WP1 Standard neutrino framework

Conv. D. Montanino e F. Vissani

PRIN NAT-NET meeting 6 Luglio 2021

The unfinished fabric of the three neutrino paradigm

Francesco Capozzi,[1] Eleonora Di Valentino,[2] Eligio Lisi,[3]
Antonio Marrone,[4,3] Alessandro Melchiorri,[5,6] and Antonio Palazzo[4,3]

arXiv:2107.00532

[Global analysis 2021 : review of 3ν knowns + focus on unknowns]

Eligio Lisi
INFN - Bari

PRIN NAT-NET, Neutrino & Astroparticle Theory NETwork 2nd meeting, 6 July 2021 (online)

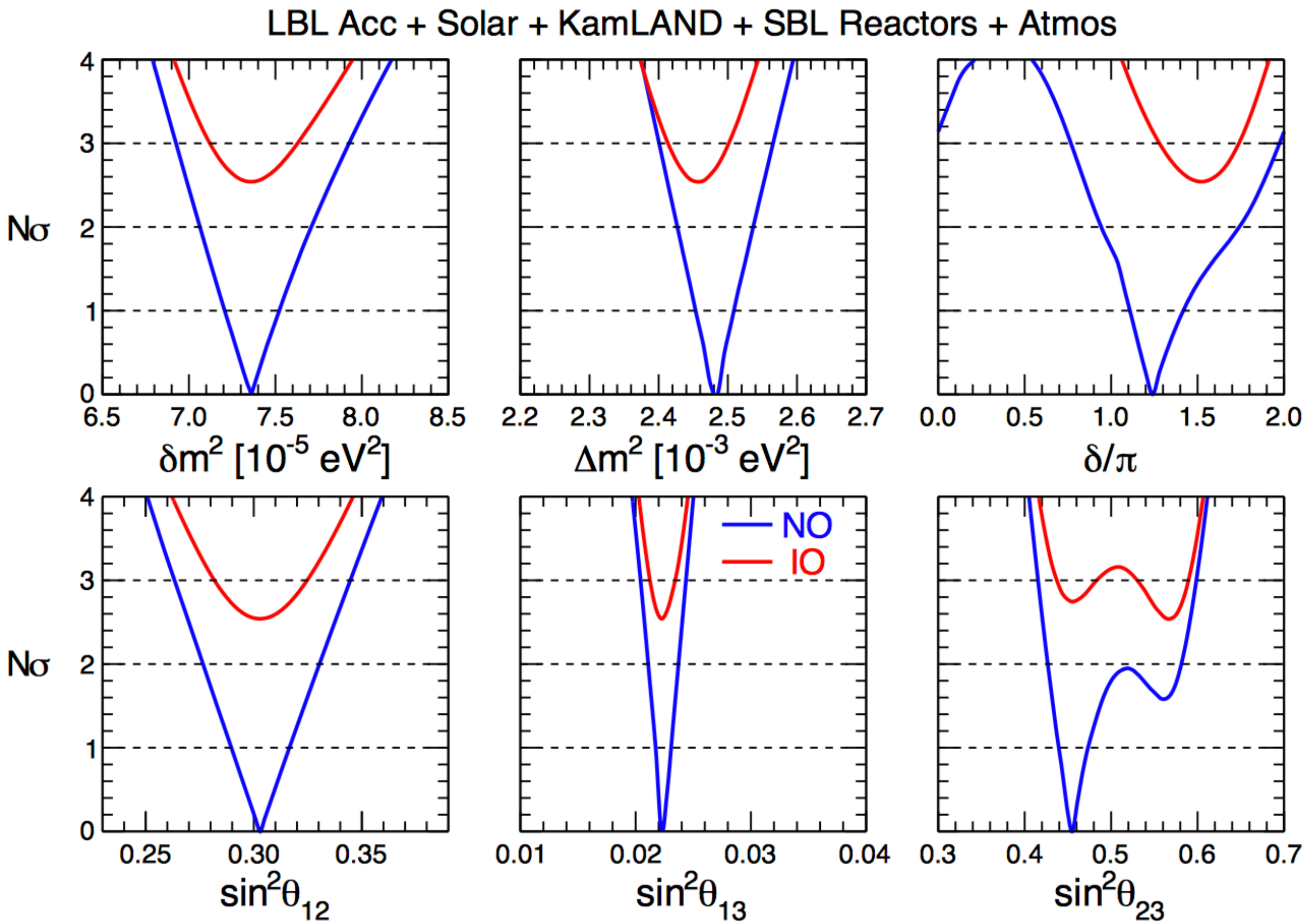
3ν knowns

δm^2	"solar" splitting
Δm^2	"atmospheric" splitting
θ_{13}	"small" mixing angle, ~O(Cabibbo)
θ_{12}	"intermediate" mixing angle
θ_{23}	"large" mixing angle $\sim\pi/4$

3ν unknowns

sign(Δm^2)	Normal/Inverted mass ordering
octant(θ_{23})	Octant of the largest mixing angle
δ	CP phase
$\langle m_{eff} \rangle$	absolute (effective) mass scale
dof = 4 or 2	Majorana or Dirac

FROM OSCILLATION DATA:



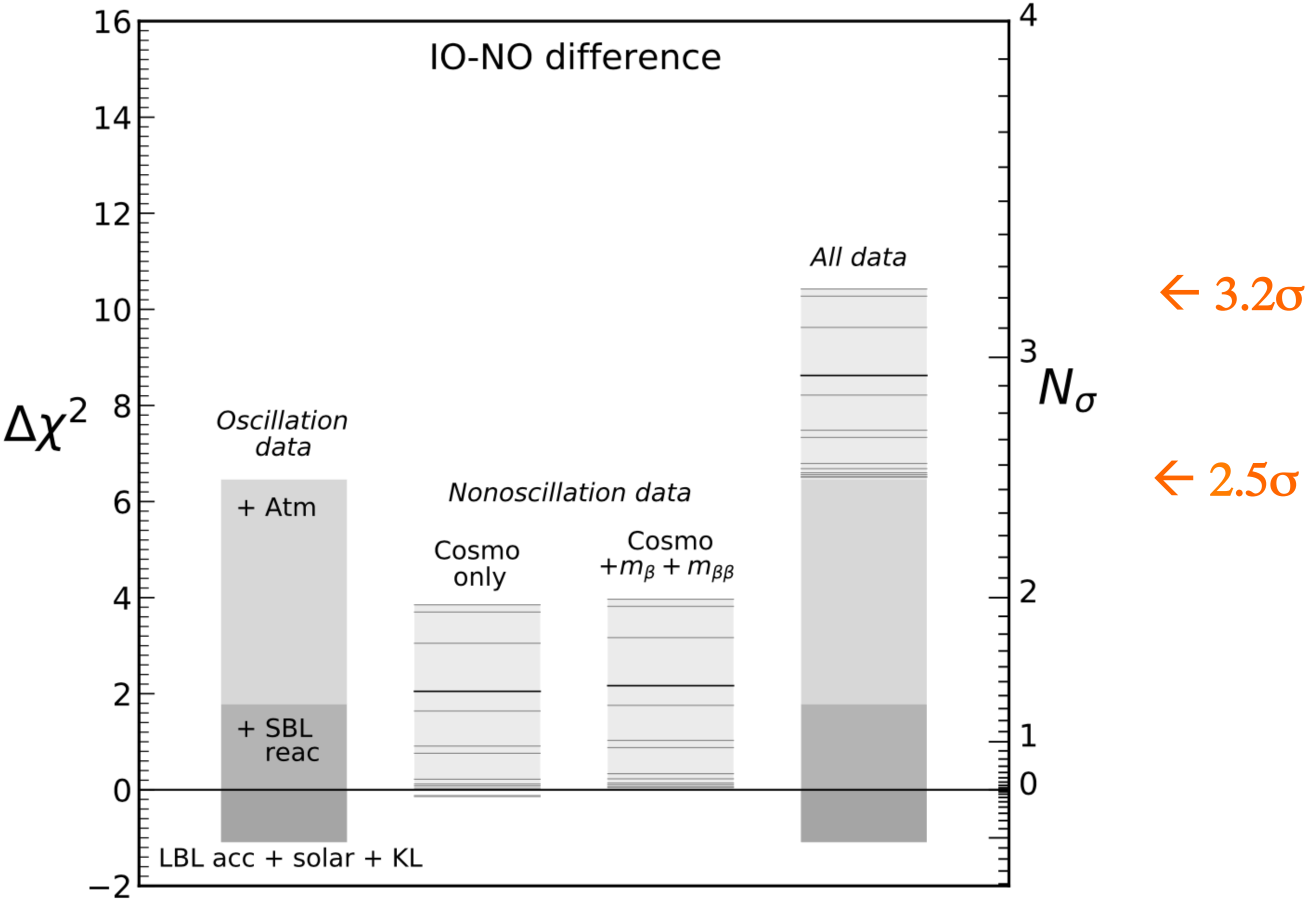
← slight preference for **CPV** (90% CL)

← slight preference for lower octant of θ_{23} (90% CL)

Preference for Normal Ordering (NO) at $\sim 2.5\sigma$

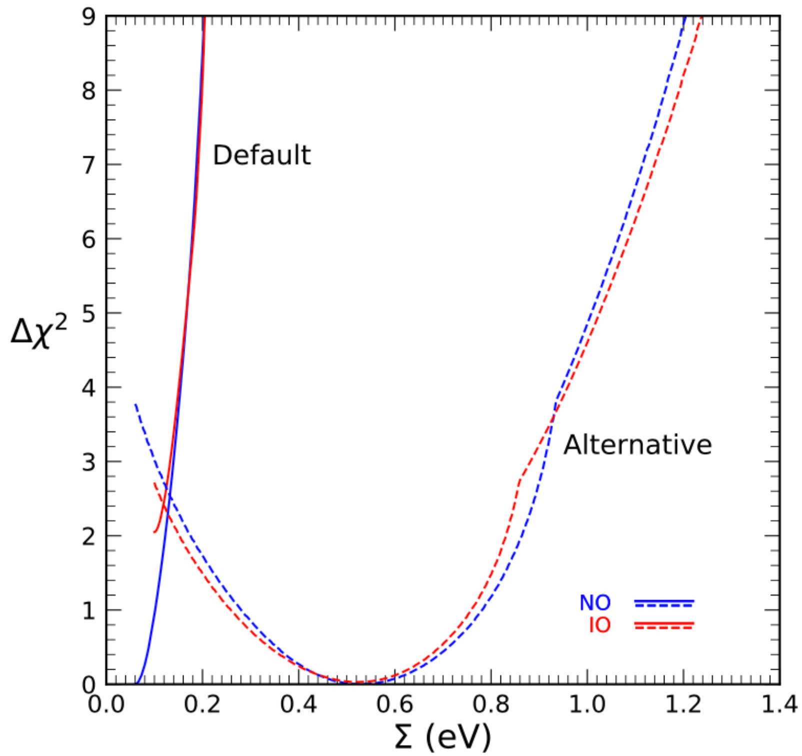
Somewhat weaker than in the past, due to T2K-NOvA accelerator data tension

FROM NONOSCILLATION DATA:



Preference for Normal Ordering (NO) may go up to ~3.2σ depending on different cosmological inputs

Two representative cosmological input options



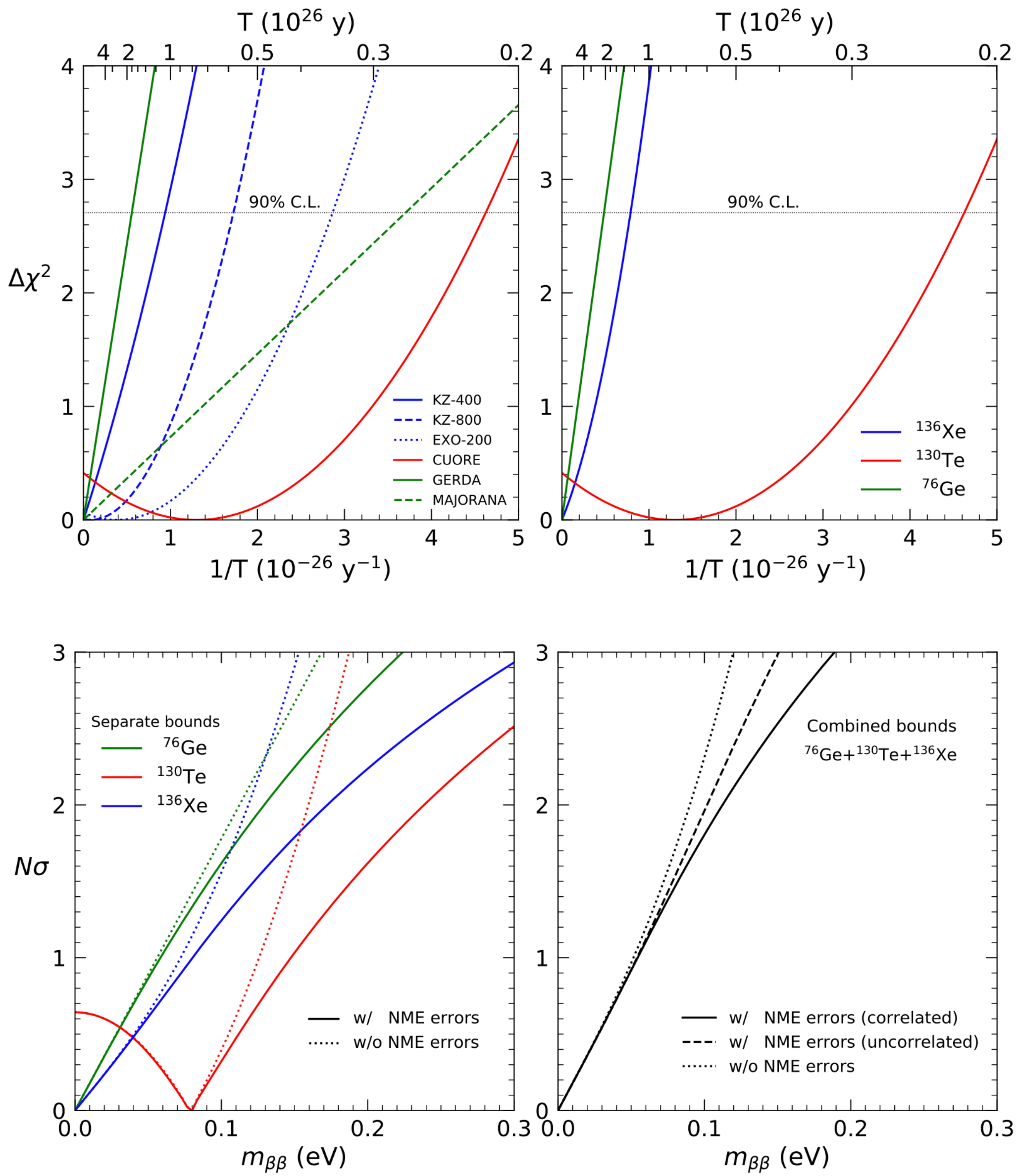
"Default": get typical mass bounds at ~0.1 eV, plus some sensitivity to NO/IO, while accepting some internal data tension (e.g., about lensing)

→ more difficult to test with (double) beta decay searches

"Alternative": get relaxed mass bounds and a possible "signal" at ~ few x 0.1 eV, but no sensitivity to NO/IO, while accepting only concordant CMB data

→ less difficult to test with (double) beta decay searches

Methodology to deal with comparable results from different $0\nu\beta\beta$ searches



from half lives...

...to effective Majorana mass

3ν knowns

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3ν unknowns

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Main message: Take care of tensions among different data in various contexts, and remain open to several outcomes about the remaining 3-nu unknowns

PHYSICAL REVIEW D **102,** 056001 (2020)

Mapping reactor neutrino spectra from TAO to JUNO

Francesco Capozzi,[1] Eligio Lisi,[2] and Antonio Marrone[3,2]
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[2]*Istituto Nazionale di Fisica Nucleare, Sezione di Bari, Via Orabona 4, 70126 Bari, Italy*
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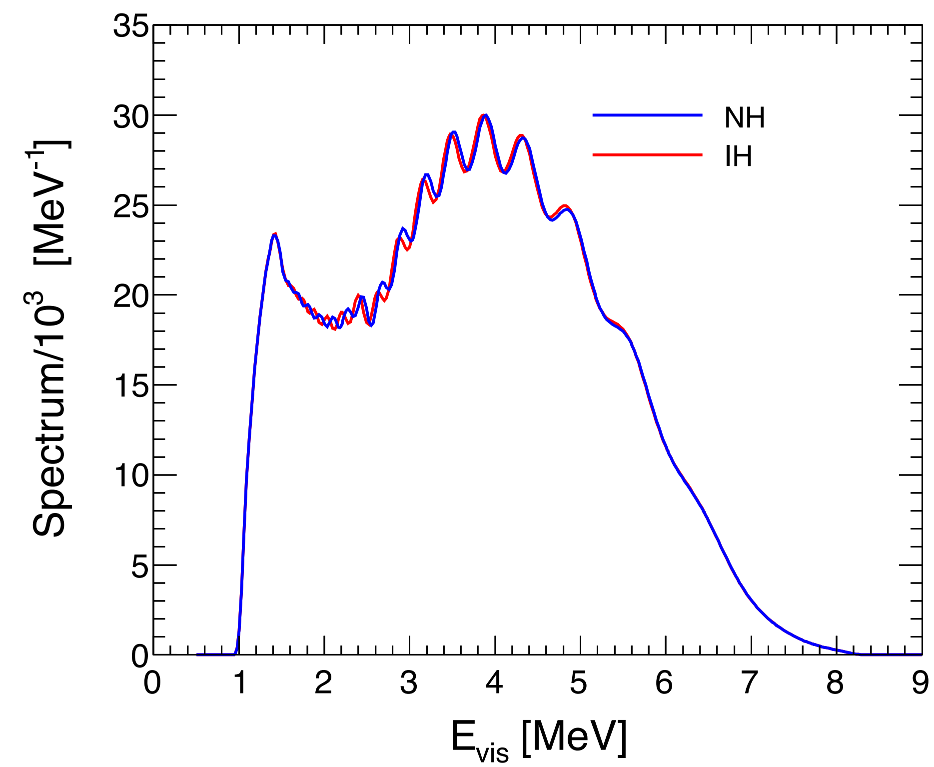
JUNO is medium-baseline reactor neutrino experiment whose main purposes are to probe the Mass Ordering and to measure the mass-mixing oscillation parameters with sub-percent precision

It will be complemented with a ton-level, high energy resolution liquid scintillator reference detector, TAO, that will measure the reactor neutrino spectrum with unprecedented accuracy



The dependence of the MO on the interference between long and short-wavelength oscillations manifests itself essentially through the displacement of the fast oscillation peaks in the low energy region (2-4 MeV)

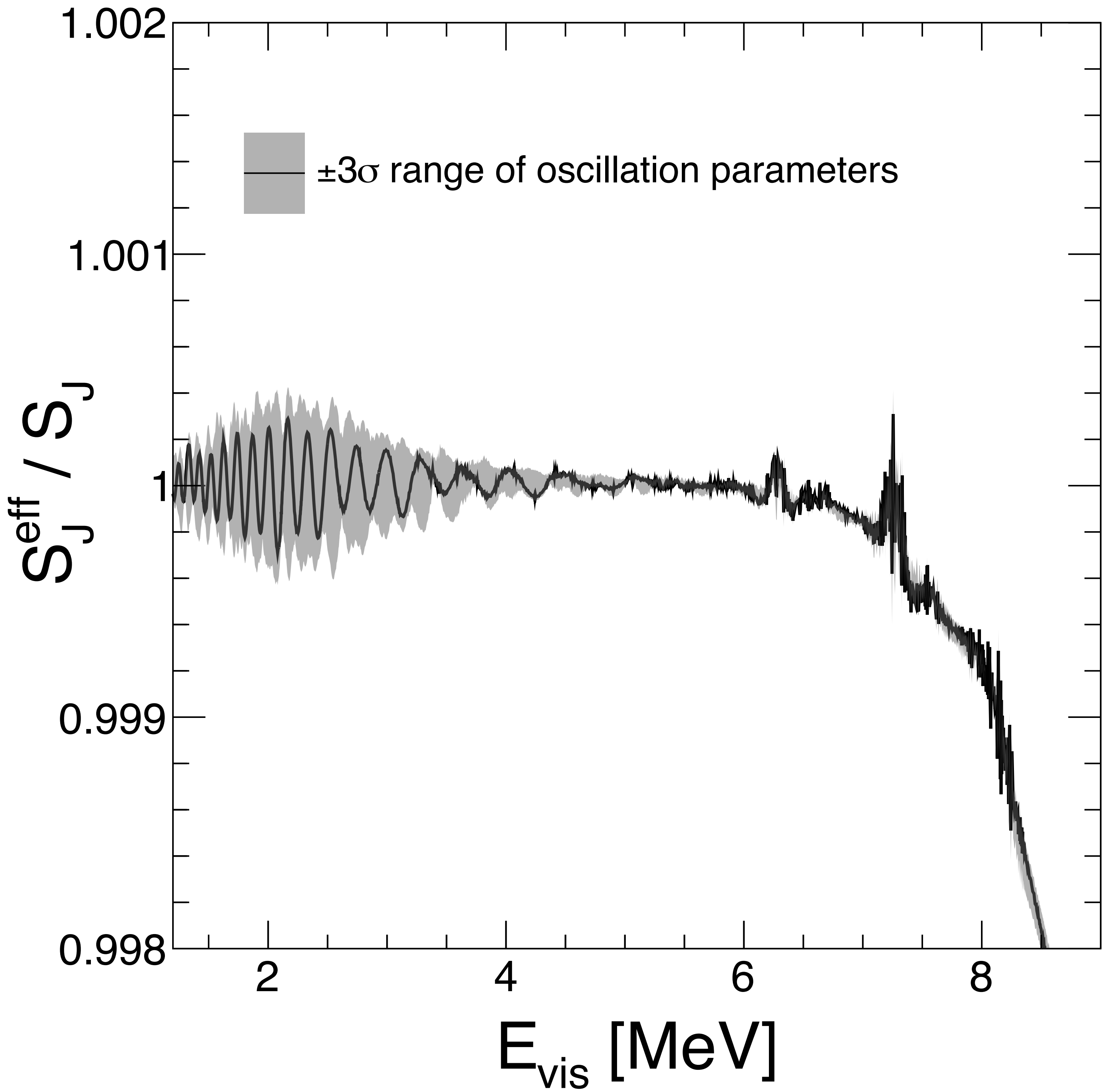
Issues explored in this work

- What will be the advantage of the TAO reference detector?
- Can the limited knowledge of the reactor antineutrino spectrum and of its fine structure have a significant effect on the mass ordering determination and on the precision measurements of the oscillation parameters?

We have shown that any observable energy spectrum of events in TAO can be mapped into a corresponding spectrum in JUNO by a proper convolution

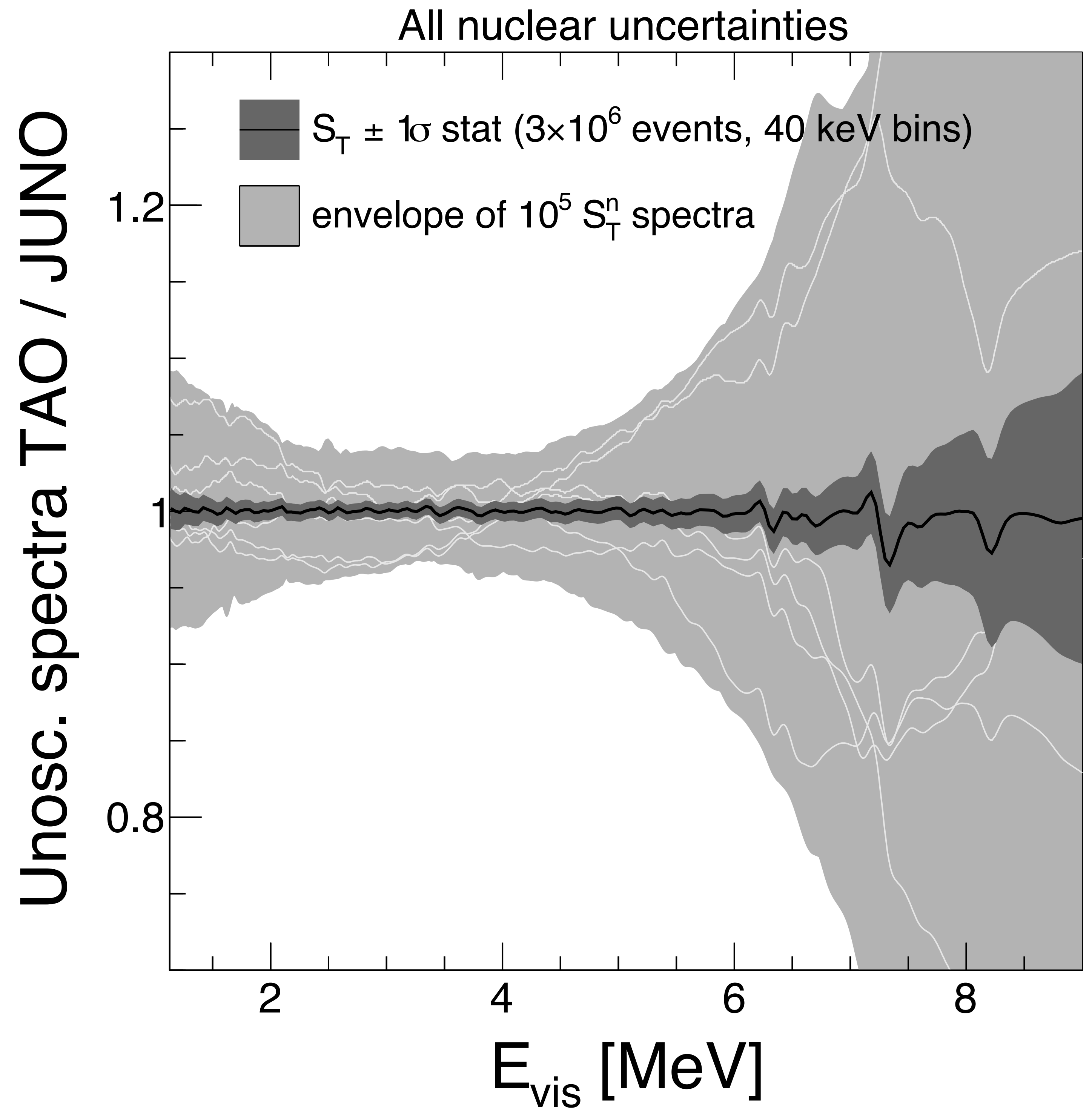
Ratio between the approximated and exact spectrum calculation (best-fit point, NO; similar results for IO and varying oscillation parameters)

In the region of interest for the mass ordering discrimination (2-4 MeV) the approximate calculation is accurate at the level of < 0.05%

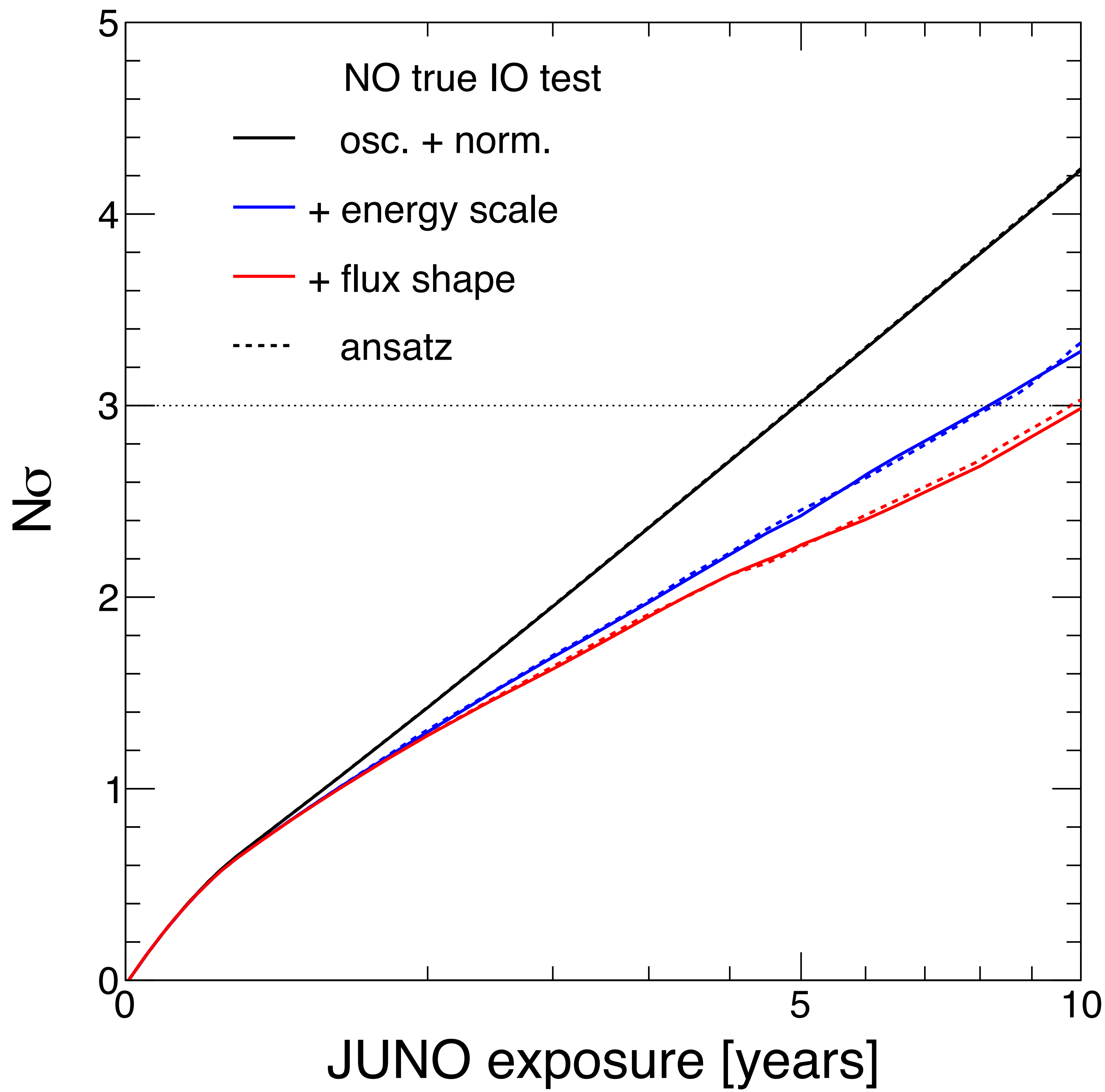


We have generated 10^5 neutrino spectra by randomly varying all nuclear inputs within their uncertainties. We also compute the associated TAO spectra that are then mapped to JUNO spectra

We have repeated the prospective JUNO data analysis testing the wrong IO scanning the simulated spectra. We have found no reduction of the sensitivity to the mass ordering. In addition, we also verified that the precision determination of several parameters remains unaltered



The fine structures of the ν spectrum do not constitute a problem for the MO sensitivity nor for the precision measurements of the oscillation parameters, even when all uncertainties in the summation calculation are taken into account



The Sun and solar neutrinos

F. L. Villante
University of L' Aquila and LNGS-INFN

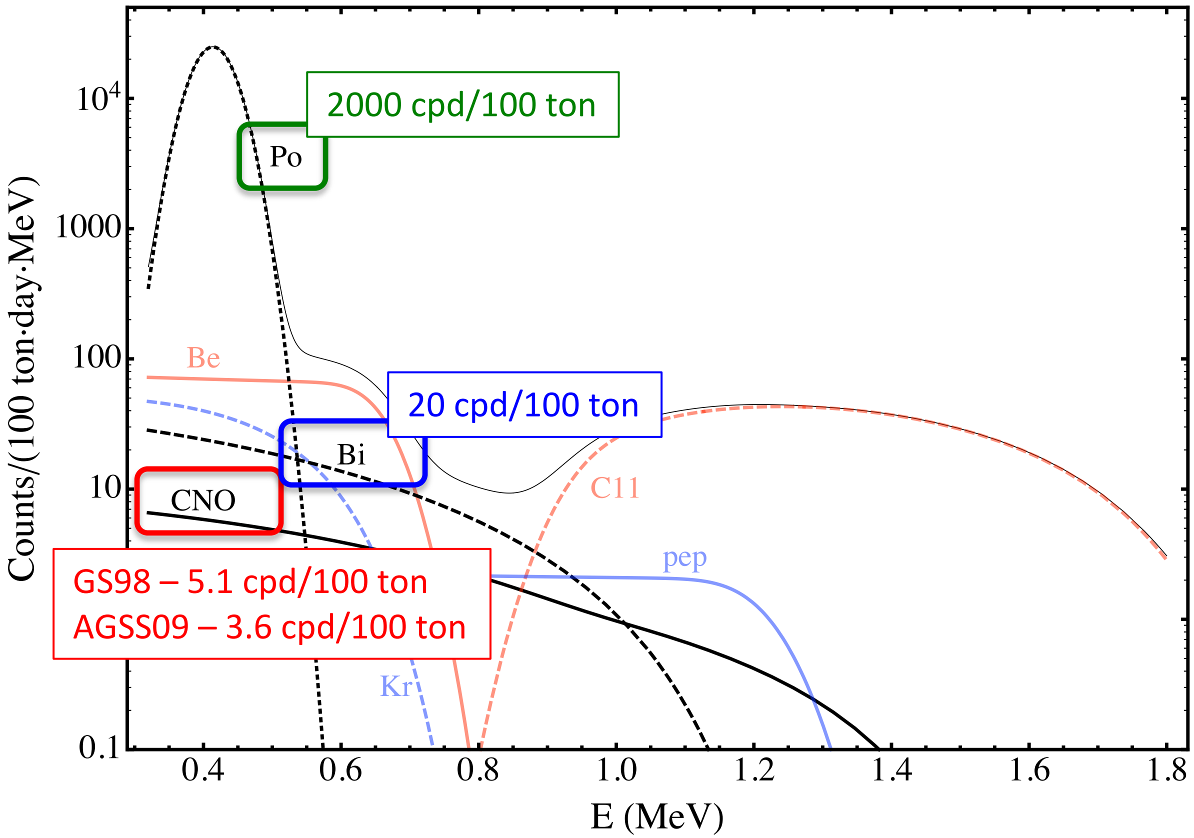
Determining ^{210}Bi with the help of ^{210}Po

$$^{210}\text{Bi} \rightarrow {}^{210}\text{Po} + e^- + \overline{\nu}_e$$

τ_{Bi} = 7.232 d

$$^{210}\text{Po} \rightarrow {}^{206}\text{Pb} + \alpha$$

τ_{Po} = 199.634 d



F.L. Villante et al. - Phys.Lett. B701 (2011) 336-341

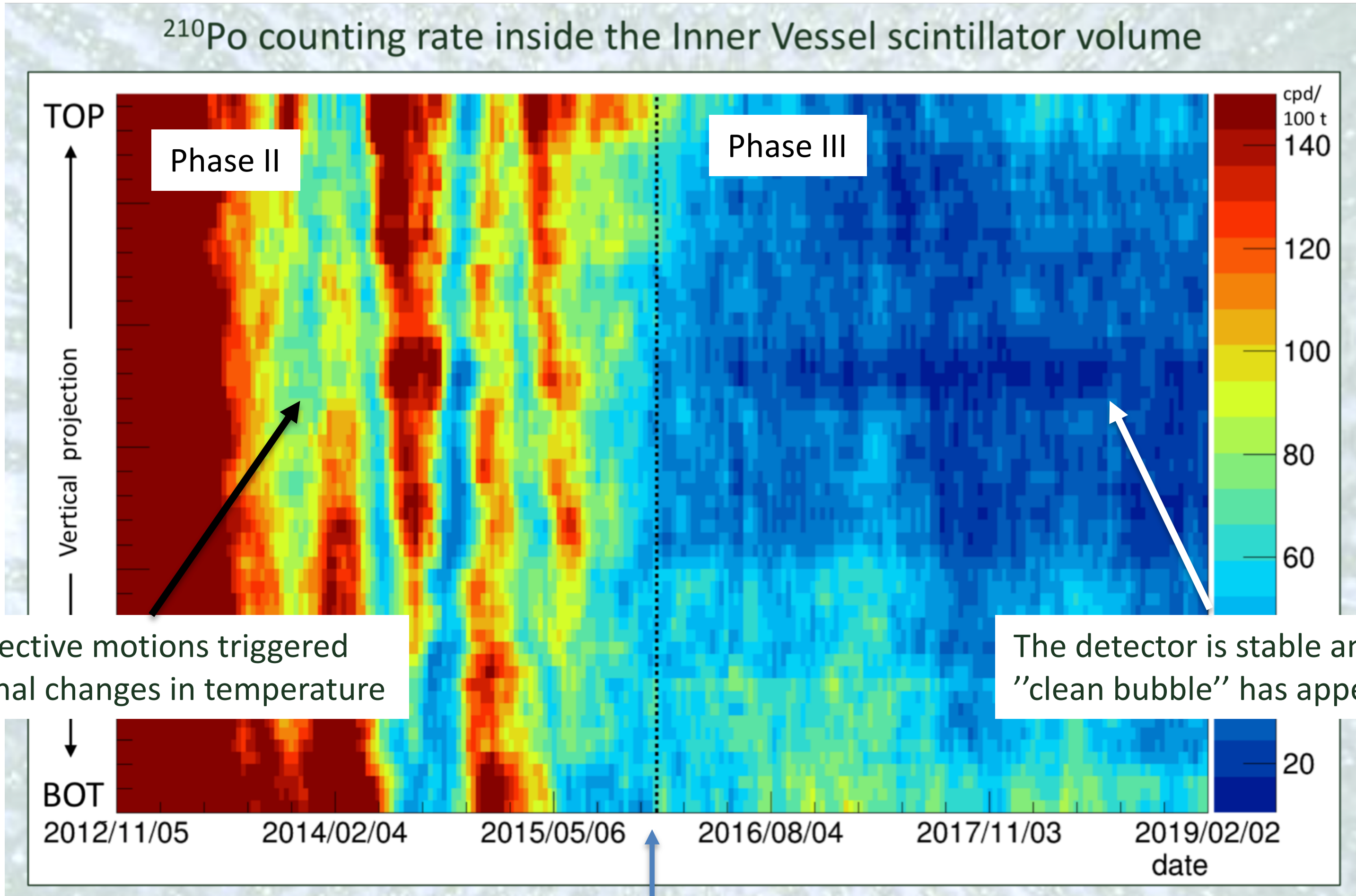
- The ^{210}Po (time and space) distribution can be used to determine ^{210}Bi

$$n_{\text{Po}}(t) = [n_{\text{Po},0} - n_{\text{Bi}}] \exp(-t/\tau_{\text{Po}}) + n_{\text{Bi}}$$

but the detector should be stable (no convective motions) over long time scales.

Towards a CNO measurement in Borexino

Alessandra Carlotta Re, talk@ NuPhys2019

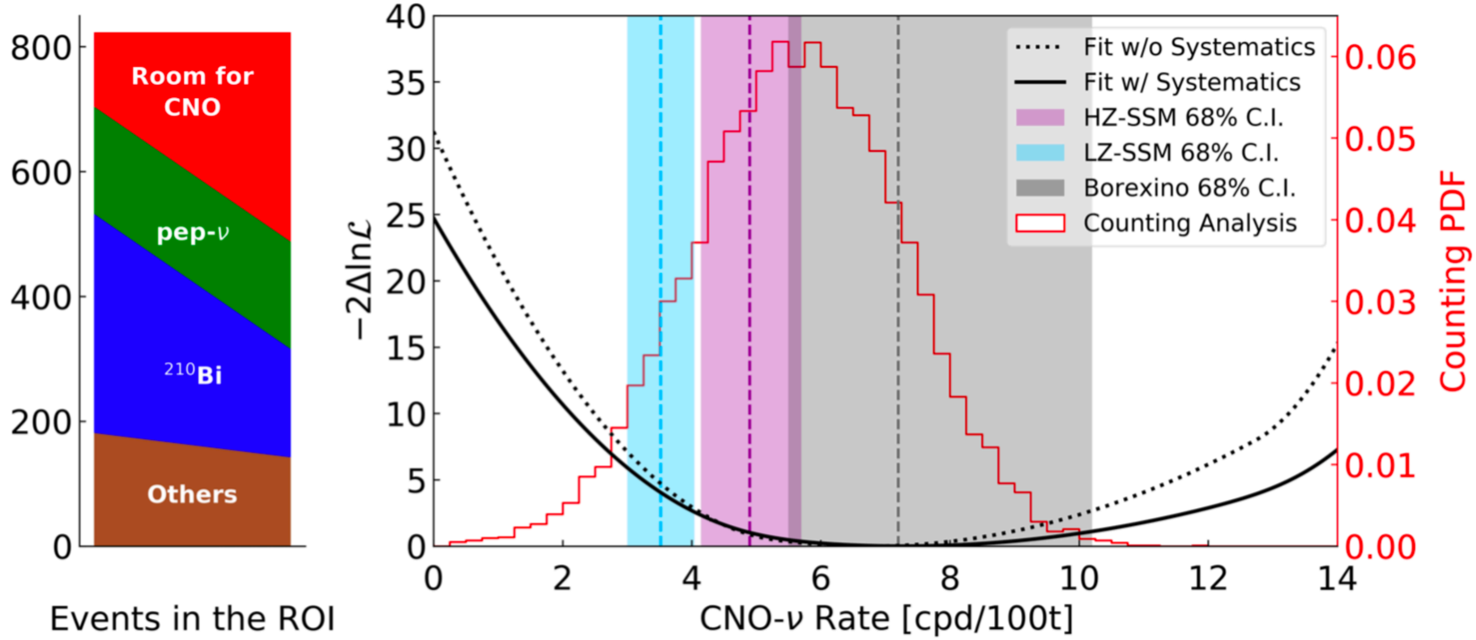


The convective motions triggered by seasonal changes in temperature

The detector is stable and a ’’clean bubble’’ has appeared

Thermal insulation of the detector

The CNO neutrino flux measured by Borexino



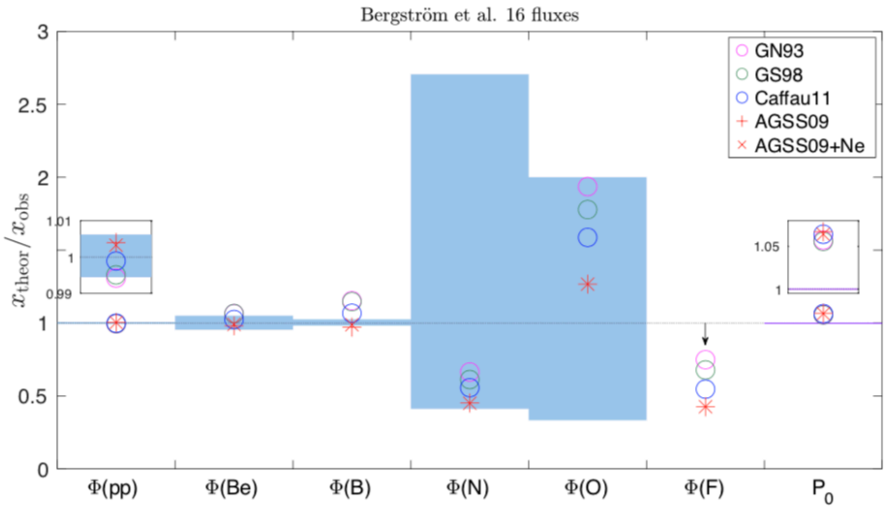
The observed CNO solar neutrino interaction rate in Borexino is:

R_{BX} (CNO) = $7.0^{+3.0}_{-1.7}$ cpd/100t   Agostini et al. (Borexino Coll.) , Nature, 2020

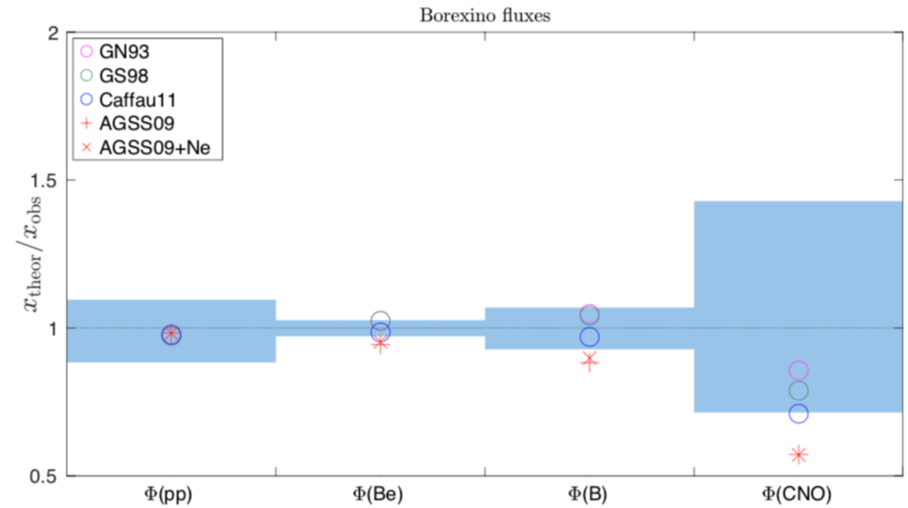
[Absence of CNO neutrino signal disfavoured at 5.0σ]

Neutrino fluxes - the present situation

Comparison between theoretical predictions and observational results:
[Salmon et al. 2021]



Pre-2020 (Bergstrom et al, 2016)



Borexino fluxes

$$\frac{N_{\rm C}+N_{\rm N}}{N_{\rm C}^{\rm SSM}+N_{\rm N}^{\rm SSM}} = \left(\frac{\Phi_{^8{\rm B}}}{\Phi_{^8{\rm B}}^{\rm SSM}}\right)^{-0.716} \times$$
$$\times \frac{R_{\rm CNO}^{\rm BX}}{R_{\rm CNO}^{\rm SSM}} \times [1 \pm 0.5\%({\rm env})$$
$$\pm 9.1\%({\rm nucl}) \pm 2.8\%({\rm diff})]$$

Agostini et al. (Borexino Coll.), EPJ 2020
Seerenelli et al, PRD 2013
Villante and Serenelli, Frontiers of Astronomy 2021

→ To exploit the full potential of future CNO determinations: improvements in nuclear cross sections (e.g. S_{114}) are needed

Conclusions

- Solar neutrino physics is entering the precision era

- Detailed knowledge of the of solar core → constraints on standard and non/standard energy generation and transfer mechanisms; solar chemical evolution paradigm, etc.

- To exploit the full potential of future measurements → improvements in the SSM constitutive physics are needed [radiative opacities and nuclear cross sections]

- Some unsolved puzzles could be addressed → Future CNO neutrino measurements, combined with precise determinations of ^{8}B and ^{7}Be fluxes, can shed light on the solar abundance problem

A PROJECT BORN IN THE PRIN NAT-NET JOURNAL CLUB!

WORKING PACKAGE 1

Primordial Black Hole Dark Matter Evaporating on the Neutrino Floor

R. Calabrese[1], D. F. G. Fiorillo[1], G. Miele[1,2], S. Morisi[1], A. Palazzo[3,4].

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[2] Scuola Superiore Meridionale, Università degli studi di Napoli "Federico II", Largo San Marcellino 10, 80138 Napoli, Italy

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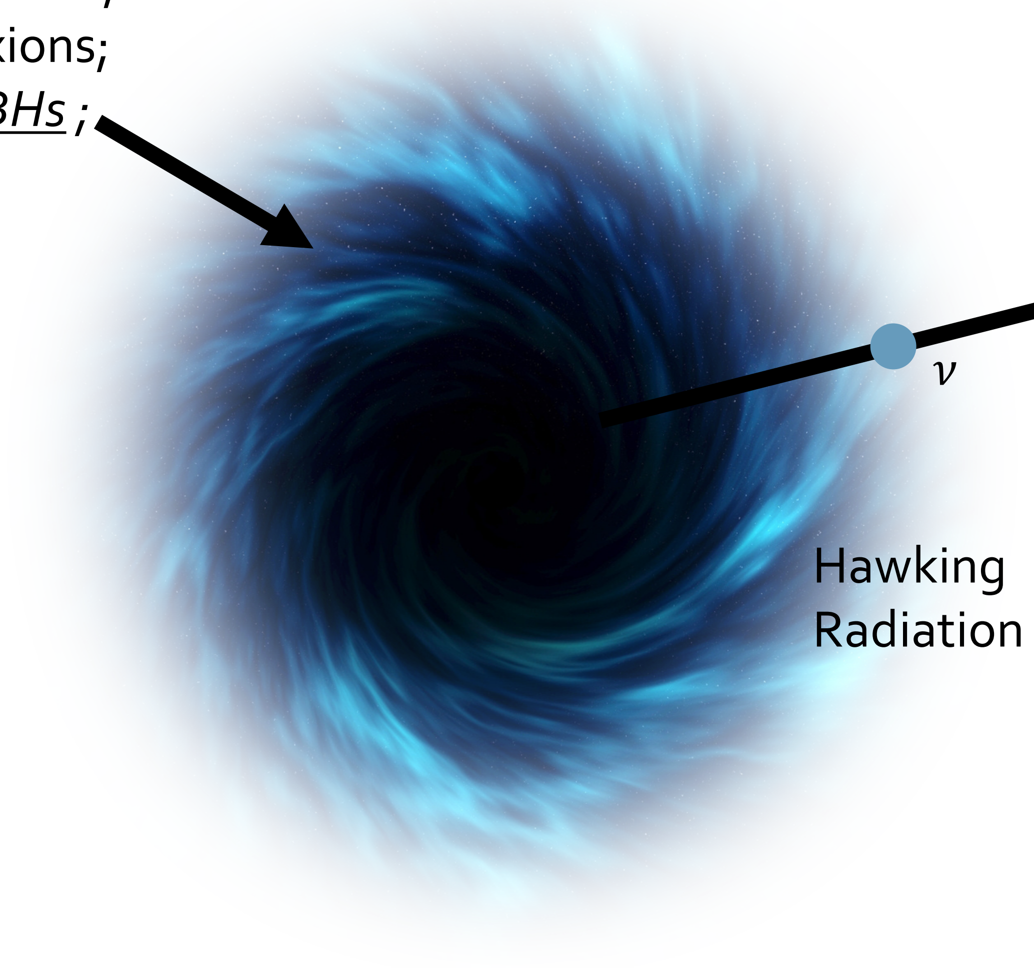
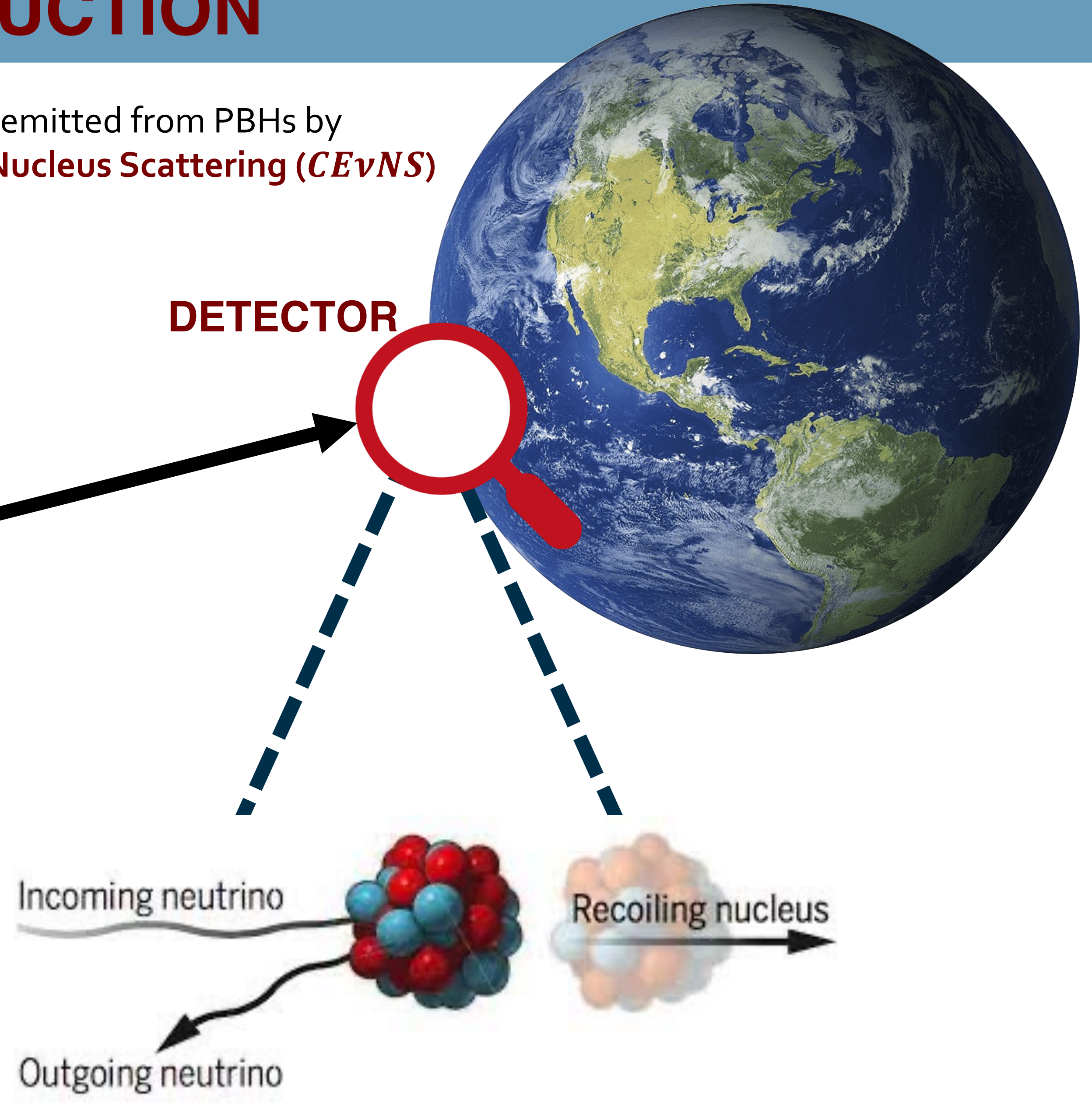
[4] Istituto Nazionale di Fisica Nucleare, Sezione di Bari, Via Orabona 4, 70126 Bari, Italy

Arxiv: 2106.02492

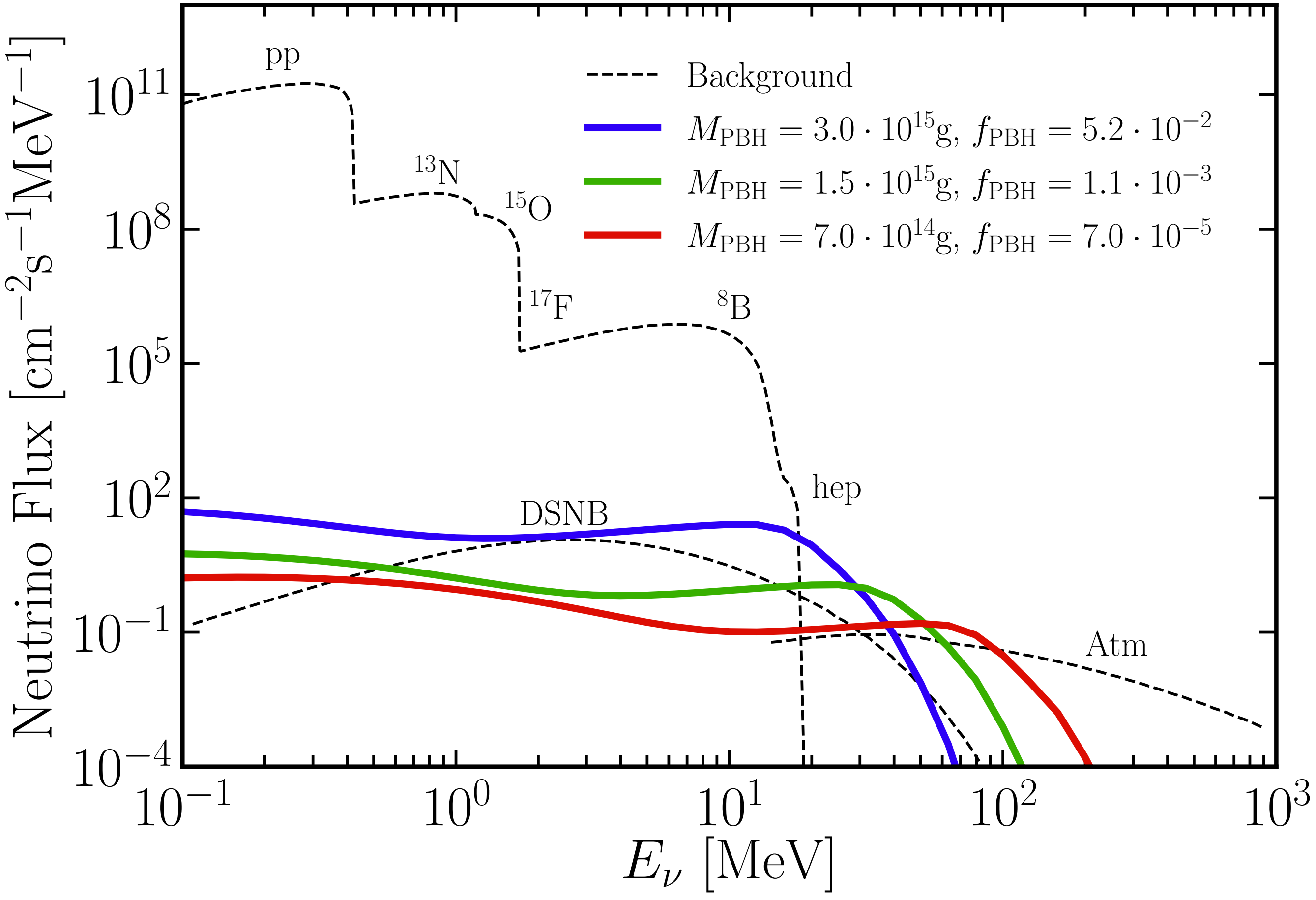
Detection of neutrinos emitted from PBHs by
Coherent Elastic Neutrino Nucleus Scattering ($CE\nu NS$)

DM candidates:
- WIMPs;
- Axions;
- *PBHs* ;
- ....





NEUTRINO FLUX

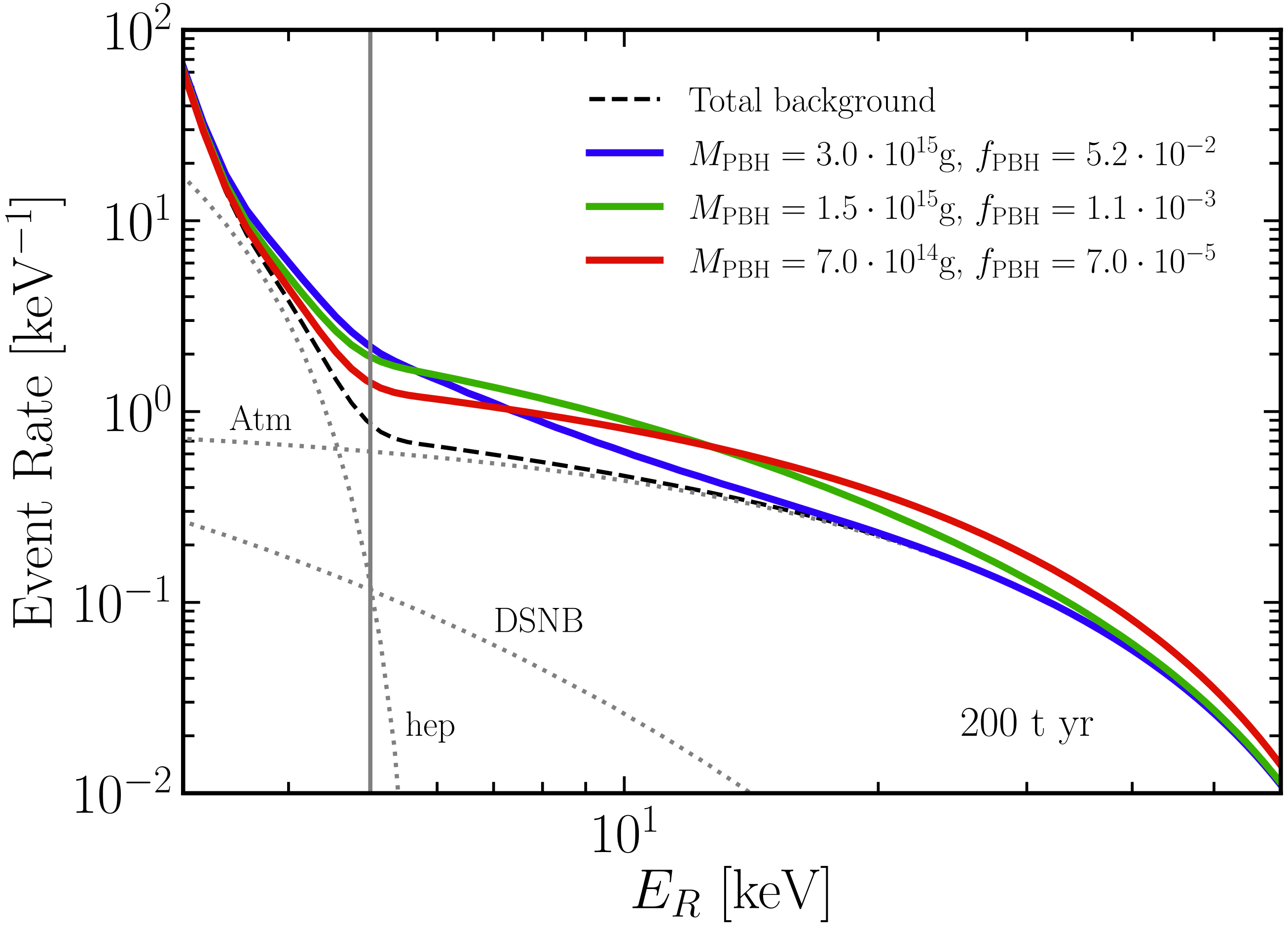


We adopted a NFW density profile for the galactic DM halo.

We can see that PBHs neutrinos are visible for energies larger than the abrupt fall-off of the solar hep neutrinos

$CE\nu NS$ is flavor blind → no need to consider oscillation

EVENT RATE

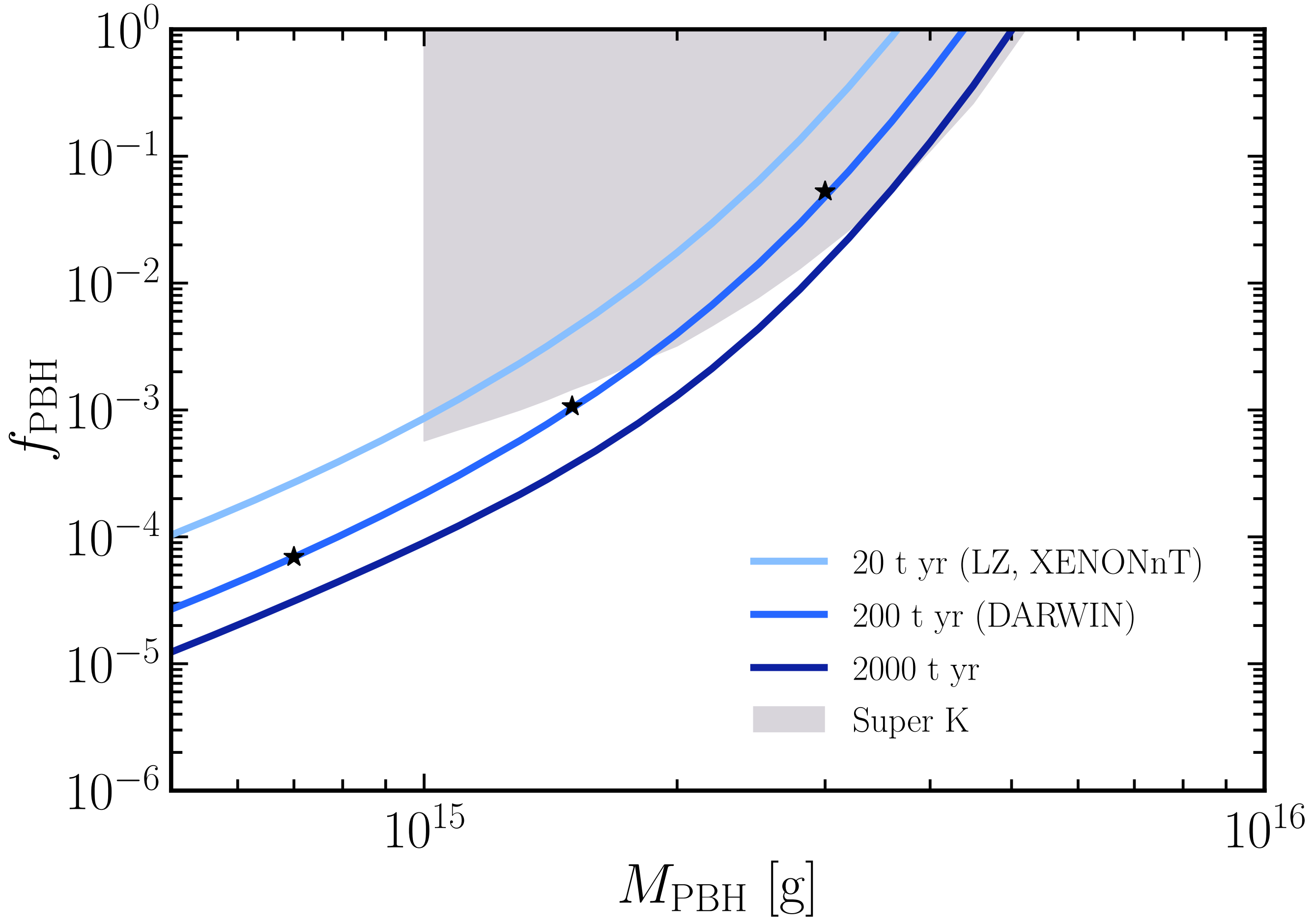


We calculated the event rate of $CE\nu NS$ in a multi-ton DM direct detection experiment (DARWIN)

The event spectrum of PBHs depends on the mass of the PBH. For higher masses it is similar to the background. For lower masses it is sensibly different.

For this reason, we have a employed a binned analysis to fully exploit the spectral information

PROSPECTIVE UPPER BOUNDS

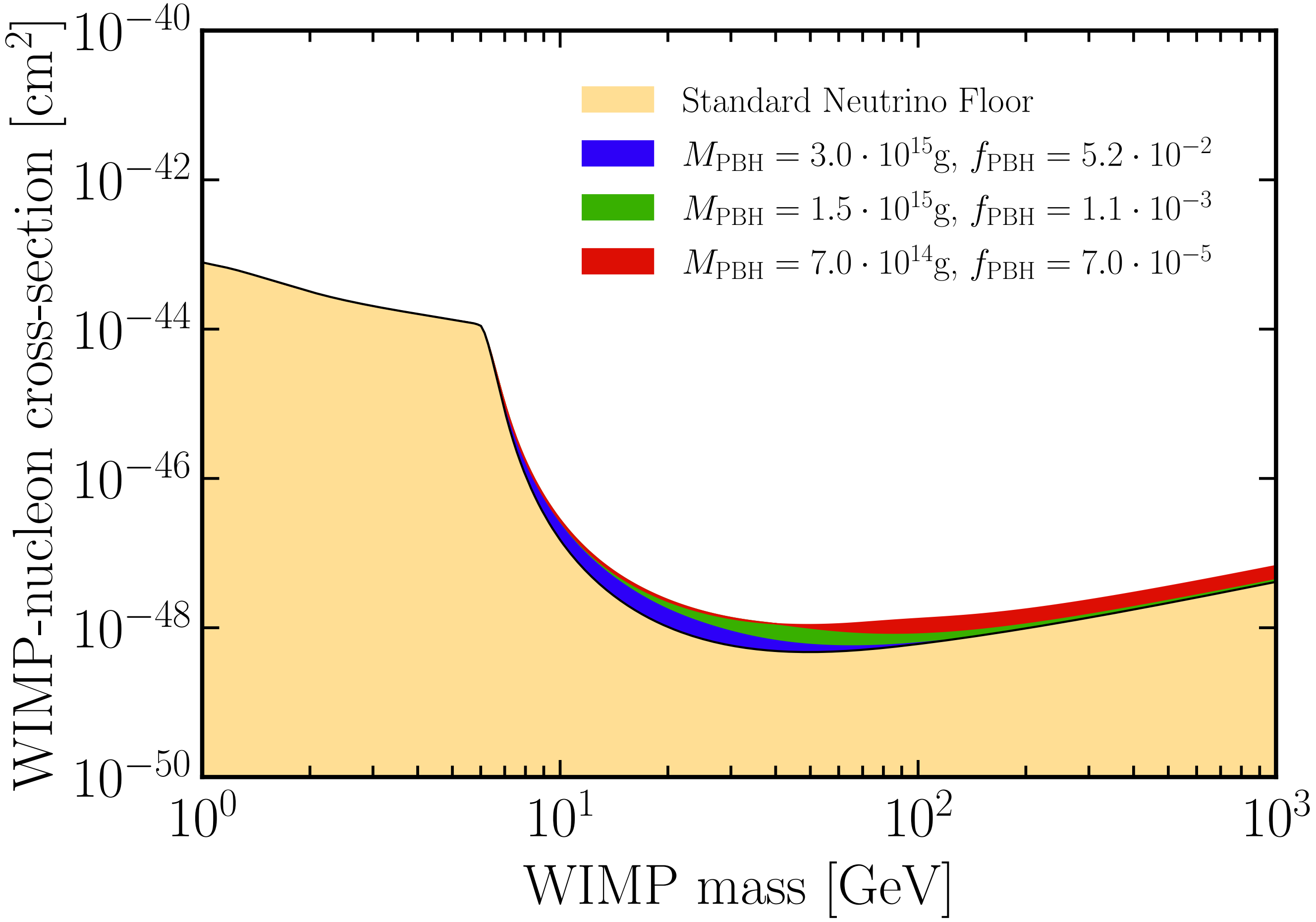


$CE\nu NS$ would allow us to improve the bounds derived from Super-Kamiokande and extend them to lower PBHs masses.

While we have limited our study to **non-rotating** PBHs and a **monochromatic mass function**, the study may be extended to more general settings.

We stress that in the context of PBHs searches the direct DM experiments would rather operate as low-energy indirect observatories, complementary to the high-energy neutrino telescopes.

NEUTRINO FLOOR



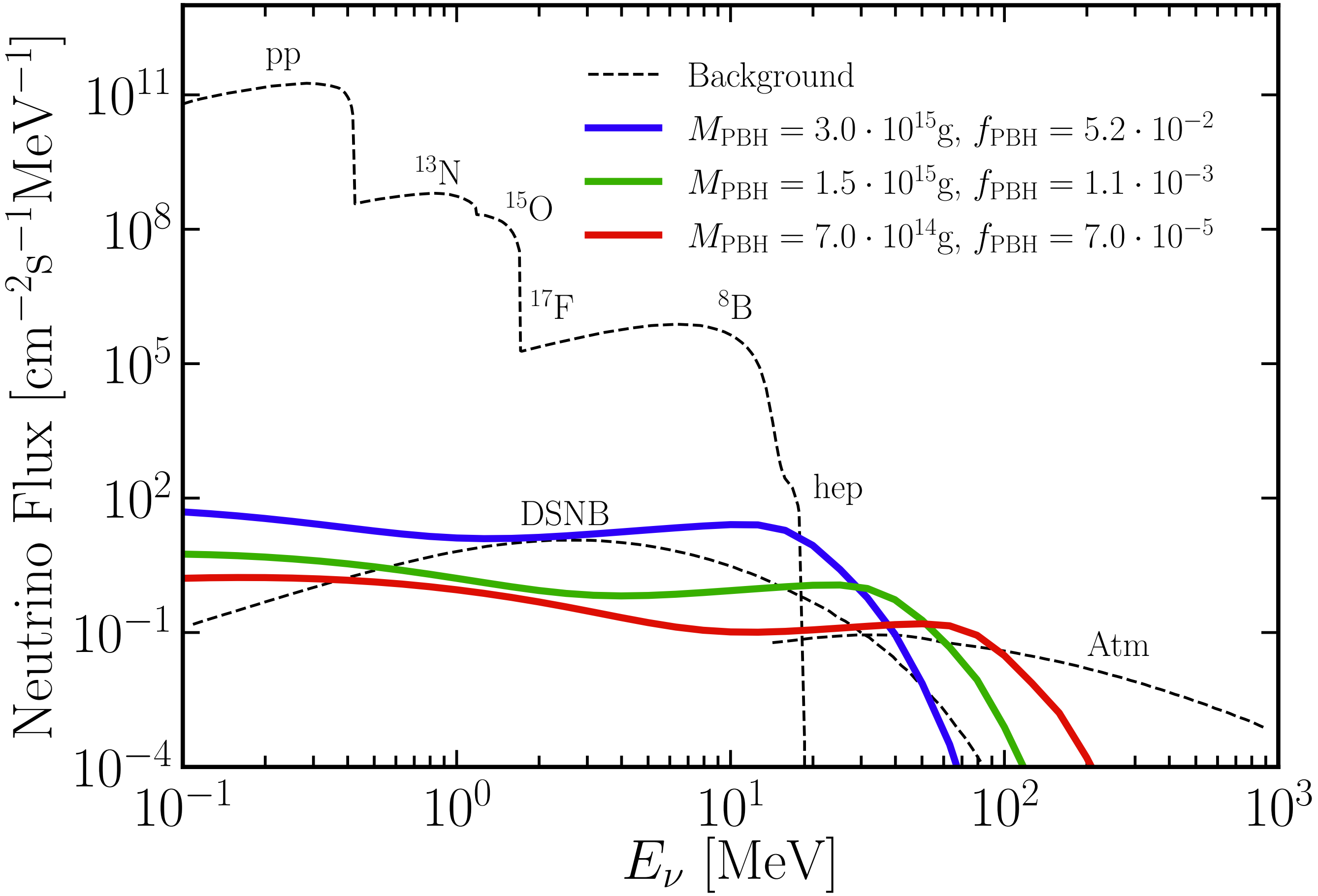
The solar, DSNB and atmospheric neutrinos constitute an irreducible background for the WIPMs searches. This background forms to the so-called "neutrino floor", an ultimate limitation to the discovery potential of the DM experiments.

Since the PBHs neutrinos lie on top of the "Standard" Background, the existence of a fraction of PBHs in the DM content would modify the neutrino floor.

We have quantified how much a signal from PBHs would heighten the "**neutrino floor**"


THANK YOU FOR THE ATTENTION

NEUTRINO FLUX



The Galactic neutrino flux generated by the evaporation of a PBH is given by

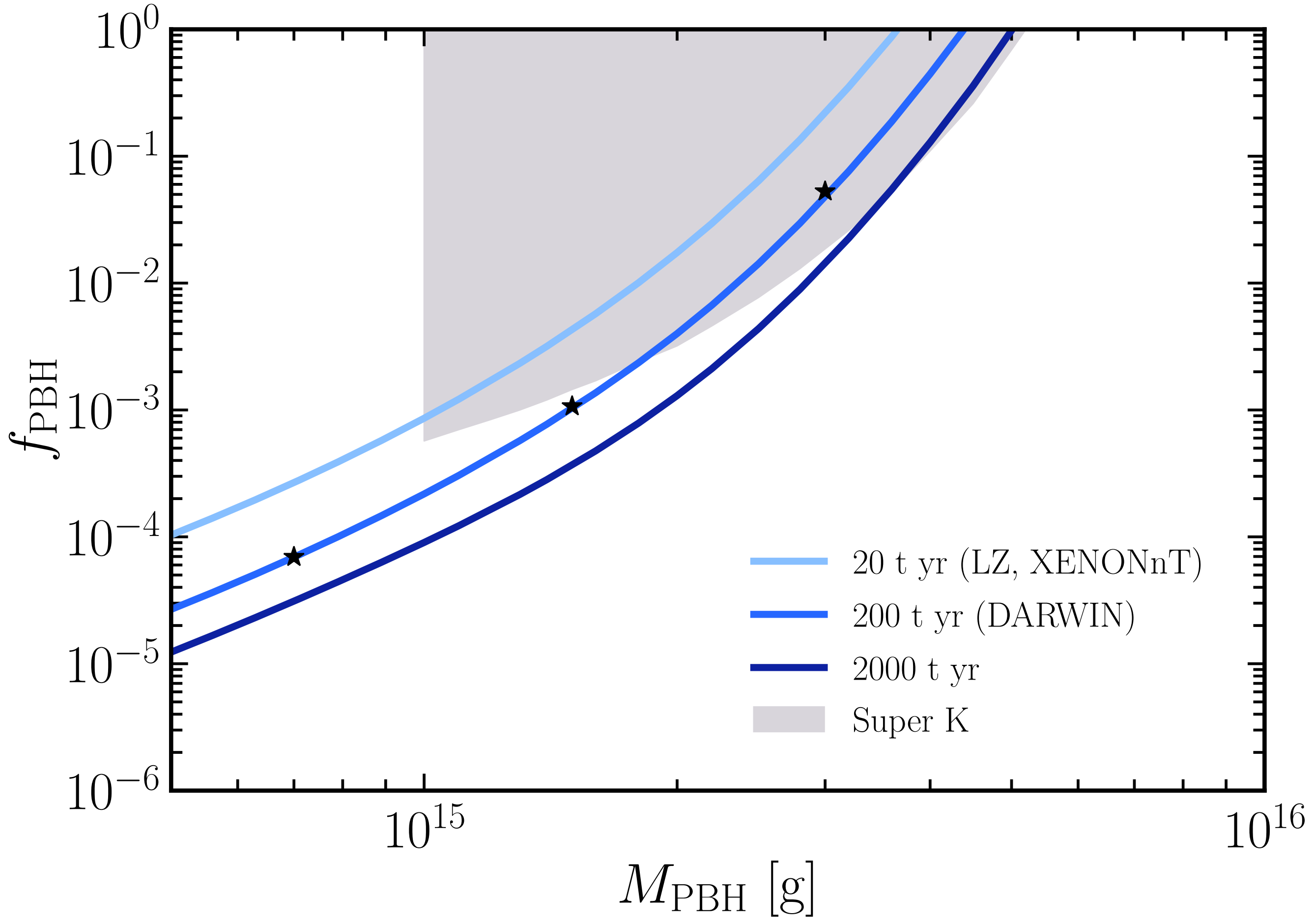
$$\frac{d\phi^{MW}}{dE_\nu} = \int \frac{d\Omega}{4\pi} \frac{dN}{dt dE_\nu} \int dl\, \frac{f_{PBH}\rho_{NFW}[r(l,\psi)]}{M_{PBH}}$$

While the Extra Galactic flux is given by

$$\frac{d\phi_\nu^{EG}}{dE_\nu} = \int dt[1+z(t)] \frac{f_{PBH}\rho_{DM}}{M_{PBH}} \frac{dN}{dt\, d\widetilde{E_\nu}}\bigg|_{\widetilde{E_\nu}=E[1+z(t)]}$$

We can see that PBHs neutrinos are visible after the abrupt fall-off of the hep neutrinos

UPPER BOUNDS



χ^2 statistic

$$\chi^2 = \min\left(-2\ln\left(\frac{L_0}{L_1}\right) + \left(\frac{1-\alpha}{\sigma_{atm}}\right)^2 + \left(\frac{1-\beta}{\sigma_{DSNB}}\right)^2 + \left(\frac{1-\gamma}{\sigma_{hep}}\right)^2\right)$$

Where

$$L_0 = \prod_i P\left(\overline{N}^i_{Bck}; N^i_{PBH} + N^i_{Bck}(\alpha,\beta,\gamma)\right)$$

$$L_1 = \prod_i P\left(\overline{N}^i_{Bck}; \overline{N}^i_{Bck}\right)$$

$$N^i_{Bck} = \alpha N^i_{atm} + \beta N^i_{DSNB} + \gamma N^i_{hep}$$

$$\overline{N}^{\,i}_{Bck} = N^i_{atm} + N^i_{DSNB} + N^i_{hep}$$

Neutrino Physics with the PTOLEMY project

Gianpiero Mangano

Dipartimento di Fisica, Università di Napoli *Federico II*

and INFN

Meeting NAT_NET, 6 luglio 2021

CNB indirect evidences

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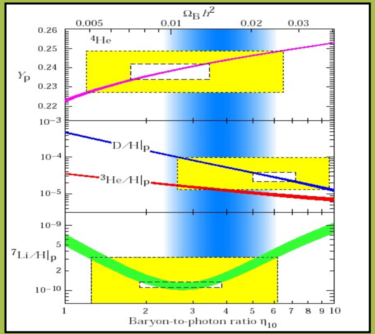
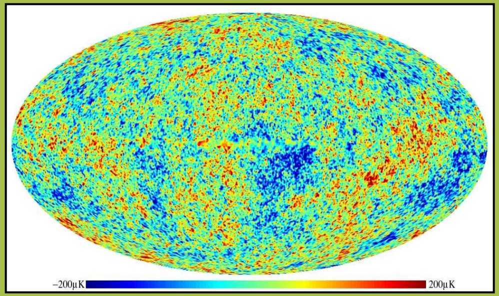
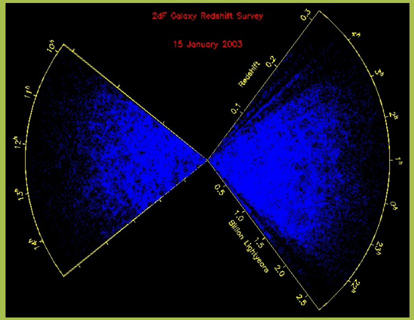
<td></td>
<td></td>
<td></td>
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<tr>
<td>Primordial Nucleosynthesis
BBN</td>
<td>Cosmic Microwave Background
CMB</td>
<td>Formation of Large Scale Structures
LSS</td>
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<td>$T \sim$ MeV</td>
<td colspan="2">$T <$ eV</td>
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<tr>
<td>flavor dependent</td>
<td colspan="2">Flavor blind</td>
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</table>

CMB+LSS: allowed ranges for N_{eff}

- Set of parameters: ($\Omega_b h^2$, $\Omega_{cdm} h^2$, h , n_s , A , b , N_{eff}) (Standard value: $N_{eff} = 3$)
- DATA: Planck , Flat Models

$$\rho_R = \rho_\gamma + \rho_\nu + \rho_x = \left(1 + \frac{7}{8}\left(\frac{4}{11}\right)^{4/3} N_{eff}\right)\rho_\gamma$$

$N_{\text{eff}} = 3.11^{+0.44}_{-0.43}$ (95 %, TT+lowE+lensing+BAO);

$N_{\text{eff}} = 2.99^{+0.34}_{-0.33}$ (95 %, TT,TE,EE+lowE+lensing +BAO).

DATA

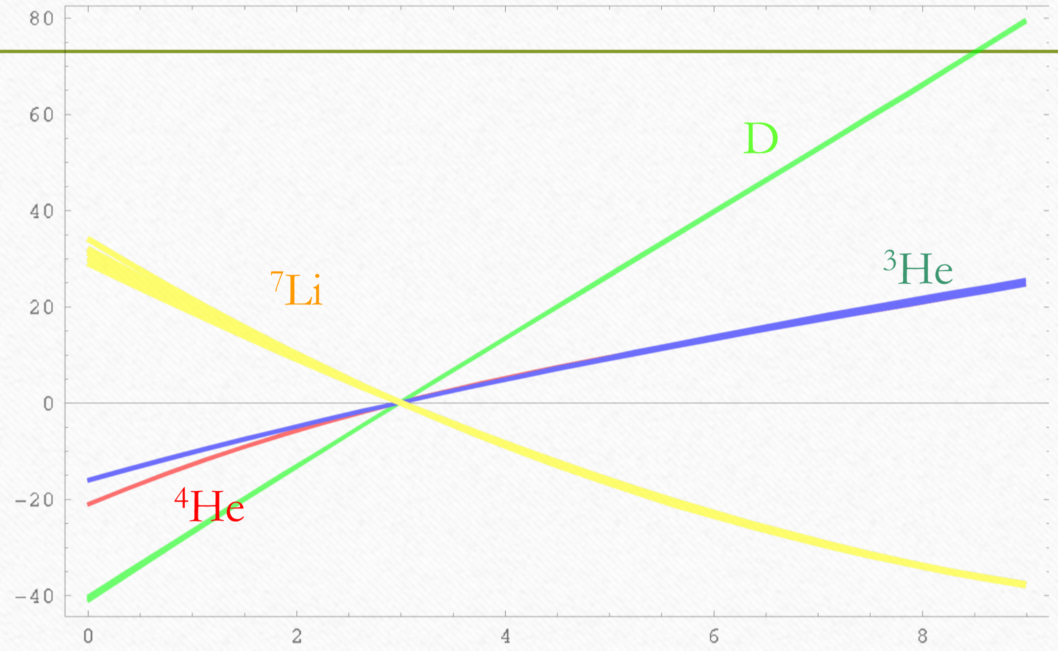
The quest for primordiality

- Observations in systems negligibly contaminated by stellar evolution (e.g. high redshift);
- Careful account for galactic chemical evolution.

Effect of neutrinos on BBN

1. N_{eff} fixes the expansion rate during BBN

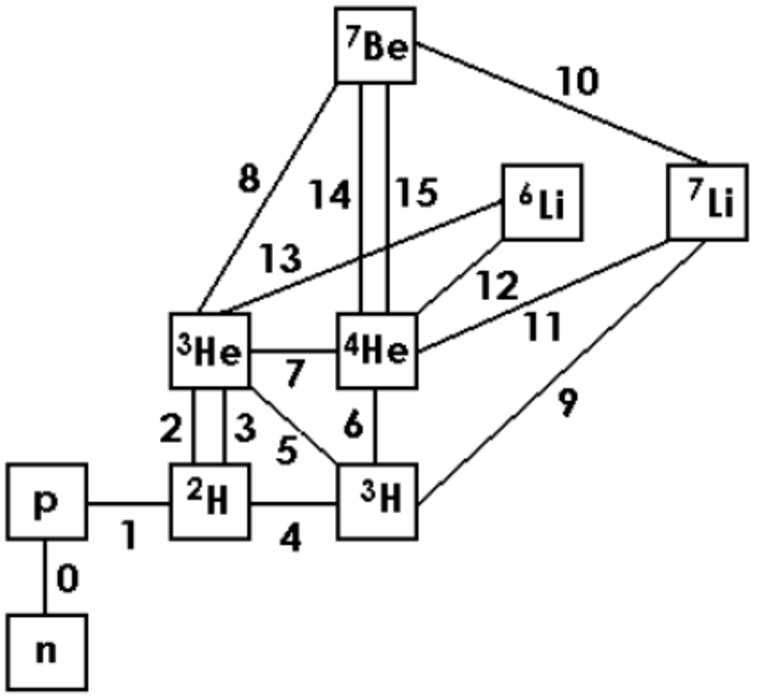
$$\rho_R = \rho_\gamma + \rho_\nu + \rho_x = \left(1 + \frac{7}{8}\left(\frac{4}{11}\right)^{4/3} N^{eff}{}_\nu\right)\rho_\gamma$$



2. Direct effect of electron neutrinos and antineutrinos on the n-p reactions

$$\nu_e + n \longleftrightarrow p + e^- \qquad e^+ + n \longleftrightarrow p + \bar{\nu}_e$$

Deuterium synthesis



Symbol	Reaction	Symbol	Reaction
R_0	τ_n	R_8	$^3\mathrm{He}(\alpha,\gamma)^7\mathrm{Be}$
R_1	$p(n,\gamma)d$	R_9	$^3\mathrm{H}(\alpha,\gamma)^7\mathrm{Li}$
R_2	$^2\mathrm{H}(p,\gamma)^3\mathrm{He}$	R_{10}	$^7\mathrm{Be}(n,p)^7\mathrm{Li}$
R_3	$^2\mathrm{H}(d,n)^3\mathrm{He}$	R_{11}	$^7\mathrm{Li}(p,\alpha)^4\mathrm{He}$
R_4	$^2\mathrm{H}(d,p)^3\mathrm{H}$	R_{12}	$^4\mathrm{He}(d,\gamma)^6\mathrm{Li}$
R_5	$^3\mathrm{He}(n,p)^3\mathrm{H}$	R_{13}	$^6\mathrm{Li}(p,\alpha)^3\mathrm{He}$
R_6	$^3\mathrm{H}(d,n)^4\mathrm{He}$	R_{14}	$^7\mathrm{Be}(n,\alpha)^4\mathrm{He}$
R_7	$^3\mathrm{He}(d,p)^4\mathrm{He}$	R_{15}	$^7\mathrm{Be}(d,p)2\,^4\mathrm{He}$

Reaction	Rate symbol	$\sigma_{^2\mathrm{H/H}} \times 10^5$
$p(n,\gamma)^2\mathrm{H}$	R_1	± 0.002
$d(p,\gamma)^3\mathrm{He}$	R_2	± 0.062
$d(d,n)^3\mathrm{He}$	R_3	± 0.020
$d(d,p)^3\mathrm{H}$	R_4	± 0.013

0.1%
87%
9%
3.8%

Di Valentino et al., Phys. Rev. D90 (2014) no. 2, 023543

Reaction	Rate symbol	$\sigma_{^2\mathrm{H/H}} \times 10^5$
$p(n,\gamma)^2\mathrm{H}$	R_1	± 0.002
$d(p,\gamma)^3\mathrm{He}$	R_2	± 0.062
$d(d,n)^3\mathrm{He}$	R_3	± 0.020
$d(d,p)^3\mathrm{H}$	R_4	± 0.013

before LUNA

0.1%
87%
9%
3.8%

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Article | Published: 11 November 2020

The baryon density of the Universe from an improved rate of deuterium burning

V. Mossa, K. Stöckel, F. Cavanna, F. Ferraro, M. Aliotta, F. Barile, D. Bemmerer, A. Best, A. Boeltzig, C. Broggini, C. G. Bruno, A. Caciolli, T. Chillery, G. F. Ciani, P. Corvisiero, L. Csedreki, T. Davinson, R. Depalo, A. Di Leva, Z. Elekes, E. M. Fiore, A. Formicola, Zs. Fülöp, G. Gervino, A. Guglielmetti, C. Gustavino, G. Gyürky, G. Imbriani, M. Junker, A. Kievsky, I. Kochanek, M. Lugaro, L. E. Marcucci, G. Mangano, P. Marigo, E. Masha, R. Menegazzo, F. R. Pantaleo, V. Paticchio, R. Perrino, D. Piatti, O. Pisanti, P. Prati, L. Schiavulli, O. Straniero, T. Szücs, M. P. Takács, D. Trezzi, M. Viviani & S. Zavatarelli -Show fewer authors

Nature **587**, 210–213(2020) | Cite this article

after LUNA

	$\sigma_{\mathrm{D}}^{(i)} \cdot 10^5$	$\delta\sigma_i^2/\sigma_{\mathrm{tot}}^2$ (%)
$R_{pn\gamma}$	0.002	0.3
$R_{dp\gamma}$	0.027	58.5
R_{ddn}	0.018	26.9
R_{ddp}	0.013	14.2

CNB direct detection

CNB: very low energy, difficult to measure directly by v-scattering

1. Large De Broglie wavelength $\lambda \sim 0.1$ cm

   Coherent scattering over nuclei (or macroscopic domain)

   Wind force on a test body,

Cross section

$\sigma_{\nu N} \sim 10^{-56}\,(m_\nu/eV)^2\ cm^2$ non relativistic

$\sigma_{\nu N} \sim 10^{-63}\,(T_\nu/eV)^2\ cm^2$ relativistic

acceleration

$n_\nu\, \beta\, NA/A\, \sigma_{\nu N}\, dp \sim (100/A)10^{-51}\,(m_\nu/eV)\ cm\ s^{-2}$

Today: Cavendish torsion balances can test acceleration as small as 10^{-13} cm s^{-2} !!

2. Accelerators:

Too small even at LHC or beyond !

3. Effects linear in G_F:

No go theorem (Cabibbo & Maiani, Langacker et al) effect vanishes if

static source - background interaction

Homogeneous v flux on the target scale

Stodolski effect: polarized electron target experiences a tourque due to helicity energy splitting in presence of a polarized (asymmetry) neutrino wind

dE $\sim g_A \, \vec{\sigma} \cdot \vec{\beta}(n_v - n_{\bar{v}})$

A '62 paper by S. Weinberg and *ν* chemical potential

PHYSICAL REVIEW VOLUME 128, NUMBER 3 NOVEMBER 1, 1962

Universal Neutrino Degeneracy

STEVEN WEINBERG*
Imperial College of Science and Technology, London, England

(Received March 22, 1962)

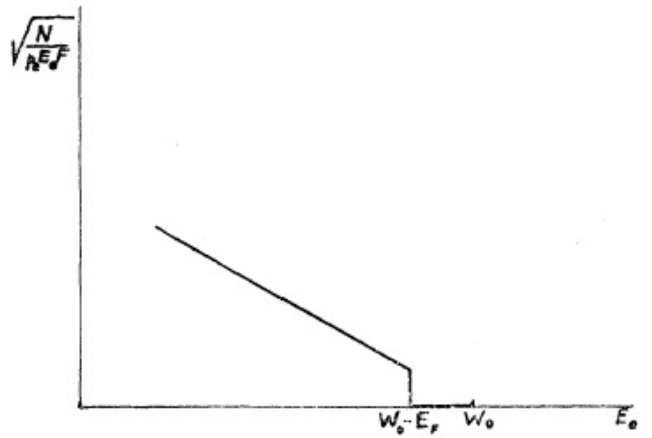


FIG. 1. Shape of the upper end of an allowed Kurie plot to be expected in a β^+ decay if neutrinos are degenerate up to energy E_F, or in a β^- decay if antineutrinos are degenerate.

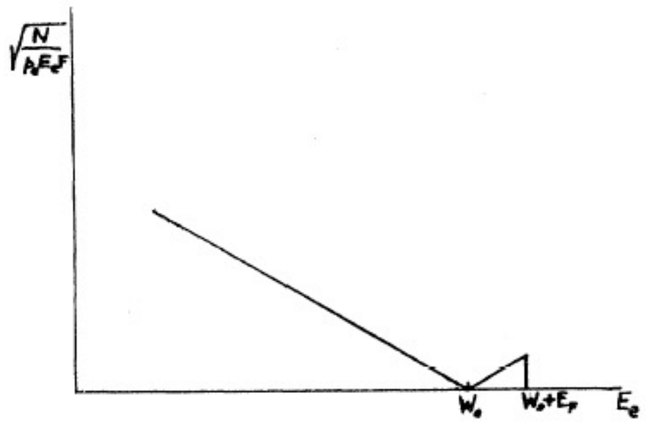
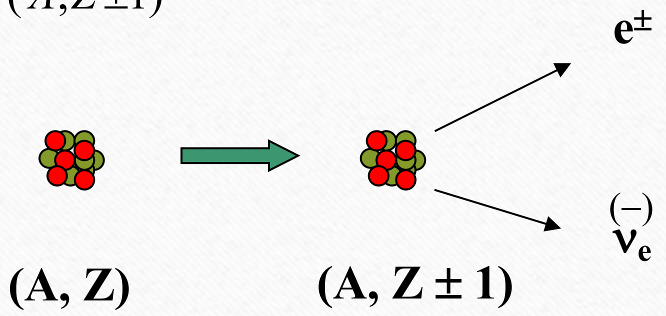


FIG. 2. Shape of the upper end of an allowed Kurie plot to be expected in a β^- decay if neutrinos are degenerate up to energy E_F, or in a β^+ decay if antineutrinos are degenerate.

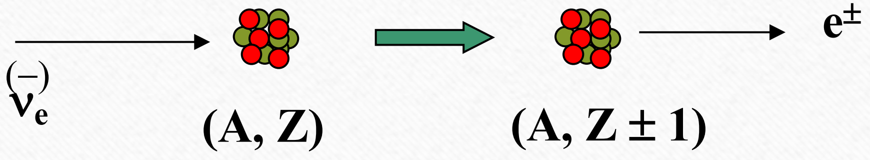
$$N_{(A,Z)} \rightarrow N'_{(A,Z\pm 1)}\; e^{\pm}\; \overset{(-)}{\nu}_e$$

$$\overset{(-)}{\nu}_e\; N_{(A,Z)} \rightarrow N'_{(A,Z\pm 1)}\; e^{\pm}$$

Beta decay



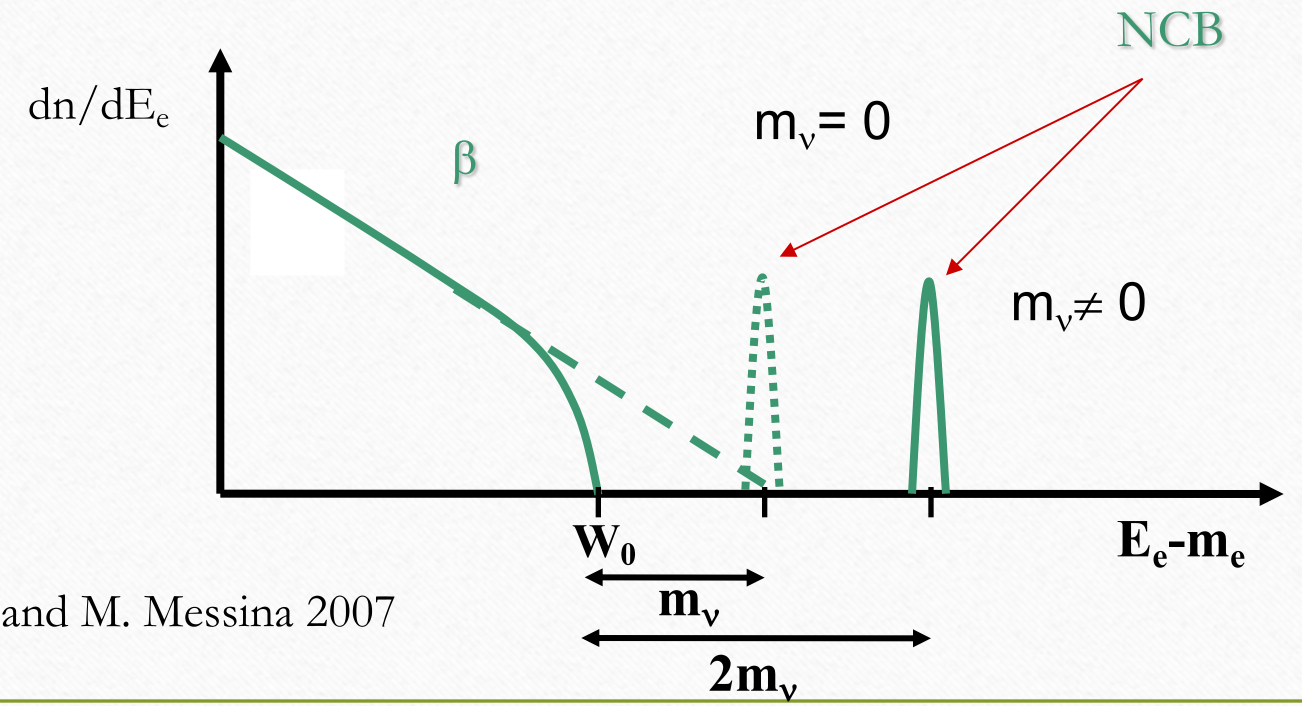
Neutrino Capture on a Beta Decaying Nucleus (NCβ)



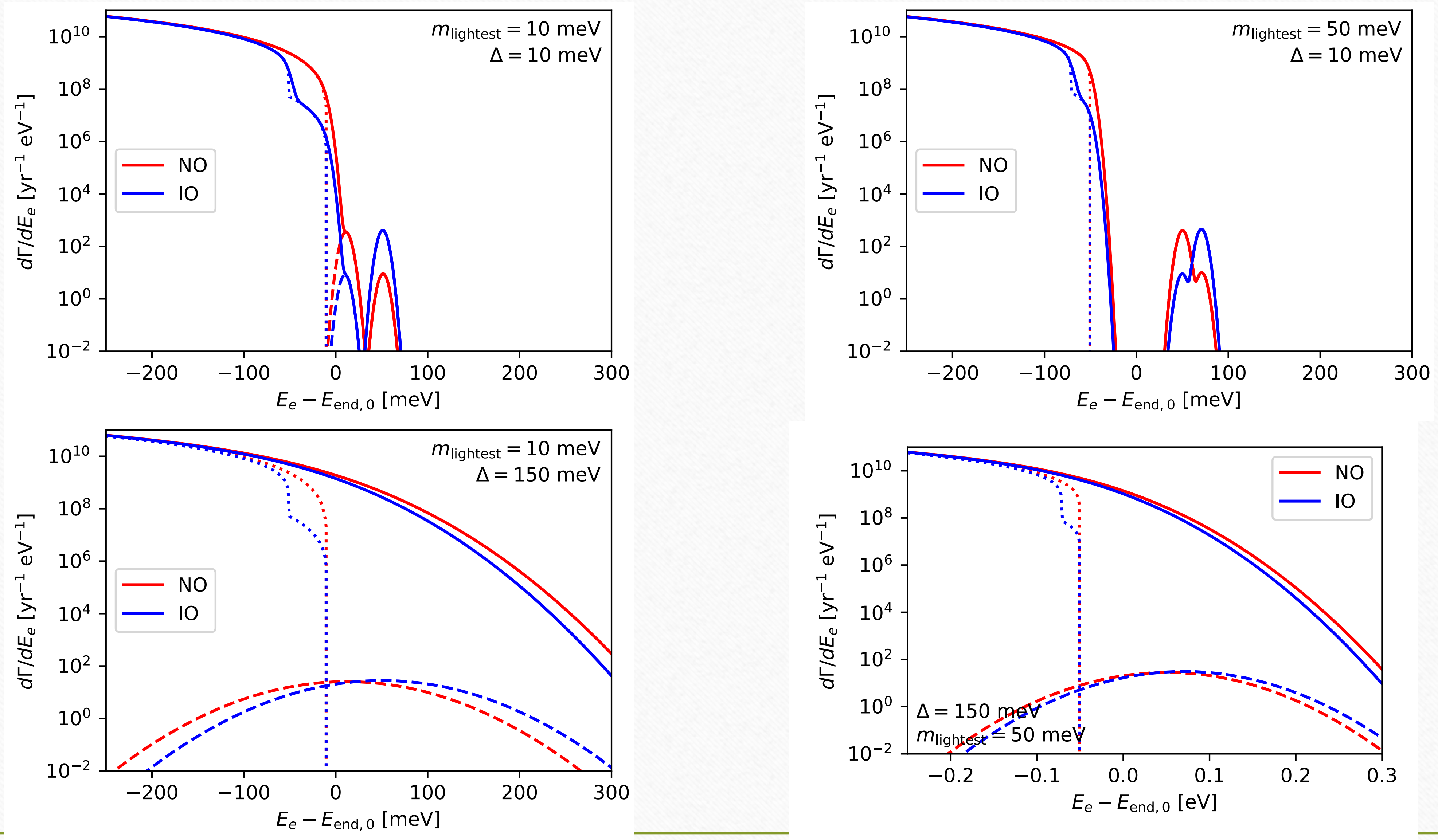
Weinberg: if neutrinos are degenerate we could observe structures around the beta decaying nuclei endpoint Q

ν's are NOT degenerate but are massive!

2 m_ν gap in electron spectrum around Q



A. Cocco, G.M. and M. Messina 2007



$m_{\mathrm{lightest}} = 10$ meV
$\Delta = 10$ meV
NO
IO
$d\Gamma/dE_e$ [yr^{-1} eV^{-1}]
$E_e - E_{\mathrm{end},0}$ [meV]
$m_{\mathrm{lightest}} = 50$ meV
$\Delta = 10$ meV
NO
IO
$d\Gamma/dE_e$ [yr^{-1} eV^{-1}]
$E_e - E_{\mathrm{end},0}$ [meV]
$m_{\mathrm{lightest}} = 10$ meV
$\Delta = 150$ meV
NO
IO
$d\Gamma/dE_e$ [yr^{-1} eV^{-1}]
$E_e - E_{\mathrm{end},0}$ [meV]
NO
IO
$\Delta = 150$ meV
$m_{\mathrm{lightest}} = 50$ meV
$d\Gamma/dE_e$ [yr^{-1} eV^{-1}]
$E_e - E_{\mathrm{end},0}$ [eV]

•Clustering and ν local density

Massive neutrinos cluster on CDM and baryonic structures. The local density at Earth (8 kpc away from the galactic center) is expected to be larger than 56 cm^{-3}

$$\frac{\partial f_i}{\partial \tau} + \frac{\boldsymbol{p}}{a m_i} \cdot \frac{\partial f_i}{\partial \boldsymbol{x}} - a m_i \nabla \phi \cdot \frac{\partial f_i}{\partial \boldsymbol{p}} = 0,$$

$$\nabla^2 \phi = 4\pi G a^2 \sum_i \overline{\rho}_i(\tau) \delta_i(\boldsymbol{x}, \tau),$$

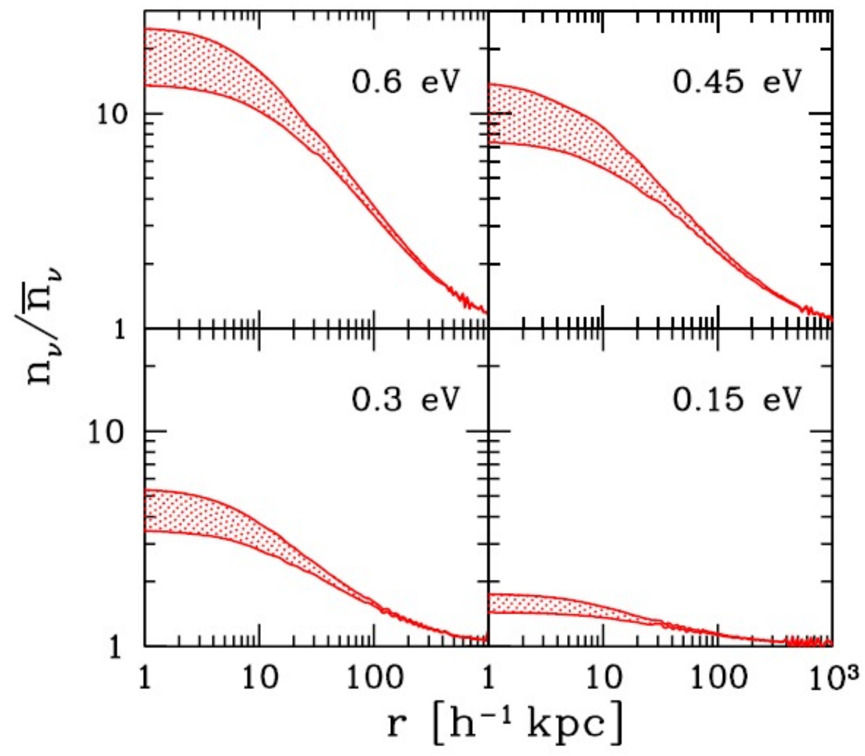
$$\delta_i(\boldsymbol{x}, \tau) \equiv \frac{\rho_i(\boldsymbol{x}, \tau)}{\overline{\rho}_i(\tau)} - 1, \qquad \rho_i(\boldsymbol{x}, \tau) = \frac{m_i}{a^3} \int d^3p\, f_i(\boldsymbol{x}, \boldsymbol{p}, \tau),$$

Neutrinos accrete when their velocity becomes comparable with protocluster velocity dispersion ($z<2$)

Usual assumption: Halo profile governed by CDM only

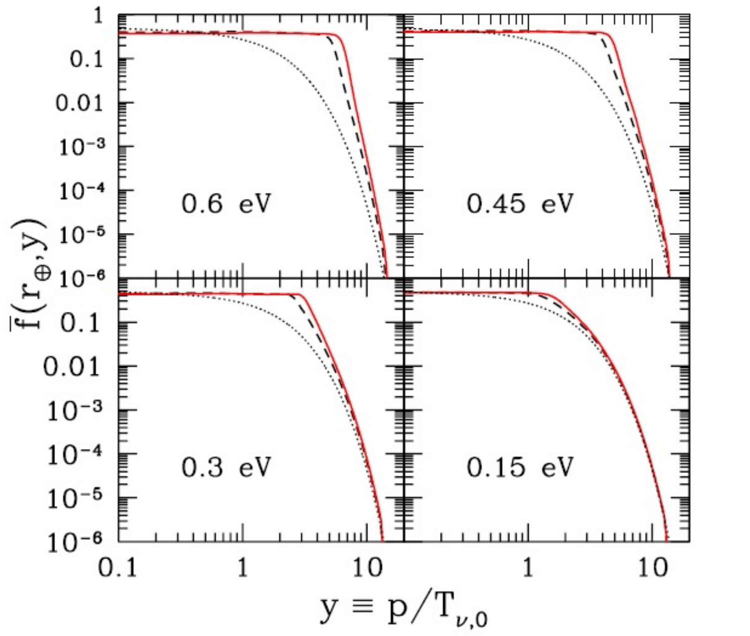
NFW universal profile

$$\rho_{\rm halo}(r) = \frac{\rho_s}{(r/r_s)(1 + r/r_s)^2},$$



Milky Way

Top curve: NFW   Bottom curve: static present MW matter profile



A. Ringwald and Y. Wong 2004

N-1-body simulations

Updated in de Salas et al 2017

The case of ^3H

$$\lambda_\beta = 2.85 \cdot 10^{-2} \frac{\sigma_{\rm NCB} v_\nu / c}{10^{-45} {\rm cm}^2} \, {\rm yr}^{-1} \, {\rm mol}^{-1} \, . \qquad \sigma_{\rm NCB}(^3{\rm H}) \frac{v_\nu}{c} = (\, 7.84 \pm 0.03 \,) \times 10^{-45} \, {\rm cm}^2 \, ,$$

m_ν (eV)	FD (events yrs^{-1})	NFW (events yrs^{-1})	MW (events yrs^{-1})
0.6	7.5	90	150
0.3	7.5	23	33
0.15	7.5	10	12

The number of NCB events per year for 100 g of ^{3}H

8 events yr^{-1} per 100g of ^{3}H (no clustering)

up to 10^2 events yr^{-1} per 100 g of ^{3}H due to clustering effect

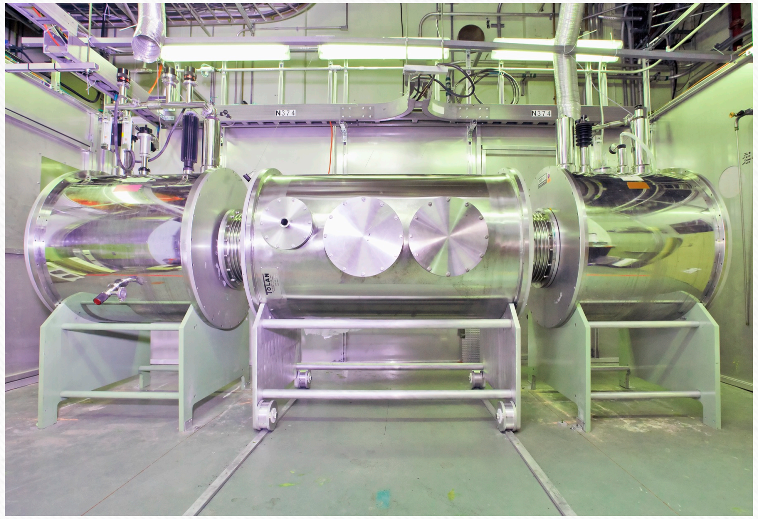
signal/background = 3 for Δ=0.2 eV if m_ν=0.7 eV

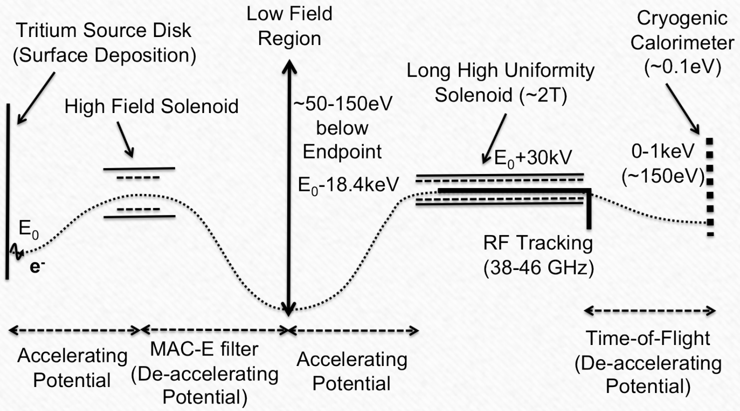
Δ=0.1 eV if m_ν=0.3 eV

The Ptolemy Project

Development of a Relic Neutrino Detection Experiment at PTOLEMY:
Princeton Tritium Observatory for Light, Early-Universe, Massive-Neutrino Yield

Pontecorvo





INFN Laboratori Nazionali del Gran Sasso, Italy,

Neutrino Physics with PTOLEMY

- Neutrino mass measurement (results expected from KATRIN exp.)
- Sterile neutrinos in the eV mass range (neutrino oscillation anomalies)
- NCB
- keV sterile neutrinos (Warm Dark Matter candidates)
- …

First analysis in **JCAP 1907 (2019) 047**

$$\frac{d\widetilde{\Gamma}_{\rm CNB}}{dE_e}(E_e) = \frac{1}{\sqrt{2\pi}(\Delta/\sqrt{8\ln 2})} \sum_{i=1}^{N_\nu} \Gamma_i \times \exp\left\{-\frac{[E_e - (E_{\rm end} + m_i + m_{\rm lightest})]^2}{2(\Delta/\sqrt{8\ln 2})^2}\right\},$$

For the fiducial model, the number of expected events per energy bin is given by:

$$\hat{N}^i = N^i_\beta(\hat{E}_{\rm end}, \hat{m}_i, \hat{U}) + N^i_{\rm CNB}(\hat{E}_{\rm end}, \hat{m}_i, \hat{U}) \,. \tag{3.3}$$

The total number of events that will be measured in a bin is the sum of $\hat{N}^i$ and a constant background:

$$\hat{N}^i_t = \hat{N}^i + \hat{N}_b \,. \tag{3.4}$$

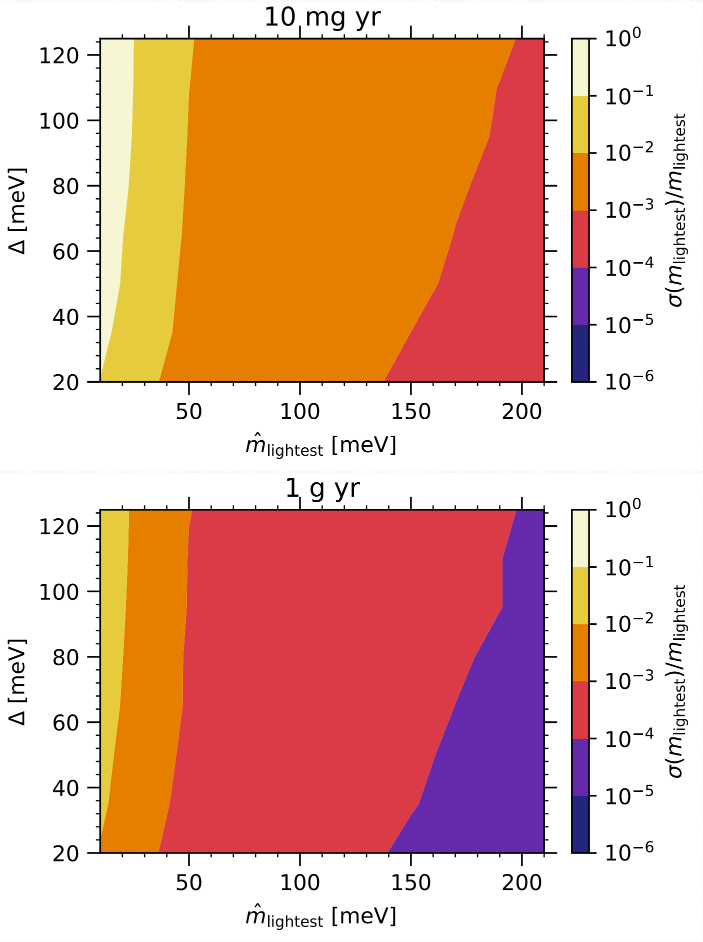
$$N^i_{\rm exp}(\hat{E}_{\rm end}, \hat{m}_i, \hat{U}) = \hat{N}^i_t \pm \sqrt{\hat{N}^i_t}\,,$$

$$\begin{aligned} N^i_{\rm th}(\boldsymbol{\theta}) = {} & N_b + A_\beta\, N^i_\beta(\hat{E}_{end} + \Delta E_{\rm end}, m_i, U) \\ & + \boxed{A_{\rm CNB}}\, N^i_{\rm CNB}(\hat{E}_{end} + \Delta E_{\rm end}, m_i, U)\,. \end{aligned} \tag{3.6}$$

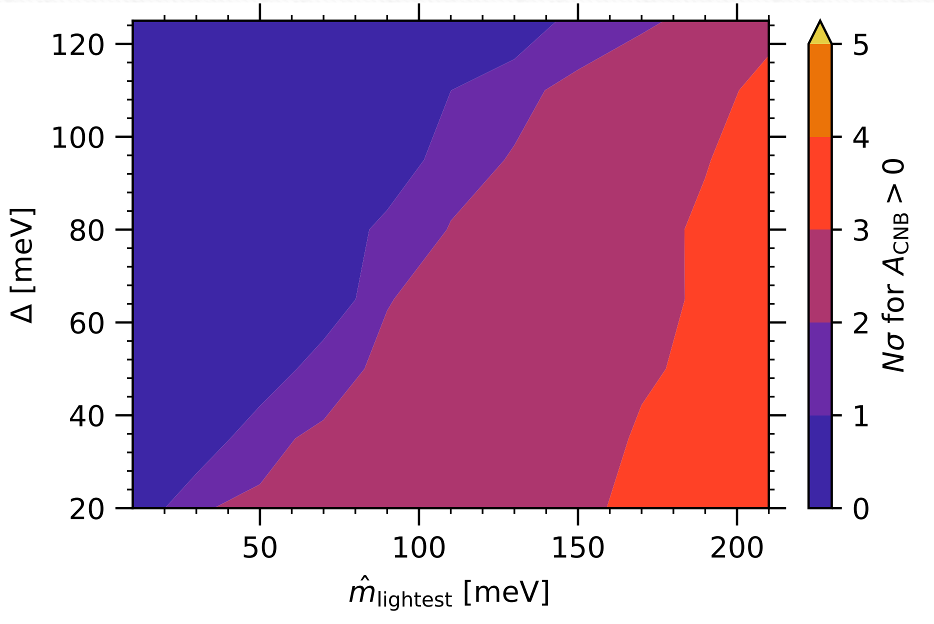
In order to perform the analysis and fit the desired parameters $\boldsymbol{\theta}$, we use a Gaussian χ^2 function:

$$\chi^2(\boldsymbol{\theta}) = \sum_i \left(\frac{N^i_{\rm exp}(\hat{E}_{\rm end}, \hat{m}_i, \hat{U}) - N^i_{\rm th}(\boldsymbol{\theta})}{\sqrt{N^i_t}}\right)^2, \tag{3.7}$$

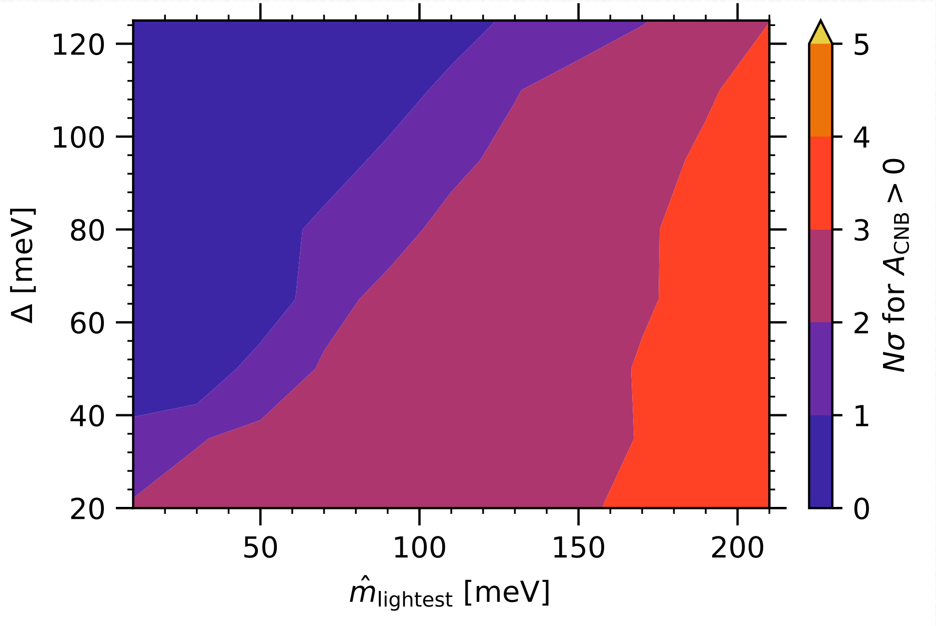
Neutrino mass sensitivity



CNB detection (100 g)

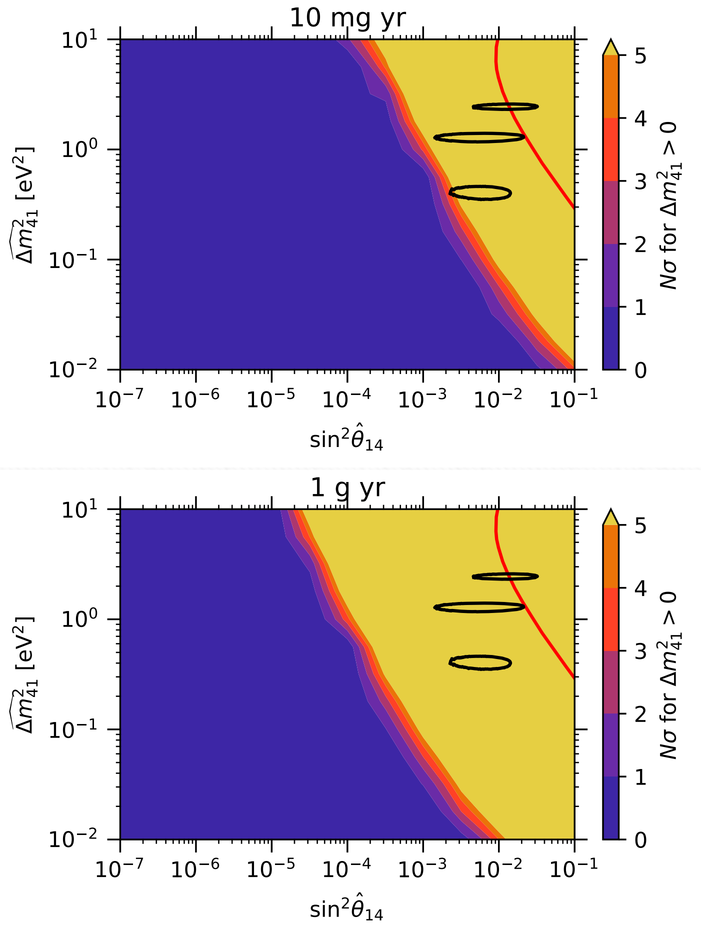


Normal ordering



Inverted ordering

eV sterile neutrinos (100 g)



A problem with graphene?

Cheipesh et al 2021

^{3}H bound in potential well of order 0.2 – 3 eV

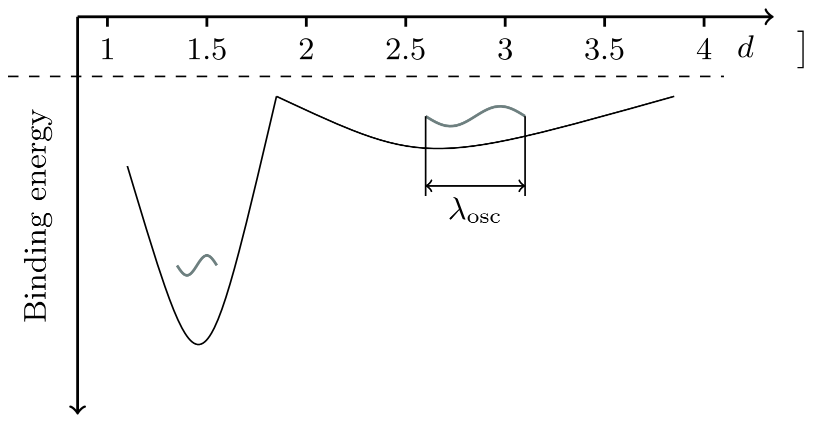


FIG. 2. **Schematic profile of the potential** that bonds the Tritium atom in the direction perpendicular to the graphene.

Potential	Source	κ, $\left[\mathrm{eV}/\ ^2\right]$	λ,]	Δ , [eV]
Chemisorption	[15]	2.15	0.16	0.60
	[13], GG	4.62	0.13	0.73
	[13], vdW-DF	4.9	0.13	0.75
Physisorption	[16]	0.08	0.37	0.26
	[15]	0.09	0.34	0.28
	[13], GG	0.18	0.29	0.33
	[13], vdW-DF	0.13	0.32	0.3
	[14], GG	0.04	0.43	0.22
	[14], LD	0.01	0.55	0.17
Migration	[18]	0.283	0.264	0.37

T BLE I. **Harmonic fit** with the stiffness κ of the chemisoption, physisorption potentials and the migration potential of the chemisorbed atom profiles near the minimum. $\lambda^2 =$ $/\sqrt{m\ _{\mathrm{ucl}}\kappa}$ and Δ is the energy broadening of the emitted electron estimated from Eq. (5).

Numbers under scrutiny!
A theoretical panel (cosmologist-graphene experts, solid state physicist) at work within Ptolemy (G.M. coordinator)
Is ^3He emitted as a free particle?

Neutrino Physics with PTOLEMY: Conclusions

Ambitious goal:

NCB detection
Sterile neutrino physics

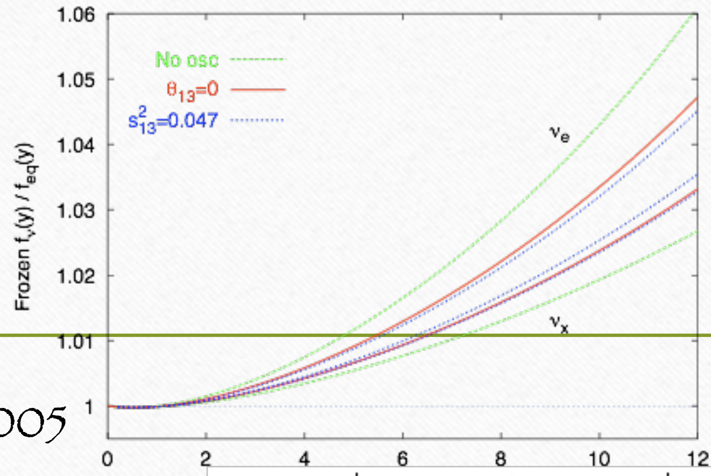
Shorter time goal:

Neutrino mass detection

Backup Slides

Weak rates:

radiative corrections $O(\alpha)$
finite nucleon mass $O(T/M_N)$
plasma effects $O(\alpha T/m_e)$
neutrino decoupling $O(G_F^2 T^3 m_{Pl})$



N_{eff}=3.046

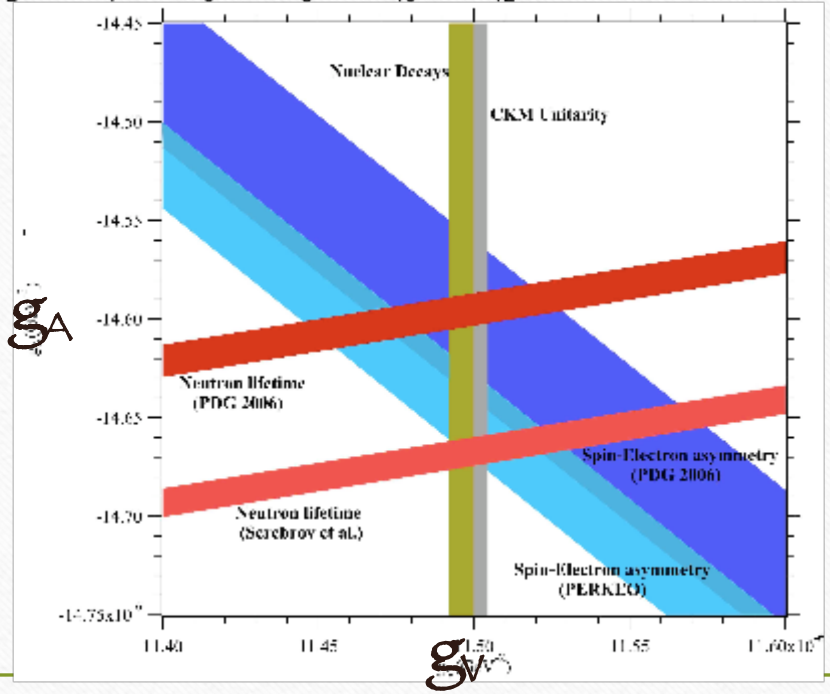
G.M. et al 2005

Main uncertainty: neutron lifetime
τ_n= 885.6 ± 0.8 sec (old PDG mean)
τ_n=878.5 ± 0.8 sec (Serebrov et al 2005)

Presently:

τ_n=880.3 ± 1.1 sec

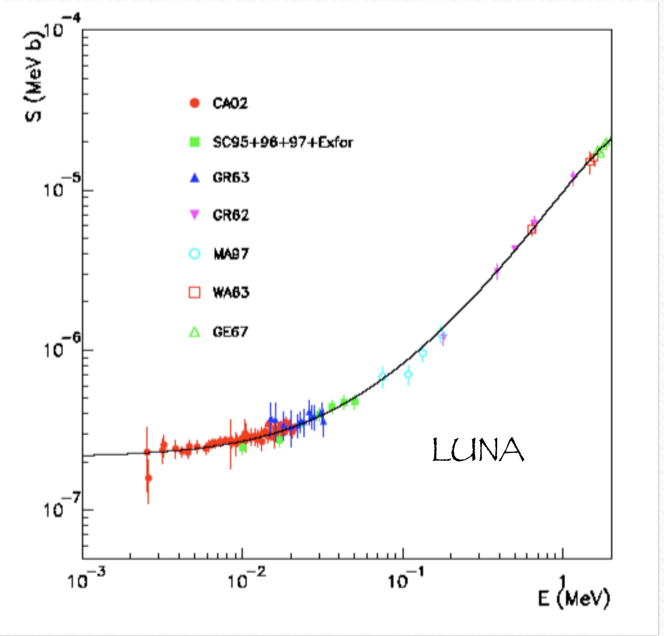
^{4}He mass fraction Y_P linearly increases
with τ_n: 0.246 - 0.249



Nico & Snow 2006

Nuclear rates:

main input from experiments
low energy range (10^2 KeV)
major improvement: underground measurements (e.g. LUNA at LNGS)

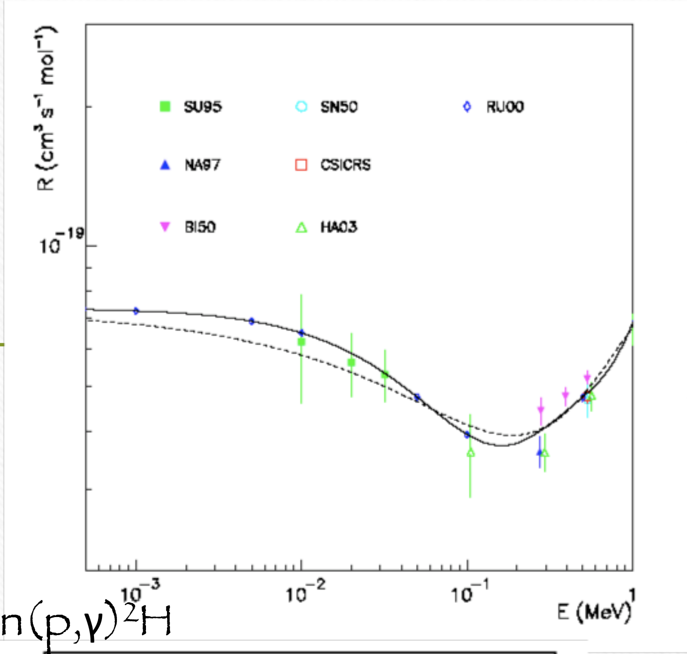


LUNA

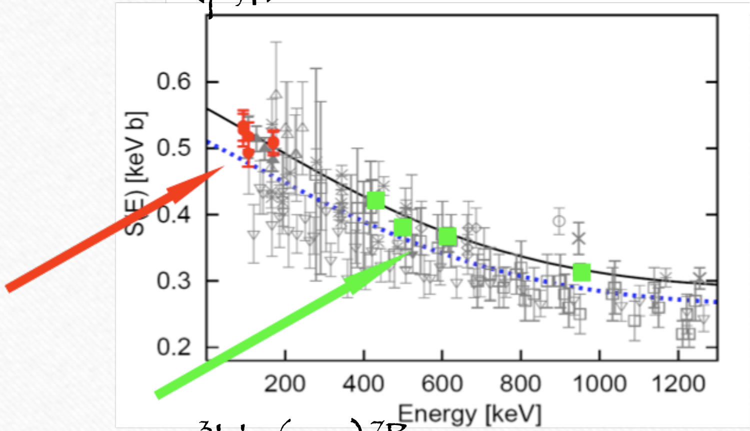
$^2H(p,\gamma)^3He$

Weitzmann Inst.

Rupak



$n(p,\gamma)^2H$



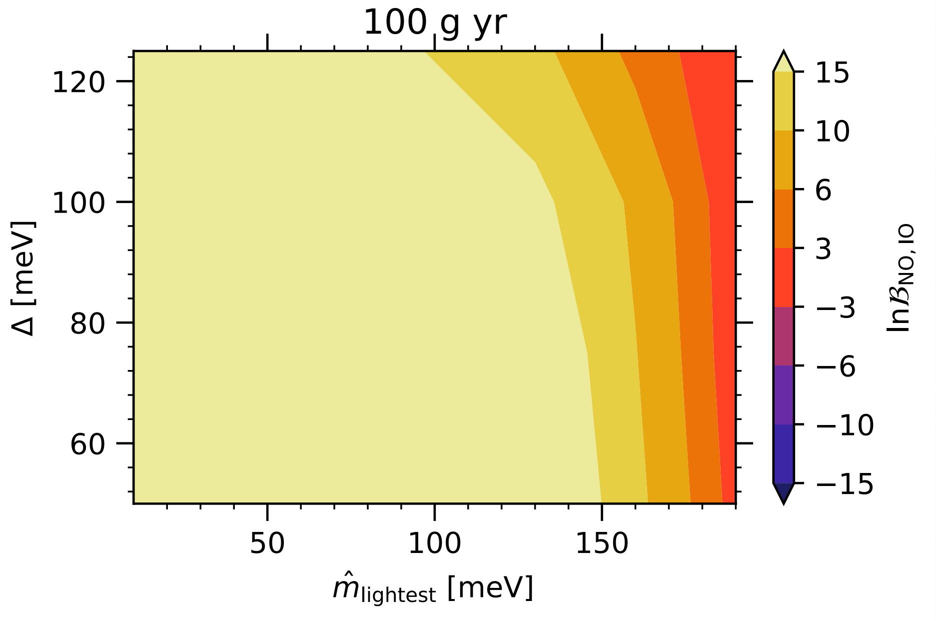
$^3He(\alpha,\gamma)^7Be$

ERNA: $S(0) \approx 0.57 \pm 0.04$ KeV b Di Leva et al 2010

Mass Ordering (Hierarchy)

Bayesian evidence

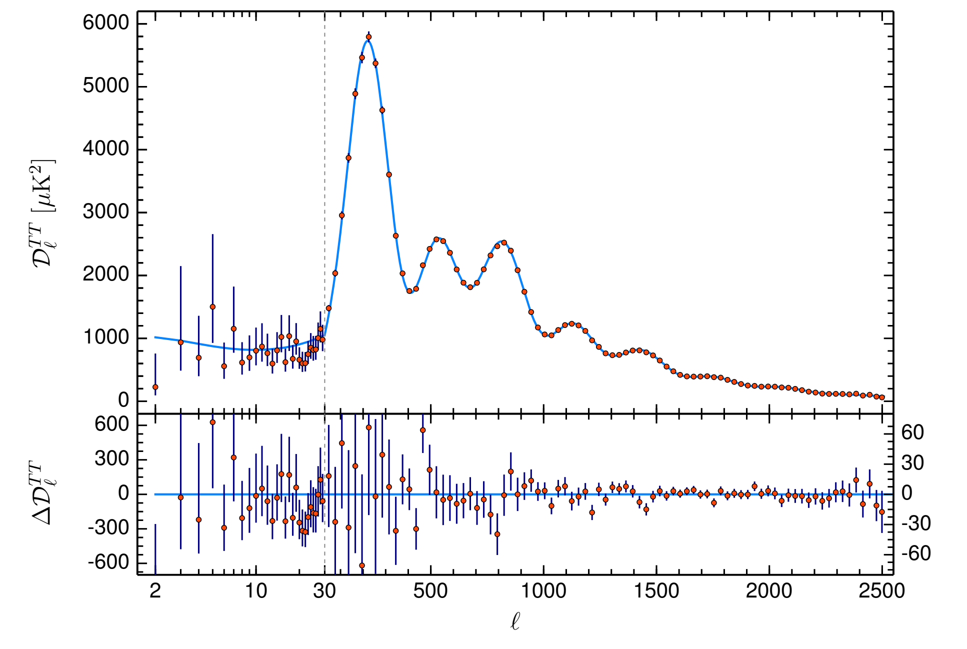
$$\frac{\int d\,\Theta\, P(d|M1)P(M1)}{\int d\,\Theta\, P(d|M2)P(M2)}$$



The CMB

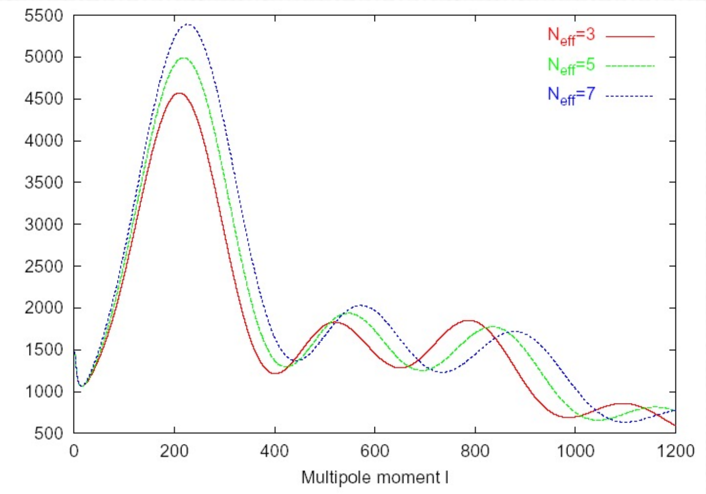
Anisotropies contain so much information abut the cosmological model!

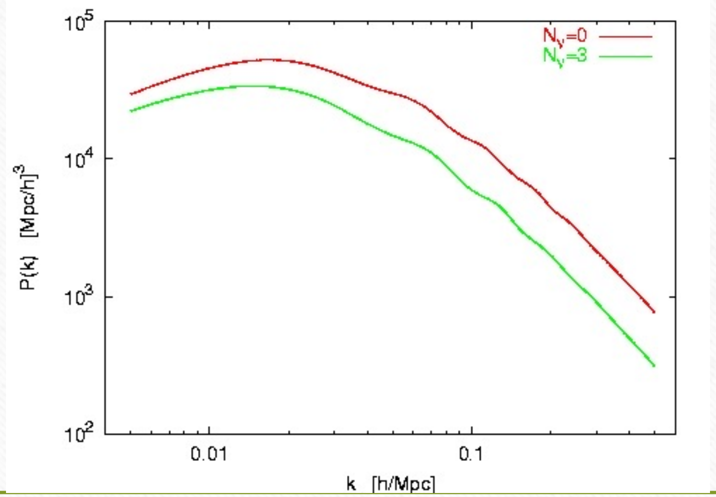
Planck 2018



Effect of CNB on CMB and LSS

Mean effect (Sachs-Wolfe, M-R equality)+ perturbations



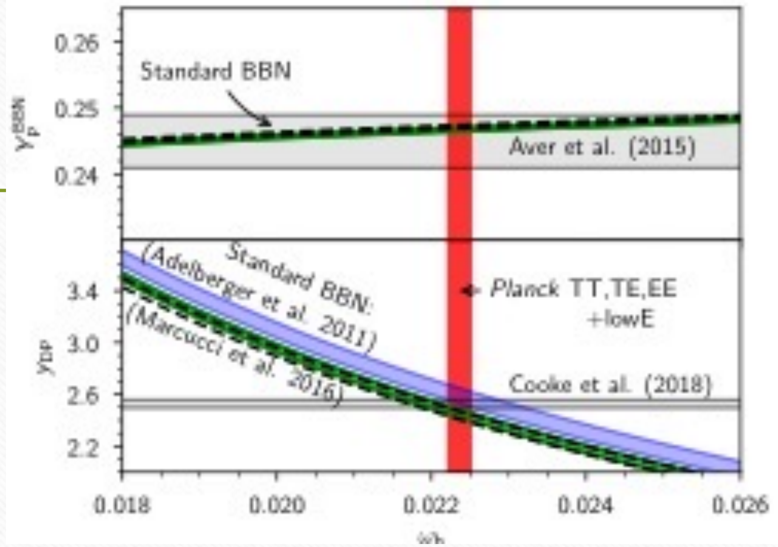


Perturbations

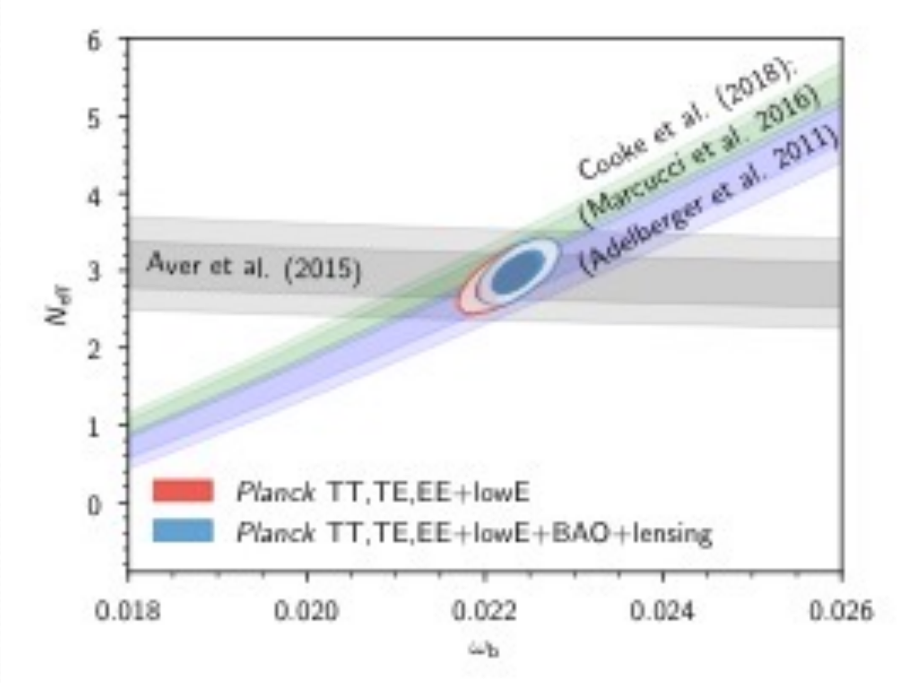
Acoustic peak amd damping tail: N_{eff}

Lensing potential on CMB: m_ν larger expansion rate suppresses clustering

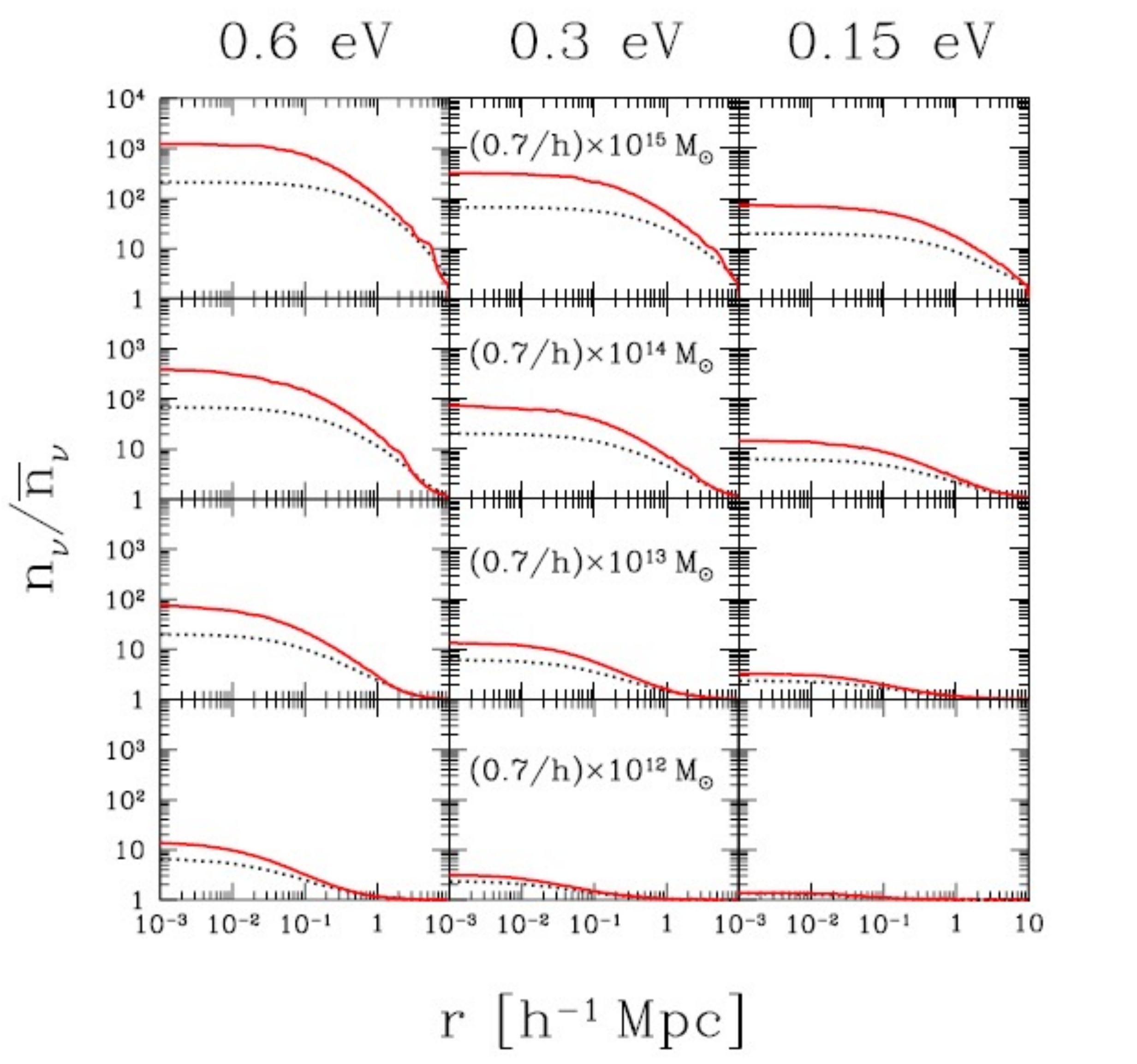
Large Scale Structure: suppression at small scales $k > 0.1$ h Mpc^{-1}



Standard BBN
Aver et al. (2015)
Y_P^{BBN}
Standard BBN:
(Adelberger et al. 2011)
(Marcucci et al. 2016)
Planck TT,TE,EE
+lowE
Cooke et al. (2018)
y_{DP}
ω_b



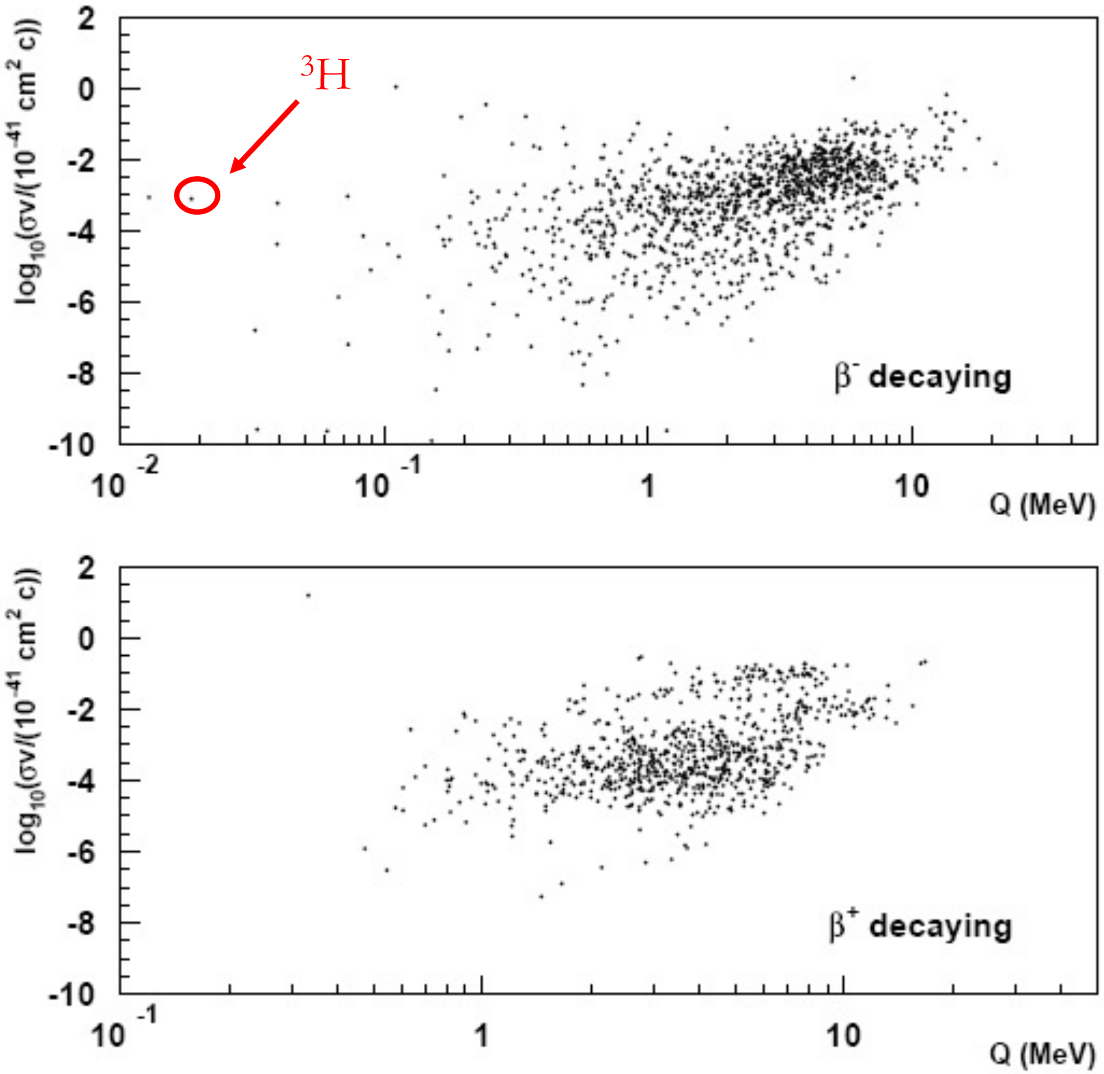
Cooke et al. (2018):
(Marcucci et al. 2016)
(Adelberger et al. 2011)
Aver et al. (2015)
N_{eff}
Planck TT,TE,EE+lowE
Planck TT,TE,EE+lowE+BAO+lensing
ω_b



A. Ringwald and Y. Wong 2004

N-1-body simulations

Beta decaying nuclei having BR($\beta^{\pm}$) > 5 % selected from 14543 decays listed in the ENSDF database



1272 β^{-} nuclei

799 β^{+} nuclei

Issues:

1. Rates

$$\lambda_\nu = \int \sigma_{\mathrm{NCB}} v_\nu \, f(p_\nu) \, \frac{d^3 p_\nu}{(2\pi)^3}\,, \quad = \frac{G_\beta^2}{2\pi^3} \int_{W_o+2m_\nu}^{\infty} p_e E_e F(Z, E_e) C(E_e, p_\nu)_\nu \cdot E_\nu p_\nu \, f(p_\nu) \, dE_e \,,$$

$$\lambda_\beta = \frac{G_\beta^2}{2\pi^3} \int_{m_e}^{W_o} p_e E_e F(Z, E_e) C(E_e, p_\nu)_\beta E_\nu p_\nu \, dE_e \,,$$

Nuclear form factors (shape factors) uncertainties: use beta observables

$$\mathcal{A} = \int_{m_e}^{W_o} \frac{C(E'_e, p'_\nu)_\beta}{C(E_e, p_\nu)_\nu} \frac{p'_e}{p_e} \frac{E'_e}{E_e} \frac{F(E'_e, Z)}{F(E_e, Z)} E'_\nu p'_\nu dE'_e$$

$$\boxed{\sigma_{\mathrm{NCB}} v_\nu = \frac{2\pi^2 \ln 2}{\mathcal{A} \, t_{1/2}}}$$

cos'è la materia per la fisica delle particelle

e perché cercare di osservarne la creazione in laboratorio

Francesco Vissani, INFN Gran Sasso & GSSI

il contesto

Nel modello standard, tutte le particelle che costituiscono la materia sono accompagnate da particelle di **antimateria**. In questo modello le differenze tra numeri leptonici $\mathrm{L_a} - \mathrm{L_b}$ dove $\mathrm{a,b} = \mathrm{e}, \mu, \tau$ sono esattamente conservate. Questa previsione è in disaccordo con i fenomeni di apparizione di nuovi sapori, osservati studiando i neutrini.

L'operatore di Minkowski-Weinberg con dimensione canonica 5 dota i neutrini di massa, dando origine alle "oscillazioni a tre sapori" che spiegano le suddette osservazioni. Se questa modifica del modello standard è corretta, l'autostato di massa del neutrino coincide con la propria antiparticella, come suggerito molti anni fa da **Majorana**.

Al momento, il modo più promettente per validare queste idee è la ricerca di una rarissima transizione nucleare, detta decadimento doppio-beta senza neutrini, nella quale **vengono create due particelle di materia** - due elettroni.

In considerazione degli sforzi sperimentali ai quali la comunità scientifica si sta approntando per cercare questa transizione:

1) ripercorriamo la storia di queste idee, evidenziando le principali difficoltà concettuali incontrate e sottolineando l'attualità e valore (anche didattica) del formalismo di Majorana

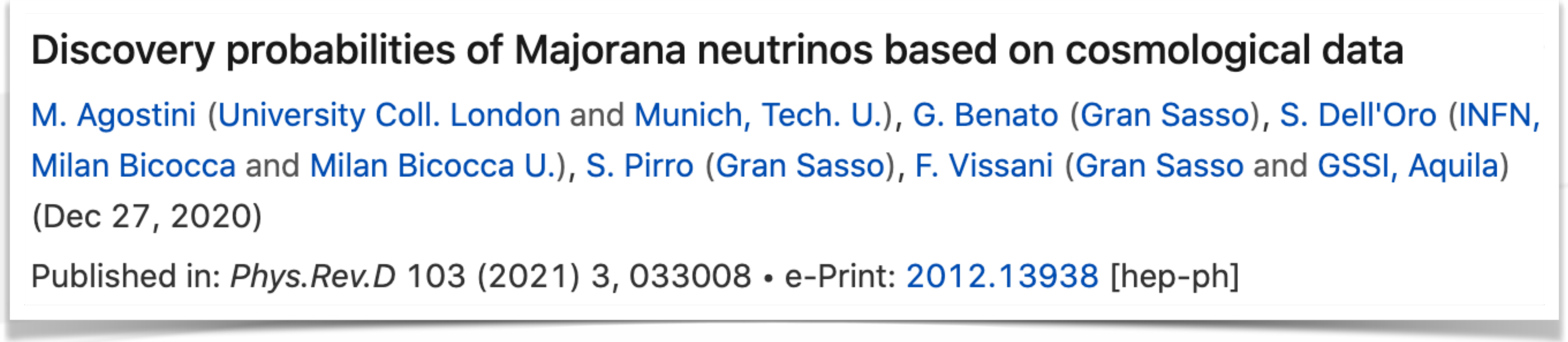
2) esaminiamo i vincoli sul processo in esame, mettendo in particolare evidenza l'importanza delle misure di cosmologia

3) ribadiamo l'enorme importanza di questi studi per la fisica oltre il modello standard

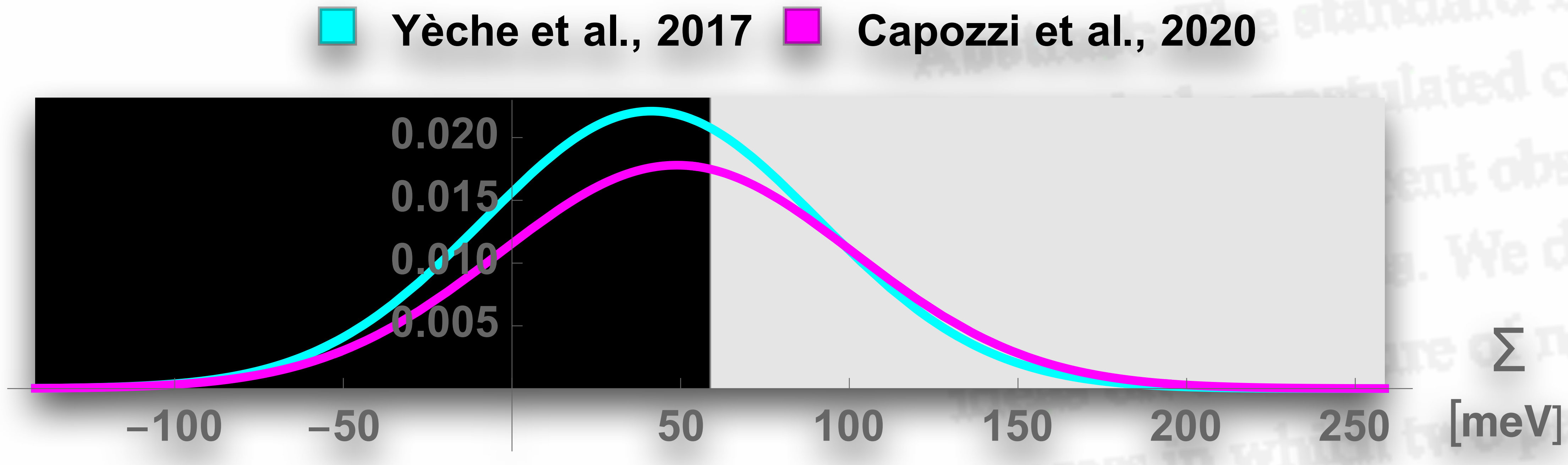
(ad oggi l'unica evidenza sperimentale che il concetto di "fisica oltre il modello standard" abbia una quale consistenza deriva proprio dallo studio della massa dei neutrini)

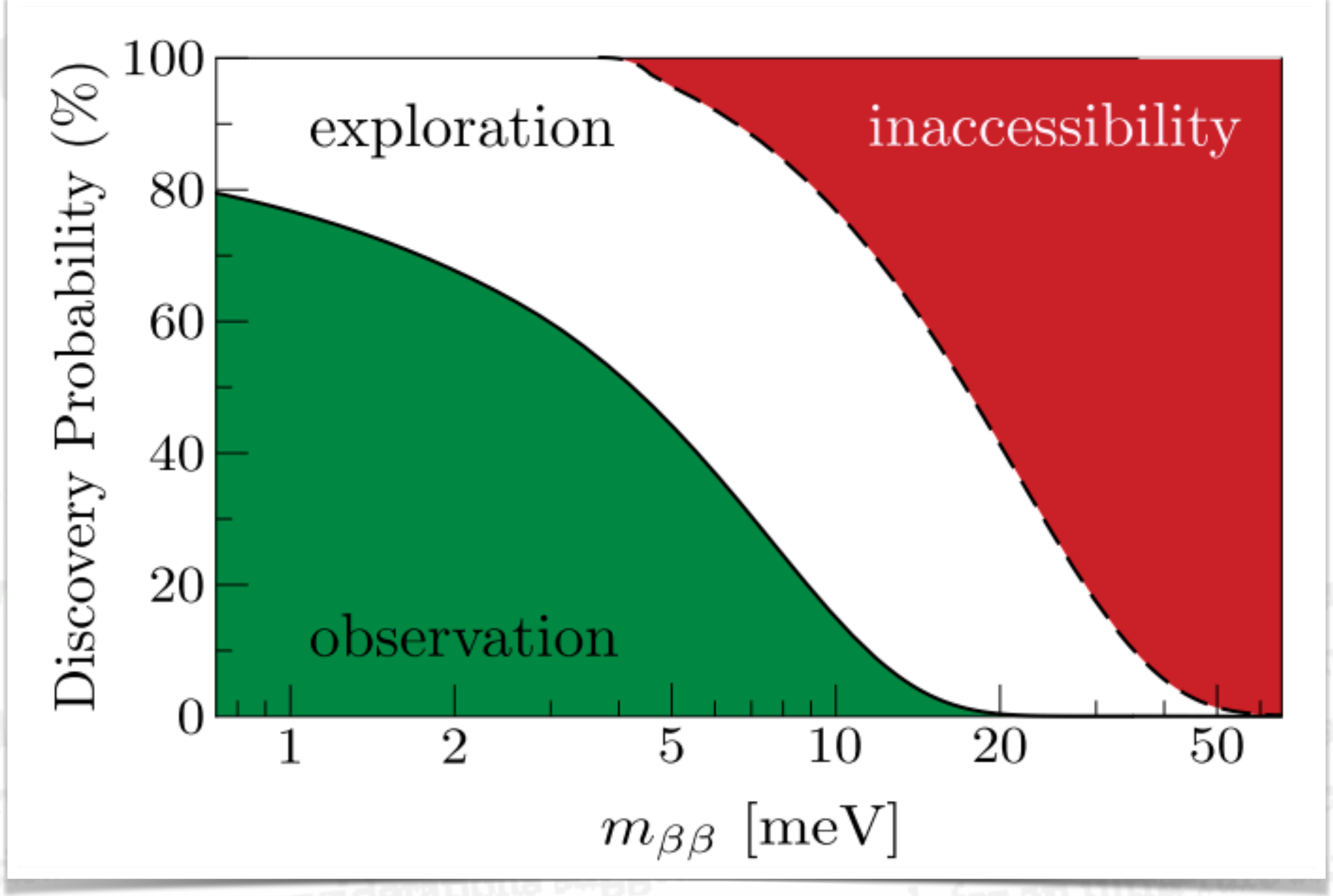
Table 2. The number of papers per decade citing a few seminal articles, including Majorana's, from their appearance to the present day. In the last two lines, a (incomplete) list of theoretical and observational facts that are of major relevance for current discussion. From https://inspirehep.net/ (accessed on December 2020). GUT, grand unified theory.

	'30s	**'40s**	**'50s**	**'60s**	**'70s**	**'80s**	**'90s**	**2000**	**2010**
Majorana [4]	3	3	8	5	17	43	67	159	745
Goeppert-M. [112]	2	2	6	0	0	18	19	41	221
Racah [18]	2	1	6	1	6	19	16	31	133
Furry [111]	0	2	6	0	1	25	30	71	351
Case [27]	-	-	1	10	10	36	43	34	36
theory	ν	**B, L**	V-A, SU(2)	SM, oscill.	SM	GUT, $\nu_\odot$	SUSY	glob.anal.	cosm.
exp. and obs.	n,e$^+$, μ	π, K	ν, V-A	$\nu_\odot$ anom.	SM, $\nu_\odot$	W, Z^0, ν_{atm}	oscill.	oscill.	Higgs, cosm.



ipotizzando che l'ordine delle masse di neutrini sia del tipo "normale" e che la massa sia di Majorana, presentiamo una nuova rappresentazione delle possibilità di avere successo o meno nella ricerca sperimentale del processo in funzione del valore del parametro sondato $m_{\beta\beta}$ basata sulle misure della cosmologia riguardanti $\Sigma = m_1 + m_2 + m_3$





DI COSA E' FATTA LA "MATERIA"?

Componenti Elementari Della Materia	Caratteristica Identificativa	Termine Vigenza Modello [Teoria] Esperimento	Motivo Della Inadeguatezza
Atomi	Specie, Massa	[1838] 1909	**[Atomi Di Elettricità] Elettroni**
Elettroni & Nuclei	Carica, Massa, Spin	[1930] 1956	**[Teoria Di Fermi] Neutroni & Neutrini**
$\mathrm{p}, \mathrm{n}, \mathrm{e}, \nu_{\mathrm{e}}, \mu \ldots$	$\mathbf{B}, \mathbf{L}_{\mathrm{e}}, \mathbf{L}_{\mu} \ldots$, " "	[1961] 1968	**[Modello Standard] Quarks**
Quark & Leptoni	$\mathbf{B}-\mathbf{L}, \mathbf{L}_{\mathrm{e}}-\mathbf{L}_{\mu}, \ldots$, " "	[1962] 2010	**[Mescolamento Leptoni] Esperimenti Di Apparizione**
Quark-Leptoni	$\mathbf{B}-\mathbf{L}$, " "	[1937] ?	**[Massa Di Majorana]** $2\mathrm{n} \to 2\mathrm{p} + 2\mathrm{e}$
Fermioni	Massa, Spin	[1977] ???	**[Supersimmetria?] ???**

Grazie per l'attenzione!

Secondo Meeting PRIN NAT-NET (WP1)
6 July 2021

Neutrino Flavor Conversions in Supernovae

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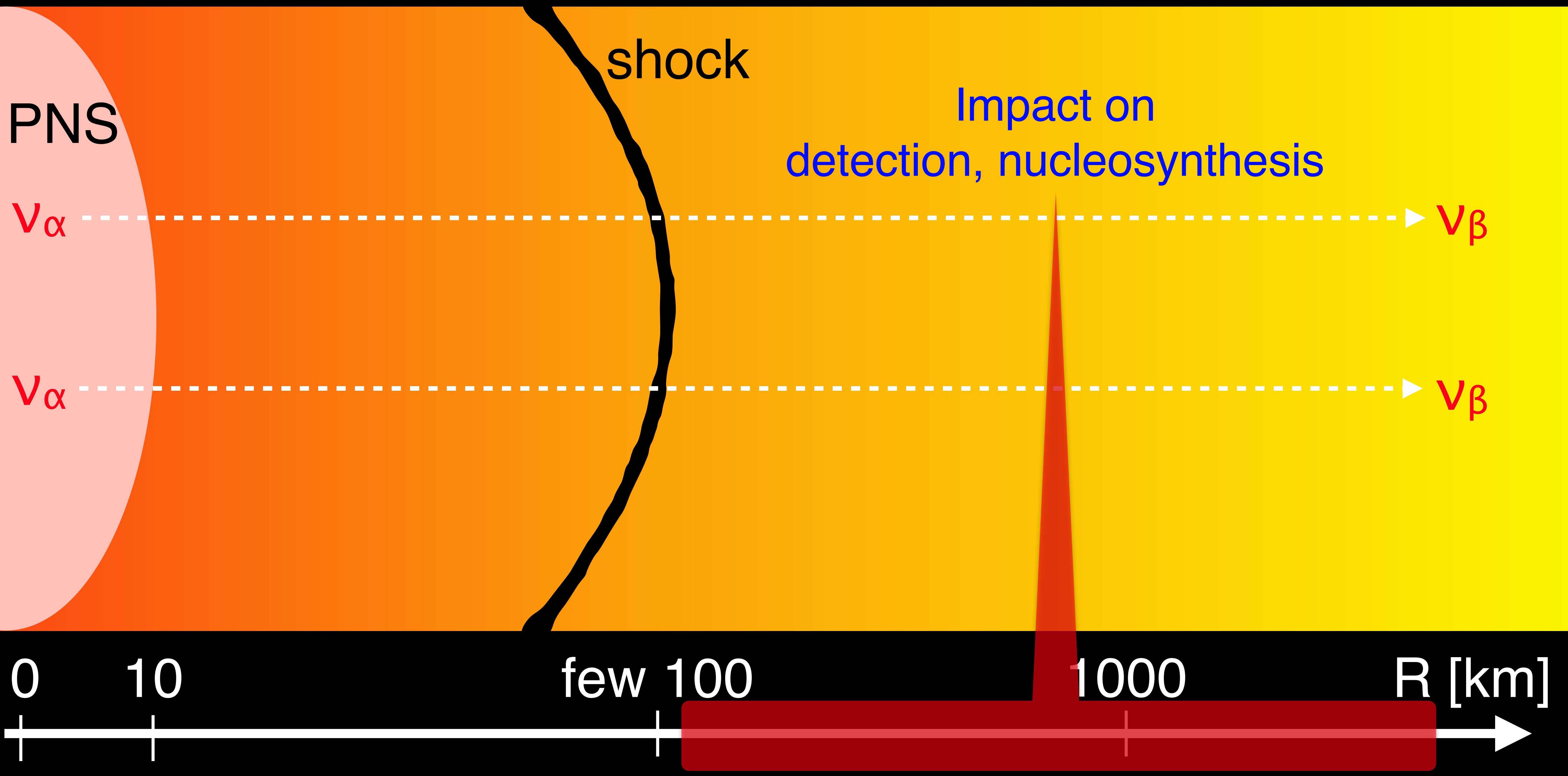
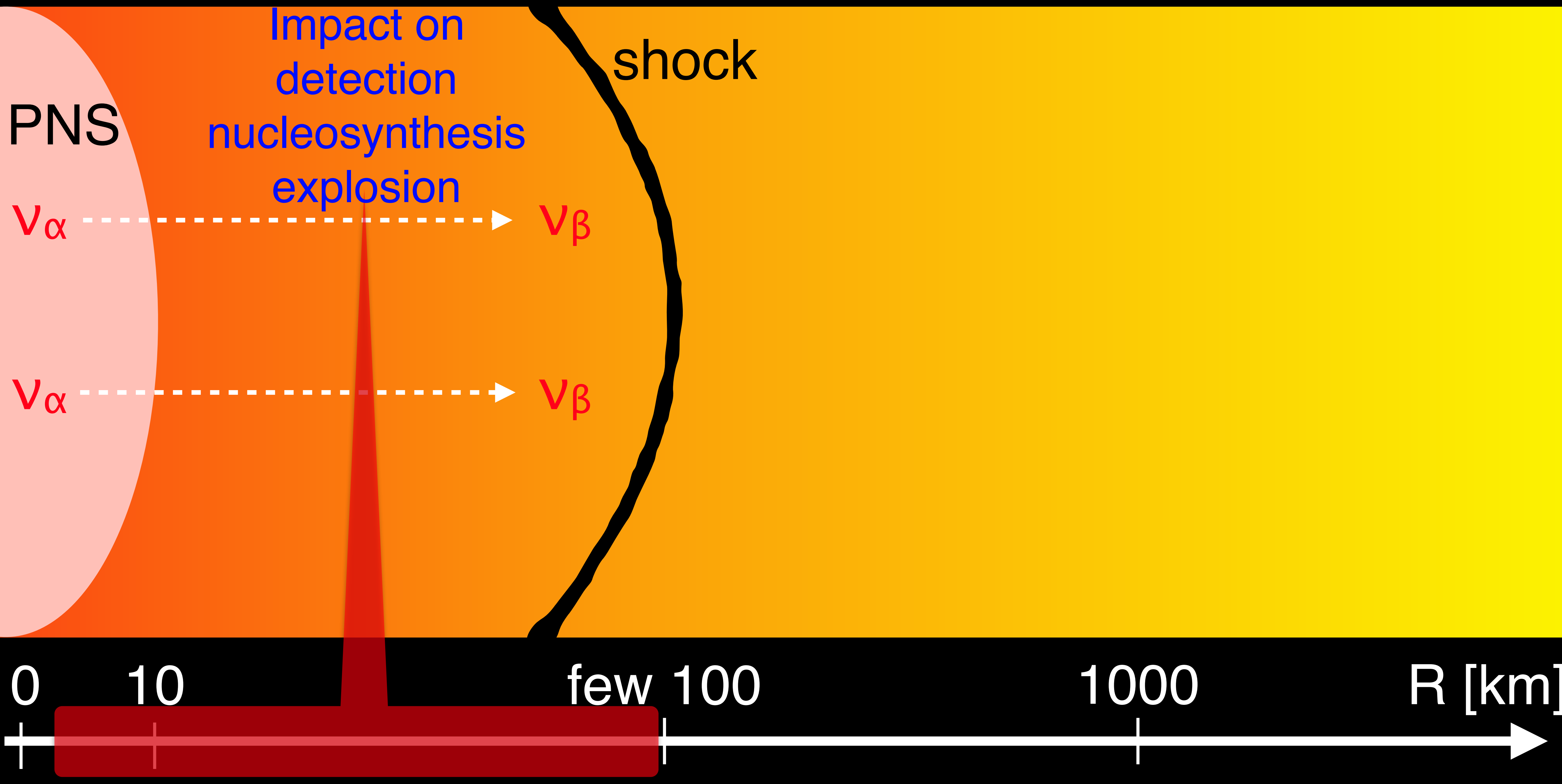
Flavor conversions: overview

Conversions can happen at different locations



Flavor conversions: overview

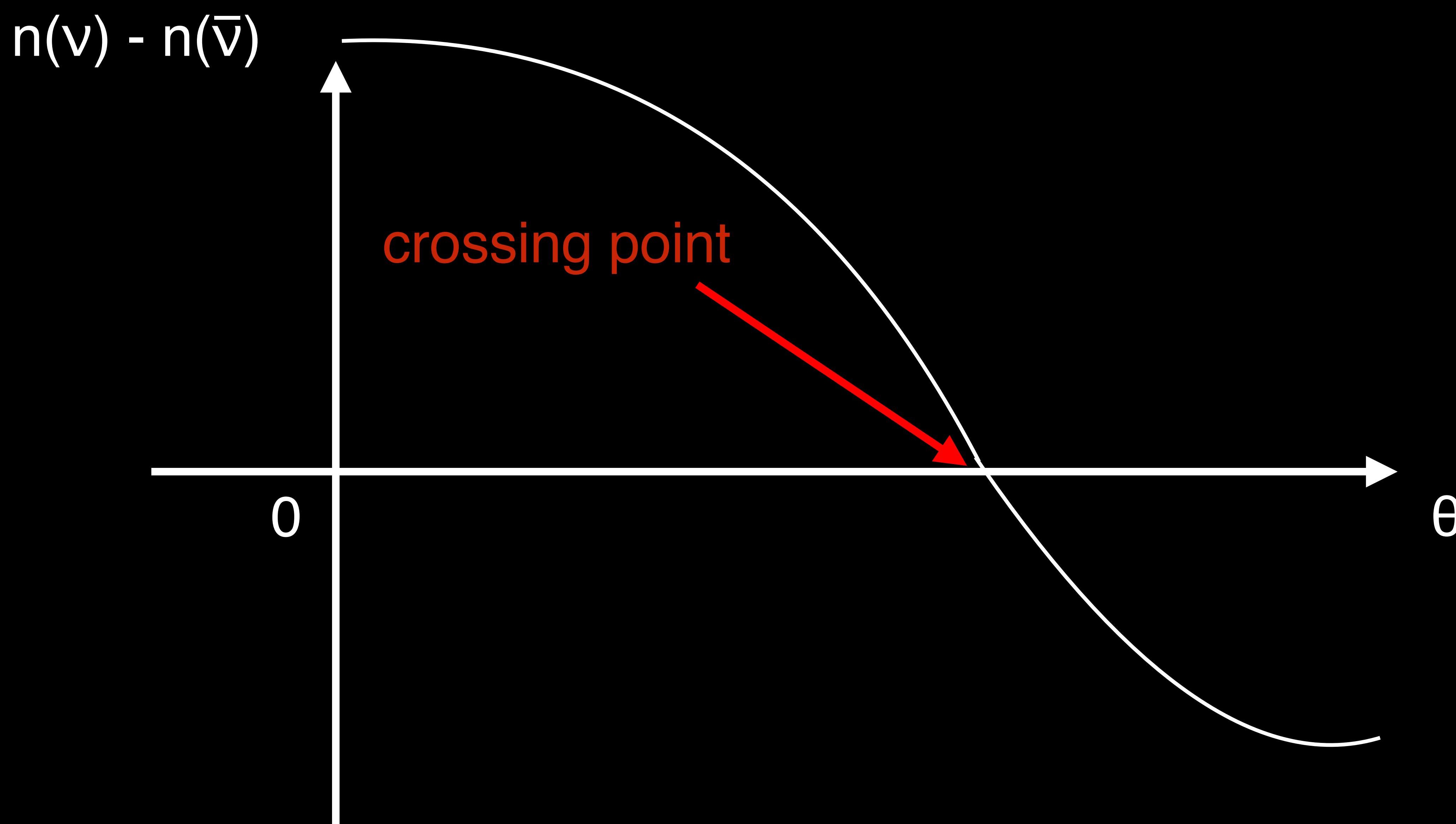
Conversions can happen at different locations



I will focus on possible conversions happening below the shock

Fast conversions

Necessary and sufficient condition for fast conversions: **angular crossing** (Morinaga, arXiv:2103.15267)

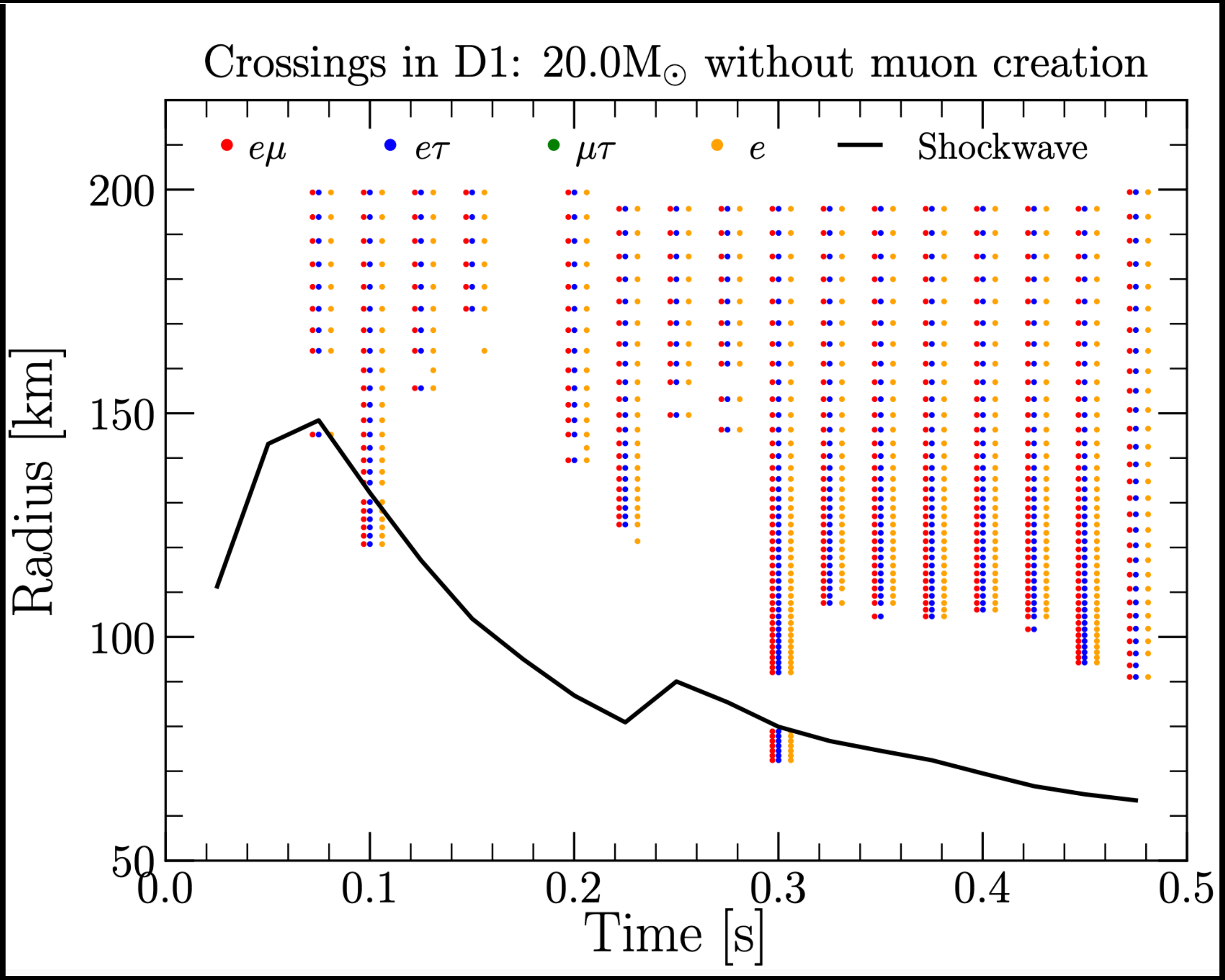


Example: $\bar{\nu}$ (ν) dominate in the forward (backward) direction

Looking at real simulations

Are crossing really happening in supernovae?

Capozzi, Abbar, Bollig, Janka, Phys. Rev. D 103 (2021) no.6, 063013



see also
Tamborra, Huedepohl, Raffelt, Janka, 2017; Abbar, Duan, Sumiyoshi, Takiwaki, Volpe, 2018; Morinaga, Nakagura, Kato, Yamada, 2019; Azari, Yamada, Morinaga, Iwakami, Okawa, Nakagura, Sumiyoshi 2019; Morinaga, Nagakura, Kato, Yamada 2020; Abbar, Capozzi, Glas, Janka, Tamborra 2021

Crossings possible both below and above the shock wave

Phenomenology of fast conversions

Fast Conversions seem to be happening.
What about their impact? Some questions:

1) What is the final outcome of fast conversions?

Abbar, Volpe, Phys. Lett. B 790 (2019), 545-550
Johns, Nagakura, Fuller, Burrows, Phys. Rev. D 102 (2020) no.10, 103017
Bhattacharyya, Dasgupta, Phys. Rev. Lett. 126 (2021) no.6, 061302
Bhattacharyya, Dasgupta, Phys. Rev. D 102 (2020) no.6, 063018
Bhattacharyya, Dasgupta, arXiv:2101.01226
Shalgar, Tamborra, arXiv:2106.15622

2) Is there a dependence on the neutrino energy?

Shalgar, Tamborra, JCAP 01 (2021), 014
Shalgar, Tamborra, arXiv:2103.12743

3) How do they develop in space and time?

Shalgar, Padilla-Gay, Tamborra,JCAP 06 (2020), 048
Bhattacharyya, Dasgupta, Phys. Rev. D 102 (2020) no.6, 063018

Phenomenology of fast conversions

Fast Conversions seem to be happening.
What about their impact? Some questions:

4) What happens in three flavours?

Chakraborty, Chakraborty, JCAP 01 (2020), 005
Capozzi, Chakraborty, Chakraborty, Sen, Phys. Rev. Lett. 125 (2020), 251801
Shalgar, Tamborra, arXiv:2103.12743

5) What is the role of collisions?

Capozzi, Dasgupta, Mirizzi, Sen, Sigl, Phys. Rev. Lett. 122 (2019) no.9, 091101
Martin, Carlson, Cirigliano and Duan, Phys. Rev. D 03 (2021), 063001
Shalgar, Tamborra, Phys. Rev. D 103 (2021), 063002

6) What happens with extremely tiny crossings?

Morinaga, Nagakura, Kato, Yamada, Phys. Rev. Res. 2 (2020) no.1, 012046
Zaizen, Morinaga, arXiv:2104.10532

Phenomenology of fast conversions

Fast Conversions seem to be happening.
What about their impact? Some questions:

7) Including fast conversions in supernova simulations?

xxxx, et al. Phys. Rev. Lett. nn (20yy) mm, ll

Still a lot of work ahead