A Stable Pion

Yang Bai

Theoretical Physics Department, Fermilab

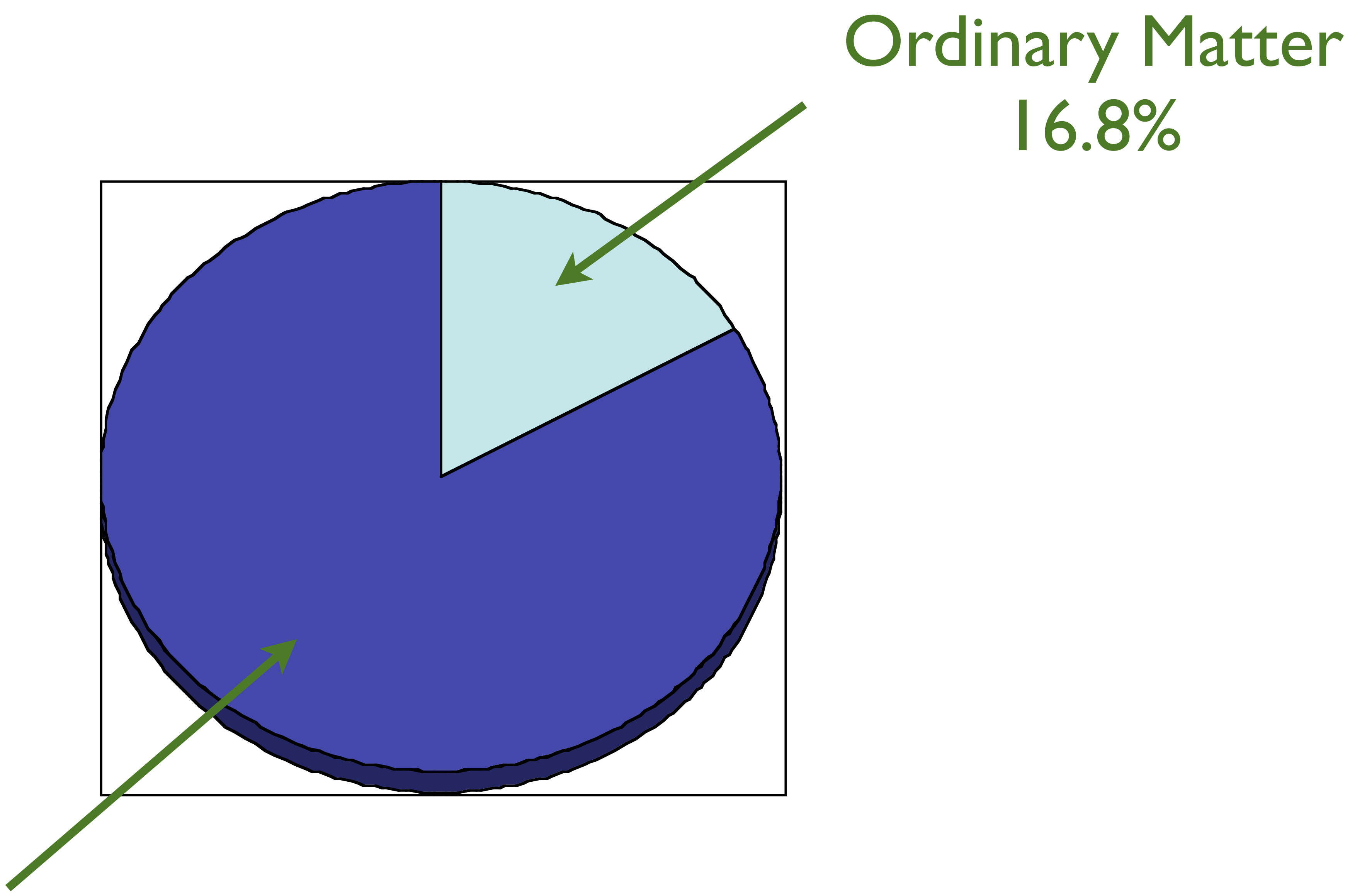
The 2010 Phenomenology Symposium

with Richard Hill,   Univ. of Chicago

arXiv:1005.0008

“No Electroweak Symmetry Breaking”

Matter Pie of Our Universe



From WMAP

WIMP

- "WIMP Miracle" relates the DM relic abundance to the DM annihilation cross section.

$$\Omega_{\rm DM} \sim \langle \sigma_A v \rangle^{-1} \sim \frac{m_\chi^2}{g^4}$$

- Three conditions to have a viable thermal DM candidate.
    - DM is stable: requires an unbroken discrete or continuous symmetry.
    - DM interacts with SM particles: requires DM charged under SM gauge symmetries or via Higgs portal.
    - Not to overclose the universe and not ruled out by the current direct detection experiments.

Discrete and Continuous Symmetries in the SM

- Parity, Charge Conjugation, Time Reversal
- Baryon number and lepton number

Citation: S. Eidelman *et al.* (Particle Data Group), Phys. Lett. B **592**, 1 (2004) (URL: http://pdg.lbl.gov)

π^0

$$I^G(J^{PC}) = 1^-(0^{-+})$$

Mass $m = 134.9766 \pm 0.0006$ MeV (S = 1.1)
$m_{\pi^\pm} - m_{\pi^0} = 4.5936 \pm 0.0005$ MeV
Mean life $\tau = (8.4 \pm 0.6) \times 10^{-17}$ s (S = 3.0)
$c\tau = 25.1$ nm

G-parity in the SM

Selection Rules Imposed by Charge Conjugation.

L. Michel

European Council for Nuclear Research (CERN) - Theoretical Study Group (*)

(ricevuto il 24 Gennaio 1953)

Charge Conjugation, a New Quantum Number *G*, and Selection Rules Concerning a Nucleon-Antinucleon System.

T. D. Lee

Columbia University - New York, N.Y.

C. N. Yang

Institute for Advanced Study - Princeton, N.J.

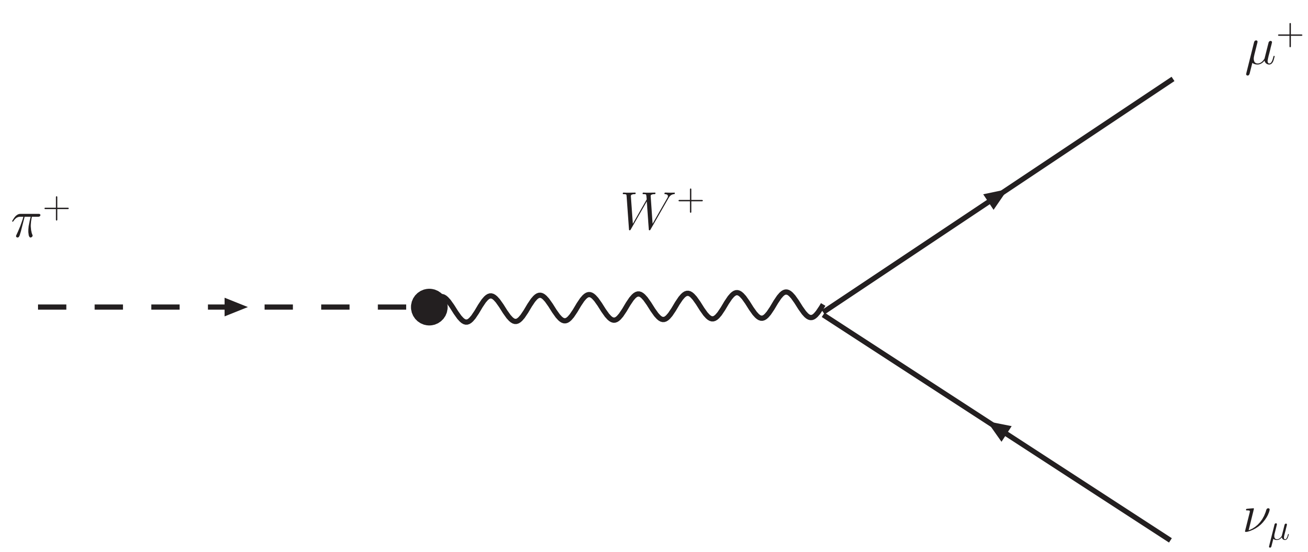
(ricevuto il 30 Gennaio 1956)

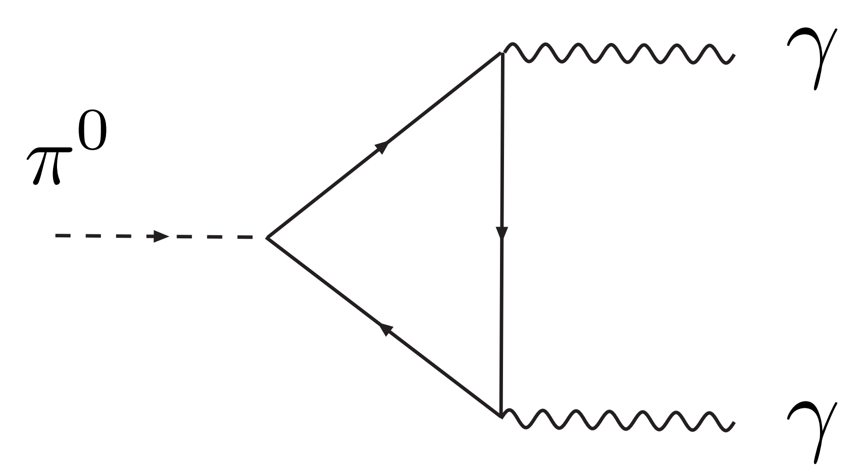
G-parity in the SM

$$G = \mathcal{C}\exp[i\pi I_2]$$

$$\pi^{\pm} \xrightarrow{G} -\pi^{\pm} \qquad \pi^{0} \xrightarrow{G} -\pi^{0}$$

- The G-parity in the SM is broken by the chiral weak interaction and nonzero hypercharges of quarks.





Why not to use the G-parity to explain the stability of the dark matter particle?

Dark Matter Sector

Dark QCD

dark pions, dark baryons,

...

dark G-parity is unbroken

dark pion is the LGP

New G-parity Odd Pions

- Make "new quarks" vector-like under SU(2) weak gauge interaction.
- Choose zero hypercharge for "new quarks".

	$SU(N)_h$	$SU(3)_c$	$SU(2)_W$	$U(1)_Y$
$\hat{\psi}_{L,R}$	N	1	2	0

quark-level

$$\hat{\psi} \xrightarrow{G} S\,\hat{\psi}^{\mathcal{C}} = S\,i\,\gamma^2\,\hat{\psi}^*$$

$$\hat{A}^b\,T^b \xrightarrow{G} (\hat{A}^b\,T^b)^{\mathcal{C}} = -\hat{A}^b\,(T^b)^*$$

$$W^a \xrightarrow{G} W^a$$

$$S = i\tau^2$$

pion-level

$$\Pi^a \xrightarrow{G} -\Pi^a$$

Π^a : $(3)_0$ Stable

General Weak Representations

	$SU(N)_h$	$SU(3)_c$	$SU(2)_W$	$U(1)_Y$
$\psi_{L,R}$	N	1	$2j+1$	0

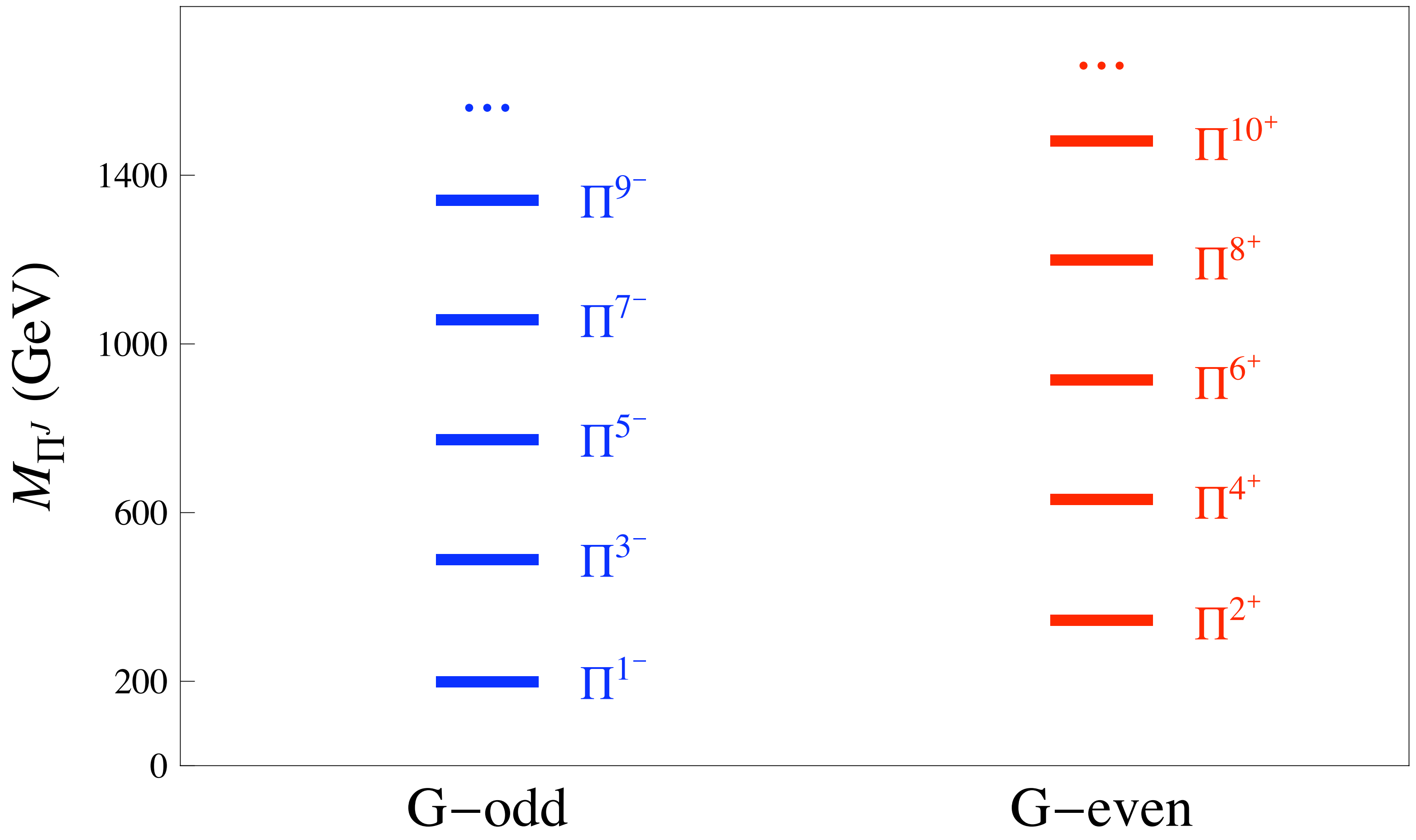
$$SU(2j+1)_L \times SU(2j+1)_R \times U(1)_B \to SU(2j+1)_V \times U(1)_B$$

pions

$$(2j+1)^2 - 1 = \sum_{J=1}^{2j} (2J+1)$$

$$M^2_{\Pi^J} \sim C_2(J)\, g_2^2\, f_\Pi^2$$

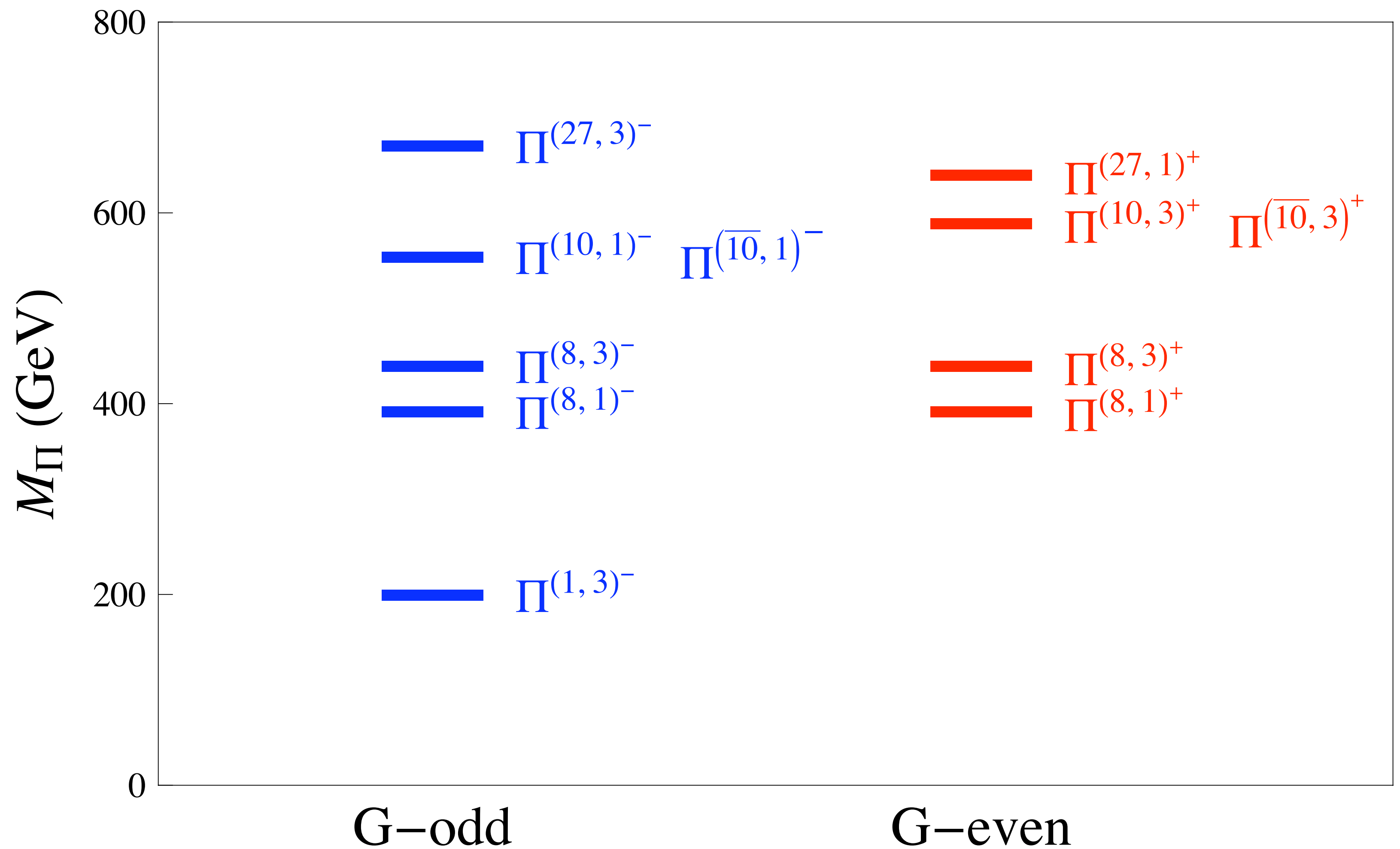
weak SU(2) is unbroken



Extension to Color SU(3)

	$SU(N)_h$	$SU(3)_c$	$SU(2)_W$	$U(1)_Y$
$\psi_{L,R}$	N	8	2	0

only possible for real representation



Phenomenologies

- LGP, a dark matter candidate, is always the neutral part of a weak triplet with hypercharge zero.
- Its mass should be below 1-2 TeV to not overclose the universe. Its spin-independent scattering cross section is around $10^{-45}\,\mathrm{cm}^2$.
- Its charged partner is a long-lived particle at colliders.
- The G-even pions behave as SM gauge boson resonances at colliders, while the NLGP pions provide final signatures with SM gauge bosons plus missing transverse energy.

Discussions

- The G-parity is unbroken from all renormalizable operators.
- Two dim-five operators violate G-parity:

$$B_{\mu\nu}\bar{\hat{\psi}}\sigma^{\mu\nu}\hat{\psi}/\Lambda_{\rm UV} \qquad\qquad H^\dagger t^a H\bar{\hat{\psi}}J^a\hat{\psi}/\Lambda_{\rm UV}$$

- Introducing a Peccei-Quinn symmetry, the LGP can still have a lifetime longer than the age of our universe.
- Hidden sector baryons are also stable. However, they only contribute a very small fraction of the dark matter density:

$$\frac{\Omega_B}{\Omega_\Pi} \sim \frac{\langle\sigma v\rangle_\Pi}{\langle\sigma v\rangle_B} \sim 4\pi\,\alpha_2^2 \sim 10^{-2}$$

Conclusions

- An unbroken and nontrivial discrete symmetry emerges in a class of models with vector-like SM gauging of fermions with QCD-like strong dynamics.

- The dark matter particle, LGP, could be a stable pion emerges in this class of models.

- The mechanism leads to testable and distinct dark matter and LHC phenomenologies.