BSM Targets at a Target-less DUNE

Chicago Workshop on Dark Matter and Neutrino Physics

March 8-10, 2023

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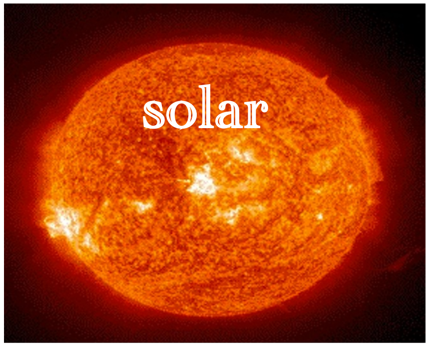
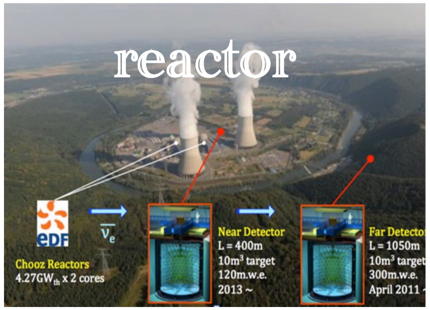
Northwestern University

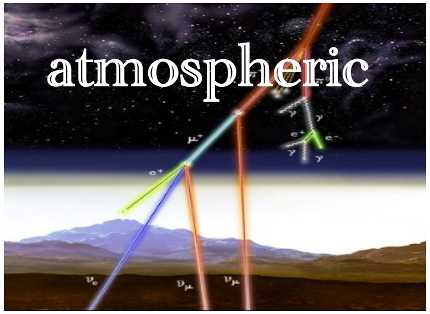
Status of Neutrino Physics in 2022



Super-Kamiokande, Borexino, SNO



MBL: Daya Bay, RENO, Double Chooz
LBL: KamLAND



IceCube, Super-Kamiokande

T2K, MINOS, NOvA

mixing angles:

$$sin^2\theta_{12} \text{ @ } 4\%$$
$$sin^2\theta_{13} \text{ @ } 3\%$$
$$sin^2\theta_{23} \text{ @ } 3\%$$

mass squared differences:

$$\Delta m^2_{21} \text{ @ } 3\%$$
$$|\Delta m^2_{31}| \text{ @ } 1\%$$

Future: DUNE, T2HK , JUNO

- Increase the precision
- CP-phase?
- Mass hierarchy?

Also:
Mass scale? Dirac or Majorana?
Sterile?

Physics goals of near detectors:

Primary role: Understanding Systematic Uncertainties

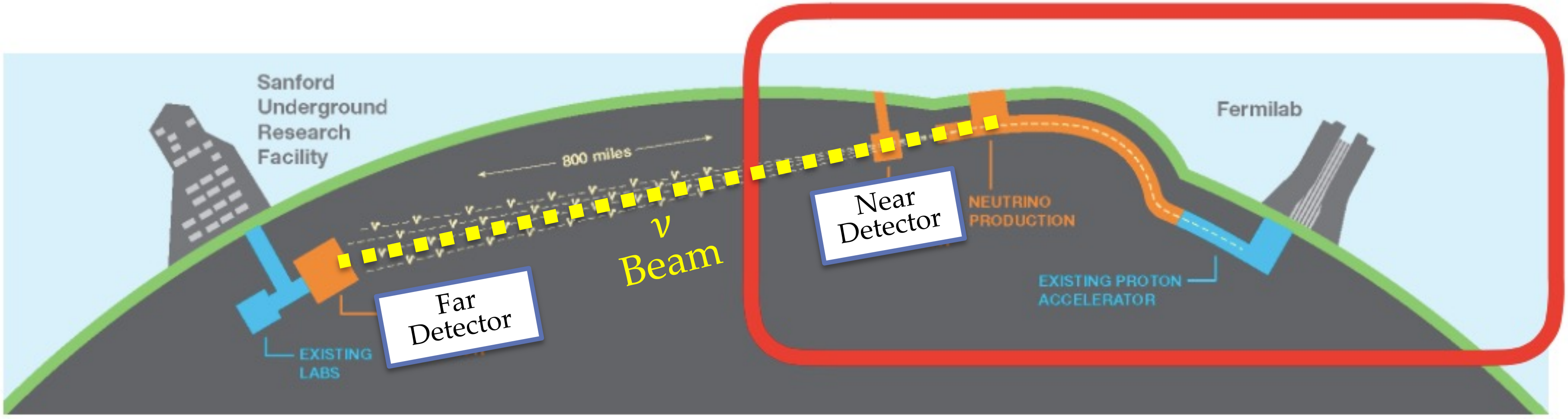
High beam luminosity +
Large fiducial mass

→

Ideal to investigate
rare/new neutrino
interactions

$\sigma < 10^{-44}$ cm^2

- Test SM predictions
- Search for BSM physics

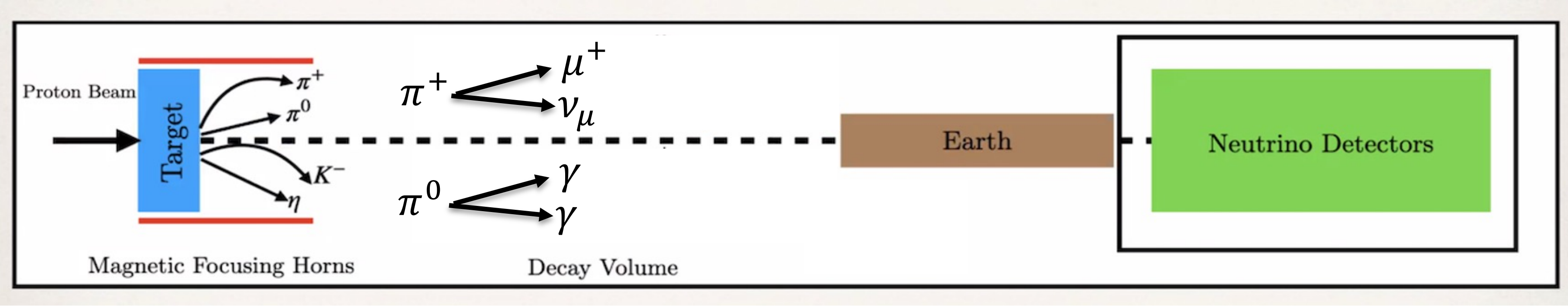


Question:

- How can we fully leverage DUNE to search for New Physics?

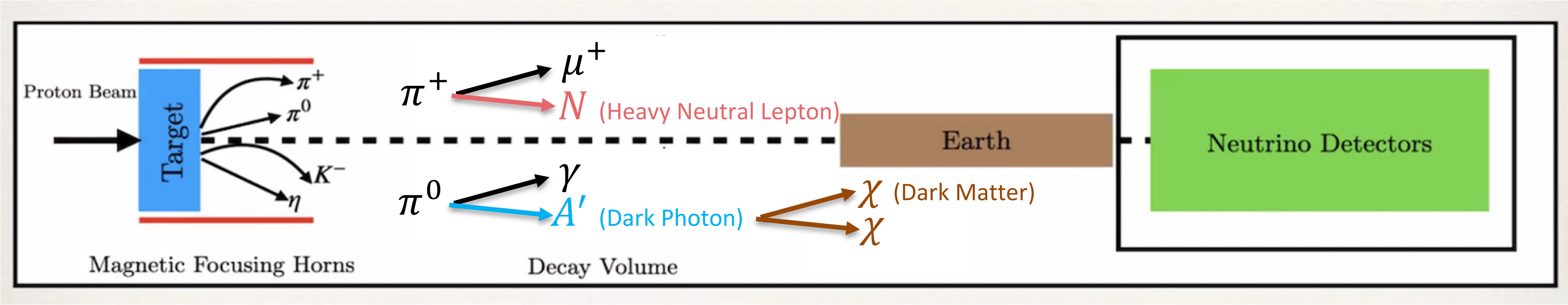
- Can DUNE probe compelling new physics beyond the reach of high energy colliders?

Neutrino Experiments as Dark Sector factories!



Credit: Kevin Kelly

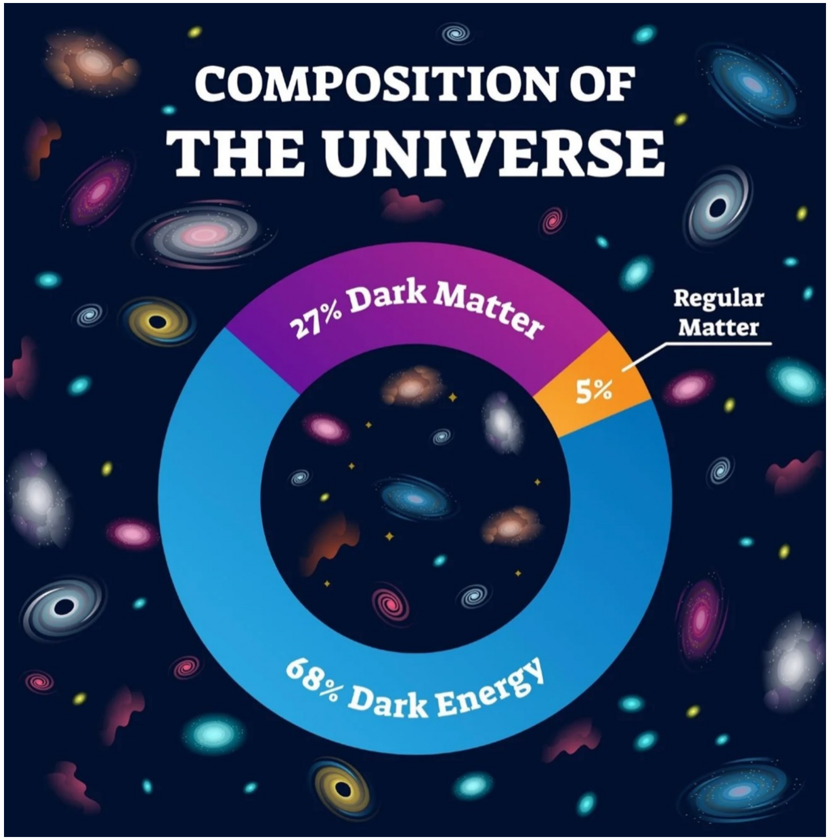
The huge fluxes of neutrinos and photos can be used for BSM searches



- **Heavy Neutral Leptons, Dark Photon, light DM, etc**

Berryman et al, PRD (2018)
Breitbach et al, JHEP (2022)
De Romeri et al, PRD (2019)
Magill et al, PRL (2019)

- Light Dark Matter
- Axion-Like Particles
- Light Z'
- SMEFT
- Conclusion



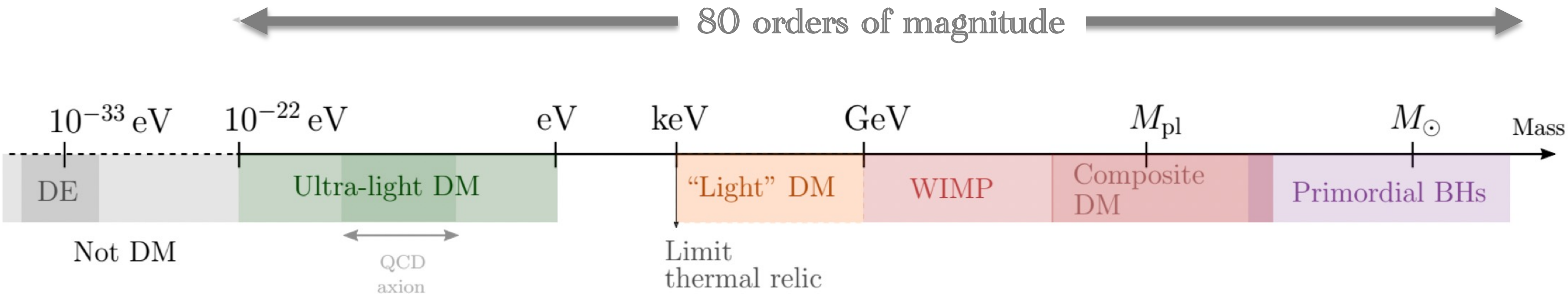
“What is Dark Matter?”

We don’t know!

There could be several kinds, making up a whole “dark sector”

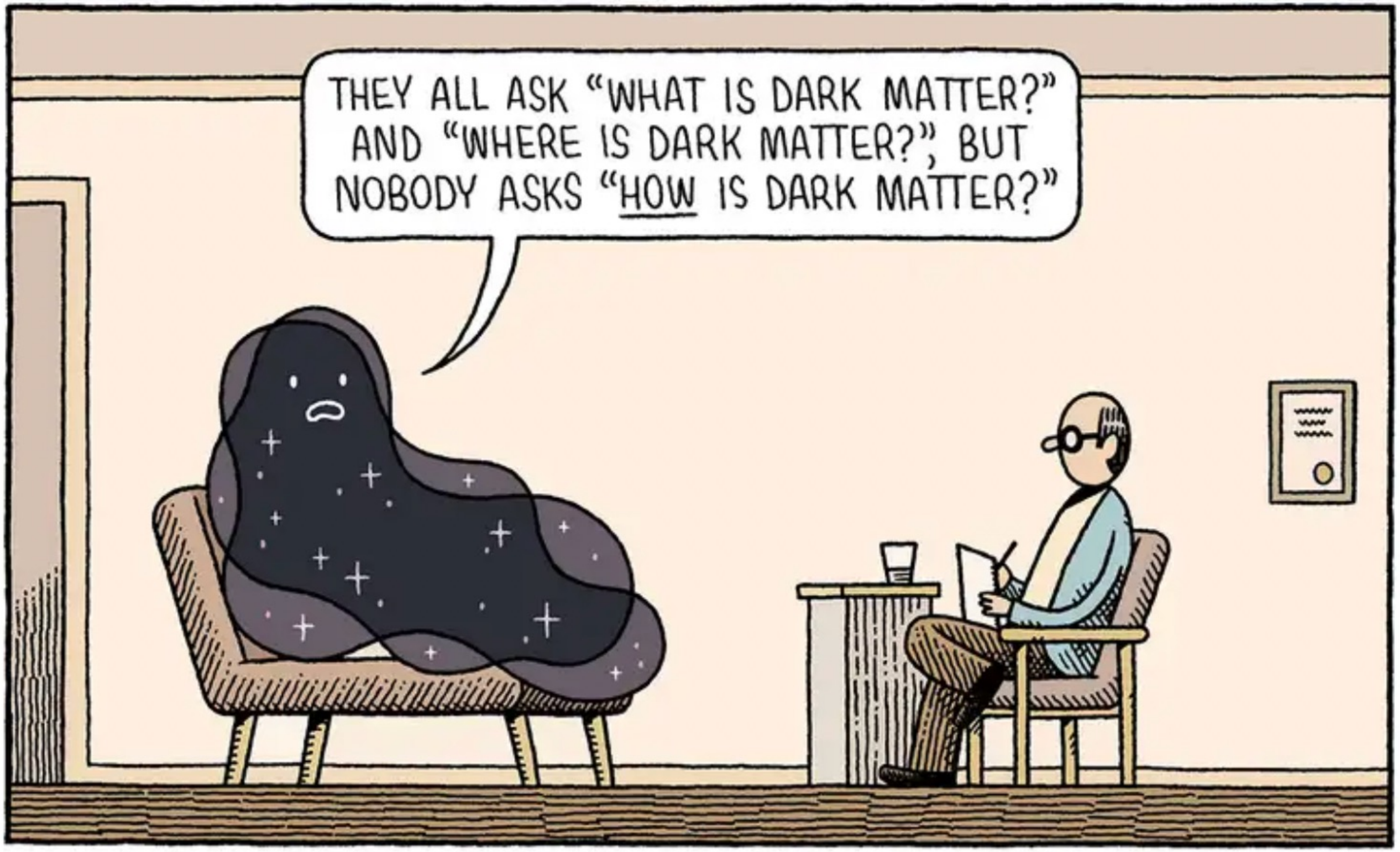
“Where is Dark Matter?”

We don’t know!



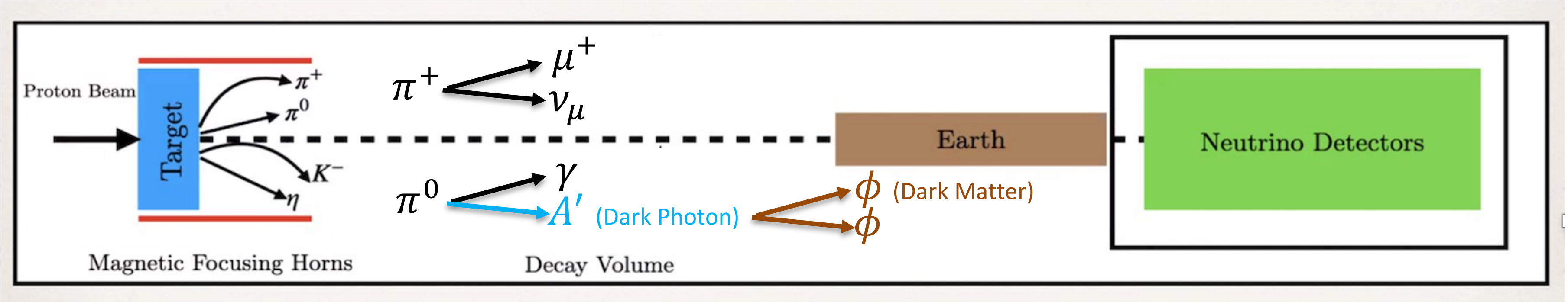
Elisa G. M. Ferreira, arXiv:2005.03254

“How is Dark Matter?”



TOM GAULD for NEW SCIENTIST

Light Dark Matter

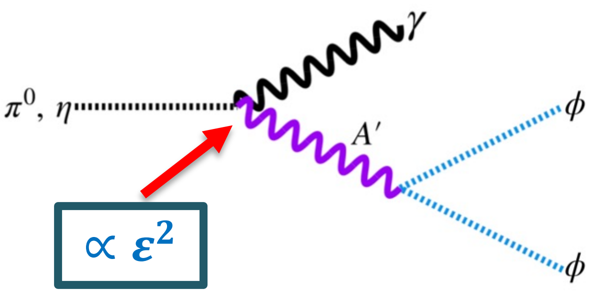


Photons at the target kinetically produce Dark Photons, which decay into dark matter:

$$\mathcal{L} \supset -\frac{\varepsilon}{2} F^{\mu\nu} F'_{\mu\nu} + \frac{M_{A'}^2}{2} A'_\mu A'^\mu + |D_\mu \phi|^2 - M_\phi^2 |\phi|^2$$

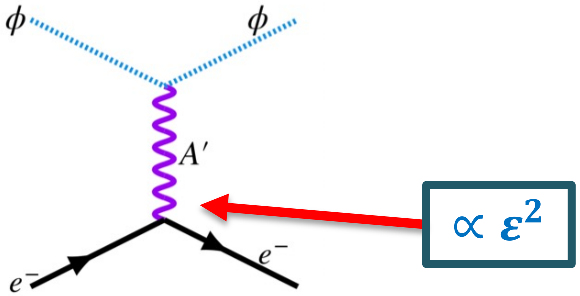
$$D_\mu = \partial_\mu - i g_D A'_\mu, \quad g_D = \sqrt{4\pi\alpha_D}$$

DM production



$\propto \varepsilon^2$

DM detection



$\propto \varepsilon^2$

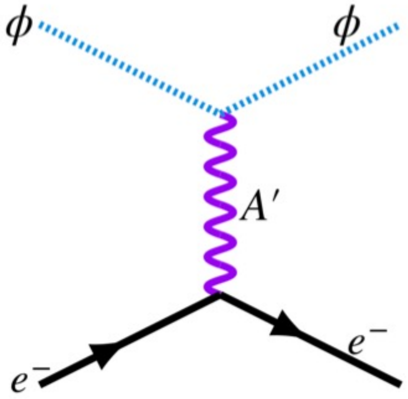
De Romeri, Kelly, Machado, PRD (2019)

(also Beam bremsstrahlung and Resonance production)

DM event rate $\sim \varepsilon^4 \alpha_D$

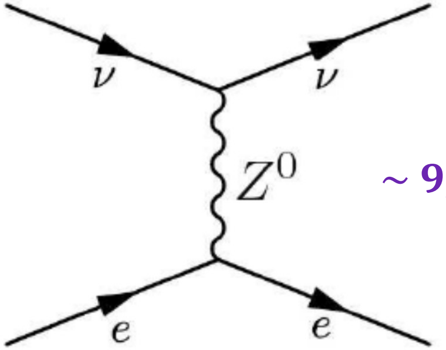
Light Dark Matter

DM signal: elastic scattering on electrons



How can we get rid of neutrinos in a neutrino detector?

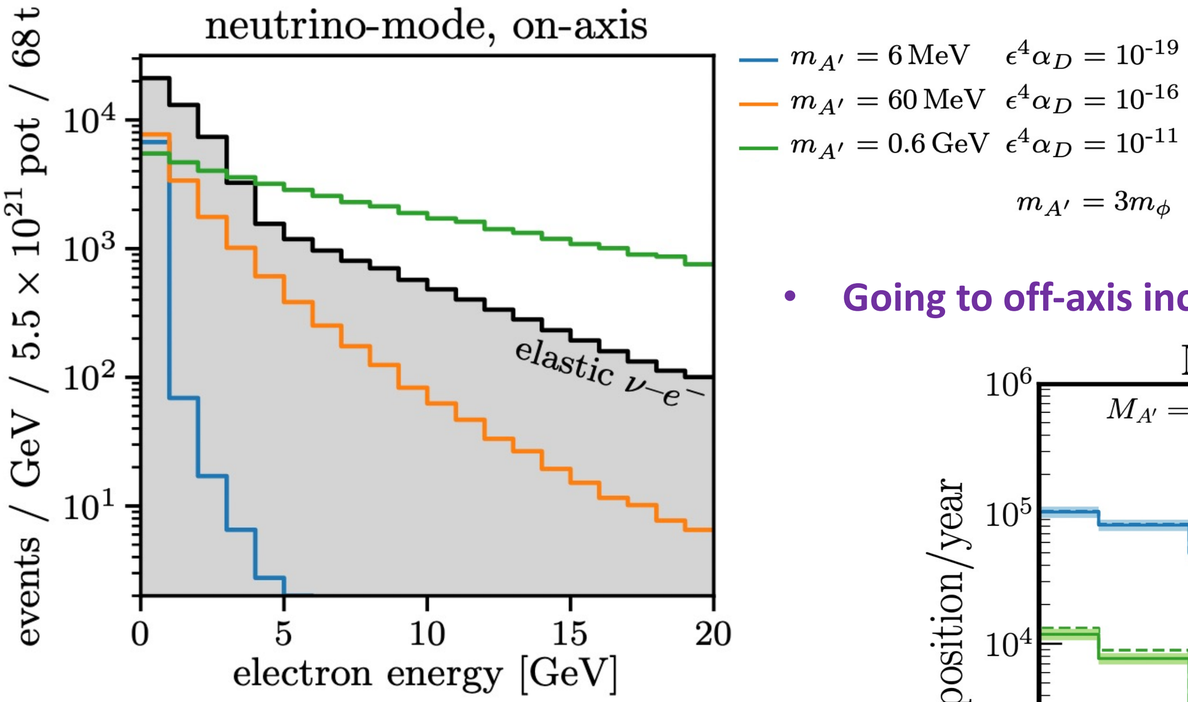
But so do neutrinos!



$\sim \mathbf{9,400}\ \boldsymbol{\nu - e}$ events / year!

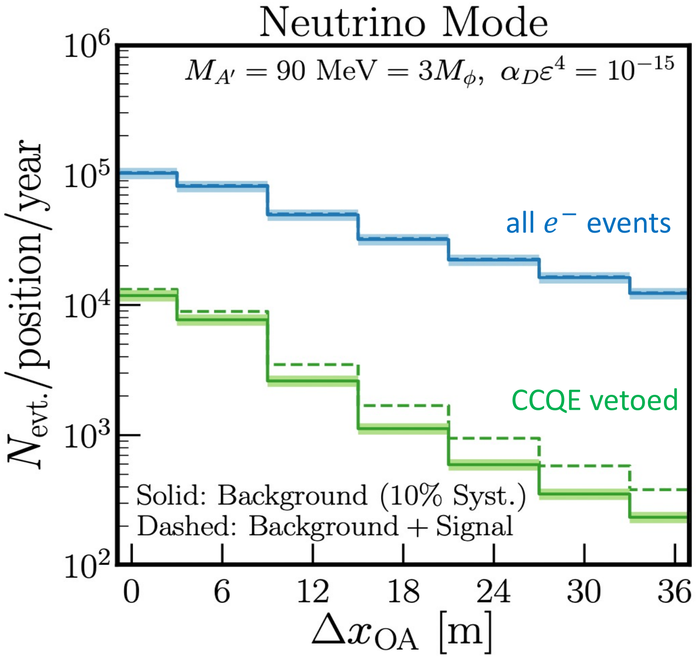
Light Dark Matter

- **Challenge: elastic neutrino-electron scattering is a huge background!**



Breitbach, Buonocore, Frugiuele, Kopp, Mittnacht, JHEP (2022)

- **Going to off-axis increases DM signal/background**



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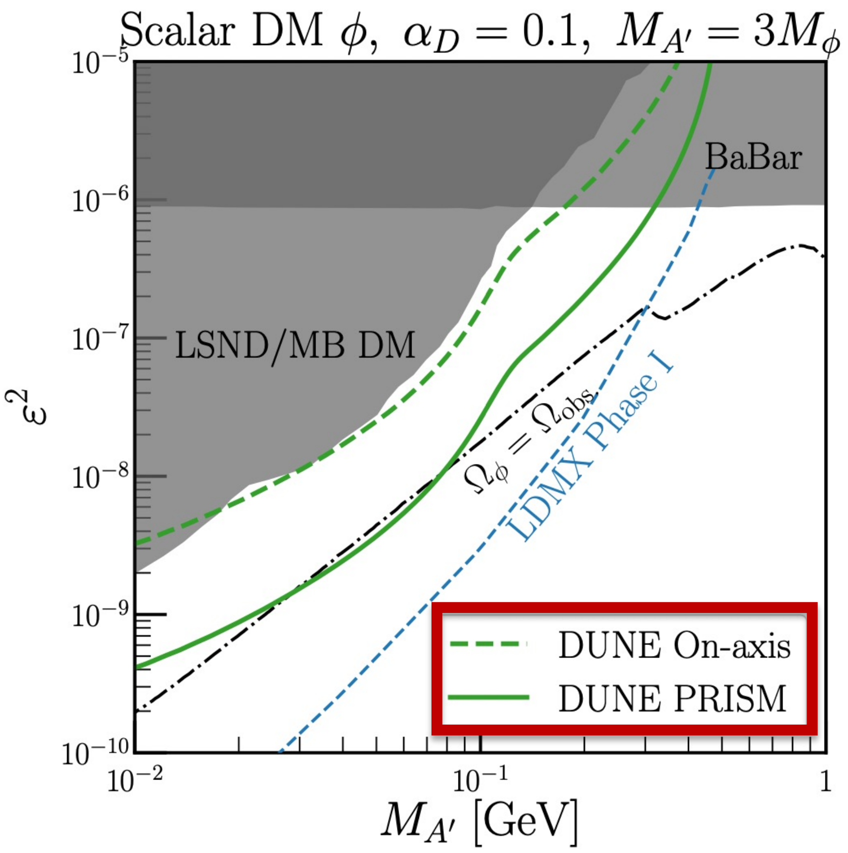
Light Dark Matter



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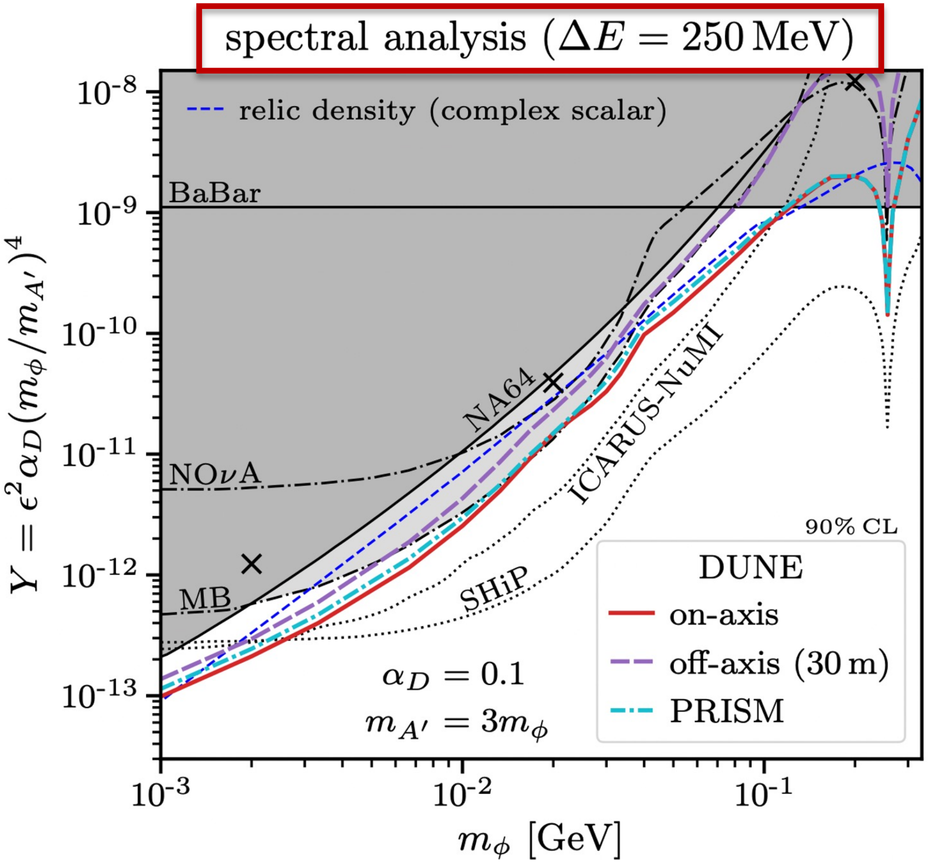

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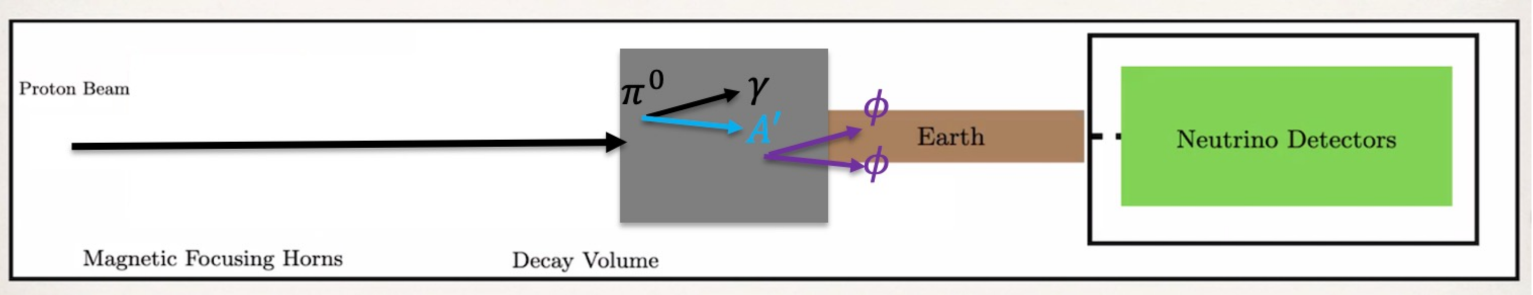
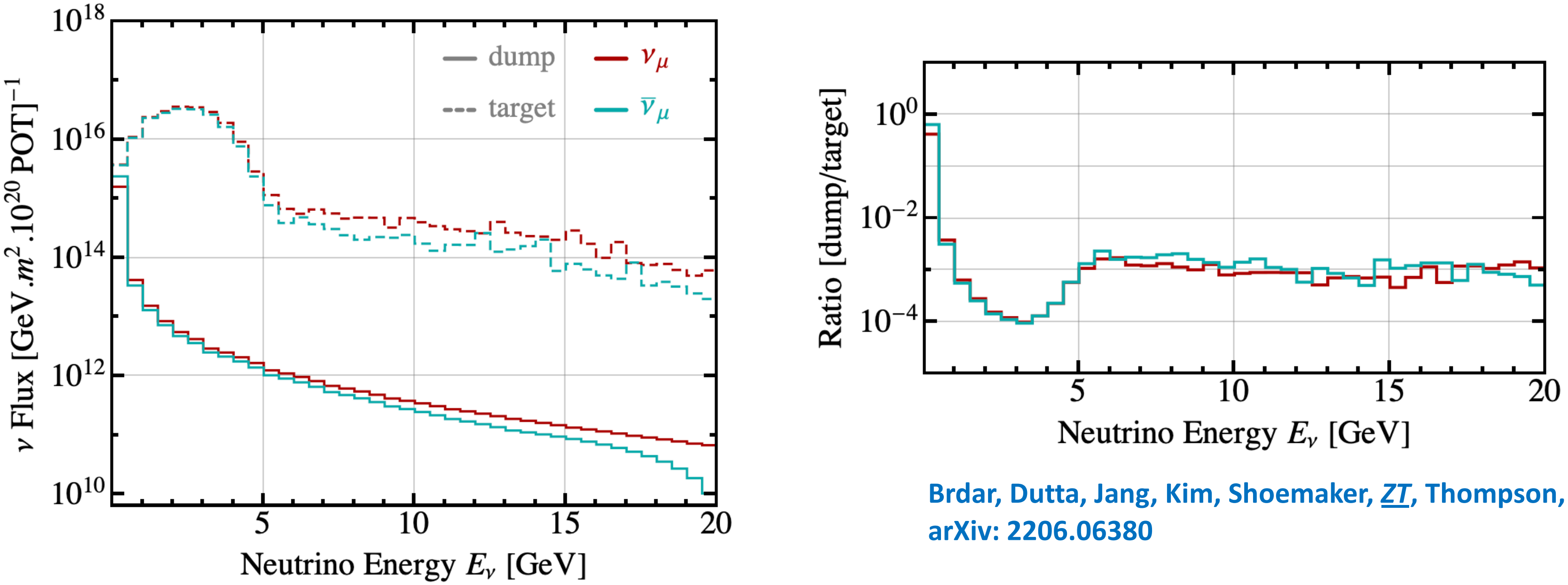
LDM at a Target-less DUNE

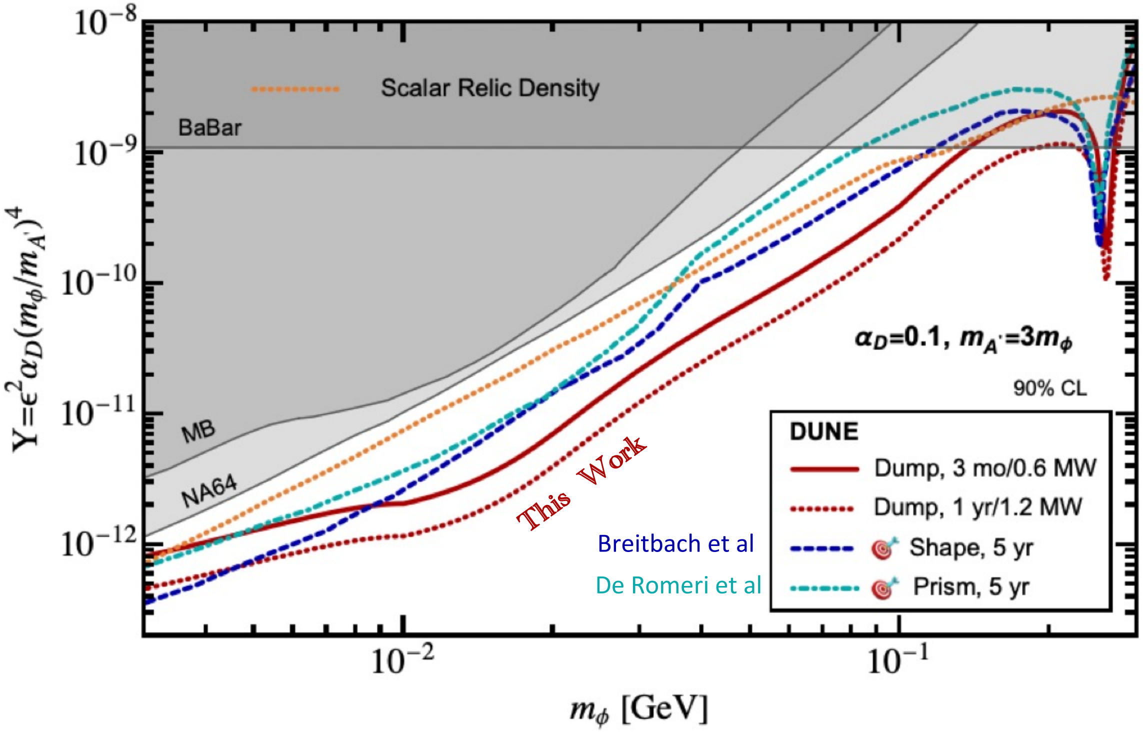


- Impinging protons directly to the dump area;
- Shorter distance between the source point and the detector → more DM signal;
- Charged mesons absorbed in the Al beam dump before decay;
- **The ν flux decreases by 3 orders of magnitude → Only 0.5 ν-e background in 3 mo-0.6 MW!**



Brdar, Dutta, Jang, Kim, Shoemaker, *ZT*, Thompson, Yu
arXiv: 2206.06380

LDM at a Target-less DUNE



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Target-less DUNE can probe the parameter space for thermal relic DM in only 3 months!

- Light Dark Matter
- Axion-Like Particles
- Light Z'
- SMEFT
- Conclusion

Axion-Like Particles (ALPs)

- **(pseudo)scalars, strongly motivated by theory and cosmology;**
- **Why is CP conserved in QCD? Solution to the strong CP problem (QCD axion);**
- **DM candidates;**

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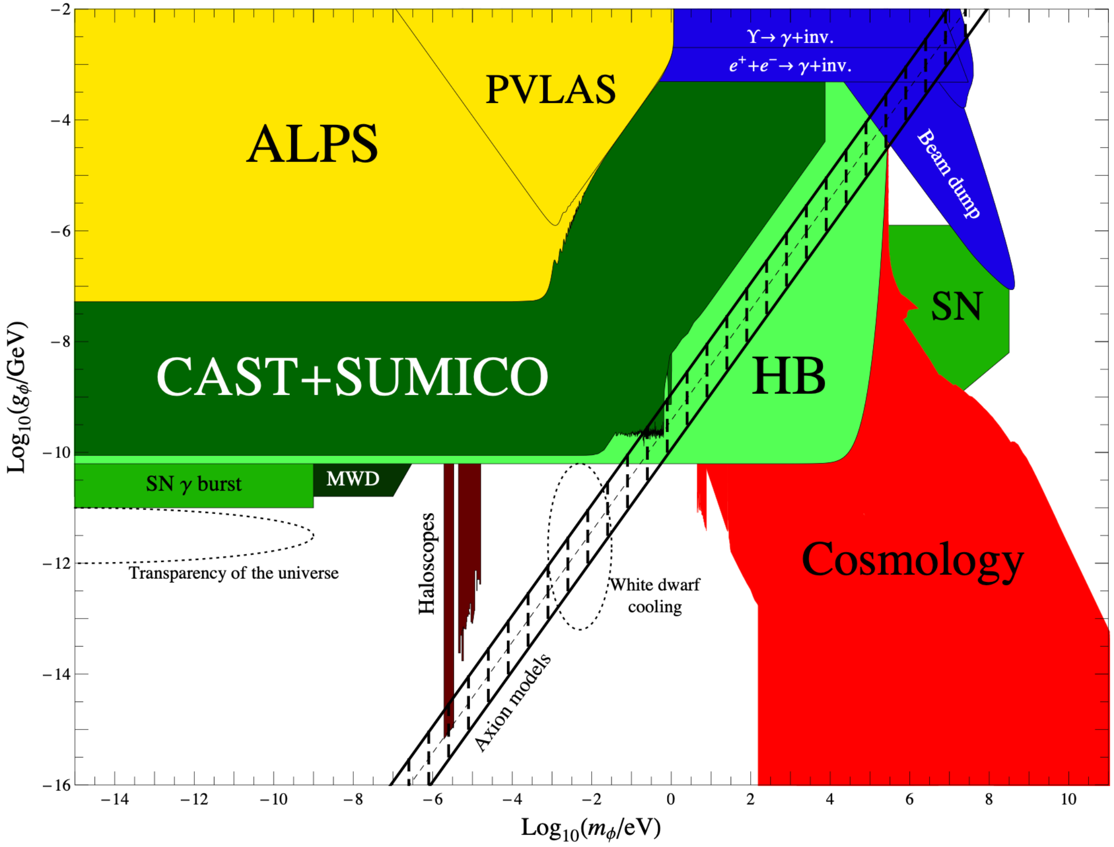

D. Cadamuro, 1210.3196 [hep-ph]

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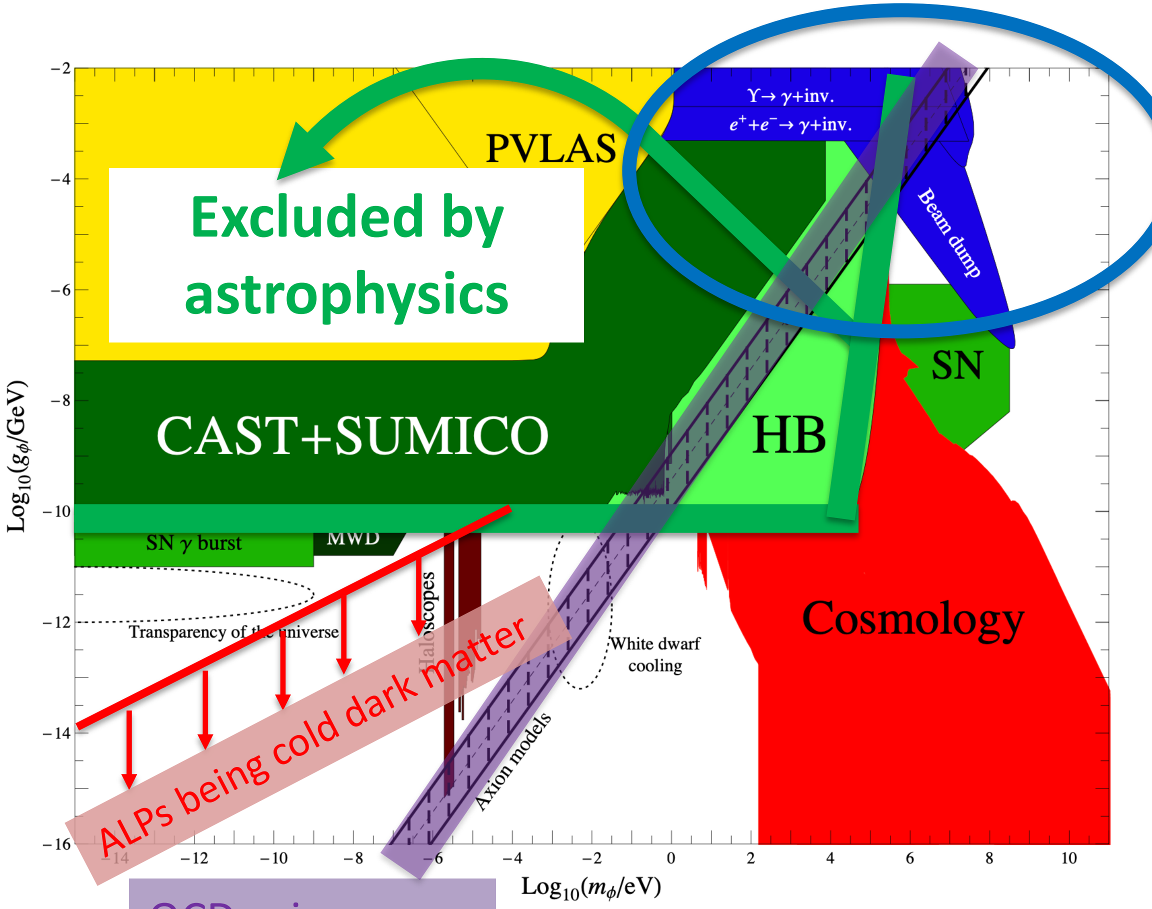


particle physics experiments

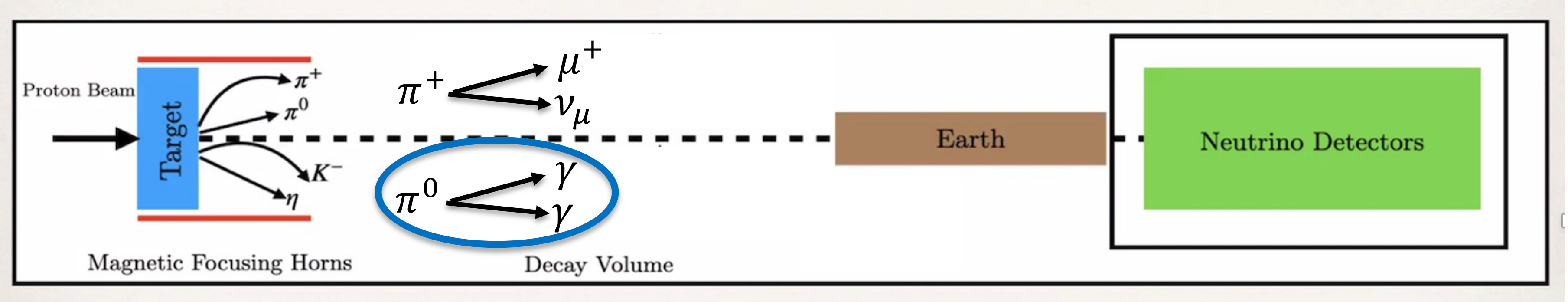
Excluded by astrophysics

ALPs being cold dark matter

QCD axion range

D. Cadamuro, 1210.3196 [hep-ph]

ALPs at Neutrino Experiments

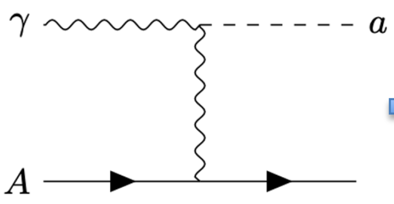


Credit: Kevin Kelly

Using photons to produce ALPs:

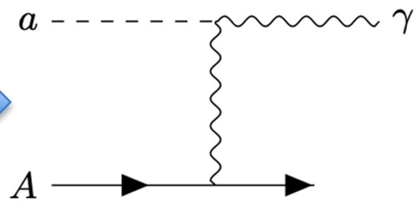
$$\mathcal{L}_{a\gamma\gamma} \supset -\frac{1}{4} g_{a\gamma\gamma} a F_{\mu\nu} \tilde{F}^{\mu\nu}$$

ALP production

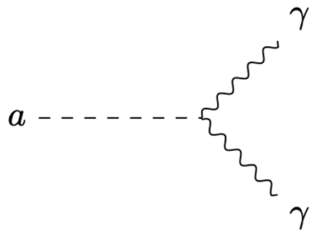


Primakoff scattering

ALP detection

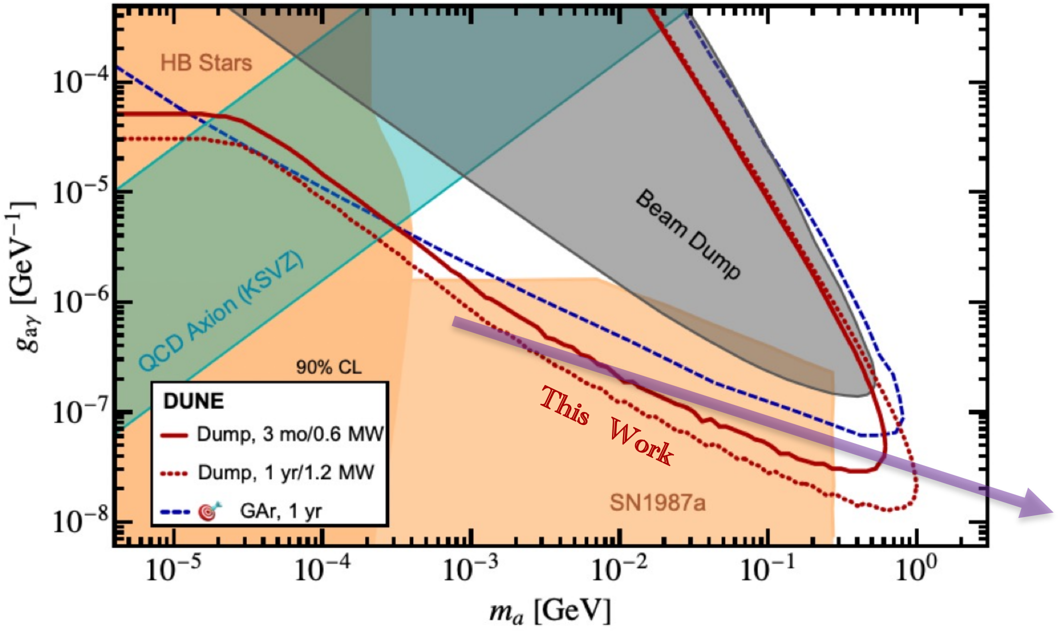


Inverse Primakoff scattering



ALP decay

ALPs at Target-less DUNE



- The only lab-based constraints!
- Can probe QCD-axion
- 3 months target-less DUNE can do better than 1 yr GAr

Brdar, Dutta, Jang, Kim, Shoemaker, *ZT*, Thompson, Yu
PRL (2021)

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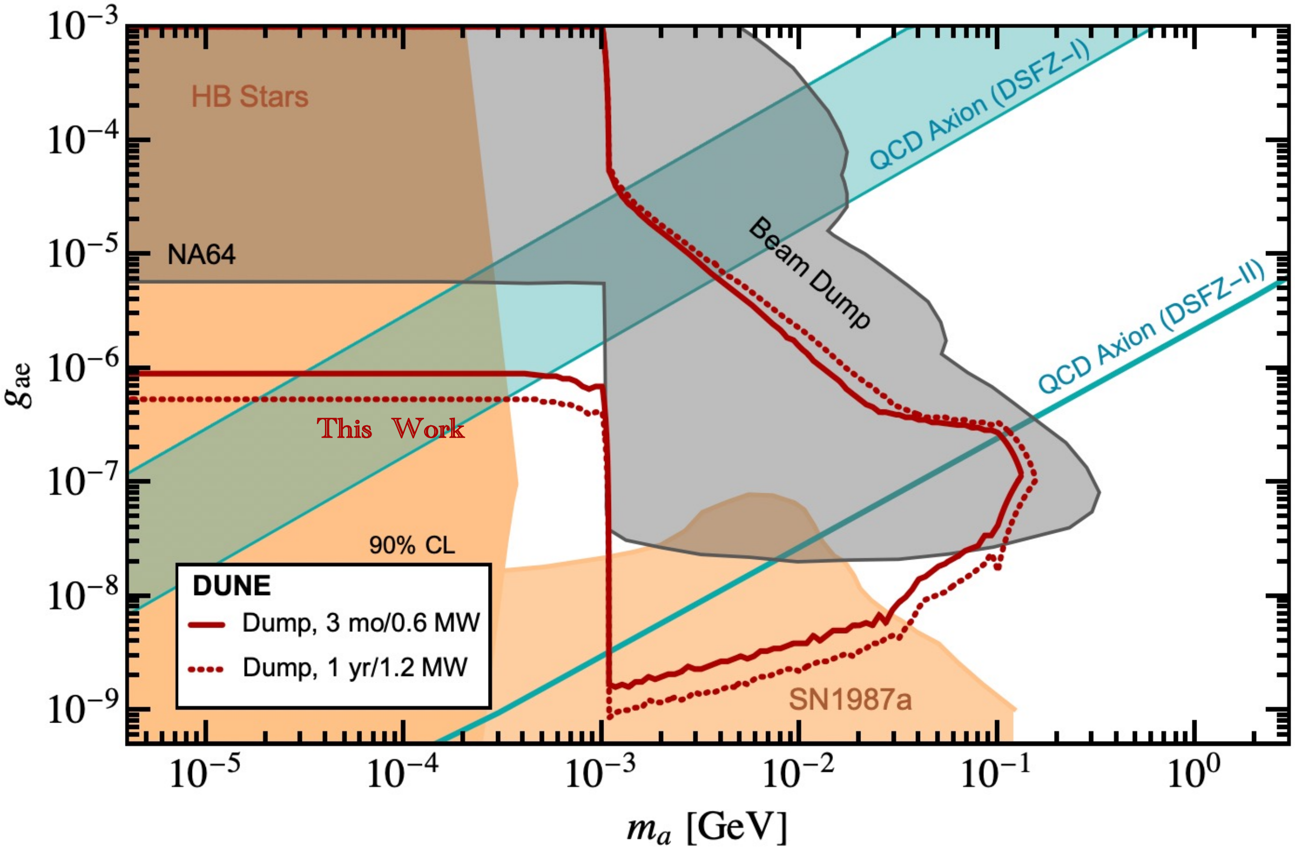

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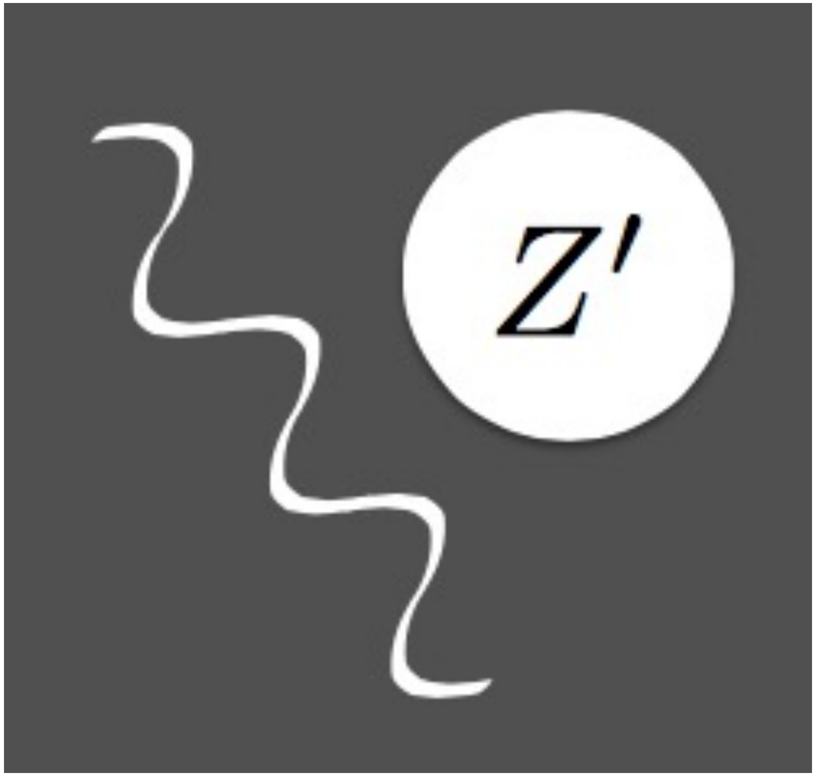
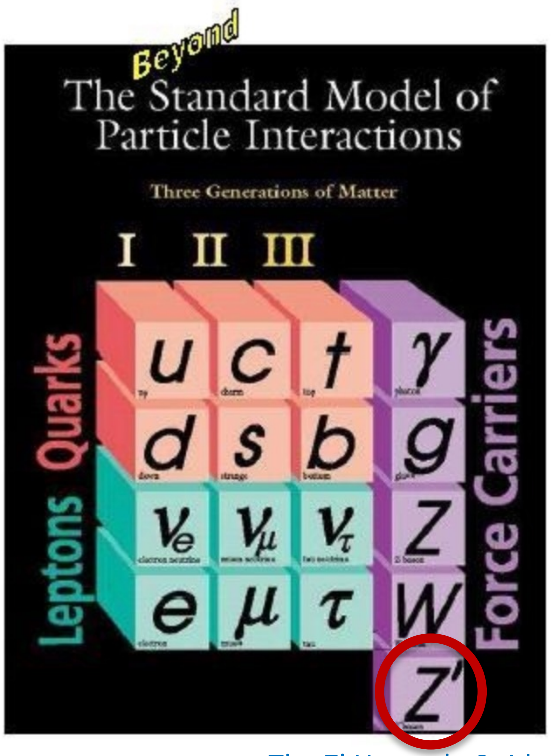


A new gauge boson?

Hypothetical gauge boson that appear in many extensions of the standard model



The Z' Hunter's Guide

- What is its mass?
- Which particles does it talk to?

Light Z'

- **Low Energy Experiments**
  - Miranda et al, JHEP (2020)
  - Coloma et al, JHEP (2021)
  - Caddedu et al, JHEP (2021)
- **Fixed Target Experiments**
  - Gninenko, PLB (2012)
  - Tsai et al, PRL (2021)
  - Bauer et al, JHEP (2018)
- **Neutrino Trident Searches**
  - Altmannshofer et al, PRL (2014)
  - Ballet et al, JHEP (2019)
- **Neutrino-Electron Scattering**
  - Harnic et al, JCAP (2012)
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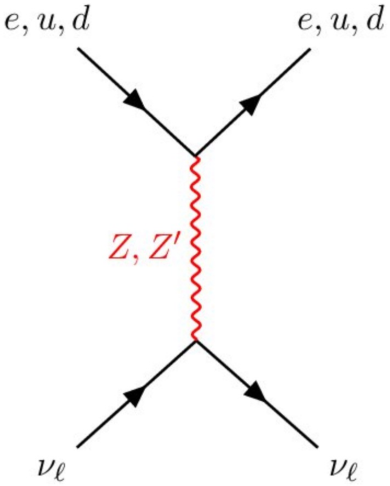
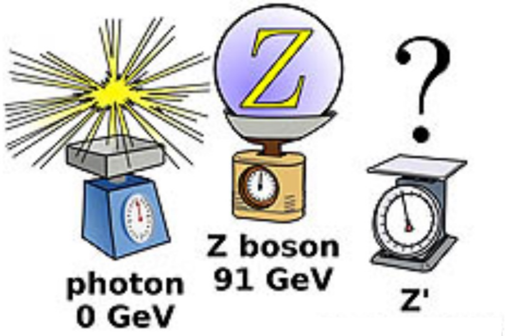
  - Ballet et al, JHEP (2019)
- **Colliders**
  - BaBar Collaboration, PRL (2014)
  - BaBar Collaboration, PRL (2017)
- **Cosmology**
  - Escudero et al, JHEP (2019)

What can we learn from neutrino experiments?

$$\mathcal{L}_{Z'}^{\text{matter}} = -g'\big(a_u\,\bar{u}\gamma^\alpha u + a_d\,\bar{d}\gamma^\alpha d + a_e\,\bar{e}\gamma^\alpha e + b_e\,\bar{\nu}_e\gamma^\alpha P_L\nu_e + b_\mu\,\bar{\nu}_\mu\gamma^\alpha P_L\nu_\mu + b_\tau\,\bar{\nu}_\tau\gamma^\alpha P_L\nu_\tau\big)Z'_\alpha$$





news.fnal.gov

The list is far from being exhaustive!

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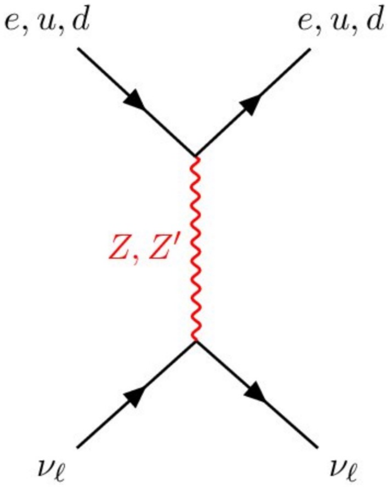

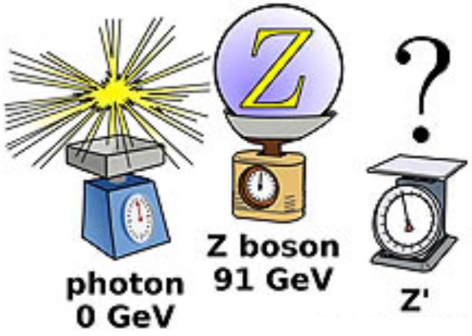

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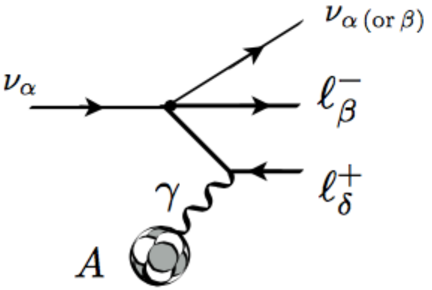
Neutrino Trident Scattering

Production of a **charged lepton pair**

in the scattering of a **neutrino**

in the Coulomb field of a **heavy nucleus/nucleon**

$$\nu_\alpha + \mathcal{N} \to \nu_\beta + \ell_\gamma^+ + \ell_\delta^- + \mathcal{N}$$



CHARM II

PLB (1990)

$$\frac{\sigma_{\text{CHARM II}}}{\sigma_{\text{SM}}} = 1.58 \pm 0.57$$

CCFR

PRL (1991)

$$\frac{\sigma_{\text{CCFR}}}{\sigma_{\text{SM}}} = 0.82 \pm 0.28$$

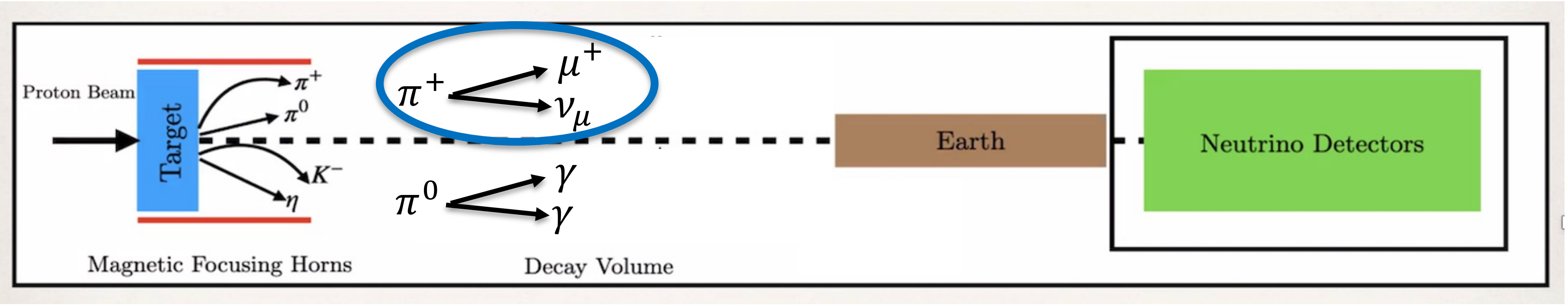
NuTeV

Vancouver 1998,
High energy physics, vol 1

$$\frac{\sigma_{\text{NuTeV}}}{\sigma_{\text{SM}}} = 0.67 \pm 0.27$$

- Very large uncertainties
- Very few events observed (~100)

Trident rates at LAr Detectors



Channel	SBND	μBooNE	ICARUS	DUNE ND
Total $e^\pm\mu^\mp$	10	0.7	1	2993 (2307)
	2	0.1	0.2	692 (530)
Total e^+e^-	6	0.4	0.7	1007 (800)
	0.7	0.0	0.1	143 (111)
Total $\mu^+\mu^-$	0.4	0.0	0.0	286 (210)
	0.4	0.0	0.0	196 (147)

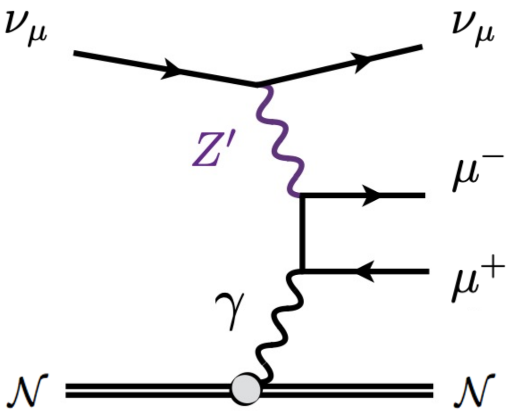
Coherent (upper) and diffractive (lower) trident events for (anti)neutrino mode

More than 9,000 trident events at DUNE!

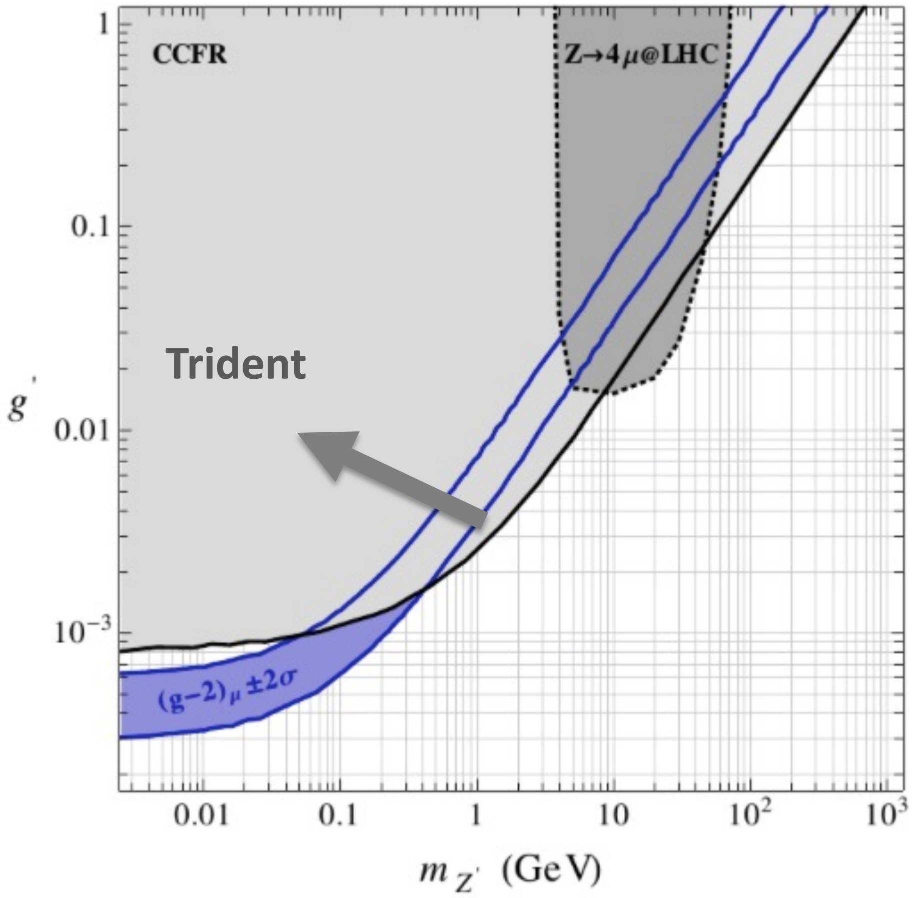
Ballett, Hostert, Pascoli, Perez-Gonzalez, *ZT* and Funchal, PRD (2019)

Light Z': L_μ-L_τ Model

- Z' only couples to muon and tau, but not to electrons;
- It can explain the muon (g-2) anomaly;
- Can be best probed using tridents;



HE colliders only have access to large masses!

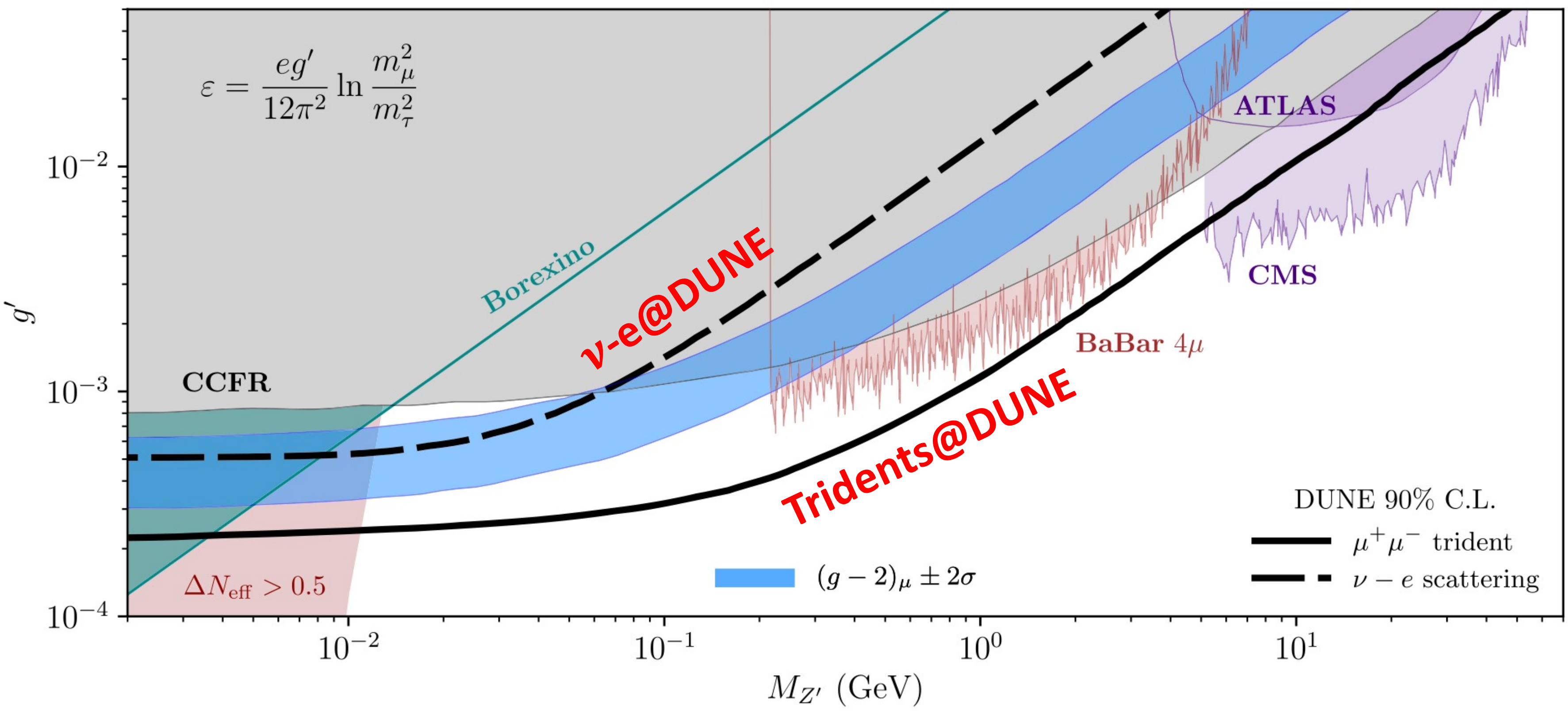


Altmannshofer, Gori, Pospelov, Yavin, PRL (2014)

Light Z': L_μ-L_τ Model

Ballett, Hostert, Pascoli, Perez-Gonzalez, ZT and Funchal, PRD (2019)

DUNE



The whole g-2 region can be probed by DUNE data!

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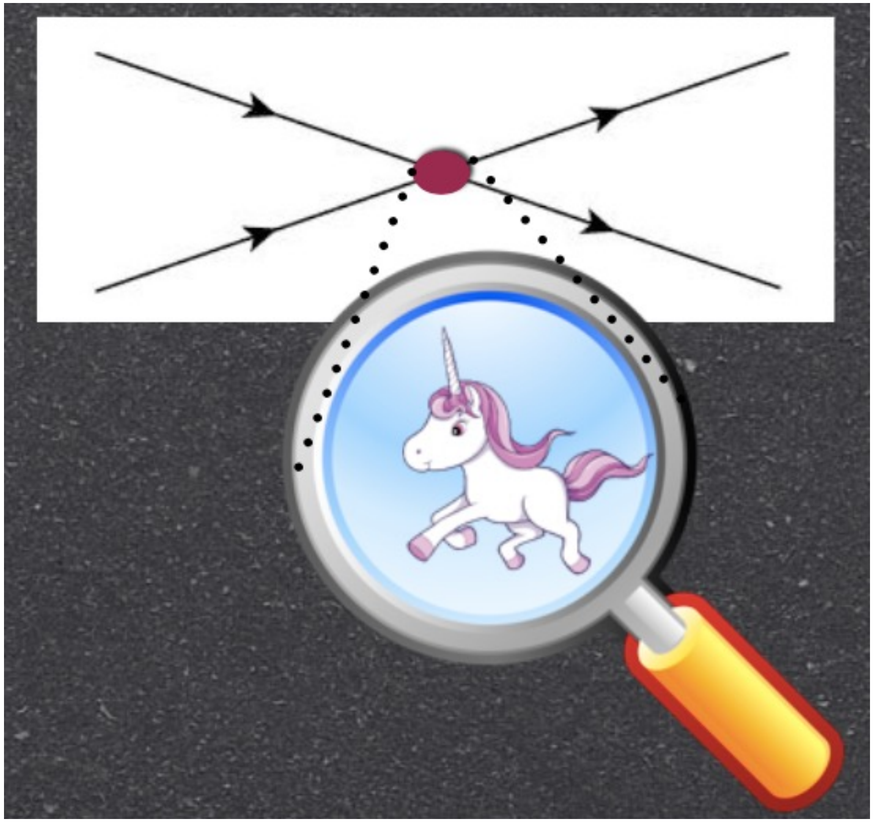
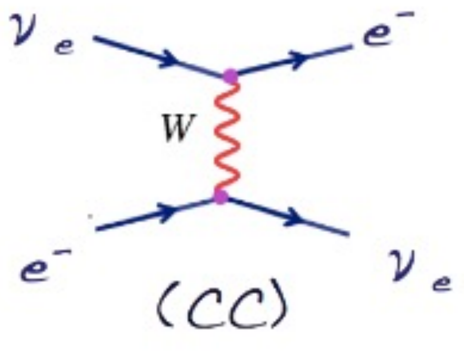
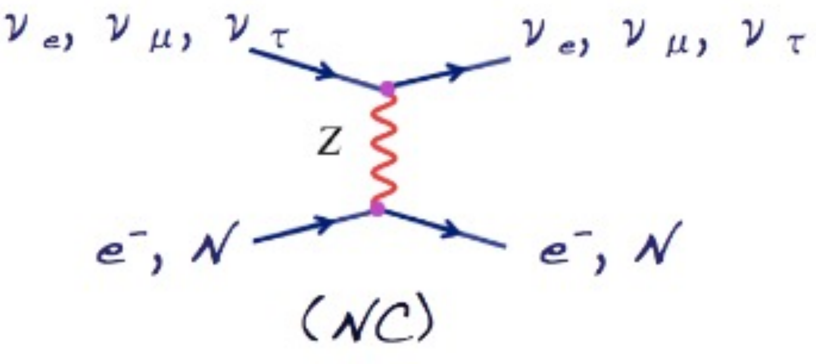
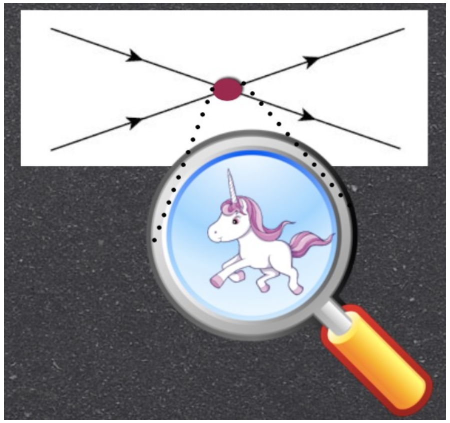


- Coherent CC and NC forward scattering of neutrinos





- New 4-fermion interactions



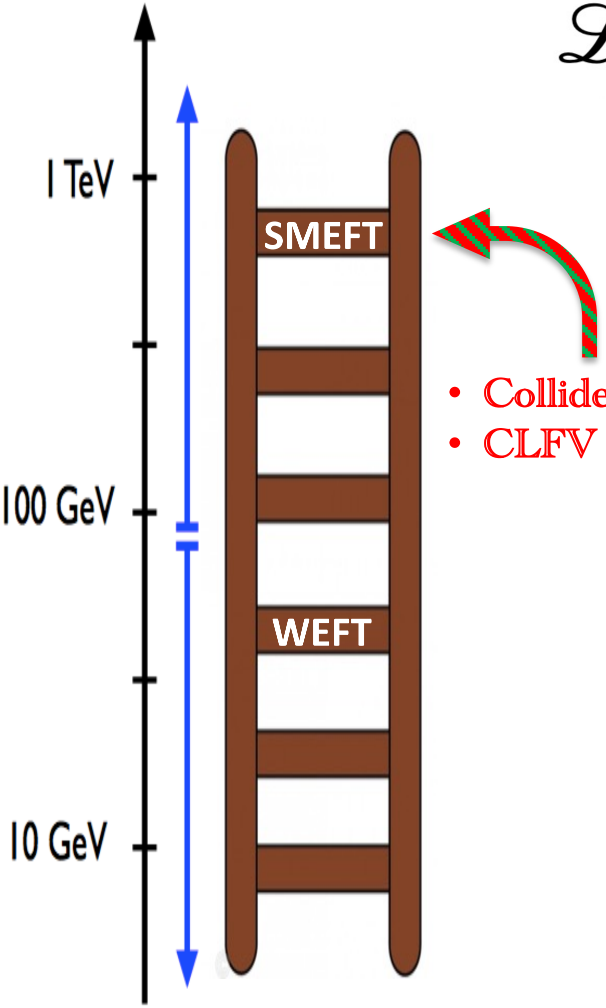
- Observable effects at neutrino production/propagation/detection?
- Using "EFT" formalism to "systematically" explore NP beyond the neutrino masses and mixing

Why EFT?

- One consistent framework to probe different aspects of particle interactions;
- Constraints from different low/high experiments can be meaningfully compared;
- Results can be translated into specific new physics models;
- We can probe very heavy particles, often beyond the reach of present colliders, by precisely measuring low-energy observables;

What's the place of neutrino experiments in this program?

EFT ladder



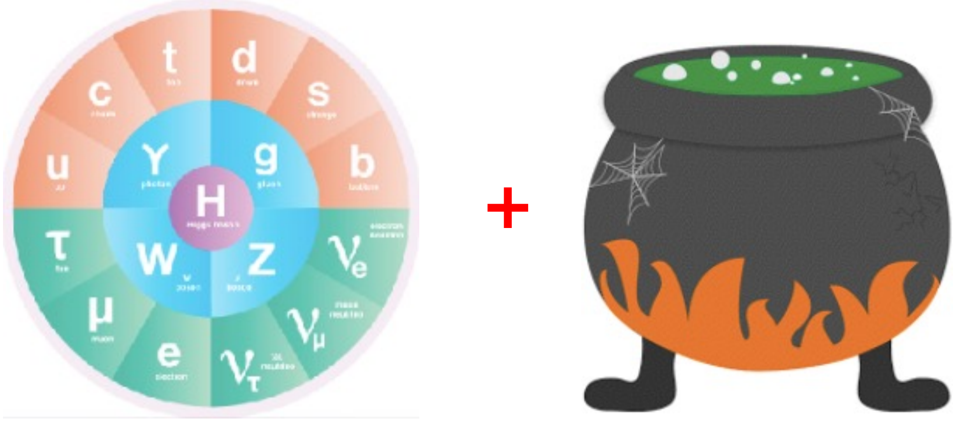
- Colliders
- CLFV

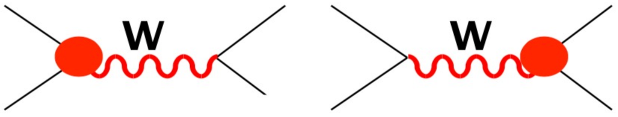
SMEFT: minimal EFT above the weak scale

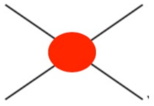
$$\mathscr{L}_{\rm SMEFT} = \mathscr{L}_{\rm SM} + \mathscr{L}_{D=5} + \boxed{\mathscr{L}_{D=6}}$$

Known SM Lagrangian

Gives neutrino Masses







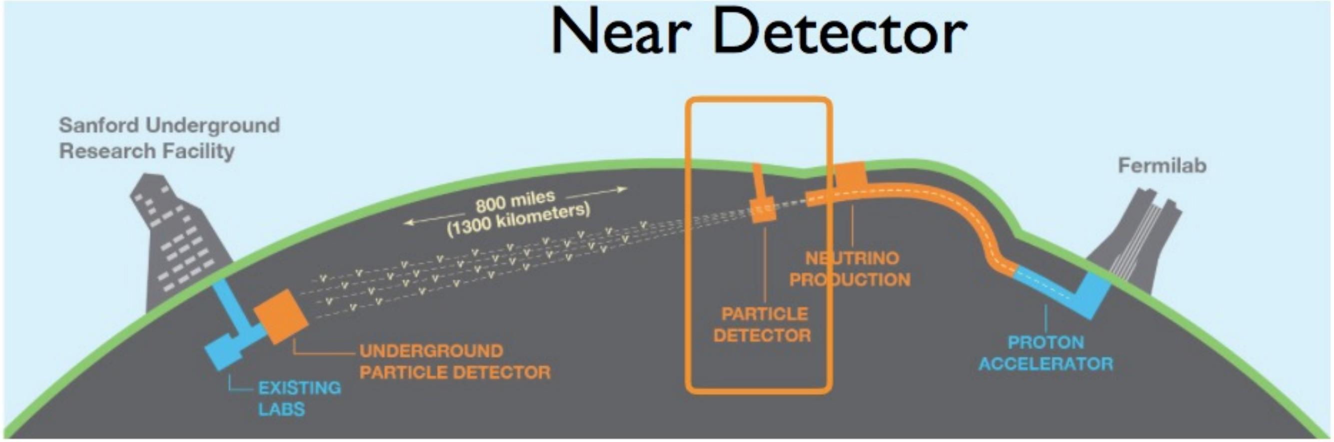
$$O_{lq}^{(3)} = (\bar l \gamma^\mu \sigma^a l)(\bar q \gamma_\mu \sigma^a q)$$

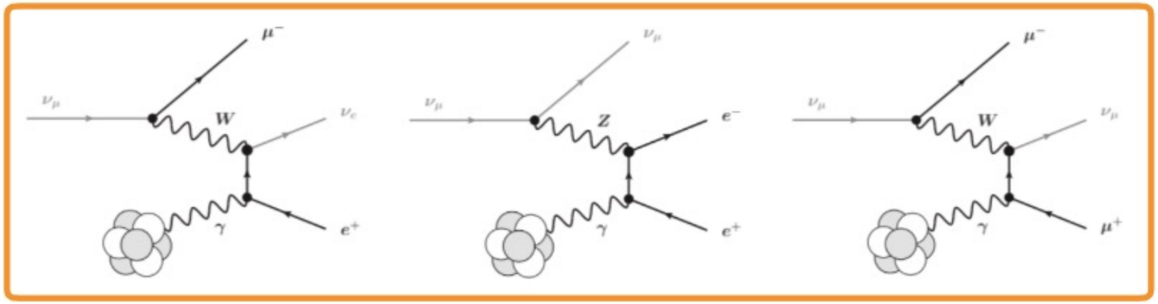
$$O_{qde} = (\bar l e)(\bar d q) + \text{h.c.}$$

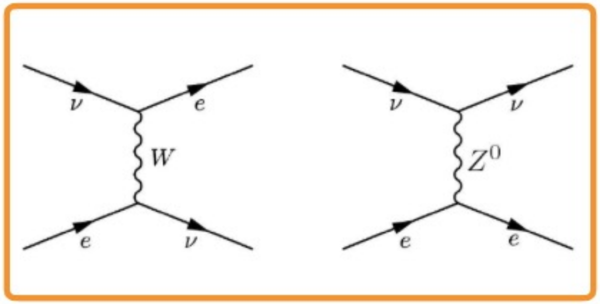
$$O_{lq} = (\bar l_a e)\epsilon^{ab}(\bar q_b u) + \text{h.c.}$$

$$O_{lq}^t = (\bar l_a \sigma^{\mu\nu} e)\epsilon^{ab}(\bar q_b \sigma_{\mu\nu} u) + \text{h.c.}$$

SMEFT at DUNE







- neutrino-electron scattering
- neutrino trident production
- neutrino-nuclei scattering

Adam Falkowski, Giovanni Grilli di Cortona and ZT, JHEP (2018)

$$\mathcal{L}_{\rm wEFT} \supset -\frac{2}{v^2}(\bar{\nu}_a \bar{\sigma}_\mu \nu_b)\left[g_{LL}^{abcd}(\bar{e}_c \bar{\sigma}_\mu e_d) + g_{LR}^{abcd}(e^c_c \sigma_\mu \bar{e}^c_d)\right]$$

Neutrino-electron scattering in EFT:

$g=g_{SM}+\delta g$

$$\sigma_{\nu_\mu e} = \frac{s}{2\pi v^4}\left[(g_{LL}^{2211})^2 + \frac{1}{3}(g_{LR}^{2211})^2\right] \approx \frac{m_e E_\nu}{\pi v^4}\left[(g_{LL}^{2211})^2 + \frac{1}{3}(g_{LR}^{2211})^2\right]$$

$$\sigma_{\bar{\nu}_\mu e} = \frac{s}{2\pi v^4}\left[(g_{LR}^{2211})^2 + \frac{1}{3}(g_{LL}^{2211})^2\right] \approx \frac{m_e E_\nu}{\pi v^4}\left[(g_{LR}^{2211})^2 + \frac{1}{3}(g_{LL}^{2211})^2\right]$$

- We define the following ratios and its deviation from 1:

$$R^i_{\nu e} \equiv \frac{x_i \sigma_{\nu_\mu e} + \bar{x}_i \sigma_{\bar{\nu}_\mu e}}{x_i \sigma^{\rm SM}_{\nu_\mu e} + \bar{x}_i \sigma^{\rm SM}_{\bar{\nu}_\mu e}} \rightarrow \begin{cases} x_\nu &= 0.9 \\ x_{\bar{\nu}} &= 0.1 \\ \bar{x}_i &= 1 - x_i \end{cases}$$

$$\delta R^i_{\nu e} = 2\frac{(1+2x_i)\,\delta g_{LL}^{2211} g_{LL,{\rm SM}}^{2211} + (3-2x_i)\,\delta g_{LR}^{2211} g_{LR,{\rm SM}}^{2211}}{(1+2x_i)\,(g_{LL,{\rm SM}}^{2211})^2 + (3-2x_i)\,(g_{LR,{\rm SM}}^{2211})^2}$$

- At DUNE:

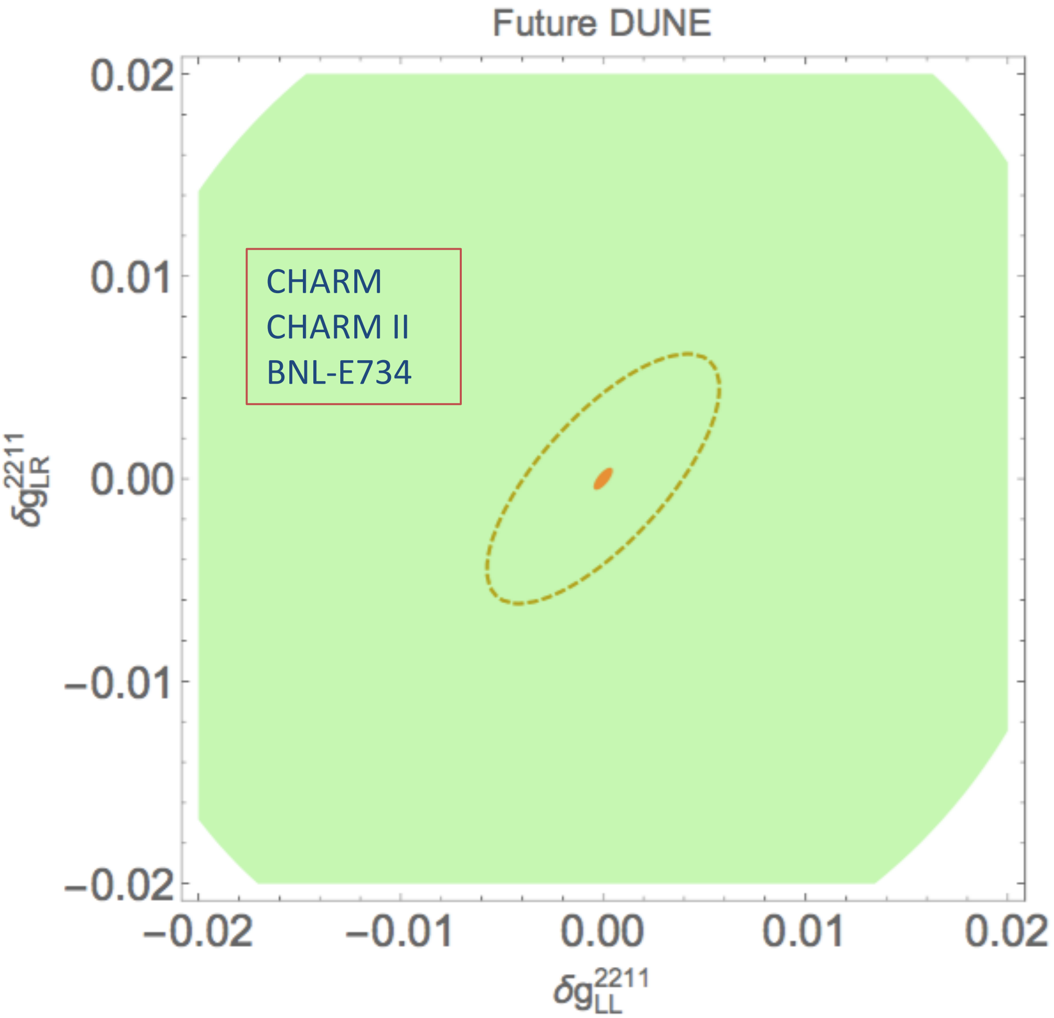
$$\boxed{-8.0\times10^{-4} < \delta R^{\nu}_{\nu e} < 8.0\times10^{-4}, \qquad -9.1\times10^{-4} < \delta R^{\bar{\nu}}_{\nu e} < 9.1\times10^{-4}}$$

- # Neutrino-electron scattering in EFT:

projected 95% CL constraints on the wEFT parameters

Dashed: 1% systematic error on the $R_{\nu e}$ measurements

Adam Falkowski, Giovanni Grilli di Cortona and ZT, JHEP (2018)



Neutrino scattering off nuclei in EFT:

- We define the following ratios and its deviation:

$$R_{\nu_a N} \equiv \frac{x\sigma_{\nu_a N \to \nu_a N} + \bar{x}\sigma_{\bar{\nu}_a N \to \bar{\nu}_a N}}{\bar{x}\sigma_{\nu_a N \to e_a^- N} + x\sigma_{\bar{\nu}_a N \to e_a^+ N}}$$

$$\delta R^i_{\nu_\mu N} \simeq 2\frac{g^\nu_{L,\mathrm{SM}}\delta g_L^{\nu_\mu} + r_i^{-1} g^\nu_{R,\mathrm{SM}}\delta g_R^{\nu_\mu}}{(g^\nu_{L,\mathrm{SM}})^2 + r_i^{-1}(g^\nu_{R,\mathrm{SM}})^2}$$

- At DUNE

$$-9.5 \times 10^{-5} < \delta R^\nu_{\nu_\mu N} < 9.5 \times 10^{-5}, \qquad -1.4 \times 10^{-4} < \delta R^{\bar{\nu}}_{\nu_\mu N} < 1.4 \times 10^{-4}$$

Adam Falkowski, Giovanni Grilli di Cortona and ZT, JHEP (2018)

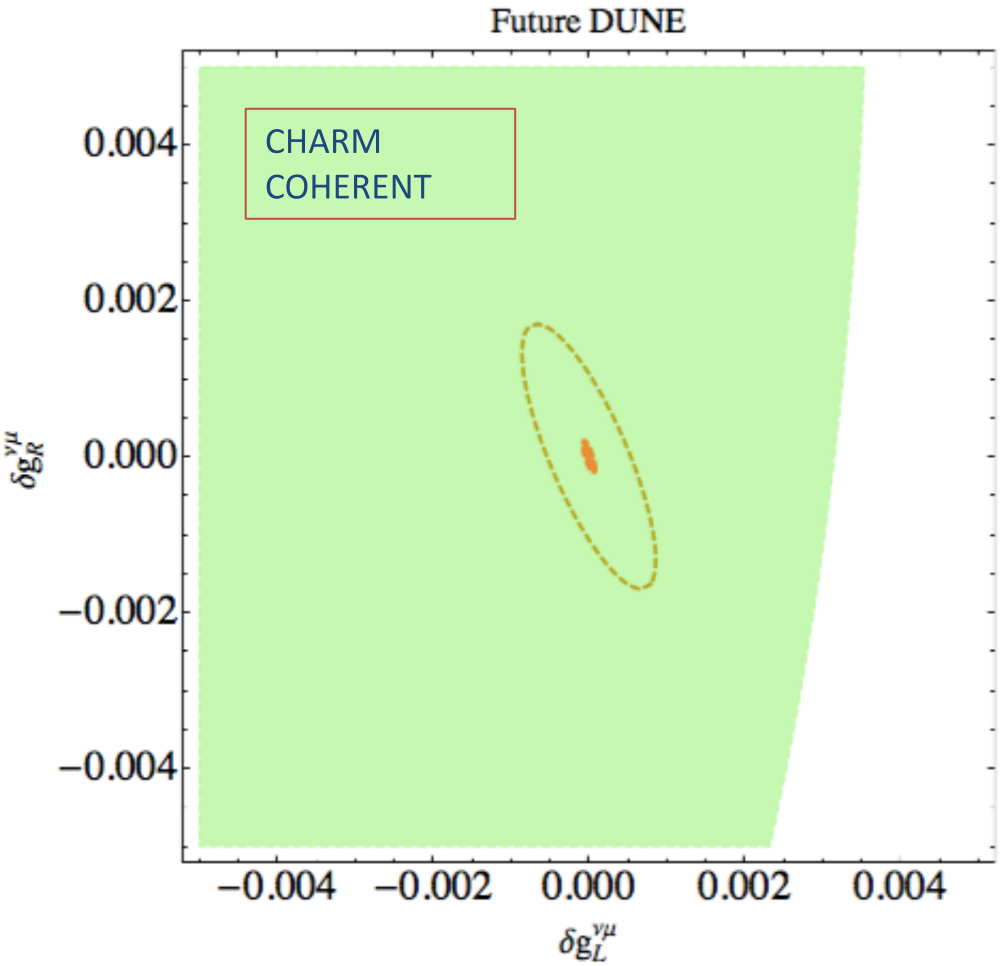
$$\mathcal{L}_{\mathrm{wEFT}} \supset -\frac{2V_{ud}}{v^2}(1 + \bar{\epsilon}_L^{de_a})(\bar{e}_a\bar{\sigma}_\mu\nu_a)(\bar{u}\,\bar{\sigma}^\mu d) - \frac{2}{v^2}(\bar{\nu}_a\bar{\sigma}_\mu\nu_a)\sum_{q=u,d}[g_{LL}^{\nu_a q}\,\bar{q}\,\bar{\sigma}^\mu q + g_{LR}^{\nu_a q}(q^c\sigma^\mu\bar{q}^c)]$$

Neutrino scattering off nuclei in EFT:

projected 95% CL constraints on the wEFT parameters

Dashed: 1% systematic error on the $R_{\nu N}$ measurements

Adam Falkowski, Giovanni Grilli di Cortona and ZT, JHEP (2018)



Trident production in EFT:

$$\mathcal{L}_{\rm wEFT} \supset -\frac{2}{v^2}(\bar{\nu}_a\bar{\sigma}_\mu\nu_b)\left[g_{LL}^{abcd}(\bar{e}_c\bar{\sigma}_\mu e_d) + g_{LR}^{abcd}(e_c^c\sigma_\mu\bar{e}_d^c)\right]$$

$$\frac{\sigma(\nu_b\gamma^* \to \nu_a\ell_c^-\ell_d^+)}{\sigma_{\rm SM}(\nu_b\gamma^* \to \nu_a\ell_c^-\ell_d^+)} = \frac{\sigma(\overline{\nu}_a\gamma^* \to \nu_b\ell_c^-\ell_d^+)}{\sigma_{\rm SM}(\overline{\nu}_a\gamma^* \to \nu_b\ell_c^-\ell_d^+)} \approx 1 + 2\frac{g_{LL,{\rm SM}}^{abcd}\delta g_{LL}^{abcd} + g_{LR,{\rm SM}}^{abcd}\delta g_{LR}^{abcd}}{(g_{LL,{\rm SM}}^{abcd})^2 + (g_{LR,{\rm SM}}^{abcd})^2}$$

- We define the following ratios:

$$R_e \equiv \frac{\sigma(\nu_\mu \to \nu_\mu e^- e^+) + \sigma(\overline{\nu}_\mu \to \overline{\nu}_\mu e^- e^+)}{\sigma(\nu_\mu \to \nu_\mu e^- e^+)_{\rm SM} + \sigma(\overline{\nu}_\mu \to \overline{\nu}_\mu e^- e^+)_{\rm SM}},$$

$$R_\mu \equiv \frac{\sigma(\nu_\mu \to \nu_\mu \mu^- \mu^+) + \sigma(\overline{\nu}_\mu \to \overline{\nu}_\mu \mu^- \mu^+)}{\sigma(\nu_\mu \to \nu_\mu \mu^- \mu^+)_{\rm SM} + \sigma(\overline{\nu}_\mu \to \overline{\nu}_\mu \mu^- \mu^+)_{\rm SM}}.$$

- Using DUNE we get:

$$R_e = 1 \pm 0.024, \qquad R_\mu = 1 \pm 0.039$$

$$-0.024 < 2\frac{g_{LL,{\rm SM}}^{2211}\delta g_{LL}^{2211} + g_{LR,{\rm SM}}^{2211}\delta g_{LR}^{2211}}{(g_{LL,{\rm SM}}^{2211})^2 + (g_{LR,{\rm SM}}^{2211})^2} < 0.024$$

$$-0.039 < 2\frac{g_{LL,{\rm SM}}^{2222}\delta g_{LL}^{2222} + g_{LR,{\rm SM}}^{2222}\delta g_{LR}^{2222}}{(g_{LL,{\rm SM}}^{2222})^2 + (g_{LR,{\rm SM}}^{2222})^2} < 0.039$$

Other relevant experiments:

- Parity-violating Møller scattering probes the electron's axial self-coupling

$$\frac{1}{2v^2} g_{AV}^{ee} \left[-(\overline{e}\overline{\sigma}_\mu e)(\overline{e}\overline{\sigma}_\mu e) + (e^c \sigma_\mu \overline{e}^c)(e^c \sigma_\mu \overline{e}^c)\right]$$

- The MOLLER collaboration in JLAB will significantly reduce the error by a factor of 5

$$g_{AV}^{ee} = 0.0225 \pm 0.0006$$

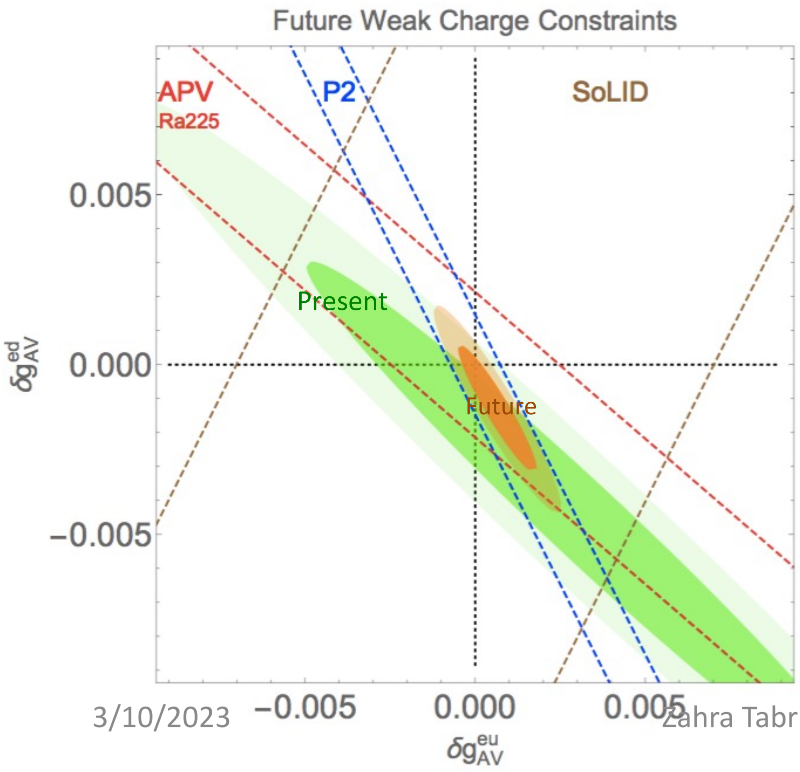
Moller collaboration, 1411.4088

Atomic Parity violation (APV):

- The effective couplings of electrons to quarks can be accessed by atomic parity violation (APV)

$$Q_W(Z,N) = -2[(2Z+N)g^{eu}_{AV} + (Z+2N)g^{ed}_{AV}] = Z(1-4s^2_W) - N$$

$$\boxed{-\frac{1}{2v^2}g^{eq}_{AV}(\bar{e}\,\bar{\sigma}_\rho e - e^c\sigma_\rho\bar{e}^c)(\bar{q}\,\bar{\sigma}^\rho q + q^c\sigma^\rho\bar{q}^c)}$$



Experiment	Year	$\Delta\sin^2(\theta_W)$
JLab-Qweak (final)		0.0008
JLab-SoLID	2022	0.00057
JLab-MOLLER	2020	0.00026
Mainz-P2	2018	0.0003
APV(^{225}Ra$^+$)		0.0018
APV(^{213}Ra$^+$/^{225}Ra$^+$)		0.0037
PVES (^{12}C)		0.0007

Erler, Horowitz, Mantry, Souder,
Ann. Rev. Nucl. Part. Sci. 64 (2014) 269–298

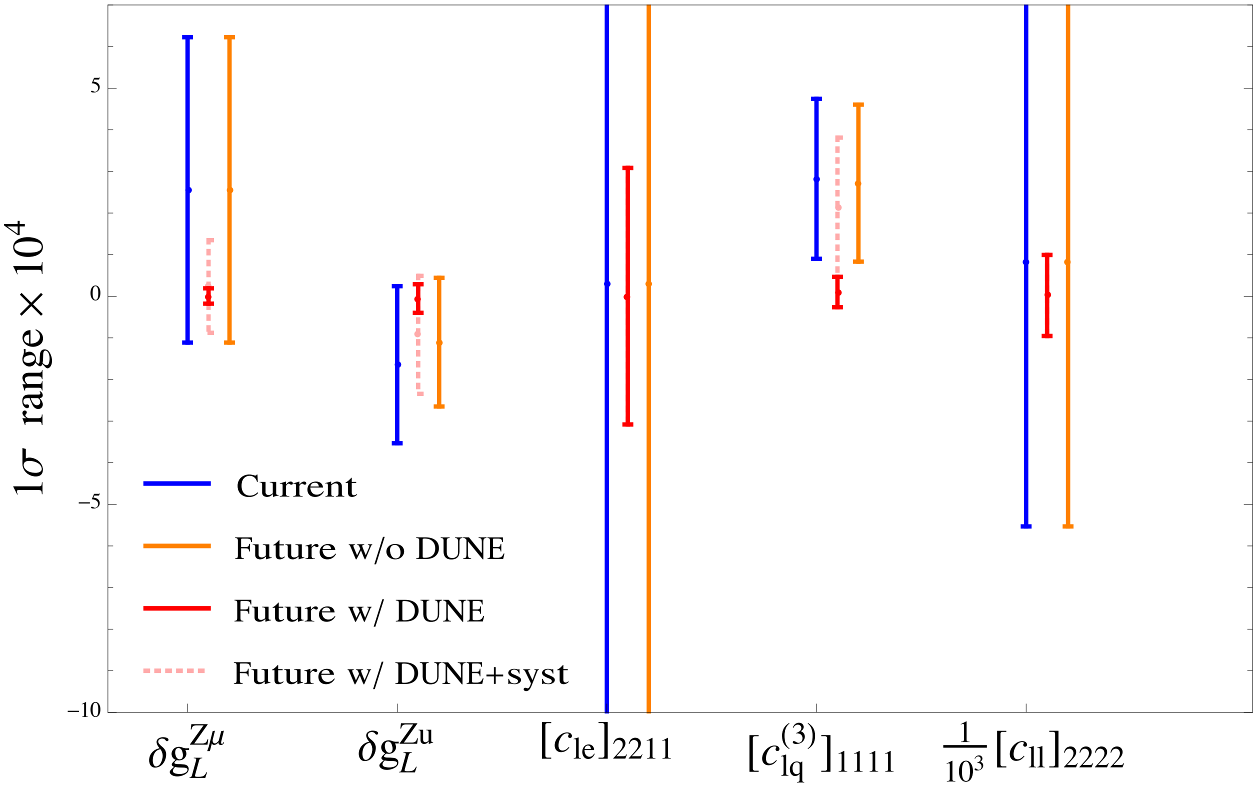
Future Now

- **Current:**

Falkowski, González-Alonso, Mimouni, JHEP (2017)

- **Future w/o DUNE:**

Mainz P2, Qweak, SoLID,225Ra+ APV, Moller



Adam Falkowski, Giovanni Grilli di Cortona and ZT, JHEP (2018)

DUNE will potentially have a dramatic impact on constraining the SMEFT parameter space.

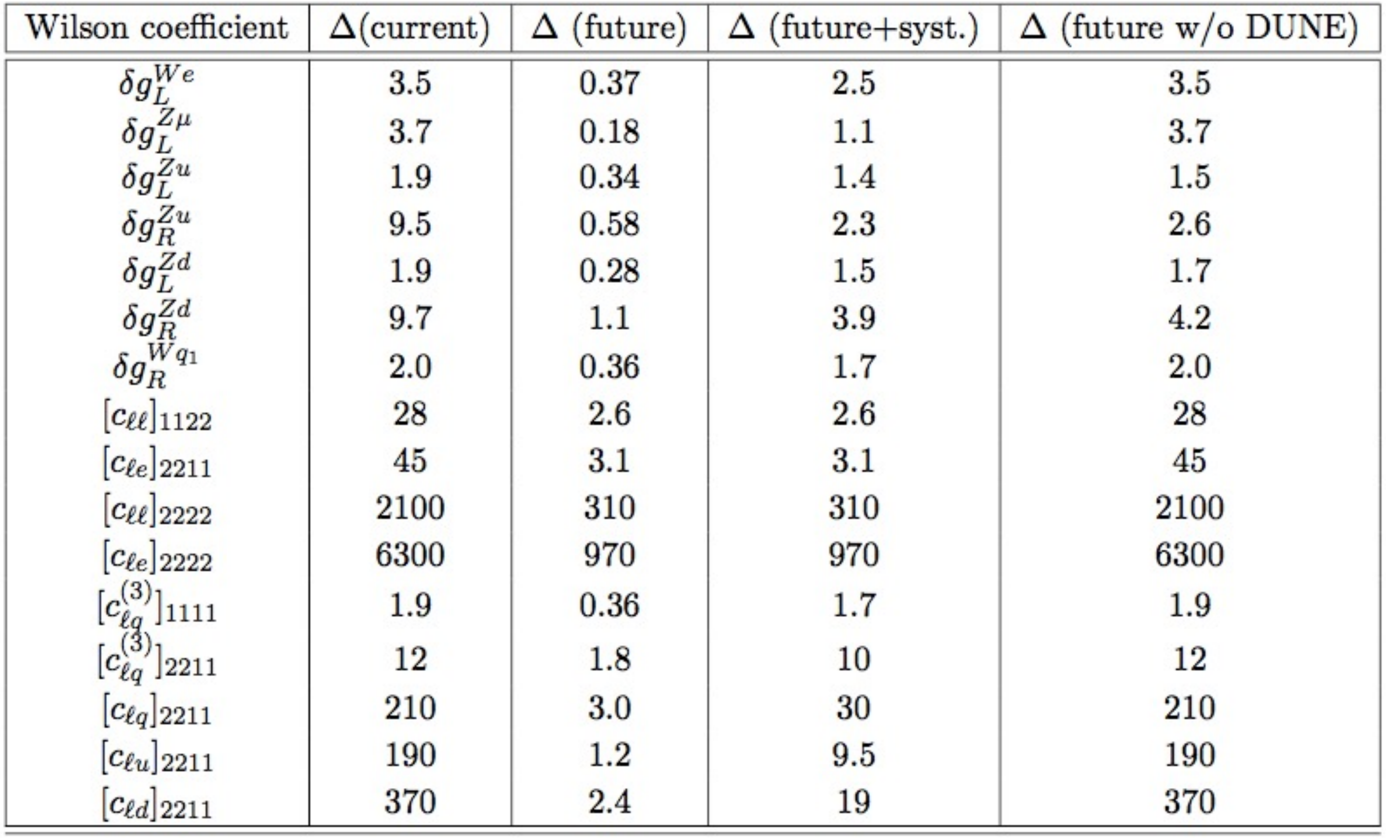
Future Now

- **Current:**

Falkowski, González-Alonso, Mimouni, JHEP (2017)

- **Future w/o DUNE:**

Mainz P2, Qweak, SoLID,225Ra+ APV, Moller



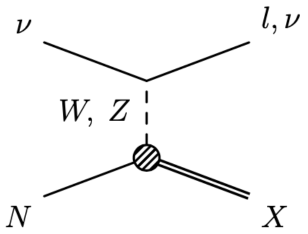
Wilson coefficient	Δ(current)	Δ (future)	Δ (future+syst.)	Δ (future w/o DUNE)
δg_L^{We}	3.5	0.37	2.5	3.5
$\delta g_L^{Z\mu}$	3.7	0.18	1.1	3.7
δg_L^{Zu}	1.9	0.34	1.4	1.5
δg_R^{Zu}	9.5	0.58	2.3	2.6
δg_L^{Zd}	1.9	0.28	1.5	1.7
δg_R^{Zd}	9.7	1.1	3.9	4.2
$\delta g_R^{Wq_1}$	2.0	0.36	1.7	2.0
$[c_{\ell\ell}]1122$	28	2.6	2.6	28
$[c_{\ell e}]2211$	45	3.1	3.1	45
$[c_{\ell\ell}]2222$	2100	310	310	2100
$[c_{\ell e}]2222$	6300	970	970	6300
$[c^{(3)}_{\ell q}]1111$	1.9	0.36	1.7	1.9
$[c^{(3)}_{\ell q}]2211$	12	1.8	10	12
$[c_{\ell q}]2211$	210	3.0	30	210
$[c_{\ell u}]2211$	190	1.2	9.5	190
$[c_{\ell d}]2211$	370	2.4	19	370

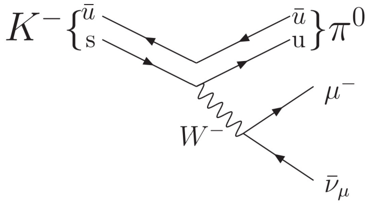
1σ uncertainty Δ in units of 10^{-4} on selected SMEFT Wilson coefficient from current and future low-energy precision measurements, assuming only one Wilson coefficient at a time.

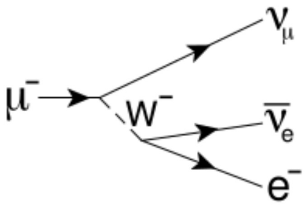
DIS: FASERν

Kaon/Muon decay: ISODAR, KDAR

Solar neutrinos: Borexino







^{7}**Be** $\boxed{{}^7\mathrm{Be} + e^- \to {}^7\mathrm{Li} + \nu_e}$

$\boxed{{}^3\mathrm{He} + p \to {}^4\mathrm{He} + e^+ + \nu_e}$ **hep**

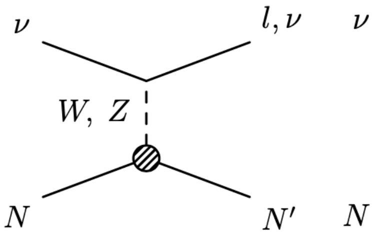
(hep)

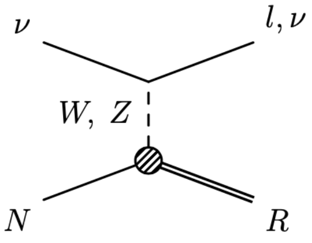
$\boxed{p + e^- + p \to {}^2\mathrm{H} + \nu_e}$ ***pep***

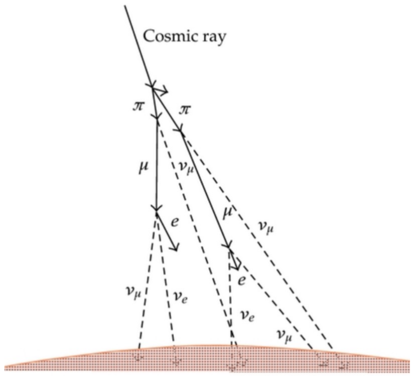
QE, Resonances: MINOS, NOvA, DUNE

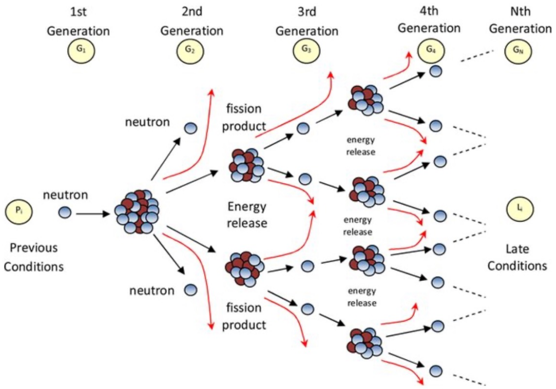
Atmospheric Neutrinos: IceCube

Beta decay and IBD: Reactor Experiments



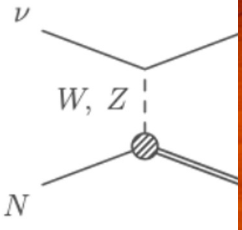






DIS: FASERν

Solar neutrinos: Borexino



$\mathrm{Be} + e^- \to {}^7\mathrm{Li} + \nu_e$

$+ p \to {}^4\mathrm{He} + e^+ + \nu_e$ **hep**

(hep)

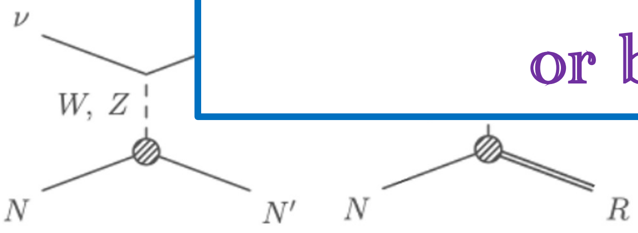
$e^- + p \to {}^2\mathrm{H} + \nu_e$ ***pep***

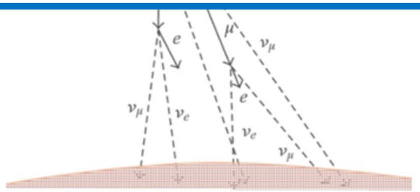
QE, Resonances: MINOS, NOvA DUNE

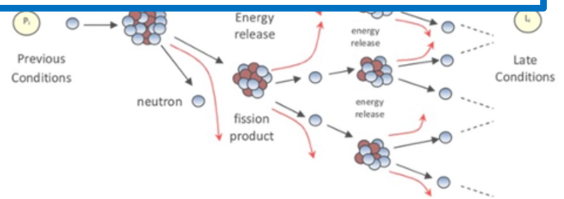
IceCube

eta decay and IBD: Reactor Experiments

Neutrino experiments give us a powerful tool to search for new physics, either by direct production or by precision measurements!

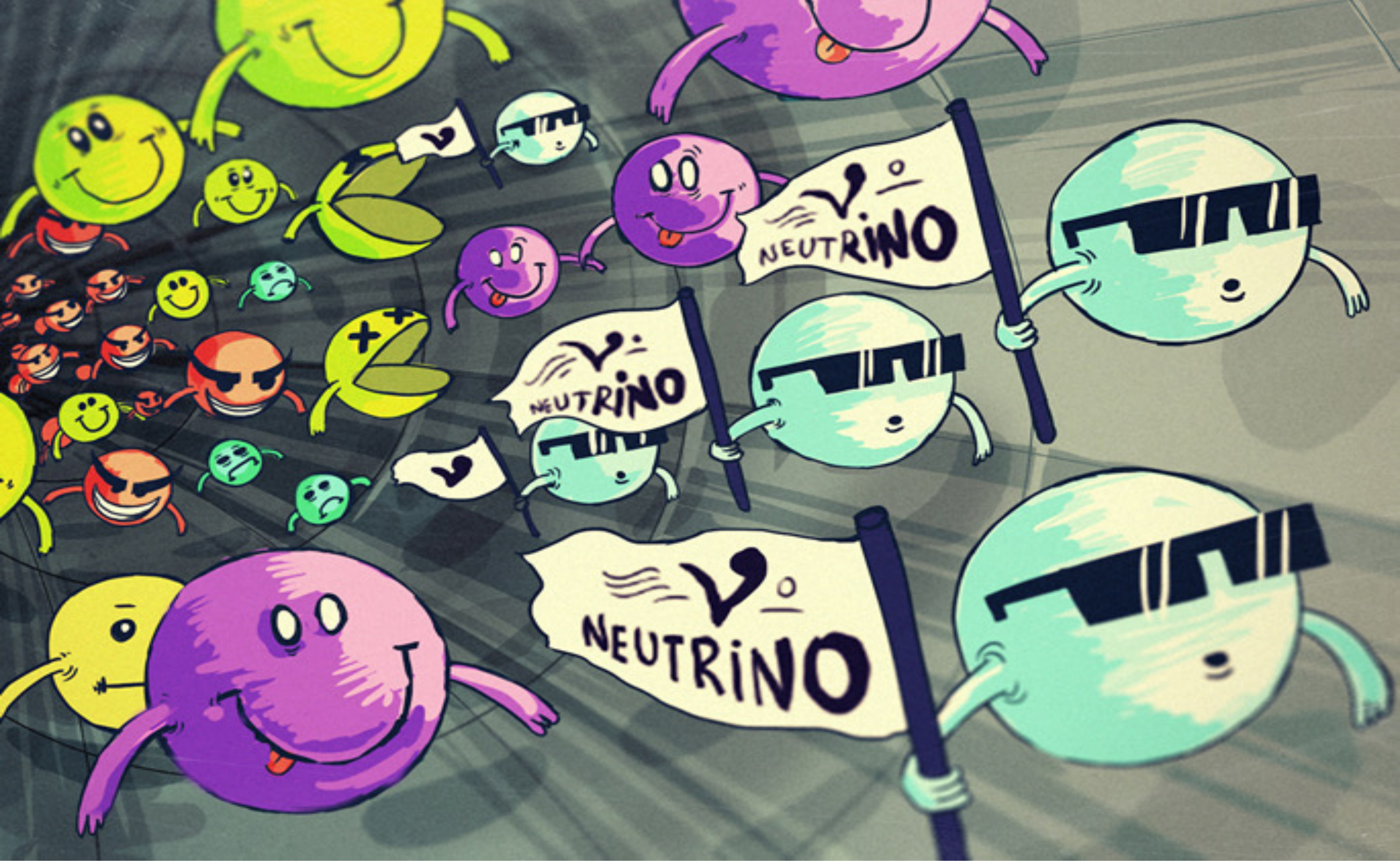






Conclusion:

- New generation of neutrino experiments are being built to answer many unknowns in the neutrino sectors;
- We can use the near detectors to directly search for dark sector (e.g.: ALPs, light DM, etc.);
- For several BSM models, near detectors give the best constraints;
- We can remove most of the neutrino background by using the target-less configuration;
- Target-less DUNE can probe the parameter space for thermal relic DM in only 3 months!
- It can also probe the region for QCD axion, and give best lab-based constraint on the parameter space of ALPs;
- We can probe very heavy particles, often beyond the reach of present colliders, by precisely measuring low-energy observables using the EFT formalism.

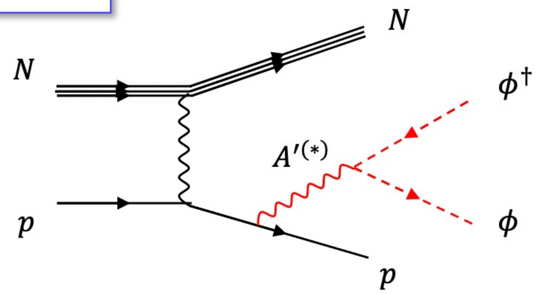


Thanks for your attention

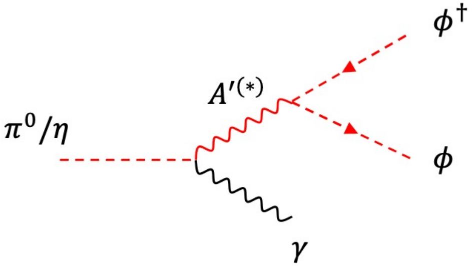
Back up Slides

Production and Detection of Dark Matter

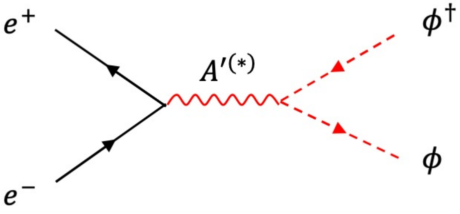
DM production



Beam bremsstrahlung

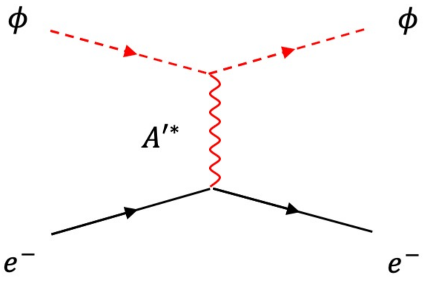


Neutral meson decays



Resonance production

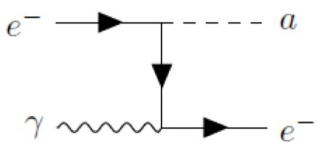
DM detection



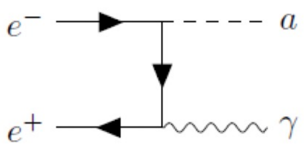
Elastic scattering with an electron

Production and Detection of ALPs

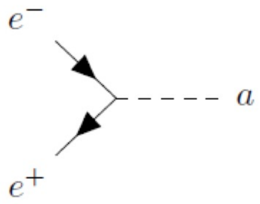
ALP production



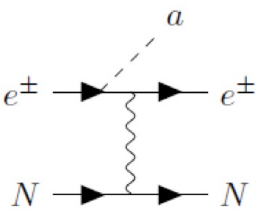
Compton



Associated production

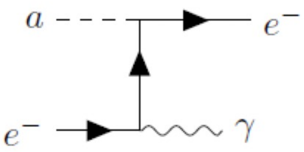


Resonant production

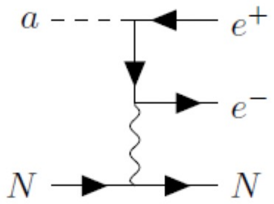


ALP-bremsstrahlung

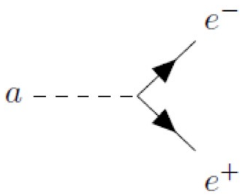
ALP detection



Inverse Compton



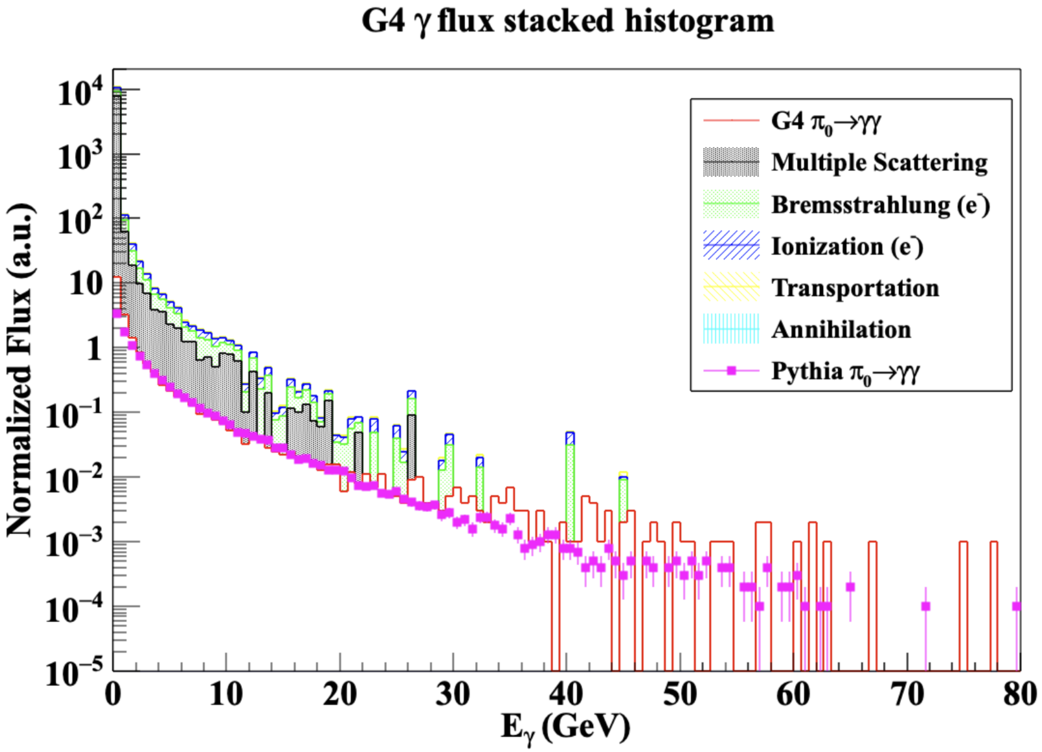
External pair conversion



Di-lepton decay

Axion Like Particles (ALPs) at DUNE:

Photon Flux from GEANT4 Simulation



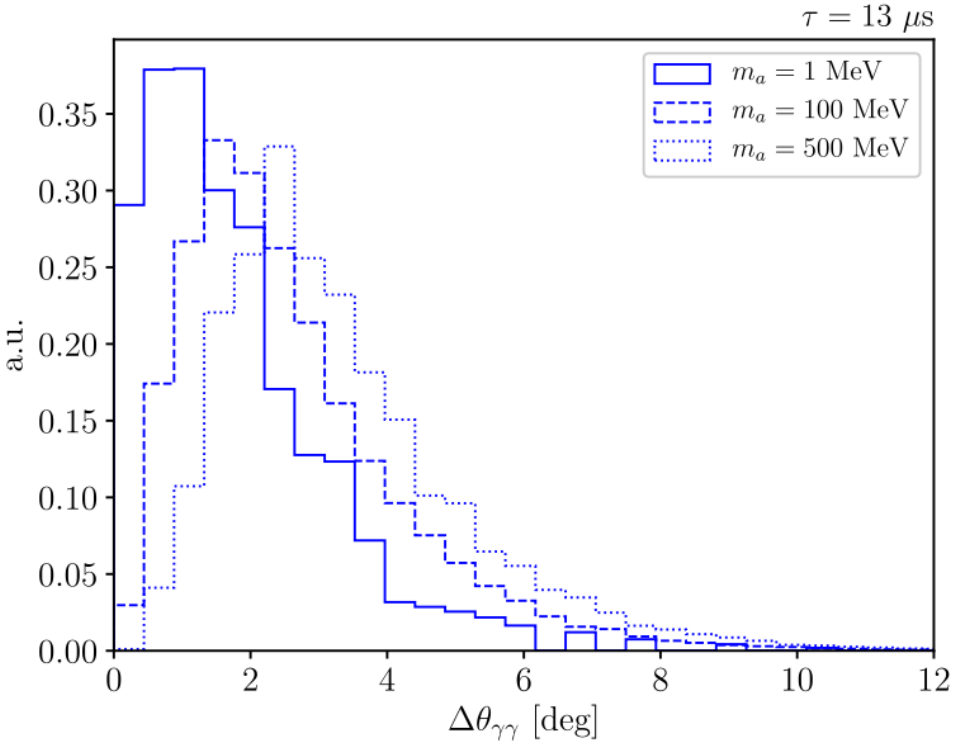
V. Brdar, B. Dutta, W. Jang, D. Kim, I. Shoemaker, **ZT**, A. Thompson, J. Yu
Phys.Rev.Lett. 126 (2021) 20, 201801

Axion Like Particles (ALPs) at DUNE:

- Coherent π^0 production $\nu + A \rightarrow \nu + A + \pi^0$

In GAr:

- We expect ~ 10^6 NC events;
- Vetoing events with hadronic activity remove ~ 80%;
- A cut on the opening angle removes the rest;



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Phys.Rev.Lett. 126 (2021) 20, 201801