Doubly-charged scalars at high-energy and high-precision experiments

BHUPAL DEV

Washington University in St. Louis

with M. J. Ramsey-Musolf (UMass) and Y. Zhang (WashU), arXiv:1805.0xxxx

PHENO 2018

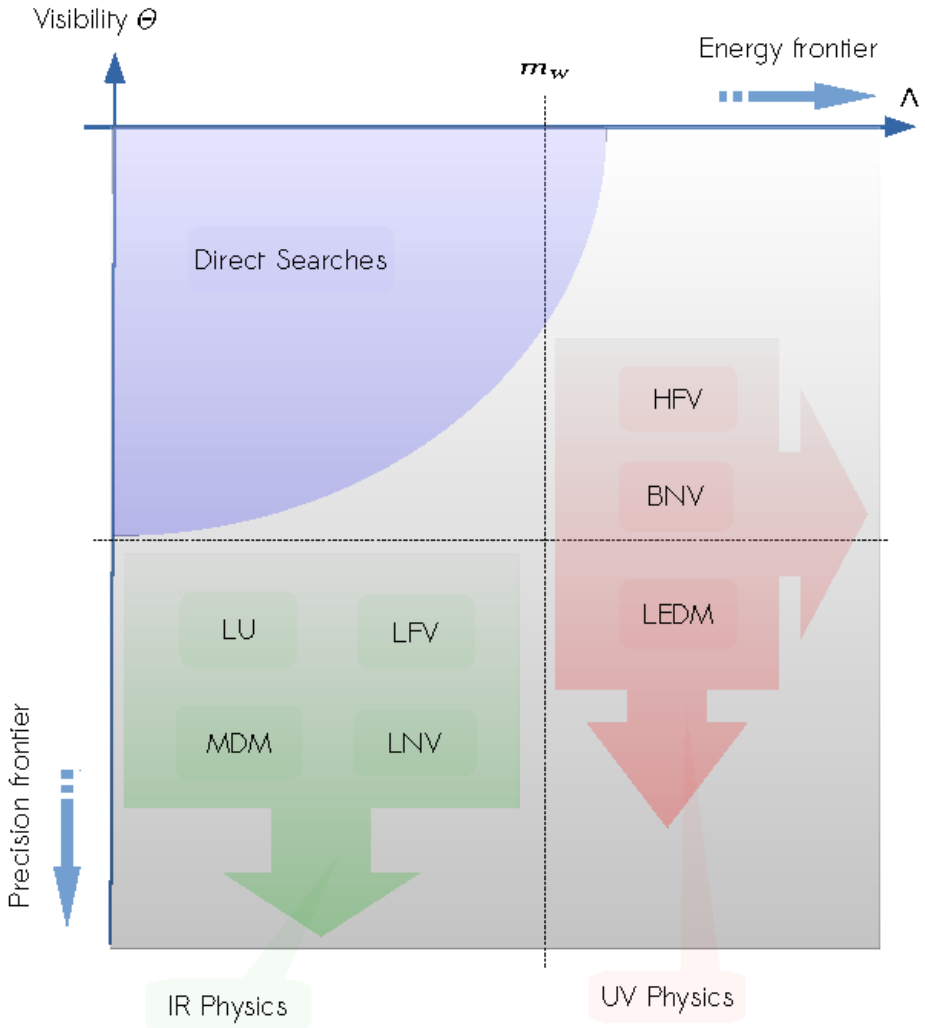
University of Pittsburgh

May 8, 2018

Outline

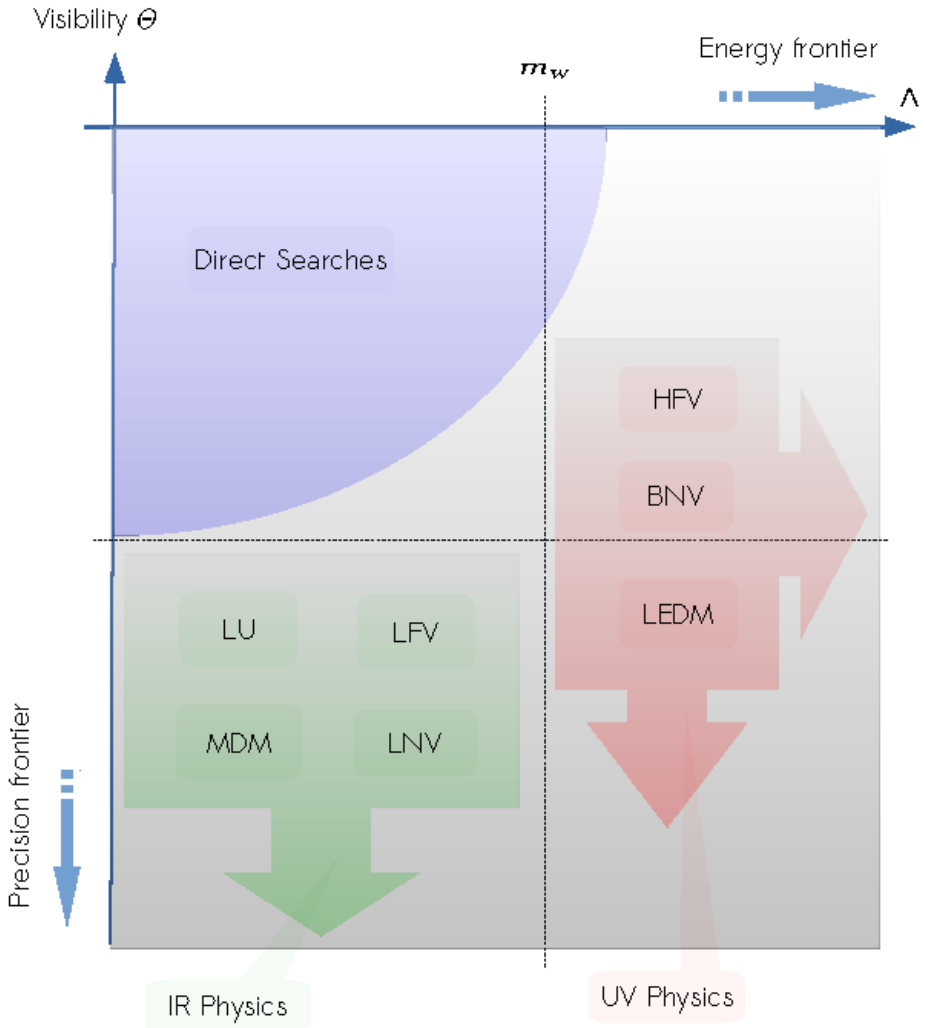
- Introduction: Energy versus Precision Frontier
- Example: LHC versus MOLLER
- A case study: Doubly charged scalar
- Conclusion

Two Frontiers: Energy versus Precision



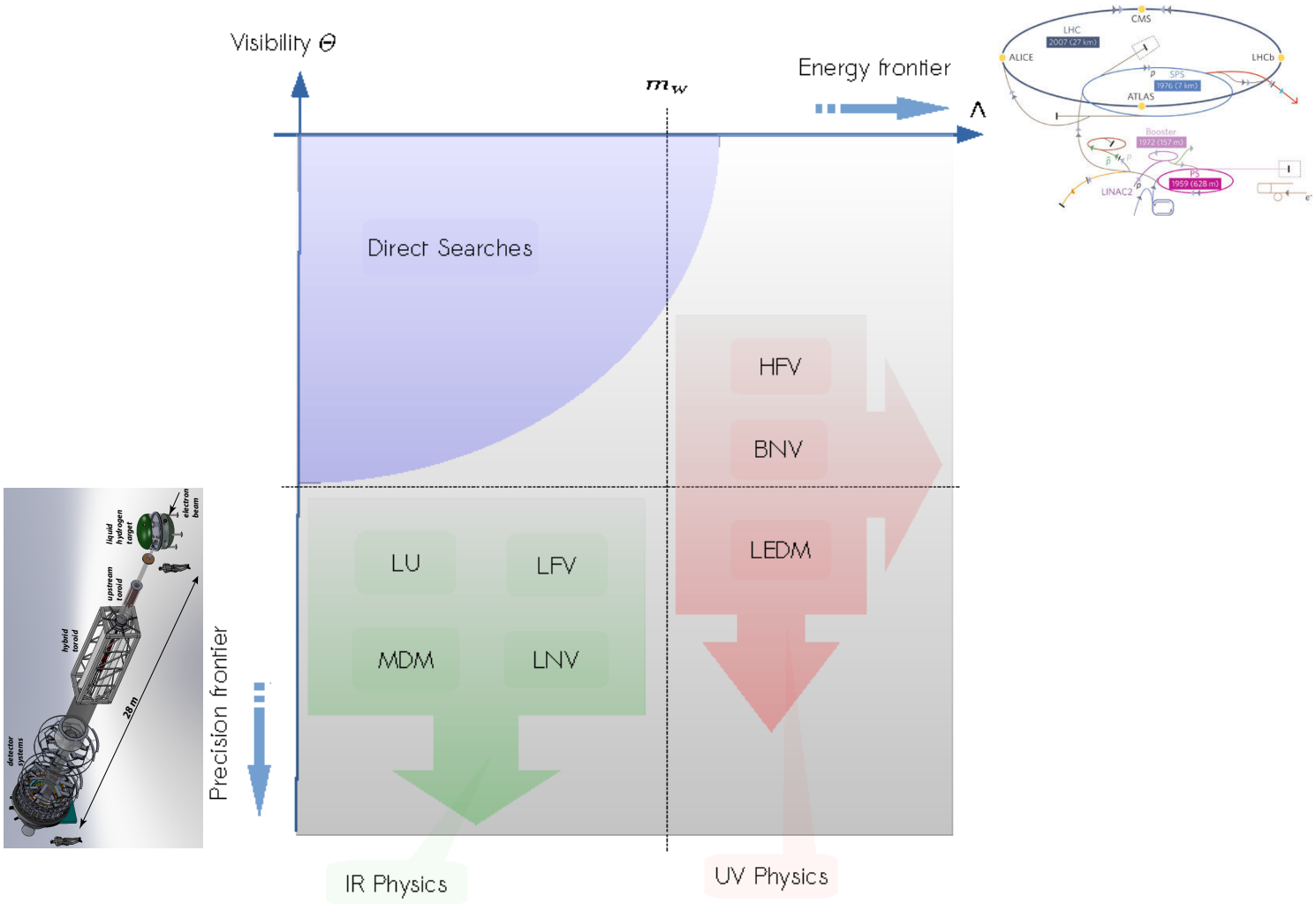
[Le Dall, Pospelov, Ritz (PRD '15)]

Two Frontiers: Energy versus Precision



Complementary and intertwined. Need input from both to probe new physics.

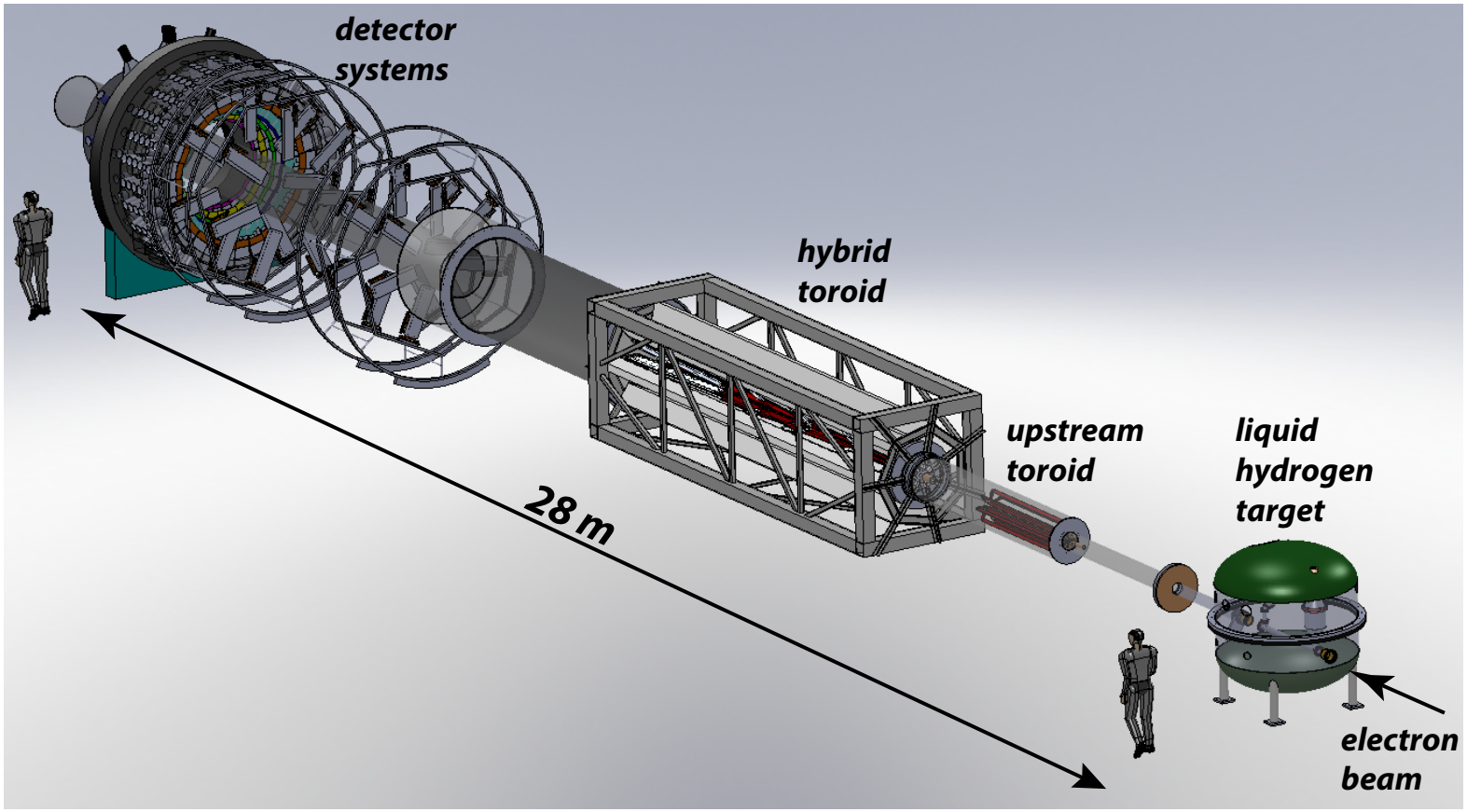
Two Frontiers: Energy versus Precision



Example: LHC versus MOLLER

MOLLER Experiment

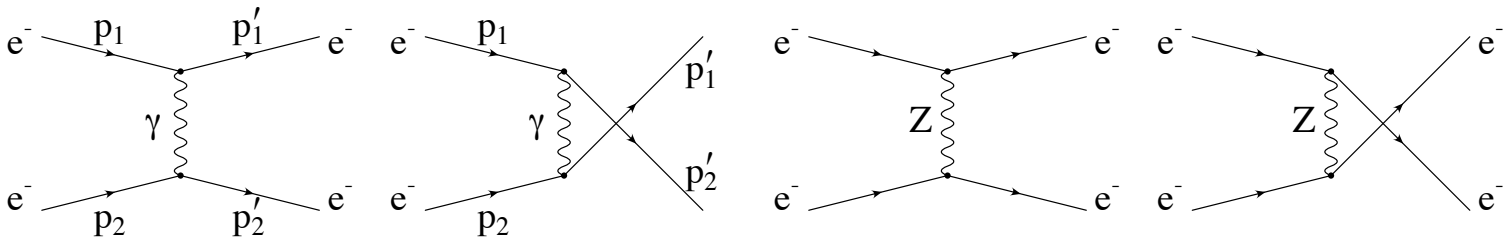
Measurement **O**f a **L**epton **L**epton **E**lectroweak **R**eaction



- Scattering of longitudinally polarized electrons off unpolarized electrons.
- Upgraded 11 GeV electron beam in Hall A at JLab.

Parity-Violating Asymmetry

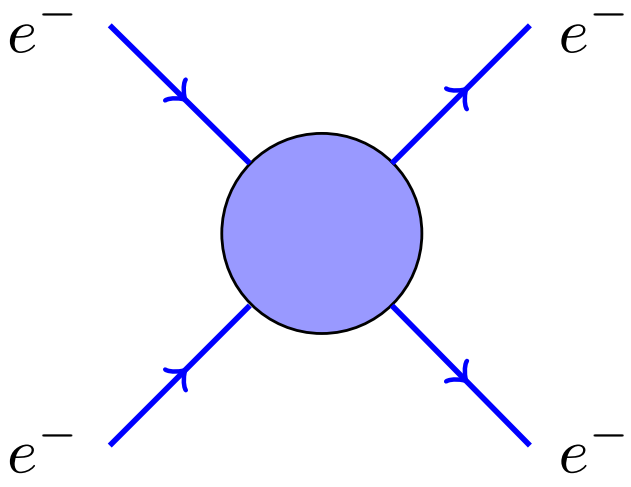
$$A_{\rm PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$$



$$A_{\rm PV}^{\rm SM} = mE\frac{G_F}{\sqrt{2}\pi\alpha}\frac{2y(1-y)}{1+y^4+(1-y)^4}Q_W^e$$

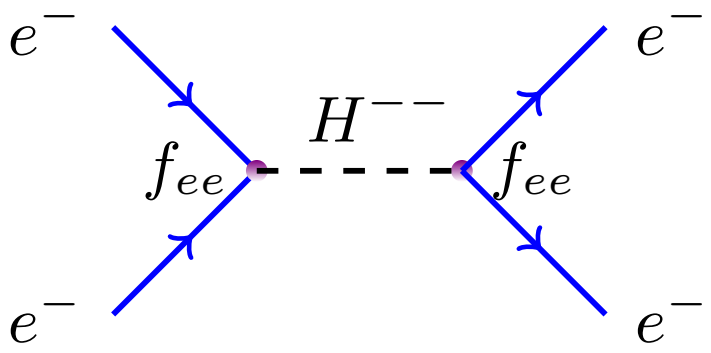
- For the MOLLER design, $A_{\rm PV}^{\rm SM} \approx 33$ ppb (including 1-loop effect).
- **Goal:** $\delta A_{\rm PV} = 0.7$ ppb. [J. Benesch *et al.* [MOLLER Collaboration], arXiv:1411.4088 [nucl-ex]]
- Achieve a 2.4% precision in the measurement of Q_W^e.

Sensitive to New Physics



$$\frac{\Lambda}{\sqrt{|g_{RR}^2 - g_{LL}^2|}} = \frac{1}{\sqrt{\sqrt{2}G_F|\Delta Q_W^e|}} \simeq 7.5 \text{ TeV}$$

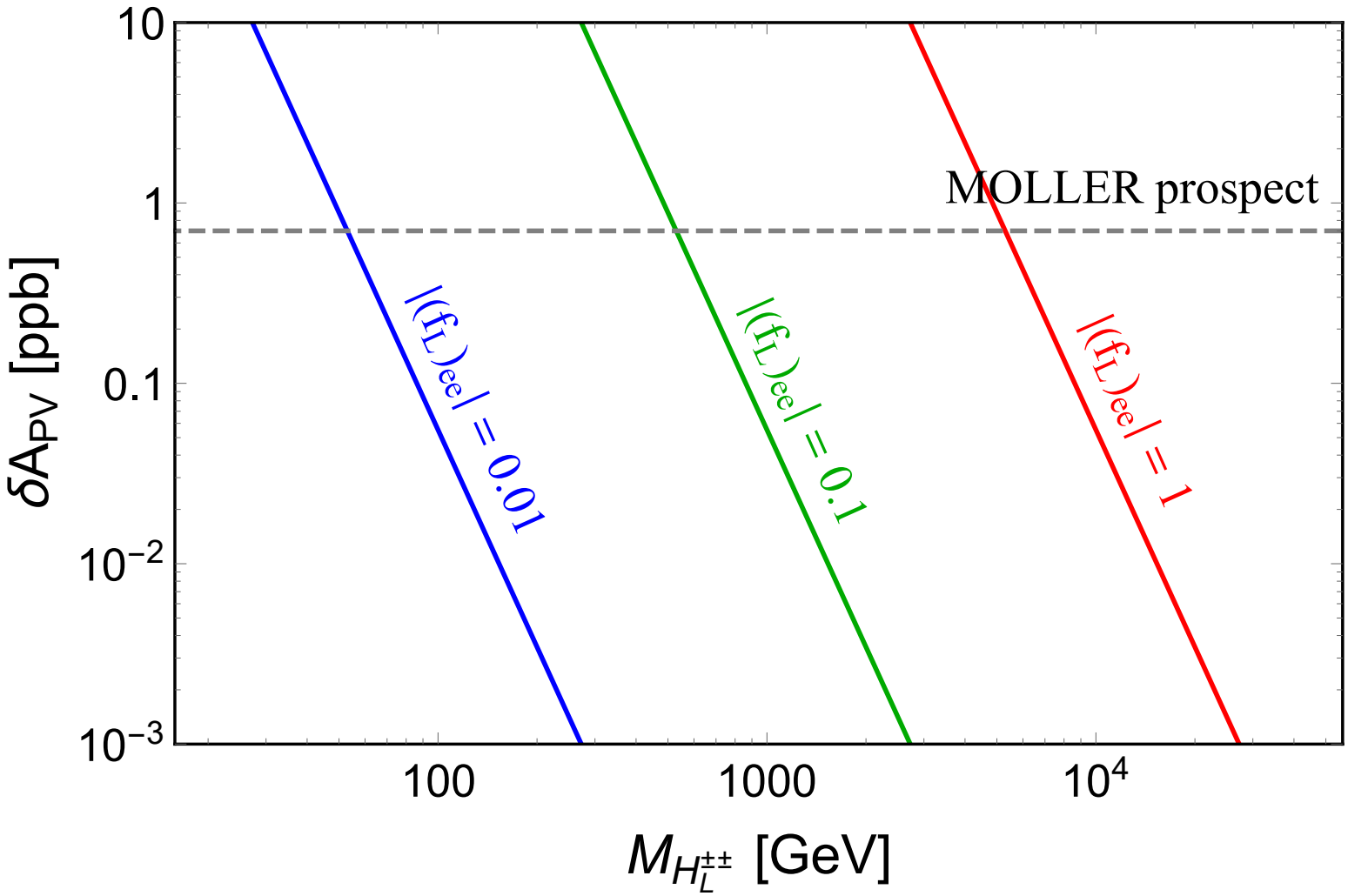
Case Study: Doubly Charged Scalar



$$\mathcal{M}_{\rm PV} \sim \frac{|(f_L)_{ee}|^2}{2(M_L^{\pm\pm})^2}(\bar{e}_L\gamma^\mu e_L)(\bar{e}_L\gamma_\mu e_L) + (L \leftrightarrow R)\,.$$

MOLLER Sensitivity : $\dfrac{M_{H_{L,R}^{\pm\pm}}}{|(f_{L,R})_{ee}|} \gtrsim 5.3$ TeV .

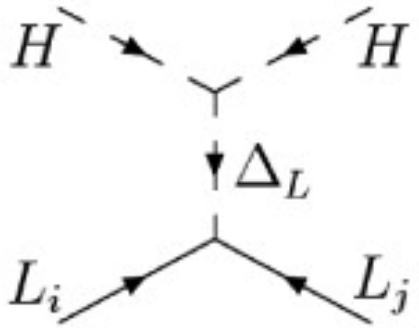
Case Study: Doubly Charged Scalar



[BD, Ramsey-Musolf, Zhang '18]

Why Doubly Charged Scalar?

Neutrino Mass via **Type-II Seesaw**



$$\mathcal{L}_Y \;=\; -\,(f_L)_{ij}\,\psi^{\mathsf{T}}_{L,\,i}C\mathrm{i}\sigma_2\Delta_L\psi_{L,\,j} \;+\; \mathrm{H.c.}$$

$$m_\nu \;=\; \sqrt{2}f_L v_\Delta \;=\; U\widehat{m}_\nu U^{\mathsf{T}}\,.$$

[Schechter, Valle (PRD '80); Mohapatra, Senjanović (PRD '81); Lazarides, Shafi, Wetterich (NPB '81)]

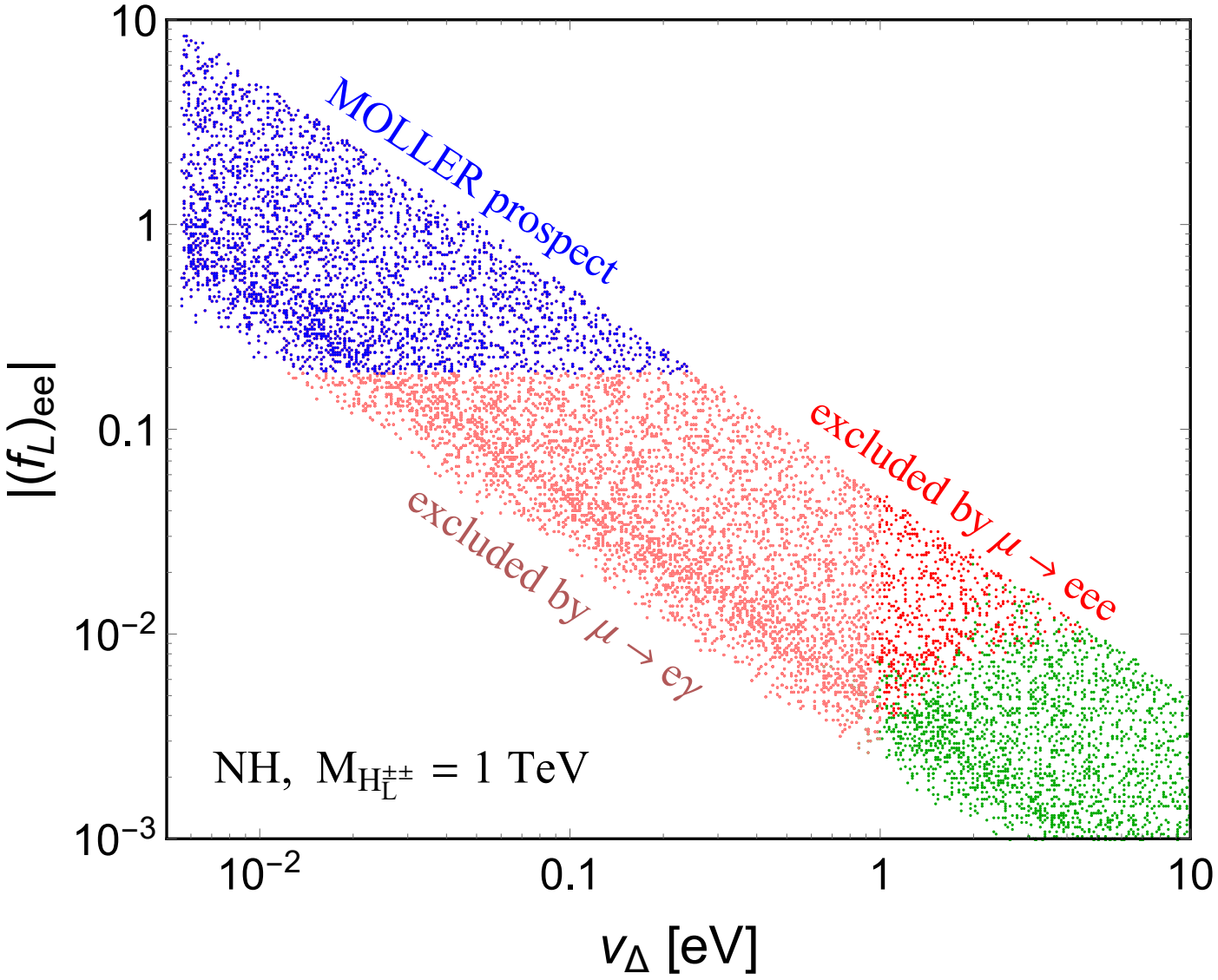
Fixes the elements of f_L (up to an overall scale)

LFV Constraints

Process	Experimental limit on BR	Constraint on	Bound $\times \left(\frac{M_{H_L}}{100\ \text{GeV}}\right)^2$
$\mu \to e\gamma$	$< 4.2 \times 10^{-13}$	$\lvert(f_L^\dagger f_L)_{e\mu}\rvert$	$< 2.4 \times 10^{-6}$
$\mu \to 3e$	$< 1.0 \times 10^{-12}$	$\lvert(f_L)_{\mu e}\rvert\lvert(f_L)_{ee}\rvert$	$< 2.3 \times 10^{-7}$
$\tau \to e\gamma$	$< 3.3 \times 10^{-8}$	$\lvert(f_L^\dagger f_L)_{e\tau}\rvert$	$< 1.6 \times 10^{-3}$
$\tau \to \mu\gamma$	$< 4.4 \times 10^{-8}$	$\lvert(f_L^\dagger f_L)_{\mu\tau}\rvert$	$< 1.9 \times 10^{-3}$
$\tau \to e^+e^-e^-$	$< 2.7 \times 10^{-8}$	$\lvert(f_L)_{\tau e}\rvert\lvert(f_L)_{ee}\rvert$	$< 9.2 \times 10^{-5}$
$\tau \to \mu^+\mu^-e^-$	$< 2.7 \times 10^{-8}$	$\lvert(f_L)_{\tau\mu}\rvert\lvert(f_L)_{\mu e}\rvert$	$< 6.5 \times 10^{-5}$
$\tau \to e^+\mu^-\mu^-$	$< 1.7 \times 10^{-8}$	$\lvert(f_L)_{\tau e}\rvert\lvert(f_L)_{\mu\mu}\rvert$	$< 7.3 \times 10^{-5}$
$\tau \to e^+e^-\mu^-$	$< 1.8 \times 10^{-8}$	$\lvert(f_L)_{\tau e}\rvert\lvert(f_L)_{\mu e}\rvert$	$< 5.3 \times 10^{-5}$
$\tau \to \mu^+e^-e^-$	$< 1.5 \times 10^{-8}$	$\lvert(f_L)_{\tau\mu}\rvert\lvert(f_L)_{ee}\rvert$	$< 6.9 \times 10^{-5}$
$\tau \to \mu^+\mu^-\mu^-$	$< 2.1 \times 10^{-8}$	$\lvert(f_L)_{\tau\mu}\rvert\lvert(f_L)_{\mu\mu}\rvert$	$< 8.1 \times 10^{-5}$

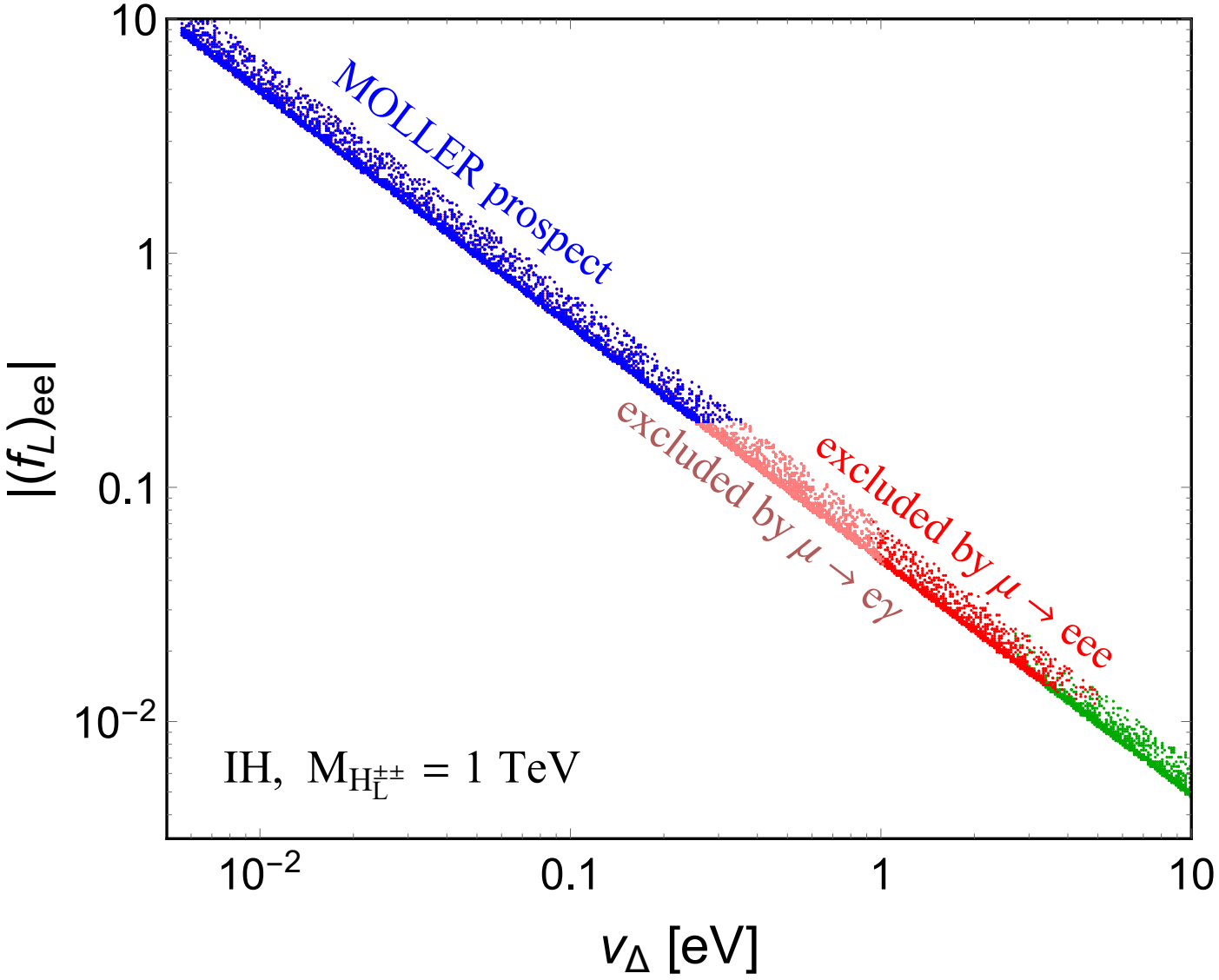
[BD, Rodejohann, Vila (NPB '17)]

MOLLER versus LFV



[BD, Ramsey-Musolf, Zhang '18]

MOLLER versus LFV



[BD, Ramsey-Musolf, Zhang '18]

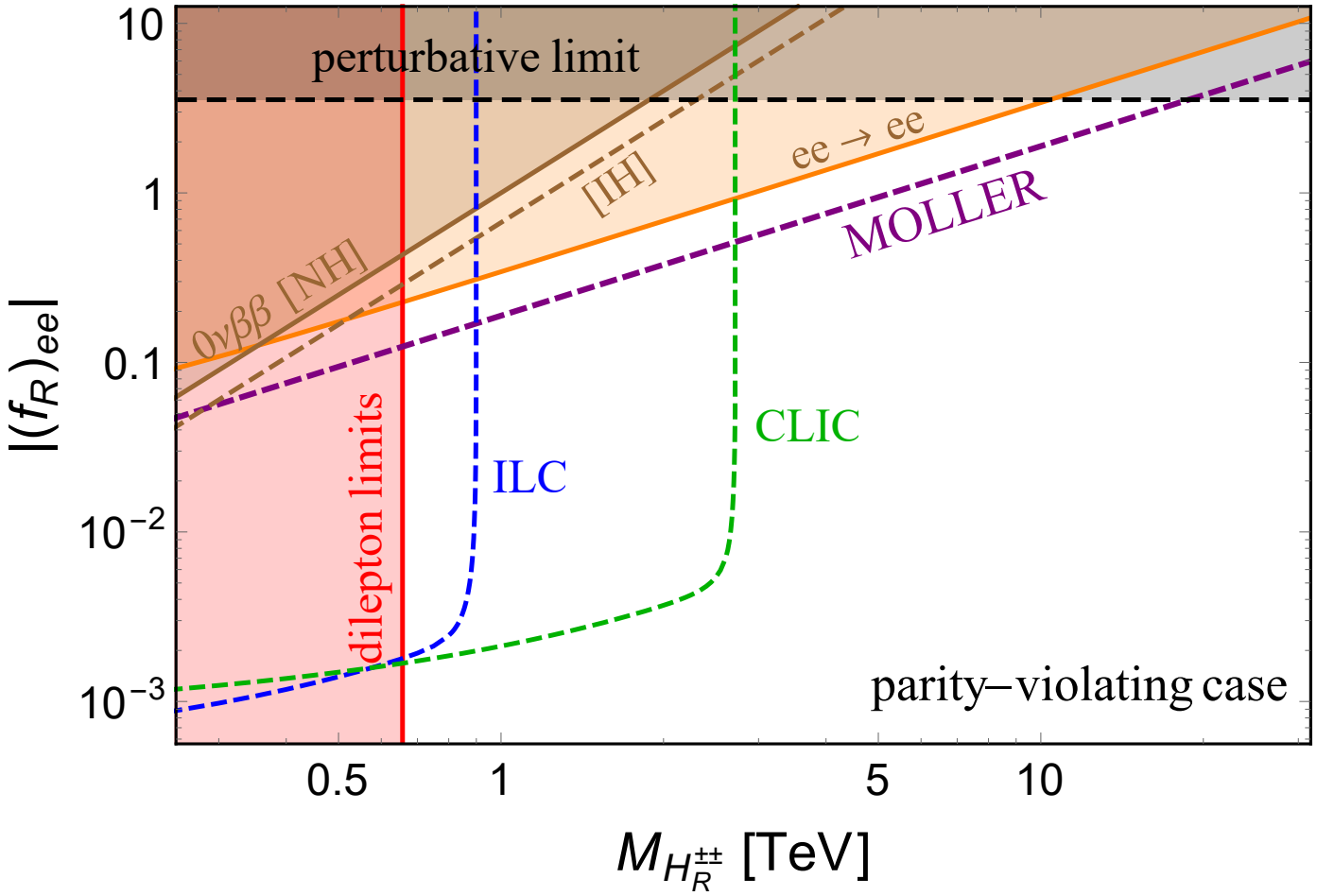
Parity-Violating Left-Right Model

$$\mathcal{L}_Y \supset -(f_R)_{ij}\,\psi^{\mathsf{T}}_{R,\,i} C i\sigma_2 \Delta_R \psi_{R,\,j} + \text{H.c.}.$$

- Could have $f_R \neq f_L$ at low scale. [Chang, Mohapatra, Parida (PRL '84)]
- f_R is not related to the neutrino oscillation data.
- LFV constraints do not restrict $(f_R)_{ee}$ anymore.
- Other relevant constraints:
  - Neutrinoless double beta decay
  - Bhabha scattering at LEP: $e^+e^- \to e^+e^-$.
  - Drell-Yan process at LHC: $pp \to \gamma^*/Z^* \to H^{++}H^{--}$.
- Future prospects at ILC/CLIC: $e^+e^- \to e^\pm e^\pm H_R^{\mp\mp}$ and $e^\pm\gamma \to e^\mp H_R^{\pm\pm}$.

[BD, Mohapatra, Zhang '18]

Parity-Violating Left-Right Model



[BD, Ramsey-Musolf, Zhang '18]

Conclusion

- Complementarity between the high-energy and high-precision experiments.
- We considered a case study of doubly-charged scalars.
- Can be probed at the MOLLER experiment up to ~ 20 TeV.
- For the parity-violating left-right scenario, goes well beyond the current constraints, as well as the future collider sensitivities.