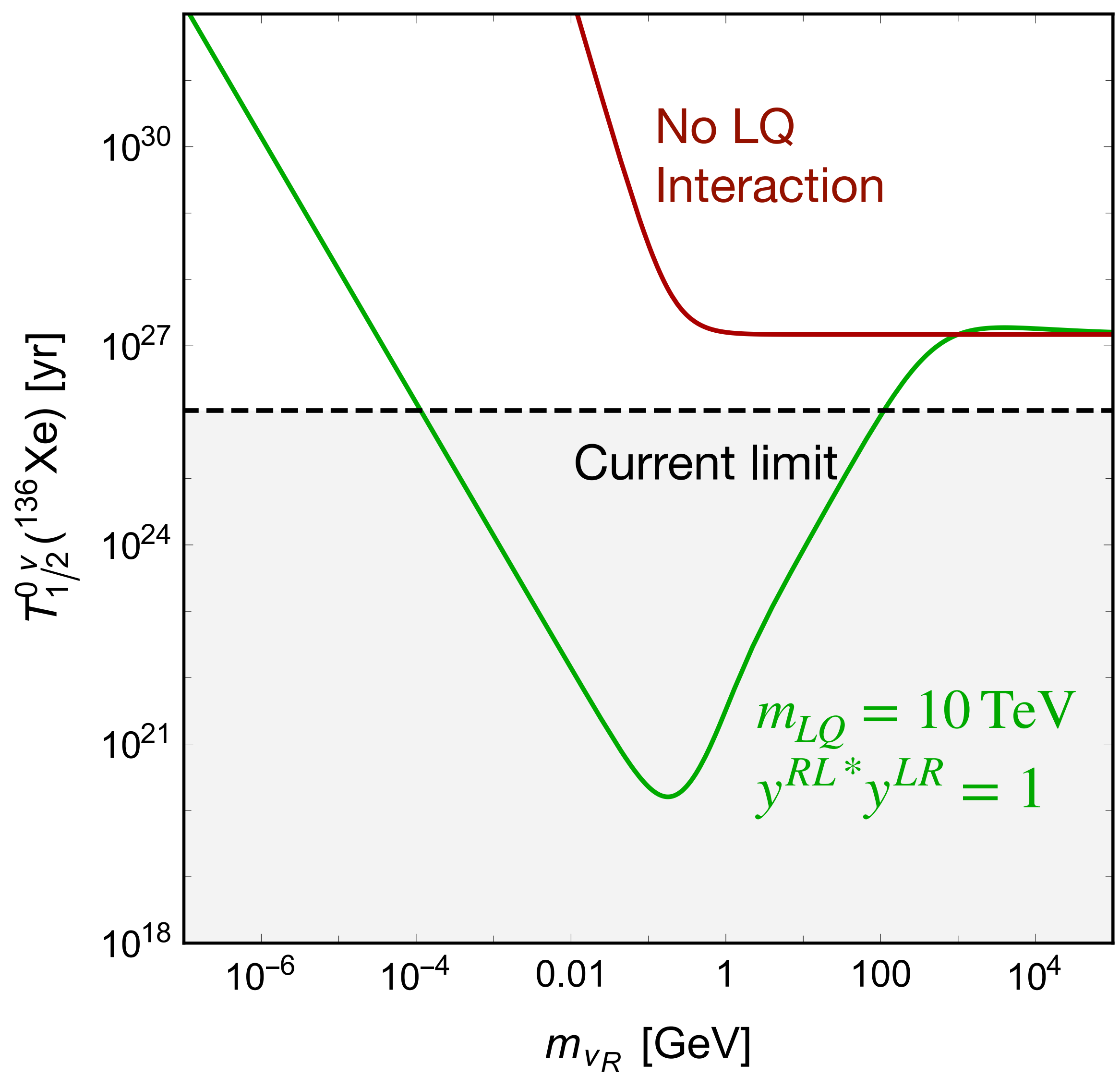


- Cannot reproduce neutrino masses/mixings

- Non-standard interactions have a large effect

- Similar large effects in more realistic models



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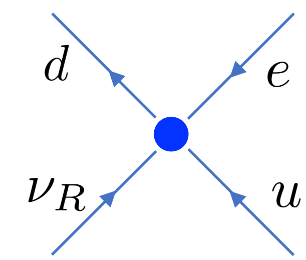
Sterile neutrinos

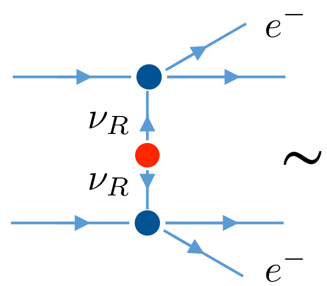
Complementarity with other probes

- The dimension-six ν_R operators also induce:
  - Neutron & nuclear β decays
  - LHC signatures, $pp \to e\nu$
- What can $0\nu\beta\beta$ say if these probes find a signal?



$\sim C_6$

β decay, $pp \to e\nu$



$\sim m_{\nu_R} C_6^2$

$0\nu\beta\beta$

Sterile neutrinos

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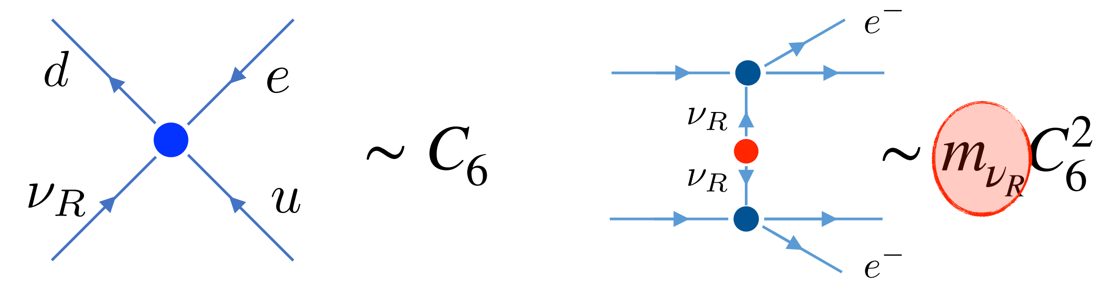


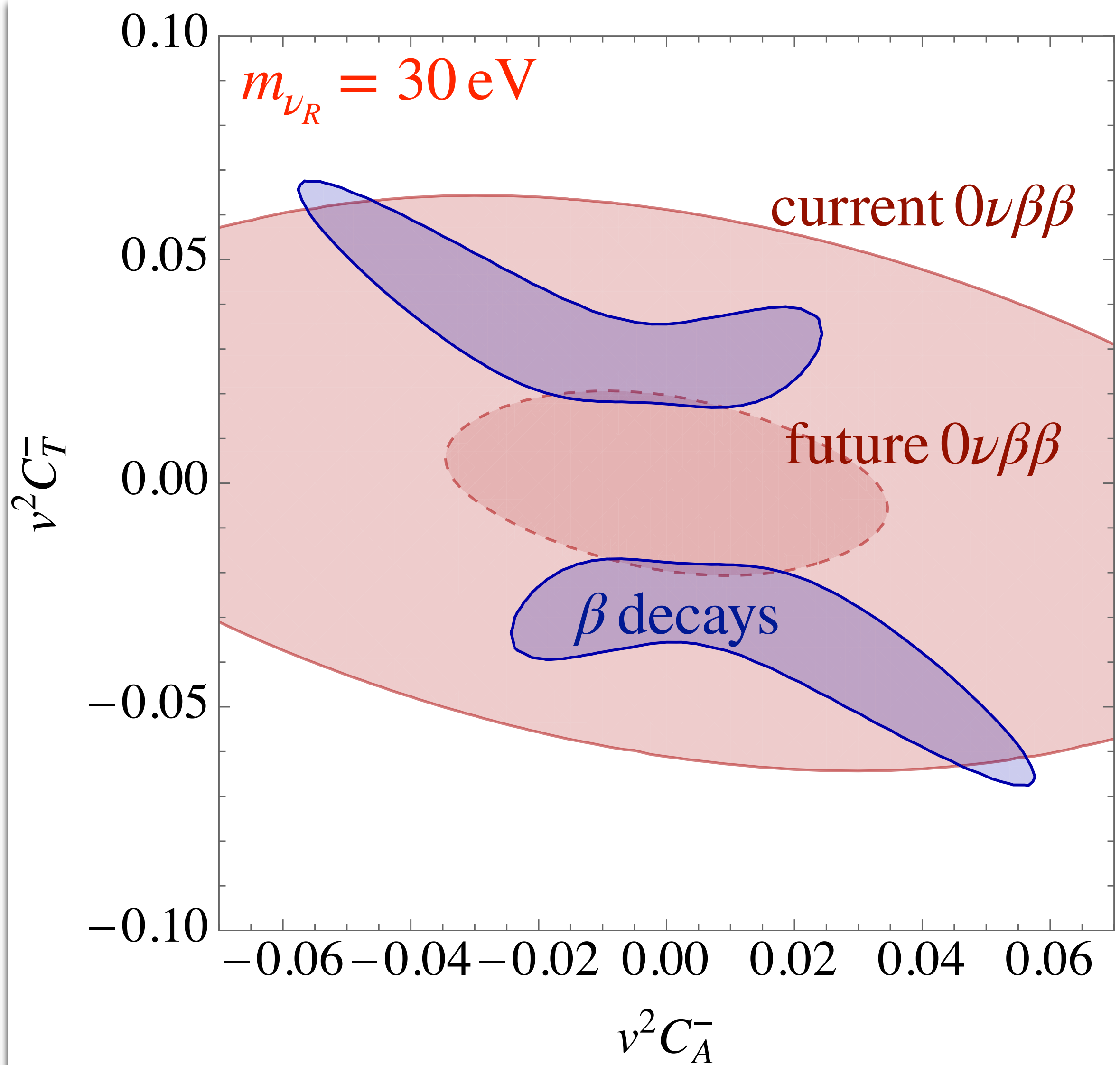
β decay, $pp \to e\nu$ $0\nu\beta\beta$

- β-decay fit has preference for BSM interactions
  - Driven by one experiment [aSPECT, '19]
  - Unclear if LHC can be satisfied in UV completions

Falkowski, González-Alonso, Naviliat-Cuncic, '20

- If such a signal is confirmed
  - $0\nu\beta\beta$ constrains m_{ν_R} for Majorana neutrinos

Tong, de Vries, WD, '20



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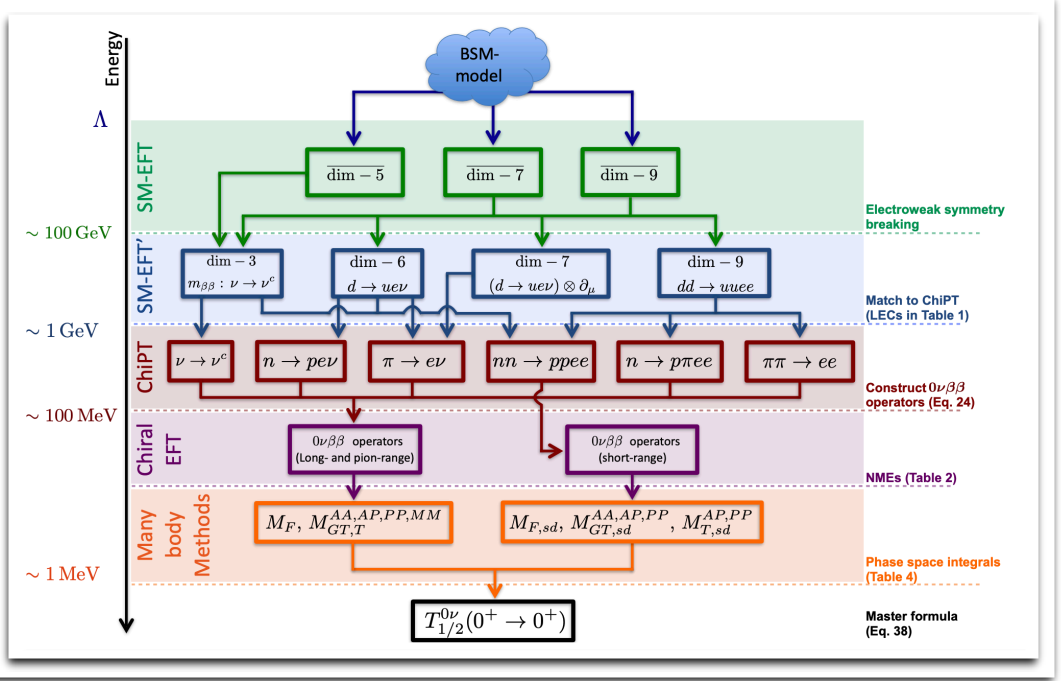
Summary

- EFTs allow one to systematically describe ΔL=2 sources
  - Standard mechanism (dim-5)
  - Dimension-7 & -9 sources
  - Effects from ν_R



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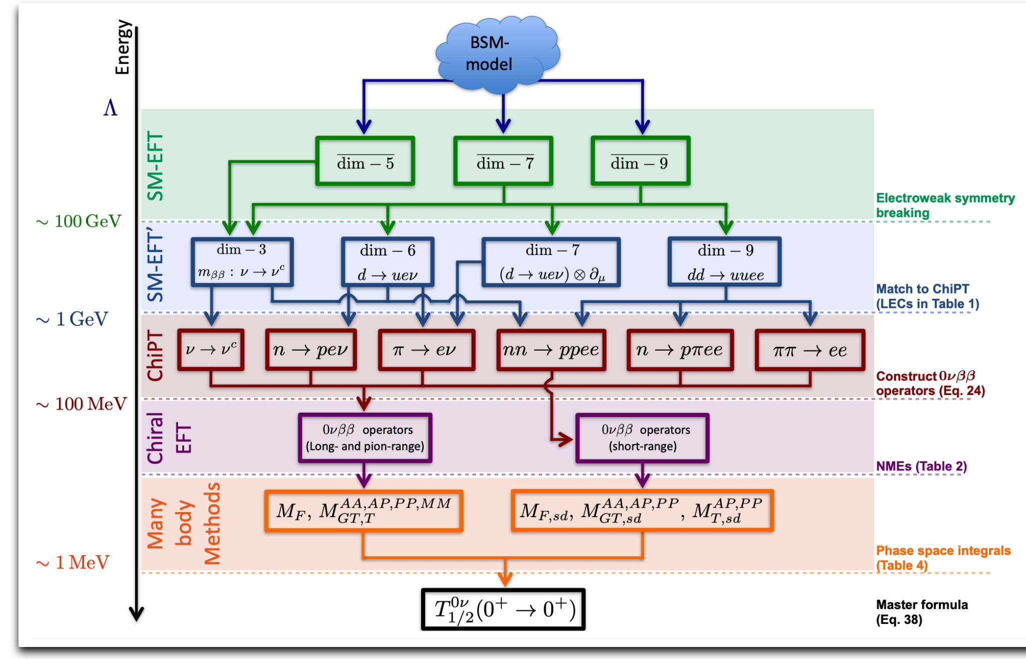
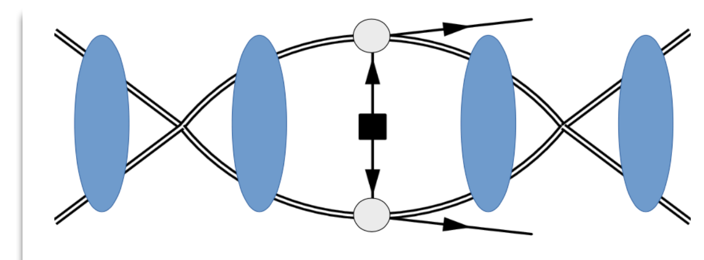
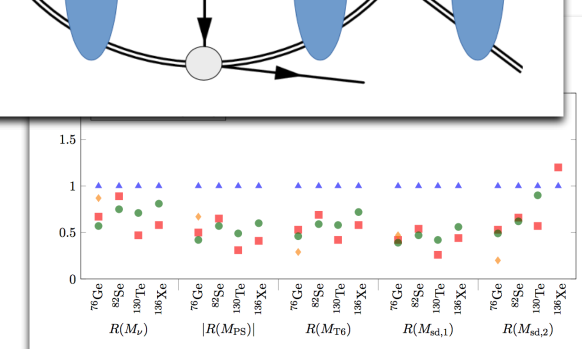


- Matching to chiral EFT involves unknown LECs
  - Renormalization requires terms beyond Weinberg counting
    - Can in principle be determined from LQCD





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  - Effect of 'new' LECs up to ~60% in light nuclei

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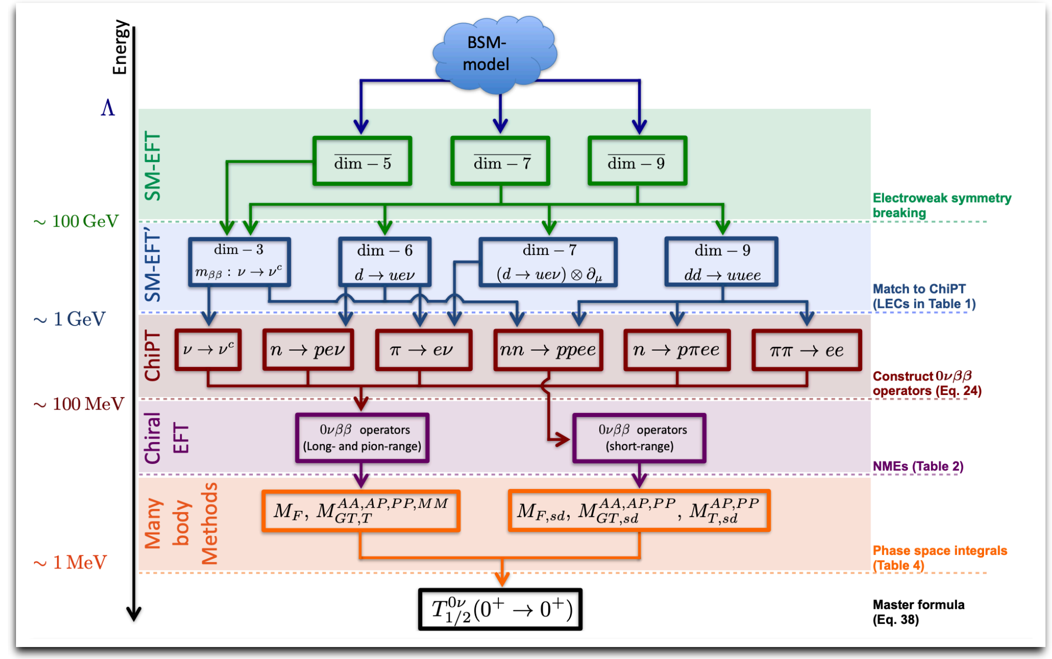

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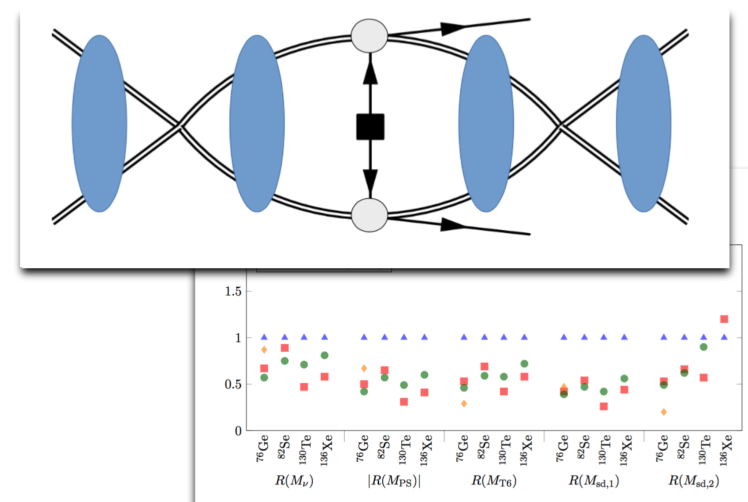
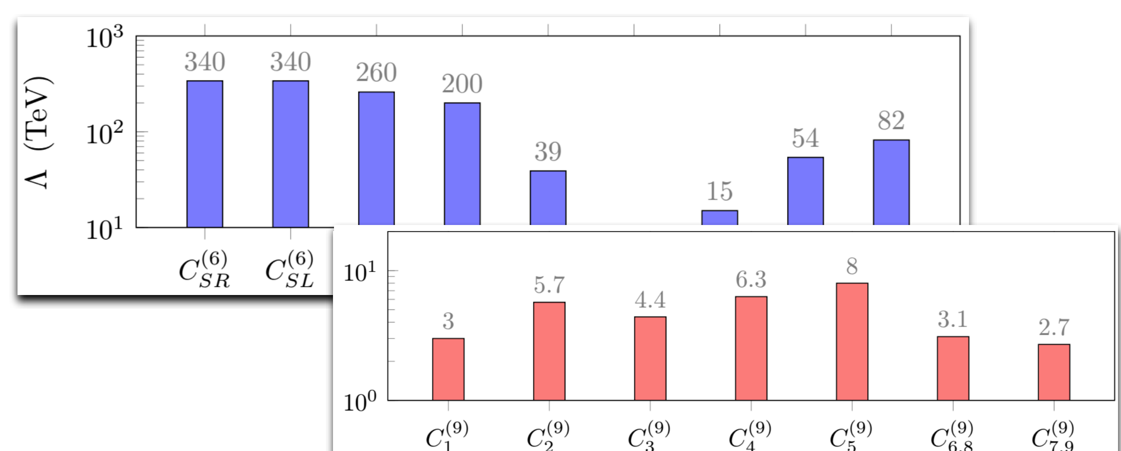


- $0\nu\beta\beta$ can probe
  - O(1-10) TeV scales for dim-9
  - O(100) TeV scales for dim-7
  - O(10) TeV scales for ν_R interactions



- Order 1 LECs + NMEs uncertainties