Tale of 3 probes: Joint Discovery Scenarios

Based on the discussion in the Snowmass white paper on
"***Synergy between cosmological and laboratory searches in neutrino physics***"
arXiv:2203.07377 [hep-ph]

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Probes of the Absolute Mass Scale

β decay

$$m_\beta \equiv \left[\sum |U_{ei}|^2 m_i^2\right]^{1/2}$$

$$m_\beta > \begin{cases} 9\,\mathrm{meV} & \mathrm{NO} \\ 50\,\mathrm{meV} & \mathrm{IO} \end{cases}$$

0ν2β decay

$$m_{\beta\beta} \equiv \left|\sum U_{ei}^2 m_i\right|$$

$$m_{\beta\beta} > \begin{cases} 0\,\mathrm{meV} & \mathrm{NO} \\ 18\,\mathrm{meV} & \mathrm{IO} \end{cases}$$

Cosmology

$$\sum m_\nu \equiv \sum_i m_i$$

$$\Sigma m_\nu > \begin{cases} 60\,\mathrm{meV} & \mathrm{NO} \\ 100\,\mathrm{meV} & \mathrm{IO} \end{cases}$$

See talks by Christine, Jason, Eleonora

Model Dependence

β decay

Kinematic measurement; model independent

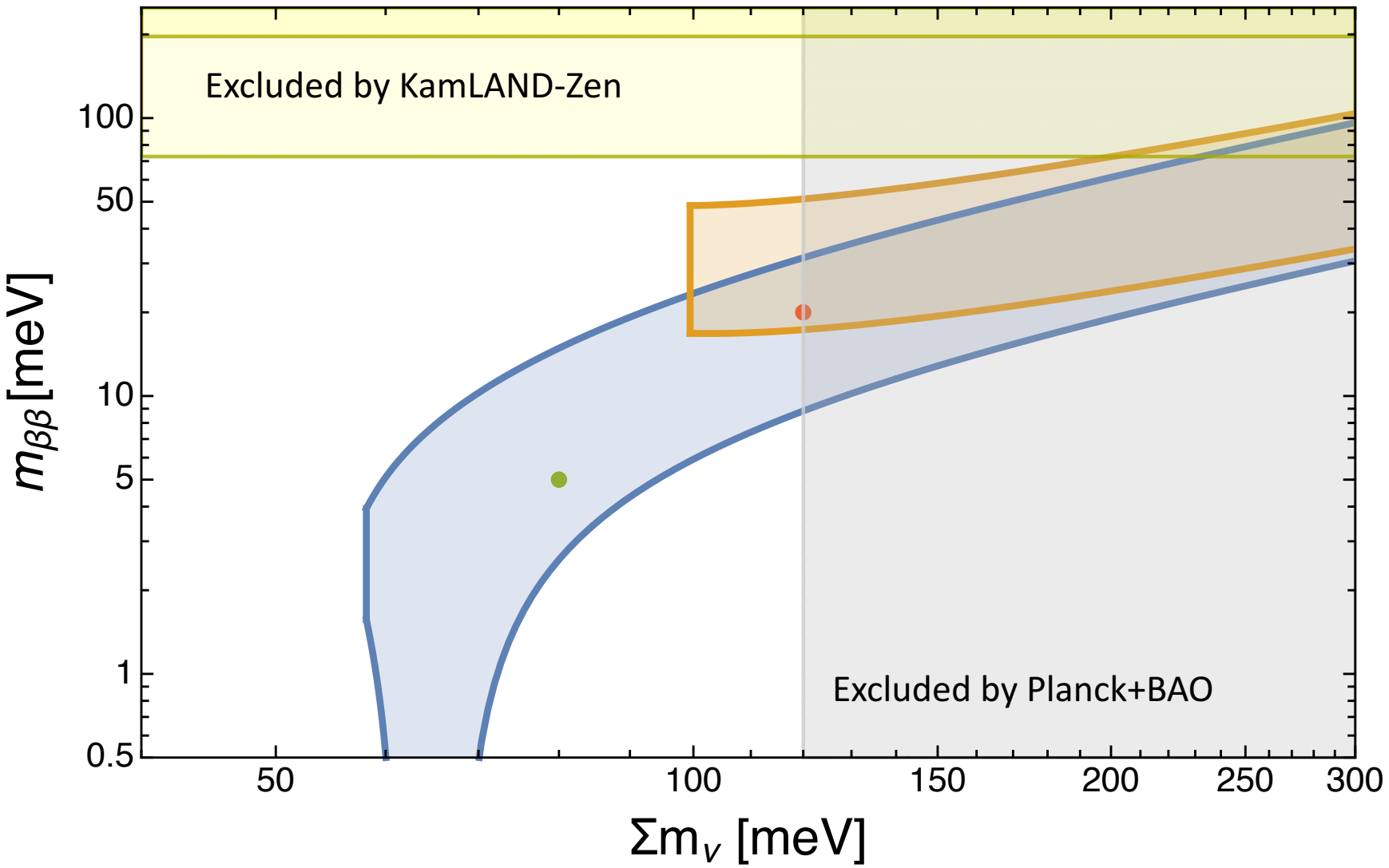
0ν2β decay

Model dependent: assumes Majorana νs, decay rate can have contributions beyond light Majorana neutrino exchange
(+ nuclear physics uncertainties)

Cosmology

Model dependent: mainly sensitive to ν energy density and its evolution over time + degeneracy with other cosmological parameters in extended models

See talks by Steen, André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Excluded by Planck+BAO
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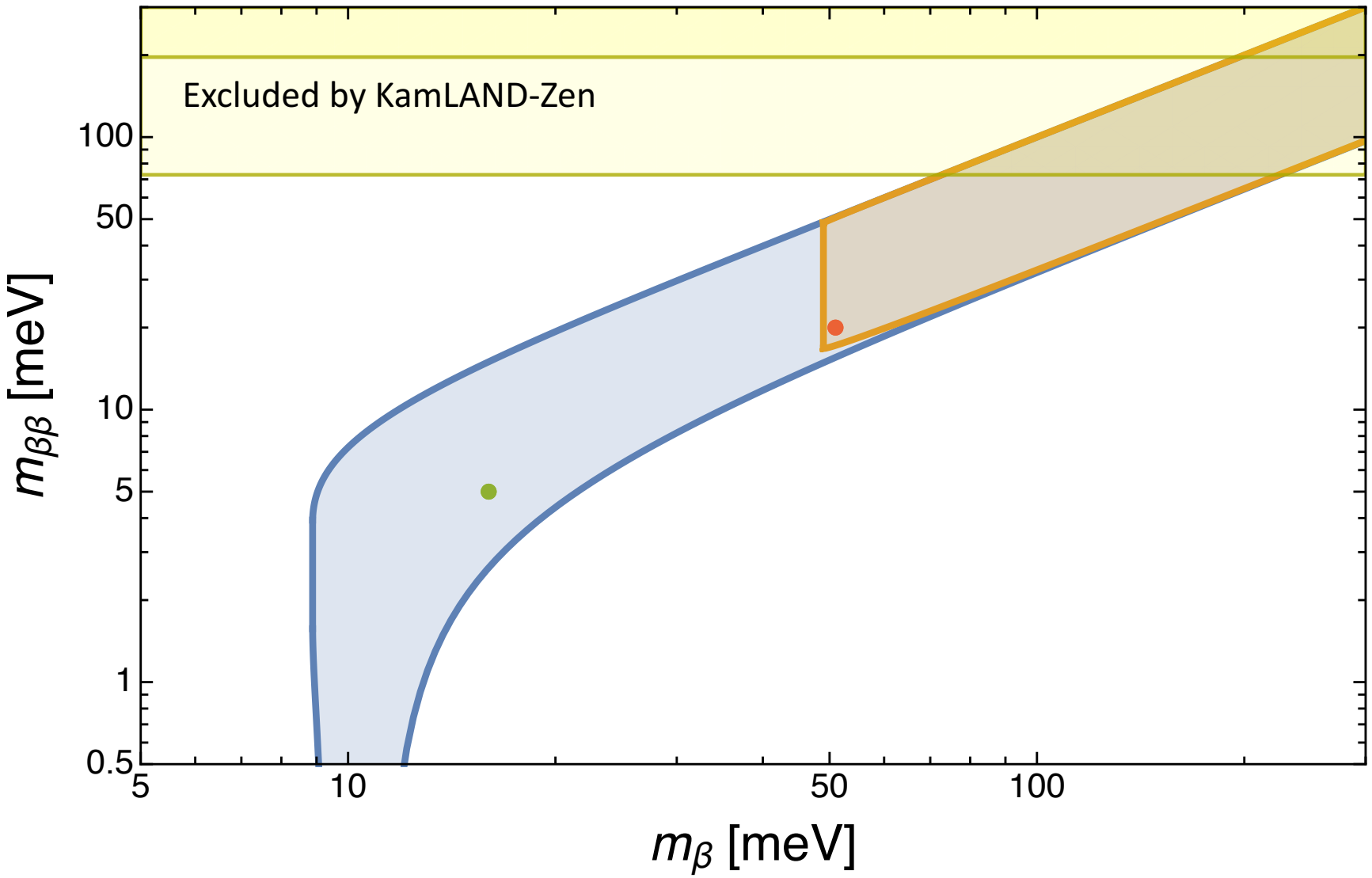
$m_{\beta\beta}$ [meV]
Σm_ν [meV]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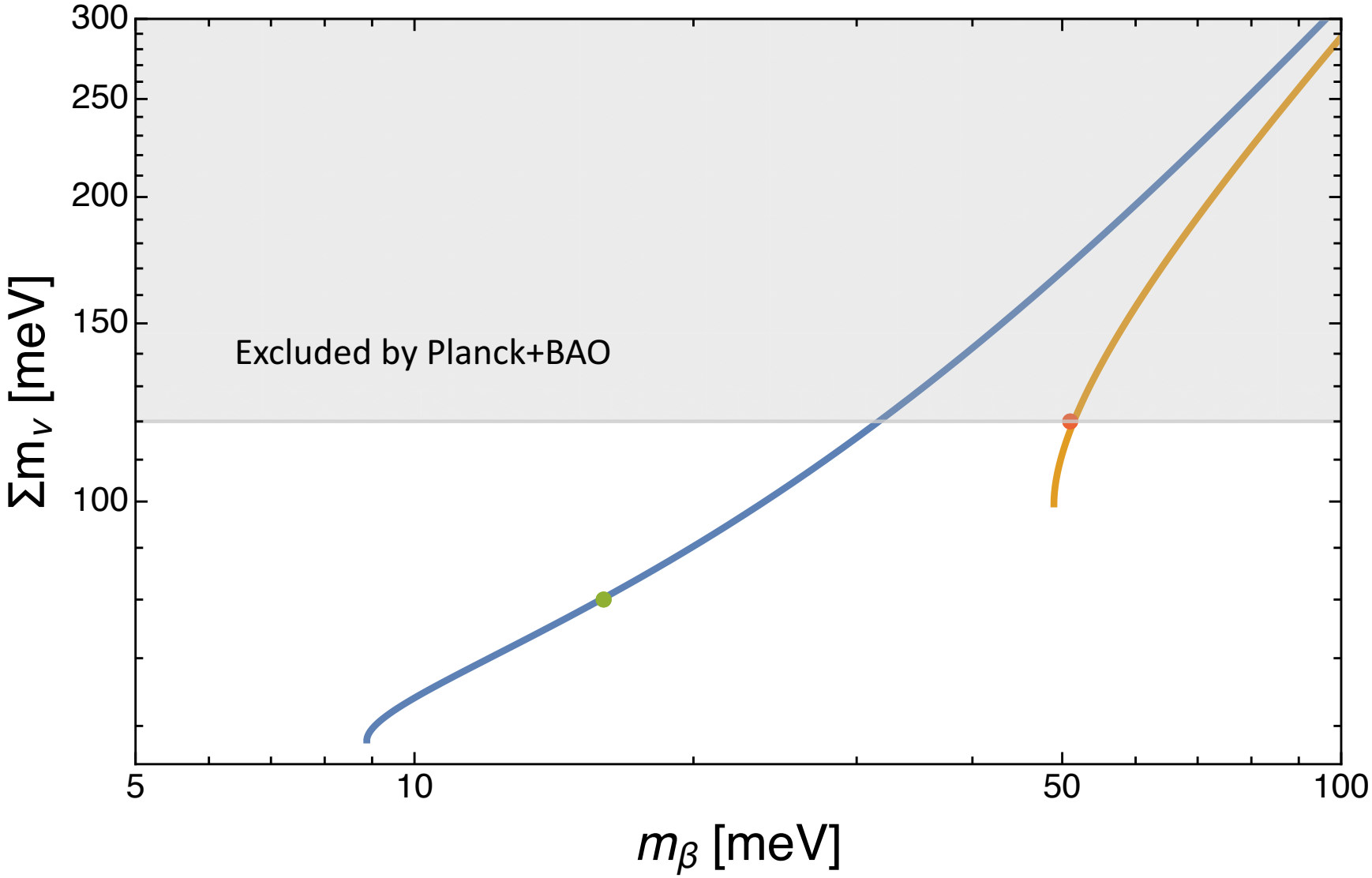
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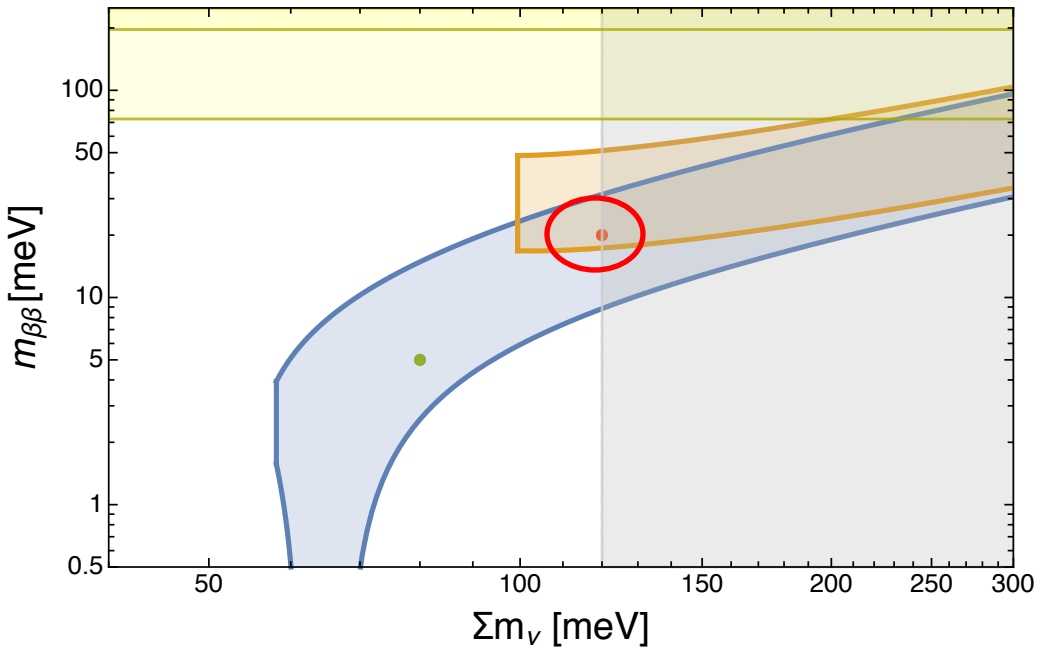
"CONCORDANCE" SCENARIOS

Scenario n.1: coherent observation of both 0nu2b and non-zero mass from cosmology

- Measurement of the mass scale
- Neutrinos are Majorana
- Ordering can be either normal or inverted
- m_β > 20 meV (NO), 50 meV (IO)
- Mild (~2sigma) detection of m_β if ordering is inverted



Assuming mbb > 18 meV and Mnu > 0.45 meV can be detected at >3σ level
and a 40meV 90% sensitivity of mb measurements

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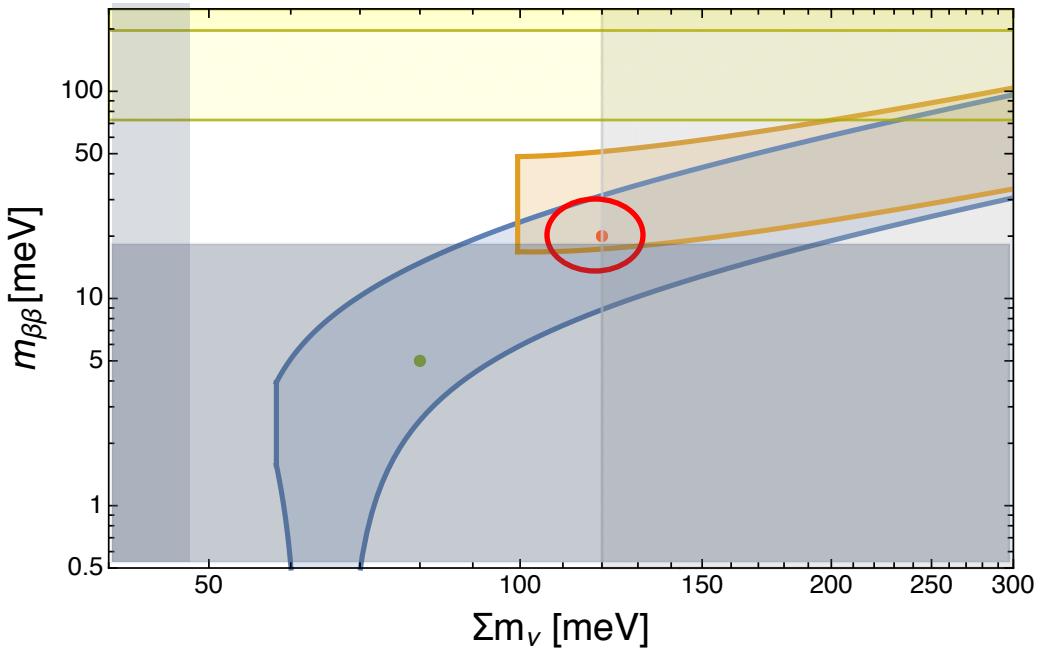

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"CONCORDANCE" SCENARIOS

Scenario n.2: observation of non-zero mass from cosmology, but no signal from 0nu2b

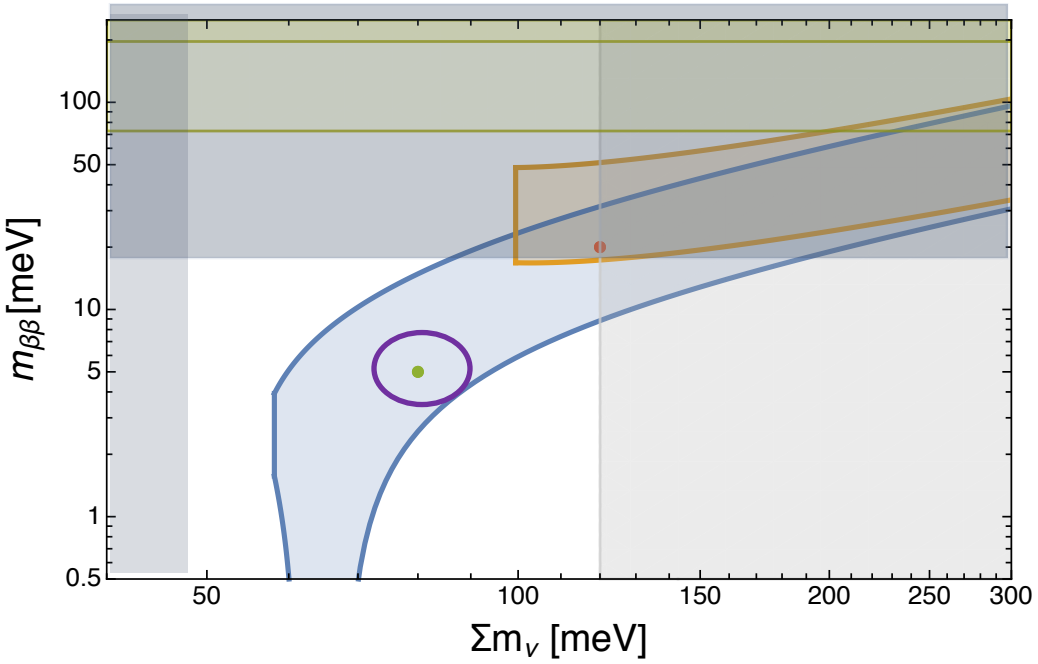
- Measurement of the mass

Either:

- neutrinos are Dirac
- either NO or IO (cosmology or m_β might tell)
- m_β?

or

- Neutrinos are Majorana
- NO
- no stat. sig. m_β signal



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Σm_ν	$m_{\beta\beta}$	m_β	M/D	NO/IO	Notes
✓	✓	✓	M	IO	Σm_ν >100 meV
✓	✓	✗	M	NO	
✓	✗	✓	D	IO	Σm_ν >100 meV
✓	✗	✗	?	NO	

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- Lack of detection of non-zero neutrino mass from cosmology will point to a failure of the standard ΛCDM model
- Laboratory probes (including oscillations) can constrain the mass scale and ordering and inform cosmology, helping in assessing the viability of alternative cosmological models
- If explanation involves modifying neutrino properties (e.g., non-standard interactions), is it something that we can probe in the lab (through e.g. CEνNS?)

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- In another scenario, we might get a tension between the cosmological measurement and 0nu2b
- Given the sensitivites, what might happen is that $m_{\beta\beta}$ is too large (or Σm_ν is too small)
- Either theoretical framework (or both!) might need revision
- E.g. light sterile neutrino contributing to 0nu2b amplitude might also be see in cosmo obs (N_{eff} or Σm_ν itself)
- Kinematic measurements will be crucial

THANKS!

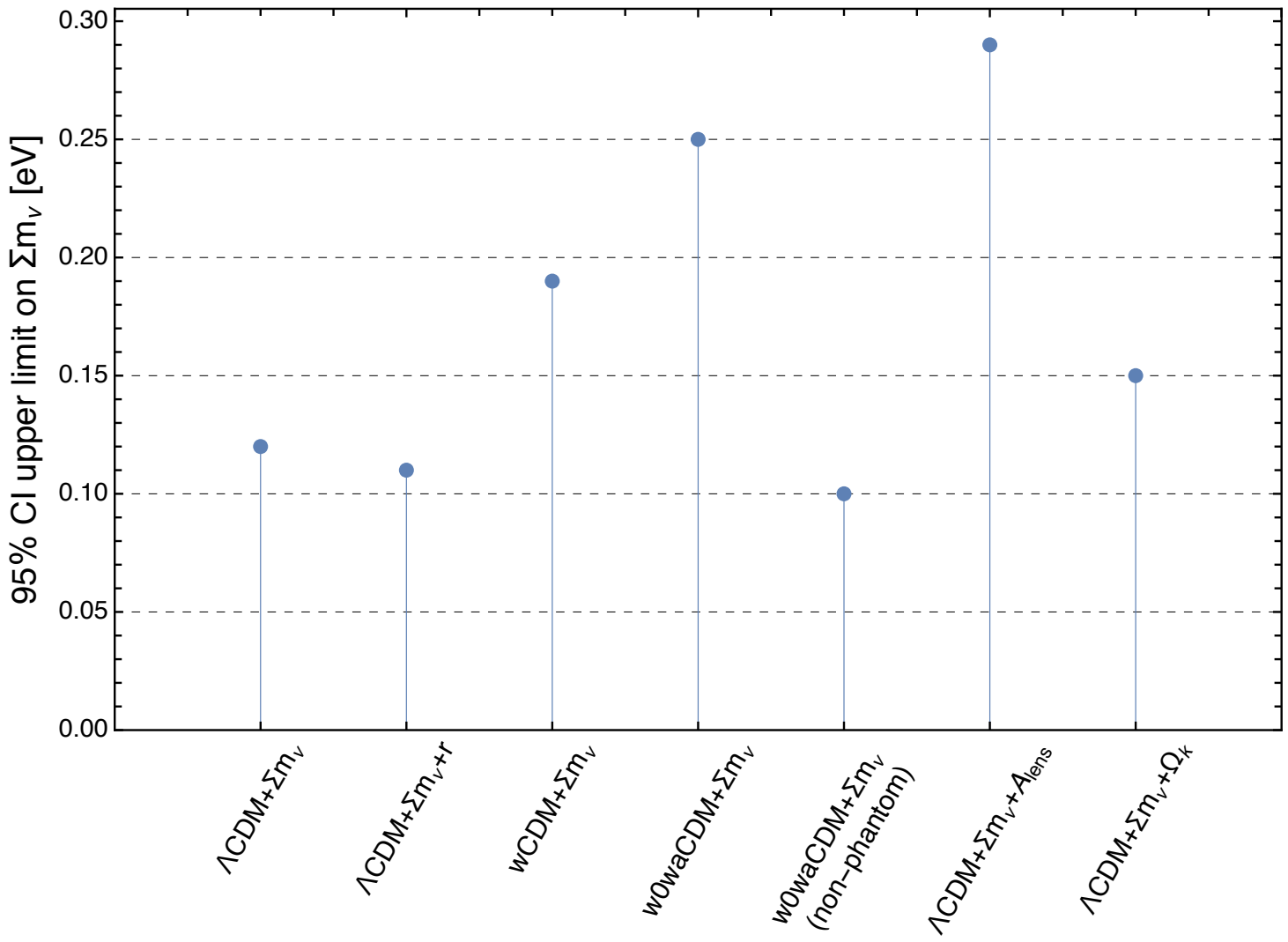
BACKUP SLIDES

ν MASSES IN ΛCDM EXTENSIONS

It is by now well known that neutrino mass constraints are degraded in:

- Dynamical DE models (but only for phantom DE!, see e.g. Vagnozzi et al. 2019)
- Non-flat models
- Models with varying lensing amplitude (which is however not a physical parameter – basically a way to eliminate the information from CMB lensing)

Data: Planck 2018 (TTTEEE+lowE+lensing) + BAO



Plot based on the results of S. Roy Choudhury & S. Hannestad (2020) arXiv 1907.12598

ν MASSES IN ΛCDM EXTENSIONS

Constraints can be loosened in alternative models, e.g.

- Neutrino decays
- Late-time phase transitions (mass-varying neutrinos)
- Low-reheating scenarios
- Long-range ν interactions
- Conversion to lighter states

In some cases, this would reopen the window for a detection in KATRIN (see e.g. Alvey et al, 2021)