

# Magnetic Moment Effect of High Energy Neutrinos

Ting Cheng

Max-Planck-Institut für Kernphysik

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**IMPRS**

**for Precision Tests of Fundamental Symmetries**

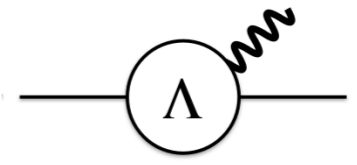
INTERNATIONAL MAX PLANCK RESEARCH SCHOOL

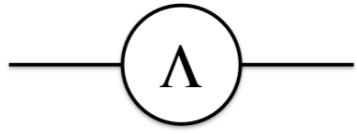


# Neutrino Magnetic Moment

Majorana:  $\mathcal{L} \supset \frac{1}{2} \mu_{\alpha\beta} \nu_{L,\alpha} \sigma_{ab} \bar{\nu}_{L,\beta}^c F^{ab} + \text{h.c.}$

Flavour change  
 $\alpha \neq \beta$   
Helicity flip


 $\nu$ MM


 $\nu$  mass

Hamiltonian:  $3 \times 3$  (3-flavour mixing)  $\rightarrow$   $6 \times 6$  (3-flavour & 2-helicity mixing)

$$\mathcal{H} = \mathcal{H}_{\text{vac}} + \mathcal{H}_{\text{MSW}} + \mathcal{H}_{\nu\text{MM}}$$

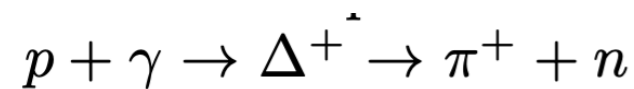
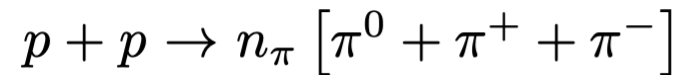
High energy neutrinos:

Small ( $1/E$ )

Filtered (MSW  $\sim$  inelastic scattering)

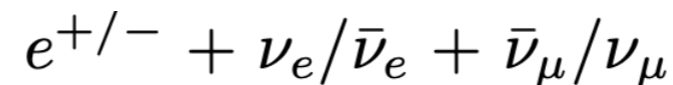
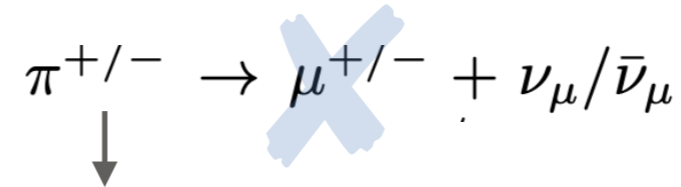
# Role of Magnetic Field

Production of high energy neutrinos:



Helicity bias

Flavour bias

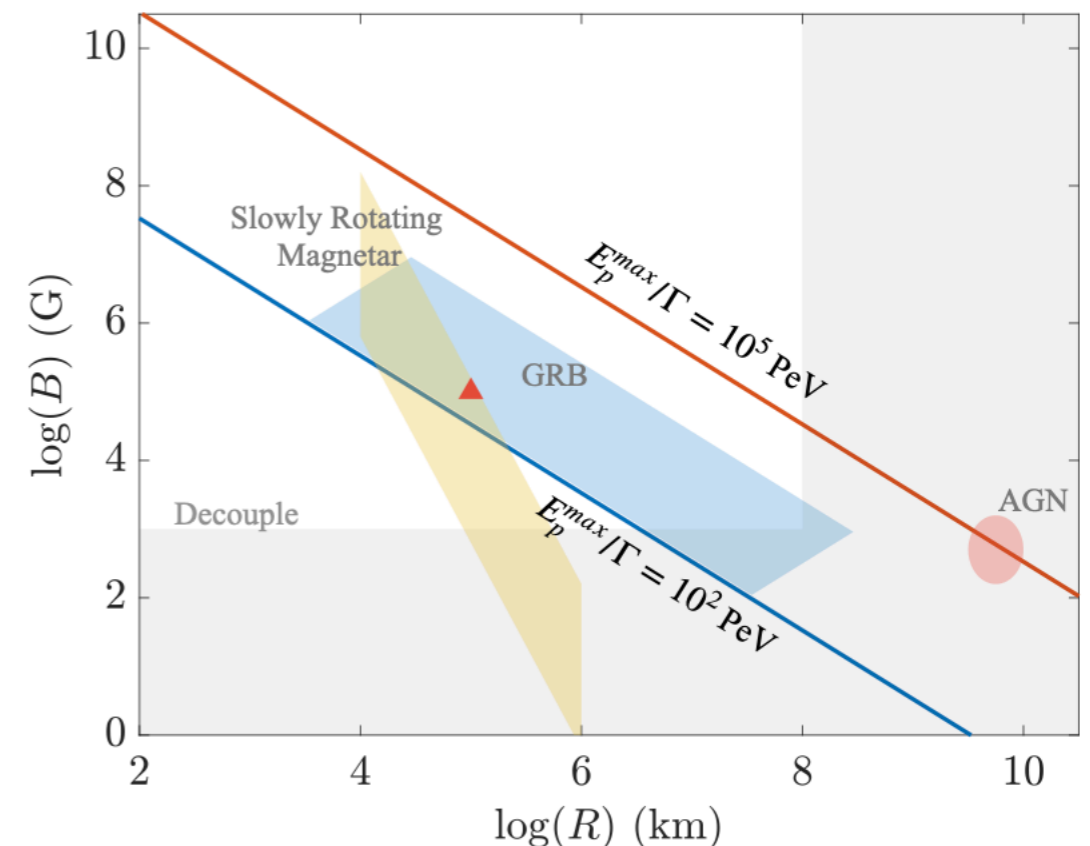


1. Acceleration (necessary condition) — proton energy

$$E_{\max}^p = \eta^{-1} e B R \Gamma \simeq 10^5 \left(\frac{1}{\eta}\right) \left(\frac{B}{3 \times 10^5 \text{G}}\right) \left(\frac{R}{10^5 \text{km}}\right) \left(\frac{\Gamma}{10^2}\right) \text{PeV}$$

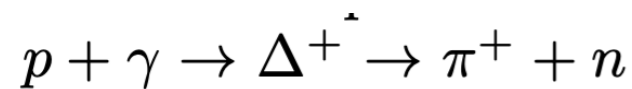
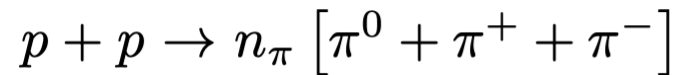
2. Cooling effects — neutrino energy and flavour

$$t_{\text{decay}}^{-1} \text{ v.s. } t_{\text{cool}}^{-1}$$



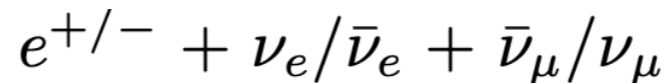
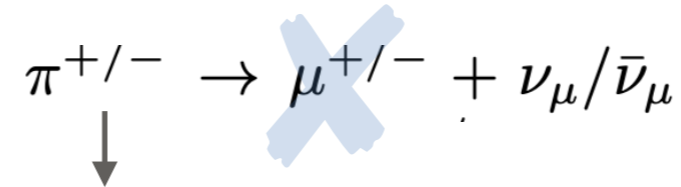
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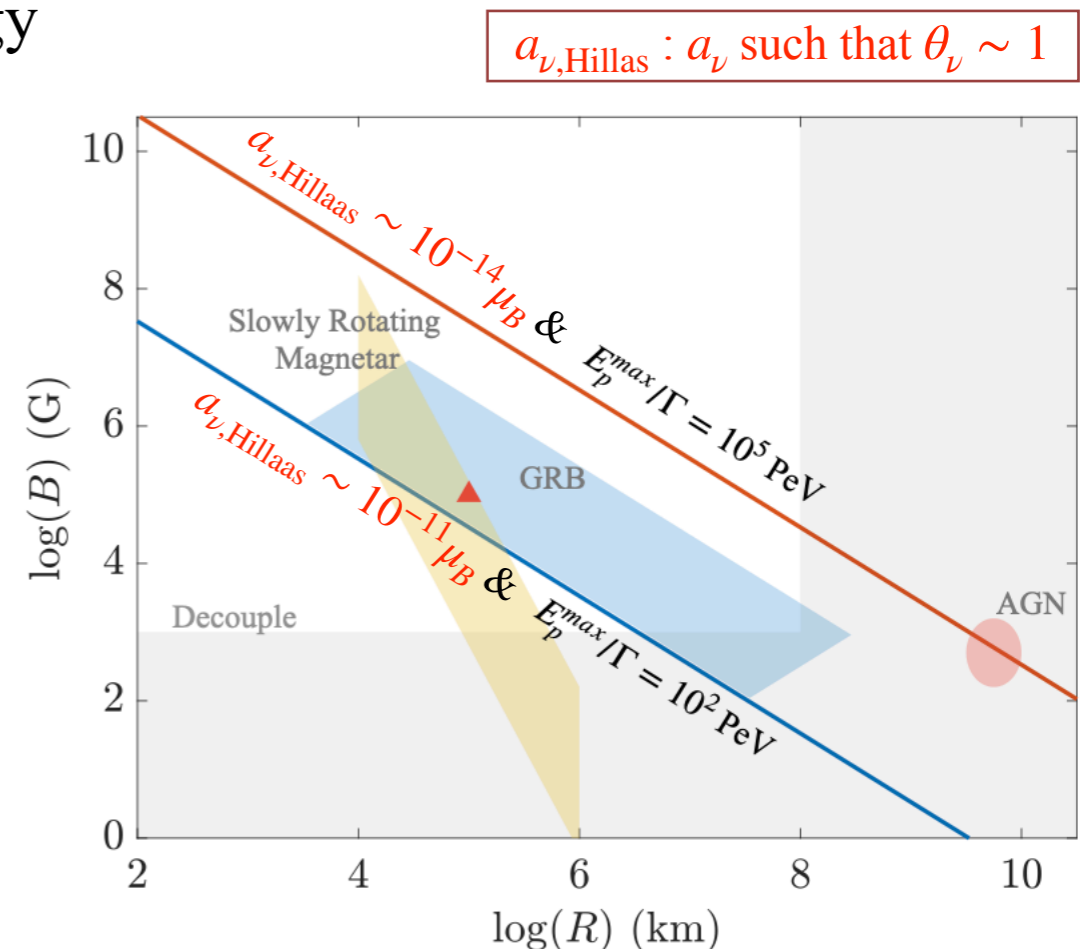
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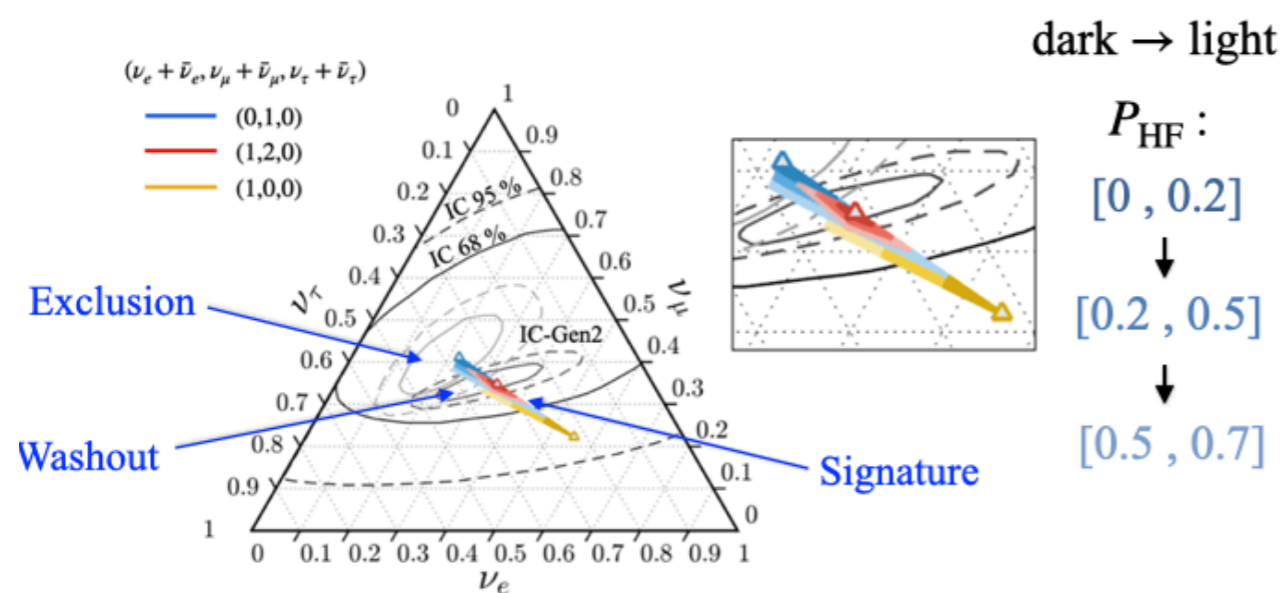
3.  $\nu$ MM effect —  $\theta_\nu \sim a_\nu \times B \times R$

MC simulation of slowly rotating magnetar:  $10^{-11} \rightarrow 10^{-15} \mu_B$



# IceCube Signatures

## Flavour Ratio



## Glashow Resonance Event (Fraction of $\bar{\nu}_e$ at 6.3 PeV)

Exclusion

Signature

Washout

