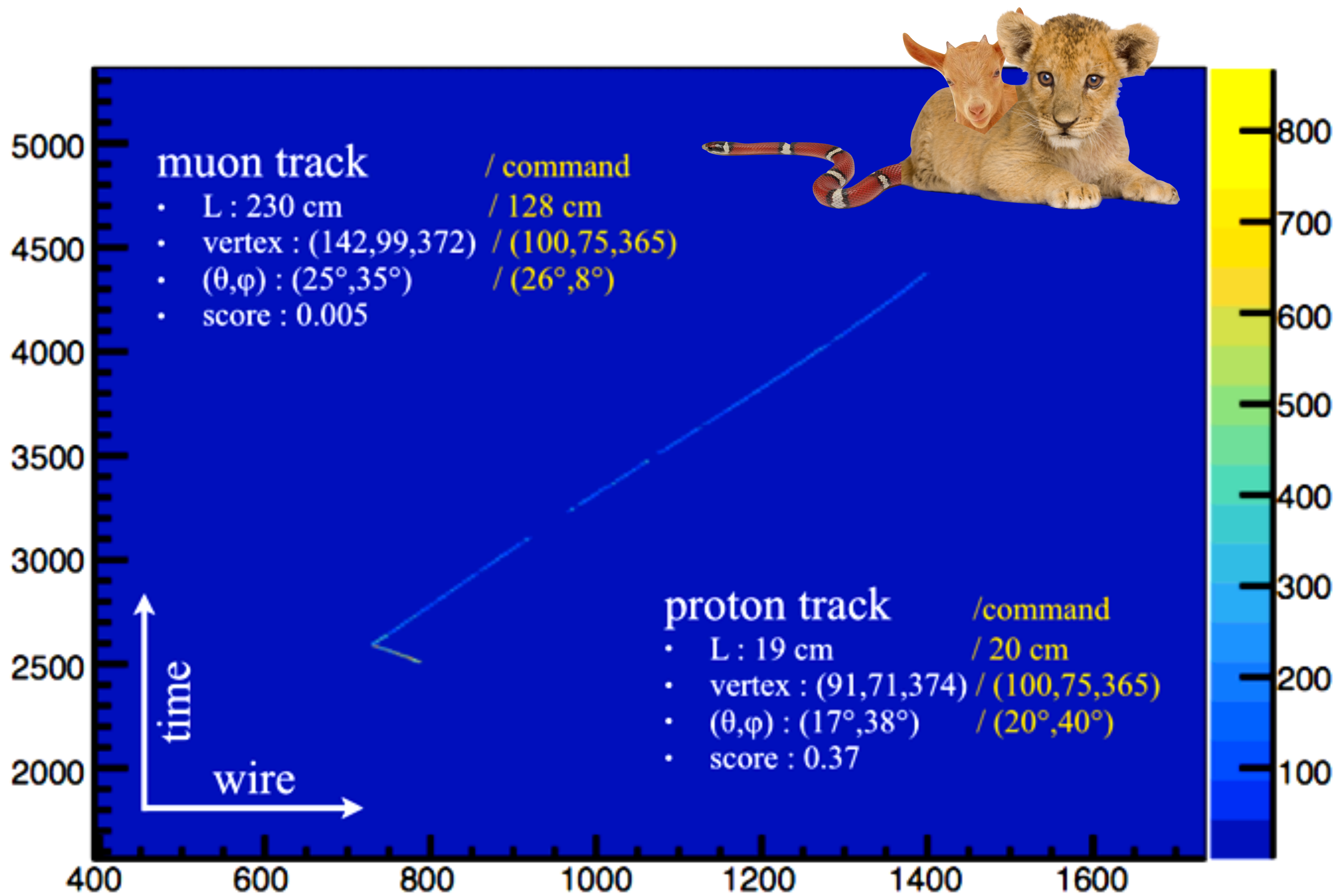
Chimera Events in the MicroBooNE Experiment



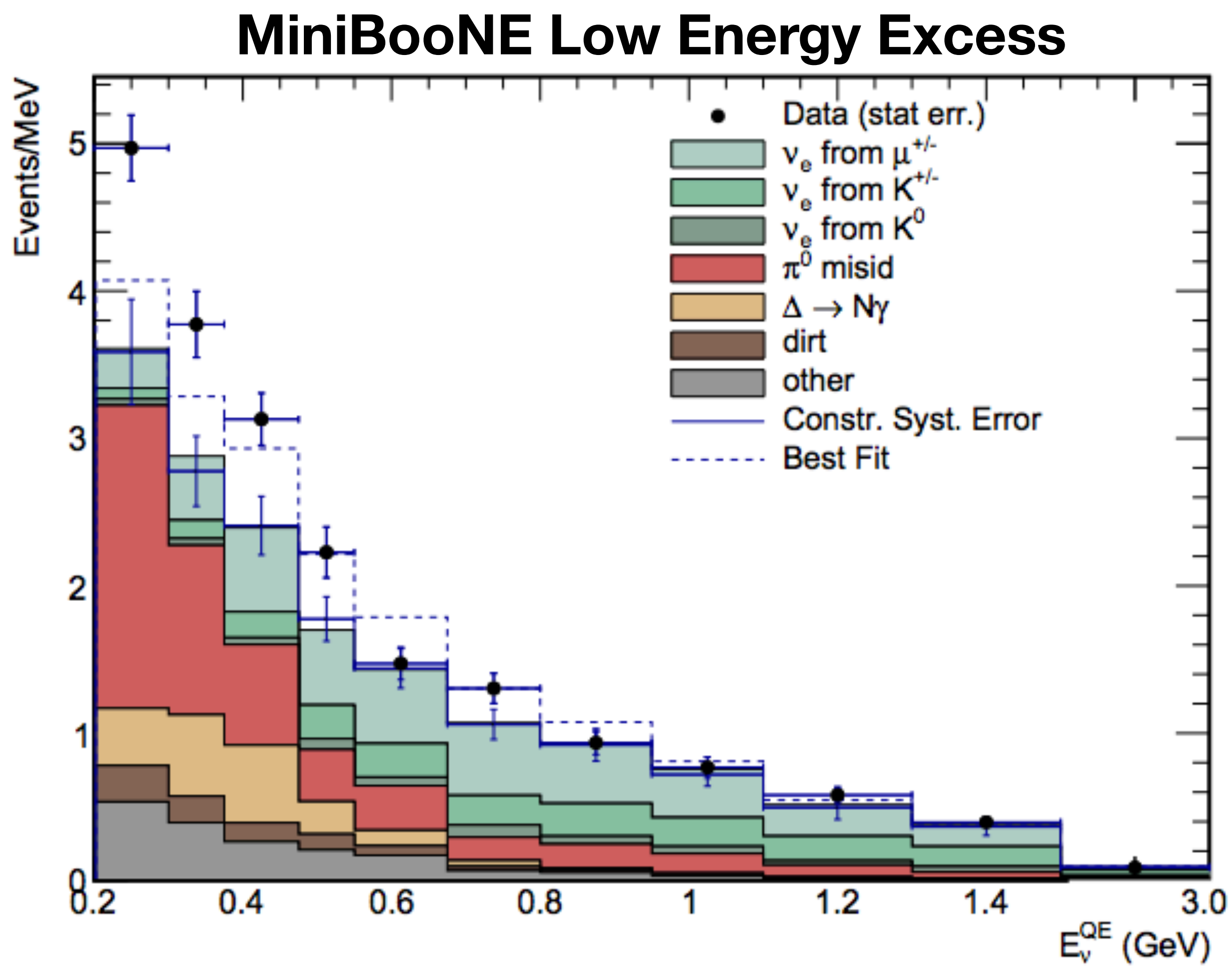
Polina Abratenko

June 10, 2019

New Perspectives

Short Baseline Low Energy Excess Search

- Major goal of MicroBooNE: investigate the excess of low energy events (LEE) observed by MiniBooNE
  - Recreate this measurement with reduced background
- Dominated by charged-current quasi-elastic (CCQE) events
- Constrain systematic uncertainties on intrinsic ν_e background with ν_μ
- Using deep learning techniques for this LEE analysis

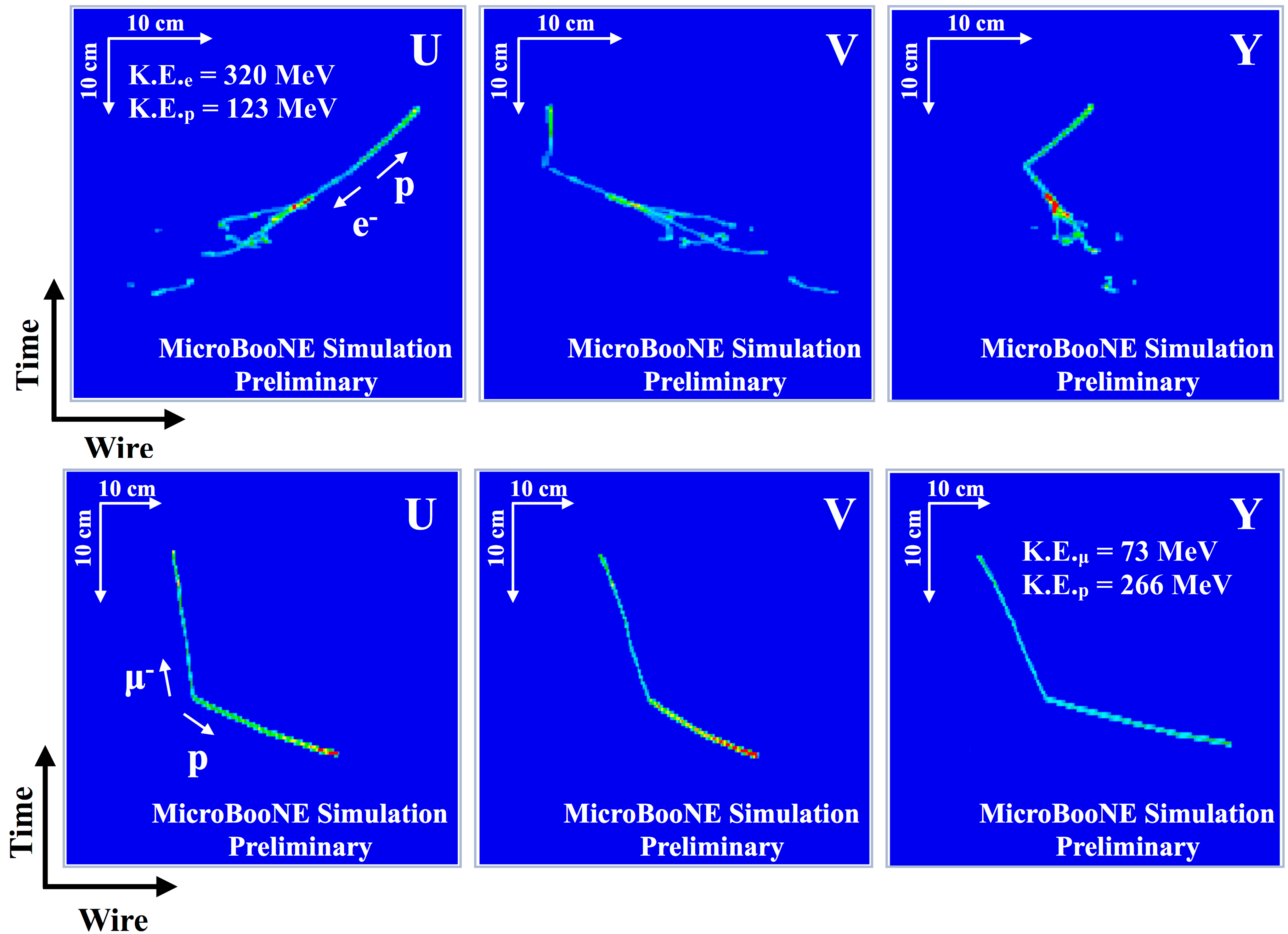


Excess is in the 200-800 MeV range

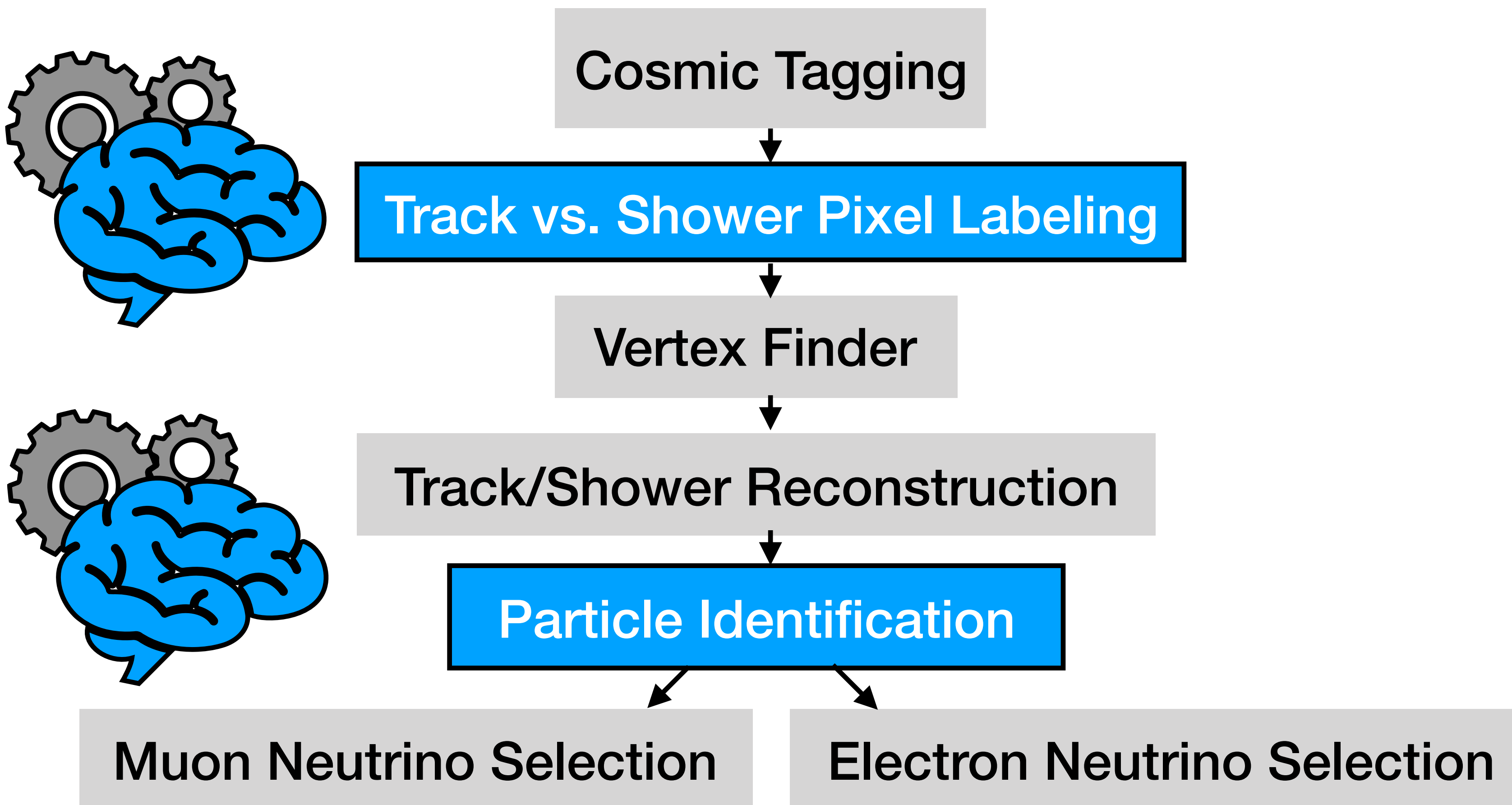
CCQE Events in MicroBooNE

ν_e

ν_μ



MicroBooNE Deep Learning LEE Analysis



Publications:
JINST 12, P03011 (2017)
Phys. Rev. D99, 092001 (2019)

Public Notes:
MICROBOONE-NOTE-1042-PUB
MICROBOONE-NOTE-1051-PUB

MicroBooNE Deep Learning LEE Analysis

- Interested in CCQE events that are:
  - Fully contained in the TPC
  - Between 200-800 MeV neutrino energy
  - Of a two-particle topology consisting of 1 lepton (electron, muon), 1 proton
- Need a good sized sample in data
  - Including all detector effects, dead wires, etc.
- MicroBooNE detector is difficult to simulate

Contributions to total cross section systematic uncertainty (arXiv:1905.09694)

Source of uncertainty	Relative uncertainty [%]
Beam flux	12.4
Cross section modeling	3.9
Detector response	16.2
Dirt background	10.9
Cosmic ray background	4.2
MC statistics	0.2
Stat	1.4
Total	23.8

MicroBooNE Deep Learning LEE Analysis

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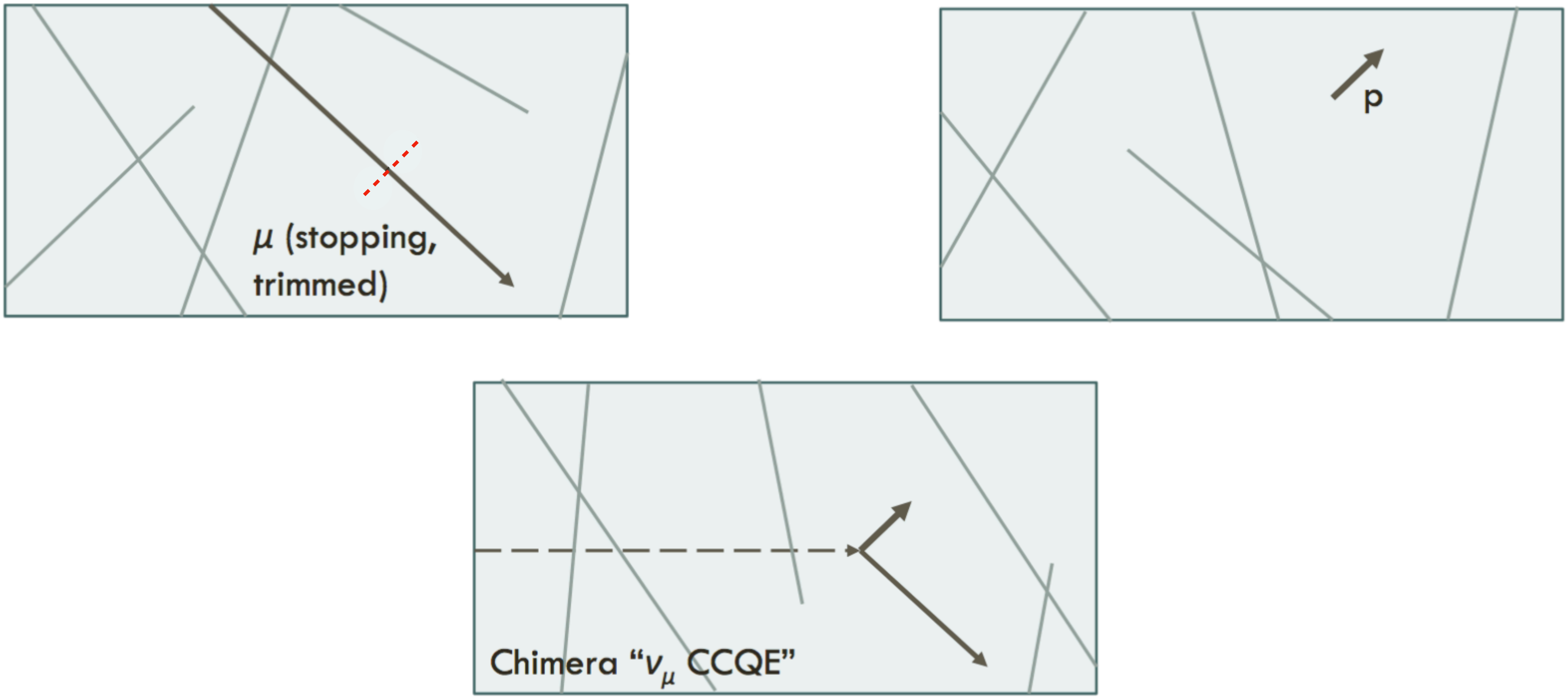
Idea:
Work with data by creating our own "chimera" CCQE-like events

Chimera Events

E.g. A ν_μ CCQE event:



Applications of Chimera Events

- Studies on systematic uncertainties: validate algorithms' performance on samples with known properties
  - Location of vertex and opening angles of lepton/proton are known
- Evaluating selection efficiency, reconstruction's energy resolution for events similar to a target final state
- Create events for re-training a network
  - First pass on MC to teach general interaction features
  - Re-train on chimeras to teach about data/MC differences

Finding the Right Tracks

- Select tracks that closely match a target topology to preserve detector effects
  - For this reason, want to avoid rotating/drastically moving tracks
- Put constraints on specific parameters and search through a pool of existing events
- Care about kinematics (angle, track length) and systematics (position)
  - Parameters: X, Y, Z, θ, ϕ, length
    - Muons and protons
  - Candidate entries must pass selection cuts
- Minimize a likelihood to choose a track, given 6 parameters as input
- To start, focus on MC BNB ν_μ-like events

Maximum Likelihood

- Say we have a defined input parameter, X
- For finding the closest matching value to this X, assume a gaussian function with mean at the value X

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\left(-\frac{1}{2}\frac{(x_i - X)^2}{\sigma^2} \right)}$$

- The width of this gaussian is configurable (σ)
- Each x_i is a candidate “closest match”

Maximum Likelihood

- We have 6 input parameters: X, Y, Z, θ, ϕ, length
- Take the log likelihood product of each gaussian:

$$\Big(-\frac{1}{2}ln(2\pi)-\frac{1}{2}ln(\sigma_x^2)-\frac{1}{2\sigma_x^2}(x_i-X)^2\Big)+\ldots+\Big(-\frac{1}{2}ln(2\pi)-\frac{1}{2}ln(\sigma_l^2)-\frac{1}{2\sigma_l^2}(l-L)^2\Big)$$

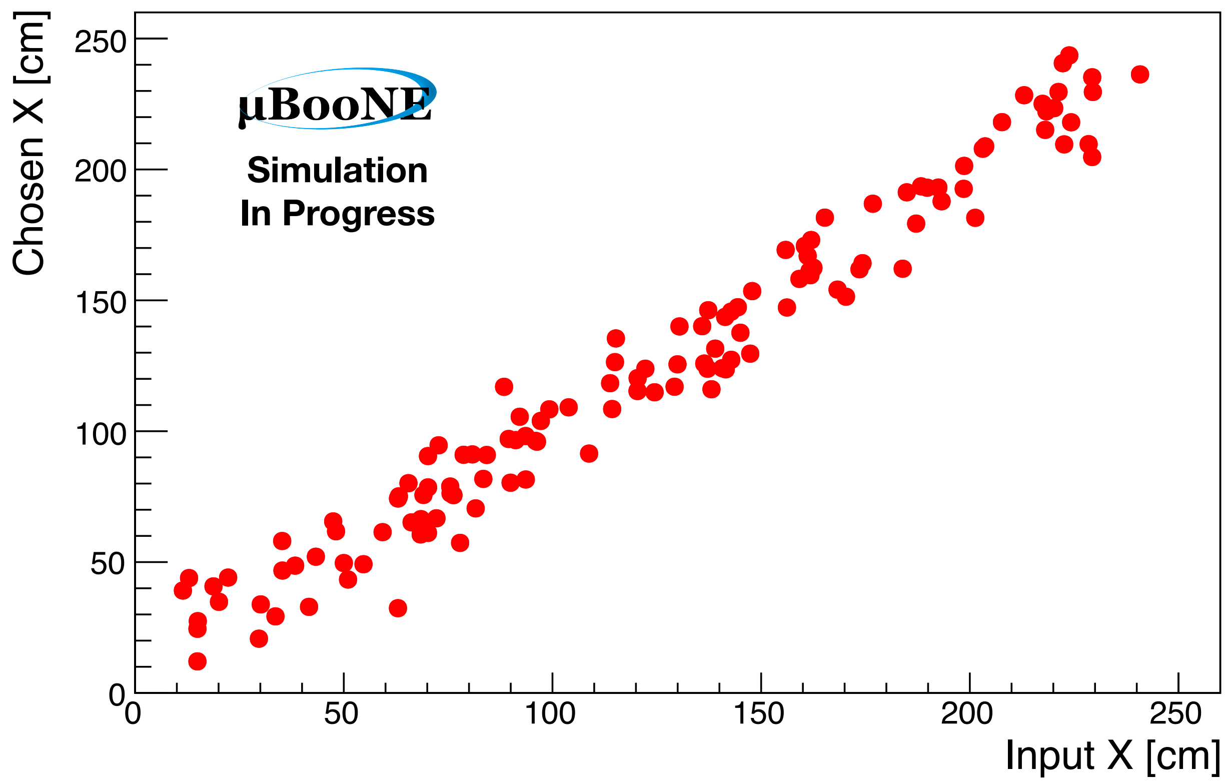
- Loop through each event and compute likelihood, then minimize
- Parameters, sigmas taken as input
    - User can feed in existing events or input desired parameter values
    - Set sigma for each parameter to control precision of match

Choosing a Track: Performance

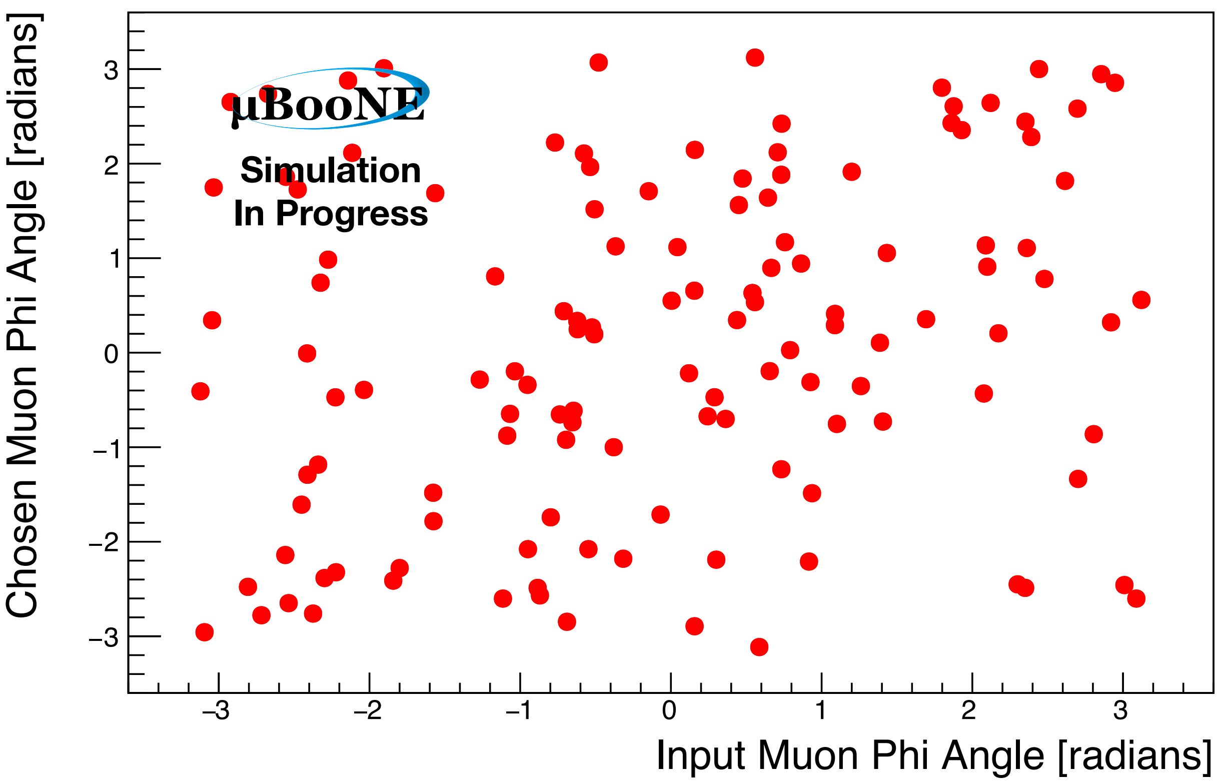
Positive correlation

No correlation

Chosen X vs. Input X



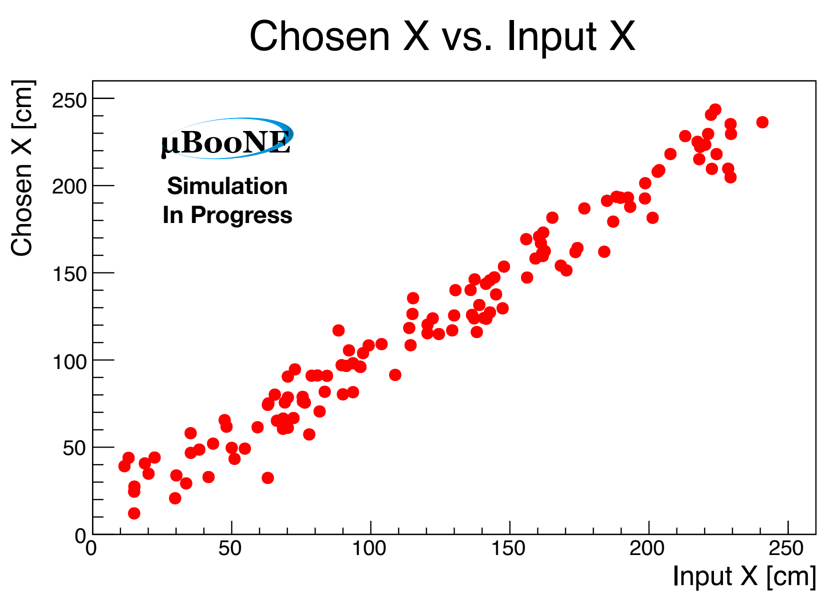
Chosen muPhi vs. Input muPhi

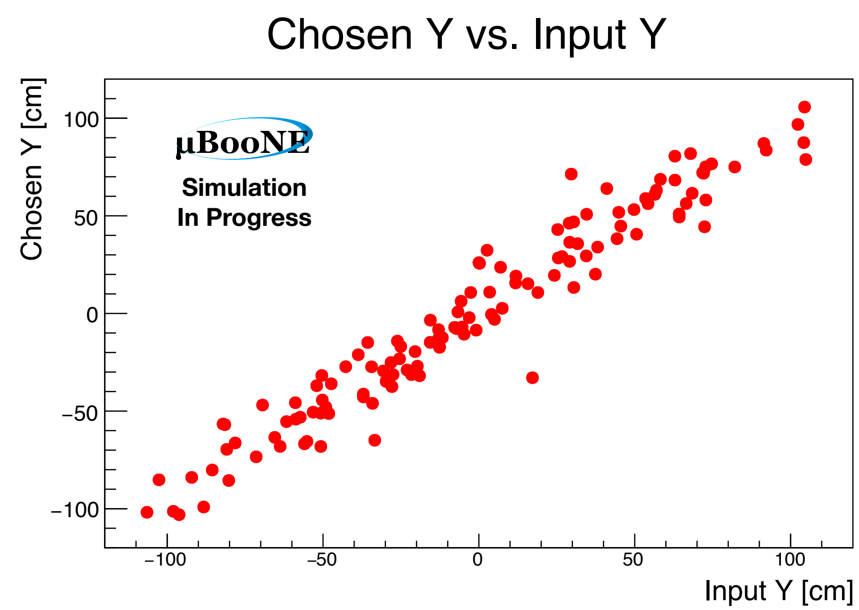


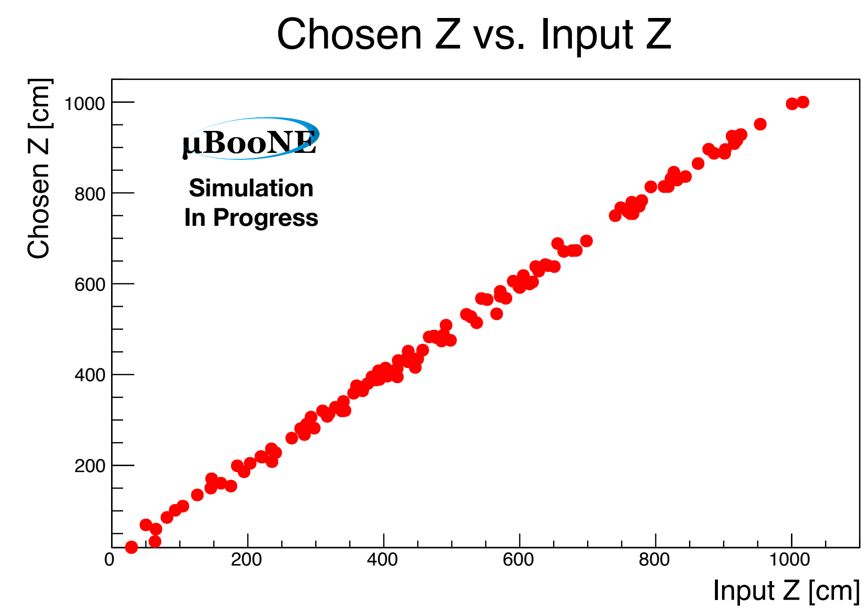
Parameters weighted equally (σ = 1.0)

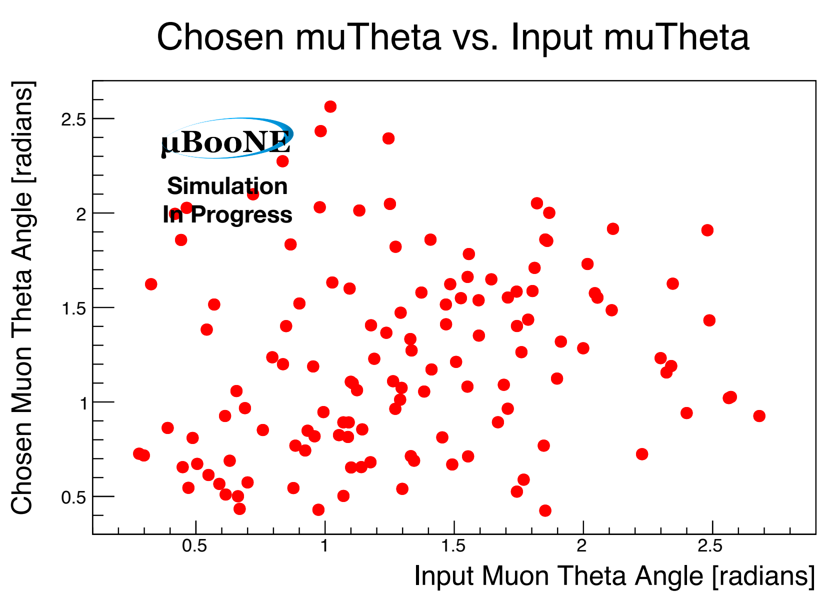
Choosing a Track: Performance

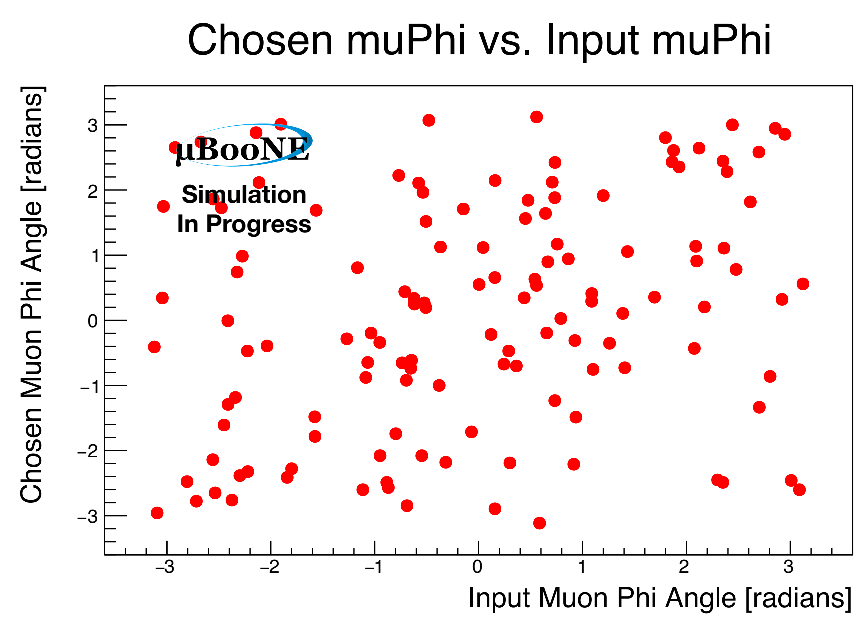
All parameters weighted equally (σ = 1.0)

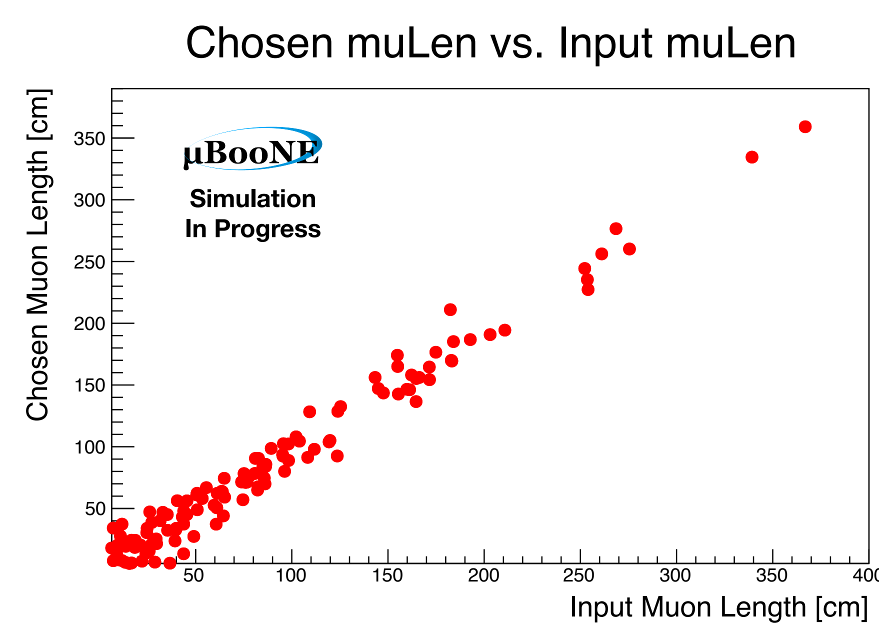




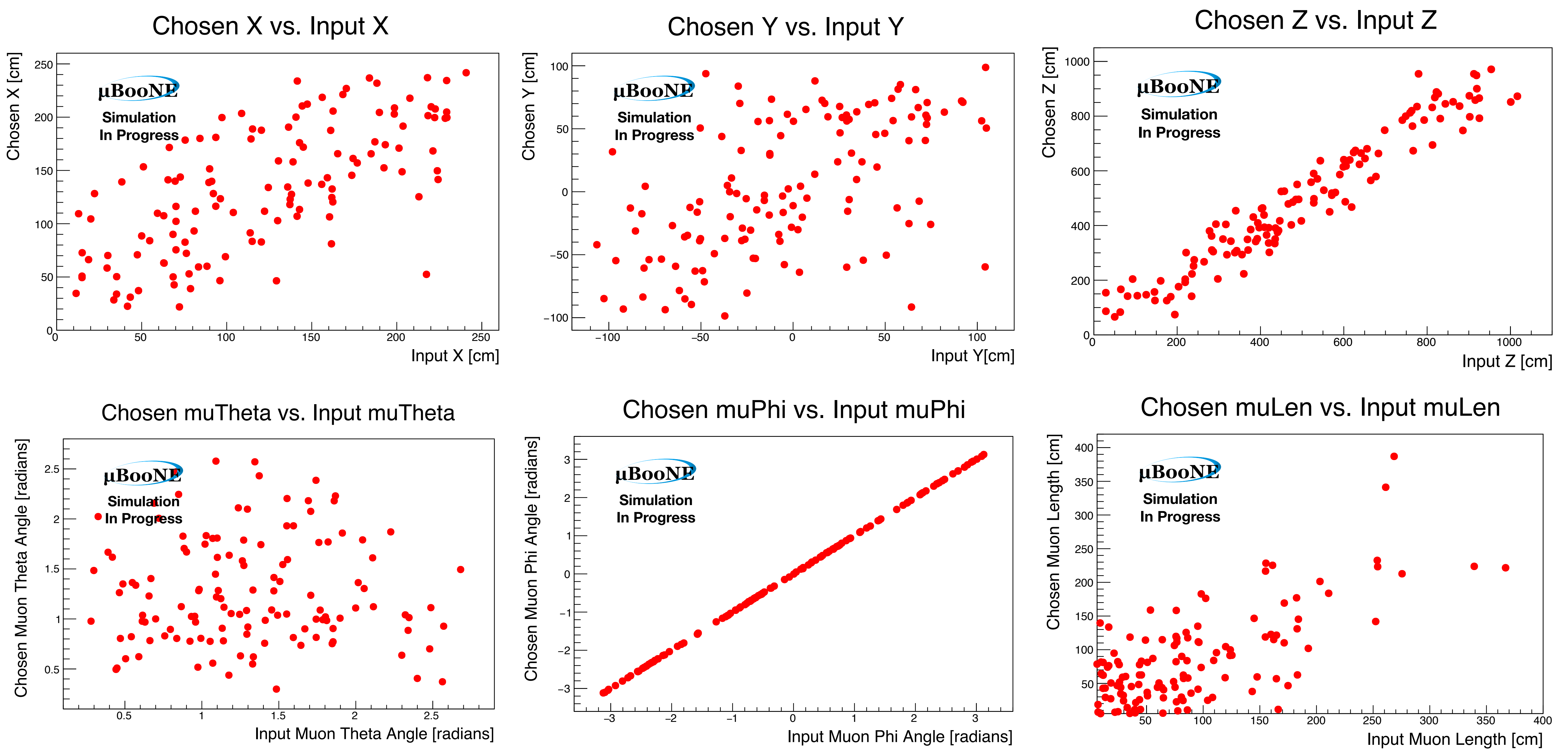






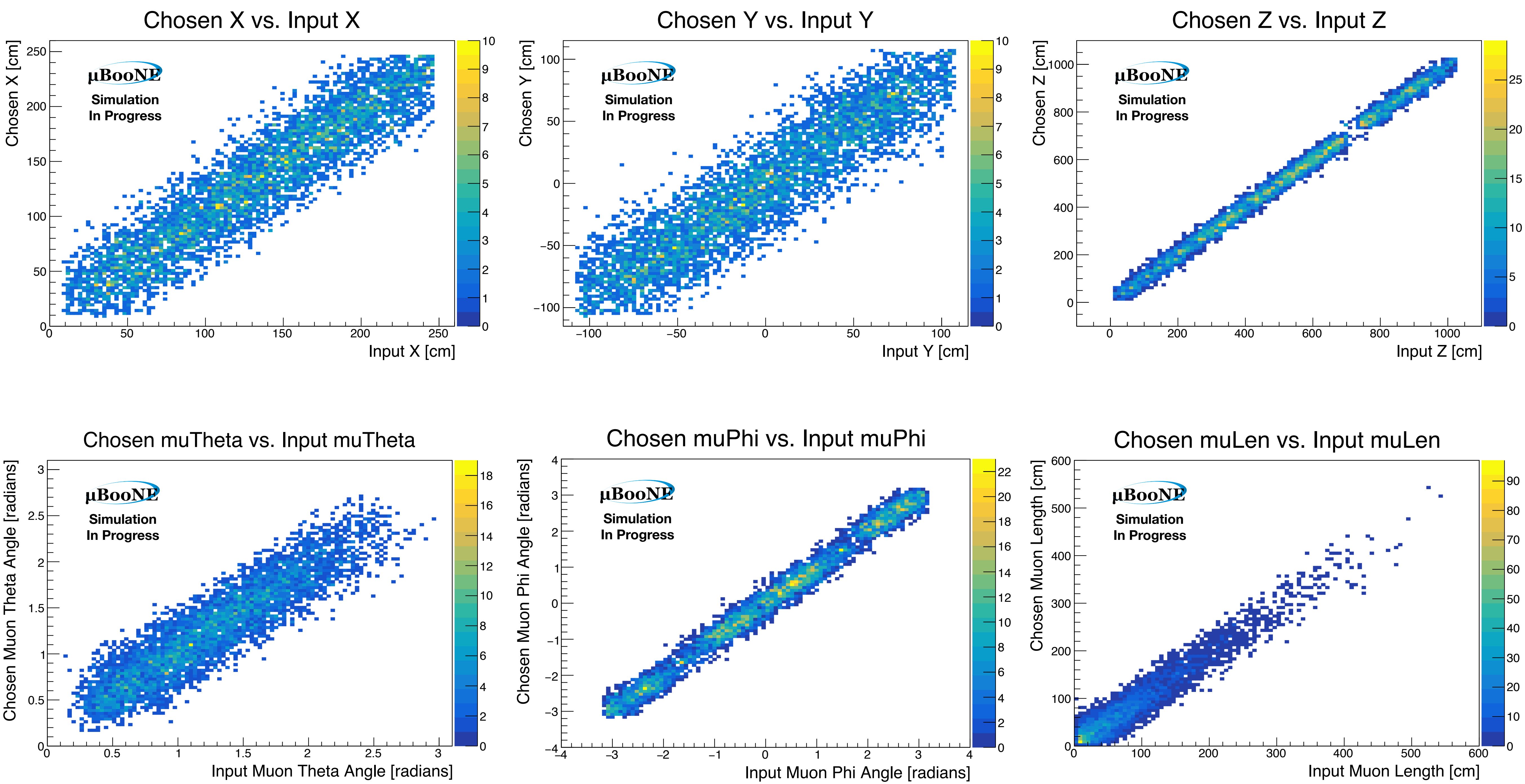


Keeping $\sigma_\phi = 0.0001$ and all other $\sigma = 1.0$, how does it affect the parameters?

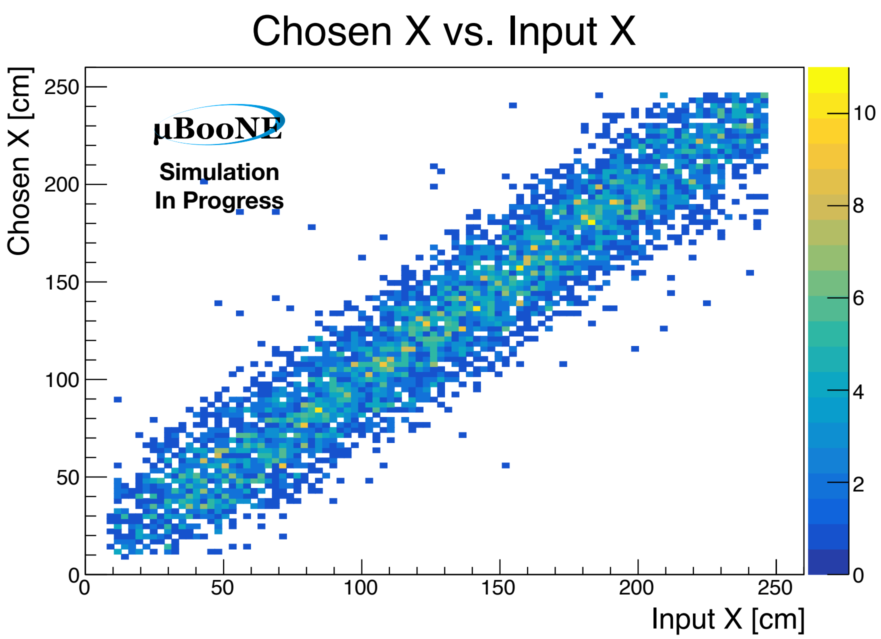


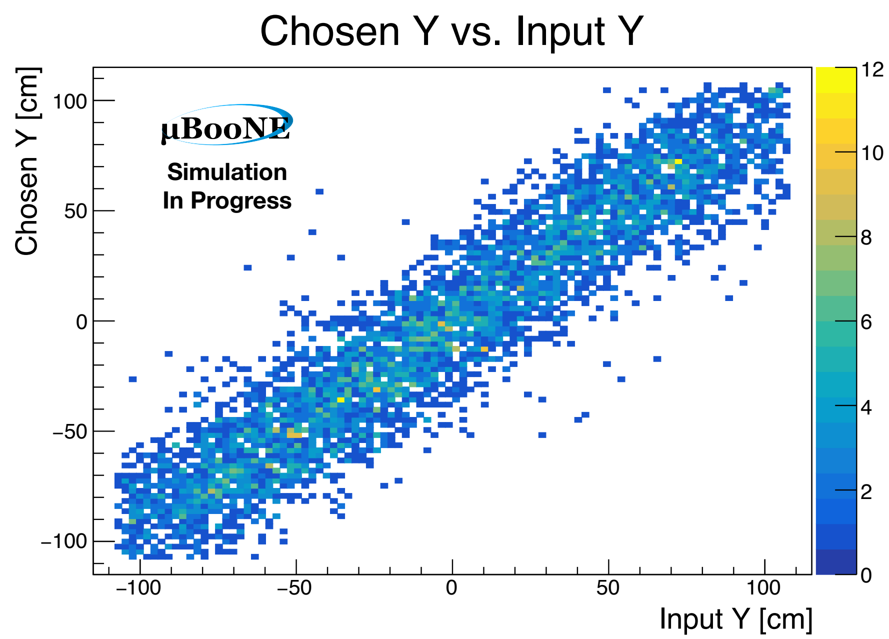
Don't need phi to be this exact

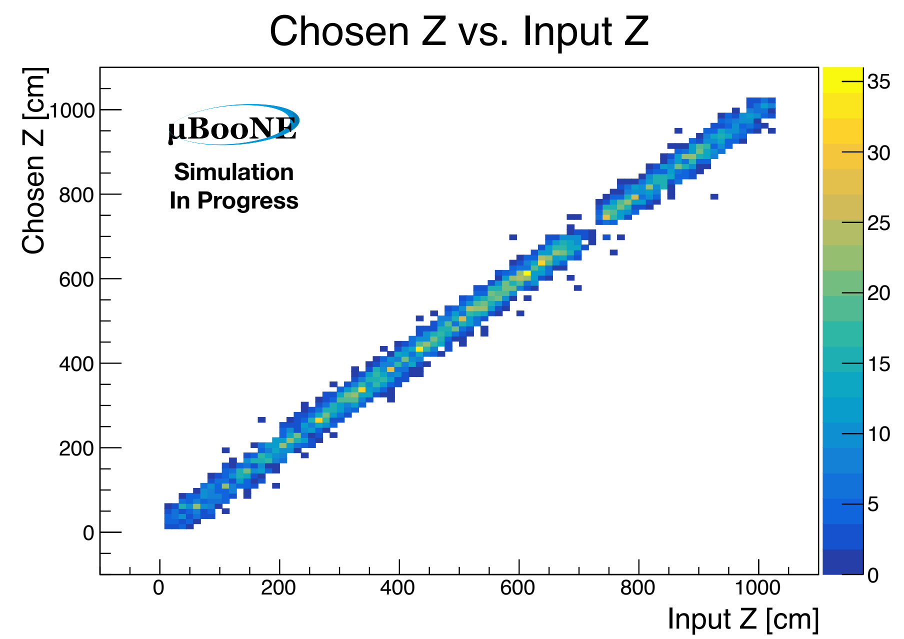
First pass at optimizing ($\sigma_\theta = 0.01$, $\sigma_\phi = 0.01$, all other $\sigma = 1.0$)

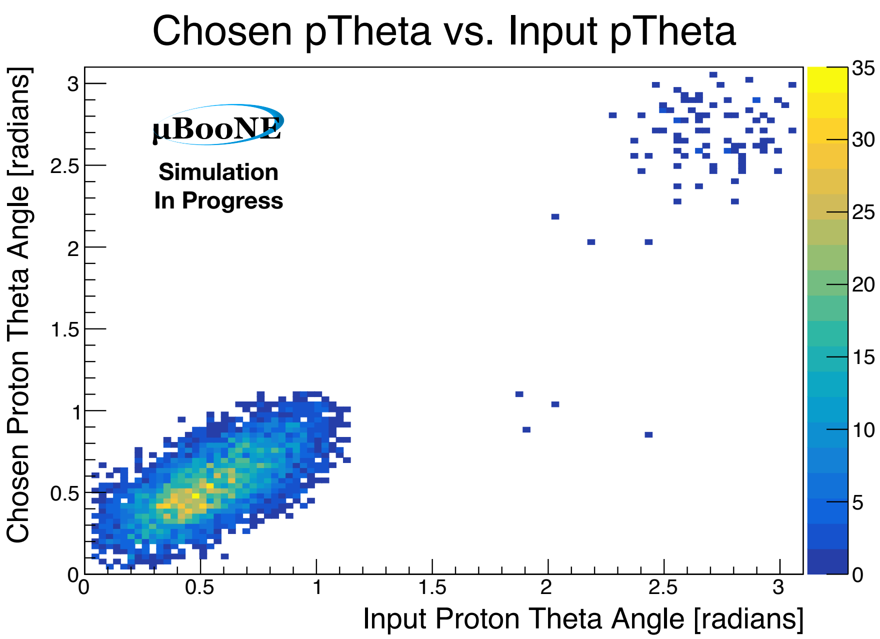


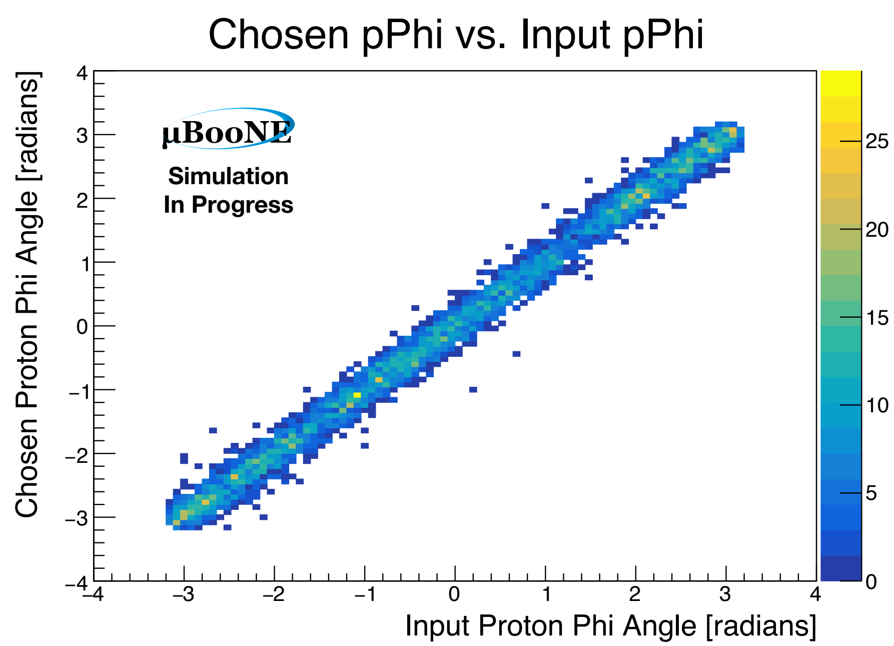
Protons with $\sigma_\theta = 0.01$, $\sigma_\phi = 0.01$, all other $\sigma = 1.0$

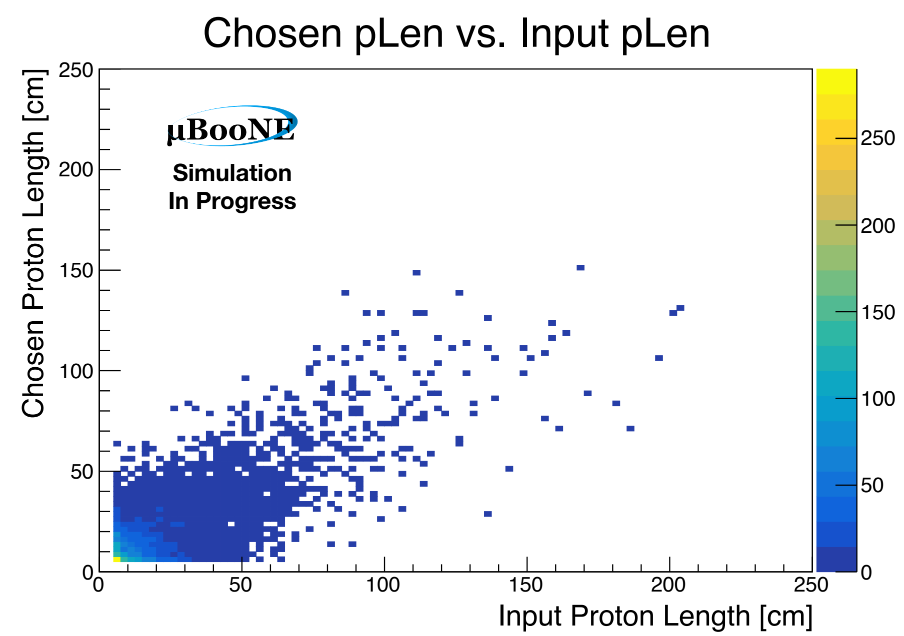






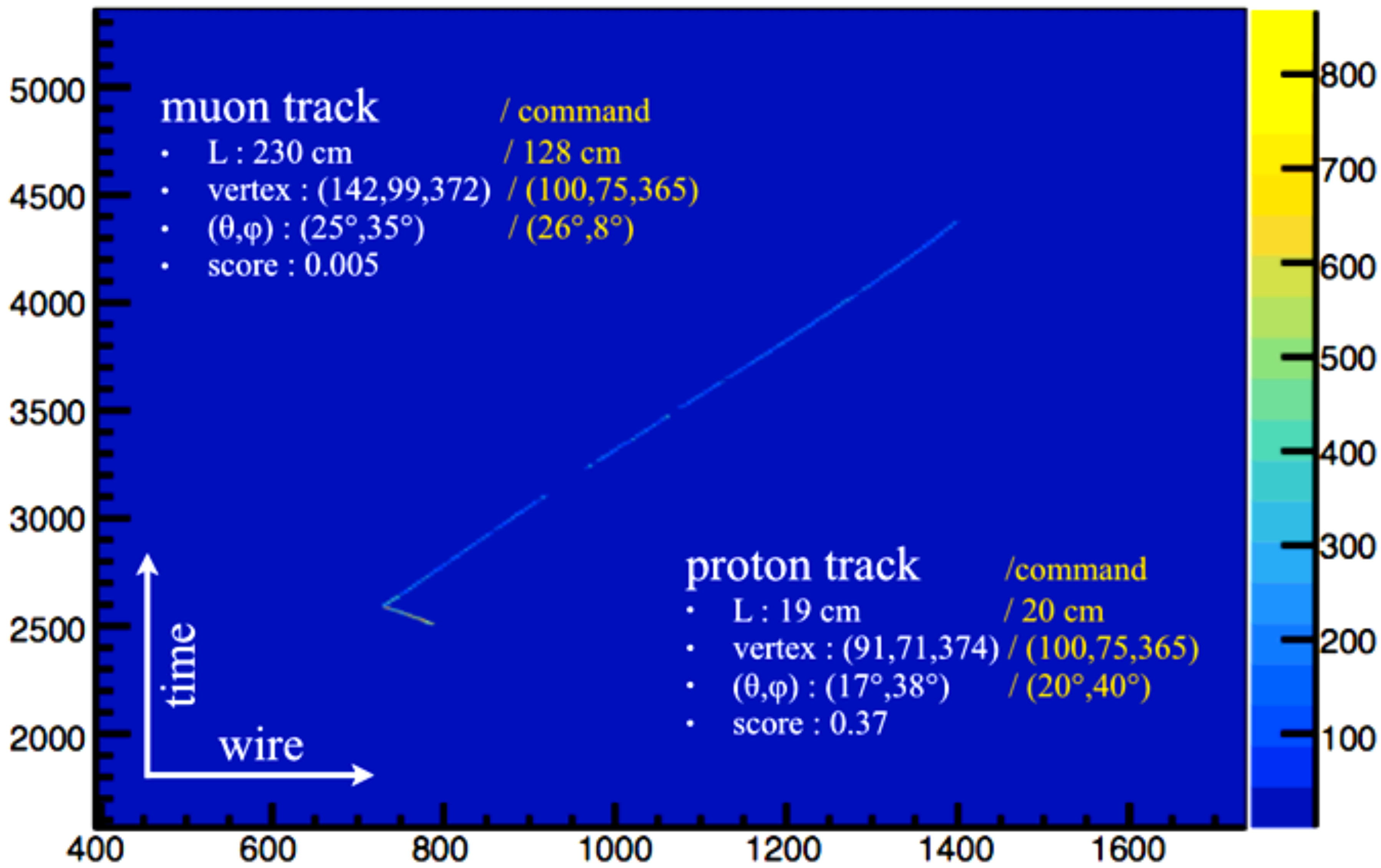






Chimera Events

The first chimera event!



Conclusion and Outlook

- We are able to find closely matching tracks successfully
- Can tune precision of each parameter: X, Y, Z, θ, ϕ, length
    - Muons and protons
    - Electrons to come!
- Next step: produce a large sample of chimera events
- Can use for systematic uncertainties in MicroBooNE going forward!

Thank you!

Backup Slides

Chimera Definition

chimera (kaɪˈmɪərə; kɪ-) *or* **chimaera**

n

1. (Classical Myth & Legend) (*often capital*) *Greek myth* a fire-breathing monster with the head of a lion, body of a goat, and tail of a serpent

2. (Art Terms) a fabulous beast made up of parts taken from various animals

3. a wild and unrealistic dream or notion

...Hopefully not!

ν_μ Event Selection

1. Reconstructed vertex is inside fiducial volume
2. Exactly two tracks reconstructed
3. Tracks are well-reconstructed*
4. Tracks are fully contained in the active volume
5. Consistency between three different initial neutrino energy reconstruction methods*
6. Cuts placed on reconstructed transverse momentum of the interaction*
7. Reconstructed $Q^2 > 0$*
8. Reject events with significant shower activity in either track

*For details, see: MICROBOONE-NOTE-1051-PUB

Detector Systematics

Systematic Sample	Relative Uncertainty [%]
Induced Charge Effect	13.0
Light Yield Model	4.7
Channel Saturation	4.3
Space Charge Effect	3.7
TPC Visibility	3.7
Electron Lifetime	2.9
Misconfigured Channels	1.8
Longitudinal Diffusion	1.7
Transverse Diffusion	1.6
PE Noise	0.4
Wire Response	0.2
Wire Noise	0.1
Electron Recombination	0.1

Latest MicroBooNE Cross-Section Measurement:
arXiv:1905.09694

MicroBooNE Signal Processing Papers:
JINST 13, P07006 (2018)
JINST 13, P07007 (2018)