NEUTRINOS & EUCLID

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CONTENTS

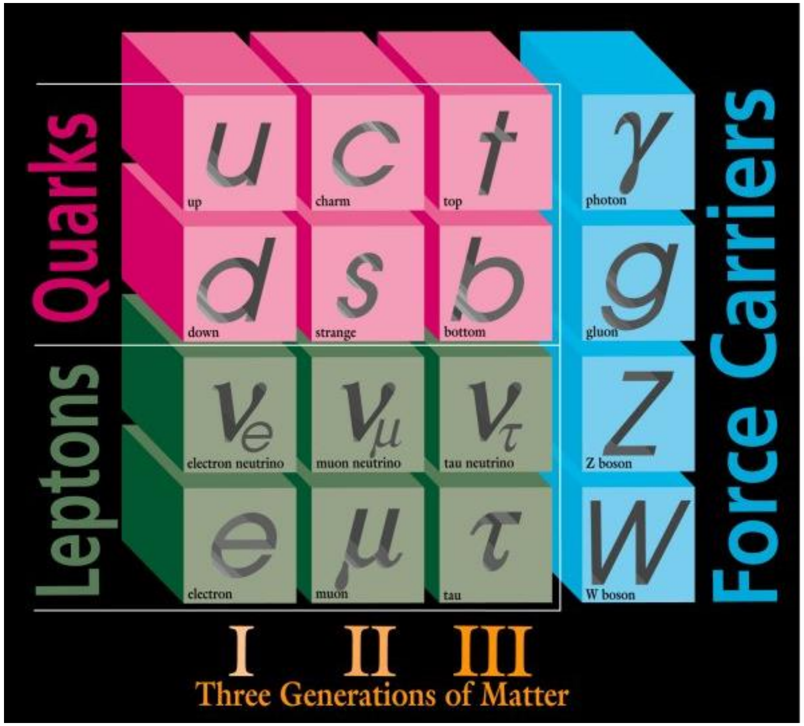
- Neutrino properties
- Matter power spectrum
- Relic neutrinos
- Neutrino mass hierarchy
- Majorana or Dirac ?

NEUTRINOS IN THE STANDARD MODEL

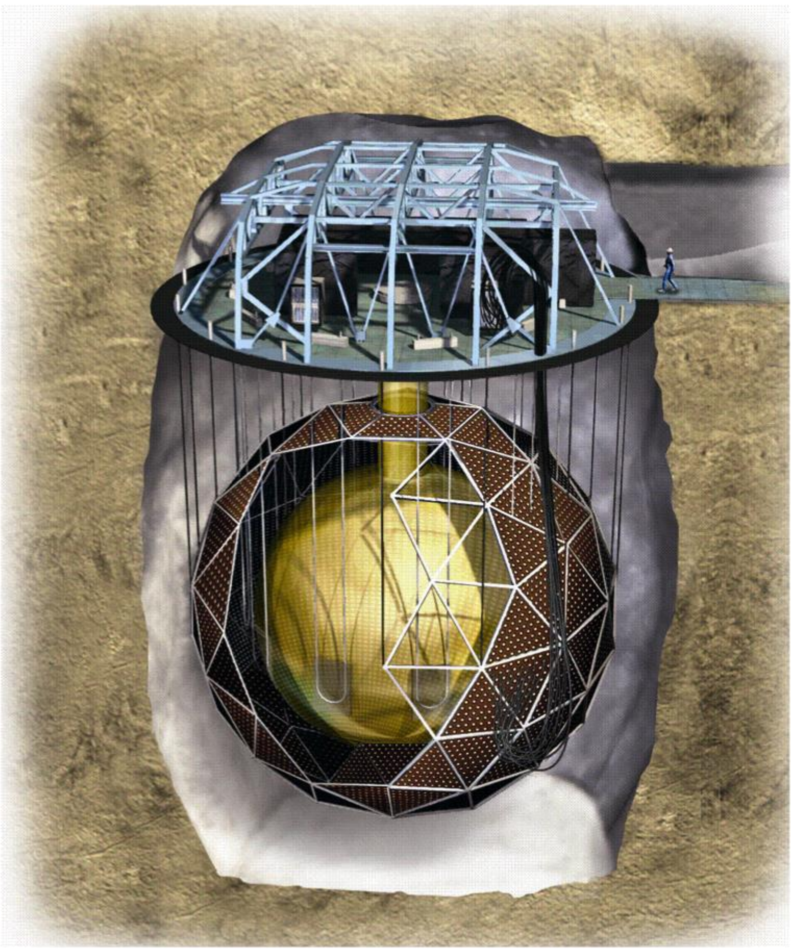
- Three neutrino generations
- Purely weak-interacting
- Only coupling to left-handed ν and right-handed $\bar{\nu}$

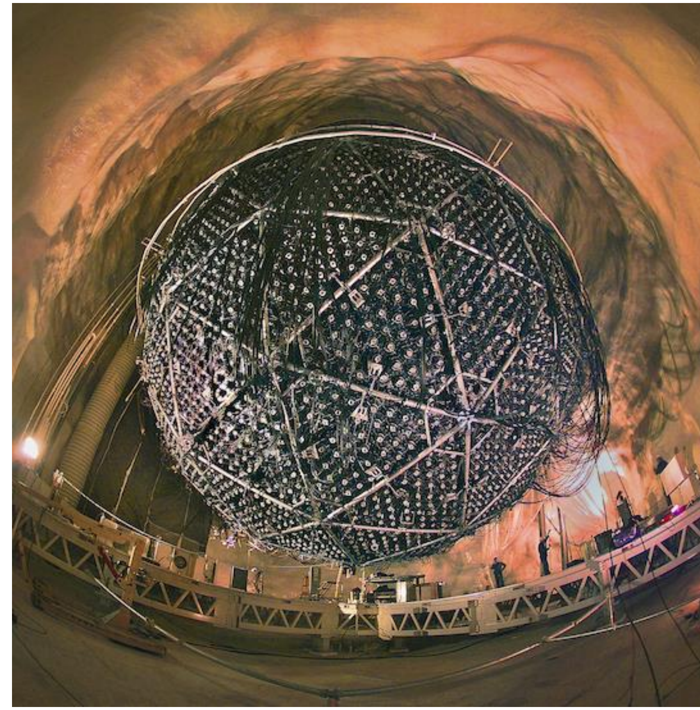
$$j_\mu = \bar{\psi}\gamma_\mu(1-\gamma_5)\psi$$

- Massless $m_{\nu,i} = 0$



THE SNO EXPERIMENT

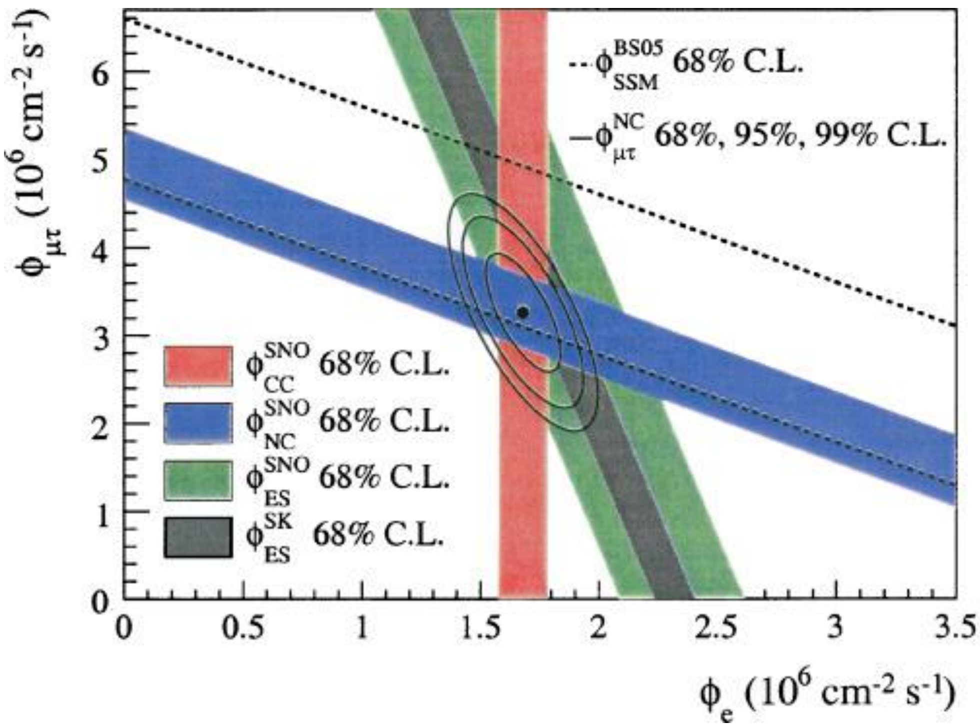




- 1000 tons heavy water detector
- Measures solar $\phi(\nu_e), \phi(\nu_{\mu\tau}), \phi(\nu_{tot})$
- Sun only produces ν_e
- *Expected flux:*

$$\phi(\nu_e) = 5.1 \times 10^6 cm^{-1} s^{-1}$$

NEUTRINO FLAVOUR OSCILLATIONS



Results:

$\phi(\nu_{tot}) = 5.1 \quad \times 10^6 cm^{-1} s^{-1}$

$\phi(\nu_e) \quad = 1.76 \times 10^6 cm^{-1} s^{-1}$

$\phi(\nu_{\mu\tau}) \quad = 3.41 \times 10^6 cm^{-1} s^{-1}$

→ Neutrinos oscillate !

$$P(\nu_e \to \nu_\mu) \propto \left(\sin\frac{c\Delta m^2 L}{E}\right)^2$$

E: Energy, L: Distance, $\Delta m = m_\mu - m_e$

→ Neutrinos have mass !

HOW TO ADD NEUTRINO MASS?

Dirac mass term: $\mathcal{L}_D = -m_D(\overline{\nu_R}\nu_L + \overline{\nu_L}\nu_R)$ → Existence of ν_R

Majorana mass term: $\mathcal{L}_M = -\frac{1}{2}M\left(\overline{\nu_R^C}\nu_R + \overline{\nu_R}\nu_R^C\right)$ → Neutrino its own anti-particle

Combine:

$$\mathcal{L}_{DM} = -\frac{1}{2}\begin{pmatrix}\overline{\nu_L} & \overline{\nu_R^C}\end{pmatrix}\begin{pmatrix}0 & m_D \\ m_D & M\end{pmatrix}\begin{pmatrix}\nu_L^C \\ \nu_R\end{pmatrix}$$

Assume $m_D \ll M$:

→ Light neutrino state: $|m_\nu| \approx \frac{m_D^2}{M}$ → Heavy neutrino state: $m_N \approx M$

Is the neutrino majorana?

MATTER POWER SPECTRUM

Density perturbation field, with matter density ρ

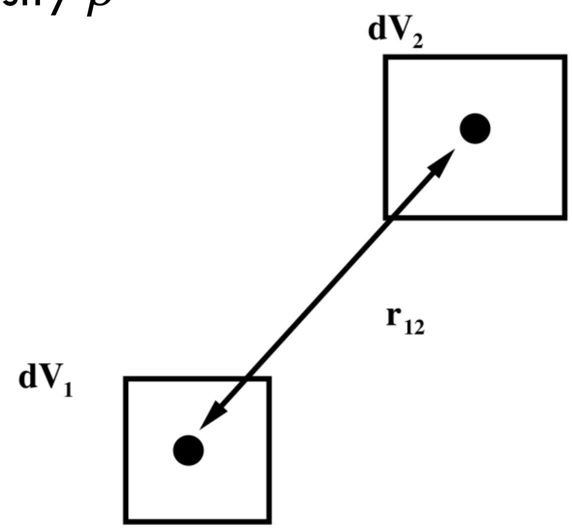
$$\delta(\boldsymbol{x}) \equiv \frac{\rho(\boldsymbol{x}) - \langle\rho\rangle}{\langle\rho\rangle}$$

Correlation function

$$\xi(\boldsymbol{r}) \equiv \langle\delta(\boldsymbol{x})\delta(\boldsymbol{x}+\boldsymbol{r})\rangle$$

Matter power spectrum $\boldsymbol{P(k)}$

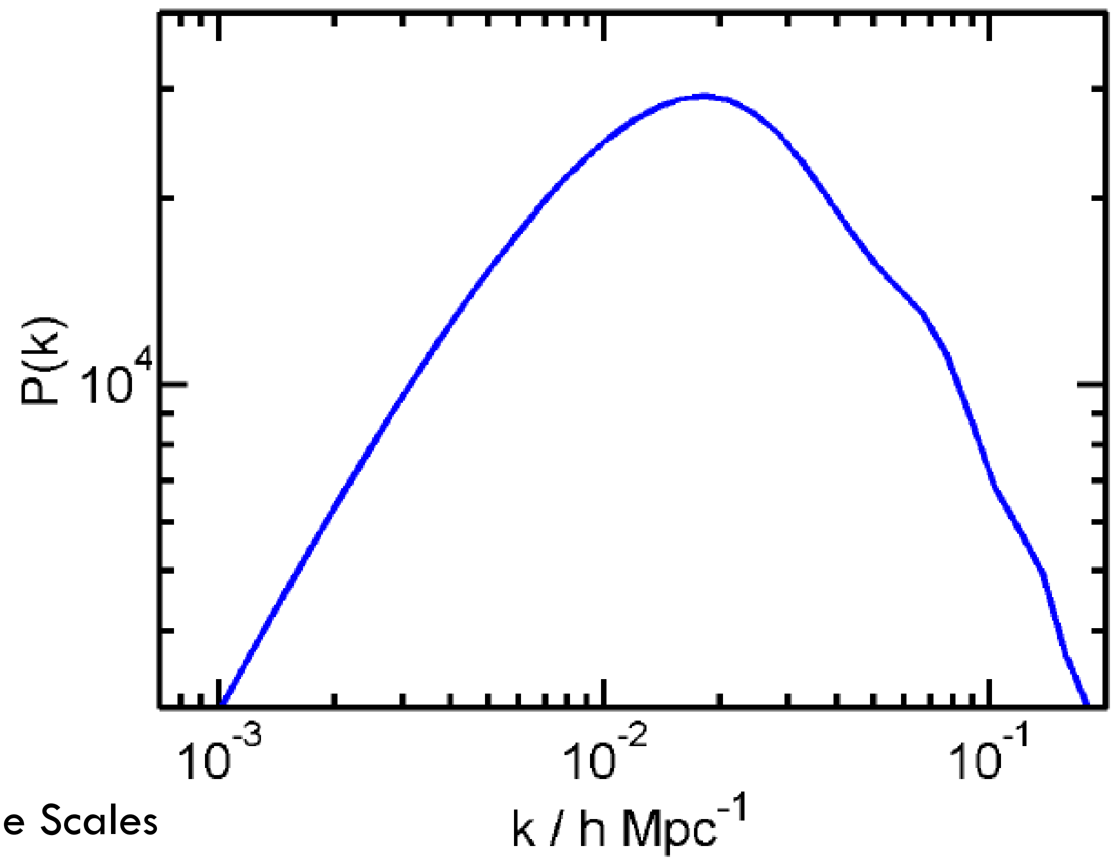
$$\xi(r) = \int \frac{d^3k}{(2\pi)^3} e^{ikr} P(k)$$



Probability to find a neighbour

$$dW = \rho_0^2[1 + \xi(r)]dV_1 dV_2$$

THE MATTER POWER SPECTRUM



$1\ Mpc = 3.26\ 10^6\ Ly$

Large Scales

Small Scales

→ Can be determined from EUCLID's weak lensing measurement

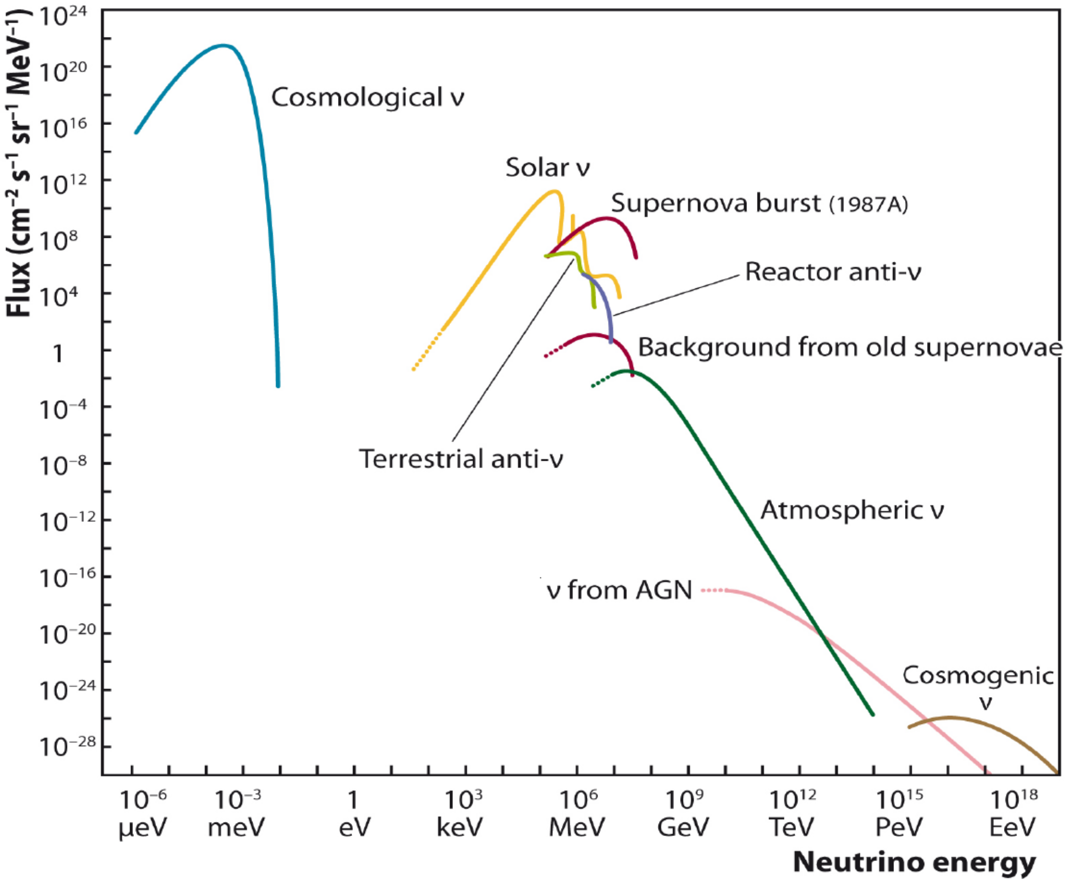
RELIC NEUTRINOS

- Standard hot big bang produces neutrinos

$$\sim 100\ N_\nu cm^{-3}$$

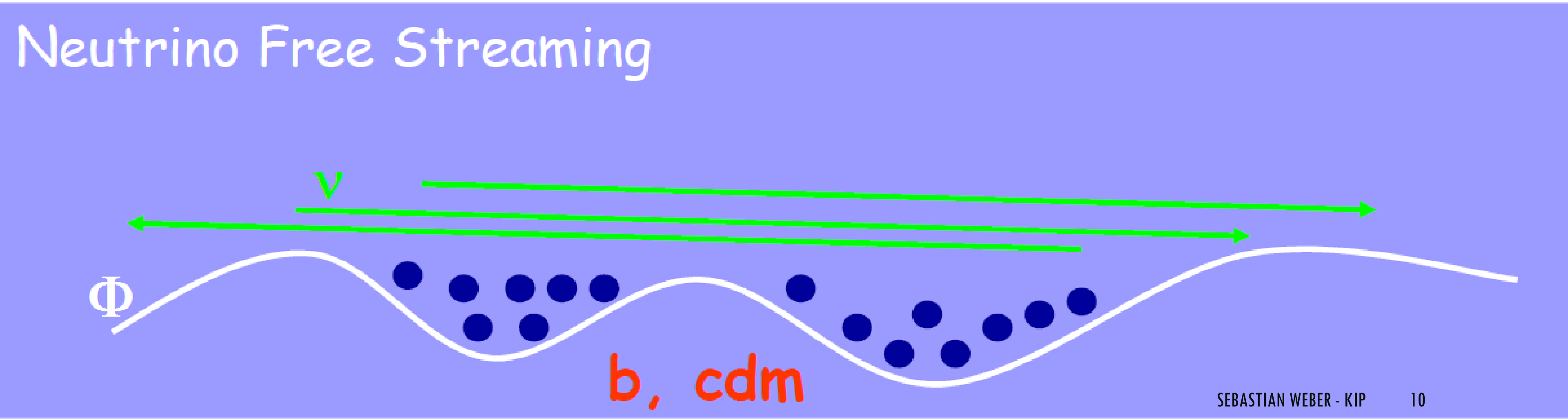
- Not yet (directly) detected!

- EUCLID could detect influence on structure formation



RELIC NEUTRINOS & STRUCTURE FORMATION

- Neutrinos decouple very early $(\sim 0.2\ s)$ from primordial plasma
- Initially $T \approx 1\ MeV$ → Neutrinos ultra-relativistic
- Still relativistic in the matter dominated universe
- Small-scale density fluctuations damped by free-streaming



RELIC NEUTRINOS – FREE STREAMING LENGTH

- Free-streaming length λ_{FS} determines damping of density fluct.

  → Neutrinos cannot be confined within λ_{FS}

- Maximum of λ_{FS} at non-relativistic transition

  → Minimum free-streaming wavenumber

$$k_{nr} \propto \left(\frac{m_\nu}{1\ eV}\right)^{1/2} h\ Mpc^{-1}$$

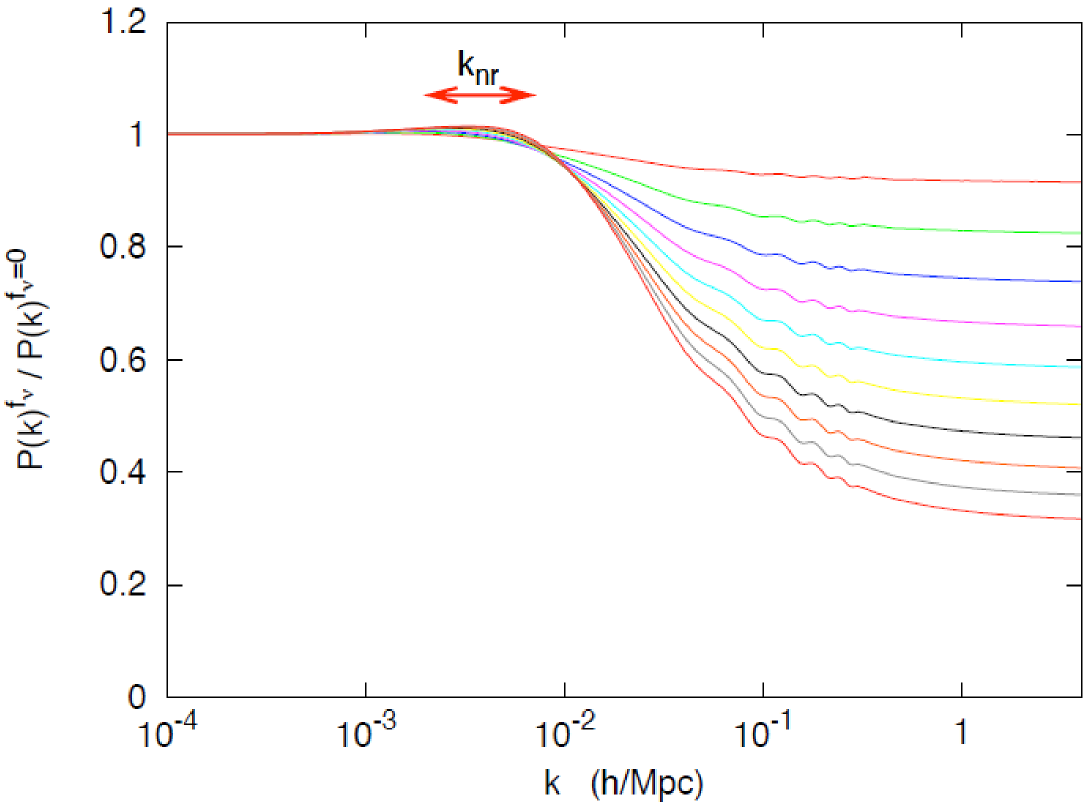
- Damping of P(k) for modes with $k > k_{nr}$ due to Neutrino mass

  → Detection of relic Neutrinos within reach of EUCLID

RELIC NEUTRINOS – POWER SPECTRUM

$3\ \nu, m = 0$

$3\ \nu, m = m_\upsilon$

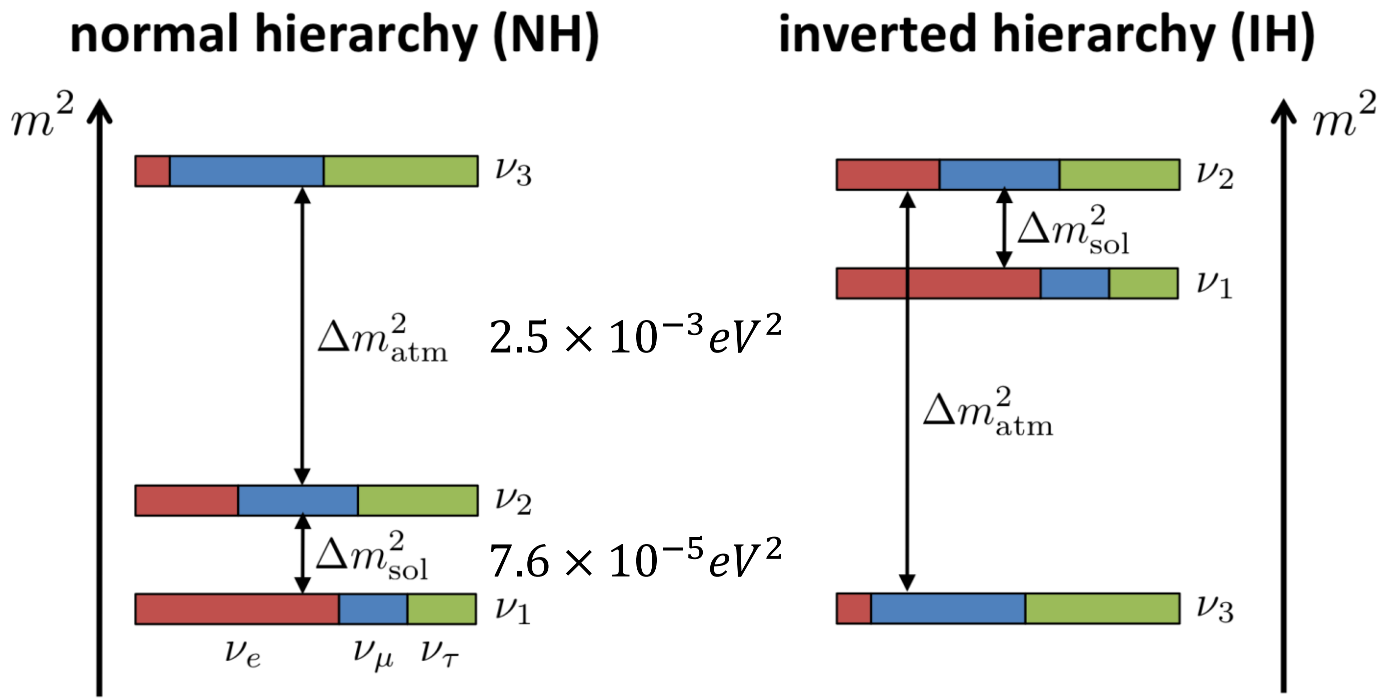


$m_\upsilon = 0.046\ eV$

$m_\upsilon = 0.46\ eV$

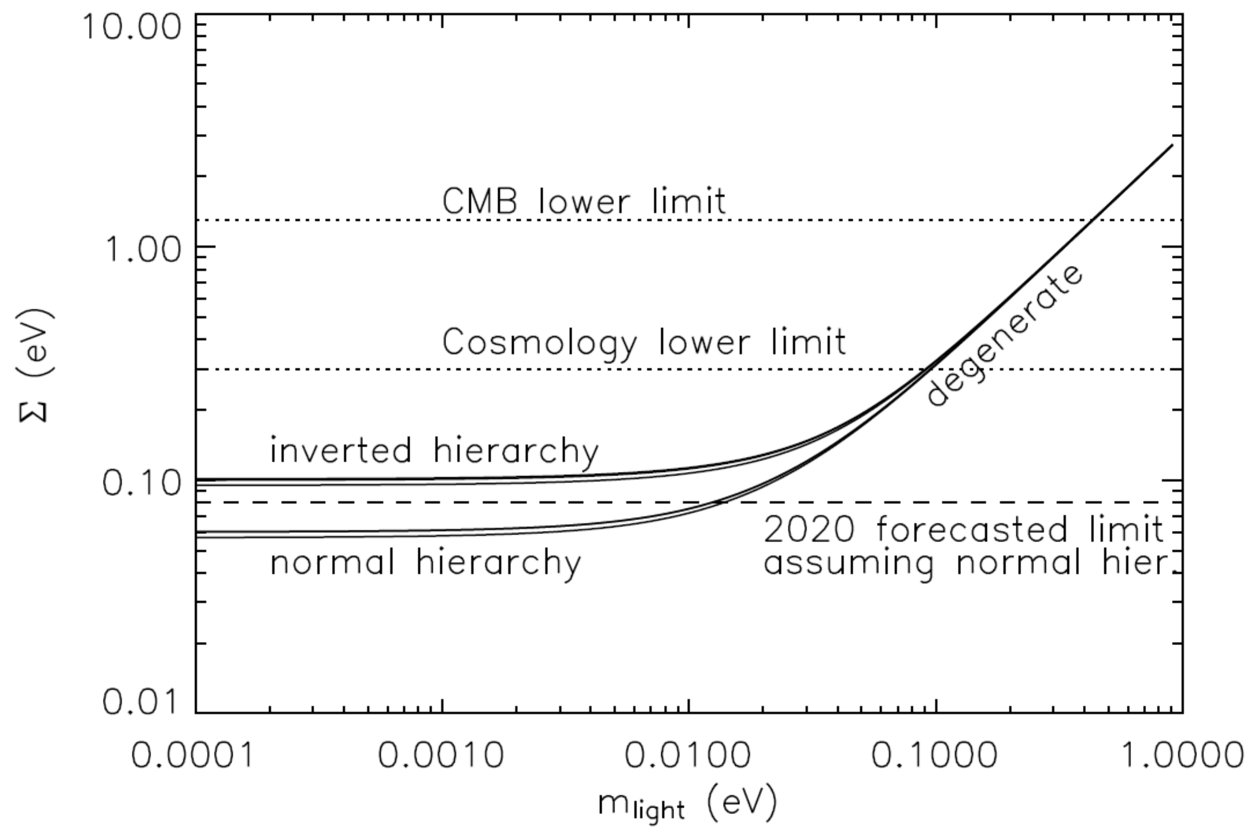
→ Higher neutrino mass leads to stronger damping! → EUCLID: $\Sigma < 0.05\ eV$

NEUTRINO MASS HIERARCHY



Third possibility: Splitting small against masses → Degenerate Case

NEUTRINO MASS HIERARCHY



→ For total mass $\sum < 0.1\ eV$, EUCLID can constrain hierarchy

NEUTRINO MASS HIERARCHY

- Neutrinos of different mass have different free streaming length

  → Detailed shape of $P(k)$ depends on individual m_{υ}

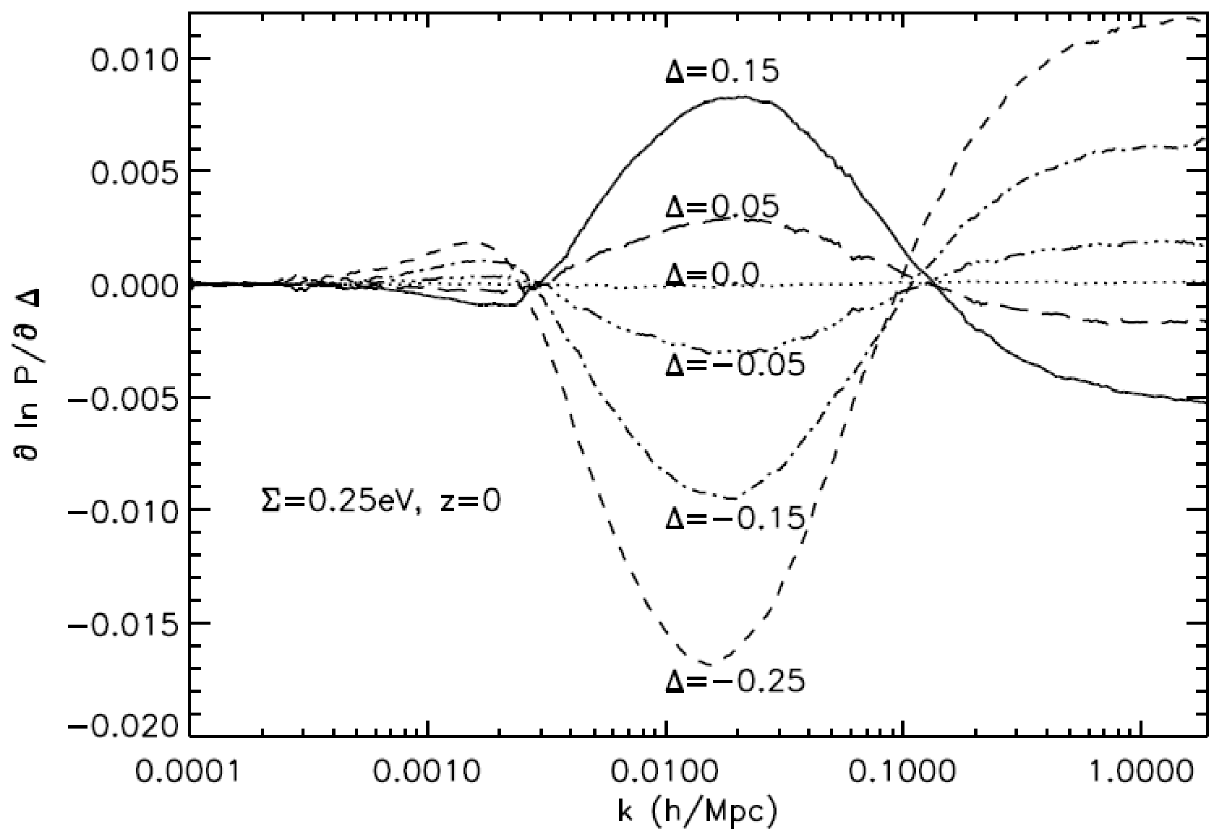
- Smaller splitting negligible, consider light mass (m) and heavy mass (M)

NH: $\Sigma = 2m + M \qquad \Delta = (M - m)/\Sigma > 0$

IH: $\Sigma = m + 2M \qquad \Delta = (m - M)/\Sigma < 0$

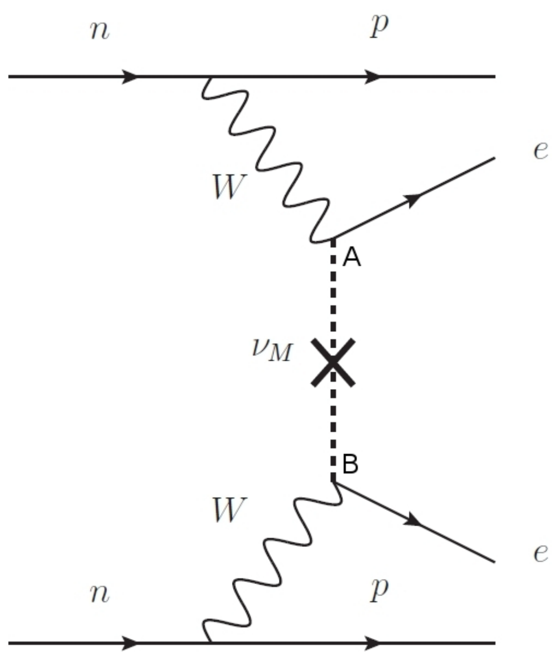
- Exploit dependece of $P(k)$ on Δ, sign of Δ gives hierarchy

NEUTRINO MASS HIERARCHY



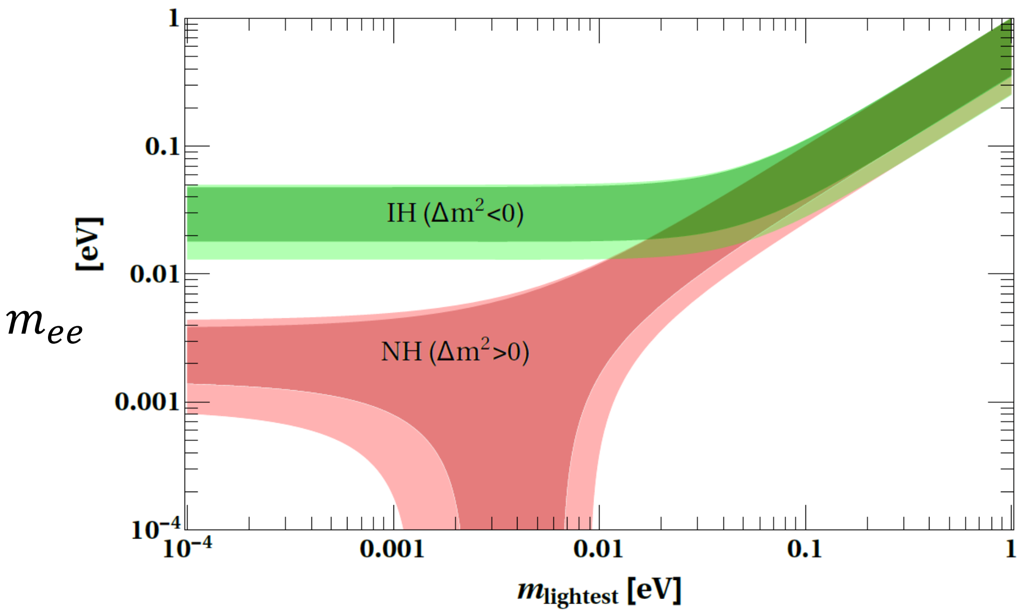
EUCLID might be able to measure this!

MAJORANA VS DIRAC



- With Majorana neutrinos, neutrinosless double-beta decay possible
  - Search: Gerda, Majorana, …
- Rate is proportional to effective mass squared m_{ee}^2
- Next generation experiments probe $m_{ee} \approx 10\ meV$

MAJORANA VS DIRAC



If no $0\nu\beta\beta$ observed

EUCLID determines IH

Neutrino is a dirac particle!

CONCLUSION

- EUCLID can perform very precise measurement of matter power spectrum
- EUCLID could detect relic neutrinos & determine the total neutrino mass
- EUCLID has a chance to determine the neutrino mass hierarchy
- EUCLID can contribute to the question if neutrinos are Majorana or Dirac