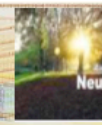

Optimizing the Greenfield Beta-Beam

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The Unanswered Questions

- What is the magnitude of θ_{13}?
  - Main channels to determine θ_{13}
    - $\nu_e \to \nu_e$ or $\bar{\nu}_e \to \bar{\nu}_e$: P_{ee} or $P_{\bar{e}\bar{e}}$; Disappearance Expts
    - $\nu_\mu \to \nu_e$ or $\nu_e \to \nu_\mu$: $P_{\mu e}$ or $P_{e\mu}$; Appearance Expts
- What is the sign of Δm^2_{31}?
  - Main channels to determine $sign(\Delta m^2_{31})$
    - $\nu_\mu \to \nu_e$ or $\nu_e \to \nu_\mu$: $P_{\mu e}$ or $P_{e\mu}$; Appearance Expts
    - "binned" $\nu_\mu \to \nu_\mu$ $P_{\mu\mu}$; Disappearance Expts
    - $\nu_e \to \nu_e$ P_{ee}; Disappearance Expts
- Is there CP violation in the lepton sector?
  - Main channel to see δ_{CP}
    - $\nu_\mu \to \nu_e$ or $\nu_e \to \nu_\mu$: $P_{\mu e}$ or $P_{e\mu}$; Appearance Expts
    - Also in principle possible using $\nu_\mu \to \nu_\mu$

Plausible Strategy to Answer the Questions

- THE WISHLIST
  - Measurement of θ_{13}
  - Measurement of $\mathrm{sgn}(\Delta m^2_{31})$
  - Measurement of δ_{CP}

- THE TOOLS
  - The Oscillation Channel: $P_{e\mu}$
  - The Beam: Beta-Beam
  - The Detector: 50 kton iron

- THE OPTIMIZATION
  - Baseline: L
  - Lorentz Boost: γ
  - Luminosity: N_β
  - Source Ions: ^{8}B and ^{8}Li OR ^{18}Ne and ^{6}He

Optimizing the Source Ions

For a given source ion:

- Flux in forward direction increases as γ^2
- Peak energy of the beam is roughly $\gamma(E_0 - m_e) \approx \gamma E_0$
- Cross-section increases as $E \propto \gamma$
- Probability roughly goes as $1/E^2 \propto 1/\gamma^2$

- Events $(N_\mu) \propto$ flux * cross-section * probability

- Sensitivity $\propto N_\mu \propto \gamma$
- Until the flux at the "most interesting" energy saturates

- Sensitivity $\propto N_\mu \propto N_\beta$ ($N_\beta \equiv$ Luminosity)

Optimizing the Source Ions

- *Demand* that shape of the event spectrum at a given L is same for both ^{8}B and ^{8}Li and ^{18}Ne and ^{6}He

- Peak energy of the beam is roughly $\gamma \mathbf{E_0}$
- Total flux is proportional to $\mathbf{N}_\beta \gamma^2$

- Spectrum with same peak energy and same total flux:

$$\frac{N_\beta^{(1)}}{N_\beta^{(2)}} = \left(\frac{E_0^{(1)}}{E_0^{(2)}}\right)^2 , \quad \frac{\gamma^{(1)}}{\gamma^{(2)}} = \frac{E_0^{(2)}}{E_0^{(1)}}$$

- $\mathbf{E_0^{(B)}/E_0^{(Ne)} \simeq 3.5 \Rightarrow \gamma^{(Ne)}/\gamma^{(B)} \simeq 3.5}$ [Accelerator]
- $\mathbf{E_0^{(B)}/E_0^{(Ne)} \simeq 3.5 \Rightarrow N_\beta^{(B)}/N_\beta^{(Ne)} \simeq (3.5)^2 \simeq 12}$ [Source]

Conclusions

- Beta-beams offer a pure, intense and well known neutrino flux with very low systematic uncertainties and very low backgrounds – ideal for precision experiments

- $\mathbf{L}$, γ, $\mathbf{N}_\beta$ and ion sources have to be chosen optimally

- $\sin^2 2\theta_{13}$ discovery: Either ^{18}Ne and ^{6}He at $\sim 700 - 900$ km or ^{8}B and ^{8}Li at the magic baseline are optimal

- Mass Hierarchy: Take ^{8}B and ^{8}Li at the magic baseline

- CP Violation: Use ^{18}Ne and ^{6}He at the short baseline

- Optimally use ^{8}B and ^{8}Li at the magic baseline + ^{18}Ne and ^{6}He at ~ 750 km two-baseline set-up for all three