Search for anti-neutrino CC coherent π production at SciBooNE

Hide-Kazu TANAKA

Massachusetts Institute of Technology

NuInt09 workshop at Sitges, Barcelona (Spain), 2009 May 18-22

Outline

- Introduction
- $\bar{\nu}$ data in SciBooNE
- Search for CC coherent π prod. in $\bar{\nu}$ data
- Summary

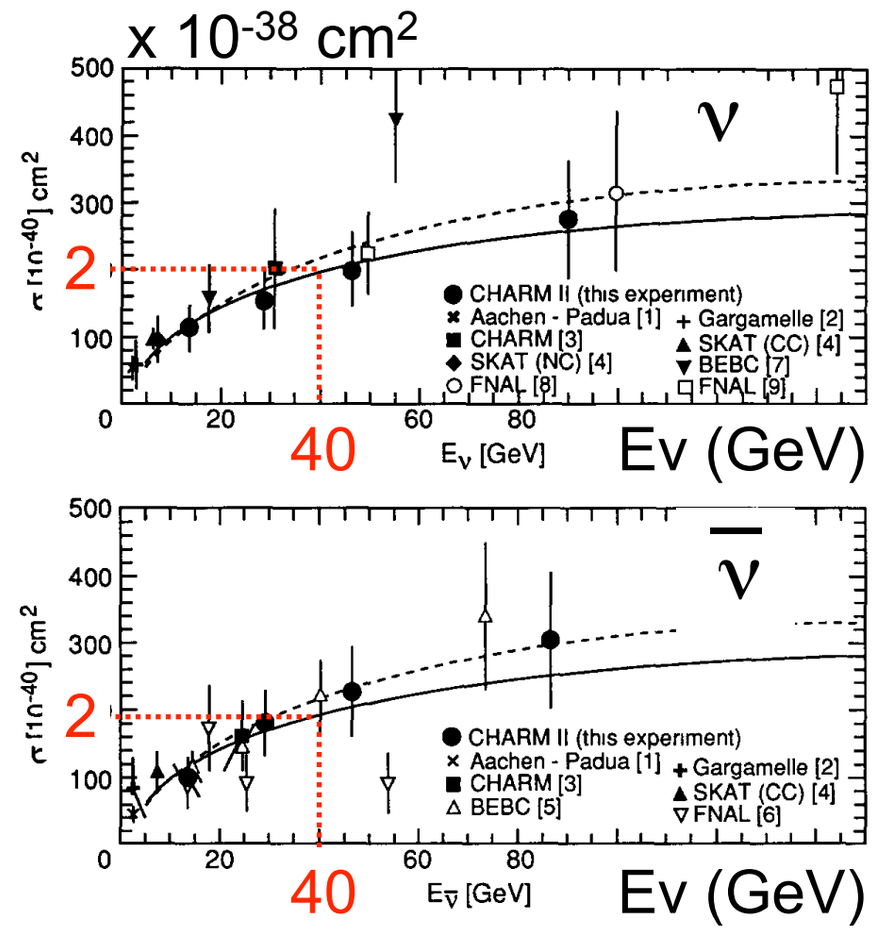
$\bar{\nu}$ Coherent pion production

Several measurements in past ('80-'90).

Measurements are at high energy region.
Rein-Sehgal model well describes the data.

High energy results and the model suggest: cross sections of coherent π prod. for ν and $\bar{\nu}$ are similar size.

σ(νCC-coh) ~ σ($\bar{\nu}$ CC-coh)



Plots from Phys.Lett. B313, 267-275 (1993)

Solid line: Rein-Sehgal model
Dotted line: Bel'kov-Kopeliovich

➜ $\bar{\nu}$ data is expected to be more sensitive to look at CC coherent π production than ν data.

∵ σ(ν CC) > σ($\bar{\nu}$ CC)

SciBooNE's $\bar{\nu}$ data

Data set

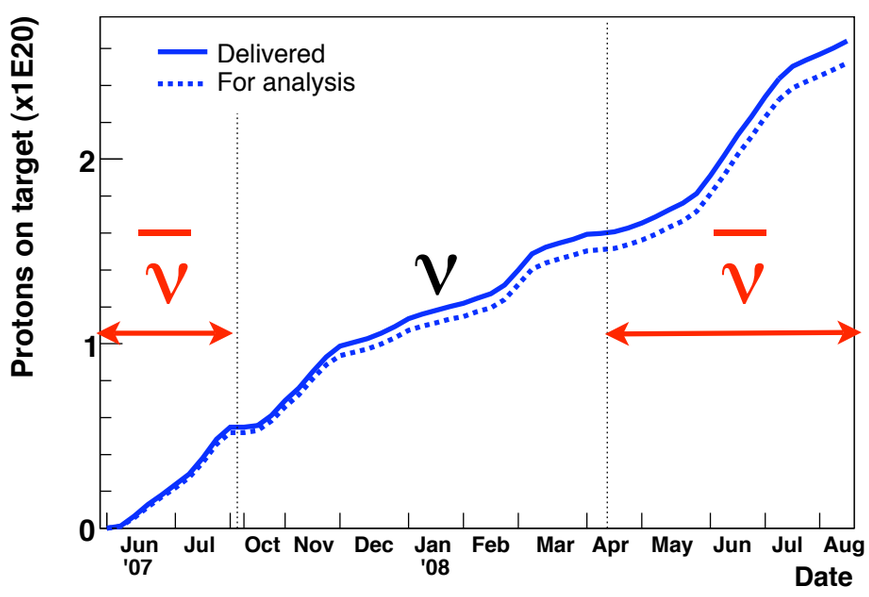
Data

2.52×10^{20} POT in total

- neutrino : 0.99×10^{20} POT
- antineutrino: 1.53×10^{20} POT

Results with full antineutrino data set will be presented in this talk.

Number of Protons on target (POT)



MC

ν Interaction (NEUT)

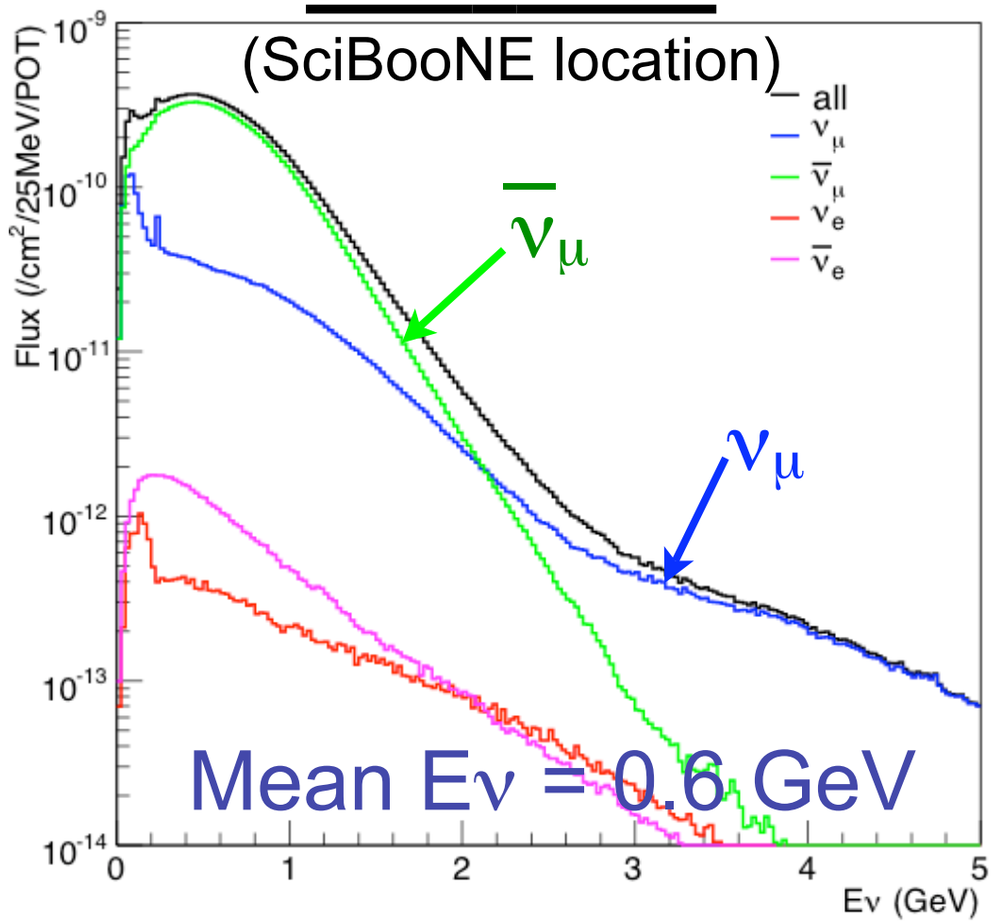
- QE
  - Llewellyn Smith, Smith-Moniz
  - M_A=1.2 GeV/c^2
  - P_F=217MeV/c, E_B=27MeV (for Carbon)
- Resonant π
  - Rein-Sehgal (2007)
  - M_A=1.2 GeV/c^2
- Coherent π
  - Rein-Sehgal (2006)
  - M_A=1.0 GeV/c^2
- DIS
  - GRV98 PDF
  - Bodek-Yang correction
- Intra-nucleus interactions

Flux prediction

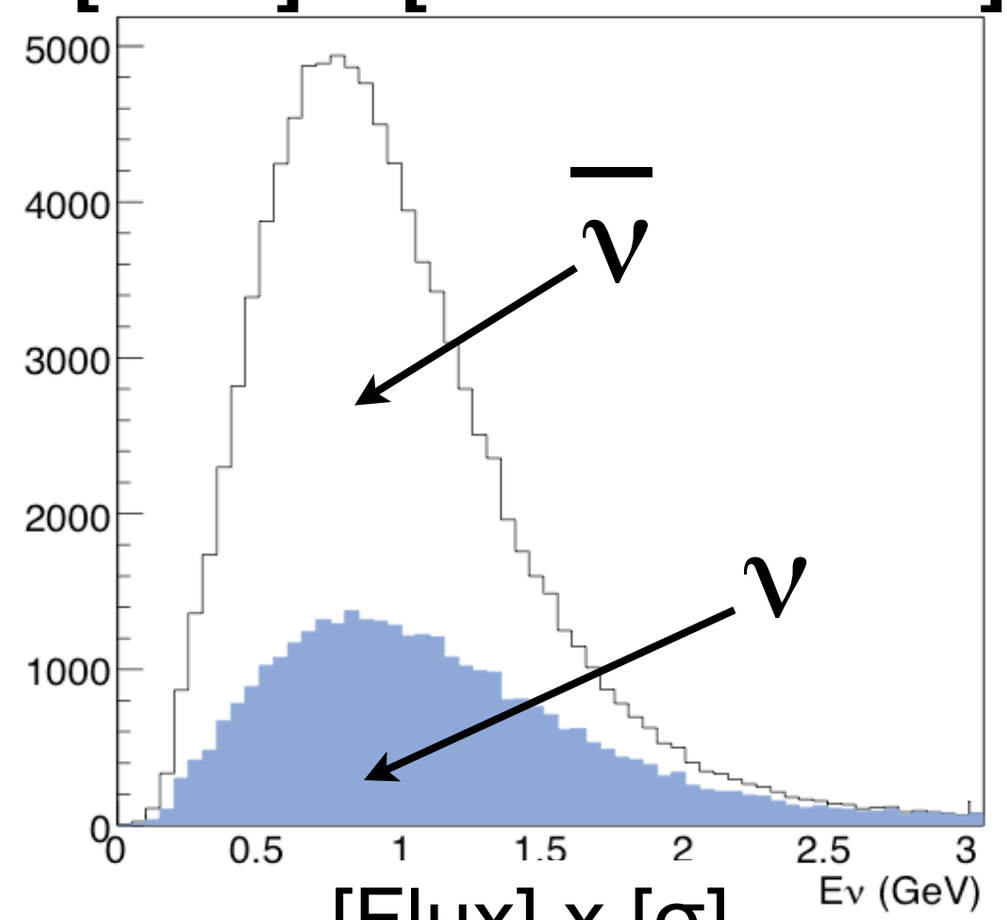
Based on
A.A. Aguilar-Arevalo, *et al.*, Phys.Rev.D**79** 072002 (2009), arXiv:0806.1449 [hep-ex].

$\bar{\nu}$ beam at SciBooNE

anti-ν Flux



[Flux] x [cross section]



$\bar{\nu}_\mu$: ~84%, ν_μ: ~16%, $\nu_e+\bar{\nu}_e$ <1%

(cf. ν mode: ν_μ 93%)

[Flux] x [σ]

$\bar{\nu}_\mu$: ~63%

ν_μ : ~36%

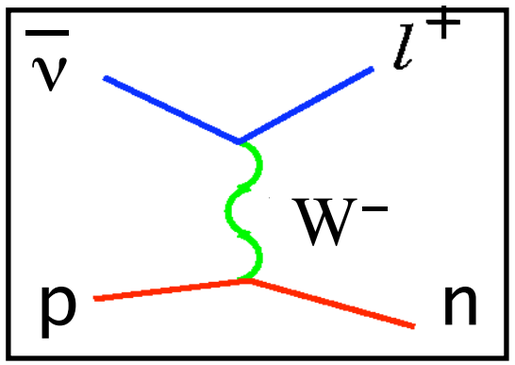
Large fraction of neutrino (wrong sign) background.

➜ Need to understand ν background.

Separating ν and $\bar{\nu}$ interactions

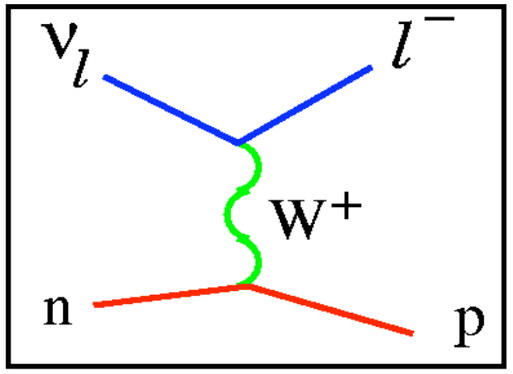
In SciBooNE energy (~1GeV) CC-QE interaction is dominant.

– **Right sign**
  - $\bar{\nu}$ CC-QE: $\bar{\nu} + p \rightarrow \mu^+ + n$



$\bar{\nu}$ CC-QE

– Wrong sign
  - ν CC-QE: $\nu + n \rightarrow \mu^- + p$



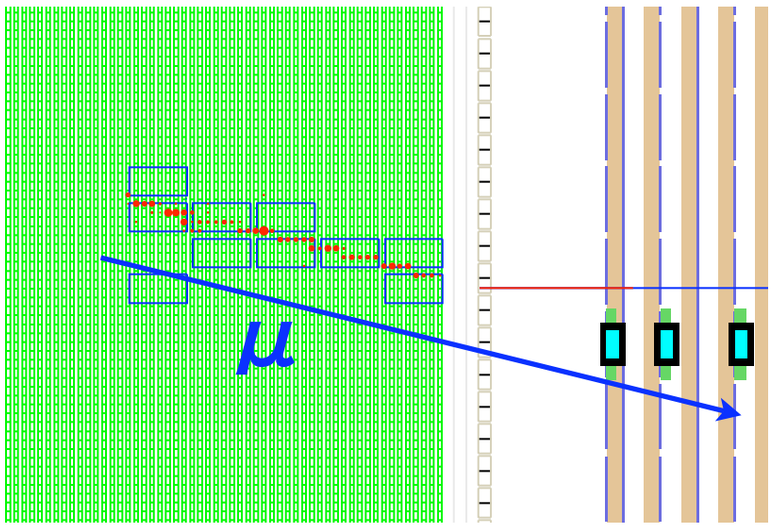
ν CC-QE

➜ Can distinguish ν and $\bar{\nu}$ CC-QE by finding **recoiled proton**

$\bar{\nu}$ CC-QE: 1 track (μ), ν CC-QE: 2 track (μ+p)

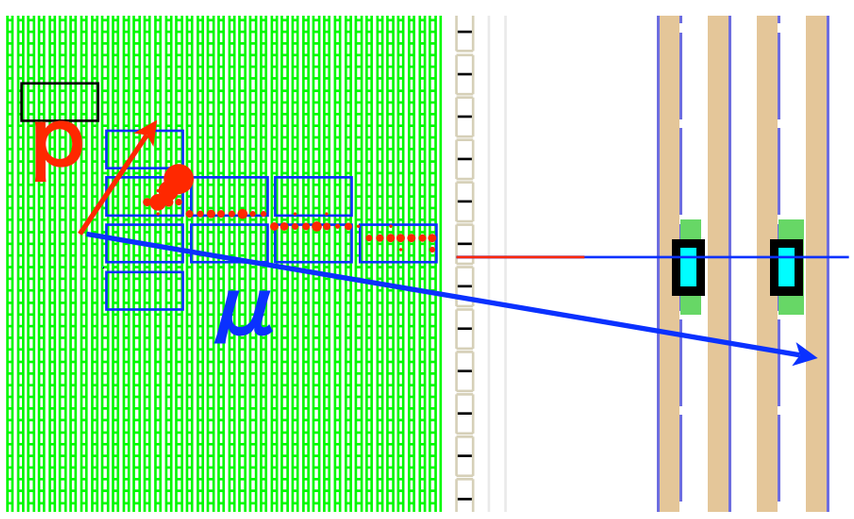
Separating ν and $\bar{\nu}$ interactions

$\bar{\nu}$ CC-QE



1-track (μ) event

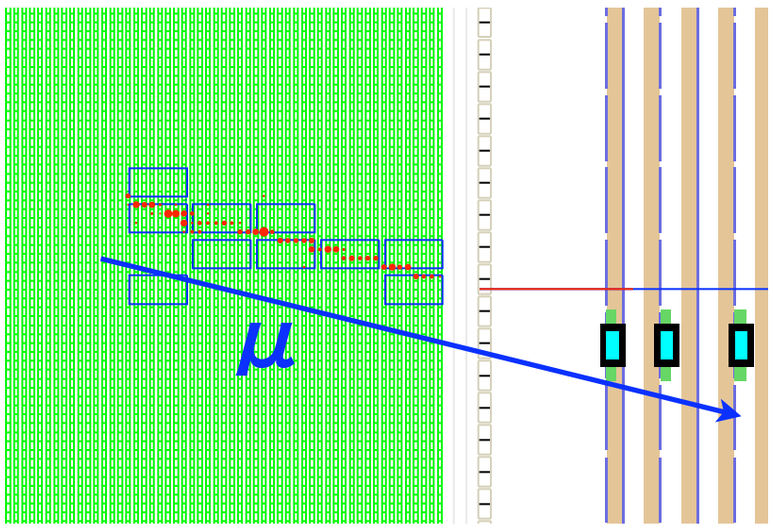
ν CC-QE



2-track (μ+p) event

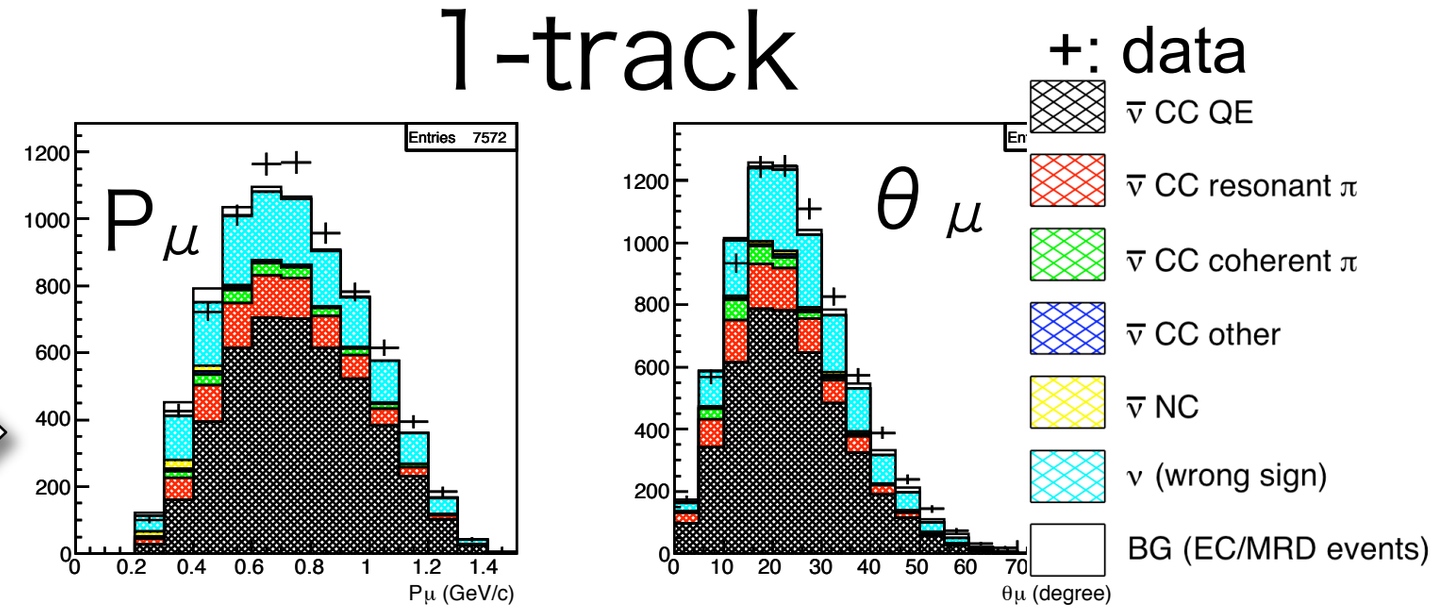
Separating ν and $\bar{\nu}$ interactions

$\bar{\nu}$ CC-QE



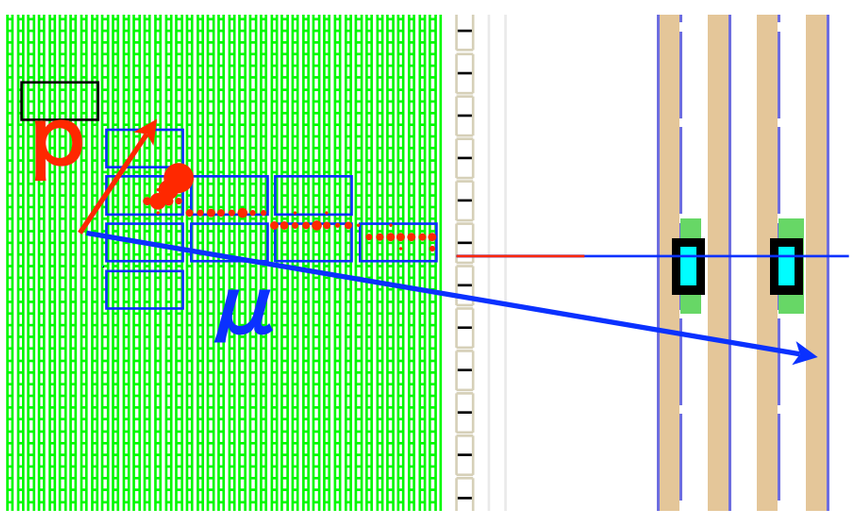
1-track (μ) event

1-track



Right sign ($\bar{\nu}$): ~80%

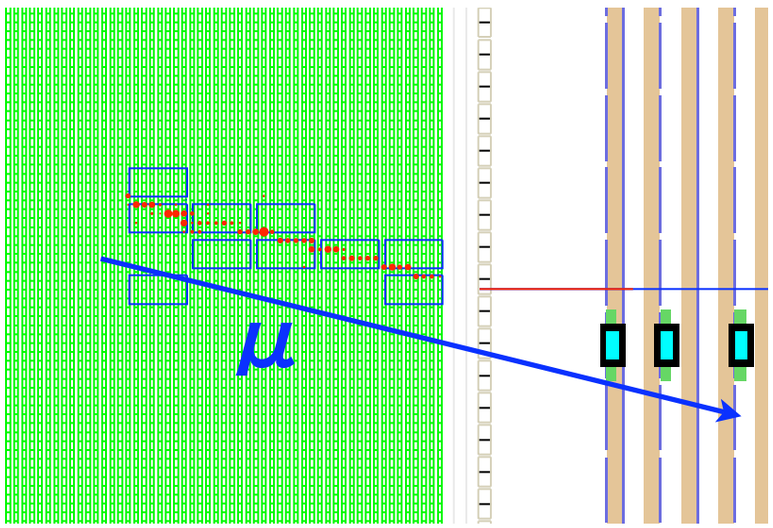
ν CC-QE



2-track (μ+p) event

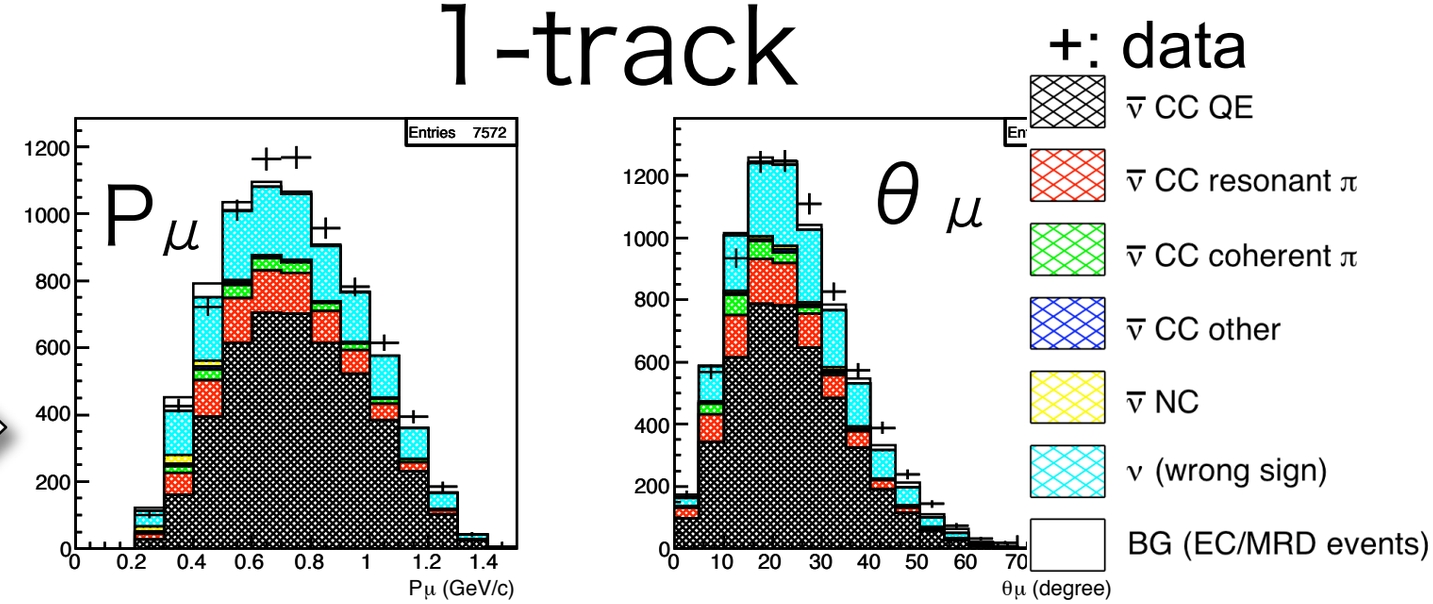
Separating ν and $\bar{\nu}$ interactions

$\bar{\nu}$ CC-QE



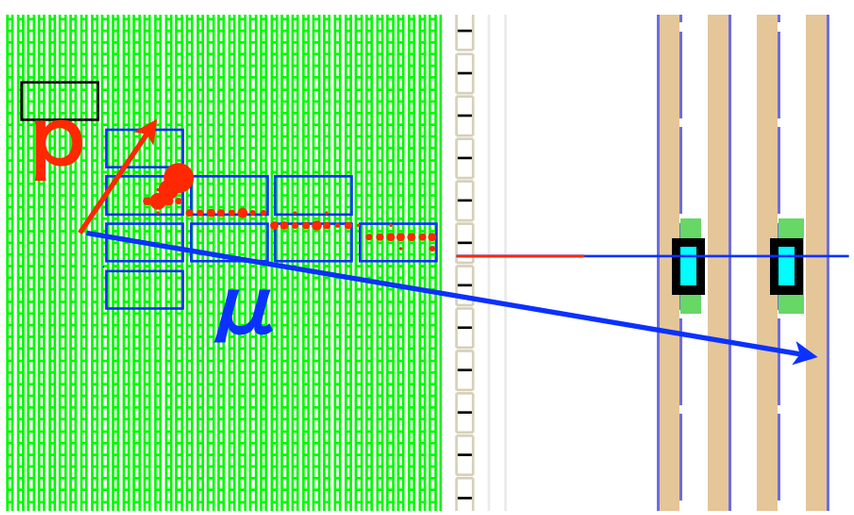
1-track (μ) event

1-track



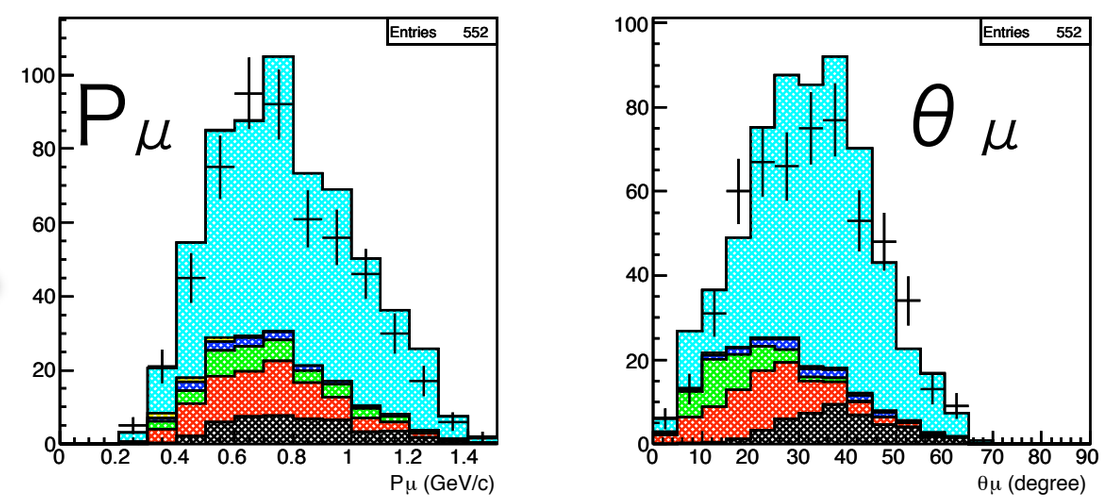
Right sign ($\bar{\nu}$): ~80%

ν CC-QE



2-track (μ+p) event

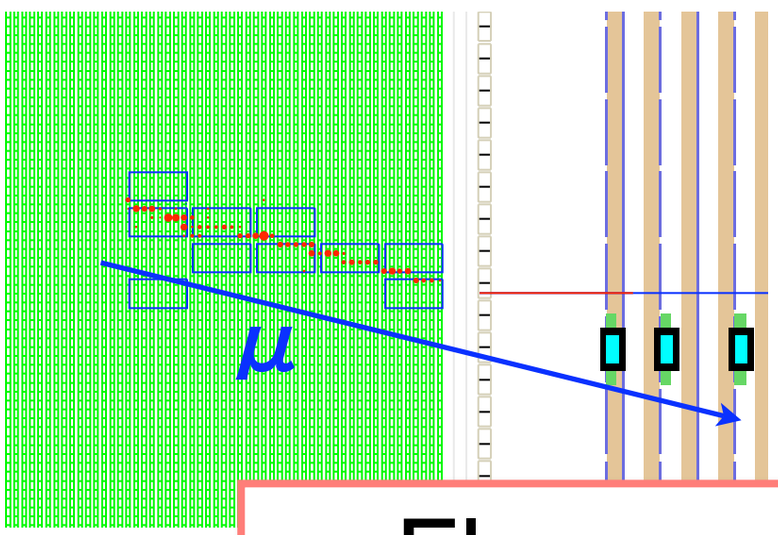
2-track, μ+p



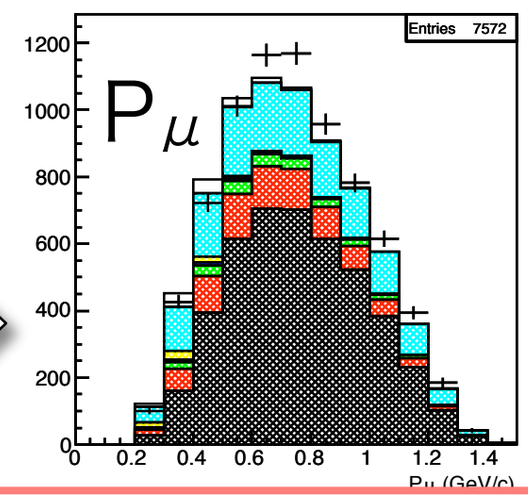
Wrong sign (ν): ~70%

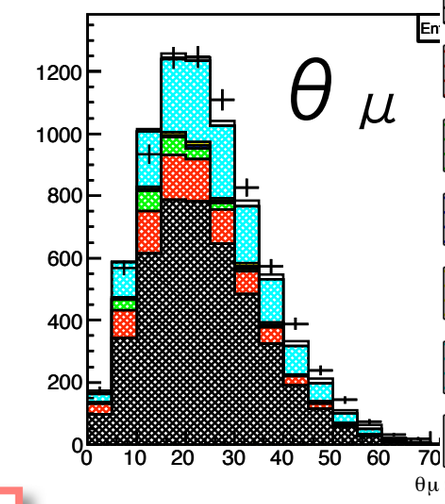
Separating ν and $\bar{\nu}$ interactions

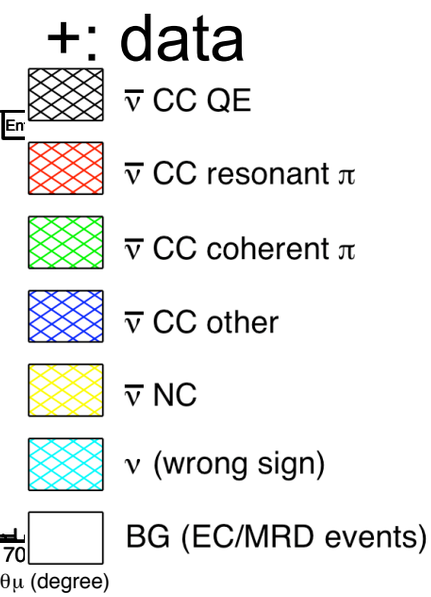
$\bar{\nu}$ CC-QE



1-track



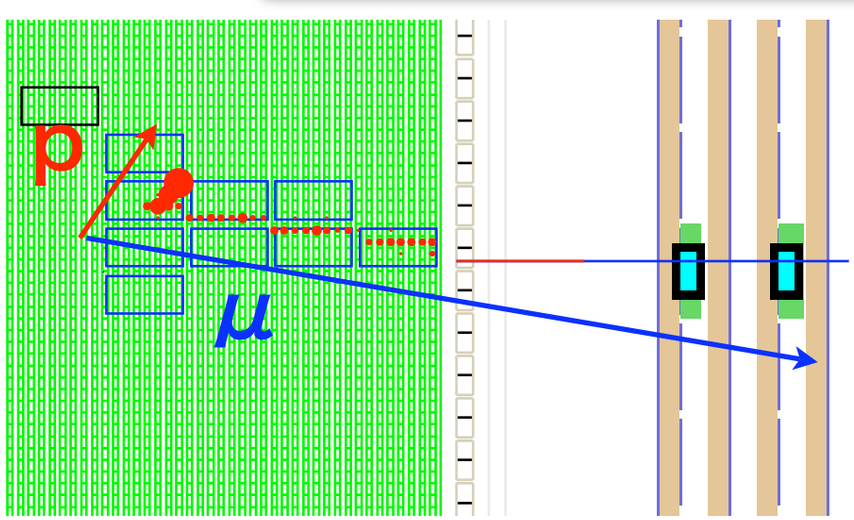




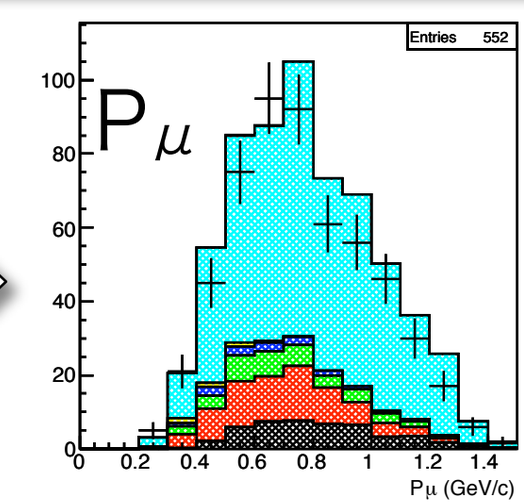
1-tr ($\bar{\nu}$): ~80%

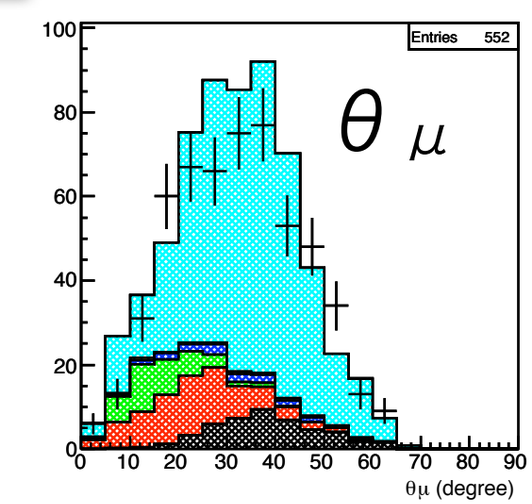
Flux prediction provides a reasonable understanding of "wrong sign" background

k, μ+p



2-track (μ+p) event





Wrong sign (ν): ~70%

Search for

$\bar{\nu}$ CC coherent π

Event selection

Use the same selection criteria as ν coherent π

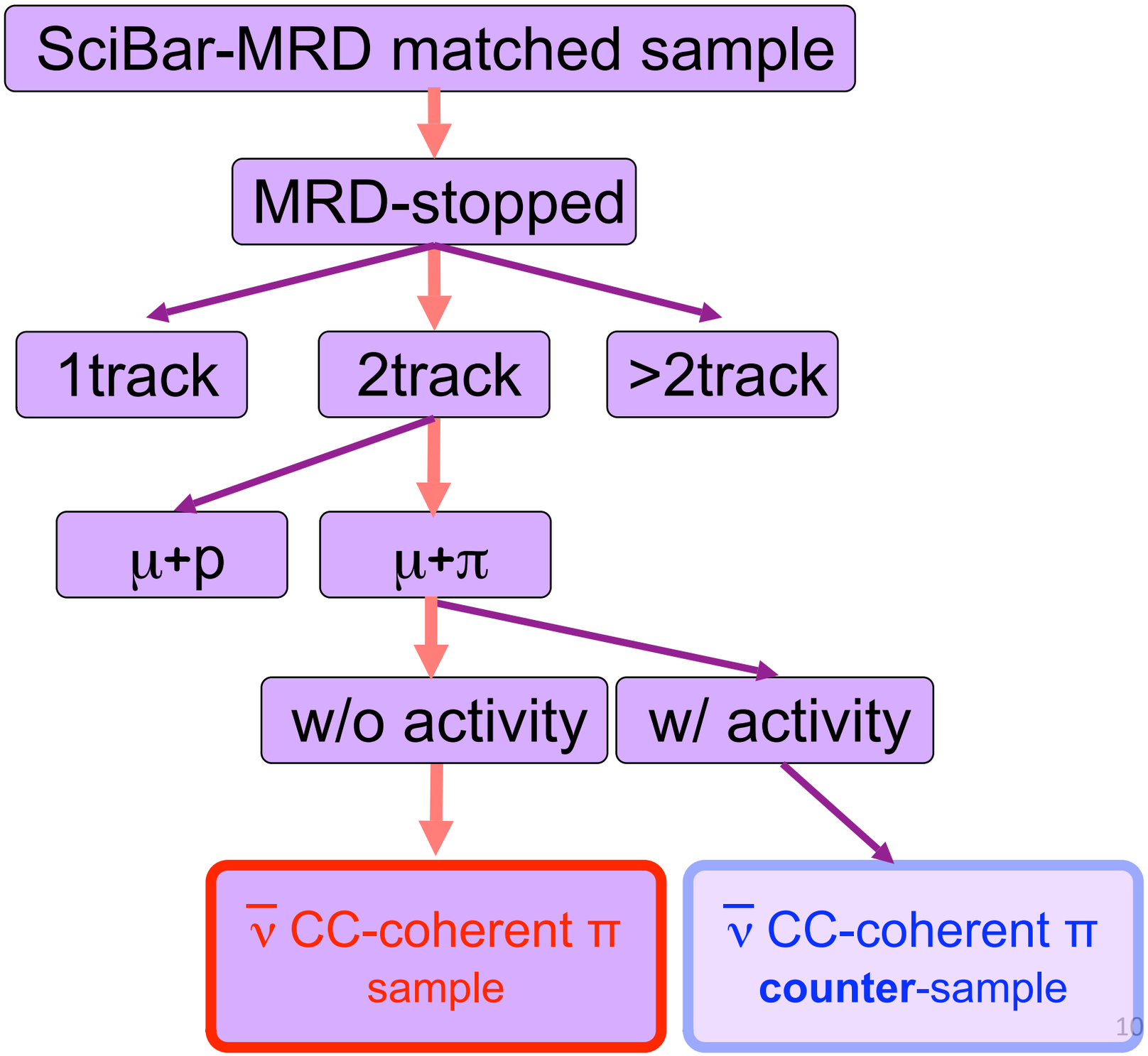
(NOTE: **no syst. error included**, **no MC tuning** yet)

Define MC normalization

Number of tracks

Particle identification

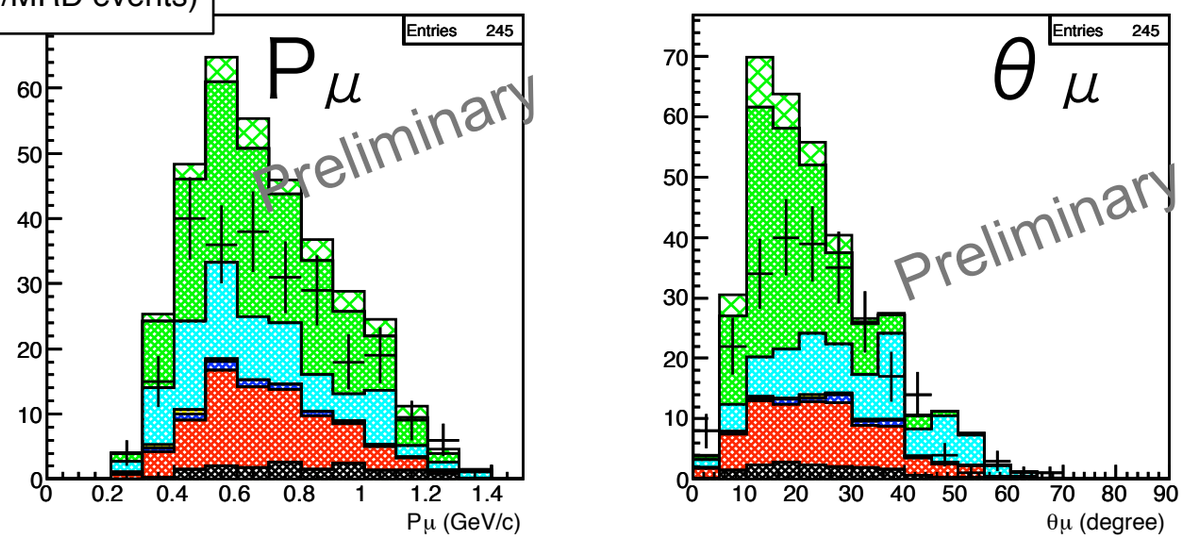
Energy deposit around the vertex



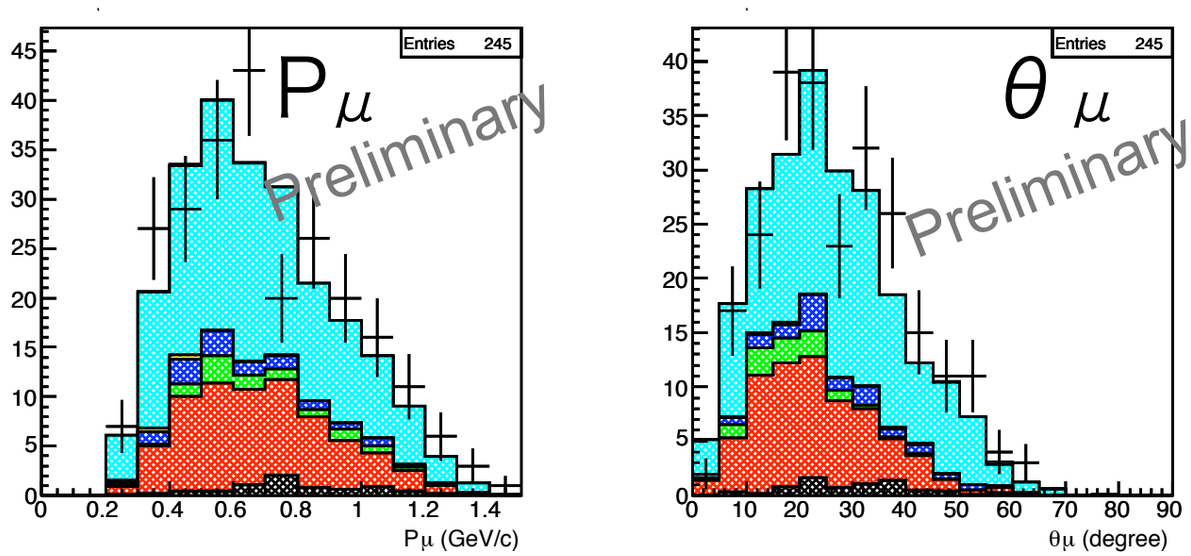
$\bar{\nu}$ CC coherent π sample

- ν CC coherent π
- $\bar{\nu}$ CC coherent π
- ν (wrong sign)
- $\bar{\nu}$ CC other
- $\bar{\nu}$ CC resonant π
- $\bar{\nu}$ CC QE
- $\bar{\nu}$ NC
- BG (EC/MRD events)

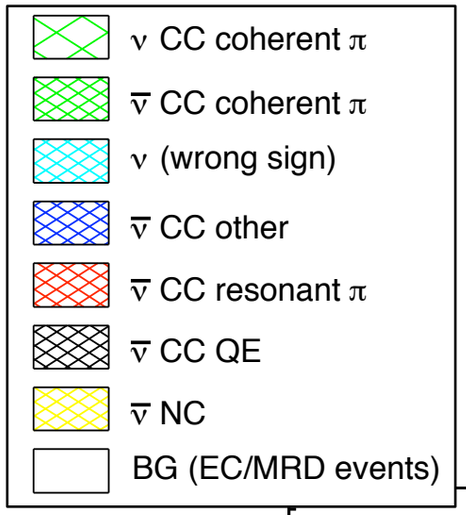
$\bar{\nu}$ Coherent-π sample (μ+π w/o activity)



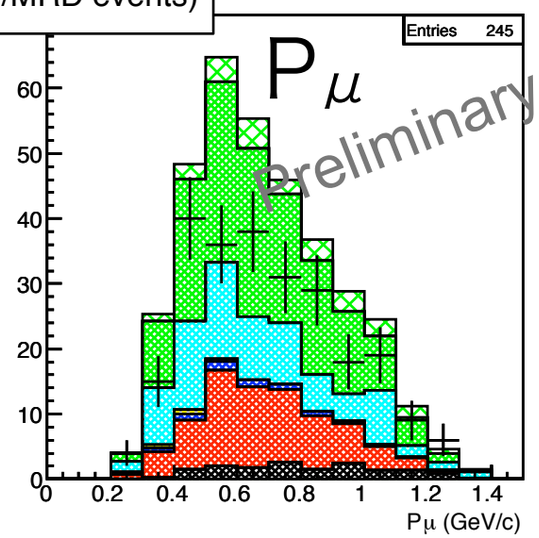
$\bar{\nu}$ Coherent−π counter-sample (μ+π w/ activity)

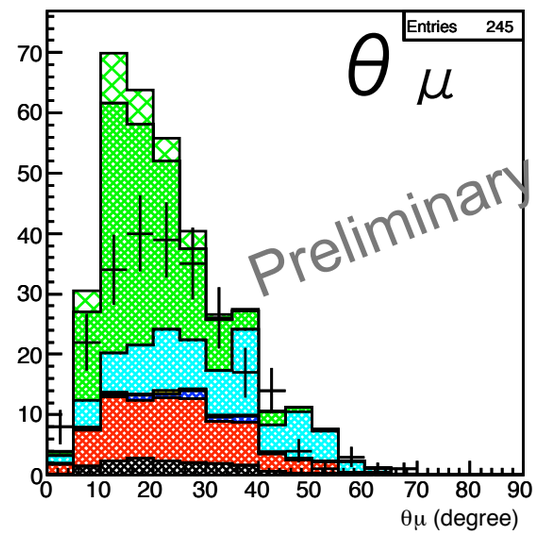


$\bar{\nu}$ CC coherent π sample

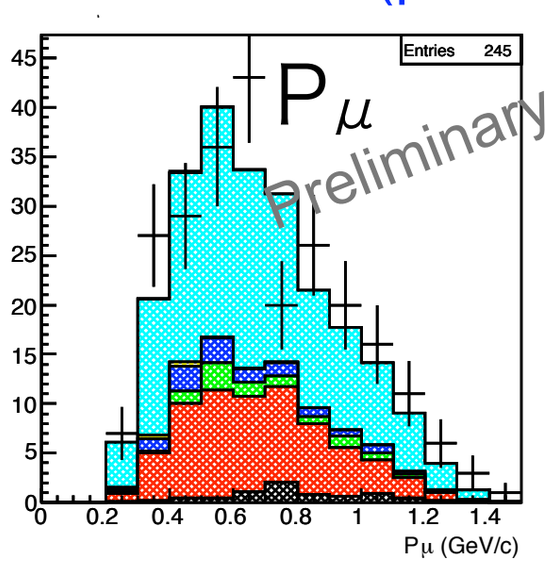


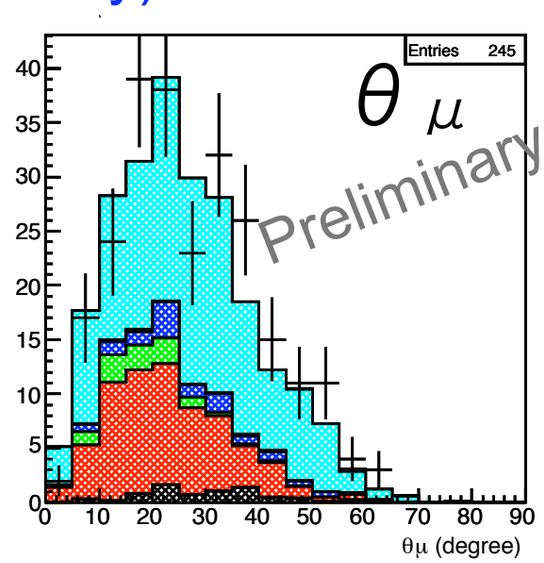
$\bar{\nu}$ Coherent-π sample (μ+π w/o activity)



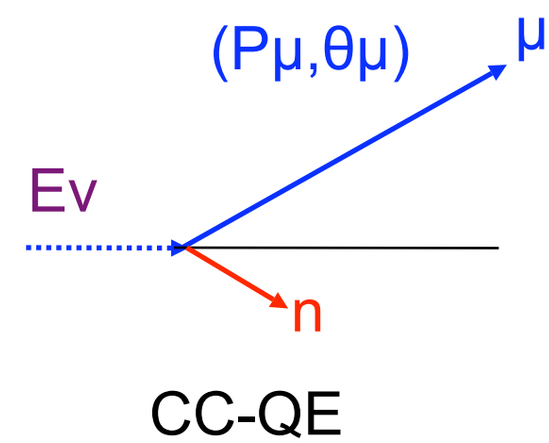


$\bar{\nu}$ Coherent−π counter-sample (μ+π w/ activity)





Ev Q^2 reconstruction assuming CC-QE (ν+p→μ+n) interaction



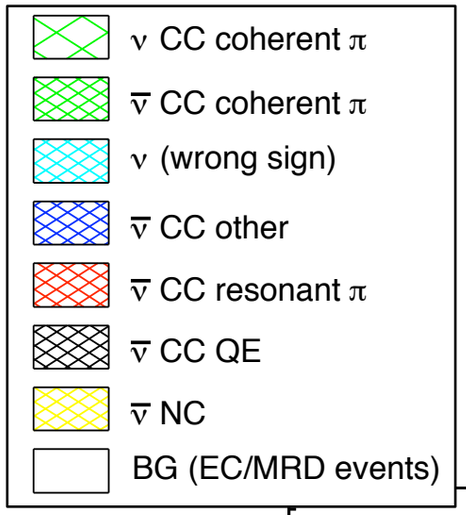
E_ν and Q^2 reconstruction uses only muon kinematics

$$Q^2_{rec} = 2E_\nu^{rec}(E_\mu - p_\mu \cos\theta_\mu) - m_\mu^2$$

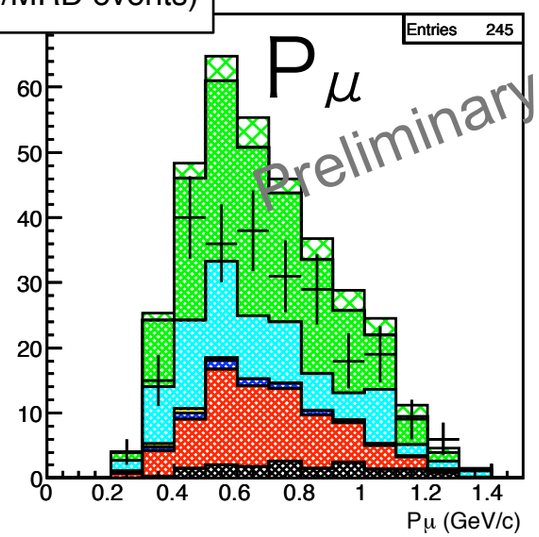
$$E_\nu^{rec} = \frac{1}{2}\frac{(M_p^2 - m_\mu^2) - (M_n - V)^2 + 2E_\mu(M_n - V)}{(M_n - V) - E_\mu + p_\mu \cos\theta_\mu}$$

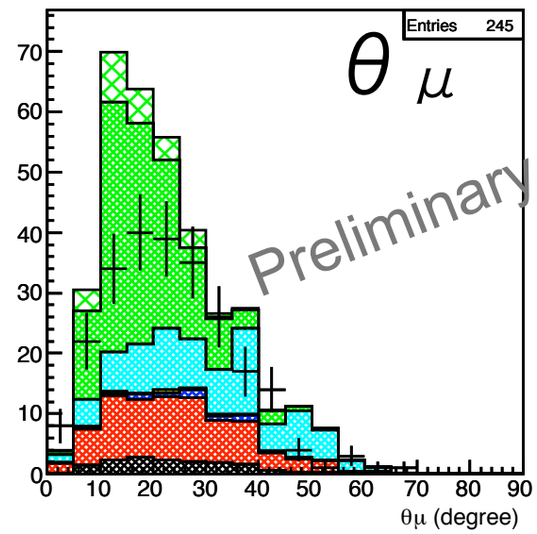
V: nuclear potential (27MeV)

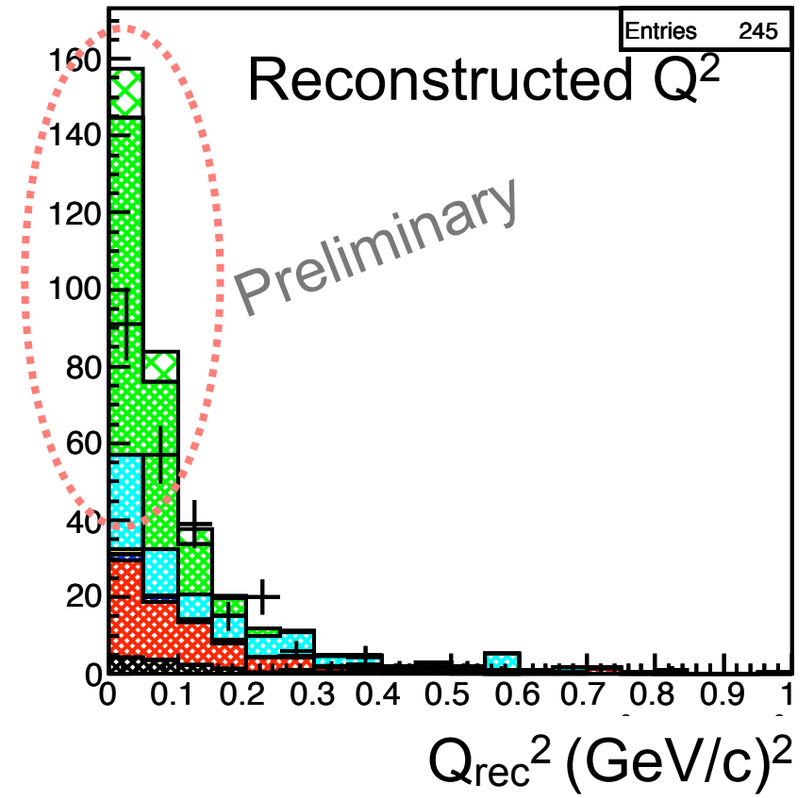
$\bar{\nu}$ CC coherent π sample



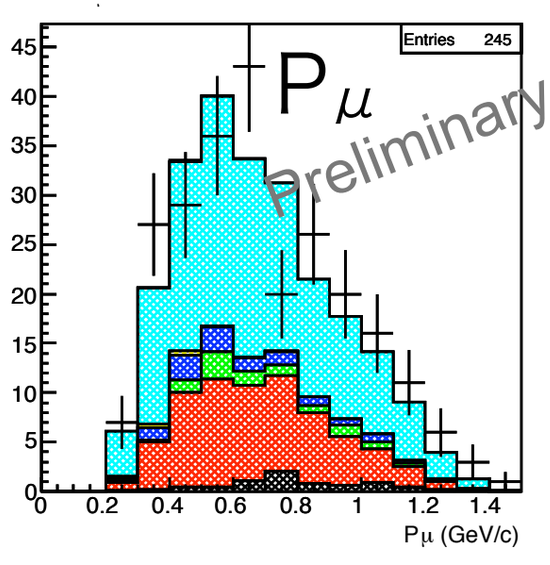
$\bar{\nu}$ Coherent-π sample (μ+π w/o activity)

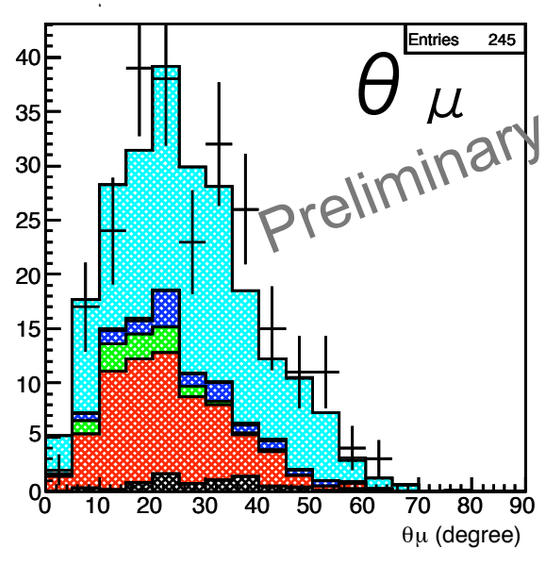


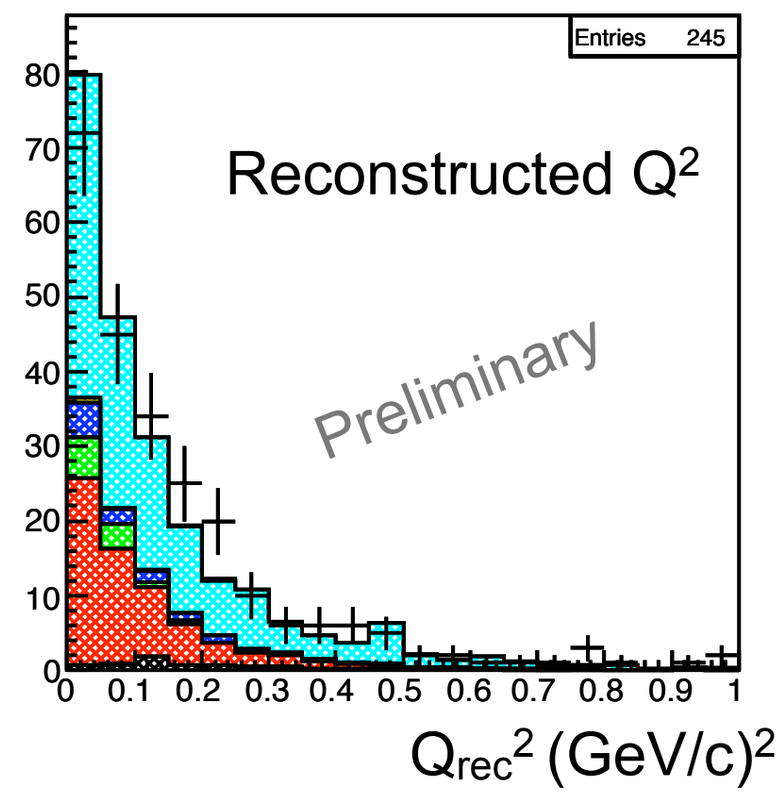




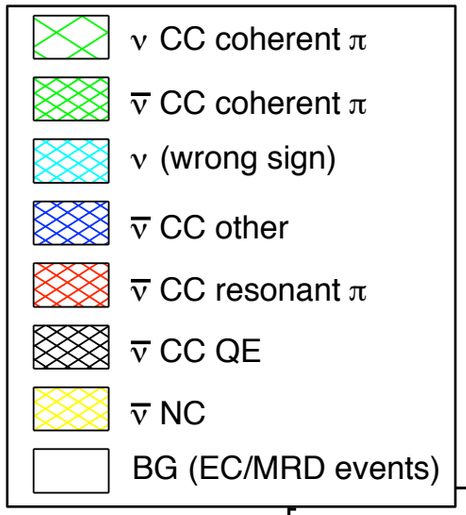
$\bar{\nu}$ Coherent−π counter-sample (μ+π w/ activity)



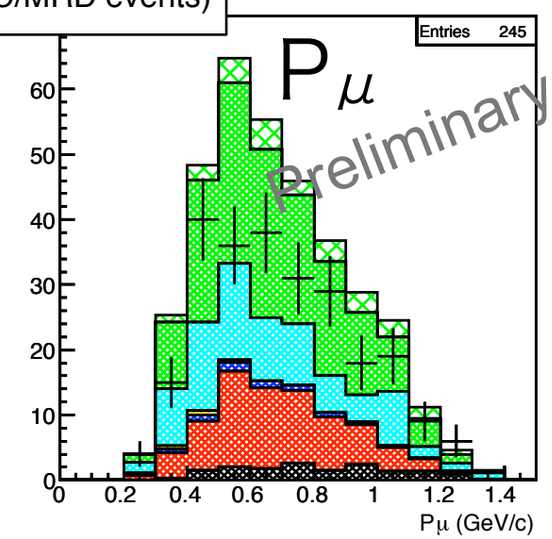


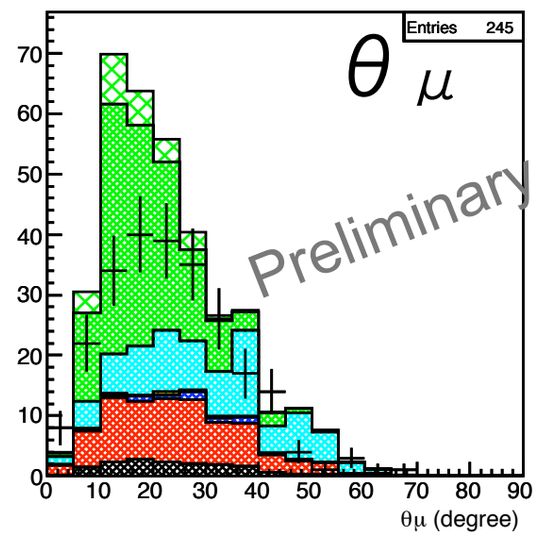


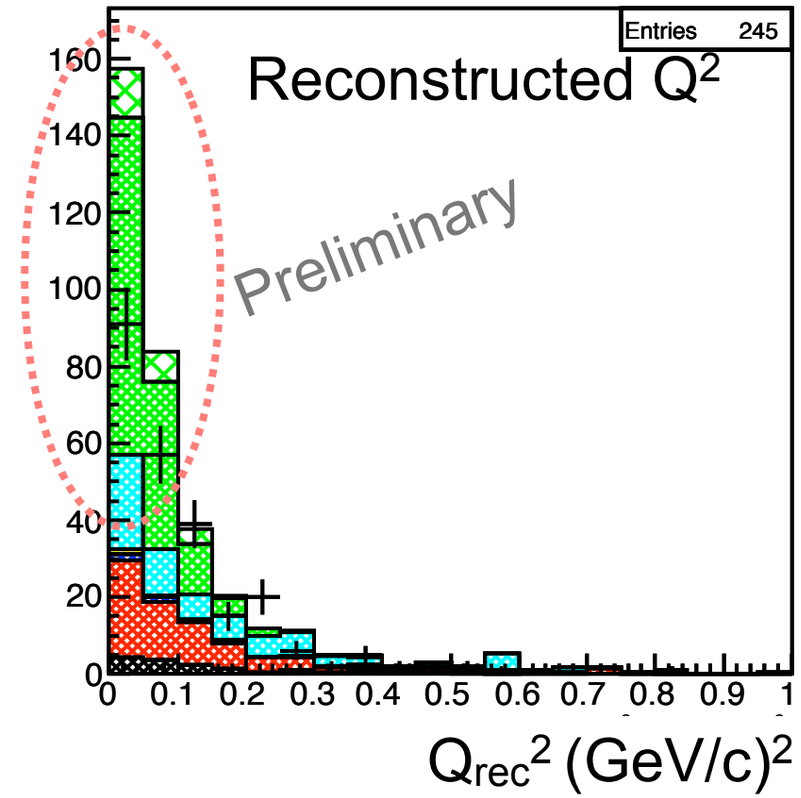
$\bar{\nu}$ CC coherent π sample



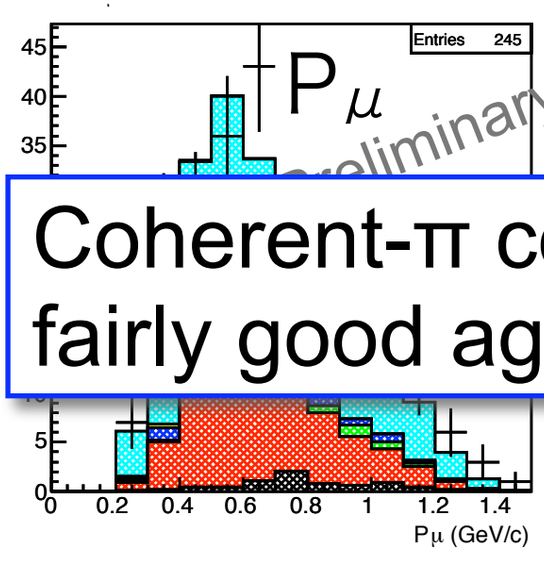
$\bar{\nu}$ Coherent-π sample (μ+π w/o activity)

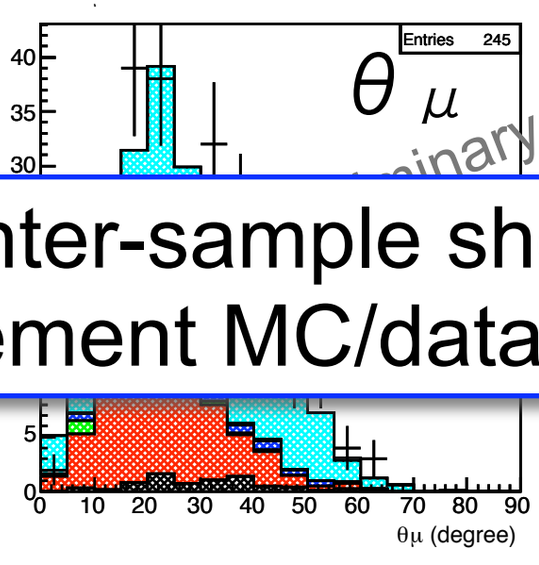


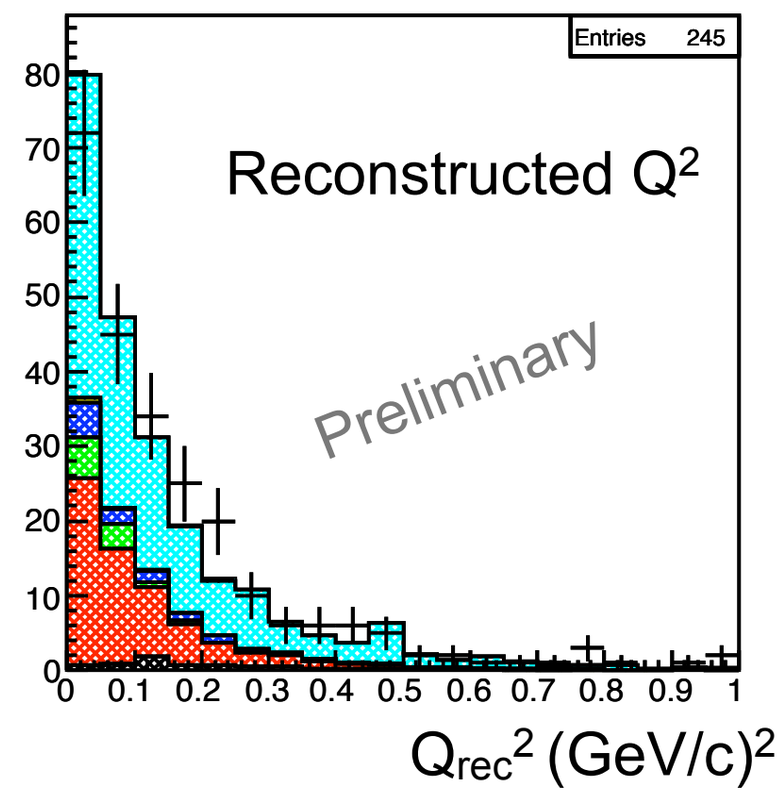




$\bar{\nu}$ Coherent−π counter-sample (μ+π w/ activity)

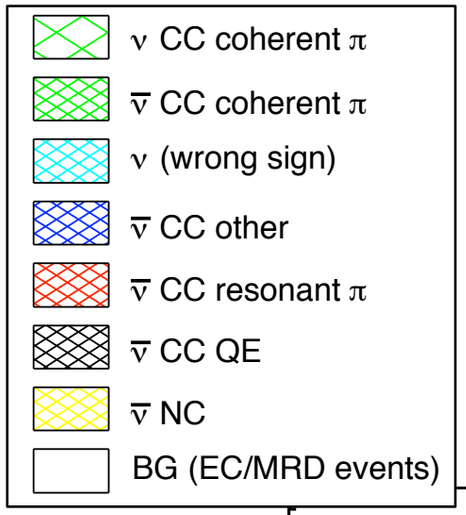




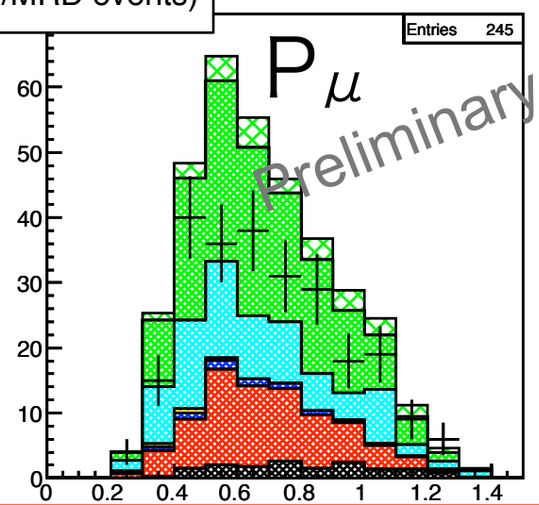


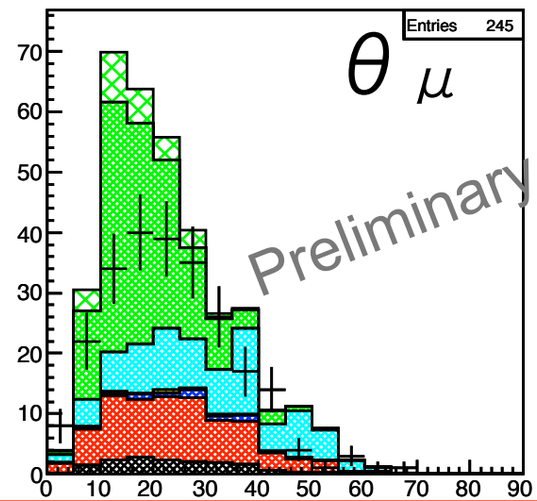
Coherent-π counter-sample show fairly good agreement MC/data

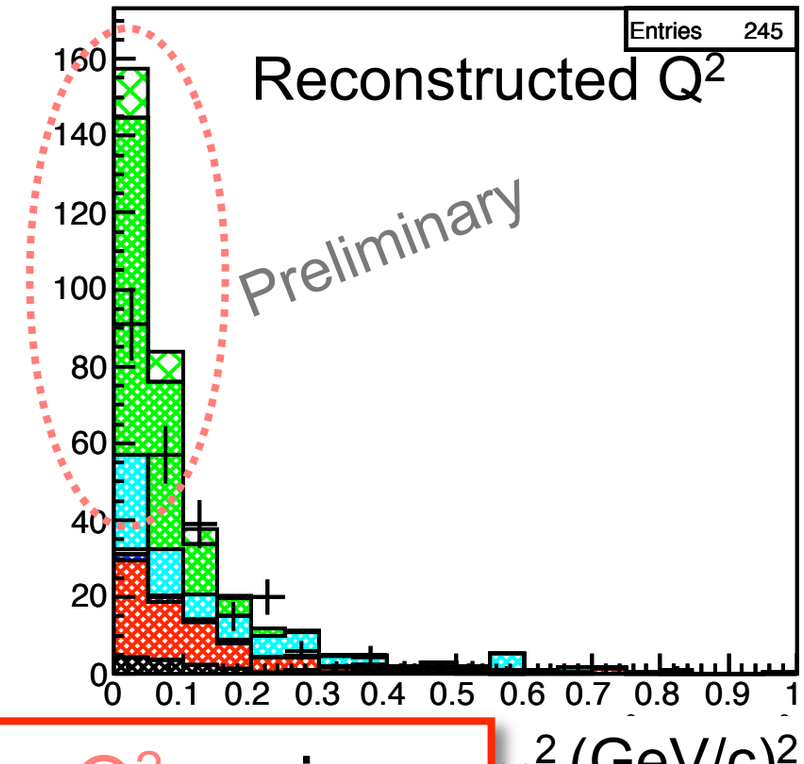
$\bar{\nu}$ CC coherent π sample



$\bar{\nu}$ Coherent-π sample (μ+π w/o activity)

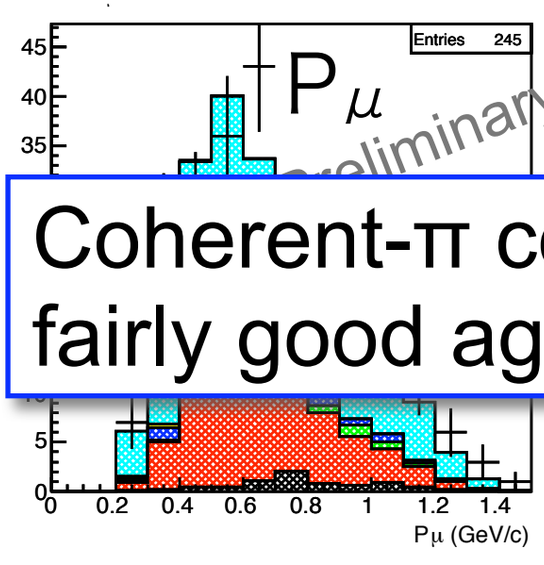


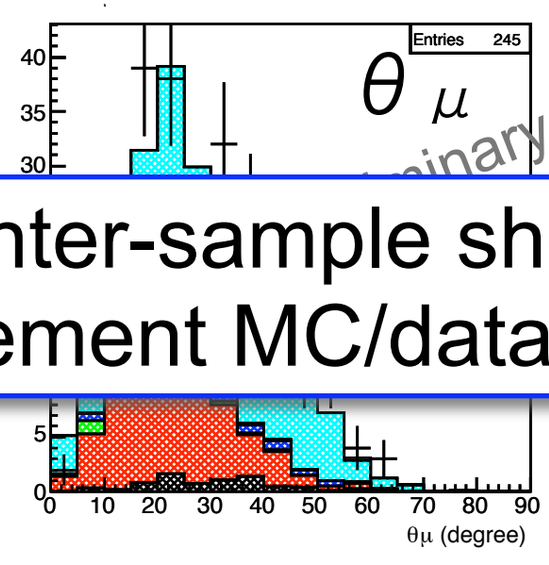


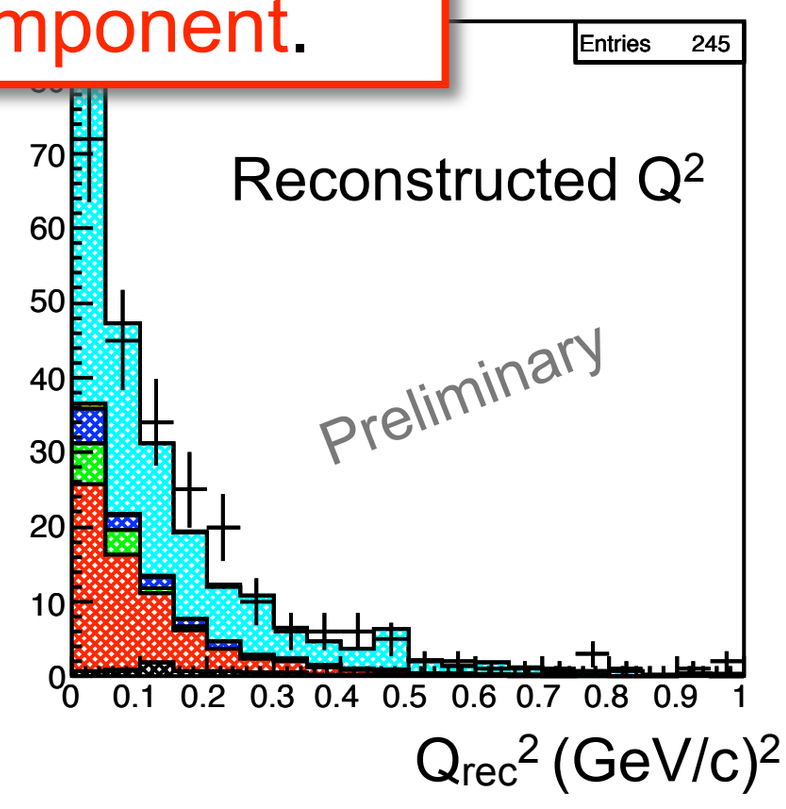


$\bar{\nu}$ coherent π sample show **data deficit** at low Q^2 region.
But data suggest non-zero CC coherent π component.

ν Coherent−π counter-sample (μ+π w/ activity)

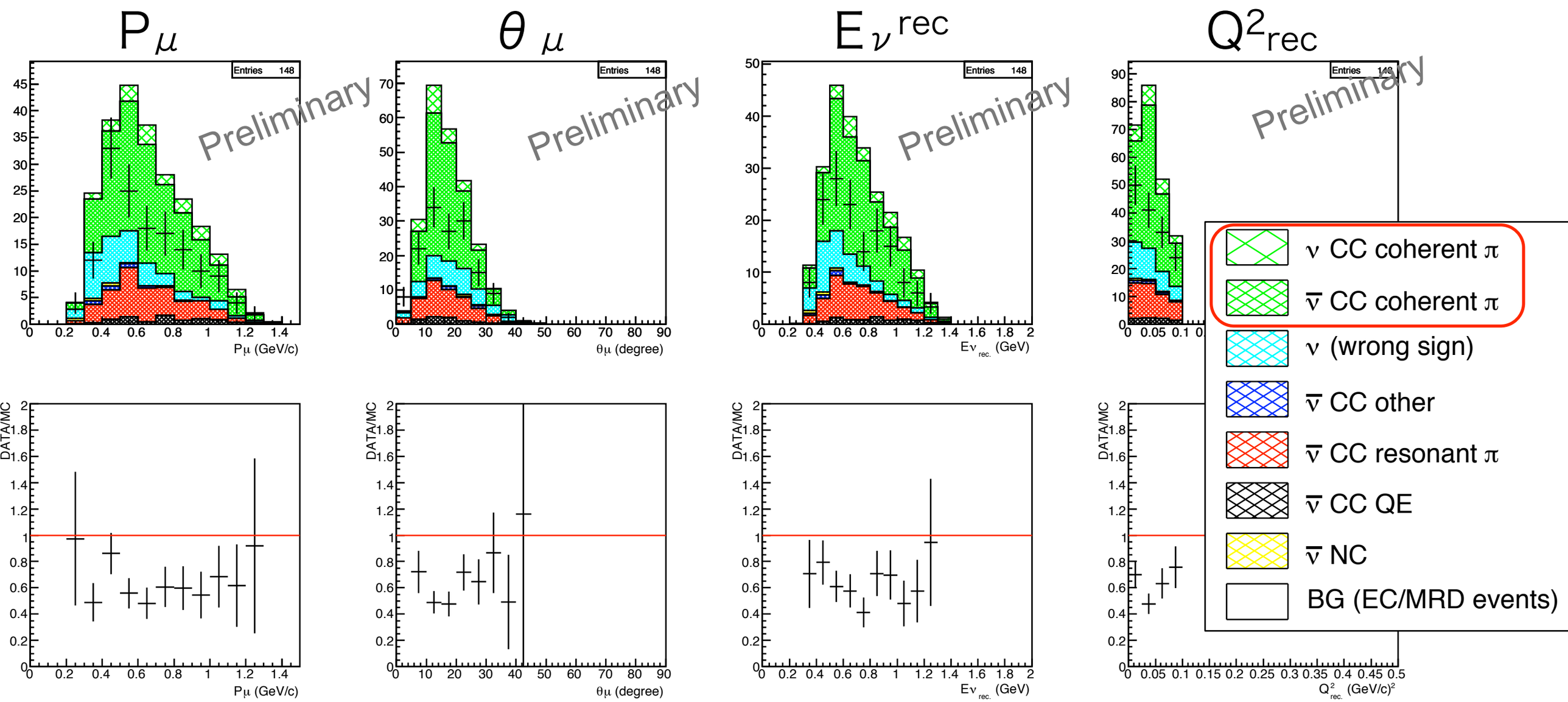






Coherent-π counter-sample show fairly good agreement MC/data

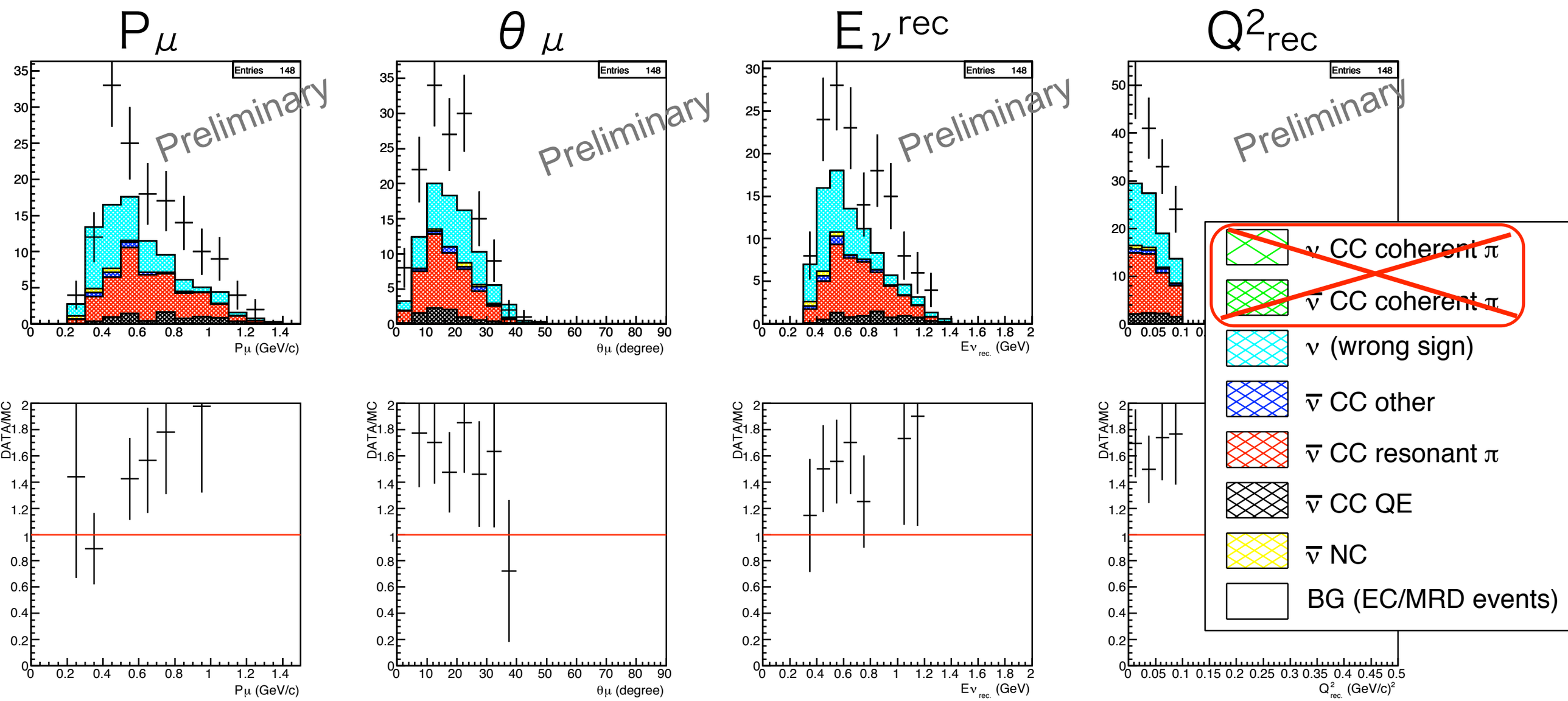
Muon distributions in $Q^2<0.1$ $(GeV/c)^2$



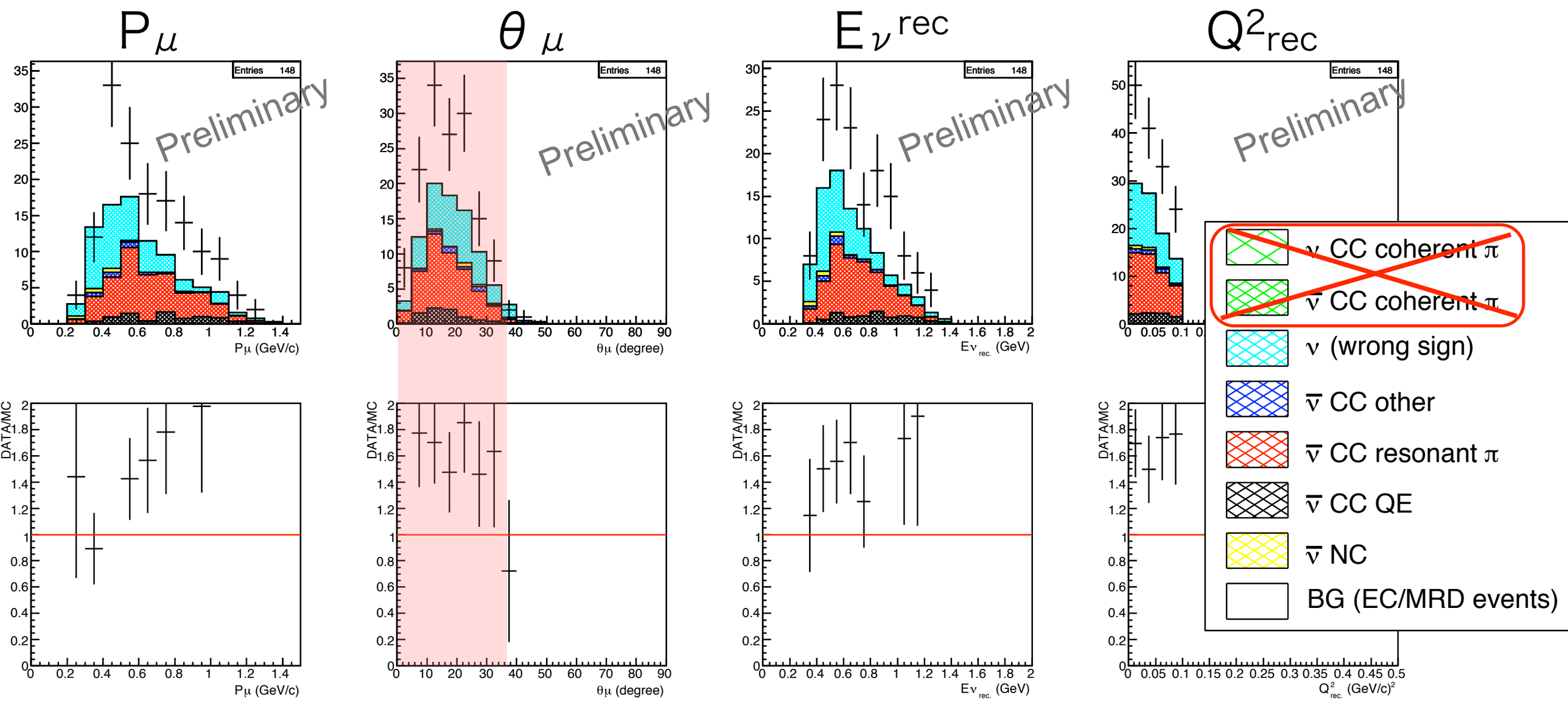
Where "data excess" come from?

➜ Remove all $(\nu+\bar{\nu})$ CC coherent π from MC prediction in coherent π sample.

Muon distributions in $Q^2<0.1$ $(GeV/c)^2$



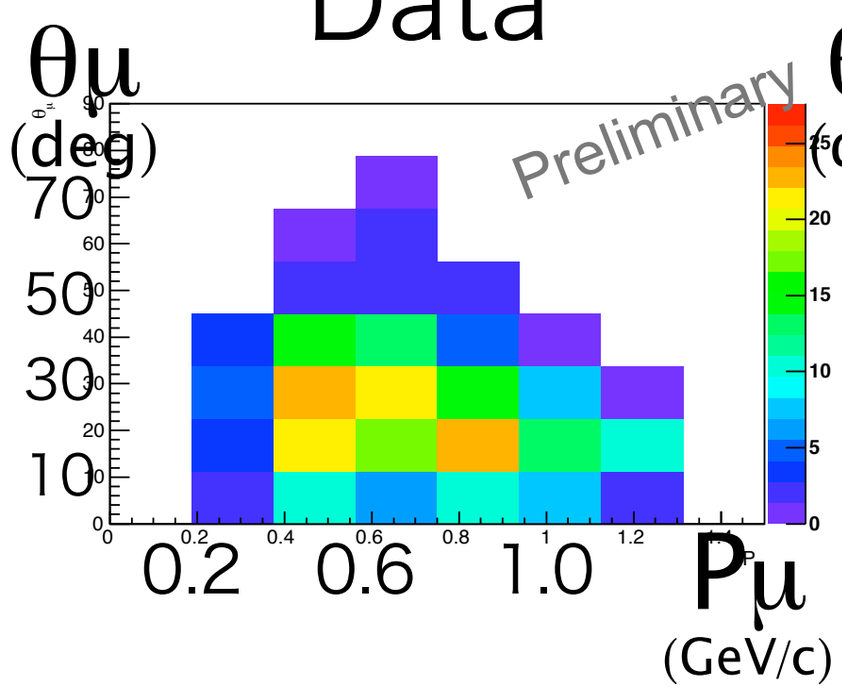
Muon distributions in Q^2<0.1 $(GeV/c)^2$



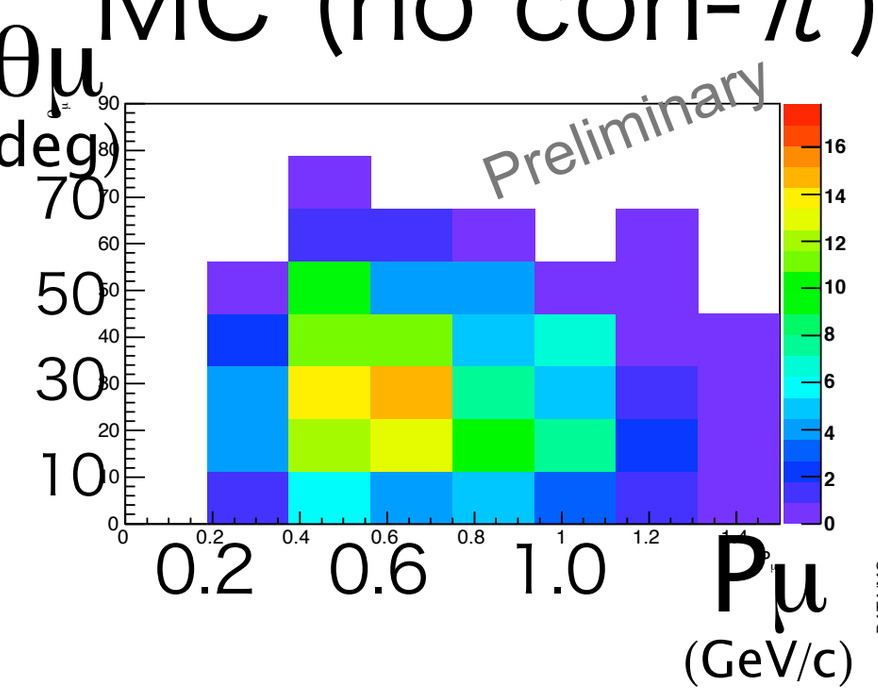
"Data excess" in <u>small θ_μ</u> ?

Coherent π sample in P_μ vs θ_μ

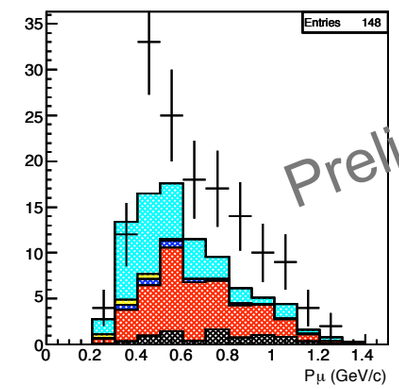
Data



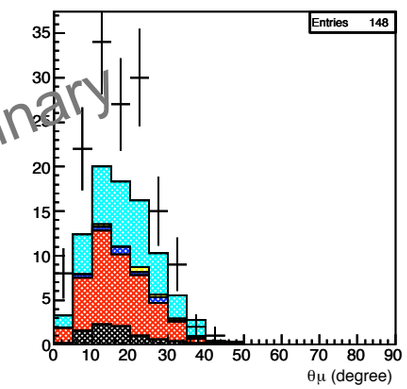
MC (no coh-π)



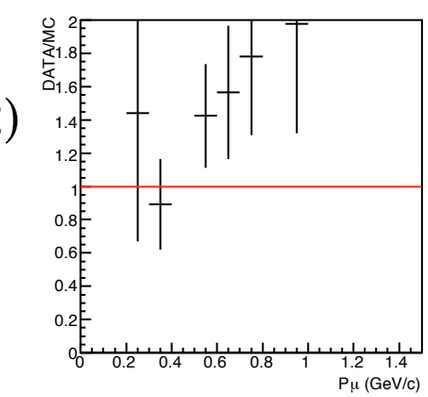
P_μ

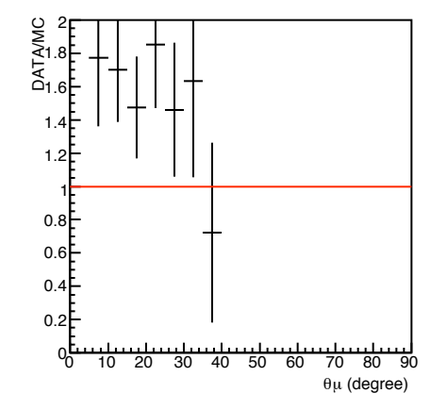


θ_μ

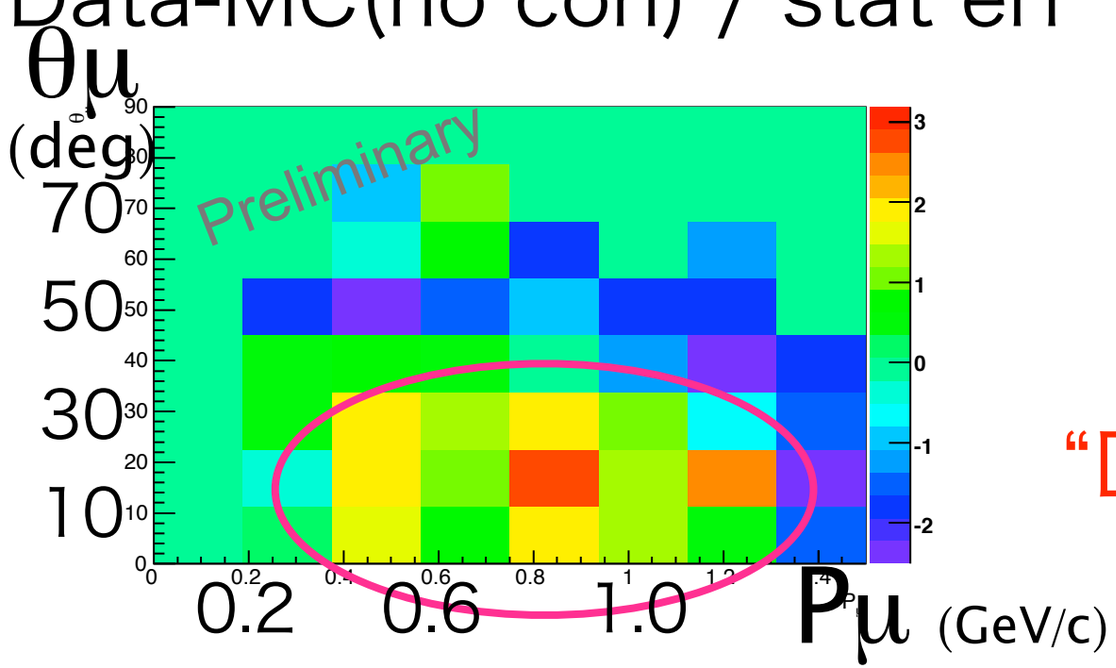


Preliminary





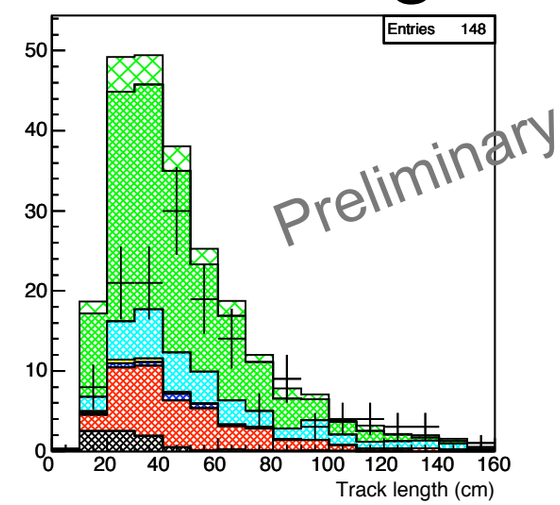
Data-MC(no coh) / stat err



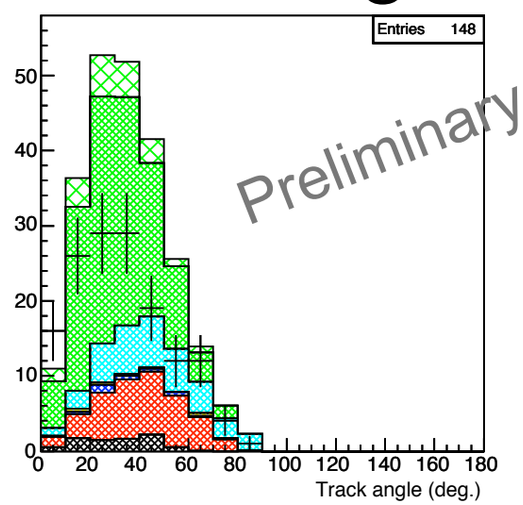
"Data excess" in small θ_μ.

Pion track kinematics in $Q^2<0.1$ $(GeV/c)^2$

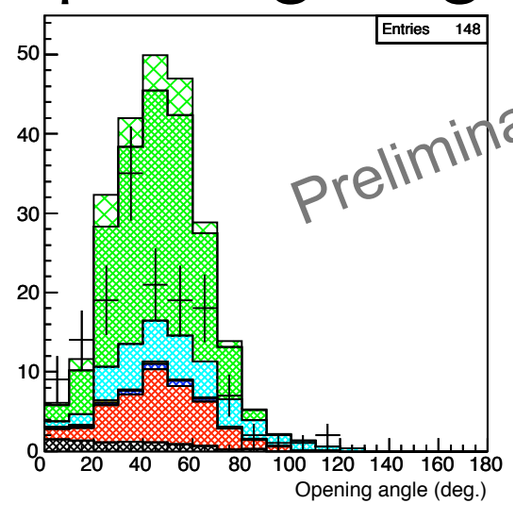
Track length

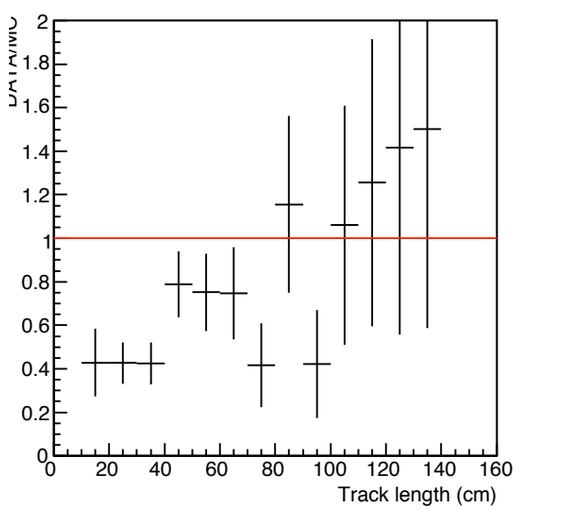


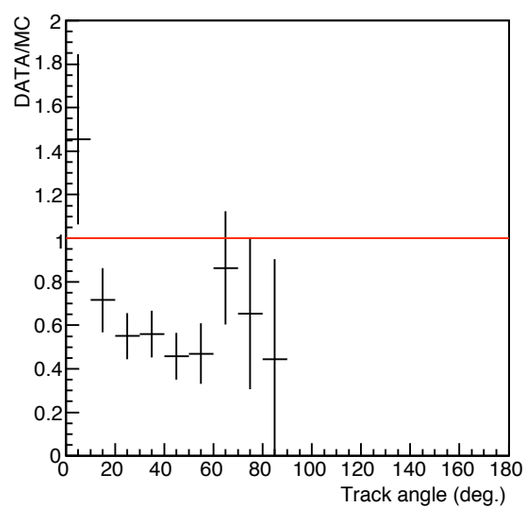
Track angle

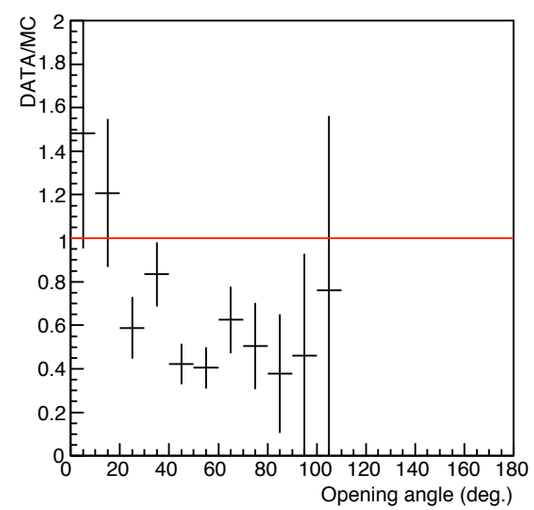


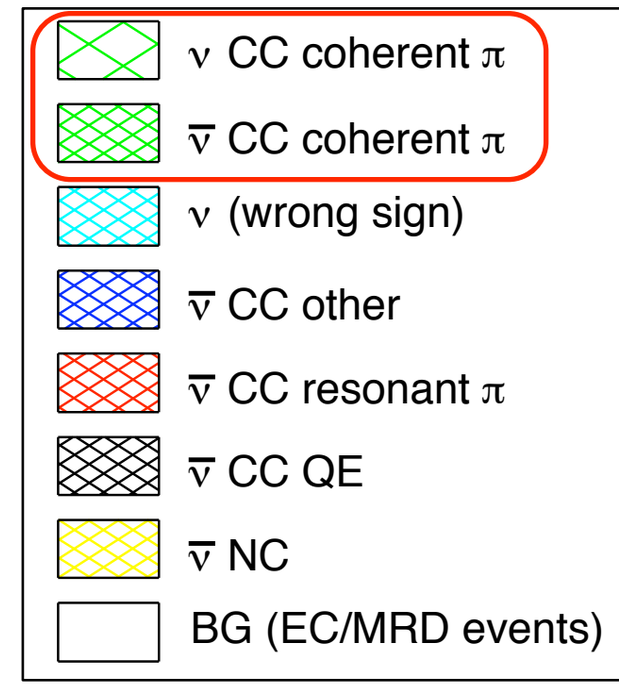
Opening angle









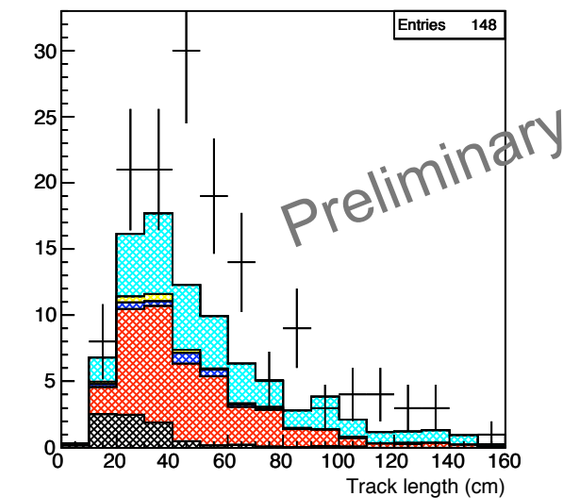


Where "data excess" come from?

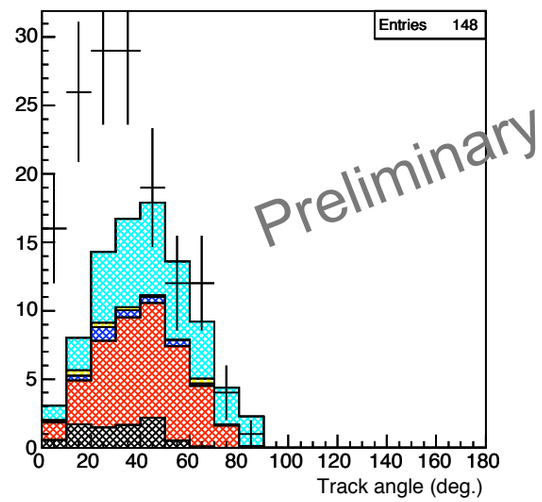
➜ Remove all $(\nu+\bar{\nu})$ CC coherent π from MC prediction in coherent π sample.

Pion track kinematics in $Q^2<0.1$ $(GeV/c)^2$

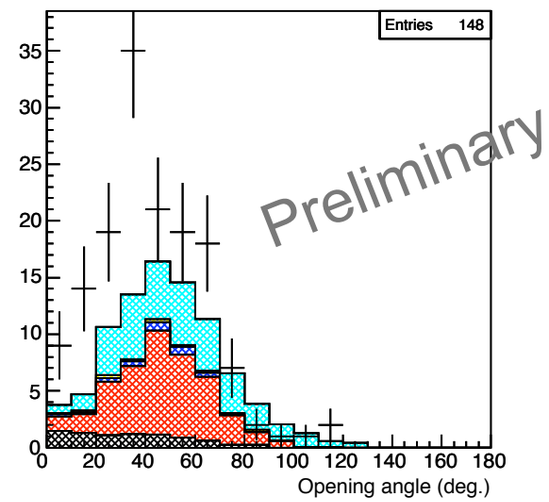
Track length

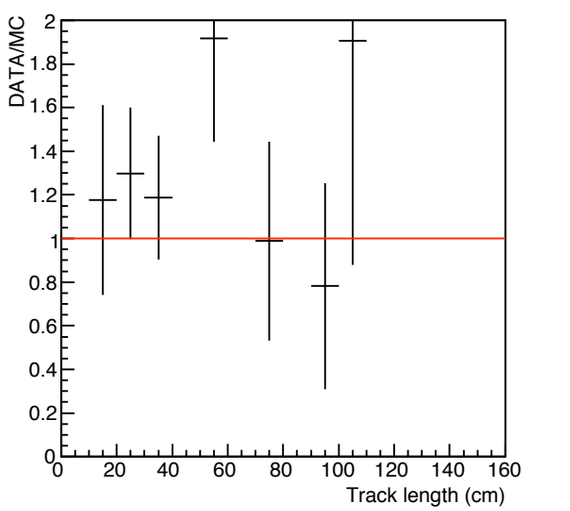


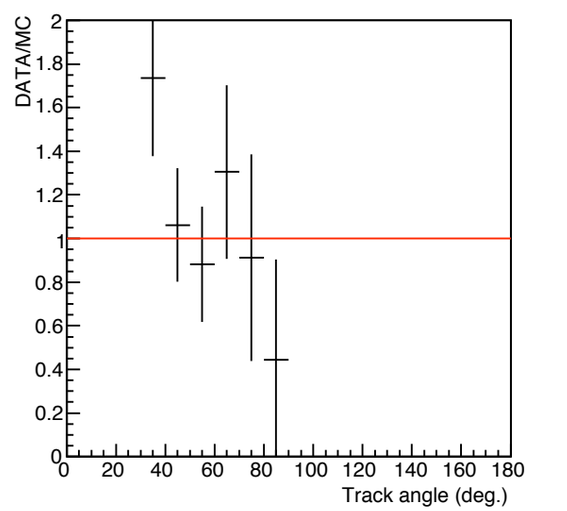
Track angle

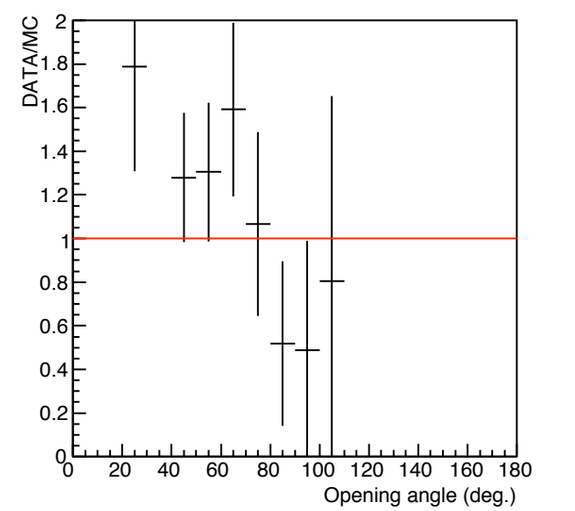


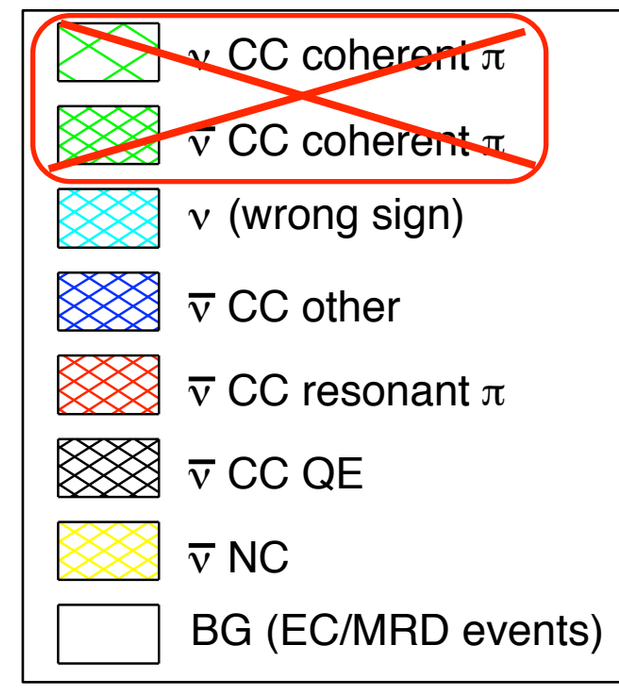
Opening angle





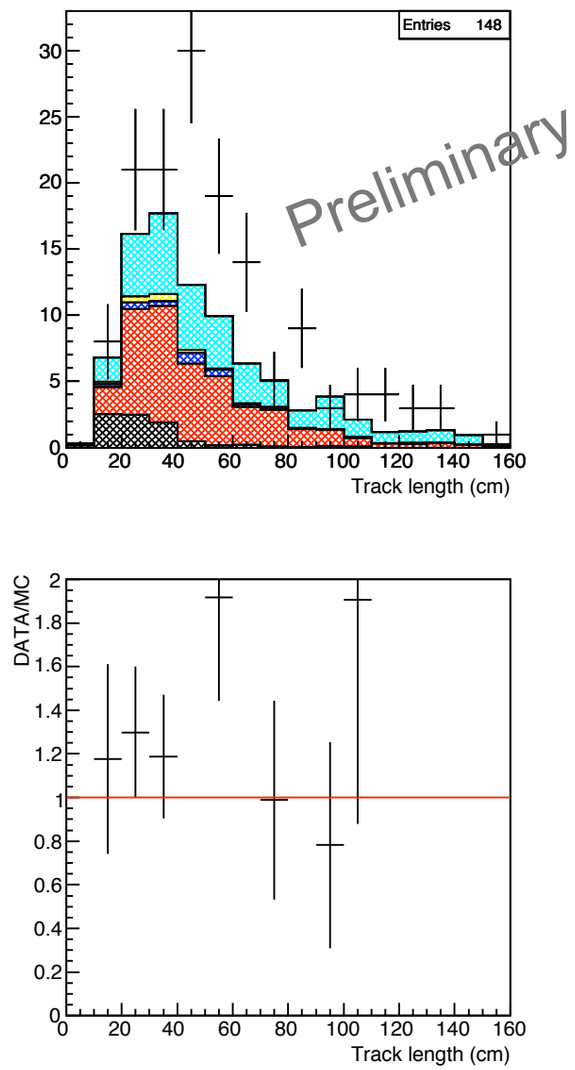




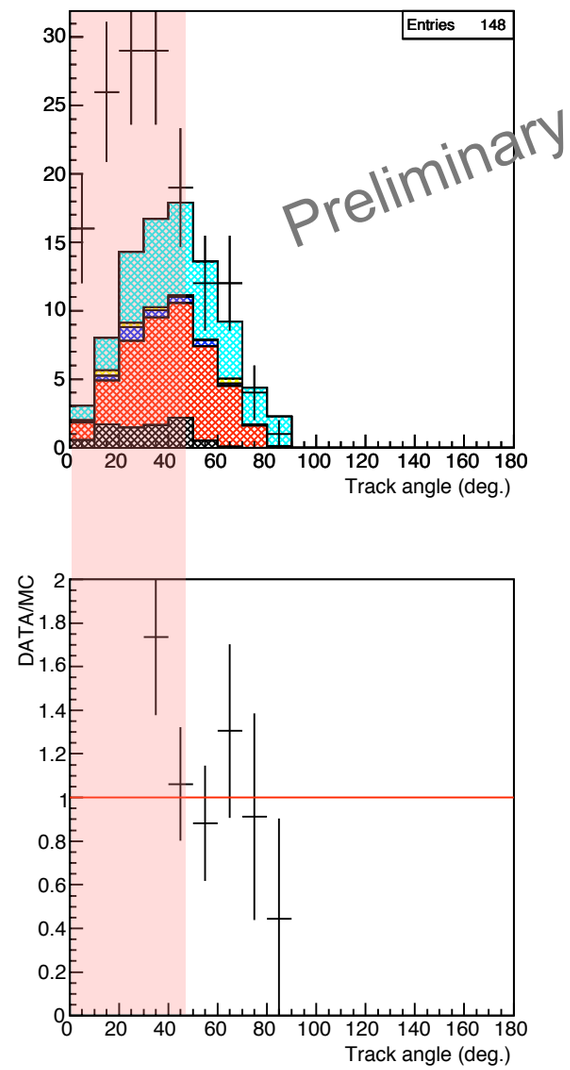


Pion track kinematics in $Q^2<0.1$ $(GeV/c)^2$

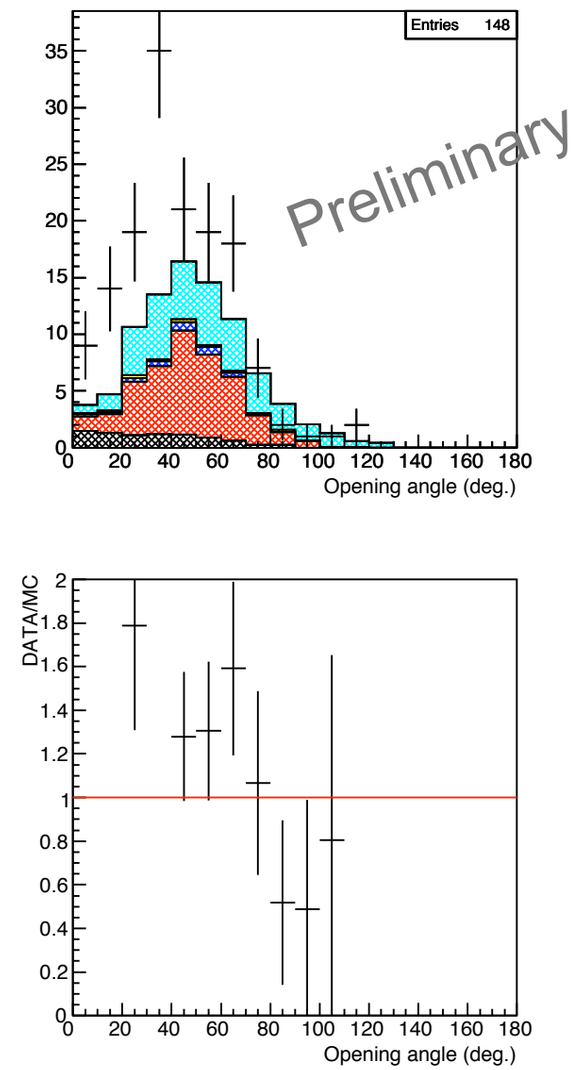
Track length

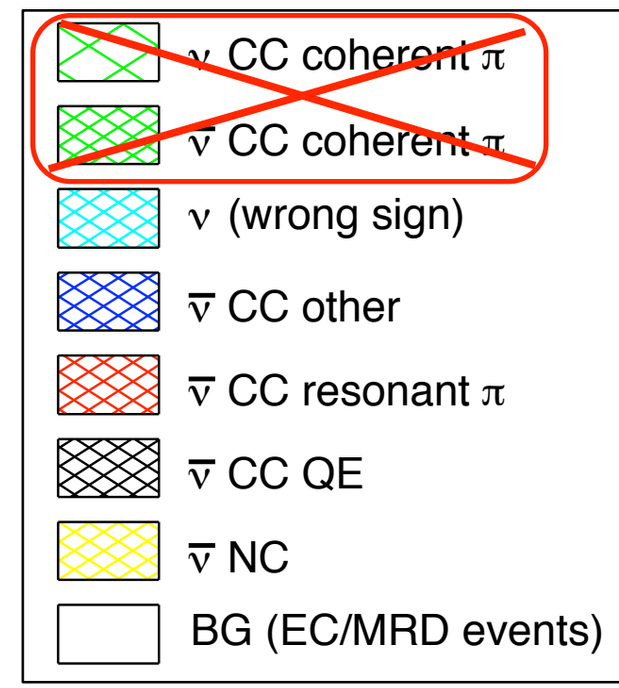


Track angle



Opening angle

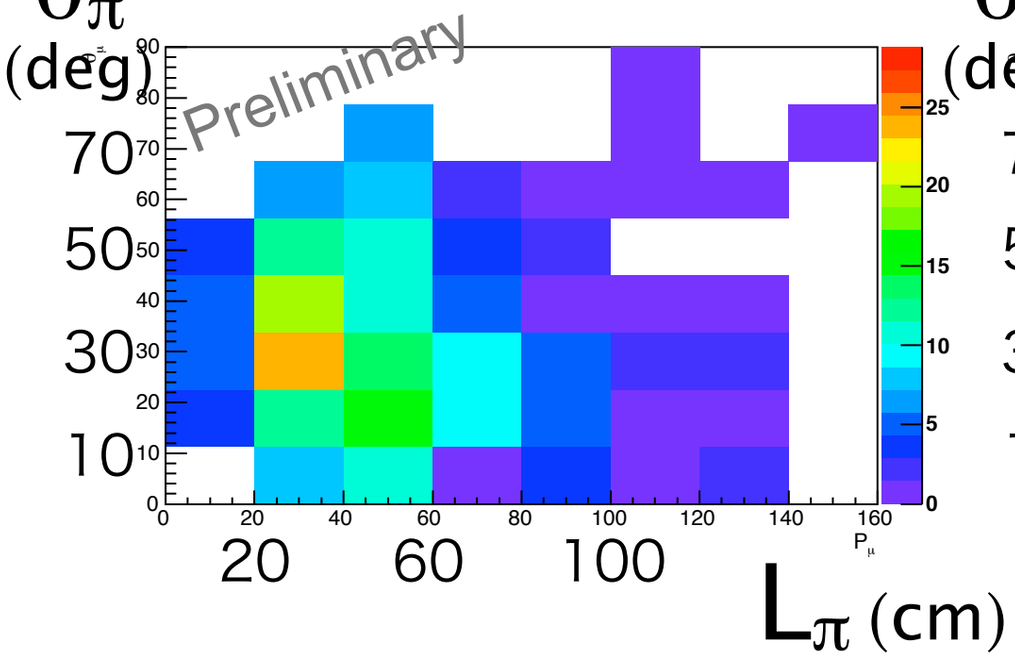




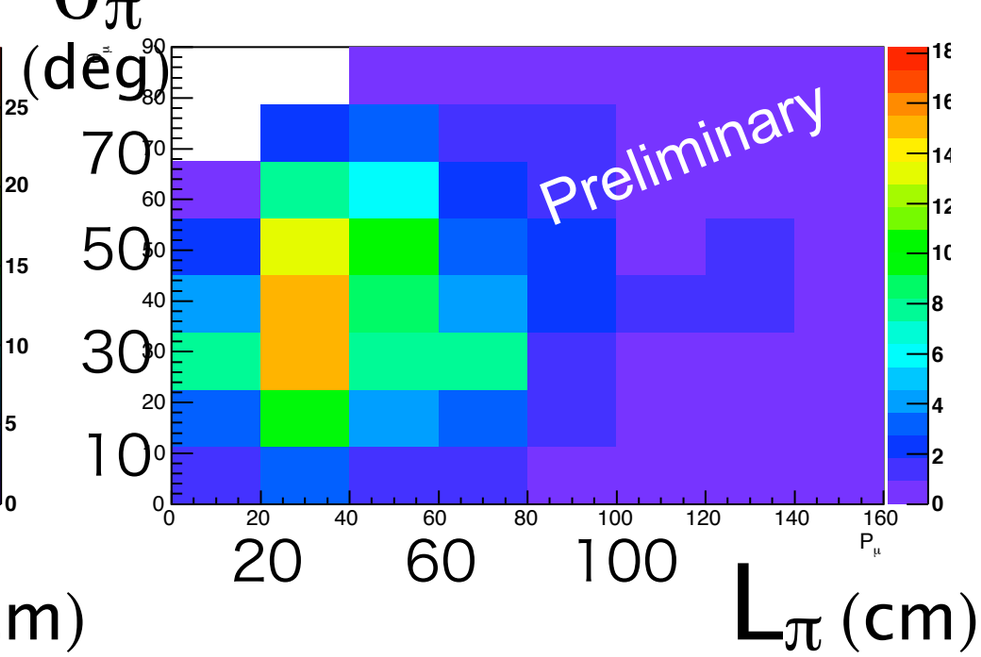
"Data excess" in <u>small θ_π</u> ?

Coherent sample in L_π vs θ_π

Data



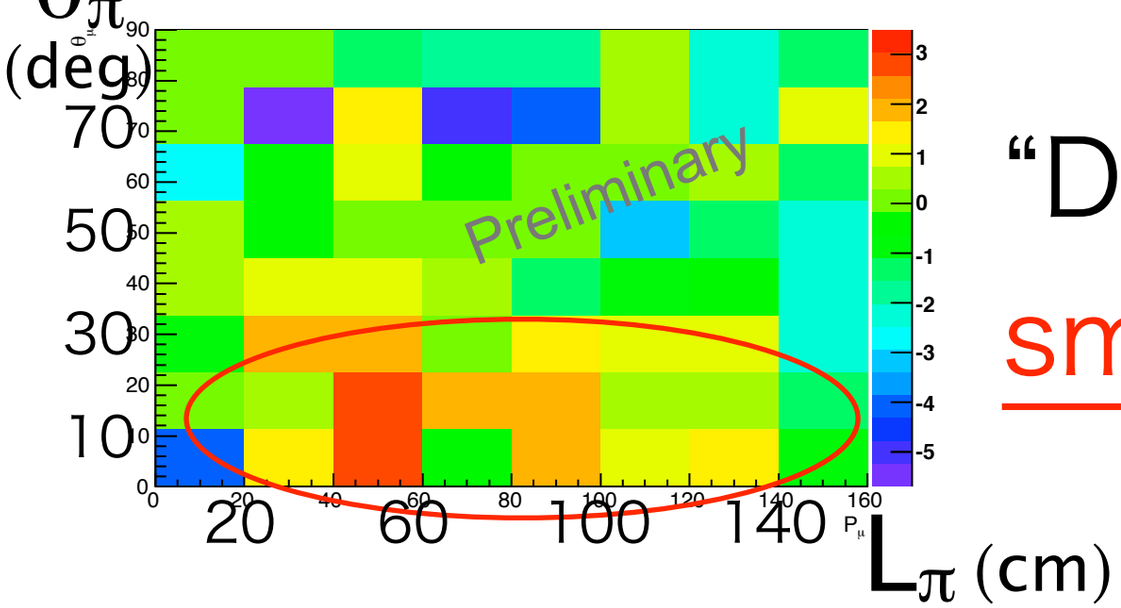
MC (no coh-π)



L_π: π track length

θ_π: π track angle wrt $\bar{\nu}$ beam dir.

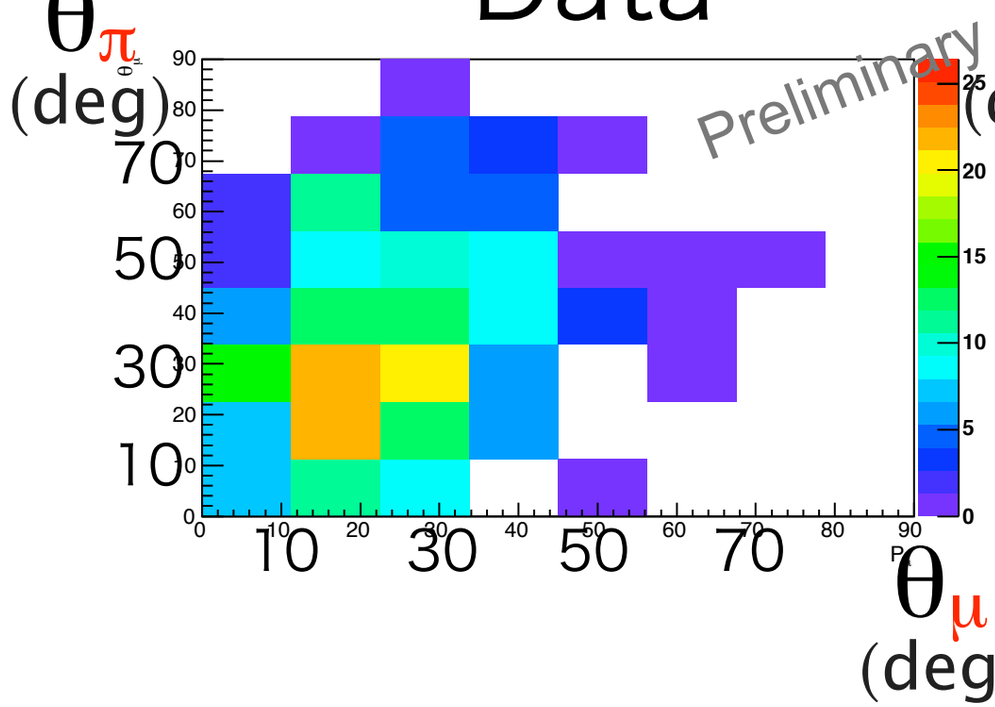
Data-MC(no coh) / stat err



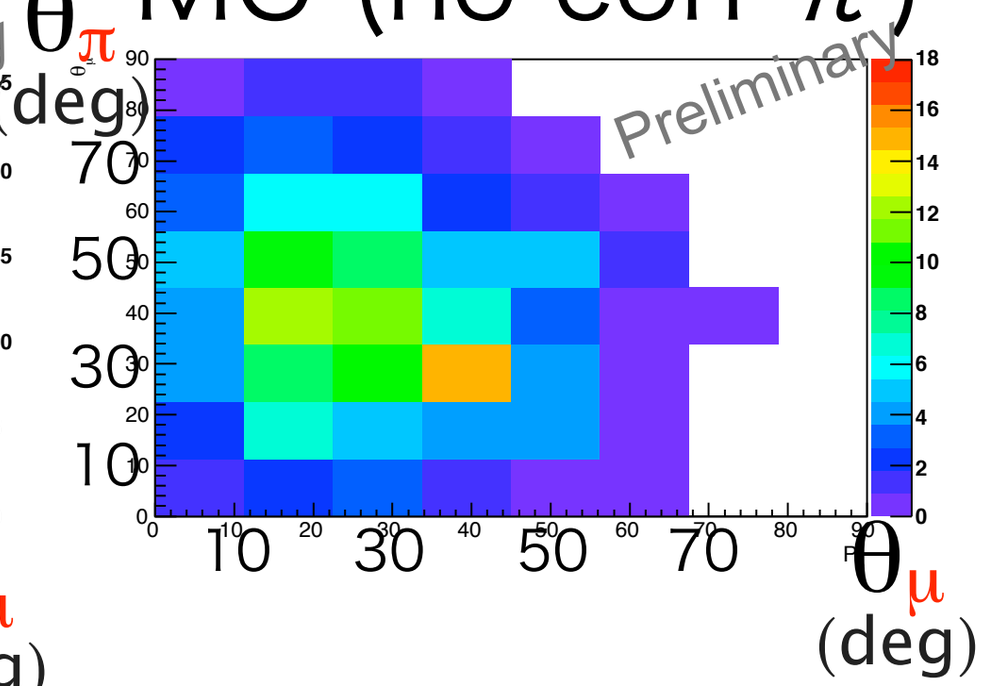
"Data excess" in small π scattered angle.

Coherent π sample in θ_μ vs θ_π

Data



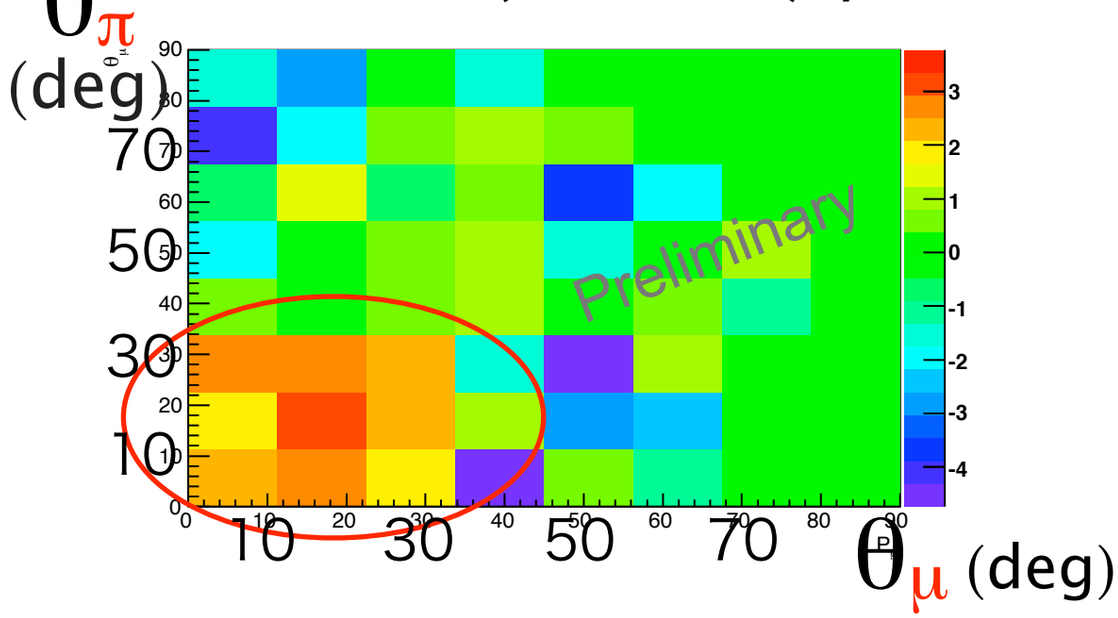
MC (no coh-π)



θ_π: π track angle wrt $\bar{\nu}$ beam dir.

θ_μ : μ track angle wrt $\bar{\nu}$ beam dir.

Data-MC(no coh) / stat err



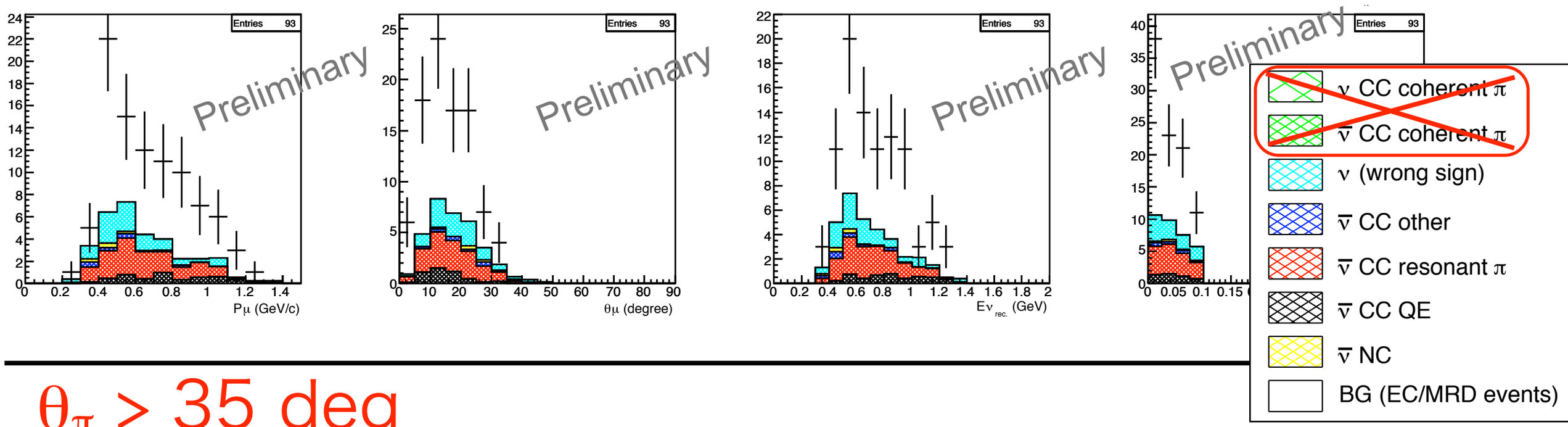
"Data excess" in

<u>small $\theta\pi$</u> && <u>small $\theta\mu$</u>

Where "data excess" come from?
Muon distributions

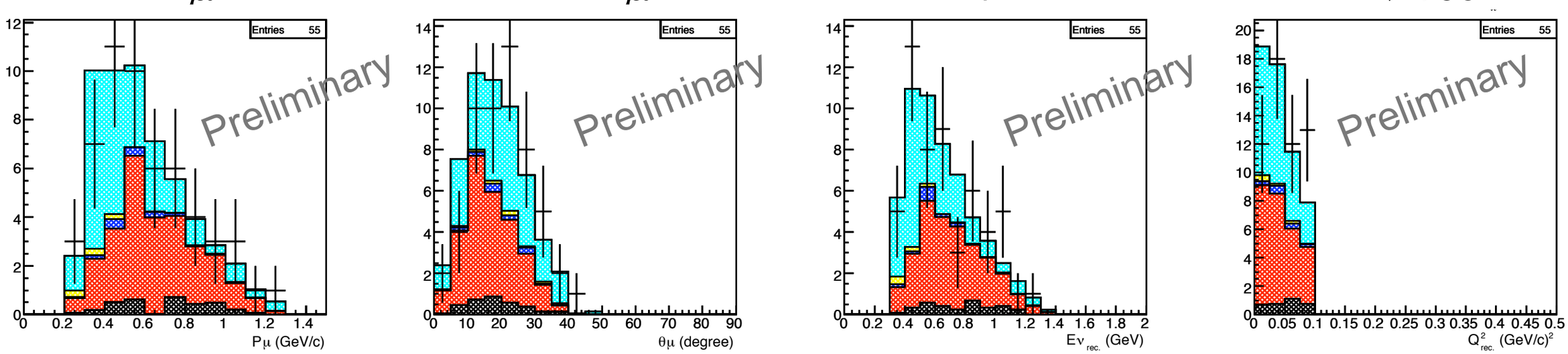
$\theta_\pi < 35$ deg

P_μ θ_μ E_ν^{rec} Q^2_{rec}



$\theta_\pi > 35$ deg

P_μ θ_μ E_ν^{rec} Q^2_{rec}

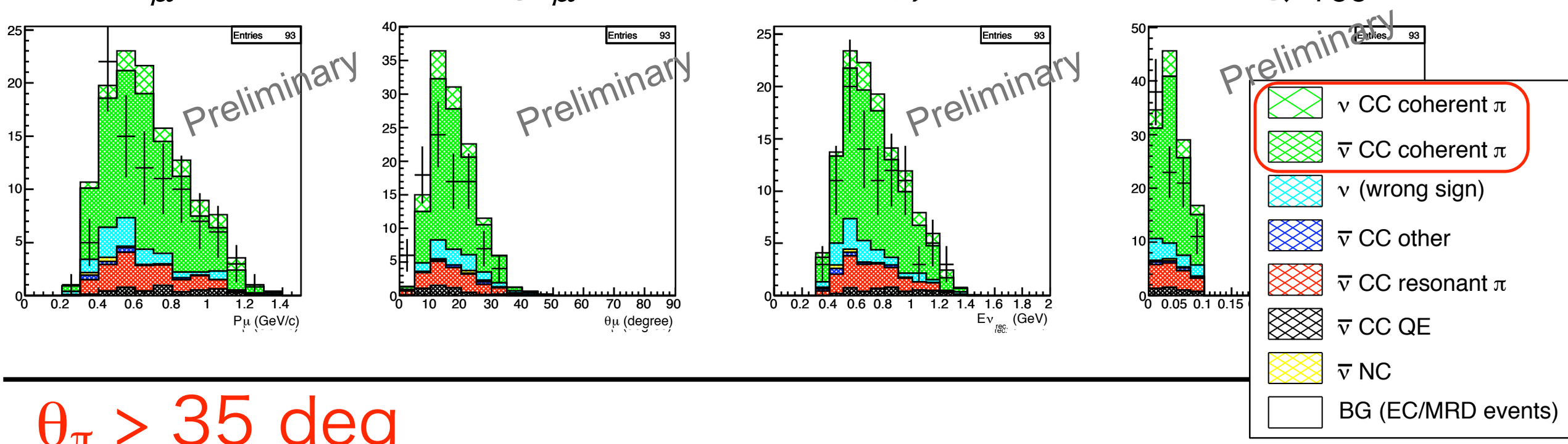


Where "data excess" come from?
Muon distributions

Put back CC coherent-π MC prediction

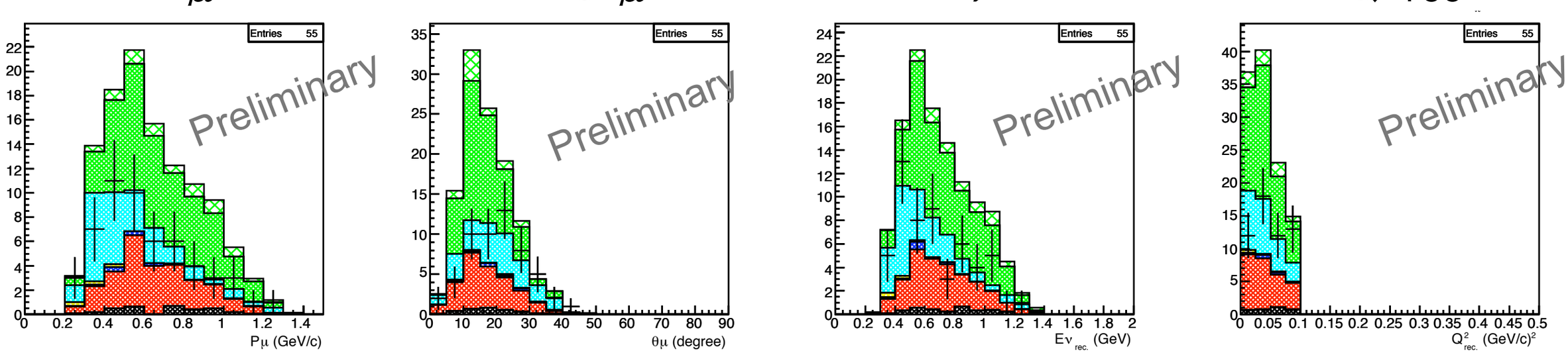
$\theta_\pi < 35$ deg

P_μ θ_μ E_ν^{rec} Q^2_{rec}



$\theta_\pi > 35$ deg

P_μ θ_μ E_ν^{rec} Q^2_{rec}

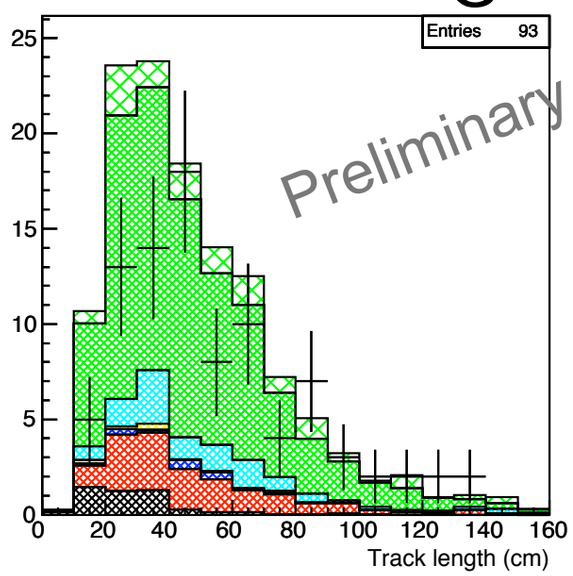


Where “data excess” come from?

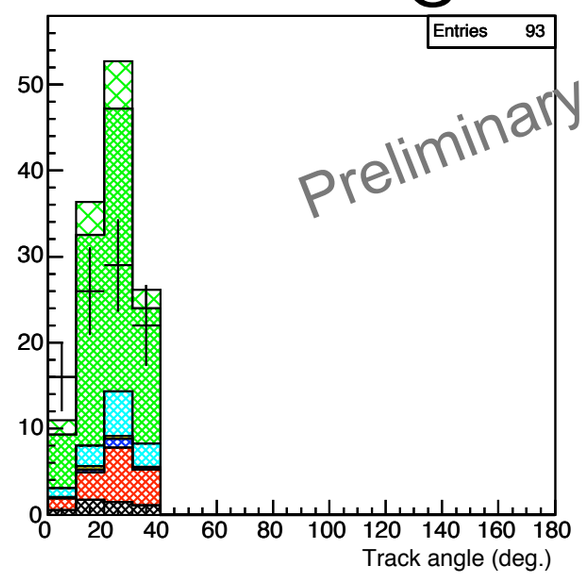
Pion track distributions

$\theta_\pi < 35$ deg

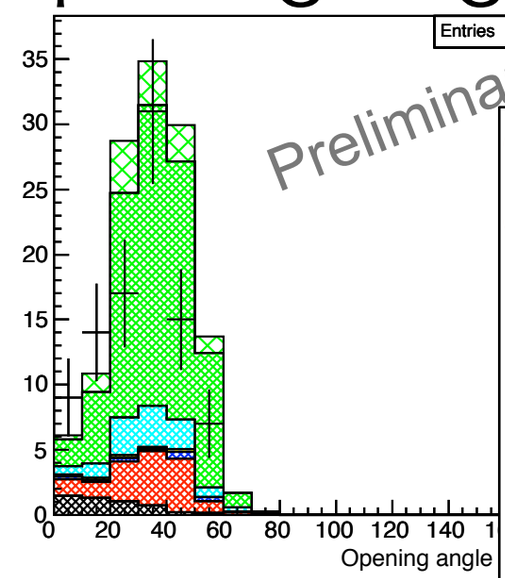
Track length

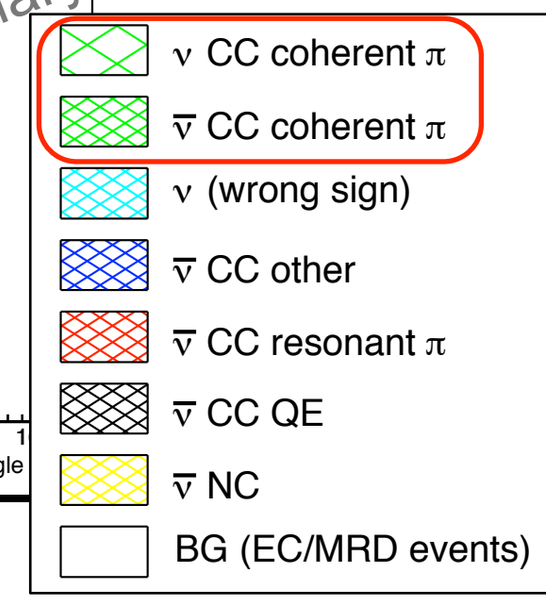


Track angle



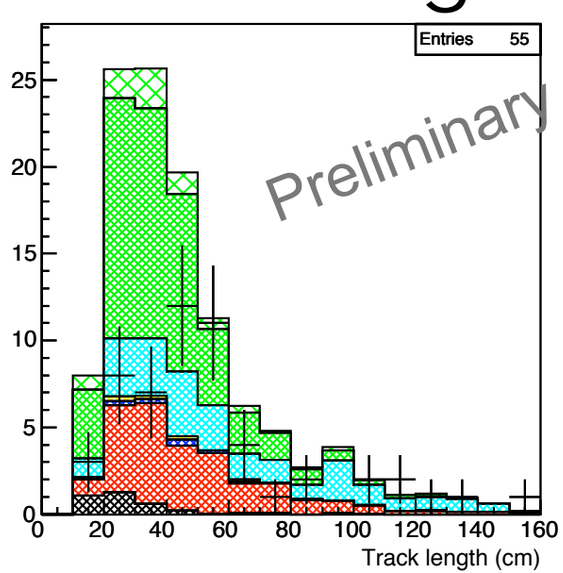
Opening angle



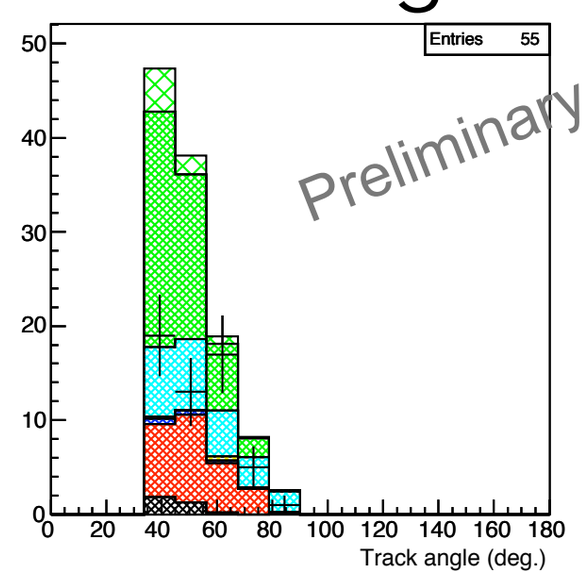


$\theta_\pi > 35$ deg

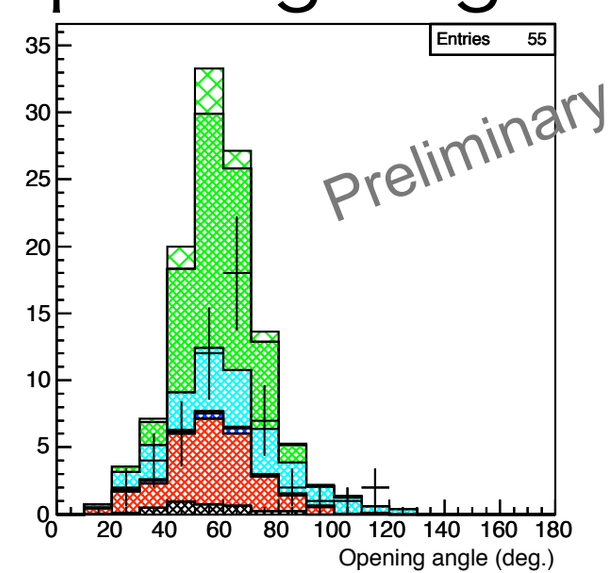
Track length



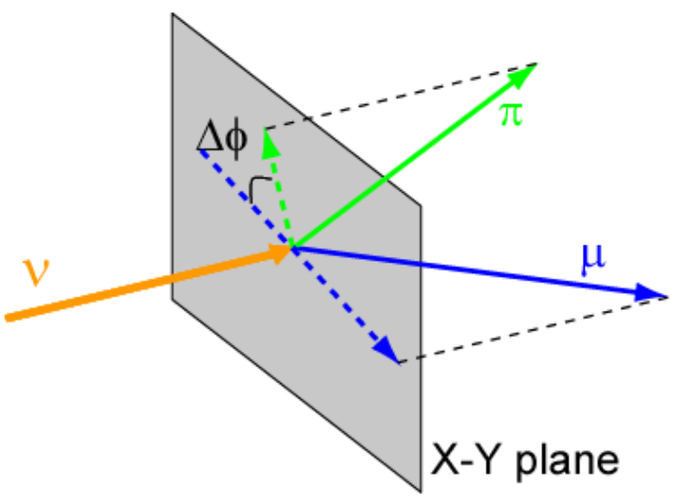
Track angle



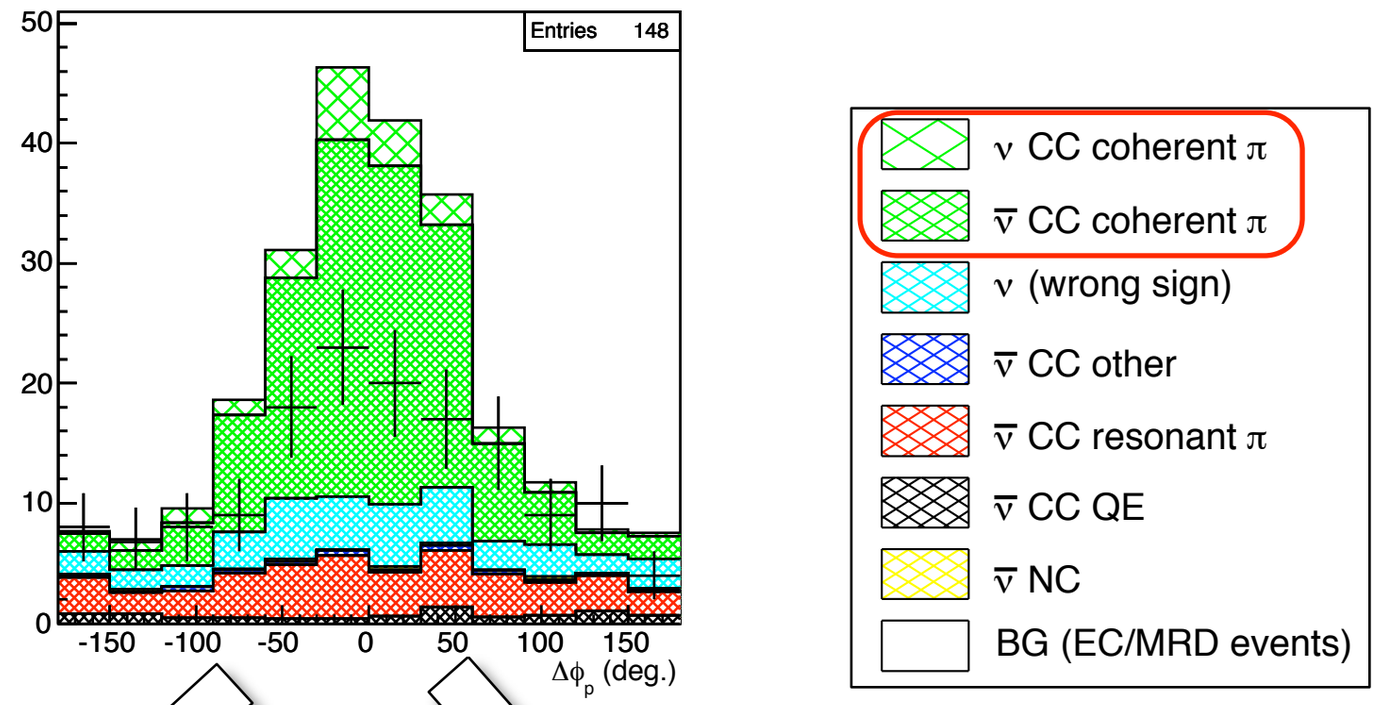
Opening angle



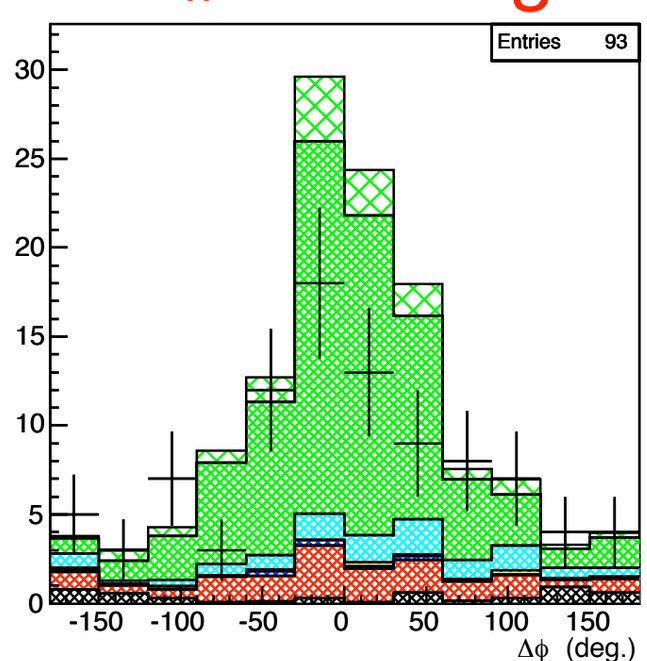
Coplanar angle difference: $\Delta\phi$



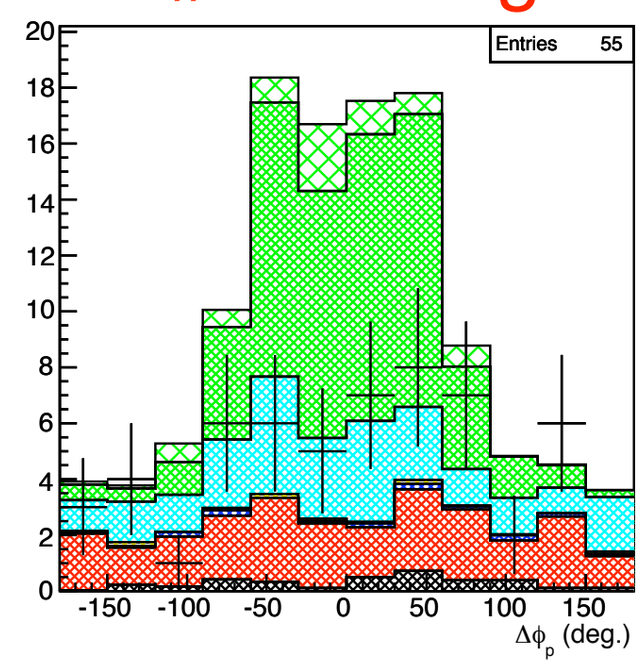
No θ_π cut



θ_π < 35 deg



θ_π > 35 deg



Summary

- Search for CC coherent π in $\bar{\nu}$ data
  - $\bar{\nu}$ data is sensitive to search for coh. π
- $\bar{\nu}$ data suggest:
  - Non-zero CC coherent π component.
    - But consistent with SciBooNE's upper limit on $\sigma(\nu$ CC coherent $\pi)$ - PRD 78, 112004(2008)
  - Pions from CC coh-π production tend to be produced more forward than prediction.
- Similar CC coh.π signature in ν data too.
- Hope to have fruitful discussion in this workshop to improve CC coherent-π model.

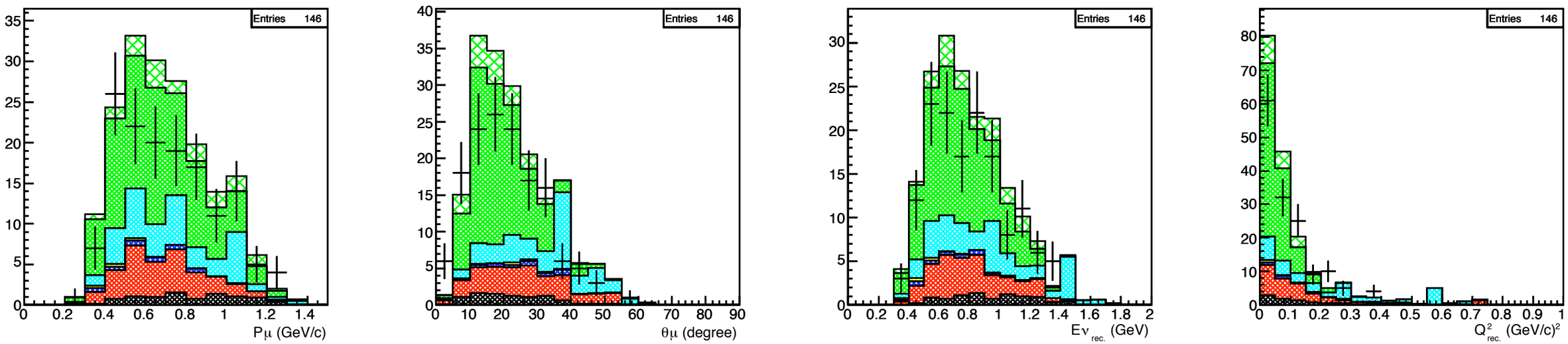
Backup

Where "data excess" come from?
Muon distributions

No Q^2 cuts

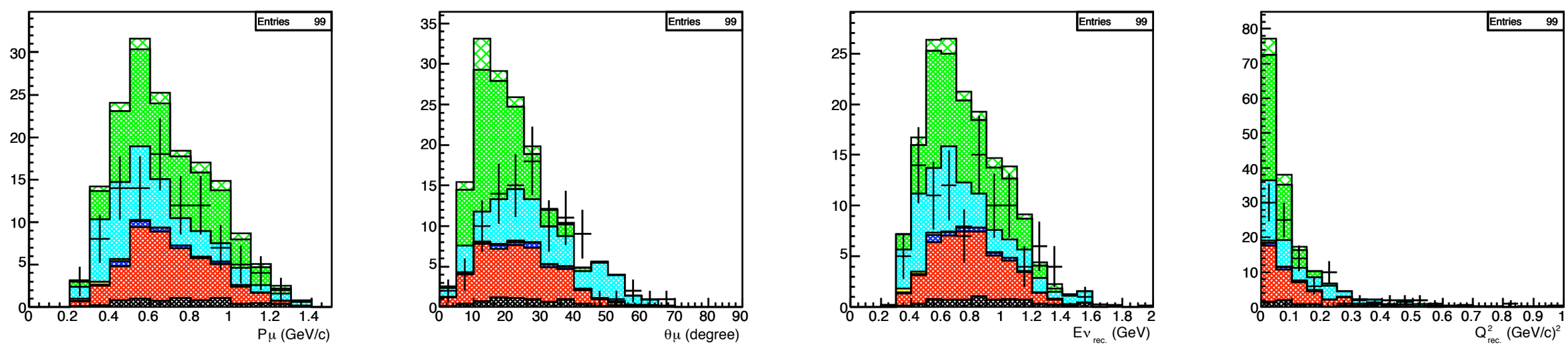
$\theta_\pi < 35$ deg

P_μ θ_μ E_ν^{rec} Q^2_{rec}



$\theta_\pi > 35$ deg

P_μ θ_μ E_ν^{rec} Q^2_{rec}



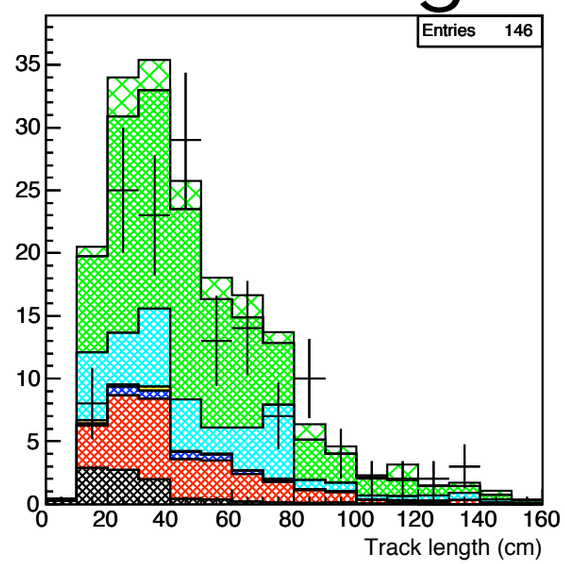
Where “data excess” come from?

2nd track distributions

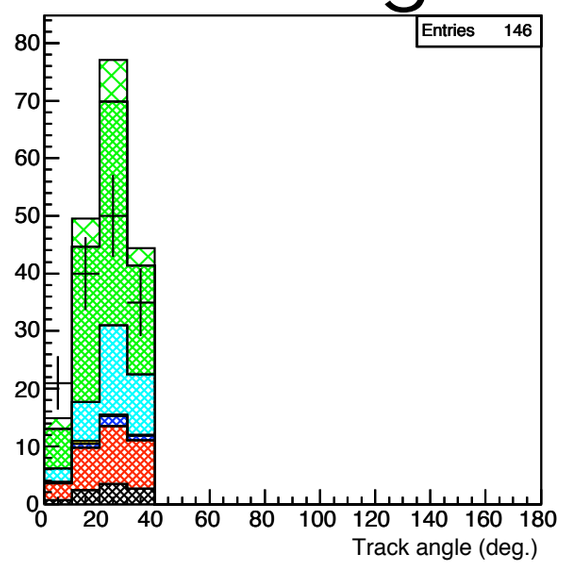
$\theta_\pi < 35$ deg

No Q^2 cuts

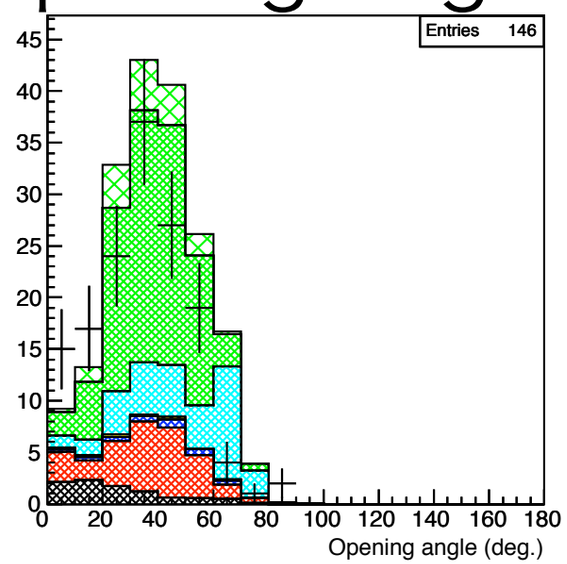
Track length



Track angle

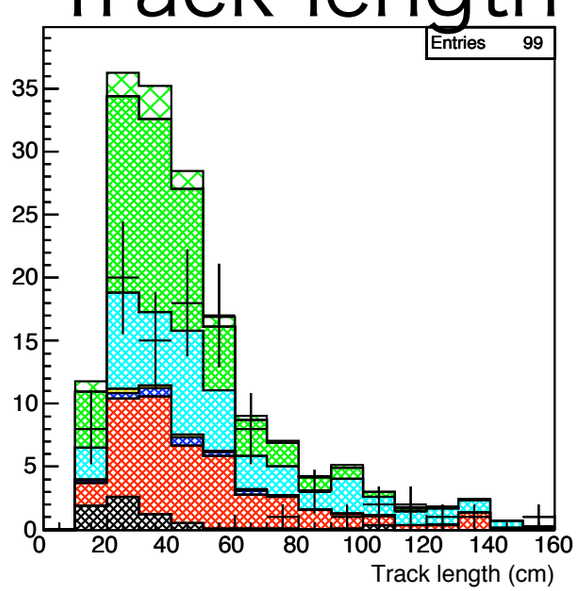


Opening angle

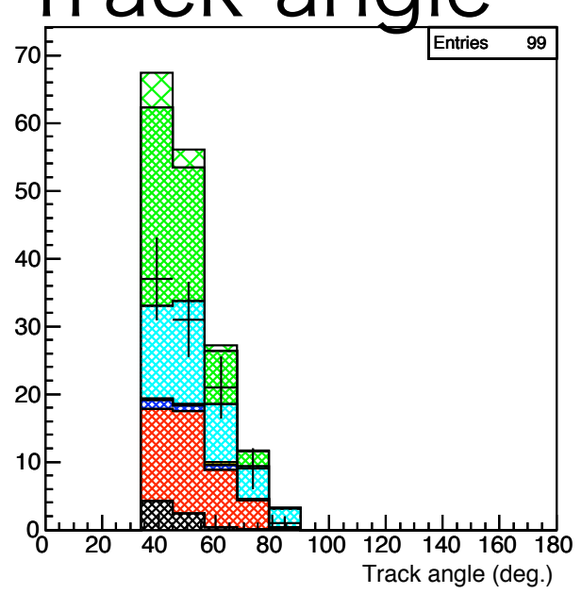
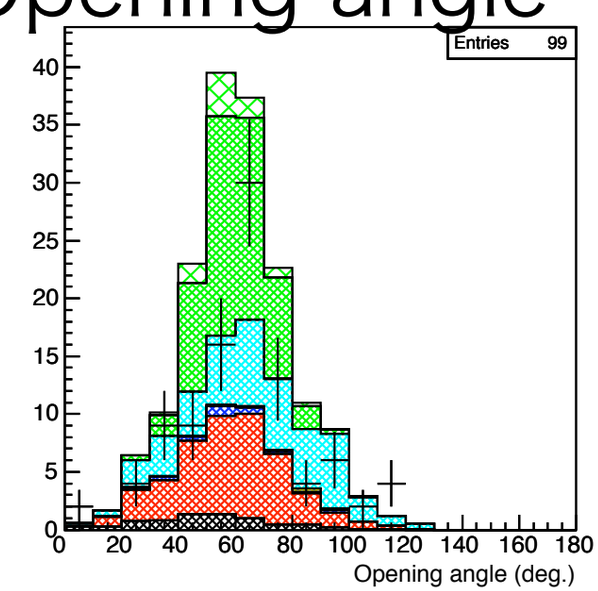


$\theta_\pi > 35$ deg

Track length



Track angle



Opening angle