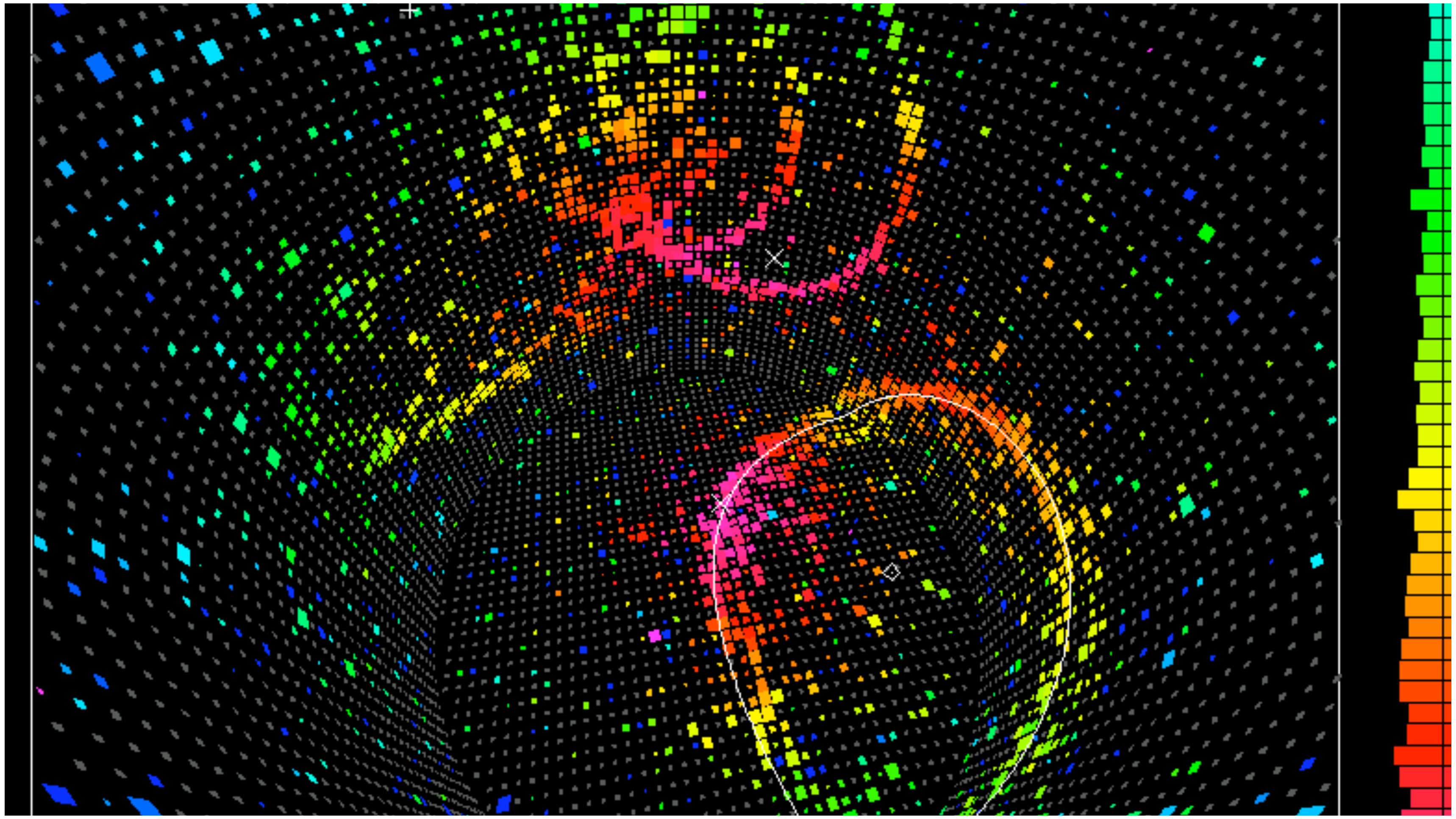

Lecture 4. NC1π^0

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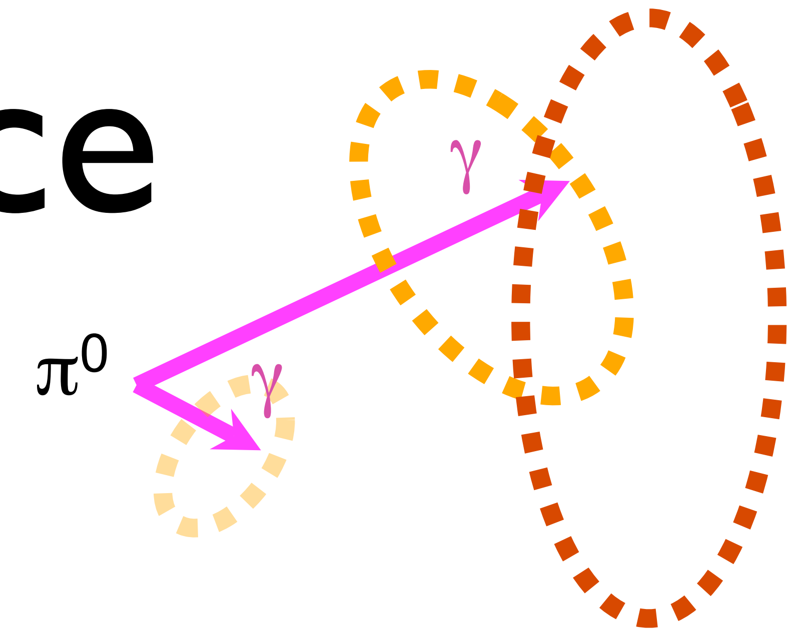
NCπ^0 Outline

- Introduction & motivation
- Event kinematics and topology
- Experimental Searches
  - Event Selections
  - Efficiencies and Systematics
  - Extracted parameters
- Upcoming measurements

K2K (1kt), MiniBooNE, SciBooNE

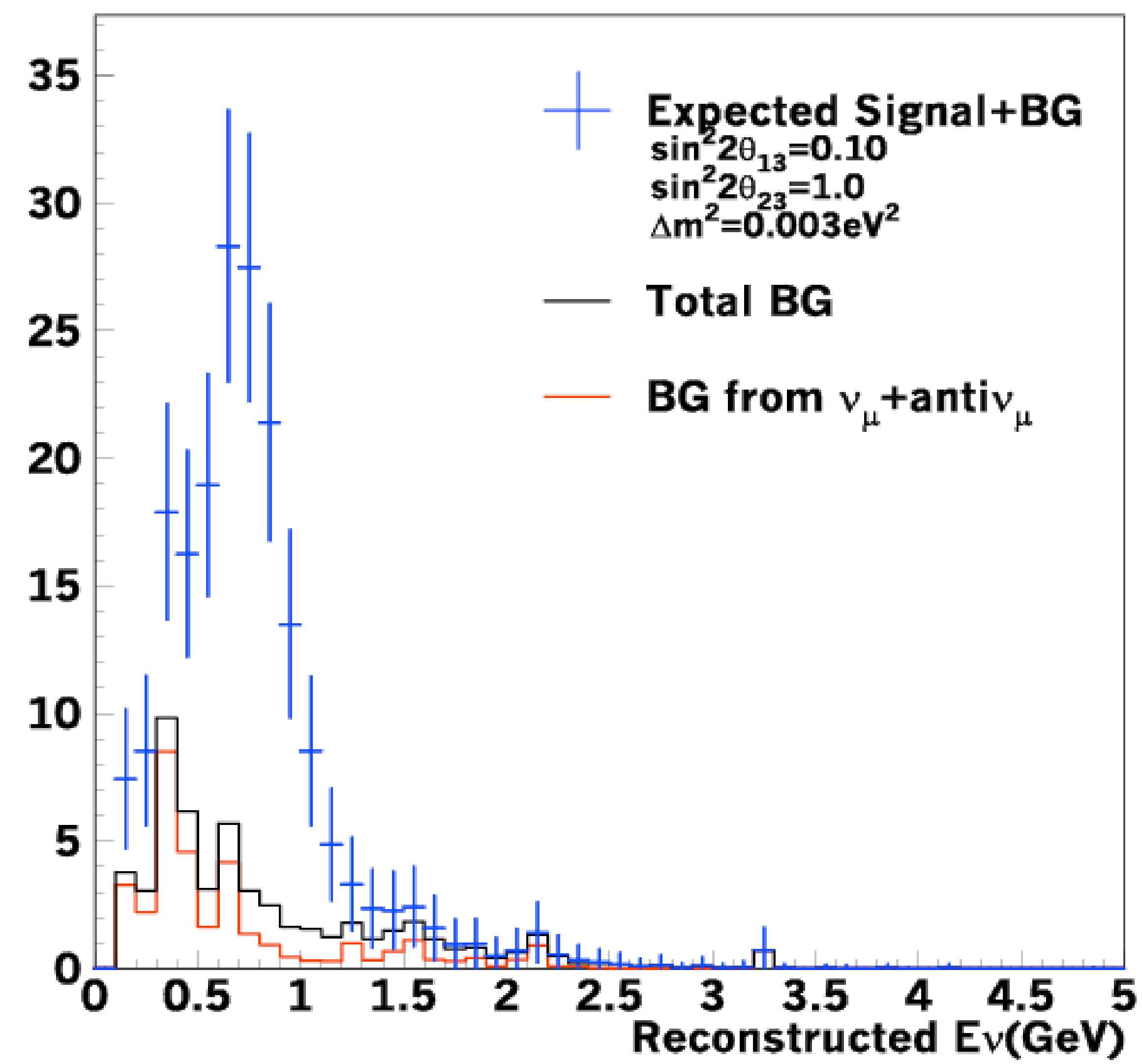
Search for θ_{13}: ν_e appearance



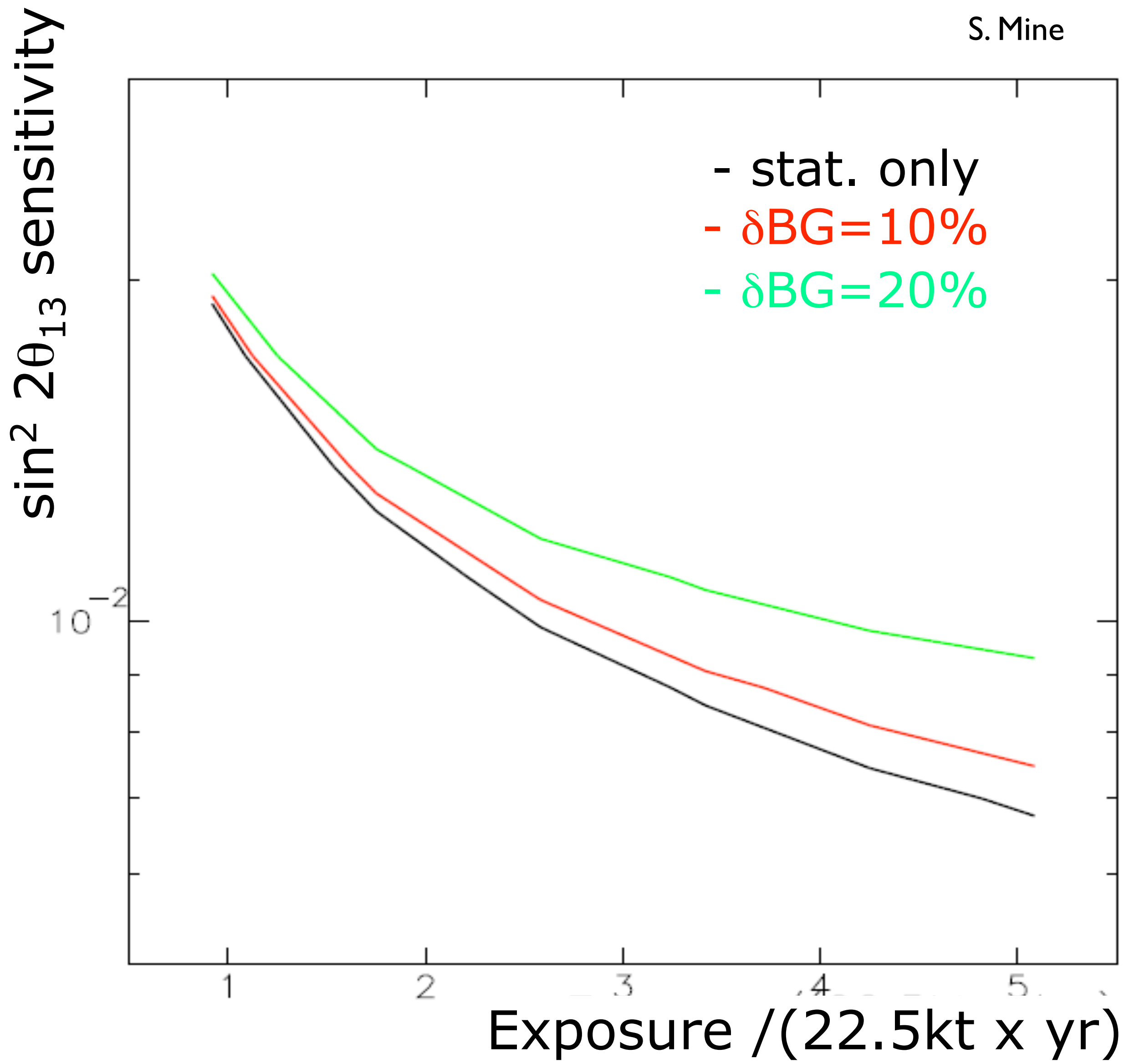
- Subdominant oscillation

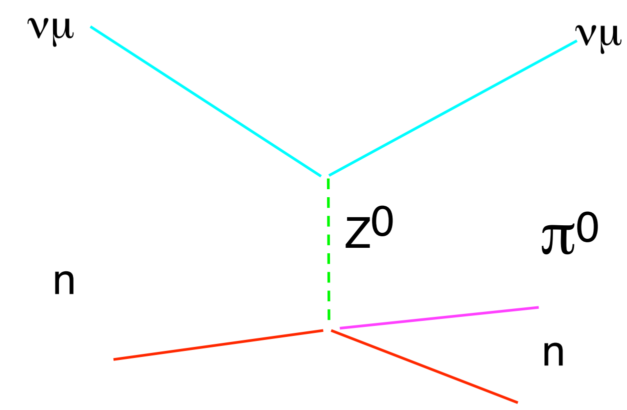
  $\sin^2 2\theta_{\mu e} \sim \sin^2\theta_{23} \cdot \sin^2 2\theta_{13}$

- Major background from NCπ^0 events
  - γ rings mimic e rings in Super-K
- Must reduce uncertainty on NCπ^0 cross section



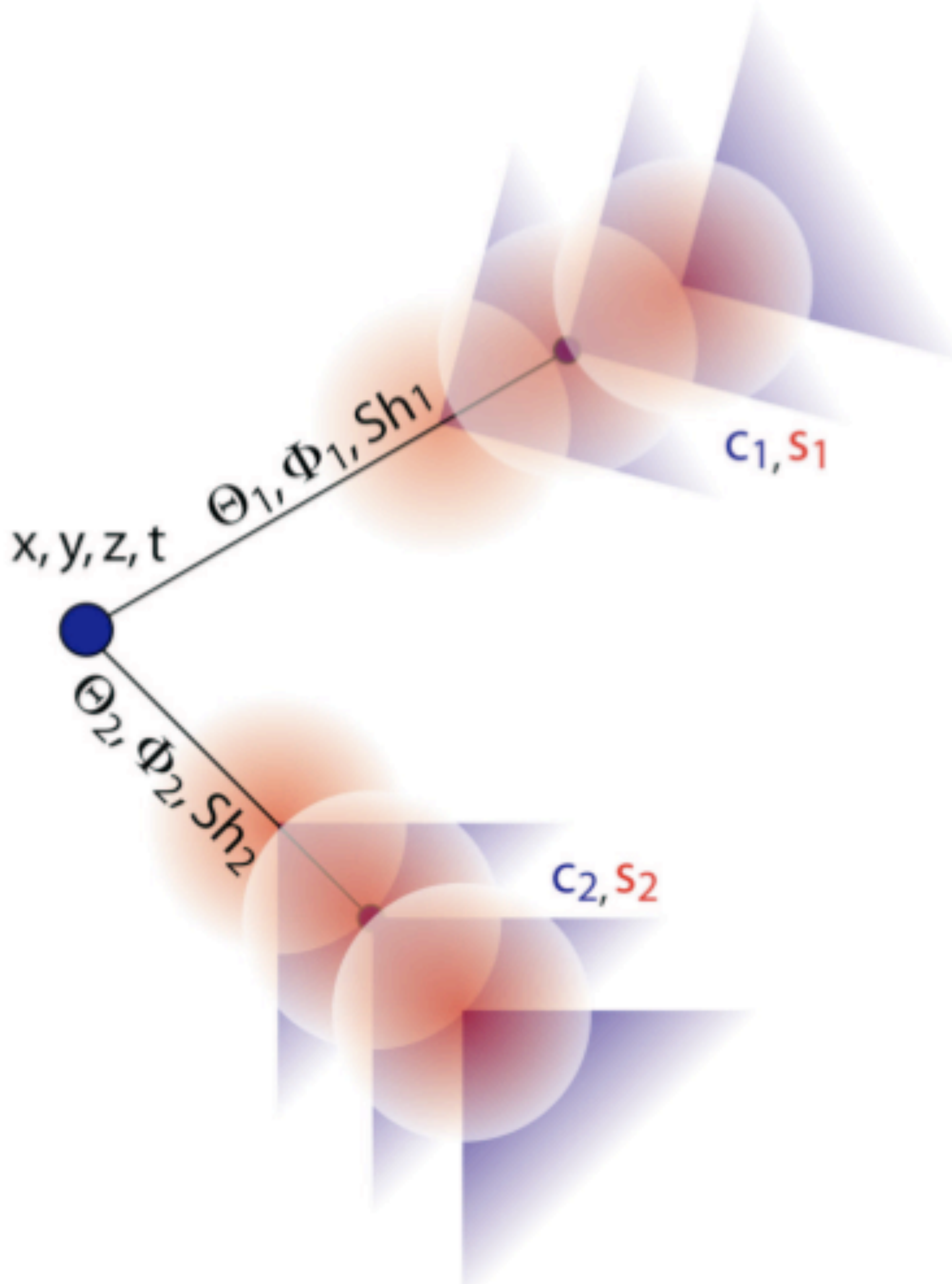
Effect of NCπ^0





- Want to reduce uncertainty in $\sigma(NC\pi^0)$ from 20% to 10%
  - improvement of factor of 2 in ultimate T2K sensitivity to θ_{13}
  - or 2.5 years vs. 4 years to 10^{-2}

NCπ^0 Reconstruction



blue = Čerenkov light
red = scintillation light

Fit event assuming two rings (14 parameters)

- decay vertex (4)
- direction of γ's (4)
- mean emission points (2)
- amount of Čerenkov/scintillation light (4)

- Assumes e-like rings

Determine event kinematics (using Čerenkov light)

$$mc^2 = \sqrt{2E_1E_2(1-\cos\theta_{12})}$$

$$\vec{p} = E_1\widehat{u_1} + E_2\widehat{u_2}$$

$$\cos\theta_{CM} = \frac{1}{\beta}\frac{|E_1 - E_2|}{E_1 + E_2}$$

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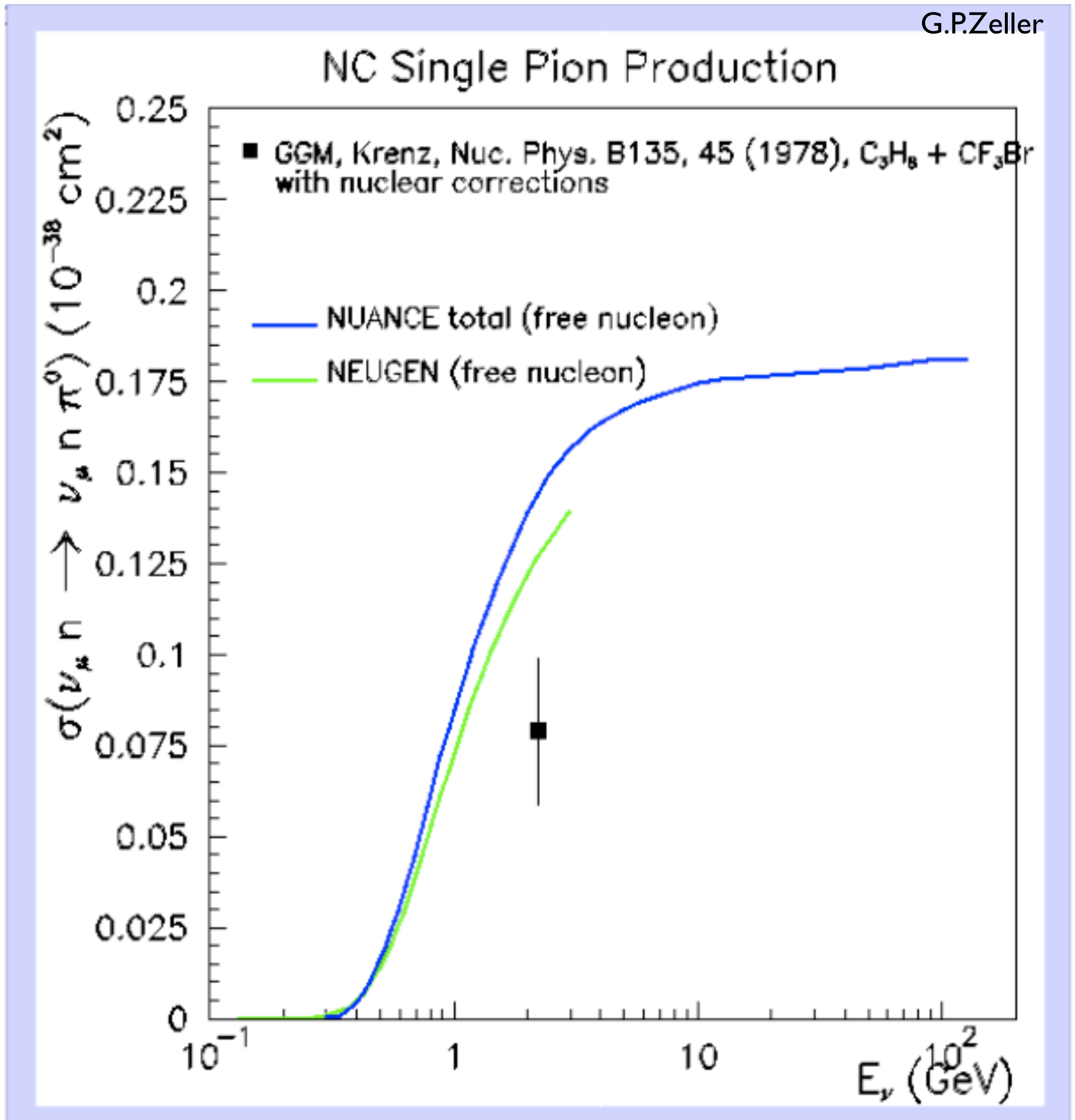
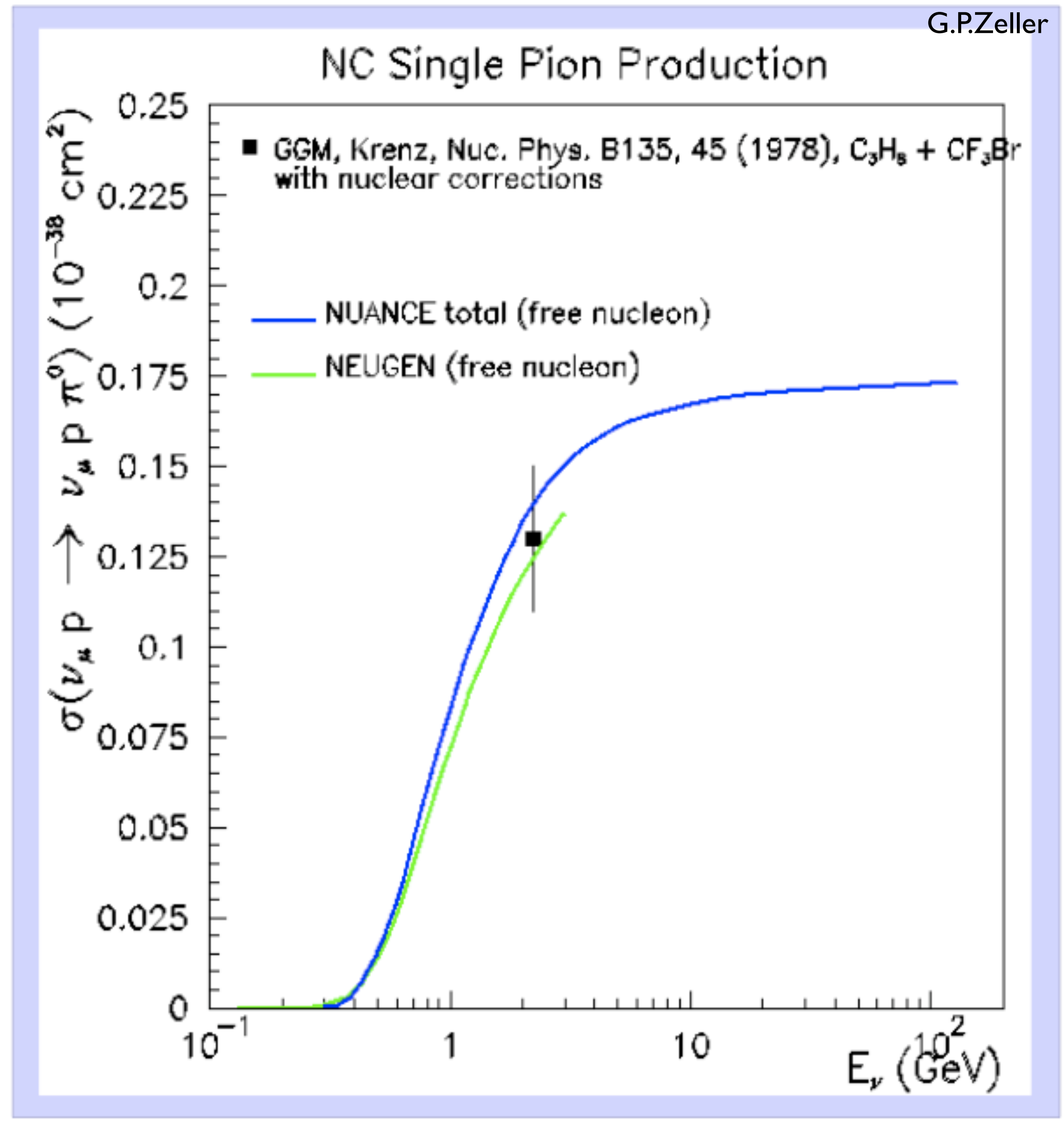
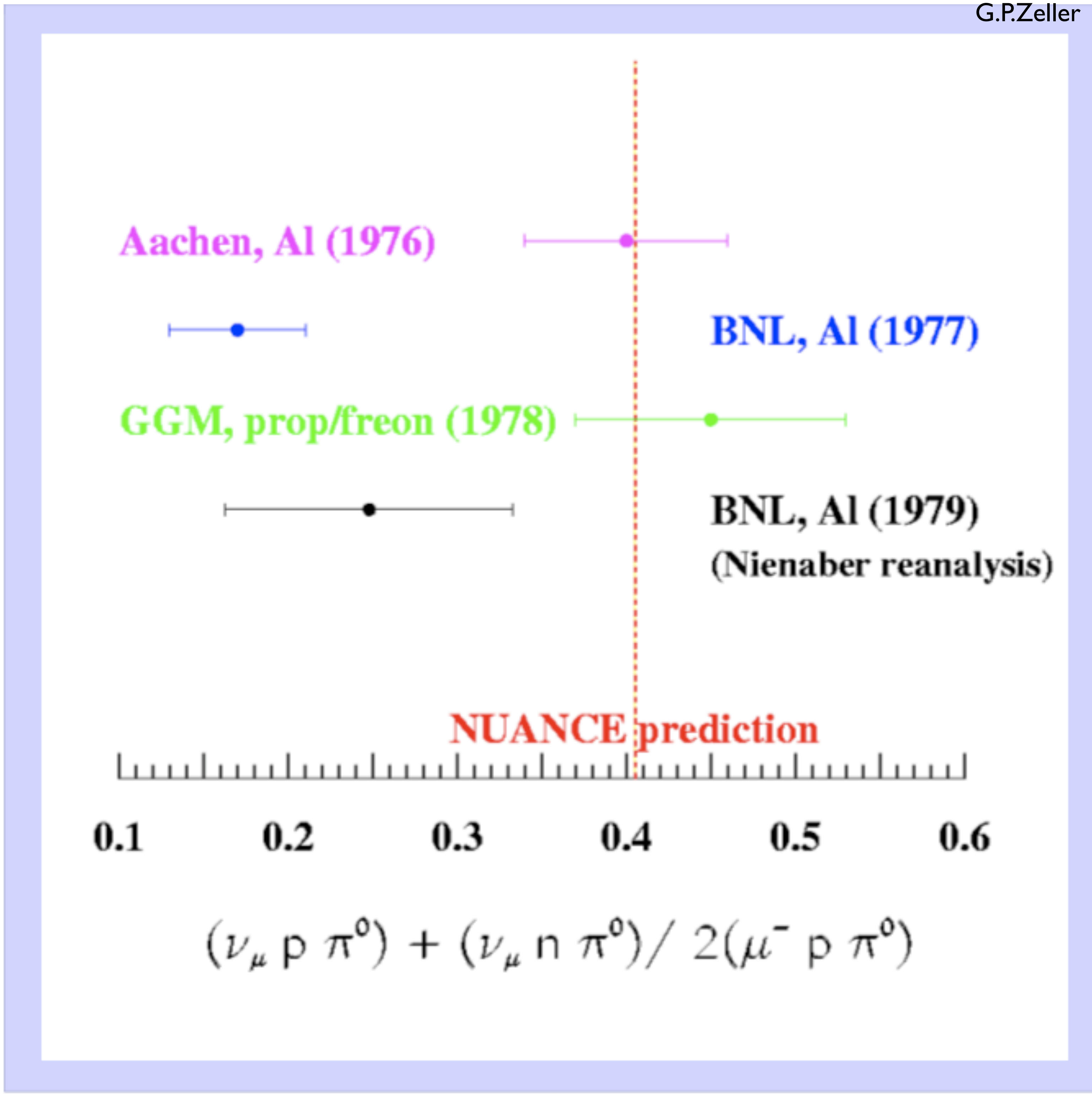
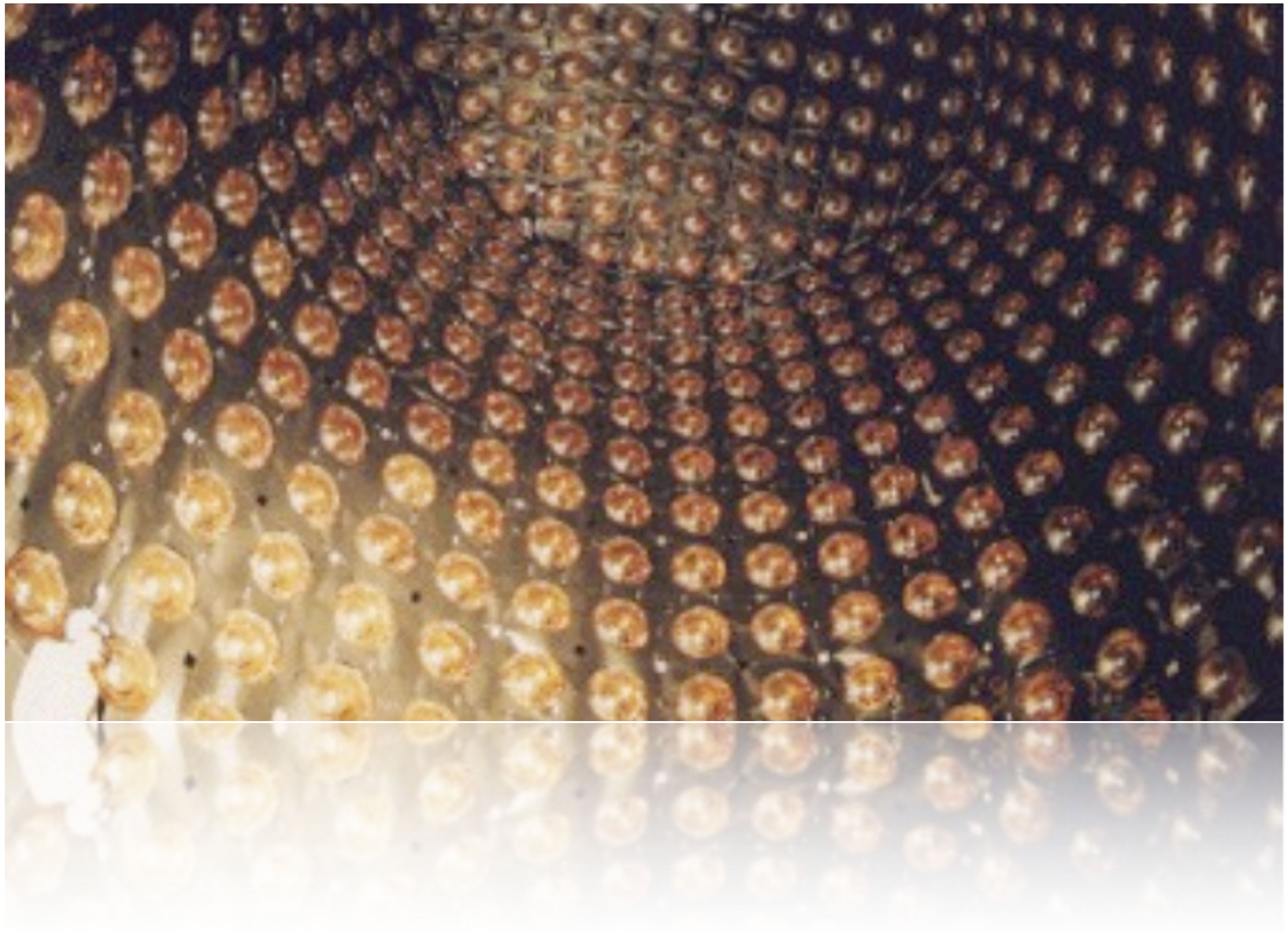
Past measurement





Past Measurements





K2K NCπ^0

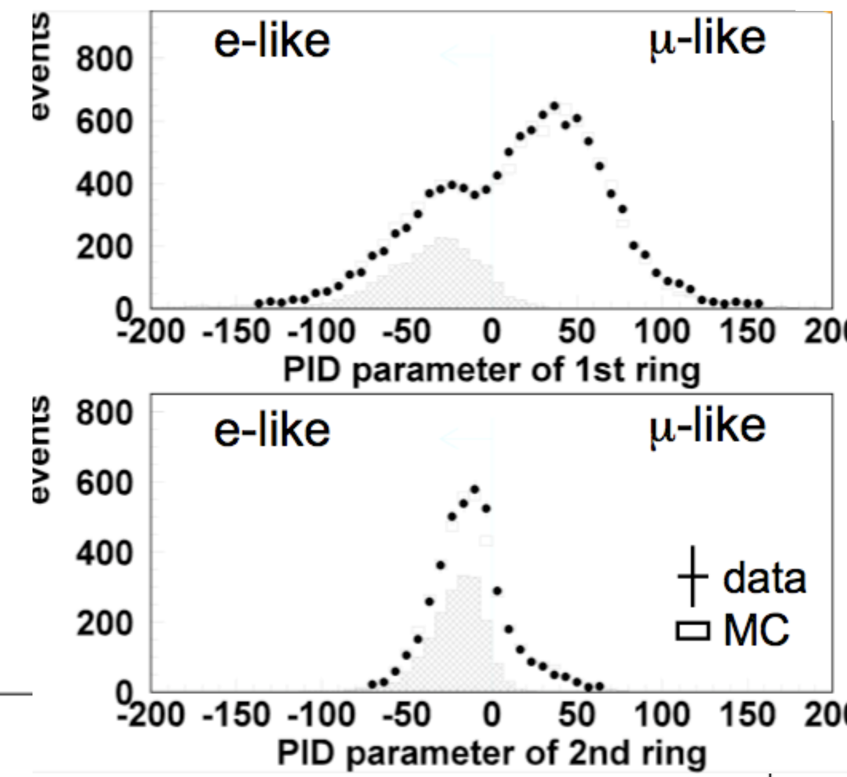
K2K NCπ^0 Analysis Goals

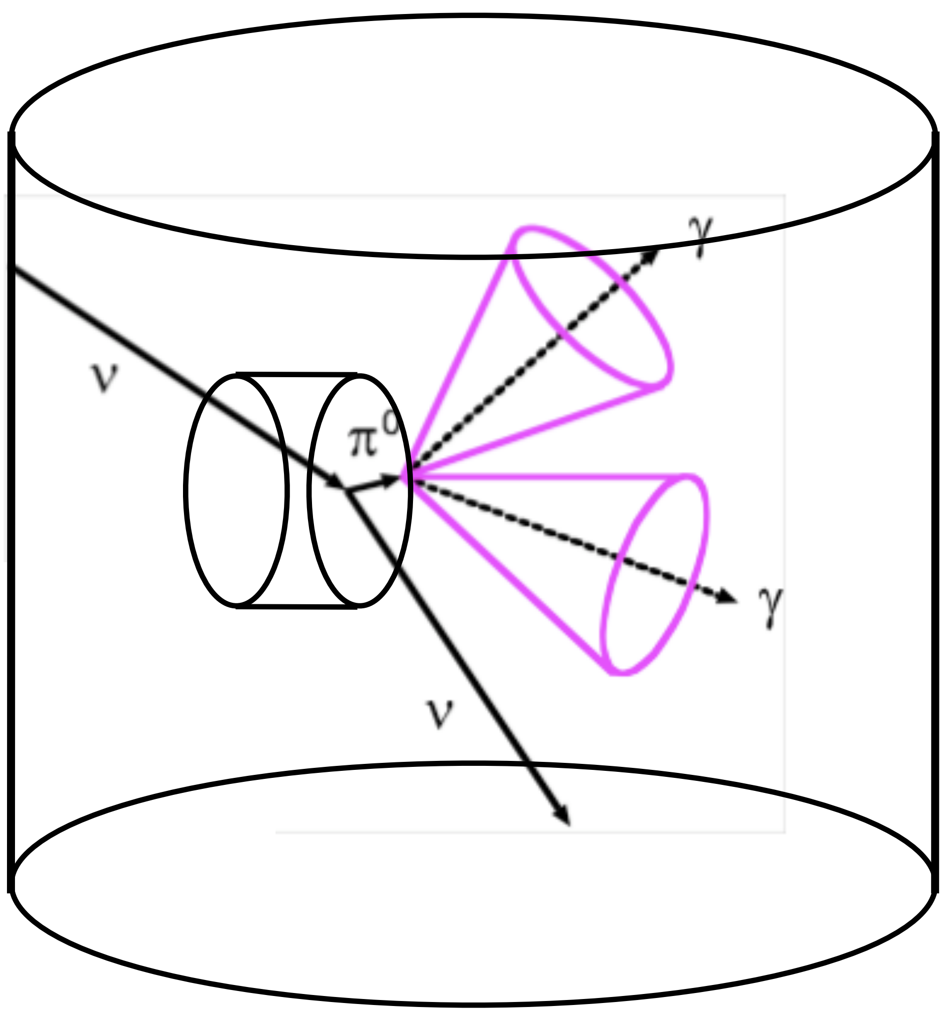
- Measure NCpi0/CC event rate on oxygen for use in nue appearance analysis.

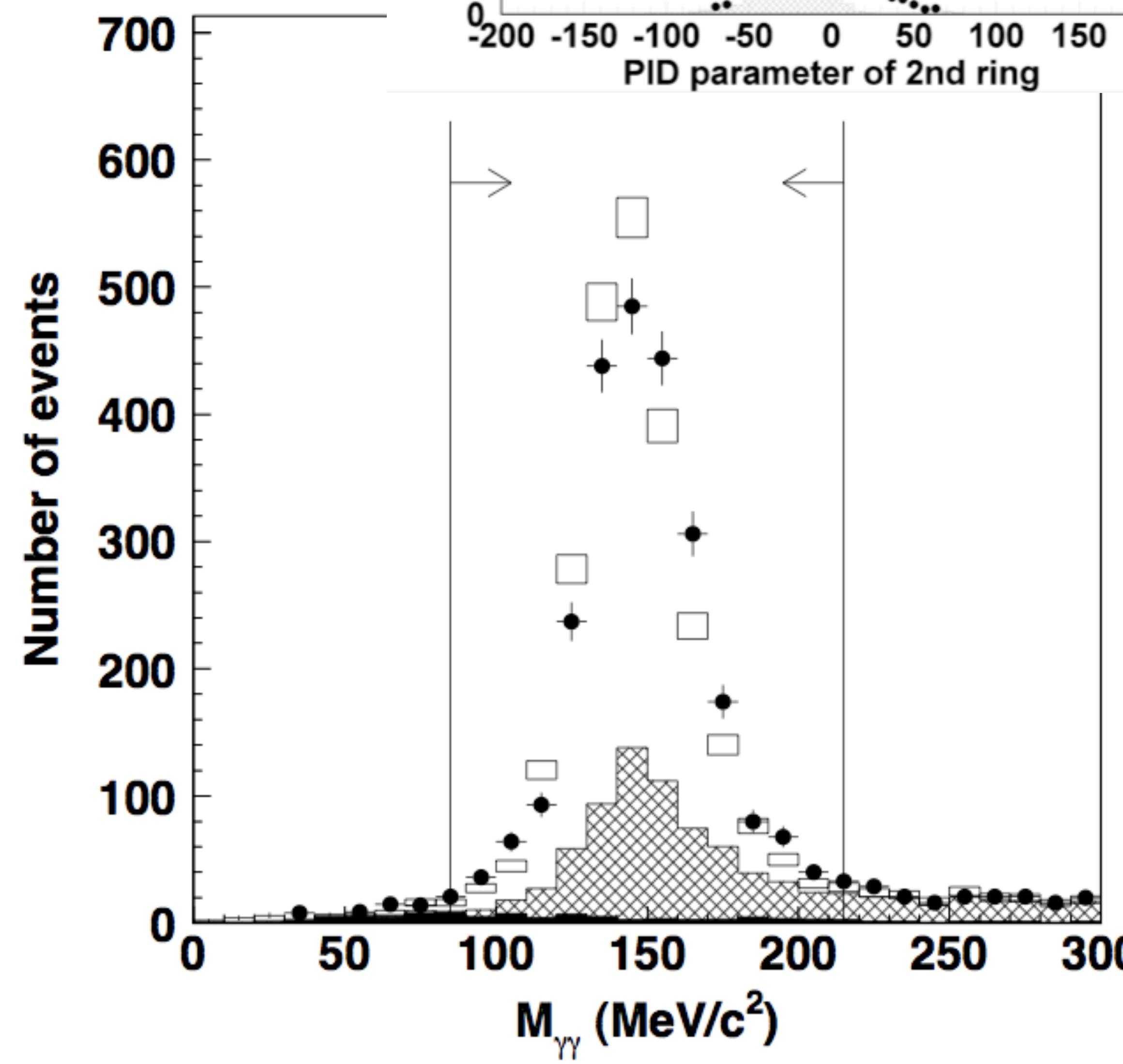
K2K Event Selection

S. Nakayama

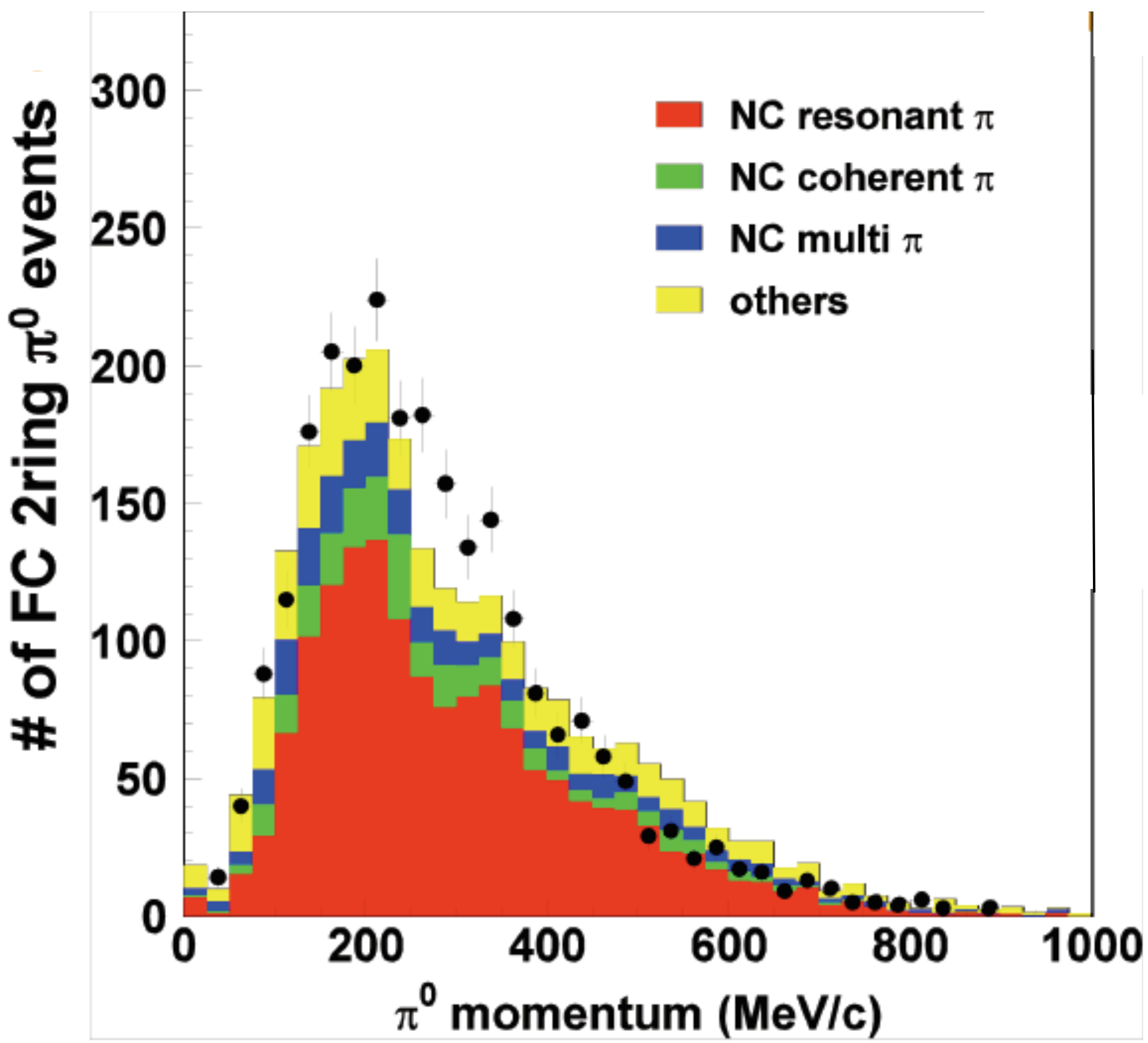
	Data	NC1π^0 efficiency
FC	45317	97 %
Two rings	11117	57 %
Both e-like	3150	48 %
Invariant mass	2496	47 %



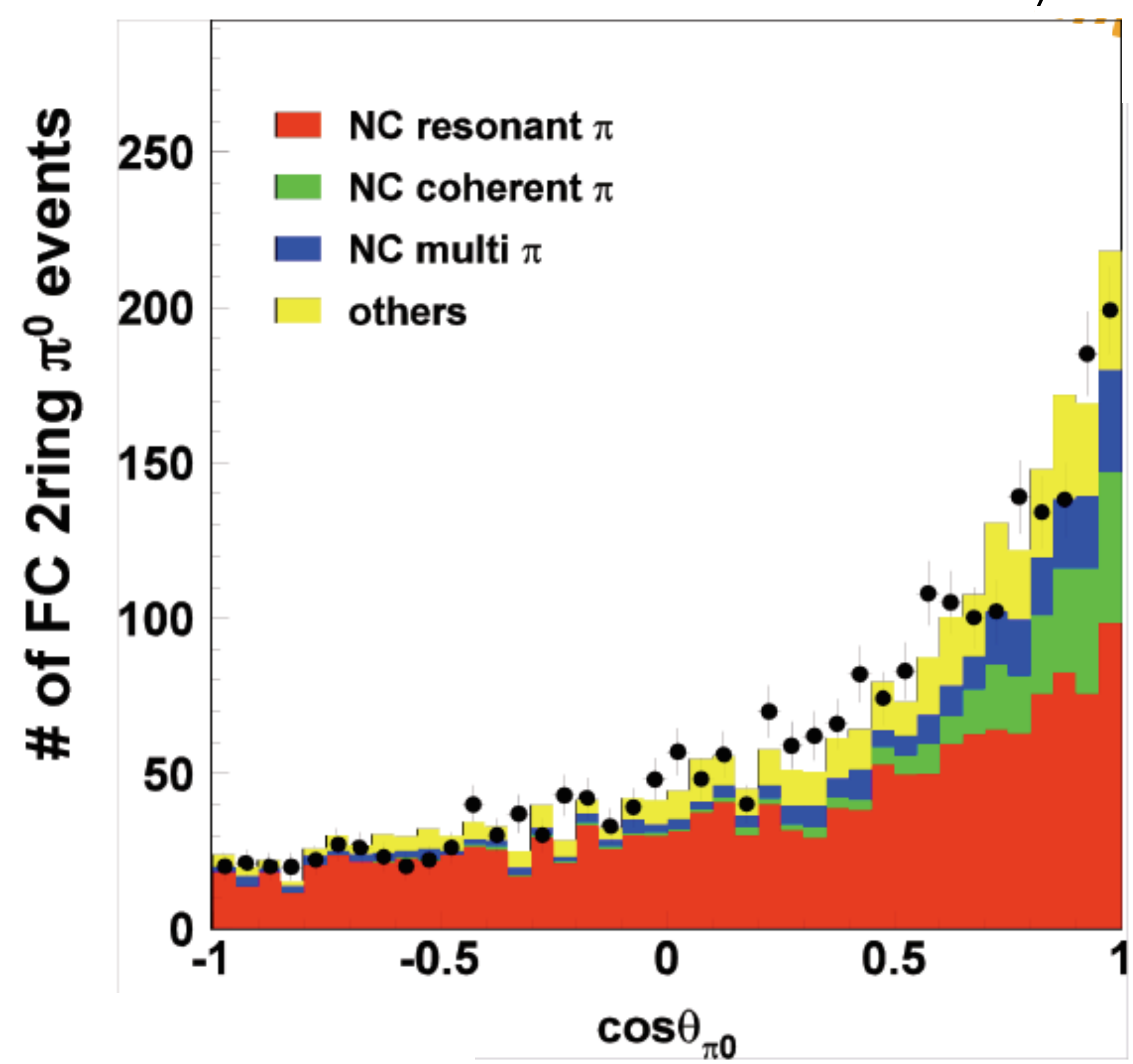




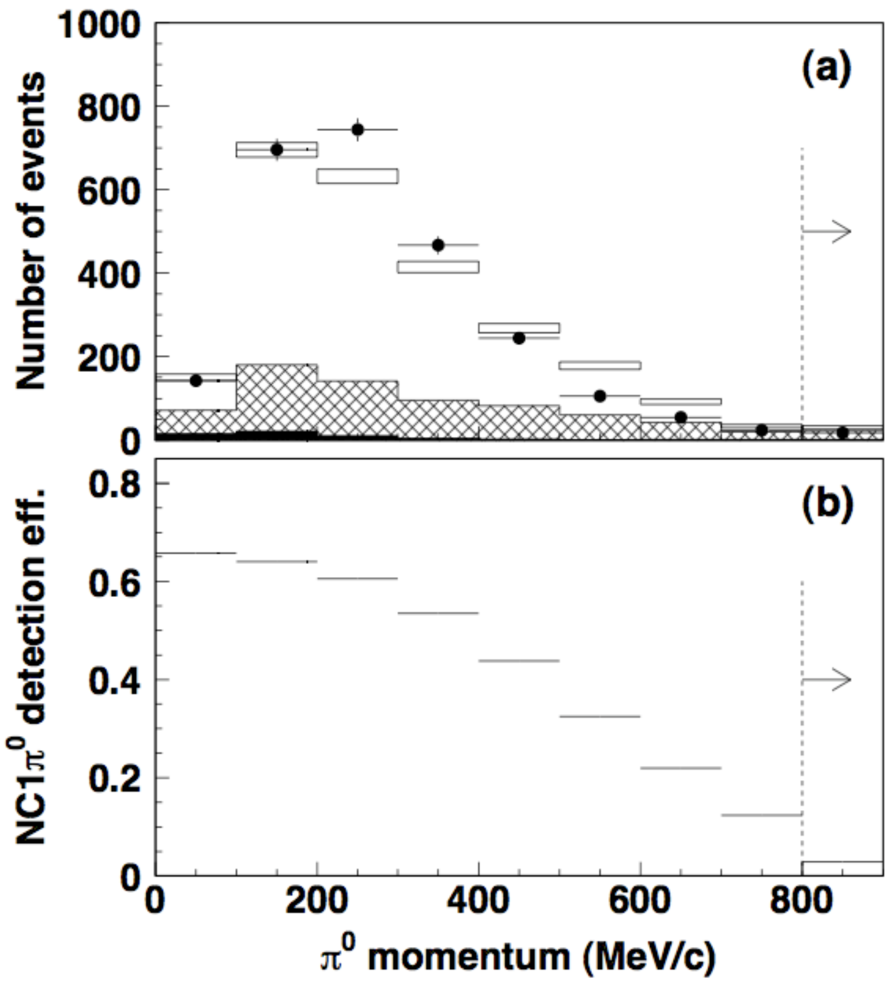
K2K Data/MC

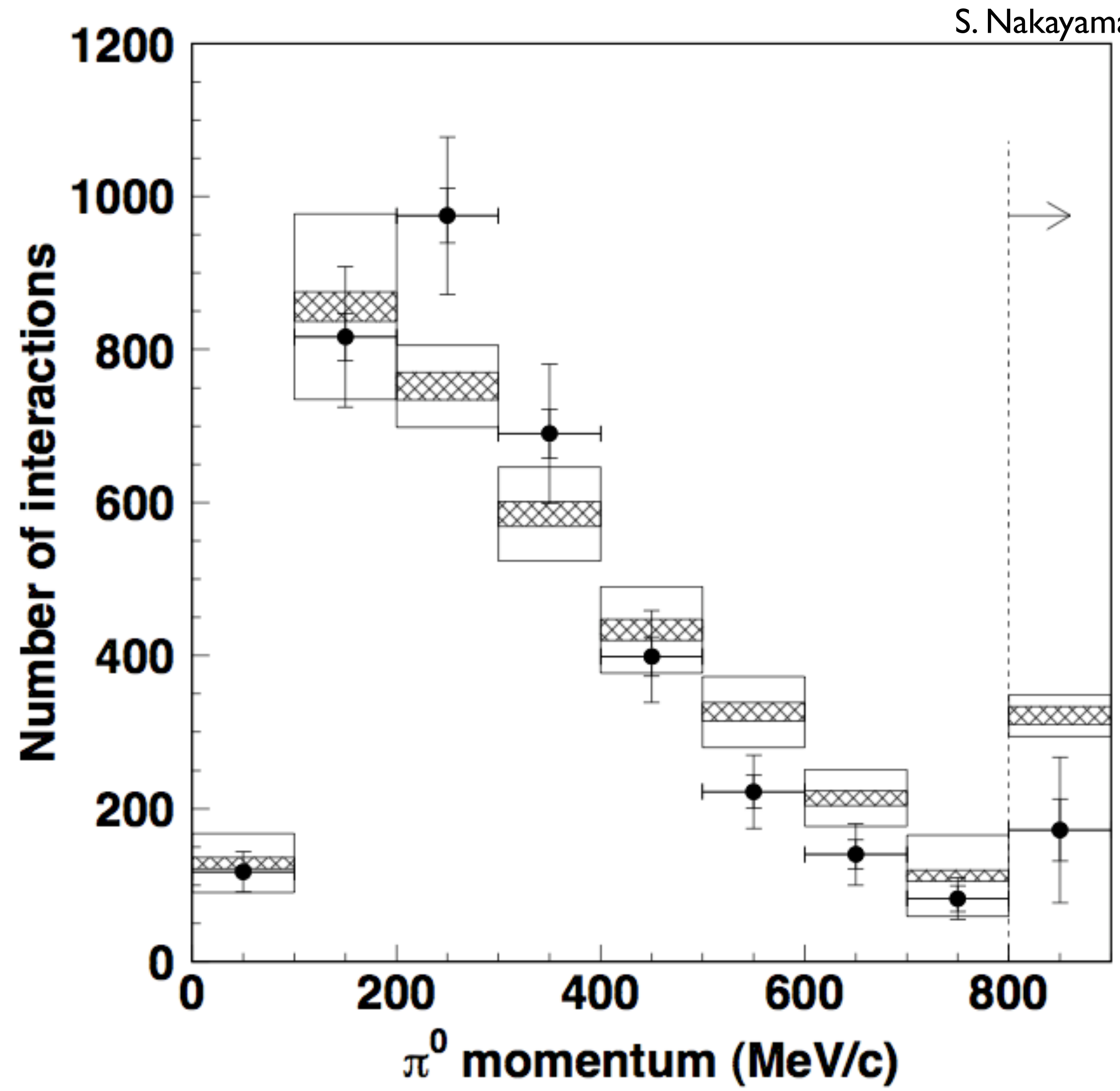


S. Nakayama



K2K π^0 Momentum





stat. sys.

$$\sigma(NC1\pi^0) / \sigma(\nu_\mu CC) = 0.063 \pm 0.001 \pm 0.006$$

at the K2K beam energy, <Eν>~1.3 GeV

K2K Systematics

Sources	Errors (%)
(A) Systematic uncertainties in background subtraction	
M_A in quasi-elastic and single meson (±10 %)	0.2
Quasi-elastic scattering (total cross section, ±10 %)	0.0
Single meson production (total cross section, ±10 %)	0.9
Coherent pion production (model dependence)	1.6
Deep inelastic scattering (model dependence)	5.1
Deep inelastic scattering (total cross section, ±5 %)	0.5
NC/CC ratio (±20 %)	3.2
Nuclear effects for pions in ^{16}O (absorption, ±30 %)	1.5
Nuclear effects for pions in ^{16}O (inelastic scattering, ±30 %)	0.7
Pion production outside the target nucleus (total cross section, ±20 %)	2.3
(B) Systematic uncertainties in fiducial volume correction	
Fiducial cut	1.6
(C) Systematic uncertainties in efficiency correction	
Ring counting	5.4
Particle identification	4.2
Energy scale	0.3

TABLE II: Summary of the systematic errors on the measurement of the number of NC1π^0 interactions.

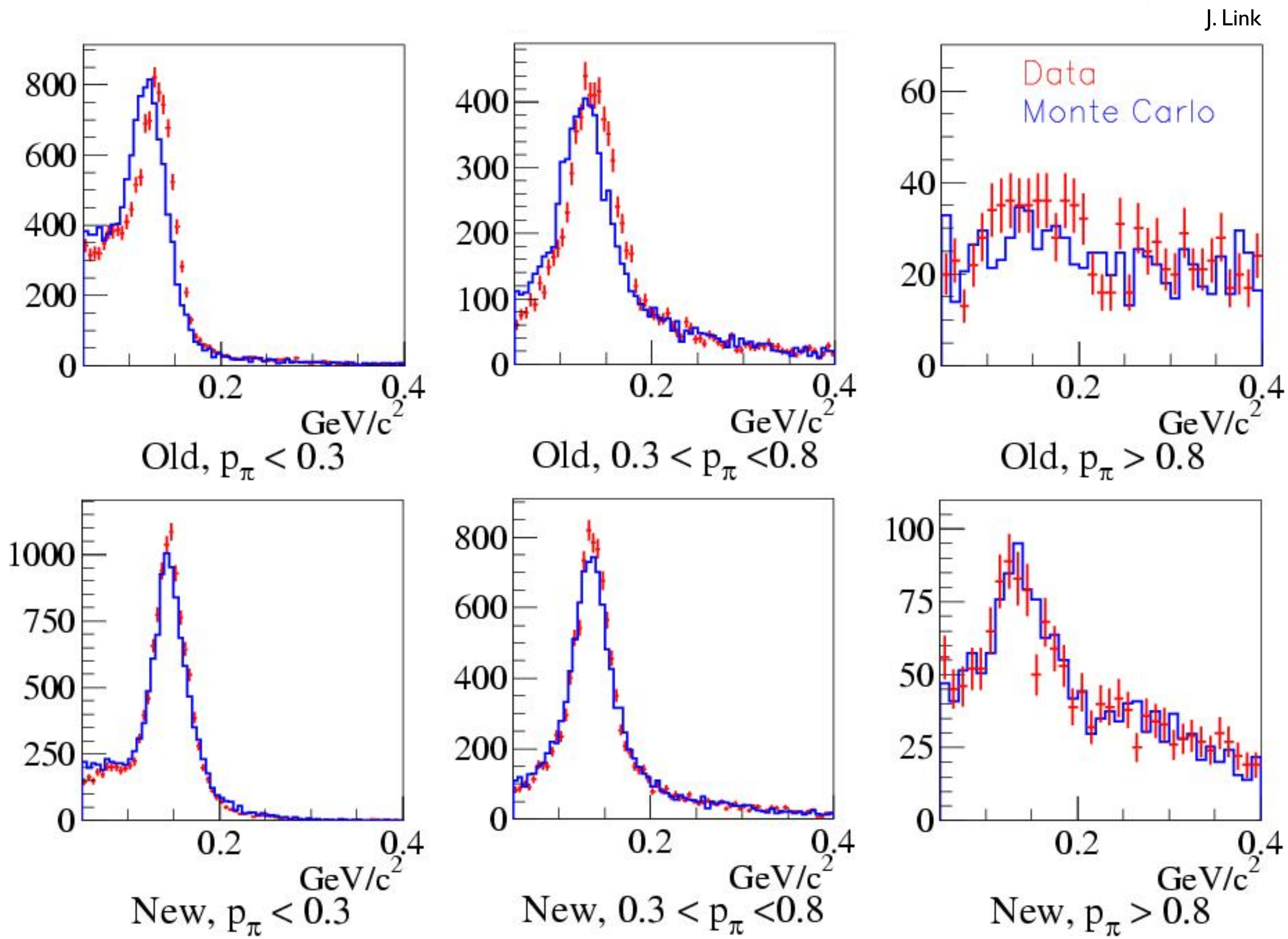
MiniBooNE NCπ^0

NCπ^0 Analysis Goals

Measure the rate of π^0 production for data-based ν_e background prediction.

Also measure coherent fraction.

Improved Reconstruction



Event Selection

Pre-cuts (Also applied in the oscillation analysis):

1 sub-event (No evidence of a decaying muon)

Tank hits > 200 (Above the muon decay endpoint)

Veto hits < 6 (Eliminates cosmic rays)

Analysis cuts:

Event radius < 500 cm (Reduces edge effects)

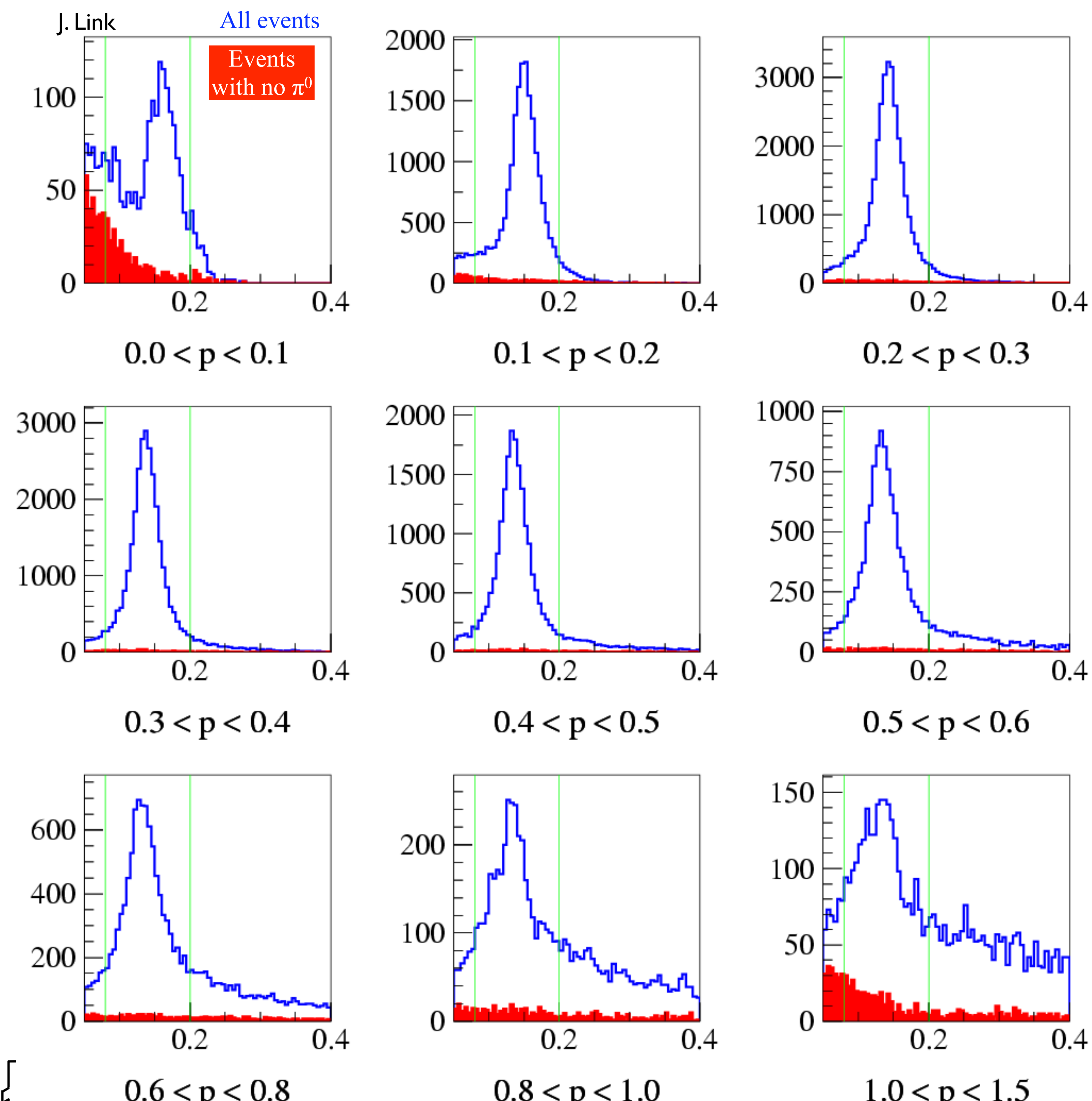
eμ likelihood difference prefers electron hypothesis

eπ likelihood difference prefers pion hypothesis

Mass window:

$80\ \mathrm{MeV}/c^2 < m_{\gamma\gamma} < 200\ \mathrm{MeV}/c^2$

Momentum reweighting



1. In bins of true momentum vs. reconstructed momentum, count MC events, over BG, in the signal window.
2. Divide by the total number of π^0 events generated in that true momentum bin.
3. Invert the matrix.
4. Perform a BG subtraction on the data in each reconstructed momentum bins.
5. Multiply the data vector by the MC unsmearing Matrix

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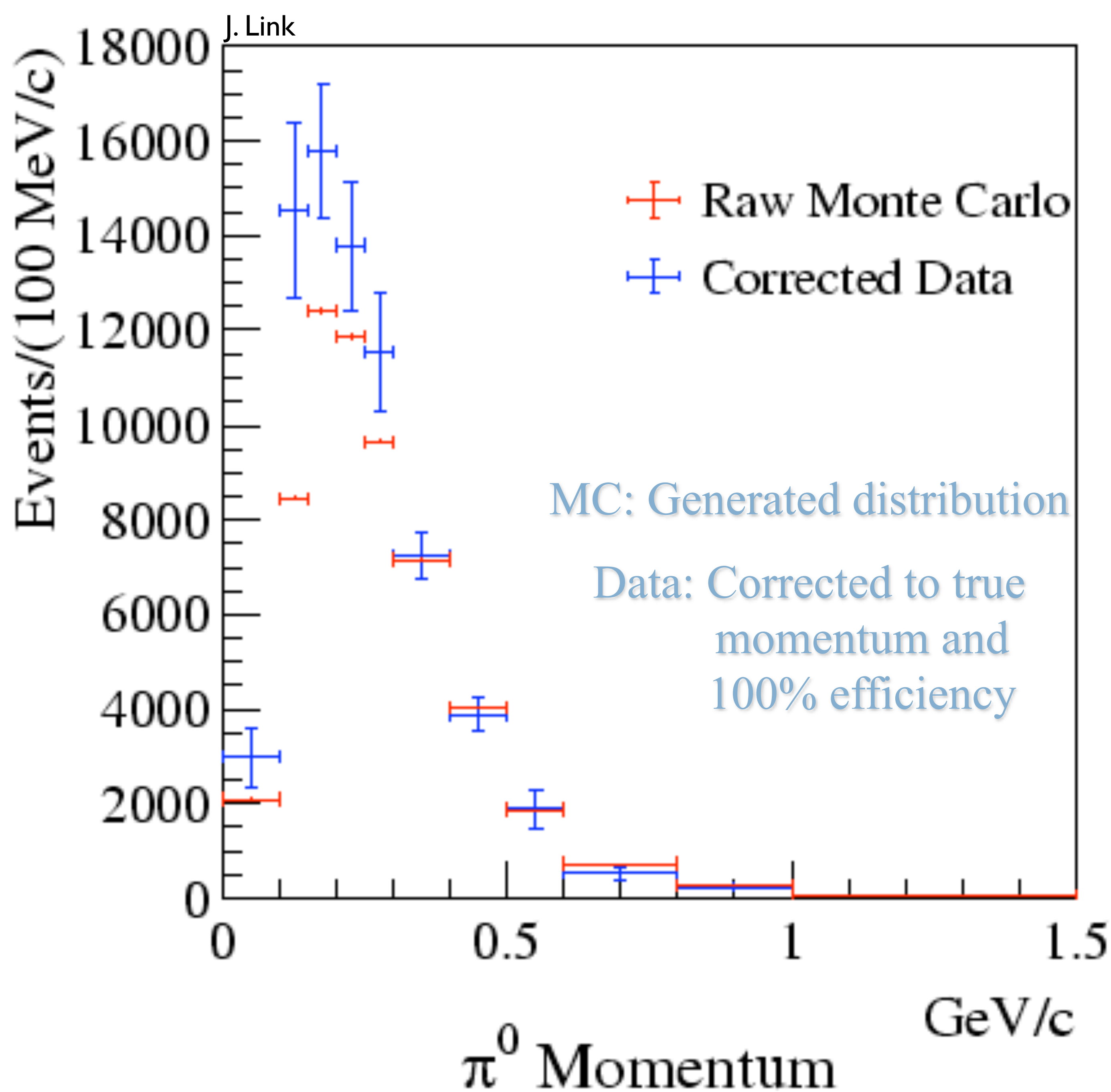
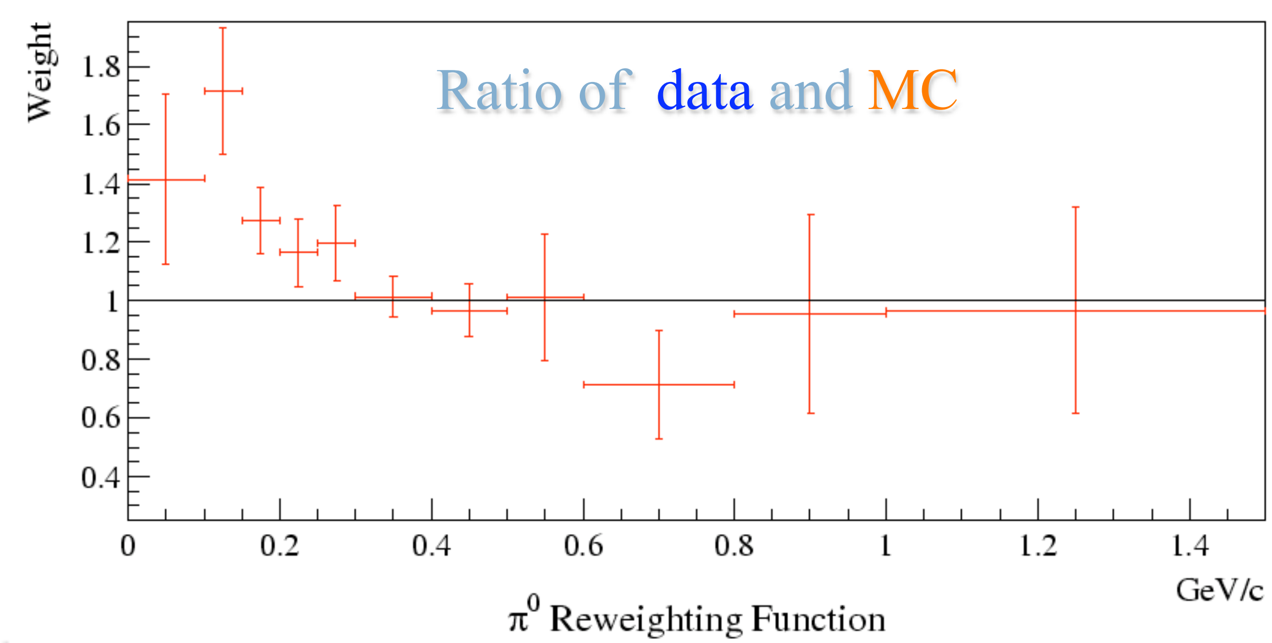
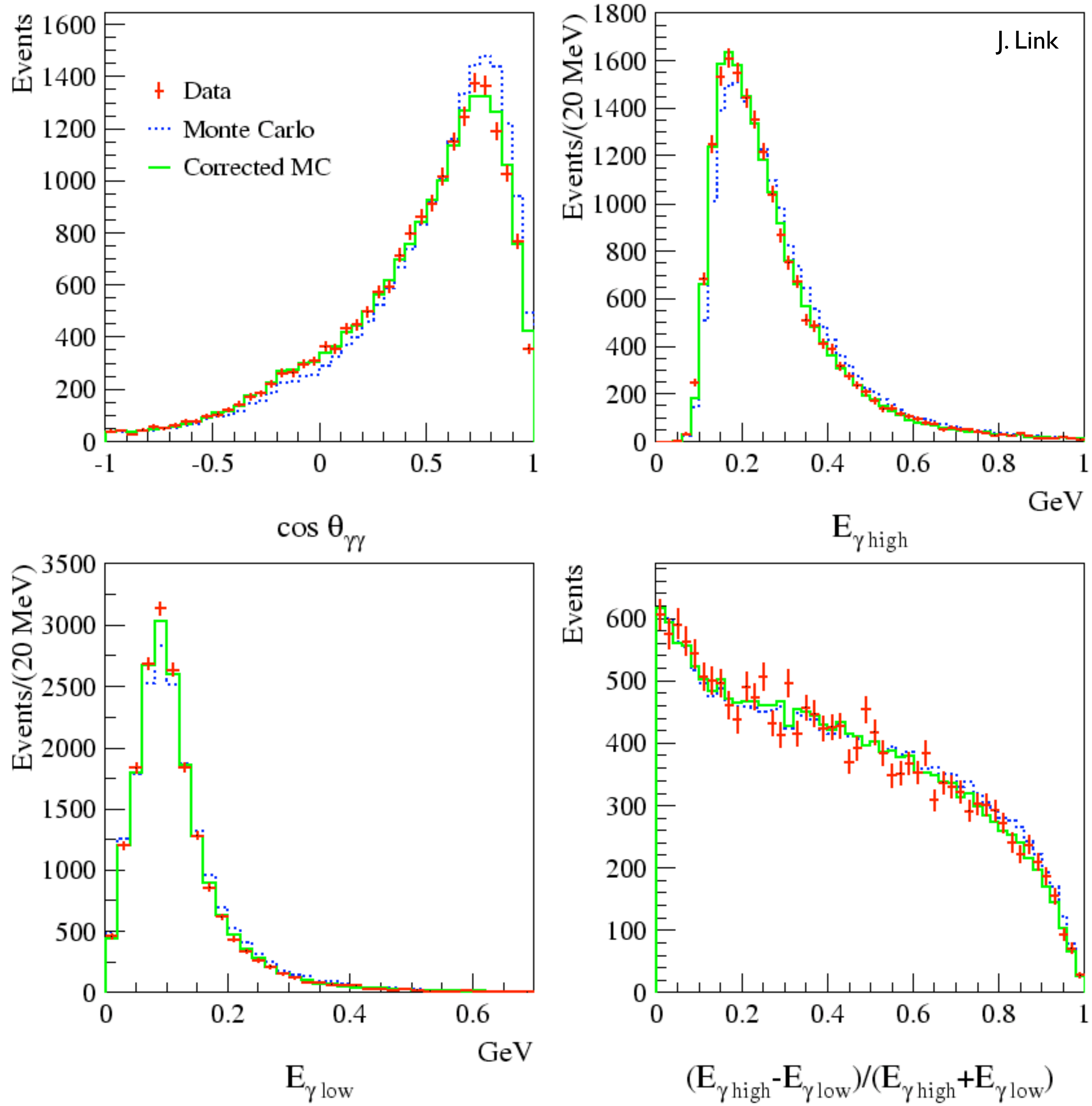
Reweighted Distributions



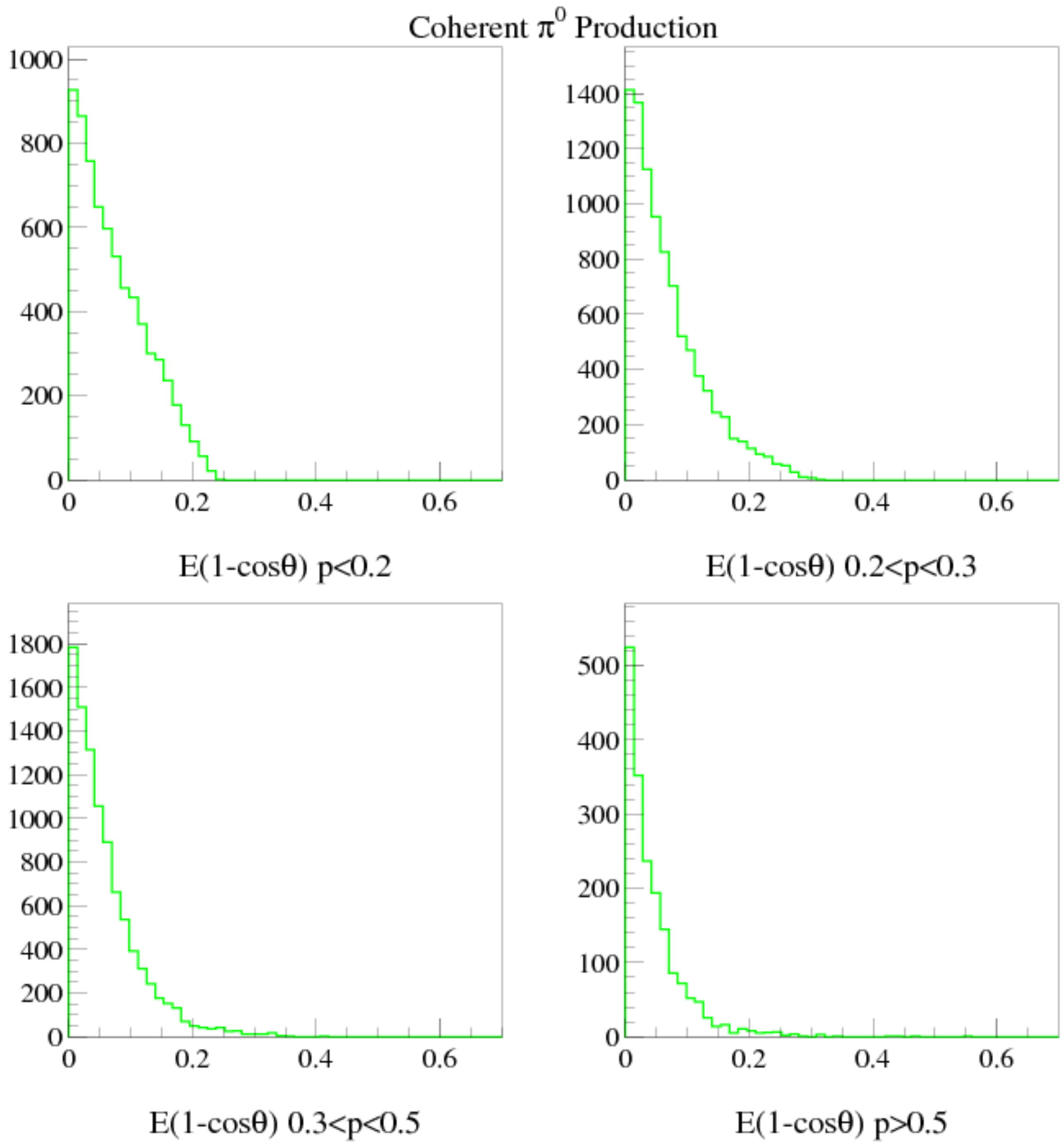
From this distribution we derive a reweighting function for Monte Carlo events.

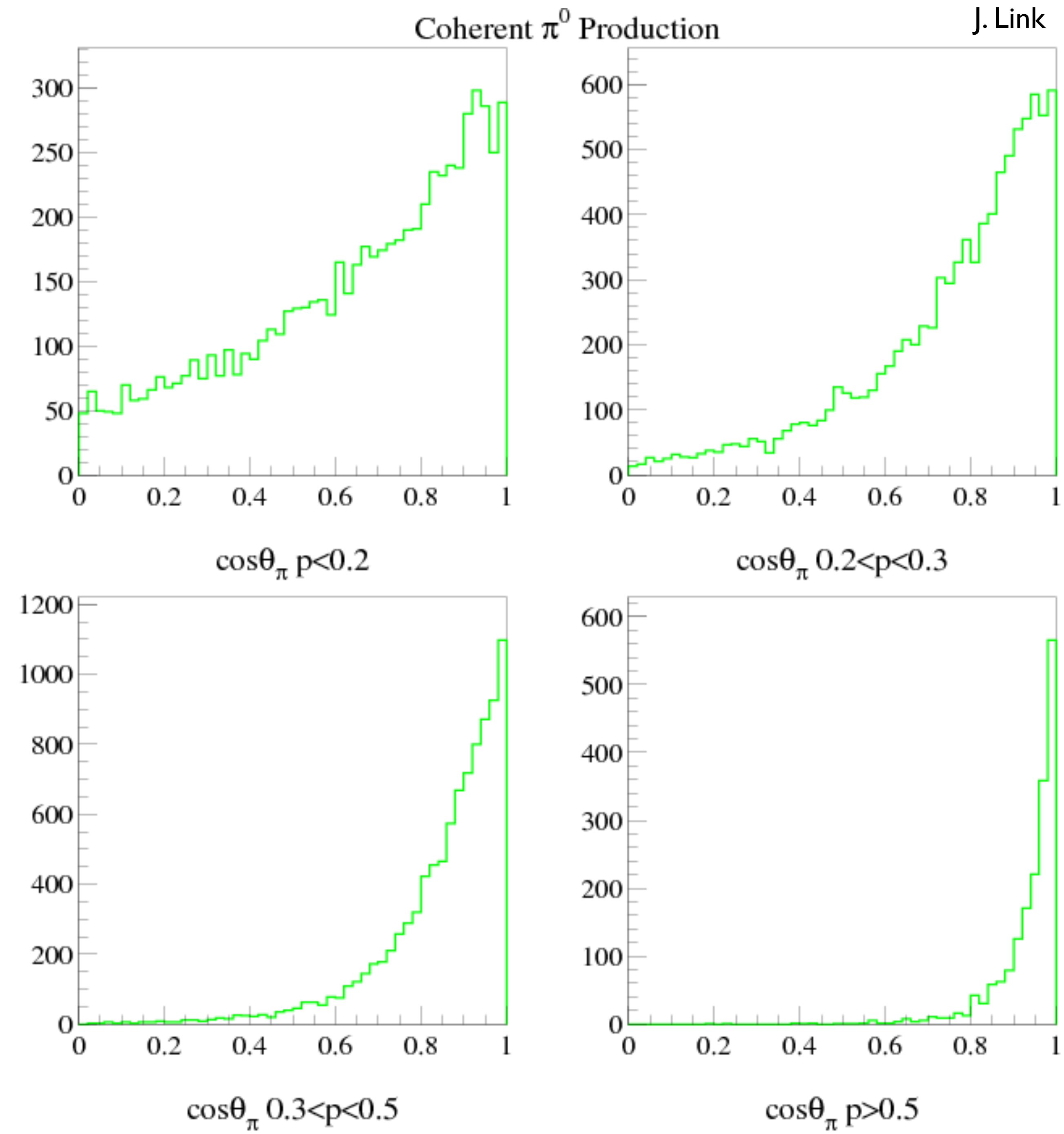


Data/MC Agreement



Coherent signature

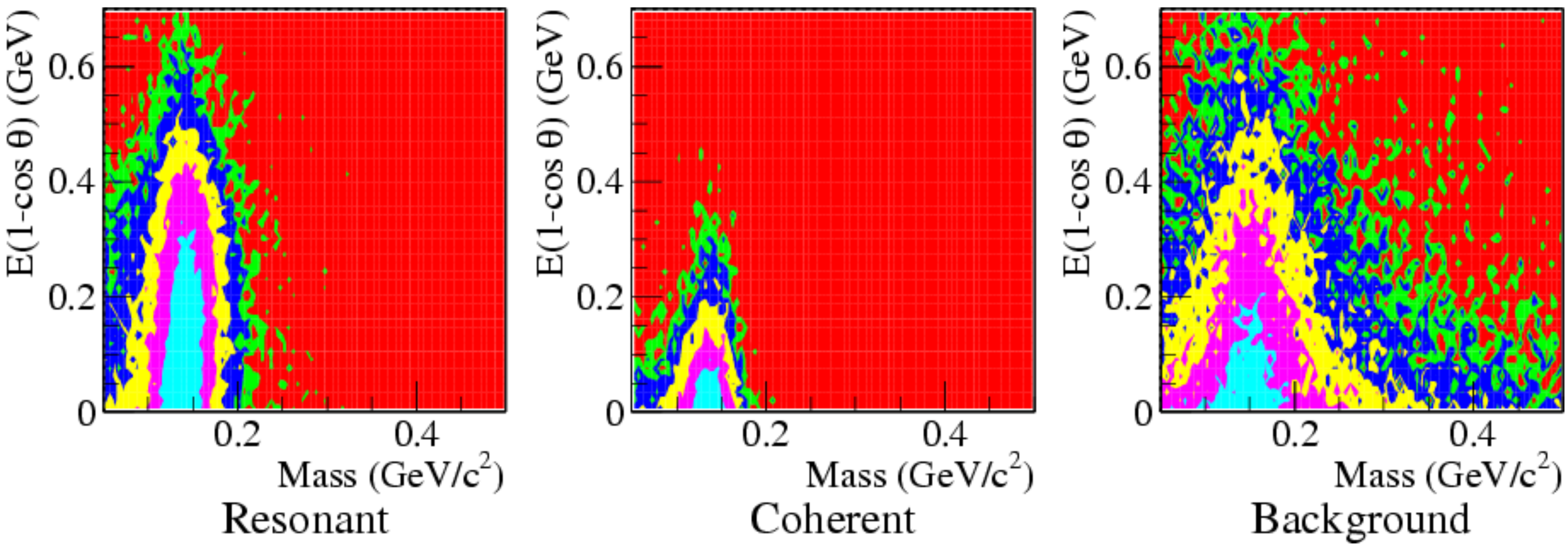




E(1-cosθ) has a more regular shape, as a function of momentum, than cosθ alone.

2D Fits

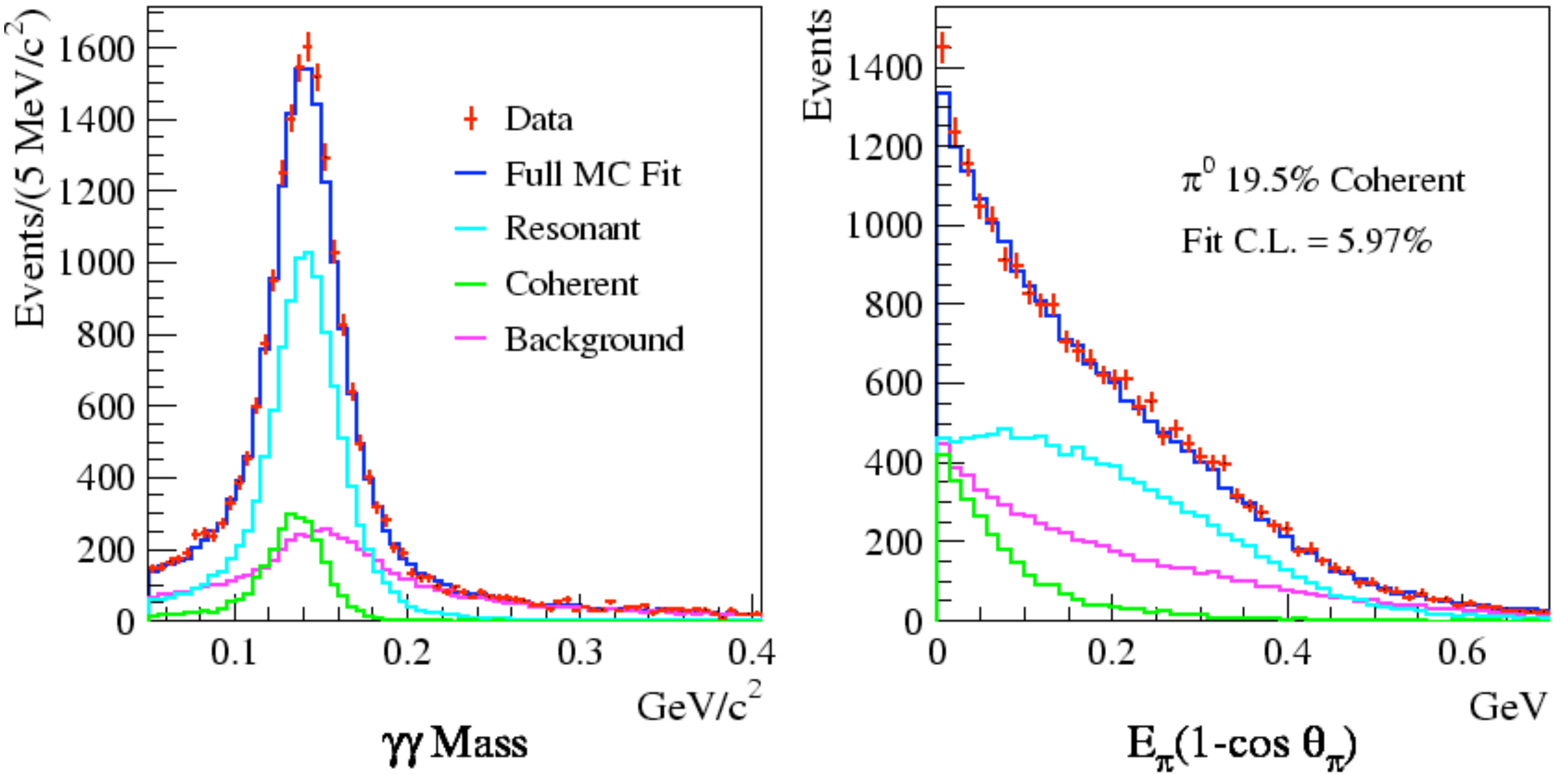
J. Link



Variable binning is used to get approx. equal numbers of events in each bin. The number of bins in each projection is varied from 15 to 25 and the average fit parameters are used.

Fit Results

J. Link



For the MiniBooNE flux and with the Nuance model we find that (19.5±1.1)% of all exclusive neutral current π^0 production is coherent.

Systematics

Source	Error
Binning	0.21
Background Model	0.64
Reweighting	0.51
Flux	0.06
Analysis Cuts	0.51
Optical Model	2.34
All Systematics	2.54

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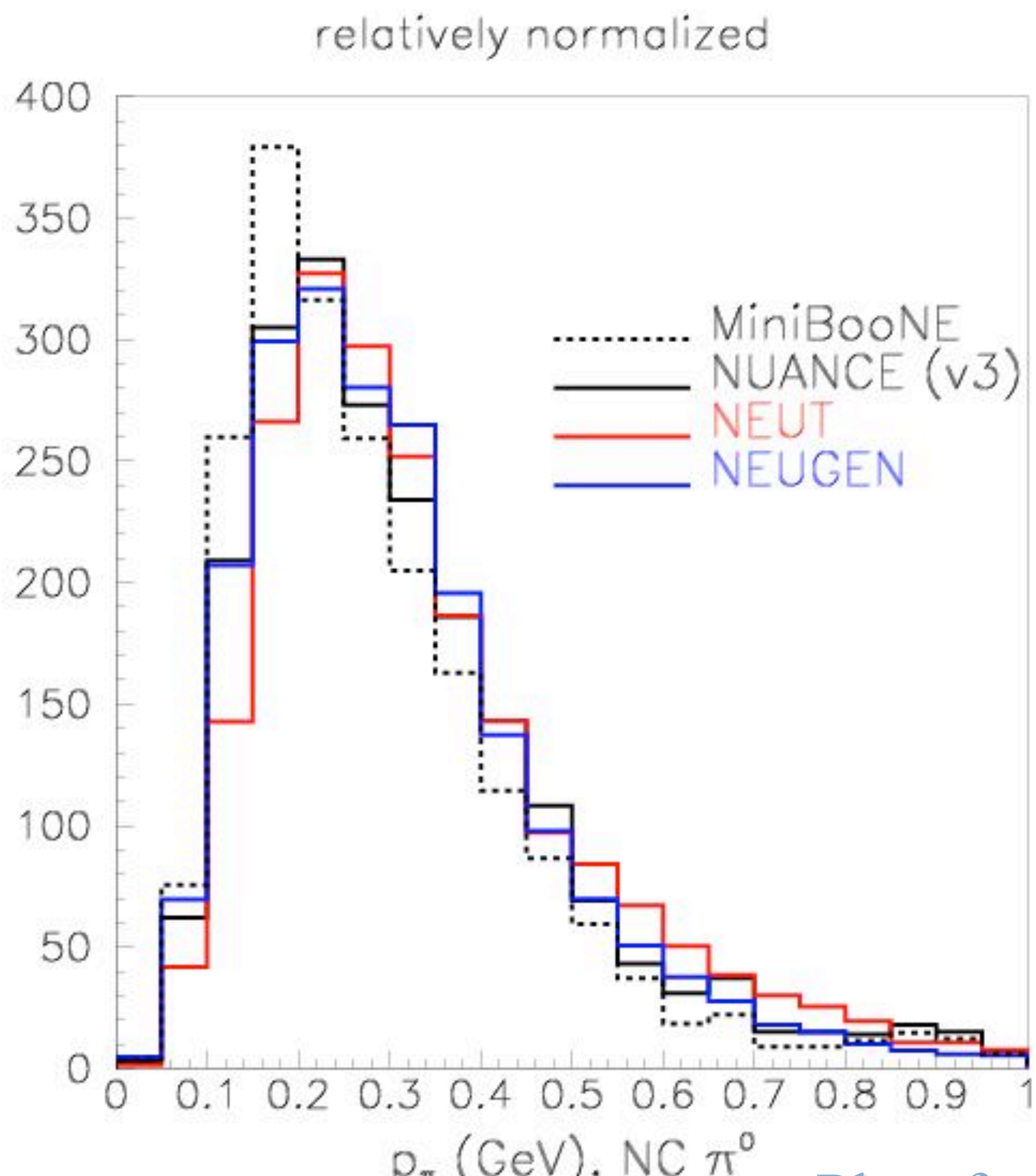
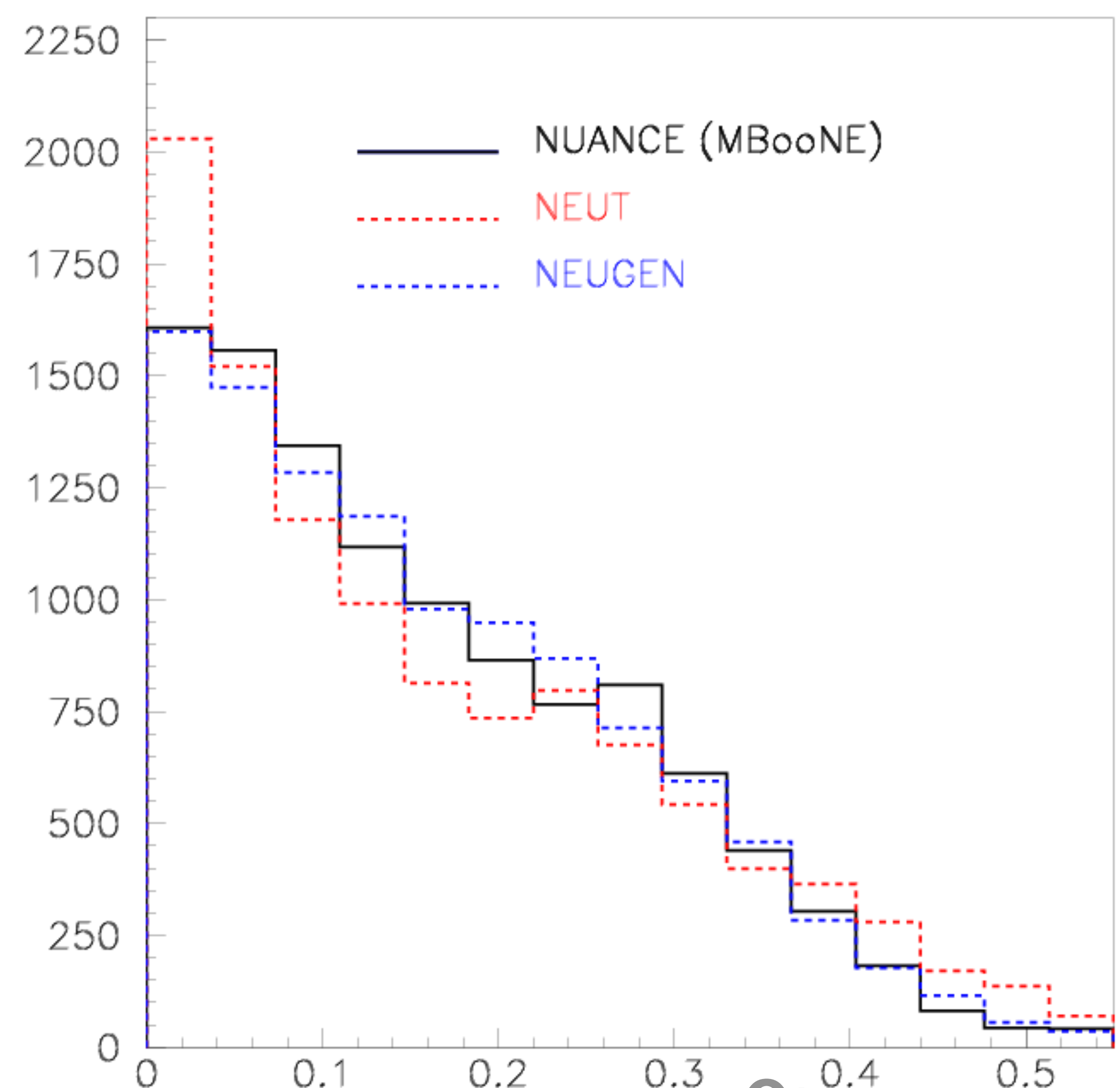
Generator Comparison





$E_\pi(1-\cos\theta)$

Plots from Sam Zeller

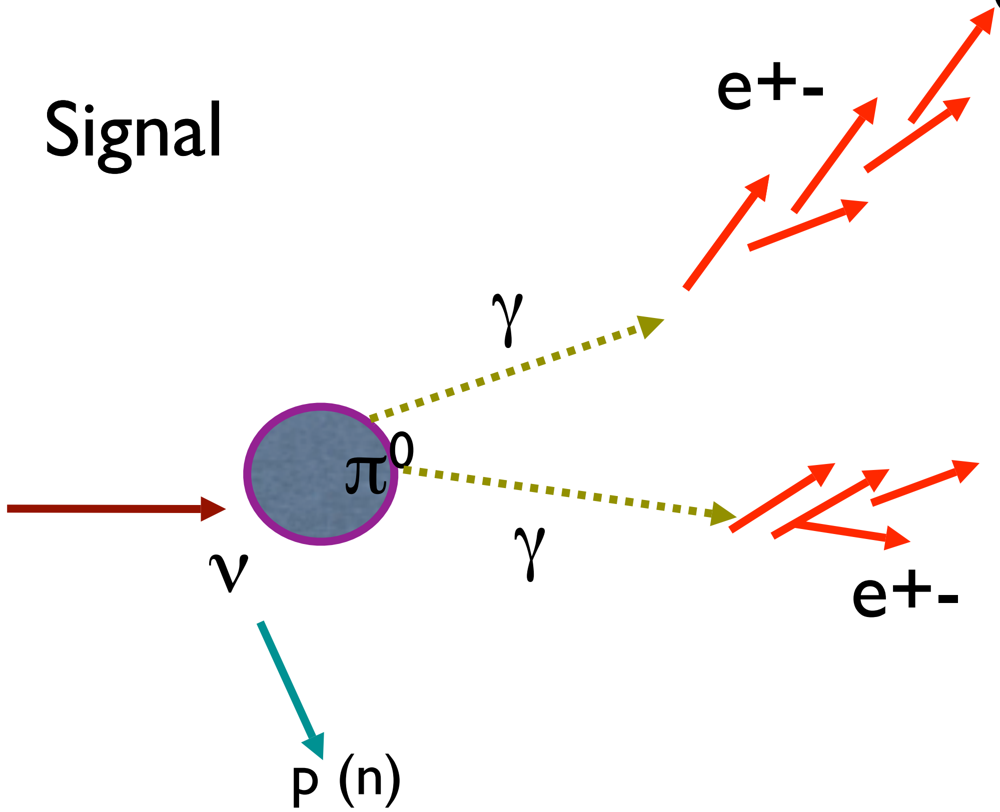
SciBooNE NCπ^0

SciBooNE NCπ^0 Analysis Goals

- Absolute cross section
  - Flux averaged
  - Differential vs. pi0 momentum

NCπ^0 signal & BG

Signal



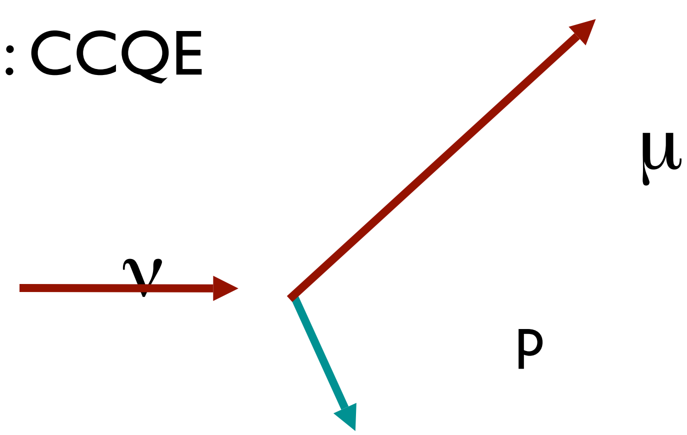
2γ from π^0

- 2 tracks in Fiducial Volume
- Disconnected
- Both tracks are not μ,p

Background μ, p common vertex or outside from detector(external)

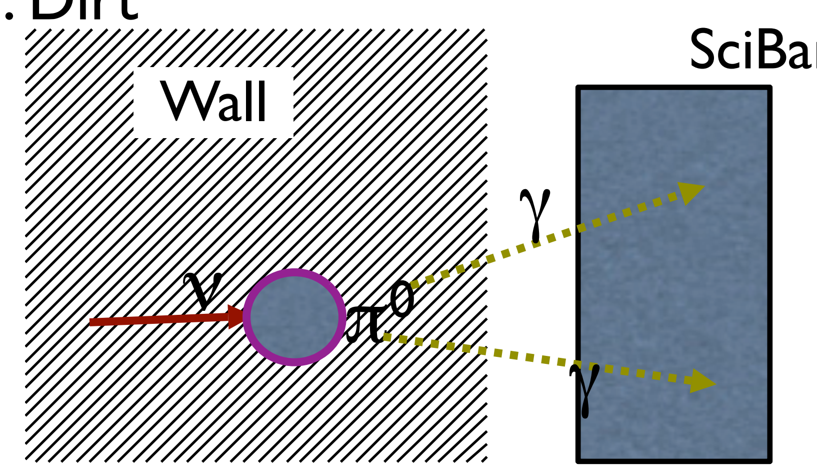
Internal B.G. : ν int. in SciBar

ex. : CCQE



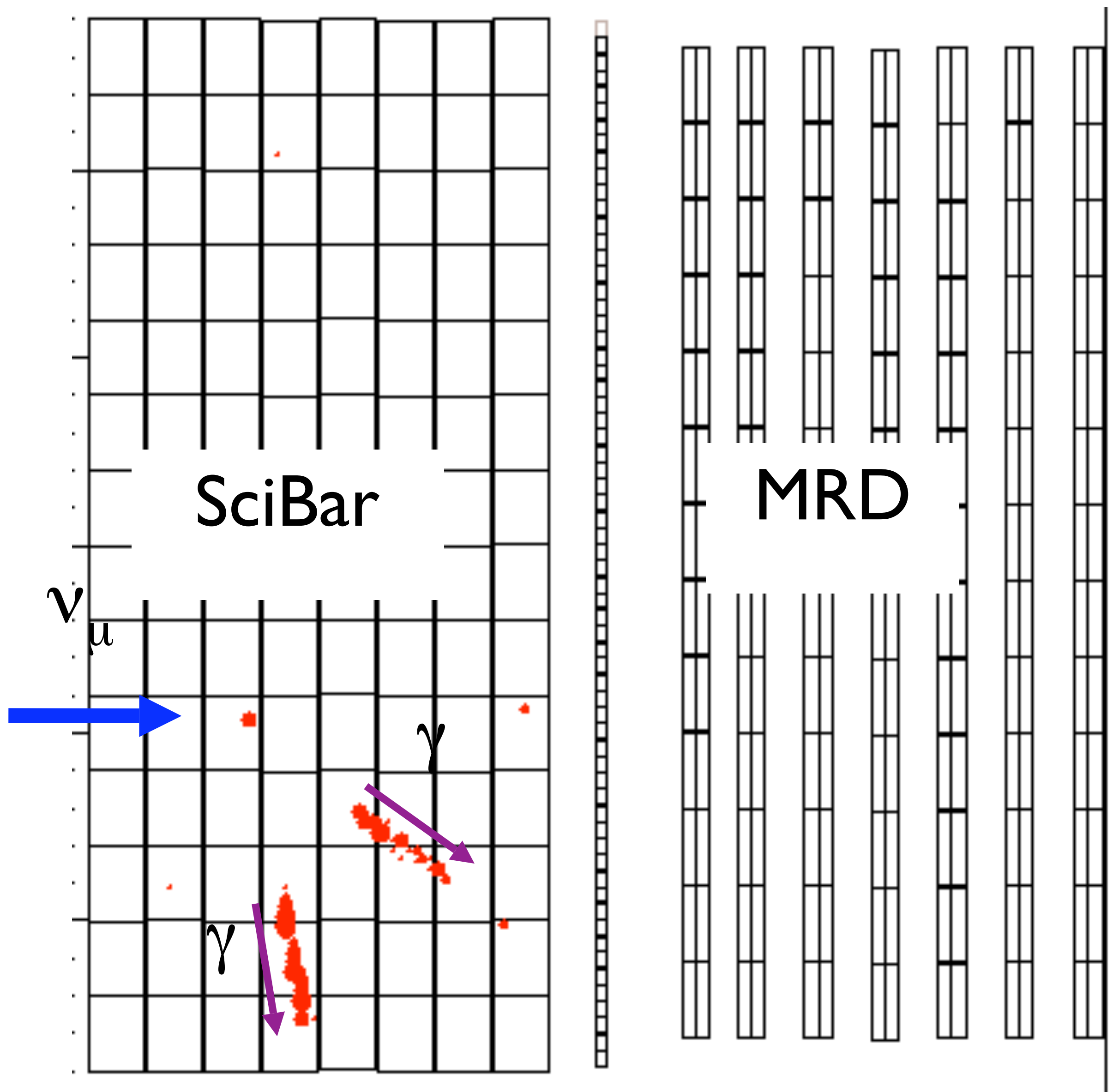
External B.G : from outside

ex : Dirt



Event Selection

NCπ^0 Candidate



Event Selection

0.Pre-Selection

- At least two tracks (2γ)
- without 1st layer hits (reject dirt)
- Tracks Stopped in SciBar (reject μ)

1. Using the track information

- Reject p using the dE/dX
- Reject μ using the decay e

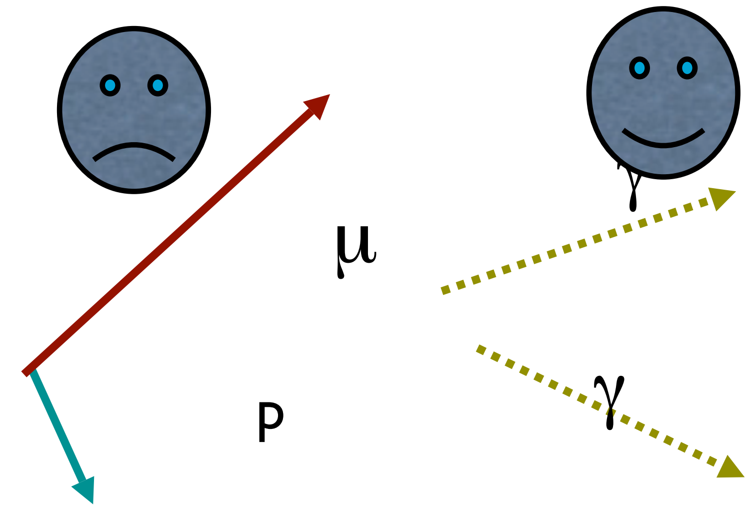
2. Using the event topology

Disconnection between 2 tracks

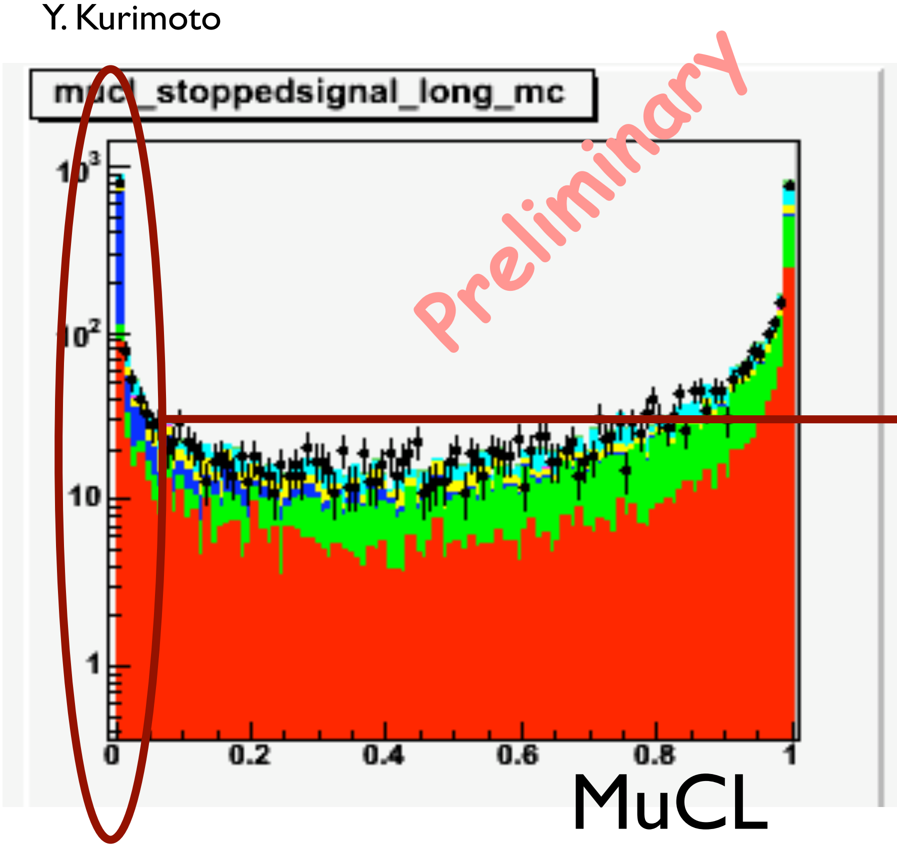
Proton rejection: dE/dx

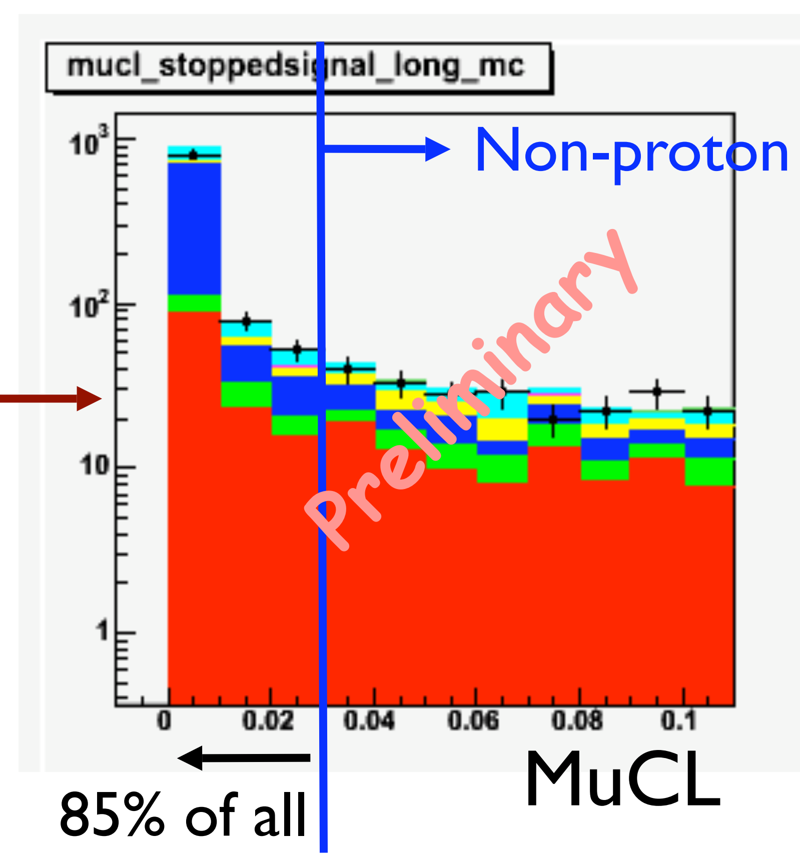
Proton have larger energy deposit than any other particle

Construct "Muon Confidence Level" to separate proton from other particle



Y. Kurimoto





85% of all protons here

Dot : data

CC w/o π0
CC w π0
NC w/o π0
NC w π0
Dirt
Cosmic

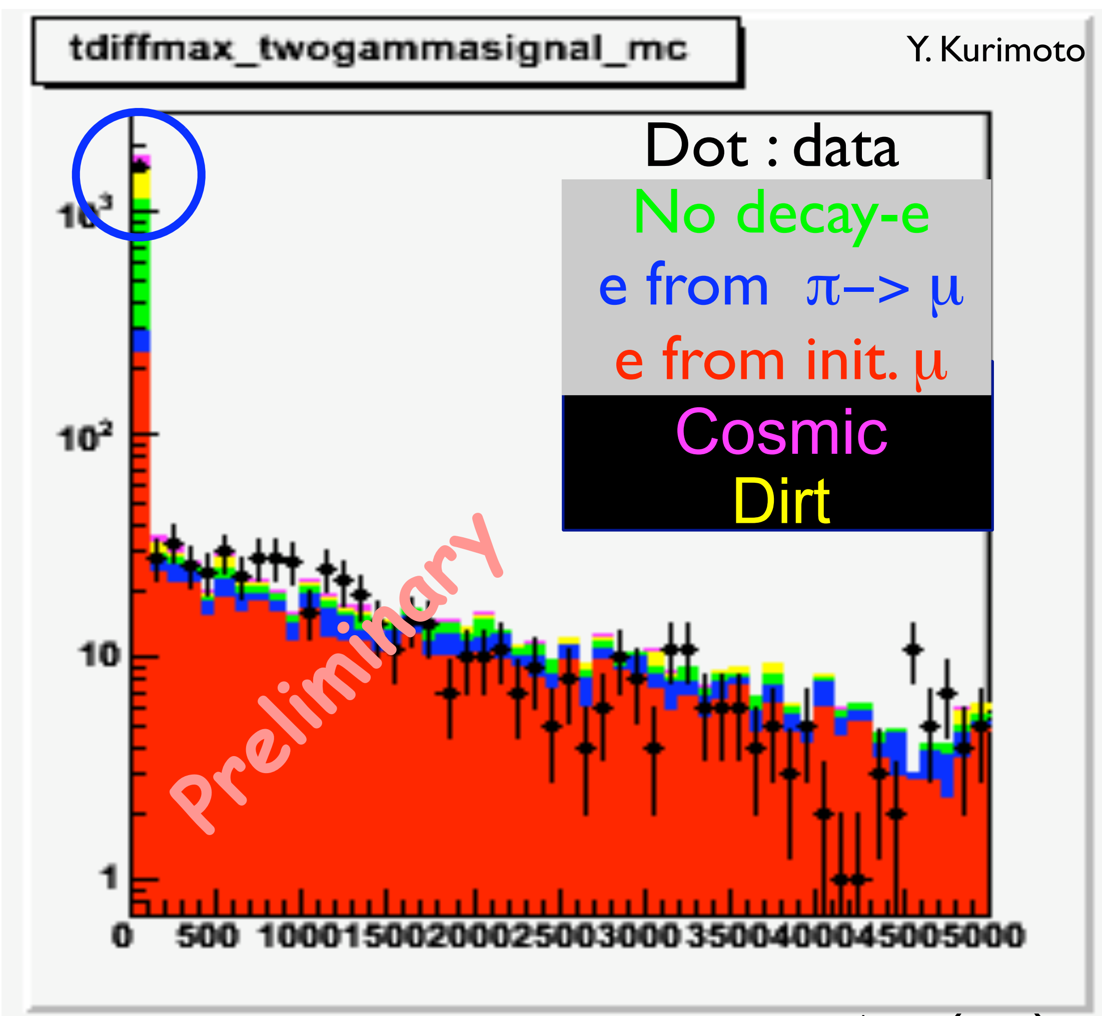
Internal
External

Non-proton-like : MuCL > 0.03

Events are required to have at least 2 non-proton-like tracks

Muon rejection

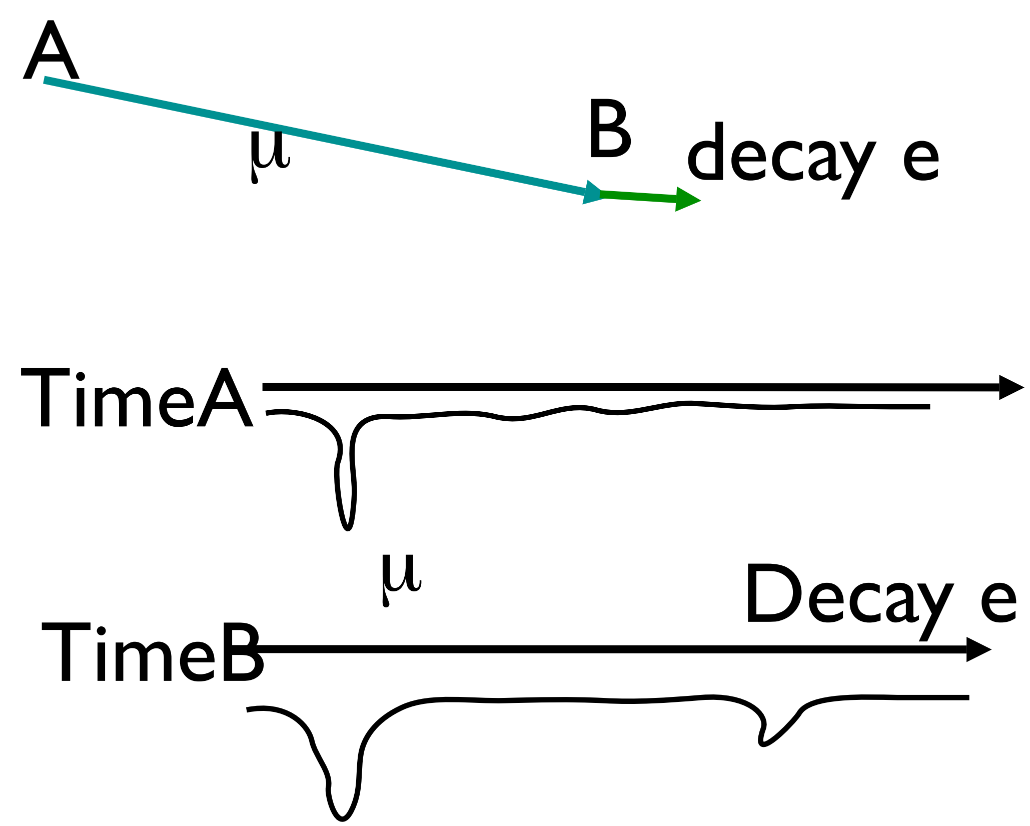
Time difference btw track edges



Δt (ns)

Internal

External



Δt = (The latest) TimeB - TimeA

Most "no decay"
even

Reject "Δt > 100 ns"

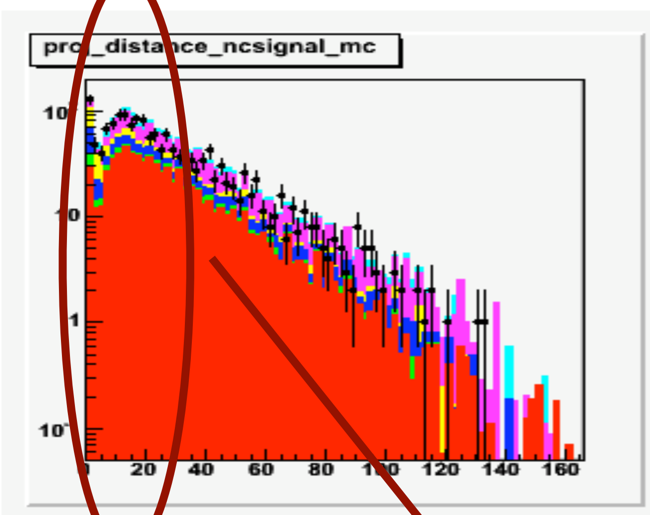
s is in the region < 100 ns (first bin)

Reject 66 % of decay-e events

Keep 95 % of no decay-e events

Track disconnection

Minimum 2D-distance between track edges



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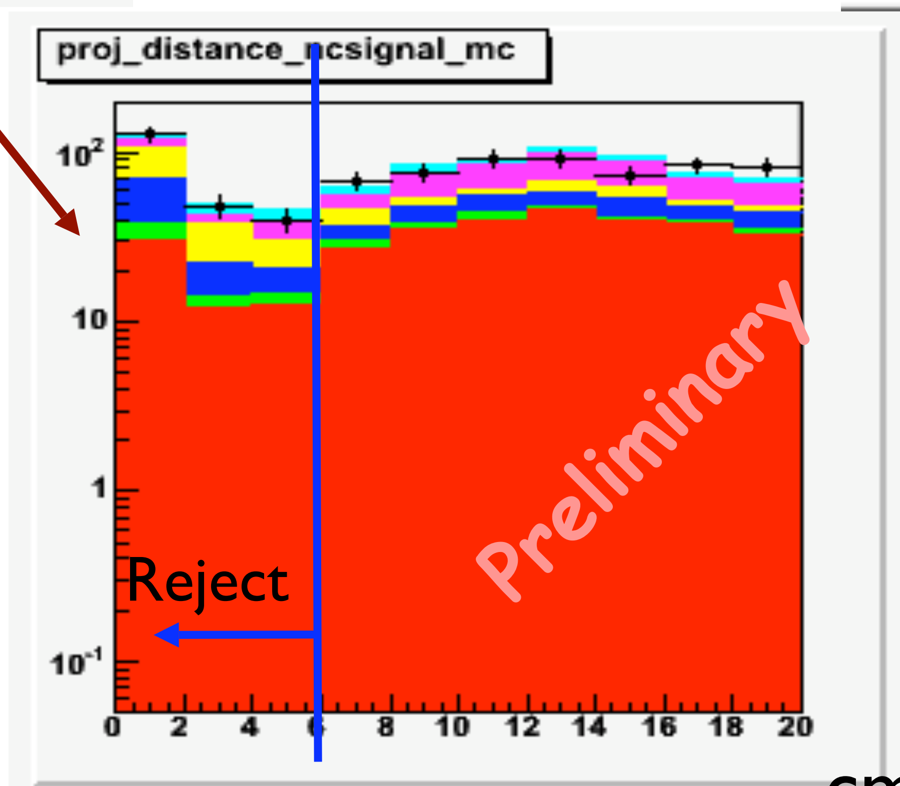


cm

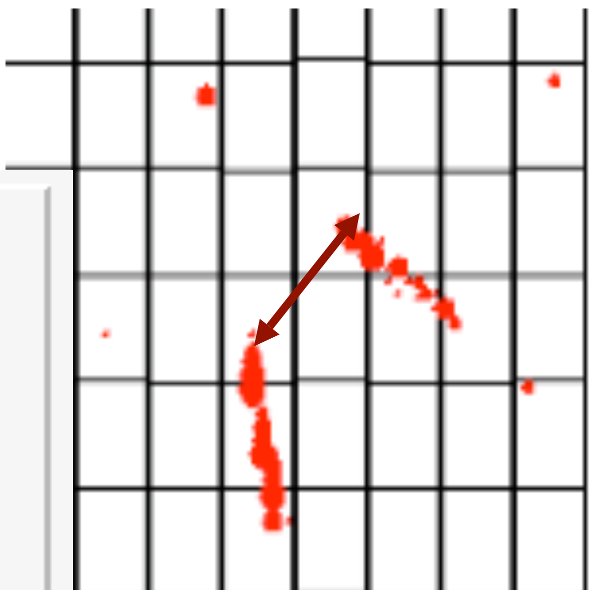
Dot : data

CC w/o π0
CC w π0
NC w/o π0
NC w π0
Dirt
Cosmic

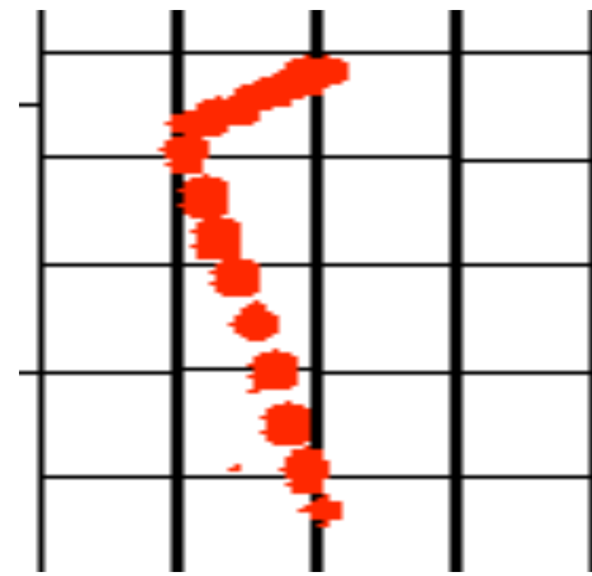
Internal
External

To get 2γ from π^0 and remove CC events

Threshold = 6cm



accepted



rejected

Reject 31 % of CC events

Keep 92 % of π^0 events (NC)

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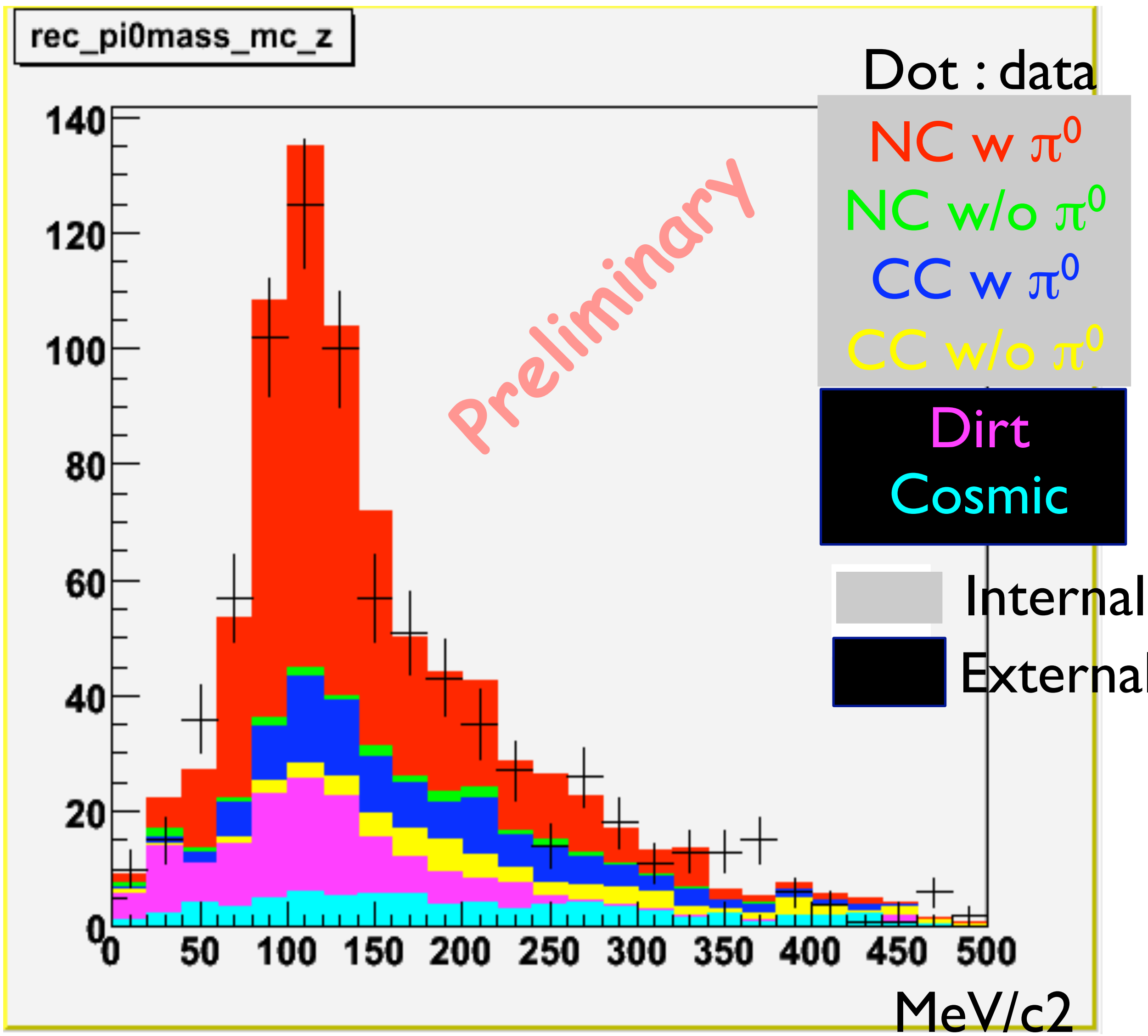
π^0 reconstruction

Reconstructed Mass

Y. Kurimoto



- Reconstructing mass using 2 tracks in SciBar after all event selection

Clear π^0 mass peak !
~850 events selecte
d
~460 π^0 events (NC)

SciBar can reconstruct π^0 !!!

→ Cross section measurement

References

- K2K
  - Phys.Lett **B**619(2005) 255-262; hep-ex/0408134
- MiniBooNE
  - Phys.Lett. **B**664:41-46,2008; arXiv:0803.3423[hep-ex]
- SciBooNE
  - Proceedings of Neutrino Oscillation Workshop (NOW2008)