Dark Photon Interpretation of LHCb search

Wei Xue

CERN

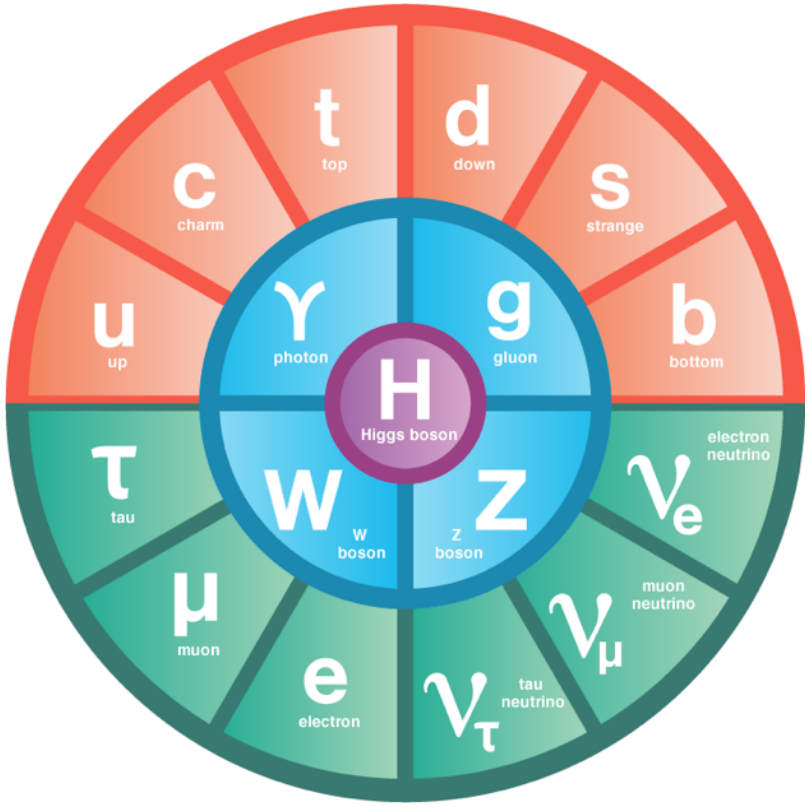
May 16, 2018

with P. Ilten, Y. Soreq, M. Williams

1801.04847

WIMP

weakly interacting massive particles



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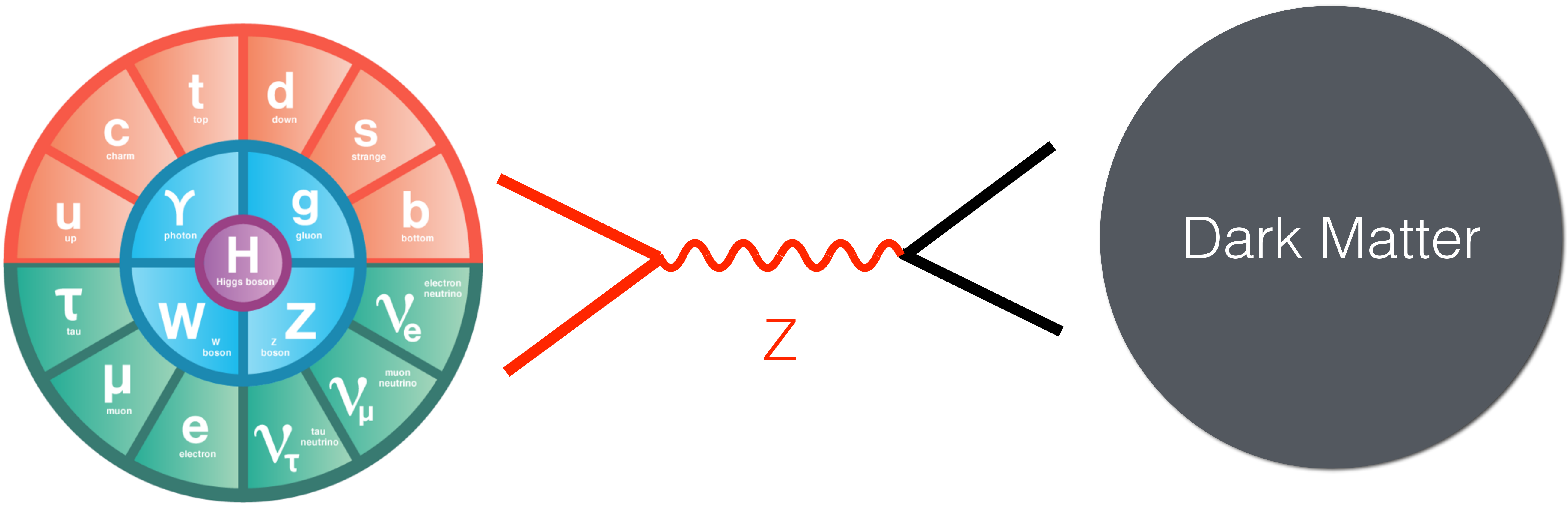

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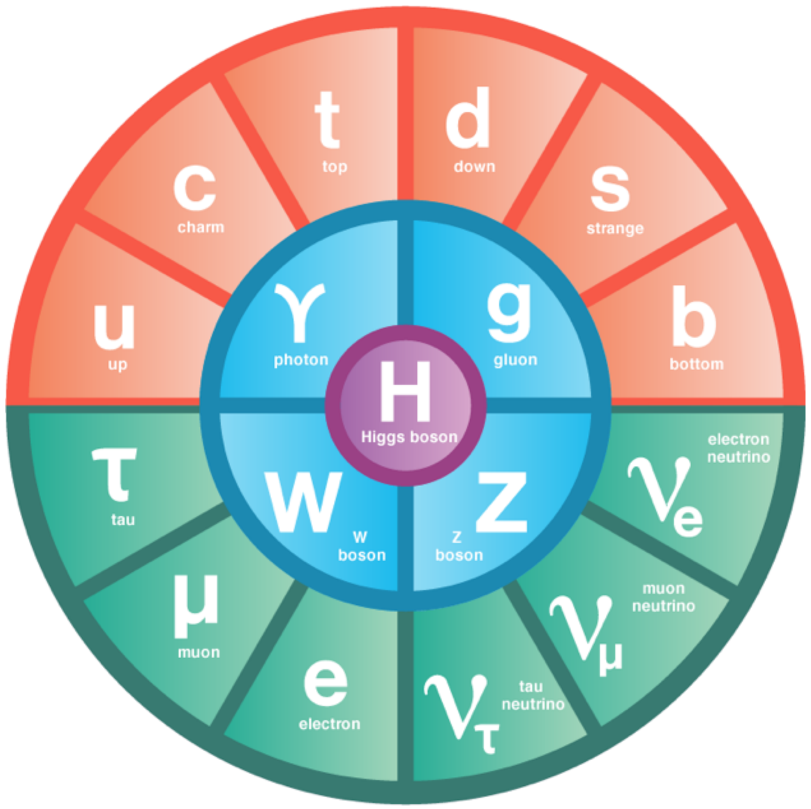
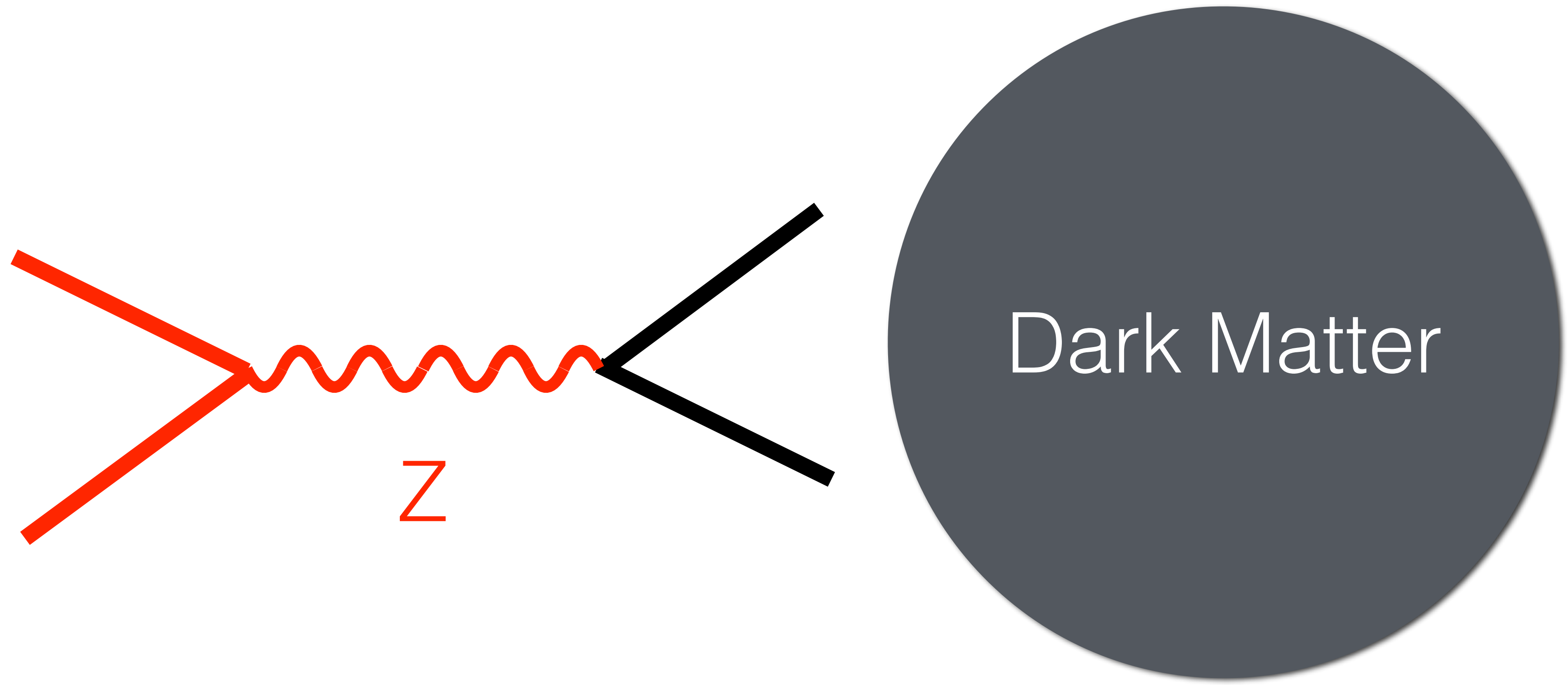
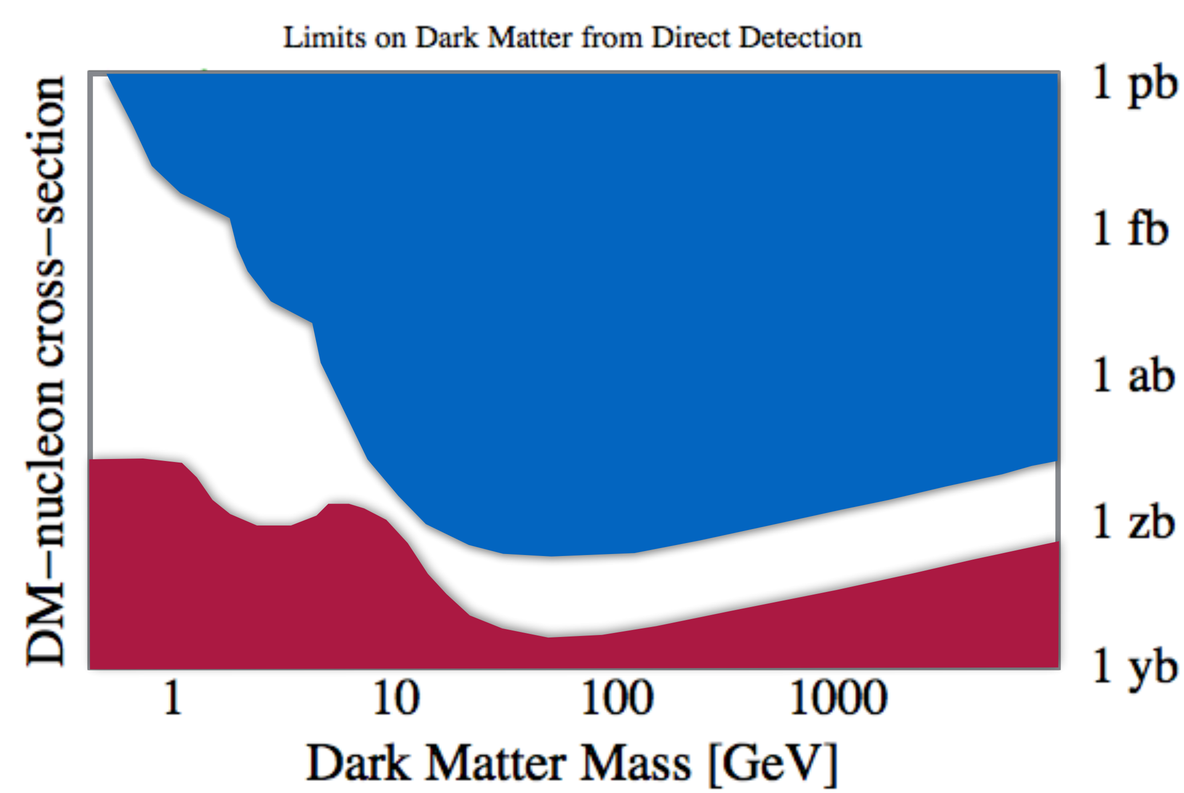
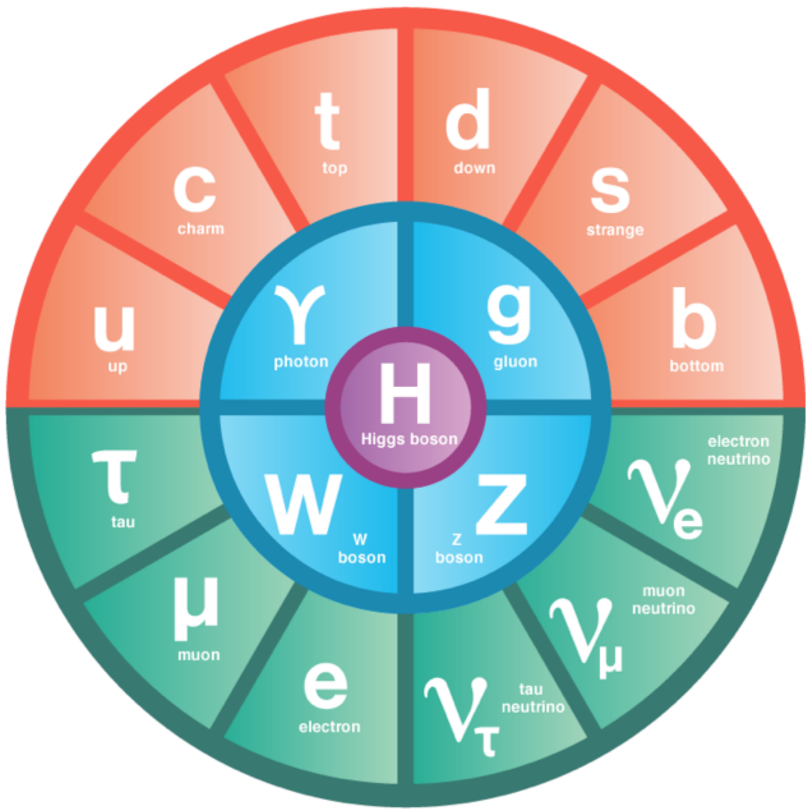


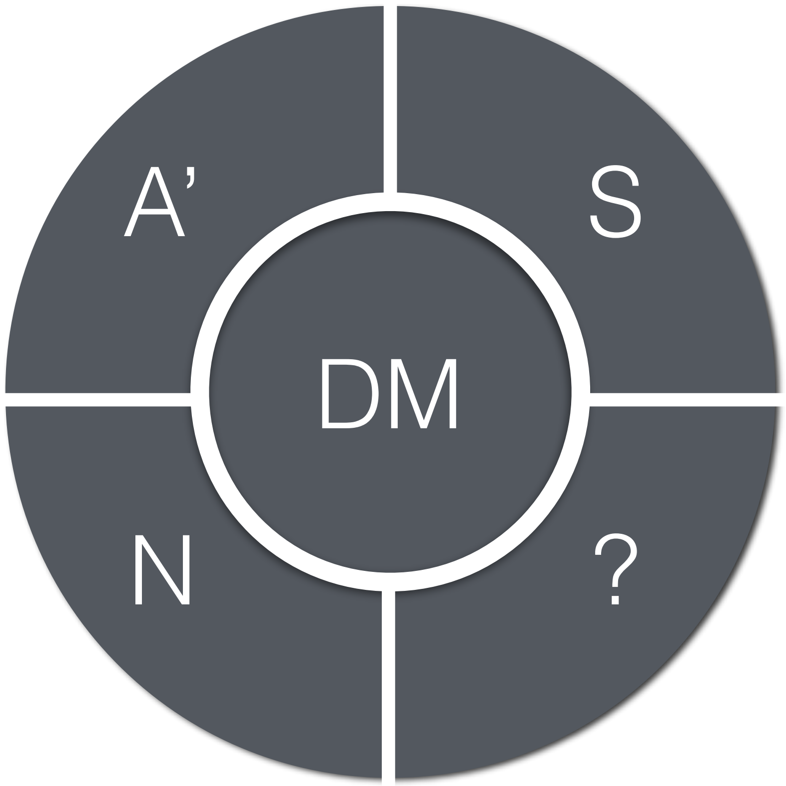




Dark Sector?

- analogous to the Standard Model
  dark sector can have rich structures





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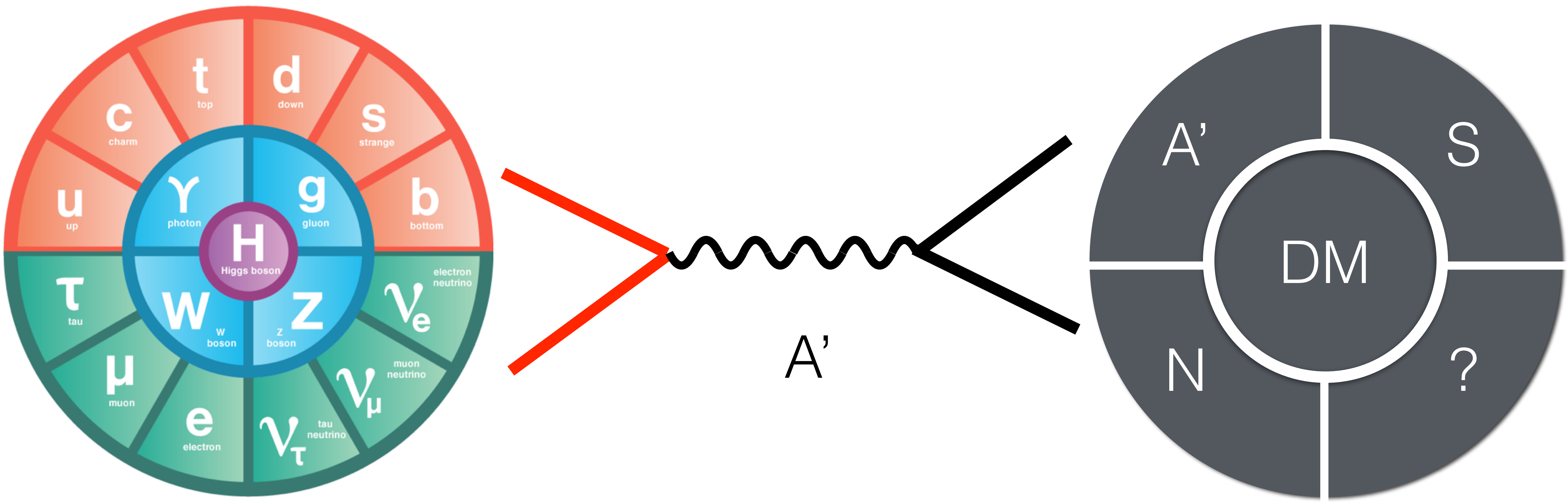
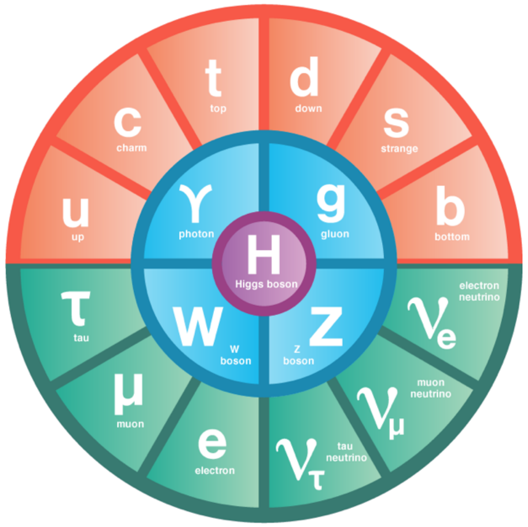


Dark Photons

- **U(1)’** dark photon can kinetically mix with photon



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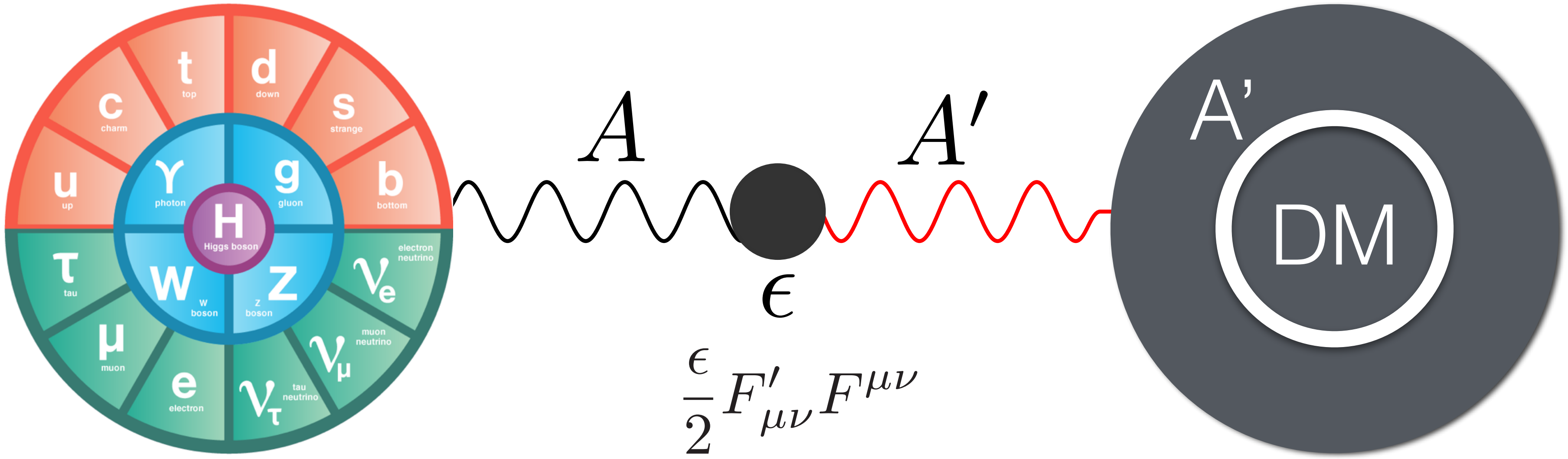

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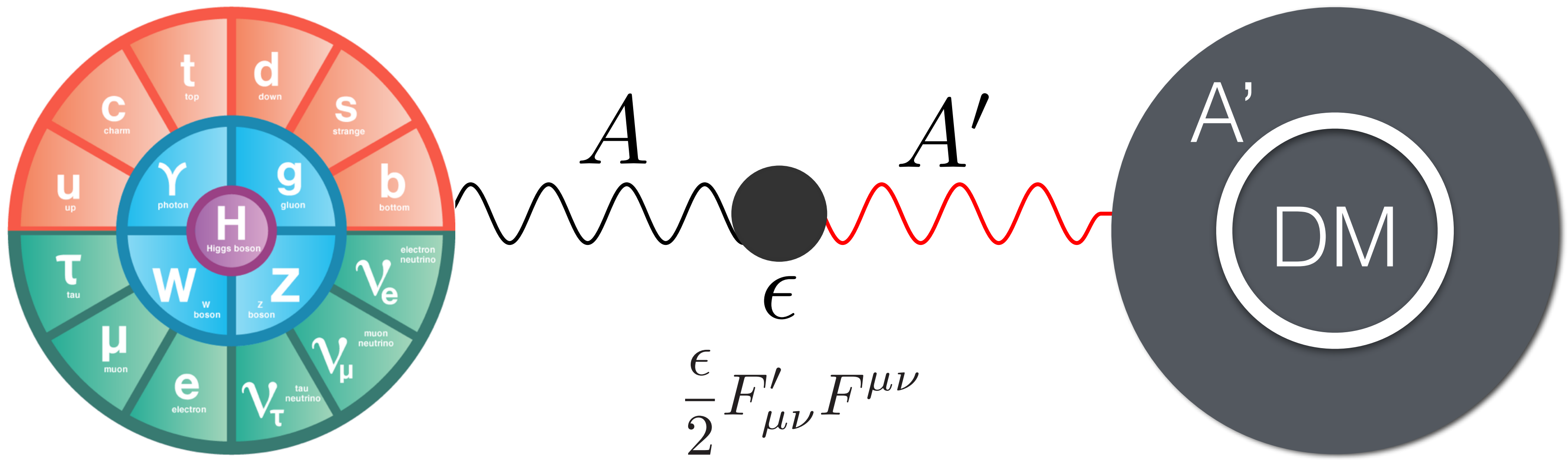
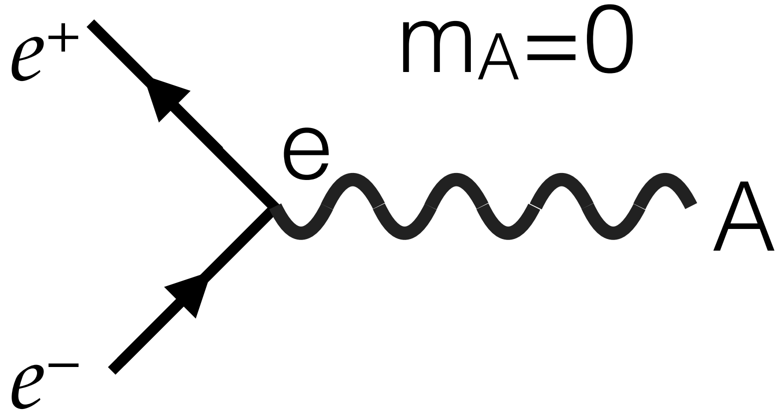


Photon

$m_A = 0$



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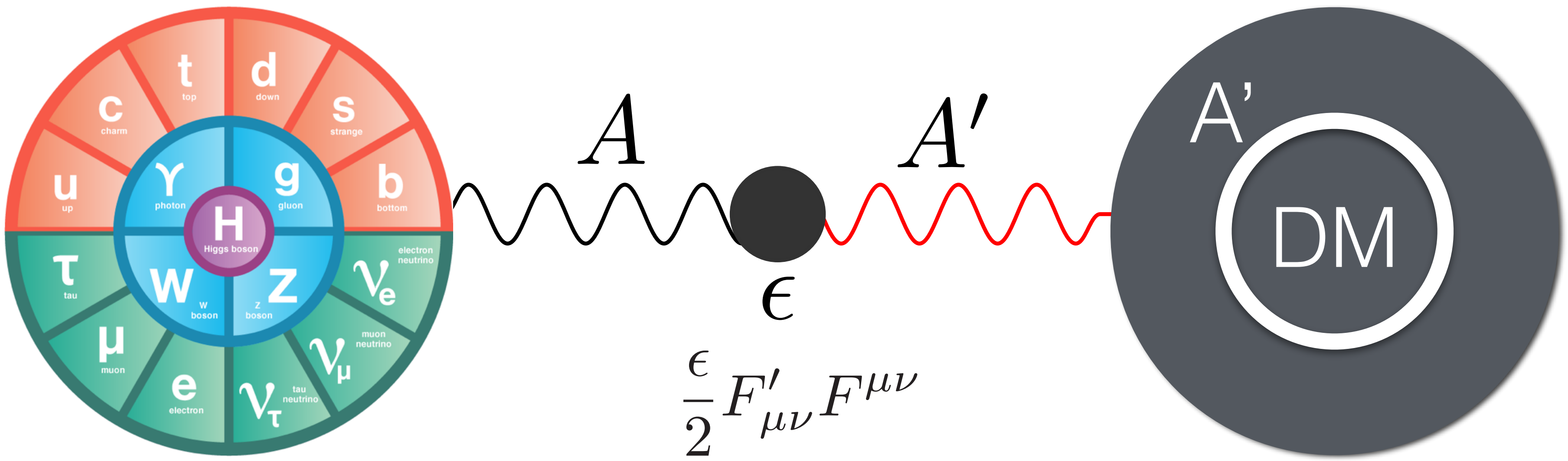
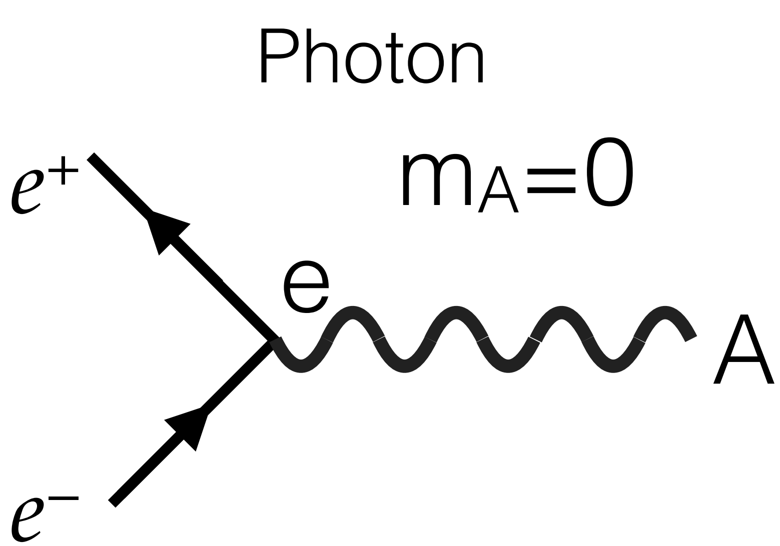
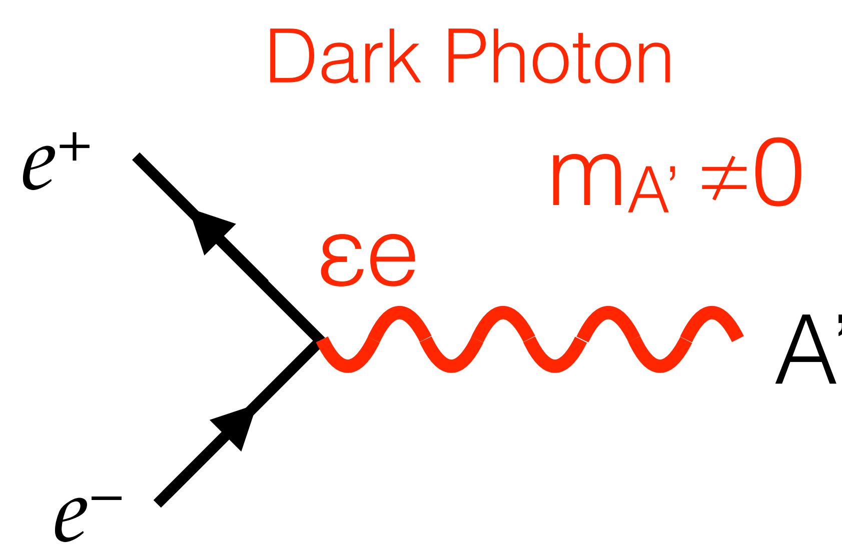


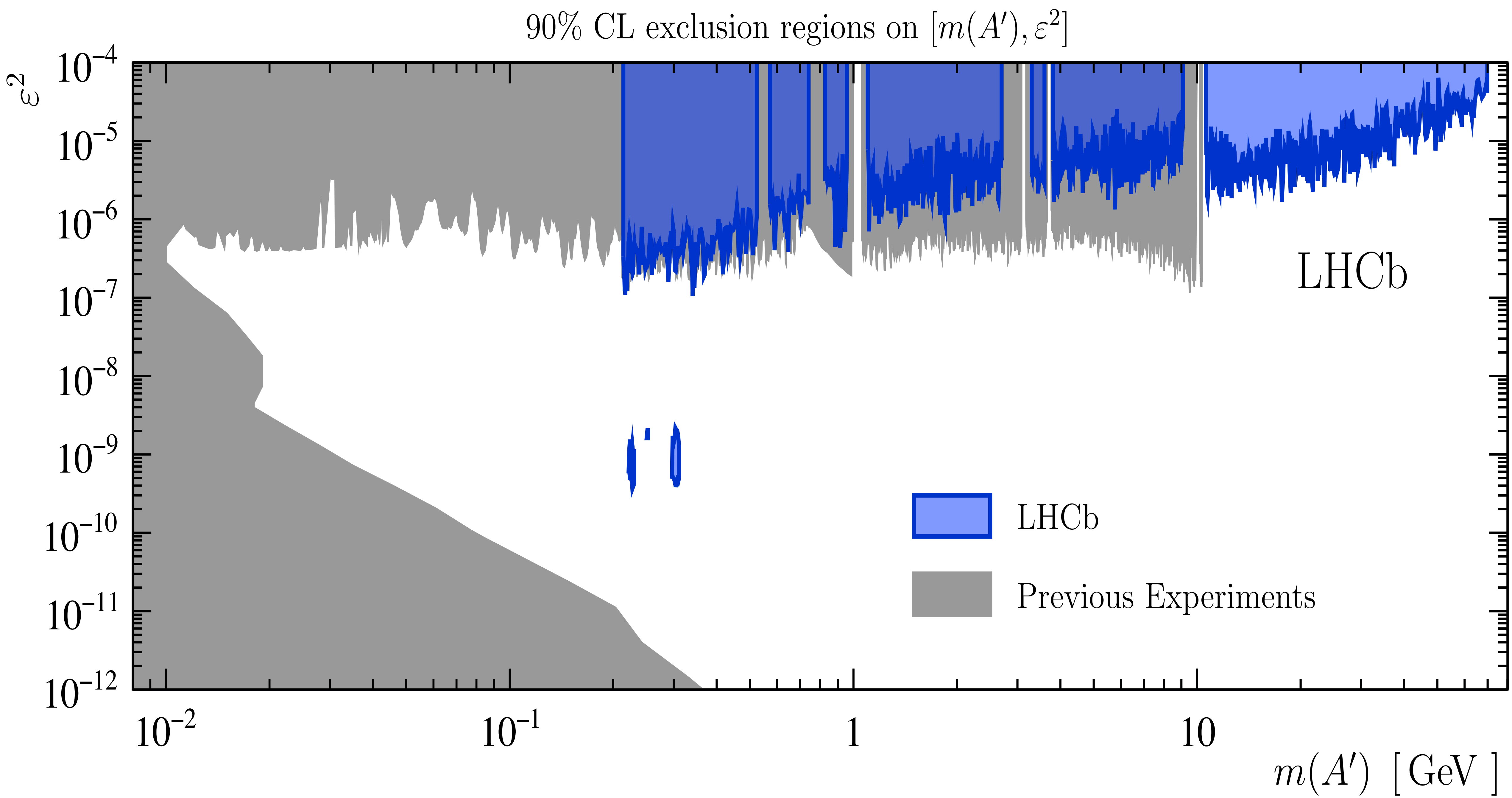




New Results from LHCb

real data

2016 data, 1.6 fb^{-1}

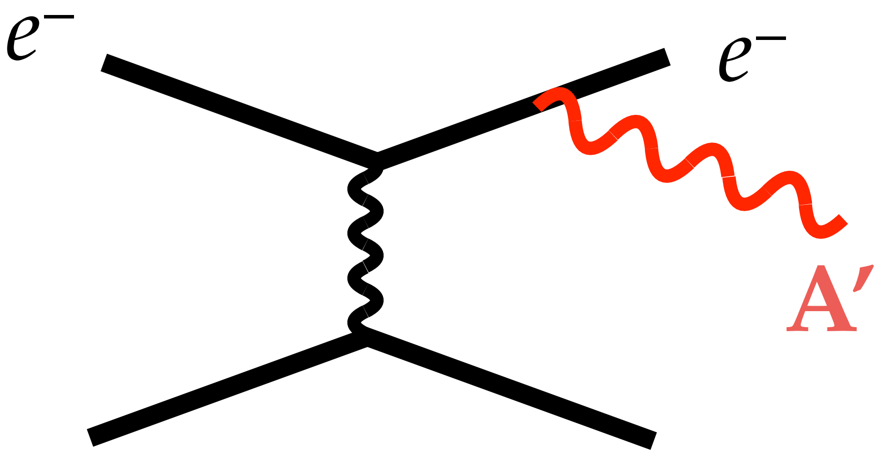


LHCb collaboration (2017), arXiv:1710.02867

produce dark photons

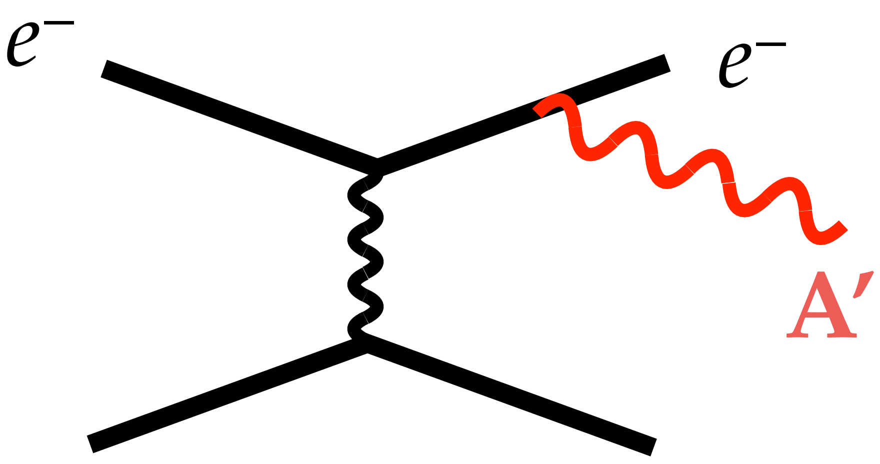
produce dark photons

- Bremsstrahlung

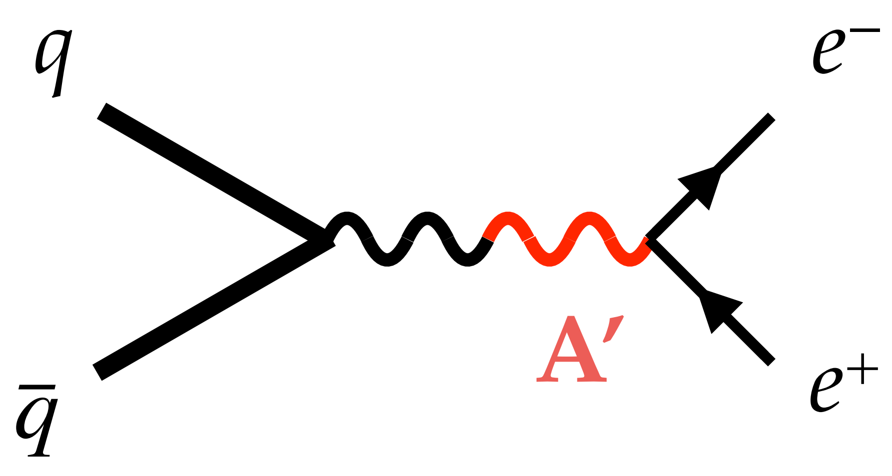


produce dark photons

- Bremsstrahlung

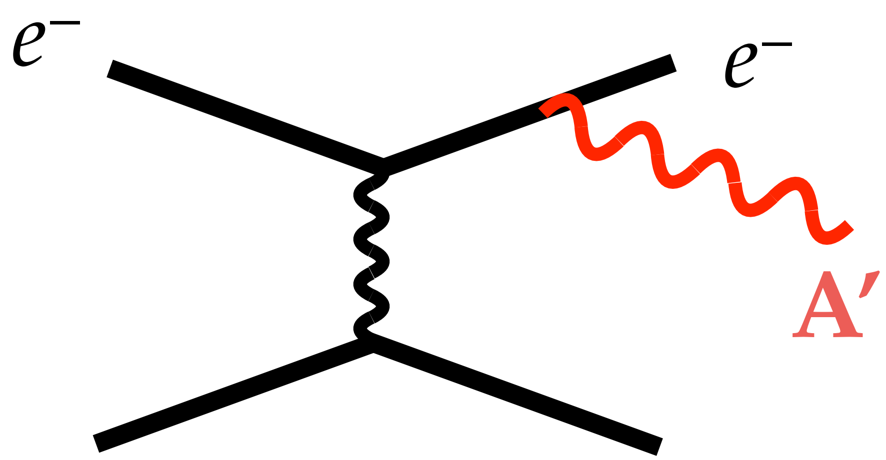


- Drell-Yan



produce dark photons

- Bremsstrahlung



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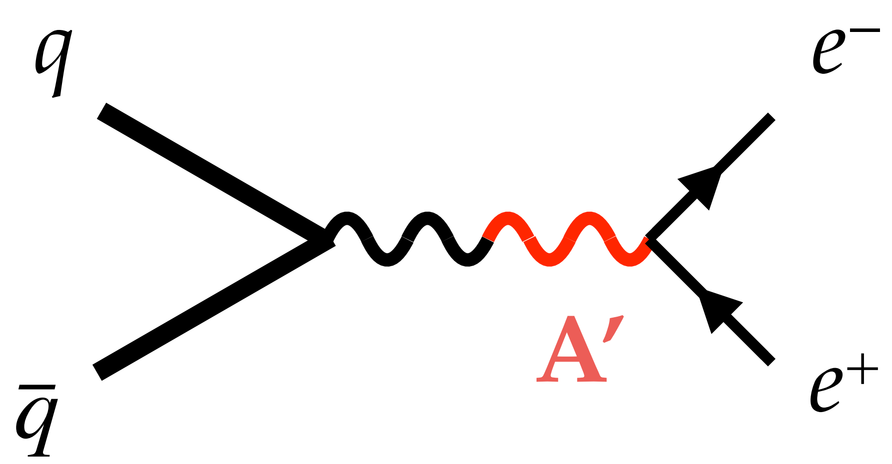
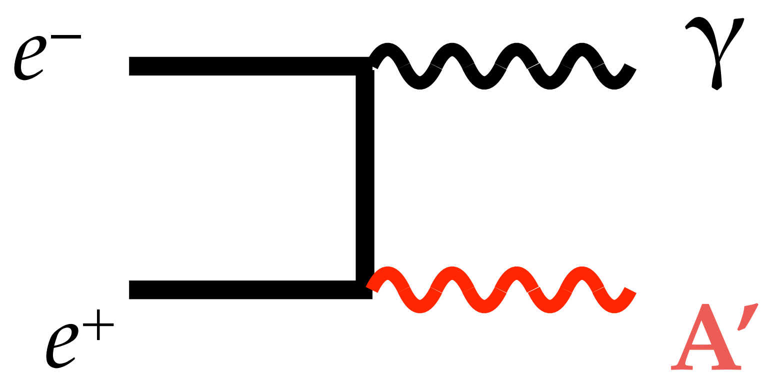
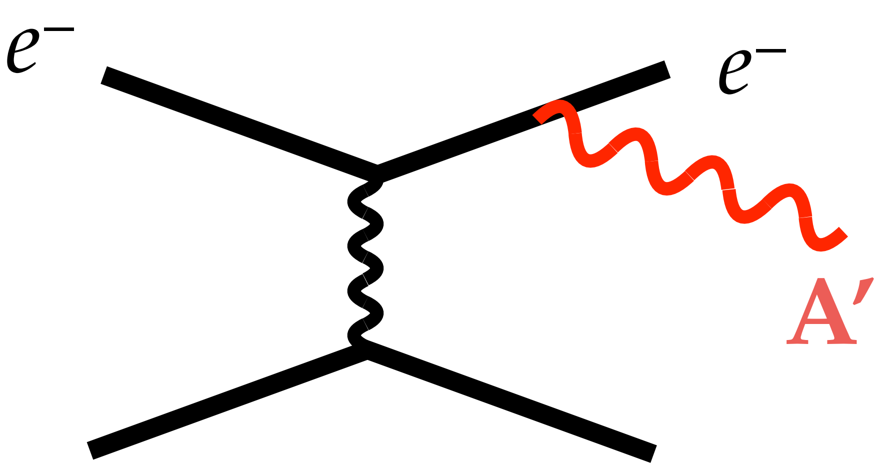


- Annihilation



produce dark photons

- Bremsstrahlung



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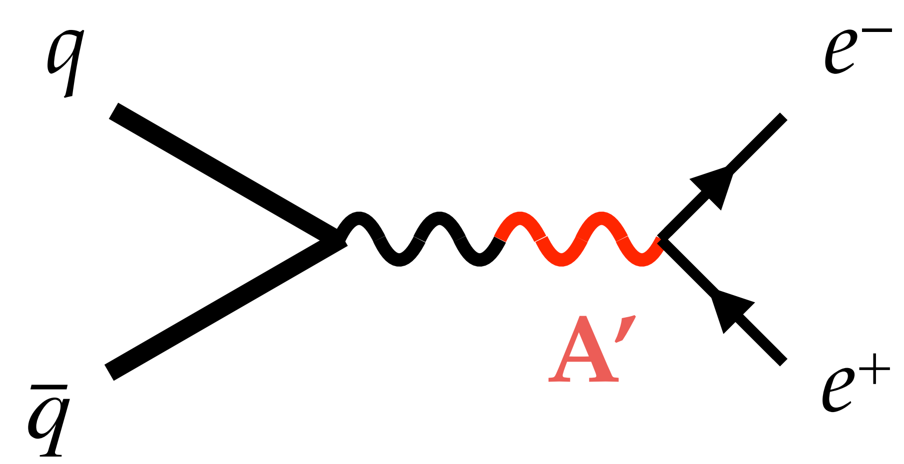

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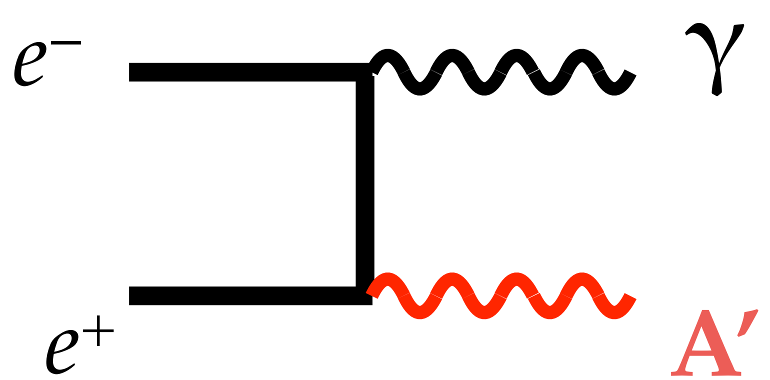
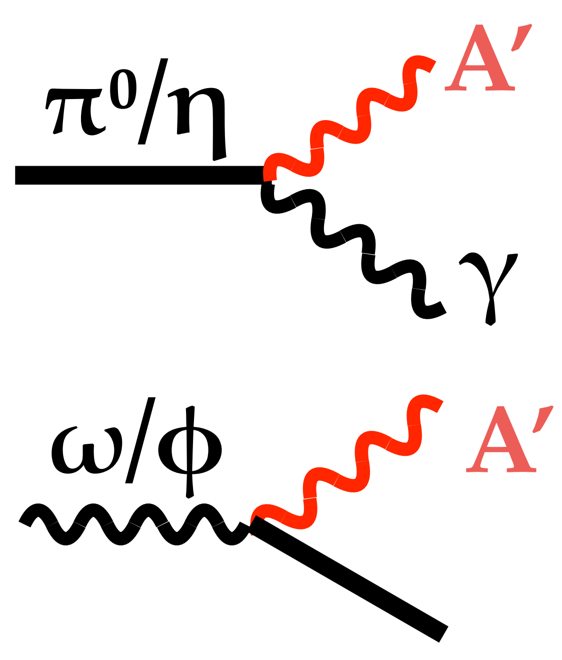
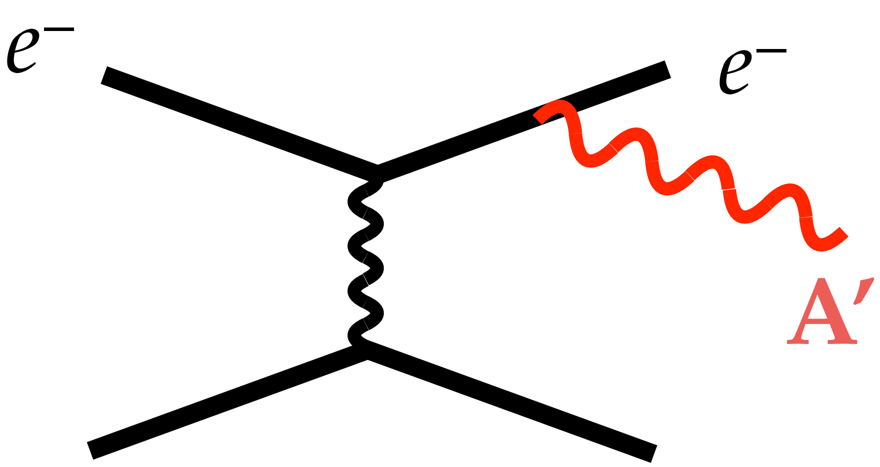


- Meson decay

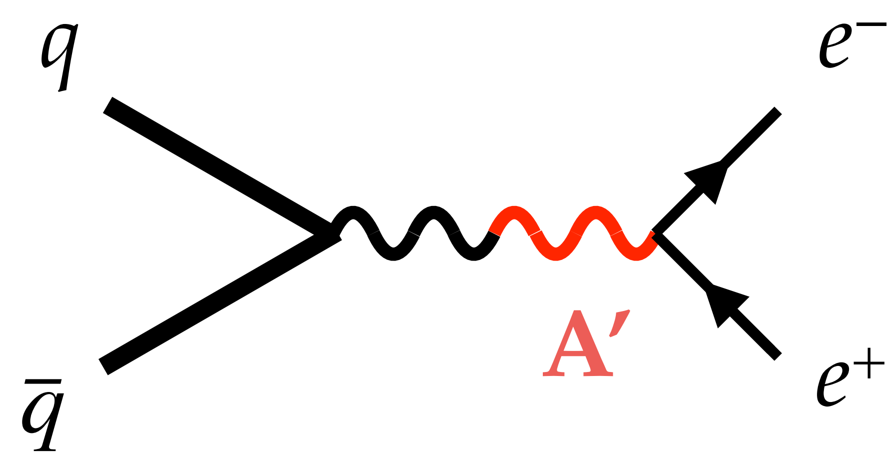


produce dark photons

- Bremsstrahlung



- Drell-Yan



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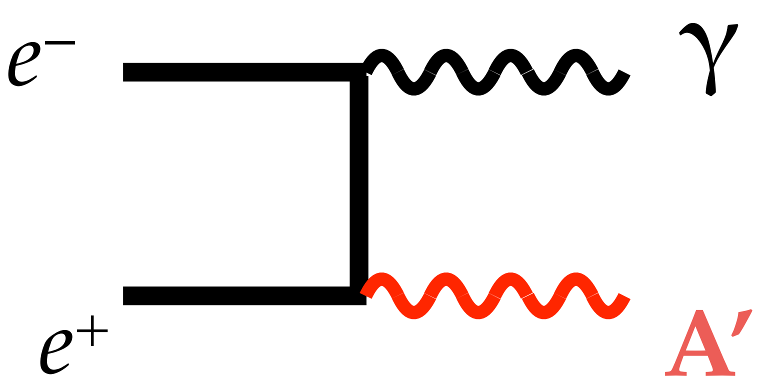

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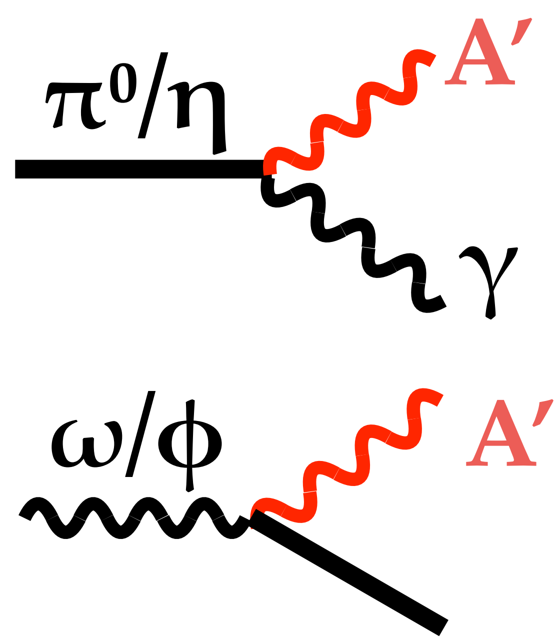
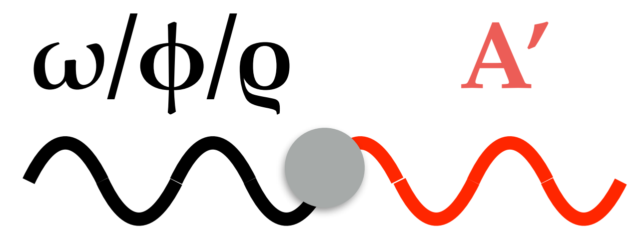
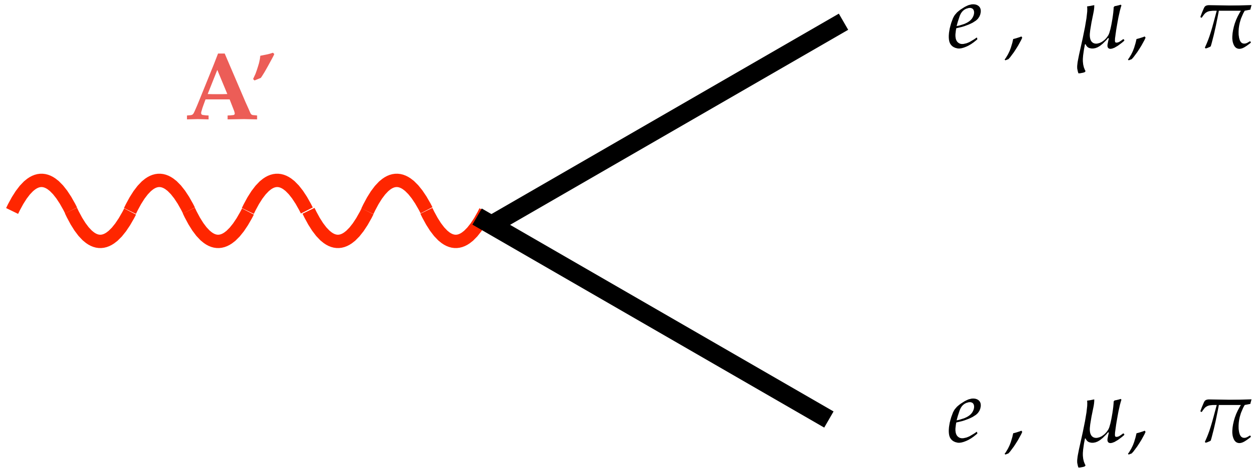


- V / A′ Mixing

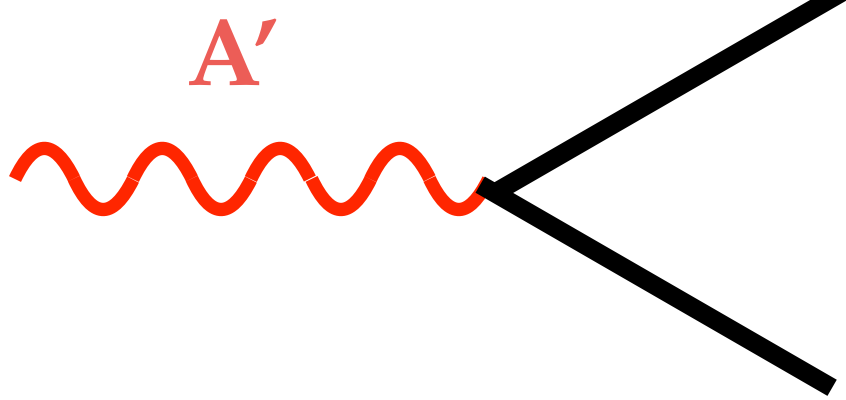


dark photons decay

- Searches



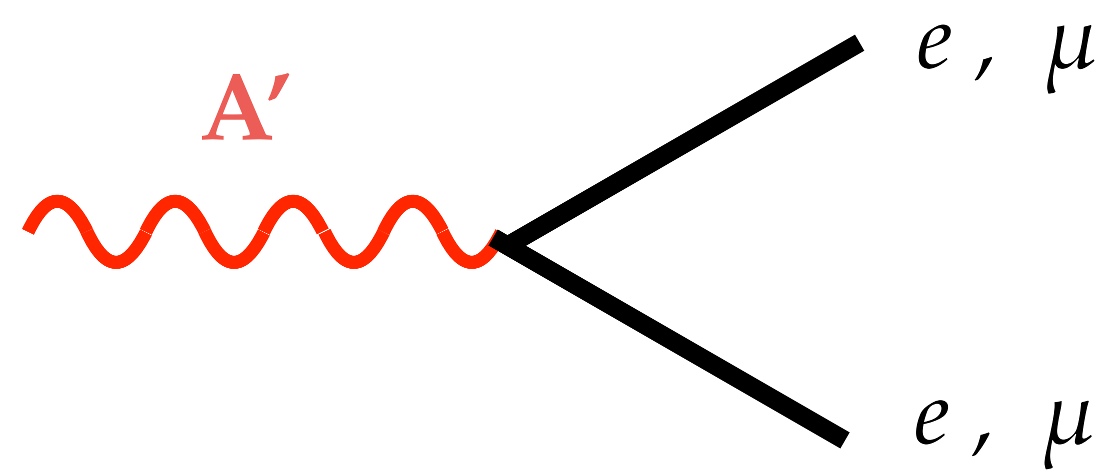
- others



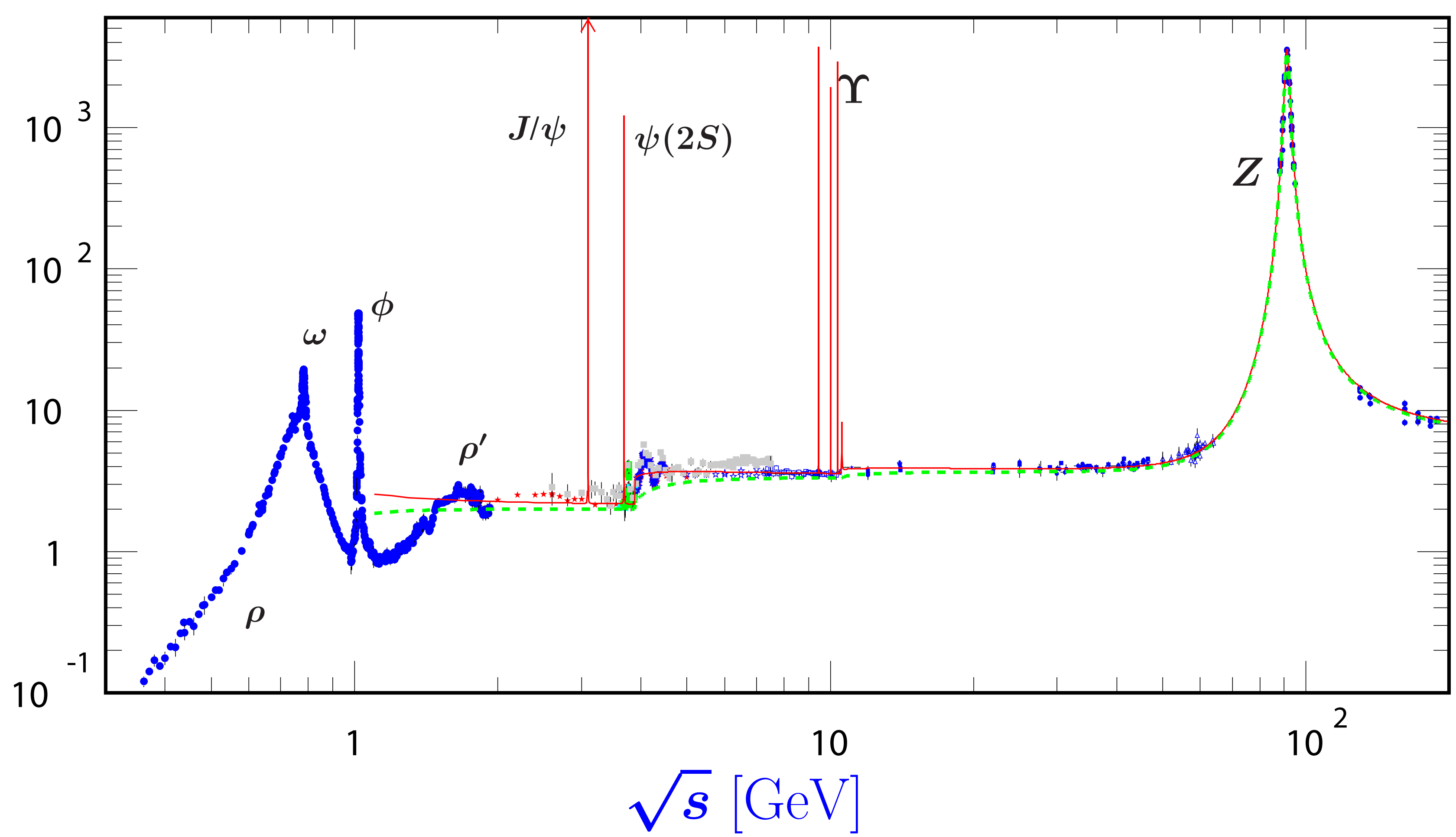
hadronic decays

3π, 4π, KK, $KK\pi$, $\pi\gamma$

dark photons decay

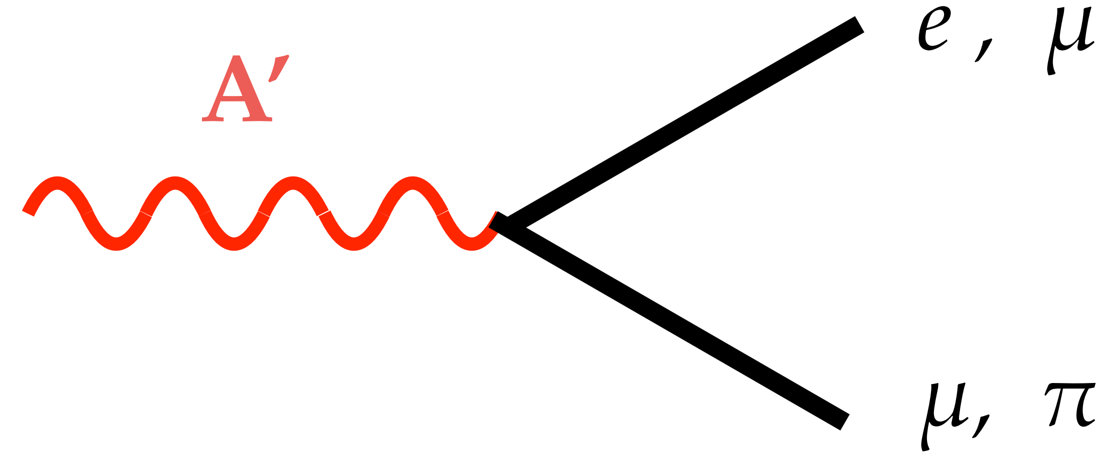


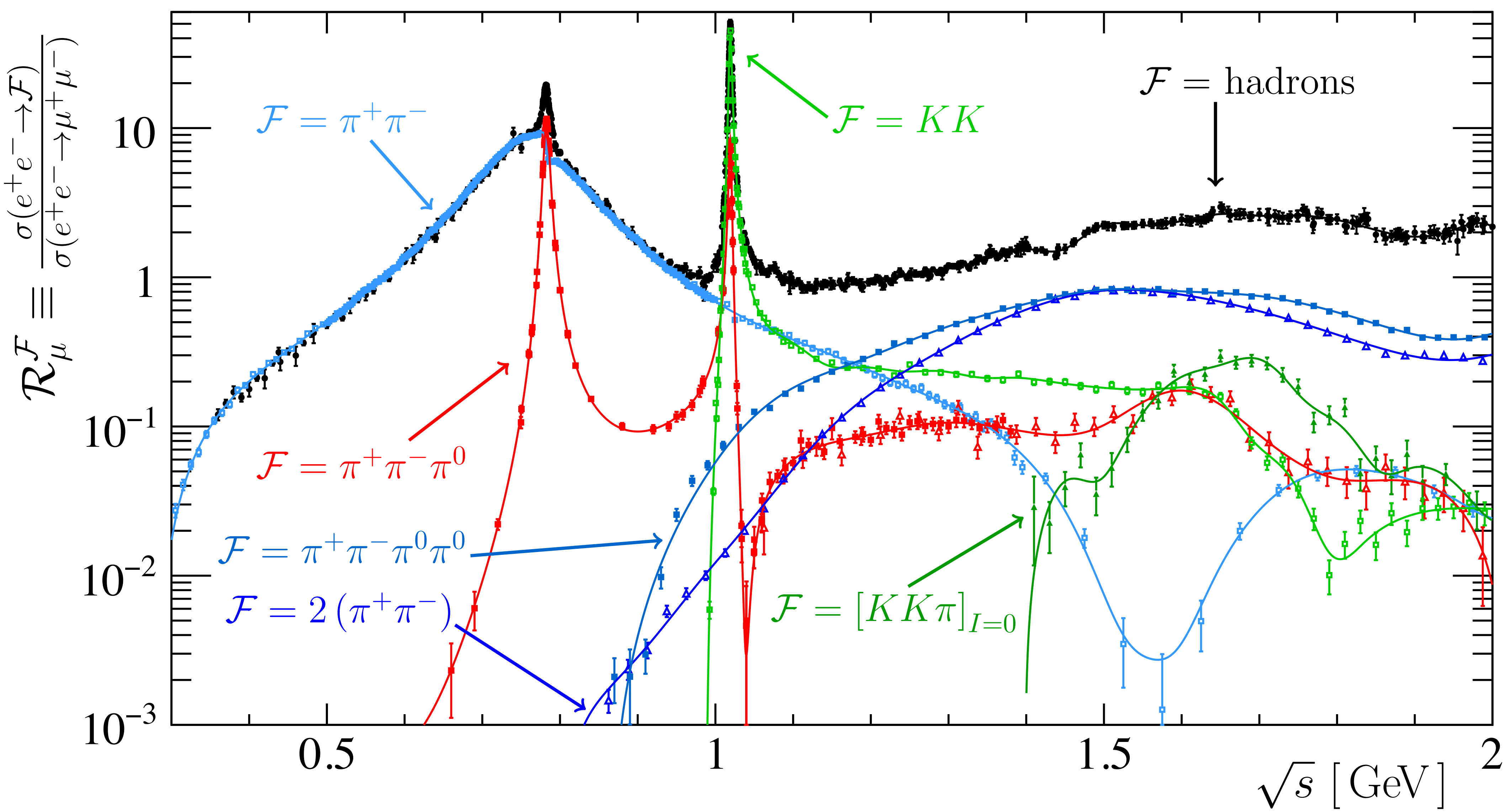
$$R \equiv \sigma\left(e^+e^- \to hadrons\right)/\sigma\left(e^+e^- \to \mu^+\mu^-\right)$$



PDG

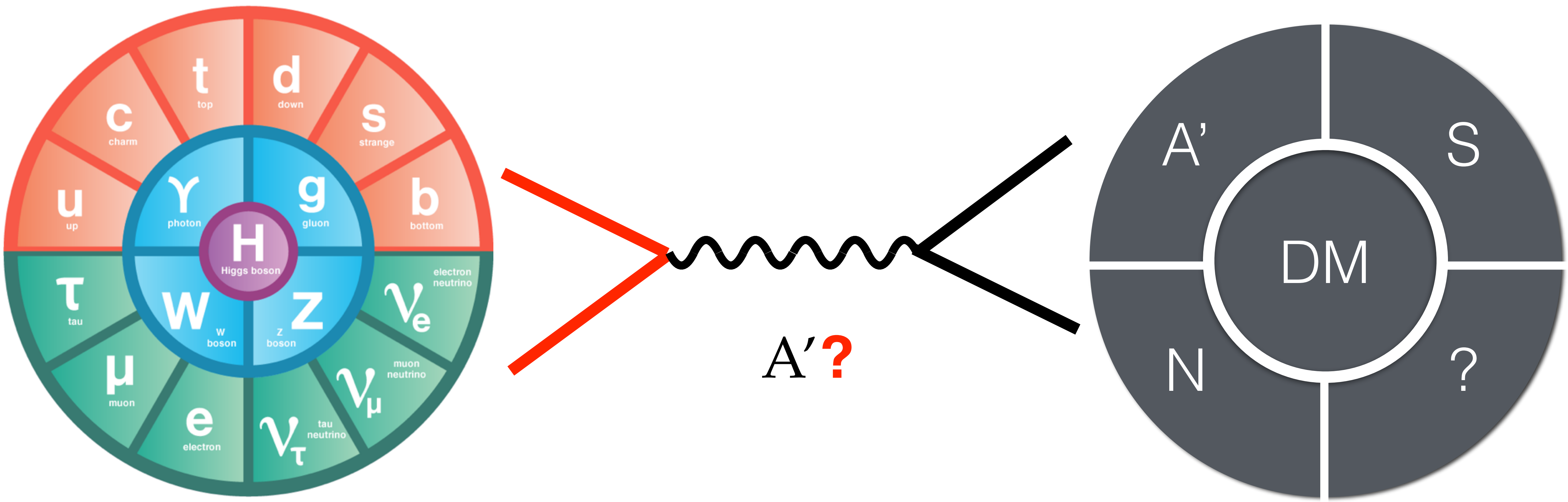
dark photons decay





Beyond Dark Photons

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



Beyond Dark Photons

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

Coupling	A'	$B-L$	B	Protophobic
g_X	εe	g_{B-L}	g_B	$g_{\not{p}}$
$x_{u,c,t}$	$\frac{2}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	$-\frac{1}{3}$
$x_{d,s,b}$	$-\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{2}{3}$
$x_{e,\mu,\tau}$	-1	-1	$-\frac{e^2}{(4\pi)^2}$	-1
$x_{\nu_e,\nu_\mu,\nu_\tau}$	0	-1	0	0

Recast
Dark Photon → Others

$$\sigma(A') \, \mathrm{BR}(A' \to \mathcal{F}) \, \mathrm{Efficiency}(\tau_{A'})$$
$$= \sigma(X) \, \mathrm{BR}(X \to \mathcal{F}) \, \mathrm{Efficiency}(\tau_X)$$

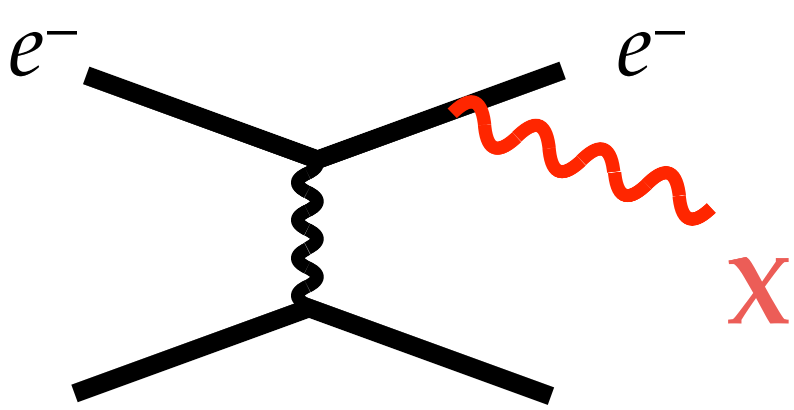
- Production
- Decay
- Lifetime

Production

$$\sigma\,(A') \; \mathrm{BR}(A' \to \mathcal{F}) \; \mathrm{Efficiency}(\tau_{A'})$$

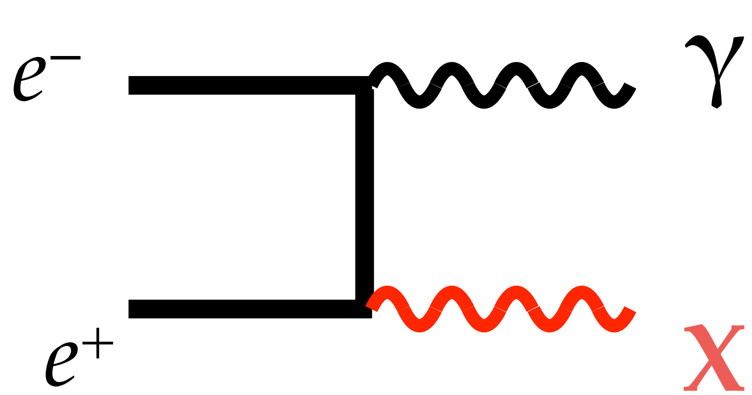
$$= \; \sigma\,(X) \; \mathrm{BR}(X \to \mathcal{F}) \; \mathrm{Efficiency}(\tau_{X})$$

- Bremsstrahlung



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

- Annihilation

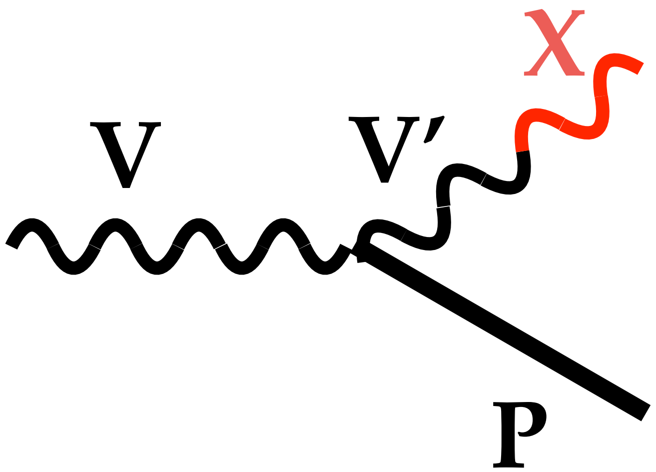


Production

σ (A') BR(A'$\rightarrow \mathcal{F}$) Efficiency($\tau_{A'}$)

= σ (X) BR(X$\rightarrow \mathcal{F}$) Efficiency(τ_X)

- Meson decay



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

U(3) meson generator

No mixing between ρ and $U(1)_B$

$$\mathrm{Tr}\left[T_\rho Q_{B-L}\right] = 0$$

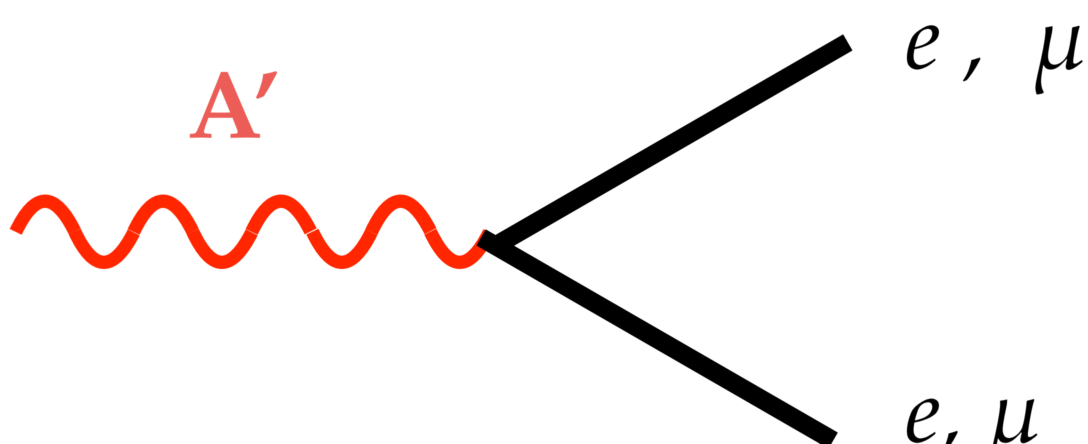
$$T_\rho = \frac{1}{2}\mathrm{diag}\{1,-1,0\} \qquad Q = \frac{1}{3}\mathrm{diag}\{2,-1,-1\} \qquad Q_{B\text{–}L} = Q_B = \frac{1}{3}\mathrm{diag}\{1,1,1\}$$

decay

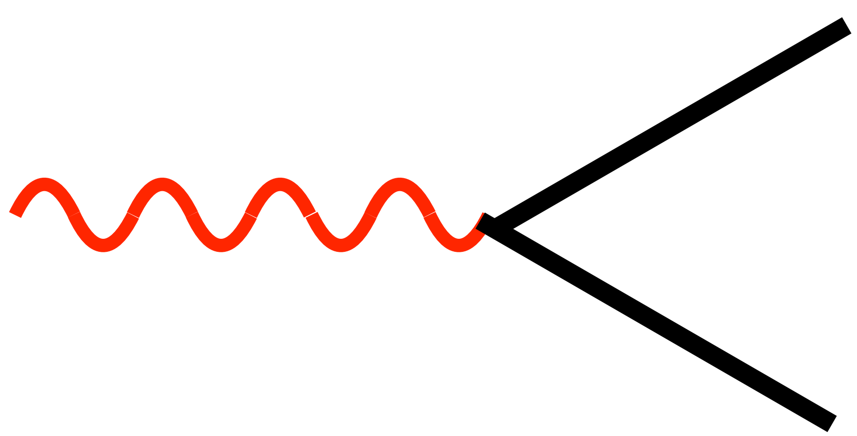
$$\sigma\,(A') \ \mathbf{BR}(A' \to \mathcal{F}) \ \text{Efficiency}(\tau_{A'})$$

$$= \ \sigma\,(X) \ \mathbf{BR}(X \to \mathcal{F}) \ \text{Efficiency}(\tau_{X})$$

Perturbative Computation



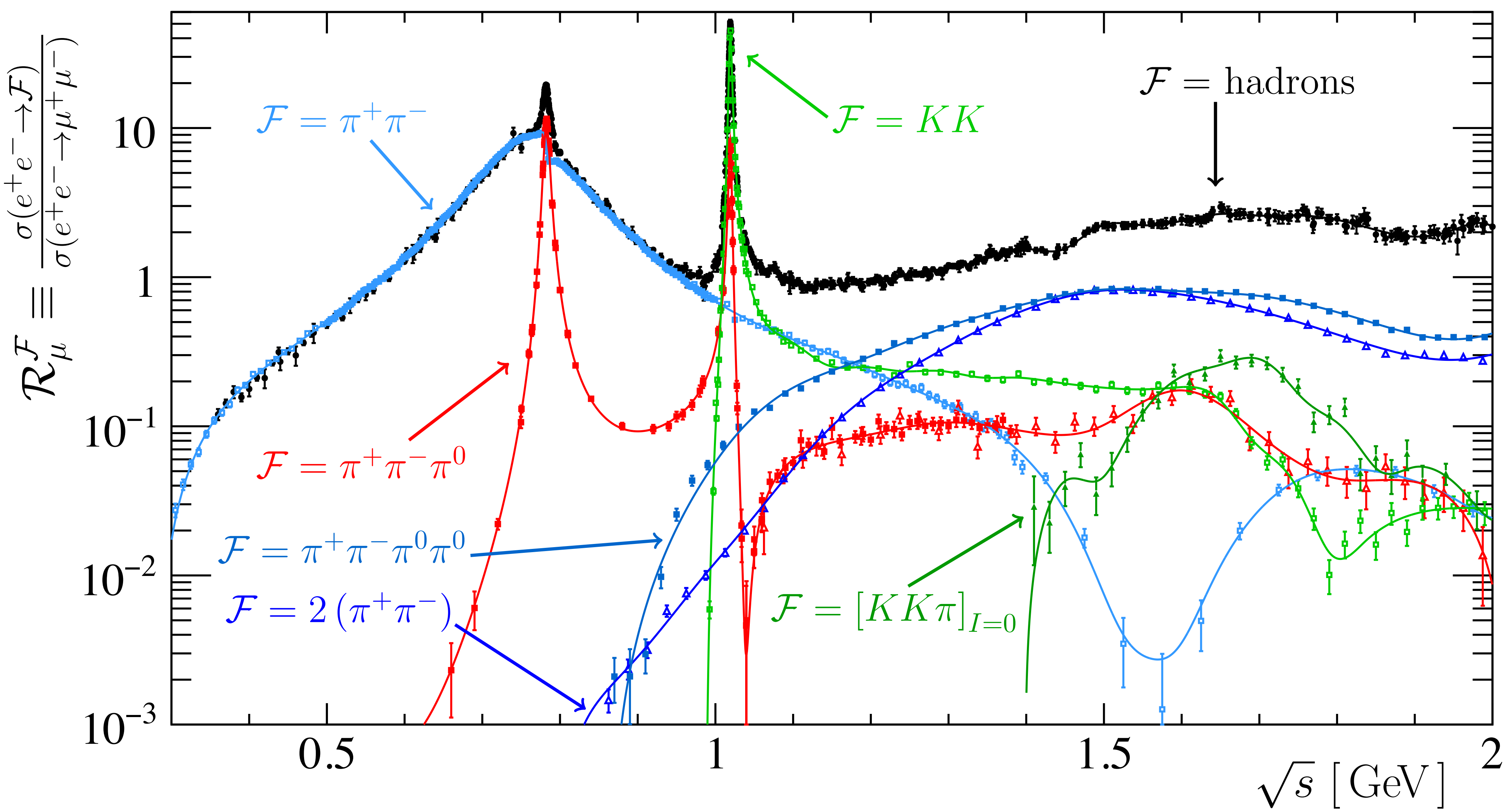
R value



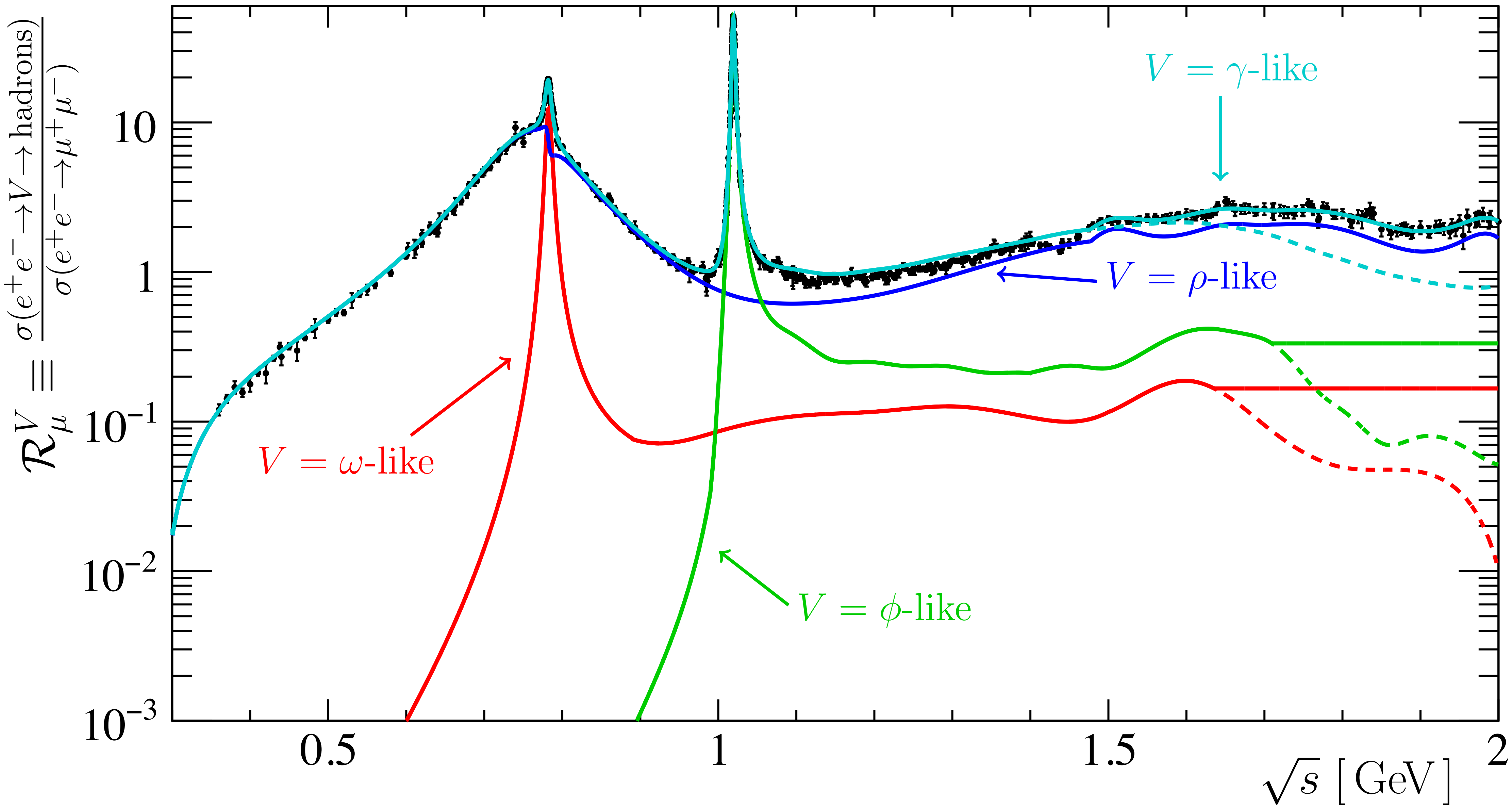
hadronic decays

$2\pi,\ 3\pi,\ 4\pi,\ KK,\ KK\pi,\ \pi\gamma$

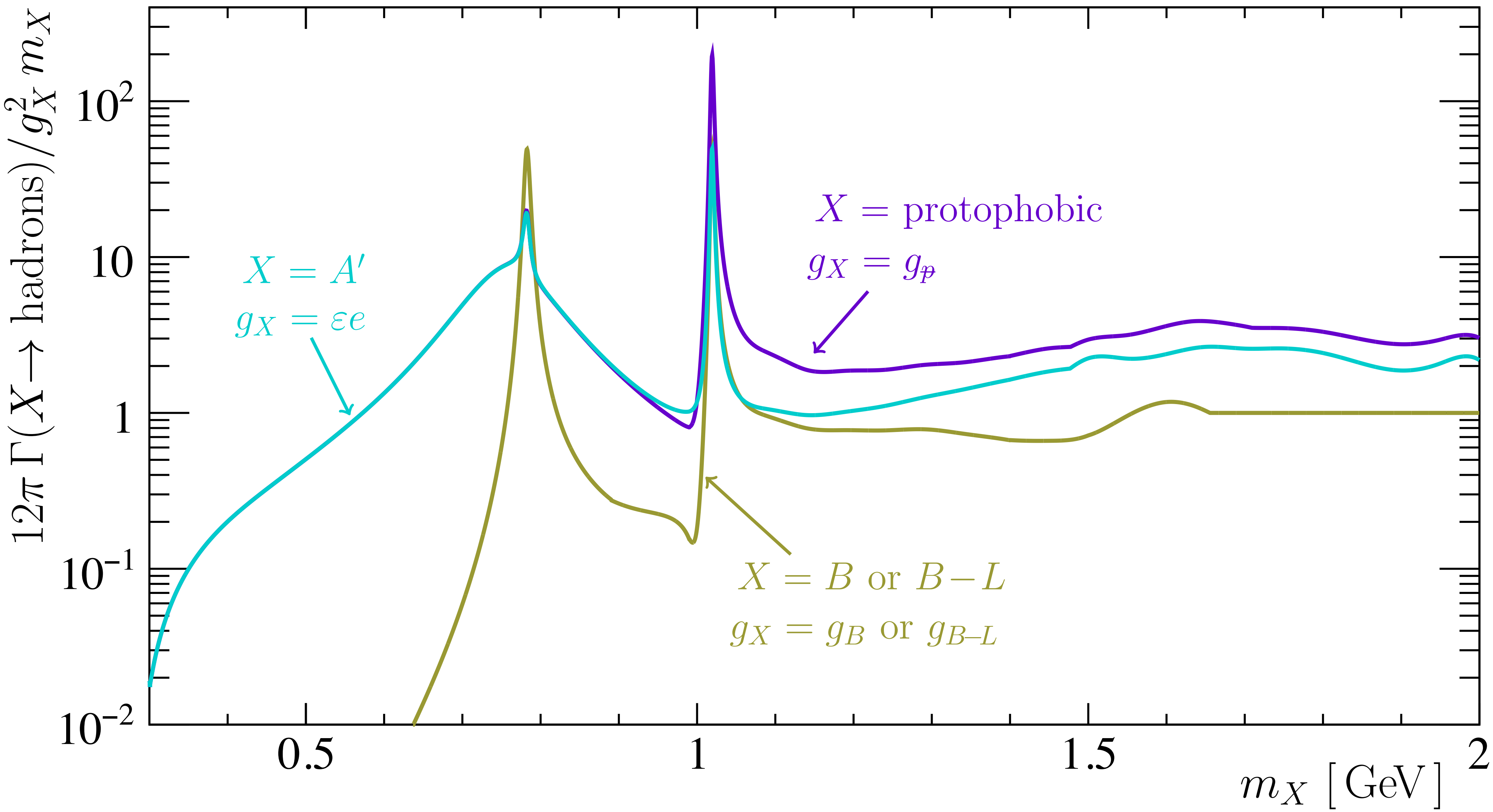
dark photons decay



vector mesons



decay



$12\pi\,\Gamma(X\to \text{hadrons})/g_X^2\, m_X$
10^2
10
1
10^{-1}
10^{-2}
0.5
1
1.5
2
m_X [GeV]
$X = A'$
$g_X = \varepsilon e$
X = protophobic
$g_X = g_{\not p}$
$X = B$ or $B-L$
$g_X = g_B$ or g_{B-L}

Efficiency

σ (A') BR(A'→$\mathcal{F}$) **Efficiency($\tau_{A'}$)**

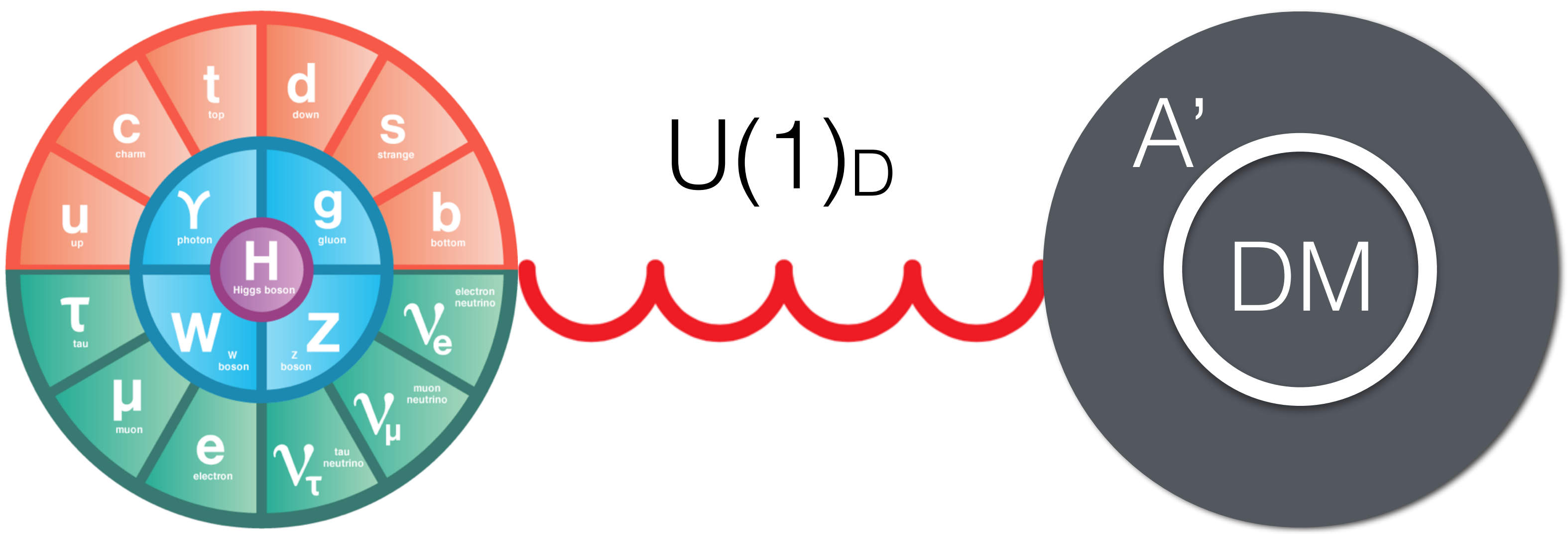
= σ (X) BR(X→$\mathcal{F}$) **Efficiency(τ_X)**

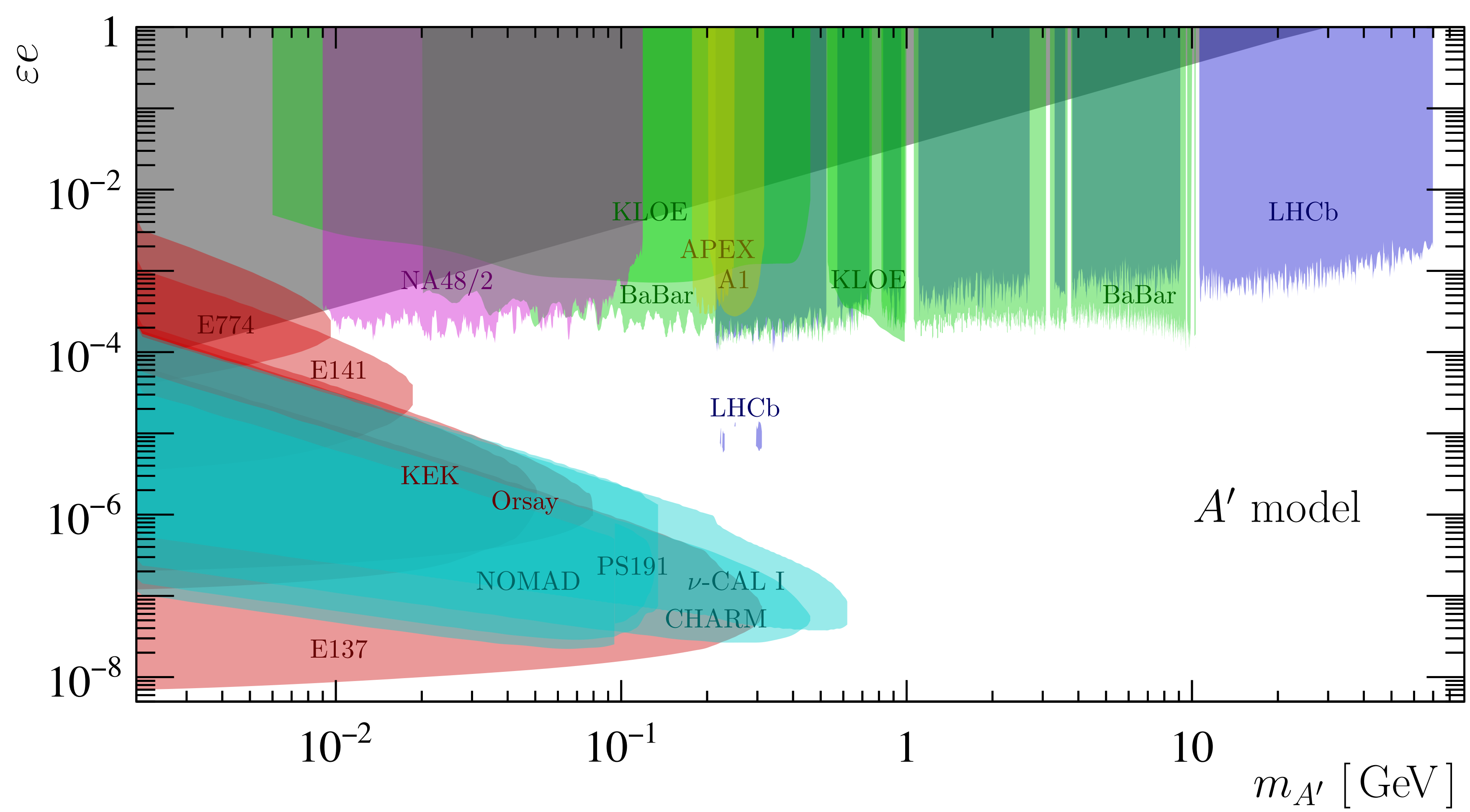
$$r_{\rm ex}^{\rm ul}(m_{A'},\varepsilon^2)$$

The upper limit on observed A' relative to the expected number of observed A' decay

$$\left[r_{\rm ex}^{\rm ul}(m_{A'},\varepsilon^2)\,\frac{\sigma_{A'}\mathcal{B}_{A'\to\mathcal{F}}}{\sigma_X\mathcal{B}_{X\to\mathcal{F}}}\right]_{\tau_X=\tau_{A'}} < \ 1$$

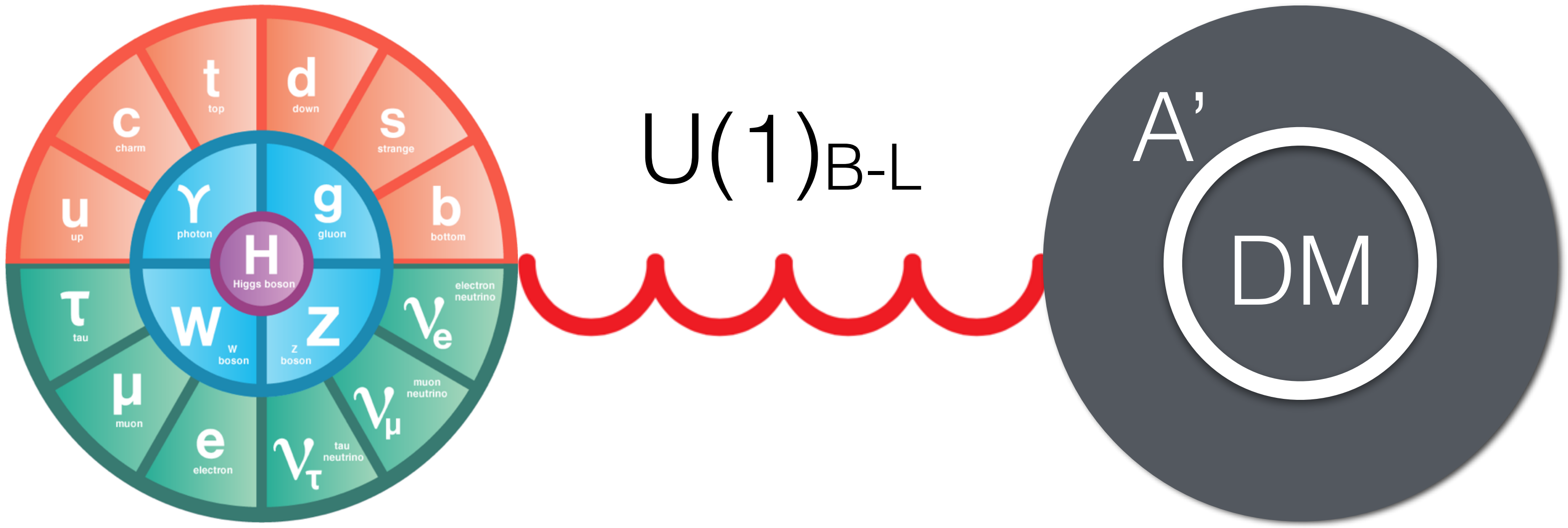
Dark Photon



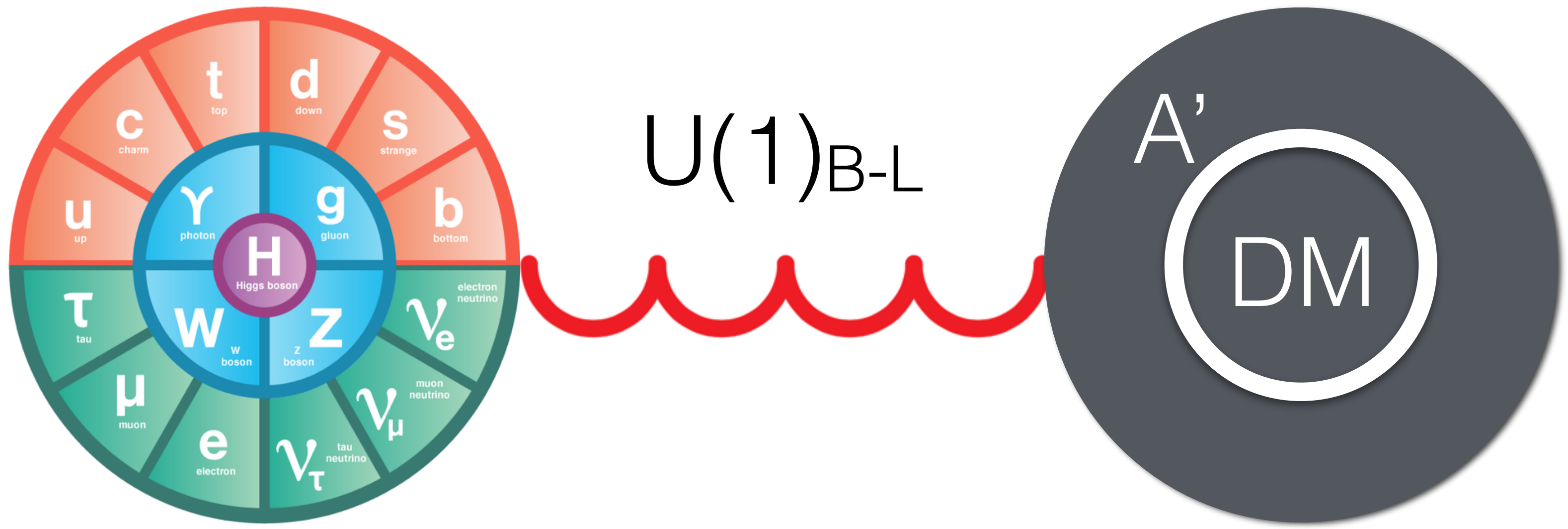


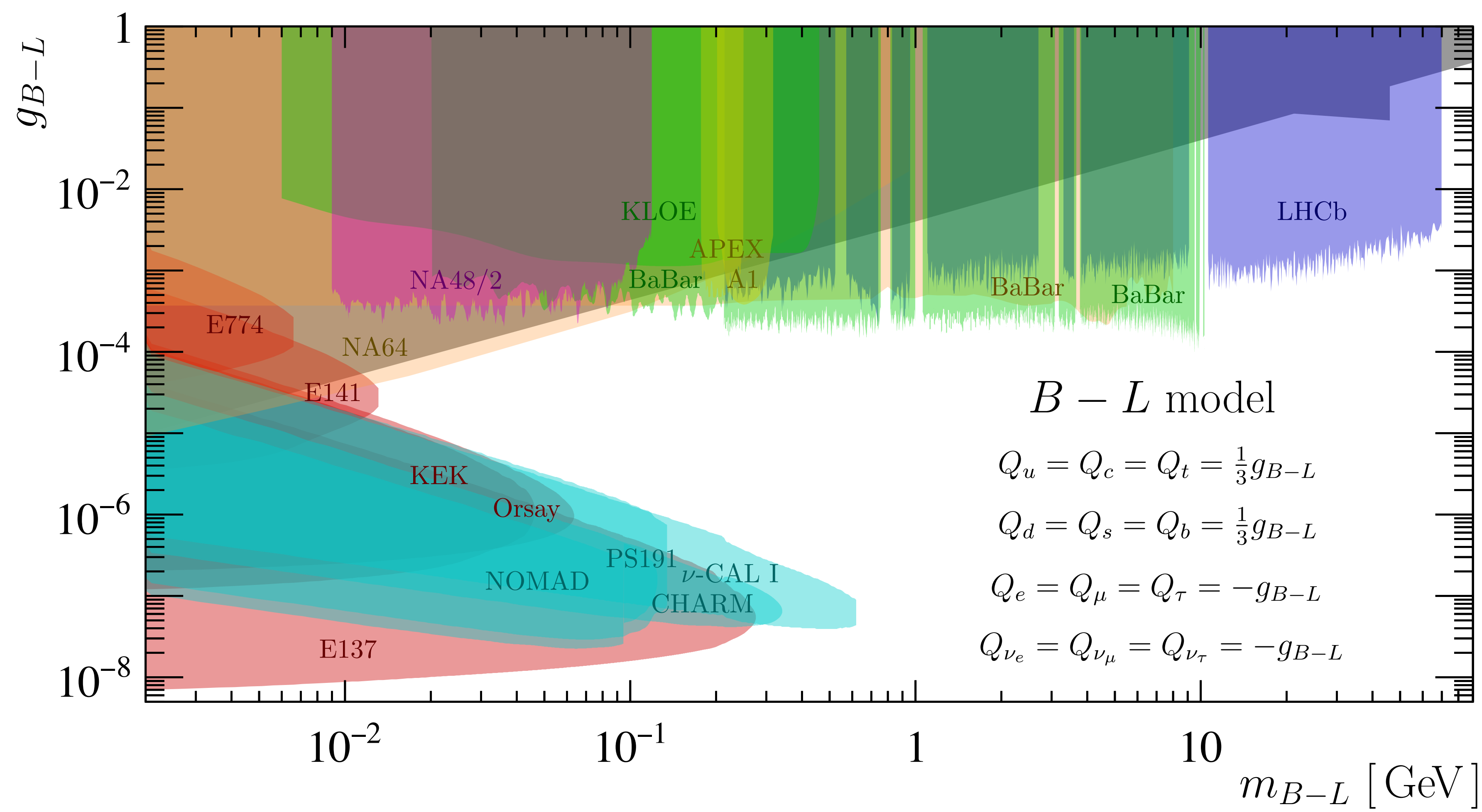
[P. Ilten, Y. Soreq, M. Williams, **WX** (2018)]

Beyond Dark Photon



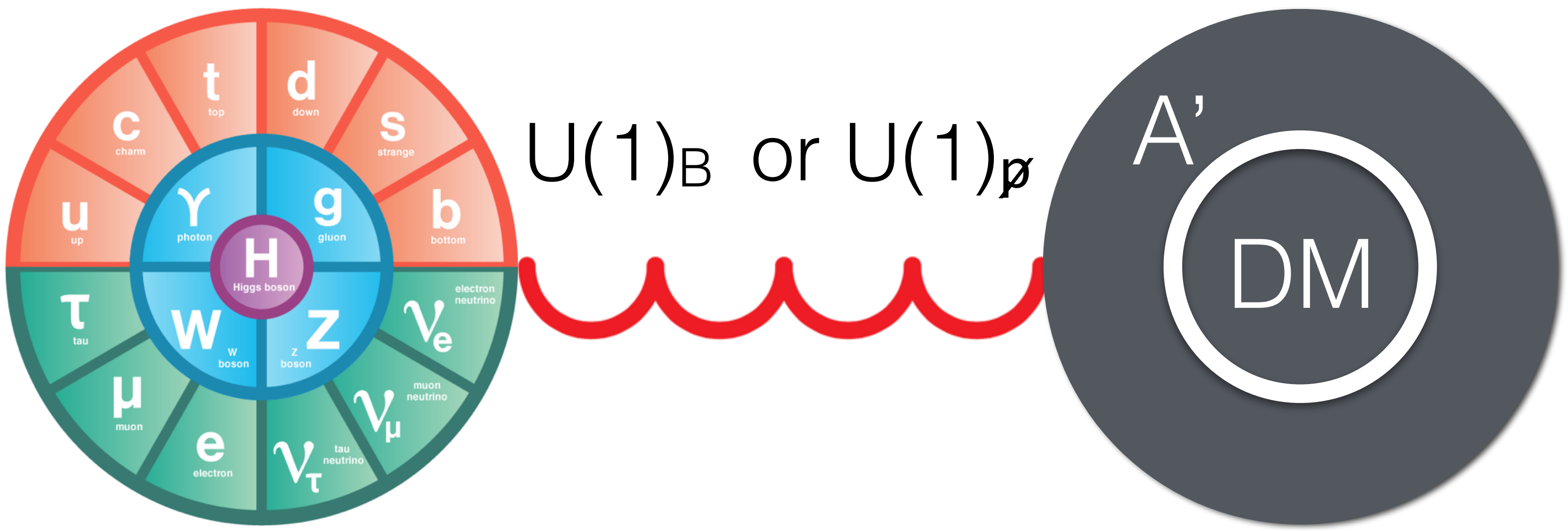
Beyond Dark Photon

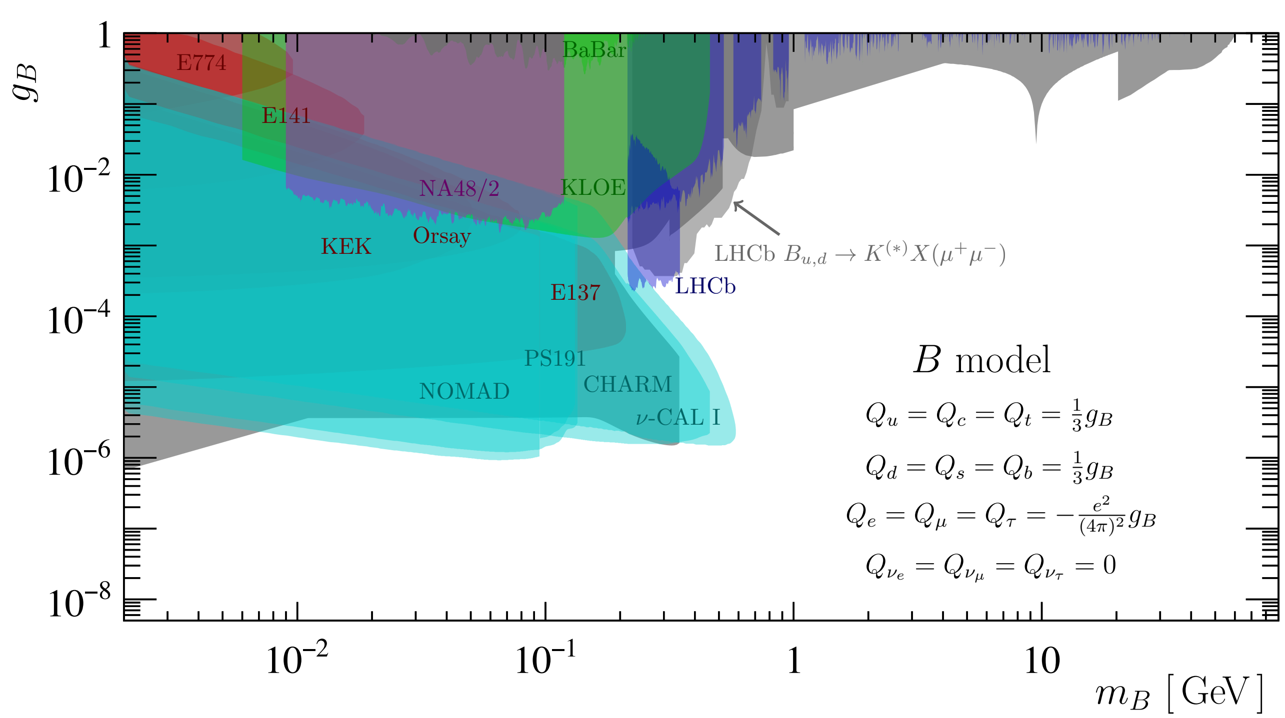


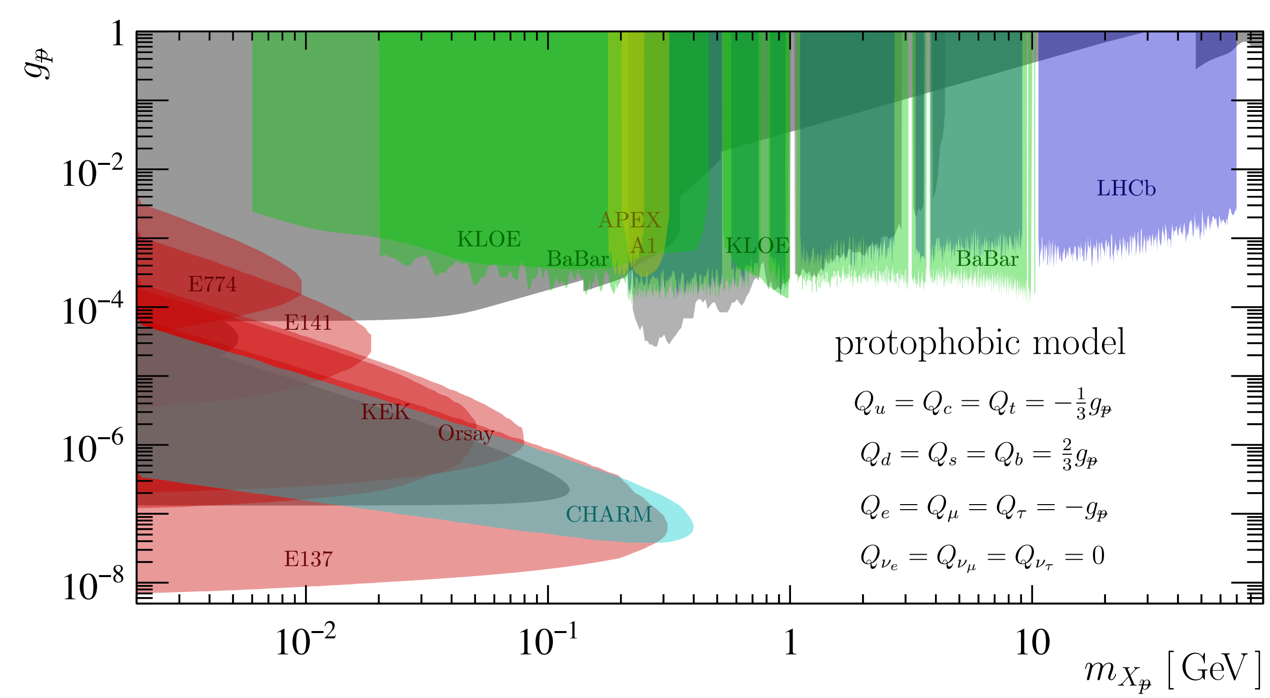


[P. Ilten, Y. Soreq, M. Williams, ***WX*** *(2018)]*

Beyond Dark Photon

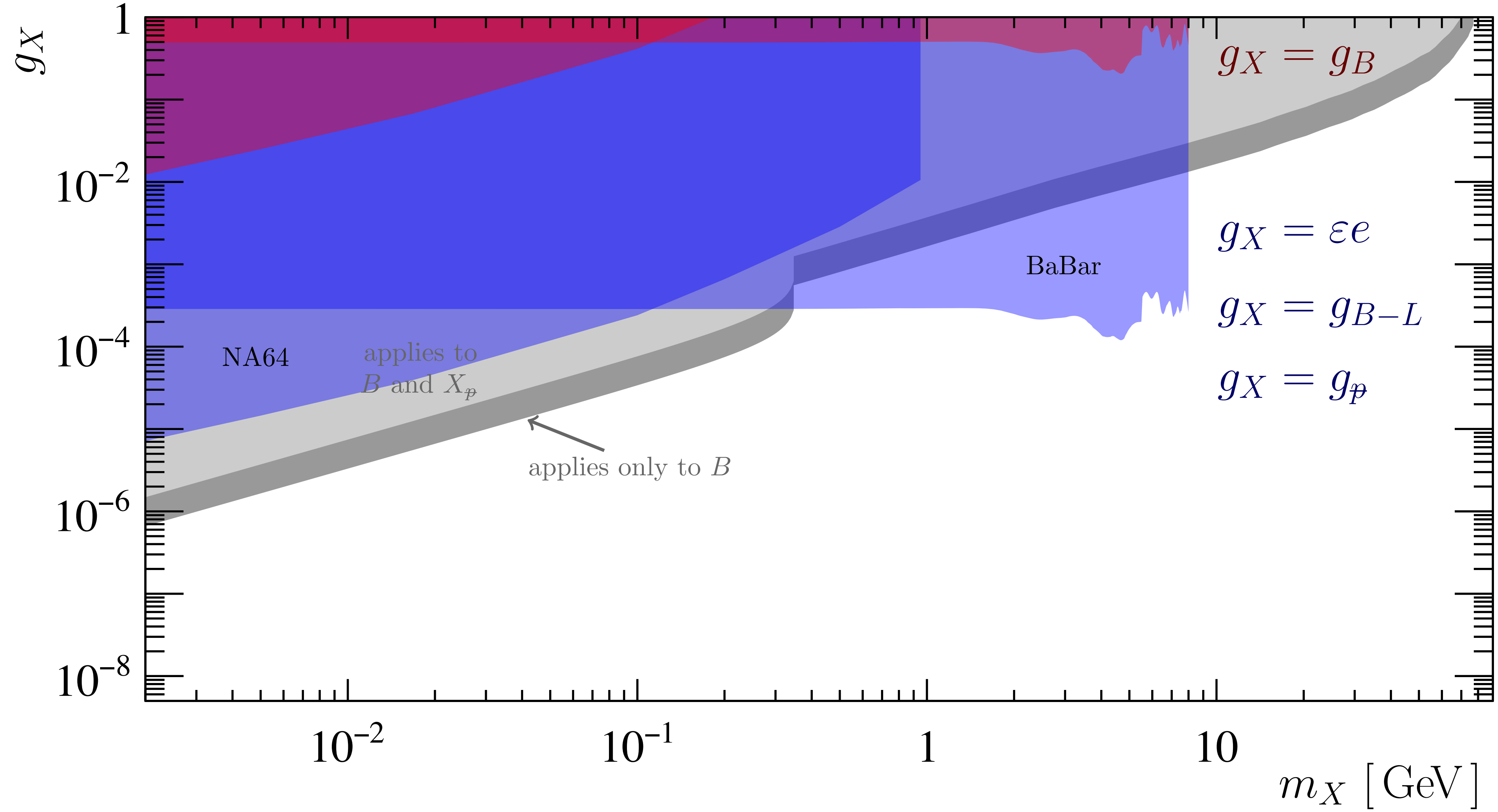






*[P. Ilten, Y. Soreq, M. Williams, **WX** (2018)]*

Invisible decay



[P. Ilten, Y. Soreq, M. Williams, **WX** (2018)]

Summary

- photon → dark photon

- dark photon → general theories (vector coupling)

- production and decay
  date-driven method for the hadronic decay rates

Thank you