Search for B and L Number Violations, Berkeley, 22 September 2007

Rare Decays in Theories with LGS

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Based on the paper:
C. Bambi, A.D. Dolgov and K. Freese,
NPB 763, 91 (2007) [arXiv:hep-ph/0606321]

Outline

- Gravitational Decays
- Problems in Theories with LGS
- Possible Solution: Classical BH Conjecture
- Phenomenology

Gravitational Decays

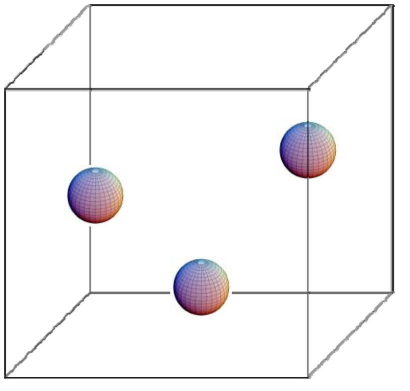
- Classical BHs violate global charges
- Virtual BHs can mediate proton decay (Zeldovich, 1976)

$$q + q \rightarrow \bar{q} + l$$

$$\dot{n}/n = n\sigma_{BH} = \sigma_{BH}|\psi(0)|^2$$

$$n \sim m_p^3 \qquad \sigma_{BH} \sim m_p^2/M_{Pl}^4$$

$$\Gamma \sim \frac{m_p^5}{M_{Pl}^4}$$



Theories with LGS

- ADD model

- Strong gravity at short (sub-mm?) distances

$$M_{Pl}^2 \sim M_*^{2+n} R^n$$

- QG effects in particle physics

p-decay in Theories with LGS

- Too fast proton decay!!!

- Solution:

  i) No LGS: $M_* \gtrsim 10^{16}\ \mathrm{GeV}$

  (Adams et al., 2001)

  ii) New suppression mechanism

Classical BH Conjecture

Classical BHs cannot have arbitrary large electric charge and angular momentum

$$\left(\frac{M_{BH}}{M_{Pl}}\right)^2 < \frac{Q^2}{2} + \sqrt{\frac{Q^4}{4} + J^2}$$

If $M_{BH} << M_{Pl}$, BH must be neutral and have 0 spin

Conjecture: virtual BHs satisfy this condition

Assumptions

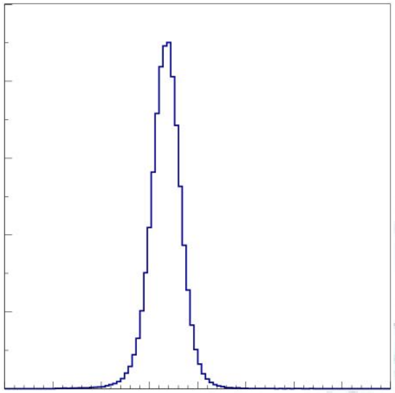
- BH coupling to 2 or 4 particles is found from dimension arguments (probability of 2 or 4 particles to be inside BH horizon):

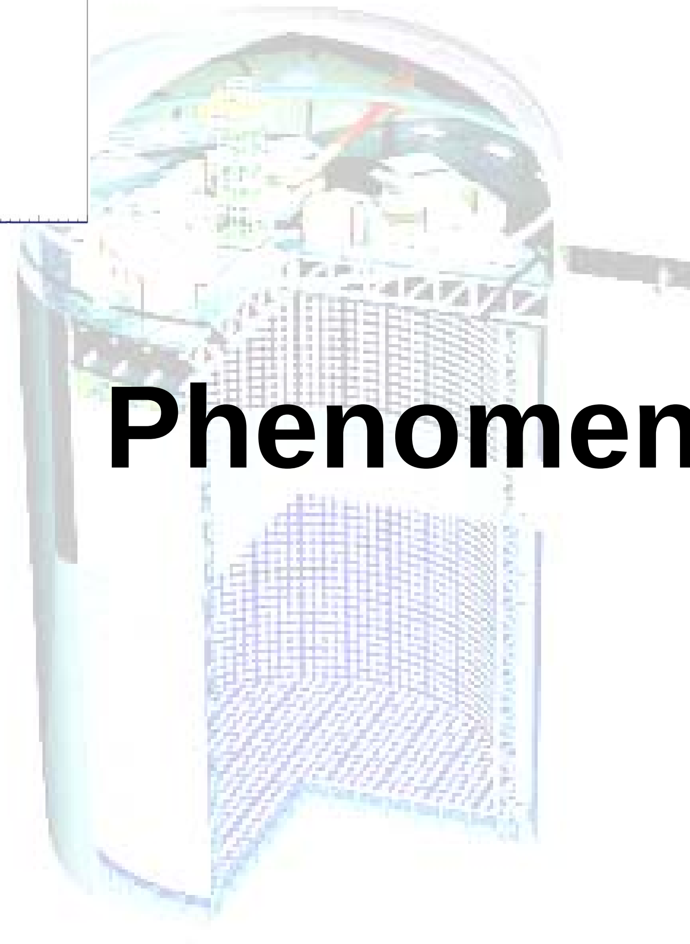
$$g_2 = R_S M_{BH} \qquad g_4 = R_S^4 M_{BH}$$

- BHs propagate only forward in time, no anti-BHs (Breaking of LI). No $\Delta E \Delta t \geqslant 1$. For example, BHs cannot be in the t-channel of a reaction

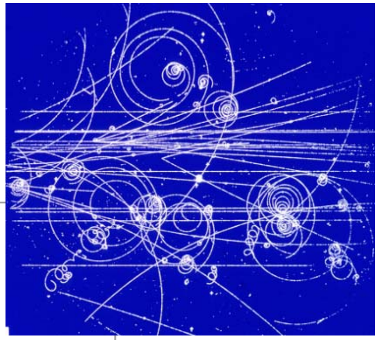
Comments

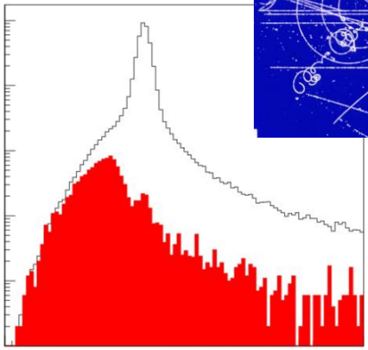
- In absence of any quantum theory of gravity, this is the simplest possibility
- Predictions are numerous and close to existing bounds
- Breaking of LI and of standard QFT rules is discussed in numerous literature





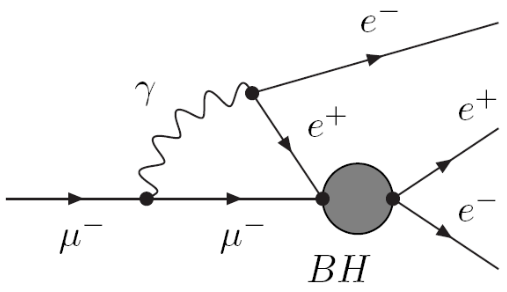
Phenomenology





Muon decay

Muon decay $\mu \to 3e$



$$\Gamma(\mu \to 3e)_n = \frac{\alpha^2 m_\mu}{2^{11}\pi^5} \left(\ln \frac{M_*^2}{m_\mu^2}\right)^2 \left(\frac{m_\mu}{M_*}\right)^{4(1+\frac{1}{n+1})} \kappa^{\frac{2}{n+1}}$$

$M_* \sim 1$ TeV, we obtain the branching ratio about $2 \cdot 10^{-12}$ for $n = 2$

$$BR(\mu^- \to e^- e^+ e^-)\Big|_{Exp} < 1.0 \cdot 10^{-12}$$

Other (Semi)-Leptonic Processes

$\mu \rightarrow e\gamma$ As above

$e^+ + e^- \rightarrow \mu + e$

$$\sigma(e^+e^- \rightarrow \mu e) \approx 7 \cdot 10^{-39}\,\mathrm{cm}^2 \left(\frac{M_{BH}}{100\,\mathrm{GeV}}\right)^{2+\frac{4}{n+1}} \left(\frac{\mathrm{TeV}}{M_*}\right)^{4+\frac{4}{n+1}}$$

$\tau \rightarrow 3l$ or $\tau \rightarrow l\gamma$ BR < 10^{-11} (BR_{Exp} < 10^{-7} – 10^{-6})

$\tau^- \rightarrow e^-e^+\bar{p},\ e^-e^-p$ Strongly suppressed

K–meson decay (1)

$$\mathbf{K} \rightarrow \mathbf{e}^+\mathbf{e}^-,\ \mu^+\mu^-,\ \mu^\pm\mathbf{e}^\mp$$

$$\Gamma(K^0 \rightarrow l\bar{l}) = \frac{g^2_{Kqq} m_K}{4\,(2\pi)^5} \left(\frac{m_q}{M_*}\right)^4 \left(\frac{m_K}{M_*}\right)^{\frac{4}{n+1}}$$

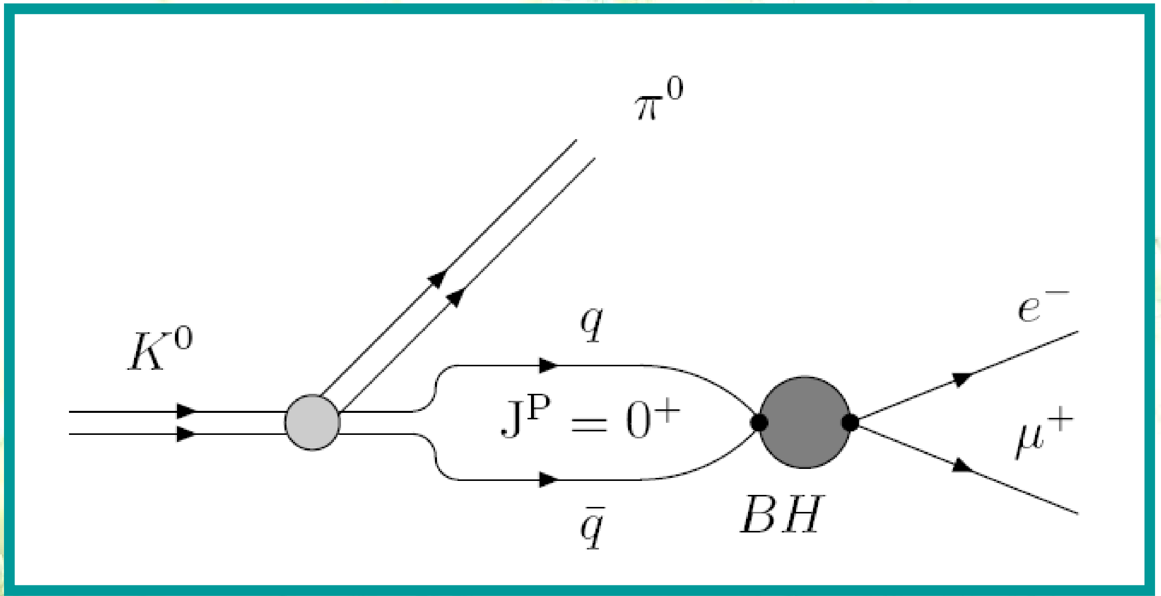
$$\mathbf{BR}(\mathbf{K^0} \rightarrow \mathbf{e}^+\mathbf{e}^-) < \mathbf{10^{-11}}$$

$$\mathbf{BR}(\mathbf{K^0} \rightarrow \mathbf{e}^\pm\mu^\mp) < \mathbf{5 \cdot 10^{-12}}$$

$$M_* > 3\ \mathrm{TeV}$$

K–meson decay (2)

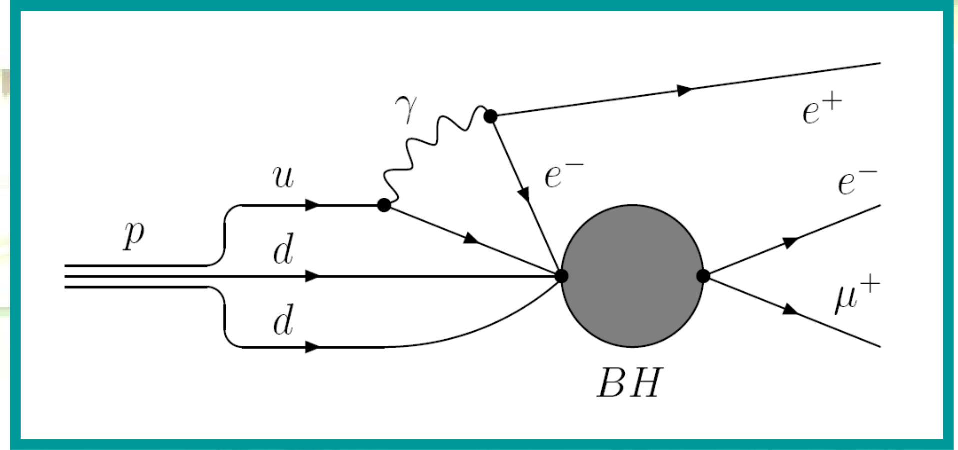
If BHs are scalars and not pseudo-scalars
(i.e. BHs have the quantum numbers of vacuum),
2 body decays are suppressed and not dangerous



Scalar BHs – Summary

1. The dominant anomalous decay mode is three body.
2. The charge of the emitted pion is the same as the charge of initial K.
3. The probabilities of the decays with charged and neutral leptons in the final states are approximately the same.

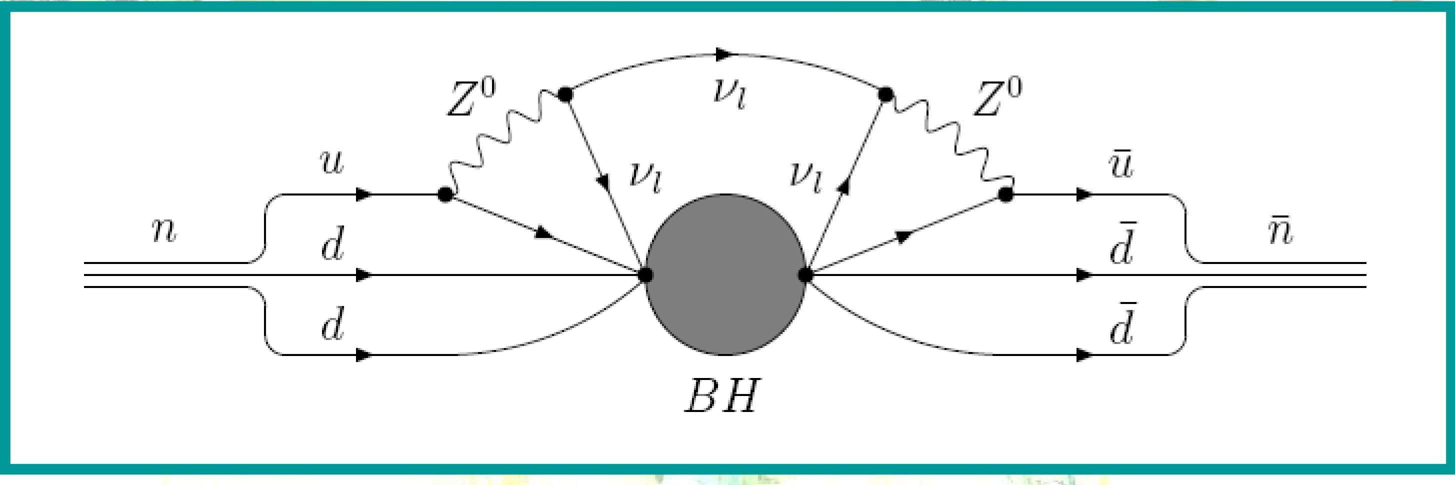
Proton Decay



$$\tau_p \approx 10^{29}\,\text{years}\left(\frac{M_*}{\text{TeV}}\right)^{10+\frac{10}{n+1}}\left(\frac{\text{TeV}}{m_p}\right)^{\frac{10}{n+1}-\frac{10}{3}}\left(\frac{100\text{MeV}}{\Lambda}\right)^{6}\ln^{-2}\left(M_*/\text{TeV}\right)\,f_p^{-1}(n)$$

$$\tau_p > 10^{33}\ \text{years} \quad \Rightarrow \quad M_* > 2\ \text{TeV}$$

Neutron–Antineutron Oscillation

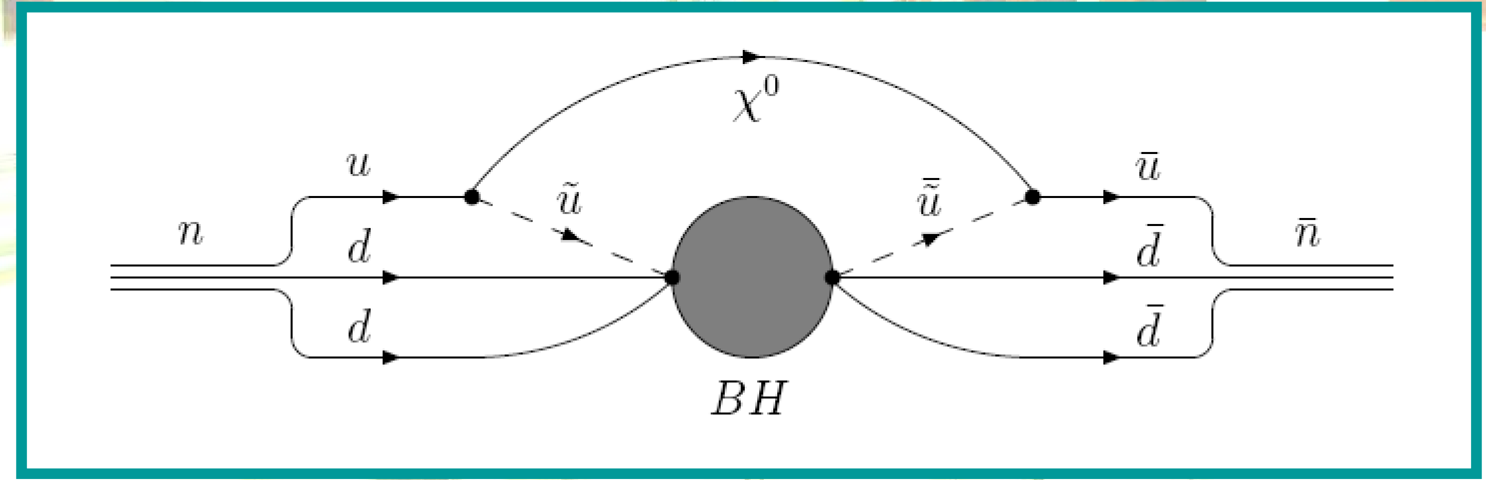


$$\tau_{n\bar{n}} = \left[\frac{2\alpha}{\pi}\ln\left(\frac{M_*}{m_Z}\right)\right]^{-2}\left(\frac{M_*}{\Lambda}\right)^{7+\frac{8}{n+1}}\Lambda^{-1}$$

With $n = 2$ and $M_* \sim 1$ TeV and $\Lambda = 100$ MeV → $3 \cdot 10^{19}$ s

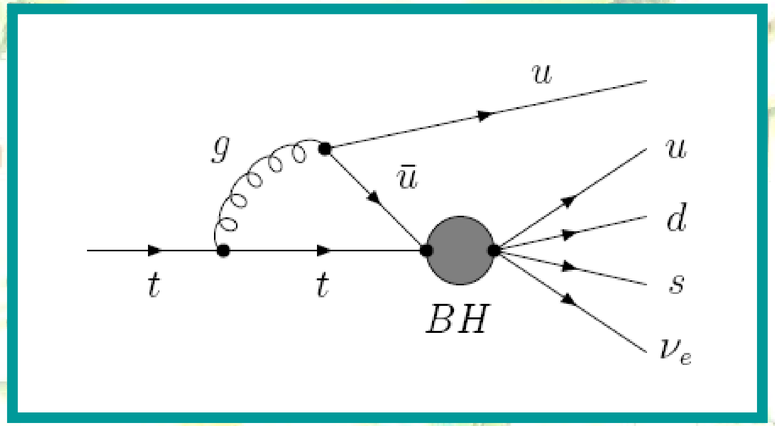
Experimental bound: $\tau_{n\bar{n}} > 1.3 \cdot 10^8$ s

Neutron–Antineutron Oscillation (SUSY Extension)



$$\tau_{\mathrm{n\bar{n}}} \approx 3 \cdot 10^9\,\mathrm{sec}\left(\frac{\mathrm{m_{SUSY}}}{300\,\mathrm{GeV}}\right)$$

Heavy Quark Decays



- *t*-quark may not be the best candidate
- *B*-mesons more promising

$$\mathrm{BR}(\mathrm{B} \rightarrow \mathrm{Pll}) \approx 10^{-11}$$

Summary

Process	Experiment	M_*, $n = 2\,(7)$
$p \to eee$	$\tau > 10^{33}$ yr	> 2 (8)
$\mu \to \gamma e$	$BR < 10^{-11}$	> 1 (10)
$\mu \to eee$	$BR < 10^{-12}$	> 1 (10)
$K \to \mu e$	$BR < 10^{-12}$	> 3 (4)
$K \to \pi\mu e$	$BR < 10^{-10}$	> 1 (1)
$n \leftrightarrow \bar{n}$	$\tau > 10^{8}$ s	> 1 (3) (MSSM)

Conclusions

- Classical BH Conjecture: simple (but very speculative) solution to dangerous gravitationally induced decays in particle physics
- Rich phenomenology, possibly accessible in near future experiments