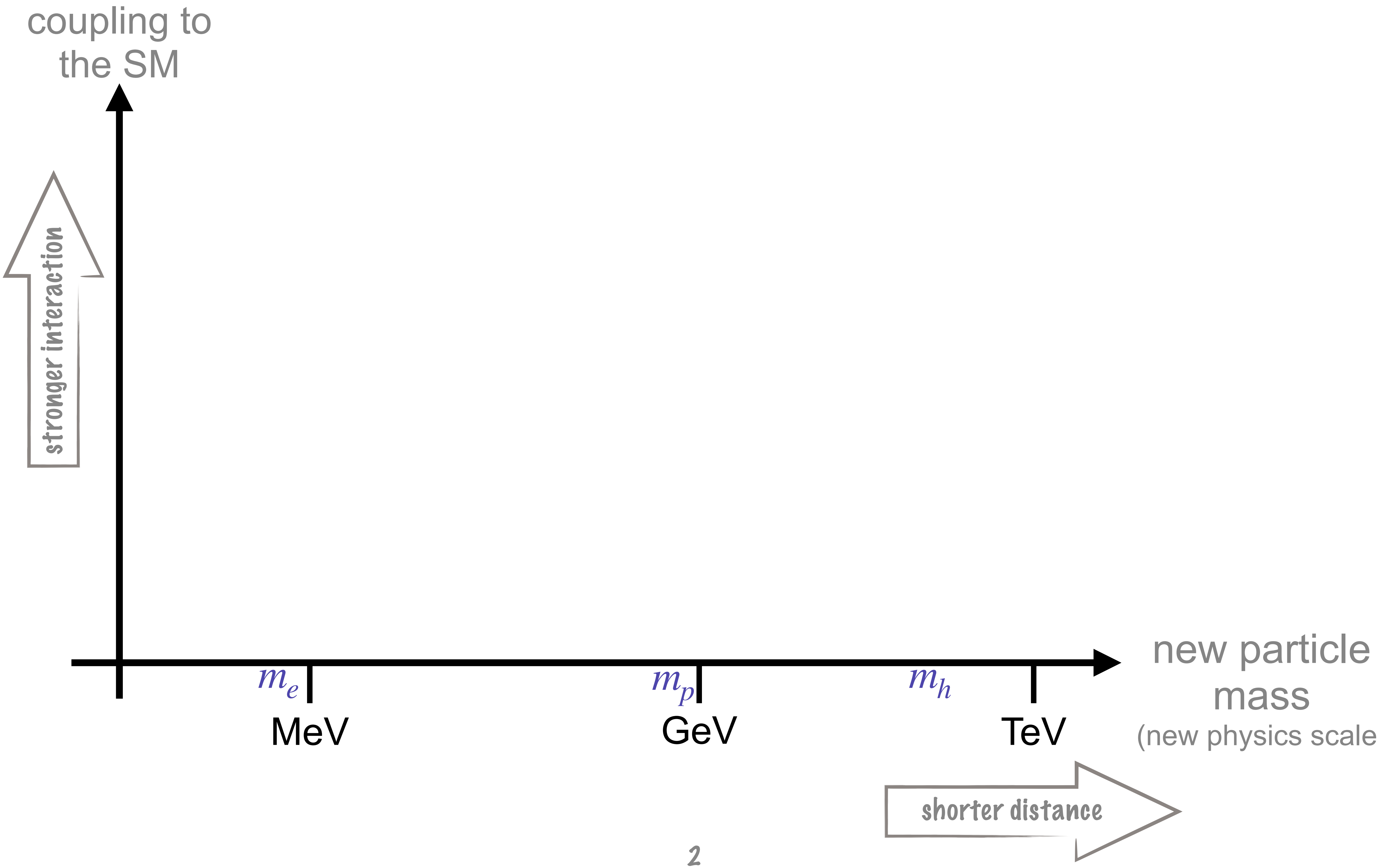
on reinterpretation of high intensity experiments

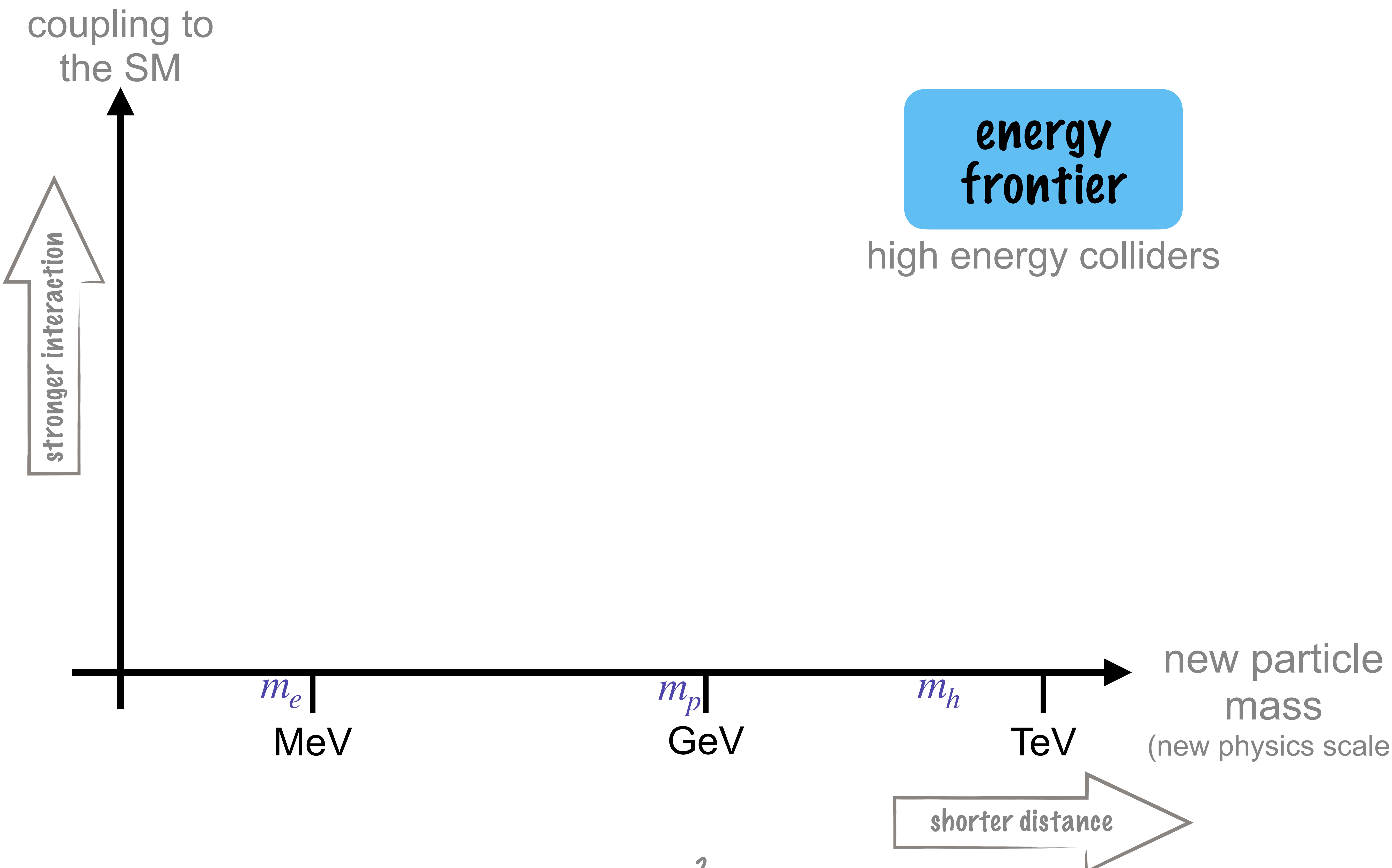
Yotam Soreq

Reinterpretation workshop, 17 Feb, 2021

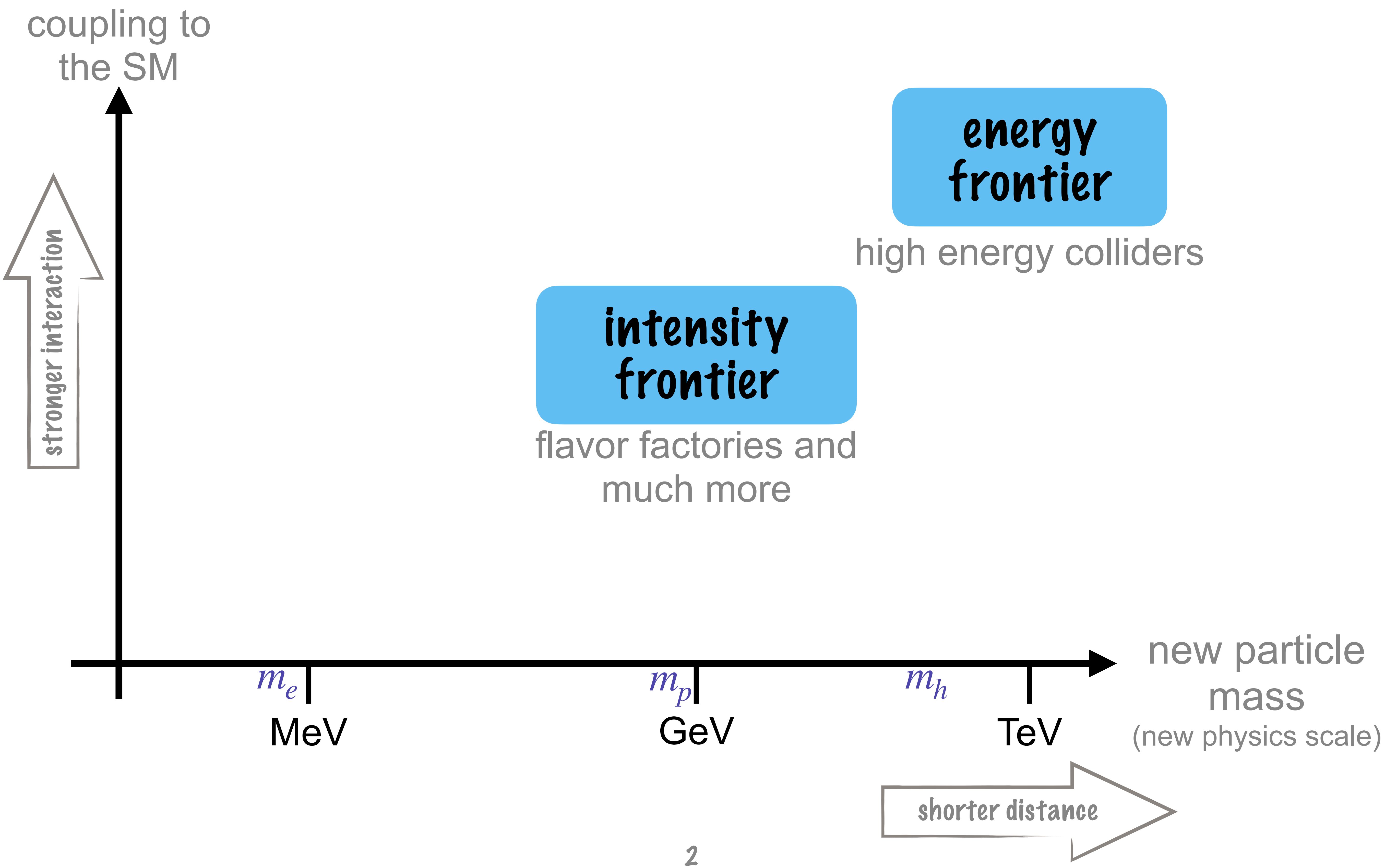
the quest for new physics



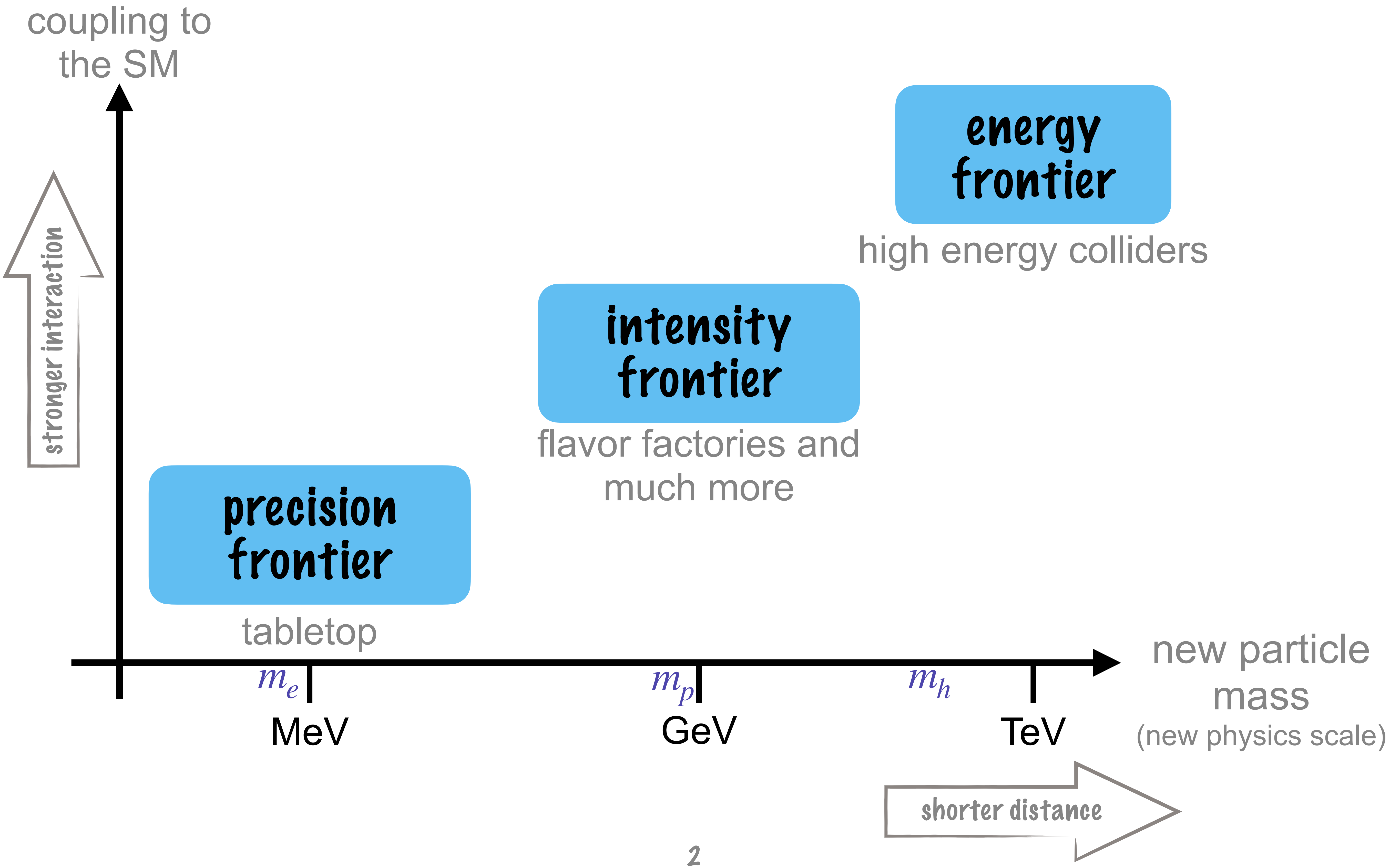
the quest for new physics



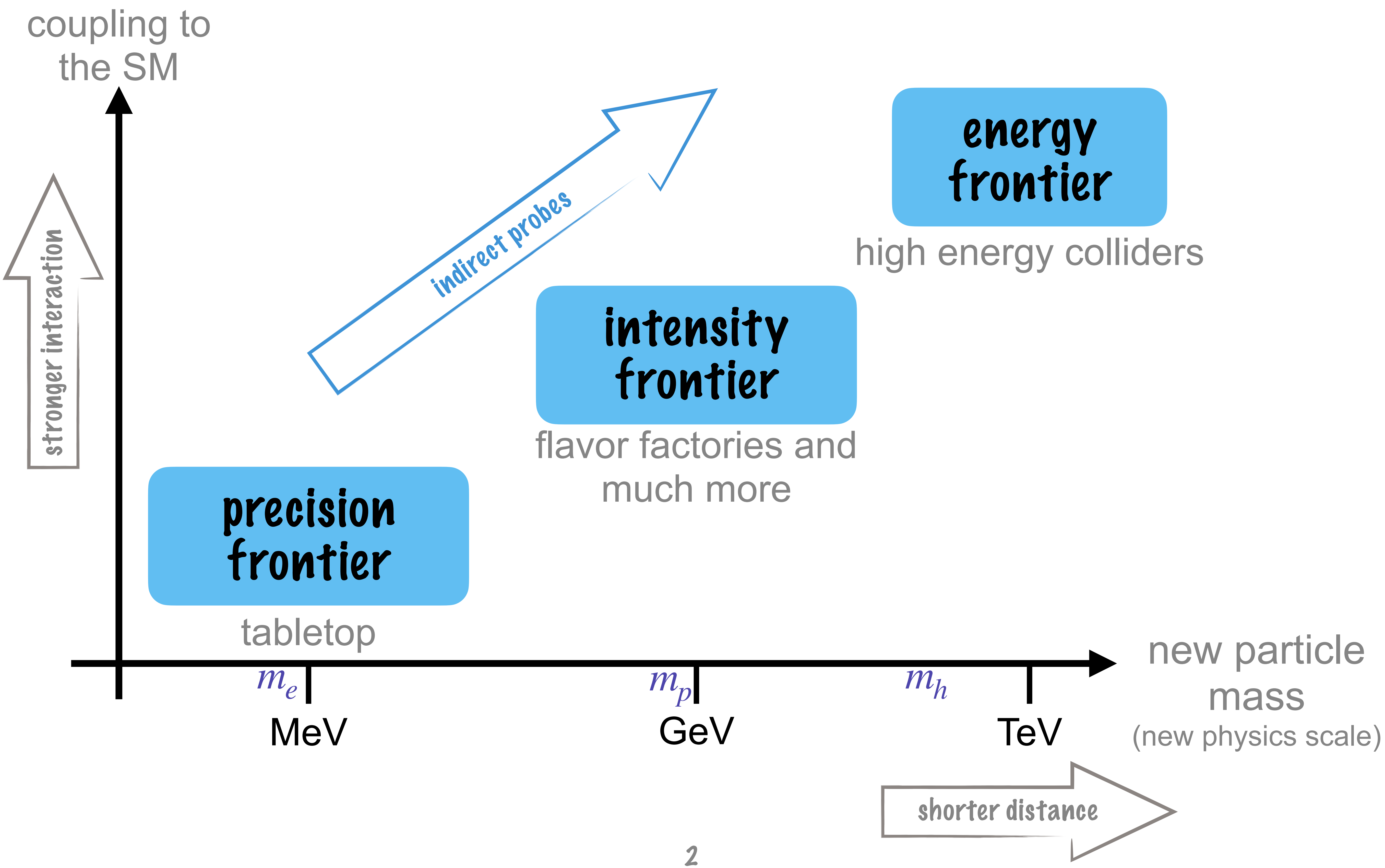
the quest for new physics



the quest for new physics



the quest for new physics



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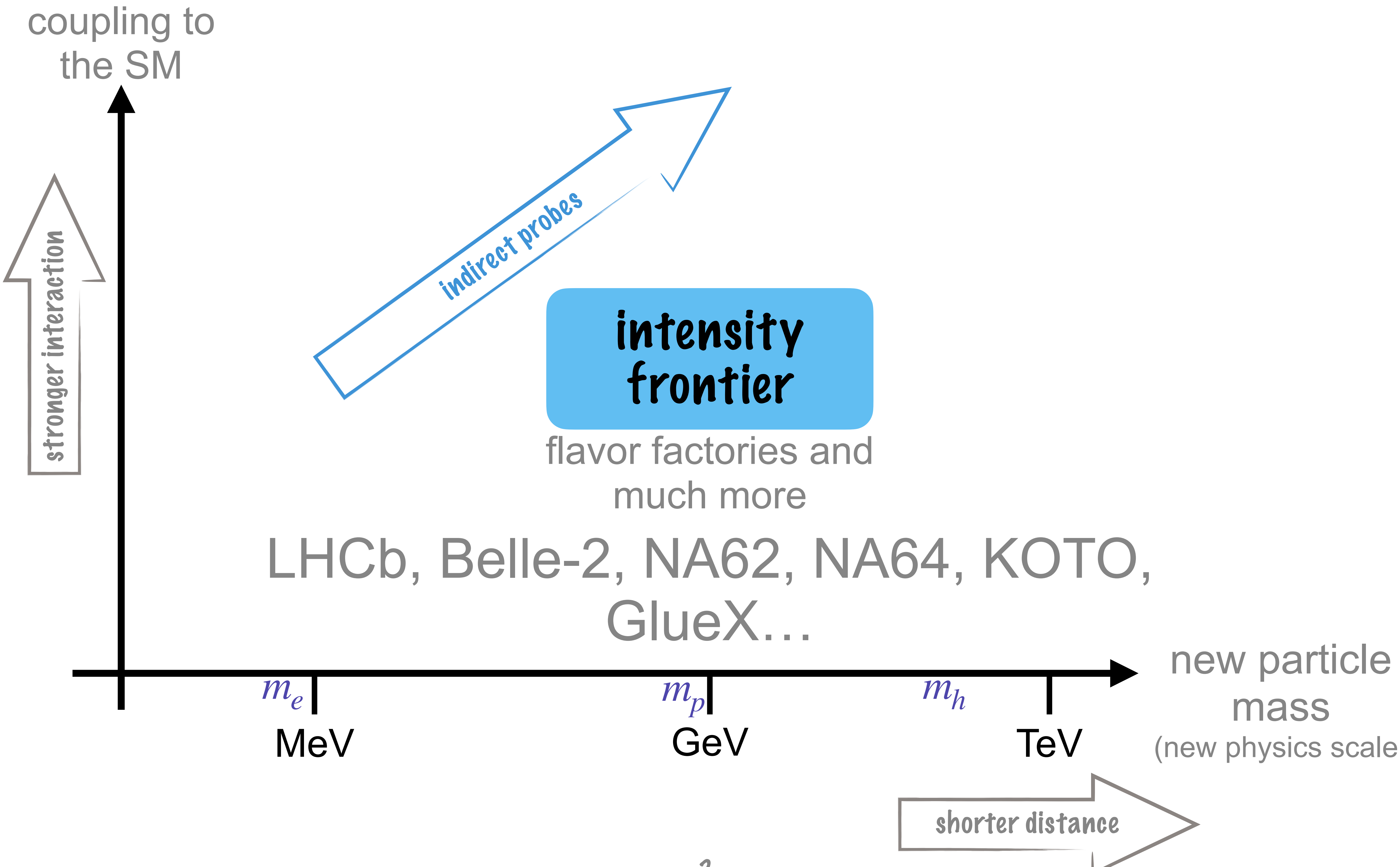

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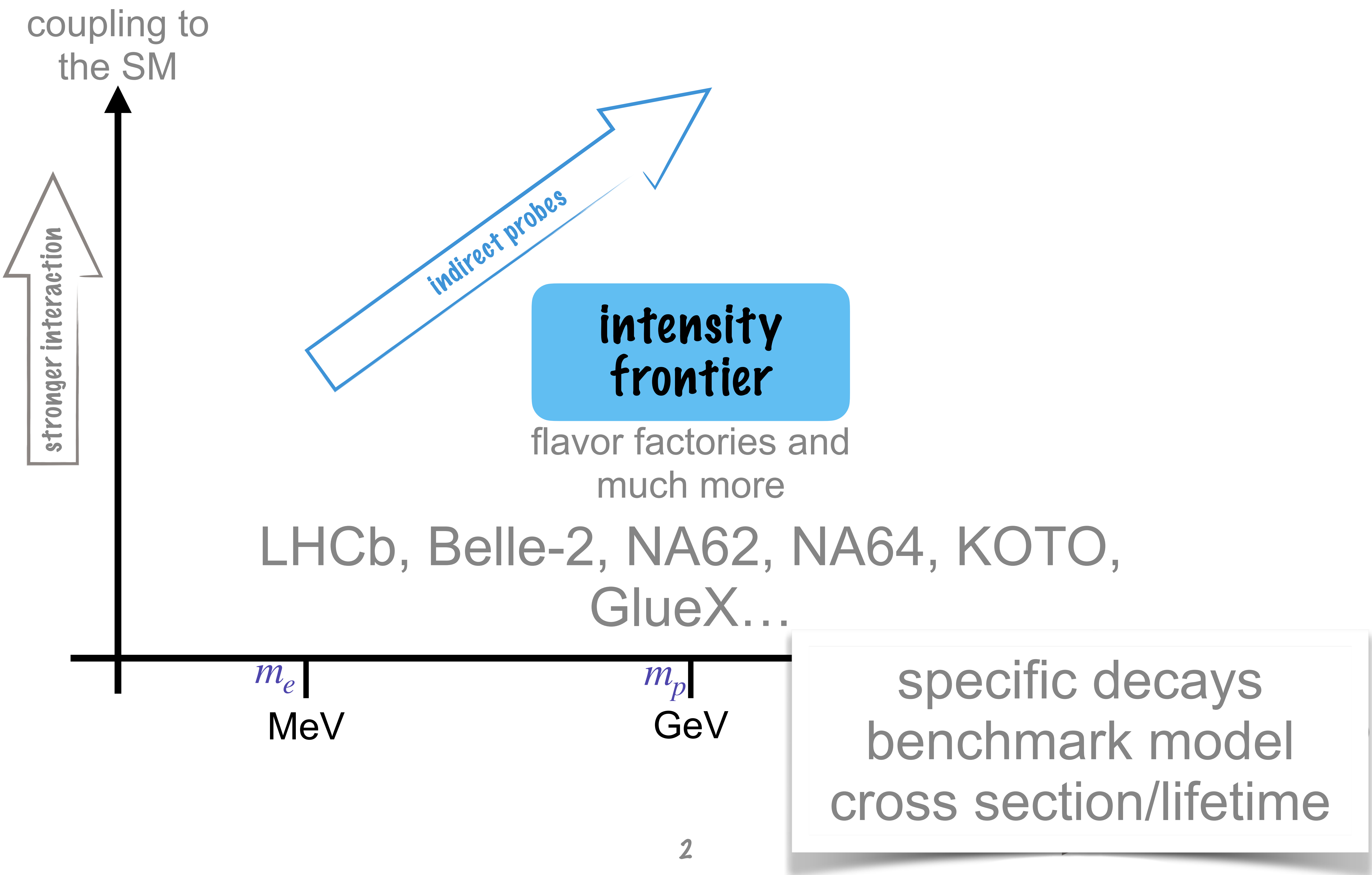

specific decays

e.g.:

$$B \to KX$$

$$K \to \pi\nu\bar{\nu}$$

$$\mu \to e\gamma$$

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calculate the rate in your model

specific decays

e.g.:

$$B \to KX$$

$$K \to \pi\nu\bar{\nu}$$

$$\mu \to e\gamma$$

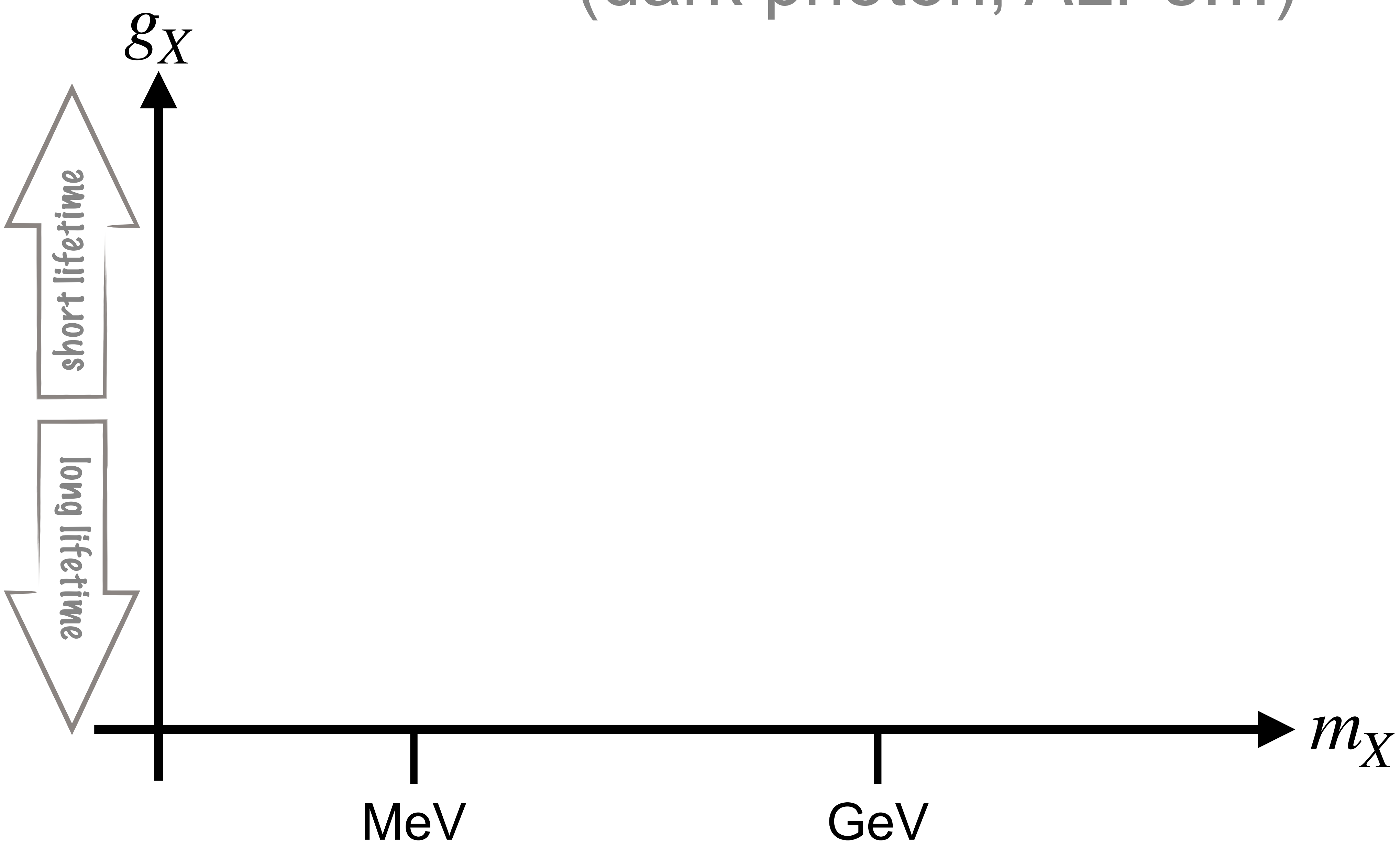
calculate the rate in your model

be careful with long-lived new particles (KOTO vs NA62)

e.g. Kitahara et al 1909.11111, Gori et al 2005.05170

benchmark moldes

(dark photon, ALPs…)



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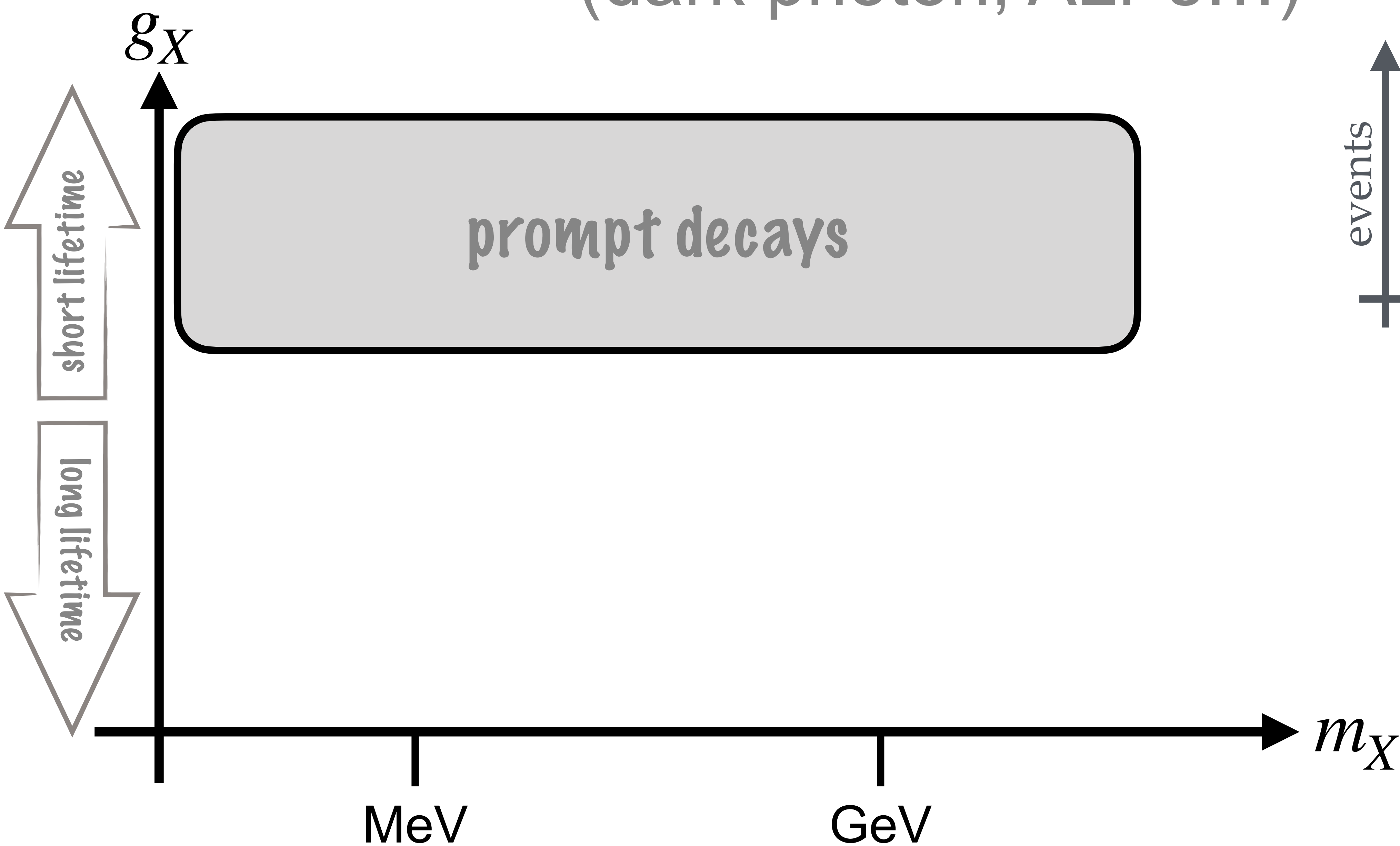
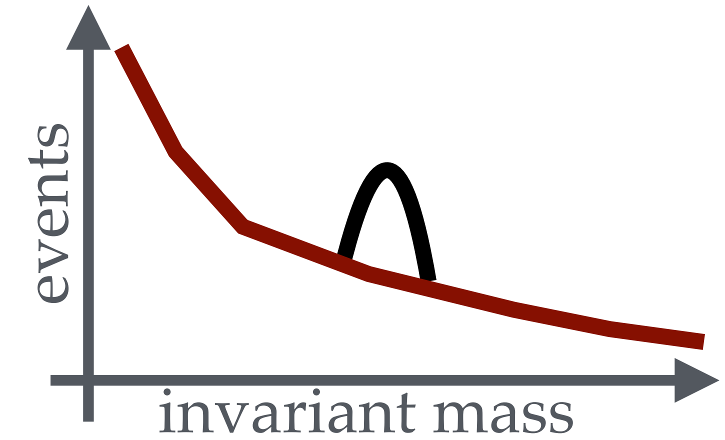
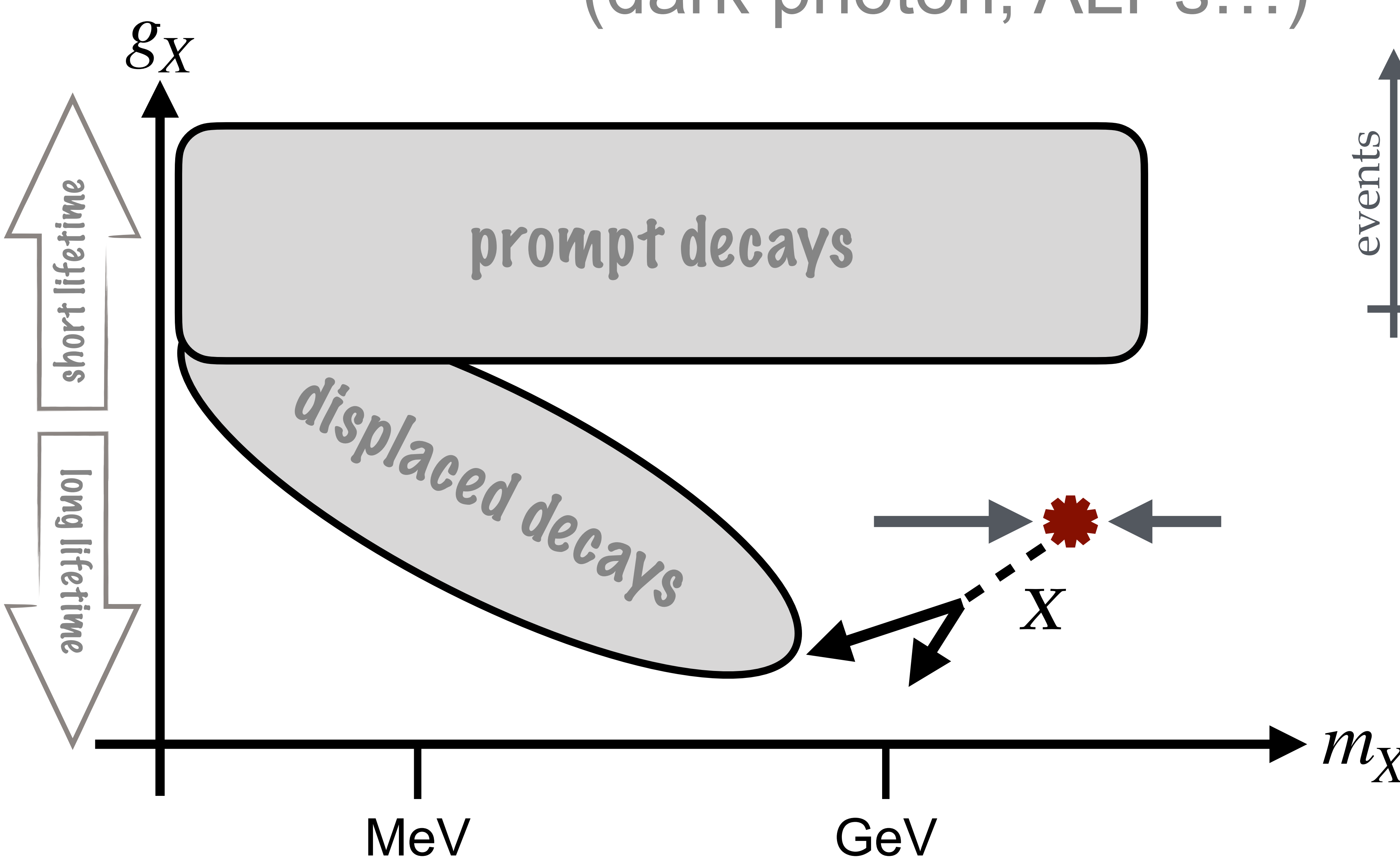


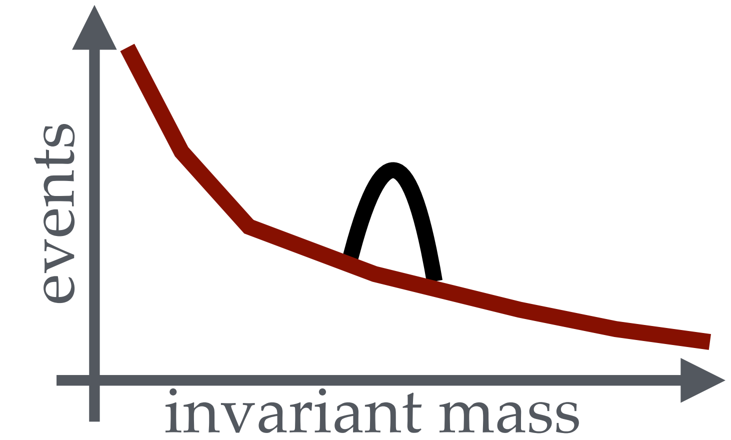


colliders
rare-decay
fixed-target

benchmark moldes

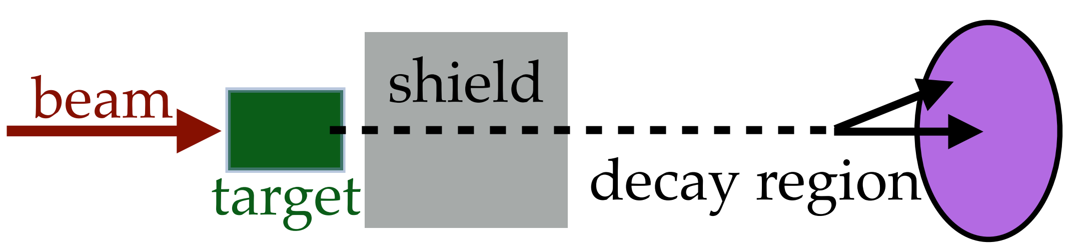
(dark photon, ALPs…)





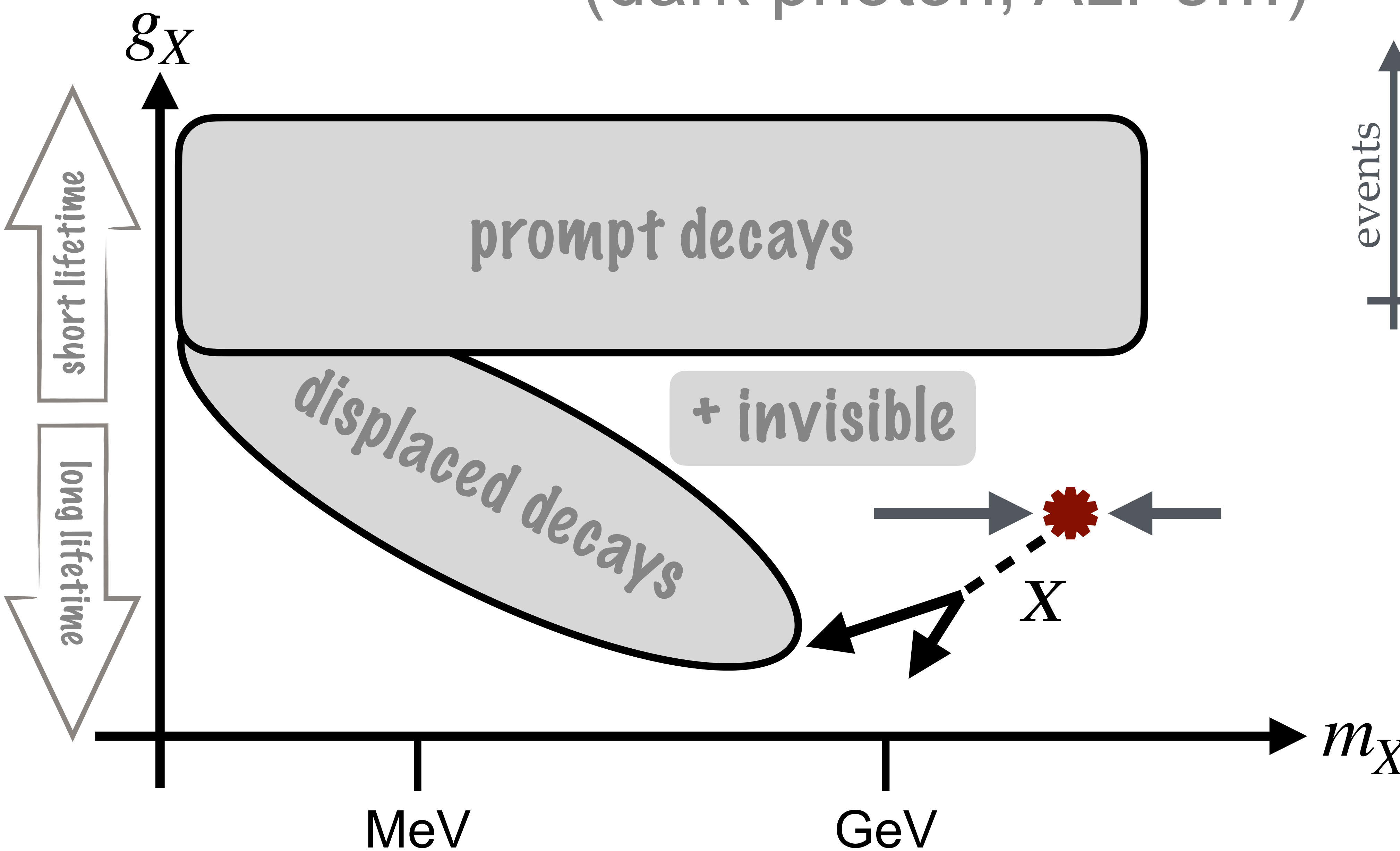
colliders
rare-decay
fixed-target

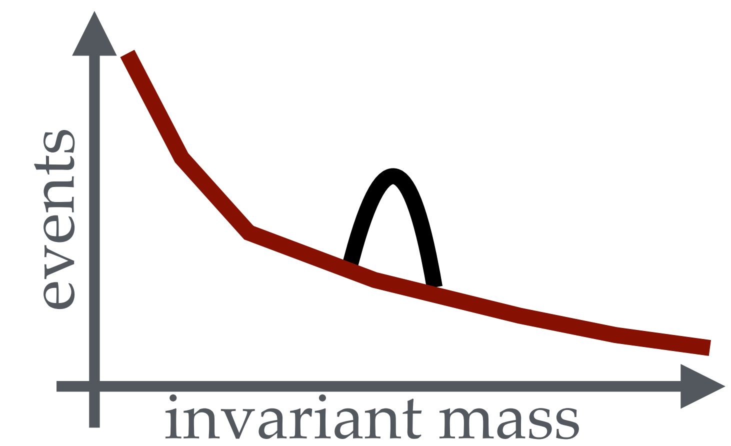
beam-dump



benchmark moldes

(dark photon, ALPs…)





colliders
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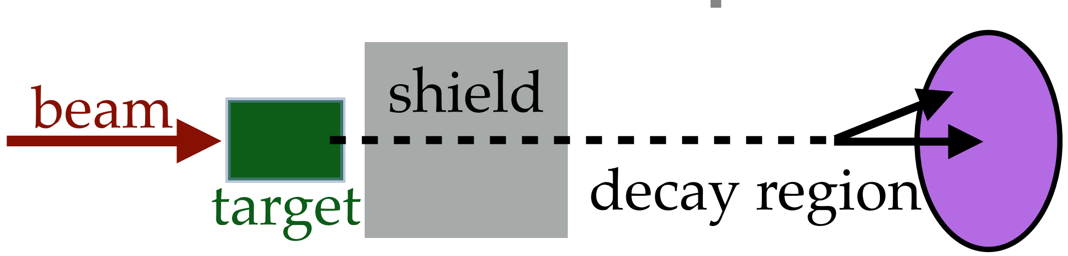
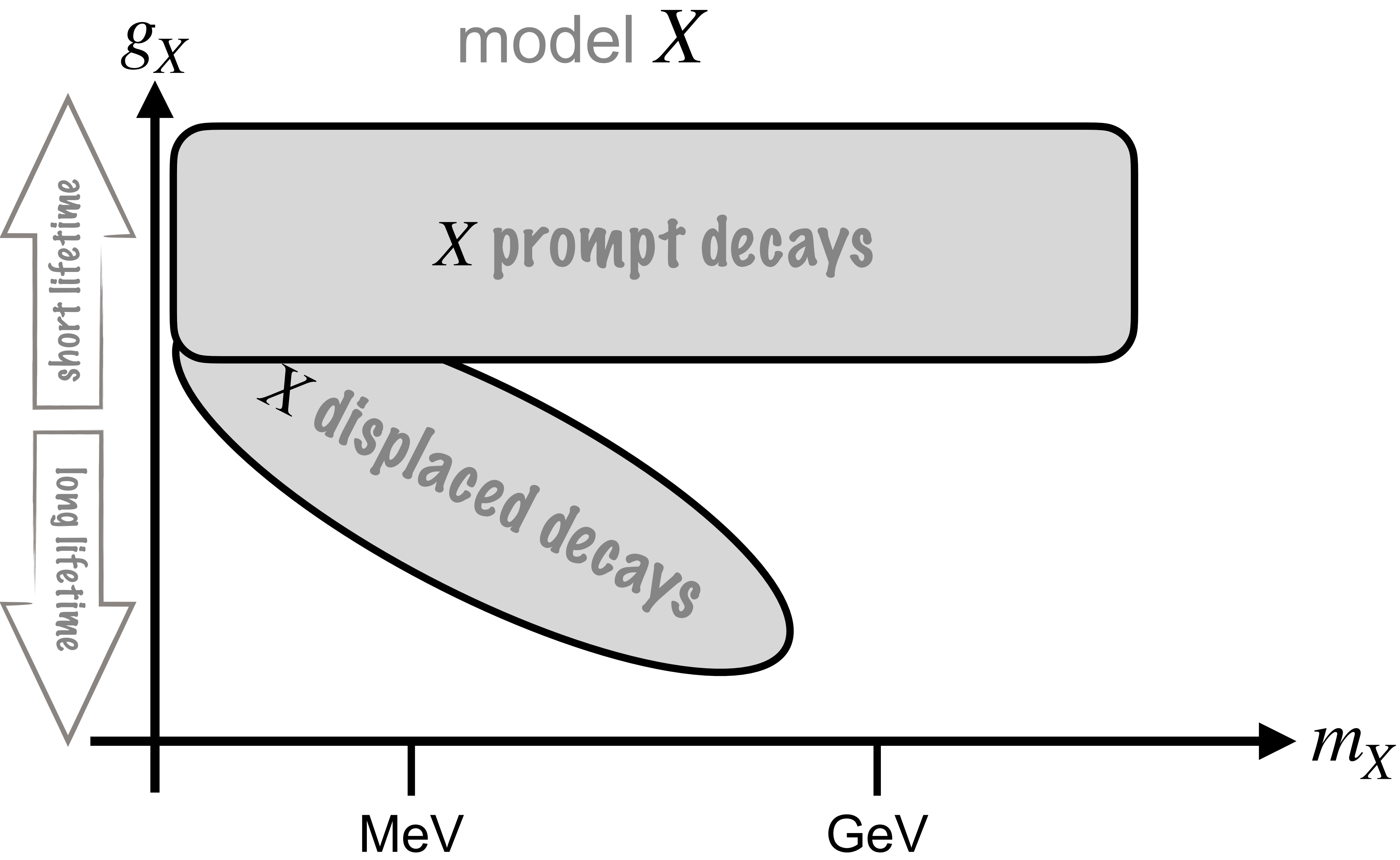
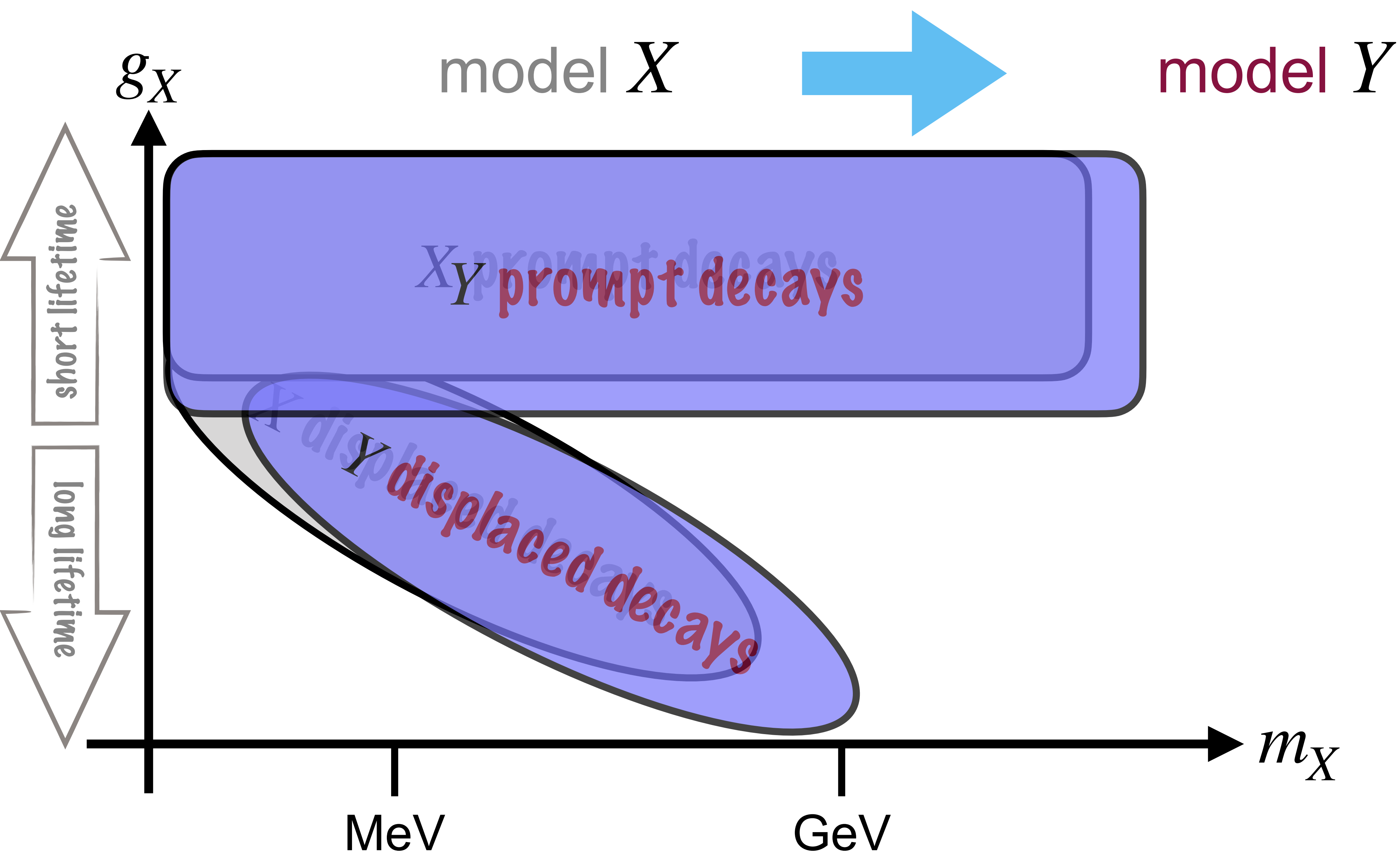


recasting



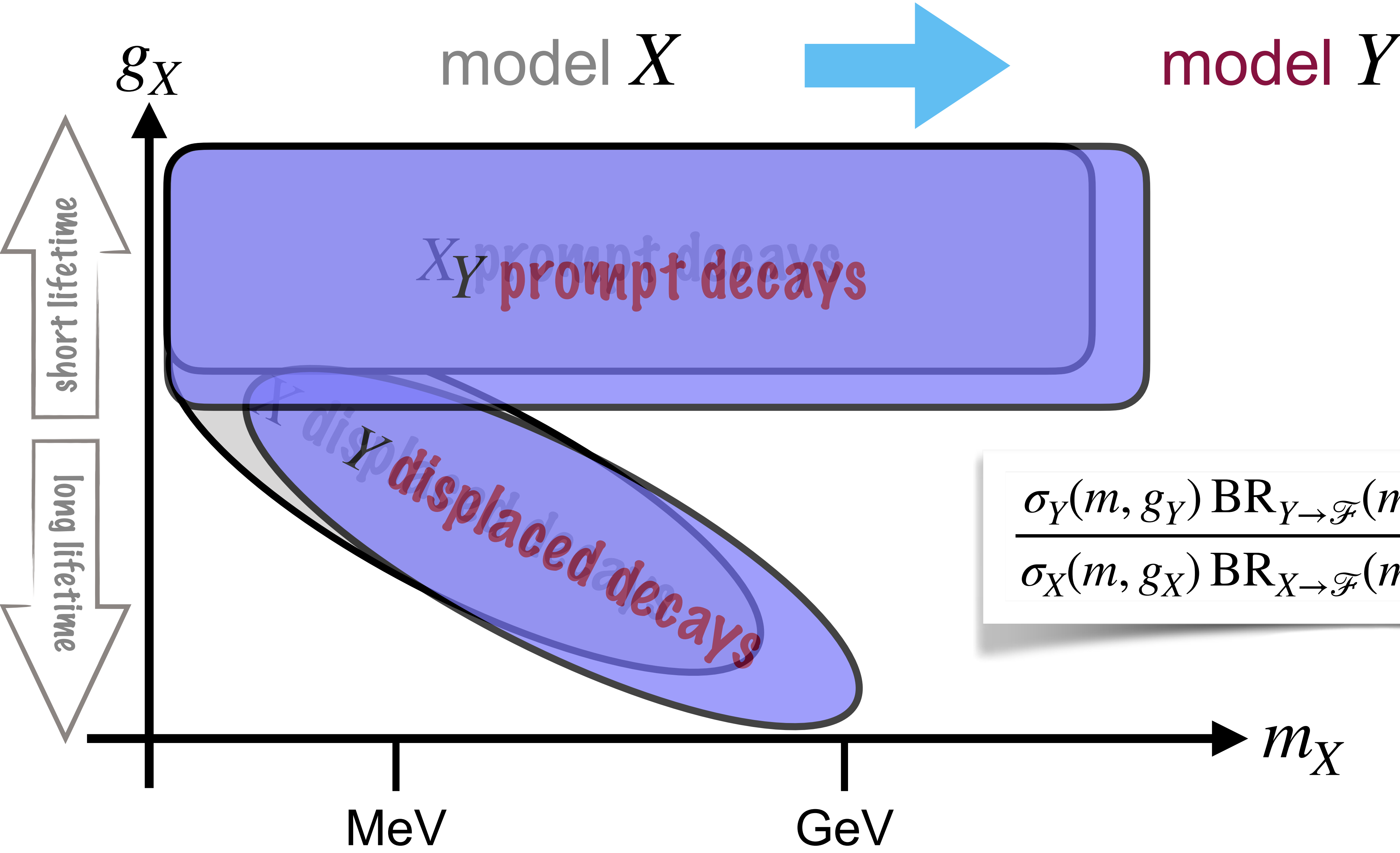
g_X
model X
short lifetime
long lifetime
X prompt decays
X displaced decays
m_X
MeV
GeV

recasting



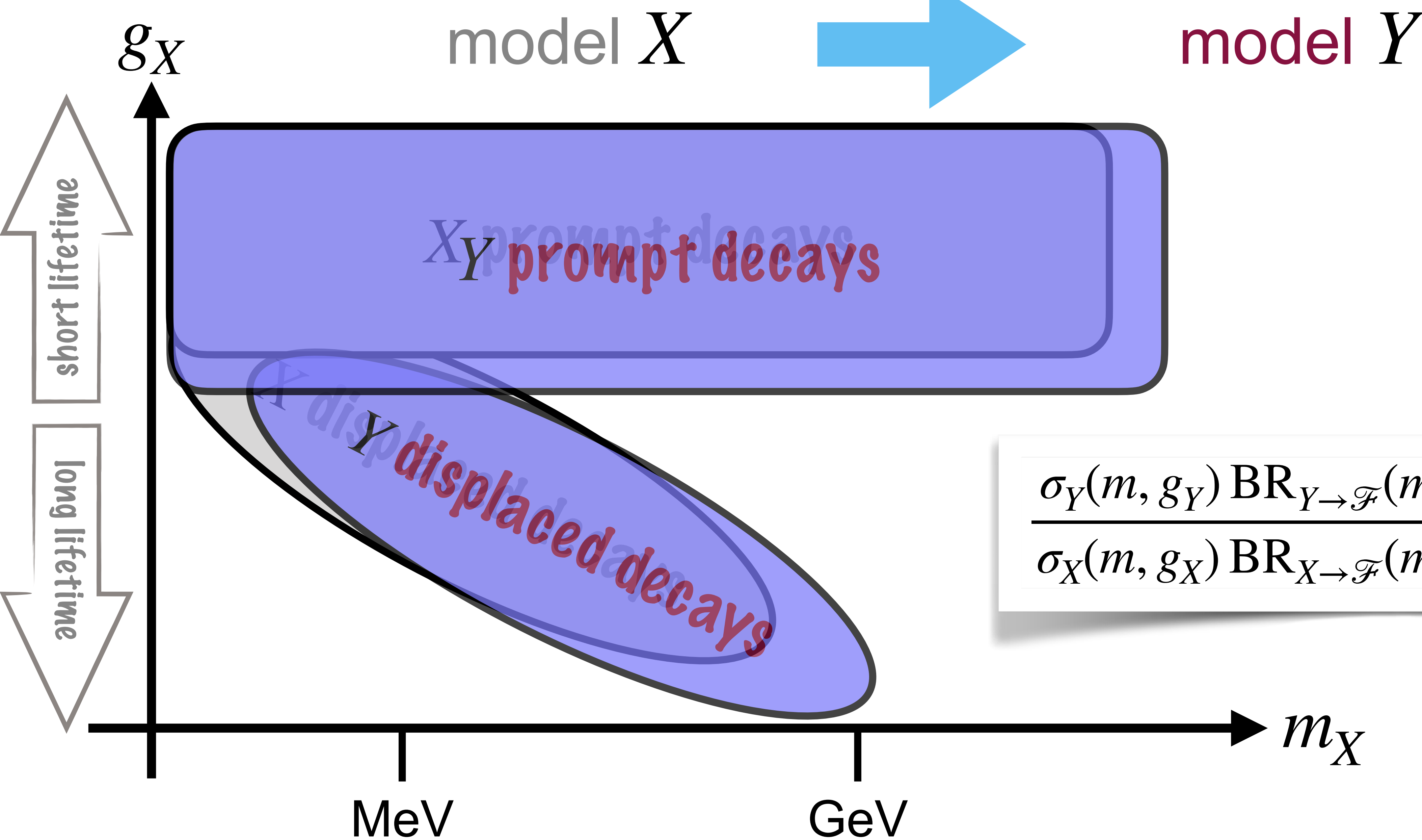
model X
model Y
g_X
short lifetime
long lifetime
X prompt decays
Y prompt decays
X displaced decays
Y displaced decays
m_X
MeV
GeV

recasting



$$\frac{\sigma_Y(m, g_Y)\,\mathrm{BR}_{Y\to\mathcal{F}}(m)\,\varepsilon(\tau_Y(m, g_Y))}{\sigma_X(m, g_X)\,\mathrm{BR}_{X\to\mathcal{F}}(m)\,\varepsilon(\tau_X(m, g_X))} = 1$$

recasting



$$\frac{\sigma_Y(m, g_Y)\,\mathrm{BR}_{Y\to\mathscr{F}}(m)\,\varepsilon(\tau_Y(m, g_Y))}{\sigma_X(m, g_X)\,\mathrm{BR}_{X\to\mathscr{F}}(m)\,\varepsilon(\tau_X(m, g_X))} = 1$$

$$\underbrace{\frac{\mathrm{BR}_{Y\to\mathscr{F}}(m)}{\mathrm{BR}_{X\to\mathscr{F}}(m)}}_{\text{depends on } X \text{ and } Y}, \quad \underbrace{\frac{\sigma_Y(m, g_Y)}{\sigma_X(m, g_X)}, \quad \frac{\varepsilon(\tau_Y(m, g_Y))}{\varepsilon(\tau_X(m, g_X))}}_{\text{depends on } X \text{ and } Y \text{ and the experiment}}$$

lifetime and branching ratios

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perturbative: leptons, photons, quarks/gluons ($m_X \gtrsim 2\,\mathrm{GeV}$)

lifetime and branching ratios

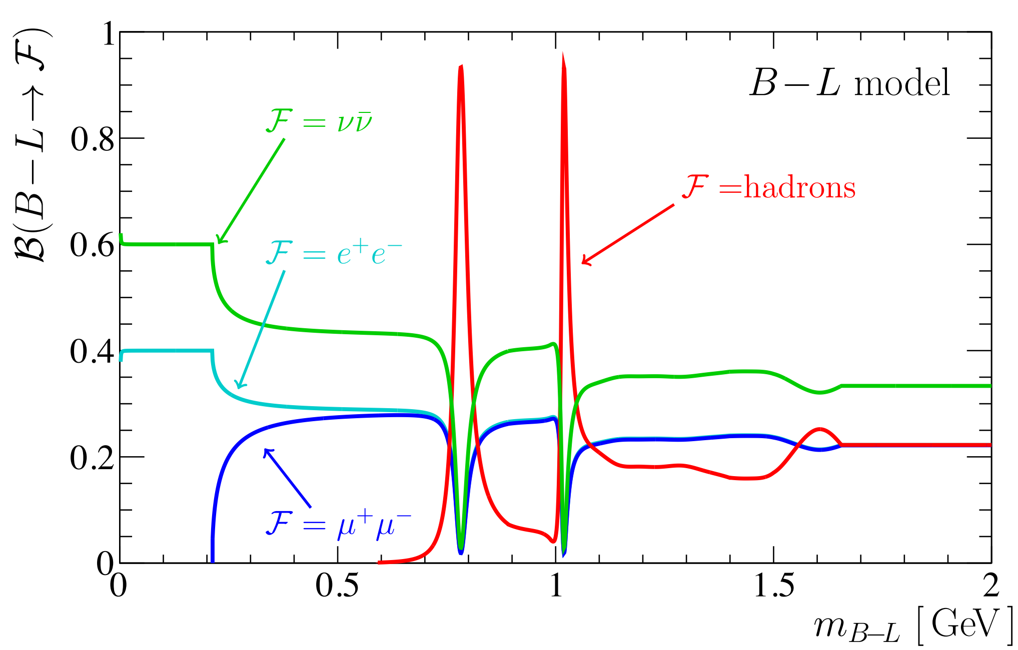
perturbative: leptons, photons, quarks/gluons ($m_X \gtrsim 2\,\mathrm{GeV}$)

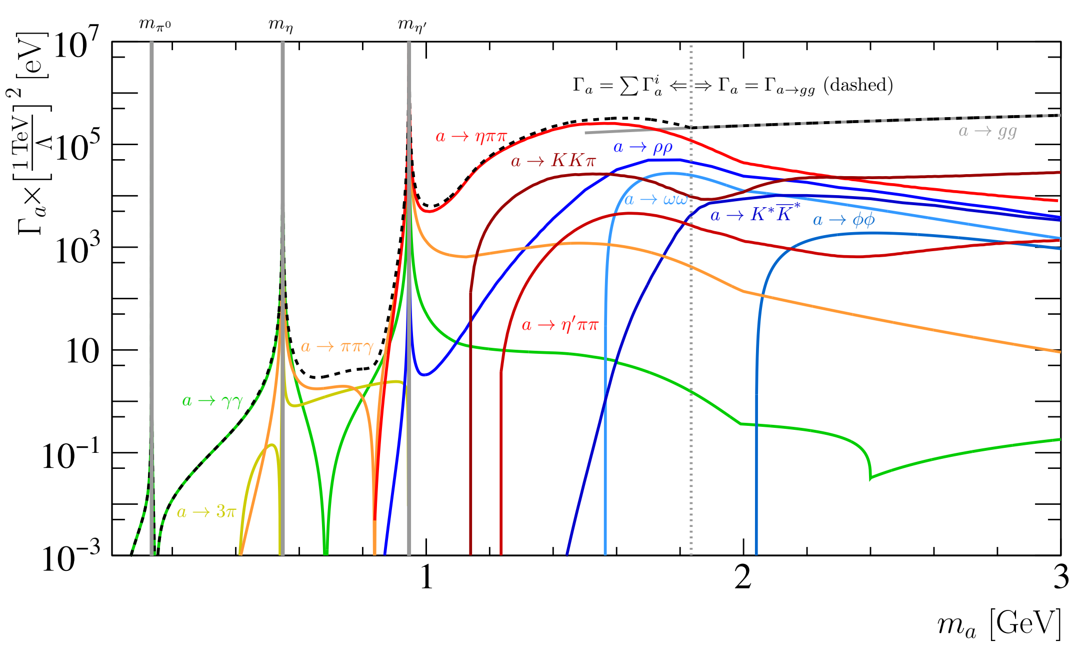
non perturbative: quarks/gluons ($m_X \lesssim 2\,\mathrm{GeV}$)

vectors: data-driven (use e^+e^- data) Ilten, YS, Williams, Xue - 1801.04847

ALPs (pseudo scalar): chiral perturbation + data-driven Aloni, YS, Williams - 1811.03474

scalars: theory models (dispersion relations) e.g. Boiarska et al 1904.10447





production

ratio of production

assuming X and Y have the same spin

x_i, y_i : the fermion charges

ratio of production

assuming X and Y have the same spin

e-beam $,e^+e^-$ collider

$$\frac{\sigma_{eZ\to eZY}}{\sigma_{eZ\to eZX}} = \frac{\sigma_{e^+e^-\to Y\gamma}}{\sigma_{e^+e^-\to X\gamma}} = \frac{(g_Y y_e)^2}{(g_X x_e)^2}$$

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p-beam bream

$$\frac{\sigma_{pZ\to pZY}}{\sigma_{pZ\to pZX}} = \frac{g_Y^2(2y_u + y_d)^2}{g_X^2(2x_u + x_d)^2}$$

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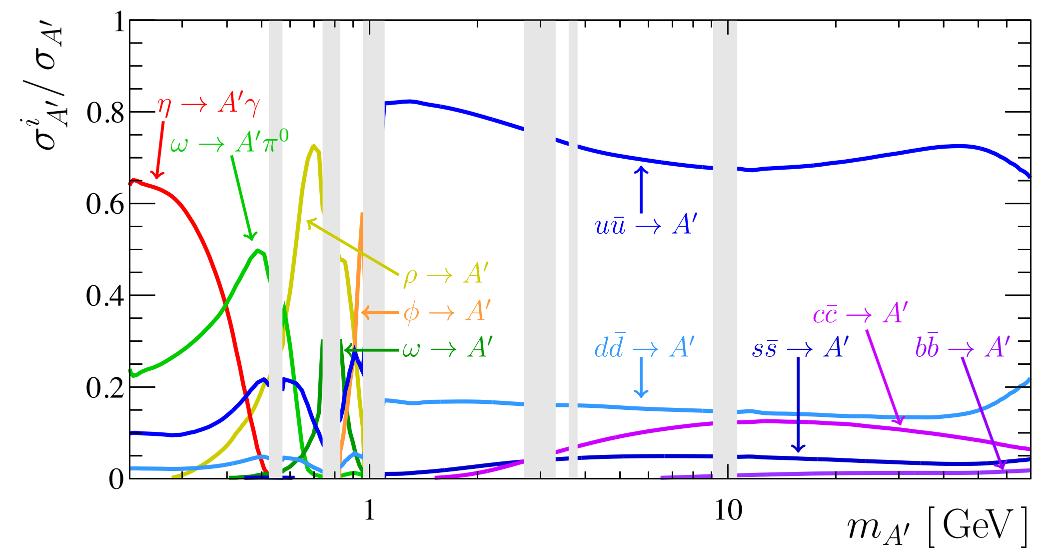
hadron-hadron inelastic
(the most challenging)



for dark photon: $\frac{\sigma_{\mathrm{DY}\to Y}}{\sigma_{\mathrm{DY}\to A'}} = \sum_{q_i} \left[\frac{\sigma_{q_i\bar{q}_i\to\gamma^*}}{\sigma_{\mathrm{DY}\to\gamma^*}}\right] \left[\frac{\sigma_{q_i\bar{q}_i\to Y}}{\sigma_{q_i\bar{q}_i\to A'}}\right]$

x_i, y_i : the fermion charges

efficiencies

ratios of efficiencies

$$\frac{\varepsilon(\tau_Y(m, g_Y))}{\varepsilon(\tau_X(m, g_X))} \approx \frac{e^{-\tilde{t}_0/\tau_Y} - e^{-\tilde{t}_1/\tau_Y}}{e^{-\tilde{t}_0/\tau_X} - e^{-\tilde{t}_1/\tau_X}}$$

$\tilde{t}_{0,1}$: effective proper-time fiducial decay region

$$g^2_{\rm max}\epsilon[\tau_X(m, g_{\rm max})] = g^2_{\rm min}\epsilon[\tau_X(m, g_{\rm min})]$$

$$\tilde{t}_1 = \tilde{t}_0(1 + L_{\rm dec}/L_{\rm sh})$$

ratios of efficiencies

$$\frac{\varepsilon(\tau_Y(m, g_Y))}{\varepsilon(\tau_X(m, g_X))} \approx \frac{e^{-\tilde{t}_0/\tau_Y} - e^{-\tilde{t}_1/\tau_Y}}{e^{-\tilde{t}_0/\tau_X} - e^{-\tilde{t}_1/\tau_X}}$$

$\tilde{t}_{0,1}$: effective proper-time fiducial decay region

prompt decays

$$1 - e^{\tilde{t}/\tau_Y}$$

$\tilde{t}$: largest proper decay time for Y being considered as prompt decay

$$g^2_{\max}\epsilon[\tau_X(m, g_{\max})] = g^2_{\min}\epsilon[\tau_X(m, g_{\min})]$$

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ratios of efficiencies

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$$1 - e^{\tilde{t}/\tau_Y}$$

invisible decays

$$\sim 1$$

(up to lifetime)

$\tilde{t}$: largest proper decay time for Y being considered as prompt decay

$$g_{\max}^2 \epsilon[\tau_X(m, g_{\max})] = g_{\min}^2 \epsilon[\tau_X(m, g_{\min})]$$

$$\tilde{t}_1 = \tilde{t}_0(1 + L_{\rm dec}/L_{\rm sh})$$

ratios of efficiencies

$$\frac{\varepsilon(\tau_Y(m, g_Y))}{\varepsilon(\tau_X(m, g_X))} \approx \frac{e^{-\tilde{t}_0/\tau_Y} - e^{-\tilde{t}_1/\tau_Y}}{e^{-\tilde{t}_0/\tau_X} - e^{-\tilde{t}_1/\tau_X}}$$

$\tilde{t}_{0,1}$: effective proper-time fiducial decay region

prompt decays

$$1 - e^{\tilde{t}/\tau_Y}$$

invisible decays

$$\sim 1$$

(up to lifetime)

long-lived (displaced)

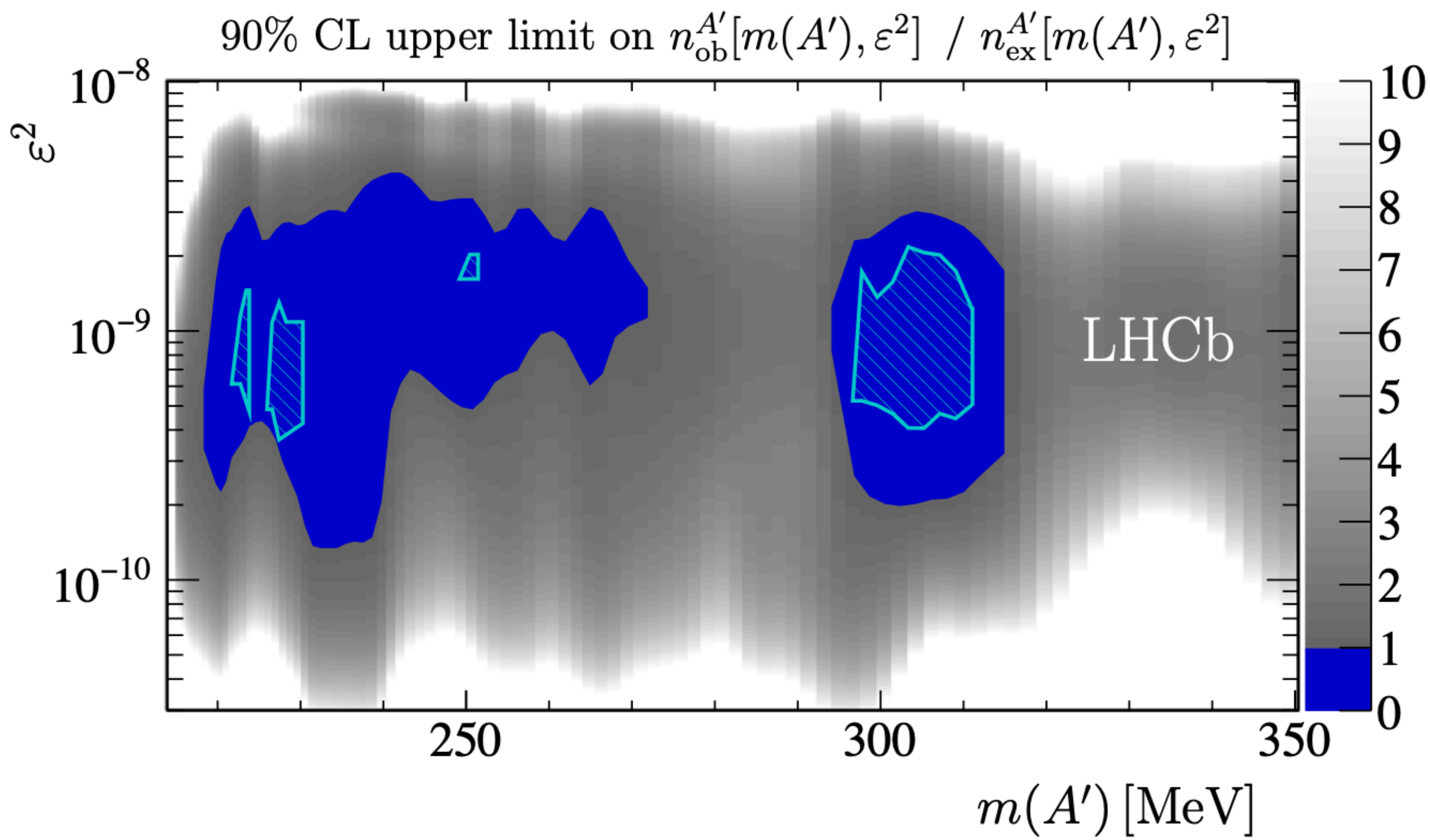
$$\frac{e^{-\tilde{t}_0/\tau_Y} - e^{-\tilde{t}_1/\tau_Y}}{e^{-\tilde{t}_0/\tau_X} - e^{-\tilde{t}_1/\tau_X}}$$

$\tilde{t}$: largest proper decay time for Y being considered as prompt decay

$$g_{\max}^2 \epsilon[\tau_X(m, g_{\max})] = g_{\min}^2 \epsilon[\tau_X(m, g_{\min})]$$

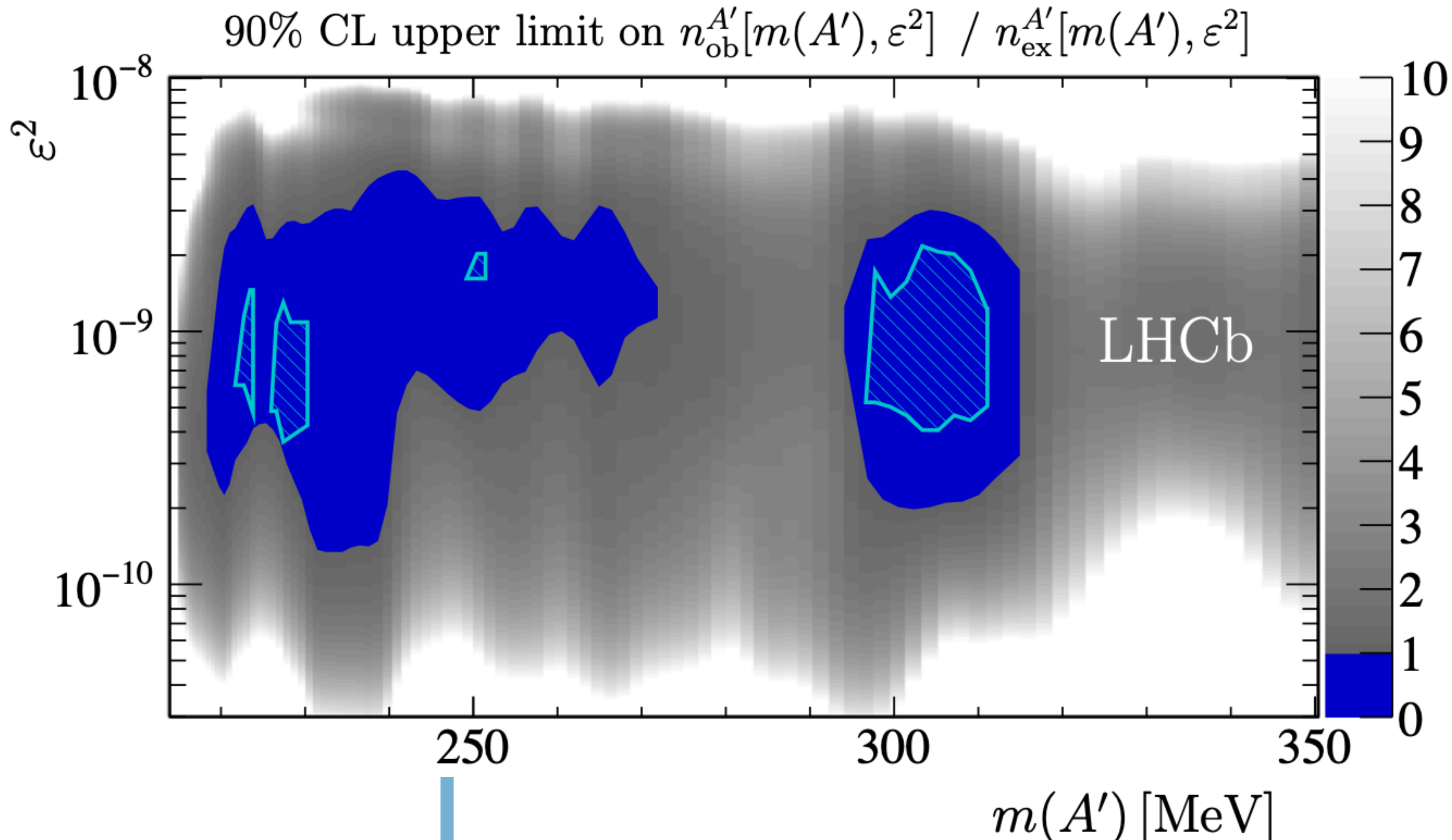
$$\tilde{t}_1 = \tilde{t}_0(1 + L_{\rm dec}/L_{\rm sh})$$

use of expected limits



LHCb - 1910.06926

use of expected limits



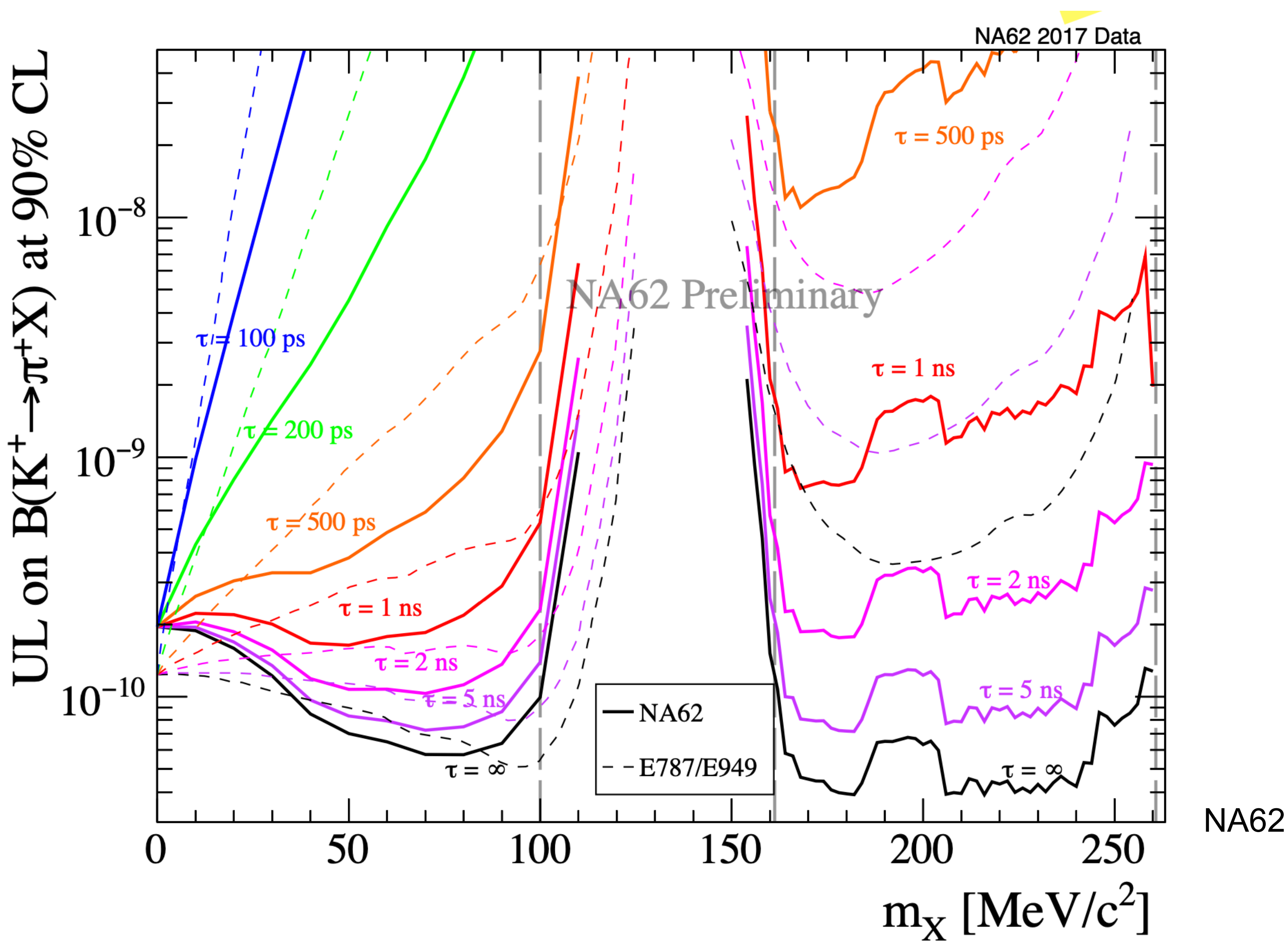
LHCb - 1910.06926

to recast:

$X = A'$

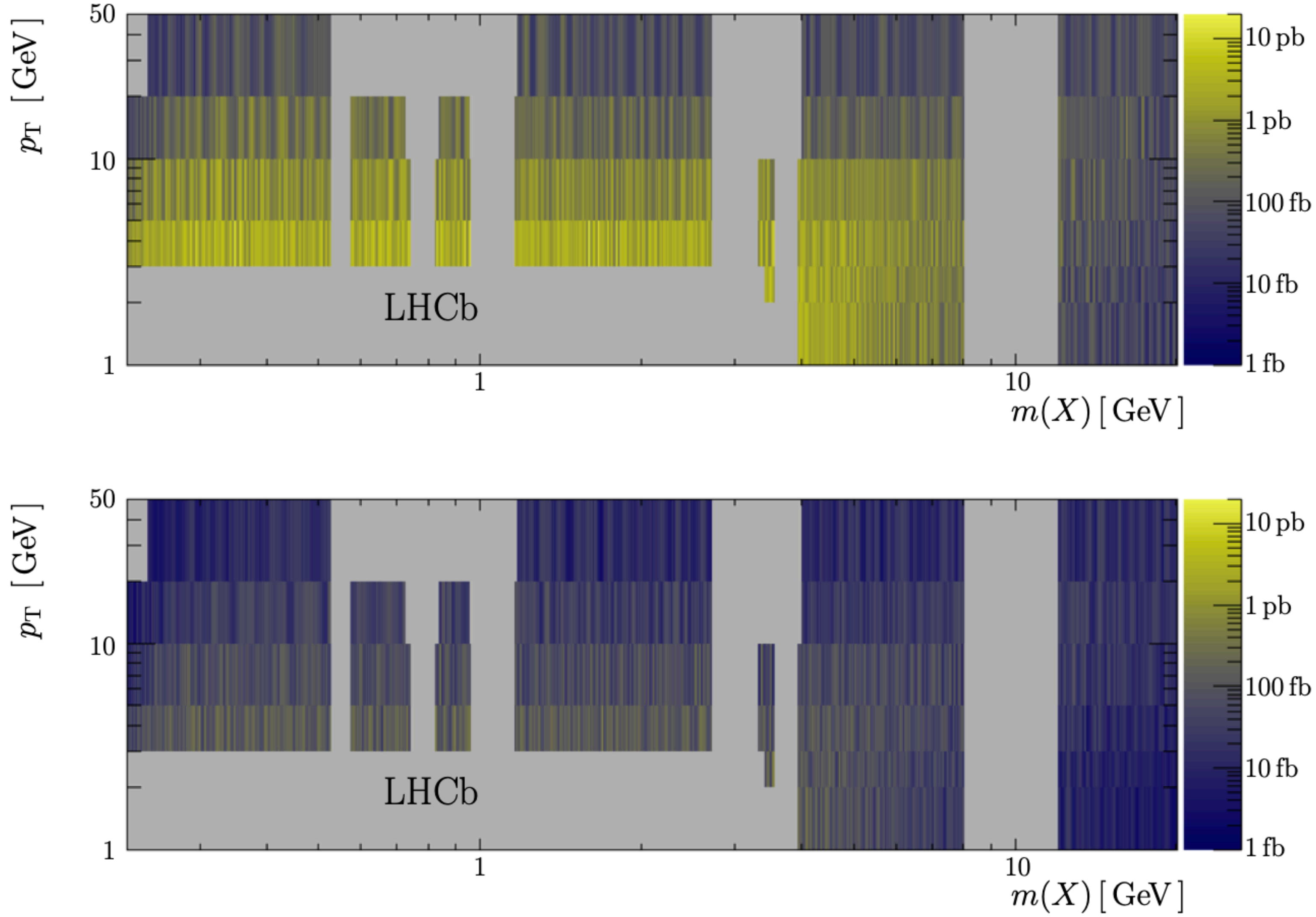
$$\left[\frac{n_{\rm ob}^{A'}}{n_{\rm ex}^{A'}}\frac{n_{\rm ex}^{A'}}{n_{\rm ex}^{Y}}\right]_{\tau_Y=\tau_{A'}} = \left[\frac{n_{\rm ob}^{A'}}{n_{\rm ex}^{A'}}\frac{\sigma_{A'}{\rm BR}(A'\to\mathscr{F})}{\sigma_Y{\rm BR}(Y\to\mathscr{F})}\right]_{\tau_Y=\tau_{A'}} < 1$$

mass vs lifetime



present the bound in terms of physical observables as m vs τ

mass vs cross section



LHCb 2007.03923

present the bound in terms of physical observables as m vs p_T vs σ

examples

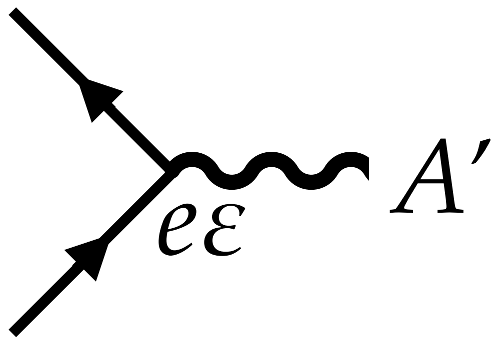
based on DarkCast

DarkCast

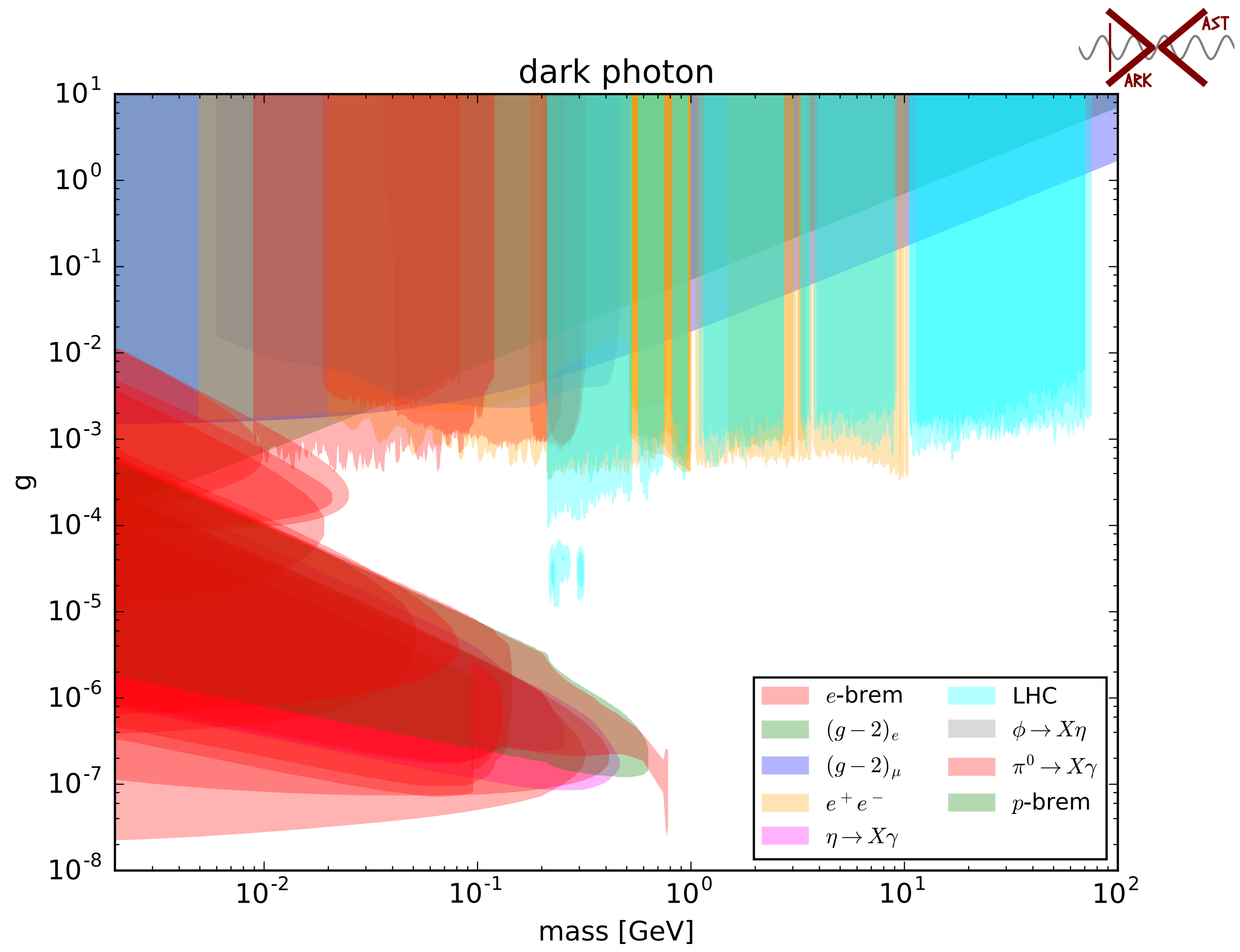
* public code for simple and fast recasting of existing dark photon bounds in terms of generic vector models.
* new in DarkCast: recast projections, mass dependent couplings, lepton models.

https://gitlab.com/philten/darkcast

dark photon

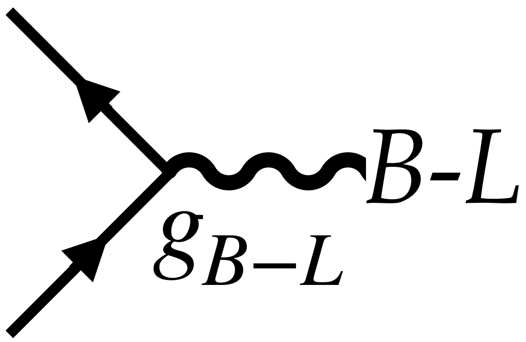


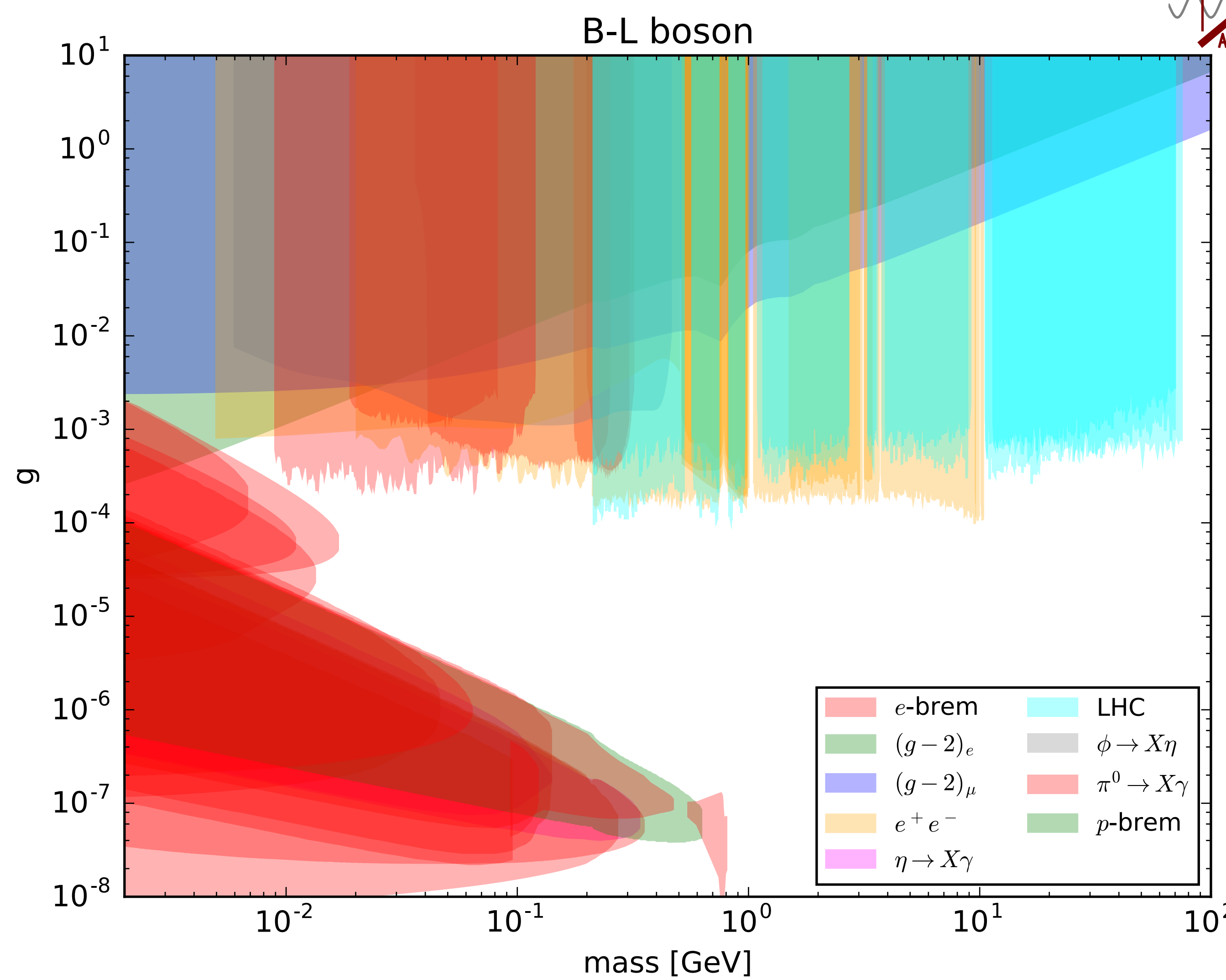
$e\varepsilon$
A'



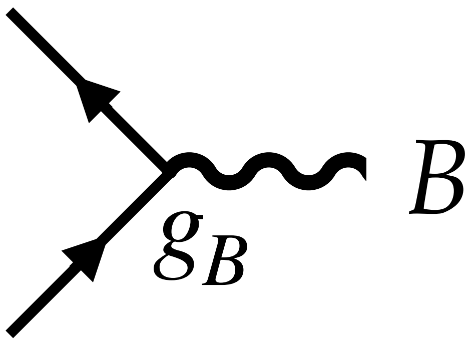
dark photon
g
mass [GeV]
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
e-brem
$(g-2)_e$
$(g-2)_\mu$
e^+e^-
$\eta \to X\gamma$
LHC
$\phi \to X\eta$
$\pi^0 \to X\gamma$
p-brem

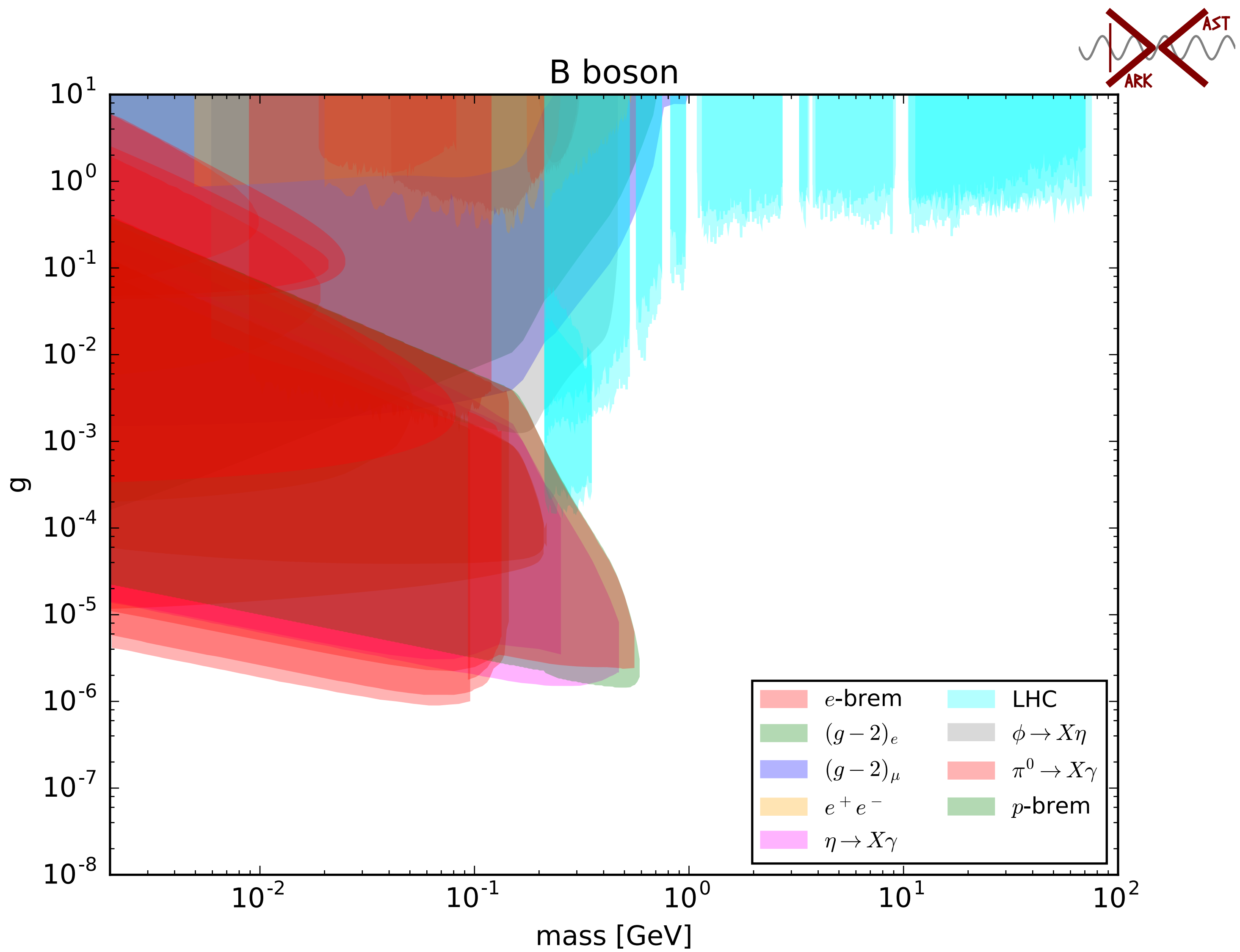
B-L gauge boson



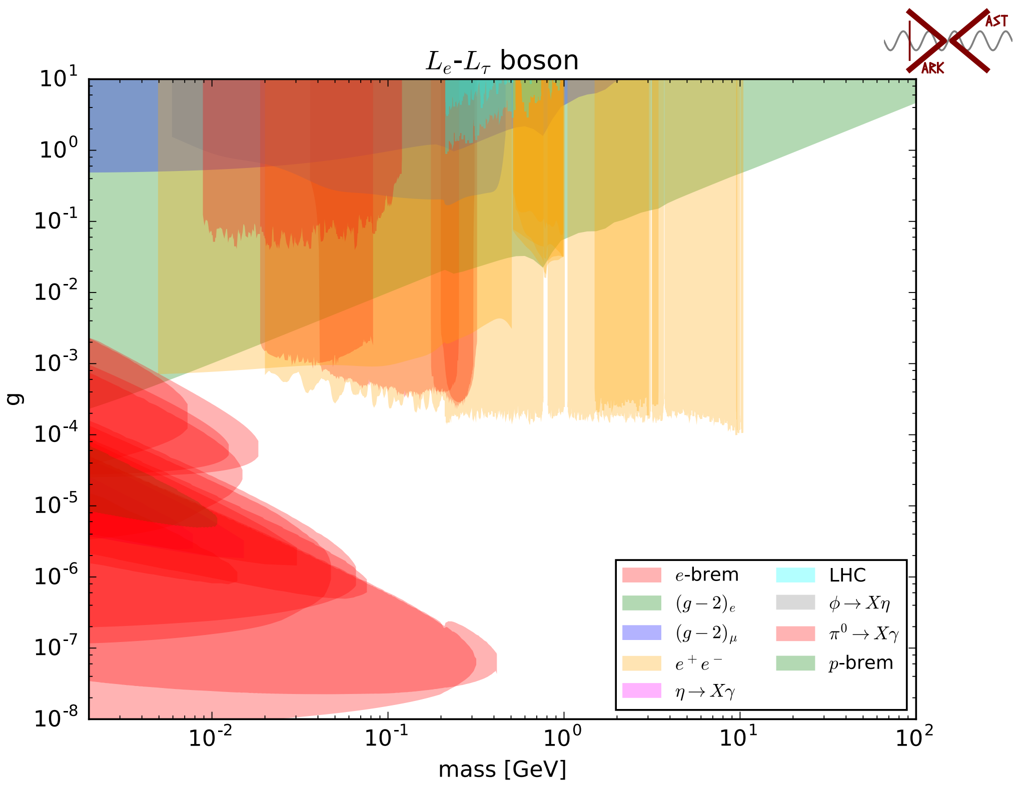


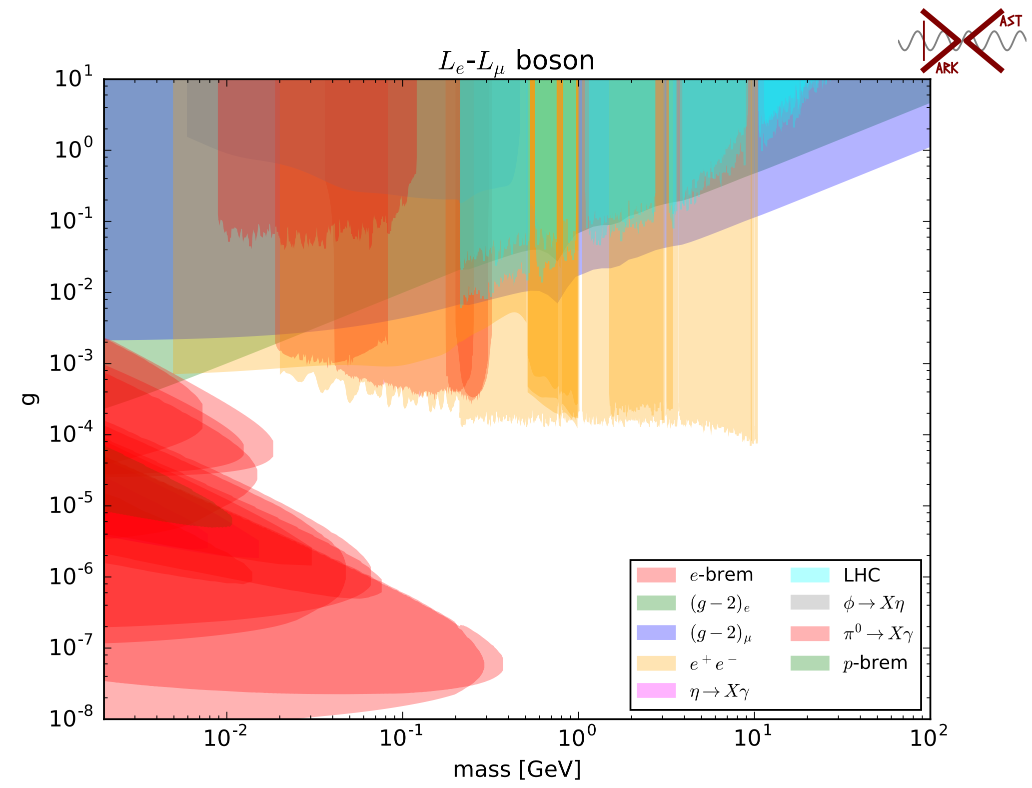
B gauge boson

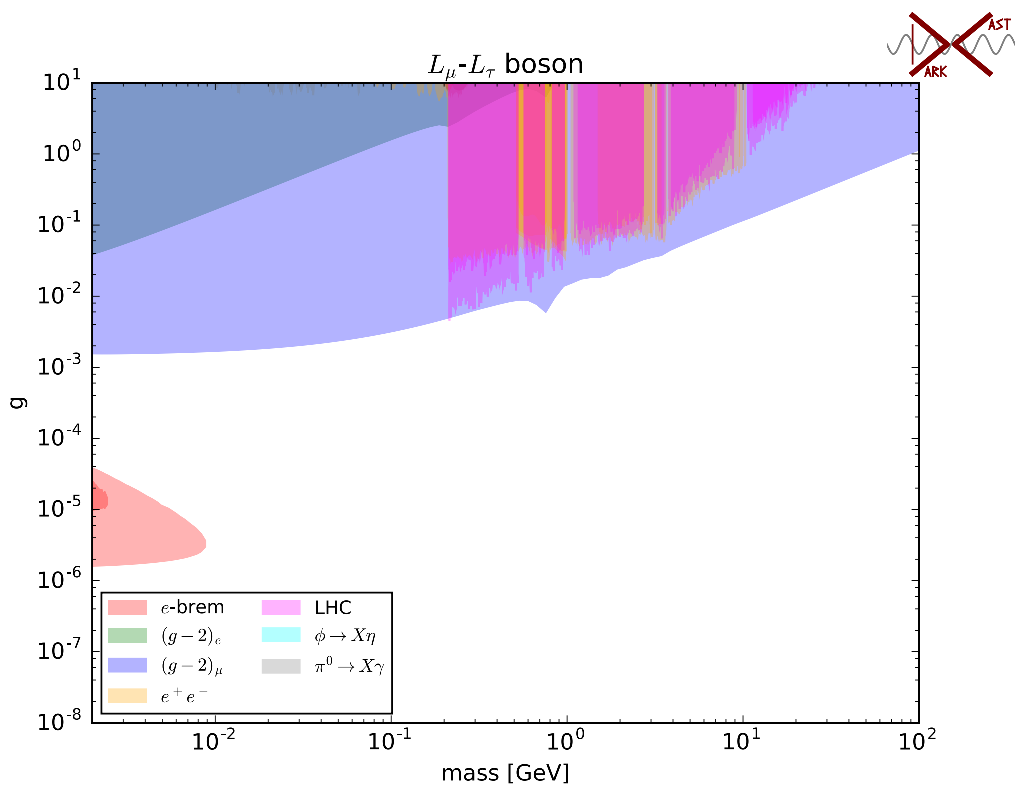




L-L gauge boson







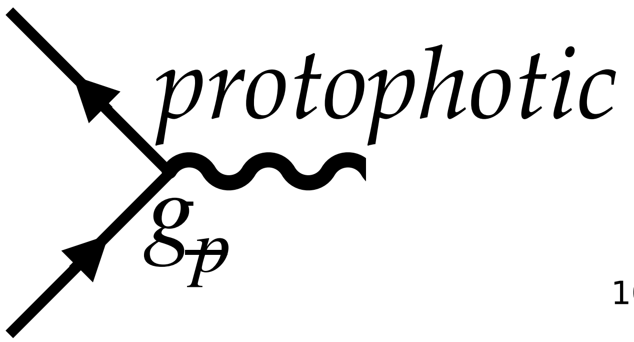
summary

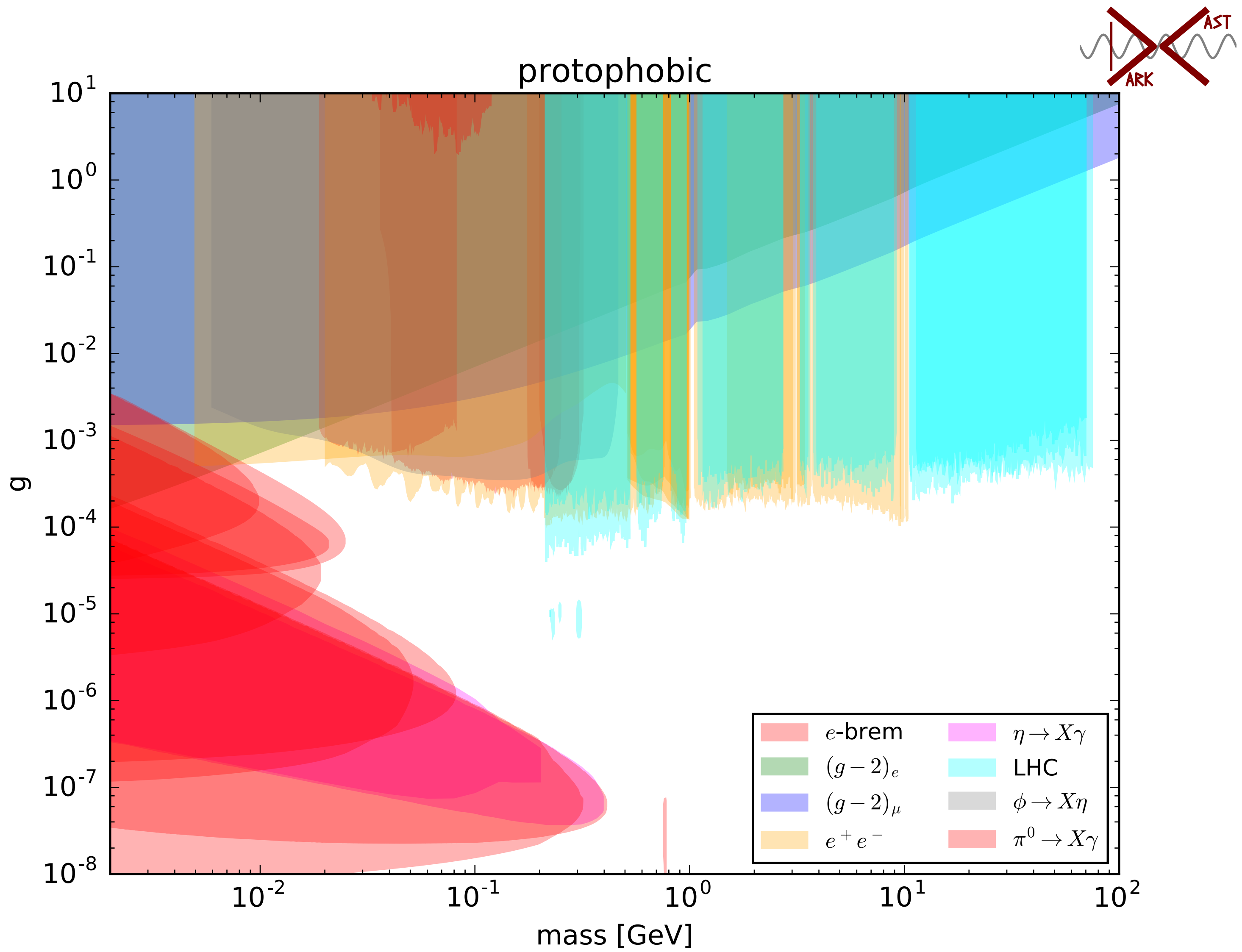
* presenting efficiencies and expected number of signal events for benchmark model (e.g. dark photon) is very useful for reinterpretation of the results

* presenting bounds on lifetime and/or cross section vs mass is very useful

backups

protophobic gauge boson





ratio of production

$$V \to XP \ : \qquad \frac{\Gamma_{V\to XP}}{\Gamma_{V\to A'P}} = \frac{g_X^2}{(\varepsilon e)^2} \frac{\left| \sum_{V'} \mathrm{Tr}[T_V T_P T_{V'}]\mathrm{Tr}[T_{V'} Q_X] \mathrm{BW}_{V'}(m_X) \right|^2}{\left| \sum_{V'} \mathrm{Tr}[T_V T_P T_{V'}]\mathrm{Tr}[T_{V'} Q] \mathrm{BW}_{V'}(m_X) \right|^2}$$

ratio of production

$V \to XP\ :$

$$\frac{\Gamma_{V\to XP}}{\Gamma_{V\to A'P}} = \frac{g_X^2}{(\varepsilon e)^2}\frac{\left|\sum_{V'}\mathrm{Tr}[T_V T_P T_{V'}]\mathrm{Tr}[T_{V'}Q_X]\mathrm{BW}_{V'}(m_X)\right|^2}{\left|\sum_{V'}\mathrm{Tr}[T_V T_P T_{V'}]\mathrm{Tr}[T_{V'}Q]\mathrm{BW}_{V'}(m_X)\right|^2}$$

$P \to X\gamma\ :$

$$\frac{\Gamma_{P\to X\gamma}}{\Gamma_{P\to A'\gamma}} = \left(\frac{g_X}{\varepsilon e}\right)^2\frac{\left|\sum_{V}\mathrm{Tr}[T_P Q T_V]\mathrm{Tr}[T_V Q_X]\mathrm{BW}_V(m)\right|^2}{\left|\sum_{V}\mathrm{Tr}[T_P Q T_V]\mathrm{Tr}[T_V Q]\mathrm{BW}_V(m)\right|^2}$$

ratio of production

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$$\frac{\Gamma_{V\to XP}}{\Gamma_{V\to A'P}} = \frac{g_X^2}{(\varepsilon e)^2} \frac{\left| \sum_{V'} \mathrm{Tr}[T_V T_P T_{V'}]\mathrm{Tr}[T_{V'} Q_X] \mathrm{BW}_{V'}(m_X) \right|^2}{\left| \sum_{V'} \mathrm{Tr}[T_V T_P T_{V'}]\mathrm{Tr}[T_{V'} Q] \mathrm{BW}_{V'}(m_X) \right|^2}$$

$P \to X\gamma$:

$$\frac{\Gamma_{P\to X\gamma}}{\Gamma_{P\to A'\gamma}} = \left(\frac{g_X}{\varepsilon e}\right)^2 \frac{\left| \sum_{V} \mathrm{Tr}[T_P Q T_V]\mathrm{Tr}[T_V Q_X] \mathrm{BW}_V(m) \right|^2}{\left| \sum_{V} \mathrm{Tr}[T_P Q T_V]\mathrm{Tr}[T_V Q] \mathrm{BW}_V(m) \right|^2}$$

$X - V$ mixing :

$$\frac{\sigma_{V\to X}}{\sigma_{V\to A'}} = \frac{g_X^2}{(\varepsilon e)^2} \times \begin{cases} (x_u - x_d)^2 & \text{for } V = \rho, \\ 9(x_u + x_d)^2 & \text{for } V = \omega, \\ 9x_s^2 & \text{for } V = \phi, \end{cases}$$