Hadron Production Measurements for the Fermilab Neutrino Program US-NA61

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FNAL Long Baseline Neutrino Program

- 120 GeV primary proton beam:
  - MINOS
    - On-axis Far-Near ratio oscillation measurement, graphite target
  - Minerva
    - Cross section measurements, graphite target
  - Nova:
    - Off-axis Far-Near ratio oscillation measurement, graphite target
  - LBNE
    - On-axis oscillation measurement, graphite target

Neutrino Flux Predictions for Wide Band Horn Neutrino Beams

- Proton beam typically very well understood
- Geometry, materials, and electromagnetics:
  - Target, horns, decay tunnel can be engineered so that these are not an issue
  - "skin depth" in horn is sometimes an issue, but solvable
- Decay of π/K mesons well understood
- Hadronic cascade that produces mesons in the target, horn, and surrounding materials has typically been the largest source of error which leads us finally to the subject of this talk:
  - *Hadron Production Measurements for Neutrino Flux Predictions*

T2K Analysis of Flux Errors

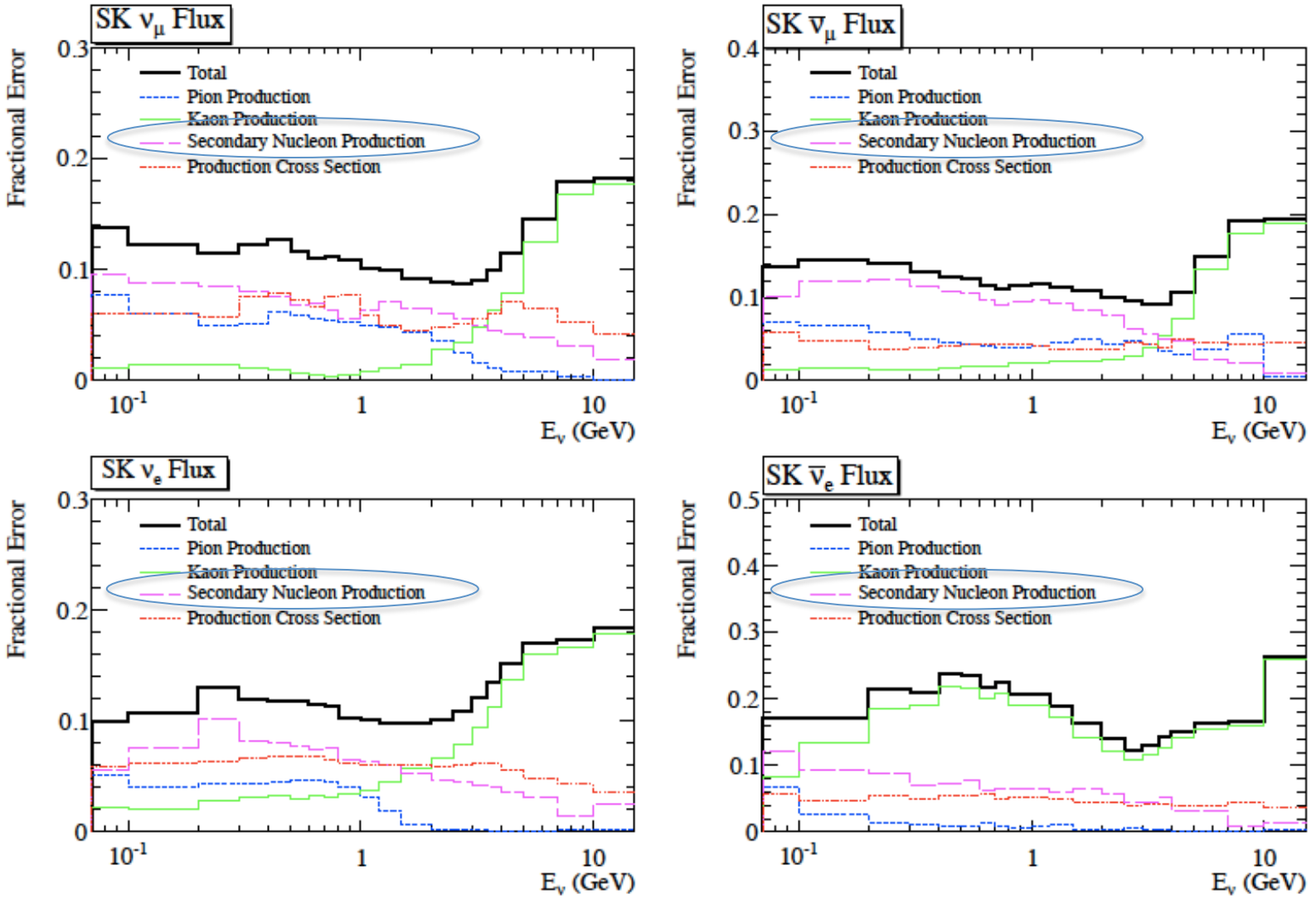
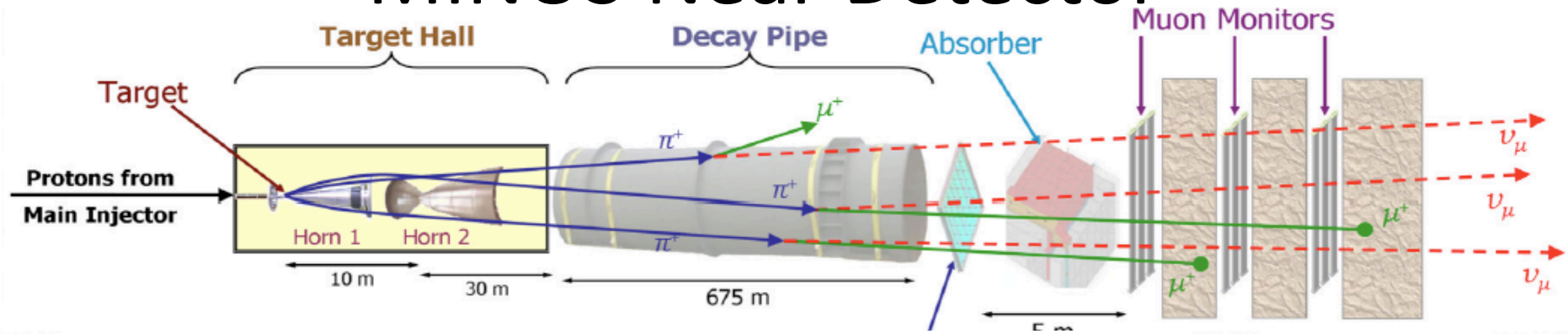


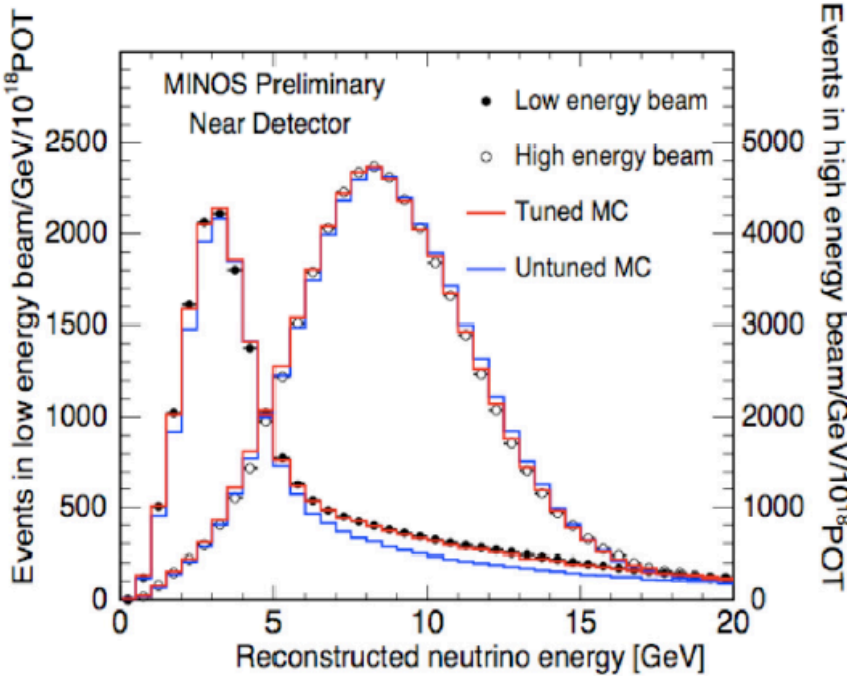
FIG. 38: Fractional flux error due to hadron production uncertainties.

NuMI Neutrino Beamline Tuning with MINOS Near Detector

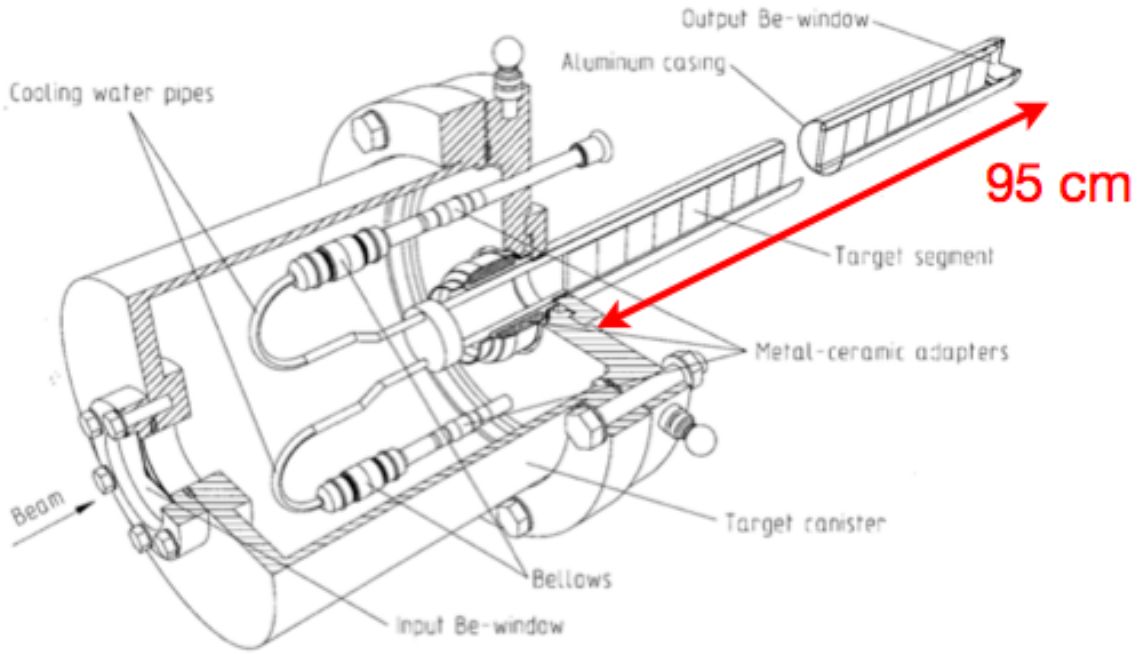


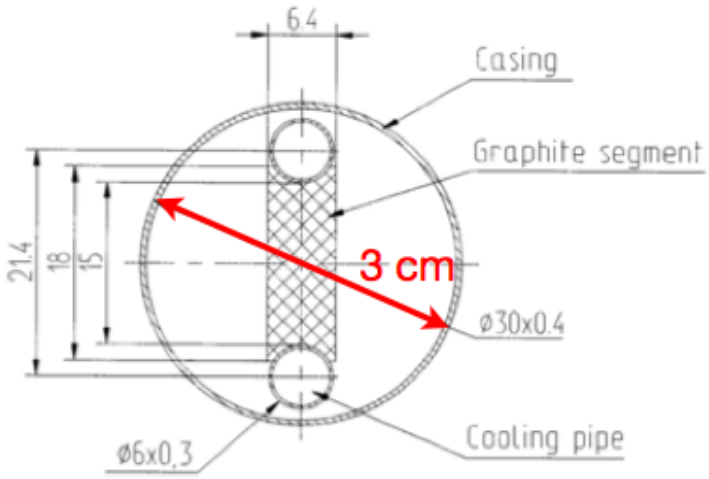
- 120 GeV Protons from Main Injector impinge on a graphite target to produce π, K
- Beam energy spectrum can be modified by varying the relative positions of target and horns
- Most data taken in the "Low Energy" configuration, which optimizes L/E for the measurement of Δm^2_{atm}
- Beam composition in the LE configuration:

91.8% ν_μ, 6.9% $\bar{\nu}_\mu$, 1.3% $\nu_e + \bar{\nu}_e$



Production from Target is Tuned

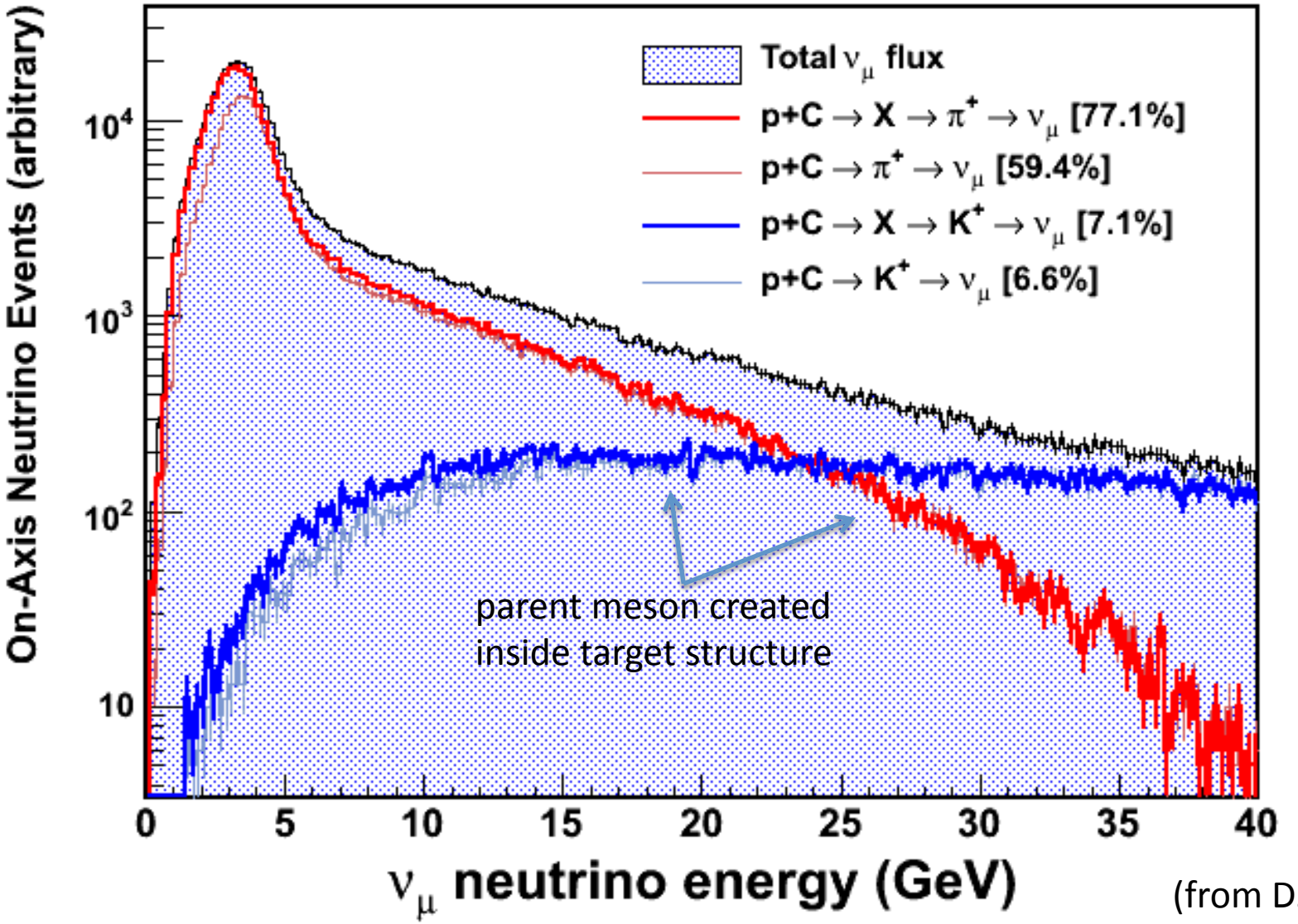




- Complex structure

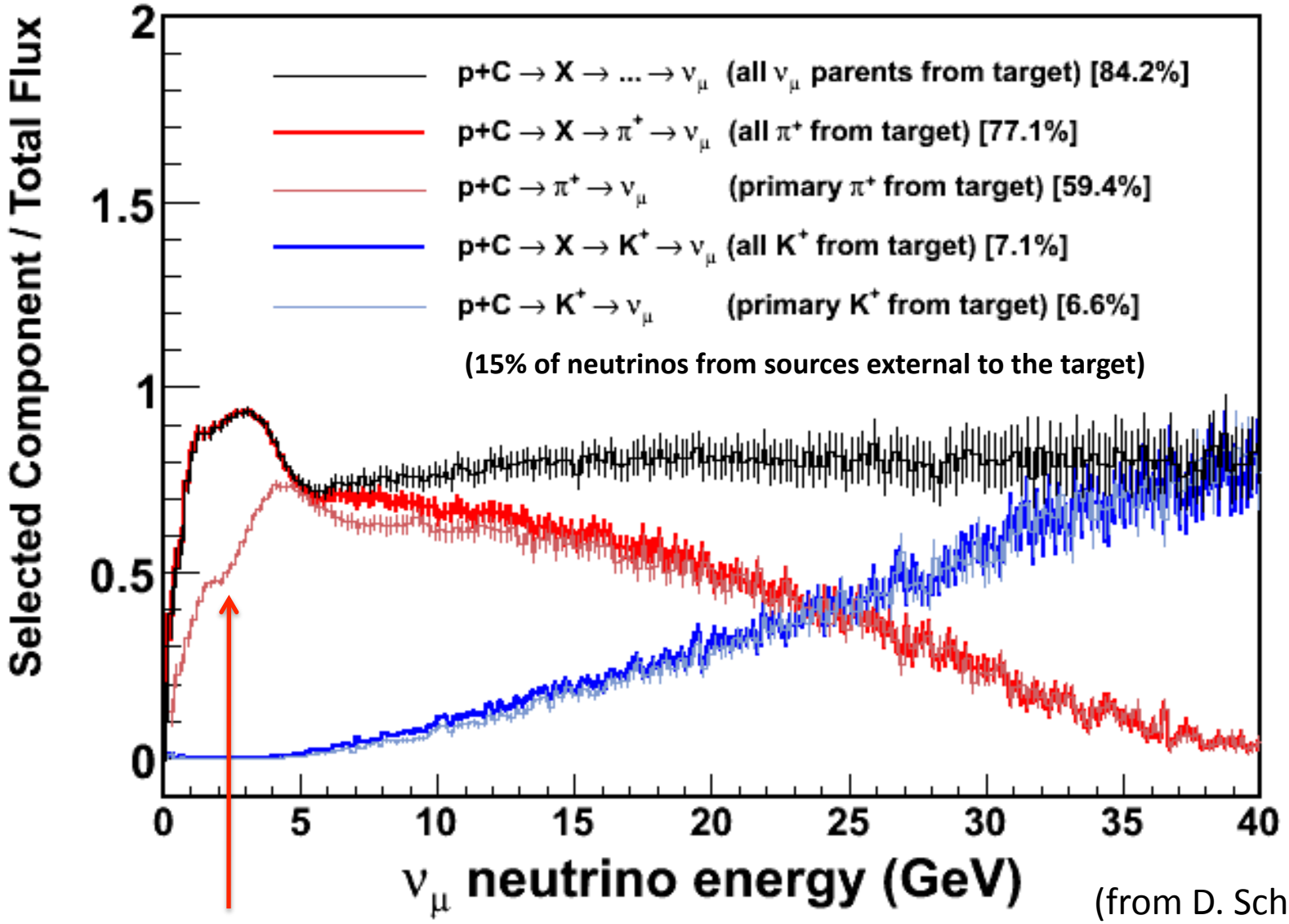
(from D. Schmitz)

NuMI Flux



(from D. Schmitz)

Fractional NuMI Fluxes



(from D. Schmitz)

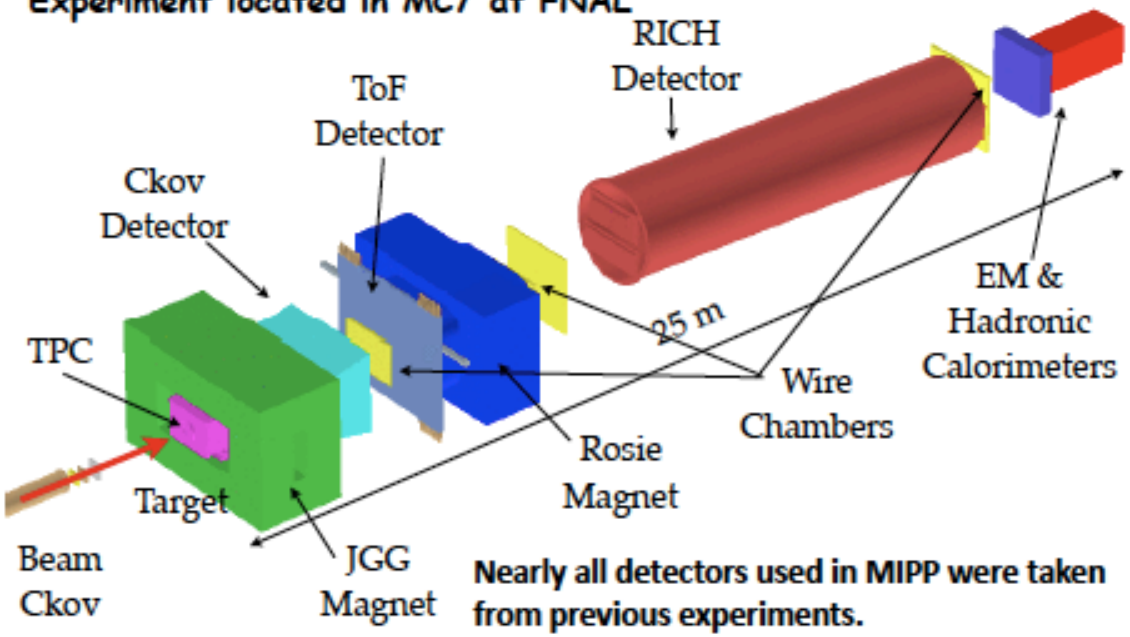
This is the piece one directly constrains with the NA49 data,
though in a model dependent way since it is extrapolated 158 GeV/c

Recent Hadron Production for Neutrino Experiments

- SPY (NOMAD...)
  - Used CERN North Area H2 beam line as a spectrometer
- HARP (K2K, MiniBooNE, MicroBooNE)
  - Used the P214 experiment to measure hadron production on neutrino targets (3 GeV/c-15 GeV/c)
- MIPP
  - Dedicated hadron production experiment 10-120 GeV/c
- NA61 (T2K)
  - Motivated by heavy ion collision physics but very capable for p-A hadron production (~30 GeV-)

Main Injector Particle Production (MIPP) Experiment

Experiment located in MC7 at FNAL

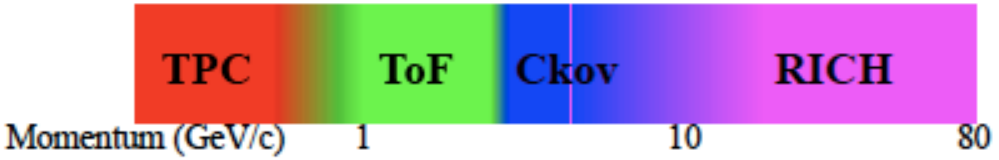


Nearly all detectors used in MIPP were taken from previous experiments.

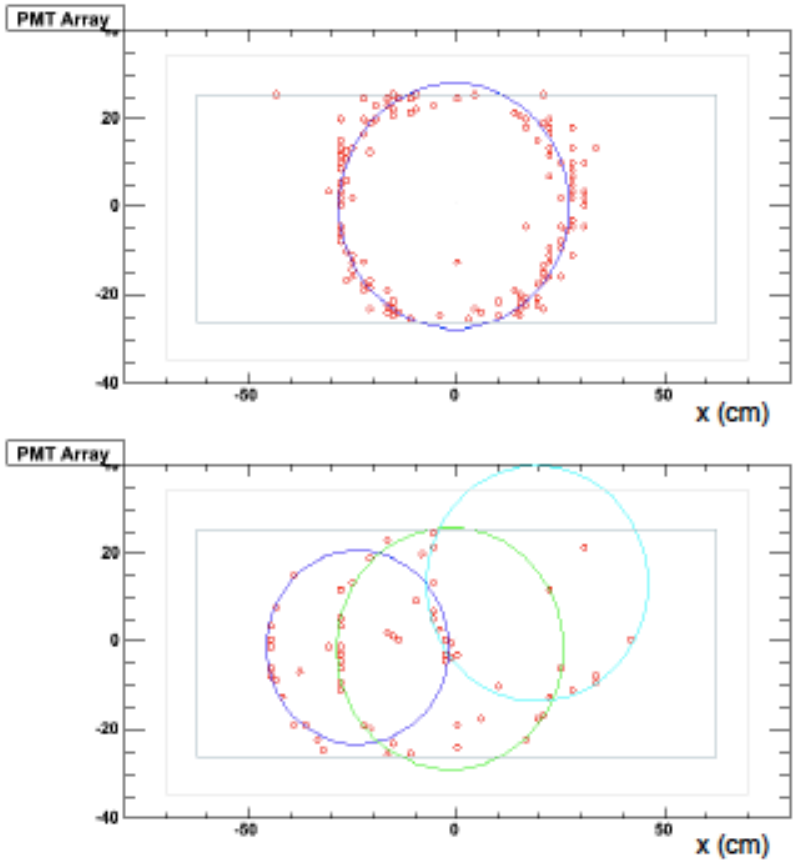
- Goal: collect comprehensive hadron production cross-section data set with particle id using various beams and targets (thick and thin).

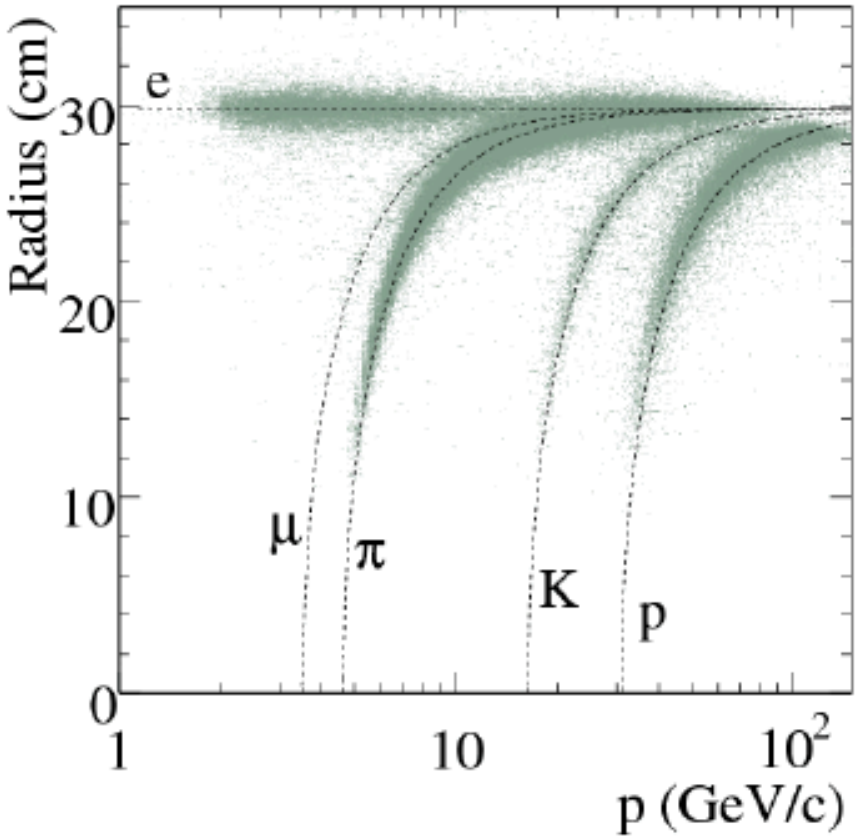
- Full acceptance spectrometer
- Two analysis magnets deflect in opposite directions
- TPC + 4 Drift Chambers + 2 PWCs

- Designed for excellent particle ID (PID) separation (2-3σ)



RICH PID Performance





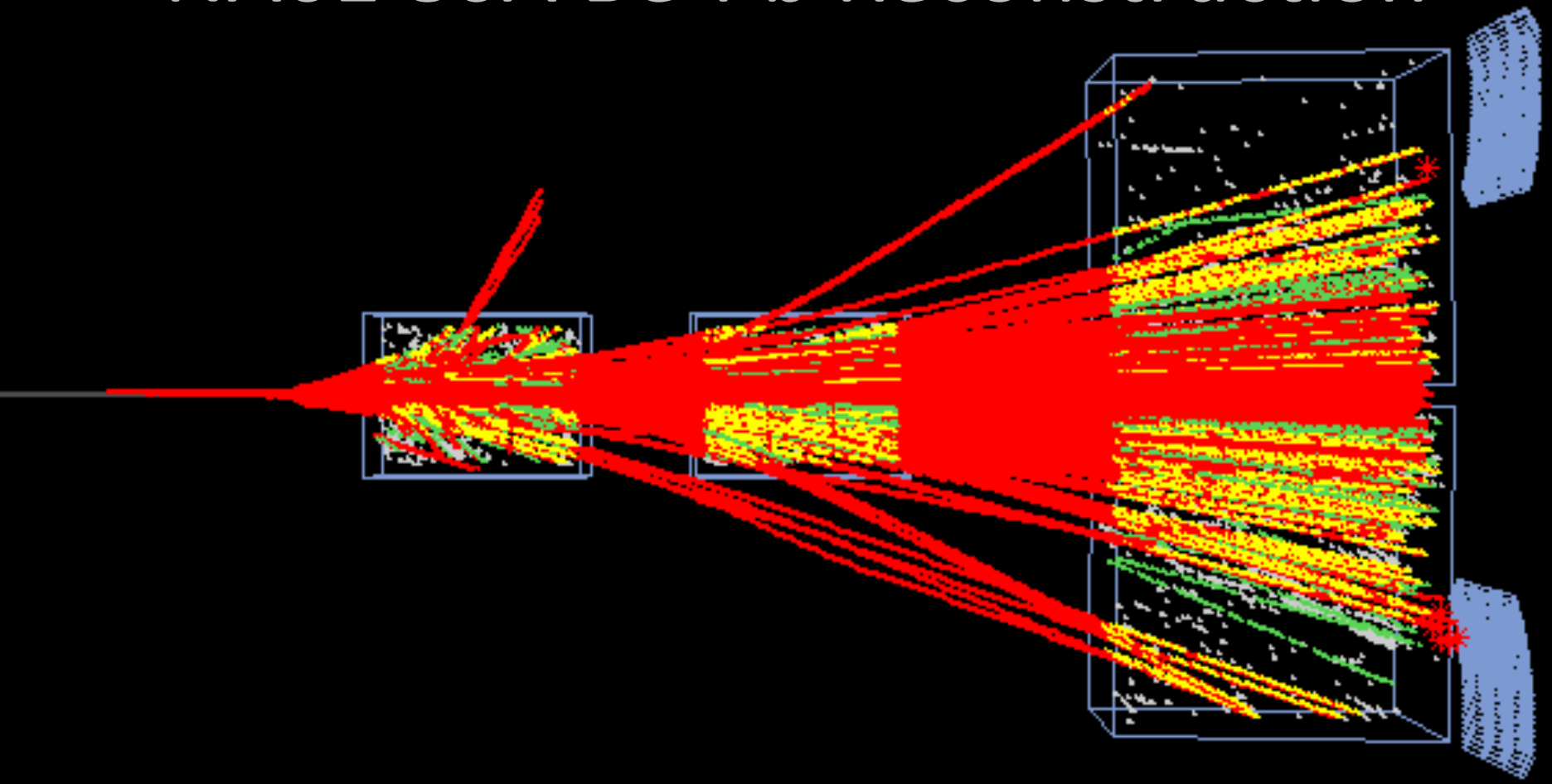
- Ckov light ring formed on array of ~2300 1/2" PMTs.
- Ring radius ~ Ckov angle ~ velocity.
- 3σ π/K separation up to 80 GeV/c, 3σ p/K separation up to 120 GeV/c

NA61/SHINE

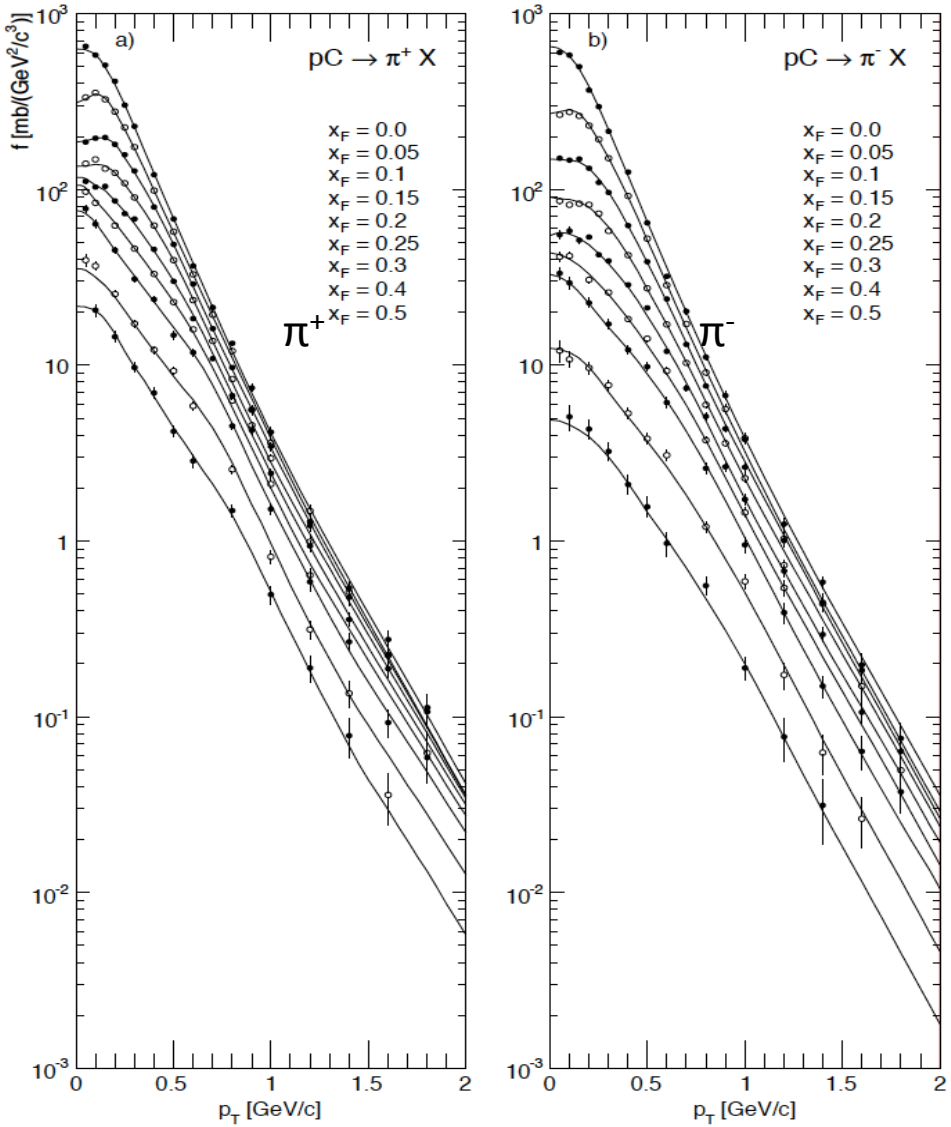
- Resurrection of NA49 heavy ion experiment
- Goals:
  - Search for phase transition in nuclear matter at SPS energies
  - Hadron production measurements for T2K neutrino program

Location:

NA61 80A Be-Pb Reconstruction

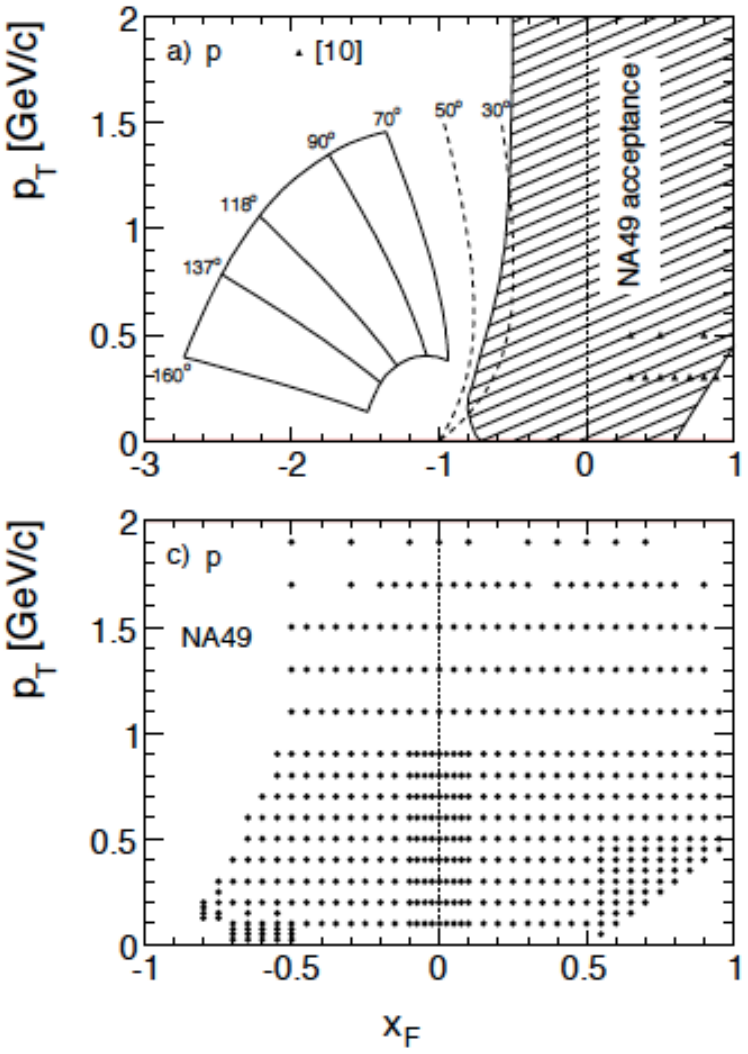


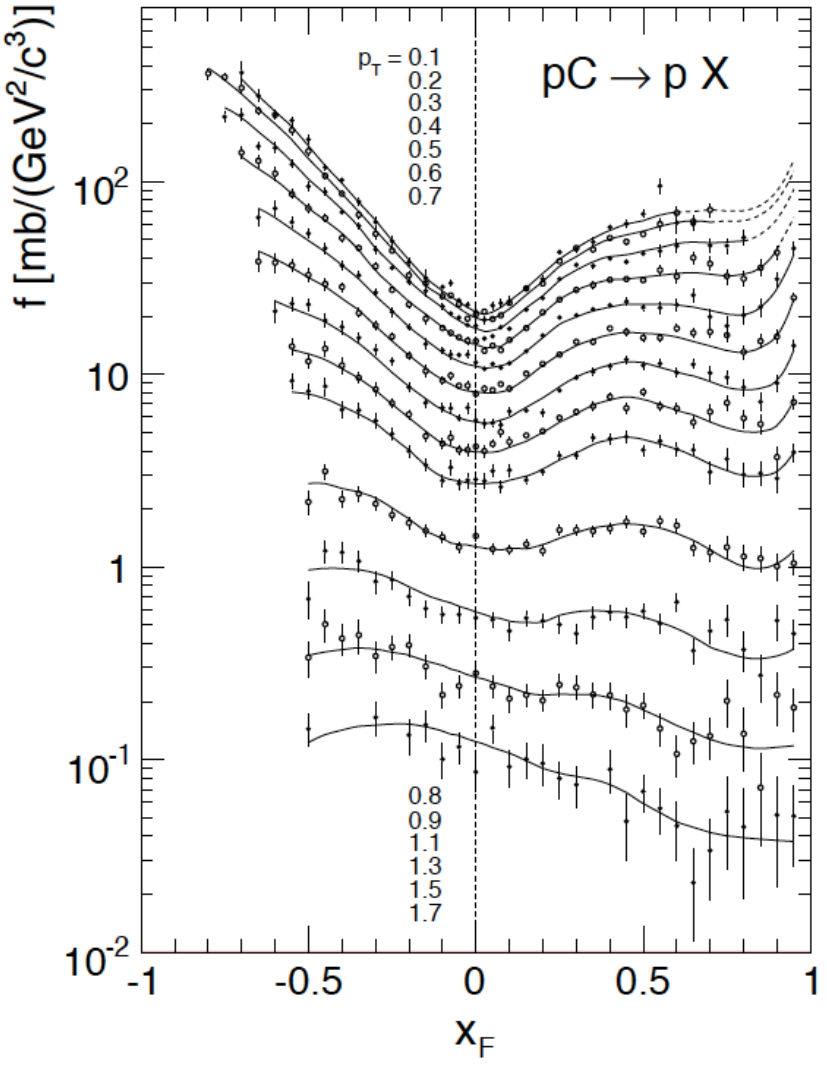
Existing Proton-C Data



- NA49 data at 158 GeV/c
  - Probably the best data available nearby 120 GeV but must be extrapolated to lower energy
- Plan is to repeat at 120 and lower energies

NA49 Proton Data at 158 GeV/c



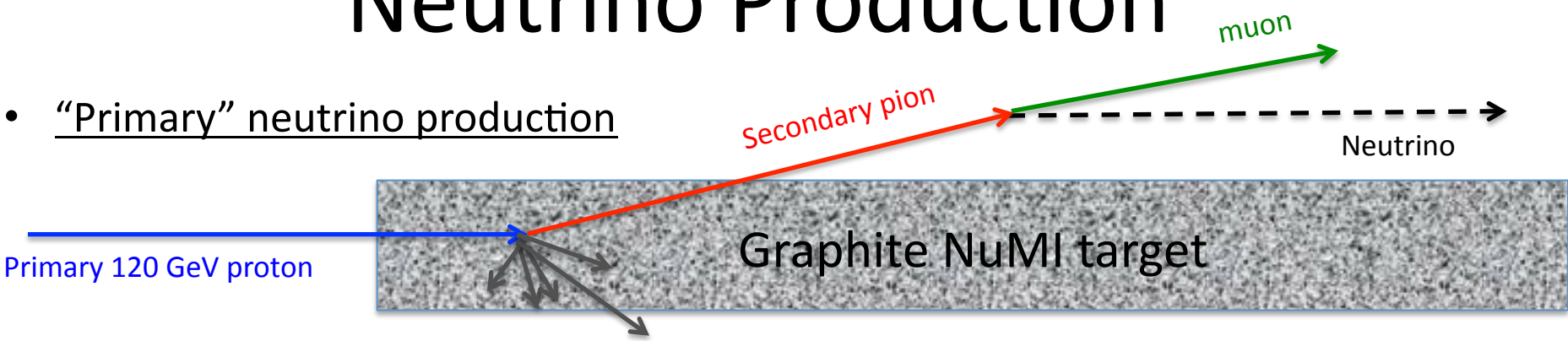


The US-NA61 Proposal

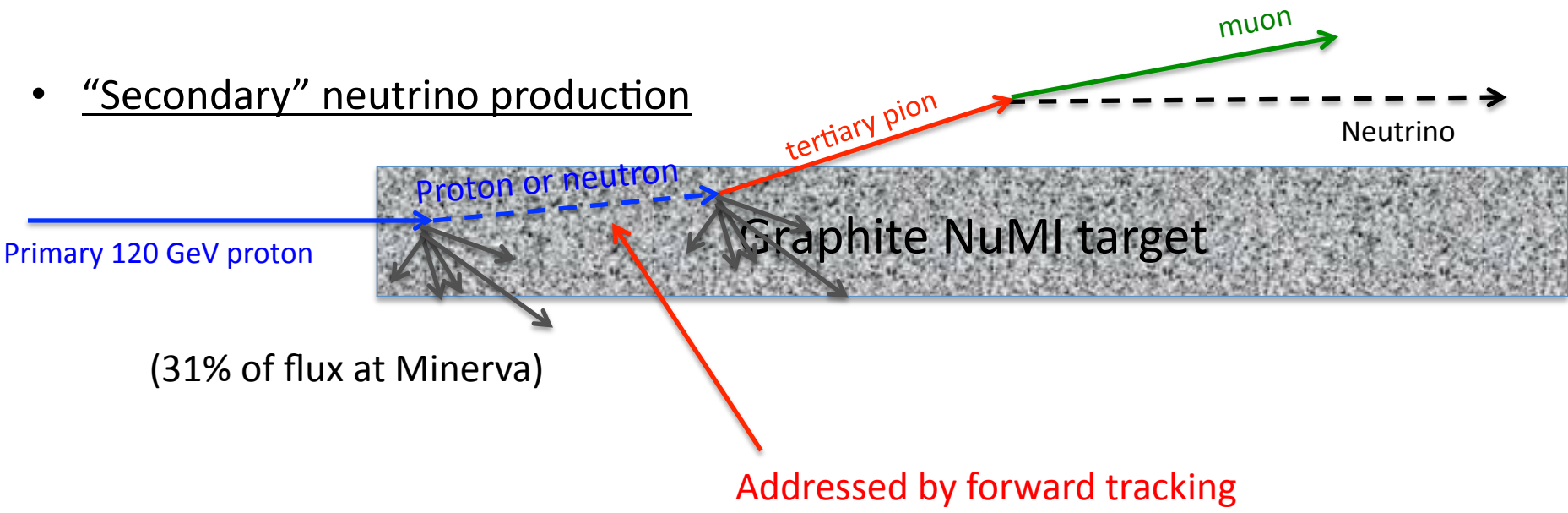
- Pilot run in summer of 2012
- Contribute to upgrades of detector
  - TOF/Beam counter electronics
    - Vittorio Paolone, University of Pittsburgh
  - Forward tracking TPC
    - Eric Zimmerman and Alysia Marino, University of Colorado
- Data runs
  - 2015-2017

Neutrino Production

- "Primary" neutrino production



- "Secondary" neutrino production

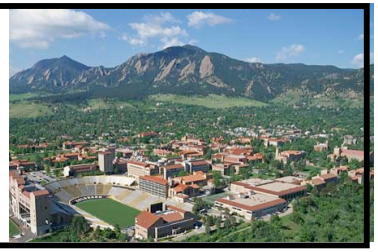


(31% of flux at Minerva)

Addressed by forward tracking

2012 Pilot Run Members

University of Colorado
Alysia Marino,
Scott Johnson
T2K, LBNE



University of Pittsburgh
Vittorio Paolone,
Istvan Danko
T2K, Minerva, LBNE

Los Alamos National Lab
Geoffrey Mills, Elena Guardincerri, Kevin Yarritu
MiniBooNE, LBNE

College of William and Mary
Leonidas Aliaga
Minerva

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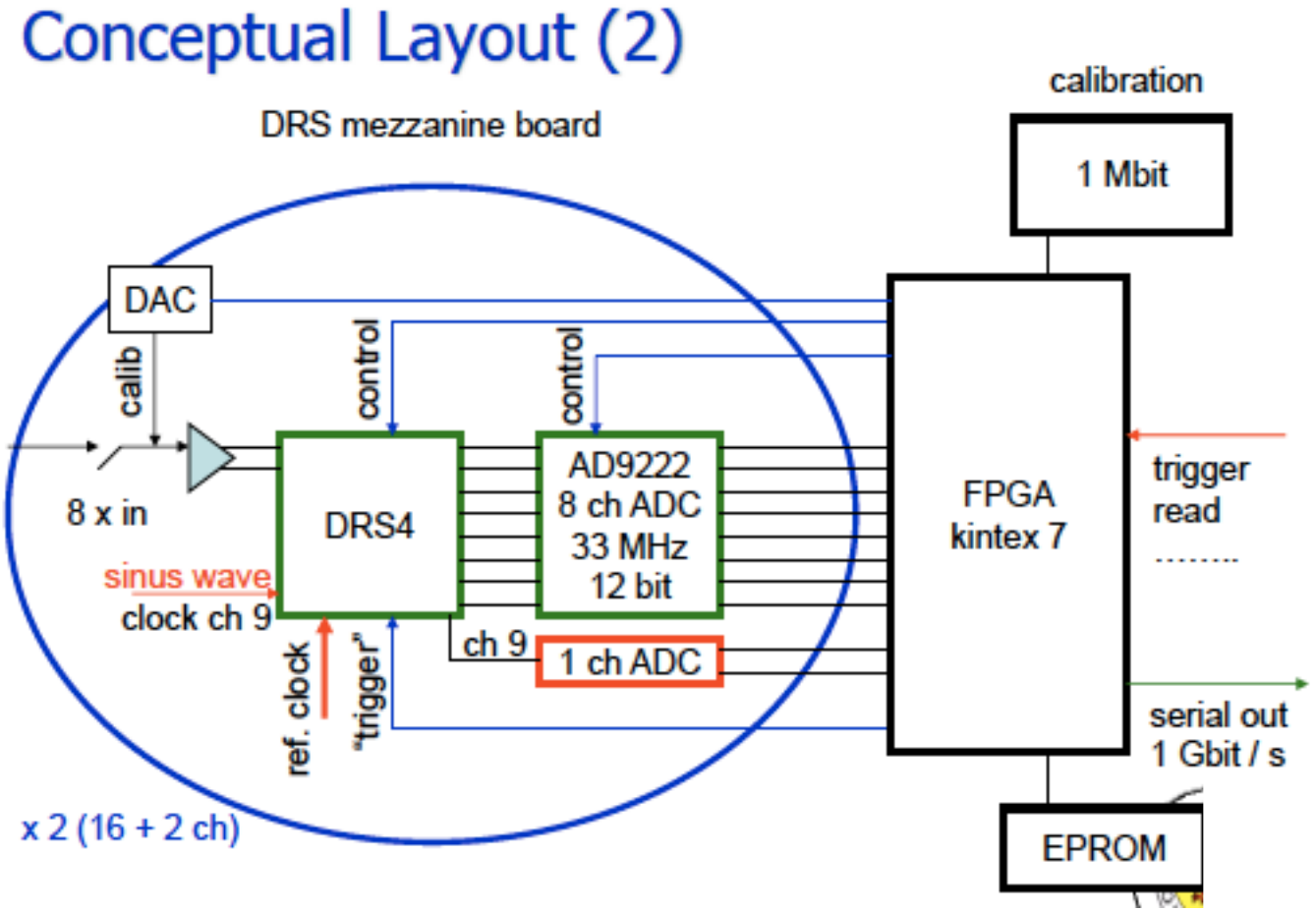
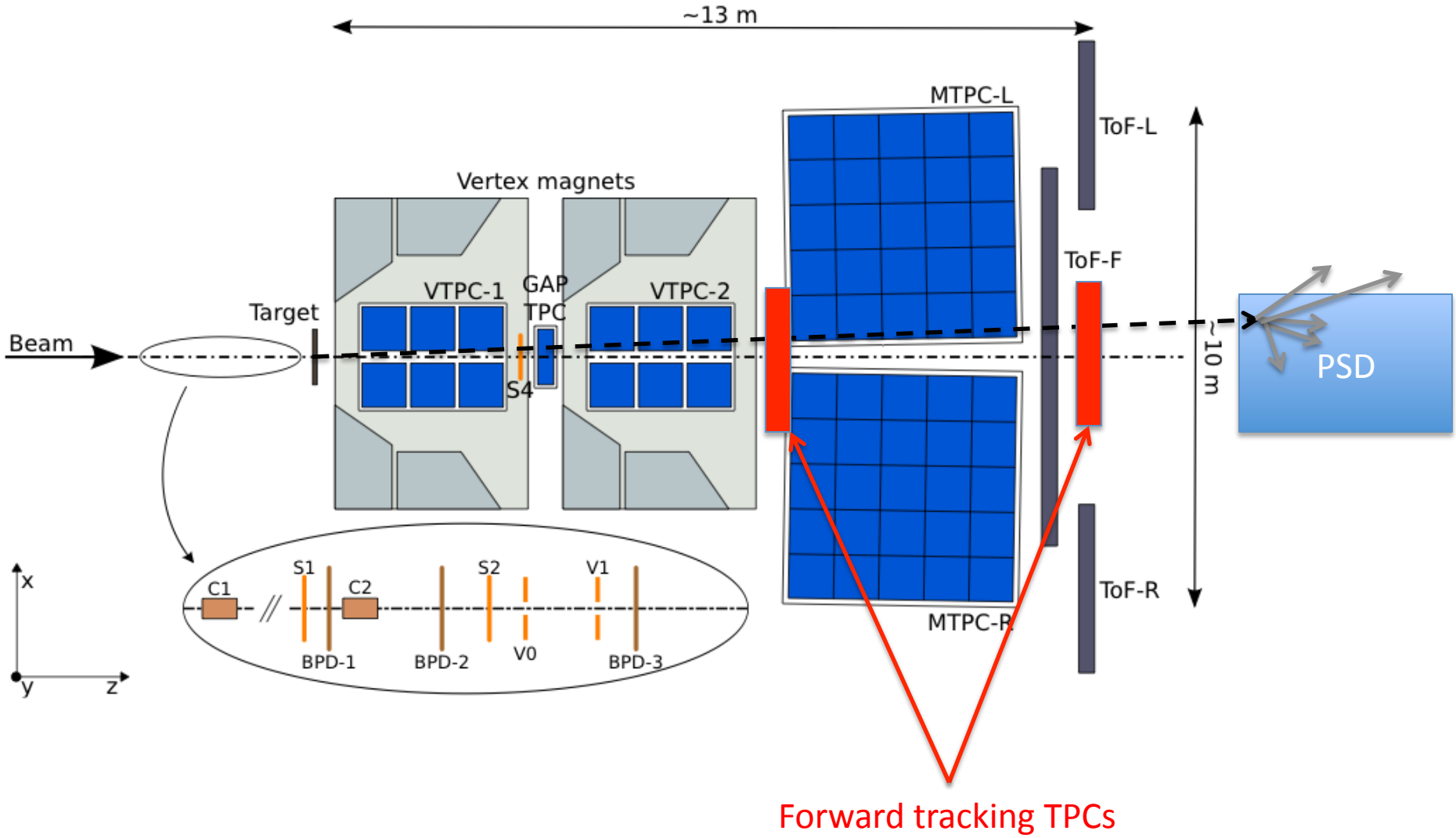
Electronics Upgrade (U. Pittsburgh)



Forward Tracking TPC (U. Colorado)



Summary

- NA61 is a good opportunity
  - Vigorous collaboration
  - Equipment is operational and runs are planne through 2017 and beyond
- US-NA61 could provide precise hadron production data for the Fermilab long baseline neutrino program
- Proposal will be submitted to DOE in February