Conventional Neutrino Beams

vs Neutrino Factories

at same high power

V. Palladino
NuFact 2000
Monterey, 22 May 2000

Proceedings
νFact 99
Lyon

Neutrino beams: μ decay vs π decay

Vittorio Palladino

University and INFN Napoli, Italy
E-mail: Vittorio.Palladino@cern.ch

Abstract

We propose a preliminary comparison, in terms of general features, yields and event rates, of neutrino factories based on muon decay and conventional neutrino beams based on pion decay. The comparison focuses on high energy neutrinos, with average energy of 10 Gev or more.

Most emphasis is given to beams designed for modern searches of long baseline neutrino oscillations. Performance for conventional short baseline neutrino experimentation is also considered.

In both type of facilities, yields and event rates increase steeply with the average energy of the neutrino parents. At equal energy of the parent, ν_μ rates about 100 times larger and ν_e rates more than 10000 times larger appear accesible to neutrino factories. This large additional yield of high energy ν_e, that can be separated by lepton number (charge) recognition in the neutrino detector, is possibly the most important new feature of neutrino factories. A much wider and complete range of physics goals, including study of the full leptonic mixing matrix and possibly of CP violation, can be addressed.

Decay of a measurable rate of muons provides a much better known and controllable neutrino flux, free of the hadronic uncertainties on the number and distribution of parent hadrons that affect conventional neutrino beams. This is likely to be one of the major advantages of neutrino factories. In addition, they can provide beams more flexible, tunable, and orientable and a more effective production of neutrinos per unit consumption of energy.

Because a much shorter shielding is required, short baseline neutrino detectors will be able to profit of much more intense and collimated beams. Sofisticated devices of small dimensions will be able to replace the traditional large coarse grain detectors.

1 Introduction

Neutrino factories based on muon decay are the subject of this workshop. My task is to collect here a number of qualitative and quantitative arguments

Preprint submitted to Elsevier Preprint *13 March 2000*

BEAM PARAMETERS

Conventional Neutrino beam vs Neutrino Factory beam

	Conventional	Neutrino Factory
parents	π^+, K^+ or π^-, K^-	μ^- or μ^+
ν_μ beam background	ν_μ $\sim$2% of $\bar{\nu}_\mu$, $\sim$1% of ν_e	$\nu_\mu : \bar{\nu}_e = 1 : 1$ none
$\bar{\nu}_\mu$ beam background	$\bar{\nu}_\mu$ $\sim$6% of ν_μ, $\sim$0.5% of $\bar{\nu}_e$	$\bar{\nu}_\mu : \nu_e = 1 : 1$ none
variation of average energy	limited	free within factor of $\sim$3
uncertainty of ν energy spectrum uncertainty of ν radial spectrum uncertainty of absolute ν flux	$\pm$10% $\pm$10% $\pm$10%	$<$ 1% $<$ 1% $<$ 1%
ν flux per year at 730 km (ν_μ per cm^2)	3×10^7 (optim. NGS) (4.5×10^{19} 400 GeV pot)	3×10^9 (10^{21} injected 50 GeV μ)

$2\ 10^{20}$ μ's/year

↓

10^{21} μ's/year

Date: Thu, 24 Feb 2000 09:20:39 +0100 (MET)
From: Friedrich DYDAK <Friedrich.Dydak@cern.ch>
To: Vittorio PALLADINO <vittorio.palladino@na.infn.it>
Subject: Re: High-intensity conventional neutrino beam (fwd)

Dear Vittorio:

Interesting reading, isn't it? I am sending this to you, to underline what importance is given to the themes which you are treating in your written contributions to Lyon'99, and what further importance it will have in Monterey.

Sincerely, Friedrich

PS: You MUST submit your two contributions, even if brief.

---------- Forwarded message ----------
Date: Wed, 23 Feb 2000 16:13:29 -0800
From: Burton Richter <BRichter@SLAC.Stanford.EDU>
To: Friedrich DYDAK <Friedrich.Dydak@cern.ch>
Cc: Alain Blondel <Alain.Blondel@cern.ch>,
Jonathan ELLIS <john.ellis@cern.ch>, Andrew SESSLER <amsessler@LBL.GOV>,
wurtele@socrates.berkeley.edu, belen.gavela.legazpi@cern.ch,
Bruno AUTIN <Bruno.Autin@cern.ch>,
Friedrich DYDAK <Friedrich.Dydak@cern.ch>,
Helmut HASEROTH <Helmut.Haseroth@cern.ch>,
Norbert Holtkamp <holtkamp@fnal.gov>, peccei@physics.ucla.edu,
Swapan Chattopadhyay <S_Chattopadhyay@LBL.GOV>, Serguey.Petcov@cern.ch,
Steve GEER <sgeer@fnal.gov>, Stanley Wojcicki <sgweg@SLAC.Stanford.EDU>,
Jonathan WURTELE <wurtele@physics.berkeley.edu>,
y.declais@ipnl.in2p3.fr, yoshiharu.mori@kek.jp,
Yoshitaka KUNO <yoshitaka.kuno@kek.jp>
Subject: Re: High-intensity conventional neutrino beam

Dear Friedrich:

I think you under-rate the difficulties of using a mixed muon-electron neutrino source and over-rate the difficulties of using a more conventional source. We are not really going to know much more about electron-neutrino properties until the KamLAND and MiniBOONE experiments are done. From what we know from the solar neutrino problem, it will take a very sophisticated detector to untangle electron and muon-neutrino interactions with the mixed neutrinos originating in a high-energy muon storage ring.

Electron and neutrino backgrounds in muon-neutrino beams produced conventionally (either horn focused, or monochromatic) are typically below one per cent. It should be easier to make a definitive determination of muon neutrino properties and mixing from those beams if they can be made intense enough and clean enough. I don't have enough information on what kind of conventional beams you can create to answer my own question. I still think it would be quite interesting to hear from someone who has done the necessary work.

Regards,

Burt

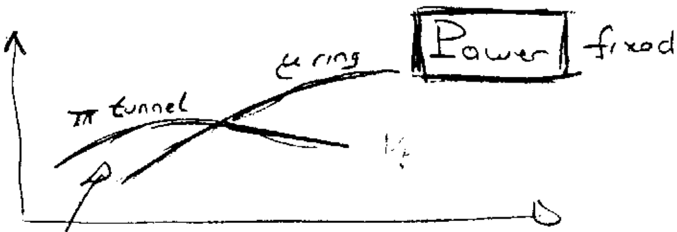
At 09:20 AM 02/16/2000 +0100, Friedrich DYDAK wrote:
>On Tue, 15 Feb 2000, Burton Richter wrote:
>>
>> I mentioned in my earlier message that for the lower energies a
>> conventional neutrino source may well be competitive and faster to build.

>> The higher the neutrino energy required, the more advantage there is for
>> the muon ring source. Could we get a talk on the potential of conventional
>> horn focused beams vs muon storage rings as a function of energy for the
>> same proton source power?
>>
>
>Dear Burt:
>
>I certainly agree that a conventional horn-focused neutrino beam is easier
>and faster to build, and that it would have a comparable beam intensity
>compared to what one gets from an associated muon storage ring.
>
>But the beam quality is very different as you know well. HERE you have
>essentially muon-neutrinos with a typical 5 - 10 % uncertainty in
>everything, with badly known backgrounds of electron-neutrinos and
>anti-neutrinos of either flavour. THERE you have well-determined
>muon-neutrinos and electron-neutrinos of equal strength, with no
>background. It is in the first instance the intense electron-neutrinos
>which make the neutrino factory superior.
>
>Why? The physics challenge is the determination if the mass-sign of
>Delta_m squared, and of the CKM elements of the neutrino mixing matrix, up
>to and including CP violation. Remaining with muon-neutrino beams alone
>does not bring us much further, so why bother with yet another round of
>conventional horn-focused neutrino beams? To attack Theta_13 and the CP
>violation phase, we need electron-neutrino beams.
>
>This said, I hasten to add that I have of course nothing against a talk
>which either agrees or disagrees with this opinion of mine, with a view to
>putting the arguments on the table.
>
>Sincerely, Friedrich
>
>

Professor Burton Richter
Director Emeritus
Stanford Linear Accelerator Center
Tel: 650/926-2601
Fax: 650/926-4500

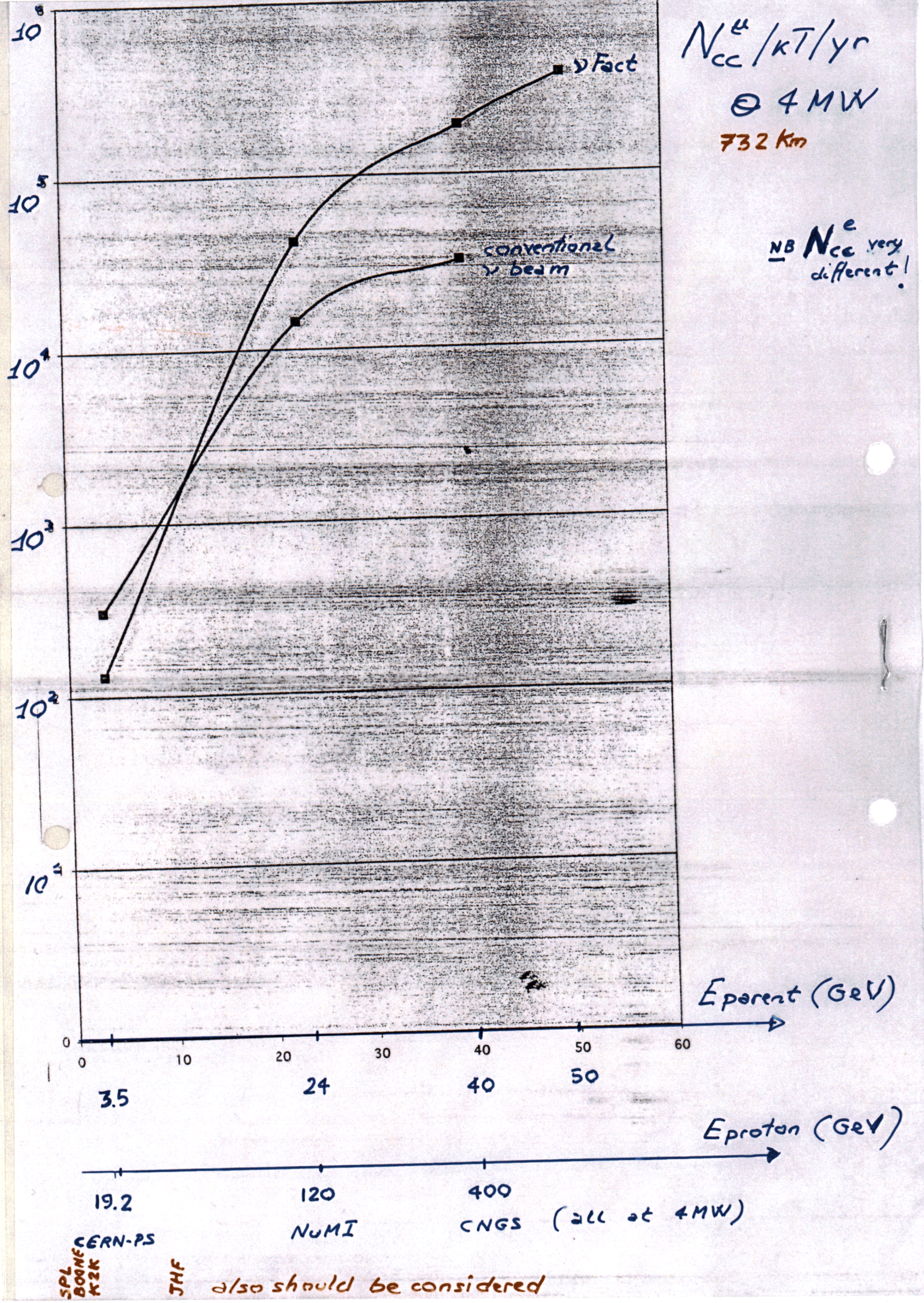
→ talk on the potential of

present on April 10 or May 8



how powerful

is this true?



N^{μ}_{cc} /kT/yr
@ 4 MW
732 Km
NB N^{e}_{cc} very different!
ν Fact
conventional ν beam
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
0
10
20
30
40
50
60
E parent (GeV)
3.5
24
40
50
E proton (GeV)
19.2
120
400
CERN-PS
NuMI
CNGS
(all at 4MW)
SPL
BOONE
K2K
JHF
also should be considered

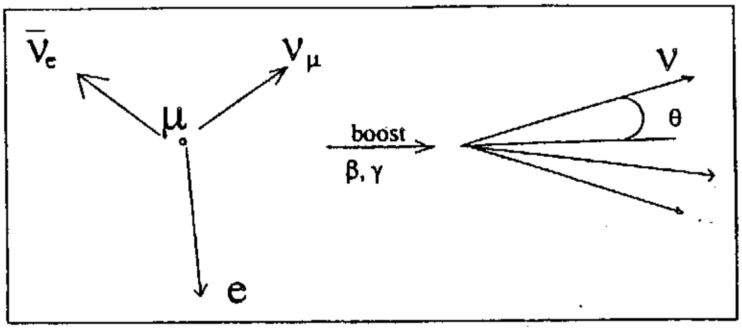


Fig. 5. Muon decay.

the smallness of the solid angle covered by the neutrino detector, most of the flux will come from pions of higher energy and line of flight parallel (or made parallel by the focusing system) to the central (proton) beam axis.

The flux of neutrinos through the neutrino detector described above can now be simply calculated for a beam where N_π pions, with γ factor γ_π, decay. At very large L, only neutrinos emitted with θ angles very close to 0 and therefore with y = 0.427 will be relevant. The detector surface element being $dS = 2\pi L^2 dcos\theta$, one gets, for large γ_π ,

$$d^2N_\nu/(dSdy)(\theta = 0) = N_\pi \gamma_\pi^2 \delta(y - 42.7\%)/(\pi L^2) \quad (4)$$

π decay
2-body

4.2 muon decay

Muon decay is a three body decay of a spin 1/2 particle (fig 5).

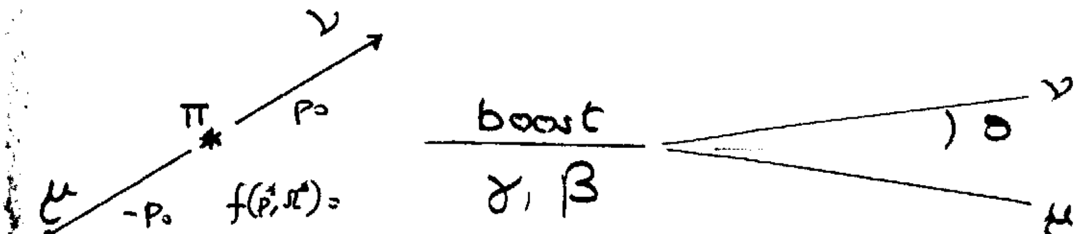
In the very forward direction, however, one obtains the same sharply peaked angular distribution of neutrinos (with forward value growing as γ^2 and width shrinking as $1/\gamma^2$). Similarly the flux of neutrinos in a detector centered on the axis of the muon storage ring straigth section and placed at a very large distance L from the region of muon decays, can be simply calculated for a straigth section where N_μ muons, with γ factor γ_μ, decay. At very large L, one gets, for large γ_μ,

$$d^2N_\nu/(dSdy)(\theta = 0) = N_\mu \gamma_\mu^2 F_\nu(y)/(\pi L^2) \quad (5)$$

μ decay
3-body

The only difference with respect to pions is that the y distributions $F_\nu(y)$ are not δ functions (at 42.7% of the parent momentum), but real distributions over the full y range. They are different for the ν_μ ($\bar{\nu}_\mu$) and $\bar{\nu}_e$ (ν_e) produced in μ^- (μ^+) decays and are shown in fig. 6. The ν_μ ($\bar{\nu}_\mu$) distribution is harder in the average ($< y >= 0.7$) than the $\bar{\nu}_e$ (ν_e) distribution ($< y >= 0.6$). We have assumed here that we are dealing with unpolarized muons.

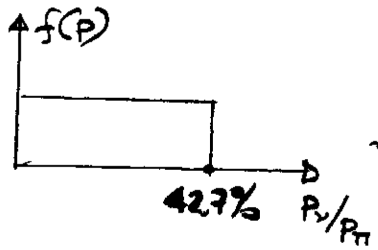
π decay



$f(\vec{p}^*, \Omega^*) = \frac{1}{4\pi}\delta(\vec{p}^* - p_0^*)$

$$f(p_\nu, \Omega) = \frac{1}{4\pi} \frac{1}{\gamma(1-\beta\cos\theta_\nu)} \delta\left[\gamma(1-\beta\cos\theta)p_\nu - \vec{p}_0^*\right]$$

$$p_\nu = \frac{p_0^*}{\gamma(1-\beta\cos\theta_\nu)}$$



$$f(p_\nu)dp_\nu = \frac{1}{2\beta\gamma p_0} dp_\nu \quad \text{flat}$$

$$f(\cos\theta_\nu) d\cos\theta_\nu = \frac{1}{2} \frac{d\cos\theta_\nu}{\gamma^2(1-\beta\cos\theta_\nu)^2}$$

strongly forward peak

$$f(\theta \to 0) \xrightarrow[\beta \to 1]{} 2\gamma^2$$

shrinking $\sim 1/\gamma^2$

at L, $dS = 2\pi L^2 d\cos\theta$

$$\left.\frac{1}{N_\pi} \frac{dN_\nu}{dS\,dy}\right|_{\theta=0} = \frac{\gamma^2}{\pi L^2} \delta(y - 42.7)$$

↓

$$P_\nu / P_\pi = Y_{max} =$$

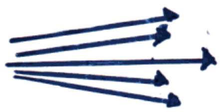
$$= \left[1 - \left(\frac{m_\mu}{m_\pi}\right)^2\right] = 42.7\%$$

NBB

$$\xrightarrow[N_\pi]{p_\pi} \dashrightarrow \vartheta_\nu = 0$$

$$p_\nu = 0.427\, p_\pi$$

WBB



$$\frac{d^2 N_\pi}{dp_\pi \, d\cos\vartheta_\pi}$$

simplified to

$$\xrightarrow[N_\pi^{\text{effective}}]{p_\pi^{\text{effective}}}$$

$$N_\pi^{\text{effective}} =$$

$$= \frac{\int dp_\pi \, d\cos\vartheta_\pi \, \frac{d^2 N_\pi}{dp_\pi \, d\cos\vartheta_\pi} \, P_{\vartheta_\nu = 0}(p_\pi, \cos\vartheta_\pi)}{\int dp_\pi \, d\cos\vartheta_\pi \; P(\dots)}$$

$$P_{\vartheta_\nu = 0}(p_\pi, \cos\vartheta_\pi) = \frac{1}{\gamma_\pi^2 (1 - \beta_\pi \cos\vartheta_\pi)^2}$$

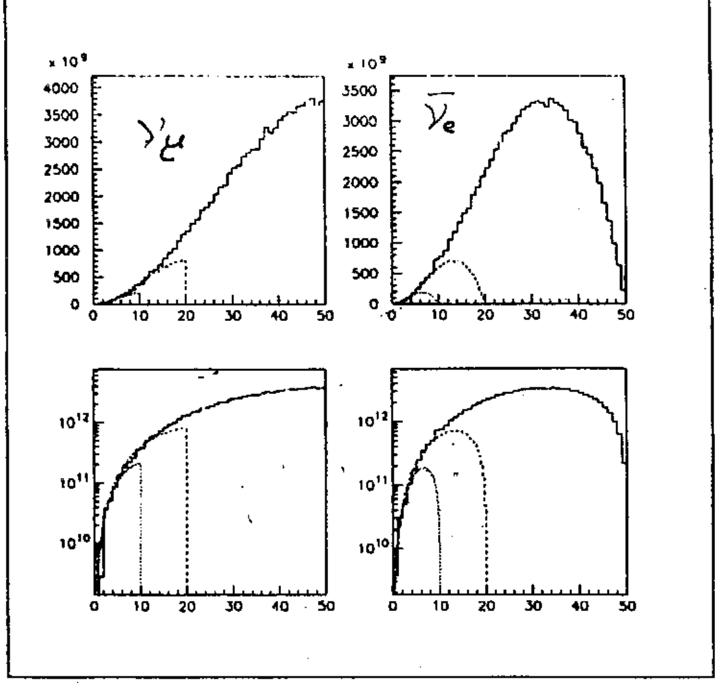


Fig. 8. Energy distribution of ν_μ (left) and ν_e (right), in linear (top) and log (bottom) scale, from an ideal μ^+ beam of 10, 20 and 50 Gev/c momentum.

F_ν

that the ν flux at low energy stays unchanged and additional flux at higher energies is gained when the muon momentum grows. One is thus lead to the conclusion that as much energy as possible should be provided to the muons in their final acceleration. This is the best use one can make of them after the difficult tasks of collection and phase space reduction will have been painfully mastered.

- comparison of the two types of neutrino facili]ties should take in account that the performance of both depends strongly on the energy of the parents.

The claim that the highest parent momentum should be sought is however only one of the aspects. Apart from the fact that on physics ground a lower energy may be sometime desirable, neutrino yield per unit time is influenced also by the number of parent decays that one is capable to induce per unit time.

In general, for both type of neutrino sources, the forward flux from N_{decay} decays of parents with γ factor γ_{decay} is

$$d^2N_\nu/(dSdy)(\theta = 0) = N_{decay}\gamma^2_{decay}F_\nu(y)/(\pi L^2) \quad (6)$$

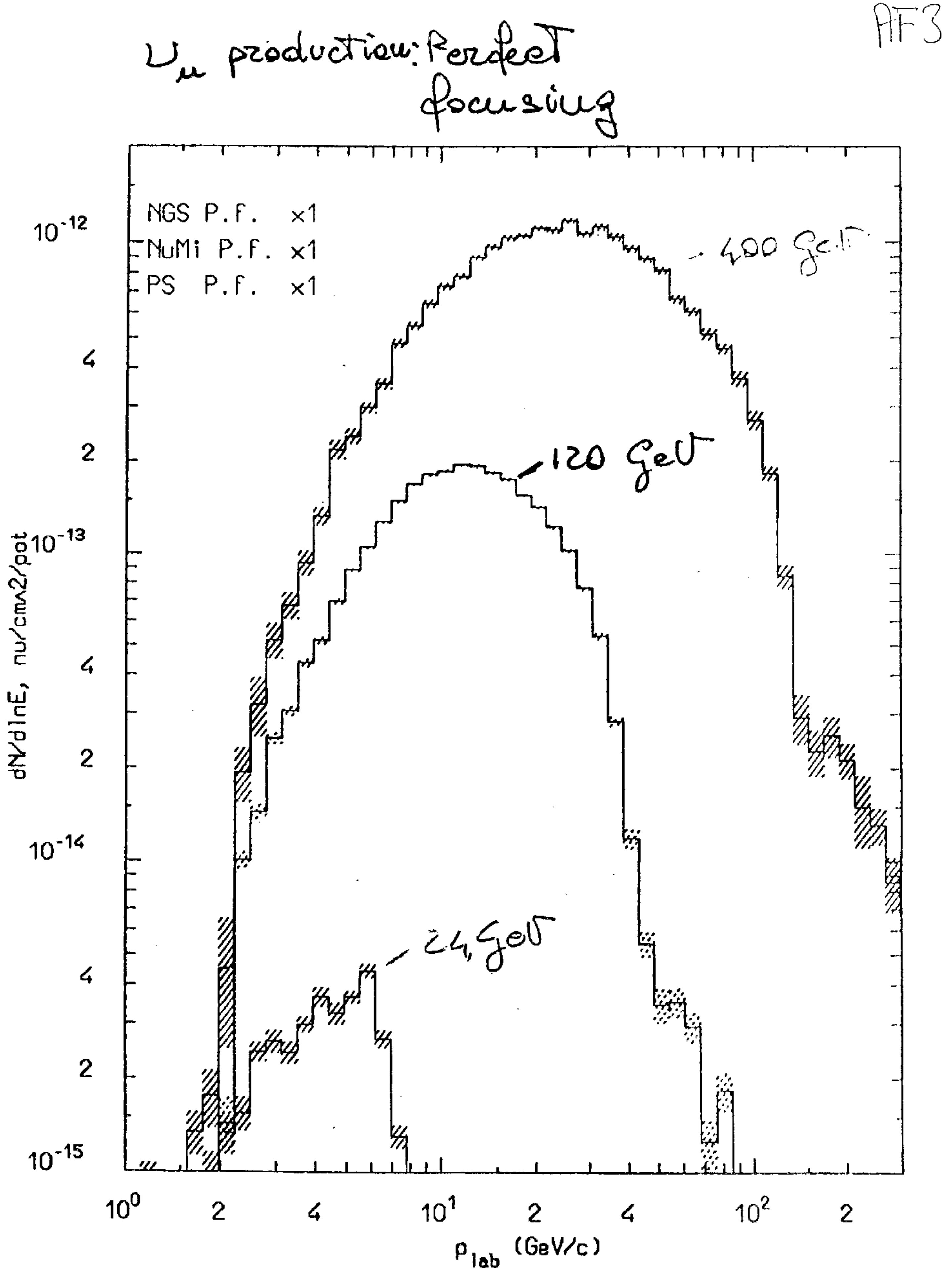
π and μ - the boost!!

N_{decay} is the number of decays of neutrino parents that any given facility is capable to provide. It multiplies a kinematical and geometrical factor that depends on the particular decay being considered only via the $F_\nu(y)$ function

$$N_{CC} \simeq N_{decay} \frac{E^3_{decay}}{m^2} \langle y \rangle \frac{1}{\pi L^2} \sigma_0 N_{TARGETS}$$

F_ν relevant for N_{cc} $\langle y \rangle E_{decay}$

$\langle y \rangle$ = 42.7% $\pi \to \nu_\mu$
70% $\mu \to \nu_\mu$
60% $\mu \to \bar{\nu}_e$


AF3
ν_μ production: Perfect focusing
NGS P.f. x1
NuMi P.f. x1
PS P.f. x1
400 GeV
120 GeV
24 GeV
dN/dlnE, nu/cm^2/pot
p_{lab} (GeV/c)

the energy of decaying ν parent is the key to high ν flux (per proton)

the advantage of the ν Fact vs conventional beams comes from

its strategy of selective acceleration of the ν parent (the μ)

in conventional ν beams protons are accelerated .... a large fraction of that energy is wasted into many useless hadrons (neutrals, undecayed π's etc....) that are dumped in the shielding

CNGS

Table 5: *Predicted performance of the new NGS reference beam. The statistical accuracy of the Monte-Carlo simulations is 1 % for the ν_μ component of the beam, somewhat larger for the other neutrino species.*

Energy region E_{ν_μ} [GeV]	1 - 30	1 - 100
ν_μ [m^{-2}/pot]	7.1×10^{-9}	7.45×10^{-9}
ν_μ CC events/pot/kt	4.70×10^{-17}	5.44×10^{-17}
$\langle E \rangle_{\nu_\mu\, fluence}$ [GeV]		17
fraction of other neutrino events:		
ν_e/ν_μ	0.8 %	
$\overline{\nu}_\mu/\nu_\mu$	2.0 %	
$\overline{\nu}_e/\nu_\mu$	0.05 %	

Table 6: *Expected number of ν_τ CC events at Gran Sasso per kt per year. Results of simulations for different values of Δm^2 and for $sin^2(2\theta) = 1$ are given for 4.5×10^{19} pot/year. These event numbers do not take detector efficiencies into account.*

Energy region E_{ν_τ} [GeV]	1 - 30	1 - 100
$\Delta m^2 = 1 \times 10^{-3}\,\mathrm{eV}^2$	2.34	2.48
$\Delta m^2 = 3 \times 10^{-3}\,\mathrm{eV}^2$	20.7	21.4
$\Delta m^2 = 5 \times 10^{-3}\,\mathrm{eV}^2$	55.9	57.7
$\Delta m^2 = 1 \times 10^{-2}\,\mathrm{eV}^2$	195	202

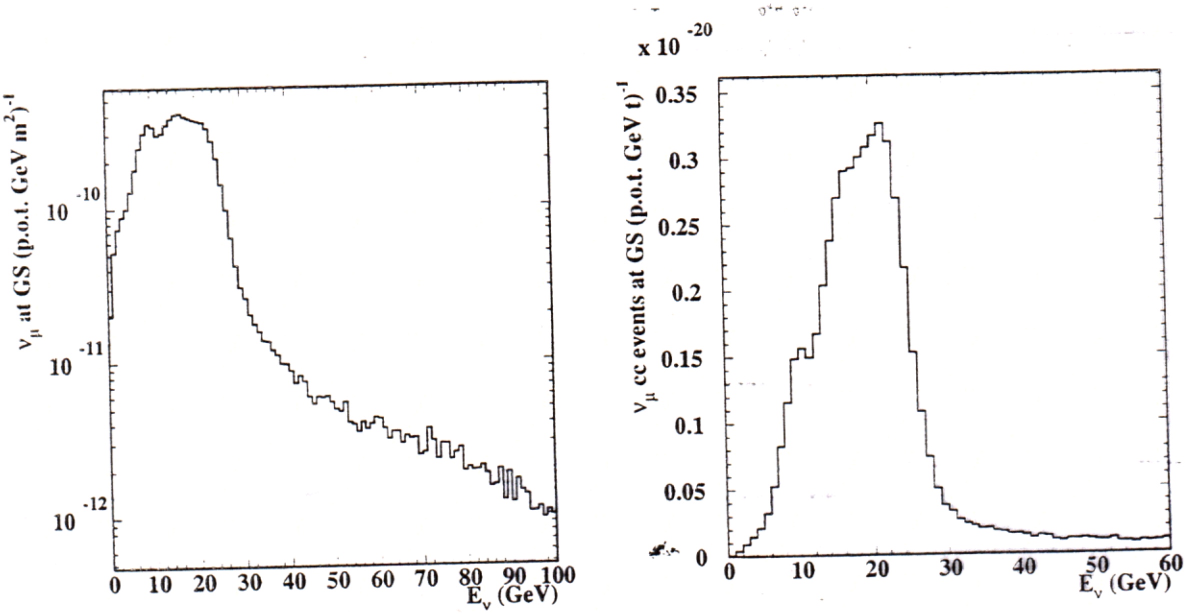


Figure 8: *Energy distribution of the ν_μ fluence (left) and of the CC ν_μ interactions (right) at Gran Sasso.*

NuMI

antiproton accumulator experience during collider Run I. Details of the GNuMI Monte Carlo used to generate the rates are given in Appendix B. Absorption by horn cooling water and by helium and air in the target hall have not been taken into account in the rate calculations, and are expected to reduce the neutrino rates by a few percent. High reliability is a premium, and increasing the thickness of the horn inner conductor at the expense of perhaps 10% of the neutrino rate may also be wise.

		Flux		*Events*	
COSMOS		ν/m^2/POT		N^{CC}/ton/year	
	ν_μ	1.90×10^{-3}	(97.6%)	3.73×10^{6}	(98.6%)
	$\bar{\nu}_\mu$	3.7×10^{-5}	(1.9%)	2.9×10^{4}	(0.77%)
	ν_e	1.0×10^{-5}	(0.53%)	2.3×10^{4}	(0.61%)
	$\bar{\nu}_e$	4.9×10^{-7}	(0.03%)	5.4×10^{2}	(0.01%)
MINOS Near		ν/m^2/POT		N^{CC}/kton/year	
	ν_μ	1.04×10^{-3}	(97.8%)	2.26×10^{9}	(98.7%)
	$\bar{\nu}_\mu$	1.9×10^{-5}	(1.8%)	1.7×10^{7}	(0.75%)
	ν_e	4.9×10^{-6}	(0.46%)	1.1×10^{7}	(0.49%)
	$\bar{\nu}_e$	2.3×10^{-7}	(0.02%)	2.7×10^{5}	(0.01%)
MINOS Far		ν/m^2/POT		N^{CC}/kton/year	
	ν_μ	1.72×10^{-9}	(97.6%)	3846	(98.7%)
	$\bar{\nu}_\mu$	3.4×10^{-11}	(1.9%)	33	(0.85%)
	ν_e	7.6×10^{-12}	(0.43%)	19	(0.48%)
	$\bar{\nu}_e$	5.4×10^{-13}	(0.03%)	0.6	(0.02%)

$< E_\nu > = 10$ GeV
" H66 "

Table 3.6: Neutrino fluxes and charged current event rates at the detector locations according to the GNuMI Monte Carlo. The MINOS near detector rate is at the beamline center, 500 m beyond the end of the decay pipe. The COSMOS rate is averaged over a 1.4 m by 1.8 m square centered on the beam line, 250 m beyond the end of the decay pipe.

Rate Uncertainties The calculation of the neutrino flux has a significant uncertainty, of order 20% at this time, because of lack of precise knowledge of the hadron production spectrum from the target. (Sections 3.3.4 and 3.3.5 will explain how to reduce this uncertainty.)

Figure 3.20 shows the source of neutrino charged current events broken down by where the decaying particle was produced, and by decay channel for

CERN PS   19.2 Gev protons

at 825 m

470	CC events in BEBC (Phys. lett. B 179 (1986) 307)			
14	ton	give	6.1 10-6	ν/m²/pot
9.1 10+18	pot			

at 732 Km	7.79 10-12	ν/m²/pot
times 5	**3.89 10-11**	
Eneutrino	**1.5 GeV**	

because L_{decay} = 50 m only
focusing outdated
....

	CERN PS	NuMI	CNGS
E proton(GeV)	19.2	120	400
E neutrino(Gev)	1.5	10	17
flux/sqm/pot	3.89 10-11	1.72 10-9	7.45 10-9
effective E pion (GeV)	3.5	24	40
gamma^2	6.3 10+2	2.7 10+4	8.3 10+4
effective Ndecay/pot	.1	.13	.15

← $P_\pi^{eff.} = P_\nu / 0.427$

← $\gamma_\pi^2 = (P_\pi / m_\pi)^2$

← $N_{\pi_{decay}}^{effective} = \dfrac{flux \cdot \pi \cdot L^2}{\gamma_\pi^2}$

using at 732 Km = L

$$\frac{1}{\pi L^2} = 6\ 10\text{-}13\ /\text{sqm}$$

$$N^{effective}_{\pi_{decay}/pot} \simeq .10 \div .15$$

roughly at all $E_{protons}$

$$\pi_{decay/pot} = \pi/pot \cdot \pi_{decay}/\pi$$

$$= \pi/pot \cdot \left(1 - e^{-L/\gamma_\pi c\tau_\pi}\right)$$

$$\simeq L/\gamma_\pi c\tau_\pi$$

for istence

NuMI	.13	=	.24	$\cdot$	46%
CNGS	.15		.42	$\cdot$	36%

E ↗ $1/E$ ↘

focus efficiency + acceptence ($p_T \sim$ constant, p_L grows)

probability of decay

	CERN PS	NuMi	CNGS
proton(GeV)	19.2	120	400
neutrino(Gev)	1.5	10	17
flux/sqm/pot	3.89 10-11	1.72 10-9	7.45 10-9
E pion (GeV)	3.5	24	40
gamma^2	6.3 10+2	2.7 10+4	8.3 10+4
Ndecay/pot	.1	.13	.15
pot/year @4MW	1.3 10+22	2.1 10+21	6.2 10+20
flux/sqcm/yr @4MW	5.1 10+7	3.6 10+8	4.610+8
CC/kT/year @4MW	3.05 10+2	1.44 10+4	3.18 10+4

$\dot{N}_{pot} = 1/E$ at fixed MW (E.Keil ...)

} see plots

νFact

use PJK

0.004 μ/p/GeV

in the ring!

4 MW $\Rightarrow$ 2.5 10^{16} GeV/s

10^{14} μ/sec

10^{21} μ/yr

($1\,yr \sim 10^7 s$)

for E_μ = 3.5 GeV

24 GeV

40 GeV

50 GeV

$\Rightarrow$ 82 GeV π give same $\langle E_\nu \rangle$ = 35

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

BNL-66971
CERN SL/99-070 AP
NEUTRINO FACTORY NOTE 09

A Cost-Effective Design for a Neutrino Factory

R.B. Palmer*
Brookhaven National Laboratory, Upton NY, USA
C. Johnson and E. Keil
CERN, Geneva, Switzerland

Abstract

The design of a neutrino factory based on a muon storage ring draws upon several tried and tested technologies, upon existing design work for other accelerator projects, e.g. neutron spallation sources, but it also depends on the development of technical solutions to certain specific requirements. These include the efficient capture of muons in a large volume of phase space, some reduction in overall phase space volume by ionization cooling, fast acceleration to the desired energy to avoid unacceptable decay losses and storage in a decay ring optimised for its purpose as a neutrino source. There is no obvious single combination of machines to achieve this aim. Here we present a scenario which relies to a large extent upon known technologies together with a relatively unambitious mix of new schemes. Some will be tried and tested during design and construction. Others during the early operational phase of the facility leading to a staged upgrade path – a well-proven strategy in the development of accelerator complexes.

Geneva, Switzerland

November 25, 1999

* Supported by US Department of Energy contract DE-AC02-98CH10886

Acceleration

min E for full sc cells 7.5 GeV min E for 1/4 sc cells 1.8 GeV

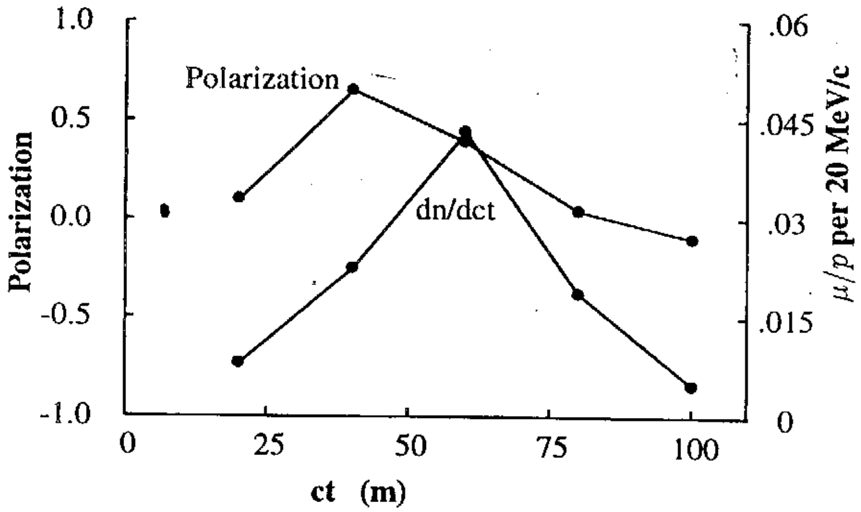
		Lin 1	Lin 2	Recirc 1	Recirc 2
p	GeV/c	.1-.7	.7-2.0	2-8.2	8.2-30
freq	MHz	175	350	350	350
Grad	MV/m	15	10	10	10
Δ p	GeV/c	.6	1.3	1.5	5.5
n		1	1	4	4

Muon Budget

	Factor	μ/24 GeV proton
Muons after Match (below 1 GeV)		0.66
Muons after Phase Rotation #1 (selected)	0.45	0.3
Muons after Phase Rotation #2 (selected)	0.7	0.21
Muons after RF Capture	0.7	0.15
Muons after Cooling	0.9	0.13
Muons after Acceleration	0.7	0.092

.004 μ/GeV/p

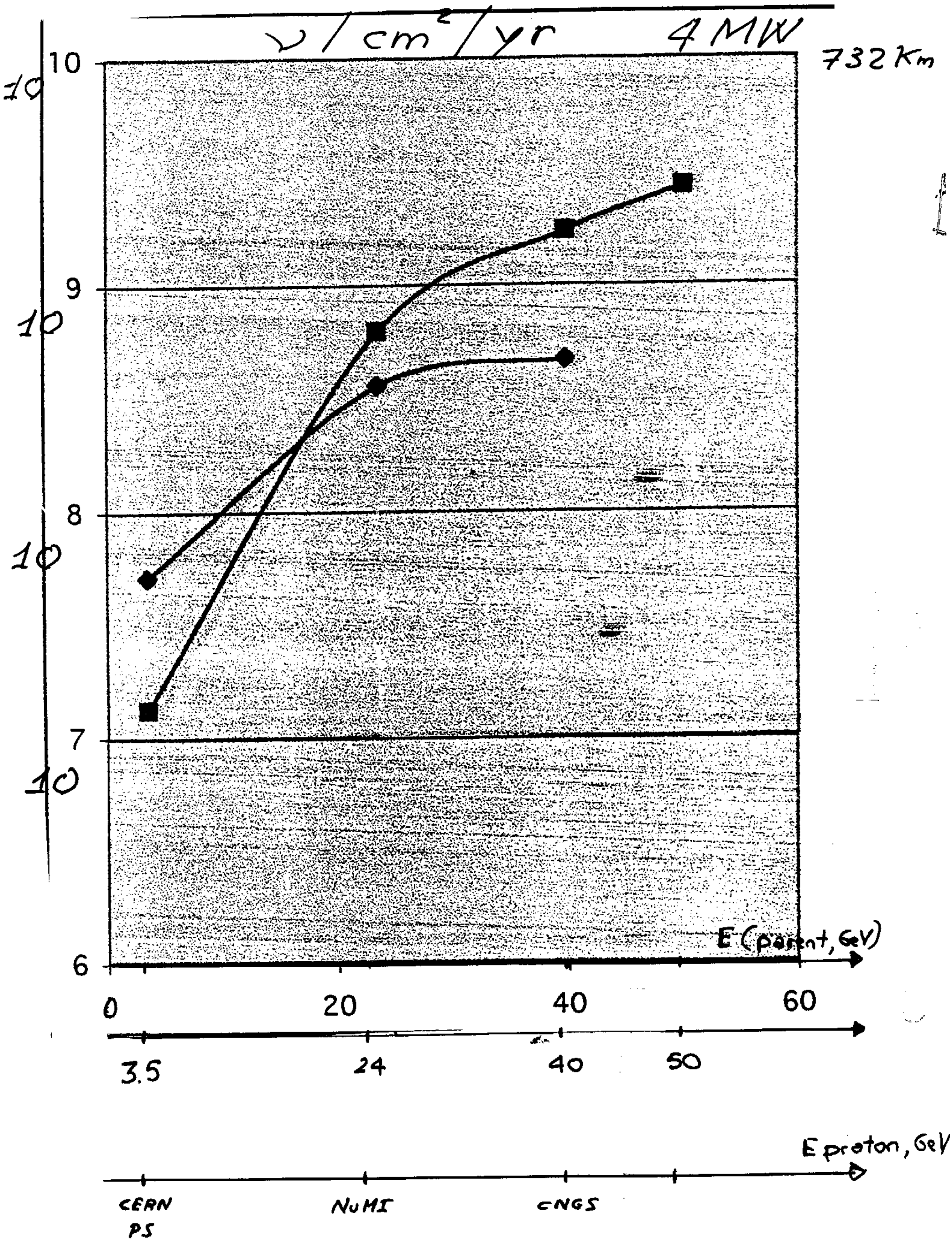
Polarization vs. position along the bunch train



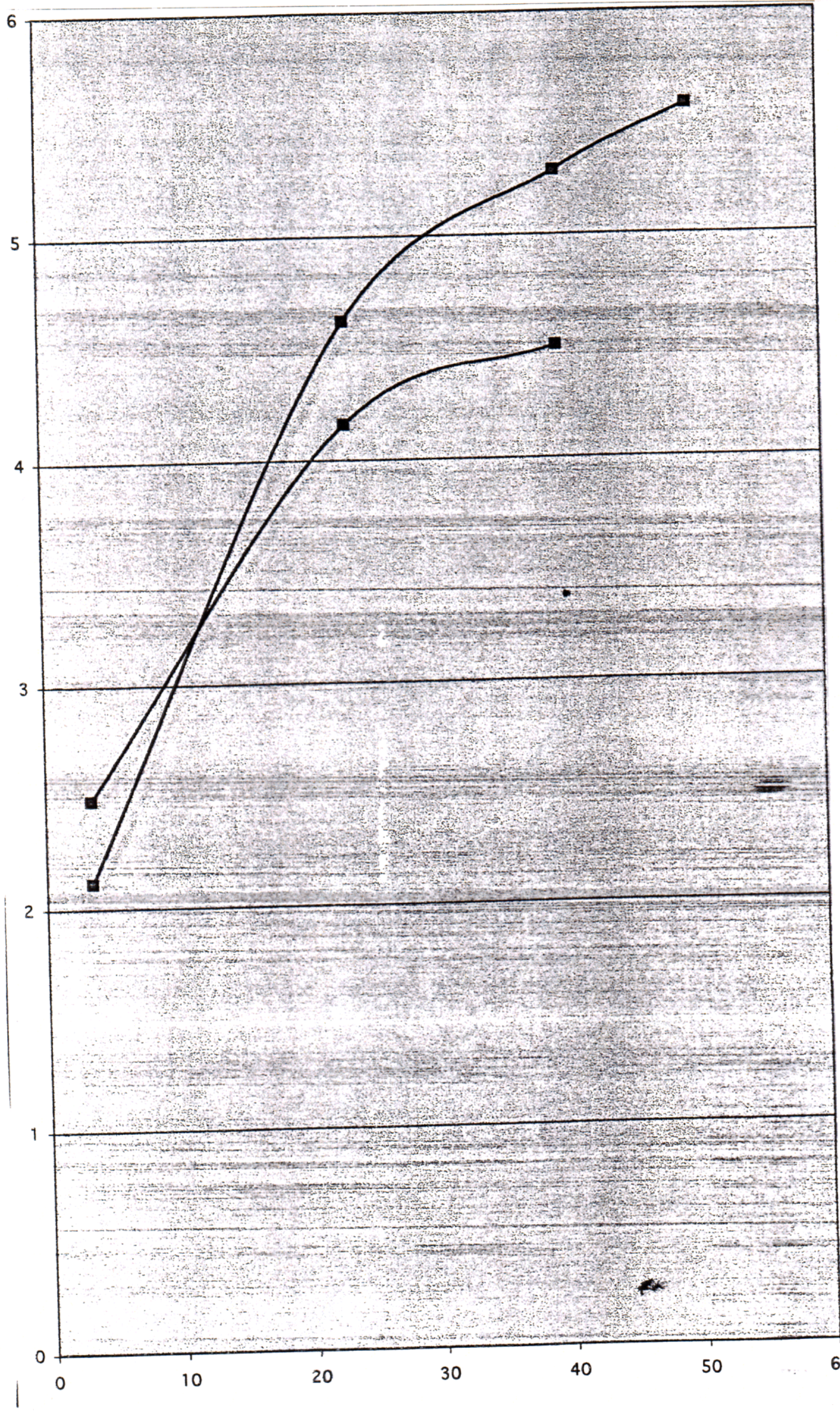
Nu Fact

E muon(Gev)	decay/yr @4MW	flux/sqcm/yr @4MW	CC/kT/year @4MW
3.5	2 10+20	1.3 10+7	1.30 10+2
24	2 10+20	6.2 10+8	4.19 10+4
40	2 10+20	1.7 10+9	1.94 10+5
50	2 10+20	2.7 10+9	3.79 10+5

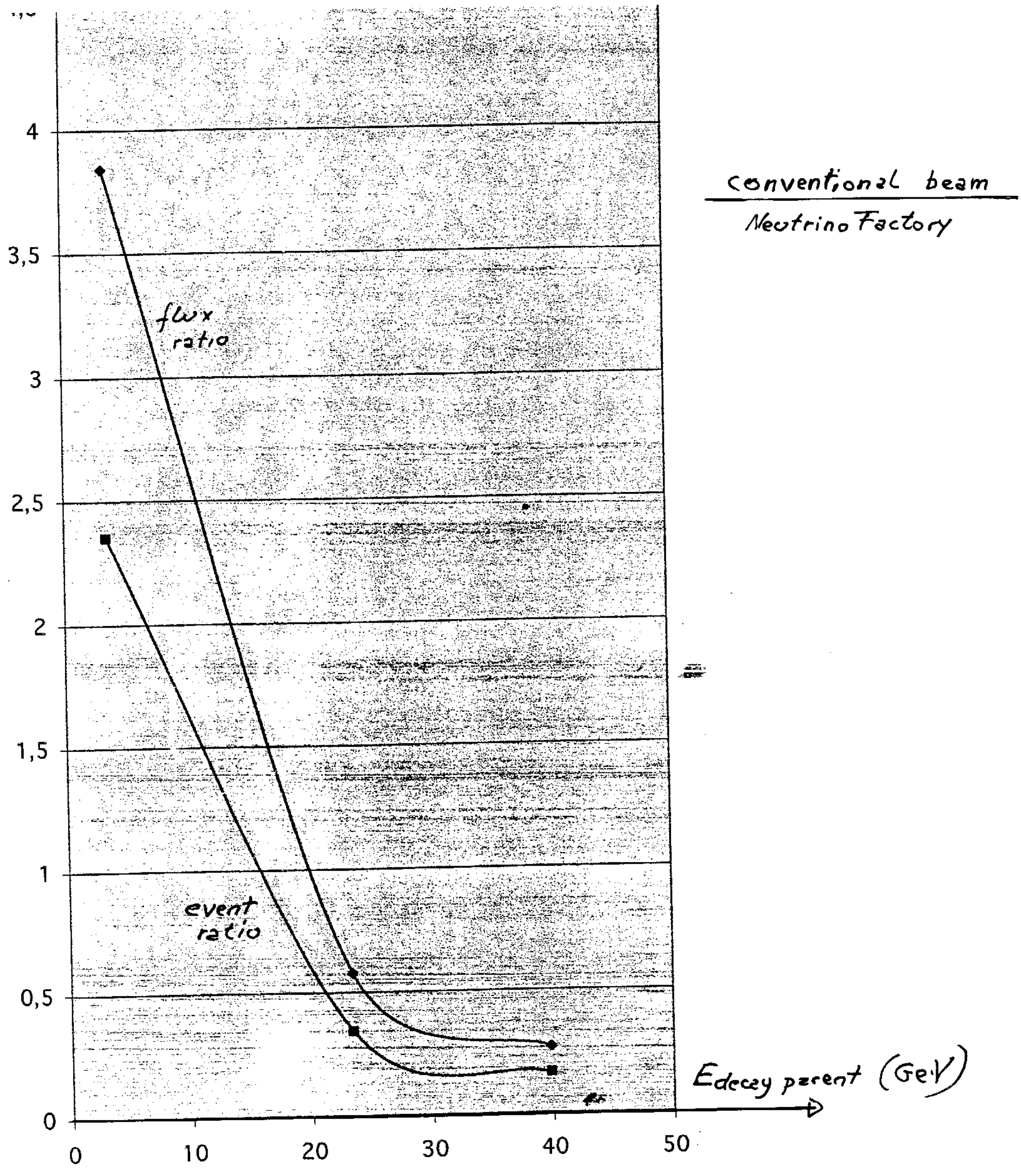
→ see plots



ν / cm² / yr
4 MW
732 Km
10
9
8
7
6
0
20
40
60
E (parent, GeV)
3.5
24
40
50
E proton, GeV
CERN PS
NuMI
CNGS



same as first plot shown



4
3,5
3
2,5
2
1,5
1
0,5
0
0
10
20
30
40
50
flux ratio
event ratio
Edecay parent (GeV)
conventional beam
Neutrino Factory

Conclusion I

νFact wins clearly out at high E_μ

where infact the limited resistence of the thin (few mm ϕ) targets typical of conventional high energy ν beams may actually further limit performance

and provides ν_e's !!!

better flux control

(N_μ much easier than $N_\pi^{eff.}$

flexibility
tunability
orientability
VLBL
2 far locations

SBL stations of unprecedented intensity

(will help flux control)

Conclusion II

however, high power conventional ν beams
do still have a role at low E

should be seriously investigated
at all high power p-drivers

SPL ... 2 GeV

....

JHF .. 50 GeV

may well give us θ_{13}

maybe $sign\{\Delta m^2_{23}\}$?

νFact can beat them ...

(... dwarf them!)

at high E_μ (and N_μ)

while providing also ν_e's

CP̸ is the driving push

νFact only capable to access it

if Δm^2_{12}, θ_{12} are kind to us