Towards a unified treatment of systematic errors

Anselmo Cervera Villanueva
IFIC (Valencia)
Andrea Donini
IFT (Madrid) & IFIC (Valencia)

EURO-ν general meeting

Strasbourg, 2 June 2010

Ingreedients

- To evaluate the performance of a given facility we need:

$$N_{\nu''}^{\,exp}(E') = \underbrace{M_{\nu''\nu'}(E',E)}_{\text{detection}}\ \underbrace{\sigma_{\nu'}(E)}_{\text{x-section}}\ \underbrace{P_{\nu'\nu}(E, A, \text{osc param})}_{\text{propagation}}\ \underbrace{\Phi_{\nu}(E)}_{\text{flux}}$$

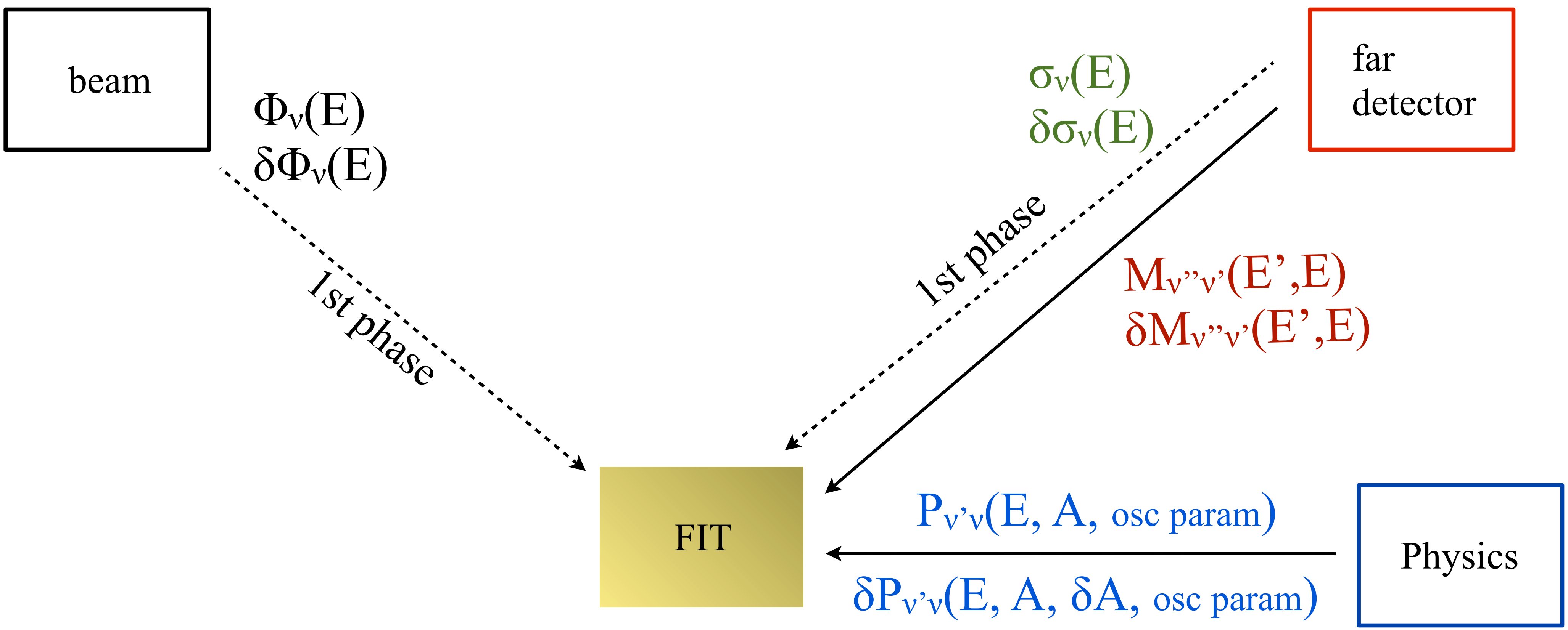
- **And $\delta N_{\nu''}^{\,exp}(E')$**

Ingreedients

- To evaluate the performance of a given facility we need:

$$N_{\nu''}^{\,exp}(E') = \underbrace{M_{\nu''\nu'}(E',E)}_{\text{detection}}\ \underbrace{\sigma_{\nu'}(E)}_{\text{x-section}}\ \underbrace{P_{\nu'\nu}(E,\, A,\, \text{osc param})}_{\text{propagation}}\ \underbrace{\Phi_{\nu}(E)}_{\text{flux}}$$

- **And $\delta N_{\nu''}^{\,exp}(E')$**

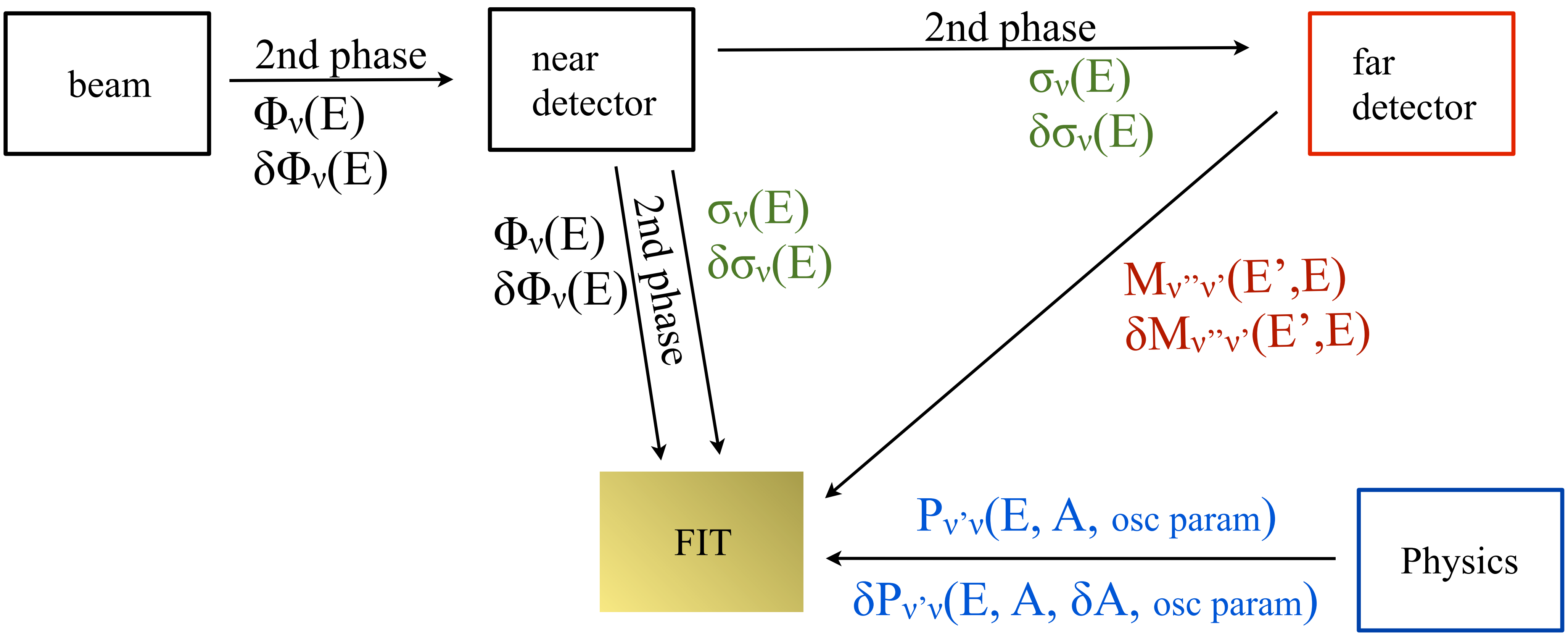


Ingreedients

- To evaluate the performance of a given facility we need:

$$N_{\nu''}^{\,exp}(E') = \underbrace{M_{\nu''\nu'}(E',E)}_{\text{detection}}\ \underbrace{\sigma_{\nu'}(E)}_{\text{x-section}}\ \underbrace{P_{\nu'\nu}(E, A, \text{osc param})}_{\text{propagation}}\ \underbrace{\Phi_{\nu}(E)}_{\text{flux}}$$

- **And $\delta N_{\nu''}^{\,exp}(E')$**



Neutrino flux

- We need input from accelerator group to understand all effects
- Its probably better to divide the error in two contributions
  - energy spectrum (normalised to unity) and total flux
- Sources of systematics:
  - Super-beam
    - p.o.t, hadron production, horn simulation, near detector, ...
  - Beta-Beam
    - Number of stored ions. Polarisation ?, ...
  - Nufact
    - Number of stored muons, beam divergence and polarization
- Beam instrumentation and near detectors for Nufact and beta-Beam
  - In a first phase the flux can be computed theoretically from few parameters (N_{μ}, γ, and P for Nufact)
  - Once near detector results are available the near detector group should provide the flux (same flux with smaller errors)
- Input for fits for all facilities:
  - Energy spectrum (normalised to unity) with error bars for each neutrino type
  - Total flux with error for each neutrino type

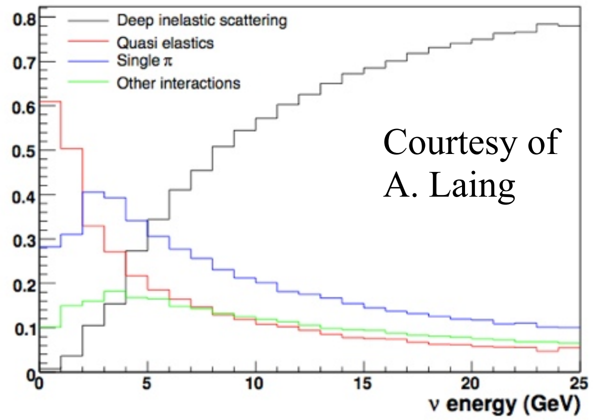
Propagation

- Source of systematics
  - matter density:
    - Which error is being assumed ?
- error on oscillation parameters. Is not a systematic
  - atmospherics are free in the fit and usually marginalised over
  - solar are kept fixed

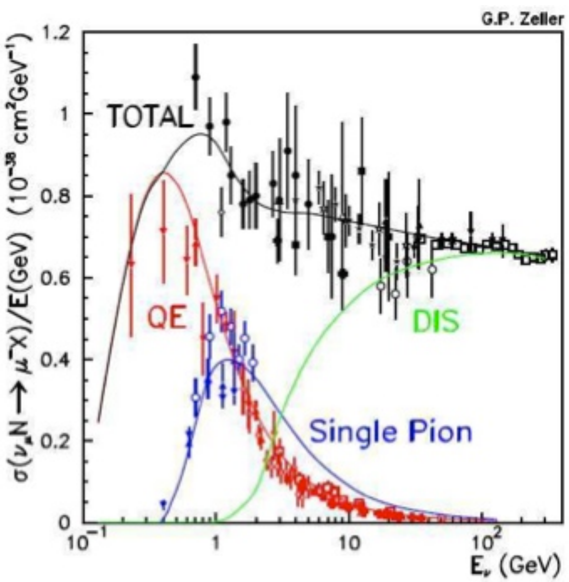
- See next talk by W. Winter

Cross section

- The oscillation fit only needs total x-section vs energy for each neutrino type
- However, detector efficiencies and backgrounds depend on the relative abundance of the different reaction types (QEL, RES, CC1pi, Coh, charm)
- The x-section used for oscillation fit (# events in far detector) must be the same used for the calculation of detector efficiencies



- Contribution to systematics are
  - difference between neutrinos and antineutrinos
  - difference between ν_e, ν_μ and ν_τ
  - x-section for specific processes:
    - i.e. charm production for MIND
- Input for fits:
  - total x-section vs energy with error bars for each neutrino type: 6 histograms (neutrinos and antineutrinos)



Far detector systematics

- See talk in previous session by A. Laing
- Sources of systematics
  - Assumptions in the simulation
    - Attenuation length in scintillator bars
    - Photodetector threshold
    - MS non gaussian tails
    - ...
  - x-sections for specific processes: QEL, RES, DIS, coh, charm, ...
  - Fiducial volume definition (vertex determination)
- Input for fits
  - response matrix for each combination of two neutrino types

$$M[\nu_e - \nu_\mu]\,(E',E)$$

Fraction of ν_e's with true energy E reconstructed as a ν_μ with energy E'

Example for MIND

- For $\overline{\nu}_\mu$, ν_e beam, searching for $\nu_e \sim \nu_\mu$ oscillation

$M[\nu_\mu - \nu_\mu]$ (E’,E) signal efficiency

$M[\nu_e - \nu_\mu]$ (E’,E) from beam

$M[\nu_\tau - \nu_\mu]$ (E’,E) from $\nu_e \sim \nu_\tau$ subdominant oscillation (A. Donini’s talk)

$M[\overline{\nu}_\mu - \nu_\mu]$ (E’,E) from beam (charge mis-id, hadron decay, ...)

~~$M[\overline{\nu}_e - \nu_\mu]$ (E’,E) from $\overline{\nu}_\mu \sim \overline{\nu}_e$ subdominant oscillation~~ → negligible

~~$M[\overline{\nu}_\tau - \nu_\mu]$ (E’,E) from $\overline{\nu}_\mu \sim \overline{\nu}_\tau$ dominant oscillation~~ → negligible ?

osc prob
x
tau-mu BR

Example for MIND

- arXiv:1004.2798. Separate CC and NC

signal efficiency (10^{-2})

$M[\nu_\mu - \nu_\mu]\ (E',E)$

true energy

rec energy

	0-2.5	2.5-3.5	3.5-4.5	4.5-5.5	5.5-6.5	6.5-7.5	7.5-10	10-15	15-20	20-25	25-30
0-2.5	0	0	0	0	0	0	0	0	0	0	0
2.5-3.5	1.78	1.26	0.01	0	0	0	0	0	0	0	0
3.5-4.5	0.49	5.94	6.54	0.20	0.04	0	0	0	0	0	0
4.5-5.5	0.08	1.71	20.24	16.07	0.68	0.03	0.01	0	0	0	0
5.5-6.5	0.04	0.39	6.04	28.25	20.72	1.59	0.07	0	0	0	0
6.5-7.5	0	0.12	1.18	7.26	31.82	20.23	1.21	0.01	0	0	0
7.5-10	0	0.09	0.70	2.31	11.22	40.36	38.50	1.38	0.01	0.01	0.01
10-15	0	0.06	0.30	0.67	1.18	2.29	26.76	47.64	2.15	0.075	0.032
15-20	0	0	0.14	0.32	0.24	0.35	0.58	19.15	40.25	2.68	0.26
20-25	0	0	0.10	0.07	0.14	0.25	0.17	0.66	24.72	33.40	2.87
25-30	0	0	0	0.12	0.07	0.06	0.12	0.15	1.77	28.15	27.86
overflow	0	0.01	0.04	0.09	0.33	0.40	0.44	0.43	0.62	4.90	37.72

$M[\nu_x^{NC} - \nu_\mu]\ (E',E)$ $x=e, \mu, \tau$ (and $\overline{\nu}$)

(10^{-3})

	0-2.5	2.5-3.5	3.5-4.5	4.5-5.5	5.5-6.5	6.5-7.5	7.5-10	10-15	15-20	20-25	25-30
0-2.5	0	0	0	0	0	0	0	0	0	0	0
2.5-3.5	0	0.01	0	0.01	0	0	0	0	0	0	0
3.5-4.5	0	0	0.02	0.01	0.02	0	0	0	0	0	0
4.5-5.5	0.03	0.05	0.02	0.02	0.01	0.01	0	0.01	0.01	0.01	0
5.5-6.5	0	0	0.02	0.02	0.01	0.04	0.01	0.01	0.01	0	0.01
6.5-7.5	0	0.01	0	0	0.02	0	0	0.01	0	0.01	0
7.5-10	0	0.01	0.01	0.01	0	0	0	0.01	0	0	0
10-15	0	0	0	0	0	0	0	0	0.01	0.01	0
15-20	0	0	0	0	0.01	0	0	0	0	0	0
20-25	0	0	0	0	0	0	0	0	0	0	0
25-30	0	0	0	0	0	0	0	0	0	0	0
overflow	0	0	0	0	0	0	0	0	0	0	0

$M[\overline{\nu}_\mu^{CC} - \nu_\mu]\ (E',E)$

(10^{-3})

	0-2.5	2.5-3.5	3.5-4.5	4.5-5.5	5.5-6.5	6.5-7.5	7.5-10	10-15	15-20	20-25	25-30
0-2.5	0	0	0	0	0	0	0	0	0	0	0
2.5-3.5	0	0	0.14	0	0	0	0	0	0	0	0
3.5-4.5	0	0	0.29	0	0	0	0	0	0	0	0
4.5-5.5	0	0	0.43	0.29	0.14	0	0	0	0	0	0
5.5-6.5	0	0	0.14	0.15	0.14	0	0	0	0	0	0
6.5-7.5	0	0	0	0.15	0	0.29	0.06	0	0	0.03	0
7.5-10	0	0	0.14	0.15	0.72	0	0.29	0.03	0.03	0	0
10-15	0	0	0	0.29	0.29	0.15	0.29	0.29	0.03	0.03	0.03
15-20	0	0	0	0.15	0	0	0	0.26	0.20	0.09	0.03
20-25	0	0	0	0	0	0	0.06	0.06	0.03	0.09	0.06
25-30	0	0	0	0	0	0	0	0	0.03	0.06	0.09
overflow	0	0	0	0.15	0	0	0	0.06	0.03	0.14	0.17

$M[\nu_e^{CC} - \nu_\mu]\ (E',E)$

(10^{-3})

	0-2.5	2.5-3.5	3.5-4.5	4.5-5.5	5.5-6.5	6.5-7.5	7.5-10	10-15	15-20	20-25	25-30
0-2.5	0	0	0	0	0	0	0	0	0	0	0
2.5-3.5	0	0	0	0	0	0	0	0	0	0	0
3.5-4.5	0	0	0	0	0	0	0	0	0	0	0
4.5-5.5	0	0	0	0.03	0	0	0	0	0	0	0
5.5-6.5	0	0	0.03	0	0	0	0	0	0	0	0
6.5-7.5	0	0	0.06	0	0	0	0	0	0	0	0
7.5-10	0	0	0	0	0	0	0	0.01	0	0	0
10-15	0	0	0	0	0	0	0	0	0	0	0
15-20	0	0	0	0	0	0	0	0	0.01	0	0
20-25	0	0	0	0	0	0	0	0	0	0	0
25-30	0	0	0	0	0	0	0	0	0	0.01	0.01
overflow	0	0	0	0	0	0	0	0	0	0	0

$M[\nu_\tau^{CC} - \nu_\mu](E',E)$ missing

Oscillation fits

- Fitting programs (i.e. Globes) should take into account:
  - Neutrino flux for each neutrino type with errors (normalization + spectrum)
  - Total x-section vs energy for each neutrino type with errors
  - Detector response matrices with errors
  - Uncertainty on matter density