Panel 4: Ancillary activities

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Ancillary?

- Any support activity to the main measurements.
- Main task is to reduce systematic errors.

Broad spectra:

- theory (neutrino-Nucleus interactions,…)
- experiments providing key measurements.
- improvement on detector simulation (hadron-nucleus interactions).
- improvement on neutrino flux predictions (LBL & atmospheric).
- Development of new experimental techniques related to the above points.
Long base line

- LBL neutrino energy spectrum is not monochromatic:
  - we need to determine event by event the energy of the neutrino.

- This estimation is not perfect and the cross-section does not cancels out in the ratio.

\[
\frac{N_{\text{events}}^{\text{far}}(E_{\nu})}{N_{\text{events}}(E_{\nu})} = \frac{\int \sigma(E'_{\nu}) \Phi(E'_{\nu}) P(E_{\nu} | E'_{\nu}) P_{\text{osc}}(E'_{\nu}) dE'_{\nu}}{\int \sigma(E'_{\nu}) \Phi(E'_{\nu}) P(E_{\nu} | E'_{\nu}) dE'_{\nu}}
\]

- The neutrino oscillations introduce differences in the flux spectrum and the ratio does not cancel the cross-sections.
The landscape around $\nu$ exp.

- Long baseline
- Detector R&D
- Improved modelling of low energy hadron interactions
- New $\nu$ production techniques
- Theory (mainly nuclear)
- Experiments
- Neutrino Flux
**Theory**

- Initial nuclei state description.
- $\nu$-nucleon cross-sections:
  - quasi elastic, pion production, SIS, DIS, ...
- Final state re-interactions.
- Particles and kinematics in final state outside the nucleus.
- Threshold effects related to charge lepton mass.
- ...

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**i.e. energy reconstruction in T2K**

- Different problems to be faced by Low energy (T2(H)K), medium energy (Dune) & high energy (atmospheric).
- eA community not very advanced in exclusive interaction description needed by neutrinos.
- Background determinations ($\text{NC}\pi^0$ & $\text{NC}\pi^+$ production).
\( \sigma_{ve}/\sigma_{v\mu} \)?

- Fundamental quantity for running and future oscillation (bot only LBL) experiments.
- Estimations might be more complex than simple phase-space.
  - Bremsstrahlung corrections.
  - Nuclear effects.
Doing $\nu A$ cross-section without $\nu$'s: $(e,e')A \& \gamma A$

- There is a lot of data outside.
- Models need to comply with them.
- It might be an interesting place to derive models beyond limited neutrino data.
$$\frac{d^2\sigma_{pA}}{dp_{\pi,K} \ldots d\theta_{\pi,K} \ldots}$$
New experimental techniques

Direct control of neutrino flux & enhance $\nu_e$ flux

NUSTORM

ENUBET

Neutrinos from stored muons

+ Perfectly known flux
+ 50% ($\nu_\mu$) 50% ($\nu_e$)
New detector technology

4π acceptance

Low momentum threshold

same far/near acceptance
Beyond LBL: atmospherics

- Atm. $\nu$ flux normalization error is $\sim$12% (SK assumes 25% error with 21% discrepancy)
- Uncertainty in ratio is small

- $\nu_e/\nu_\mu$
- anti-neutrino/neutrino @ threshold
Hadron interactions

- Neutrino event reconstruction relies on observing final state particles
  - Significantly affected by hadronic scattering within nuclei
- In particular, very few measurements of proton scattering exist!
- New measurements essential for constraining crucial part of interaction models

protons lose large fraction of energy in hadronic scattering within Ar nucleus

Almost no data on Ar above 50 MeV!

Nuclear effects on recoil protons in Ar

proton-nucleus scattering data with MC model

+ Interactions in detector material.