Summary WG1 (I): Pheno

S. Choubey and P. H.
Focussed sessions...lots of discussion
• Many questions...some answers
• We learnt something about what we know and about what we do not
Why we are here?

Neutrino masses imply a new physics scale $\Lambda$? What?

- If $\Lambda \gg v$ there is an explanation of why $\nu$ are so light

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \frac{\alpha_i}{\Lambda} O_{i}^{d=5} + \sum_i \frac{\beta_i}{\Lambda^2} O_{i}^{d=6} + \ldots$$

  - $\nu$ mass
  - e, $\mu$ dipole moment, etc.
  - NSI

- If $\Lambda \ll v$, no explanation of why $\nu$ are so light, but "hidden" sector could be related to other fundamental questions: dark matter, dark energy,...
We have a good chance to learn something more about this new physics with neutrino and other flavour physics experiments by testing the Standard scenario.

<table>
<thead>
<tr>
<th>Masses</th>
<th>Angles</th>
<th>CP-phases</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_1^2 &lt; m_2^2, m_3^2$</td>
<td>$\theta_{12}, \theta_{23}, \theta_{13}$</td>
<td>$\delta, \alpha_1, \alpha_2$</td>
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Physics potential ISS report

CP phase

One baseline!

Two baselines!

Hierarchy

Lower energy

Higher energy
Upgrading $\beta$-beams

To improve on the hierarchy larger $E, L$ needed:

$$\text{Li}/B \text{ at } \gamma=350 : \ E_{\text{max}} \sim \gamma E_0$$

New detector technology...
MIND, TASD detector ...
less mass

Two baselines:

$L=7000\text{km}$ magic
$L=2000\text{km}$ peak
@MIND type detector

$10^{19}$  $2 \times 10^{18}$

Fernández-Martínez

$10^{19}$ needed ballpark for this game!
Agarwalla

700km+7000km
Even larger $\gamma$

Unbeatable!
\[ \beta\text{-beam } \gamma = 350 \text{ and/or } 10^{19} \text{ ions...} \]

Are we crazy?

It seems not (completely) yet... from joint session WG1-WG3
By changing ions we change end-point energy $E_0$

Physics-reach scaling law:

$$\frac{N^{(1)}_\beta}{N^{(2)}_\beta} \approx \left(\frac{E^{(1)}_0}{E^{(2)}_0}\right)^2, \quad \frac{\gamma^{(1)}}{\gamma^{(2)}} \approx \frac{E^{(2)}_0}{E^{(1)}_0}$$

Or $\gamma/N_\beta$ duality…

It could indeed fit in LHC upgrades…
If the $$$ machines are there, probably one can do something about other difficulties...

- x10 ion production
- Decay ring
- Activation issues...

Greenfield scenarios will be considered within the new EuroNu design study (to the extent that manpower permits)
Downgrading $\beta$-beams

What if $\theta_{13}$ is large (ie within 90% D-Chooz reach)?

W. Winter’s wish list and question

- $5\sigma$ independent confirmation of $\theta_{13} > 0$
- $3\sigma$ mass hierarchy determination for any (true) $\delta_{CP}$
- $3\sigma$ CP violation determination for 80% (true) $\delta_{CP}$

What is the minimal $\beta$-beam for that?
Standard $\gamma=350$, He/Ne $\beta$-beam seems to be near optimal but not a particularly downgraded version therefore...
Other physics with 100Kton-> Megaton detectors?

(i) Atmospheric data for free: **must be included in all analyses!**

Eg. Hierarchy:

Maltoni

\[ \nu_e, \nu_\mu \]

Optimization of WC analysis is foreseeable and most welcome!
(ii) Solving dark-matter degeneracies

Neutrino spectra at MIND from dark matter annihilation can discriminate between decay channels
Claim: Maybe possible to determine neutrino mass hierarchy at extremely small $\theta_{13}$ using galactic supernova neutrinos.

Effect: Crucially dependence on the mass hierarchy of collective neutrino oscillations in SN

Strategy: Using Earth matter effect to diagnose collective SN neutrino flavor transitions
(iii) Supernova neutrinos  mass hierarchy at small $\theta_{13}$

Galactic SN @ 10 kpc by 2003(15): Ratio of spectra in two 0.4 Mton WC detectors, one shadowed by the Earth, the other not.

Mirizzi

Canfranc’s shadowing prob=0.568
More on the downgraded LE NuFact

\[ N_\mu = 10^{21} \, y^{-1} \quad E_\mu = 5 \text{GeV} \quad L = 1290 \text{ km} \]

What if we used a non-magnetized detector?

WC, LAr become alternatives...

Discrimination between $\nu/\bar{\nu}$ still possible to some extent:

But also:

\[ \mu \text{ decay vs. capture} \]

Angular dependence

n tagging
Some more GloBES curves...

![Graph showing CP violation at 3σ](image)
Non-standard $\nu$ interactions

\begin{align*}
L &= L_{SM} + \sum_i \frac{\alpha_i}{\Lambda} O_i^{d=5} + \sum_i \frac{\beta_i}{\Lambda^2} O_i^{d=6} + \ldots \\
&= f \left( H^\dagger \gamma^\rho P_L L \beta \right) \left( \overline{L}_\alpha \gamma^\rho P_L H \right) f
\end{align*}

Eg: $d=8$

- First preliminary SK analysis on the subject! Mitsuka
- Future constraints from Opera Esteban-Pretel, Blennow
- Future constraints from NuFact Uchinami, Ota's poster

If combining baselines was necessary to resolve degeneracies in the $3\nu$ family case, it is even more important if there are NSI...
Sensitivity at $\nu$ factory

Statistical + systematic errors + some correlations of errors +

$\sin^2 2\theta_{13}$ reach no NSI

$\sin^2 2\theta_{13}$ reach fit including $\epsilon_{e\tau}^m$

$|\epsilon_{\alpha\beta}^m|$ reach ($@ 3\sigma$)

Kopp-Ota-Winter, 0804.2261v1 [hep-ph]
It will be important to continue exploring what type of generic new physics the future facilities could access:

- Non-standard interactions
- Low see-saw scale: EW, or even lower
- Exotic explanations of LSND, dark matter, dark energy

We could expect that the old faithfull $\nu$ will continue to bring in surprises...
One example...

See-saw II: Pair-production of charged triplet scalars at LHC

\[ \text{BR}(H^{+} \rightarrow l_{a}^{+} l_{b}^{+}) \sim |M_{ab}|^{2} \]

LHC, ν oscillation physics complementarity!