STERILE NEUTRINOS
From cosmology to the LHC

The νMSM model

- *T. Asaka and M. Shaposhnikov Phys.Lett.B620(2005)17*
- *M.Shaposhnokov Nucl.Phys.B763(2007)49*

- **Minimum extension of the SM to accomodate massive neutrinos**

- *See-saw* formula for active neutrinos $m_\nu = -M^D(1/M_I)(M^D)^T$
  - Majorana mass M_I
  - Dirac mass $M_D = fv$ $v = 174$ GeV vac exp val of Higgs field

- Usual choice: f as in quark sector, $M = 10^{10}$-10^{15} GeV
- Alternative choice: small f

- Inputs: $m(\nu_1) = 10^{-5}$ eV, $m(\nu_2) = 9$ meV, $m(\nu_3) = 50$ meV and mixings

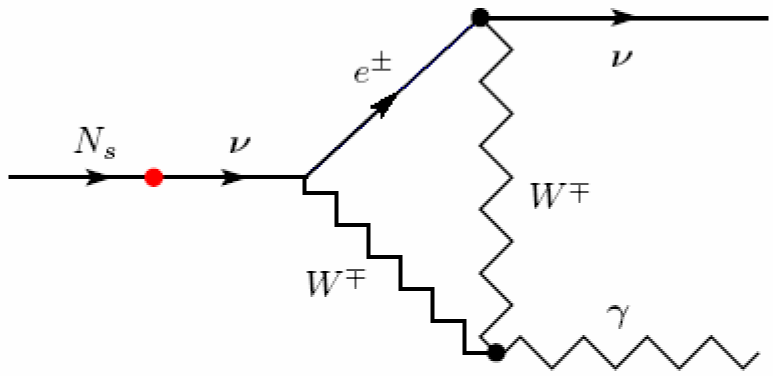
Three sterile neutrinos

- Three singlet RH neutrinos N_1 N_2 N_3
- N_1 with very large lifetime,
  almost stable ⇒ DARK MATTER
- Best : $m(N_1)$ ~10 keV
- *Warm dark matter*
- N_2, N_3 almost degenerate (leptogenesis)
- **With masses 100 MeV-few GeV**

Subdominant radiative decay channel: $N \to \nu\gamma$.

Photon energy:

$$E_\gamma = \frac{M_s}{2}$$

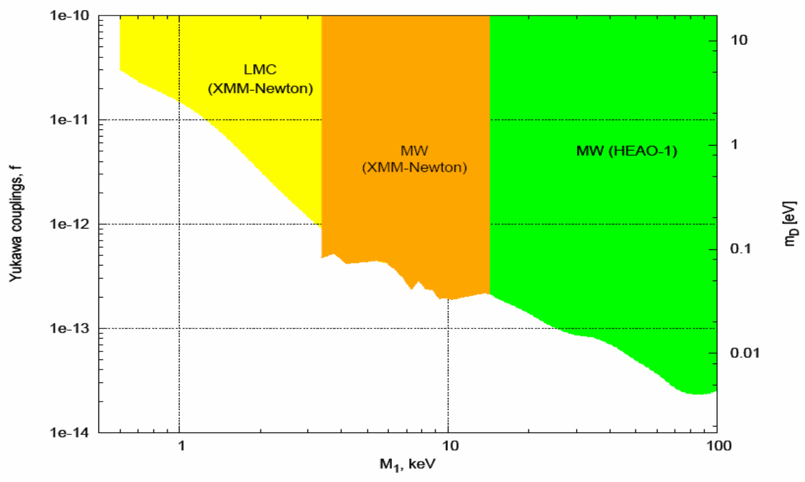


Radiative decay width:

$$\Gamma_{\rm rad} = \frac{9\,\alpha_{\rm EM}\,G_F^2}{256 \cdot 4\pi^4}\,\sin^2(2\theta)\,M_s^5$$

Limits from cosmology

Search for N_1 radiative decays

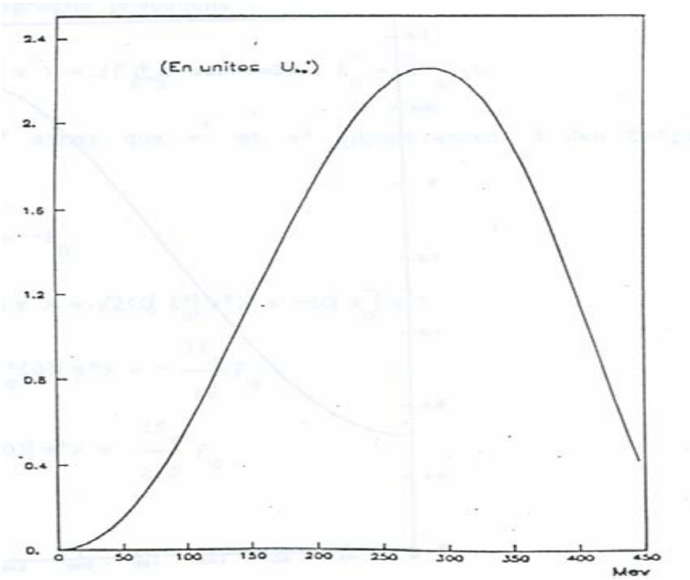


Big Bang nucleosynthesis, N_2, N_3

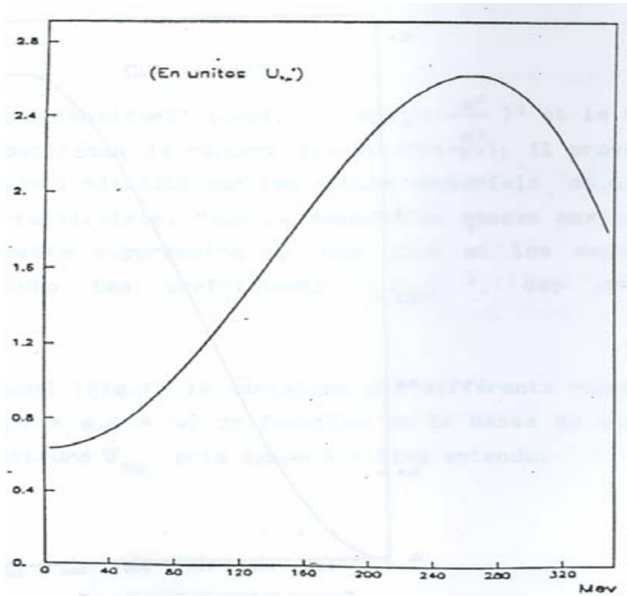
$U^2 < 10^{-8}\ (1/m(GeV))^2$

Production of heavy neutrinos

- Mixed with active neutrinos
- In all weak decays they appear at level U^2_{Nl}
  - Change of kinematics

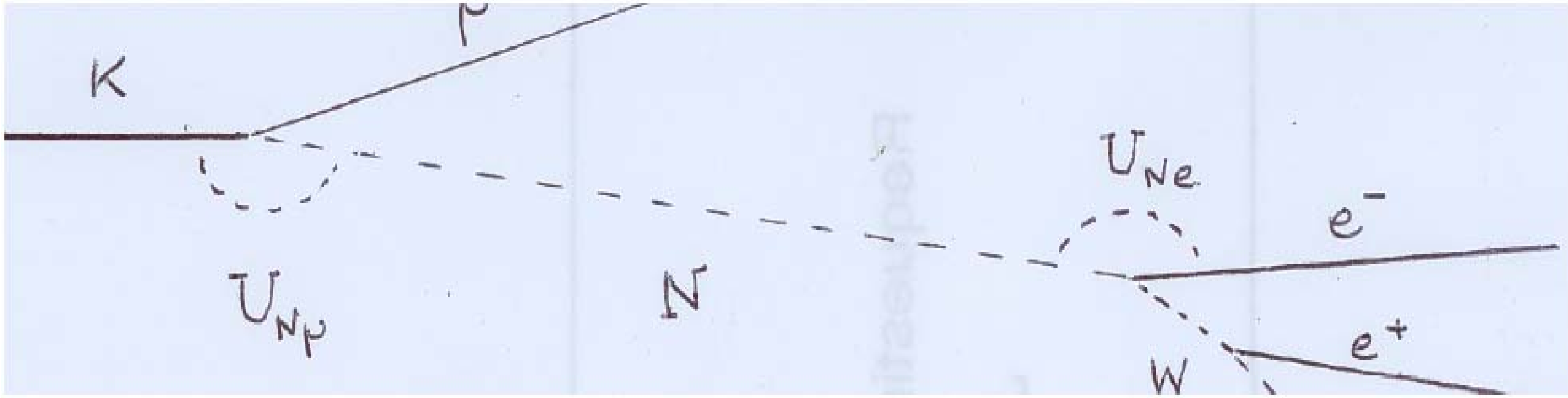


$K \to eN$



$K \to \mu N$

Decays of heavy neutrinos

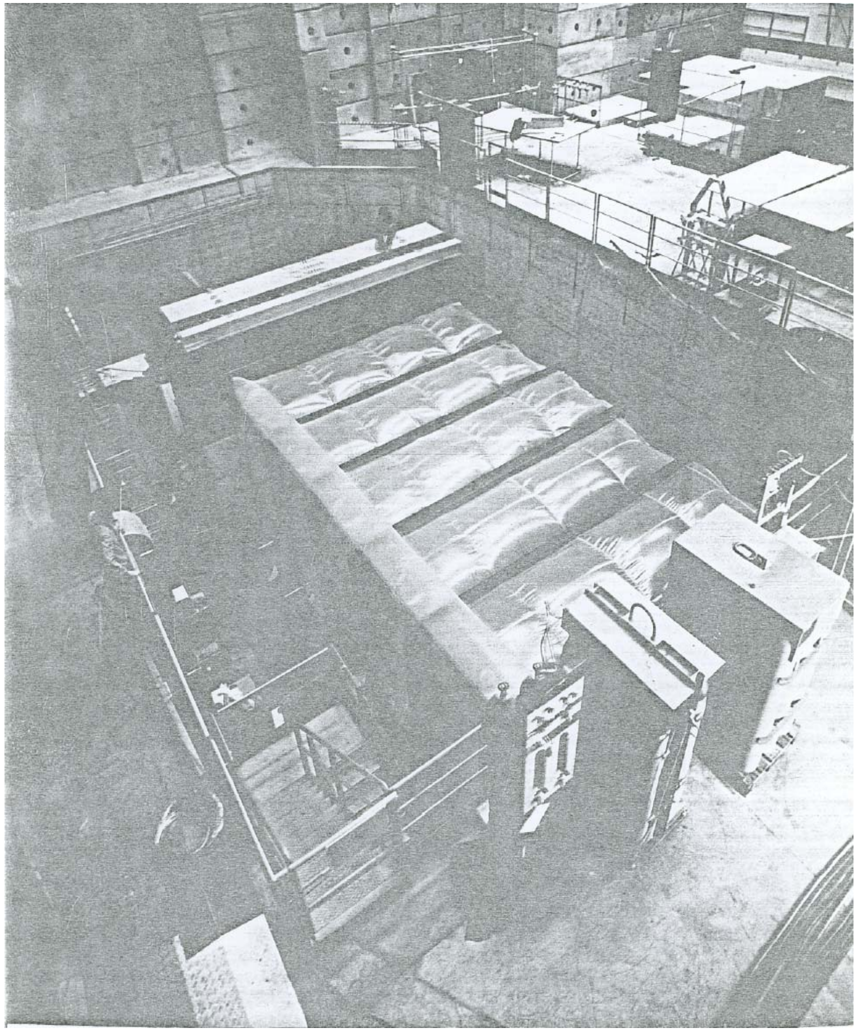


Purely weak decays:

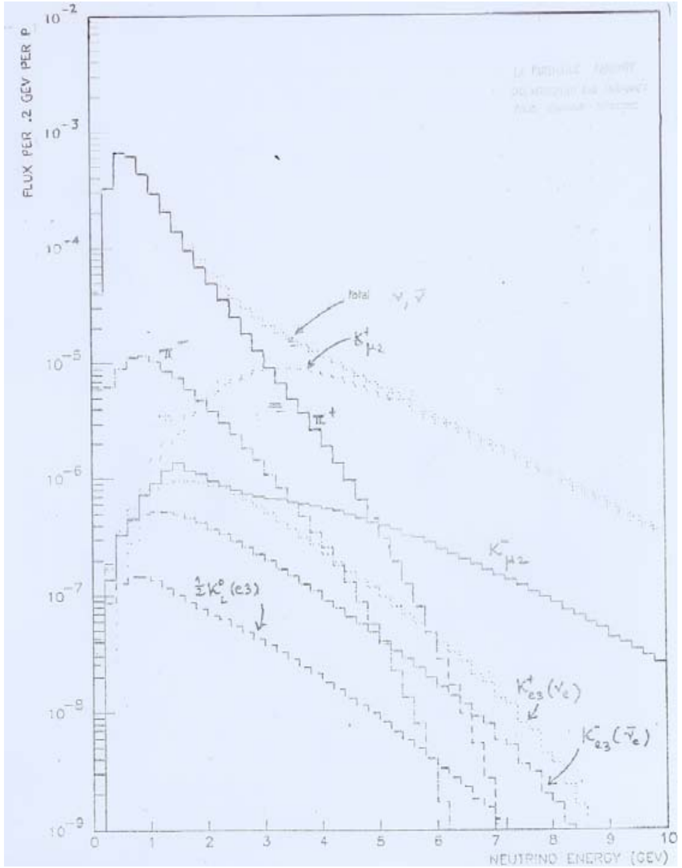
modes depend on the mass $e^+e^-\nu$, $\mu e\nu$, $\mu^+\mu^-\nu$, $e^-\pi^+$, $\mu^-\pi^+$….

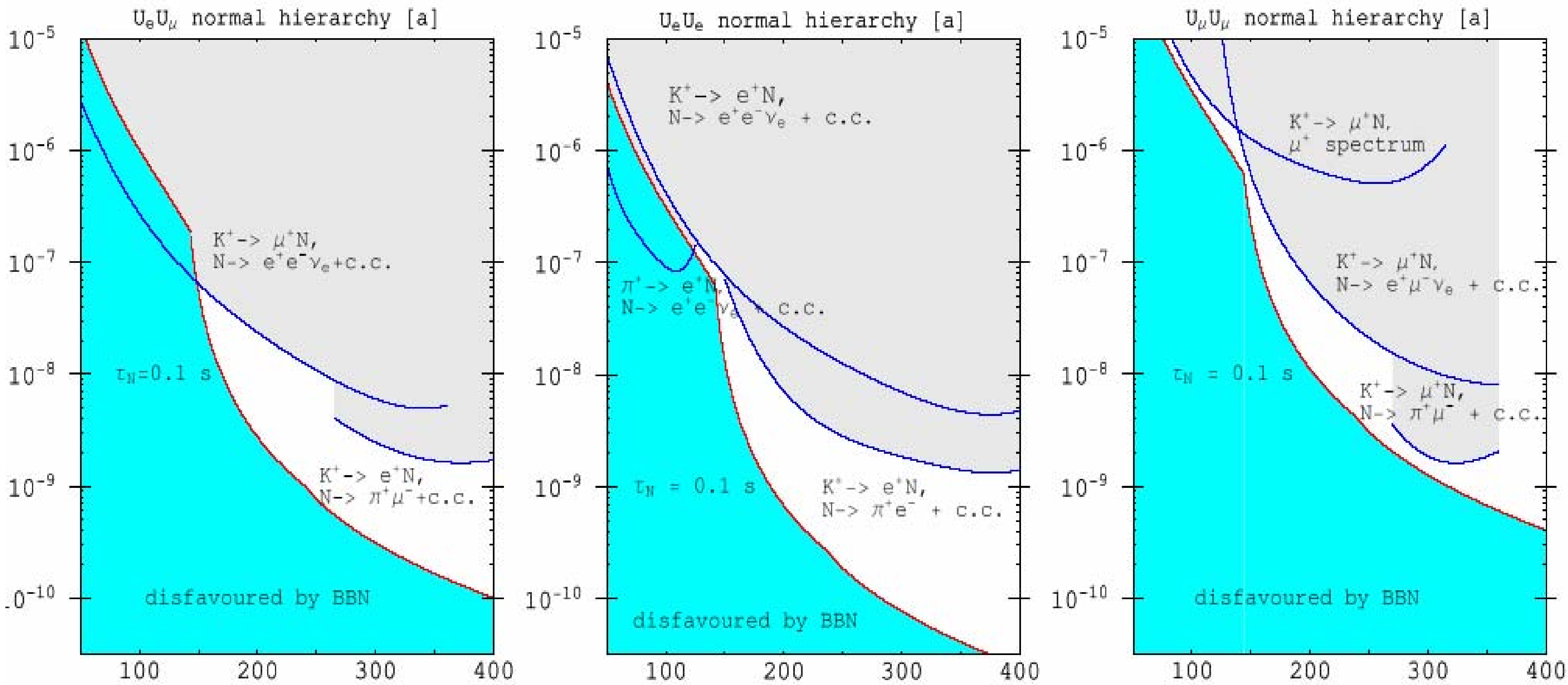
Lifetime for $e^+e^-\nu$ $\tau = 2.8\ 10^4\ (1/m(\mathrm{MeV})^5)(1/U^2)$

PS191 experiment



$5\ 10^{18}$ pots 19 GeV

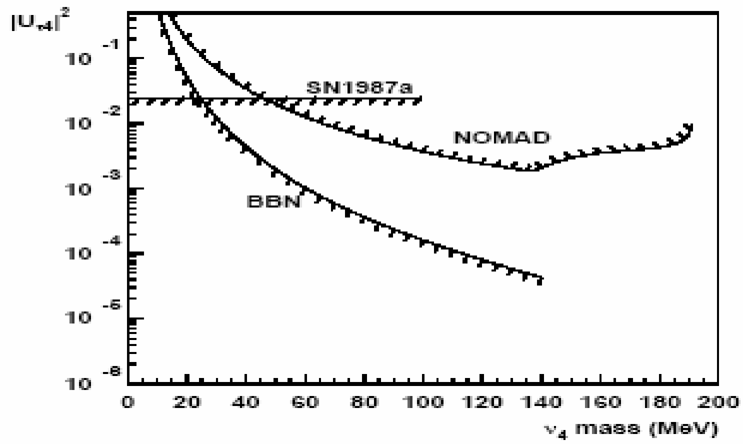




$U_e U_\mu$ normal hierarchy [a]
$K^+ \to \mu^+ N$, $N \to e^+ e^- \nu_e$ + c.c.
$K^+ \to e^+ N$, $N \to \pi^+ \mu^-$ + c.c.
τ_N=0.1 s
disfavoured by BBN
$U_e U_e$ normal hierarchy [a]
$K^+ \to e^+ N$, $N \to e^+ e^- \nu_e$ + c.c.
$\pi^+ \to e^+ N$, $N \to e^+ e^- \nu_e$ + c.c.
$K^+ \to e^+ N$, $N \to \pi^+ e^-$ + c.c.
τ_N = 0.1 s
disfavoured by BBN
$U_\mu U_\mu$ normal hierarchy [a]
$K^+ \to \mu^+ N$, μ^+ spectrum
$K^+ \to \mu^+ N$, $N \to e^+ \mu^- \nu_e$ + c.c.
$K^+ \to \mu^+ N$, $N \to \pi^+ \mu^-$ + c.c.
τ_N = 0.1 s
disfavoured by BBN
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
100
200
300
400

Mixing to the ν_τ

- With the NOMAD experiment, 450 GeV p
- *Source* $D_s \Rightarrow \tau\, \nu_\tau$



Possible improvements

- Modern ν beams NuMI, T2K
- 120 GeV, 5 10^{20} pots
  - Large π, K production and also D mesons
  - $\Rightarrow$ *improvement in* U^2 *limits*
  - Furthermore, mass range can be extended to 1.3 GeV

What about the LHC?

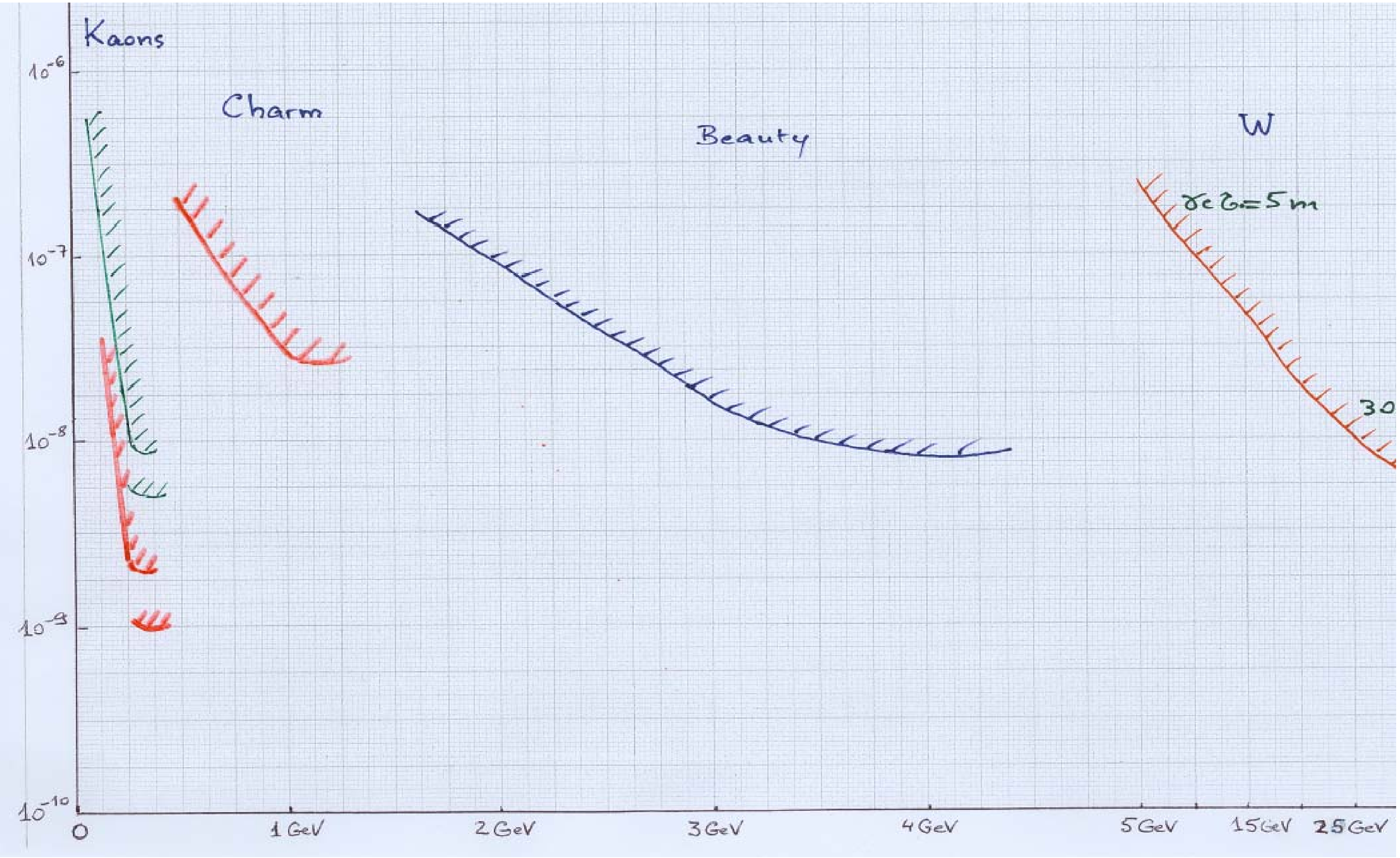
- LHCb
- 10^{12} B mesons/year of 100 GeV/c

  Mass region extended to 4 GeV

- ATLAS/CMS
- $3\ 10^{8}$ W/year

  Mass region extended to 50 GeV

Rough expectations



Conclusion

- *The νMSM is an appealing model*
- It is possible to test it rather simply in the laboratory: NuMI, LHC
- *An add-on decay volume in the near hall of NuMI could give valuable limits (or find sterile neutrinos!)*