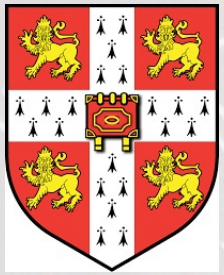

Charting the Fifth Force Landscape

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UK HEP Forum 2021

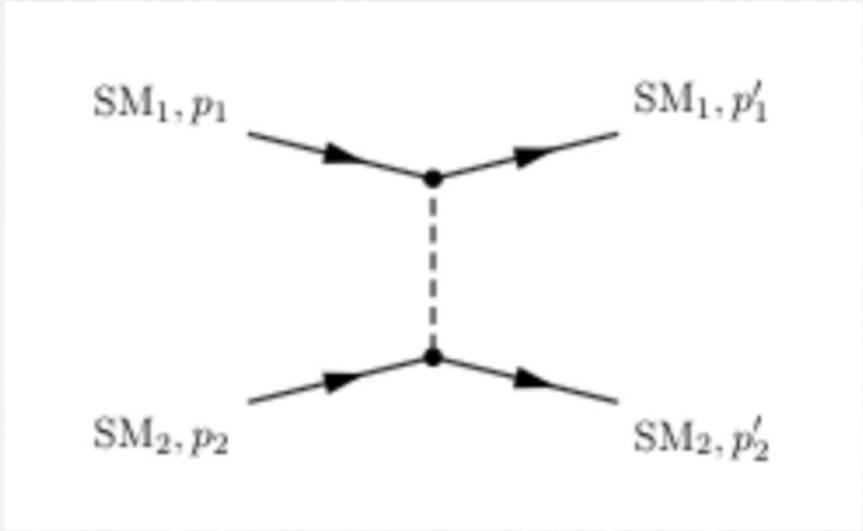
Based on 2009.12399 with Matthew McCullough

Motivation

- Could light neutral states from hidden sectors open a window to the Dark Universe?

- Exchange of new light states between ordinary nucleons generates a “fifth” force

  e.g. The Yukawa Potential



- Forces are “long-range” : cannot use EFT to generalise effects on observables
  ⇨ searches operate on a model-by-model basis

Can we find a general framework?

The Framework

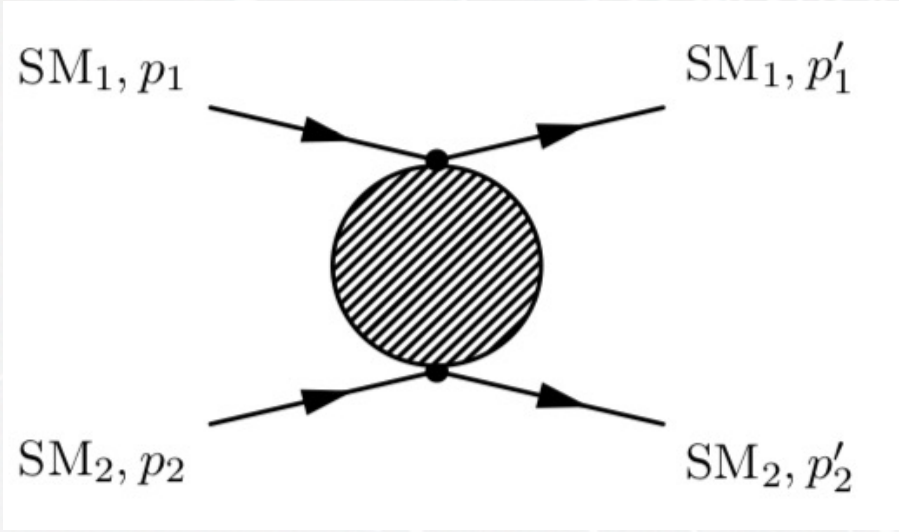
- Consider SM states of mass *M* coupled weakly to a **scalar** composite operator $\mathcal{O}_{DS}$:

$$\mathcal{L}_{\rm int} = \lambda \bar{\Psi}_{SM} \Psi_{SM} \mathcal{O}_{DS}$$

- At $\mathcal{O}(\lambda^2)$ this generates a potential

$$V(\boldsymbol{r}) = -\frac{1}{4M^2} \int d^3\boldsymbol{q}\, \frac{\mathcal{M}^{\rm NR}}{(2\pi)^3} e^{i\boldsymbol{q}\cdot\boldsymbol{r}} \quad ,$$

(Born Approx.)



where

$$i\mathcal{M}^{\rm NR} = -4i\lambda^2 M^2 \underbrace{\langle \mathcal{O}_{DS}(x)\mathcal{O}_{DS}(y)\rangle^{\rm NR}}_{\equiv \Delta(q)}$$

- Express $\Delta(q)$ using the Källén-Lehmann spectral representation:

Unitarity, Causality, Locality

$$\Delta(q) = 2\int_0^\infty \mu d\mu \, \frac{\rho(\mu^2)}{q^2 - \mu^2 + i\epsilon}$$

for $\rho(\mu^2)$ real and positive-definite.

Born Approx.

$$V(r) = -\frac{\lambda^2}{2\pi r}\int_0^\infty \mu d\mu \, \rho(\mu^2) e^{-\mu r} \quad .$$

$\boldsymbol{\rho} \geq 0 \Rightarrow$

1. Attractive Force
2. No turning points

Most general form of the potential from scalar operator exchange within QFT!

Valid **whatever** the form of the hidden sector: perturbative, strongly coupled, minimal, complex ….

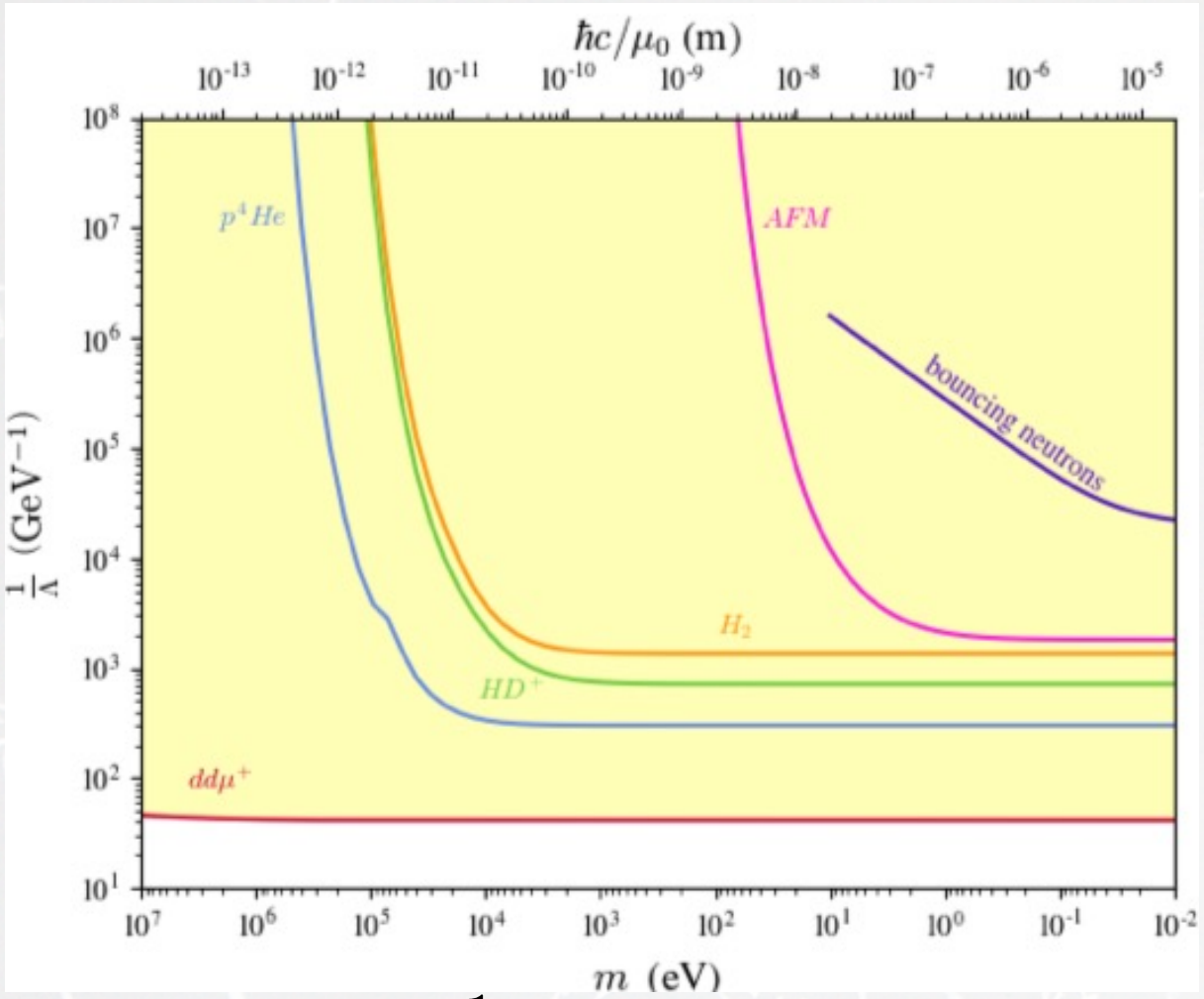
$$\rho(q^2) = -\frac{1}{\pi}\mathrm{Im}\{\Delta(q)\}$$

All experimental observables can be re-cast in terms of $\boldsymbol{\rho}$

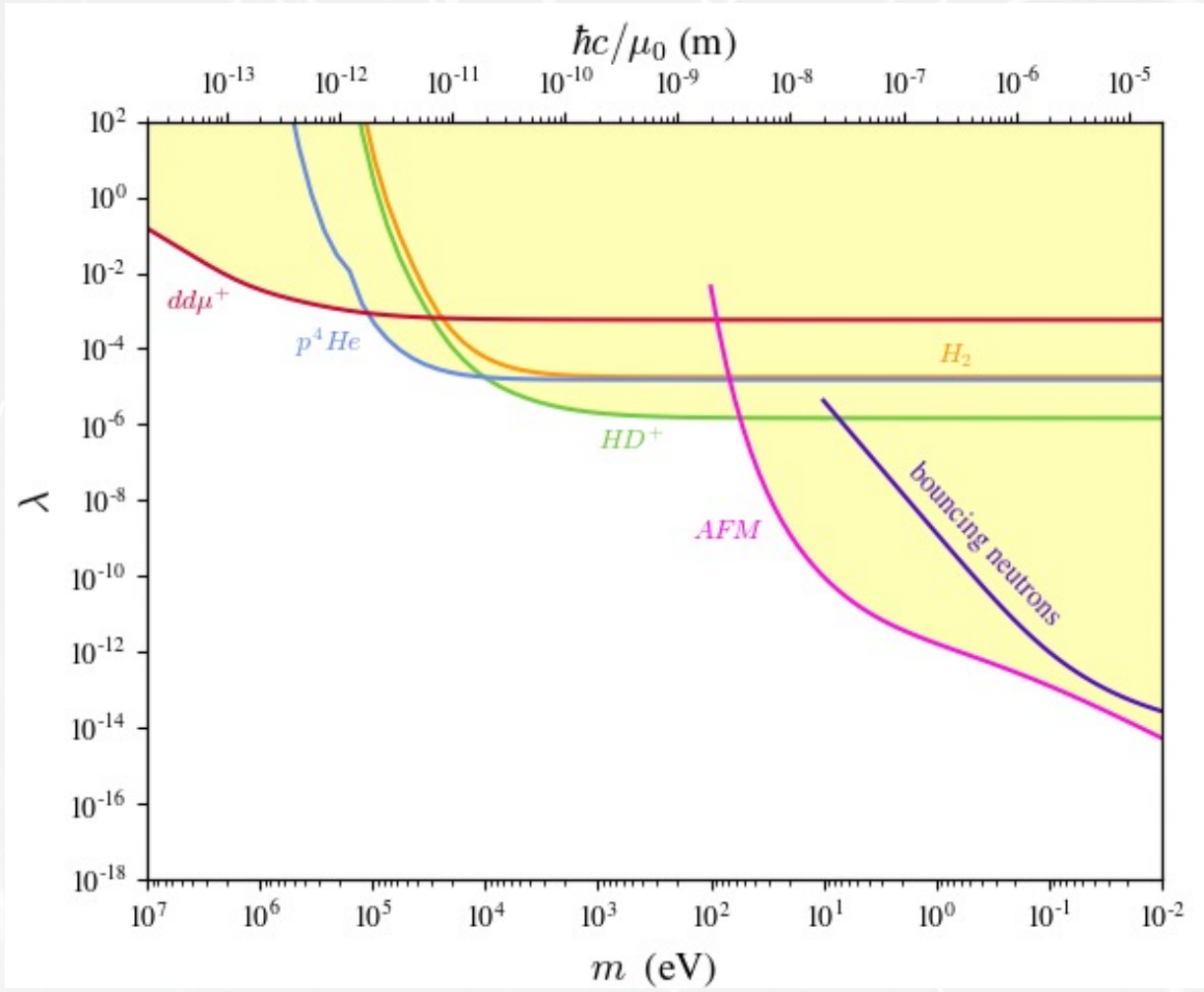
Results from loop exchange obtained simply via optical theorem – no need for loop calculations!

Straightforward to extract limits on any model

The Experimental Landscape



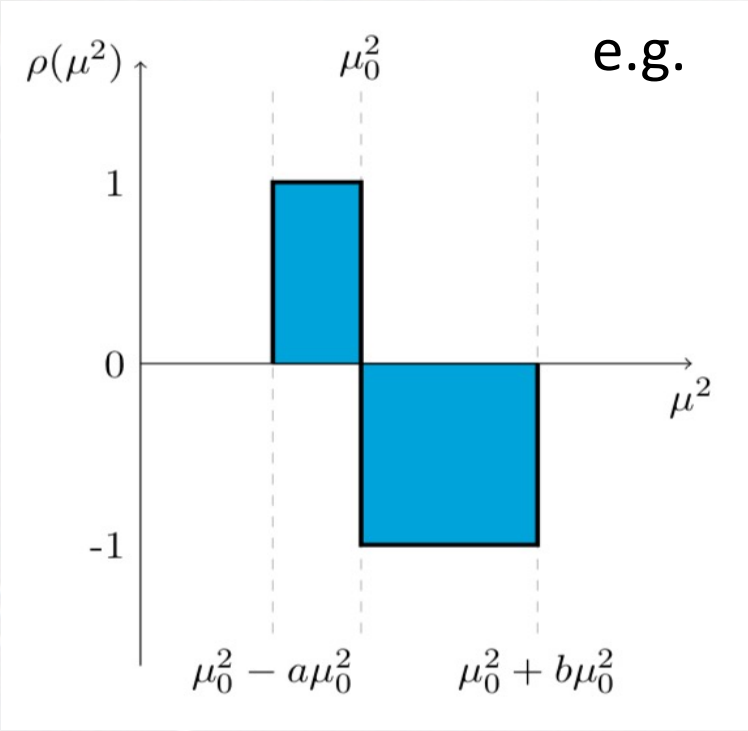
$$\frac{1}{\Lambda}\mathcal{O}_{SM}\bar{\psi}\psi$$



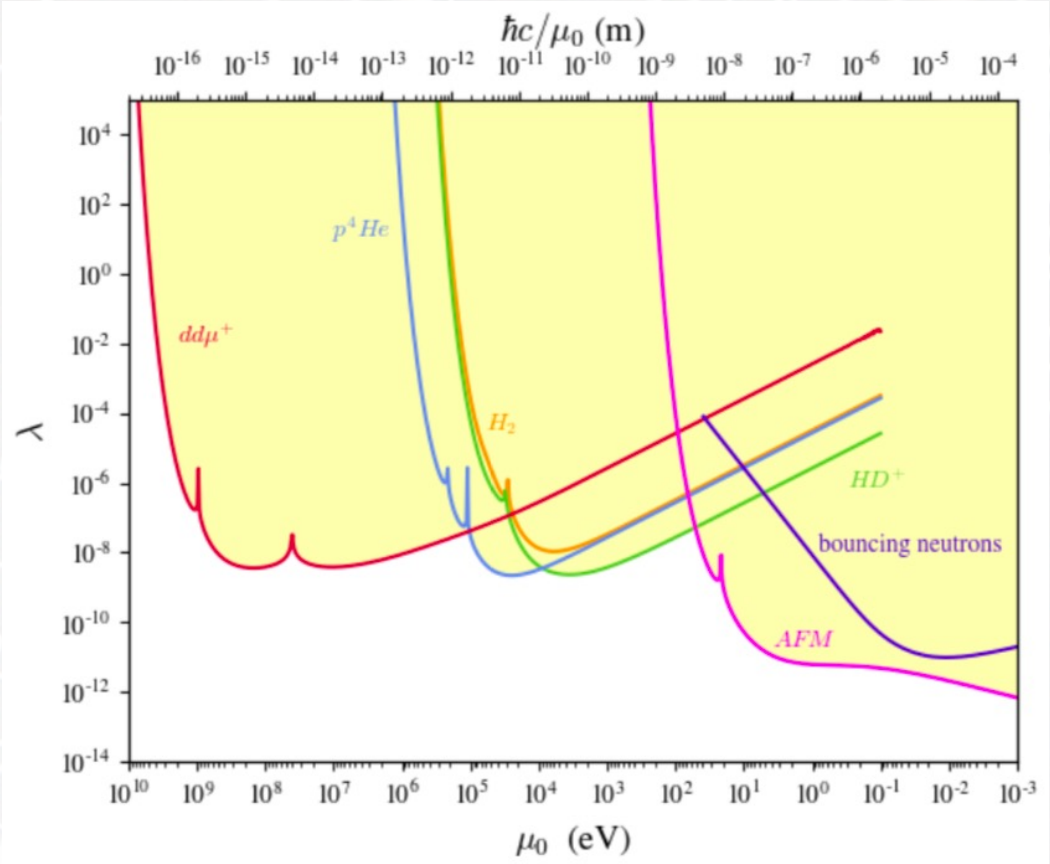
Yukawa

Beyond QFT?

What happens if positivity of $\rho(\mu^2)$ relaxed? i.e. violations of causality, unitarity …



If b> a potential develops a **turning point** in *r*



Caveat: similar effects could arise from different spin operators interfering…

Summary and Conclusions

1. **All** possible scalar fifth forces can be encapsulated by a single, real, positive definite spectral function
2. Potentials from loop exchange can be obtained easily
3. Observables can be expressed in completely general terms ⇨ straightforward extraction of limits to any model
4. Unique opportunity to consider more speculative scenarios such as violation of QFT fundamentals
5. The landscape of possible scalar fifth forces is much richer than the simple Yukawa scenario and worth pursuing!