Charged-current cross section measurements in MiniBooNE

Teppei Katori for the MiniBooNE collaboration
Indiana University
DNP06, Nashville, Oct., 26, 06

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1. Introduction

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BB 2 A Search for ν_μ - ν_e oscillation with the MiniBooNE Experiment

MiniBooNE is a ν_μ-ν_e appearance oscillation experiment

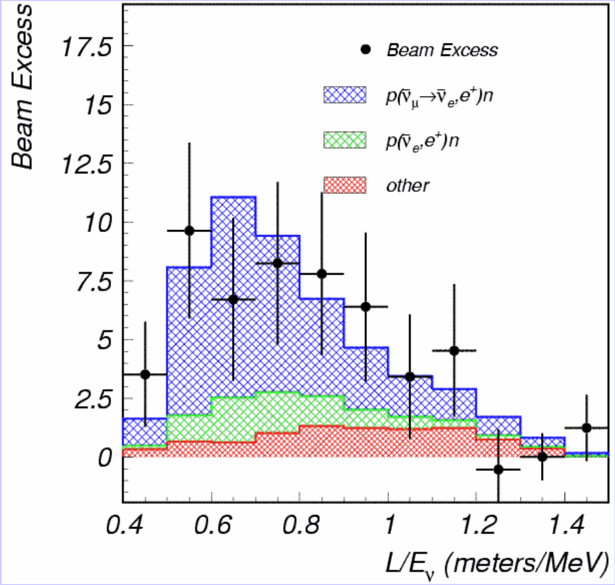
$$\nu_\mu \xrightarrow{oscillation} \nu_e + n \rightarrow e^- + p$$

This experiment is motivated to test LSND experiment at Los Alamos, where non-zero neutrino appearance signal was observed.

$$\bar{\nu}_\mu \xrightarrow{oscillation} \bar{\nu}_e + p \rightarrow e^+ + n$$

$$P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e) = (0.264 \pm 0.067 \pm 0.045)\%$$

LSND oscillation signal



If LSND is confirmed, it must be something beyond the standard model, including sterile neutrino, Lorentz violation, CPT violation, etc... (very exciting)

1. Introduction

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with the MiniBooNE Experiment

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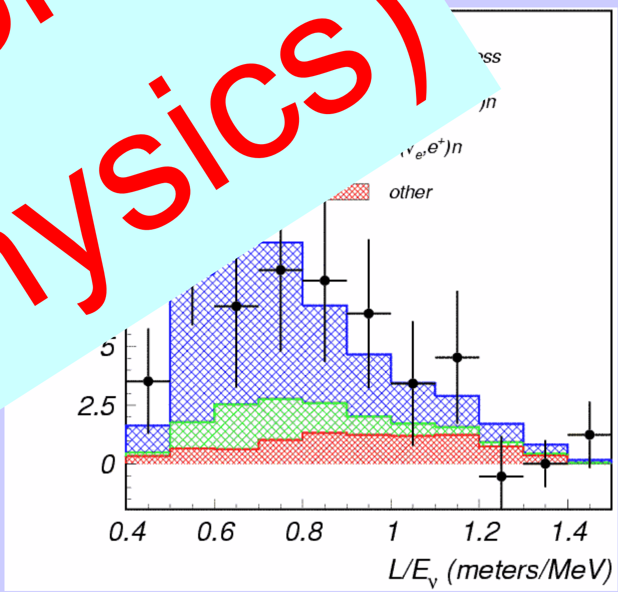
was observed.

$$\bar{\nu}_\mu \xrightarrow{oscillati...}$$

$P($ ... $)\%$

signal



If LS... ...g beyond the standard model, including
sterile... ...T violation, etc... (very exciting)

...lobal three-parameter model for neutrino
...ation using Lorentz violation

Neutrino Interaction
(no oscillation physics)

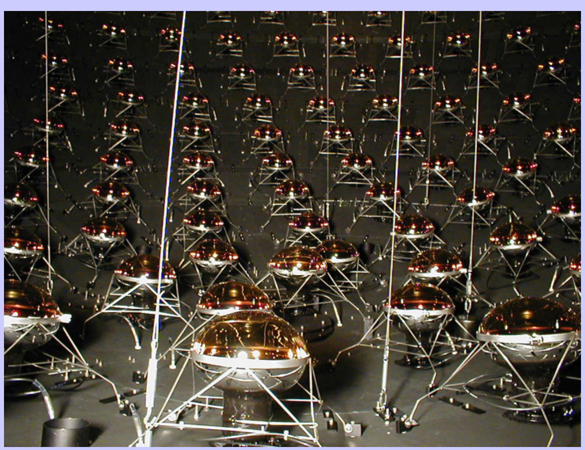
1. MiniBooNE experiment

Cerenkov detector
- 6m radius spherical tank
- filled with mineral oil ($0.85 g/cm^3$)
- inner tank is covered by 1280 PMT
- outer tank is covered by 240 veto PMT

Neutrino Beam
- Fermilab Booster (~8GeV) provides primary beam
- Secondary beam is focused by magnetic horn

MiniBooNE tank

PMT arrays



veto PMT arrays

trailer for the mineral oil

1. MiniBooNE experiment

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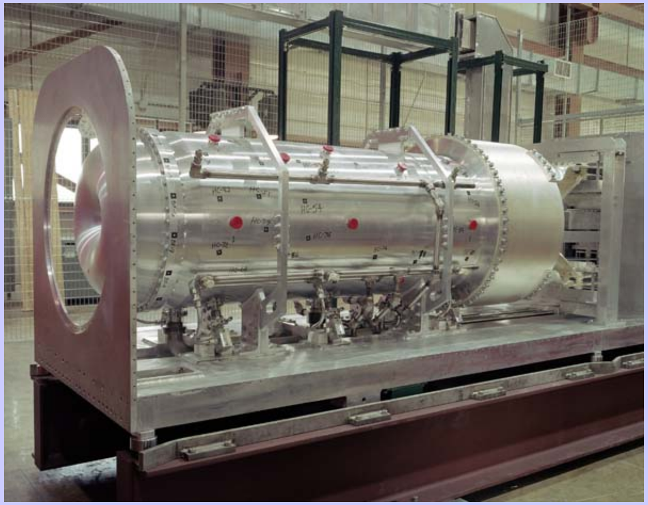
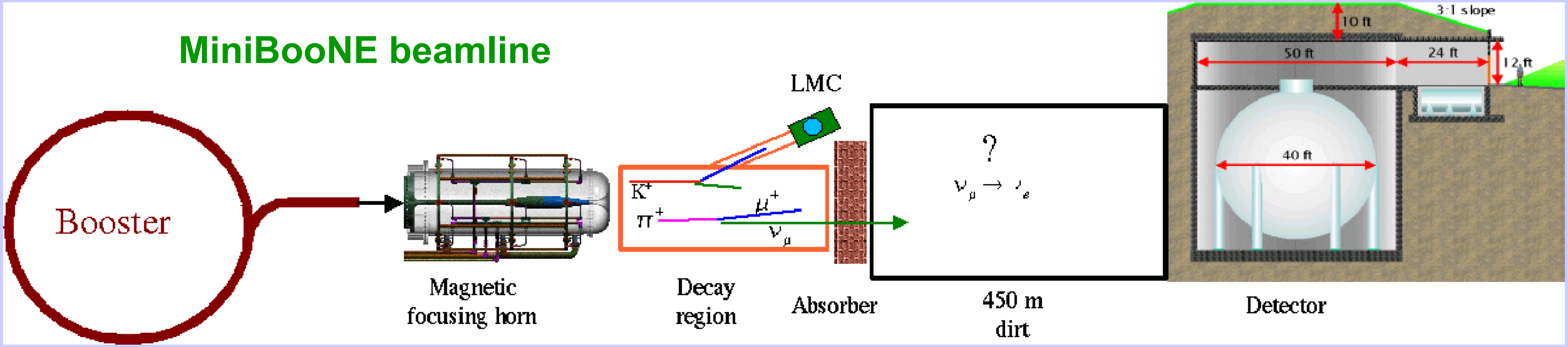
BB 4 Future Prospects for the Booster Neutrino Beam line at FNAL

Magnetic focussing horn





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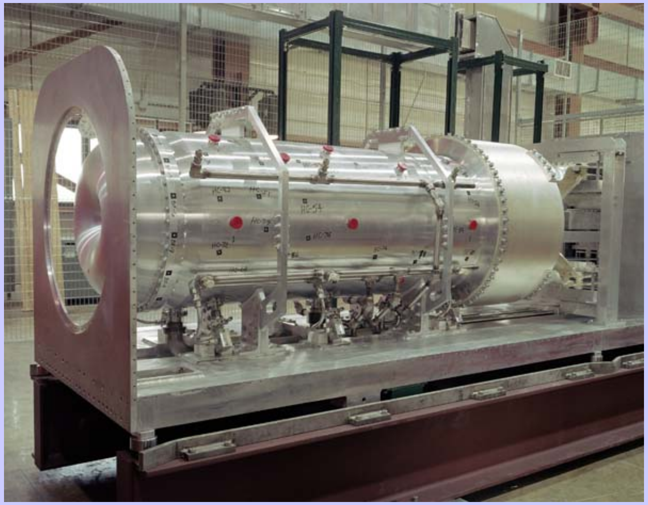


Since 2006, horn current is switched to negative value, so negative pions are focussed to create antineutrino beam.

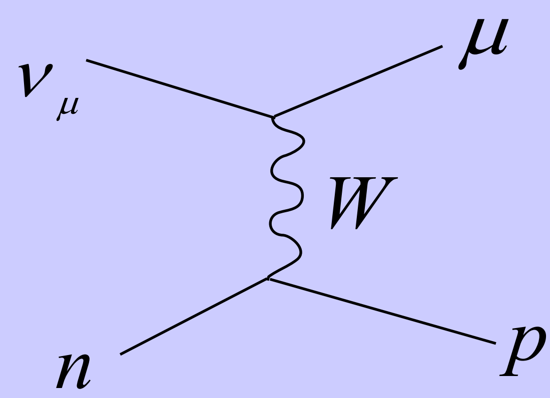
BB 5 Free Proton Charged Current Cross Section using MiniBooNE Anti-Neutrino Data

2. Charged-current quasi-elastic (CCQE) Interaction

2. CCQE interaction

Charged-current quasi-elastic (CCQE) interaction is the most fundamental interaction for neutrino physics

$$\nu_\mu + n \rightarrow \mu^- + p$$



This is very important for MiniBooNE to measure CCQE interaction by series of reasons;

(1) determine neutrino flux uncertainty
(2) test cross section models ...etc

2. CCQE interaction in MiniBooNE

Charged Current Quasi-Elastic (CCQE)

$$\nu_\mu + n \rightarrow \mu^- + p$$

Neutral Current Elastic (NC EL)

$$\nu_\mu + p/n \rightarrow \nu_\mu + p/n$$

Charged Current π^+ production (CC π^+)

$$\nu_\mu + p \rightarrow \mu^- + p + \pi^+$$

Charged Current CC π^0 production (CC π^0)

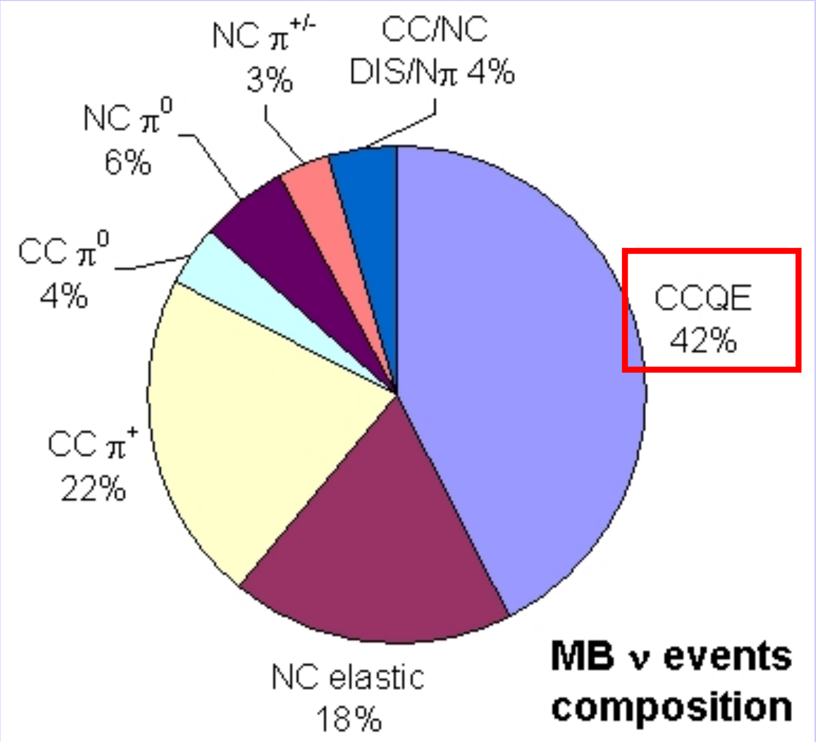
$$\nu_\mu + n \rightarrow \mu^- + p + \pi^0$$

Neutral Current NC $\pi^\pm$ production (NC $\pi^\pm$)

$$\nu_\mu + p/n \rightarrow \nu_\mu + n/p + \pi^\pm$$

Neutral Current NC π^0 production (NC π^0)

$$\nu_\mu + n \rightarrow \nu_\mu + n + \pi^0$$



about ~340,000 event in our 5.7E20 POT sample

MB CCQE interaction MC:

NUANCE code with Smith-Moniz Fermi Gas model

3. Event selection

3. Event selection

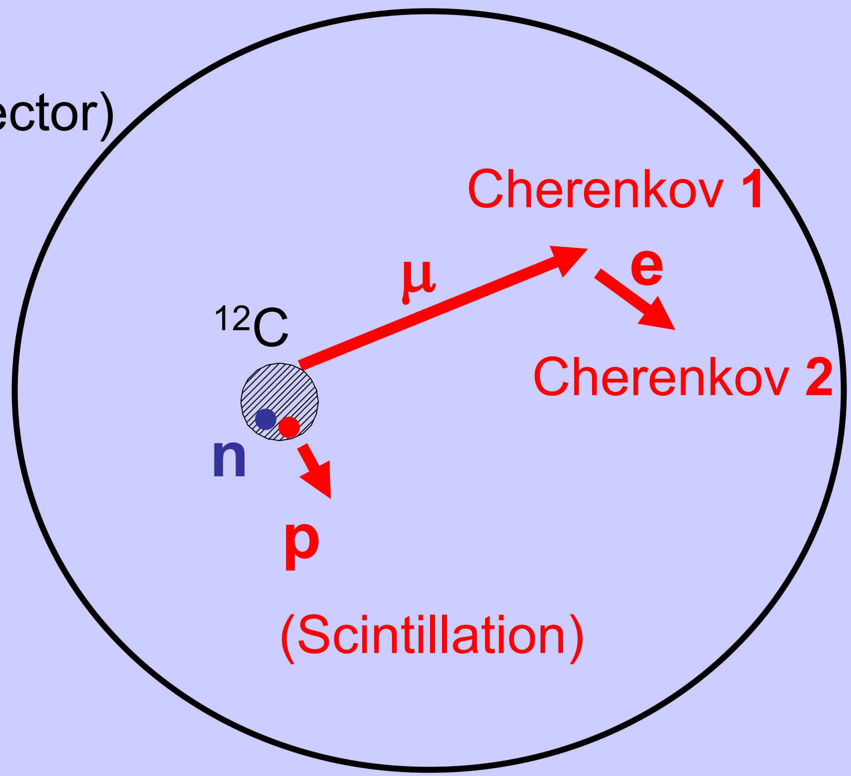
CCQE event selection 100% relies on muon signal.

(1) low level cuts: veto and timing of muon and decayed electron signal

(2) high level cuts: Fisher discriminant from muon light signatures

MiniBooNE detector
(spherical Cherenkov detector)

ν-beam



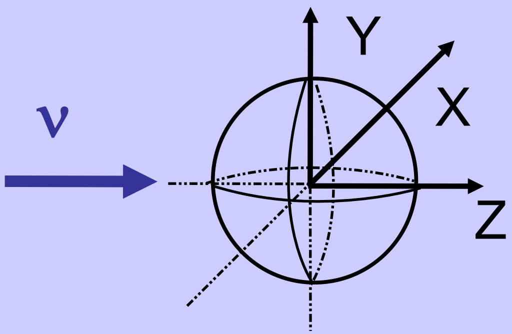
muon like Cherenkov light and subsequent decayed electron like Cherenkov light are the signal of CCQE event (purity~90%)

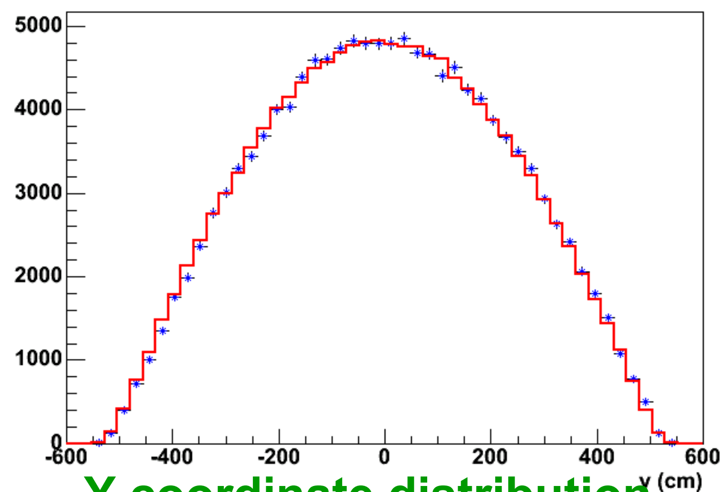
BB 3 A measurement of neutrino nucleon elastic scattering in MiniBooNE

4. Data and MC comparison

4. Muon coordinate reconstruction

MC describes CCQE muon coordinate distribution very well.
(preliminary, statistical error only)

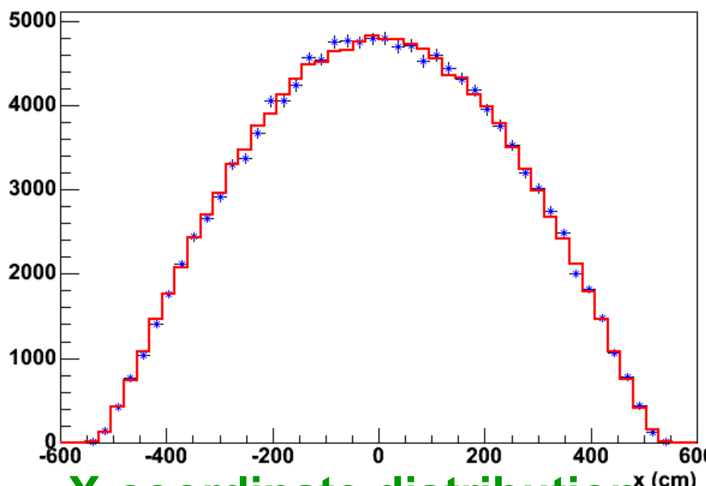




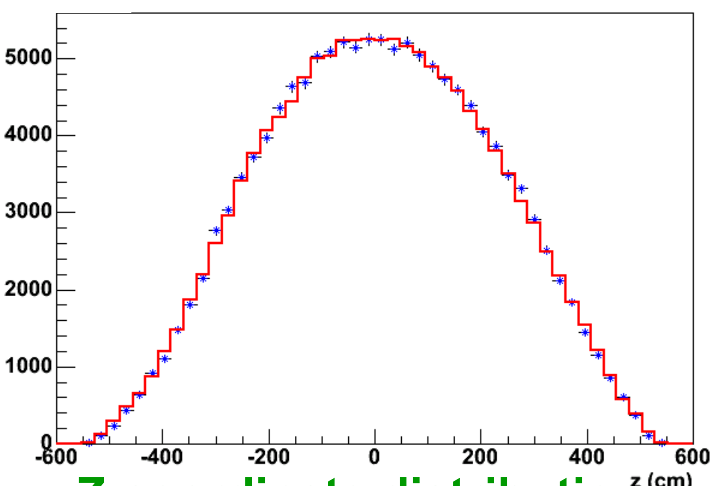
Y-coordinate distribution

Reconstructed muon track center

BB6 Event Reconstruction and Particle Identification for MiniBooNE Experiment



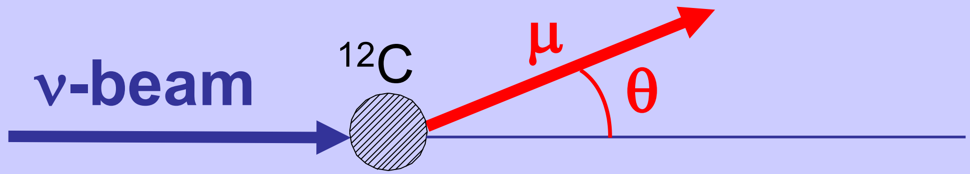
X-coordinate distribution



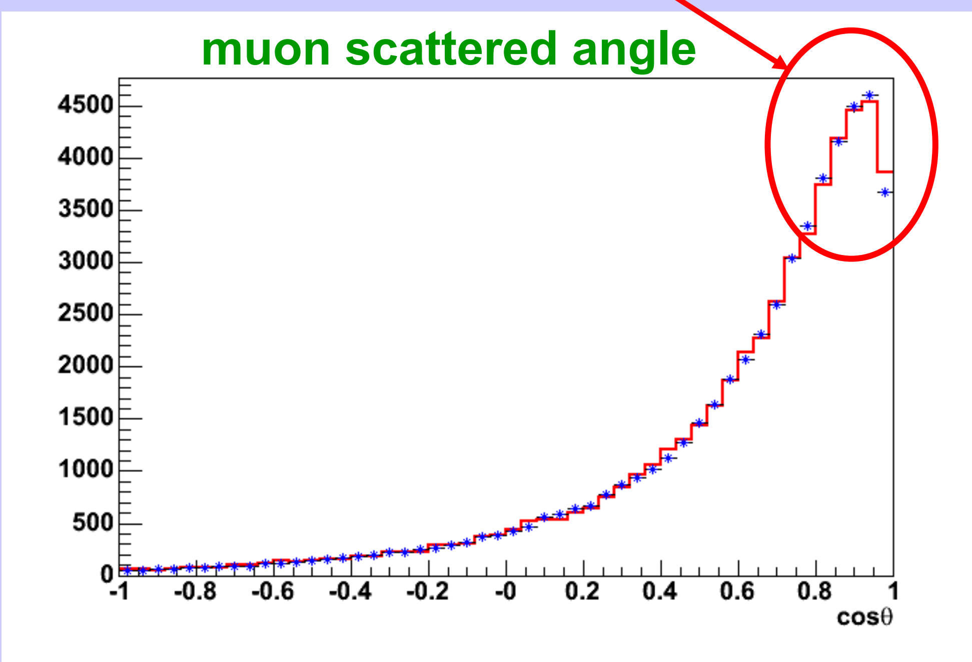
Z-coordinate distribution

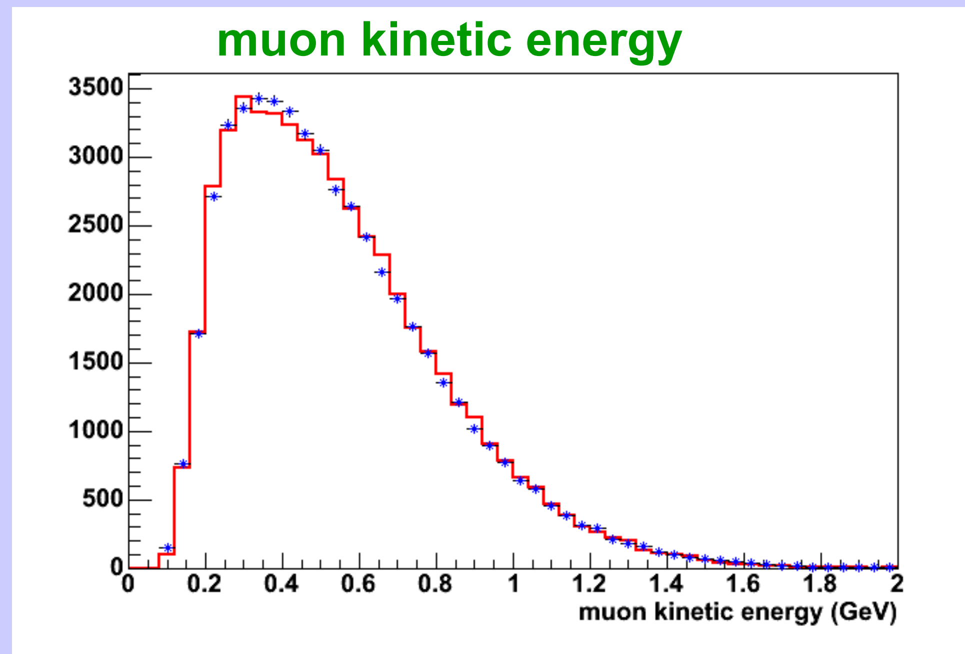
4. Muon kinematics reconstruction

MC also describes CCQE muon direction and energy distribution very well, too. (preliminary, statistical error only)

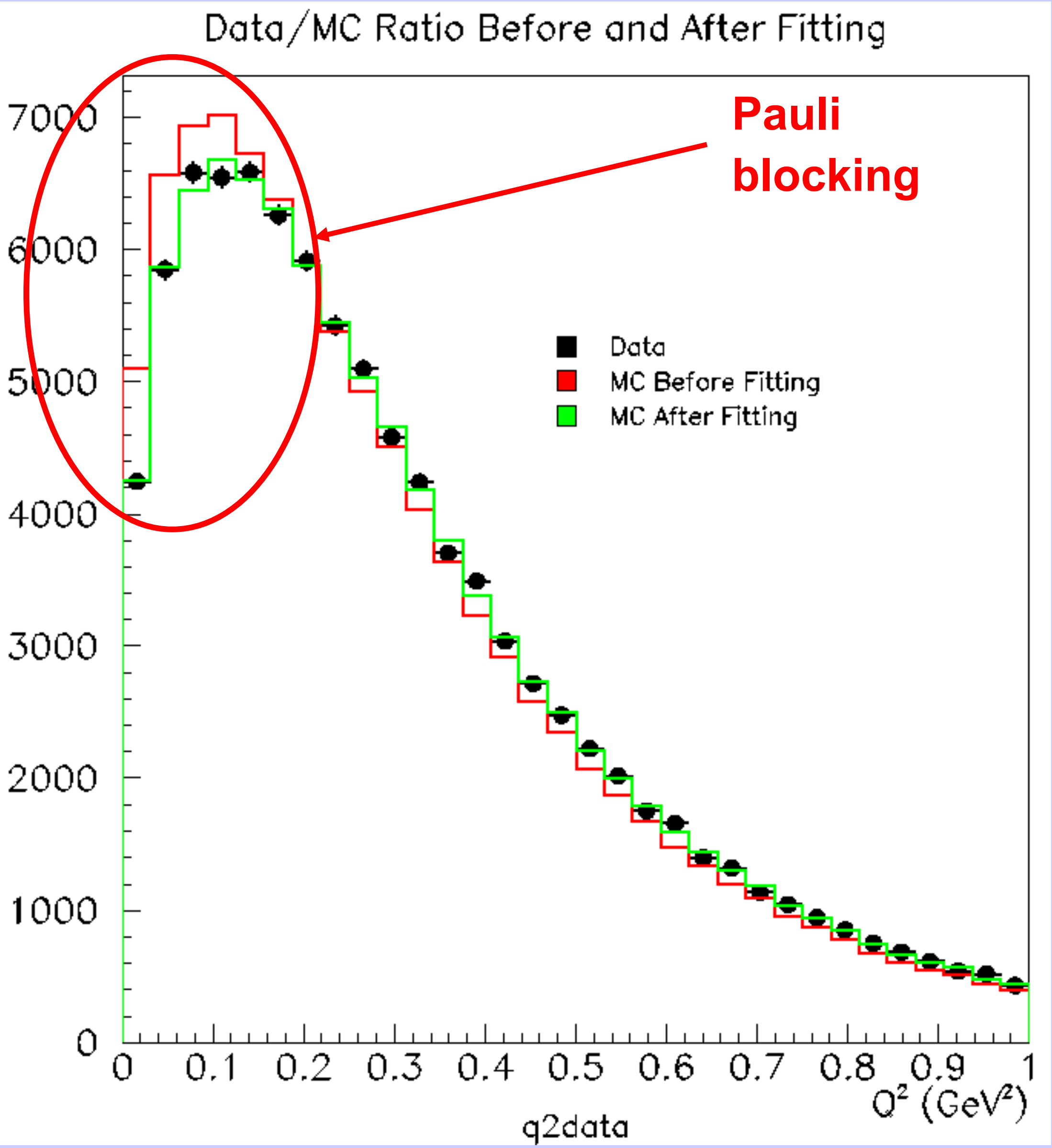


Pauli blocking (see next)





4. Q^2 (four momentum transfer)



(preliminary, statistical error only)

black dots: data

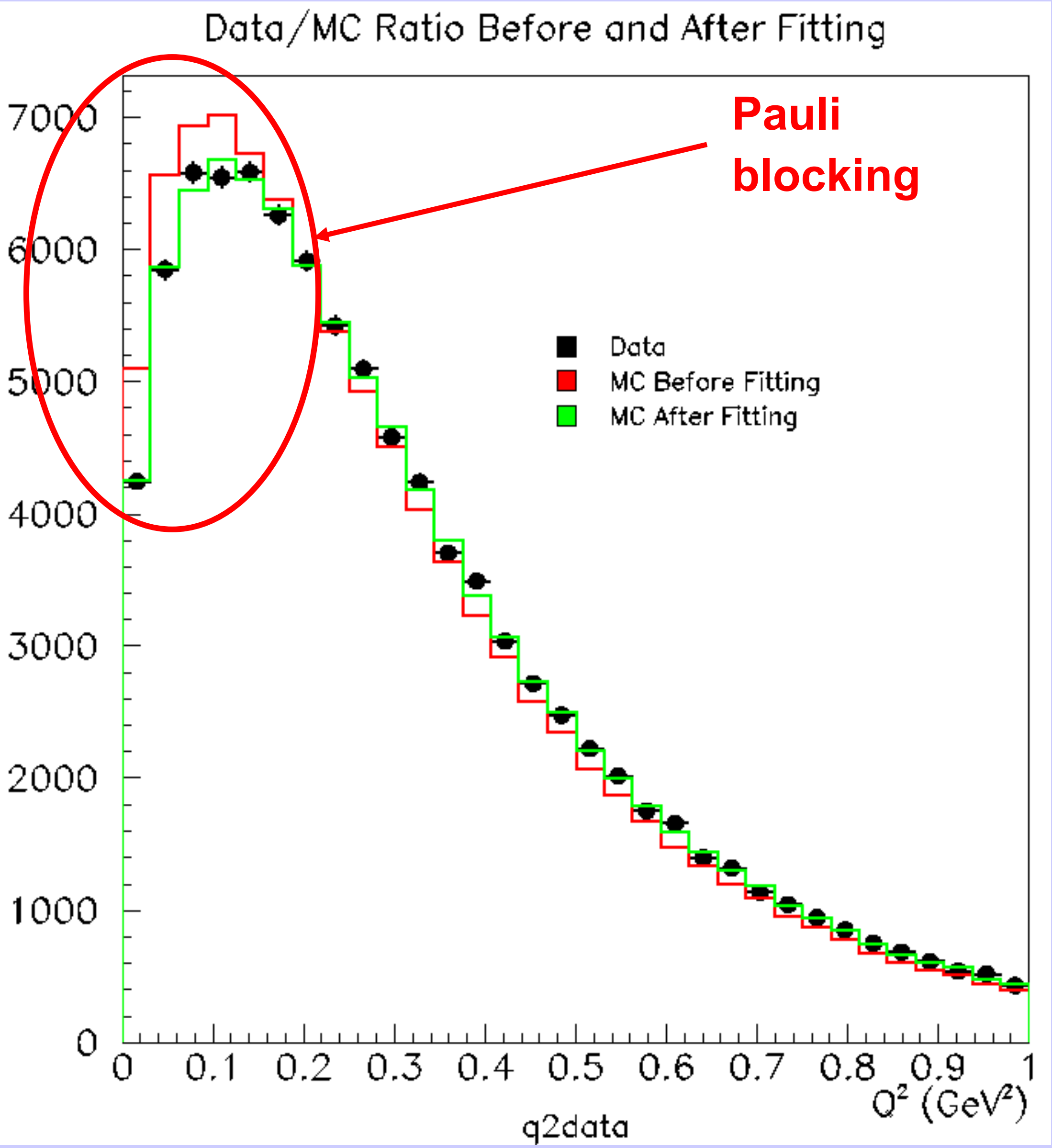
red line: MC, with old xs model

green line: MC, with new xs model

There is a large discrepancy in our data and old MC at very first few bins, this is the region where electron scattering experiment cannot measure the cross section

In order to achieve data-MC agreement in our sample, we modify Smith-Moniz Fermi gas model in NUANCE

4. Q^2 (four momentum transfer)



(preliminary, statistical error only)

black dots: data

red line: MC, with old xs model

green line: MC, with new xs model

First, M_A (axial mass) is chosen so that the large Q^2 region in our data is described correctly by MC

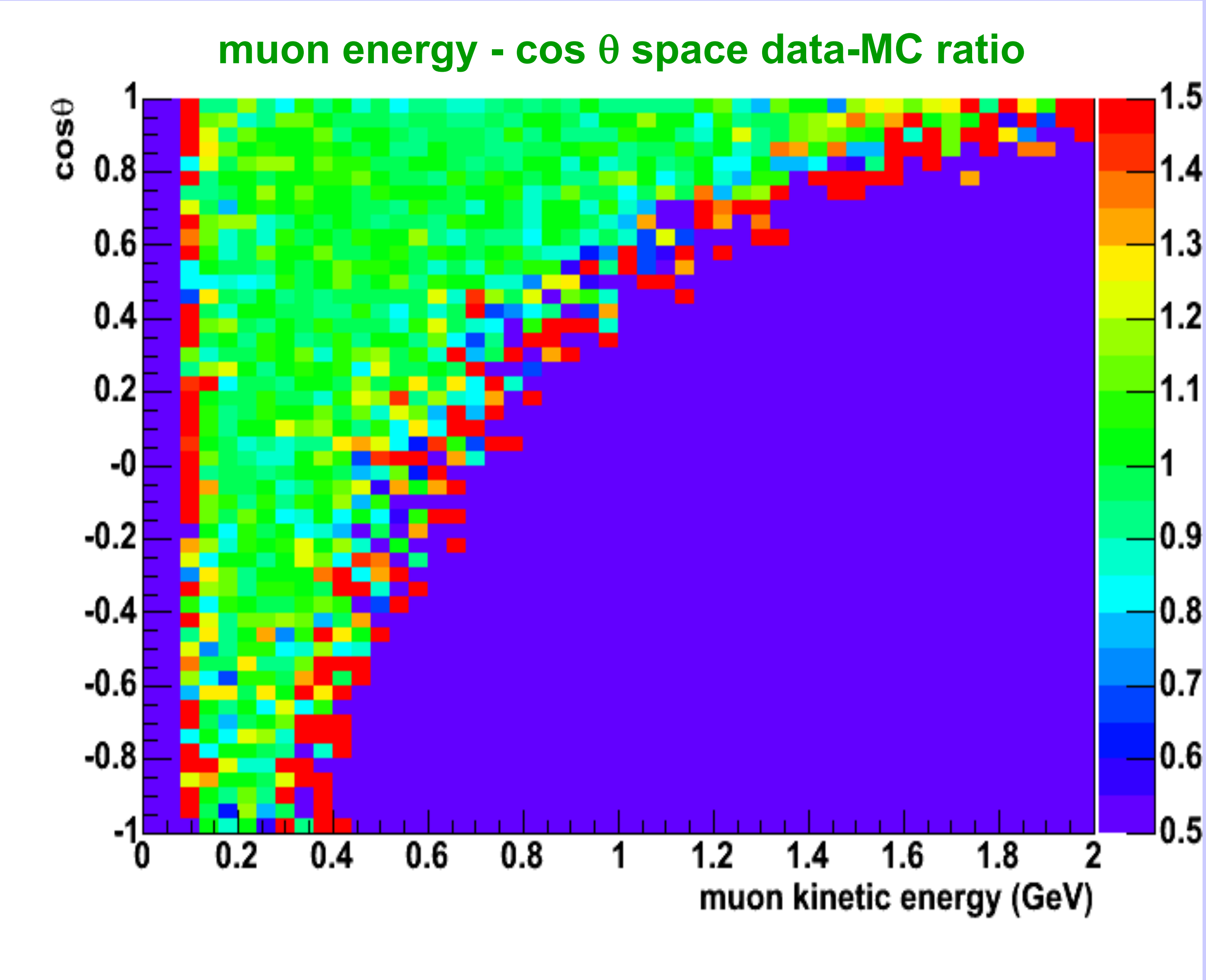
M_A = 1.35GeV

Second, we scale up around 0.7% the lower bound of Fermi sea to enhance Pauli blocking so that the low Q^2 region in our data is described correctly by MC

LB_{scale} = 1.0066

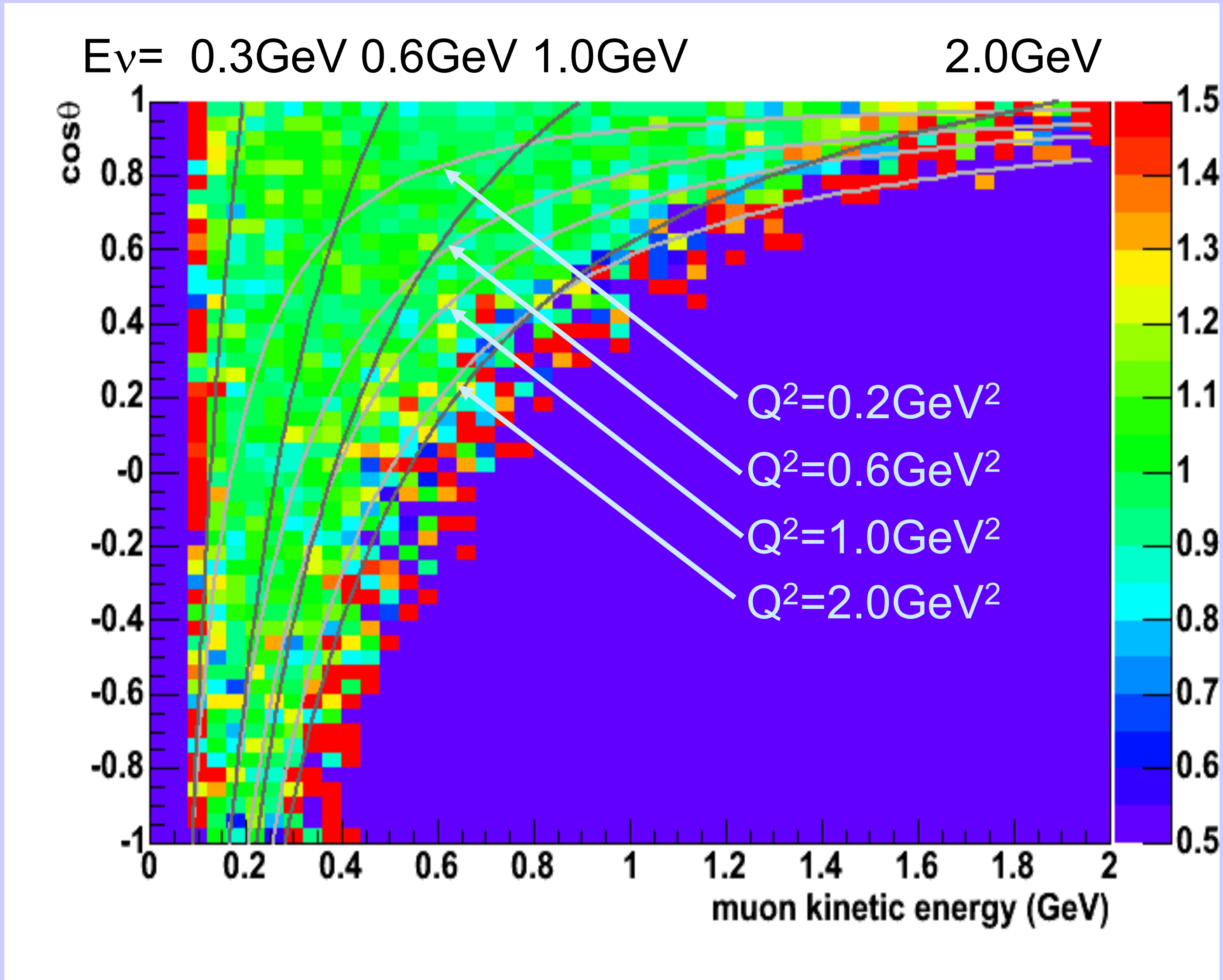
4. Kinematics space

The data-MC ratio of kinematics space (the data-MC ratio of efficiency) shows data and MC efficiency agree in the vast region of kinematics phase space. So our new cross section model is consistent between data and MC for current our analysis (preliminary).



4. Kinematics space

Since 2dim efficiency space agrees between data and MC, obviously both reconstructed neutrino energy and Q^2 distributions agree for data and MC (preliminary).

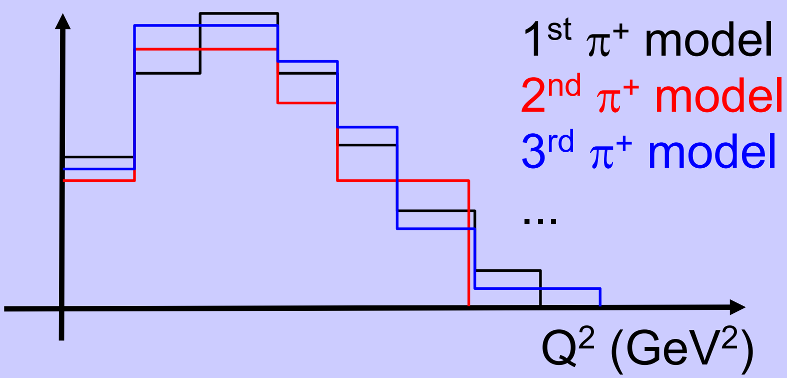


5. Systematic errors

Multisim method

>1000 times fake experiments with different parameter set give the variation of correlated systematic errors for each uncorrelated error matrix (in progress)

ex) π^+ error for Q^2 distribution



correlated

uncorrelated

π^+ production	(8 parameters)
π^- production	(8 parameters)
K^+ production	(7 parameters)
K^0 production	(9 parameters)
cross section	(10 parameters)
beam model	(8 parameters)
π^0 yield	(9 parameters)
dirt model	(1 parameters)
detector model	(>60 parameters)

6. Conclusions

MiniBooNE is a ν_μ-ν_e appearance oscillation experiment.

CCQE interaction is the most fundamental process in neutrino scattering experiment.

MiniBooNE successfully describes CCQE interaction in Pauli blocked area where electron scattering cannot measure. So now whole kinematics region are covered correctly by MC.

The evaluation of systematic errors is in progress.

Thank you for your attention.

BooNE collaboration

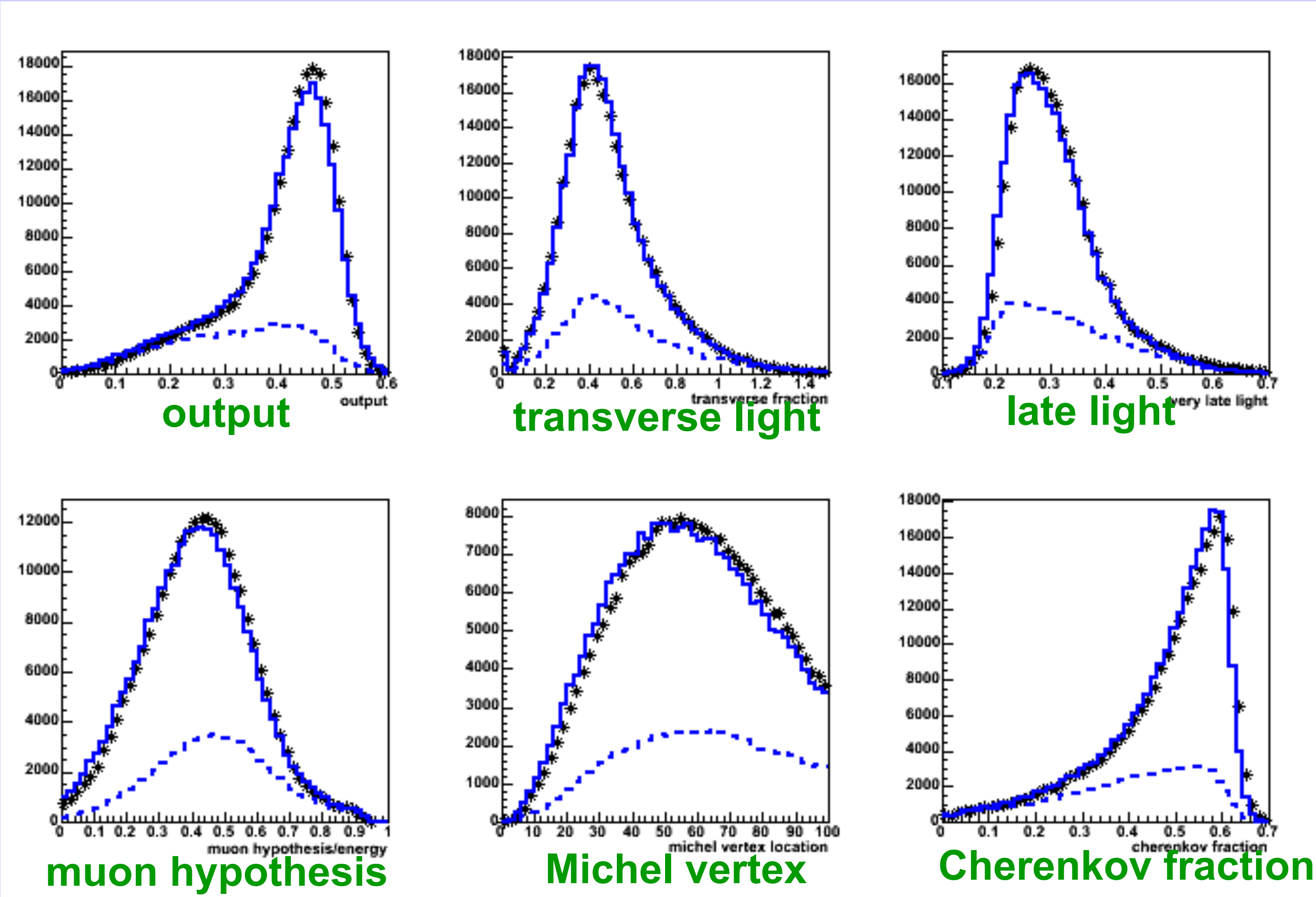
University of Alabama
Bucknell University
University of Cincinnati
University of Colorado
Columbia University
Embry Riddle Aeronautical University
Fermi National Accelerator Laboratory
Indiana University

Los Alamos National Laboratory
Louisiana State University
University of Michigan
Princeton University
Saint Mary's University of Minnesota
Virginia Polytechnic Institute and State University
Western Illinois University
Yale University

Backup

3. Fisher discriminant

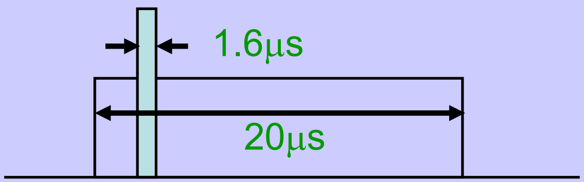
Fisher discriminant makes a hyper ellipsoid surface enclosed signals. Our output relies on 5 input variables.



2. Beam

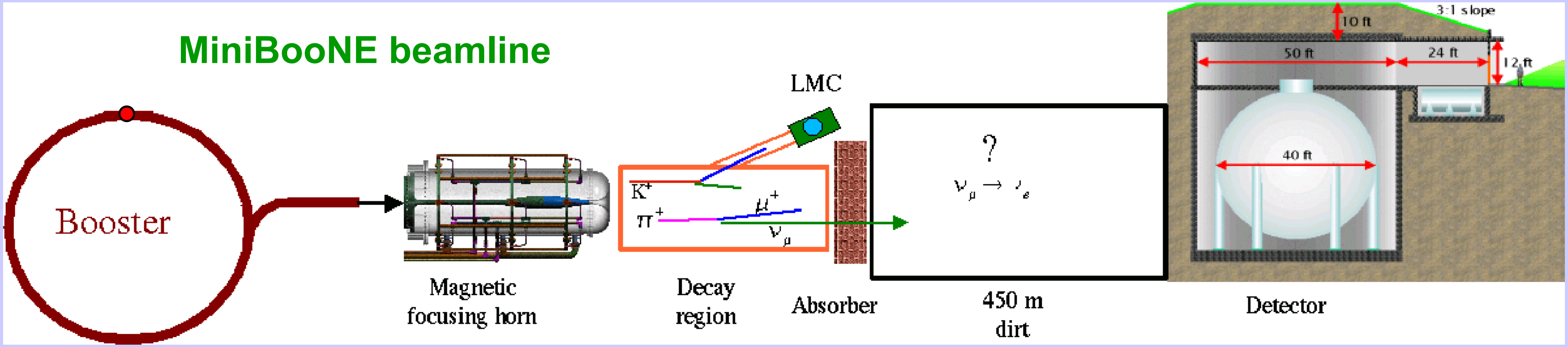
Protons are delivered from Fermilab Booster (~8GeV) to MiniBooNE beam line.

- 1 spill = ~4E12 protons
- beam trigger window (DAQ window) = 20μs
- ~ 5 spills / sec (~ 5Hz)
- ~1 neutrino interaction / minute (very high statistics)



Beam macro structure

Booster



2. Beam

Muon neutrino beam is created by pion decay in flight (DIF).
Need careful study about Kaon production.

$$\pi^+ \to \mu^+ + \nu_\mu$$

$$\mu^+ \to e^+ + \nu_e + \bar{\nu}_\mu$$

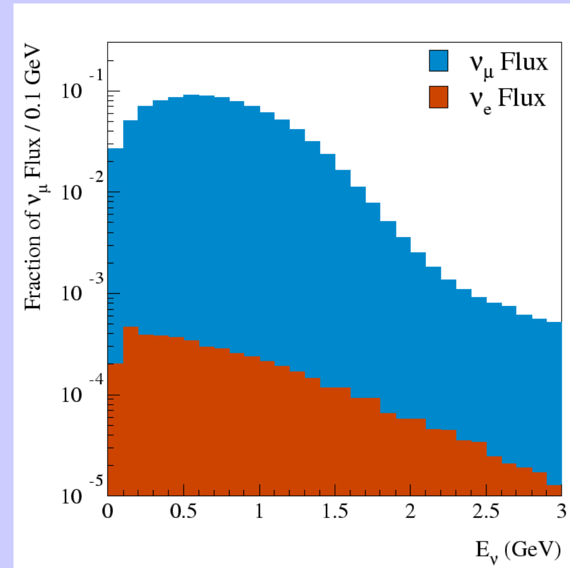
$$K^+ \to \mu^+ + \nu_\mu,\ K^+ \to e^+ + \nu_e$$

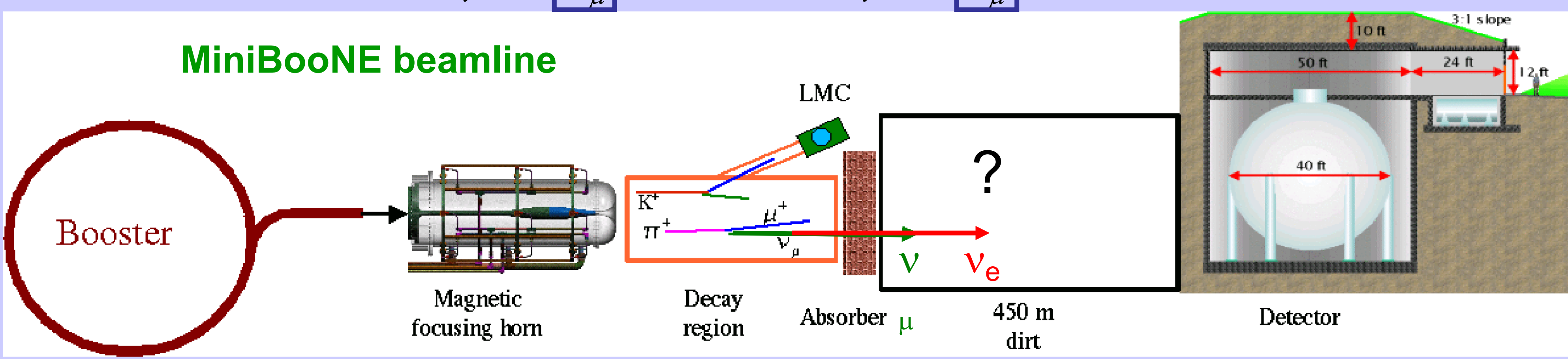
$$K^+ \to \pi^0 + \mu^+ + \nu_\mu,\ K^+ \to \pi^0 + e^+ + \nu_e$$

$$K^0 \to \pi^+ + e^- + \bar{\nu}_e,\ K^0 \to \pi^- + e^+ + \nu_e$$

$$K^0 \to \pi^+ + \mu^- + \bar{\nu}_\mu,\ K^0 \to \pi^- + \mu^+ + \nu_\mu$$

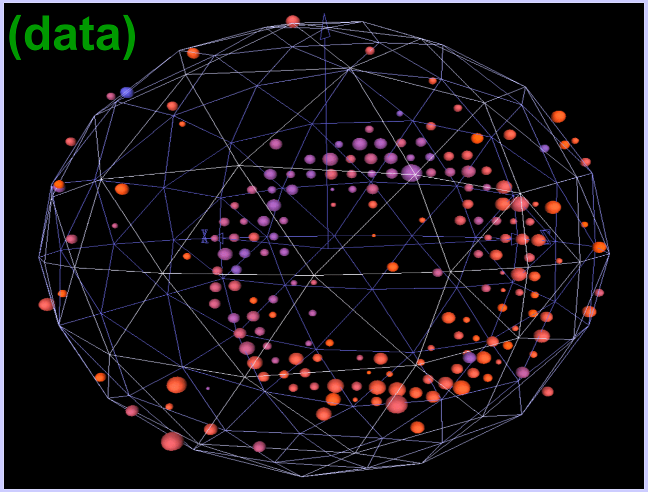
neutrino flux prediction





3. Detector

Cherenkov ring image (data)

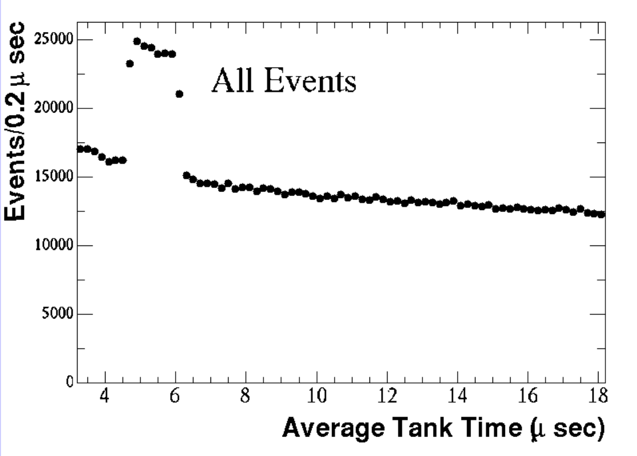


Cherenkov detector

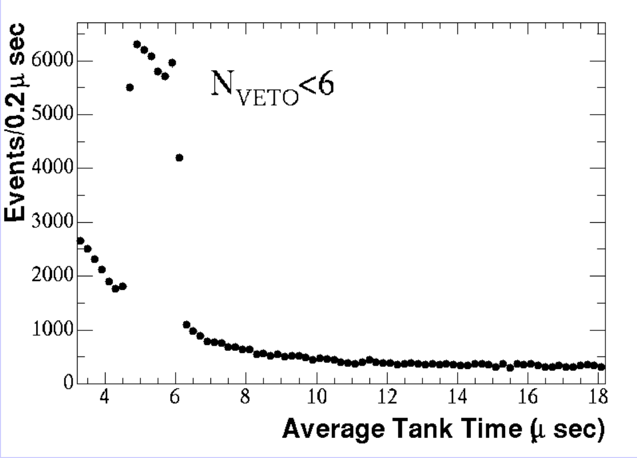
- 6m radius spherical tank
- filled with mineral oil (0.85g/cm^3)
- inner tank is covered by 1280 PMT
- outer tank is covered by 240 veto PMT

Simple hits (PMT multiplicity) and timing information tell neutrino event!

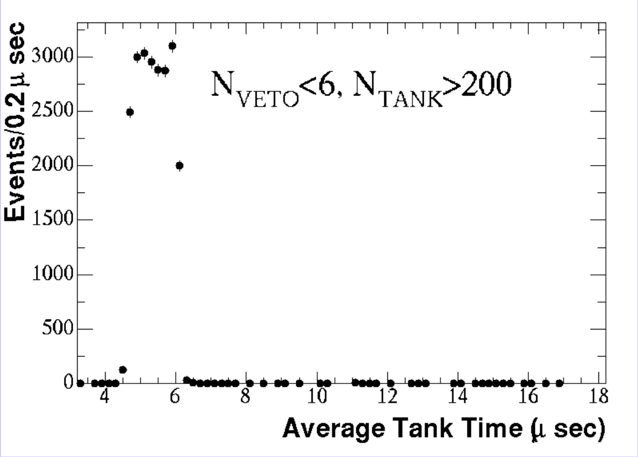
- 1st time cluster



- 1st time cluster
- Veto hits < 6



- first time cluster
- Veto hits < 6
- Tank hits > 200



4. Neutrino interaction

Charged Current Quasi-Elastic (CCQE)

$$\nu_\mu + n \rightarrow \mu^- + p$$

Neutral Current Elastic (NC EL)

$$\nu_\mu + p/n \rightarrow \nu_\mu + p/n$$

Charged Current π^+ production (CC π^+)

$$\nu_\mu + p \rightarrow \mu^- + p + \pi^+$$

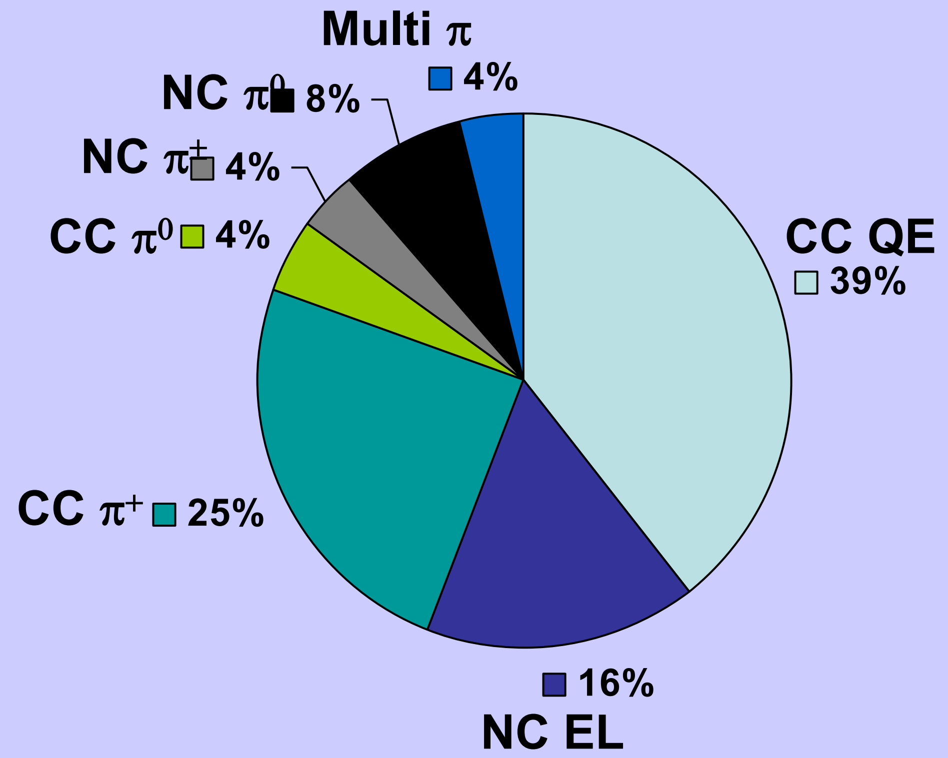
Charged Current CC π^0 production (CC π^0)

$$\nu_\mu + n \rightarrow \mu^- + p + \pi^0$$

Neutral Current NC $\pi^\pm$ production (NC $\pi^\pm$)

$$\nu_\mu + p/n \rightarrow \nu_\mu + n/p + \pi^\pm$$

Neutral Current NC π^0 production (biggest misID)

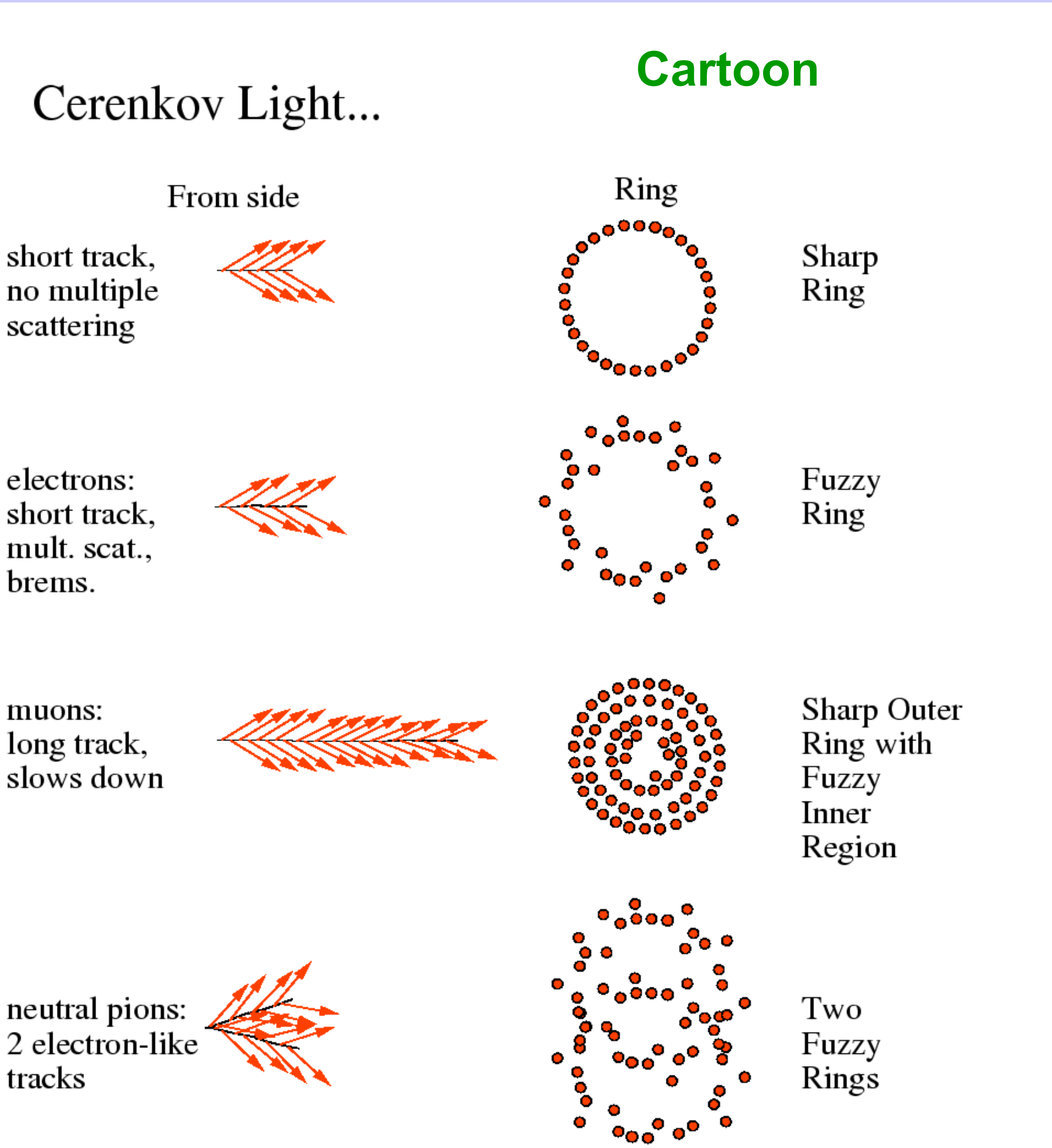


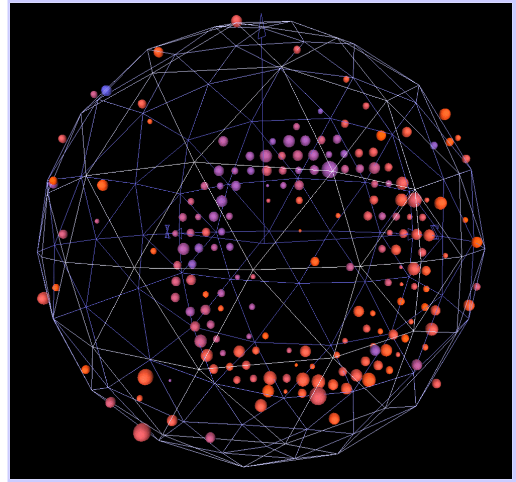
π^0 makes similar Cherenkov ring with electron (signal of neutrino oscillation)

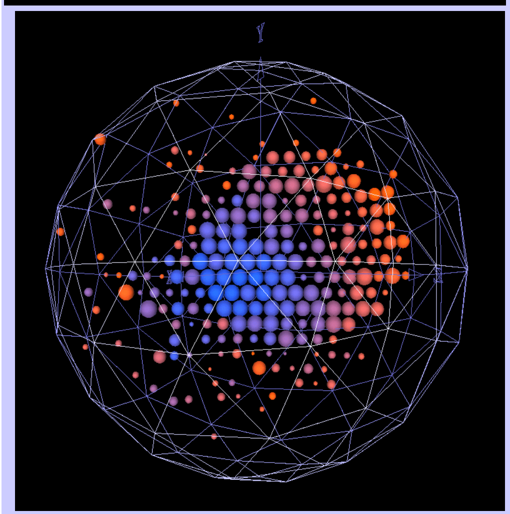
$$\nu_\mu + n \rightarrow \nu_\mu + n + \pi^0 \quad \longleftrightarrow \quad \nu_e + n \rightarrow e^- + p$$

4. Neutrino interaction

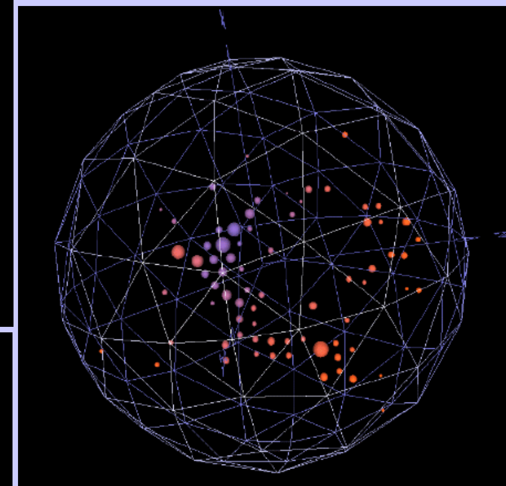
Event topology

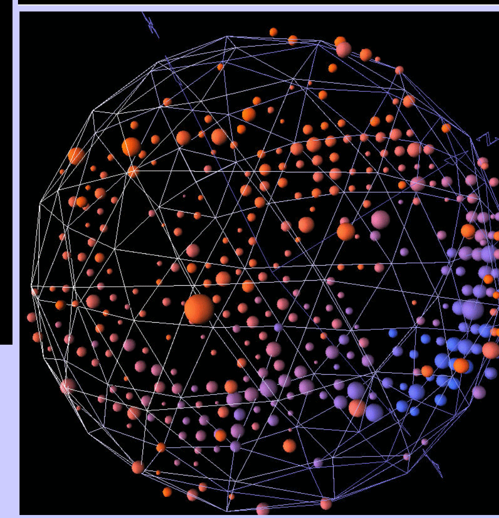






Data ("typical" event)





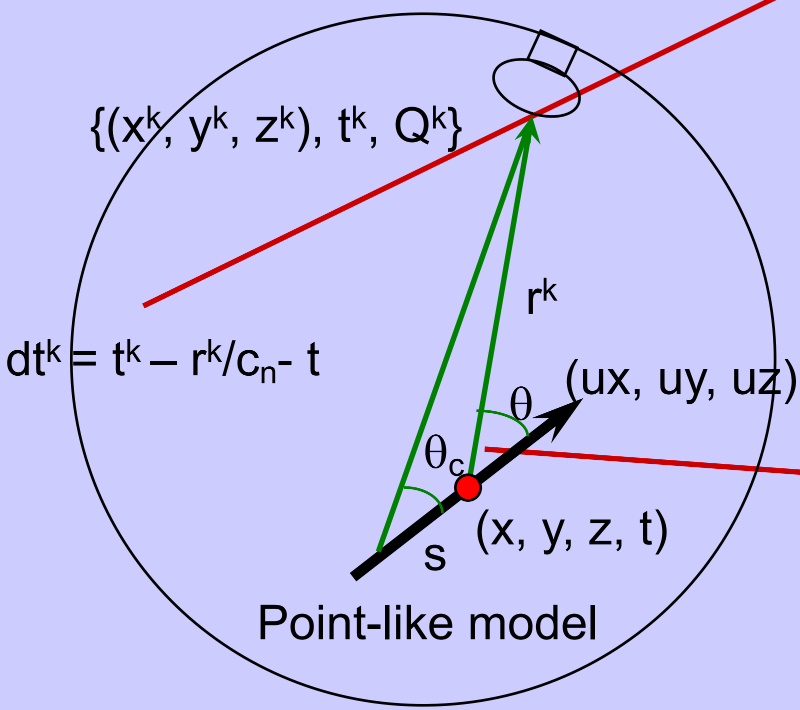
5. Event reconstruction

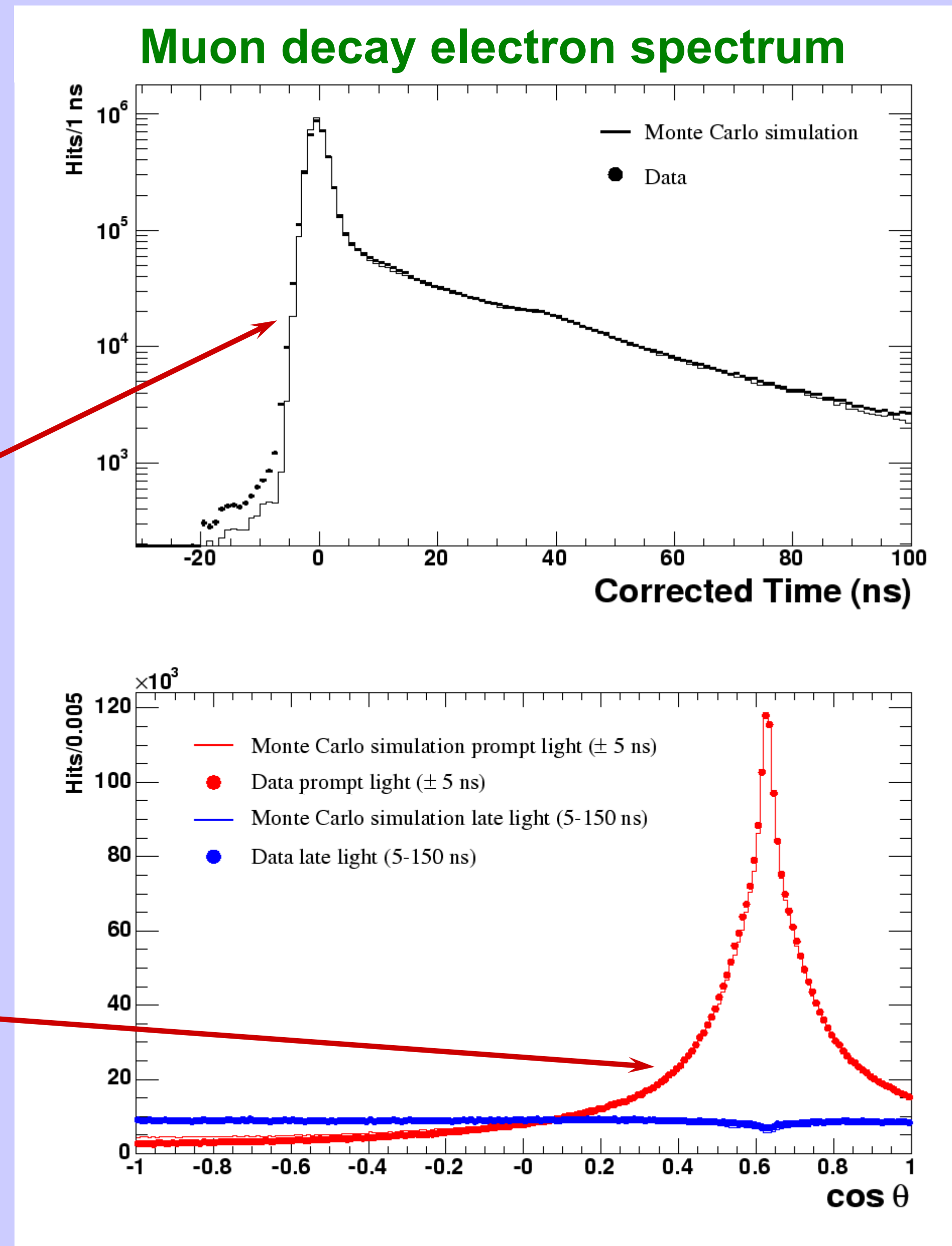
An event consists of a set of charge, time, and spatial information of each PMT

$\{(x^k, y^k, z^k), t^k, Q^k\}$; k=1,2,...N PMT hits

Many reconstructed variables are available for various analysis:

- vertex, track length, time cluster, particle direction, event topology, energy, etc

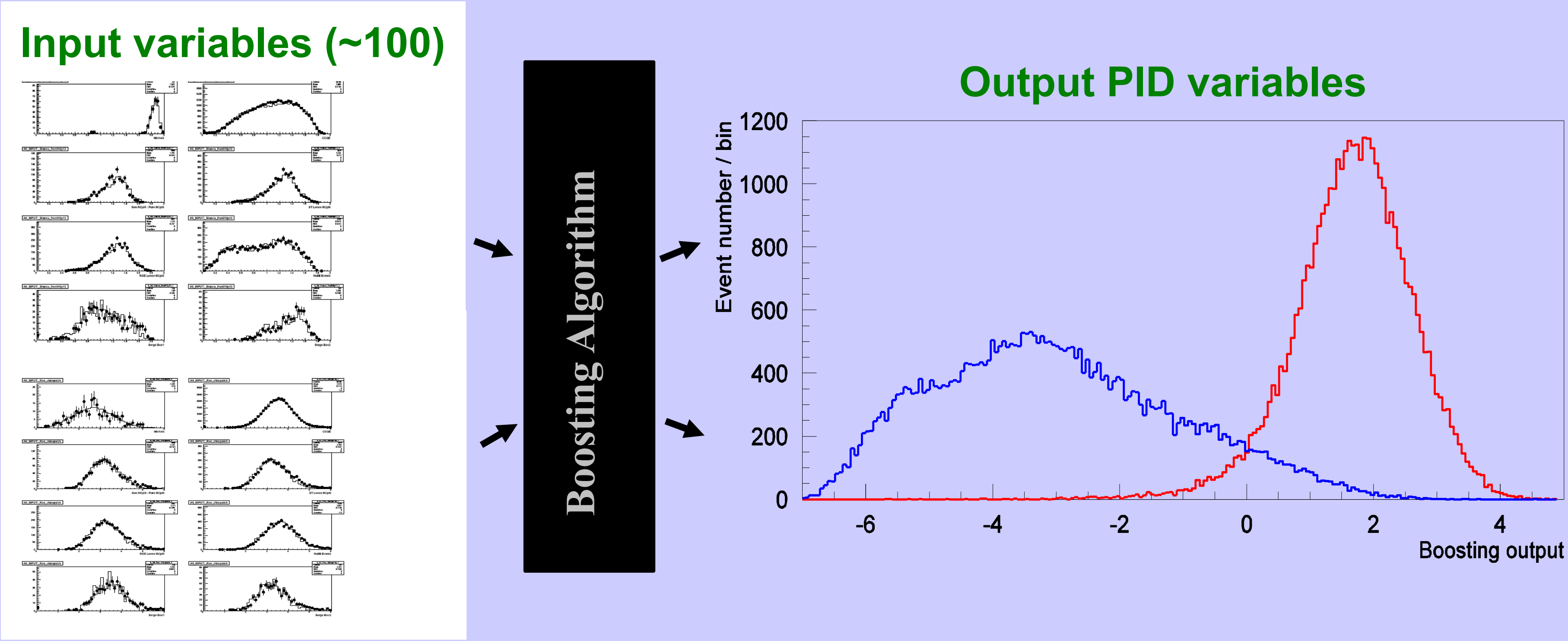




6. Particle ID

Boosted Decision Trees

- a kind of data learning method (e.g., neural network,...)
- ~100 input variables
- combined many weak classifiers (~1000 weak trees) to make strong "committee"
- Designed to classify signal and background
  - Signal = oscillation ν_e CCQE events
  - Background = everything else (misID)

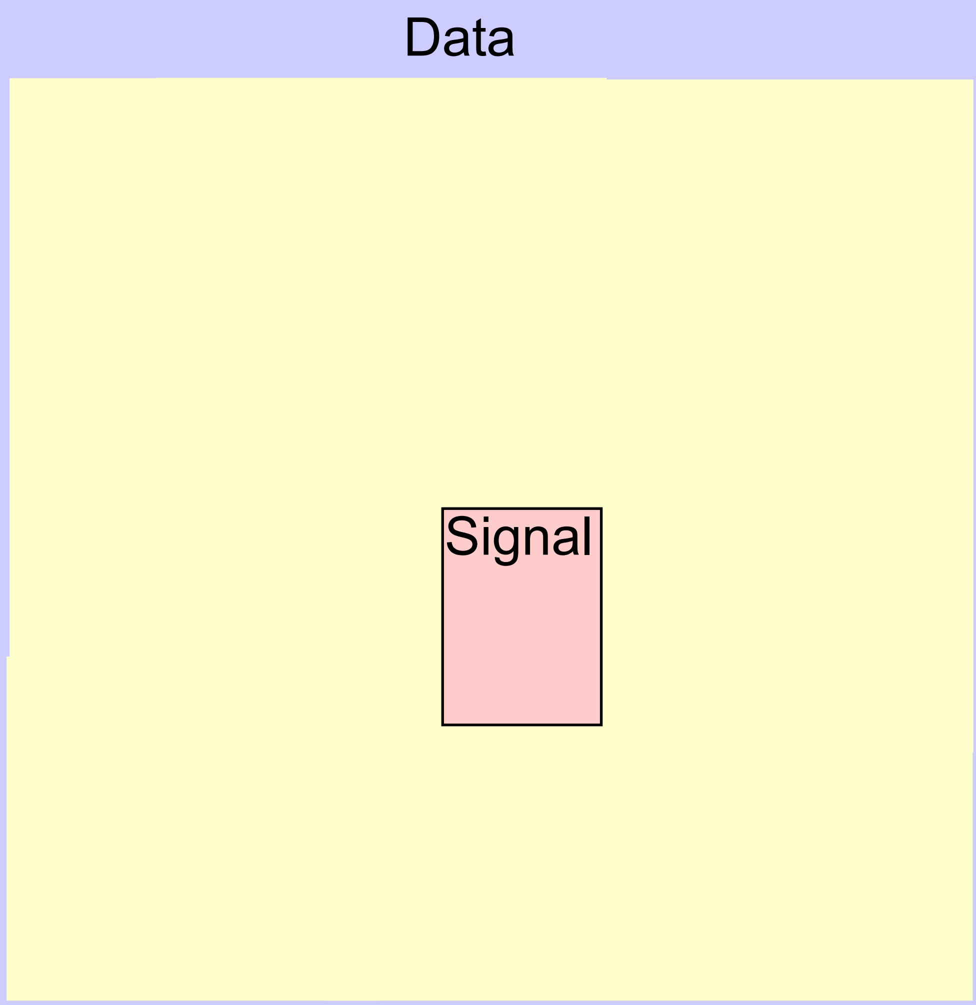


7. Blind analysis

Data consists with n-dimensional space (time cluster, energy, particle direction etc)

Blind analysis prevents all analysers from looking in the signal region (ν_e CCQE interaction)

Once we are confident about all systematics, we can look in the signal region ("open" the box)



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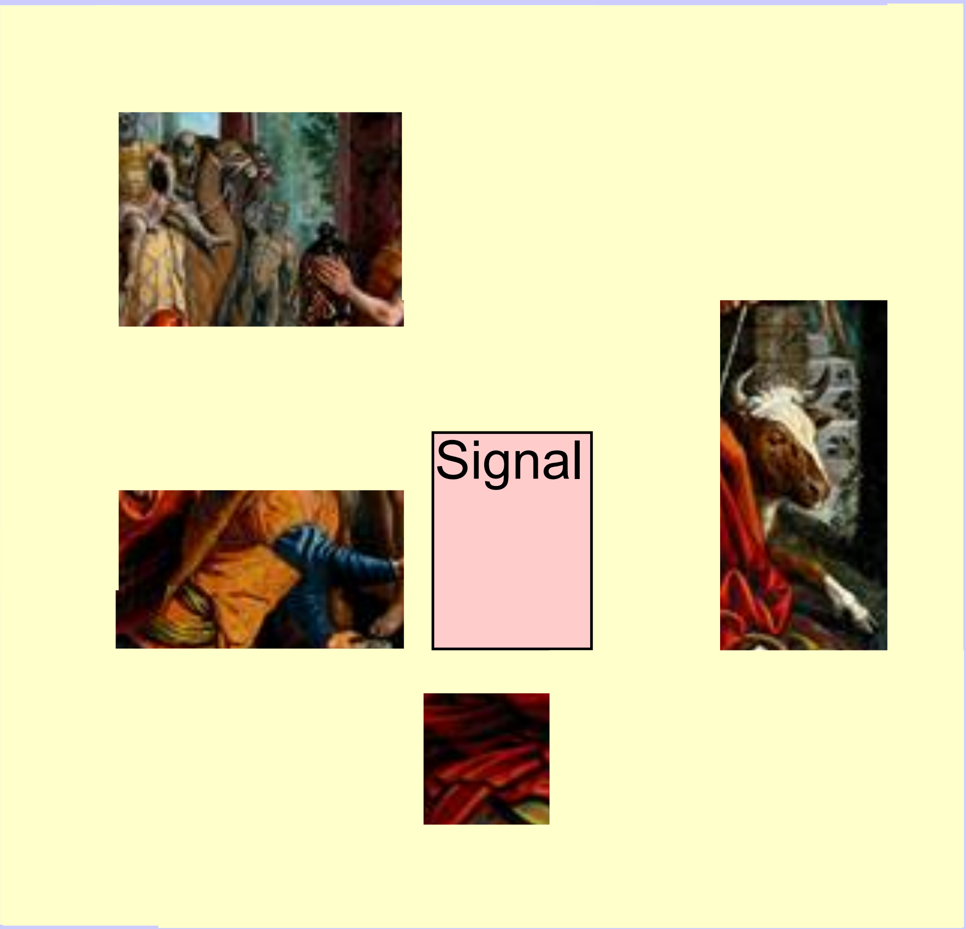
Systematics are checked by using various "open boxes", which they are believed not to include oscillation signal from MC study

Data



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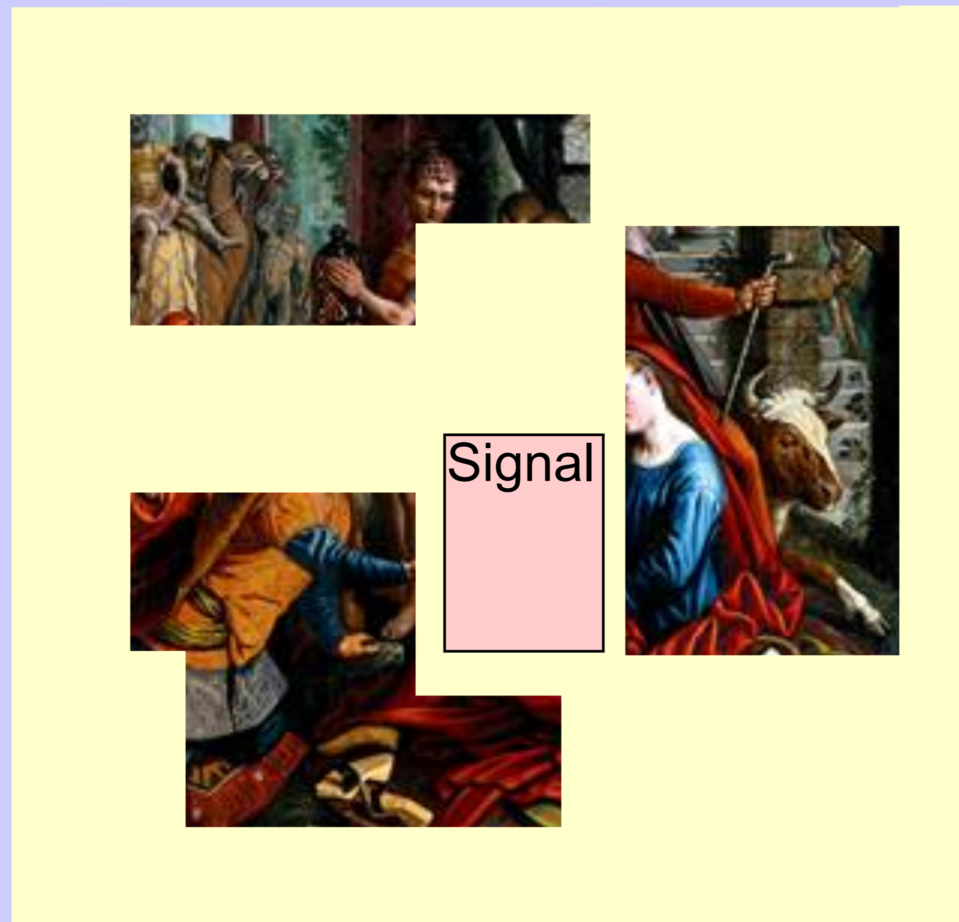


7. Blind analysis

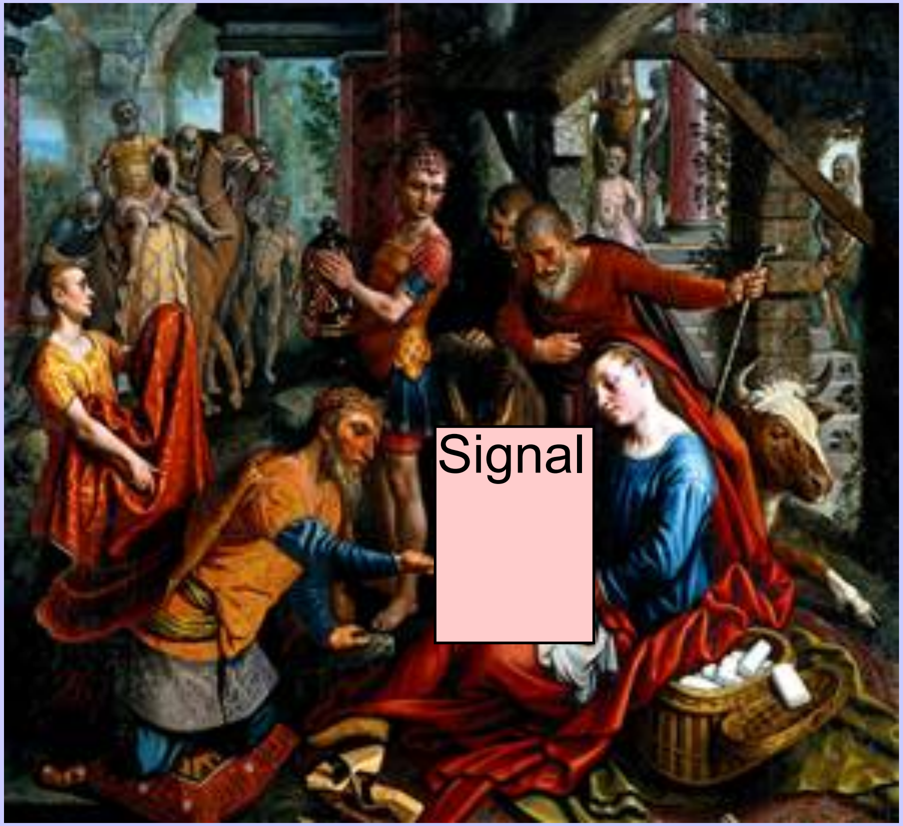
Data consists with n-dimensional space
(time cluster, energy, particle direction etc)

Blind analysis prevents all analysers from looking in the signal region (ν_e CCQE interaction)

Now, the analysis of MiniBooNE is the final stage, we opened all region out side of well defined signal region for the final check of systematics

We will open the box soon!

Data



8. Result

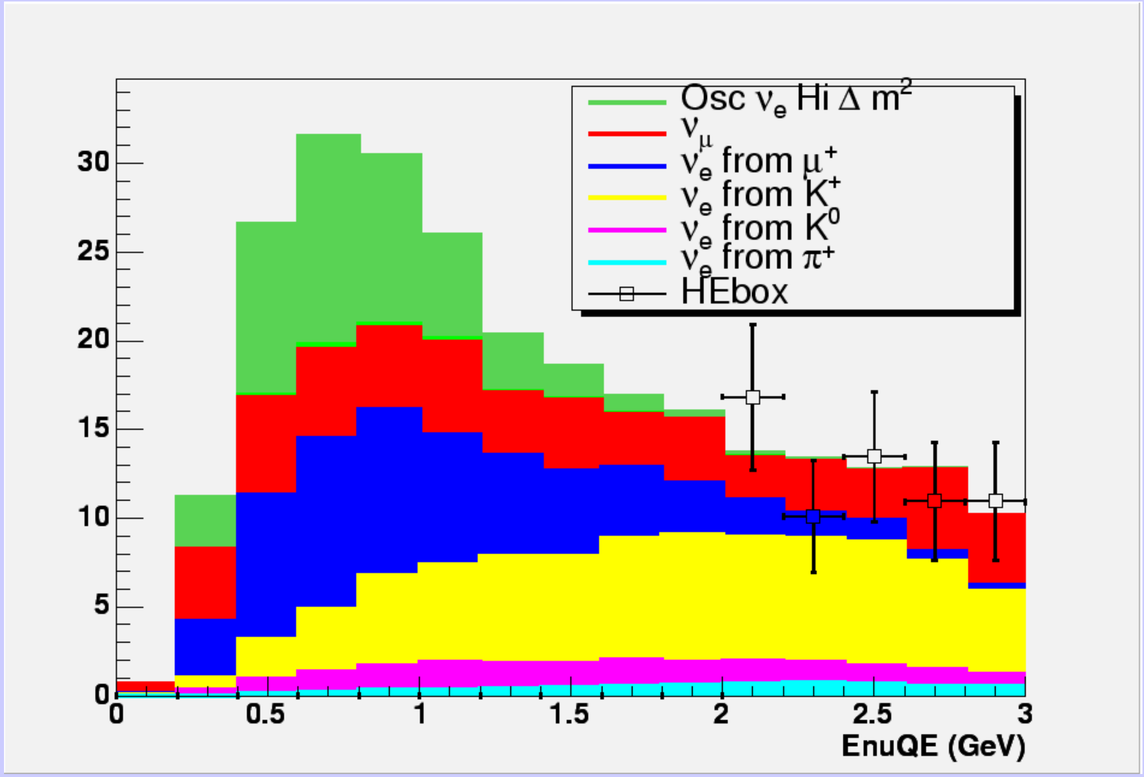
Electron energy spectrum of ν_e charged current quasi elastic event (ν_eCCQE).

$$\nu_\mu \xrightarrow{oscillation} \nu_e + n \rightarrow e^- + p$$

Blind analysis is used, and the box is not "opened" yet (no result, yet).

We are expecting our first result soon!

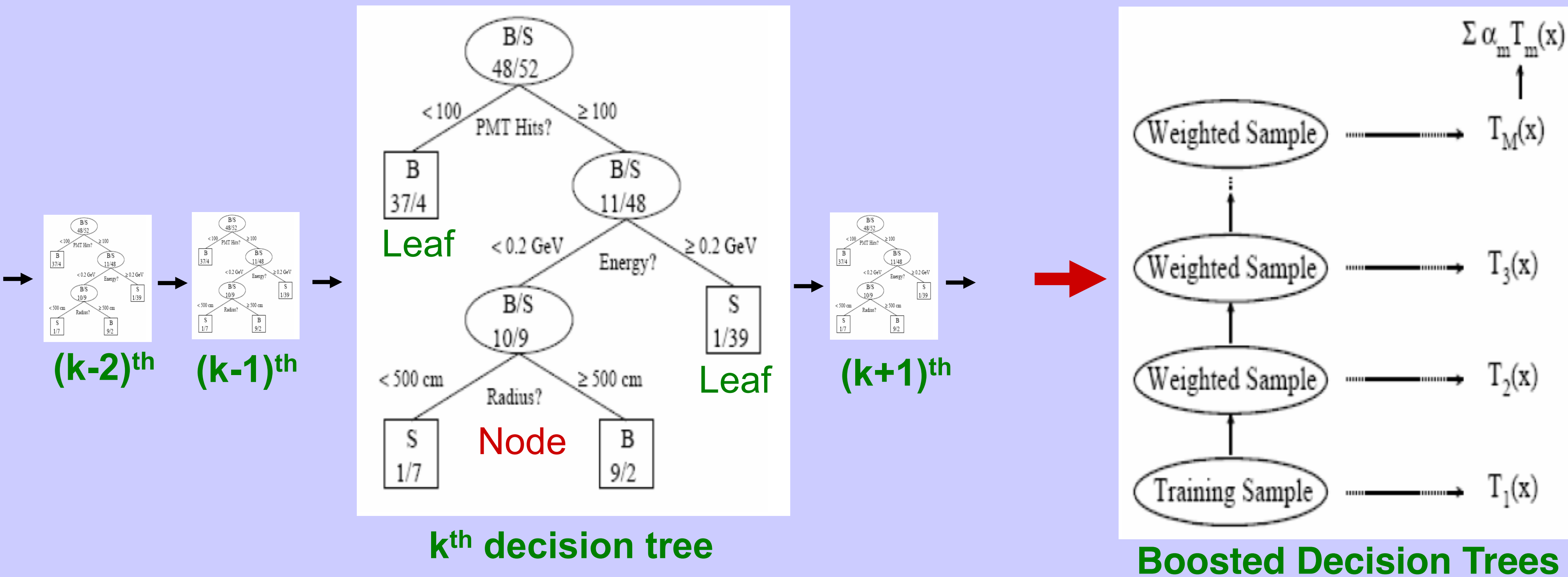
Expected ν_e appearance oscillation spectrum (Δm^2=1.00eV^2, $\sin^2 2\theta$=0.004)



5. Particle ID

Boosted Decision Tree

- a kind of data learning method (e.g., neural network,...)
- training sample (MC simulation) is used to train the code
- combined many weak classifiers (~1000 weak trees) to make strong "committee"

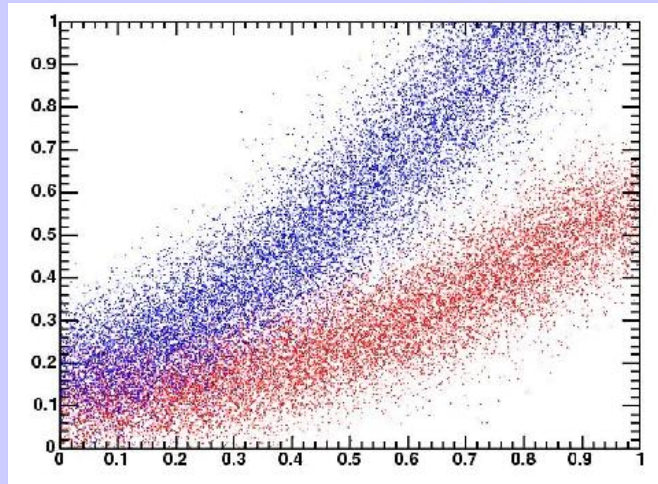


5. Particle ID

Example of classification problem

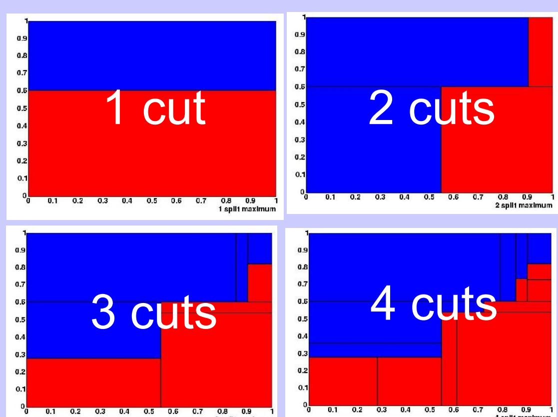
The goal of the classifier is to separate blue (signal) and red (background) populations.

Fake data sample

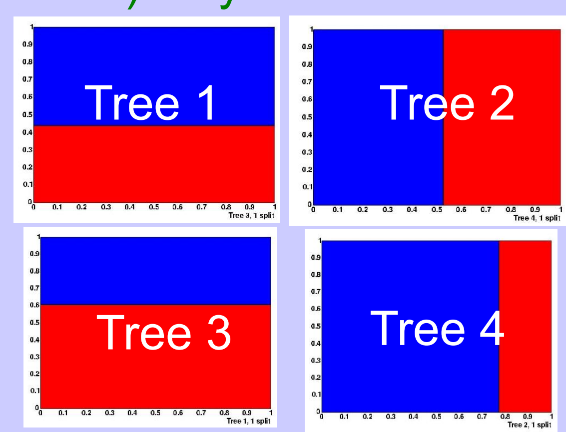


Two ways to use decision trees. 1) Multiple cuts on X and Y in a big tree, 2) Many weak trees (single-cut trees) combined

1) Development of a single decision tree

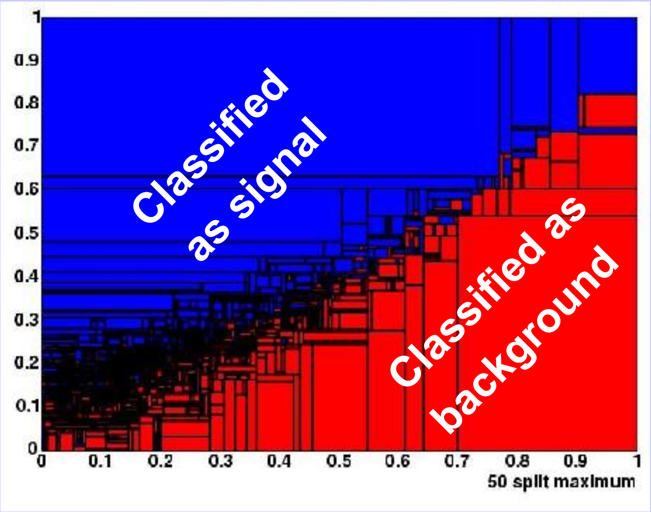


2) Many weak trees (single cut trees) only 4 trees shown

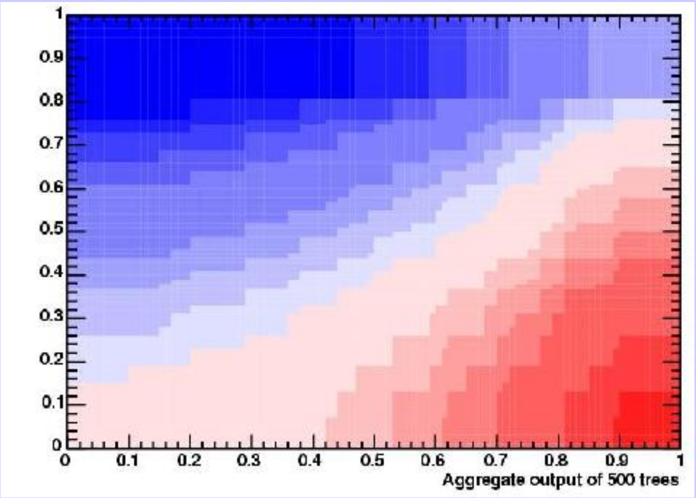


5. Particle ID

Single decision tree



500 weak trees committee



Boosting Algorithm has all the advantages of single decision trees, and less suceptibility to overtraining.