Early universe phenomenology of strongly interacting scenarios

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Confining new physics sectors

New physics could plausibly be an $SU(N)$ confining sector:

$$U(1) \times SU(2) \times SU(3) \times SU(N)$$

(Hidden valley scenario, Strassler & Zurek hep-ph/0604261)

What are the implications for collider phenomenology, informed by cosmology?

Could be origin of composite dark matter (good)

Or stable charged/colored relics (bad)

Or composite leptoquarks (interesting for B decay anomalies)

A nonhidden composite scenario

Hyperquarks Ψ^A of SU(N) could be charged under SM gauge group, including SU(3) color.

For hadron colliders, this allows for gg fusion to resonantly produce $\tilde{\pi} = \Psi\bar{\Psi}$ bound states.

To see $\tilde{\pi}$ decay (*e.g.*, $\tilde{\pi} \to \gamma\gamma$), we might like Ψ to be charged

Challenge: how to avoid charged/colored stable relics?
JC, W. Huang, G.D. Moore, 1607.07865: they could generically occur

Two possibilities:

- hyperbaryon number not conserved;
- it is conserved, but charged relic can decay into neutral hyperbaryon dark matter

Dangerous relic example

Suppose vectorlike hyperquark Ψ_A of $SU(N)$ has same hypercharge as $u_{R,j}$ quarks.* Its baryonic bound state

$$B = (\Psi)^N$$

carries hypercharge and QCD color, but it can bind with N quarks to form stable scalar relic

$$\tilde{B} = (\bar{u}_R\,\Psi)^N$$

which is neutral but strongly interacting (SI).

Highly subdominant SI DM could be consistent with direct detection since it doesn't penetrate to underground detectors
De Luca, Mitridate, Redi, Smirnov, Strumia, 1801.01135

Whether its relic density can be sufficiently suppressed is model-dependent: *e.g.,* is confinement scale Λ bigger or smaller than $M_\Psi/20$?

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*Even if Ψ_A has $Y = 0$, $(\Psi)^N$ can bind with u quarks to make charged relic

Violating hyperbaryon number

Can break hyperbaryon conservation with N scalars Φ_i^A carrying only $SU(N)$:

$$\mathcal{L} = -\underbrace{\lambda_{ij}\,\bar{\Psi}_a^A\,\Phi_{i,A}\,u_{R,j}}_{\text{portal to SM}} - \underbrace{\mu\,\epsilon^{A_i,\dots,A_N}\,\Phi_{1,A_1}\dots\Phi_{N,A_N}}_{\text{hyperbaryon violation}}$$

If Φ_i are heavy, integrate them out,

$$\mathcal{L} \to \frac{\mu\lambda^N}{m_\Phi^{2N}}\left(\bar{\Psi}\,u_R\right)^N$$

so charged hyperbaryon $(\Psi)^N$ decays into N quarks u_R. If Φ is light, then colored bound state $U = \Phi^*\Psi$ mixes with u_R, and decays by mass mixing, dominantly

$$U \to h\,t, \quad U \to W\,b$$

Constrained by LHC searches for top partners

Could also couple to leptons

If Ψ has hypercharge $y = 1$ and $N = 3$, can give SU(3) color to Φ and coupled to $e_{R,i}$:

$$\mathcal{L} = -\lambda_i \, \bar{\Psi}_a^A \, \Phi_{A,a} \, e_{R,i} - \mu \, \epsilon^{abc} \epsilon^{ABC} \Phi_{A,a} \Phi_{B,b} \Phi_{C,c}$$

Gives composite vectorlike lepton $E = \bar{\Psi}\Phi$, constrained by searches for

$$E \to Z \, e_i$$

again from mass mixing. Constraints are weak, ruling out range

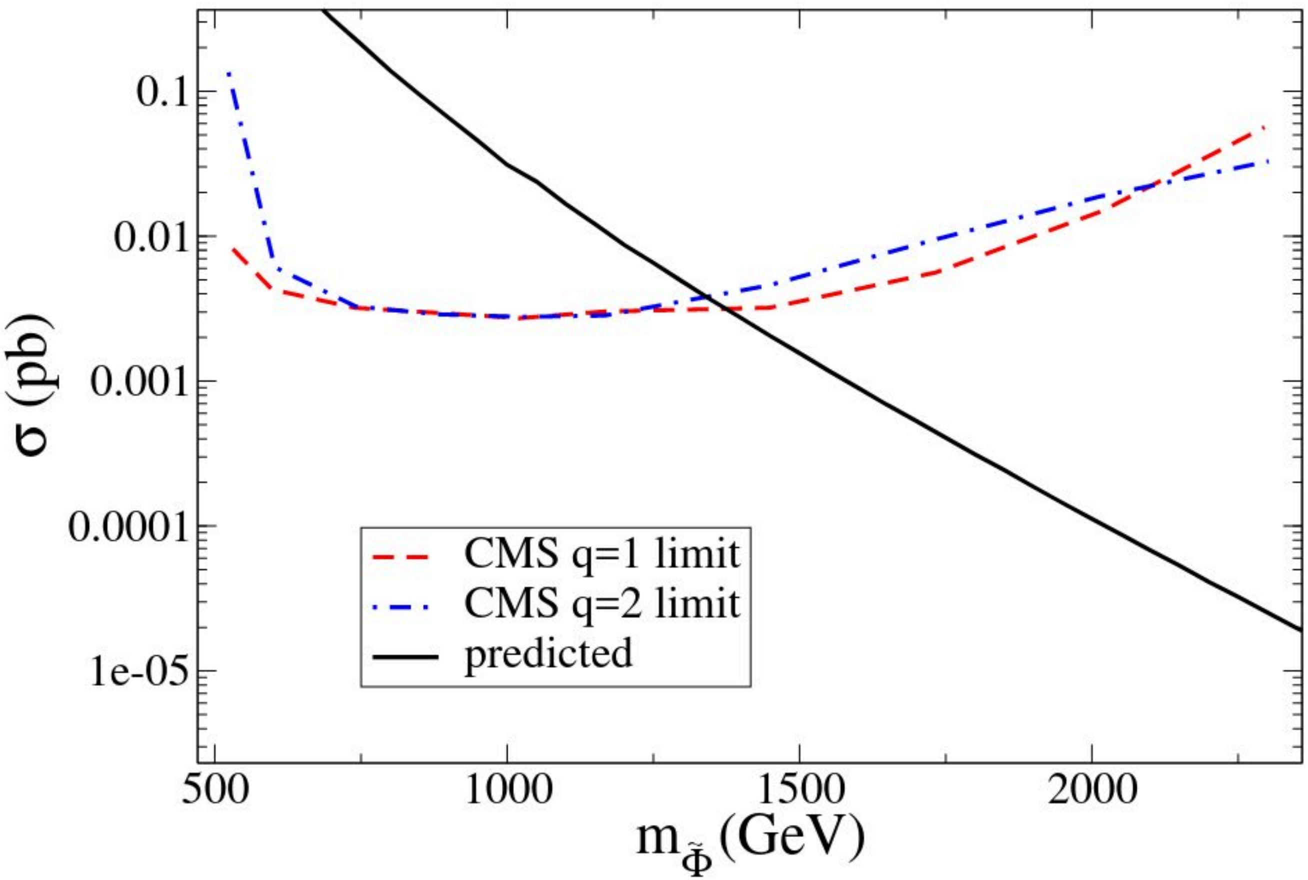
$$m_E \in (110 - 180) \, \mathrm{GeV}$$

(ATLAS, 1506.01291)

Conserved hyperbaryons

Consider neutral hyperquark S_A, SM-charged Ψ_A, mediator Φ,

$$\mathcal{L} = -\lambda\,\bar S^A \underbrace{(\Phi\Psi_A)}_{\text{SM singlet}} - \lambda'\,\Phi\,\underbrace{(\bar f^c f')}_{\text{SM fermions}}$$

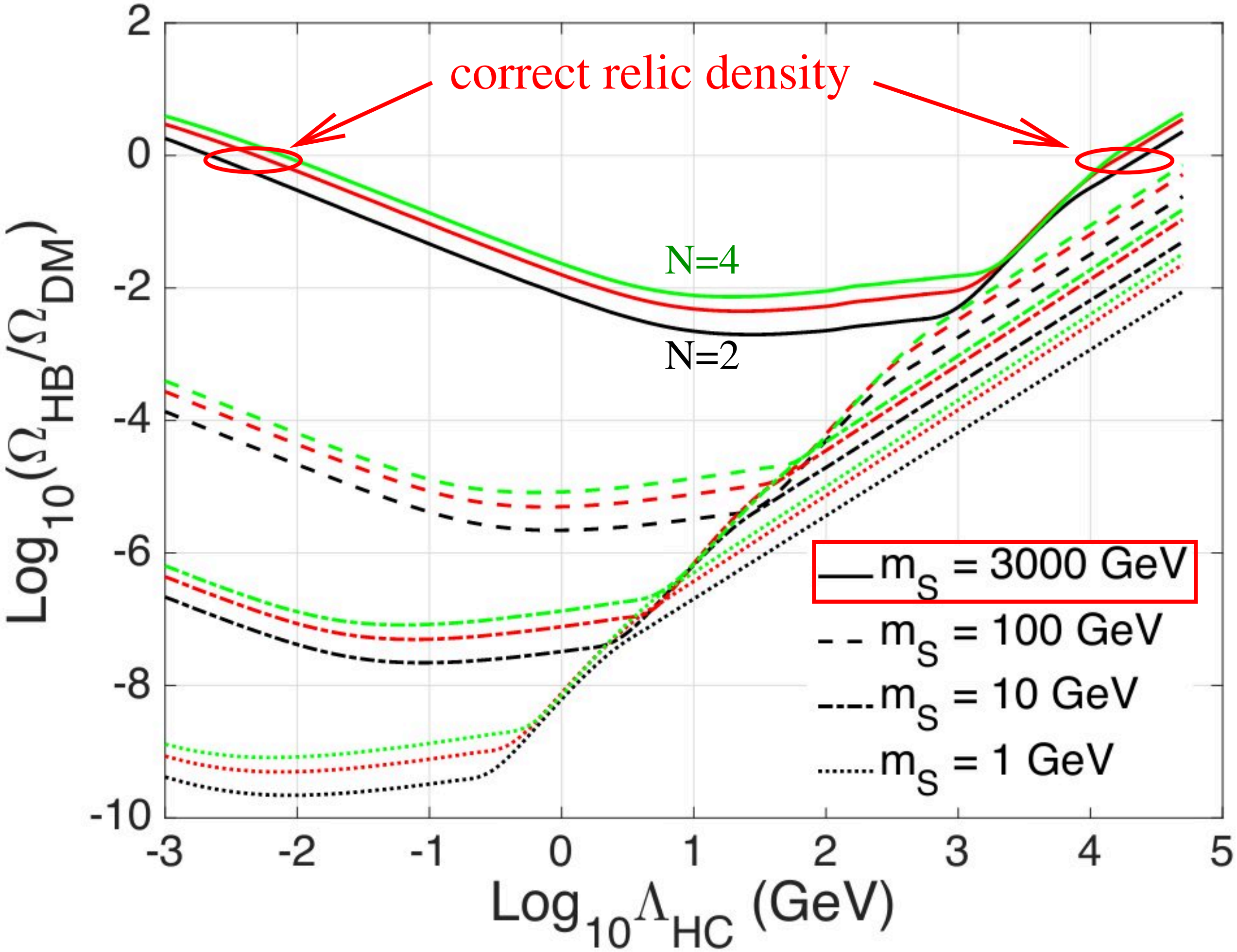


$(S)^N$ is neutral hyperbaryon DM candidate. $\bar S^A \Psi_A$ "meson" has same quantum numbers as $\bar f' f^c$: could be scalar leptoquark (or diquark, dilepton).

Constrained by CMS leptoquark searches, $m_{LQ} \gtrsim 1.3$ TeV

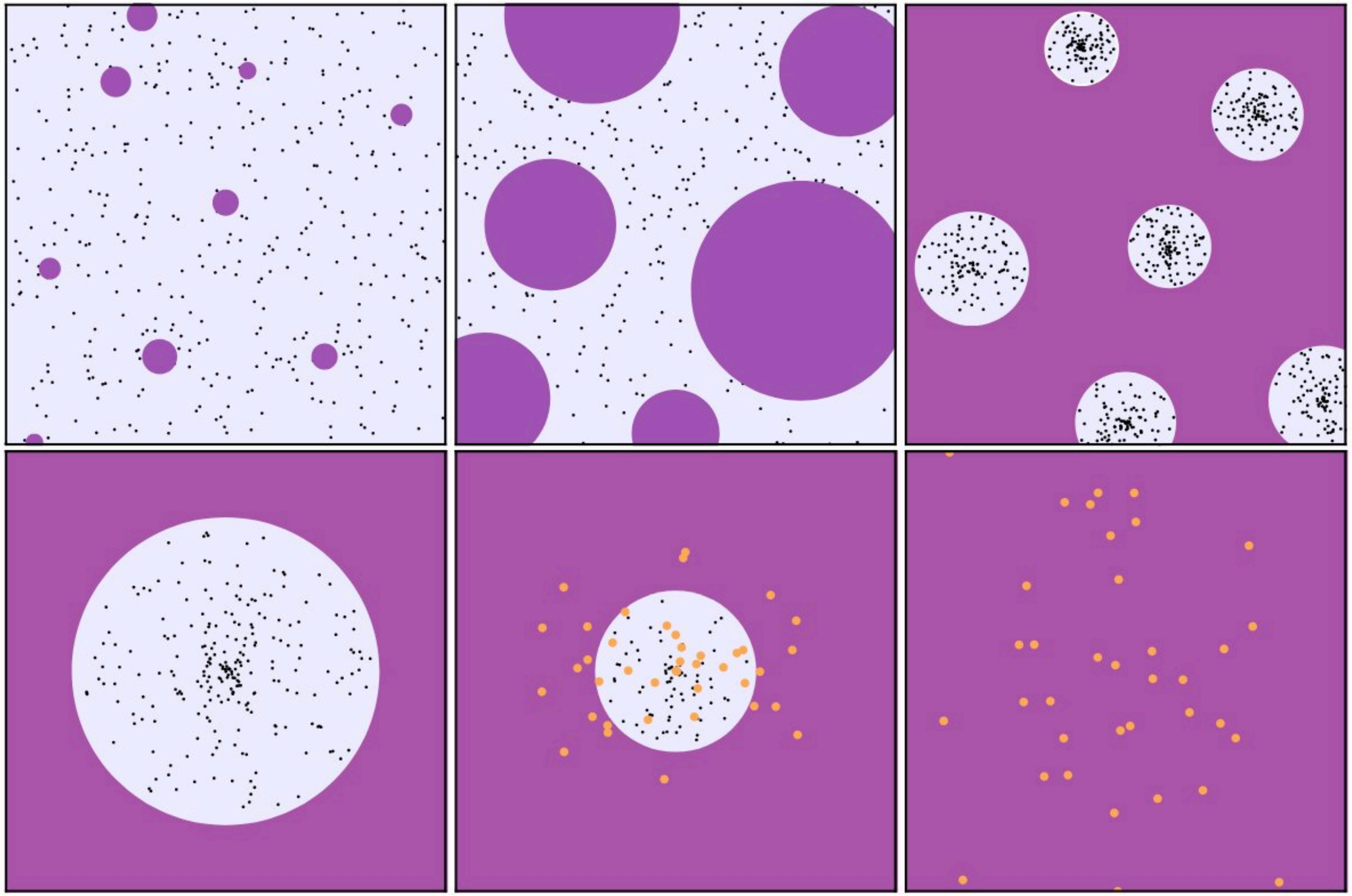
Composite baryon DM relic density

TeV scale is also suggested for the DM mass, if phase transition is not 1st order:



New mechanism for relic density

Asadi, Kramer, Kuflik, Ridgway, Slatyer, Smirnov, 2103.09822 note that for 1st order transition, hyperquarks get squeezed together, enhancing hyperbaryon production at high masses, $1 - 100\,\mathrm{PeV}$.



However not all confinement transitions are 1st order

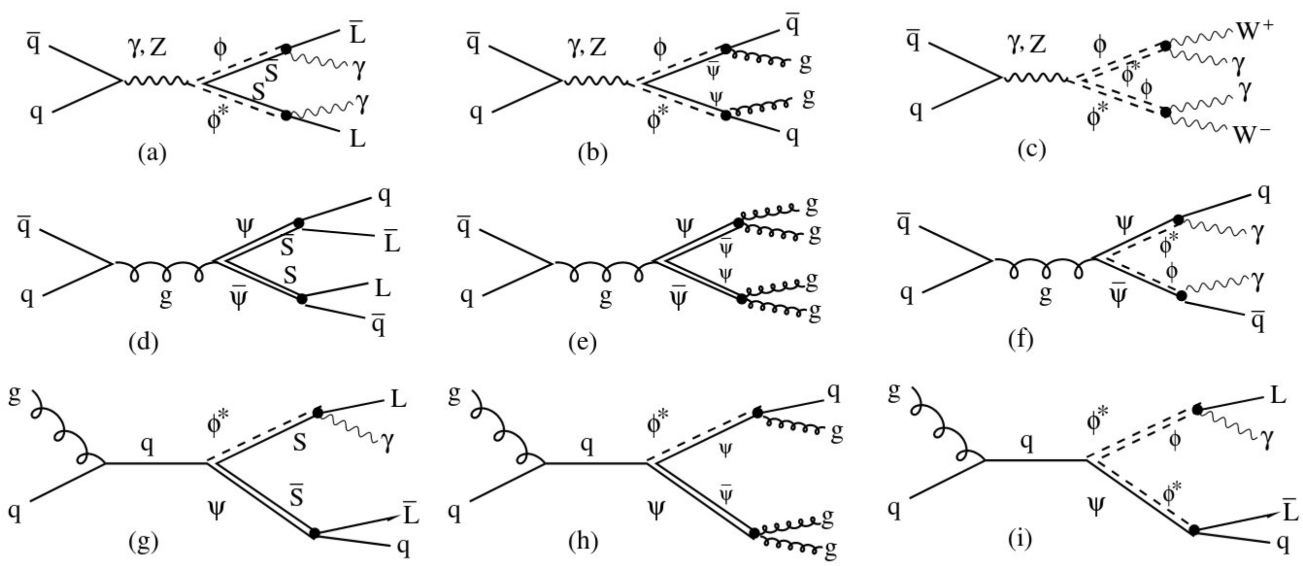
Composite leptoquarks for B anomalies

JC, 1710.02140: consider couplings to SM quark Q and lepton L doublets,

$$\mathcal{L} = \tilde{\lambda}_i\,\bar{Q}_{i,a}\,\phi_A^a\,\Psi^A + \lambda_i\,\bar{S}_A\,\phi_a^{*A}\,L_i^a$$

Bound states:

$(S)^N$ = dark hyperbaryon,
$\bar{S}\Psi$ = composite vector/scalar leptoquark,
$\bar{S}\phi$ = composite heavy lepton partner,
$\bar{\Psi}\phi$ = composite heavy quark partner
$\bar{\Psi}\Psi$, $\Psi\phi^*$, $\phi^*\phi$ = mesons



Composite states can be pair produced,
$\to$ jets, leptons, γ, W

CMS constrains $m_{LQ} \gtrsim 1.2\,\mathrm{TeV}$ (1703.03995).

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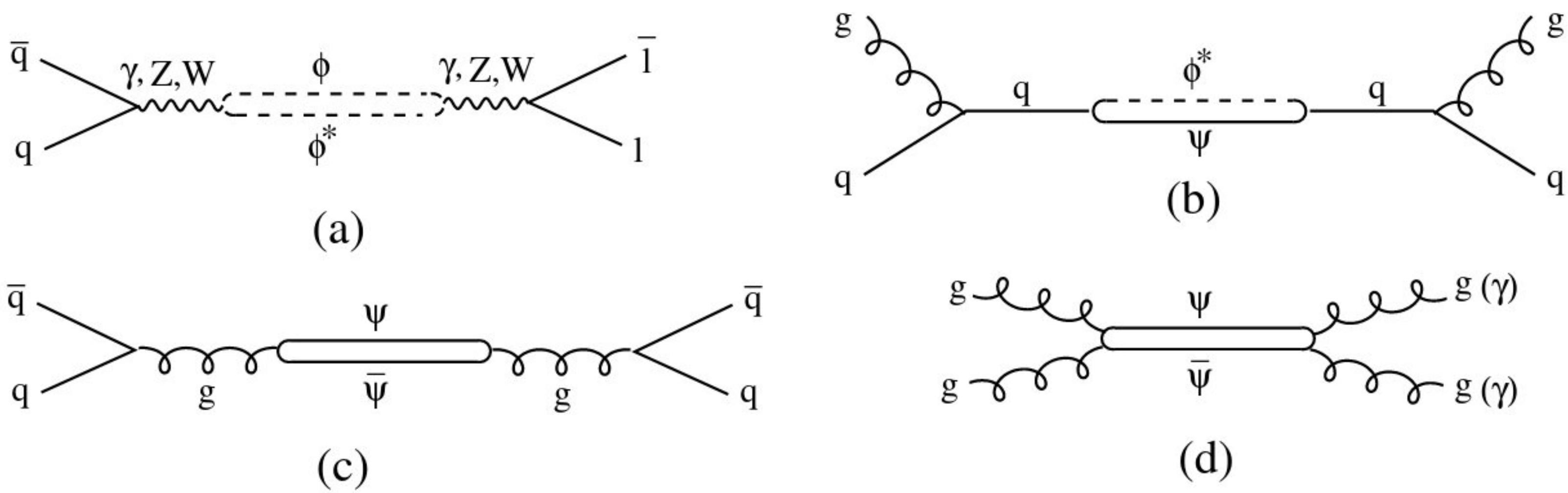
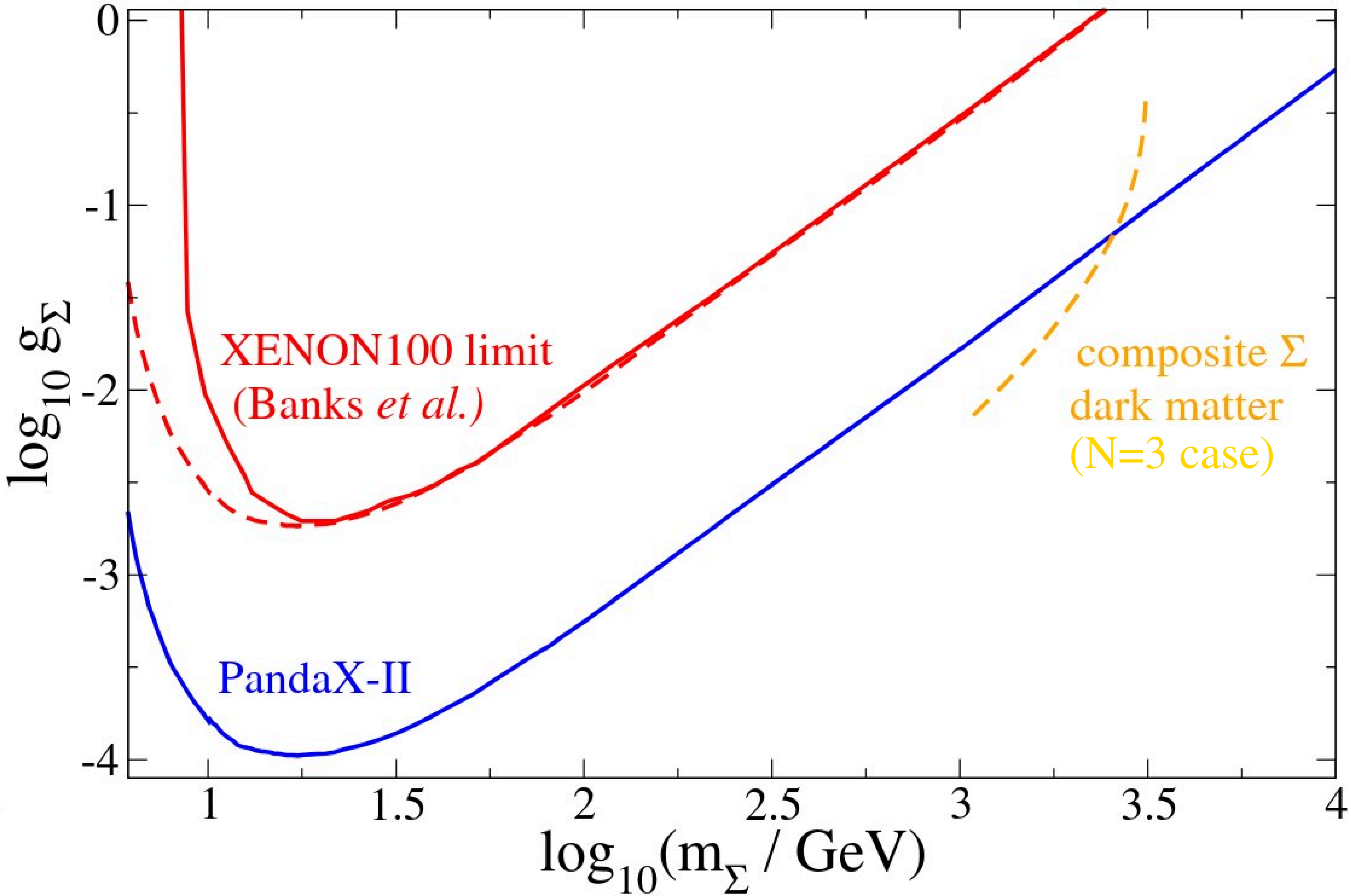
Mesonic bound states $\bar{\Psi}\Psi$, $\bar{\Psi}\phi$, $\phi^*\phi$, can be resonantly produced:



Diphotons, di-jets, dimuons constrain $m_{\rm meson} \gtrsim 1.5$ TeV

Direct detection

S hyperquark gets magnetic moment at one loop.
DM hyperbaryon must be heavier than $\sim 3.5\,\mathrm{TeV}$.



Summary

Simple $SU(N)$ confining sectors can provide composite "baryonic" DM, plus abundant states accessible to LHC.

Requires portal fields charged under $SU(N)$ and SM.

These interactions can facilitate decay of potentially dangerous charged/SI relics.

DM is naturally at the TeV scale (or higher) to acquire right relic density & satisfy direct detection constraints.

This fits with TeV-scale bounds from LHC on other composite states: leptoquarks, heavy fermion partners, diquarks, dileptons