Fermilab SCD Post-Doc Talk

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March 3, 2020

A quick reminder about myself…

MicroBooNE

- dQ/dx Calibration and Lifetime
- Detector Systematics
- Systematics and constraint for the eLEE analysis
- Sensitivity

ICARUS

- Production
- FTS and Metadata

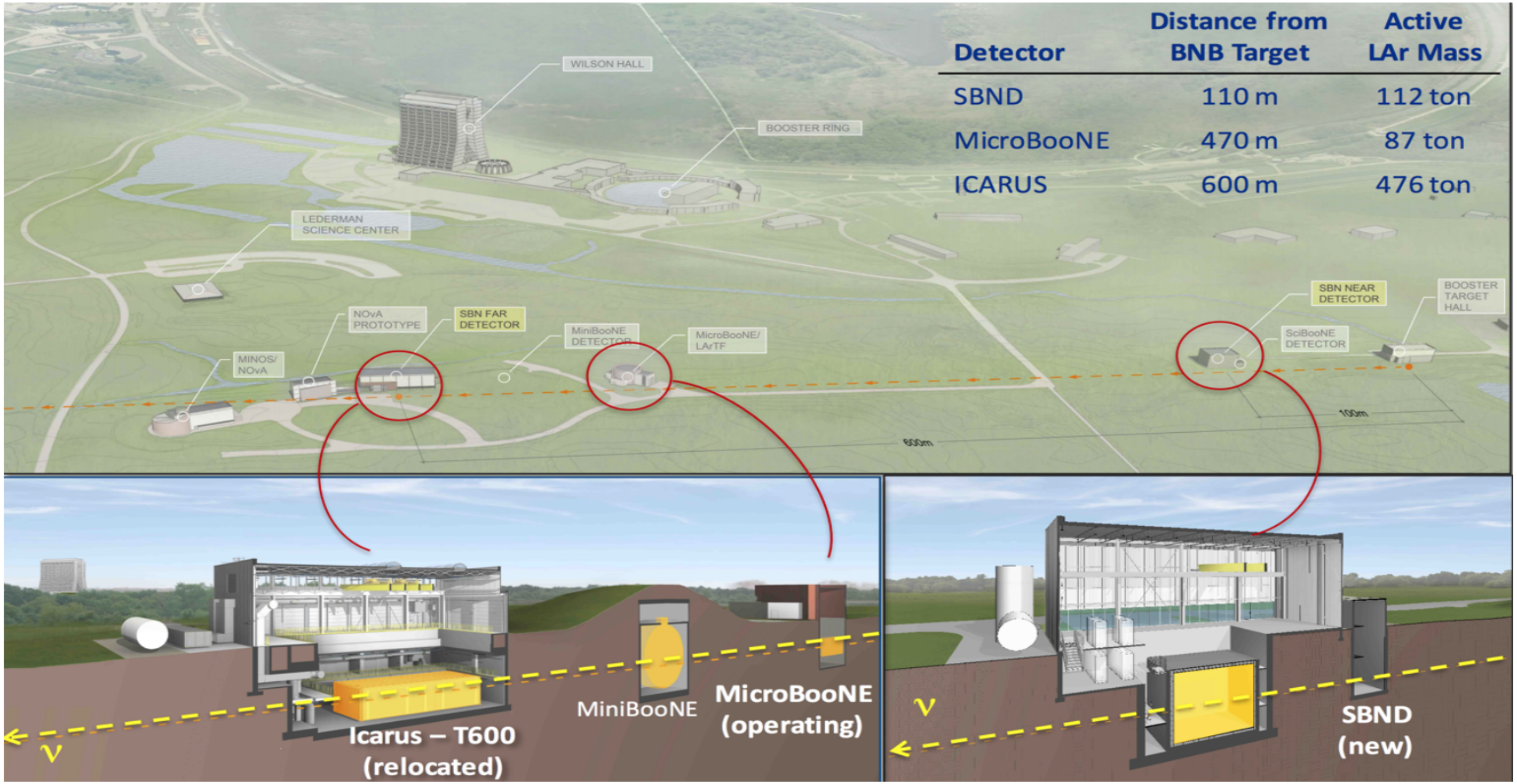
SBN

- MC Production Co-convenor
- Sensitivity (SBNfit)

SciDAC-4

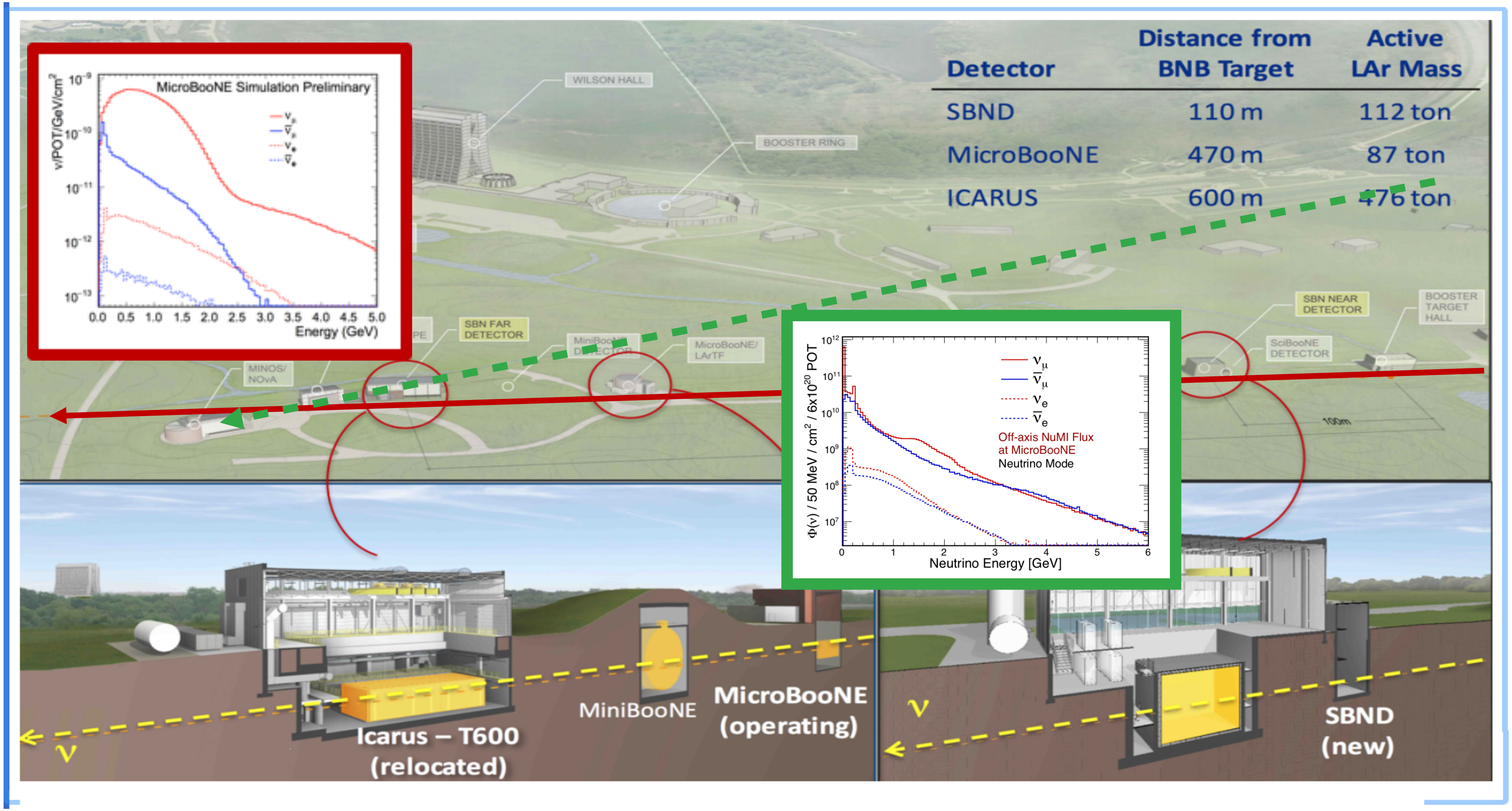
- Accelerating the Feldman Cousins Correction within SBNfit framework on HPC

SBN Program



Detector	Distance from BNB Target	Active LAr Mass
SBND	110 m	112 ton
MicroBooNE	470 m	87 ton
ICARUS	600 m	476 ton

SBN Program



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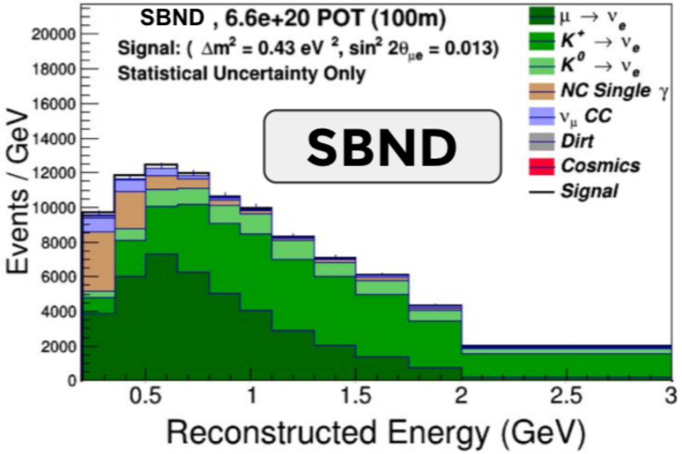
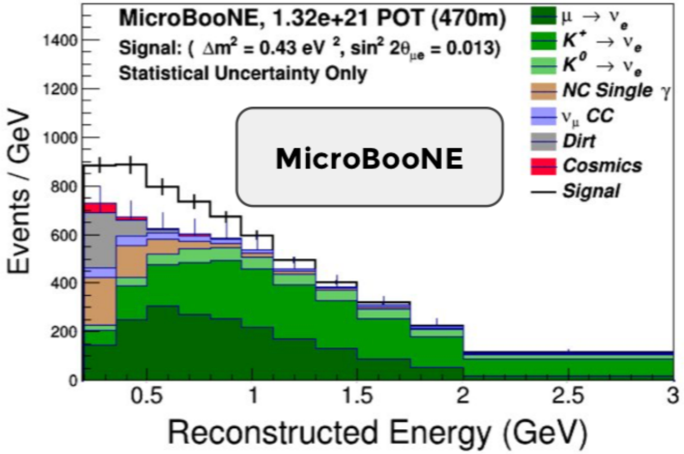
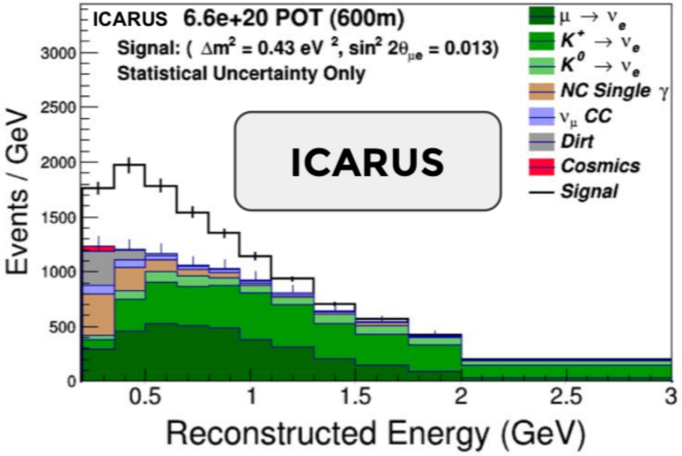
1. Explore Sterile ν Oscillations

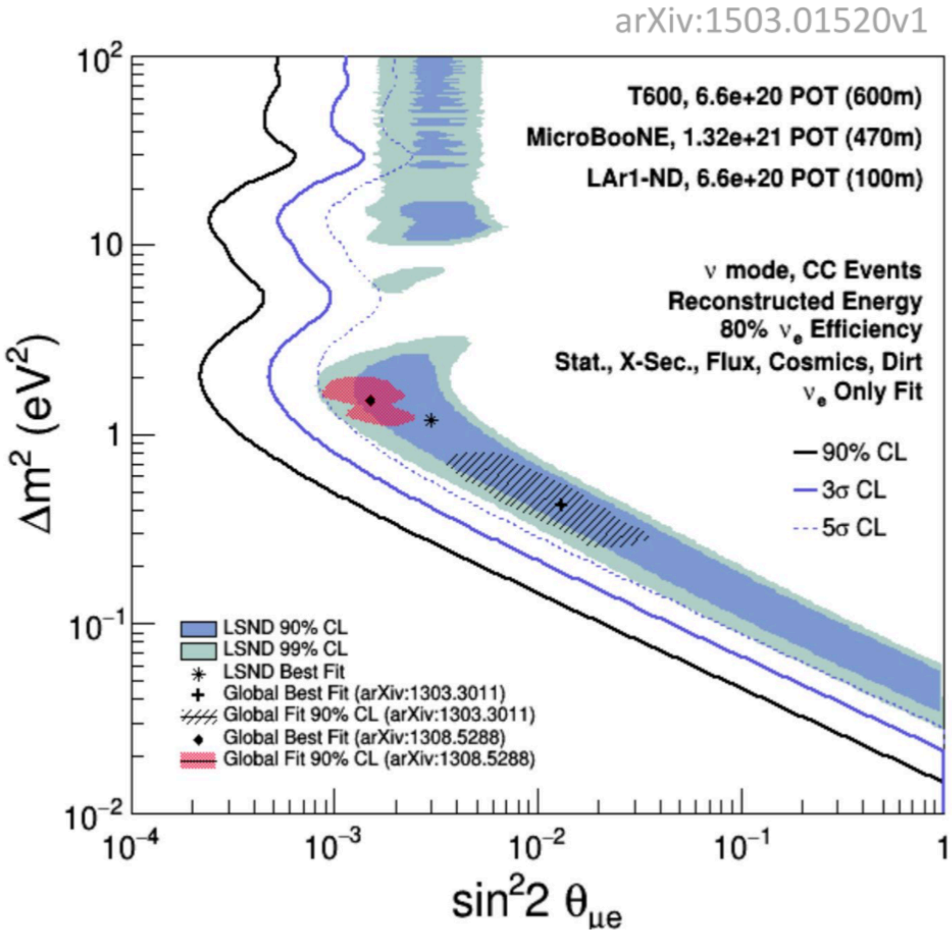




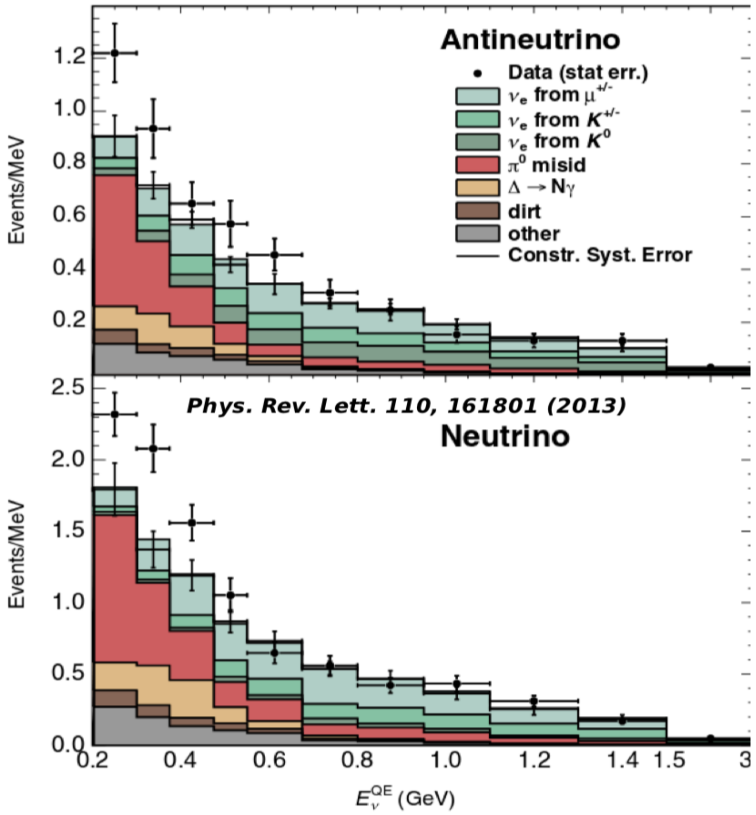


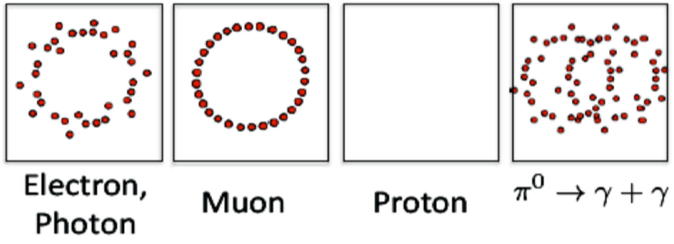
- Detailed **sensitivity analysis** includes cosmics backgrounds, correlated flux & cross section systematics, and beam backgrounds.

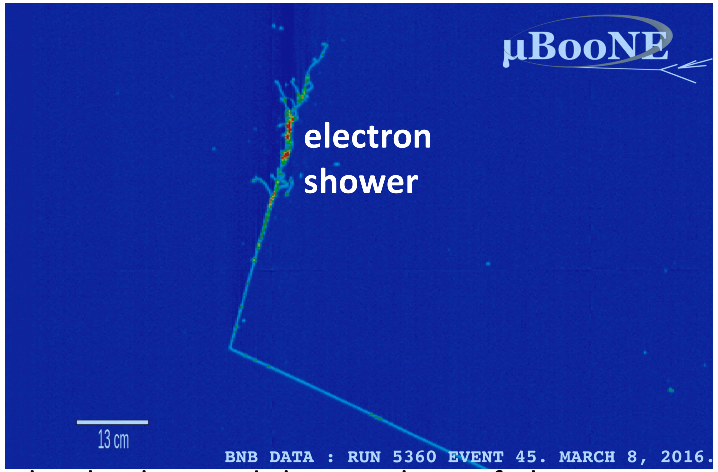
- The SBN program will exclude the LSND 99% CL region at 5σ in 3 years of taking data in the BNB

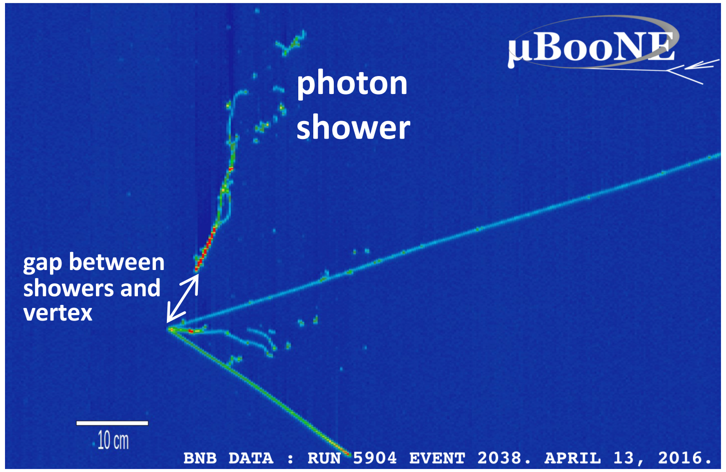


2. MiniBooNE Follow-up

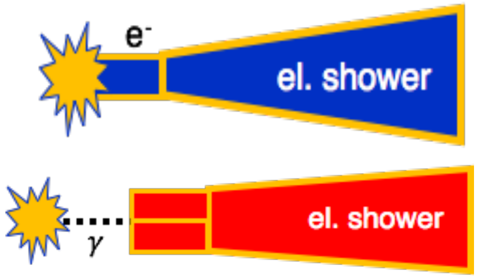




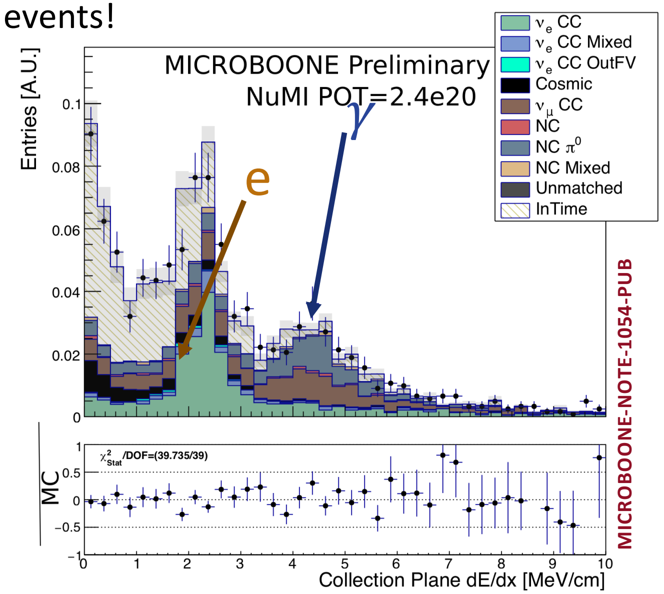




Clearly observed the topology of electromagnetic events!

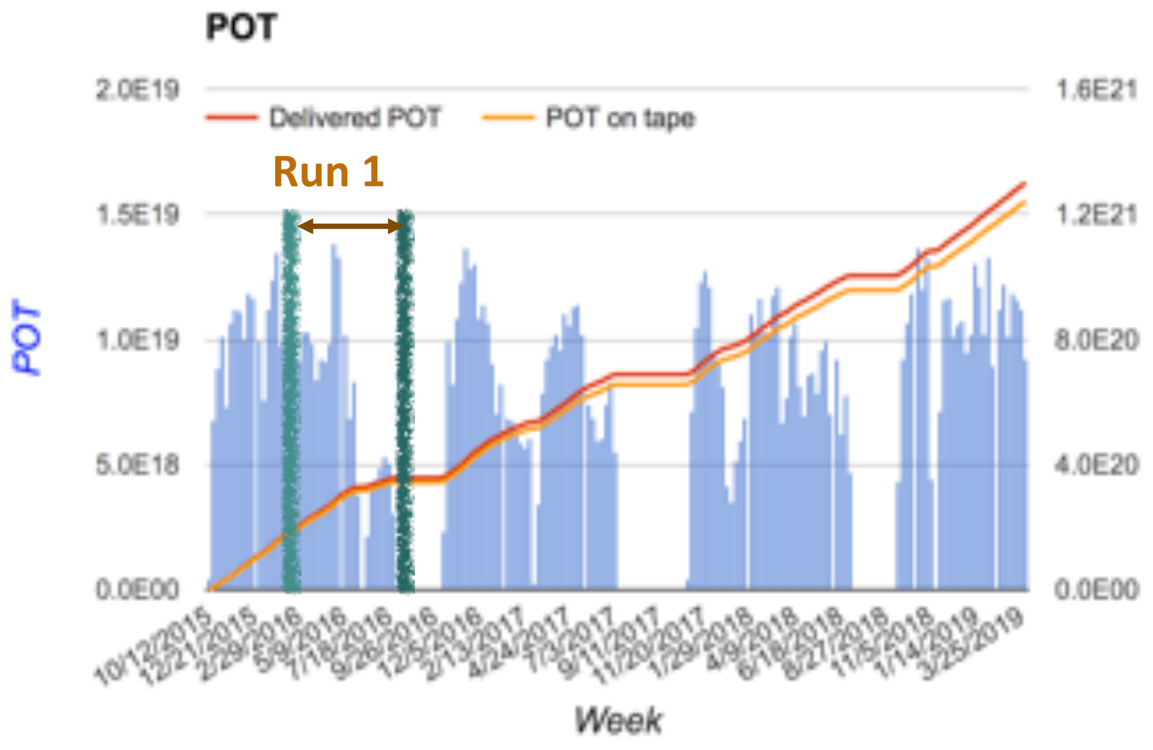


Calorimetric capabilities can distinguish e from γ at the start of shower using dE/dx information

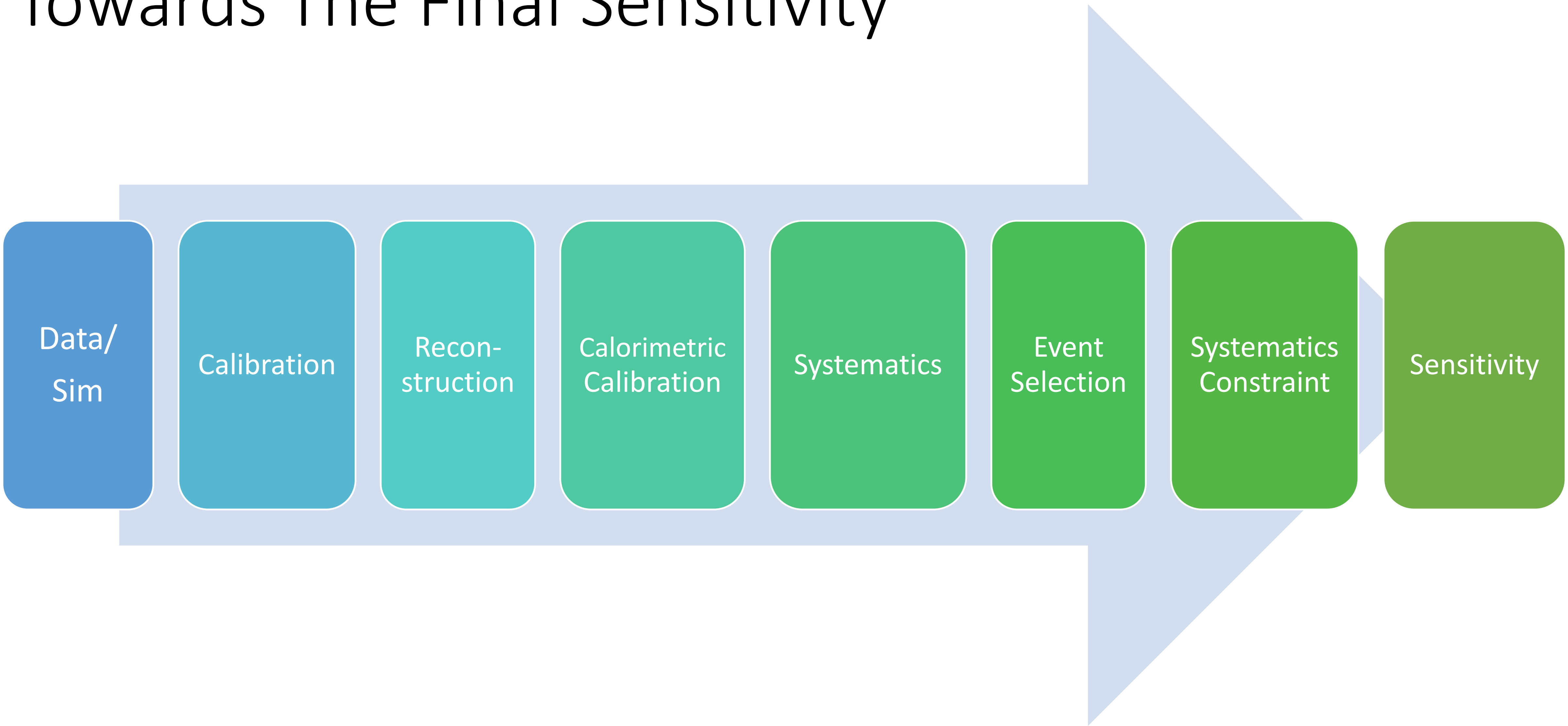


Data Collected by MicroBooNE

- Surface-based, 85 ton active volume liquid argon
- Collecting cosmic and neutrino data since Fall 2015 with good uptime and purity
- Target is to make data collected until July 2019 available to be analyzed



Towards The Final Sensitivity



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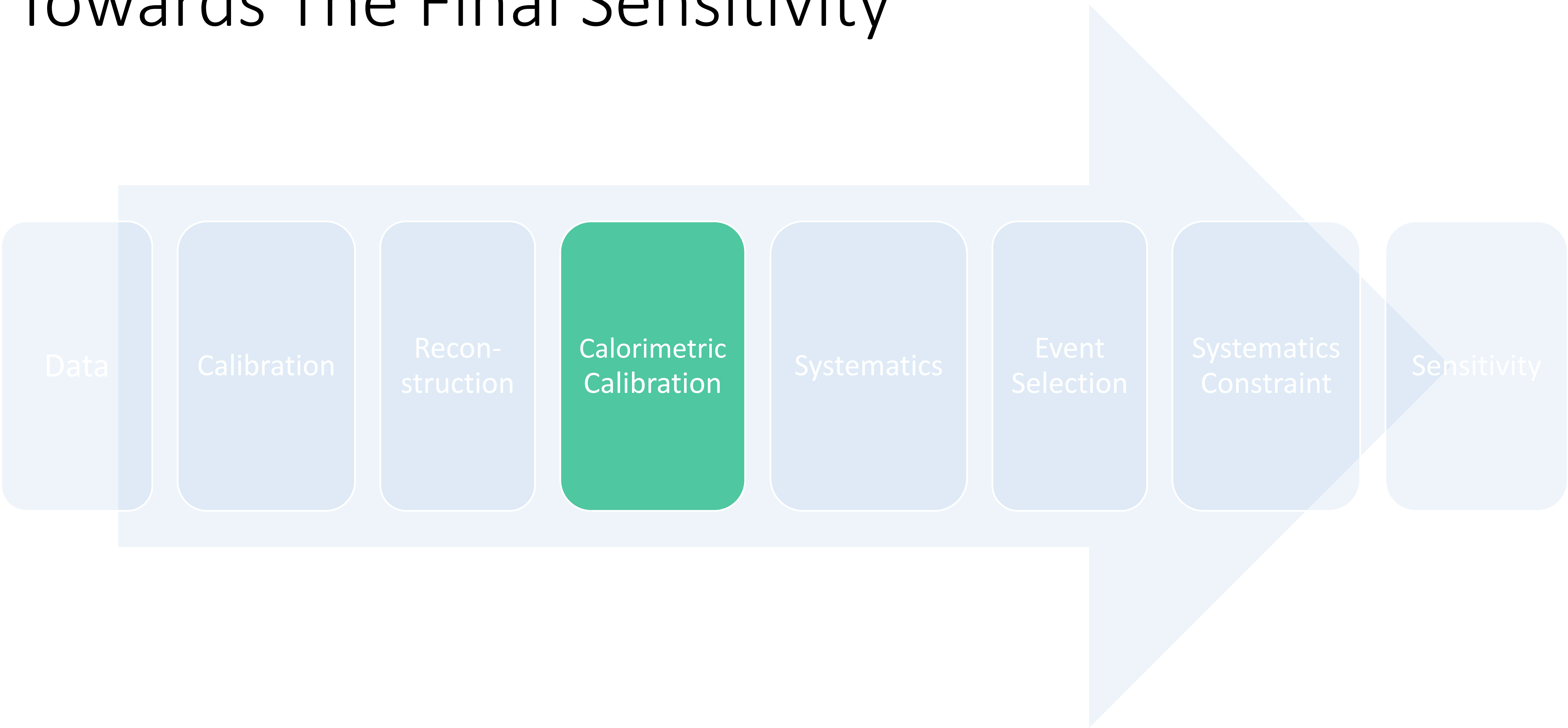
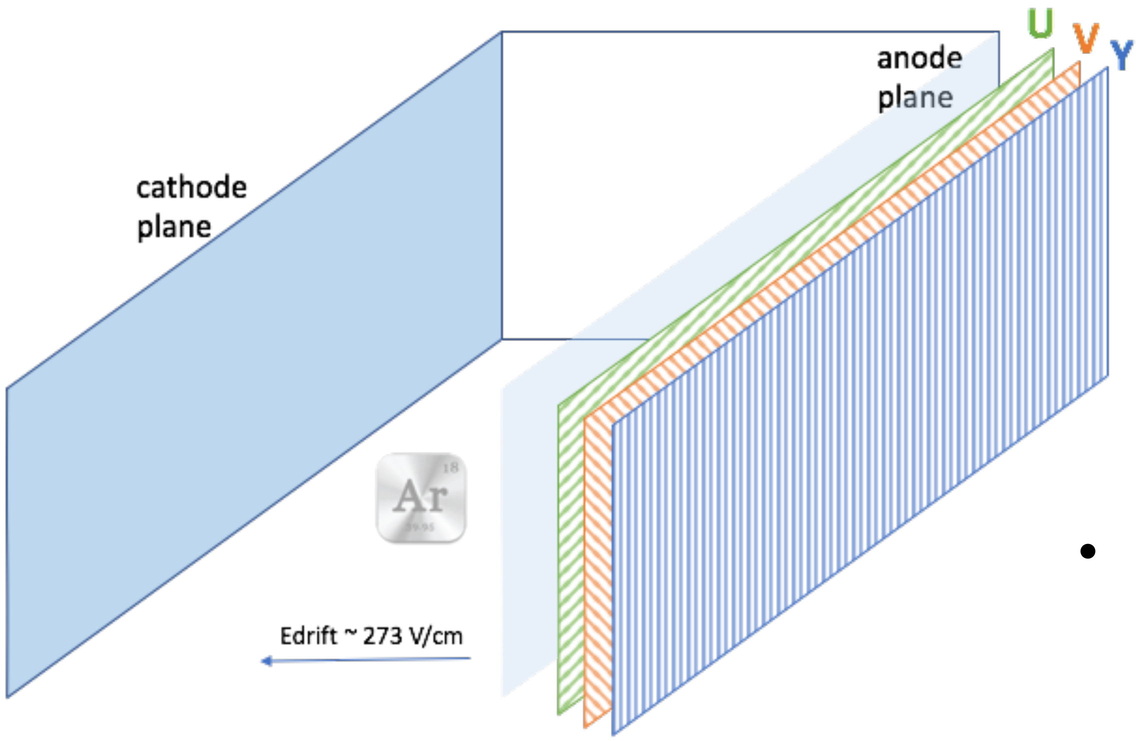


LArTPC

(Liquid Argon Time Projection Chamber)



- Start with a large volume of liquid argon and a cathode and and anode

LArTPC

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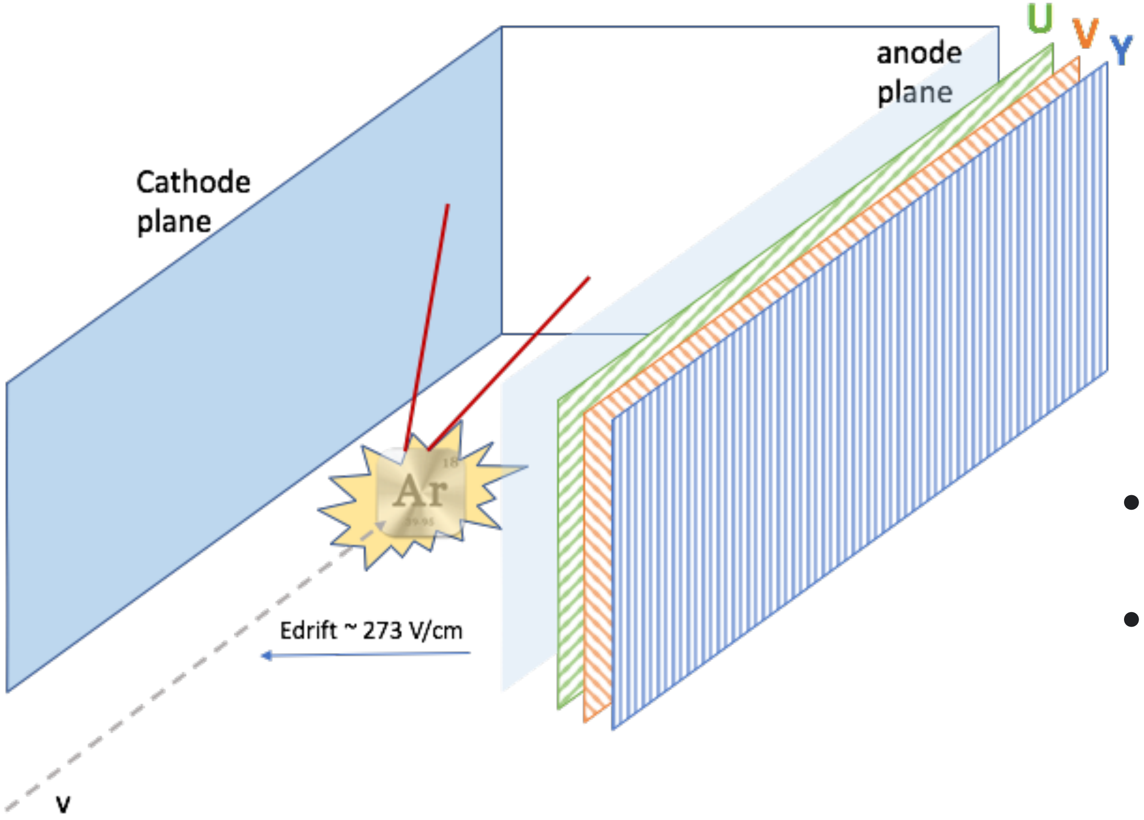
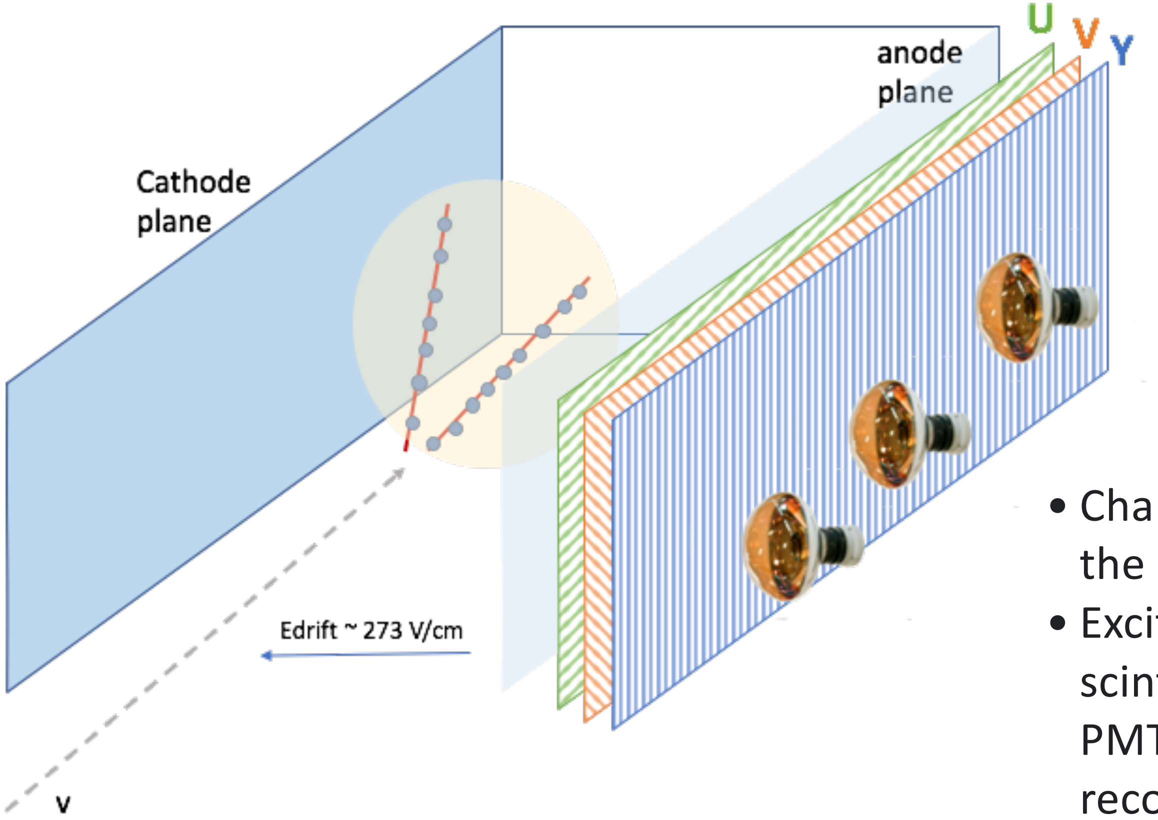


- Neutrino enters the large volume of liquid argon.
- Neutrino interacts with argon and produces charged particles

LArTPC

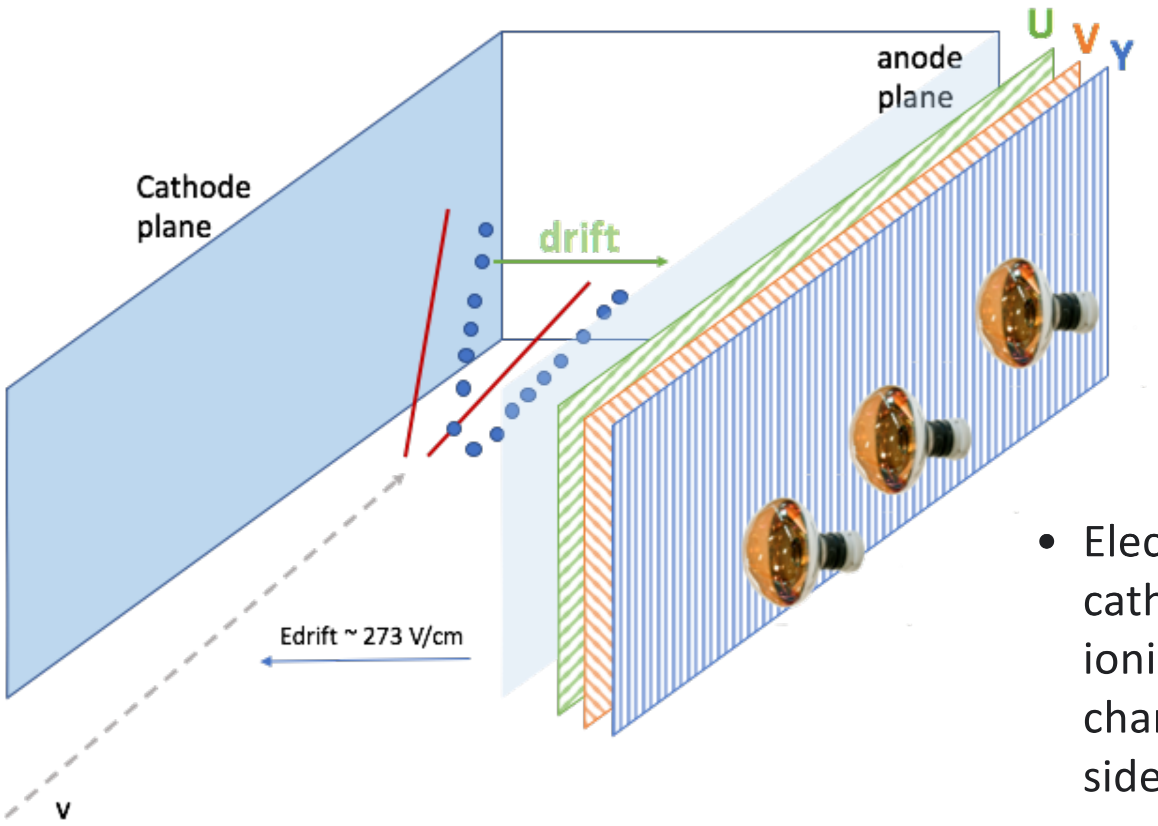
(Liquid Argon Time Projection Chamber)



- Charged particle can ionize/excite the argons.
- Excited argons produce scintillation light and arrays of PMTs behind the wire planes recorded the lights.

LArTPC

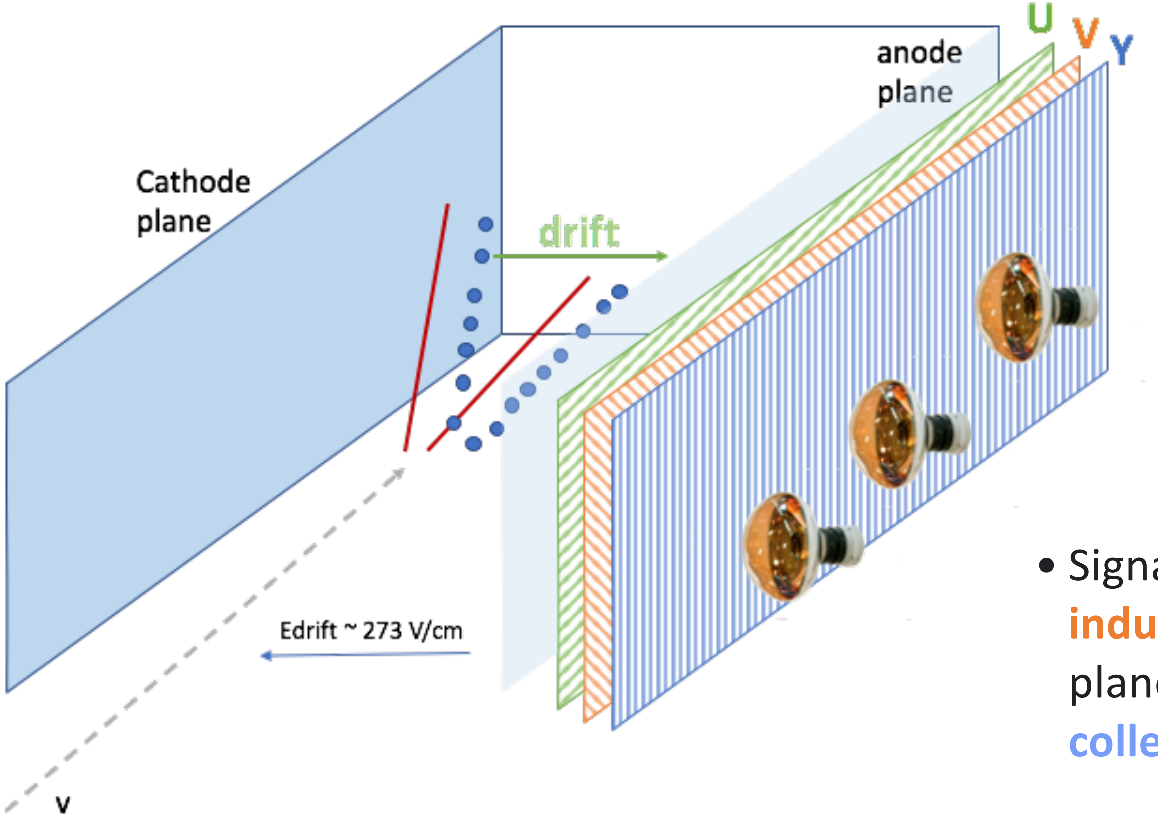
(Liquid Argon Time Projection Chamber)

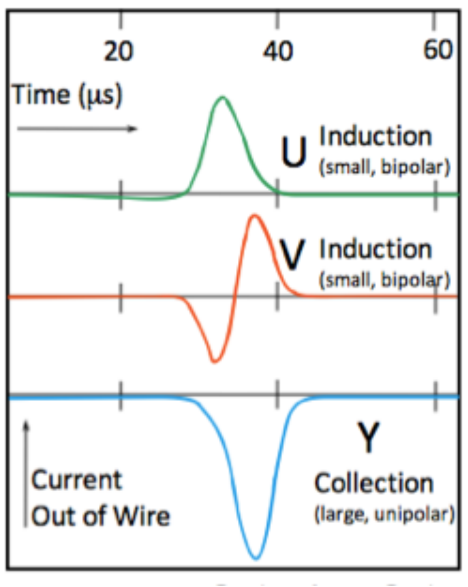


- Electric field set up between the cathode and the anode drift the ionized electron to the wire chamber planes on the anode side of the detector.

LArTPC

(Liquid Argon Time Projection Chamber)





- Signals from the event are **induced** by the first two wire planes and electrons are **collected** by the last plane

When electron drift through the argon…

Space Charge Effect

Cause distortion the magnitude and direction of drift electric field

Recombination

Cause underestimation of particle energy loss

Temporal Variation

Change in detector response over time. Most significant time-dependent change : changes in Argon purity.

Diffusion

Bias in reconstructed charge due to wider signal reconstructed att the longest drift distance.

Electron Attenuation

Electronegative contaminants capture some drifting electrons and reduce the final measured dQ/dx

LArTPC Detector Effects

dQ/dx Variation

Various convoluted detector effects vary the dQ/dx in **YZ plane** and in the **drift direction X** inside the TPC. Detector instability and argon purity causes **time variation**

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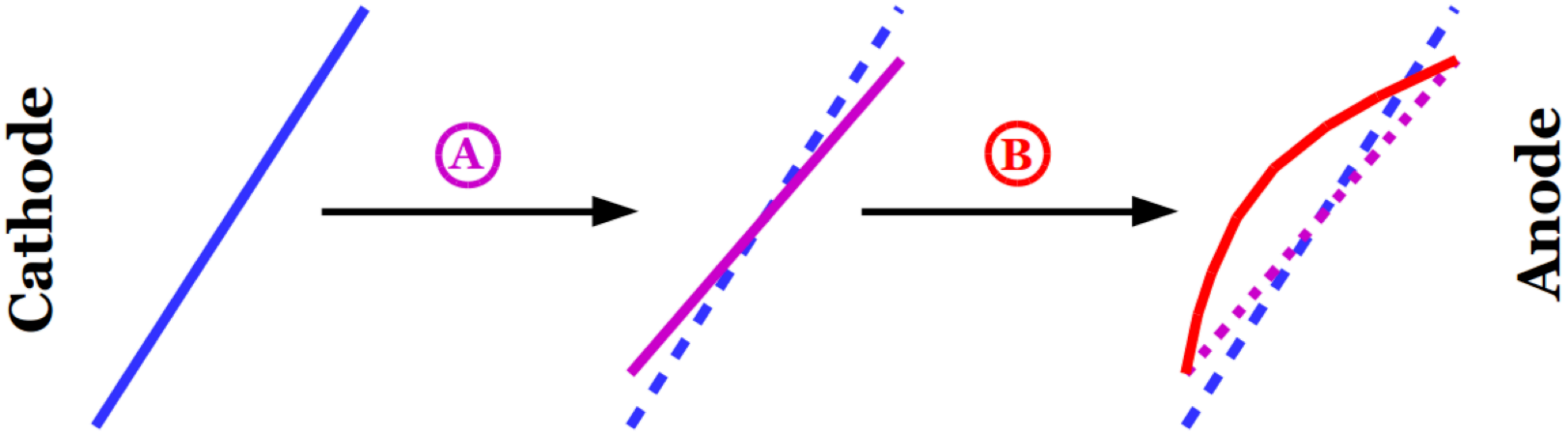
A bit more about space charge…

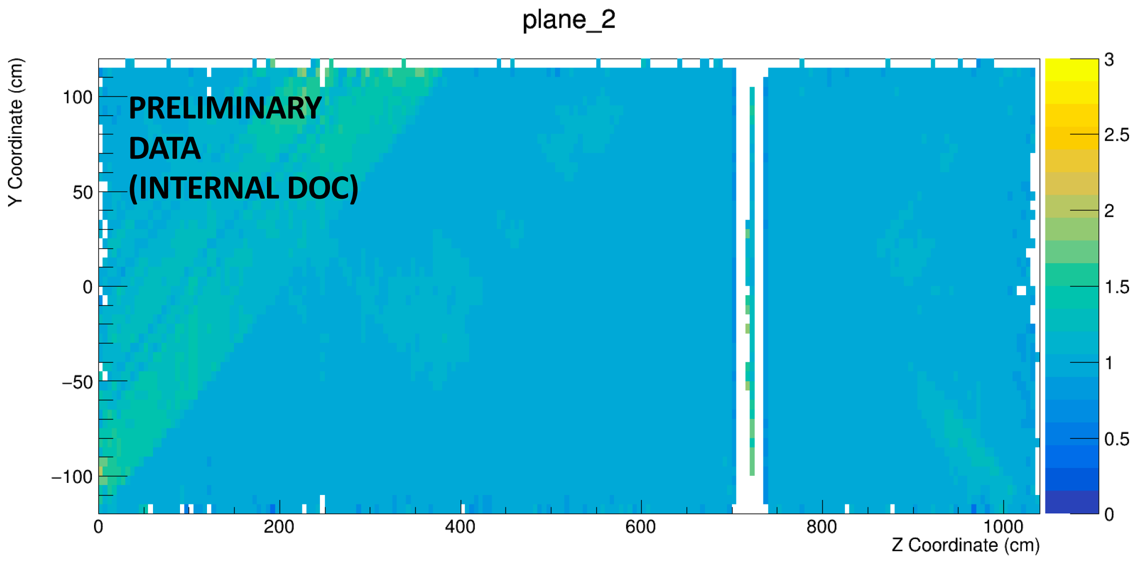


Two distinct features:

- A **squeezing** of the sides of the tracks in the transverse TPC directions that somewhat resemble a rotation (“A”)
- A **bowing** of the track toward the cathode that is most pronounced in the middle of the TPC (“B”).
- We simulate this effects and correct it out at the calibration stage.

dQdx Calibration

Corrects for the misconfigured TPC channels, ~~space charge effect~~, transverse diffusion



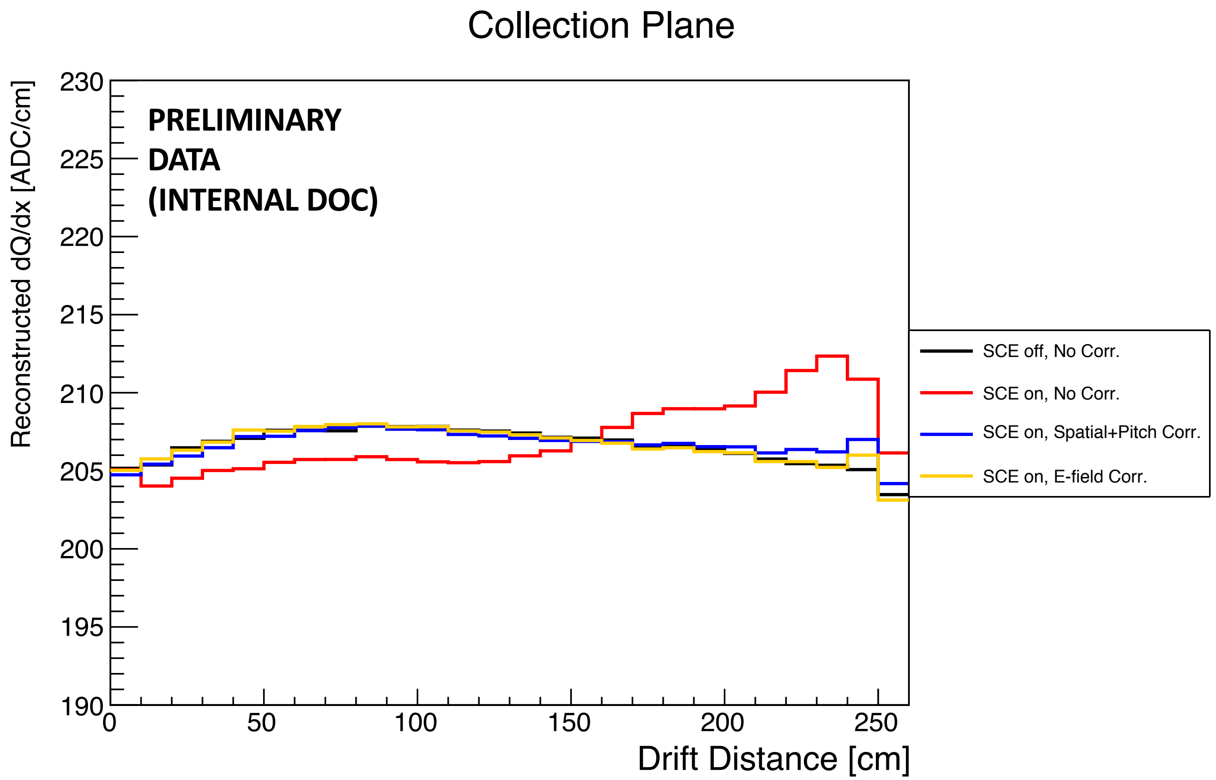
$$(dQ/dx)^{data}_{Corrected} = (dQ/dx)_{Reconstructed} \cdot C_{YZ}$$

$$(dQ/dx)^{MC}_{Corrected} = (dQ/dx)_{Reconstructed} \cdot C_{YZ} \cdot$$

This YZ map is used to ”smear” simulation to mimic data when we overlaid some cosmic data as part of our simulation also known as ”overlay”

dQdx Calibration

- First calibration in LArTPC using the dedicated data-driven Space Charge Effects map provided by the University of Bern, CSU, and University of Minesota colleagues.
- Show that we can recover our “perfect calibration” sample to a good precision.
- Better detector simulation effects that better match our data as the input for the simulation



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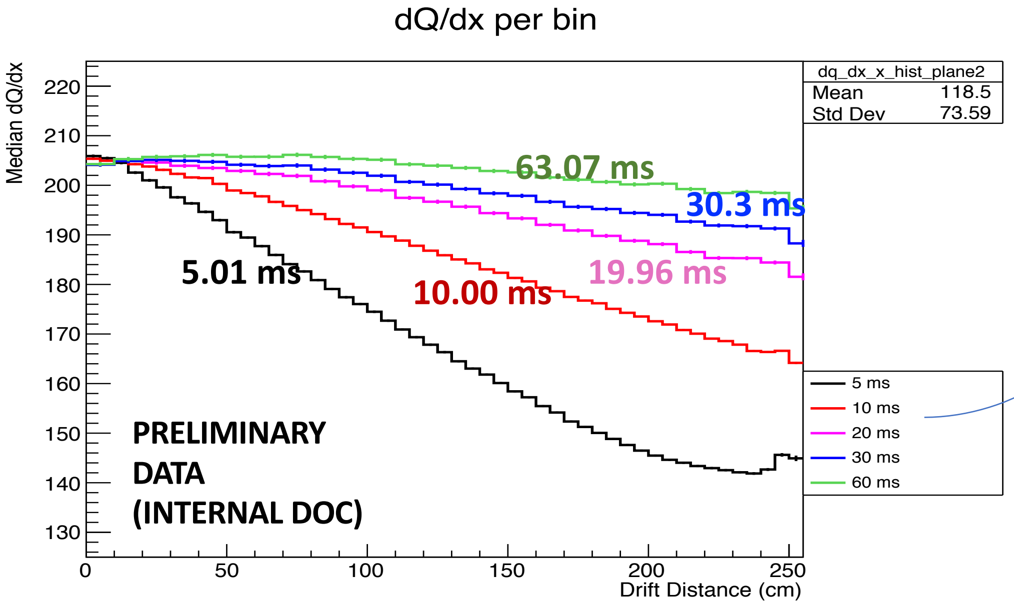
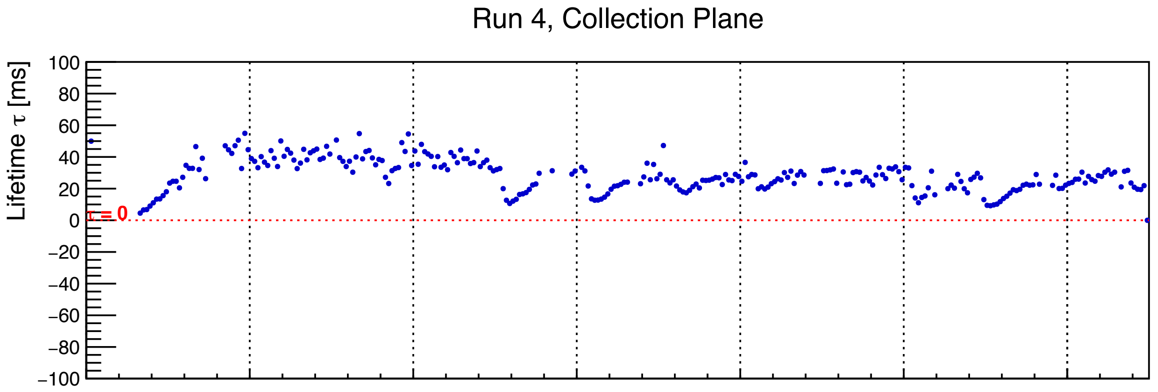
Electron Lifetime

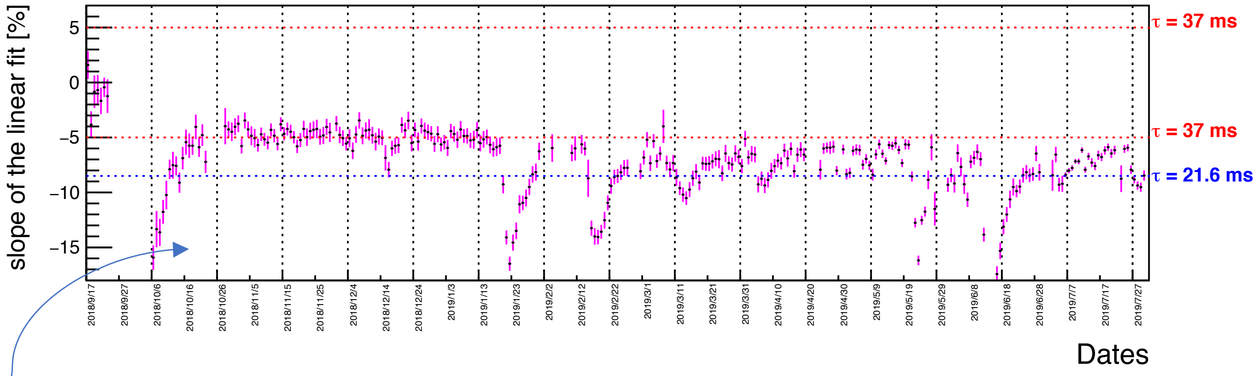
- Once the SCE are corrected, we can disentangle the electron lifetime effect from the convoluted and t dependent detector effects

$$\frac{Q_A}{Q_C} = \exp(-t_{\text{drift}}/\tau) \Rightarrow \tau_0 = \frac{(1/slope)}{v_d}$$

- Errors on the measurement is < 0.5%



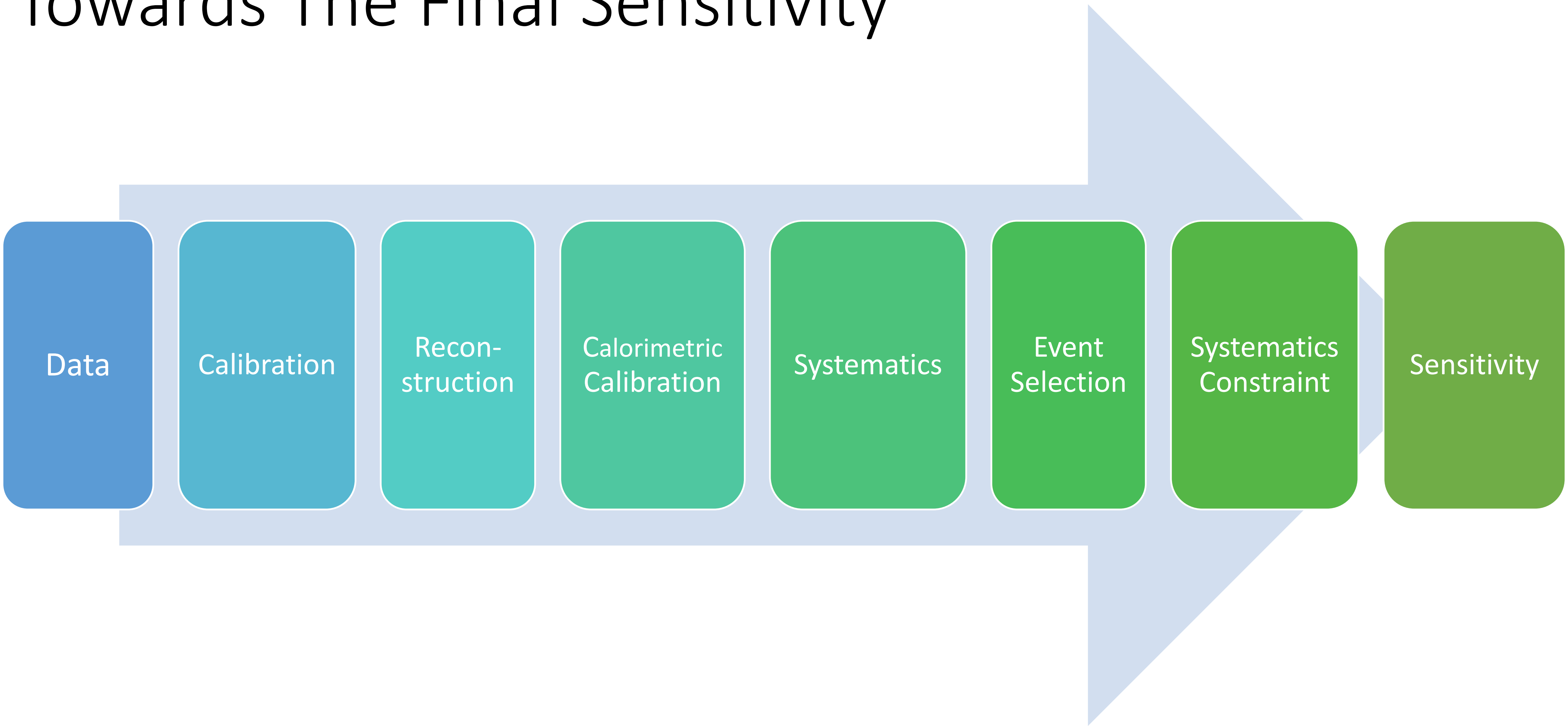




Ensure that we are extracting the lifetimewithin 1% for smaller lifetime

The value extracted in data will be used as the input drift lifetime and will be calibrated later

Towards The Final Sensitivity



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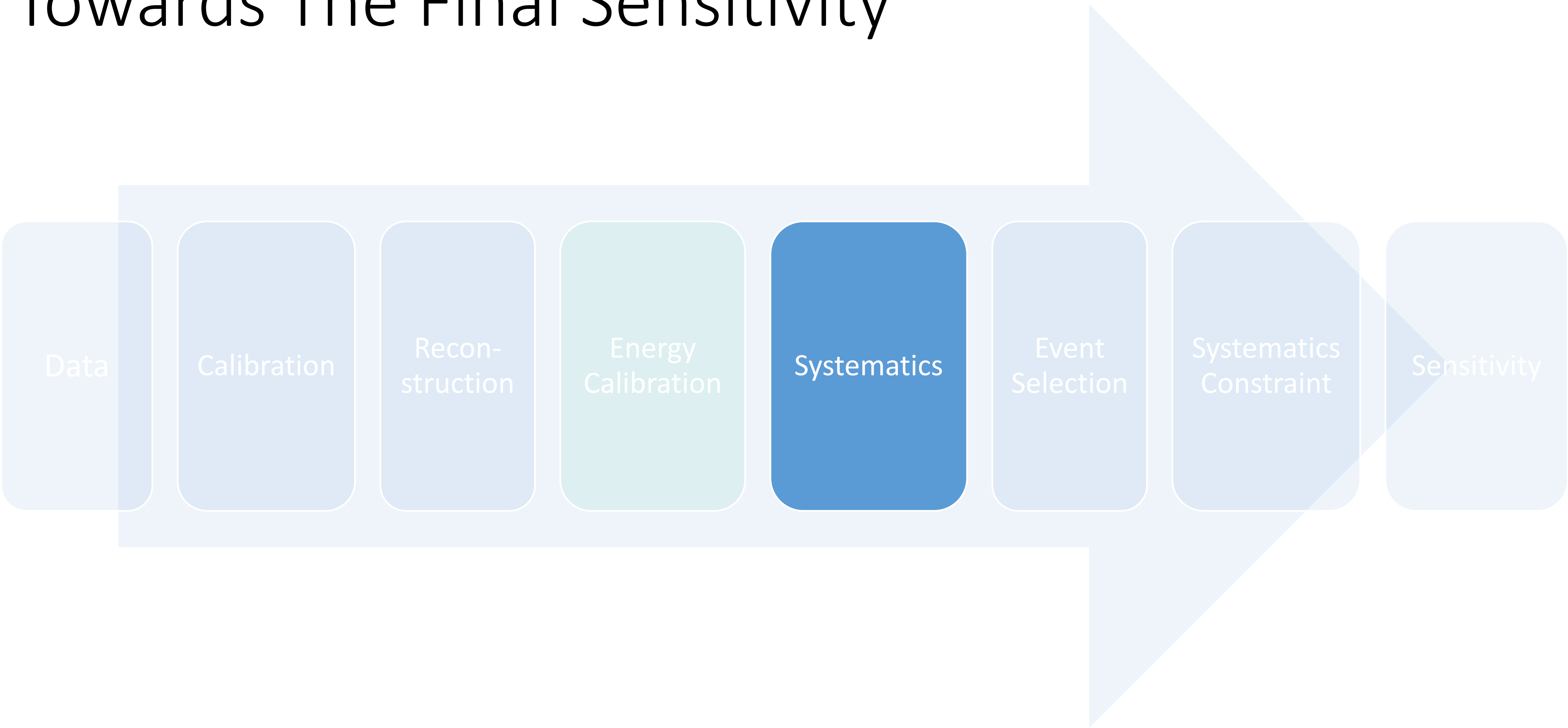


Flux and Cross Section Systematics

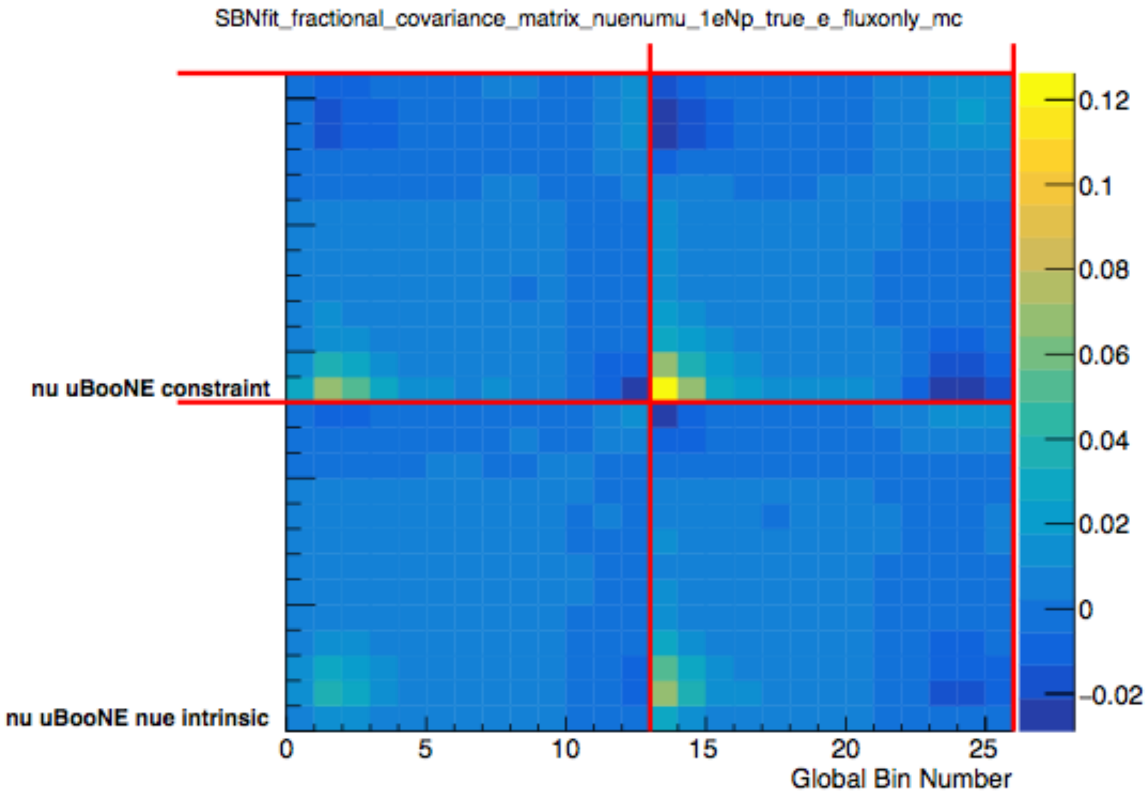
The flux and cross-section systematics are all calculated by weighing a central value according to different variations.

For example, axial mass for CC quasi-elastic, π absorption probability for neutrino interactions, and horn current, $\pi^{\pm}$ production in flux.

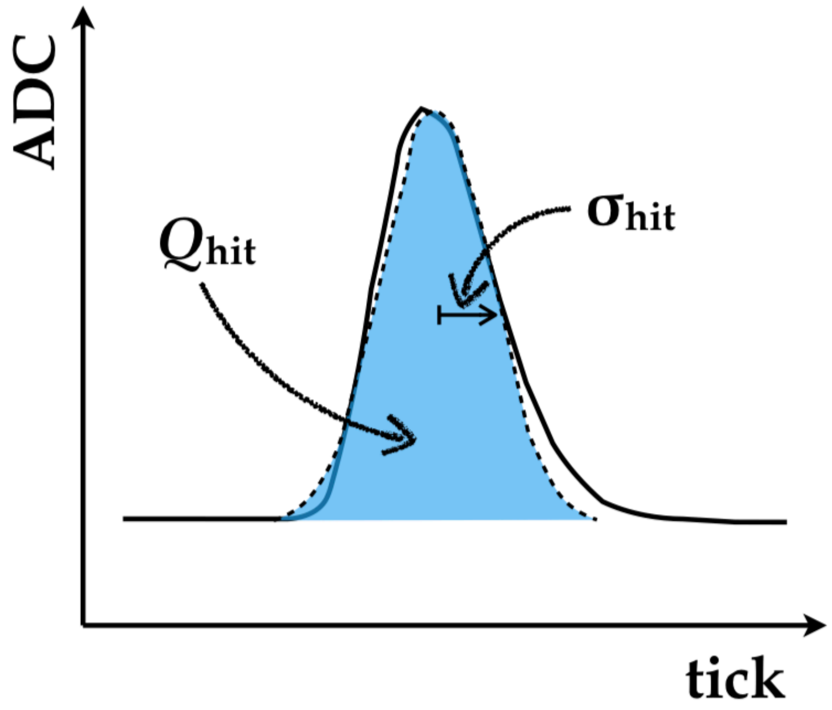
The covariance matrix :

$$E_{ij}^{sys} = \frac{1}{N} \Sigma_k^{\mathrm{N}} (N_i^{CV} - N_i^k)(N_j^{CV} - N_j^k)$$

Where N is the total number of variations, N_i^k is the value in the CV in the i-th bin of the k -th variation and N_i^{CV} is that of the central value.



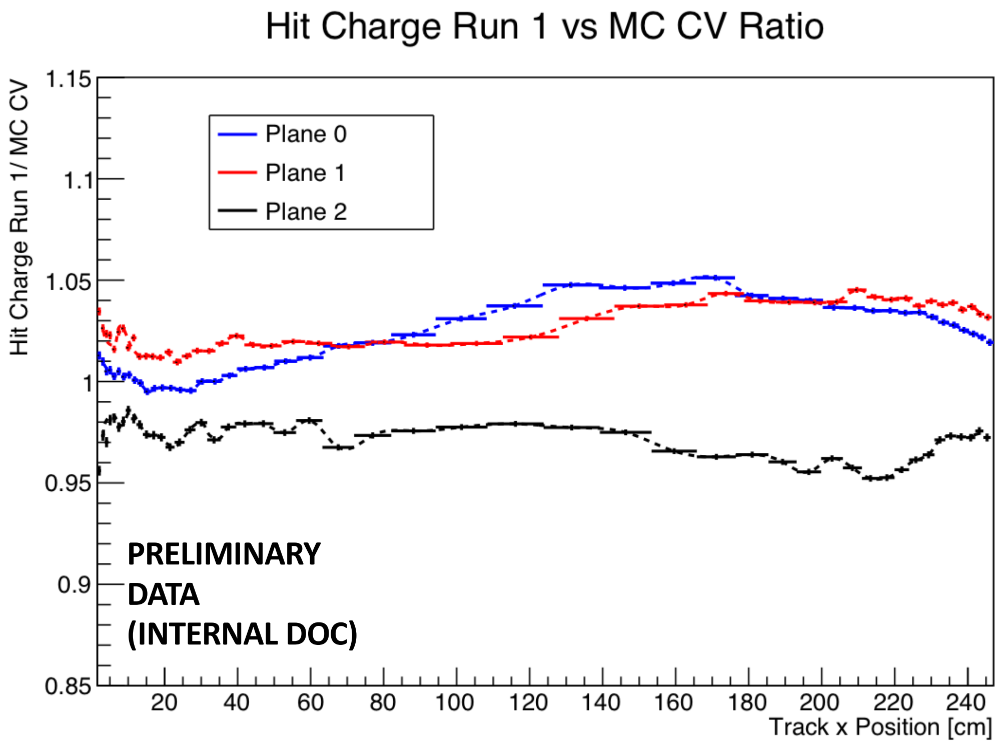
Detector Systematics



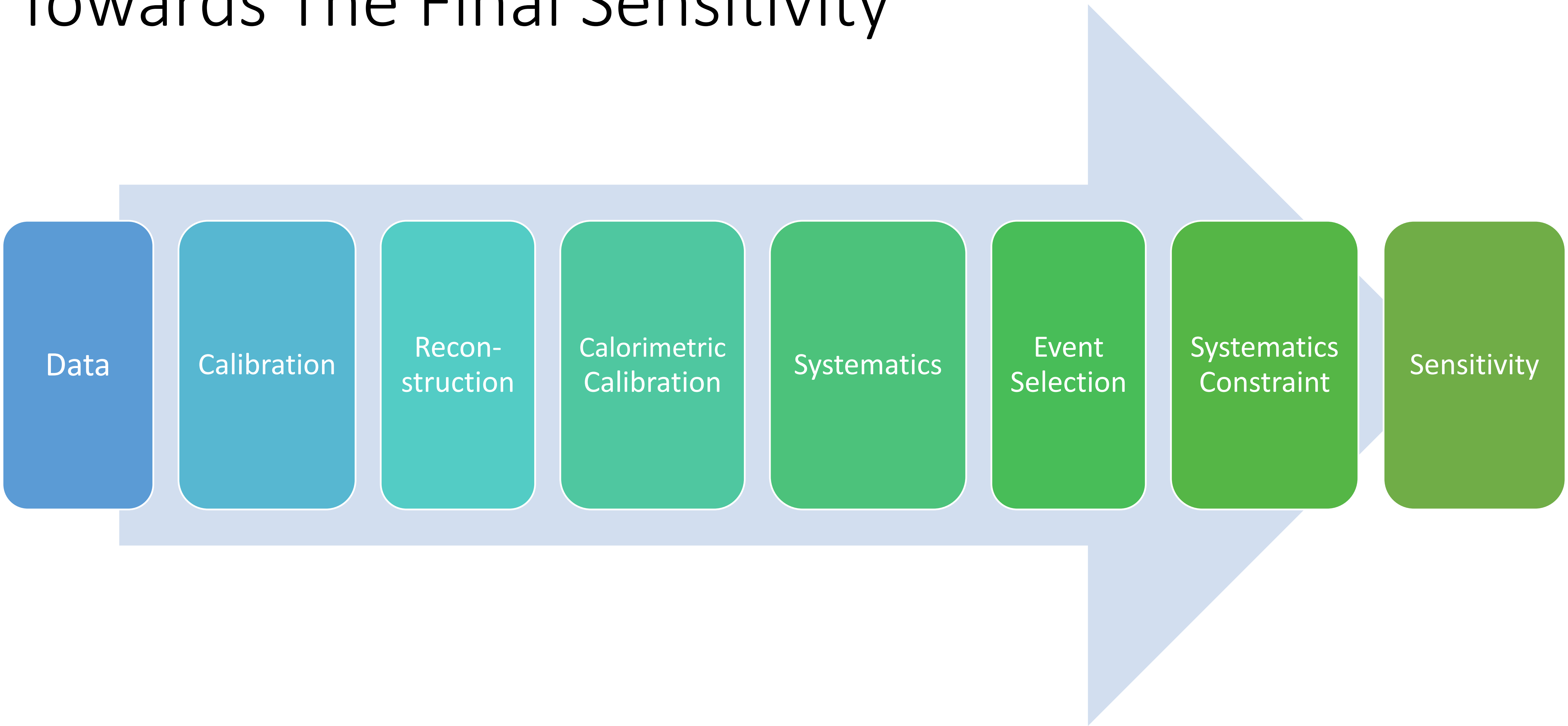
- New method for detector systematics based on comparisons between data and MC, propagated to physics analyses by wire modification.
- Consider the detector's response to an energy deposition as a function of the relevant variables: x, (y, z), (θ, ϕ), and dE/dx
- Characterize the detector's response in terms of the charge and width of gaussian hits — using these as proxy for wire waveform properties

Detector Systematics

- Measure the values of *Q* and σ of hits vs. x
- Look at difference in data and simulation to bound detector differences in *Q* and σ, then perform a fit to those points to get the continuous functions *RQ* and *R*σ
- Modify hits/wavefroms in simulation by that difference and rerun reconstruction, treating difference as a systematic
- The same ratio is also extracted in other variables and then propagated as alternate samples to the central value.



Towards The Final Sensitivity



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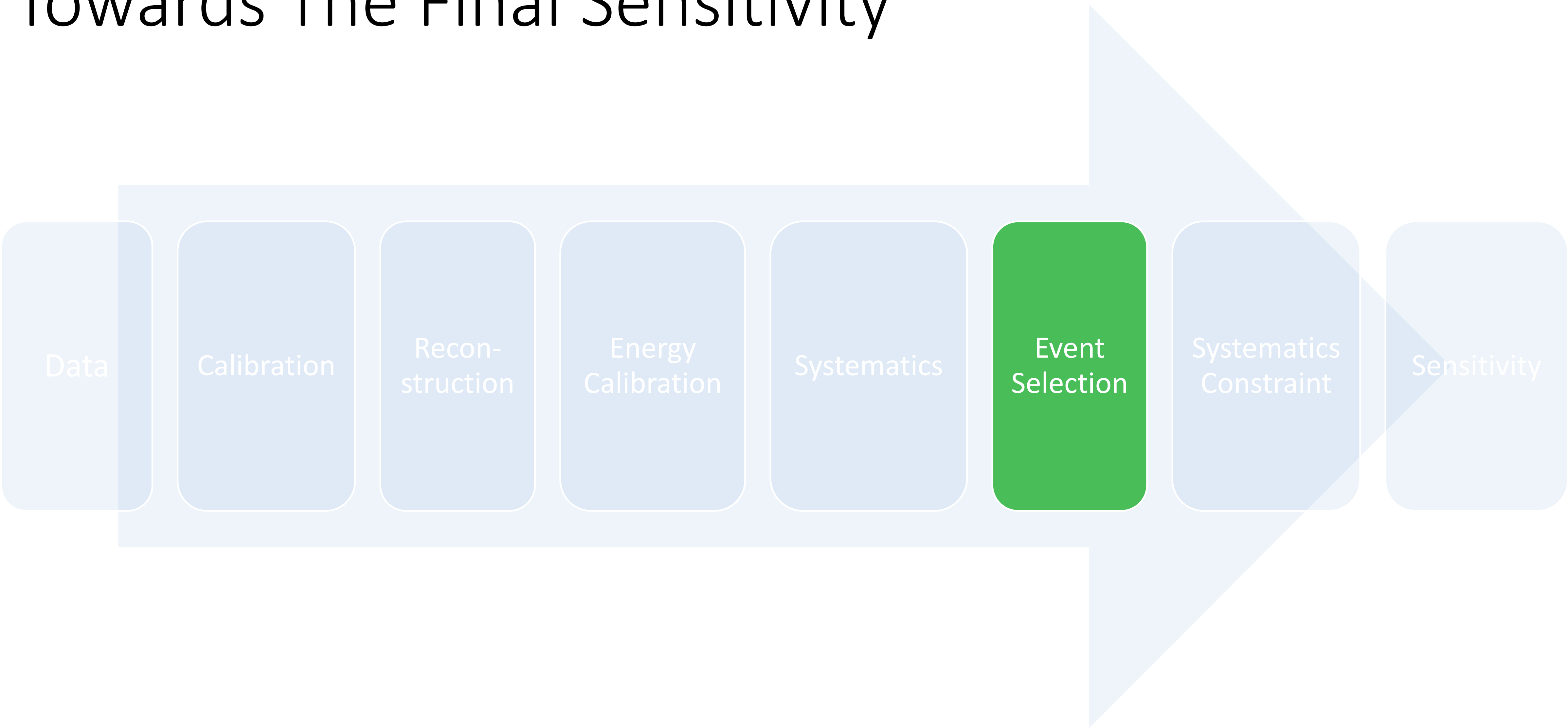


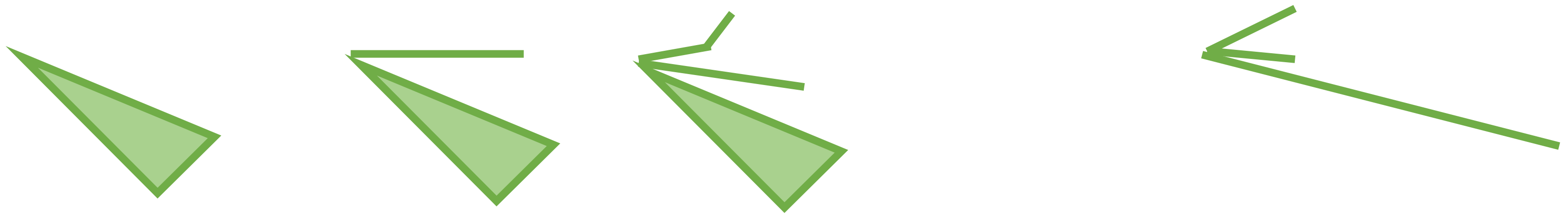
Event Selection

- Working with 'Pandora' pattern-recognition reconstruction framework (standard reconstruction tool in MicroBooNE) focusing on the excess related to electron channels.
- Muon Neutrino selection is used to constrain systematics

Electron Neutrino Selections

1e0p0π 1eNp0π 1eXpXπ

Muon Neutrino Selection



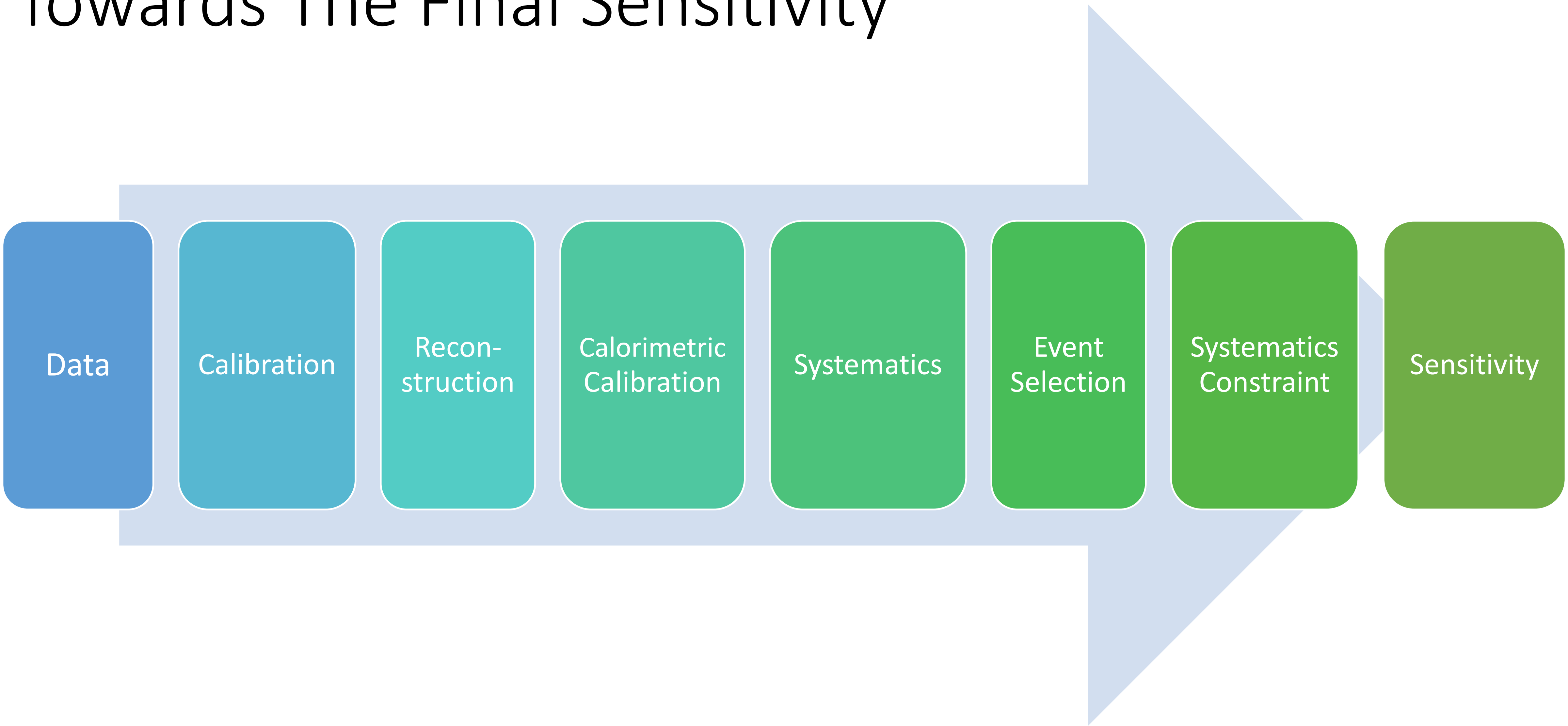
SBNfit

- Framework designed to perform simultaneous fits across data from multiple, correlated distributions.
- Developed by MicroBooNE/SBN collaborators at Columbia University (Georgia Karagiorgi, Mark Ross–Lonergan, Guanqun, Davio Cianci, et al.)

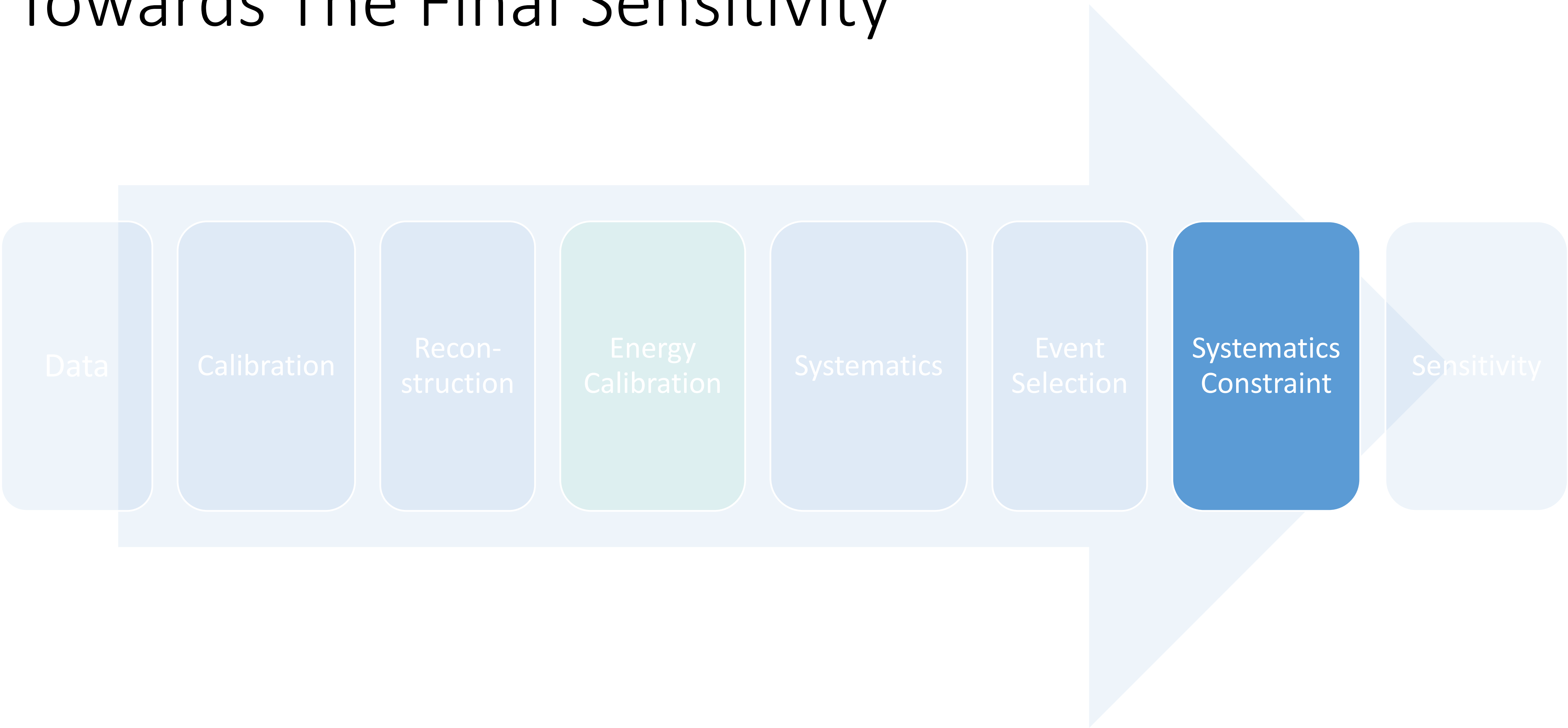
Multi-mode	Multi-detector	Multi-channel
• Neutrino/anti-neutrino • BNB/Numi Beam	• SBN: • SBND+MicroBooNE+ICARUS • MiniBooNE+MicroBooNE • SBN+DUNE	• 1 electron only • 1 electron + N proton • 1 muon + N proton

Allows for combined fitting of ***arbitrarily large*** number of modes, detectors and channels simultaneously, fully accounting for systematic correlations.

Towards The Final Sensitivity



Towards The Final Sensitivity



Constraining Systematics

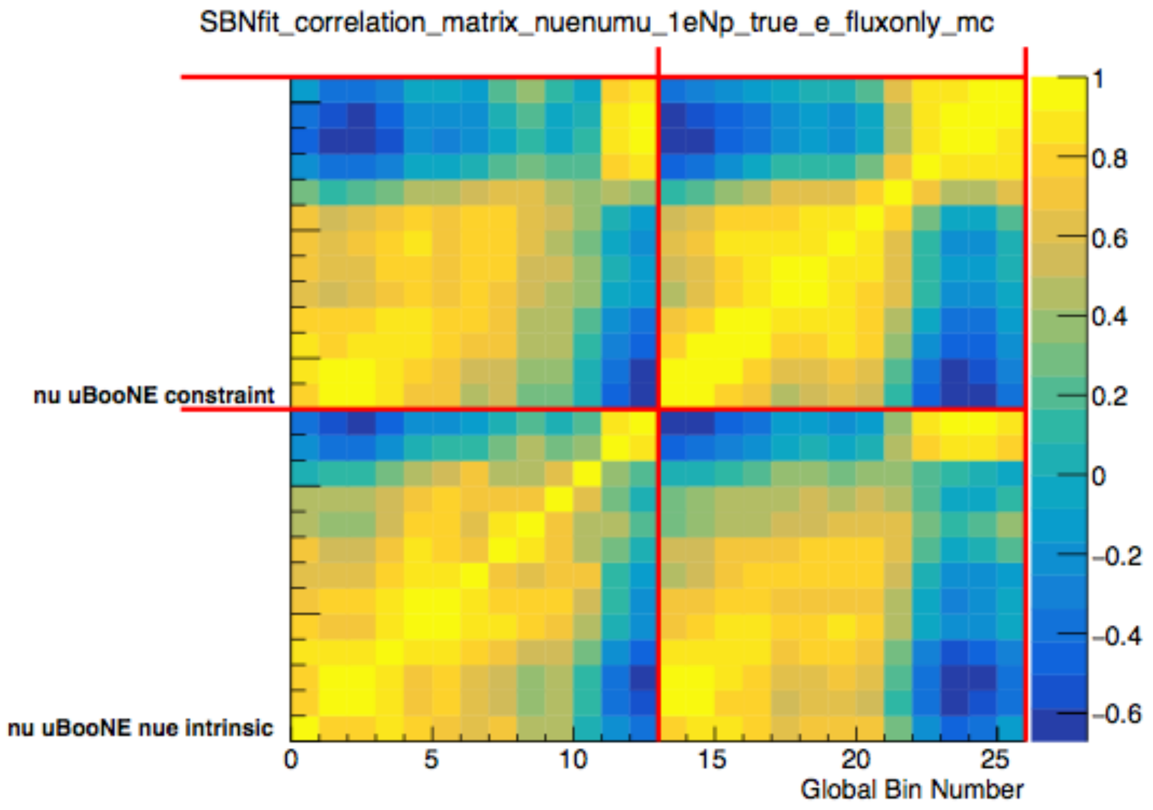
Each detector shares the same neutrino flux and argon cross-sections measurement is highly correlated.

Exploit the correlations between the $\nu_\mu - \nu_e$ channels to reduce systematic uncertainties.

Combined analysis:

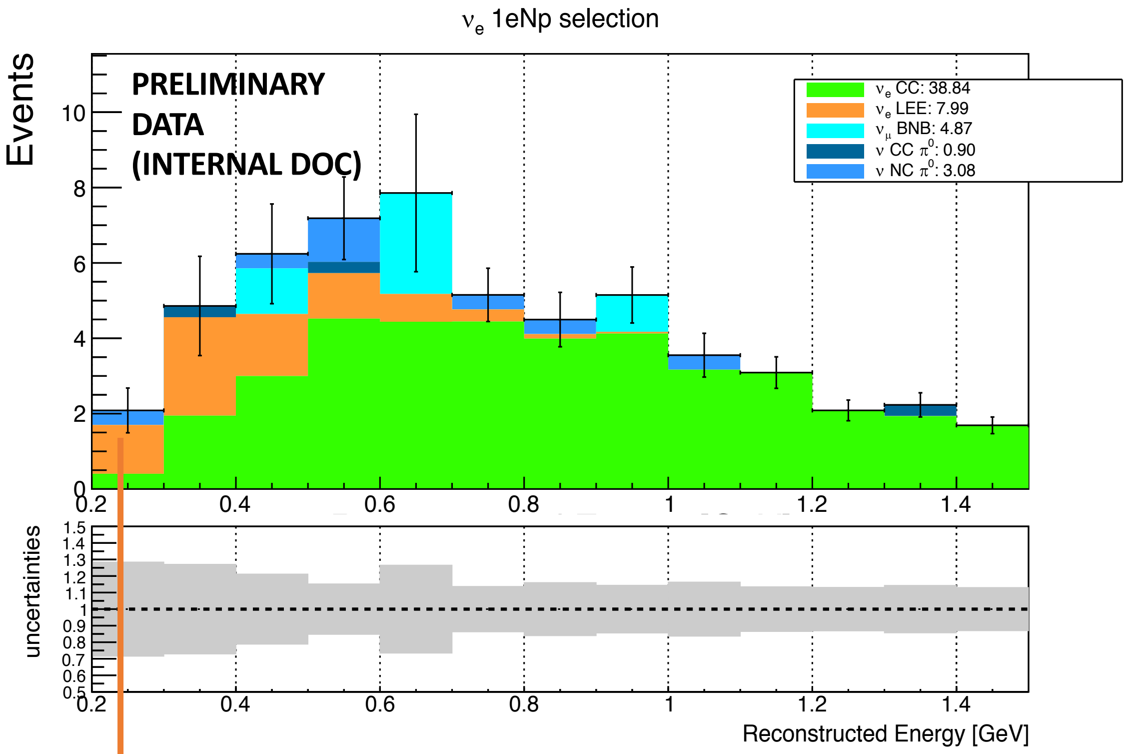
1) using multiple selections and observables

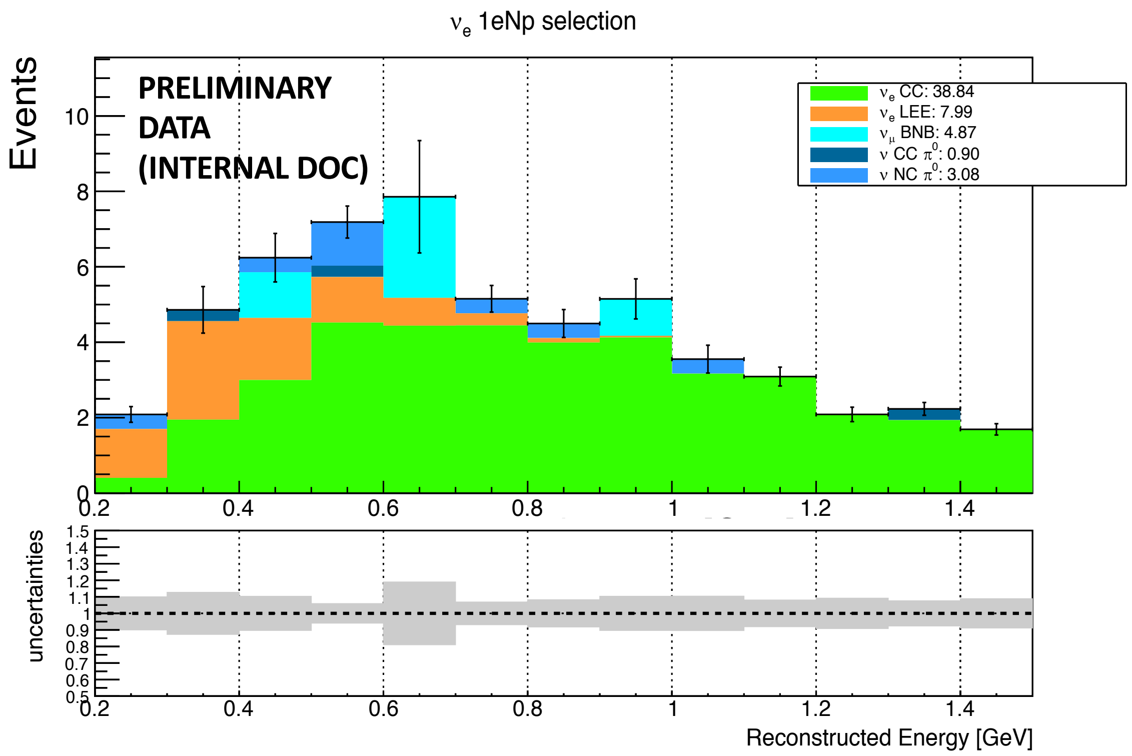
2) taking into account correlated systematic uncertainties through a covariance matrix



Constraining Systematics using ν_μ selection

Not final selection

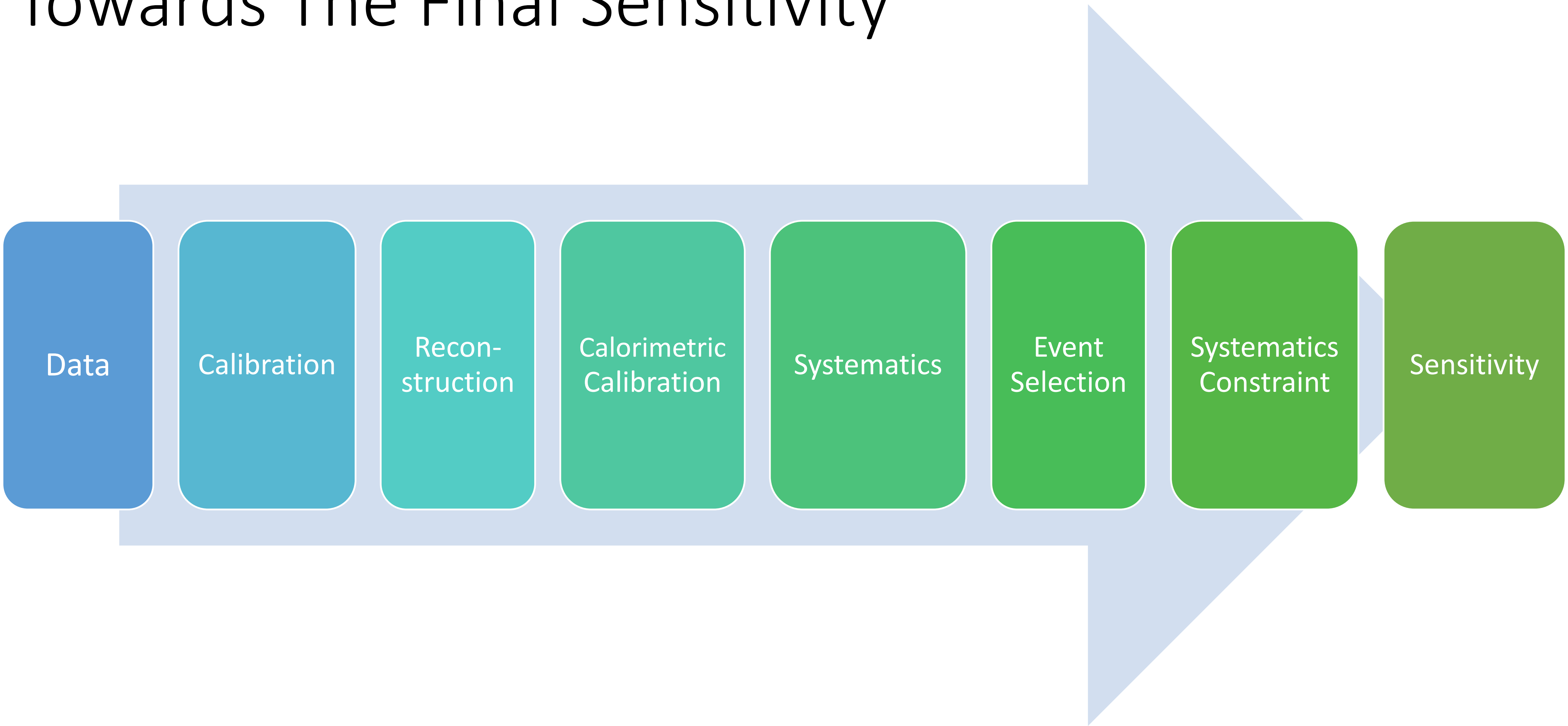




Unfolded MiniBooNE low-energy-excess. Weighted from true neutrino energy.

50% reduction in systematics

Towards The Final Sensitivity



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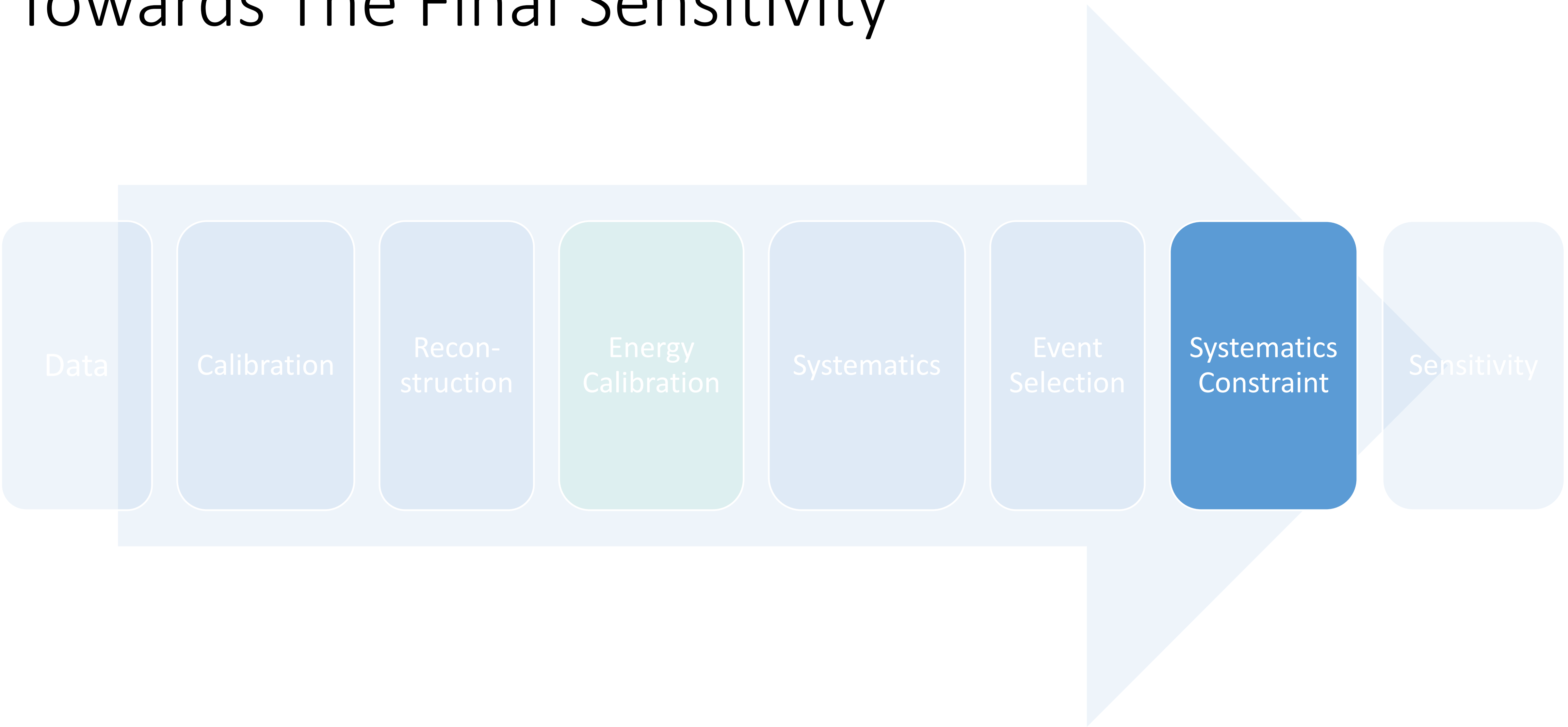


Sensitivity

Cartoon example

[On-going work]

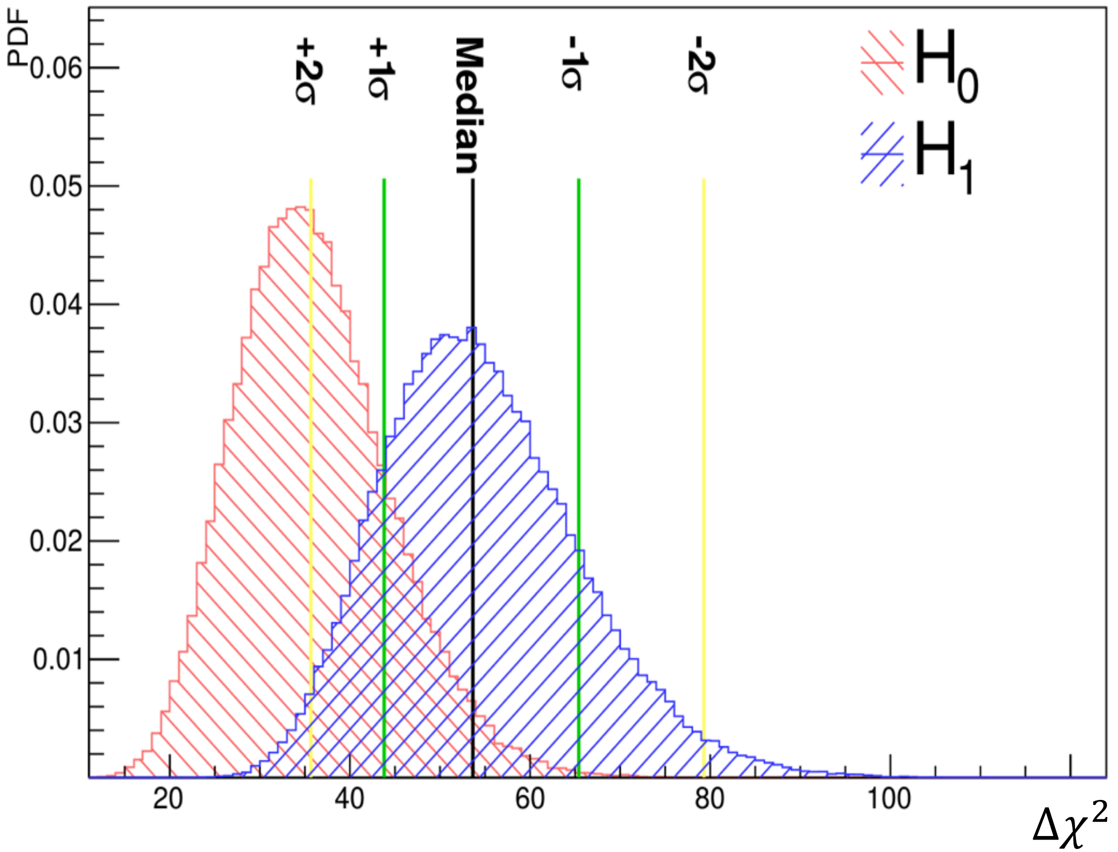
Have to simulate many experiments under the H0 hypothesis (no low energy excess), and H1 hypothesis .

For each toy experiment, $\Delta\chi^2$ is calculated as

$$\Delta\chi^2 = \sum_{i,j=1}^{N}\left((n^i-\mu^i_{H_1})E^{-1}_{i,j}(n^j-\mu^j_{H_1}) - (n^i-\mu^i_{H_0})E^{-1}_{i,j}(n^j-\mu^j_{H_0})\right)$$

to obtain the $\Delta\chi^2$ distribution.

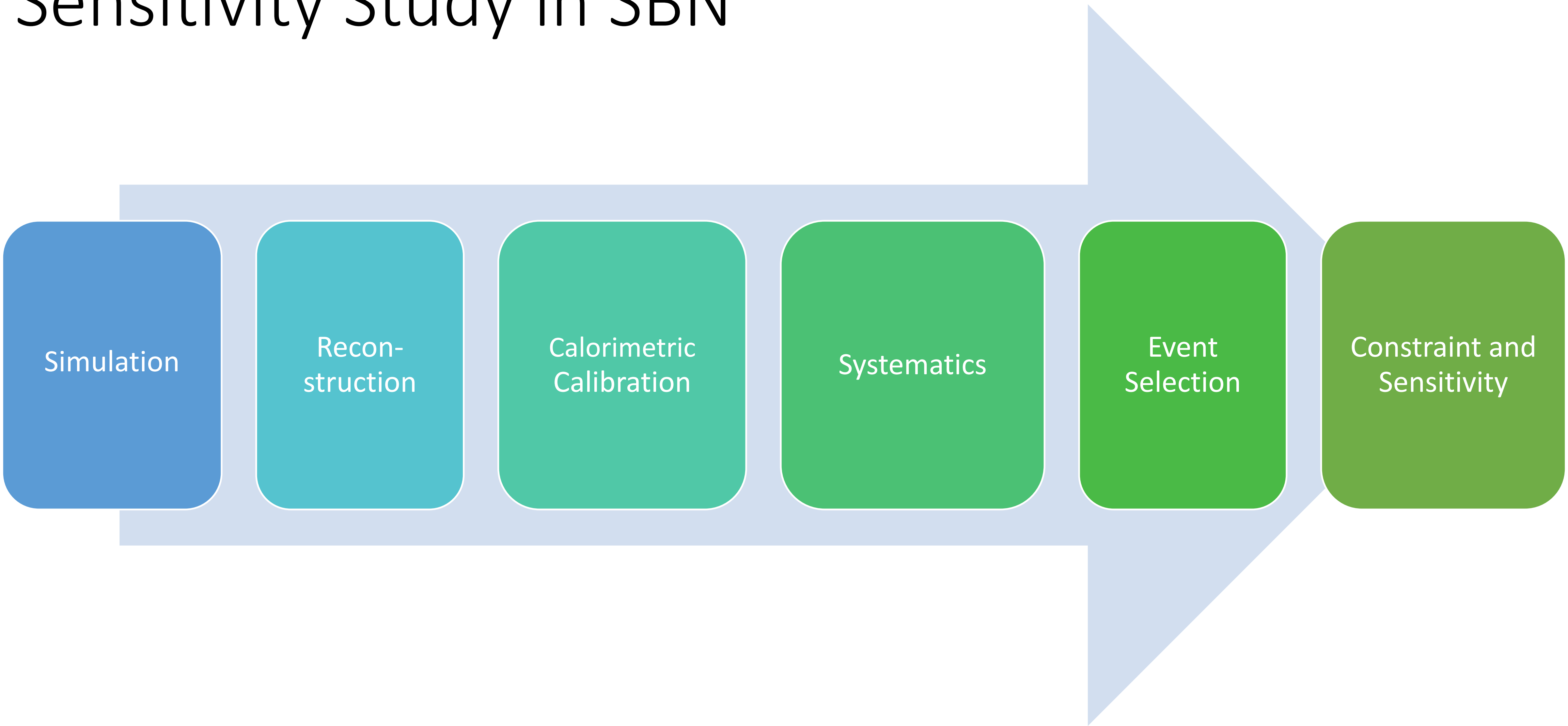
The sensitivity quoted is the median sensitivity.



Looking Ahead

- Finalizing the systematics constraint, to include the $1e0p0\pi$ and ν_μ channel in the constraint.
- Working on including detector systematics into the constraint and the final sensitivity.
- Finalizing the analysis internal note to be circulated to the group's Editorial Board
- Target: Neutrino 2020.

Sensitivity Study in SBN



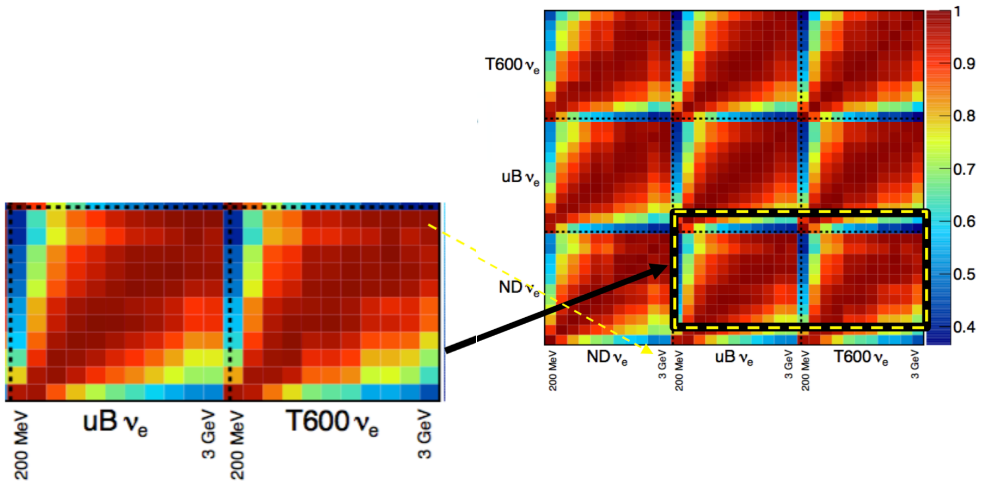
SBNfit χ^2 Test Statistics for Oscillation Analysis

- Use covariance-matrix based approach
- Test Statistics:

$$\chi^2(\Delta m^2_{i1}, U_{\alpha i}, \phi_{ij}) = \sum_{k=1}^{M}\sum_{l=1}^{M} \left[N_k^{\text{null}} - N_k^{\text{osc}}(\Delta m^2_{i1}, U_{\alpha i}, \phi_{ij})\right] E_{kl}^{-1} \left[N_l^{\text{null}} - N_l^{\text{osc}}(\Delta m^2_{i1}, U_{\alpha i}, \phi_{ij})\right]$$

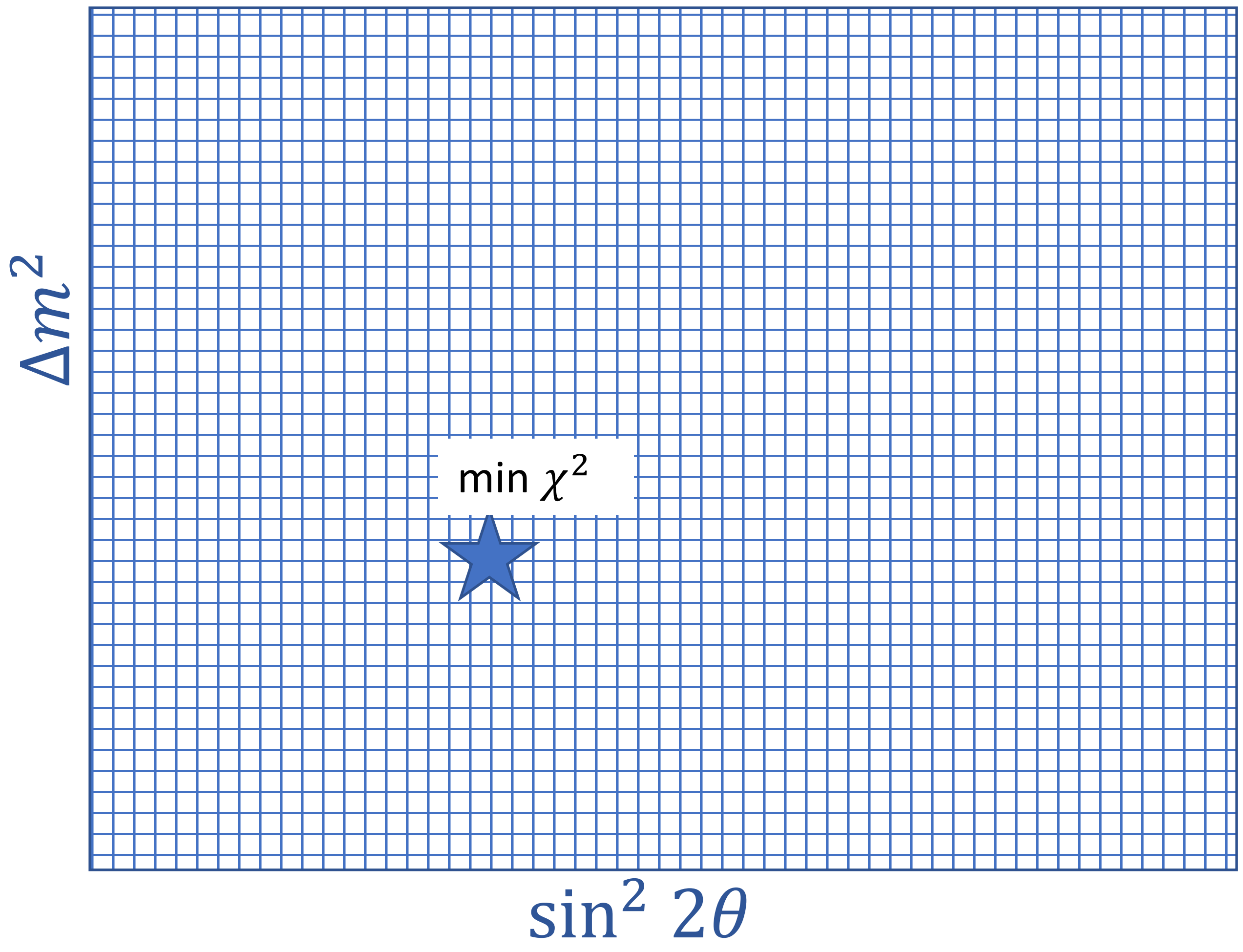
3 scenarios:
3 parameters: 3N+1
7 parameters: 3N+2
12 parameters: 3N+3

3 Detector ν_e Background Systematics Correlation Matrix
(flux and cross section systematics)



Feldman cousins method

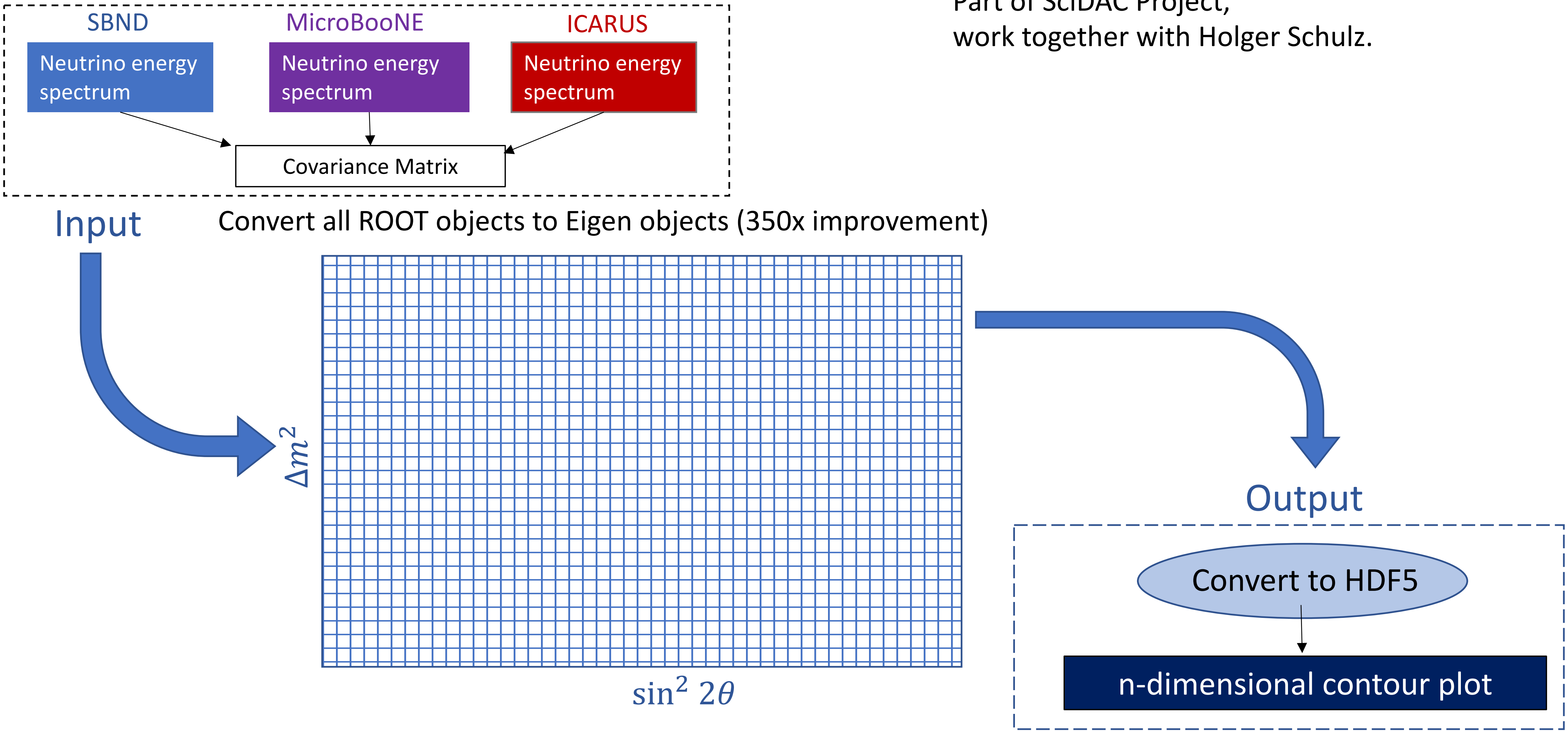
Ideally, 100*20*20, but we perform the test with 100*100*100



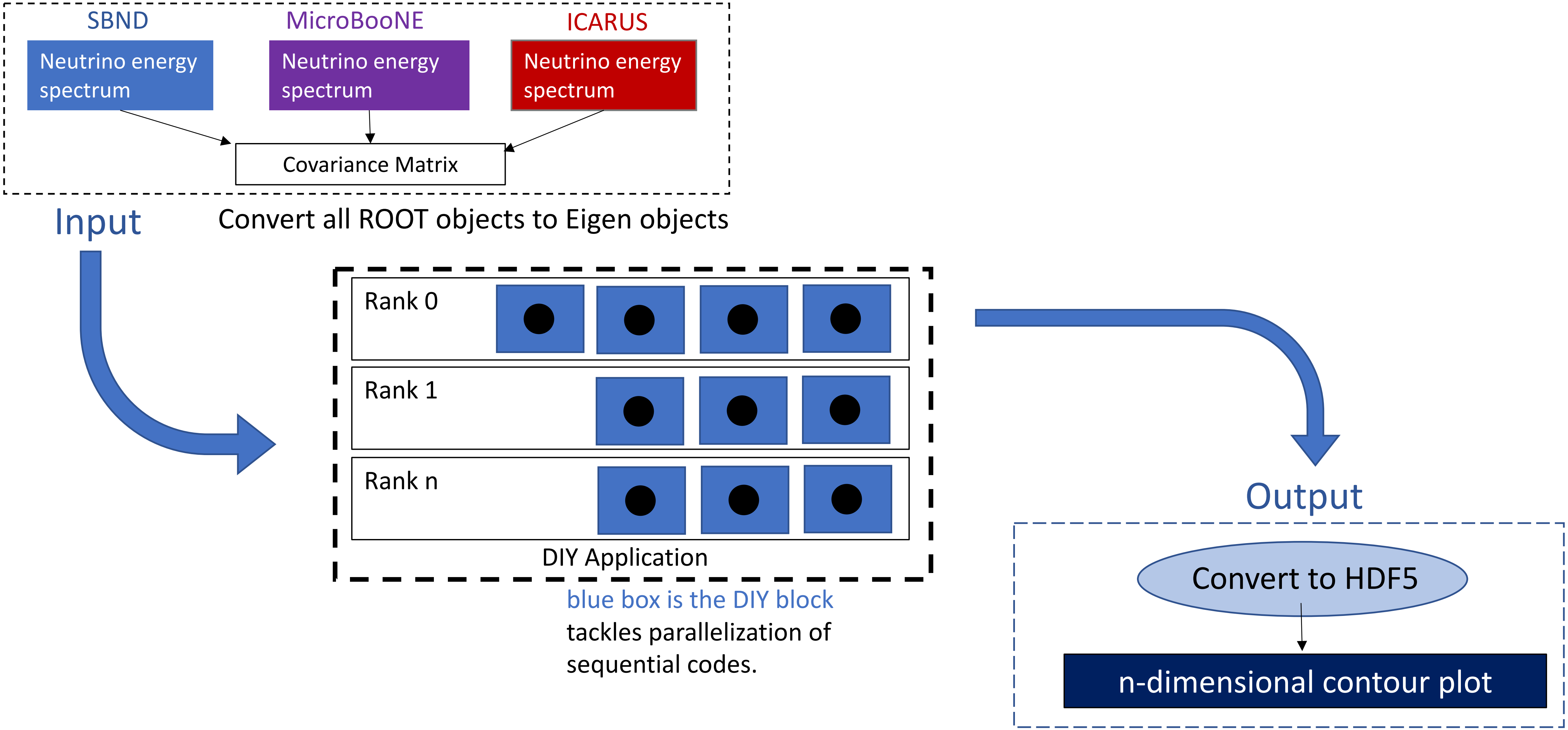
1. Given observed data spectrum D
2. Find the grid point with the minimum χ^2
3. Calculate $\Delta\chi^2$ at each grid point
4. Calculate exactly the value of that 90% of experiments would be in by generating pseudo experiments.
5. Do this for 3σ (10^4 pseudo experiments/"universes") and 5σ ($\sim 10^8$ pseudo experiments/"universes")

Accelerating SBNFit Feldman Cousins on HPC

Part of SciDAC Project,
work together with Holger Schulz.



Accelerating SBNFit Feldman Cousins on HPC



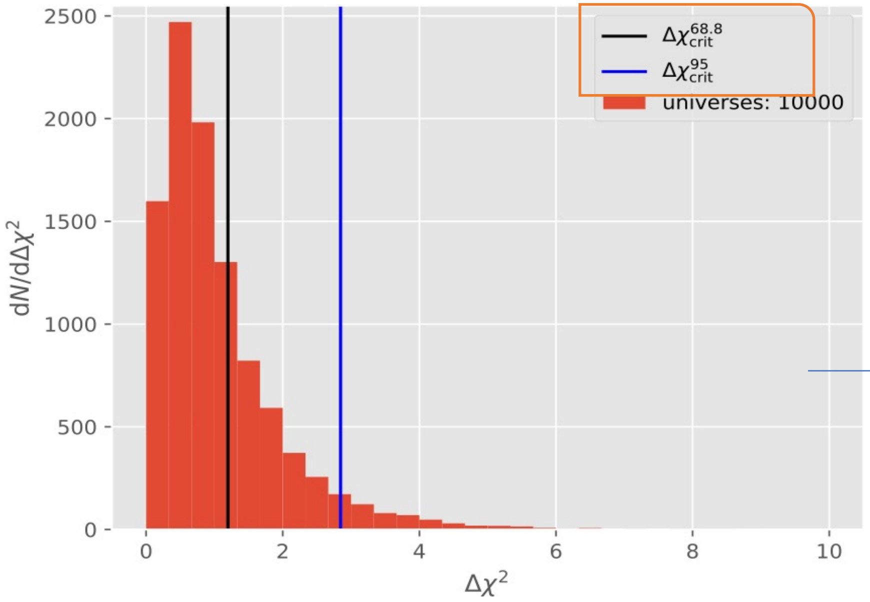
Contour Plots

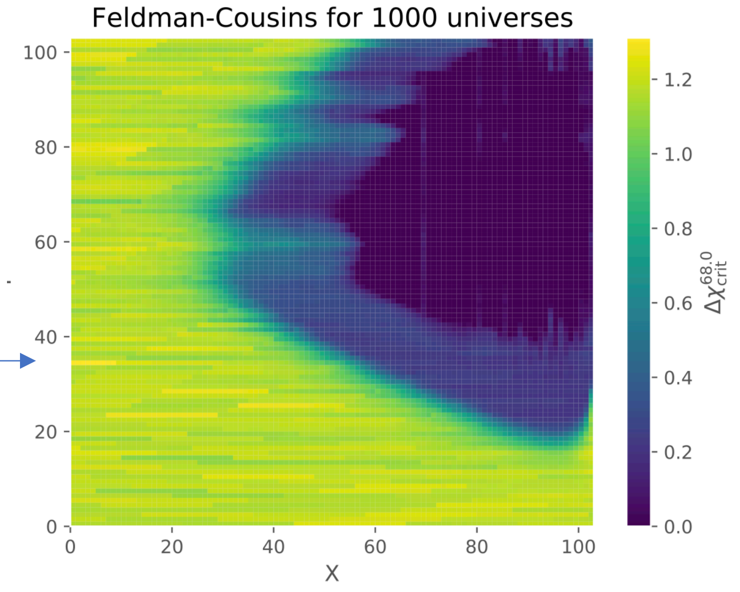
Output

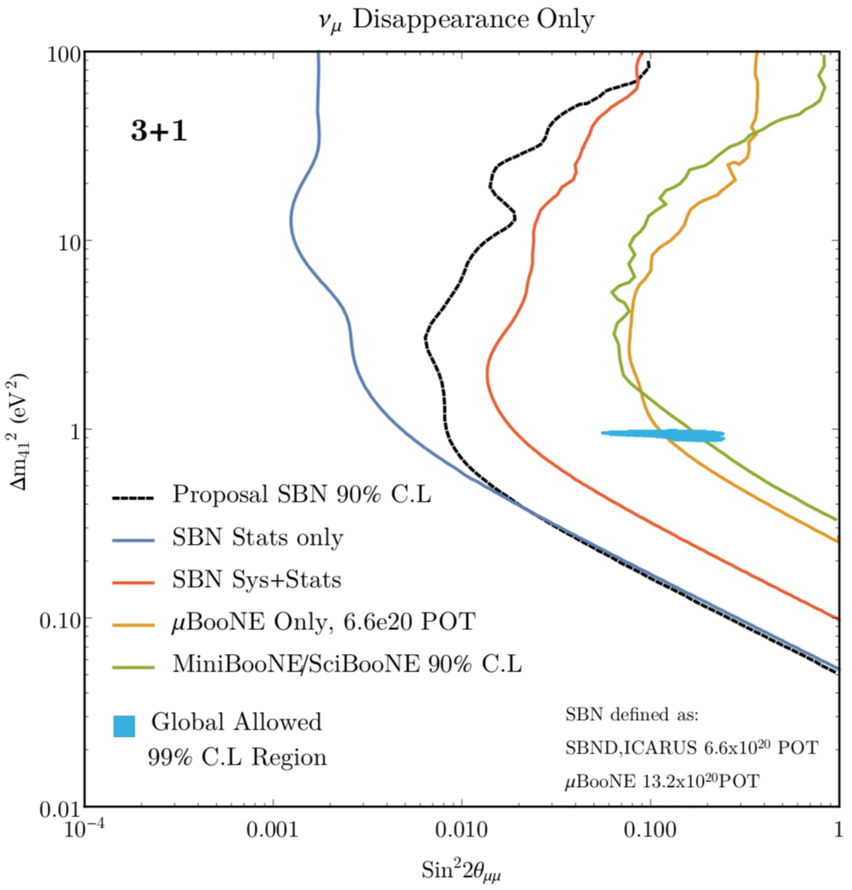
Convert to HDF5

↓

n-dimensional contour plot

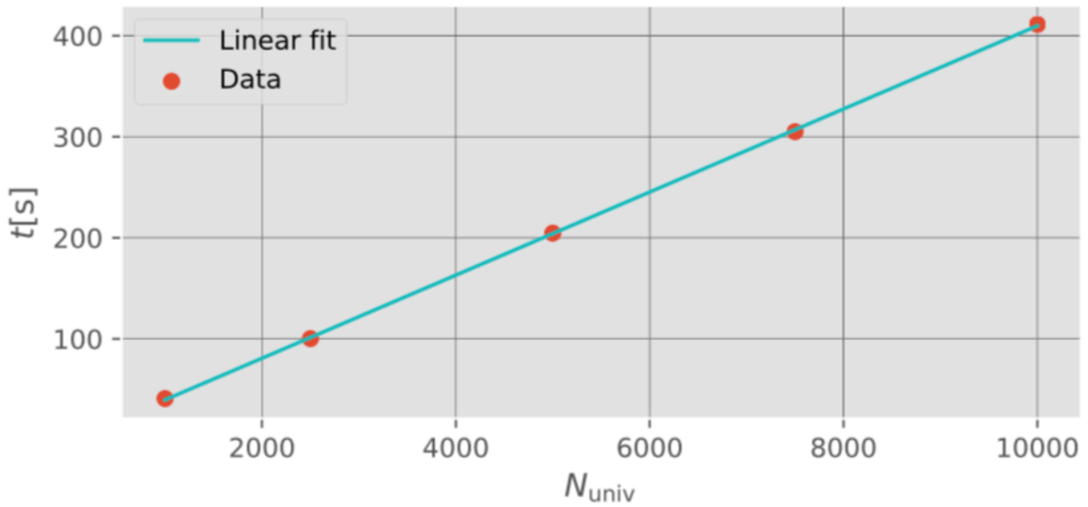


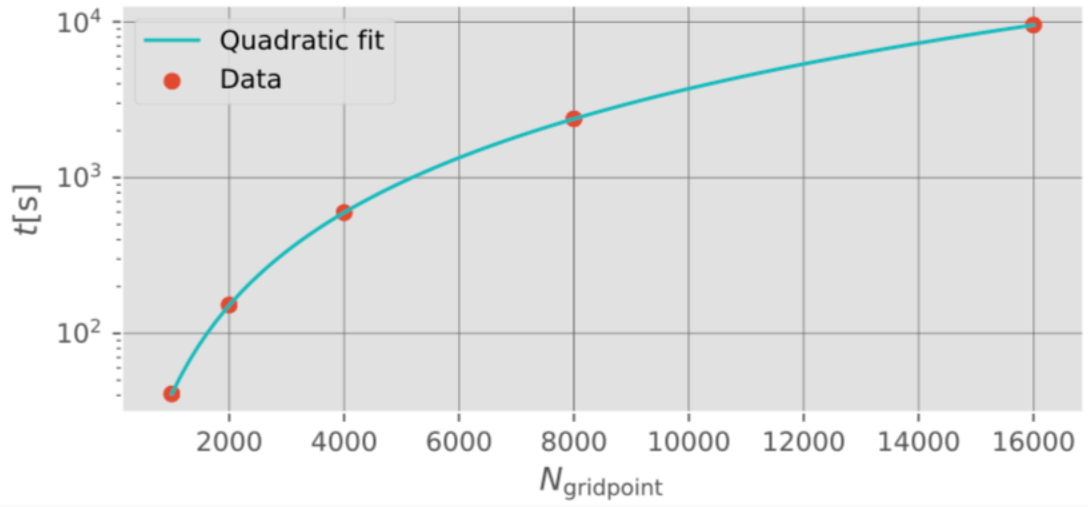




D. Cianci et al., **Phys. Rev . D** 96, 055001 (2017)

Scaling with N universes & N grid points

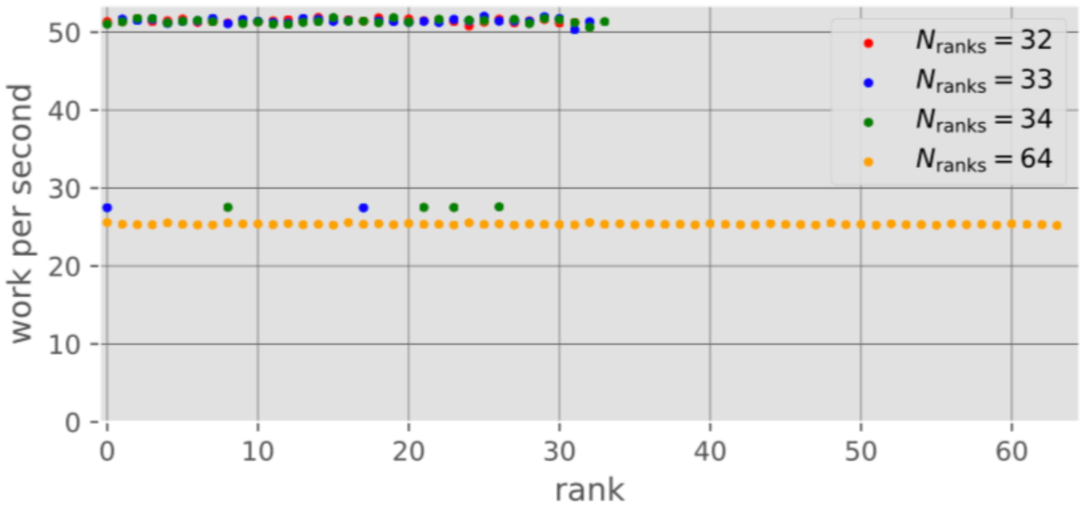




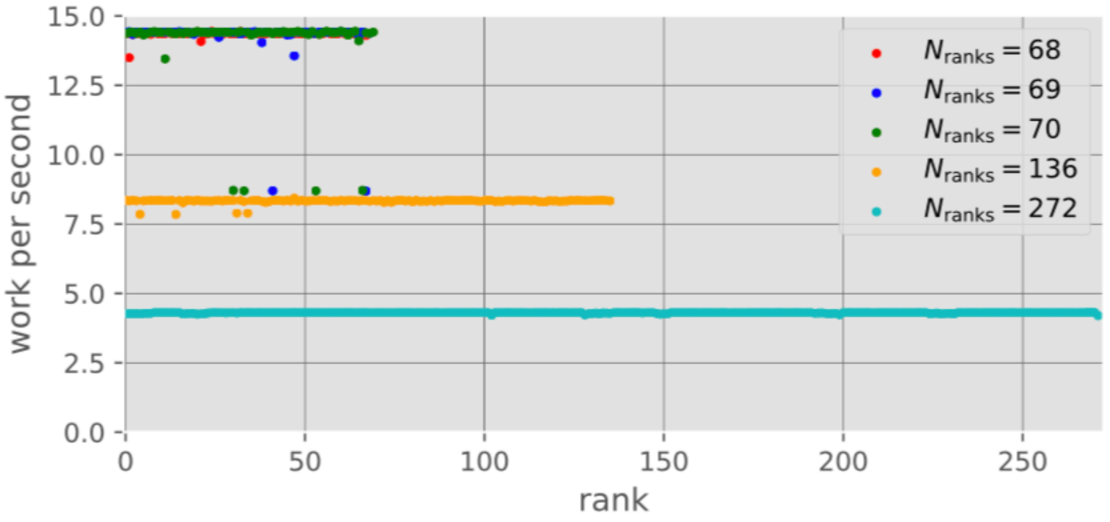
Scaling of the program run time with the number of universes, demonstrating a linear dependence on Nuniv

Scaling of the program run time with the number of grid points, demonstrating a quadratic dependence on Nuniv.

Scaling on single node

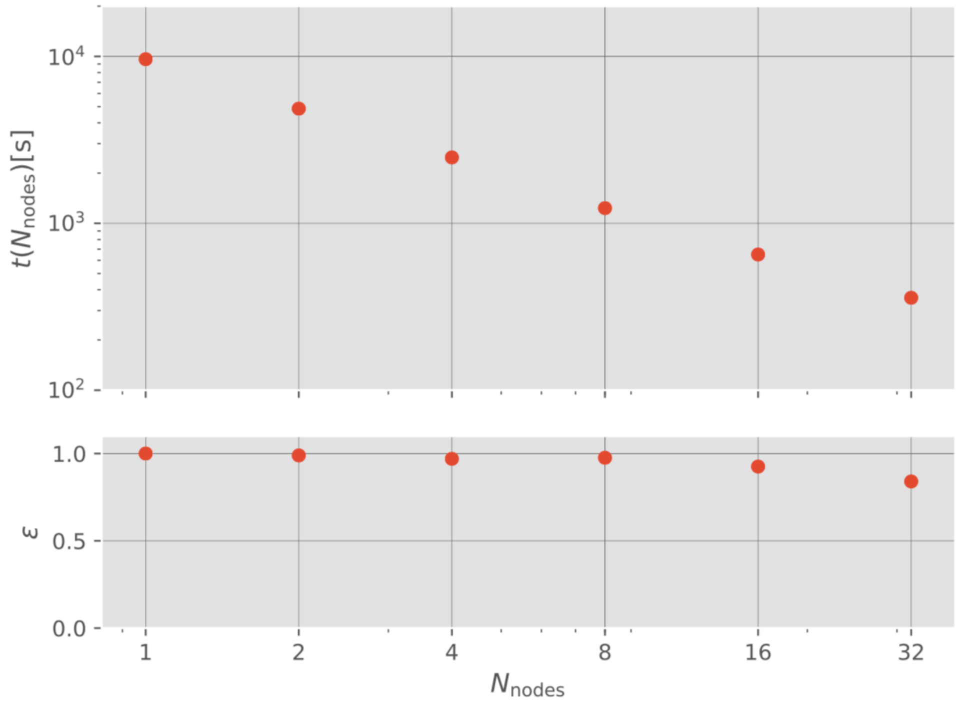


Measurement of the single Haswell node performance for a fixed problem size.



Measurement of the single KNL node performance for a fixed problem size

Scaling on Multi-node



Strong scaling measurements on Haswell nodes.
Generally good scaling up to the point where the amount of work per rank becomes relatively small.

	$N_{univ} = 10^4$ (3σ)	$N_{univ} = 10^8$ (5σ)
Cori phase 1 (Haswell)	7.2×10^5	7.2×10^3
Cori phase 2 (KNL)	1.2×10^6	1.2×10^4

Table 3: Upper boundaries on grid sizes that can be processed when running *a full day* on all of Cori phase 1/2.

Looking Ahead

- **Technical paper** that highlights the improvement gained from the parallelization and its scalability at HPC titled **"Grid-based minimization at scale: Feldman-Cousins corrections for SBN"** has been submitted to arXiv: https://arxiv.org/abs/2002.07858
- **Physics paper**
  - A broader-scope SBN sensitivity/physics paper (in discussion)
    - Perform the non-FC method vs FC method. Compare the sensitivity outcomes for the two methods.
    - Testing the effects of different parameterizations of systematics, study biases and model dependencies of the current analysis
- Plan is to continue optimizing SBNfit fitting framework using GPU accelerators (Kokkos to replace Eigen3) and move away from the grid-based approach to allow us to probe higher dimension (3N+2 scenario).
- Plan to present the results on technical conferences (ICHEP).

Backup