

Simplified Sensitivity Calculations for the SBN Proposal

PITT PACC SBN Physics Workshop

Daniele Gibin (Padova University and INFN)
for the ICARUS Collaboration

- Challenging surface operation (as pointed out by C. Rubbia)
 - Several cosmic rays overlap each trigger
 - Cosmic ray can produce fake ν_e events degrading sensitivity
 - Mitigation with concrete Overburden and cosmic ray tagger
- Promising MC estimation for the SBN proposal
- Necessary MC validation with data eventually with a test set up, invaluable information from MicroBooNE cosmic ray events
- Description of a simplified method to compute experimental sensitivity:
- Possible impact of different systematics on the sensitivity;
- Conclusions

Some considerations on the sensitivity calculation

- The search for neutrino oscillations at FNAL SBN facility relies on the combined analysis of the data from multiple “identical” detectors operated in the same way at different positions along the neutrino beam;
- Data by the different detectors should be selected and analyzed in the same way;
- The calculation of experimental sensitivity requires:
 - Realistic estimate of detector performance, efficiencies and backgrounds;
 - Coherent treatment of the total data sample as well as realistic estimation of the related systematics, including correlations between different data sets and detectors

Some considerations on the sensitivity calculation - 2

- An unified χ^2 approach to the treatment of statistical/systematic uncertainties contributing to the experimental sensitivity has been defined in the SBN proposal:

$$\chi^2 = (N^{null} - N^{osc}(\Delta m^2, \sin^2 2\theta))(E^{total})^{-1}(N^{null} - N^{osc}(\Delta m^2, \sin^2 2\theta))$$

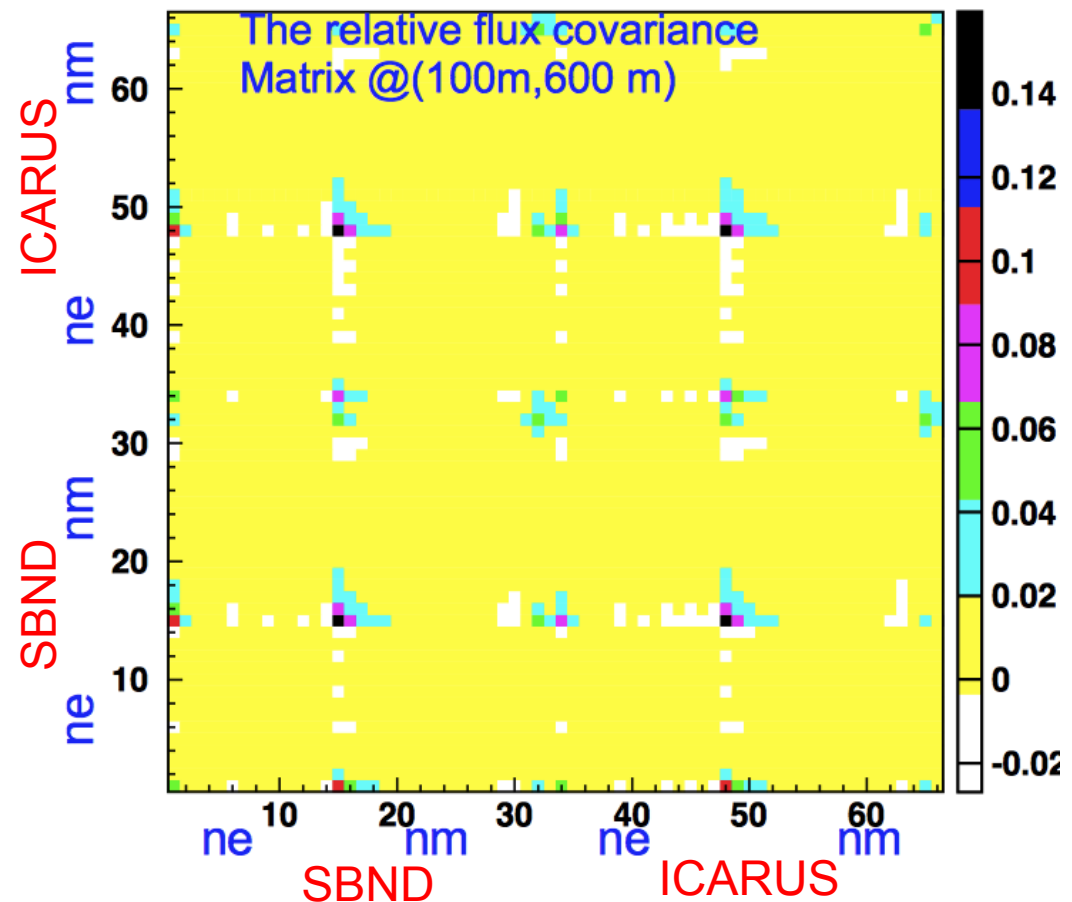
N^{null} and N^{osc} : event spectra w/o and w oscillations

E^{total} is the global error matrix adding together the relevant error matrices for statistics, flux, cross-section, cosmic background and detector response.

$$E^{total} = E^{stat} + E^{flux} + E^{cross\ sect} + E^{cosmic\ bck} + E^{detect}$$

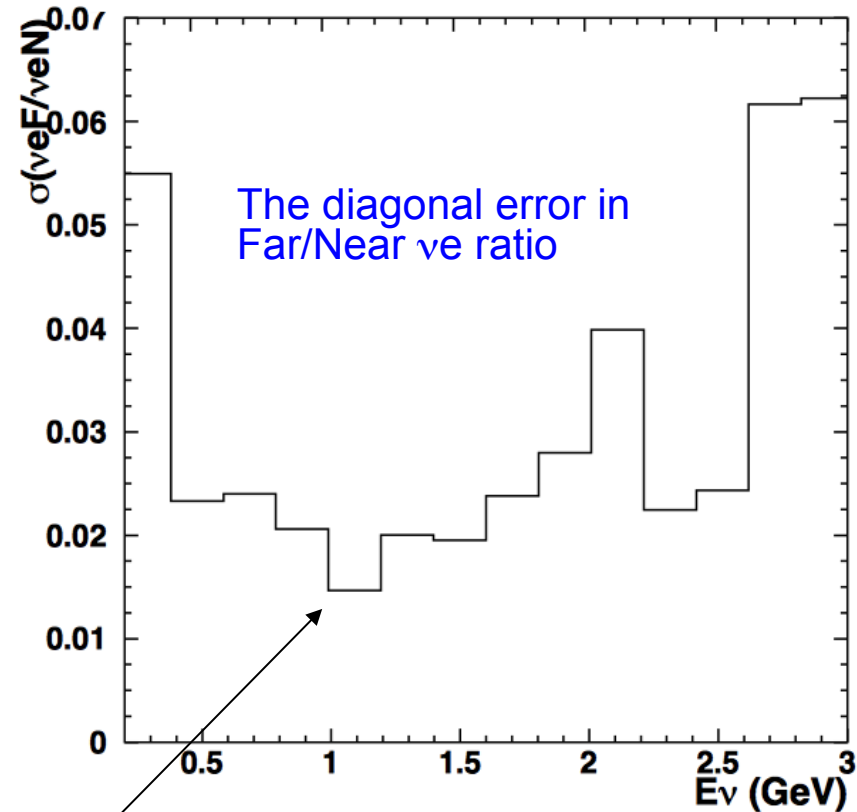
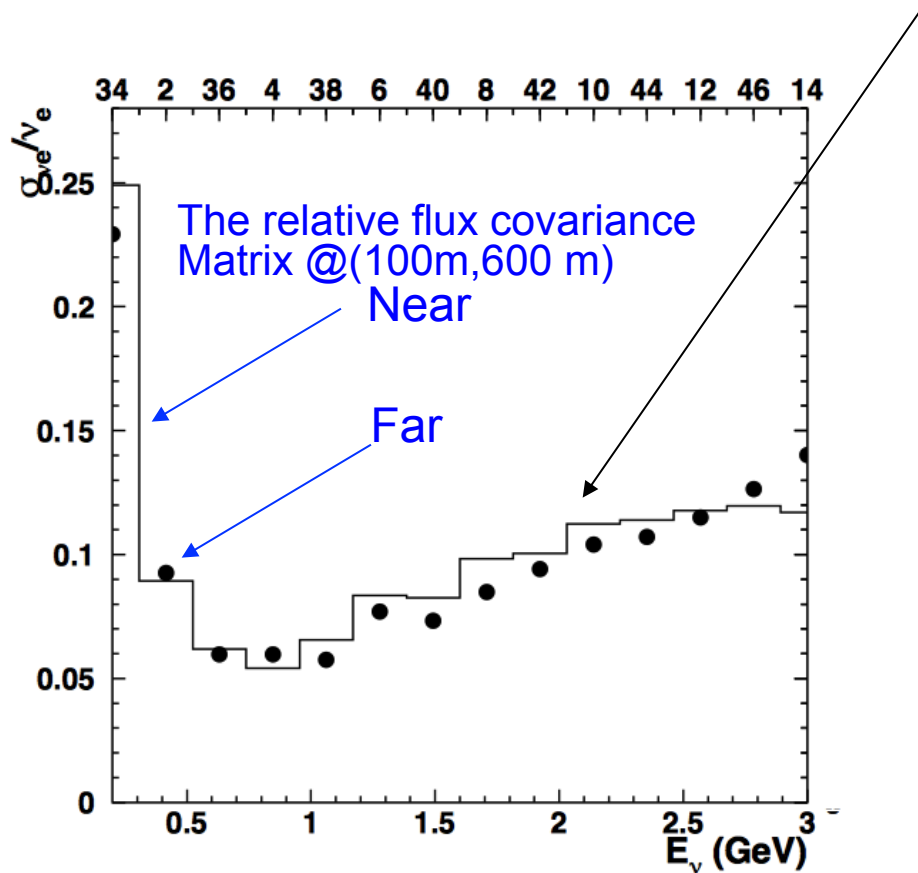
Flux systematic

- The flux error matrix computed for the SBN proposal describes the BNB flux systematic error, in case of Near-Far only, as a 4-fold error matrix including both ν_e and ν_μ flavors and f.i. the two detector positions at 100 m and 600 m.
- It is computed as a function of the *true* neutrino energy
- It is quite complex and conveys plenty of information (like differential/total flux uncertainty at each station, and in the extrapolation from one position to the other)



Differential flux systematic

- Typical uncertainty of the absolute error in flux prediction at a *single detector* is $\sim 6\text{-}7\%$.



- The flux errors cancel out to $\sim 2\%$ in the comparison of Near and Far detector

Integral flux systematic

- The integrated ν_e and ν_μ fluxes at different locations:
 - The integrated flux uncertainty is 6% (ν_μ), 7% (ν_e) in each detector;
 - The knowledge of a neutrino flavor flux permits to predict the other flavor one with similar ($\sim 6\%$) precision;
 - The flux extrapolation from the Near to Far position for the same neutrino flavor is very precise: 4‰(ν_μ) 9‰ (ν_e) .

		Near		Far	
		ν_e	ν_μ	ν_e	ν_μ
Near	ν_e	7	6	0.9	6
	ν_μ	6	6	6	0.4
Far	ν_e	0.9	6	7	6
	ν_μ	6	0.4	6	6

N.B. Numbers are in %

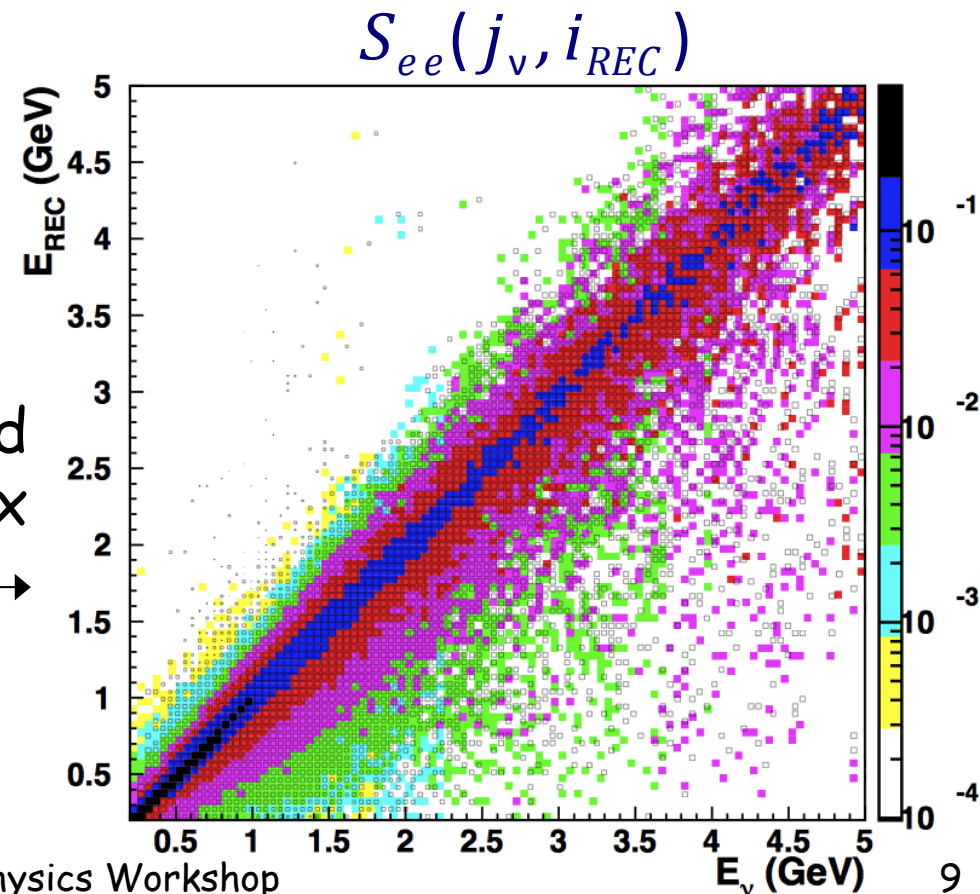
- The same conclusions hold also for the *reconstructed* electron neutrino events n_e

A simplified approach to the sensitivity calculation

- Approximation representing a fast alternative to a full MonteCarlo propagation of the neutrino events for each Δm^2 and $\sin^2 2\theta$
- Useful independent test of results by full MC simulations
- Correlation between different detectors and different neutrino flavors are described by matrices;
- The detector response is modeled via smearing matrix (from MC simulation) transforming true E_ν to reconstructed E_{REC}
- Similar treatment of expected spectra without/with oscillation
- Straightforward inclusion of different systematic uncertainties contributions;
- Some test cases of the sensitivity for the ν_e appearance from anomalous ν_μ oscillations (please notice that only SBND and ICARUS are considered in the following)

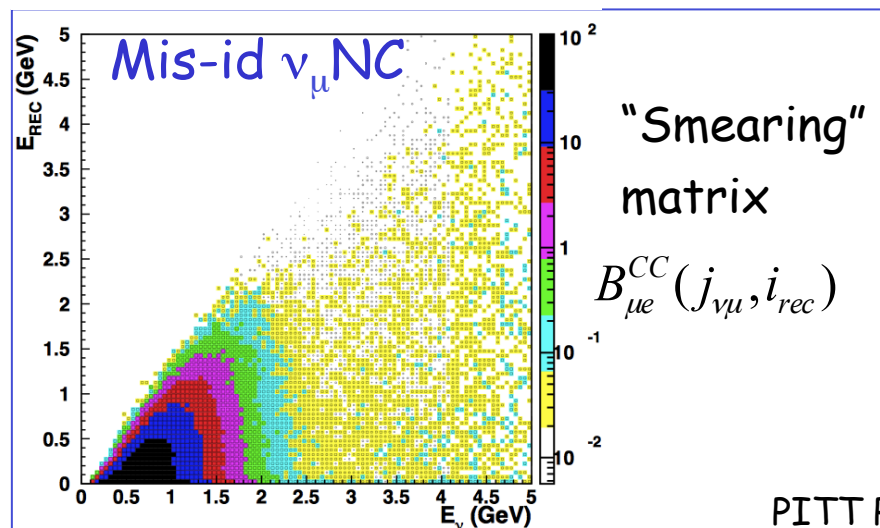
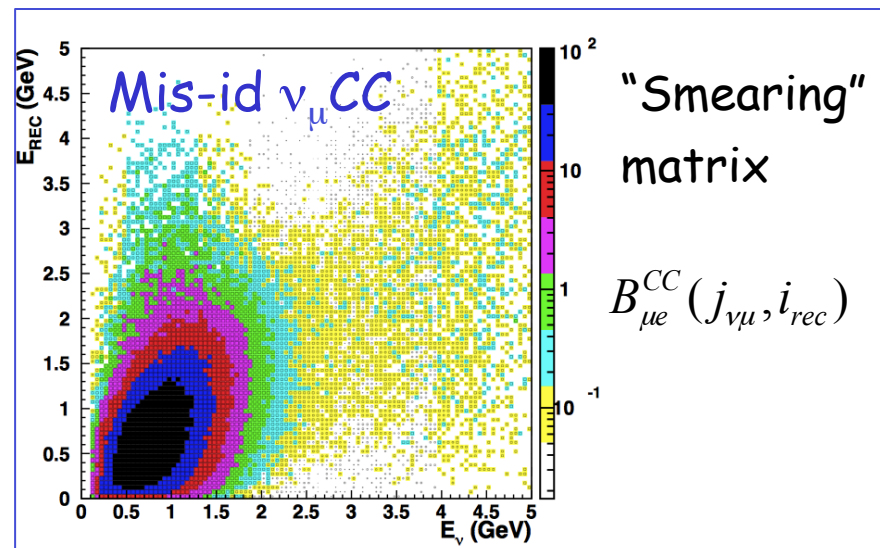
The ν_e signal: event energy reconstruction

- The ν_e CC event energy reconstruction is modeled by MC simulation of the intrinsic ν_e
- The visible hadronic and leptonic energy are separately corrected to account for the undetected/not contained energy as a function of the vertex position
- The reconstructed energy is close to the true E_ν , with a $\sim 20\%$ smearing;
- The detector response is simulated with a $S_{ee}(j_\nu, i_{REC})$ smearing matrix transforming E_ν to E_{REC} \longrightarrow



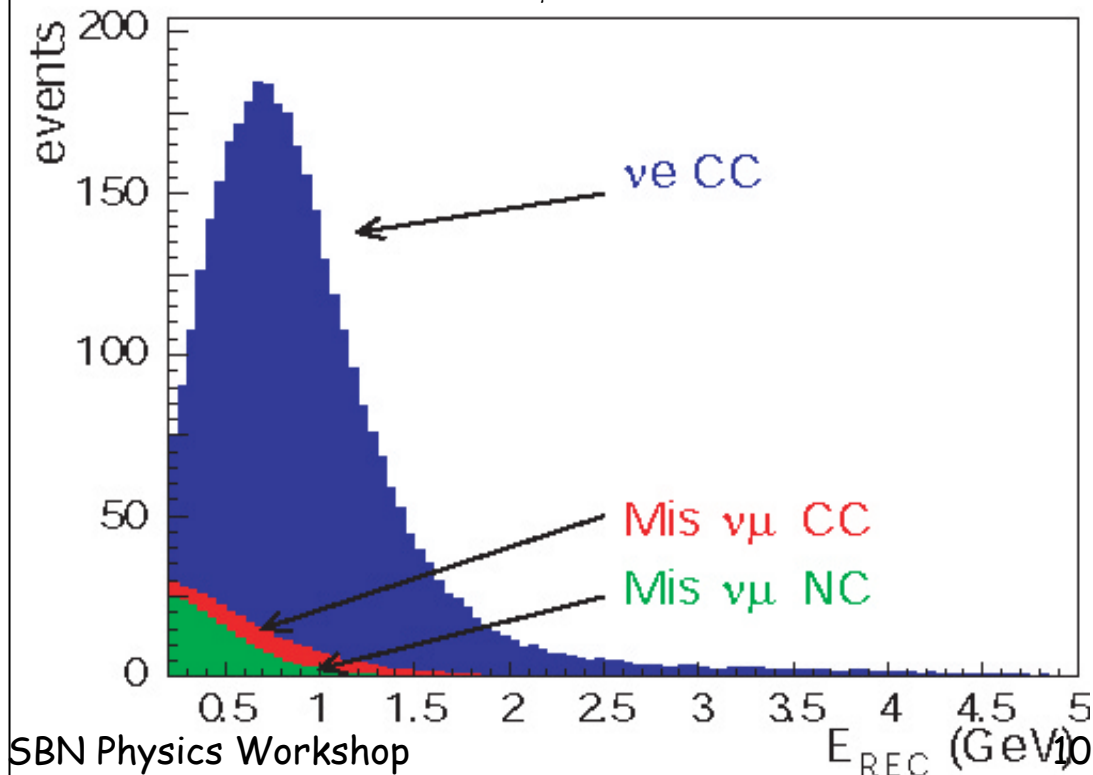
Background from misidentified NC and CC

- Mis-id NC (1.5‰) and CC (.2‰) is adopted, supported by event scan., E_{rec} is computed in the same way as for the true ν_e



- Reconstructed n_e spectrum

$$n_{i_{rec}}^{NC,CC} = \sum_{j_{\nu\mu}} B_{\mu e}^{NC,CC}(j_{\nu\mu}, i_{rec}) * \nu_{j_{\nu\mu}}$$



The expected ν_e spectra

- At each SBN detector the reconstructed un-oscillated ν_e spectrum is factorized as

$$n_{e0} = S_{ee} (\nu_e CC)_0 + (B_{\mu e}^{NC} + B_{\mu e}^{CC}) (\nu_\mu CC)_0 + n_e^{dirt} + n_e^{cosmic} \quad \leftarrow \text{No oscillation}$$

using the previously defined reconstruction matrices S_{ee} for ν_e and $B_{\mu e} = B_{\mu e}^{NC} + B_{\mu e}^{CC}$ for the misidentified $\nu_\mu CC$ and $\nu_\mu NC$, applied to the un-oscillated neutrino spectra $(\nu_e CC)_0$ and $(\nu_\mu CC)_0$, while n_e^{dirt} and n_e^{cosmic} are the expected contributions from "dirt" & cosmic backgrounds

- In case of oscillation the reconstructed ν_e spectrum at each detector

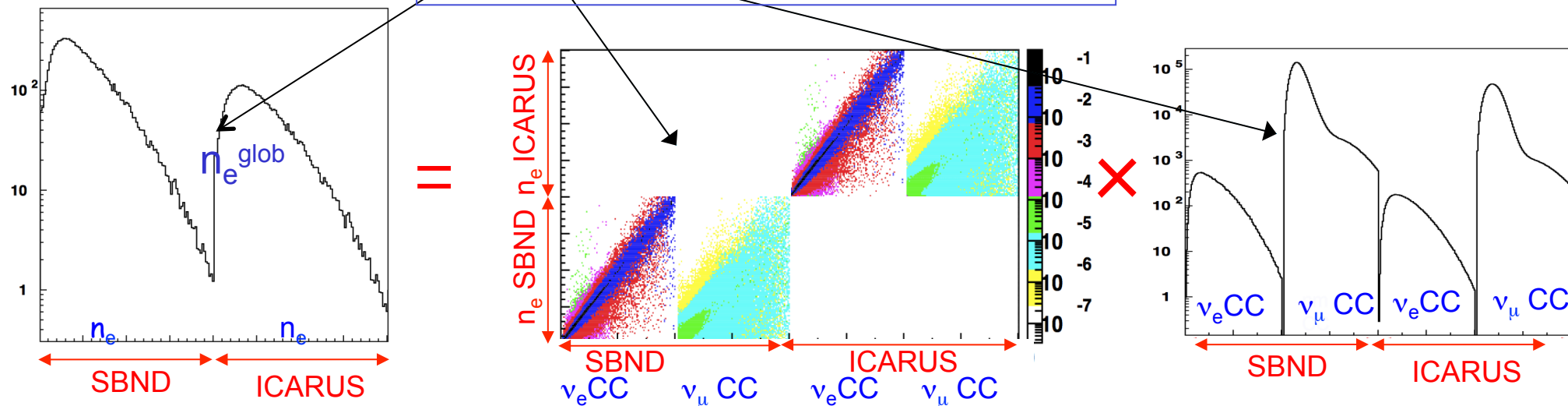
$$n_{eOsc} = S_{ee} (\nu_e CC)_{Osc} + (B_{\mu e}^{NC} + B_{\mu e}^{CC}) (\nu_\mu CC)_{Osc} + n_e^{dirt} + n_e^{cosmic} \quad \leftarrow \text{With oscillation}$$

is expected to be generated by the oscillated neutrino spectra $(\nu_e CC)_{Osc}$ and $(\nu_\mu CC)_{Osc}$

From true ν CC to reconstructed electron spectra

- The measurement of the neutrino spectra by the detectors corresponds to a linear transformation mapping the 4-fold vector ν CC to the two-fold vector n_e with a 2×4 -fold matrix T :

$$n_e = T * \nu\text{CC} + n^{\text{dirt}} + n^{\text{cosmic}}$$



Reconstructed spectra

Detector response

Neutrino CC spectra

$$U(n_e) = T * V(\nu\text{CC}) * T^T + E^{\text{det}} + E^{\text{dirt}} + E^{\text{cosmic}}$$

Reconstructed n_e Error matrix

Sensitivity computation

- The oscillation excess can be searched for exploiting: the ratio

$$R_{eNF}(E_{REC}) = n_{eFar}/n_{eNear} :$$

- profit of the excellent precision of the BNB MC in extrapolating the Near to Far beam once it has been measured the Near site;
- $R_{eNF}(E_{REC})$ measures the *change* in the oscillation probability with the distance i.e. the *relative* variations of spectrum at Far Vs Near;
- $R_{eNF}(E_{REC})$, apart from second order effects, is robust against any *common* Near/Far systematic uncertainty, like f.i. cross-sections;
- *Robust estimator against common un-modeled distortions on Near and Far spectra* which could generate a fake signal in a shape-only analysis;
- Residual systematics due to differences between Near and Far detector have to be carefully considered and kept under control.

- The direct exploitation of n_{eFar} and n_{eNear} spectra

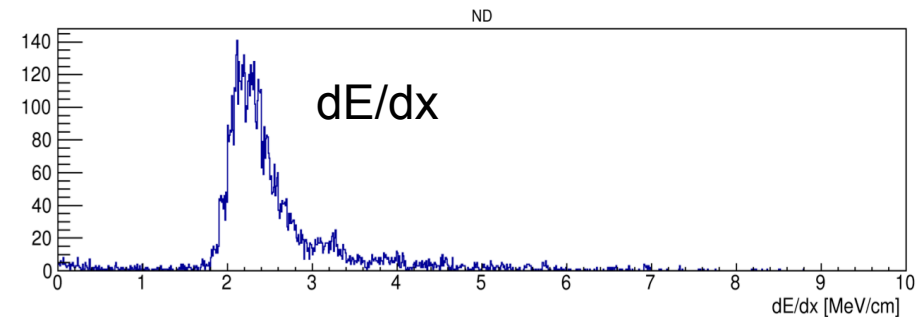
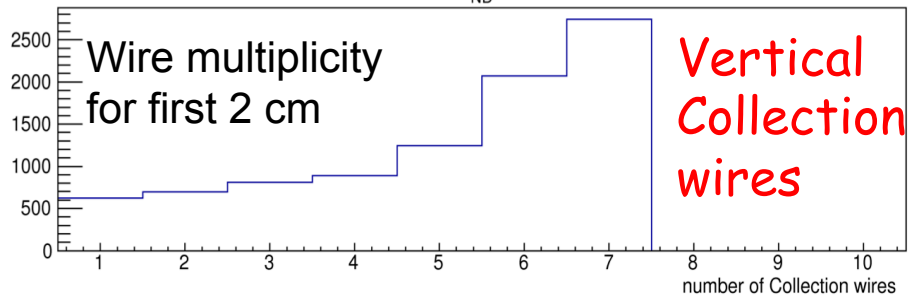
- Full experimental information;
- Limited in addition by *common* Near/Far systematic effects

Detector related systematics

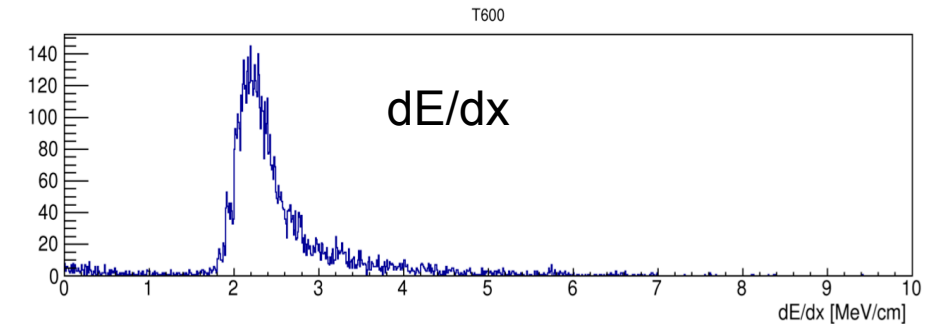
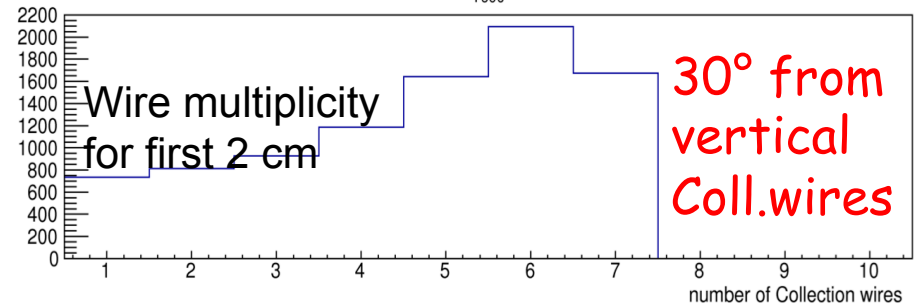
- Differences between the Near and Far detectors:
 - Light collection systems and time identification of off beam interactions;
 - Veto counter coverage and efficiency;
 - Electric drift field (absolute value and homogeneity);
 - ICARUS / SBND TPC wires orientation;
 - Read-out electronics (shaping, sampling time, S/N ratio, noise etc.) ;
 - Detector calibrations;
 - LAr purity levels;
 - Drift lengths and space charge effects induced by cosmics;
 - Event rate at Far and Near sites;
 - Background levels from c-rays and beam dirt events;
 - Different aspect ratios of Near-Far detectors through possible variations of event /acceptance/efficiency/purity;
 -
- At the moment an overall global error is used in the calculations

Example: effects from different wire orientation on e-id

SBND



ICARUS T600



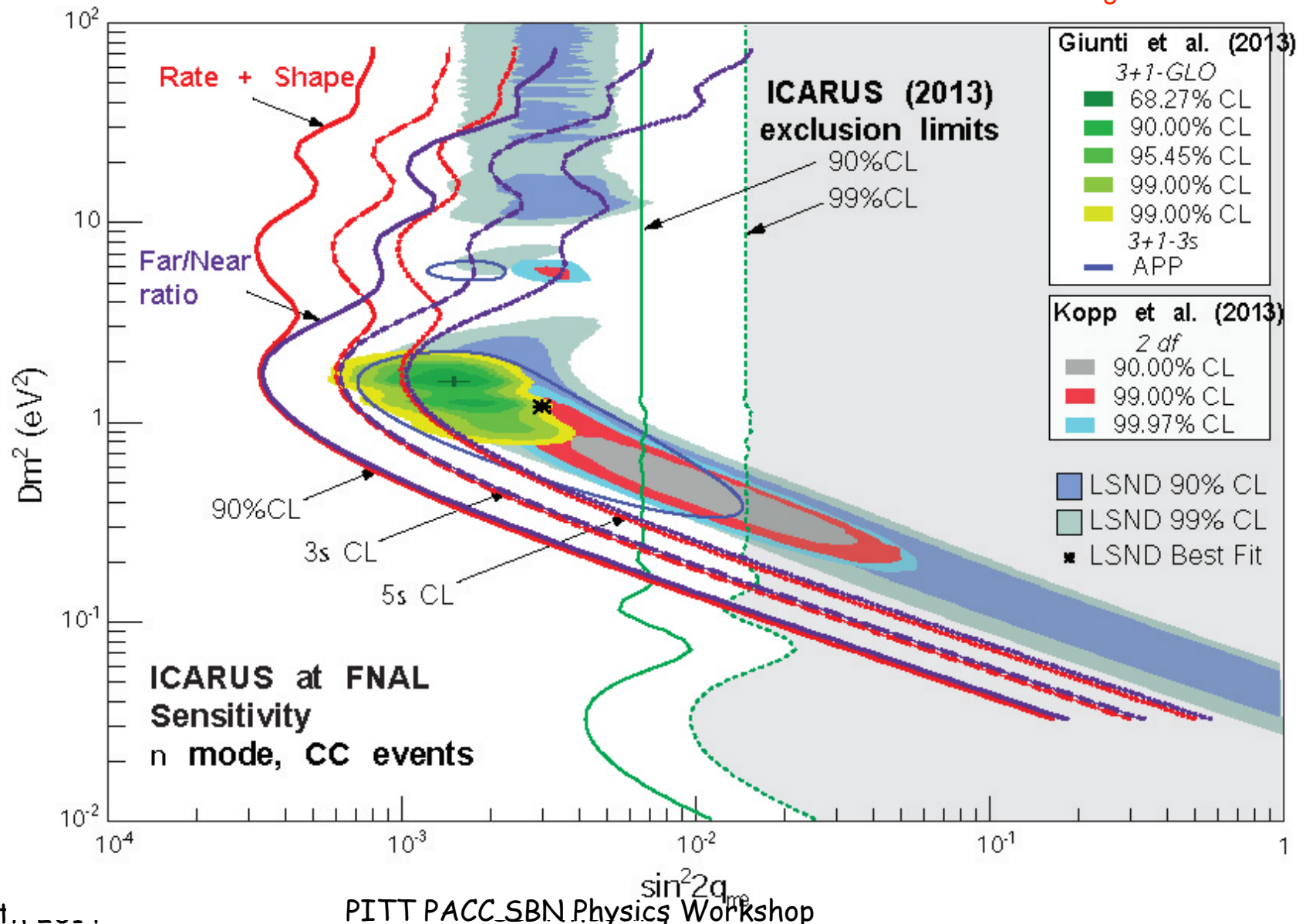
- Requiring $dE/dx < 3.4$ MeV/cm the electron identification efficiency is 90% (ICARUS-T600) and 89.86% (SBND) \Rightarrow Negligible $\sim 1\%$ effect;
- 3 (7) % difference requiring at least 3 (5) collection wires: up to 0.7% contribution to systematics (naïvely assuming to control at 10% level);
- Possible mitigation by exploiting the electron track length together with the number of Collection wires) and possibly the Induction wires

Example of computation for 80% ν_e efficiency

6.6e20 pot

FN ratio (blue) Rate+shape (red), including $\sigma_{\text{glob}}=12\%$

$\epsilon=80\%$
 $\sigma_{\text{rel}}=1\%$

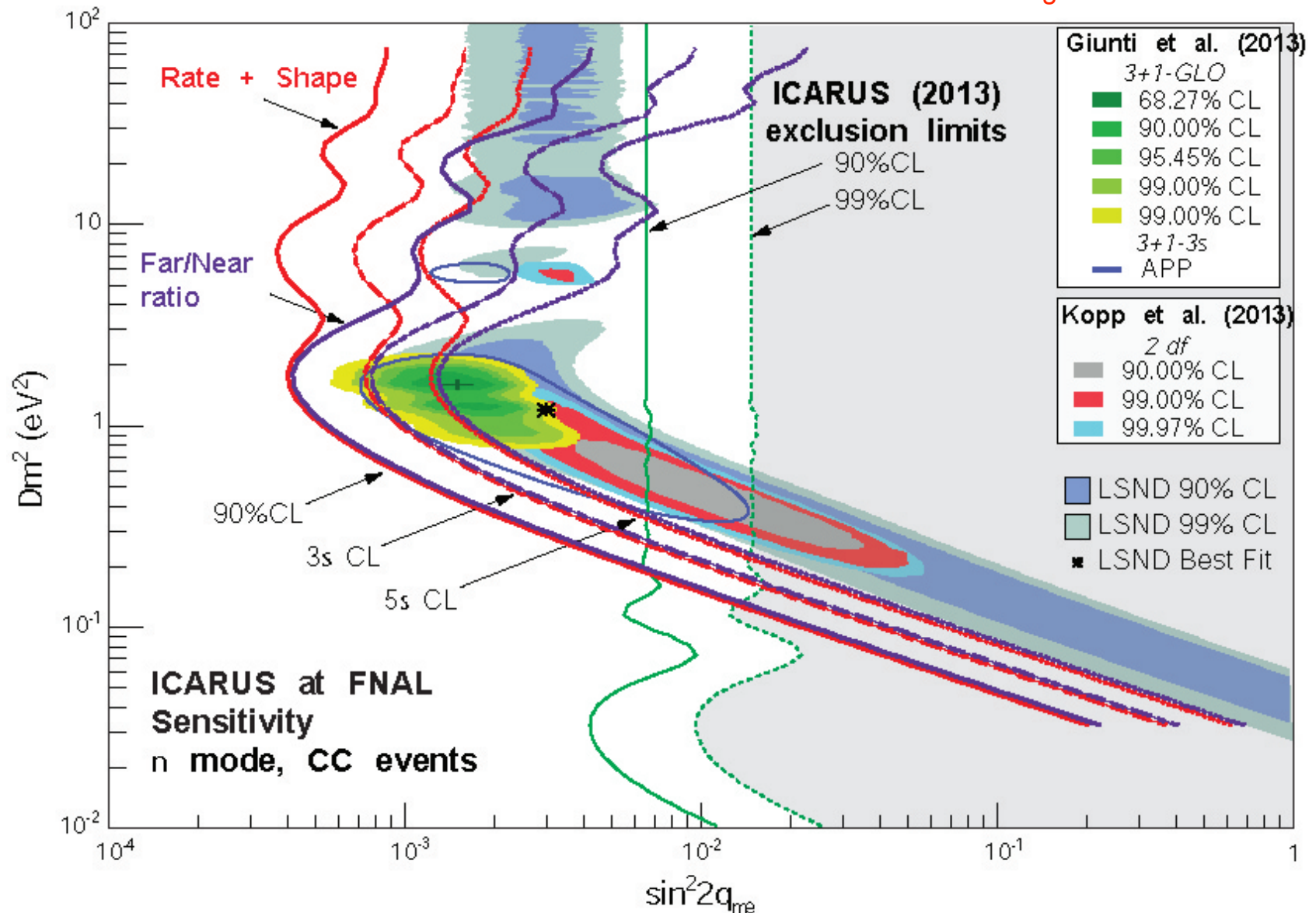


Example of computation for 50% νe efficiency

6.6e20 pot

FN ratio (blue) Rate+shape (red) including $\sigma_{\text{glob}}=12\%$

$\epsilon=50\%$
 $\sigma_{\text{rel}}=1\%$

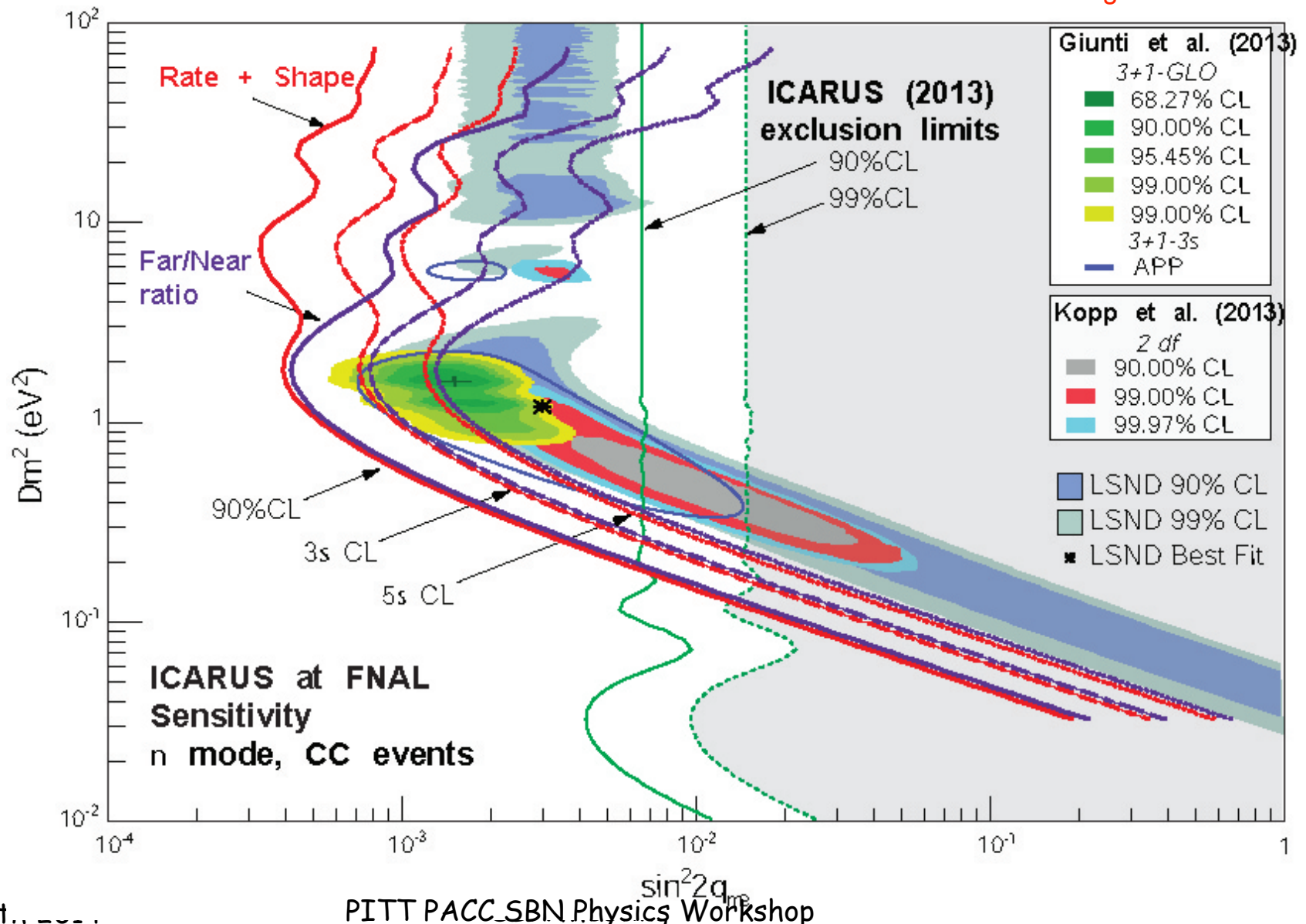


Example of computation for 80% ν_e efficiency

6.6e20 pot

FN ratio (blue) Rate+shape (red), including $\sigma_{\text{glob}}=12\%$

$\epsilon=80\%$
 $\sigma_{\text{rel}}=3\%$

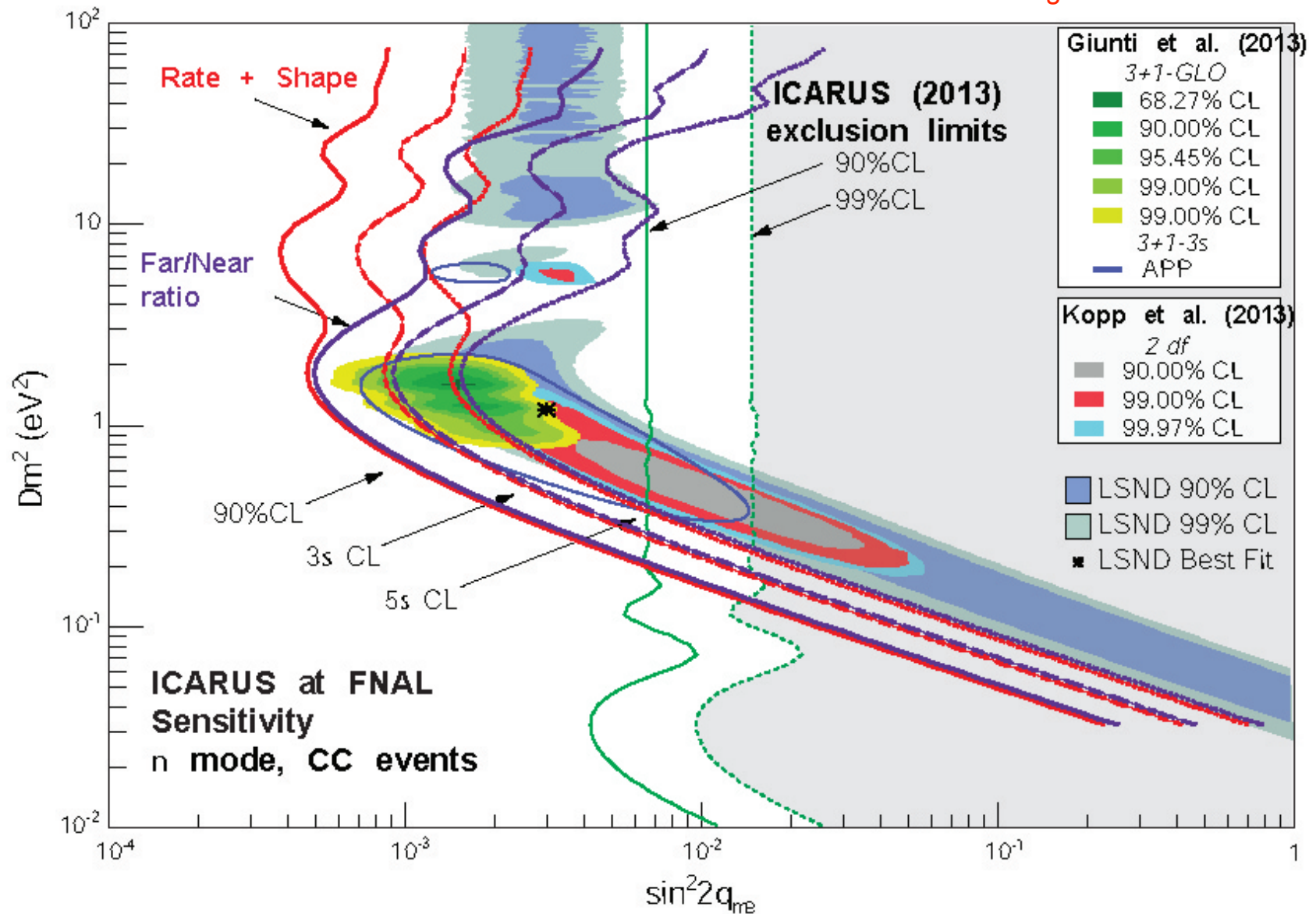


Example of computation for 50% νe efficiency

6.6e20 pot

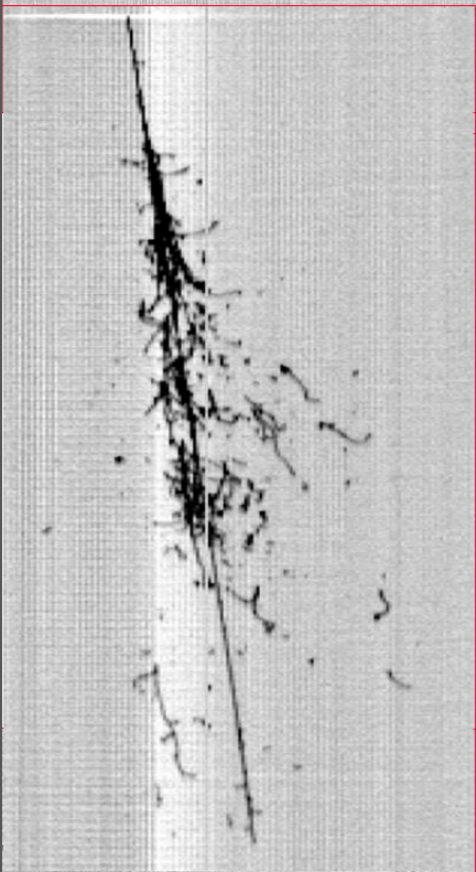
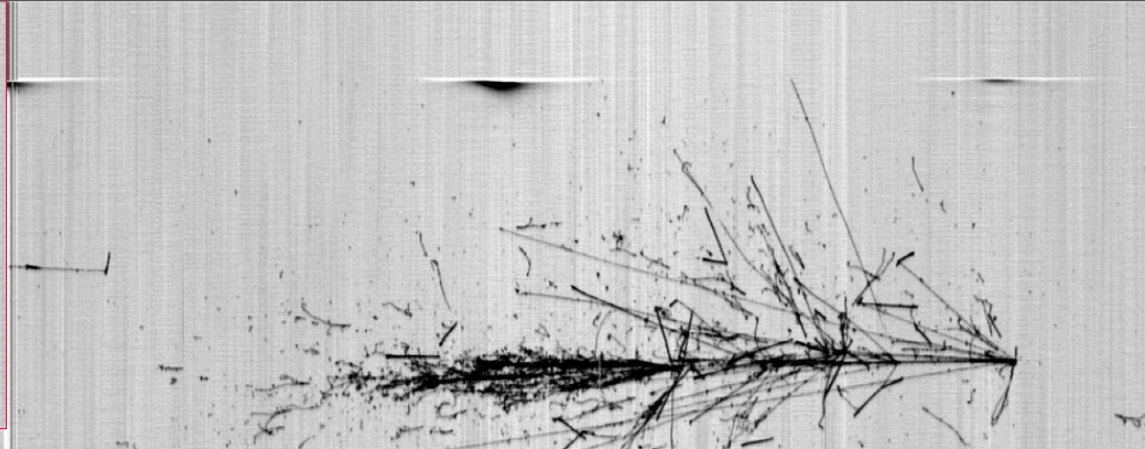
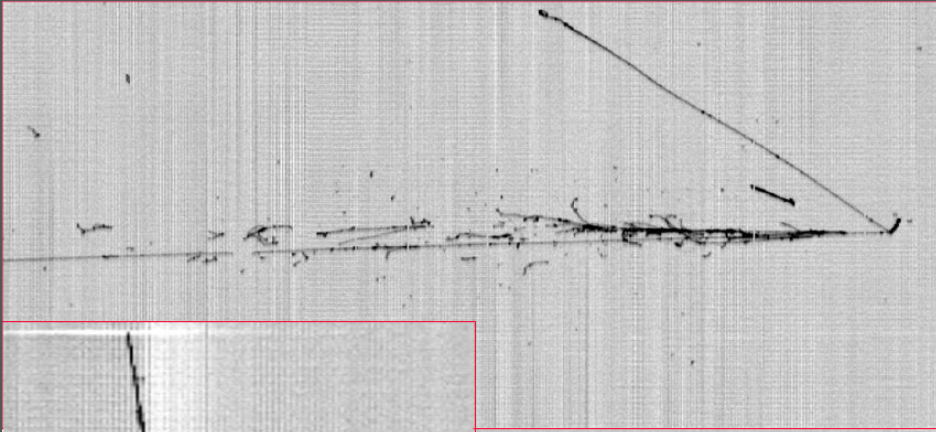
FN ratio (blue) Rate+shape (red) including $\sigma_{\text{glob}}=12\%$

$\epsilon=50\%$
 $\sigma_{\text{rel}}=3\%$



Conclusions

- A coherent method including systematical and statistical errors for multiple detector measurements permitting independent cross checks of sensitivity computation
- MC should be directly validated/replaced whenever possible by experimental measurement,
- Detector systematics sources have been addressed, more detailed study to be done; global residual N/F difference very relevant and need to be kept at the few percent level;
- Good 5σ coverage of the LSND parameter region for $6.6e20$ pot requires high ν_e detection efficiency and detector systematics at few percent level.
- Similar studies to be performed for ν_e and ν_μ disappearance sensitivities and global ν_e and ν_μ analysis.



Thank you !

