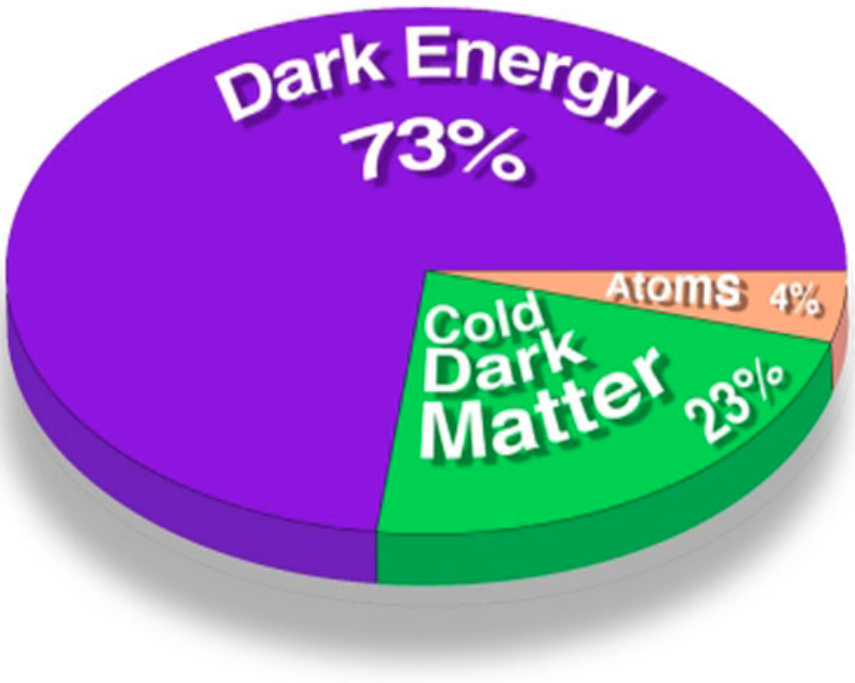
The two-component Dark Matter in the vectorlike hypercolor extension of the Standard Model.

Maxim Bezuglov (JINR, MIPT); Vitaly Beylin (SFedU); Vladimir Kuksa (SFedU)

The Mystery of Dark Matter(DM)

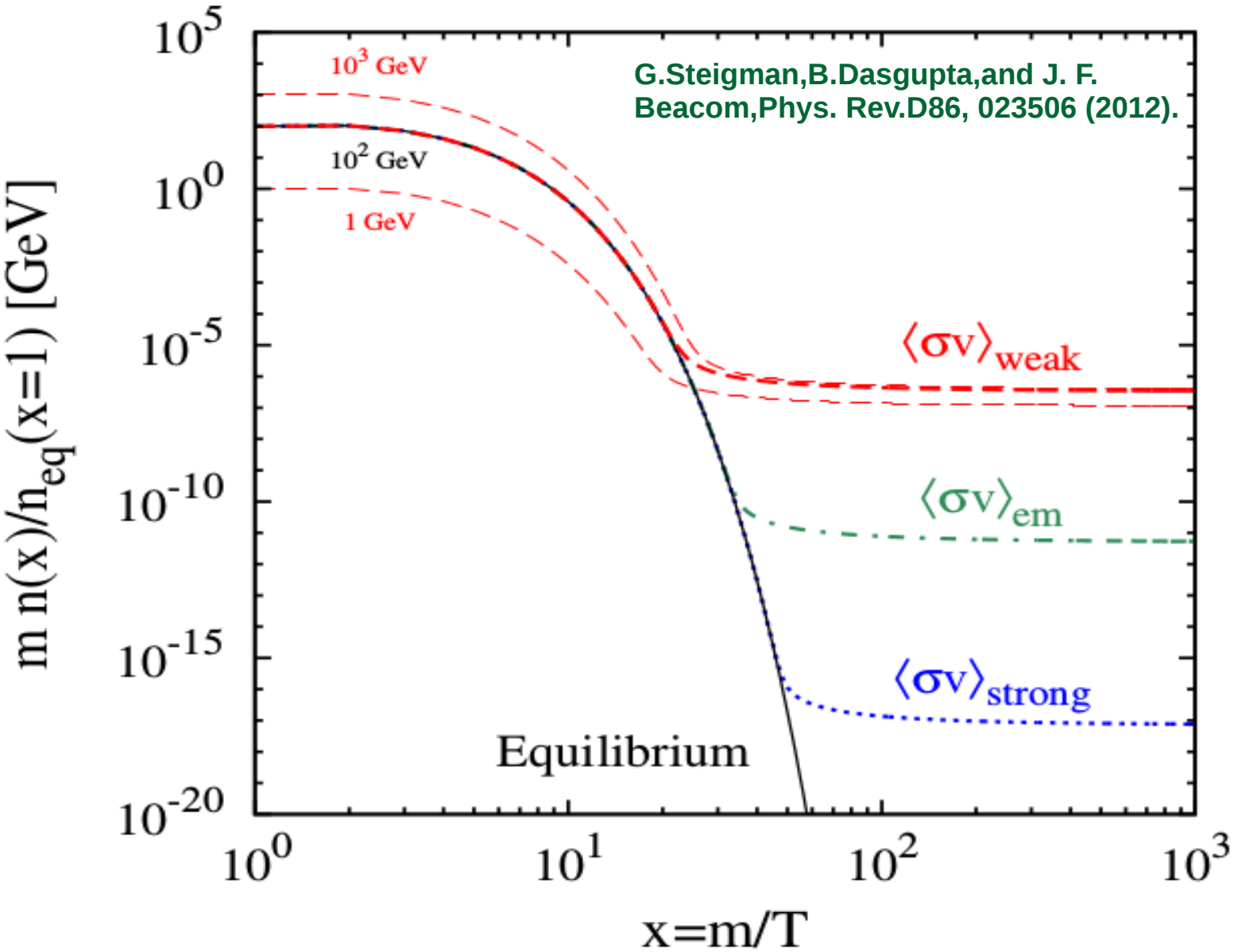


Dark Matter candidates:

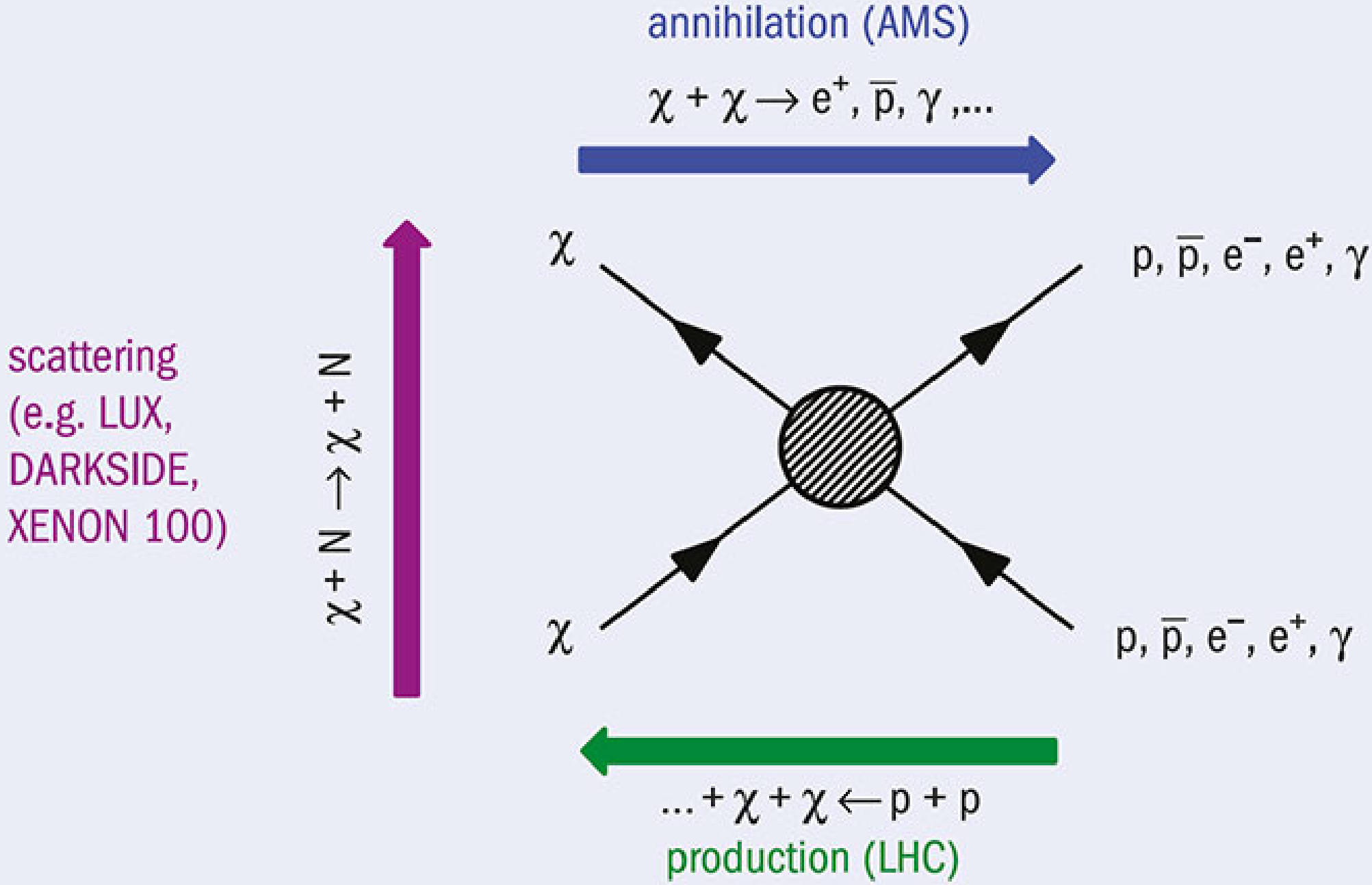
Axions
Sterile neutrinos
Primordial black holes
Modifications of gravity
WIMPs

Simple, one-component WIMP DM

$$\frac{dn}{dt} + 3Hn = \frac{d(na^3)}{a^3 dt} = \langle \sigma v \rangle \left(n_{eq}^2 - n^2 \right)$$



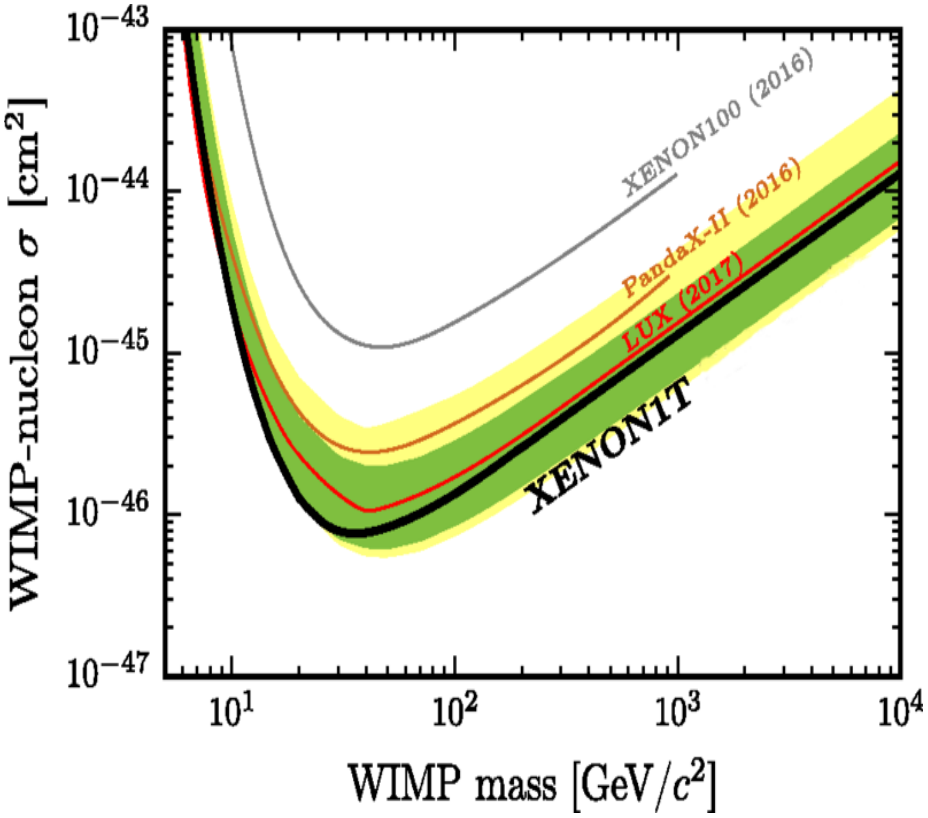
The Quest for Dark Matter



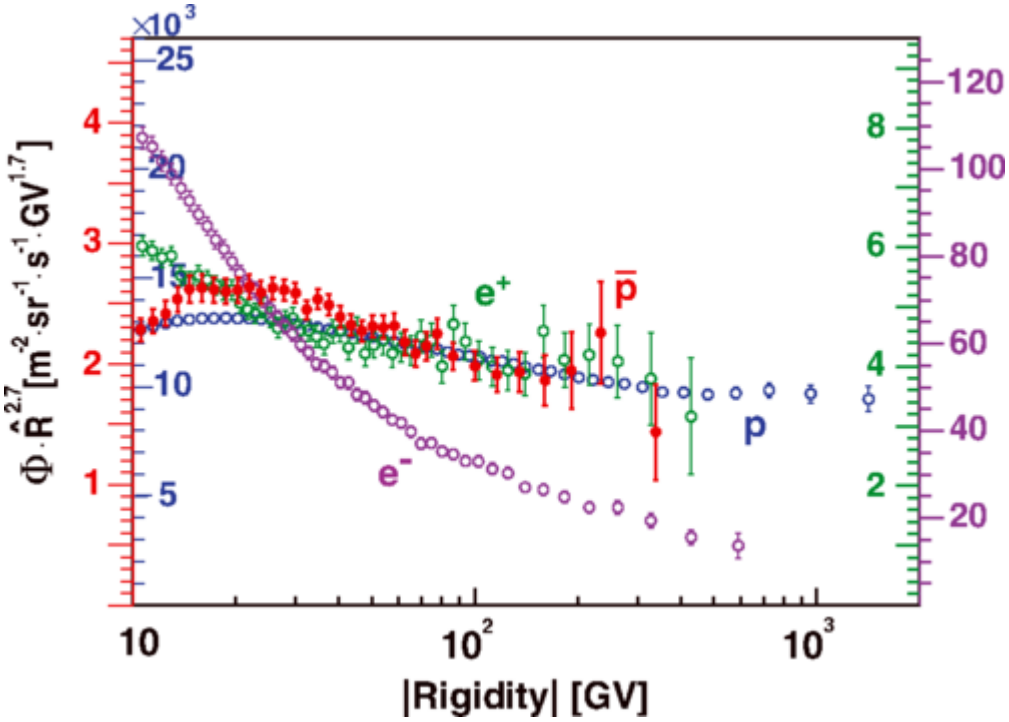
http://cerncourier.com/cws/article/cern/66896

The Quest for Dark Matter

Direct experiments(XENON1T)



Indirect experiments(AMS)



E. Aprile et al. (XENON Collaboration)
Phys.Rev. Lett. 119, 181301 (2017)

M. Aguilar et al. (AMS Collaboration)
Phys. Rev. Lett. 117, 091103

The Model

$$\tilde{Q}_H = \begin{pmatrix} \tilde{U} \\ \tilde{D} \end{pmatrix} \qquad Y_Q = 0$$

Gauge group:

$$\underbrace{SU(2)_{HC}}_{\text{Hypercolor Interaction, form confinement states(} \Lambda_{HC} \sim 1TeV \text{)}} \otimes \underbrace{SU(2)_W}_{\text{Weak Interaction}}$$

Additional scalar particle($\tilde{\sigma}$) which gives masses to H-quarks

---

Effective Lagrangian is constructed on the violation of the global SO(4) symmetry

$B_H = \begin{pmatrix} B^0 \\ \bar{B}^0 \end{pmatrix}$ H-baryon, posses additive conserving quantum number

$\tilde{P}_H = \begin{pmatrix} \tilde{\pi}^+ \\ \tilde{\pi}^0 \\ \tilde{\pi}^- \end{pmatrix}$ H-pion, Nambu–Goldstone bosons, posses multiplicative conserving quantum number

<u>Our model naturally contains at least two stable particles!</u>

Beylin, V.; Bezuglov, M.; Kuksa, V.; Volchanskiy, N., *Adv. in High Energy Phys.*, vol. 2017, 1765340

Roman Pasechnik, Vitaly Beylin, Vladimir Kuksa, Grigory Vereshkov, Phys. Rev. D 88, 075009 (2013)

Model parameters

$m_{\tilde{\pi}}$ -Mass of H-pions and H-baryons at the tree level

$M_{\tilde{\sigma}}$ -Mass of H-sigma

U H-sigma and its vacuum expectation value.

θ -Mixing angel between Higgs boson and H-sigma,
We define here: $S_\theta \equiv \sin\theta$

$$|S_\theta| \leq 0.1$$

Roman Pasechnik, Vitaly Beylin, Vladimir Kuksa, Grigory Vereshkov, Phys. Rev. D 88, 075009 (2013)

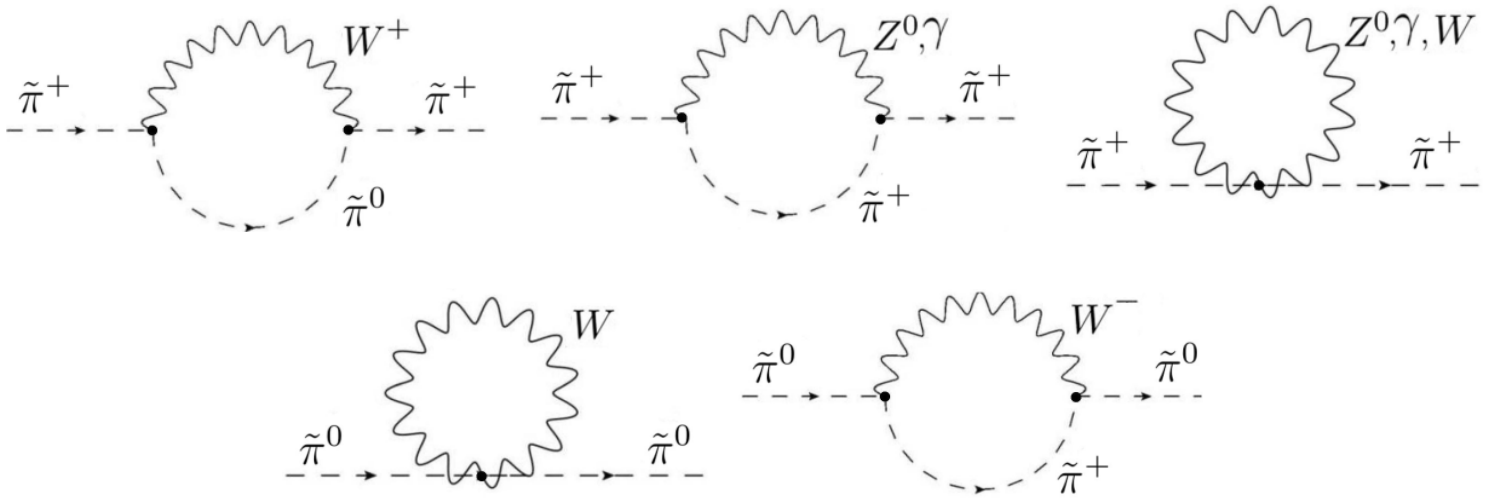
Mass splitting

$$B_H = \underbrace{\begin{pmatrix} B^0 \\ \bar{B}^0 \end{pmatrix}} \qquad \tilde{P}_H = \left.\begin{pmatrix} \tilde{\pi}^+ \\ \tilde{\pi}^0 \\ \tilde{\pi}^- \end{pmatrix}\right\} m_{\tilde{\pi}^\pm} - m_{\tilde{\pi}^0} \approx 163 MeV$$

$$\frac{|m_{\tilde{\pi}} - M_B|}{m_{\tilde{\pi}}} \lesssim 0.03$$

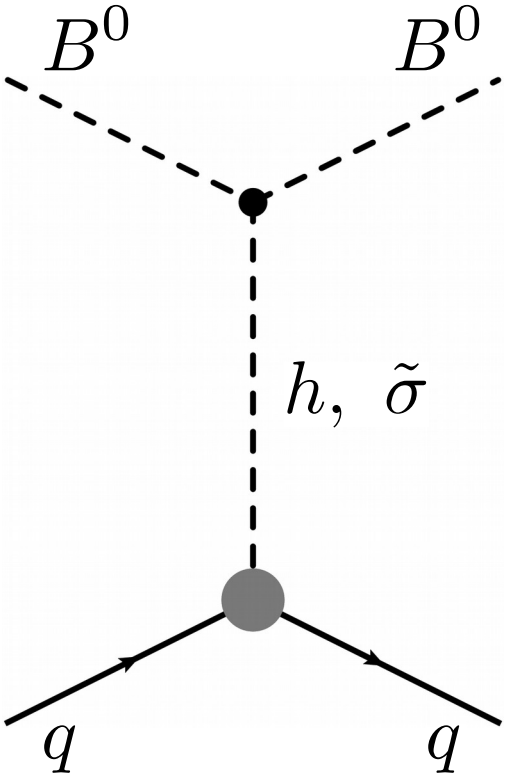
$\tilde{\pi}^0$-stable particle

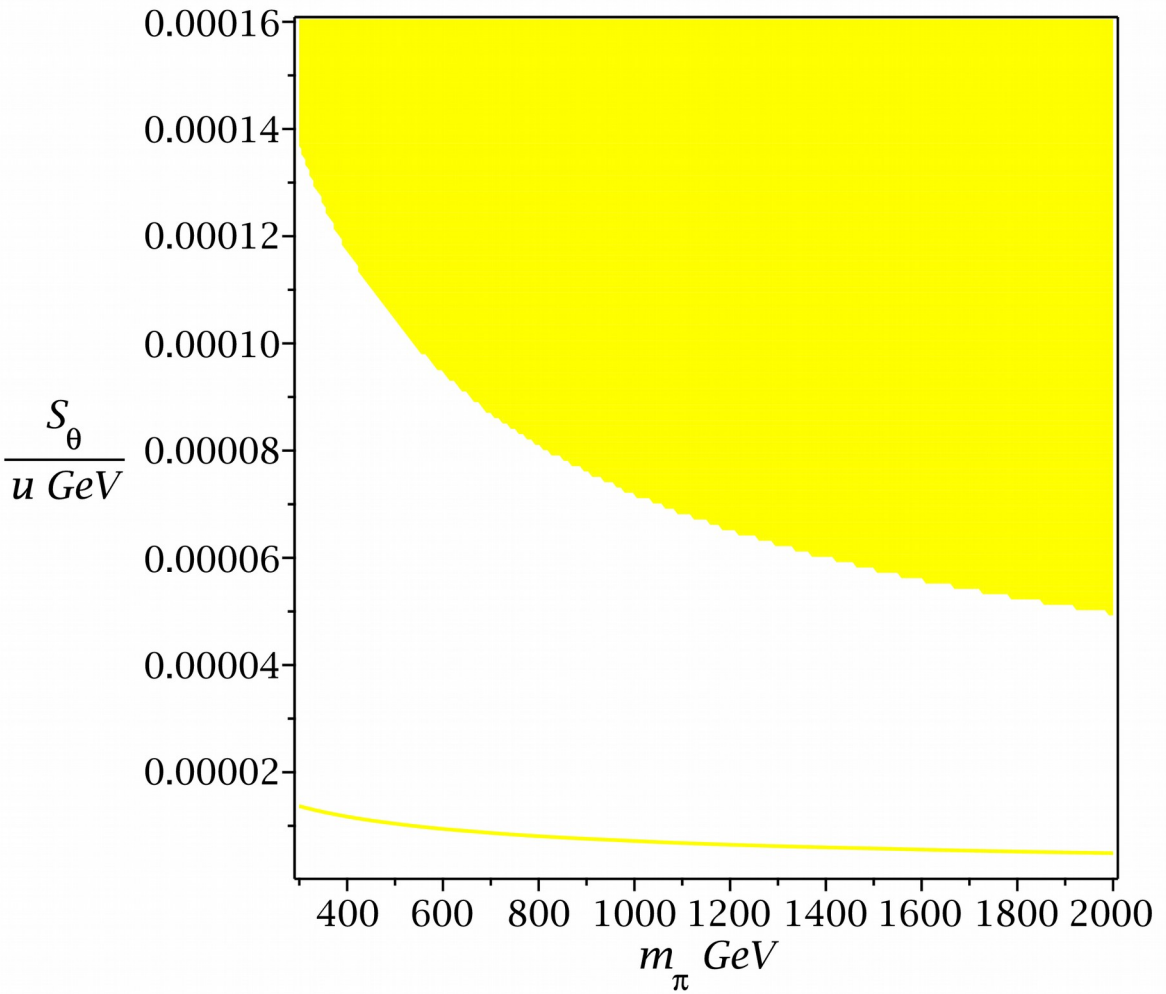
$$\tilde{\pi}^+ \to \tilde{\pi}^0 + (\pi^+,\ e^+\nu_e,\ \mu^+\nu_\mu)$$



Interaction with ordinary matter

$$\sigma_{BN} \approx 3 * 10^{-43} \left(\frac{S_\theta M_B}{u} \right)^2 cm^2, \qquad M_H^2 \ll M_\sigma^2, M_B^2, \quad C_\theta \approx 1$$





Two-component DM relic

Five Bolzman equations for five components:

$$B_H = \begin{pmatrix} B^0 \\ \bar{B}^0 \end{pmatrix} \qquad \tilde{P}_H = \begin{pmatrix} \tilde{\pi}^+ \\ \tilde{\pi}^0 \\ \tilde{\pi}^- \end{pmatrix}$$

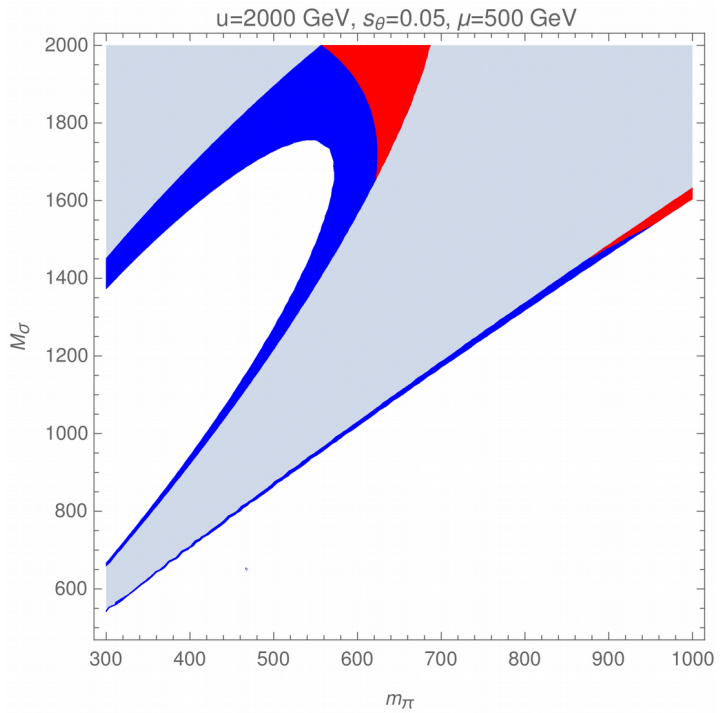
$$n_B = n_{B^0} + n_{\bar{B}^0} \qquad n_{\tilde{\pi}} = n_{\tilde{\pi}^+} + n_{\tilde{\pi}^0} + n_{\tilde{\pi}^-}$$

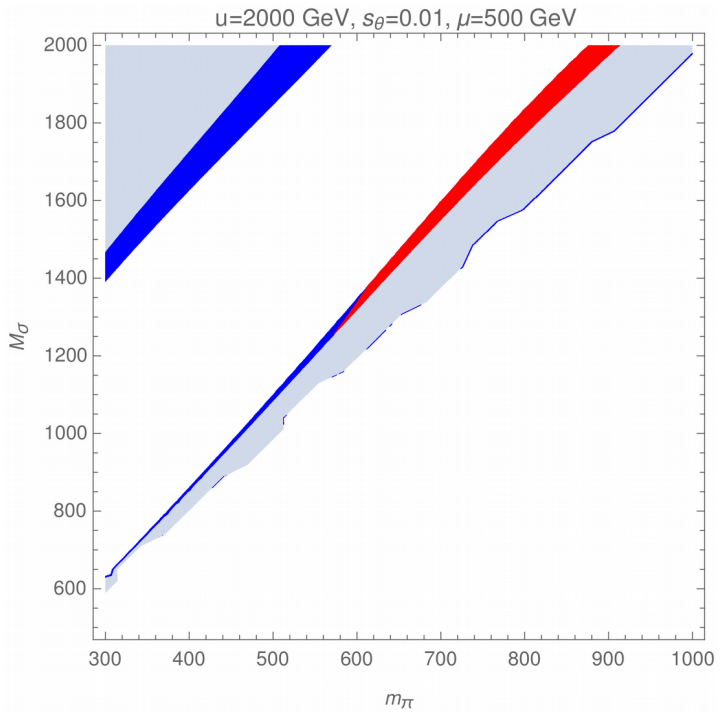
(Co)annihilation processes: $\tilde{\pi}^0\tilde{\pi}^0, \tilde{\pi}^+\tilde{\pi}^-, \tilde{\pi}^\pm\tilde{\pi}^0 \to XY$

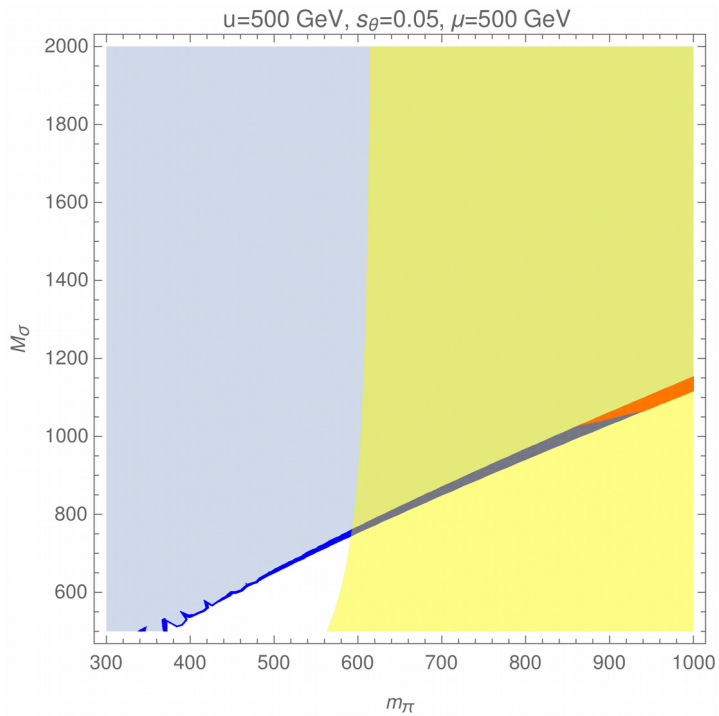
Component mixing: $\tilde{\pi}^+\tilde{\pi}^-, \tilde{\pi}^0\tilde{\pi}^0 \to B^0\bar{B}^0$

$$\frac{da^3 n_{\tilde{\pi}}}{a^3 dt} = \overbrace{< \bar{\sigma v} >_{\tilde{\pi}} \left(n_{\tilde{\pi}}^2 - (n_{\tilde{\pi}}^{eq})^2 \right)} - \overbrace{< \sigma v >_{\tilde{\pi}\tilde{\pi}} \left(n_{\tilde{\pi}}^2 - \frac{9}{4} n_B^2 \right)} + \underbrace{+ < \sigma v >_{BB} \left(n_B^2 - \frac{4}{9} n_{\tilde{\pi}}^2 \right)}_{B^0\bar{B}^0 \to \tilde{\pi}^+\tilde{\pi}^-, \tilde{\pi}^0\tilde{\pi}^0}$$

+one for B

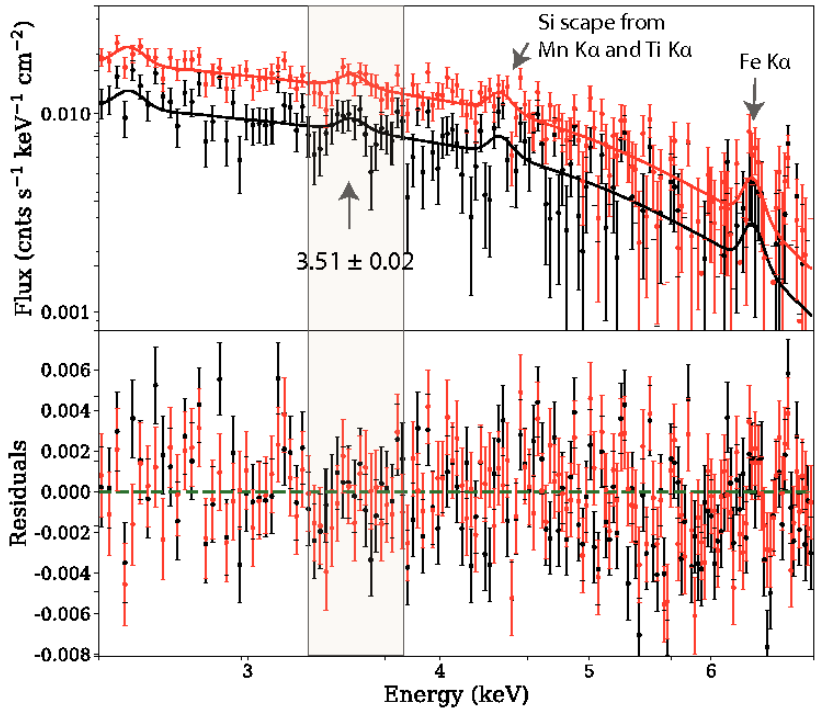

u=2000 GeV, s_θ=0.05, μ=500 GeV
M_σ
m_π
2000
1800
1600
1400
1200
1000
800
600
300
400
500
600
700
800
900
1000


u=2000 GeV, s_θ=0.01, μ=500 GeV
M_σ
m_π
2000
1800
1600
1400
1200
1000
800
600
300
400
500
600
700
800
900
1000


u=500 GeV, s_θ=0.05, μ=500 GeV
M_σ
m_π
2000
1800
1600
1400
1200
1000
800
600
300
400
500
600
700
800
900
1000

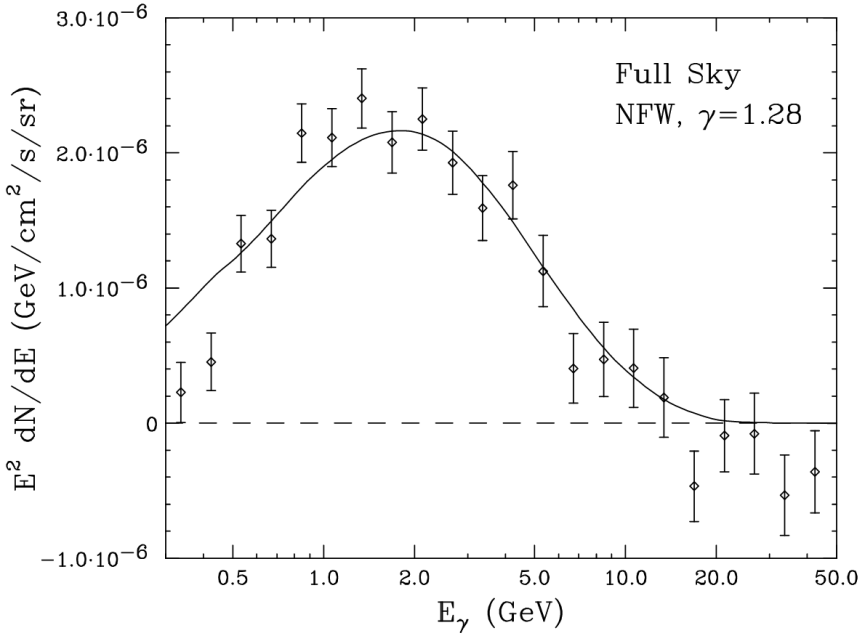
Future plans

3.5 keV anomaly from Chandra



Nico Cappelluti et al ApJ 854 179 (2018)

1-3 GeV anomaly from Fermi



Daylan Tansu, et al. Physics of the Dark Universe 12 (2016): 1-23.

Conclusions

The simplest vectorlike hypercolor extension of the SM with one H-quark doublet is considered.

The set of pseudo-goldstone bosons contains two neutral stable particles which can be close in mass.

If these particles are interpreted as the DM carriers, the model does not contradict to the current experimental data on the DM relic abundance.

The model naturally suggests that the Dark Matter has two components; relative concentrations of these components were studied in details.

It is shown that interaction of this DM particles with nucleons satisfies the constraints of LUX and XENON

Analysis of specific annihilation signals and deep inelastic scattering of high-energy cosmic rays off the DM is in progress

Thank you for your attention!