Mezze~ - 01

Recent Results from the

ν_μ NOMAD ν_τ

Neutrino Oscillation MAgnetic Detector

Experiment

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for

The NOMAD Collaboration:

150 physicists from:

AUSTRALIA Melbourne, Sydney

CERN

CROATIA Zagreb

FRANCE LAPP Annecy, Paris LPNHE, Saclay DAPNIA

GERMANY Dortmund.

ITALY Cosenza, Firenze, Padova, Pavia, Pisa, Roma 3.

RUSSIA INR Moscow, JINR Dubna.

SPAIN Valencia.

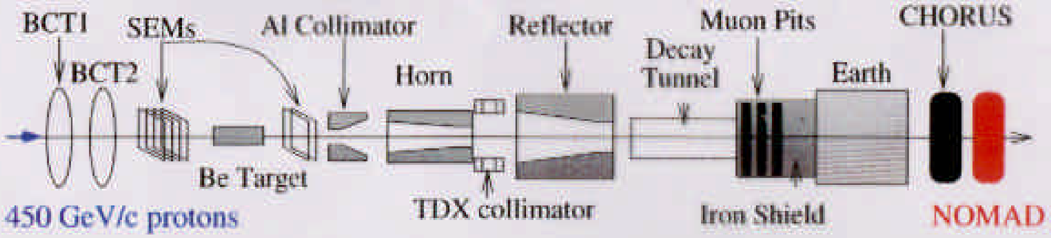
SWITZERLAND Lausanne, ETH Zurich.

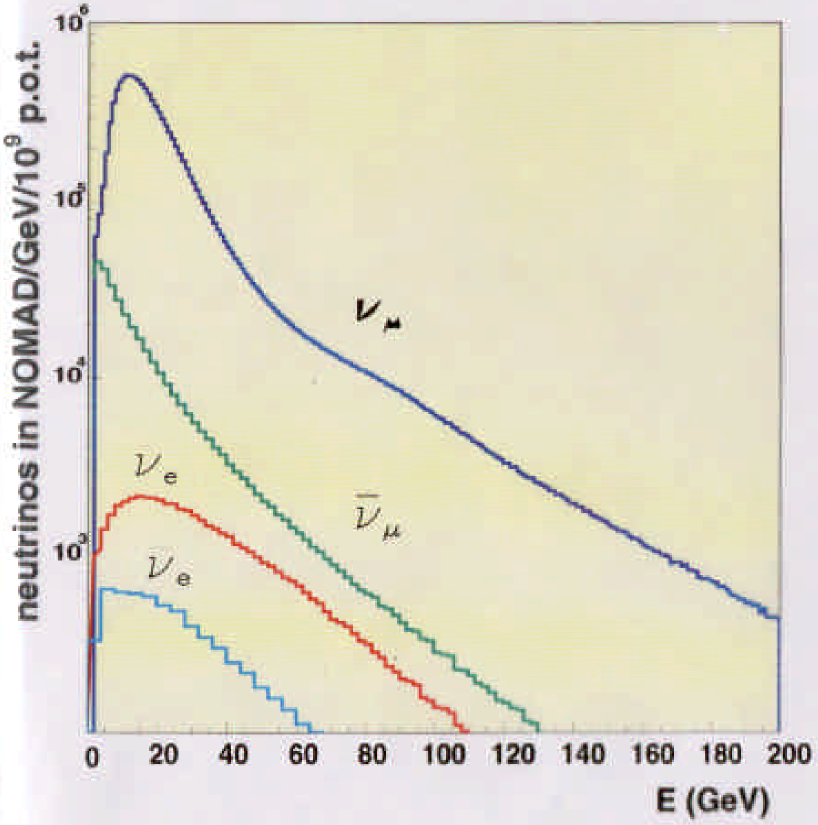
USA Harvard, Johns Hopkins, South Carolina, UCLA.

XIX International Conference on Neutrino Physics and Astrophysics

June 16-21,2000, - Sudbury, Canada

CERN Wide Band Beam (WANF)





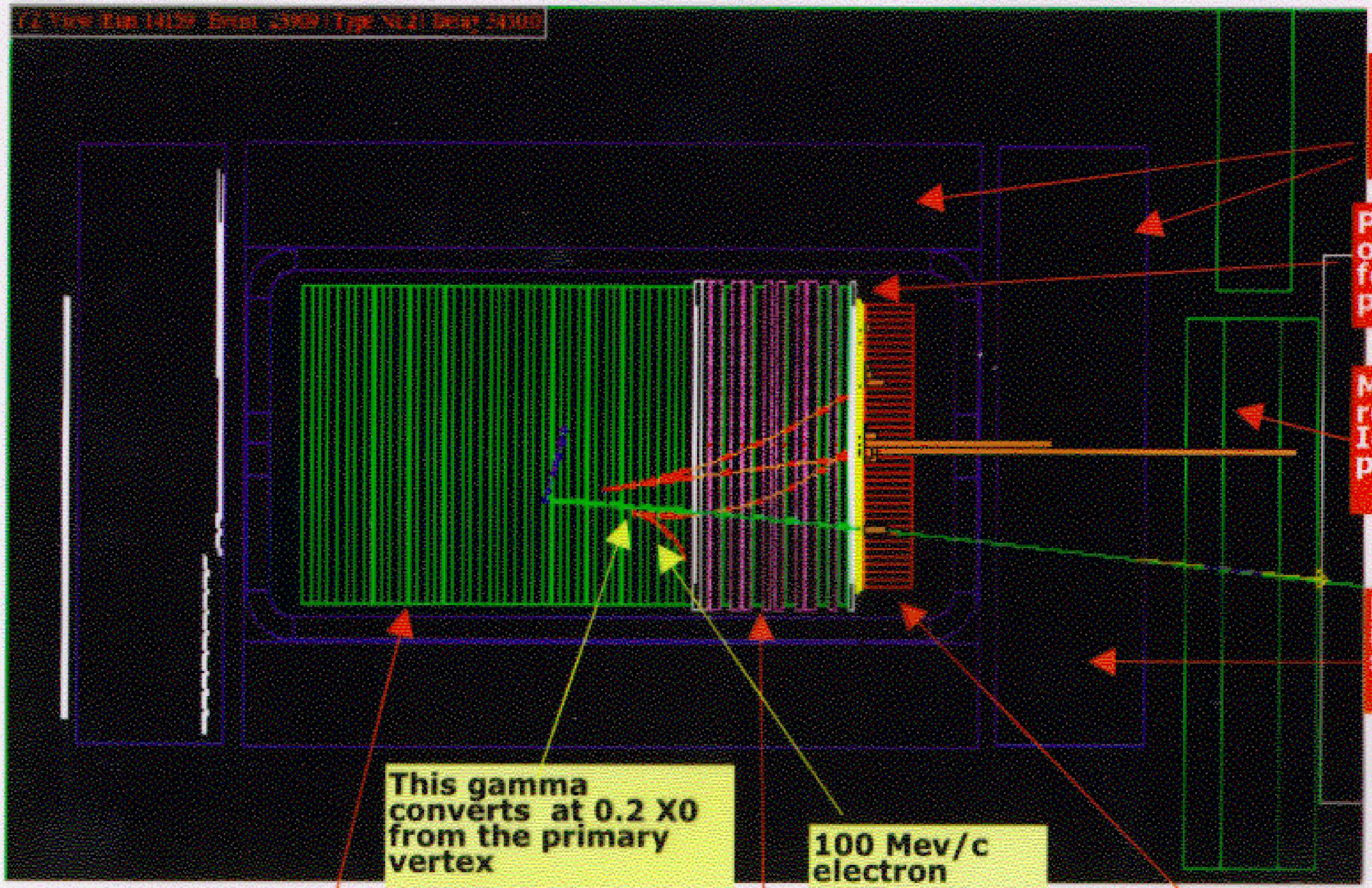
Distance of detector from target $\sim 800m$.

Effective neutrino flight path $\sim 600m$.

Flavour	Rel. Flux	$\langle E_\nu \rangle\ (GeV)$
ν_μ	1	23.5
$\overline{\nu}_\mu$	0.061	19.2
ν_e	0.0094	37.1
$\overline{\nu}_e$	0.0024	31.3

ν_τ flux is negligible (less than 0.1 expected interactions in 4 years).

NOMAD DETECTOR Full data sample (1995-98) 1.35 10^6 ν_μ CC



MAGNET: 0.4 T. Recycled from the UA1 experiment

PRESHOWER: 1.6 X0 of lead antimony followed by proportional tubes.

MUON CHAMBERS: recycled from UA1. Identify muons with p>3.5 GeV/c

HCAL: magnet iron instrumented with scintillators.

Electrons are identified by TRD, preshower and ECAL

This gamma converts at 0.2 X0 from the primary vertex

100 Mev/c electron

2.7 ton TARGET: 11 planes of Drift Chambers (DC). Density: 0.1 g/cm3 Resolution: 3% (p< 10 GeV/c)

9 planes of TRD interspersed with 5 planes of DC

ECAL: 875 lead glass towers. Resolution: $3\%/E^{1/2}$.

The ν_τ search: general principles

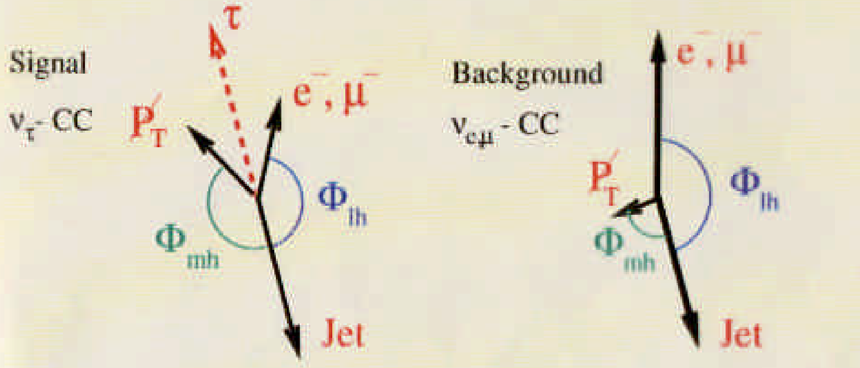
Appearance experiment. ν_τ is detected by CC interactions $\nu_\tau + N \rightarrow \tau^- + X$

Indirect τ identification through its secondary visible decay products. Analyses are specialized in Low and High Multiplicity events, separated by a cut on the hadronic momentum $p_H > 1.5\ GeV/c$.

$$\tau^- \rightarrow \begin{cases} e^- \overline{\nu}_e \nu_\tau & 17.8\% \\ h^- (n\pi^\circ)\nu_\tau & 49.5\% \\ \pi^-\pi^-\pi^+ (n\pi^\circ)\nu_\tau & 15.2\% \\ \hline \text{TOTAL} & 82.5\% \end{cases}$$

Kinematic criteria to extract the signal from background.

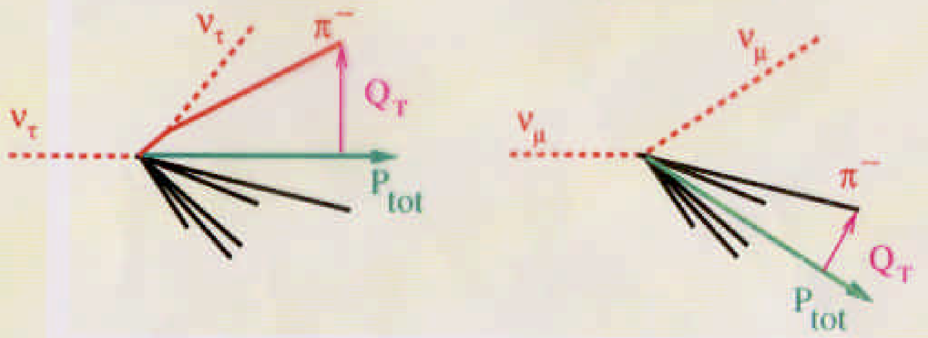
Electron decay, the main source of backgrounds are ν_e CC $\Longrightarrow$ kinematics based on the missing momentum and angular relations in the transverse plane.



Hadronic decays, the main source of background are neutral current $\Longrightarrow$ isolation between the τ visible decay product(s) and the hadronic jet.

Signal

Background from NC



Nomad analysis in its maturity

The optimal rejection power is achieved using the full topology of the events, in principle 5 degrees of freedom + internal structures.

A probability density function, $pdf\ \mathcal{L}$ can be defined, describing the probability for an event with a given set of variables X_i to be signal ($\mathcal{L}_S$) or background ($\mathcal{L}_B$).

The global $pdf\ \mathcal{L}$ is subdivided into n-dimensional partial pdf's with n up to 4 (higher values are not practical given the statistic of the MonteCarlo samples) chosen among the most discriminating internal correlations of X_i.

Event classification is based on likelihood ratio between the signal and background hypotheses: $ln\lambda = ln\frac{\mathcal{L}_S}{\mathcal{L}_B}$

The optimal treatment would be to fit the shape of the tail of $ln\lambda$. In practice $ln\lambda$ is subdivided into bins. The position of the bins is decided exclusively taking into account the sensitivity of the analysis (sensitivity is defined in Cousins & Feldman, Phys. Rev. D57(1998)3873.).

The independent measurements from different decay modes and signal bins are combined within the frequentist Unified Approach.

Three important steps for a solid analysis

DATA SIMULATOR: The large kinematical suppression and the use of likelihood functions exploiting multidimensional correlations require precise knowledge of the backgrounds down to $\mathcal{O}(10^{-5})$. Not possible to rely only on the MonteCarlo predictions.

- Use identified ν_μ^{CC} in both Data (DS) and MonteCarlo (MCS) samples and replace the leading μ^- by the appropriate MC particle: ν for neutral currents, τ for the signal, e^- for ν_e^{CC}.
- Compute efficiency for signal and background as $\epsilon = \epsilon_{MC}\frac{\epsilon_{DS}}{\epsilon_{MCS}}$
- In this ratio the systematics of the method itself, of the MC hadronic simulation and of the nucleon Fermi motion cancels.

Search for τ^+ candidates: Given the beam composition and the published limits no τ^+ signal is expected → Search for τ^+ in the data and demonstrate that background predictions agree with data.

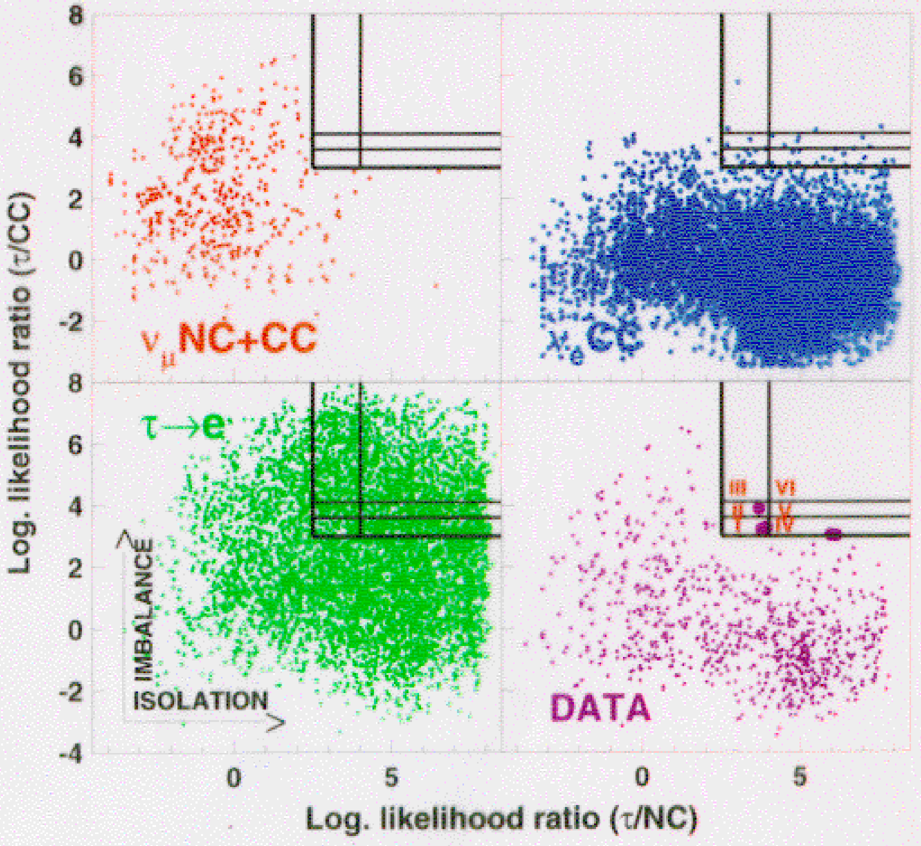
Blind Analysis To avoid ANY bias in selecting the events, define a "signal" region (box) and never look at the data there. Robust prediction of backgrounds must be demonstrated before opening the box. The choice between different analyses in each decay channel is made according to their sensitivity, before opening the box

$\tau \longrightarrow e\nu_\tau\overline{\nu_e}$ (ν_e CC are 1.5% of ν_μ CC).

Electrons from ν_e CC

Discriminated by a 4D likelihood function mainly based on the topology in the transverse plane:

$$\mathcal{L}_{\rm CC} = [[Q_{\rm Lep}, \rho_{\rm TV}, \rho_H], p_T^m, M_T, E_{vis}]$$



Electrons and γ from Neutral Currents

- Select well measured electrons with tight identification criteria.
- Exploit the excellent performance of the detector (at signal efficiency $\sim 20\%$):
  - e^-/π^- rejection: $\mathcal{O}(10^6)$
  - e^-/π° rejection: $\mathcal{O}(10^4)$

The remaining neutral current background is rejected by a 3D likelihood function mainly based on the isolation of the candidate electron from the hadronic jet:

$$\mathcal{L}_{\rm NC} = [[[\theta_{\nu T}, \theta_{\nu H}], \theta_{\rm min}, Q_T], M_T, E^{\rm TV}]$$

Events are classified in the plane defined by the 2 likelihood functions

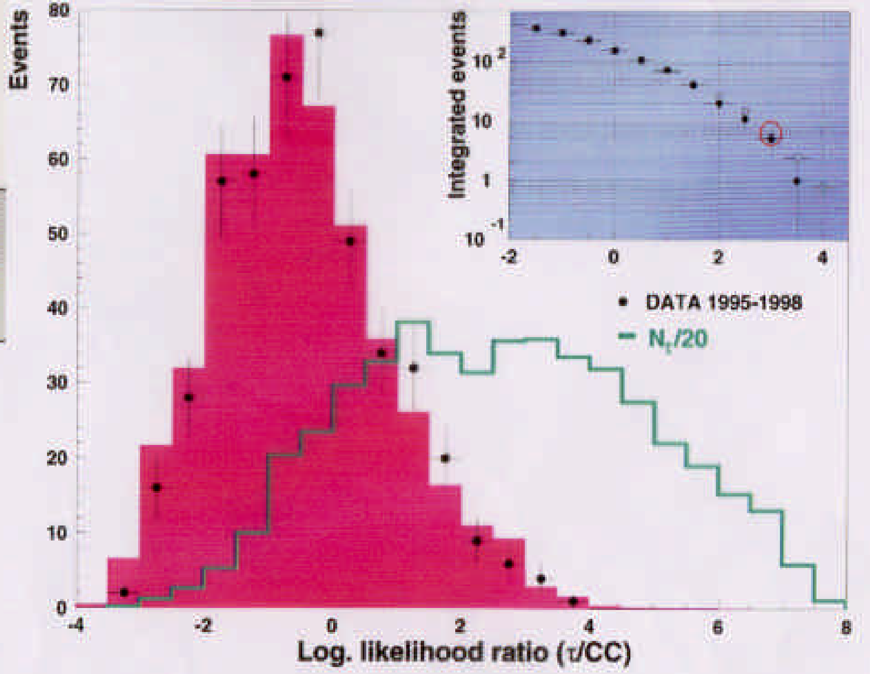
The selected (blind) region is further subdivided in 6 bins.

$\tau \to e\nu_\tau\overline{\nu_e}$, final results

Analysis	Bin #	Tot bkgnd	Data	N_τ
$\tau^- \to e^-\overline{\nu}_e\,\nu_\tau$	I	$0.85^{+0.26}_{-0.16}$	2	134
(E_{vis} > 12 GeV)	II	$0.46^{+0.23}_{-0.12}$	1	128
	III	$0.18^{+0.18}_{-0.08}$	0	639
	IV	1.85 ± 0.22	2	535
	V	0.78 ± 0.15	0	389
	VI	0.16 ± 0.08	0	1388
(E_{vis} < 12 GeV)	I+IV+V	0.77 ± 0.26	0	247
	II+III+VI	0.27 ± 0.13	0	650

$N_\tau = N_\mu/\varepsilon_\mu \times \sigma_\tau/\sigma_\mu \times \sum_i(\epsilon_i \times BR_i)$ =number of oscillated events in case of $P(\nu_\mu \to \nu_\tau) = 1$.

Very good agreement between Data and Background Monte Carlo.



$\tau \rightarrow h^-(+n\pi^0)\nu_\tau$ inclusive (B.R. = 49.5%)

A new analysis scheme that unifies the selection of the 1 prong hadronic decays.

1) τ **daughter candidate tag** maximizing

$$\lambda_{\rm cand} = \mathcal{L}^{\tau}_{\rm cand}/\mathcal{L}^{\rm random}_{\rm cand}$$

2 γ events

π° candidate $\mathcal{L}_{\pi^\circ} = [M_{\pi^\circ}, \theta_{\gamma\gamma}, E_\gamma^{max}/E_{vis}]$

ρ candidate $\mathcal{L}_\rho = [\mathcal{L}_{\pi^\circ}, M_\rho, \theta_{\pi^-\pi^\circ}, E_{\pi^\circ}/E_{vis}]$

τ daughter candidate $\mathcal{L}_{cand} = [\mathcal{L}_\rho, I_G, Y_{BJ}, \theta_{\rho H}]$

1 γ events:

ρ candidate $\mathcal{L}_\rho = [M_\rho, \theta_{\pi^-\pi^\circ}, E_{\pi^\circ}/E_{vis}]$

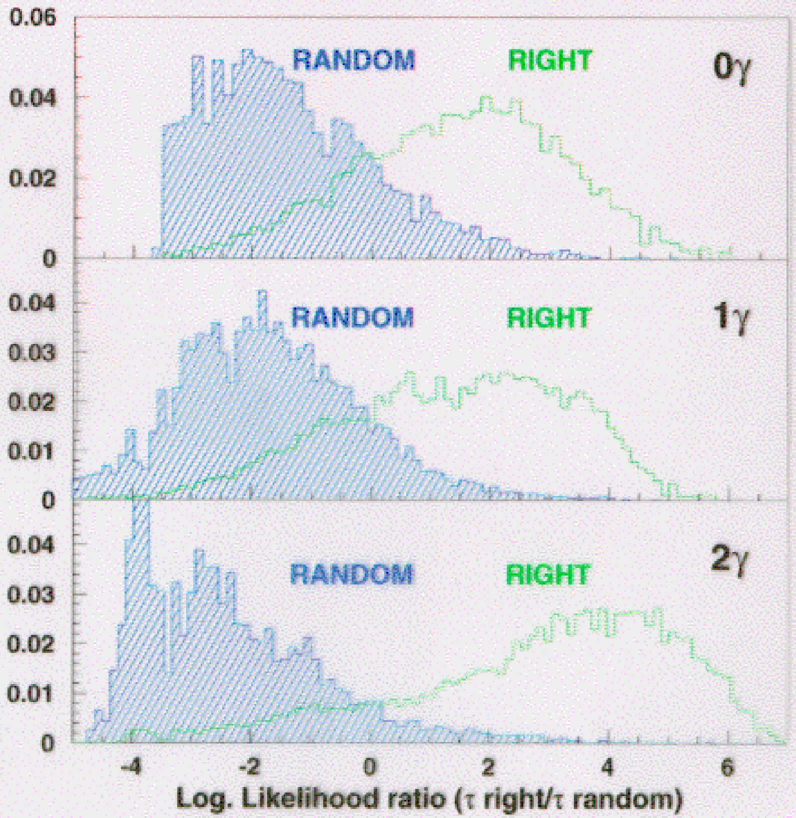
τ daughter candidate $\mathcal{L}_{cand} = [\mathcal{L}_\rho, I_G, Y_{BJ}, \theta_{\rho H}]$

A cut on $\lambda_\rho = \mathcal{L}^\tau_\rho/\mathcal{L}^{\rm BKGND}_\rho$ is subsequently made for the 1γ and 2γ topologies.

0 γ events:

τ daughter candidate $\mathcal{L}_{cand} = [I_G, Y_{BJ}, \theta_{\pi H}]$

$\mathcal{L}_{cand}$ distributions for the right and the random choices of the τ daughter in the τ MC sample.



$\tau \to h^-(+n\pi^0)\nu_\tau$ inclusive (continue)

2) Jet consistency: In the background events the choice of the candidate is mostly made inside the hadronic jet. It is essential to check the quality and structure of the remaining jet after the candidate selection.

3) Lepton Veto A three step procedure:

- No identified lepton at the primary vertex
- A most likely lepton candidate tag based on kinematical criteria.
- Tighter lepton veto criteria, based on ECAL, HCAL and μ chambers information, against the tagged lepton candidate.

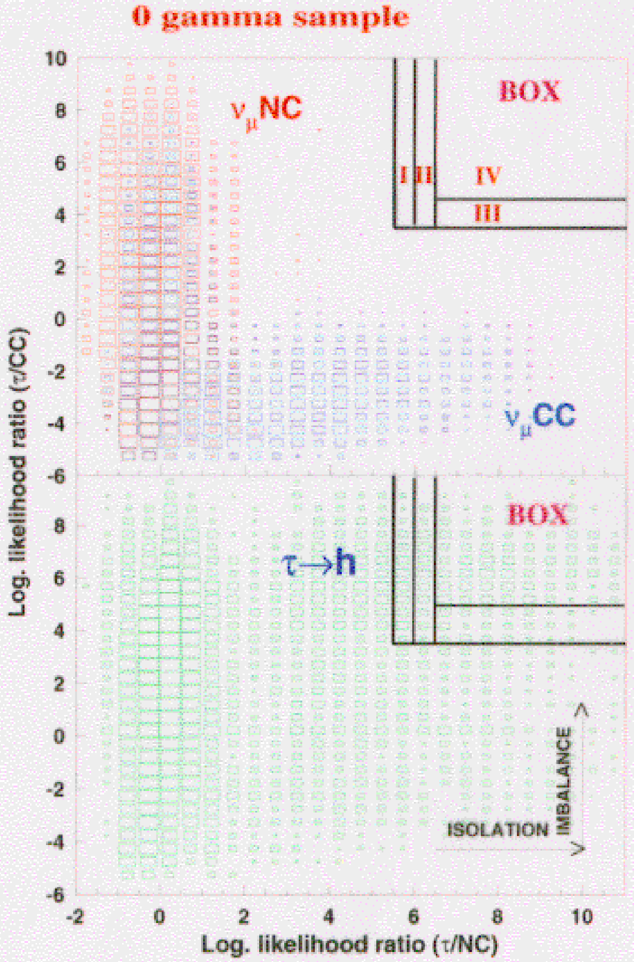
4) Final kinematical selection Two likelihood functions are built to separate signal from NC and CC events:

$$\mathcal{L}_{NC} = [[[\theta_{\nu T}, \theta_{\nu H}], \theta_{min}, Q_T], p_T^m, p_T^H]$$

$$\mathcal{L}_{CC} = [[I_G, P_T^{lep}/p_T^m, \theta_{\nu,lep}], p_T^m, M_T, E_{vis}]$$

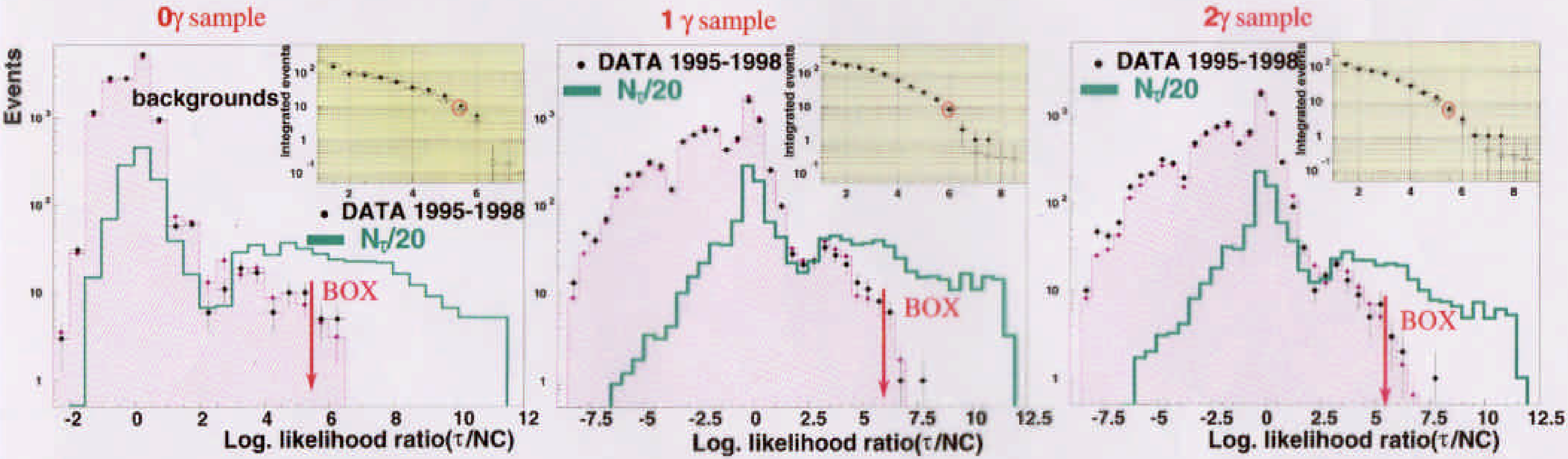
Again the event candidate selection is made in the plane defined by the 2 likelihood functions

$\tau \to h^-(+n\pi^0)\nu_\tau$ inclusive, final results

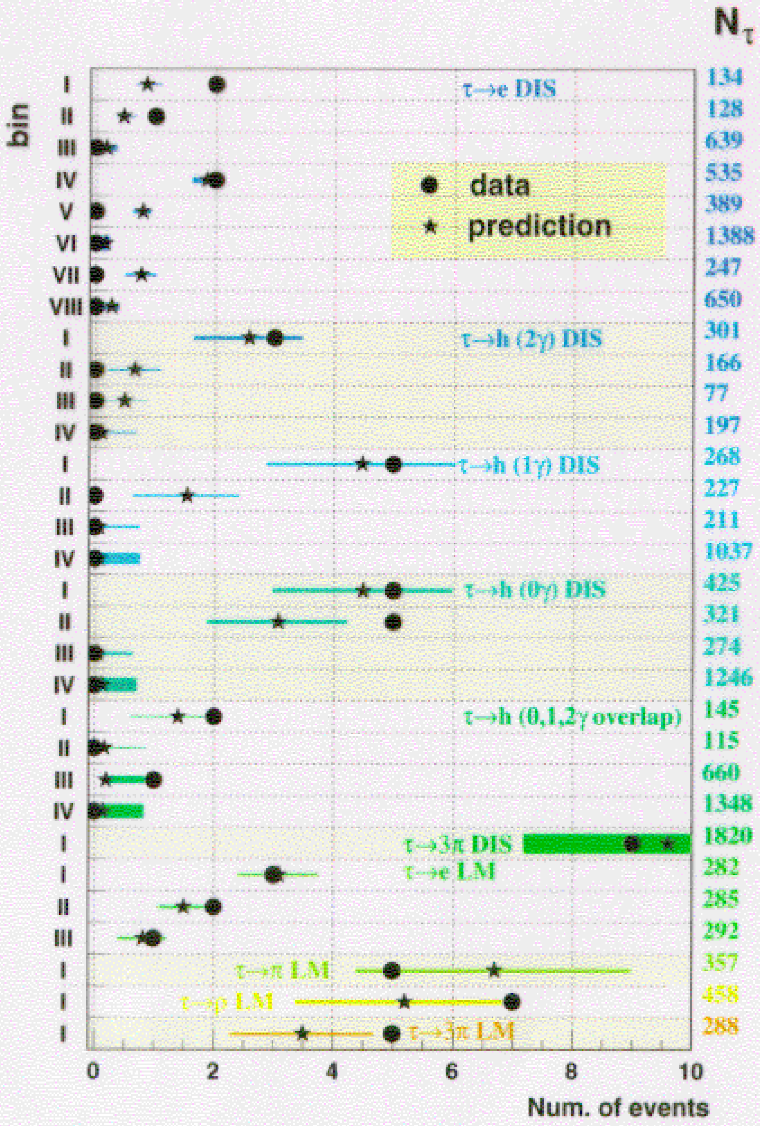


Analysis	Bin	Tot. bkg.	Data	N_τ
$\nu_\tau h(0\gamma)$	I	4.49 ± 1.50	5	425
$\nu_\tau h(0\gamma)$	II	3.07 ± 1.17	5	321
$\nu_\tau h(0\gamma)$	III	$0.05^{+0.60}_{-0.03}$	0	274
$\nu_\tau h(0\gamma)$	IV	$0.12^{+0.60}_{-0.05}$	0	1246
$\nu_\tau h(1\gamma)$	I	4.47 ± 1.58	5	268
$\nu_\tau h(1\gamma)$	II	1.54 ± 0.89	0	227
$\nu_\tau h(1\gamma)$	III	$0.07^{+0.70}_{-0.04}$	0	211
$\nu_\tau h(1\gamma)$	IV	$0.07^{+0.70}_{-0.04}$	0	1037
$\nu_\tau h(2\gamma)$	I	2.57 ± 0.91	3	301
$\nu_\tau h(2\gamma)$	II	0.66 ± 0.44	0	166
$\nu_\tau h(2\gamma)$	III	0.49 ± 0.40	0	77
$\nu_\tau h(2\gamma)$	IV	$0.11^{+0.06}_{-0.63}$	0	197
$\nu_\tau h(\text{overlap})$	I	1.40 ± 0.77	2	145
$\nu_\tau h(\text{overlap})$	II	$0.17^{+.70}_{-0.08}$	0	115
$\nu_\tau h(\text{overlap})$	III	$0.20^{+0.70}_{-0.06}$	1	660
$\nu_\tau h(\text{overlap})$	IV	$0.14^{+0.70}_{-0.06}$	0	1348

Data and MonteCarlo agreement: $\mathcal{L}_{NC}$ distributions



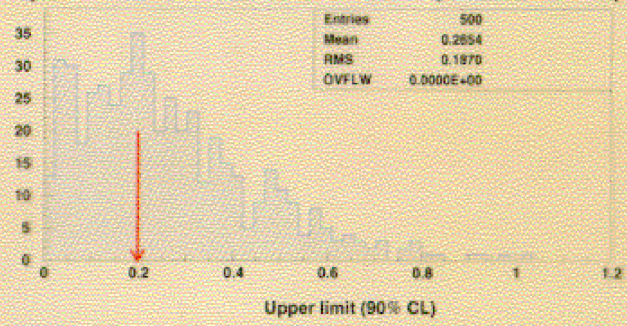
Final results, no evidence for oscillation



FINAL LIMIT ON P($\nu_\mu \to \nu_\tau$): $2.03 \cdot 10^{-4}$

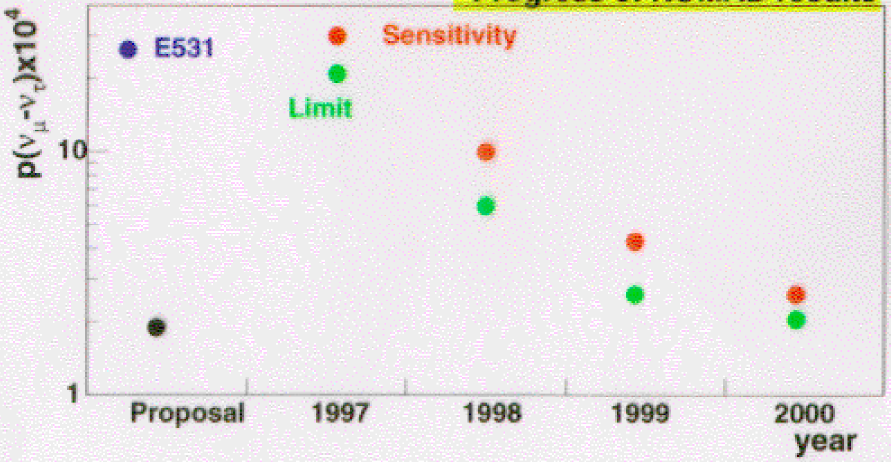
FINAL SENSITIVITY ON P($\nu_\mu \to \nu_\tau$): $2.6 \cdot 10^{-4}$

Probability to obtain this limit (or smaller): 46%



55.2 ± 5.4 expected events, 58 found. Total N_τ = 14937

Progress of NOMAD results



NOMAD as a ZERO background experiment

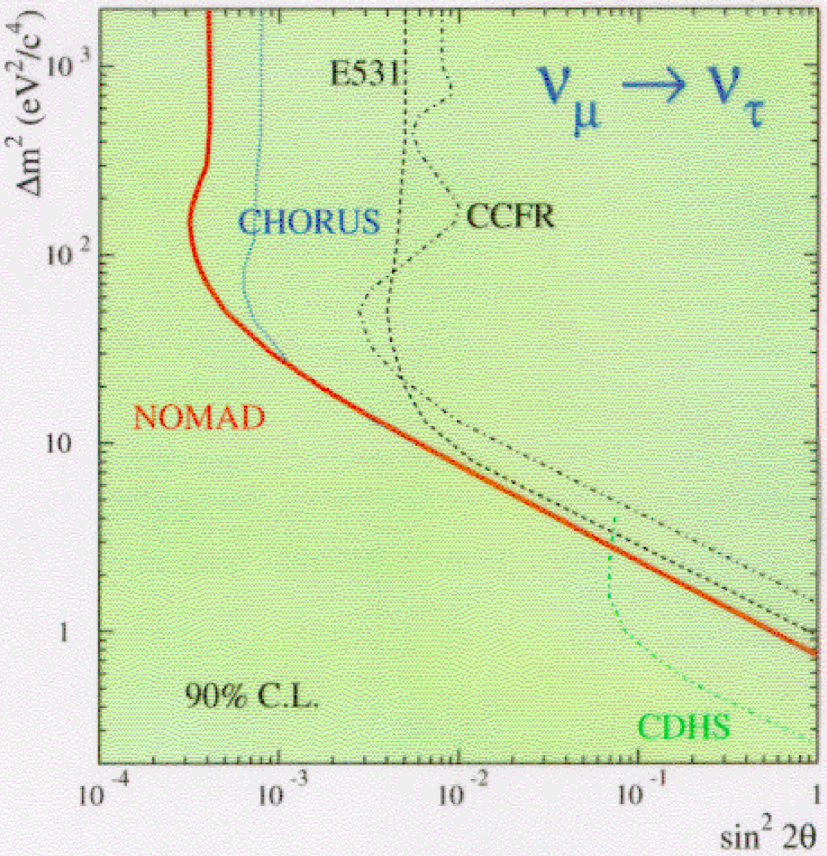
Most of the NOMAD sensitivity is in the bins with a background prediction close to zero:

Analysis		Bin	Tot. bkg.	N_τ	Data
$\nu_\tau \bar{\nu}_e e$	DIS	III	$0.28^{+0.31}_{-0.09}$	903	0
$\nu_\tau \bar{\nu}_e e$	DIS	VI	0.25 ± 0.09	1694	0
$\nu_\tau h(0\gamma)$	DIS	III	$0.05^{+0.60}_{-0.03}$	274	0
$\nu_\tau h(0\gamma)$	DIS	IV	$0.12^{+0.60}_{-0.05}$	1246	0
$\nu_\tau h(1\gamma)$	DIS	III	$0.07^{+0.70}_{-0.04}$	211	0
$\nu_\tau h(1\gamma)$	DIS	IV	$0.07^{+0.70}_{-0.04}$	1037	0
$\nu_\tau h(2\gamma)$	DIS	IV	$0.11^{+0.60}_{-0.06}$	197	0
$\nu_\tau h(\text{overl.})$	DIS	III	$0.20^{+0.70}_{-0.06}$	660	1
$\nu_\tau h(\text{overl.})$	DIS	IV	$0.14^{+0.70}_{-0.06}$	1348	0
			$\mathbf{1.29^{+1.60}_{-0.18}}$	**7570**	1

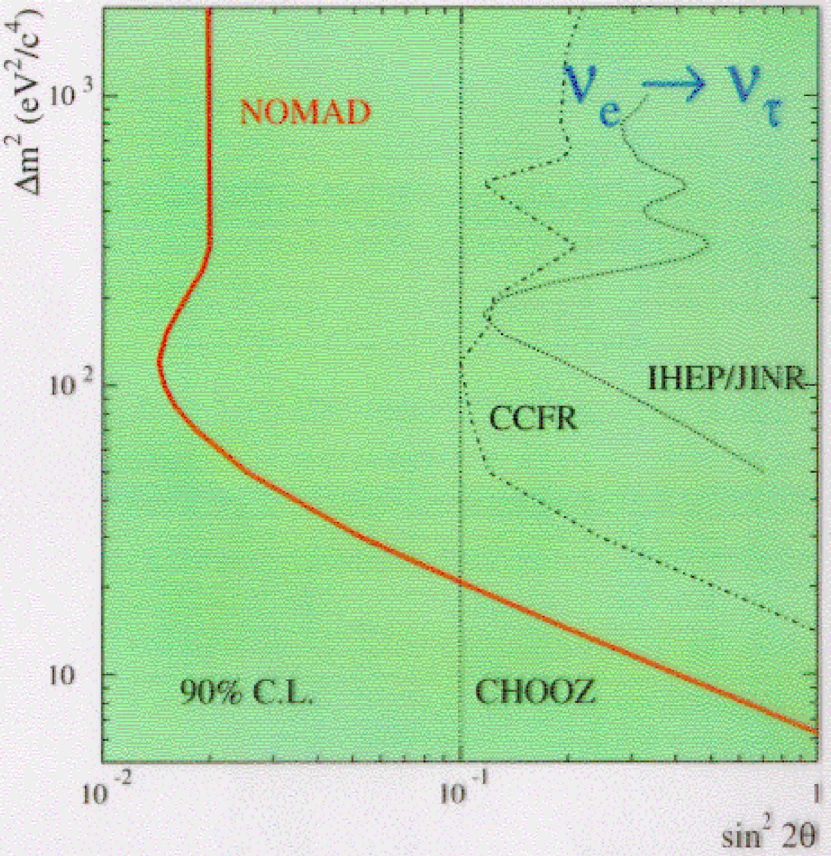
75% of the final sensitivity comes from the low background bins

NOMAD exclusion plots (preliminary)

Still room for progress, i.e. $\tau \rightarrow \nu_\tau\ 3\pi$ DIS analysis.



$P(\nu_\mu \rightarrow \nu_\tau) \leq 2.03 \cdot 10^{-4}$, sensitivity : $2.6 \cdot 10^{-4}$



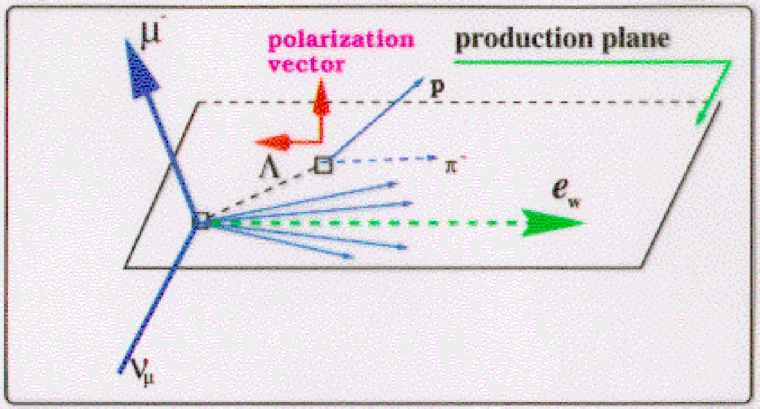
Computed with the proper ν_e flux, 100 times smaller than the ν_μ flux.

$P(\nu_e \rightarrow \nu_\tau) \leq 1.00 \cdot 10^{-2}$, sensitivity: $1.3 \cdot 10^{-2}$

Status of the ν_μ -ν_e oscillation search

- The beam ν_e contamination in the interesting region for oscillations is $\sim 1\%$
- Nomad has a sample of ~ 7000 identified ν_e CC events with a background contamination of a few %. The limiting factor is the systematic uncertainty of the ν_e component of the beam and of the event reconstruction. For a sensitivity of $0.5 \cdot 10^{-3}$ on $P(\nu_\mu \rightarrow \nu_e)$ or better the overall systematic uncertainty must be smaller than $\sim 7\%$.
- Two complementary methods of predicting the ν_e component of the beam which is due to K^+, K^0_L and μ decays:
  - Conventional MonteCarlo simulation from the primary proton interaction to the final neutrino flux in NOMAD.This relies on the particle production cross sections input into the Monte Carlo and suitably modified to agree with the measurements of SPY.
  - Empirical parametrization of the particle production cross sections using ν_μ , $\overline{\nu}_\mu$, $\overline{\nu}_e$ (not ν_e !) data of NOMAD and the π/K measurements of SPY experiment at SPS.
- We have achieved significant improvements in the following areas:
  - Description of the secondary meson production using Fluka Standalone + SPY reweighting.
  - Precise description of the shape of the proton beam and of the primary interactions downstream the target.
  - Accurate description of the beam transport and of the material along the beam.
  - Detailed description of the magnetic field in the Horn and the Reflector conductors.
- We decided to do a BLIND analysis. The control samples are ν_μ CC spectrum, the $\overline{\nu}_\mu$ and $\overline{\nu}_e$ CC rates and spectra in the neutrino beam as well as the $\overline{\nu}_\mu$ CC spectrum and ν_μ CC rate and spectrum in separate antineutrino beam run.
- We need a few more checks before opening the box.

Measurement of Λ polarization in $\nu_\mu N \to \mu^- \Lambda X$



NOMAD observed both

longitudinal polarization

along the exchanged W-boson direction

related to:

polarized nucleon strangeness

- $P_x(x_F < 0) = -0.21 \pm 0.04 \pm 0.02$

spin transfer mechanism

- $P_x(x_F > 0) = -0.09 \pm 0.06 \pm 0.03$

transverse polarization

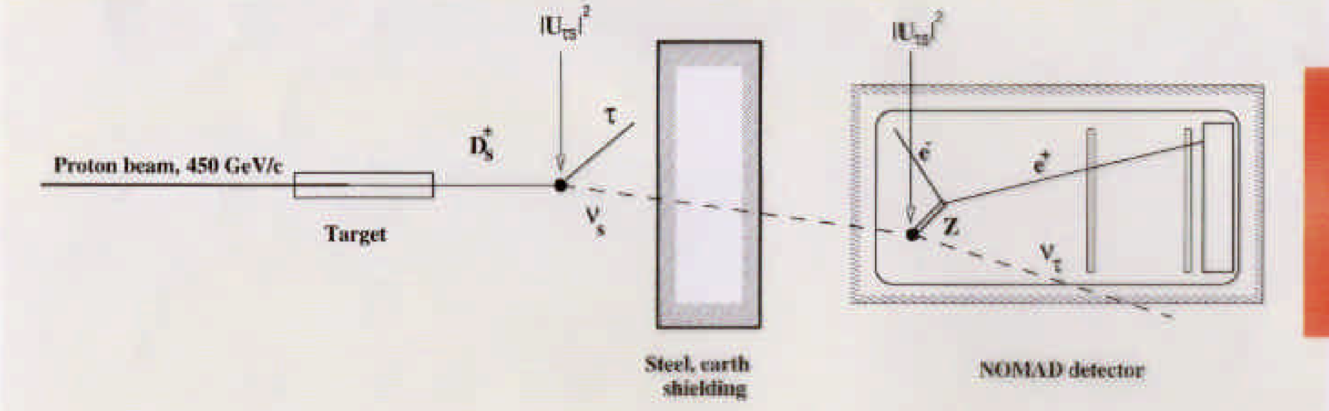
orthogonal to the Λ production plane

- observed for the first time in νN DIS: $P_y = -0.22 \pm 0.03 \pm 0.01$
- similar behaviour as in unpolarized hadron-hadron

for details see the corresponding NOMAD poster

Search for heavy neutrino mixing to the tau neutrino

This search is performed for the first time for the heavy neutrino mass [illegible] ≤ 200 MeV.



For details see the corresponding NOMAD poster

NOMAD limit on the lifetime of heavy neutrino with

$m = 33.9\ MeV/c^2$.