Hadron Measurements for the LBNE Beam

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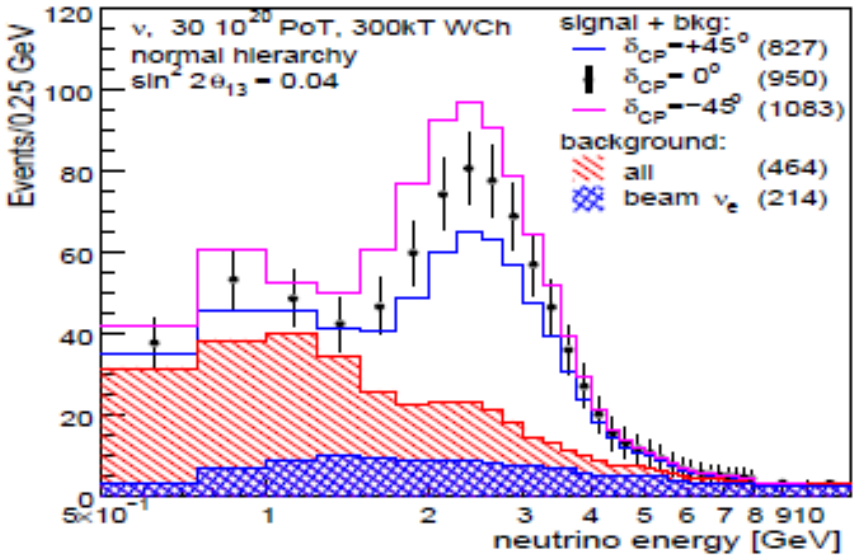
LBNE Requirements

- LBNE is now going through CD-1 effort
  - Determination of project options
    - Detectors, facilities, beams, etc.
  - Determine cost range
- Precise requirements unknown at this point
  - Studies are currently underway
  - Can make some general statements however

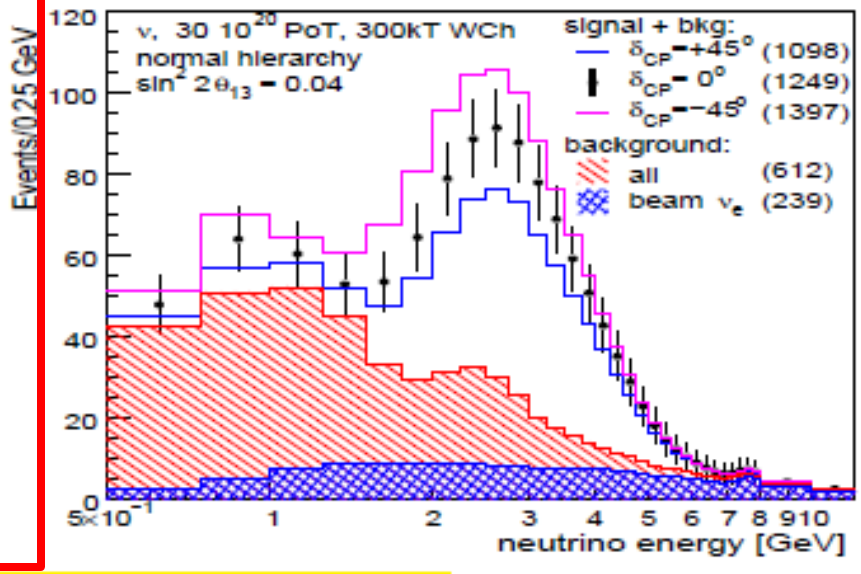
First Round LBNE Studies

- Example: Water Cherenkov far detector
  - rates from study by M. Bishai, BNL
    - my own interpretation of consequences
  - 300kT far detector mass
  - 120 GeV beam
  - ~2 MW-yr (3×10^{21} pot)
  - $\sin^2\theta_{13}$=0.04 ??? (includes matter effects)

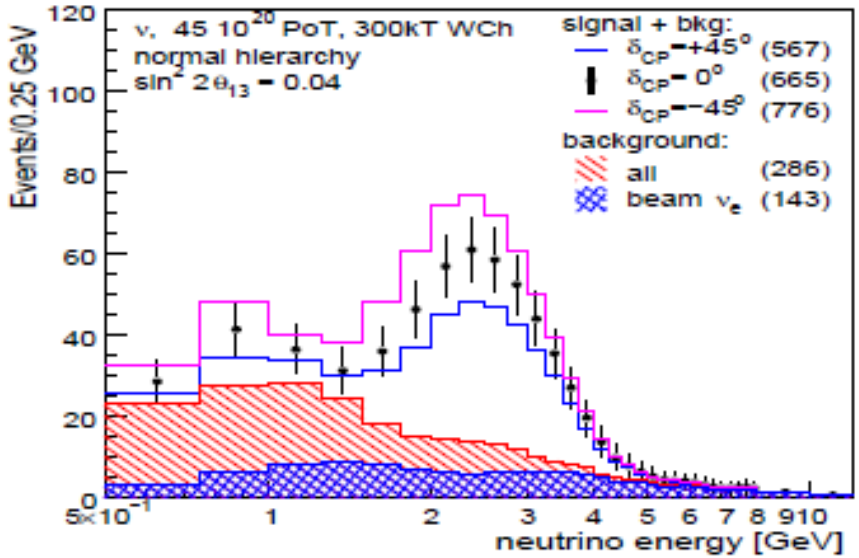
120 GeV no plug



120 GeV, 350kA



60 GeV no plug 0.75× beam power

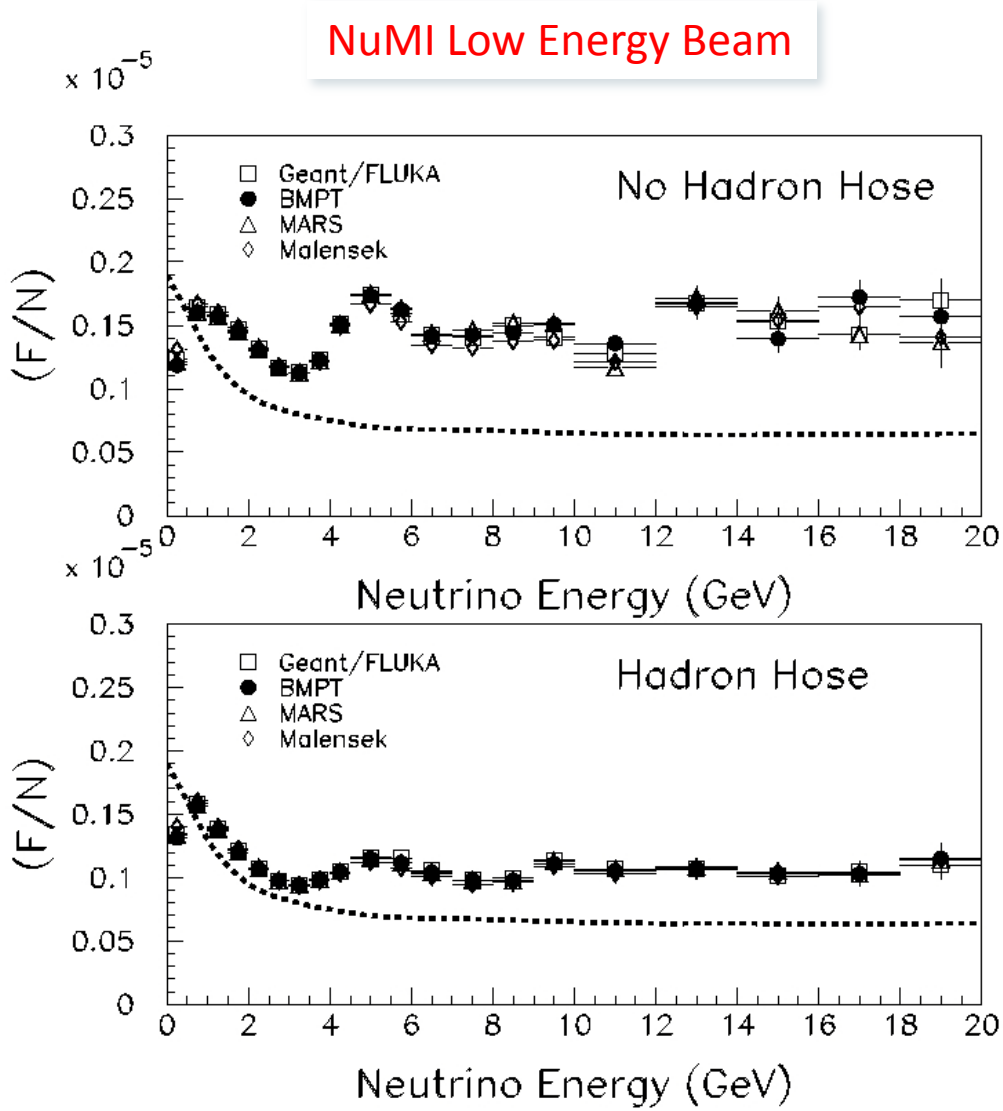


M. Bishai

NuMI Far Detector Extrapolation

(picture from S. Kopp)

- Large variations in F/N flux ratios
- neutral current processes sensitive to higher energy tails



Example LBNE Sensitivity

Statistical error only

- Backgrounds
  - N_{bkg} = 464±**21**(stat)
  - σ_{rel} ~ 4.6%
- $\sin^2\theta_{13}$ Sensitivity (δ_{CP}=0°)
  - N_{app}=272 excess events (~13 σ)
- CP Sensitivity
  - $N_{\delta CP=45°}$ - $N_{\delta CP=0°}$ = 123 events (5.6 σ)
  - $N_{\delta CP=0°}$ - $N_{\delta CP=-45°}$ = 133 events (6.3 σ)

LBNE Systematic Errors

- In previous example, stat error is 4.6%
  - *Would like to keep total systematic error < ~4.6%*
- $N_{observed}$ = Flux ⊗ Cross Section ⊗ Efficiency
  - Error budget : 2.7% for each
  - Near-Far comparison:
    - Identical detectors
    - Constraint on *Flux ⊗ Cross Section ⊗ Efficiency*

Suggests we would like to know the flux ~<3-4%

Our Task

A most difficult challenge facing the LBNE program is the determination of the LBNE neutrino source flux. By itself, the near detector system, although providing an important cross check on the flux and cross section models, will not provide a complete determination of the neutrino flux at the far detector location. Significant far detector flux uncertainties will arise due to uncertainties in the neutrino nuclear cross sections and the finite size of the neutrino source combined with the close proximity of the near detector.

However**,** ***a complete knowledge of the momentum and position of all decaying particles producing neutrinos in the decay region is sufficient to predict the neutrino flux exactly***, modulo neutrino oscillation effects. Thus, the extrapolation of the flux to the far detector will rely on the knowledge of the spatial distribution and momentum of meson decays in the decay region.

Factors in determining fluxes

✓• the phase space (x,y,z,px,py,pz) distribution of the primary protons

✓• the geometry and materials of the target, horn, and decay region

✓• the electromechanical characteristics of the horn system

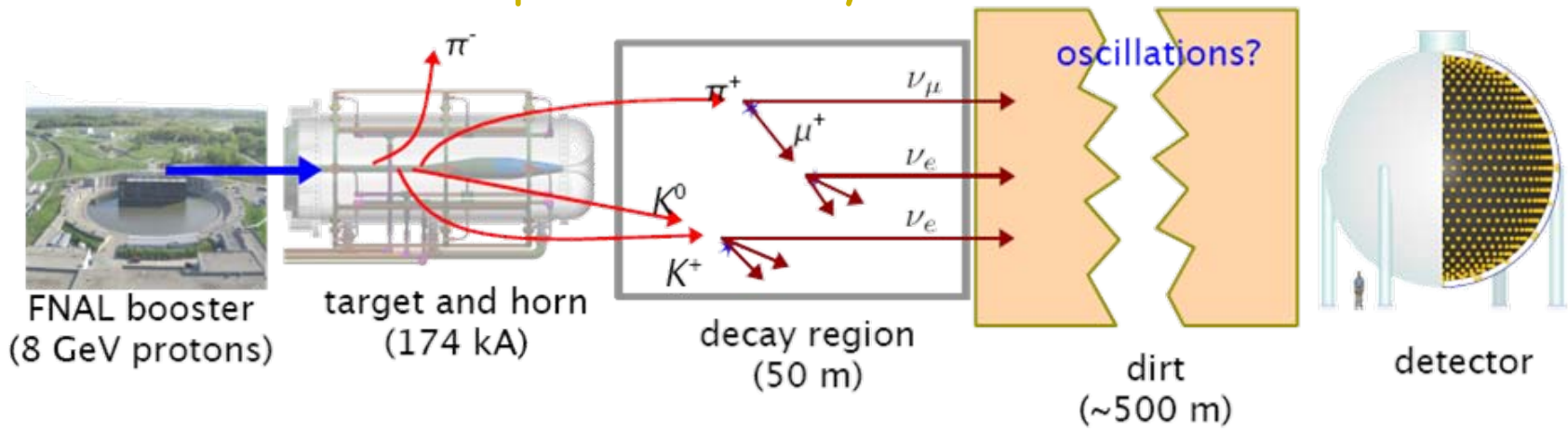
?• the production and absorption cross sections of K and π mesons in the hadronic cascade through the target, horns, and decay region

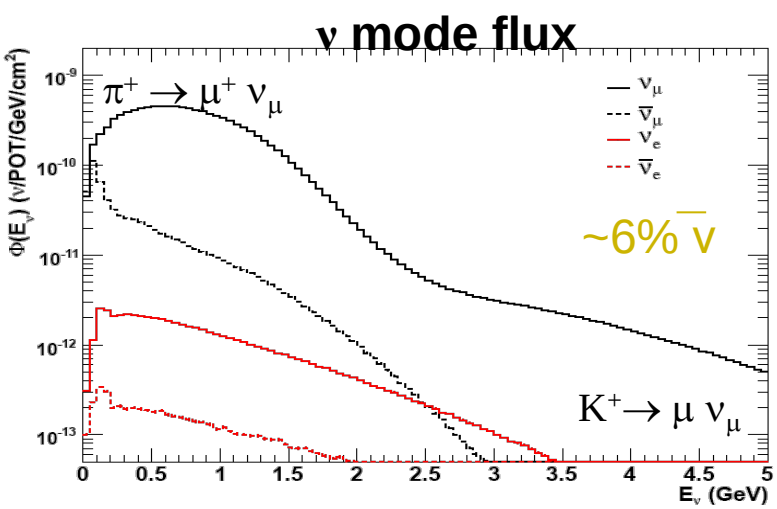
✓• the momentum and angular distributions of neutrinos in meson decays

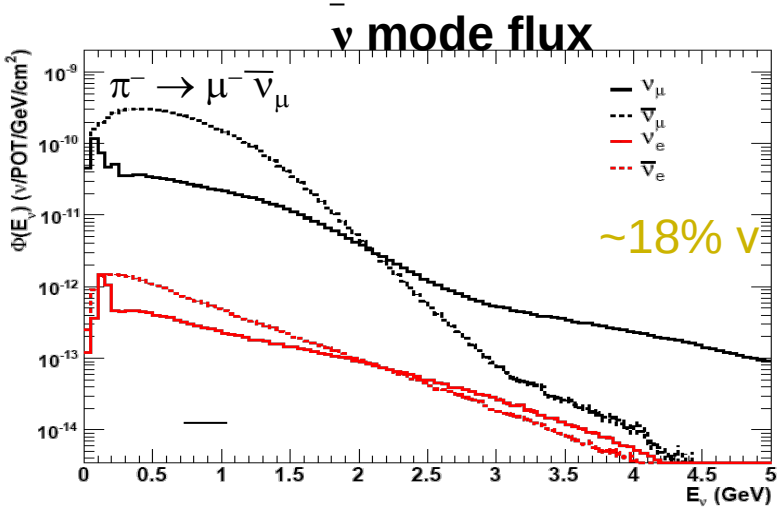
Past experience at MiniBooNE

- MiniBooNE
  - 8 GeV proton beam from FNAL booster
  - Beryllium target from LANL
  - Single horn
- Forward meson production measured at HARP
  - Simple dipole spectrometer, NOMAD drift chambers
  - TOF and Cherenkov PID

Appearance experiment: it looks for an excess of electron neutrino events in a predominantly muon neutrino beam



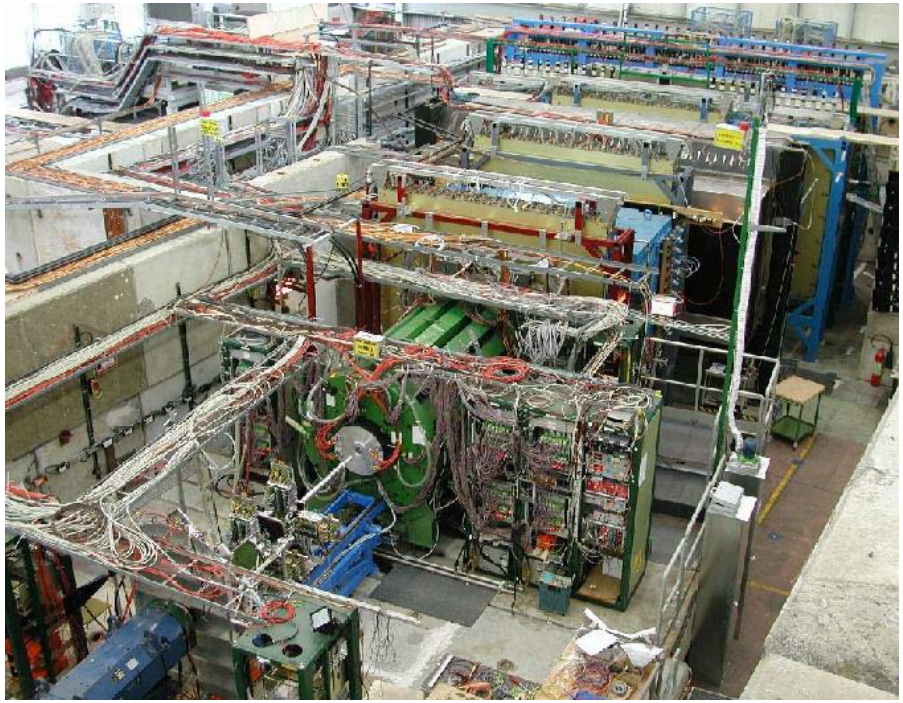




neutrino mode: $\nu_\mu \rightarrow \nu_e$ **oscillation search**

antineutrino mode: $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ **oscillation search**

HARP Physics Goals



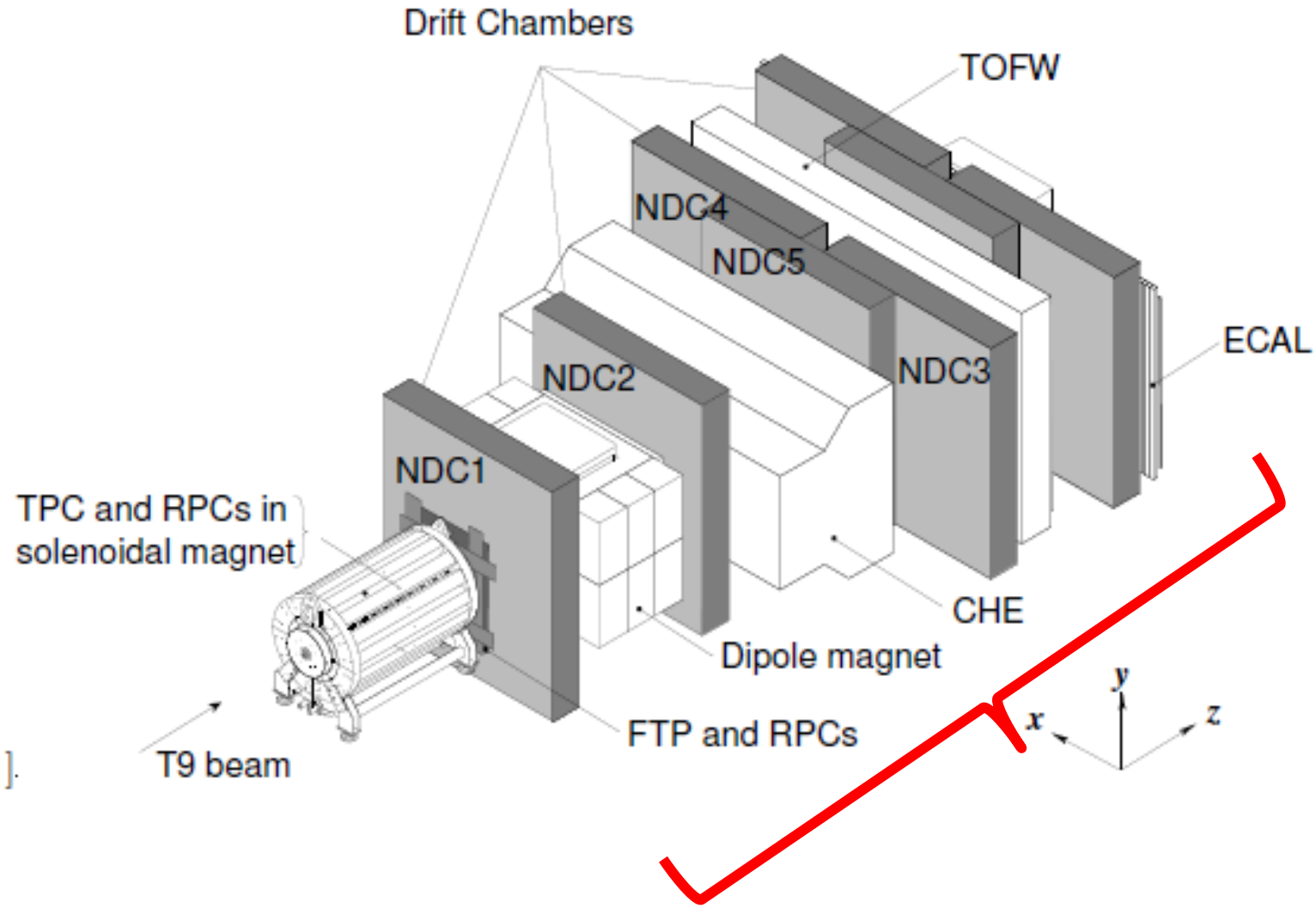
Systematic study of HAdRon Production:

Beam energy: *2-15 GeV*

Target: *from hydrogen to lead*.

- Input for precise calculation of *atmospheric neutrino flux*
- Input for prediction of neutrino fluxes for the *MiniBooNE* and *K2K* experiments
- Pion/kaon yield for the design of the proton driver of *neutrino factories* and SPL-based *super-beams*
- Input for *Monte Carlo* generators (GEANT4, e.g. for LHC, space applications)

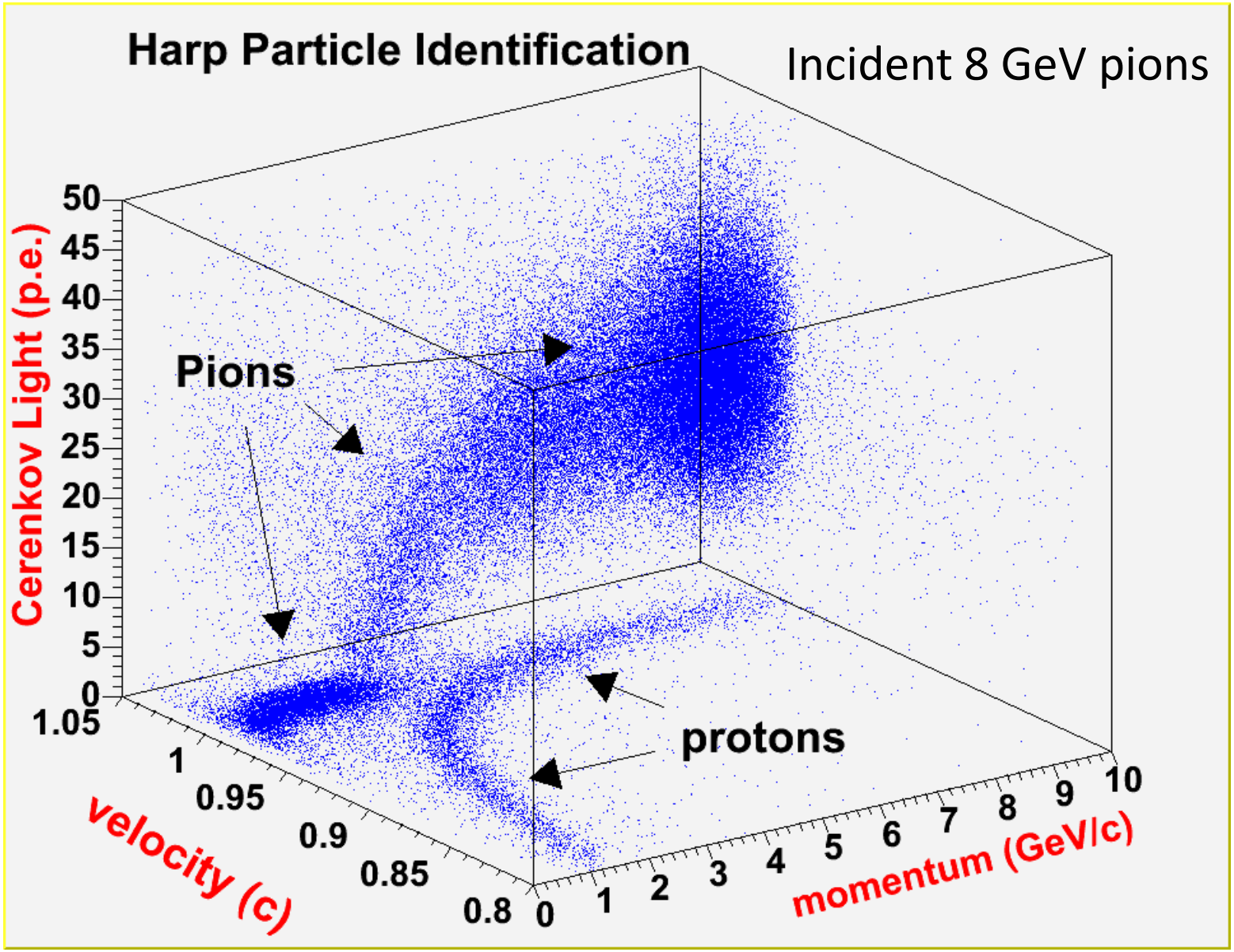
Forward Harp detector



Essential Features

- Good incident beam definition
  - Tracking, momentum, PID
- Secondary Particle ID over entire spectrum
  - Multi-particle: tracking momentum
  - HARP had ambiguities TOF ~ 170 ps
    - K/π separation $p>2GeV$
    - p/π separation $p>4GeV$
- Target out runs for background subtraction
  - We didn't do enough….

HARP Forward Particle Identification

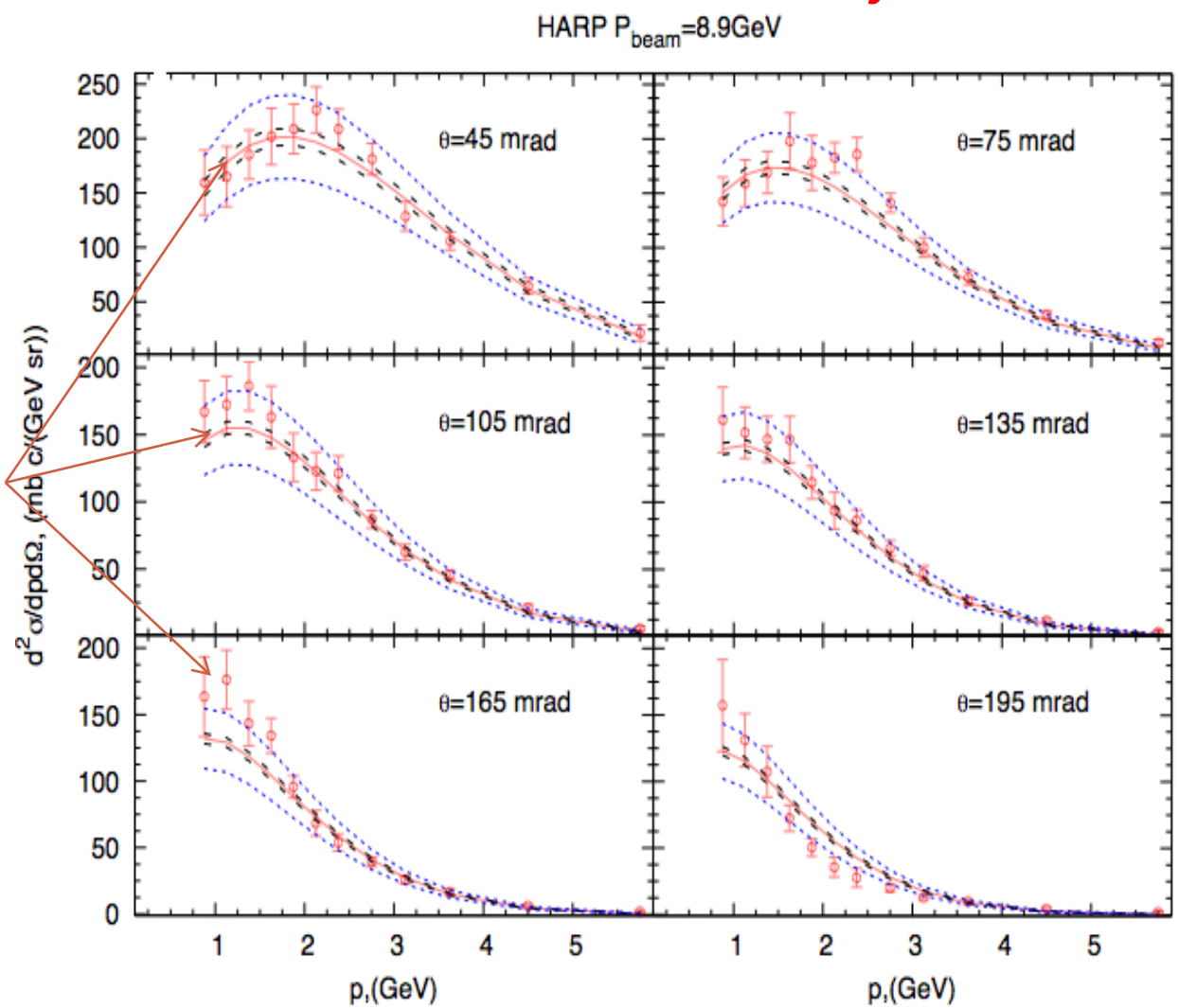


π^+ Production Cross Section at 8 GeV

- Bottom Line:
  - ~5% error on cross section
  - *Resulted in ~10% error on flux*

HARP collaboration, hep-ex/0702024

Target out subtraction



LBNE Hadron Strategy (?)

- External measurements:
  - Develop Fermilab program, MIPP-X
  - Participate in NA61?
- In situ measurements
  - ~10^8 particles/cm^2/pulse (difficult at high intensity)
    - Ionization yields
  - Muon measurements after the beam dump
    - Suitable for high energy muons
  - Low intensity measurements (prior to HI running)
    - Could measure complete post-horn meson spectrum

LBNE Hadron Measurements

- Low intensity in situ measurements
  - Resonant beam extraction onto target/horn system
  - Single arm spectrometer approach
    - Narrow aperture, scan across beam tunnel
    - Magnet momentum measurement
    - TOF/Cerenkov/Shower Counter (traditional)
    - Rolled into beam for measurement and then removed

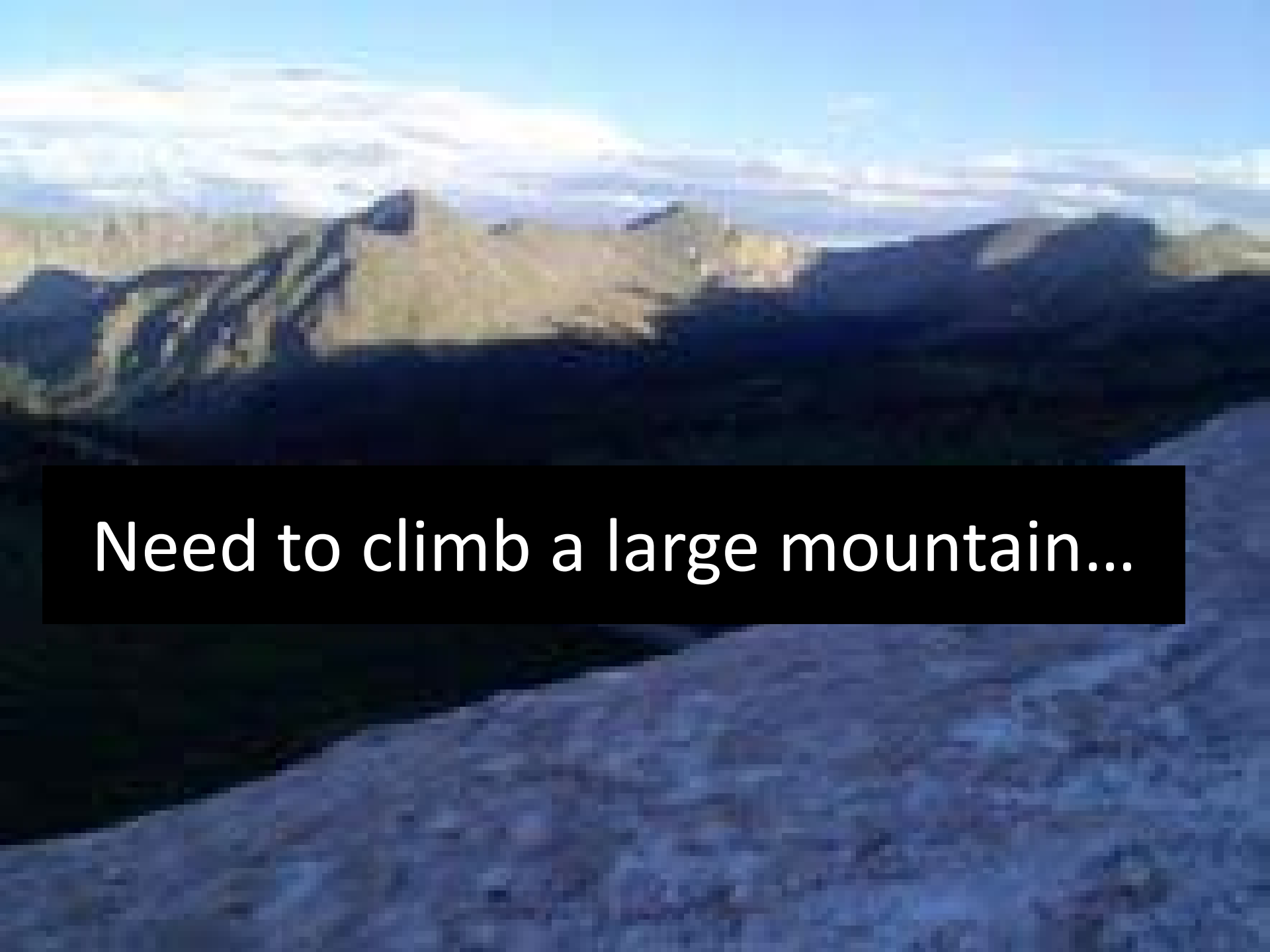
Fermilab MIPP Program and LBNE

- Measure meson production post-horn
  - Measure thick target and secondary interactions directly
  - Could be done in test beam setting

- Staged with horn test stand
  - Requires “MIPP”-X experimental apparatus following horn test stand
  - May be a rate problem with short horn-like duty factor ?

Summary

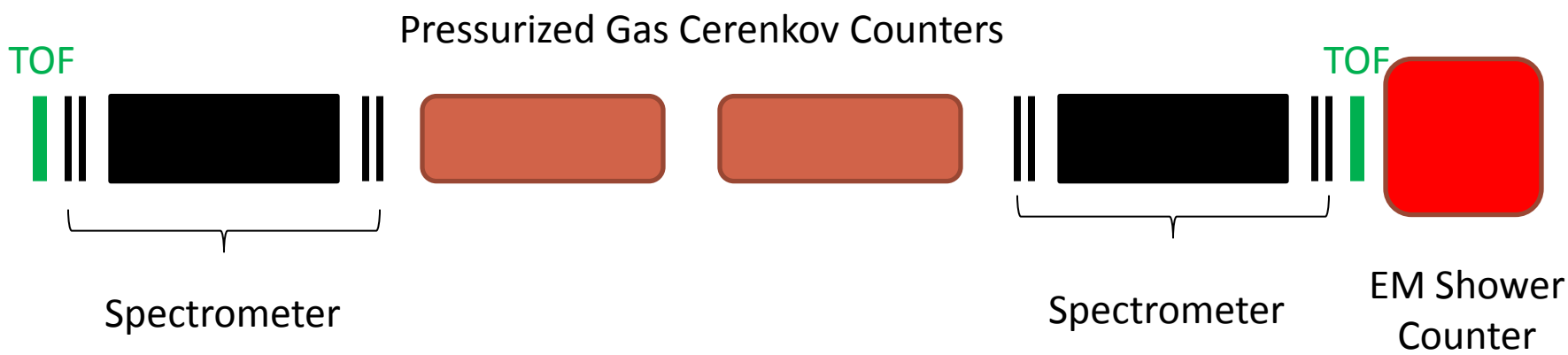
- LBNE should demand a completely understood neutrino beam
- This would make cross section measurements a reality instead of a hopeful endeavor
- The technology exists today to achieve this



Need to climb a large mountain…

Single arm spectrometer

- lowered into of decay tunnel alcove
- single particle inclusive spectra measurement
- separation of π/K/p
- requires slow “resonant” beam extraction



LBNE Target Area

Muon Measurements

- Iron muon spectrometer following beam dump
- Effective at high muon energies

- For low muon energies (<~2-3 GeV), muons merge with hadronic showers