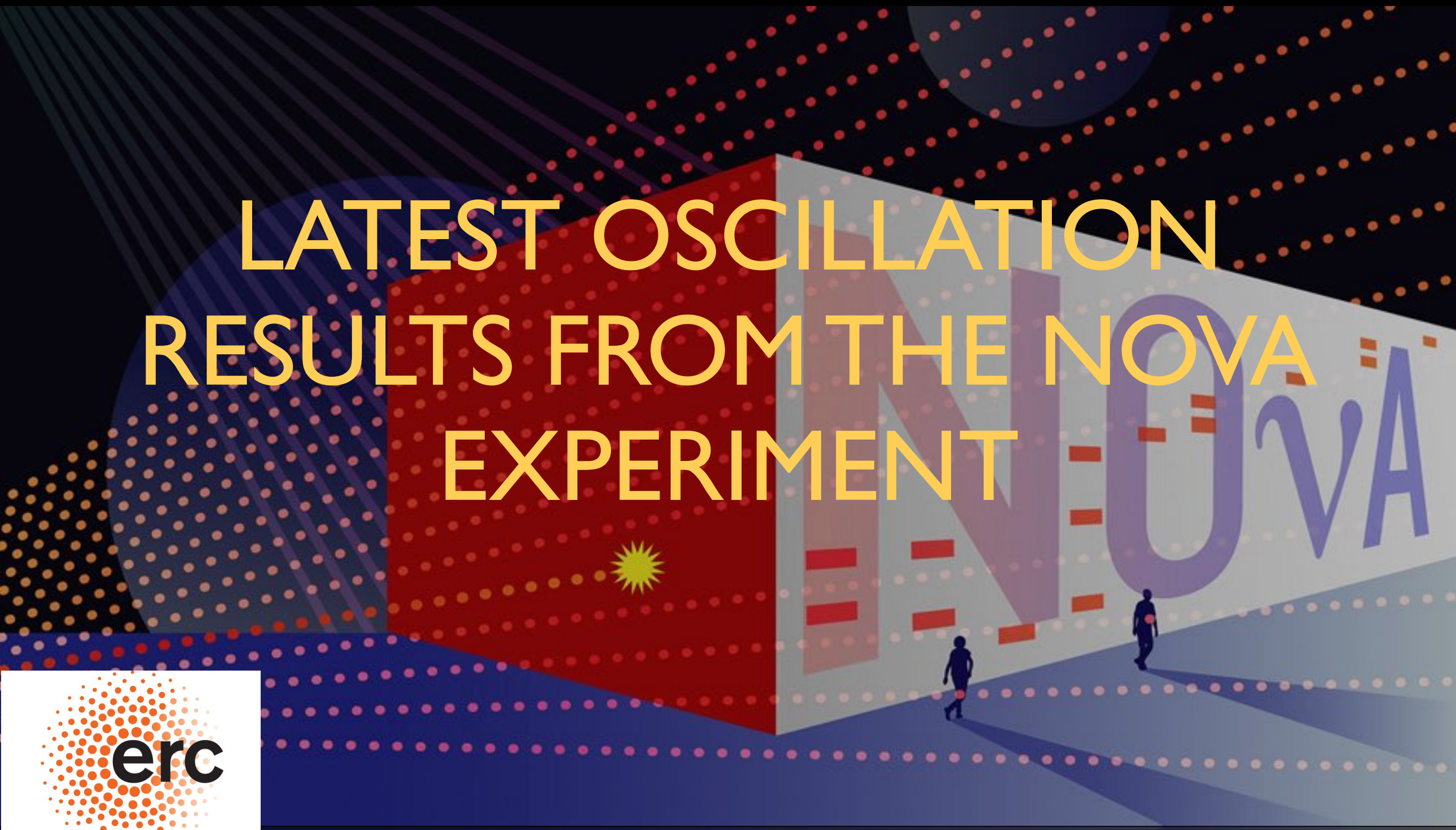
LATEST OSCILLATION RESULTS FROM THE NOVA EXPERIMENT



Bruno Zamorano

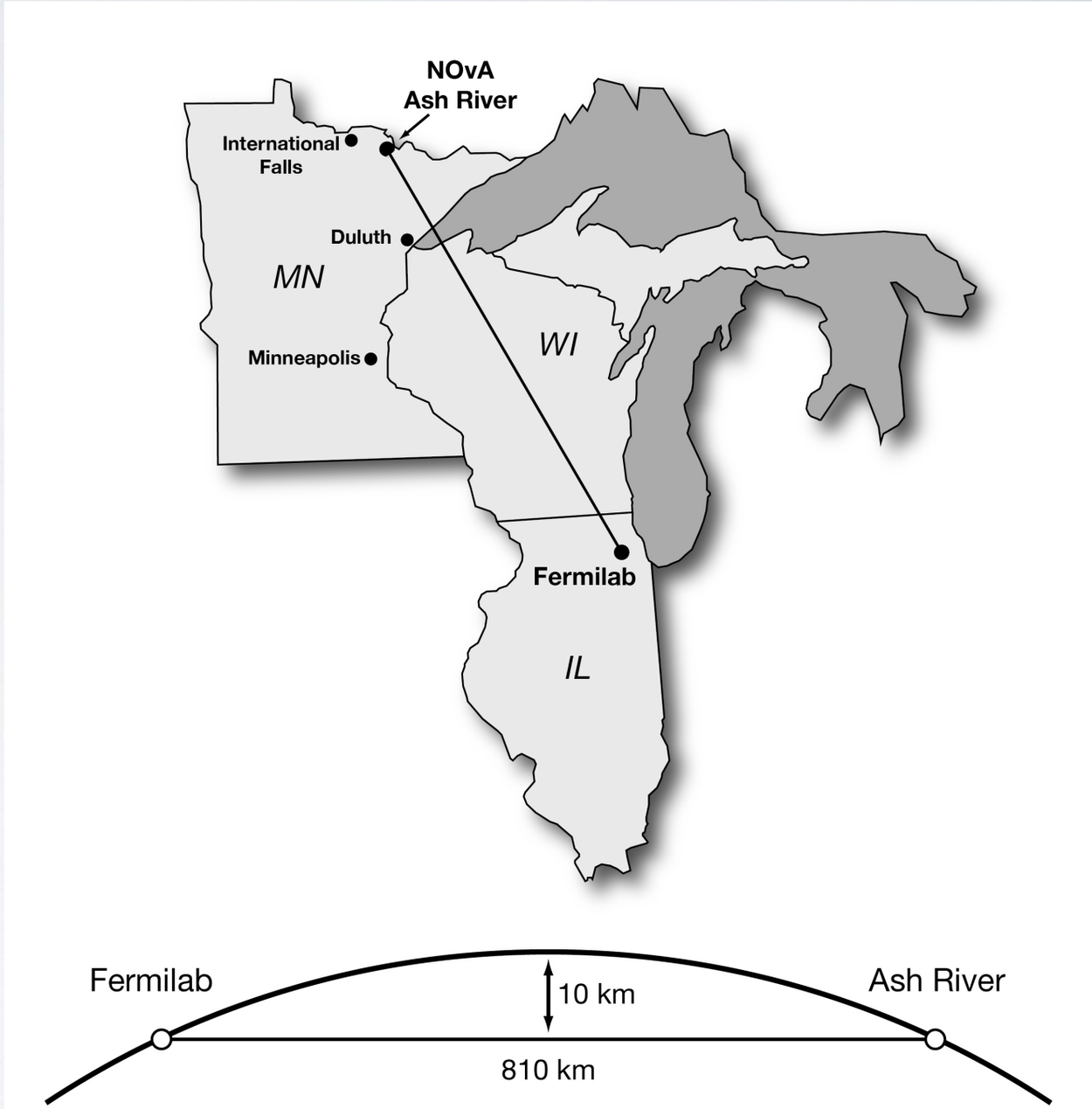
EPS - Venice - 6th July 2017

European Research Council
Established by the European Commission

University of Sussex

The NOvA experiment

- NuMI Off-Axis ν_e Appearance, the leading neutrino oscillation experiment in the NuMI beam
- Two totally active scintillator detectors:
  - Far Detector: 14 kT, on surface
  - Near Detector: 300 T, 105 m underground
- 14 mrad off-axis narrowly peaked muon neutrino flux at 2 GeV, L/E ~ 405 km/GeV
- ν_μ disappearance channel: θ_{23}, Δm^2_{32}
- ν_e appearance channel: mass hierarchy, δ_{CP}, θ_{13}, θ_{23} and octant degeneracy



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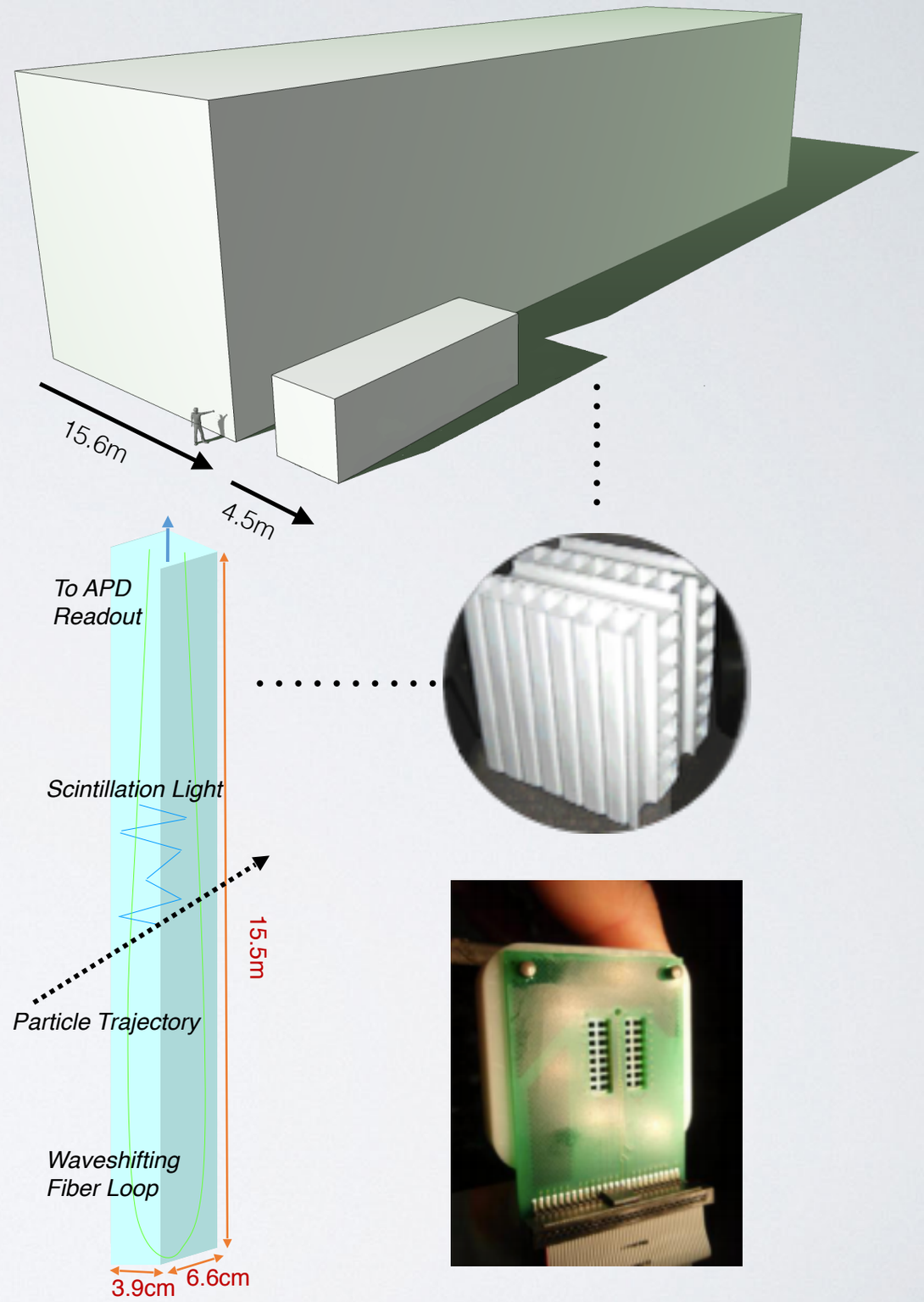

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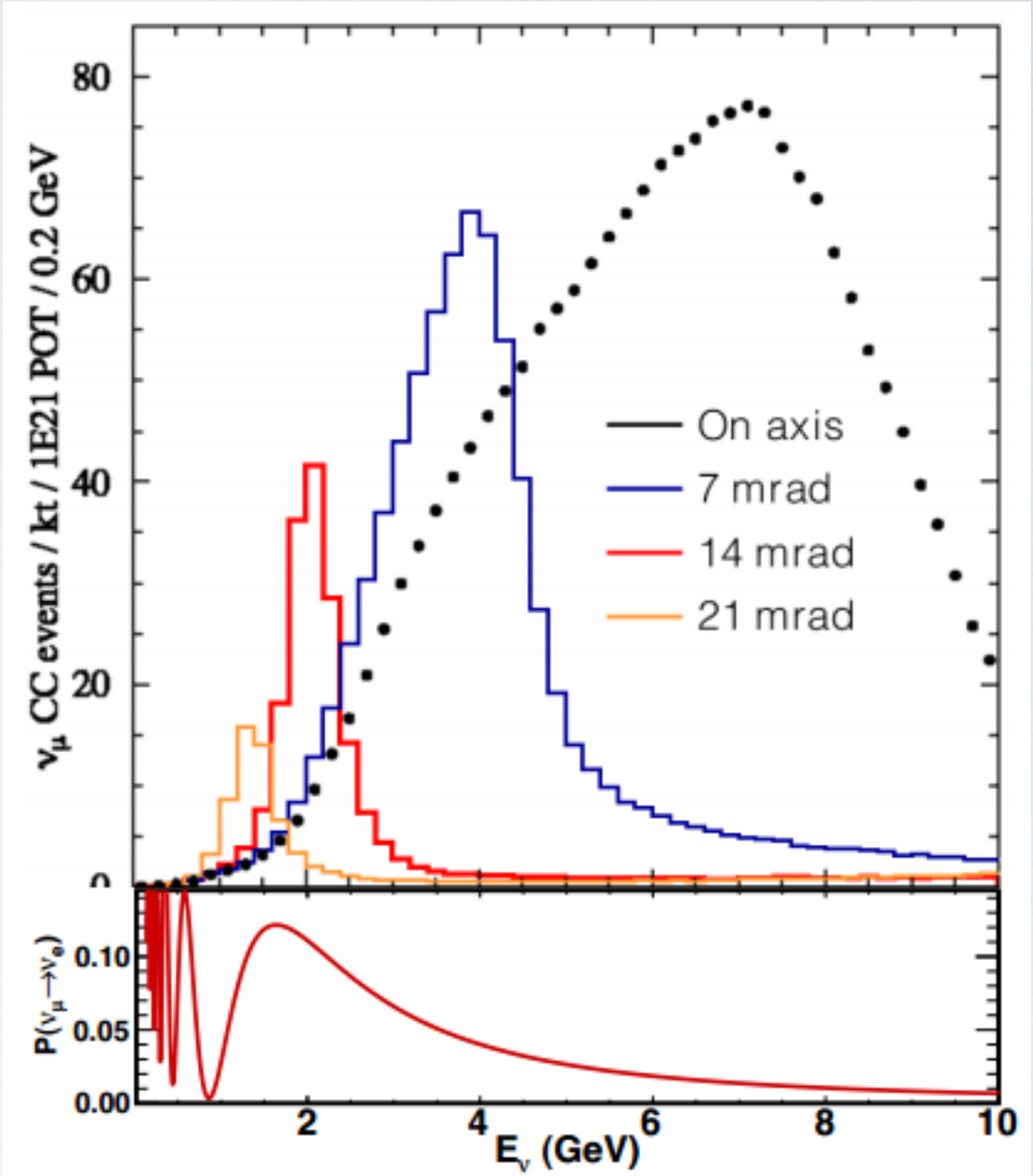
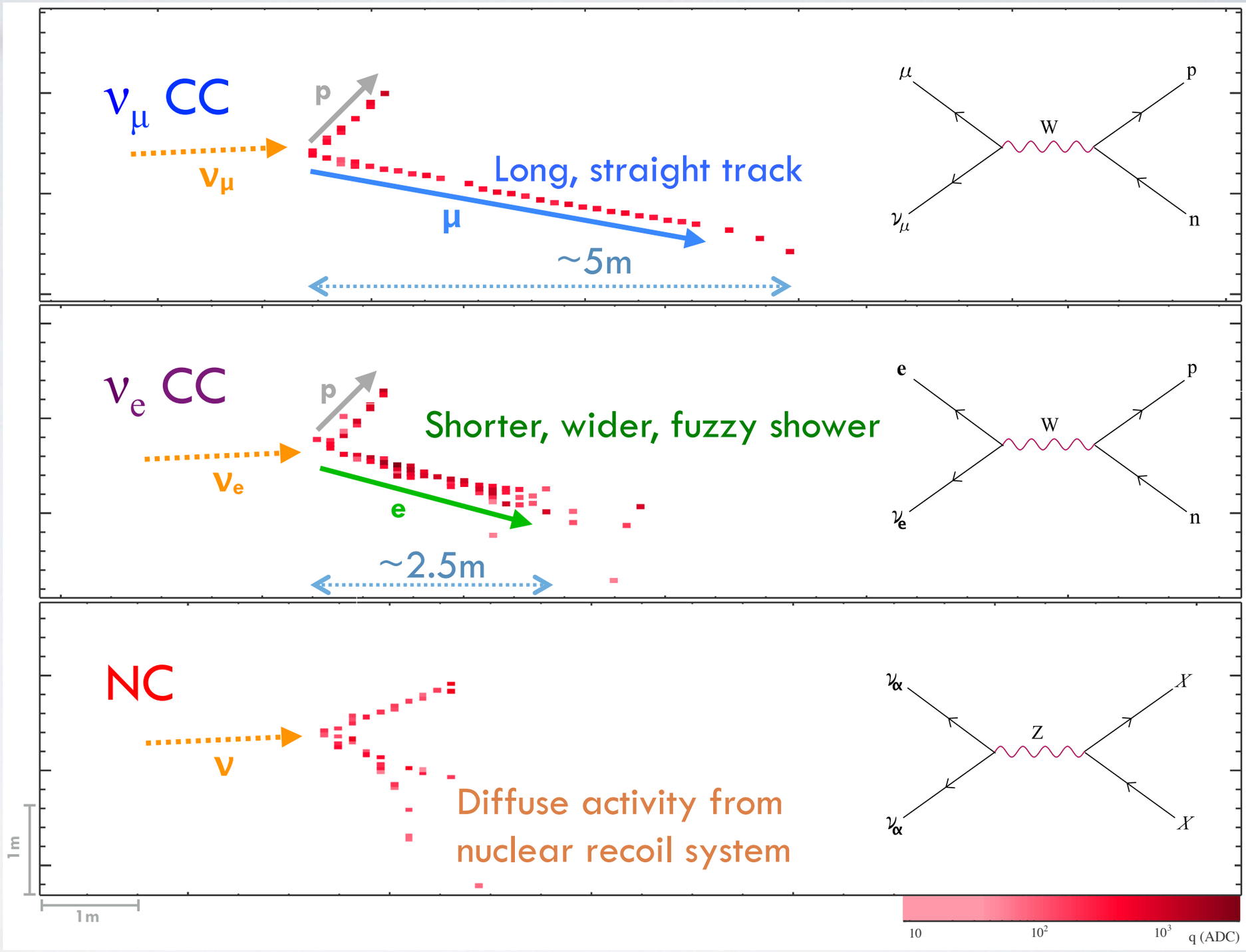


Also: neutrino cross sections at the ND, sterile neutrinos, supernovae…

The NOvA experiment

- Superb granularity for a detector this scale
- Outstanding event identification capability

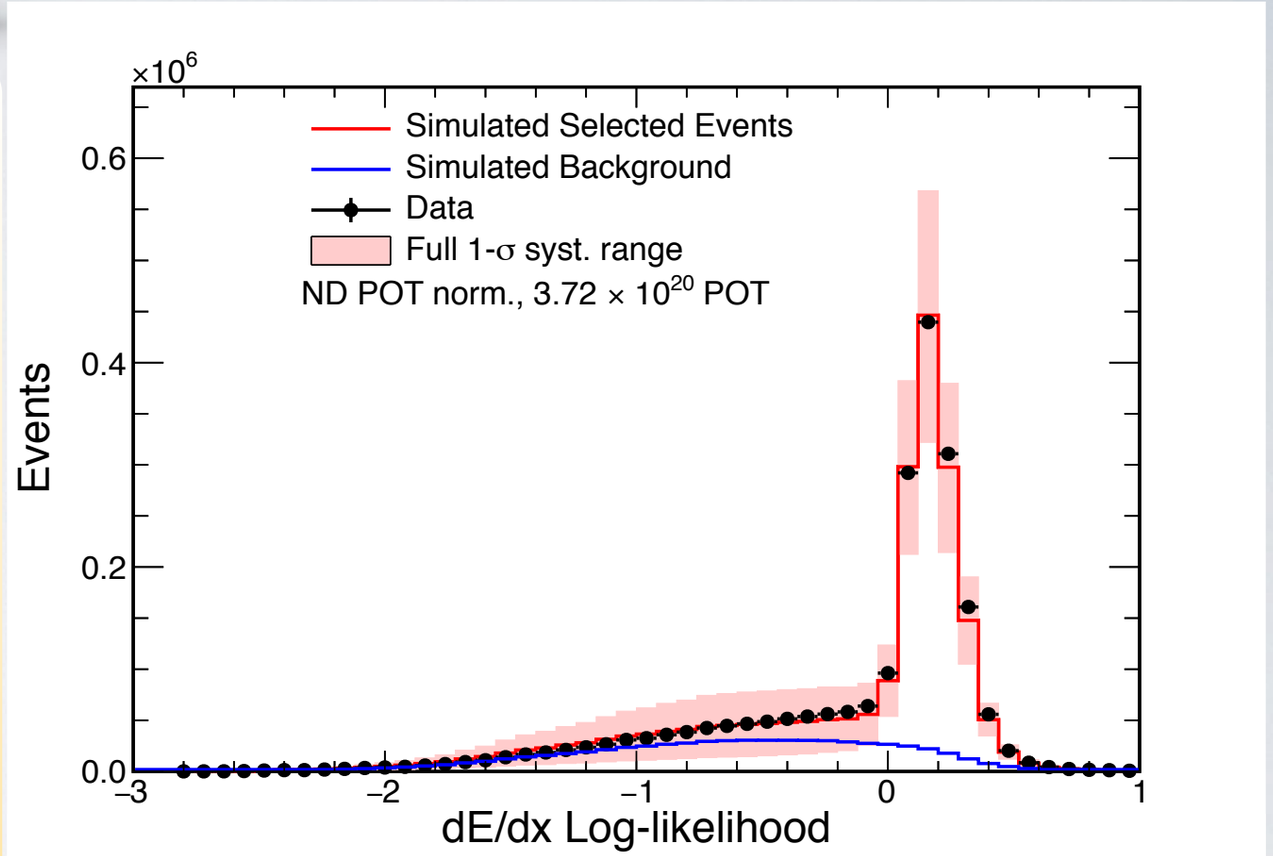


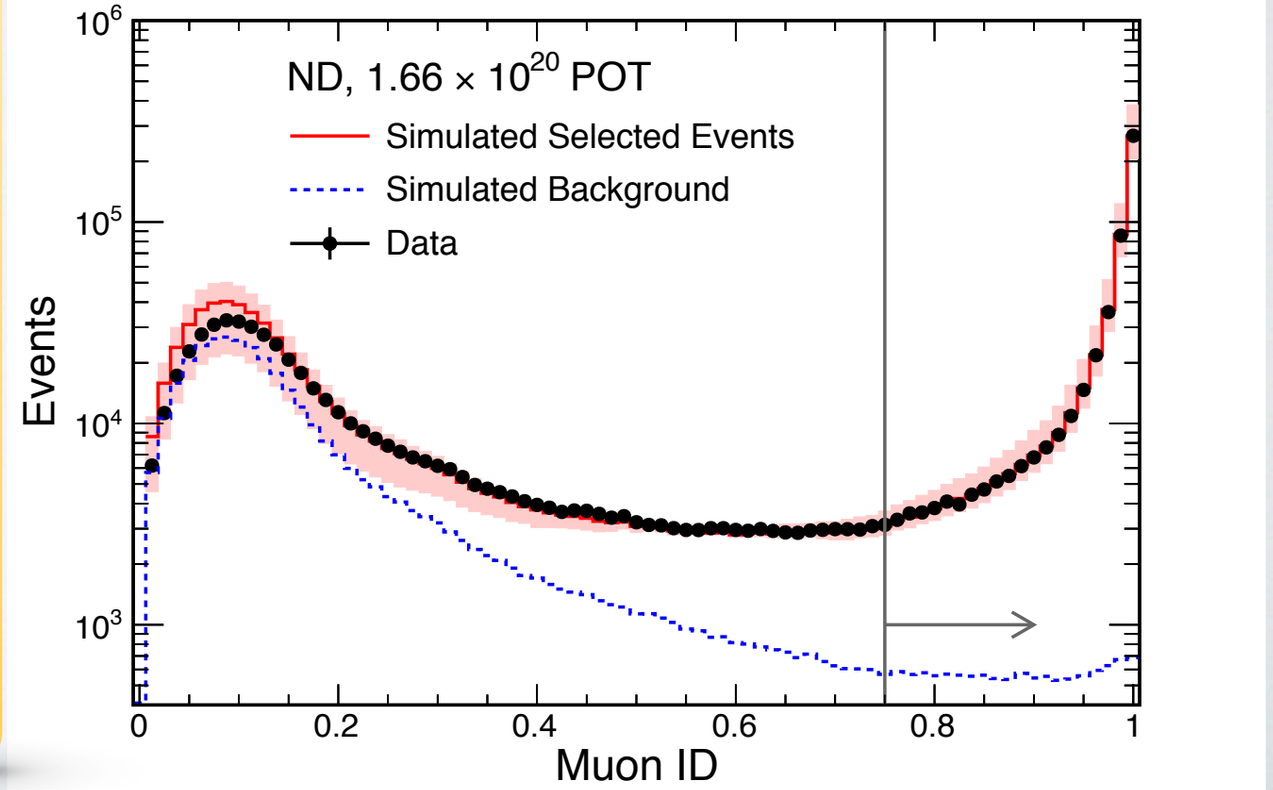
1 radiation length = 38 cm

(6 cell depths, 10 cell widths)

Signal selection: ν_μ CC

- First: basic containment cuts: require a buffer of no activity around the event
- Muon ID: 4-variable k-nearest neighbours algorithm to identify muons
  - Track length
  - dE/dx along track
  - Scattering along track
  - Track-only plane fraction
- Keep events with muon-ID > 0.75

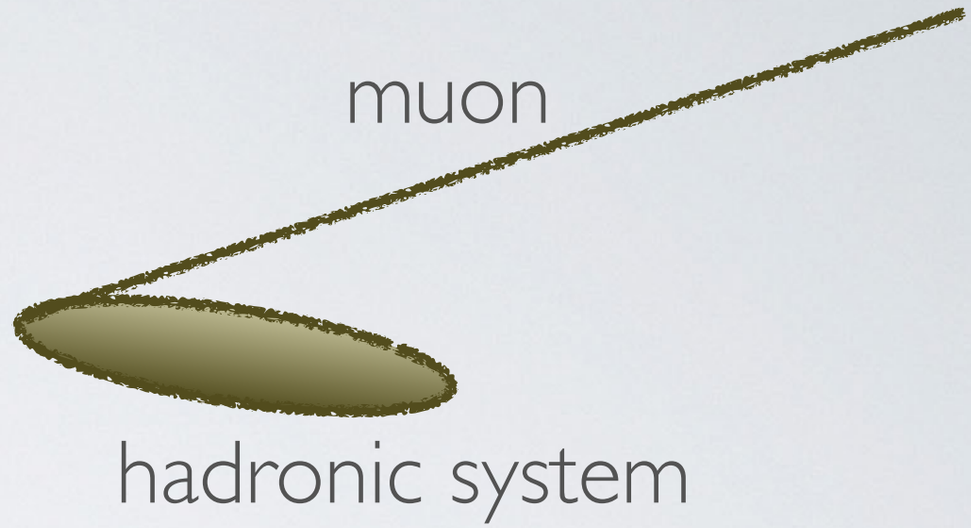


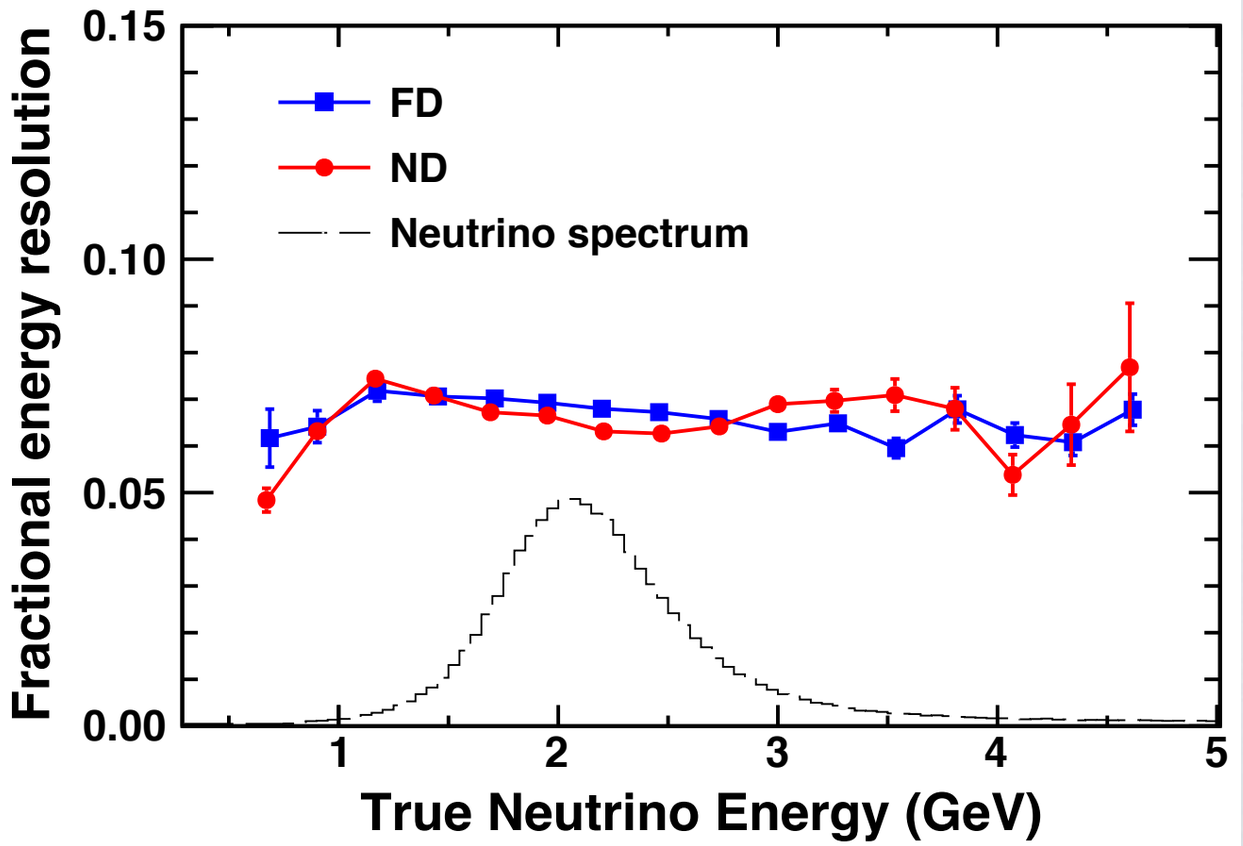


Muon neutrino disappearance

Energy estimation

- Muon track: **length ⇒ E_μ** (Res: ~4%)
- Highly active detector: calorimetric measurement of E_{had}
- Hadronic system: **Σ Total visible E ⇒ E_{had}** (Res: ~20%)
- Reconstructed neutrino energy is the sum of them: **$E_\nu = E_\mu + E_{had}$**
- Neutrino energy resolution: 7%
- Narrow energy and identical detectors reduces impact of cross sections & FSI





Muon neutrino disappearance

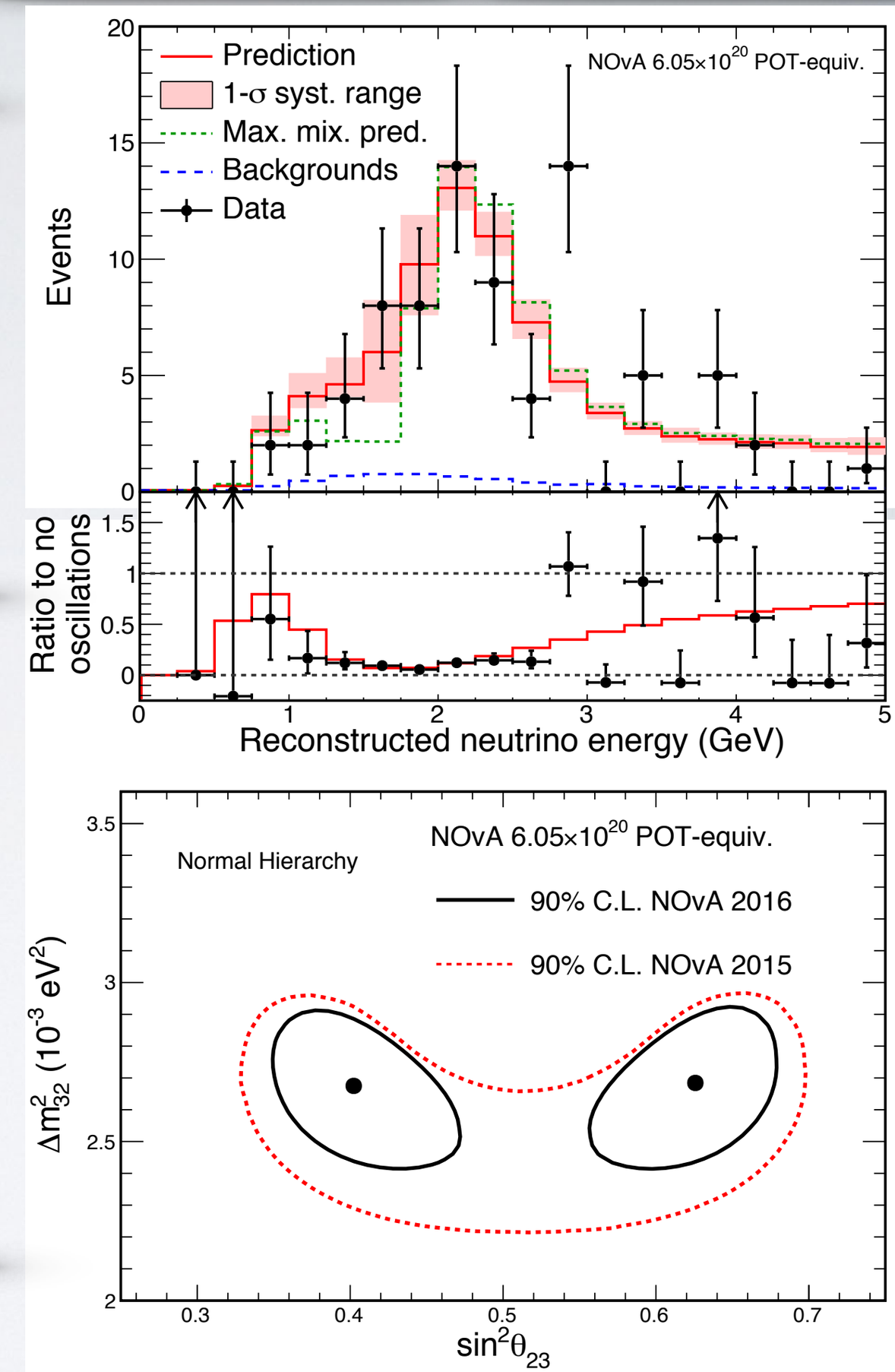
- 78 events in the FD for 473 w/o osc.
- 82 (3.9 beam bkg, 2.7 cosmic) at best fit
- $\mathbf{X}^2$/NDF = 41.6/17 driven by tail
- Systematics included in the fit have negligible pull terms (< 0.5)

$$|\Delta m^2_{32}| = 2.67 \pm 0.11 \times 10^{-3}\ eV^2$$

$$\sin^2\theta_{23} = 0.404^{+0.030}_{-0.022}$$

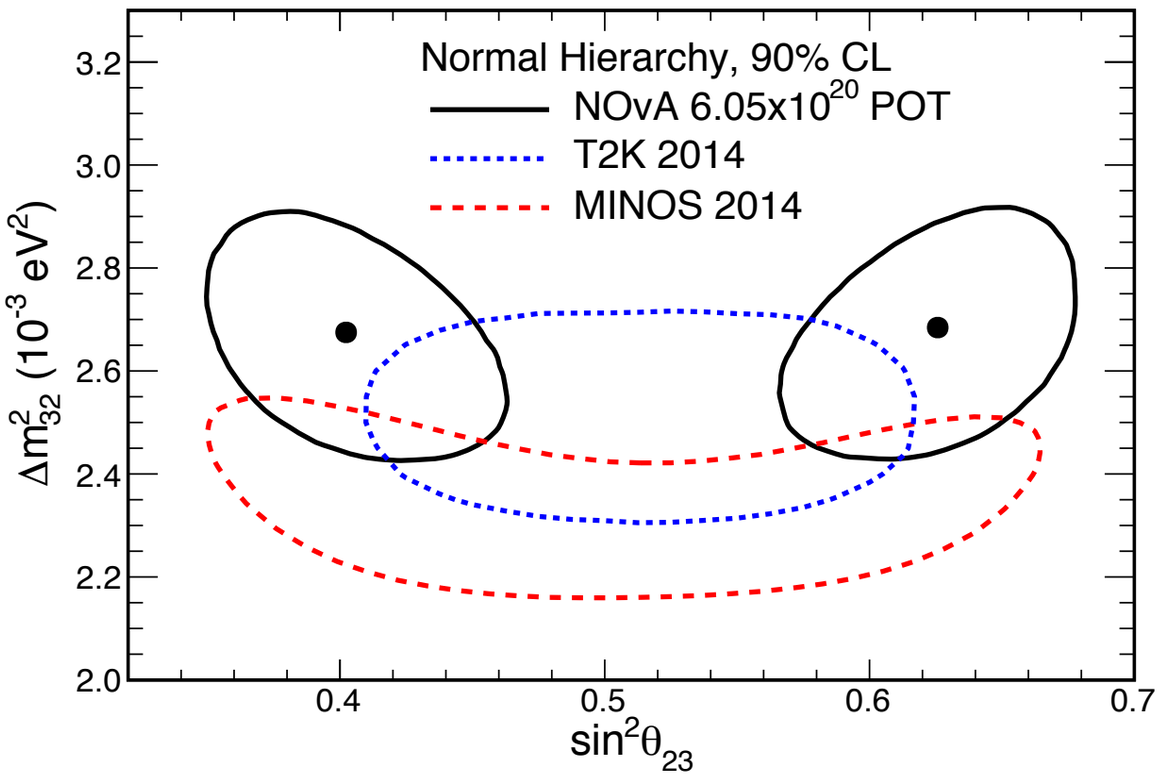
$$= 0.624^{+0.022}_{-0.030}$$

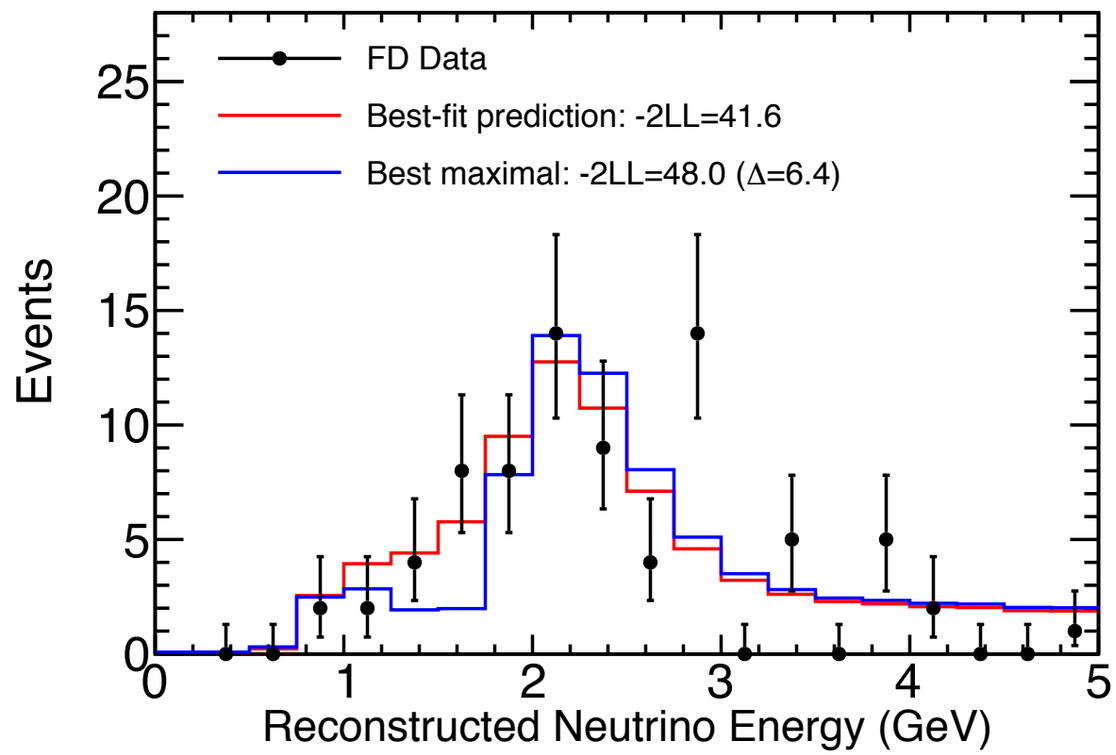
Maximal mixing disfavoured at 2.6σ



Muon neutrino disappearance

Comparison with other experiments





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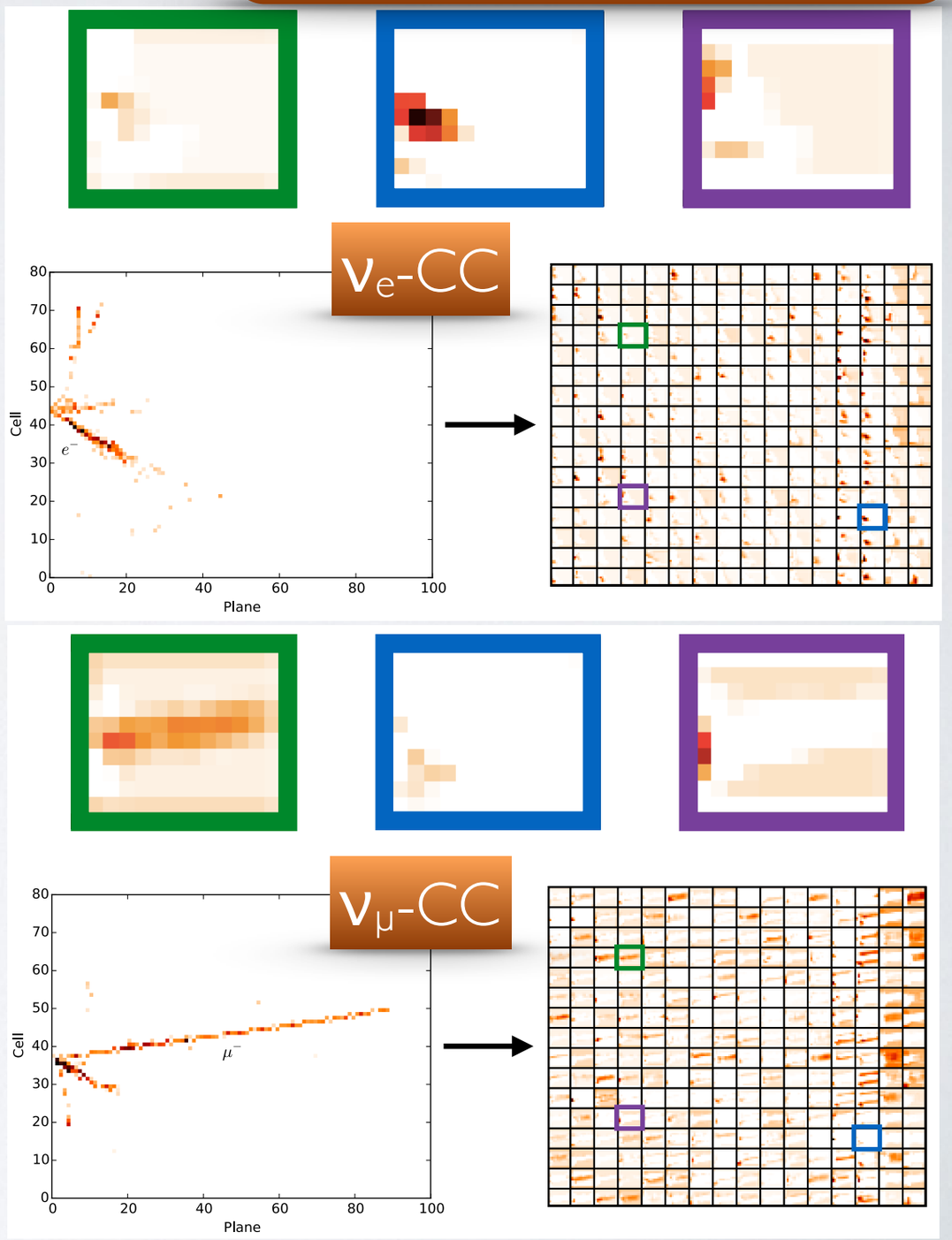
Phys. Rev. Lett. 118, 151802 (2017)

Electron neutrino appearance

Event selection

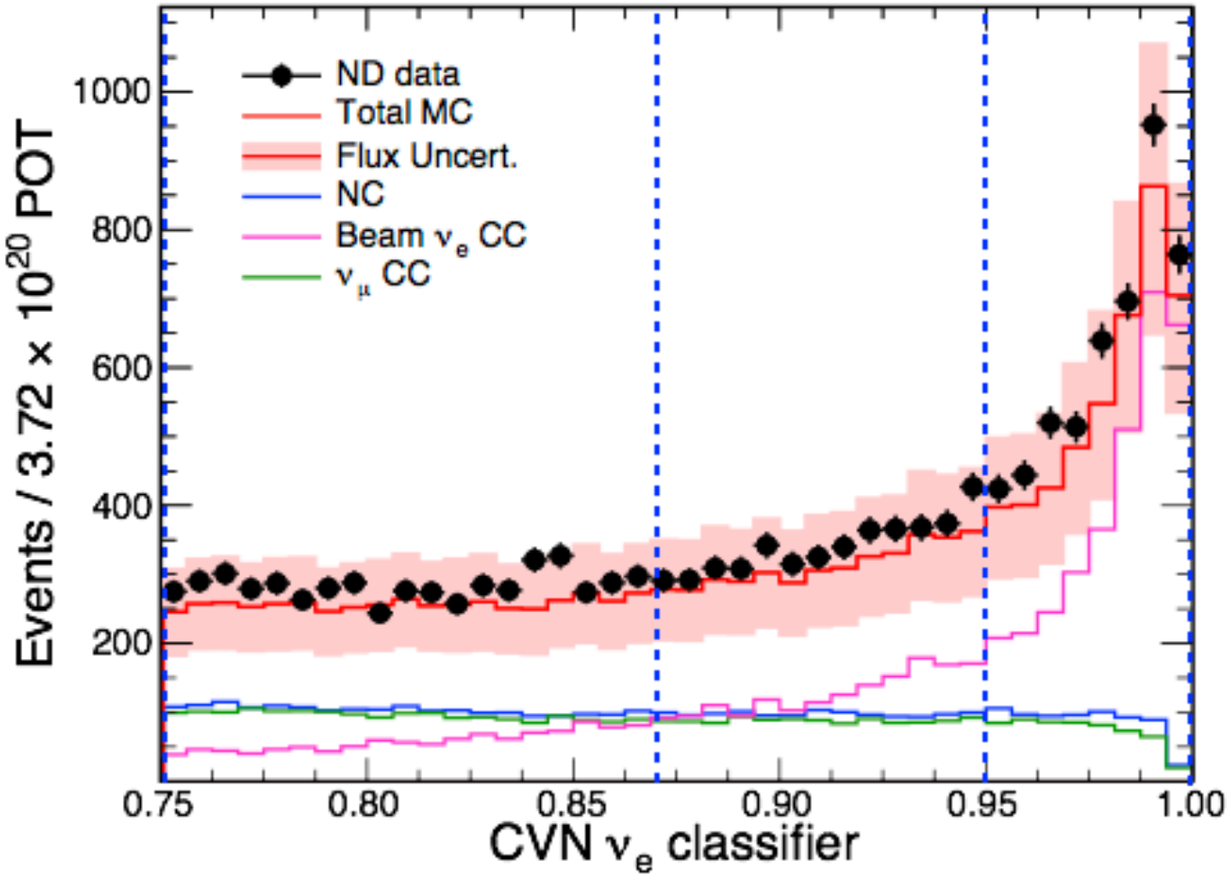
A. Aurisano et. al, JINST 11 P09001 (2016)

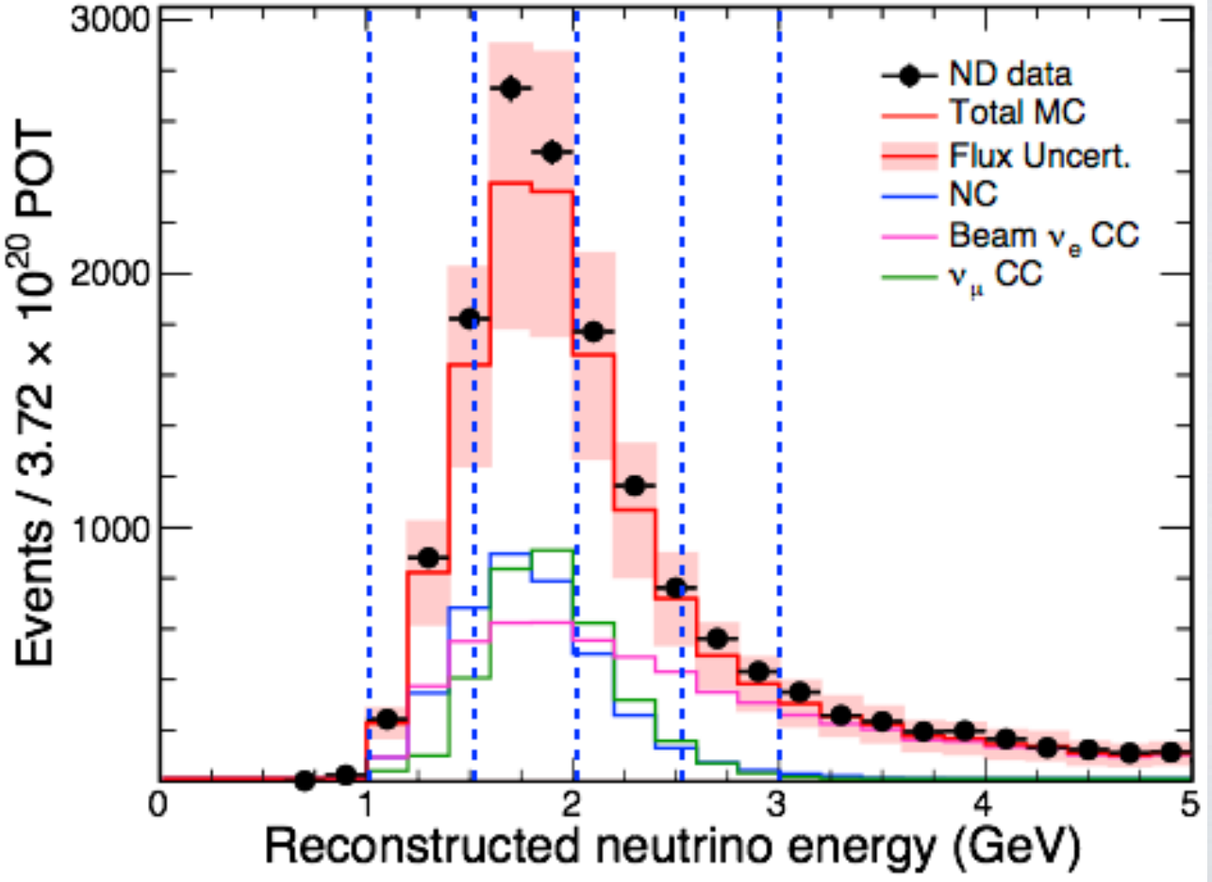
- Event selection based on ideas from computer vision and deep learning
- Calibrated hit maps are inputs to Convolutional Visual Network (CVN)
- Series of image processing transformations applied to extract abstract features
- Extracted features used as inputs to a conventional neural network to classify the event
- **Improvement in sensitivity from CVN equivalent to 30% more exposure**



Electron neutrino appearance

- Selection optimised for parameter measurement (increased signal efficiency by including lower purity bins)
- Constrained beam backgrounds with dedicated decompositions: beam ν_e from ν_μCC and these from the distribution of Michel electrons
- Analysis uses four bins of energy and three bins of CVN

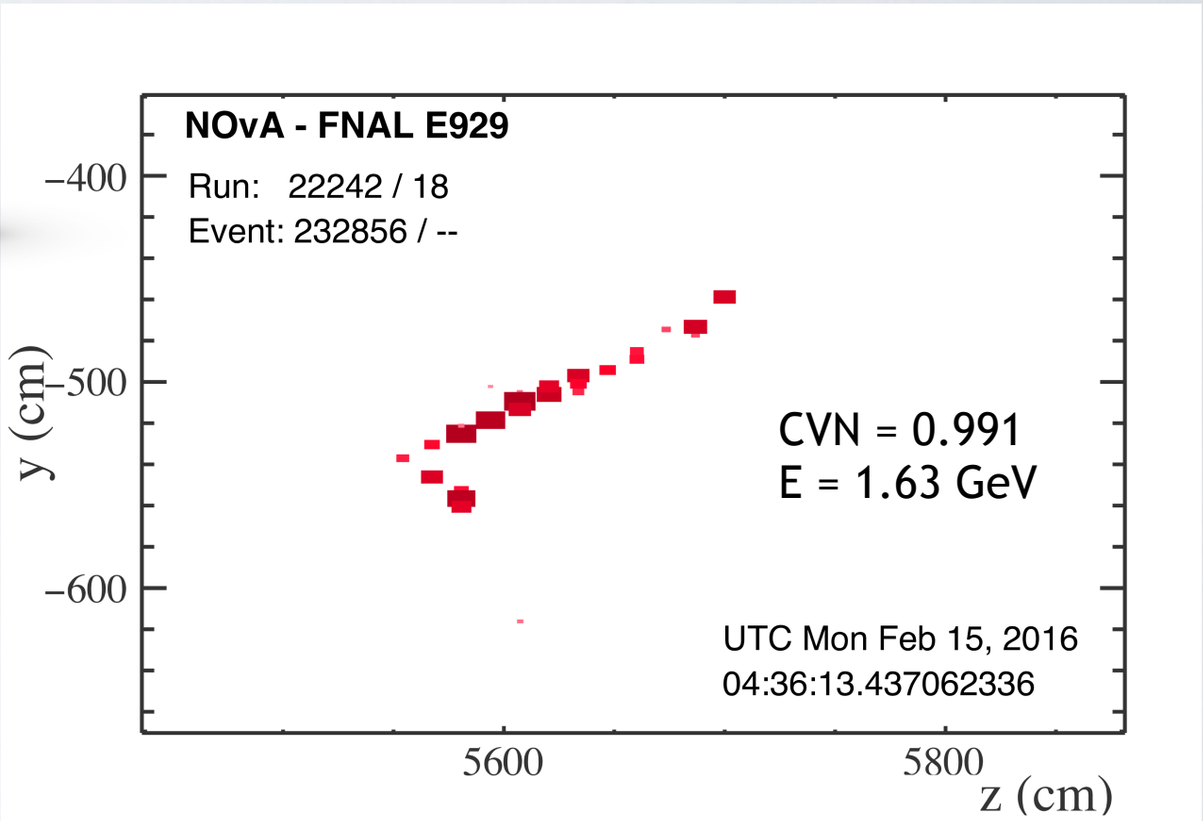


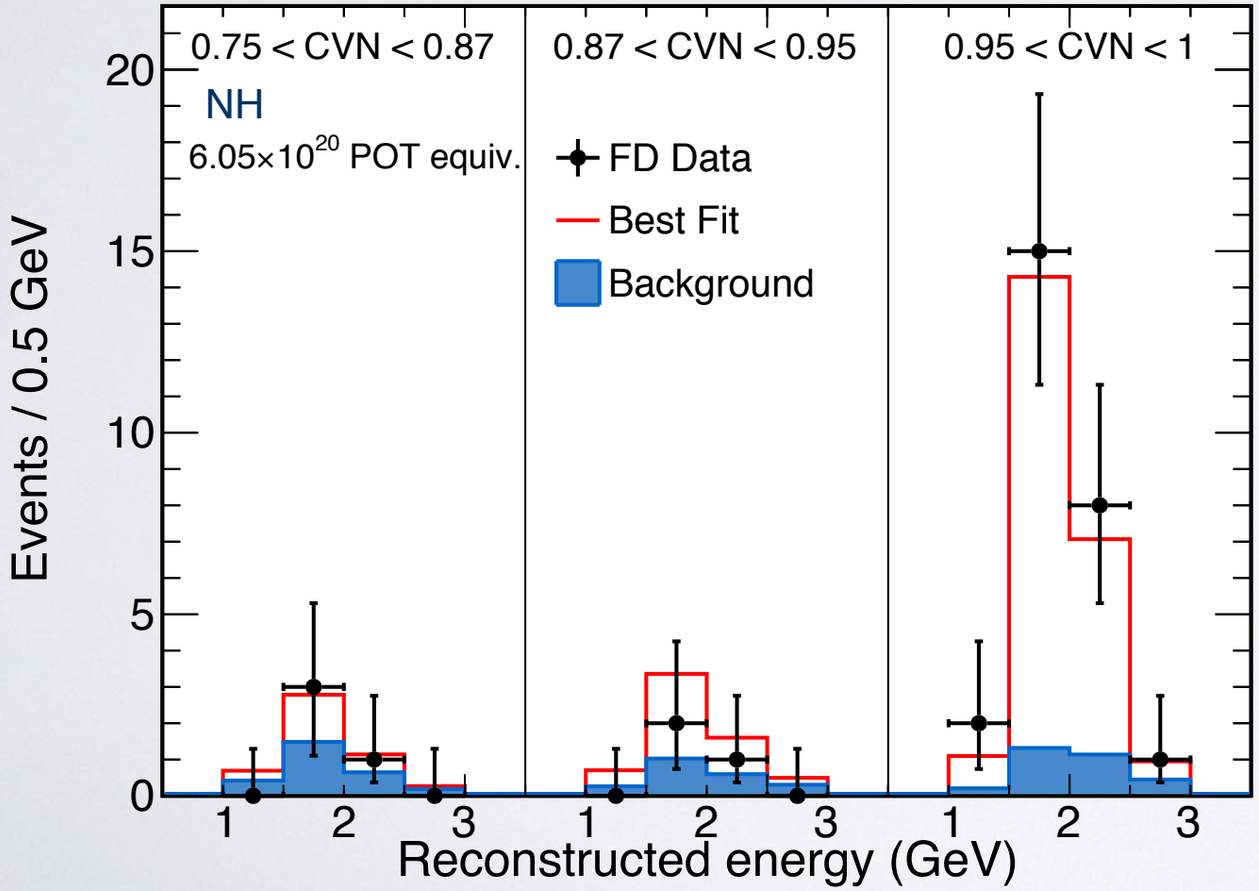


Electron neutrino appearance

Far detector selected events

- **Observed 33 events in the FD** (background 8.2 ± 0.8)





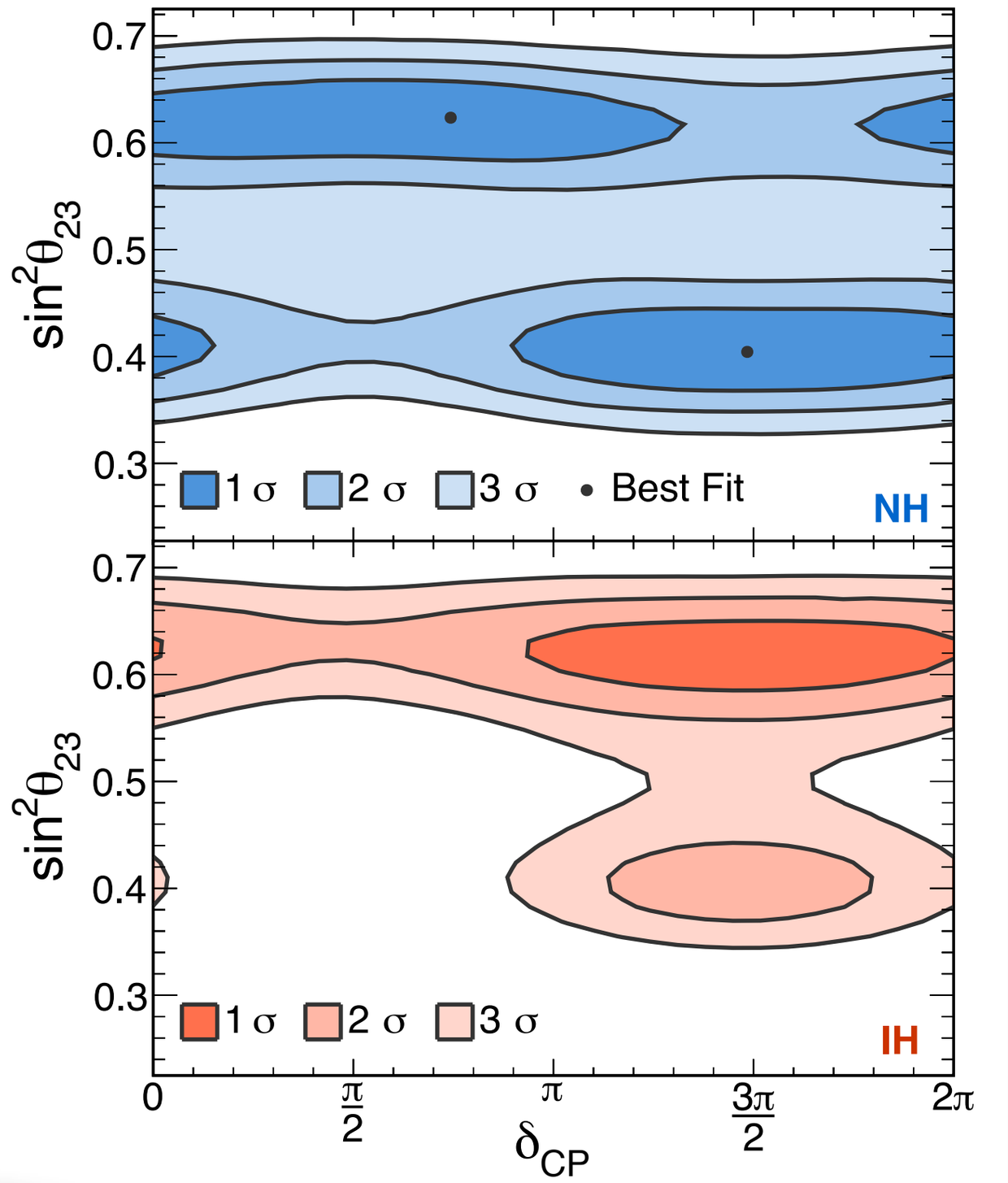
Selectors from 2015 analysis show consistent results

LID: 34 events, 12.2 ± 1.2 bkg
LEM: 33 events, 10.3 ± 1.0 bkg

Electron neutrino appearance

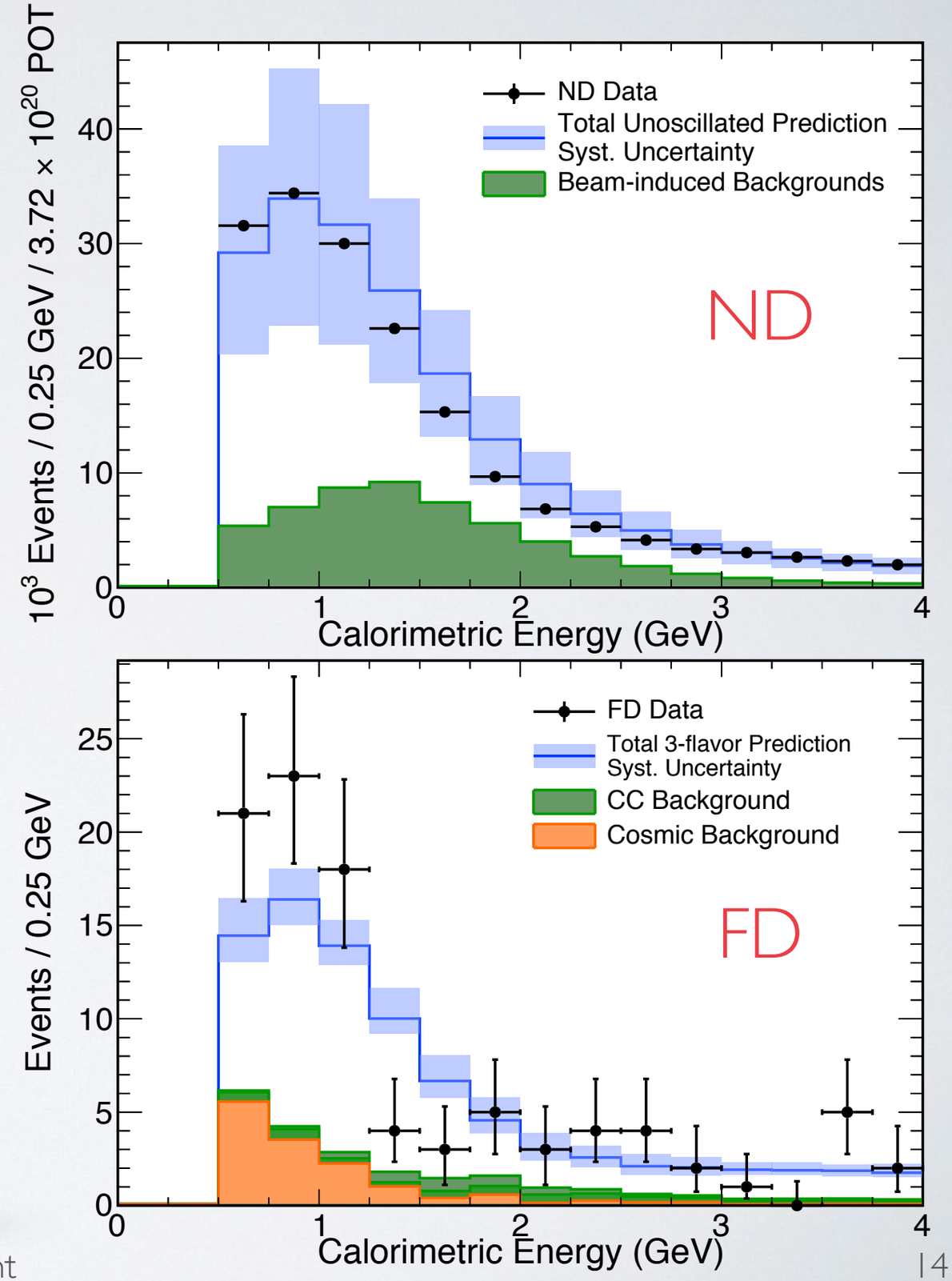
- Full joint-analysis including disappearance constraints
- Best fit to NH, $\delta_{CP} = 1.49\pi$ and $\sin^2(\theta_{23}) = 0.40$
- But best fit IH-NH has $\Delta X^2 = 0.47$
- Both octants and hierarchies allowed at 1σ
- 3σ exclusion of IH, lower octant around $\delta_{CP} = \pi/2$
- Antineutrino data will resolve degeneracies

Phys. Rev. Lett. 118, 231801 (2017)



NC disappearance

- Search for active-sterile oscillation by measuring NC spectrum in both detectors
- 95 events observed for 83.5 ± 9.7 (stat.) ± 9.4 (syst.) expected
- No evidence of oscillations involving sterile neutrinos
- Promising future sensitivities



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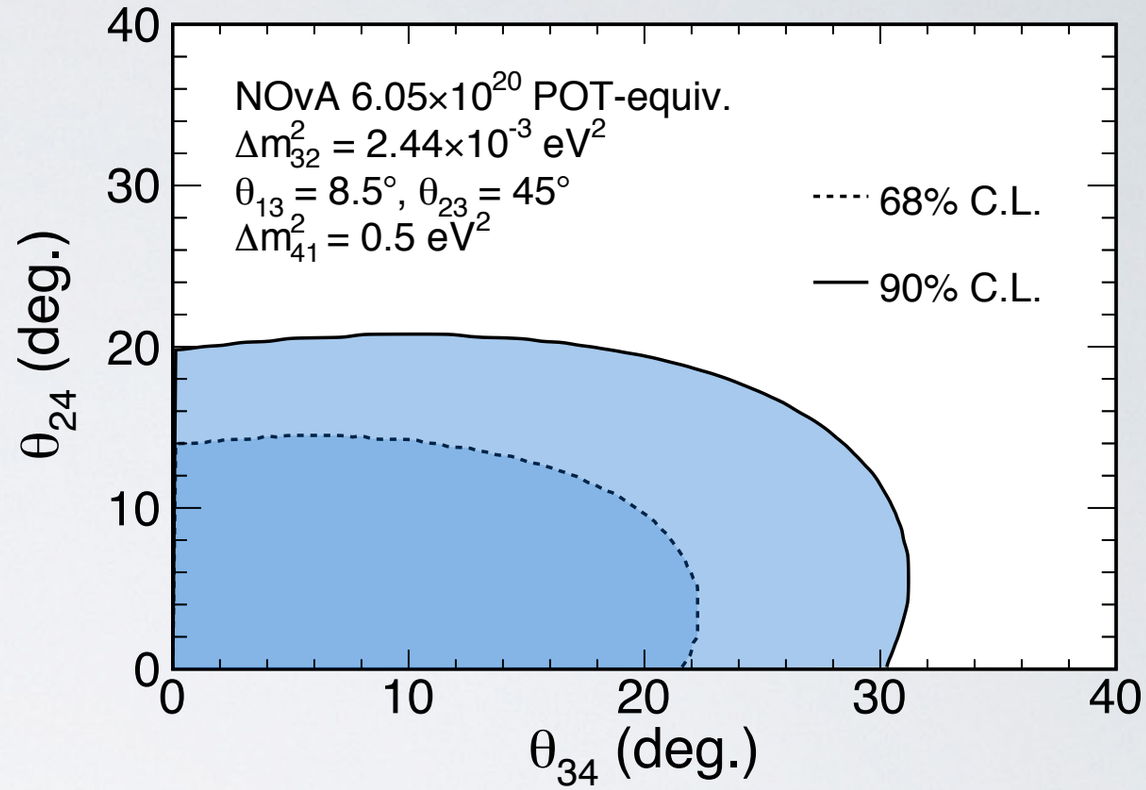
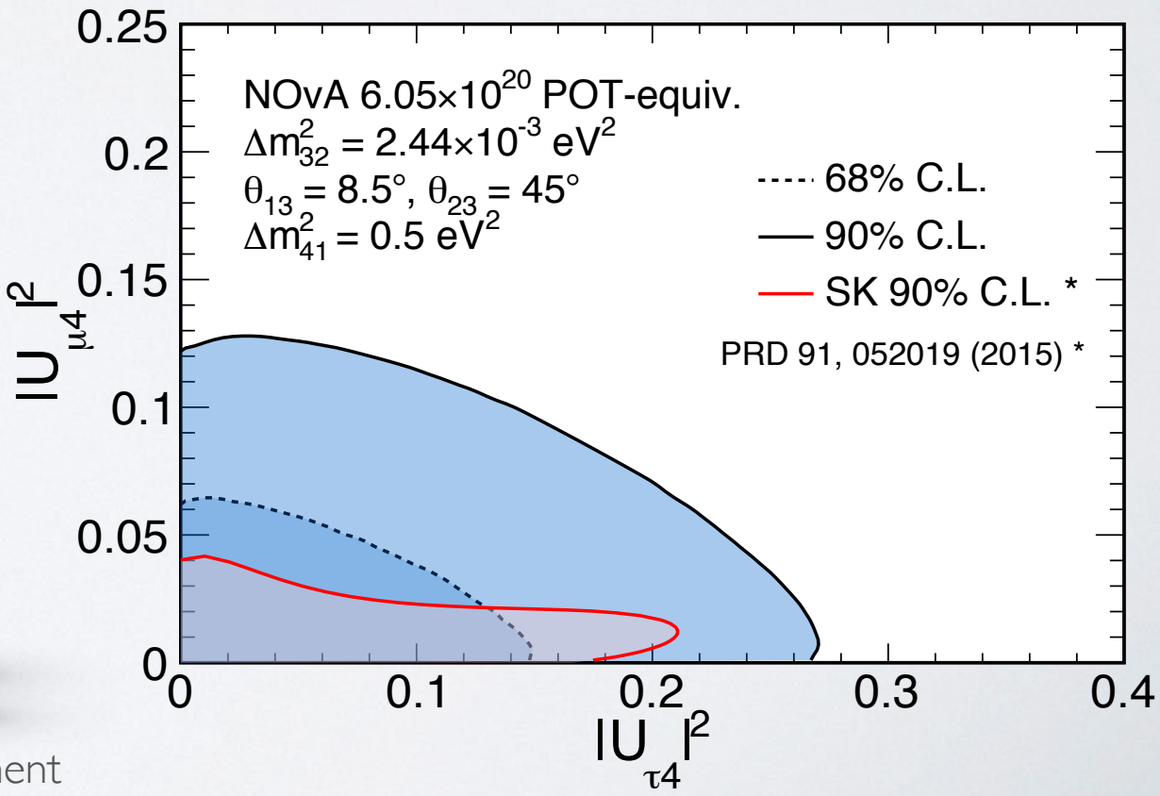
arXiv: 1706.04592

(submitted to PRD)





Conclusions

- Indubitable observation of neutrino disappearance (78 obs, 473 exp.)
- Best fit for θ_{23} is non-maximal. Maximal mixing disfavoured at 2.6σ
- Small preference for normal hierarchy. Region in inverted hierarchy, lower octant and around $\delta_{CP} = \pi/2$ excluded at 3σ
- Neutral current event rate shows no evidence of sterile neutrinos
- Currently taking antineutrino data

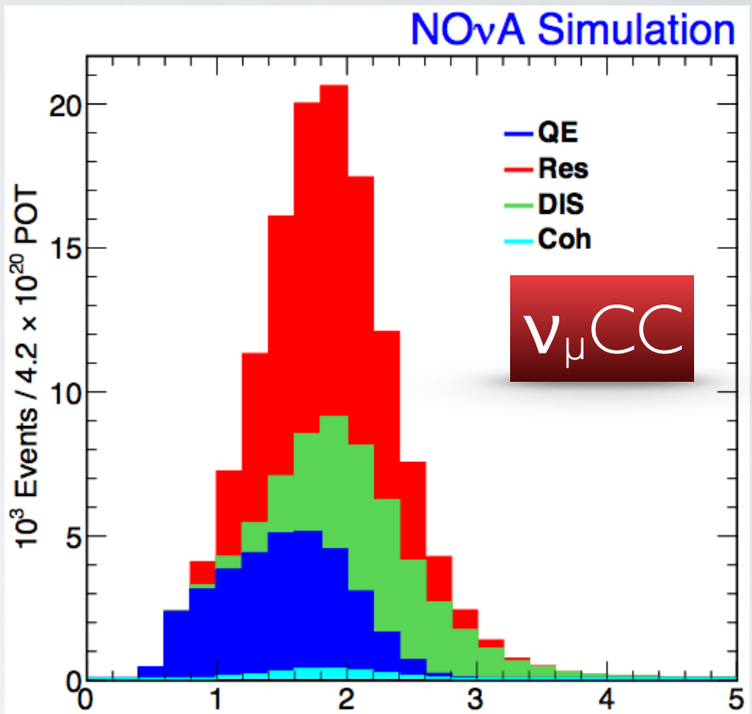
THANK YOU FOR YOUR ATTENTION

www-nova.fnal.gov

BACKUP

ND measurements

- Uniquely sensitive to QE, RES and DIS (almost equally across the three)
- Absolute cross section or yield measurements will be limited to ~10% due to flux uncertainties
- Ability to measure a huge number of FSI channels



- ν_μCC inclusive and channels (0-π, 2p2h, Coh, π^0, …)
- ν_eCC inclusive and channels (0-π, π^0, …)
- NC inclusive and channels (π^0, 2p2h, …)
- ν_μ on ν_e scattering (flux constraint)

And all of the above with antineutrinos