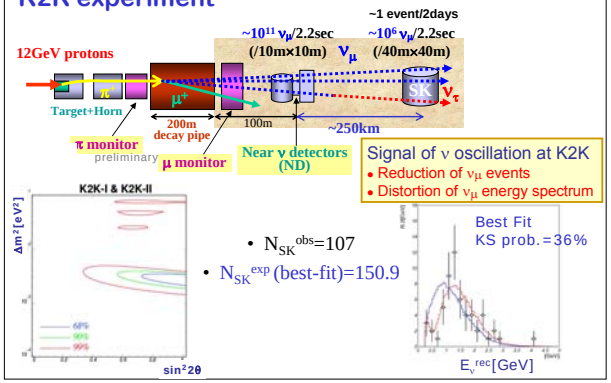
Measurement of inclusive π^0 production in the charged-current Interactions of Neutrinos in a 1.3 GeV wide band beam

C.Mariani
Columbia University

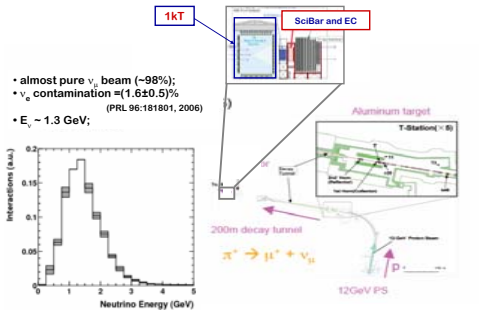
K2K experiment



Signal of ν oscillation at K2K
- Reduction of ν_μ events
- Distortion of ν_μ energy spectrum

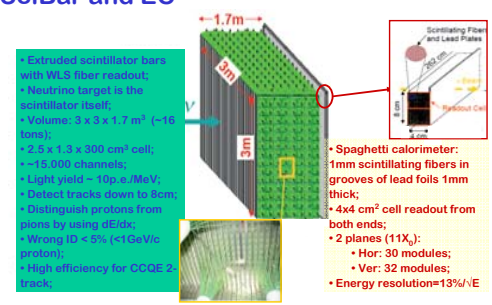
- N_{SK}^{obs}=107
- N_{SK}^{exp} (best-fit)=150.9

K2K near detector and neutrino beam



- almost pure ν_μ beam (~98%);
- ν_e contamination =(1.6±0.5)% (PRL 96:181801, 2006)
- E_ν ~ 1.3 GeV;

SciBar and EC



- Extruded scintillator bars with WLS fiber readout;
- Neutrino target is the scintillator itself;
- Volume: 3 x 3 x 1.7 m³ (~16 tons);
- 2.5 x 1.3 x 300 cm³ cell;
- ~15.000 channels;
- Light yield ~ 10p.e./MeV;
- Detect tracks down to 8cm;
- Distinguish protons from pions by using dE/dx;
- Wrong ID < 5% (<1GeV/c proton);
- High efficiency for CCQE 2-track;

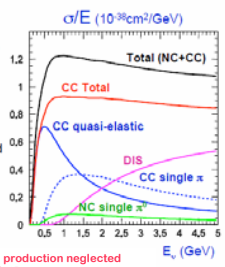
- Spaghetti calorimeter: 1mm scintillating fibers in grooves of lead foils 1mm thick;
- 4x4 cm² cell readout from both ends;
- 2 planes (11X_0):
  - Hor: 30 modules;
  - Ver: 32 modules;
- Energy resolution=13%/√E

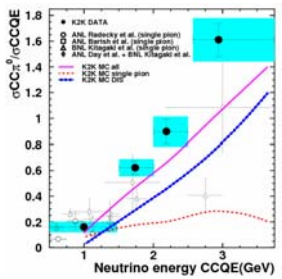
K2K neutrino interaction MC

- CC quasi elastic (CCQE: ~40% of all CC)
  - Smith and Moniz with M_A=1.1GeV
- CC single π (resonance production) (~38% of all CC)
  - Rein & Sehgal's with M_A=1.1GeV
- DIS (~18% of all CC)
  - GRV94 + JETSET with Bodek and Yang correction at low q^2.
- CC coherent π (2~3% in all CC)
  - Rein & Sehgal model based on PCAC.
- NC

+ Nuclear Effects

CC Coherent pion production neglected according to the SciBar measurement (Hasegawa et al. PRL 95:252301, 2005)





479 π^0's are reconstructed in data and 380 in MC.
The overall efficiency is 7.8 % and the purity is 66.5 %.

SciBar/EC measured the CC inclusive π^0 production on Carbon.

$$\frac{\sigma_{CC\pi^0}}{\sigma_{CCQE}} = 0.443 \pm 0.033(stat.) \pm 0.036(syst.)$$

The measurement shows an excess respect to our MC (49±16)% interpreted as an excess on the CC DIS cross section.

$$\frac{\sigma_{CC-DIS}}{\sigma_{CCQE}} = 0.381 \pm 0.013(stat.) \pm 0.046(syst.)$$

The K2K results are in agreement with the previously experimental data (although the experimental errors are reduced by a factor 2) and show a good consistency between all of them.

Likelihood Fit description

We perform a maximum likelihood fit of

$$L = L_{CC\pi^0}(f_{norm}, R_{nQE/QE}, S_{\pi^0}(E_i)) \times L_{norm}(f_{norm}, R_{nQE/QE}) \times L_{syst}$$

where Poiss(n, μ) is the poissonian for n events with expectation value μ;

$$L_{CC\pi^0} = \prod_i \prod_k Poiss(data_k(E_i), pred_k(E_i))$$

We fit the 4-dimensional reconstructed neutrino energy distribution H_k.
- H_k is the number of events in the bin k of 1-dimensional histogram;
- k=1,30 labels 30 bins between 0-5 GeV for every reconstructed neutrino energy;
- $data_k$ = number of events observed in bin k;
- $pred_k$ = number of events expected in bin k = $f_{norm} \times \left[S_{\pi^0} \times \sum_i H_i^{Sign} + \sum_i H_i^{Bkg} \right]$

$$L_{norm} = \prod_s Poiss(n_s, pred_s), \qquad s = \{1TQE, 2TQE, 2TnQE.p, 2TnQE.\pi\}$$

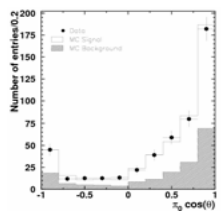
$\frac{\sigma_{CC\pi^0}}{\sigma_{CC\pi^0}^{MC}}$

n_s and $pred_s$ are respectively the number of events observed in data and expected by MC for the different normalization sub-samples.

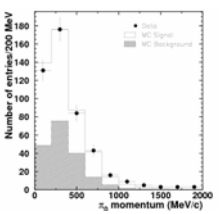
L_{syst} is a term used in the systematic errors evaluation.

Energy Range GeV	Cross Section Ratio $R_\pi = \frac{\sigma_{CC\pi^0}}{\sigma_{CCQE}}$
> 0.0	0.443 ± 0.033(stat.)± 0.036(syst.)
0.0 - 1.5	0.160 ± 0.057(stat.)±0.012(syst.)
1.5 - 2.0	0.621 ± 0.070(stat.)±0.043(syst.)
2.0 - 2.5	0.898 ± 0.106(stat.) $^{+0.074}_{-0.070}$(syst.)
≥ 2.5	1.611 ± 0.163(stat.)±0.114(syst.)

Reconstructed π^0 cosθ after fit

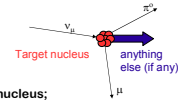


Reconstructed π^0 momentum after fit



Inclusive signal definition

We define signal an event with:



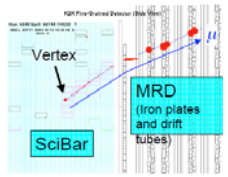
- 1 or more π^0's from the neutrino interaction vertex;
- 1 or more π^0's from a re-interaction inside the target nucleus;
- 1 or more η (decaying either in π^0's or photon pairs).

CC normalization sample

The total number of selected CC interaction are 11606 (20.2x10^{18} POT), the simulated neutrino interactions are 1500000.

CC selection cut (eff.49.5%, pur.97.5%)

At least one track reconstructed in SciBar;
Track should be in FV: 10.9 m³;
Track should be matched with MRD ;



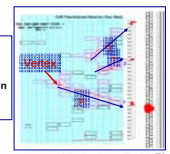
CCQE samples

1T-QE: a single reconstructed track;
2T-QE: 2 reconstructed tracks with $\Delta\theta_p$< 20°;
2T-nQE-π: 2 reconstructed tracks with $\Delta\theta_p \geq$ 20°, pion like;
2T-nqe-p: 2 reconstructed tracks with $\Delta\theta_p \geq$ 20°, proton like.

Experimental signature and gamma selection

Muon ID: one track matched to a MRD track corresponding to the muon produced in the CC interaction;

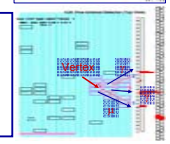
CC π^0 features:
A muon track to define the neutrino interaction vertex, plus two photon conversions (tracks disconnected from the neutrino interaction vertex and pointing to it in SB, or/and a narrow cluster in the EC;
Possibly other tracks and/or EC clusters.



CC π^0 selection:
Photon tracks should be reconstructed in FV: 13.3 m³;
Not matched with a MRD 3D reconstructed track;
In time within 10 ns with the muon track;

Pointing within 25 cm and disconnected >20 cm (in both views) to the interaction vertex;

EC $E_{vert.\ Cluster}$ > 50 MeV
EC $E_{hor.\ Cluster}$ > 25 MeV



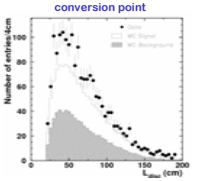
π^0 combinatorial and reconstruction

Photon candidates per event should be ≥ 2;

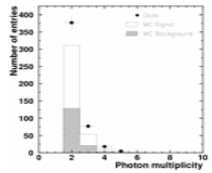
In 21% of the events selected we have >2 candidates, in this case we reconstruct the π^0 mass as follows:

- If all photons reconstructed in SB: π^0 vertex closest to μ vertex (15%);
- If 1 or more photons are reconstructed in the EC: best mass (6%).

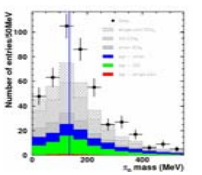
Disconnection: distance between the neutrino rec. Vertex and photons conversion point



Photon candidate multiplicity per event



π^0 invariant mass



Reconstructed neutrino energy before fit