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Flavor Portal to Dark Matter

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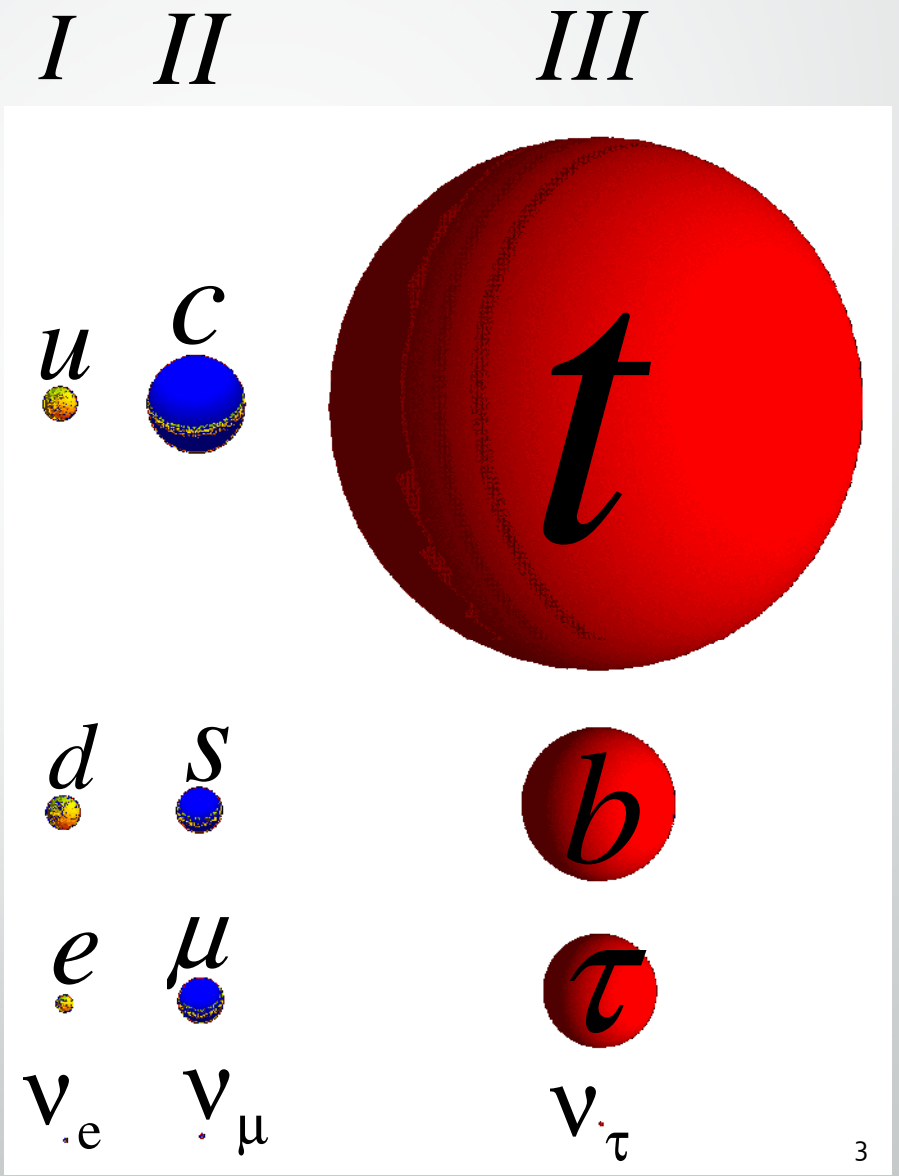
Outline

- Quark masses and CKM elements
- Froggatt Nielsen and Flavour Symmetries
- Flavour Portal to Dark Matter
  - Explicit U(1) model
  - Relic Density
  - Direct detection
  - Flavour constraints (Kaon mixing)
- Conclusion and Outlook

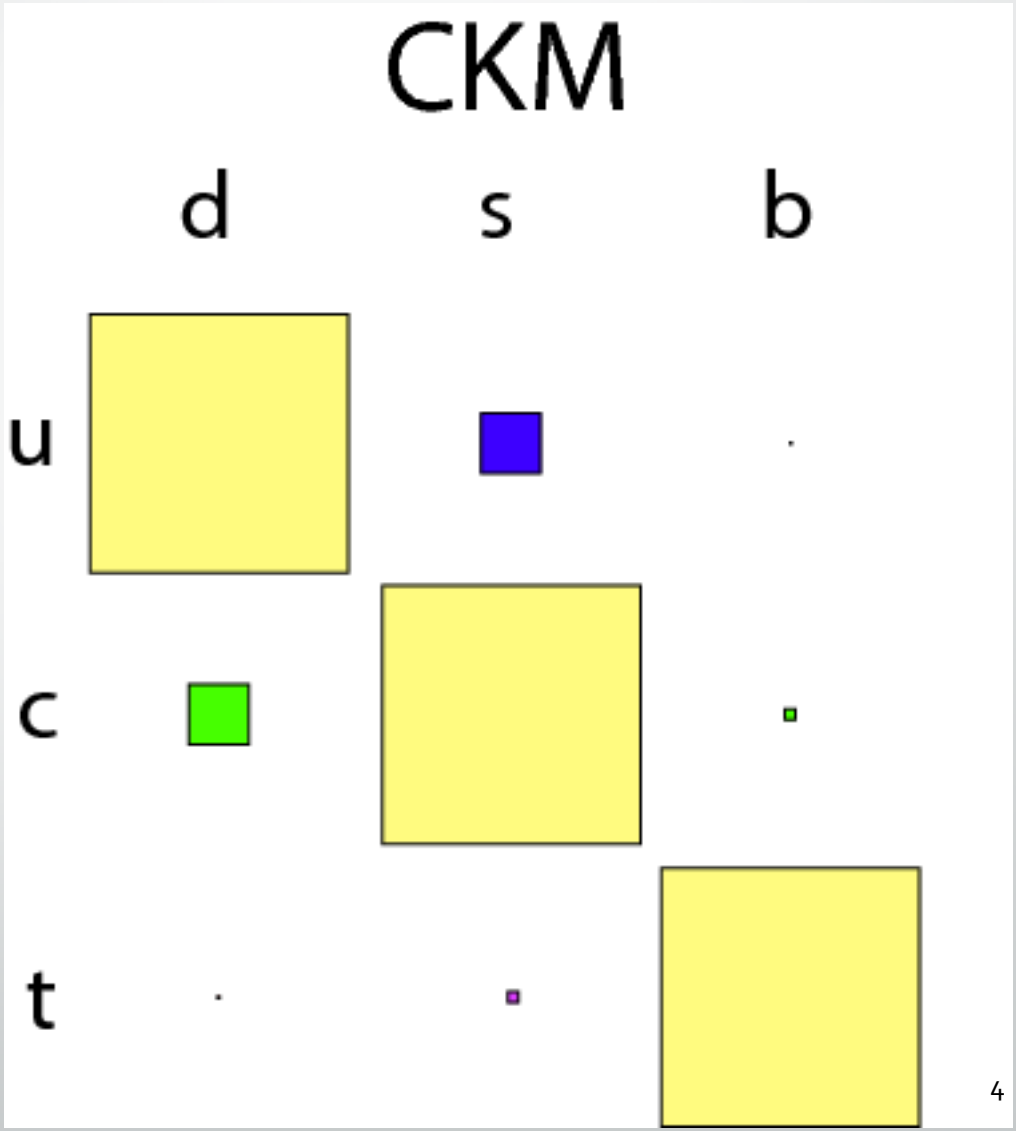
Quark masses

- Volume of the sphere is proportional to the mass
- Quark masses are strongly hierarchical



CKM elements

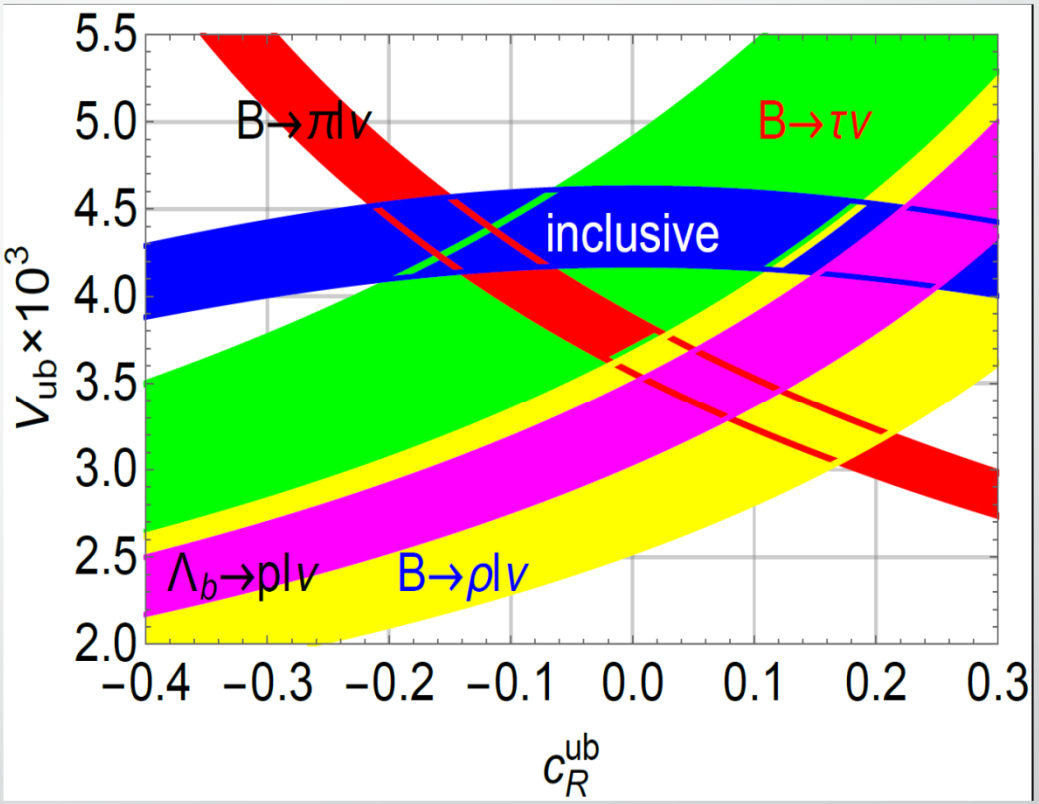
- V_{ub}
  - $B \to \pi \ell \nu$
  - $B \to X_u \ell \nu$
  - $B \to \rho \ell \nu$
  - $B \to \tau \nu$
- V_{cb}
  - $B \to D \ell \nu$
  - $B \to D^* \ell \nu$
  - $B \to X_c \ell \nu$
- V_{us}
  - Kaon decays



CKM elements are hierarchical

CKM elements

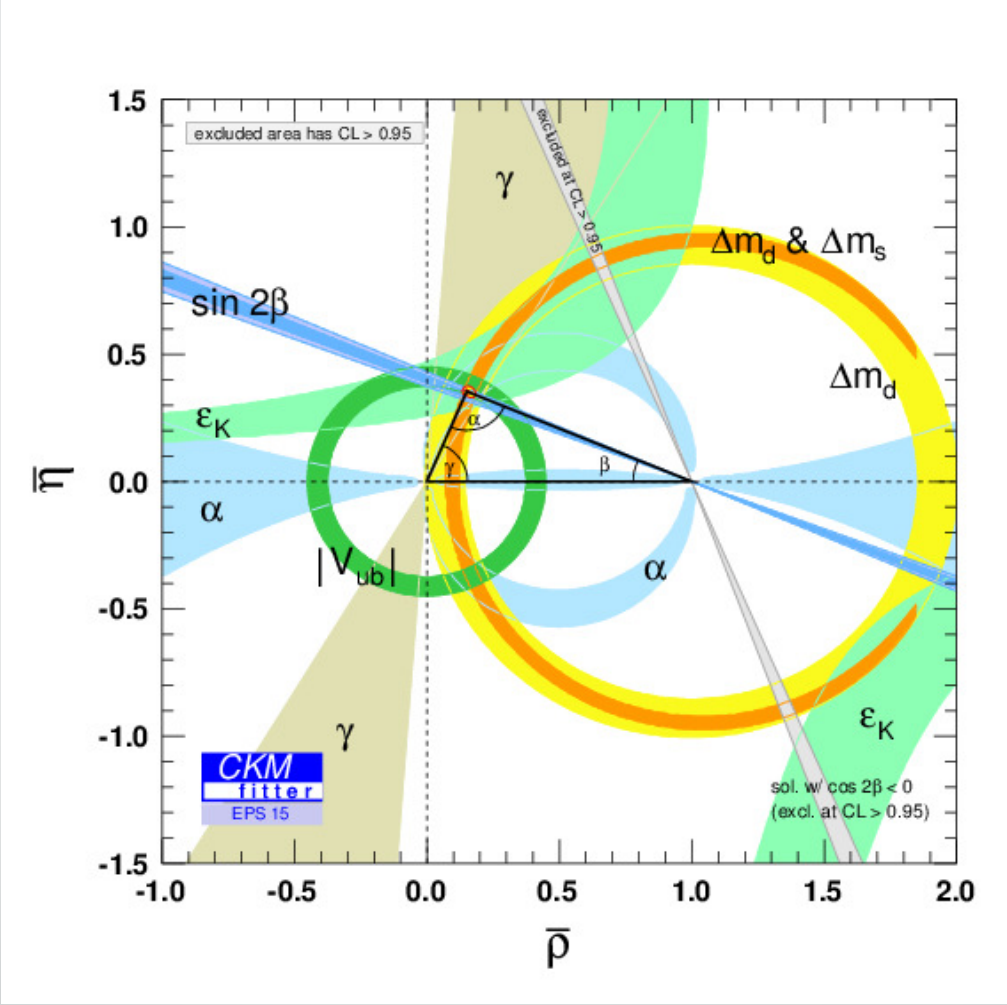
- Inclusive and exclusive determinations of the V_{ub} and V_{cb} do not agree well.
- Right-handed W-b-u coupling?



Update of AC, S. Pokorski '2014

No new physics in CKM elements

Global CKM fit



- CKM fit work very well
- Strong constraints on New Physics

Flavour Puzzle

- How do we explain the hierarchy of the CKM elements and the quark masses?

$$\frac{m_c}{m_t} \approx \varepsilon^4, \frac{m_u}{m_t} \approx \varepsilon^8$$

$$|V| \approx \begin{pmatrix} 1 & \varepsilon & \varepsilon^3 \\ \varepsilon & 1 & \varepsilon^2 \\ \varepsilon^3 & \varepsilon^2 & 1 \end{pmatrix}$$

$$\frac{m_s}{m_b} \approx \varepsilon^3, \frac{m_d}{m_b} \approx \varepsilon^5$$

$$\varepsilon \approx 0.23$$

- Hints for a organizing principle?
- Dynamical Explanation?

Froggatt Nielsen Mechanism

Froggatt Nielsen '79, Leurer Seiberg Nir '92, '93

- SM fermions are charged under a new flavour symmetry
- Vector-like fermions $Q_L, Q_R, D_L, D_R, U_L, U_R$ charged under the flavour symmetry are added
- SM scalar singlets ϕ with flavour charge breaks the flavour symmetry (flavons) by the vev v_ϕ

U(1) Example

Chankowski et al. ‘05

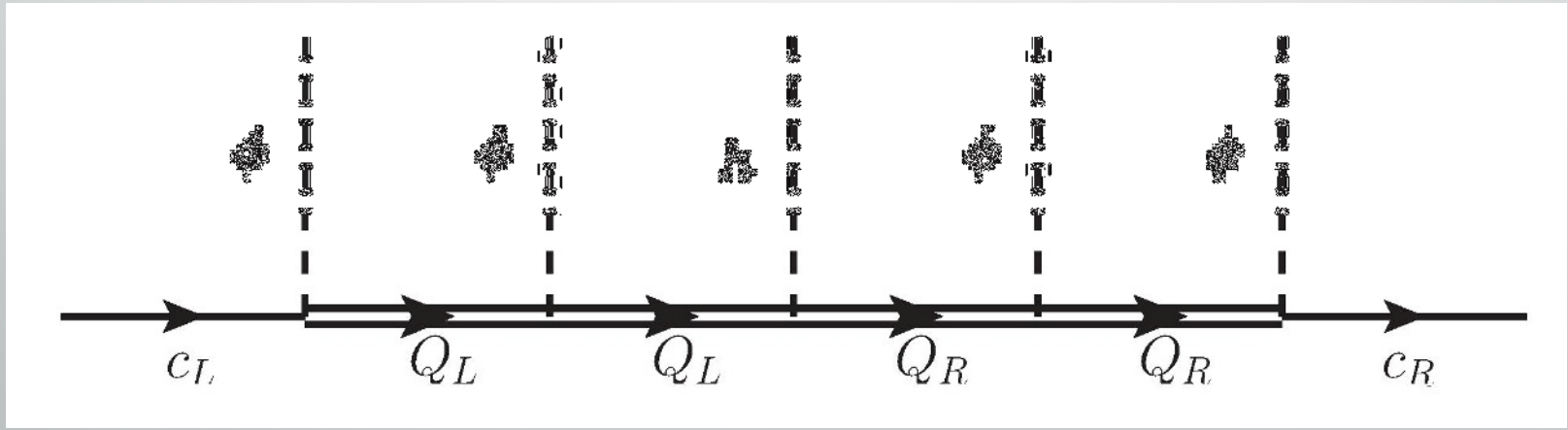
$$Q(q_1, q_2, q_3) = (3, 2, 0)$$
$$Q(u_1, u_2, u_3) = (-3, -2, 0)$$
$$Q(d_1, d_2, d_3) = (-4, -2, -2)$$

$$y^u_{ij} = a^u_{ij} \varepsilon^{Q(q_i)+Q(u_j)}$$

$$y^d_{ij} = a^d_{ij} \varepsilon^{Q(q_i)+Q(d_j)}$$

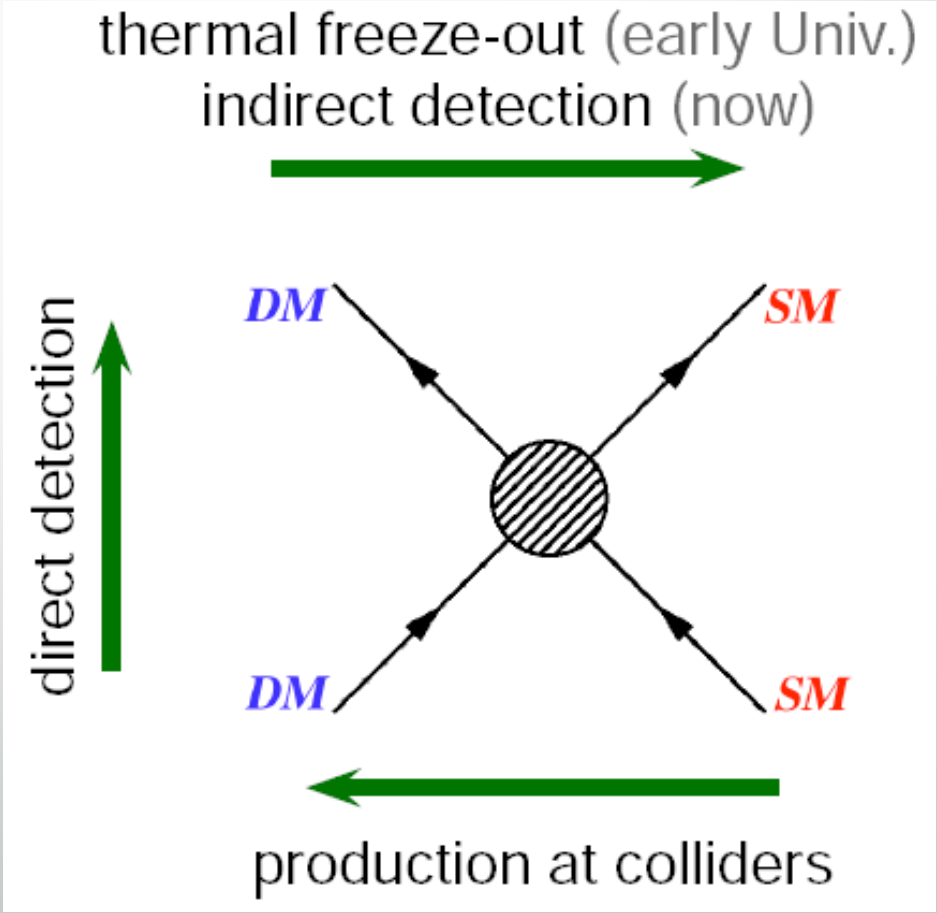
$$\varepsilon = \frac{v_\phi}{M}$$

$$O\left(\left|a^q_{ij}\right|\right) = 1$$



Dark Matter

- Existence established on cosmological scales
- Weakly interacting
- SM singlet?!
- Why is it stable?
- How is it connected to the SM (relic density)



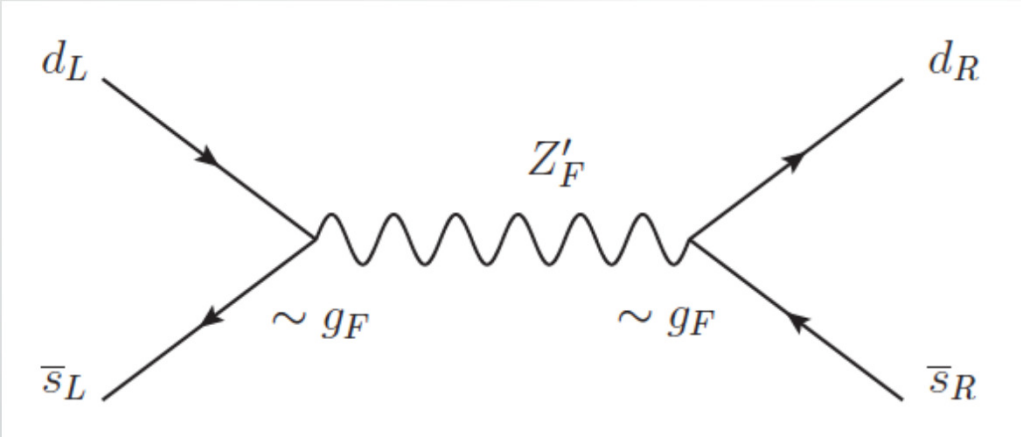
Flavour Portal to Dark Matter

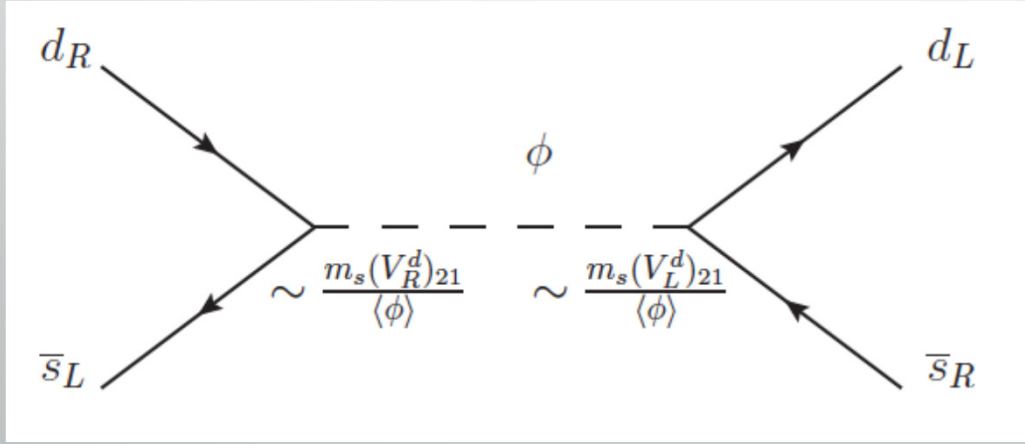
L. Calibbi, AC, B. Zaldivar '14

- DM is a SM singlet but is charged under the flavour symmetry
  - Minimal (no additional quantum number etc.)
  - Stability can be ensured
- Flavour interactions connect DM with the Standard Model
- Flavour symmetry
  - Global: Flavon exchange
  - Local: Flavour gauge boson exchange

Flavour Constraints

- Best constraints from Kaon mixing on U(1) models
  - SM is smallest
  - Flavour charges are highest

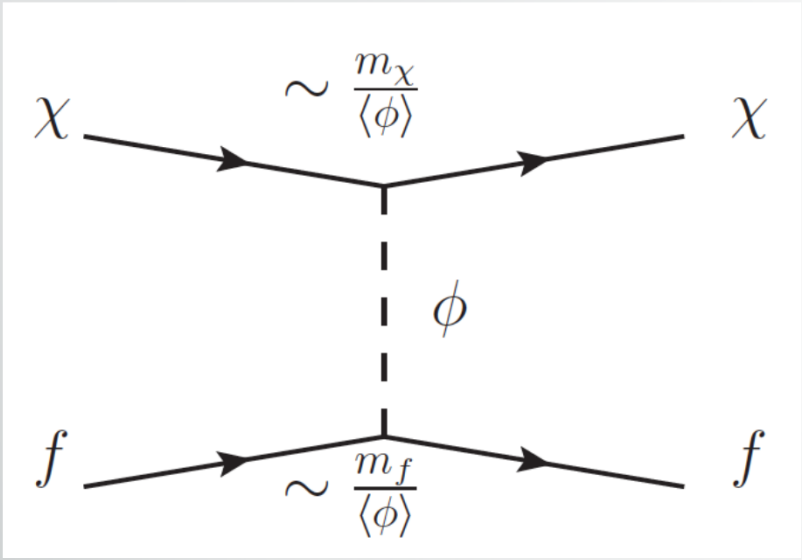




Calibbi, Lalak, Pokorski, '12

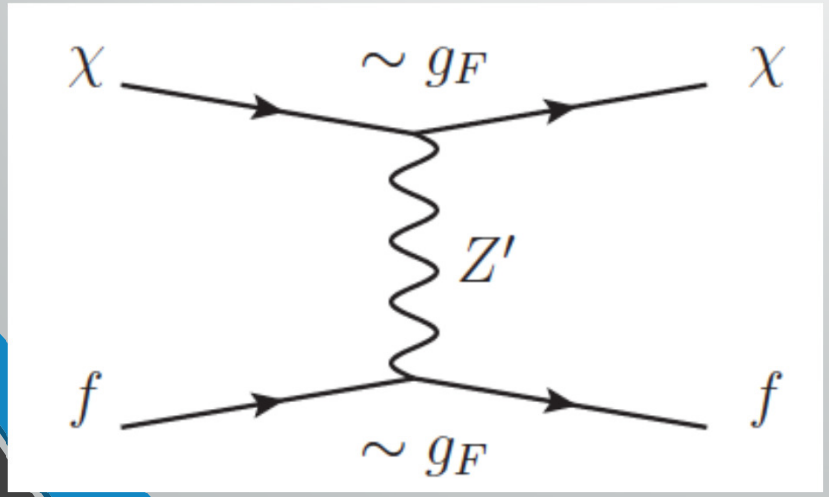
Direct Detection

- Spin independent



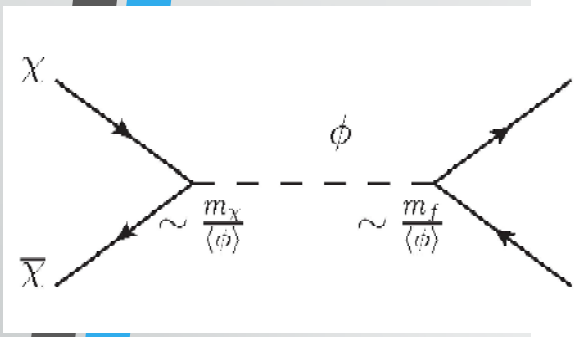
$$\sigma_\phi^{\rm SI} \sim \frac{\lambda_\chi^2 \lambda_{\phi N}^2}{m_\phi^4} \mu_{\chi N}^2$$

MFV-like couplings



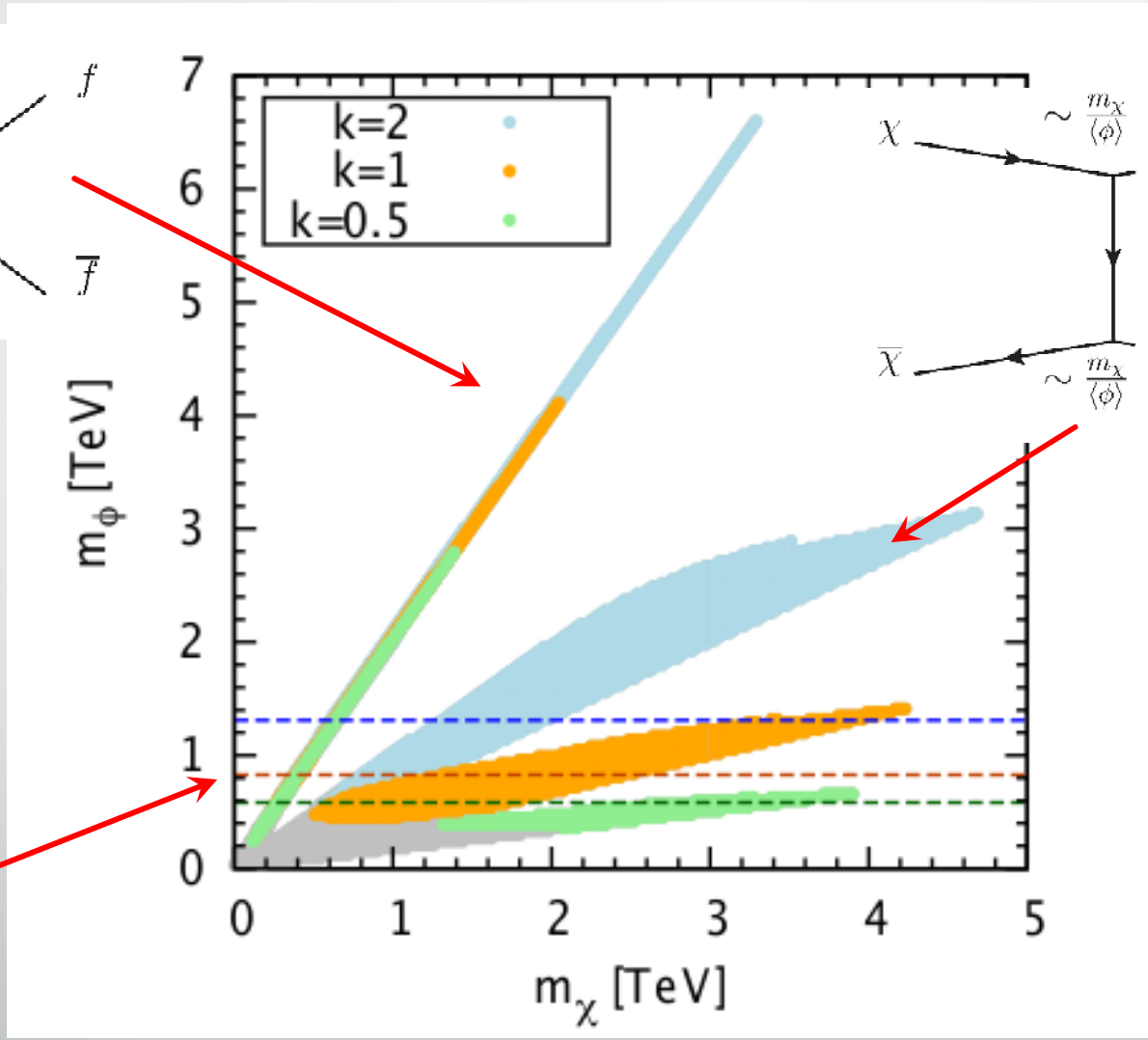
$$\sigma_{Z'}^{\rm SI} \sim \frac{g_F^2 \lambda_{Z'N}^2}{m_{Z'}^4} \mu_{\chi N}^2$$

Flavon Exchange: Relic Density



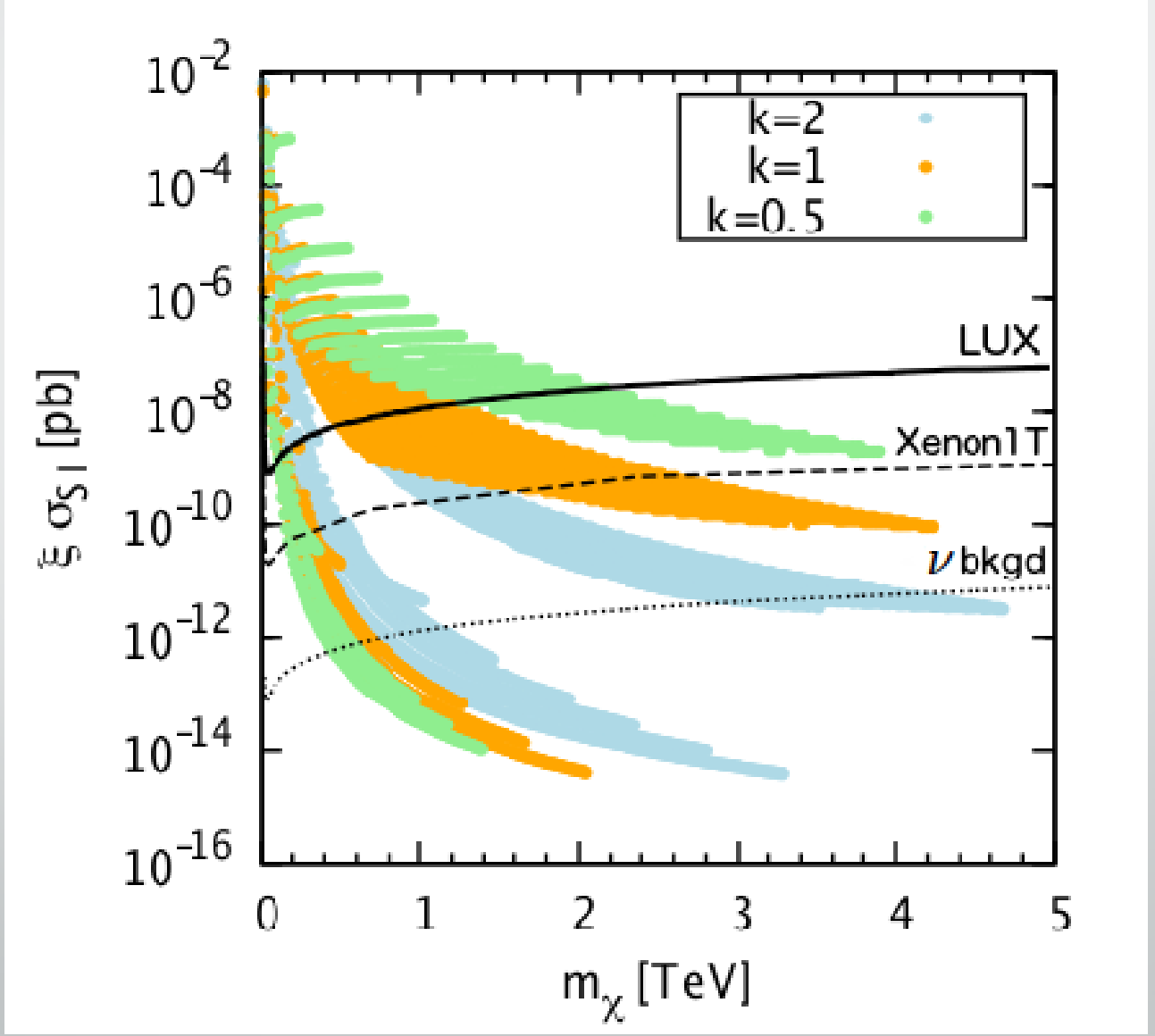
$$k = \frac{m_\phi}{v_\phi}$$

Flavour constraints



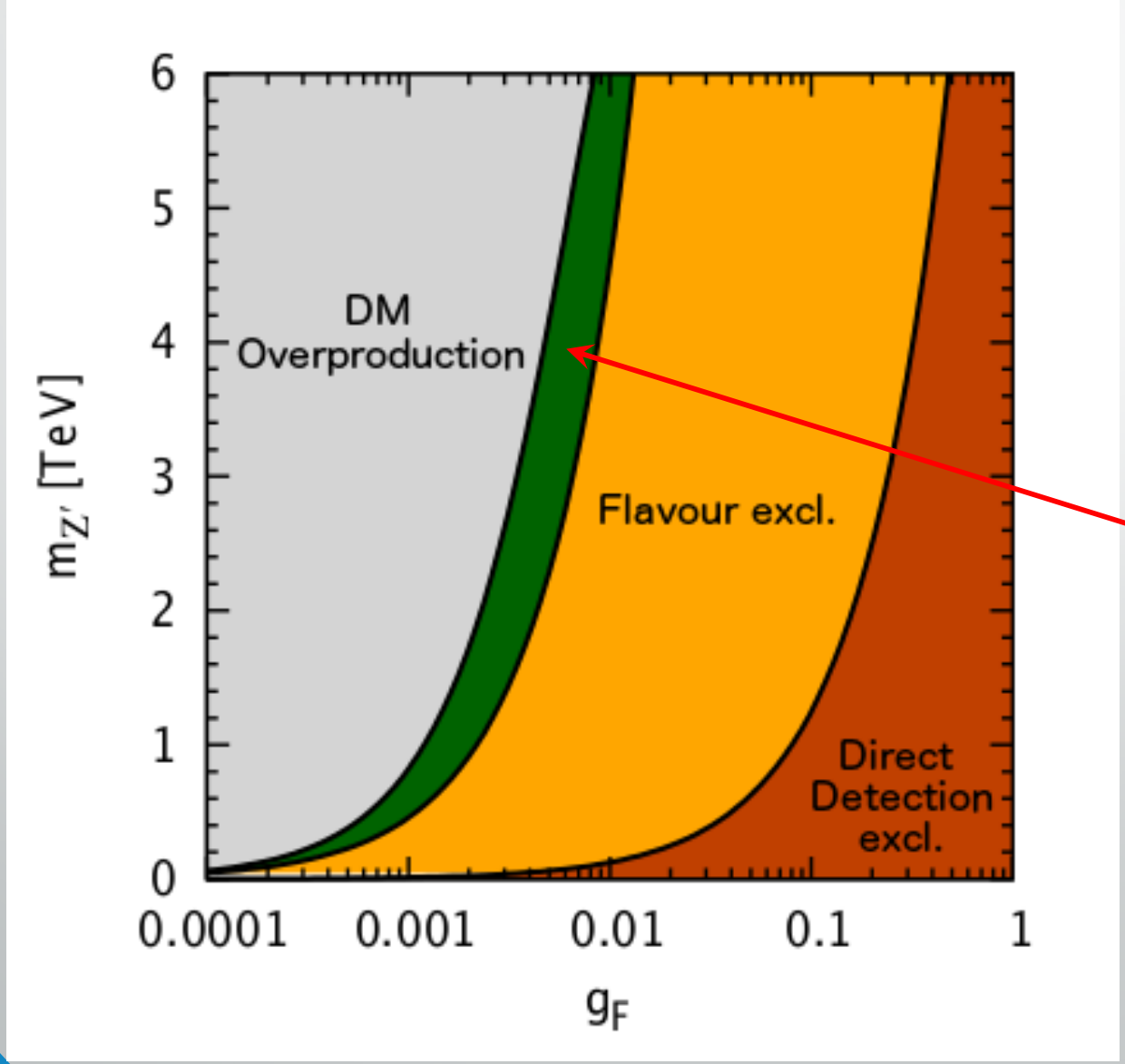
Flavon exchange: Direct Detection

$$k = \frac{m_\phi}{v_\phi}$$



Z′ exchange

- Relic density works of the resonance $m_\chi = \frac{m_{Z'}}{2}$



allowed

Conclusions

- Flavour symmetries explain the hierarchy of quark masses and mixing
- In a general class of models, Dark Matter is charged under some flavour symmetry and interacts with the SM via
  - Flavons (scalars)
  - Flavour gauge bosons (vectors)
- In abelian models one finds strong constraints from Kaon Physics

Outlook

- DM with different Flavour Symmetries
  - SU(3) with DM Bishara, Greljo, et al., '15
  - SU(2)xU(1) can explain the $b \to s\mu\mu$ anomalies Falkowski, Nardecchia, Ziegler '15
  - A4, etc…
- Effects in ε'/ε
- Inclusion of the lepton sector
  - Effects in semileptonic Kaon decays

    Talk of Lewis Tunstall