SciBooNE's neutral current $\pi 0$ production measurement

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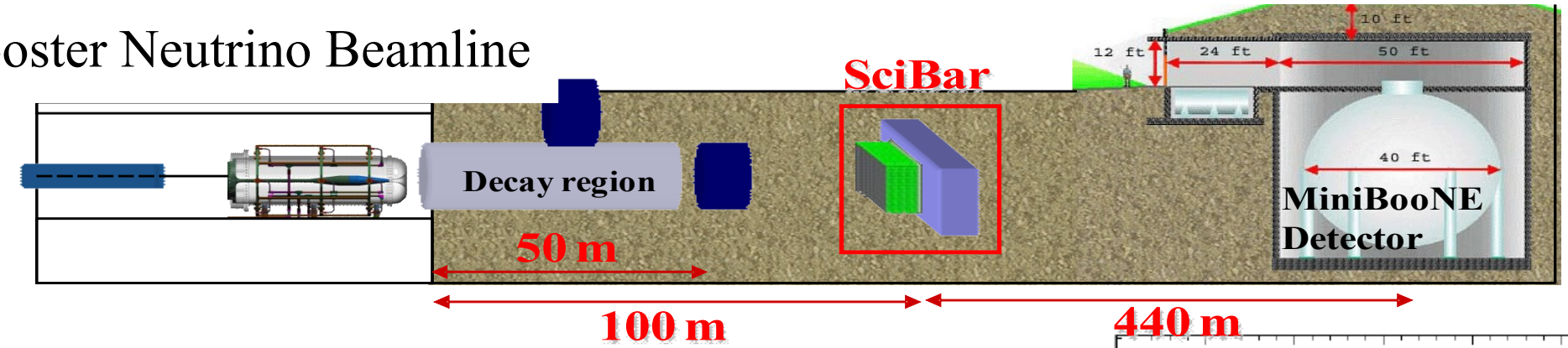
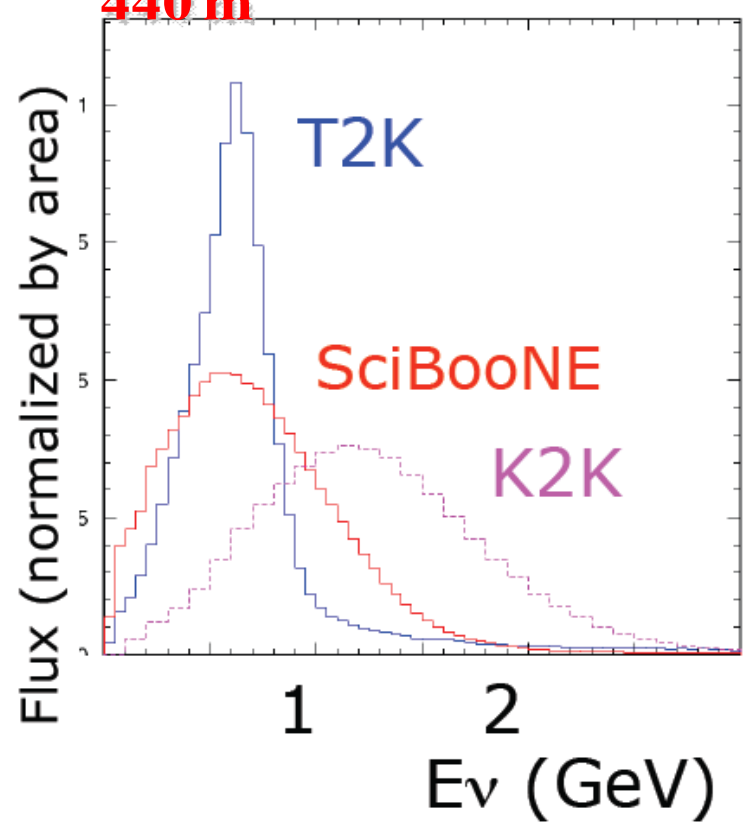
Introduction

SciBooNE (FNAL E954)

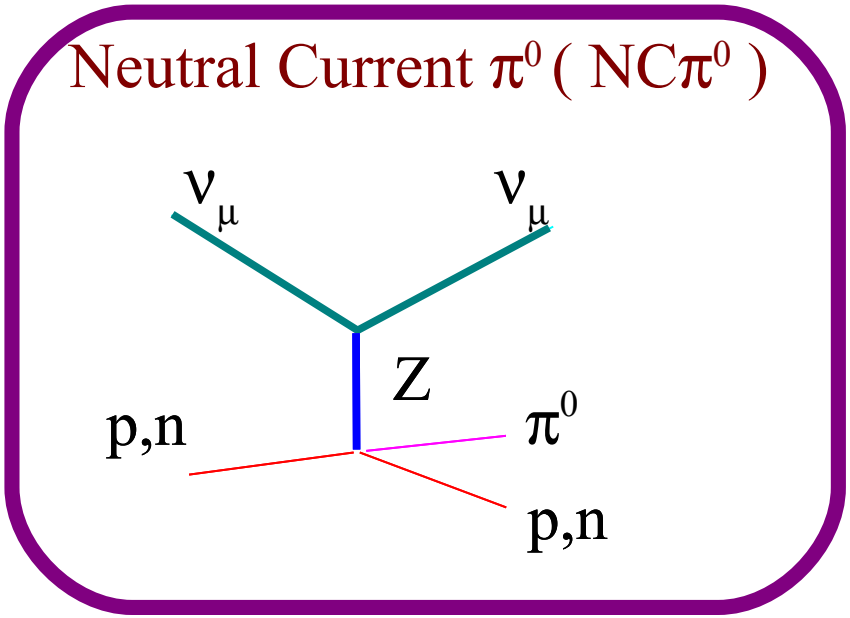
Booster Neutrino Beamline



- Precise measurements of neutrino- and antineutrino-nucleus cross sections near 1 GeV
  - Essential for future neutrino oscillation experiments (T2K)
  - Few past measurement in region, all low statistics
- Neutrino energy spectrum measurements and flavor measurement
  - MiniBooNE/SciBooNE joint ν_μ disappearance
  - ν_e measurement



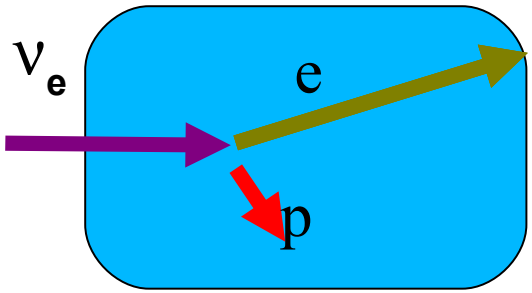
Neutral Current π^0 Production



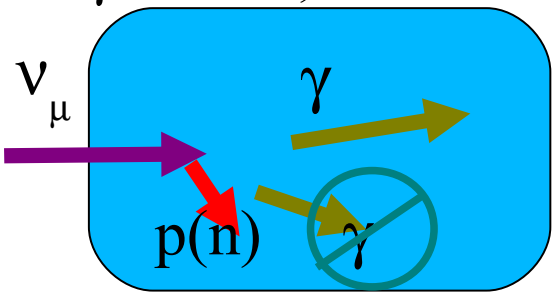
NCπ^0 is the main background of the search for ν_μ to ν_e oscillation

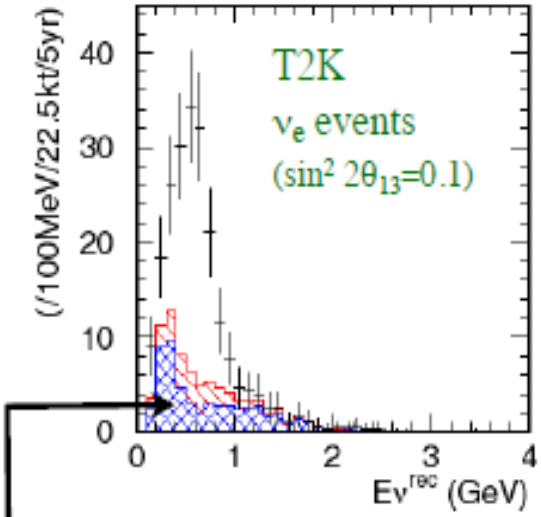
- gamma mimics electron from ν_e

The ν_e signal : electron



The background from NCπ^0 :
One γ from π^0 , miss another γ





– Signal: CC-QE (ν+n→e+p)
– Background
- Beam ν_e
- NC-1π^0

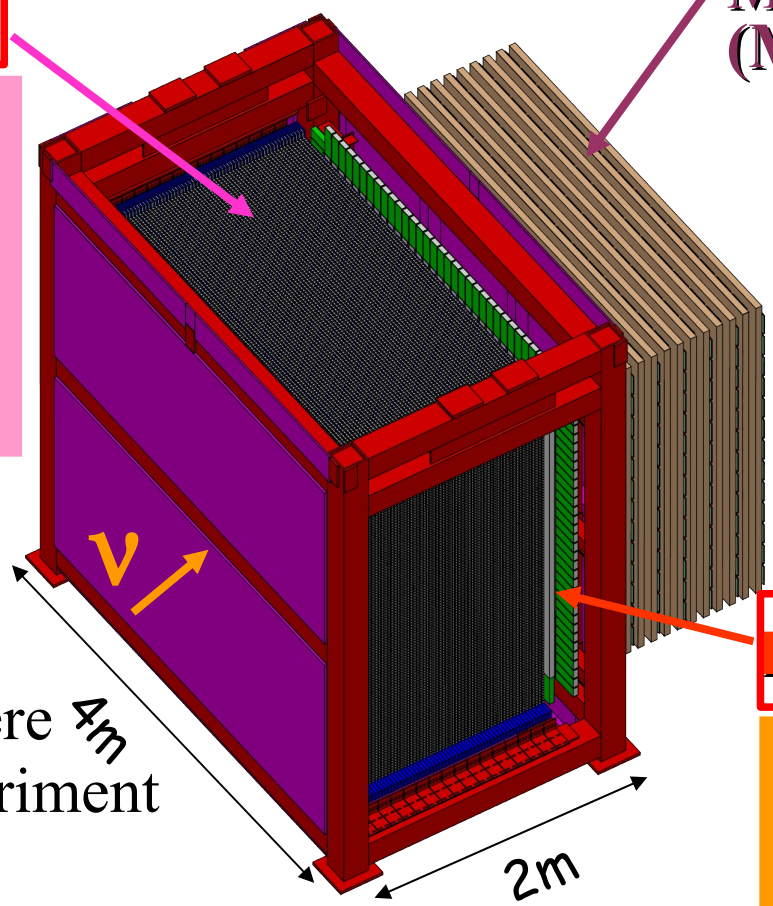
SciBooNE detector

SciBar

- 14,336 scintillator bars (15 tons)
- detect all charged particles
- p/π separation using dE/dx

Muon Range Detector (MRD)

- 12 2”-thick steel + scintillator planes
- measure muon momentum with range up to 1.2 GeV/c



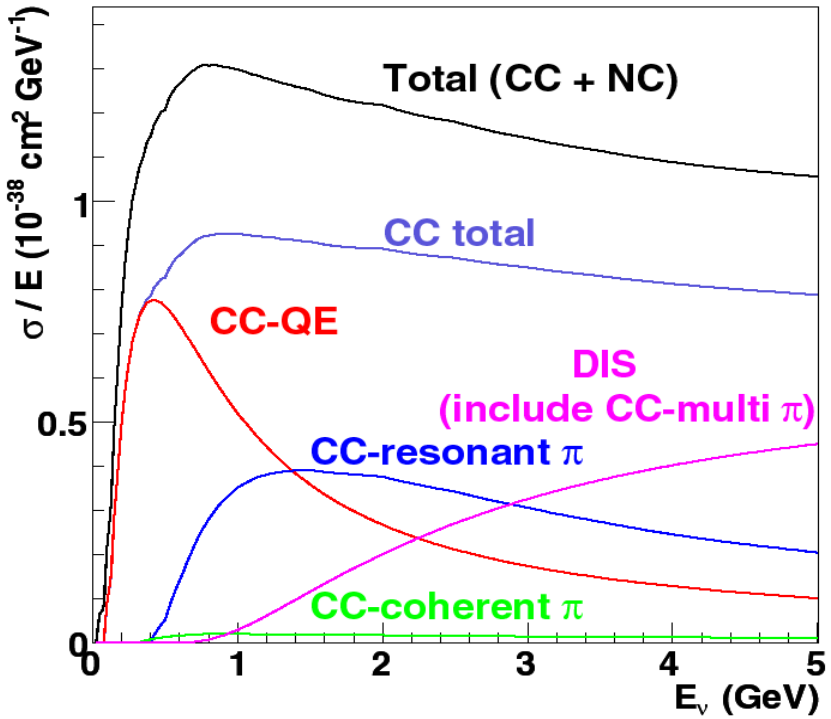
Electron Catcher (EC)

- spaghetti calorimeter
- 2 planes (11 X_0)
- identify π^0 and ν_e

SciBar and EC were used in K2K experiment

No NCπ0 measurement by such a full active scintillating detector

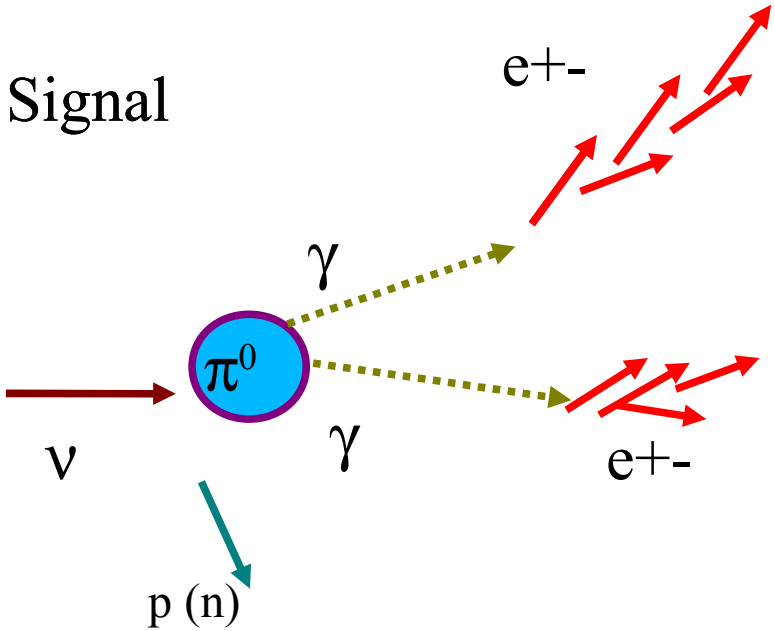
Neut



- QE
  - Llewellyn Smith, Smith-Moniz
  - M_A=1.2GeV/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
- Deep Inelastic Scattering
  - GRV98 PDF
  - Bodek-Yang correction
- Intra-nucleus interactions

NCπ^0 signal and background

Signal



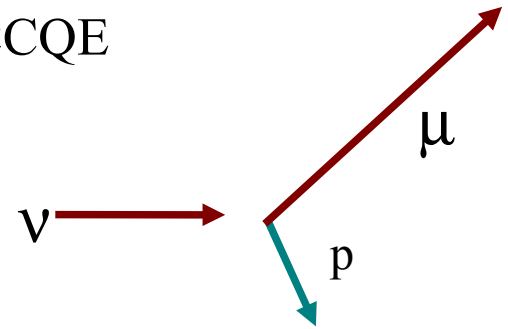
2γ from π^0

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

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

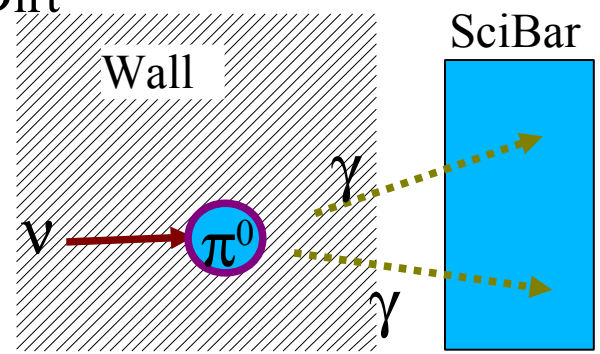
Internal B.G. : ν int. in SciBar

ex. : CCQE



External B.G : from outside

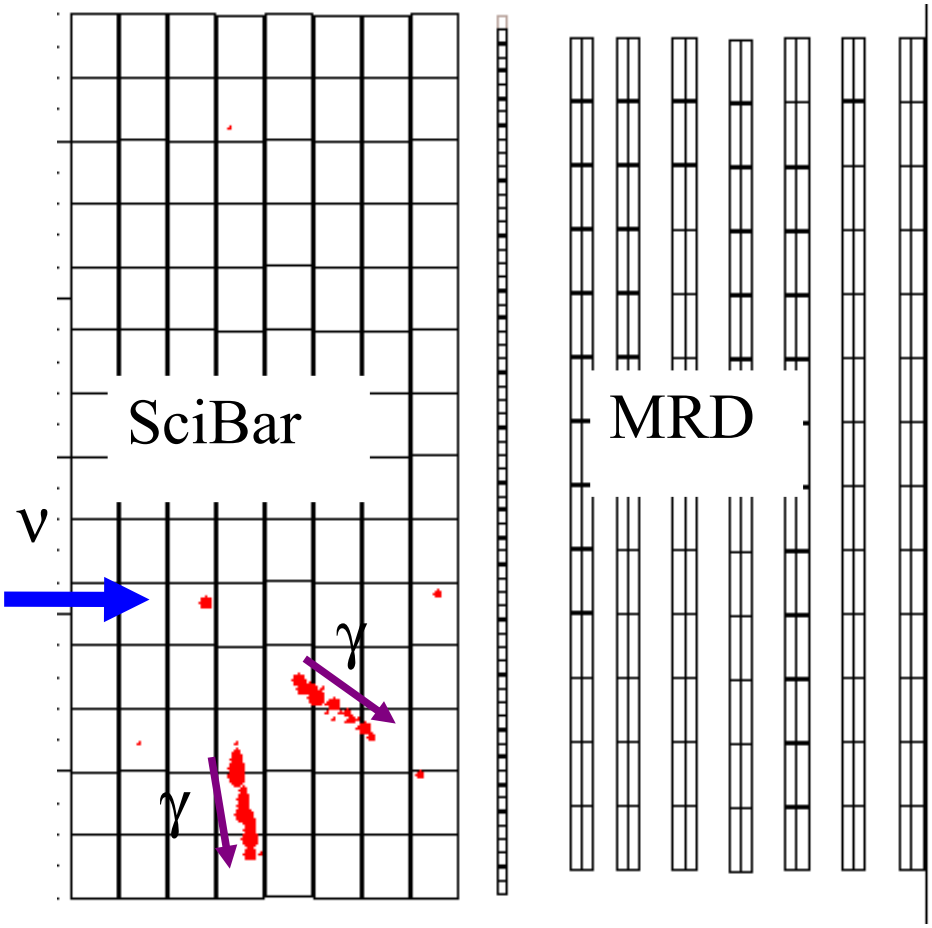
ex : Dirt



Event Selection

Event Selection

NCπ^0 Candidate



Event Selection

0.Pre-Selection

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

1. Charged current reduction

- Reject μ using the decay e
- Track disconnection
- Reject p using dE/dx

2. Dirt reduction

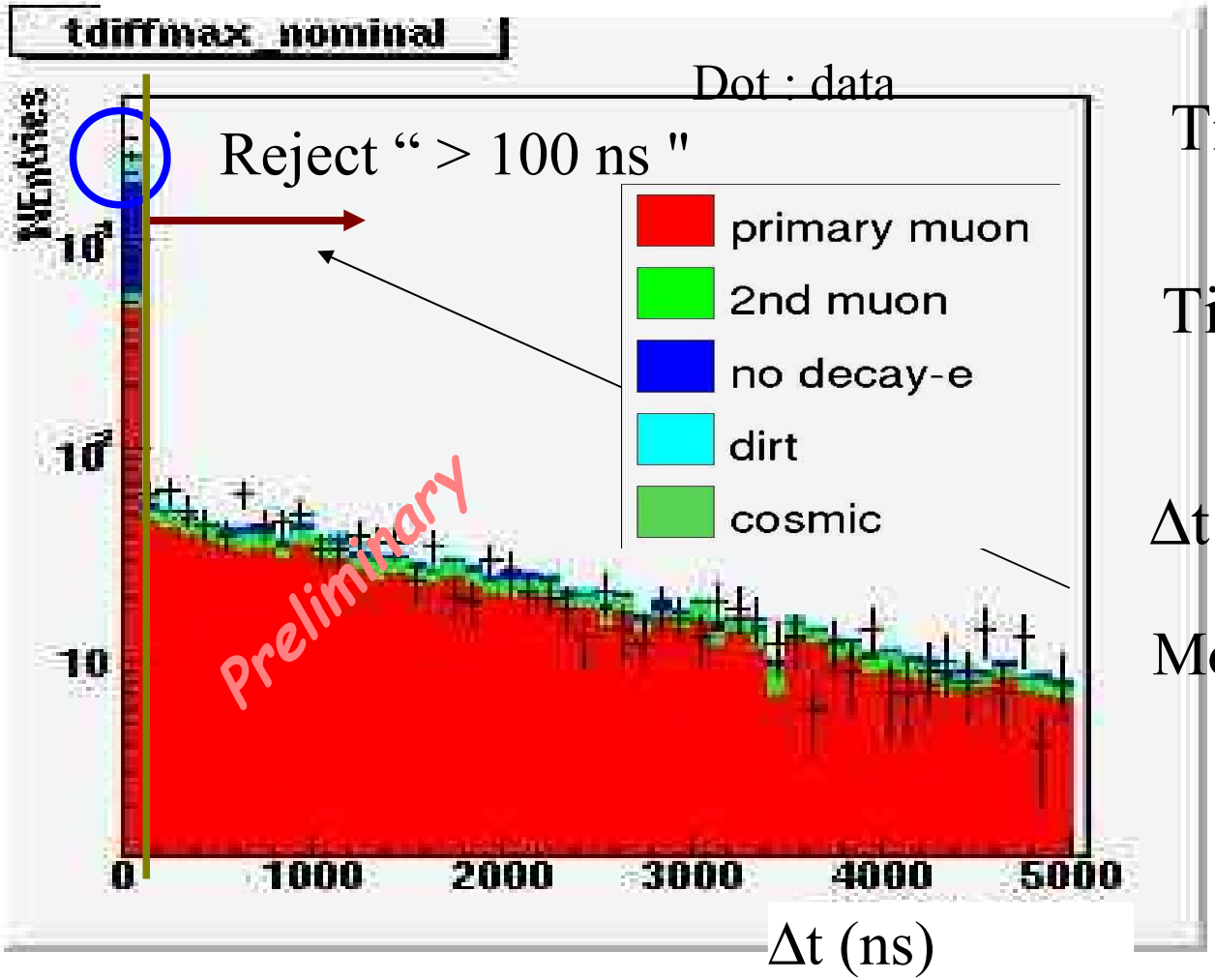
- Track merge
- π0 vtx reconstruction

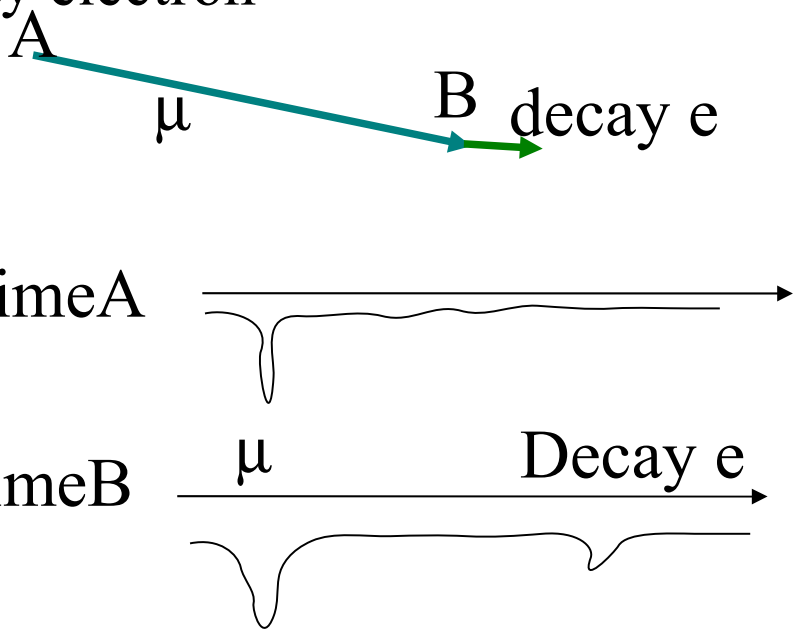
Muon rejection with the decay election

There are muons stopping in SciBar

These muons can be removed using the decay electron

Time difference btw track edges





Δt = (The latest) TimeB - TimeA

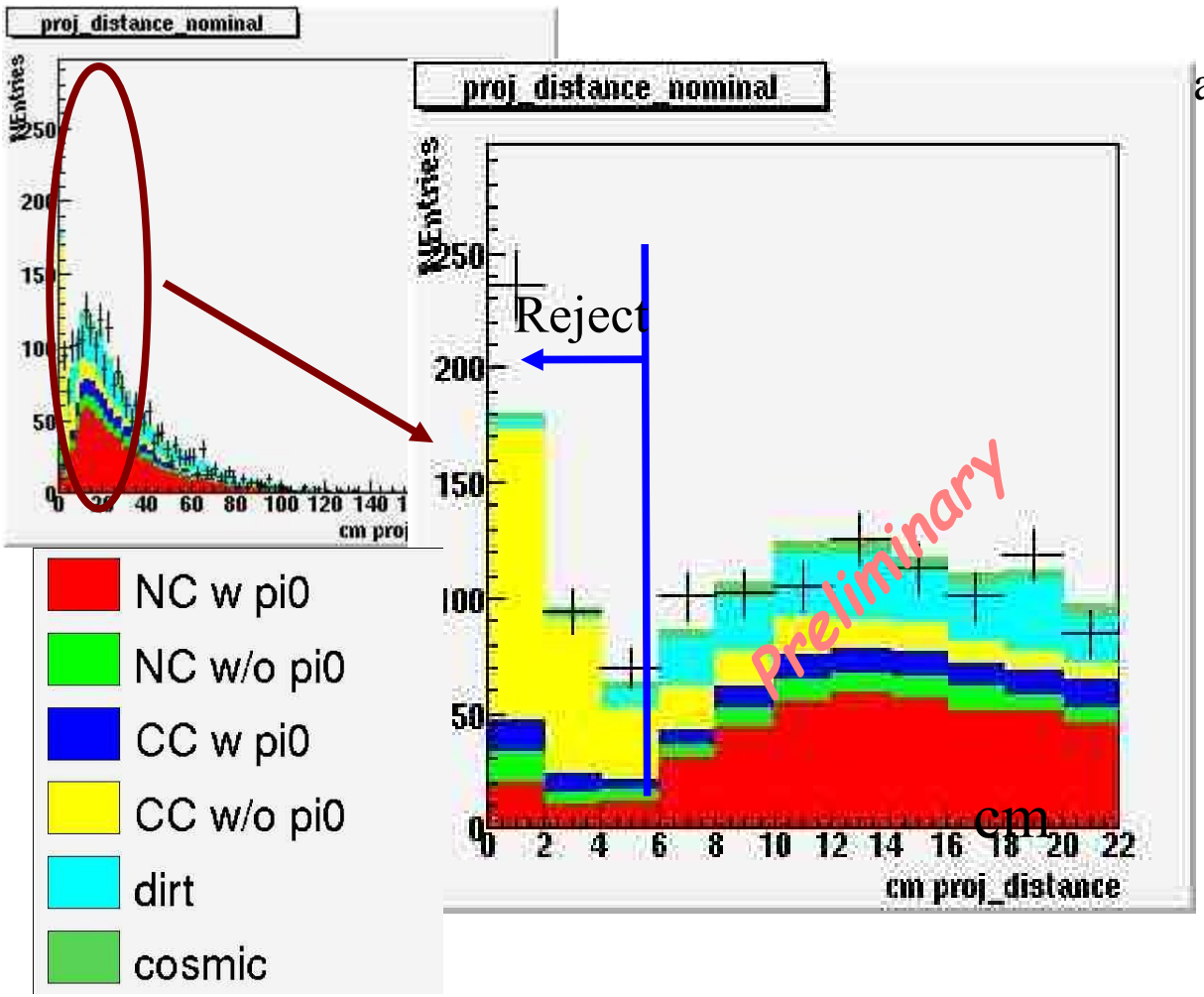
Most "no decay" events is < 100 ns

MC is normalized by CC inclusive sample

The disconnection between tracks

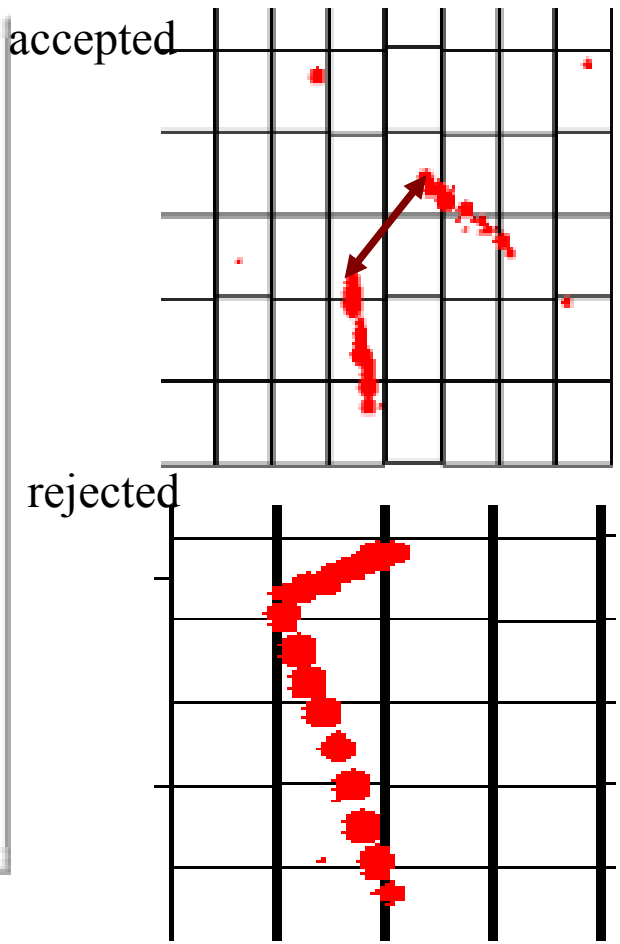
The distance between tracks (after all events selection)

Minimum 2D-distance between track edges



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

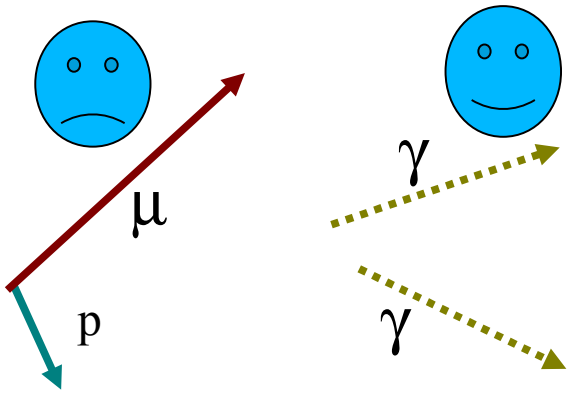
Threshold = 6cm

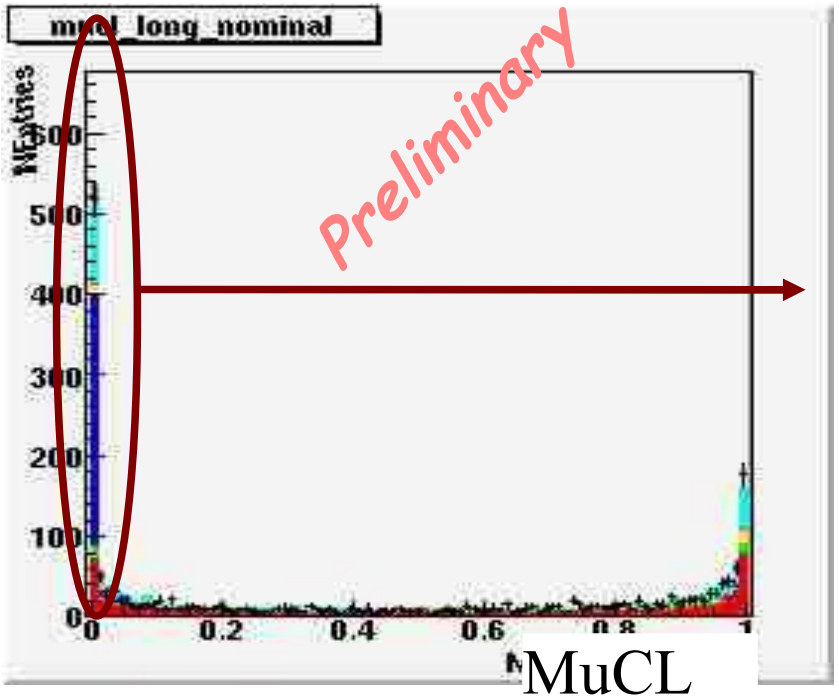


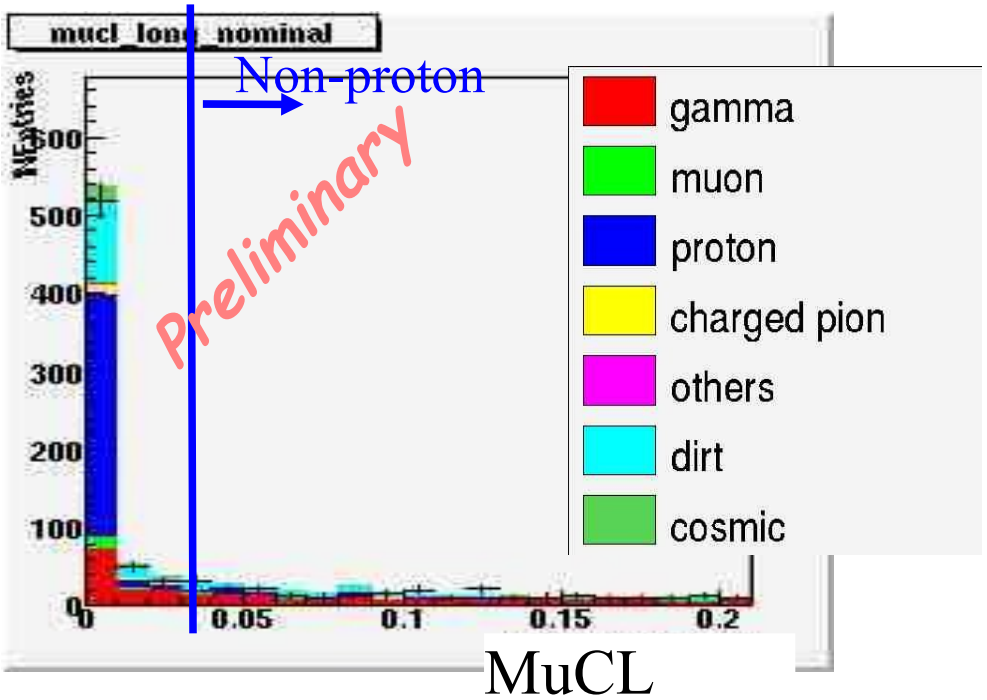
Proton rejection using dE/dx

Proton have larger energy deposit than any other particle

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





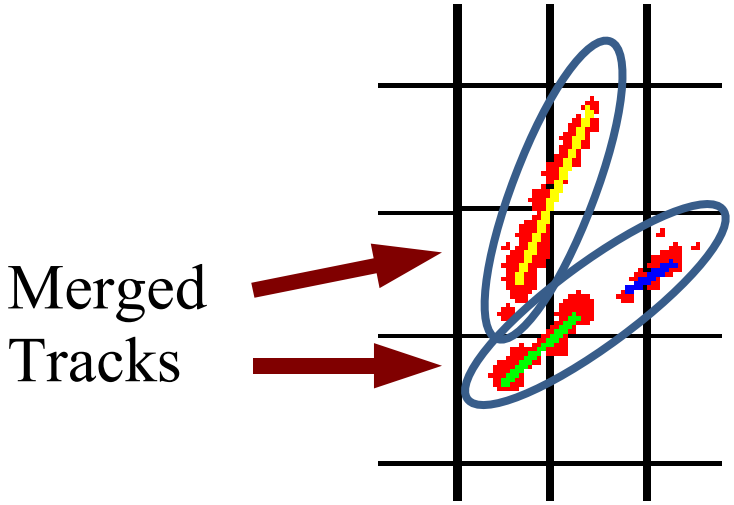


Non-proton-like : MuCL > 0.03

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

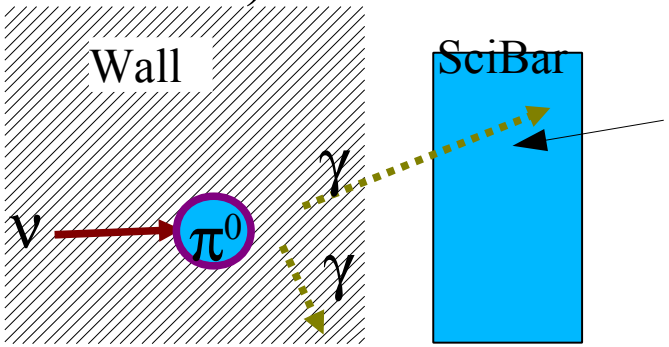
Track Merge

Some part of single γ make two clusters



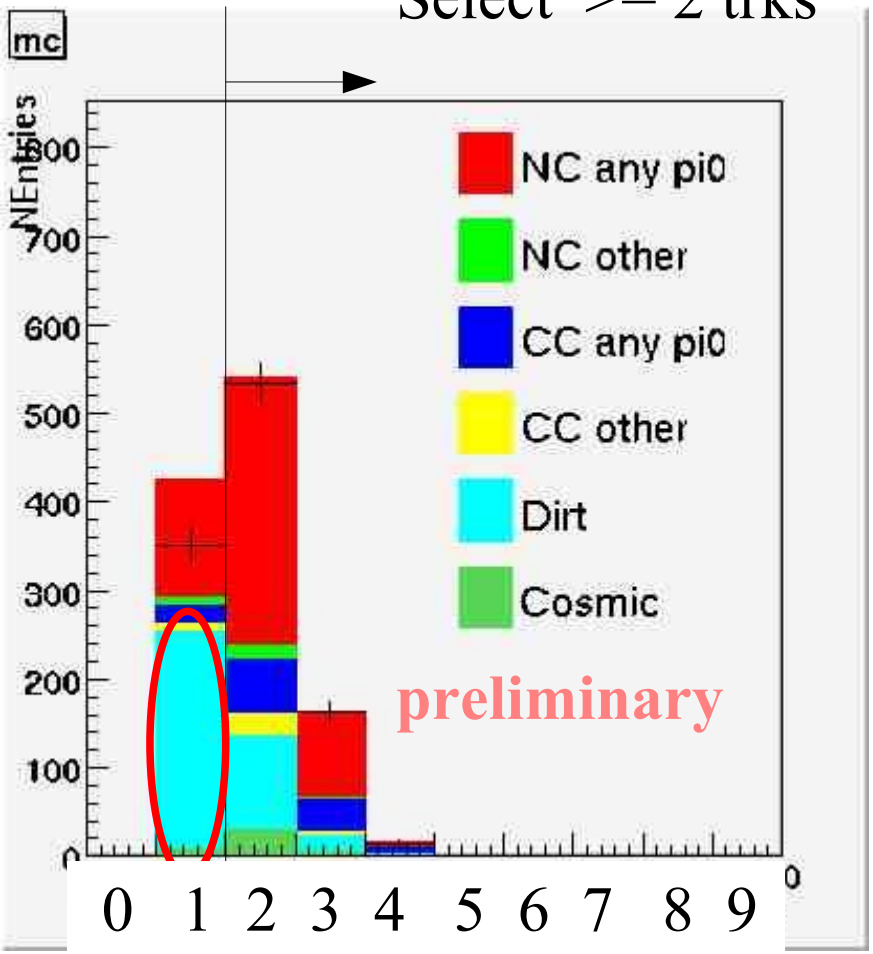
Merge track with same direction

- γ energy reconstruction
- Dirt rejection (one γ from outside makes two tracks)



This γ makes 2 clusters

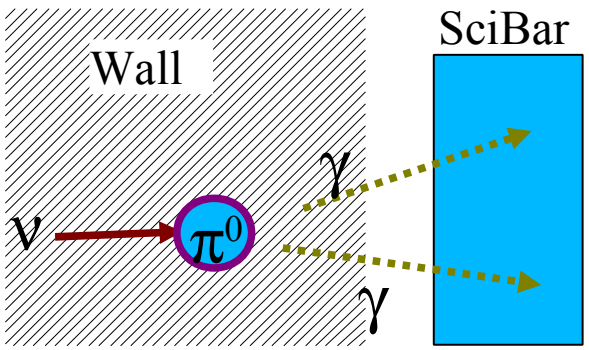
Select >= 2 trks



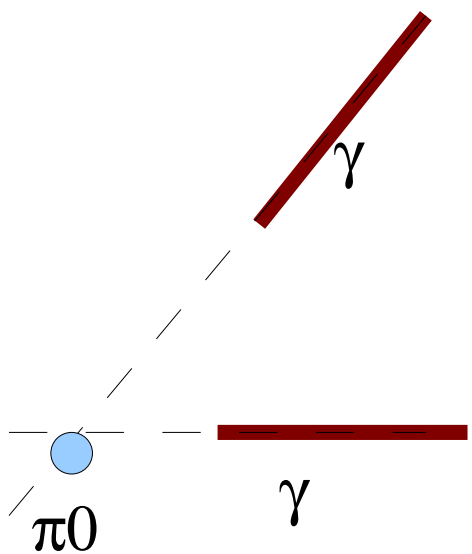
merged tracks

Reconstructed π0 vertex

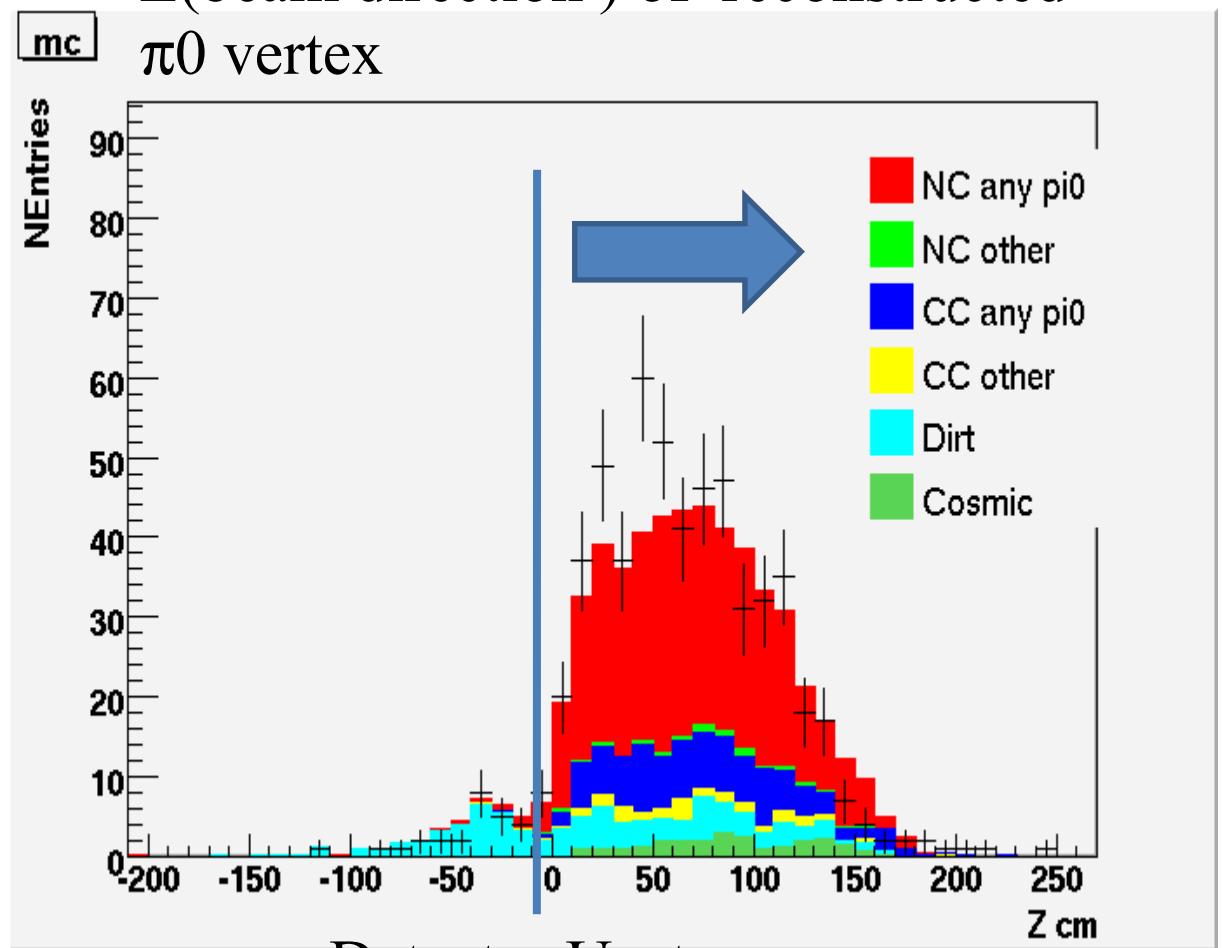
Most of the dirt b.g. come from π0



π0 reconstruction vertex



Z(beam direction) of reconstructed π0 vertex



Detector Upstream

Event Summary

CC reduction

	Data	MC(tot)	NC w $\pi 0$	BG
preselection	3624	3552	1021	2531
μ rejection	2455	2380	942	1438
trk disconnect	2055	2051	901	1150
p rejection	1062	1114	523	591
trk merge	656	639	356	283
dirt rejection	545	499	314	185

Dirt reduction

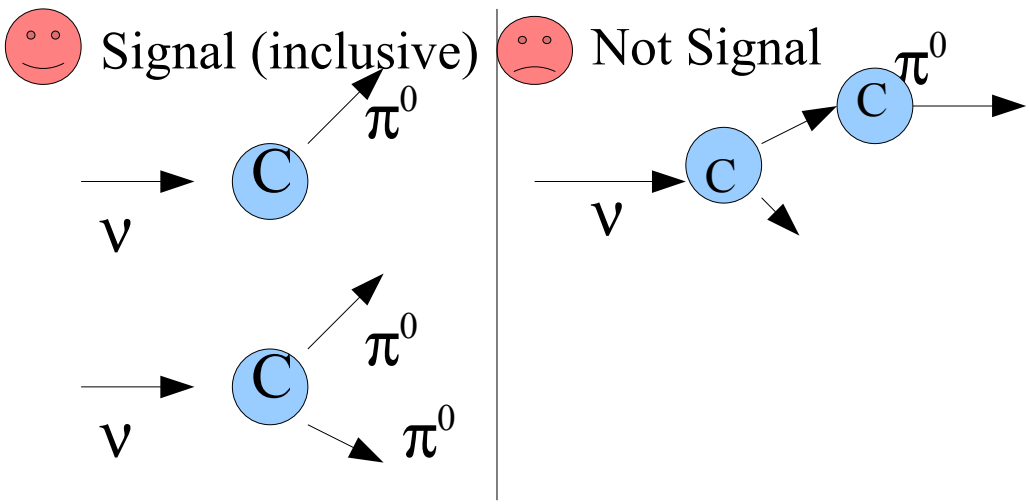
Good agreement between Data and MC

$\pi 0$ reconstruction

π^0 Kinematics (1)

- ~ 500 events selected
- ~ 300 events estimated as signal by MC

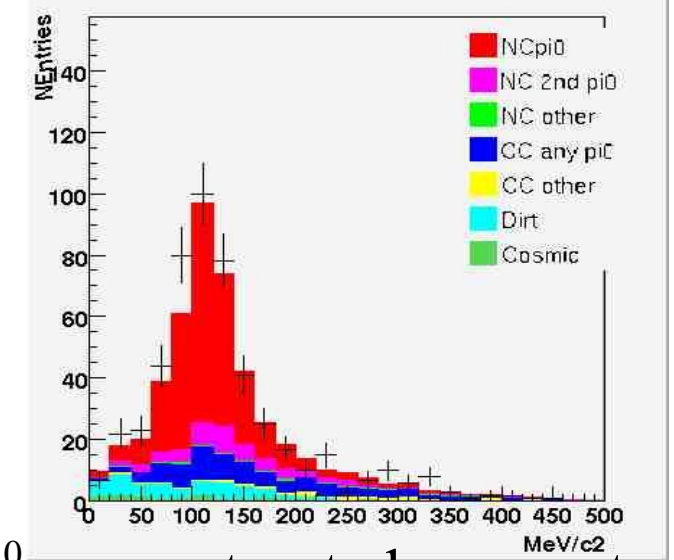
Signal : π0 from ν target nucleus



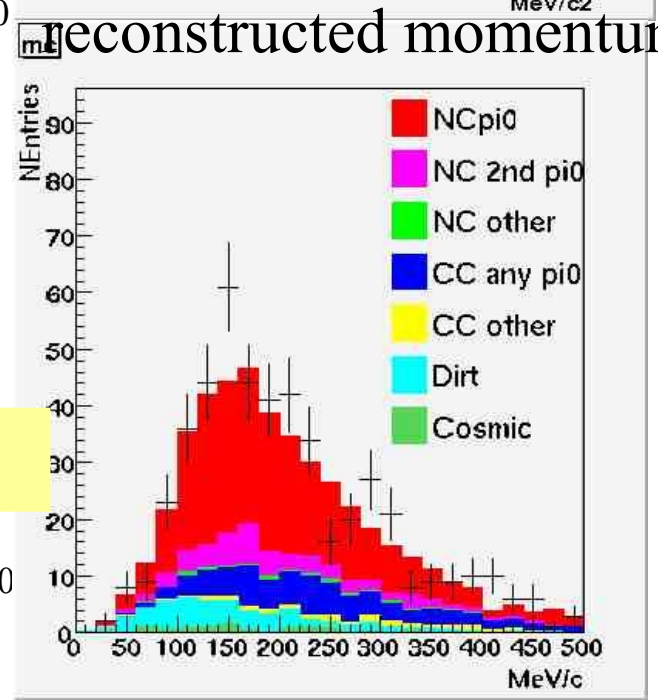
Clear π0 peak is observed

SciBar can do NCπ0 measurement

π^0 reconstructed mass

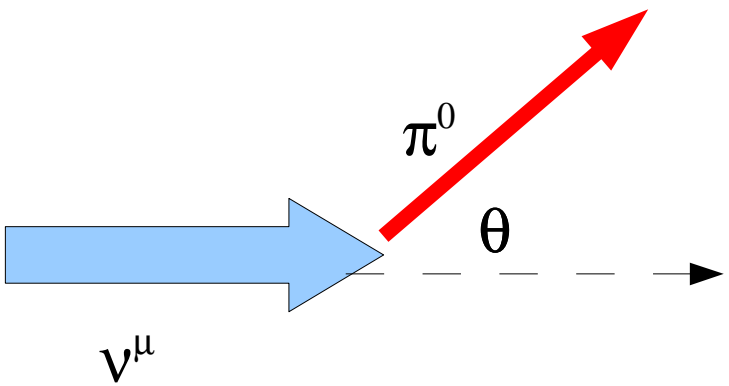


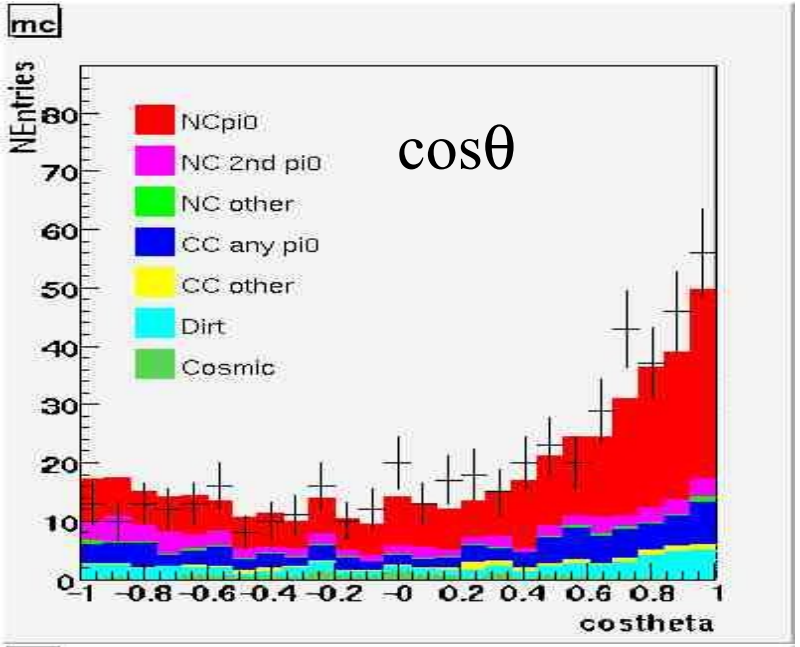
π^0 reconstructed momentum

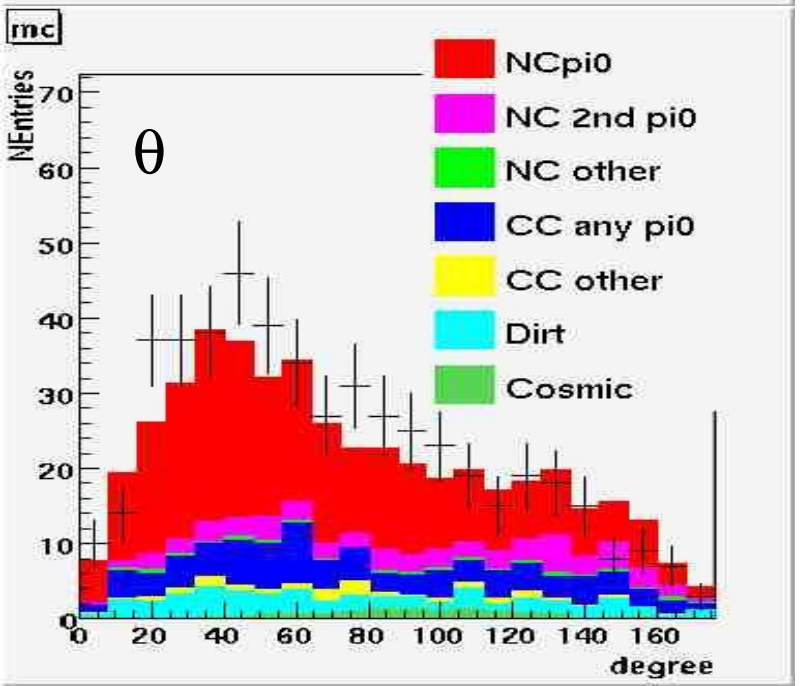


π^0 Kinematics (2)

$\pi 0$ reconstructed angle



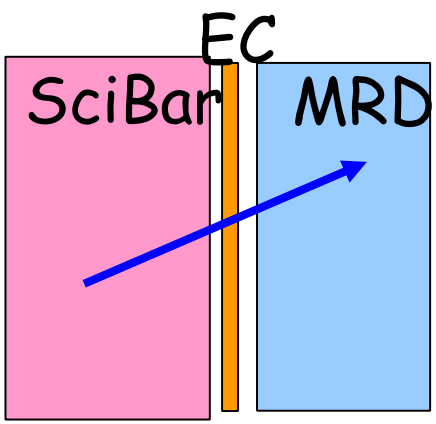




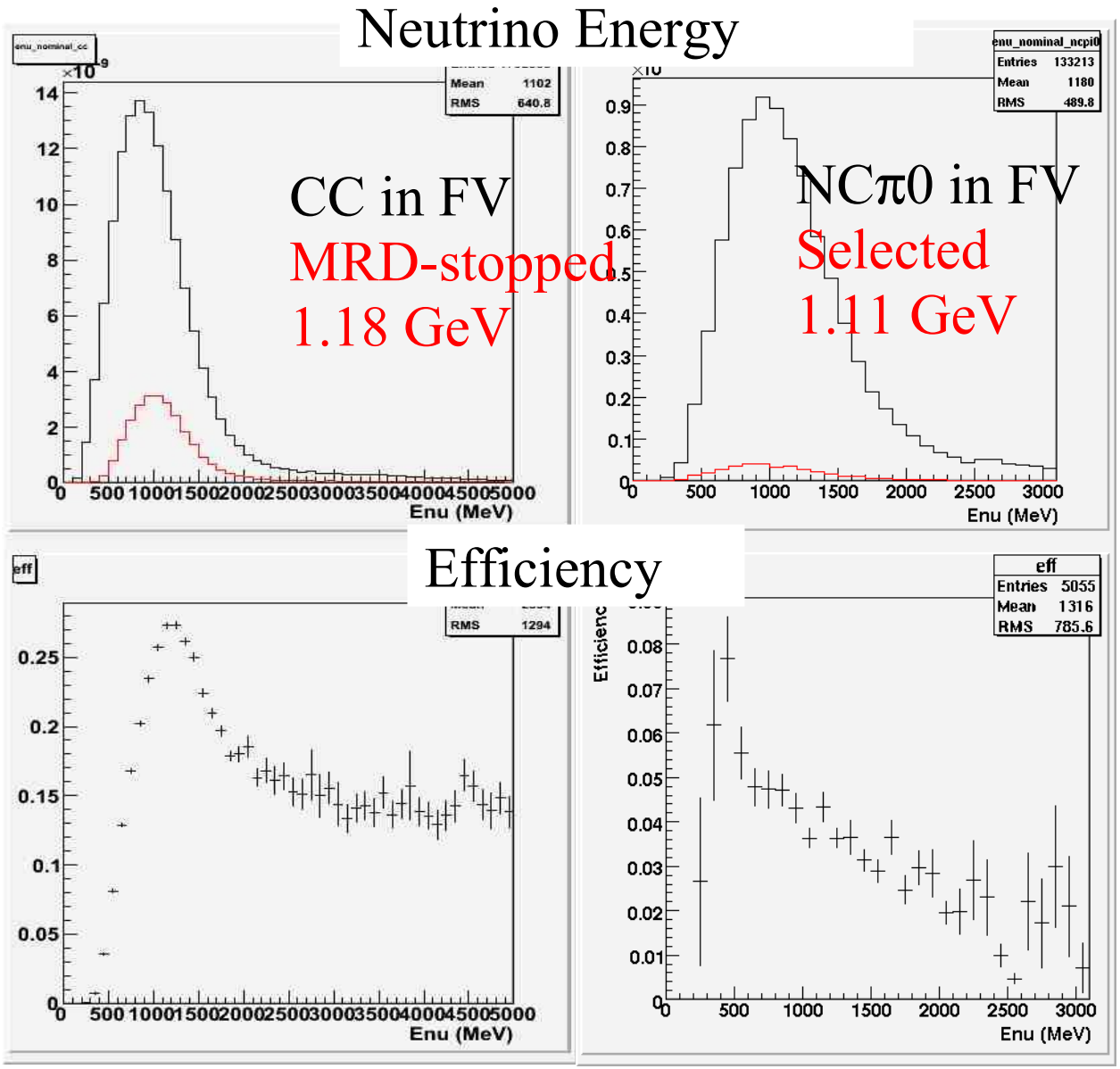
Cross section ratio to CC inclusive

Ratio to charged current

- Use σ(NCπ0)/σ(CC) to reduce the systematics of neutrino flux
- Use MRD-stopped events for charged current events



MRD stopped event (~22k events)
(muon contained in MRD)



Similar energy region between two samples

Result (preliminary)

$$\frac{\sigma(NC\pi 0)}{\sigma(CC)} = 7.7 \pm 0.6\ (\text{stat.}) \pm \underbrace{0.6\ (\text{sys.})}_{\text{Preliminary}} \times 10^{-2}$$

Systematics study just started . Some of them were not included yet

MC default expectation is 6.8×10^{-2}

(Neut + MiniBooNE flux prediction)

Our measurement is consistent with MC

Status of systematics study

Already estimated

	frac. err. (%)
Detector	-4.1 +2.9
ν int. model	-0 +2
Nucl. Effect	-3.5 +3.8
ν flux	-2.3 +2.3
Dirt density	-4.0 +4.0
total	-7.1 +7.1

Not yet estimated

- π interaction in Detector
- γ reconstruction efficiency

Summary

- SciBooNE can do NCπ0 measurement
- Preliminary cross section ratio is presented

$$\frac{\sigma(NC\pi 0)}{\sigma(CC)} = 7.7 \pm 0.6\ (stat.) \pm 0.6\ (sys.)\ \times 10^{-2}$$

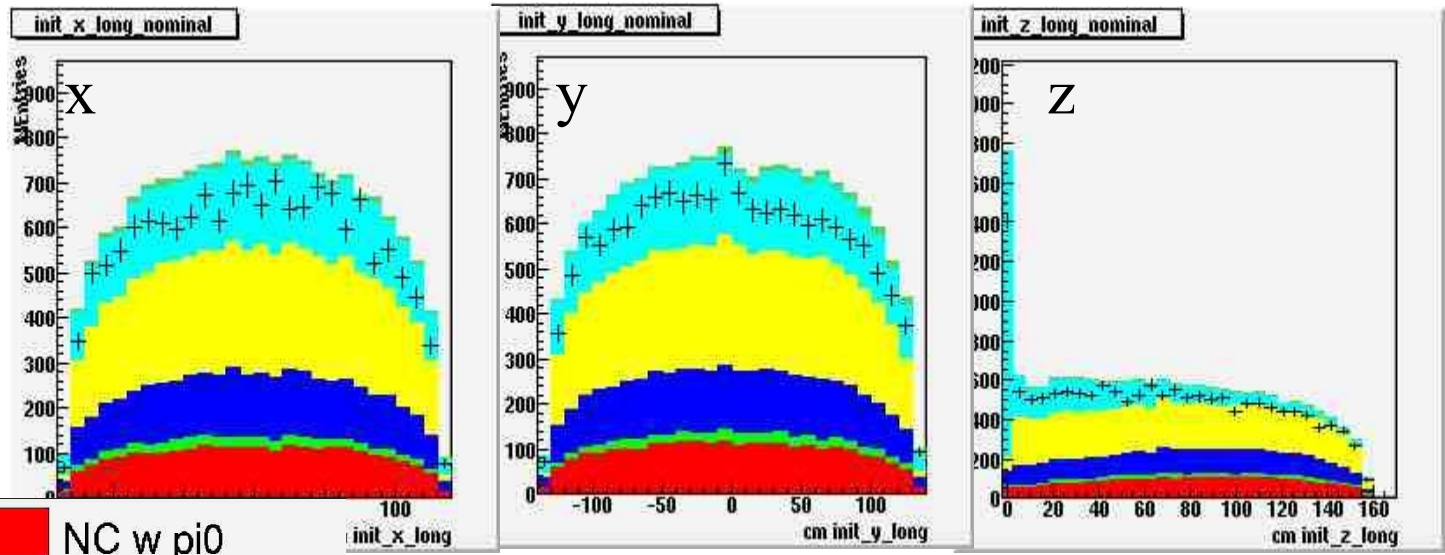
- Some of systematics have to be estimated
- Consistent with MC estimation
- Final result of this cross section ratio will be in autumn

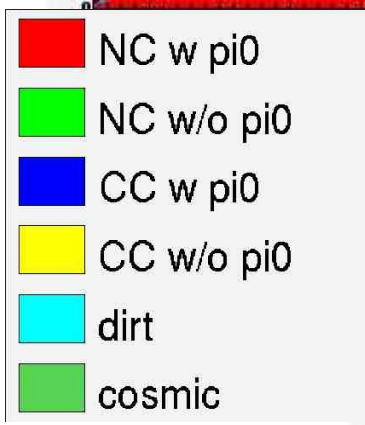
Backup

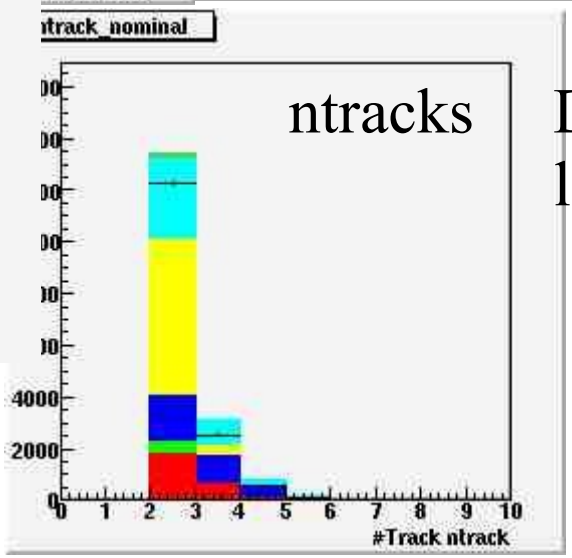
>= 2 Tracks selection

>= 2 tracks in FV
First layer veto
Stop in SciBar
Decay-e rejection
Track disconnection
Two gamma selection
Track merge
Dirt rejection

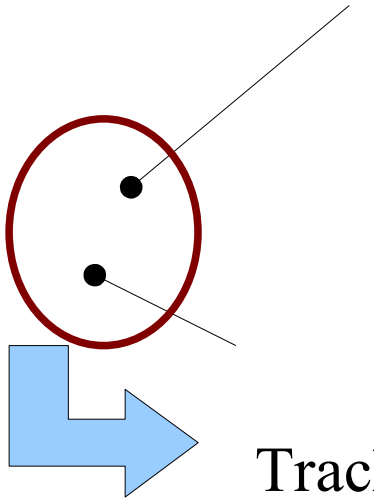
Upstream edge position of the longest track







Dirt contribution is a lot



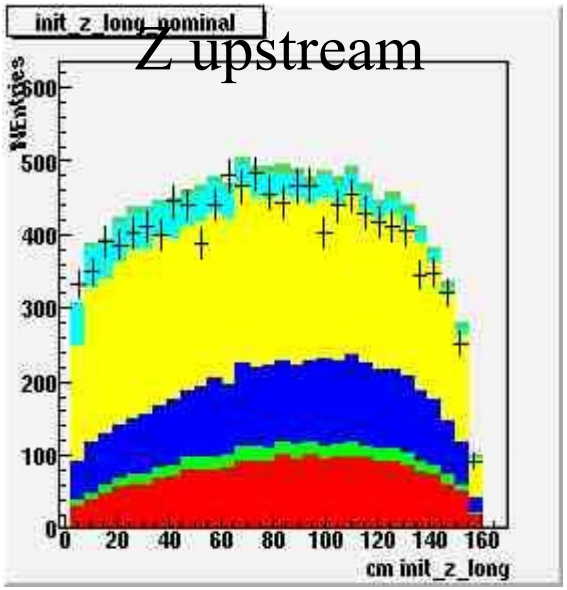
Track edge pair with minimum distance should be in FV

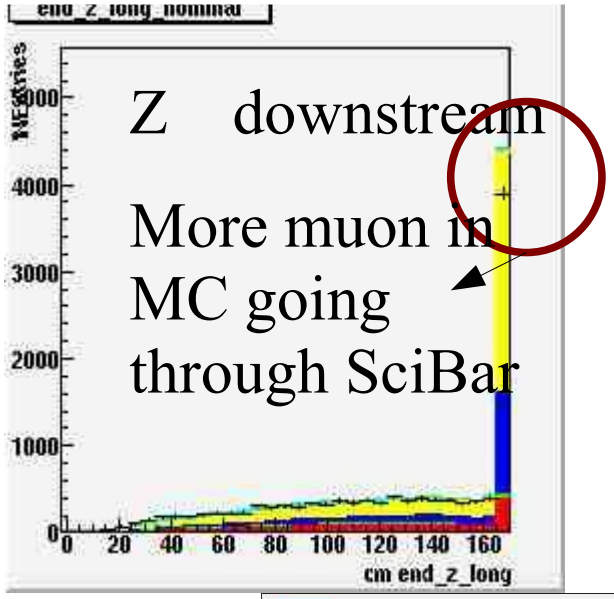
1st Layer veto

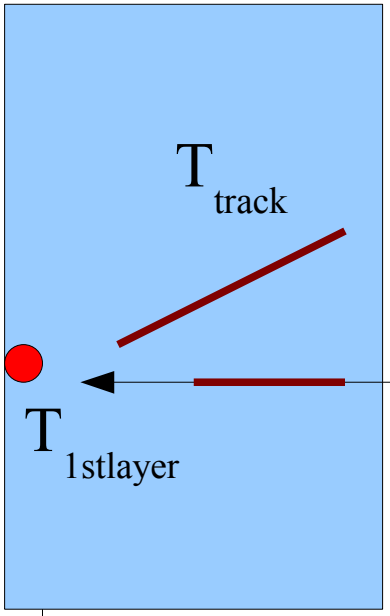
First Layer Veto

>= 2 tracks in FV
First layer veto
Stop in SciBar
Decay-e rejection
Track disconnection
Two gamma selection
Track merge
Dirt rejection

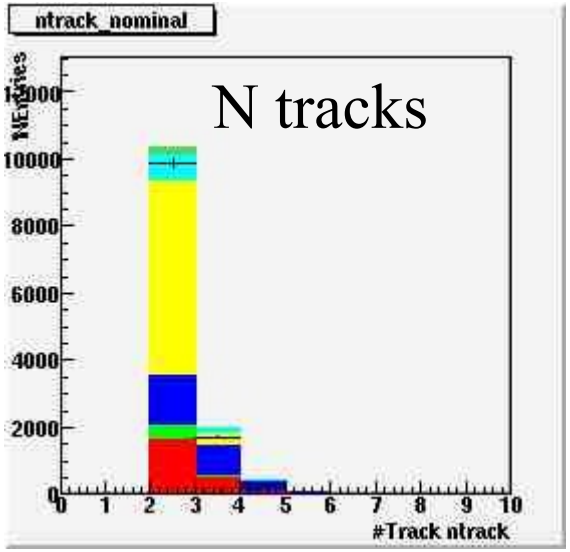
Edge z position of the longest track

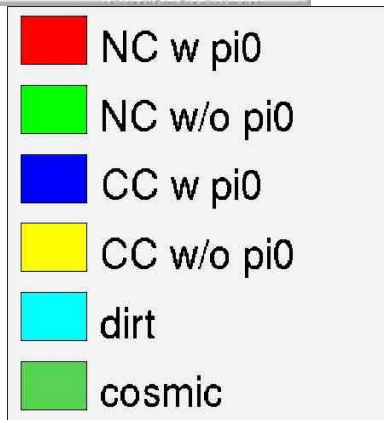






1st layer hits are not always associated with tracks



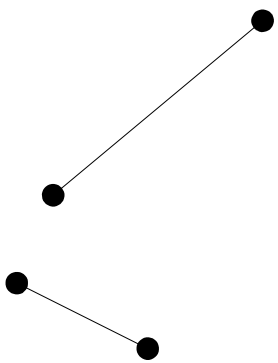


Reject $|T_{track} - T_{1stlayer}|$ <100ns

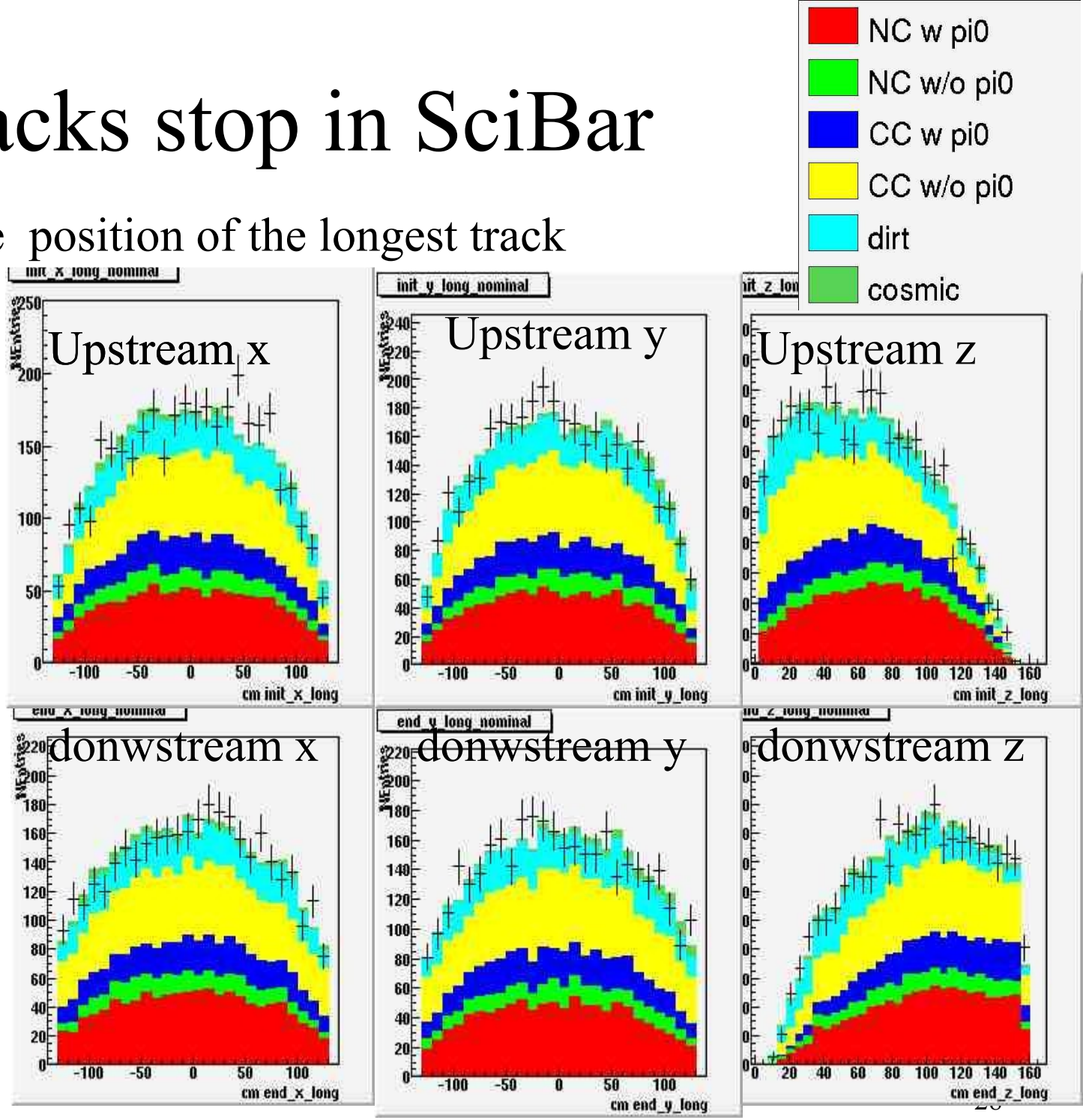
Tracks stop in SciBar

Edge position of the longest track

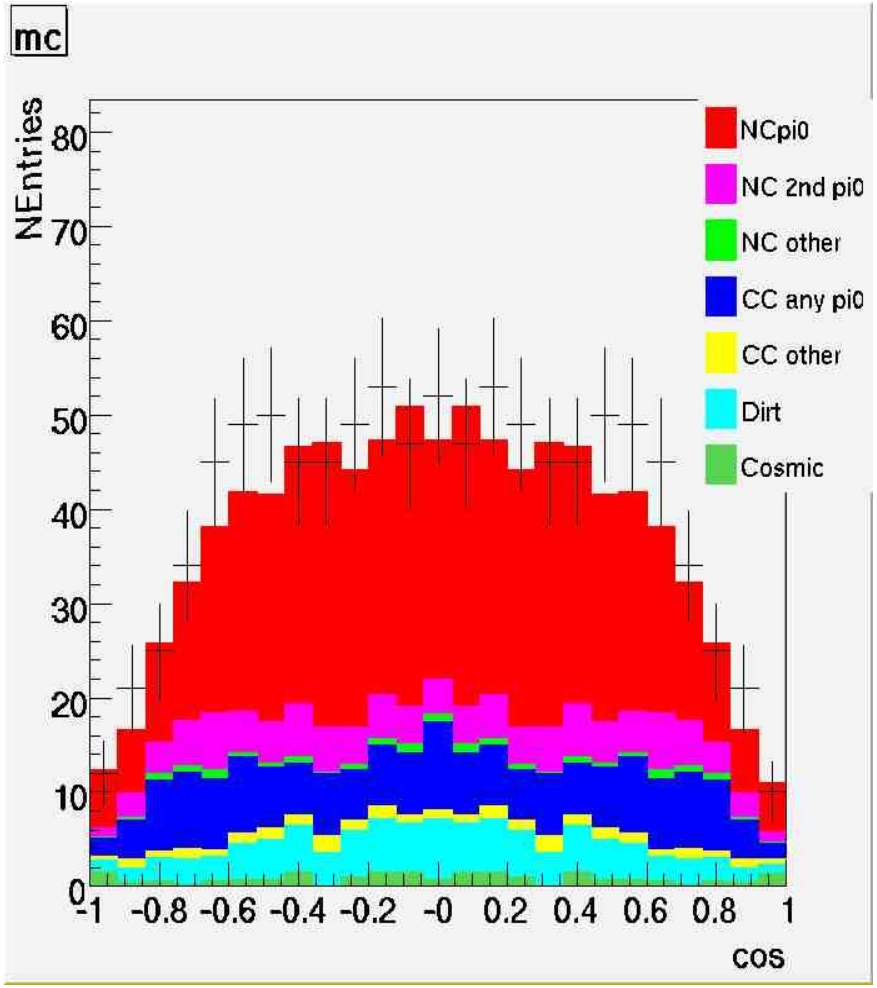
>= 2 tracks in FV
First layer veto
Stop in SciBar
Decay-e rejection
Track disconnection
Two gamma selection
Track merge
Dirt rejection

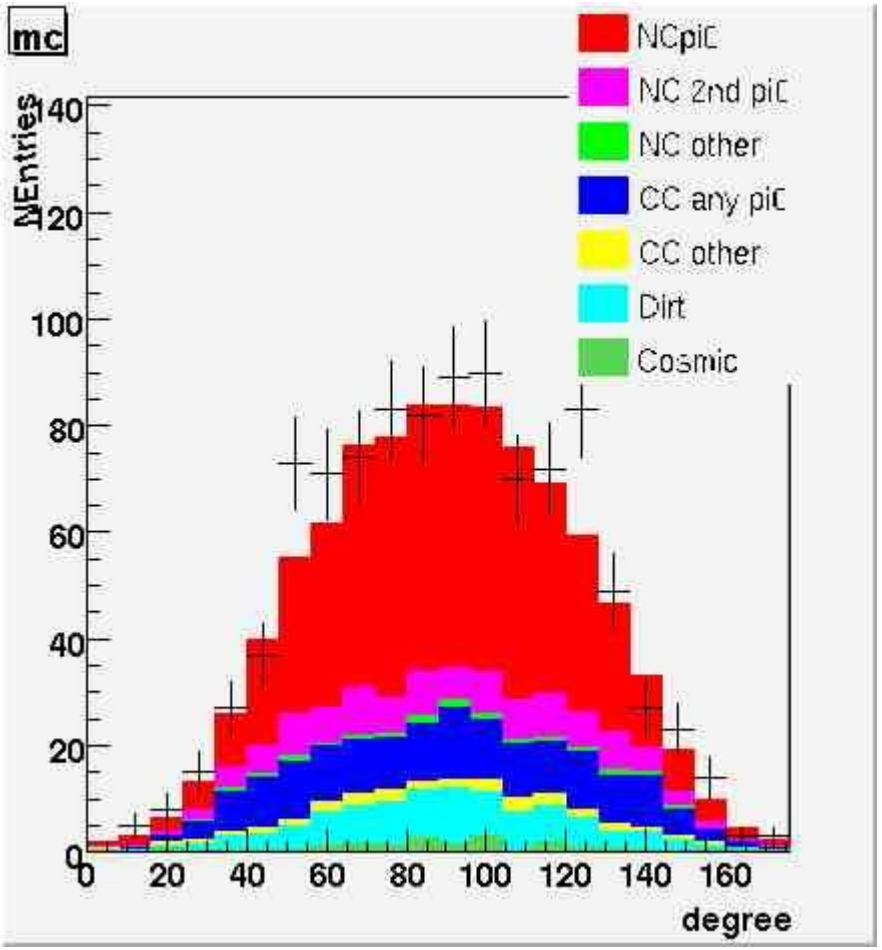


Any edge in FV



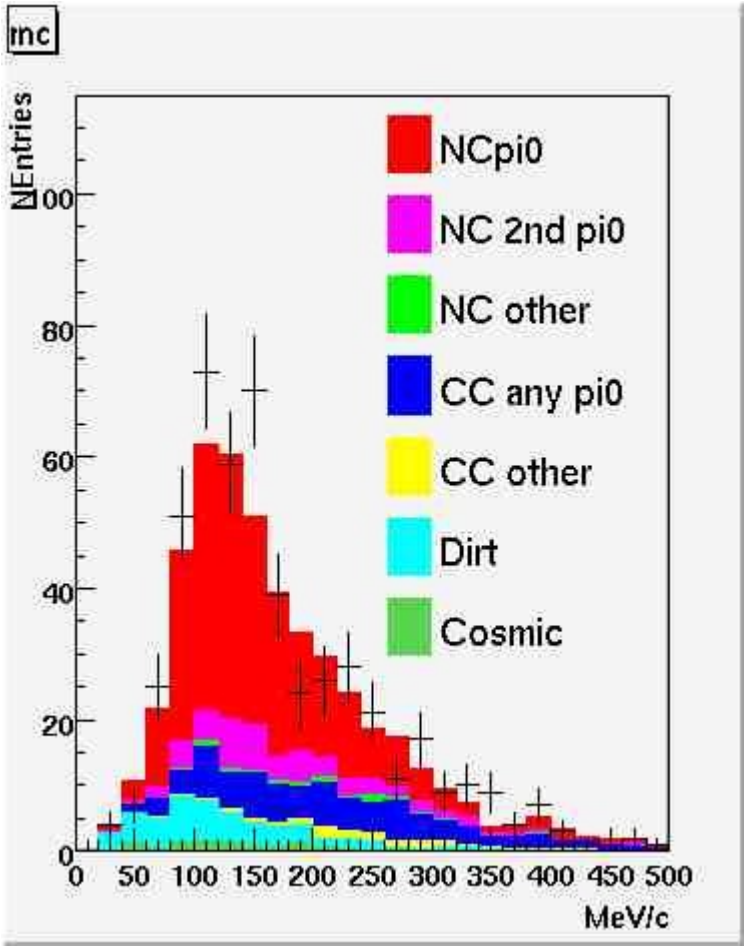
Gamma angle respect to π0 direction at π0 rest frame



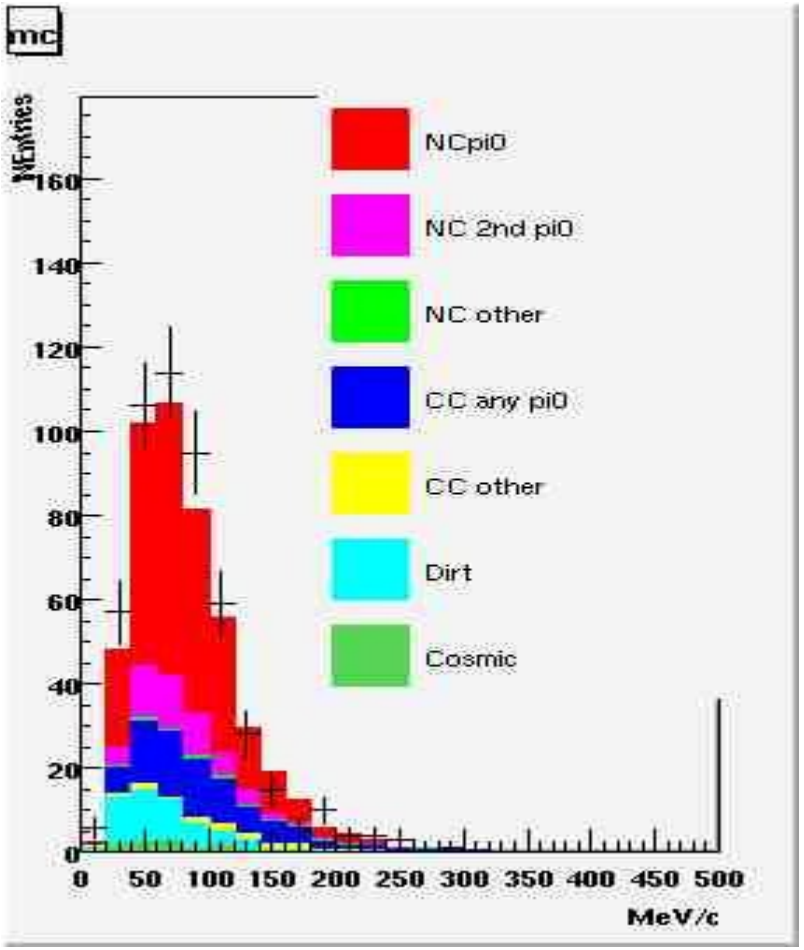


Gamma reconstruction

γ energy (larger one)

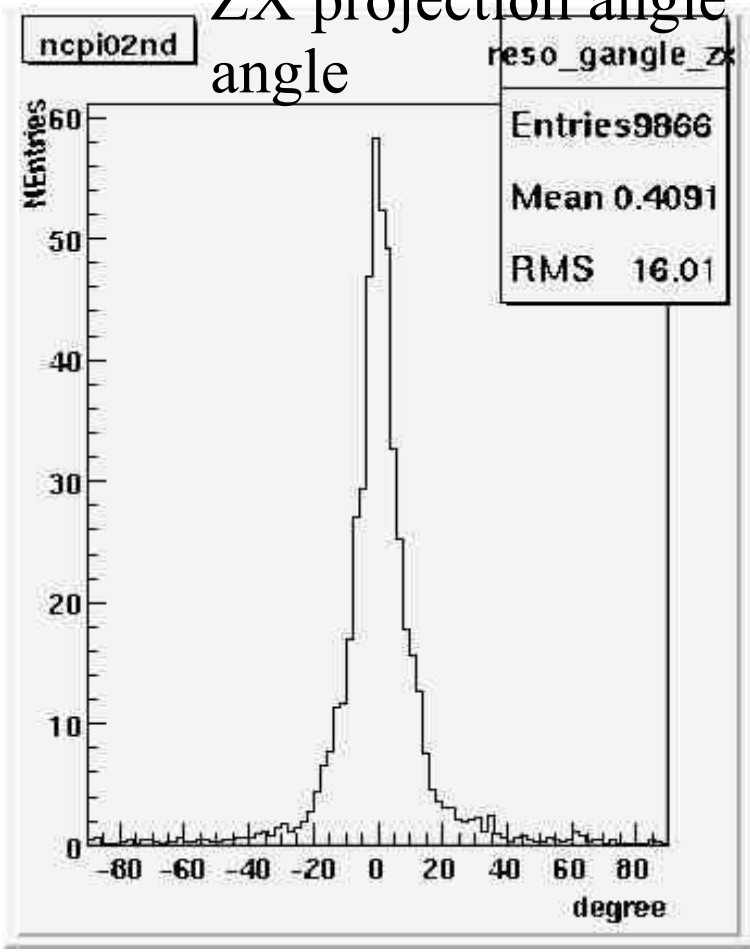


γ energy (smaller one)

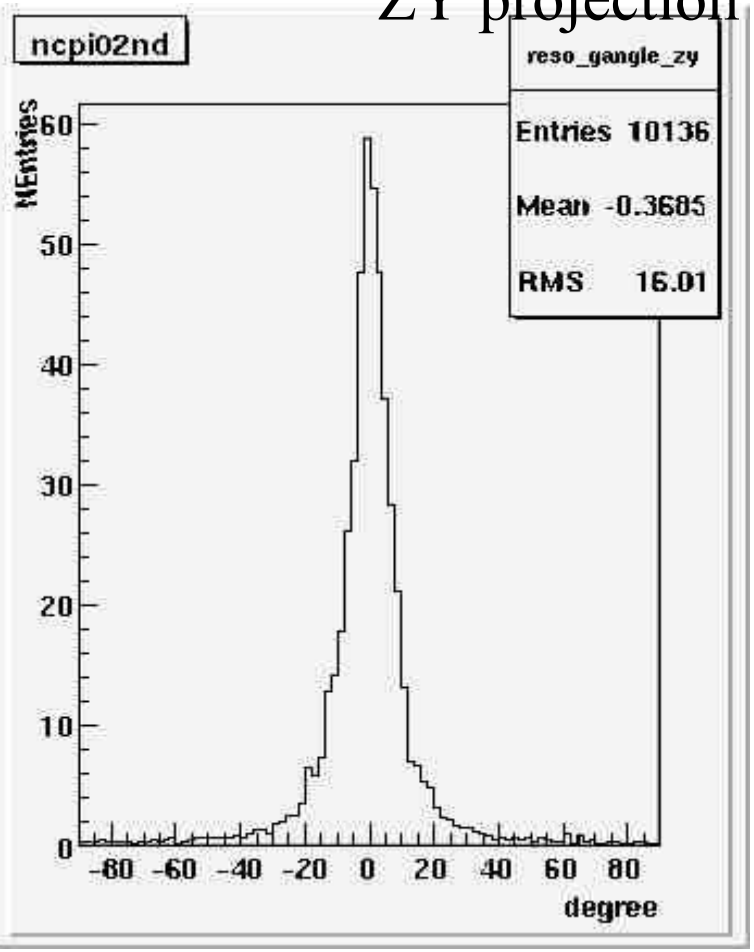


Gamma angle resolution

ZX projection angle angle

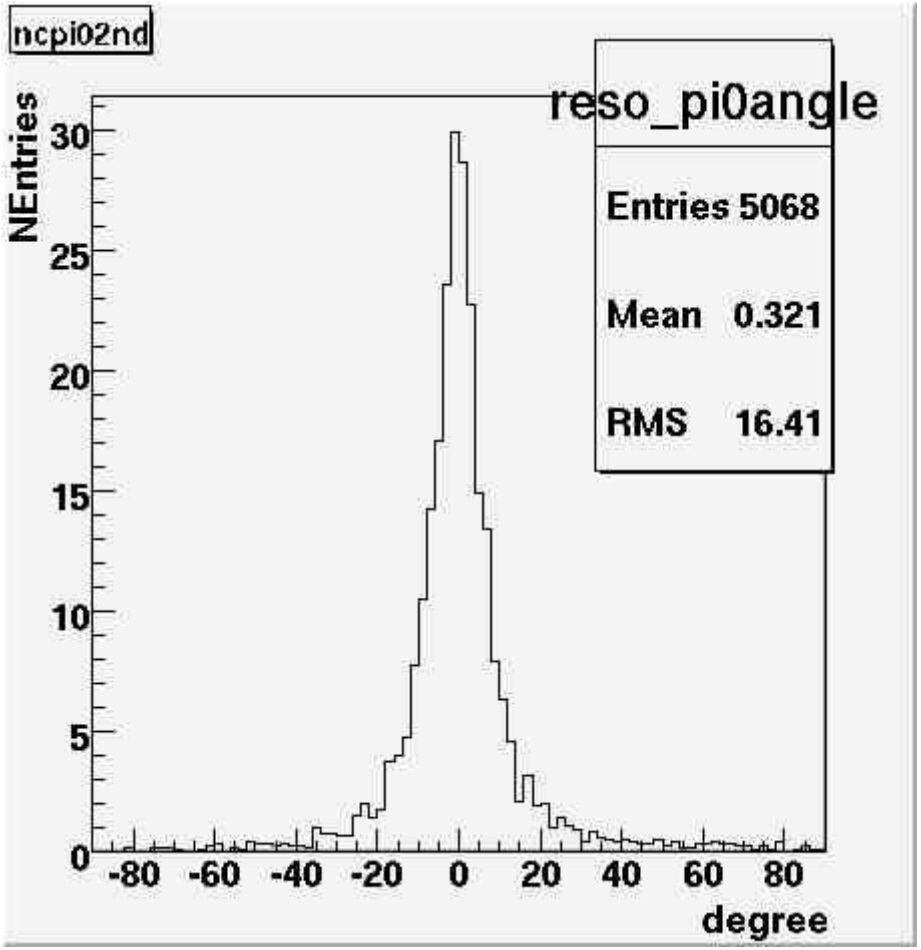


ZY projection



RMS = 16 degree

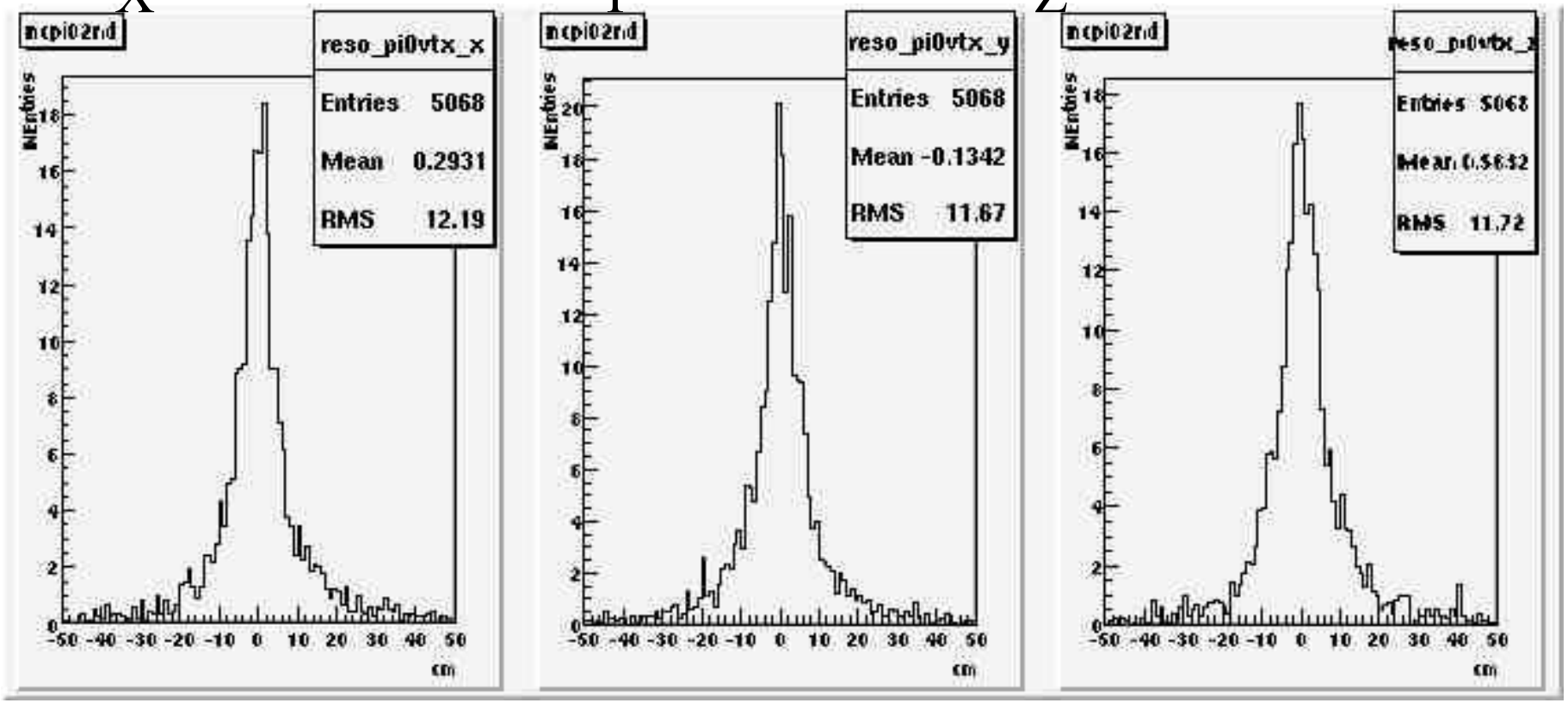
π0 angle resolution



RMS = 16 degree

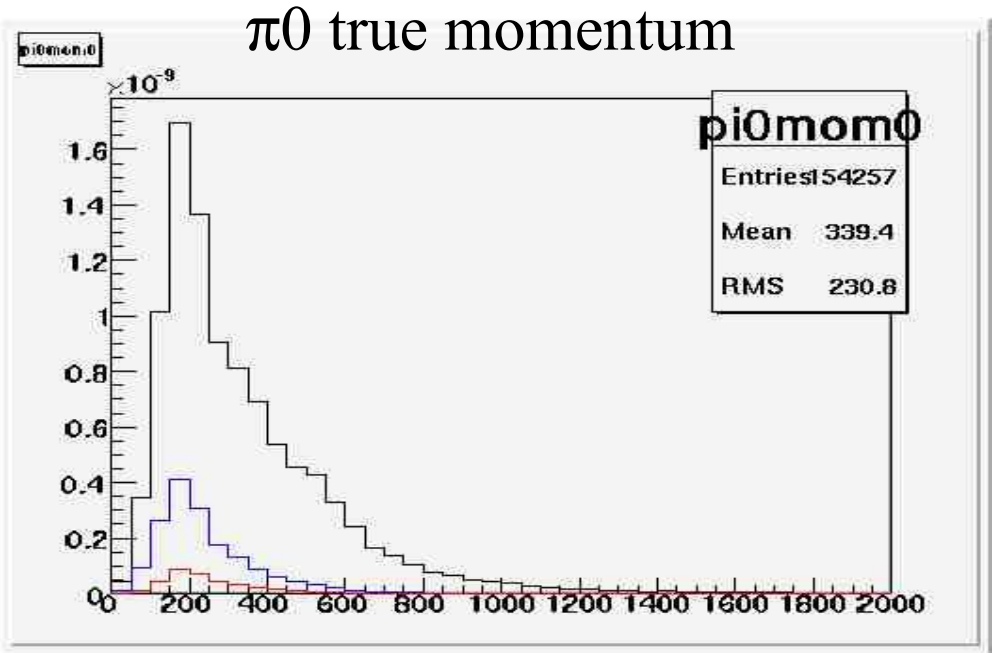
π0 vertex resolution

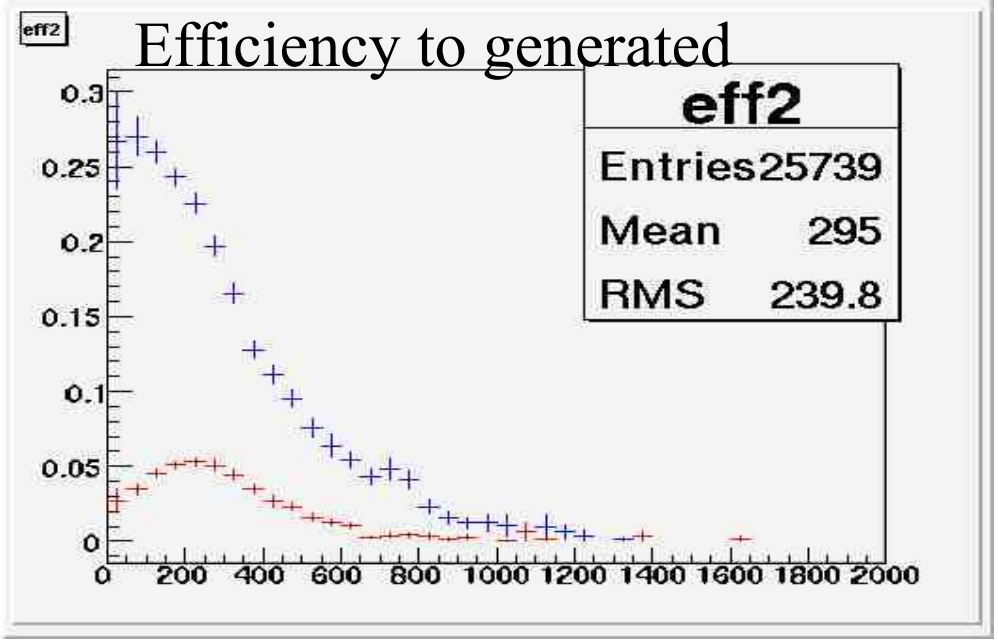
X Y Z



RMS = 12 cm

π0 true Momentum





Generated

2γ Converted in SciBar

Selected

Cross section ratio

$$\frac{\sigma(NC\pi 0)}{\sigma(CC)} = \frac{N_{data} - N_{bg}}{N_{mrd\ stopped}} \frac{\varepsilon_{cc}}{\varepsilon_{ncp0}} \frac{1}{p_{cc}}$$

$N_{data} = 502$

$N_{bg.} = 203$

N_{data} : selected events (data)

$N_{bg.}$: estimated background by MC

ε_{cc} : efficiency for CC inclusive

$\varepsilon_{nc\pi 0}$: efficiency for signal

p_{cc} : purity for CC inclusive

$\varepsilon_{cc} = 18.9\ \%$

$\varepsilon_{nc\pi 0} = 3.8\ \%$

$p_{cc} = 88.7\ \%$

Summary of systematic uncertainty

Detector Response

1 p.e. Resolution
Cross talk to next channel
Scintillation quenching
energy threshold
Pion int. in detector
TDC dead time

Physics uncertainty

π int. at target nucleus
MA
Fermi momentum
Proton re-scattering

Dirt uncertainty

Density of dirt

Beam uncertainty

1000 Weight method

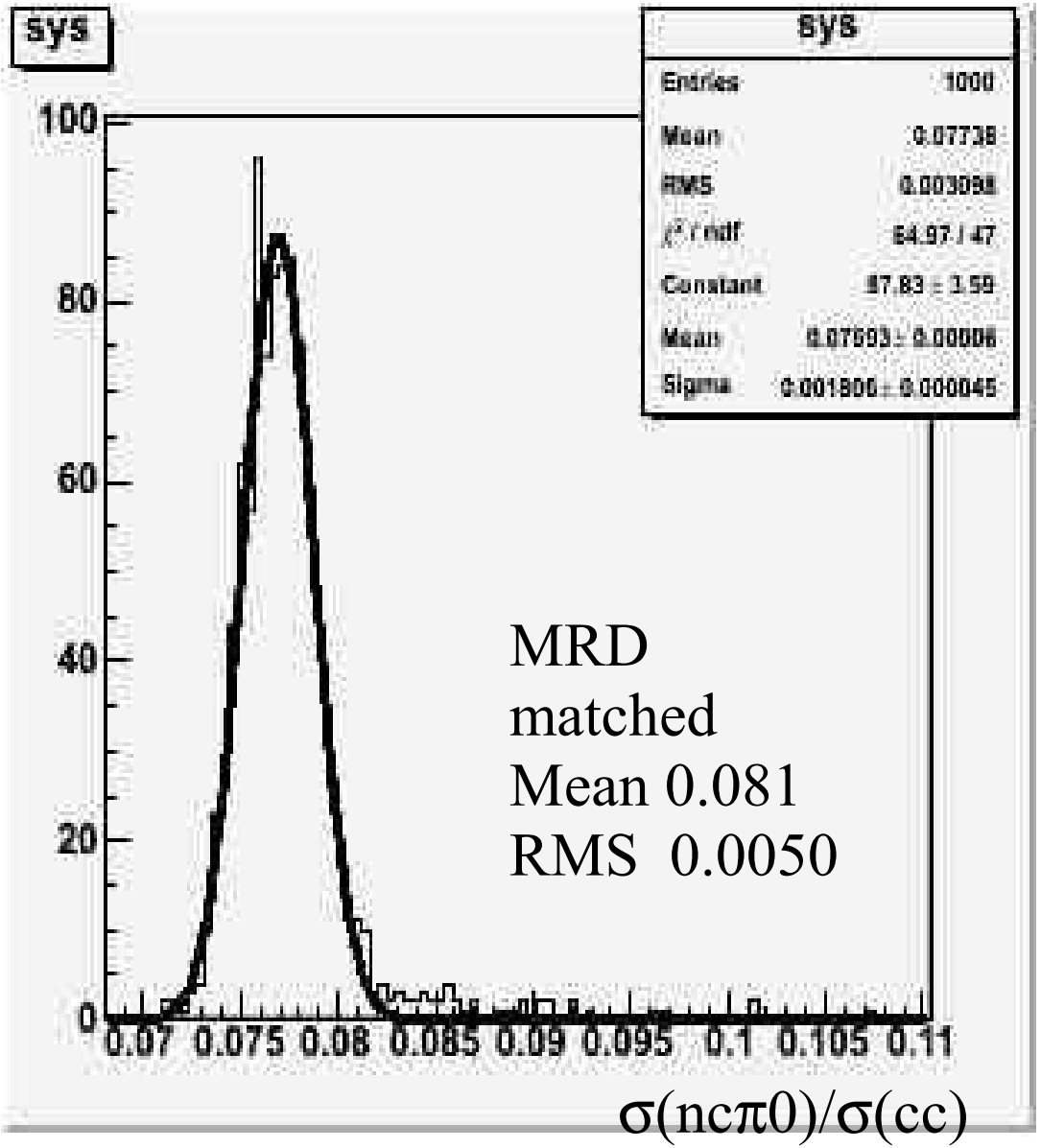
Others (later slides)

Red : done
Black not yet

Neutrino Beam uncertainty

- Pi+ production (SW)
- Pi- production (SW)
- K+ production (FS)
- K0 production (FS)
- Horn skin effect
- Horn current
- Be-nucleon x-section
- Be-pion x-section

Spectrum reweighting
using 1,000 multisim draws
(See Nakaji's slides@ July CM)



Detector Response

	Δr total (%)	from N_{bg} (%)	from ε_{cc} (%)	from $\varepsilon_{nc\pi_0}$ (%)
1pereso 0.3	-1.1	-1.3	0.3	0
1pereso 0.7	2.7	1.1	-0.2	1.7
Kalk 2.75 %	1.1	0.8	0.5	1.5
Kalk 3.55 %	-3.8	-3.1	0	-0.8
Birk small	-1.2	0.9	0.3	-2.2
Birk large	0	0.7	0.3	-0.9
total	-4.1 +2.9%			

Physics uncertainty

	Er (%)	from N_{bg} (%)	from ε_{cc} (%)	from $\varepsilon_{nc\pi^0}$ (%)
π abs +30 %	3.8	2.8	0.2	0.9
π abs -30 %	-3.6	-2.7	-0.2	-0.7
π chex +30 %	0.2	-0.1	0	0.3
π chex -30 %	0	0.3	0	-0.3
π inel +30 %	0	0.8	0.1	-0.8
π inel -30 %	0.4	-0.5	0	0.9
M_A 1.1 GeV/c2	2.5	2	1.5	-1
total	-3.5 +4.6 %			