Search for sterile neutrinos

From cosmology to the LHC

The νMSM model

Minimum extension of the SM to accomodate massive neutrinos

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

•*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 v. e. v. 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
- $\Rightarrow N_1$ Best choice $m(N_1) \sim 10$ keV
- *Very large lifetime, practically stable.*
    - WARM DARK MATTER
- $\Rightarrow N_2, N_3$ almost degenerate (leptogenesis)
    - *Masses in range100 MeV-few GeV*

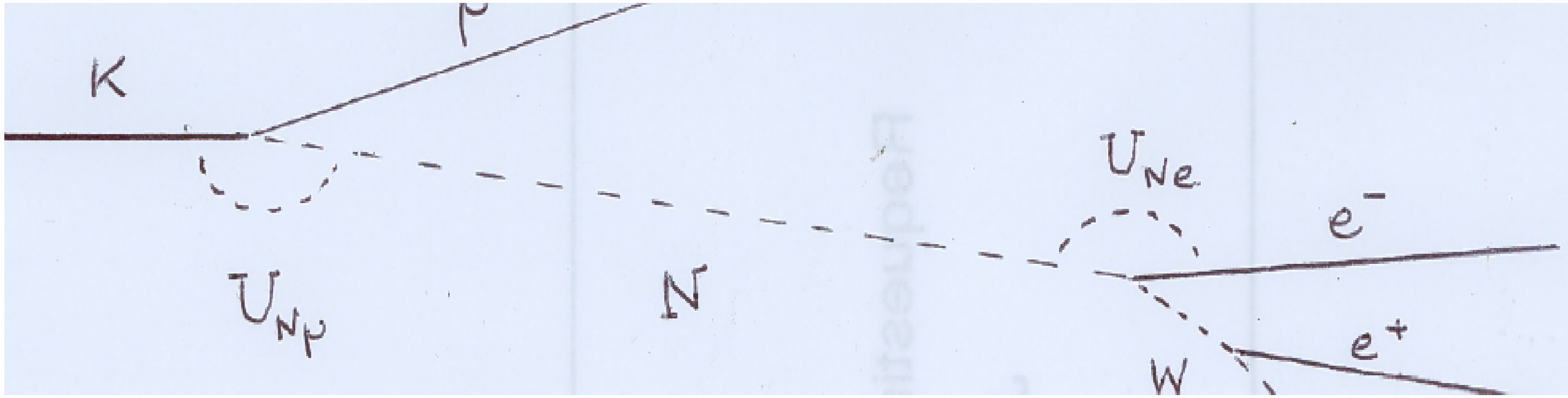
Heavy neutrinos at accelerators

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

Their mass is limited by the parent particle

$\pi \Rightarrow e\, N$	$m(N) < 130$ MeV
$\pi \Rightarrow \mu\, N$	$m(N) < 20$ MeV
$K \Rightarrow e\, N$	$m(N) < 450$ MeV
$K \Rightarrow \mu\, N$	$m(N) < 350$ MeV
… $W \Rightarrow e\, N$	$m(N) < 80$ GeV

Decays of heavy neutrinos



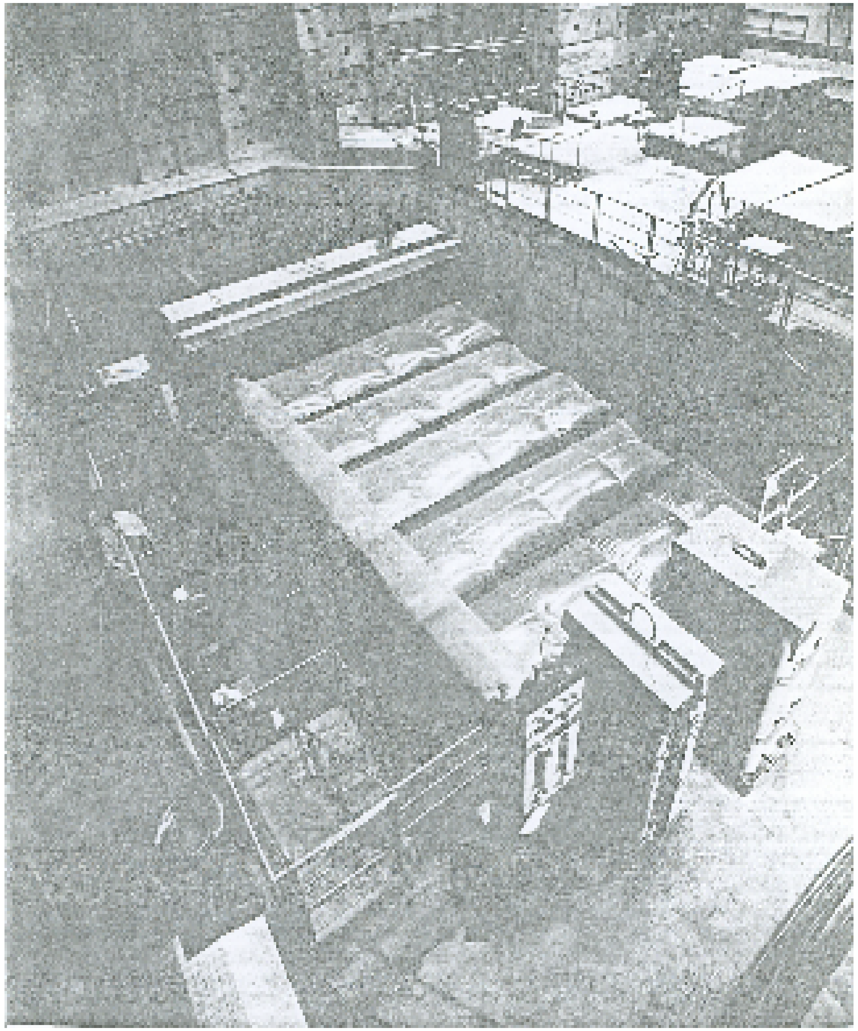
Purely weak decays:

modes depend on the N mass

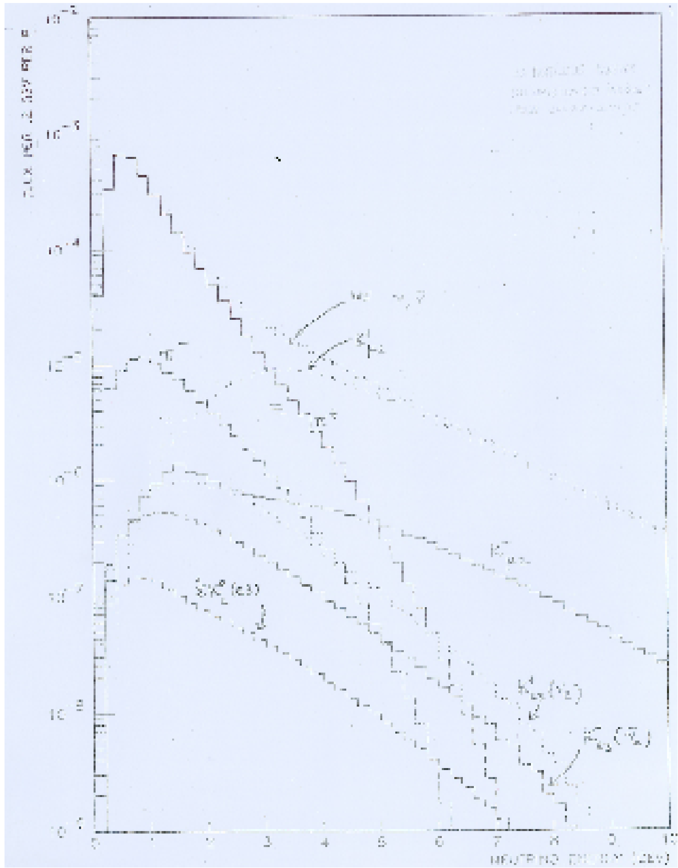
first open channel $e^+e^-\nu$, then $\mu e\nu$, $\mu^+\mu^-\nu$, $e^-\pi^+$, $\mu^-\pi^+$….

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

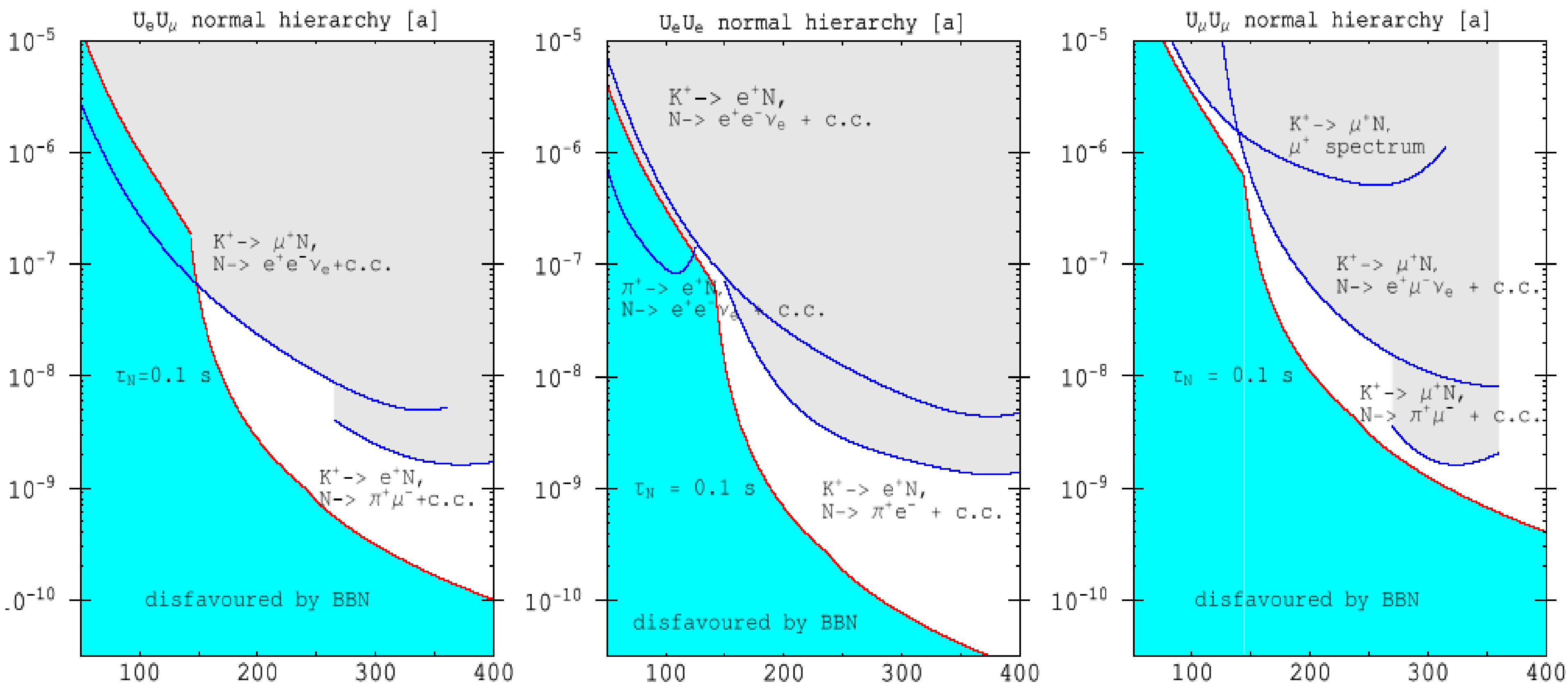
PS191 experiment (1984!)



5 10^{18} pots 19 GeV



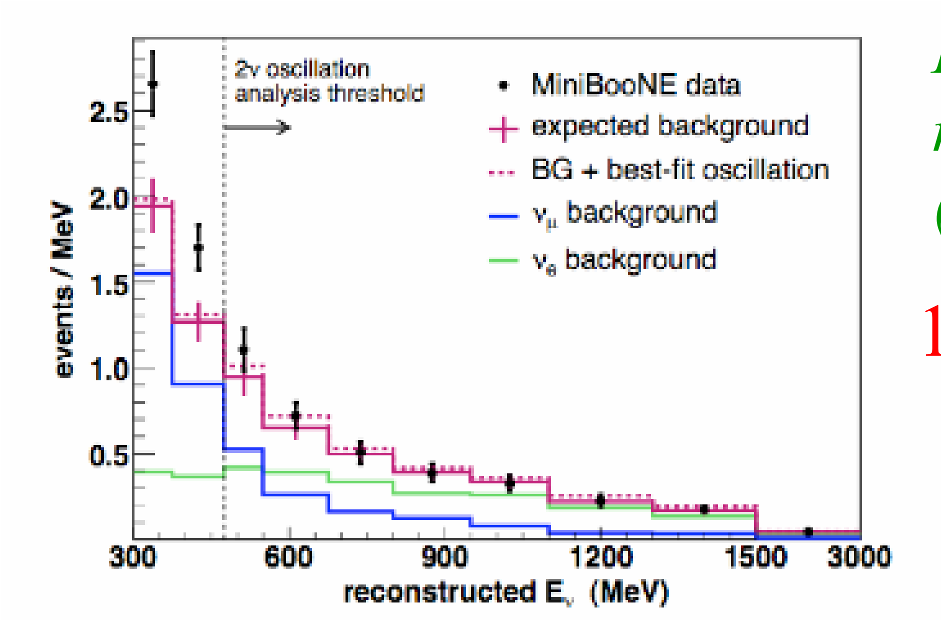
PRESENT LIMITS



MiniBoone excess ?

About 100 events depositing 300-400 MeV energy

Obtained with 5 10^{20} pots of 8 GeV



Decay of the N_2 component mixing predominantly to μ (testing $U_{N\mu}{}^2$)

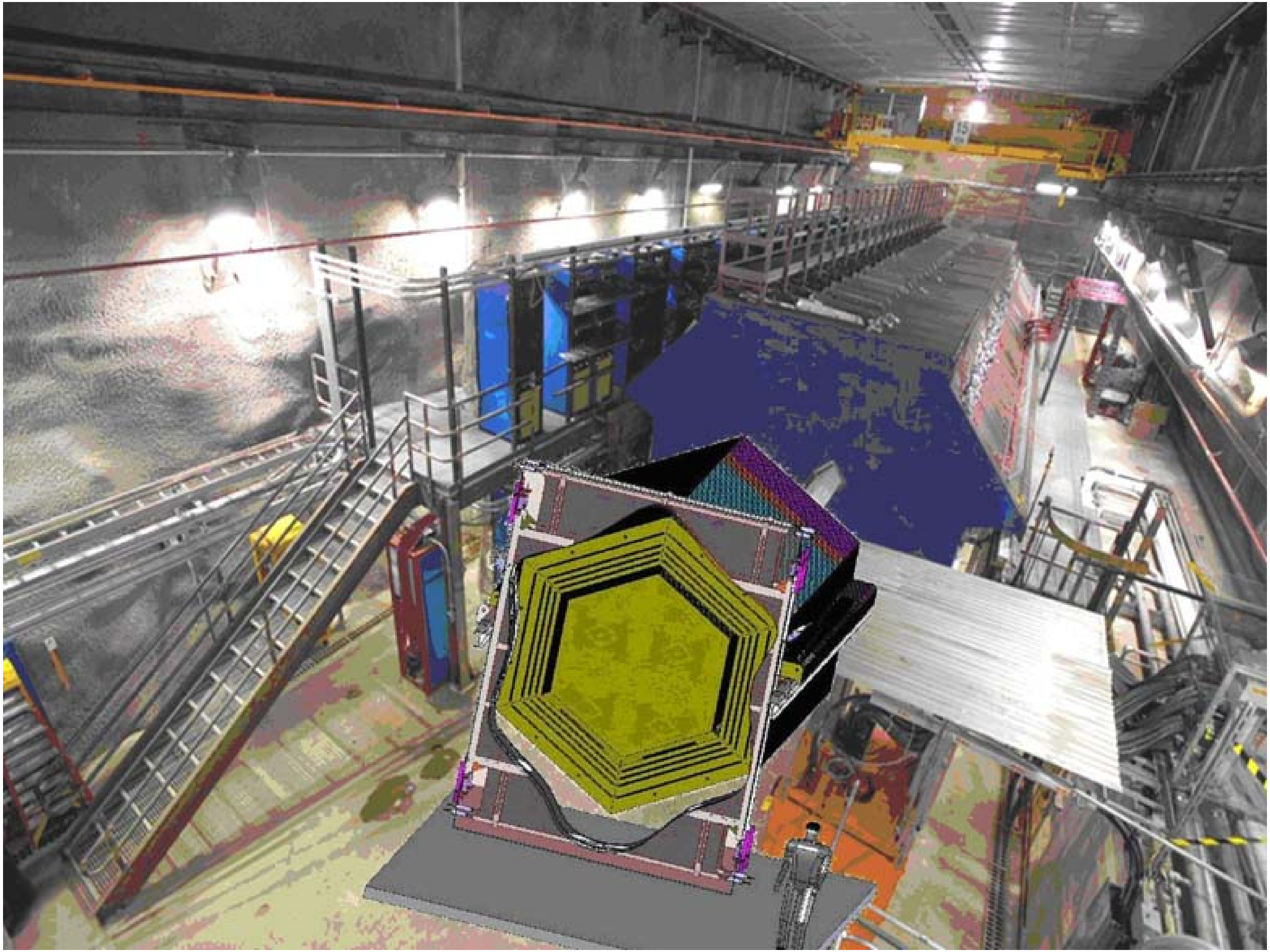
150 MeV < m < 350 MeV

U^2 = few 10^{-8}

NOT EXCLUDED !!

Improving on PS191

- Modern ν beam: NuMI (*25 years later*)
- 120 GeV, 16 10^{20} pots
  - Large π, K production
  - $\Rightarrow$ *improvement in U^2 limits*
  - Furthermore, with D production mass range can be extended to 1.3 GeV



What about the LHC ?

•LHCb

•10^{12} B mesons/year of 100 GeV/c

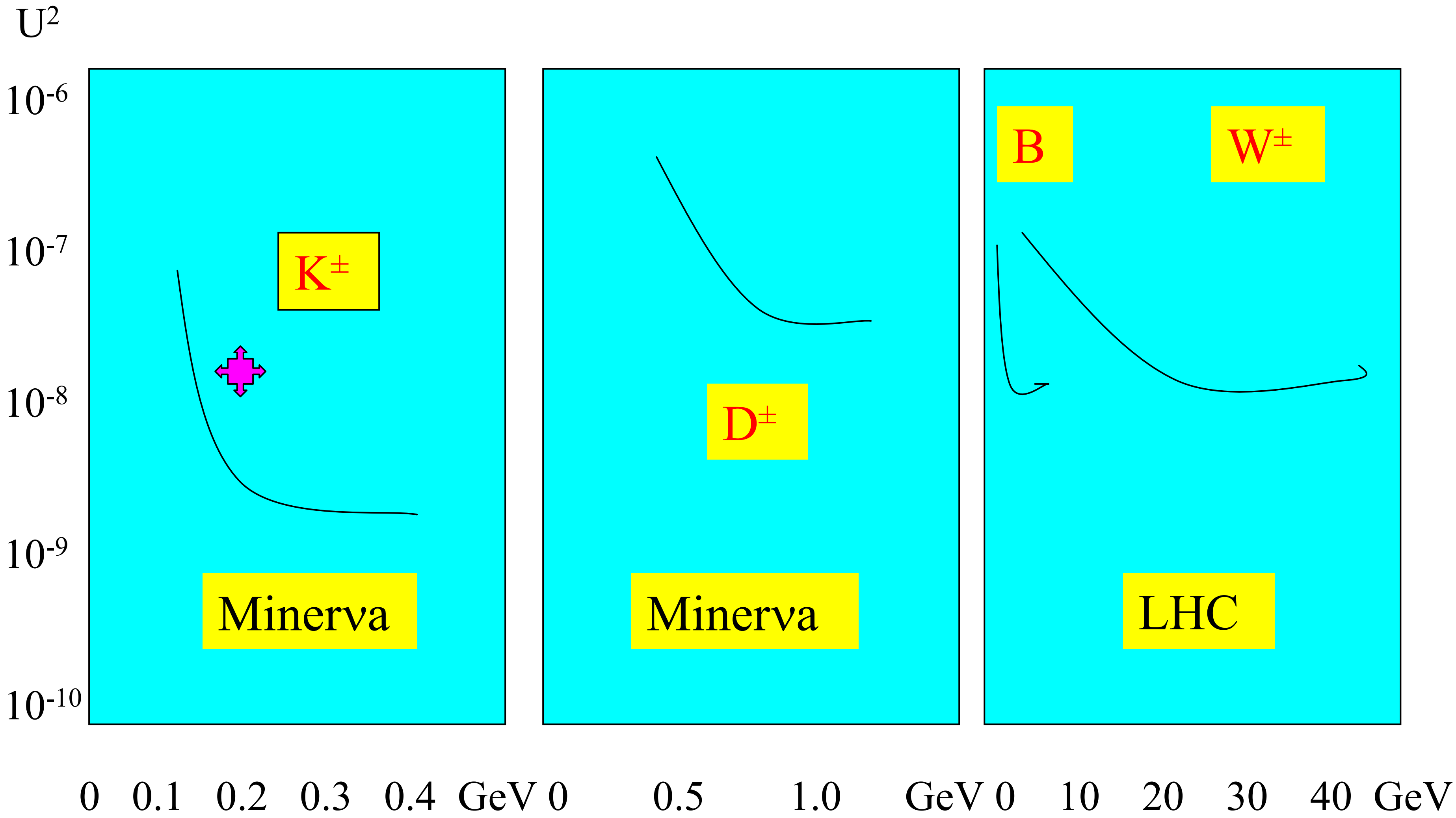
Mass region extended to 4 GeV

•ATLAS/CMS

•3 10^8 W/year

Mass region extended to 50 GeV

Conclusion: rough expectations



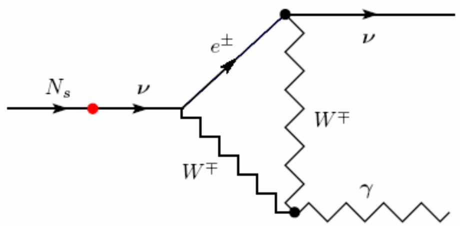
Decay of a 10 keV neutrino

$N_1 \Rightarrow 3\ \nu$, but also radiative decay

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

Photon energy:

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



Radiative decay width:

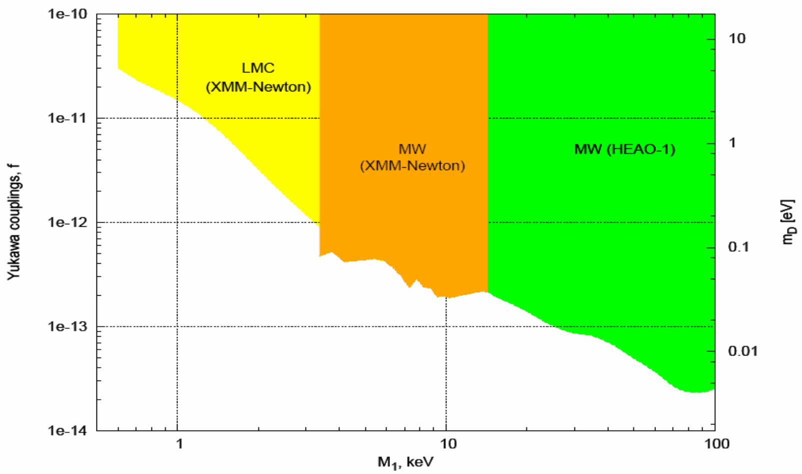
$$\Gamma_{\rm rad} = \frac{9\,\alpha_{\rm EM}\,G_F^2}{256\cdot 4\pi^4}\,\sin^2(2\theta)\,M_s^5$$

Almost stable $\Rightarrow$ DARK MATTER

- $\Rightarrow$ *Warm dark matter*

Limits from cosmology

Search for N_1 radiative decays

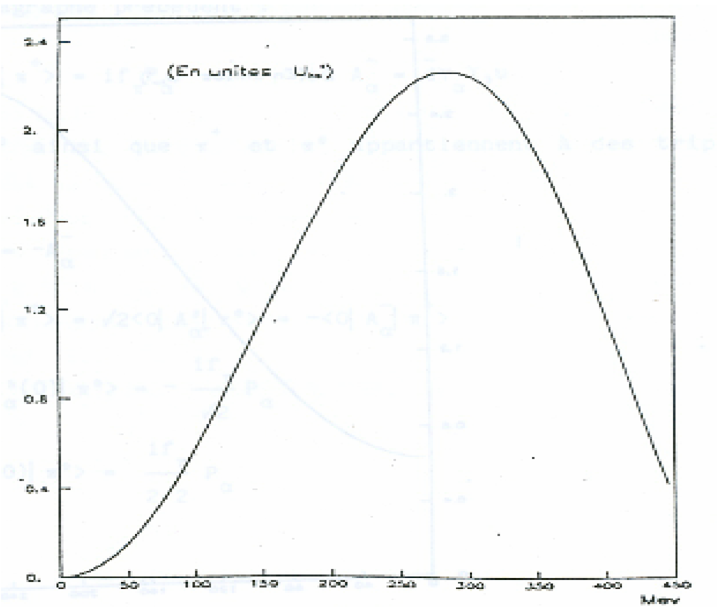


Big Bang nucleosynthesis, N_2, N_3

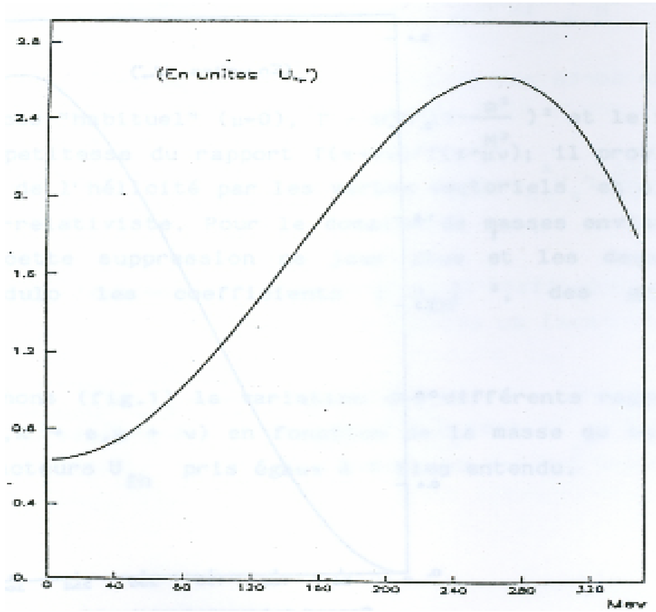
$U^2 < 10^{-8}\ (1/m(\mathrm{GeV}))^2$

Change in kinematics

Helicity conservation revisited



$K \to eN$



$K \to \mu N$

Guesstimates

N produced in Kaon decays

$\Rightarrow$ Flux $3\ 10^{16}\ U^2$

Corrections due to kinematics x 3

And also from focalisation x 5

Decay probability :

$\beta\gamma c\,\tau(m) = 10^{13}\ E(MeV)/m^6\ U^2$

m = 150 MeV $U^2 = 10^{-7}$

m = 200 MeV $U^2 = 4\ 10^{-8}$

m = 250 MeV $U^2 = 2\ 10^{-8}$