Baryon number violation

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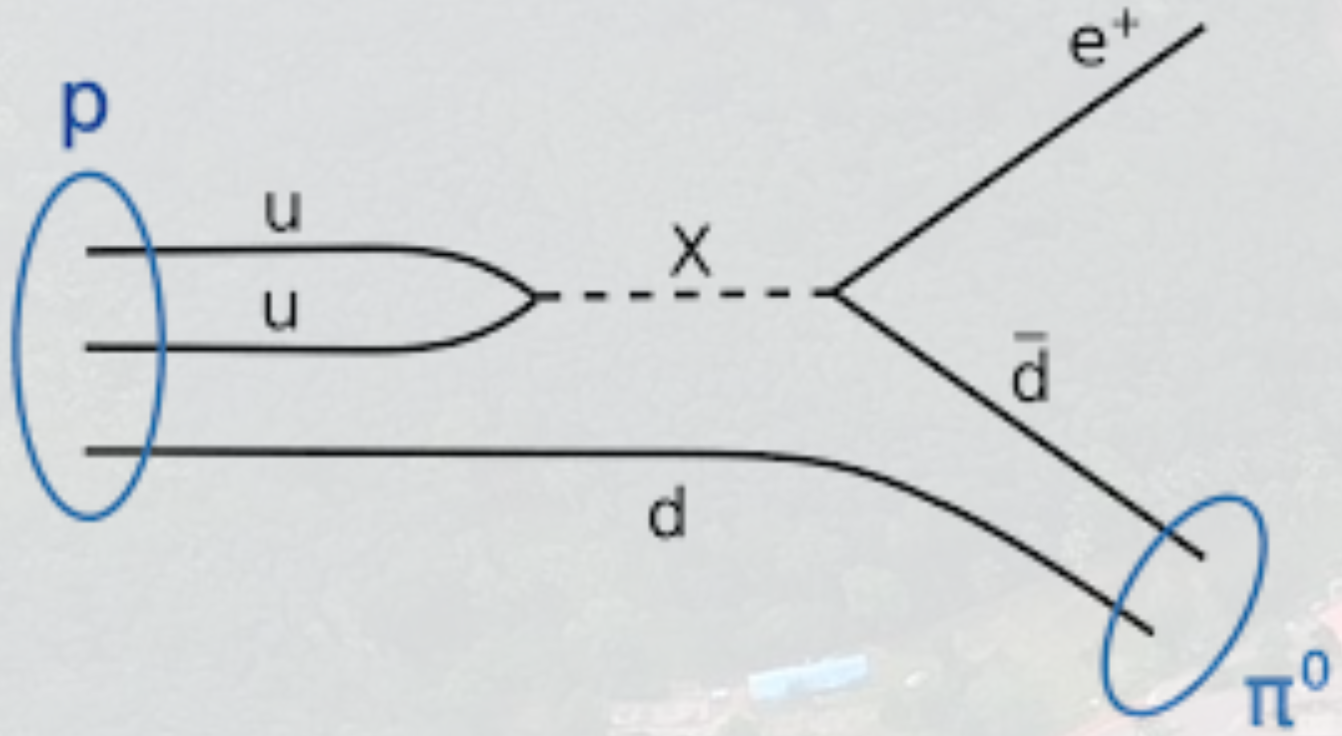


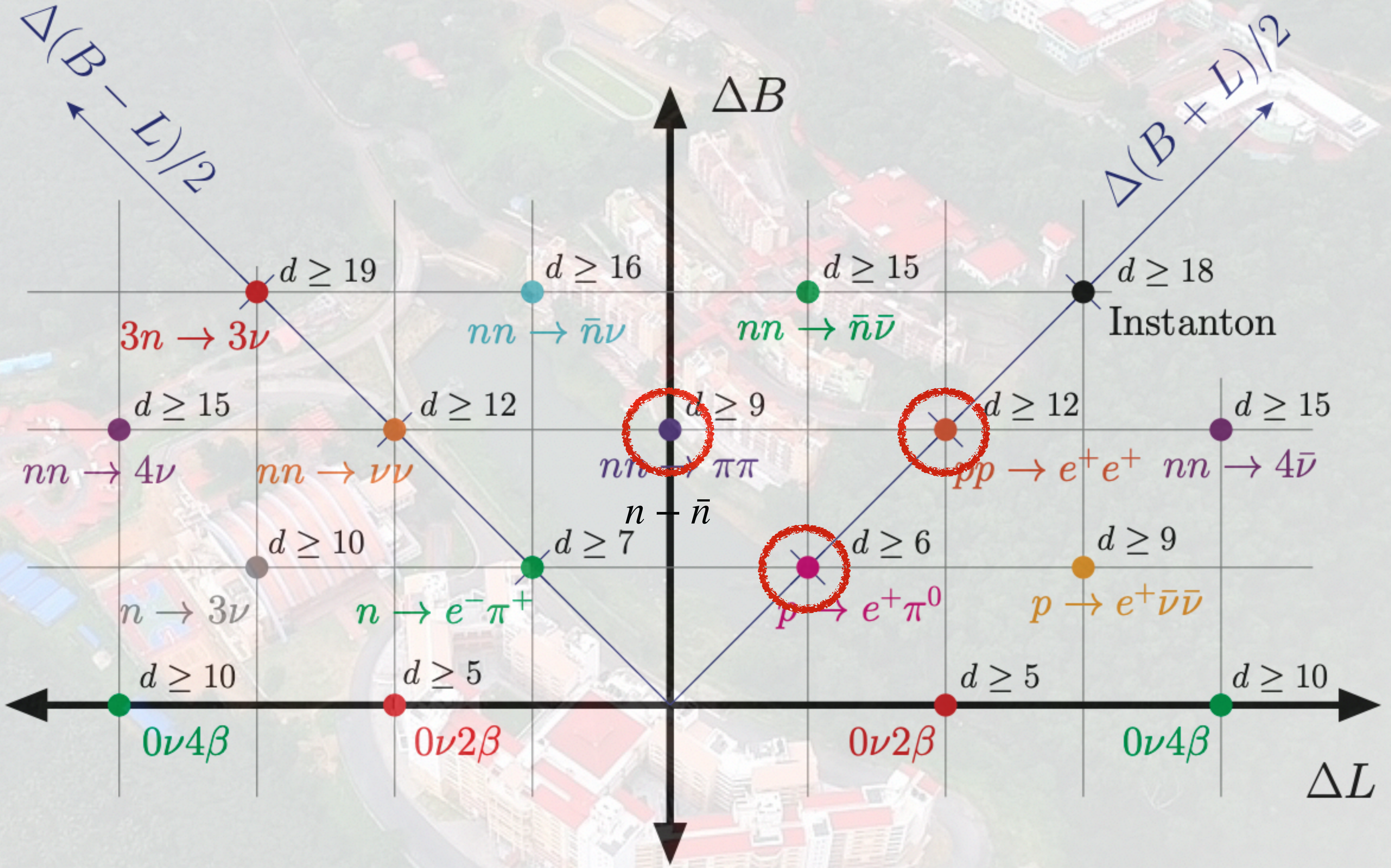
Assuming perturbative couplings to ‘X’ particle

Quark level dim-6

$$\begin{aligned}\mathcal{L}_{d=6} = &\; y^{1}_{abcd}\epsilon^{\alpha\beta\gamma}(\overline{d}^{C}_{a,\alpha}u_{b,\beta})(\overline{Q}^{C}_{i,c,\gamma}\epsilon_{ij}L_{j,d}) \\ &+ y^{2}_{abcd}\epsilon^{\alpha\beta\gamma}(\overline{Q}^{C}_{i,a,\alpha}\epsilon_{ij}Q_{j,b,\beta})(\overline{u}^{C}_{c,\gamma}\ell_{d}) \\ &+ y^{3}_{abcd}\epsilon^{\alpha\beta\gamma}\epsilon_{il}\epsilon_{jk}(\overline{Q}^{C}_{i,a,\alpha}Q_{j,b,\beta})(\overline{Q}^{C}_{k,c,\gamma}L_{l,d}) \\ &+ y^{4}_{abcd}\epsilon^{\alpha\beta\gamma}(\overline{d}^{C}_{a,\alpha}u_{b,\beta})(\overline{u}^{C}_{c,\gamma}\ell_{d}) + \mathrm{h.c.}\,,\end{aligned}$$

$$\Gamma(p \to e^{+}\pi^{0}) \simeq \frac{1}{2\times 10^{34}\,\mathrm{yr}}\left|\frac{y^{j}_{1111}}{(3\times 10^{15}\,\mathrm{GeV})^{-2}}\right|^{2}.$$

Effective operators: quark level….assuming perturbative new physics



Julian Heeck and Volodymyr Takhistov
Phys. Rev. D 101, 015005

arXiv:1910.07647

Neutron-Antineutron Oscillation Search using a 0.37 Megaton·Year Exposure of Super-Kamiokande

K. Abe *et al.* (Super-Kamiokande Collaboration)
Phys. Rev. D **103**, 012008 – Published 21 January 2021

- As a BNV process that violate both B and B-L, neutron-antineutron oscillation provides a unique probe of baryon number violation
- Most of the models predicting $n - \bar{n}$ correspond to energy scales of $10^2 - 10^3$ TeV, well above the scales that can be probed by accelerators

	Events	$T_{n-\bar{n}}$ (10^{32} yrs)	$\tau_{n\to\bar{n}}$ (10^8 s)
Expected	9.3	4.3	5.1
Observed	11	3.6	4.7

$10^{-34} GeV$

$$\mathcal{L} = i\bar{n}\gamma^\mu\partial_\mu n - \frac{m_n}{2}\left[\bar{n}n + \bar{n^c}n^c\right] - \frac{\epsilon}{2}\left[\bar{n^c}n + \bar{n}n^c\right]$$

Phys. Rev. D **87**, 075004 Jonathan M. Arnold, Bartosz Fornal and Mark B. Wise
Physics Letters B 777 (2018) 324–331 Nima Assad, Bartosz Fornal*, Benjamín Grinstein

BNV with suppressed proton decay in 4 dimensions : at high scale

The only leptoquark and diquark models with a triplet or sextet color structure that do not suffer from tree-level proton decay. The primes indicate the existence of dim 5 proton decay channels.

Field	$SU(3)_c \times SU(2)_L \times U(1)_Y$ reps.
Scalar leptoquark	$(3,2)'_{\frac{7}{6}}$
Scalar diquark	$(3,1)_{\frac{2}{3}}$, $(6,1)_{-\frac{2}{3}}$, $(6,1)_{\frac{1}{3}}$, $(6,1)_{\frac{4}{3}}$, $(6,3)_{\frac{1}{3}}$
Vector leptoquark	$(3,1)'_{\frac{2}{3}}$, $(3,1)_{\frac{5}{3}}$, $(3,3)'_{\frac{2}{3}}$
Vector diquark	$(6,2)_{-\frac{1}{6}}$, $(6,2)_{\frac{5}{6}}$

Possible interaction terms between the scalars

operator	$SU(3) \times SU(2) \times U(1)$
XQQ, Xud	$(\bar{6}, 1, -1/3)$
XQQ	$(\bar{6}, 3, -1/3)$
Xdd	$(3, 1, 2/3)$, $(\bar{6}, 1, 2/3)$
Xuu	$(\bar{6}, 1, -4/3)$
$X\bar{Q}e$	$(3, 2, 7/6)$
$X\bar{L}u$	$(\bar{3}, 2, -7/6)$
$X\bar{L}d$	$(\bar{3}, 2, -1/6)$
XLL	$(1,1,1)$, $(1,3,1)$
Xee	$(1,1,2)$

Possible vector color triplet and sextet representations.

Operator	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	p decay
$\overline{Q_L^c}\gamma^\mu u_R V_\mu$	3	2	−5/6	tree-level
	$\bar{6}$	2	−5/6	–
$\overline{Q_L^c}\gamma^\mu d_R V_\mu$	3	2	1/6	tree-level
	$\bar{6}$	2	1/6	–
$\overline{Q_L}\gamma^\mu L_L V_\mu$	3	1, 3	2/3	dim 5
$\overline{Q_L^c}\gamma^\mu e_R V_\mu^*$	3	2	−5/6	tree-level
$\overline{L_L^c}\gamma^\mu u_R V_\mu^*$	3	2	1/6	tree-level
$\overline{L_L^c}\gamma^\mu d_R V_\mu^*$	3	2	−5/6	tree-level
$\overline{u_R}\gamma^\mu e_R V_\mu$	3	1	5/3	dim 7
$\overline{d_R}\gamma^\mu e_R V_\mu$	3	1	2/3	dim 5

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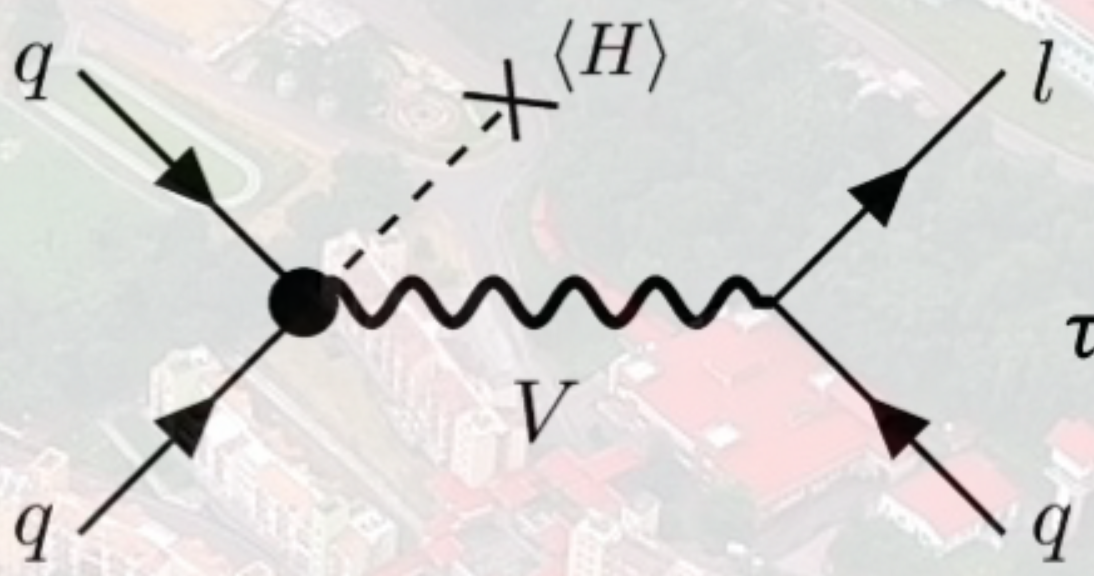
BNV with suppressed proton decay in 4 dimensions : at high scale

Vectors:

- Though tree-level proton decay is absent, there could be dim-5 operator that leads to proton-decay.

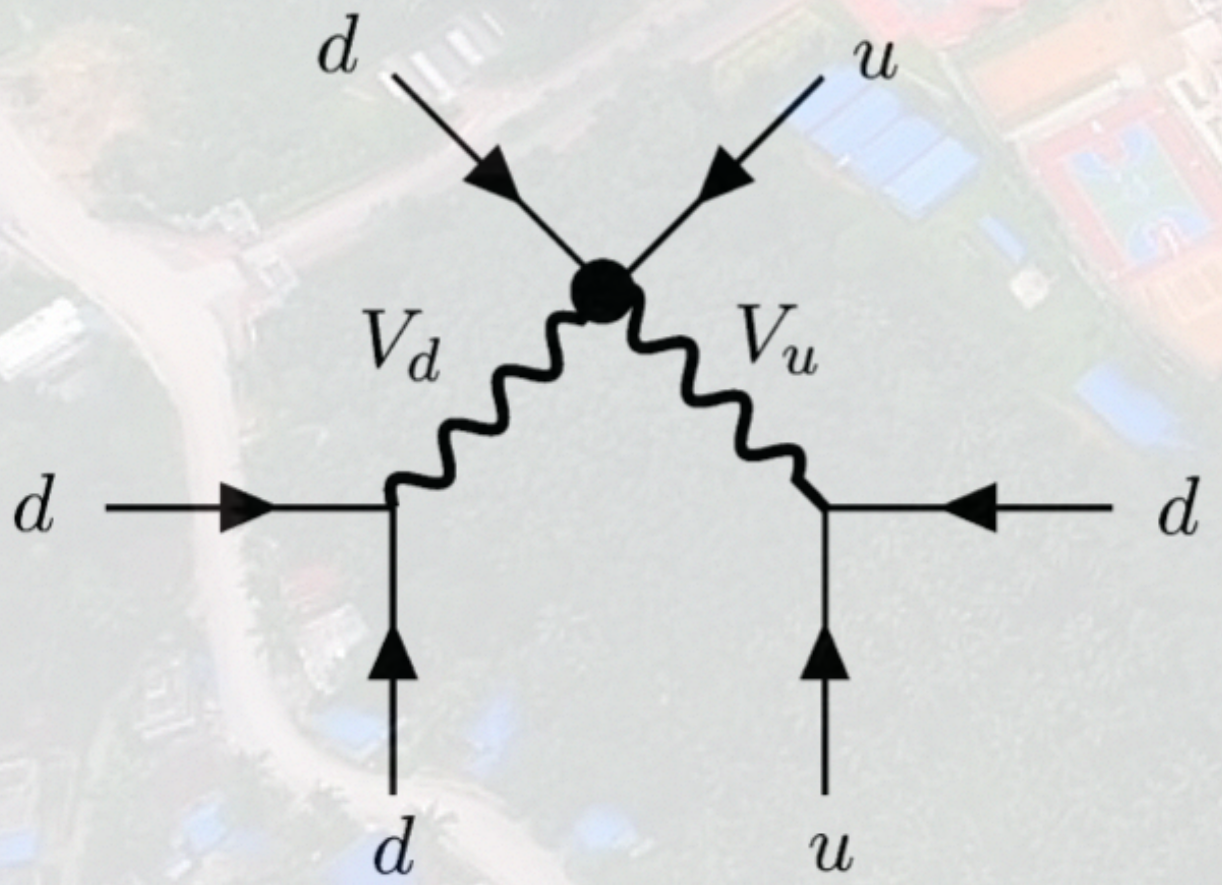
vector leptoquark representations $(3,1)_{\frac{2}{3}}$ and $(3,3)_{\frac{2}{3}}$

$$\frac{1}{\Lambda}(\overline{Q_L^c}H^\dagger)\gamma^\mu d_R V_\mu\,,\quad \frac{1}{\Lambda}(\overline{Q_L^c}\tau^A H^\dagger)\gamma^\mu d_R V_\mu^A\,,$$



Proton decay through a dimension five interaction

$$\tau_p \approx \left(2.5\times 10^{32}\ \text{years}\right)\left(\frac{M}{10^4\ \text{TeV}}\right)^4\left(\frac{\Lambda}{M_{\rm Pl}}\right)^2$$



Process mediating $n-\bar{n}$ oscillations via the vector diquark $(6,2)_{-\frac{1}{6}}$

- This operator does not exist if we gauge $U(1)_{B-L}$.
- In the light of null results from ΔB=1 searches, the possibility of discovering *neutron-antineutron* oscillations has recently gained increased interest

$$M \gtrsim 2.5\ \text{TeV}\left(\frac{10^8\ \text{TeV}}{\Lambda}\right)^{1/4} \gtrsim 90\ \text{TeV}$$

Phys. Rev. D **87**, 075004 Jonathan M. Arnold, Bartosz Fornal and Mark B. Wise

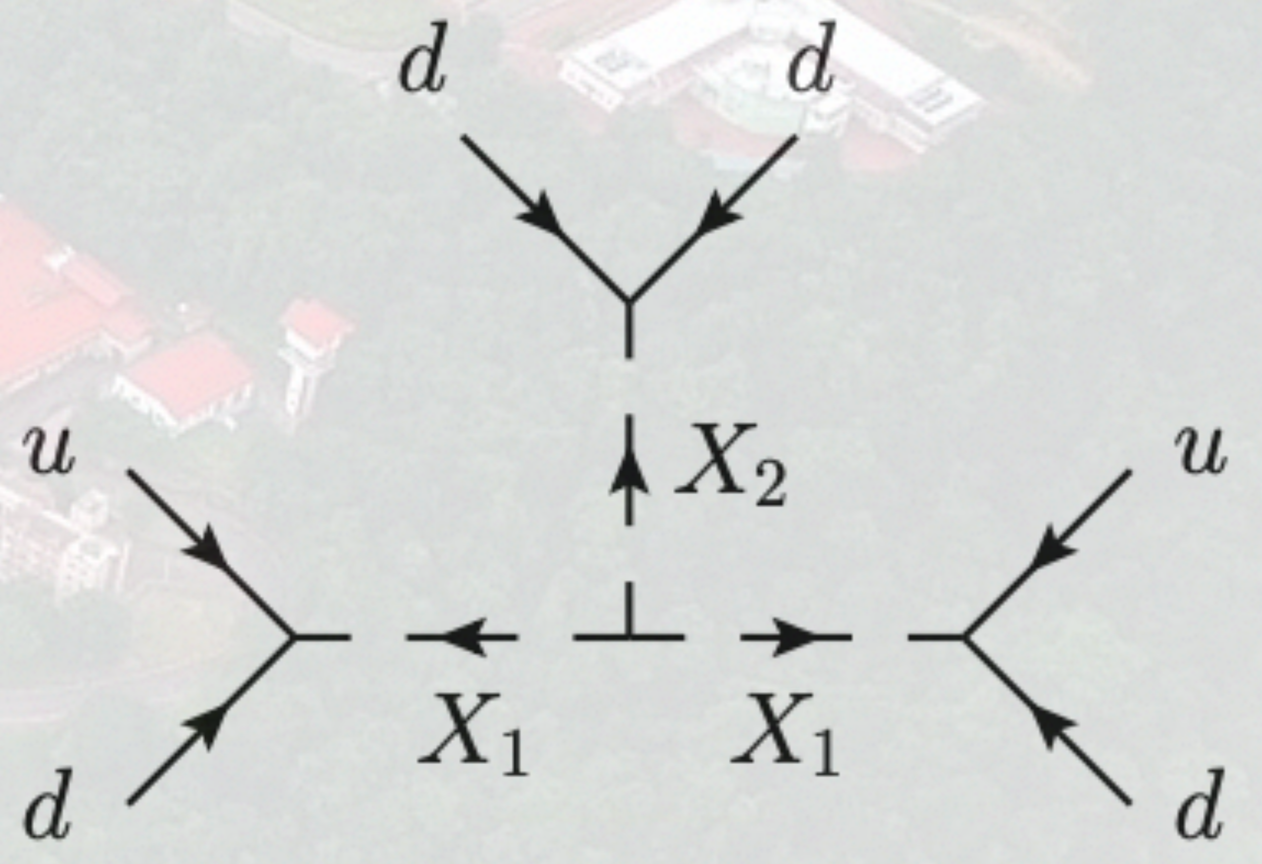
BNV with suppressed proton decay in 4 dimensions : at high scale

Scalars:

$$X_1 \in (\bar{6}, 1, -1/3), \;\; X_2 \in (\bar{6}, 1, 2/3)$$

$$\mathcal{L} \;=\; - g_1^{ab} X_1^{\alpha\beta} \left(Q_{L\alpha}^{a} \epsilon Q_{L\beta}^{b}\right) - g_2^{ab} X_2^{\alpha\beta} (d_{R\alpha}^{a} d_{R\beta}^{b})$$
$$- g_1^{\prime ab} X_1^{\alpha\beta} (u_{R\alpha}^{a} d_{R\beta}^{b}) + \lambda X_1^{\alpha\alpha'} X_1^{\beta\beta'} X_2^{\gamma\gamma'} \epsilon_{\alpha\beta\gamma} \epsilon_{\alpha'\beta'\gamma'}$$

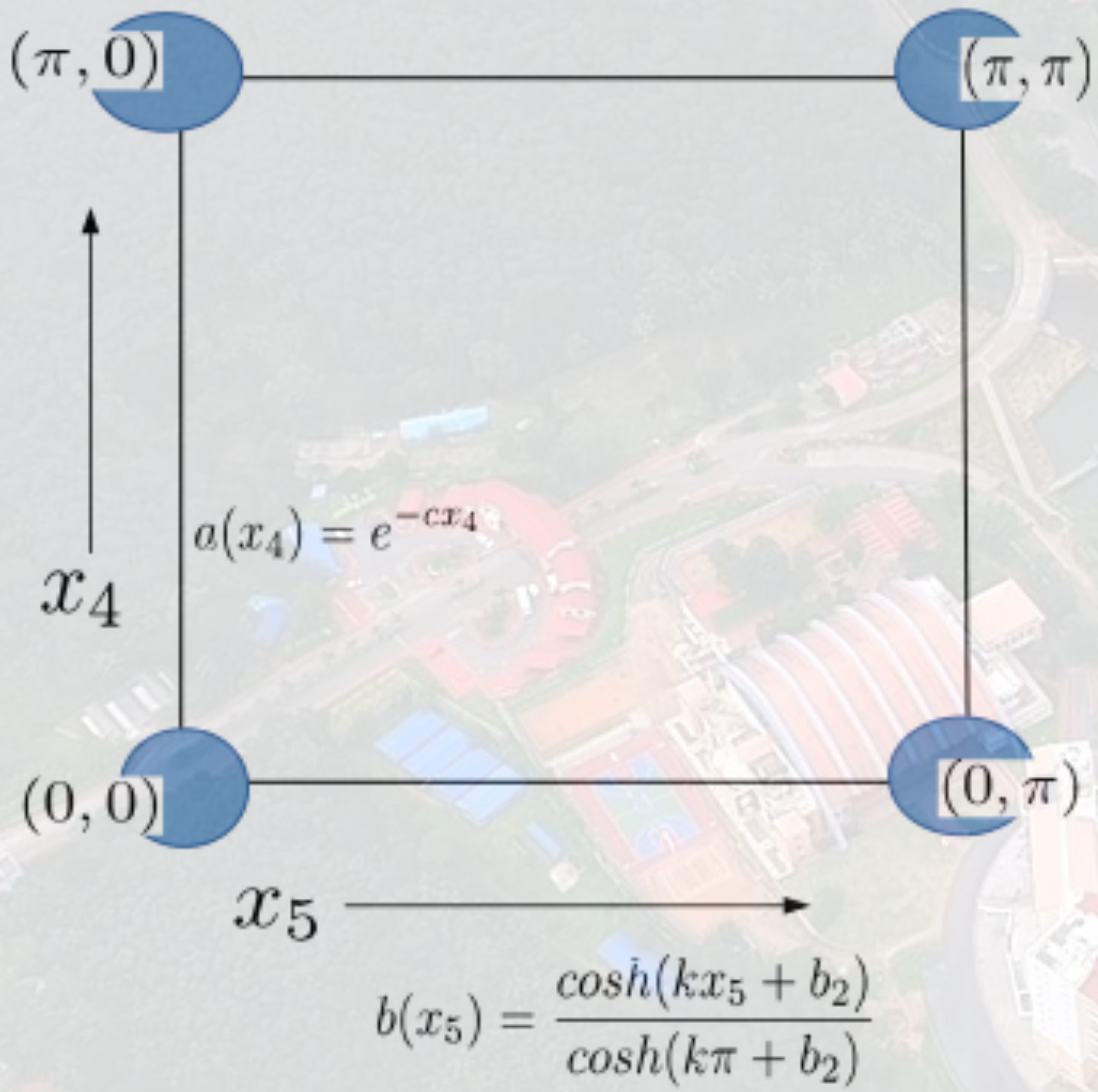
- No proton decay



Interaction which leads to neutron-antineutron oscillations.

- Assuming all scalars to have same mass and the the Yukawa to be $\sim \mathcal{O}(1)$, one obtains $M \gtrsim 500 TeV$
- This model do not encourage other BNV processes like $pp \to e^+ e^+$, $nn \to \nu\nu$, $\ldots$
- A common feature in all these models are perturbative couplings with very heavy mass mediators

Neutron-antineutron oscillation: generation from six dimensions

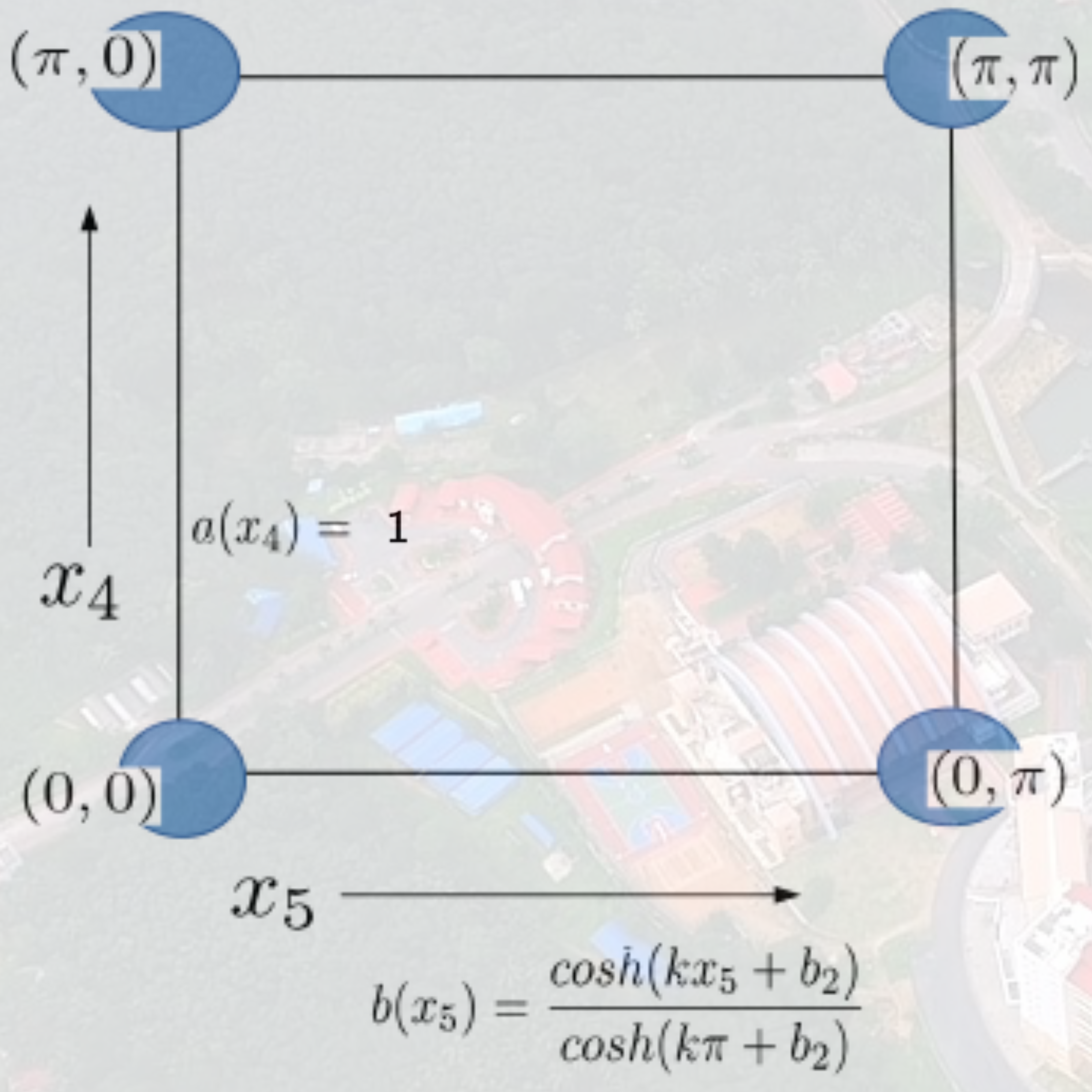


$$M^4 \otimes S^1/Z_2 \otimes S^1/Z_2$$

$$ds_6^2 = b^2(x_5)[a^2(x_4)\eta_{\mu\nu}dx^\mu dx^\nu + dx_4^2] + dx_5^2$$

$$\begin{aligned} \mathcal{L} \;&=\; \sqrt{-g_6}\,(M_6^4 R_6 - \Lambda_6) \\ &+\; \sqrt{-g_5}\,[V_1(x_5)\,\delta(x_4) + V_2(x_5)\,\delta(x_4 - \pi R_y)] \\ &+\; \sqrt{-\tilde{g}_5}\,[V_3(x_4)\,\delta(x_5) + V_4(x_4)\,\delta(x_5 - \pi r_z)] \end{aligned}$$

Neutron-antineutron oscillation: generation from six dimensions



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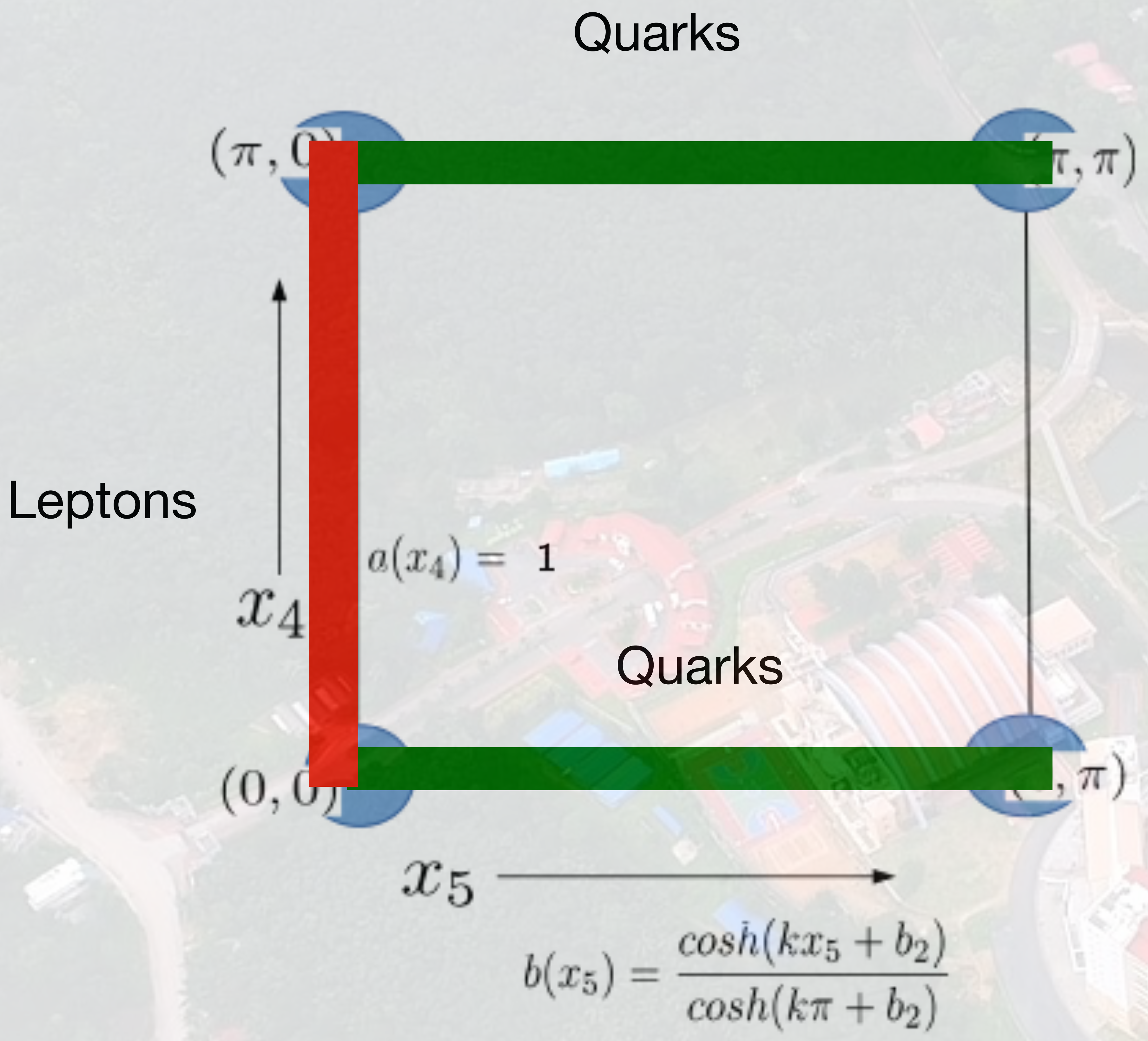
Large b_2 limit : Induced cosmological constant vanishes

MTA, Debajyoti Choudhury : *Phys.Rev.D* 106 (2022) 3, L031701

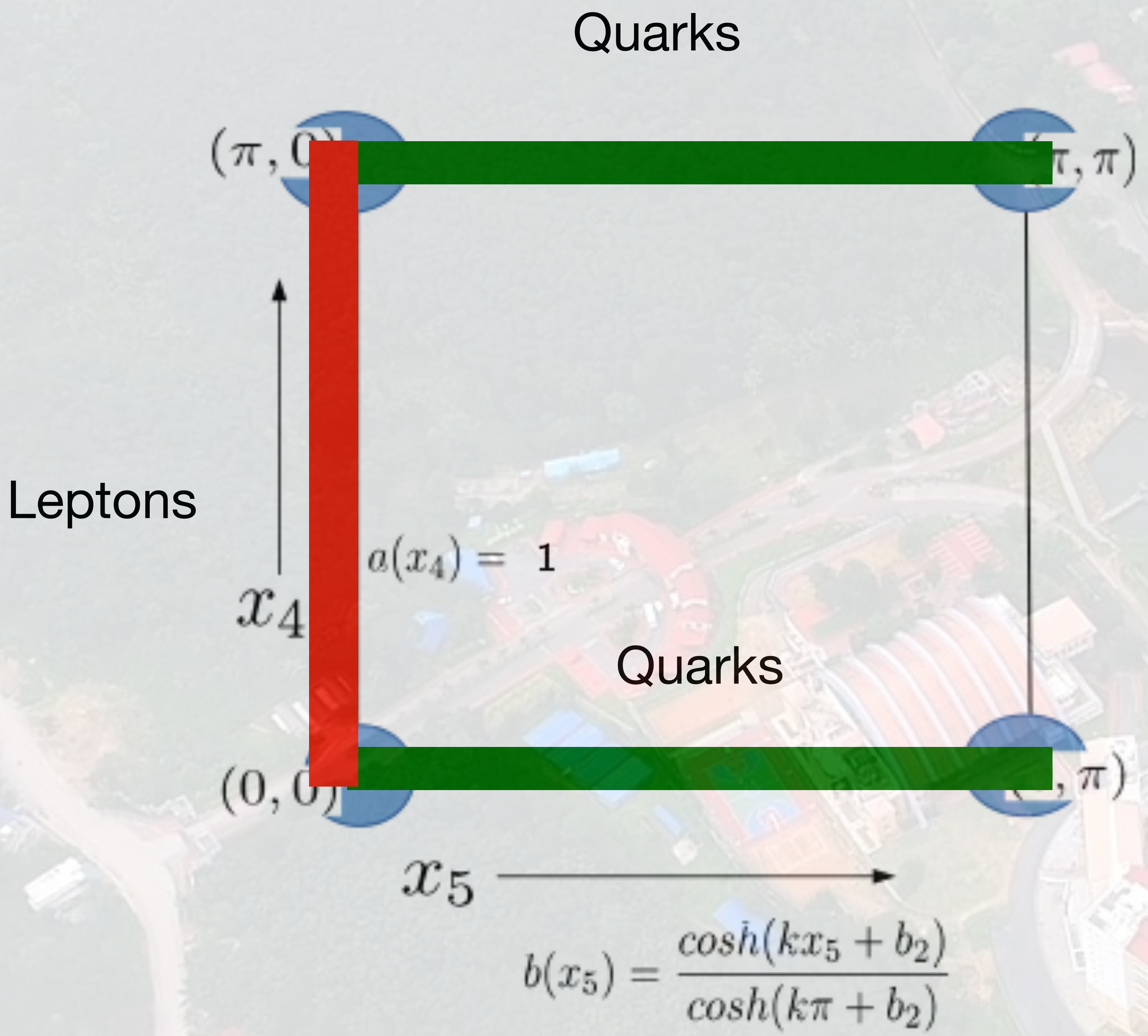
Neutron-antineutron oscillation: generation from six dimensions



$$
\begin{aligned}
\mathcal{L}_{\text{fermion}} &= \frac{1}{2} b^4(x_5) \left(\bar{Q}\, i\Gamma^a\, E_a^M\, D_M\, Q \right) \overline{\Delta}(x_4) \\
&\quad + b^5(x_5) \left(\bar{L}\, i\Gamma^a\, E_a^M\, D_M\, L \right) \delta(x_5) \\
\overline{\Delta}(x_4) &\equiv \delta(x_4) + \delta(x_4 - \pi R_y)
\end{aligned}
$$

$$
\begin{aligned}
\mathcal{L}_{\text{scal}} = \sqrt{2r_z}\Big[& y_{ud}\phi\overline{u^c}d + \sqrt{4r_z R_y}\, y_{ue}\phi^*\overline{u^c}e\ \delta(x_5) \\
& + z_{dd}\omega\overline{d^c}d + \lambda M\phi^2\omega \Big] \overline{\Delta}(x_4) + h.c..
\end{aligned}
$$

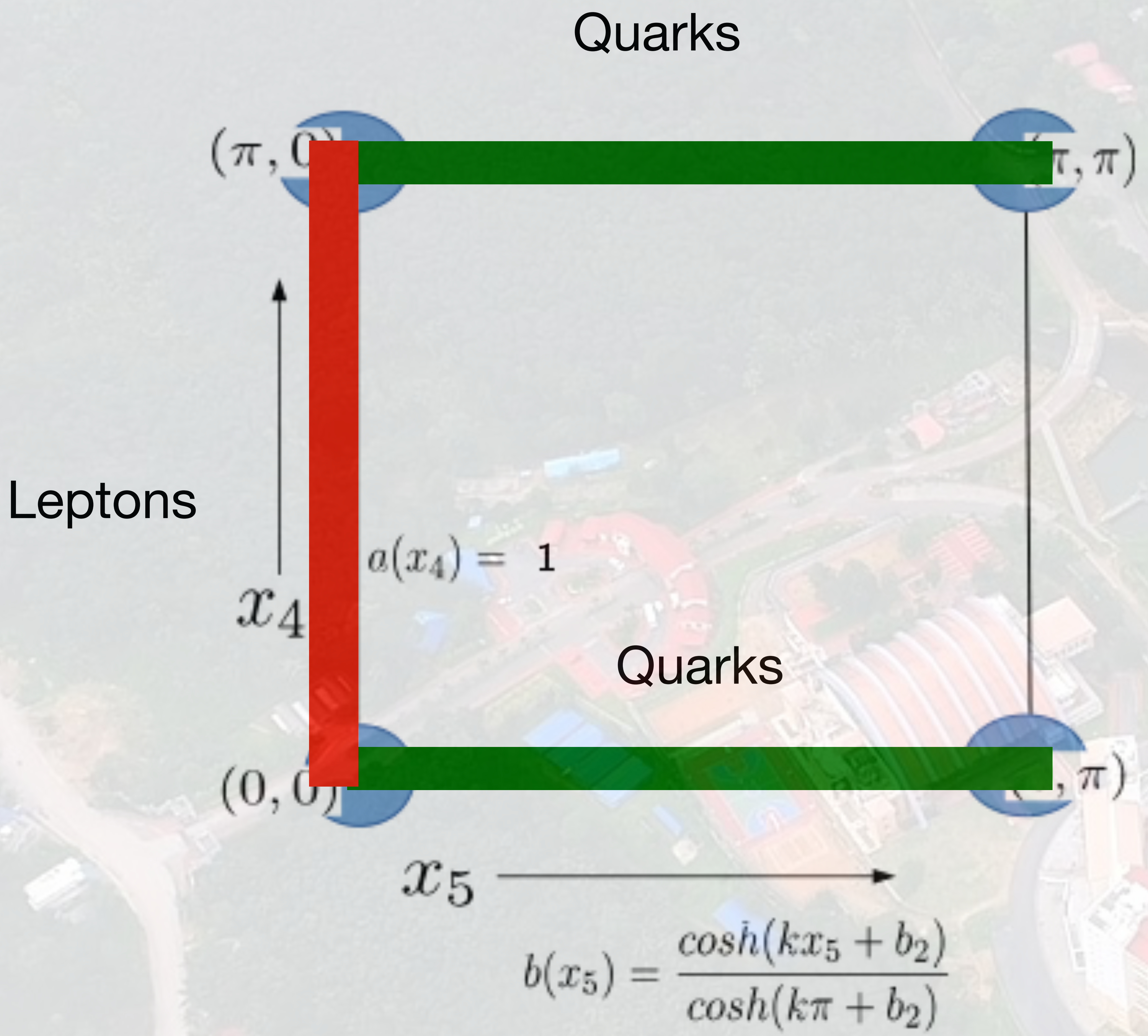
Neutron-antineutron oscillation: generation from six dimensions



$$\begin{aligned}\mathcal{L}_{int} &= \eta_{ud}\phi\overline{u^c}d + \eta_{ue}\phi^*\overline{u^c}e + \zeta_{dd}\omega^*\overline{d^c}d \\ &+ \rho M\phi^2\omega + h.c. \, ,\end{aligned}$$

$$\begin{aligned}\zeta_{dd} &= (2r_z)^{-1}z_{dd}\int dx_5 b^2\chi_\phi\chi_d^2 \\ \eta_{ud} &= (2r_z)^{-1}y_{ud}\int dx_5 b^2\chi_\phi\chi_u\chi_d \\ \rho &= (2r_z)^{-1}\lambda\int dx_5 b^2\chi_\phi^2\chi_\omega \\ \eta_{ue} &= y_{ue}b^2(0)\chi_\phi(0)\chi_u(0)\end{aligned}$$

Neutron-antineutron oscillation: generation from six dimensions



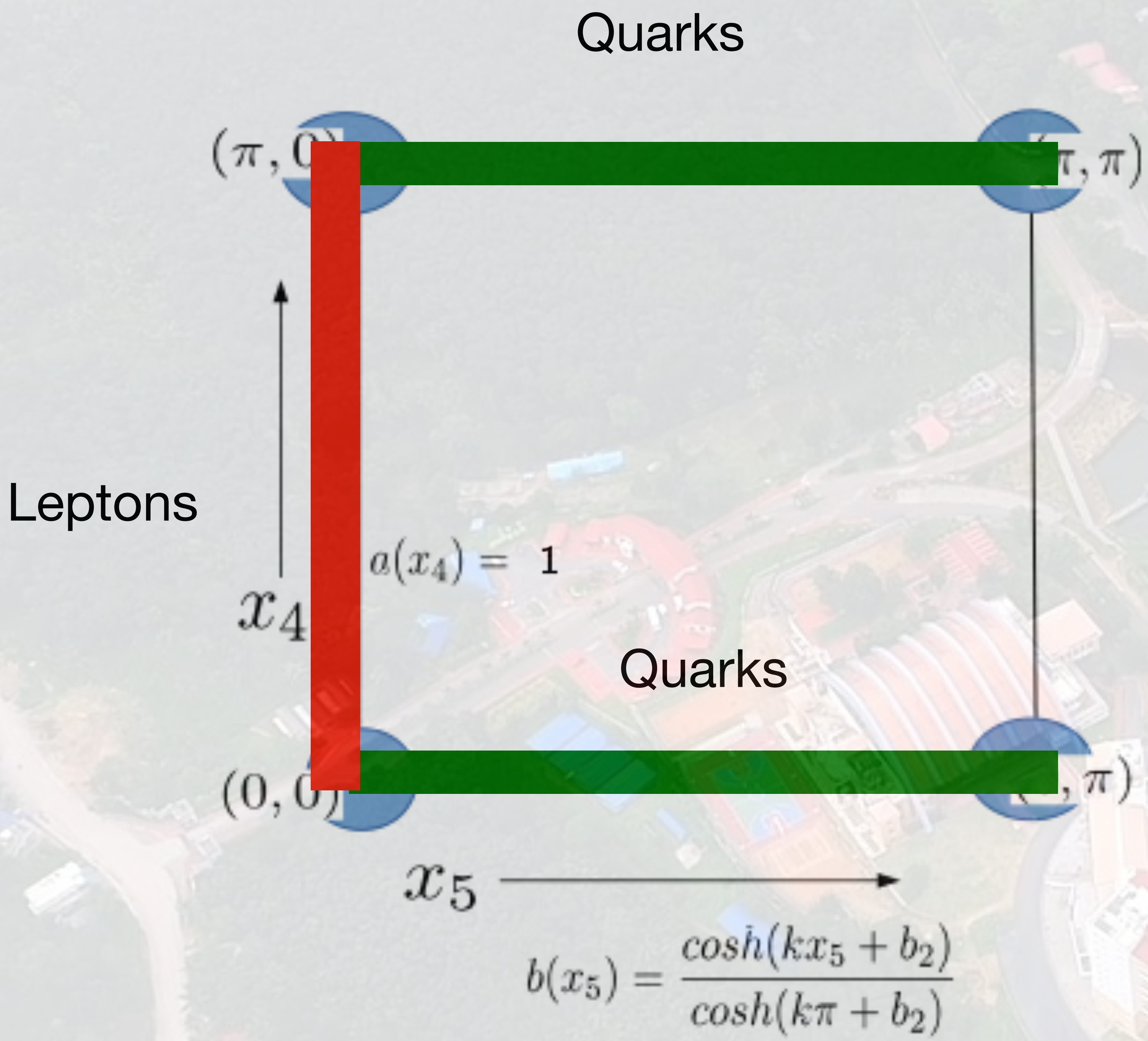
$$C^p = \frac{\eta_{ud}\eta_{ue}}{m_\phi^2} \, , \quad C^{nn} = \frac{\rho M}{m_\phi^2 m_\omega^4} \eta_{ud}^2 \, \zeta_{dd}$$

$$\eta_{ue} \; = \; y_{ue} b^2(0) \chi_\phi(0) \chi_u(0)$$

$$|\Delta m| \; = \; |\langle \bar{n} | H_{eff} | n \rangle| \; = \; 8\xi^2 C^{nn}/3$$

MTA, Debajyoti Choudhury : *Phys.Rev.D* 106 (2022) 3, L031701

Neutron-antineutron oscillation: generation from six dimensions

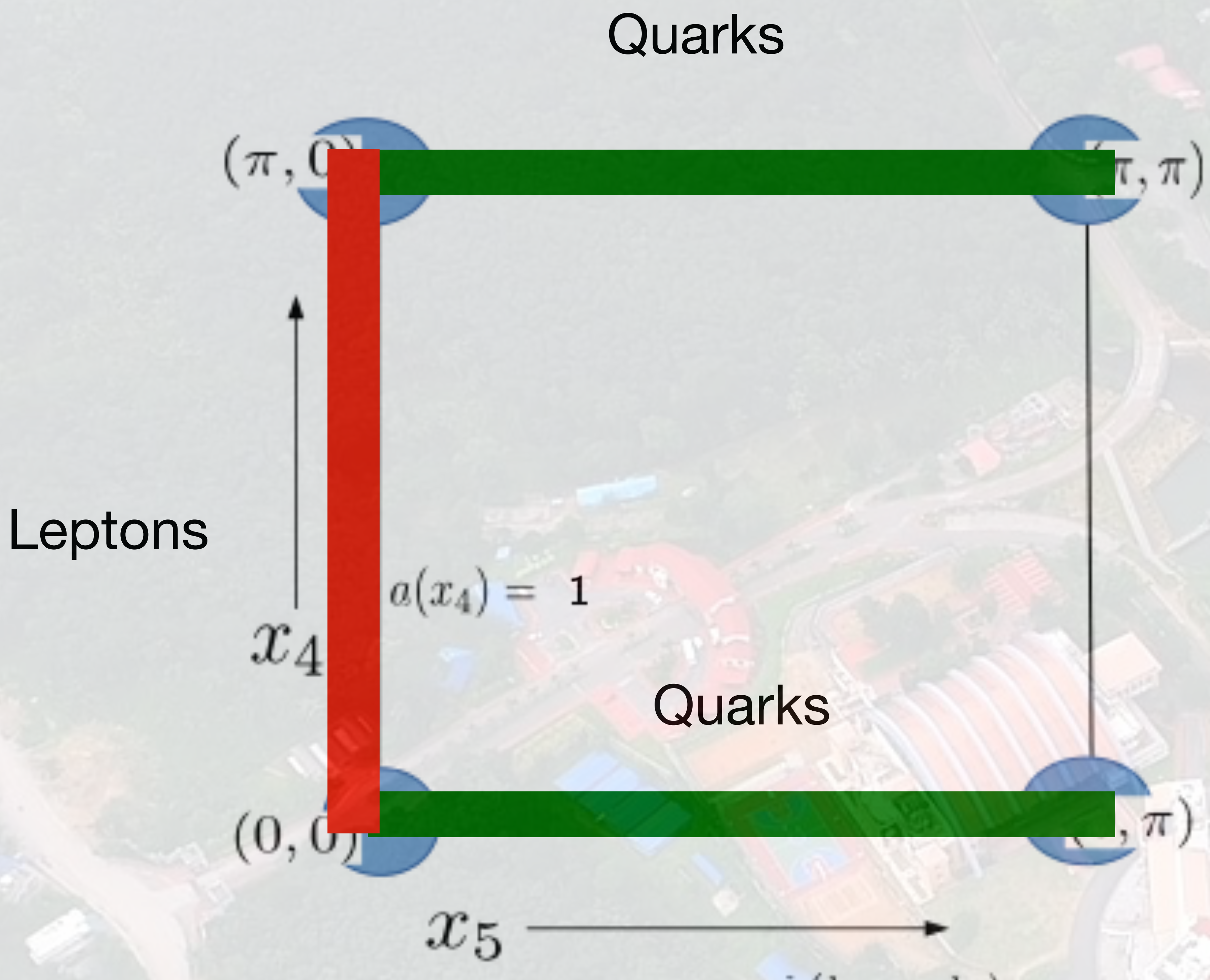


Much more important are the flavour sector observables. While n-$\bar{n}$ oscillation needs only the $d - d - \omega$ coupling, it is conceivable that the $s - s - \omega$ coupling is unsupressed as well. This would result in an effective flavour changing Hamiltonian of the form $\mathcal{H}^{\Delta S=2} = m_\phi^{-2}(\bar{s^c} P_R s)(\bar{d} P_L d^c)$, thereby contributing to K^0–$\bar{K}^0$ oscillation

$$\frac{Re(\zeta_{dd}\zeta^*_{ss})}{8m_\omega^2} \lesssim \frac{G_F^2 M_W^2}{16\pi^2}\mathcal{F}^0 \sim 10^{-7}\mathrm{TeV}^{-2}$$

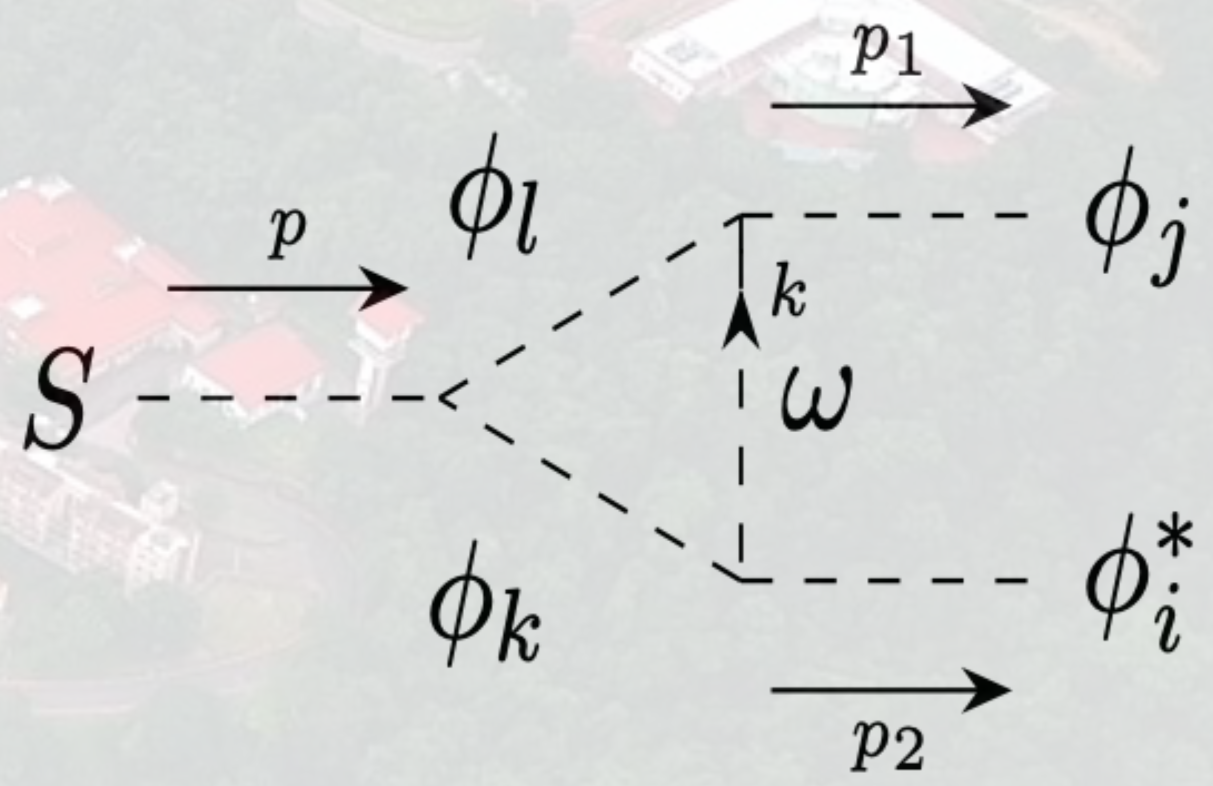
MTA, Debajyoti Choudhury : *Phys.Rev.D* 106 (2022) 3, L031701

Neutron-antineutron oscillation: generation from six dimensions



$$b(x_5) = \frac{cosh(kx_5 + b_2)}{cosh(k\pi + b_2)}$$

$$-V \ \ni \ M\left[\rho_{ij}\phi_i\phi_j\omega + \widetilde{\rho}_{ij}\phi_i^*\phi_j S\right] + h.c.$$



$$\epsilon_B \approx \frac{M^2}{4\pi^2 m_S^2 \beta} \log\left(\frac{x_\omega - x_\phi + 1 + \beta}{x_\omega - x_\phi + 1 - \beta}\right) \mathcal{A}_\rho$$

$$\mathcal{A}_\rho \equiv Im\left[\widetilde{\rho}^*_{12}(\rho^\dagger\widetilde{\rho}\rho)_{12}\right] / \sum_{i,j} |\widetilde{\rho}_{ij}|^2$$

In the parameter space where the nuetron-anti-neutron oscillation is observable, $m_\phi \sim m_\omega = 3TeV$, and $M \sim m_S = 10TeV$, the asymmetry required for baryogenesis is obtained for $\mathcal{A}_\rho \lesssim 2.2 \times 10^{-9}$.

Zurab Berezhiani[a,*] and Luís Bento[b,†] Phys.Rev.Lett. 96 (2006) 081801

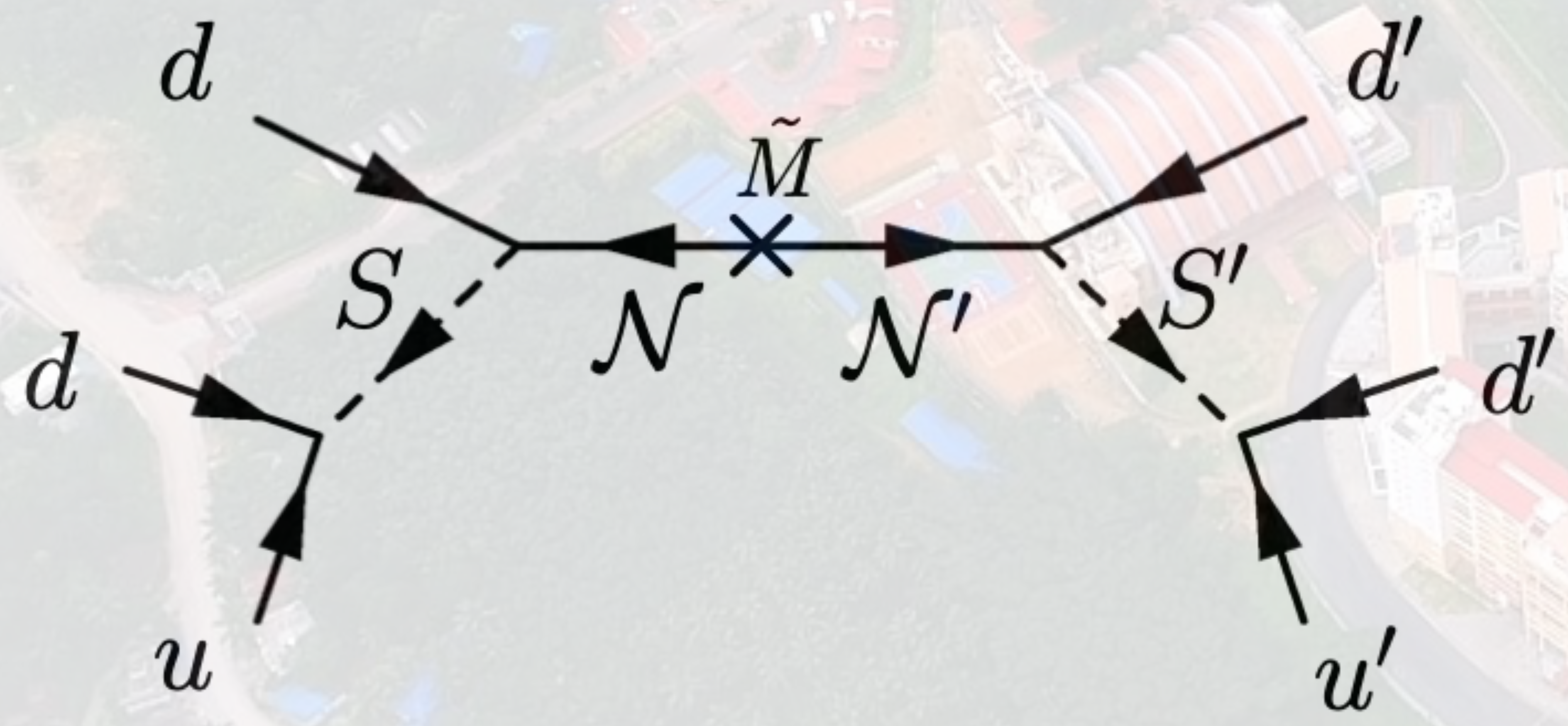
David McKeen,[1,*] Maxim Pospelov,[2,3,†] and Nirmal Raj[1,‡] Phys. Rev. Lett. **127**, 061805

Neutron-mirror neutron oscillation

$$G' \;=\; SU(3)' \times SU(2)' \times U(1)'$$

$$q'_L = (u', d')_L,\; l'_L = (\nu', e')_L \text{ and } u'_R, d'_R, e'_R$$

$$\mathcal{O}_9^{\rm mix} \sim \frac{1}{\mathcal{M}^5}(udd)(u'd'd') + \frac{1}{\mathcal{M}^5}(qqd)(q'q'd')$$



$$\delta m \sim \left(\frac{10\,\text{TeV}}{\mathcal{M}}\right)^5 \times 10^{-15}\,\text{eV}$$

$$\lesssim 10^{-17}\text{ eV},\ \text{or } \tau_{nn'} \gtrsim 10\text{ s},$$

Neutron-antineutron oscillation: generation at low-scale

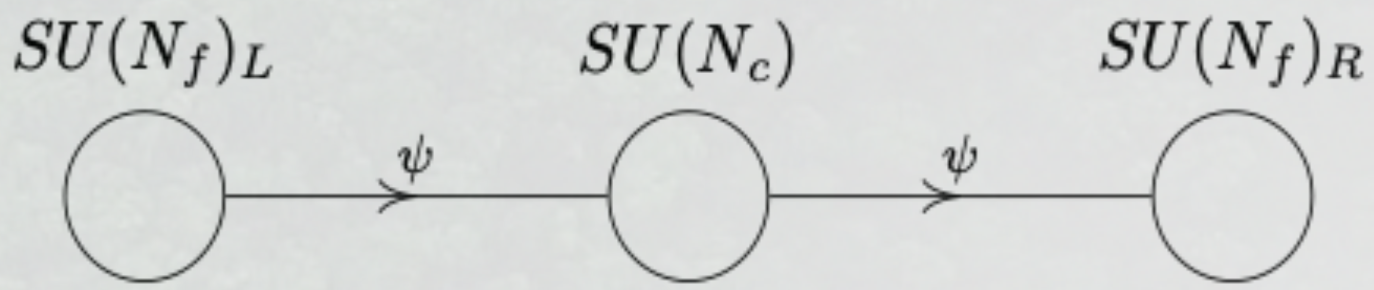
- To understand the low-scale New Physics contribution to neutron-antineutron oscillation

$10^{-34} GeV$

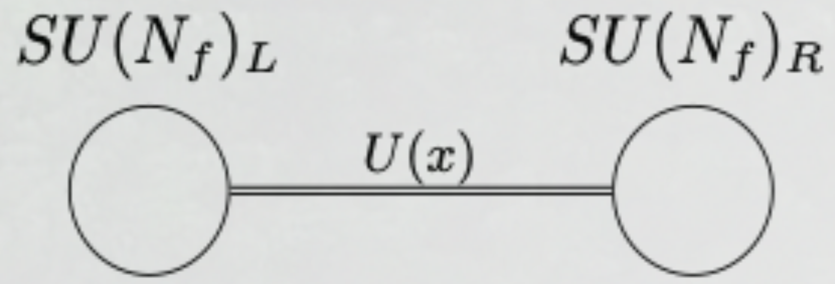
$$\mathcal{L} = i\bar{n}\gamma^\mu\partial_\mu n - \frac{m_n}{2}\left[\bar{n}n + \bar{n^c}n^c\right] - \frac{\epsilon}{2}\left[\bar{n^c}n + \bar{n}\bar{n^c}\right]$$

- The chiral symmetry $U(1)_V \times SU(N_f)_L \times SU(N_f)_R \to U(1)_V \times SU(N_f)_V$ with $U(1)_A$ being anomalous.

- Preservation of $U(1)_V$ demands baryon number conservation.



$$\begin{aligned}\mathcal{L}_{eff} &= \mathcal{L}^{(2)}_{N\pi} + \mathcal{L}^{(2)}_{\pi\pi} \ , \\ \mathcal{L}^{(2)}_{N\pi} &= \bar{\Psi}\left(i\gamma^\mu\partial_\mu - m + \frac{1}{2}g_{N\pi}\gamma^\mu\gamma_5 u_\mu\right)\Psi\end{aligned}$$

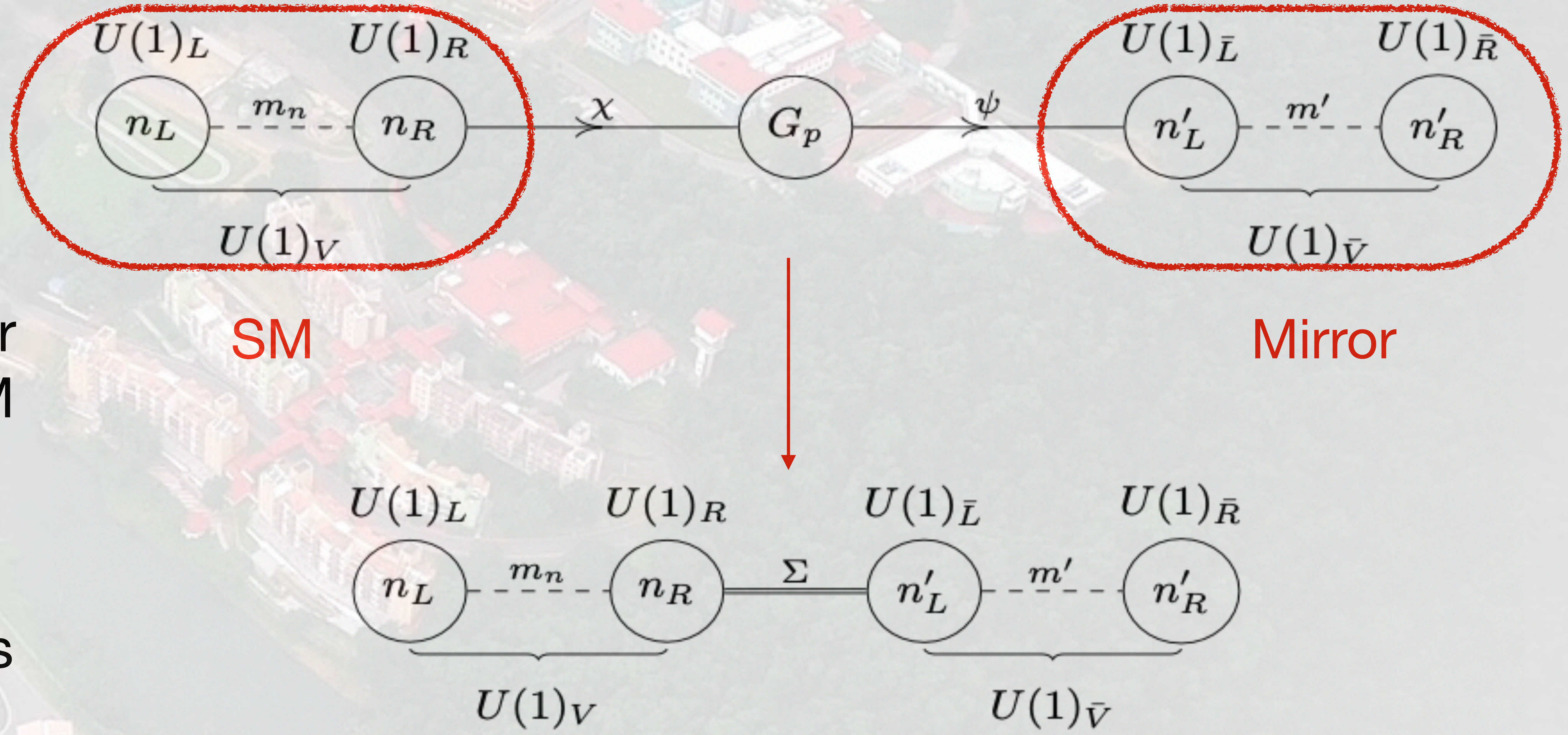


where, $u_\mu = i\xi^\dagger\nabla_\mu U(x)\xi^\dagger$. In particular, the nucleon-pion interaction is given by,

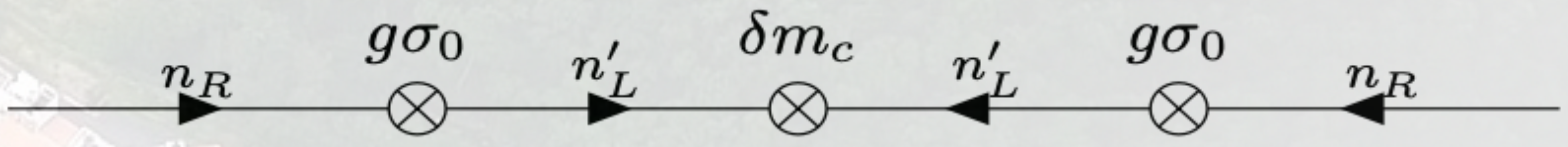
$$\mathcal{L}^{(2)}_{N\pi} = \bar{\Psi}\left(i\gamma^\mu\partial_\mu - m\right)\Psi - \frac{g_{N\pi}}{2f_\pi}\bar{\Psi}\gamma^\mu\gamma_5\Psi\partial_\mu\pi(x)^a T^a$$

Neutron-antineutron oscillation: generation at low-scale

Toy model



- The condensate Σ breaks $U(1)_V \times U(1)_{\bar{V}} \to U(1)_{V-\bar{V}}$. Thus, if the mirror baryon number breaks, it will percolate into SM baryon number to preserve $U(1)_{V-\bar{V}}$
- And there are new pions that mediate the interaction between the SM and mirror baryons



$$\begin{aligned}\mathcal{L}^{(2)}_{N\pi} &= \bar{\Psi}\Big(i\gamma^\mu\partial_\mu - m\Big)\Psi - \frac{g_{N\pi}}{2f_\pi}\bar{\Psi}\gamma^\mu\gamma_5\Psi\partial_\mu\pi(x)^a T^a \\ &+ \bar{\Psi}'\Big(i\gamma^\mu\partial_\mu - m'\Big)\Psi' - \frac{g_{N'\Pi}}{2f_\Pi}\bar{\Psi}'\gamma^\mu\gamma_5\Psi'\partial_\mu\Pi(x)^a T^a \\ &+ g\sigma\bar{\Psi}'_L(1 + i\gamma^5\frac{\pi_p}{g_\pi})\Psi_R + h.c. \,,\end{aligned}$$

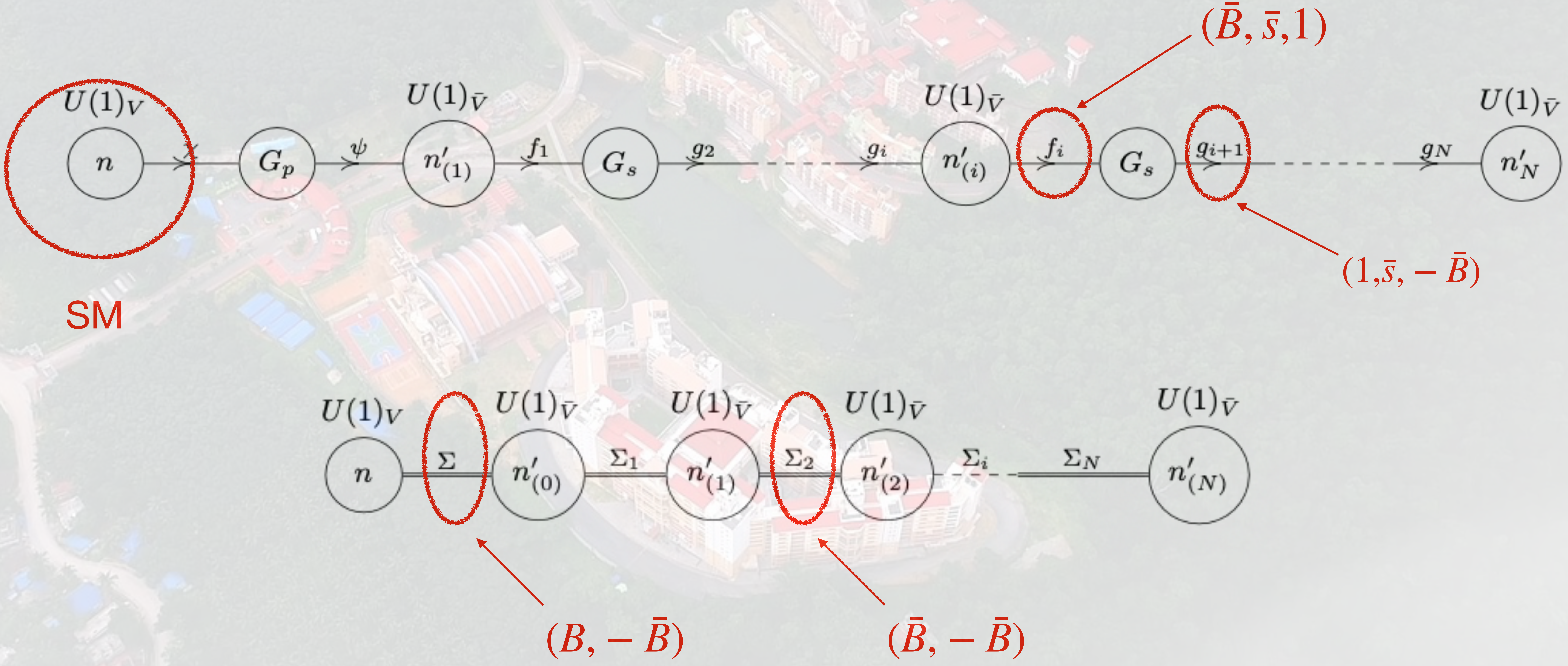
$$\mathcal{L} = -m_n\frac{m'}{g\sigma_0}\bar{n}_L n'_R + \delta m_c \bar{n}'^c_R n'_R$$

MTA Phys.Rev.D 107 (2023) 5, 055021

Neutron-antineutron oscillation: generation at low-scale

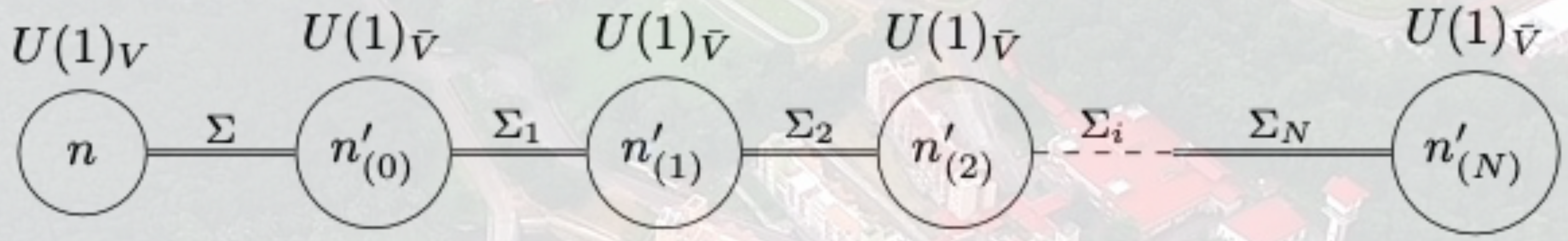
Linear Moose model

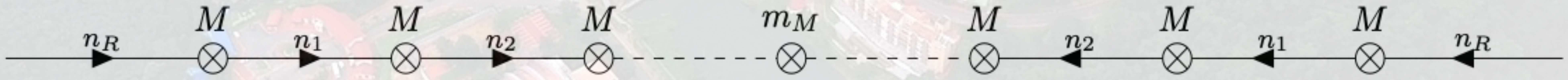
- Expanding on the toy model with multiple QCD-like gauge groups



Neutron-antineutron oscillation: generation at low-scale

Linear Moose model





$$\mathcal{L}^{(2)}_{N\pi} \supset \bar{n}\Big(i\gamma^\mu\partial_\mu - m_n\Big)n - \frac{m_M}{2}\left(\frac{m}{M}\right)^{2N}\frac{y^2v^2}{m^2+y^2v^2}\bar{n}_R n^c_R + \mathcal{L}_{int}$$

$$\frac{\epsilon}{2} = \frac{m_M}{2}\left(\frac{m}{M}\right)^{2N}\frac{y^2v^2}{m^2+y^2v^2}$$

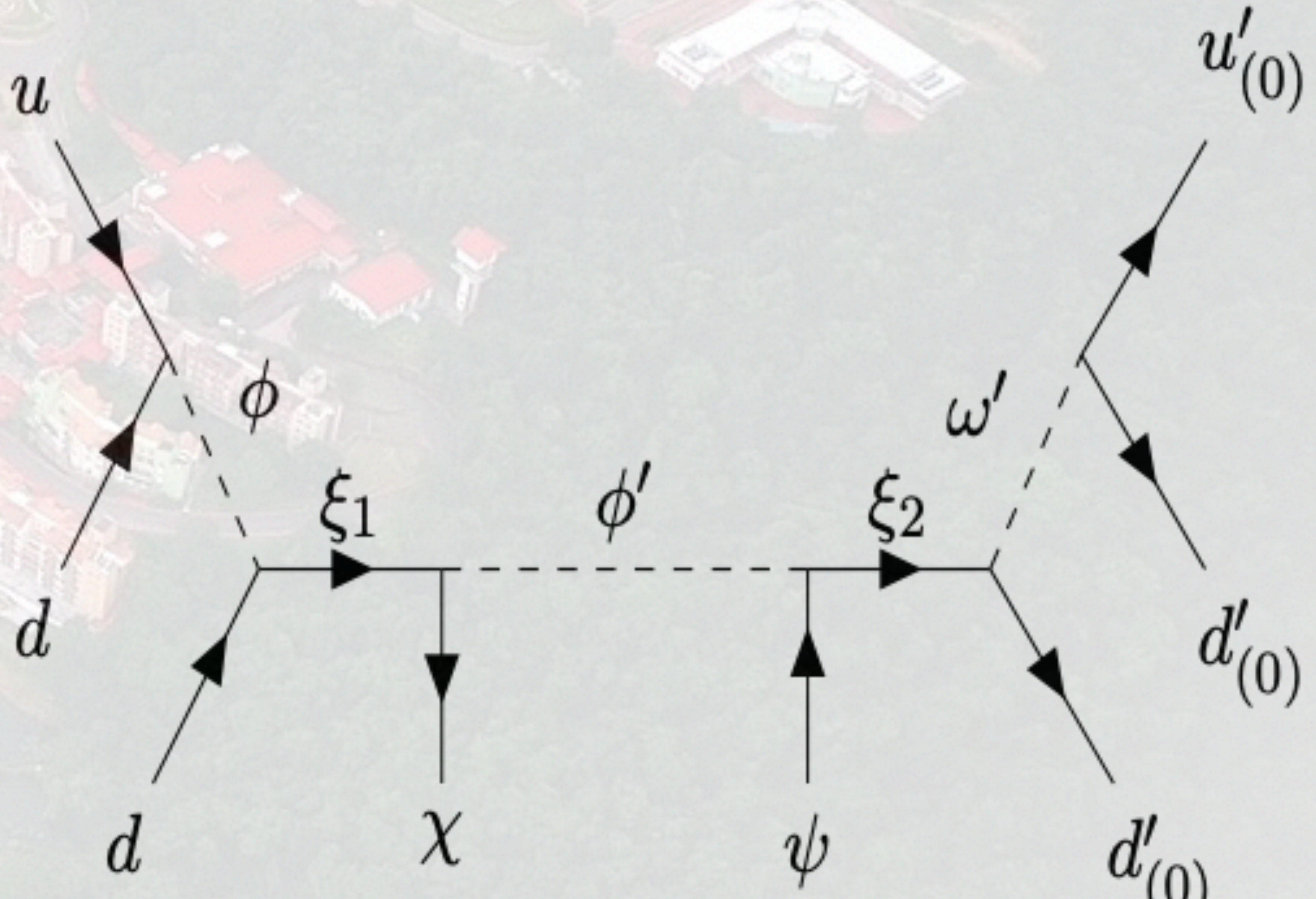
With Yukawa couplings of $\mathcal{O}(1)$, $\frac{m}{M} \sim 0.1$, and $m_M \sim \mathcal{O}(1\ GeV)$, we get $\epsilon \sim 10^{-34} GeV$ for $\sim \mathcal{O}(10)$ gears. This result translates to neutron-antineutron oscillation time period of $10^8 s$, which is within the reach of the current and future experiments [15].

MTA *Phys.Rev.D* 107 (2023) 5, 055021

Neutron-antineutron oscillation: generation at low-scale

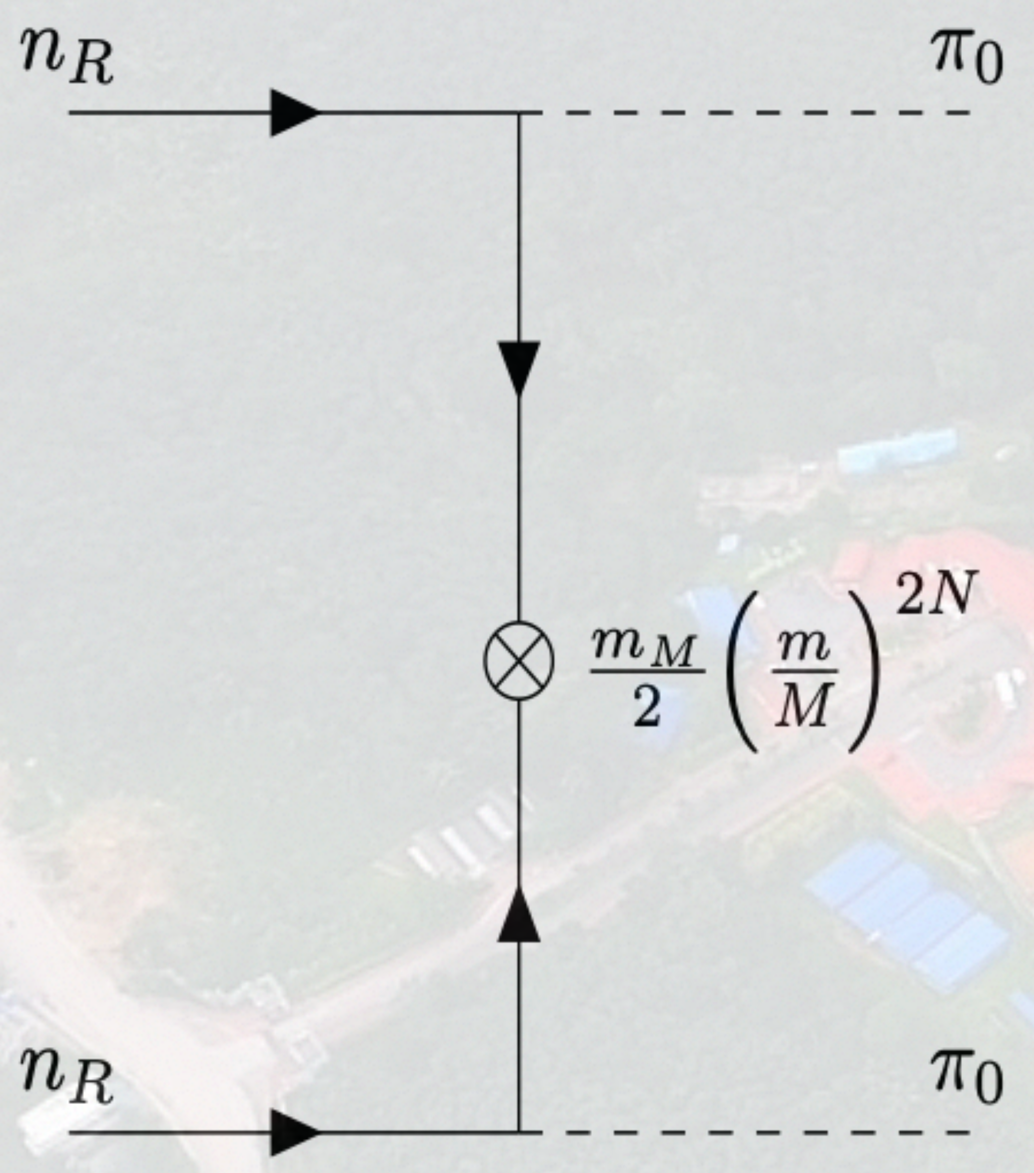
Field	SM QCD $SU(3)_c$	$G_p \equiv G_s$ $SU(3)_p$	mirror QCD $SU(3)_{c'}$	$U(1)_Y$	$SU(2)_w$	B	$\bar{B}$
ϕ	$\overline{3}$	1	1	$\frac{2}{3}$	1	$\frac{2}{3}$	0
ϕ'	1	3	1	0	1	0	0
ω'	1	1	$\overline{3}$	0	1	0	$\frac{2}{3}$
ξ_1	1	1	1	0	1	1	0
ξ_2	1	1	1	0	1	0	1
u_R and d_R	3	1	1	$\frac{4}{3}$ and $-\frac{2}{3}$	1	$\frac{1}{3}$	0
$u'_{(0)}$ and $d'_{(0)}$	1	1	3	0	1	0	$\frac{1}{3}$
χ and ψ	1	3	1	0	1	1 and 0	0 and 1

$$\mathcal{L} = \frac{\lambda_1\lambda_2\lambda_3\lambda_4\lambda_5\lambda_6}{m_\phi^2 m_{\phi'}^2 m_\xi^2 m_{\omega'}^2}\, \bar{\chi}\psi\, \overline{(u'd'd')}_{(0)L}(udd)_R$$
$$= y\, \bar{n}'_{(0)L}\Sigma_0 n_R|_{\text{upon confinement}} \;,$$



$v = m \sim 2$ GeV, $\frac{m}{M} \sim 0.1$ and $m_M \sim \mathcal{O}(10$ GeV), the neutron-antineutron oscillation time period predicted by the model matches with the experimental limit for $N = 10$ sites in the linear moose chain.

Neutron-antineutron oscillation: generation at low-scale



Since the inverse seesaw mechanism, occurs naturally with unsuppressed Yukawa coupling, it is ruled out directly by the luminosity study of the Neutron Star [37, 38]. The elastic SM neutron converting to mirror neutron in presence of a Nucleon ($\mathcal{N}\ n \to \mathcal{N}\ (n \to n^0)$), leaves a hole behind in the Fermi sea. This is refilled quickly by the neutrons with higher energy, and thus releasing the excess energy that can be measured in the luminosity [39]. This constraint, on the other hand, relaxes for mirror neutron states with mass $\gtrsim 2$ GeV, since enough energy is not available in the Neutron Star for the conversion.

Nevertheless, double neutron annihilation ($nn \to \pi_0\pi_0$), shown in Fig.7, can occur. The exotic pions that are charged under baryon number, escapes the NS while leaving behind two holes, which again leads to the release of excess energy. This baryon number violating process is mediated by the mirror neutrons in the inverse seesaw potential, and the amplitude for the processes is suppressed by $(yv)^2 m_M (\frac{M}{m})^{2N}$. Though the process needs to be studied in detail, the Neutron Star can decay unless these exotic pions are also massive ($\gtrsim 2$ GeV). Moreover, in [40] it was noted that mirror neutron states with mass $\lesssim 2$ GeV will soften the equation of state of Neutron Stars by reducing the Fermi pressure. Thus significantly affecting the stability of observed massive Neutron Stars.

Since in the previously mentioned process the final legs are SM singlets, it will also contribute to the dineutron invisible decay amounting to instability of the nucleus. Such processes are studied by the analyzing the energy deposition at the detectors arising from the deexcitation of the excited nuclei after nn decays. In particular, at the $SNO+$ detector, this process leads to gamma rays in $5-10$ MeV range [41]. The current partial lifetime limit on $nn \to invisible$ is $> 1.5 \times 10^{28}$ years. Though this is lesser than the neutron-anti neutron oscillation time period ($T_{n-\bar{n}} > 1.89 \times 10^{32}$) years in nucleus, it will strongly constraint the linear moose model. On the other hand, the model is safe from both Neutron Star and $SNO+$ measurements if these exotic states are heavier than 2 GeV. This is also motivated because states much heavier than SM neutron do not take part in Big Bang nucleosynthesis.

Mode	Sensitivity (90% CL) [years]	Current limit [years]
$p \to e^+\pi^0$	1.2×10^{35}	1.4×10^{34}
$p \to \overline{\nu}K^+$	2.8×10^{34}	0.7×10^{34}
$p \to \mu^+\pi^0$	9.0×10^{34}	1.1×10^{34}
$p \to e^+\eta^0$	5.0×10^{34}	0.42×10^{34}
$p \to \mu^+\eta^0$	3.0×10^{34}	0.13×10^{34}
$p \to e^+\rho^0$	1.0×10^{34}	0.07×10^{34}
$p \to \mu^+\rho^0$	0.37×10^{34}	0.02×10^{34}
$p \to e^+\omega^0$	0.84×10^{34}	0.03×10^{34}
$p \to \mu^+\omega^0$	0.88×10^{34}	0.08×10^{34}
$n \to e^+\pi^-$	3.8×10^{34}	0.20×10^{34}
$n \to \mu^+\pi^-$	2.9×10^{34}	0.10×10^{34}

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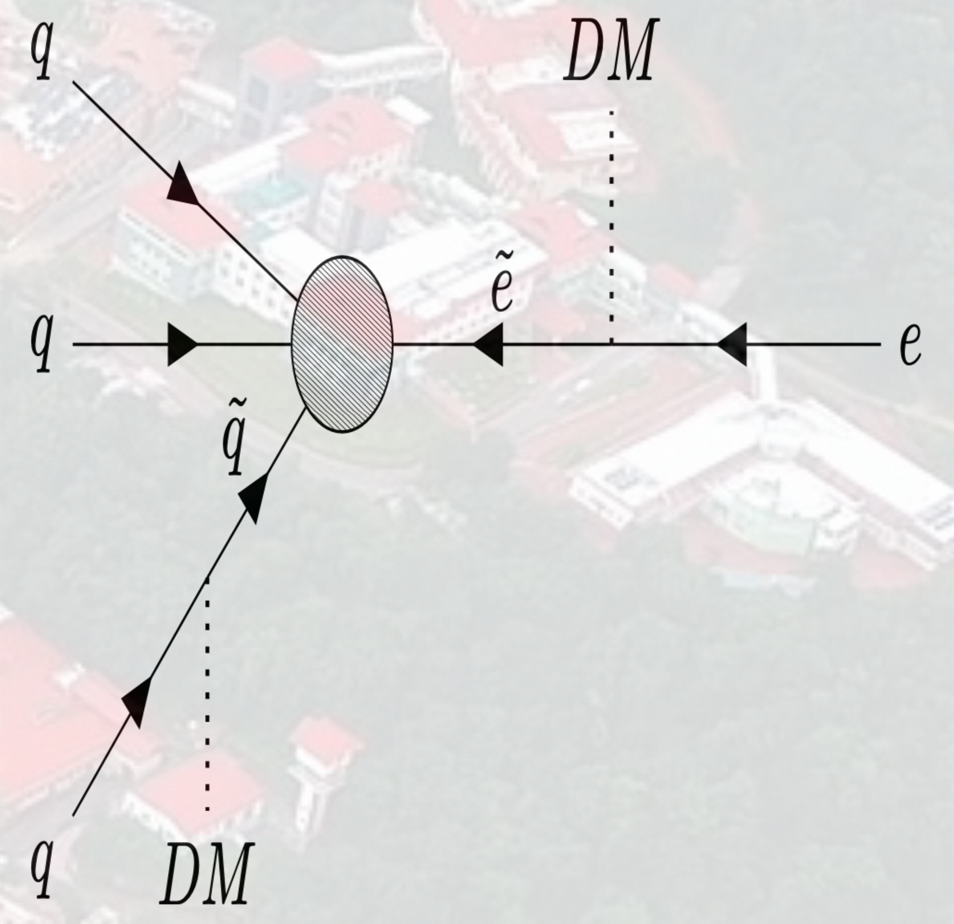
- With the next generation of experiments with higher sensitivity probing even further, the New Physics models would require further complicated structures.

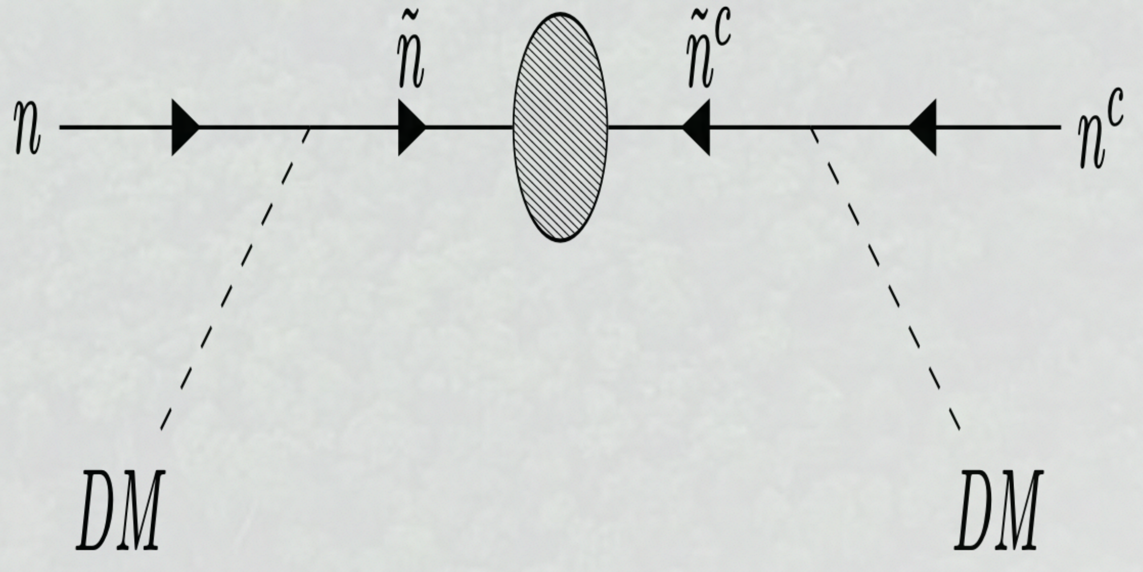
- There exists two phenomena that lack clear evidence in terrestrial experiments

  A. Baryon number violation

  B. Dark Matter

- Its curious to wonder whether both are connected. Does Dark Matter act as a catalyst for BNV ?





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Dark matter induced nucleon decay: model and signatures

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Abstract: If dark matter (DM) carries anti-baryon number, a DM particle may annihilate with a nucleon by flipping to anti-DM. Inspired by Hylogenesis models, we introduce a single component DM model where DM is asymmetric and carries B and L as -1/2. It can annihilate with a nucleon to an anti-lepton and an anti-DM at leading order or with an additional meson at sub-leading order. Such signals may be observed in proton decay experiments. If DM is captured in the Sun, the DM induced nucleon decay can generate a large flux of anti-neutrinos, which could be observed in neutrino experiments. Furthermore, the anti-DM particle in the final state obtains a relatively large momentum (few hundred MeV), and escapes the Sun. These fast-moving anti-DM particles could also induce interesting signals in various underground experiments.

PHYSICAL REVIEW D **84,** 096008 (2011)

Baryon destruction by asymmetric dark matter

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We investigate new and unusual signals that arise in theories where dark matter is asymmetric and carries a net antibaryon number, as may occur when the dark matter abundance is linked to the baryon abundance. Antibaryonic dark matter can cause induced nucleon decay by annihilating visible baryons through inelastic scattering. These processes lead to an effective nucleon lifetime of 10^{29}–10^{32} yrs in terrestrial nucleon decay experiments, if baryon number transfer between visible and dark sectors arises through new physics at the weak scale. The possibility of induced nucleon decay motivates a novel approach for direct detection of cosmic dark matter in nucleon decay experiments. Monojet searches (and related signatures) at hadron colliders also provide a complementary probe of weak-scale dark-matter-induced baryon number violation. Finally, we discuss the effects of baryon-destroying dark matter on stellar systems and show that it can be consistent with existing observations.

PHYSICAL REVIEW D **84**, 096008 (2011) Hooman Davoudiasl,[1,*] David E. Morrissey,[2,†] Kris Sigurdson,[3,‡] and Sean Tulin[2,§]

(Assisted/induced) baryon number violation

Asymmetric Dark Matter

- Antibaryonic dark matter
- Baryon number transfer between visible and dark sectors through New Physics at weak scale
- Here, the DM is a fermion/scalar pair (ψ, ϕ) with total baryon number $B_\psi + B_\phi = -1$
- In this hylogenesis scenario, the universe is net B-symmetric. The baryon asymmetry carried in the invisible sector is equal and opposite to that in visible baryons.
- These antibaryonic DM annihilate baryonic matter and mimic nucleon decay

$$m_{\Psi,\Phi} \approx 2-3\ \mathrm{GeV} \qquad \Phi N \longrightarrow \bar{\Psi} M\ , \qquad \Psi N \longrightarrow \Phi^\dagger M$$

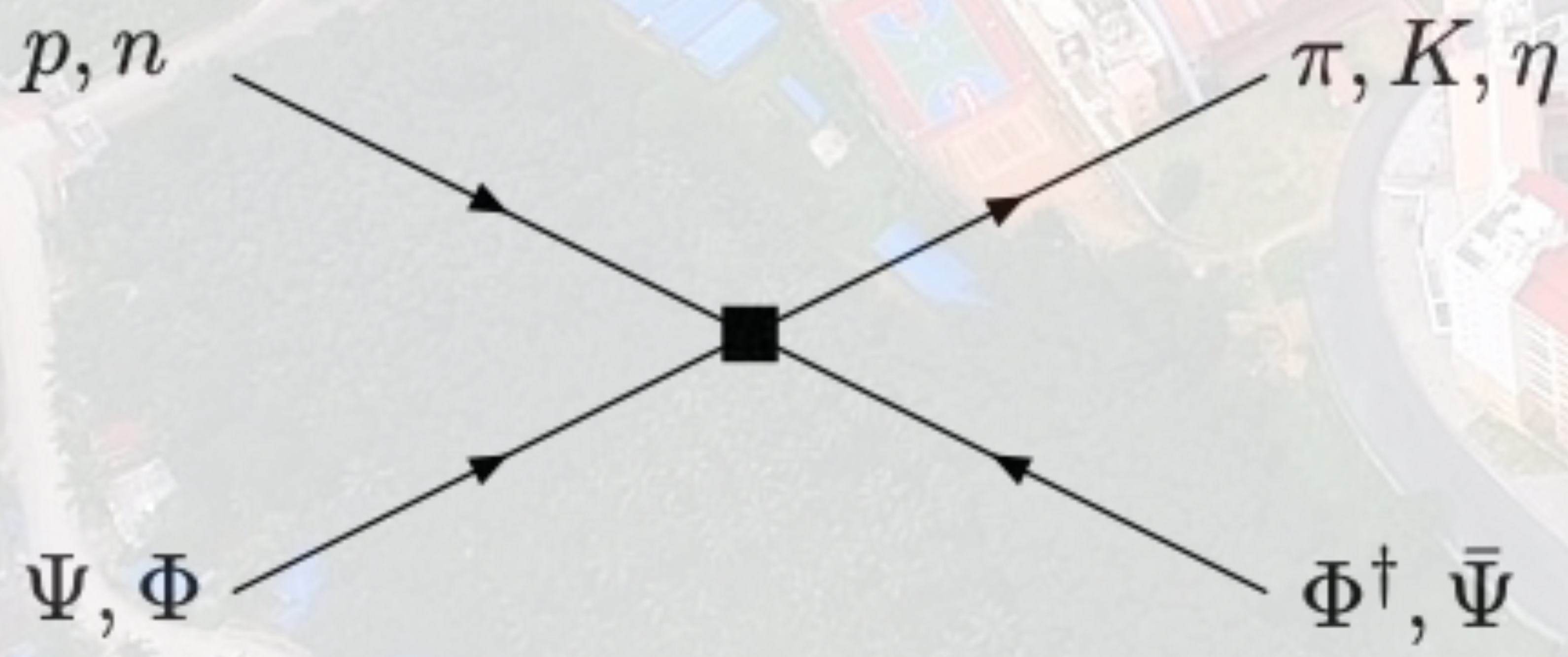
PHYSICAL REVIEW D **84**, 096008 (2011) Hooman Davoudiasl,[1,*] David E. Morrissey,[2,†] Kris Sigurdson,[3,‡] and Sean Tulin[2,§]

(Assisted/induced) baryon number violation

Asymmetric Dark Matter

- Effective induced BNV lifetime can be defined as $\tau^{-1} = n_{DM}(\sigma v)_{IND}$ where $n_{DM} = \rho_{DM}/(m_\psi + m_\phi)$

$$\mathscr{L}_{\text{eff}} \sim \frac{1}{\Lambda^3} u_R^i d_R^j d_R^k \Psi_R \Phi$$



$$\tau_N^{-1} \approx (10^{32}\ \text{yrs})^{-1} \times \left(\frac{\rho_{DM}}{0.3\,\text{GeV/cm}^3}\right)\left(\frac{(\sigma v)_{IND}}{10^{-39}\,\text{cm}^3/\text{s}}\right)$$

$$(\sigma v)_{IND} \approx 10^{-39}\ \text{cm}^3/\text{s} \times \left(\frac{\Lambda_{IND}}{1\ \text{TeV}}\right)^{-6}$$

(Assisted) baryon number violation
from 4k+2 dimensions

- Clifford Algebra in 4k+2 dimensions

$$\{\Gamma_M, \Gamma_N\} = 2\eta_{MN}$$

$$\Gamma^{4k+3} = \alpha\Gamma^0\Gamma^1\Gamma^2....\Gamma^{4k+1}$$

$$P_\pm = \tfrac{1}{2}(1 \pm \Gamma^{4k+3}) \qquad \psi_\pm = P_\pm\psi$$

$$\psi^c = C\psi \equiv (C\Gamma^0)\psi^*$$

$$\begin{aligned}\Gamma^M &= -(C\Gamma^0)\Gamma^{M*}(C\Gamma^0)^{-1}\\ &= -C(\Gamma^M)^T C^{-1}\,.\end{aligned}$$

$$[C\Gamma^0, \Gamma^{4k+3}] = 0 \text{ in } 4k{+}2\text{−dimensions.}$$

- This is unlike in 4k dimensions.

- Thus the fermion representation and its charge conjugate must satisfy the same Weyl condition

MTA, Akshay Anilkumar *Phys.Rev.D* 109 (2024) 9, 095039

Some properties of six dimensions

- Witten anomaly constrains the number of $SU(2)_W$ doublets to appear in multiples of 3
- Although non-vanishing reducible anomalies like $[SU(2)_W]^4$,$[SU(3)_c]^2[SU(2)_W]^2$, $[SU(2)_W]^2[U(1)_Y]^2, \ldots$ are manageable via Green-Schwarz mechanism, irreducible anomalies like $[SU(3)_c]^3[U(1)_Y]$ require the chiral assignment $Q_+, \mathscr{U}_-, \mathscr{D}_-$ for quarks and $L_\pm, \mathscr{E}_\mp, \mathscr{N}_\mp$ for leptons
- A combination of 5th and 6th component of the Hypercharge gauge boson becomes the Dark Matter candidate

Some properties of six dimensions

- On compactifying on T^2 the Lorentz generators break to $\Sigma^{MN} \rightarrow \Sigma^{\mu\nu}$ and Σ^{45} and the fermions become $\Psi_{\pm} = \psi_{\pm l} f_l + \psi_{\pm r} f_r$
- This residual Σ^{45} generates a rotational invariance $U(1)_{45}$
- Interestingly, on orbifolding, the square T^2/Z_2 would break this $U(1)_{45}$ down to a Z_4 symmetry since its invariant under $\pi/2$ rotations.
- Under this generator, the fermions $\psi_{\pm l}$ are charged $\pm 1/2$ and $\psi_{\pm r}$ are charged $\mp 1/2$
- All the operators in this geometry should keep this symmetry preserved.
- Thus, on a square T^2/Z_2 the baryon and lepton number violating operators should satisfy the selection rule $\frac{3}{2}\Delta B \pm \frac{1}{2}\Delta L = 0 \ mod \ 4$
- Other orbifolds like T^2/Z_3, makes sure that proton decay along with other $\Delta B = 2, \ \Delta L = 2$ processes are also suppressed. Except for neutron-antineutron oscillation

(Assisted) baryon number violation

6 dimensions

- Thus geometry plays a crucial role. But for generality, lets assume a simple T^2/Z_2, in which all the operators are allowed.
- The gamma matrices are

$$\Gamma^\mu = \gamma^\mu \otimes \sigma^1 \ , \Gamma^4 = \gamma^5 \otimes \sigma^1 \ , \Gamma^5 = \mathbb{1} \otimes \sigma^2 \qquad \Gamma^7 = \Gamma^0\Gamma^1\Gamma^2\Gamma^3\Gamma^4\Gamma^5 = \mathbb{1} \otimes \sigma^3$$

$$\begin{aligned} C &= i\Gamma^4\Gamma^2\Gamma^0 \\ &= \gamma^5\gamma^2\gamma^0 \otimes \sigma^1 \end{aligned} \qquad [C\Gamma^0, \Gamma^7] = 0$$

(Assisted) baryon number violation

6 dimensions

- Model independent baryon number and lepton number violating operators in six-dimensions are,

6D Lorentz symmetry	$\Delta B = 1 = \Delta L$	$\Delta B = 2 = \Delta L$
Scalar	$\frac{1}{\Lambda_6^4} C_1^S (\mathcal{Q}_+^T C \mathcal{U}_-)(\mathcal{E}_-^T C \mathcal{Q}_+)$	
Vector	$\frac{1}{\Lambda_6^4} C_1^V (\mathcal{Q}_+^T C \Gamma^M \mathcal{Q}_+)(\mathcal{Q}_+^T C \Gamma_M L_+)$	$\frac{1}{\Lambda_6^{14}} C_2^V (\mathcal{Q}_+^T C \Gamma^M \mathcal{Q}_+)^2 (\mathcal{Q}_+^T C \Gamma^N L_+)^2$
Mixed		$\frac{1}{\Lambda_6^{14}} C_2^L (\mathcal{Q}_+^T C \mathcal{U}_-)^2 (\mathcal{Q}_+^T C \Gamma^M L_+)^2$ $\frac{1}{\Lambda_6^{14}} C_2^Q (\mathcal{Q}_+^T C \mathcal{E}_-)^2 (\mathcal{Q}_+^T C \Gamma^M \mathcal{Q}_+)^2$

(Assisted) baryon number violation

on orbifolding to 4 dimensions

- After orbifolding, the operators with least number of KK-modes are

$$\Psi_\pm(x^\mu, x^4, x^5) = \frac{1}{R}\sum_{n,m}\Big(\psi_{\pm l}^{(n,m)}(x^\mu) f_{\pm l}(x_4, x_5) + \psi_{\pm r}^{(n,m)}(x^\mu) f_{\pm r}(x_4, x_5)\Big) \ ,$$

Operators	$\Delta B = 1 = \Delta L$	$\Delta B = 2 = \Delta L$
Scalar	$\frac{C_1^S}{\Lambda_4^2}(q_{+l}^{(0,0)T}\gamma^2\gamma^0\mathcal{U}_{-l}^{(1,0)})(\mathcal{E}_{-l}^{T(1,0)}\gamma^2\gamma^0 q_{+l}^{(0,0)})$	$\frac{C_2^S}{\Lambda_4^8}(q_{+l}^{(0,0)T}\gamma^2\gamma^0\mathcal{U}_{-l}^{(1,0)})^2(\mathcal{E}_{-l}^{T(1,0)}\gamma^2\gamma^0 q_{+l}^{(0,0)})^2$
Vector	$\frac{C_1^V}{\Lambda_4^2}(u_{-r}^{(0,0)T}\gamma^2\gamma^0\gamma^\mu\mathcal{D}_{-l}^{(1,0)})(u_{-r}^{(0,0)T}\gamma^2\gamma^0\gamma_\mu\mathcal{E}_{-l}^{(1,0)})$	$\frac{C_2^V}{\Lambda_4^8}(u_{-r}^{(0,0)T}\gamma^2\gamma^0\gamma^\mu\mathcal{D}_{-l}^{(1,0)})^2(u_{-r}^{(0,0)T}\gamma^2\gamma^0\gamma_\mu\mathcal{E}_{-l}^{(1,0)})^2$

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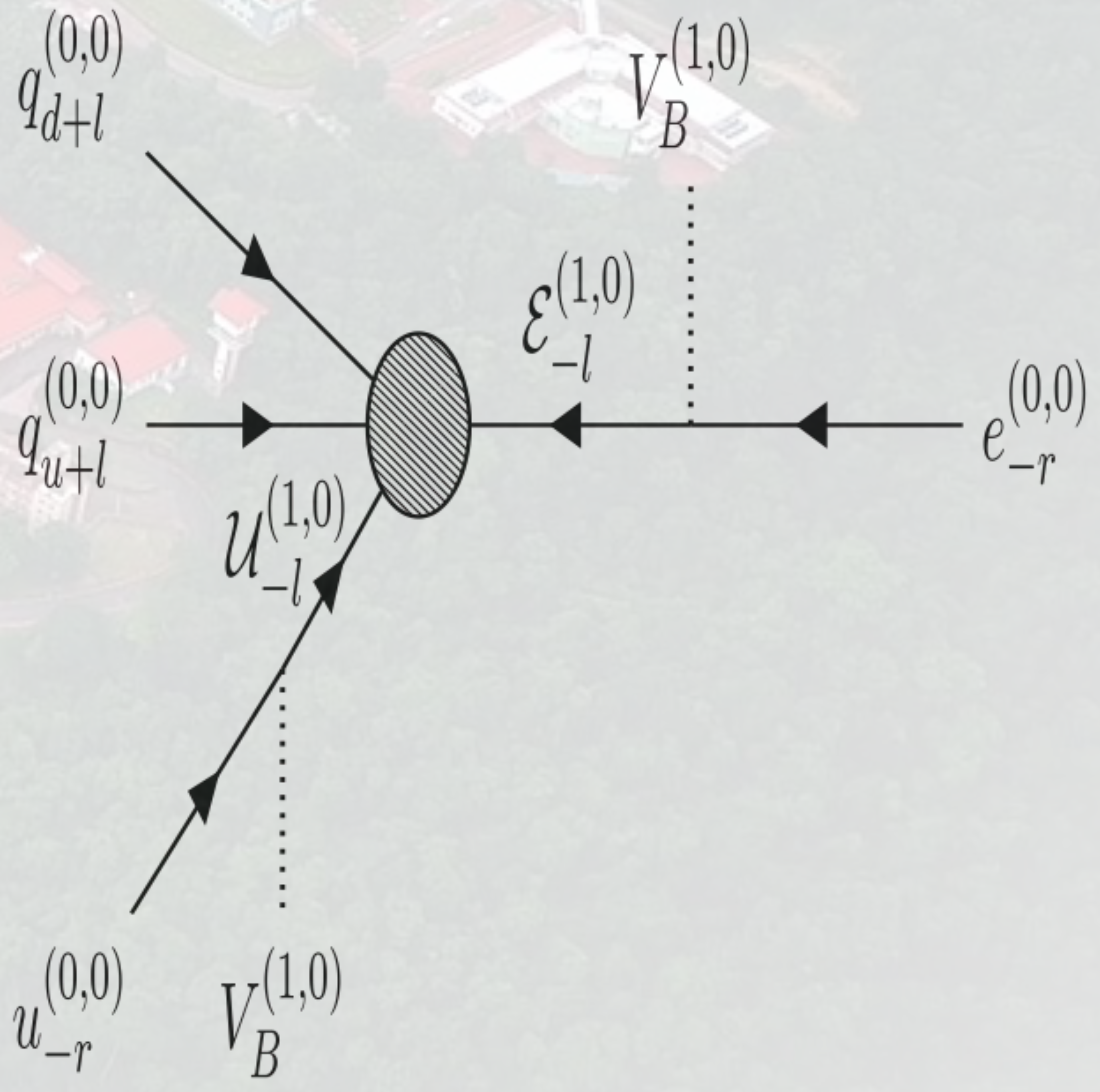
(Assisted) $\Delta B = 1,\ \Delta L = 1$ process

$$\mathcal{O}_1 = \frac{C_1^S}{\Lambda_4^2}\left(q_{+l}^{(0,0)T}\gamma^2\gamma^0\mathcal{U}_{-l}^{(1,0)}\right)\left(\mathcal{E}_{-l}^{T(1,0)}\gamma^2\gamma^0 q_{+l}^{(0,0)}\right)$$
$$+\frac{C_1^V}{\Lambda_4^2}\left(u_{-r}^{(0,0)T}\gamma^2\gamma^0\gamma^\mu\mathcal{D}_{-l}^{(1,0)}\right)\left(u_{-r}^{(0,0)T}\gamma^2\gamma^0\gamma_\mu\mathcal{E}_{-l}^{(1,0)}\right)$$



$$C_{\mathrm{AND}}\mathcal{O}_{\mathrm{AND}} = y_u y_e g_Y^2\frac{C_1^S}{\Lambda_4^2}\frac{1}{M_{KK}^2}\left(q_{+l}^{T(0,0)}\gamma^2\gamma^0 u_{-r}^{(0,0)}\right)$$
$$\times\left(e_{-r}^{T(0,0)}\gamma^2\gamma^0 q_{+l}^{(0,0)}\right)V_B^{(1,0)}V_B^{(1,0)},$$

$$C_{p\to e} = y_u y_e g_Y^2\frac{C_1^S}{16\pi^2\Lambda_4^2}\left(\frac{M_s}{M_{KK}}\right)^4$$

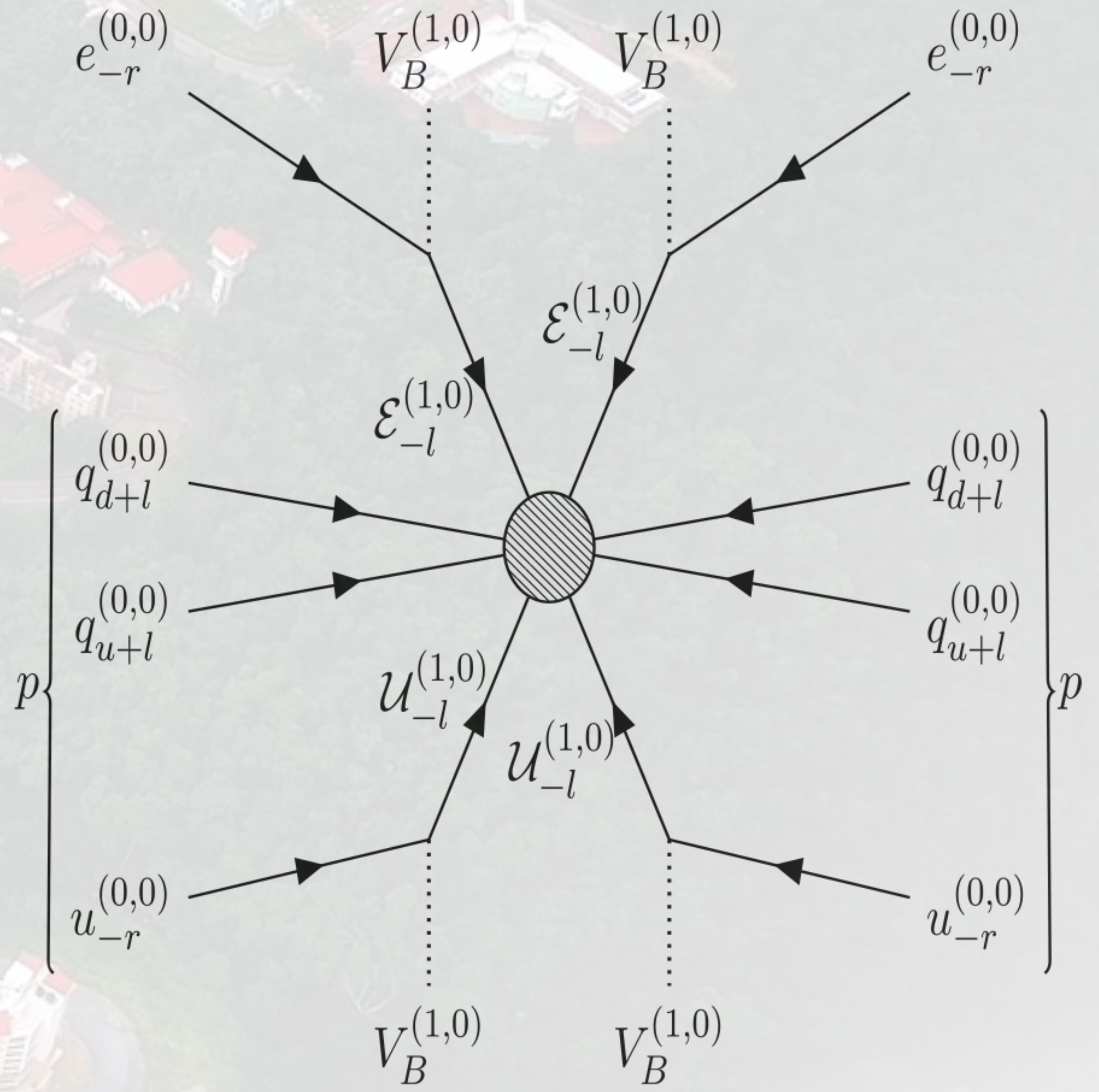
$$\Gamma_{p\to e} = \frac{1}{2\times 10^{34}}\left|\frac{C_{p\to e}}{(3\times 10^{15}\ \mathrm{GeV})^{-2}}\right|^2$$

(Assisted) $\Delta B = 2,\ \Delta L = 2$ process

$$\mathcal{O}_2 = \frac{C_2^S}{\Lambda_4^8}(q_{+l}^{(0,0)T}\gamma^2\gamma^0\mathcal{U}_{-l}^{(1,0)})^2(\mathcal{E}_{-l}^{T(1,0)}\gamma^2\gamma^0 q_{+l}^{(0,0)})^2$$
$$+\frac{C_2^V}{\Lambda_4^8}(u_{-r}^{(0,0)T}\gamma^2\gamma^0\gamma^\mu\mathcal{D}_{-l}^{(1,0)})^2(u_{-r}^{(0,0)T}\gamma^2\gamma^0\gamma_\mu\mathcal{E}_{-l}^{(1,0)})^2$$

$$C_{\mathrm{ANNA}}\mathcal{O}_{\mathrm{ANNA}} = y_u^2 y_e^2 g_Y^4\frac{C_2^S}{\Lambda_4^8 M_{KK}^4}(q_{+l}^{(0,0)T}\gamma^2\gamma^0 u_{-r}^{(0,0)})^2$$
$$\times(e_{-r}^{T(0,0)}\gamma^2\gamma^0 q_{+l}^{(0,0)})^2 V_B^{(1,0)}V_B^{(1,0)}V_B^{(1,0)}V_B^{(1,0)}$$

$$\boldsymbol{DM + p \to DM + \bar{p} + e^+ + e^+}$$



$$\mathcal{O}_{VVppee} = \frac{1}{(\Lambda_{VVppee})^4}(\bar{p}^c p)(\bar{e}^c e)V_B^{(1,0)}V_B^{(1,0)}$$

$$\tau_{\mathrm{ANNA}} = 5\times 10^{33}\text{years}\left(\frac{\Lambda_{VVppee}}{300\ \mathrm{GeV}}\right)^8$$

Summary:

- There's room at low energies for interesting New Physics models
- Generation of BNV can be at very low energies
- Limits from $nn \to invisible$ processes
- Dark Matter being a catalyst to baryon number violation can be the reason for the rarity of events
- Other places in the galaxy with higher Dark Matter density would be efficient regions to generate the required baryon number violation
- Interesting signatures would be antineutrino and positron fluxes from DM spikes

Thank you

Dinucleon and Nucleon Decay to Two-Body Final States with no Hadrons in Super-Kamiokande

Super-Kamiokande Collaboration arXiv:1811.12430

The Super-Kamiokande (SK) water Cherenkov detector, with a fiducial volume of 22.5 kilotons, contains 1.2×10^{34} nucleons. SK lies one kilometer under Mt. Ikenoyama in Japan's Kamioka Observatory. The detector is cylindrical with a diameter of 39.3 meters and a height of 41.4 meters, optically separated into an inner and an outer region. Eight-inch photomultiplier tubes (PMTs) line the outer detector facing outwards and serve primarily as a veto for cosmic ray muons, and 20-inch PMTs face inwards to measure Cherenkov light in the inner detector [12].

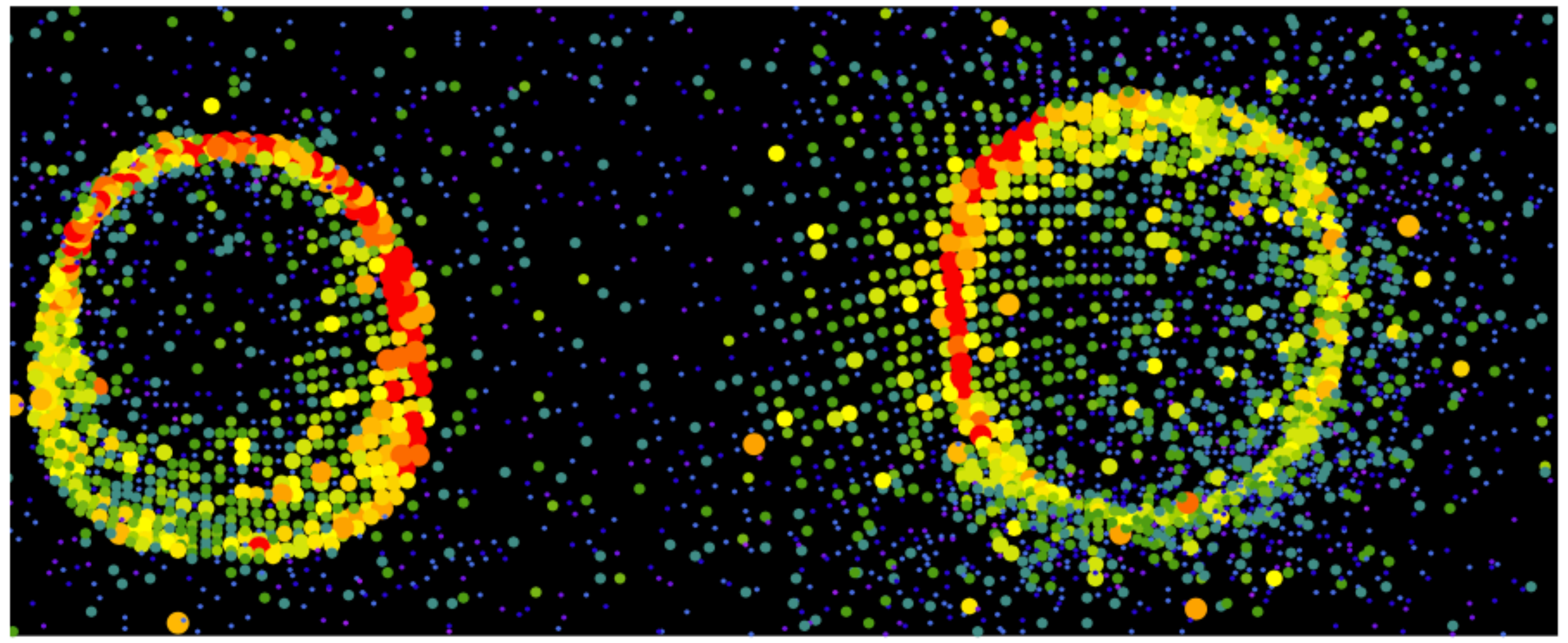
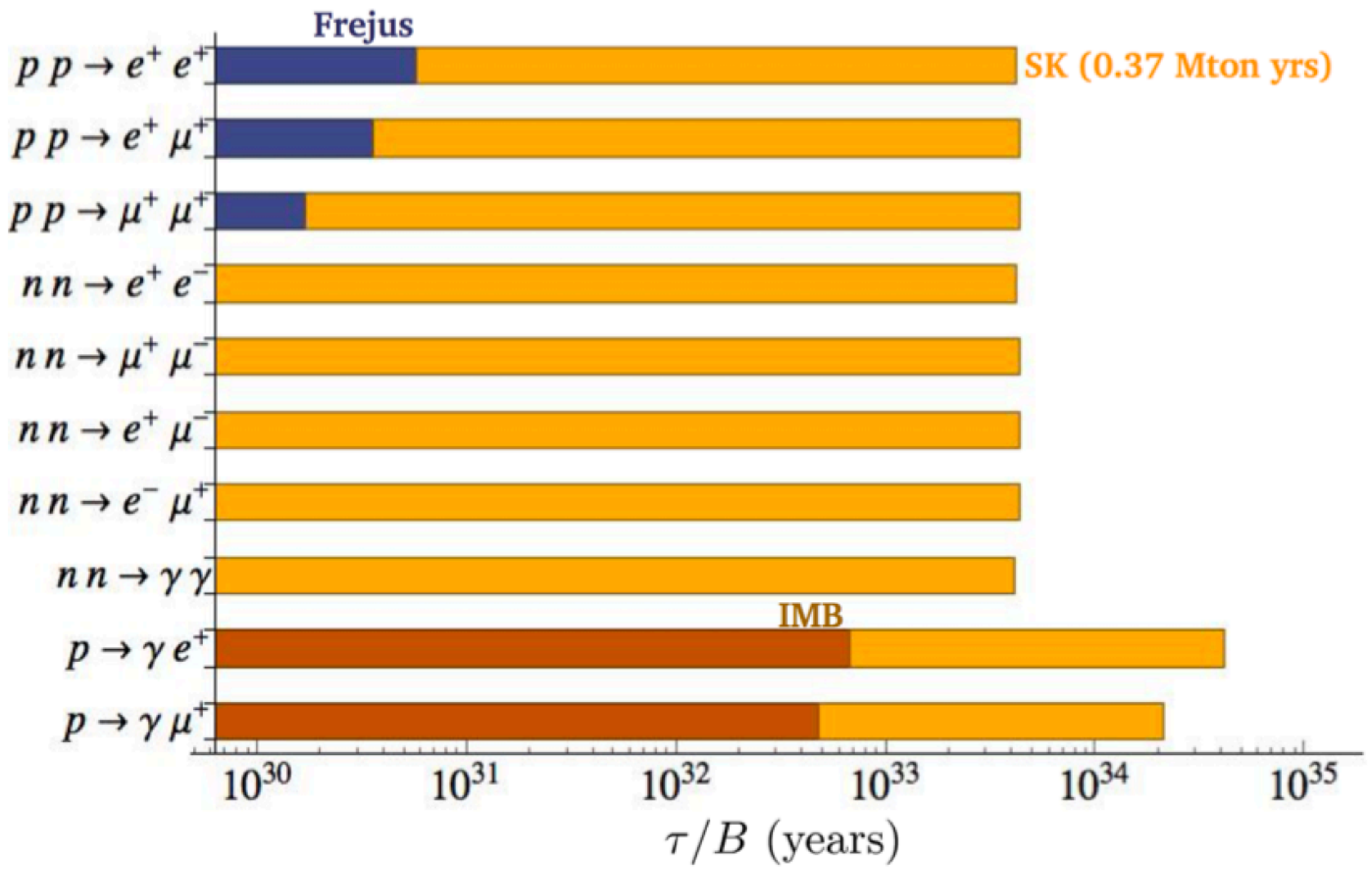


FIG. 1. (color online) An SK event display of a typical $pp \to e^+\mu^+$ event shown in θ-ϕ view. The non-showering ring (from the μ^+) is on the left and the showering ring (from the e^+) is on the right. The energy of each ring is approximately 900 MeV.



The following selection criteria are applied to signal MC, atmospheric ν MC, and data:

(A1) Events must be fully contained in the inner detector with the event vertex within the fiducial volume (two meters inward from the detector walls),

(A2) There must be two Cherenkov rings,

(A3) Both rings must be showering for the $pp \to e^+e^+$, $nn \to e^+e^-$, $nn \to \gamma\gamma$ and $p \to e^+\gamma$ modes; one ring must be showering and one ring must be non-showering for the $pp \to e^+\mu^+$, $nn \to e^+\mu^-$, $nn \to e^-\mu^+$ and $p \to \mu^+\gamma$ modes; both rings must be non-showering for the $pp \to \mu^+\mu^+$, $nn \to \mu^+\mu^-$ modes (see note in [19]),

(A4) There must be zero Michel electrons for the $pp \to e^+e^+$, $nn \to e^+e^-$, $nn \to \gamma\gamma$ and $p \to e^+\gamma$ modes; there must be less than or equal to one Michel electron for the $pp \to e^+\mu^+$, $nn \to e^+\mu^-$, $nn \to e^-\mu^+$ and $p \to \mu^+\gamma$ modes; there is no Michel electron cut for the $pp \to \mu^+\mu^+$, $nn \to \mu^+\mu^-$ modes (see note in [20]),

(A5) The reconstructed total mass, M_{tot}, should be $1600 \leq M_{tot} \leq 2050$ MeV/c^2 for the dinucleon decay modes; the reconstructed total mass should be $800 \leq M_{tot} \leq 1050$ MeV/c^2 for the nucleon decay modes,

(A6) The reconstructed total momentum, P_{tot}, should be $0 \leq P_{tot} \leq 550$ MeV/c for the dinucleon decay modes; for the nucleon decay modes, it should be $100 \leq P_{tot} \leq 250$ MeV/c for the event to be in the "High $P_{\rm tot}$" signal box and $0 \leq P_{tot} \leq 100$ MeV/c for the event to be in the "Low $P_{\rm tot}$" signal box,

(A7) [SK-IV nucleon decay searches only] There must be zero tagged neutrons.

Decay mode	Lifetime limit per oxygen nucleus ($\times 10^{33}$ years)	Lifetime limit per nucleon ($\times 10^{34}$ years)
$pp \to e^+e^+$	4.2	—
$nn \to e^+e^-$	4.2	—
$nn \to \gamma\gamma$	4.1	—
$pp \to e^+\mu^+$	4.4	—
$nn \to e^+\mu^-$	4.4	—
$nn \to e^-\mu^+$	4.4	—
$pp \to \mu^+\mu^+$	4.4	—
$nn \to \mu^+\mu^-$	4.4	—
$p \to e^+\gamma$	—	4.1
$p \to \mu^+\gamma$	—	2.1

arXiv:1811.12430 (Dinucleon and Nucleon Decay to Two-Body Final States with no Hadrons in Super-Kamiokande)

Mode	Sensitivity (90% CL) [years]	Current limit [years]
$p \to e^+\pi^0$	1.2×10^{35}	1.4×10^{34}
$p \to \overline{\nu}K^+$	2.8×10^{34}	0.7×10^{34}
$p \to \mu^+\pi^0$	9.0×10^{34}	1.1×10^{34}
$p \to e^+\eta^0$	5.0×10^{34}	0.42×10^{34}
$p \to \mu^+\eta^0$	3.0×10^{34}	0.13×10^{34}
$p \to e^+\rho^0$	1.0×10^{34}	0.07×10^{34}
$p \to \mu^+\rho^0$	0.37×10^{34}	0.02×10^{34}
$p \to e^+\omega^0$	0.84×10^{34}	0.03×10^{34}
$p \to \mu^+\omega^0$	0.88×10^{34}	0.08×10^{34}
$n \to e^+\pi^-$	3.8×10^{34}	0.20×10^{34}
$n \to \mu^+\pi^-$	2.9×10^{34}	0.10×10^{34}

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Mode	Sensitivity (90% CL) [years]	Current limit [years]
$p \to e^+\nu\nu$	$10.2\ \times10^{32}$	$1.7\ \times10^{32}$
$p \to \mu^+\nu\nu$	$10.7\ \times10^{32}$	$2.2\ \times10^{32}$
$p \to e{+}X$	$31.1\ \times10^{32}$	$7.9\ \times10^{32}$
$p \to \mu^+X$	$33.8\ \times10^{32}$	$4.1\ \times10^{32}$
$n \to \nu\gamma$	$23.4\ \times10^{32}$	$5.5\ \times10^{32}$
$np \to e^+\nu$	$6.2\ \times10^{32}$	$2.6\ \times10^{32}$
$np \to \mu^+\nu$	$4.2\ \times10^{32}$	$2.0\ \times10^{32}$
$np \to \tau^+\nu$	$6.0\ \times10^{32}$	$3.0\ \times10^{32}$

TABLE IV. Parameters of past (KAM [114, 115]), running (SK [116, 117]), and future (HK-3TankLD and HK-1TankHD) water Cherenkov detectors. The KAM and SK have undergone several configuration changes and parameters for KAM-II and SK-IV are referred in the table. The single-photon detection efficiencies are products of the quantum efficiency at peak ($\sim 400\,\mathrm{nm}$), photo-electron collection efficiency, and threshold efficiency. Most right column (HK-1TankHD) shows another design under study which consist of one tank instrumented with high density PMTs.

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	KAM	SK	HK-3TankLD	HK-1TankHD
Depth	1,000 m	1,000 m	650 m	650 m
Dimensions of water tank				
diameter	15.6 m ϕ	39 m ϕ	74 m ϕ	74 m ϕ
height	16 m	42 m	60 m	60 m
Total volume	4.5 kton	50 kton	774 kton	258 kton
Fiducial volume	0.68 kton	22.5 kton	560 kton	187 kton
Outer detector thickness	~ 1.5 m	~ 2 m	$1 \sim 2$ m	$1 \sim 2$ m
Number of PMTs				
inner detector (ID)	948 (50 cm ϕ)	11,129 (50 cm ϕ)	40,000 (50 cm ϕ)	40,000 (50 cm ϕ)
outer detector (OD)	123 (50 cm ϕ)	1,885 (20 cm ϕ)	20,000 (20 cm ϕ)	6,700 (20 cm ϕ)
Photo-sensitive coverage	20%	40%	13%	40%
Single-photon detection efficiency of ID PMT	unknown	12%	24%	24%
Single-photon timing resolution of ID PMT	~ 4 nsec	2-3 nsec	1 nsec	1 nsec

Scalar LeptoQuark and Scalar Diquark

The Lagrangian for the singlet LeptoQuark S_2 $(\bar{3}, 2, \frac{5}{3})$ and singlet Diquark $DQ_2(\bar{3}, 2, -\frac{5}{3})$ interactions with the fermions given by,

$$\mathcal{L}_S = y^{(+-)} \bar{\mathcal{Q}^C}_+ S_2 \mathcal{E}_- + z^{(-+)} \bar{\mathcal{U}^C}_- (DQ_2) \mathcal{Q}_+ + h.c., \tag{38}$$

where $y^{(+-)}$ and $z^{(-+)}$ are complex 3×3 Yukawa coupling matrices.

Vector LeptoQuark and Scalar Diquark

The interaction of the vector LeptoQuark and scalar Diquark with the fermions given as,

$$\mathcal{L}_{SV} = z^{(-+)} \bar{\mathcal{U}^C}_- (DQ_2) \mathcal{Q}_+ + w^{(++)} \bar{\mathcal{Q}^C}_+ \Gamma^M V_{3M} L_+ + h.c., \tag{39}$$

where the V_{3M} is the vector triplet LeptoQuark and the DQ_2 is the scalar Diquark doublet.

Scalar LeptoQuark and Vector Diquark

The coupling of the scalar LeptoQuark and vector Diquark with the fermions is:

$$\mathcal{L}_{VS} = y^{(+-)} \bar{\mathcal{Q}^C}_+ S_2 \mathcal{E}_- + x^{(++)} \bar{\mathcal{Q}^C}^a_+ \Gamma^M \epsilon^{ab} DQ_{3M} \mathcal{Q}^b_+ + h.c., \tag{40}$$

Vector LeptoQuark and Vector Diquark

The interaction becomes,

$$\mathcal{L}_{VV} = x^{(++)} \bar{\mathcal{Q}^C}^a_+ \Gamma^M \epsilon^{ab} DQ_{3M} \mathcal{Q}^b_+ + w^{(++)} \bar{\mathcal{Q}^C}_+ \Gamma^M V_{3M} L_+ + h.c., \tag{41}$$

where the V_{3M},DQ_{3M} are the triplet vector Leptoquark and Diquark.