IRN meeting, October 2024, Paris

# Systematics for $\nu$ LBL experiments : ancillary measurements

# Inter-experiments collaboration : LBL and beyond

Contribution to EPPS IRN document (Sec.2.4, 2.5, 2.6)

S.Bolognesi (IRFU, CEA) for the editors of the draft

# LBL : today → tomorrow

Candidates in data (per experiment) :

| Sample | Current statistics in data from LBL running experiment | Next generation LBL ultimate statistics |
|---|---|---|
| $\nu_\mu$ | 300-400 | x25 |
| $\bar{\nu}_\mu$ | 100-150 | x100 |
| $\nu_e$ | 100-200 | x15 |
| $\bar{\nu}_e$ | 15-30 | x100 |

Ultimate results of next-generation LBL will be limited by systematic uncertainties

Today systematics :

| Flux | xsec | detector | total |
|---|---|---|---|
| <3 % (5 %) | 3 % (10-15 %) | 2-5 % | 3-6 % (~15 %) |

The ultimate goal of the next generation LBL experiment is to reach 1-2 % for neutrinos and 2-3 % on antineutrinos

**Going below today systematics is extremely challenging** : needs improved near detector complex and improved ‘models’

# Oscillation measurement

$$N_{\nu_\alpha}(E_\nu^{rec}) = \int \phi(E_\nu^{true})\,\sigma(E_\nu^{true})\,P_{\nu_\alpha}(E_\nu^{true})\,R(E_\nu^{true}, E_\nu^{rec})\,dE_\nu^{true}$$

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what we want to measure

Flux : how many neutrino are produced by the beamline

Neutrino-nucleus xsec : how often neutrinos interact in our detector

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→ **Near Detectors !**

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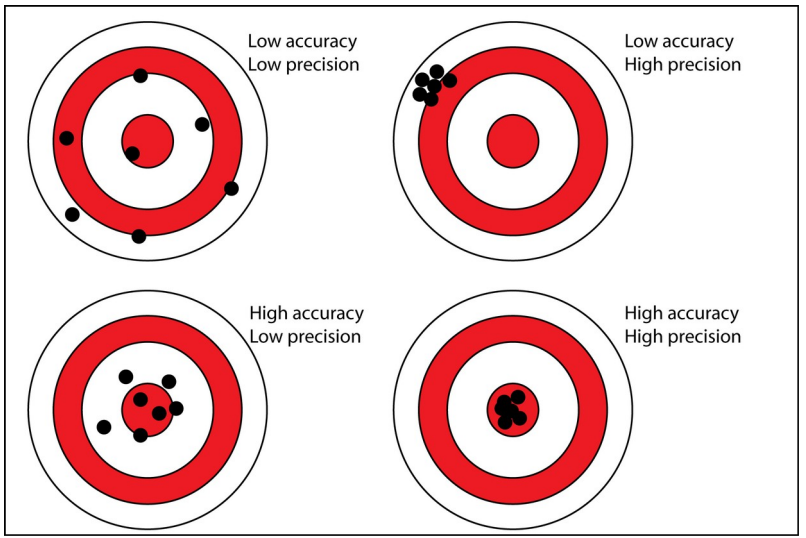
- we need to encode the correct uncertainties and propagate the measurement from near to far detectors

→ **(informed) model/'priors'**

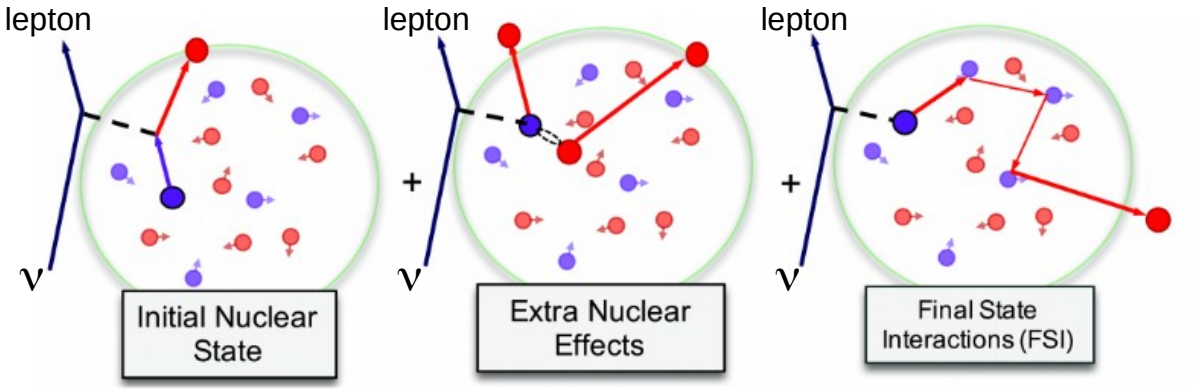
# We need (tuned) models

- Crucial : **improve the ‘priors’ ! Having very good models of flux and cross-section** to be sure to encode all the relevant degrees of freedom (avoid bias).

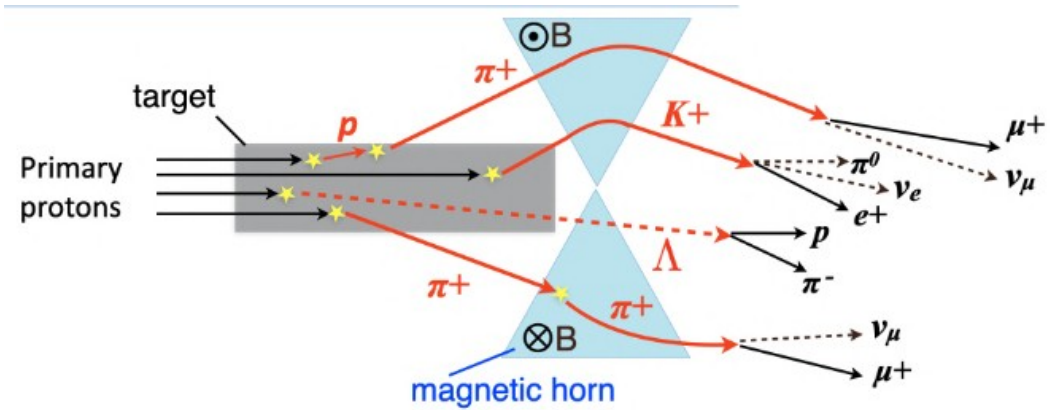
**The challenge of next-generation LBL is not the precision but the accuracy !**



# Systematics effects



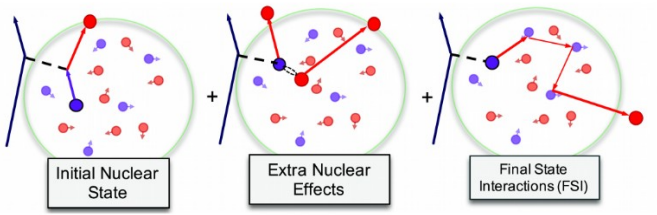

**Nuclear effects in neutrino-nucleus interaction** change the cross-section and the neutrino energy reconstruction




**Nuclear effects in proton/hadron-nucleus interaction** change the flux (rate and energy) of produced beam neutrinos

# Strategy document

**Crucial to have ancillary measurements for ultimate oscillation precision :**

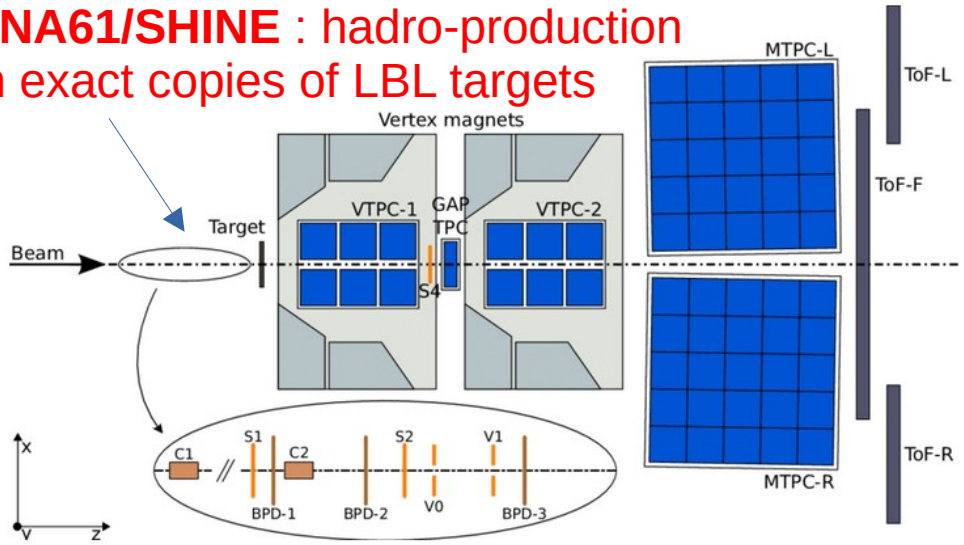



- hadron-nucleus scattering
- electron-nucleus scattering

} **test-beams** + detectors (eg, prototypes) at CERN

- neutrino-nucleus scattering → Need **neutrino beam** → see next talk

- **NA61/SHINE** : hadro-production in exact copies of LBL targets




Already existing and running at CERN (large physics program)
→ need to ensure its continuation for the next generation of LBL

# The role of Europe (and CERN)

**Europe is uniquely placed to play a major role in these ancillary measurements, especially leveraging CERN infrastructures**
(+ R&D for future near and far detectors, see other talks)

→ establishing these activities at CERN would allow Europe to have a major contribution to over-sea LBL experiments: CERN would consitute **a central Europen hub with critical mass and advanced and large infrastructure**

→ Europe is in a unique position : participating to both next-generation LBL experiment, we can lead the inter-experimental studies/comparison/combination for the ultimate precision : **aim to establish CERN as the 'pivot' around which the two experiments could meet and collaborate**

# The role of Europe (and CERN), beyond LBL

The understanding of neutrino, as door to New Physics and as messangers from cosmos, does not rely on LBL only !
**Europe has important contributions to non-LBL neutrino experiments !**

- those experiments are fostering **important R&D** which would profit to everybody if supported by **Neutrino Platform and DRD at CERN**

- the results of all neutrino experiments (including LBL) should be jointly discussed to distillate the best understanding of neutrino nature and its role in physics : **CERN would be a perfect place for inter-experimental joint activities (workshops, software sharing)**

**Aim : build a coherent European neutrino physics strategy and thus make the European community the key actor of the overall neutrino physics domain.**

# BACK-UP

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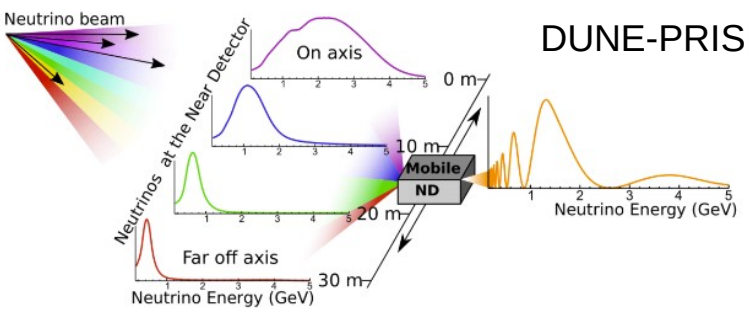
- One of the major differences between what we measure at the ND and FD is the neutrino energy distribution
→ **'PRISM' approach** : explore different off-axis angles by moving the near detector at different off-axis angles




DUNE-PRISM

IWCD at HK