Systematic Studies for a Photon-like Low Energy Excess Search at MicroBooNE

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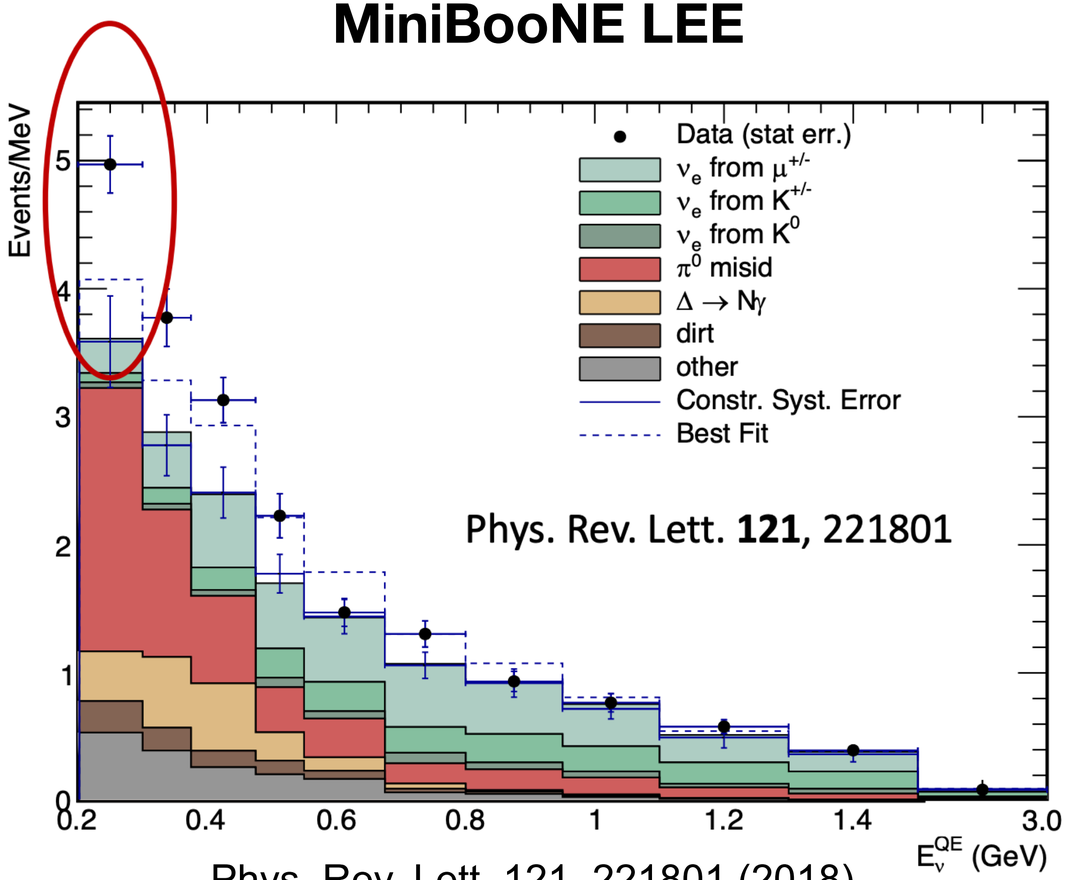
Motivation

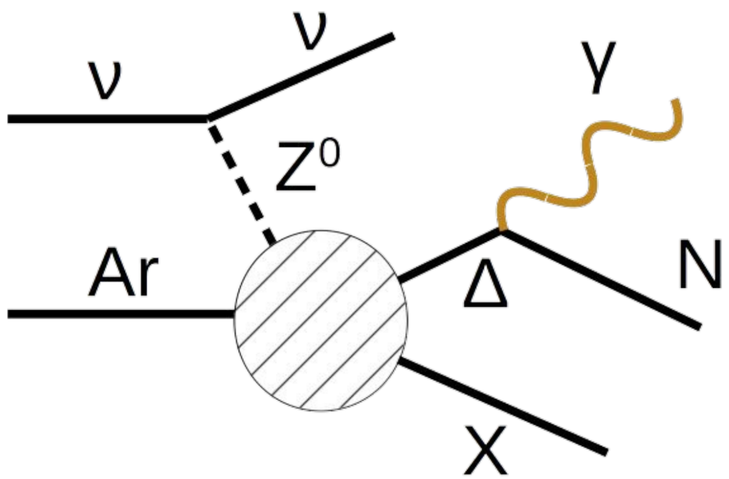
- MiniBooNE Cherenkov detector along the booster neutrino beam
- Observed low energy excess (LEE) of electron neutrino like events.
- Use data from MicroBooNE, a liquid argon time projection chamber (LArTPC), to test an explanation as neutral current (NC) Δ radiative decay
- Develop a Boosted Decision Tree analysis to select NC delta radiative and related events in simulation.
- Perform a measurement upon MicroBooNE unboxing to determine likelihood

MiniBooNE LEE

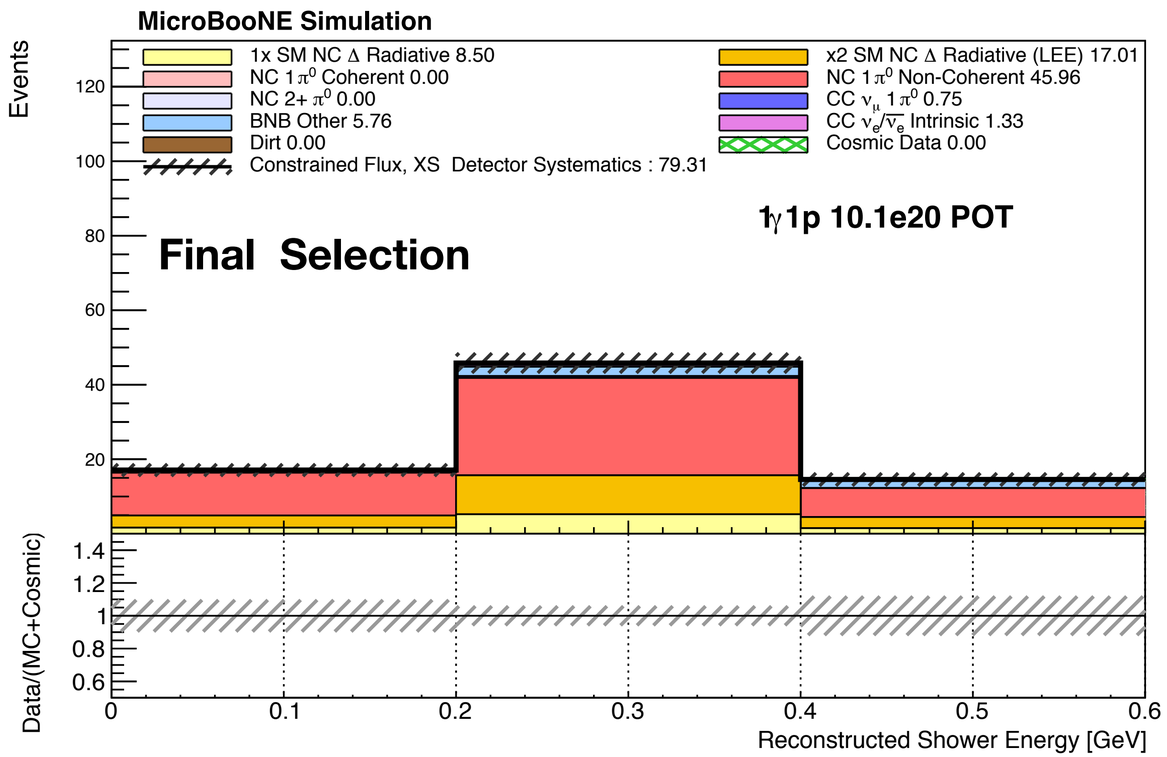


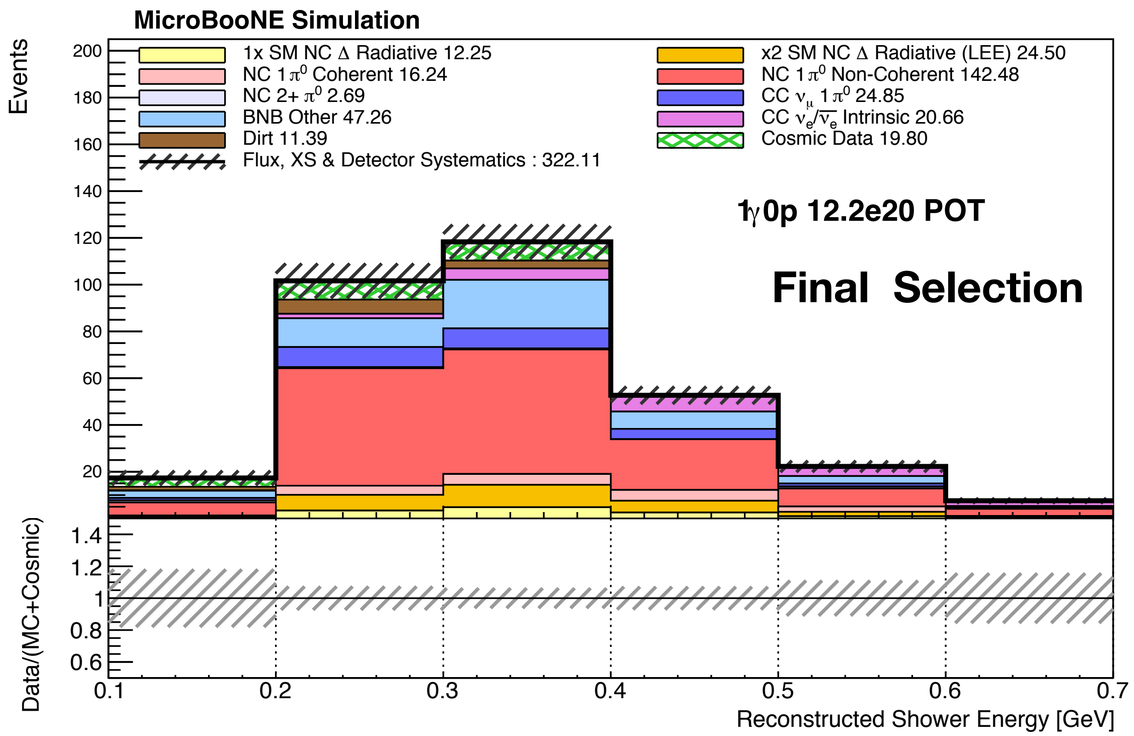
Phys. Rev. Lett. 121, 221801 (2018),

NC Δ Radiative Decay



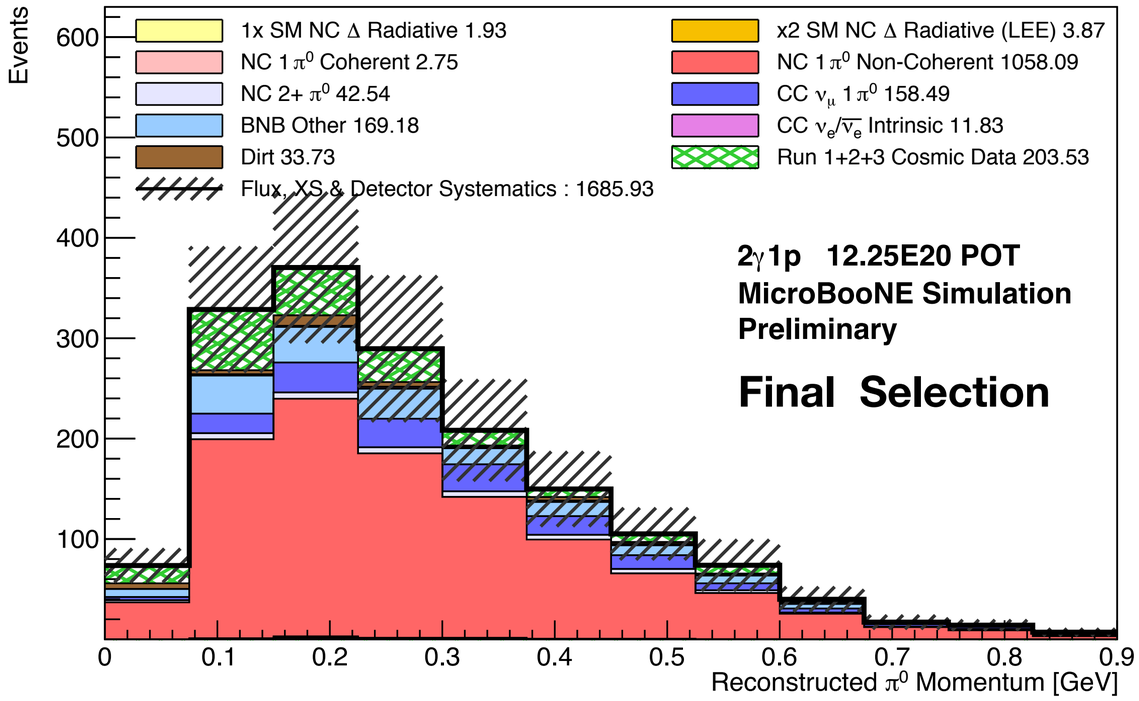
Signal $1\gamma\,\Delta \rightarrow N\gamma$ Analysis

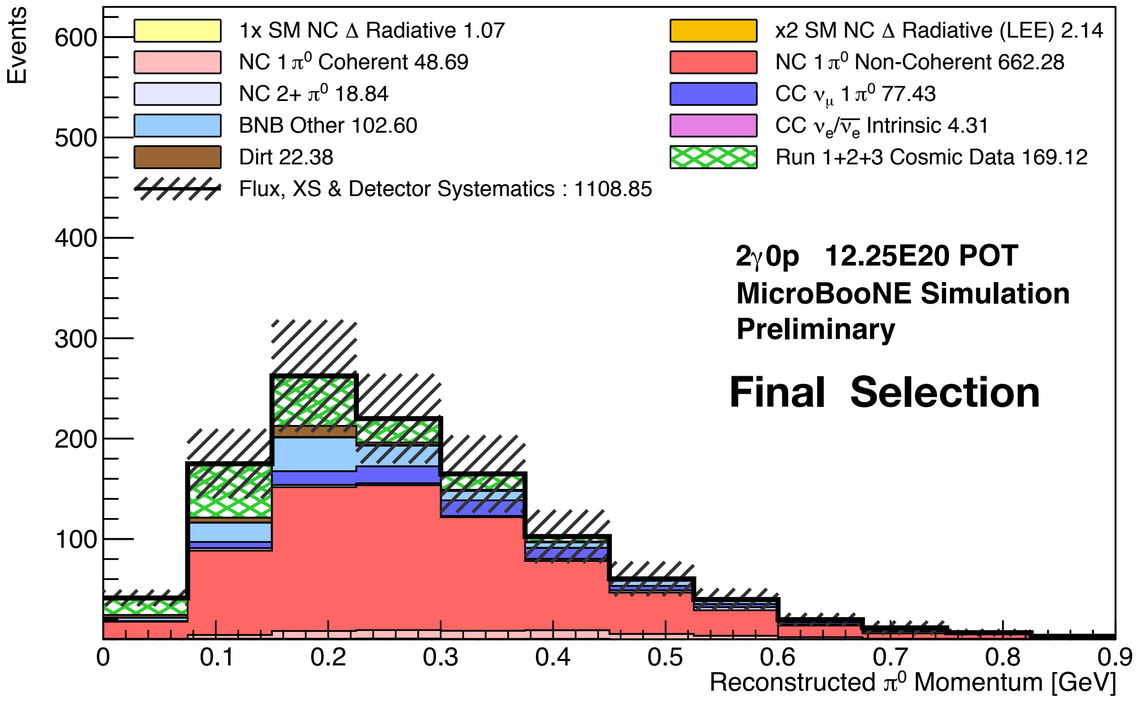




- Central Value MC is sum of Booster Neutrino Beam (BNB) NC π^0 and BNB Other (Thick black line)
- ~85% of backgrounds from π^0
- See Kathryn Sutton's talk from New Perspectives 1.0 (https://indico.fnal.gov/event/23110/contributions/190692/)

Dominant Background 2γ NC π^0 Analysis





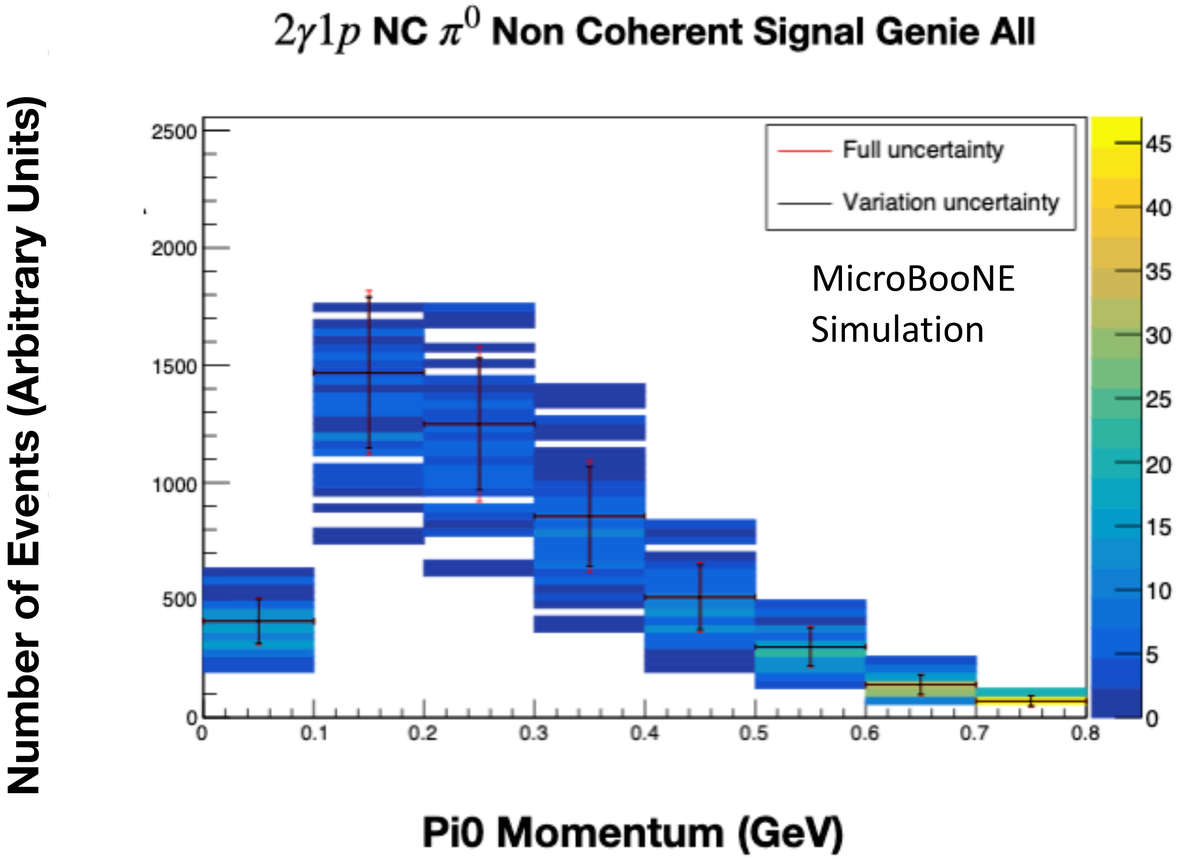
- World's highest stats NC π^0 sample in Argon (See Andrew Mogan's slides)
- Used to constrain most dominant background to our primary signal.
- See Andrew Mogan's talk (https://indico.fnal.gov/event/44451/contributions/192094/)

Event Reweighting Method

- Events are generated via a custom Genie v3 build for MicroBooNE and the MicroBooNE flux simulation.

  http://www.genie-mc.org/
- Evaluates how a shift from underlying CV parameters would impact the likelihood of an event occurring
- Events are given weights based on their "probability" in this universe
- Results can be used to generate correlation/covariance matrices or error bands
- All plots are at final stage of BDT analysis
- Currently including 47 **flux** (13) and **cross-section** (34) re-weighable systematics

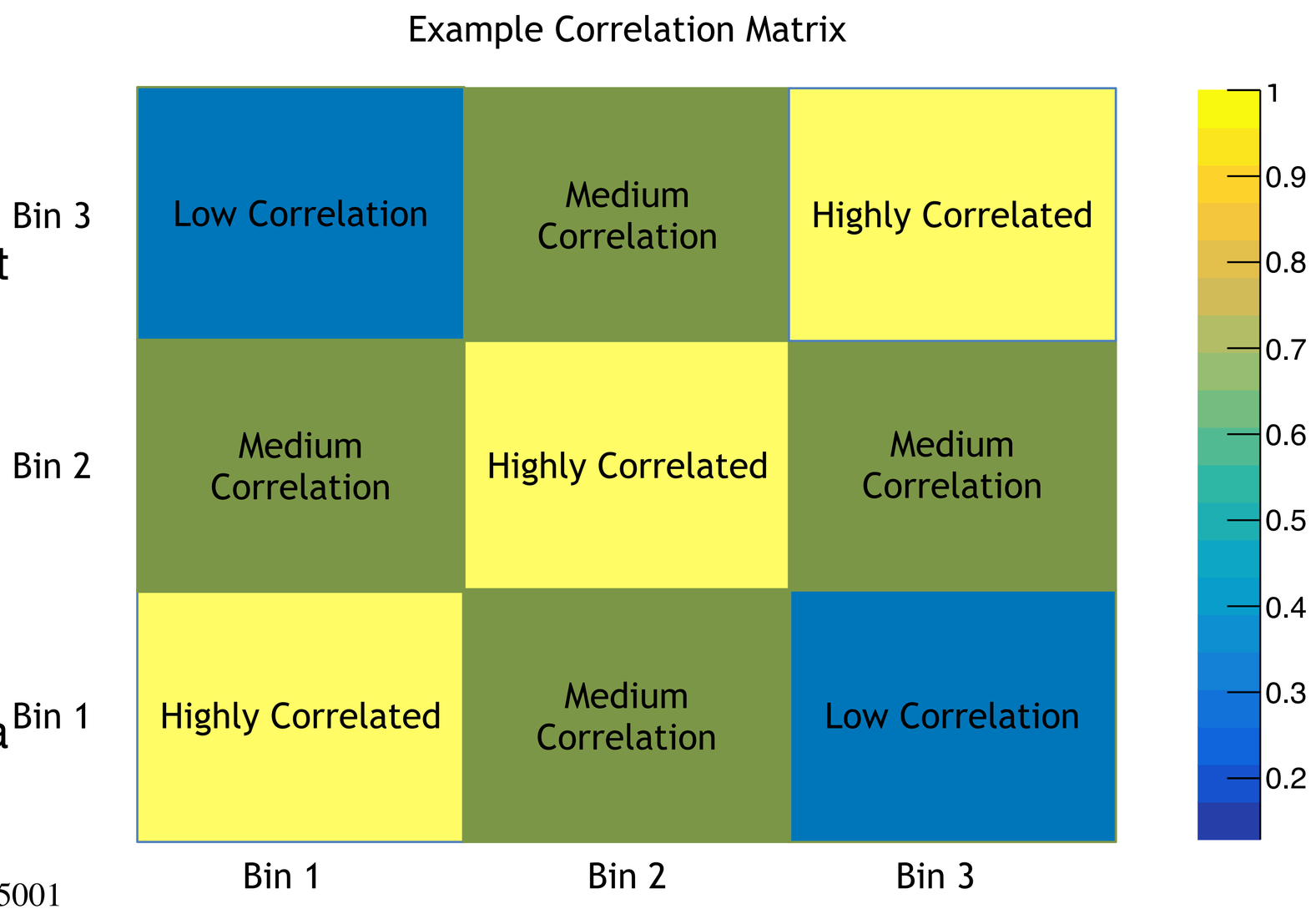
Combined Genie Variations



Black bar is uncertainty of particular variation in title
Red bar (barely visible) is combined uncertainty from all final analysis variations

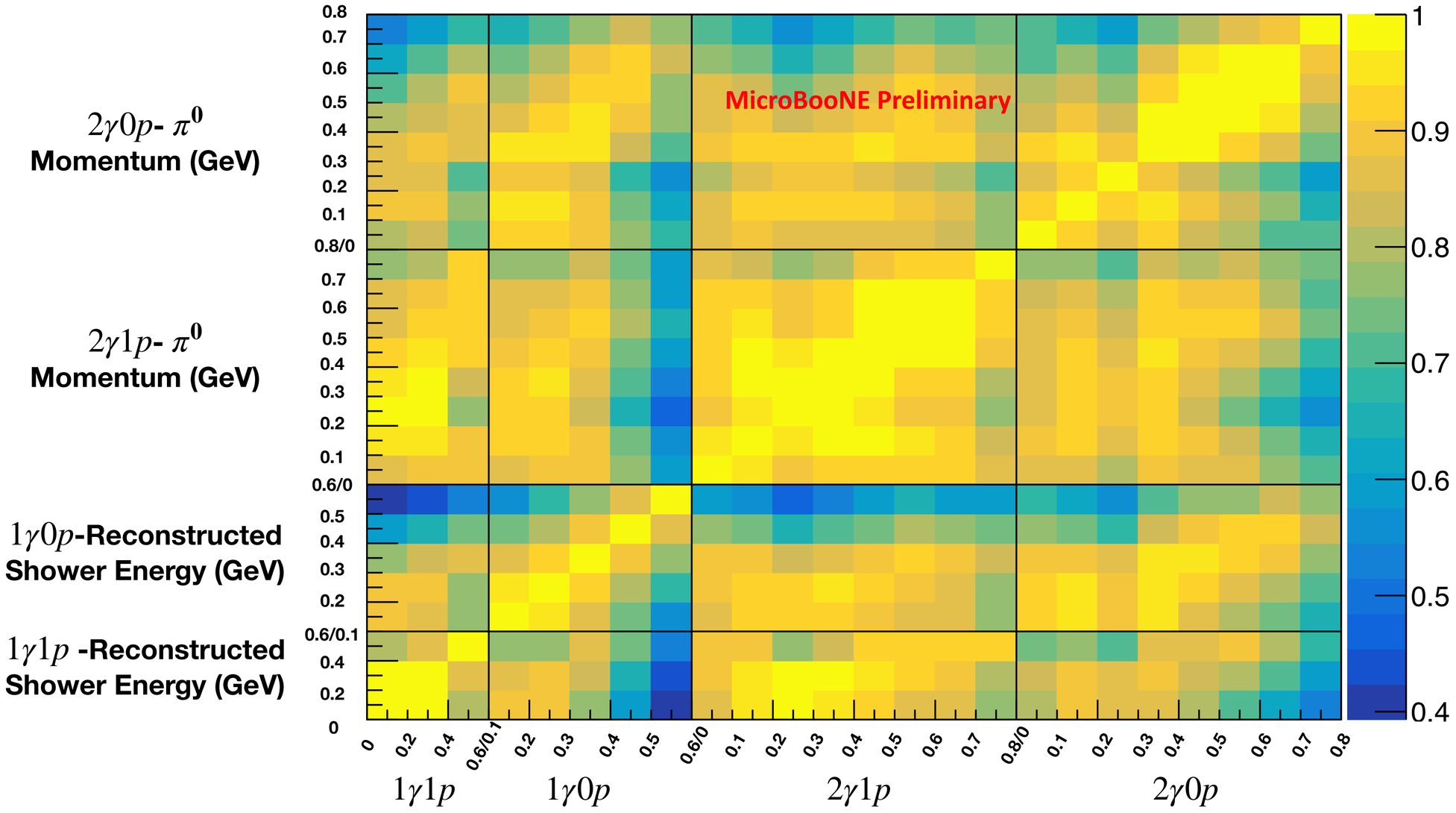
Short Baseline Neutrino Fitting Module: SBNFit

- "SBNfit is a fitting framework that allows for combined fit … with full systematic correlation taken into account "
- Correlation matrices show how correlated bins of data are.
- Performs constraint analysis and in process of testing data fits



Cianci et al., PhysRevD.96.055001

Collapsed (combined subchannels) Correlation Matrix



High correlation between signal and backgrounds

Constraint Estimation

- We evaluate the level of constraint on the uncertainty of the final $1\gamma 1p$ signal by considering the NC (neutral current) π^0 sideband ($2\gamma 1p$) measurement using the following the method.
- Form a matrix of $1\gamma 1p$ backgrounds and $2\gamma 1p$ selection (M_{ij}).
- For the $2\gamma 1p$ portion assume $\sigma_i^{\text{data}} = \sqrt{N_i^{\text{data}}}$, and $N_i^{\text{data}} = N_i^{MC}$
- Calculate a new matrix $(M_{ij}^{-1})^{new} = M_{ij}^{-1} + 1/N_i^{MC}$ and re-invert for constrained uncertainty on the $1\gamma 1p$ bins.

Variation Description	**Unconstrained Uncertainty** $1\gamma 1p$	**Constrained Uncertainty** $1\gamma 1p$	**Unconstrained Uncertainty** $1\gamma 0p$	**Constrained Uncertainty** $1\gamma 0p$
All genie variables combined	22.64%	7.21%	13.82%	4.48%
Fractional cross section for N charge exchange	9.58%	6.69%	1.58%	1.10%
Axial mass for NC resonance ν production	18.94%	5.45%	10.44%	3.01%
Variation of angle of π with respect to detector z axis	7.83%	4.91%	0.98%	0.62%
Vector mass for NC resonance ν production	8.06%	4.77%	4.41%	2.61%
Fractional cross section for N charge exchange	9.32%	4.36%	4.18%	1.96%
Skin Depth-electric currents penetrate conductor	4.93%	3.41%	4.01%	2.77%
π absorption probability	5.12%	3.26%	3.33%	2.13%
Primary Hadron SW Central Spline Variation for π^+	4.51%	3.23%	3.86%	2.76%
N absorption probability.	4.91%	3.21%	4.61%	3.02%

Highest uncertainty variations following constraint estimation

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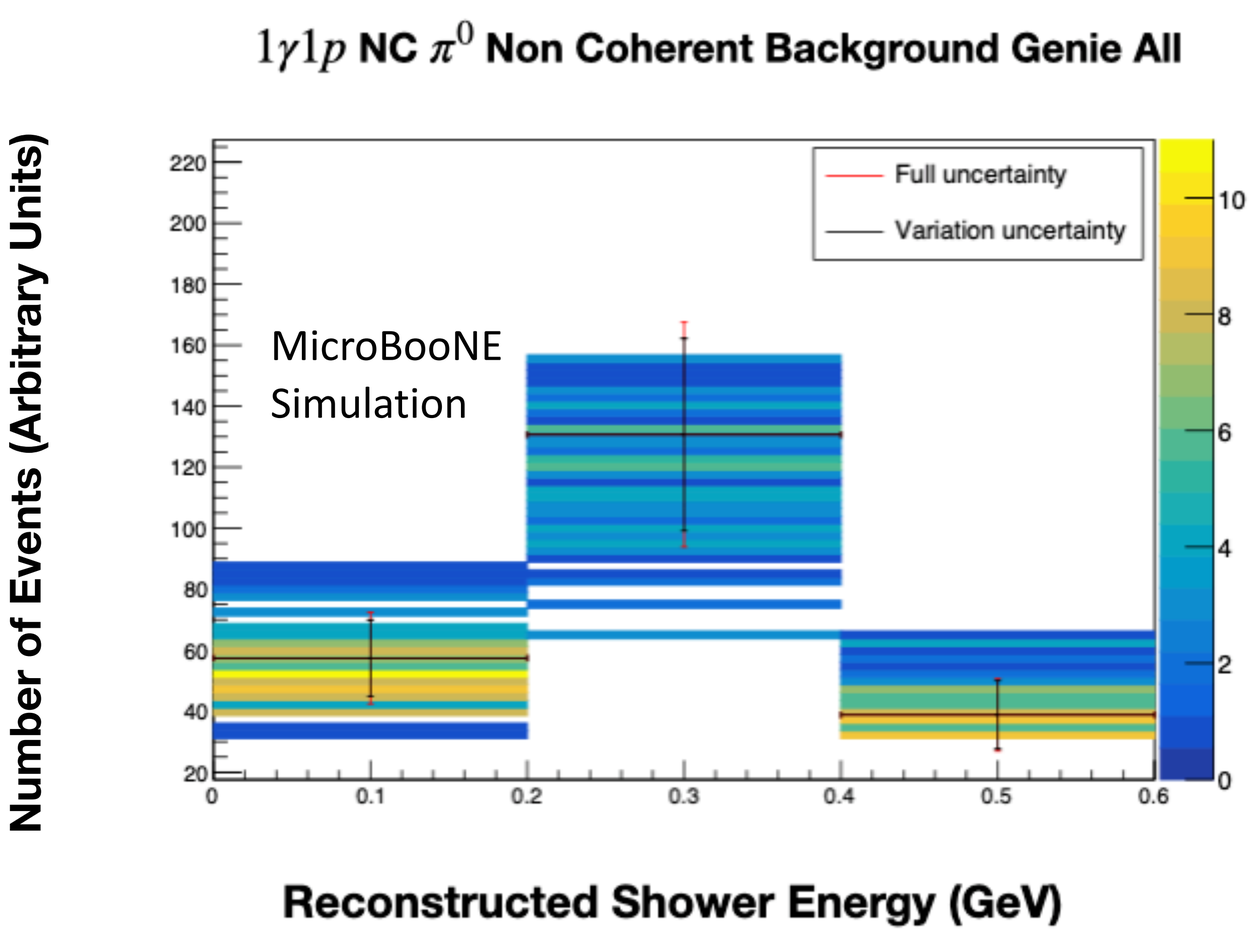
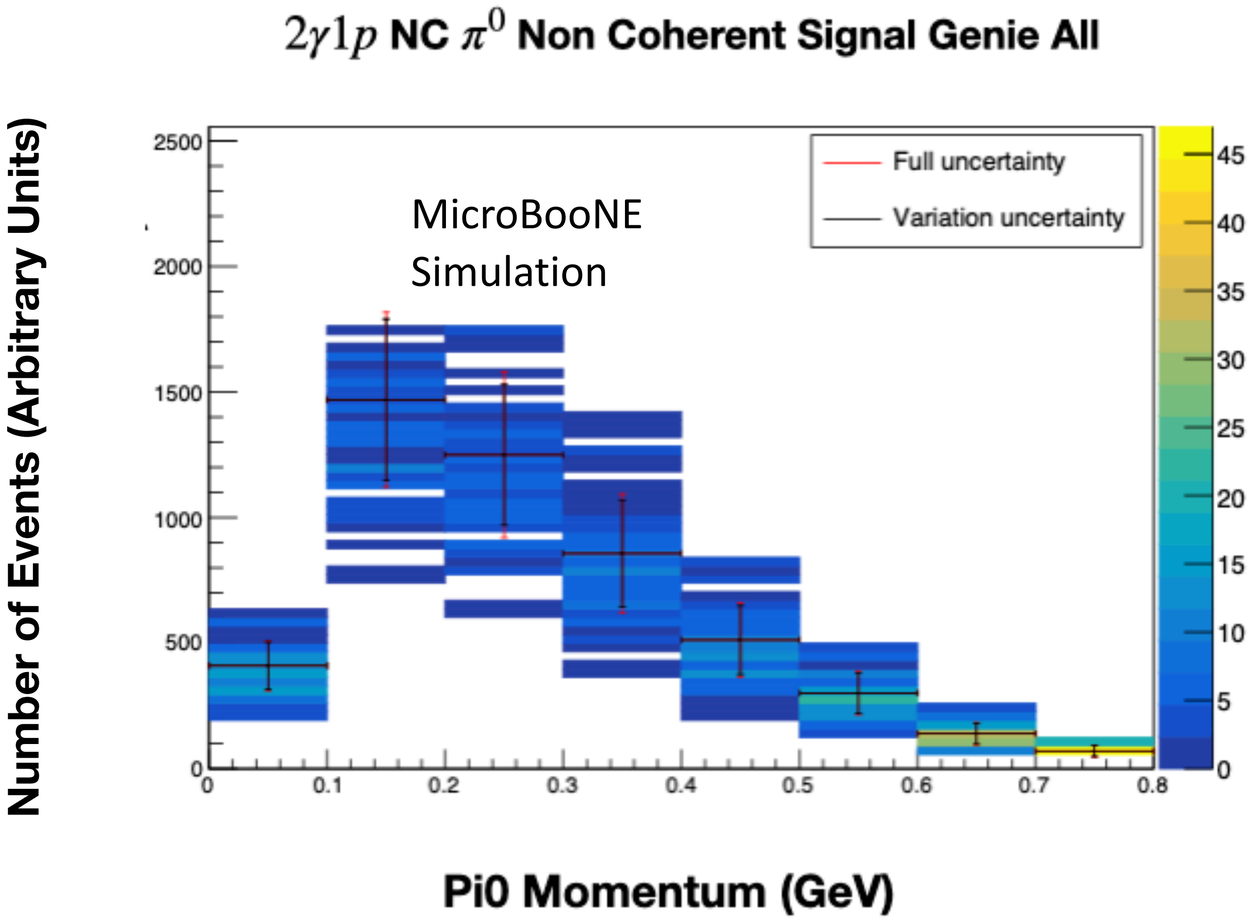
Combined Genie Variation

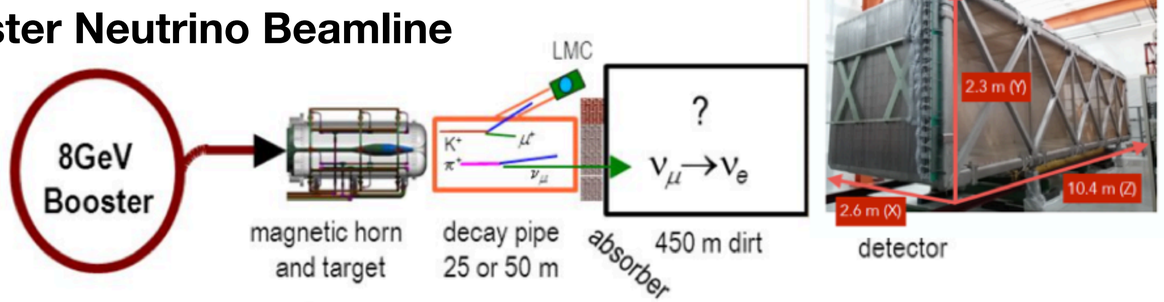




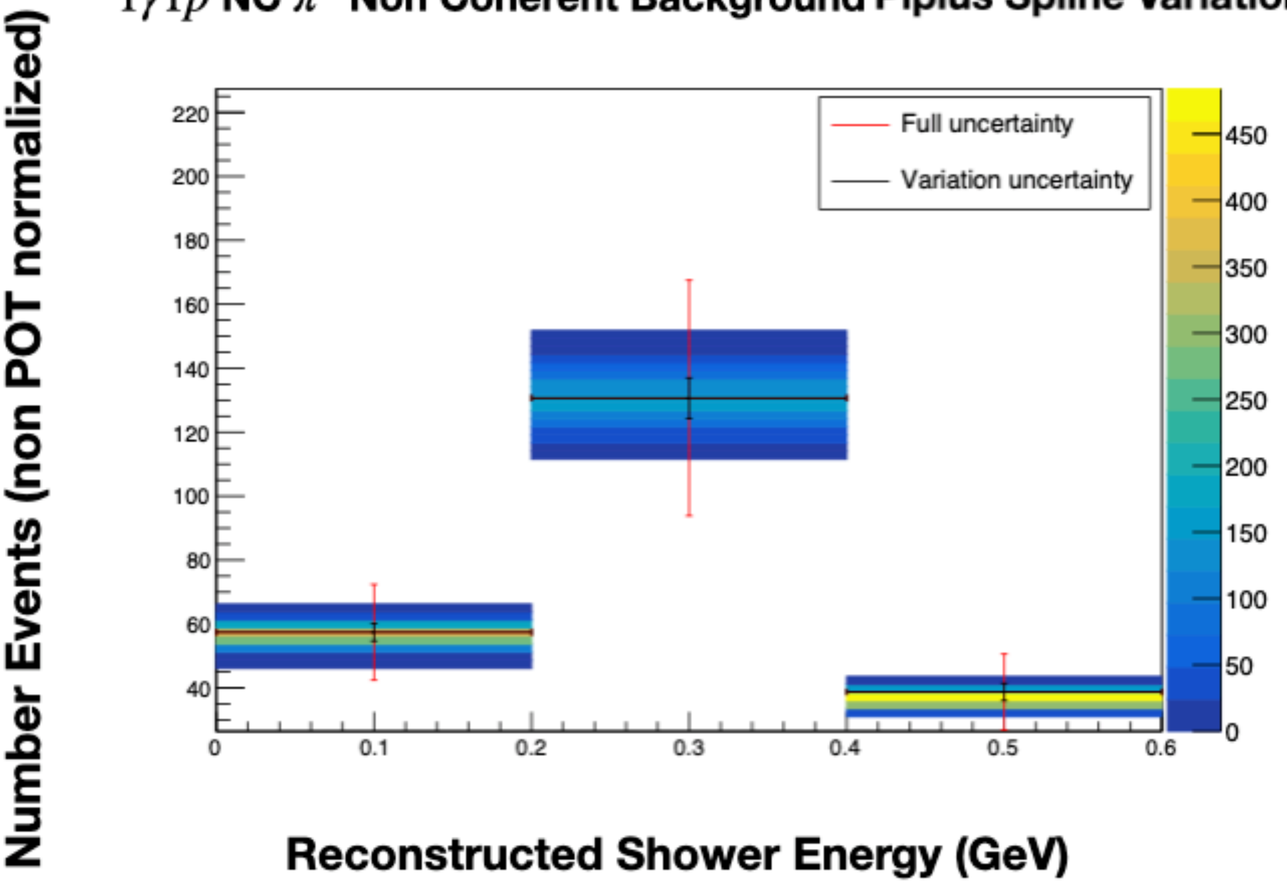
Variation plots using the Eventweight Method for combined GENIE variations on NC π^0 non-coherent signal subchannels. (majority of all NC π^0). Y axis correlates to number of events but is not normalized to the POT of the detector. Coloration depicts the number of “multisims" that are in each bin of x and y.
“GENIE All” (the combined GENIE variation) includes a number of highly correlated parameters for our backgrounds i.e. NC Resonance Axial Mass, so the constraint is powerful (3.11 reduction factor)

Flux π^+ Variations

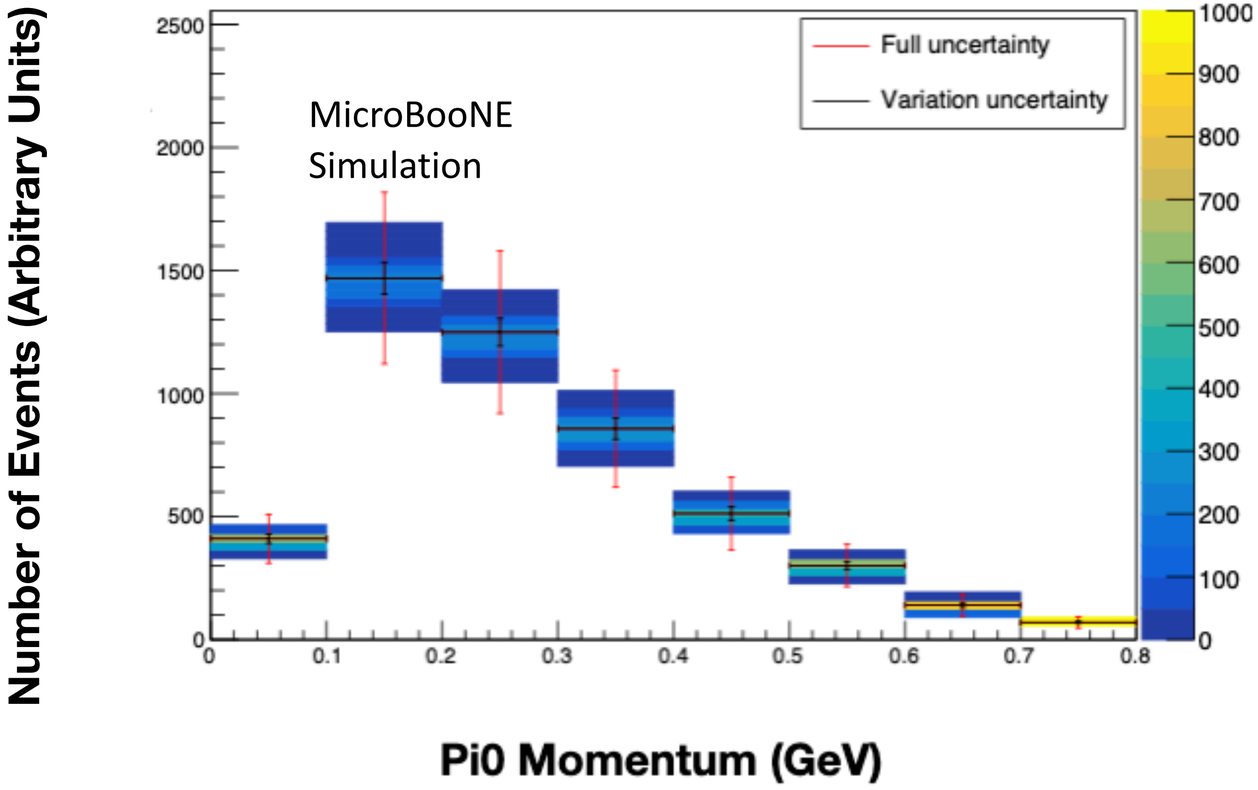
Booster Neutrino Beamline



$1\gamma 1p$ NC π^0 Non Coherent Background Piplus Spline Variation



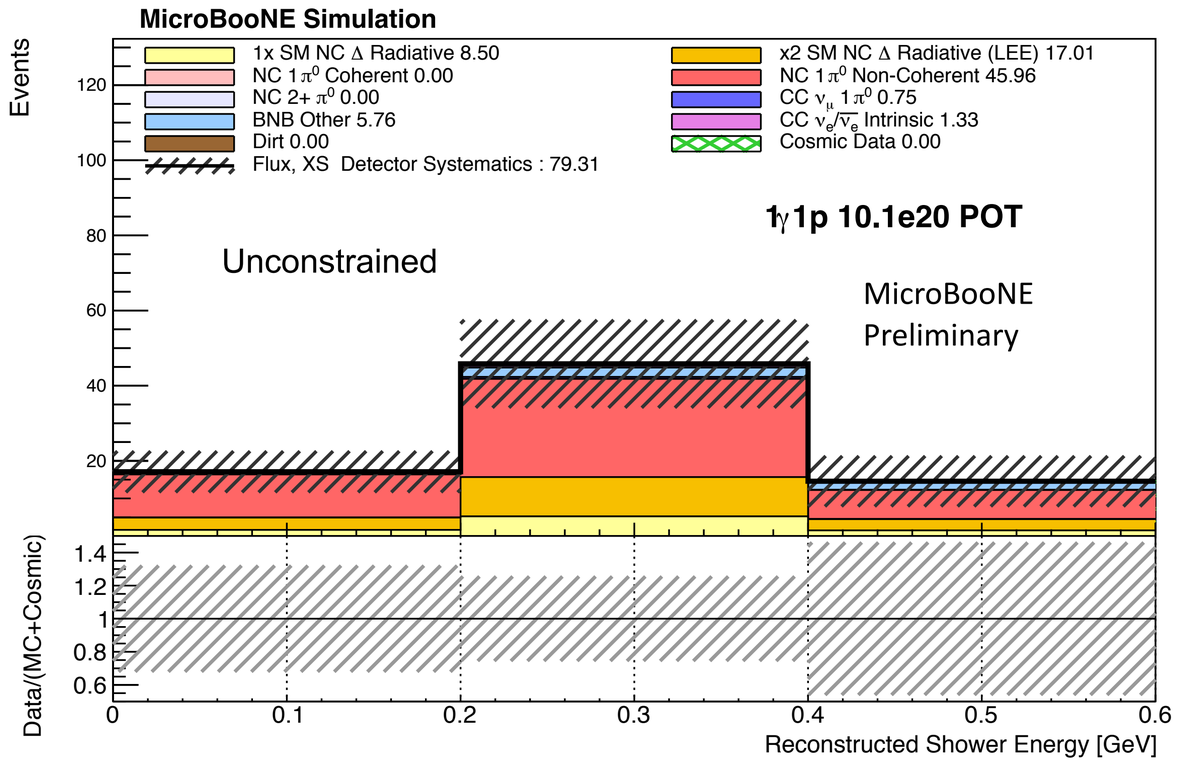
$2\gamma 1p$ NC π^0 Non Coherent Signal Piplus Spline Variation

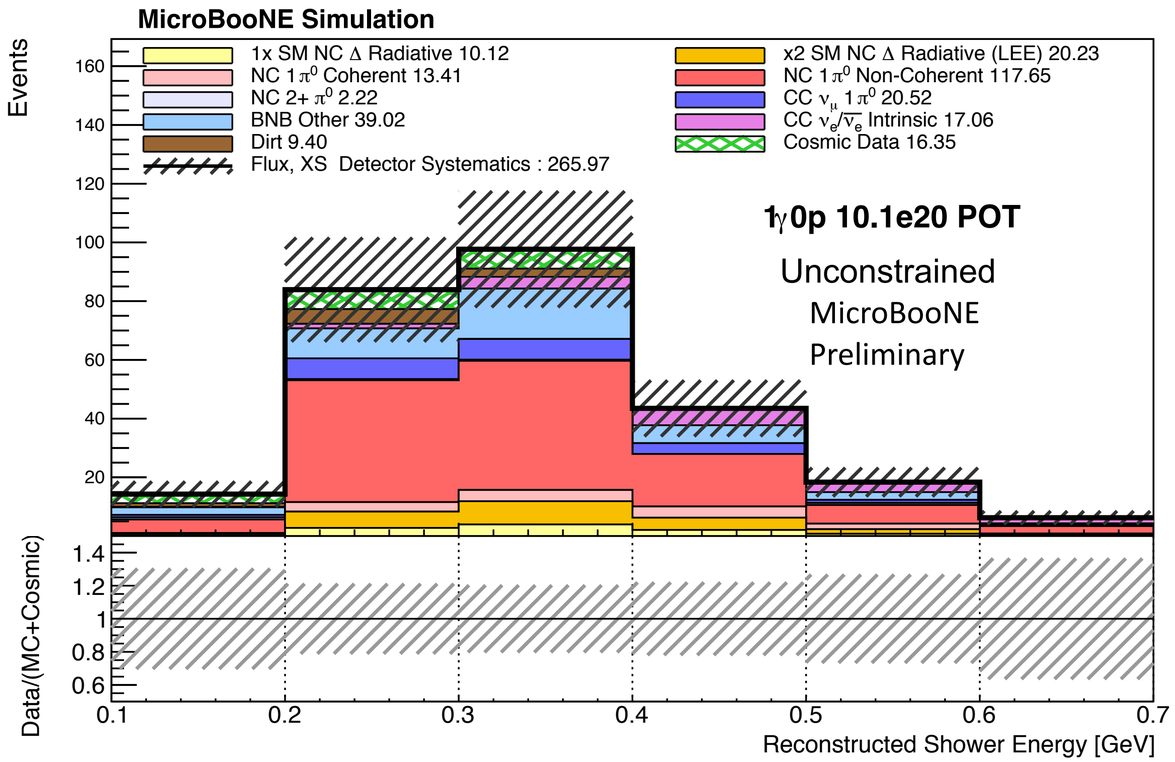


Variation plot illustrating the central Sanford Wang π^+flux uncertainty effect on the $NC\pi^0$ non-coherent signal in the final $2\gamma 1p$ and $2\gamma 0p$ selection. As the primary signal for neutrino production it has a comparably large uncertainty compared to other flux variations.
Flux variations have smaller uncertainties but aren't specific to our signal so the constraint is only somewhat effective (1.40 reduction factor)

Results

- A complete flux and cross section systematic study has been performed for the single photon analysis.
- **The per bin constraint on the $1\gamma 1p$ and $1\gamma 0p$ effectively shows a ~x3 reduction in systematics**
- Testing for data analysis is underway using simulated uncertainties and matrices.





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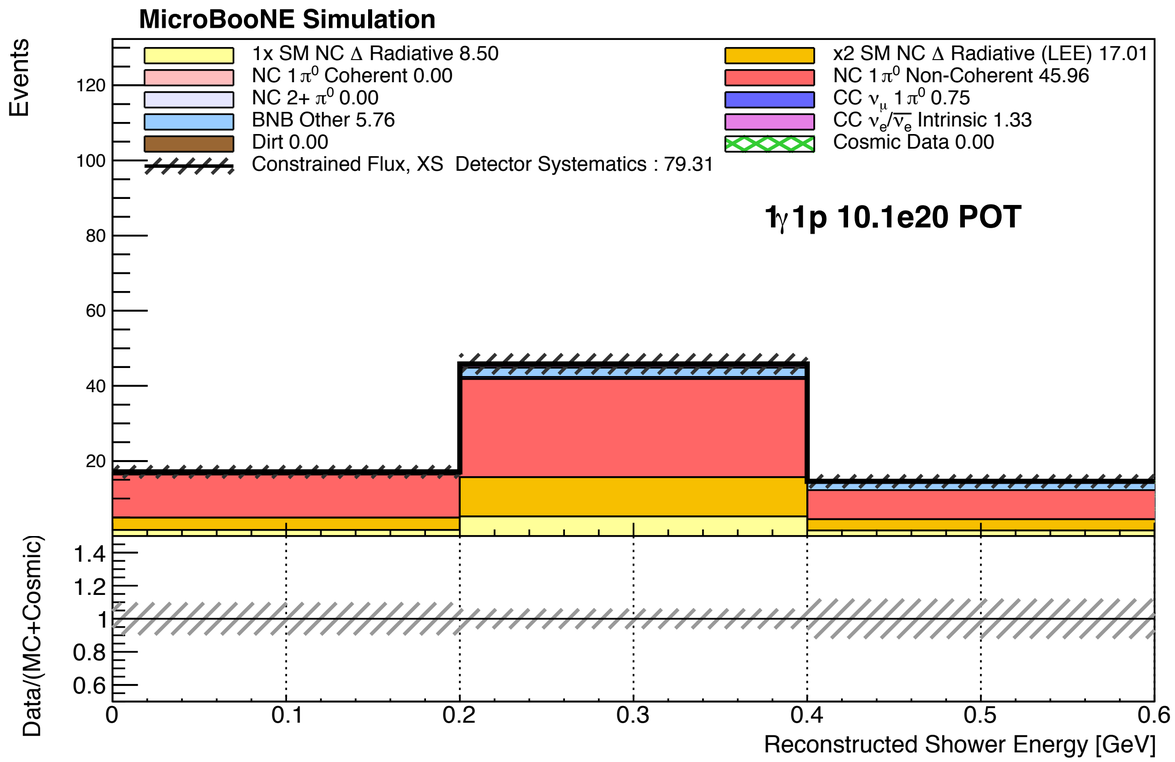
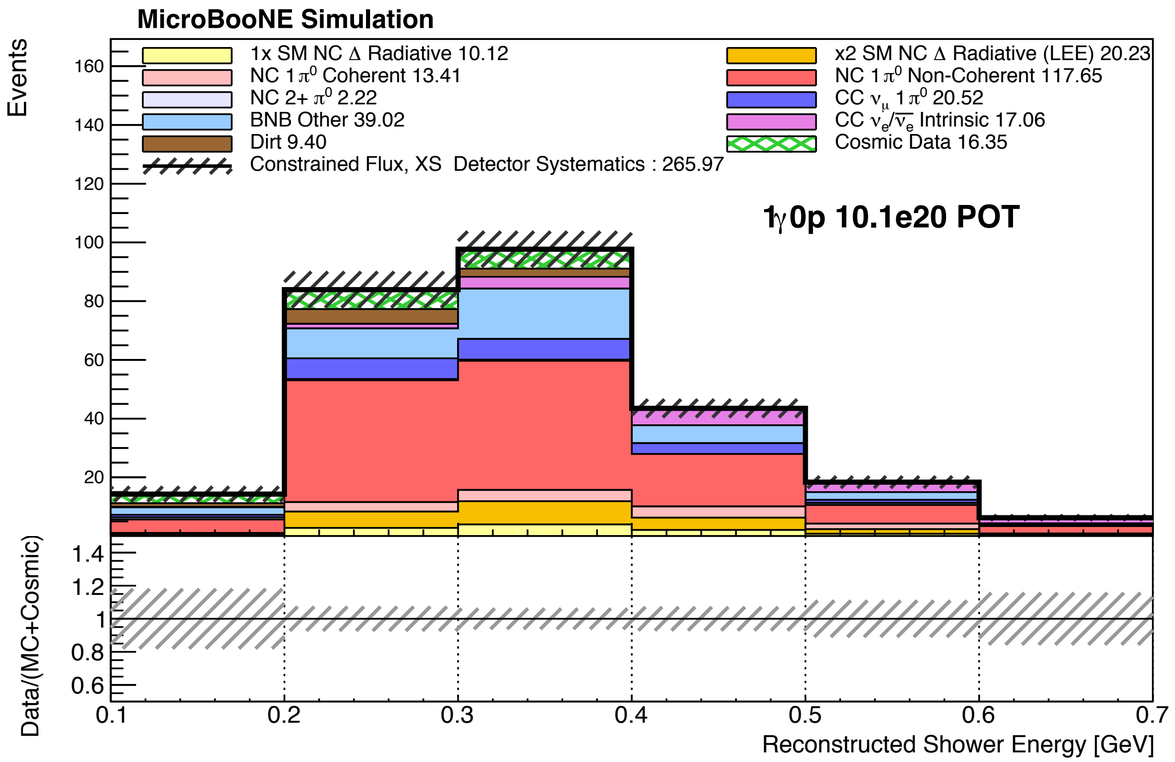
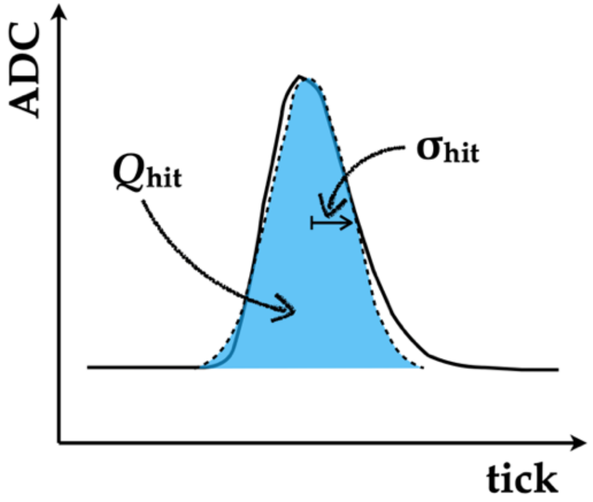




MicroBooNE Detector Systematics



Anode Wire Response Modification

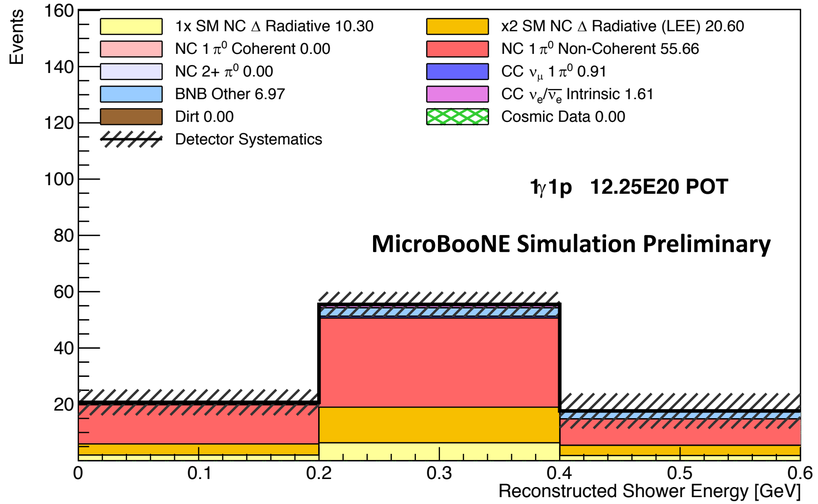
- Modify charge signal waveforms on anode wires in MC to better match what is observed in data
- Cover residual and unknown detector effects

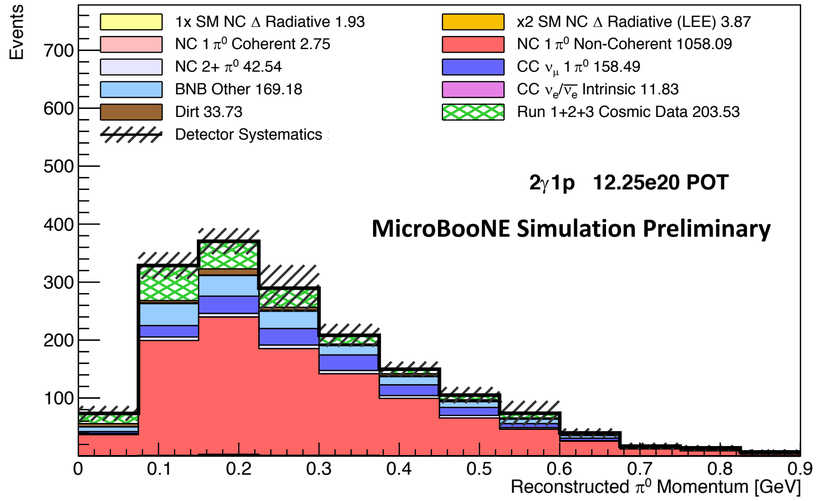
Comprehensive detector effects coverage with 10 variations

Category	subcategory	Effects Captured
Wire Response Modification	X (WireX)	Diffusion, Argon purity, SCE
	YZ (WireYZ)	Individual wire response and SCE residuals
	θ_{XZ} (AngleXZ)	long range induced charge effects, signal processing, deconvolution effects
	θ_{YZ} (AngleYZ)	
	dE/dx	Affects local charge deposition, e.g. recombination
Light Yield	25% down (LY)	Mis-modeling of light production
	Attentuation (LYAtt)	
	Rayleigh (LYRay)	
Other	SCE [1]	Alternate SCE corrections
	Recombination (Recom2)	Mis-modeling of charge recombination effects

[1] SCE: Space Charge Effect

The preliminary results indicate the total detector effects at final stage for primary 1g1p and 2g1p selections are in general less than 20 %.





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Backup

What systematics are included?

Currently including 47 **flux** (13) and **cross-section** (34) re-weighable systematics

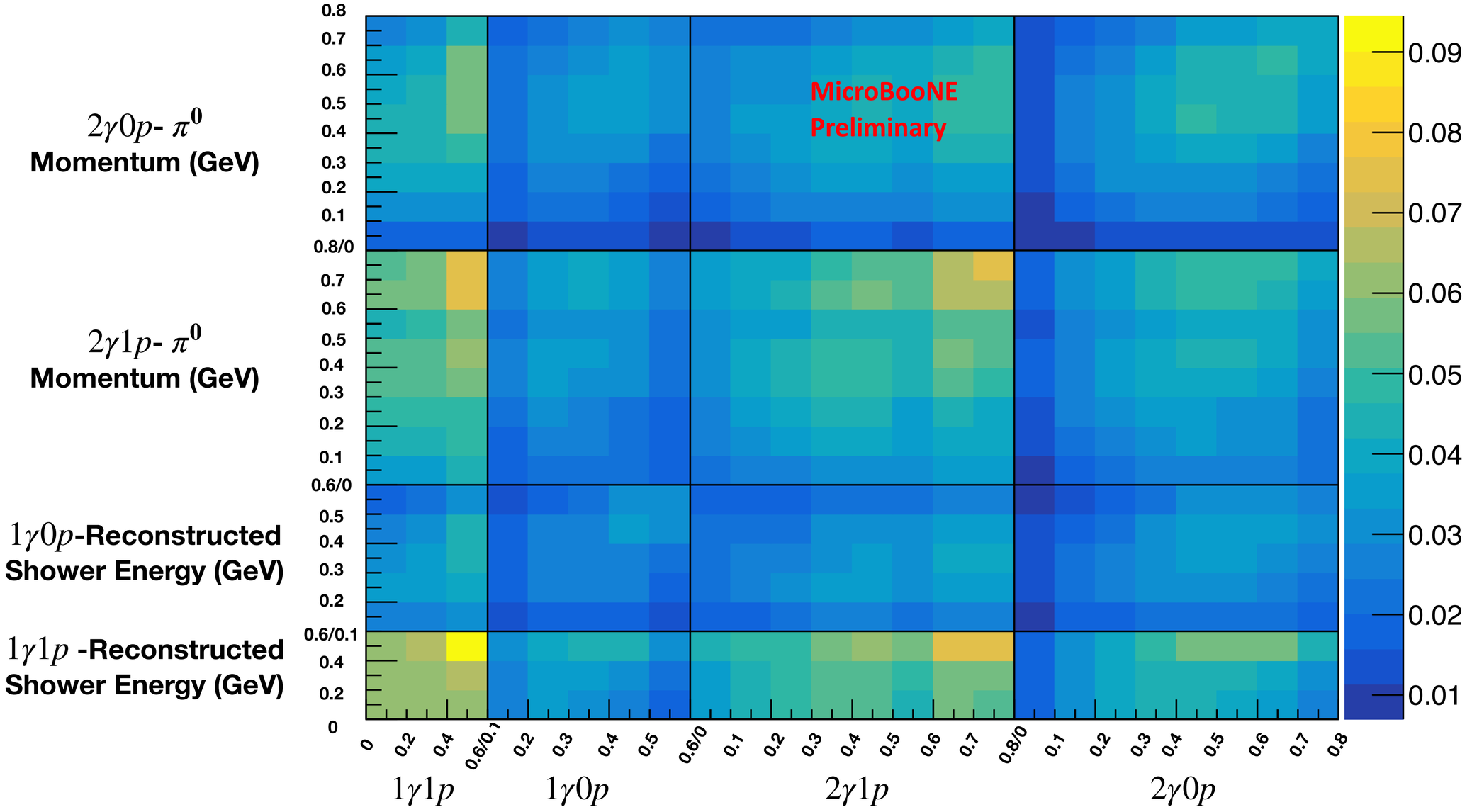
Flux Systematics

expskin_FluxUnisim
horncurrent_FluxUnisim
kminus_PrimaryHadronNormalization
kplus_PrimaryHadronFeynmanScaling
kzero_PrimaryHadronSanfordWang
nucleoninexsec_FluxUnisim
nucleonqexsec_FluxUnisim
nucleontotxsec_FluxUnisim
piminus_PrimaryHadronSWCentralSplineVariation
pioninexsec_FluxUnisim
pionqexsec_FluxUnisim
piontotxsec_FluxUnisim
piplus_PrimaryHadronSWCentralSplineVariation

Genie Cross-Section Systematics

genie_AGKYpT_Genie
genie_AGKYxF_Genie
genie_DISAth_Genie
genie_DISBth_Genie
genie_DISCv1u_Genie
genie_DISCv2u_Genie
genie_FormZone_Genie
genie_IntraNukeNabs_Genie
genie_IntraNukeNcex_Genie
genie_IntraNukeNinel_Genie
genie_IntraNukeNmfp_Genie
genie_IntraNukeNpi_Genie
genie_IntraNukePIabs_Genie
genie_IntraNukePIcex_Genie
genie_IntraNukePIinel_Genie
genie_IntraNukePImfp_Genie
genie_IntraNukePIpi_Genie
genie_NC_Genie
genie_NC_Genie
genie_NonResRvbarp1pi_Genie
genie_NonResRvbarp2pi_Genie
genie_NonResRvp1pi_Genie
genie_NonResRvp2pi_Genie
genie_ResDecayEta_Genie
genie_ResDecayGamma_Genie
genie_ResDecayTheta_Genie
genie_ccresAxial_Genie
genie_ccresVector_Genie
genie_cohMA_Genie
genie_cohR0_Genie
genie_ncelAxial_Genie
genie_ncelEta_Genie
genie_ncresAxial_Genie
genie_ncresVector_Genie
genie_qema_Genie

Collapsed (combined subsamples) Fractional Covariance Matrix



Not visually informative but used in analysis