Discovering Long-lived particles at DUNE

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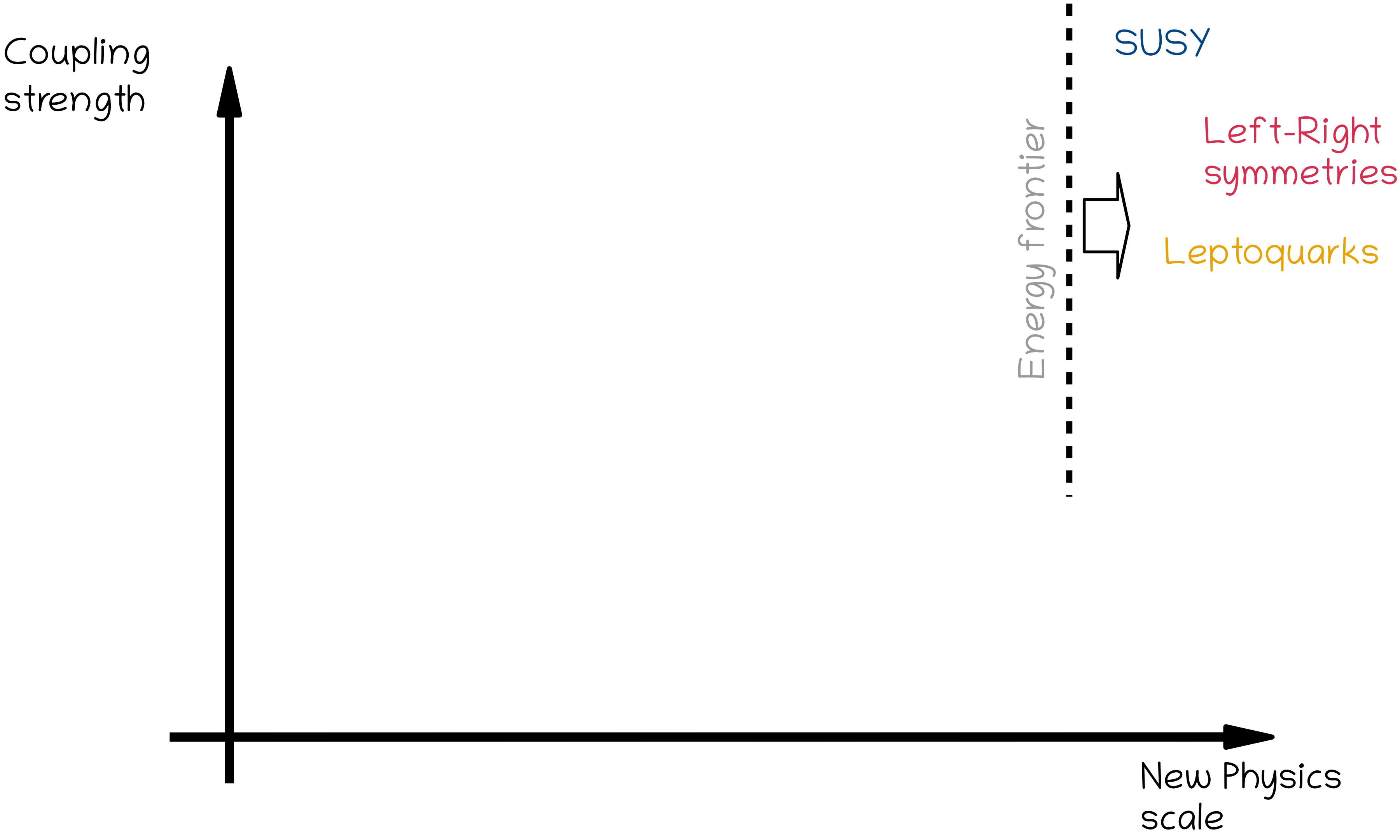
Based on arXiv:2309.06492, in collaboration with Justo Martín-Albo and Salvador Urrea
(and 2202.03447, in collaboration with Pilar Hernández and Salvador Urrea)

DUNE ND-GAr Meeting - Nov 14th, 2023

Where is the New Physics?



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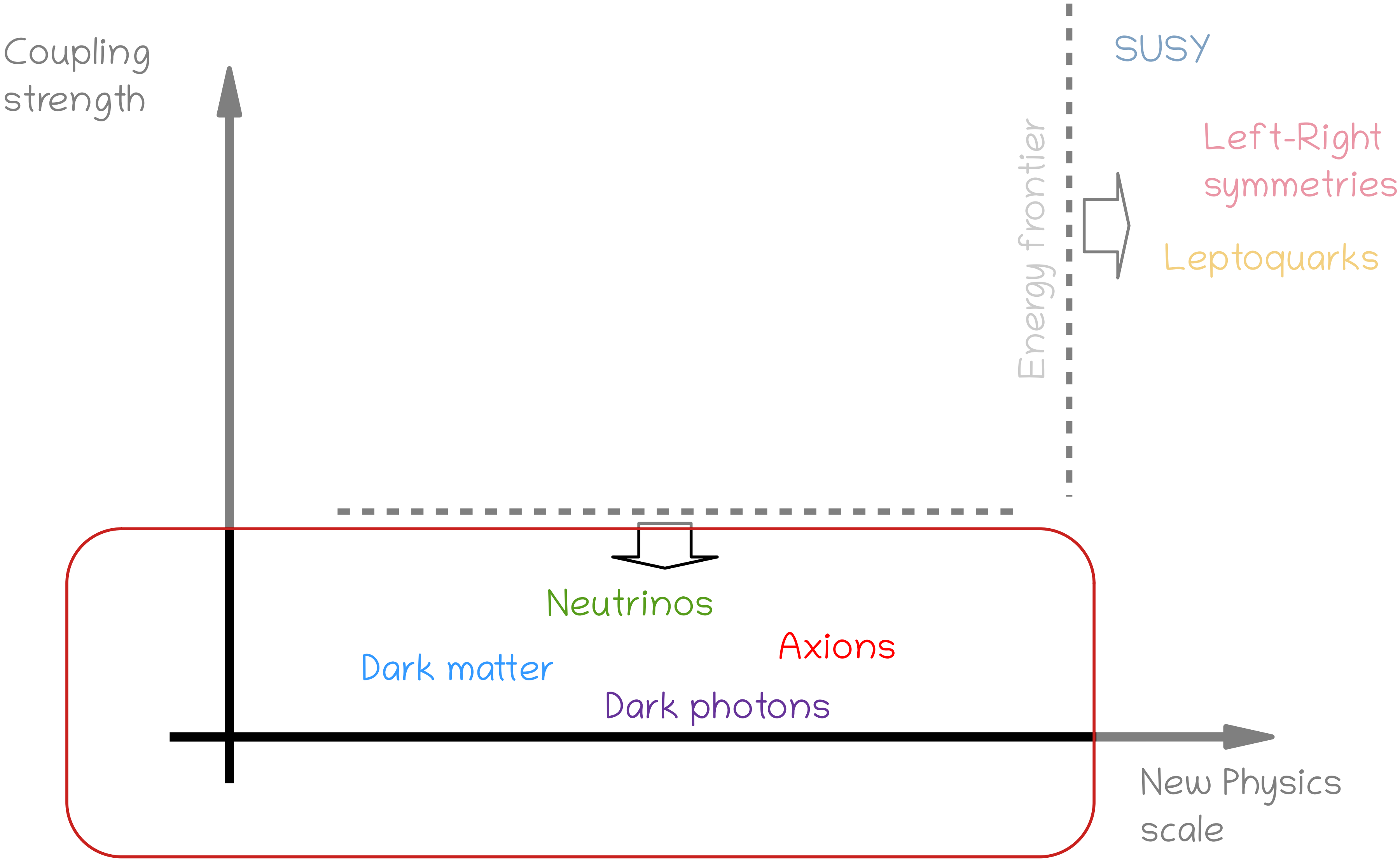
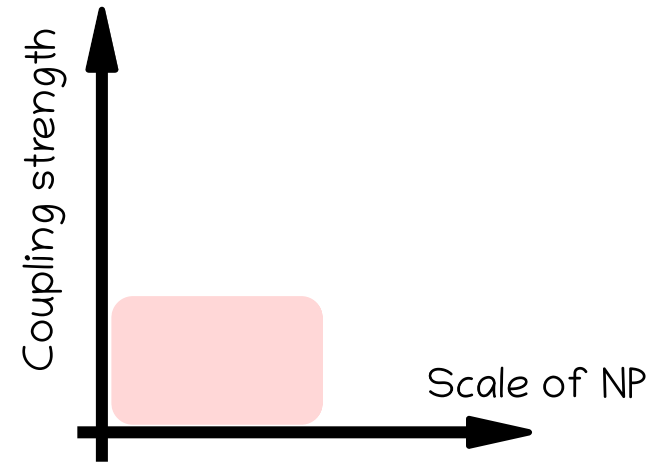
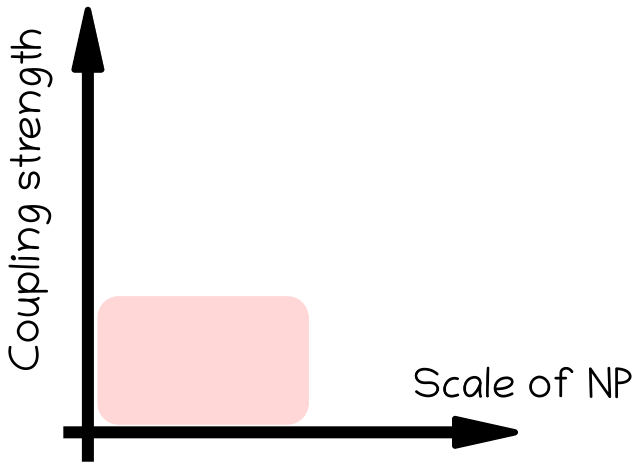


Signals at neutrino experiments



- Feebly-interacting particles
  - intense sources needed
  - large detectors needed
- We may search for two types of signals
  - Feeble interactions
  - Long-lived particle decays

Signals at neutrino experiments



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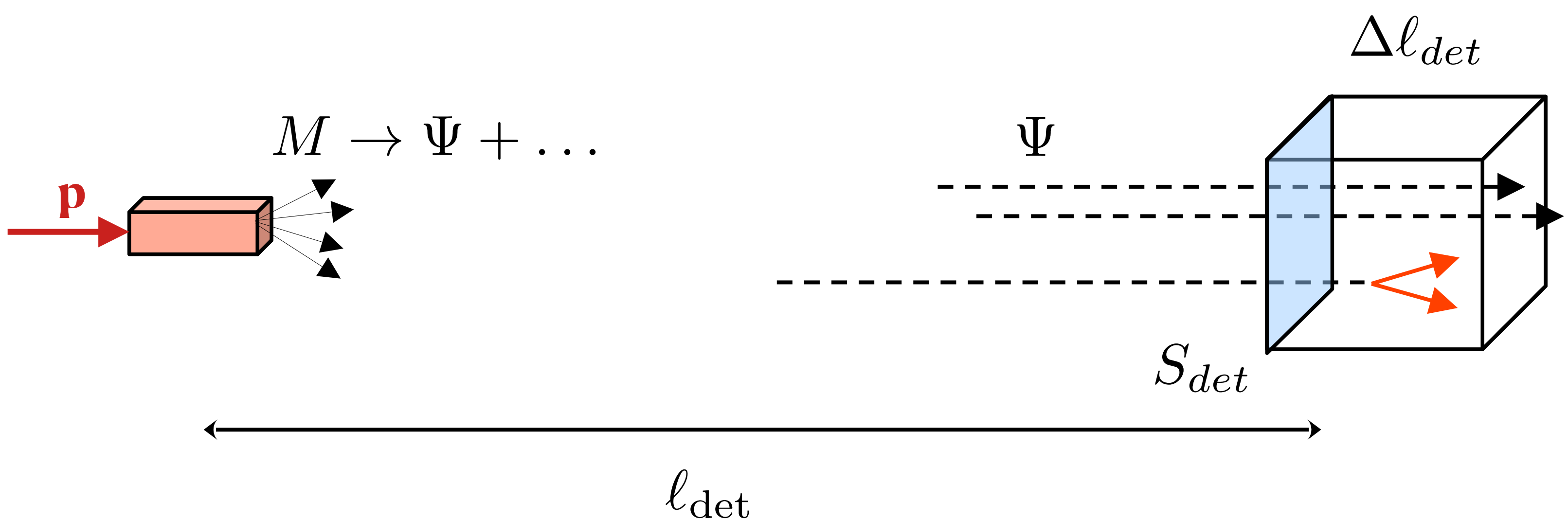
this talk

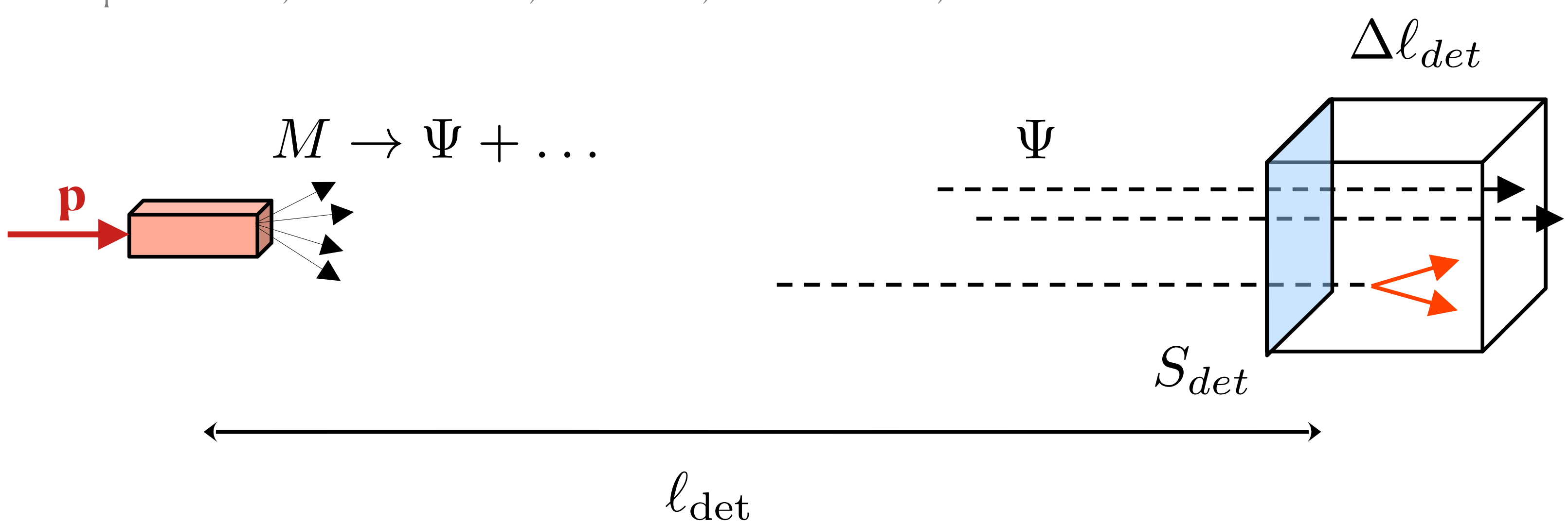
DUNE is a fixed target experiment



DUNE is a fixed target experiment

Many works in the literature:

Berryman et al, 1912.07622; Jerhot et al, 2201.05170; Kelly, Kumar & Liu, 2011.05995; Batell, Huang & Kelly, 2304.11189; Brdar et al, 2011.07054; Coloma et al, 2007.03701; Co, Kumar & Liu, 2210.02462; Capozzi et al, 2108.03262; Dev et al, 2104.07681;...



Expected number of decays

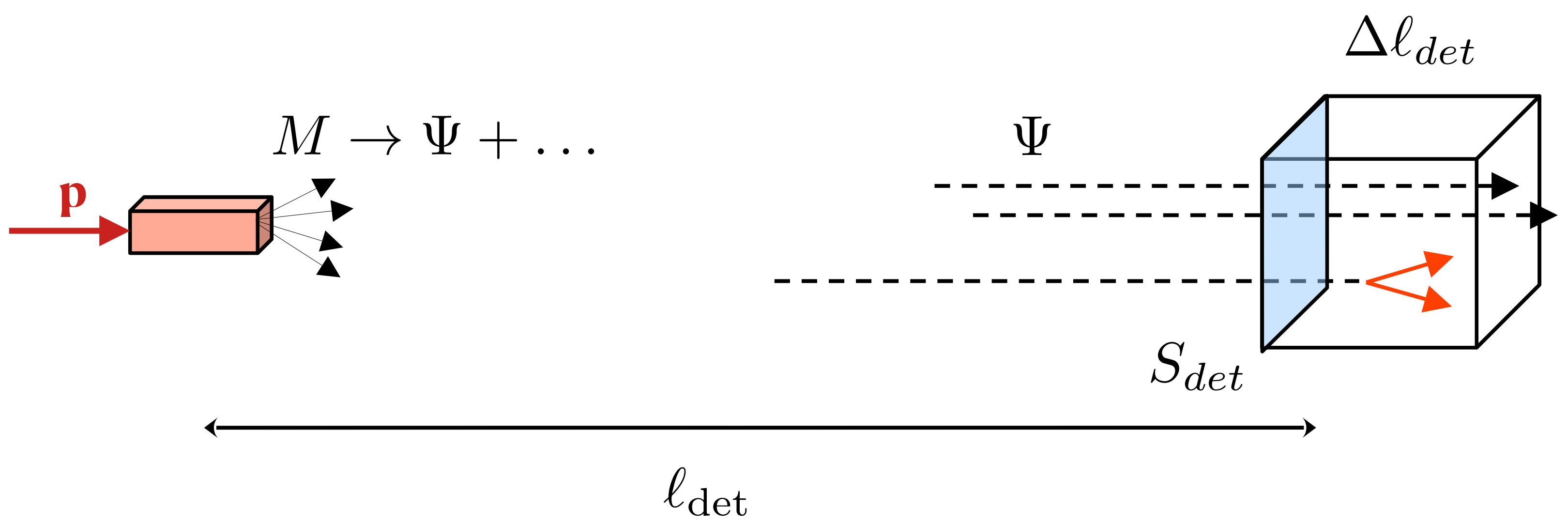
$$N_{ev} = N_M \mathrm{BR}(M \to \Psi)\mathrm{BR}(\Psi \to \mathrm{Vis})\, \epsilon_{det} \int dS \int dE_\Psi\, \mathcal{P}(c\tau_\Psi/m_\Psi, E_\Psi, \Omega_\Psi)\, \frac{dn^{M\to\Psi}}{dE_\Psi dS}$$

Number of particles produced

Is the final state observable?

Decay probability within detector

Dependence with energy and angle



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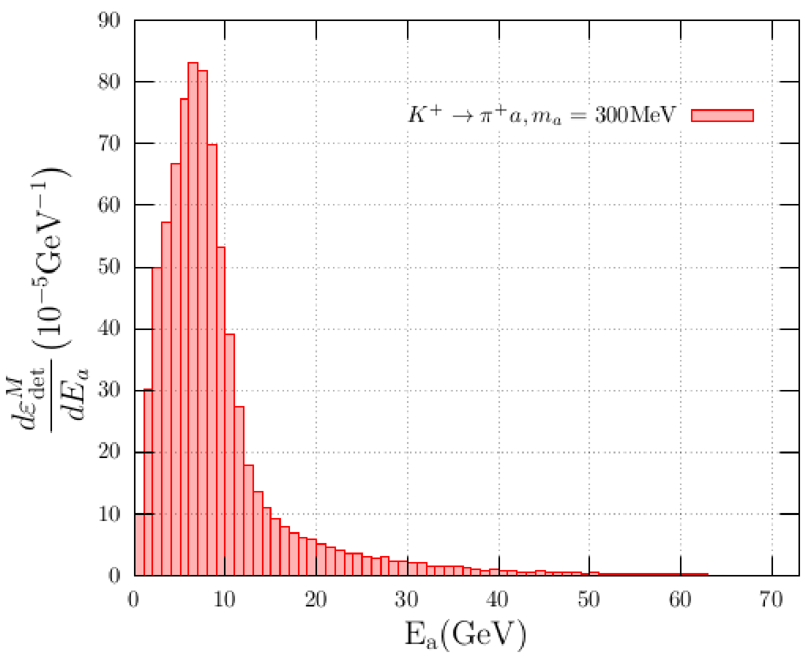
Model-dependent

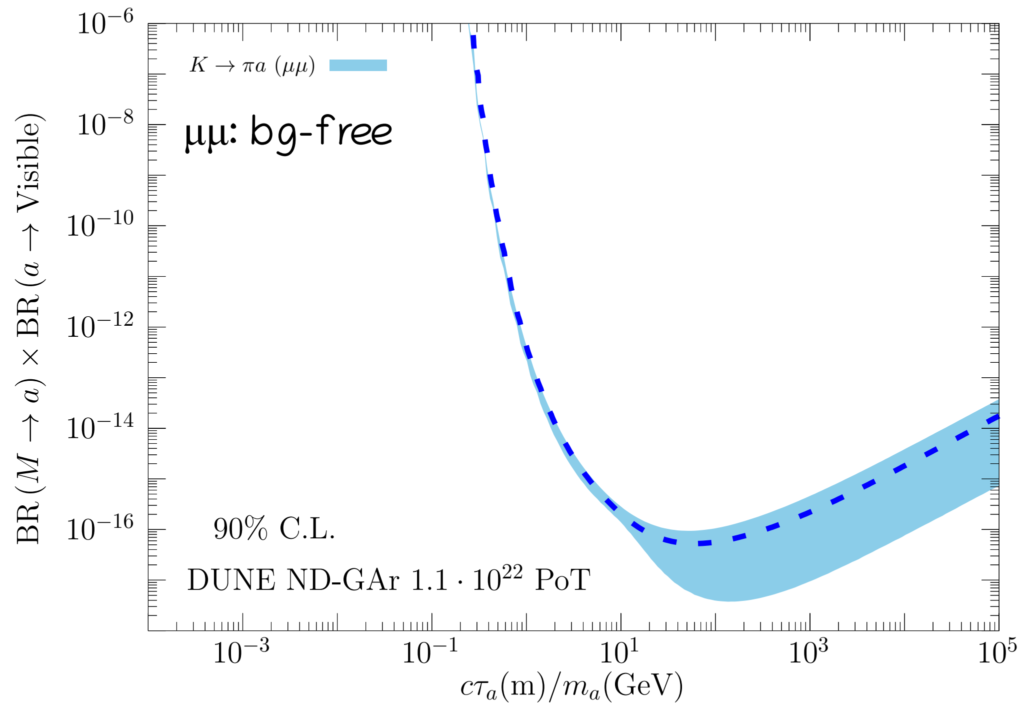
Model-dependent

For related model-independent LLP searches using neutrino facilities see e.g.
Arguelles et al, 1910.12839,
Coloma, Hernandez, Munoz, Shoemaker, 1911.09129;
Coloma, Hernandez, Urrea, 2202.03447;
Batell, Huang & Kelly, 2304.11189;
Mishra et al, 2211.13253;
...

Model-independent sensitivity

$$N_{ev} = N_M \mathrm{BR}(M \to \Psi) \mathrm{BR}(\Psi \to \mathrm{Vis}) \epsilon_{det} \int dS \int dE_\Psi \, \mathcal{P}(c\tau_\Psi / m_\Psi, E_\Psi, \Omega_\Psi) \frac{dn^{M\to\Psi}}{dE_\Psi dS}$$





Coloma, Martín-Albo and Urrea, 2309.06492

DUNE near detectors will record

$\sim 10^8$ neutrino interactions per year...

Also, the GAr-ND will not be ready until phase II

Few works on LLP at DUNE including backgrounds:

Ballett, Boschi & Pascoli, 1905.00284; Breitbach et al, 2102.03383

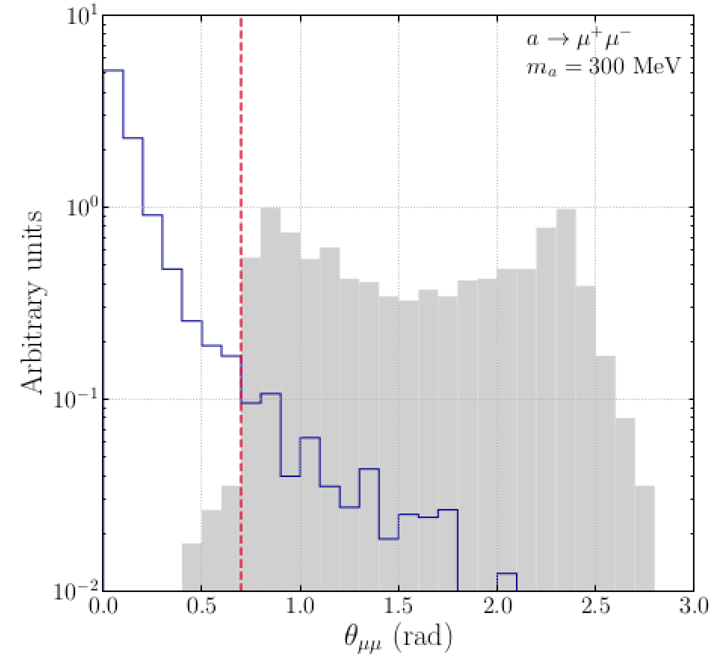
Backgrounds vs signal

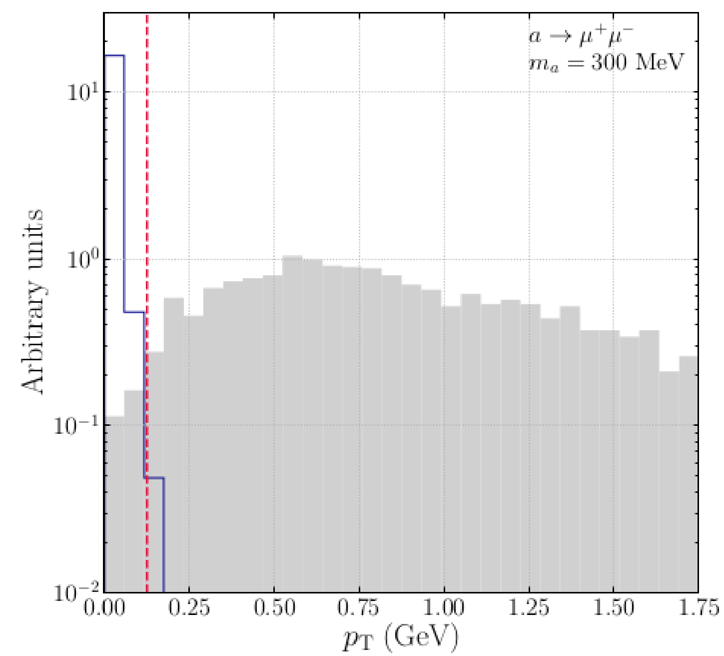
Main signals considered:
- two photons
- two charged leptons
- three pions

Main backgrounds to these searches arise from neutrino interactions

→ A priori, can be mitigated with appropriate cuts

More on this in the next talk
by Justo Martin-Albo!





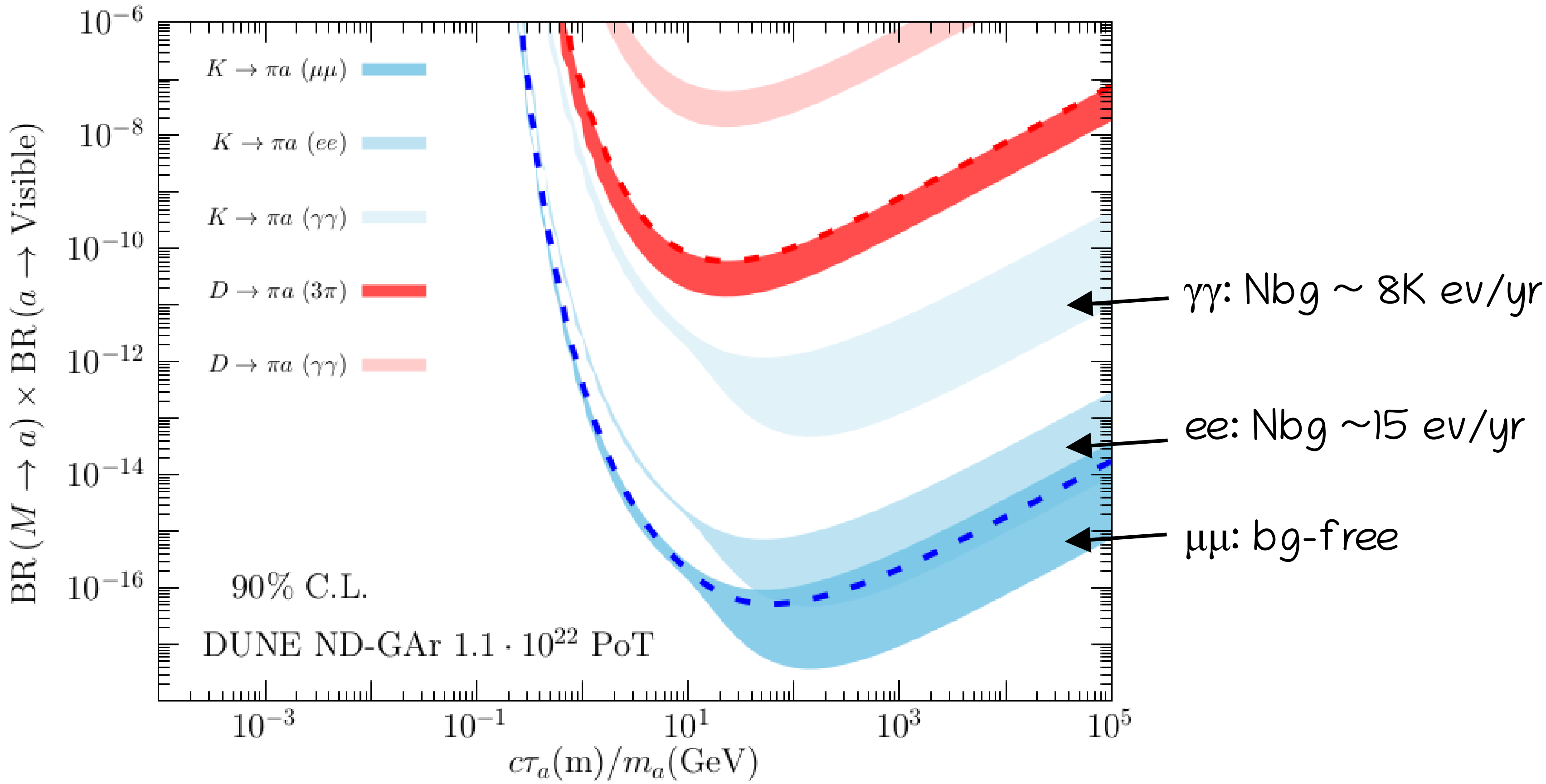
Backgrounds

	Selection cut	Signal efficiency		Background rate/yr	
		ND-LAr	ND-GAr	ND-LAr	ND-GAr
$\mu^+\mu^-$	Two μ-like tracks only	1.00	1.00	3545674	70656
	PID μ and opposite charge sign	0.40	1.00	6226	124
	Transverse momentum < 0.125 GeV/c	0.40	0.99	99	2
	Angle between muons < 0.7 rad	0.40	0.94	0	0
e^+e^-	Two e-like tracks/showers	0.10	1.00	9432	145
	Reconstructed ALP direction	**0.10**	0.99	180	15
$\gamma\gamma$	Two γ showers only	0.05	0.79	36276	14222
	Reconstructed ALP direction	0.05	0.79	6938	**7923**
	Angle between γ showers	**0.05**	—	**1367**	—
$\pi^+\pi^-\pi^0$	Two μ-like tracks, two γ showers	0.04	0.81	2030490	40462
	PID $\pi^\pm$ and charge sign	0.04	0.81	431035	8589
	Transverse momentum < 0.2 GeV/c	0.04	0.79	17182	342
	Angle between pions < 0.15 rad	**0.04**	0.69	**946**	19

Coloma, Martín-Albo and Urrea, 2309.06492

Model-independent sensitivity

$$N_{ev} = N_M \mathrm{BR}(M \to \Psi) \mathrm{BR}(\Psi \to \mathrm{Vis}) \epsilon_{det} \int dS \int dE_\Psi \, \mathcal{P}(c\tau_\Psi/m_\Psi, E_\Psi, \Omega_\Psi) \frac{dn^{M\to\Psi}}{dE_\Psi dS}$$



Coloma, Martín-Albo and Urrea, 2309.06492

Model-independent sensitivity

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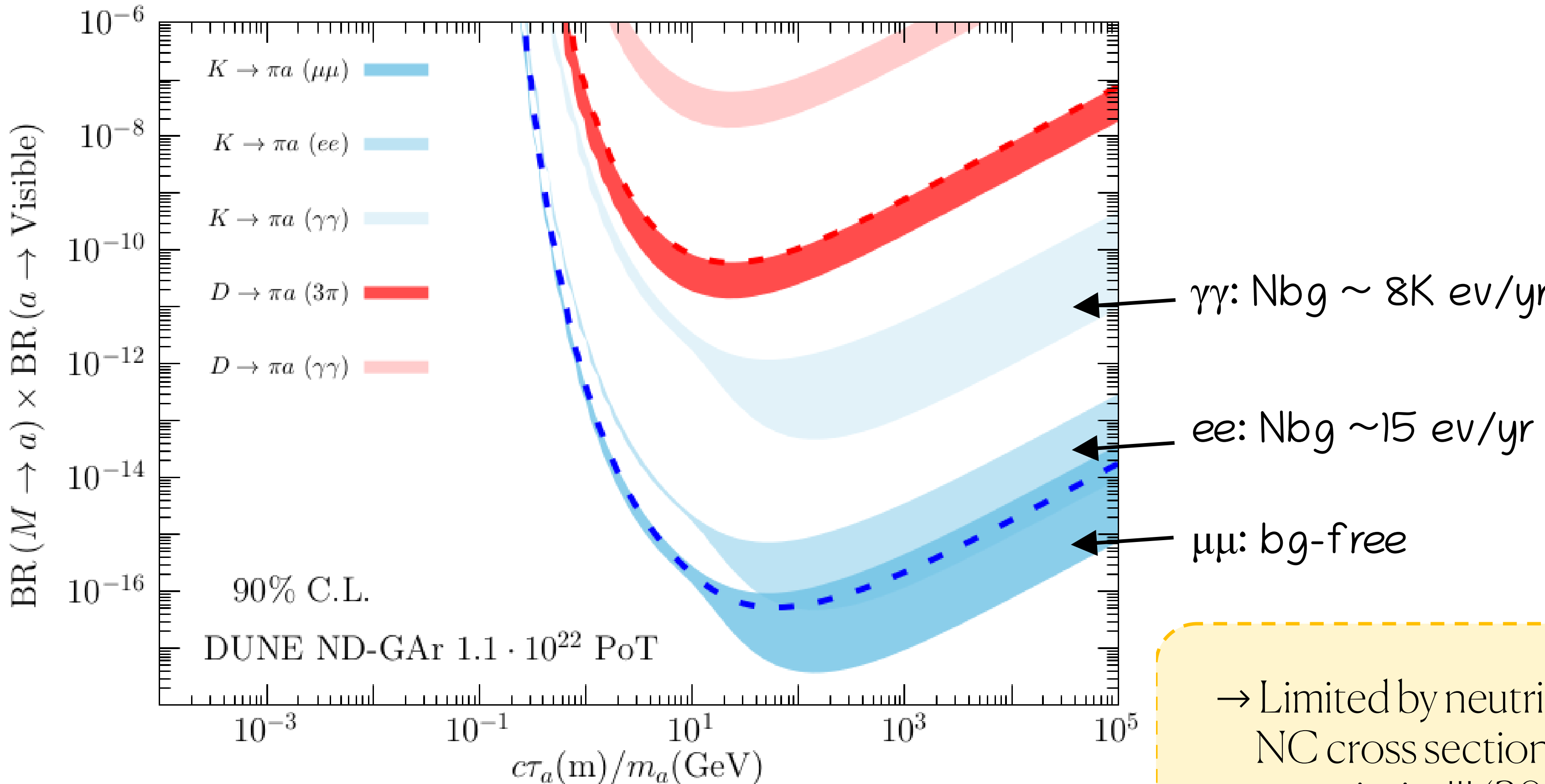


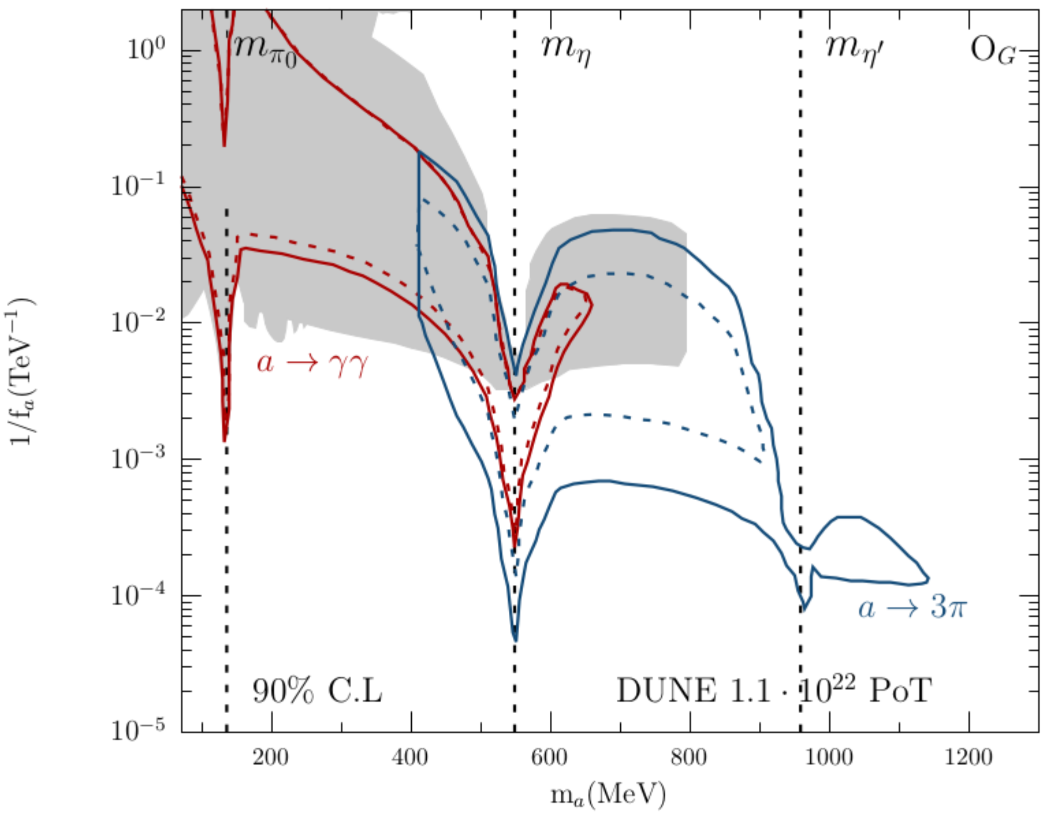
→ Limited by neutrino NC cross section uncertainties!!! (20%)

Coloma, Martín-Albo and Urrea, 2309.06492

Specific ALP scenarios

Main production mechanisms:
- mixing with mesons
- gluon fusion

$$\frac{\alpha_s}{8\pi f_a} a G^b_{\mu\nu} \widetilde{G}^{b\mu\nu}$$



Main decay channels:
- two photons
- three pions

Cheng, Li and Salvioni, 2110.10691
Aloni, Soreq, Williams, 1811.03474

Coloma, Martín-Albo and Urrea, 2309.06492
(see also Kelly, Kumar and Liu, 2011.05995; Jerhott et al, 2201.05170)

Specific ALP scenarios

Main production mechanisms:

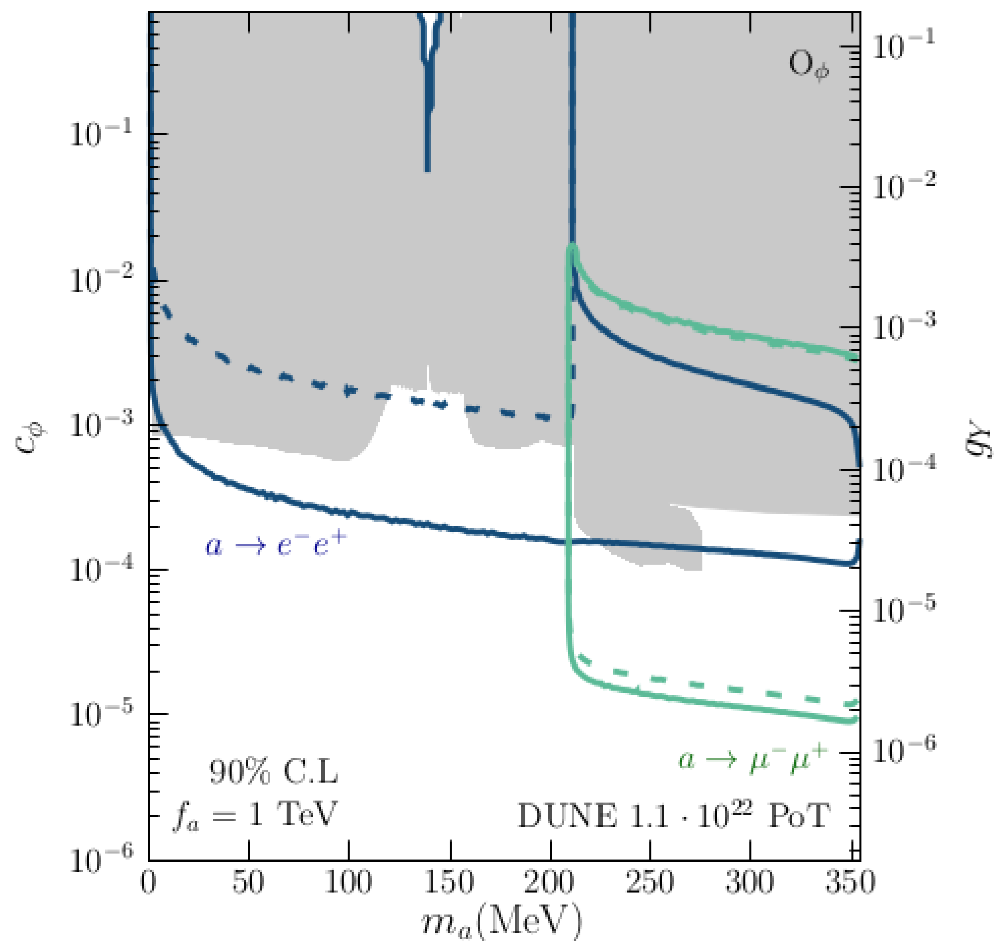
- Kaon decays: K → π a
- ~~B decays~~

Main decay channels:

- two charged leptons
- two photons

(results for O_W operator in backup slides)

$$c_\phi \frac{\partial^\mu a}{f_a} \phi^\dagger i \overleftrightarrow{D}_\mu \phi$$



Coloma, Martín-Albo and Urrea, 2309.06492
(see also Coloma, Hernandez, Urrea, 2202.03447)

Specific ALP scenarios

Main production mechanisms:

- $D \to \pi a$

Carmona et al, 2101.07803
Martin-Camalich et al, 2002.04623

Main decay channels:

- two photons
- three pions

Cheng, Li and Salvioni, 2110.10691
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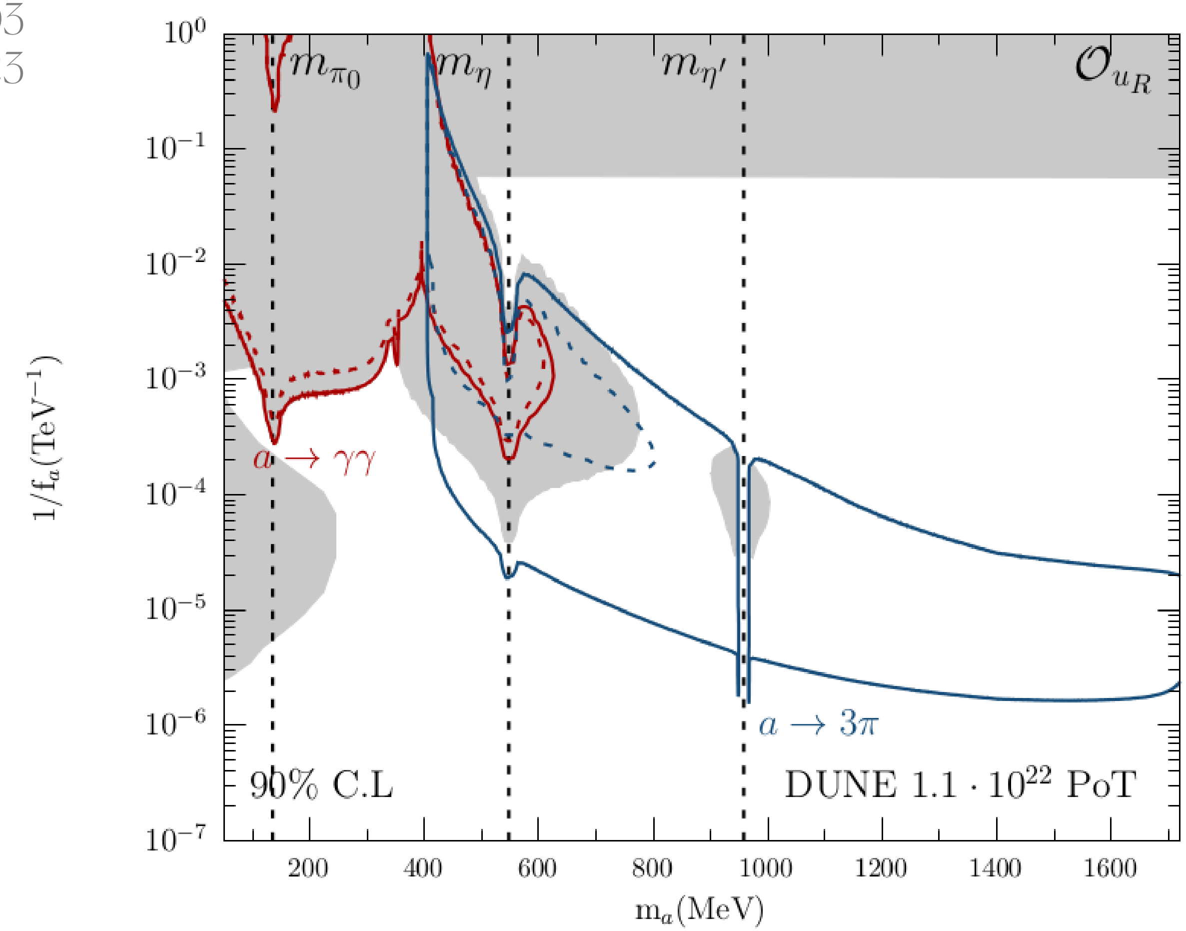
$$\frac{\partial_\mu a}{f_a}\bar{u}_{R,i}\gamma^\mu u_{R,j}$$



Summary

- In this work we have computed the main backgrounds for some of the relevant long-lived particle decay channels
  - our background analysis applies to multiple LLP scenarios: dark photons, axion-like particles, dark scalars,…
  - unlike previously assumed, the two-photon channel is far from being background free, for both LAr-ND and GAr-ND
- We have computed sensitivities both detectors, following a model-independent approach
  - the LAr-ND capabilities are limited for these searches, mostly due to the low efficiencies assumed
  - a Gaseous TPC will be key to ensure an improvement over current limits
- Our results are still preliminary: a full analysis, including reconstruction effects and pile-up, is needed → a PhD student will start working on this soon

Thanks!

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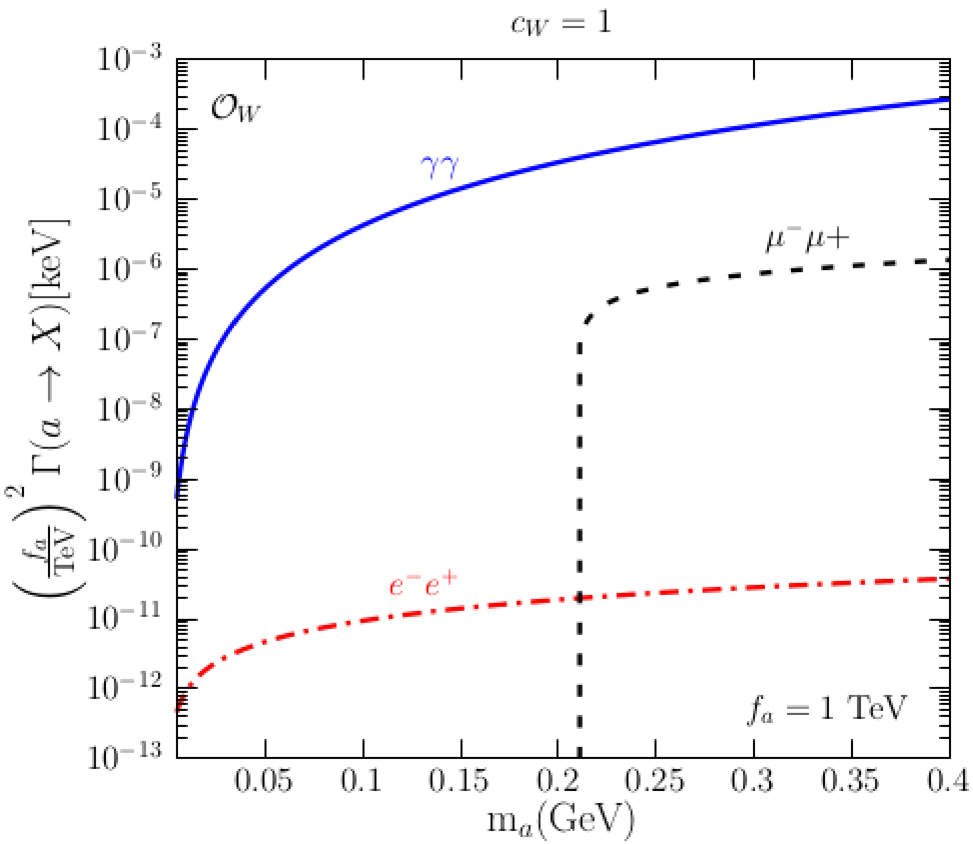
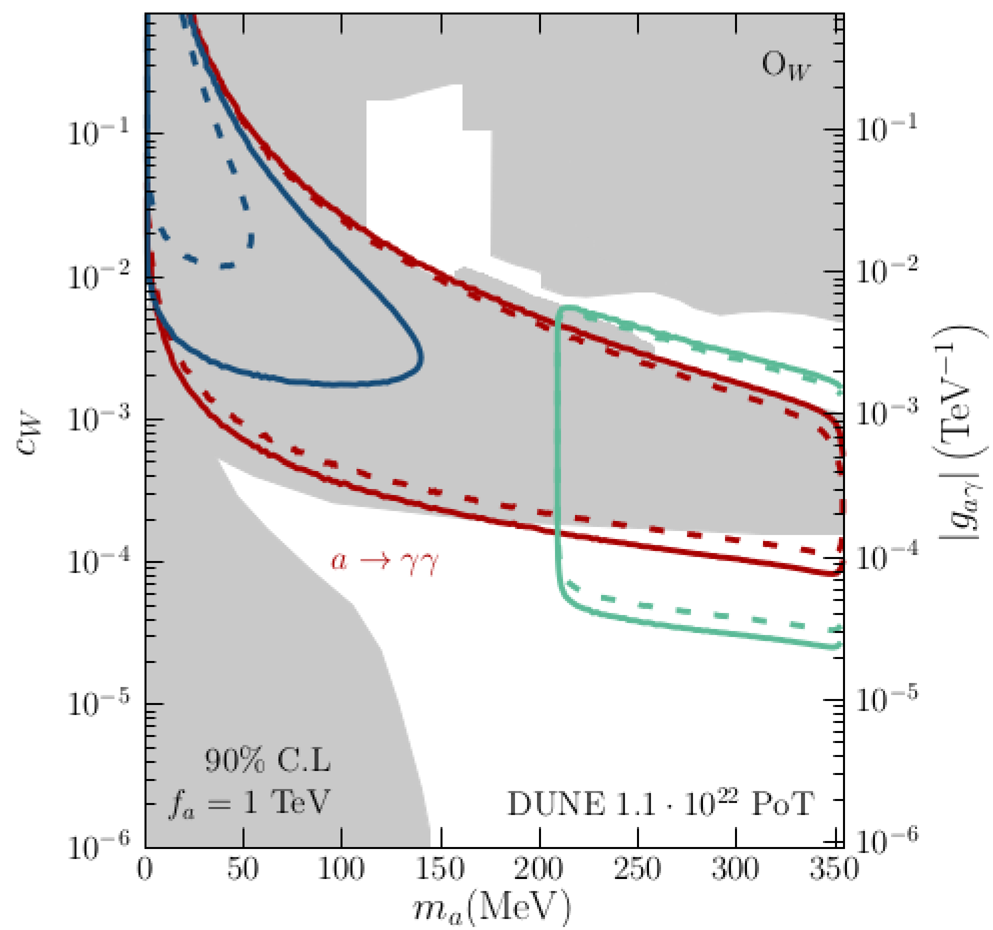
Backup

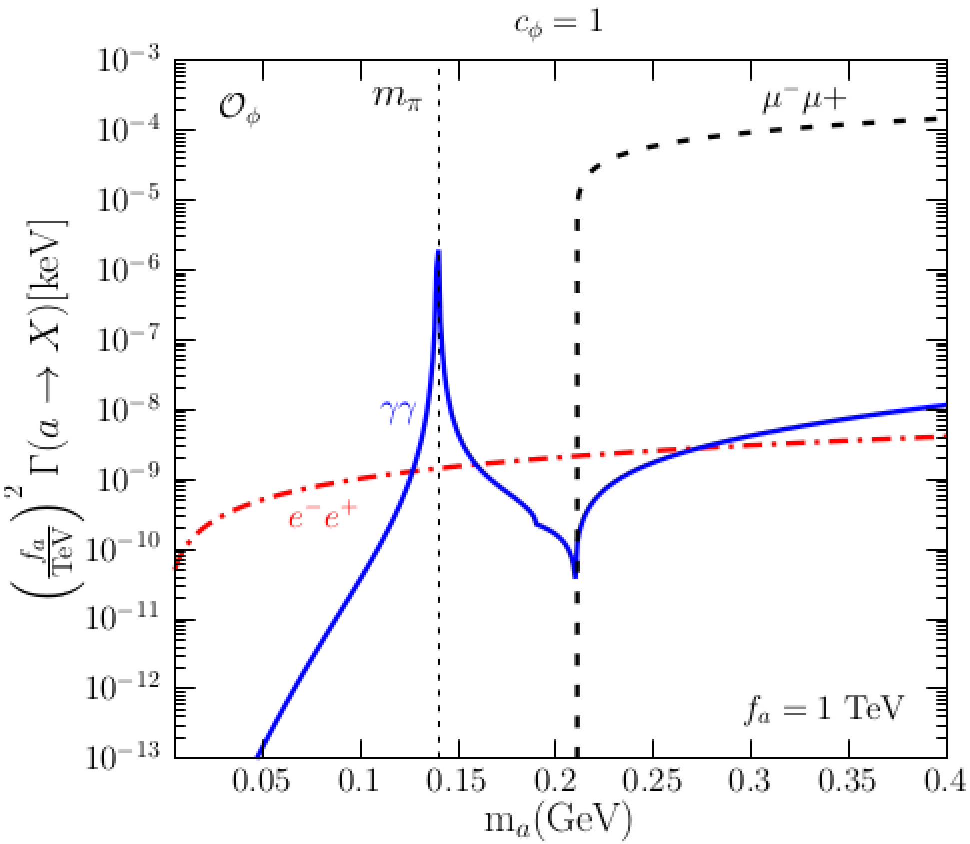
Specific ALP scenarios

$$c_W \frac{a}{f_a} W^I_{\mu\nu} \widetilde{W}^{\mu\nu I}$$





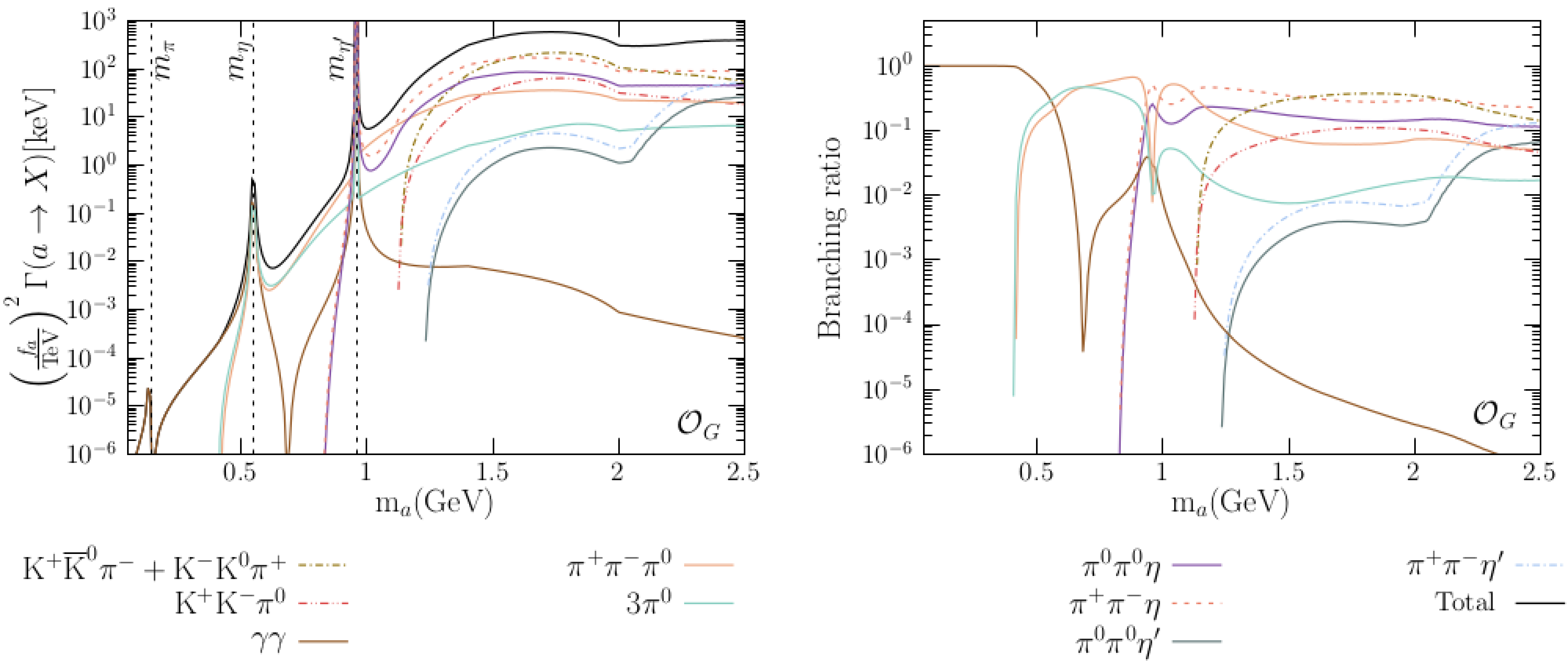
Decay widths



$$c_\phi \frac{\partial^\mu a}{f_a} \phi^\dagger i \overleftrightarrow{D}_\mu \phi$$

Branching ratios into mesons

$$\frac{\alpha_s}{8\pi f_a} a G^b_{\mu\nu} \widetilde{G}^{b\mu\nu}$$



Computed as in Cheng, Li and Salvioni, 2110.10691
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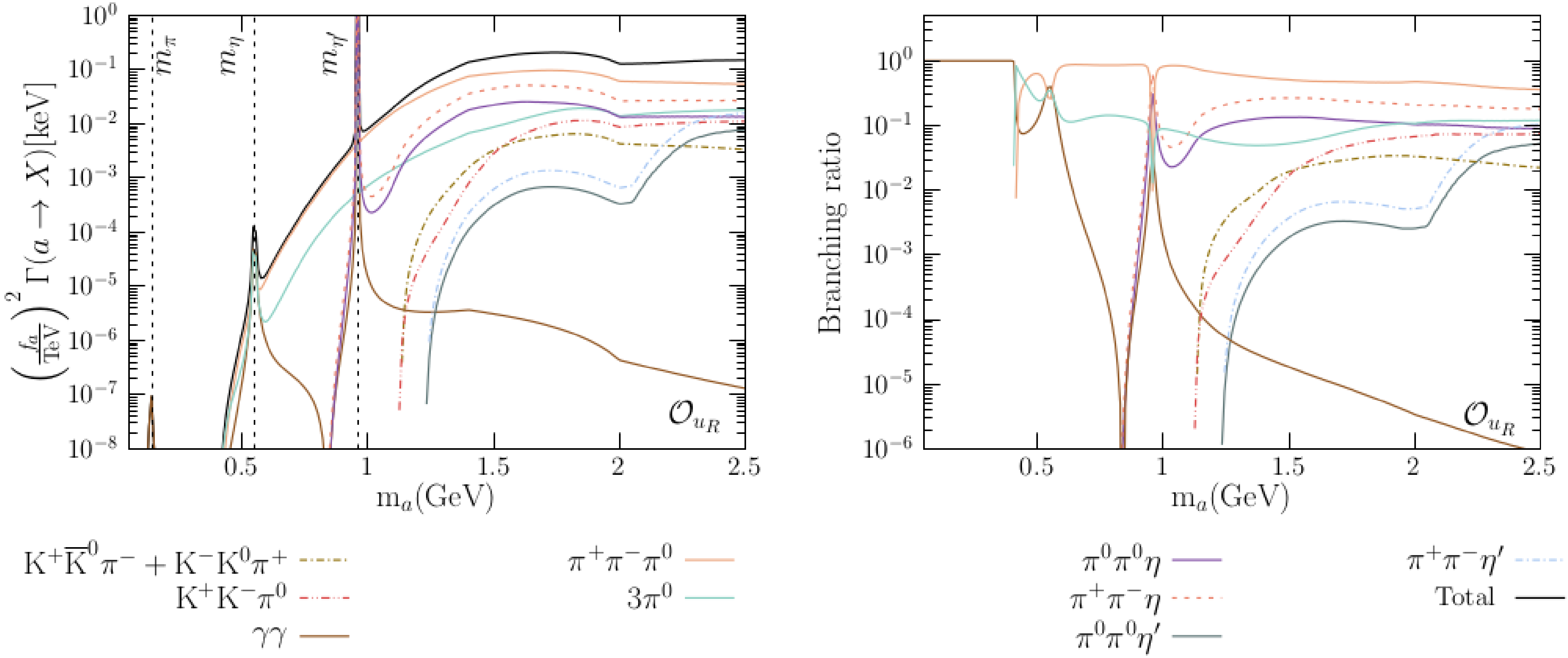

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