A Flavon Portal to Dark Matter *

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***1705.xxxxx**

with Fatemeh Elahi & Nirmal Raj

Mini outline

Why?

- Flavor puzzle & Froggat-Nielsen mechanism
- Flavon as DM mediator

$U(1)_{FN}$-flavored fermionic DM

- DM DM $\longrightarrow$ flavons: relic abundance
- Bounds: kaons, colliders, direct & indirect detection

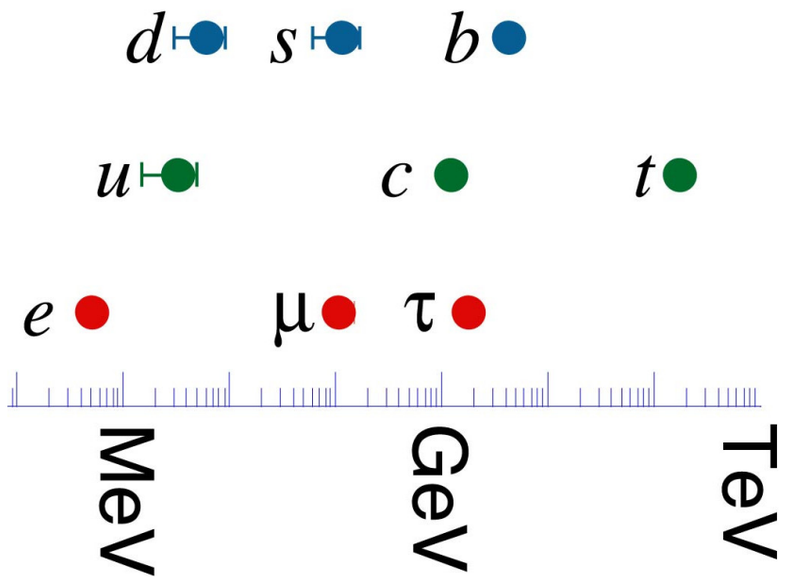
Discussion / Conclusions

Flavor puzzle

SM fermion masses span

a wide range of scales

$$m_e/m_t \sim 10^{-6}$$



V_{CKM} pattern ?

The SM Yukawas

$$Y^u_{ij}\bar{Q}_i\tilde{H}u_j + Y^e_{ij}\bar{L}_iHe_j + \dots$$

provide no clue

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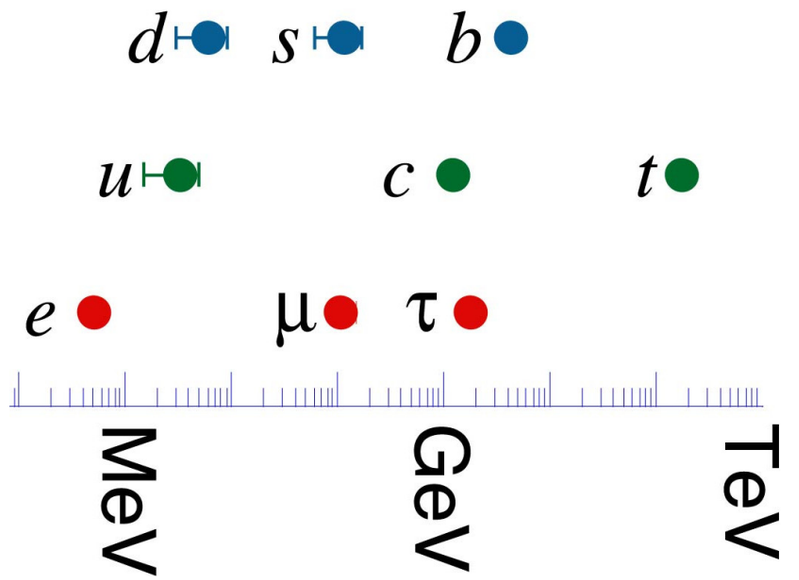

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provide no clue

even more puzzling for ν-masses…

Froggatt-Nielsen Mechanism*

Extend $G_{SM} \to G_{SM} \times G_{\text{flavor}}$. Introduce vector-like fermions $F, \bar{F}$ & flavored complex scalar S (**flavon**)

$$SFf + \Lambda_{\text{FN}} F\bar{F} \qquad (f \text{ SM fermion})$$

which generates effective flavor-invariant operators

$$\left(\frac{S}{\Lambda_{\text{FN}}}\right)^{m_{ij}} \bar{Q}_i \tilde{H} u_j + \left(\frac{S}{\Lambda_{\text{FN}}}\right)^{n_{ij}} \bar{Q}_i H d_j + \dots$$

*Froggatt, Nielsen ‘79

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Fermion mass hierarchy upon $\langle S \rangle \neq 0$. Non-trivial mixing arises depending on flavor charges.

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Yukawas are now powers of $\epsilon \equiv \langle S \rangle / \Lambda_{\text{fN}}$.

Cabbibo angle ≈ 0.23

Flavon as DM mediator

Let's entertain the idea of regarding S, the flavon, **as a mediator** to the dark sector

1. Links flavor puzzle to the SM-DM communication

2. The Froggatt-Nielsen flavon is subject to low energy (lepton flavor violation, M^0-$\bar{M}^0$ mixing, flavor-violating meson decays) and high energy bounds (decays of S to different-flavor fermions)

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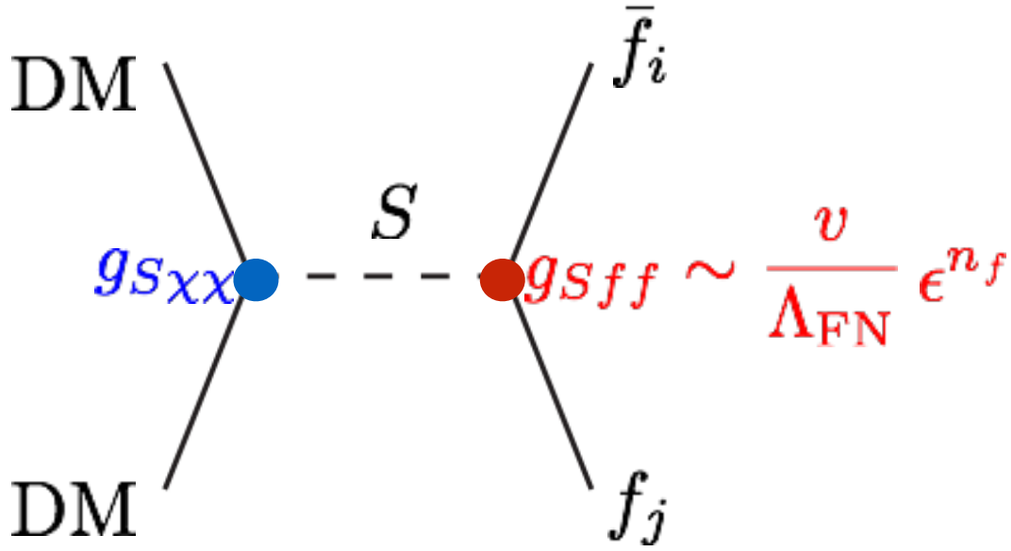
→ Automatic constraints on DM

Flavon as DM mediator

What does promoting S to a mediator to the dark sector tell us about annihilation?

- DM DM $\longrightarrow$ $\bar{f}_i f_j$ automatically suppressed



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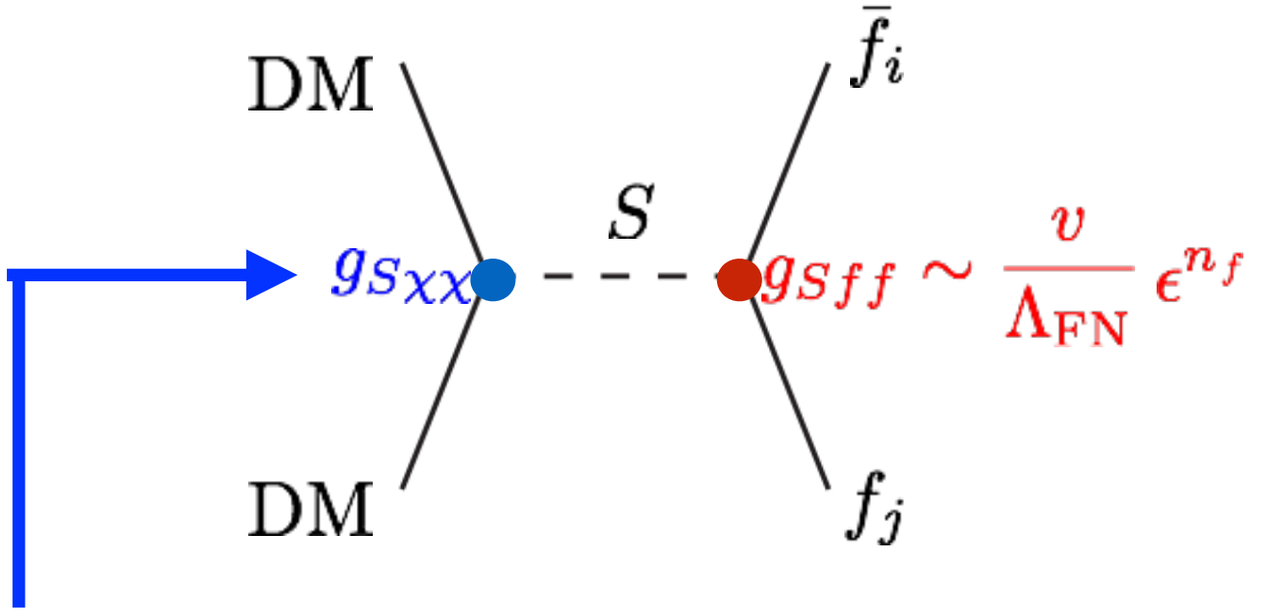


suppressed from flavor (powers of ϵ) and from scale separation (v versus $\Lambda_{\rm FN}$)

not necessarily small

Flavon as DM mediator

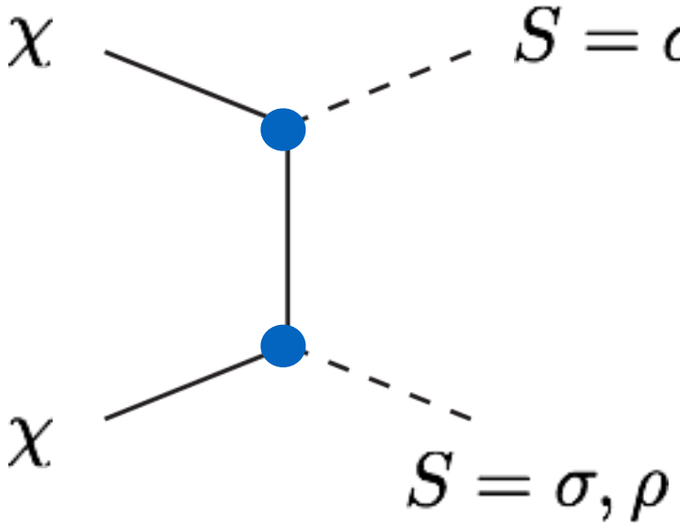
- DM DM $\longrightarrow F\bar{F}$
  Absent if $m_{DM} < \Lambda_{\mathrm{FN}}$, i.e. when DM in the low energy theory.

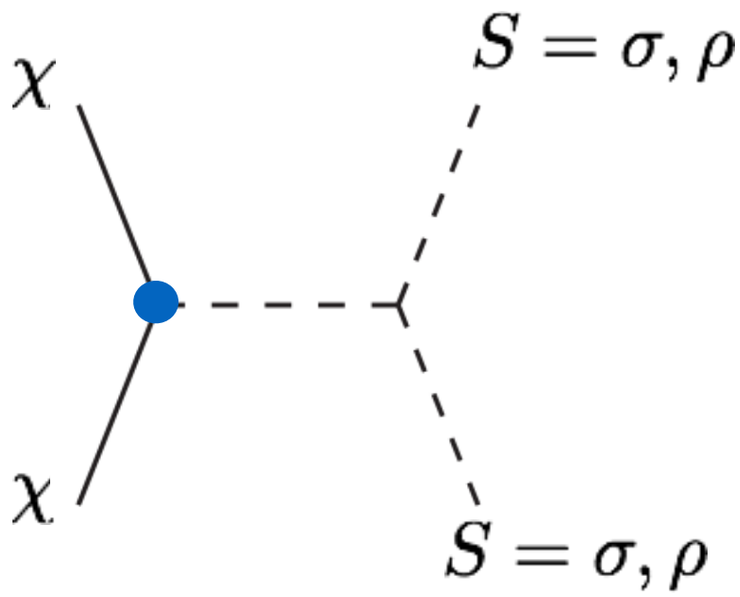
- DM DM $\longrightarrow HH$
  Higgs portal $|DM|^2|H|^2$ (scalar) or $\Lambda_{\mathrm{FN}}^{-1}\overline{DM}DM|H|^2$ (fermion). Latter is suppressed.

→ Fermion DM χ with mass below the cutoff

Flavon as DM mediator

A relic of the right size, $\langle \sigma v \rangle_{\rm thermal}$, could be set by annihilation into flavons





Two flavor quanta of definite CP

$$S = \frac{v_s + \sigma + i\rho}{\sqrt{2}}$$

Possibilities : $\chi\chi \to \sigma\rho$, $\chi\chi \to \rho\rho$, and $\chi\chi \to \sigma\sigma$

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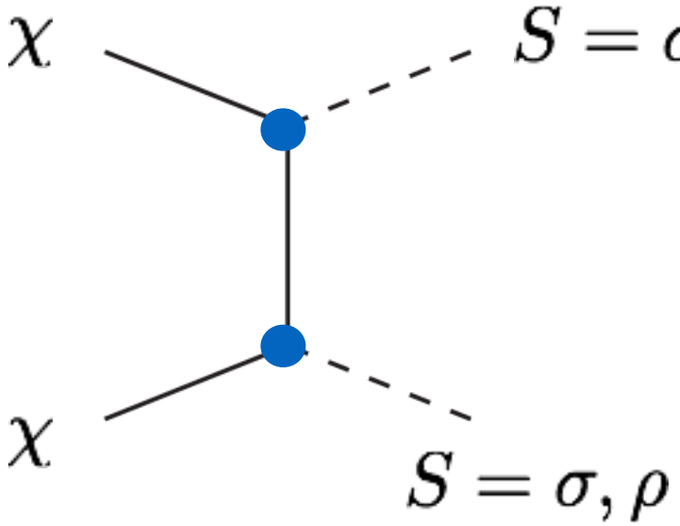

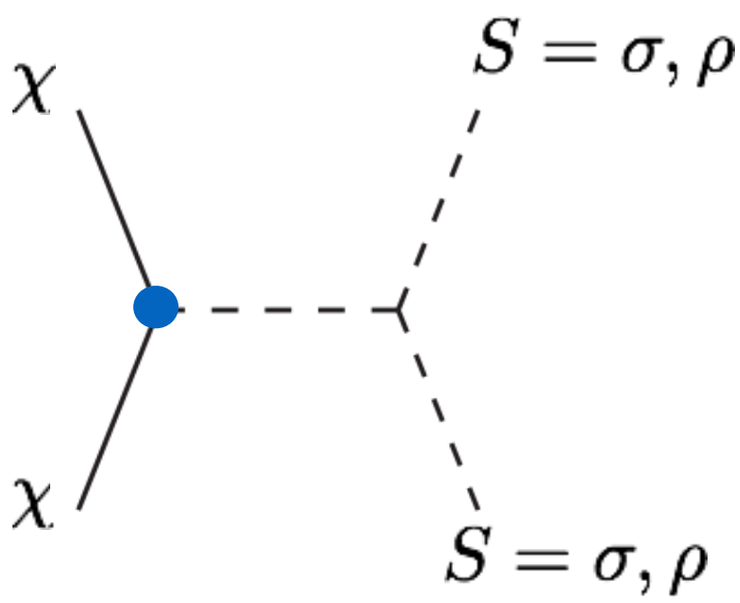

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s-wave p-wave

Flavon as DM mediator

Immediate concerns

- Mass of pseudoscalar flavon ρ?

- Stability of DM

- To charge or not to charge χ?

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- To charge or not to charge χ?

neutral χ

$$\frac{\bar{\chi}\chi|S|^2}{\Lambda_{\rm FN}}$$

$\mathcal{Q}_S = -1$

charged χ

$$(S/\Lambda_{\rm FN})^n \, S\bar{\chi}_L\chi_R$$

$\mathcal{Q}_{\chi_L} + \mathcal{Q}_{\chi_R} = (n+1)$

Flavon as DM mediator

Immediate concerns

- Mass of pseudoscalar flavon ρ? Explicit breaking

- Stability of DM Z_2-parity

- To charge or not to charge χ?

neutral χ

unfavored

$$\frac{\chi\chi|S|^2}{\Lambda_{\rm FN}}$$

charged χ

$$(S/\Lambda_{\rm FN})^n \, S\bar{\chi}_L\chi_R$$

$\mathcal{Q}_S = -1$

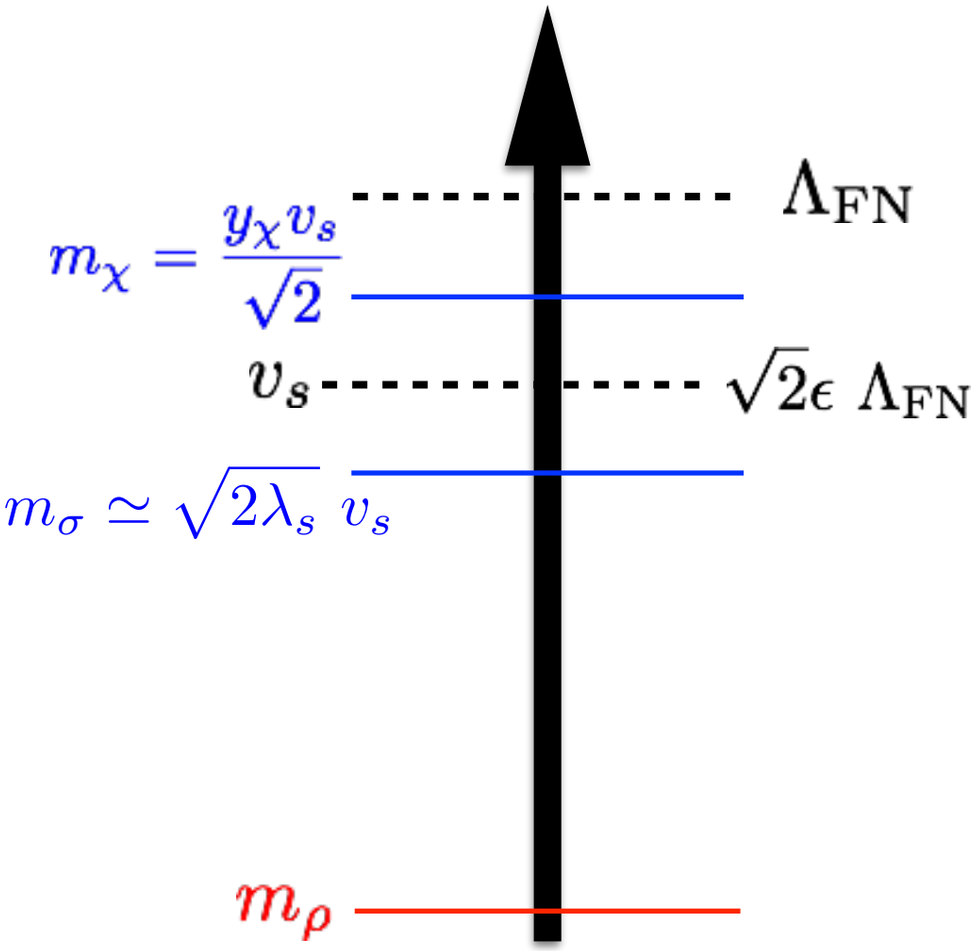
$\mathcal{Q}_{\chi L} + \mathcal{Q}_{\chi R} = (n+1)$

$U(1)_{FN}$-charged DM

From $y_\chi \, (S/\Lambda_{\rm FN})^n S \bar{\chi}_L \chi_R$

m_χ from flavor-breaking

$$m_\chi = \sqrt{2} y_\chi v_s \epsilon^n$$



EW-sized coupling possible

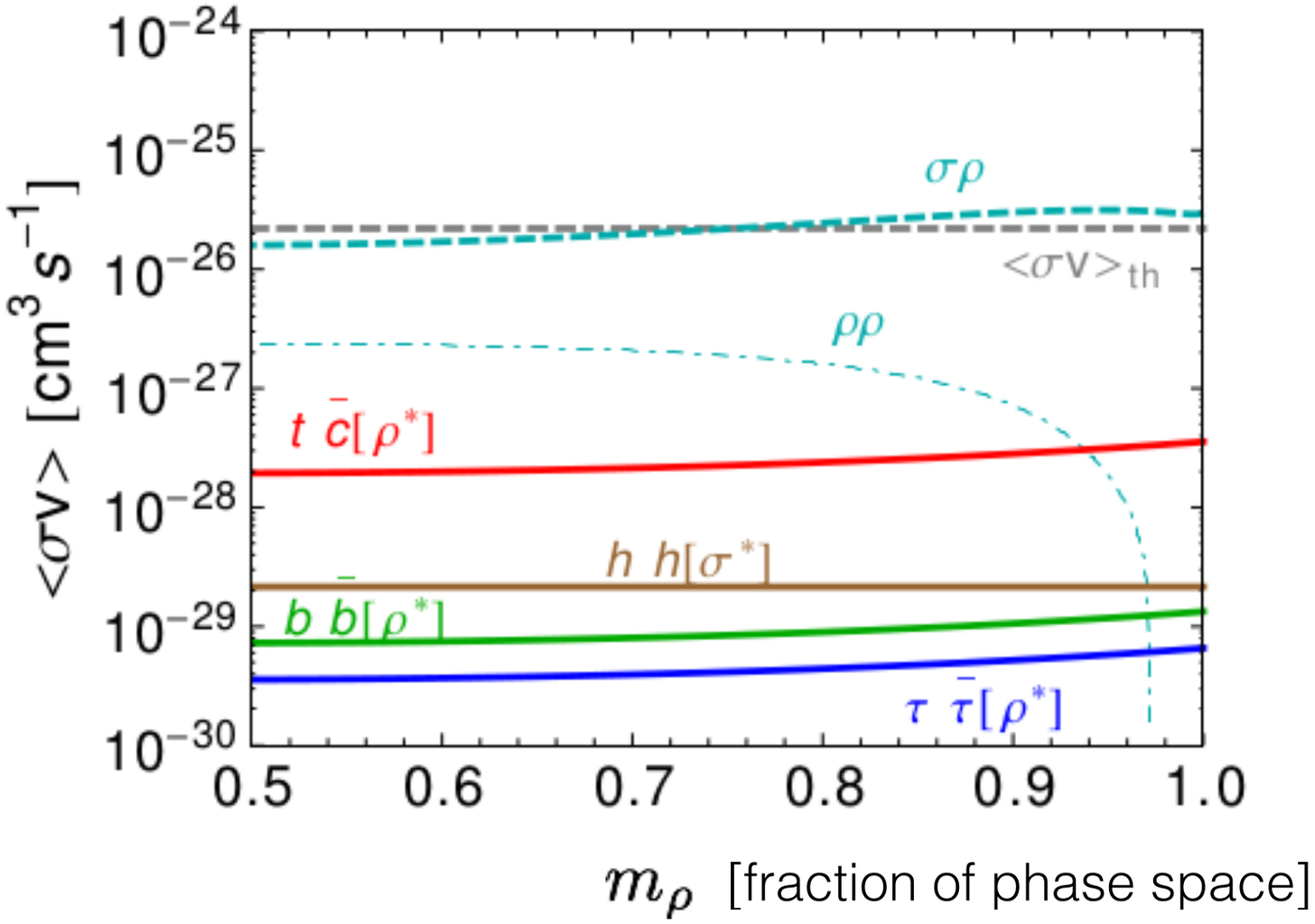
$$g_{s\chi\chi} = (n+1)(y_\chi/\sqrt{2})\epsilon^n$$

Parameter space $\{y_\chi,\ \lambda_s,\ v_s,\ m_\rho,\ \lambda_{hs},\ n\}$

DM $\longrightarrow$ flavons : relic abundance

n=0 class

With $\{y_\chi,\ \lambda_s,\ v_s,\ \lambda_{hs}\} = \{1.5,\ 0.5,\ 1\ \text{TeV},\ 0.13\}, \quad m_\chi \sim m_\sigma \approx 1\ \text{TeV}$



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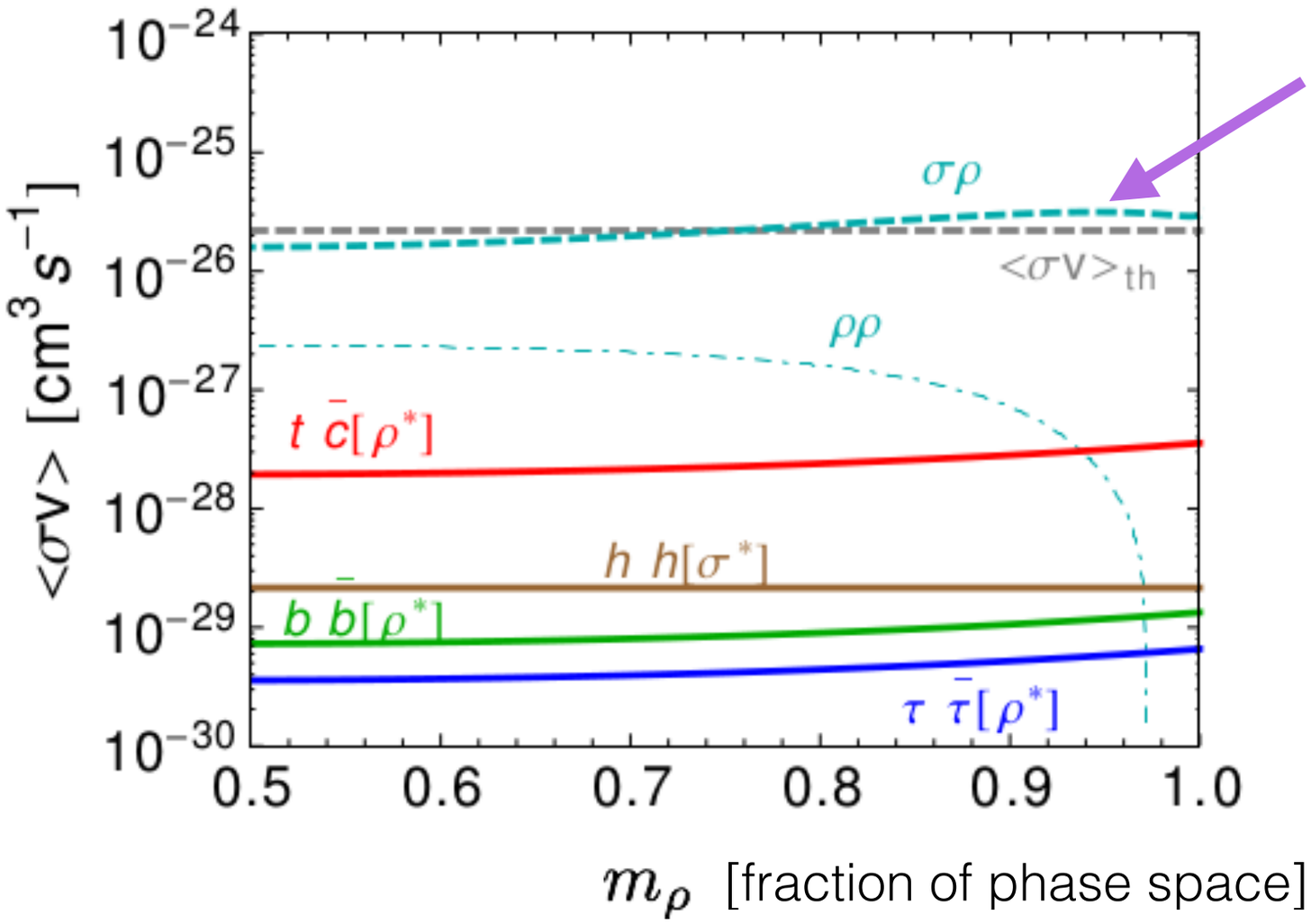

$\langle\sigma v\rangle$ indeed dominated by flavon mode $\sigma\rho$

DM $\longrightarrow$ flavons : relic abundance

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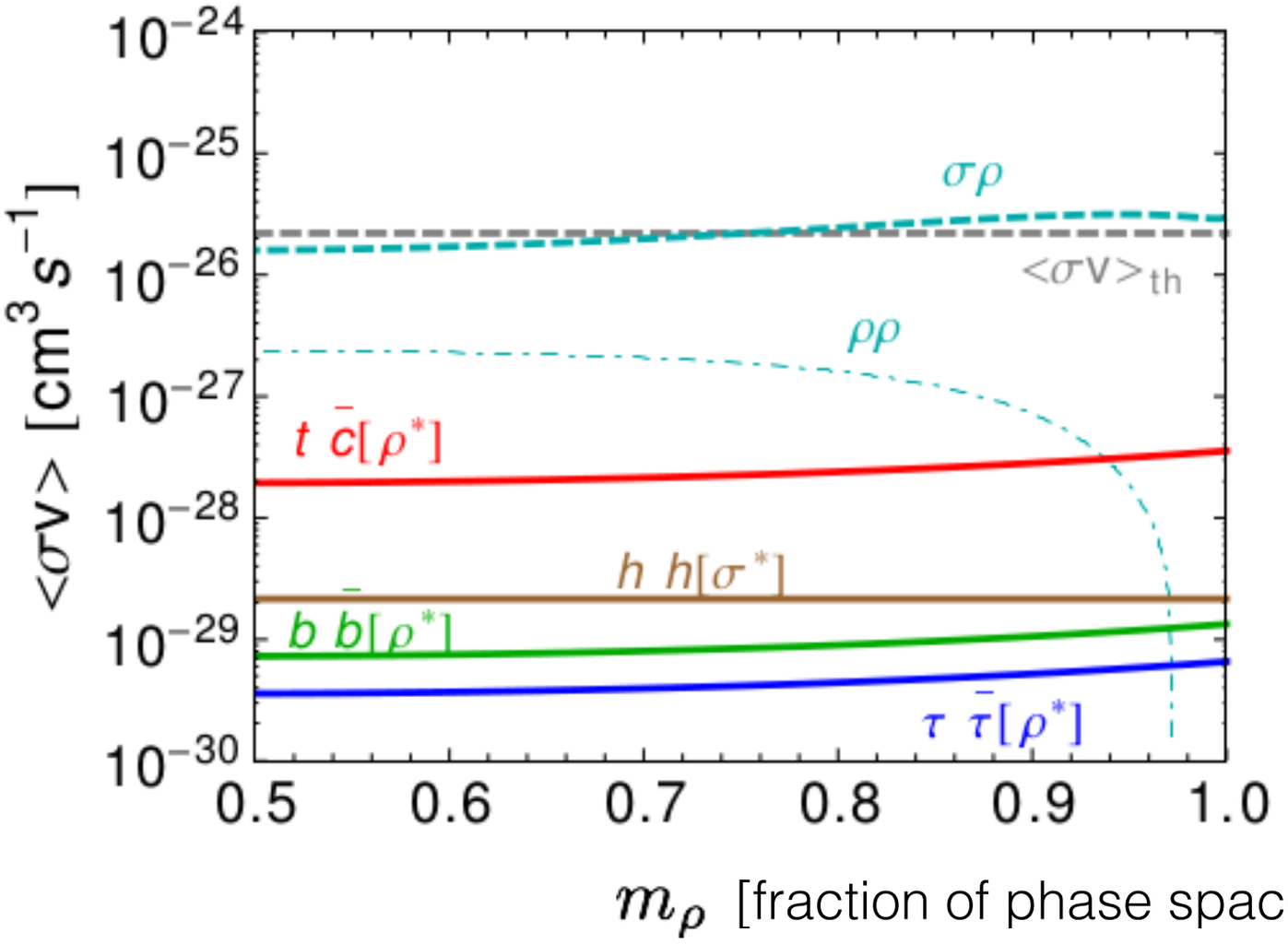
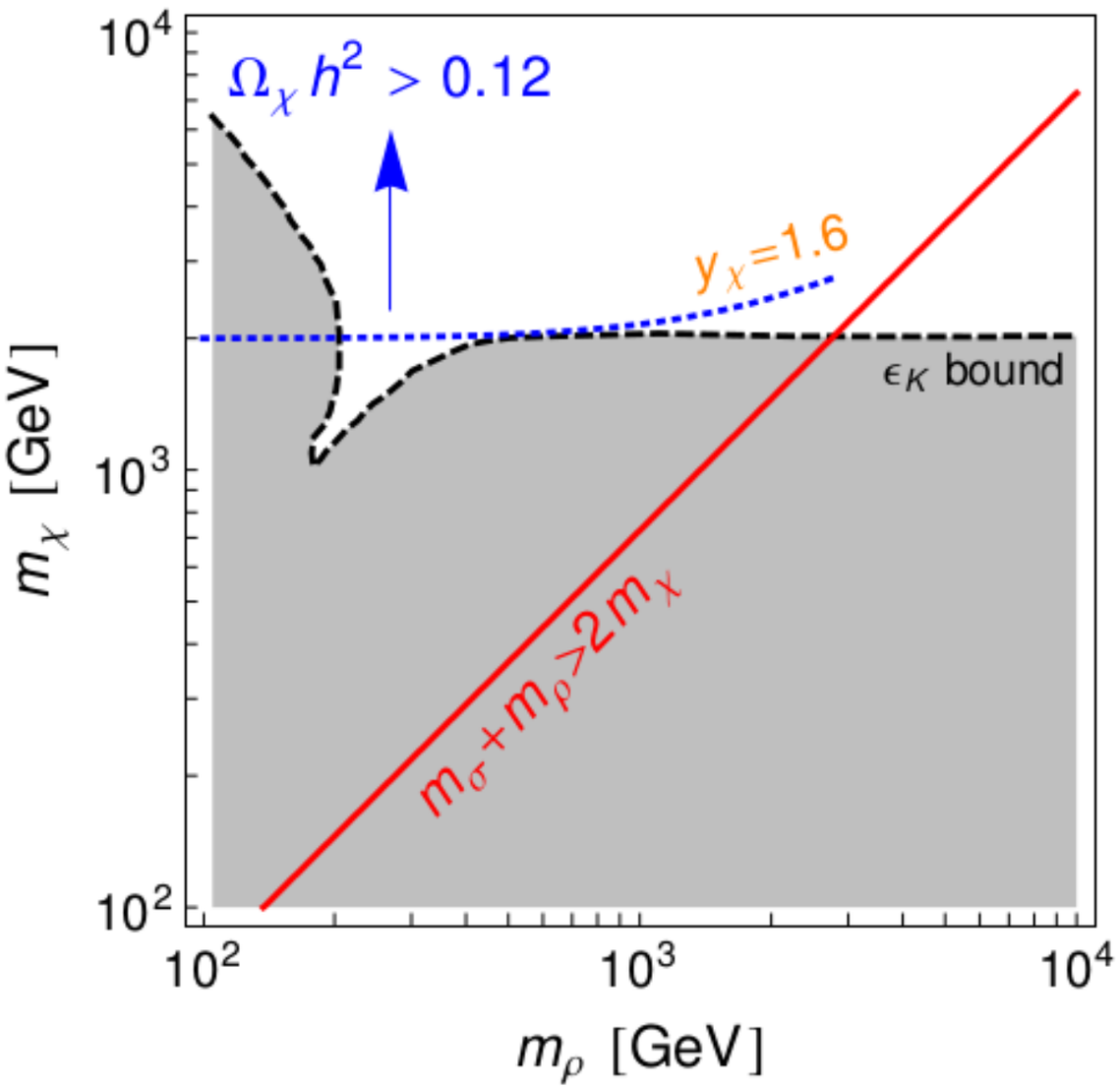


} Too tiny for Higgs & fermions

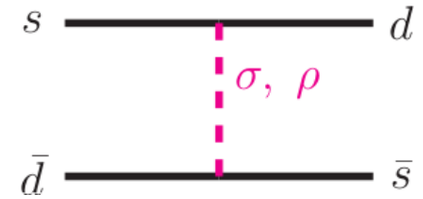
Bounds: kaon mixing

$K^0 - \bar{K}^0$ mixing constrains m_ρ and v_s ➡ bound on m_χ



- $\sigma, \rho \to q_i \bar{q}_j$

  tree-level K^0-mixing



- ϵ_K the most stringent*

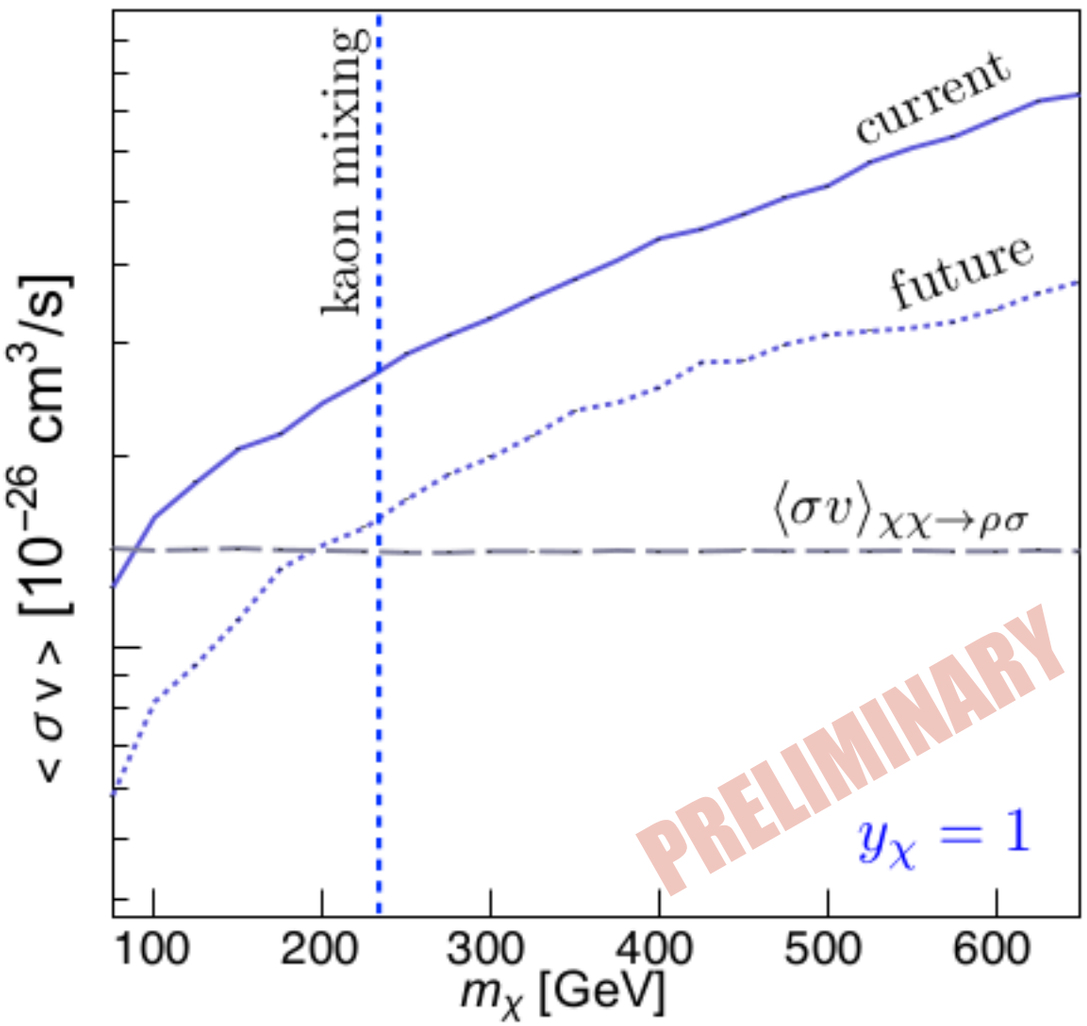
- Shape determined by Wilson coefficients $\propto \left(\frac{1}{m_\sigma^2} \pm \frac{1}{m_\rho^2}\right)$

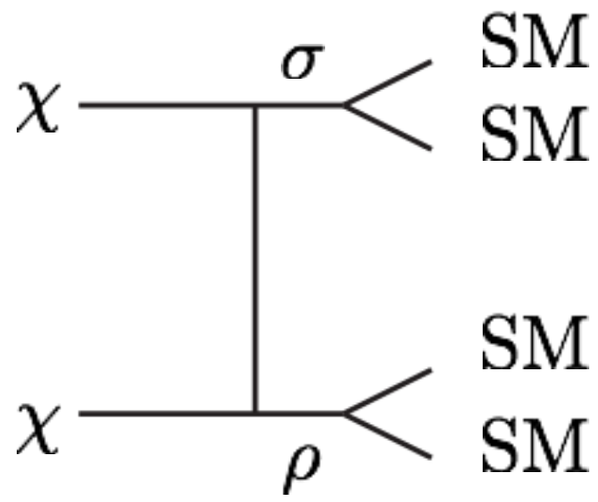
*Bauer, Schell, Plehn ‘16

Bounds: indirect detection

Apply FermiLAT $b\bar{b}$ limit to our s-wave $\langle\sigma v\rangle[\chi\bar{\chi} \to \sigma\rho]$,
i.e. find N_γ for each m_χ

Not direct, but **cascade**!





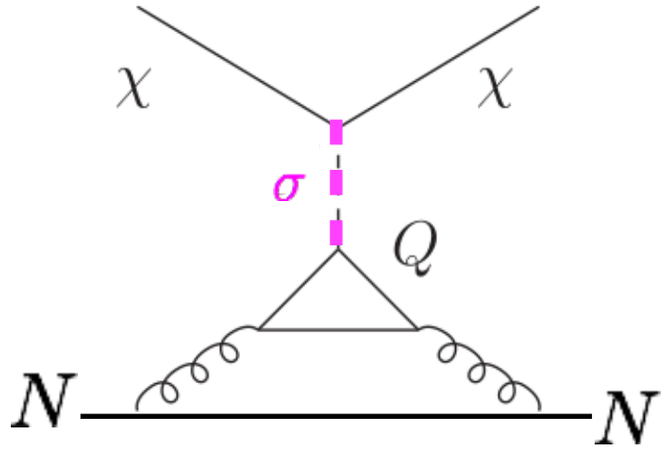
$E_\rho \neq E_\sigma$

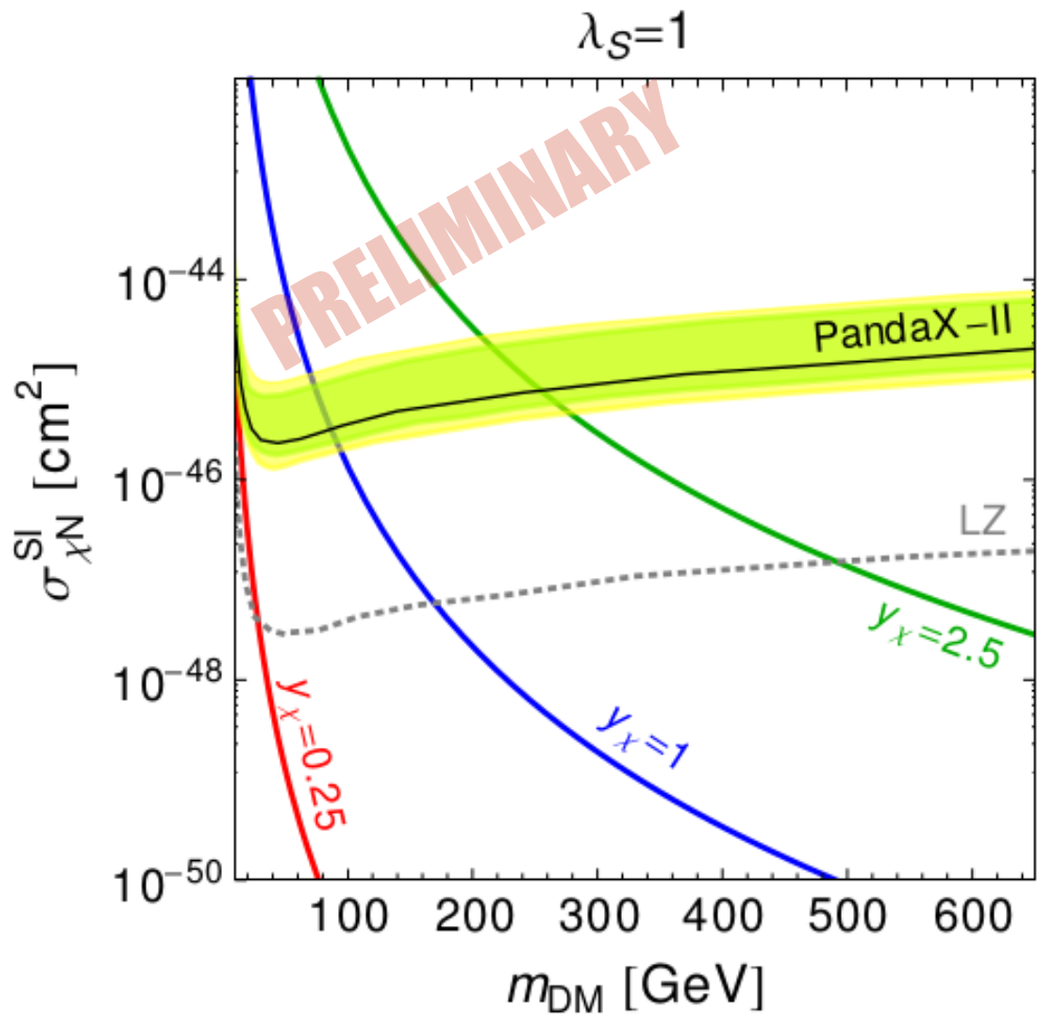
$$N_\gamma = N_\gamma(\rho \to \mathrm{SM\ SM})|_{E_\rho} + N_\gamma(\sigma \to \mathrm{SM\ SM})|_{E_\sigma}$$

Bounds: direct detection

Nucleon-χ scattering via flavon exchange.

Spin-independent for σ only.





$1/m_\sigma^2$-suppression. The $g_{\sigma qq}$ go as powers of $\epsilon \approx 0.23$ (largest ones $g_{\sigma bb}$ & $g_{\sigma tc}$).

Bounds: colliders

Looking for χ at LHC13

Pheno of ρ flavon*

- Couplings to $b\bar{b}$ and $t\bar{c}$ are the largest
- So are its BRs

Signal

Add χ with $m_\chi > m_\rho$.
Look for

$$E_{\mathrm{T}} + X \qquad X = j, t, b$$

Challenges

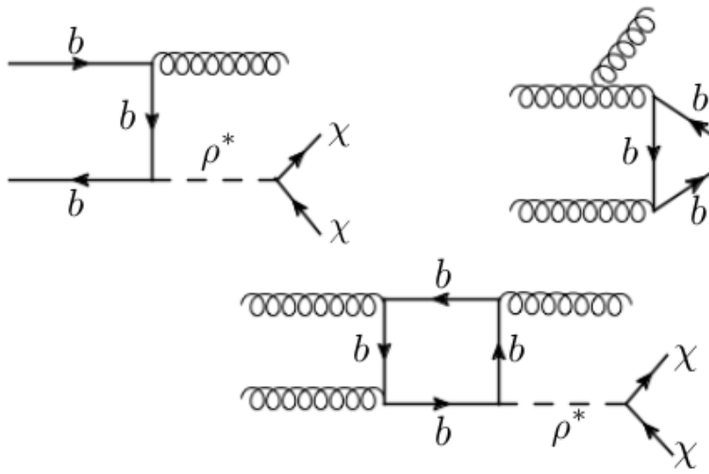
- Pair-produced χ only
- Low PDFs for b & c

*Bauer, Schell, Plehn ‘16

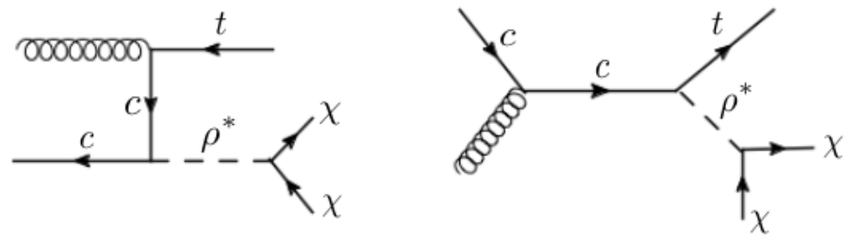
Bounds: colliders

Signal: DM and heavy quarks $\quad E_{\mathrm{T}} + X \quad (X = j, t, b)$

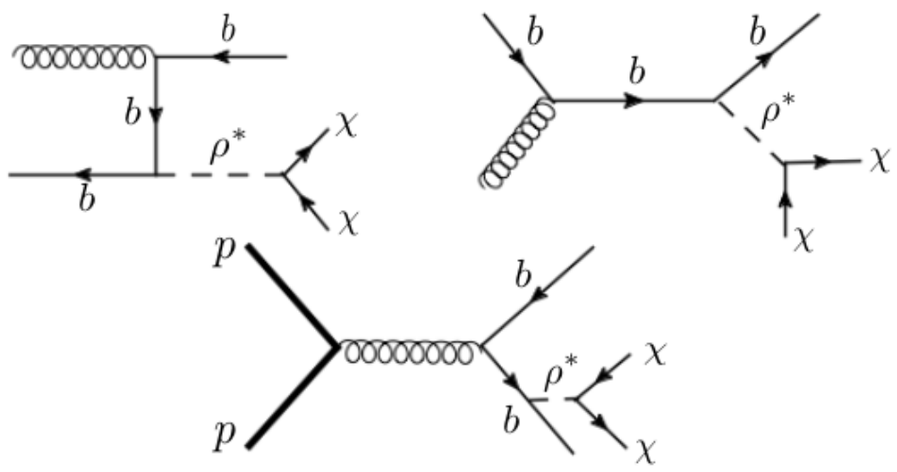
Monojets



Mono-t



Mono-b



Conclusions

- We explored freeze-out conditions for fermionic DM to be embedded in Froggatt-Nielsen.

- $U(1)_{\mathrm{FN}}$-charged DM comprises several classes of models generically relying on CP-even + CP-odd flavon annihilation with $O(1)$ couplings.

- Strongest constraints set by the CPV parameter ϵ_K , with FermiLAT able to probe our scenario.

- LHC & DD are weaker. Signatures & BKGs sketched for colored mono-X.

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THANK YOU

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Signal: DM and heavy quarks $\quad E_{\mathrm{T}} + X \quad (X = j, t, b)$

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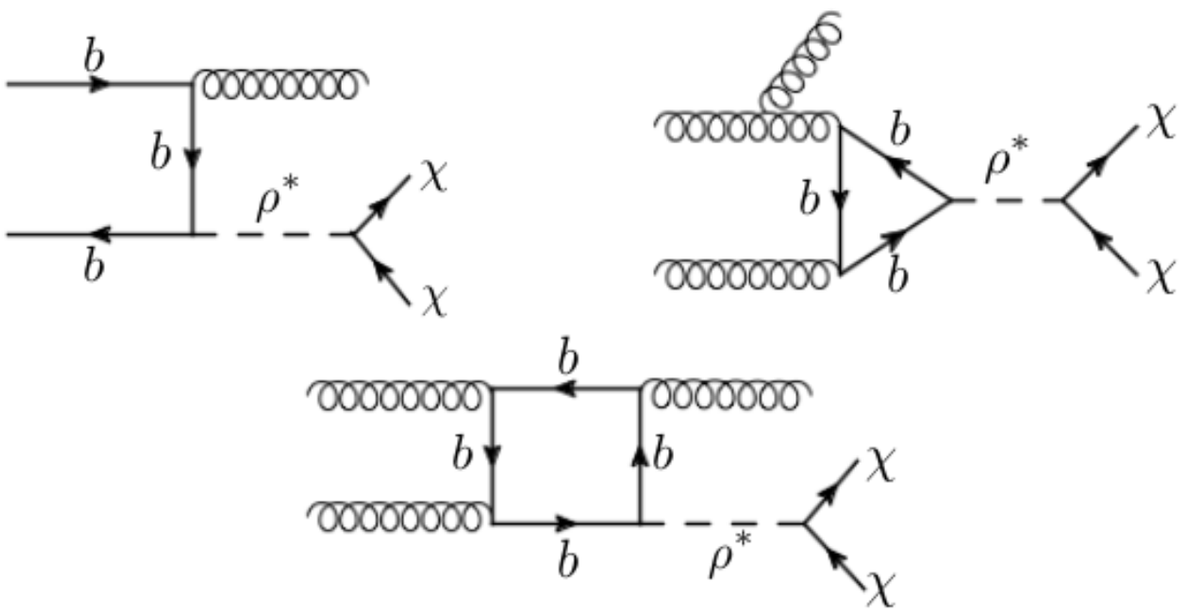

Main backgrounds

Jet mismeasurement

$Z(\nu\bar{\nu}) + j$

$W(\nu\ \ell_{\mathrm{fake}})$

$W(\nu\ \ell_{\mathrm{miss}}) + j$

Missed j in multijet

Backup

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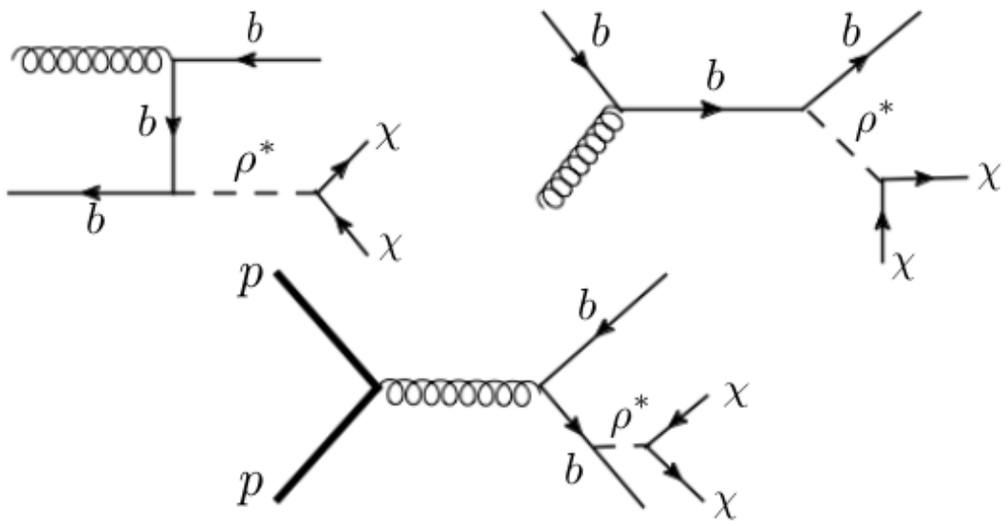
Mono-b



Main backgrounds

Misidentify j/c as b in

$Z(\nu\bar{\nu}) + j/c$

$W(\nu\ \ell_{\mathrm{miss}}) + j/c$

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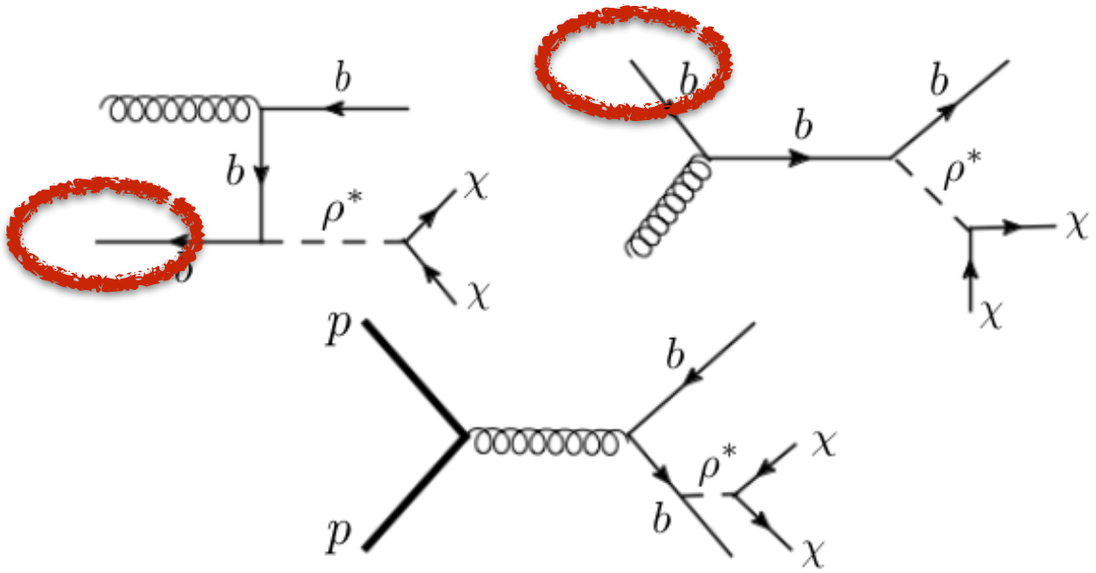
Mono-b



pdf-suppressed

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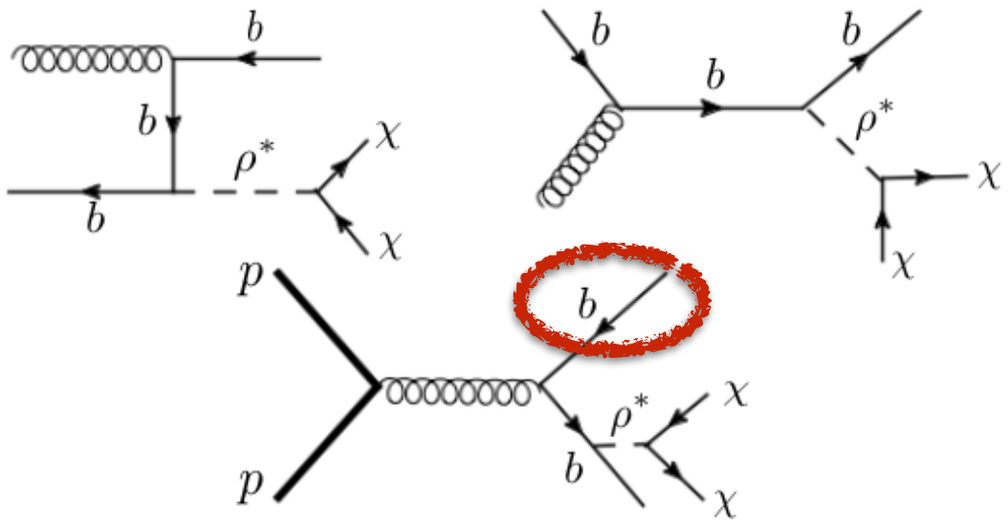

b missed

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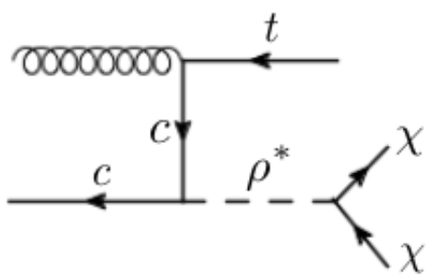
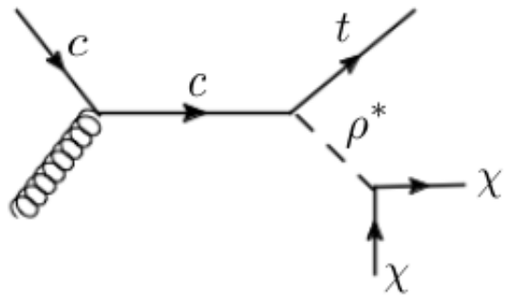
Mono-t





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Mismeasured jets in multi-j

Backup

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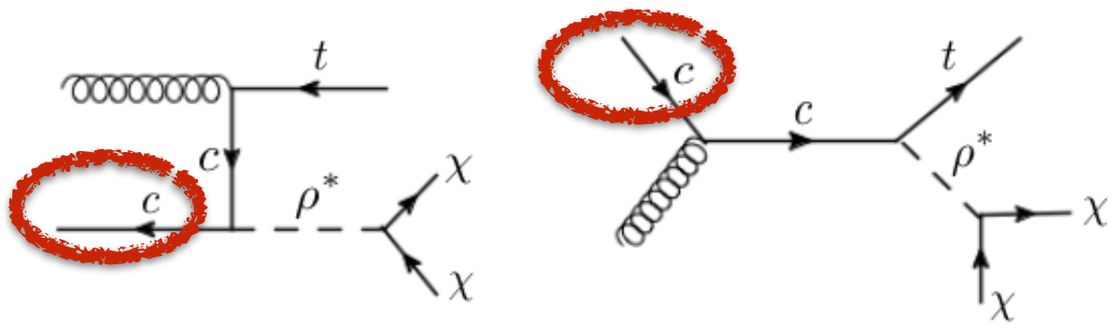
Mono-t



higher pdf than b

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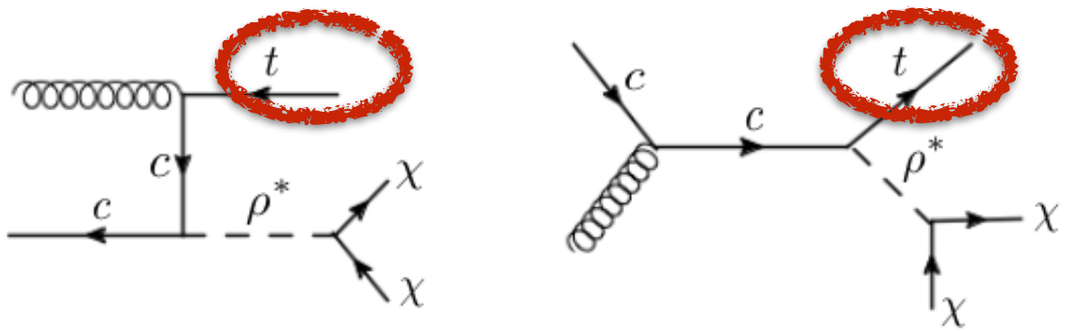
Signal: DM and heavy quarks $E_{\mathrm{T}} + X \quad (X = j, t, b)$

Mono-t



Main backgrounds

Mismeasured jets in multi-j

reconstruct t_{hadronic}

Backup

Resizing the cascade indirect detection cross section

$$\langle \sigma v \rangle_{\text{cascade}} = \langle \sigma v \rangle_{\text{direct}} \frac{N_\gamma(\chi\bar{\chi} \to b\bar{b})}{N_\gamma(\chi\bar{\chi} \to \sigma\rho)}$$

Pseudoscalar mass

$$V(H,S) \supset -b^2(S^2 + S^{\dagger 2}) \xrightarrow{UV} \lambda'_{sy} S^2 Y^2 + H.c.$$