



# Probing New Physics at COHERENT with EFTs

Rencontres de Moriond - EW

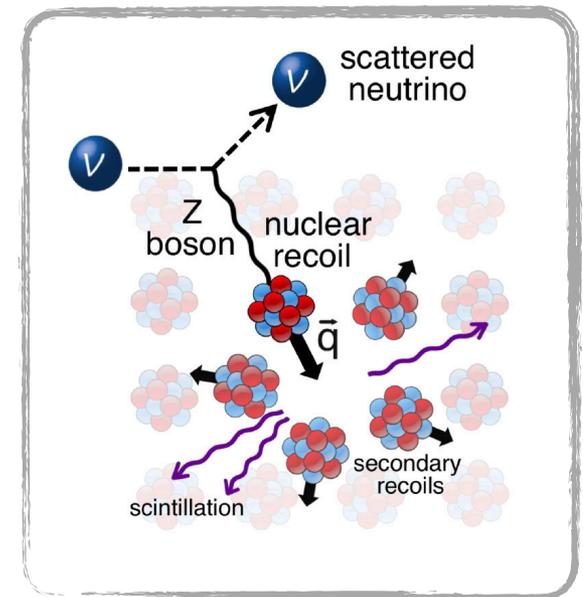
March 2026

**Martín González-Alonso**  
IFIC, CSIC - UV



# CE $\nu$ NS 101

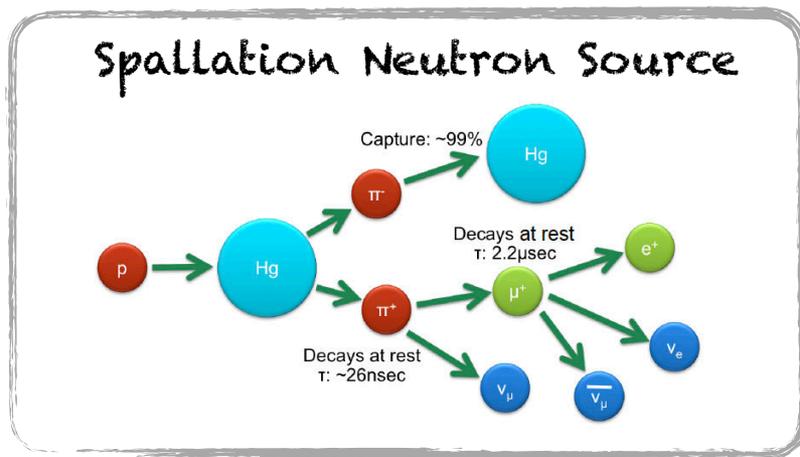
- $\nu N \rightarrow \nu N$ : for  $E_\nu$  small enough the neutrino does not resolve the nucleus  
→  $\sigma \sim N^2$  ! *Coherent* Elastic Neutrino-Nucleus Scattering (CE $\nu$ NS) [Freedman'74]
- Extremely challenging experimentally (very small nuclear recoil)



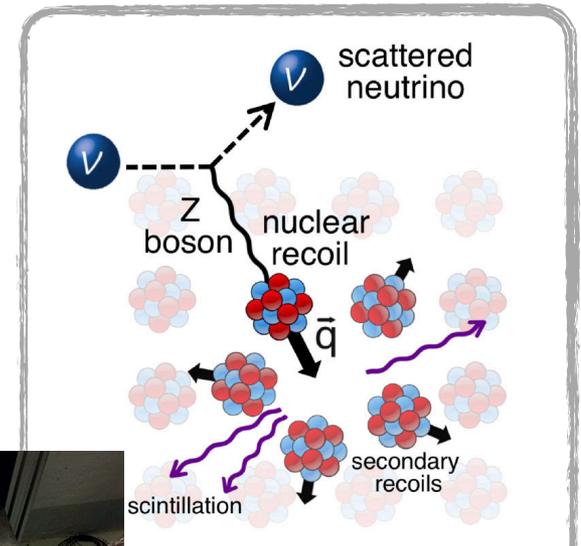
[from COHERENT coll.]

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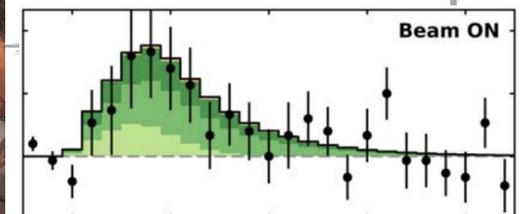
[Scholberg, IPA18]



COHERENT SNS SPALLATION NEUTRON SOURCE

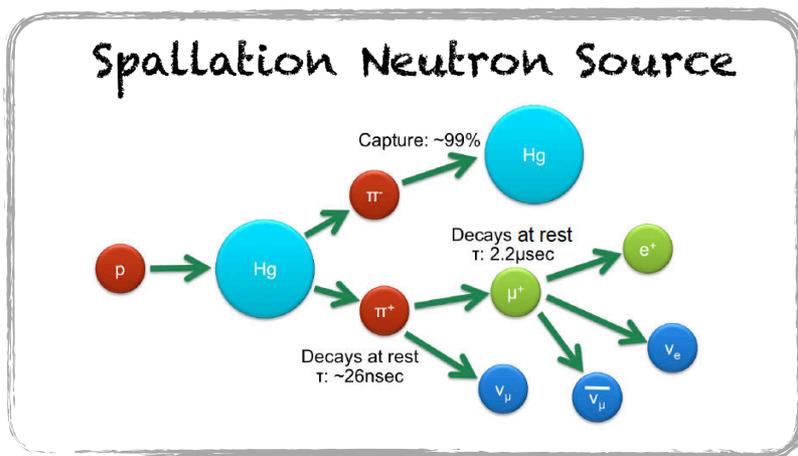


[Image credit: Duke U.]

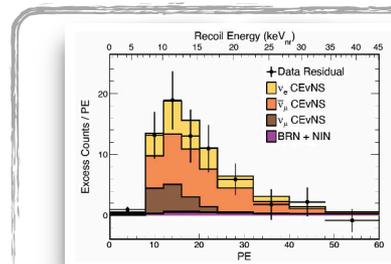
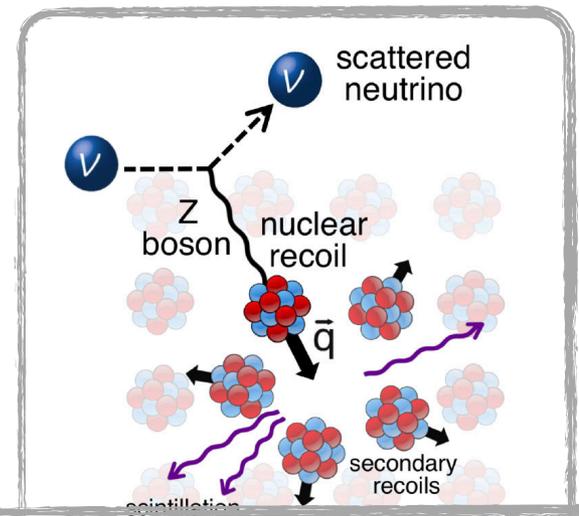


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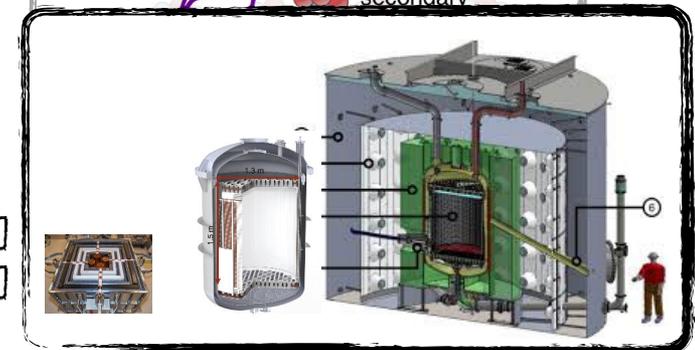
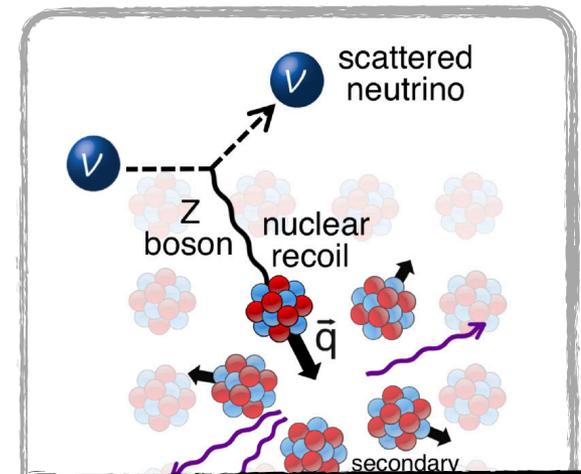
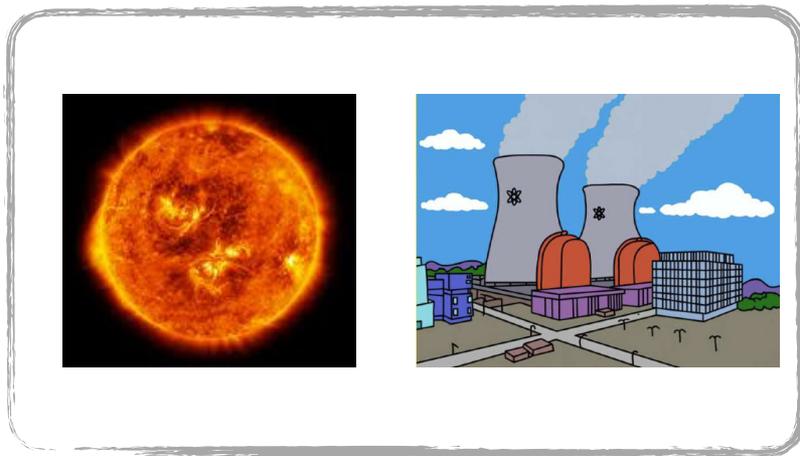
[Scholberg, IPA18]



[Green, Mag7s'25]

# CE $\nu$ NS 101

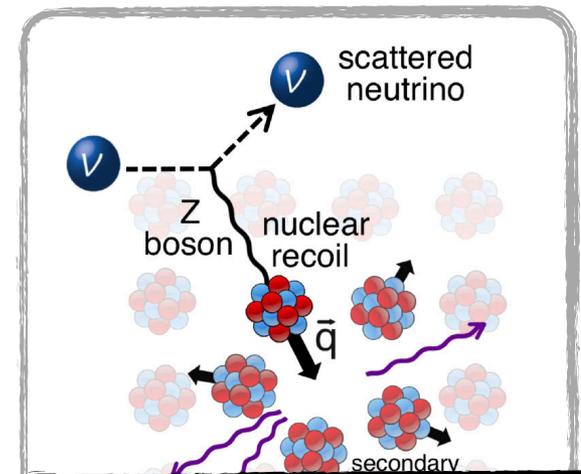
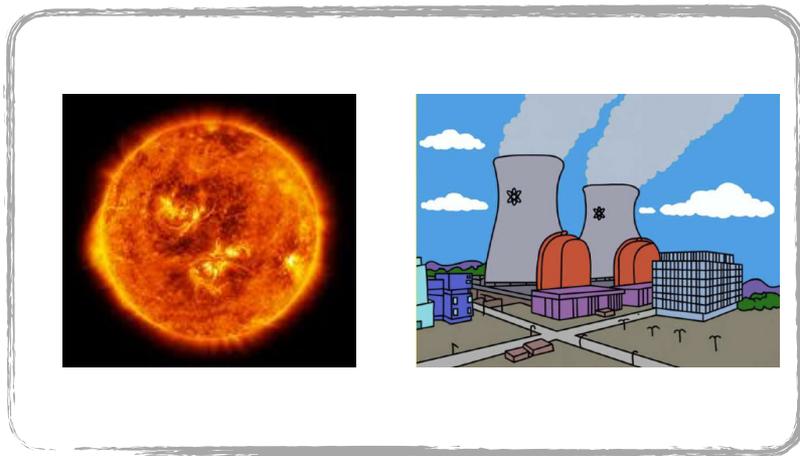
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[3.7 $\sigma$ , CONUS+'25]  
[2.6-4.5 $\sigma$ , XENONnT'24, Panda-X'24, LZ'25]  
"Neutrino fog"

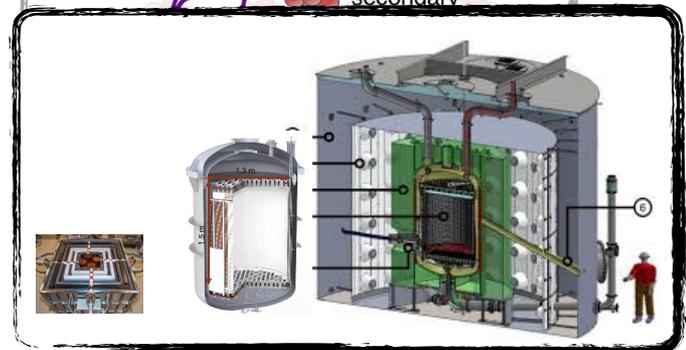
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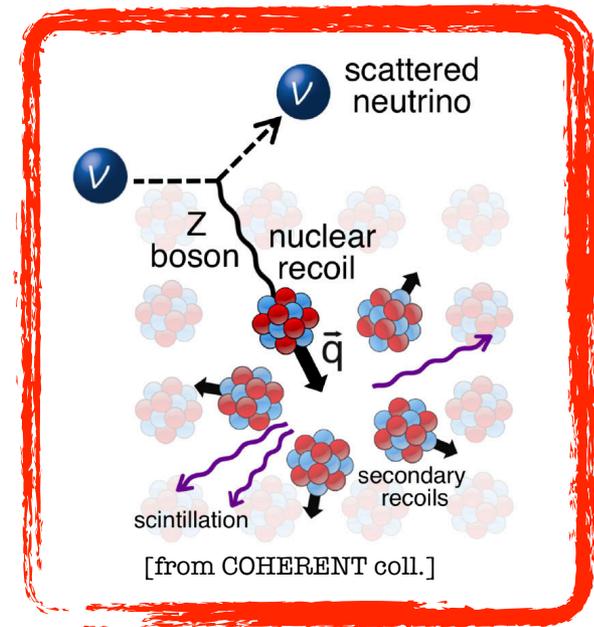


- Many more expts coming up!  
[See e.g. [Serra's talk yesterday](#)]

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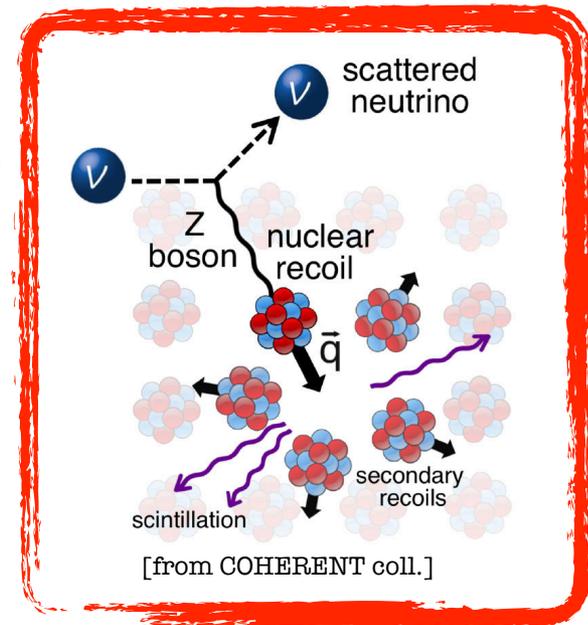
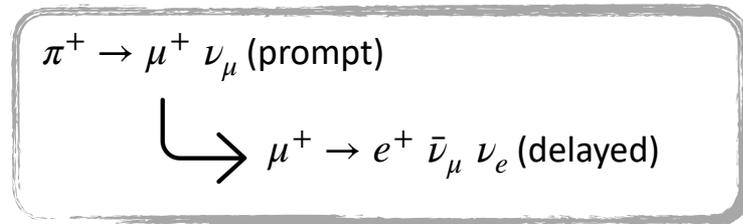
# CE $\nu$ NS: pheno analyses



Lots of pheno analyses: electroweak (mixing angle), nuclear physics (neutron skin), electromagnetic neutrino properties, light mediators, non-standard NC interactions, ...

[Barranco et al'05, Scholberg'06, Cadeddu et al'18, Papoulias-Kosmas'18, Shoemaker'17, Liao-Marfatia'17, Cadeddu et al'18, Aristizabal et al'18, Denton et al'18, Altmannshofer et al'19, Giunti'20, Coloma et al'20, Skiba-Xia'22, Hoferichter et al'20, Miranda et al'20, Atzori et al'22, Coloma et al'22, De Romeri et al'23, Bresó-Pla et al'23, Aristizábal et al'25, Li et al'25, de Romeri et al'25, Liao et al'25, Atzori Corona et al'25, Bresó-Pla et al'25, de Romeri et al'26, ... and many other works]

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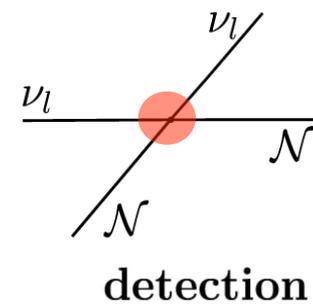
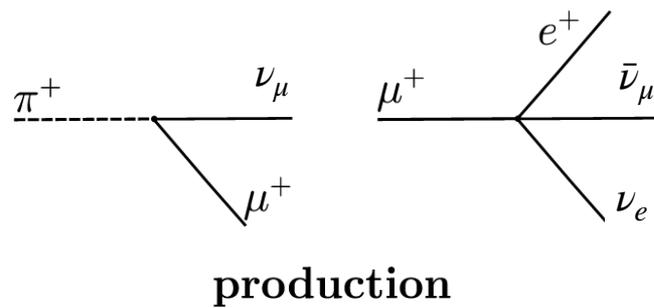
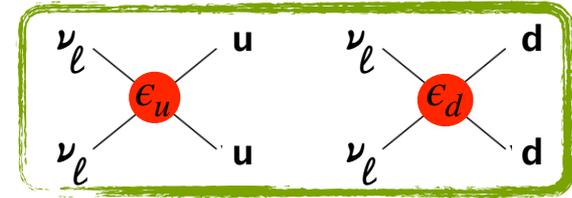
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I'll focus on COHERENT-like exp. & "heavy" BSM searches → EFT

# LEFT (=WET, NSI, ...)

[Barranco et al'05, Scholberg'06, ...]

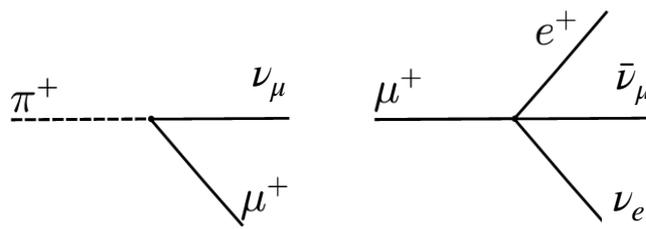
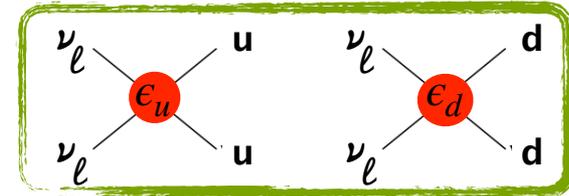
$$\mathcal{L} = -\frac{1}{v^2} \sum_{q=u,d} \left( g_V^{qq} + \epsilon_V^{qq} \right) (\bar{q} \gamma^\mu q) (\bar{\nu}_\ell \gamma_\mu P_L \nu_\ell)$$



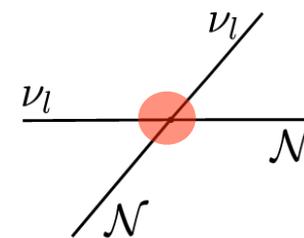
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production



detection

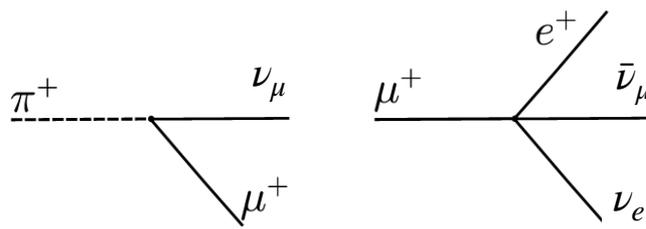
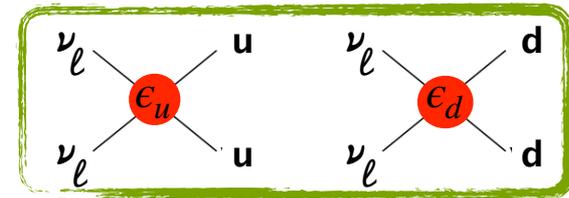
$$\frac{dN^{\text{prompt/delayed}}}{dT} = N_T \sum_{f=\nu_e, \nu_\mu, \bar{\nu}_\mu} \int dE_\nu \frac{d\phi_f^{\text{SM}}}{dE_\nu} \frac{d\tilde{\sigma}}{dT}$$

$$\frac{d\tilde{\sigma}}{dT} = \frac{m_N \mathcal{F}^2(q^2)}{8\pi v^4} \tilde{Q}(\epsilon_q)^2 \left( 1 - \frac{m_N T}{2E_\nu^2} - \frac{T}{E_\nu} \right)$$

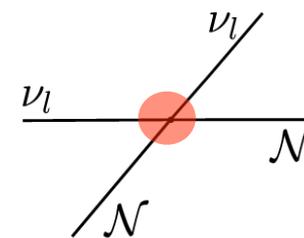
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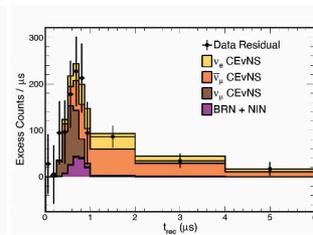
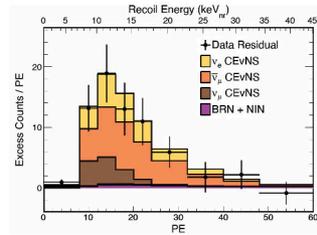
$$\tilde{Q}^2 = Q_{SM}^2 + 4 Q_{SM} ((A+Z)\epsilon_u + (2A-Z)\epsilon_d)$$

# LEFT (=WET, NSI, ...)

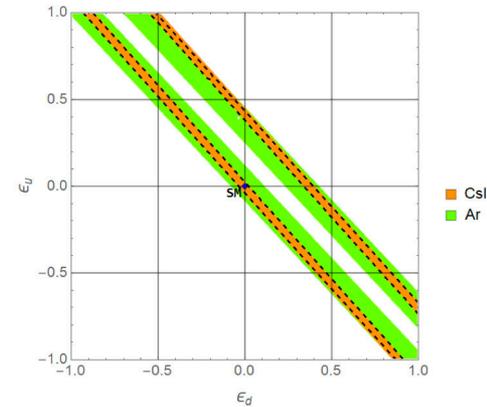
[Breso-Pla, Falkowski, MGA, Monsálvez-Pozo, 2301.07036 JHEP]

## COHERENT data

LAr + CsI  
recoil & time distribution  
(664 data)



$$0.67\epsilon_u + 0.74\epsilon_d = -0.002 \pm 0.010,$$

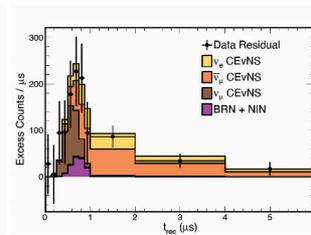
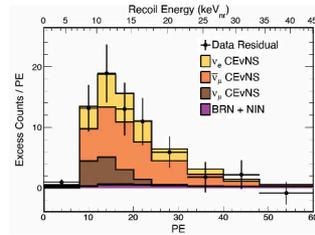


# LEFT $\rightarrow$ SMEFT

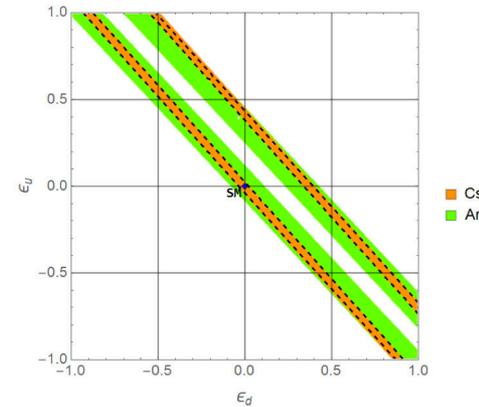
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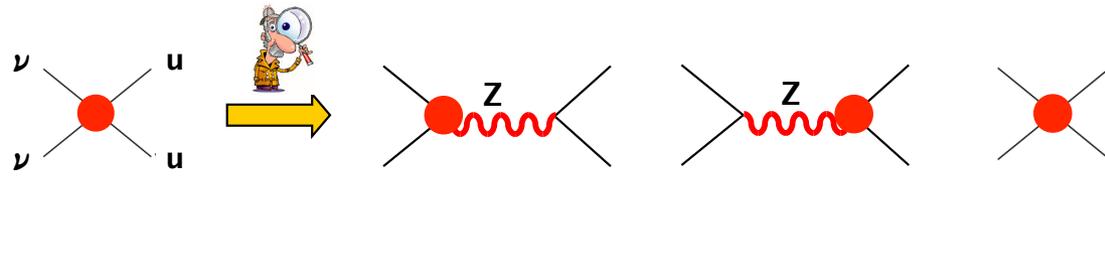
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LEFT/SMEFT  
Matching



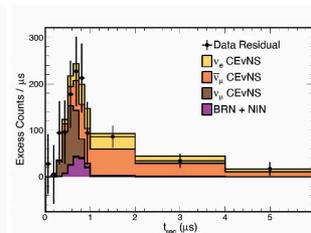
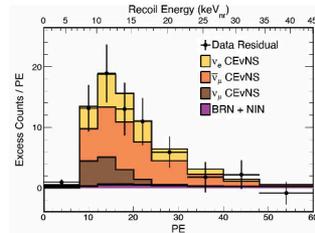
$$0.71 c_{\ell q}^{(1)} - 0.04 c_{\ell q}^{(3)} + 0.34 c_{\ell u} + 0.37 c_{\ell d} - 0.67(\delta g_L^{Zu} + \delta g_R^{Zu}) - 0.74(\delta g_L^{Zd} + \delta g_R^{Zd}) + 0.26 \delta g_L^{Z\nu} = -0.003 \pm 0.010$$

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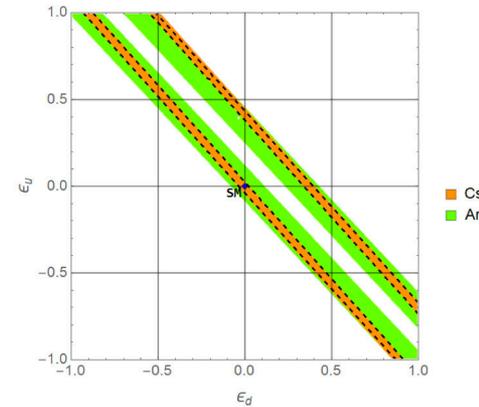
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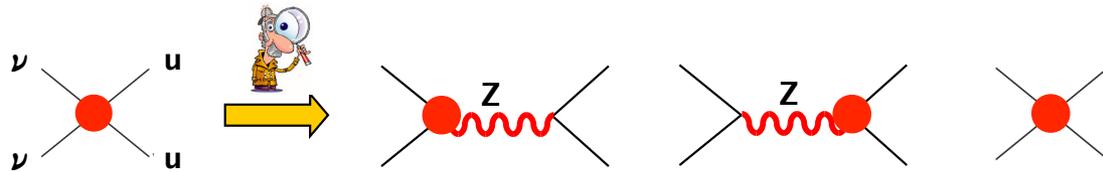
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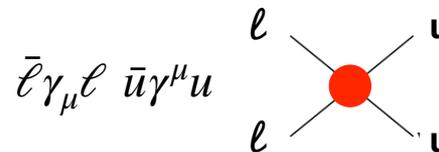
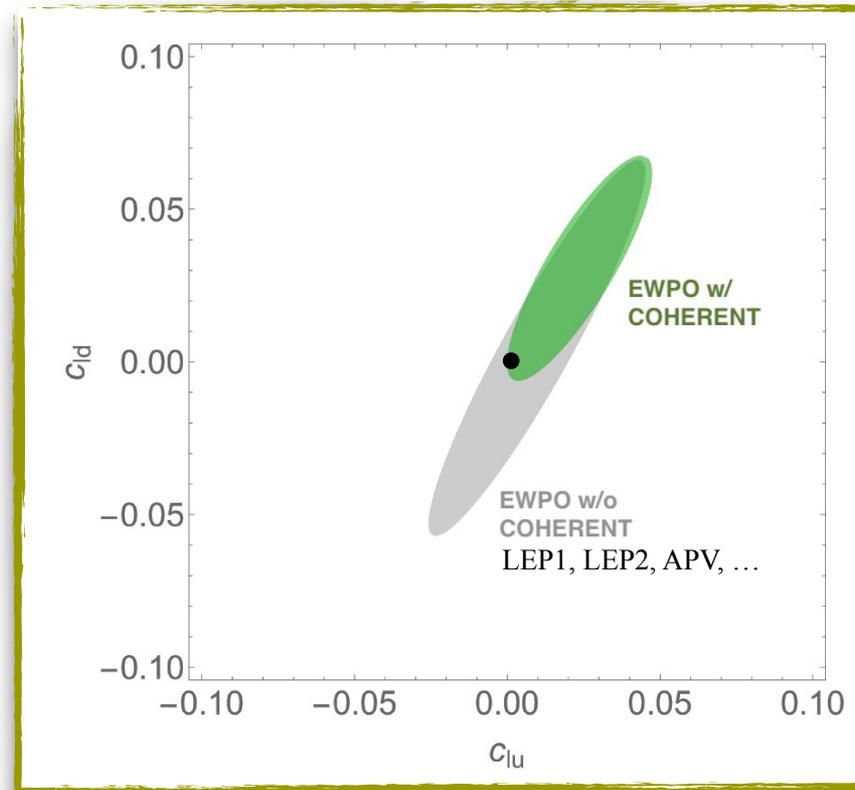
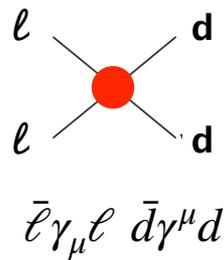
Competitive?

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## Flavor-universal SMEFT (18 free parameters)

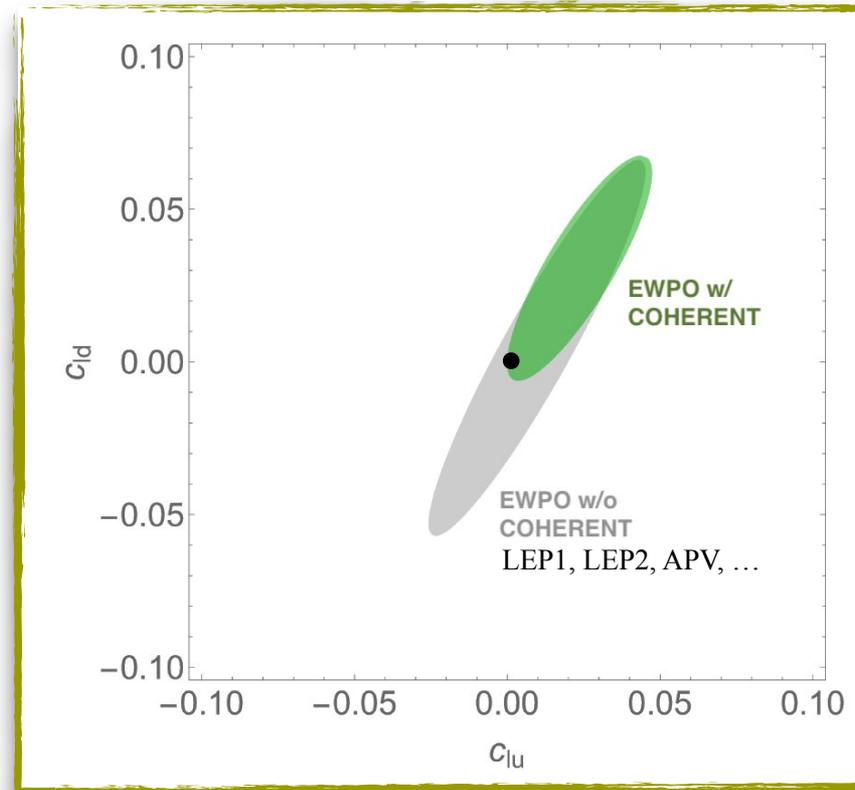
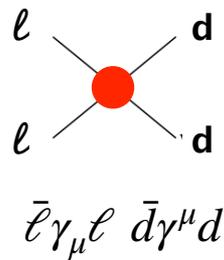


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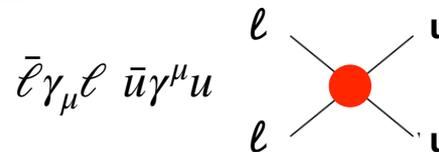
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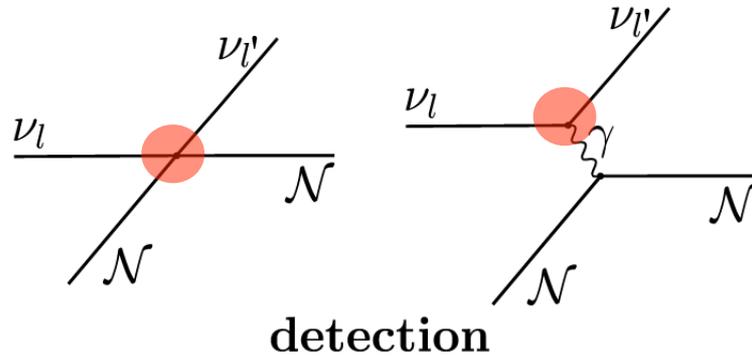
\*Much more impact in the flavor general fit (backup slide)



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# LEFT + general flavor structure? + $\nu_R$ ?

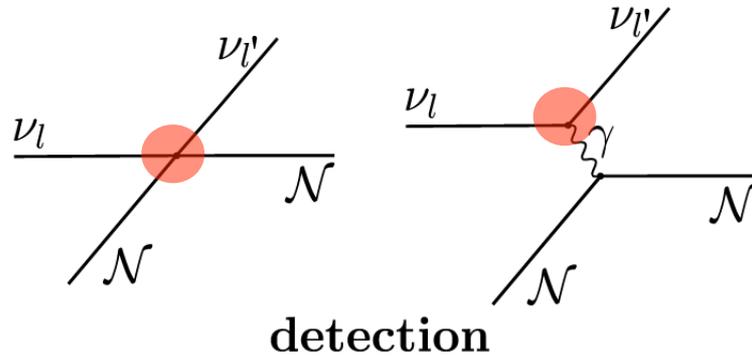
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PS: tensor not coherently enhanced (like axial) !!

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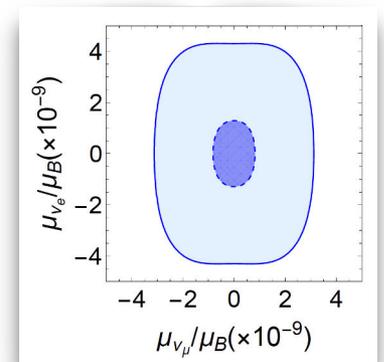


$$\frac{d\sigma_f}{dT} = f(\epsilon_i, \mu_\nu)$$

**COHERENT data**

**Bounds**  
**on  $\epsilon_i, \mu_\nu$**

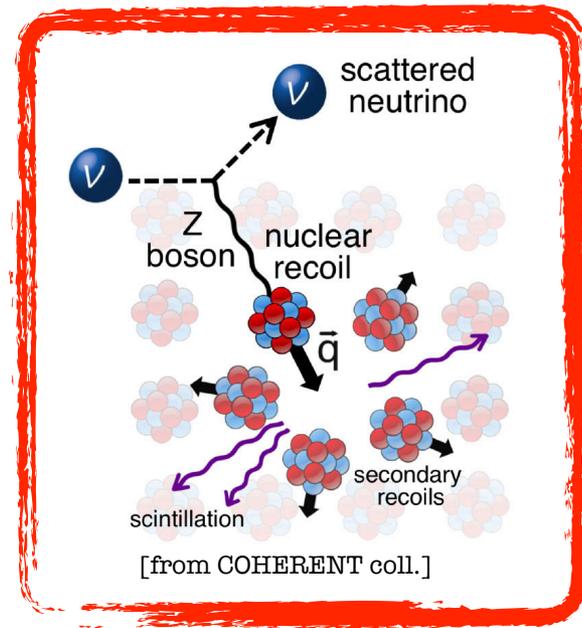
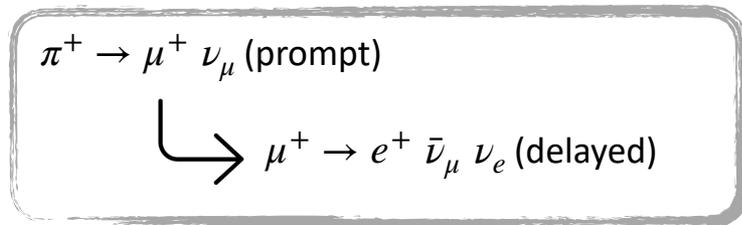
( $\nu$ LEFT / GNIs)



[Breso-Pla, Cruz-Alzaga, MGA, Prakash'25, de Romeri et al.'22, Li et al'20, Aristizábal et al'19, Papoulias et al'19, Han et al'20, Majumdar et al'19, Aristizábal et al'18, Papoulias-Kosmas'18,... and many other works]

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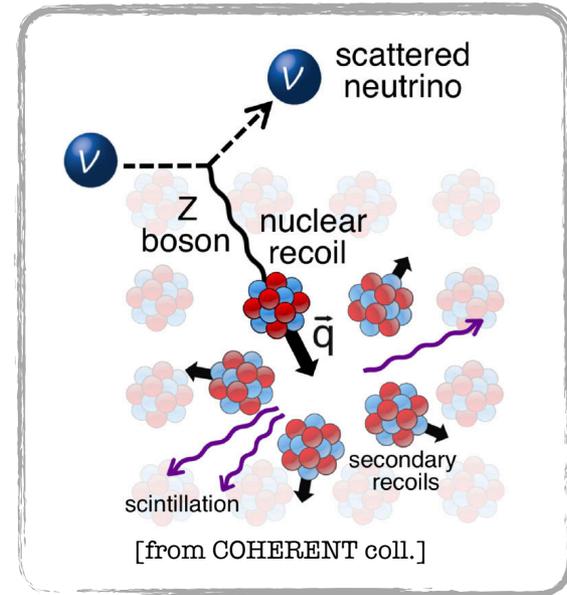
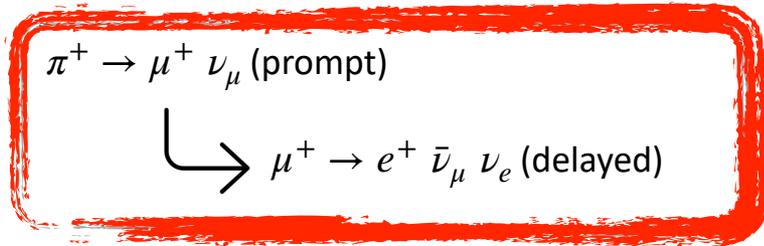
# CE $\nu$ NS: pheno analyses



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[Barranco et al'05, Scholberg'06, Cadeddu et al'18, Papoulias-Kosmas'18, Shoemaker'17, Liao-Marfatia'17, Cadeddu et al'18, Aristizabal et al'18, Denton et al'18, Altmannshofer et al'19, Giunti'20, Coloma et al'20, Skiba-Xia'22, Hoferichter et al'20, Miranda et al'20, Atzori et al'22, Coloma et al'22, De Romeri et al'23, Bresó-Pla et al'23, Aristizábal et al'25, Li et al'25, de Romeri et al'25, Liao et al'25, Atzori Corona et al'25, Bresó-Pla et al'25, de Romeri et al'26, ...]

# CE $\nu$ NS: pheno analyses



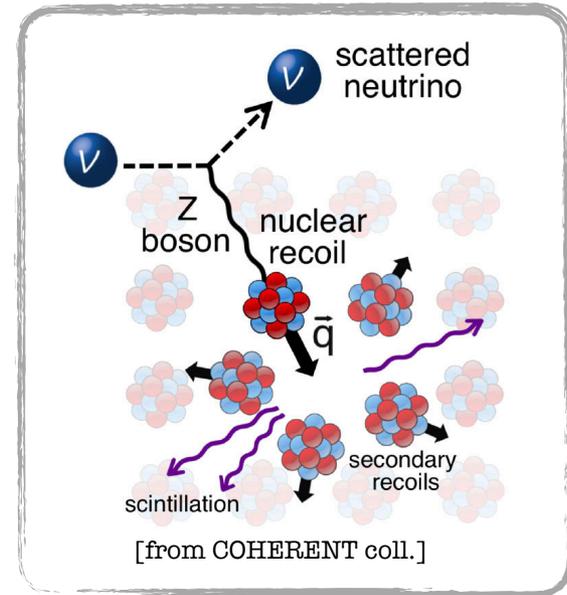
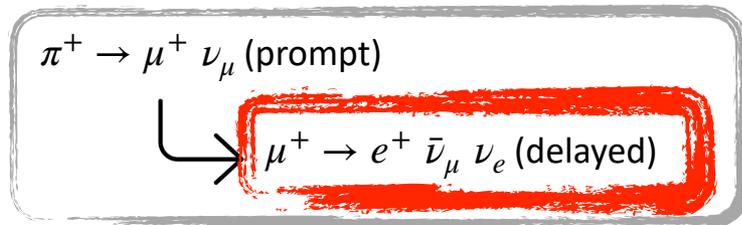
Can we also learn about  
NP in production ?

[Bresó-Pla, Cruz-Alzaga, MGA & Prakash,  
**2502.18175 PRL**]

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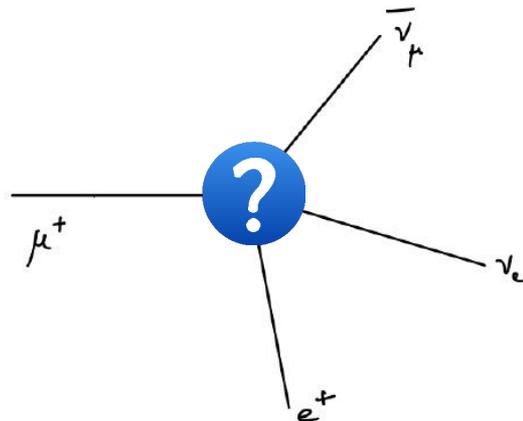
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[Bresó-Pla, Cruz-Alzaga, MGA & Prakash, **2502.18175\_PRL**]



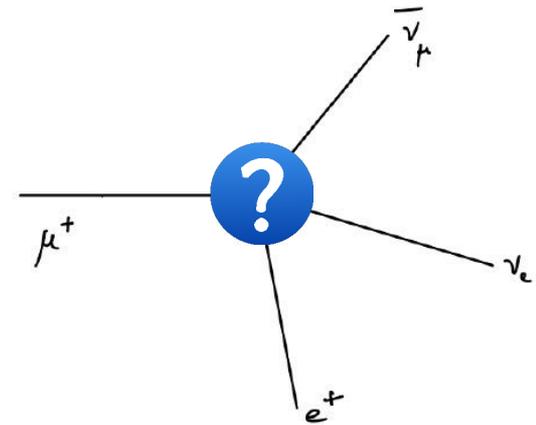
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# Muon decay

$$\mathcal{L} = -\frac{4G_F}{\sqrt{2}} \sum_{X,\eta,\epsilon} g_{\epsilon\eta}^X (\bar{e}_\epsilon \Gamma^X \nu_e)_\rho ((\bar{\nu}_\mu)_\gamma \Gamma_X \mu_\eta) + h.c..$$

- 10 interactions (with SM flavor structure)\*
- Standard Model:  $g_{LL}^V \rightarrow 1$ ; others  $\rightarrow 0$ .



\*With the normalization constraint ( $G_F$  comes from  $\mu$  decay):  $\sum_{\epsilon,\eta} \left[ \frac{1}{4} |g_{\epsilon\eta}^S|^2 + |g_{\epsilon\eta}^V|^2 + 3 |g_{\epsilon\eta}^T|^2 \right] = 1$

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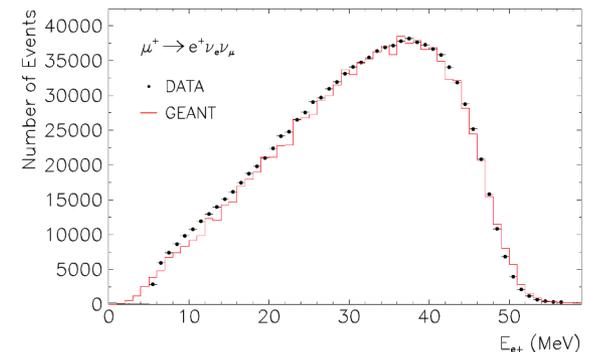
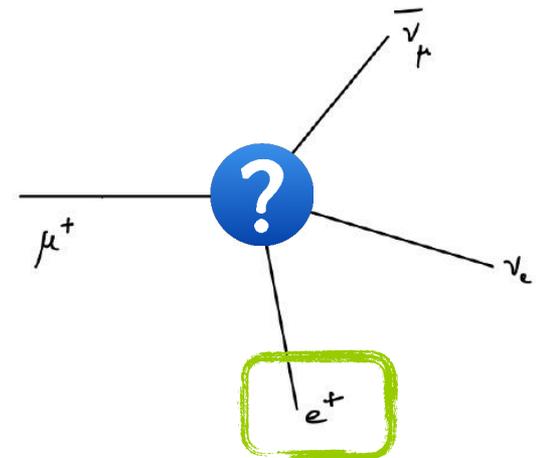
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- $e^\pm$  detection  $\rightarrow$  constraints on  $g_{\epsilon\eta}^X$  couplings (long used).

$$\frac{d\Gamma}{dy_e} = \frac{1}{2} \Gamma y_e^2 \left( 3(1 - y_e) + \frac{2\rho}{3}(4y_e - 3) \right) \quad [\text{Michel, 1950}]$$

$$y_e = 2E_e/m_\mu$$

Some combinations are tightly constrained, some others are not.

[ $e^\pm$  measurements are unable to disentangle the combination  $|g_{LL}^V|^2 + \frac{1}{4}|g_{LL}^S|^2$ ]



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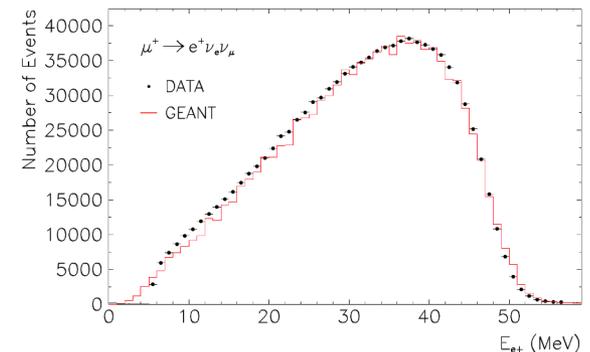
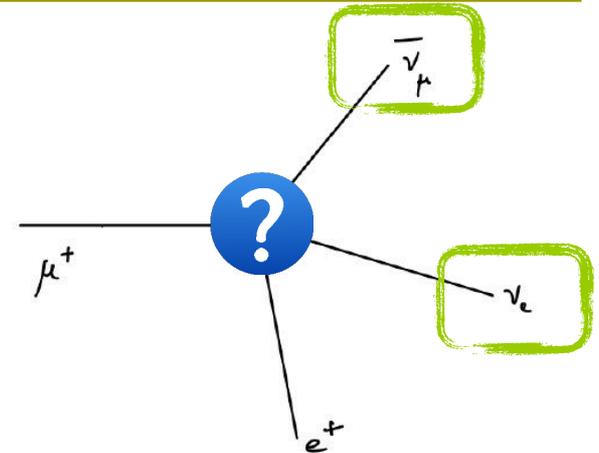
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- **What about (anti)neutrino detection?**



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# Muon decay parameters

- For left-handed neutrinos ( $\nu_e$ ):

$$\frac{d\Gamma_{\nu_L}}{dE_\nu} = \frac{24\Gamma_\mu}{m_\mu} P_{\nu_L} \left[ y^2 (1 - y) + \frac{8}{9} w_{\nu_L} y^2 \left( y - \frac{3}{4} \right) \right],$$

$$y = 2E_\nu/m_\mu$$

Agrees with Fetscher'94  
(typo in the PDG review)

- Same for antineutrinos ( $\bar{\nu}_\mu$ ):

$$\frac{d\Gamma_{\bar{\nu}_L}}{dE_{\bar{\nu}}} = \frac{24\Gamma_\mu}{m_\mu} P_{\bar{\nu}_L} \left[ y^2 \left( \frac{1}{2} - \frac{y}{3} \right) + \frac{8}{9} w_{\bar{\nu}_L} y^2 \left( \frac{3}{4} - y \right) \right],$$

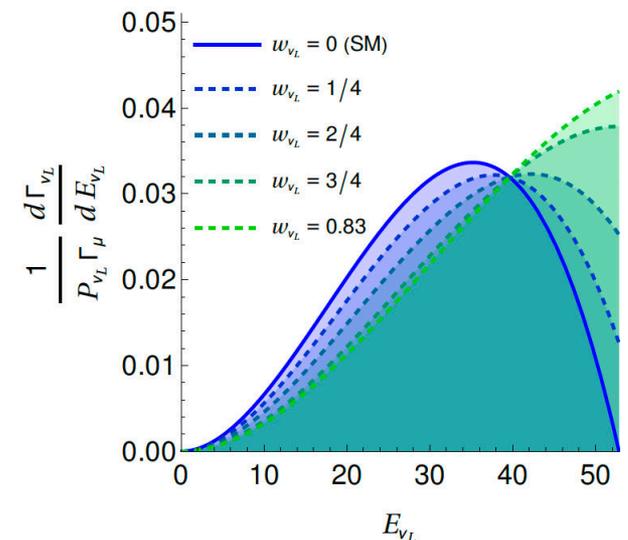
Not derived before AFAIK

$$P_{\nu_L} = |g_{LL}^V|^2 + |g_{LR}^V|^2 + \frac{1}{4}|g_{RR}^S|^2 + \frac{1}{4}|g_{RL}^S|^2 + 3|g_{RL}^T|^2,$$

$$P_{\nu_L} w_{\nu_L} = \frac{3}{16} \left( 4|g_{LR}^V|^2 + |g_{RR}^S|^2 + |g_{RL}^S + 2g_{RL}^T|^2 \right),$$

$$P_{\bar{\nu}_L} = |g_{LL}^V|^2 + |g_{RL}^V|^2 + \frac{1}{4}|g_{RR}^S|^2 + \frac{1}{4}|g_{LR}^S|^2 + 3|g_{LR}^T|^2,$$

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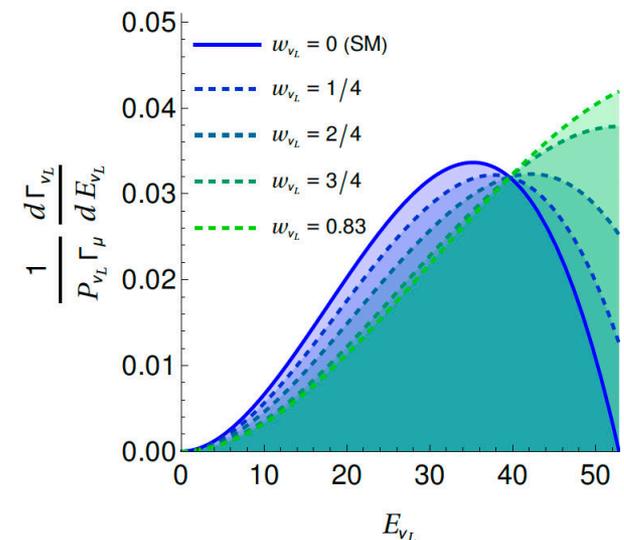
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- Same for antineutrinos ( $\bar{\nu}_\mu$ ):

$$\frac{d\Gamma_{\bar{\nu}_L}}{dE_{\bar{\nu}}} = \frac{24\Gamma_\mu}{m_\mu} P_{\bar{\nu}_L} \left[ y^2 \left( \frac{1}{2} - \frac{y}{3} \right) + \frac{8}{9} w_{\bar{\nu}_L} y^2 \left( \frac{3}{4} - y \right) \right],$$

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$$\begin{aligned} P_{\nu_L} &= |g_{LL}^V|^2 + |g_{LR}^V|^2 + \frac{1}{4}|g_{RR}^S|^2 + \frac{1}{4}|g_{RL}^S|^2 + 3|g_{RL}^T|^2, \\ P_{\nu_L} w_{\nu_L} &= \frac{3}{16} \left( 4|g_{LR}^V|^2 + |g_{RR}^S|^2 + |g_{RL}^S + 2g_{RL}^T|^2 \right), \\ P_{\bar{\nu}_L} &= |g_{LL}^V|^2 + |g_{RL}^V|^2 + \frac{1}{4}|g_{RR}^S|^2 + \frac{1}{4}|g_{LR}^S|^2 + 3|g_{LR}^T|^2, \\ P_{\bar{\nu}_L} w_{\bar{\nu}_L} &= \frac{3}{16} \left( |g_{RR}^S|^2 + |g_{LR}^S|^2 - 4|g_{LR}^T|^2 \right). \end{aligned} \quad (5)$$



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Only one experimental extraction!  
[KARMEN, PRL'98]

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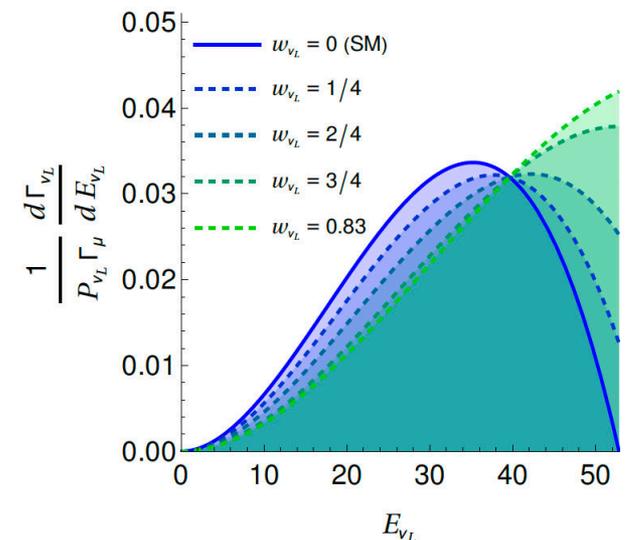
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Not derived before AFAIK

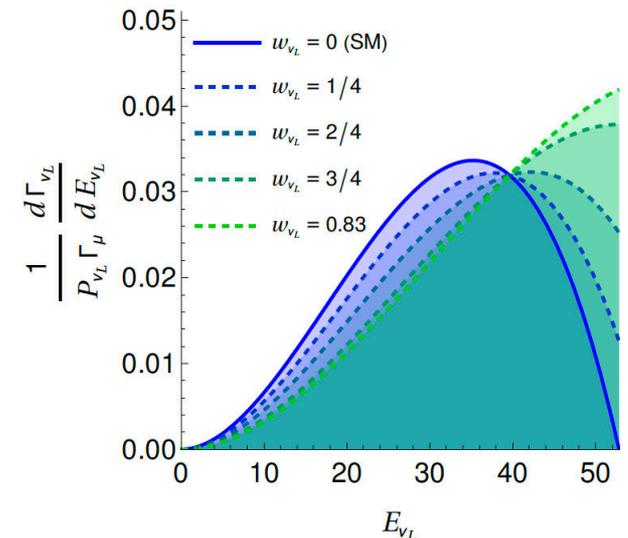
Never extracted!

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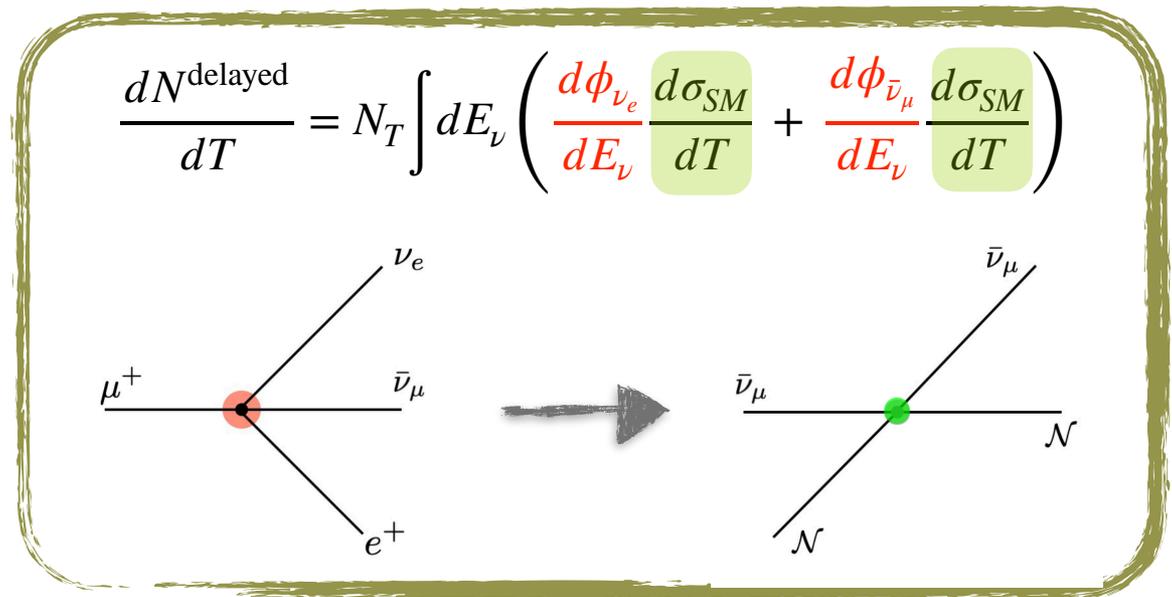
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Never extracted!

→ **COHERENT!**



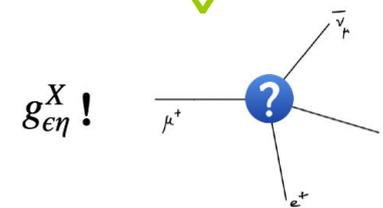
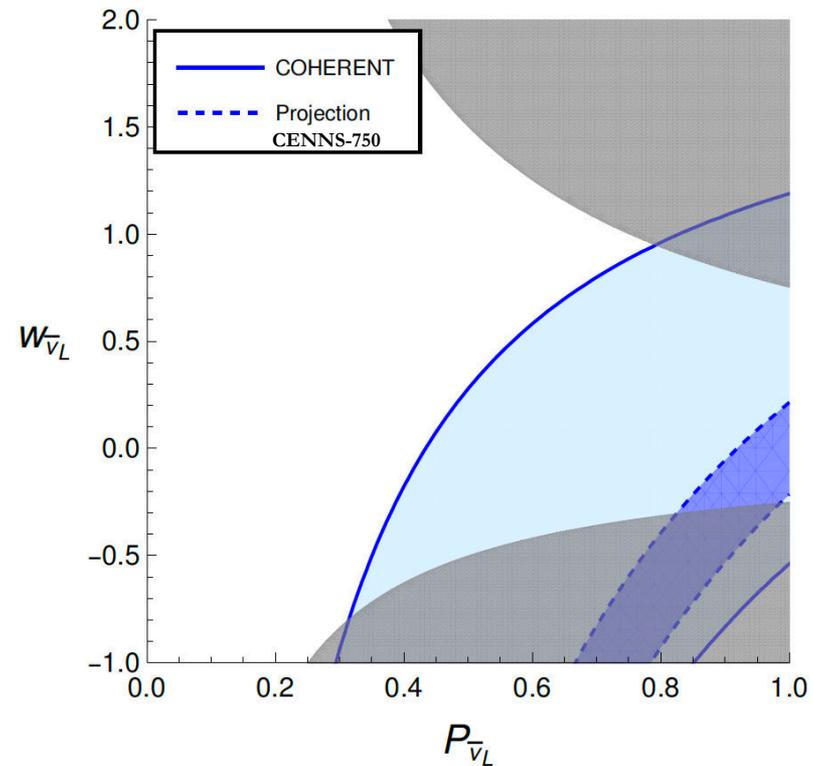
# Muon decay parameters $\rightarrow$ COHERENT

COHERENT data  
LAr + CsI  
recoil & time distribution  
(664 data)



$$0.54 P_{\nu_L} + 0.84 P_{\bar{\nu}_L} + 0.40 (P_{\nu_L} w_{\nu_L} - P_{\bar{\nu}_L} w_{\bar{\nu}_L}) = 1.25(21)$$

First extraction ever  
of these parameters!

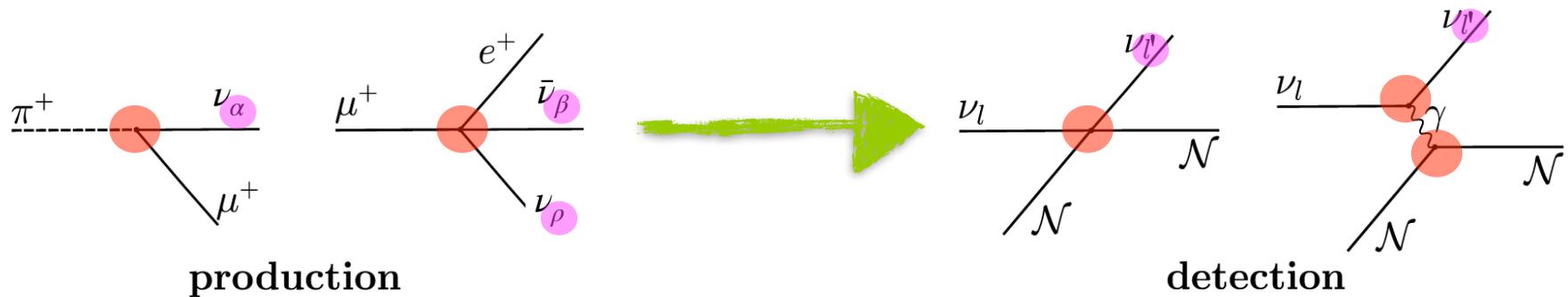


# NP everywhere

[Bresó-Pla, Cruz-Alzaga, MGA & Prakash, 2505.01275 JHEP]

- **General EFT study (νLEFT):**

NP in CEνNS (vector, scalar,  $\mu_\nu$ ),  $\pi$  decay and  $\mu$  decay; general flavor structure ( $\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\tau$ ),  $N \nu_R$ .



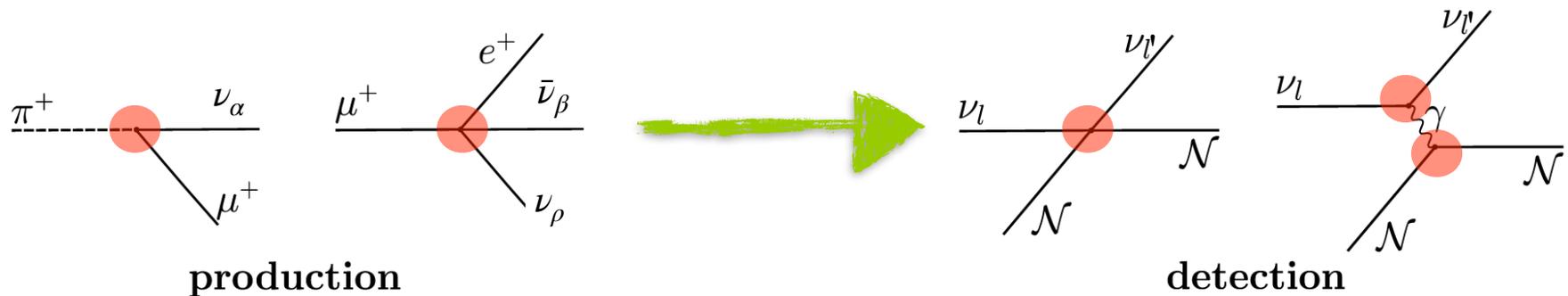
Many Wilson Coefficients!

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$$\frac{dN^{\text{prompt/delayed}}}{dT} = N_T \int dE_\nu \sum_f \frac{d\phi_f^{\text{SM}}}{dE_\nu} \frac{d\tilde{\sigma}_f}{dT}$$

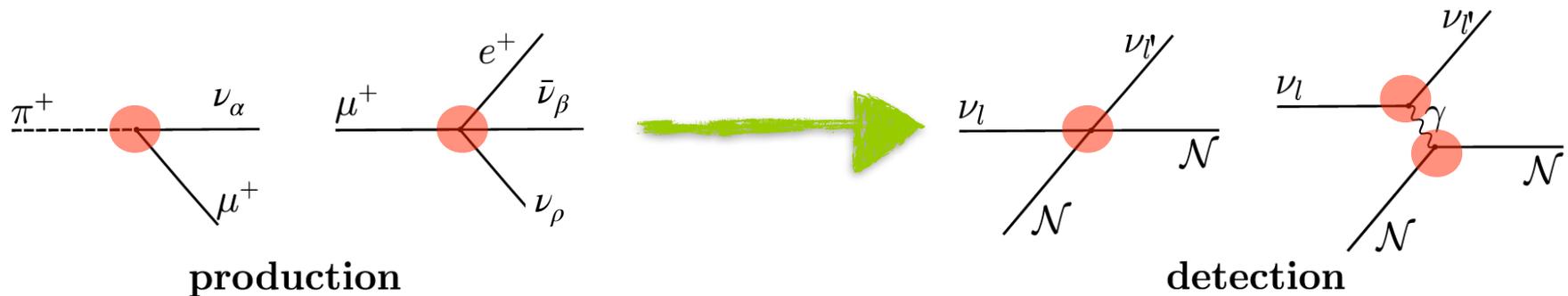
$$\frac{d\tilde{\sigma}_f}{dT} = \frac{m_N \mathcal{F}^2(q^2)}{8\pi v^4} \left\{ (\tilde{Q}_V^f)^2 \left( 1 - \frac{m_N T}{2E_\nu^2} - \frac{T}{E_\nu} \right) + (\tilde{Q}_S^f)^2 \frac{m_N T}{2E_\nu^2} \right. \\ \left. + (\tilde{Q}_F^f)^2 \frac{v^2}{2m_N T} \left( 1 - \frac{T}{E_\nu} \right) + (\tilde{Q}_{SF}^f)^2 \frac{v}{2E_\nu} \left( 1 - \frac{T}{2E_\nu} \right) \right\},$$

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f(production, detection)

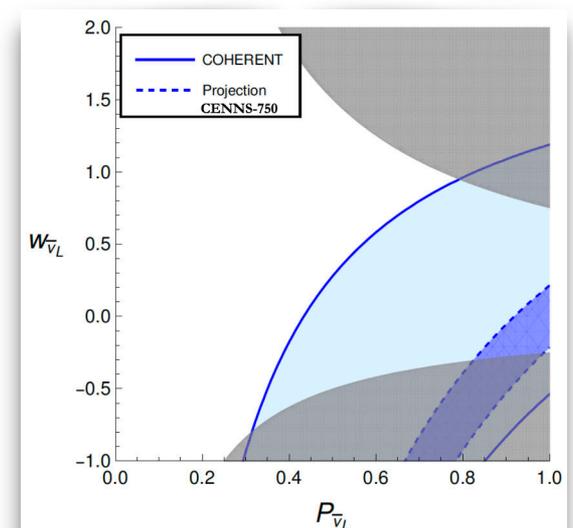
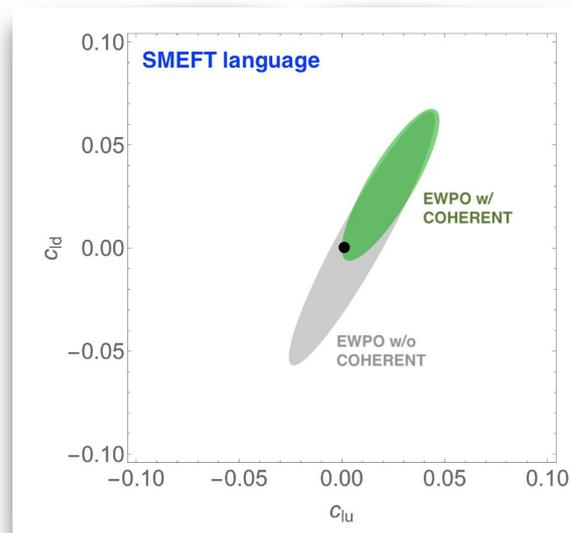
# Summary

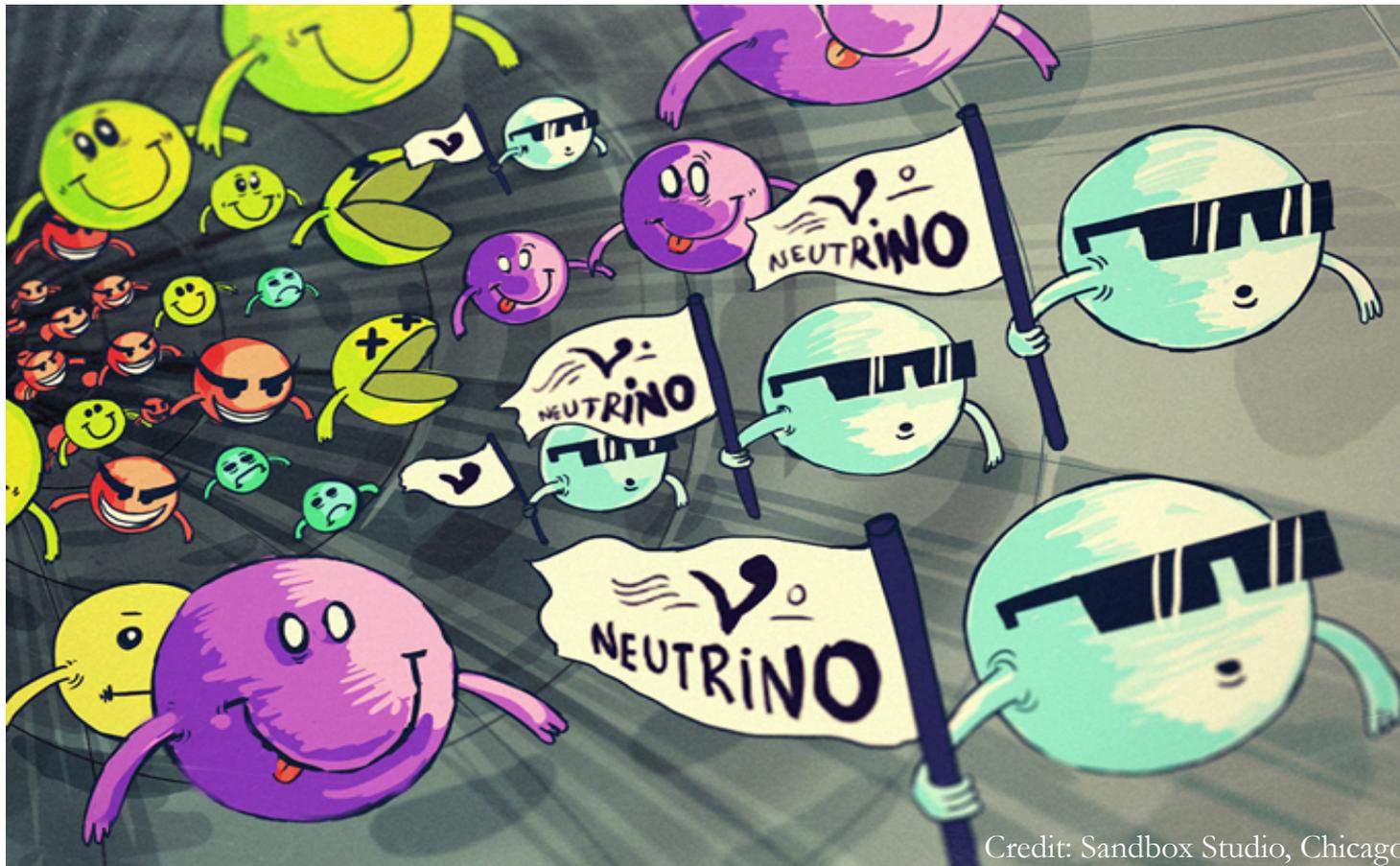
- CEvNS: discovery (2017) to precision
- Low-energy process  $\rightarrow$  EFT
  - Competitive EWPO (SMEFT fit)
  - Full  $\nu$ LEFT results available (for  $\pi$ DAR production)
- CEvNS  $\rightarrow$  sensitive to NP in neutrino production.
  - **1st extraction** of  $\bar{\nu}_\mu$  Michel parameters ( $E_{\bar{\nu}_\mu}$  distribution).

EFT!!



Just the beginning!





Credit: Sandbox Studio, Chicago

# Thanks!

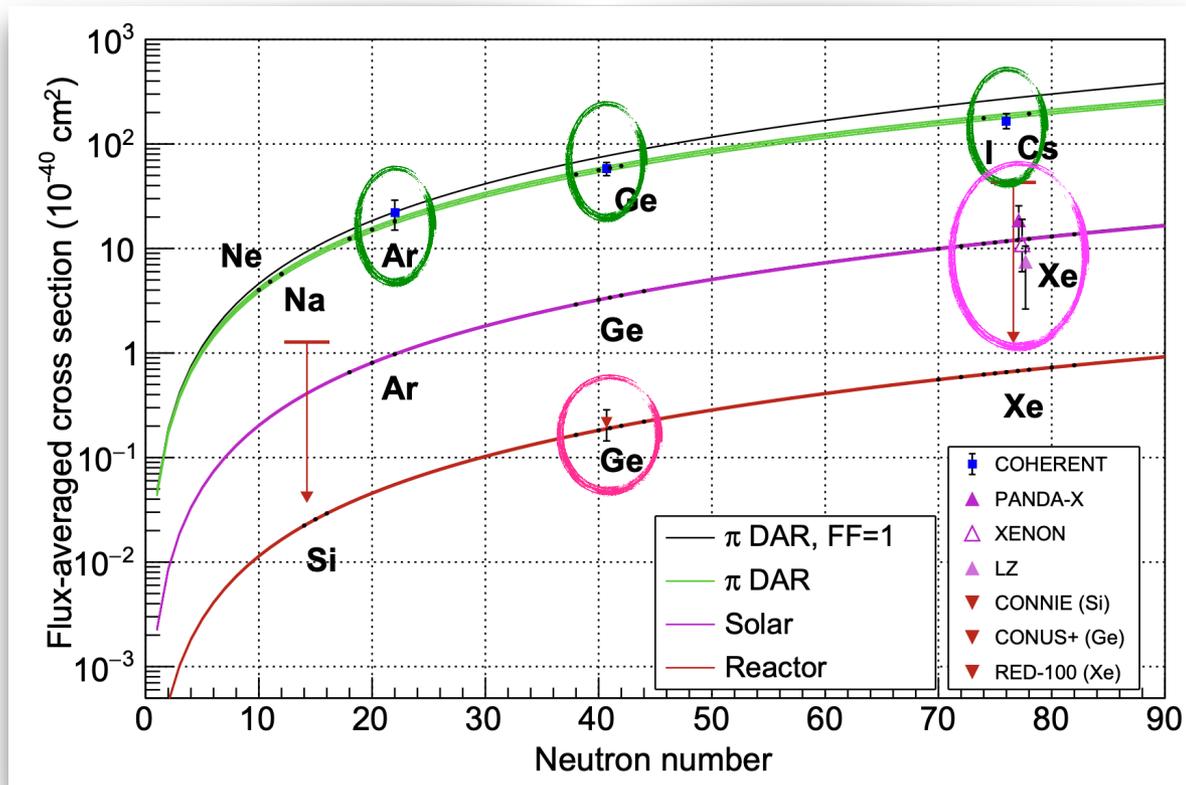
Grant **PID2023-146220NB-I00** and  
grant **CNS2022-135595** funded by



# Backups

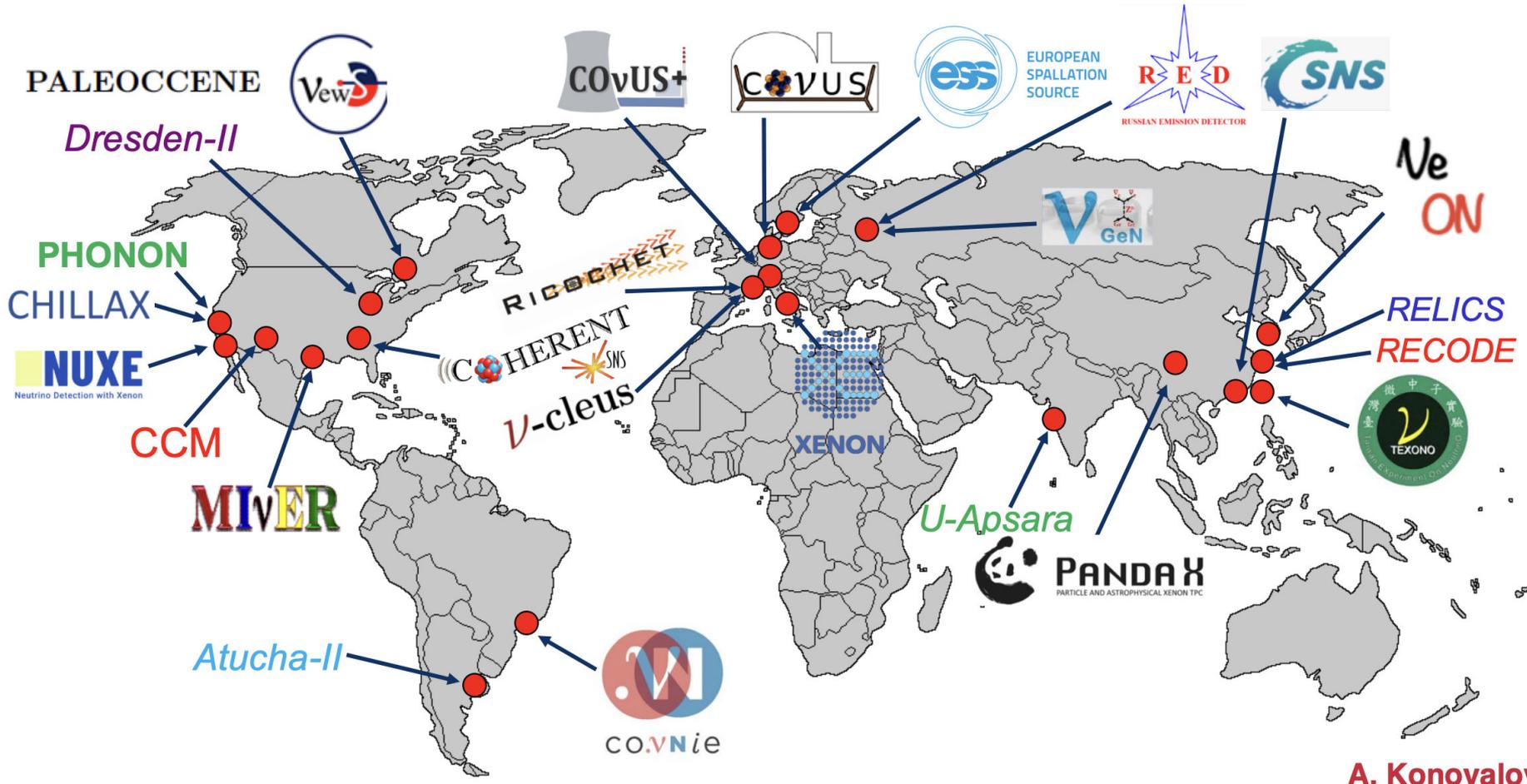
# CE $\nu$ NS 101

- $\nu N \rightarrow \nu N$ : for  $E_\nu$  small enough the neutrino does not resolve the nucleus  
→  $\sigma \sim N^2$  ! *Coherent* Elastic Neutrino-Nucleus Scattering (CE $\nu$ NS) [[Freedman'74](#)]
- Extremely challenging experimentally (very small nuclear recoil)
- COHERENT observed CE $\nu$ NS for the 1st time in 2017 at the SNS [[Akimov et al.'17](#)]
  - Now measured with different detectors & targets (discovery → precision)



# CE $\nu$ NS 101

## The Wide World of CE $\nu$ NS



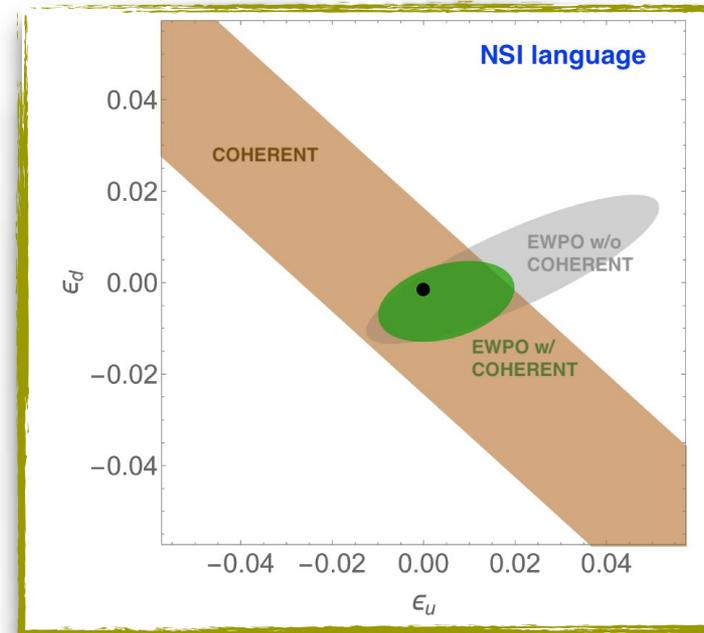
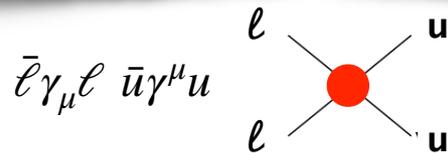
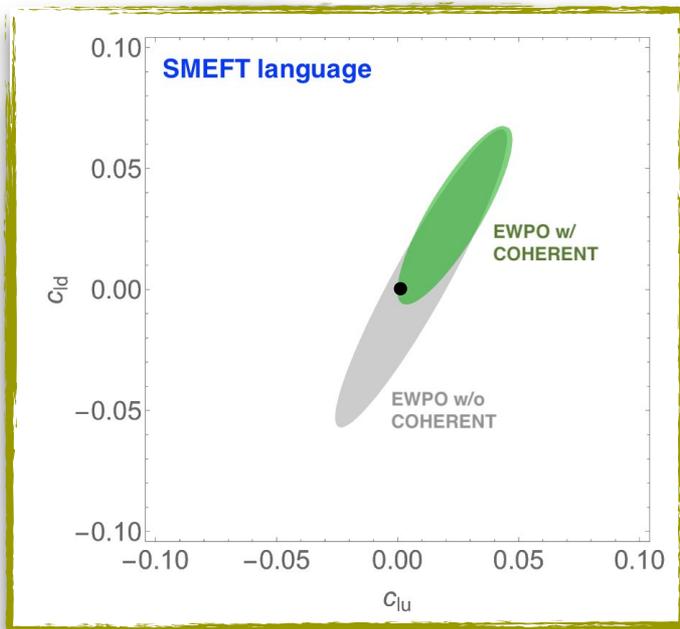
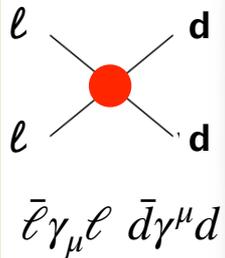
M.P. Green | Exp. Summary | Mag7s 2025

A. Konovalov

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# COHERENT in the SMEFT

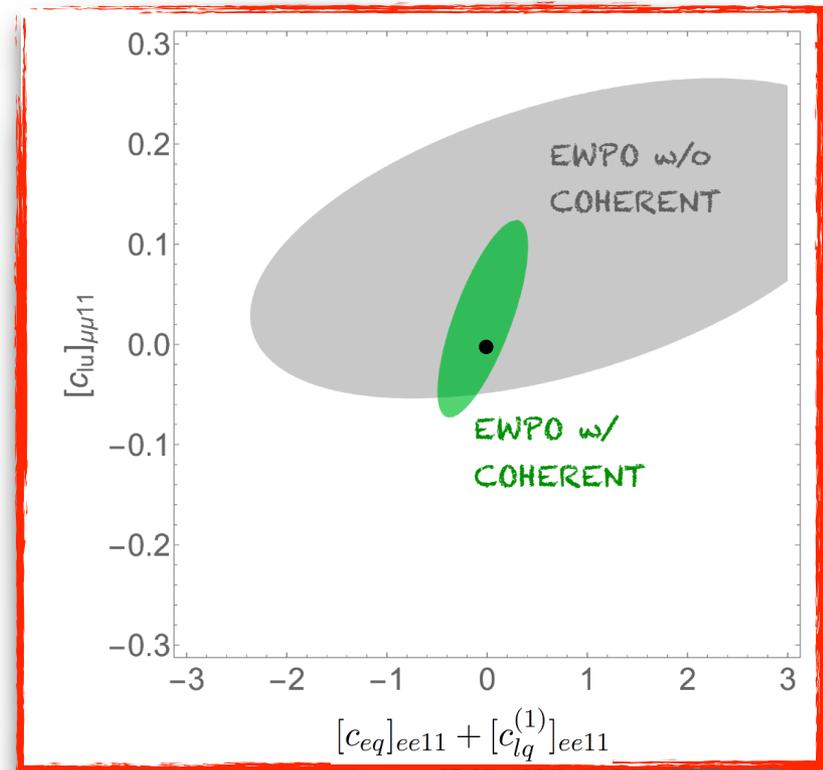
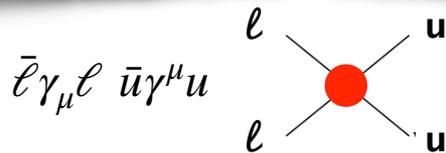
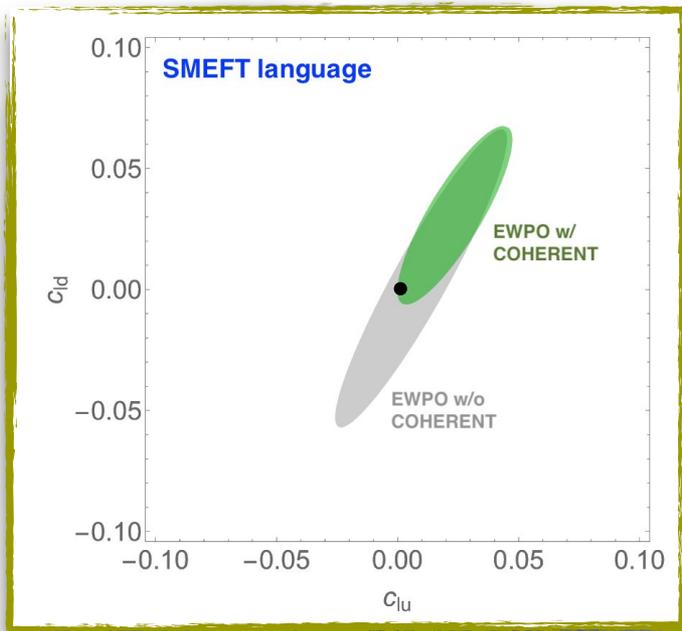
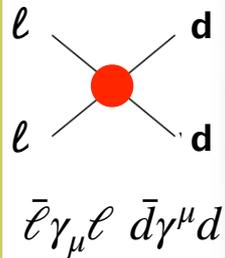
- Global fit to Electroweak precision observables in the flavor-universal SMEFT



18 free parameters

# COHERENT in LEFT $\rightarrow$ SMEFT

- Global fit to Electroweak precision observables in the ~~flavor universal~~ SMEFT



18 free parameters



65 free parameters

# Muon decay parameters $\rightarrow$ COHERENT

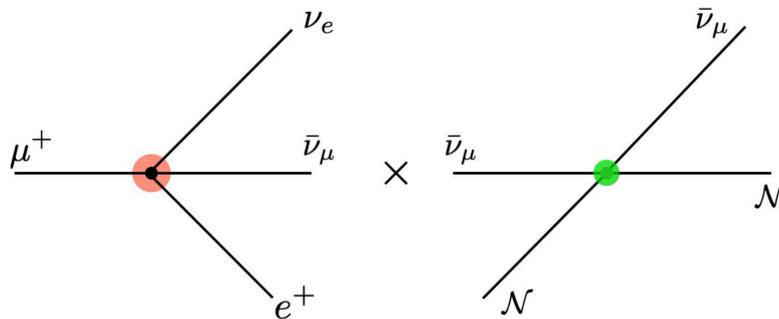
- Let's allow for NP only in muon decay (SM detection + SM pion decay + Flavor diagonal):

$$\begin{aligned} \frac{dN^{\text{delayed}}}{dT} &= N_T \int dE_\nu \left( \frac{d\phi_{\nu_e}}{dE_\nu} \frac{d\sigma_{SM}}{dT} + \frac{d\phi_{\bar{\nu}_\mu}}{dE_\nu} \frac{d\sigma_{SM}}{dT} \right) \\ &= N_T \int dE_\nu \left( x_{\nu_e} \frac{d\phi_{\nu_e}^{SM}}{dE_\nu} \frac{d\sigma_{SM}}{dT} + x_{\bar{\nu}_\mu} \frac{d\phi_{\bar{\nu}_\mu}^{SM}}{dE_\nu} \frac{d\sigma_{SM}}{dT} \right) \\ &= N_T \int dE_\nu \left( \frac{d\phi_{\nu_e}^{SM}}{dE_\nu} \frac{d\tilde{\sigma}_{\nu_e}}{dT} + \frac{d\phi_{\bar{\nu}_\mu}^{SM}}{dE_\nu} \frac{d\tilde{\sigma}_{\bar{\nu}_\mu}}{dT} \right) \end{aligned}$$

$$\frac{d\sigma_{SM}}{dT} = \frac{m_N \mathcal{F}^2(q^2)}{8\pi v^4} Q_{SM}^2 \left( 1 - \frac{m_N T}{2E_\nu^2} - \frac{T}{E_\nu} \right)$$

$$\frac{d\tilde{\sigma}_f}{dT} = \frac{m_N \mathcal{F}^2(q^2)}{8\pi v^4} x_f Q_{SM}^2 \left( 1 - \frac{m_N T}{2E_\nu^2} - \frac{T}{E_\nu} \right)$$

$\tilde{Q}_f^2$  ( $f = \nu_e, \bar{\nu}_\mu$ ) Flavor dependent!



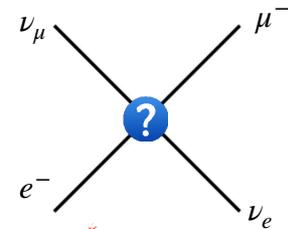
$$\begin{aligned} x_{\bar{\nu}_\mu} &= P_{\bar{\nu}_L} - \frac{4}{3} P_{\bar{\nu}_L} w_{\bar{\nu}_L} + \frac{4}{3} P_{\nu_L} w_{\nu_L}, \\ x_{\nu_e} &= P_{\nu_L} - \frac{4}{3} P_{\nu_L} w_{\nu_L} + \frac{4}{3} P_{\bar{\nu}_L} w_{\bar{\nu}_L}, \end{aligned}$$

Trivial implementation  
in existing & future analyses!

# NP in muon decay $\rightarrow$ COHERENT event rate

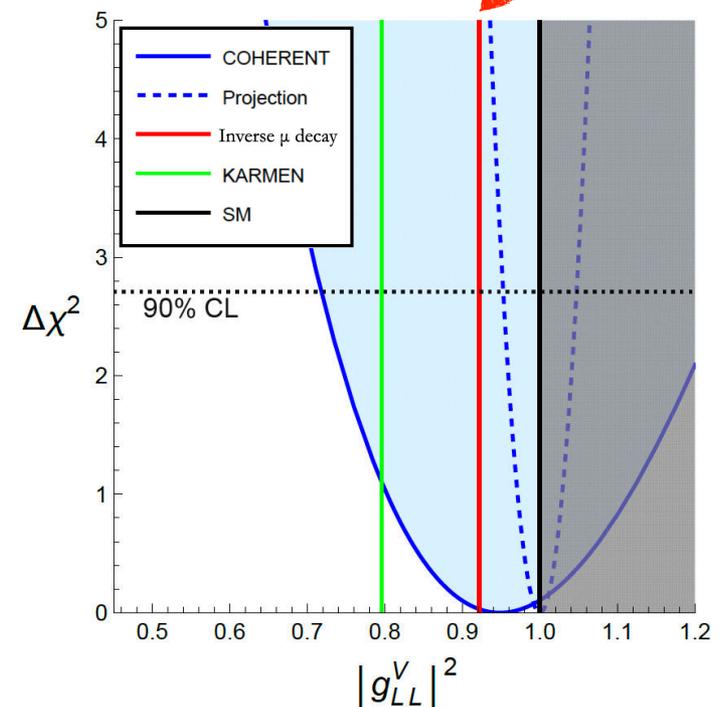
$$\{P_{\nu_L}, P_{\bar{\nu}_L}, w_{\nu_L}, w_{\bar{\nu}_L}\} \longrightarrow g\epsilon\eta^X!$$

$$\begin{aligned} P_{\nu_L} &= |g_{LL}^V|^2 + |g_{LR}^V|^2 + \frac{1}{4}|g_{RR}^S|^2 + \frac{1}{4}|g_{RL}^S|^2 + 3|g_{RL}^T|^2, \\ P_{\nu_L} w_{\nu_L} &= \frac{3}{16} \left( 4|g_{LR}^V|^2 + |g_{RR}^S|^2 + |g_{RL}^S|^2 + 2|g_{RL}^T|^2 \right), \\ P_{\bar{\nu}_L} &= |g_{LL}^V|^2 + |g_{RL}^V|^2 + \frac{1}{4}|g_{RR}^S|^2 + \frac{1}{4}|g_{LR}^S|^2 + 3|g_{LR}^T|^2, \\ P_{\bar{\nu}_L} w_{\bar{\nu}_L} &= \frac{3}{16} \left( |g_{RR}^S|^2 + |g_{LR}^S|^2 - 4|g_{LR}^T|^2 \right). \end{aligned} \quad (5)$$



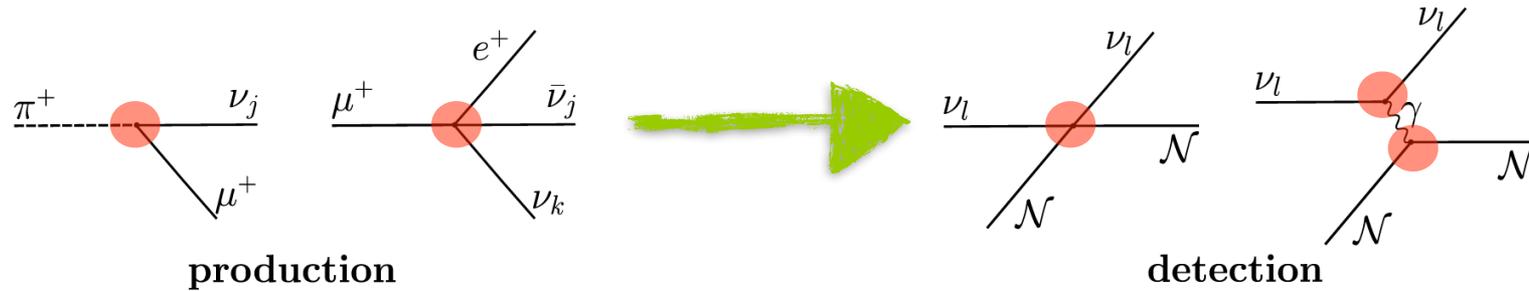
Interesting case:  $\{g_{LL}^V, g_{LL}^S\}$

- $e^\pm$  measurements don't help (norm:  $|g_{LL}^V|^2 + \frac{1}{4}|g_{LL}^S|^2 = 1$ ).  
COHERENT does
- Current data not competitive,  
but it will lead in the future.  
 $\rightarrow$  It should be included in future PDG fits.



# Complete $\nu$ LEFT study

[2505.01275,  
Bresó-Pla, Cruz-Alzaga, MGA & Prakash]



$$\mathcal{L} \supset -\frac{2V_{ud}}{v^2} \left\{ \left[ \mathbb{I} + \tilde{\epsilon}_L^{ud} \right]_{\alpha\beta} (\bar{u}\gamma^\mu P_L d)(\bar{l}_\alpha \gamma_\mu P_L \nu_\beta) + \left[ \epsilon_R^{ud} \right]_{\alpha\beta} (\bar{u}\gamma^\mu P_R d)(\bar{l}_\alpha \gamma_\mu P_L \nu_\beta) \right. \\ + \left[ \tilde{\epsilon}_L^{ud} \right]_{\alpha\beta} (\bar{u}\gamma^\mu P_L d)(\bar{l}_\alpha \gamma_\mu P_R \nu_\beta) + \left[ \tilde{\epsilon}_R^{ud} \right]_{\alpha\beta} (\bar{u}\gamma^\mu P_R d)(\bar{l}_\alpha \gamma_\mu P_R \nu_\beta) \\ + \frac{1}{2} \left[ \epsilon_S^{ud} \right]_{\alpha\beta} (\bar{u}d)(\bar{l}_\alpha P_L \nu_\beta) - \frac{1}{2} \left[ \epsilon_P^{ud} \right]_{\alpha\beta} (\bar{u}\gamma^5 d)(\bar{l}_\alpha P_L \nu_\beta) \\ + \frac{1}{2} \left[ \tilde{\epsilon}_S^{ud} \right]_{\alpha\beta} (\bar{u}d)(\bar{l}_\alpha P_R \nu_\beta) - \frac{1}{2} \left[ \tilde{\epsilon}_P^{ud} \right]_{\alpha\beta} (\bar{u}\gamma^5 d)(\bar{l}_\alpha P_R \nu_\beta) \\ \left. + \frac{1}{4} \left[ \epsilon_T^{ud} \right]_{\alpha\beta} (\bar{u}\sigma^{\mu\nu} P_L d)(\bar{l}_\alpha \sigma_{\mu\nu} P_L \nu_\beta) + \frac{1}{4} \left[ \tilde{\epsilon}_T^{ud} \right]_{\alpha\beta} (\bar{u}\sigma^{\mu\nu} P_R d)(\bar{l}_\alpha \sigma_{\mu\nu} P_R \nu_\beta) \right\} \\ + h.c., \quad (2.2)$$

$$\mathcal{L} \supset \mathcal{L}_{\text{QED}} - \frac{[\mu\nu]_{\alpha\beta}}{2} (\bar{\nu}_\alpha \sigma^{\mu\nu} P_R \nu_\beta) F_{\mu\nu} + h.c. - \sum_{q=u,d} \frac{\mu_q}{2} (\bar{q}\sigma^{\mu\nu} P_R q) F_{\mu\nu} + h.c. \\ - \frac{1}{v^2} \sum_{q=u,d} \left\{ \left[ g_V^{qq} \mathbb{I} + \epsilon_V^{qq} \right]_{\alpha\beta} (\bar{q}\gamma^\mu q)(\bar{\nu}_\alpha \gamma_\mu P_L \nu_\beta) + \left[ \tilde{\epsilon}_V^{qq} \right]_{\alpha\beta} (\bar{q}\gamma^\mu q)(\bar{\nu}_\alpha \gamma_\mu P_R \nu_\beta) \right. \\ + \left[ g_A^{qq} \mathbb{I} + \epsilon_A^{qq} \right]_{\alpha\beta} (\bar{q}\gamma^\mu \gamma^5 q)(\bar{\nu}_\alpha \gamma_\mu P_L \nu_\beta) + \left[ \tilde{\epsilon}_A^{qq} \right]_{\alpha\beta} (\bar{q}\gamma^\mu \gamma^5 q)(\bar{\nu}_\alpha \gamma_\mu P_R \nu_\beta) \\ + \left[ \tilde{\epsilon}_S^{qq} \right]_{\alpha\beta} (\bar{q}q)(\bar{\nu}_\alpha P_R \nu_\beta) + h.c. + \left[ \tilde{\epsilon}_P^{qq} \right]_{\alpha\beta} (\bar{q}i\gamma^5 q)(\bar{\nu}_\alpha P_R \nu_\beta) + h.c. \\ \left. + \left[ \tilde{\epsilon}_T^{qq} \right]_{\alpha\beta} (\bar{q}\sigma^{\mu\nu} q)(\bar{\nu}_\alpha \sigma_{\mu\nu} P_R \nu_\beta) + h.c. \right\}$$

$$\mathcal{L} \supset -\frac{2}{v_0^2} \sum_{X,\eta,\epsilon} \left[ \hat{h}_{\epsilon\eta}^X \right]_{\alpha\beta} (\bar{e}_\epsilon \Gamma^X (\nu_\beta)_\rho) ((\bar{\nu}_\alpha)_\gamma \Gamma_X \mu_\eta) + h.c. \\ = -\frac{2}{v^2} \sum_{X,\eta,\epsilon} \left[ h_{\epsilon\eta}^X \right]_{\alpha\beta} (\bar{e}_\epsilon \Gamma^X (\nu_\beta)_\rho) ((\bar{\nu}_\alpha)_\gamma \Gamma_X \mu_\eta) + h.c.$$

- COHERENT event rate calculated using a QFT approach [Falkowski, MGA & Tabrizi'20].

$$\sum_j R_{aj}^S \equiv \frac{dN_{aj}^S}{dt dE_\nu d\mathbf{T}} = \frac{\kappa}{E_\nu} \sum_{k,l,j} e^{-i \frac{L\Delta m_{kl}^2}{2E_\nu}} \int d\Pi_{P'} \mathcal{M}_{\alpha k}^P \bar{\mathcal{M}}_{\alpha l}^P \int d\Pi_D \mathcal{M}_{j k}^D \bar{\mathcal{M}}_{j l}^D$$

