RESULTS FROM NOMAD

ν_μ NOMAD ν_τ

Neutrino Oscillation MAgnetic Detector

Alberto Marchionni

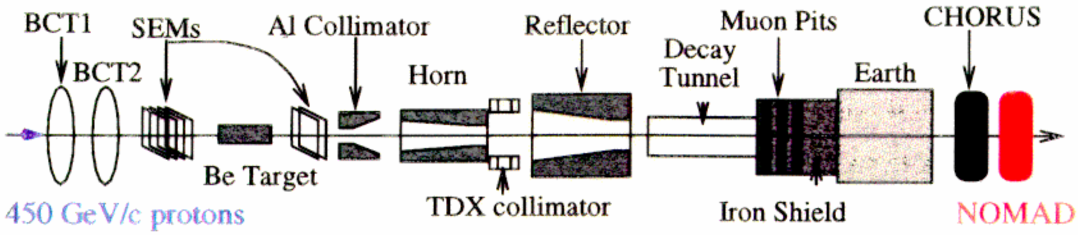
Istituto Nazionale di Fisica Nucleare, Sezione di Firenze

for the NOMAD Collaboration:

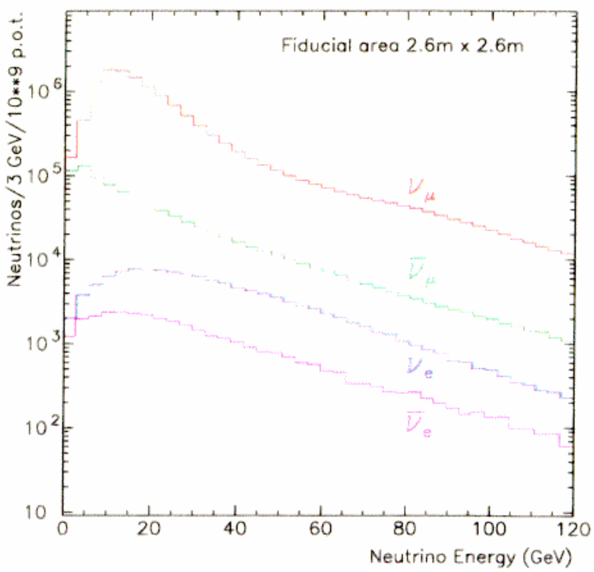
LAPP Annecy, CERN, Cosenza, Dortmund, ETH Zurich, JINR Dubna, Florence, Harvard, Johns Hopkins, Lausanne, Melbourne, INR Moscow, Padova, Paris VI and VII, Pavia, Pisa, Rome III, CEN Saclay, Sydney ANSTO, Sydney Univ., UCLA, Urbino, Zagreb

XXVI SLAC Summer Institute on Particle Physics
August 3-14, 1998

The CERN Neutrino Beam



- NOMAD detector: 835 m from the target
- distance ν source - detector: $\langle L \rangle = 620$ m



	Flux		CC interactions	
Neutrino	$\langle E_\nu \rangle [GeV]$	rel. abund.	$\langle E_\nu \rangle [GeV]$	rel. abund.
ν_μ	23.6	1.0	44.1	1.0
$\overline{\nu_\mu}$	18.4	0.055	40.6	0.021
ν_e	37.5	0.009	56.6	0.015
$\overline{\nu_e}$	30.3	0.0025	50.7	0.0016
ν_τ	~ 35			$\simeq 5 \times 10^{-6}$

Why NOMAD ?

- An experiment to detect ν_τ CC interactions through different τ decay channels

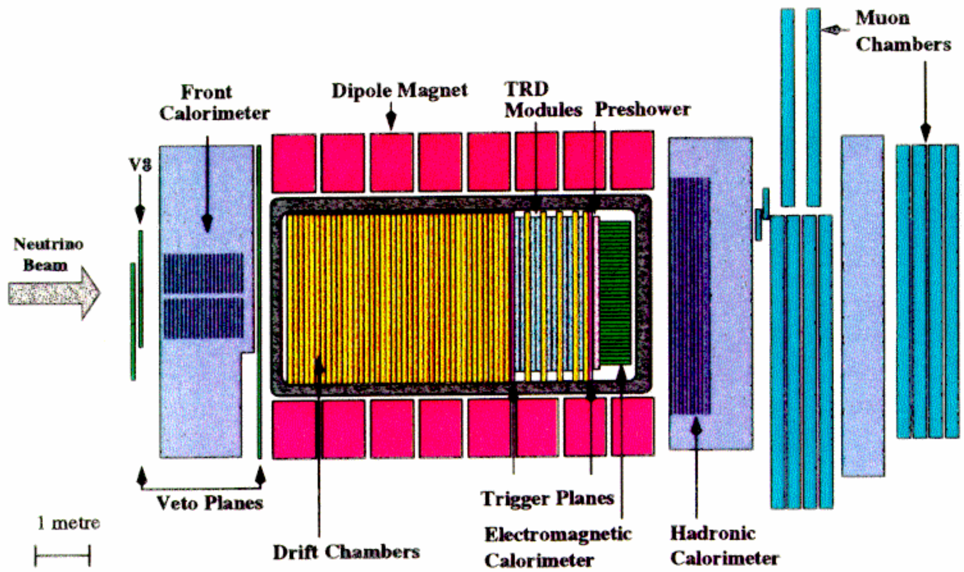
Detectable τ decay modes	BR
$\tau^- \rightarrow e^- \nu_\tau \overline{\nu}_e$	17.8%
$\tau \rightarrow h^-(+n\pi^0)\nu_\tau$	49.8%
$\tau^- \rightarrow \pi^- \pi^- \pi^+ (n\pi^0)\nu_\tau$	14.9%
Total	82.5%

- Discriminate ν_τ CC interactions from $\nu_e(\nu_\mu)$ CC and ν NC interactions by means of a detailed kinematical reconstruction of the event

- A detector with the following capabilities:
  - precise measurement of charged particles
  - good identification of electrons and muons
  - accurate measurement of electromagnetic showers
  - detection of neutral hadrons

- An experiment sensitive to the cosmologically relevant mass range
  $\langle \mathrm{L/E} \rangle_{\nu_\mu} = 1.4 \times 10^{-2}$ Km/GeV $\Longrightarrow$ maximum sensitivity for $\Delta \mathrm{m}^2 \simeq 90$ eV^2

NOMAD Detector



- Drift Chambers (target and momentum measurement)

  $44 + 5$ DC (each 2% X_0). Total fiducial mass of 2.7 tons with an average density of 0.1 g/cm^3

  Momentum resolution $\sim 3.5\%$ ($p < 10$ GeV/c)

- Transition Radiation Detector (TRD) for $e^{\pm}$ identification

  9 modules (polypropylene radiator followed by a plane of straw tubes)

  π rejection $\simeq 10^3$ @ $\varepsilon(e) \geq 90\%$ for isolated tracks in a momentum range from 1 to 50 GeV/c

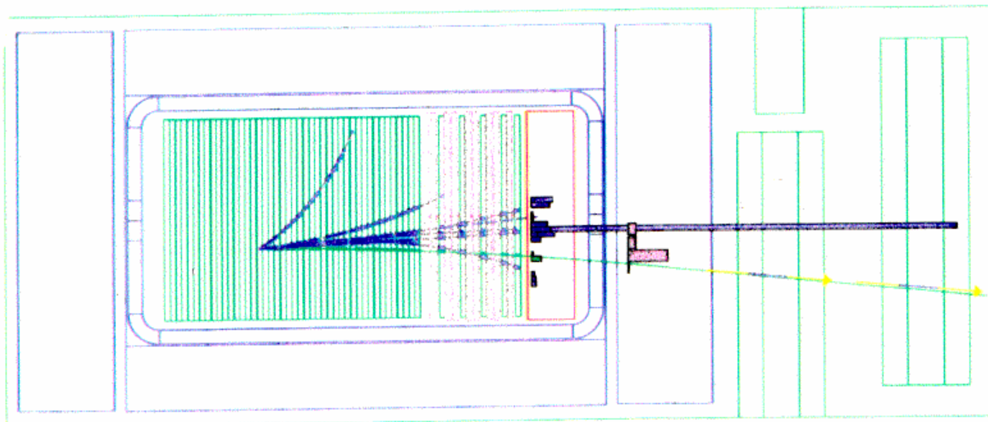
- Lead glass Electromagnetic Calorimeter

  $\sigma(E)/E = 3.2\%/\sqrt{E(GeV)} \oplus 1\%$

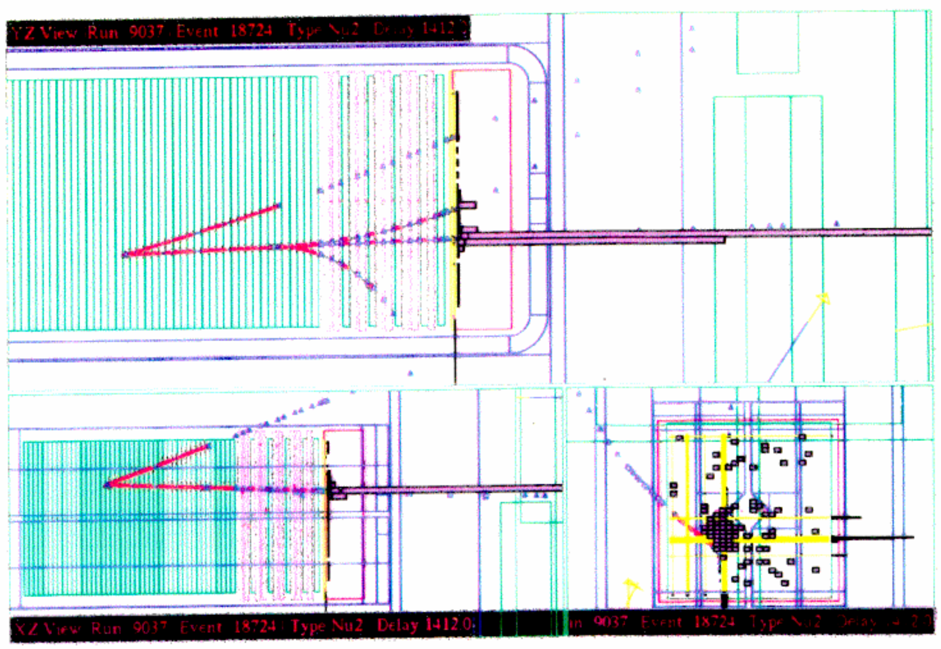
- Muon Chambers

  $\varepsilon \approx 97\%$ for $p_\mu > 5$ GeV/c

ν_μ CC candidate (run 8744, event 228)



ν_e CC candidate (run 9037, event 18724)

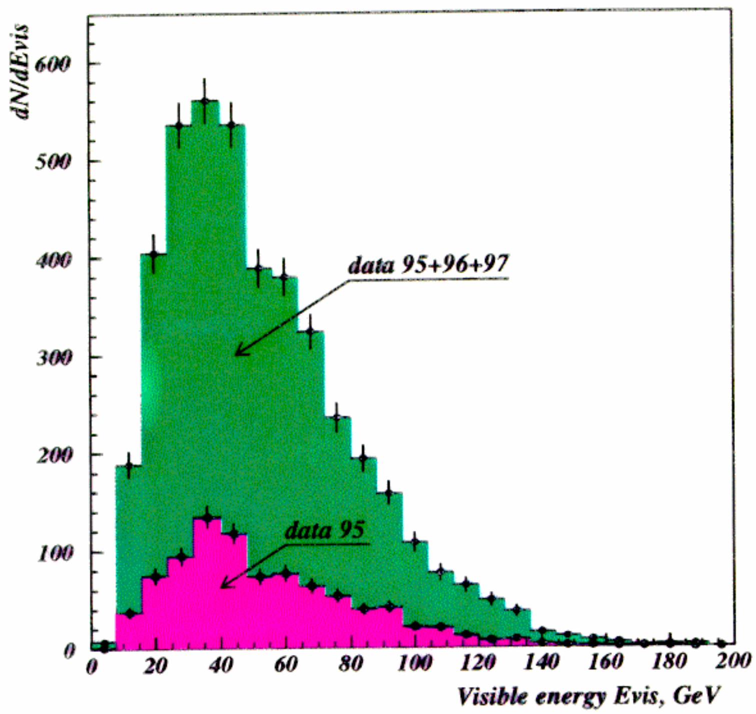


Search for $\nu_\mu \rightarrow \nu_e$ oscillations

- NOMAD is sensitive to $\nu_\mu \rightarrow \nu_e$ oscillations through the measurement of $R_{e\mu}$:

$$R_{e\mu} = \frac{(\nu_e CC/\nu_\mu CC)_{data}}{(\nu_e CC/\nu_\mu CC)_{expected}}$$

Spectrum of ν_eCC in NOMAD

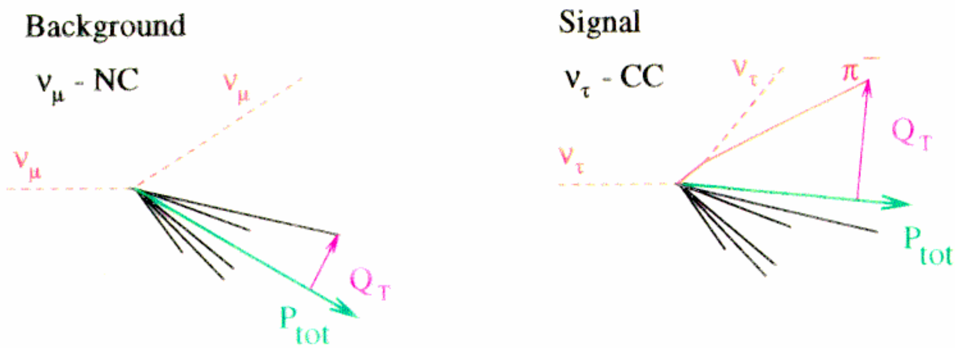


- Working to accurately evaluate the systematic error on $(\nu_e CC/\nu_\mu CC)_{expected}$, due to the uncertainty on the knowledge of the neutrino beam composition (include SPY results on the measurement of the K/π ratio in p-Be interactions)

- The analysis of the full 1995+96+97 data is not completed yet

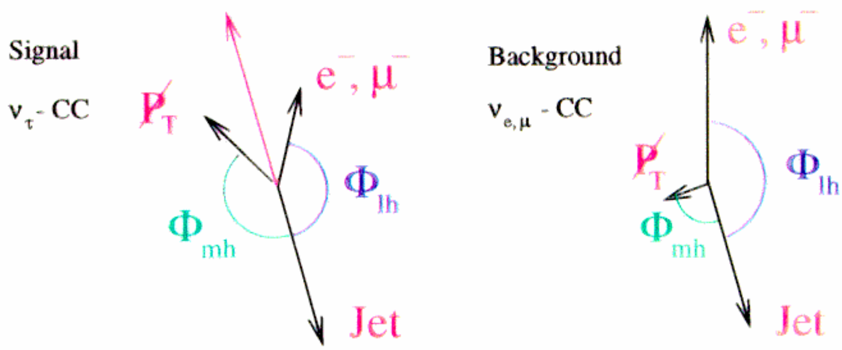
ν_τ identification criteria

- Isolation of τ decay products from the hadronic jet



Q_T = component of the momentum of visible τ decay products perpendicular to the total visible momentum vector

- Kinematical configuration in the plane perpendicular to the incoming ν direction



- amount of imbalance

  magnitude of the missing transverse momentum $\not{p}_T$

- direction of imbalance

  angle ϕ_{lh}

  angle ϕ_{mh}

- transverse mass $M_T = \sqrt{(|\,\vec{\not{p}}_T\,| + |\,\vec{p}_T^{\,l}\,|)^2 - (\vec{p}_T^{\,Jet})^2}$

The Likelihood technique

- These and other variables can be used to separate the signal from the background
- Each variable X_i provides some degree of separation
- Optimize the analysis by building probability density functions for the signal and the background, approximated by the product of the probability density functions of the set $X_{i=1,N}$ of variables used

$$L = \prod_{i=1}^{N} P(X_i)$$

where $P(X_i)$ can be one or n-dimensional probability density functions

- Use the Likelihood ratio L_R (or the log of this ratio) to discriminate between signal and background

$$L_R = \frac{L_{Signal}}{L_{Background}}$$

$\tau^- \to e^- \nu_\tau \overline{\nu}_e$ channel

1. Data samples

Year	ν_μ CC
95	180,000
96	380,000
97	382,000
Total 95-97	942,000

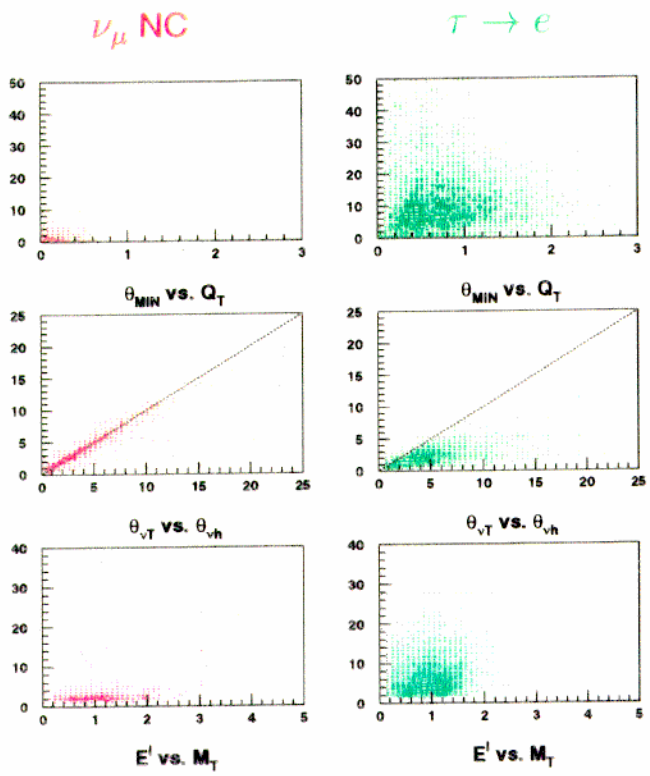
2. Selection of the electron candidate

- Only 1 prompt electron in the event
  * emerging from the primary vertex ($\Delta z < 15$ cm)
  * identified by TRD, preshower and electromagnetic calorimeter
- $E_{electron} > 1.5$ GeV
- Not consistent with a conversion

  invariant mass between e^- candidate and any positive track

  $M(e^-, +) > 50$ MeV

3. Rejection of NC interactions



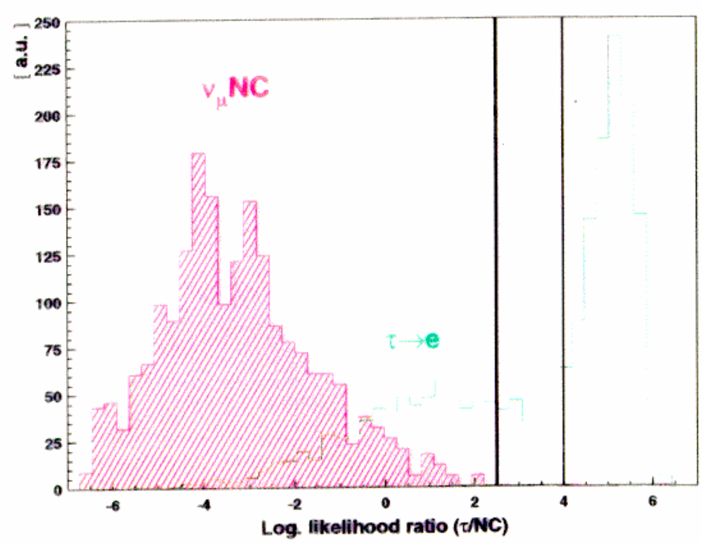
θ_{MIN}: minimum angle between $\vec{p}_{ele}$ and any $\vec{p}_h$ of the hadronic system

$\theta_{\nu T}$: angle between the incident ν direction and the total momentum of the event

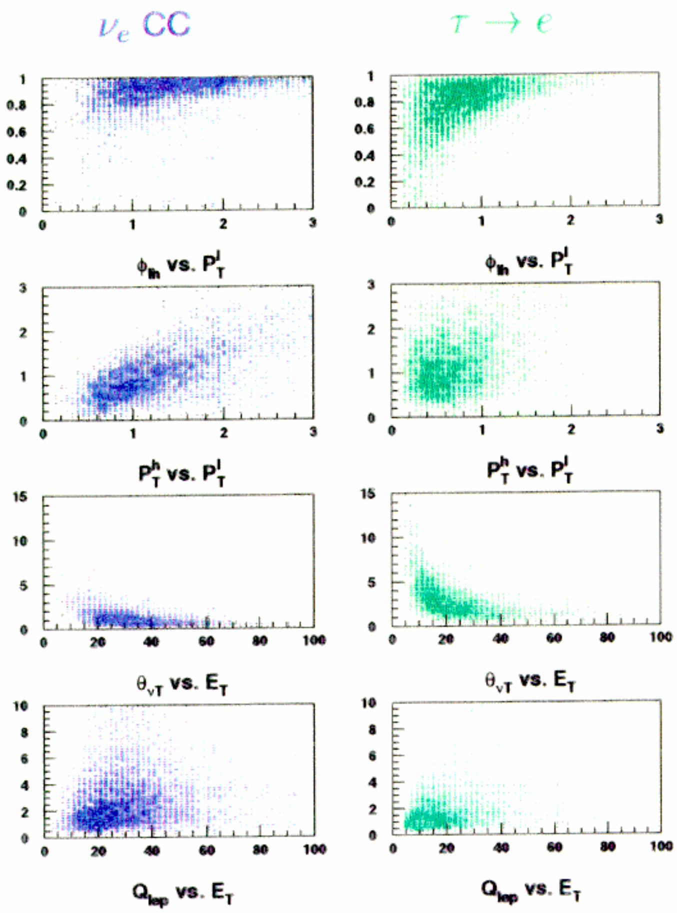
$\theta_{\nu h}$: angle between the incident ν direction and the total hadron momentum

E^l: electron energy

$$L(\tau/\nu NC) = [[[\theta_{\nu T}, \theta_{\nu h}], \theta_{MIN}, Q_T], E^l, m_T]$$



4. Rejection of ν_e CC interactions



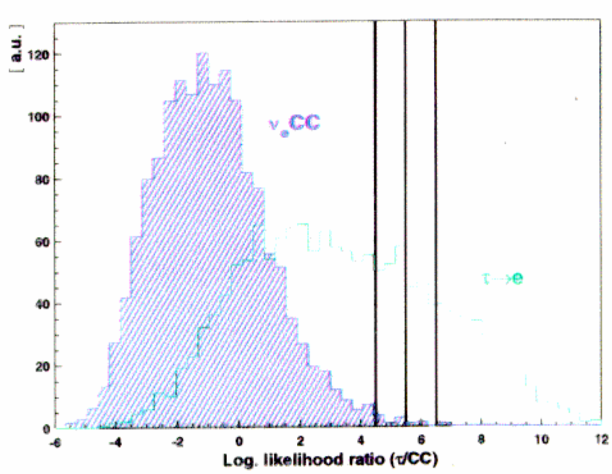
P^l_T: electron transverse momentum

P^h_T: hadronic jet transverse momentum

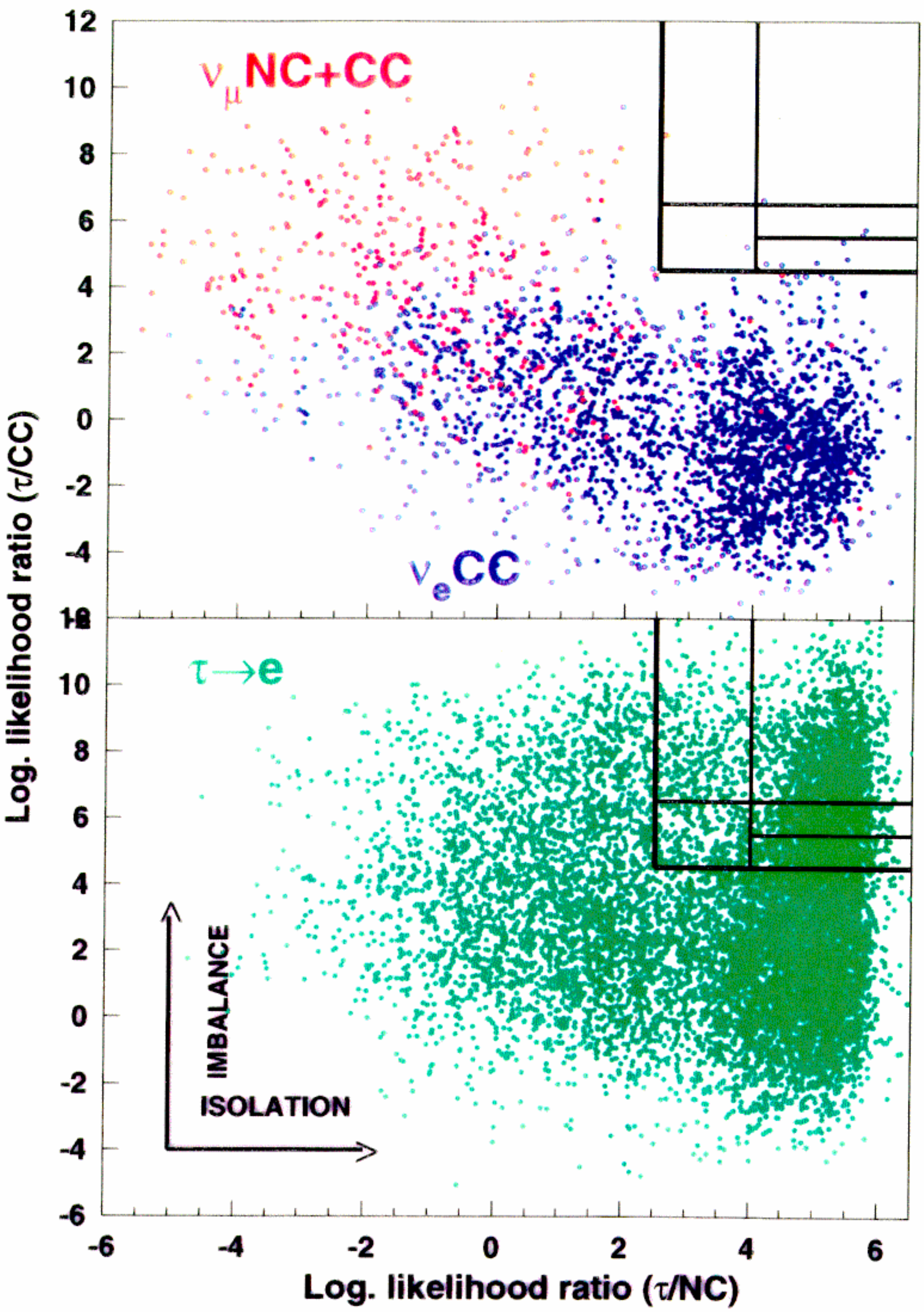
E_T: total visible energy in the event

Q_{lep}: electron momentum component perpendicular to the hadronic jet momentum

$$L(\tau/\nu_e CC) = [p^l_T, p^h_T, \phi_{lh}][E_T, \theta_{\nu T}, Q_{lep}]$$



5. Definition of the 'signal region'

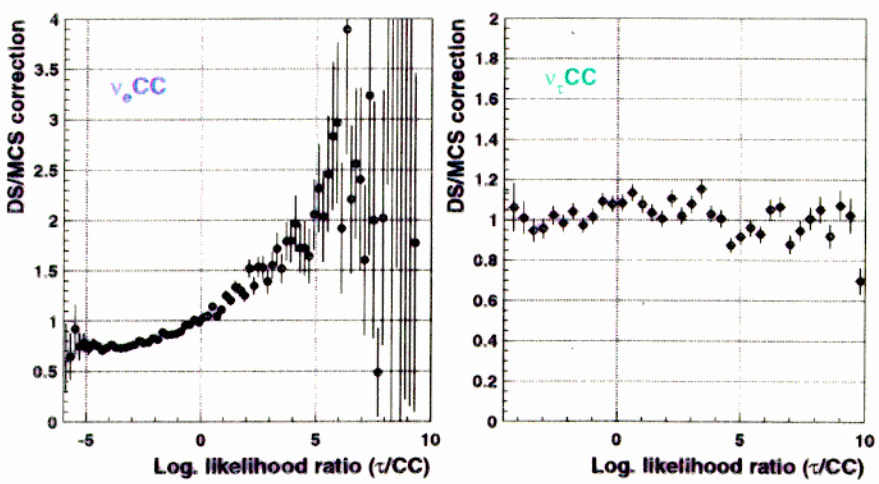


6. Data simulator corrections

- Use the data itself to compute efficiencies for cuts involving the hadronic system
- The Data Simulator:

  start from a measured ν_μ CC event, remove the identified muon and replace it by another lepton (tau, electron,ν)
- Signal and background efficiencies (except for ν_μ CC events), are obtained through the formula

$$\epsilon = \epsilon_{MC} \times \frac{\epsilon_{DS}}{\epsilon_{MCS}}$$



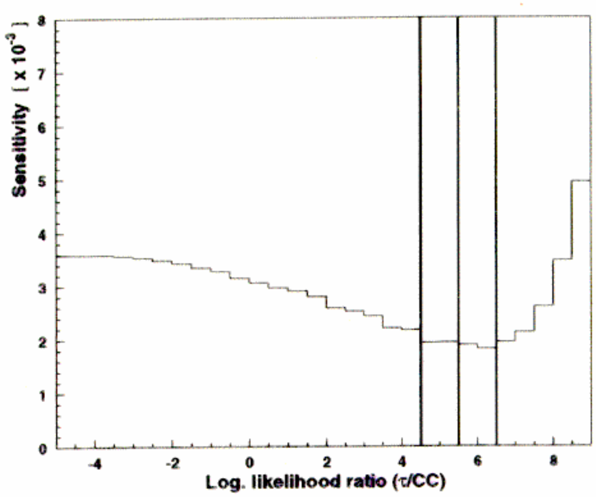
7. A blind analysis method

– In order to avoid biases

$\Longrightarrow$ do not look at the data in the signal box before a full understanding of the sensitivity of the analysis based on MC and Data Simulator

– Compute the sensitivity to choose the signal box

'The sensitivity is defined as the average upper limit one would get from an ensemble of experiments with the expected background and no true signal' , from G.J.Feldman and R.D.Cousins Phys. Rev. D 57 (1998) 3873.



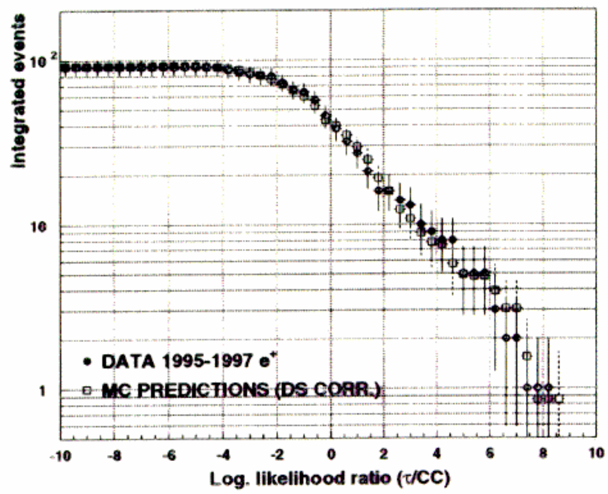
– Make sure to be able to predict the background in the signal box $(L(\tau/\nu NC) > 2.5, L(\tau/\nu_e CC) > 4.5)$

Survival fraction from MC					
e^+ sample			e^- sample		
ν_μ CC	ν NC	$\overline{\nu}_e$ CC	ν_μ CC	ν NC	ν_e CC
2.8×10^{-6}	2.1×10^{-6}	3.6×10^{-4}	$< 4 \times 10^{-7}$	$< 1 \times 10^{-6}$	2.3×10^{-4}

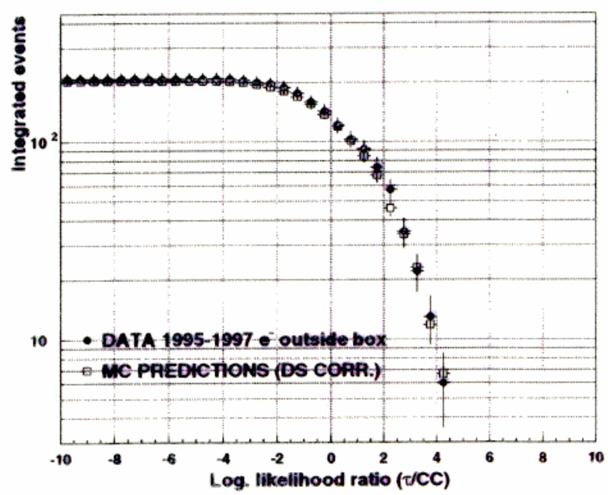
Background and efficiencies DS corrected			
ν NC + ν_μ CC bkgrnd	ν_e CC bkgrnd	ϵ_τ	N_τ
$0^{+0.4}$	6.6 ± 0.8	$4.1 \pm 0.3\%$	2904

$N_\tau = N_\mu \times (\sigma_\tau/\sigma_\mu) \times B_T \times \epsilon_\tau$

- Show good agreement between MC and data for
  - the positive data (τ^+ search), where no signal is expected in NOMAD

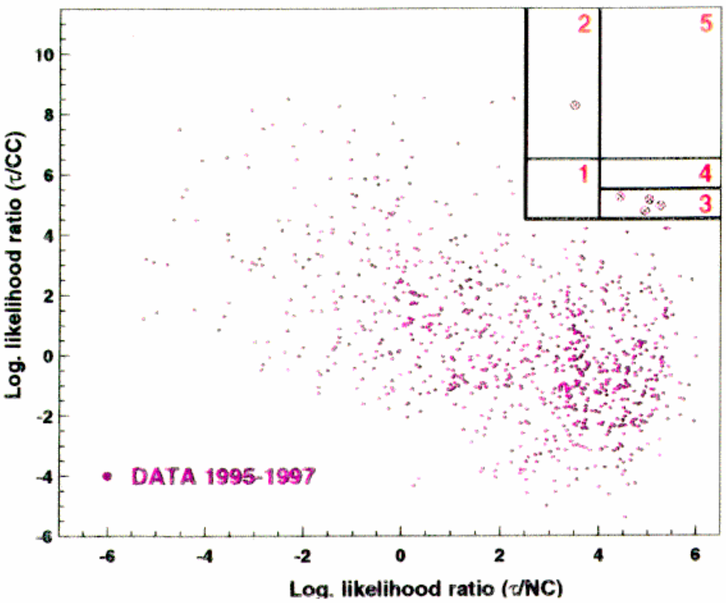


  - the data outside the 'signal box'



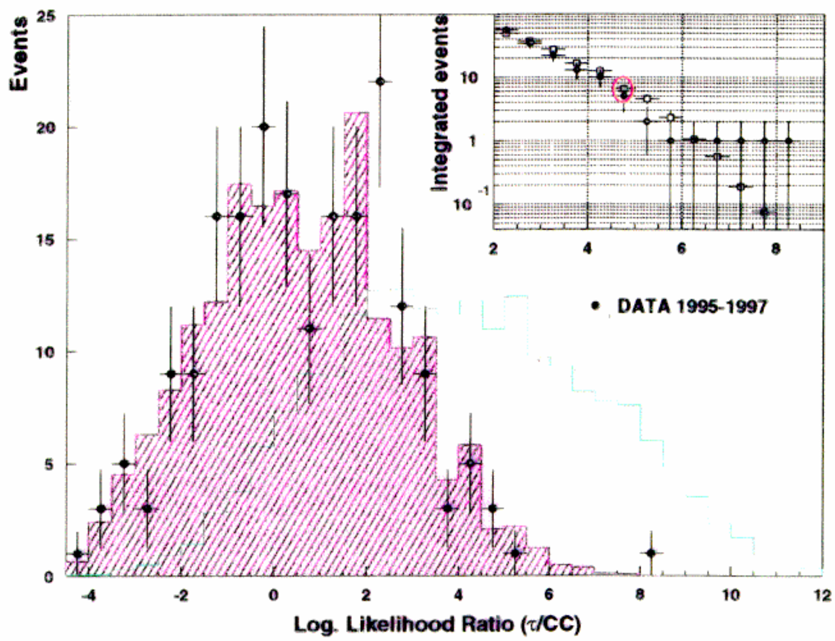
- then OPEN THE BOX

8. Box opening



Bin	N_τ	Exp. Bkgnd	Data
1	240	1.52 ± 0.38	0
2	273	0.23 ± 0.16	1
3	646	3.10 ± 0.57	4
4	543	1.31 ± 0.40	0
5	1202	0.46 ± 0.27	0
Tot	2904	6.6 ± 0.8	5

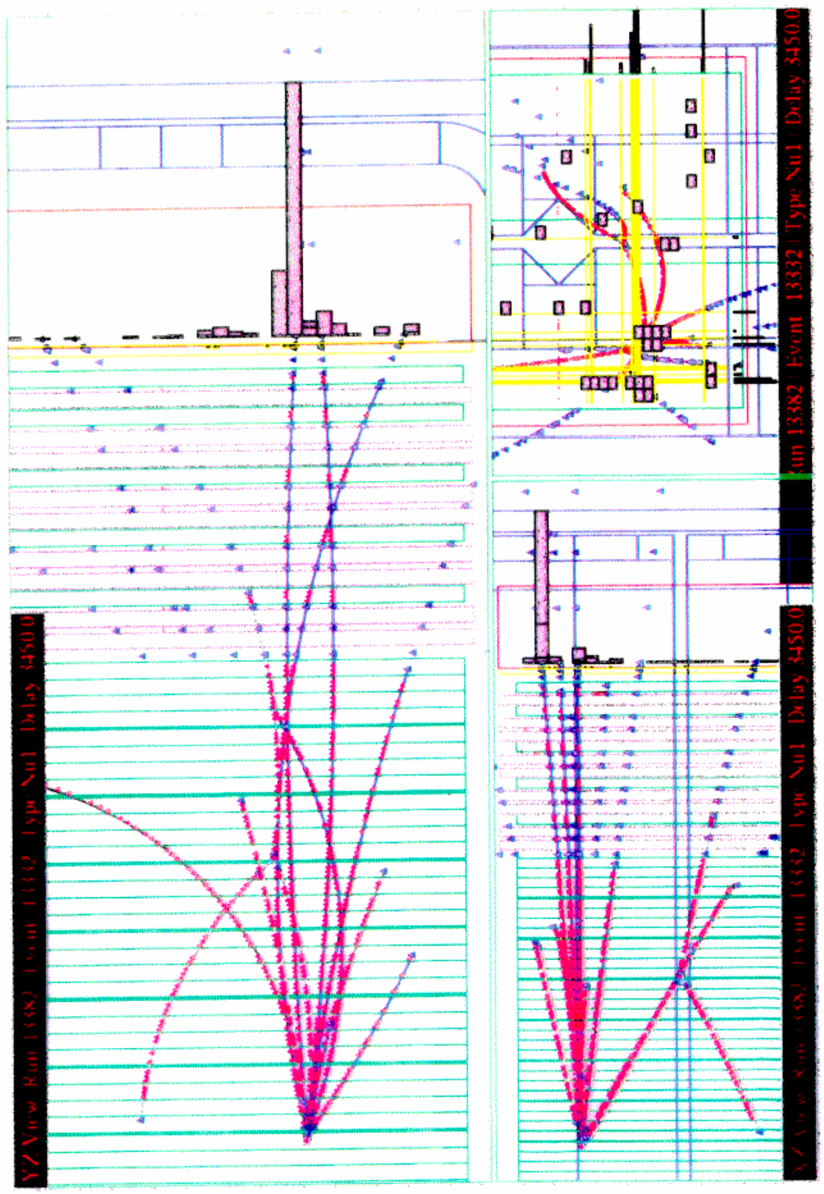
No evidence for oscillation



9. Example of a $\tau^- \to e^- \nu_\tau \overline{\nu}_e$ candidate

Run 13382, Event 13332

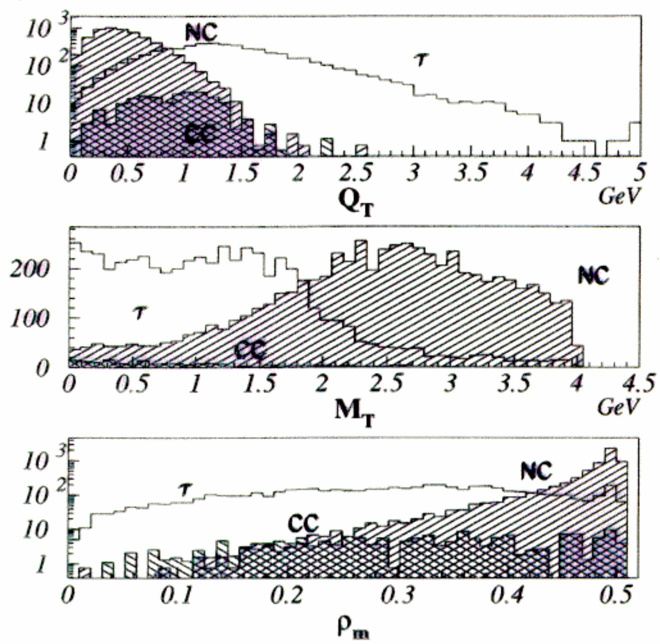
$$L(\tau/\nu NC) = 3.5,\ L(\tau/\nu_e CC) = 8.1$$



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

1. Data sample: 95-97 data
2. Selection of the π^- candidate
   - No identified muons in the event
   - No negative primary track with $p_T > 0.8$ outside the acceptance region of the μ-chambers
   - No primary electron in the event
   - Select π candidate as the highest or second highest p_T track in the event
3. Rejection of NC+CC backgrounds

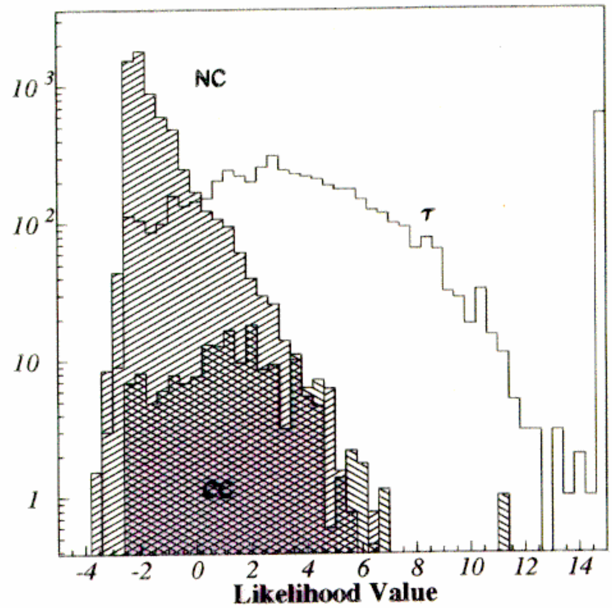
   $M_T < 4$ GeV, $p_T^{had} > 1.3$ GeV

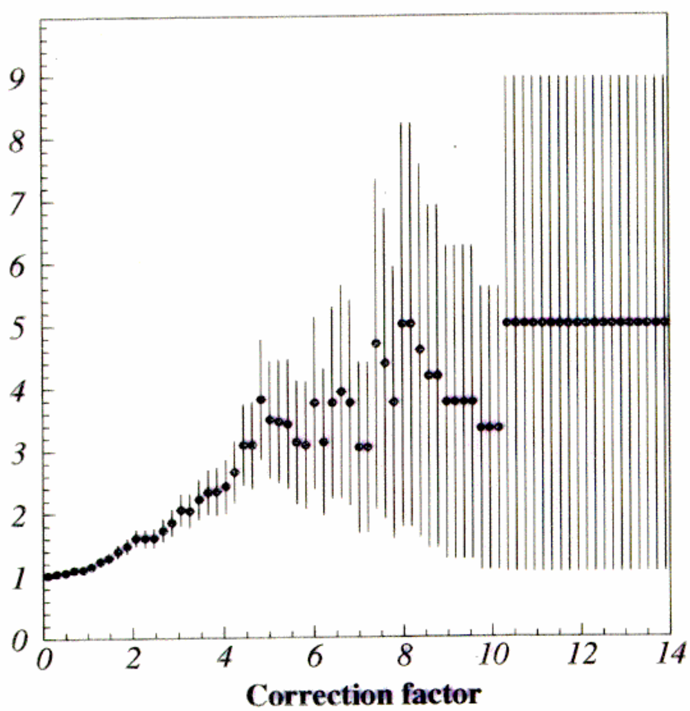


$$\rho_m = \frac{|\vec{\not p}_T|}{(|\vec{p}_T^{\,\pi}| + |\vec{p}_T^{\,had}| + |\vec{\not p}_T|)}$$

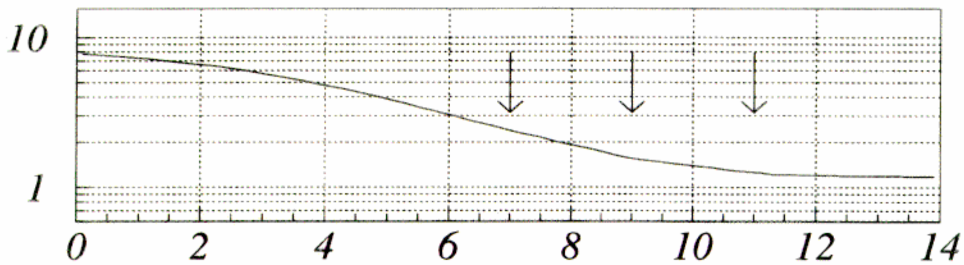
4. Likelihood and Data Simulator corrections

$$L = ([Q_T, M_T, \rho_m], \frac{p^{\pi}}{E_{vis}}, p_T^{had})$$

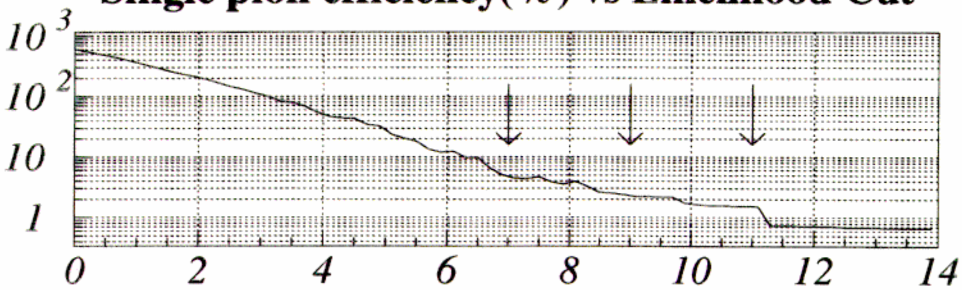




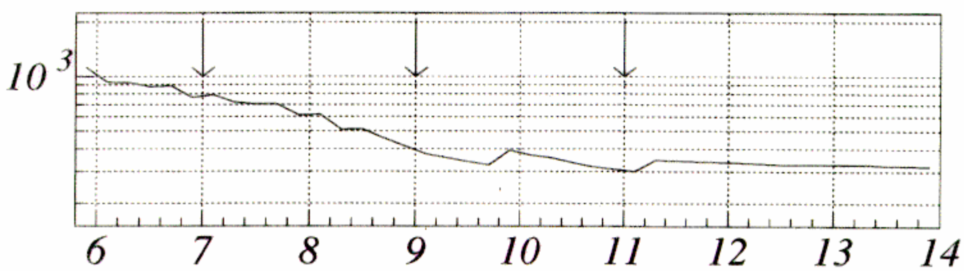
5. Sensitivity



Single pion efficiency(%) vs Likelihood Cut

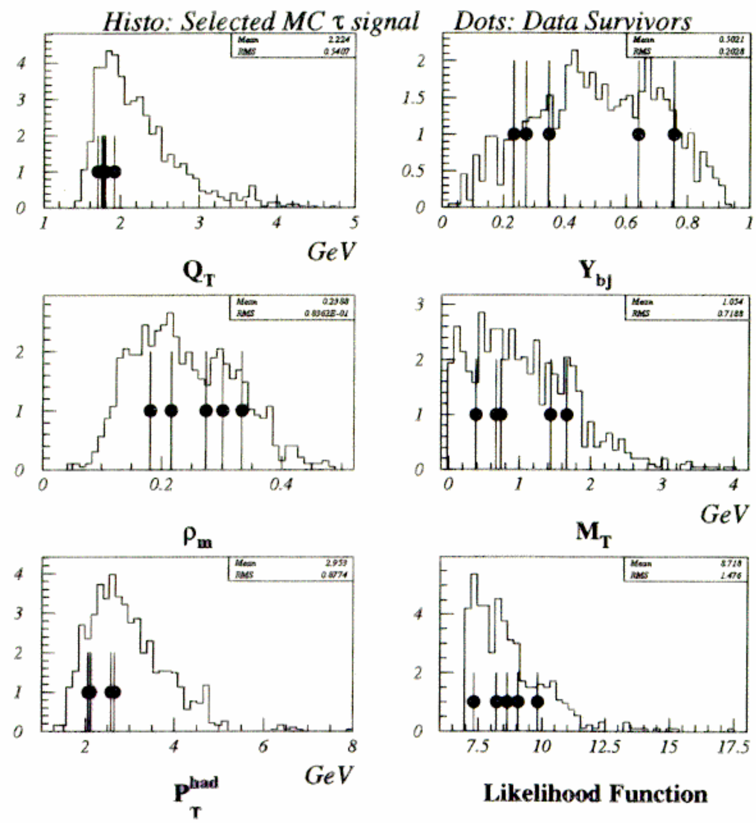


Predicted background vs Likelihood Cut



Effciency/Sensitivity vs Likelihood Cut

6. Box opening



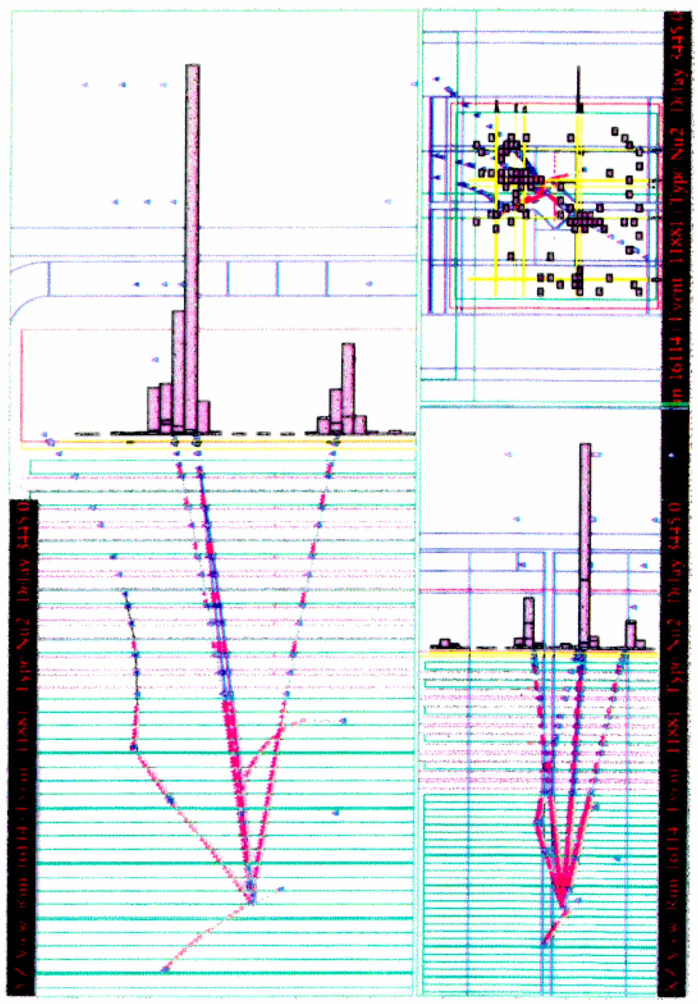
Likelihood	N_τ	Expected Bkgnd	Data
7-9	664	2.3 ± 0.8	3
9-11	234	$1.1^{+0.8}_{-0.6}$	2
> 11	1133	$1.1^{+0.7}_{-0.5}$	0

7. Example of a $\tau^- \to \pi^- \nu_\tau$ candidate

Run 16114 Event 11881

$p_\pi = 6.9$ GeV

$L = 9.8$, $Q_T = 1.8$ GeV, $M_T = 0.4$ GeV, $\rho_m = 0.21$



Results

- '95 Analysis

CERN-EP/98-57 (to be published in Phys. Lett. B)

$$P(\nu_\mu \to \nu_\tau) < 2.1 \times 10^{-3}$$

- Updated analysis summary

Channel	Data	est. backg.	N_{obs}	N_τ
$\tau^- \to e^- \nu_\tau \overline{\nu}_e$ DIS	95-97	6.6 ± 0.8	5	2904
$\tau^- \to e^- \nu_\tau \overline{\nu}_e$ LM	95	$0.5^{+0.6}_{-0.2}$	0	218
$\tau^- \to h^- (+n\pi^0) \nu_\tau$ DIS	95-97	4.5 ± 1.2	5	2031
$\tau^- \to h^- (+n\pi^0) \nu_\tau$ LM	95	$0.1^{+0.3}_{-0.1}$	1	198
$\tau^- \to \rho^- \nu_\tau$ DIS	95-97	$5^{+1.2}_{-0.9}$	5	1900
$\tau^- \to \pi^- \pi^- \pi^+ \nu_\tau$ DIS	95-96	7.0 ± 2.7	5	1011
$\tau^- \to \pi^- \pi^- \pi^+ (+n\pi^0) \nu_\tau$ LM	95	$0.4^{+0.6}_{-0.4}$	0	108
Total		24.1 ± 3.3	21	8370

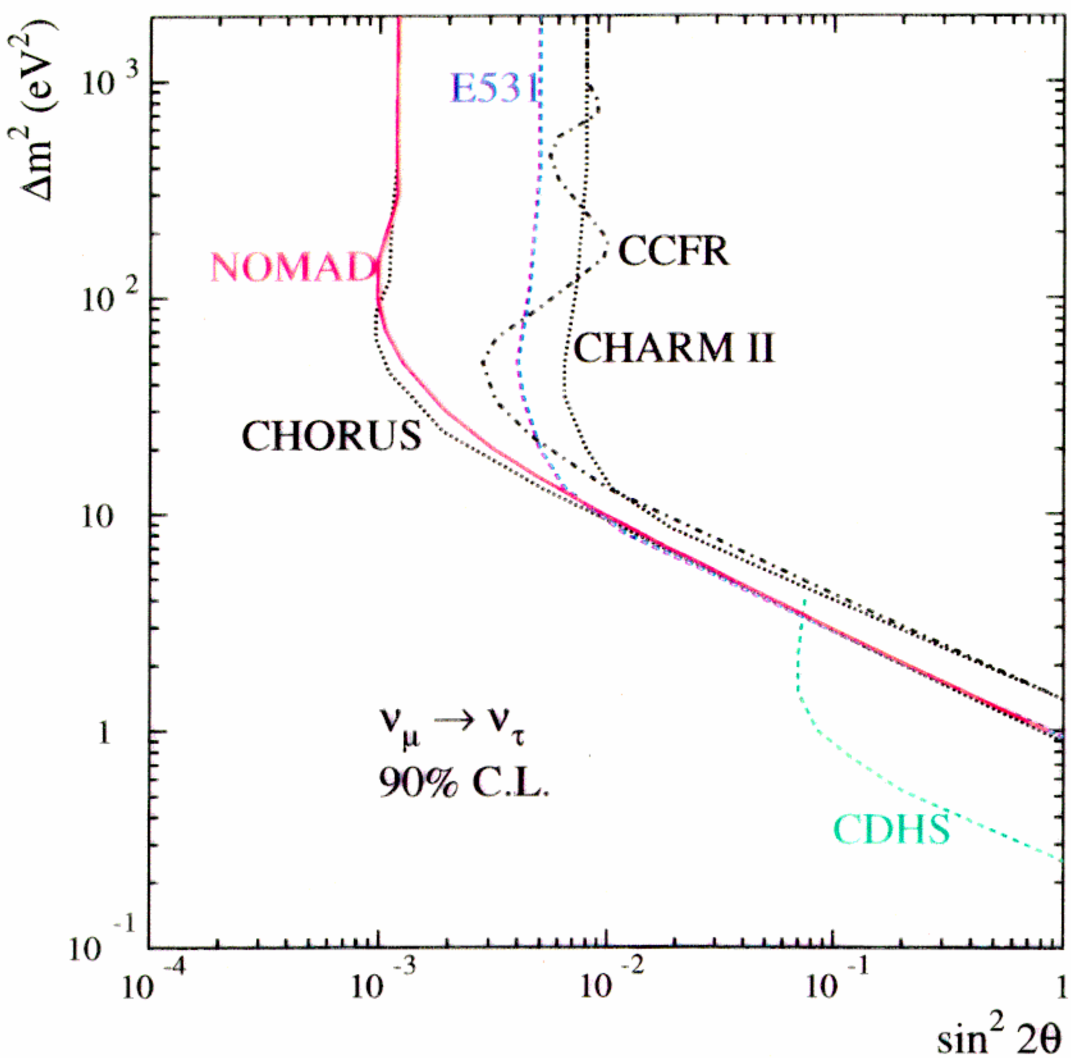
$$P(\nu_\mu \to \nu_\tau) < 0.6 \times 10^{-3}$$

approximate sensitivity 0.8×10^{-3}

Exclusion plots

- $\nu_\mu \to \nu_\tau$

$sin^2(2\theta) < 1.2 \times 10^{-3}$ at large Δm^2, 90% C.L.



- $\nu_e \rightarrow \nu_\tau$

PRELIMINARY