

Hidden Photons

Patrick Foldenauer

based on [M. Bauer, PF, J. Jaeckel; 1713.xxxxx]

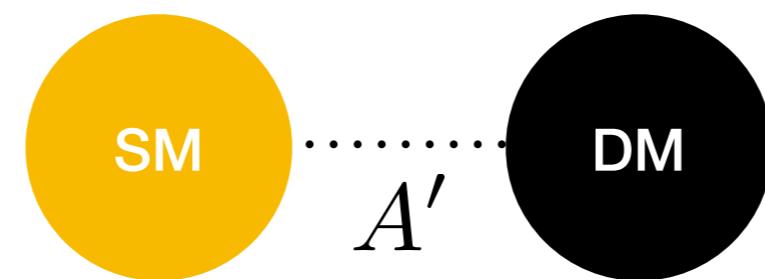
Outline

- Motivation
- Minimal hidden photons
- Anomaly-free extensions
- Conclusion

Motivation

Hidden Photon (HP) = gauge boson associated with **extra U(1)**

- Why do we care about HPs?
- HP A' can play role of mediator between SM matter and dark sector



- Gauge Unification in UV theories like String Theory etc.
- BUT: must be broken at low energies → extra low rank groups

$$G_{\text{UV}} \rightarrow G_{\text{SM}} \times U'(1) \times \dots$$

Minimal Hidden Photons

Kinetic Mixing

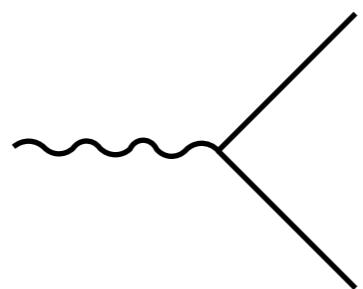
Abelian symmetries allow for mixed kinetic term

$$\mathcal{L}_{\text{kin}} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} - \frac{\epsilon}{2}F_{\mu\nu}F'^{\mu\nu}$$


Kinetic Lagrangian can be diagonalized via $A^\mu \rightarrow A^\mu - \epsilon A'^\mu$

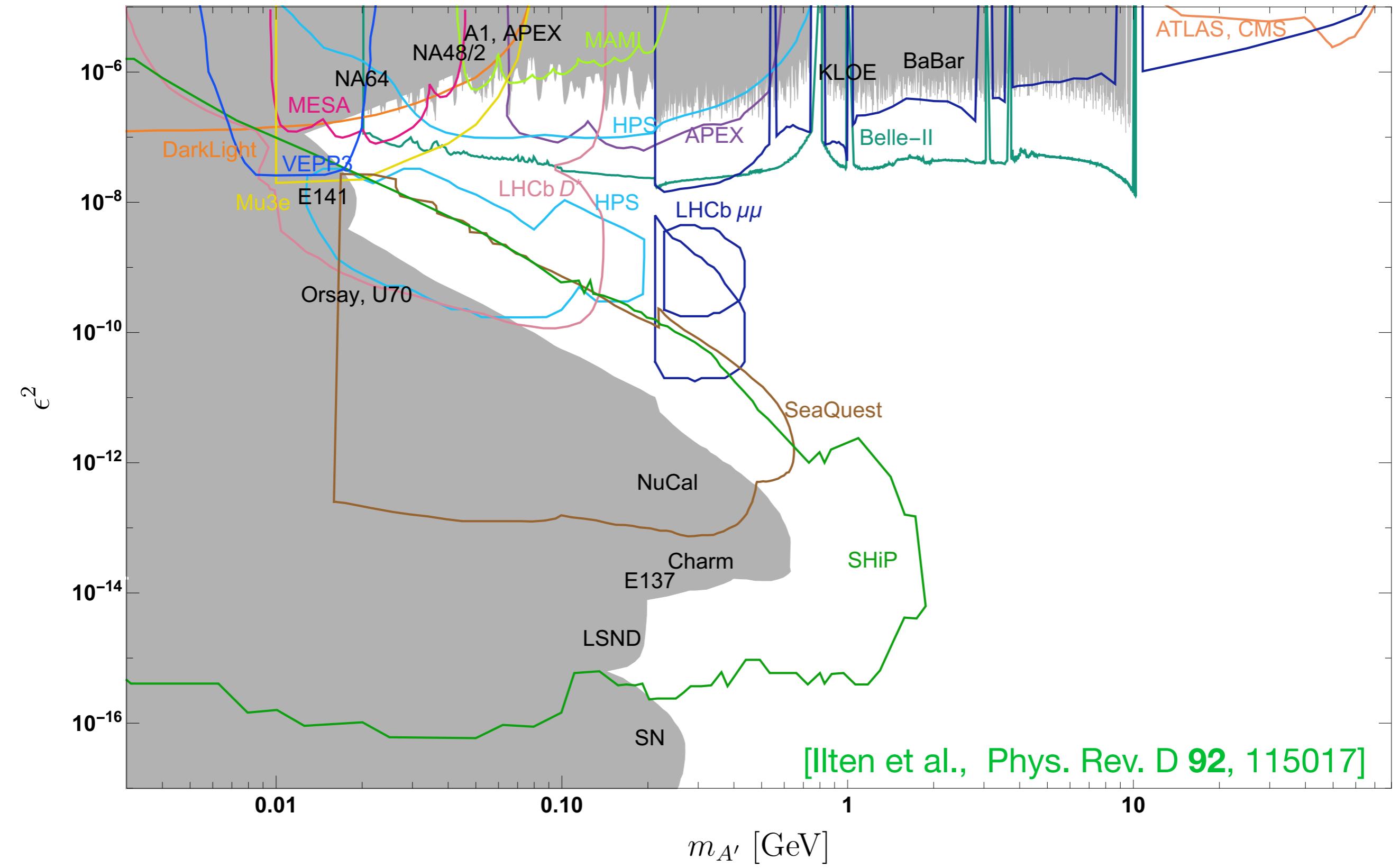
$$\mathcal{L}_{\text{kin}} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}F'_{\mu\nu}F'^{\mu\nu}$$

This induces a small coupling of the HP to the EM current

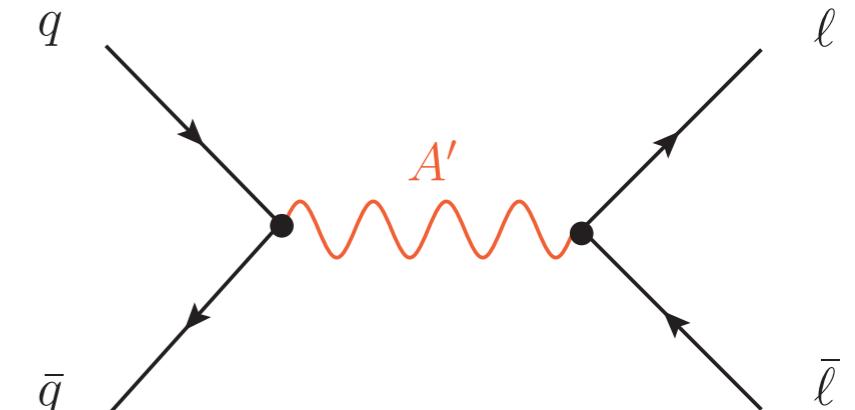
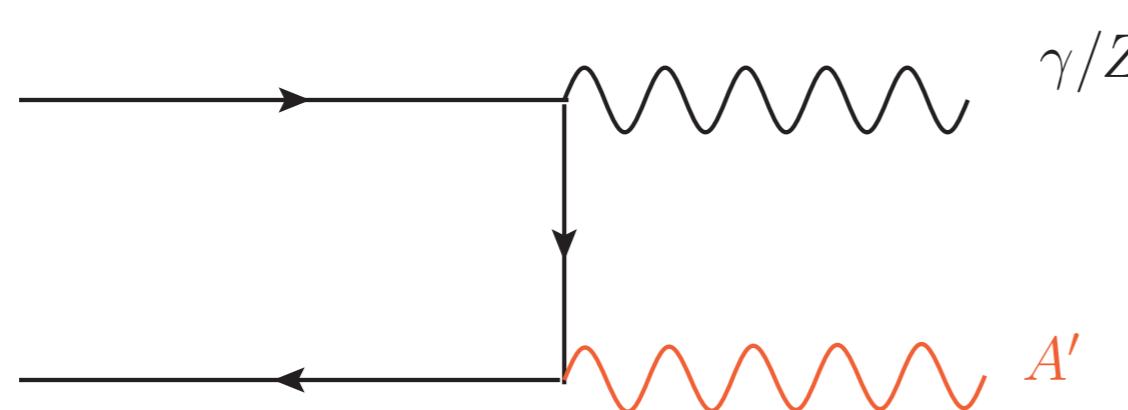


$$eA_\mu J_{\text{EM}}^\mu - \epsilon eA'_\mu J_{\text{EM}}^\mu$$

Current status



Collider searches

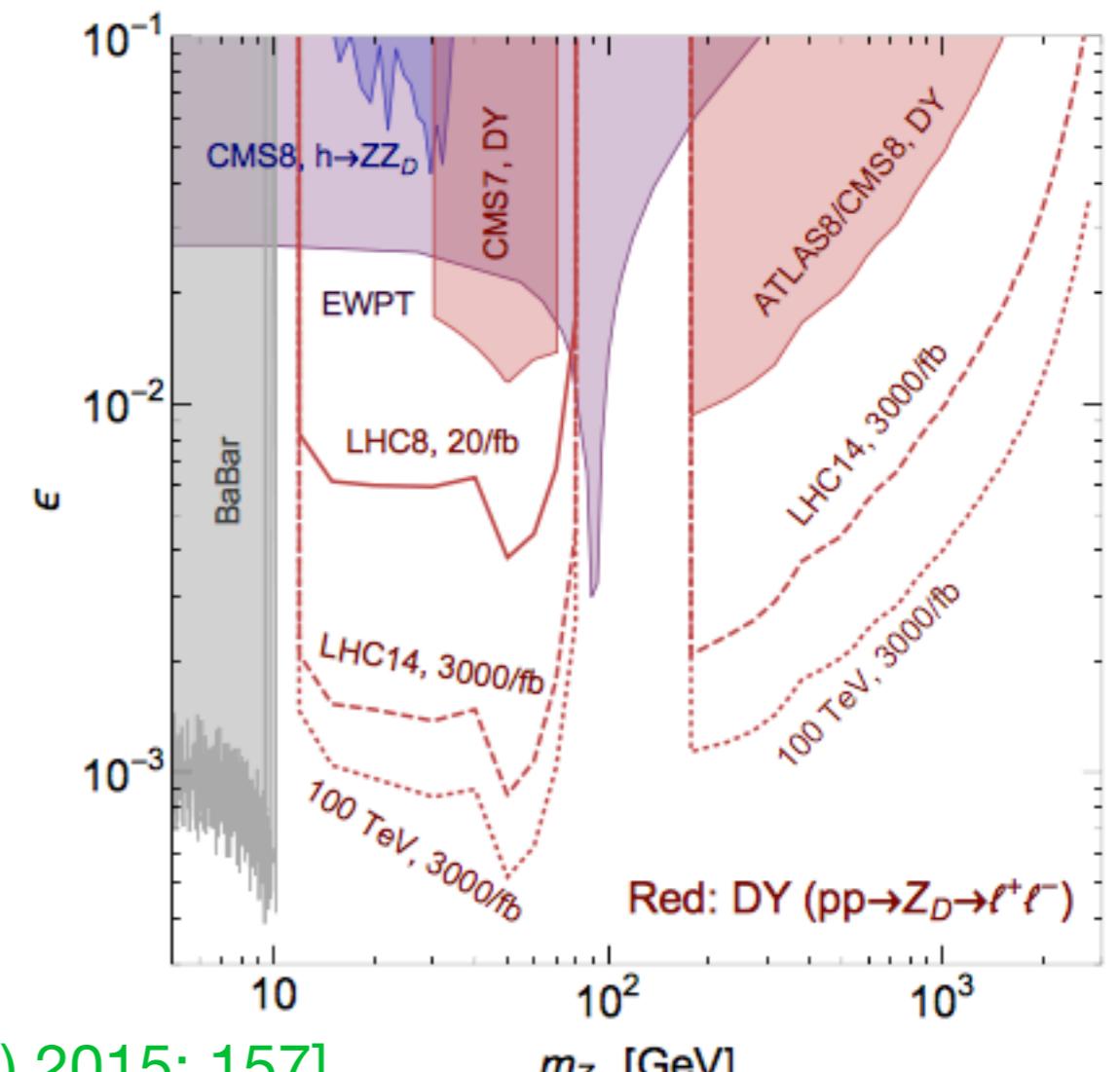


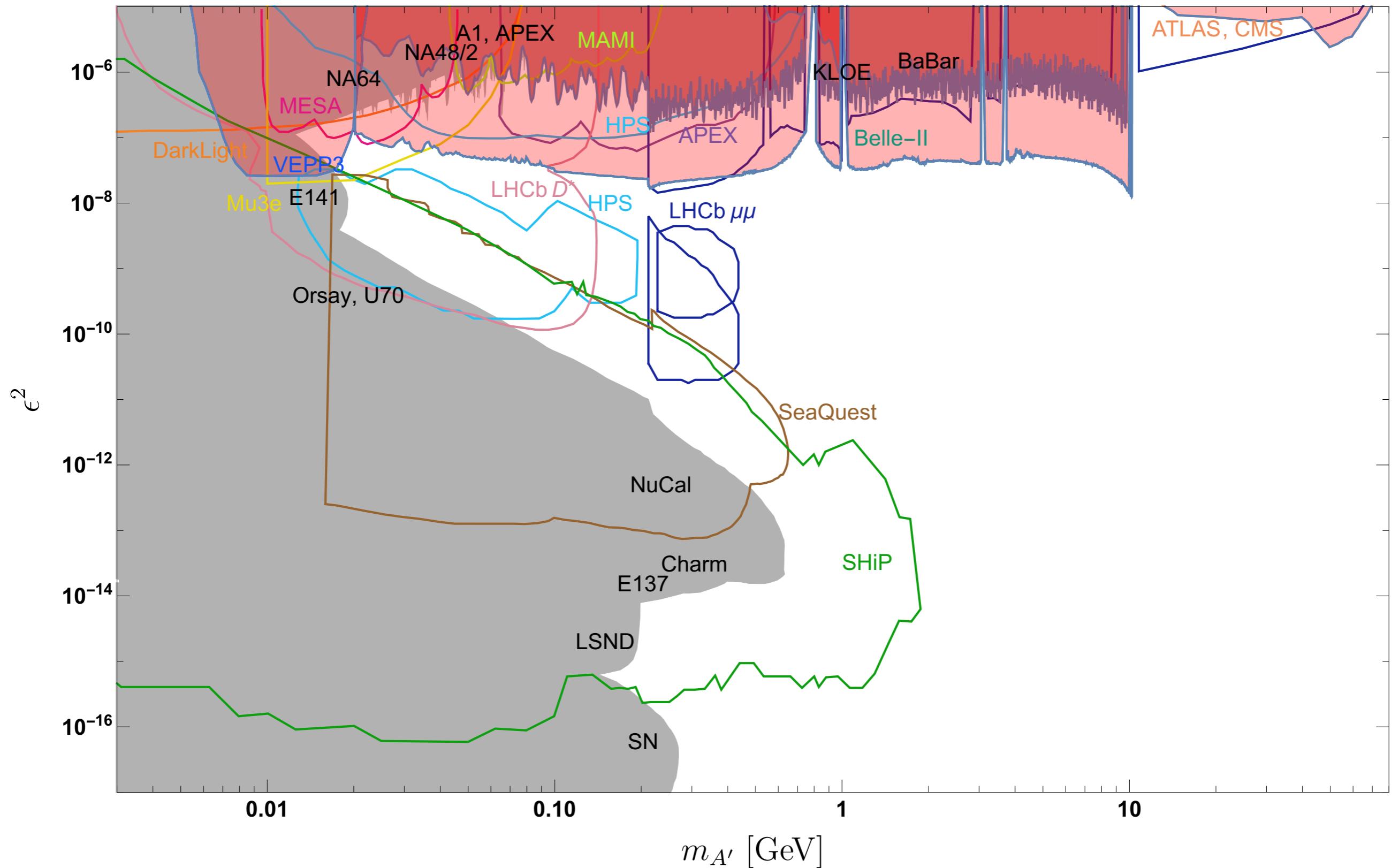
HP signal in Drell-Yan production scales as

$$S \propto \sigma \text{BR} \propto \frac{\epsilon^4}{m_{A'}^2}$$

Find 95% CL limit (for high statistics mass bin) from scaling

$$\frac{S}{\sqrt{B}} = \frac{\hat{S}\epsilon^2}{\sqrt{B}} = \text{const}$$





Meson decays

1. Mesons with large production cross section \rightarrow very abundant!

2. Choose decay with big BR

e.g. $BR(D^{*0} \rightarrow D^0 \gamma) \approx 38\%$

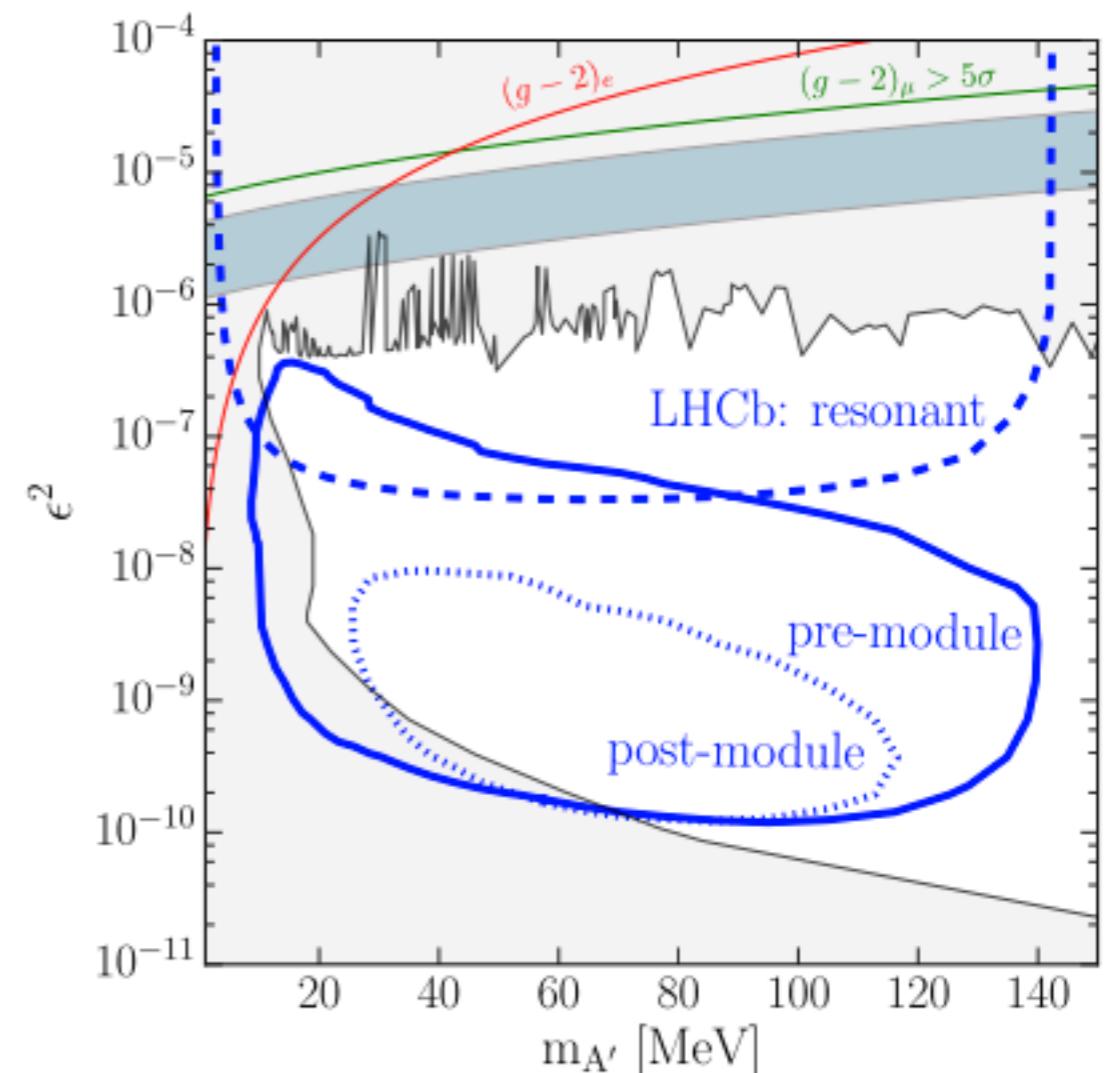
Search for resonant decay

$$D^{*0} \rightarrow D^0 A' \rightarrow D^0 \ell^+ \ell^-$$

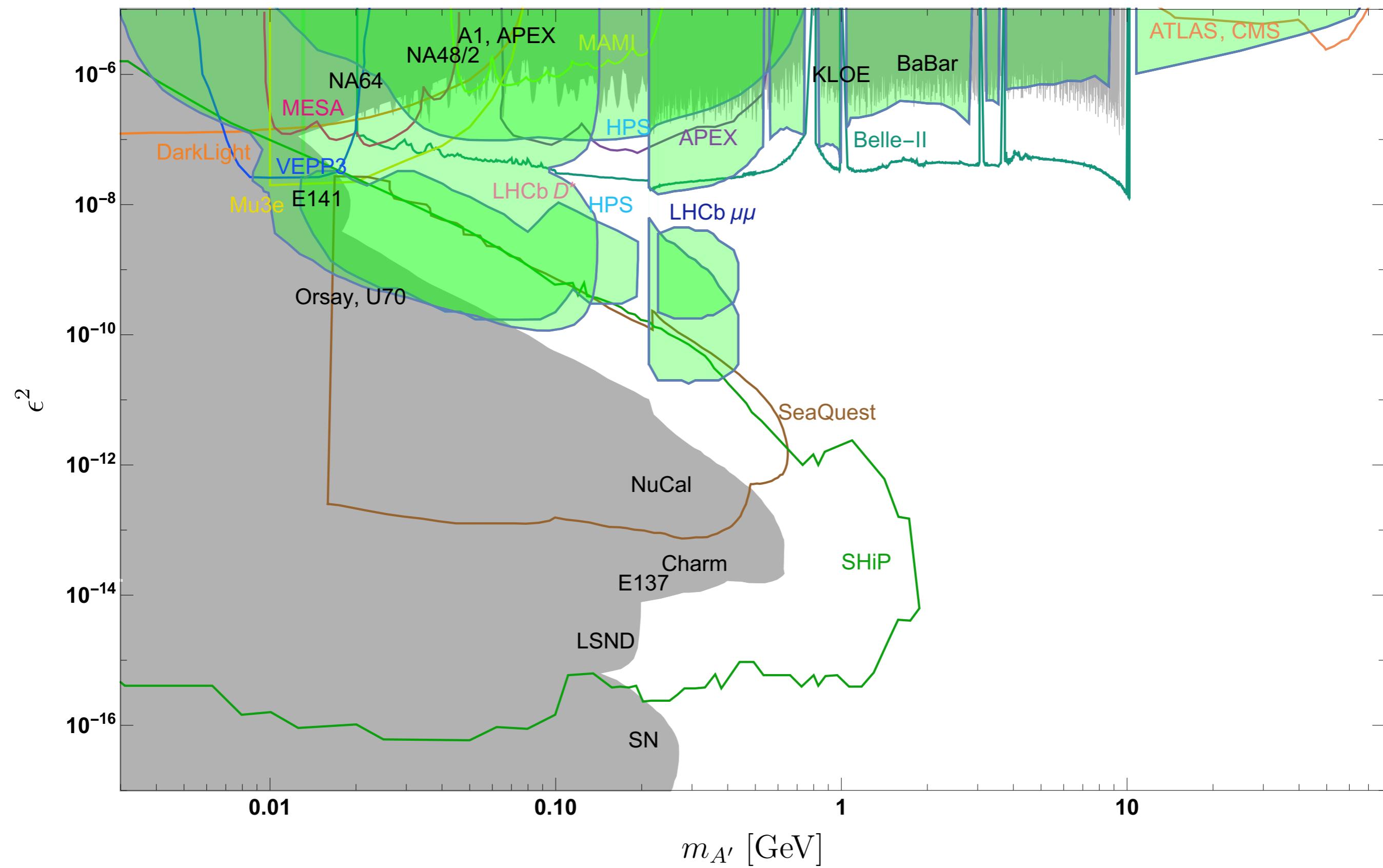


Displaced vertices for small ϵ !

$$\Delta m_D = 142.12 \text{ MeV}$$

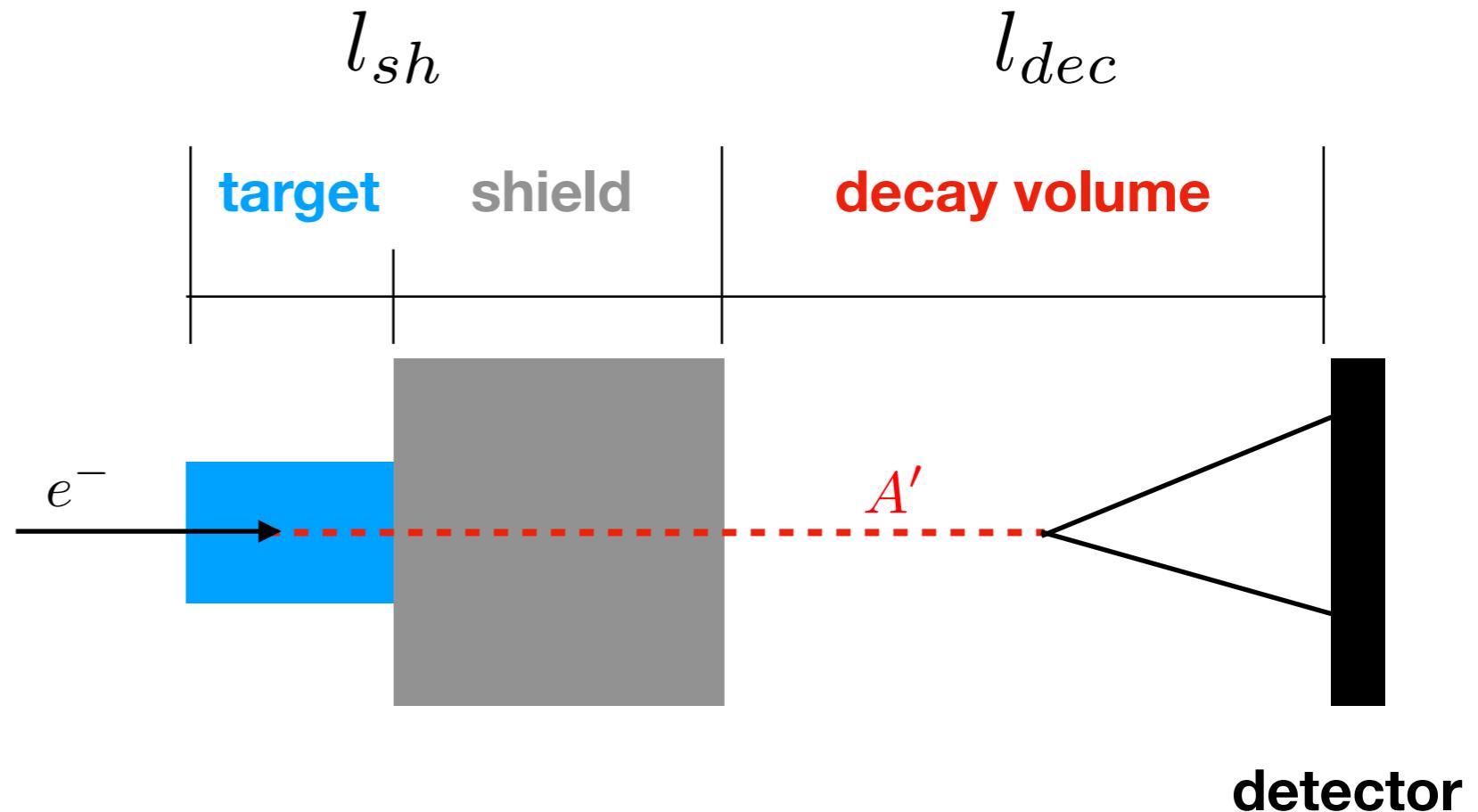
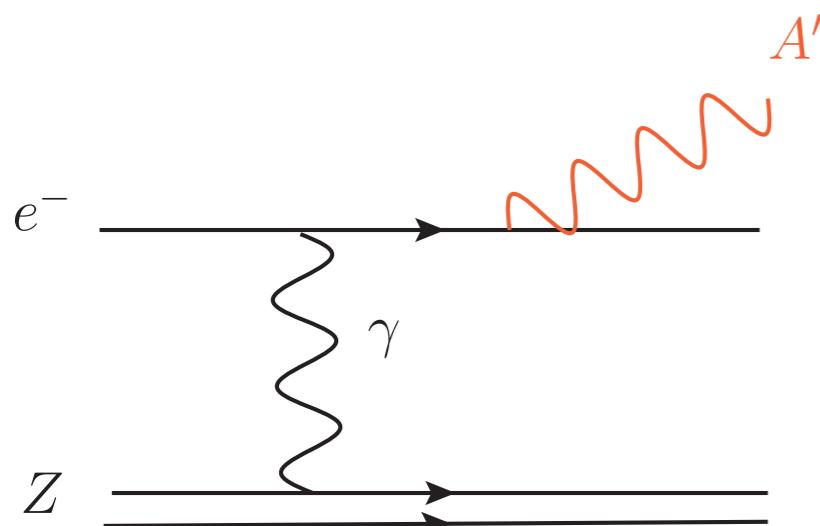


[Ilten et al., Phys. Rev. D 92, 115017]



Beam Dump

Dump beam of charged particles into target with high atomic number Z



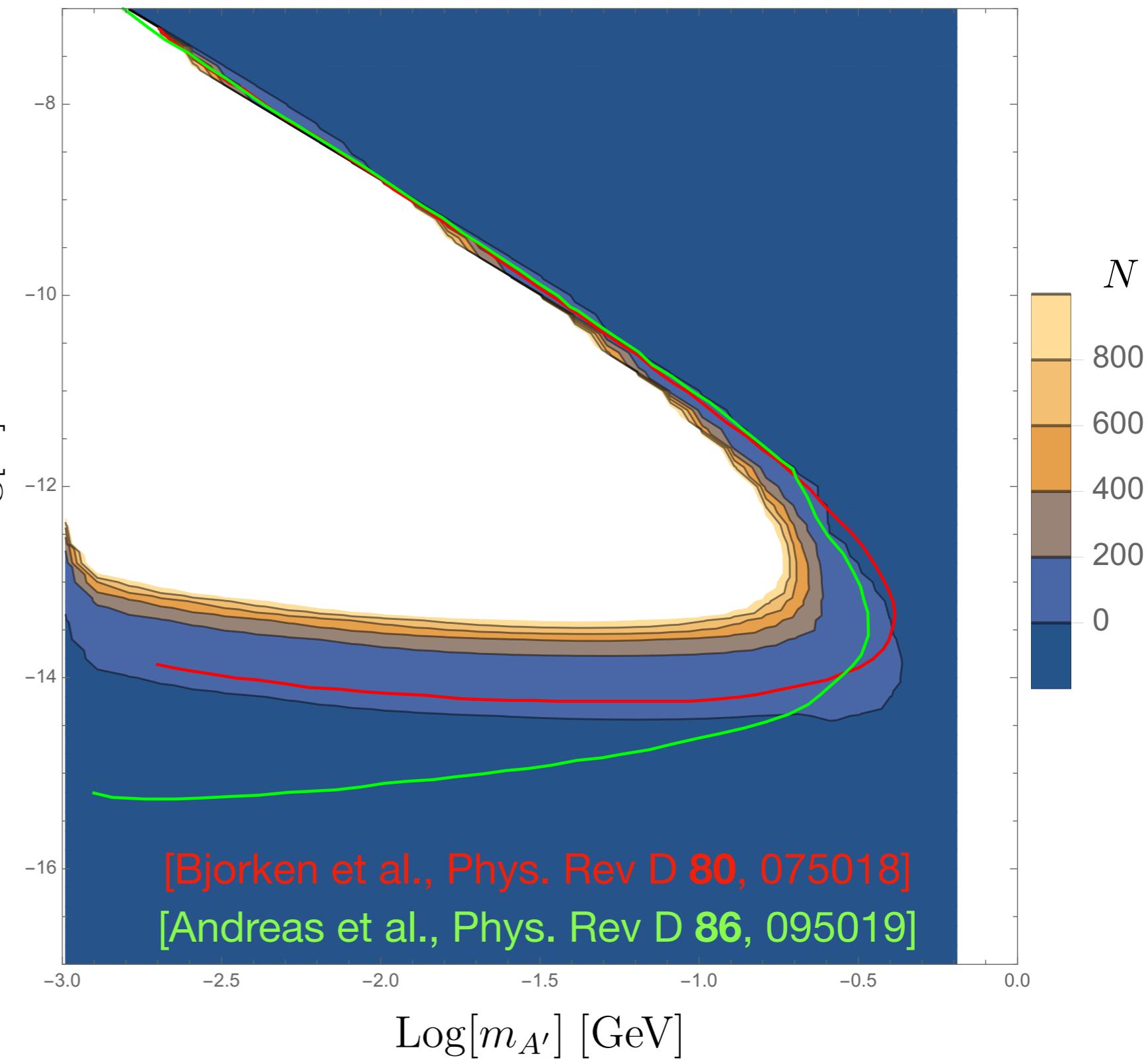
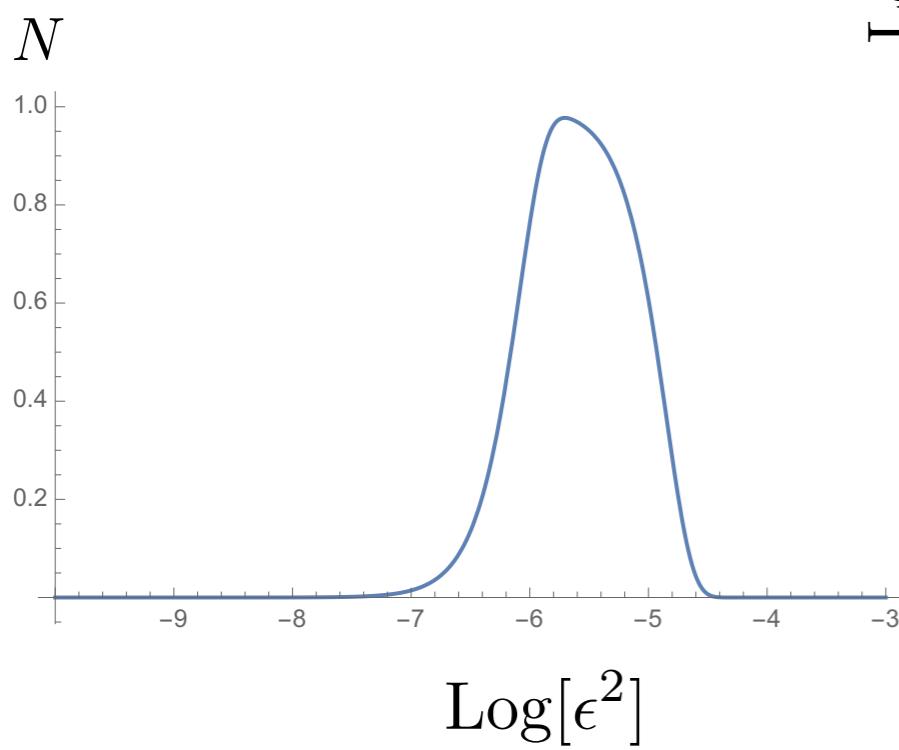
Charged particles interact with material and generate Bremsstrahlung HPs

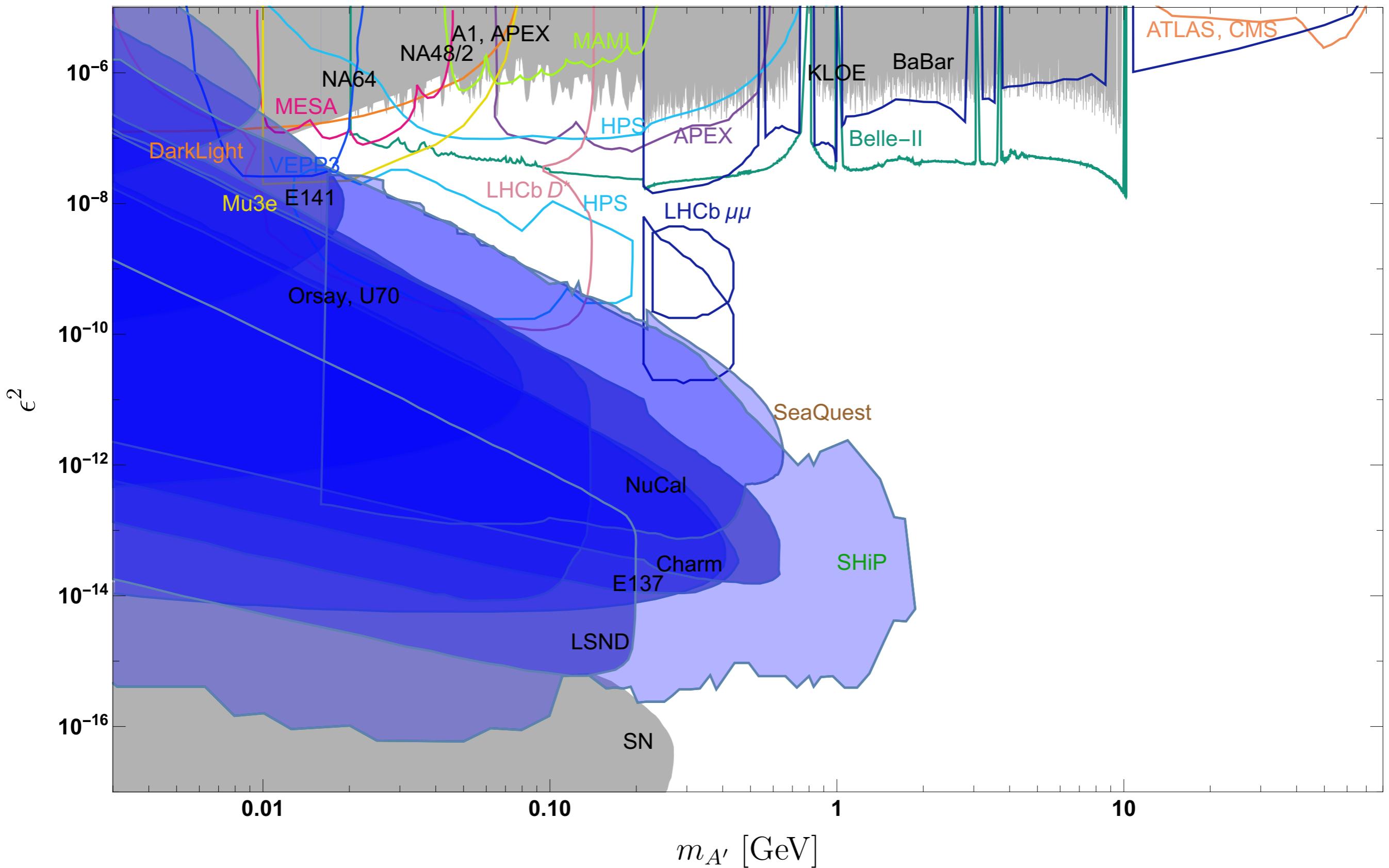
Beam Dump

For fixed mass m :

$$N \propto e^{\frac{-l_{sh}}{l_0}} \left(1 - e^{\frac{-l_{dec}}{l_0}} \right)$$

$$l_0 = \gamma \beta \tau(m, \epsilon)$$





Anomaly-free Extensions

Beyond the minimal case

- SM could be charged under new $U(1)$
- There are 4 additional global groups in the SM

$B - L$

$L_\mu - L_e$

$L_e - L_\tau$

$L_\mu - L_\tau$

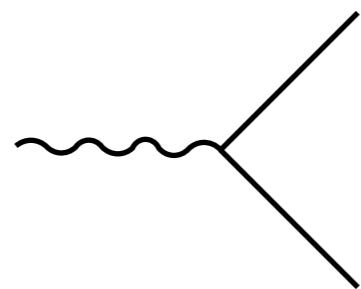
- couples to quarks and leptons

- couples to muons and electrons

- couples to taus and electrons

- couples to taus and muons

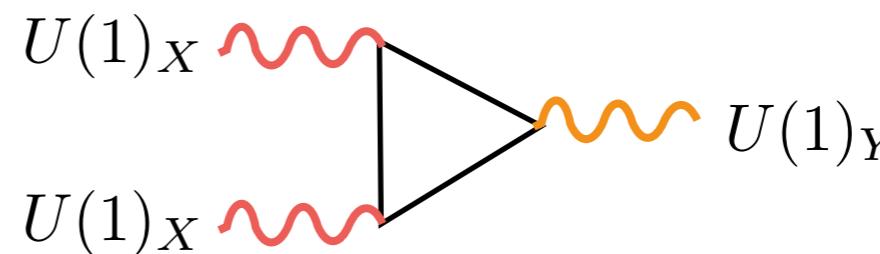
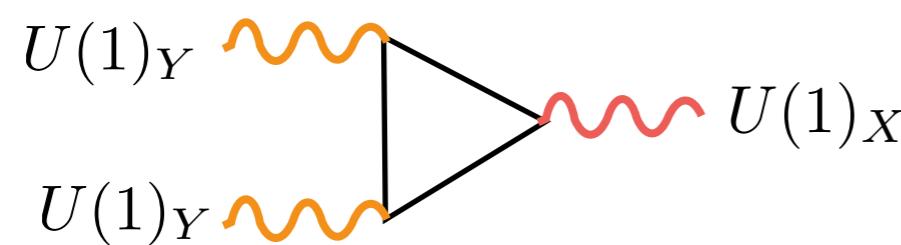
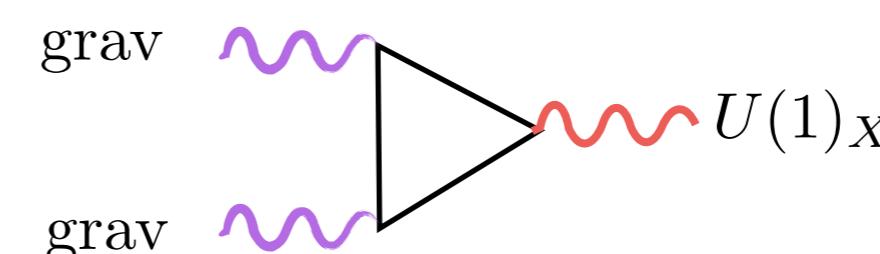
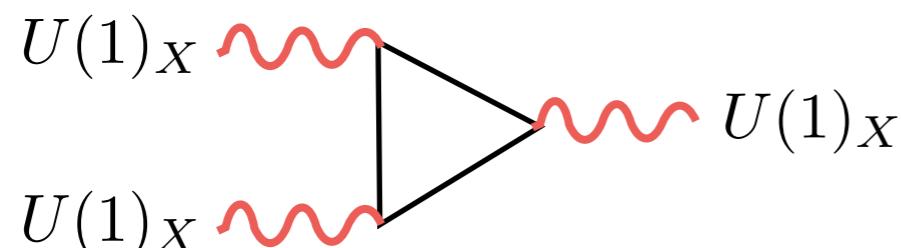
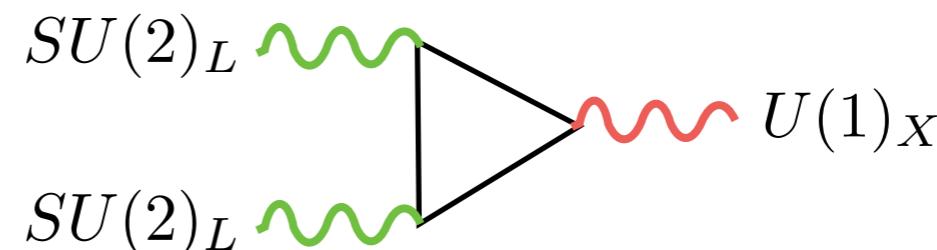
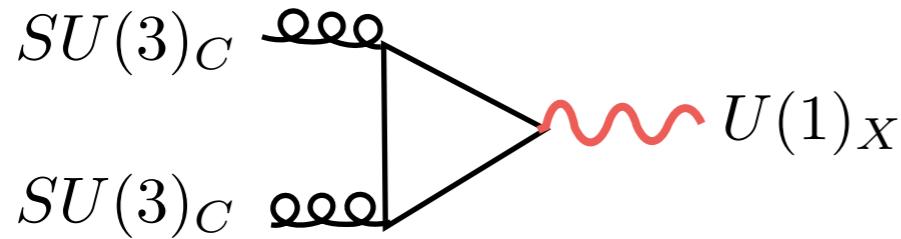
- Gauging these symmetries introduces new interaction



$$g' Q'_f \bar{f} \gamma^\mu f A'_\mu$$

Why are those 4 groups special?

Because the triangle gauge anomalies cancel exactly!



Theorem guarantees exact cancellation to all orders if it works on 1-loop level

[S. Adler (1969). Physical Review. 177 (5): 2426]
[Bell, Jackiw (1969) Il Nuovo Cimento A. 60:47]

Gauge Photon Mass

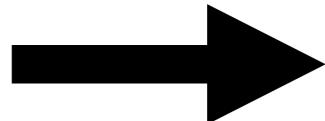
Higgs breaking mechanism of new symmetry:

$$\mathcal{L} = (\partial_\mu - ig' A'_\mu)(\partial^\mu + ig' A'^\mu)$$

$$\supset g'^2 f^2 A'_\mu A'^\mu$$

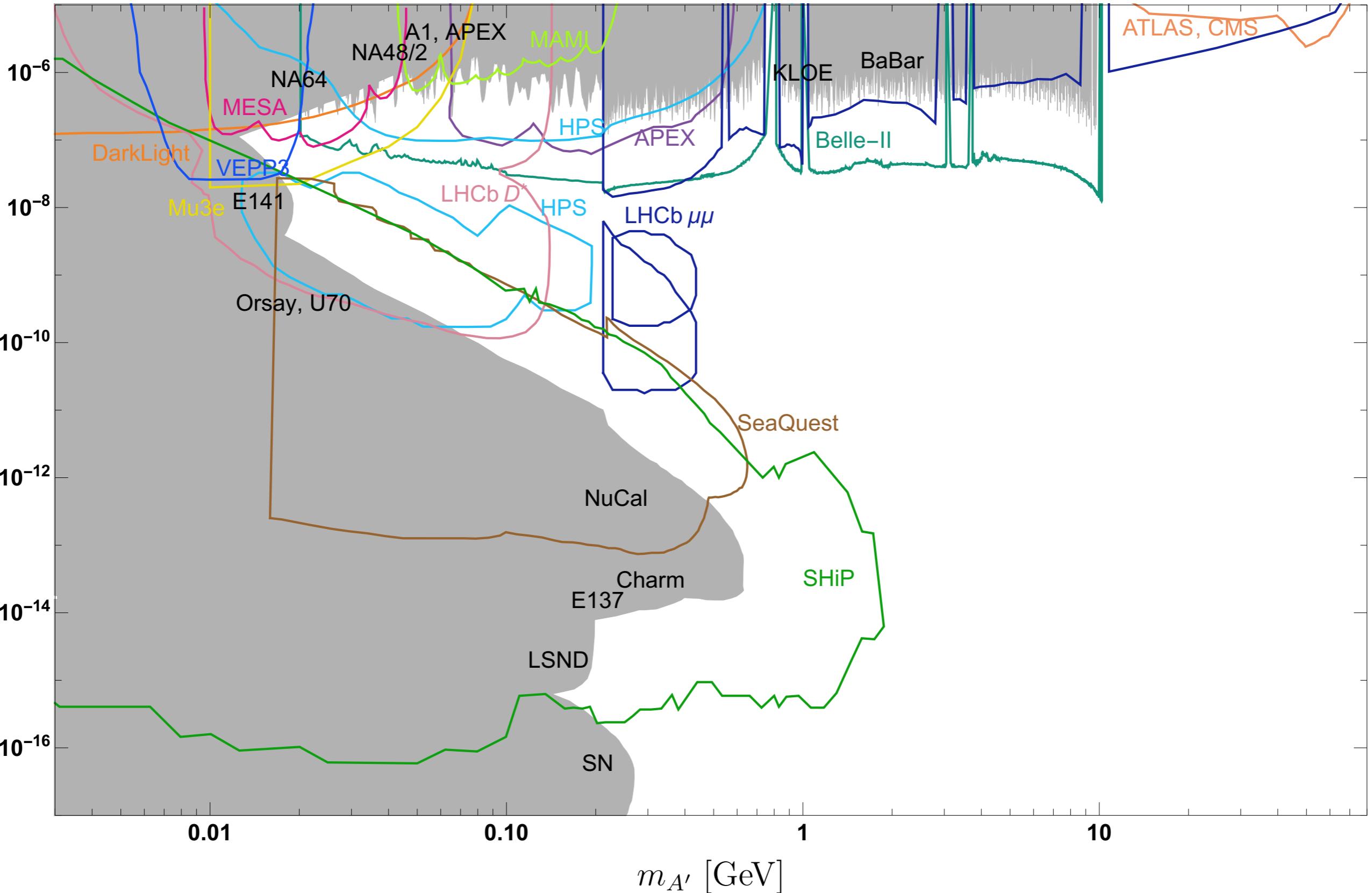

$$m_{A'} = g'^2 f^2$$

Either very heavy **or** light **and** weakly coupled!

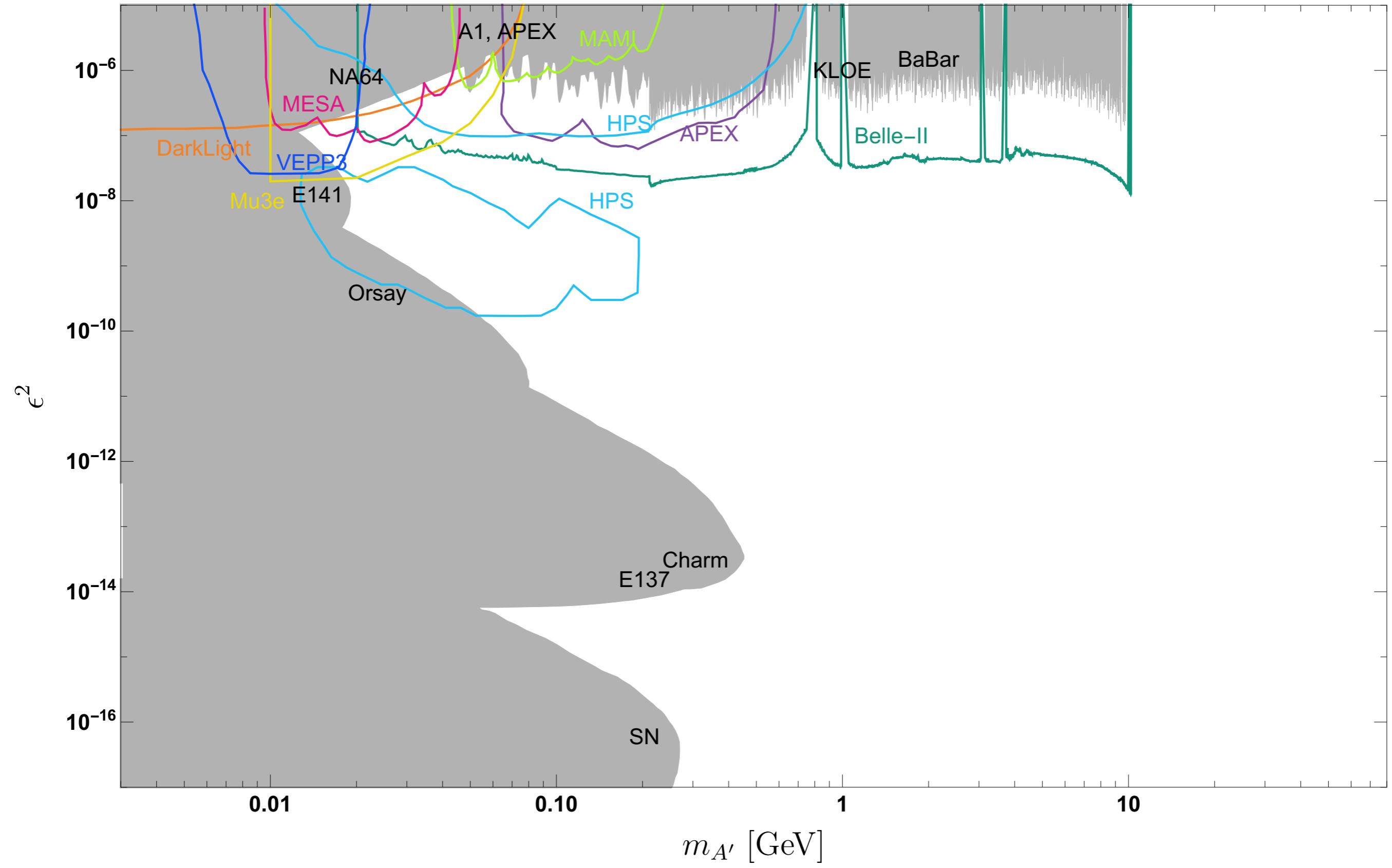


Prime target for HP searches!

Review constraints



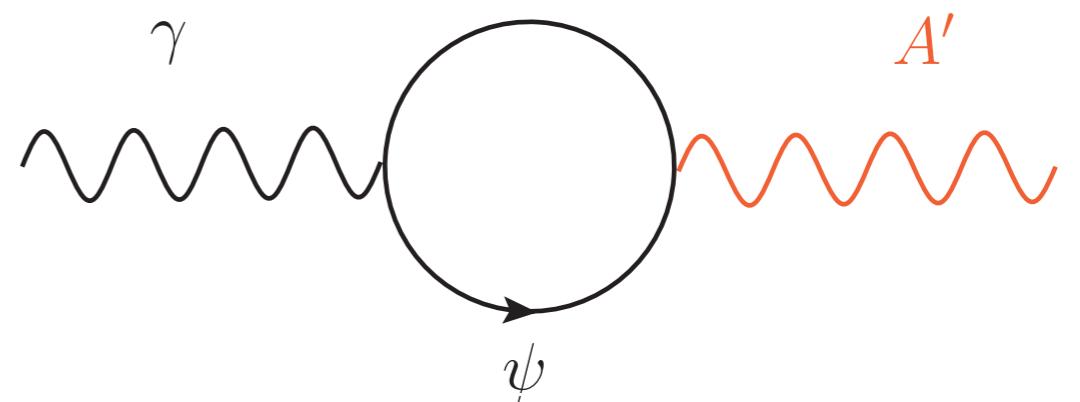
Only leptonic



Induced Mixing

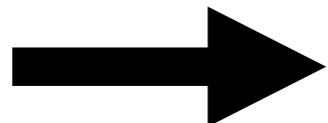
Even if we do not assume a mixing term in the Lagrangian,
it is generated at the 1-loop level:

$$\frac{\epsilon}{2} F^{\mu\nu} \textcolor{red}{F}'_{\mu\nu}$$



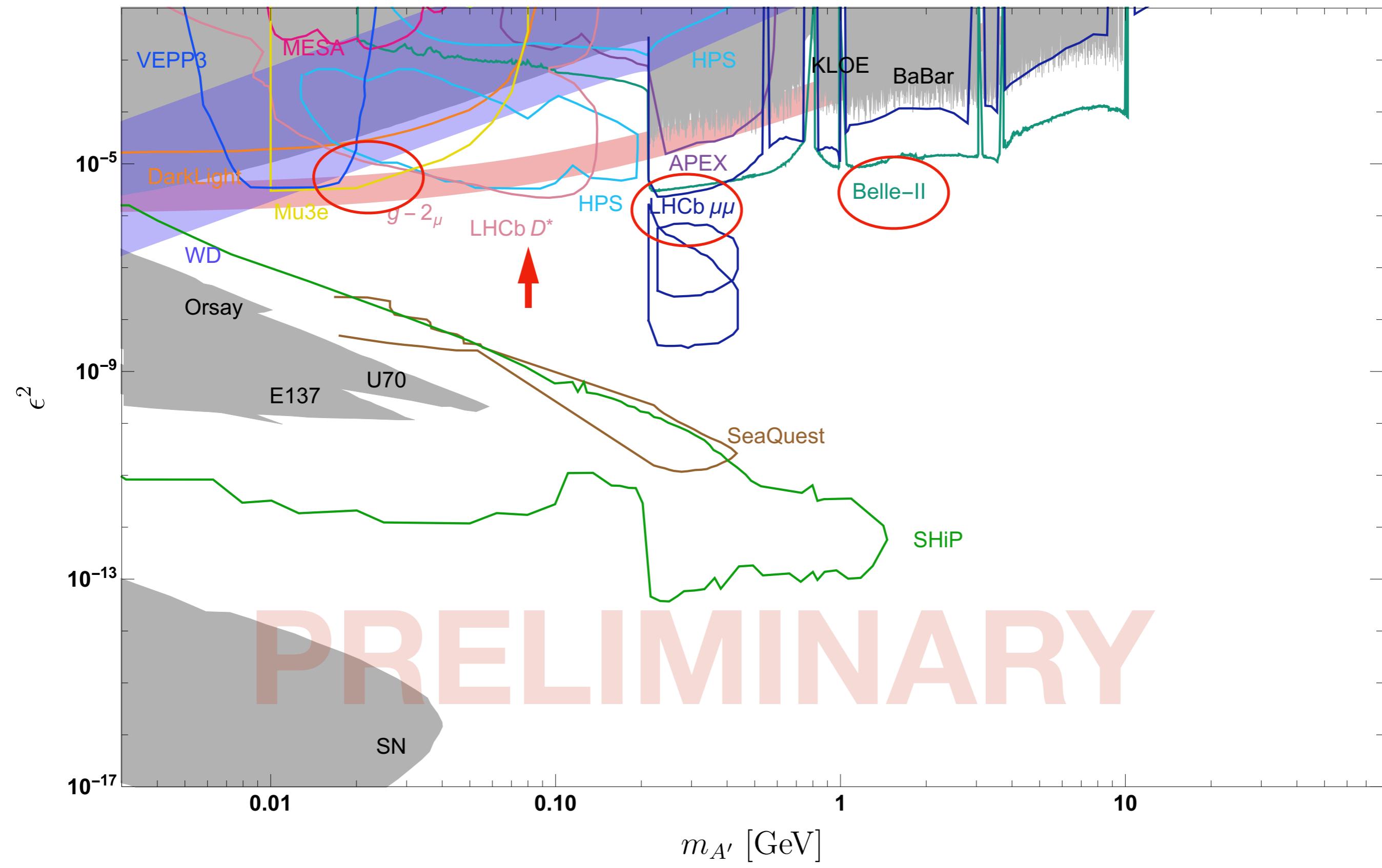
$$\epsilon = \frac{g g'}{2 \pi^2} \int_0^1 dx \ x(1-x) \log \left[\prod_\psi \left(1 - x(1-x) \frac{q^2}{m_\psi^2} \right)^{\left(N_C^\psi \frac{Y_\psi}{2} Q'_\psi \right)} \right]$$

suppressed compared to gauge coupling $\epsilon_{\text{eff}} = g'/e$



introduces hierarchy in couplings!

$L_\mu - L_\tau$



Conclusion

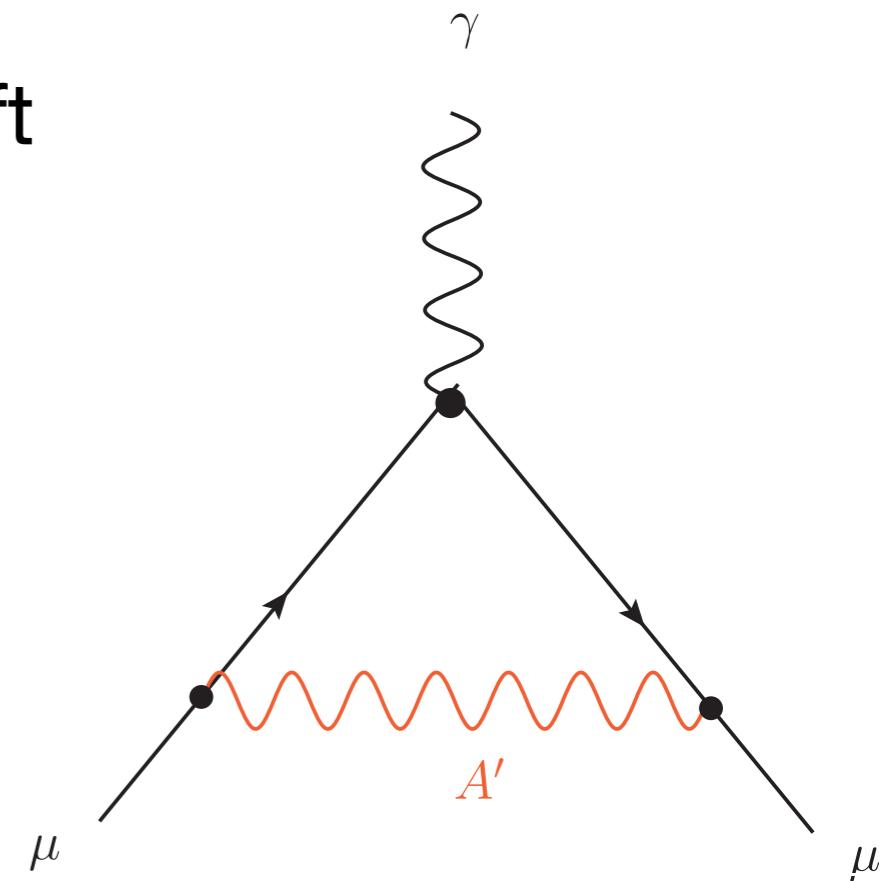
- Gauge couplings can dramatically reshape the landscape of HP constraints
- Different experiments are sensitive to different scenarios!
- Possibly Mu3e can probe $(g - 2)_\mu$
- Dedicated searches at LHCb/ Belle-II could put more stringent constraints on $L_\mu - L_\tau$
- Still a lot of work to do!

Thank You!

Anomalous magnetic moment

If HP couples to muons induced positive shift
in the anomalous magnetic moment

$$\Delta a_\mu = \frac{g'^2}{4\pi^2} \frac{m_\mu^2}{m_{A'}^2} \int_0^1 du \frac{u^2(1-u)}{1-u+u^2 \frac{m_\mu^2}{m_{A'}^2}}$$



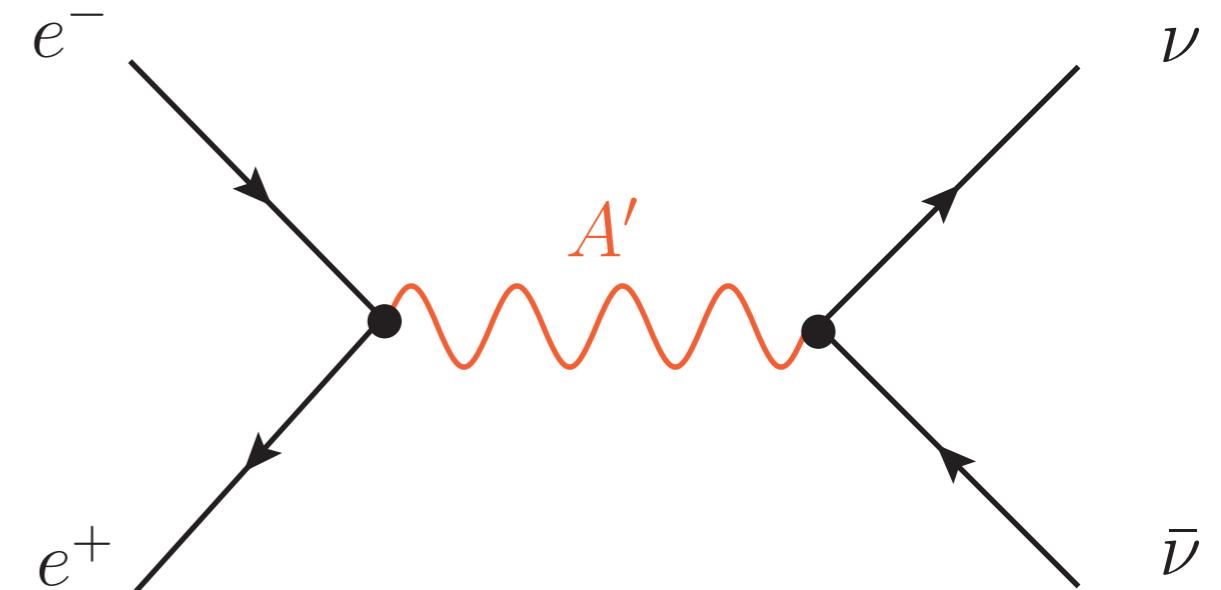
Explanation of observed 3.6σ discrepancy

$$\Delta a_\mu^{\text{obs}} = (2.87 \pm 0.80) \times 10^{-9}$$

White Dwarf Cooling

If HP is produced in WD plasma
can escape and decay into neutrinos

→ extra cooling mechanism!

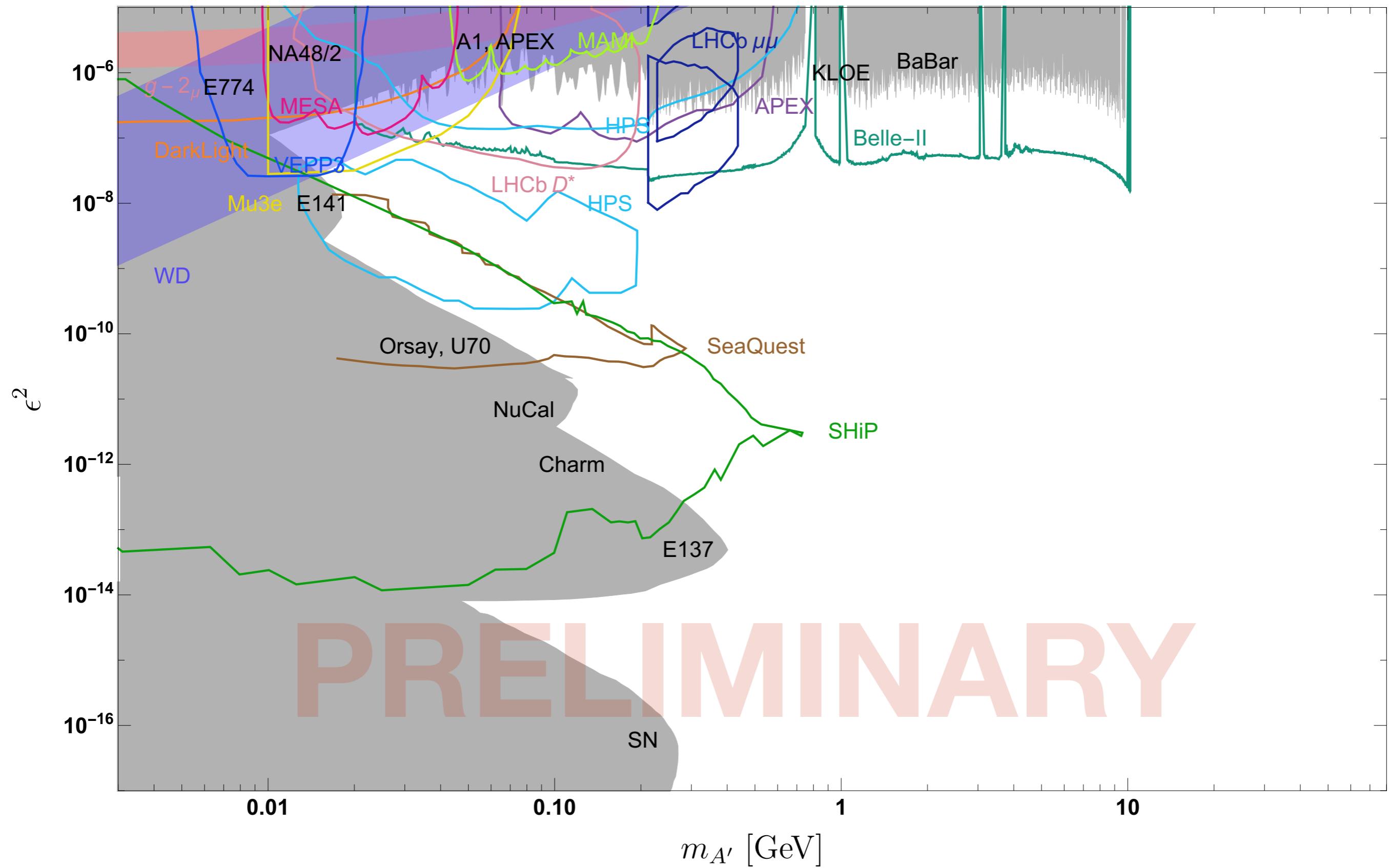


$$\mathcal{L}_6 = - \underbrace{\frac{g'^2}{m_{A'}^2} Q'_\nu (Q'_e + \epsilon c_W \frac{e}{g'})}_{C_\psi G_\psi} (\bar{e} \gamma^\mu e) (\bar{\nu} \gamma_\mu \nu)$$

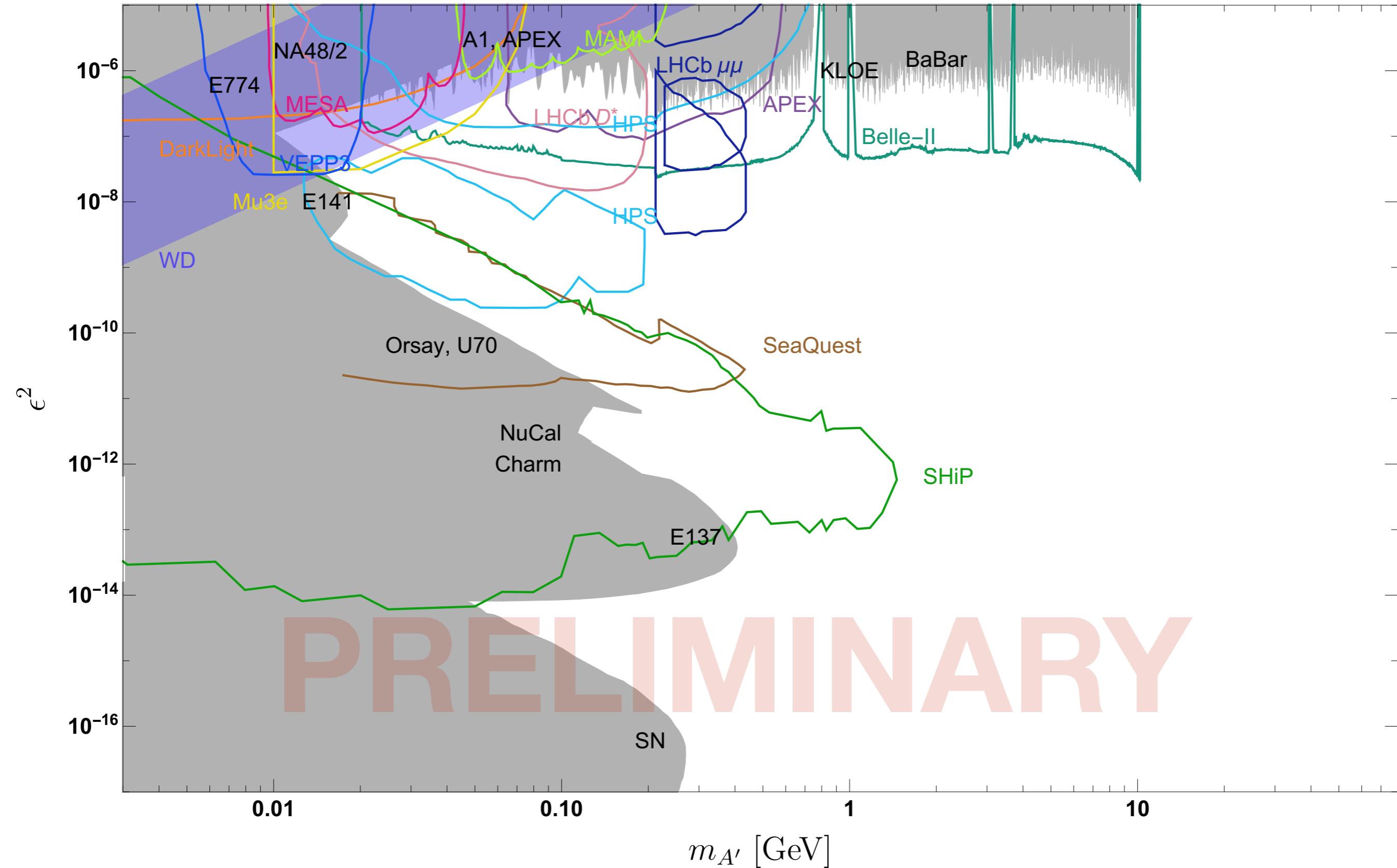
$$G_F \lesssim C_\psi G_\psi \lesssim 400 G_F$$

[Dreiner et al., Phys. Rev. D 88, 043517]

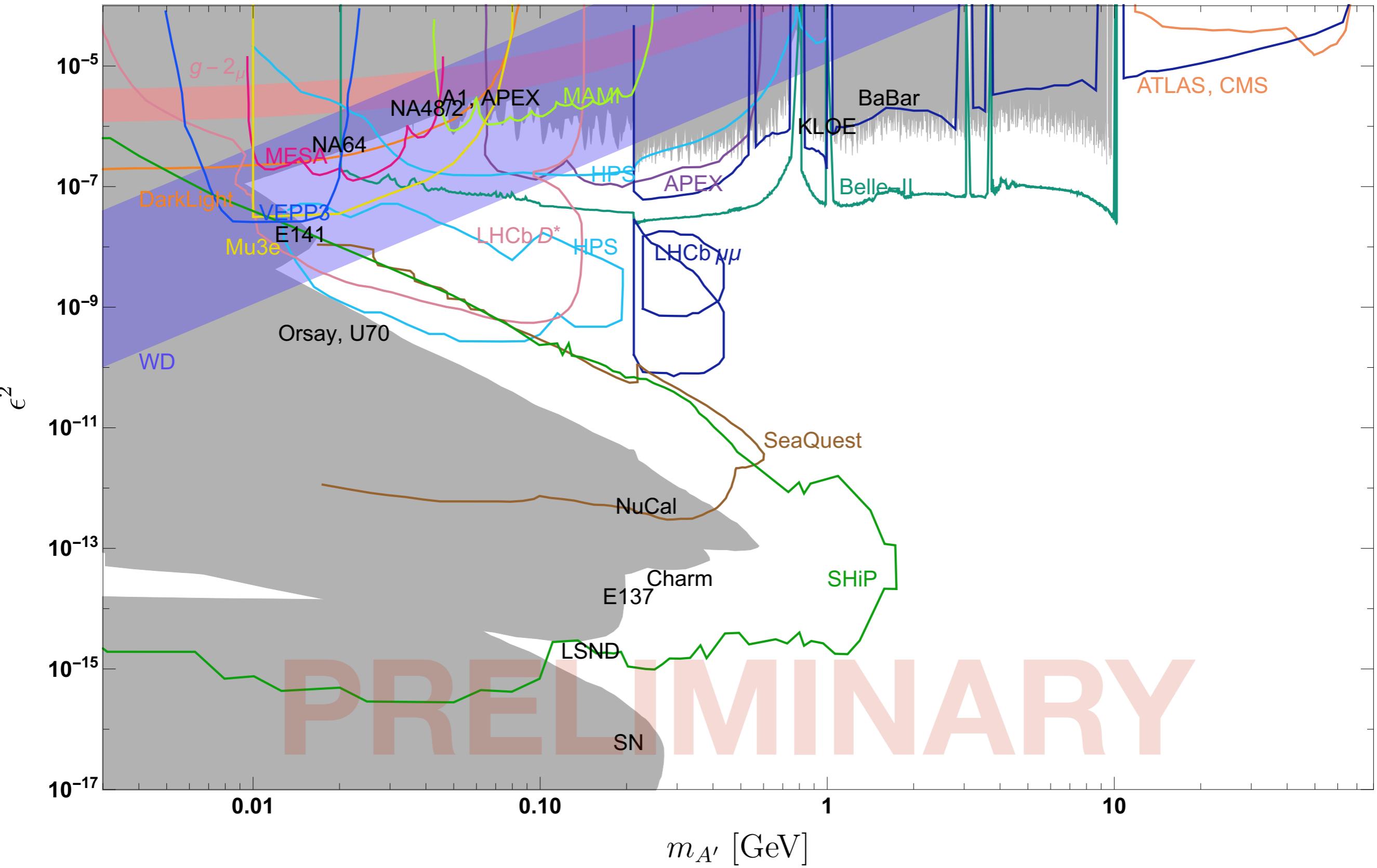
$L_\mu - L_e$



$L_e - L_\tau$



$B - L$



Example: Lepton groups

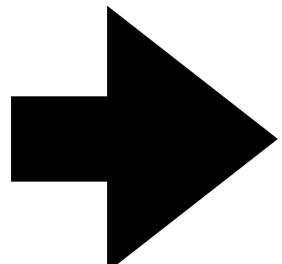
$$SU(2)^2 U(1)_X : \quad d_1 + d_2 = 0$$

$$U(1)_X^3 : \quad 2(d_1^3 + d_2^3) + e_1^3 + e_2^3 = 0$$

$$\text{grav}^2 U(1)_X : \quad 2(d_1 + d_2) + e_1 + e_2 = 0$$

$$U(1)_Y^2 U(1)_X : \quad 2 \cdot \left(\frac{1}{2}\right)^2 (d_1 + d_2) + (-1)(e_1 + e_2) = 0$$

$$U(1)_Y U(1)_X^2 : \quad 2 \cdot \left(\frac{1}{2}\right) (d_1^2 + d_2^2) + (-1)(e_1^2 + e_2^2) = 0$$



Is solved for

$$d_1 = -d_2 = d \quad e_1 = -e_2 = e \quad d = e$$

$L_\mu - L_e$

$L_e - L_\tau$

$L_\mu - L_\tau$