Indirect Constraints on Third Generation Baryon Number Violation

Gael Finauri

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MAX-PLANCK-INSTITUT
FÜR PHYSIK

based on M. Beneke, GF, A. A. Petrov 2404.09642

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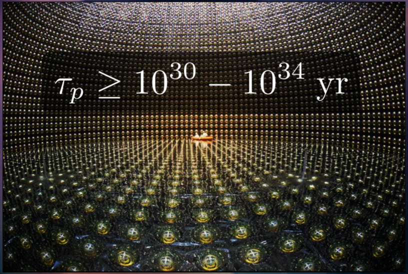

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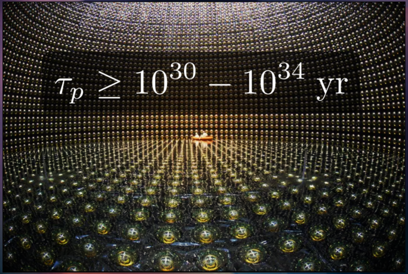

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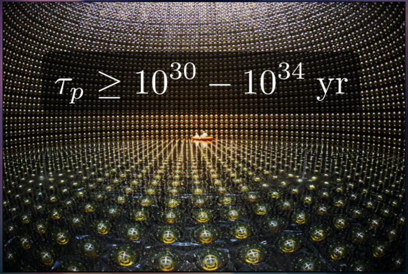

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But what if BNV needs third generation quarks?

B-anomalies

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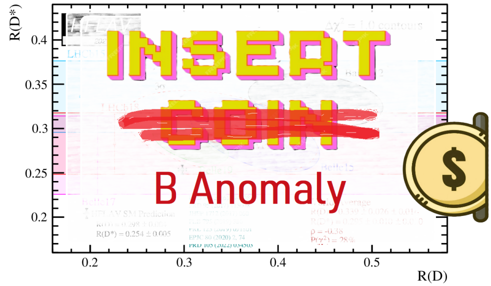
explained by New Physics at scales $\Lambda_{\text{fl}} \sim 1 - 10$ TeV



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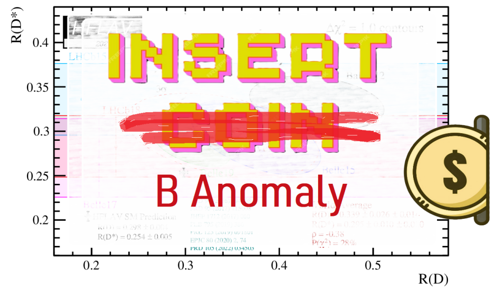

Natural questions:

- If BNV comes only from b quarks, can $\Lambda_{\text{BNV}} \sim \Lambda_{\text{fl}} \ll 10^{15}$ GeV be possible?

Why?

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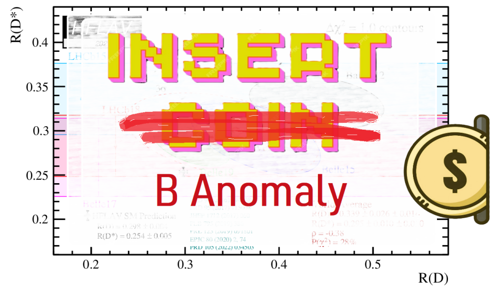

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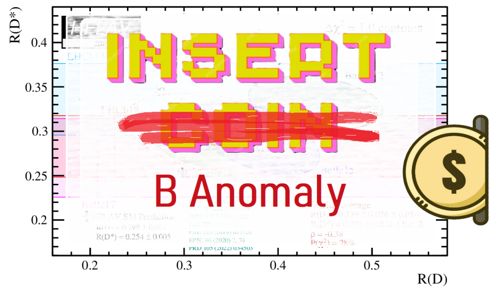

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- Would it lead to observable BNV B decays?

Answer: Don't know!

Proton would still decay through virtual b quarks, <u>constraining Λ_{BNV}</u>

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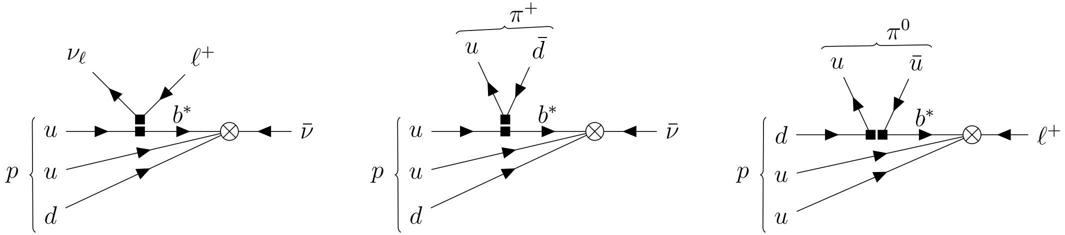

- $p \to \ell^+ \nu_\ell \bar{\nu}$
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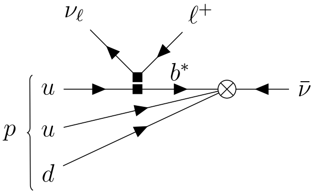

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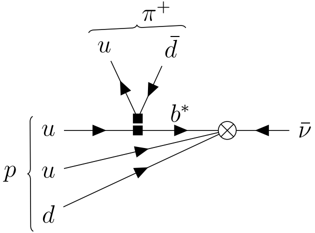

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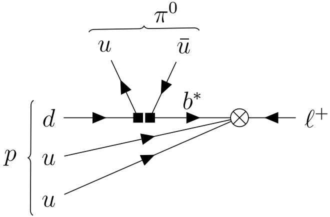

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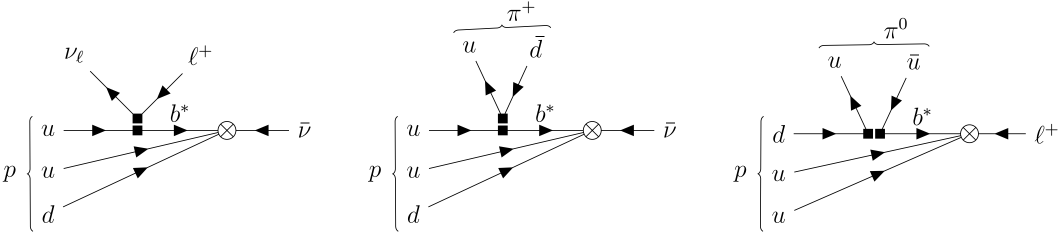

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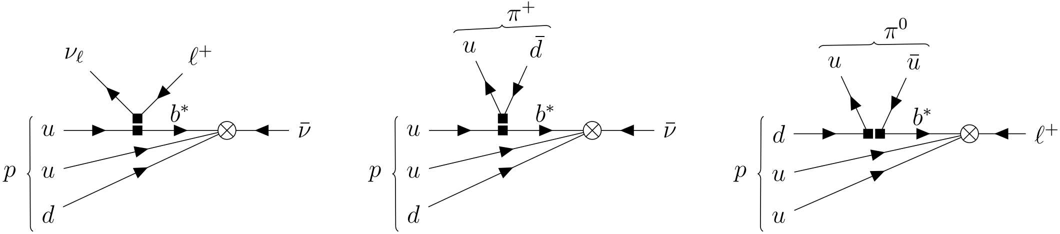

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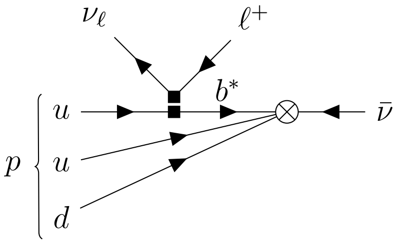
most suppressed $\Gamma(p \to f)$ → smallest Λ_{BNV} from τ_p constraints → highest $\Gamma(\bar{B} \to X\ell)$

Results for $p \to \ell^+ \nu_\ell \bar{\nu}$

Experimental bounds [Super-Kamiokande 2014]

- $\Gamma(p \to e^+ \nu\nu) < 1.23 \cdot 10^{-64}$ GeV
- $\Gamma(p \to \mu^+ \nu\nu) < 0.95 \cdot 10^{-64}$ GeV



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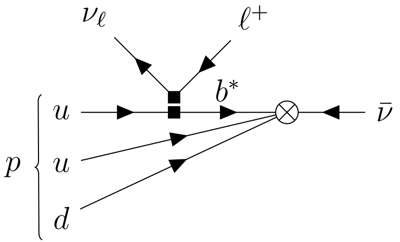
C_ν is the unknown dimensionless Wilson coefficient in the Weak Effective Theory (WET)



$$\Gamma(p \to \ell^+ \nu_\ell \bar{\nu}) = \frac{|C_\nu|^2}{\Lambda^4_{\text{BNV}}} \frac{|V_{ub}|^2 G_F^2 m_p^7}{7680 \pi^3 m_b^2} 10^{-3} \text{GeV}^4 \times \begin{cases} 1.028\,, & \text{for } p \to e^+ \nu_e \bar{\nu} \\ 0.933\,, & \text{for } p \to \mu^+ \nu_\mu \bar{\nu} \end{cases}$$

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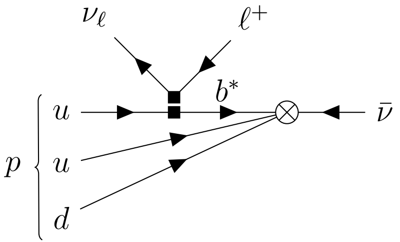

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Using the experimental constraints

$$\left.\frac{\Lambda_{\text{BNV}}}{\sqrt{|C_\nu|}}\right|_{p \to e^+ \nu_e \bar{\nu}} > 6.59 \cdot 10^9 \text{ GeV} \qquad \left.\frac{\Lambda_{\text{BNV}}}{\sqrt{|C_\nu|}}\right|_{p \to \mu^+ \nu_\mu \bar{\nu}} > 6.86 \cdot 10^9 \text{ GeV}$$

rather **high**! Already showing that $\Lambda_{\text{BNV}} \sim \Lambda_{\text{fl}}$ is ruled out!

Results for $p \to \pi^+ \bar{\nu}$

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$\Gamma(p \to \pi^+ \nu) < 5.35 \cdot 10^{-65}$ GeV

Assume factorization, true up to
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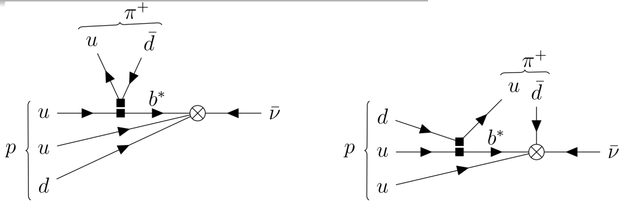

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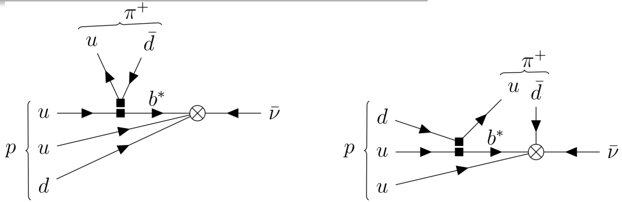

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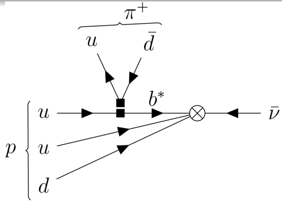

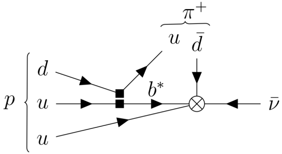

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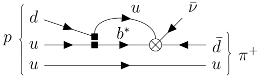

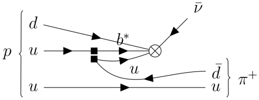

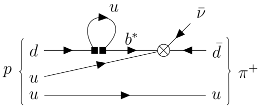

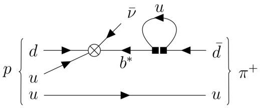

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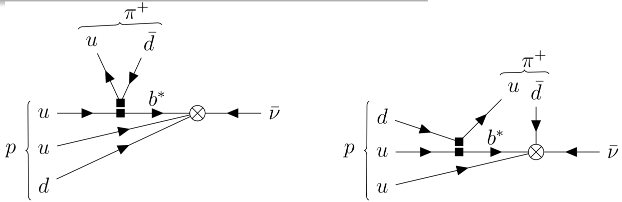

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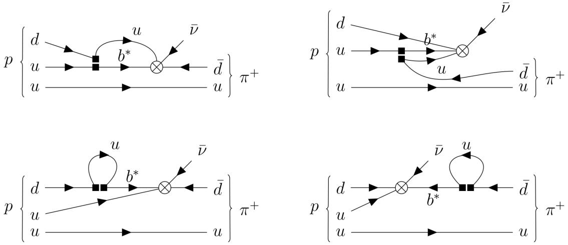

Using the experimental constraints

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less effective than leptonic decay

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Strongest experimental bounds [Super-Kamiokande 2020]

- $\Gamma(p \to \pi^0 e^+) < 0.87 \cdot 10^{-66}$ GeV
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two independent operators contributing

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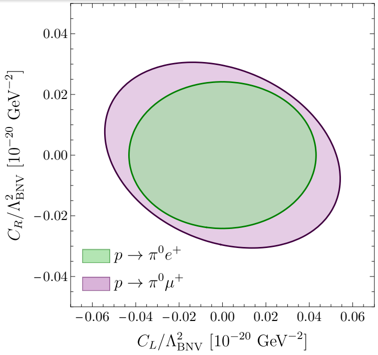

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these coefficients are <u>10 times more constrained with respect to C_ν</u>

Estimates for inclusive BNV B decays

We can estimate the branching ratio using $\Lambda_{\mathsf{BNV}} > 6 \cdot 10^9$ GeV

$$\mathcal{B}(\bar{B} \to X\ell) \approx \frac{m_b^5}{2^{10} 3 \pi^3 \Gamma_{\mathsf{tot}}^B \Lambda_{\mathsf{BNV}}^4}$$

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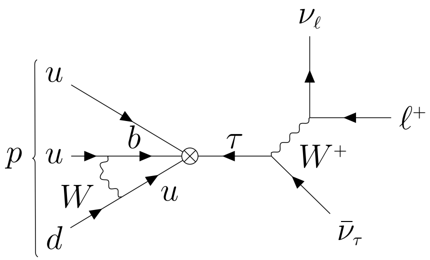
However...

what about operators with τ lepton? Not directly constrained by p decay!

BNV Operators with b and τ

Both b and τ have to be virtual!
Efficiently constrained by loop induced effects



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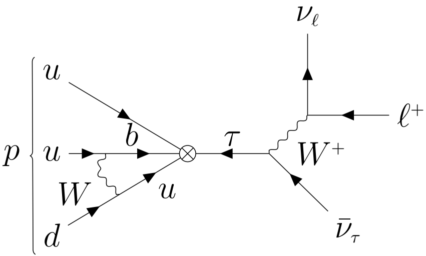

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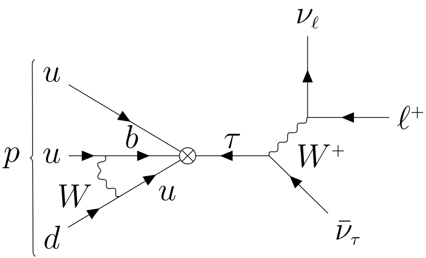

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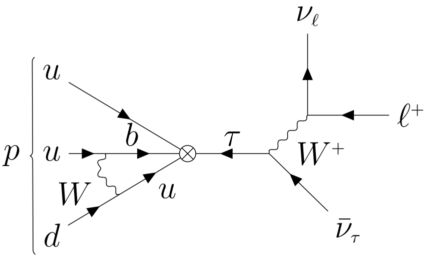

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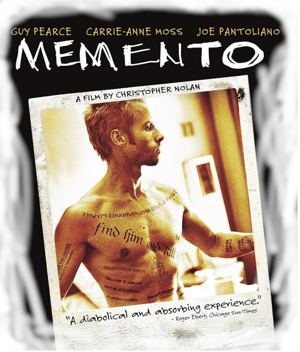
$$\mathcal{B}(B^0 \to p\mu^-)|_{\text{exp}} < 2.6 \cdot 10^{-9}$$ [LHCb 2022]

Left-Handed b SMEFT Operators



Left-Handed b SMEFT Operators

$$Q_{RR} = \varepsilon^{abc}[\widetilde{d}_p^a P_R u_r^b]\,[\widetilde{u}_s^c P_R \ell_t]$$

$$Q_{RL} = \varepsilon^{abc}[\widetilde{d}_p^a P_R u_r^b]\,[\widetilde{u}_s^c P_L \ell_t]$$

$$Q_{LR} = \varepsilon^{abc}[\widetilde{d}_p^a P_L u_r^b]\,[\widetilde{u}_s^c P_R \ell_t]$$

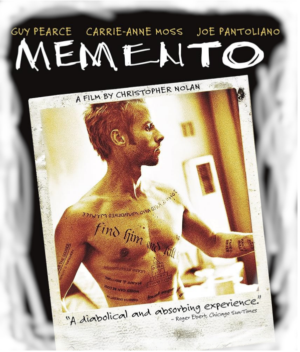
$$Q_{LL} = \varepsilon^{abc}[\widetilde{d}_p^a P_L u_r^b]\,[\widetilde{u}_s^c P_L \ell_t]$$

$$Q_{R\nu} = \varepsilon^{abc}[\widetilde{d}_p^a P_R u_r^b]\,[\widetilde{d}_s^c P_L \nu_t]$$

$$Q_{L\nu} = \varepsilon^{abc}[\widetilde{d}_p^a P_L u_r^b]\,[\widetilde{d}_s^c P_L \nu_t]$$

one loop SMEFT→WET
matching known

[W. Dekens, P. Stoffer, 2019]



Left-Handed b SMEFT Operators

Wilson coefficients in the WET are not all independent, due to CKM rotation of the left-handed d quarks

$$Q_{RR} = \varepsilon^{abc}[\widetilde{d}_p^a P_R u_r^b]\,[\widetilde{u}_s^c P_R \ell_t]$$

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one loop SMEFT$\rightarrow$WET matching known

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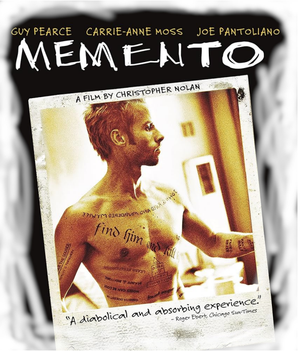

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$$C_{RL}^{111} = C_{duq}^{111} \,,$$

$$C_{R\nu}^{111} = -V_{ud} C_{duq}^{111} - V_{cd} C_{duq}^{112} - V_{td} C_{duq}^{113} \,,$$

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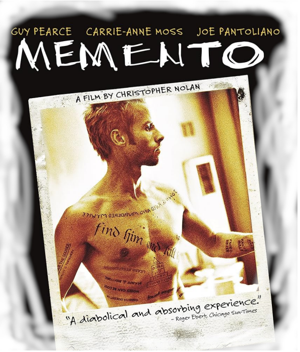

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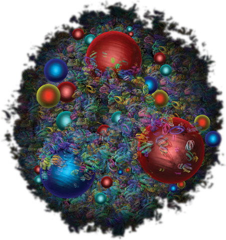
me: "... we should be careful, only in the assumption of dim-6 interactions..."

MB: "you become even more famous if you state wrong no-go theorems!"

Thank You!

Backup Slides

… in B Physics



Theoretical predictions are affected by the **non-perturbative** nature of hadronic QCD

However nature provided an intrinsic perturbative scale $m_b \sim 5$ GeV

$\Rightarrow$ B decays employing **Effective Field Theories** (HQET, SCET, …) to separate perturbative physics from universal non-perturbative inputs