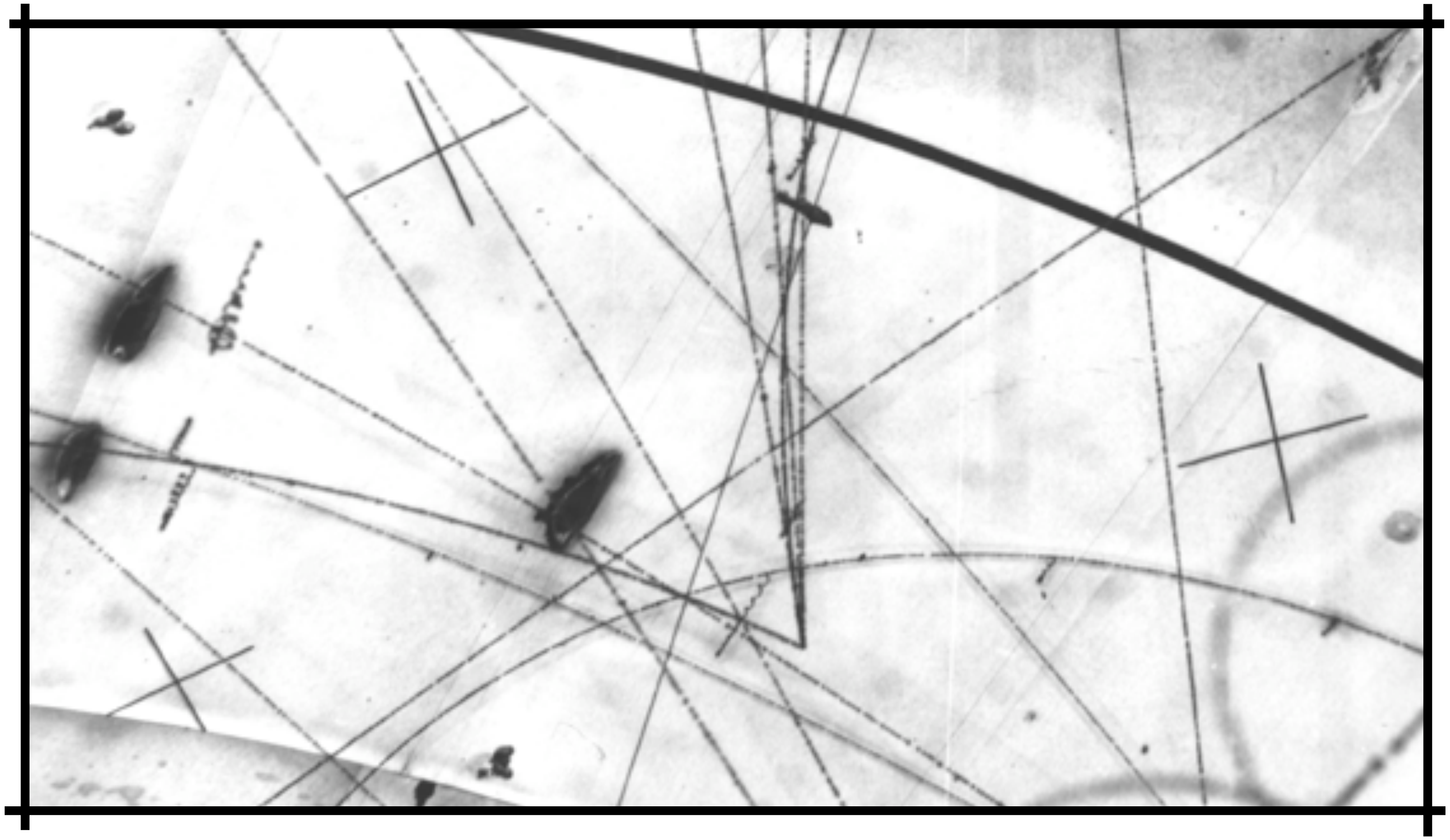


Lecture 6. Antineutrinos

Antineutrino Outline

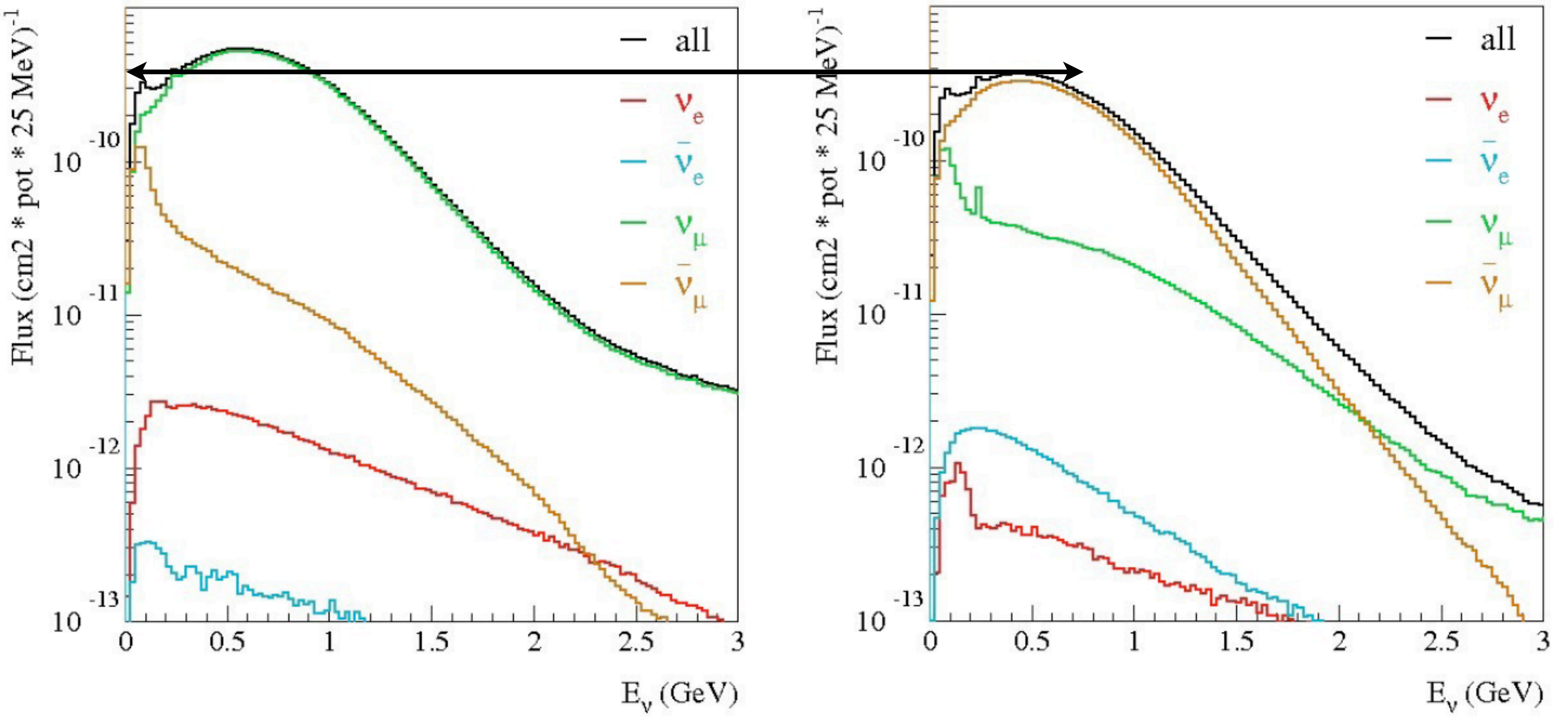
- Introduction
- Wrong sign backgrounds
- MiniBooNE
- SciBooNE

MiniBooNE, SciBooNE

Motivation

- CP Violation in leptons, if it exists, will be observed as a difference in oscillation probabilities between neutrinos and antineutrinos
  - Probably a few percent effect!
- Need to understand antineutrino cross sections just as well as neutrino

Size Matters



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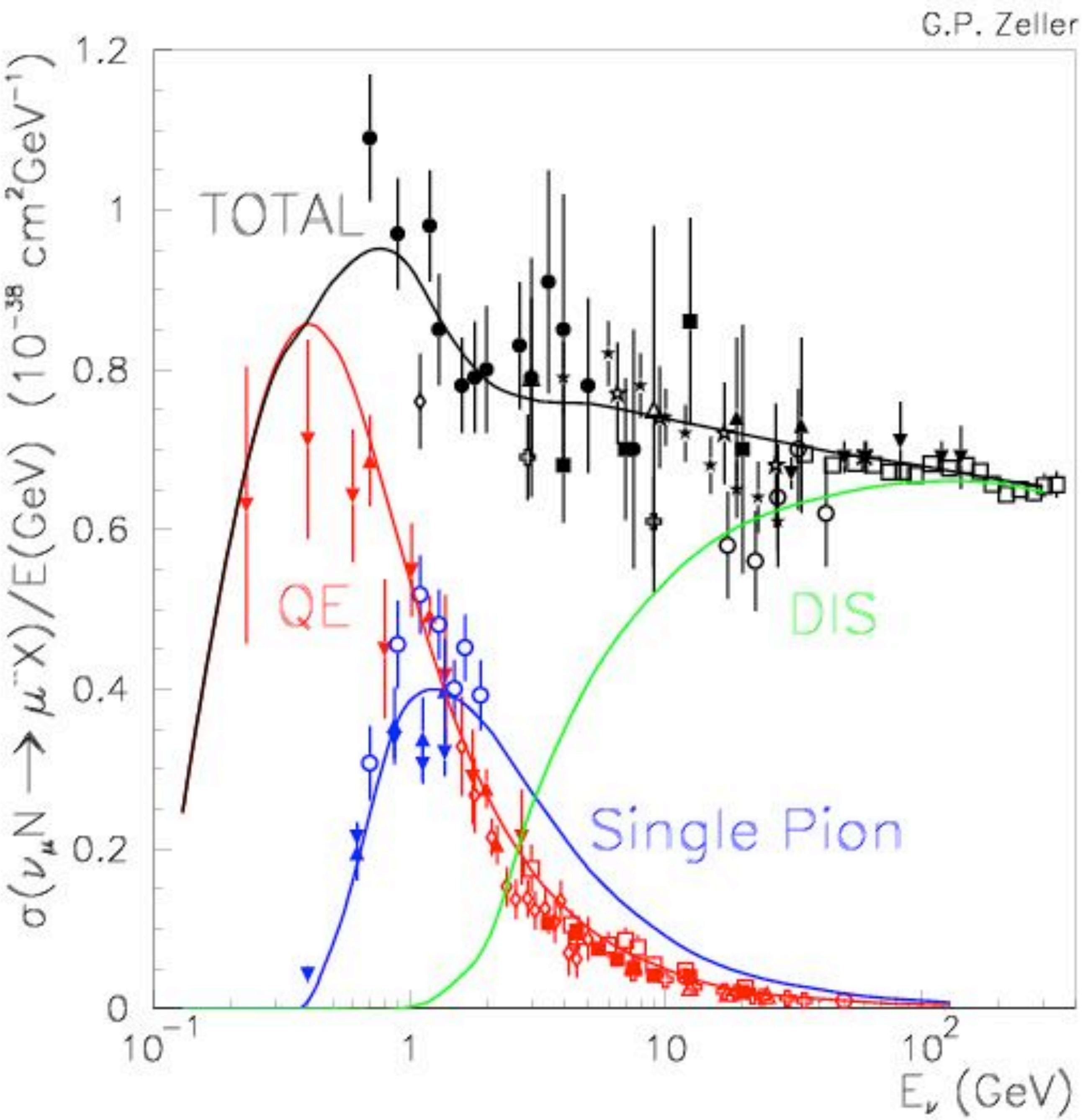
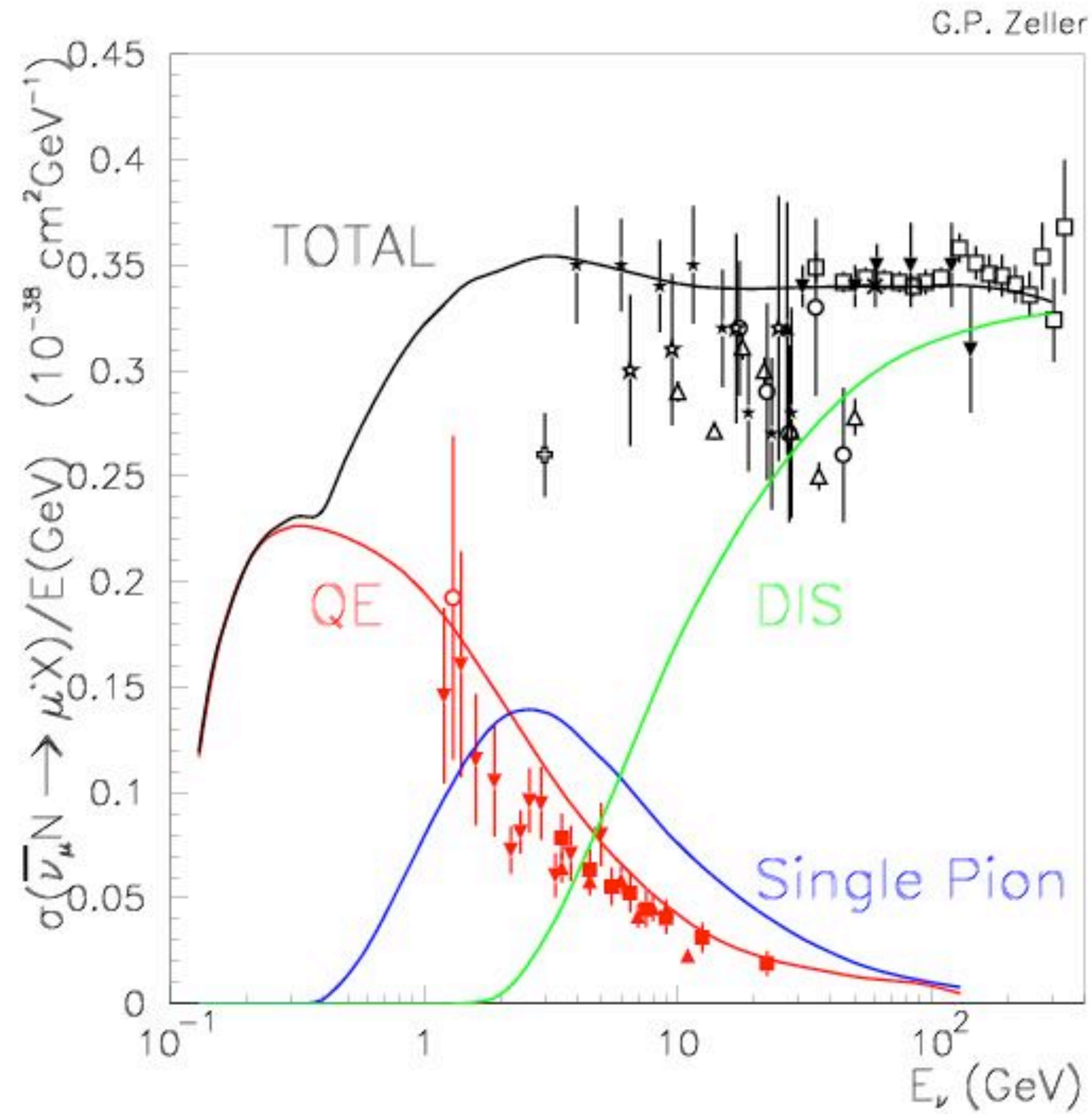
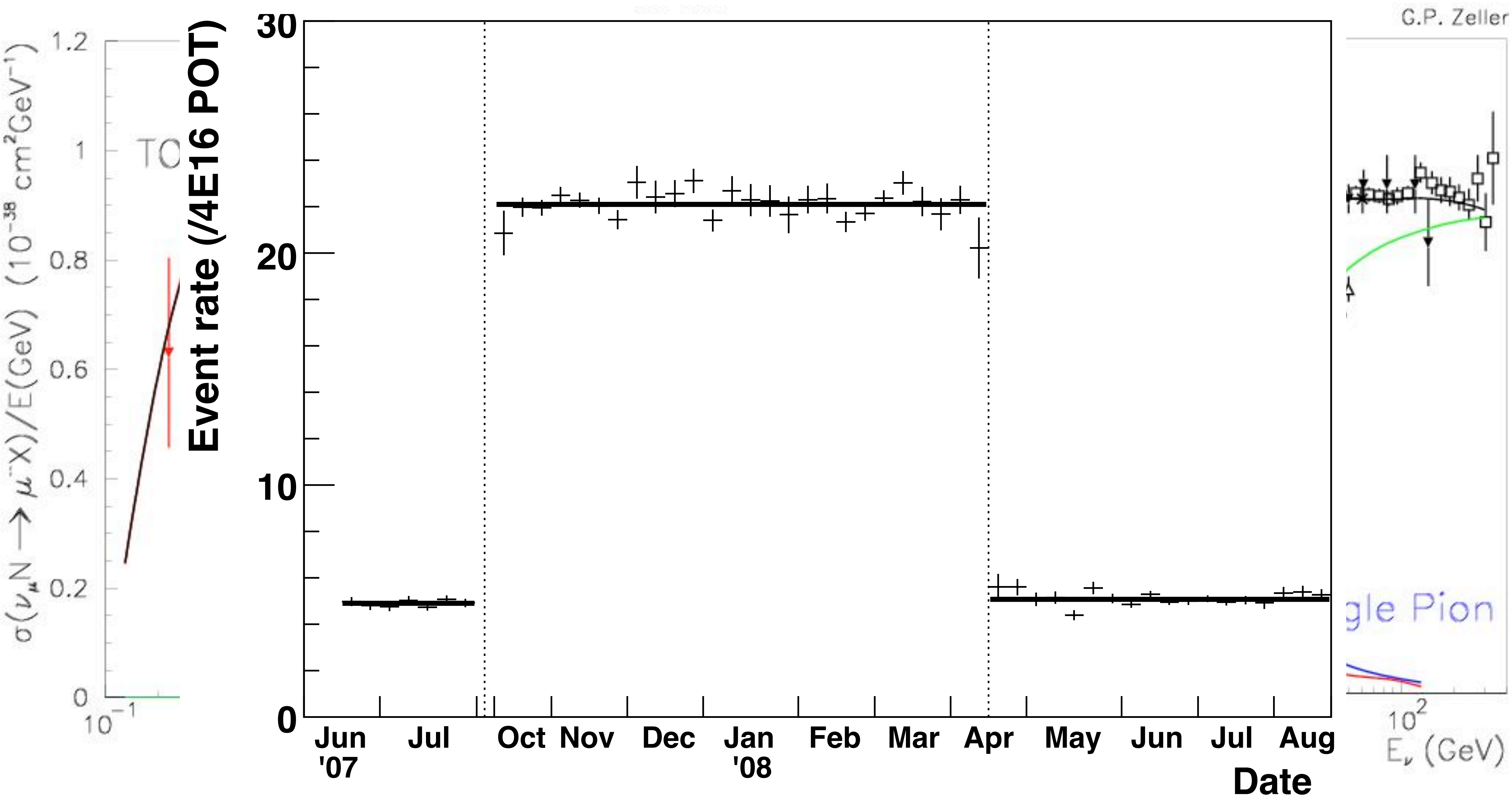
Size Matters





Size Matters

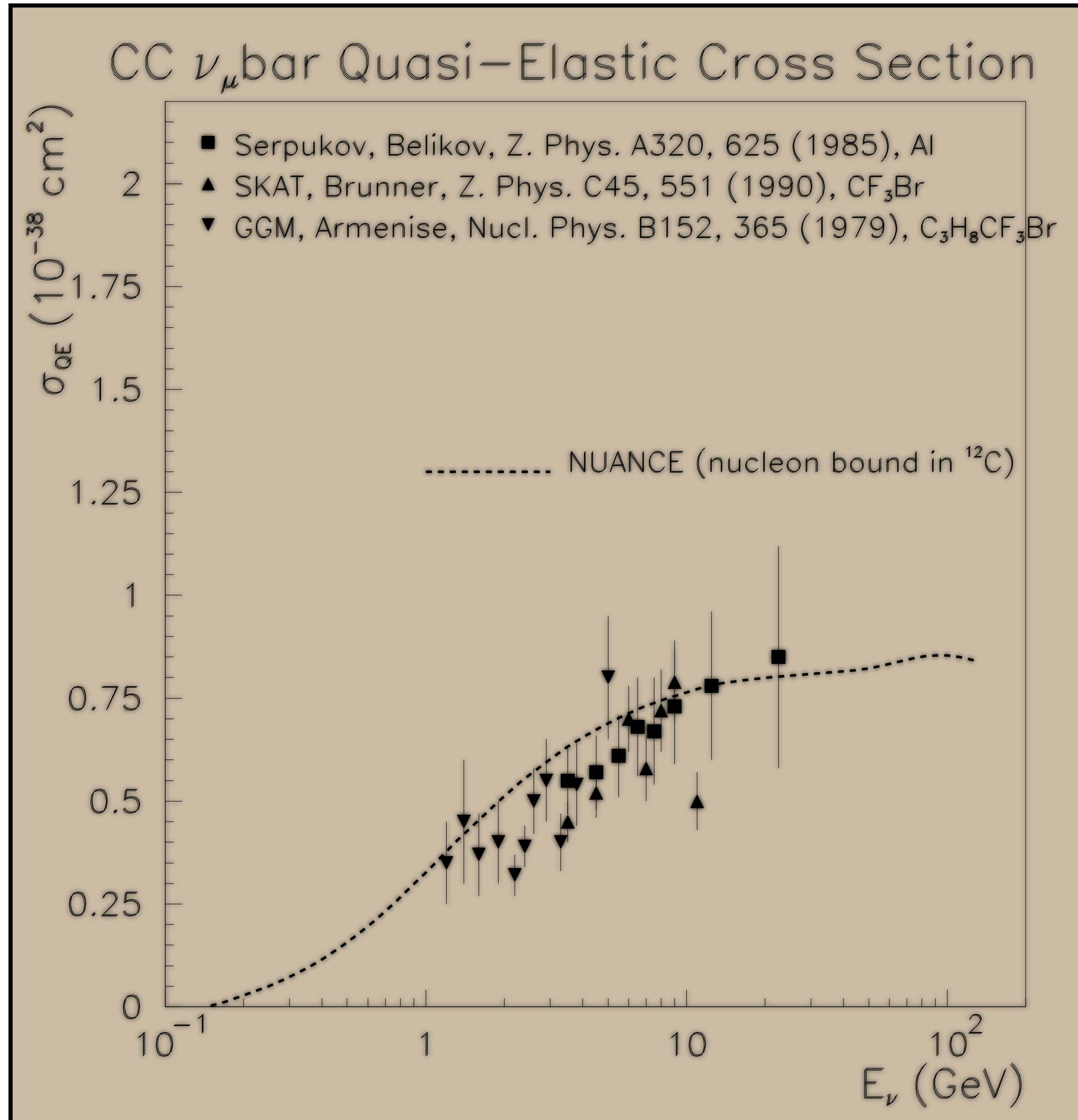


Status of $\bar{\nu}_\mu$ σs

- Very few data, especially at low energy
- Not much understanding of nuclear targets
- $\bar{\nu}_\mu$ CCQE
  - ~1700 events
- $\bar{\nu}_\mu$ NCπ^0
  - Only one (1) measurement ever.
- $\bar{\nu}_\mu$ CCπ^-
  - ~1300 events

$\bar{\nu}_\mu$ CC QE Scattering

G.P. Zeller



- Few $\bar{\nu}_\mu$ QE measurements
- None below 1 GeV

$\bar{\nu}_\mu$ CC QE Scattering

<E>	Experiment	target	date	#QE evts
2 GeV	Gargamelle	$C_3H_8CF_3Br$	1979	766
1.3 GeV	BNL	H_2	1980	13
16 GeV	FNAL	NeH_2	1984	405
6-7 GeV	SKAT	CF_3Br	1988	92
9 GeV	SKAT	CF_3Br	1990	159
5-7 GeV	SKAT	CF_3Br	1992	256
				1691

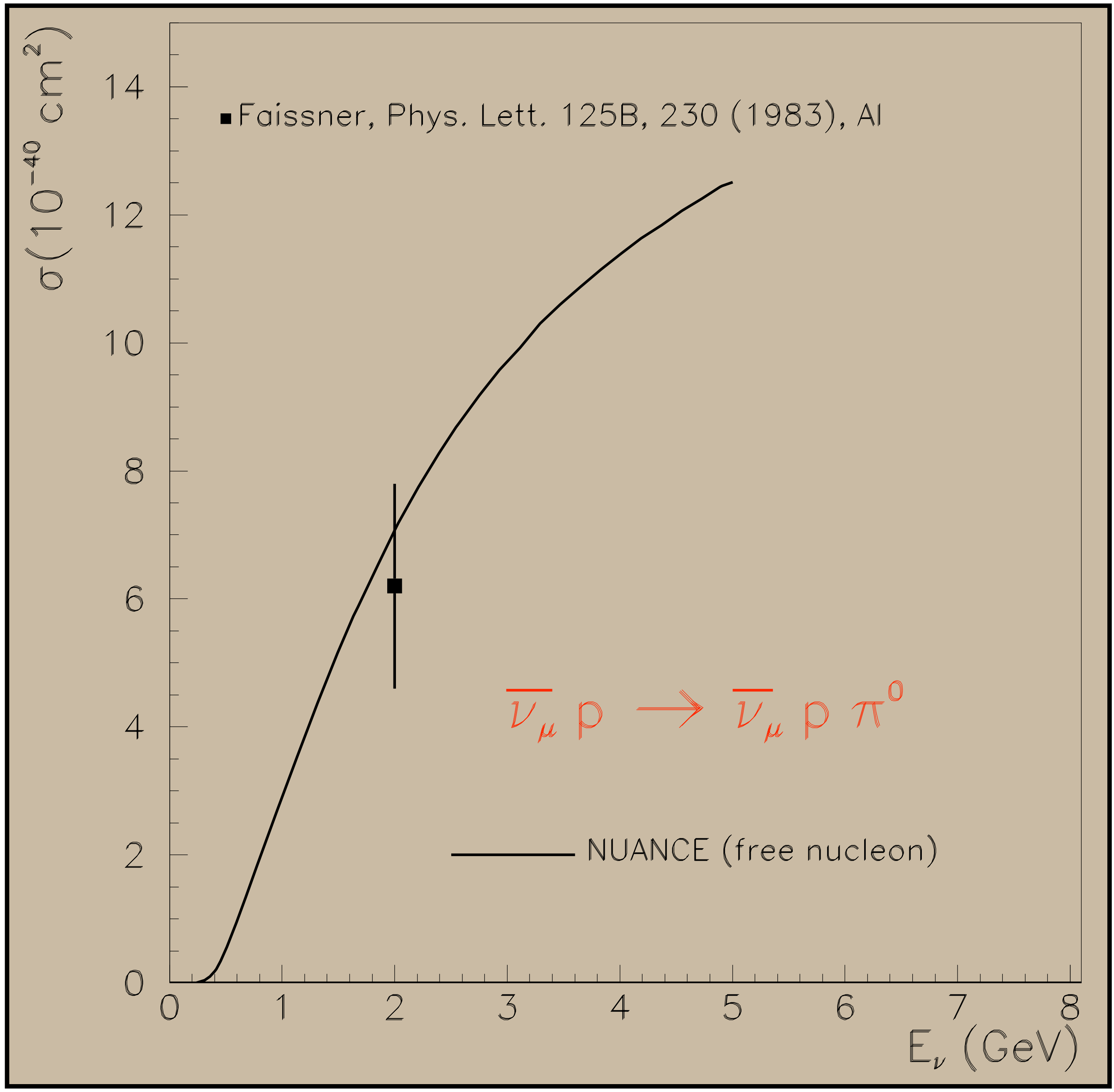
$CC\pi^-$ Events

<E>	Experiment	target	date	$\#CC\pi^-$ evts
1.5 GeV	Gargamelle	$C_3H_8CF_3Br$	1979	282
5-70 GeV	FNAL	H_2	1980	247
5-200 GeV	BEBC	D_2	1983	300
25 GeV	BEBC	H_2	1986	375
7 GeV	SKAT	CF_3Br	1989	120
				1324

$\bar{\nu}_\mu$ NC π^0

- Only one measurement of $\bar{\nu}_\mu N \rightarrow \bar{\nu}_\mu N \pi^0 N$ to date[1]
  - 25% uncertainty at 2 GeV
- Important for $\bar{\nu}_e$ appearance searches
- Coherent production more apparent in antineutrino scattering

G.P. Zeller



[1] This appeared as a footnote in Faissner et al., Phys. Lett. 125B, 230 (1983)

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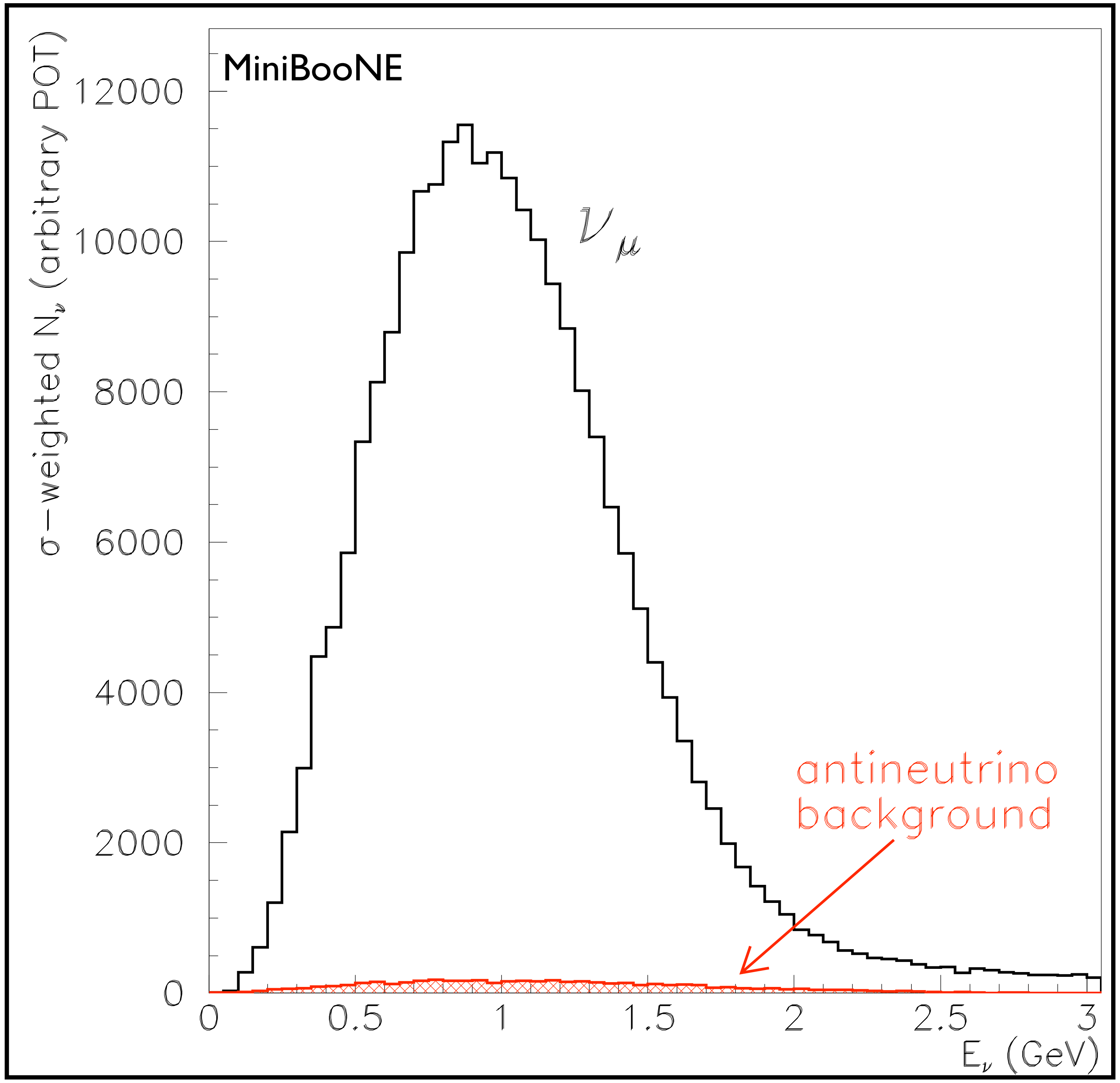
Wrong Sign BGs

- In neutrino running, wrong sign backgrounds are very small (2%)
- In antineutrino running they are much larger (~30%)
- Cherenkov calorimeters cannot distinguish μ^- from μ^+
- Need a way to extract the WS BGs!

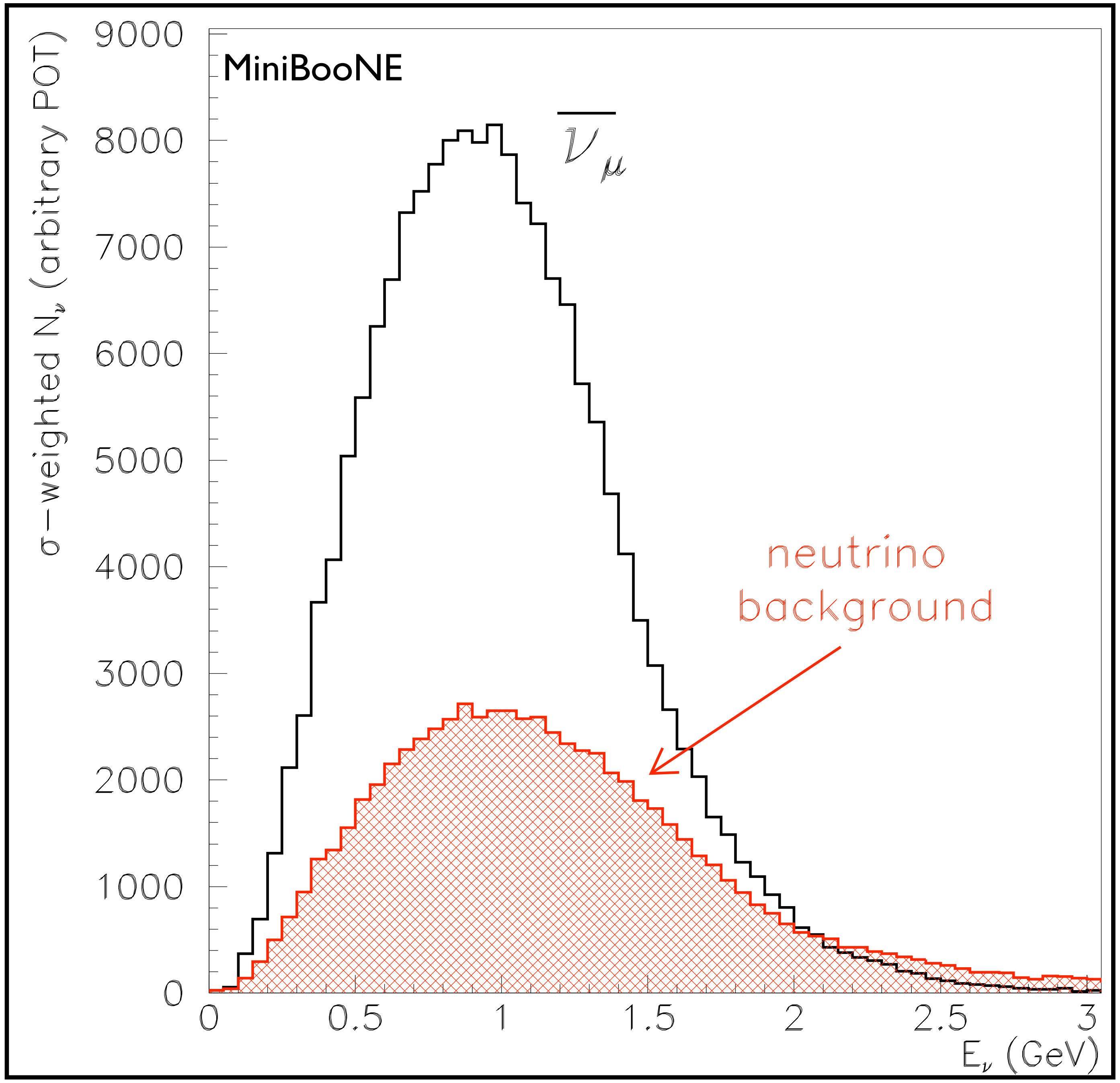
Gang of Four



Wrong Sign BGs

- In neutrino running, wrong sign backgrounds are very small (2%)
- In antineutrino running they are much larger (~30%)
- Cherenkov calorimeters cannot distinguish μ^- from μ^+ (event by event)
- Need a way to extract the WS BGs!

Gang of Four



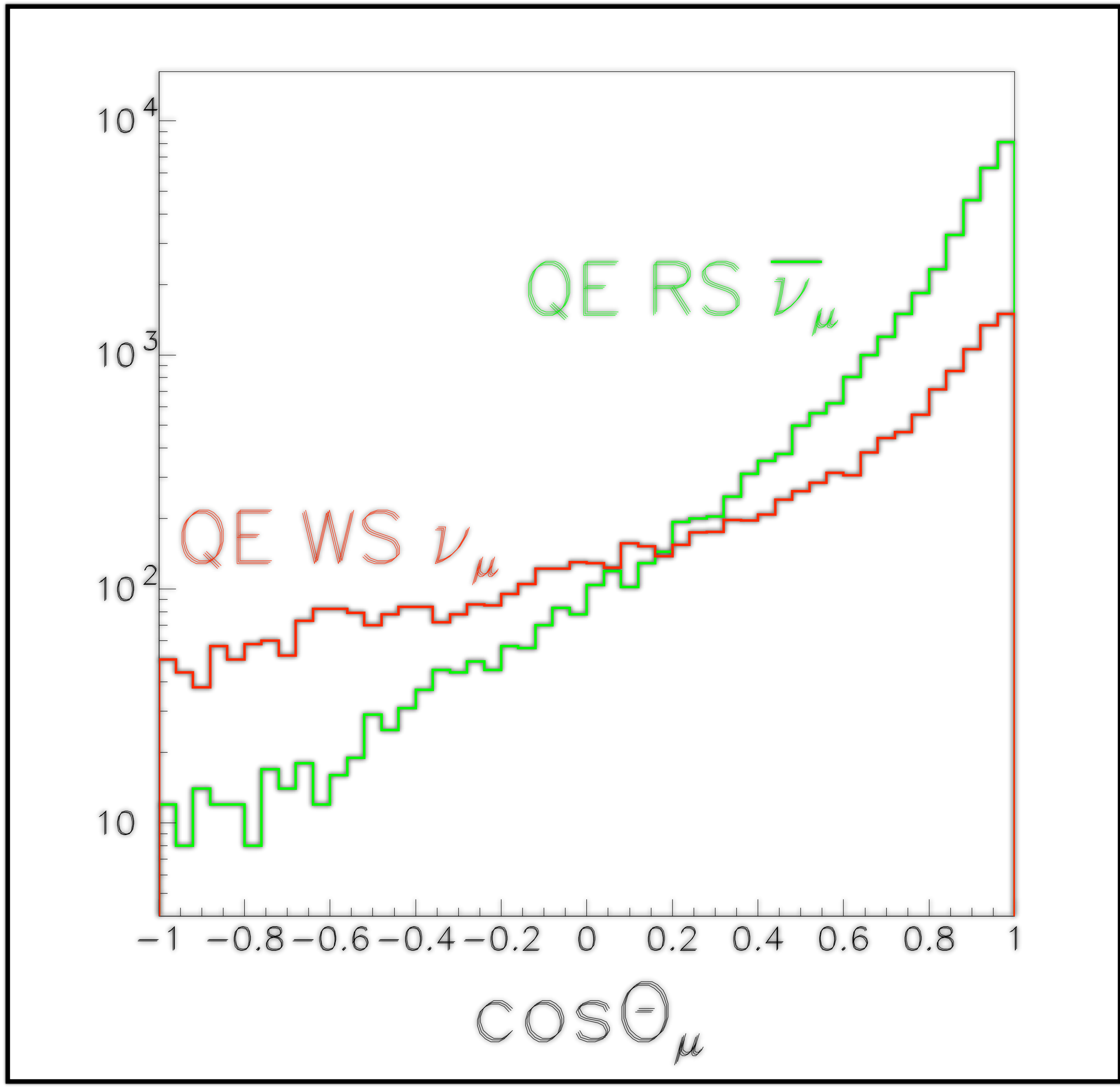
Constraining WS BGs

- MiniBooNE has developed three methods of constraining the overall fraction of ν, $\bar{\nu}$
  - Independent constraints
  - Sensitive to total WS fraction
    - Not sensitive to energy spectrum of WS events
- SciBooNE uses precise tracking to distinguish nu from nubar
  - Event-by-event separation

MB WS BG Constraints: μ Direction

Gang of Four

- Softer Q^2 spectrum for antineutrino events means more forward-peaked μ
- Can fit angular distribution shape and extract RS/WS fractions
- Using generated muon directions, can extract WS fraction with 5% uncertainty



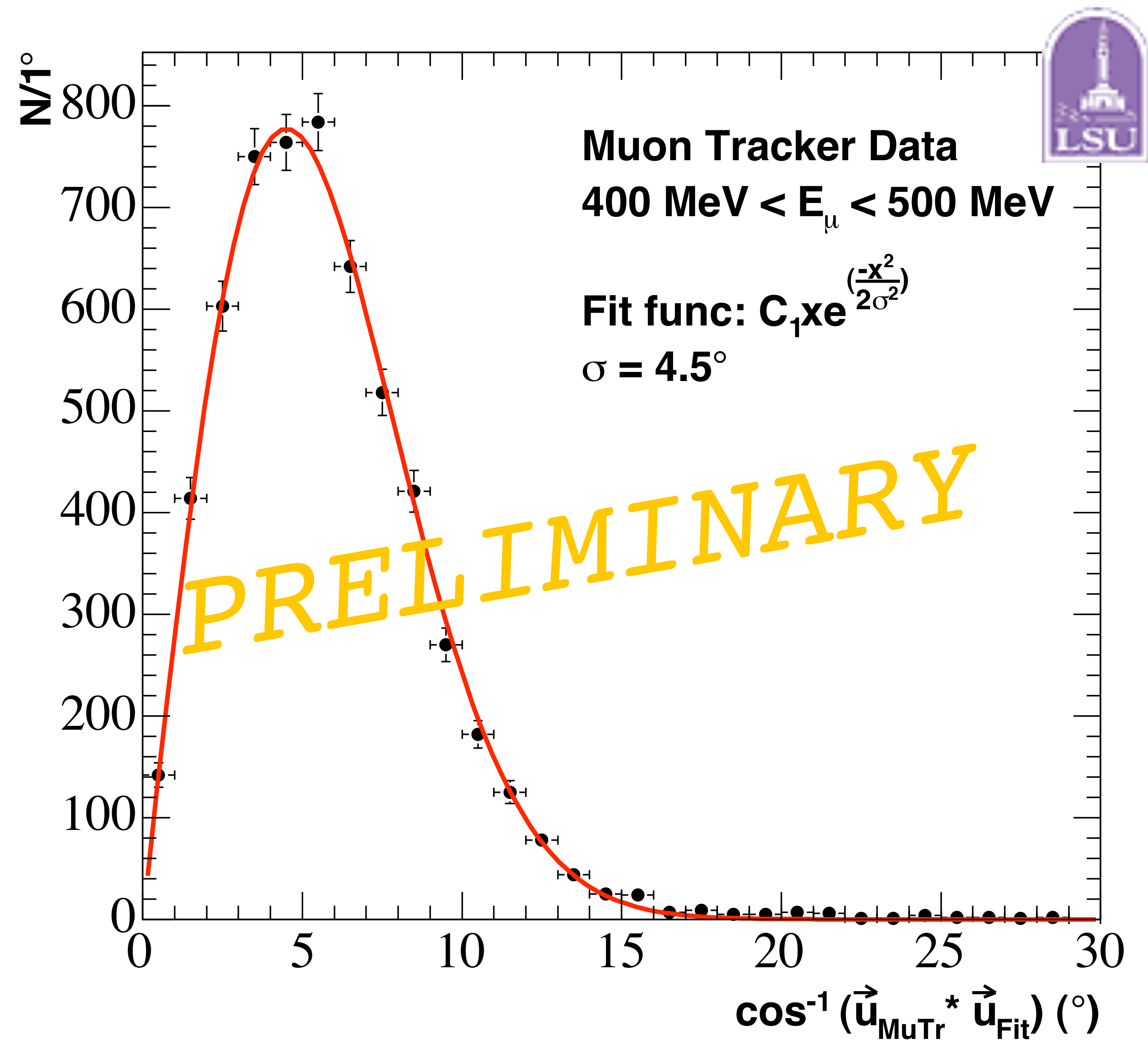
MB WS BG Constraints: μ Direction

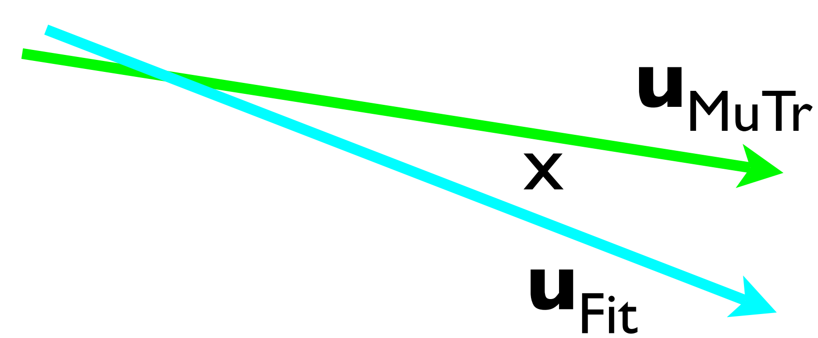
- MiniBooNE has very good angular reconstruction
- Tested with cosmic muon calibration system
- Fit distribution of

$$\cos^{-1}(\vec{u}_{MuTr} \cdot \vec{u}_{Fit})$$

$$xe^{-x^2/2\sigma^2}$$

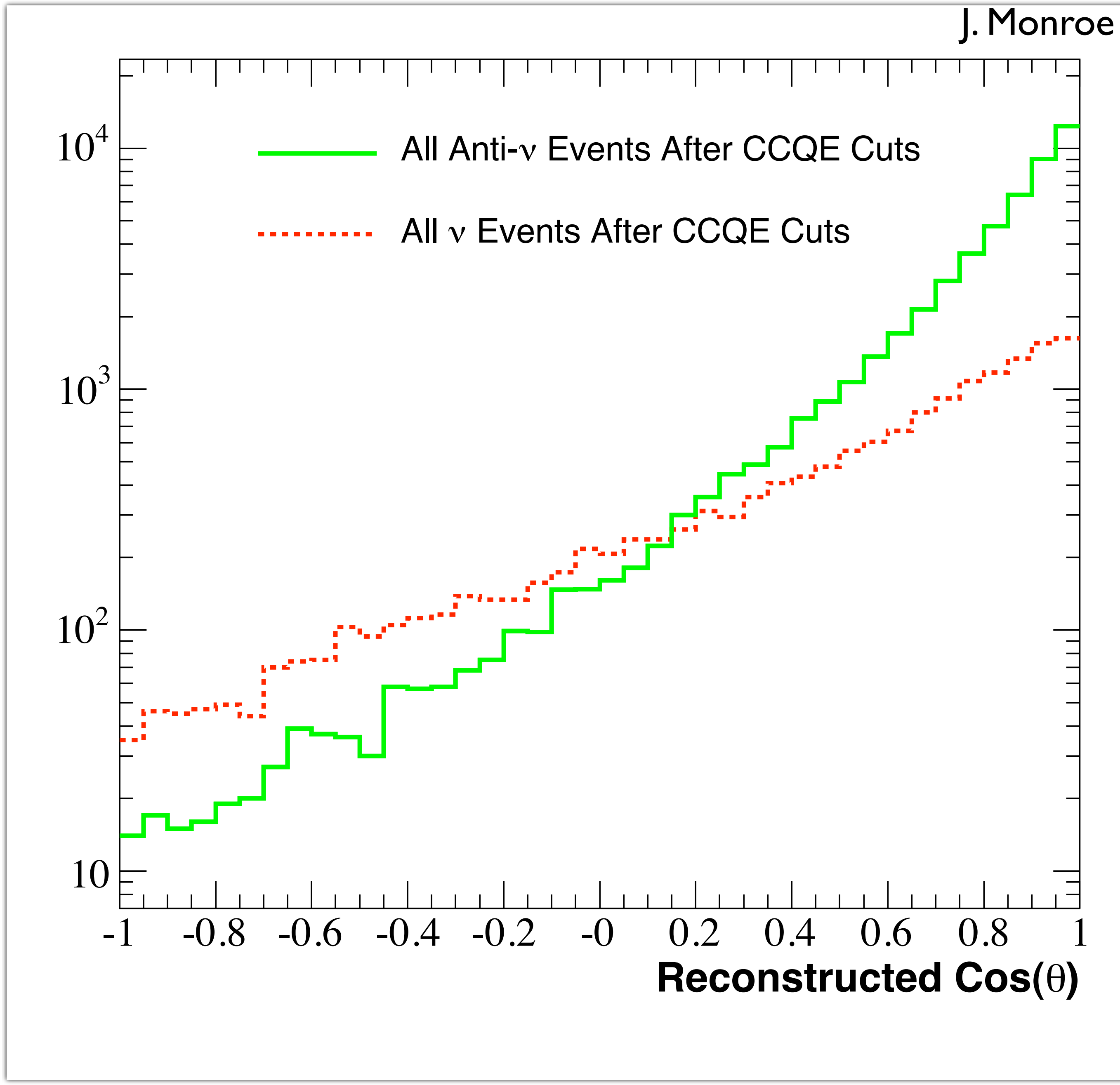
- (projection of a 2D Gaussian)
- Extract intrinsic resolution of muon tracker
- Angular resolution = 4.0°



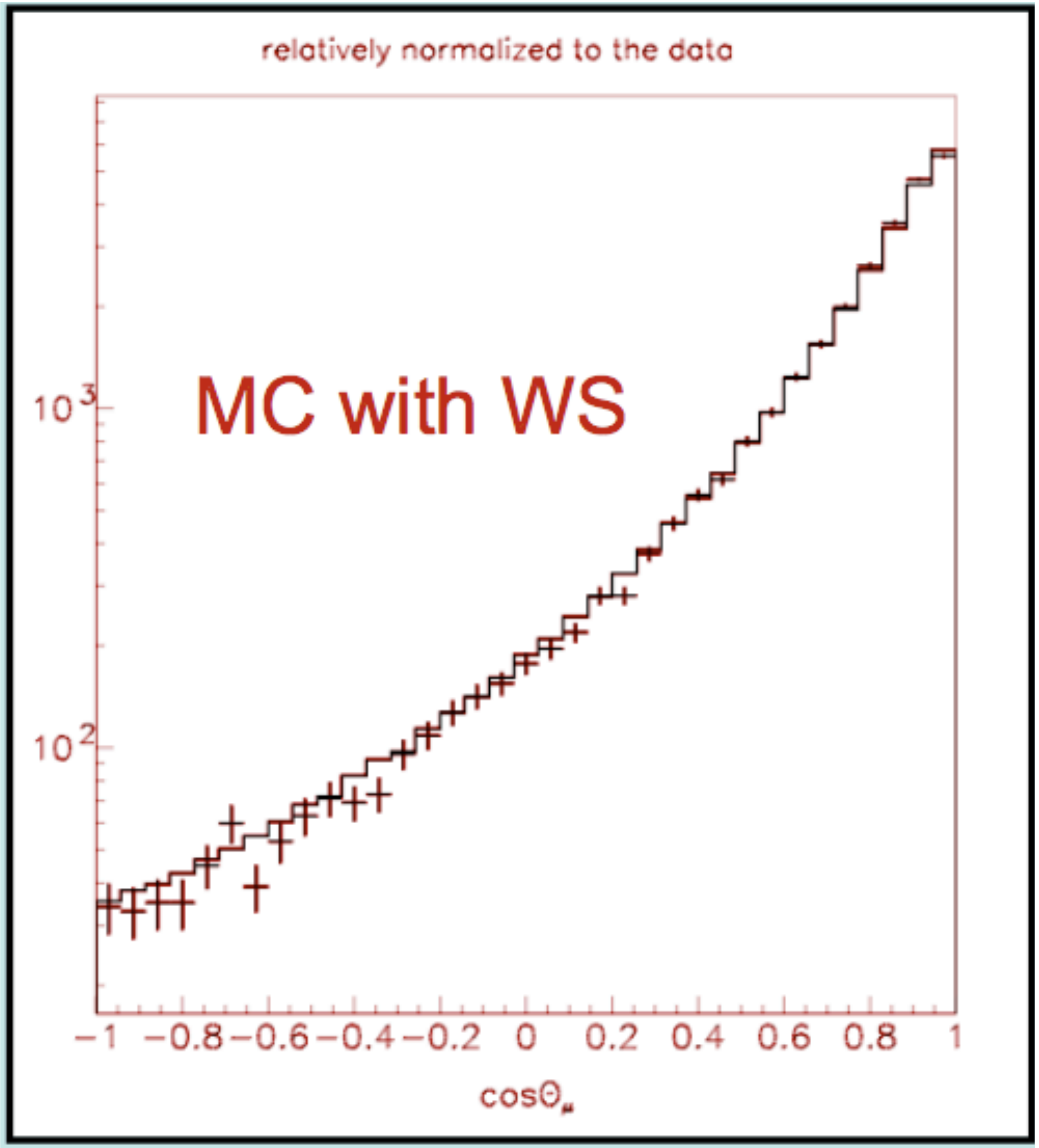


MB WS BG Constraints: μ Directions

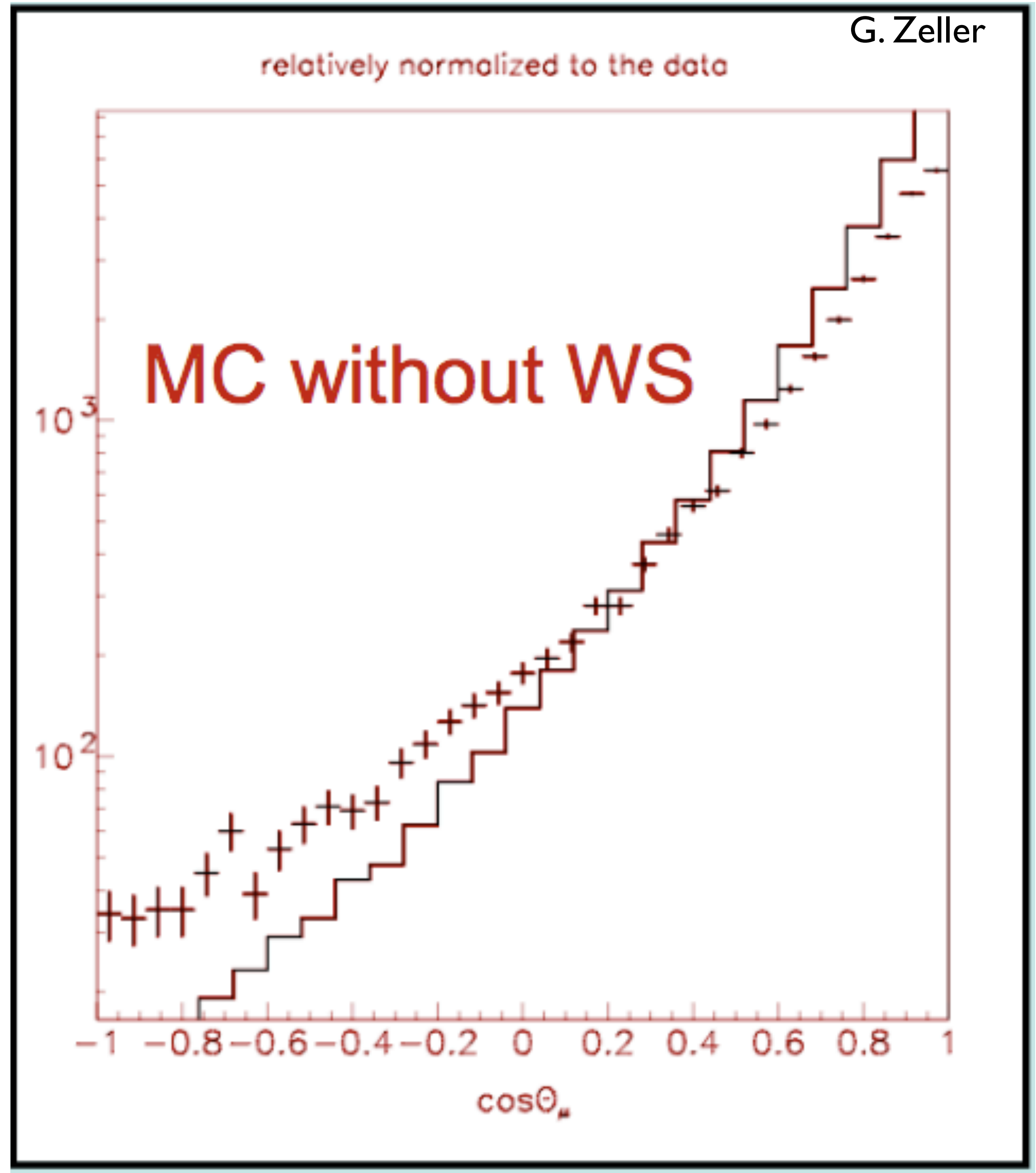
- Reconstruction has little effect on this constraint
- WS fraction can be measured to 7% with reconstructed angles
- Can also use Q^2 distributions
  - Similar precision
    - Stronger constraint
    - Poorer resolution
    - Larger uncertainties



Comparison with Data



G. Zeller



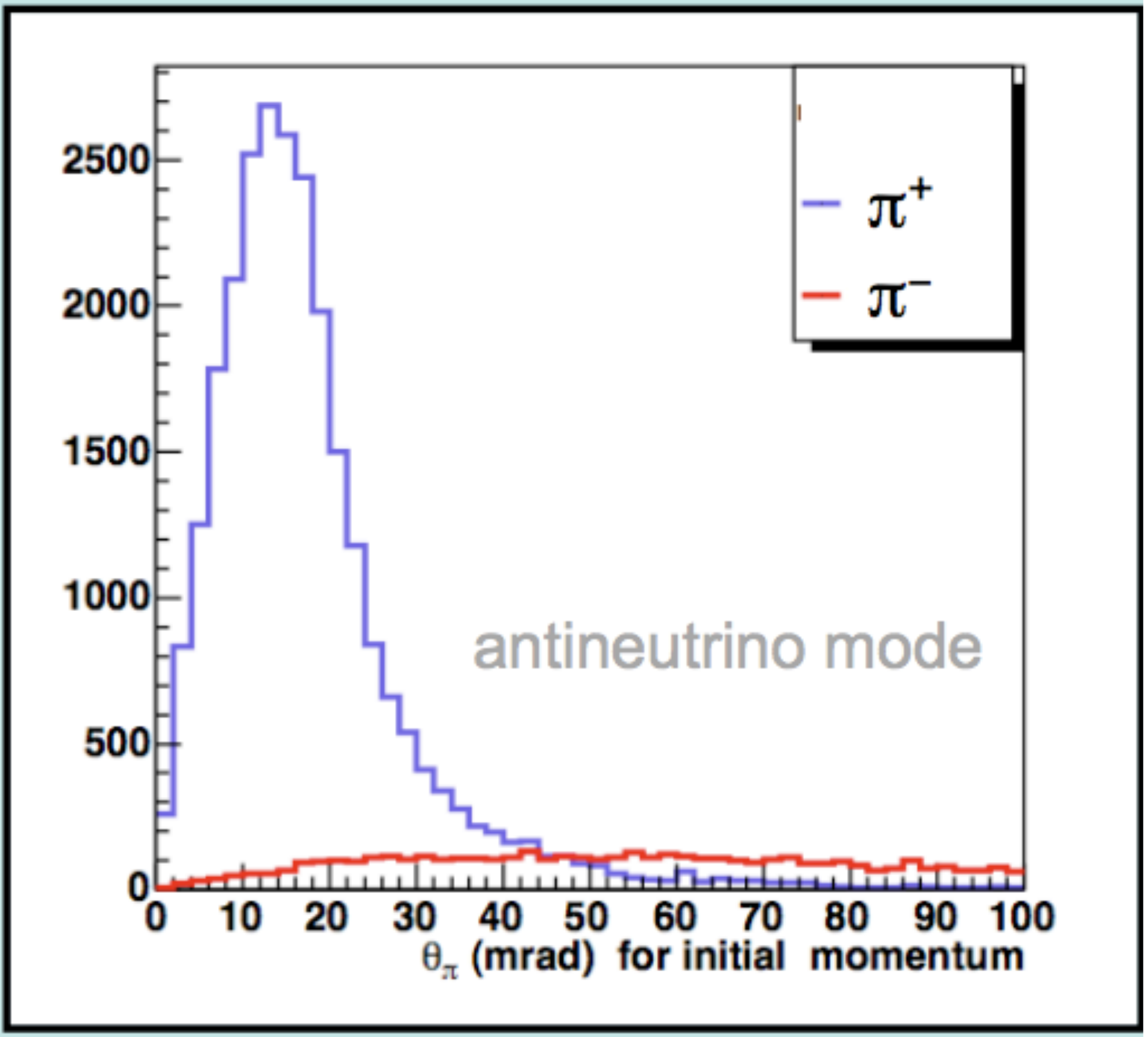
MB WS BG Constraints: CCπ^+ Selection

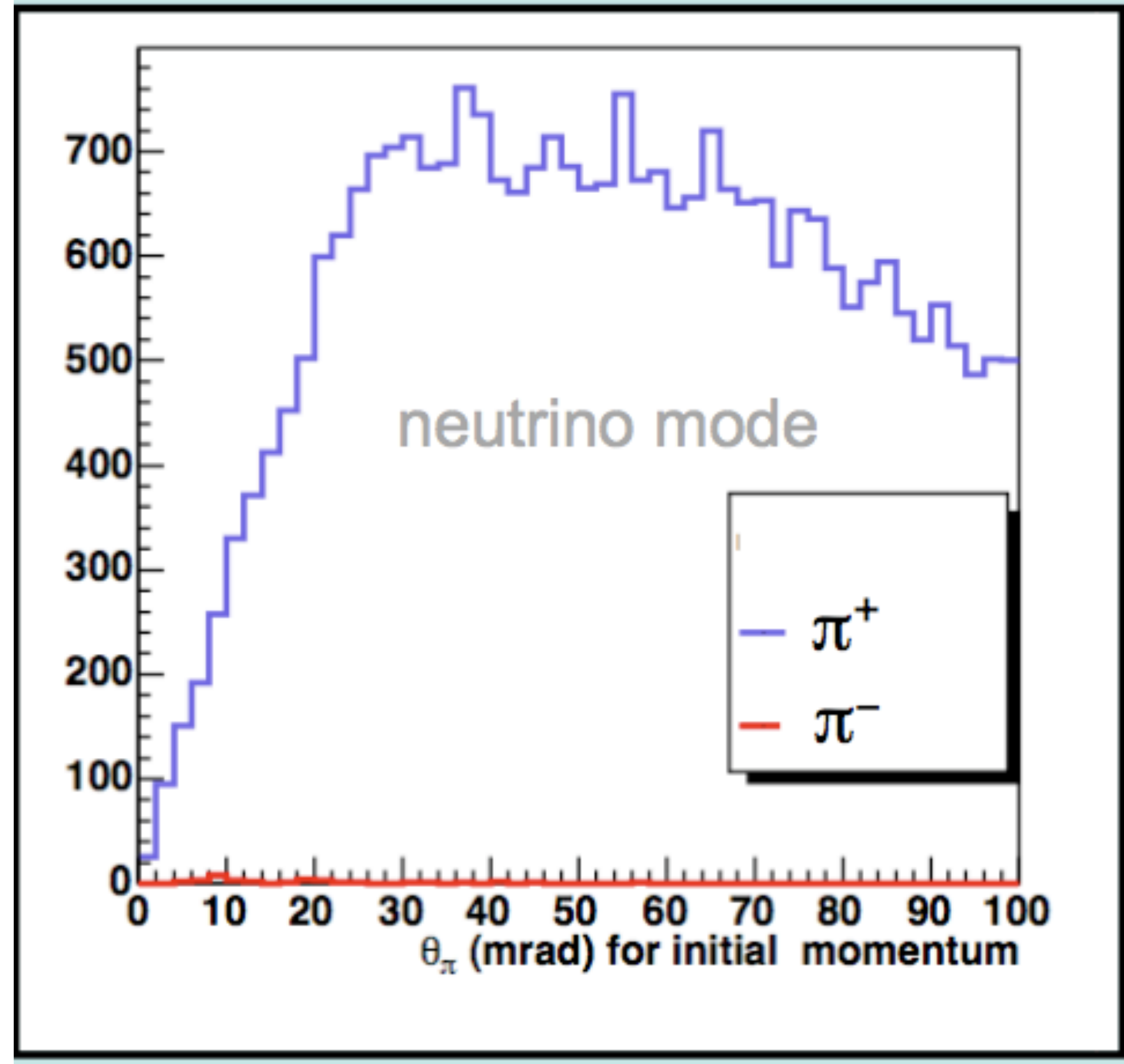
- Use CCπ+ event selection:
- Tag $\nu_\mu N \rightarrow \mu^- \pi^+ N$ events with two Michel electrons
- π- captured by carbon, do not decay
  - Cannot tag $\bar{\nu}_\mu N \rightarrow \mu^+ \pi^- N$ events: only 1 Michel
- Two Michel sample is 86% pure WS
- Constrain WS fraction with 15% uncertainty

Neutrino type	# before cuts	# after cuts
ν_μ (WS)	30,539	2,525
$\bar{\nu}_\mu$ (RS)	71,547	461
Total	102,086	2,986

Beam Pions

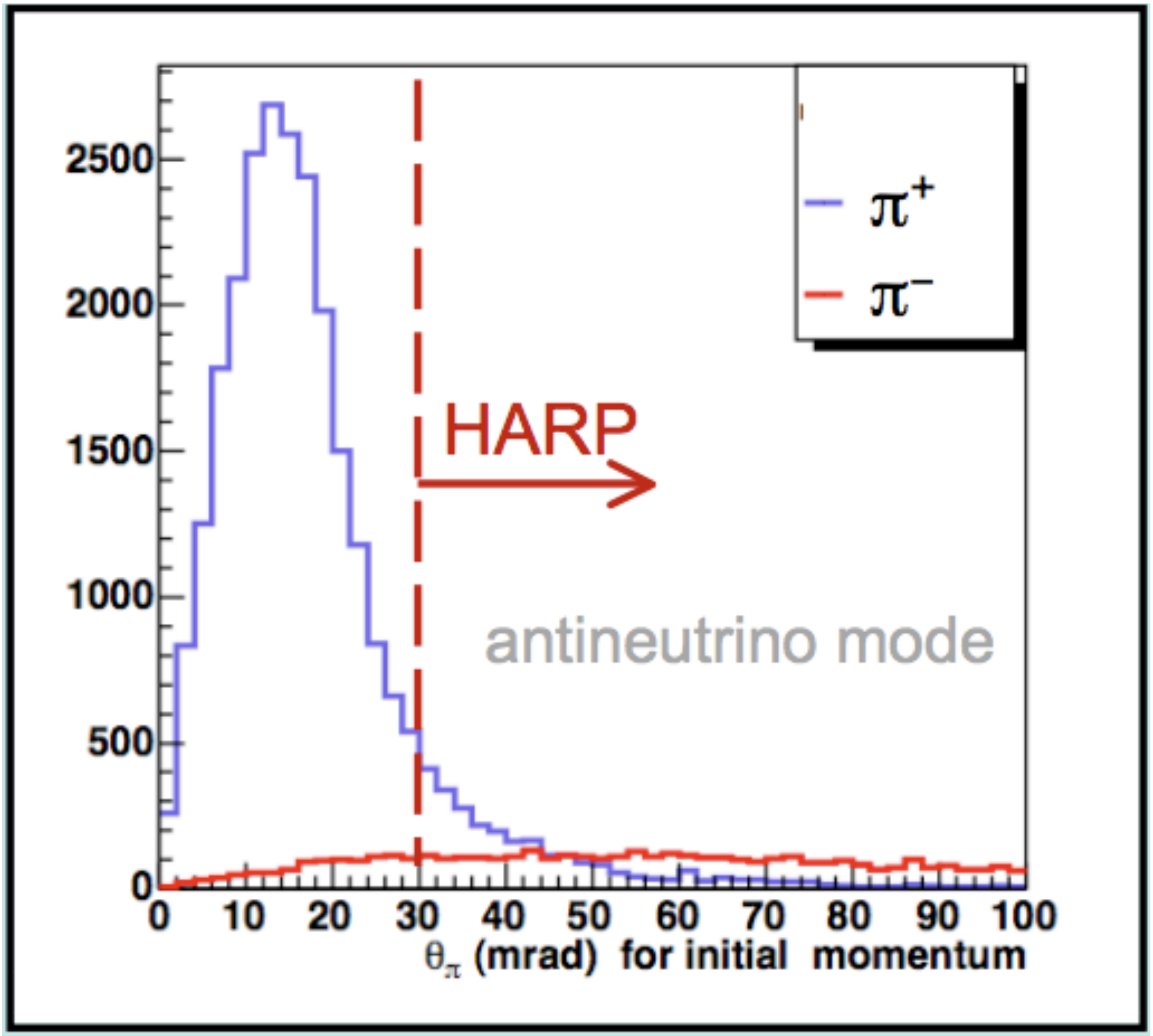
J. Nowak



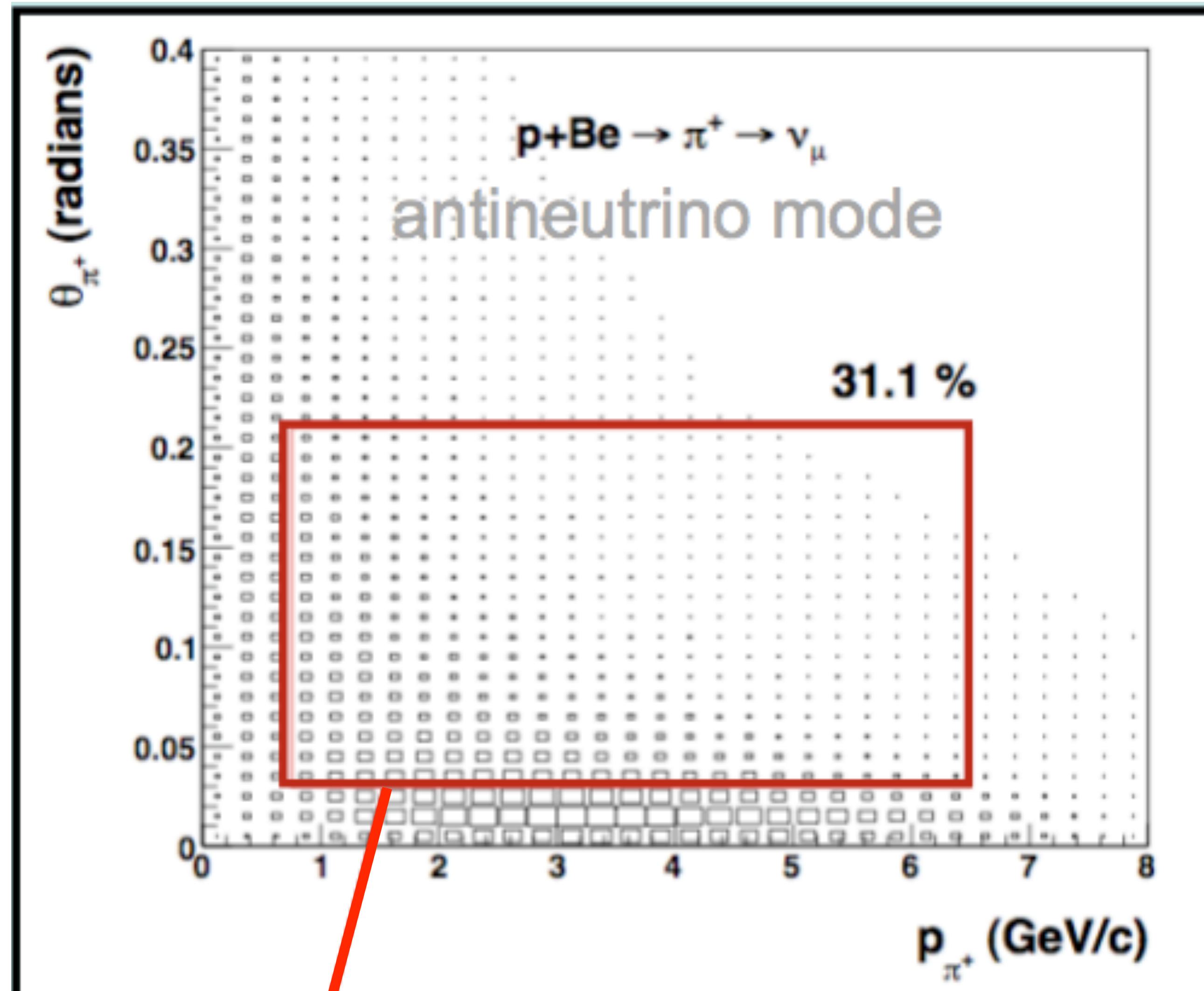


HARP Coverage

J. Nowak



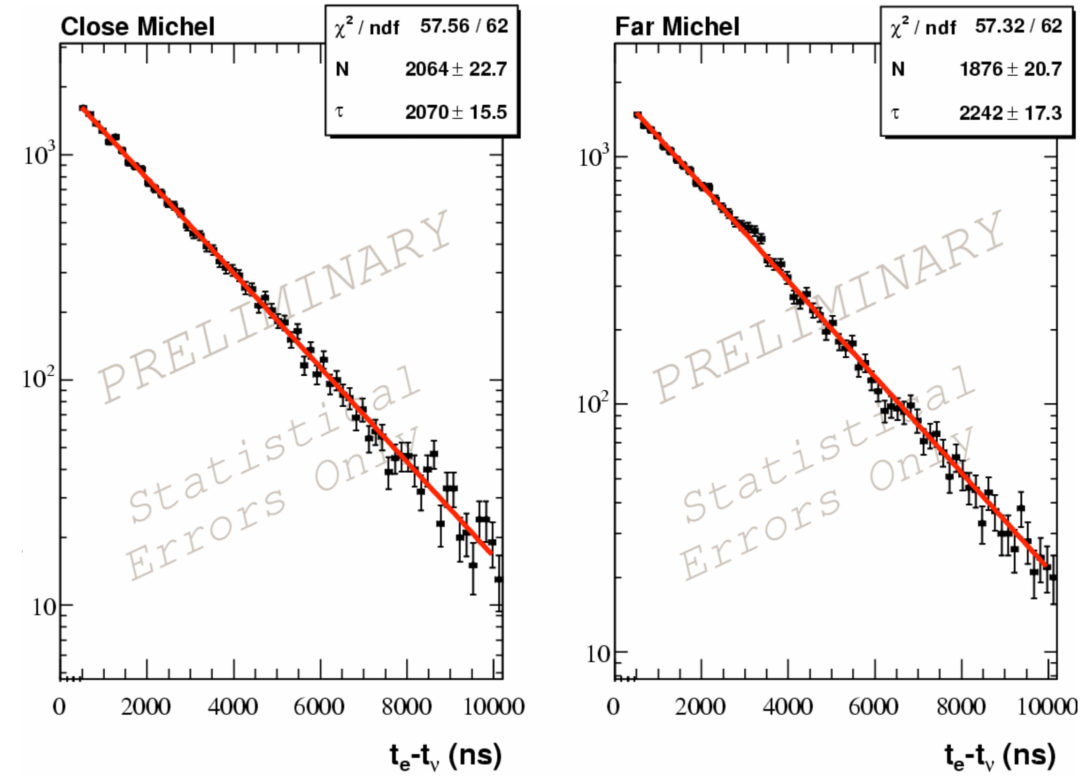
D. Schmitz



Kinematic boundary of HARP measurements

MB WS BG Constraints: μ Lifetime

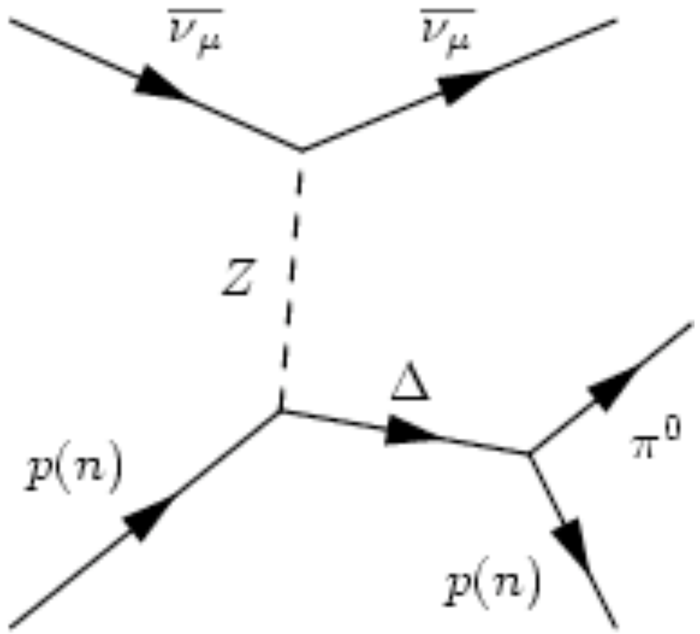
- Use muon decay rate in mineral oil to constrain WS BGs
- 8% μ- capture probability on carbon
  - $\tau_{\mu-}$=2.026μs, $\tau_{\mu+}$=2.197μs
- Can extract WS contribution with 30% uncertainty
- Independent of kinematics and reconstruction



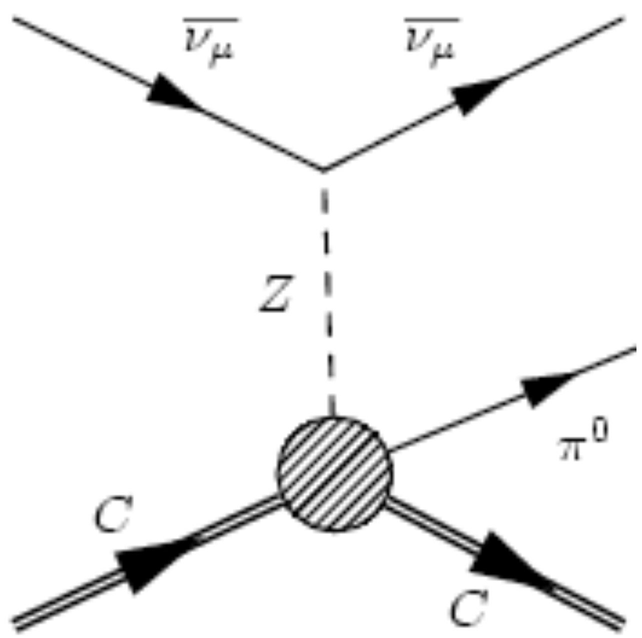
μ^- lifetime μ^+ lifetime

Comparison of muon lifetimes from $CC1\pi^+$ data sample

$\bar{\nu}_\mu$ NC π^0 production



- Resonant Production



- Coherent Production

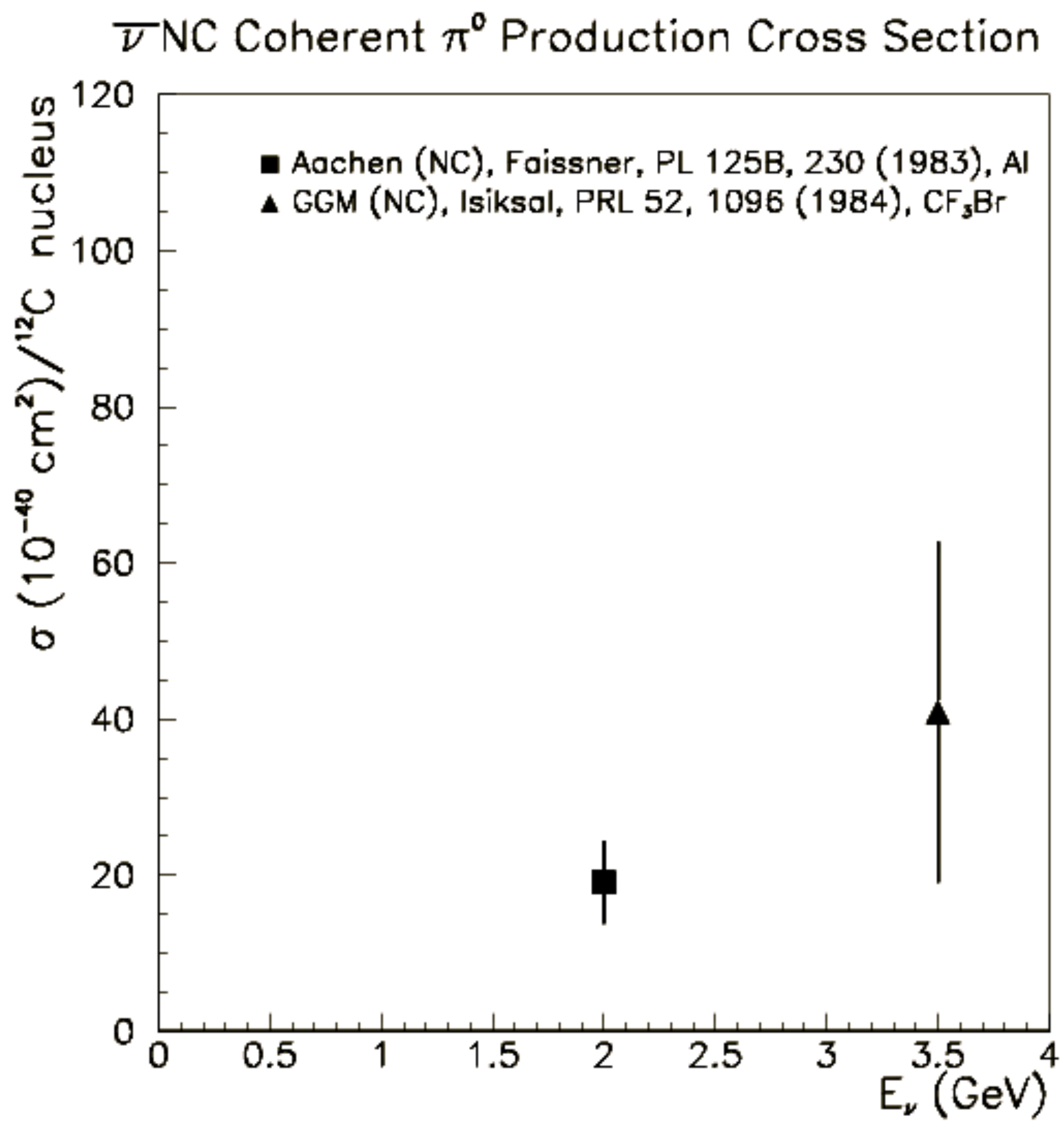
NC π^0 production?

$$\overline{\nu_\mu} \rightarrow \overline{\nu_e} \left(\nu_\mu \rightarrow \nu_e\right)$$

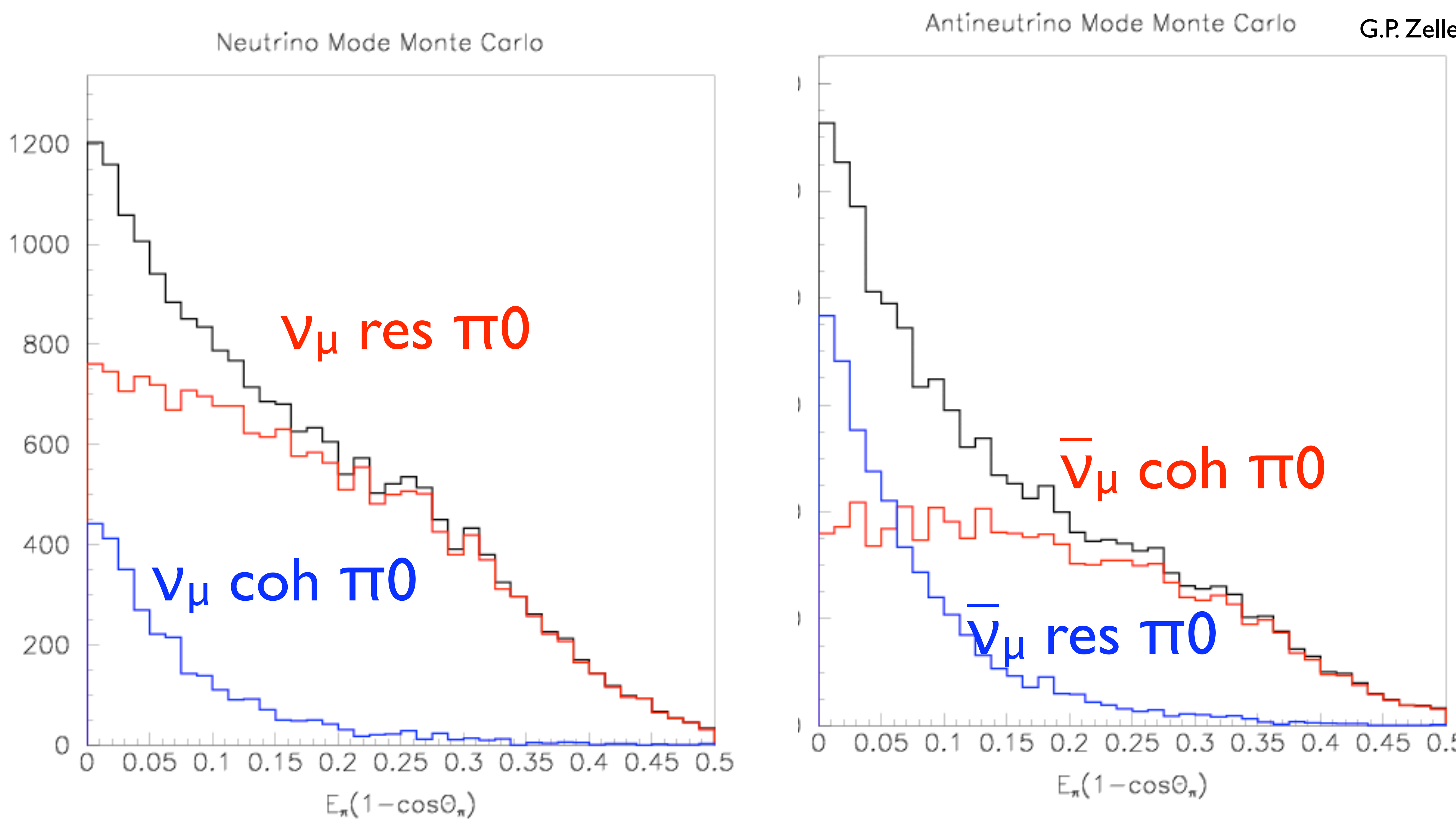
NC π0 events are the dominant background to oscillation searches

Coherent events especially!

G.P. Zeller



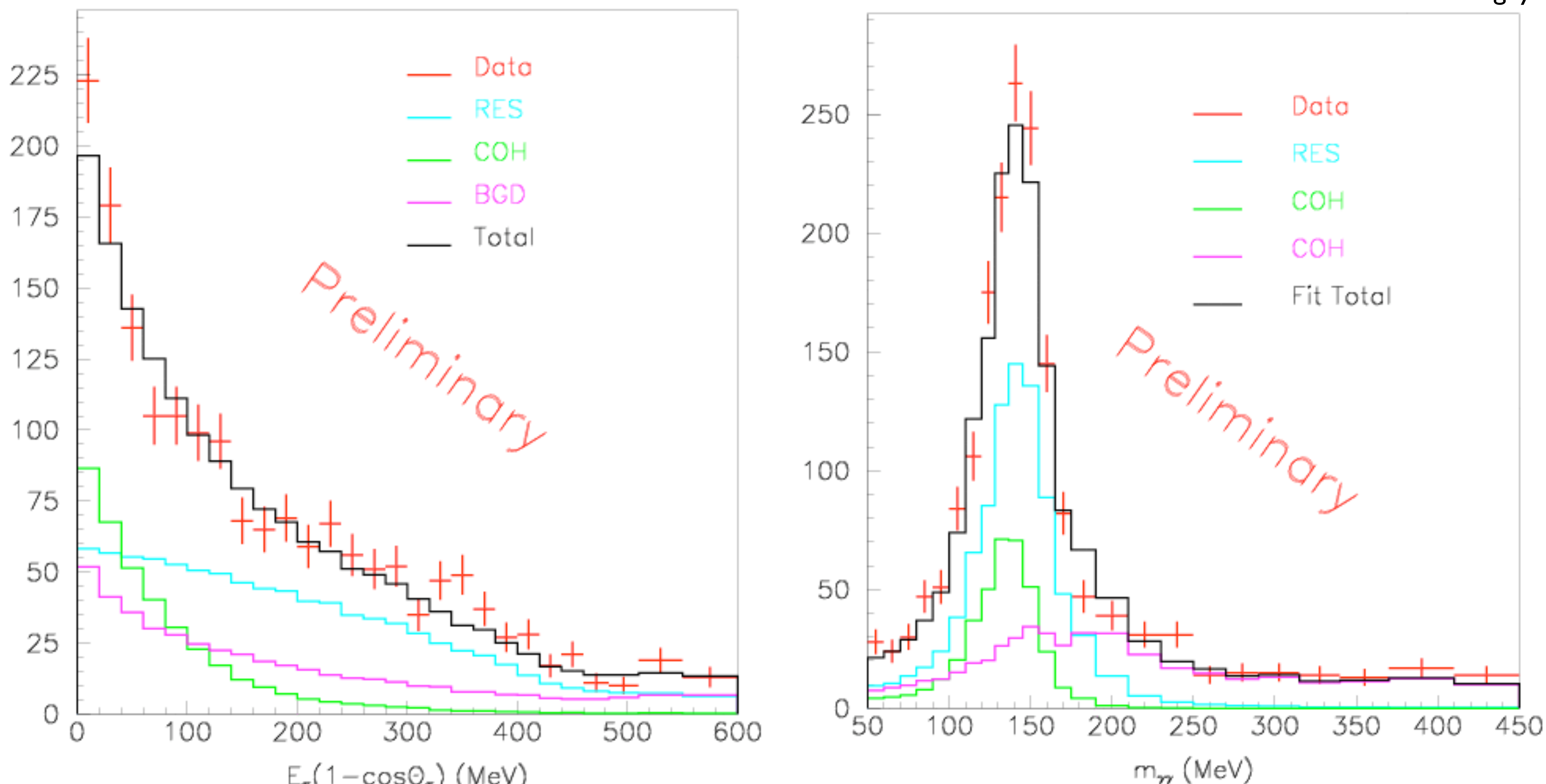
ν vs. $\bar{\nu}$



G.P. Zeller

- MiniBooNE clearly sees evidence for coherent NC π^0 production in both neutrino and antineutrino modes at a rate that is ~1.5x lower than the R-S model prediction, which is the most widely used model in ν expts

V. Nguyen



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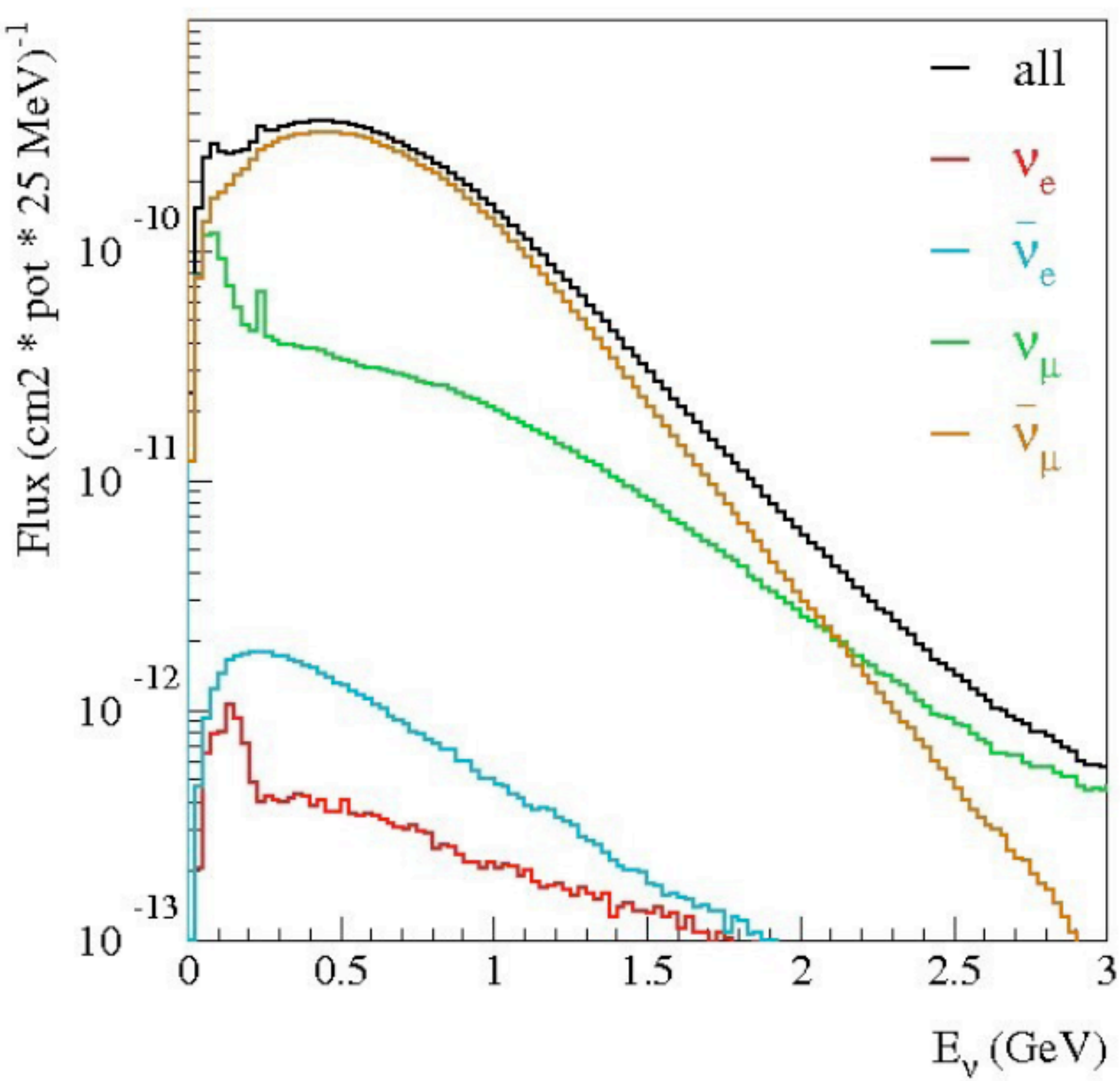
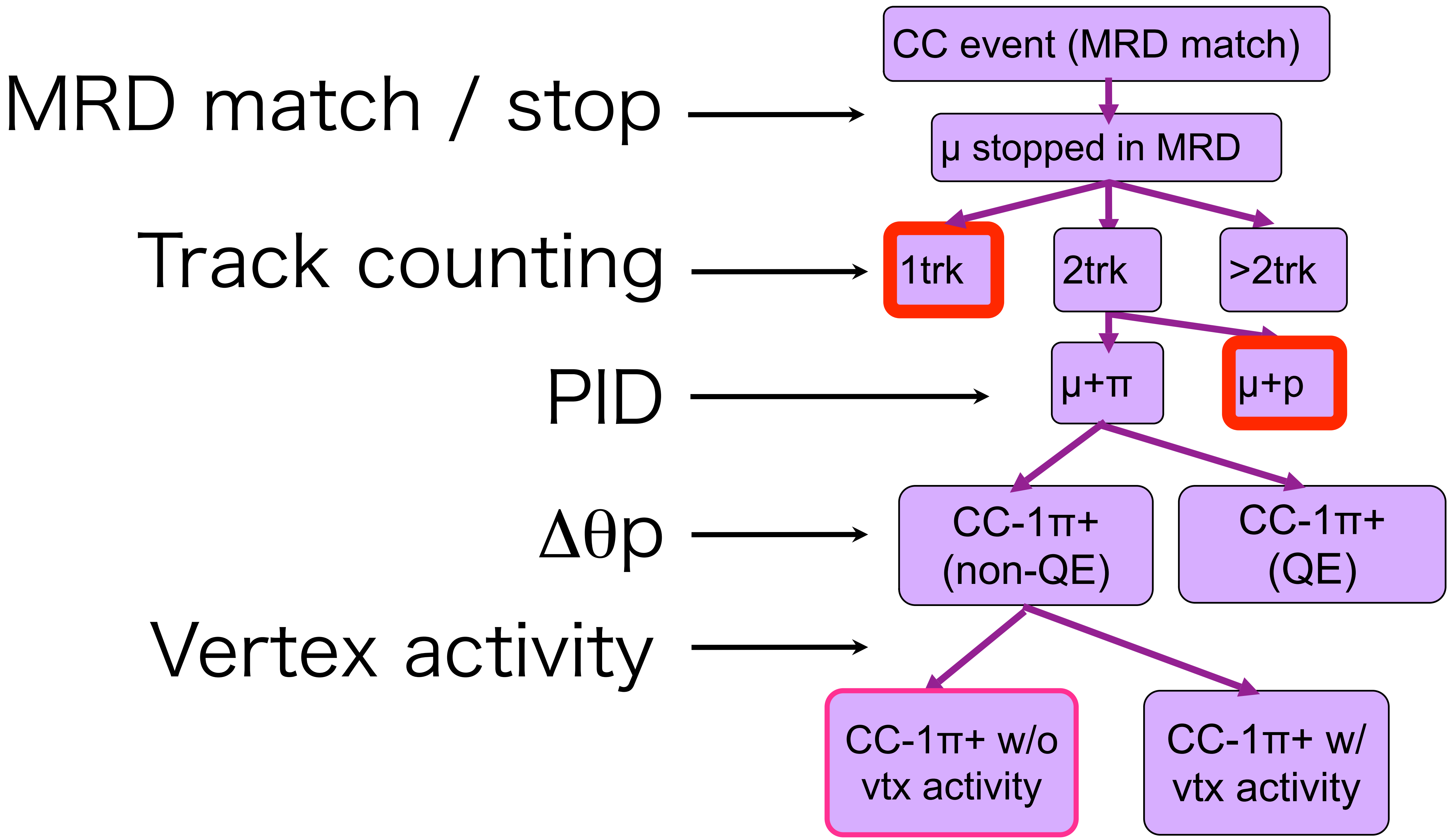
SciBooNE $\bar{\nu}$ Flux



Event selection

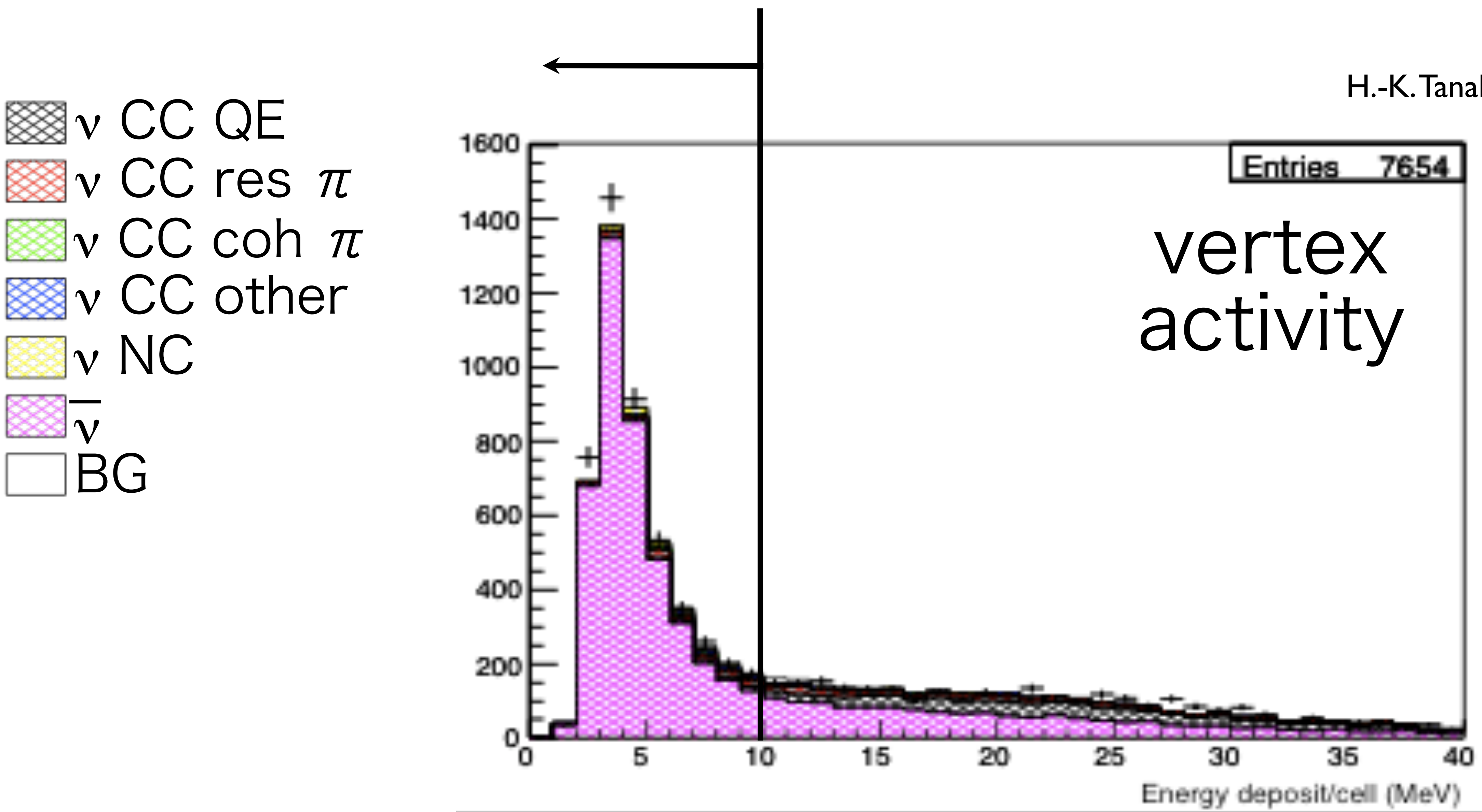


SciBooNE サイブーン

Extracting $\bar{\nu}$

$\bar{\nu}$ CCQE: $\bar{\nu}+p\rightarrow\mu+n$

➜1 track w/o vtx activity



"no activity" ≡ less than 10 MeV

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Muon dist

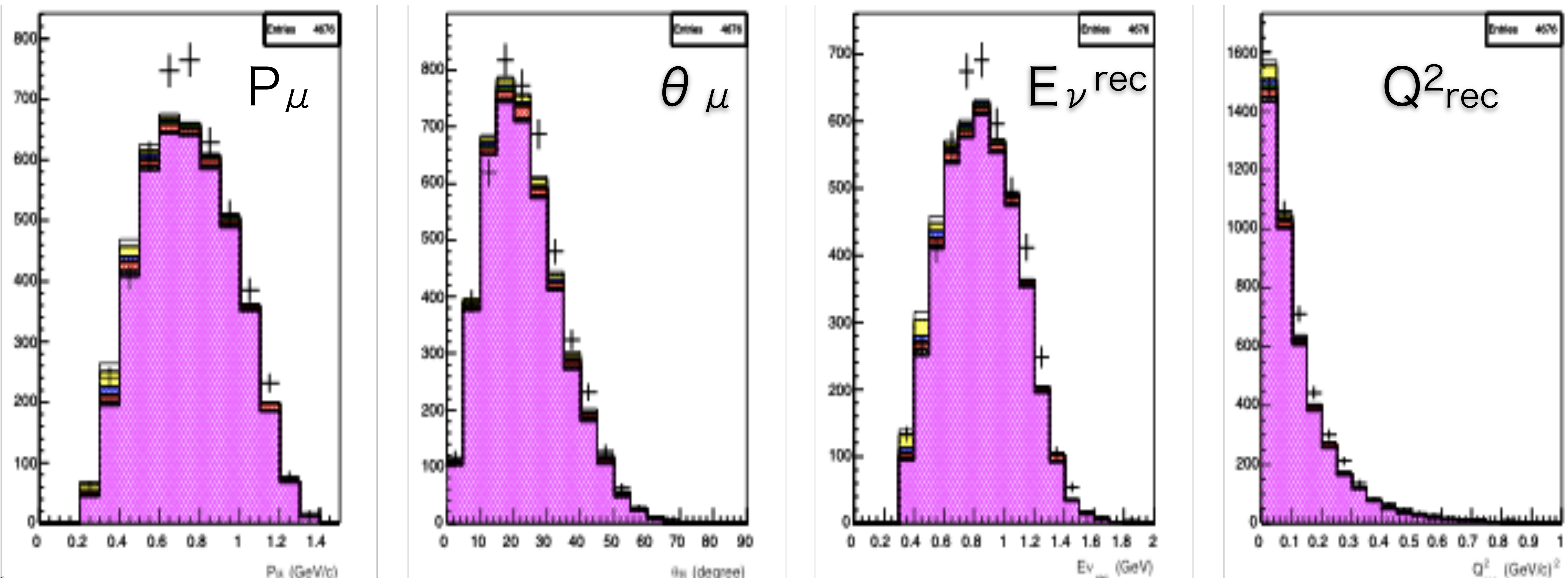
~1trk, no activity~

93% pure $\bar{\nu}$ sample

4,676 events

- ν CC QE
- ν CC res π
- ν CC coh π
- ν CC other
- ν NC
- $\bar{\nu}$
- BG

H.-K. Tanaka



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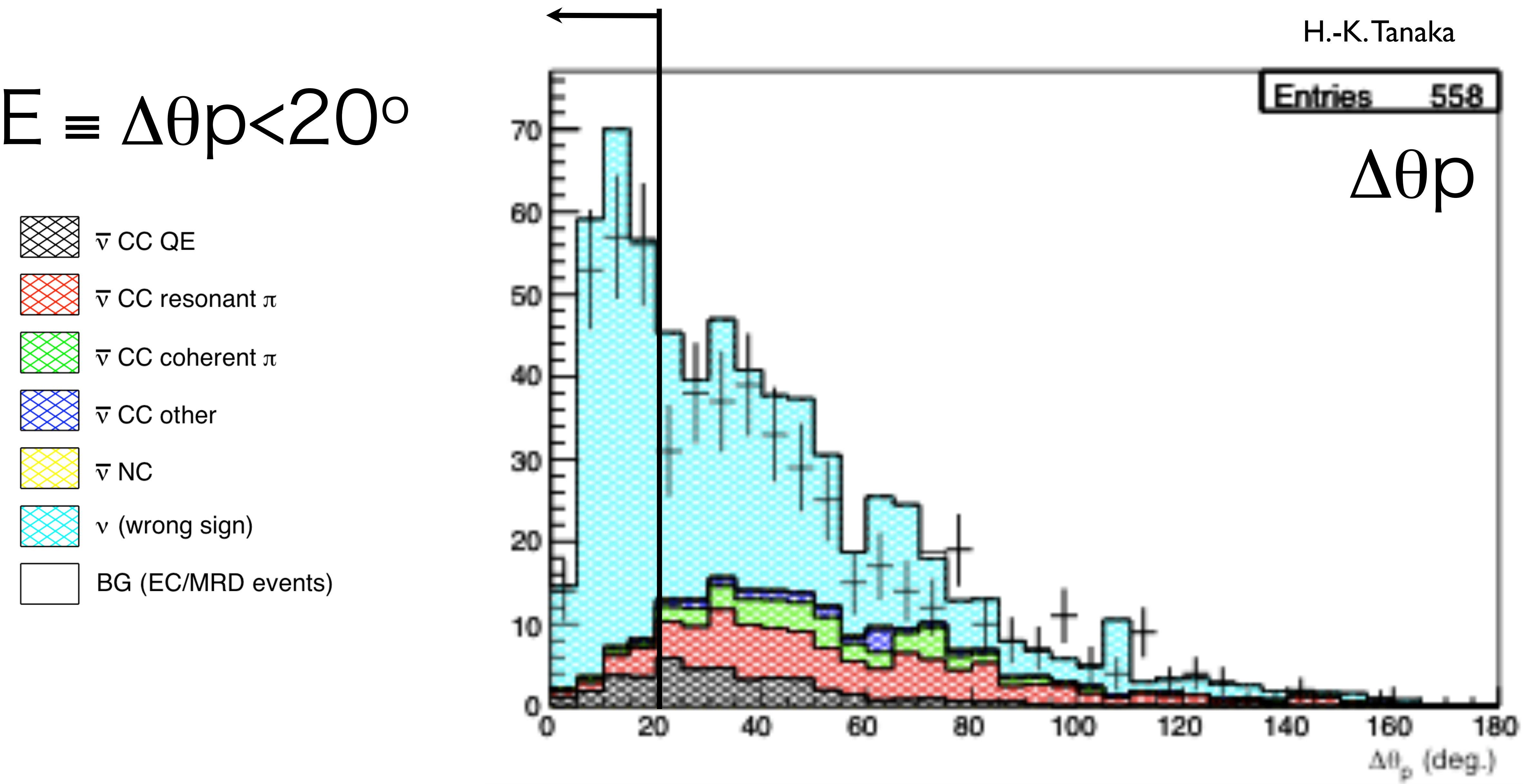
Extracting ν

ν CCQE: ν+n→μ+p

➜2trk & μ+p & QE

QE ≡ Δθp<20°



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Muon dist~2trk, μ+p, QE~

180 events

89% pure $\bar{\nu}$ sample

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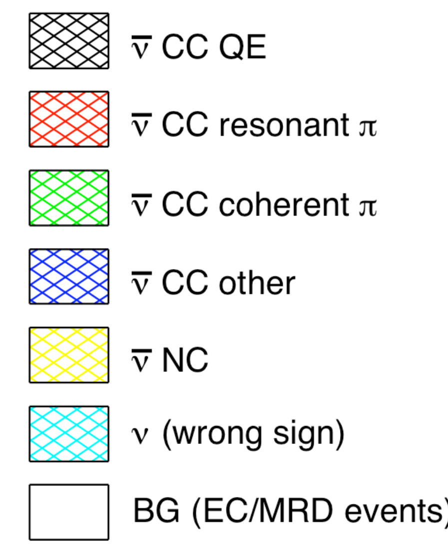

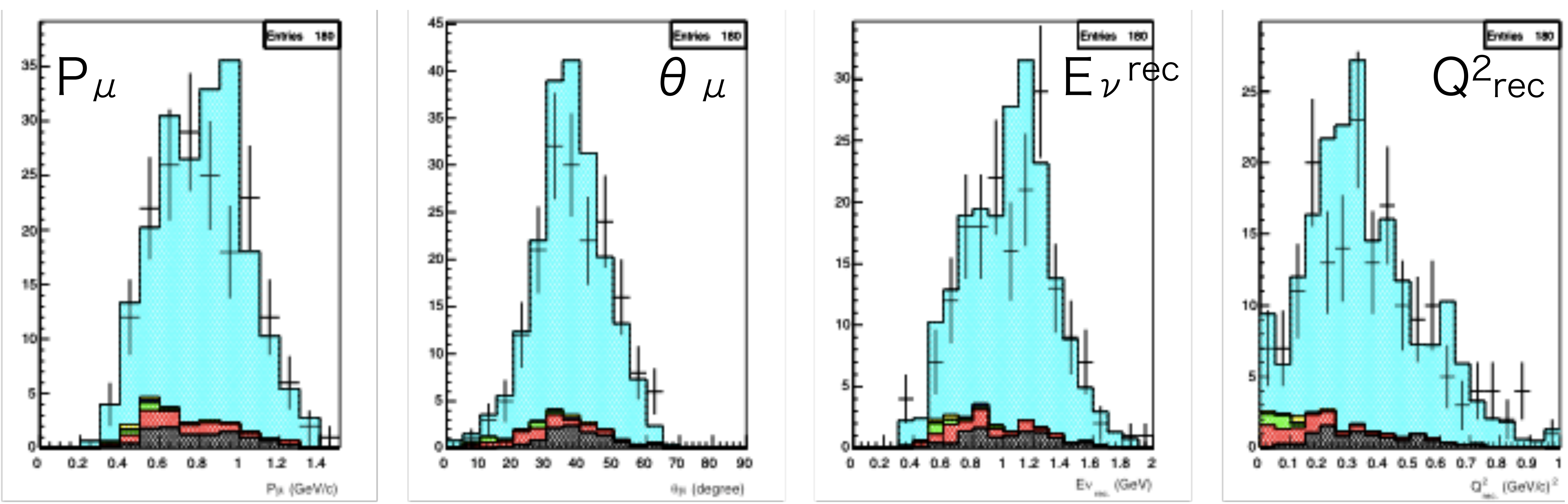

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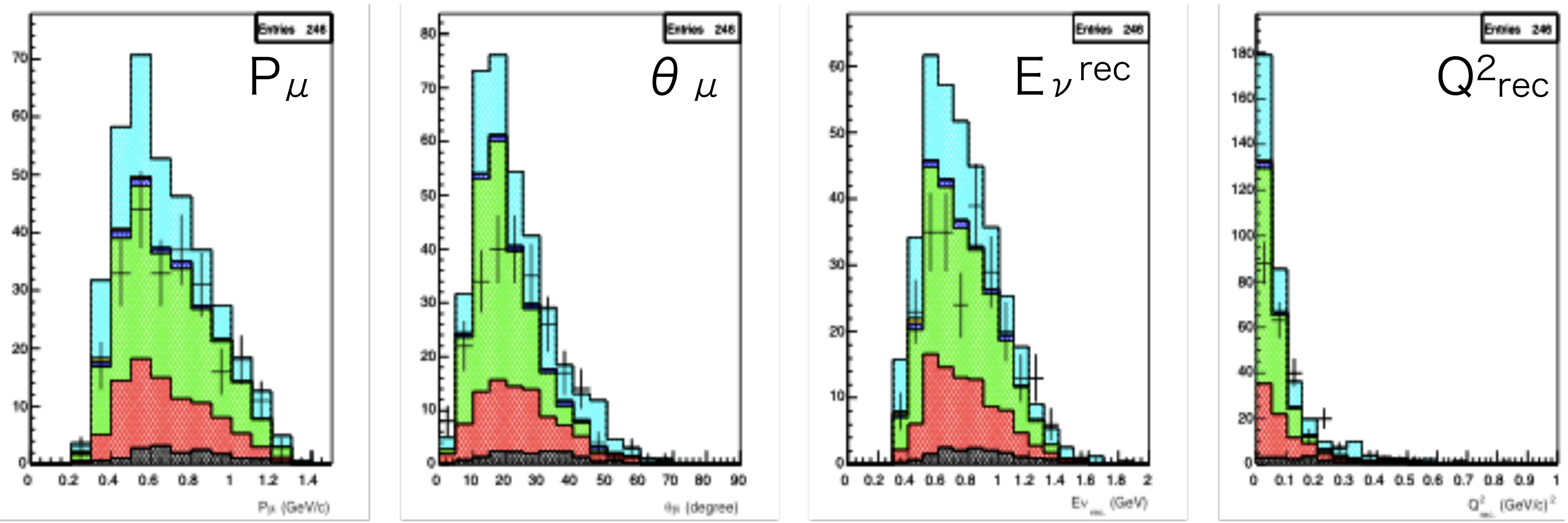
ν Coherent pion search

サイブーン
Sci BooNE

H.-K.Tanaka

Muon distributions~$\mu + \pi$, nQE, fwd, **no activity**~

246 events



Need to understand wrong sign backgrounds before extracting coherent cross section

Dziękuję!