

T2K-SK Systematic Uncertainties

3rd Workshop on Neutrino Near Detectors
based on gas TPCs
20th May

James Imber
LLR – Ecole Polytechnique

T2K-SK Systematic Uncertainties

- Current Status
 - Selected Methods
 - Near-term prospects
- Future developments
 - T2K systematics in the SK-Gd Era

Current Status

- Uncertainties updated in 2017 for new far detector event selection
- Uncertainty related to observing particles propagating through the tank
 - Final state topology (FS)
- “Top-down” approach – constrain each FS with equivalent non-beam data compared with MC
- Uncertainty from each selection criteria
- ToyMC to combine errors and convert format for OA group

Atmospheric Neutrinos

- Allow distortions (shift, smear) of atmospheric neutrino MC distributions by FS and region in (*towall*, *wall*) space
- Distributions in log-likelihood ratio for different hypotheses (e.g. e-like vs. μ -like)
- Samples divided into $N_{\text{decay-e}} = 0, 1, 2+$ to emphasise different components

for each cut variable X:

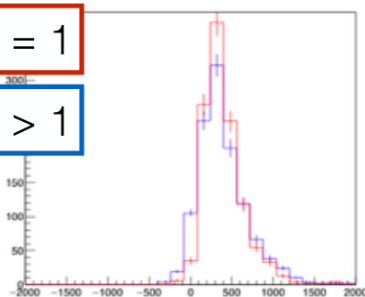
$$X \rightarrow \alpha X + \beta$$

“smear” parameter shifts width of distribution of X

“bias” parameter shifts mean of distribution of X

$$\alpha = 1$$

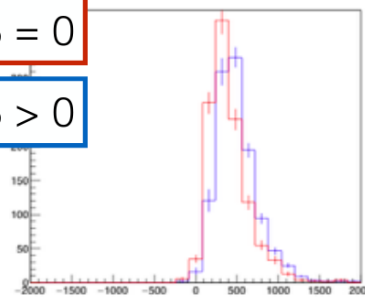
$$\alpha > 1$$



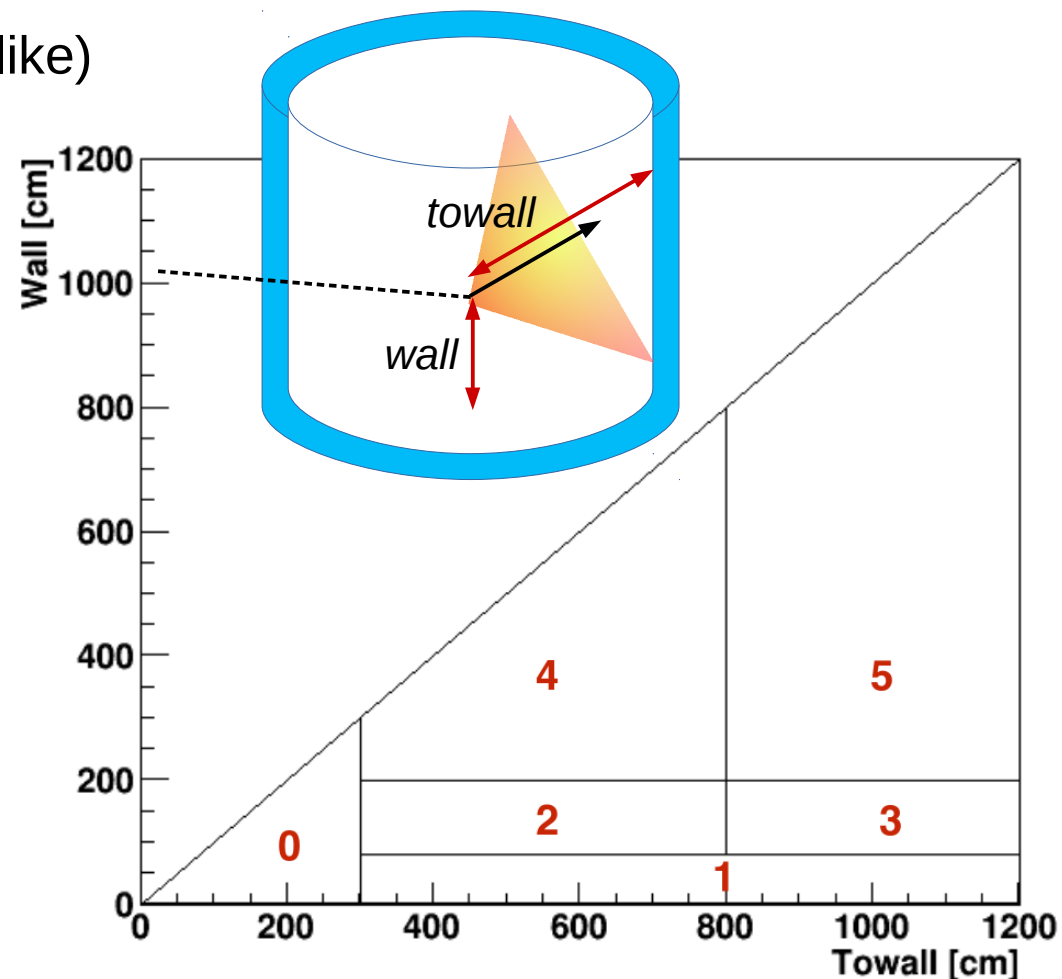
μ like \longleftrightarrow e like

$$\beta = 0$$

$$\beta > 0$$

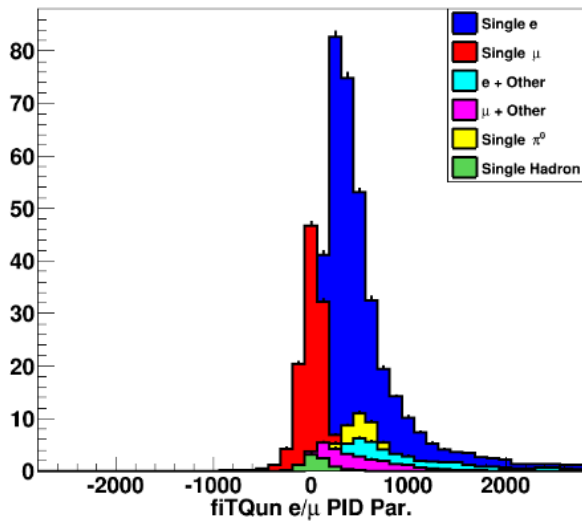


μ like \longleftrightarrow e like

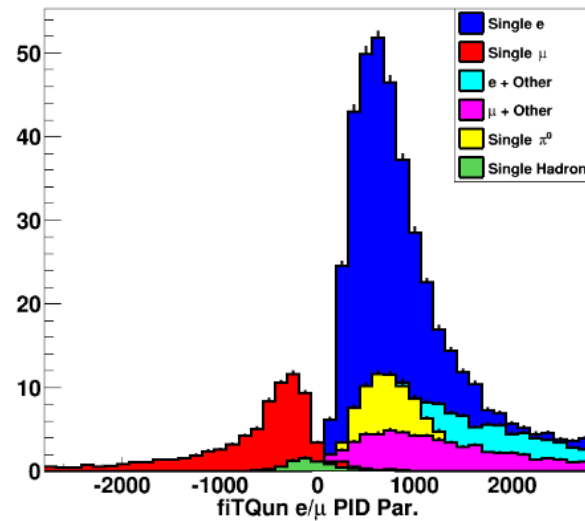


0 decay electrons

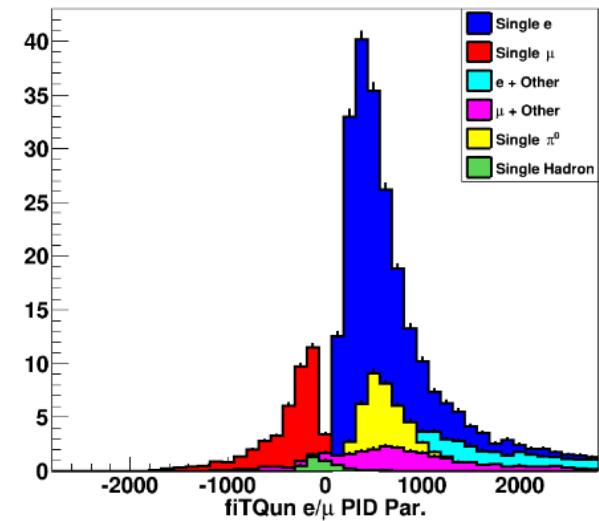
Detector Region 0 Sample 0



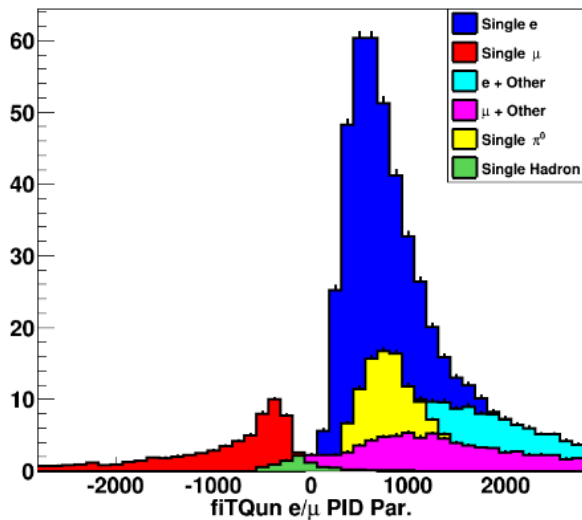
Detector Region 1 Sample 0



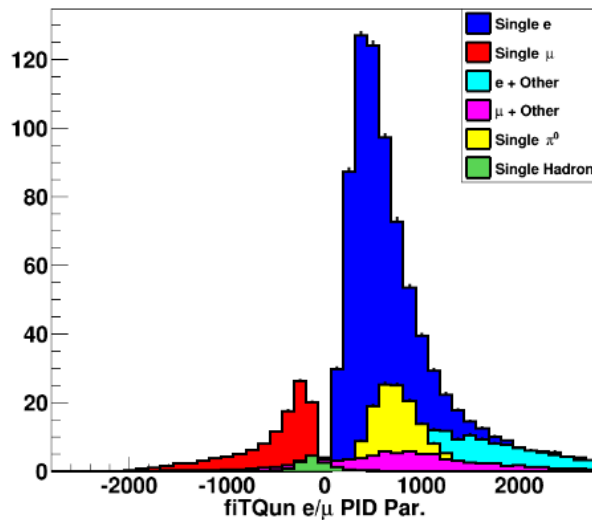
Detector Region 2 Sample 0



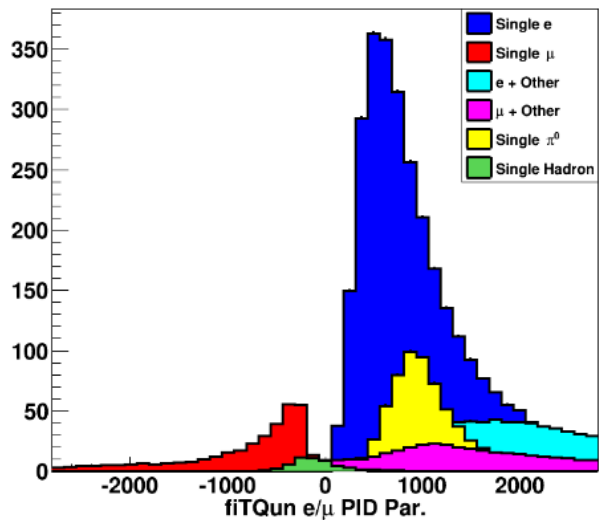
Detector Region 3 Sample 0



Detector Region 4 Sample 0

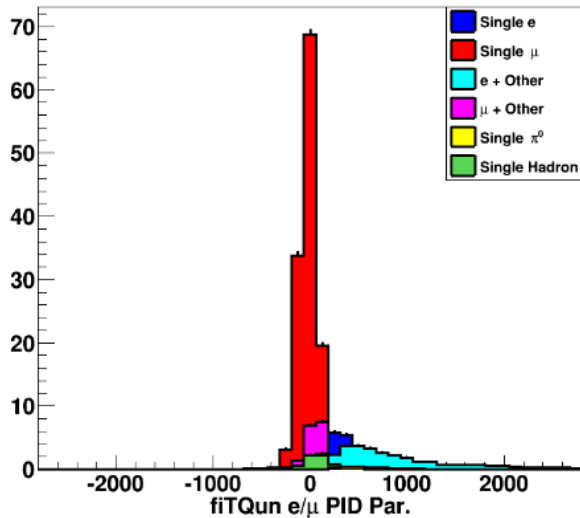


Detector Region 5 Sample 0

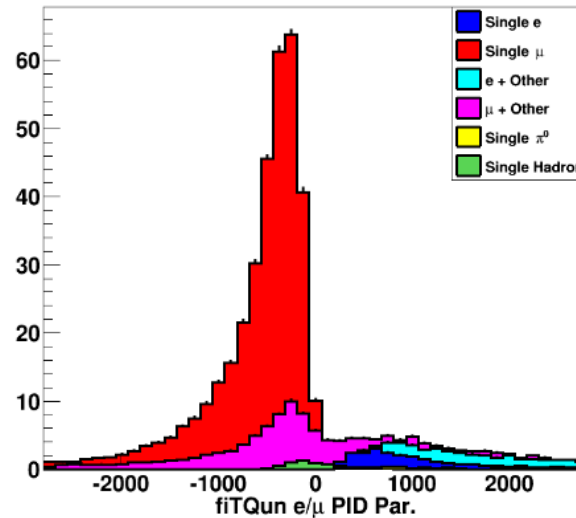


1 decay electrons

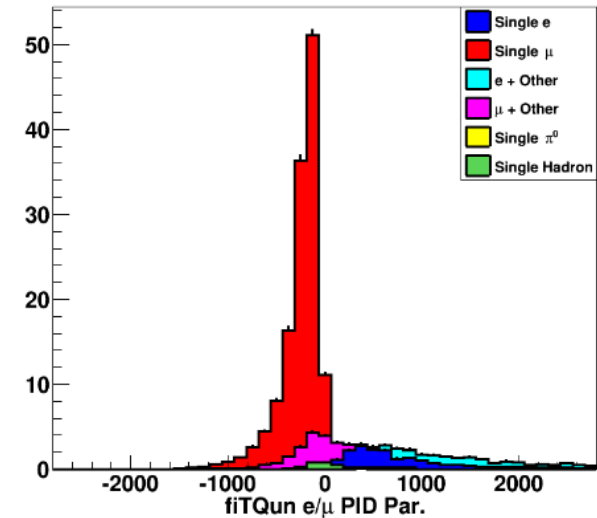
Detector Region 0 Sample 1



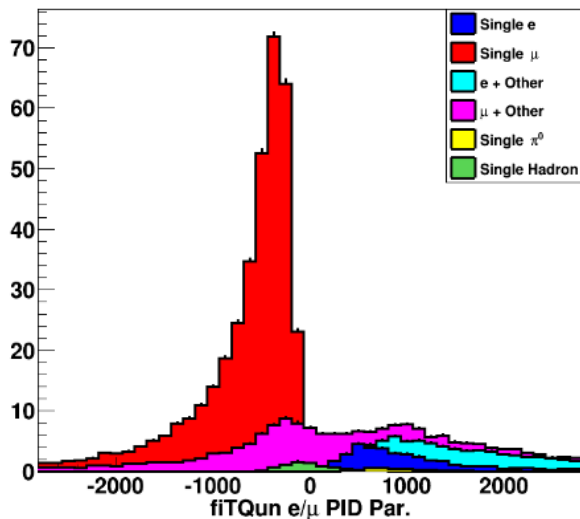
Detector Region 1 Sample 1



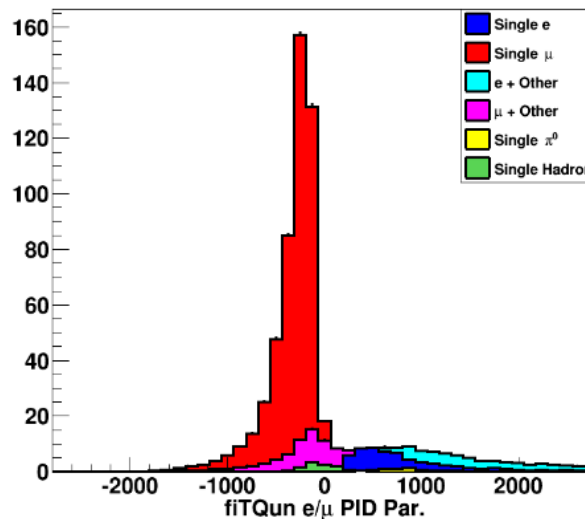
Detector Region 2 Sample 1



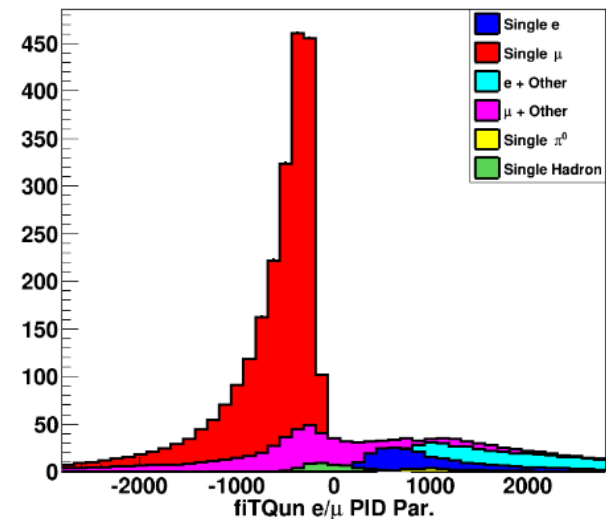
Detector Region 3 Sample 1



Detector Region 4 Sample 1

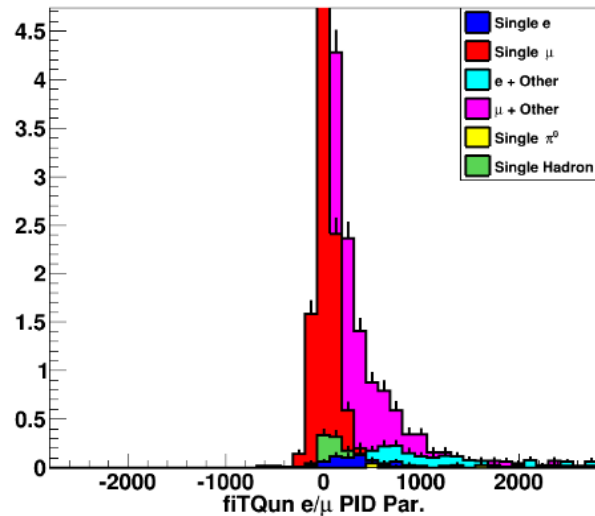


Detector Region 5 Sample 1

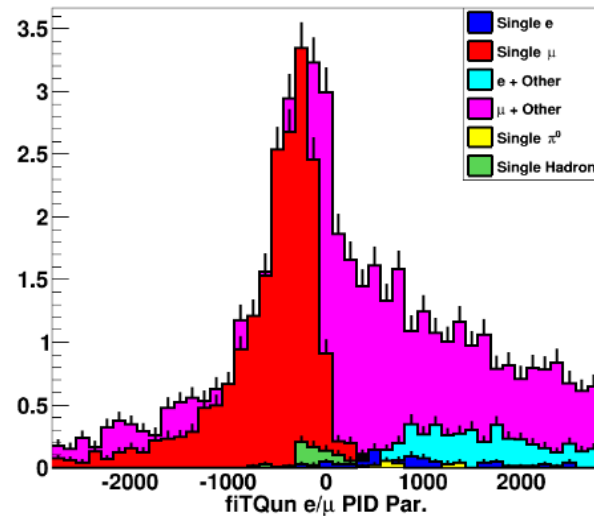


2+ decay electrons

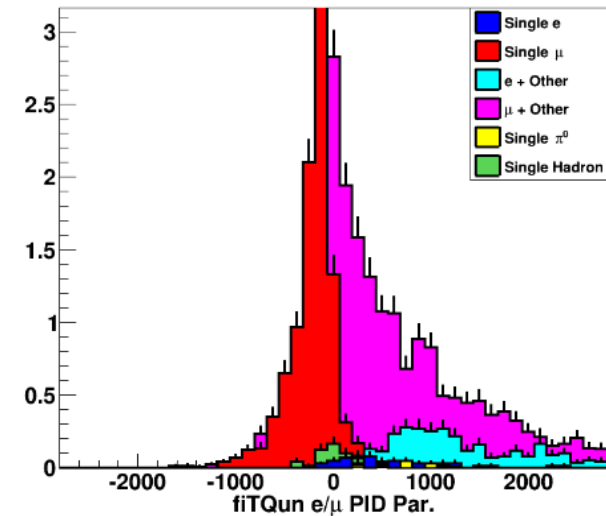
Detector Region 0 Sample 2



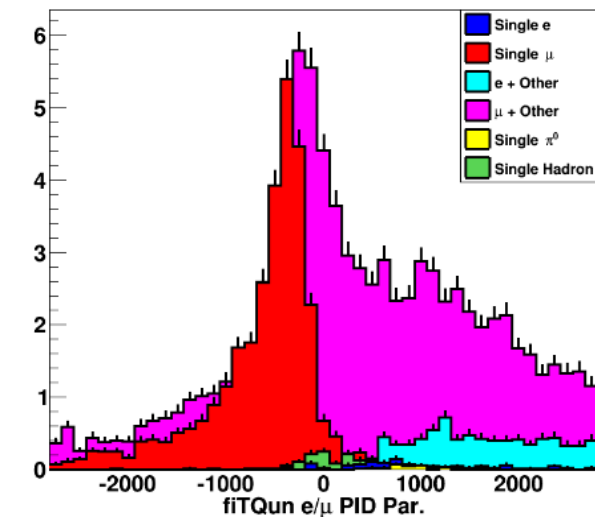
Detector Region 1 Sample 2



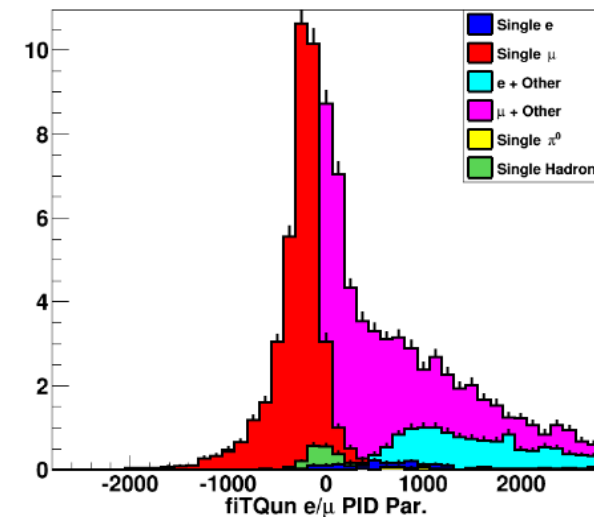
Detector Region 2 Sample 2



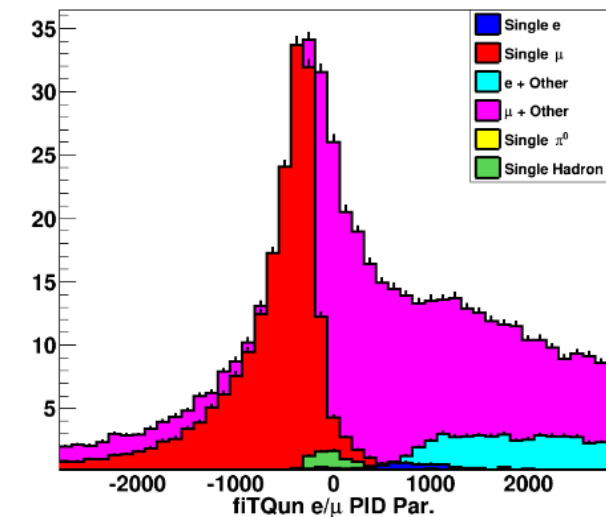
Detector Region 3 Sample 2



Detector Region 4 Sample 2

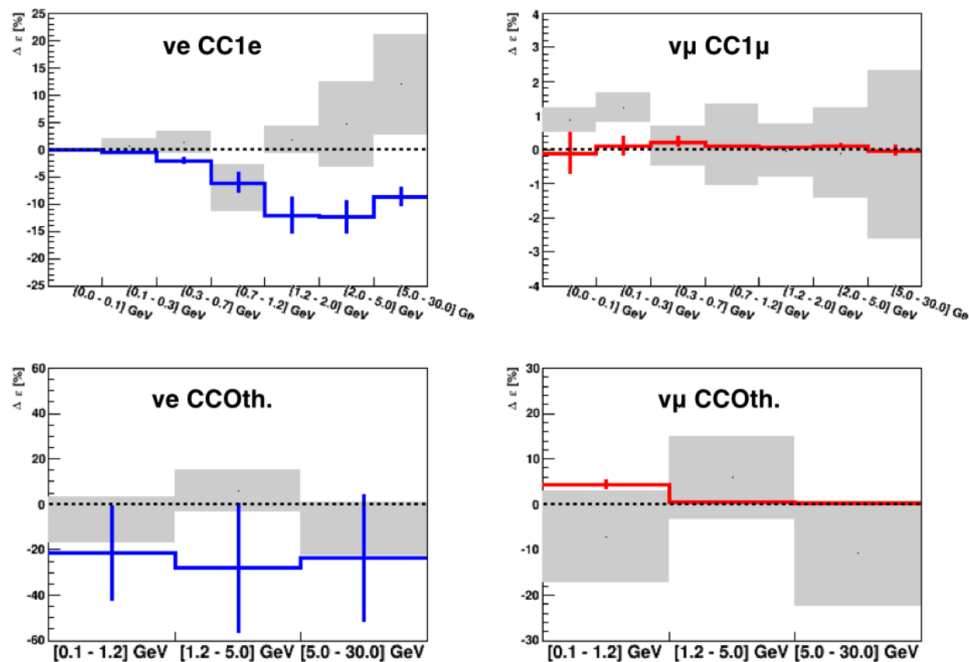


Detector Region 5 Sample 2

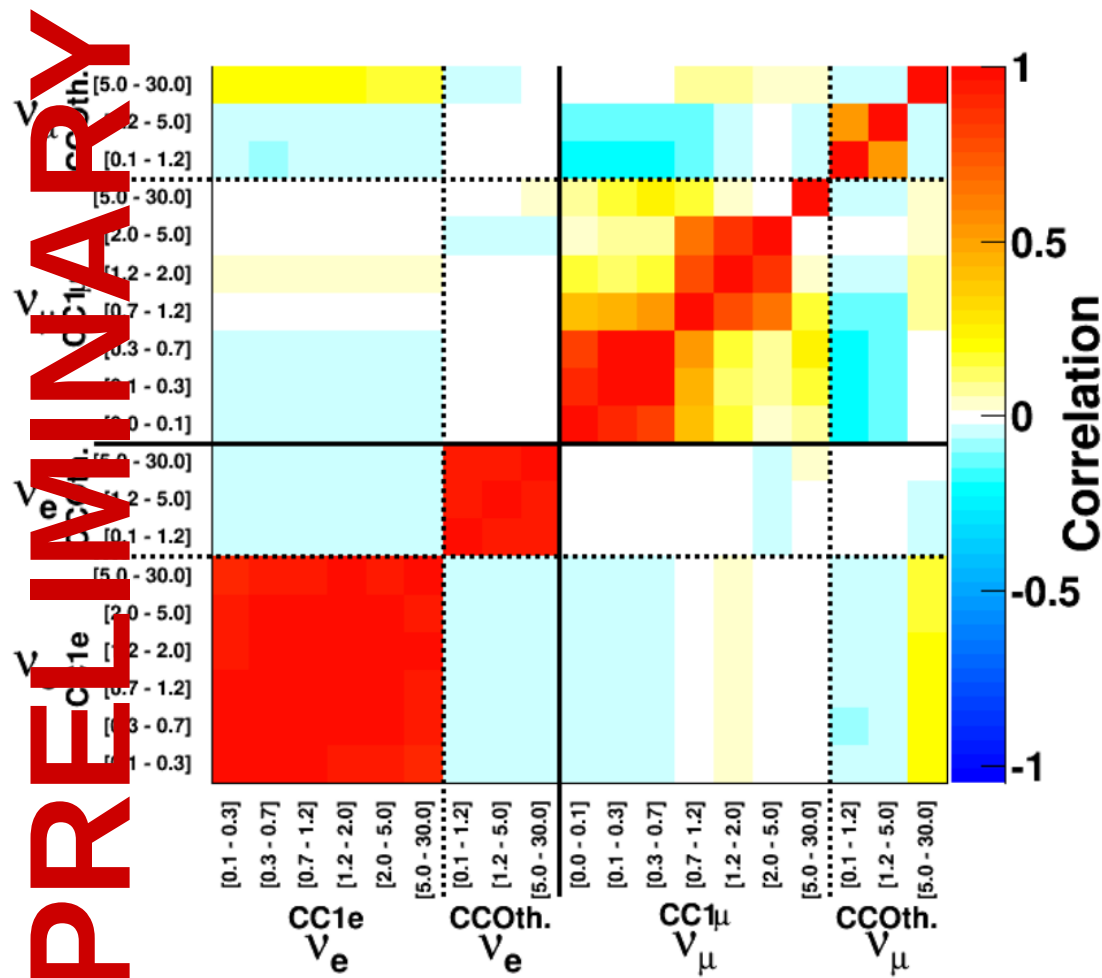


Atm. Fit Results

- Fit using differential evolution MCMC
- Use MCMC chain to extract fractional uncertainty on FS modes with covariance using T2KMC



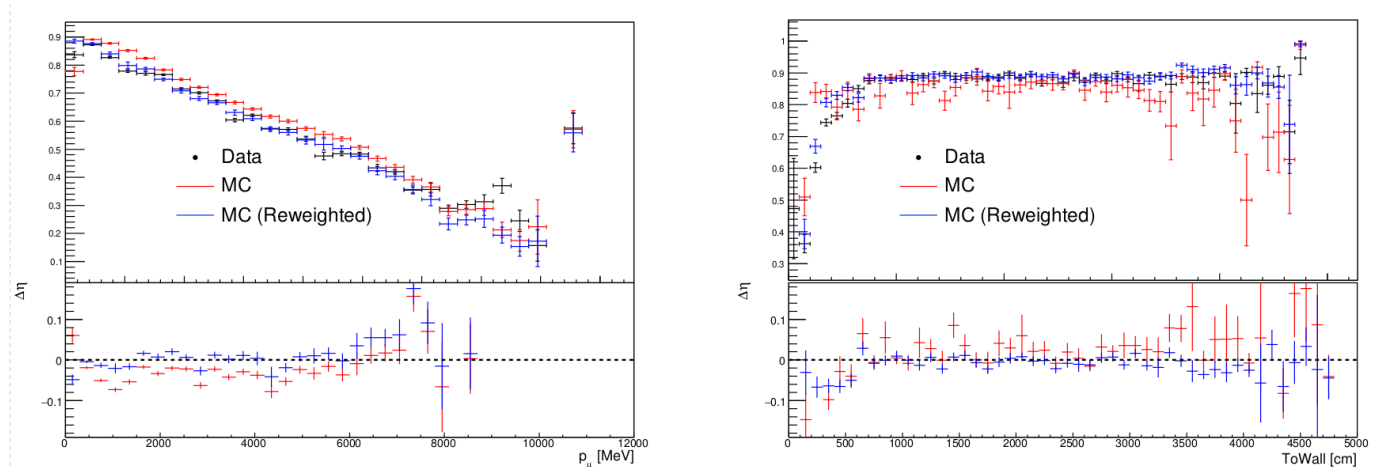
*previous results in grey



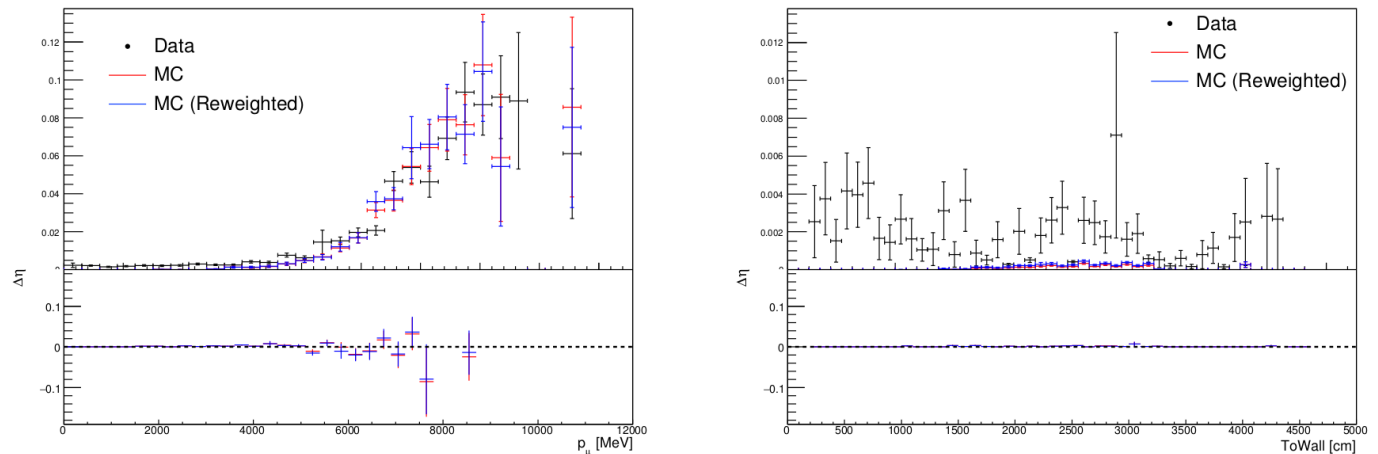
Cosmic-Ray Muons

- Decay electron tagging
 - Reweight MC to match T2KMC distributions in *momentum* and *towall*

Tagging efficiency

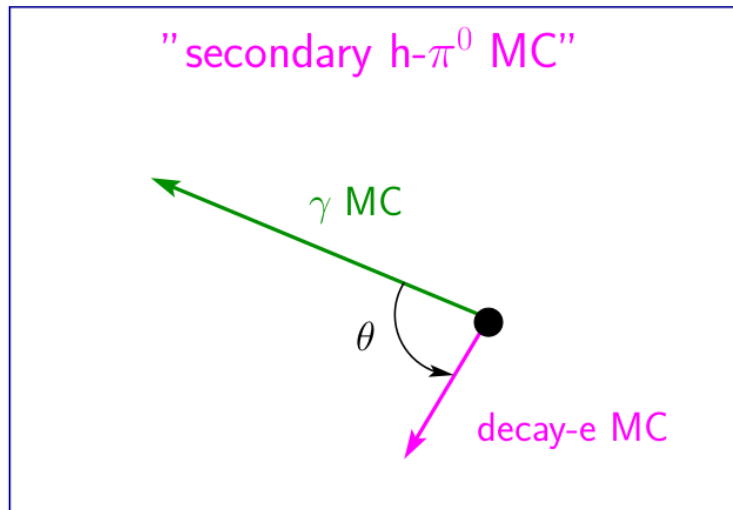
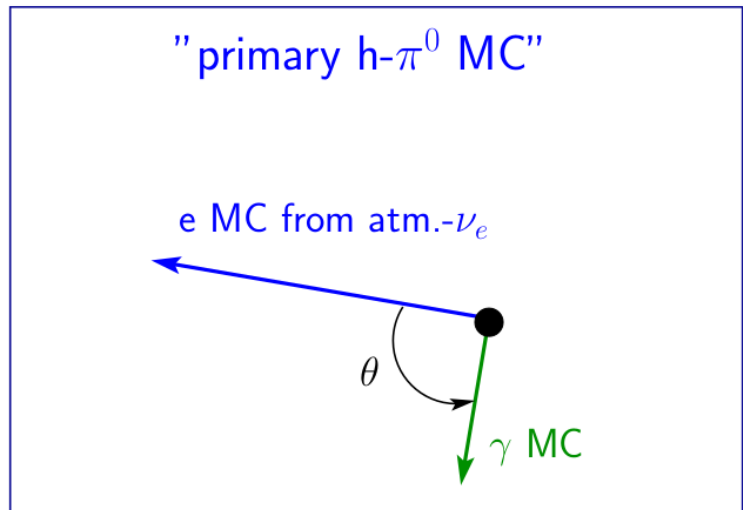
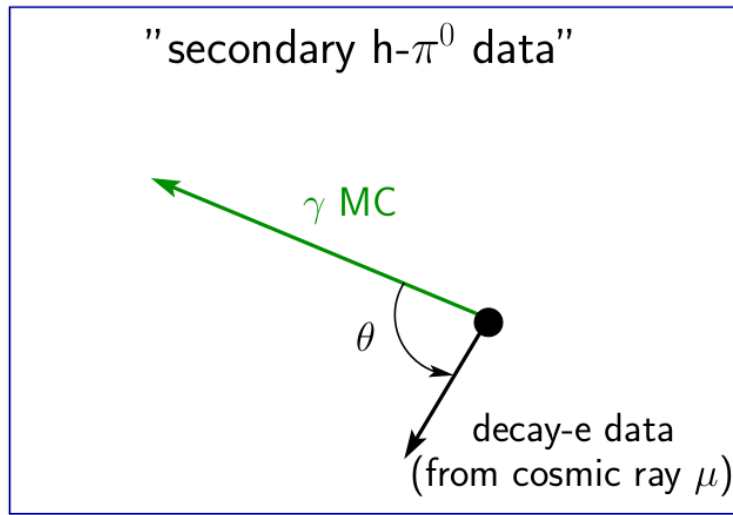
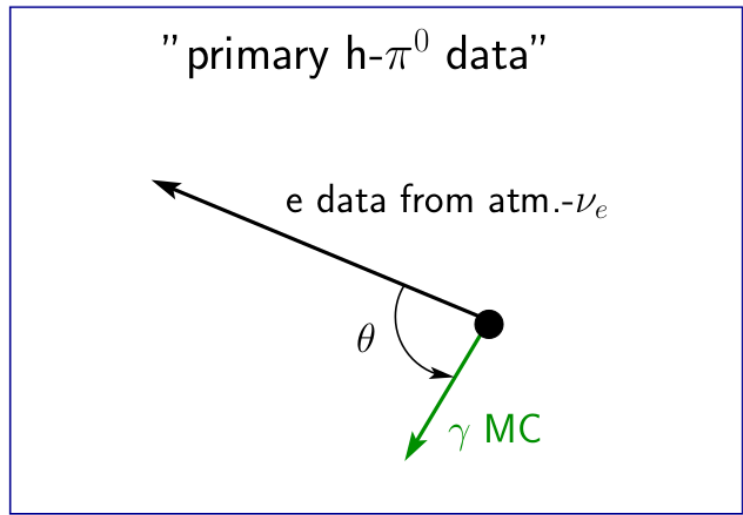


Fake detection



Hybrid- π^0 samples

- Single ring events combined (data+MC, MC+MC) to match kinematics of two-ring π^0 events in the T2K MC



- Repeated for MC-data comparison of higher energy ring and lower energy ring
- Pass all samples through ν_e event selection

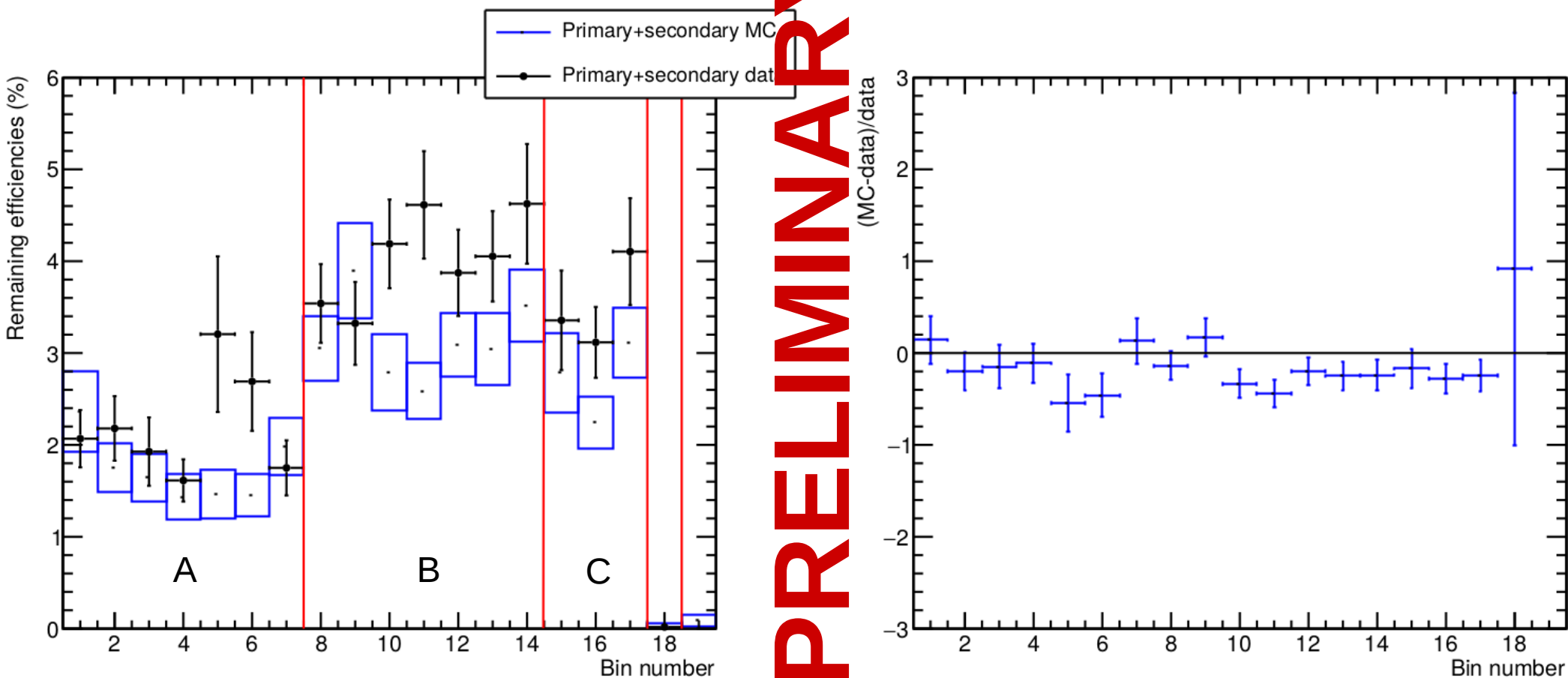
Hybrid- π^0 – NC π^0 sample

- Uncertainty from fractional difference in remaining efficiency between data and MC

A: $p < 300$ MeV

B: $300 \text{ MeV} < p < 700$ MeV

C: $700 \text{ MeV} < p < 1250$ MeV



Changes for 2017

- fiTQun based selection has reduced sample backgrounds with large uncertainties
- Using shape of distributions has reduced “fit” derived uncertainty in atm-nu fit
- CCeOth. error has increased
- Vertex position uncertainty reduced

Total error by sample

***NOT** totally fair comparison,

change will be **smaller** than it appears!

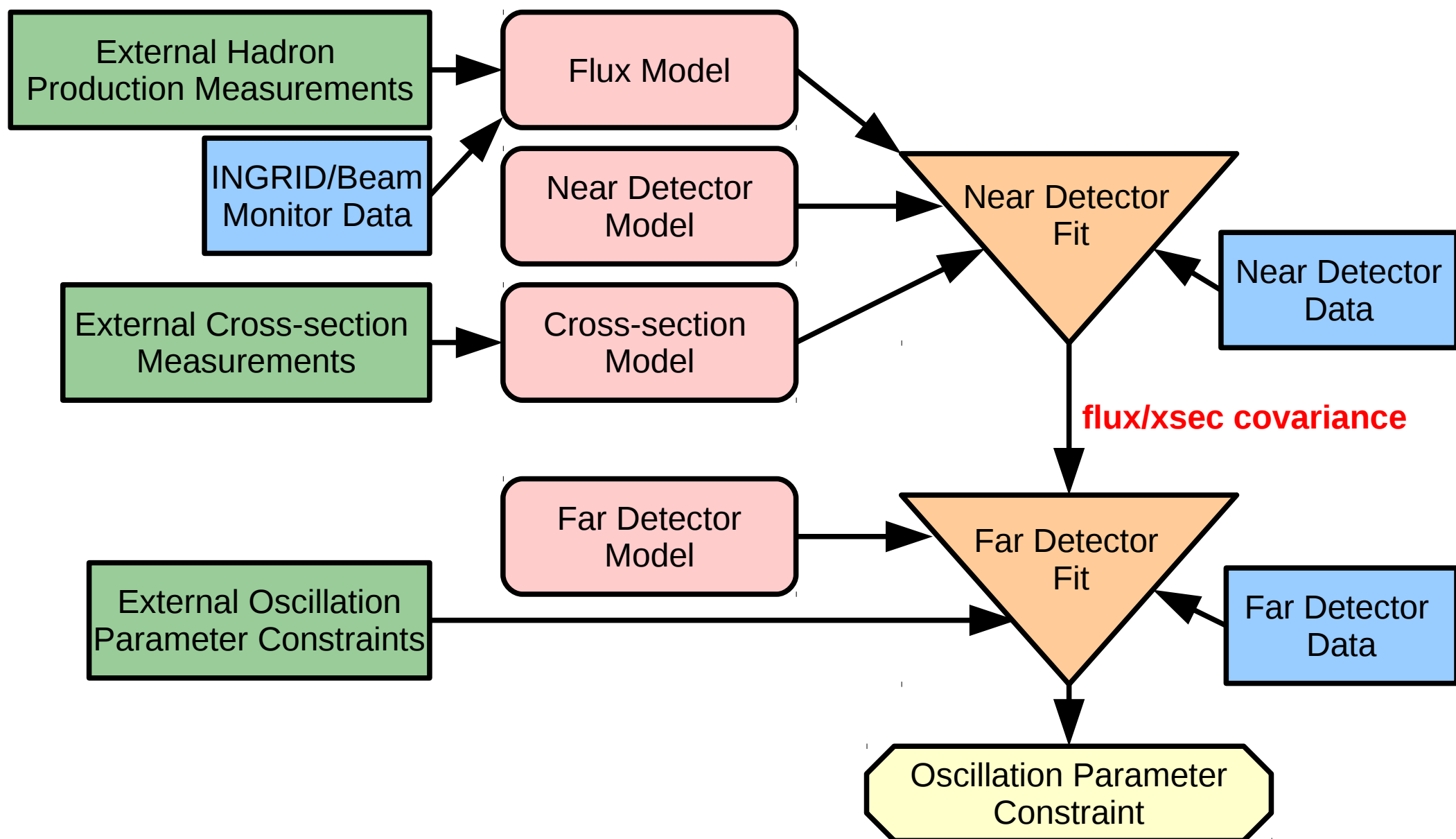
Sample	2016 % error	2017 % error
nue CCQE	4.4*	2.9
numu CCQE	4.2	2.2
nuebar CCQE	4.7*	3.7
numubar CCQE	3.5	1.8
nue CC1pi	18.4*	17.2

PRELIMINARY

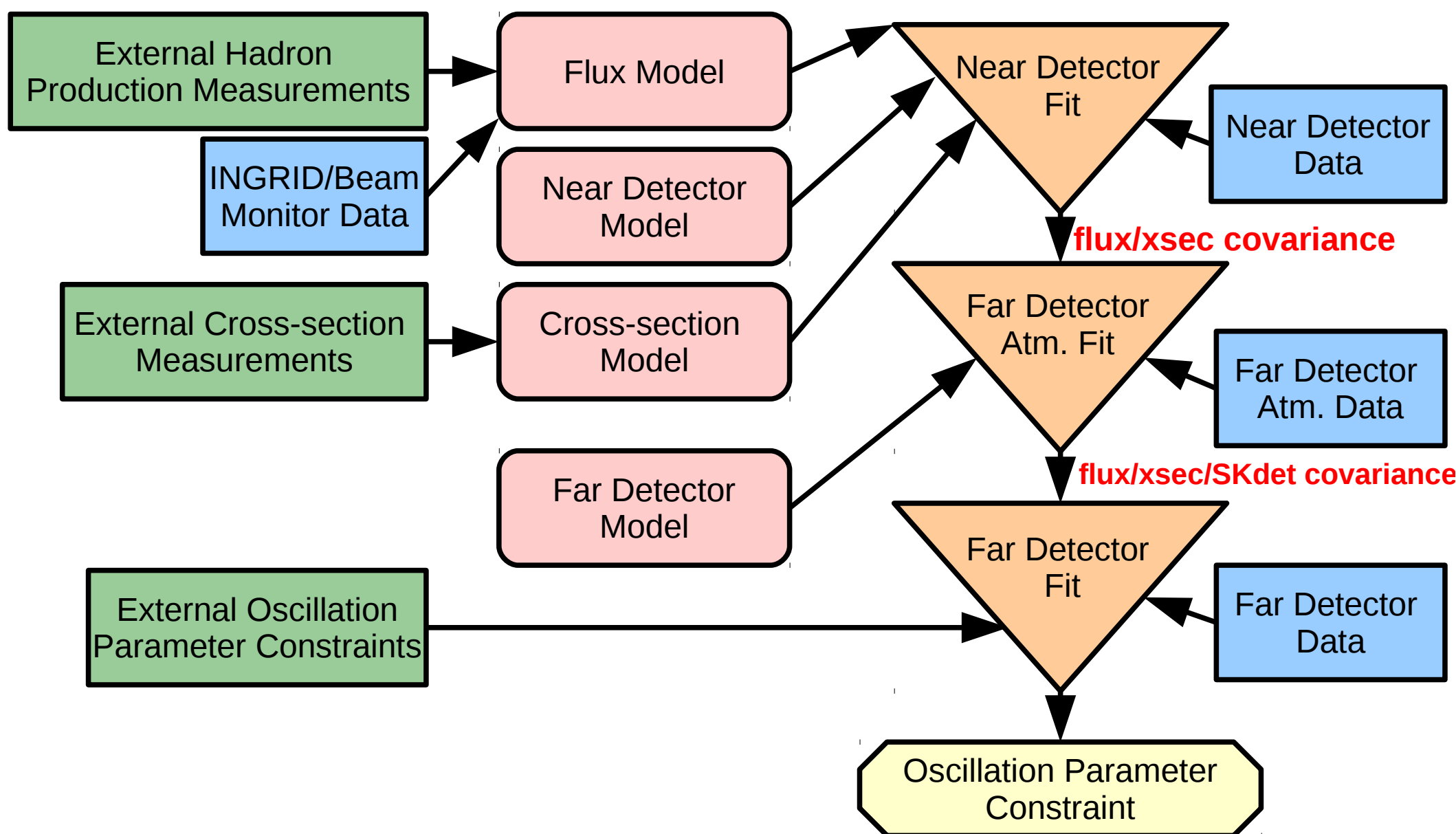
Near Future Improvements

- Consider “limiting uncertainty”
- Additional Atm. samples to help reduce shift/smear parameter degeneracies in the fit (eg. π^0 enhanced sample)
- Unify Cross section
 - Atmospheric fit marginalises over cross-section parameters
 - Apply T2K cross-section uncertainties and propagate covariance
 - Natural path to full SK + T2K oscillation analysis

T2K Oscillation Analysis Overview



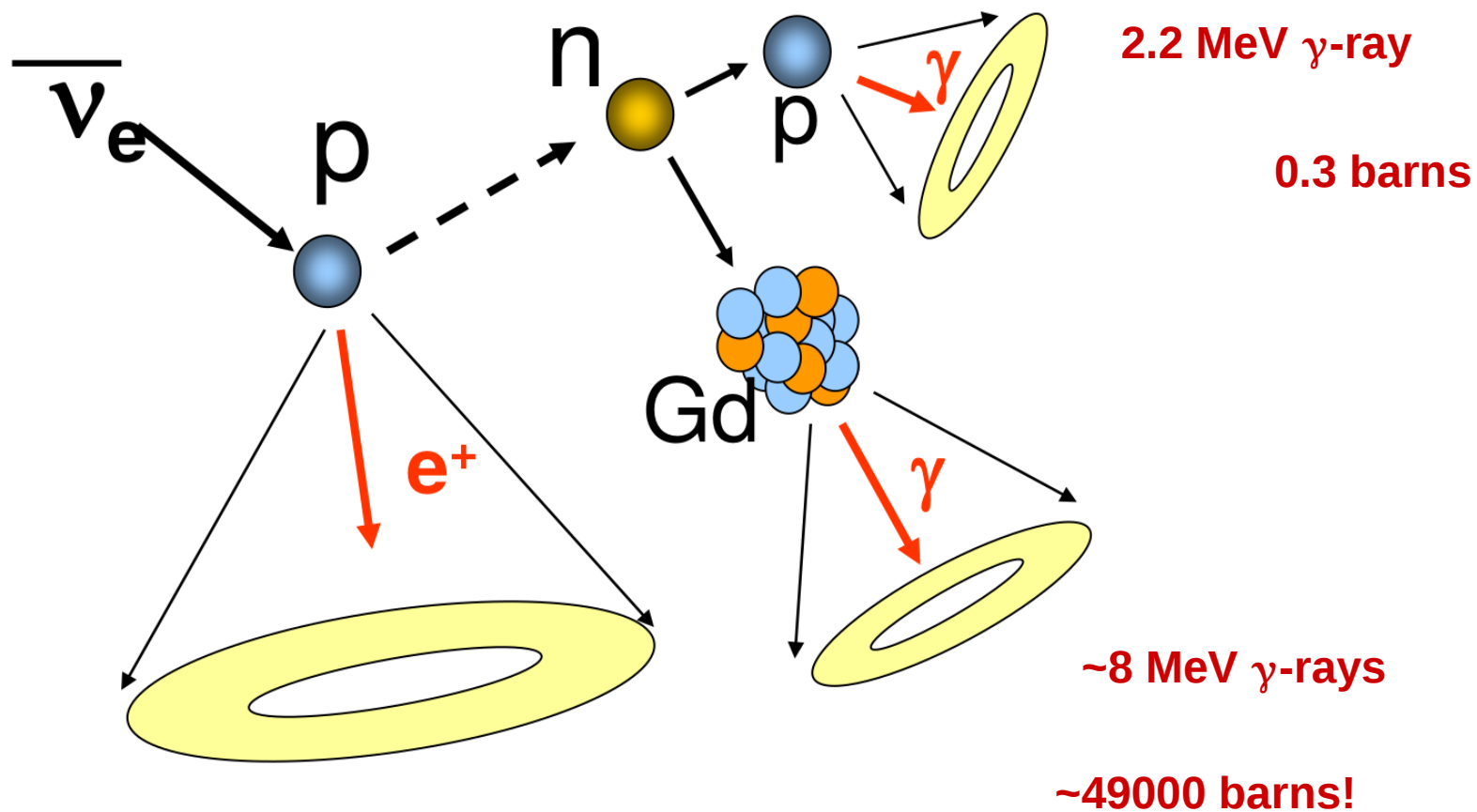
T2K Oscillation Analysis Overview



SK Uncertainties with Gadolinium

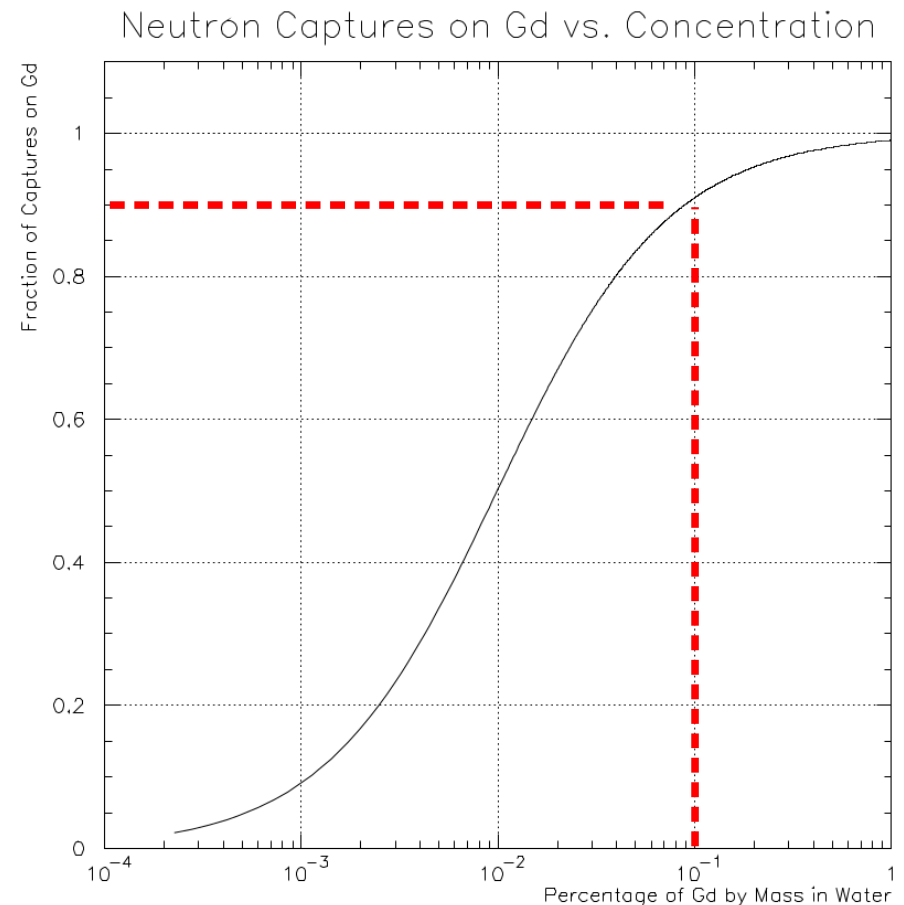
Gadolinium Doping

- Neutron Capture → Delayed Coincidence



Gd in Super-Kamiokande

- 0.1% Gd loading (0.2% $\text{Gd}_2(\text{SO}_4)_3$) gives ~90% efficiency for neutron capture
- For Super-K this means dissolving 200 tonnes of $\text{Gd}_2(\text{SO}_4)_3$
- For T2K
 - $\nu/\bar{\nu}$ separation
 - Energy reconstruction
 - Neutrino interaction 1p1h vs. 2p2h



Uncertainties with SK-Gd

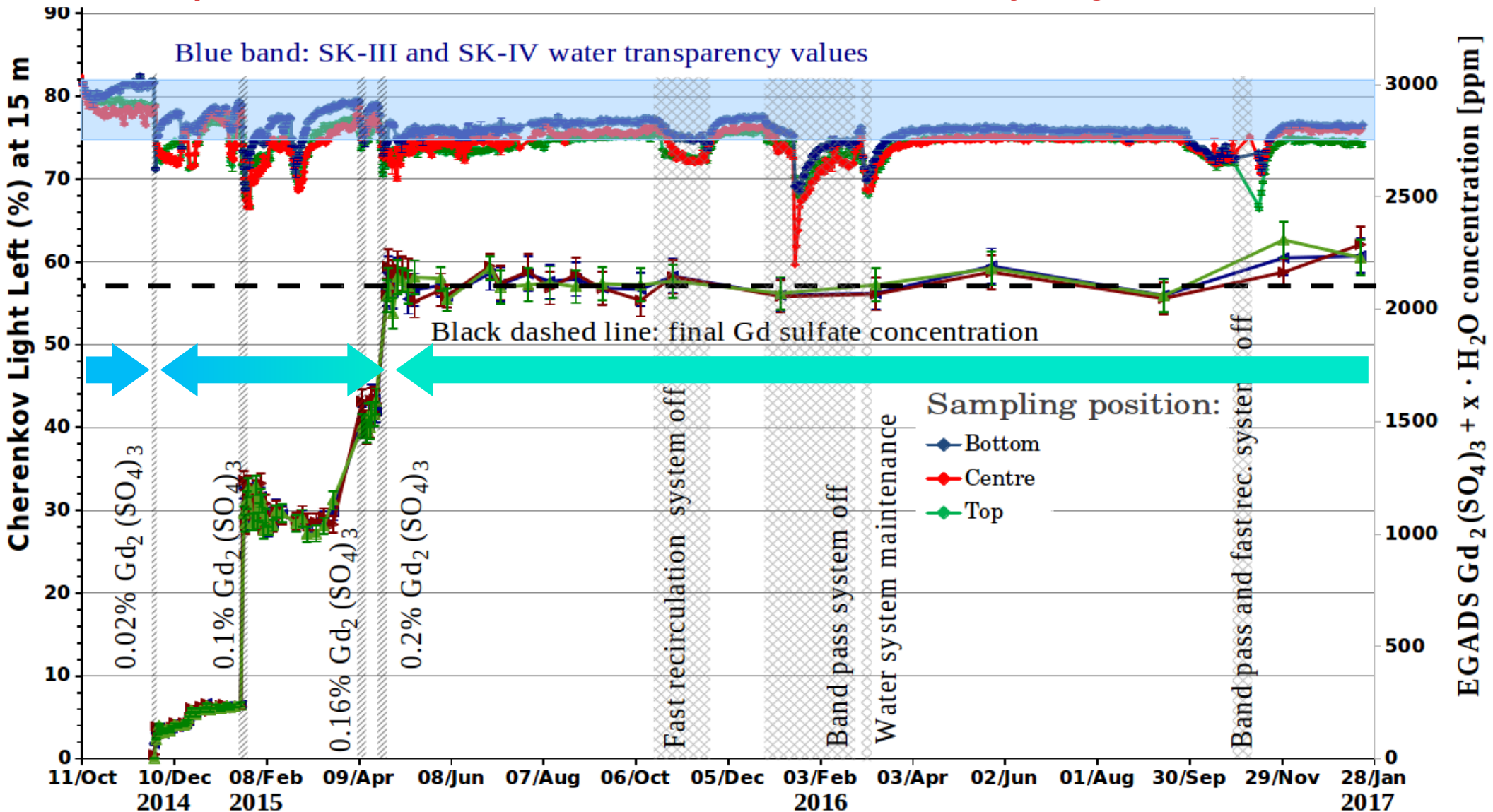
- New event selections
- No large atmospheric/cosmic samples available
- Switch to “bottom-up” approach
- Uncertainties derived from set of fundamental detector tuning parameters in the simulation
 - Scattering, absorption, material properties
- T2K MC with Gd is in development
 - **Now**: n-tagging and pure water quality shortly
 - **Next**: Studies with n-tagging and modified water quality
 - requires retuning of APFit and fiTQun

EGADS

- Evaluating Gadolinium's Action on Detector Systems
- 200tn Water Cherenkov detector – SK in miniature
- Designed to test all aspects of Gd loading, long term and under experimental conditions
 - Water transparency
 - Detector material resistance
 - Selective filtration system

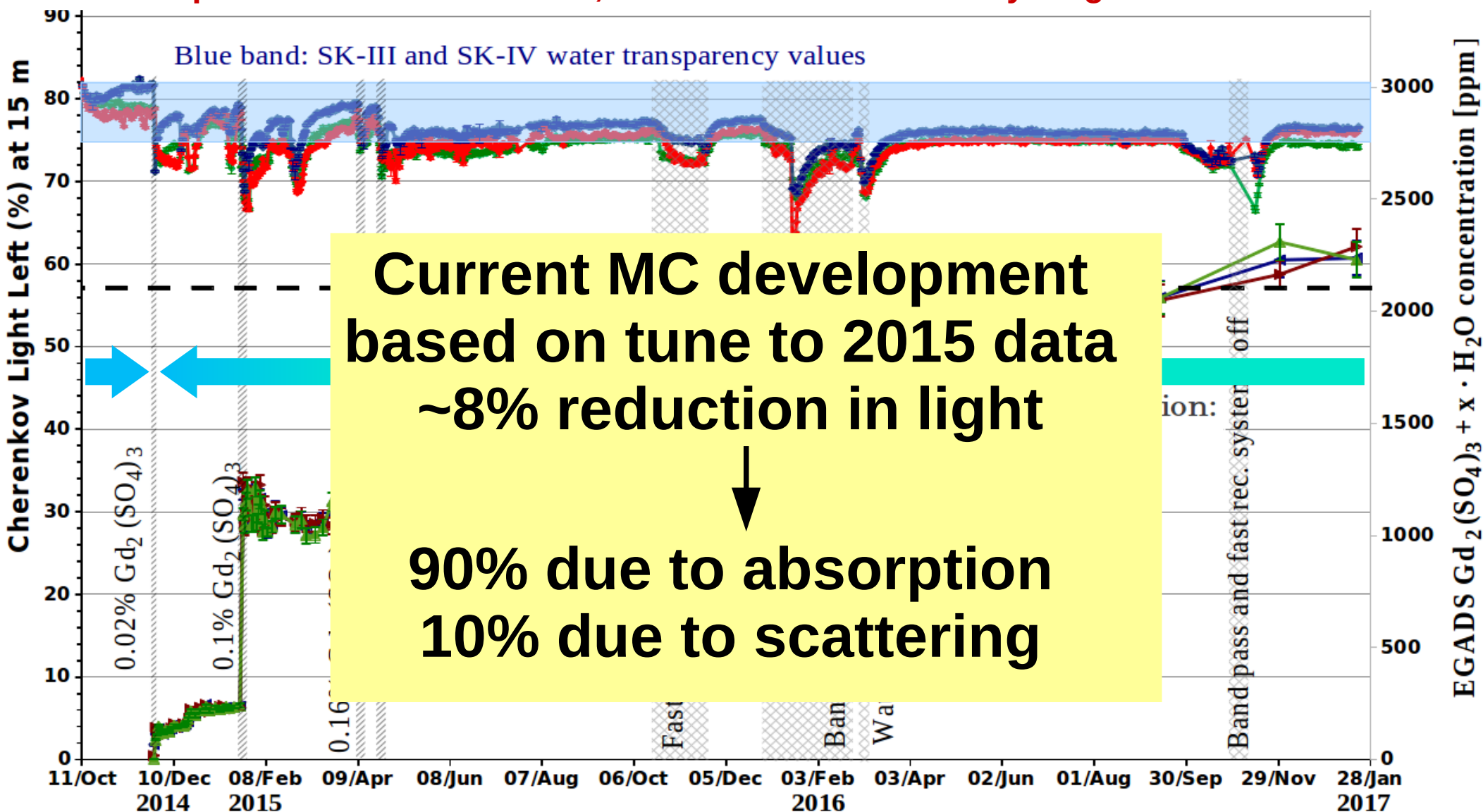
EGADS Water Quality

Stable Operation – No Loss of Gd, >99.99% remains after cycling the tank >350 times



EGADS Water Quality

Stable Operation – No Loss of Gd, >99.99% remains after cycling the tank >350 times



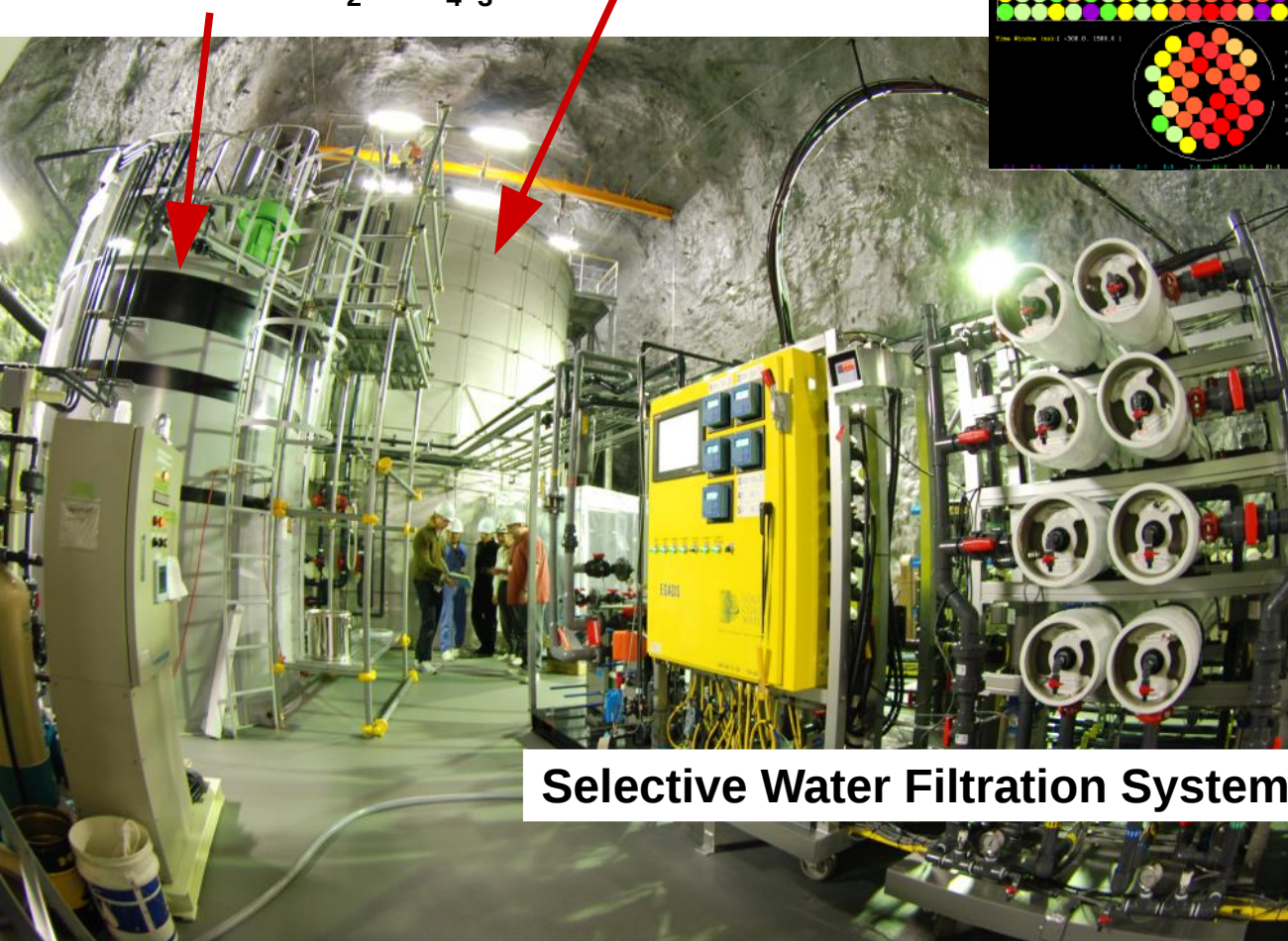
Summary

- A lot of work went into producing errors for the new event selection
- Further improvements possible
- A number of developments are in the pipeline
 - Near term: How we use the existing uncertainties
 - Longer term: Development of new methods

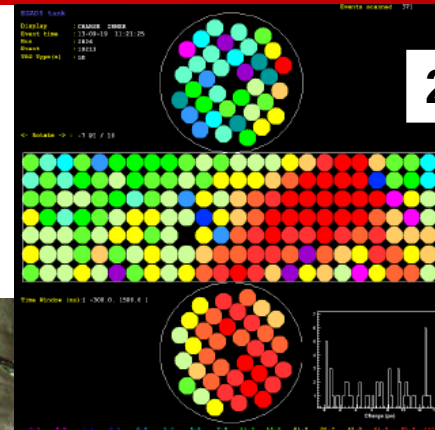
Supplementary

EGADS

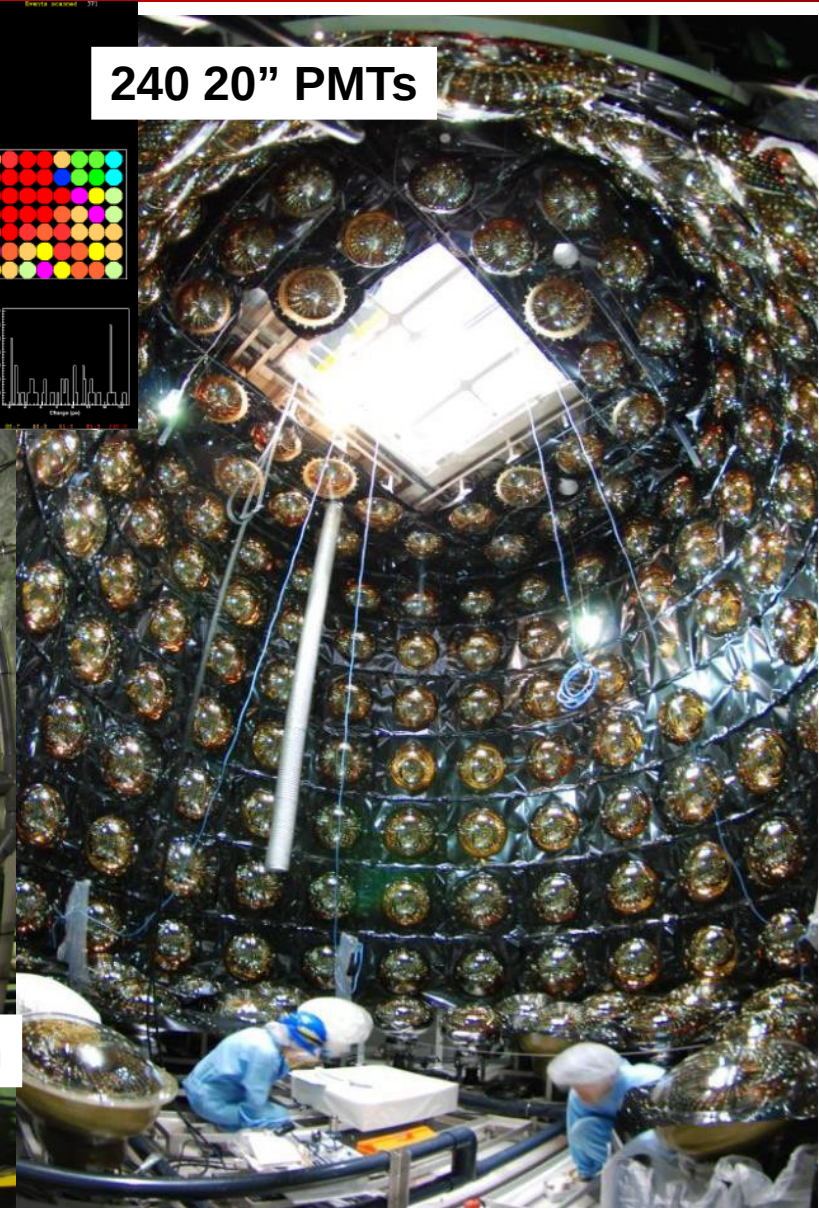
15m³ tank for
dissolving $\text{Gd}_2(\text{SO}_4)_3$ 200m³ tank



Selective Water Filtration System

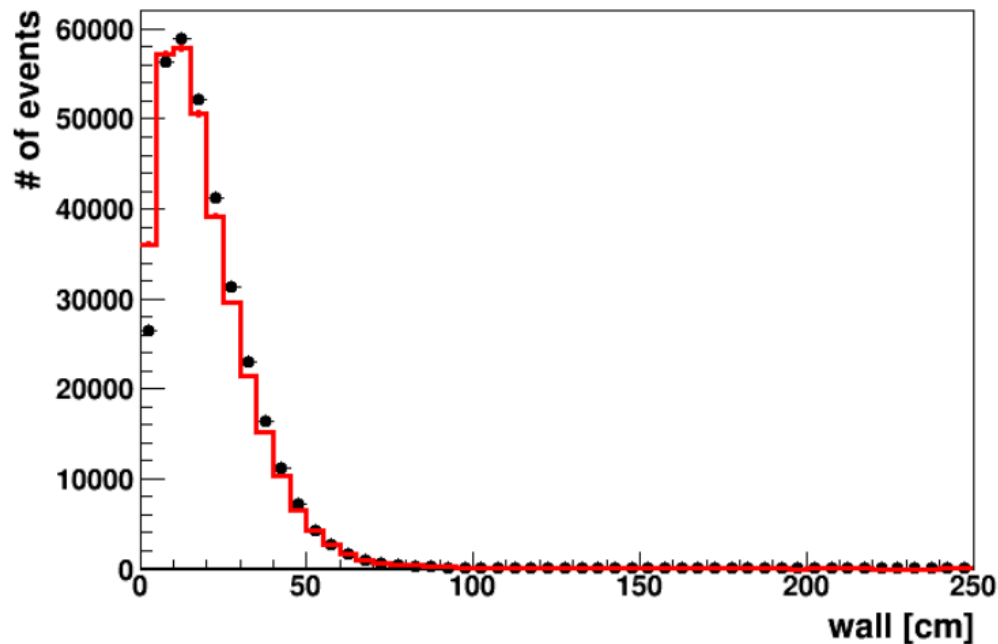


240 20" PMTs



Cosmic-Ray Muons

- Vertex resolution
 - Compare *wall* distribution of data and MC



2.5 cm difference in resolution

Apply +2.5 and -2.5 cm shift to MC

$\Delta N \sim 0.5\%$