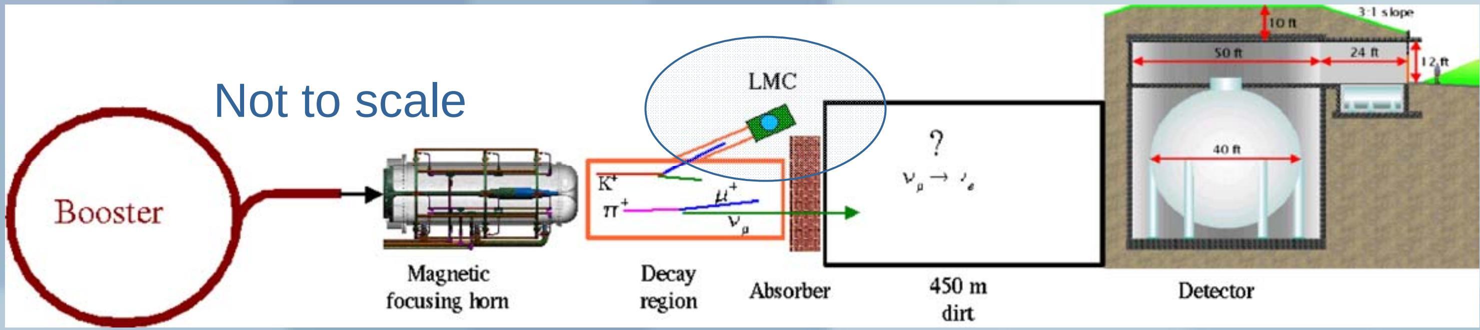
The MiniBooNE Little Muon Counter Detector

Martin Tzanov
University of Colorado

- **Purpose,**
- **Instrumentation,**
- **Event Reconstruction,**
- **Data analysis,**
- **Preliminary results,**
- **Conclusions and future.**

MiniBooNE Beamline



MiniBooNE Beam:

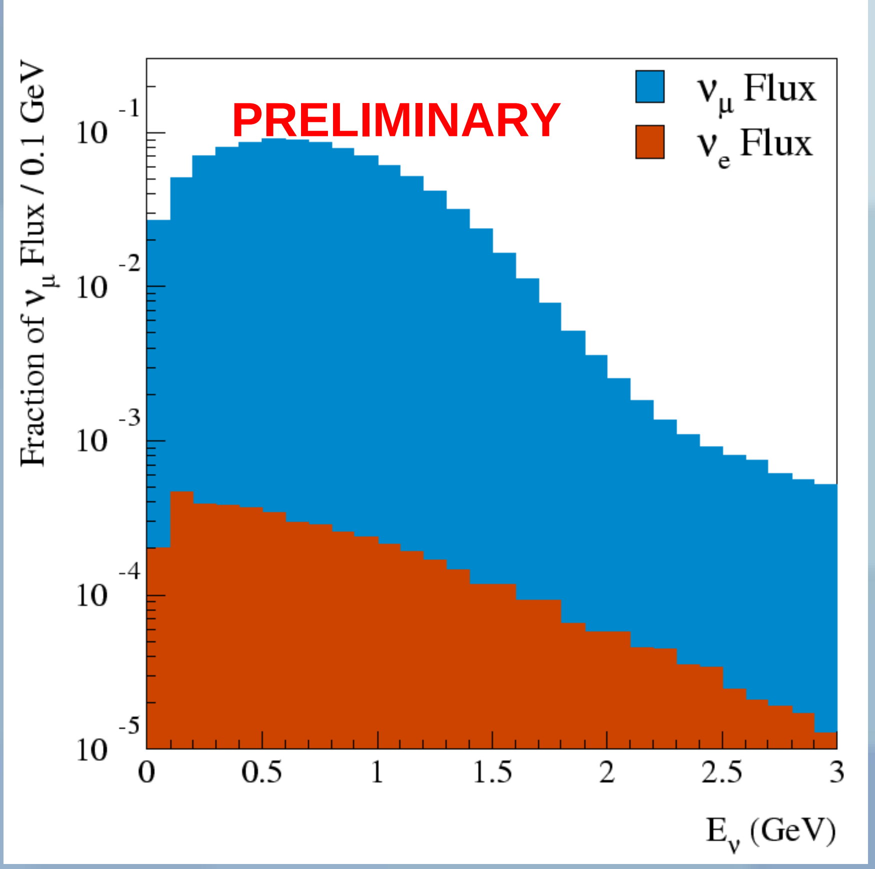
- **8GeV primary proton from the FNAL booster,**
  - **-5 pulses every second with 5E12 POT.**
- **Horn focusing for mesons produced in p-Be interactions,**
- **99% ν_μ beam from meson decays in the 50m decay pipe**
  - **- mostly from $\pi^+ \to \mu^+ + \nu_\mu$,**

LMC

- **monitors the mesons produced in the p-Be,**
- **provides information (constraint) of the kaon flux in the MiniBooNE decay pipe.**

MiniBooNE Flux Prediction

- GEANT4 based Monte Carlo simulates the neutrino flux in MiniBooNE beamline,
- high purity ν_μ beam – 99%,
- small ν_e component – intrinsic ν_e
  - background for ν_e appearance $\nu_\mu \to \nu_e$,
- ν_e from kaon decays is not well known
  - comparable rate to the oscillation signal



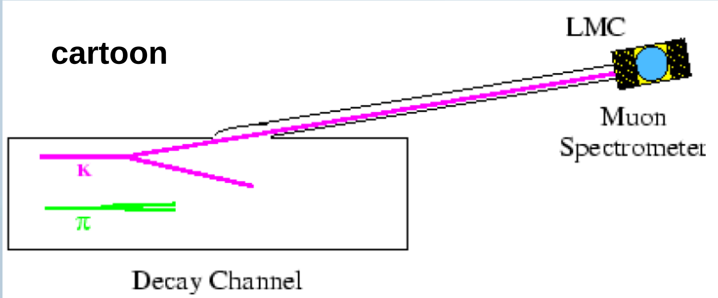
LMC - Off-Axis Detector

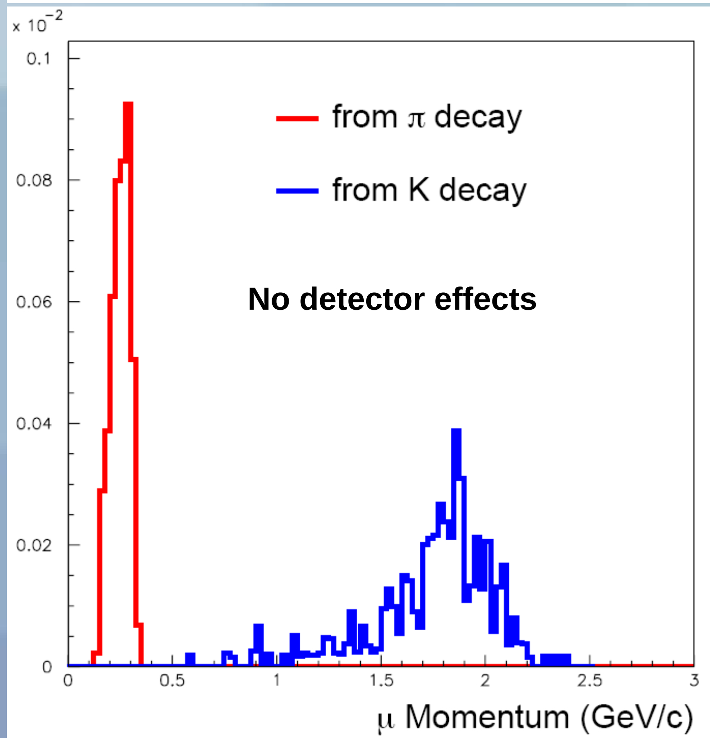
Phase space in two-body decays limits the accessible kinematic region of the products:

- **High-p_T μ's come from K^+ decay (mostly),**
- **use of off-axis muon detector can allow and effective |p| separation.**

Separation at 7^0 (see the plot):

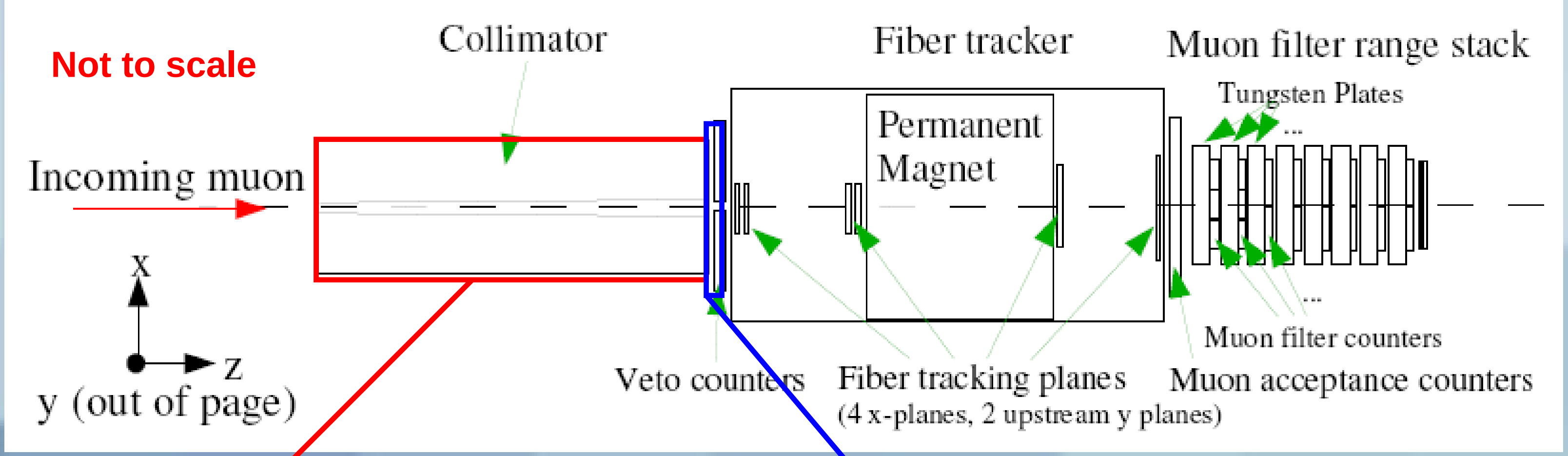
- **clear separation of μ from π and K^+,**
- **High K/ π ratio,**
- **Most π's have too high energy to produce μ at this angle.**





LMC Detector Construction

LMC Layout and Components – Collimator and Veto



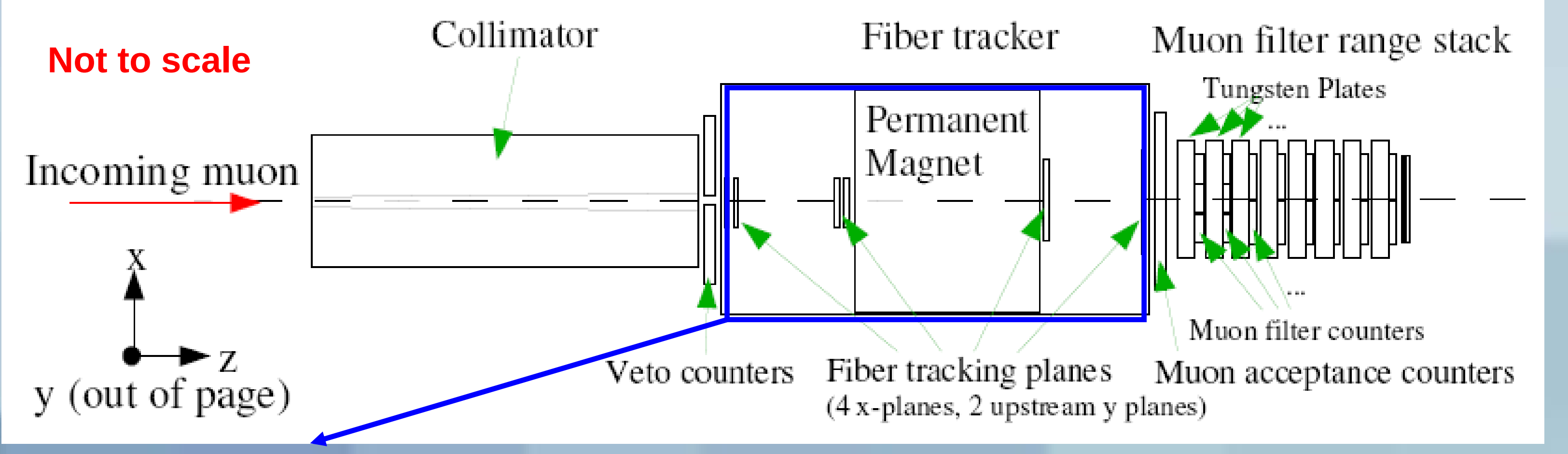
Collimator:

- designed to accept tracks originating in the decay pipe of MiniBooNE beamline
- 2.06m long - constructed from steel with inner tungsten core,
- Inner hole has 5mm downstream and 3mm upstream radius.

Veto Counters:

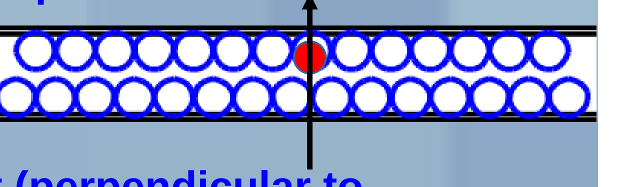
- designed to reject tracks which are not exiting through the downstream hole of the collimator,
- 4 scintillation counter situated between the collimator and the first plane of the fiber tracker.

LMC Layout and Components – Fiber Tracker



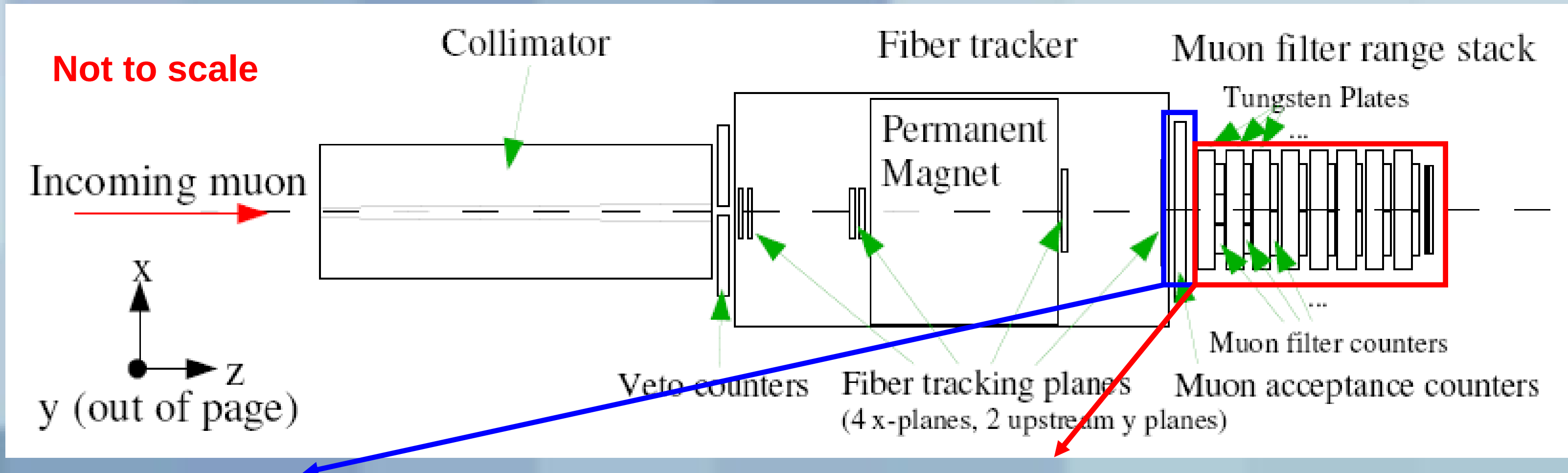
Fiber tracker spectrometer – analyses track momentum

- **Permanent magnet - provides constant magnetic field B_y = 2.27 kG along 23cm in z.**
- **6 fiber planes consisting of 1mm fibers. Each plane consists of two subplanes staggered at ½ fiber diameter – removes inefficiencies if track passes between two fiber of one subplane.**
  - **4 planes cover the bending direction of the magnet. (2 upstream and 2 downstream of the magnet)**
  - **remaining 2 planes are situated upstream of the magnet (perpendicular to both the beam and magnet bend direction).**



- **dry interface to light-guide fibers,**
- **160 6-stage Hamamatsu R1666 ¾" PMT's mounted on active custom bases**
  - **active base - 4 PMT's per base, preamp, postamp, 1HV channel.**

LMC Layout and Components – Muon Filter and Acceptance



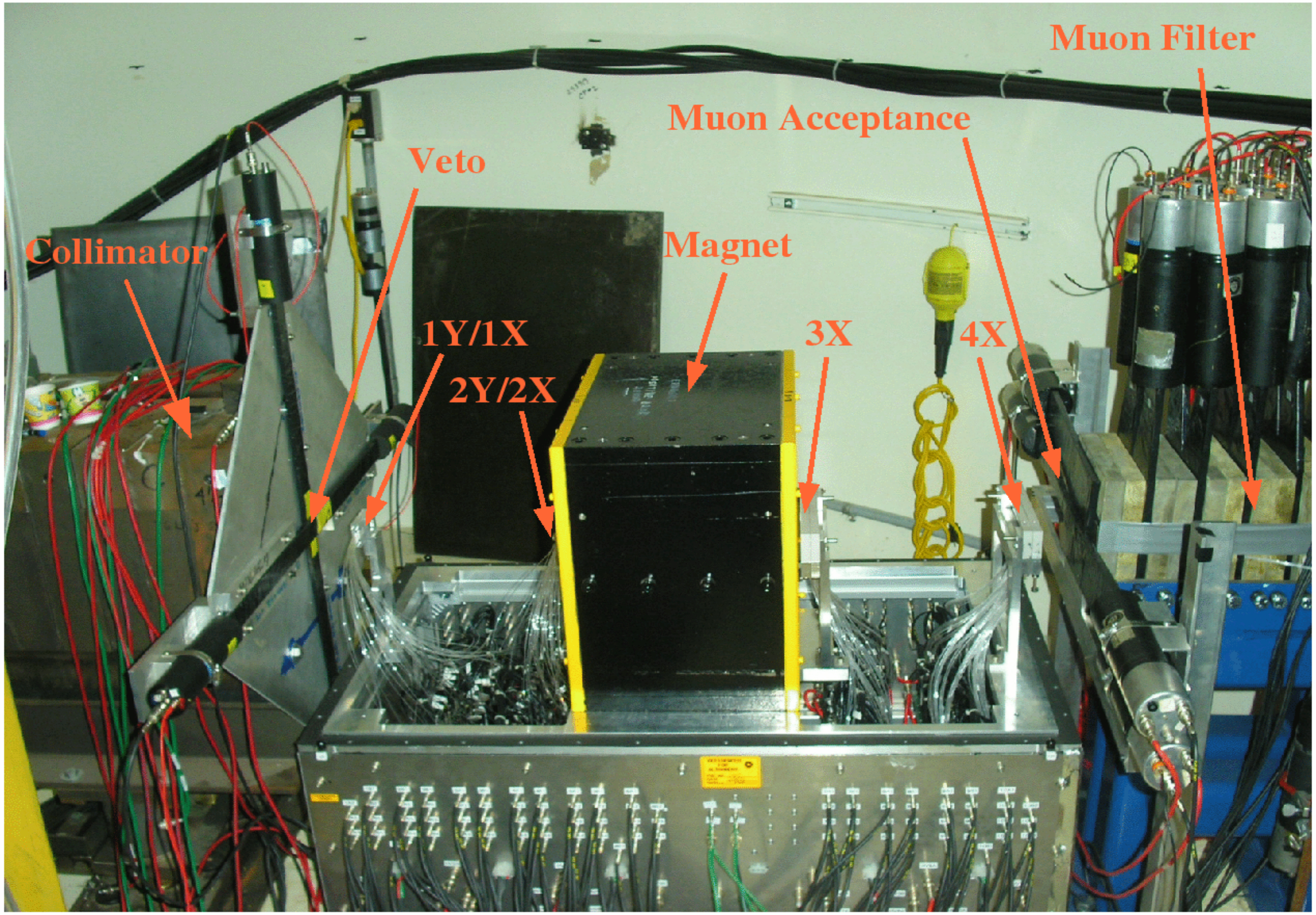
Muon acceptance counters:

- **four scintillation counters situated downstream of the fiber tracker**
  - **two of the counters are placed in the beam**
  - **one is placed above the beam**
  - **one is placed below the beam**

Muon filter range stack:

- **designed to identify muons from range,**
- **consists from 8 2" thick tungsten sheets alternating with scintillation counters,**
- **a muon with energy 1.3GeV will pass through the muon filter.**

LMC Installed



Event Reconstruction

- We form 6-plane coincidence with the following requirements
  - all hits are within 10ns time window (5ns about the hits mean time),
  - multiple hits per plane are allowed within the coincidence window,

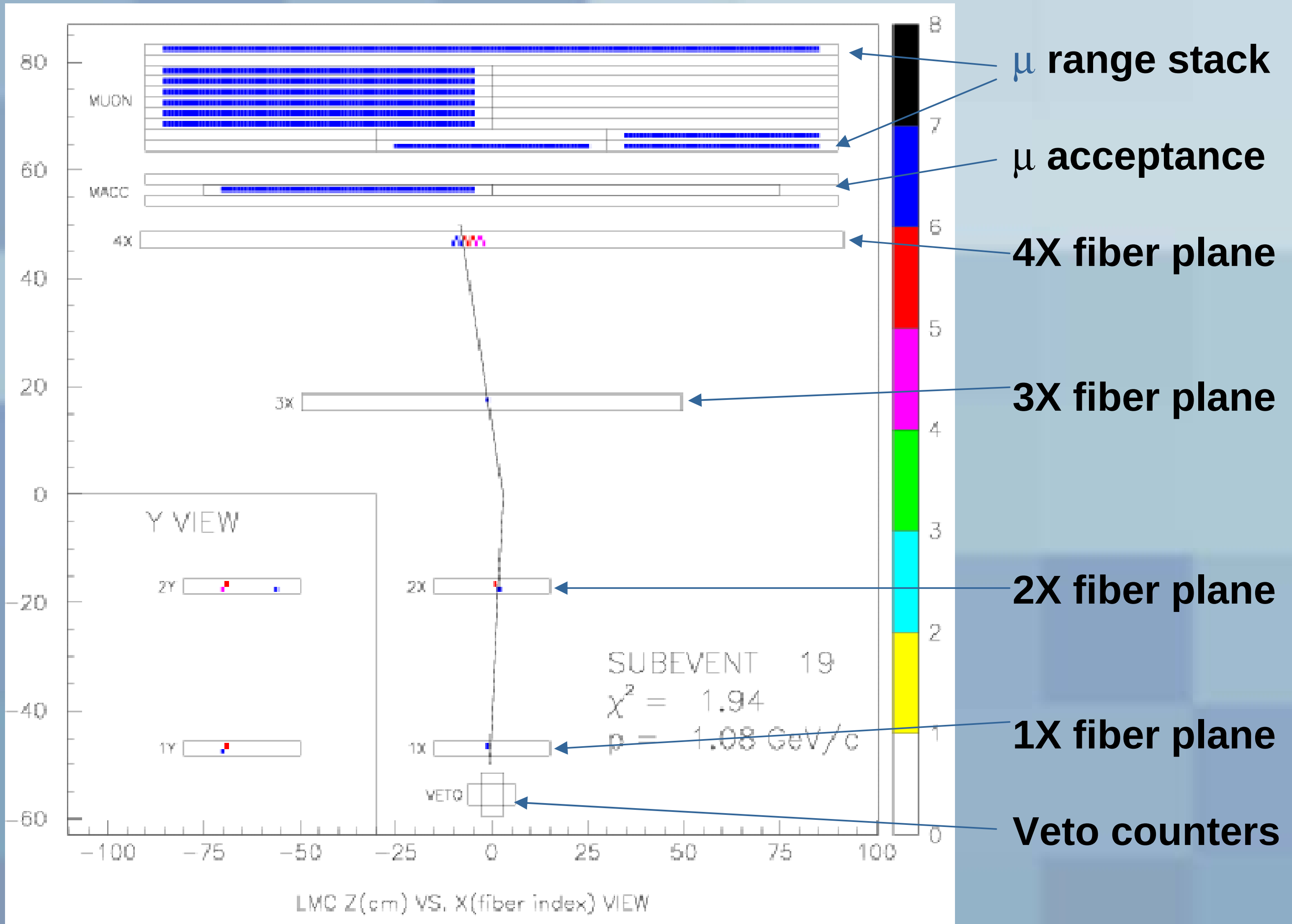
- Track fitting algorithm is performed to determine:
  - track momentum and momentum uncertainty,
  - χ^2/dof for each fitted 6-fold coincidence is obtained.

- All hits from the veto, muon acceptance counter and the filter which fall into the coincidence window are added.

- Muon filter penetration (range) is determined as the most downstream filter layer which has a hit in a counter.
  - one inefficient layer is allowed.

This event reconstruction procedure is used for both data and Monte Carlo.

Event Display for LMC



LMC Monte Carlo – Detector Simulation

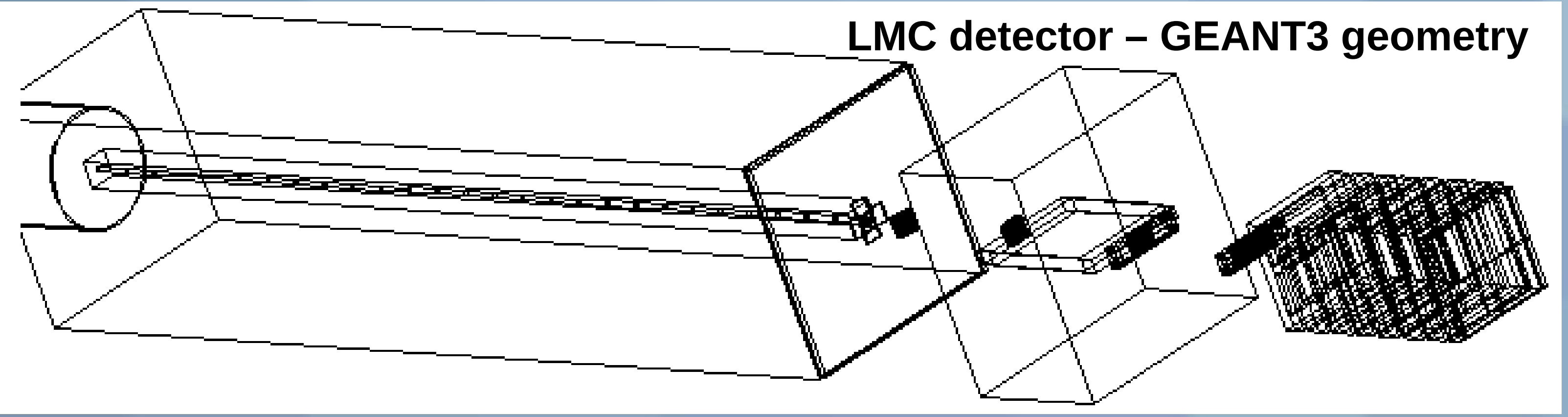
LMC Monte Carlo is generated in two stages:

- **Input flux generation,**
- **LMC detector simulation.**

LMC detector response is simulated with GEANT3 hit level Monte Carlo

- **includes exact geometry and material definitions,**
- **the input is a flux of particles,**
- **the output is hits in the active volumes of the detector,**

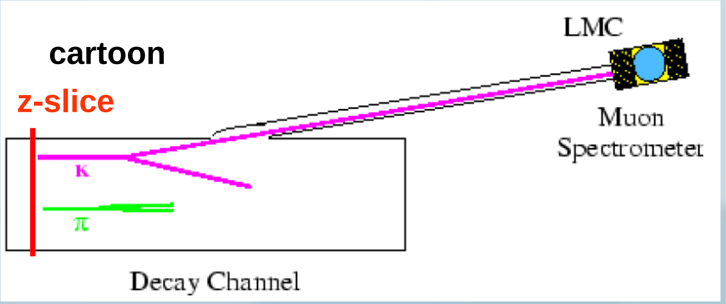
The output from the LMC MC undergoes the same event reconstruction procedure as data.



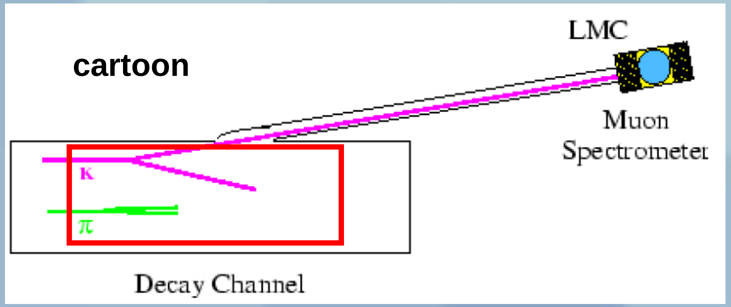
LMC Monte Carlo – Input Fluxes

Inputs to the GEANT3 MC:

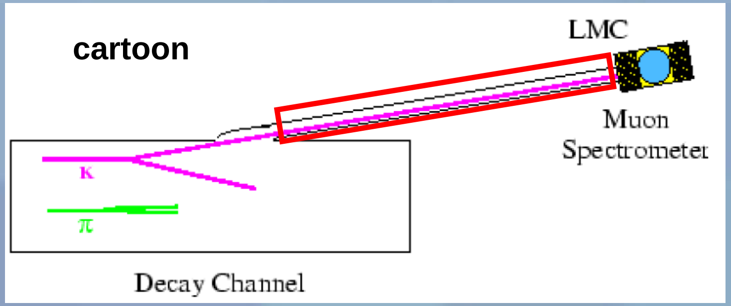
- Fast Monte Carlo - re-decays π and K flux at a z slice in MiniBooNE decay pipe which is generated by the MiniBooNE beam MC. Simulates only signal for the LMC as well as muons,which passed through dirt (dirt muons).



- A flux of all particles hitting the MiniBooNE decay pipe wall near the LMC opening. Generated by the MiniBooNE GEANT4 beam MC. Simulates both signal and beam related background. AKA Full/Cocktail Monte Carlo



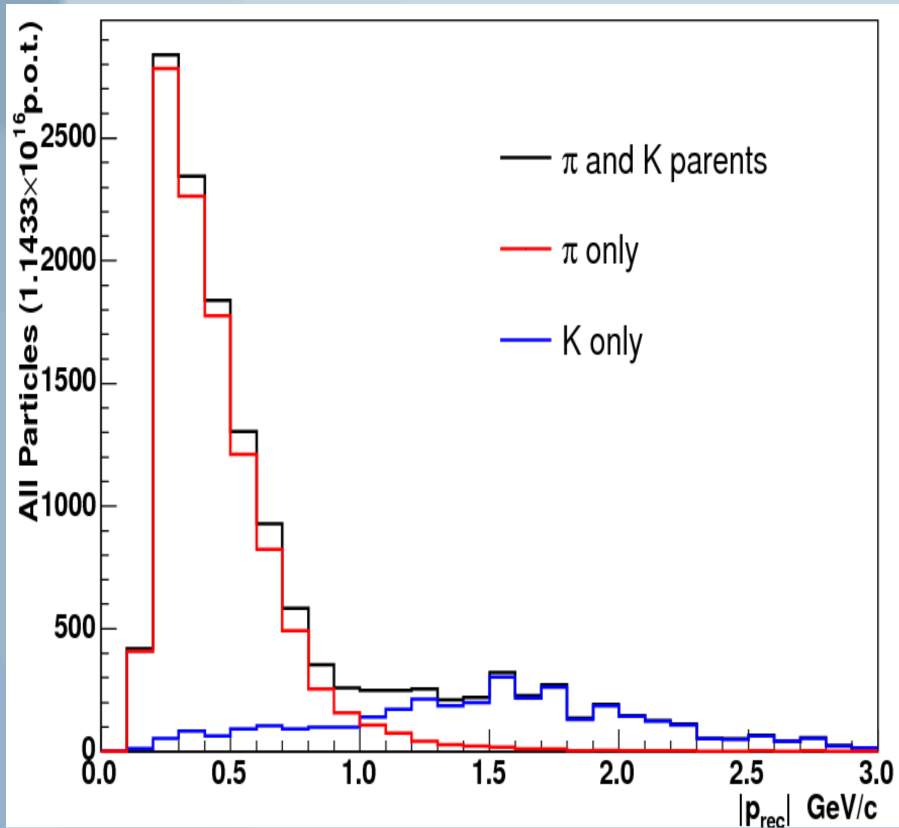
- Gas of various types of particles used to study the response of the LMC detector. A sample of leptons or hadrons with flat energy spectrum is used to illuminate the LMC detector.



LMC Monte Carlo – Parentage

- **Parentage information is propagated through the entire process.**

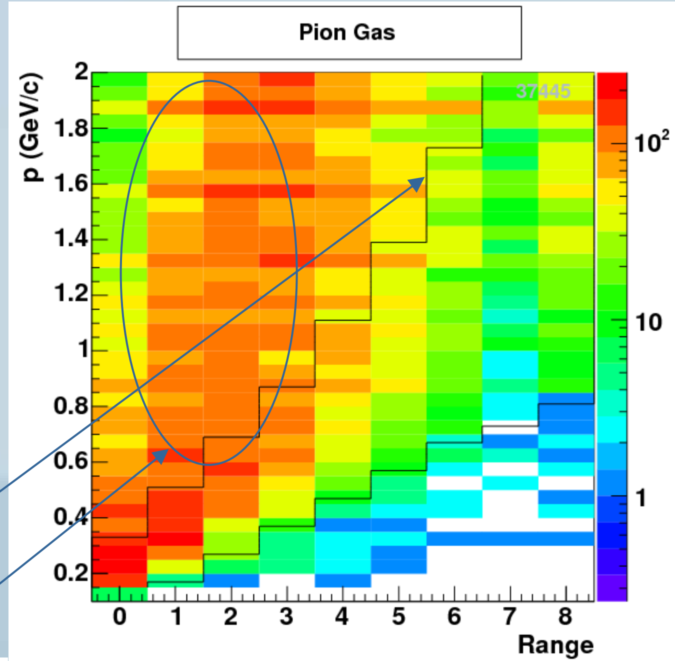
- **Plot shows the reconstructed momentum by parent for Fast MC. Includes detector effects.**

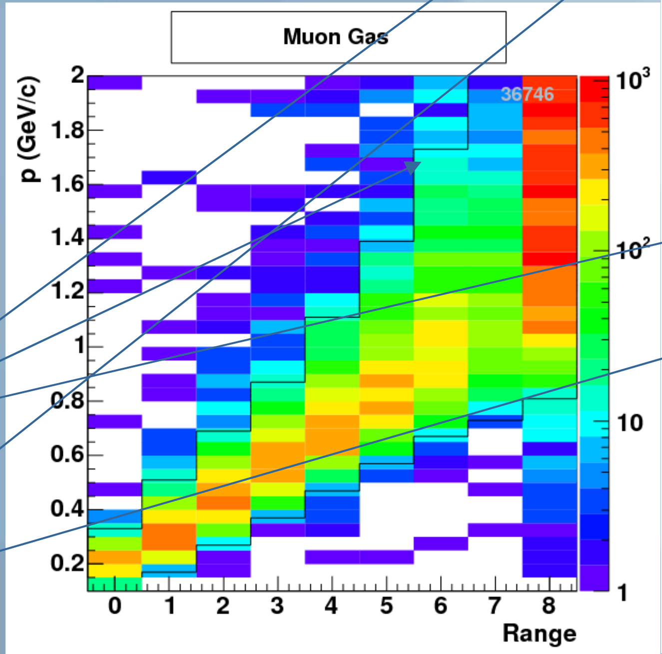


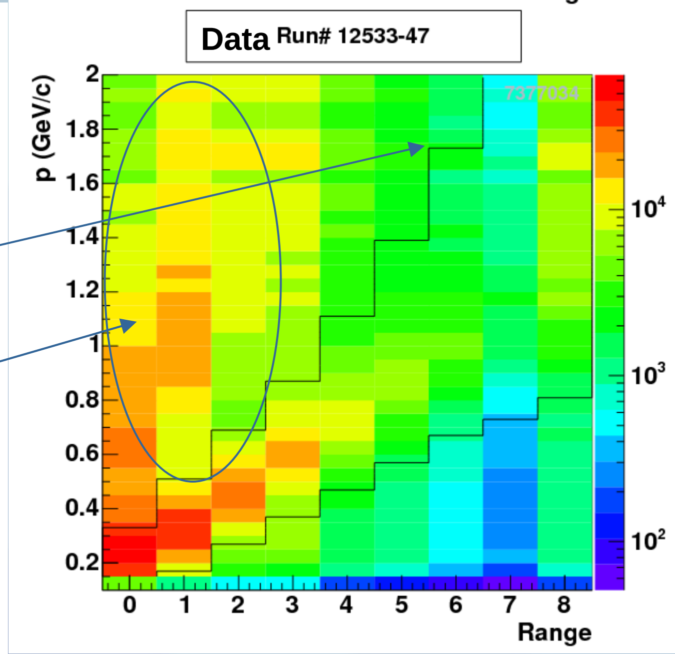
Muon ID

Designed as a simple cut based on muon gas Monte Carlo:

- **Set of limits on reconstructed momentum and reconstructed penetration in the muon filter (range),**
- **requiring muon acceptance efficiency to be higher than 95%.**
- **Fiber tracker measures the momentum properly,**
- **Muon filter identifies muons,**
- **Range=8 has highest purity.**







Muon ID cut- Black lines

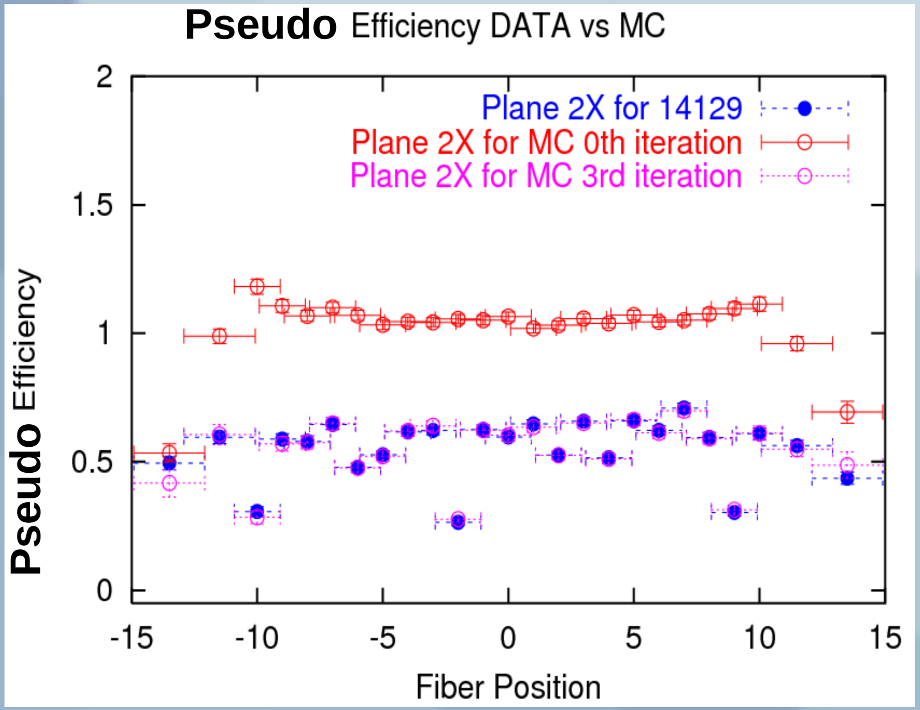
Hadrons – Ovals

Fiber Efficiency

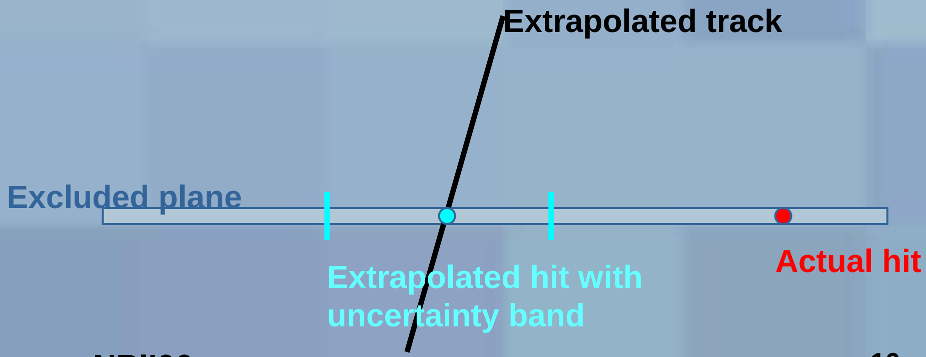
Pseudo efficiency:

- **algorithm looks for 5-fold coincidences when 1 plane is excluded (2X on the plot)**
- **hit is simulated in the excluded plane by extrapolating the fit which includes the remaining 5 planes.**
- **a probability is assigned to each PMT based on the proximity to the simulated hit:**

$$pseudoeff_i = \frac{\sum_{5-fold\ coinc.} H_i}{\sum_{5-fold\ coinc.} P_i}$$



H_i =1 if there is a hit and 0 if no hit in the excluded plane
P_i – probability that the fiber is part of the reconstructed track.



Absolute efficiency of the fibers is obtained from iteration and is found to be about 90-95% per plane.

Data vs. Signal MC

Analysis Cuts:

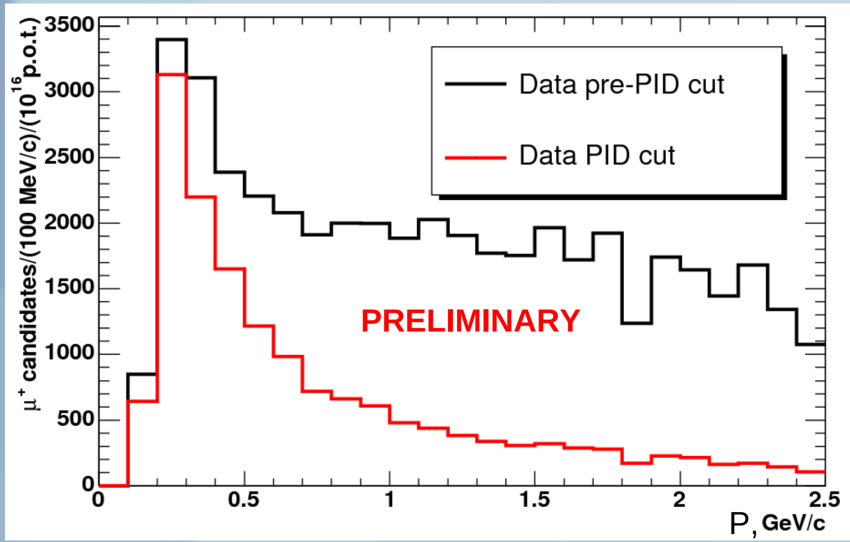
- **Well reconstructed track,**
- **No veto hits,**
- **Muon ID cut (red histograms only).**

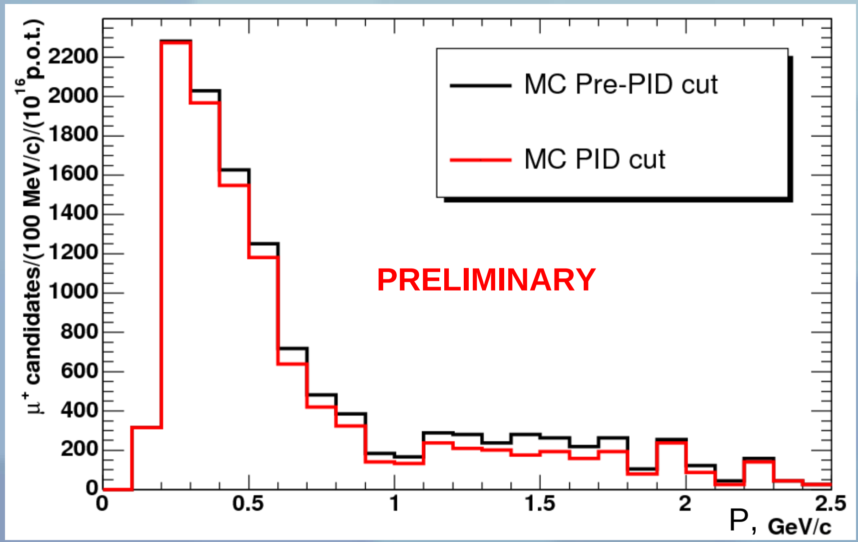
Plots show the reconstructed momentum for both data and MC.

- **Muon ID cut removes much more events from data than from signal Monte Carlo,**

- **This large fraction of events cut out from data are coming from different sources of background, which are not simulated.**

This is an upper limit on the kaon flux normalization (no background MC).





Backgrounds

Beam related backgrounds which are simulated by the full Monte Carlo:

- simulated using GEANT4 beam Monte Carlo,
- includes
  - interactions in the air of the decay pipe,
  - interactions in the surrounding dirt,
  - proper ratio of signal/background,
  - muons from pion decaying within the LMC detector.
- very slow (it will take months to obtain)

Accidentals/Pile-up:

- the reason we run at 1/10th of the normal neutrino beam intensity.
  -accidentals were significantly decreasing the efficiency.
- code which overlays data and Monte Carlo streams is used to to study the effect of accidental (testing stage).
  - Early indication show that accidentals are not a problem at this beam intensity.

Beam-off-target data:

- $e^{-1.7}$ =18% of all protons do not interact in the target,
- beam was aimed in the air gap between the target and the horn,
- handle on proton-air interaction background.

Conclusions and Future

Conclusions:

- **LMC provides an important internal check of the Kaon flux,**
- **Monte Carlo is developed and running (needs more statistics),**
- **Preliminary muon spectrum is extracted,**
- **Preliminary Data/MC comparison.**

Future:

- **Run large sample of full Monte Carlo,**
- **Data/MC comparison for special runs (beam-off-target, different horn current settings) – important checks,**
- **Extract background subtracted muon spectrum,**
- **Evaluate systematic errors,**
- **Include the LMC measurement as a constraint to hadron production fits.**