Fermilab

Proton decay from quark and lepton compositeness

Benoît Assi

Pheno Symposium (U. Pittsburgh) - May 8, 2023

Based on: 2112.15132, 2211.02211 with Bogdan Dobrescu (Fermilab)

Substructure

Quark and lepton compositeness

Can we write down such a model?

Fermions in SM chiral ⇒ chiral composite dynamics

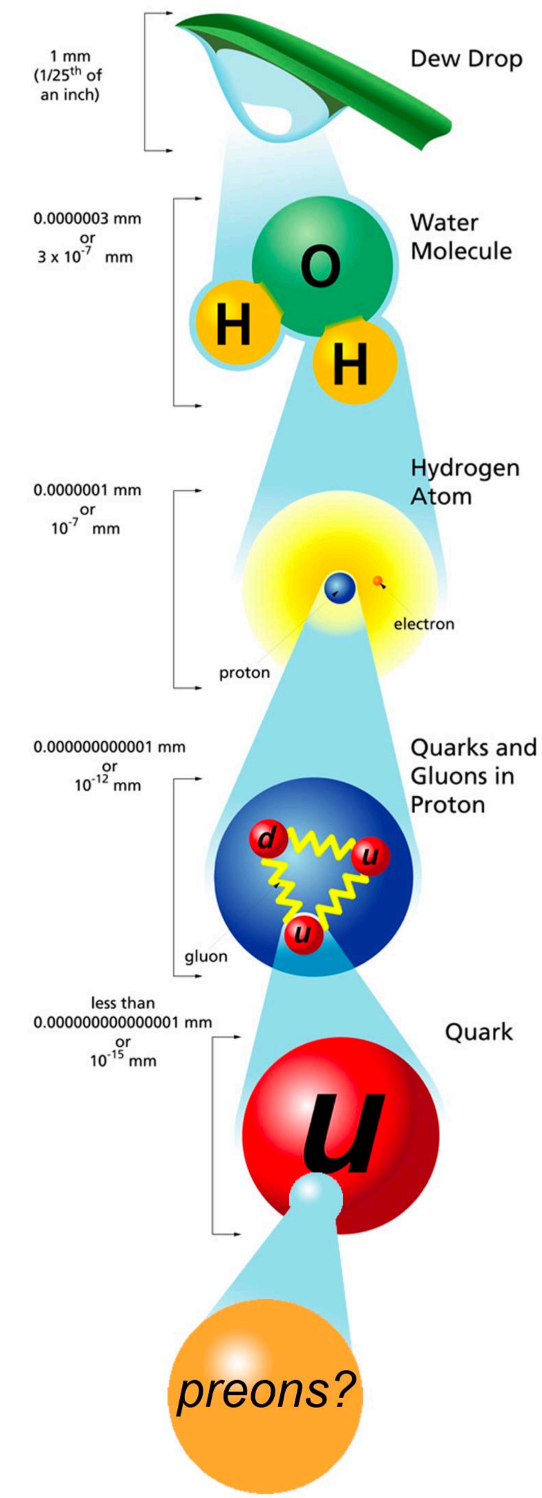
A spectrum of light bound states can arise

Model in a nutshell

Chiral preons charged under $SU(15)_p \times \mathrm{SM}$ bind into prebaryons under $SU(15)_p$

Prebaryons include all 3 generations of SM matter and composite vector-like states

Higgs doublets are di-prebaryon bound states analogous to deuteron in QCD



Preons: from GUT scale to confinement

Fields charged under $SU(15)_p \times SO(10)$

field	spin	$SU(15)_\mathrm{p}$	$SO(10)_\mathrm{global}$	comments
Ψ	$1/2$	15	16	massless preons
ψ_2, ψ_3, ψ_4	$1/2$	15	1	
Ω	$1/2$	$\overline{120}$	1	
$\mathcal{A}$	0	$\overline{105}$	1	flavor-dependent couplings

Preon states $(\Psi, \psi_{2,3,4}, \Omega)$ massless chiral fermions

$\Rightarrow$ **chiral prebaryons** can form

Fields charged under $SU(15)_p \times \mathrm{SM}$

Fermion	$SU(15)_\mathrm{p}$	$SU(3)_c \times SU(2)_W$	$U(1)_Y$
ψ_Q	15	$(3, 2)$	$+1/6$
ψ_U	15	$(\overline{3}, 1)$	$-2/3$
ψ_D	15	$(\overline{3}, 1)$	$+1/3$
ψ_L	15	$(1, 2)$	$-1/2$
ψ_E	15	$(1, 1)$	$+1$
$\psi_1, \ldots, \psi_4$	15	$(1, 1)$	0
Ω	$\overline{120}$	$(1, 1)$	0

Why this choice? An $SU(N)$ gauge theory with $(N+4)$ fundamentals has **anomaly cancelled** by a symmetric 2-tensor

$SO(10)$ symmetry breaking and re-labelling $\Psi \to \psi_{U,Q,E,D,1}$ where SM-singlet LH fermion $\psi_1 \leftrightarrow \psi_N$ is conjugate of RH neutrino

Confinement and prebaryons

Fermion	$SU(15)_{\rm p}$	$SU(3)_c \times SU(2)_W$	$U(1)_Y$
ψ_Q	15	$(3, 2)$	$+1/6$
ψ_U	15	$(\overline{3}, 1)$	$-2/3$
ψ_D	15	$(\overline{3}, 1)$	$+1/3$
ψ_L	15	$(1, 2)$	$-1/2$
ψ_E	15	$(1, 1)$	$+1$
$\psi_1, \ldots, \psi_4$	15	$(1, 1)$	0
Ω	$\overline{120}$	$(1, 1)$	0

$SU(15)_p$ interactions ⇒ composite chiral prebaryons: $(\Psi\Omega\Psi, \Psi\Omega\psi_i, \psi_i\Omega\psi_j)$

Bound states**: 3 generations** of SM fermions $(\Omega_{Qi}, \Omega_{Li}, \Omega_{Ui}, \Omega_{Di}, \Omega_{Ei})$ and 12 vectorlike fermions charged under SM gauge group

6 gauge singlet Weil fermions $(\Omega_{ij}, \Omega_{Ni})$ and premesons $(\Psi\sigma^\mu\Psi, \Psi\sigma^\mu\psi_i, \psi_i\sigma^\mu\psi_j)$

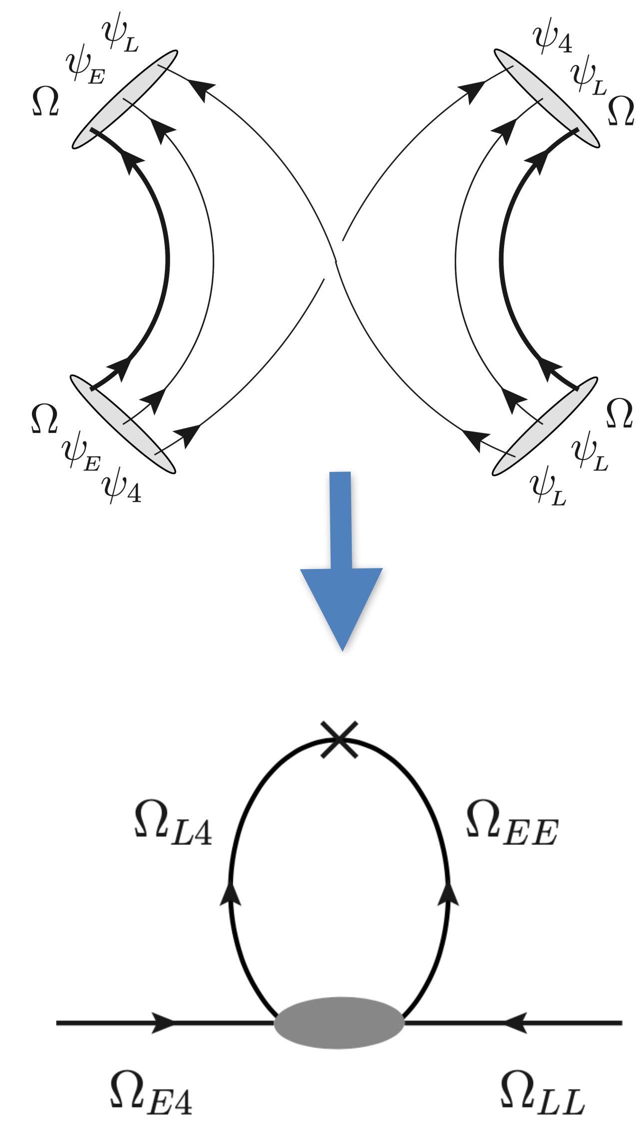
vectorlike fermion	component LH , RH	$SU(3)\times SU(2)\times U(1)$
$\Omega_{8,2}$	$\Omega_{QU}^{(8,2)}$, $\overline{\Omega}_{QD}^{(8,2)}$	$(8, 2, -1/2)$
$\Omega_{6,1}$	$\Omega_{QQ}^{(6,1)}$, $\overline{\Omega}_{UD}^{(\overline{6},1)}$	$(6, 1, +1/3)$
$\Omega_{3,3}$	$\Omega_{QL}^{(3,3)}$, $\overline{\Omega}_{QQ}^{(\overline{3},3)}$	$(3, 3, -1/3)$
$\Omega_{3,2}$	Ω_{QE} , $\overline{\Omega}_{UL}$	$(3, 2, +7/6)$
$\mathcal{L}_2$	$\Omega_{QU}^{(1,2)}$, $\overline{\Omega}_{QD}^{(1,2)}$	$(1, 2, -1/2)$
$\Omega_{3,1}$	Ω_{UU} , $\overline{\Omega}_{DE}$	$(3, 1, -4/3)$
$\mathcal{Q}$	Ω_{Q4} , $\overline{\Omega}_{DL}$	$(3, 2, +1/6)$
$\mathcal{D}_2$	$\Omega_{QL}^{(3,1)}$, $\overline{\Omega}_{UE}$	$(3, 1, -1/3)$
$\mathcal{D}_1$	$\Omega_{UD}^{(3,1)}$, $\overline{\Omega}_{D4}$	$(3, 1, -1/3)$
$\mathcal{L}_1$	Ω_{L4} , $\overline{\Omega}_{LE}$	$(1, 2, -1/2)$
$\mathcal{U}$	Ω_{DD} , $\overline{\Omega}_{U4}$	$(3, 1, +2/3)$
$\mathcal{E}$	Ω_{E4} , $\overline{\Omega}_{LL}$	$(1, 1, +1)$

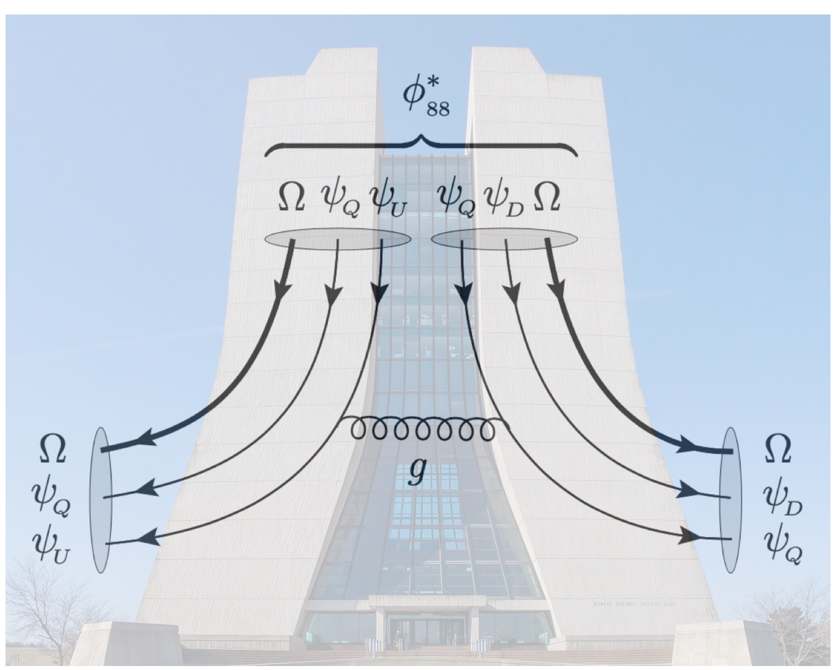
Higgs and other scalars

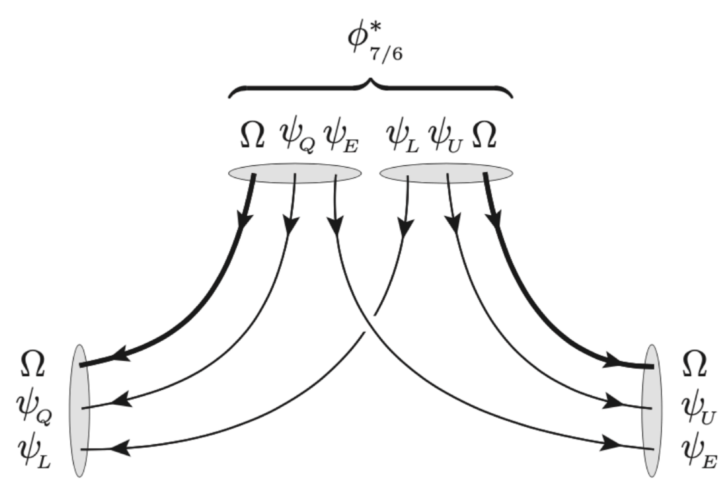
Di-prebaryons lighter than Λ_{pre} are bound by remnant $SU(15)$, SM gauge and A exchange

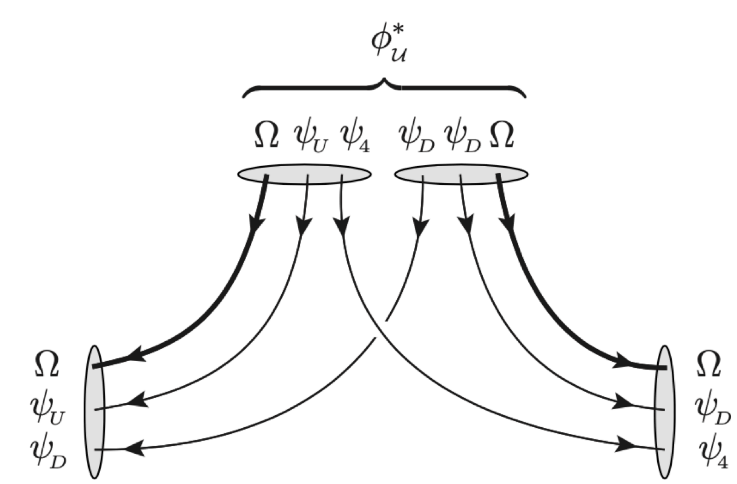
Higgs: $H_{(u,d)}(1{,}2, \pm 1/2) \equiv \Omega_{(U,D)4}\Omega_{Q3}(1{,}2, \mp 1/2)$ give rise to up (down)-type quark masses

Deepest bound: $(8{,}2, + 1/2)$ with largest Dirac mass and Yukawa coupling $y_{88}\phi^*_{88}\Omega^{(8,2)}_{QU}\Omega^{(8,2)}_{QD}$







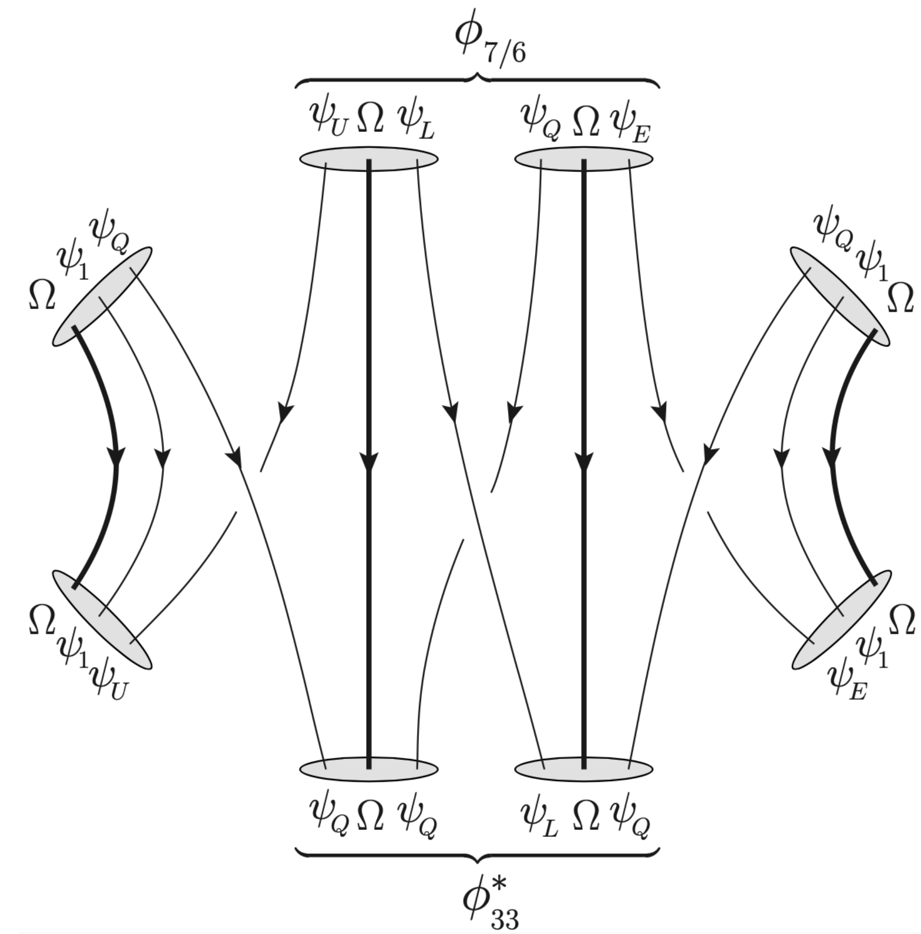


Compositeness and proton decay

Proton decay at $\Lambda_{\rm pre}$, e.g. **8-baryon operator**:

$$\frac{\tilde{C}_8}{\Lambda_{\rm pre}^8}\left(\Omega_{Q4}\Omega_{DL}\right)\left(\overline{\Omega}^{\bar{3},3}_{QQ}\overline{\Omega}^{(3,3)}_{QL}\right)\left(\Omega_{Q1}\Omega_{Q1}\right)\left(\overline{\Omega}_{D1}\overline{\Omega}_{41}\right)$$

$$\to \frac{\tilde{C}_8 c_\phi^2 y_{_{7/6}} y^*_{33}}{2(4\pi)^4\Lambda_{\rm pre}^4}\phi_{_{7/6}}\phi^\dagger_{33}(\Omega_{Q1}\Omega_{Q1})(\overline{\Omega}_{U1}\overline{\Omega}_{E1})$$



Identifying prebaryons with SM fermions and **VEVs:**

$$C_8\, c_\phi^2\,\frac{m_{_{7/6}} m_{_{33}}}{2(4\pi)^4 N^3 N_c^2 \Lambda_{\rm pre}^4}(q_L^1 q_L^1)(\overline{u}^c\overline{e}^c)$$

Combining with latest super-K limit**:**

$$\tau\left(p\to\pi^0 e^+\right) > 1.6\times 10^{34}\,\text{yr} \Rightarrow \boxed{\frac{\Lambda_{\rm pre}}{|\,C_8\,|^{1/4}} > 1.0\times 10^4\ \text{TeV}\left(\frac{m_{_{7/6}} m_{_{33}}}{1\ \text{TeV}^2}\right)^{1/4}}$$

Novel baryon-number violating signatures

Ω_{ij} **RH neutrinos** may be lighter than the proton $\Rightarrow$ **exotic** decay modes:

$$\boxed{p \to \bar{N}^0 \pi^+, p \to \bar{N}^0 K^+, n \to \bar{N}^0 \pi^0}$$

Dominant decay $p \to \bar{N}^0 \pi^+$ for wide range of $m_N < m_p - m_{\pi^+}$ with operator:

$$\frac{\tilde{C}_N}{\Lambda_{\rm pre}^8} \left(\Omega_{Q4}\Omega_{DL}\right) \left(\overline{\Omega}_{QQ}^{\bar{3},3}\overline{\Omega}_{QL}^{(3,3)}\right) \left(\Omega_{Q1}\Omega_{Q1}\right) \left(\overline{\Omega}_{D1}\overline{\Omega}_{41}\right) \text{ with } \overline{\Omega}_{41} \equiv N_R \equiv \bar{N}_0$$

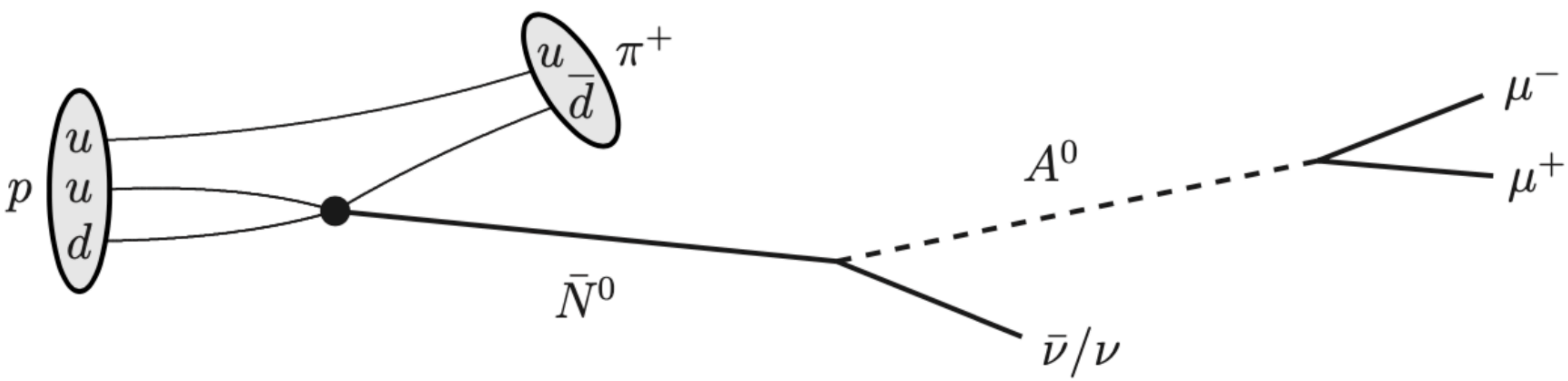
Inducing SM proton decay operator:

$$\frac{1}{M_{qqdN}^2} \left(u_L d_L\right) \left(d_R N_R\right) \text{ with } M_{qqdN} = \frac{16\pi^2 N^{3/2} N_c \Lambda_{\rm pre}^2}{c_\phi \left(C_N m_{\mathcal{Q}} m_{33}\right)^{1/2}}$$

Novel baryon-number violating signatures

Update search: $p \to \pi^+\bar{\nu}$ sensitive to the $p \to \pi^+\bar{N}_0$ decay with $m_N > 100\ \mathrm{MeV}$ may result in stable N^0 and B-violation

Future experiments: N^0 can decay within the detector $\Rightarrow$ many final states within reach



Decay of $p \to \bar{N}^0\pi^+$ followed by the decay $\bar{N}^0 \equiv \Omega_{41}$ to light pseudoscalar

Summary

Proposed chiral $SU(15)_p \times \mathrm{SM}$ gauge theory in which preon confinement gives rise to exactly **3 generations** of SM prebaryons

Composite heavy vector-like fermions present with Higgs and heavy di-prebaryons

Unique proton decay modes at confinement scale $\Rightarrow$ **novel and exotic signatures**

Outlook

Improved understanding of strongly coupled chiral gauge theories

Grand unifying the model above the compositeness scale

Composite vectorlike fermions and scalars possibly within reach of LHC

Proton decay signatures searchable for at DUNE and SuperK detectors