# Recent Updates on fiTQun,
# a New Event Reconstruction Algorithm
# for Water Cherenkov Detectors

Shimpei Tobayama (UBC)
for Team fiTQun

Hyper-Kamiokande Meeting
January 15, 2013

# Introduction

- fiTQun: New Super-K event reconstruction algorithm
  - Can be applied to any Hyper-K detector configuration straightforwardly
- A maximum likelihood fitter
  - Using the charge and time information from the PMTs, fit particle track parameters by maximizing the likelihood function:

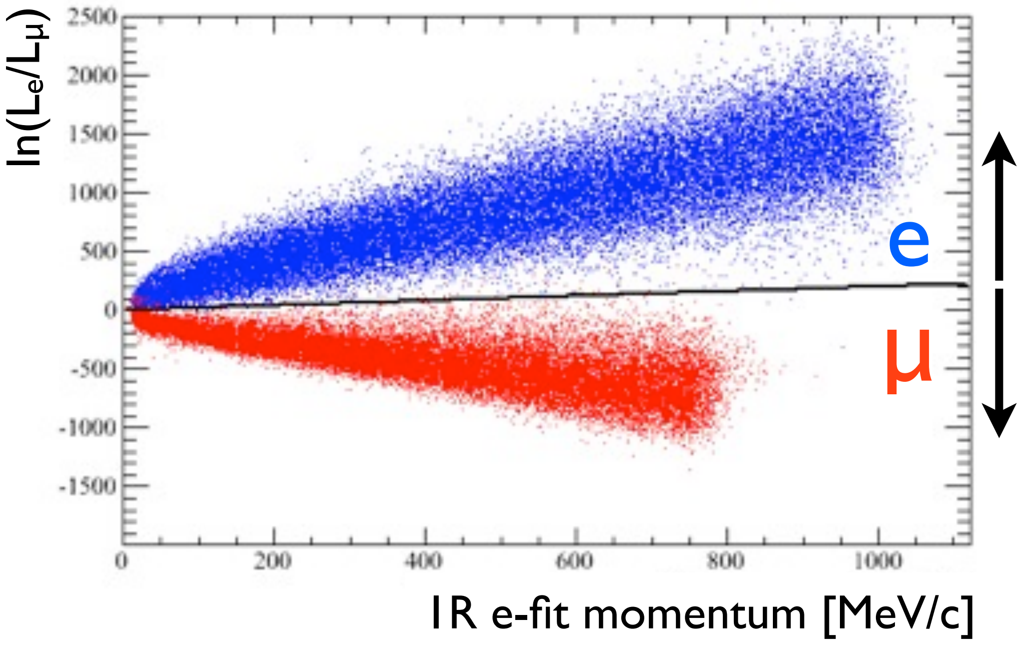
i-th PMT's charge, time

$$L(\mathbf{x}) = \prod_{i}^{\mathrm{unhit}} \underset{\substack{\uparrow \\ \text{Unhit probability}}}{P(i\mathrm{unhit}|\mathbf{x})} \prod_{i}^{\mathrm{hit}} \underset{\substack{\uparrow \\ \text{Hit probability}}}{P(i\mathrm{hit}|\mathbf{x})} \underset{\substack{\uparrow \\ \text{Charge likelihood}}}{f_q}(\overset{\downarrow}{q_i}|\mathbf{x}) \underset{\substack{\nwarrow \\ \text{Time likelihood}}}{f_t}(\overset{\downarrow}{t_i}|\mathbf{x})$$

  - All parameters (vertex, direction, momentum etc.) are fit simultaneously

# PID/Number of Rings

- Distinguish between different event topologies by making a cut on the best-fit likelihood ratio:
  - e.g. One-ring e/μ separation by cutting on the likelihood ratio of 1R-e and 1R-μ hypotheses



*Sample: particle gun e/μ p<1GeV/c

ID as electron

ID as muon

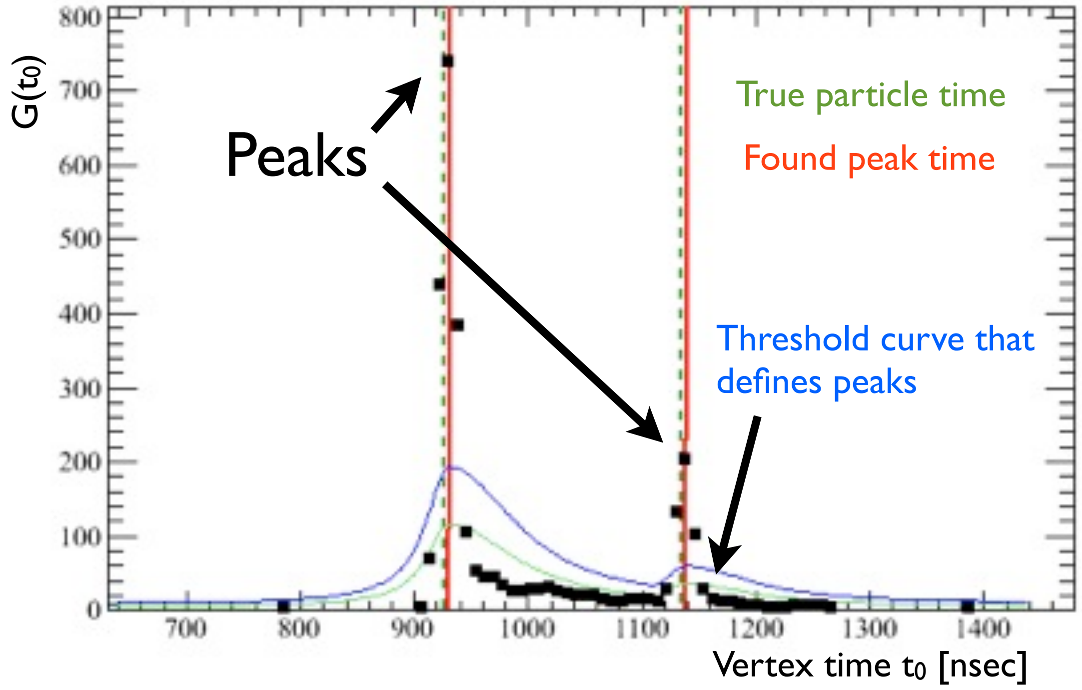
- Separation of e/$\pi^0$, μ/$\pi^+$, and number of ring determination are done in a similar manner

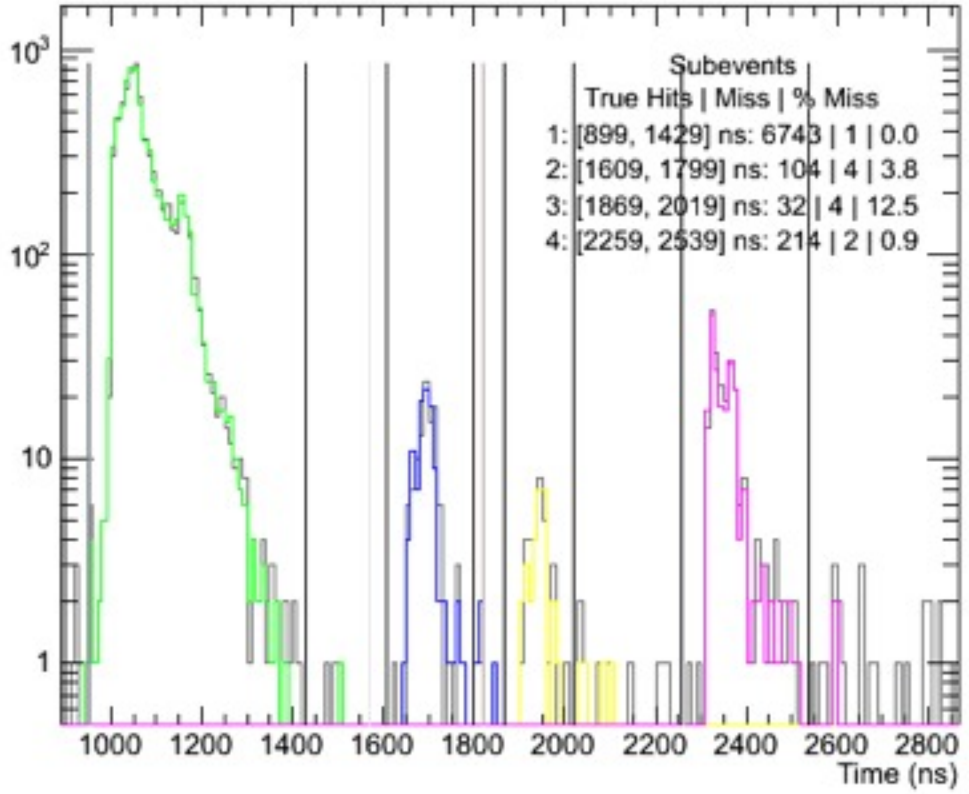
# Current features (New since Aug.)

- Subevent algorithm - Count and fit decay electrons
  - Peak finder, time clustering
  - In-gate decay charge masking & fitting
- One ring fit (e, μ, $\pi^+$)
  - Reduced fit failures by improving parameter seeding
- $\pi^0$ fit - Further seeding optimization
- Multi-ring fit & Ring counting
  - 2/3/4 ring fits with all possible combinations of e/μ/$\pi^+$ rings

# Peak Finder & Clustering

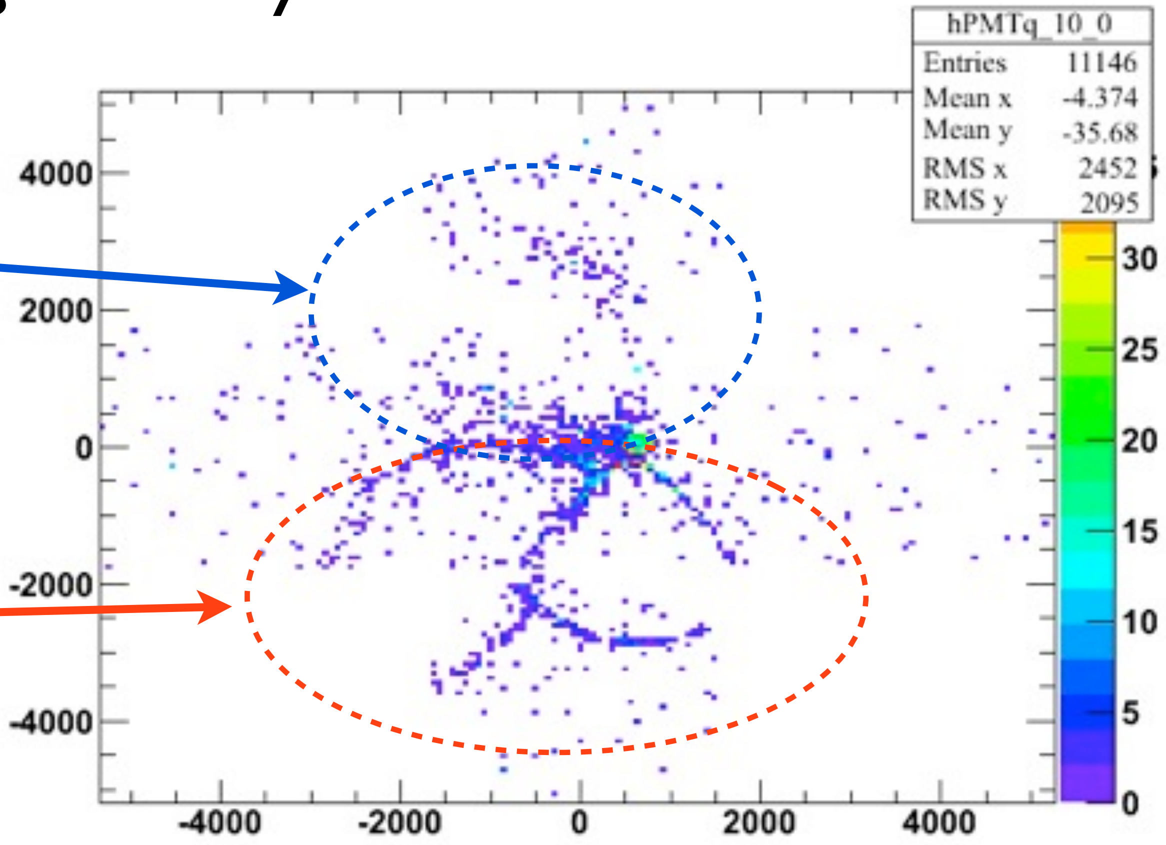
- Peak finder
  - Determine the number and time of subevents (primary particles, decay electrons) in an event
  - Use TOF-corrected hit time
- Time clustering (spliTChan)
  - Separate subevents into different time windows in raw hit time, so that they can be fitted independently





# In-gate Decays

- Some clusters have multiple subevents
  - e.g. when decay happens early (in-gate decays)
- Hits from multiple subevents are present in the same time window
  - Primary particle momentum is overestimated
    - Due to charge from in-gate decay electrons
- ~1/6 of single-μ events have in-gate decays



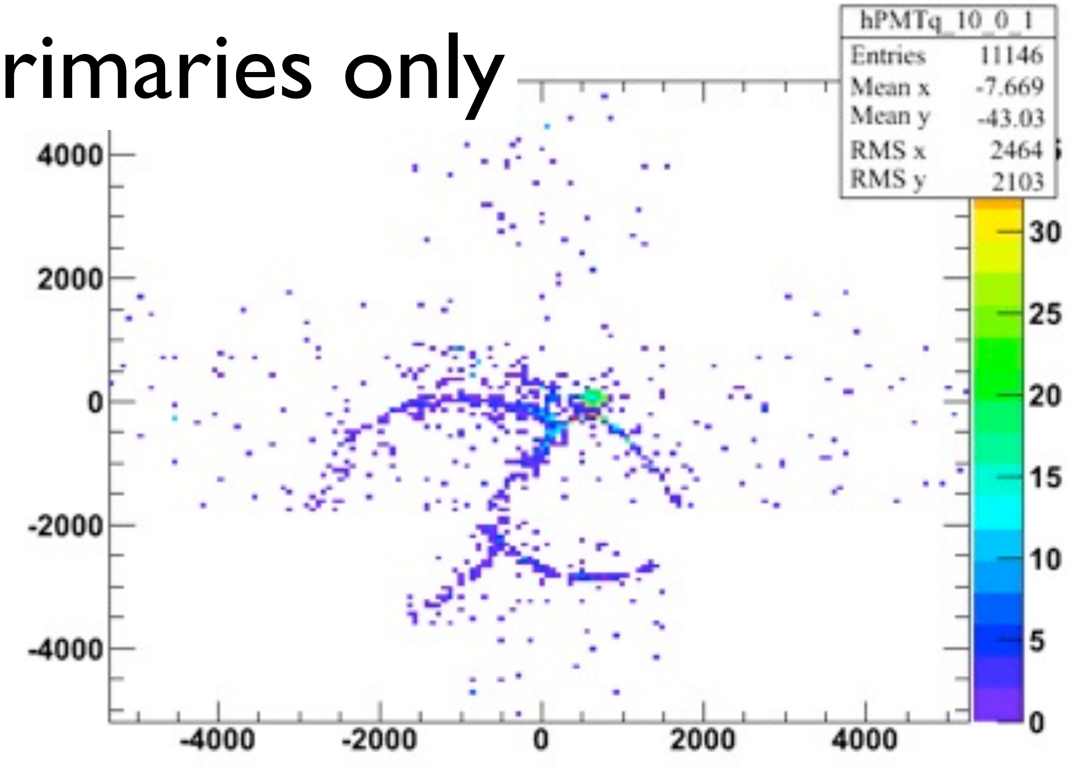
In-gate decay electron

Primary particles

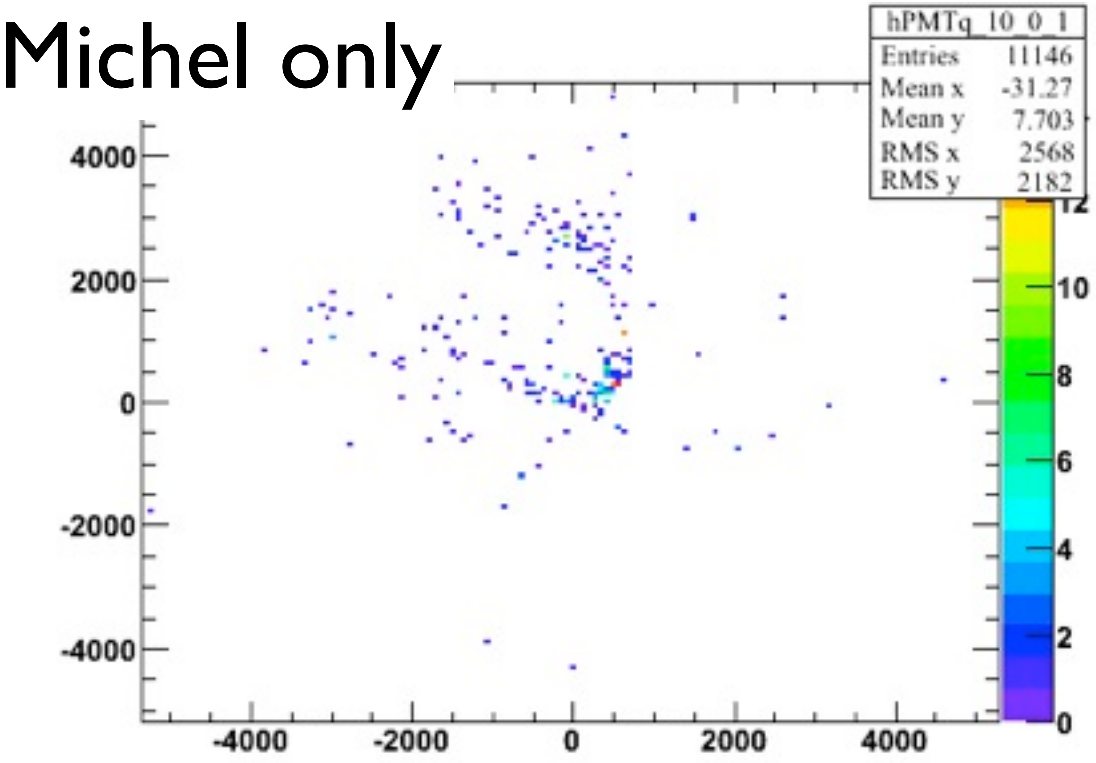
# Charge Masking & Fitting In-gates

- Fit each in-gate subevent found by the peak finder by masking out hits that are not caused by the subevent
  - Masking suppresses the momentum overestimation
- Vertex, direction and momentum is reconstructed for ALL decay electrons that are found by the peak finder

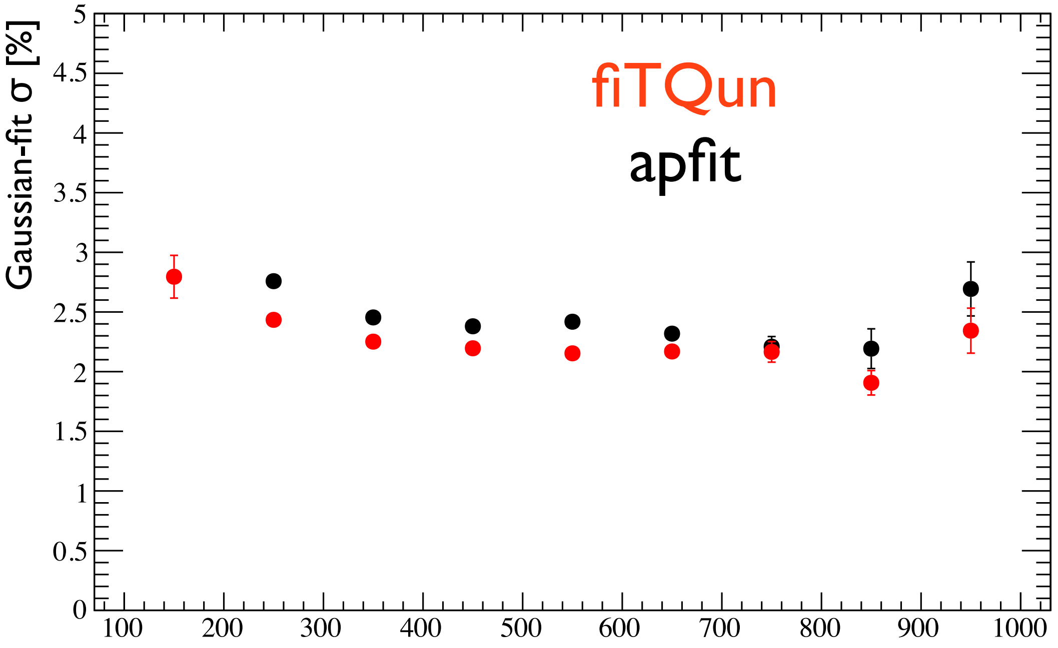
Primaries only



Michel only



# Single Muon Fit Resolution

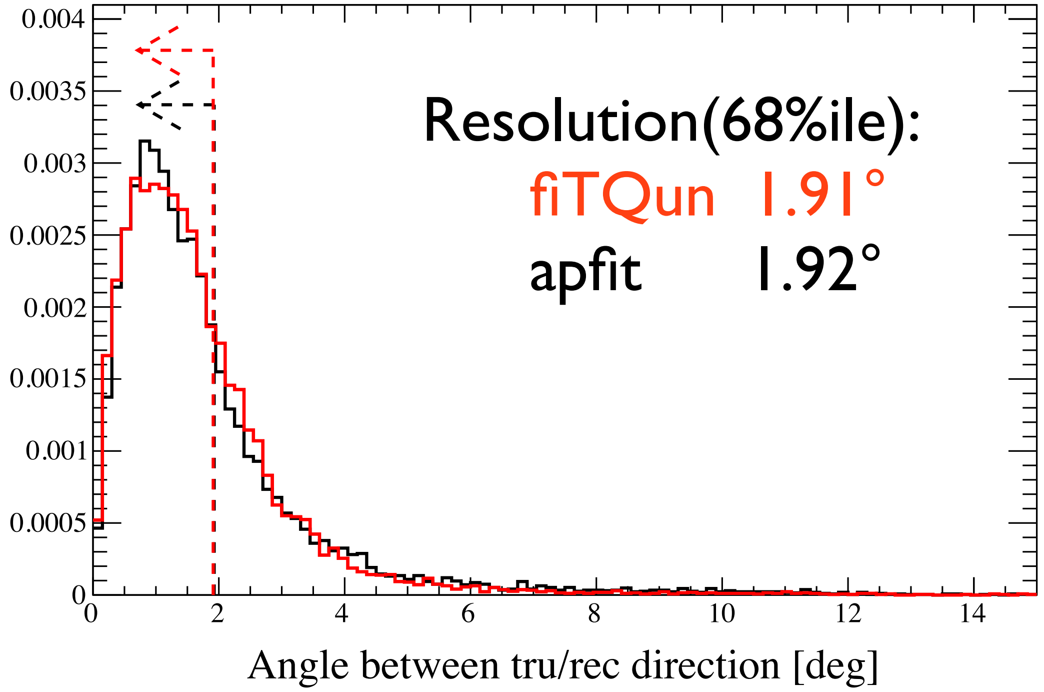


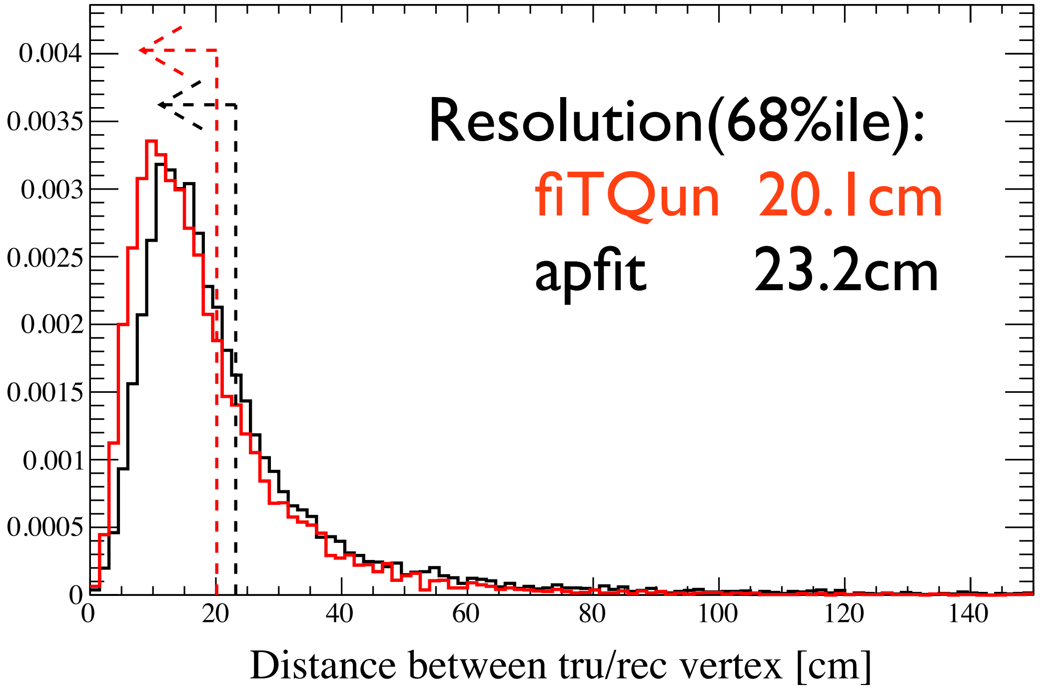
Momentum resolution

*Sample information:
T2K $\nu_\mu$ CCQE, fully contained,
true fiducial volume, one-ring events

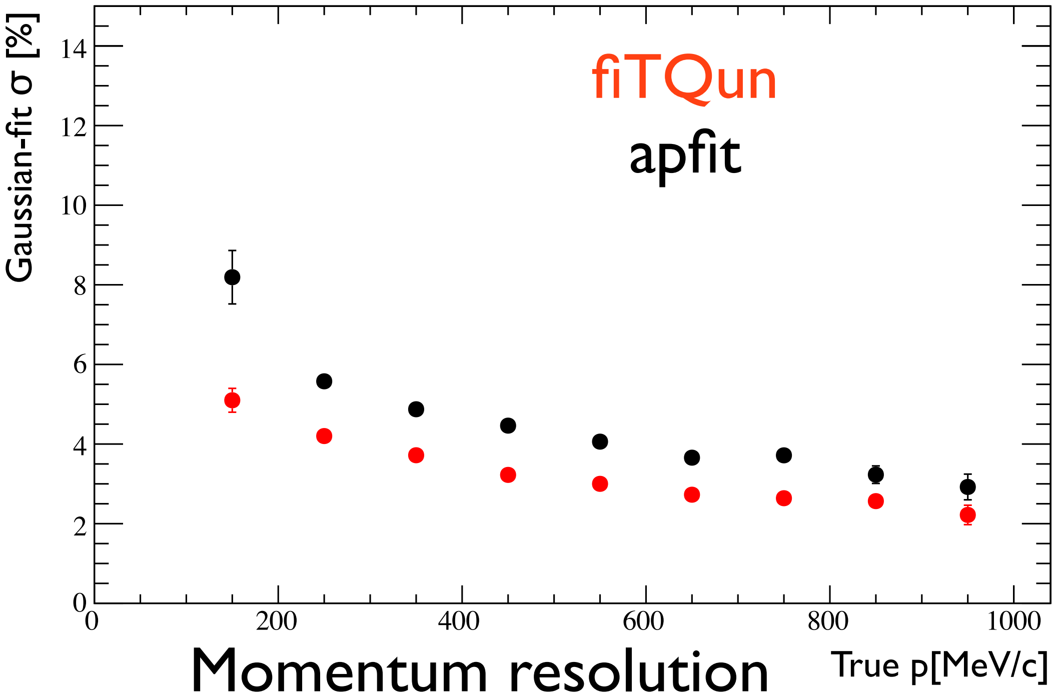
## Better momentum and vertex resolution compared to apfit

**Nuclear de-excitation γ's, decay electrons are present in this sample





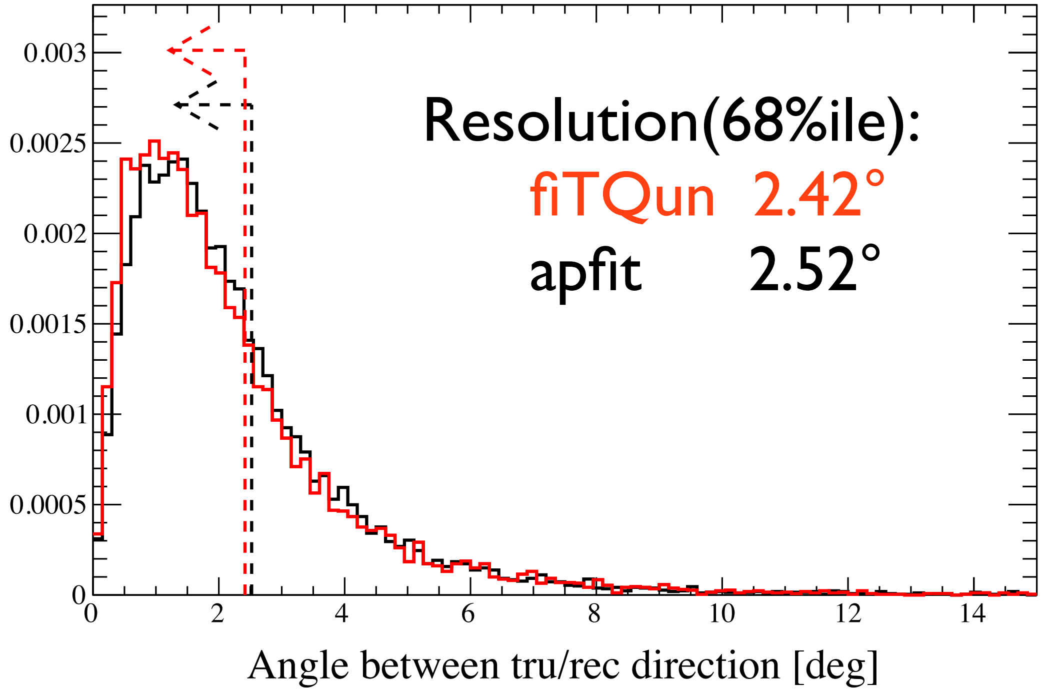
# Single Electron Fit Resolution



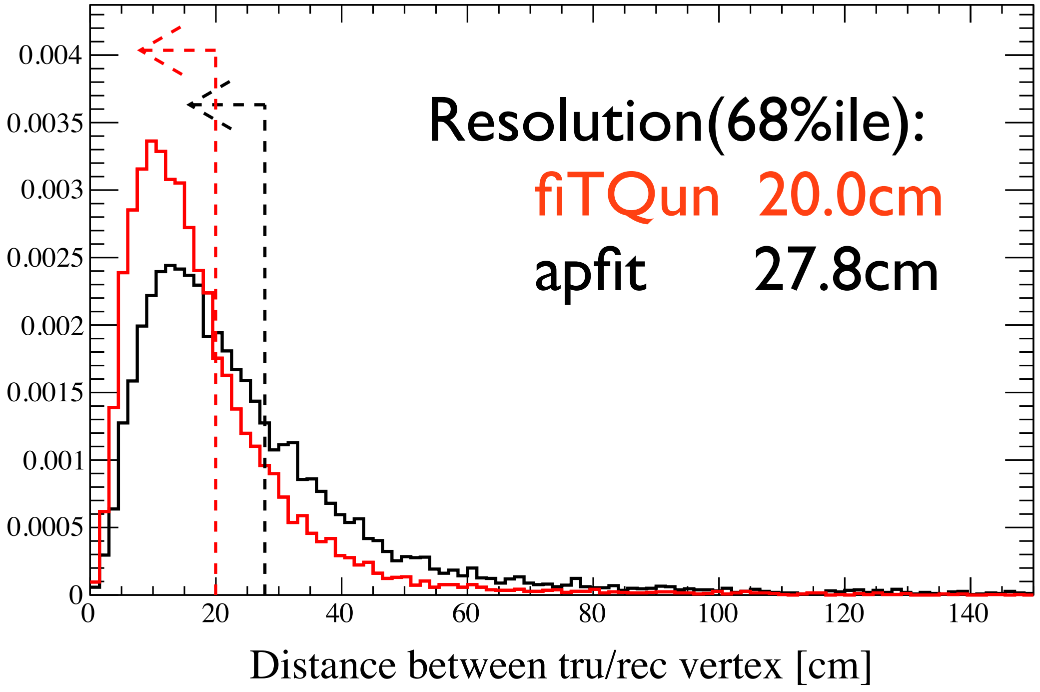
Momentum resolution

*Sample information:
T2K $\nu_e$ CCQE, fully contained,
true fiducial volume, one-ring events

More significant resolution improvement for electrons

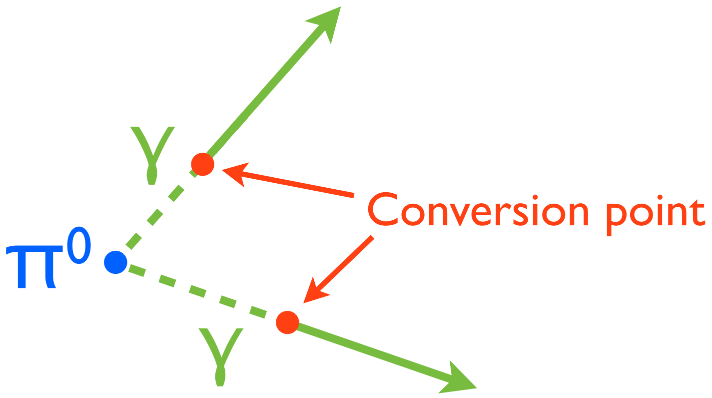


Resolution(68%ile):
fiTQun 2.42°
apfit 2.52°

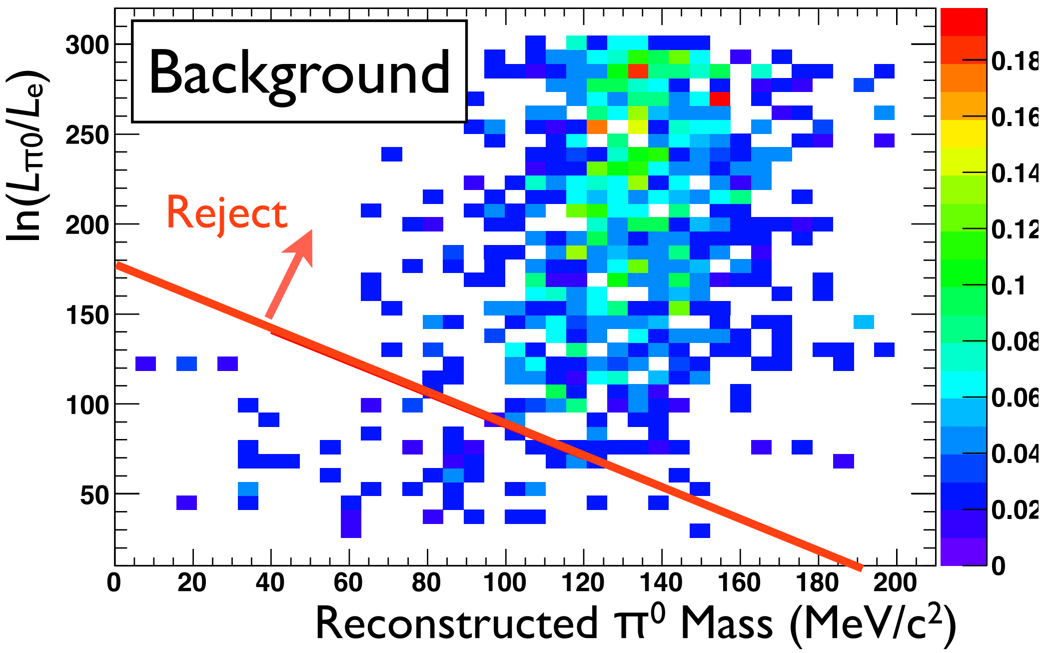


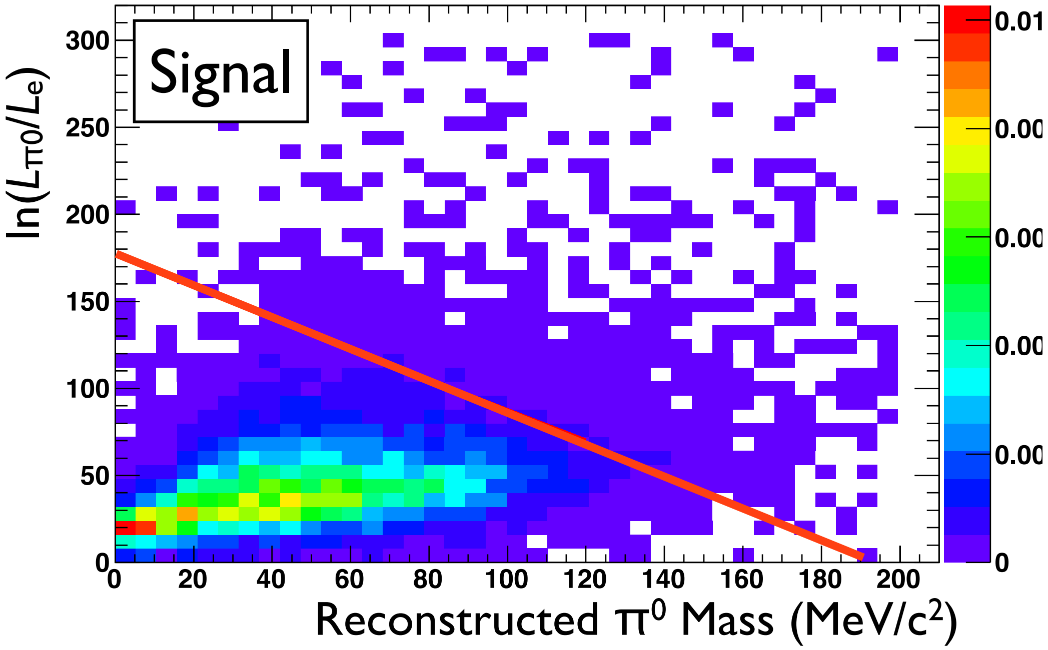
Resolution(68%ile):
fiTQun 20.0cm
apfit 27.8cm

# $\pi^0$ Fitter



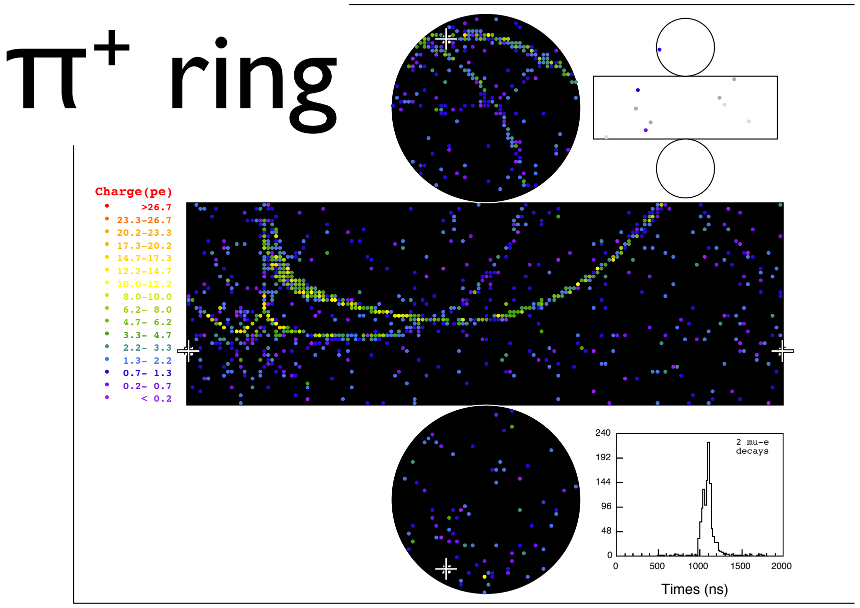
- Dedicated $\pi^0$ fitter
  - Fit the two decay $\gamma$ rings, considering $\gamma$ conversion length
- Able to find low energy $\gamma$ ring well
- Provides significant improvement of $\pi^0$ background rejection for T2K $\nu_e$ appearance
  - Make a cut using likelihood ratio of $\pi^0$ and 1-ring electron hypothesis
  - $\pi^0$ background reduced to <1/3 compared to standard $\nu_e$ selection

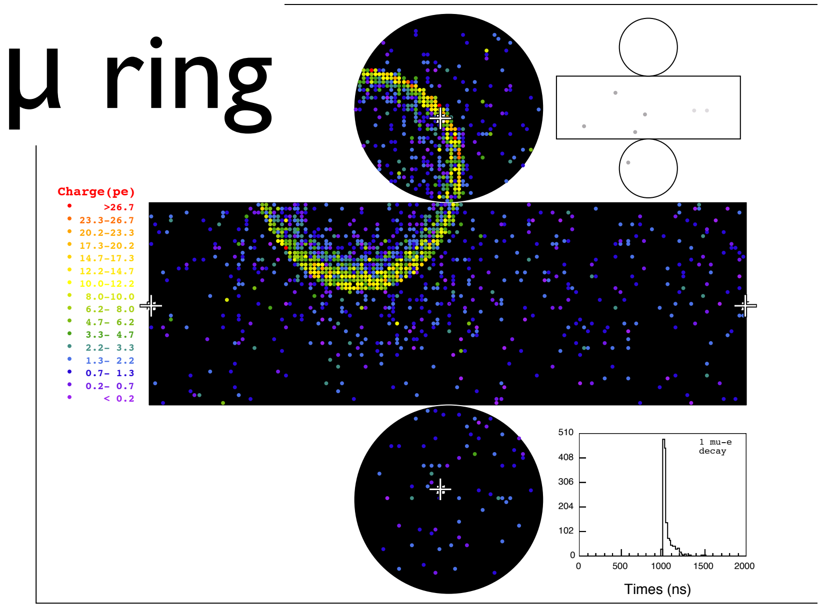


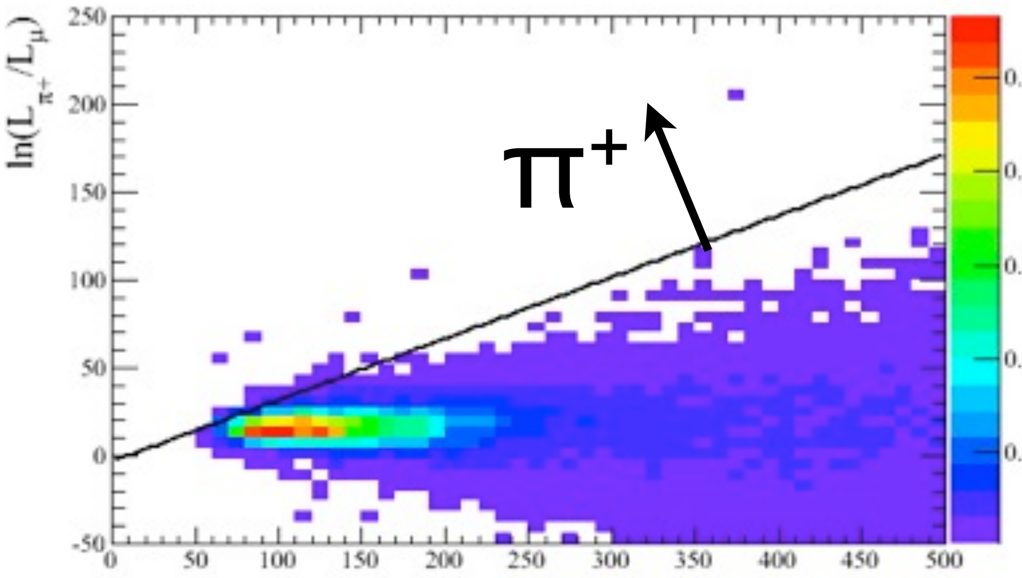


# $\pi^+$ Fitter

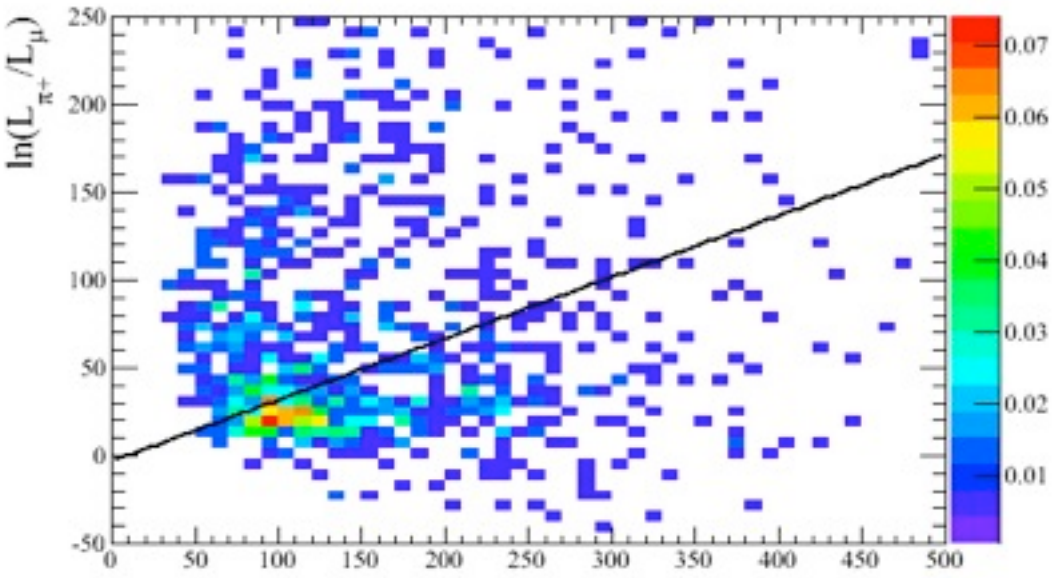
- $\pi^+$ often hadronically interacts with nuclei
    - Produces sharp, hollow rings
- Fit the $\pi^+$ rings, with an additional fit parameter which characterizes the thickness of the ring
- $\mu/\pi^+$ separation seen in the likelihood ratio to one-ring $\mu$ fit


$\pi^+$ ring


$\mu$ ring



T2K $\nu_\mu$ CCQE



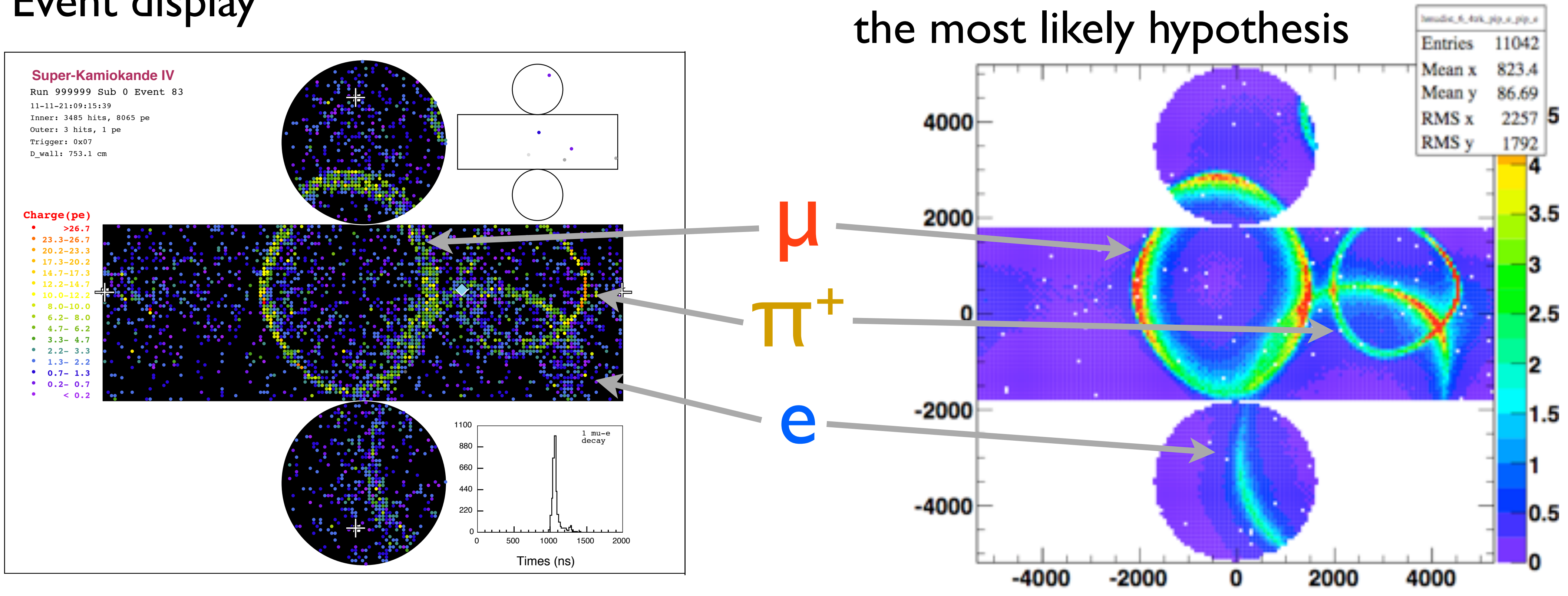
T2K $\nu_\mu$ NC w/ visible $\pi^+$

# Multi-Ring Fitter

- Construct multi-ring hypotheses by combining 1-ring framework
- Multi-ring fitter - fit up to four rings, using e & $\pi^+$ rings
    - $\pi^+$ hypothesis covers μ-ring as well, since μ produces similar charge pattern as $\pi^+$, with a ring filled inside
- Accept the hypothesis with the best likelihood to PID each ring

Event display

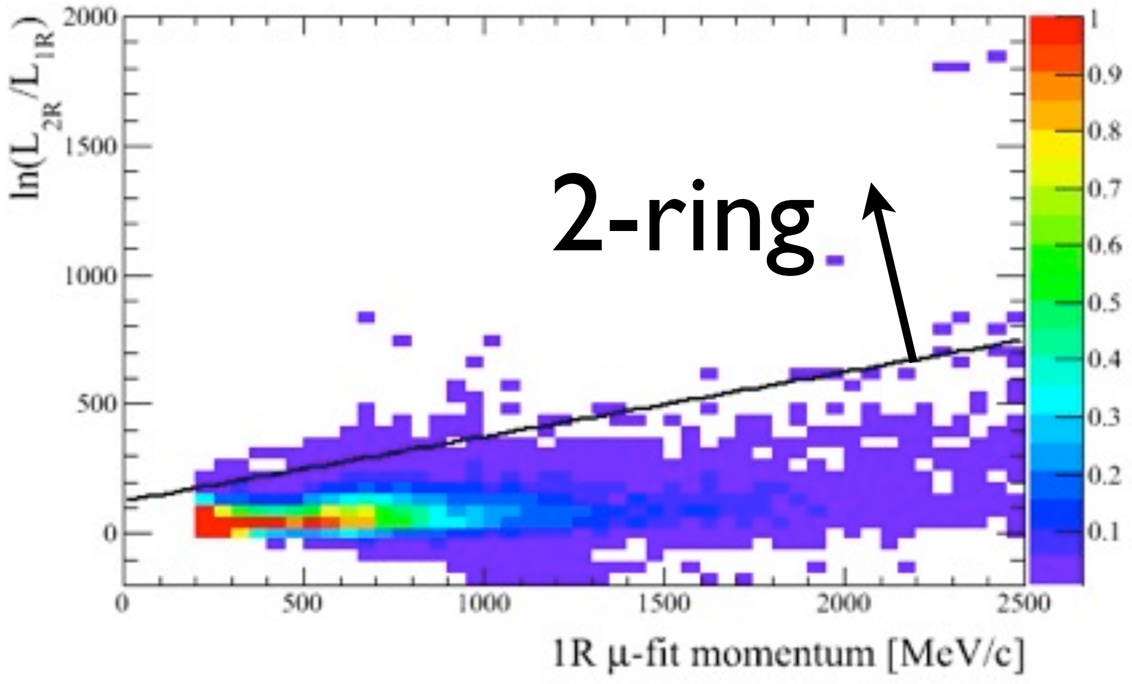
fiTQun predicted charge of the most likely hypothesis



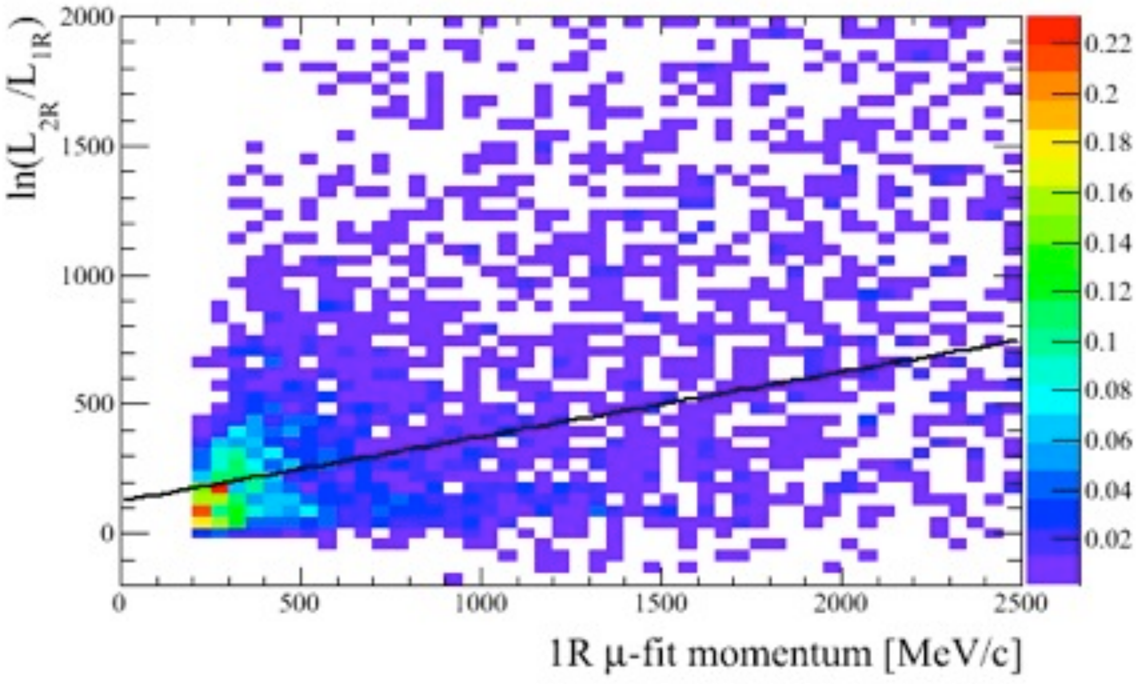
# Ring counting

- To determine the number of rings, make a cut on the likelihood ratio between best-fit n-ring and (n+1)-ring hypotheses
  - e.g. One-ring cut is done by cutting on the likelihood ratio of 1-ring and 2-ring hypotheses

T2K $\nu_\mu$-CCQE w/o visible $\pi^+$/p



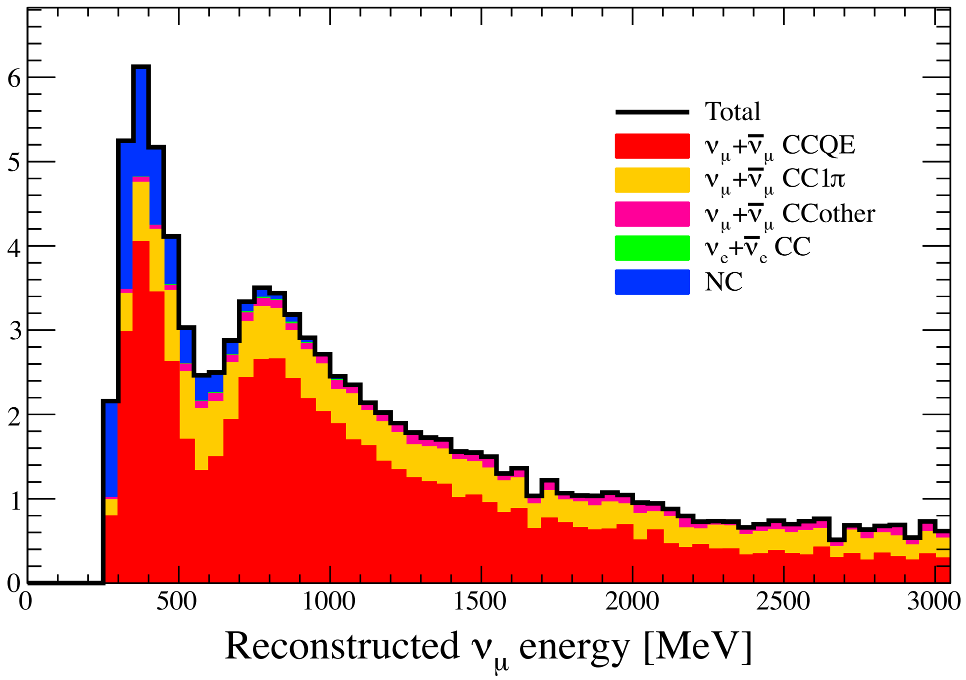
T2K $\nu_\mu$-other w/ 2 or more visible particles



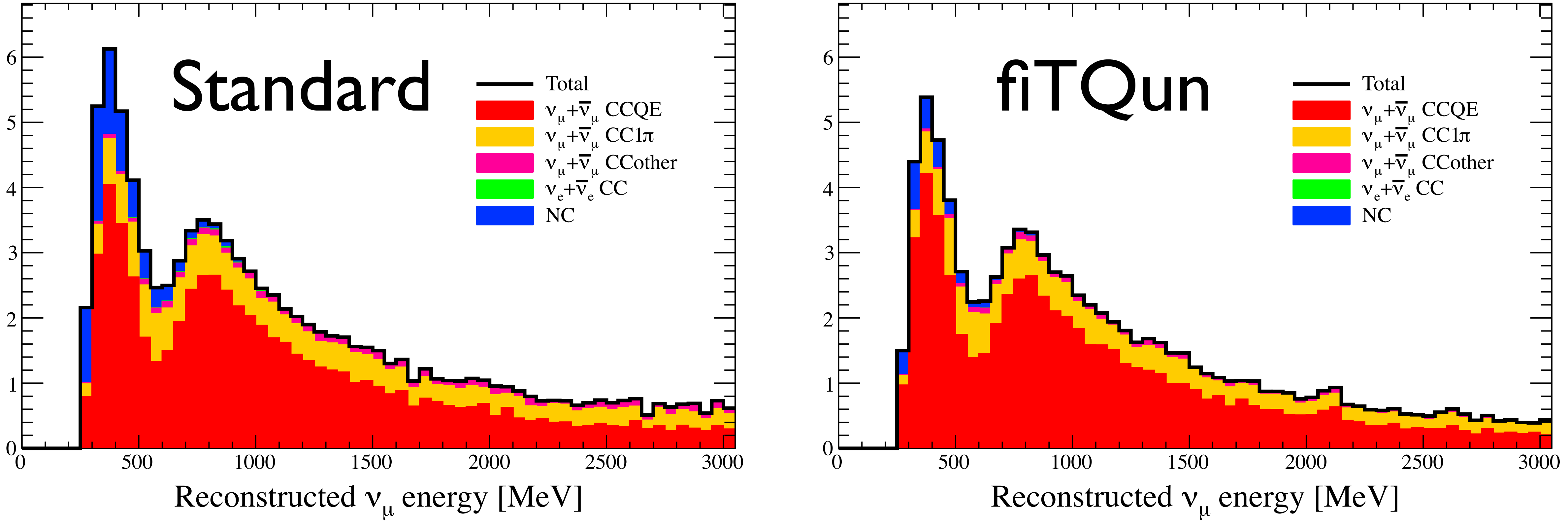
# Improving T2K $\nu_\mu$ Disappearance

- Main backgrounds are $\nu_\mu$ CC1$\pi$ and NC
- Around 600MeV(oscillation dip), about half of the entries are backgrounds, filling up the dip
- One of the largest systematics come from NC selection efficiency
  - >100% error assigned to NC events in published analyses
- Reducing NC backgrounds is crucial for a precise measurement
  - Most background are due to $\pi^+$ ring mis-identified as muon
- Use fiTQun $\pi^+$ fitter to reduce $\pi^+$ backgrounds

T2K event rate after standard $\nu_\mu$ selection cuts



# Standard vs. fiTQun $\nu_\mu$ selection



*T2K event rate after $\nu_\mu$ selection cuts @$6\times10^{20}$POT

Reduction rate to
standard selection:

| | |
|---|---|
| $\nu_\mu+\bar{\nu}_\mu$ CCQE | 4.8% |
| $\nu_\mu+\bar{\nu}_\mu$ CC1$\pi$ | 21.5% |
| $\nu_\mu+\bar{\nu}_\mu$ CCoth. | 53.7% |
| $\nu_e+\bar{\nu}_e$ CC | 92.1% |
| NC | 61.2% |

- Significant reduction of NC background by $\pi^+$ cut
- Large CC non-QE reduction by fiTQun 1-ring cut
- Signal efficiency loss is mostly at >3GeV
  - fiTQun efficiency is higher at <1GeV
- Signal purity 60.6%→69.3%

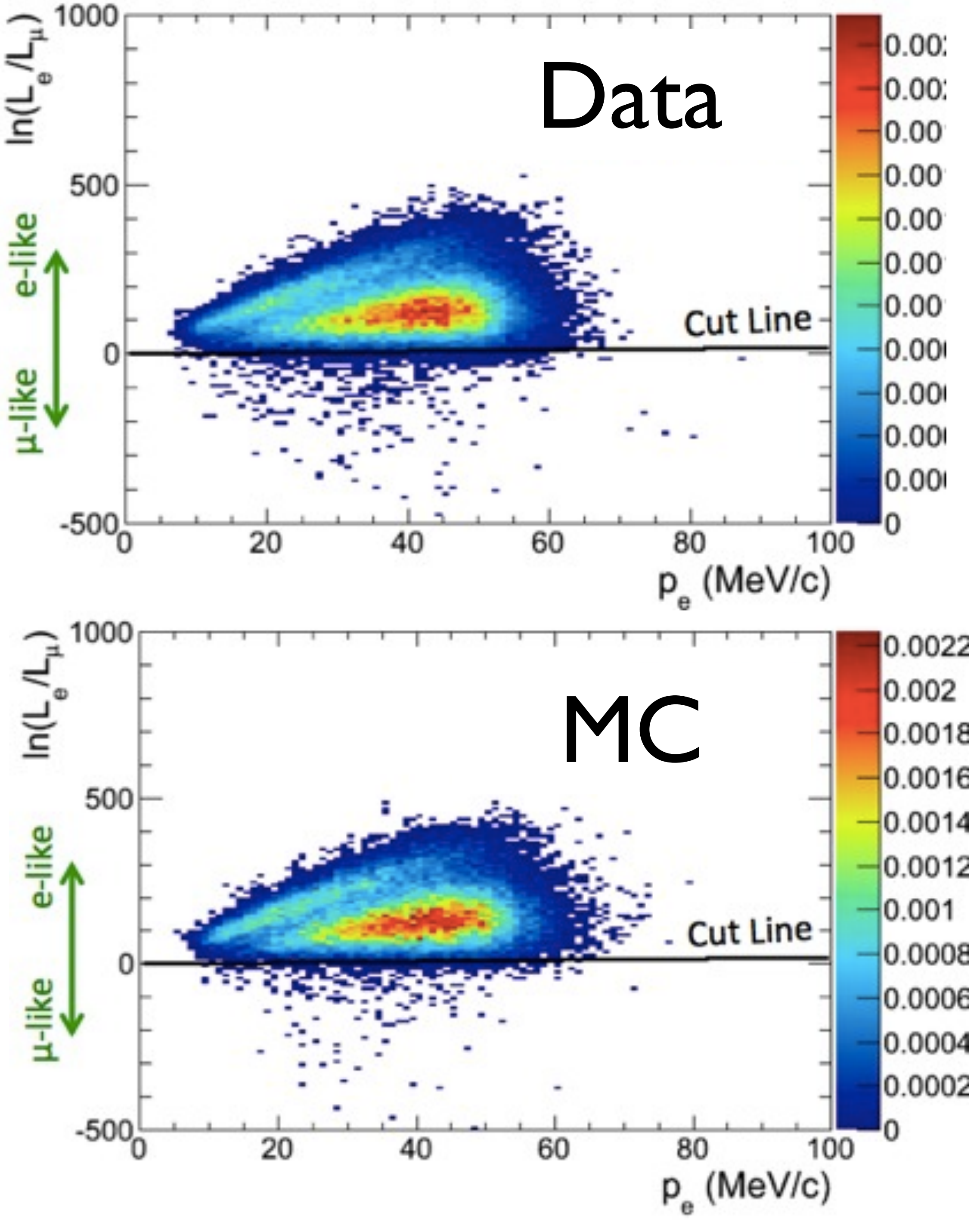
# Fitting complex event topologies

- The multi-ring fitter is applicable to event topologies that are relevant to proton decay and atmospheric ν
- e.g. for proton decay:
    - e+e+e fit for $e^+ + \pi^0$, e+e+$\pi^+$ fit for $\pi^0 + \pi^+$
- fiTQun multi-ring fitter is sensitive to dim rings in the presence of bright rings
    - Improve signal efficiency from current analyses
- Background reduction by new particle hypotheses, better particle identification and improved resolution
- One can also easily construct arbitrary analysis-specific event hypotheses - multi-ring fitter result can be used as a seed
    - Imposing kinematic constraints potentially improves power

# Validation Using SK Data

- Data/MC agreement has been studied using SK control sample:
  - Stopping cosmic-ray muons & decay electrons
  - Atmospheric neutrino
  - Hybrid $\pi^0$
- Reasonable agreement seen in various distributions
  - Currently studying the sources of discrepancies
    - Simulation of light reflections, nuclear de-excitation γ etc.

Decay-e PID likelihood



# Adapting fiTQun for Hyper-K

- Interfacing fiTQun with WCSim(Blair Jamieson)
    - First check fitter response with SK geometry
- The modularized design of fiTQun allows relatively easy adaptation to Hyper-K
- Other than the scattered light calculation, fiTQun runs properly on any detector geometry
- Start by approximating scattered light using the existing machinery for SK(assume cylindrical tank)
- As tank geometry becomes ready in WCsim, generate new scattering table which allows precise calculation of scattered light in HK

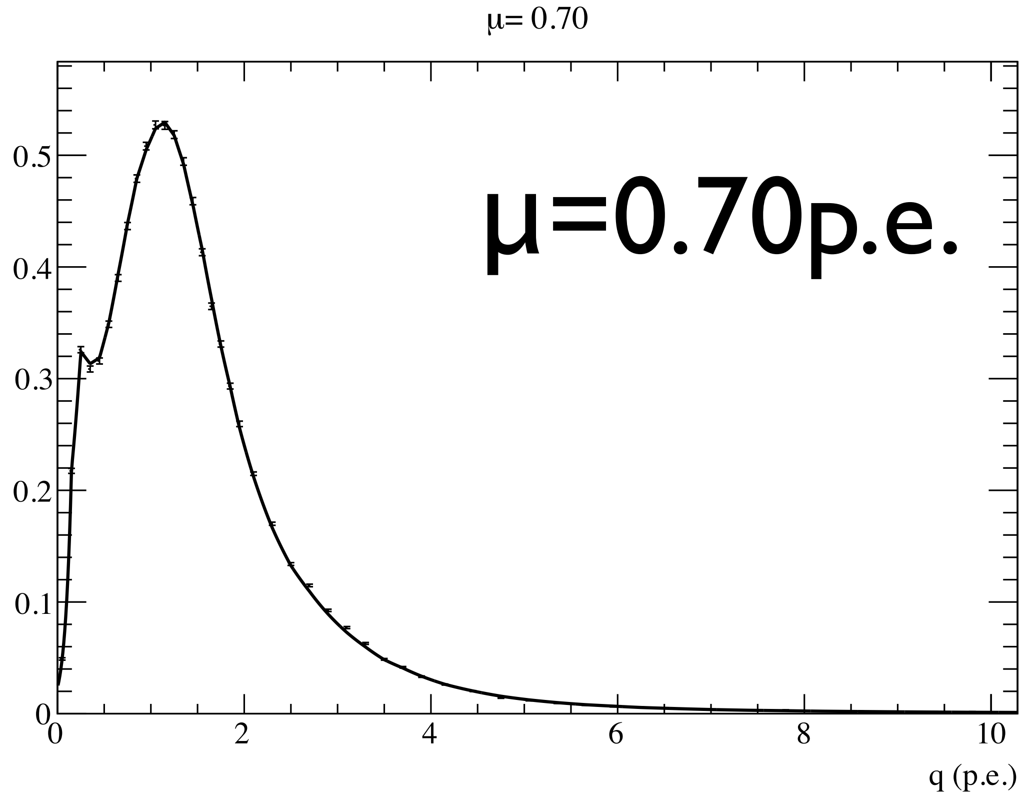
# Summary

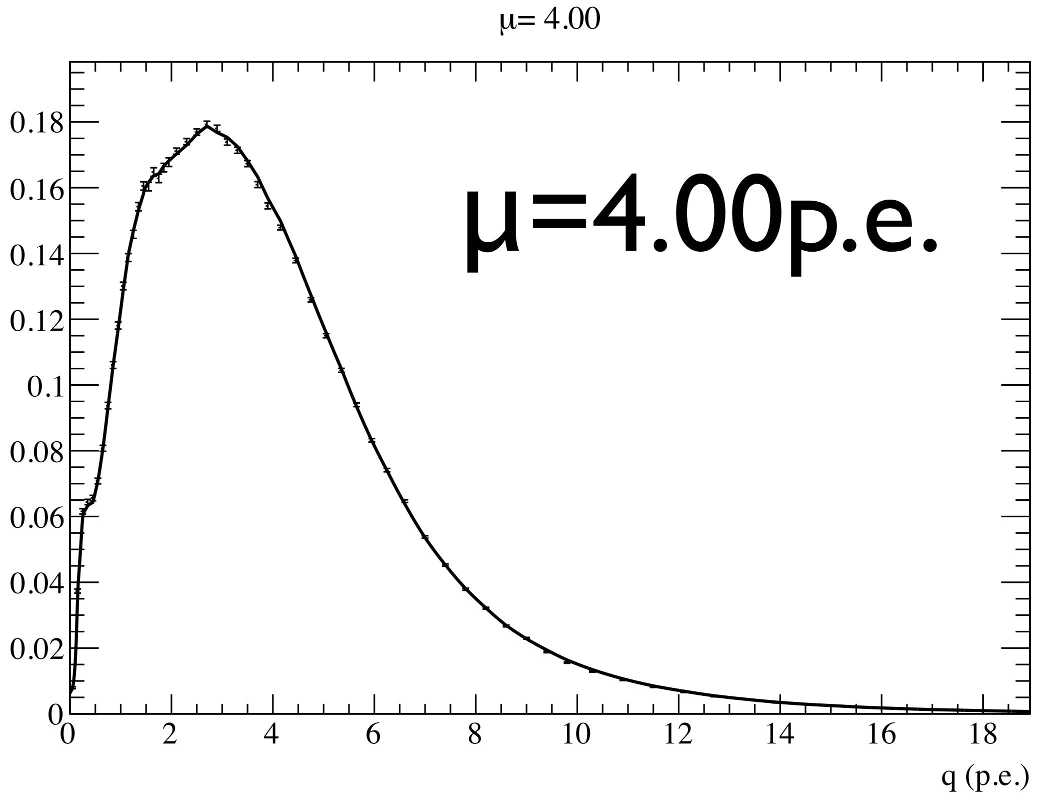
- fiTQun demonstrates improved particle identification performance and resolutions compared to the existing SK reconstruction framework
    - New particle hypothesis such as $\pi^+$
- Significant background reduction is expected in various high-energy physics studies at SK/HK
- Functions that are essential for T2K, atmospheric ν and proton decay analyses are now all available
- Validation using SK control sample is ongoing
- Started modifying the code to support Hyper-K

# Backup

# Charge Likelihood

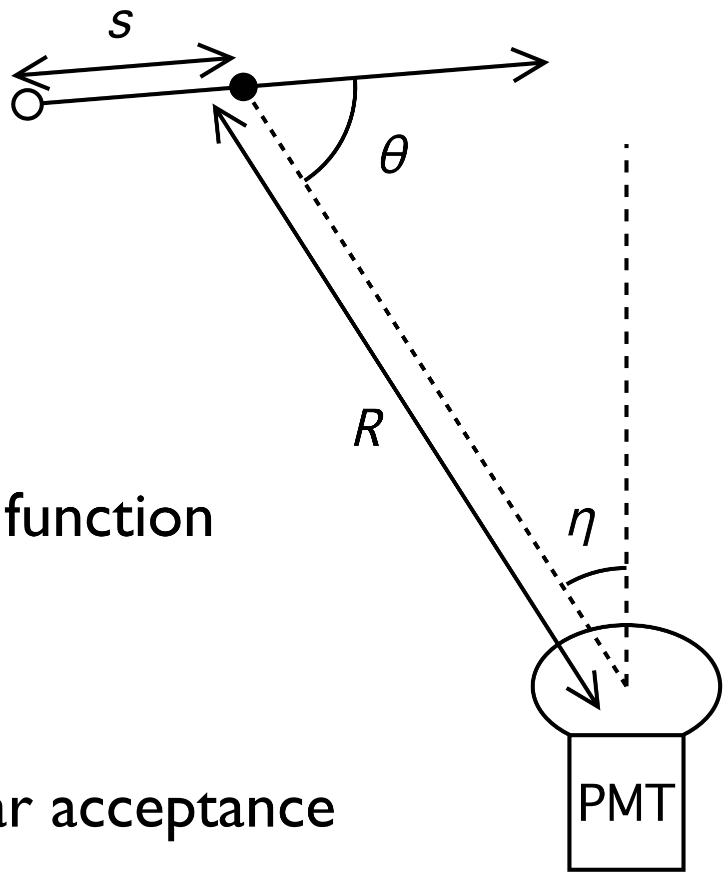
- Given the mean # of p.e.'s liberated at i-th PMT...
  - Hit/unhit prob. → Poisson prob.+corrections
  - Charge likelihood: $f_q(q|\mu)$
    - Probability of observing charge q given mean μ





# Predicted Charge μ

- Expected number of photoelectrons liberated at each PMT, given track parameters **x**
  - $P_{\rm hit}, f_q, f_t:$ functions of μ
- For direct light, predicted charge is:



Cherenkov emission profile　　Light transmission function

$$\mu^{\rm dir} = \Phi(p)\int ds\, g(p,s,\cos\theta)\Omega(R)T(R)\epsilon(\eta)$$

Light yield　　Solid angle subtended by PMT　　PMT angular acceptance

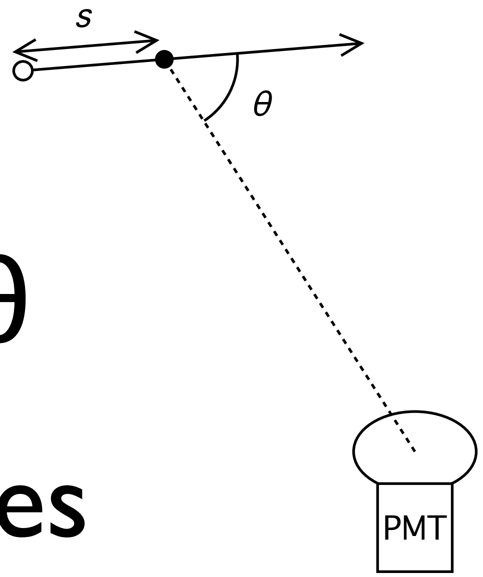
*s*: Distance particle traveled along the track

**R*,θ,η are functions of s

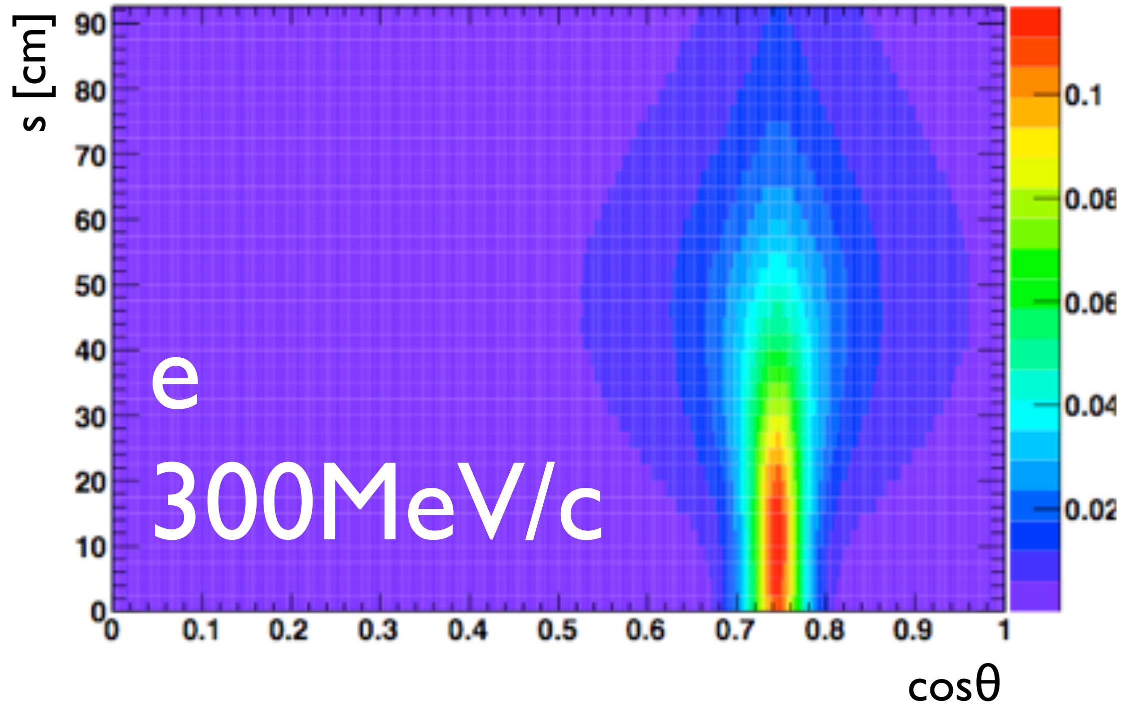
- Scattered/reflected light is also treated separately

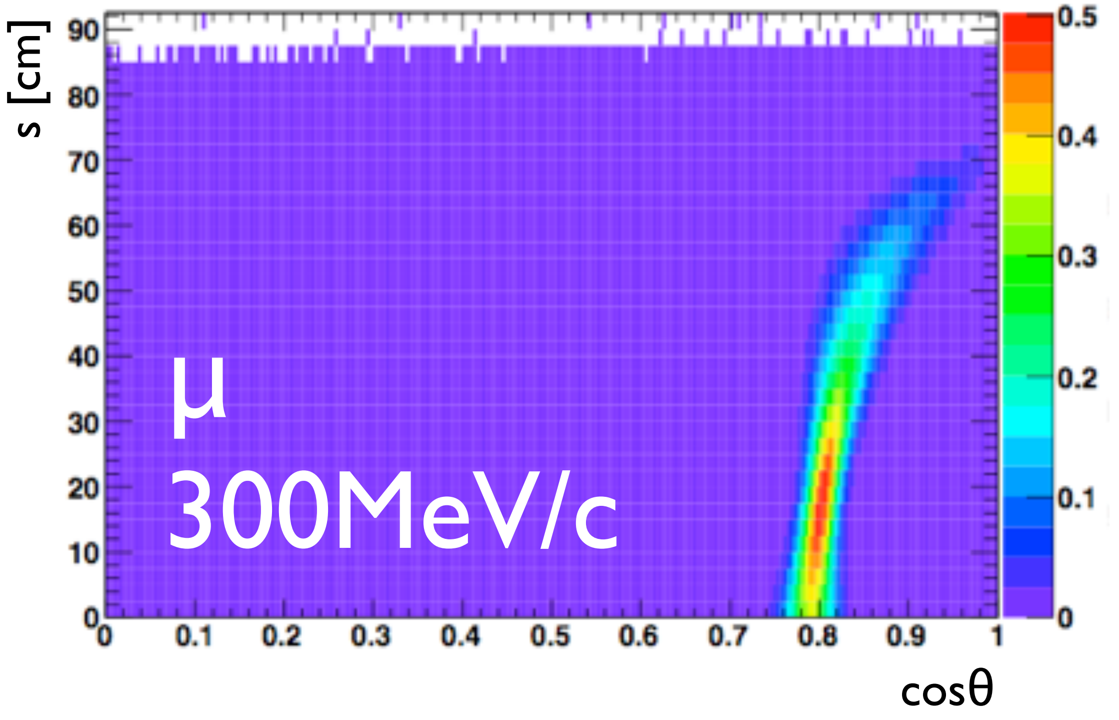
# Cherenkov Emission Profile

$$\mu^{\text{dir}} = \Phi(p) \int ds\, g(p, s, \cos\theta) \Omega(R) T(R) \epsilon(\eta)$$



- Fraction of photons emitted in direction θ
- Profiles are different between particle types
  - Creates different charge patterns



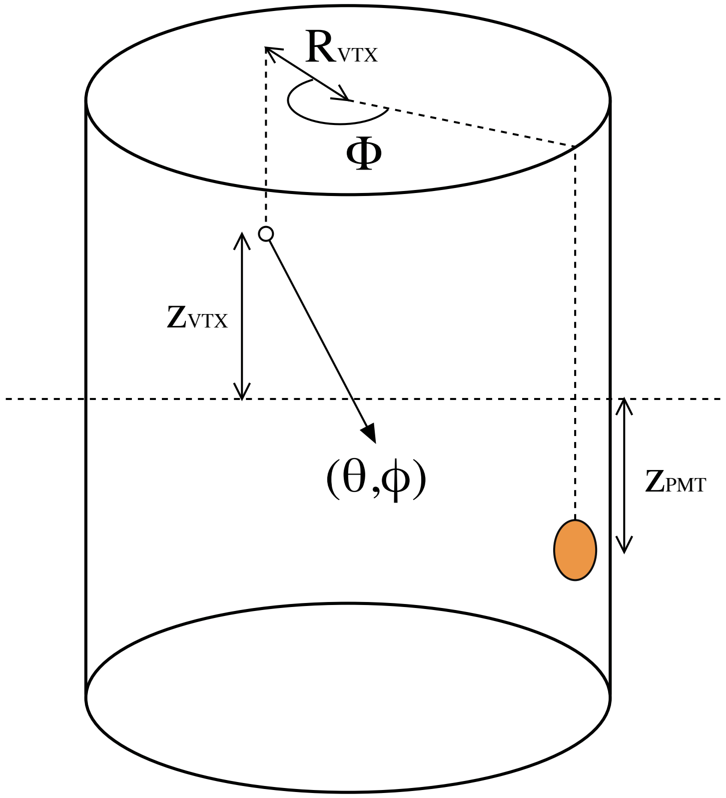


# Scattered Light

$$\mu^{\text{sct}} = \Phi(p_0)\int ds\rho(s)\Omega(s)T(s)\epsilon(s)A(s)$$

Scattering table:

$$A(s) = A(z_{\text{PMT}}, z_{\text{vtx}}, r_{vtx}, \Phi, \Theta, \phi) = \frac{d\mu^{\text{sct}}}{d\mu^{\text{dir}}}$$

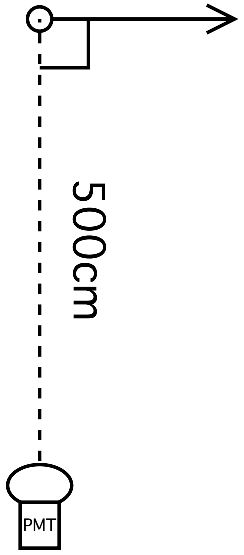


- Ratio of scattered light to direct light
- Using SKDETSIM, shoot 3MeV/c electrons(point-like Cherenkov source) randomly, and fill a 6-D histogram
  - Multiple scattering was turned off
- Linearly interpolate at run time

# Parabolic approximation

Integral is CPU-intensive

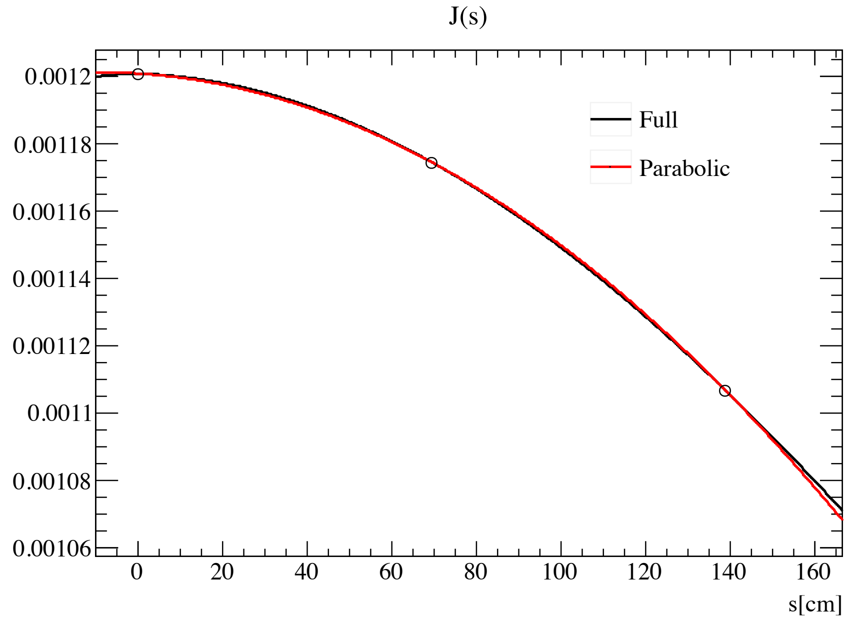
$$\mu^{\mathrm{dir}} = \Phi(p) \int ds g(s) \Omega(s) T(s) \epsilon(s)$$



Acceptance factors $J(s) = \Omega(s) T(s) \epsilon(s)$ vary slowly as a function of s

Approximate it by parabola, perform the integral in advance

$$\begin{aligned} \mu^{\mathrm{dir}} &= \Phi(p) \int ds g(s) (j_0 + j_1 s + j_2 s^2) \\ &= \Phi(p) (I_0 j_0 + I_1 j_1 + I_2 j_2) \end{aligned}$$

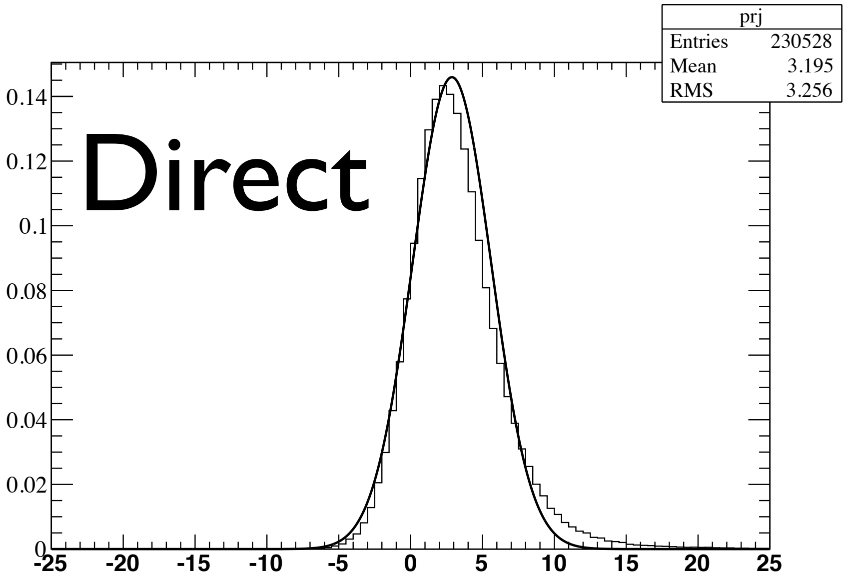


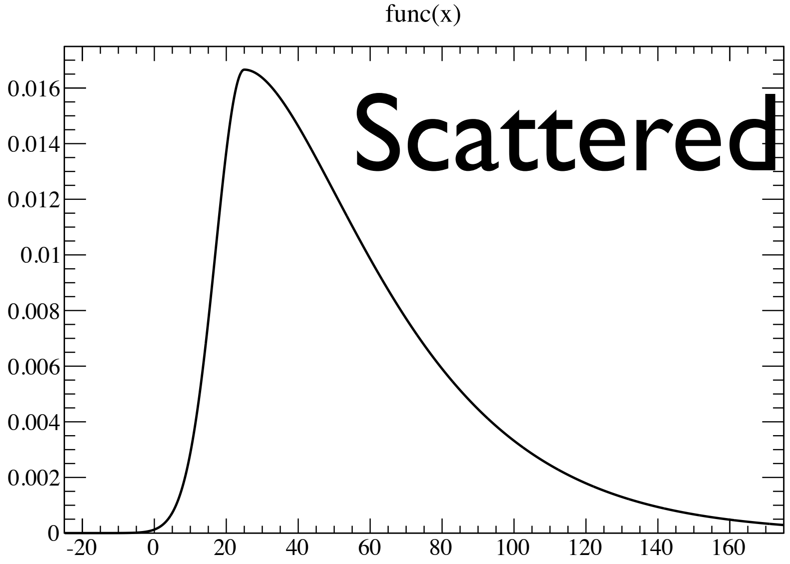
Determine $j_n$, read off the integral values $I_n$ from table

Similar thing is done for scattered light

# Time Likelihood

- Make primitive time likelihood functions separately for direct and scattered light





- Based on the relative strength of direct/scattered light, time PDF is constructed on the fly:

$$f_t(t_c) = w \cdot f_t^{\mathrm{dir}}(t_c) + (1-w) \cdot f_t^{\mathrm{sct}}(t_c)$$

$$w = \frac{1 - e^{-\mu_{\mathrm{dir}}}}{1 - e^{-\mu_{\mathrm{dir}}} e^{-\mu_{\mathrm{sct}}}}$$

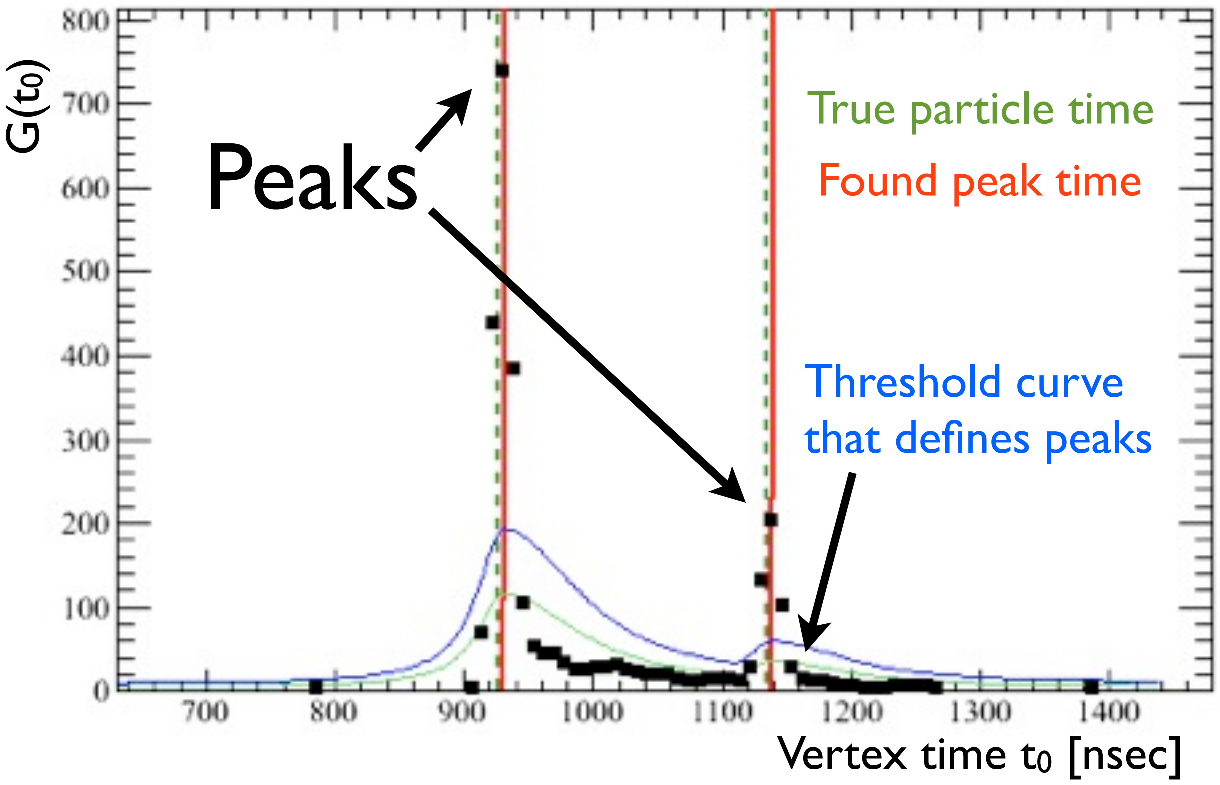
$t_c$: corrected time

# Counting decays: Peak Finder

- Provides with the number and time of decay e's in an event
- Hit-time based vertex goodness:

$$G(\mathbf{x}, t_0) = \sum_{\text{hit}} \exp(-(T^i_{\text{res}}/\sigma)^2/2) \qquad T^i_{\text{res}} = t^i_{\text{hit}} - t_0 - |\mathbf{R}^i_{\text{PMT}} - \mathbf{x}|/c_n$$

  - G is large for correct vertex position **x** and time $t_0$
- fiTQun vertex pre-fitter - fit **x**, $t_0$ by maximizing G(**x**, $t_0$)
- Using the pre-fitter vertex, scan trough $t_0$ evaluating the goodness, and search for peaks of G($t_0$) that correspond to particle time



# True Peak Selection

At each peak candidate, draw:

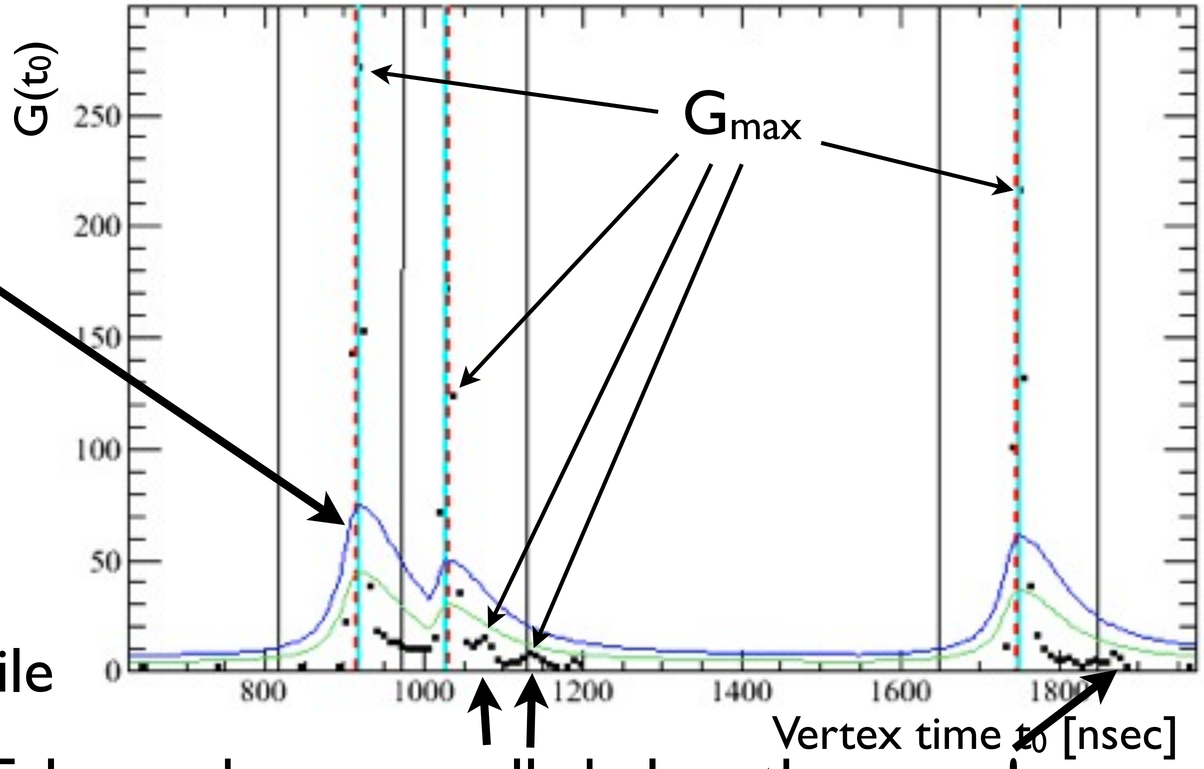
$G_{thr}=G_{max}*0.25*f(\tau)$

$$f(\tau) = 1/(1 + (\tau/\gamma)^2)$$

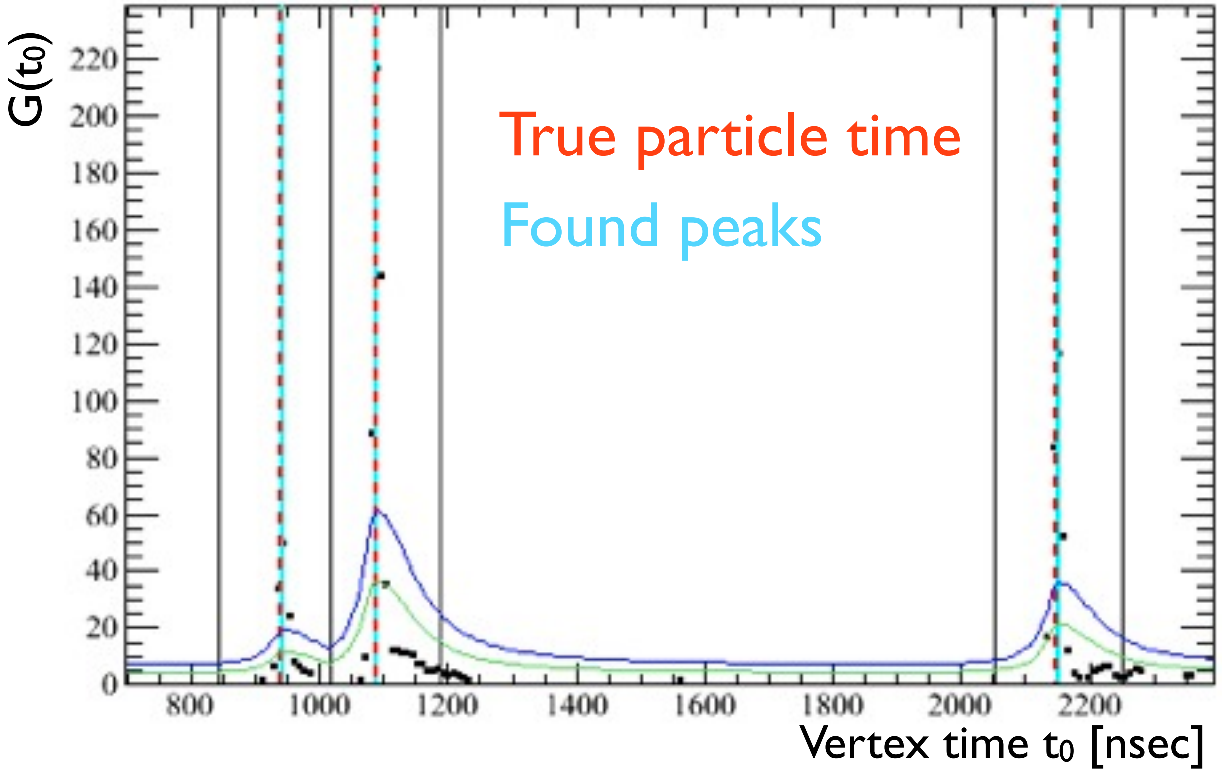
$\tau$: $t_0$-$t_{peak}$, $\gamma$=25nsec ($\tau$<0), 70nsec($\tau$>0)

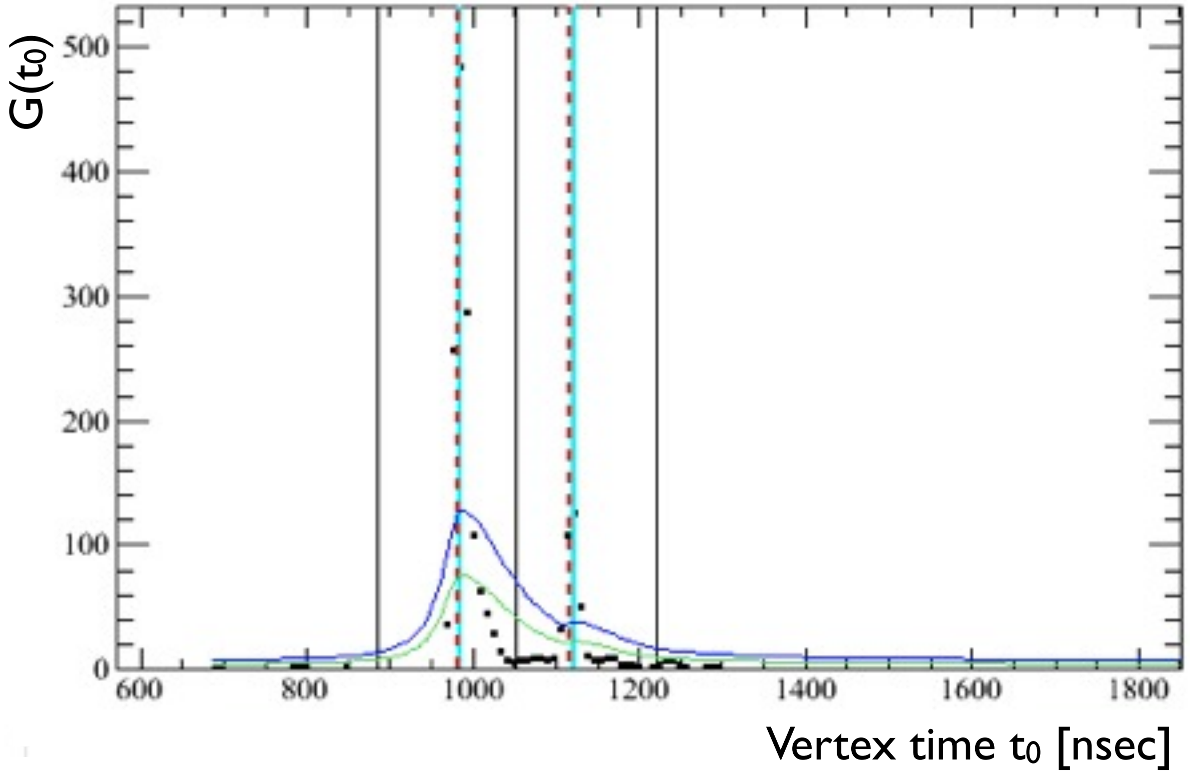
"True peak" if $G_{max}>G_{thr}$

Peak finder correctly find real particle peaks while ignoring false peaks(due to reflections etc.)



False peaks are usually below the curve!

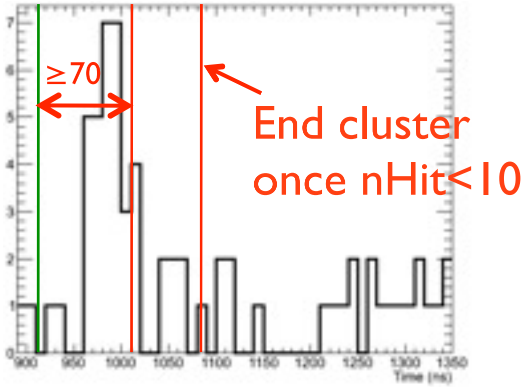




# Clustering algorithm(spliTChan)

- Scan through the raw hit-time distribution(by sliding a 70ns window) and look for clusters of hits

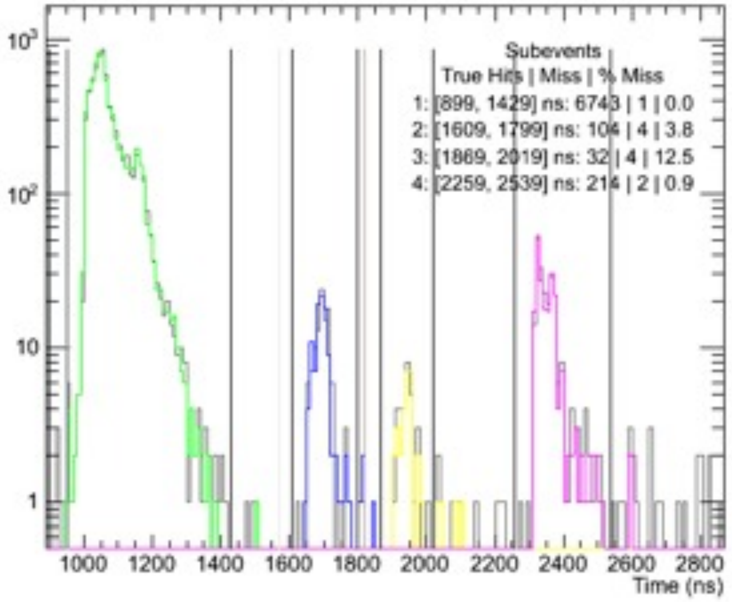
Start cluster when nHit>10



End cluster once nHit<10

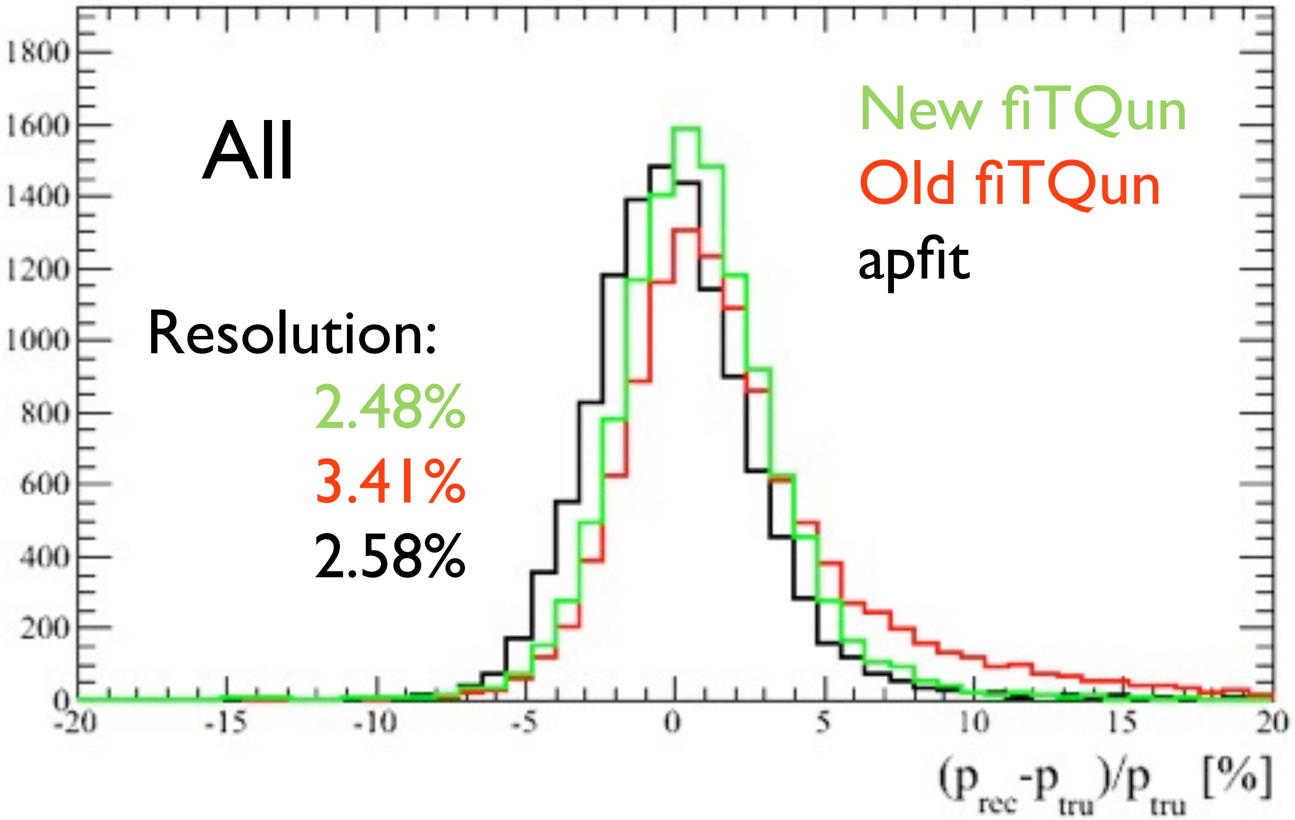
- Separate sub-events(primary particles, decay electrons) into different time windows, so that they can be fitted independently

- Can identify and isolate most particles that are well separated in time



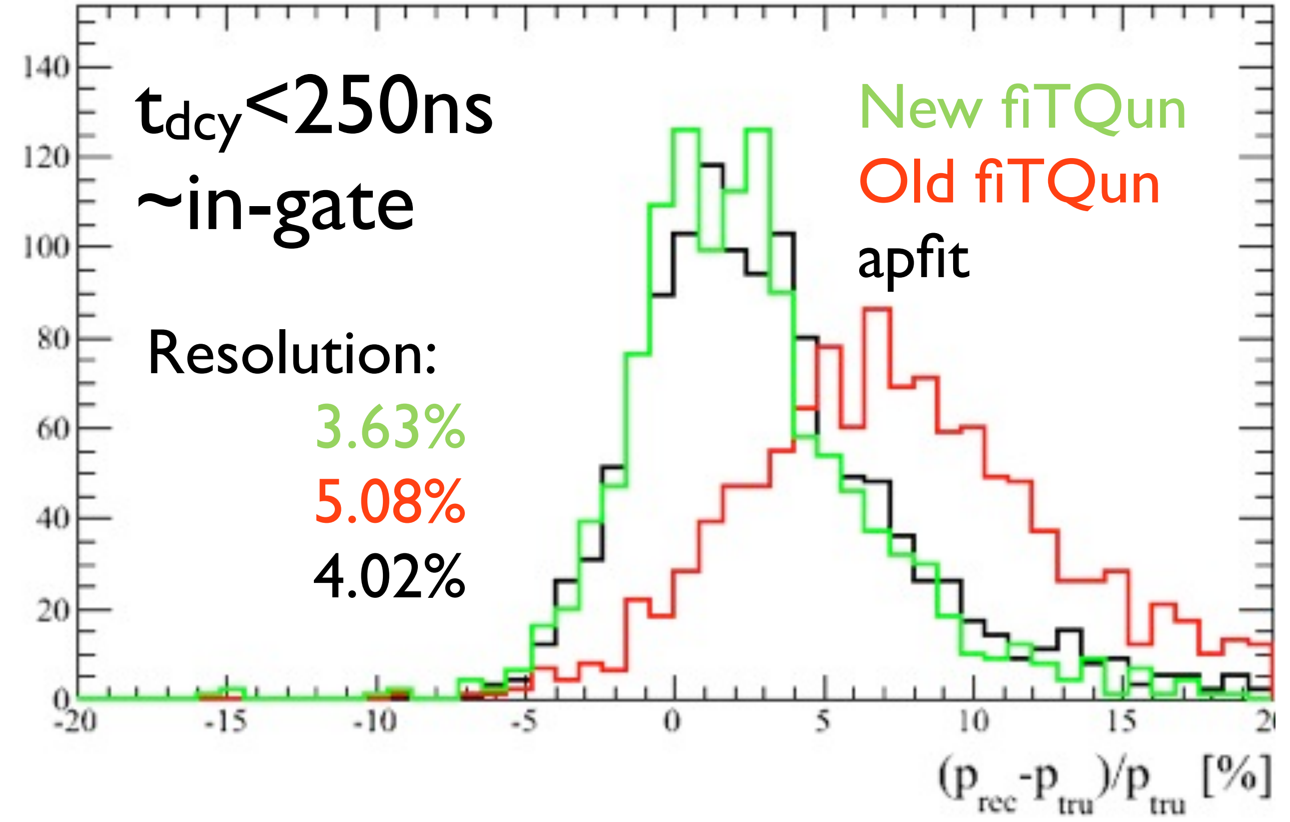
Subevents
True Hits | Miss | % Miss
1: [899, 1429] ns: 6743 | 1 | 0.0
2: [1609, 1799] ns: 104 | 4 | 3.8
3: [1869, 2019] ns: 32 | 4 | 12.5
4: [2259, 2539] ns: 214 | 2 | 0.9

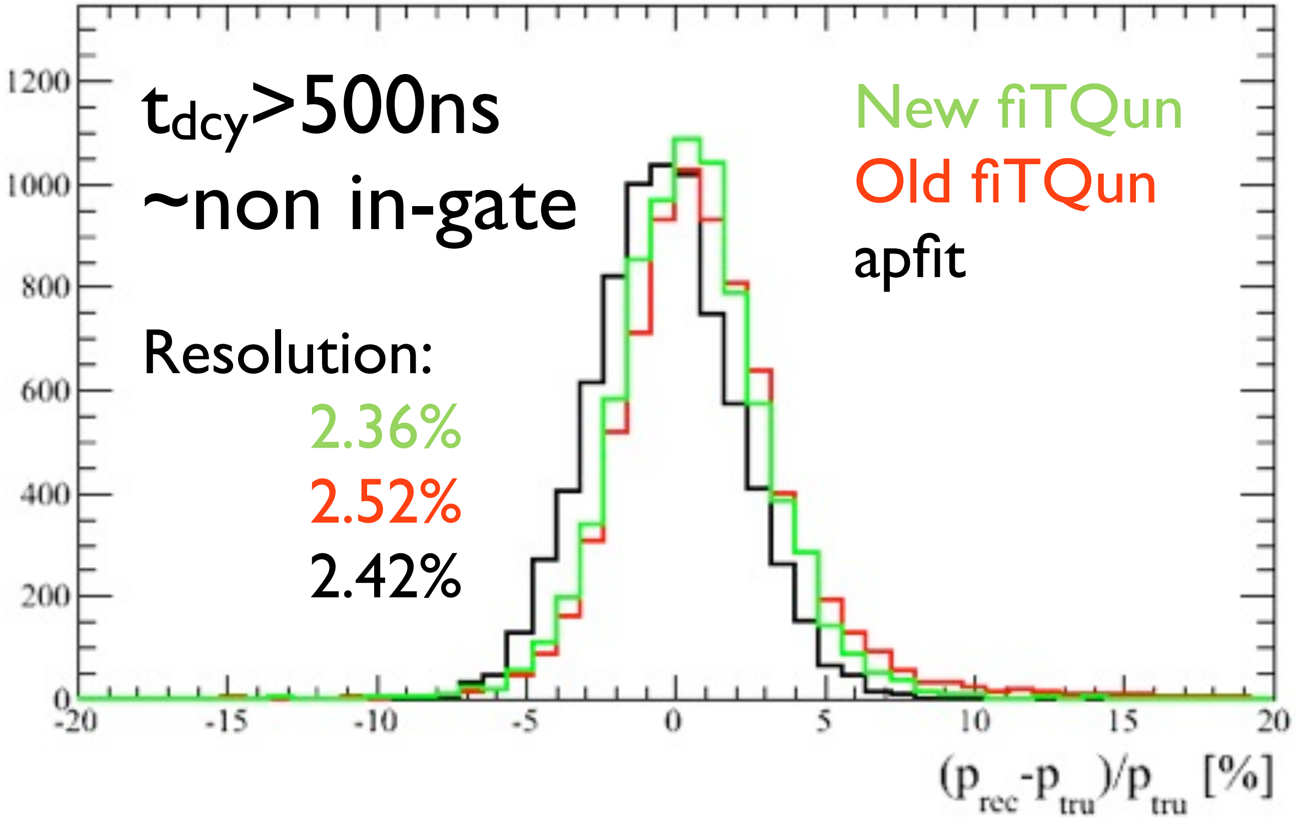
# CCQE μ momentum resolution



*Sample: Raw T2K $\nu_\mu$ (unoscillated)
FC trueFV CCQE, nring==1

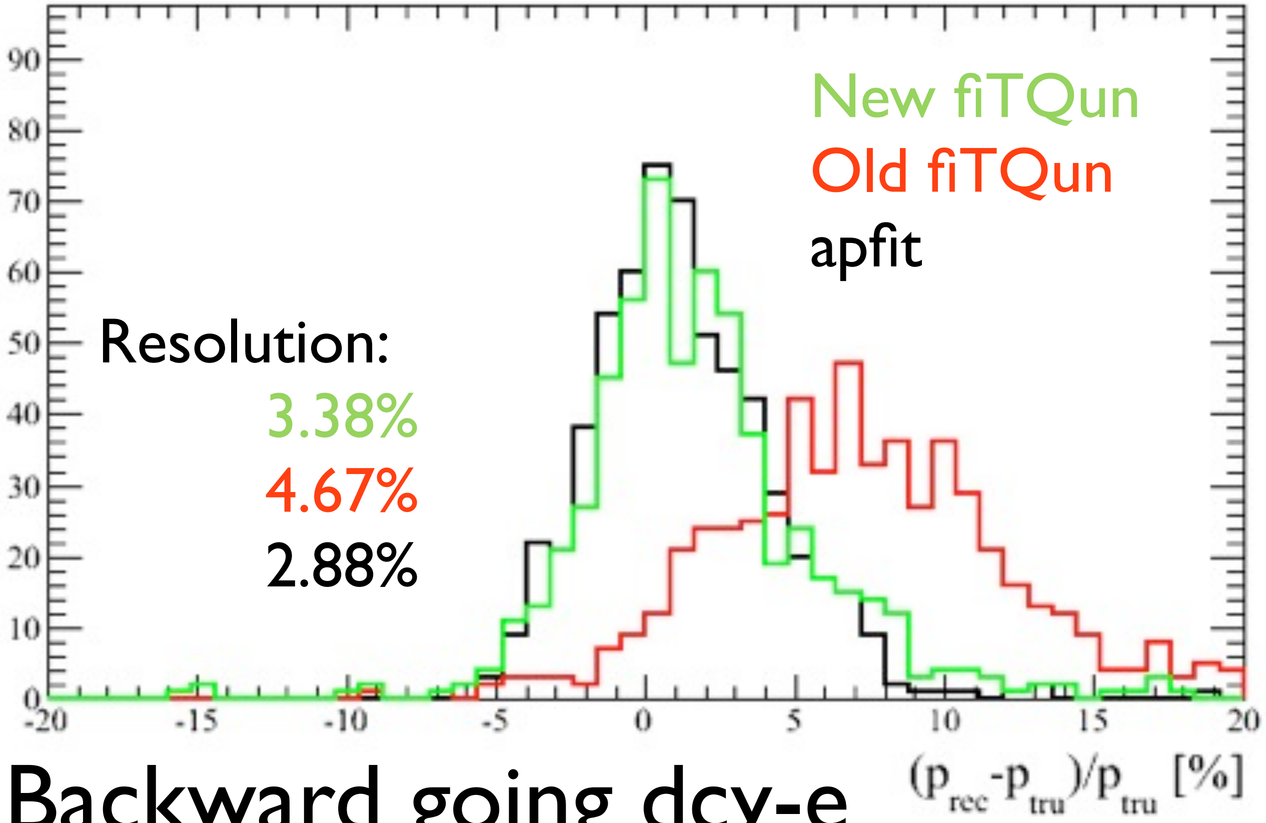
- Compared to the old version of fiTQun, μ-momentum resolution on non-particle-gun sample has been improved significantly
    - More robust to decay e's and nuclear γ's
- fiTQun has a momentum-dependent momentum bias which smears out the 1-D momentum resolution plot (next slide)



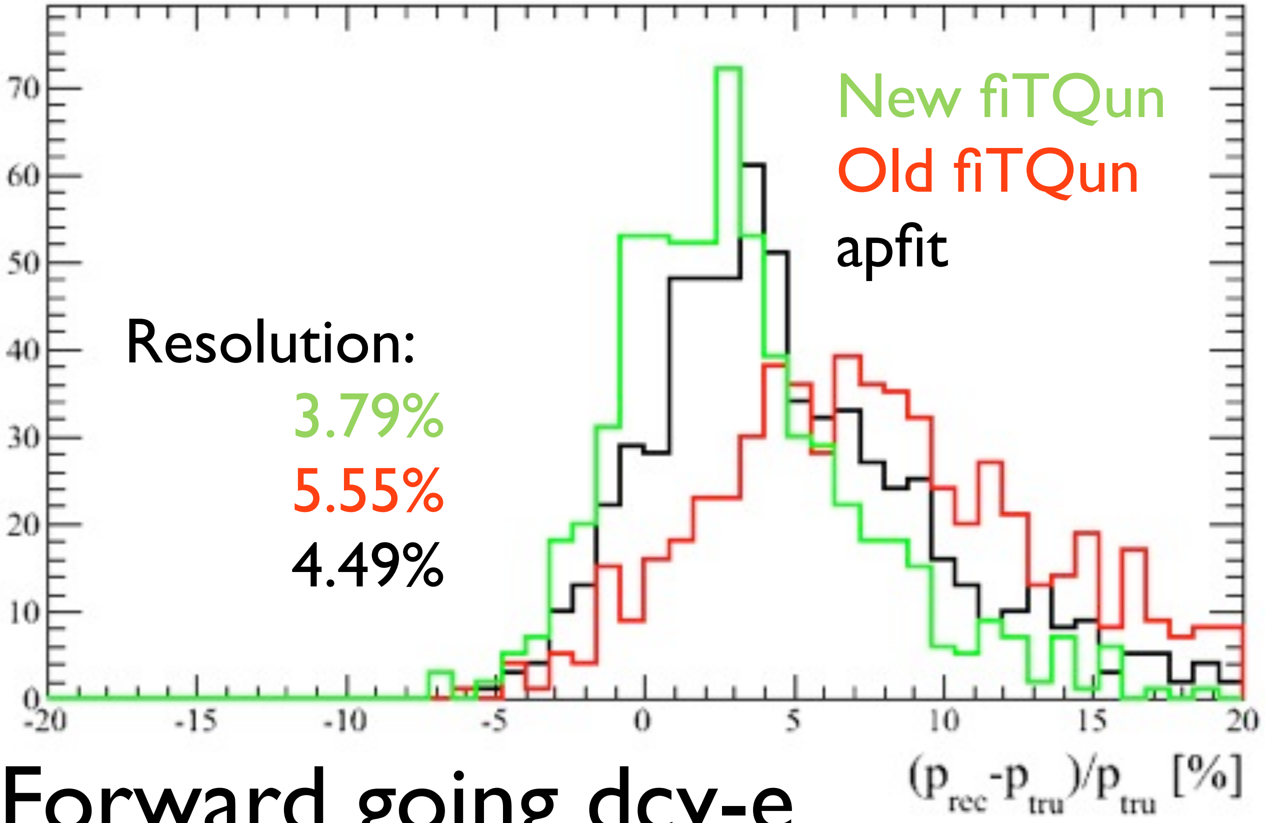


# Overlapping charge

*Sample: Raw T2K $\nu_\mu$ (unweighted), FC trueFV CCQE, nring==1, tdcy<250ns(~in-gate)



Backward going dcy-e

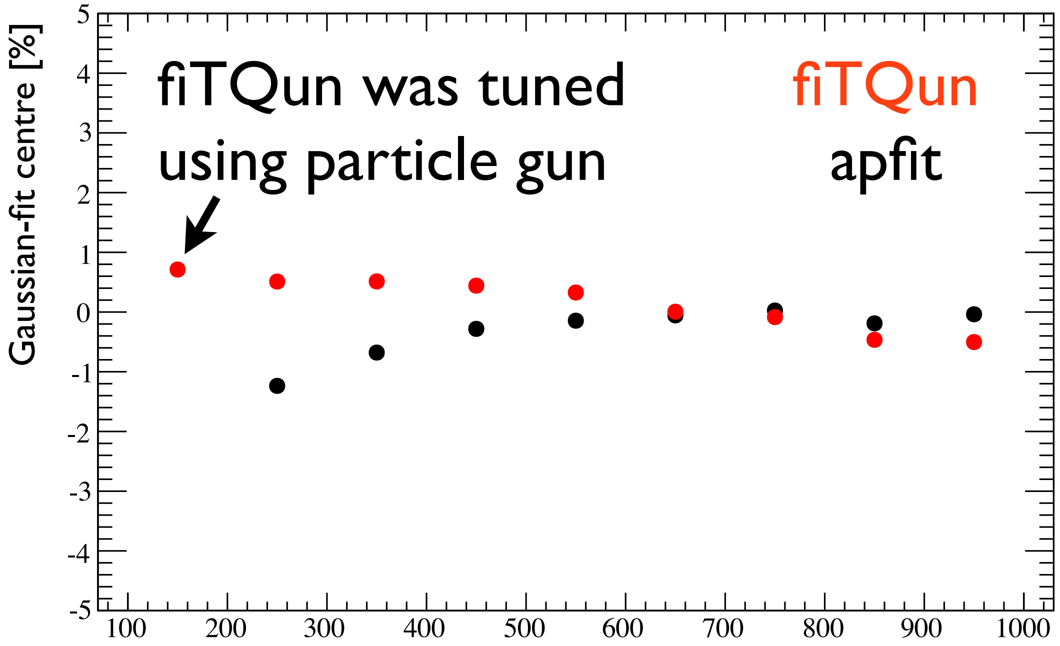


Forward going dcy-e

- Hits caused by direct light from Michel's are masked
- When charge from Michel rings overlap with primary rings, those additional charge wouldn't be removed by the masking
  - Momentum gets overestimated → tail on the right side
- Reflected light from Michel's also causes some overestimation

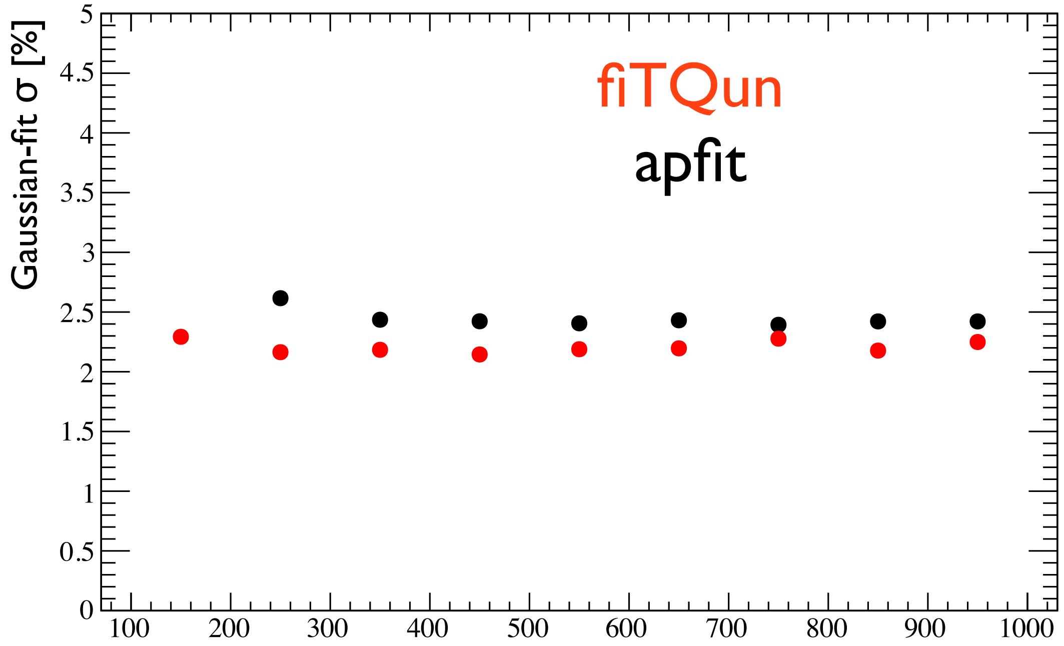
# Muon momentum resolution

Muon particle gun sample (FC, True FV, nring==1):



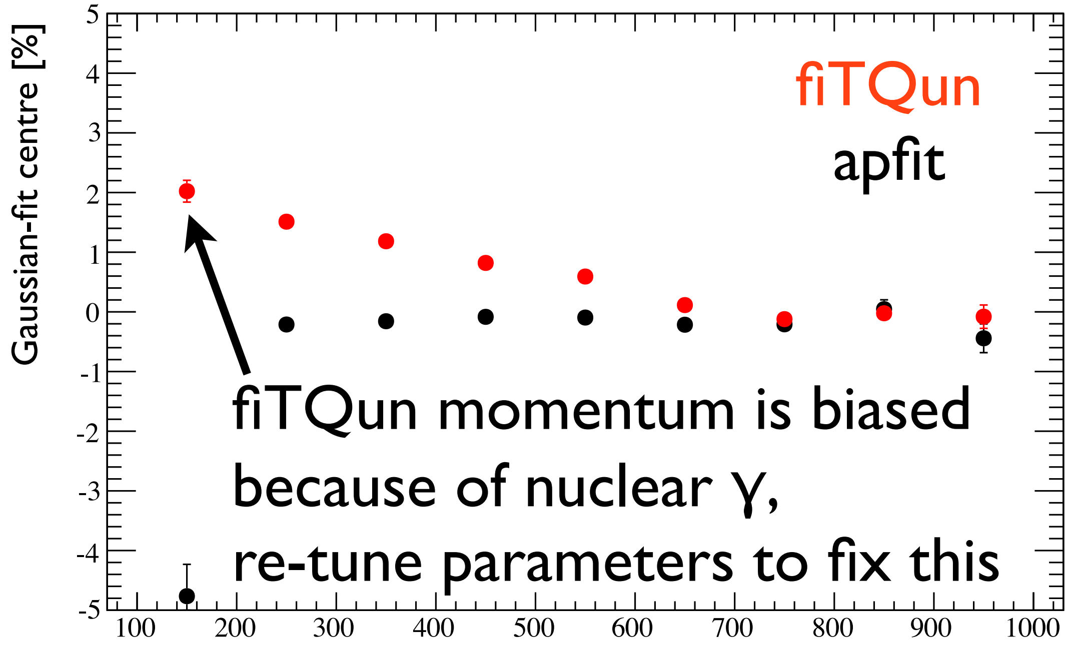
fiTQun was tuned using particle gun

Bias



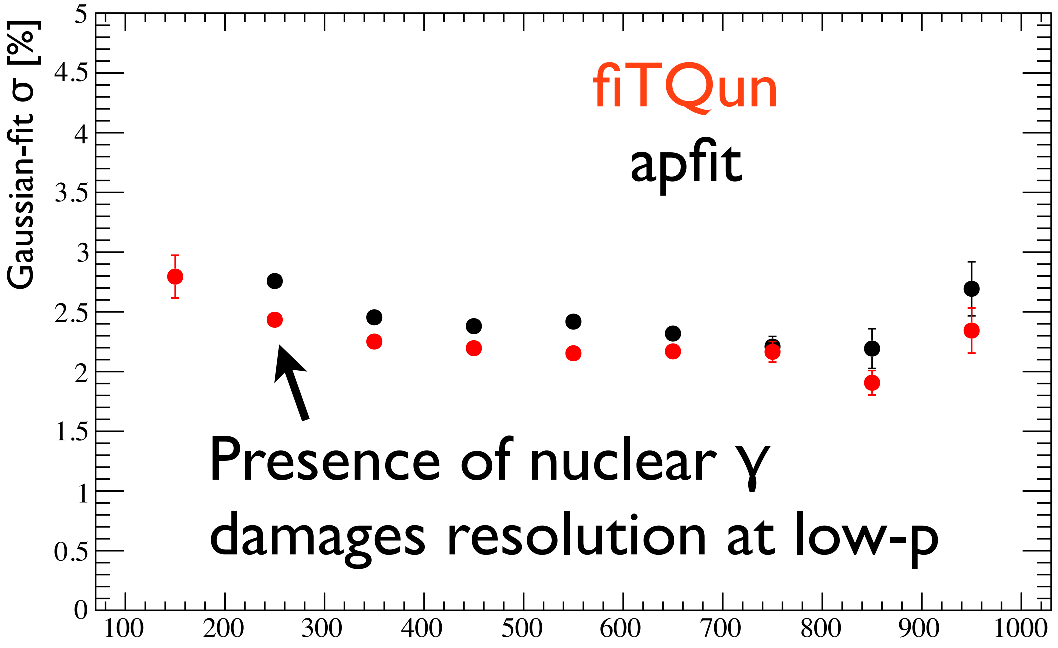
Resolution

T2K $\nu_\mu$ CCQE sample (FC, True FV, nring==1):



fiTQun momentum is biased because of nuclear γ, re-tune parameters to fix this

Bias

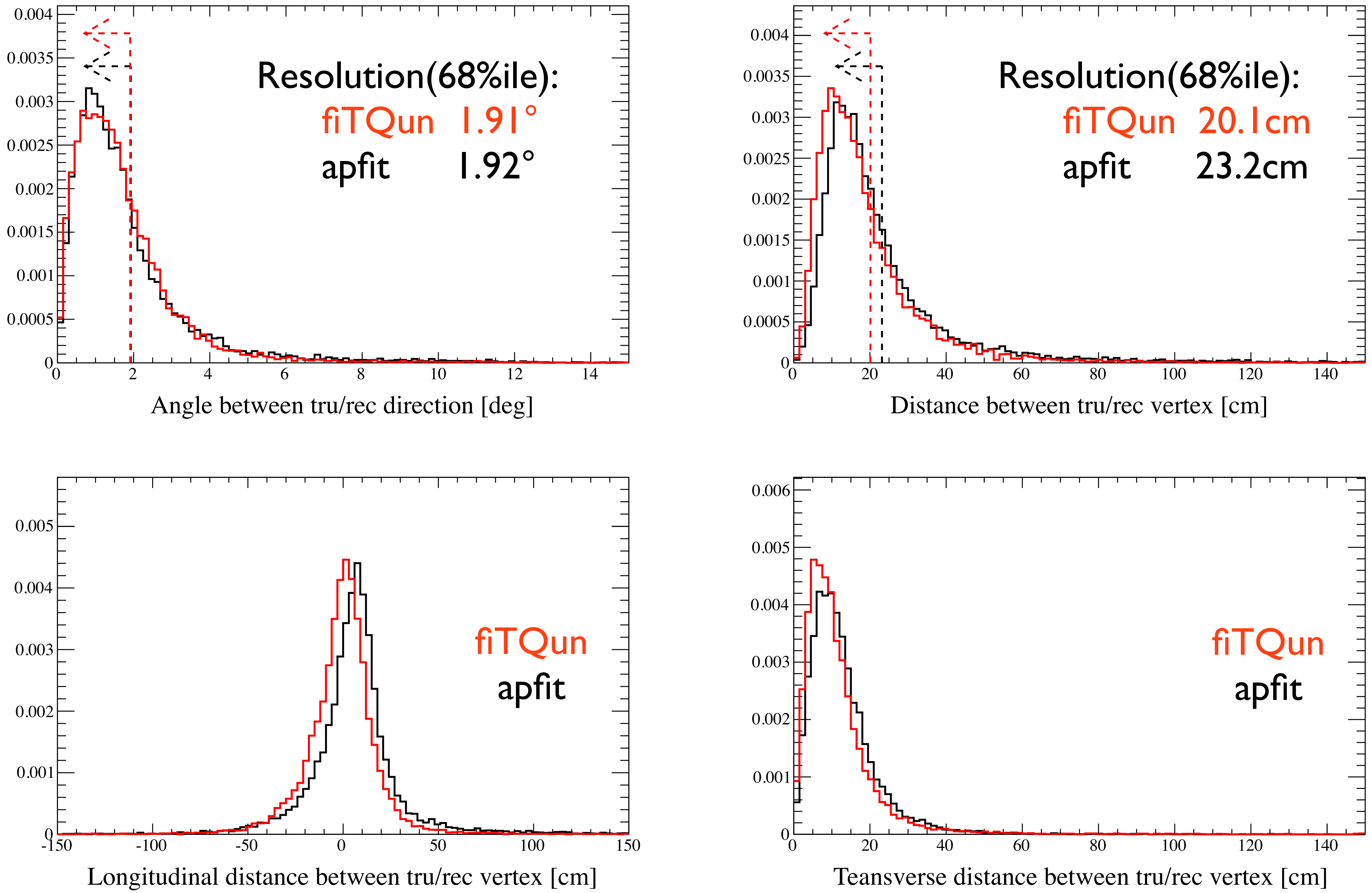


Presence of nuclear γ damages resolution at low-p

Resolution

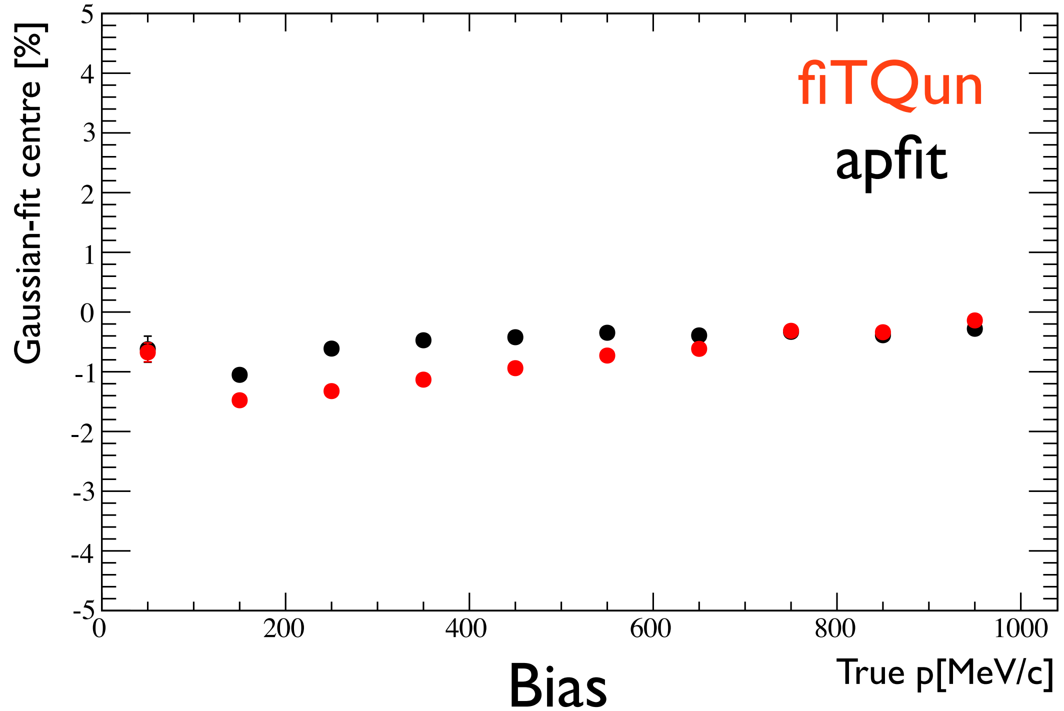
# Muon vertex/direction resolution

T2K $\nu_\mu$ CCQE sample (FC, True FV, nring==1):

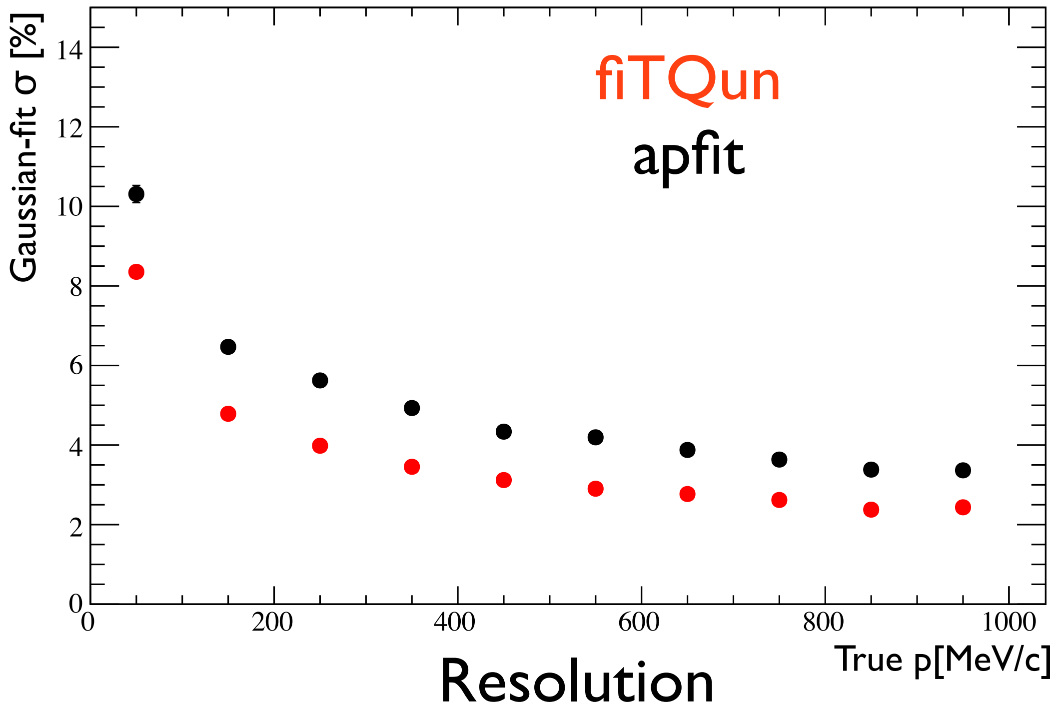


# Electron momentum resolution

## Electron particle gun sample (FC, True FV, nring==1):

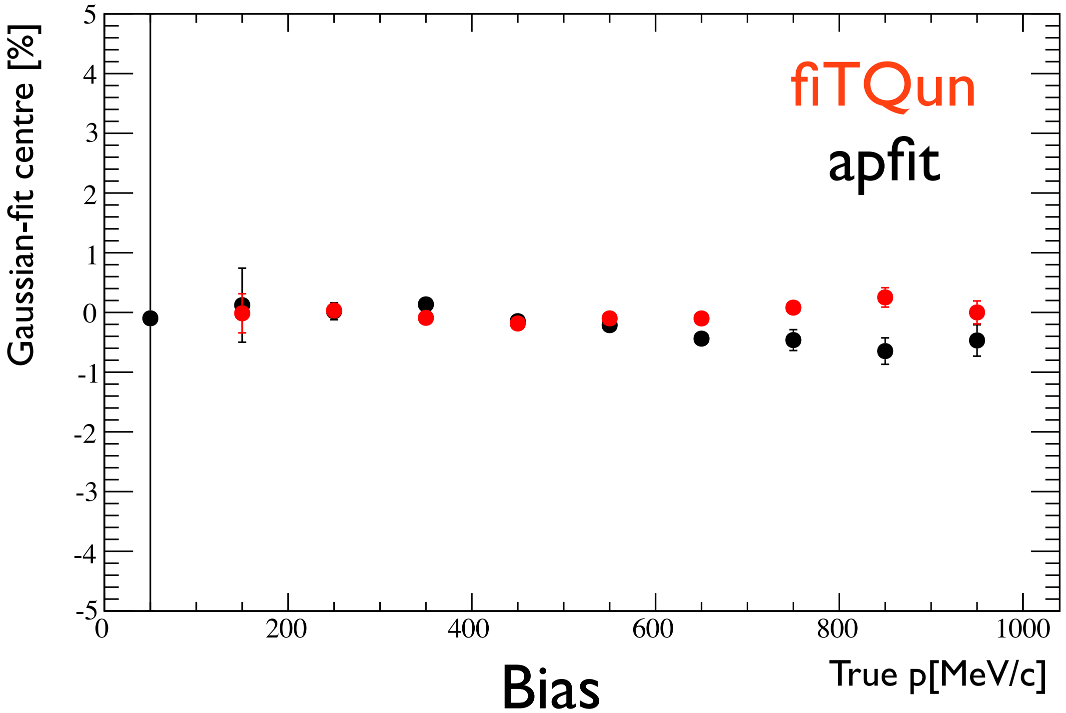


Bias

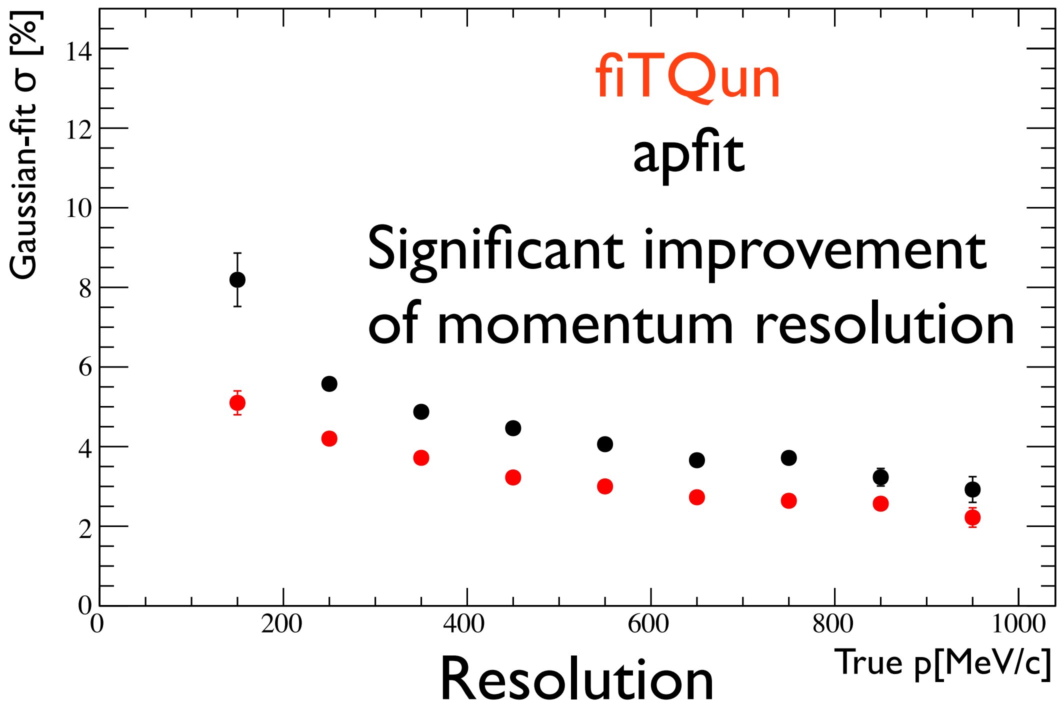


Resolution

## T2K $\nu_e$ CCQE sample (FC, True FV, nring==1):



Bias

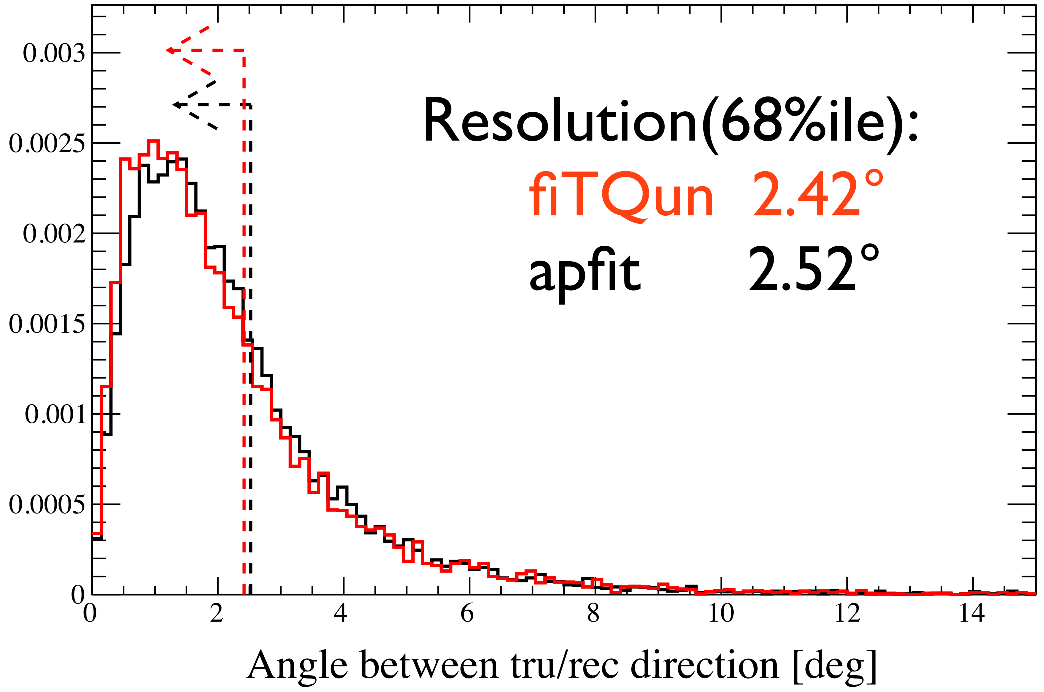


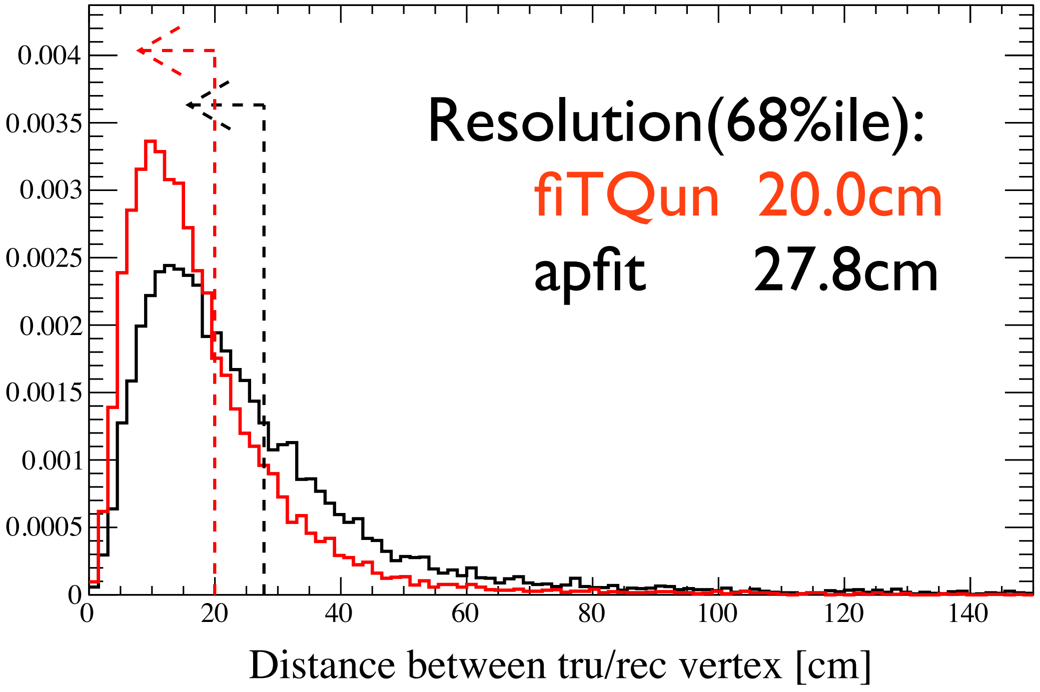
Significant improvement of momentum resolution

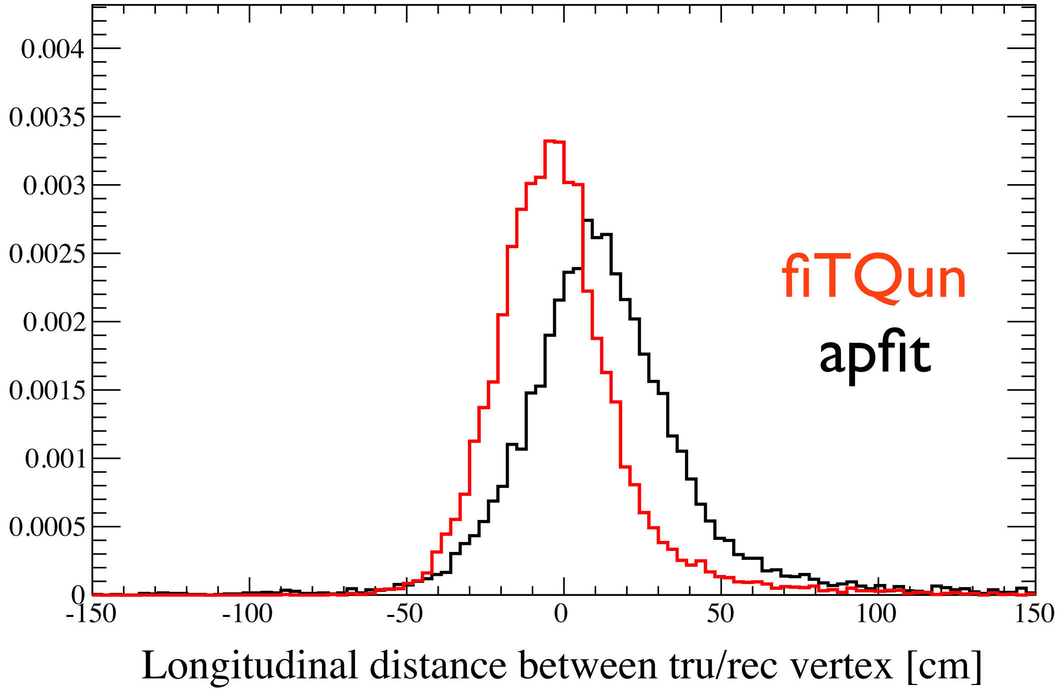
Resolution

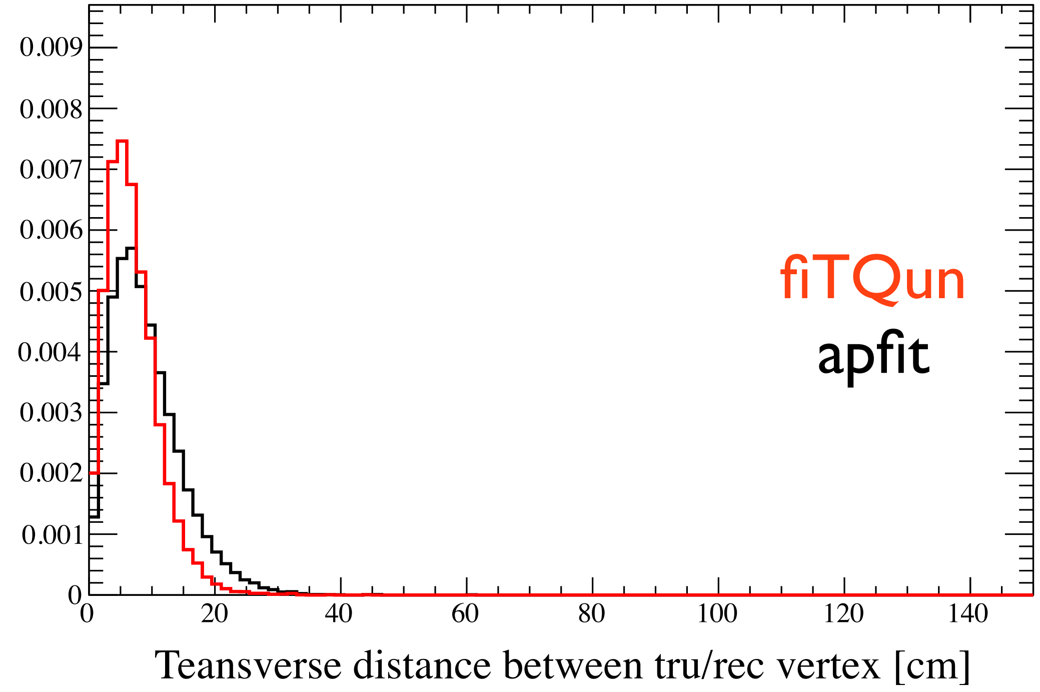
# Electron vertex/direction resolution

T2K $\nu_e$ CCQE sample (FC, True FV, nring==1):



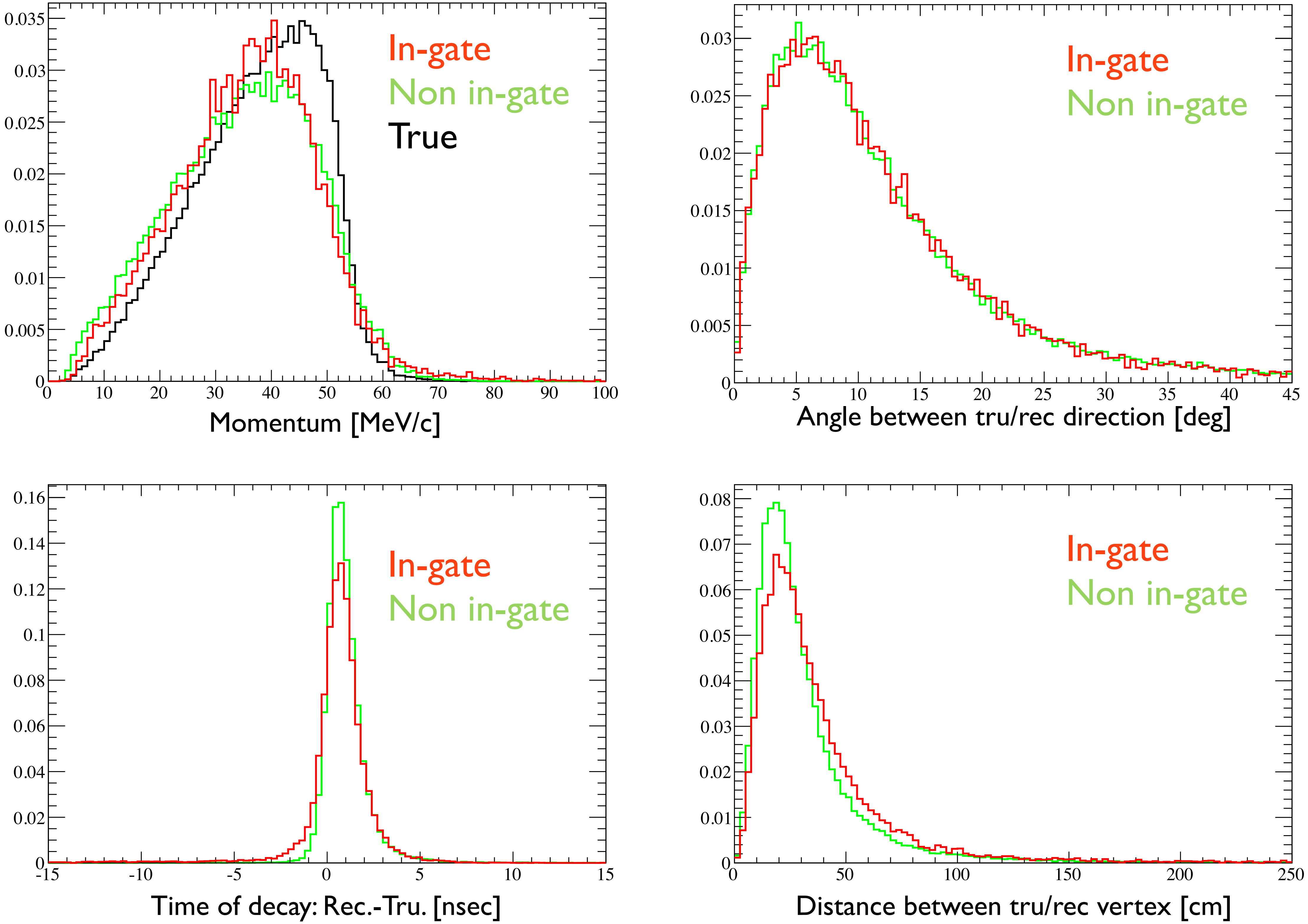






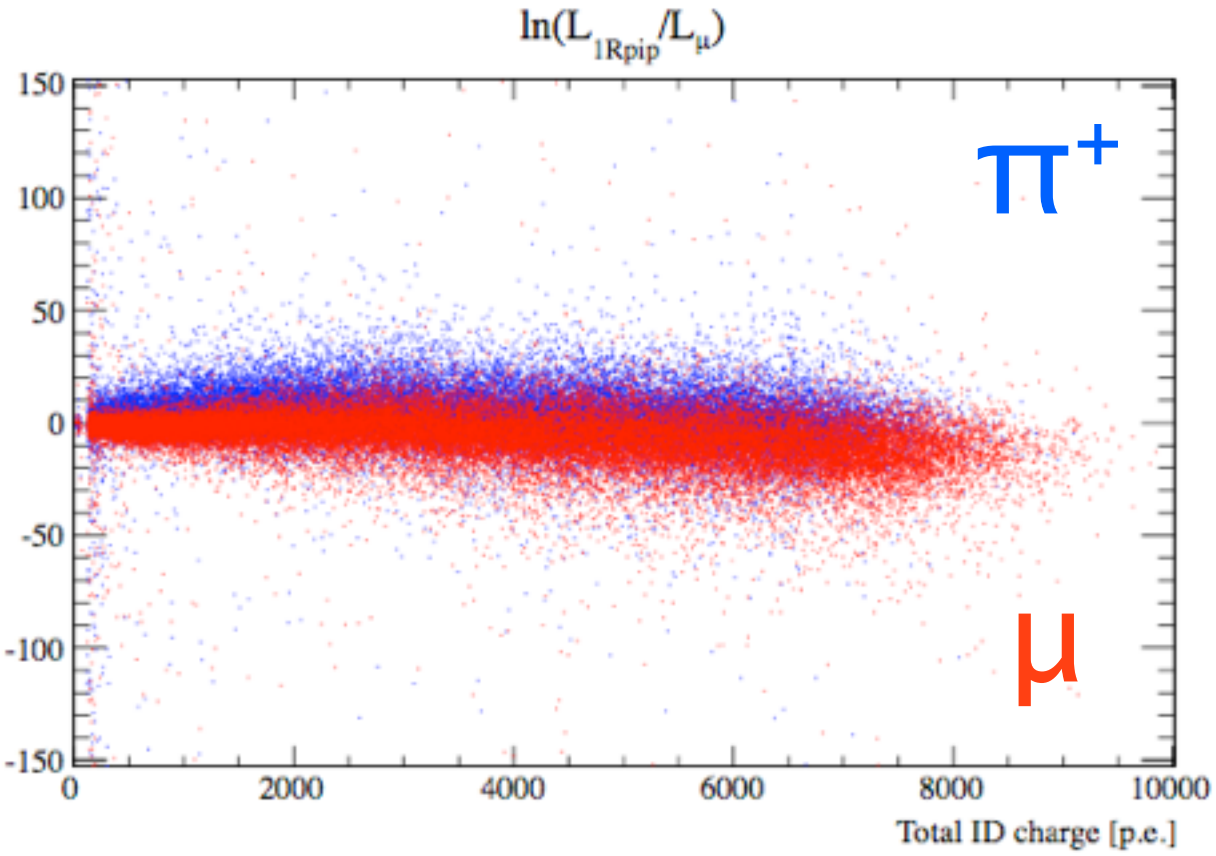
# Decay electron reconstruction

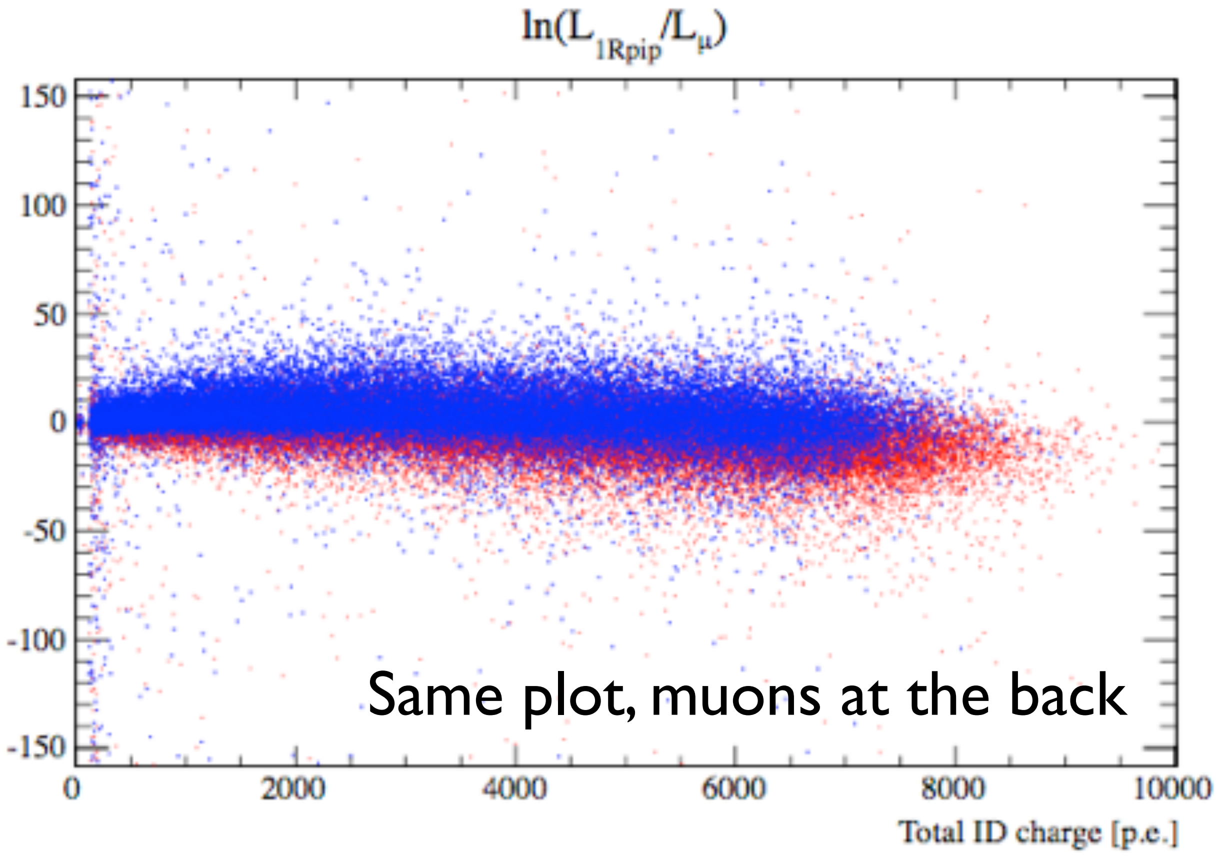
*Sample: Raw (unweighted) T2K $\nu_\mu$, FC, True FV
Only selecting true decay electrons in the plots



# $\mu/\pi^+$ separation, w/o kink

- Apply straight-track $\pi^+$ hypothesis to both $\pi^+$ & $\mu$ samples, p<1GeV/c
- When hadronic interaction is turned off, only slight separation of $\pi^+/\mu$ is seen

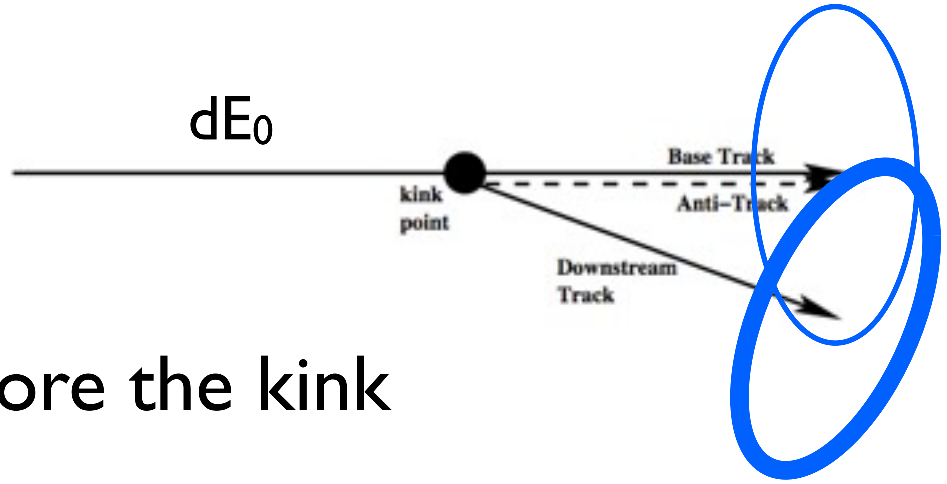


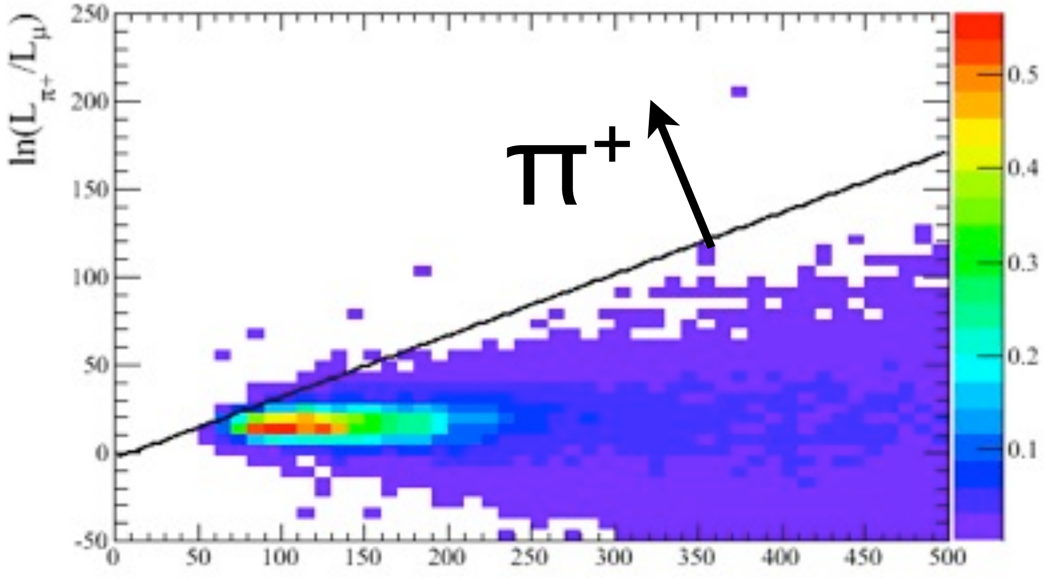


Same plot, muons at the back

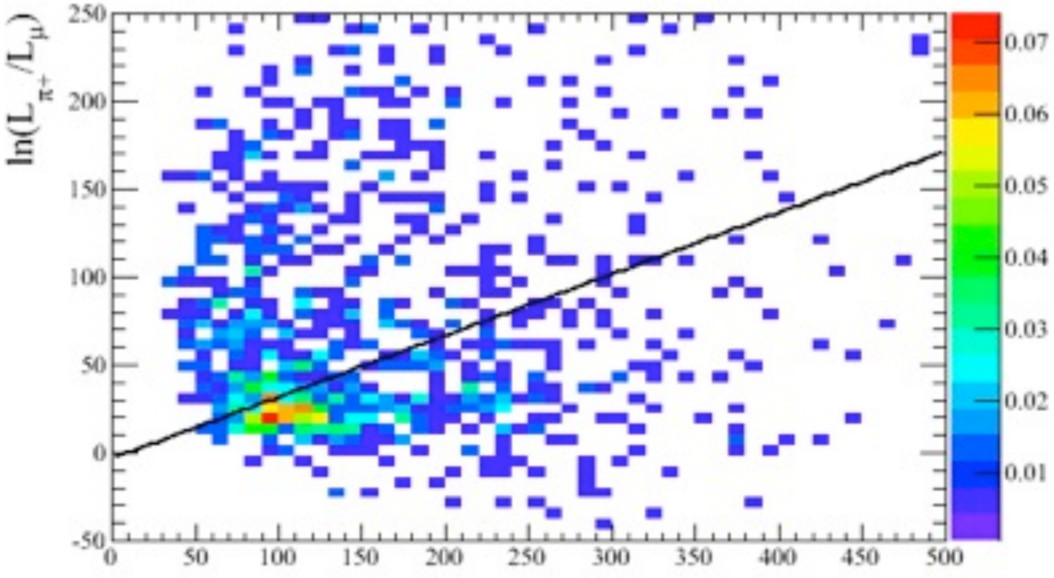
# Upstream track $\pi^+$ Fitter

- $\pi^+$ track often has a kink due to hadronic interactions with nuclei
  - Produces sharp, hollow upstream ring
- Fit the upstream track - 8 parameter fit
  - Additional parameter $dE_0$: energy lost before the kink
    - Characterizes the thickness of the ring
- $\mu/\pi^+$ separation seen in the likelihood ratio to 1-ring μ fit





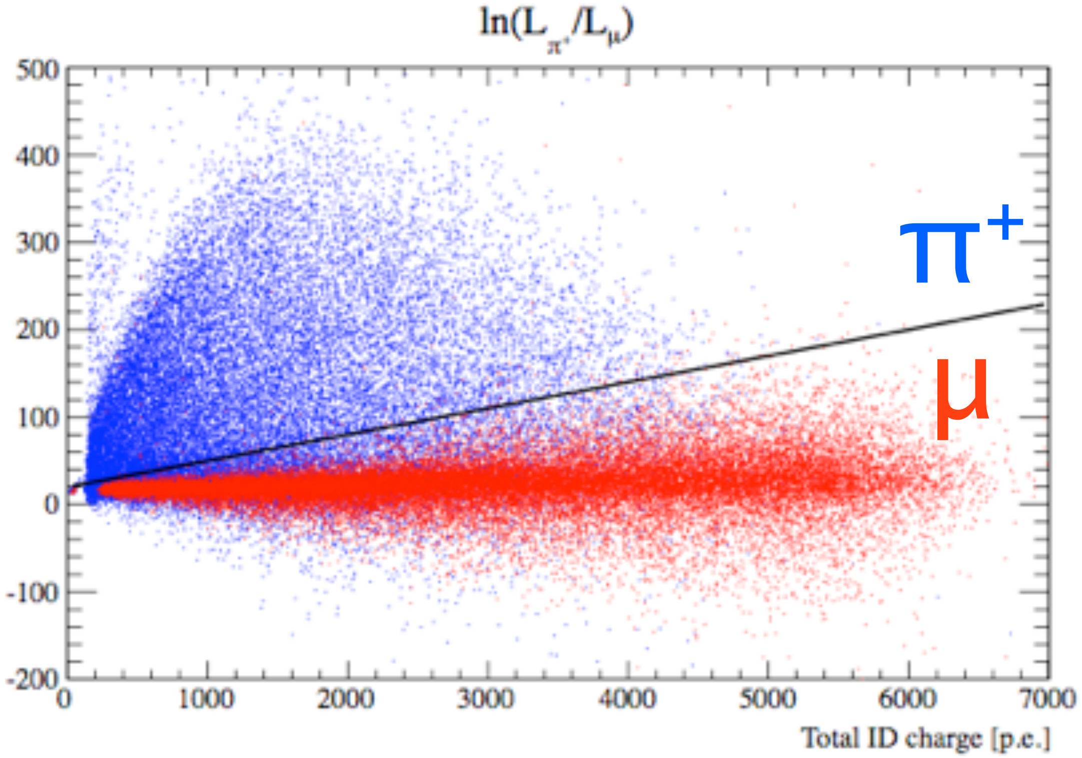
T2K $\nu_\mu$ CCQE



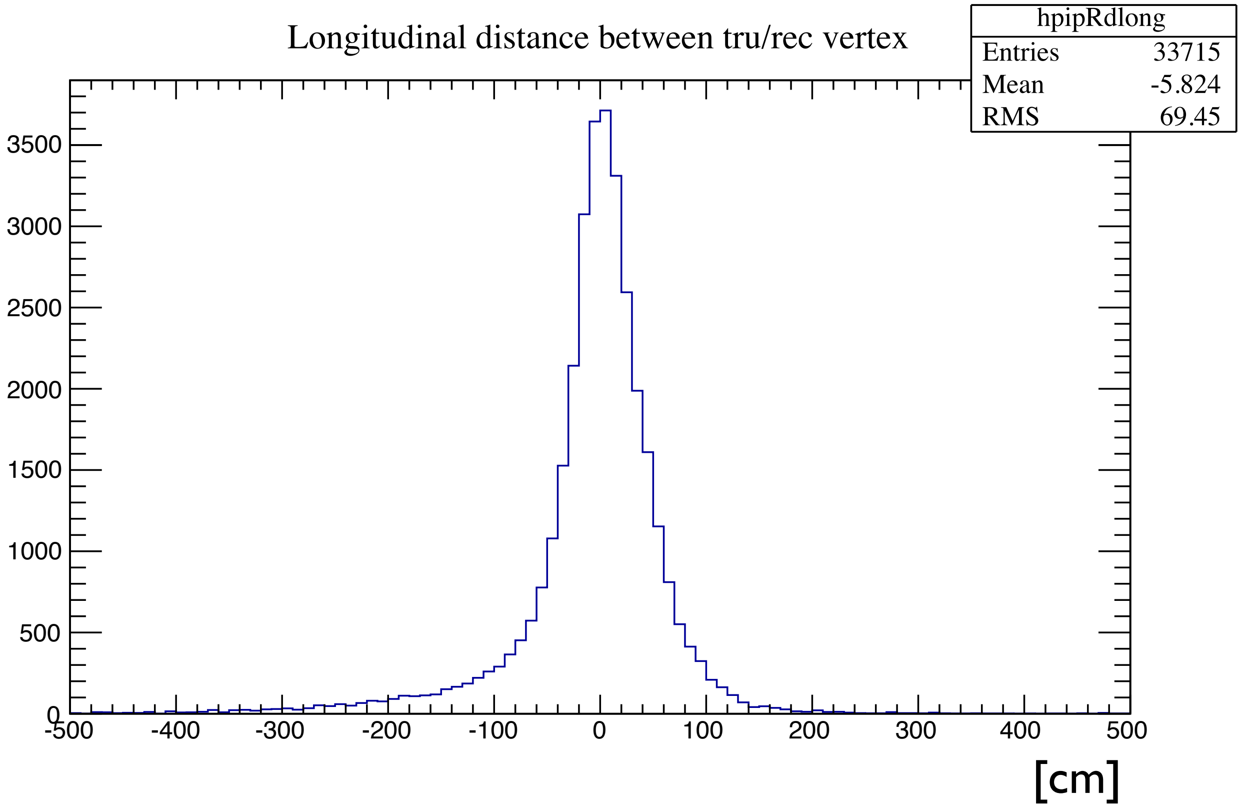
T2K $\nu_\mu$ NC w/ visible $\pi^+$

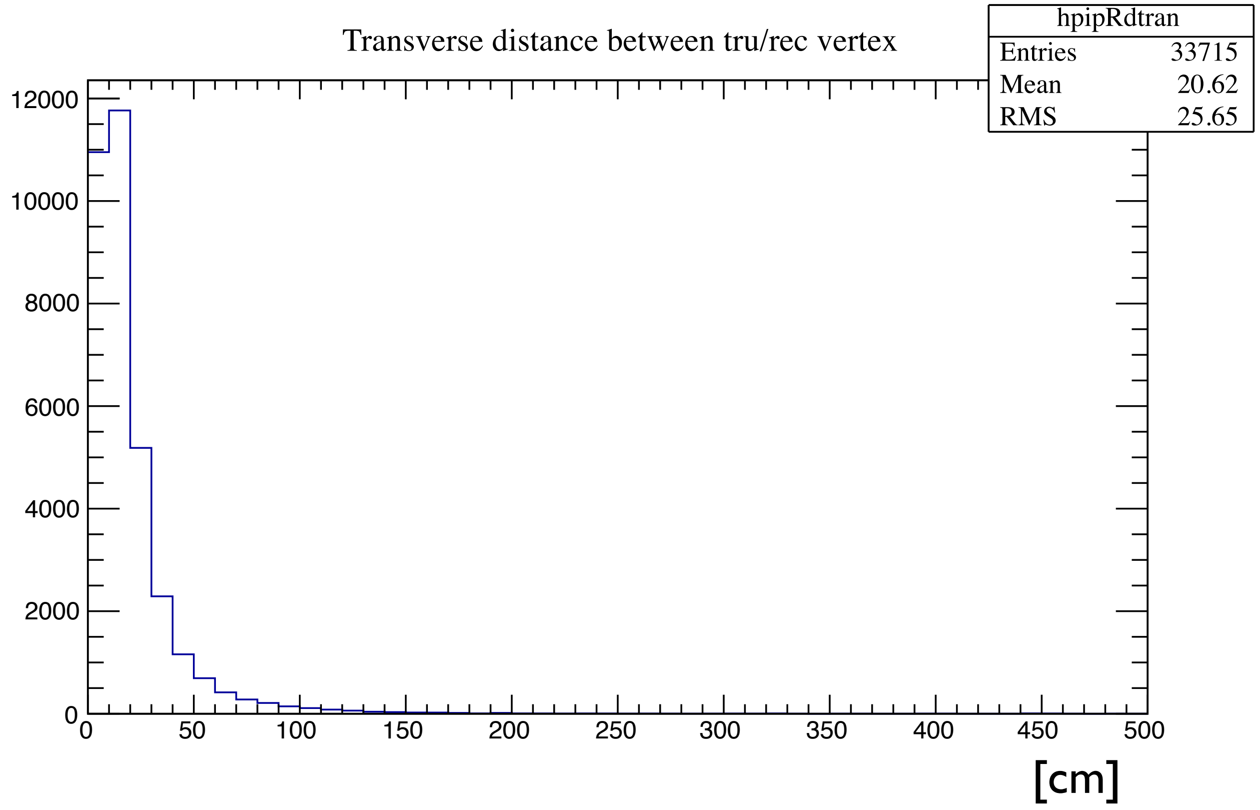
# Upstream track $\pi^+$ Fitter

- μ and $\pi^+$ produce similar charge pattern, since the mass of the two are similar
- Difference is seen since $\pi^+$ makes the kink, producing hollow rings, while such thing rarely happens for μ
- Apply both 1R μ and upstream $\pi^+$ fits
- Make a line cut on the likelihood ratio
  - Since the underlying charge pattern is similar, the upstream $\pi^+$ hypothesis reproduces muon rings, simply by adjusting the $dE_0$ parameter
    - Always $\ln(L_{\pi^+}/L_\mu) >\approx 0$



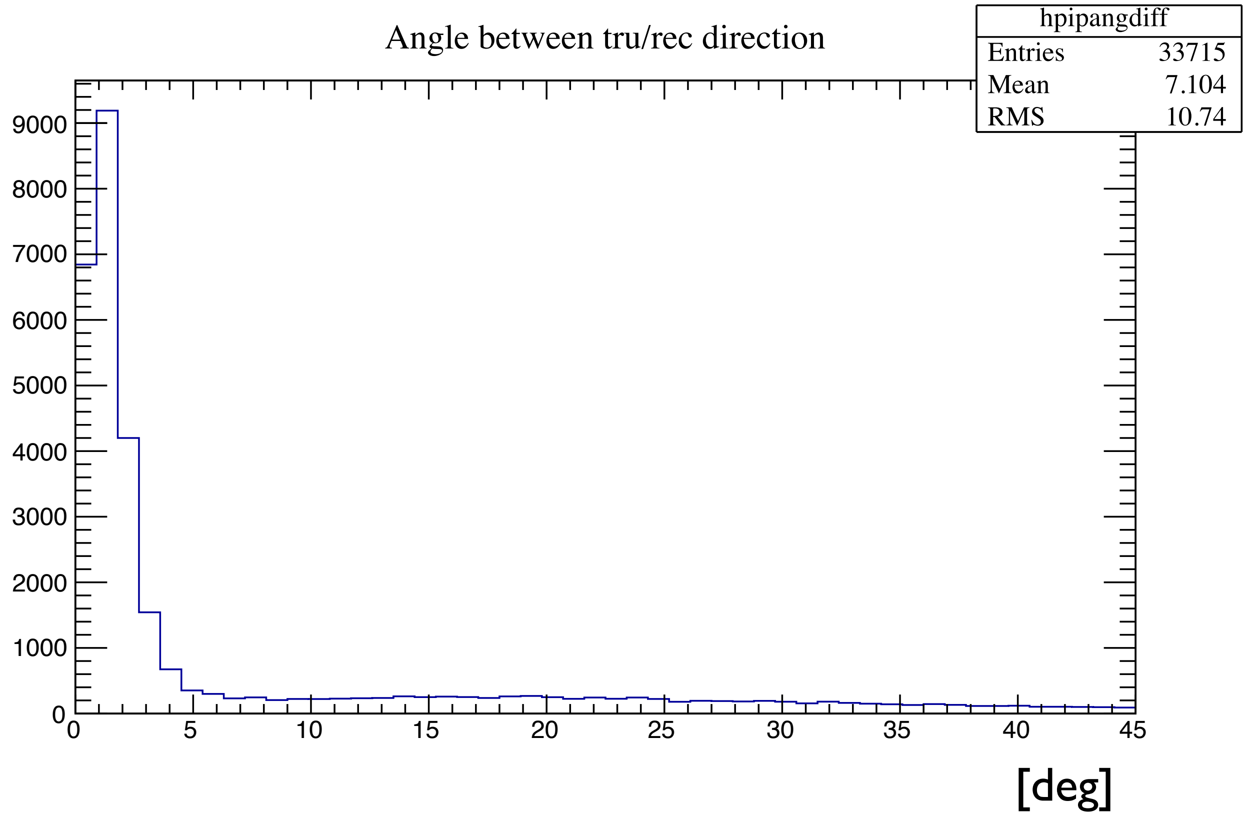
# Upstream $\pi^+$ fitter resolution


Longitudinal distance between tru/rec vertex


Transverse distance between tru/rec vertex

*$\pi^+$ particle gun sample
200~800MeV/c

Tail is due to the fitter not finding the upstream ring correctly→ (e.g. downstream ring was found)

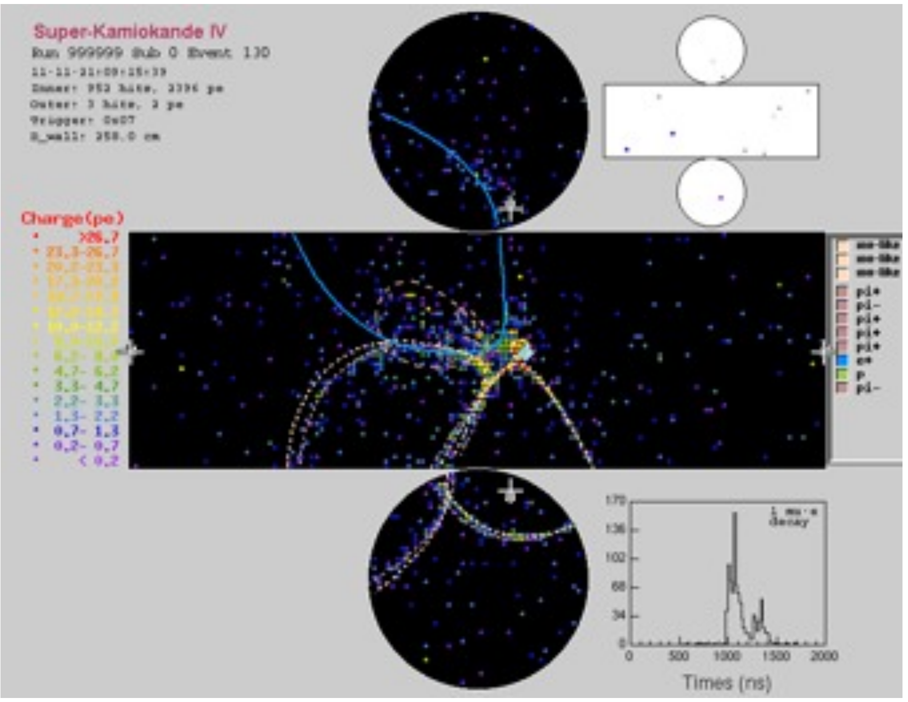

Angle between tru/rec direction

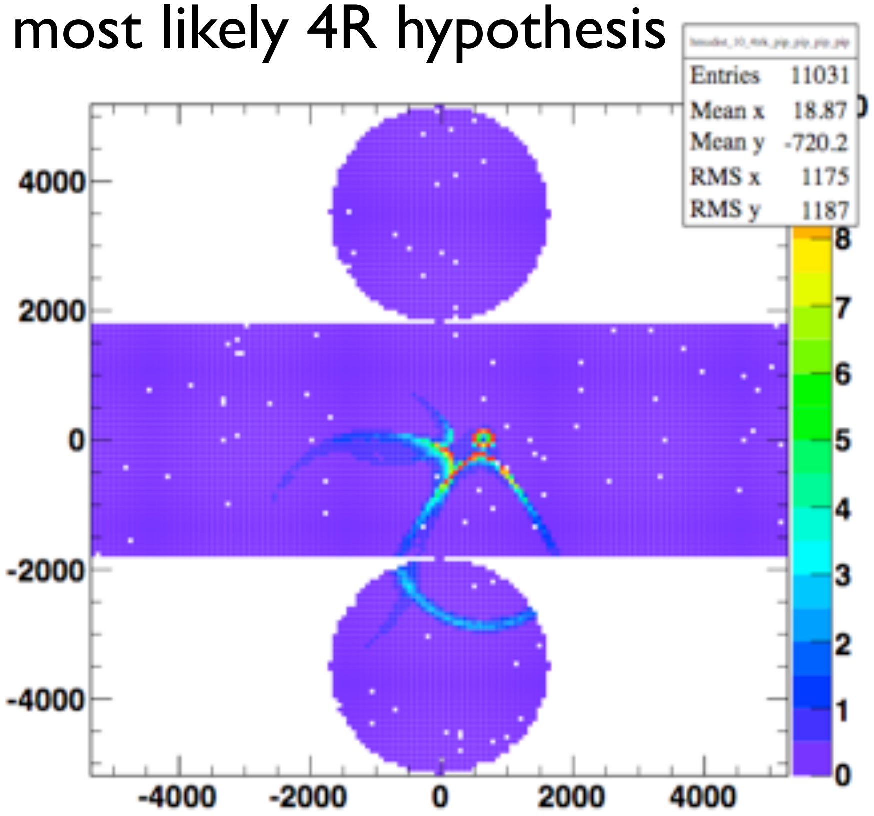
# MR Fit Event Displays

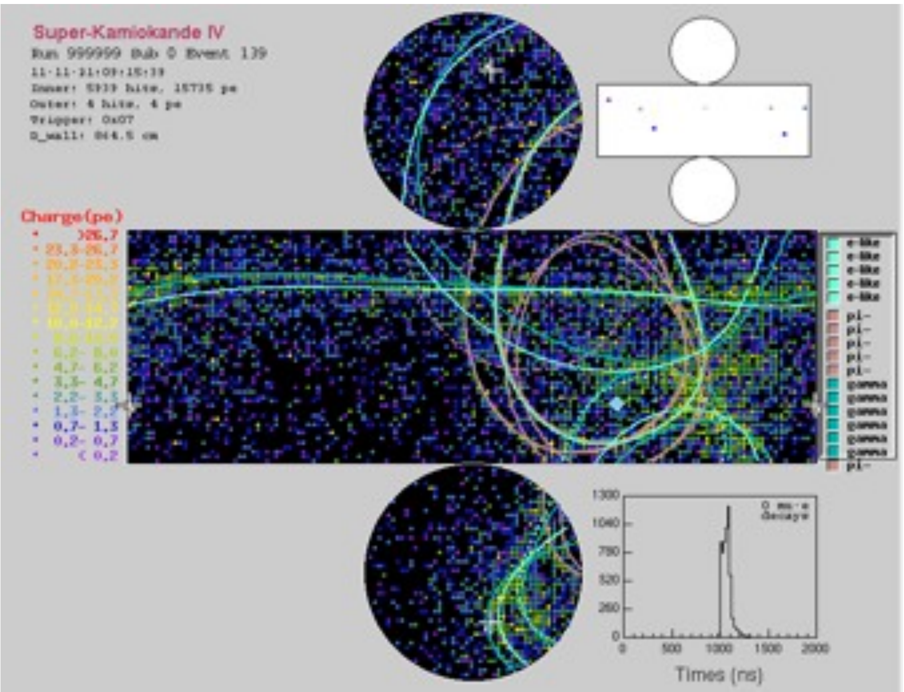
*T2K-SK MC $\nu_\mu$ multi-ring events

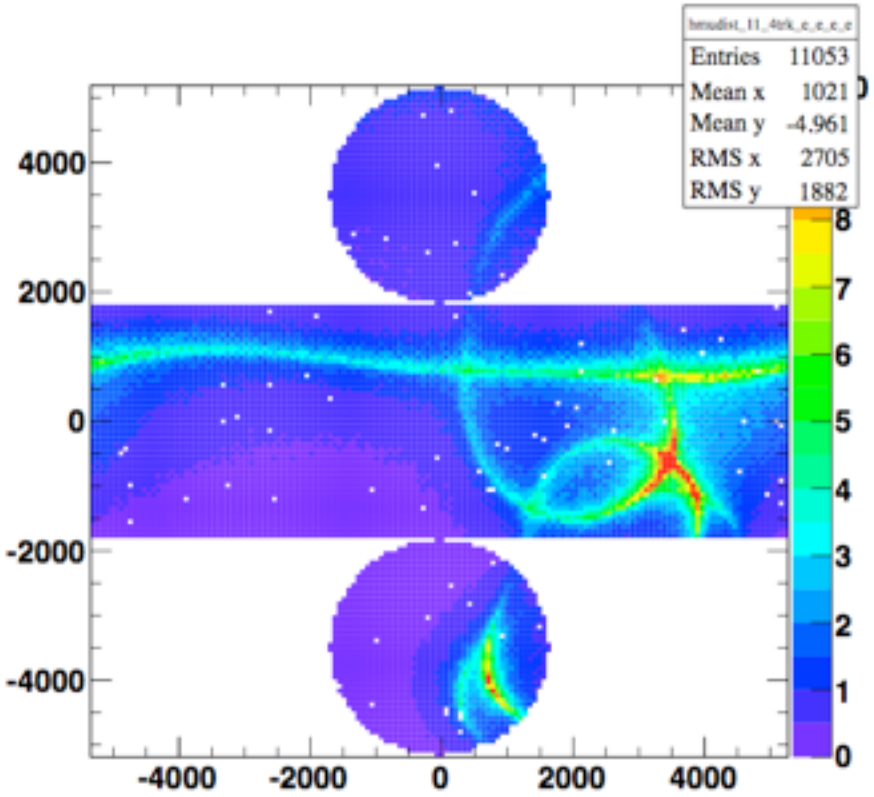
Event display

fiTQun predicted charge of the most likely 4R hypothesis



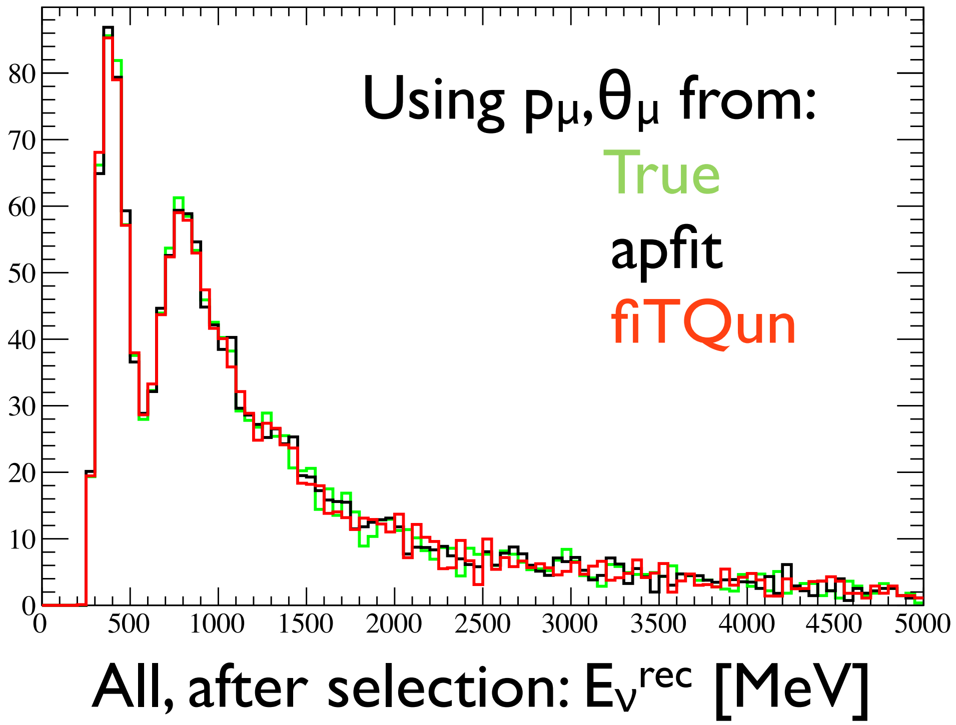


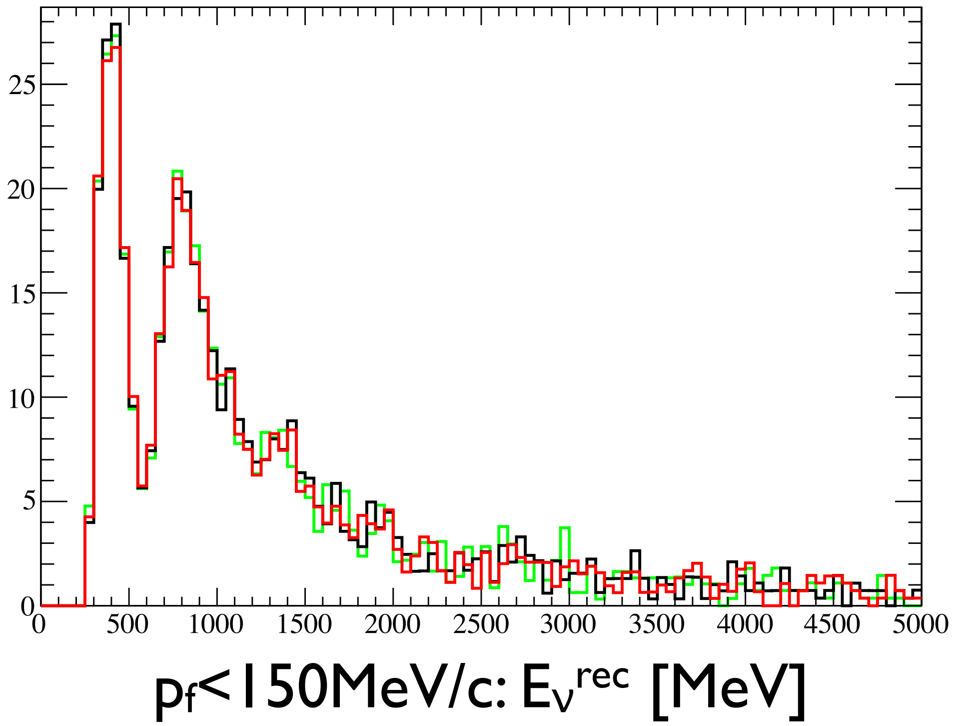




# Reconstructed $\nu_\mu$ energy (QE formula)

*Sample: T2K $\nu_\mu$ CCQE, maximal osc., after standard $\nu_\mu$ selection cuts





- $E_\nu^{rec}$ resolution is limited by the fermi motion of target neutrons, not the resolution of $p_\mu$, $\theta_\mu$ reconstruction
- Both apfit/fiTQun resolution is sufficiently good for $E_\nu$ reconstruction, no difference is seen between the two

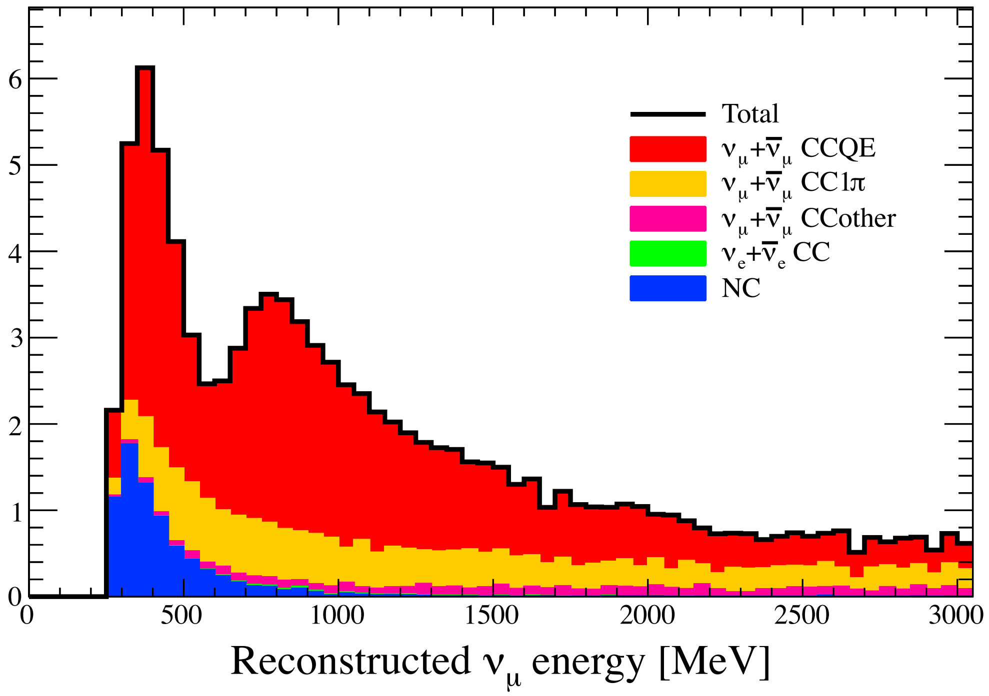
# T2K $\nu_\mu$ selection

- Standard cuts: FC, FV, 1-ring, μ-like, $p_\mu^{rec}$>200MeV/c, $n_{dcy}$<=1
- Main backgrounds are $\nu_\mu$ CC1π and NC
- Around 600MeV(oscillation dip), about half of the entries are backgrounds, filling up the dip
- One of the largest systematics come from NC selection efficiency
  - 100% PID error assigned to NC in previous analysis
- Reducing NC background improves $\theta_{23}$, $\Delta m^2_{23}$ sensitivity

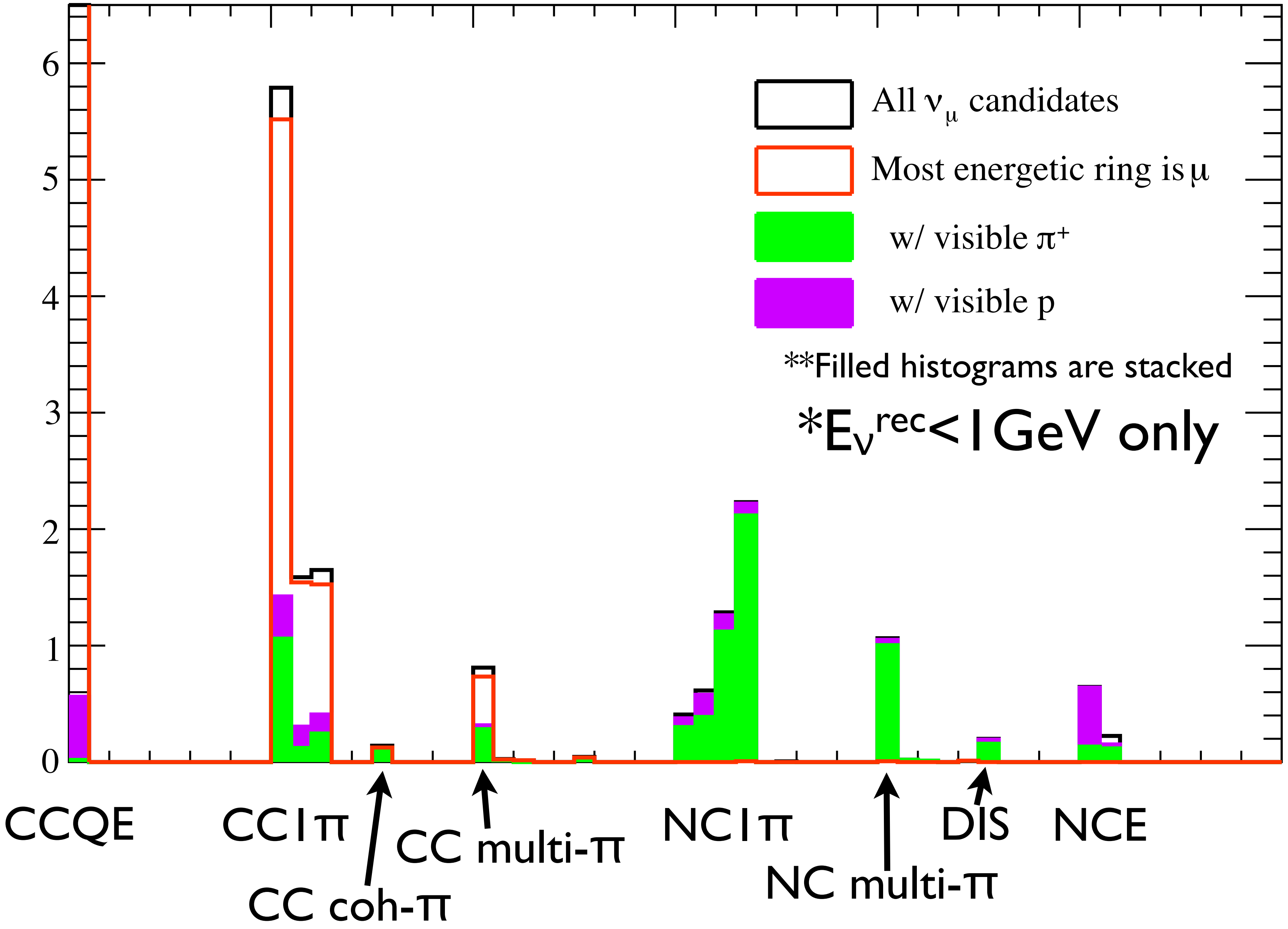
*In the following slides, osc. parameters are:

| | |
|---|---|
| $\sin^2 2\theta_{12}$ | 0.8704 |
| $\sin^2 2\theta_{23}$ | 1.0 |
| $\sin^2 2\theta_{13}$ | 0.1 |
| $\delta_{CP}$ | 0 |
| $\Delta m^2_{21}$ | $7.6\times10^{-5}$eV$^2$ |
| $\Delta m^2_{32}$ | $2.4\times10^{-3}$eV$^2$ |
| Hierarchy | Normal |

T2K event rate after standard $\nu_\mu$ selection cuts



# $\nu_\mu$ backgrounds by NEUT mode



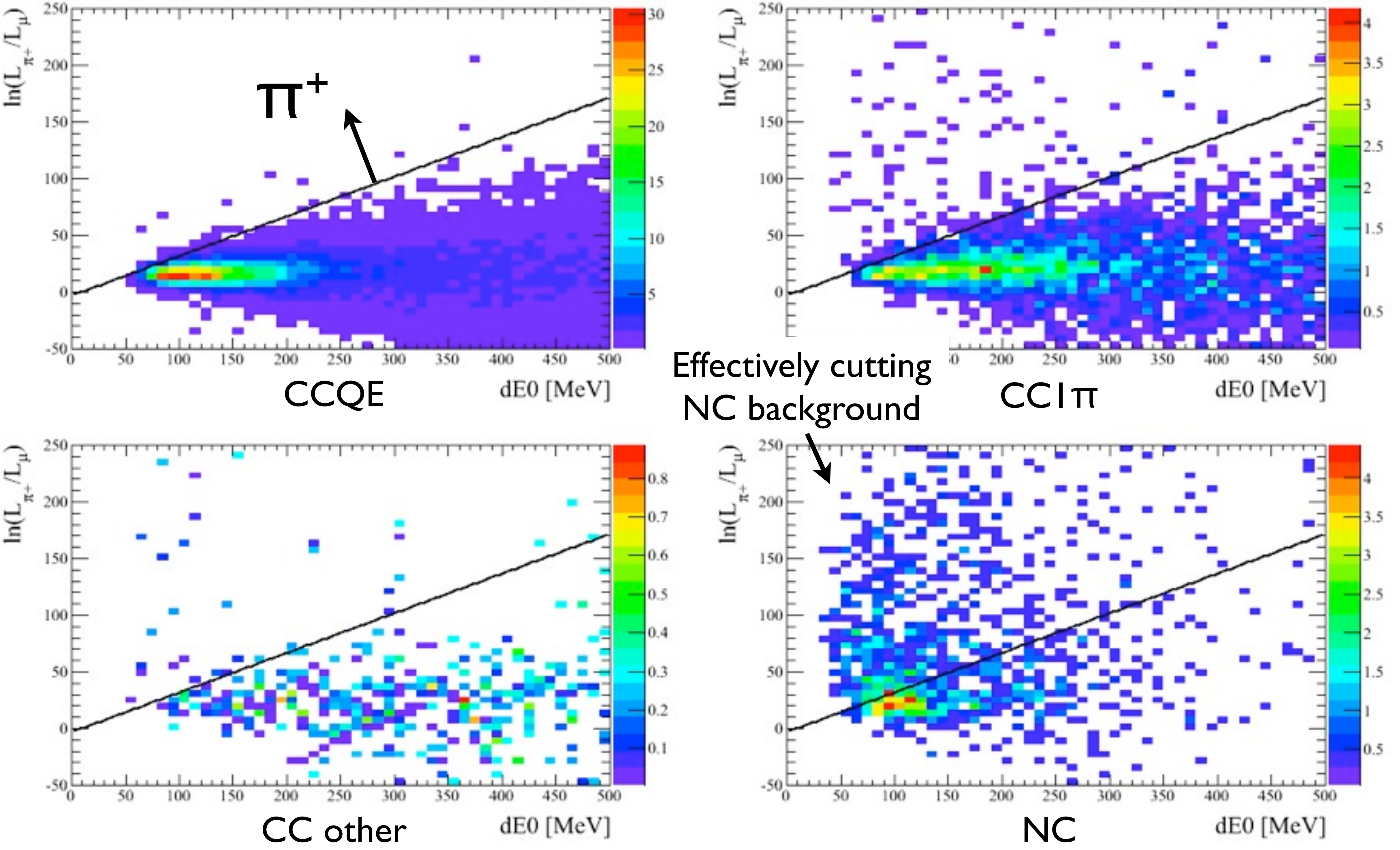
- For most CC backgrounds, μ is the most energetic ring
- NC backgrounds are mostly due to $\pi^+$ rings, mis-ID'd as μ
- NCE background is largely from proton rings

# fiTQun $\nu_\mu$ selection

- Use fiTQun upstream $\pi^+$ fitter to reduce $\pi^+$ backgrounds
  - Take the best-fit likelihood ratio of 1-ring $\mu$ fit and upstream $\pi^+$ fit
    - $\pi^+$'s favour $\pi^+$ hypothesis over $\mu$ hypothesis
      - Thin ring, small $dE_0$ → $\mu$-fit can't reproduce the ring
    - $\mu$'s almost equally favour $\mu$ and $\pi^+$ hypotheses
      - $\pi^+$ fit returns large $dE_0$ → emulates $\mu$-like ring
    - Make a line cut in $dE_0$ - $\ln(L_{\pi+}/L_\mu)$ space
- To select 1-ring events, compare the best-fit likelihood values of 1-ring and 2-ring hypotheses
- We can now make all the $\nu_\mu$ selection cuts using fiTQun variables only:
  - 1-ring, $\mu$-like(vs. e-like), $\mu$-like (vs. $\pi^+$-like), 1R$\mu$-FV, $p_\mu^{rec}$>200MeV/c, $n_{dcy}$<=1

# $\pi^+$ rejection cut

*T2K $\nu_\mu$, all fiTQun $\nu_\mu$ cuts, except the 1R cut and $\pi^+$ cut, are applied



$\pi^+$

CCQE

CC1π

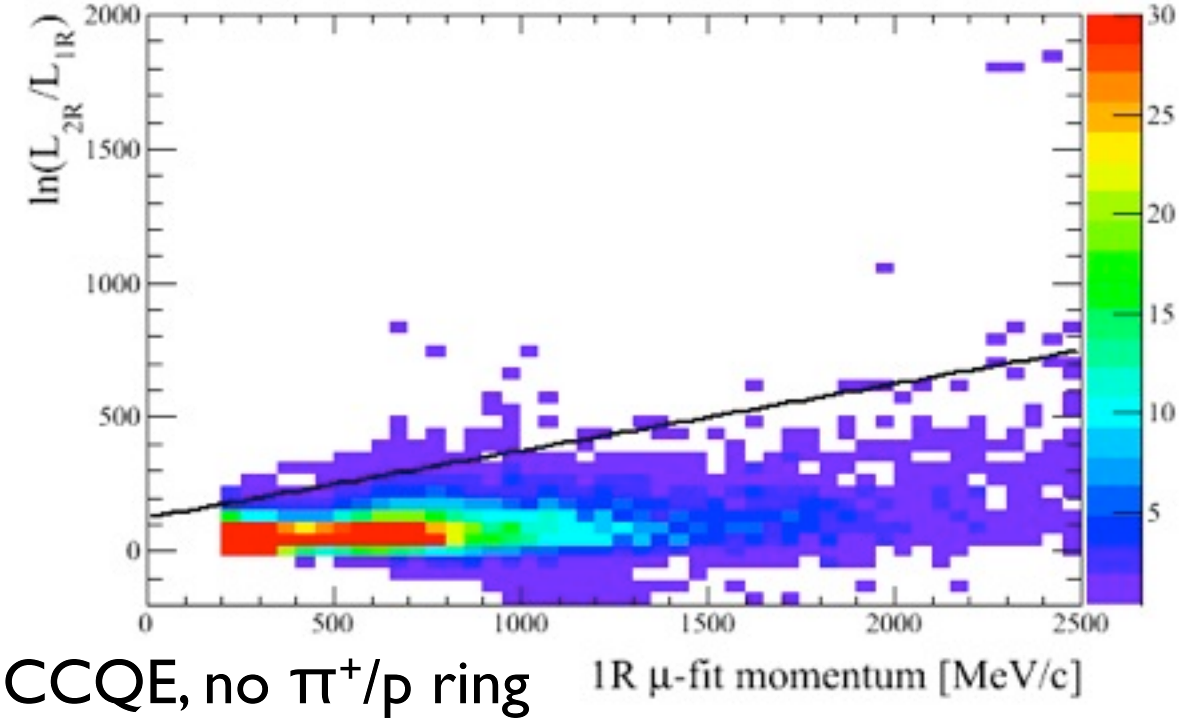
CC other

NC

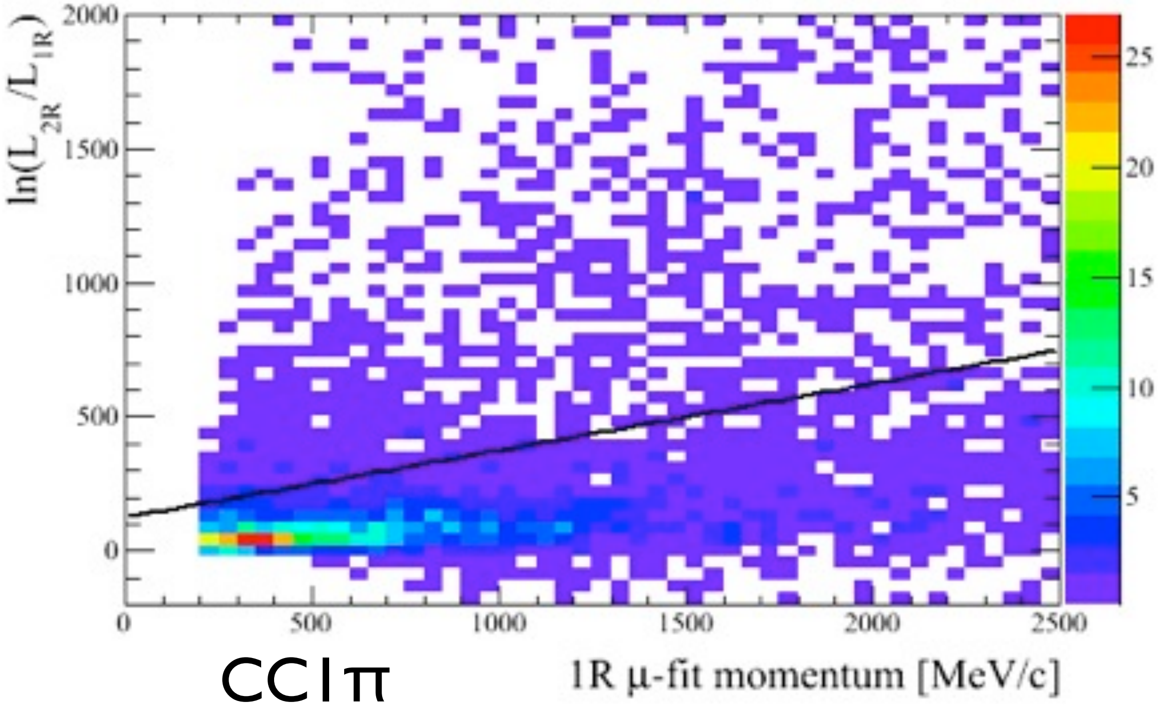
Effectively cutting NC background

# One-ring cut

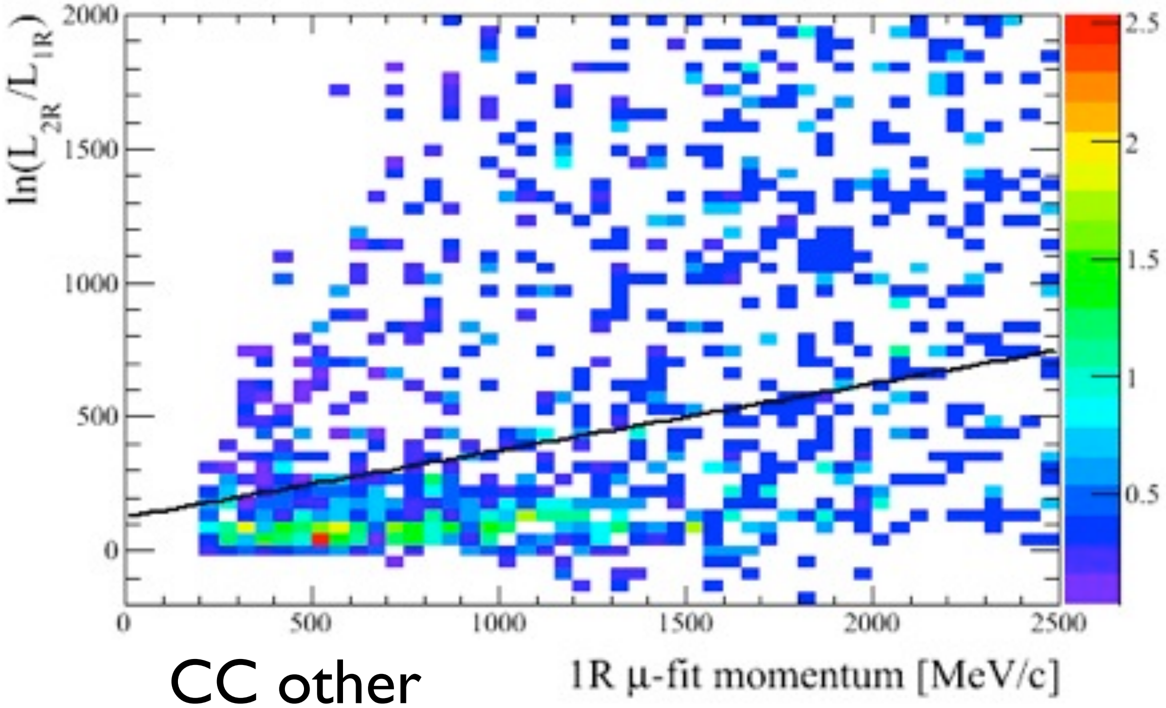
*T2K $\nu_\mu$, all fiTQun $\nu_\mu$ cuts, except the 1R cut and $\pi^+$ cut, are applied



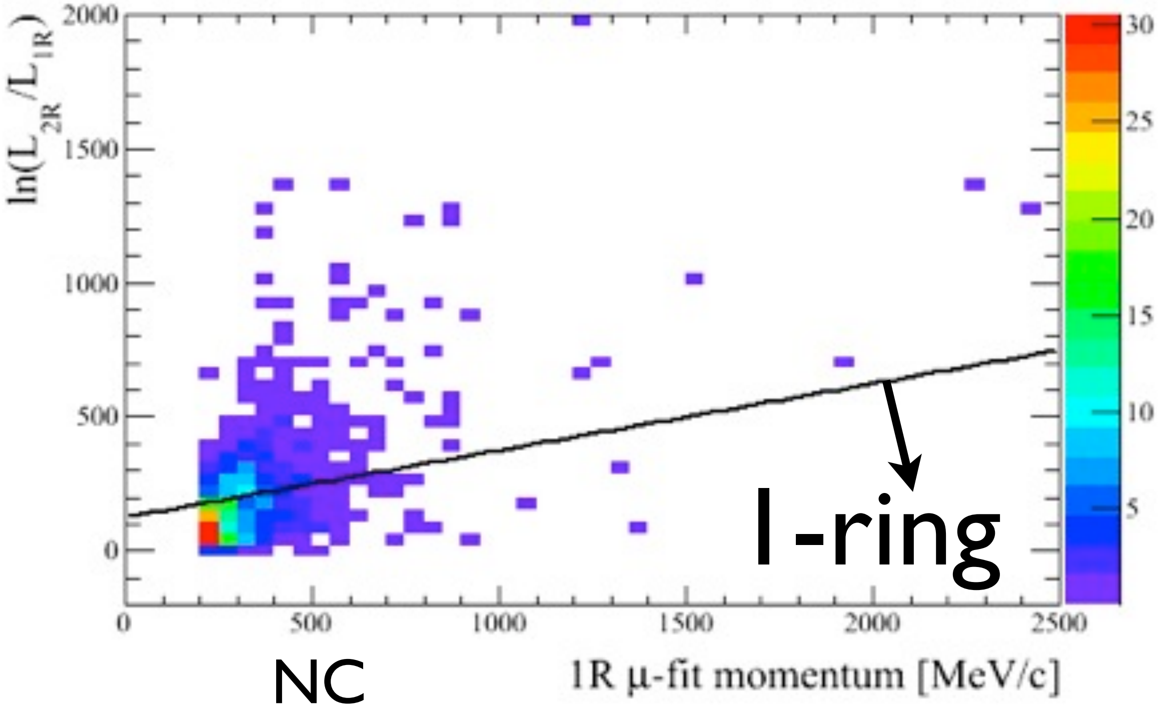
CCQE, no $\pi^+$/p ring



CC1$\pi$



CC other



NC

# Selection efficiencies

*T2K event rate @ 6x$10^{20}$POT, after each $\nu_\mu$ selection cut, w/ 3-flvr. osc.

## Standard selection

Signal purity:
**60.6%**

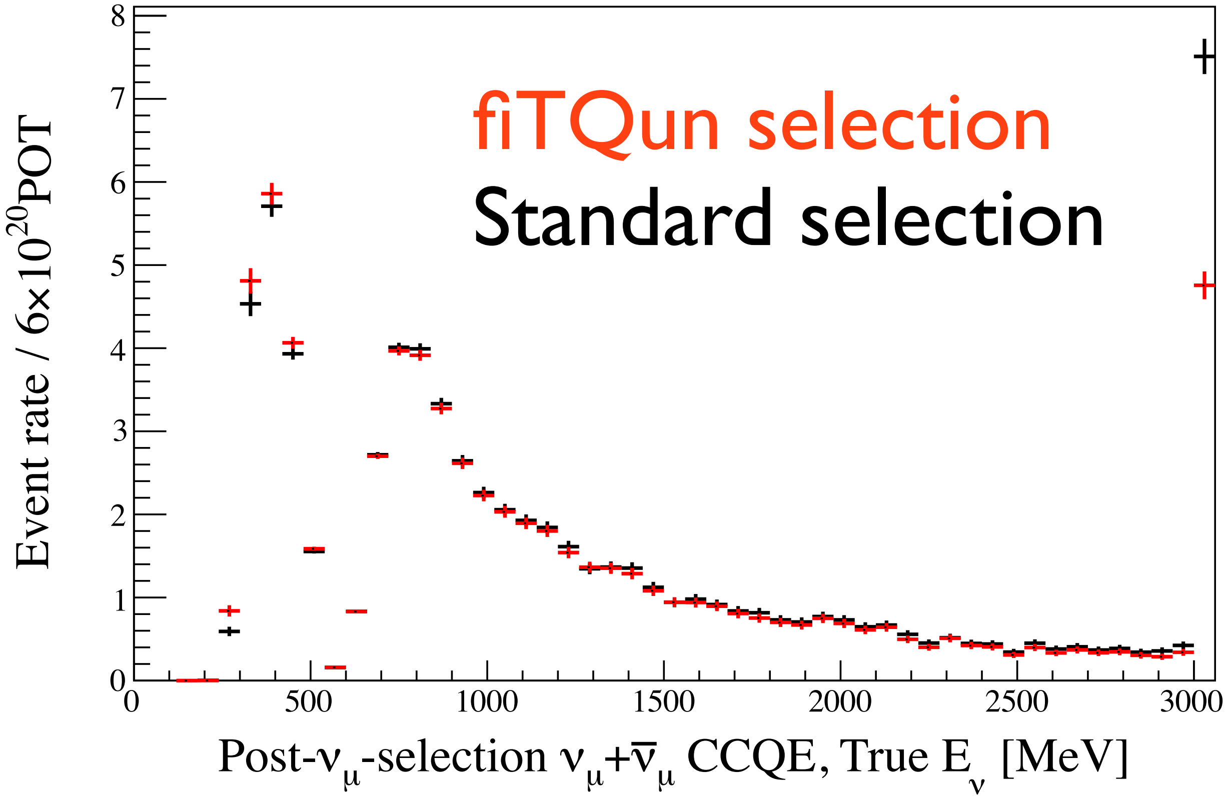
| @ 6x$10^{20}$POT | $\nu_\mu+\bar{\nu}_\mu$ CCQE | $\nu_\mu+\bar{\nu}_\mu$ CC1$\pi$ | $\nu_\mu+\bar{\nu}_\mu$ CC oth. | $\nu_e+\bar{\nu}_e$ CC | NC |
|---|---|---|---|---|---|
| FC trueFV | 81.83 | 68.06 | 87.82 | 38.88 | 102.74 |
| FCFV | 78.09 | 67.36 | 88.26 | 38.63 | 86.26 |
| 1-ring | 73.72 | 39.73 | 18.25 | 30.04 | 24.95 |
| $\mu$-PID | 72.46 | 38.50 | 16.03 | 0.29 | 8.21 |
| $p_\mu^{rec}$>200MeV/c | 71.86 | 38.40 | 16.02 | 0.29 | 7.98 |
| $N_{dcy}$<=1 | **71.03** | **28.93** | **9.32** | **0.29** | **7.63** |
| **Efficiency [%]** | **86.8** | **42.5** | **10.6** | **0.7** | **7.4** |

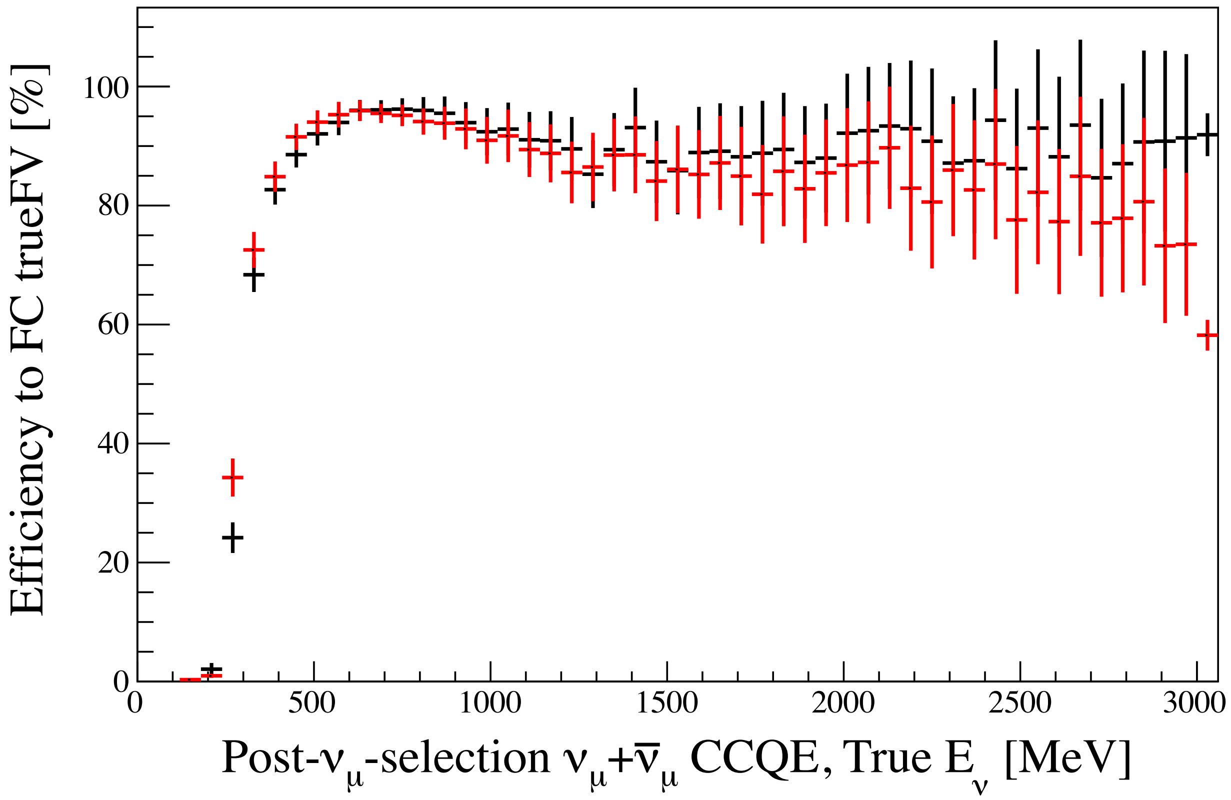
## fiTQun selection

Signal purity:
**69.3%**

| @ 6x$10^{20}$POT | $\nu_\mu+\bar{\nu}_\mu$ CCQE | $\nu_\mu+\bar{\nu}_\mu$ CC1$\pi$ | $\nu_\mu+\bar{\nu}_\mu$ CC oth. | $\nu_e+\bar{\nu}_e$ CC | NC |
|---|---|---|---|---|---|
| FC trueFV | 81.83 | 68.06 | 87.82 | 38.88 | 102.74 |
| FCFV | 80.57 | 65.58 | 72.11 | 35.01 | 91.61 |
| 1-ring | 73.09 | 33.67 | 12.50 | 29.42 | 42.07 |
| $\mu$-PID(w/ $\pi^+$ cut) | 70.14 | 30.81 | 8.01 | 0.02 | 3.41 |
| $p_\mu^{rec}$>200MeV/c | 68.38 | 30.61 | 7.97 | 0.02 | 3.07 |
| $N_{dcy}$<=1 | **67.62** | **22.71** | **4.32** | **0.02** | **2.96** |
| **Efficiency [%]** | **82.6** | **33.4** | **4.9** | **0.1** | **2.9** |
| **Reduction rate to std. sel. [%]** | **4.8** | **21.5** | **53.7** | **92.1** | **61.2** |

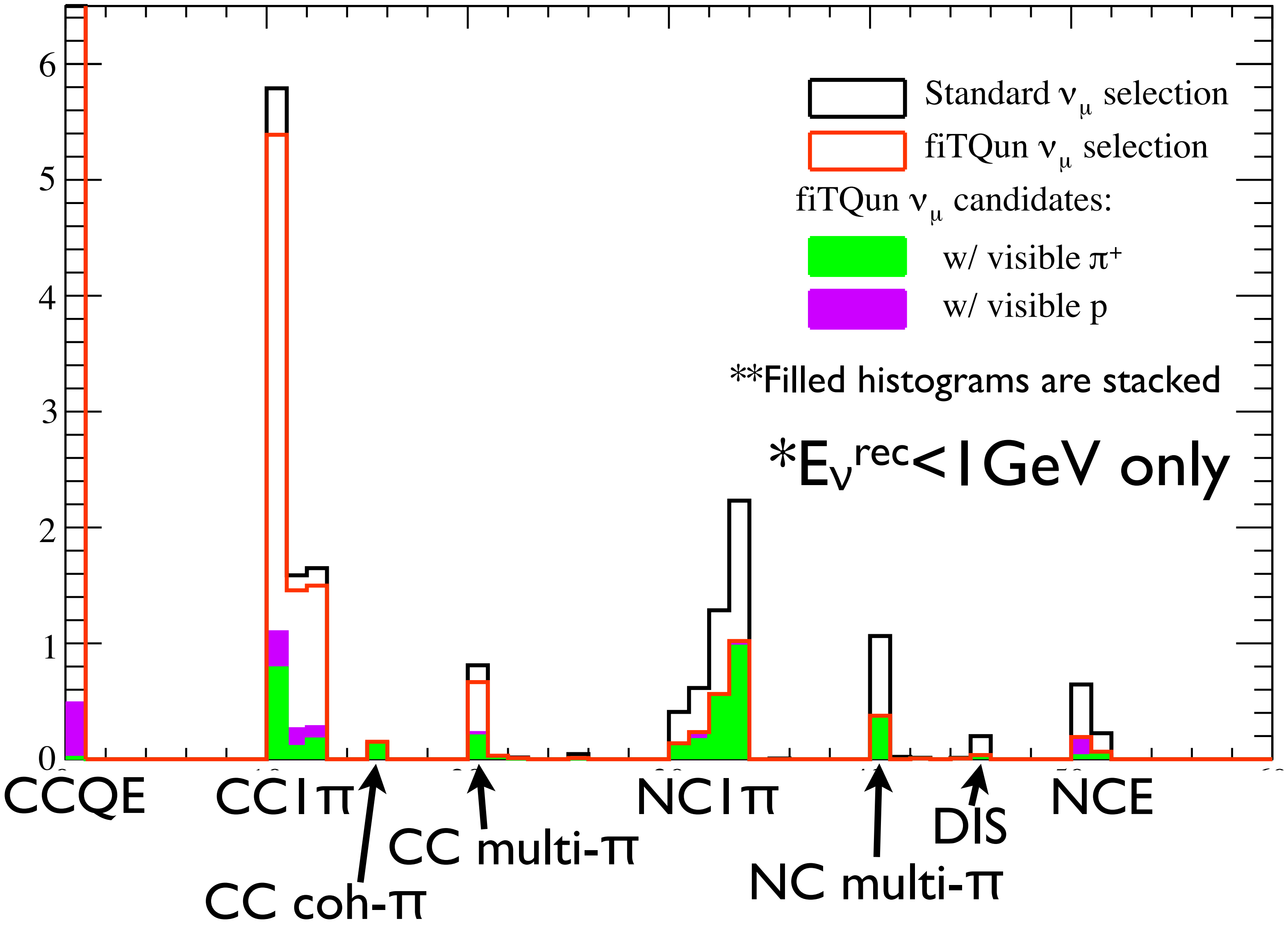
# Signal efficiency comparison





- Around the oscillation dip, signal efficiency of fiTQun selection is not worse compared to standard selection
    - Efficiency is higher at lower energy (<600MeV)
- Signal loss by fiTQun selection is mostly in the high-energy tail region (>3GeV)

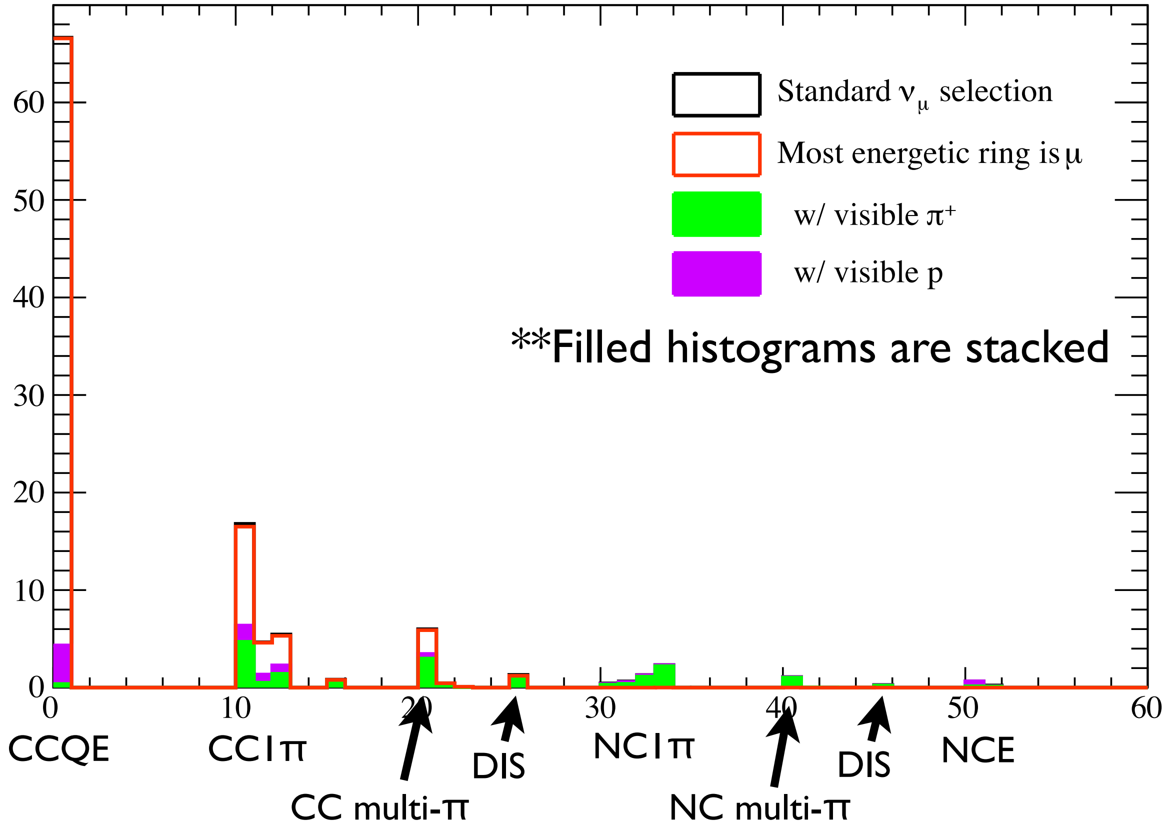
# fiTQun $\nu_\mu$ selection: backgrounds

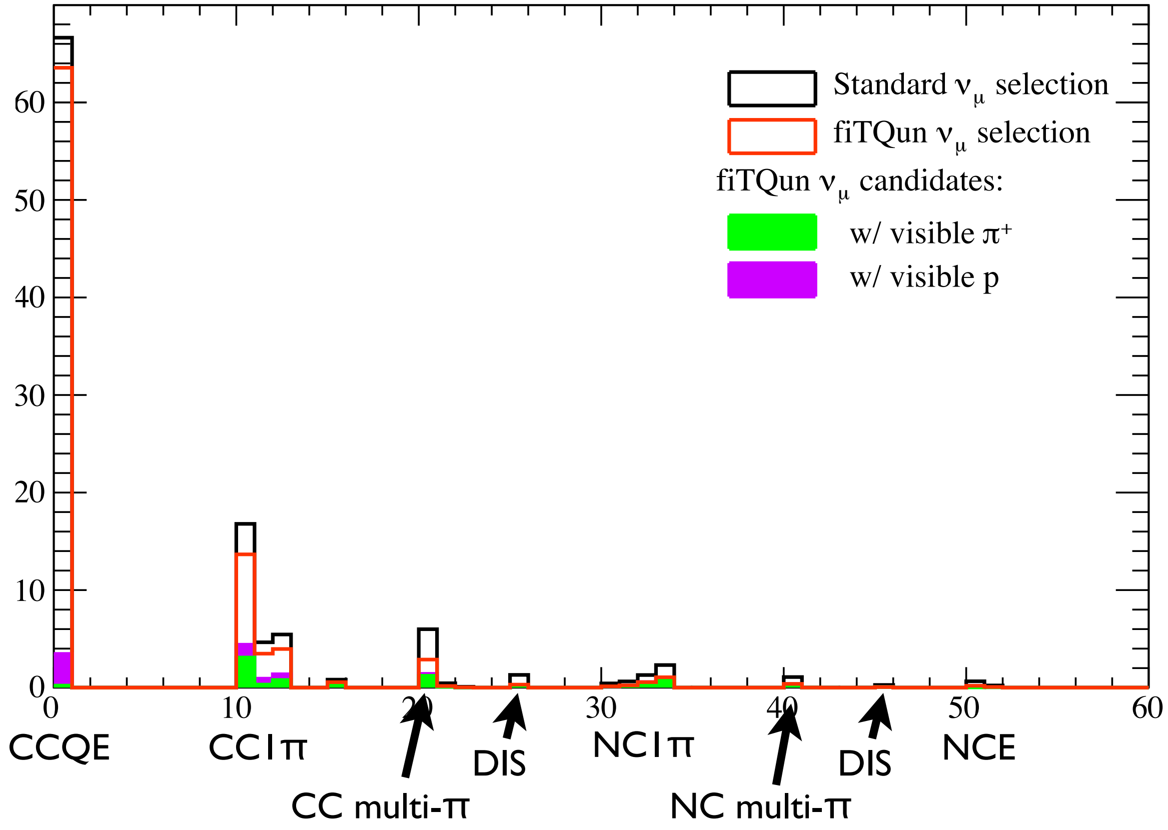


- Significant reduction of NC backgrounds; $\pi^+$'s are properly identified
- Single proton ring events are mostly rejected by $\pi^+$ cut, large reduction of NCE background
  - Proton hypothesis - only partially implemented now, could work even better
- CC background reduction by $\pi^+$ cut(for events w/ invisible $\mu$) and 1-ring cut
  - Reduction by 1-ring cut is seen more in the higher energy region(not included in this plot)

# Including higher energy events...

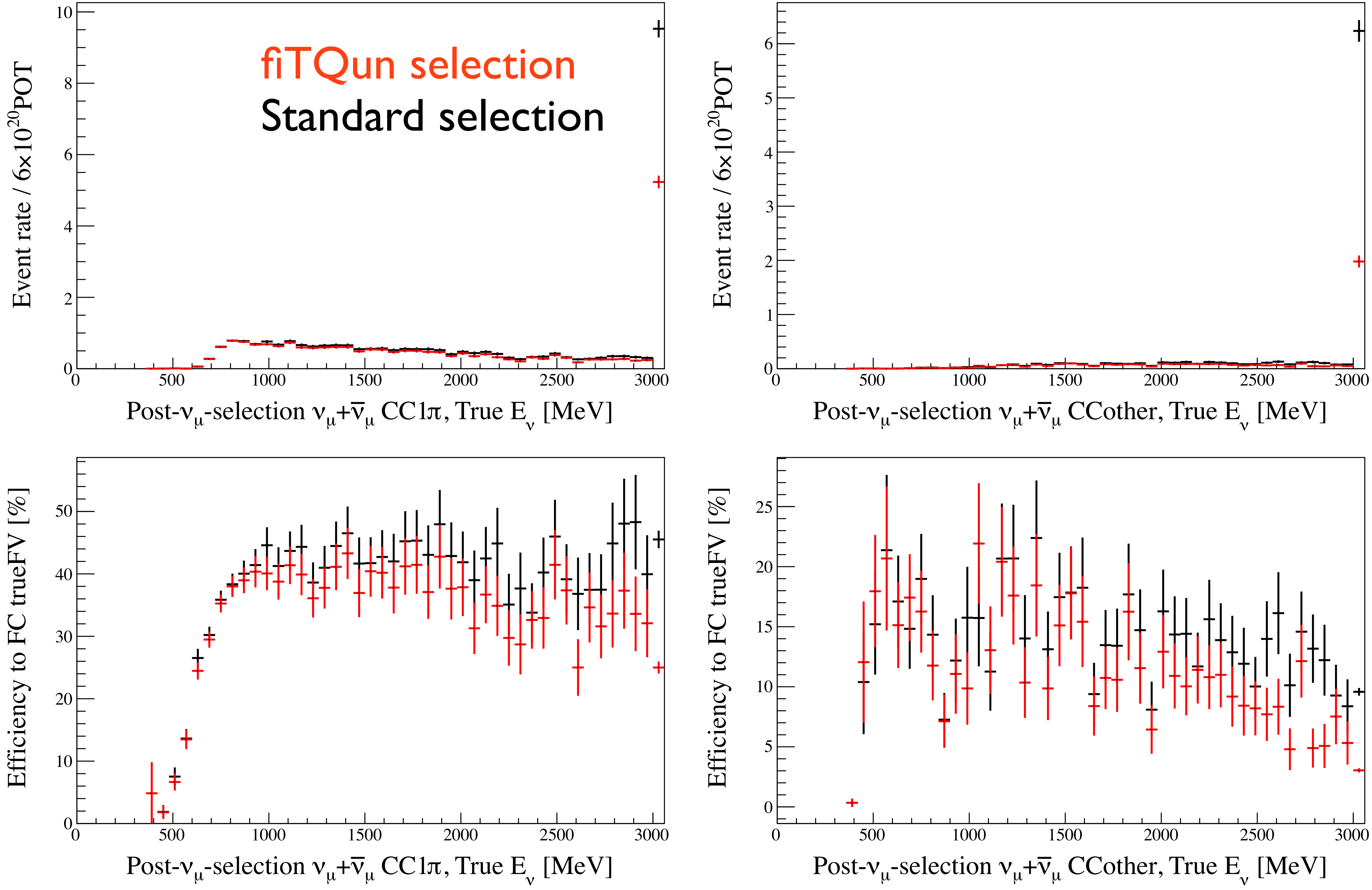
*Includes full range of $E_\nu^{rec}$



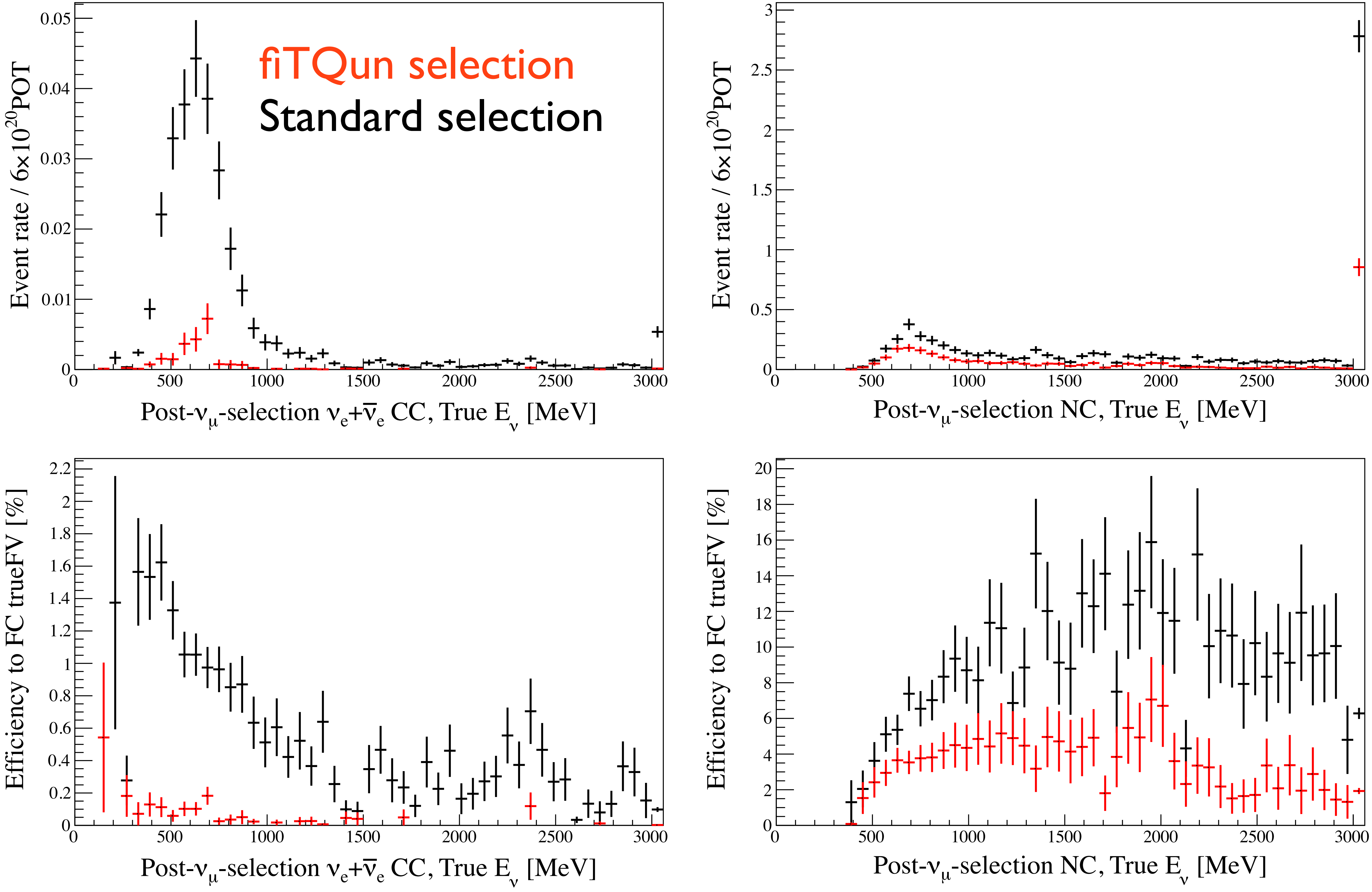


- Larger CC background reduction for higher energy events
  - Multi-ring fitter is sensitive to darker rings in the presence of bright rings
    - fiTQun 1-ring cut rejects $\pi^+$/p rings which are missed by apfit 1-ring cut
- CCQE efficiency loss is mainly in the higher energy region
  - Need to optimize the the 1-ring cut criterion to maximize sensitivity, balancing background rejection and signal efficiency

# $\nu_\mu$ selection efficiencies



# $\nu_\mu$ selection efficiencies



# Processing time

- Effort was made to reduce CPU time
  - 1R fit takes ~40% less time now compared to older versions
- Overall, fiTQun requires x3~5 more CPU time compared to apfit+POLfit
  - Depends on the type of event (# of hits/rings/sub-events etc.)
    - fiTQun uses all PMTs while apfit, in general, uses hit PMTs only
- Difference between apfit tends to get smaller for more complex event topology

| Average time per event [sec] | apfit+POLfit | fiTQun | | | | |
|---|---|---|---|---|---|---|
| | | Total | Sub-evt+1R | $\pi^0$ | CM $\pi^0$ | MR |
| e particle gun 0-500MeV/c | **52.1** | **229.7** | 33.1 | 26.0 | 33.5 | 137.2 |
| $\pi^0$ particle gun 0-500MeV/c | **84.4** | **256.4** | 37.0 | 34.3 | 26.8 | 158.3 |

*Measured on SciNet GPC