



DARKCAST

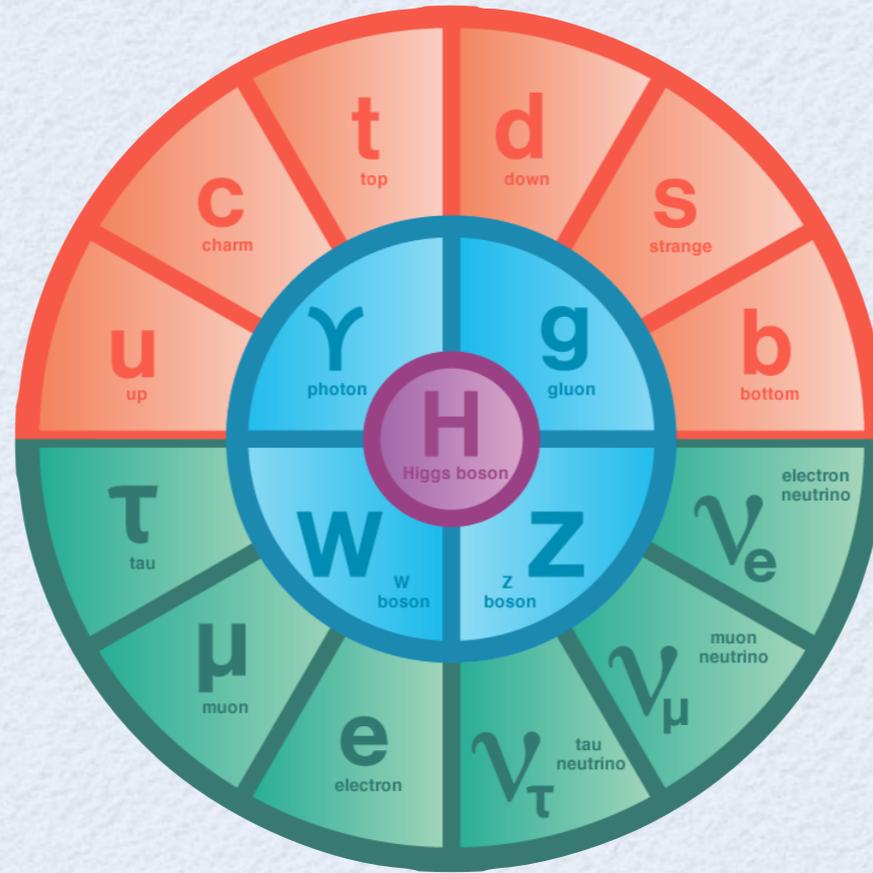
Yotam Soreq

based on:

P. Ilten, YS, M. Williams, W. Xue - 1801.04847

gitlab.com/philtten/darkcast

(Re)interpreting the results of new physics searches at the LHC
Imperial College, London, 3rd April, 2019



if the Standard Model is so successful,
why do we look for new physics?

PORTALS TO DARK SECTORS



PORTALS TO DARK SECTORS



dark photons like

$$X_{\mu}$$

spin-1 (vector)

couples to currents

PORTALS TO DARK SECTORS



dark photons like

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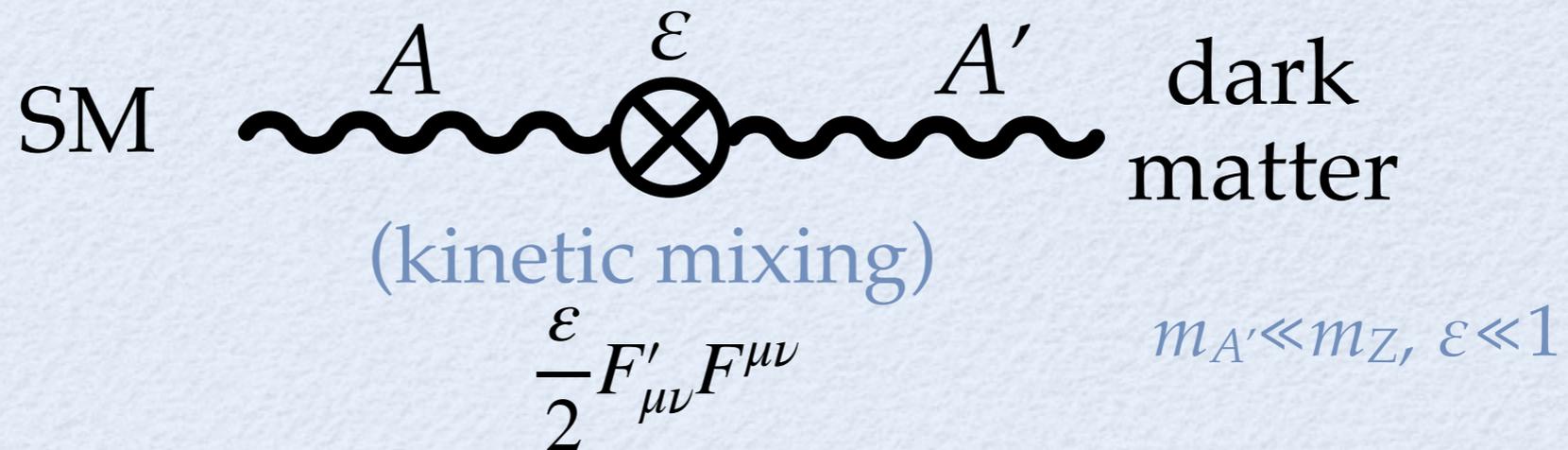
spin-1 (vector)

couples to currents

other possibilities: ALP, Higgs, fermion

DARK PHOTON-KINETIC MIXING

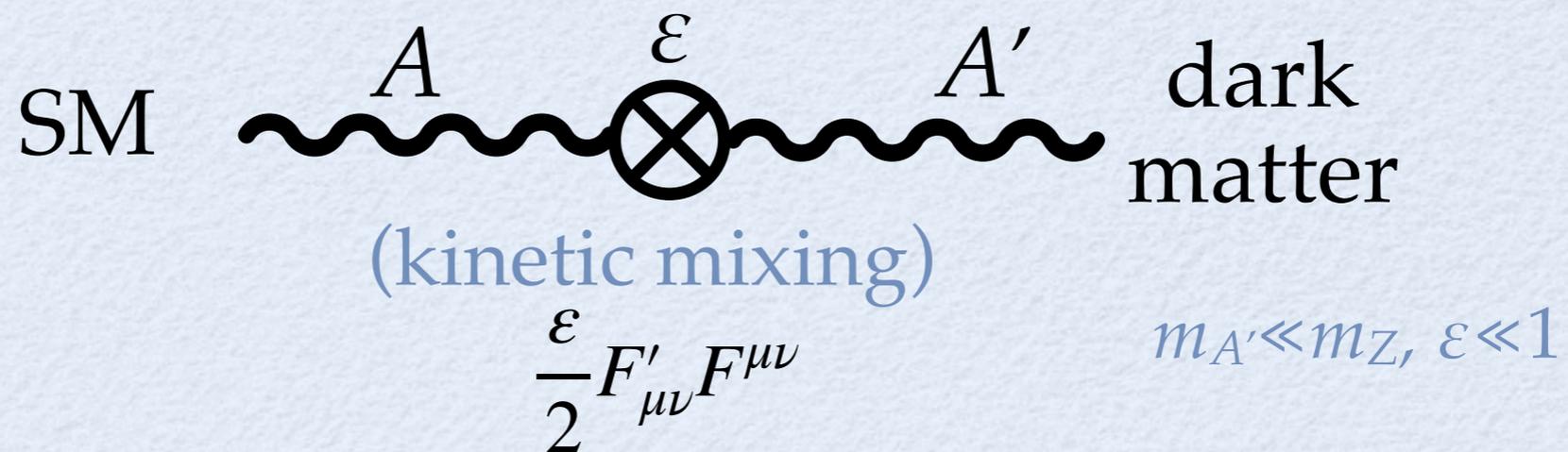
portal between the standard model and dark matter



Holdom, 86'

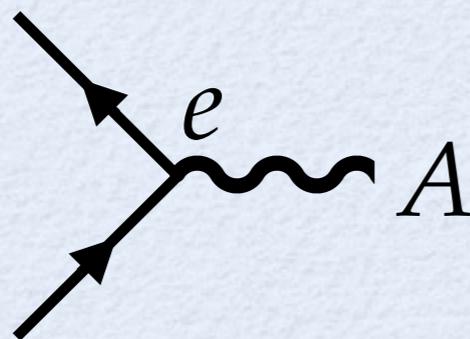
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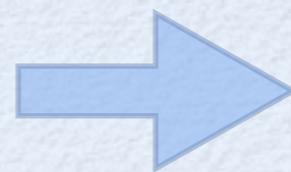


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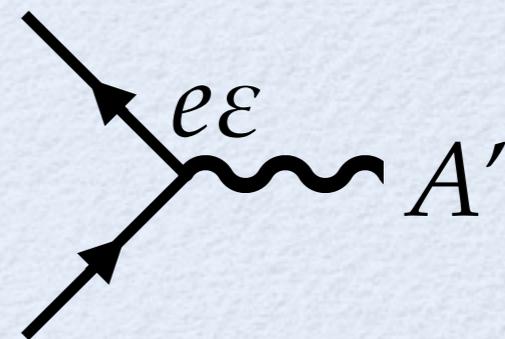
electromagnetic process



$$m_A = 0$$



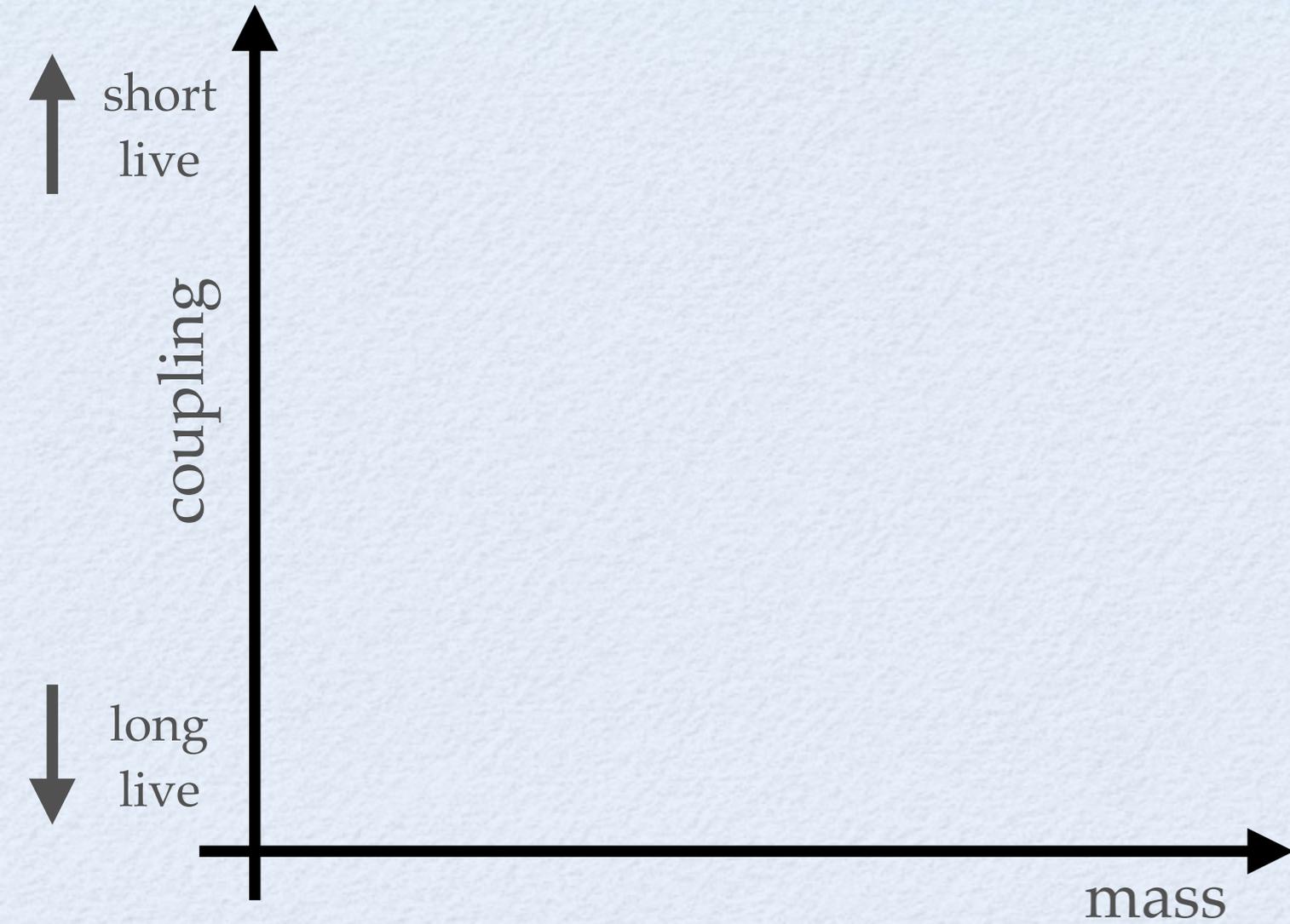
dark photon process



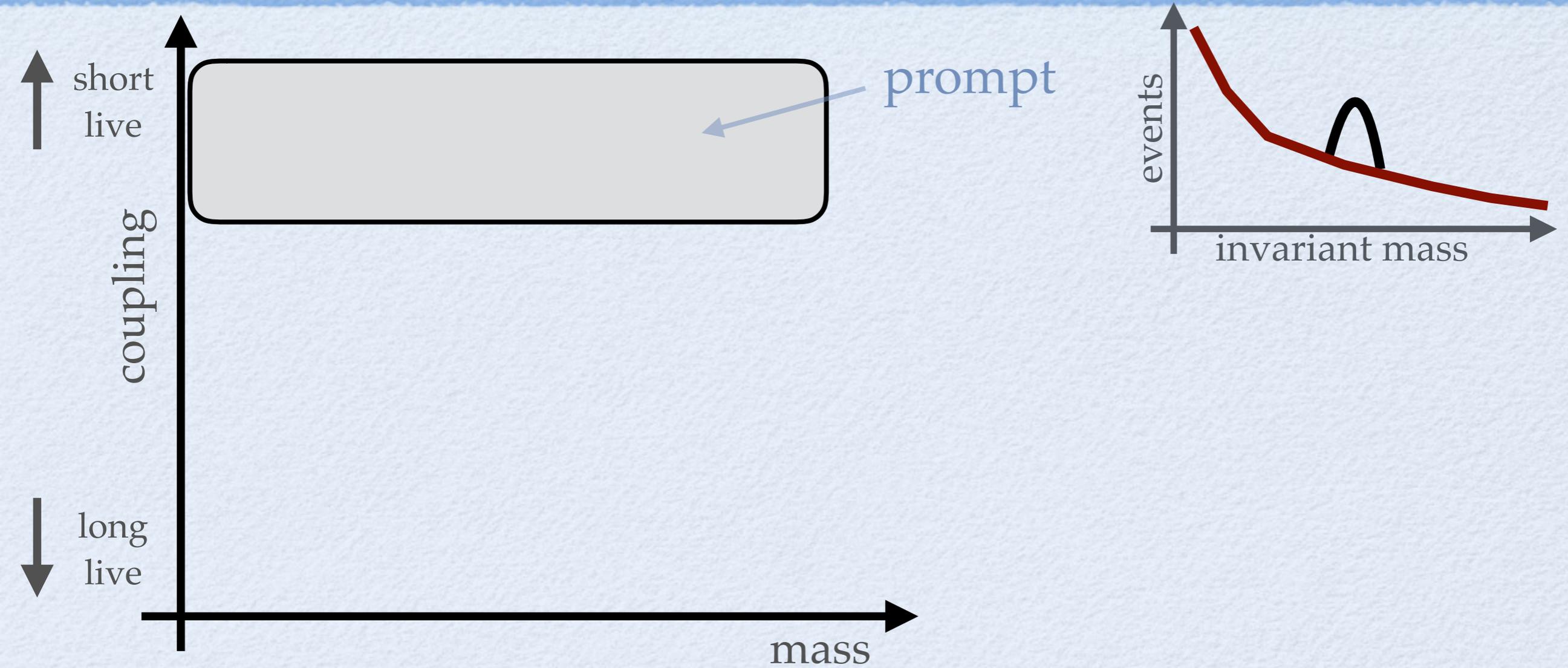
+ mass effect
($m_{A'} > 0$)

dark photon searches

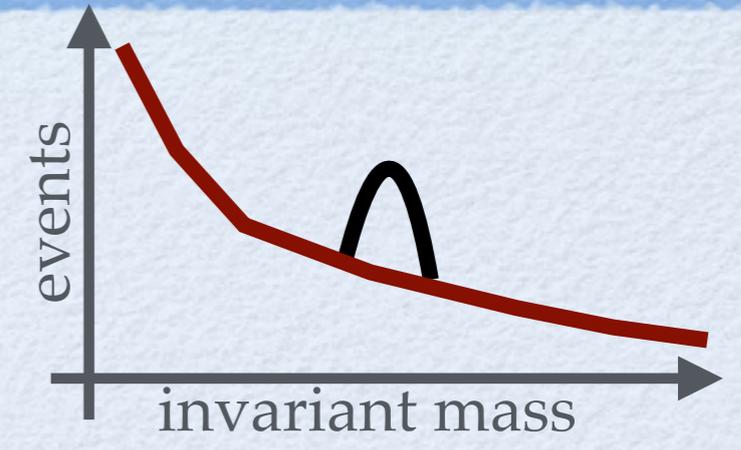
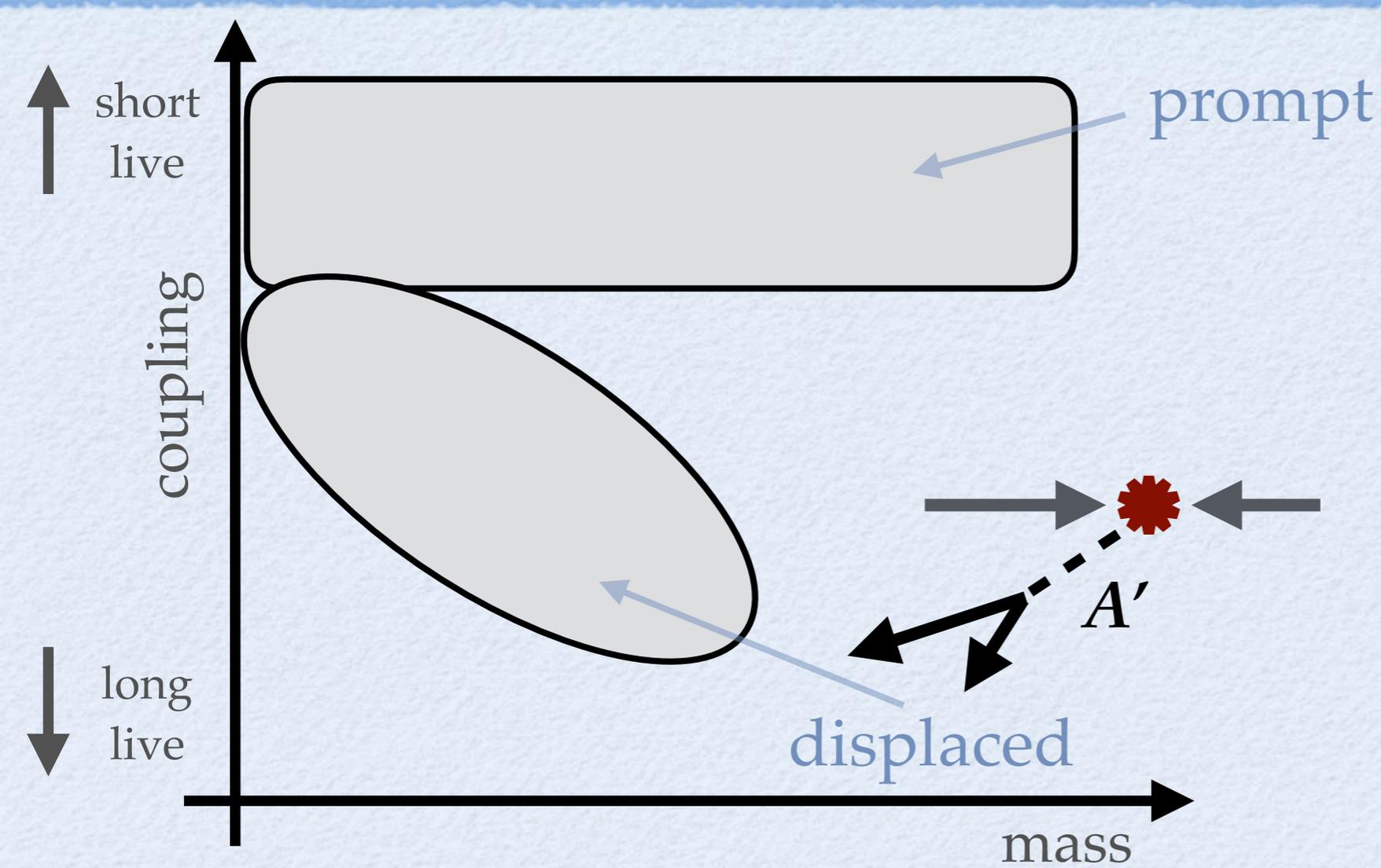
SIGNATURES AND EXPERIMENTS



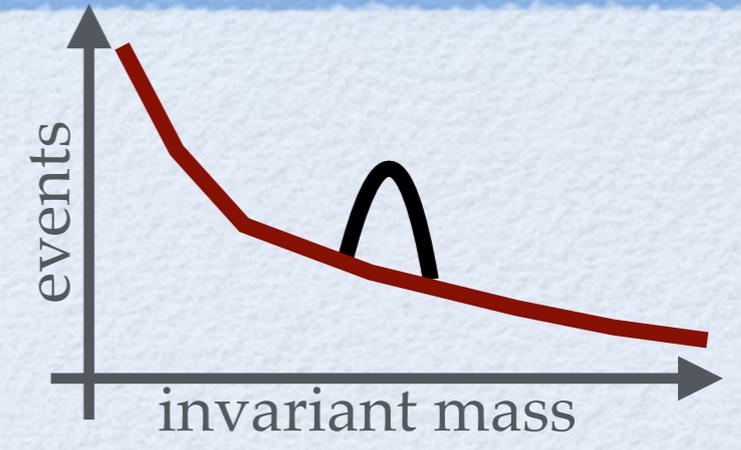
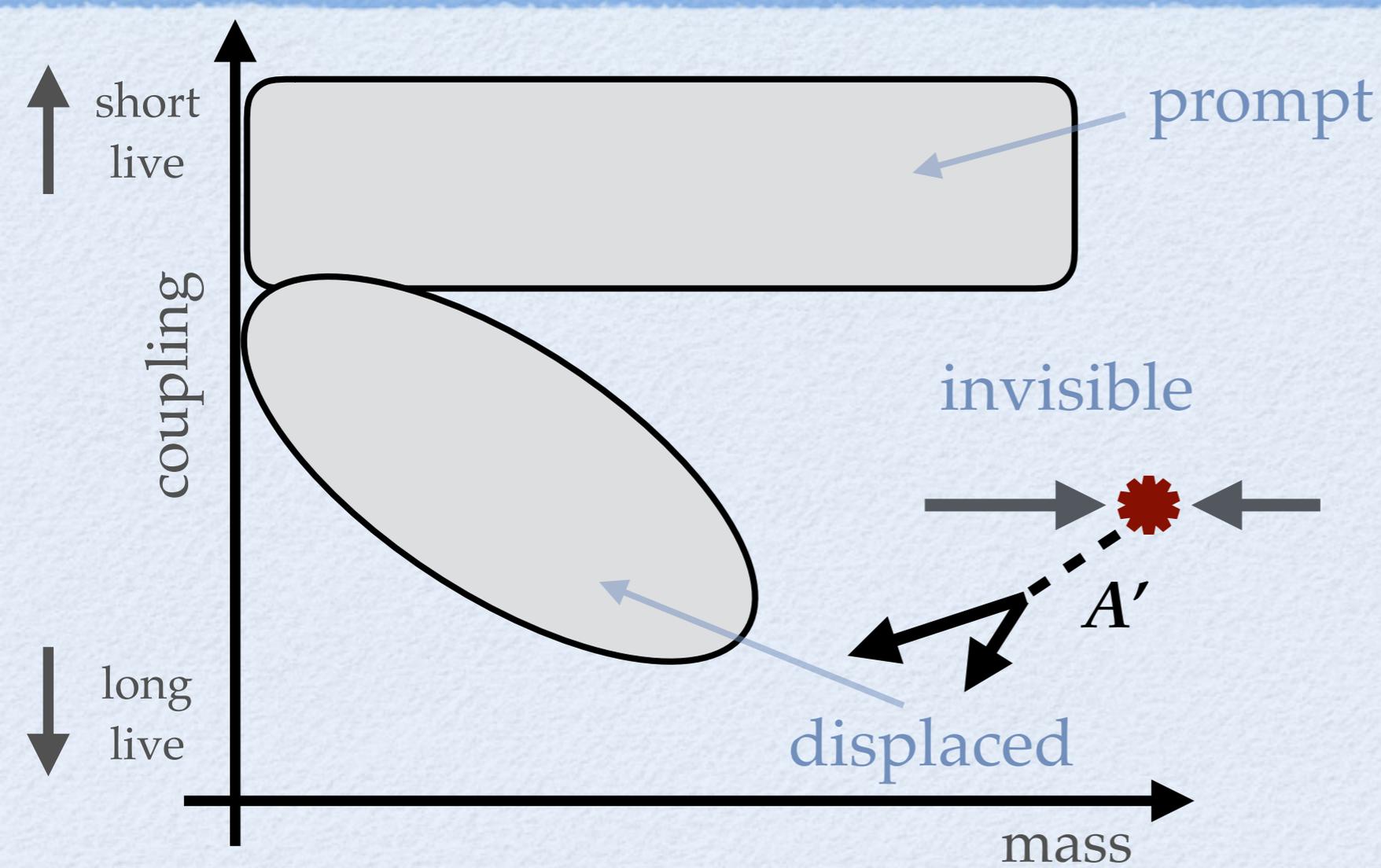
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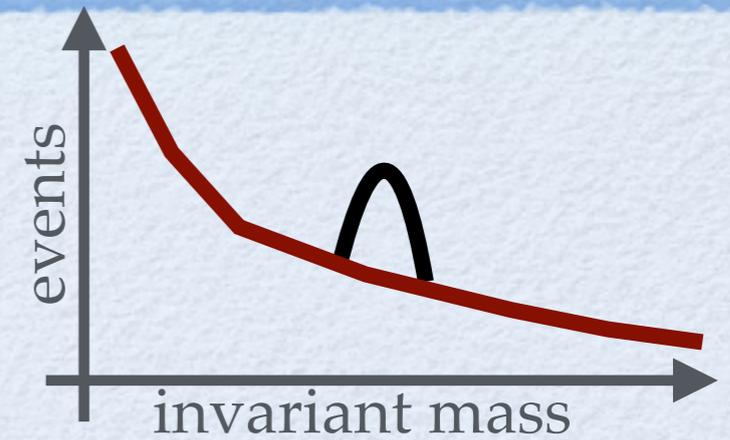
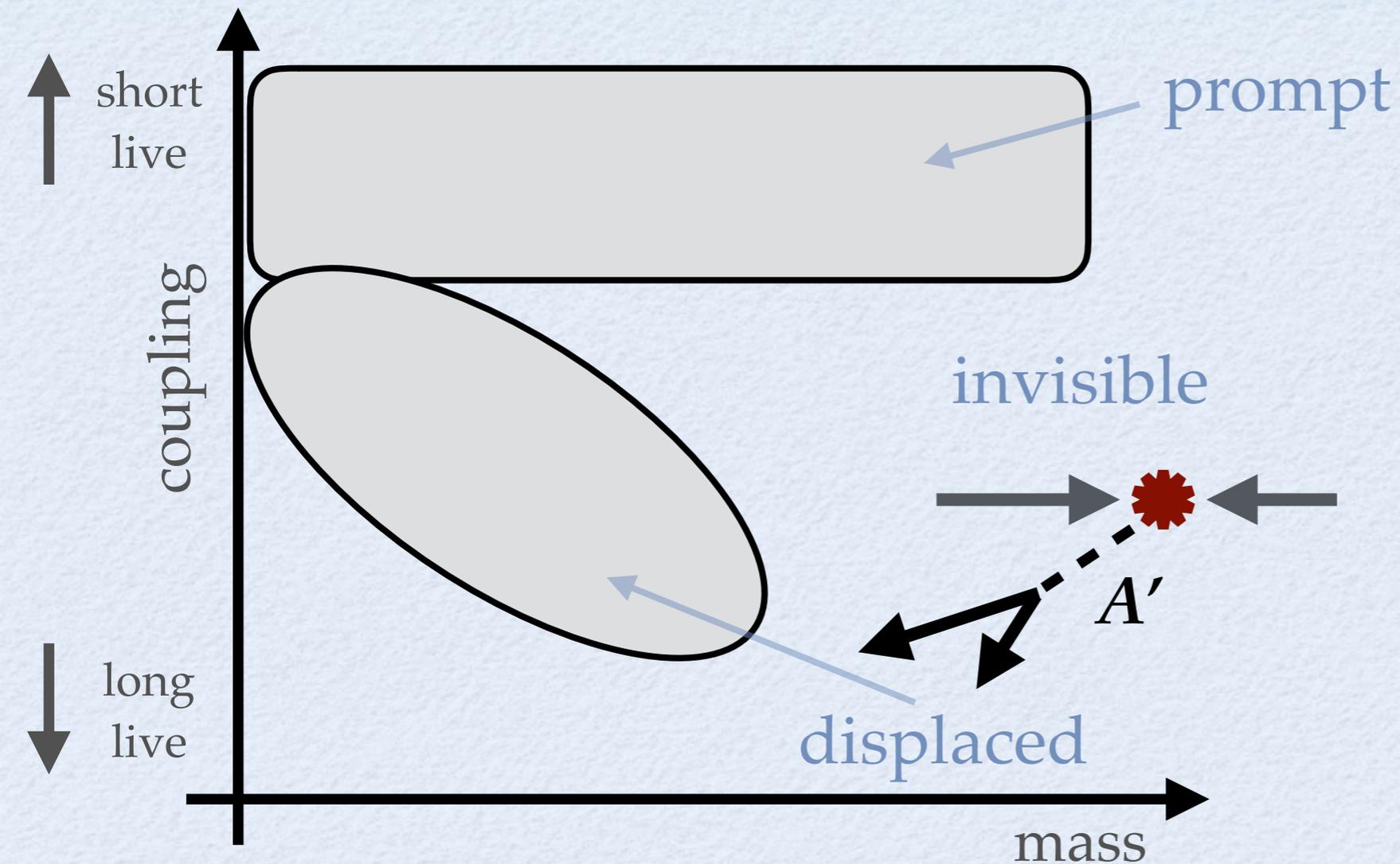
SIGNATURES AND EXPERIMENTS



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SIGNATURES AND EXPERIMENTS



collider:

B-factories
LHCb / ATLAS / CMS
KLOE

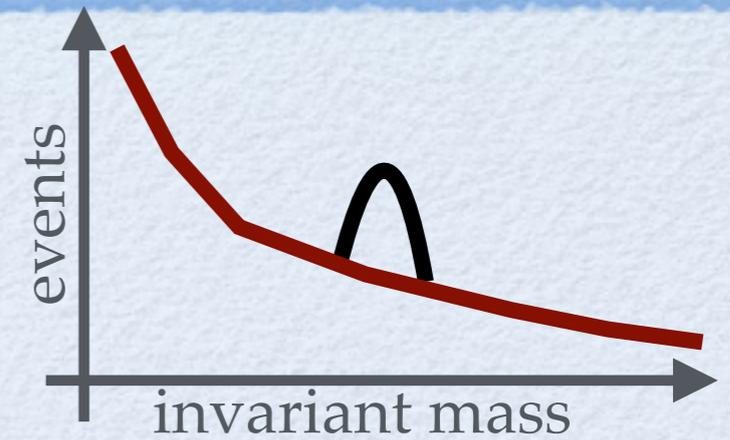
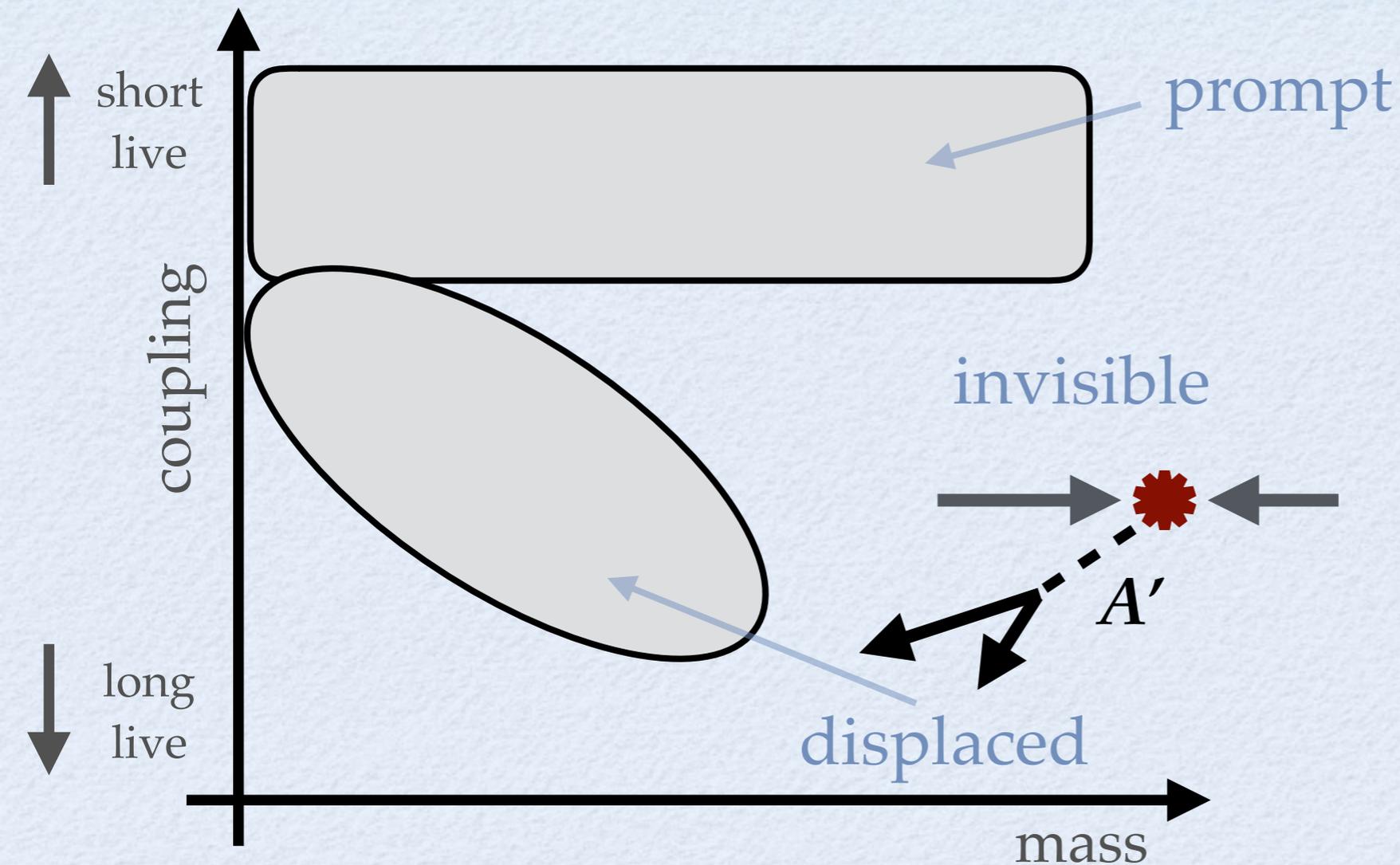
rare decays:

NA48, NA62
B-factories, LHCb,
Mu3e

fixed target:

HPS, PrimEx, GlueX

SIGNATURES AND EXPERIMENTS



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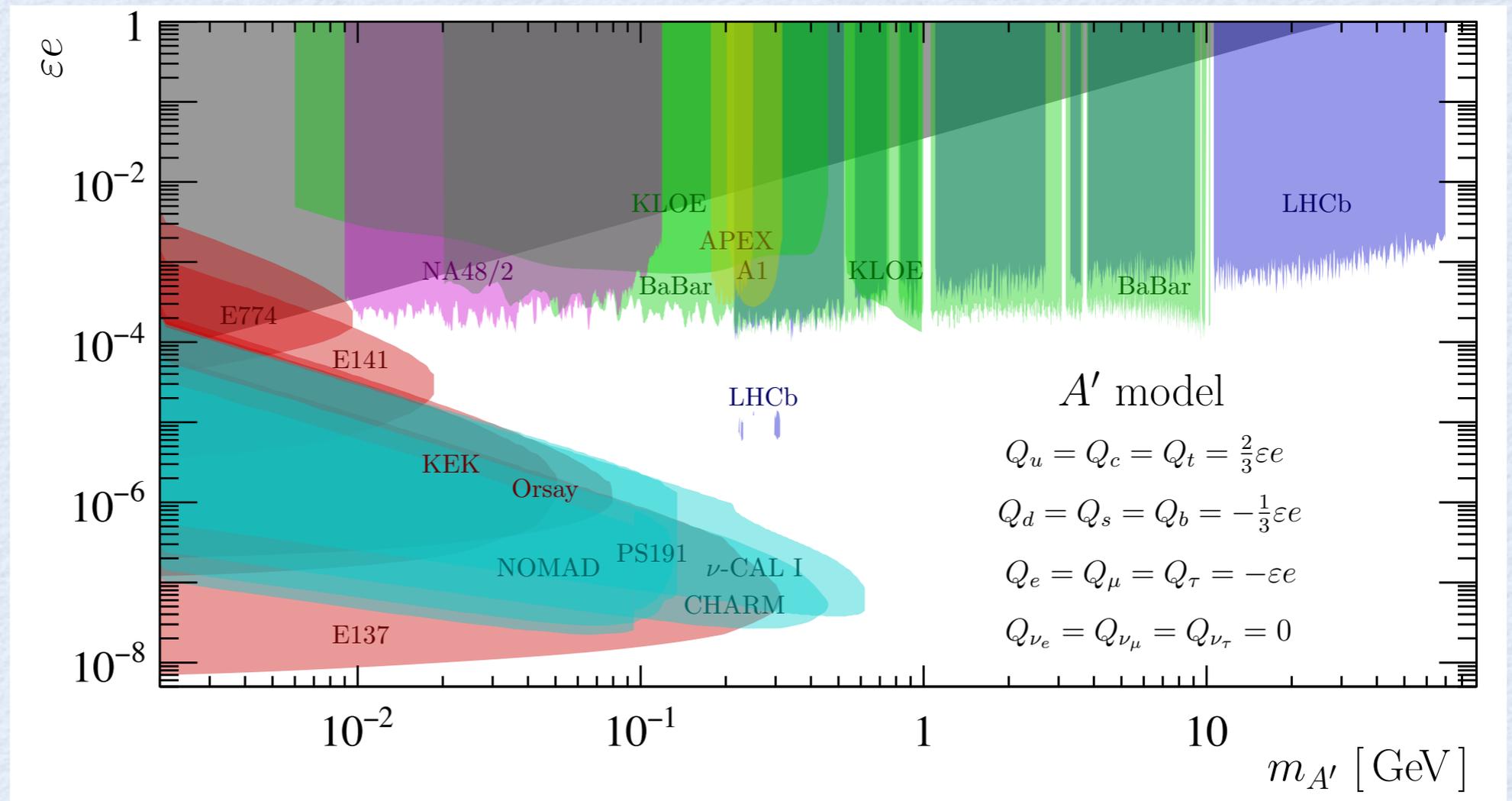
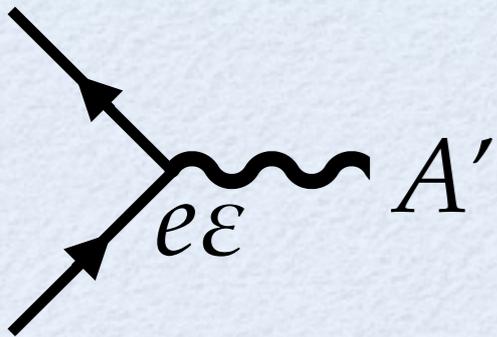
HPS, PrimEx, GlueX

beam-dump:

E774, NA64, E141, KE, Orsay, E137,
NOMAD, PS191, nuCAL, FASER



DARK PHOTON SEARCHES



electron beam dump

proton beam dump

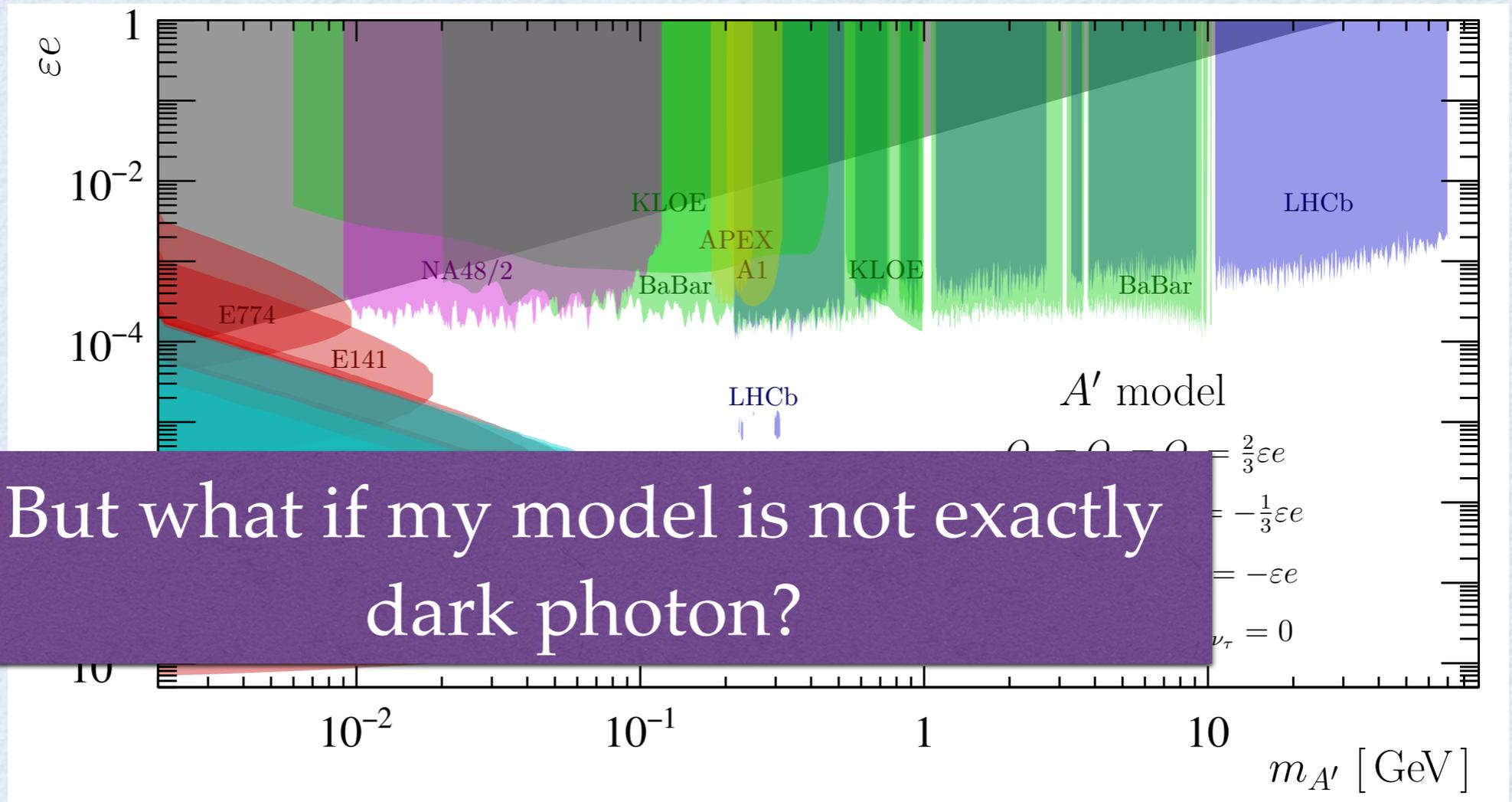
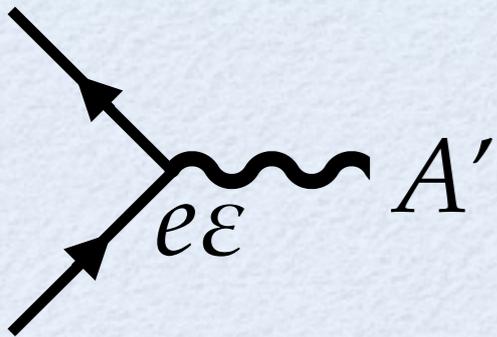
e^+e^- collider

pp collider

meson decays

e on fixed target

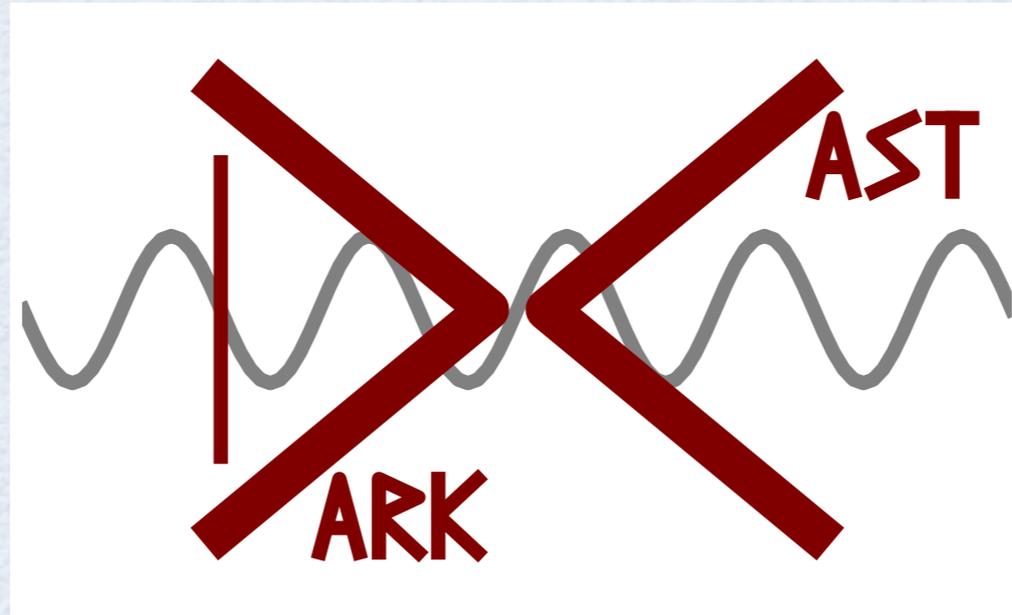
DARK PHOTON SEARCHES



But what if my model is not exactly dark photon?

electron beam dump
 proton beam dump
 e^+e^- collider

pp collider
 meson decays
 e on fixed target



simple recasting

BEYOND THE DARK PHOTON MODEL

the canonical dark
photon model - A'
(no invisible decays)

$m_{A'}, \epsilon$ ← free parameters
equivalent for coupling

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equivalent for coupling

generic vector resonances - X

$$\mathcal{L} \subset g_X \sum_f x_f \bar{f} \gamma^\mu f X_\mu + \sum_\chi \mathcal{L}_{X\chi\bar{\chi}}$$

SM currents

X - dark matter interaction
(invisible decays)

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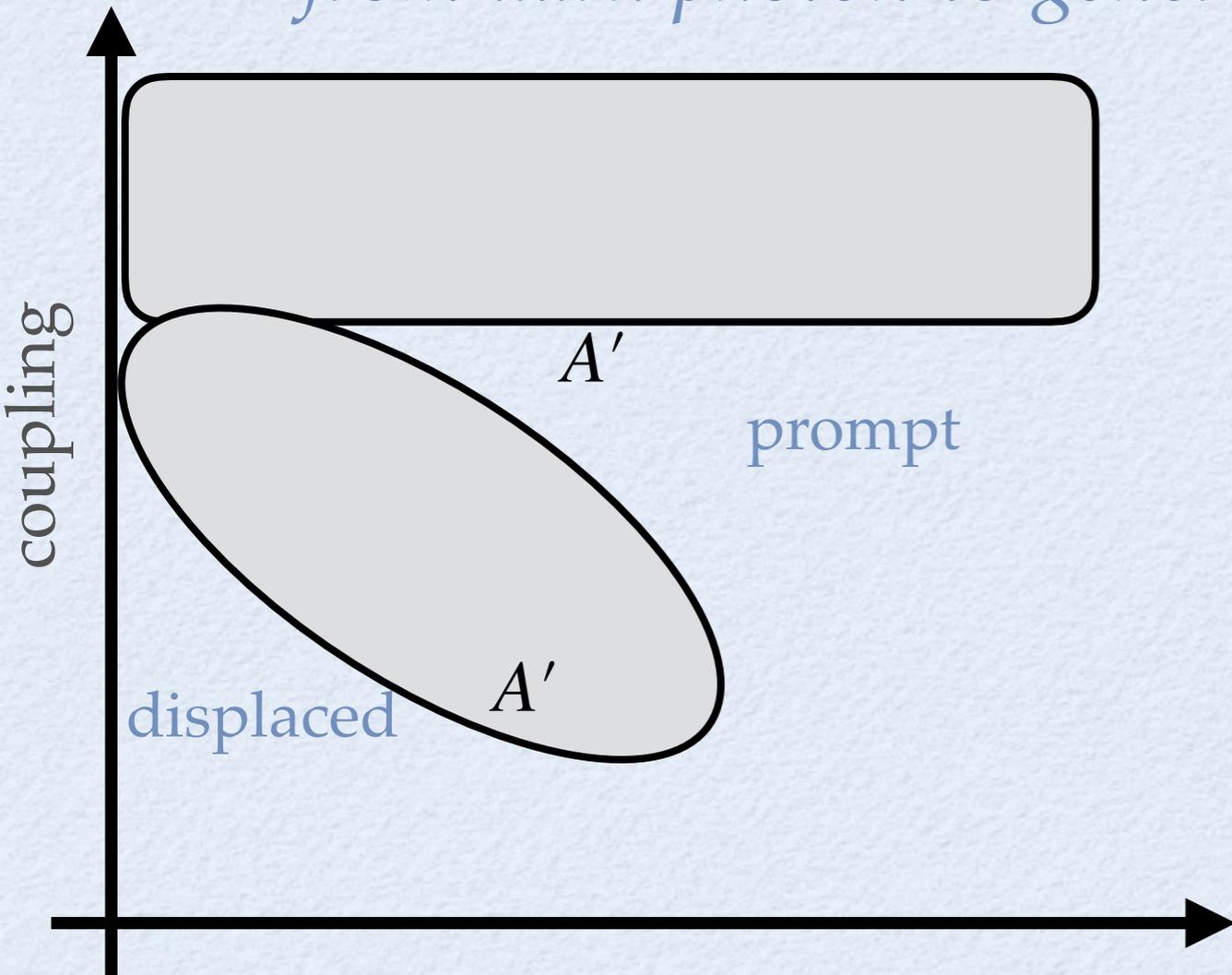
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assumptions for recasting:

- only vector coupling
- the dark photon, A' , bounds are given

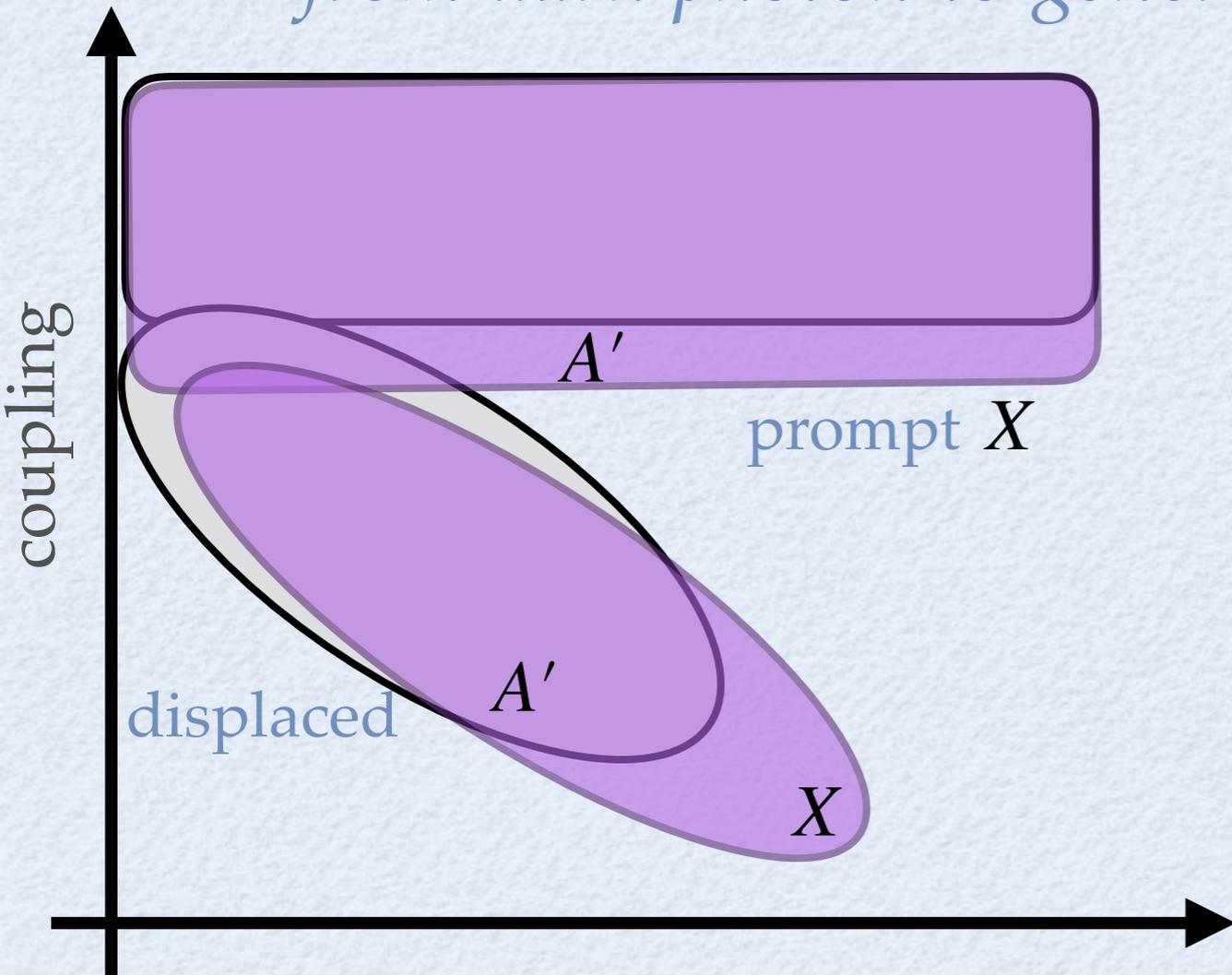
BEYOND THE DARK PHOTON MODEL

from dark photon to generic model $A' \rightarrow X$



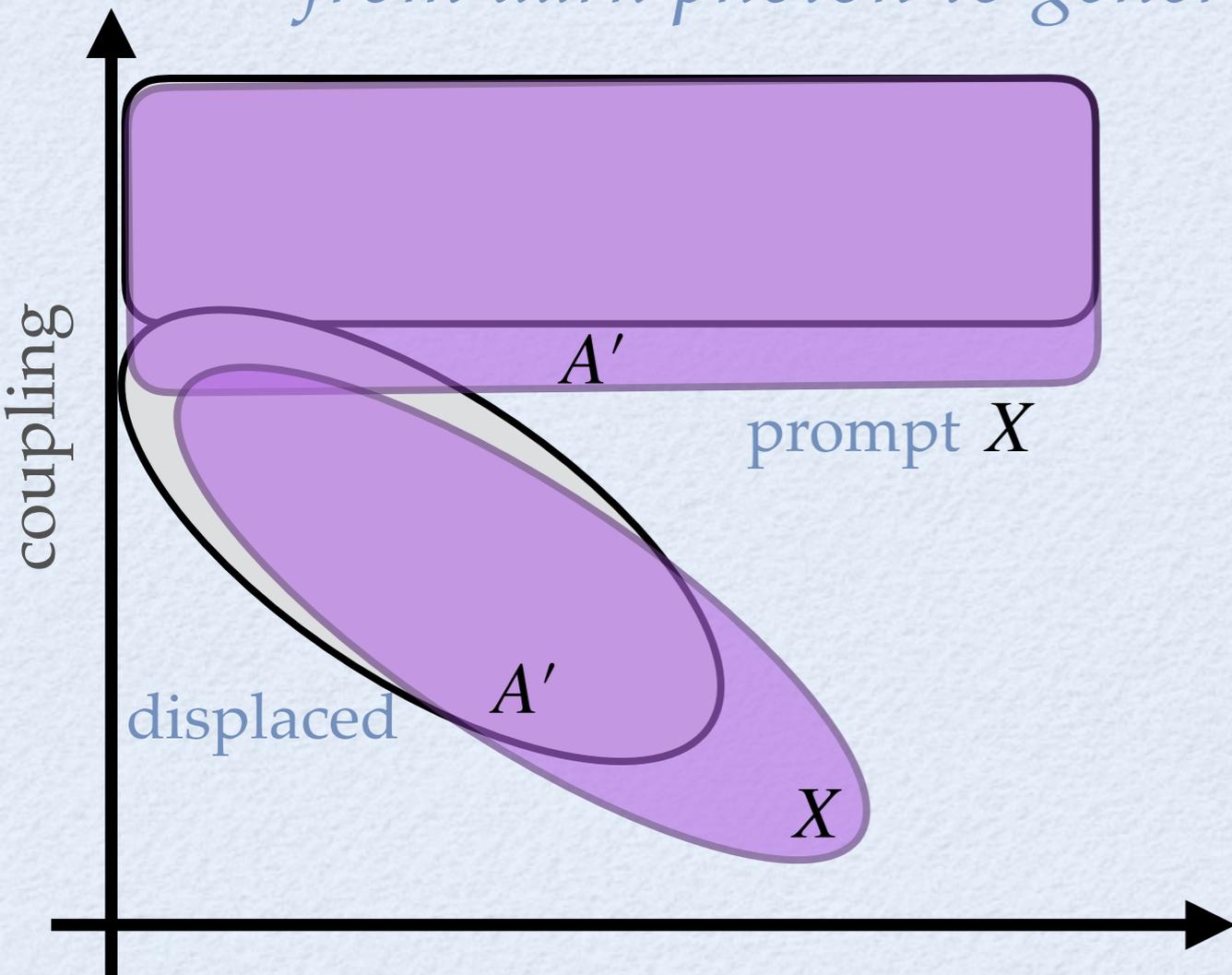
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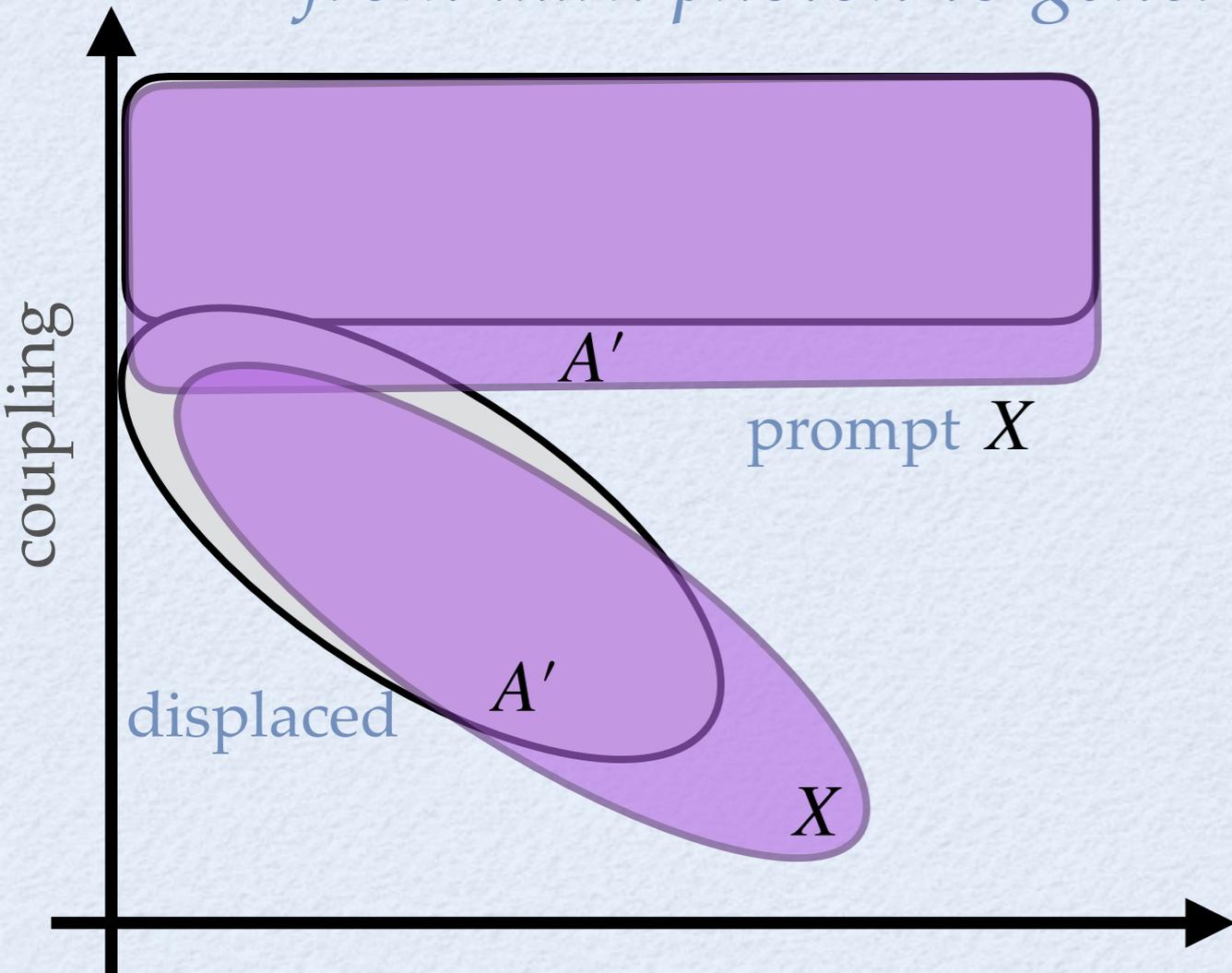


recasting by solving

$$\frac{\sigma_X(m, g_X) \text{BR}_{X \rightarrow \mathcal{F}}(m) \varepsilon(\tau_X(m, g_X))}{\sigma_{A'}(m, g_{A'}) \text{BR}_{A' \rightarrow \mathcal{F}}(m) \varepsilon(\tau_{A'}(m, g_{A'}))} = 1$$

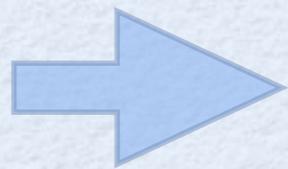
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$$\frac{\text{BR}_{A' \rightarrow \mathcal{F}}(m)}{\text{BR}_{X \rightarrow \mathcal{F}}(m)},$$

depends on
only X

$$\frac{\sigma_{A'}(m, g_{A'})}{\sigma_X(m, g_X)}, \quad \frac{\varepsilon(\tau_{A'}(m, g_{A'}))}{\varepsilon(\tau_X(m, g_X))}$$

depends on X and the
experiment

branching ratio

RATIOS OF BRANCHING RATIOS

perturbative: $\Gamma_{X \rightarrow f\bar{f}} = \frac{\mathcal{C}_f (g_X x_f)^2}{12\pi} m_X \left(1 + 2 \frac{m_f^2}{m_X^2} \right) \sqrt{1 - 4 \frac{m_f^2}{m_X^2}}$

for leptons and quarks ($m_X > 2\text{GeV}$)

$x_f =$ the charge of f
 $\mathcal{C}_f = 1, 1/2, 3$ for ℓ, ν, q

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- “mix” with measured vector meson “currents” in ee
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RATIOS OF BRANCHING RATIOS

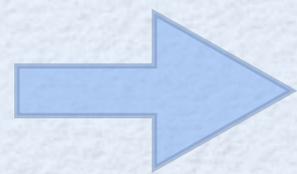
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→
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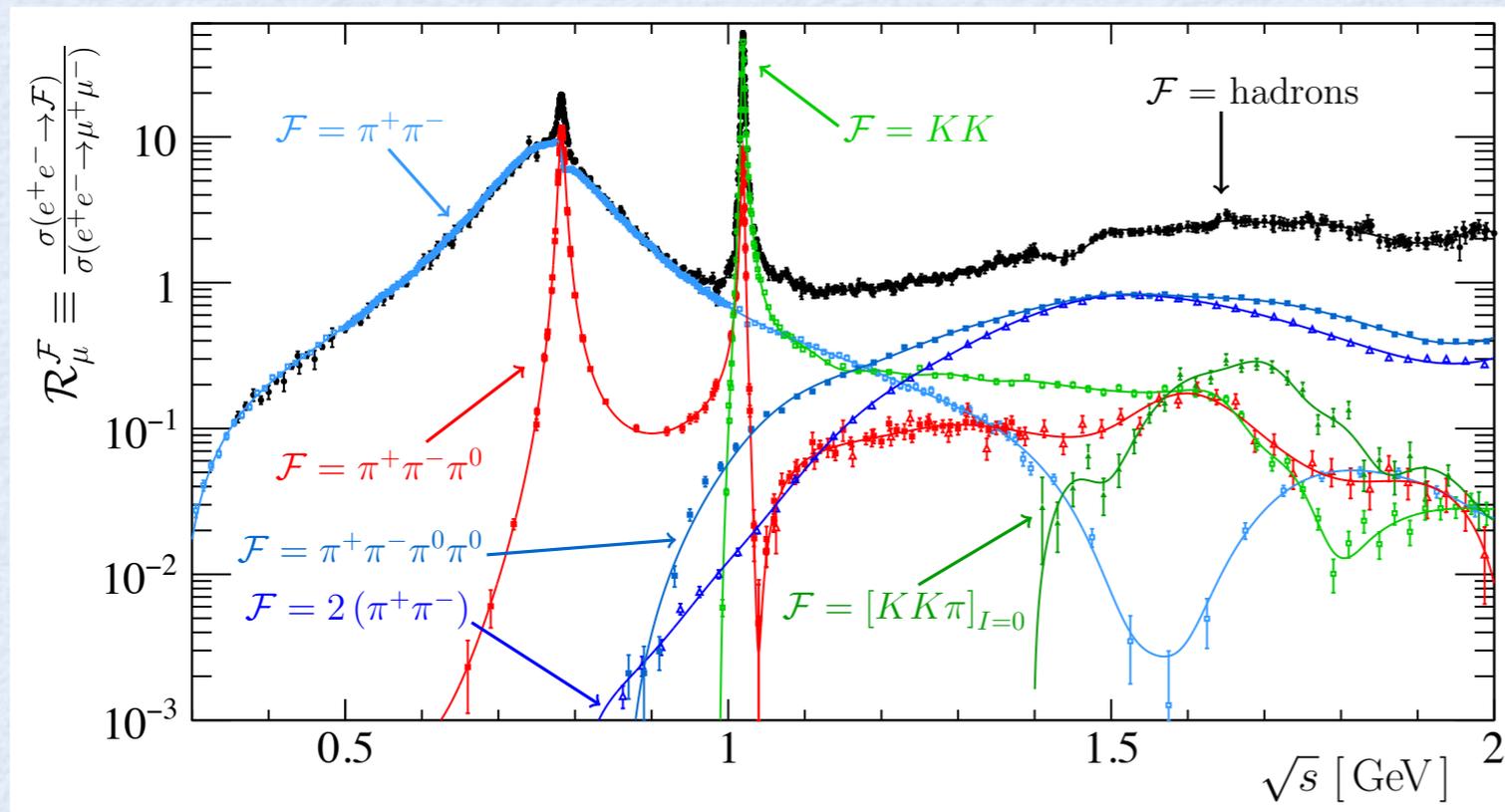


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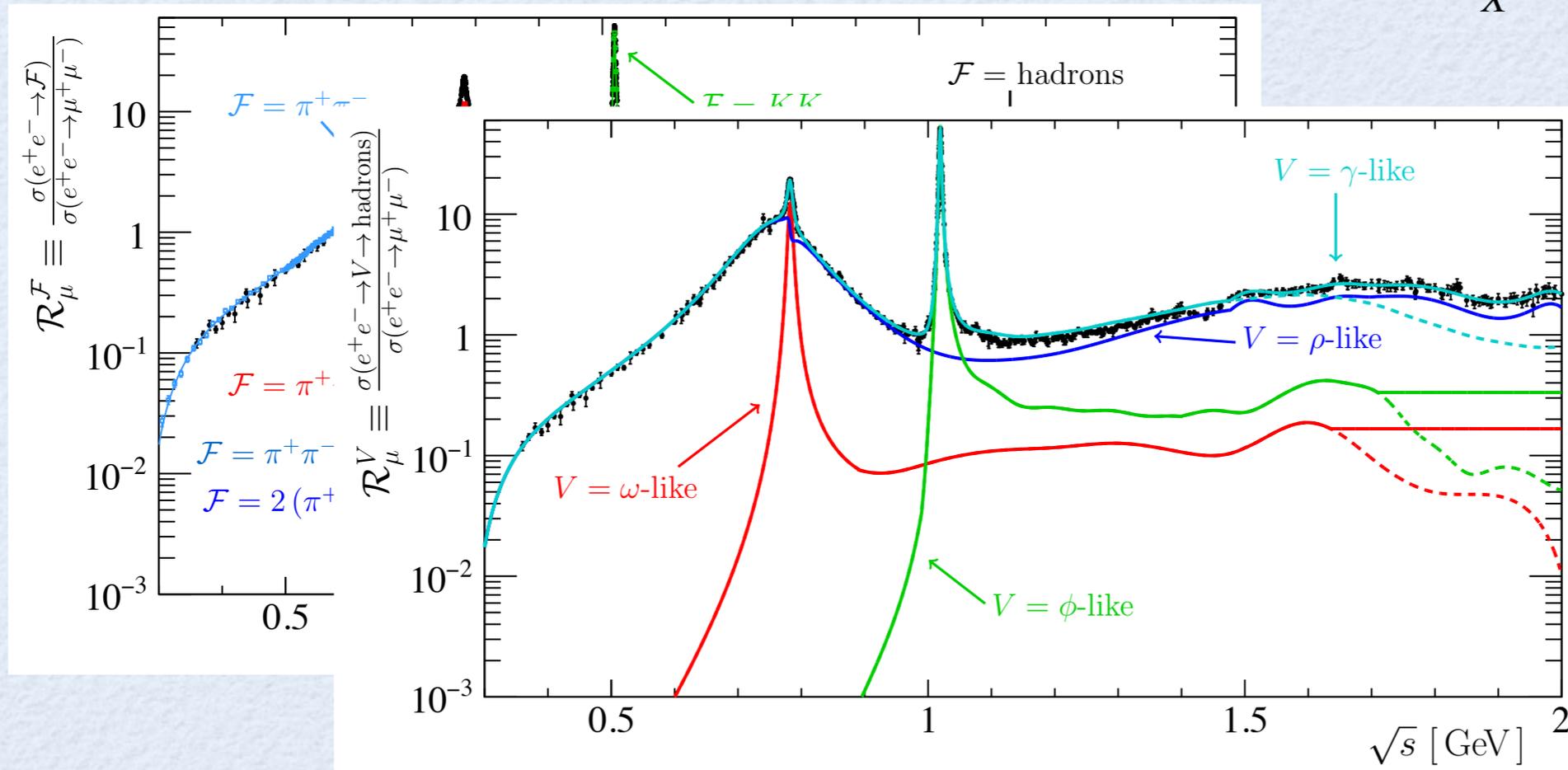
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production

RATIOS OF PRODUCTION

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electron-beam Bremsstrahlung,
ee annihilation

$$\frac{\sigma_{eZ \rightarrow eZX}}{\sigma_{eZ \rightarrow eZA'}} = \frac{\sigma_{e^+e^- \rightarrow X\gamma}}{\sigma_{e^+e^- \rightarrow A'\gamma}} = \frac{(g_X x_e)^2}{(e\varepsilon)^2}$$

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proton-beam Bremsstrahlung

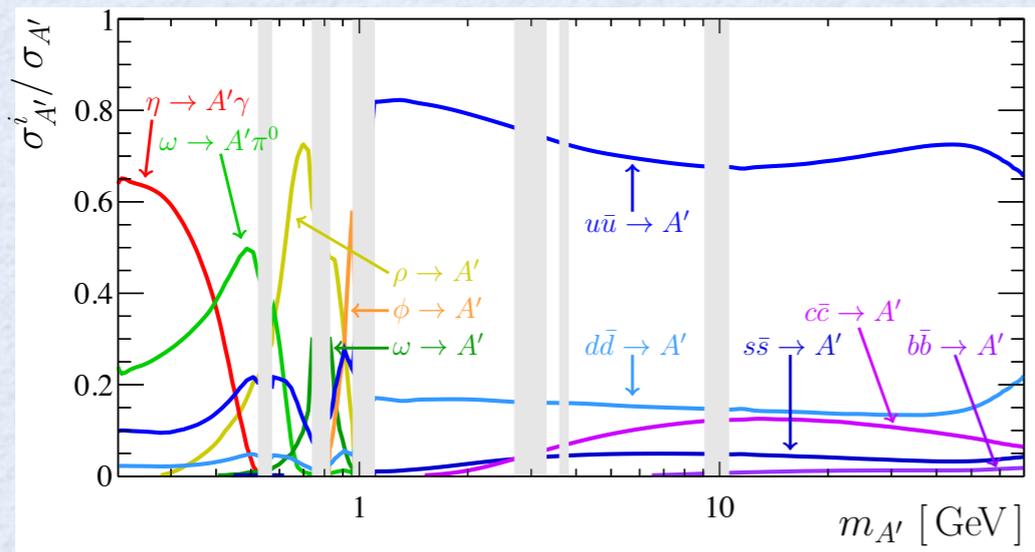
$$\frac{\sigma_{pZ \rightarrow pZX}}{\sigma_{pZ \rightarrow pZA'}} = \frac{g_X^2 (2x_u + x_d)^2}{(e\varepsilon)^2}$$

RATIOS OF PRODUCTION

electron-beam Bremsstrahlung,
ee annihilation

proton-beam Bremsstrahlung

Drell-Yan



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$$\frac{\sigma_{\text{DY} \rightarrow X}}{\sigma_{\text{DY} \rightarrow A'}} = \sum_{q_i} \left[\frac{\sigma_{q_i \bar{q}_i \rightarrow \gamma^*}}{\sigma_{\text{DY} \rightarrow \gamma^*}} \right] \left[\frac{\sigma_{q_i \bar{q}_i \rightarrow X}}{\sigma_{q_i \bar{q}_i \rightarrow A'}} \right]$$

relative fraction
(from MC)

$$\frac{9(g_X x_{q_i})^2}{(e\epsilon)^2} \times \begin{cases} 1/4 & \text{for } q_i = u, c \\ 1 & \text{for } q_i = d, s, b \end{cases}$$

RATIOS OF PRODUCTION

$V \rightarrow XP$:
vector meson decay

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

↑
mixing with
 $U(3)$ QN

↑
Bright-Wigner

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Bright-Wigner

$P \rightarrow X\gamma$:
radiative meson decay

$$\frac{\Gamma_{P \rightarrow X\gamma}}{\Gamma_{P \rightarrow A'\gamma}} = \left(\frac{g_X}{\epsilon e} \right)^2 \frac{\left| \sum_V \text{Tr}[T_P Q T_V] \text{Tr}[T_V Q_X] \text{BW}_V(m) \right|^2}{\left| \sum_V \text{Tr}[T_P Q T_V] \text{Tr}[T_V Q] \text{BW}_V(m) \right|^2}$$

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$X - V$ mixing :

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

efficiencies

RATIOS OF EFFICIENCIES

signature	$\frac{\epsilon(\tau_{A'})}{\epsilon(\tau_X)}$
invisible	≈ 1
prompt	$1 - e^{-\tilde{t}/\tau_X}$
Long-lived (displaced)	$\frac{e^{-\tilde{t}_0/\tau_X} - e^{-\tilde{t}_1/\tau_X}}{e^{-\tilde{t}_0/\tau_{A'}} - e^{-\tilde{t}_1/\tau_{A'}}}$

$$\epsilon(\tau_{A'}) \approx 1$$

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

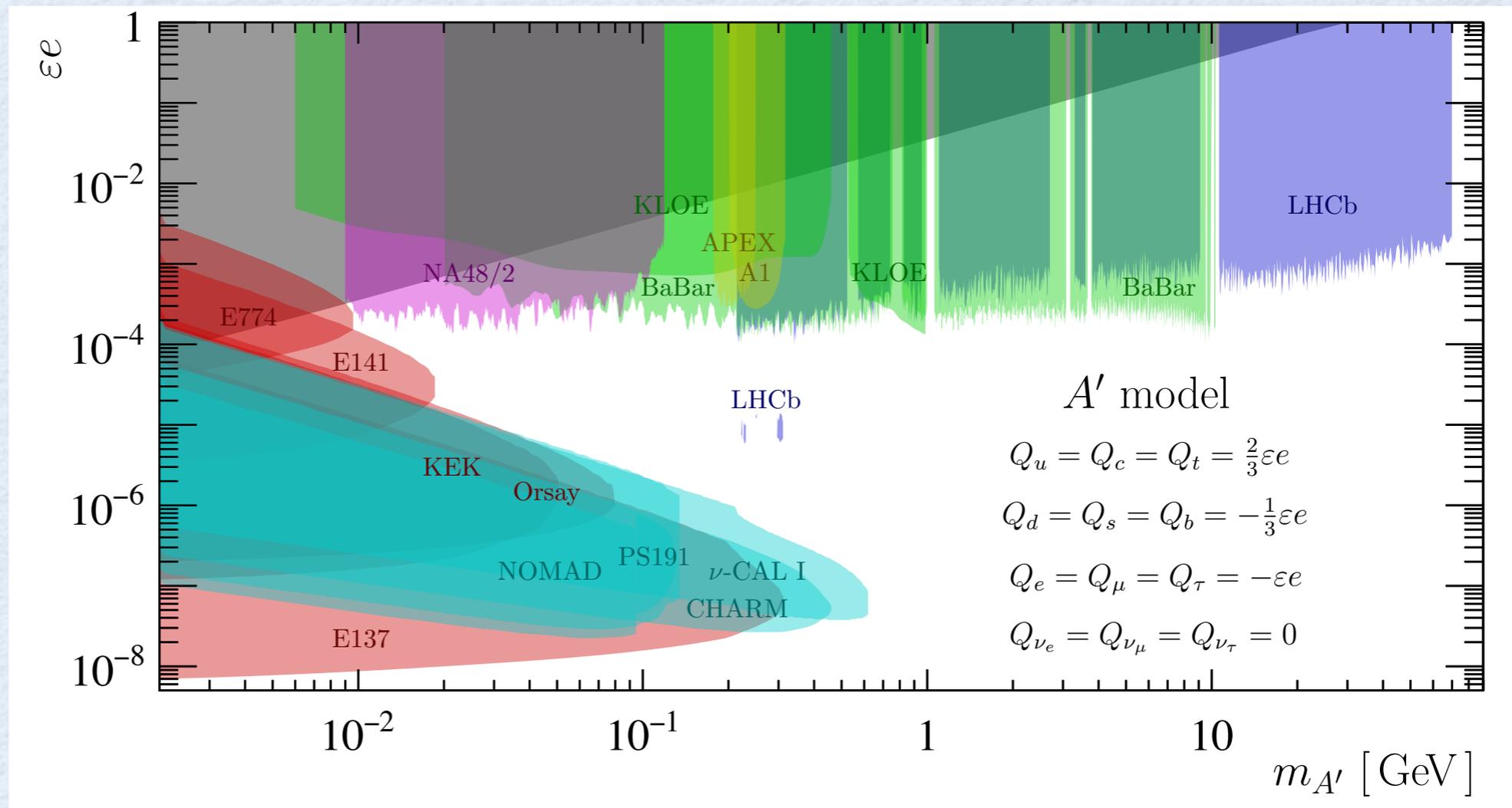
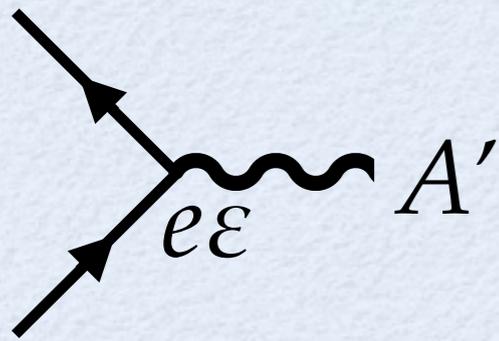
$$\epsilon_{\text{max}}^2 \epsilon[\tau_{A'}(\epsilon_{\text{max}}^2)] = \epsilon_{\text{min}}^2 \epsilon[\tau_{A'}(\epsilon_{\text{min}}^2)]$$

(finding average boost)

LHCb provide expected limits

Examples

DARK PHOTON



electron beam dump

proton beam dump

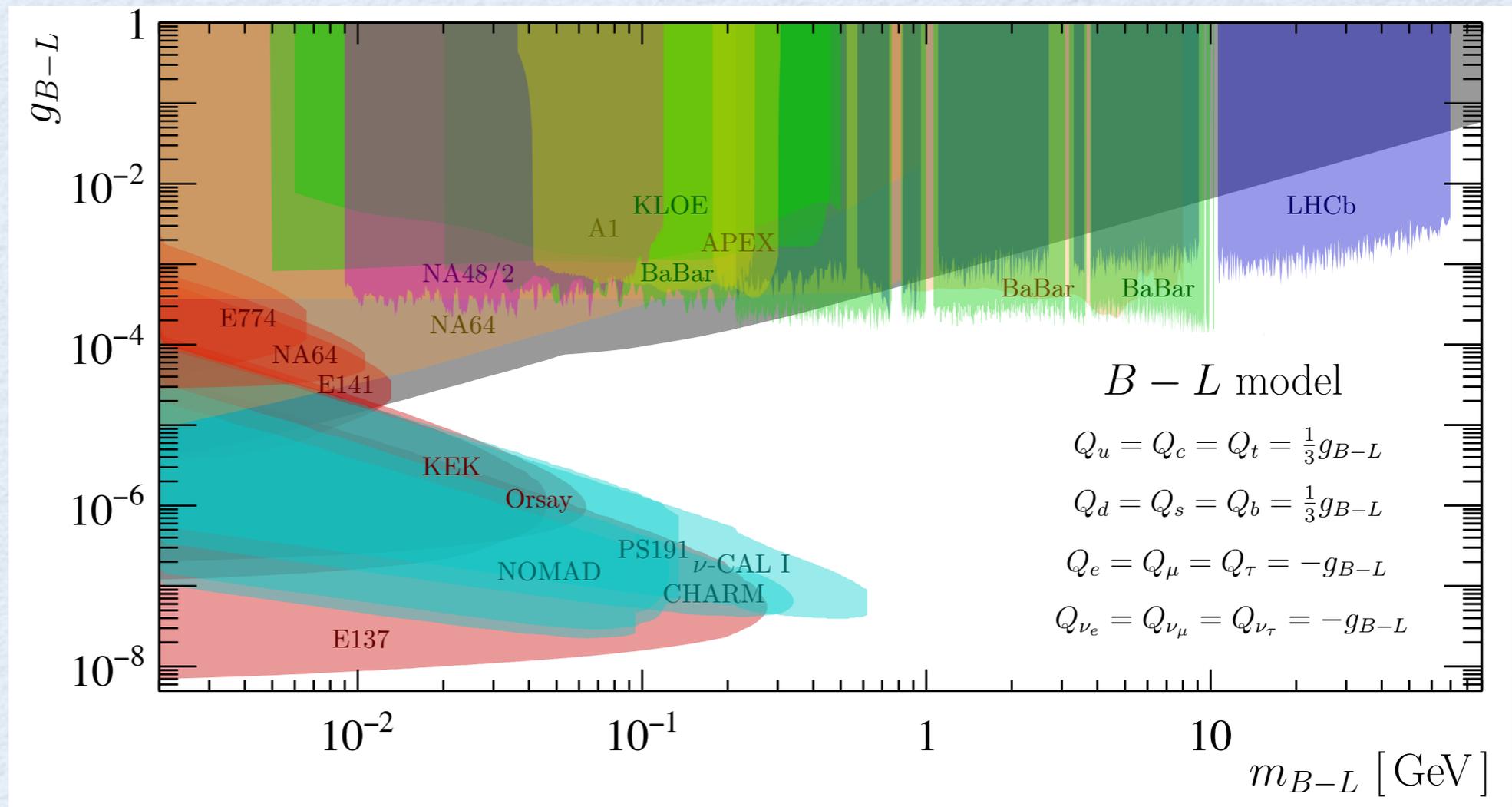
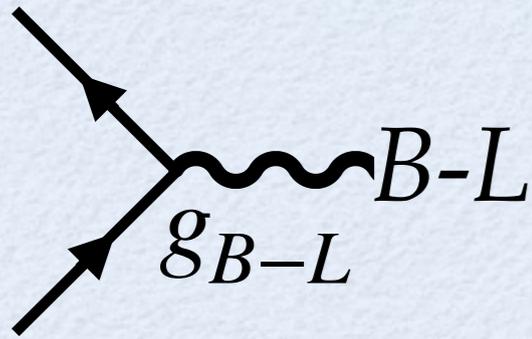
e^+e^- collider

pp collider

meson decays

e on fixed target

B-L GAUGE BOSON



electron beam dump

proton beam dump

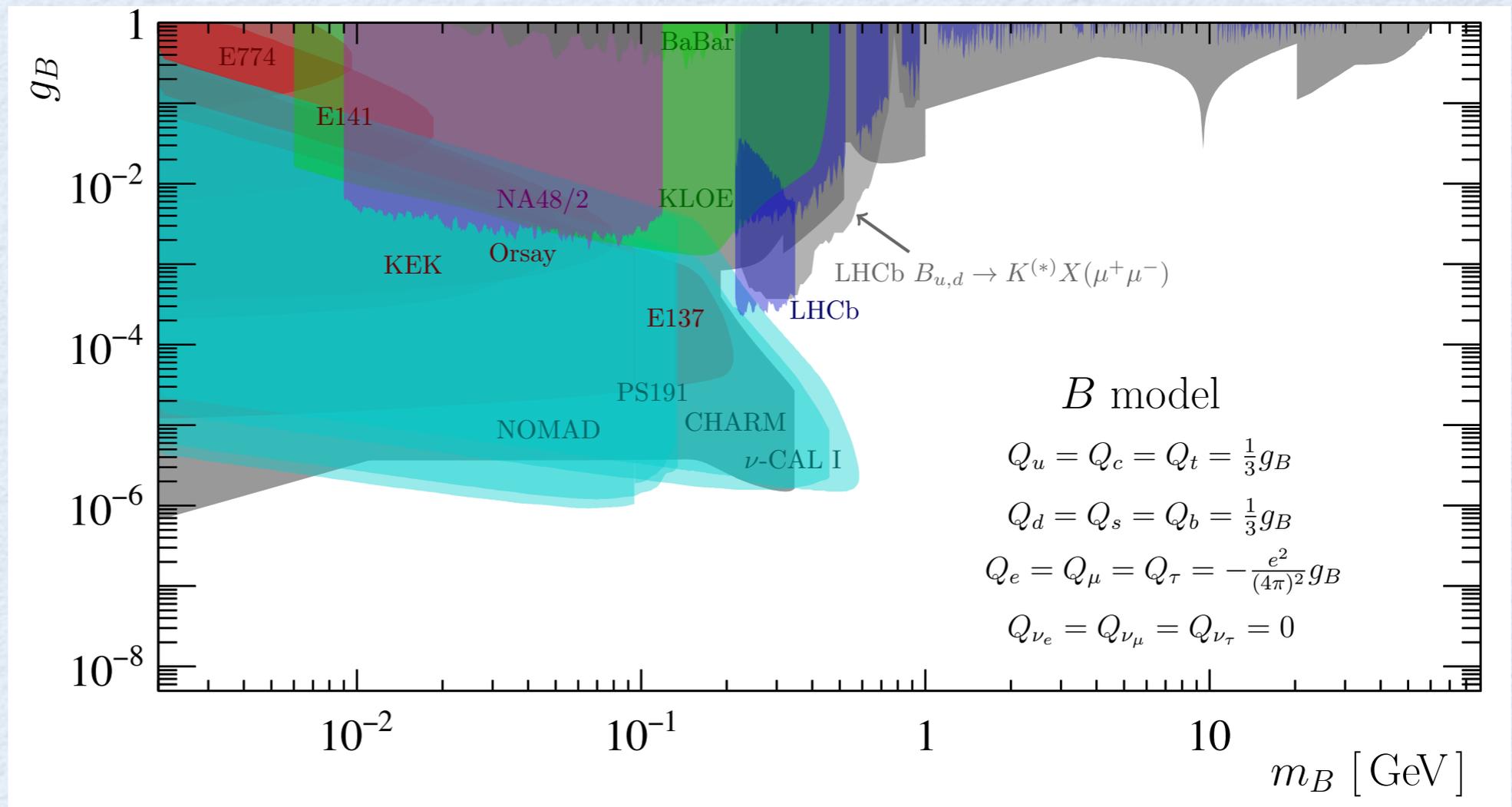
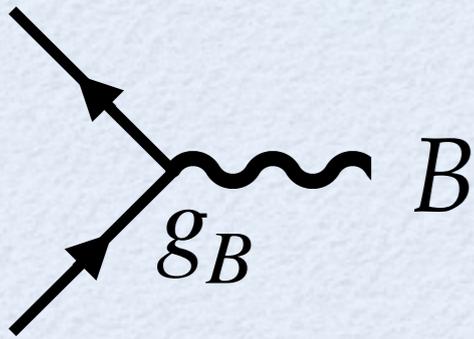
e^+e^- collider

pp collider

meson decays

e on fixed target

B GAUGE BOSON



electron beam dump

proton beam dump

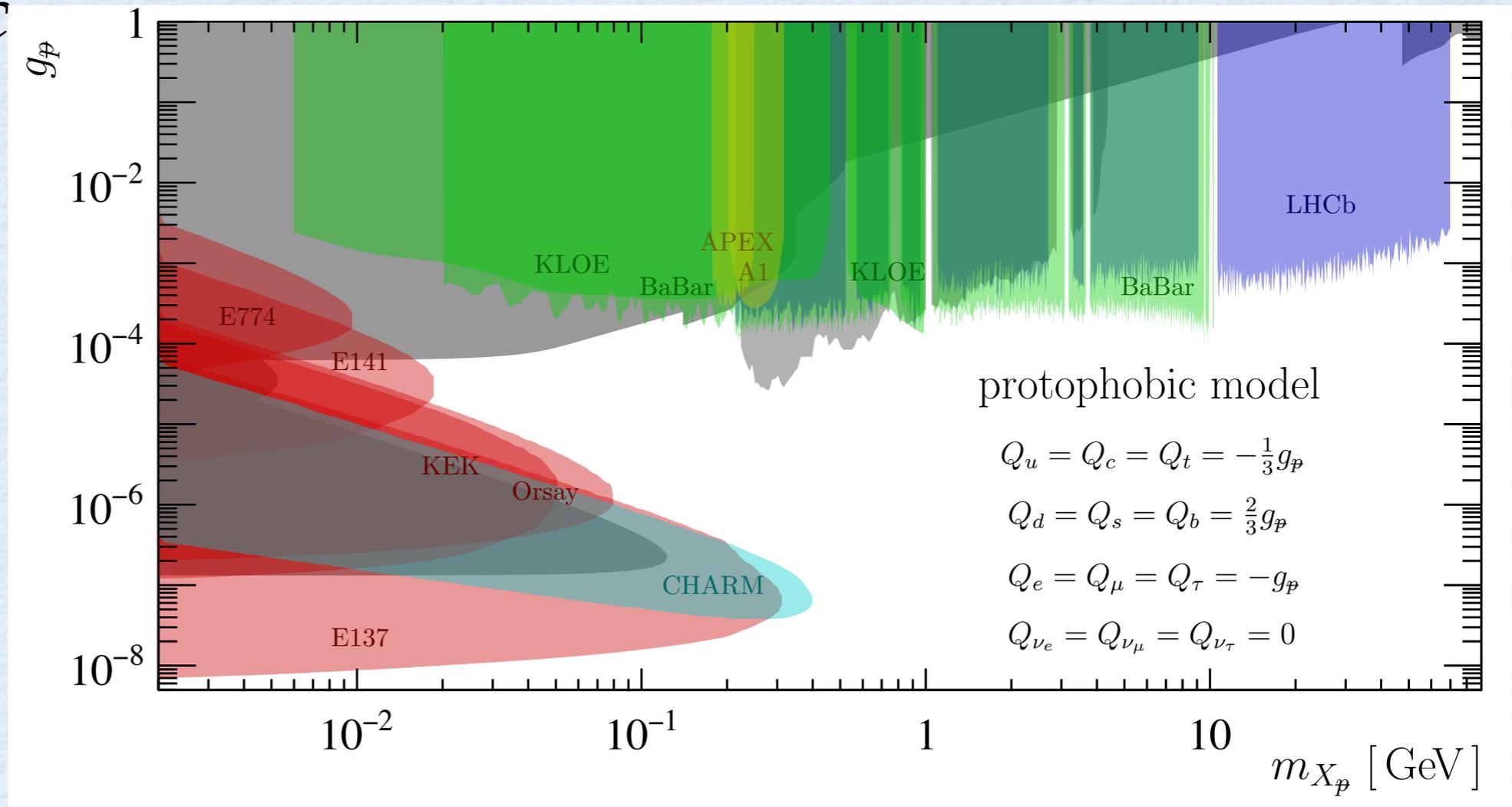
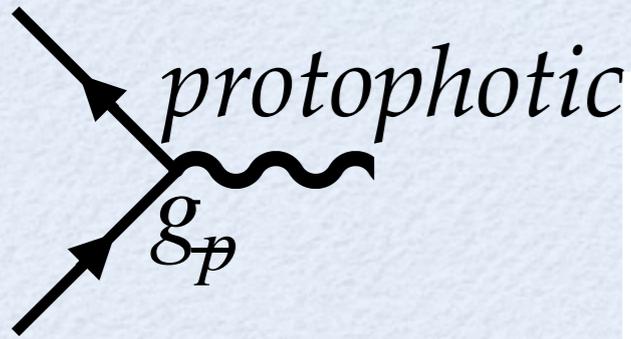
e^+e^- collider

pp collider

meson decays

e on fixed target

PROTOPHOBIC GAUGE BOSON



electron beam dump

proton beam dump

e^+e^- collider

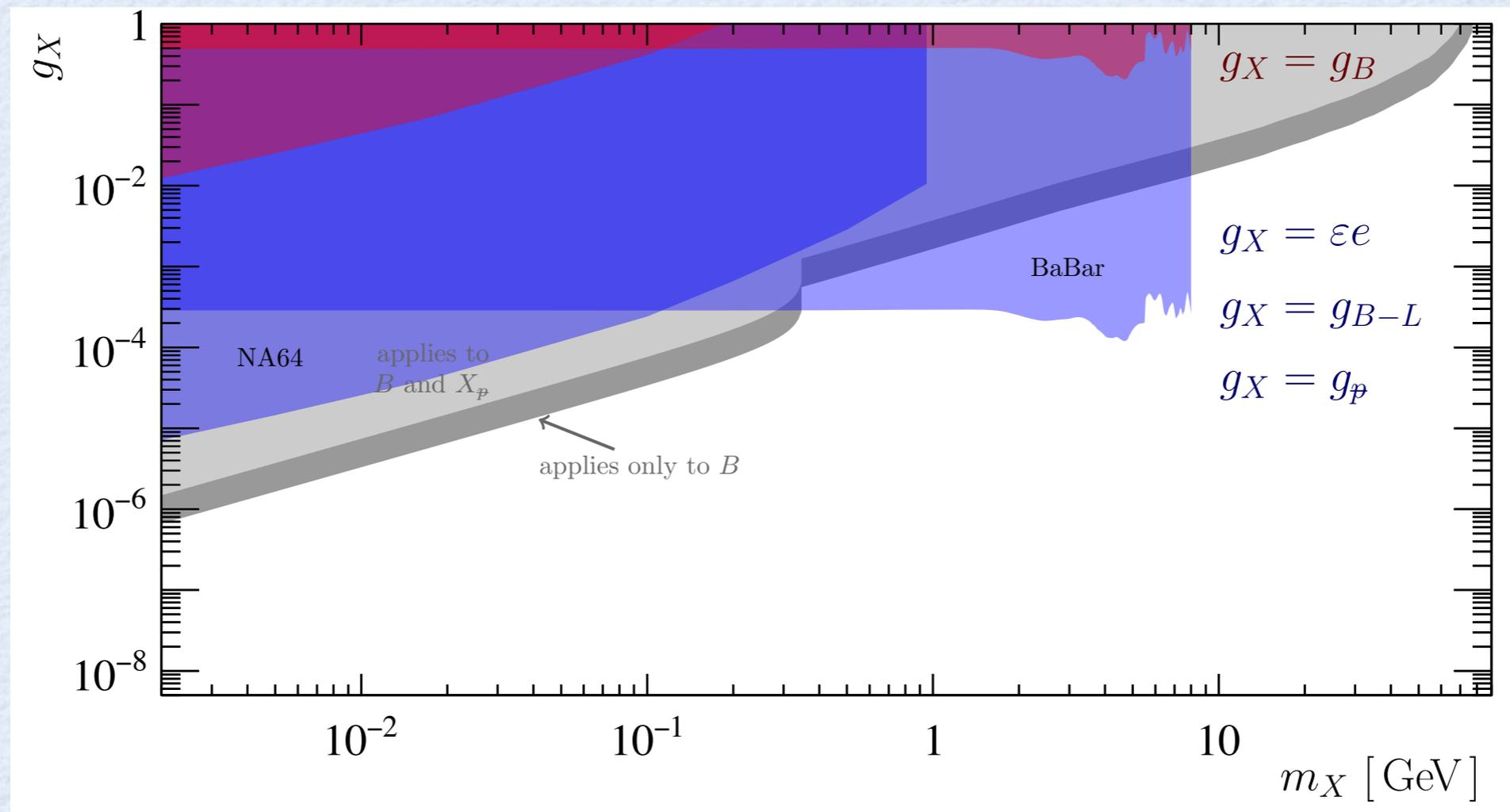
pp collider

meson decays

e on fixed target

BEYOND THE DARK PHOTON MODEL

assuming dominant invisible decay



OUTLOOK

- DarkCast - is a simple tool to calculate branching ratios, width and recasting!
- Axion like particle addition - in progress
- Suggestion and request are very welcome!

BACKUP SLIDES

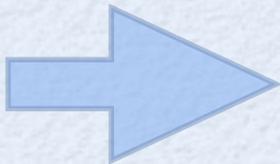
BEYOND THE DARK PHOTON MODEL

from dark photon to generic model $A' \rightarrow X$

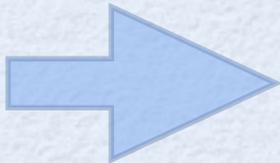
recasting from model A' to model X by solving

$$\sigma_{A'}(m, g_{A'}) \text{BR}_{A' \rightarrow \mathcal{F}}(m) \varepsilon(\tau_{A'}(m, g_{A'})) = \sigma_X(m, g_X) \text{BR}_{X \rightarrow \mathcal{F}}(m) \varepsilon(\tau_X(m, g_X))$$

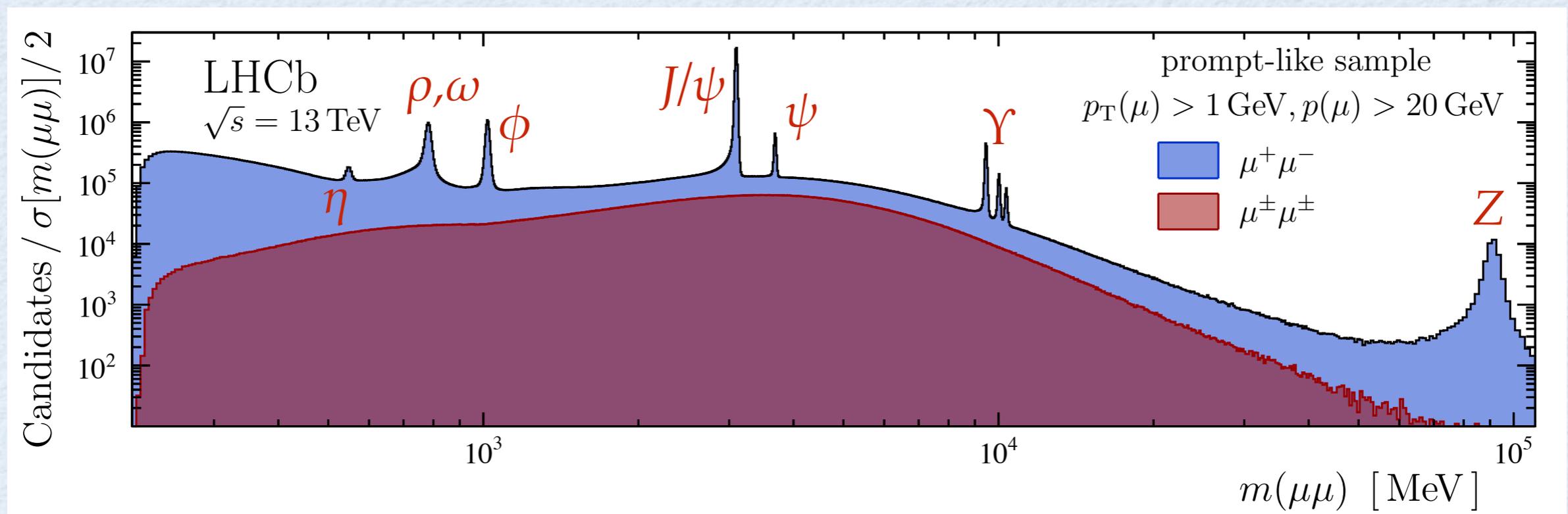
for a given mass and couplings


$$g_X = f(m, g_{A'})$$

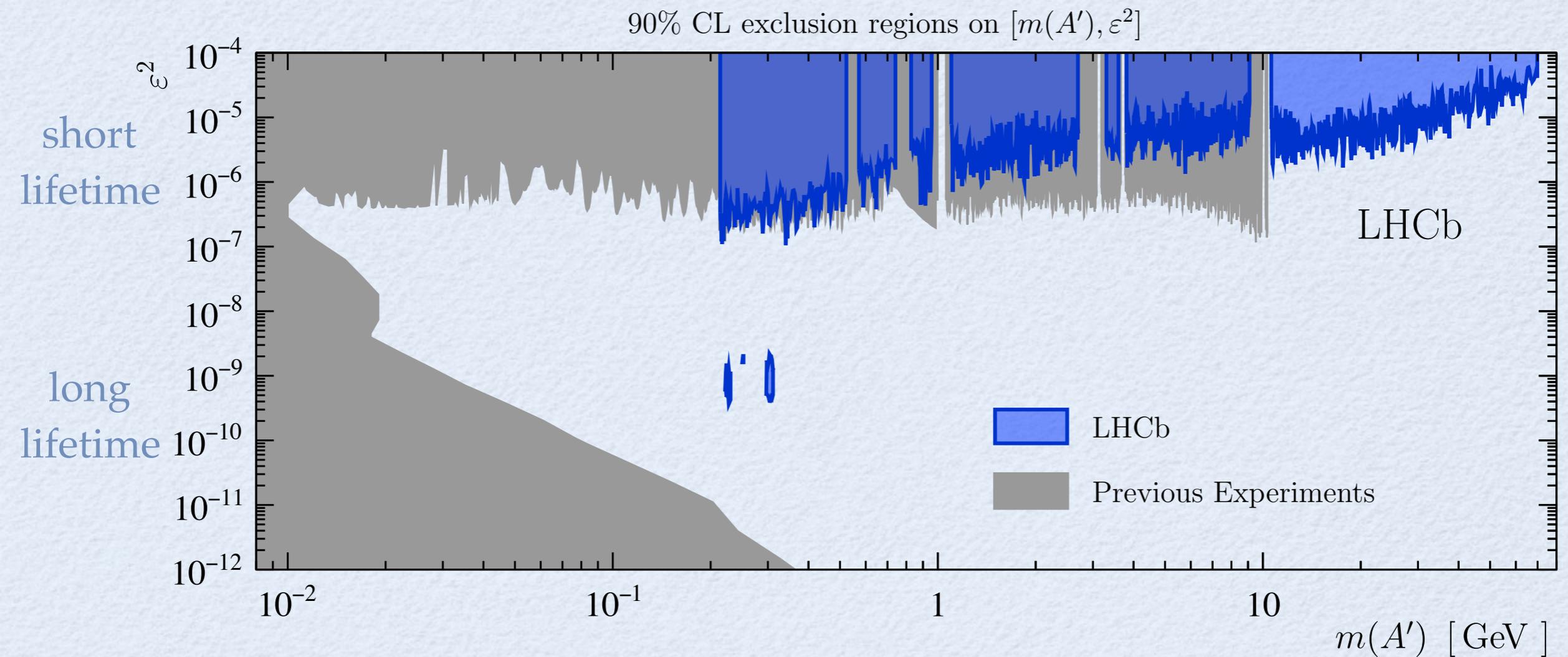
calculate three ratios


$$\frac{\text{BR}_{A' \rightarrow \mathcal{F}}(m)}{\text{BR}_{X \rightarrow \mathcal{F}}(m)}, \quad \frac{\sigma_{A'}(m, g_{A'})}{\sigma_X(m, g_X)}, \quad \frac{\varepsilon(\tau_{A'}(m, g_{A'}))}{\varepsilon(\tau_X(m, g_X))}$$

LHCb RESULT WITH 2016 DATA

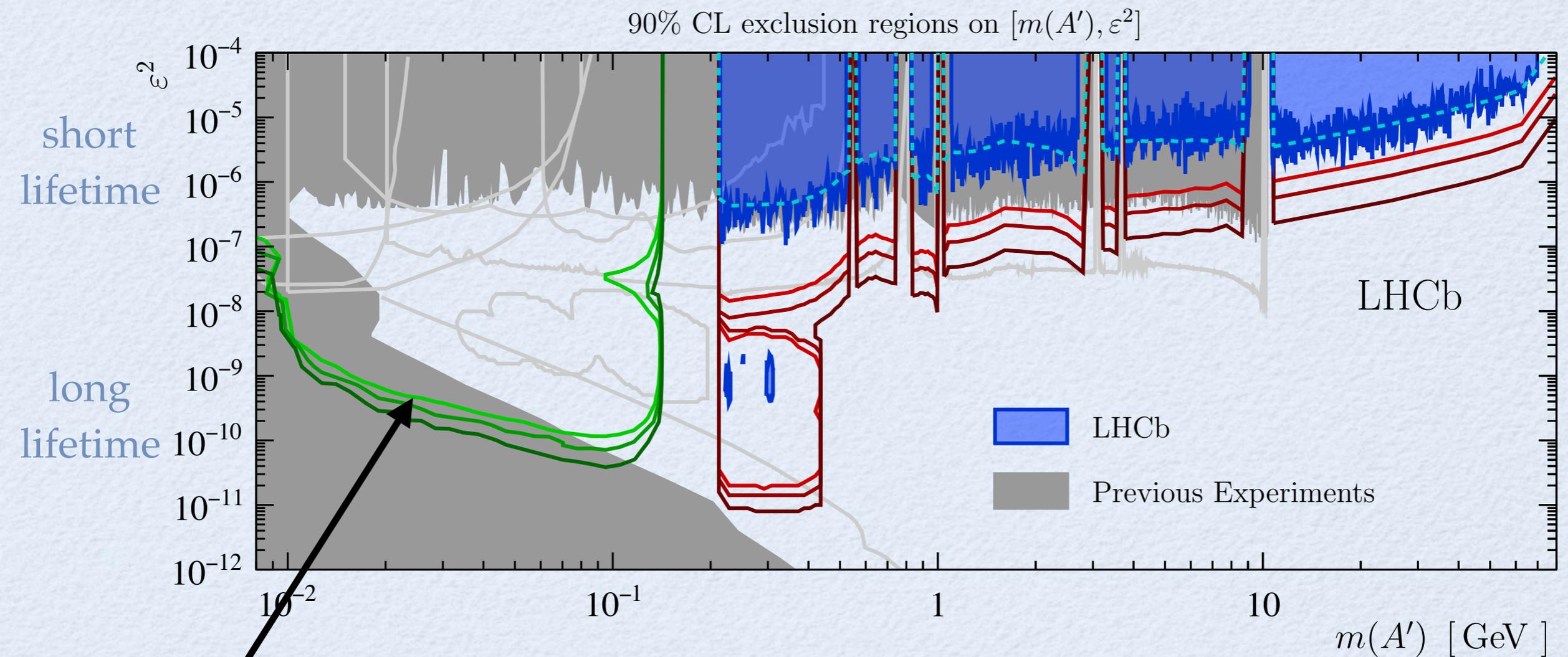


LHCb RESULT WITH 2016 DATA



LHCb, 1710.02867

LHCb RESULT WITH 2016 DATA



$D^* \rightarrow DA', A' \rightarrow e^+e^-$

Ilten, Thaler, Williams, Xue,
1509.06765

LHCb, 1710.02867

DISPLACED RECAST

$$\epsilon(\tau) = e^{-\tilde{t}_0/\tau} - e^{-\tilde{t}_1/\tau}$$

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

decay volume
shielding

$$\epsilon_{\text{max}}^2 \epsilon[\tau_{A'}(\epsilon_{\text{max}}^2)] = \epsilon_{\text{min}}^2 \epsilon[\tau_{A'}(\epsilon_{\text{min}}^2)]$$

approximate upper edge $\tau_X(g_X^{\text{max}}) \approx \tau_{A'}(\epsilon^{\text{max}})$

approximate lower edge $\left[\frac{\sigma_X \mathcal{B}_{X \rightarrow \mathcal{F}}}{\tau_X} \right]_{g_X^{\text{min}}} \approx \left[\frac{\sigma_{A'} \mathcal{B}_{A' \rightarrow \mathcal{F}}}{\tau_{A'}} \right]_{\epsilon^{\text{min}}}$