Neutrino Oscillation Working Group Summary

Neutrino Oscillation Working Group

Outline

- First results from “Super Conventional Neutrino Beams”
- Searches for new heavy neutral particles in a very intense proton beam
- Update on the Large Magnetic Detector
- Long base line sites for an European Nufact
- E.O.I. For the Large Magnetic Detector

Super Conventional Beams

- Goal of the study is to answer the question: Can a conventional neutrino beam of very high intensity compete with the Nufact?
  - Precision measurement of dm^2_{23} θ_{23}
  - Measurement or stringent limit for θ_{13}
  - Sign of dm^2_{23}
  - Measurement of a CP violation phase δ

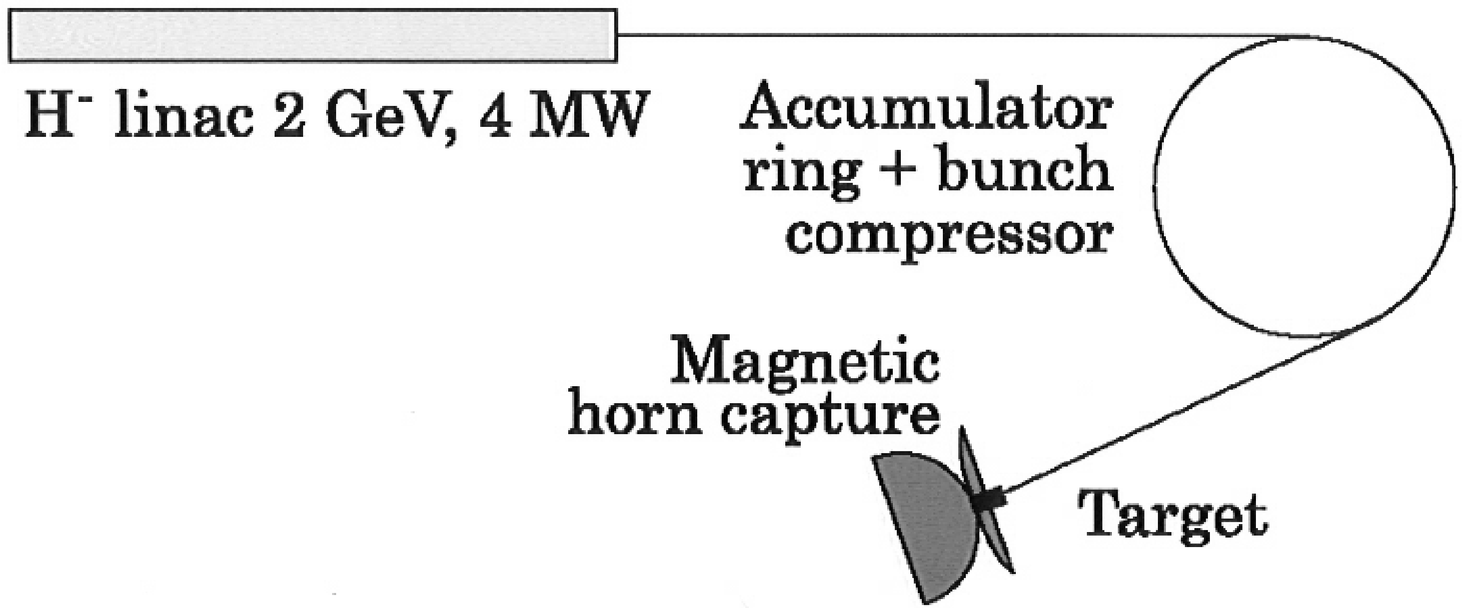
Working group approach

- Do not try to study all possible Super neutrino beams. Concentrate in current “default” design for European Nufact
  - Proton beam of 2.2 GeV
  - 4 MW power
- Other “Super beams” are possible at higher energies
  - Different beam backgrounds
  - Different detector backgrounds and systematic errors

State of the art

- Compute neutrino fluxes from 2.2 GeV pion (Alain, Mauro, JJ, Simone)
  - Provides ν_μ (ν_μ) beam from π^+ (π^-)
  - Provides ν_e (ν_e) beam from μ^+ (μ^-) decay
- Consider large detectors at O(100) Km
  - Dave Casper Large water detector “SuperK like”
  - Mauro Mezzeto Large scintillator detector “SuperMiniBoone”

Nufact layout II



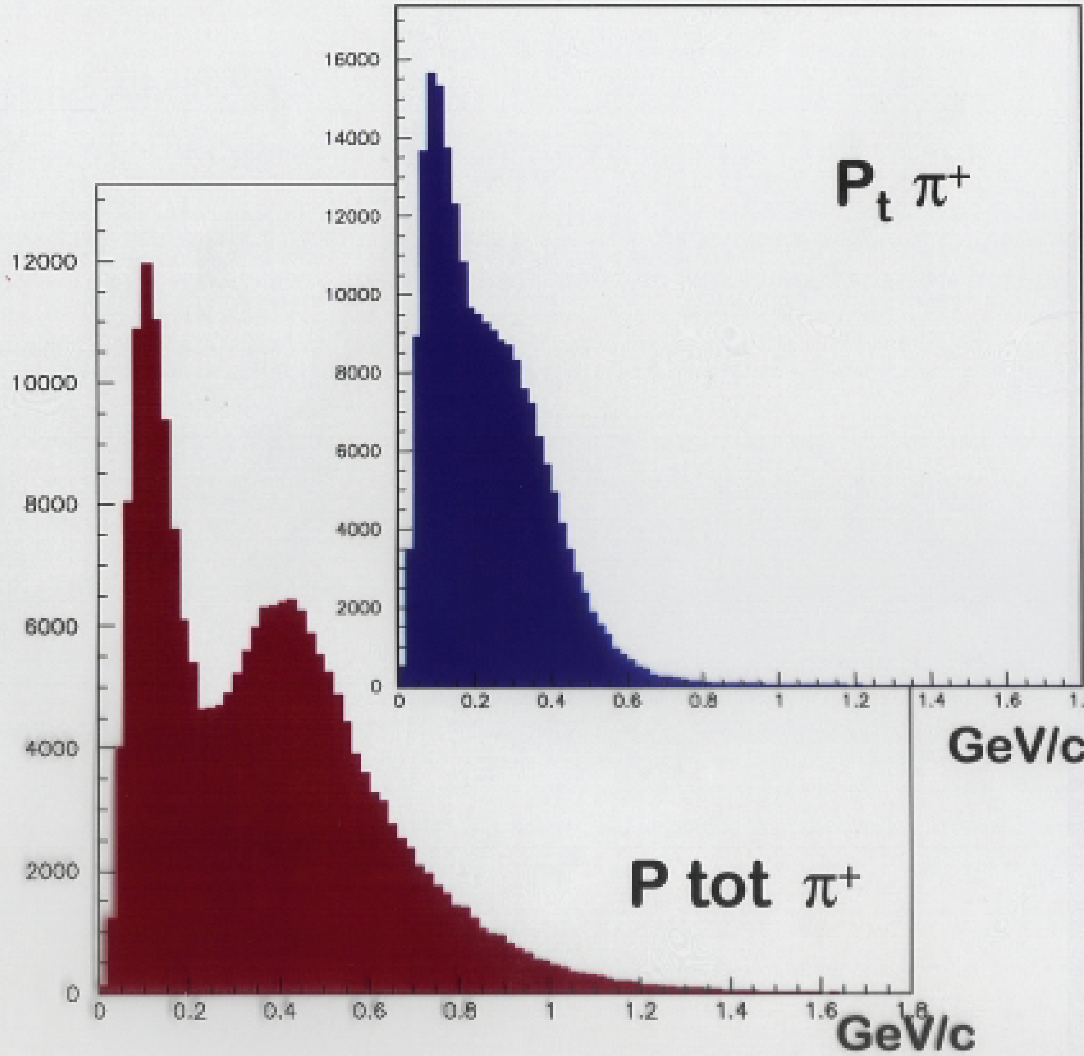
- **4 MW proton beam at 2.2 GeV**

  $\approx 10^{16}$ p.o.t./sec

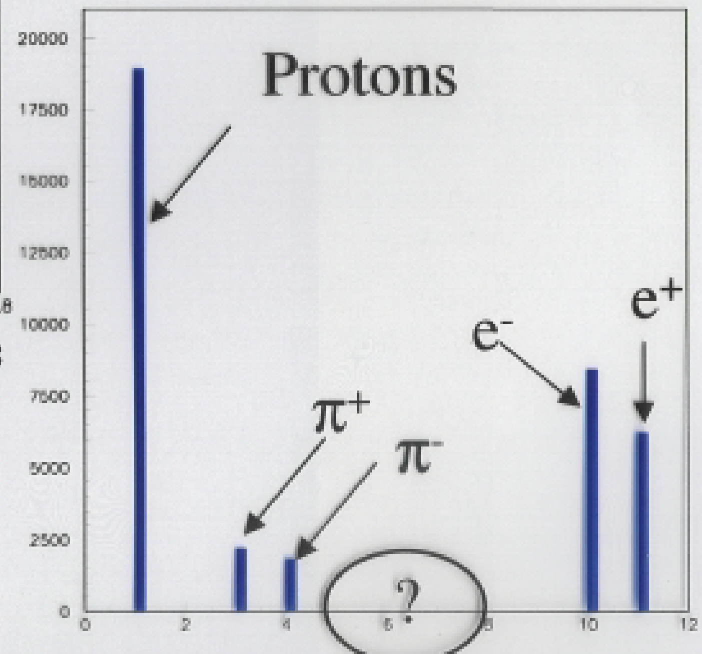
  Rep. Rate = 75 Hz
- **Hg liquid target**
- **Focusing system: Horn**

A.B. S. Gilardoni, M. Donega

Particles at target

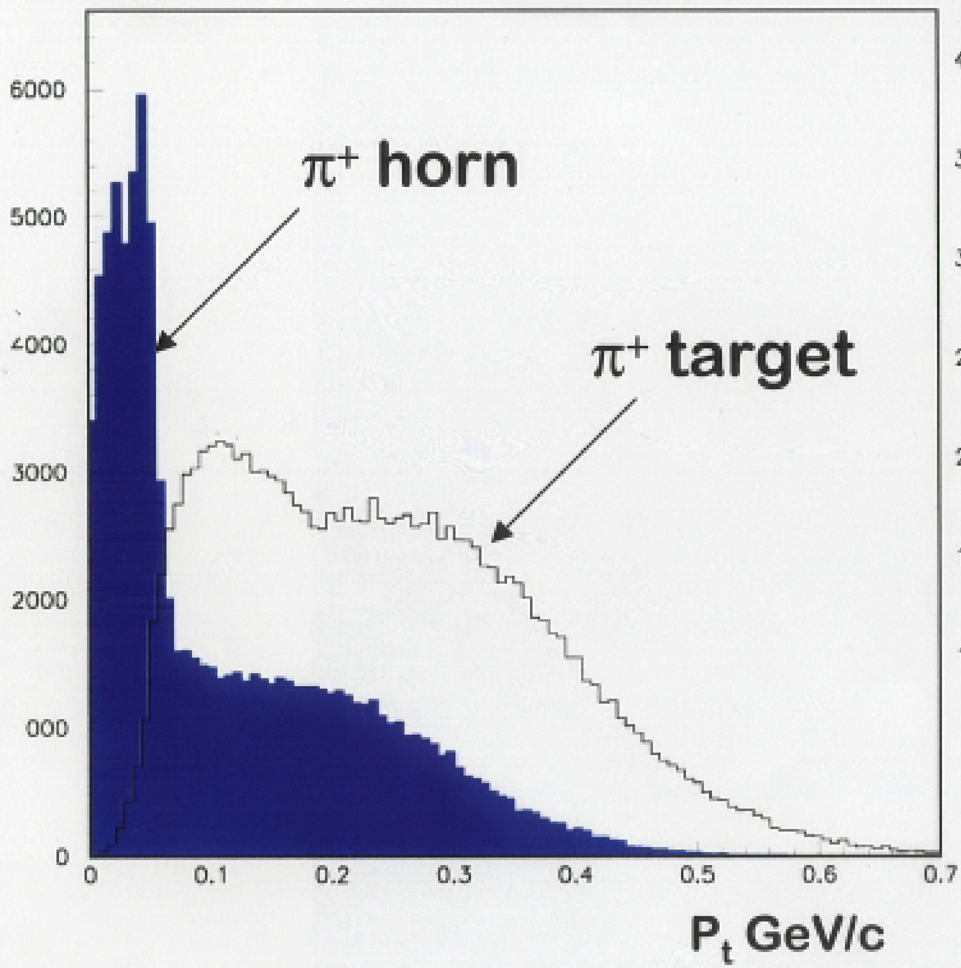


- **No Kaons? YES! No Kaons (Harp needed...)**
- **20% more π^+ Vs π^-**

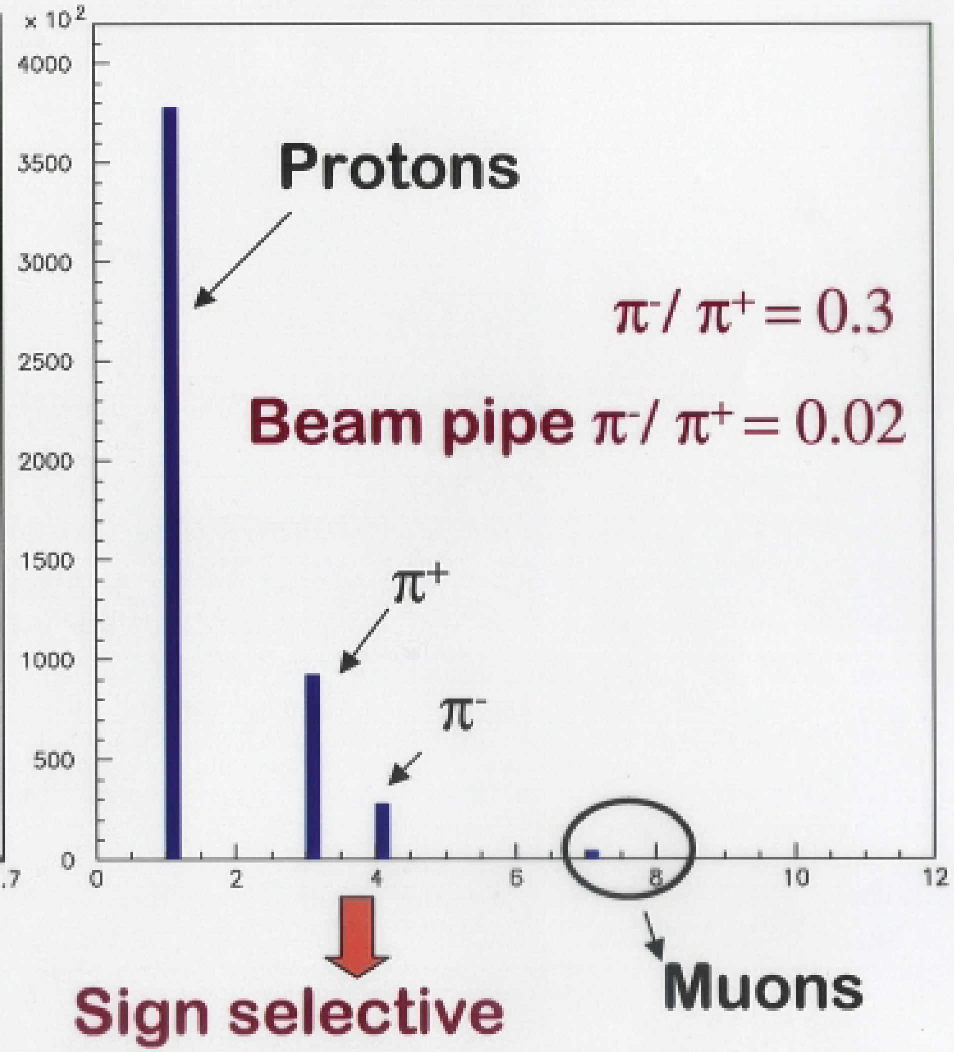


After the horn

P_t distribution



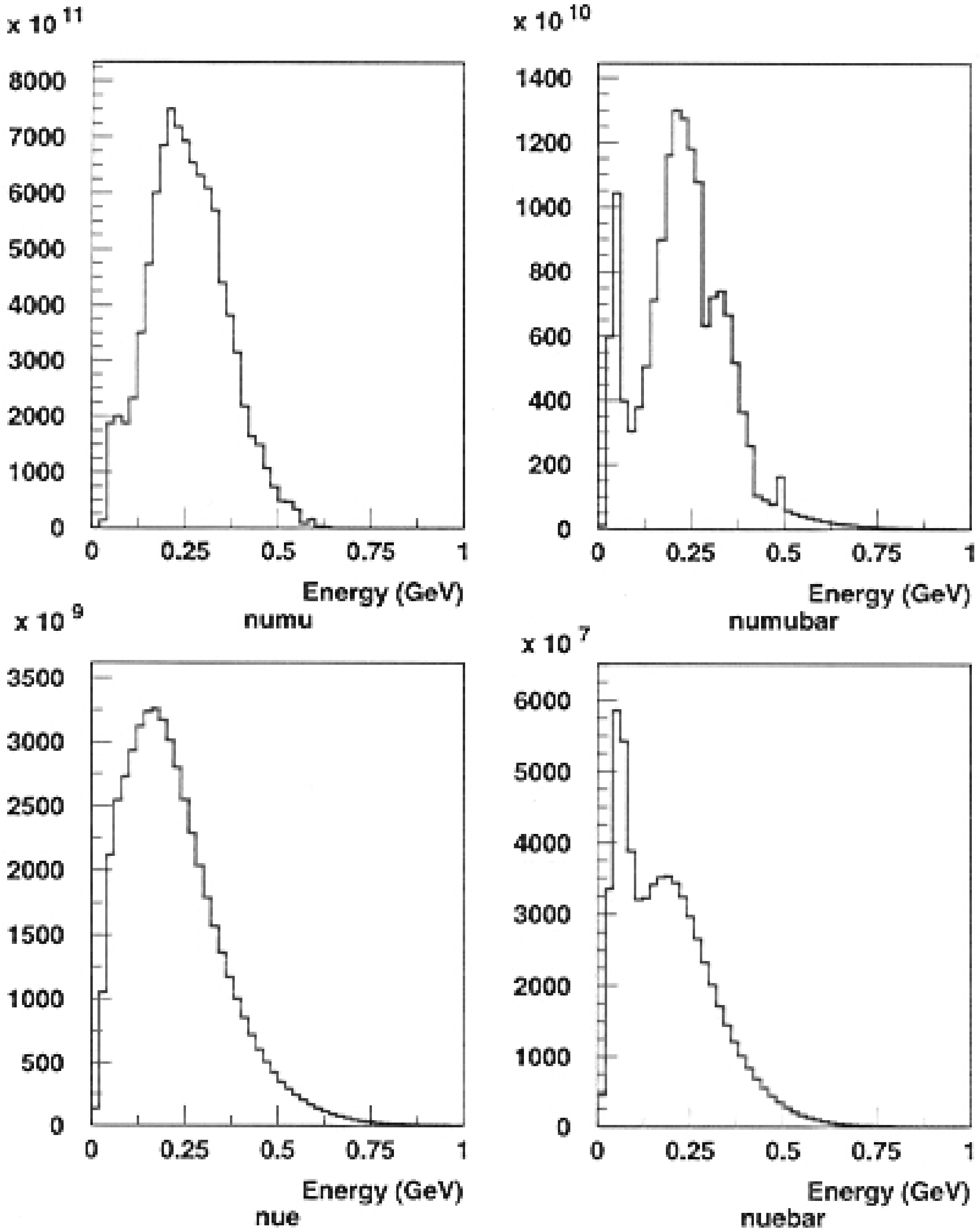
Population



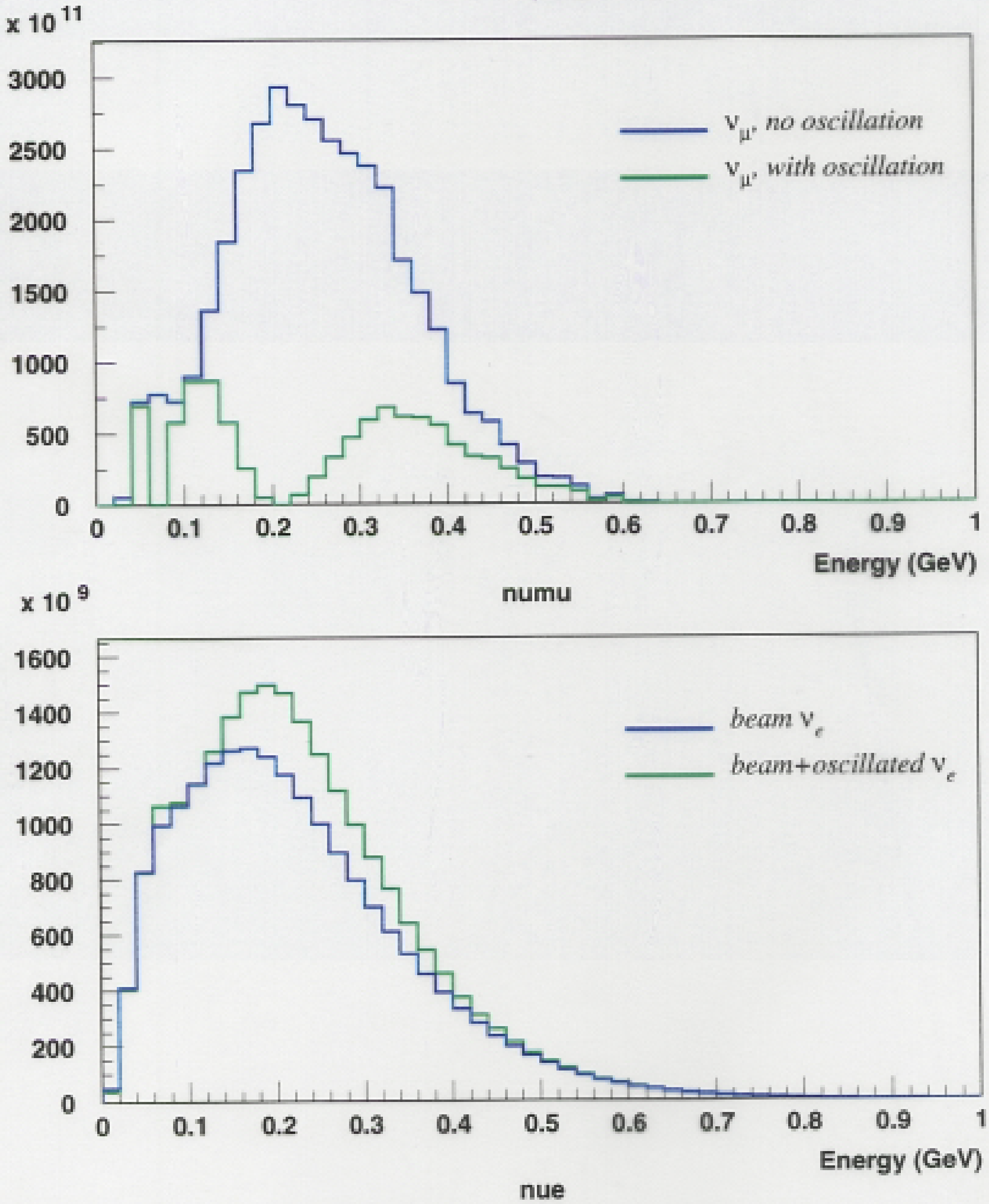
Features of low energy SB

- Pure pion beam out of horn
  - No kaons
  - Beam background from $\pi \to \mu \to e$
- Low energy neutrinos (250 MeV)
  - Quasielastic cross section regime
  - "Short" distances (O(100) Km) for maximal oscillation
  - "Large" detector needed (O(100) Kton) to compensate low cross section
  - "Clean" signature (small detector backgrounds)

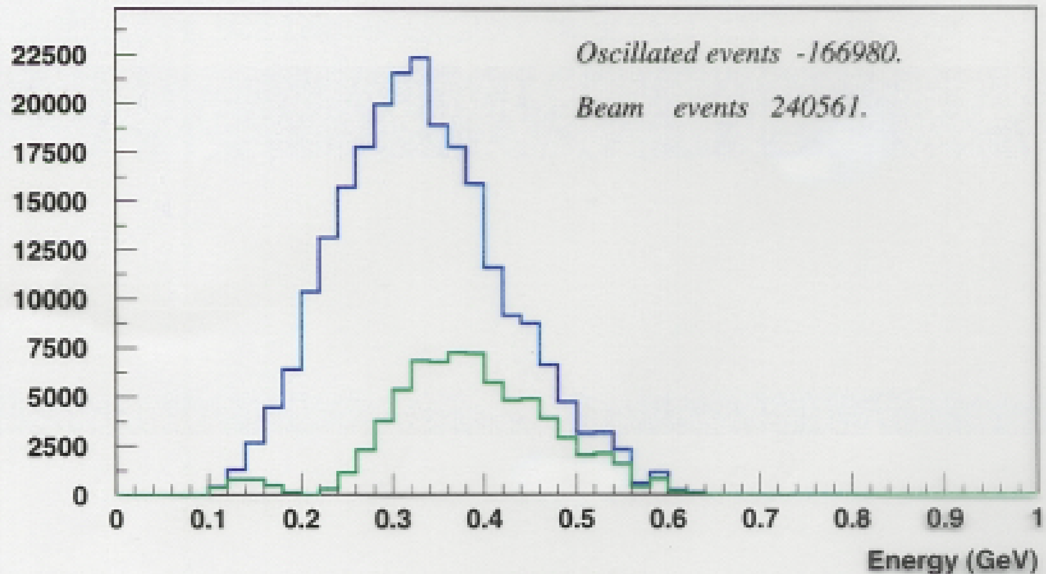
Super Beam Fluxes at 50 km ($\nu/10m^2/20meV$)



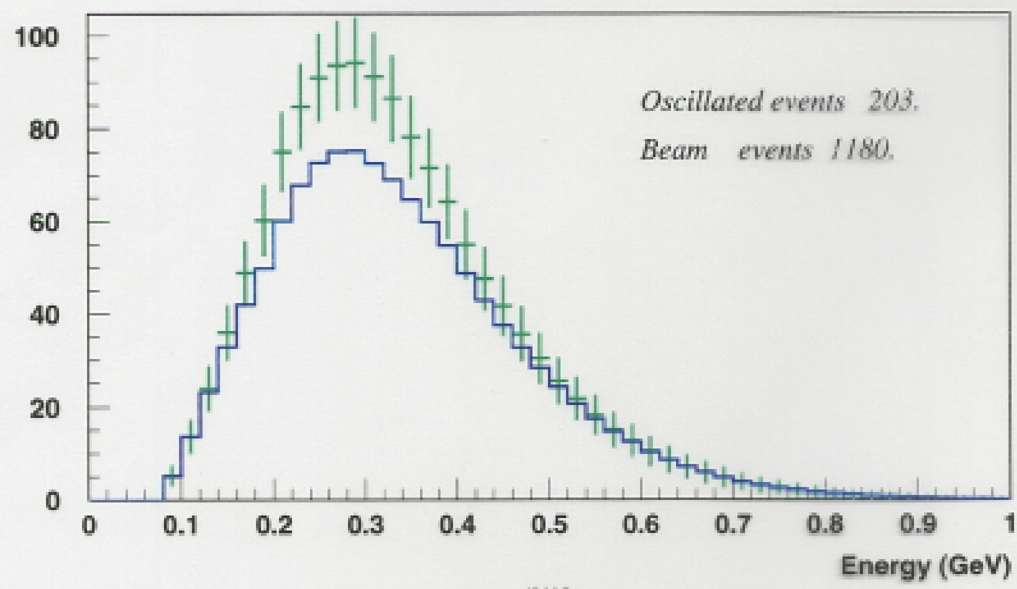
sin²2θ=0.002, 80km, ~~10~~ 100 kton,4years, fluxes



$\sin^2 2\theta$=0.002, 80km, 10kton,4years, interactions

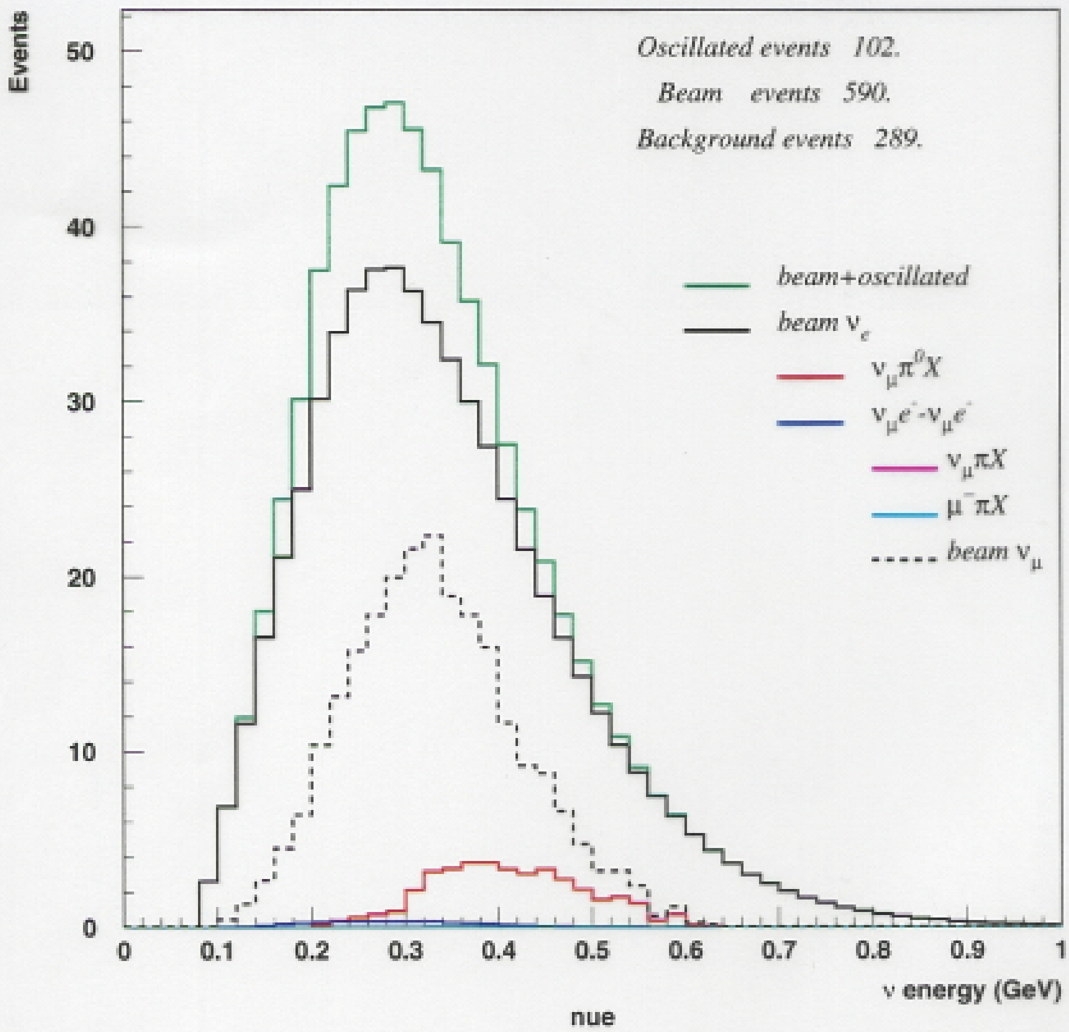


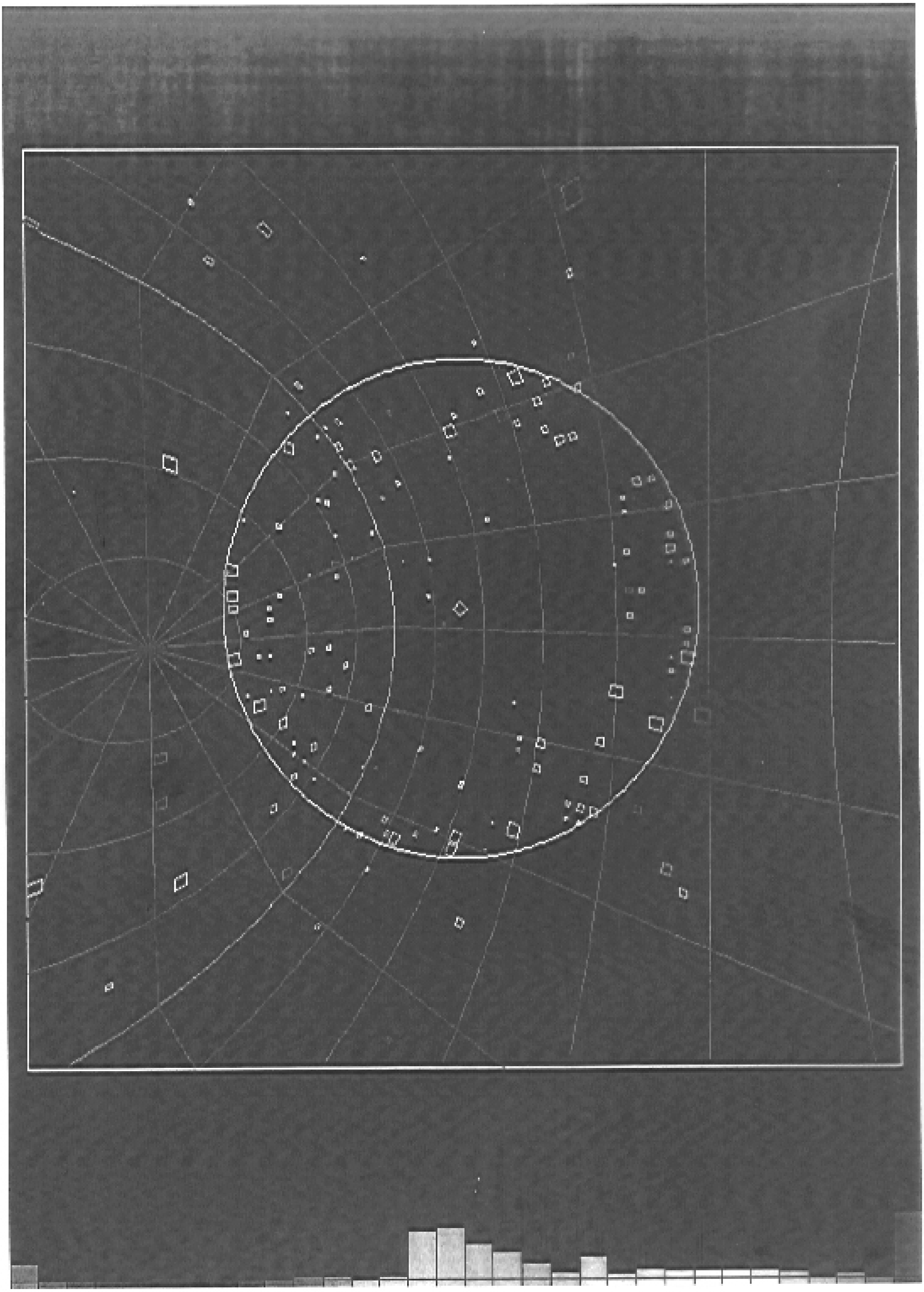
numu CC



nue

sin^{2}2θ=0.002, 80km, ~~10~~ 100kton,4years, NueOsc and bckg. with Boone ε

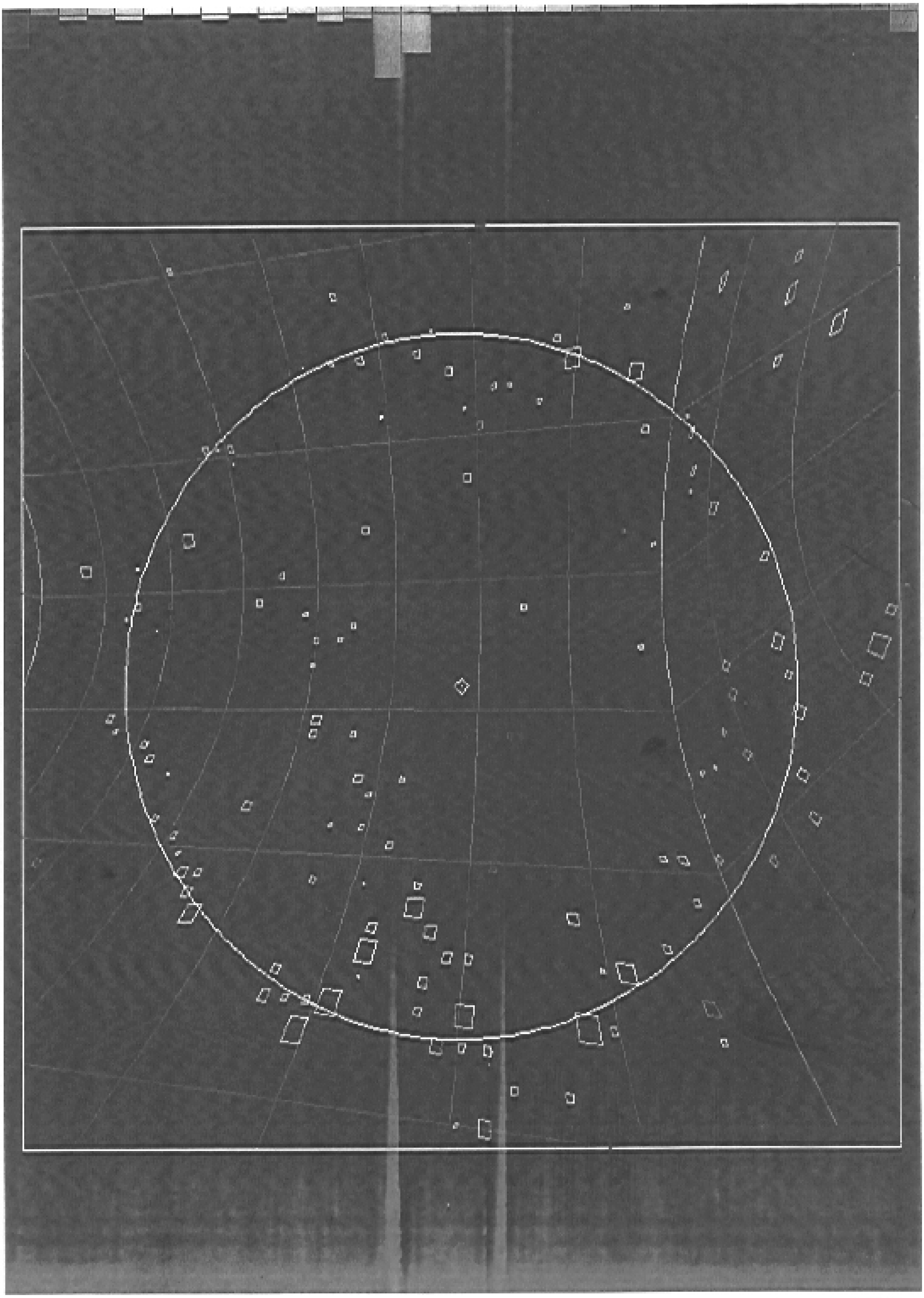


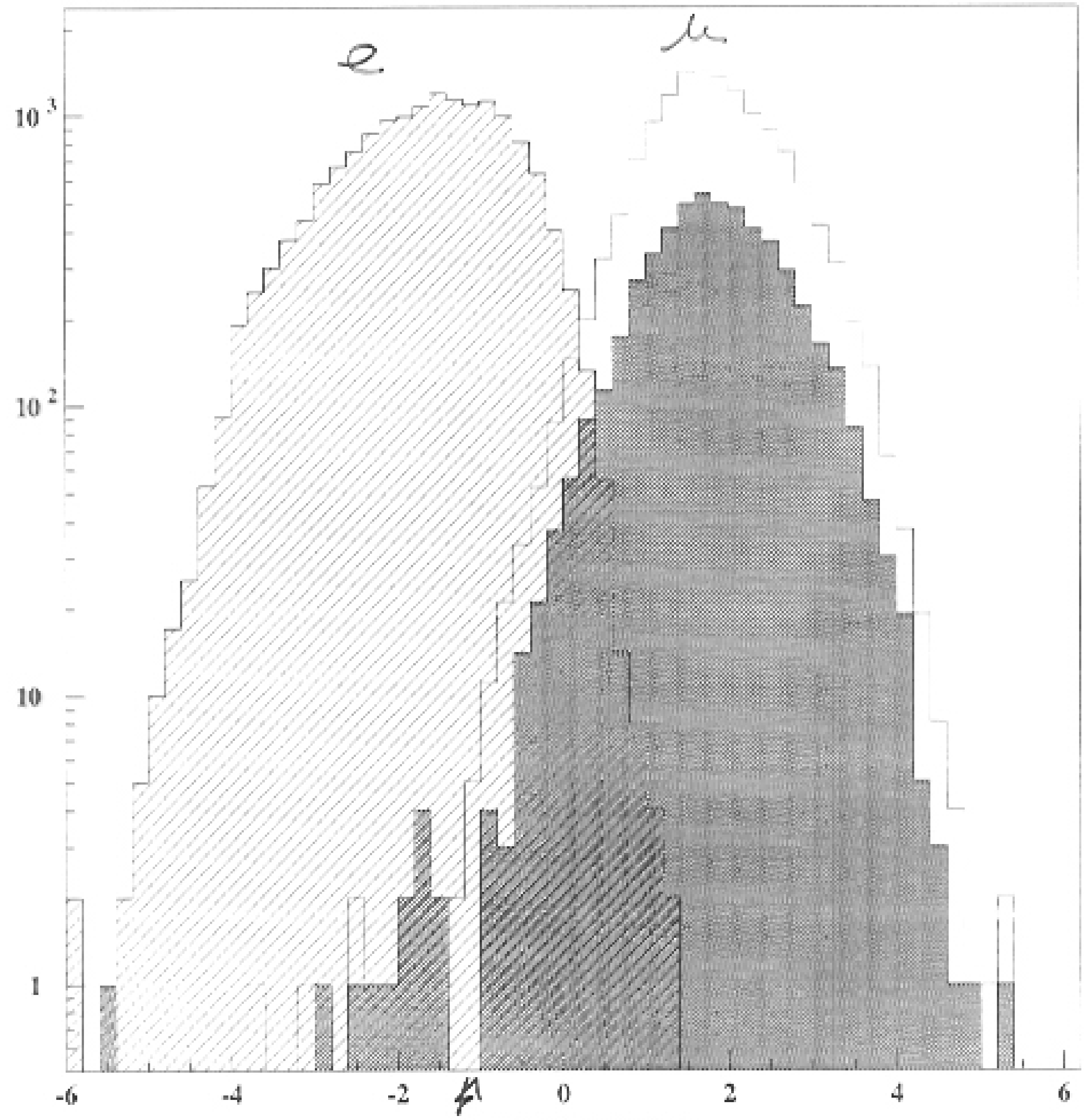


μ 200 MeV

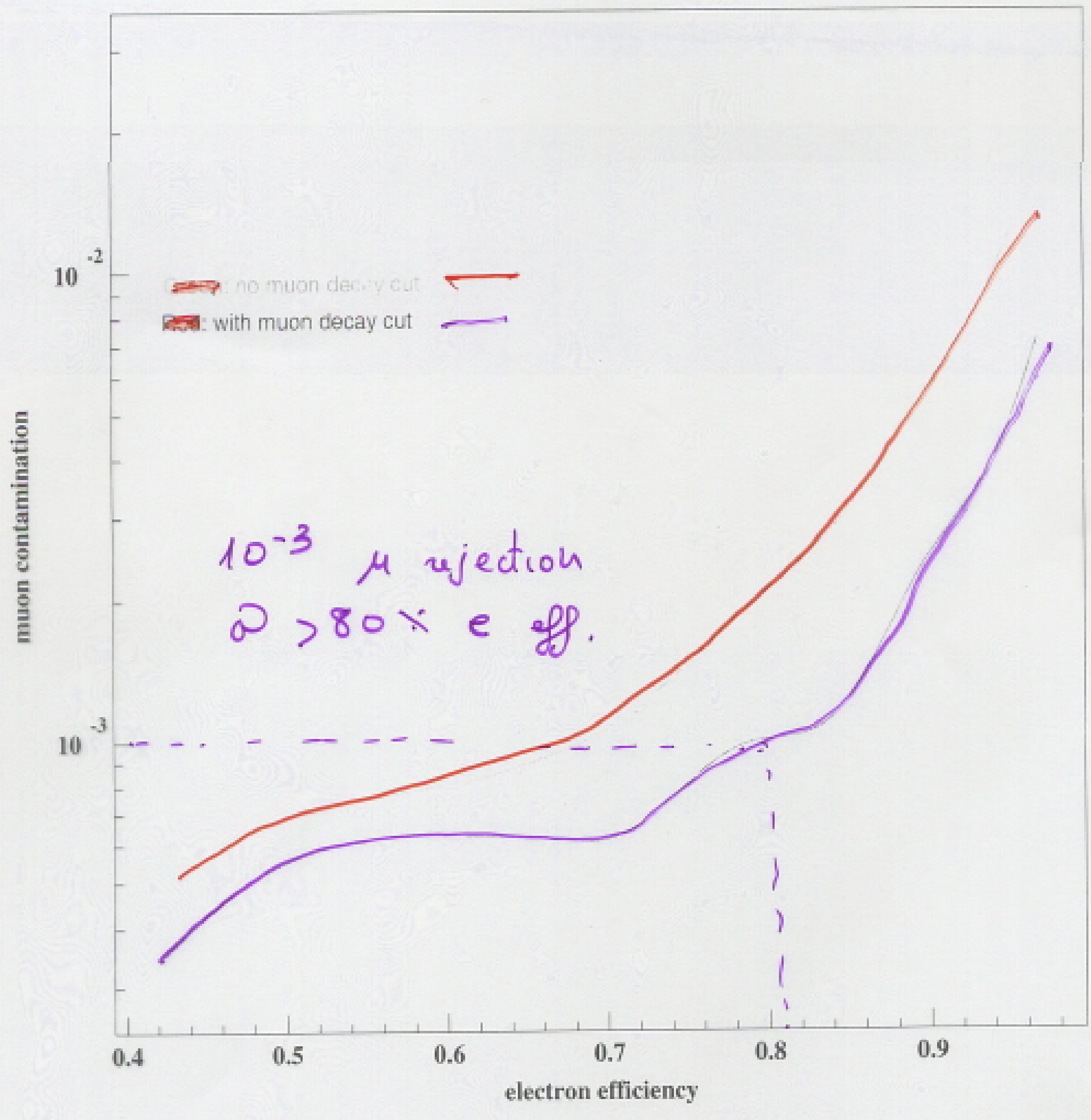
R ~~3[illegible]~~ MeV

R 30 MeV





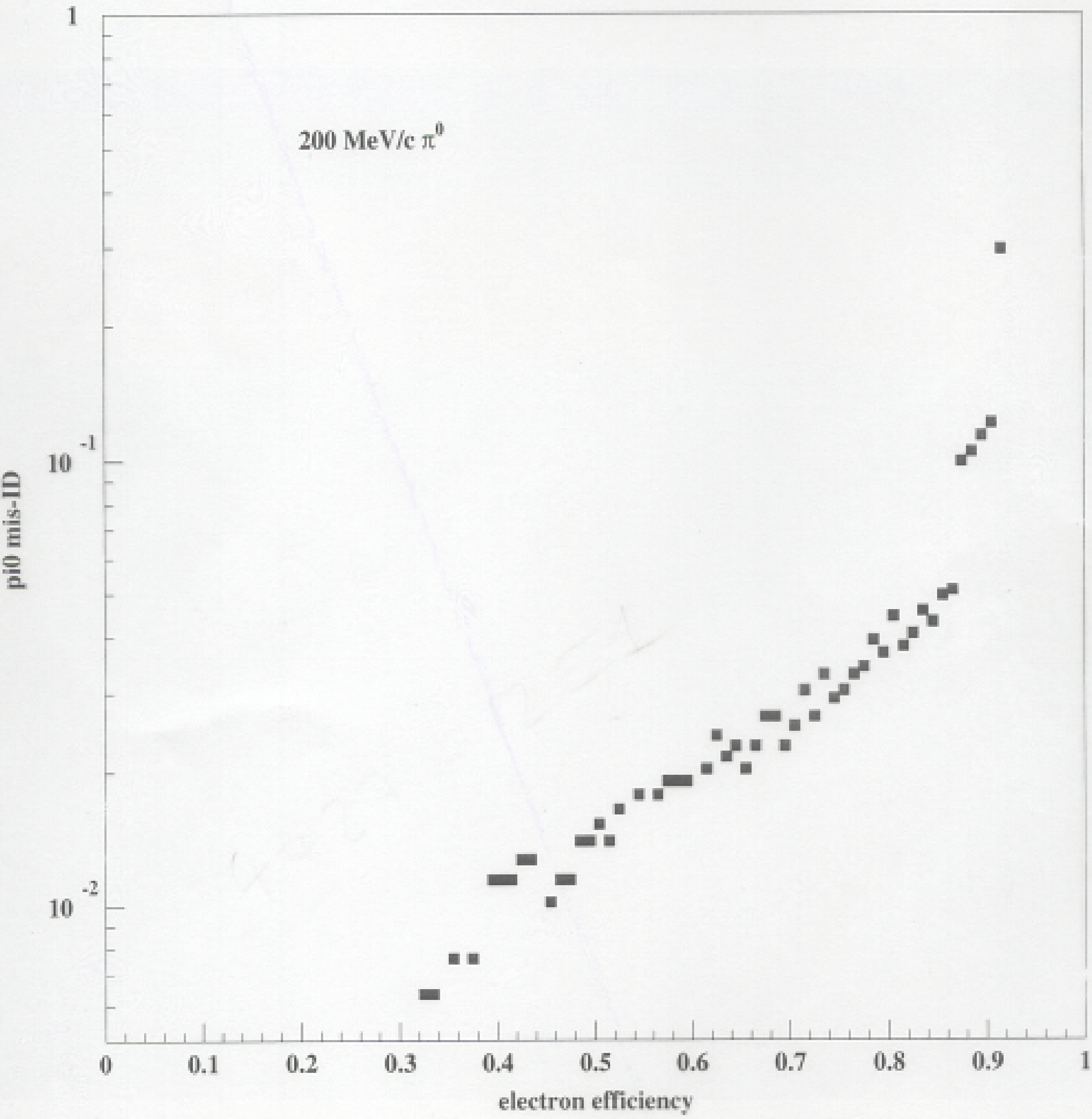
Dave Casper



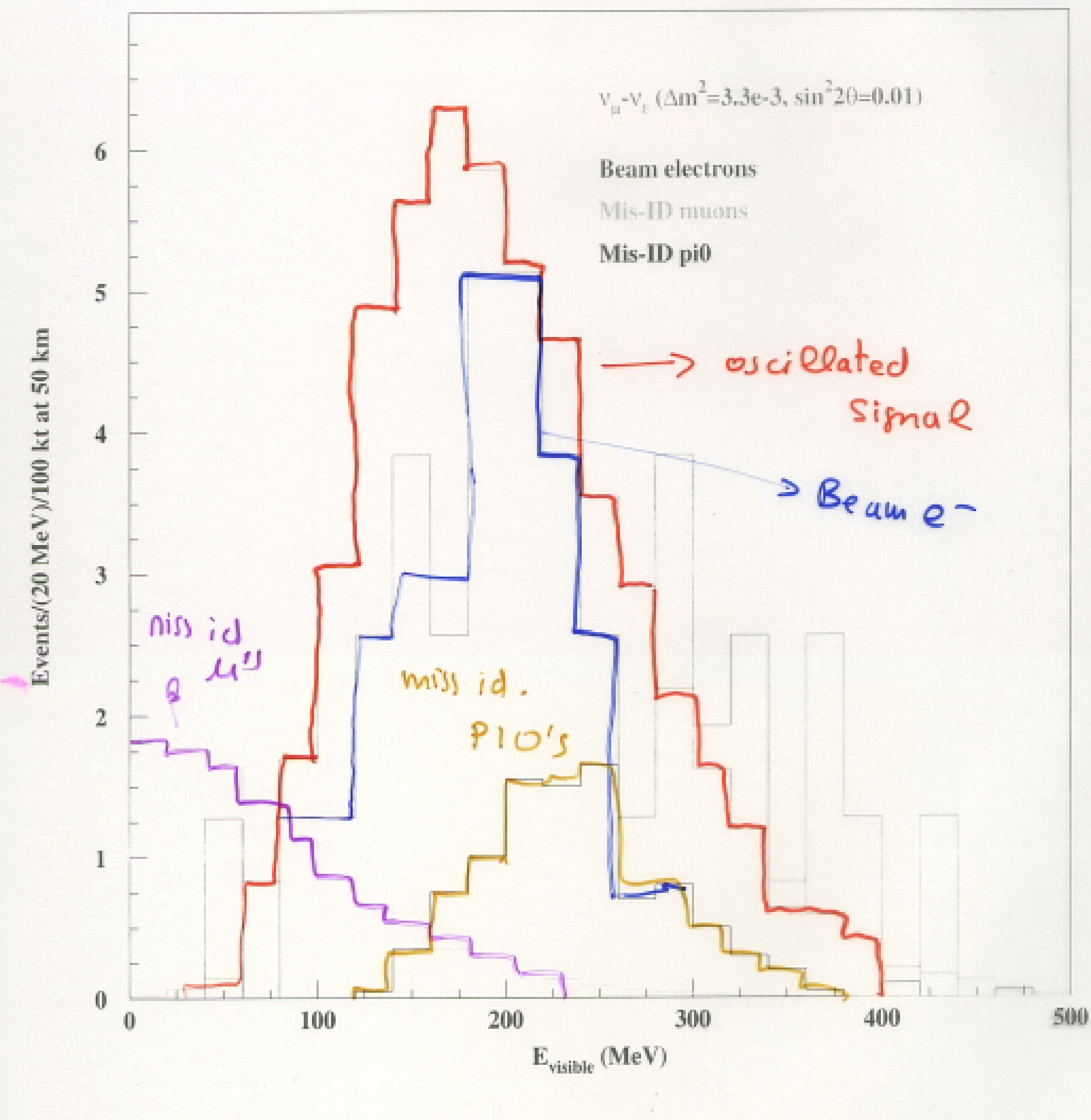
no muon decay cut
with muon decay cut
10 -2
10 -3
muon contamination
0.4
0.5
0.6
0.7
0.8
0.9
electron efficiency
10-3 μ rejection
@ >80% e eff.

CASPER

Pi ⁰ Rejection



CASPER


ν_μ-ν_τ (Δm^2=3.3e-3, $\sin^2 2\theta$=0.01)
Beam electrons
Mis-ID muons
Mis-ID pi0
Events/(20 MeV)/100 kt at 50 km
$E_{visible}$ (MeV)
0
1
2
3
4
5
6
0
100
200
300
400
500
→ oscillated signal
→ Beam e⁻
miss id μ's
miss id. PI0's

Systematic errors

With the following assumptions:

- No kaon produced by primary proton interactions:

$$\begin{array}{ccc} \pi^+ & \longrightarrow & \mu^+\nu_\mu \\ & & \downarrow \\ & & e^+\nu_e\overline{\nu}_\mu \end{array}$$

  ν_μ spectrum predicts by itself ν_e spectrum.

- differential π production cross sections carefully measured by Harp.
- A close detector exists reducing the systematic errors in ν_e prediction, neutrino interaction cross sections and background rejections.
- A status of the art beam monitor is built following the K2K and MiniBoone experience.

the systematic errors should be of about 5% (conservative), with 2% as a final goal.

As an example MiniBoone, without the close detector, with kaons in the beam line and before Harp, quotes 10% as conservative and 5% as possible.

1% Possible ?

Sensitivity on θ_{13}

- No transformation from neutrino energy to visible energy and energy resolution are introduced at this moment.
- Sensitivity is calculated as a counting experiment with the integral number of events.
- $p(\nu_\mu \to \nu_e) \simeq sin^2(\theta_{13}) sin^2(\theta_{23}) sin^2(1.27 \delta m^2_{32} L/E)$. $sin^2(2\theta_{23})$ and δm^2_{32} are assumed to be well measured both by LBL experiments and by ν_μ disappearance in this experiment.

$$\sigma_{\rm stat} = \sqrt{\rm beam + osc + bkg}$$

$$\sigma_{\rm syst} = ({\rm beam + bkg}) \cdot 5\%(2\%)$$

$$\text{significance} = \frac{\rm osc}{\sigma}$$

With $sin^2(2\theta_{13}) = 0.002$, a 100kton detector at 80 km from the target, 4 years of run at 10^{23} pot/year:

Oscillated events	102
Beam ν_e events	590
Background events (from μ^-, π° and π)	289
Significance (statistical only)	3.2
Significance (stat+syst 5% (2%))	1.9 (2.8)

This sensitivity is two orders of magnitude better than the Chooz limit and one order of magnitude better of the (optimistic) predictions for Minos and Icarus.

But two orders of magnitudes worse than NUFACT

First Results

- Sensitivity to θ_{13}
  - Dominated by beam background from μ decay
  - Preliminary: two orders magnitude improvement over current results (one order at least over next generation)
  - Still, at least two orders of magnitude worst than Nufact
- Can this result be improved?
  - Optimize decay tunnel
  - Reduce systematics to 1 %
  - But no miracles

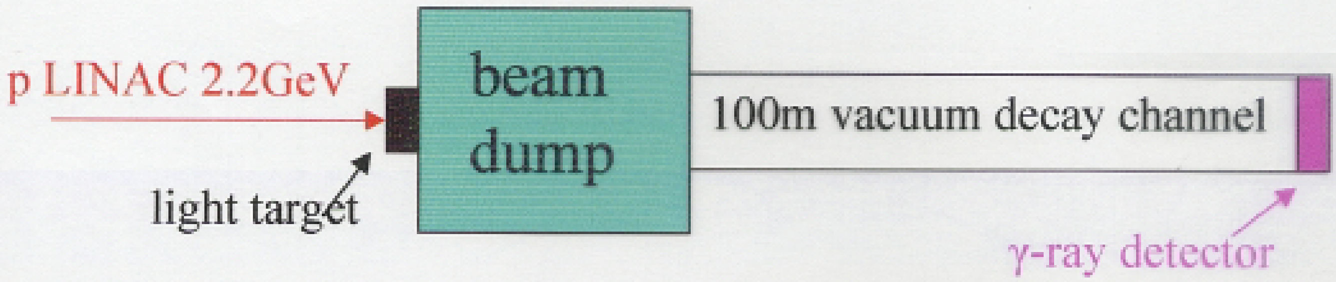
Preliminary conclusions

- Big improvement on θ_{13}. Still, not competitive with Nufact
- Requires a very large detector "Super K" size.
- Intermediate step towards Nufact? Not obvious
  - Detector requires ≈ 5 years or more to build
  - Need a new lab at O(100) Km (GS is out of question)
  - Serious investment in terms of money & man power

Search for heavy particles

- Idea proposed by P. Dalpiez
- Origin of cosmic gamma bursts. A new, heavy, neutral particle (e.g, axion of 5 eV)?
- If so, an experiment in the very intense 2.2 proton Beam could detect it
  - a --> $\gamma\gamma$. Two simultaneous photons in a detector
  - Light target followed by beam dump and long decay tunnel

EXPERIMENTAL SEARCH FOR A HEAVY AXION



$$pN \longrightarrow a^0 + \ldots\ldots$$
$$\quad\quad\quad\quad \hookrightarrow \gamma\gamma$$

E_γ=100-700 MeV
$\theta_{\gamma\gamma}$(max)= 10 mrad

Multiple scattering from target: (D.Bettoni)
Carbon (C) X_0 = 18.8cm and λ_I = 86.3 g/cm² = 38.1 cm
Tungsten(W) X_0 = 0.35cm and λ_I = 185 g/cm² = 9.6 cm

mater. \ λ_I	1	2	3
C	10mr	14mr	18mr
W	40mr	57mr	72mr

A light target λ_I thick, open the beam less than 1m over 100m.
A 2m diameter γ detector have a sufficient acceptance.

The $\sigma_{pN\text{--}a..}=10^{-39}$cm²/s corresponding to weak cross section at 0.7GeV.

$N_a/s = \sigma . N_p . N_N = 10^{-39}cm^2 x\ 1.3x10^{17}s^{-1}x236x10^{23}=3000/s$

If the axion mean path is of the order of 1000Km in 100m decays:

$N_{events}/s = 0.3/s$ → γ?

7

1 ev / 10C

Update on Large Magnetic Detector

- New calculations presented by A. Cervera
- Update of wrong sign analysis with:
  - More conservative hadronic shower smearing
  - Increased statistics
  - Improved cuts
- Study of the impact of charge misidentification
  - Seems manageable

Wrong sign muons

$$\mu^+ \longrightarrow e^+ + \bar{\nu}_\mu + \nu_e$$

$\bar{\nu}_\mu + N \longrightarrow \mu^+ + X$ (right sign muon) — $\bar{\nu}_\mu$ CC

$\bar{\nu}_\mu + N \longrightarrow \bar{\nu}_\mu + X$ — $\bar{\nu}_\mu$ NC

$\nu_e + N \longrightarrow e^- + X$ — ν_e CC

$\nu_e + N \longrightarrow \nu_e + X$ — ν_e NC

BACKGROUNDS

$\nu_e \overset{\text{osc}}{\sim} \nu_\mu$

$\nu_\mu + N \longrightarrow \mu^- + X$ (wrong sign muon) — ν_μ CC — SIGNAL

Having a very pure neutrino beam

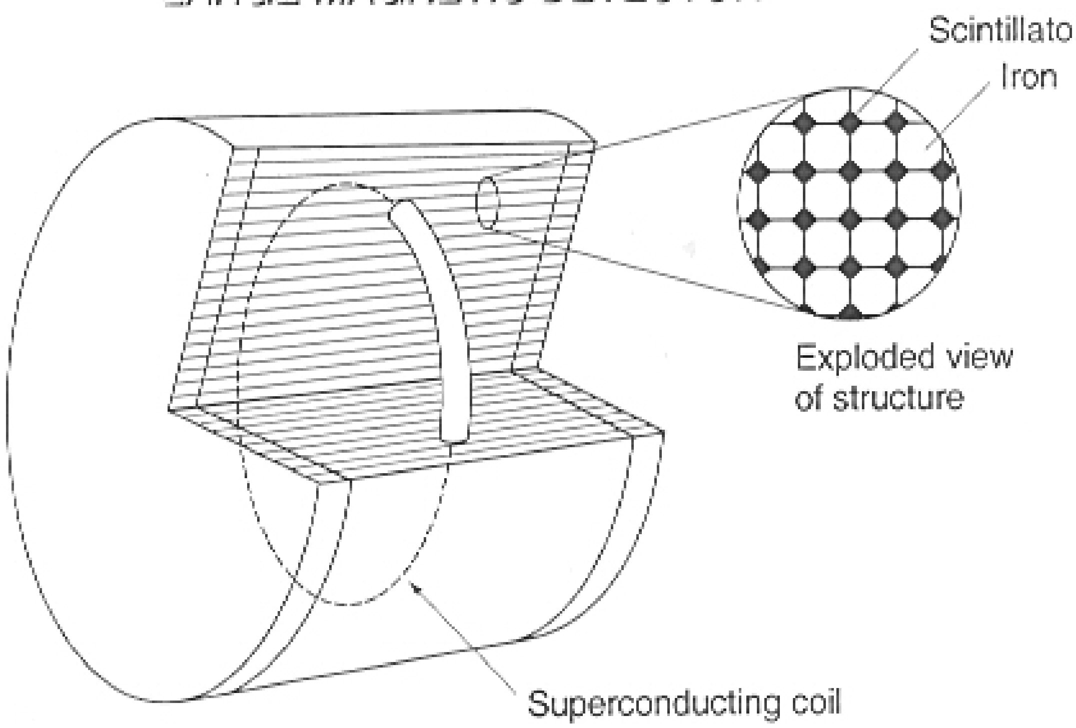
50 % $\overline{\nu}_\mu$ 50 % ν_e

the neutrino oscillation search is very clear

The detector

- We need large mass $\Longrightarrow$ 40 Kton
- Reasonable muon identification
- Good charge identification $\Longrightarrow$ 1 tesla magnetic field
- Reasonable hadronic shower resolution
- Reasonable angular resolution $\Longrightarrow$ Reasonable granularity

LARGE MAGNETIC DETECTOR



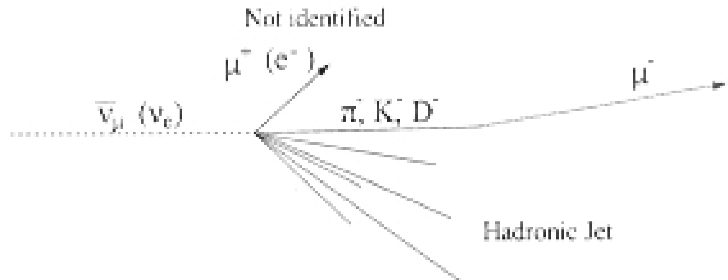
Dimension: radius 10 m, length 20 m
Mass: 40 kt iron, 500 t scintillator

Potencial Backgrounds

Charged currents ($\bar{\nu}_\mu$+ ν_eCC)

- ν_eCC : We assume the worst case in which there is not electron identification. Then $\pi^-, K^-, D^- \longrightarrow \mu^-$ decay.
- $\bar{\nu}_\mu$CC

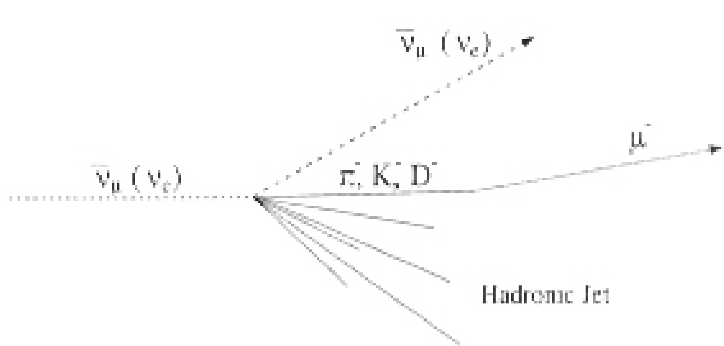
1. The μ^+ is not recontructed. Then some particle of the hadronic jet decays into a μ^-.



2. The charge of the μ^+ is misidentified.

Neutral currents ($\bar{\nu}_\mu$+ ν_eNC)

- $\pi^-, K^-, D^- \longrightarrow \mu^-$ decay



Update

- We have reupdated the previous analysis
- With more statistics
  1. 10^7 $\overline{\nu}_\mu$CC
  2. 10^7 $\overline{\nu}_\mu$NC
  3. 10^7 ν_eCC
- With different smearing
  1. Previous analisys (MINOS fine grain)

$$\delta\theta_{had} = \frac{9.0}{\sqrt{E}} + \frac{25.0}{E}$$

  2. This analisys (MINOS proposal, more conservative!!)

$$\delta\theta_{had} = \frac{16.67}{\sqrt{E}} + \frac{12.15}{E}$$

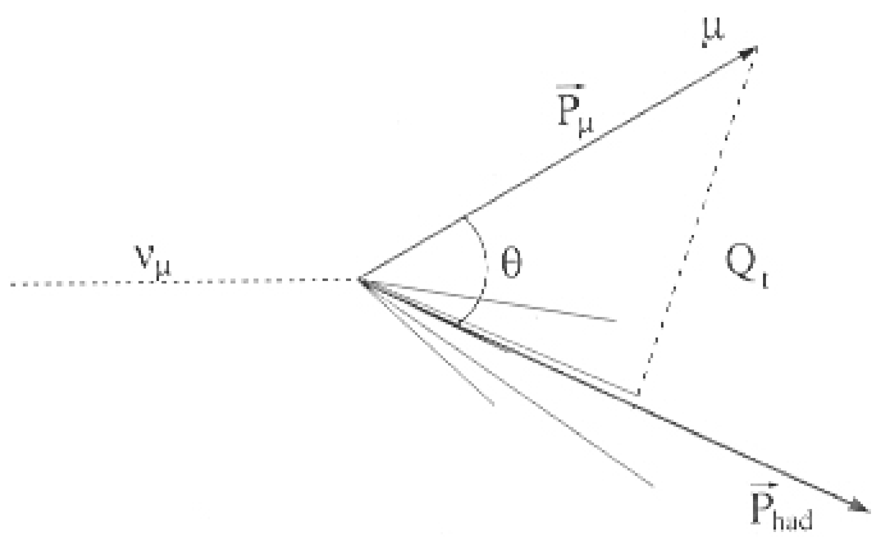
- With both polarities (stored μ^+ and μ^-)
- With a detailed study of the charge identification

Physical variables

The detector provides information about:
$\vec{P}_\mu$,E_{had}, and θ_{had}.

The most simple analisys we can think on is based in two variables:

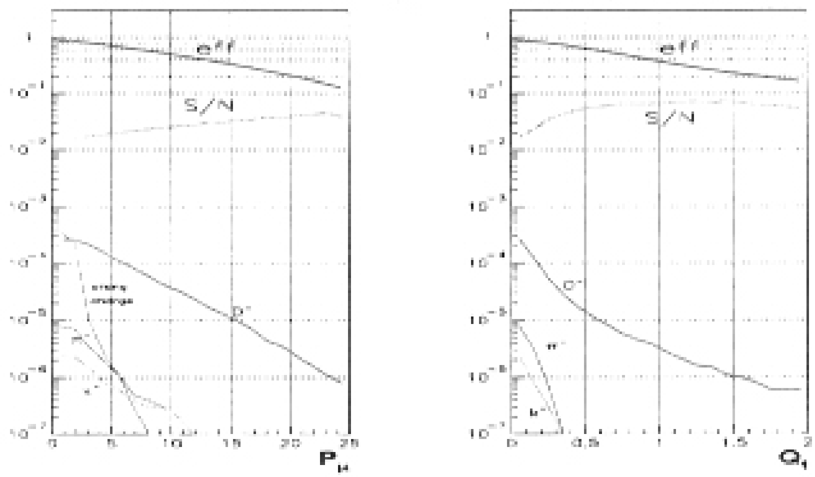
- The momentum of the muon P_μ
- Q_t



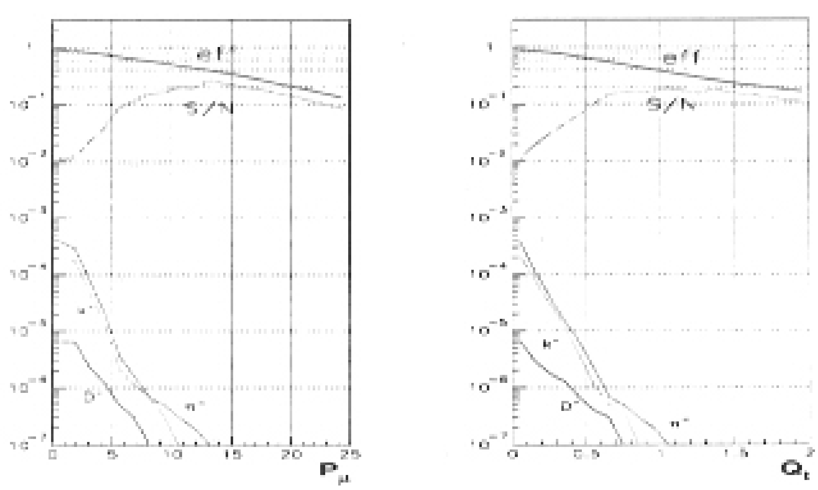
$$Q_t = P_\mu \sin\theta$$

50 GeV muon beam

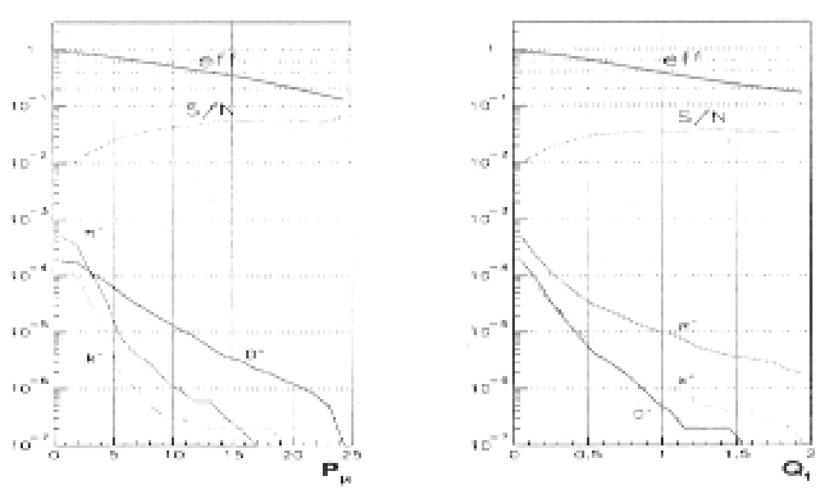
$\overline{\nu}_\mu$ CC events



ν_eCC events

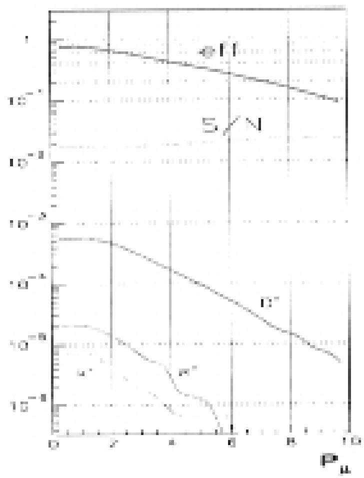


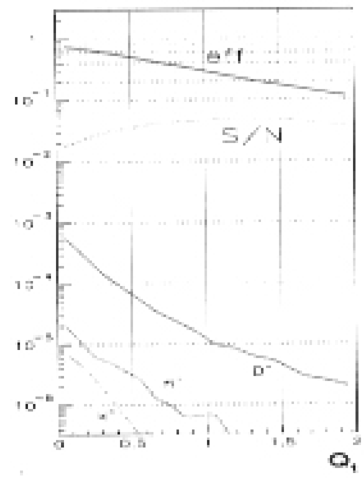
$(\overline{\nu}_\mu+\nu_e)$ NC events



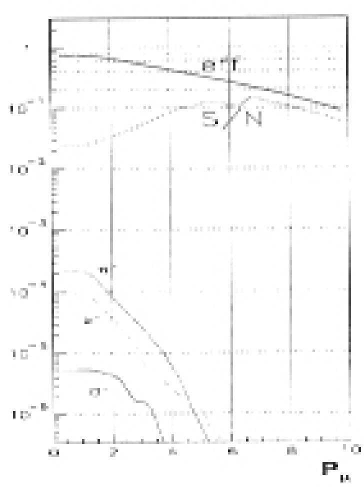
20 GeV muon beam

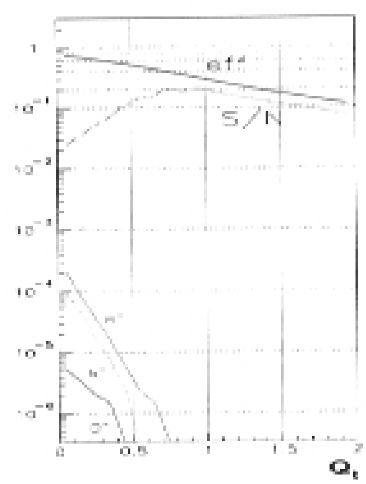
$\overline{\nu}_\mu$ CC events



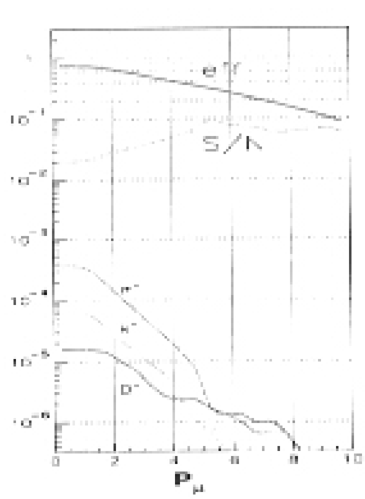


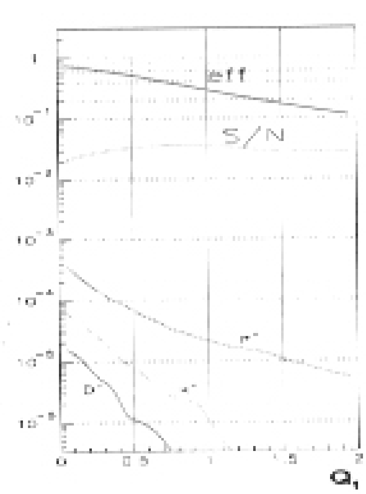
ν_eCC events





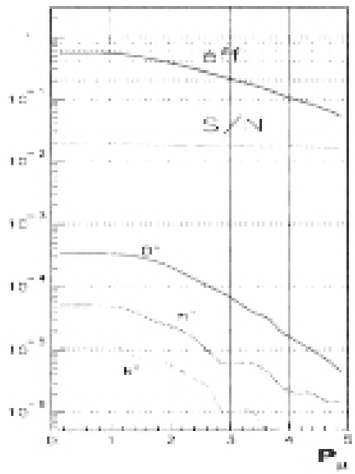
$(\overline{\nu}_\mu+\nu_e)$ NC events

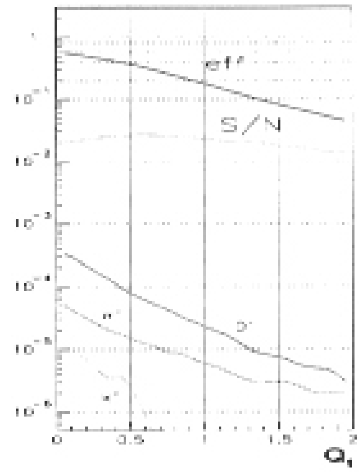




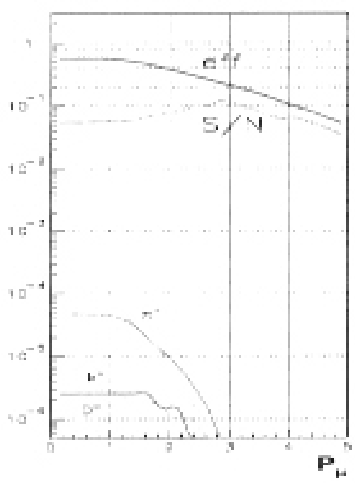
10 GeV muon beam

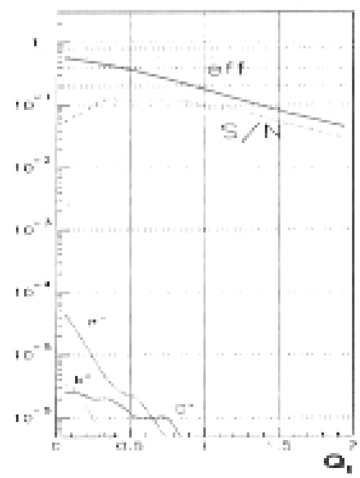
$\overline{\nu}_\mu$ CC events



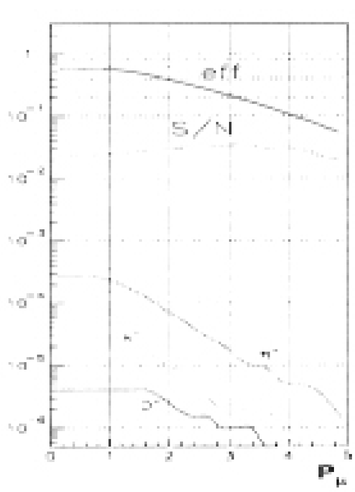


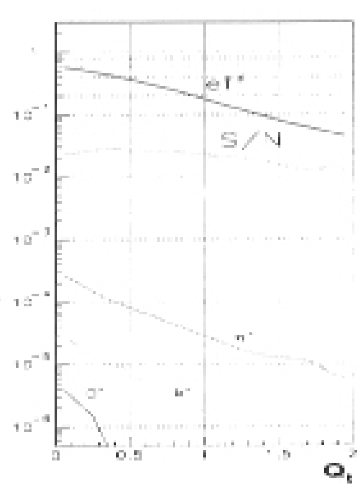
ν_eCC events





$(\overline{\nu}_\mu + \nu_e)$ NC events

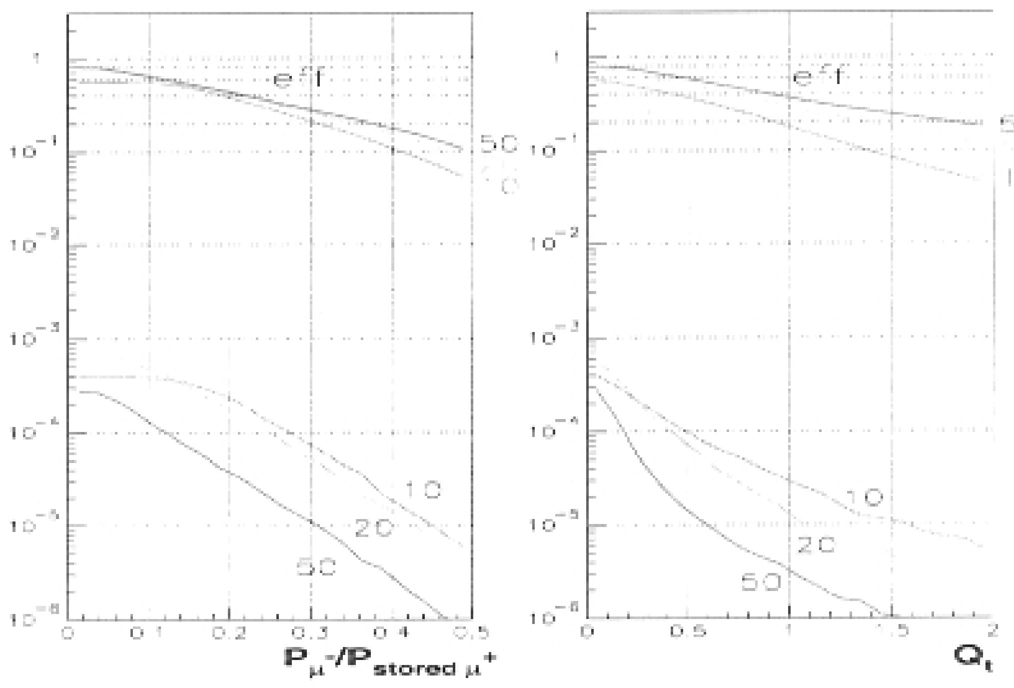




Dependence of the backgrounds on the muon-beam momentum

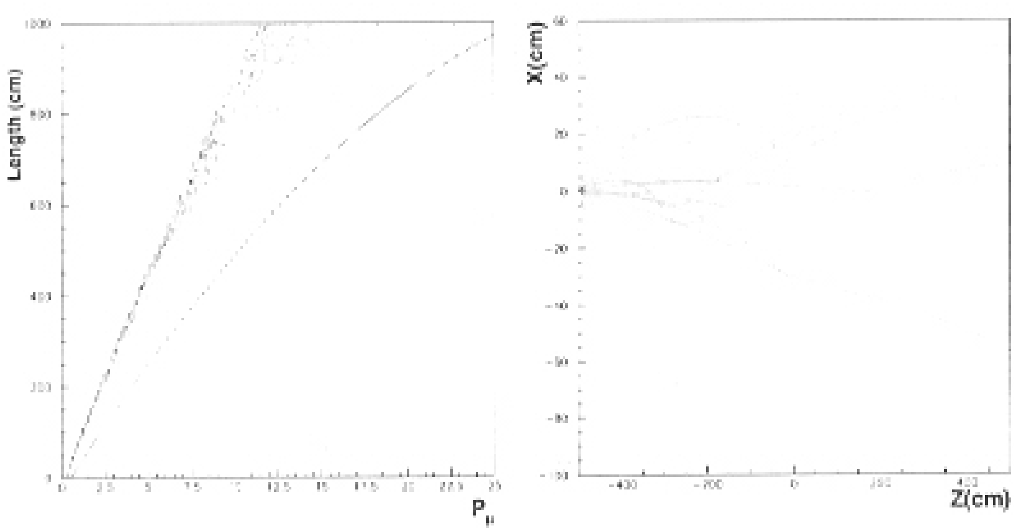
Muon-beam momentum (GeV/c)	Charm production (%)	Lost muon (%)	Charm background (%)
10	0.3	10.8	0.041
20	0.7	4.0	0.068
50	1.2	1.4	0.046

Efficiency and bg-reject for $\overline{\nu}_\mu$CC

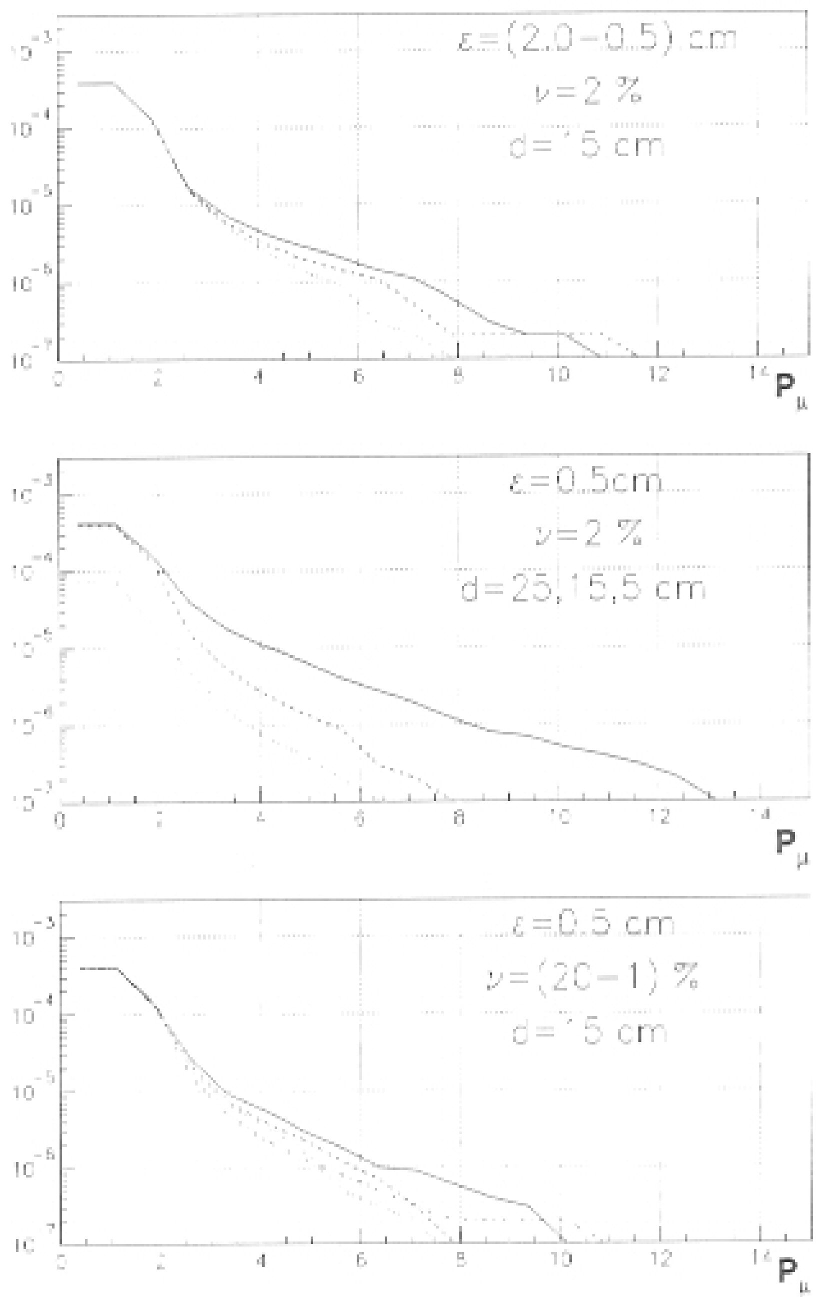


Tracks in whose we have misidentified the charge

- Tracks with very low number of hits
- Tracks with high momentum and relatively low number of hits
- Tracks with a very unlikely high angle scatter



- ϵ = transverse resolution
- ν = percentage of lost hits
- d = distance between measurement planes



This kind of background can be easely controlled (10^{-7}) with a reasonable cut in momentum

Long baseline sites for an European Nufact

- Presented by H. Wenninger
- An European Nufact will have a “short base line” site in Gran Sasso (at 730 Km)
- A long base line site must:
  - Be located at O(3000) Km from CERN
  - Sufficiently deep (cosmic background=
  - Have existing infrastructure and good access
  - Supportive local community

FROM THE ν.OSC WORKING GROUP CONVENERS (DYDAK, GOMEZ-CADENAS)

Expression of Interest for a Large Magnetic Detector

- A liquid argon TPC is with ICARUS on the way at Gran Sasso
- We need a large magnetic detector as the main workhorse at BOTH 732 and 3000 Km
- Therefore, we feel that is necessary to:
  - State the interest in a large magnetic detector
  - Submit a letter of intent to the SPSC and to the Gran Sasso Scientific Committee

Long baseline neutrino experiments

New sites /optimum 3000 km Spain, Norway, Finland

Criteria:
distance from CERN, depth, background
existing infrastructure, access
local community

La Palma (Canary islands)
astronomical observatories
Tunnels (1km long) under 800m of basaltic stone

CUPP (Centre for Underground Physics **Pyhäsalmi)**
Cosmic ray observatory
960m to 1200m   2296 km from CERN

Hammerfest / Spitzbergen

Michel Mayoud /Mark Jones / Aude Wiart
Position decay ring
neutrino beam to near detector   Gran Sasso
neutrino beam to far detector   Hammerfest
La Palma
Pyhäsalmi

Expression of Interest for a Large Magnetic Detector

- In the opinion of the convenors of the Nufact oscillation working group
  - The Nufact is now one of three options for the future of CERN after the LHC
  - Money must be spent in 2009 (machine R &D)
- In parallel we need to develop a concrete detector scenario around a short and a long baseline
  - Gran Sasso
  - Canary Islands or Northern Scandinavia

Conclusions

- Significant progress for Super neutrino beam studies. Preliminary conclusions: Interesting but not alternative to Nufact
- Update on Large Magnetic Detector. Charge misidentification seems manageable
- Prospects for sites under way (did you notice how beautiful La Palma is?)
- We feel that a LOI stating the interest of the LMD should be submitted to CERN and Gran Sasso