EFT analysis of neutrino oscillation data

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In collaboration with

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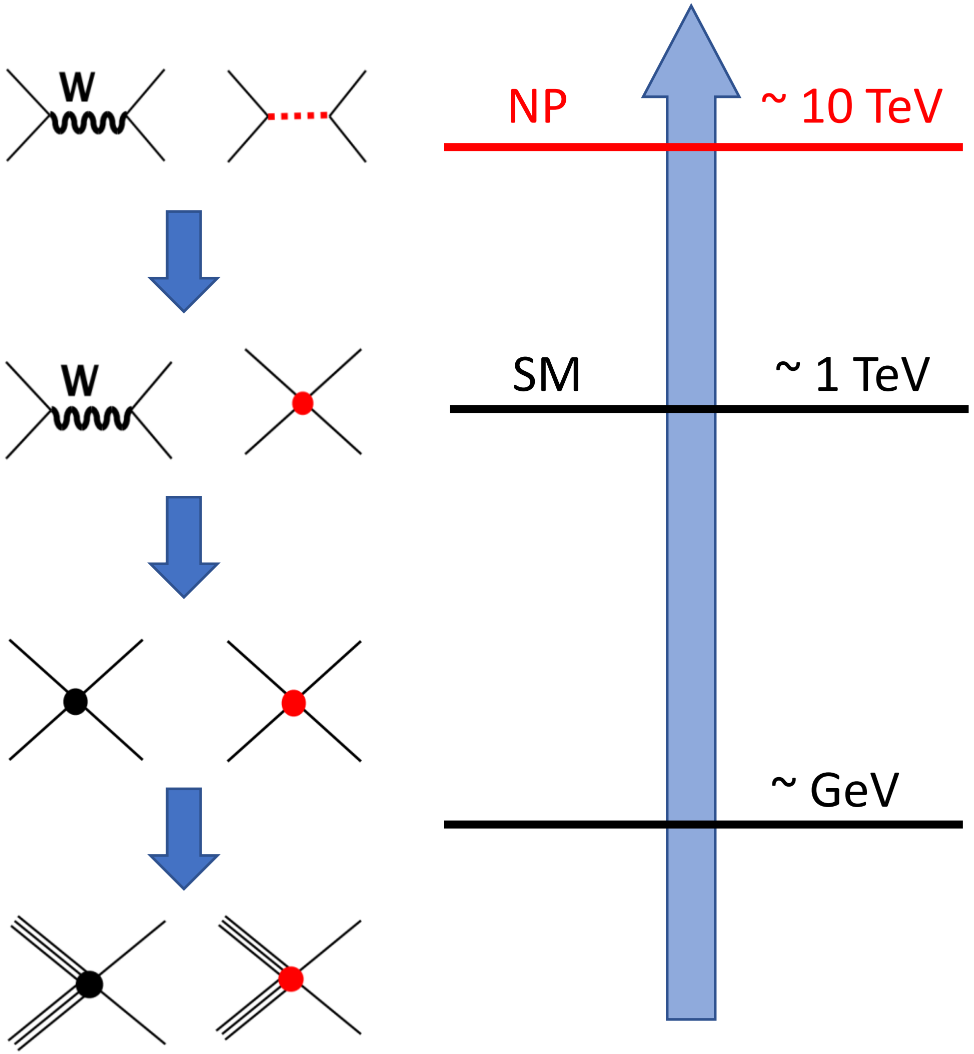
EFTs for low energy observables



$\mathcal{L}(\mathrm{x}) = \mathcal{L}(\mathrm{SM}, \mathrm{bSM})$

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \frac{1}{\Lambda^2}\sum_i c_i O_i^{d=6}$$

Standard Model EFT

[Buchmuller & Wyler'86, Leung et al.'86, Grzadkowksi et al., 10, Jenkins et al'13, ...]

$$\mathcal{L}_{d\to ul^-\bar{\nu}_l} = -\frac{4G_F V_{ij}}{\sqrt{2}}\left[\bar{l}_L\gamma_\mu\nu \cdot \bar{u}\gamma^\mu d_l + \sum_{\rho\delta\Gamma}\epsilon^\Gamma_{\rho\delta}\bar{l}_\rho\Gamma\nu \cdot \bar{u}\Gamma d_\delta\right]$$

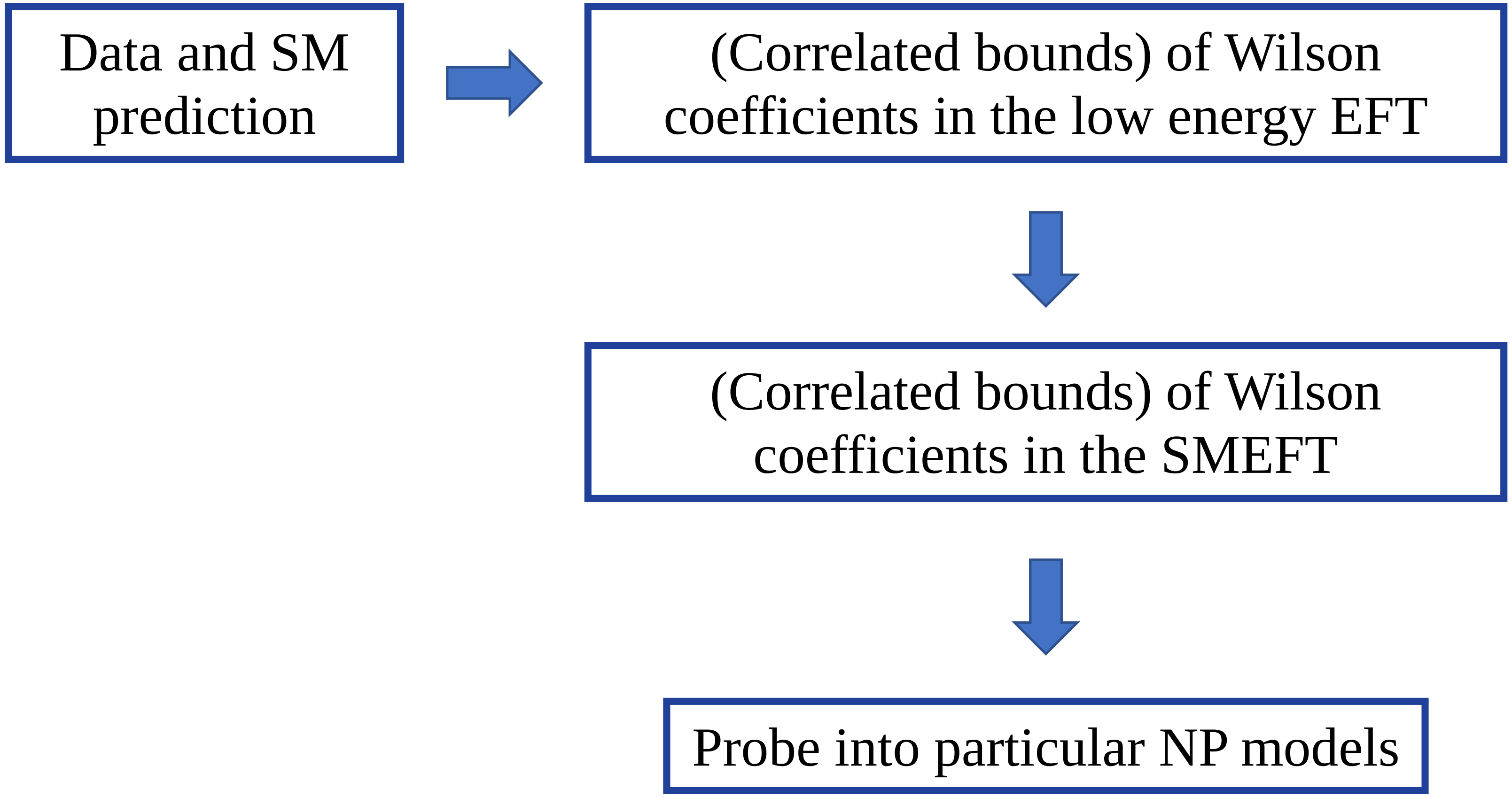
Low energy EFT

[Cirigliano et al'09, Aebischer al.'15, Jenkins et al'18, ...]

$$\mathcal{L}_{\pi,N,\ldots} = \cdots$$

EFTs for low energy observables

We can use low energy precision measurement for NP searches:



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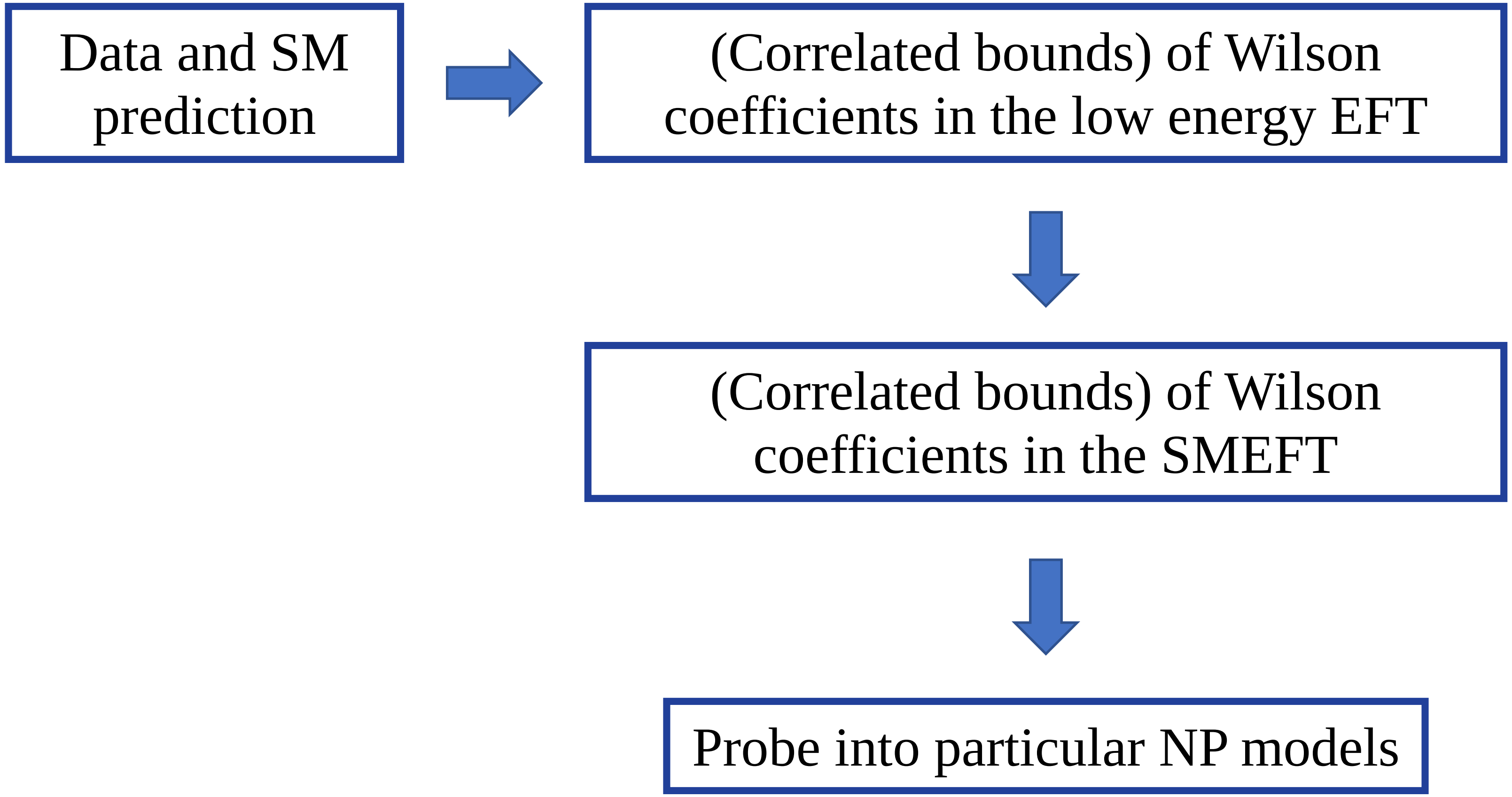

- Model independent approach
- Comparison between experimental inputs
- Efficiency

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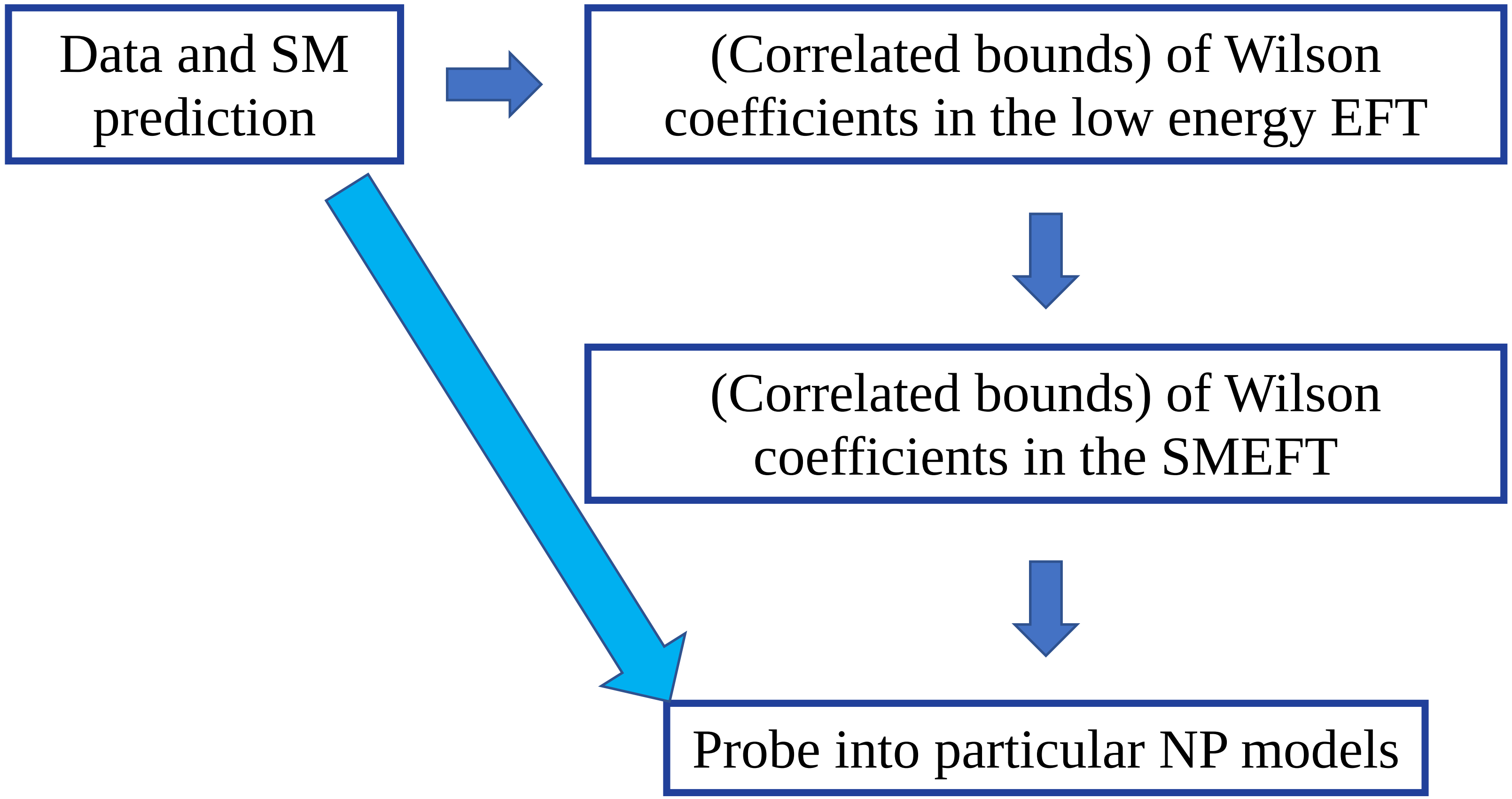

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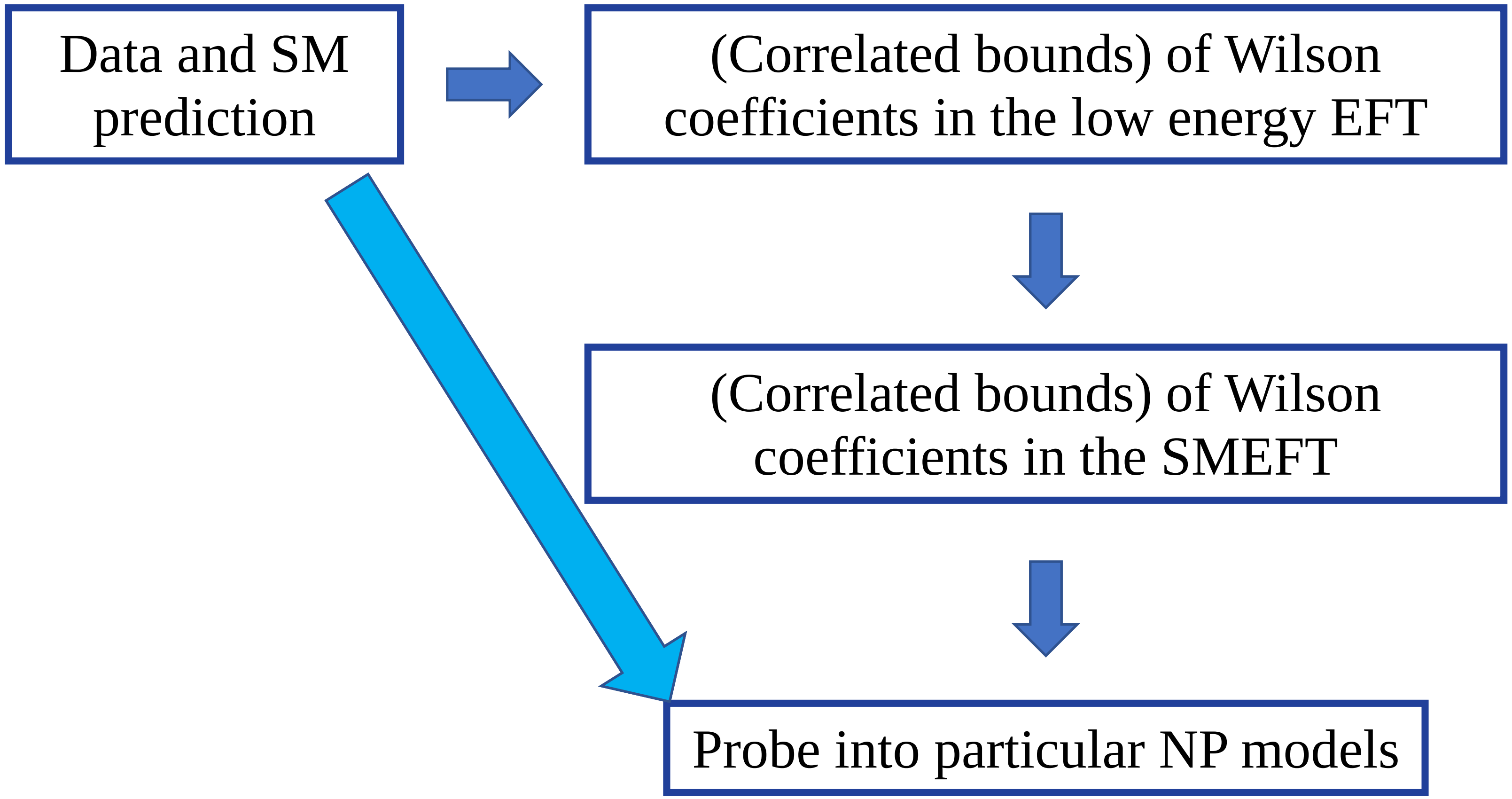

- Model independent approach
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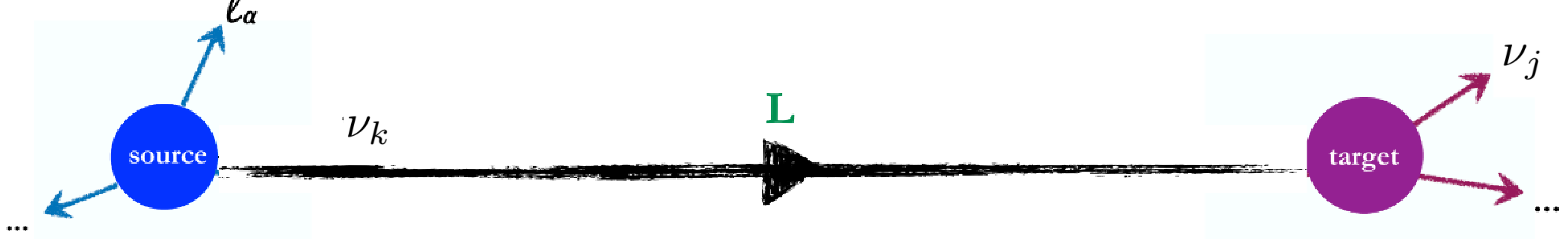
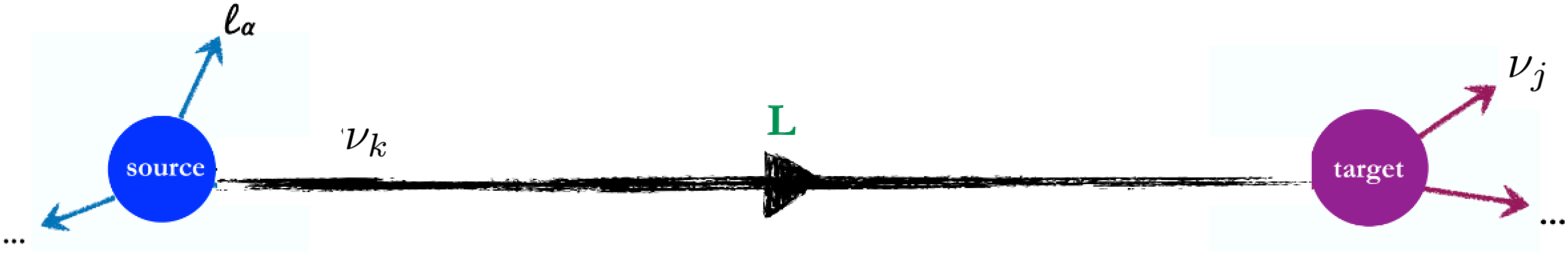
Can we use this approach for neutrino oscillation observables?

Neutrino oscillation observables in QFT



Neutrino oscillation observables in QFT



-How can we properly introduce NP effects into these settings?

· CC x CC: [Falkowski, González-Alonso, & Tabrizi, ‘20]

· CC x NC: This talk

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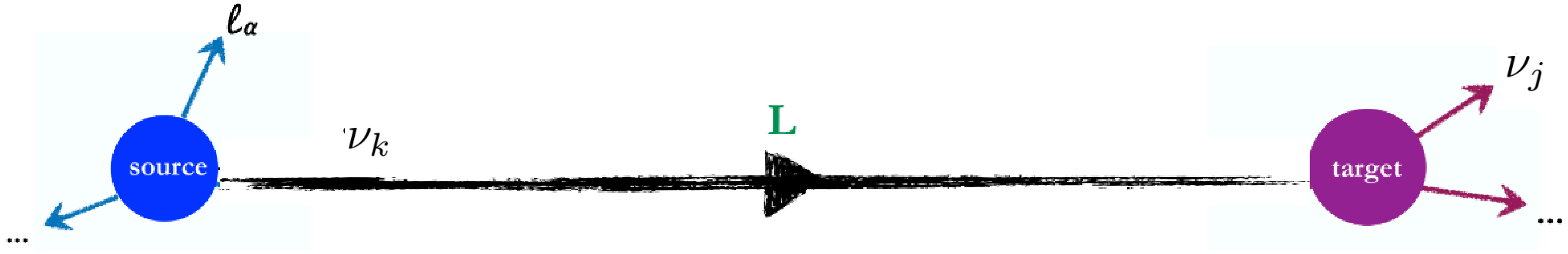

-How can we properly introduce NP effects into these settings?

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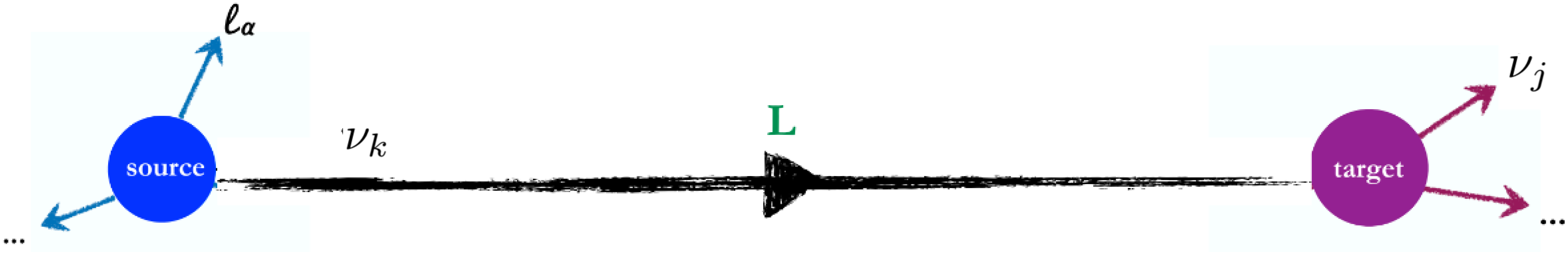
Caveats:

-NP effects present both on production and detection

-No matter effects in neutrino propagation

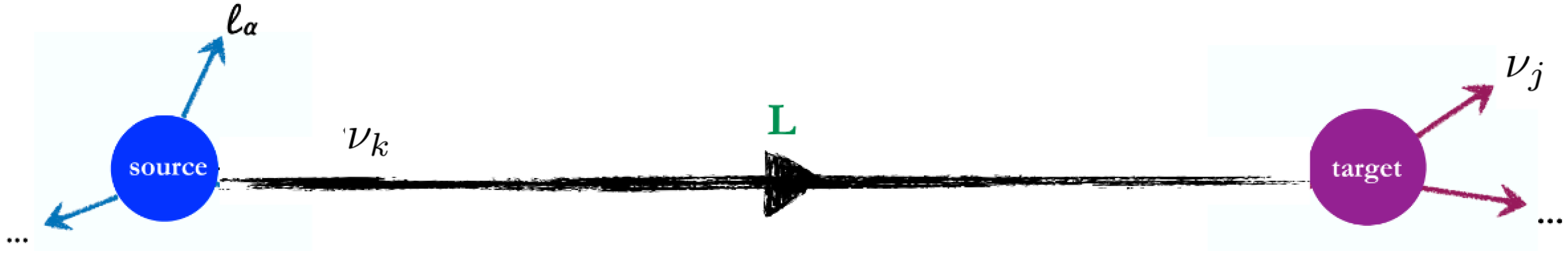
-Ability to incorporate NP "polluting" SM inputs

Neutrino oscillation observables in QFT



$$R_\alpha = \sum_j \frac{\kappa}{E_\nu} \sum_{k,l} e^{-i\frac{L\Delta m^2_{kl}}{2E_\nu}} \int d\Pi_{P'} \mathcal{M}^P_{\alpha k} \bar{\mathcal{M}}^P_{\alpha l} \int d\Pi_D \mathcal{M}^D_{jk} \bar{\mathcal{M}}^D_{jl}$$

Neutrino oscillation observables in QFT



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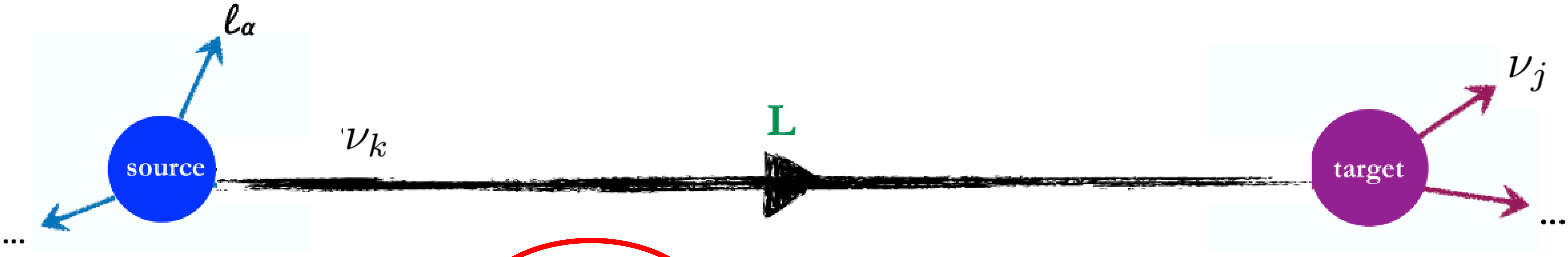
Geometric factor

$\kappa = N_S N_T / (32\pi L^2 m_S m_T)$

Neutrino oscillation observables in QFT



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Oscillation factor

$$\Delta m_{kl}^2 \equiv m_k^2 - m_l^2$$

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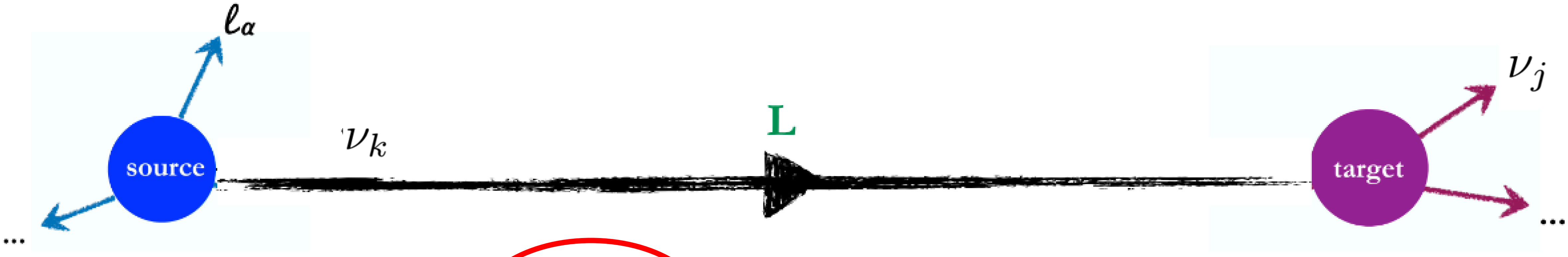

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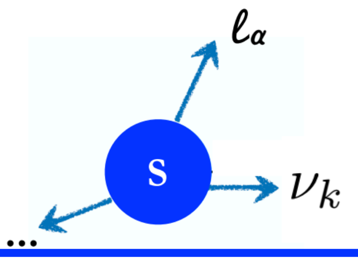
Production piece

$$\mathcal{M}^P_{\alpha k} \equiv \mathcal{M}(S \to X_\alpha \nu_k)$$



Detection piece

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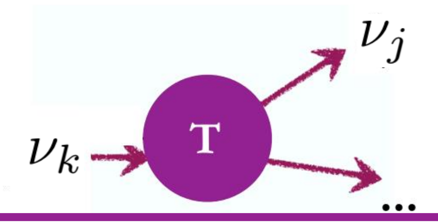

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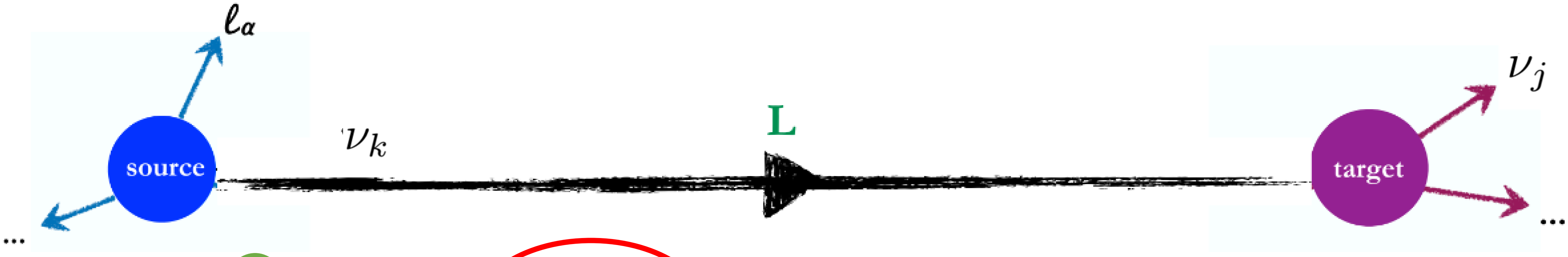

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Sum over outgoing mass indices

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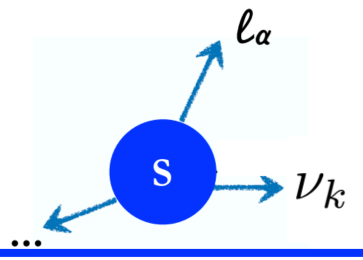

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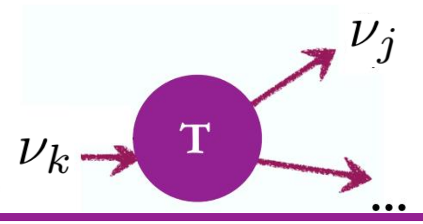

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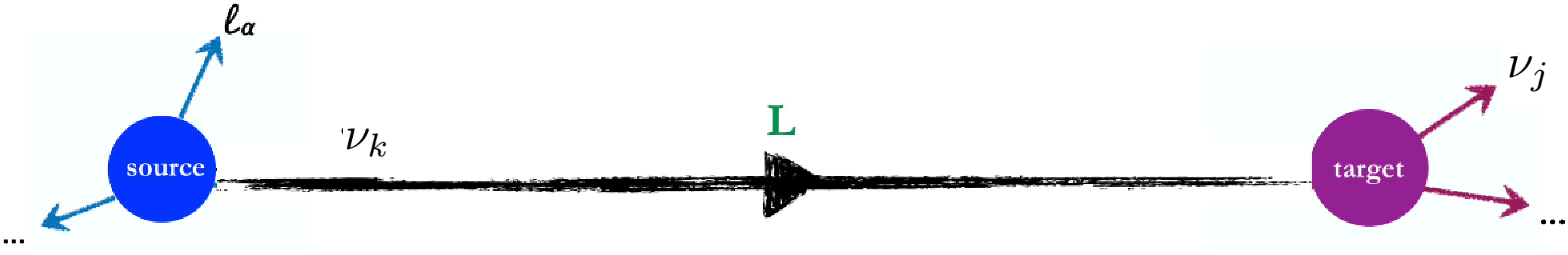

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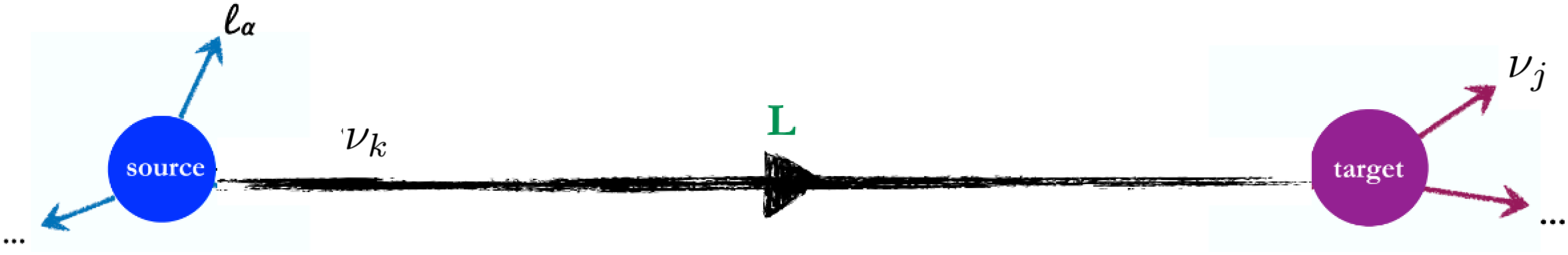

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Differences with the "factorized" approach when:

- -NP effects present both on production and detection
- -Flavor-violating couplings

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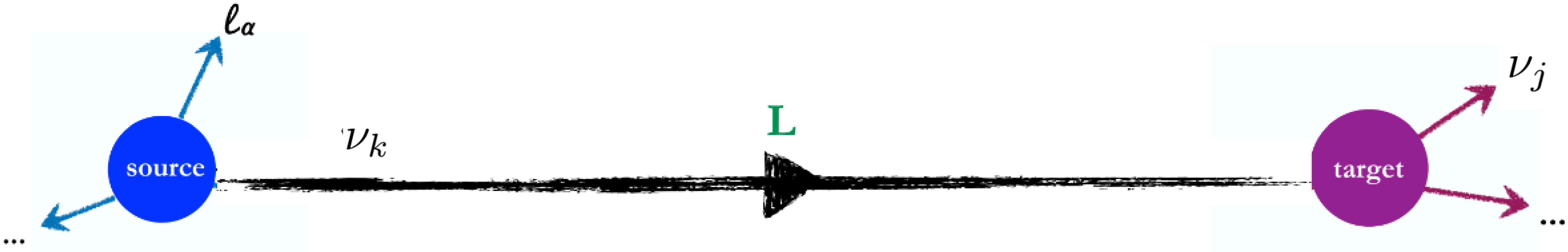

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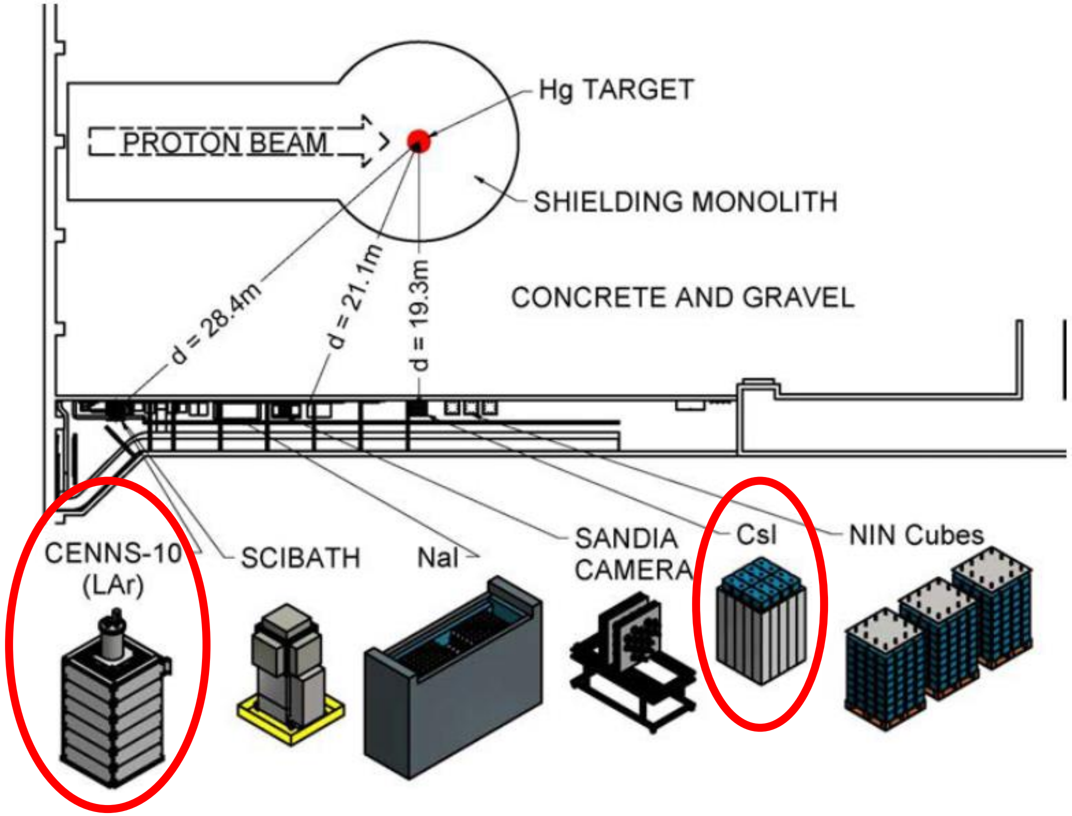
Extensible to include RH neutrinos, Majorana neutrinos and neutrino magnetic moments!!

COHERENT experiment



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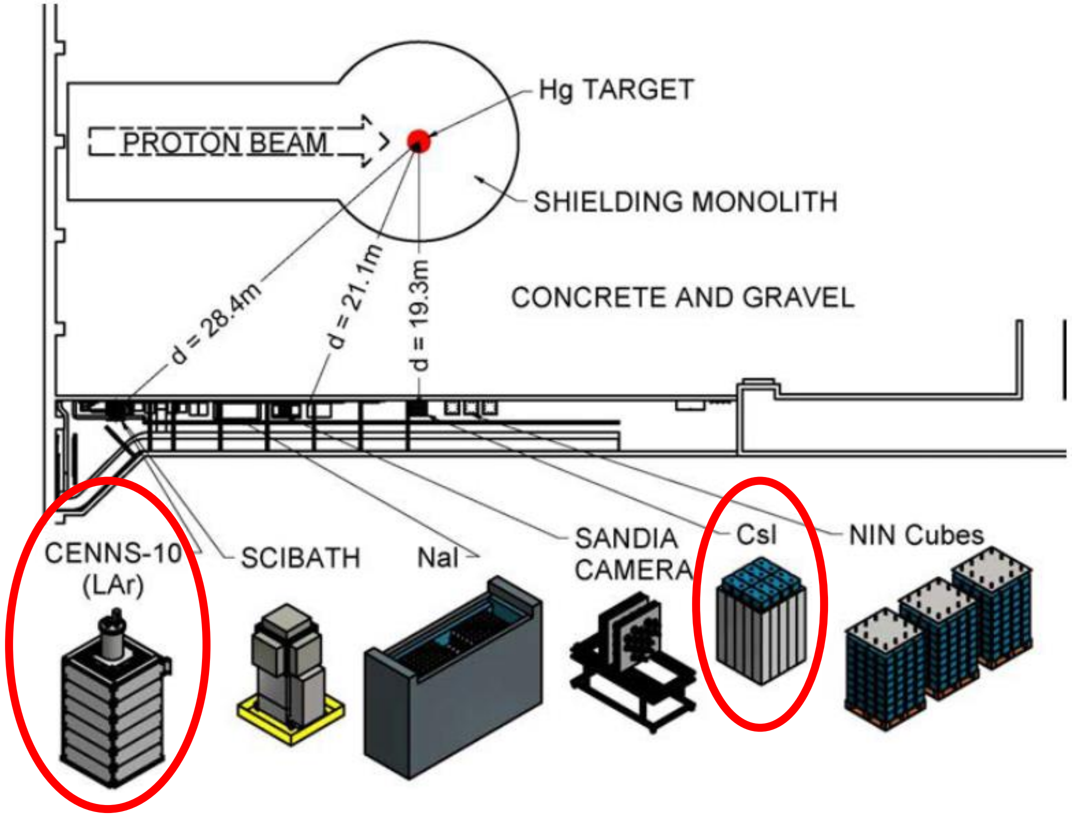

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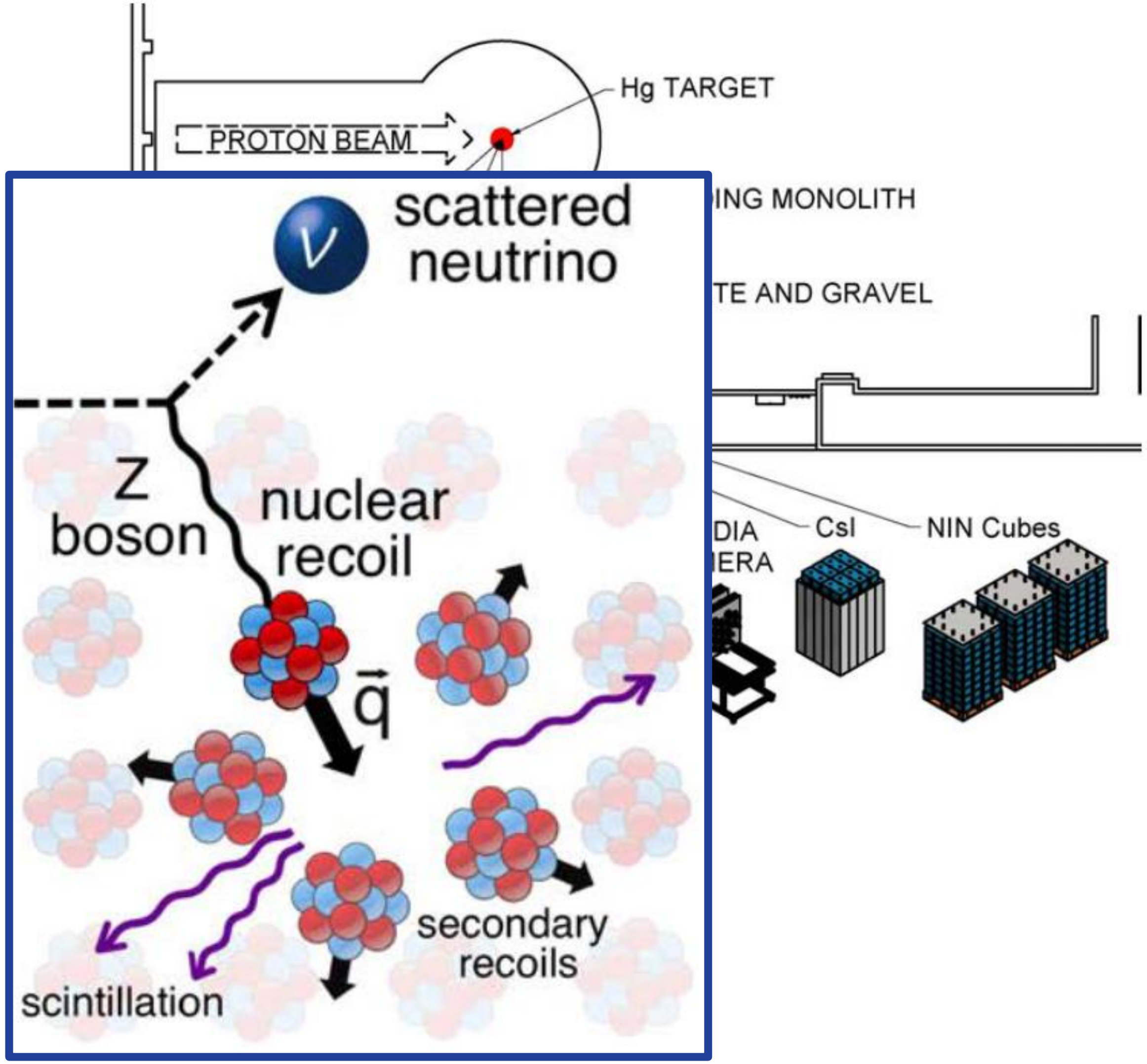

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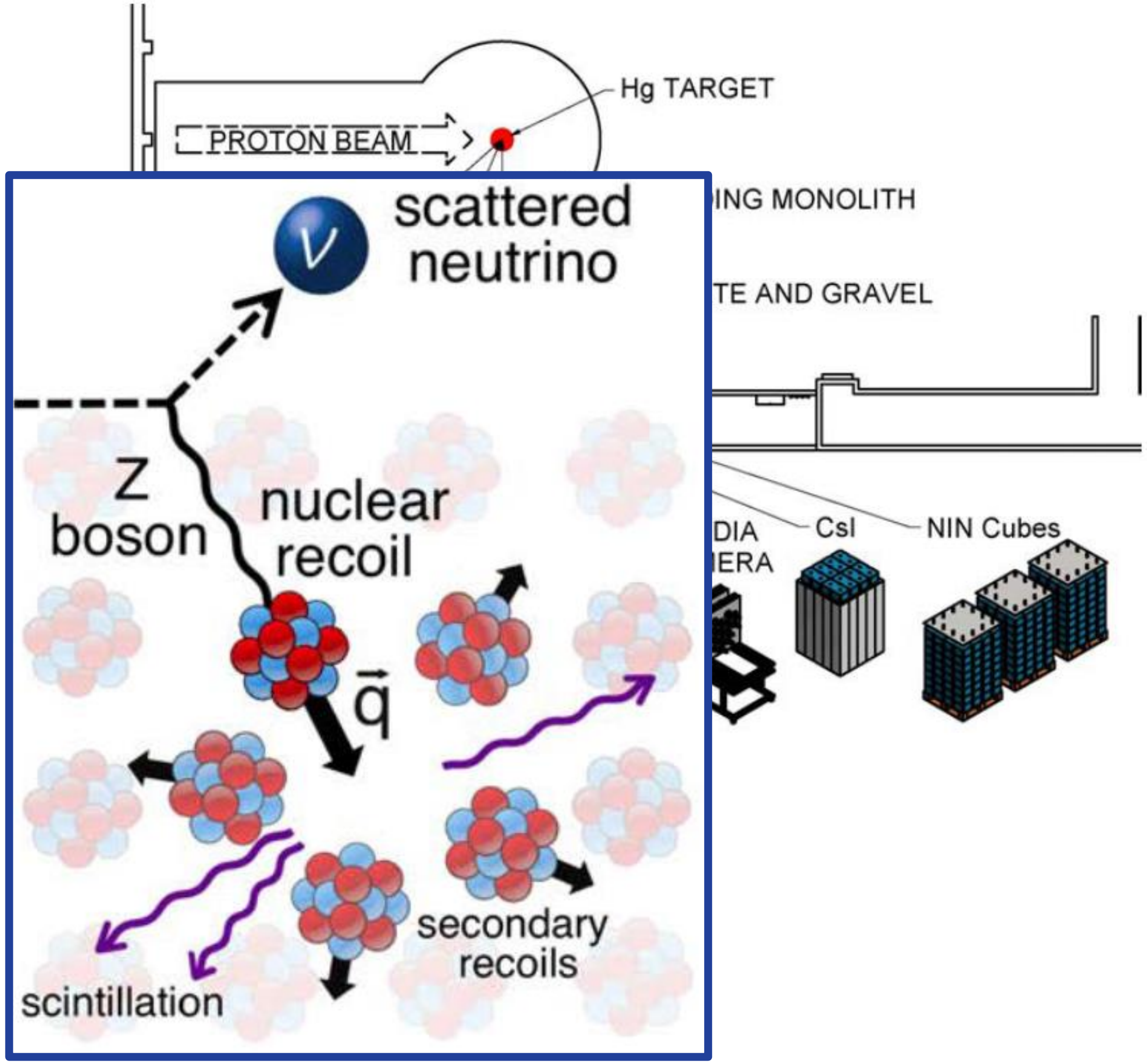

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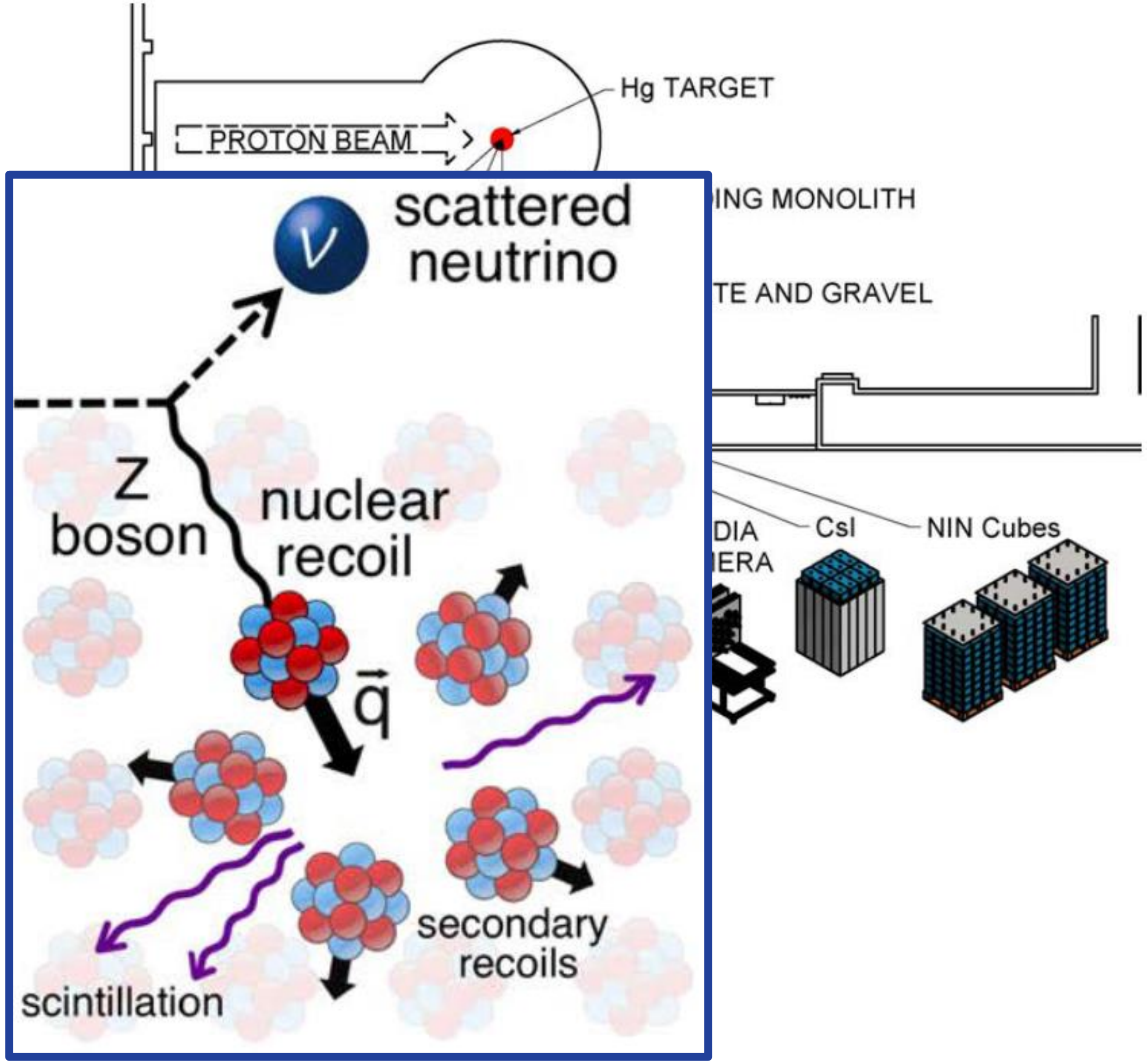

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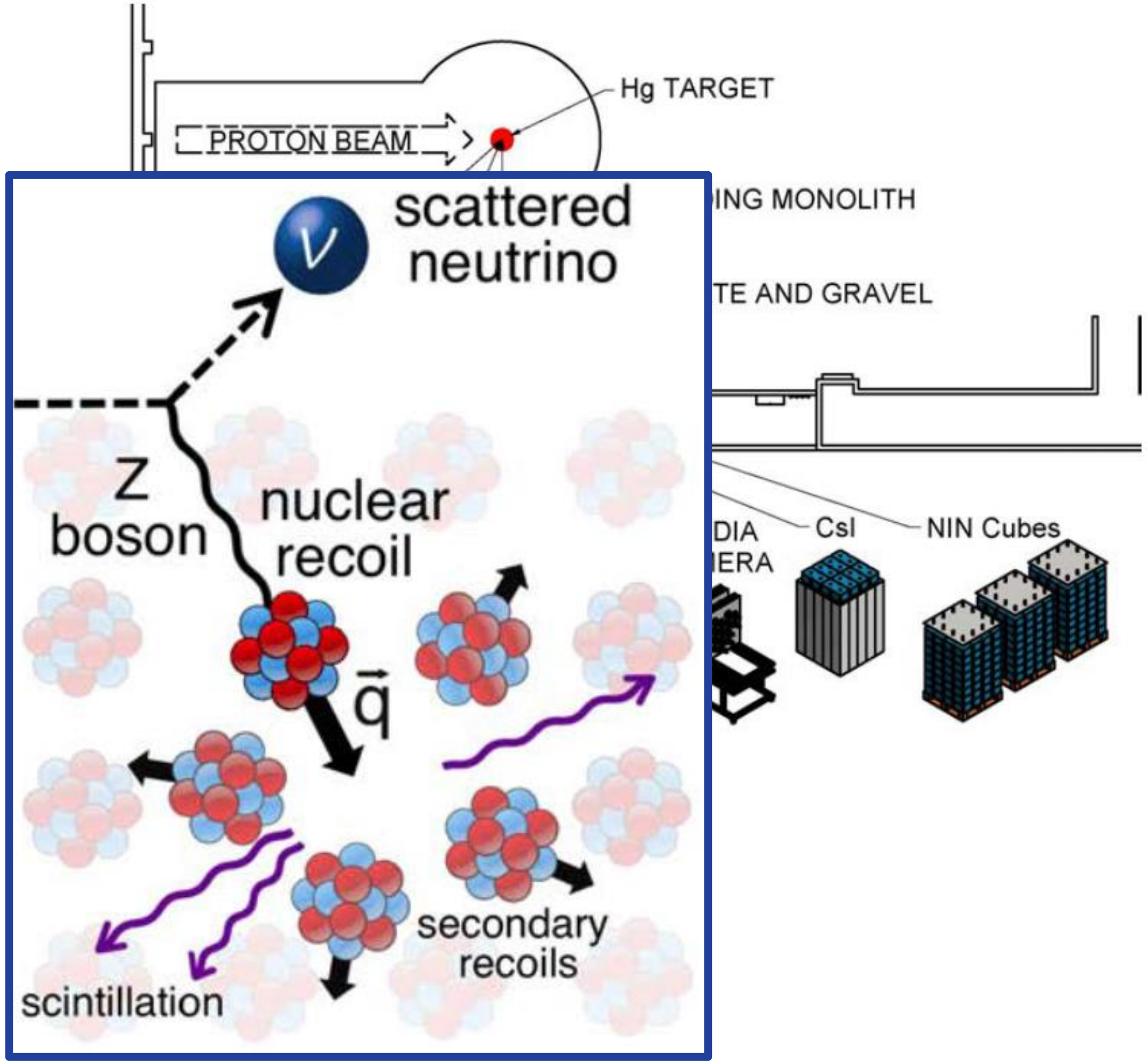

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-Production involves a charged current interaction and detection involves a neutral current interaction
⟶ **perfect scenario for our formalism!!**

NP at the COHERENT experiment

What NP effects enter the COHERENT observables?

-Pion decay production piece:

$$\mathcal{L} \subset -\frac{2V_{ud}}{v^2}\{[1+\epsilon_L]_{\alpha\beta}\,(\bar{u}\gamma^\mu P_L d)\,(\bar{l}_\alpha \gamma_\mu P_L \nu_\beta) + [\epsilon_R]_{\alpha\beta}\,(\bar{u}\gamma^\mu P_R d)\,(\bar{l}_\alpha \gamma_\mu P_L \nu_\beta) + \\ -\frac{1}{2}\,[\epsilon_P]_{\alpha\beta}\,(\bar{u}\gamma^5 d)\,(\bar{l}_\alpha P_L \nu_\beta)\}$$

-Muon decay production piece:

$$\mathcal{L} \subset -\frac{2}{v^2}\left[\left(\delta_{\alpha a}\delta_{\beta b} + [\rho_L]_{a\alpha\beta b}\right)(\bar{l}_a \gamma^\mu P_L \nu_\alpha)\,(\bar{\nu}_\beta \gamma_\mu P_L l_b) - 2\,[\rho_R]_{a\alpha\beta b}\,(\bar{l}_a P_L \nu_\alpha)\,(\bar{\nu}_\beta P_R l_b)\right]$$

-Detection piece:

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NP at the COHERENT experiment

PROBLEM: Production contributions are suppressed by the decay inputs

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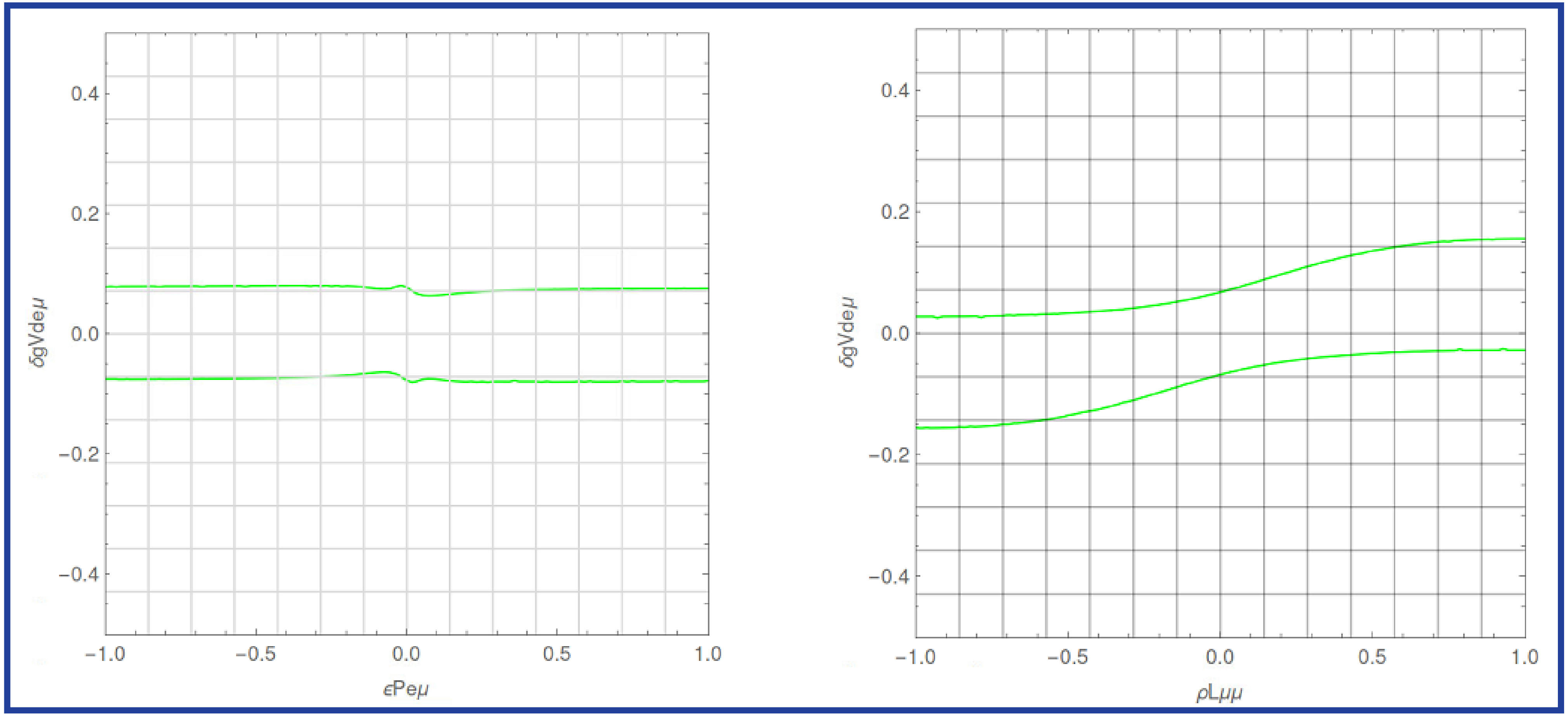
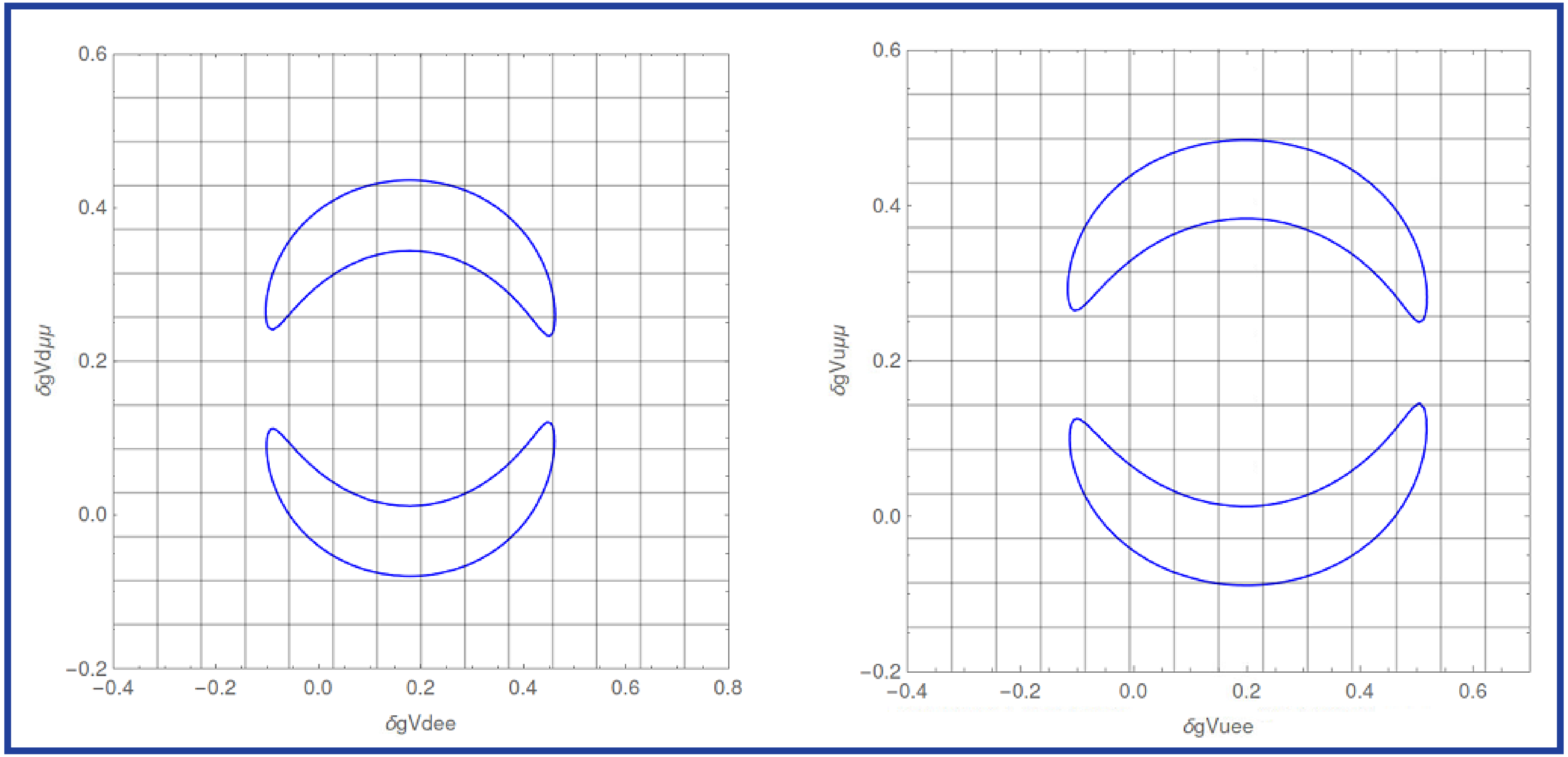
Preliminary results

-Impact from our formalism:



Preliminary results

-Limits on detection WC: We recover the limits obtained in the literature [Miranda et al. ´20, Atzori Corona et al. ’22, Coloma et al. ’22…] ⟶ **complete results coming soon**



Conclusions

- We have developed an EFT based formalism for the description of NP affecting neutrino oscillation observables. This setup allows us to:
  - understand the UV meaning and limitations of the production/detection NSIs
  - **take into account NP in production & detection**
  - **take into account NP affecting SM input**
  - connect with specific NP models or interactions (e.g. leptoquarks)"

- We have succesfully applied this framework for the description of **BSM physics at the COHERENT experiment,** recovering previous results **(full results coming soon!!)**

- We have quantitatively determined the small impact of NP coming from production

- **Outlook:** Link the limits obtained within LEFT to bounds in the SMEFT