A look at anti-neutrino oscillations

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Outline

- Introduction
- Event selection
- Comparison of MC and data
- Near and Far comparisons
- Summary

Introduction

- Compare expected and observed number of anti-neutrinos at Far detector
- In lowest order approximation, assuming that anti-neutrinos have the same oscillation parameters, we expect that R is the same for two detectors:

  R = number of anti-neutrinos/number of neutrinos
- Make a first, simple attempt to calculate R_far/R_near
- Use MC to study selection of neutrino and anti-neutrino – this is not data to MC comparison
- Systematic effects are ignored

Data and MC samples

- Use all available data from June 1st though December 31st
- Near data: 5,185,231 spills with 1.00e20 PoT
- Far data: 3,087,818 spills with 5.57e19 PoT – used all R1.18.2 FD sntp ntuples at Fermilab afs space
- Use R1.18.2 LE-10 carrot MC

  Near: 789 “n130....L010185” sntp files

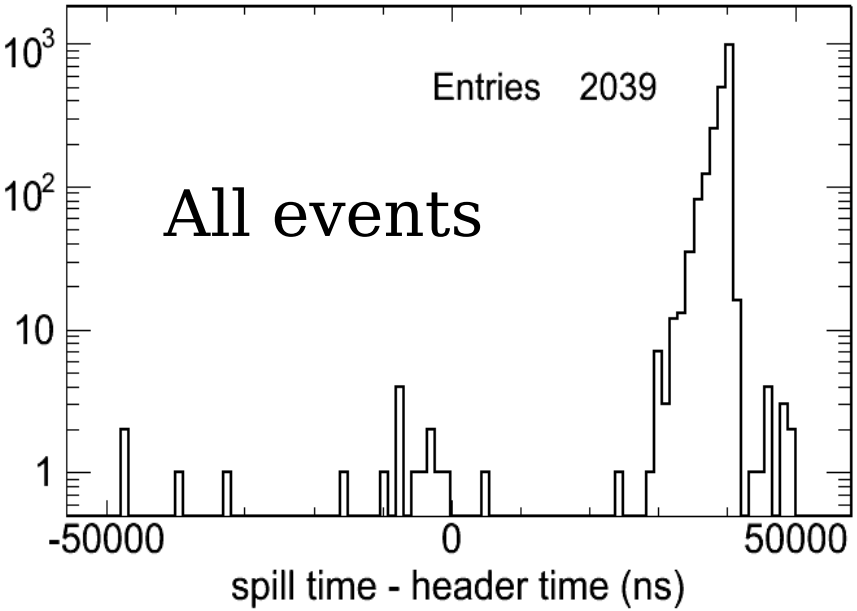
  2.42e13 PoT * 315469 snarls = 7.63e18 PoT

  Far: 100 “f210....L010185” sntp files

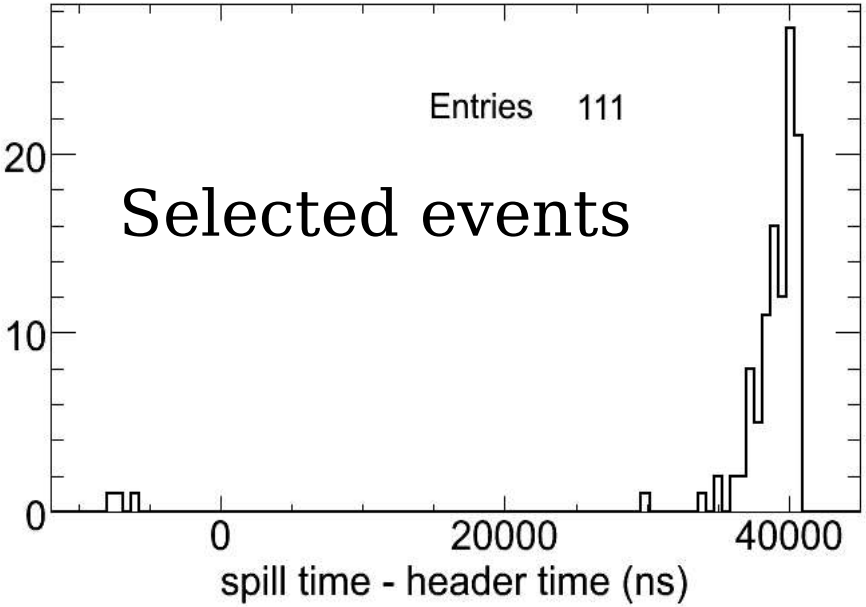
  2.90e20 PoT * 100 files
- Apply beam quality cuts
- Select events in the fiducial volume
- Require “good” track quality
- Use David's pid method to select CC events
- Apply advertised corrections to shower energy and muon momentum from range

Far timing and beam cuts

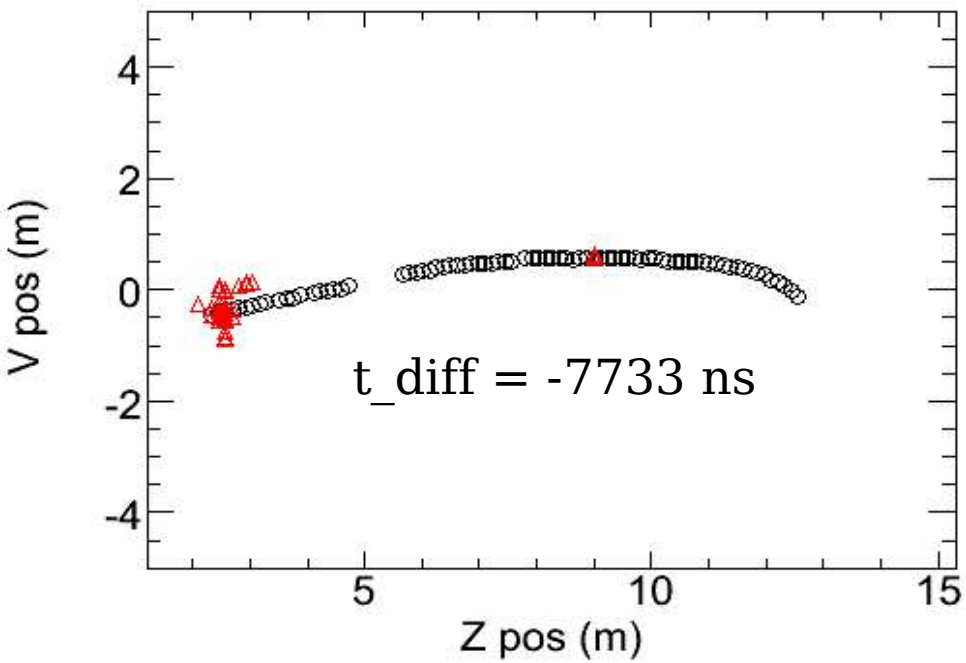
- For FD require close in time spill:
  |header time – spill time| < 0.1ms
- Header time is VldContext of NtpStRecord
- Remove events with LI digits:
  evthdr.litime > 0.0

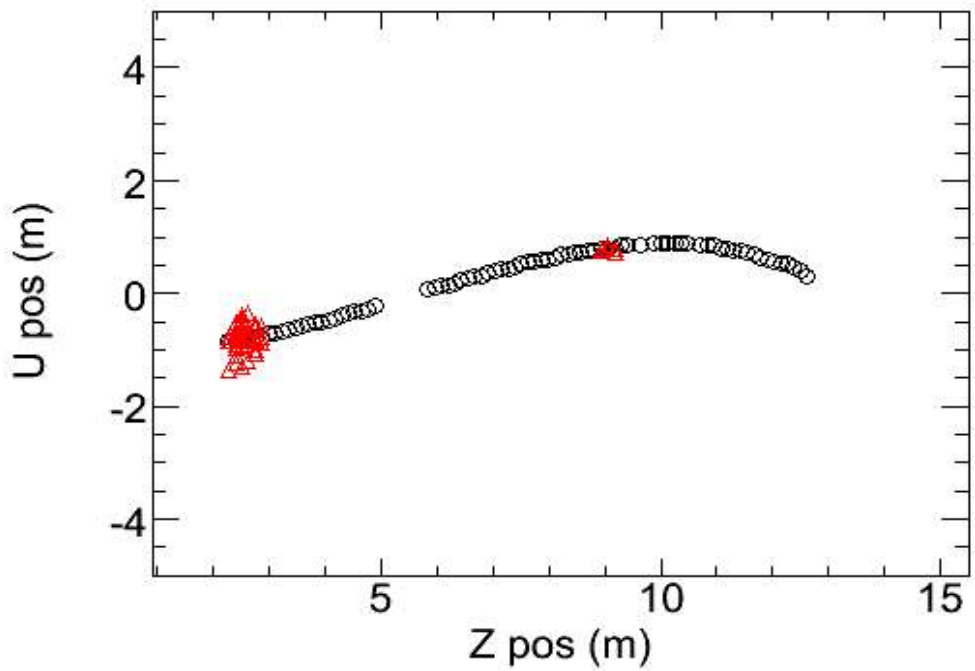


- Apply loose beam quality cuts for both detectors
- 0.5 < tortgt < 30 (in units of e12)
- 170kA < |max_horn_cur| < 190kA
- 0.0001m < beam_width_x = 0.0015
- 0.0001m < beam_width_y < 0.0015



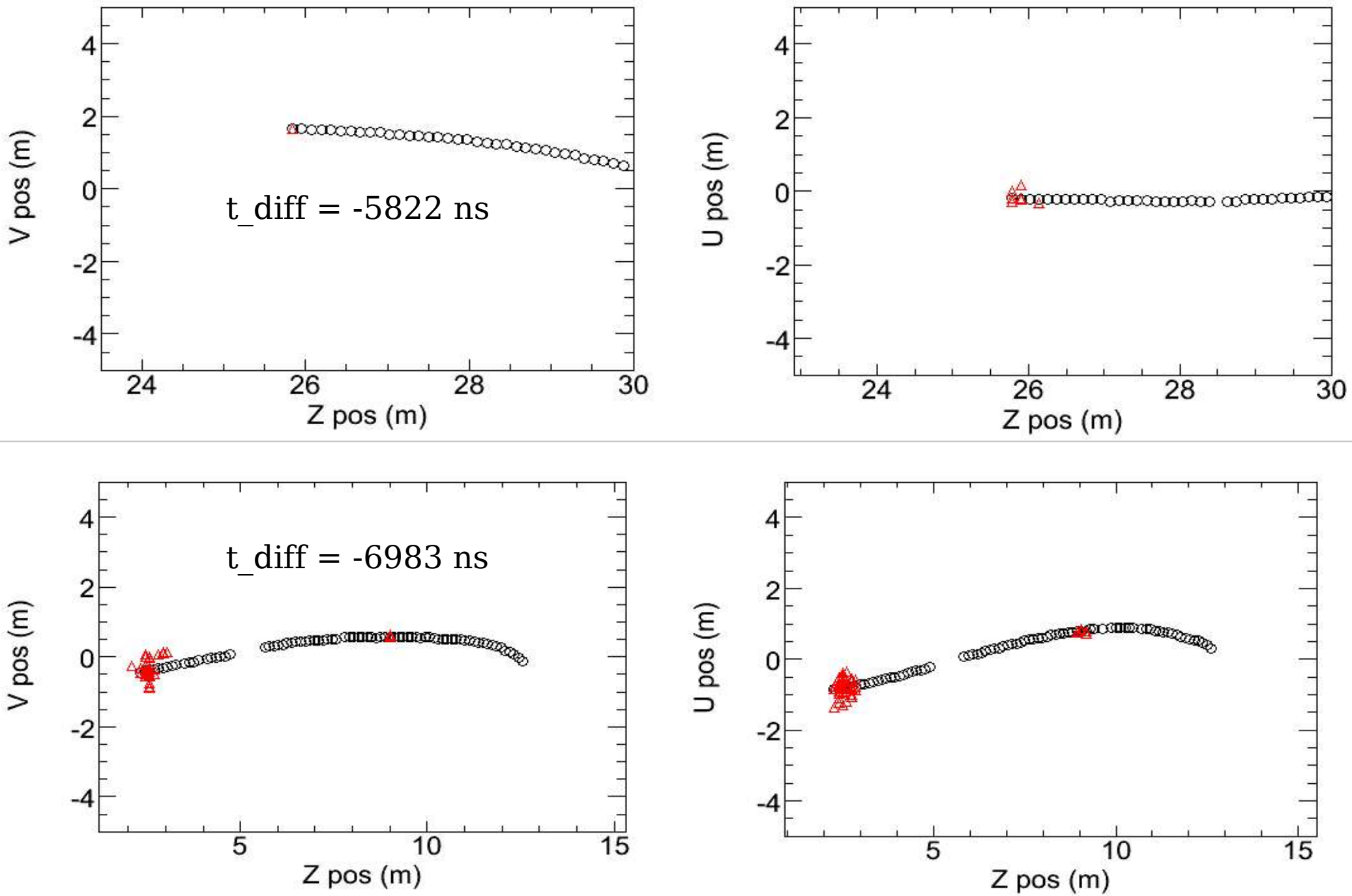
Out of time FD events





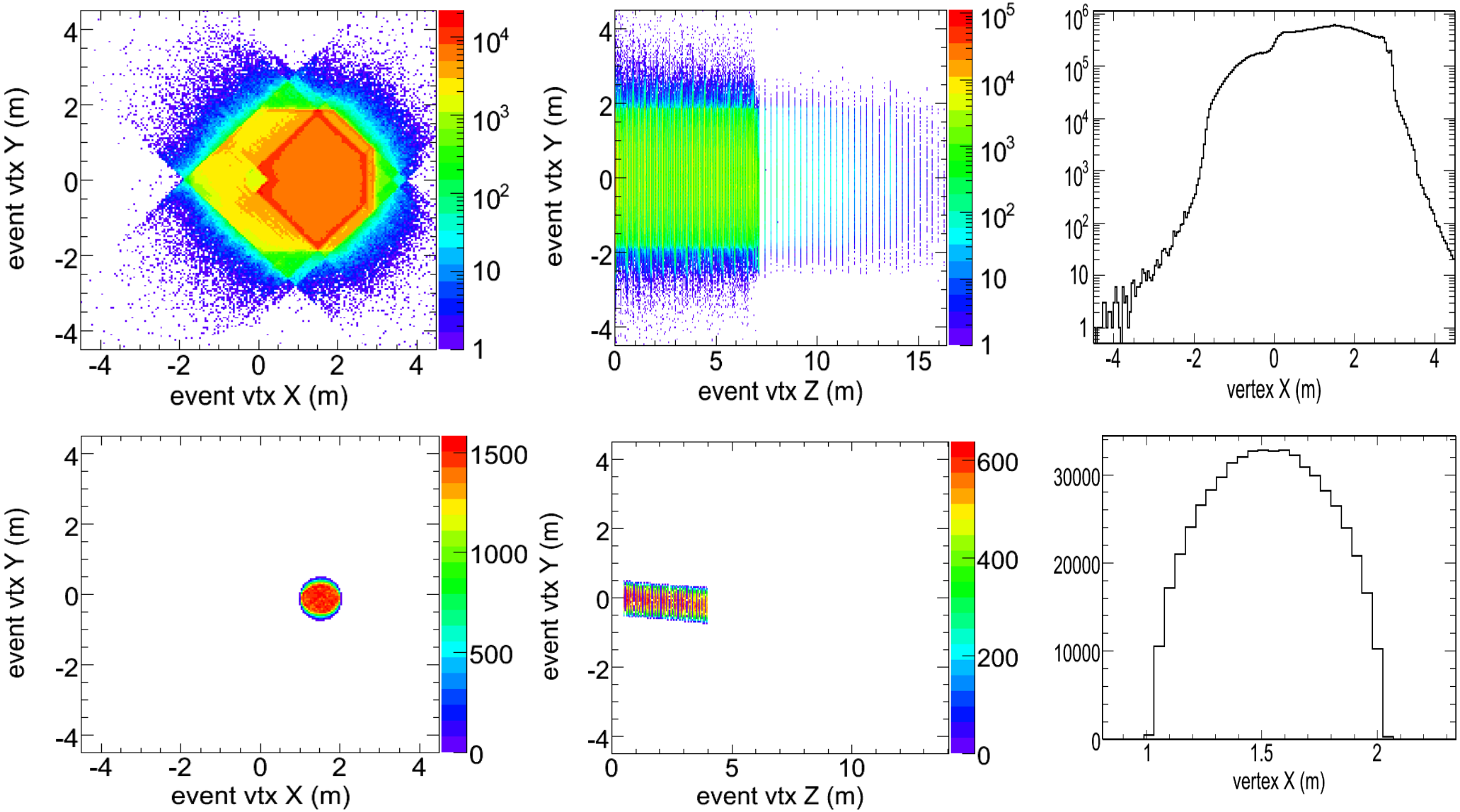
- There are three events that seem to have wrong timing
- I will look very carefully at these events
- Include them in the total sample

Out of time FD events



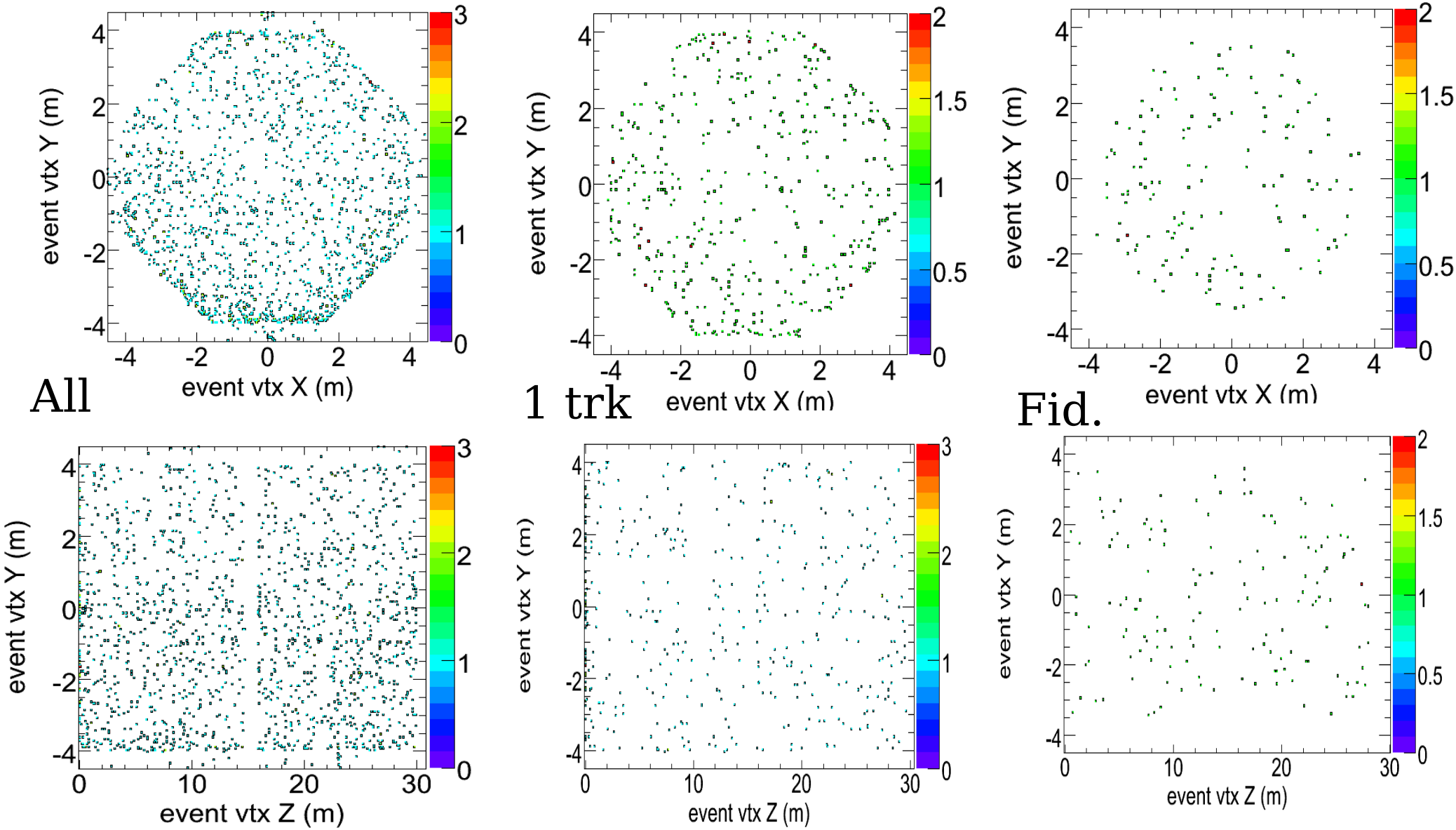
Near fiducial volume

- sqrt((vtx_X - beam_X)^2 + (vtx_Y – beam_Y)^2) < 0.5m
- beam_X = 1.529m, beam_Y = – 0.058 * vtx_Z
- 0.5 m < vtx_Z < 4.0 m



Far fiducial volume

- 0.5m < sqrt(trk_vtx_X^2 + trk_vtx_Y^2) < sqrt(14.0) m
- 0.5m < trk_vtx_Z < 14.3m OR 16.2m < trk_vtx_Z < 28.0



Track quality cut

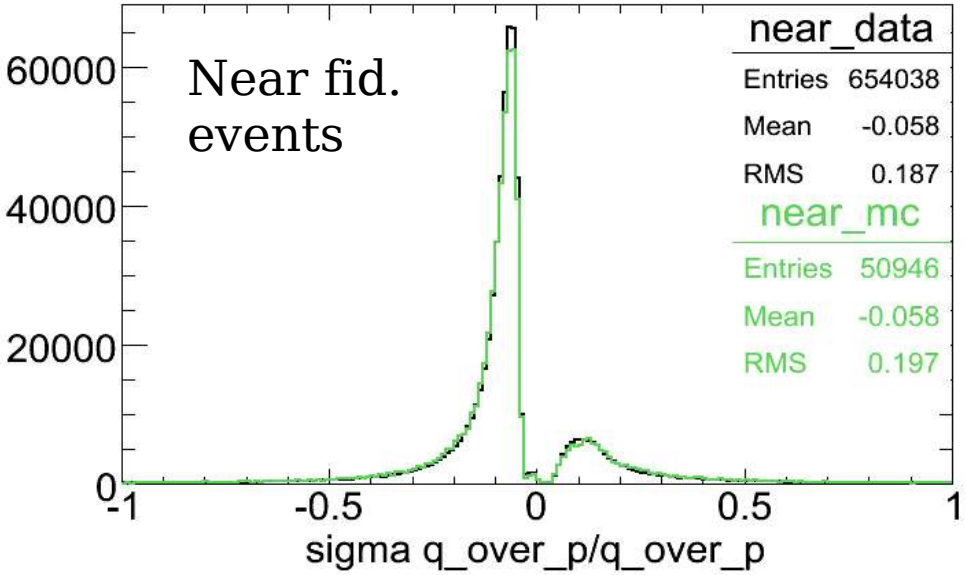
- Event contains exactly 1 track
- Good fit: sigma q_over_p/q_over_p < 0.3 and fit.pass = true
- Far: cosine of track direction (at the vertex) with beam axis > 0.6
- Track is stopping if:

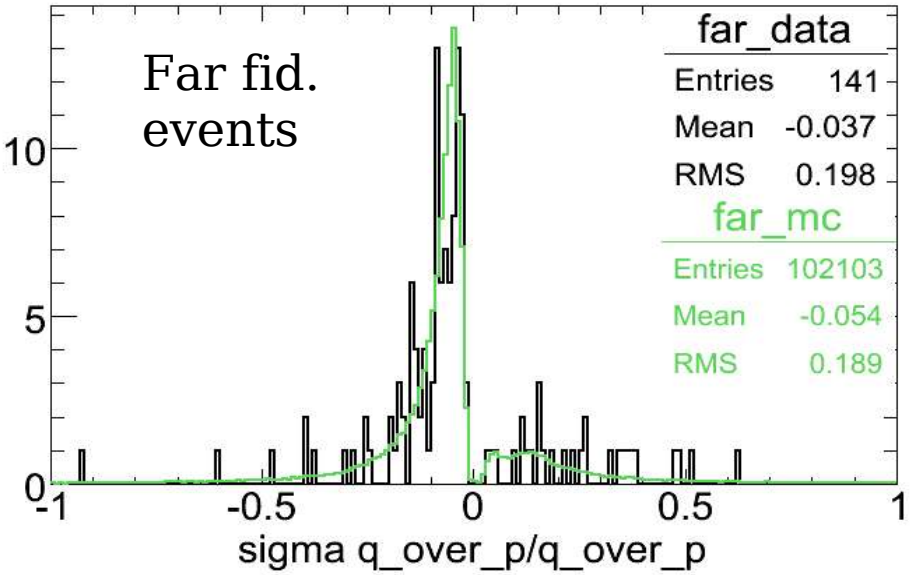
Near: strip 17 < trk_end_U < strip 47 (partial U)

strip 20 < trk_end_V < strip 50 (partial V)

trk_end_Z < 15.0m

Far: track's end vertex is in the fiducial volume

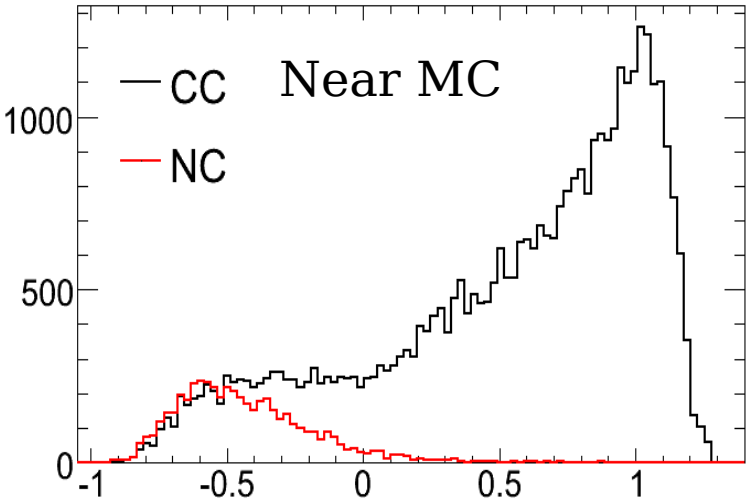


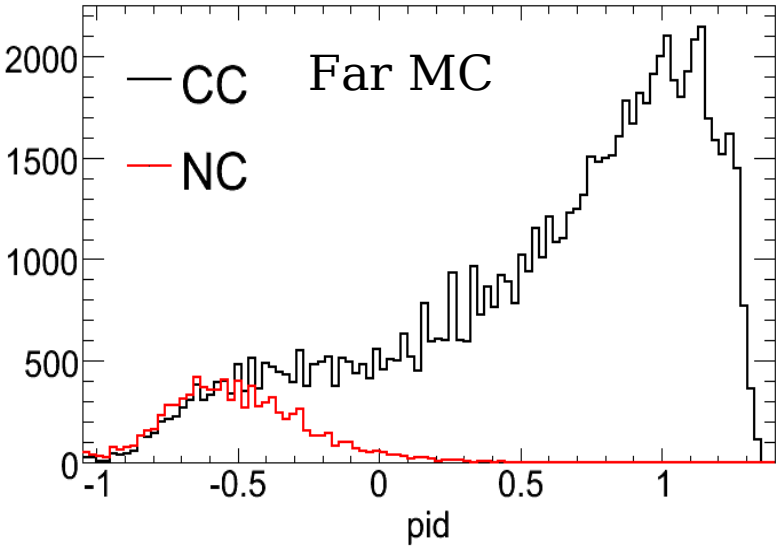


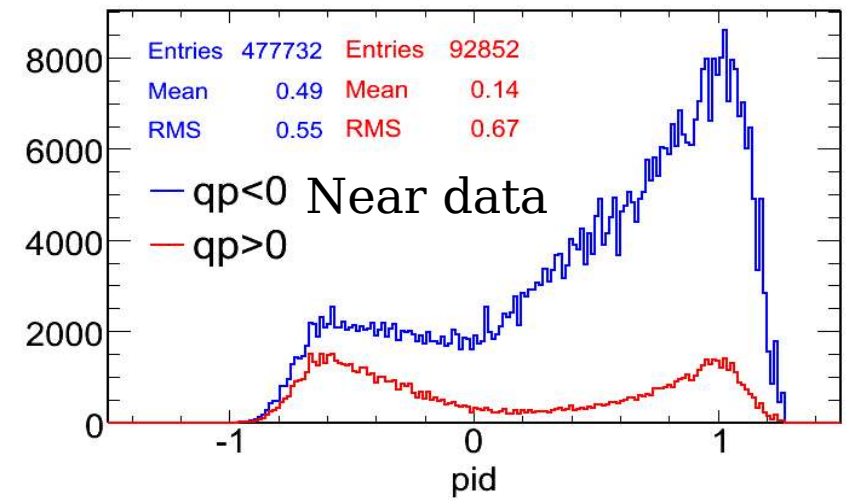
CC selection (MC)

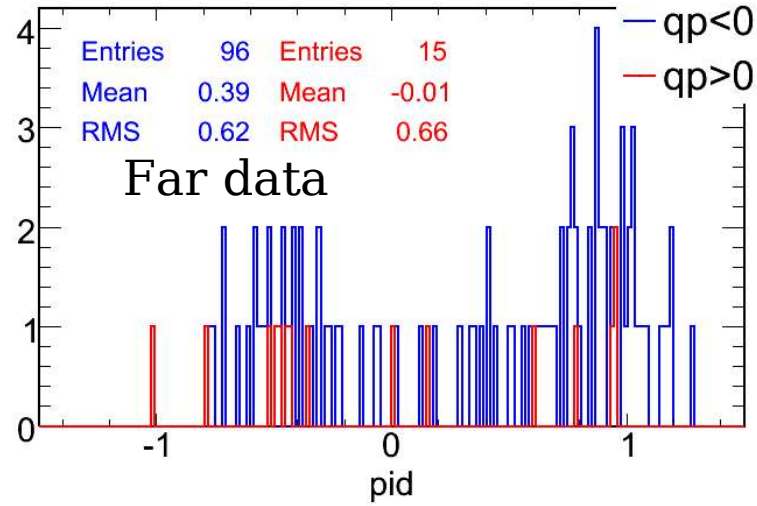
- Use David's pid method to select CC events
- Calculate PDF for MC events that passed fiducial and track cuts
- From <u>these events</u> select CC sample with pid > 0.0
- Efficiency = Selected events/All events
- Purity = CC events/Selected events

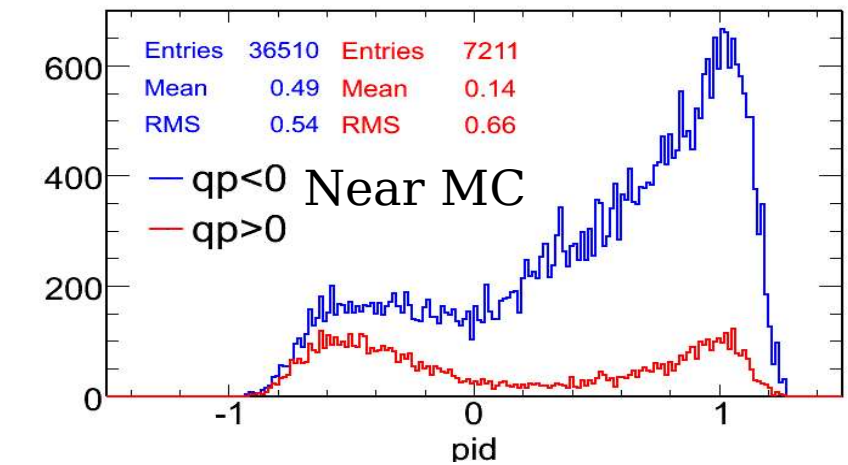
	ND, pid > 0.0	ND, pid > -0.2	FD, pid > 0.0	FD, pid > -0.2
Efficiency	73.90%	79.50%	74.60%	79.90%
Purity	99.10%	97.80%	99.50%	98.50%

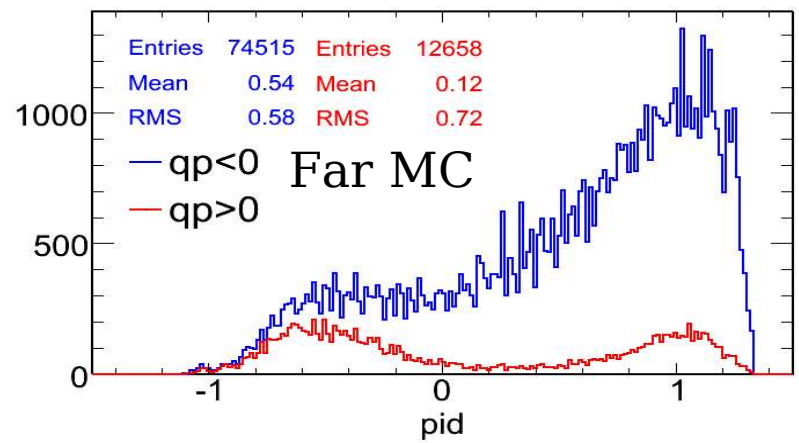


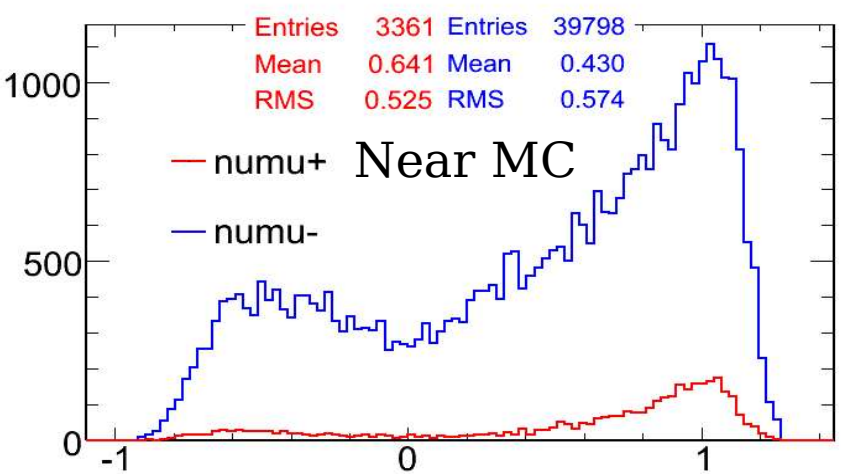


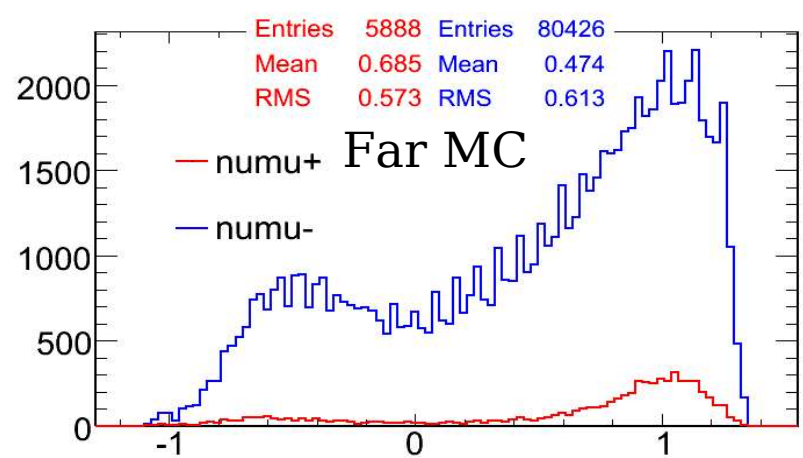

Entries 477732 Entries 92852
Mean 0.49 Mean 0.14
RMS 0.55 RMS 0.67
qp<0
qp>0
Near data
pid


Entries 96 Entries 15
Mean 0.39 Mean -0.01
RMS 0.62 RMS 0.66
qp<0
qp>0
Far data
pid


Entries 36510 Entries 7211
Mean 0.49 Mean 0.14
RMS 0.54 RMS 0.66
qp<0
qp>0
Near MC
pid


Entries 74515 Entries 12658
Mean 0.54 Mean 0.12
RMS 0.58 RMS 0.72
qp<0
qp>0
Far MC
pid


Entries 3361 Entries 39798
Mean 0.641 Mean 0.430
RMS 0.525 RMS 0.574
numu+
numu-
Near MC


Entries 5888 Entries 80426
Mean 0.685 Mean 0.474
RMS 0.573 RMS 0.613
numu+
numu-
Far MC

Selection results for MC

	ND, events	ND %	FD, events	FD %
Total	2,588,384		184,230	
1 event/snarl			173,284	
Single track	2,001,093		145,400	
Fiducial	56,966	100.00%	107,308	100.00%
Good track	43,721	76.75%	88,762	82.72%
Trk direction			87,173	81.24%
PID > 0.0	32,293	56.69%	65,016	60.59%
Qp < 0	28,796	50.55%	59,238	55.20%
Qp > 0	3,497	6.14%	5,778	5.38%

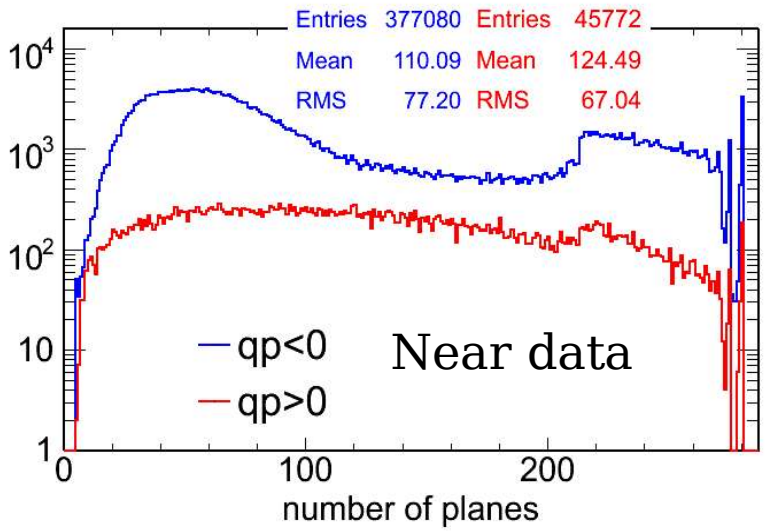
	Numu+	Numu-	Nue+	Nue-	CC	NC	Sign purity
ND, Qp < 0	97	28,678	16	5	28,646	150	0.34%
FD, Qp < 0	42	59,190	6	0	59,075	163	0.07%
ND, Qp > 0	2747	740	0	10	3370	127	26.94%
FD, Qp > 0	4918	853	0	7	5603	175	17.34%

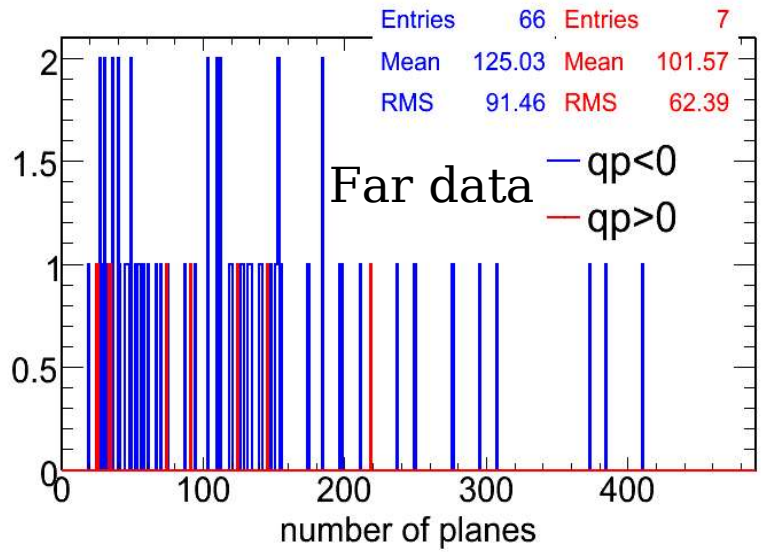
Selection results for data

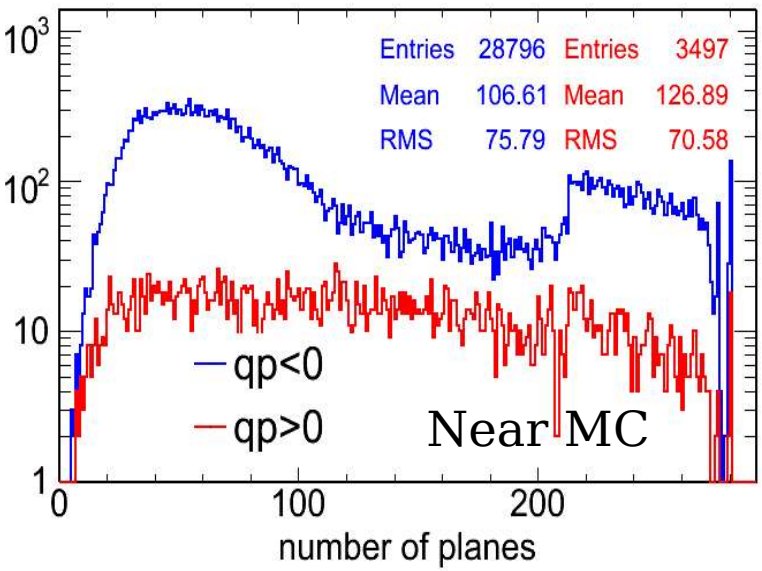
	ND, spills	FD, spills
Total spills	5,185,231	3,087,818
# of events>0	4,666,638	2,937
Timing		2,363
Beam cuts	4,420,503	1,829
1 event		1,787

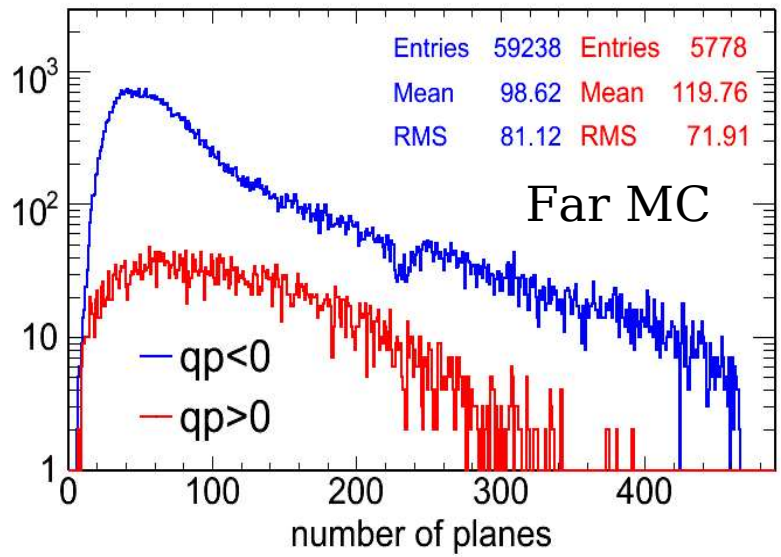
	ND, events	ND %	FD, events	FD %
Total events	33,996,045		1,787	
Single track	26,349,698		448	
Fiducial	763,713	100.00%	149	100.00%
Good fit	570,584	74.71%	117	78.52%
Trk direction			111	74.50%
PID > 0.0	422,852	55.37%	73	48.99%
Qp < 0	377,080	66.09%	66	44.30%
Qp > 0	45,772	8.02%	7	4.70%

Number of planes

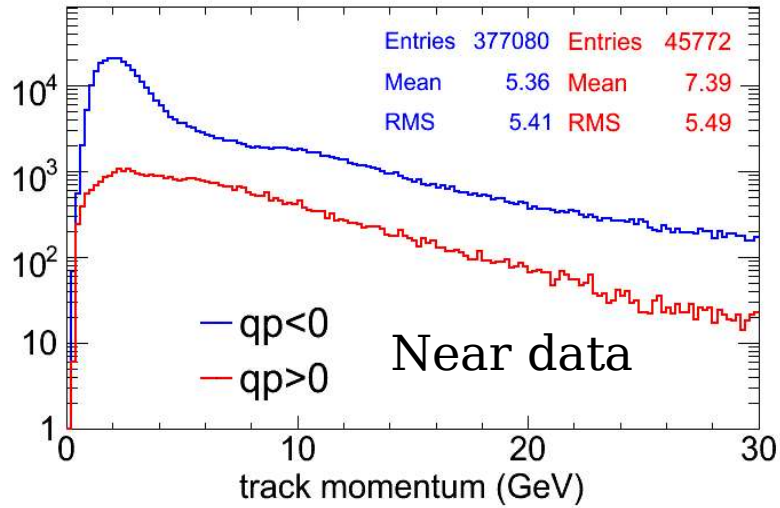


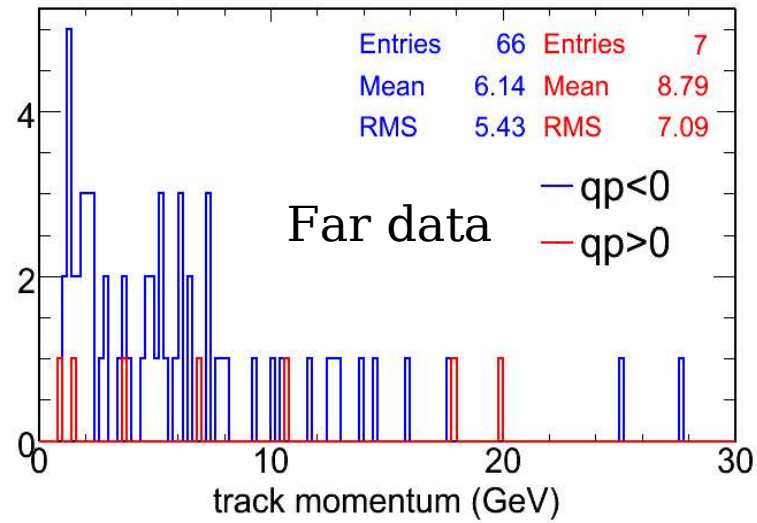


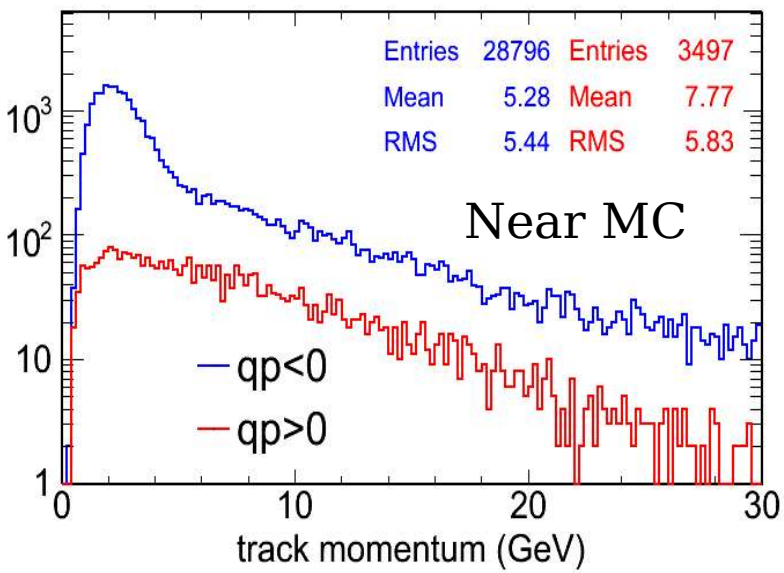


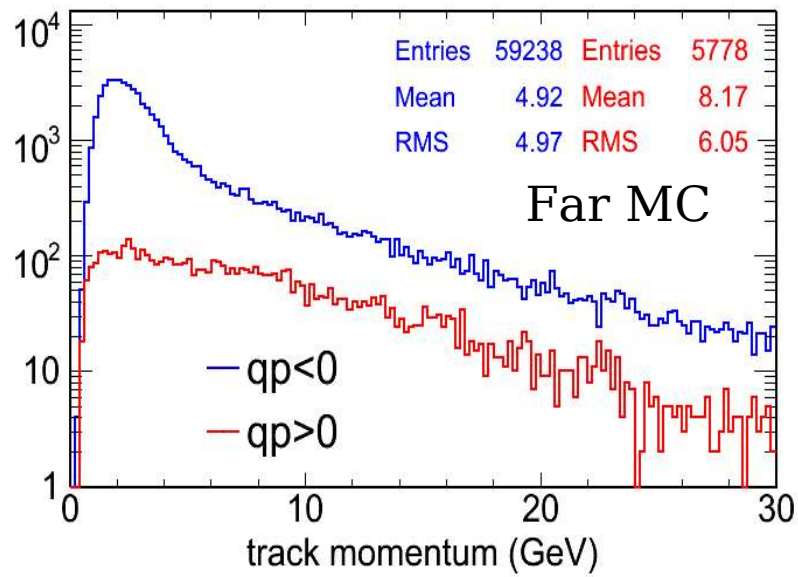


Muon momentum

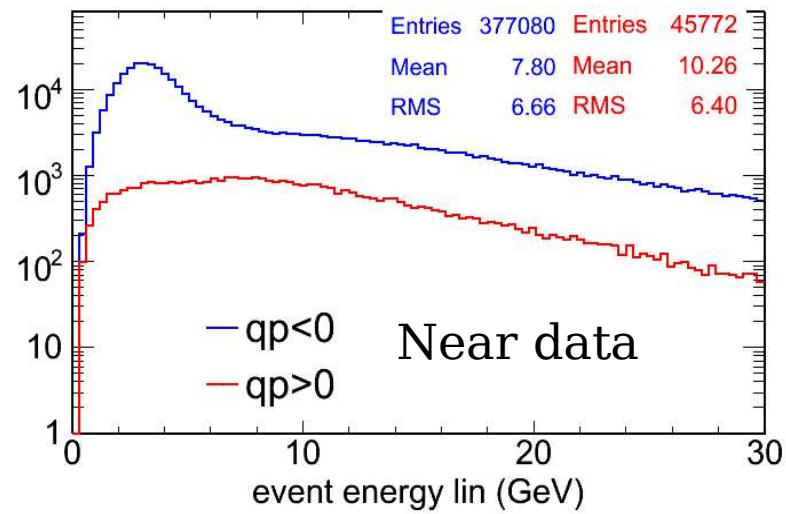


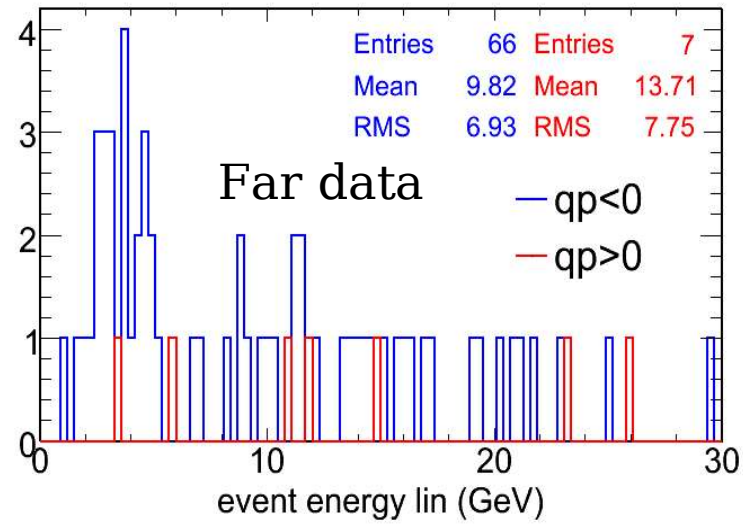


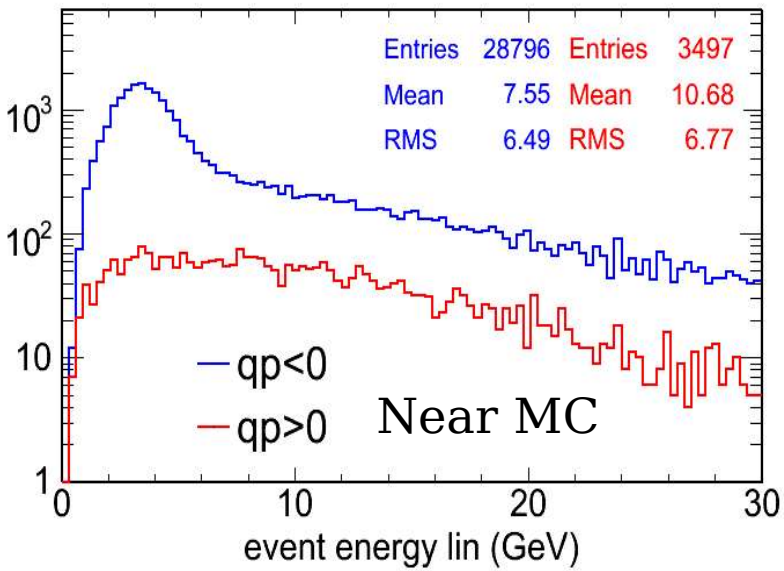


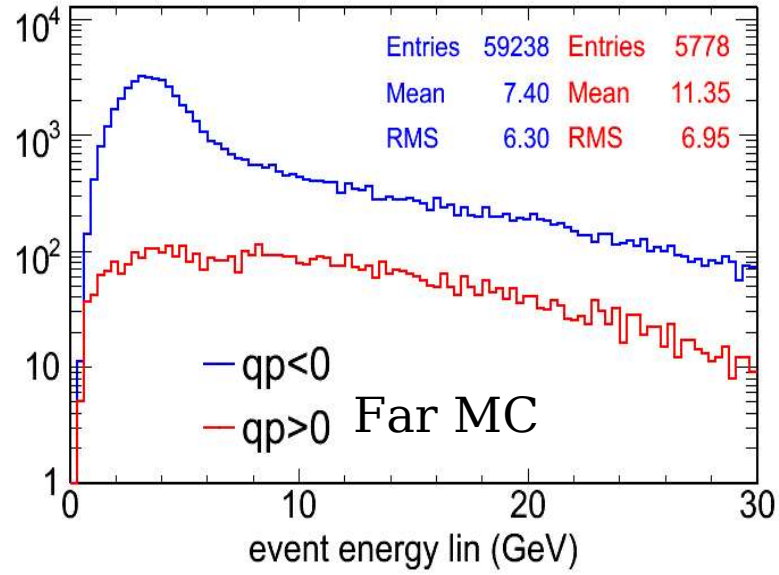


Event energy









Anti-neutrino to neutrino ratio

	Qp < 0	Qp > 0	R	Error	“Pure” R	Error	
ND data	377,080	45,772	12.14%	0.06%	8.87%	0.04%	
ND MC	28,796	3,497	12.14%	0.22%	8.87%	0.16%	
FD data	66	7	11%	4%	9%	3%	
FD MC	59,238	5,778	9.75%	0.13%	8.06%	0.11%	

- Correct number of anti-neutrinos by removing neutrino contamination, using MC sign purity
- Far and Near ratios are consistent within errors, after corrrection
- The error on the ratio is dominated by small number of events at the FD

Summary

- This is my first attempt to compare ratio of neutrinos and anti-neutrinos at the two detector
- The error on this measurement is dominated by low number of events at the Far detector
- Systematics are important and have to be understood
- Difference in energy spectrum of neutrinos and anti-neutrinos at ND implies that neutrinos and anti-neutrinos have different oscillated spectrum at the Far detector
- How well can me measure this ratio?