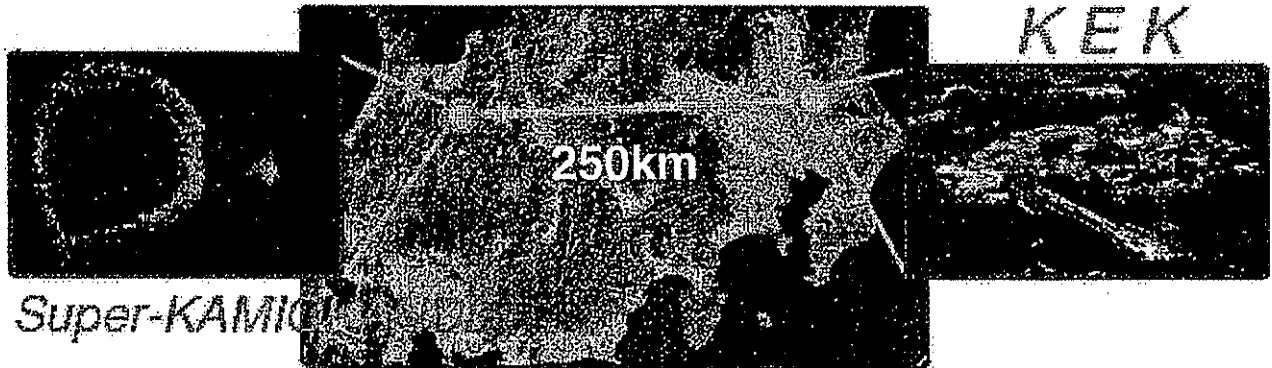


First Results of K2K

Y. Itow (ICRR, Univ of Tokyo)
for K2K collaboration

@ ~~La Thuile 2000~~

TMU JUL 5, 2000



Contents










- Introduction
- KEK PS ν beam line
- ν interaction at front detector
- ν event at Super-K

K2K





Collaboration Member Institutes

[E-mail / Phone / Fax Directory] [K2K Members] [K2K Home Page]







JAPAN

-  [KEK National Laboratory for High Energy Physics](#)
-  [Institute for Cosmic Ray Research \(ICRR\), University of Tokyo](#)
-  [Kobe University](#)
-  [Kyoto University](#)
-  [Niigata University](#)
-  [Okayama University](#)
-  [Osaka University](#)
-  [Science University of Tokyo](#)
-  [Tohoku University](#)

KOREA

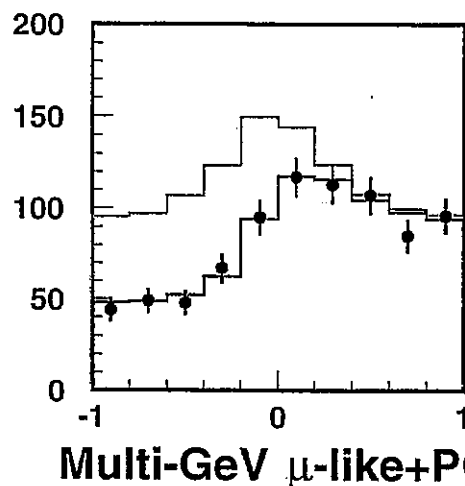
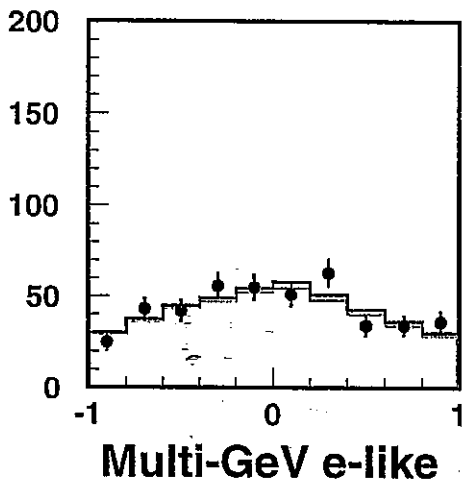
-  [Chonnam University](#)
-  [Dongshin University](#)
-  [Korea University](#)
-  [Seoul National University](#)

USA

-  [Boston University](#)
-  [University of California at Irvine](#)
-  [University of Hawai'i at Manoa](#)
-  [Los Alamos National Lab](#)
-  [State University of New York at Stony Brook](#)
-  [University of Washington at Seattle](#)

MOTIVATION

Atmospheric neutrinos in Super-Kamiokande



⇒ The first evidence of $\nu_\mu \leftrightarrow \nu_x$ oscillation
 $\Delta m^2 = (2 \sim 6) \times 10^{-3} \text{ eV}^2$ (Atm- ν +Up- μ)

Non-acclerator exp. with atm ν_μ beam

Large L/E

intense $\nu_\mu + \nu_e$



Accelerator LBL with well-defined ν_μ beam

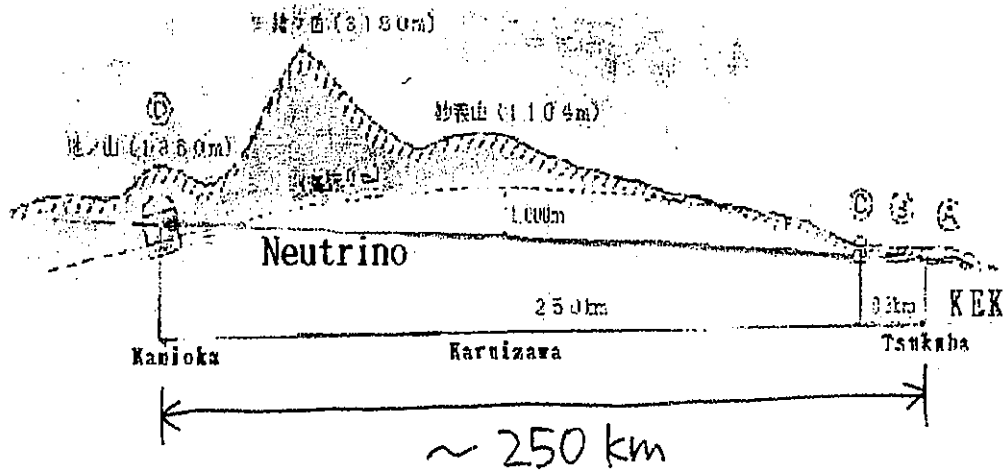
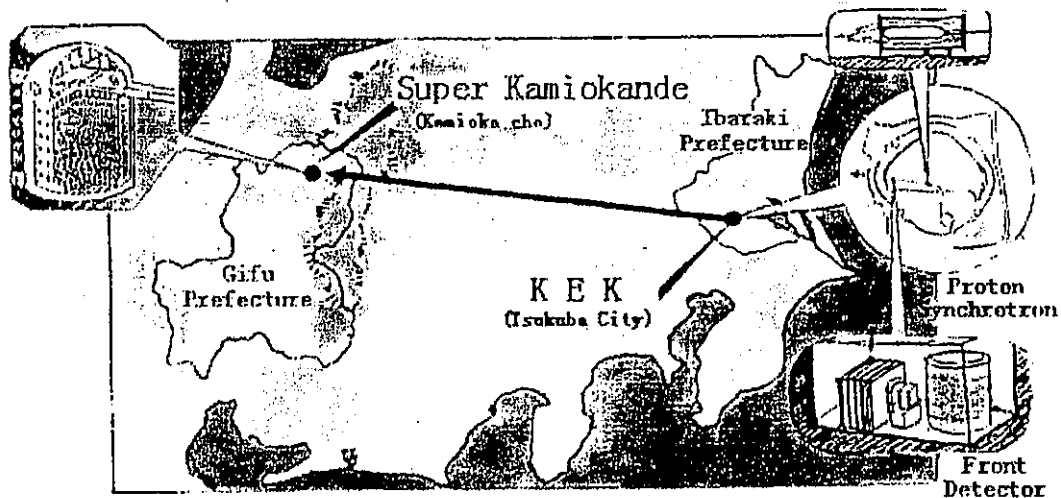
Known L/E

pure ν_μ

1. 長基線ニュートリノ振動実験 (K2K)

LONG Base-line neutrino oscillation experiment

KEK to Kamioka

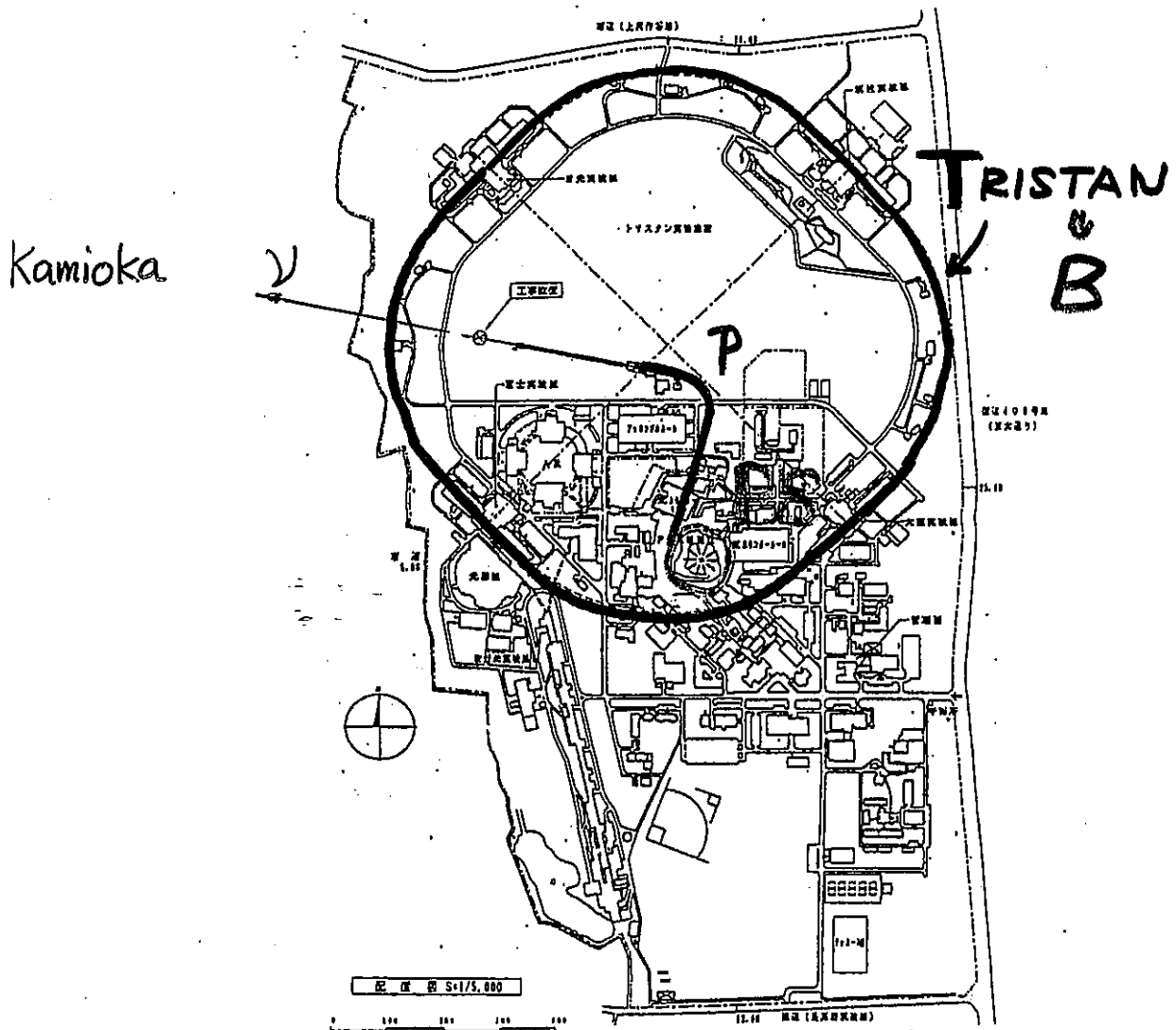


12GeV-PS (KEK) ν_μ Super-Kamiokande (神岡宇宙素粒子研究施設)

History

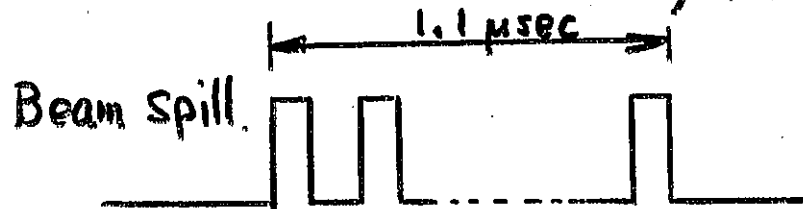
- '98 Sep ↓ construction of front detectors
- '99 Feb ↓
- Feb 3 First fast extraction
- Mar 13 ↓ Engineering run (horn @ 175kA, 3E12 ppp)
- 25 ↓
- Apr 14 ↓ Neutrino run (horn @ 250kA)
- 15 ↓ Horn water leak
- May 8 ↓ Neutrino run (@ various horn current)
- 14 ↓ Horn current feeder broken
- Jun 4 ↓ Neutrino run (horn @ 200kA, 4.5E12 ppp)
- 28 ↓ The 1st SK-event
- Jul ↓ Summer shutdown
- Oct ↓ (new Horn with 3mm ϕ target / endurance test)
- Oct 30 ↓ Neutrino run (new horn @ 250kA 5E12 ppp)
- Nov 24 ↓ 2 more !
- '00 Jan 13 ↓ Neutrino run (new horn @ 250kA 5.5E12 ppp)
- Mar ↓
- '00 May ↓ Neutrino run (horn @ 250kA, 5.5 E12 ppp)
- JUN ↓

KEK site



KEK PS 12 GeV

- Fast Extraction : every 2.2 sec



$\sim 6 \times 10^{12}$ protons/spill

- Aim 1×10^{20} P.O.T. in 3 years
(18 months)

SCF1 event

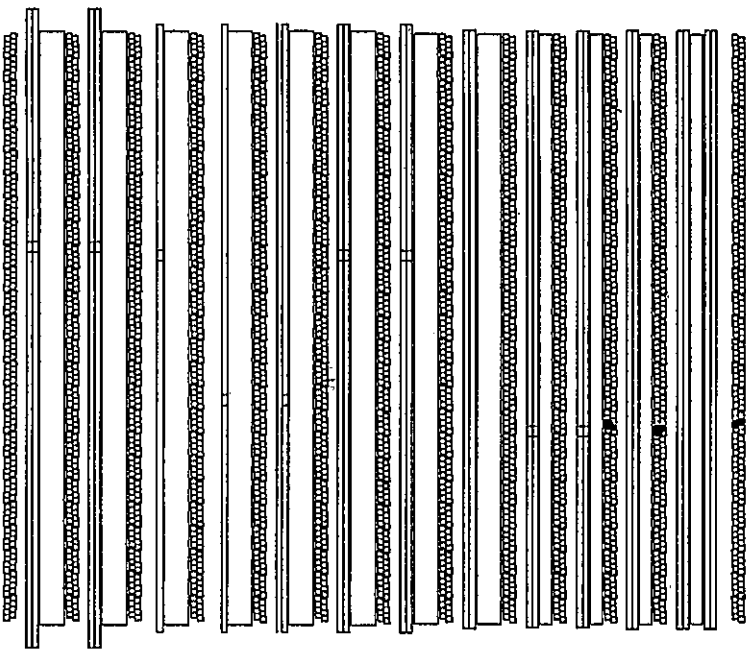
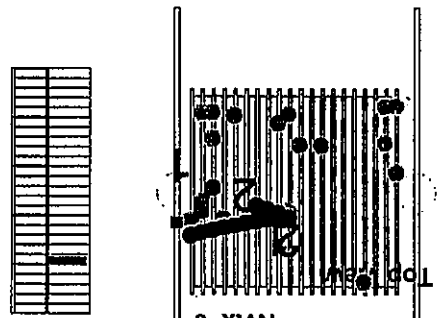
K2K Fine-Grained Detector

Run 167 Spill 43873 TRGID 1

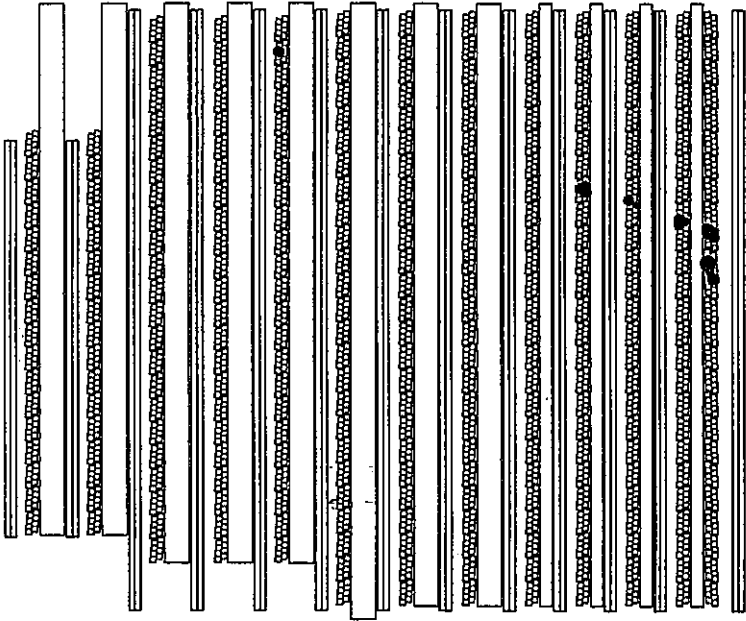
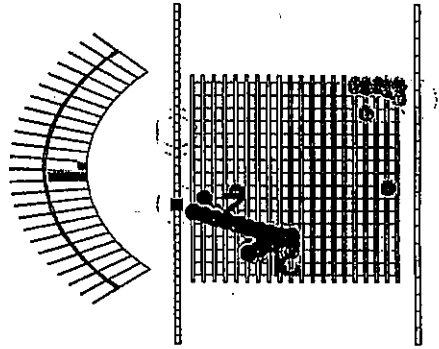
99 3 17 1 26 59 0

Nvtx 0

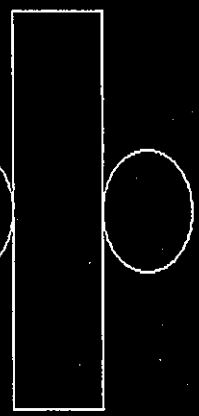
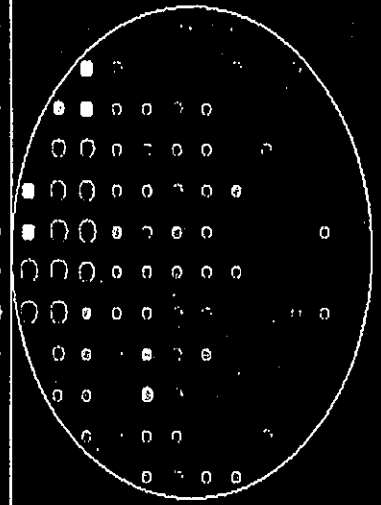
Top View



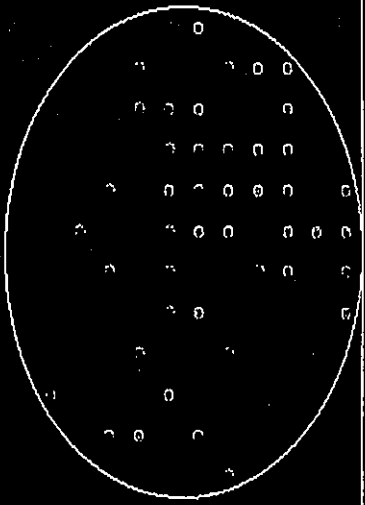
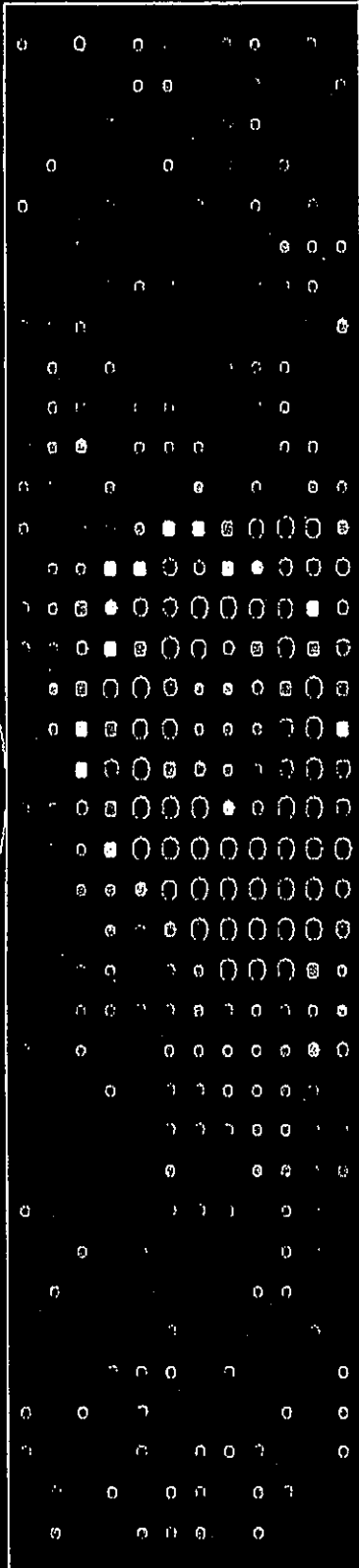
Side View



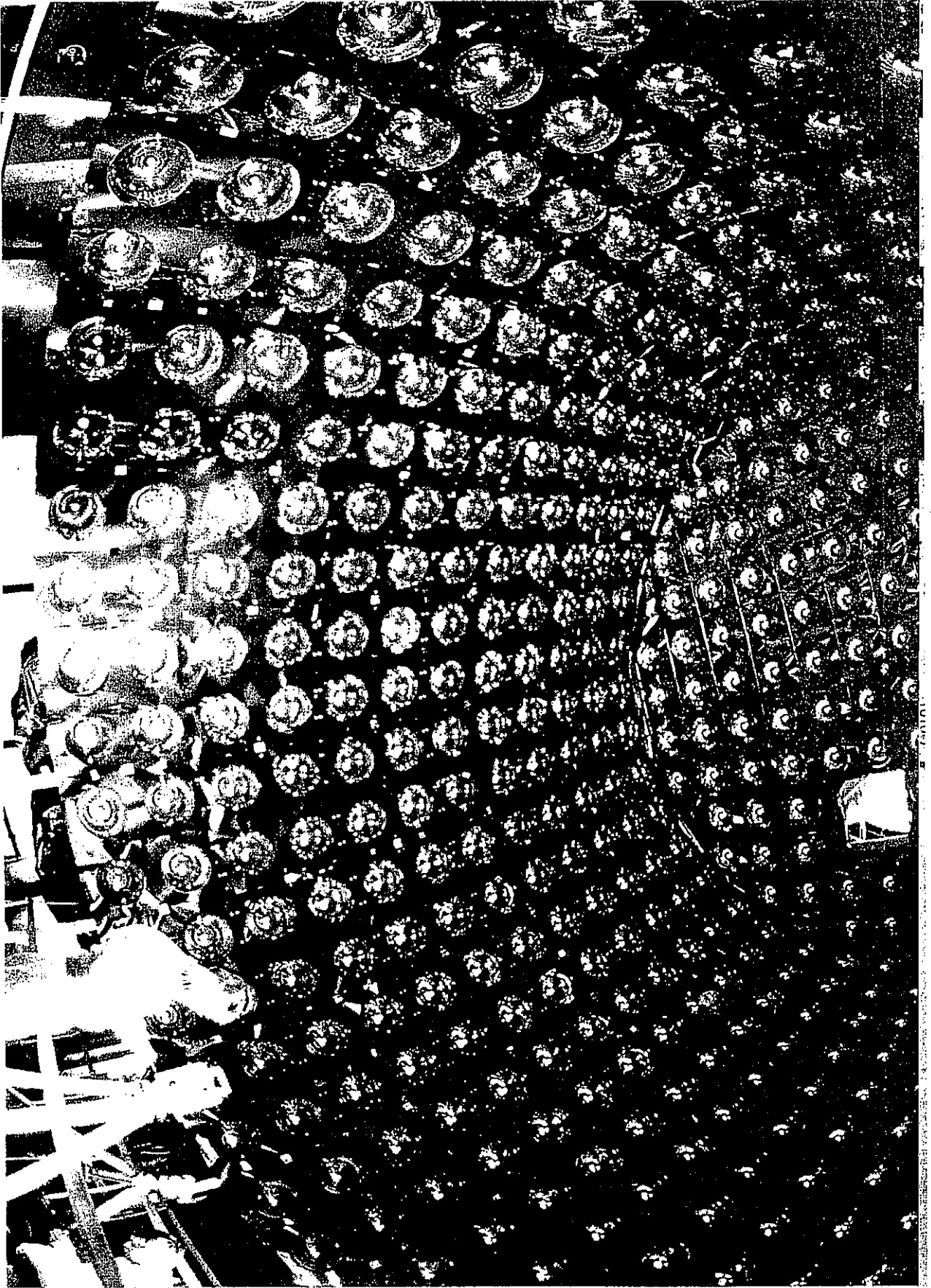
Current: 0 INNER
 Event Time: Sat Mar 6 1999 13:37:47
 Run Number: 583
 Spill Number: 25916
 Trigger Number: 113513
 Trigger Type: 0x01 = SPILL_ON:SELF
 Total PE ID/DD: 53065, 0
 NumHits ID/DD: 402
 Time Diff: 00:00:02.180674



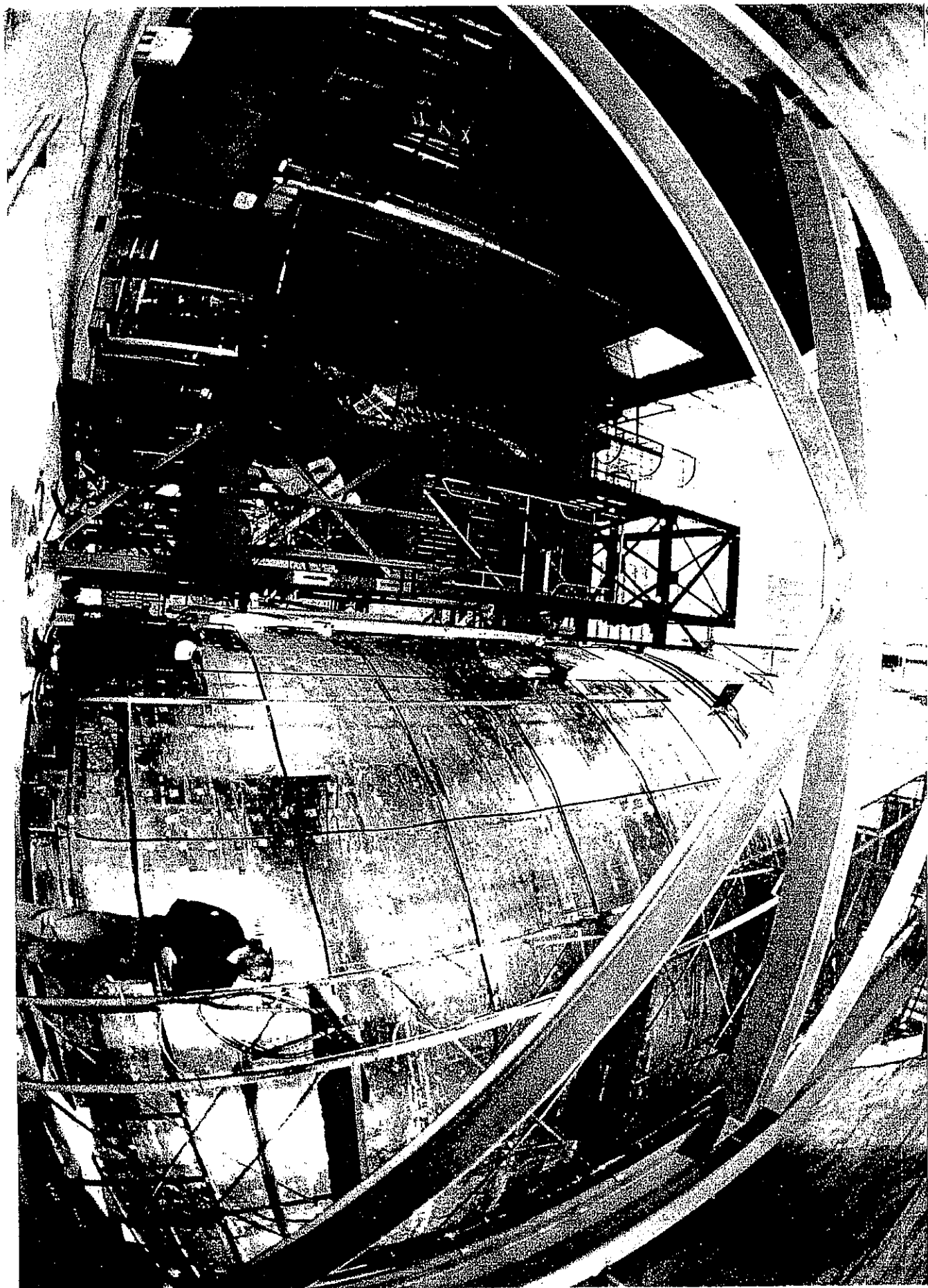
<- SpIn ->: 8 PI/8



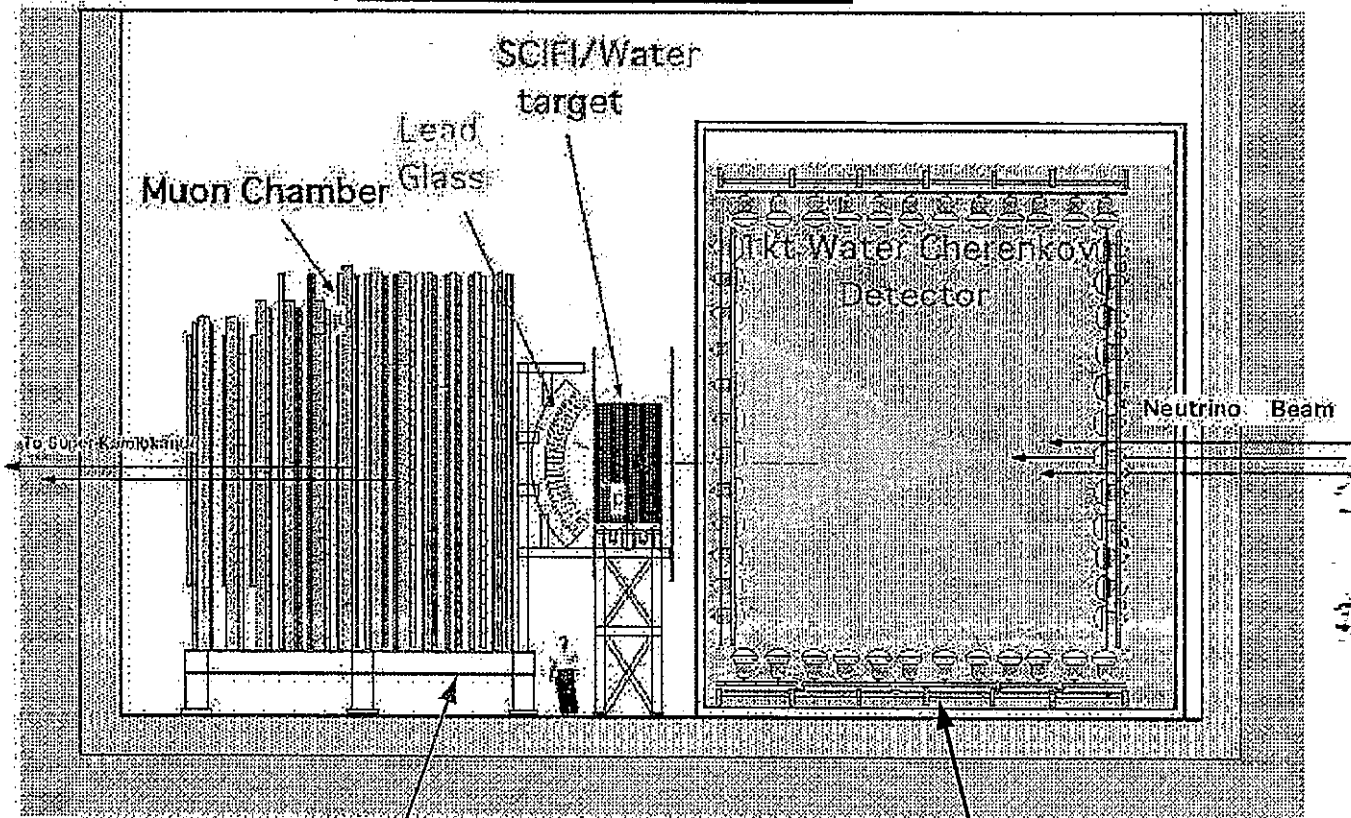
70.8 74.6 78.4 82.2 86.1 89.9 93.7 97.6 101.4 105.2



1998 NOV



Front Detector



v-beam flux
 v-beam profile
 v energy distribution

Fine Grain Detector
 SCFI tracker+ water cell
 Lead Glass
 MUC (Fe+drift tube)

1kt water cherenkov
 680 20" PMT+water

- fine grained, good Δx
- good $\Delta V, \Delta \Phi v$

- miniture of SK
- direct comparison to SK
- proof SK MC

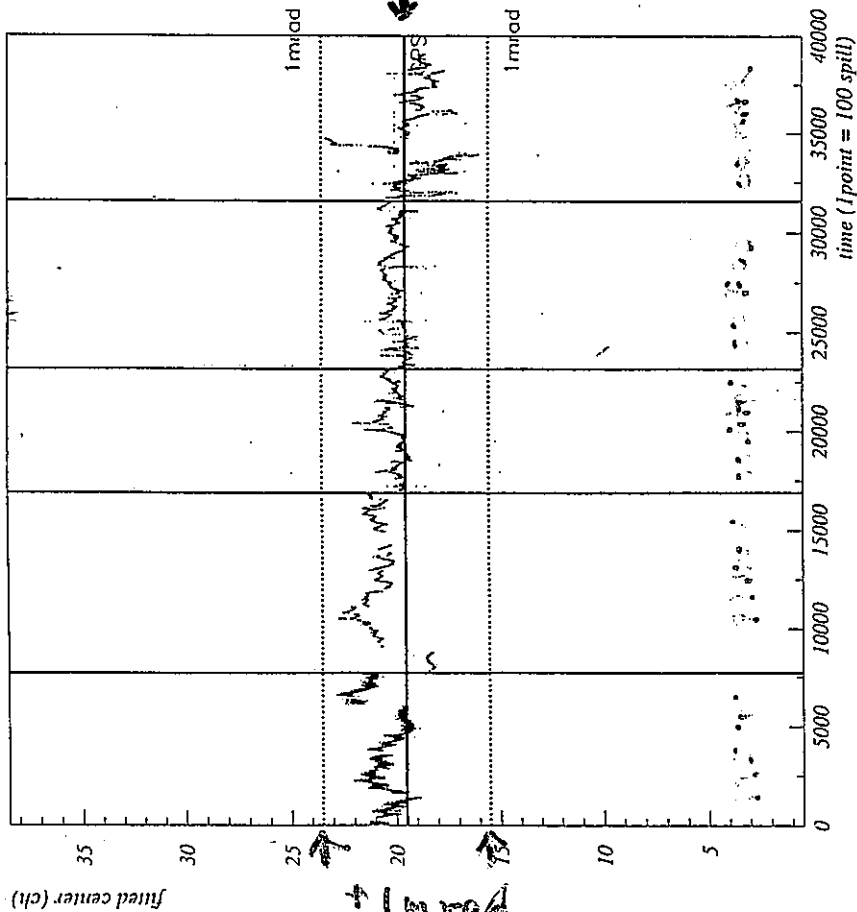
⇓
E. v, v-profile

⇓
v event rate

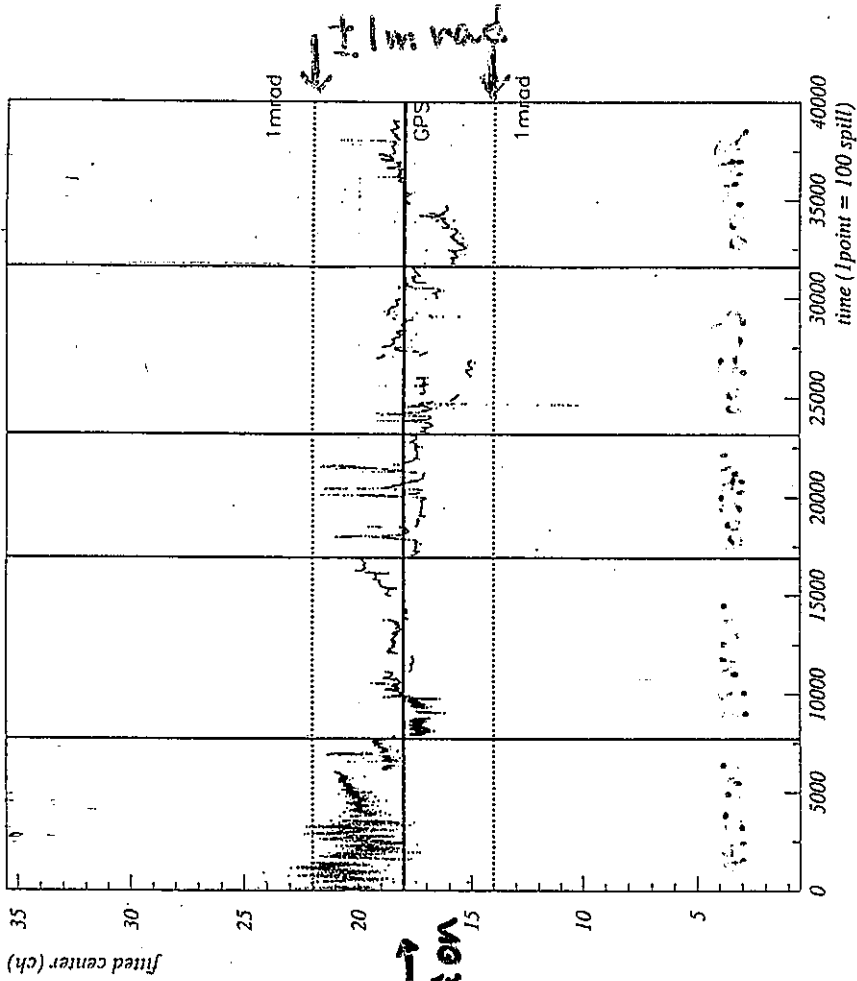
Aiming of proton beam

Horizontal

Horizontal



Vertical



Beam monitor&Front detector

Check ν -beam/ ν -interaction MC

Direction to Super-K ?

μ -monitor : μ profile at dump

1kt, MUC : ν -beam profile

Absolute flux ?

Current transformer : proton beam current

1kt, SCFI, MUC : ν -beam int. rate

E_ν distribution ?

π -monitor : kinematics of π

1kt, SCFI, MUC : cc interaction

How to extrapolate to Super-K?

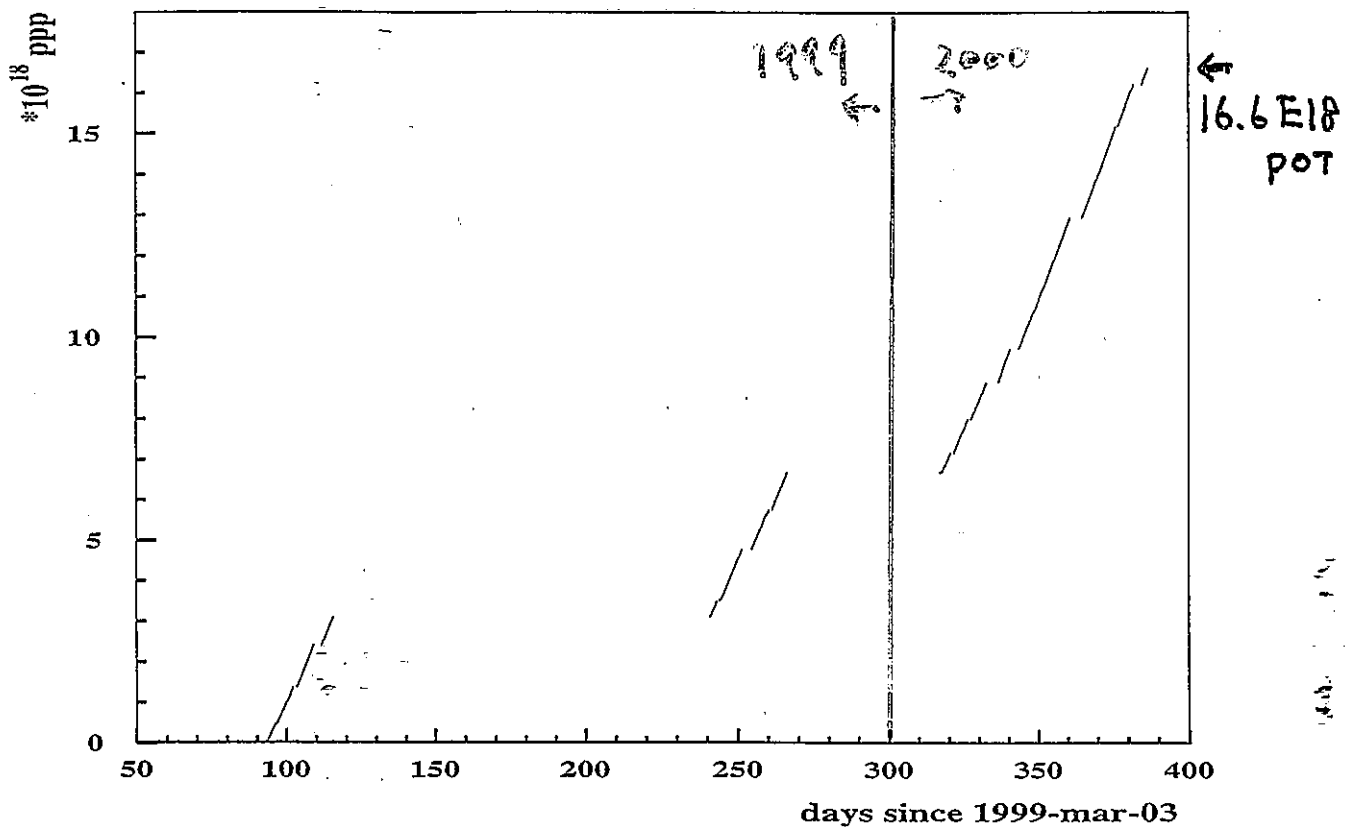
π -monitor : kinematics of π

ν -interaction model ?

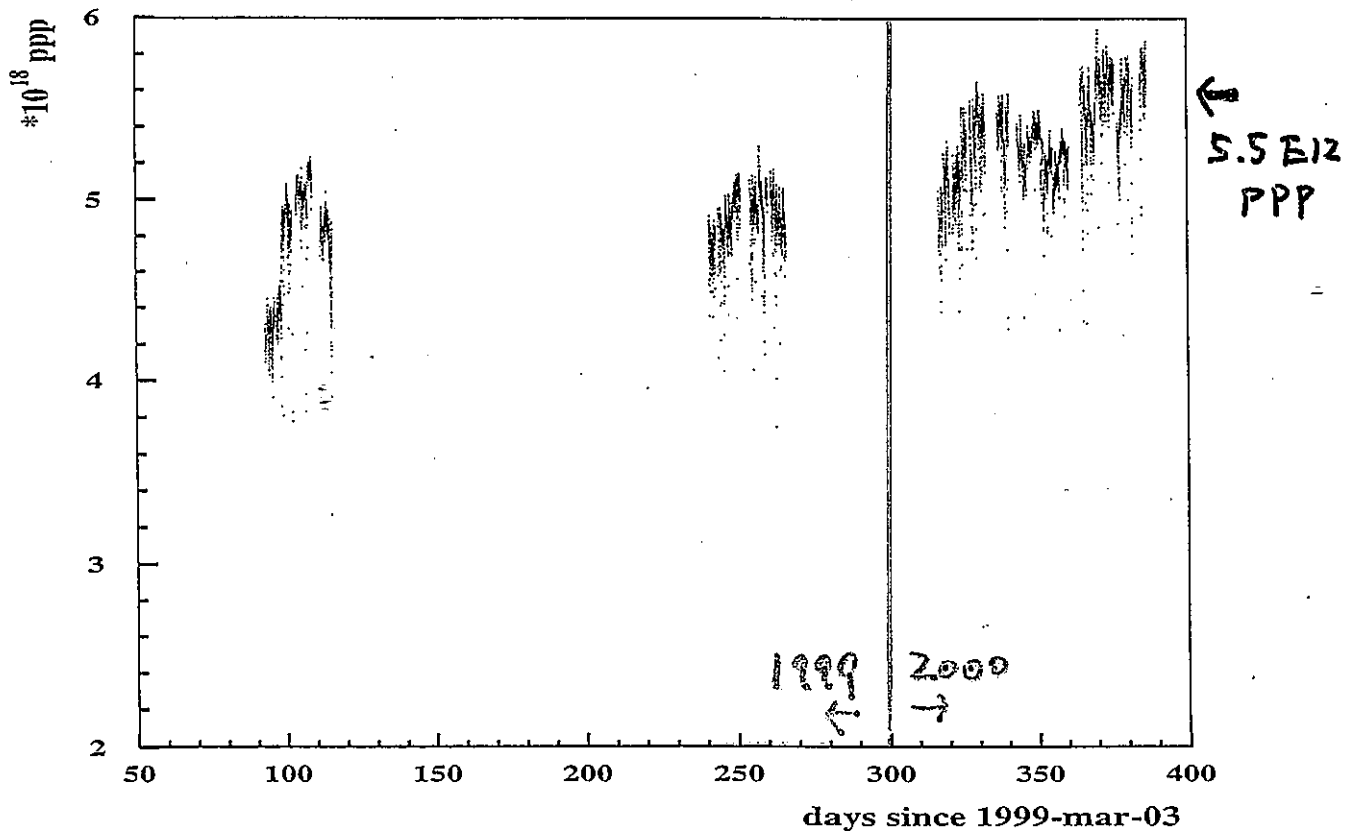
1kt : NC π^0 , cc 1π , etc..

SCFI : ccQE, etc...

TGT-CT(CT16) sum

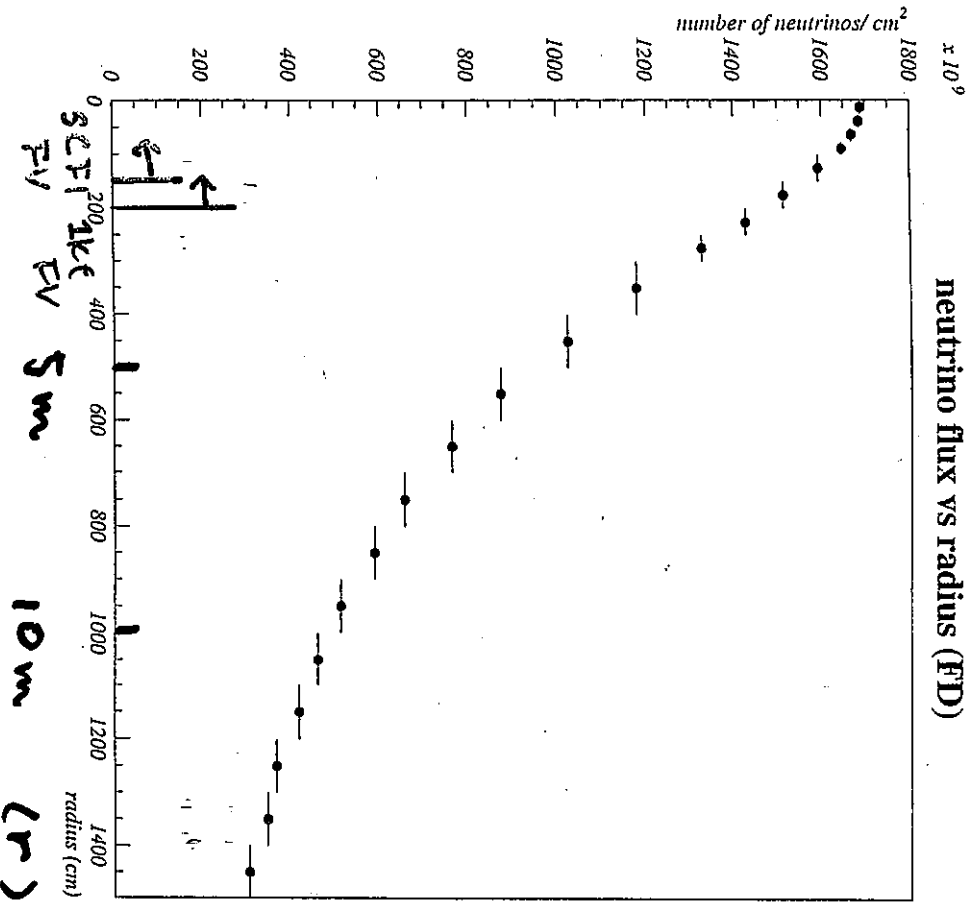


TGT-CT(CT16)



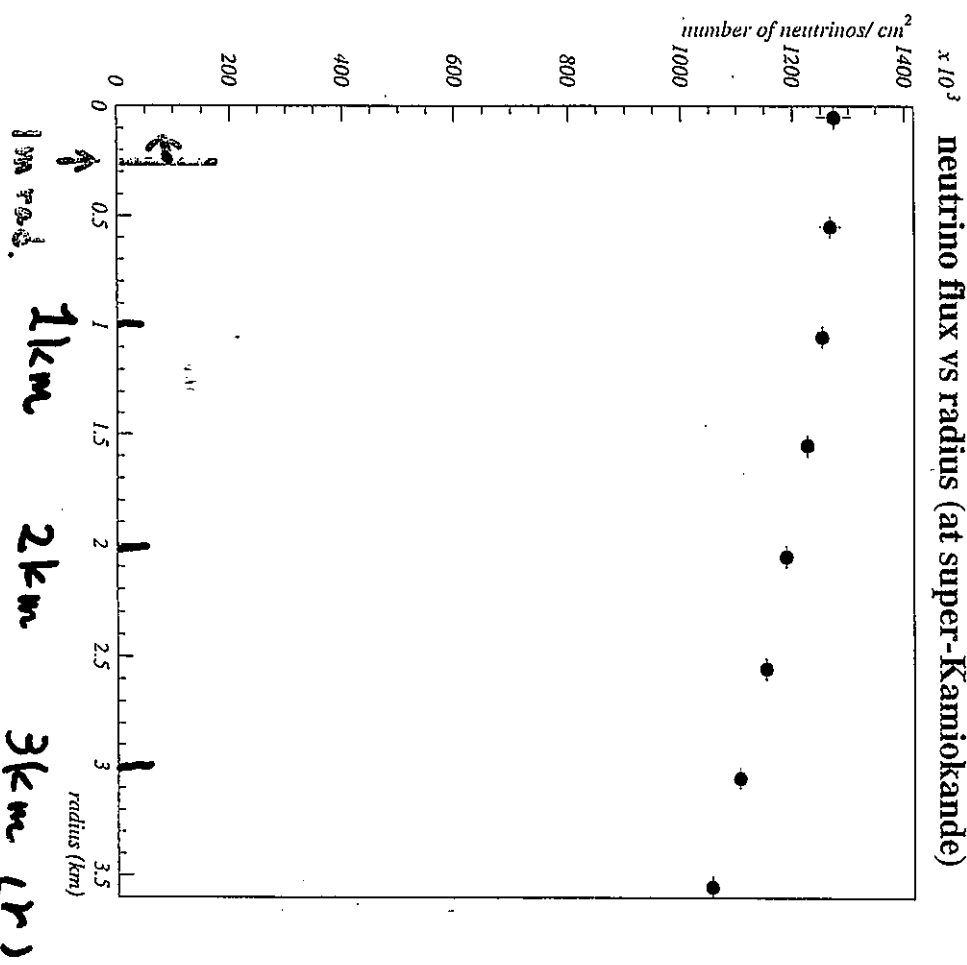
②FD

neutrino flux vs radius (FD)



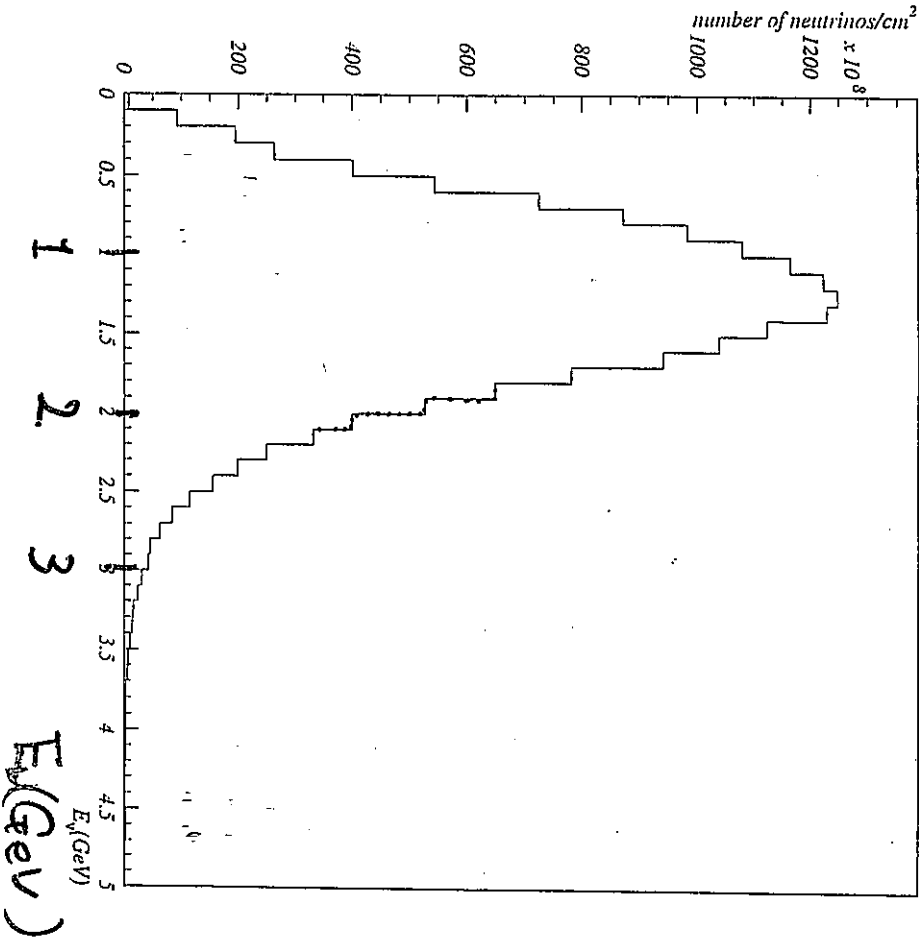
②SK

neutrino flux vs radius (at super-Kamiokande)



@ F D

Neutrino flux at Front Detector (KEK)

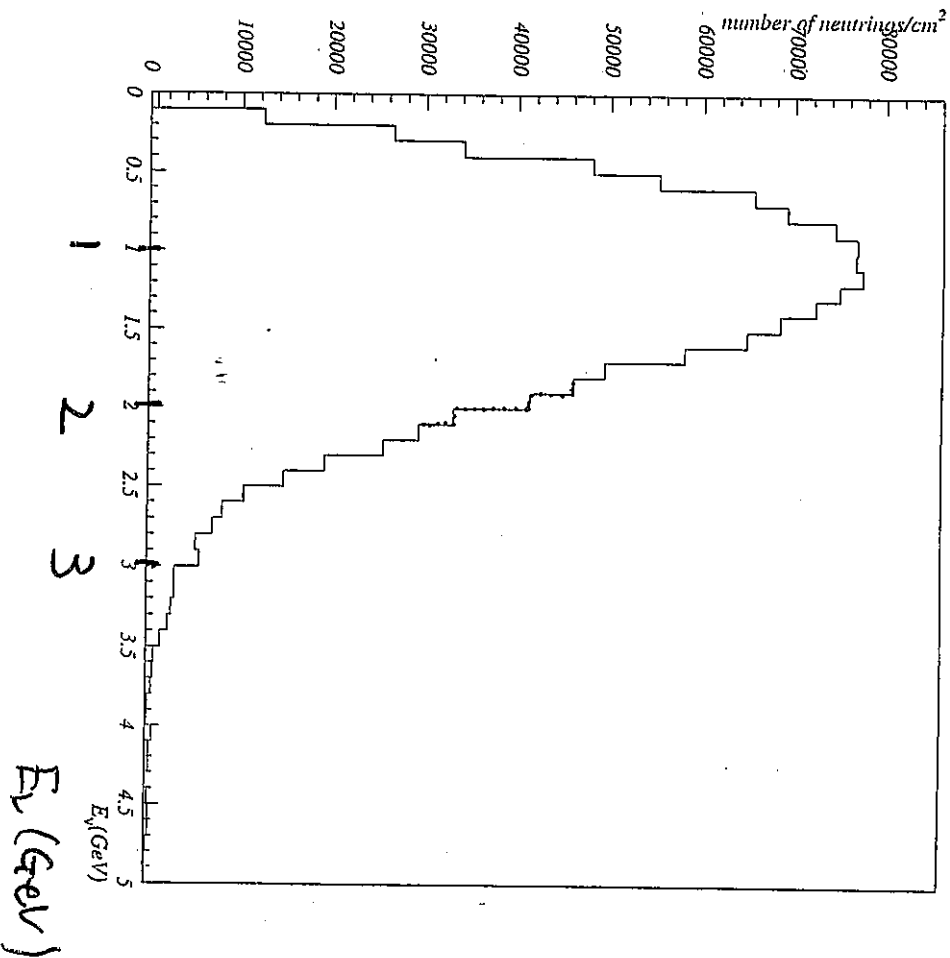


NOV

NOV 3cm φ 2.50kA

@ SK

Neutrino flux at Super-Kamiokande



NOV



November 19, 1998

Experimental Hall ("Hole")
for Front Detector

H-ON MONITOR

SK: $\sim 50\text{m}/250\text{km} = 0.2\text{mrad}$
(for $\theta \leq 3\text{mrad}$)
 E_r spect \sim nearly identical

$V_e/V_p \sim 1\%$

angular div: 3mrad

$E_{\text{peak}} \sim 1.0\text{ GeV}$

$\langle E \rangle \sim 1.4\text{ GeV}$

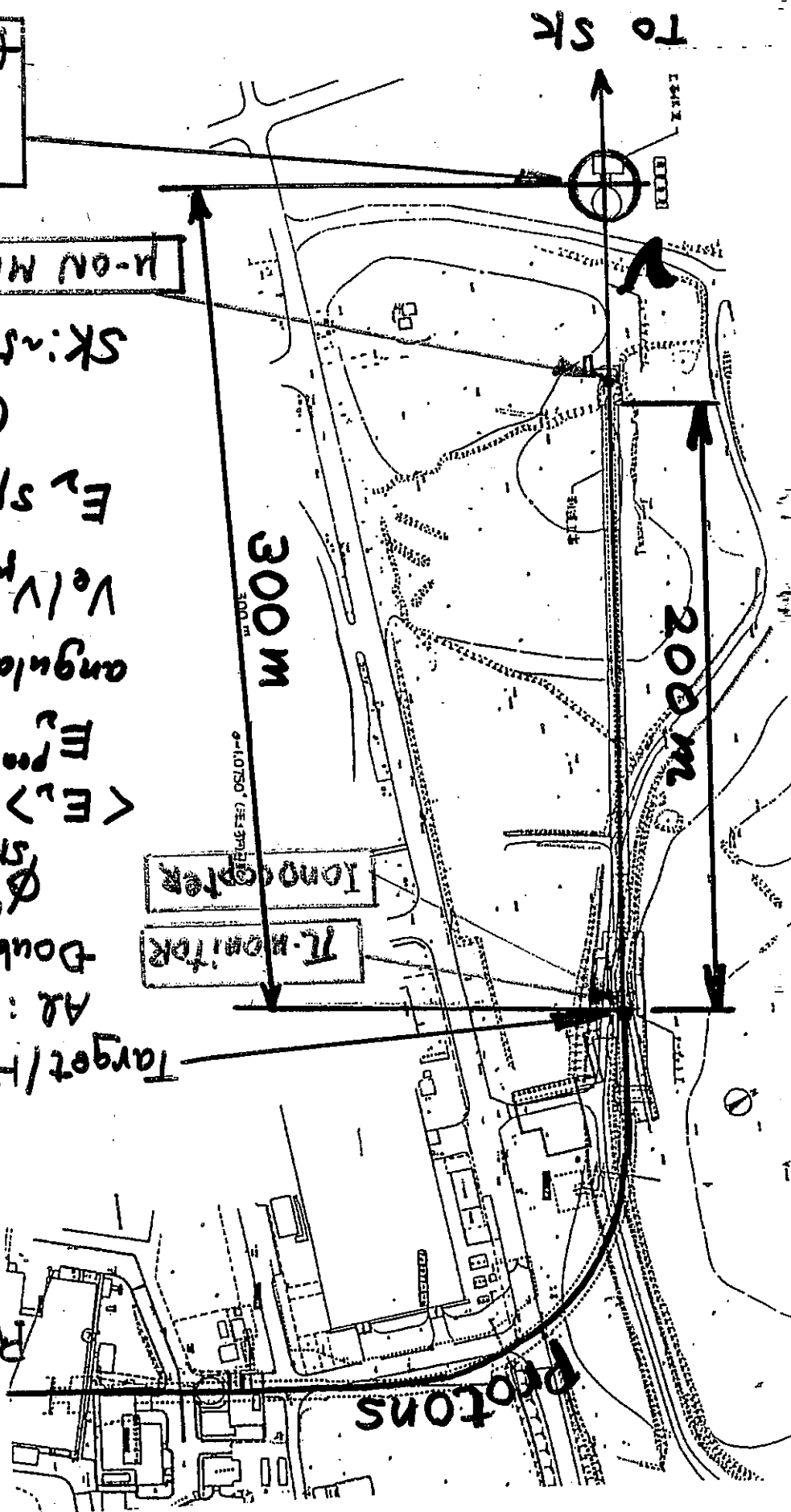
$\phi_{\text{horn}}^{\text{SK}} = 14 \times \phi_{\text{SK}}^{\text{bare}}$

Double horn: 250KA

AL: $2\text{cm} \phi \times 65\text{cm}$

Target/HORN

Proton beam mon.
SEC
gunn. pt.
C.T.



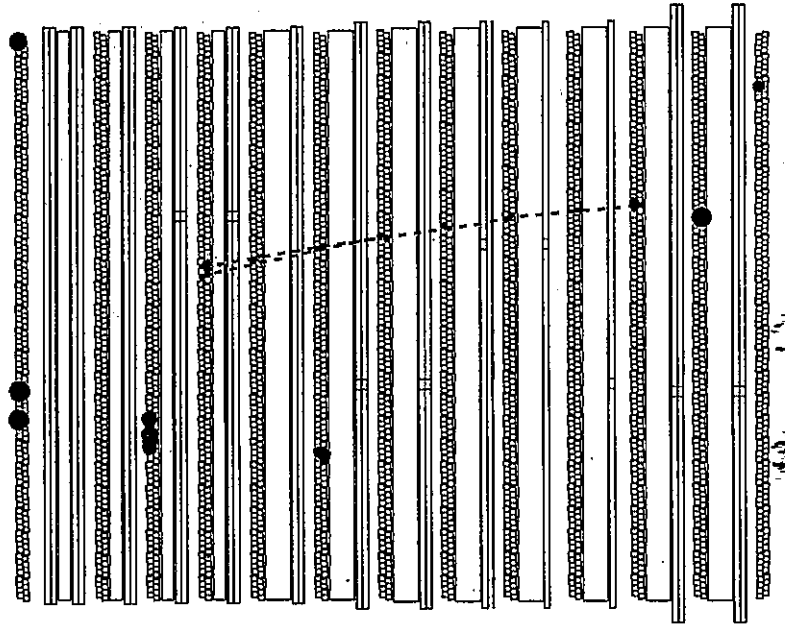
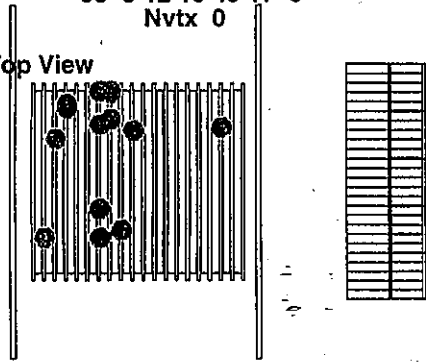
MUC event

K2K Fine-Grained Detector

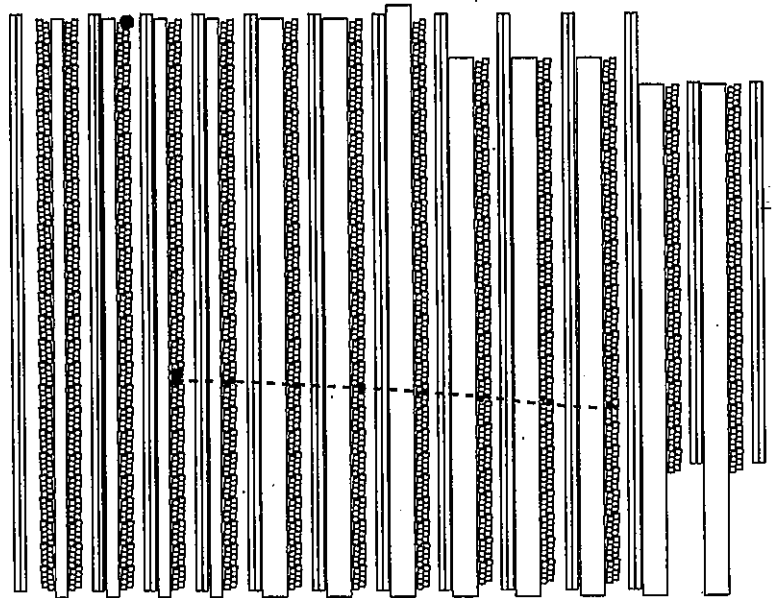
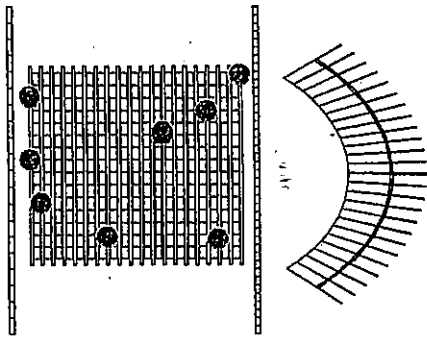
Run 1032 Spill 6253 TRGID 1

99 5 12 10 40 17 0
Nvtx 0

Top View



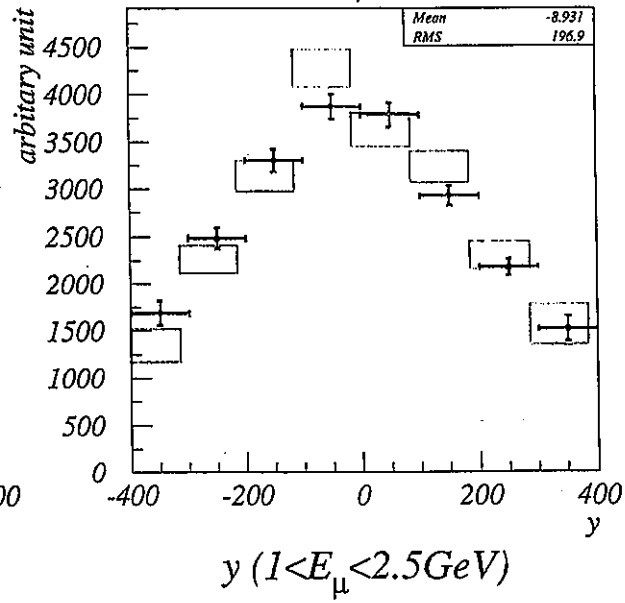
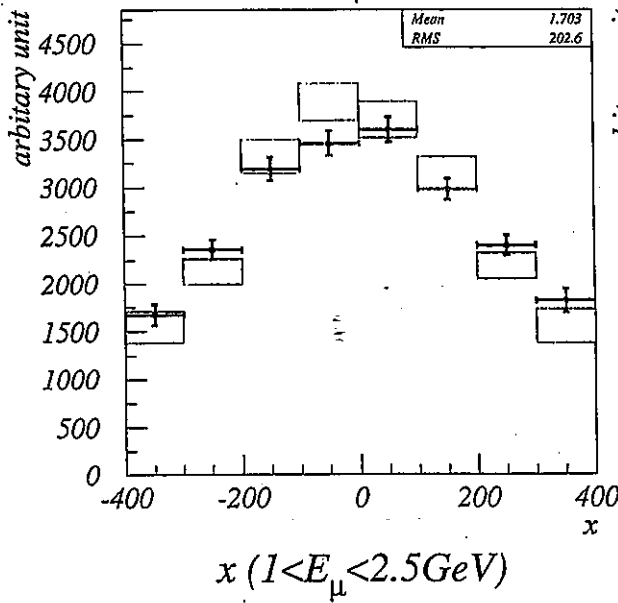
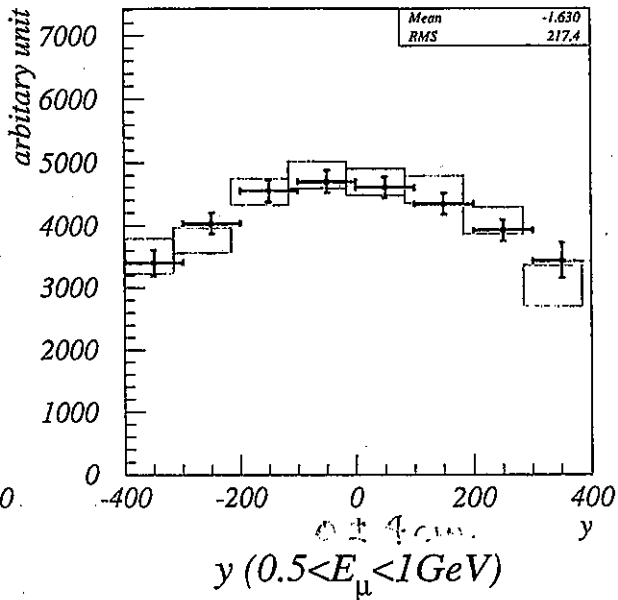
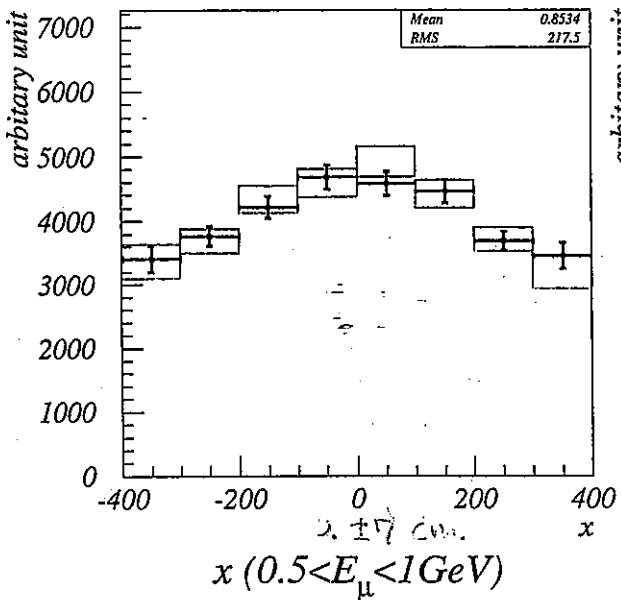
Side View



Center of ν profile

Horizontal \leftarrow | \rightarrow Vertical

Fe events (Nov. DATA vs. MC-250kA)

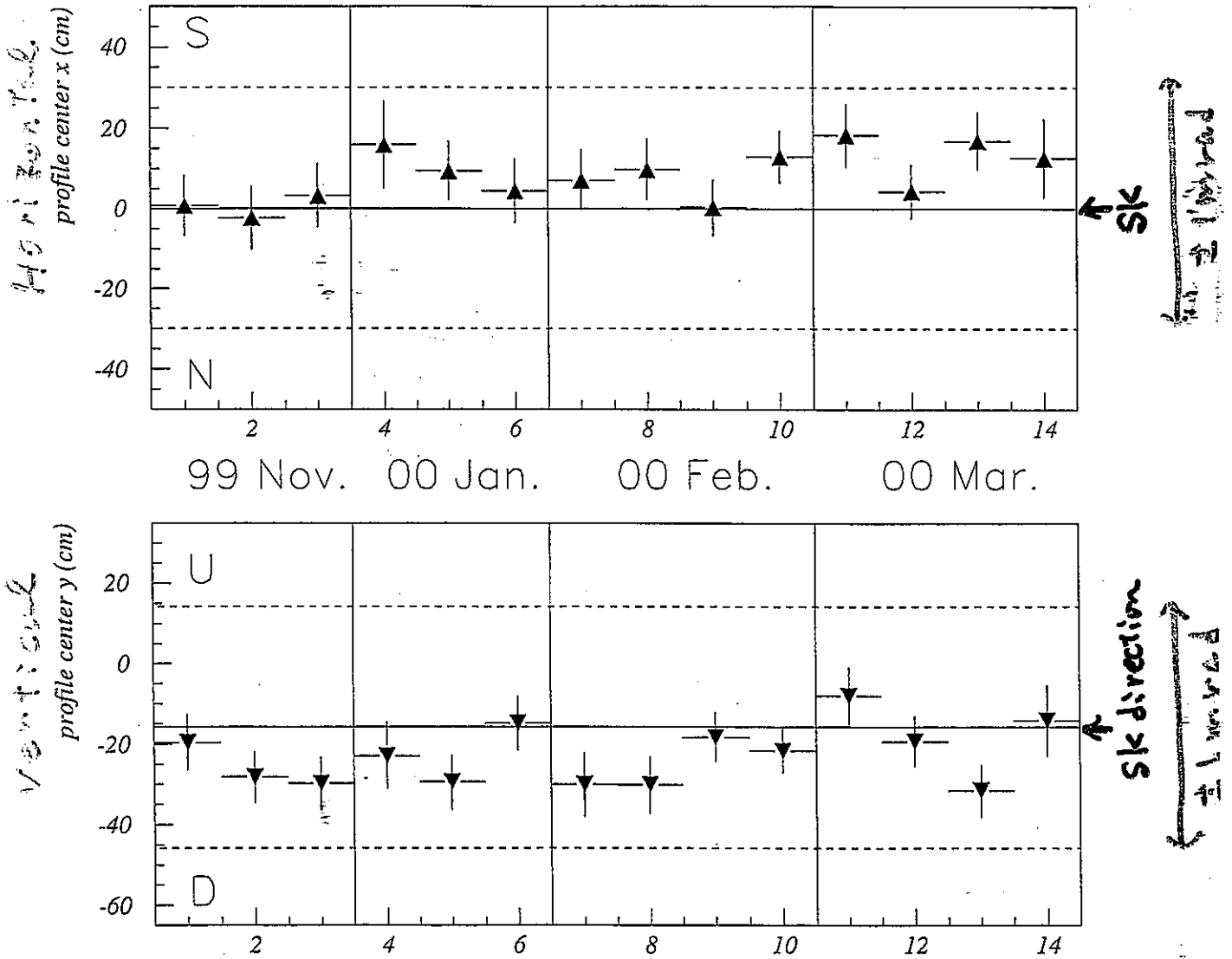


lower E_ν \updownarrow higher E_ν

ν -beam center \Rightarrow $< 30 \text{ cm}$
 \downarrow
 $< 1 \text{ mrad}$.

W beam aiming by μ chamber.

neutrino profile stability



CC measurement by SCFI

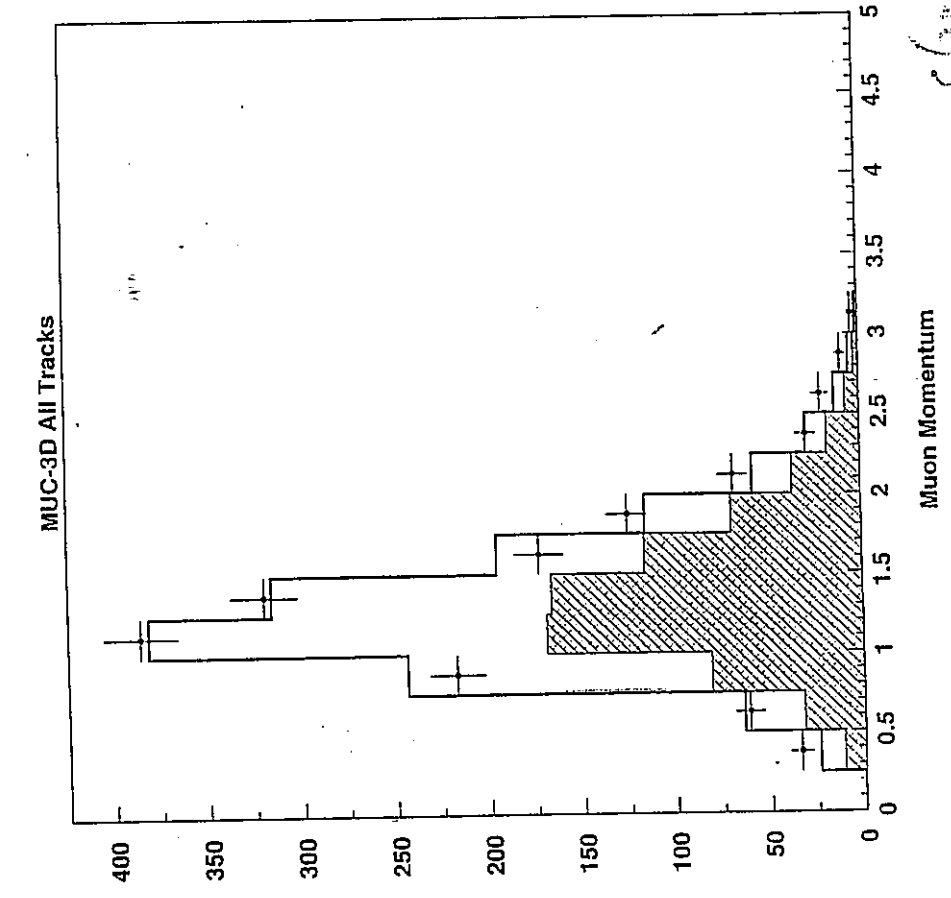


Fig.

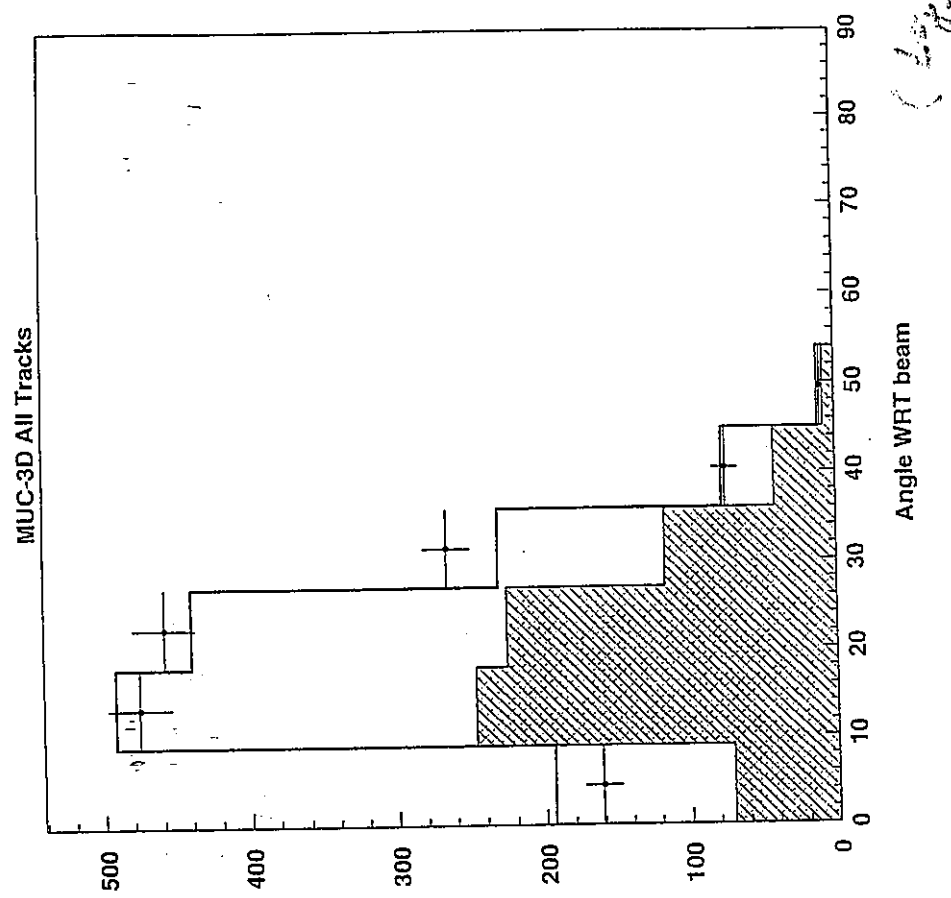


Fig.

ν event rate measurement



- pure water target
- FV cut ($r > 2m, |z| < 2m$)
p.e. cut ($E_{vis} \geq \sim 100 \text{ MeV}$) only
 \Rightarrow no #ring, FC/PC cut
- 2- ν reaction/ 1- ν reaction $\approx 10\%$
 \Rightarrow use sum of PMT signal (flush ADC)
- Similar selection bias as Super-K
(cc and also nc)



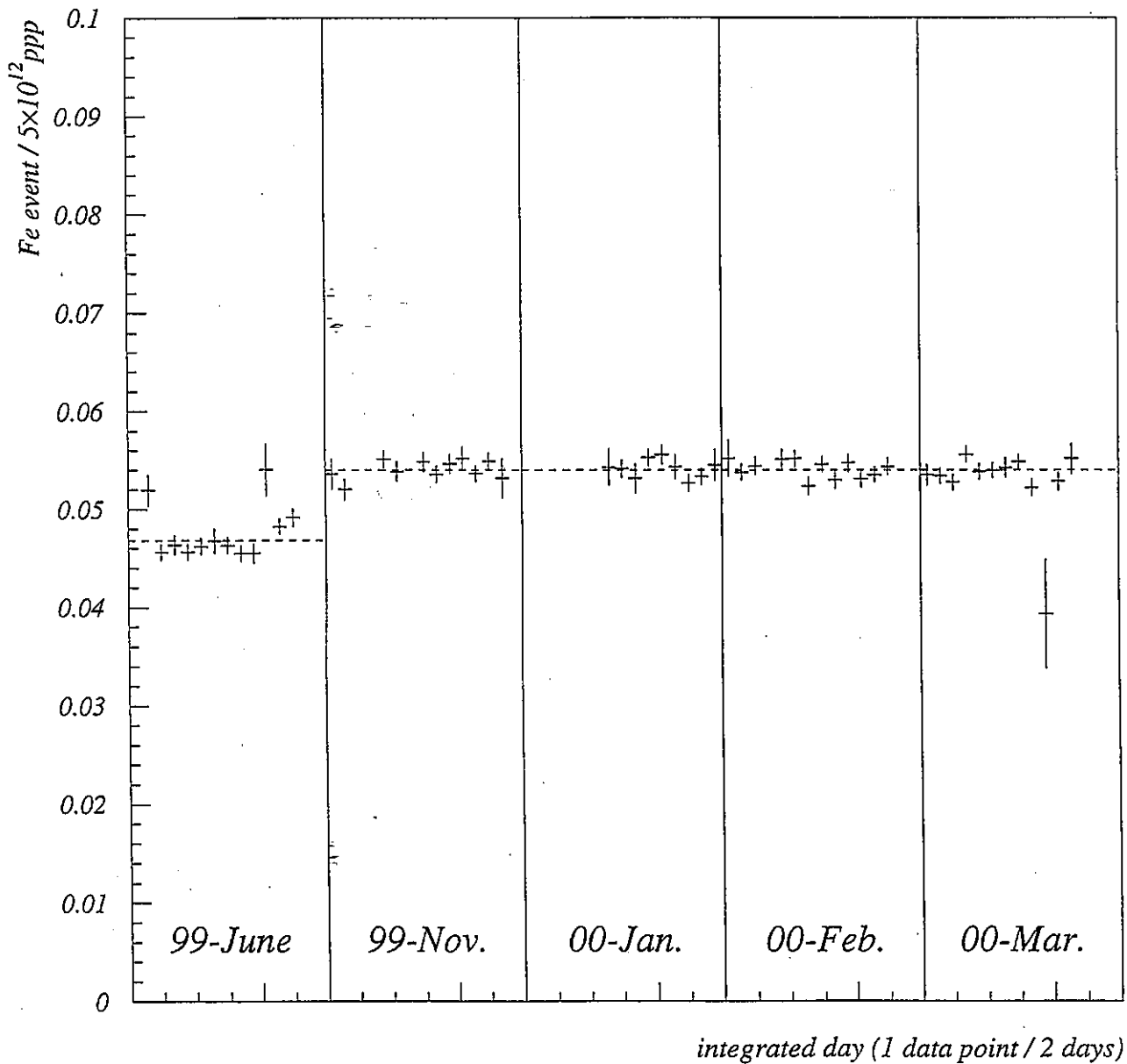
- water+Al+CH (7:2:1) target
- 1 good track stopped in MUC
Vertex with any prongs in SCFI
(acceptance $\times \sim 30\text{deg}, \geq \sim 500\text{MeV}$)
- cc only



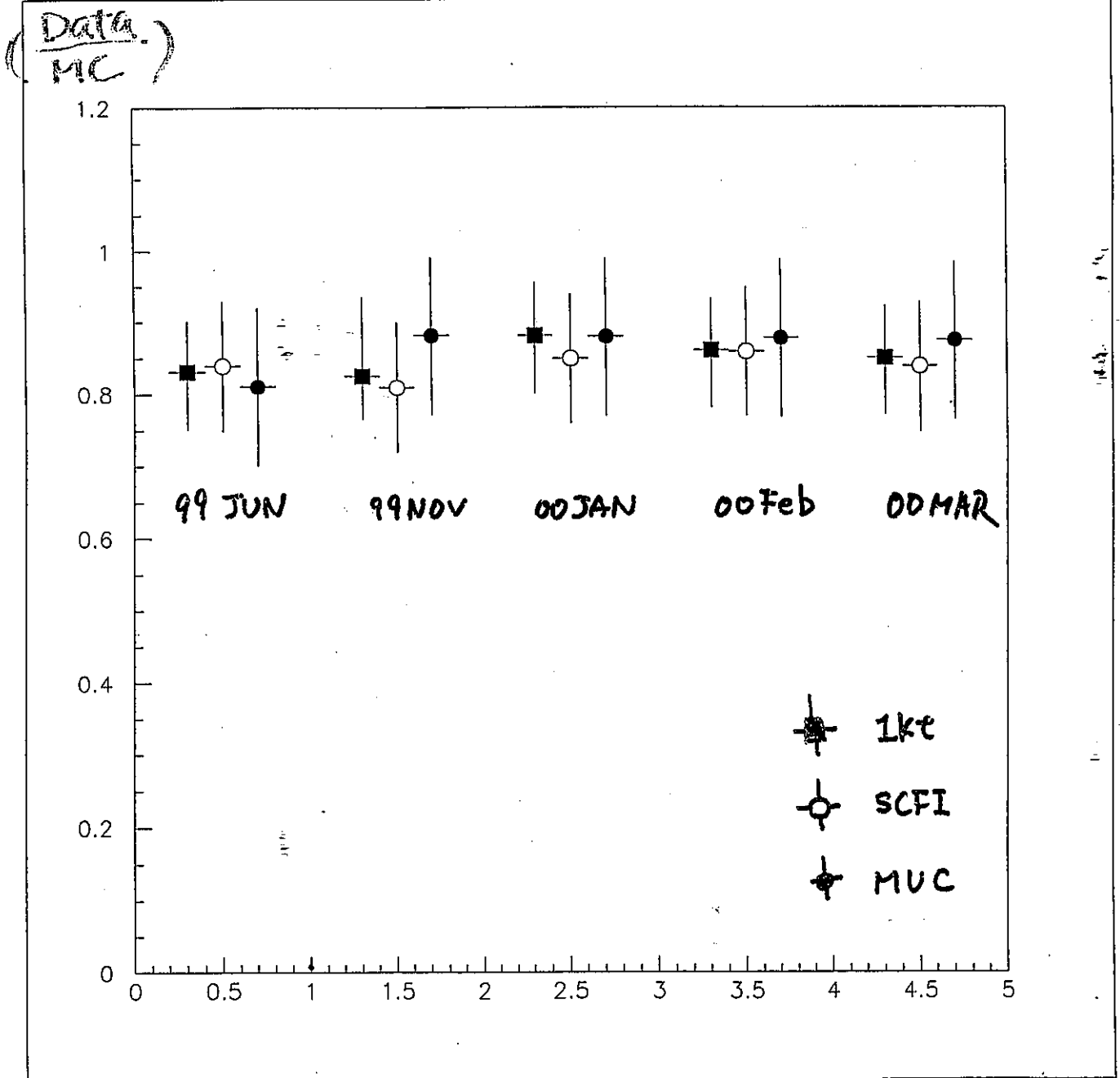
- Fe target
- any long tracks contained in MUC
(acceptance $\geq \sim 200 \text{ MeV}$)
- cc only

U rate stability (by MVC)

Fe event rate stability (99 June - 00 Mar.)

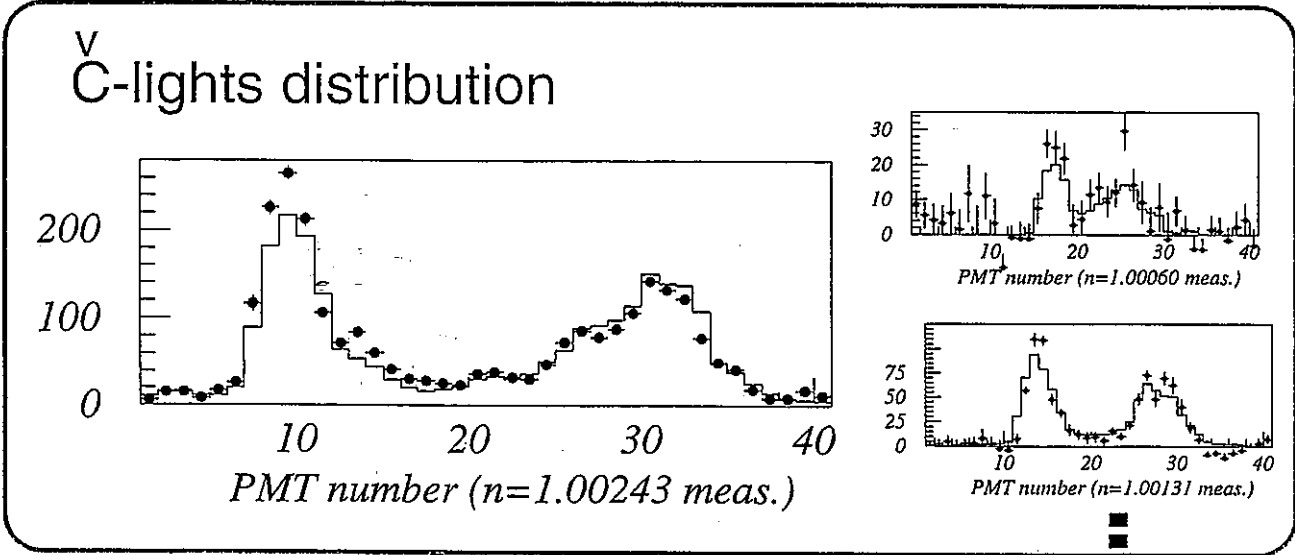
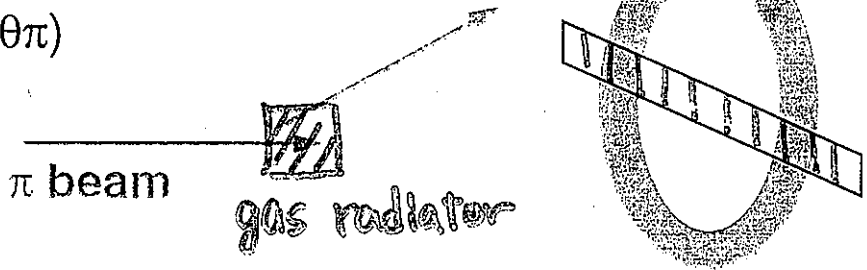


Consistency of v rate @ 3 FD (1ke, SCFI, MUC)

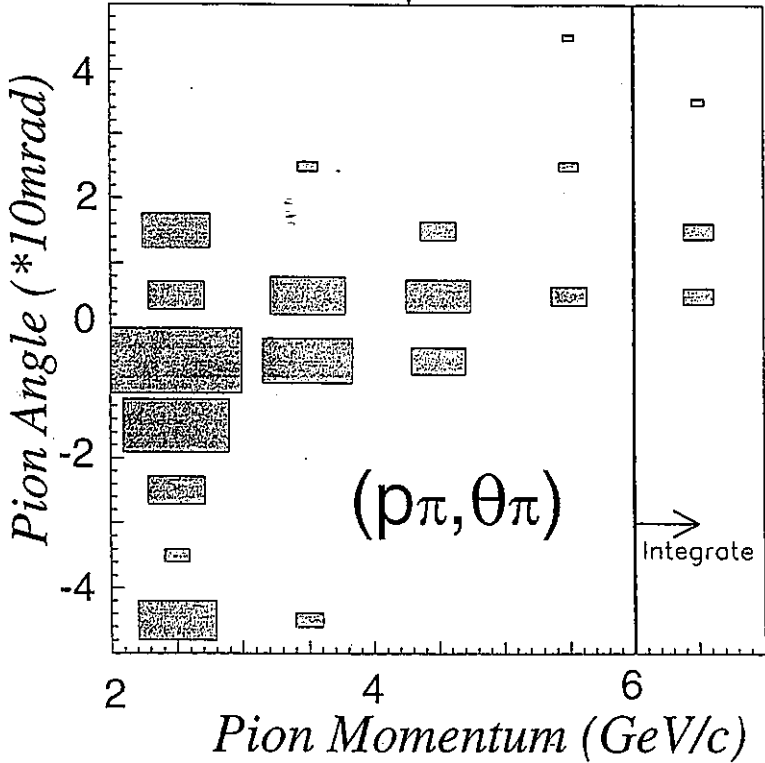


π-monitor

∇
 C-lights from π beam w/ various refractive index
 \rightarrow determine (p_π, θ_π)



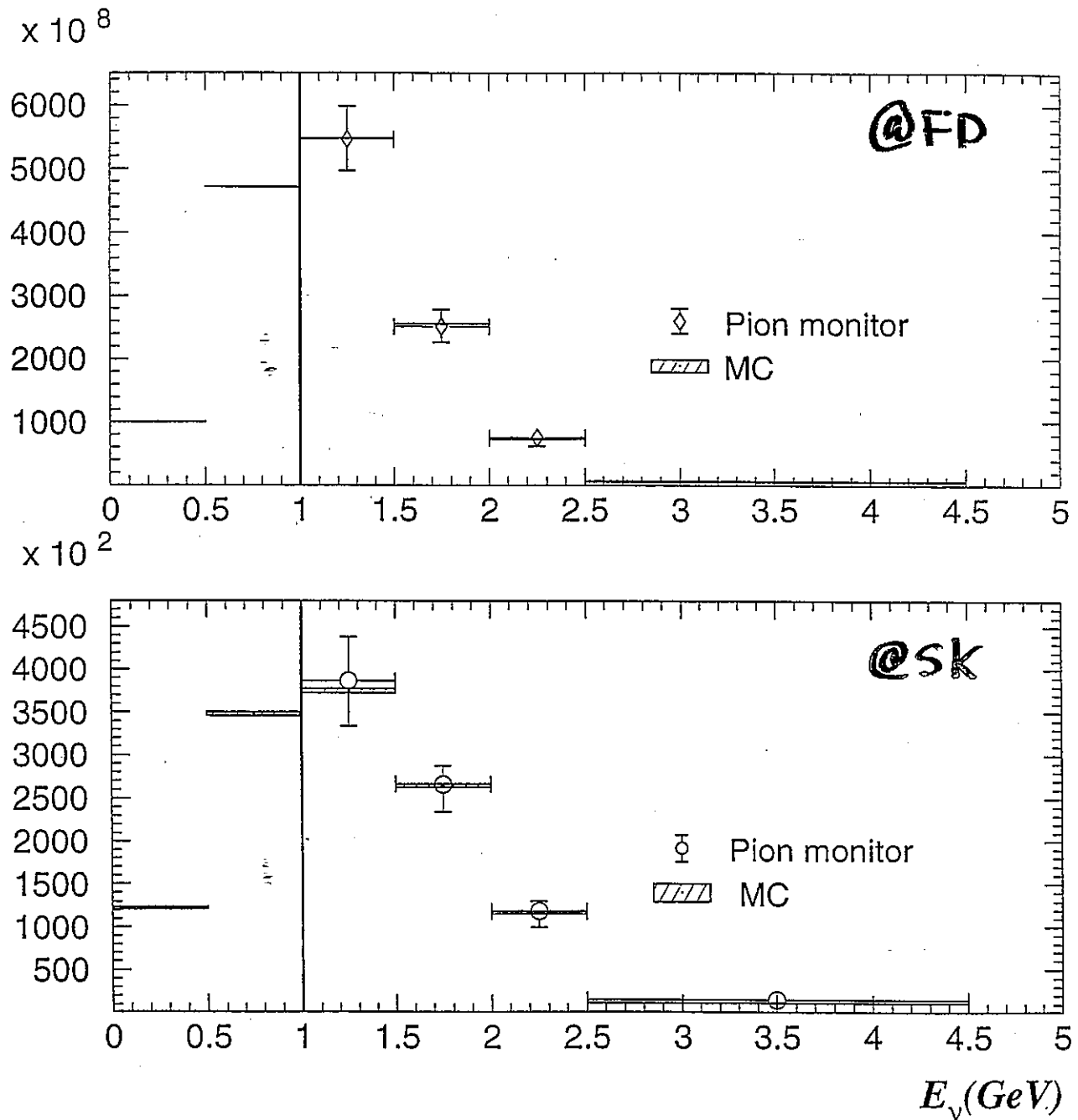
(p_π, θ_π) fit \downarrow



\rightarrow Ev

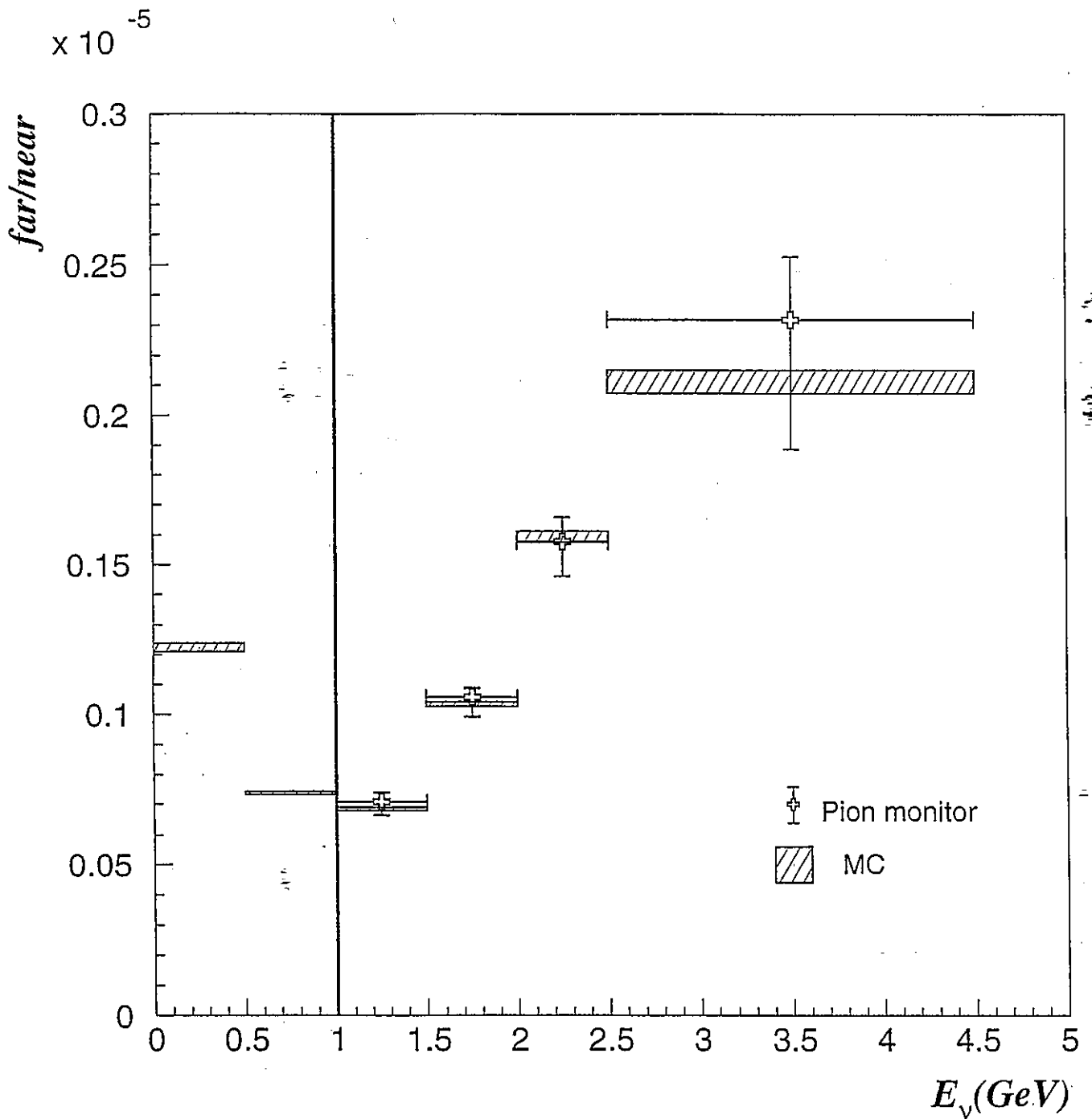
ν flux prediction

JL monitor vs beam MC



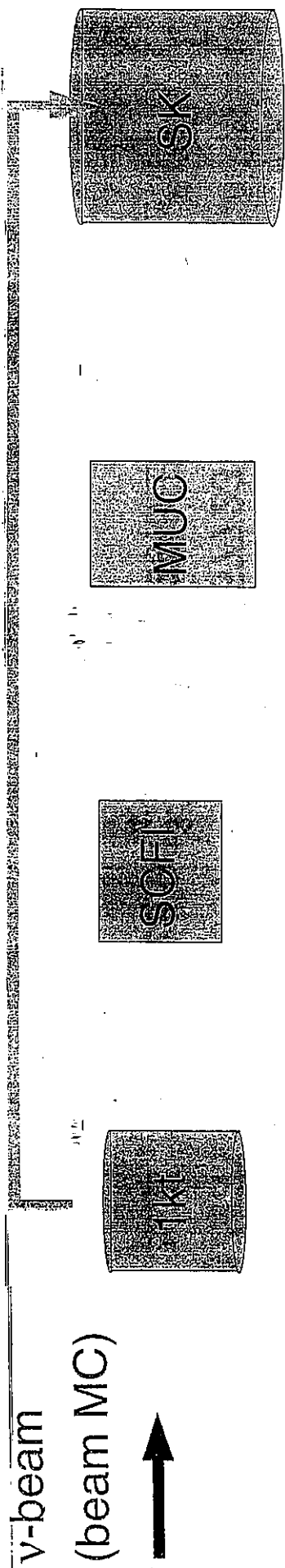
$\frac{\text{@SK}}{\text{@FD}}$ prediction

π -monitor vs Beam MC



Summary of ν events of FD/SK (Jun&Nov)

N 1kt x Far/Near (beam MC)



Fid. mass	H2O 50.3 t	H2O+Al 5.94t	Fe 312 t	H2O 22.5 kt
Fid. radius	2.0m	2.0m	3.0m	
Eff.	0.71	0.27	0.33	0.82
POT	13.5 E18	12.4 E18	15.0 E18	16.6 E18
obs ν	47486	1997	157723	17
SK expect	29.2 ^{+3.5} _{-3.3}	28.9 ^{+3.7} _{-4.1}	29.8 ± 4.6	

Expected event rate @ SK

using 1kt event rate

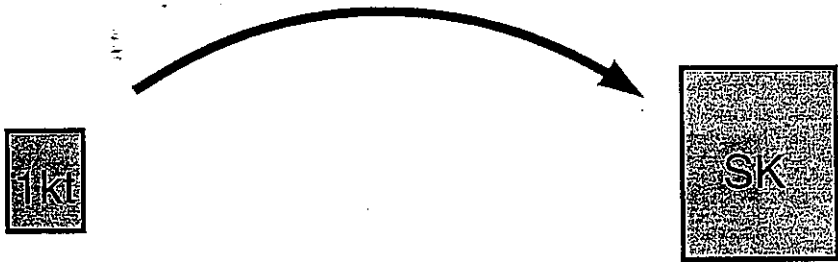
$$N_{SK} = \eta_{SK} \times \frac{N_{1kt}}{\eta_{1kt}} \times \frac{POT_{SK}}{POT_{1kt}} \times \boxed{\frac{\Phi_{SK}}{\Phi_{1kt}}} \times \frac{M_{SK}}{M_{1kt}}$$

by beam MC

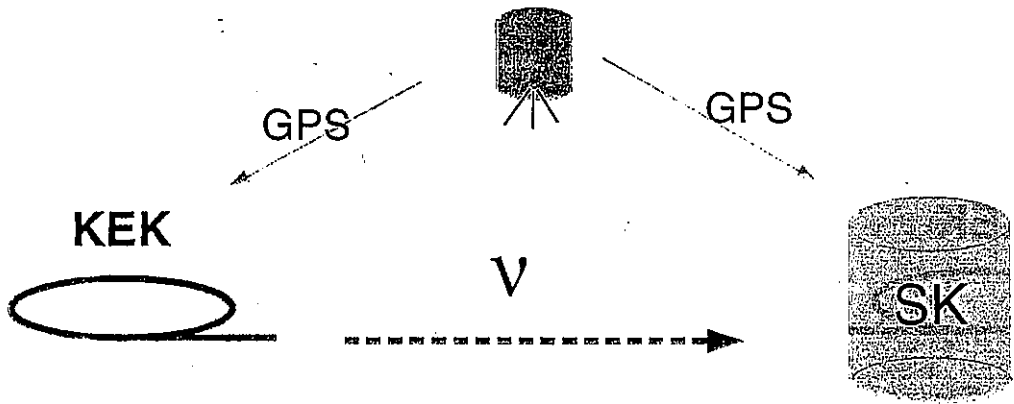
- detection eff. @ SK : $\eta_{SK} = 0.81 \sim 0.82$
- fid. mass far/near ratio : $M_{SK}/M_{1kt} = 22.5k / 50.3$
- flux far/near ratio : $\Phi_{SK}/\Phi_{1kt} \Rightarrow$ by beam MC/ π -mon
- observed event @ 1kt : N_{1kt}
- detection eff. @ 1kt : $\eta_{1kt} = 0.70$

• typical systematic errors

Nkt	8 ~10% (fiducial err ~ 8 %)
POT normalization	~ 3 % \rightarrow 1%
Far/Near	+ 8 % -10% \rightarrow +5.8%, -7.4%
η_{SK}	5% \rightarrow 3%
+14%, -15% \rightarrow ~ \pm 10%	



Search for FC event@Super-K



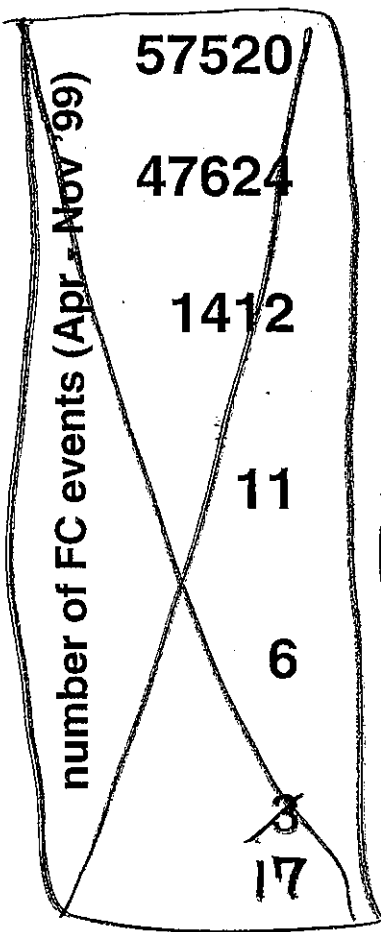
T_{KEK} :kicker timing

T_{SK} :trigger timing

GPS reduction

$$-500\mu s < T_{SK} - T_{KEK} - TOF < 500\mu s \quad \text{save} \rightarrow$$

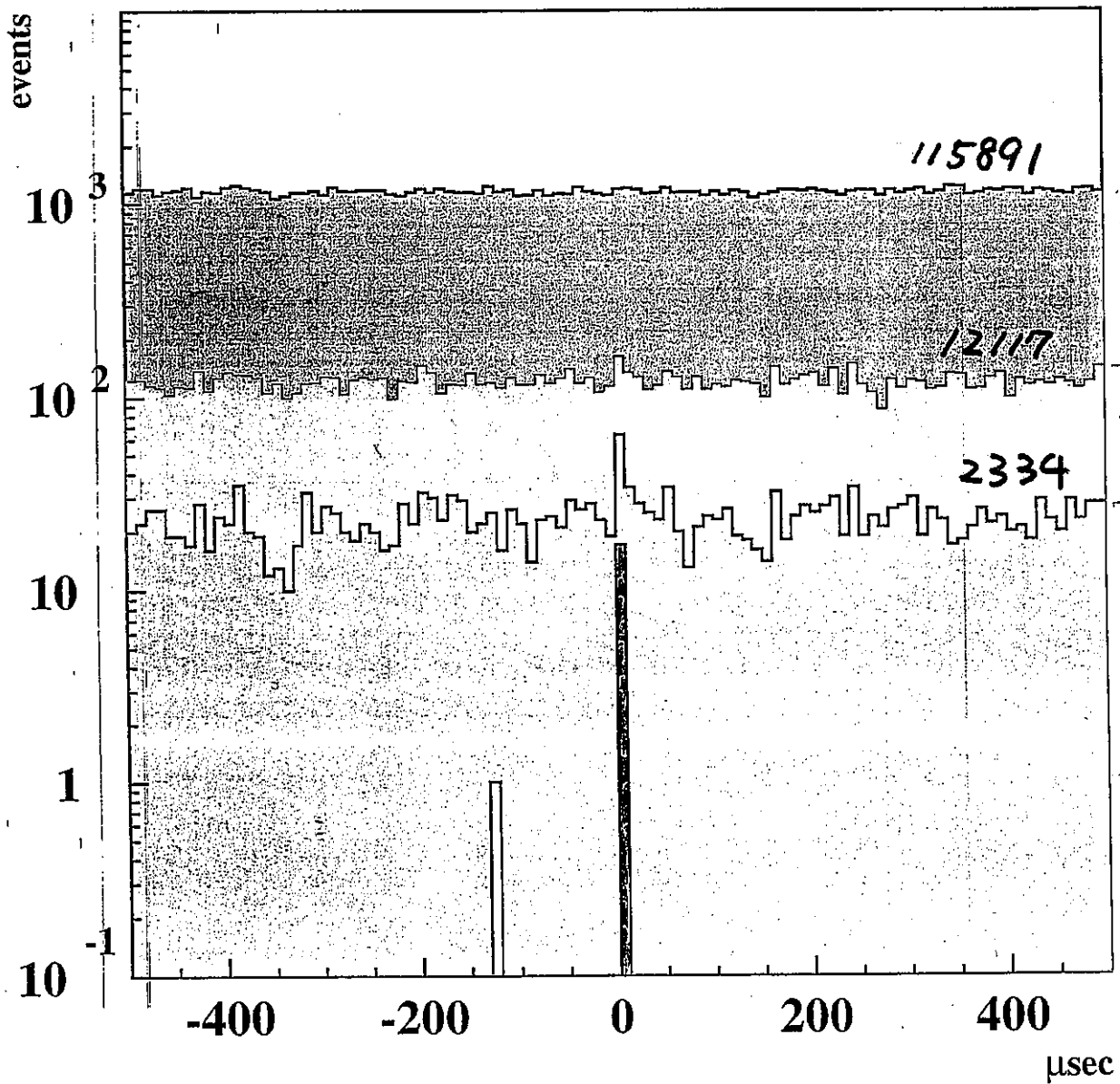
(0μ) $(+1.1\mu)$



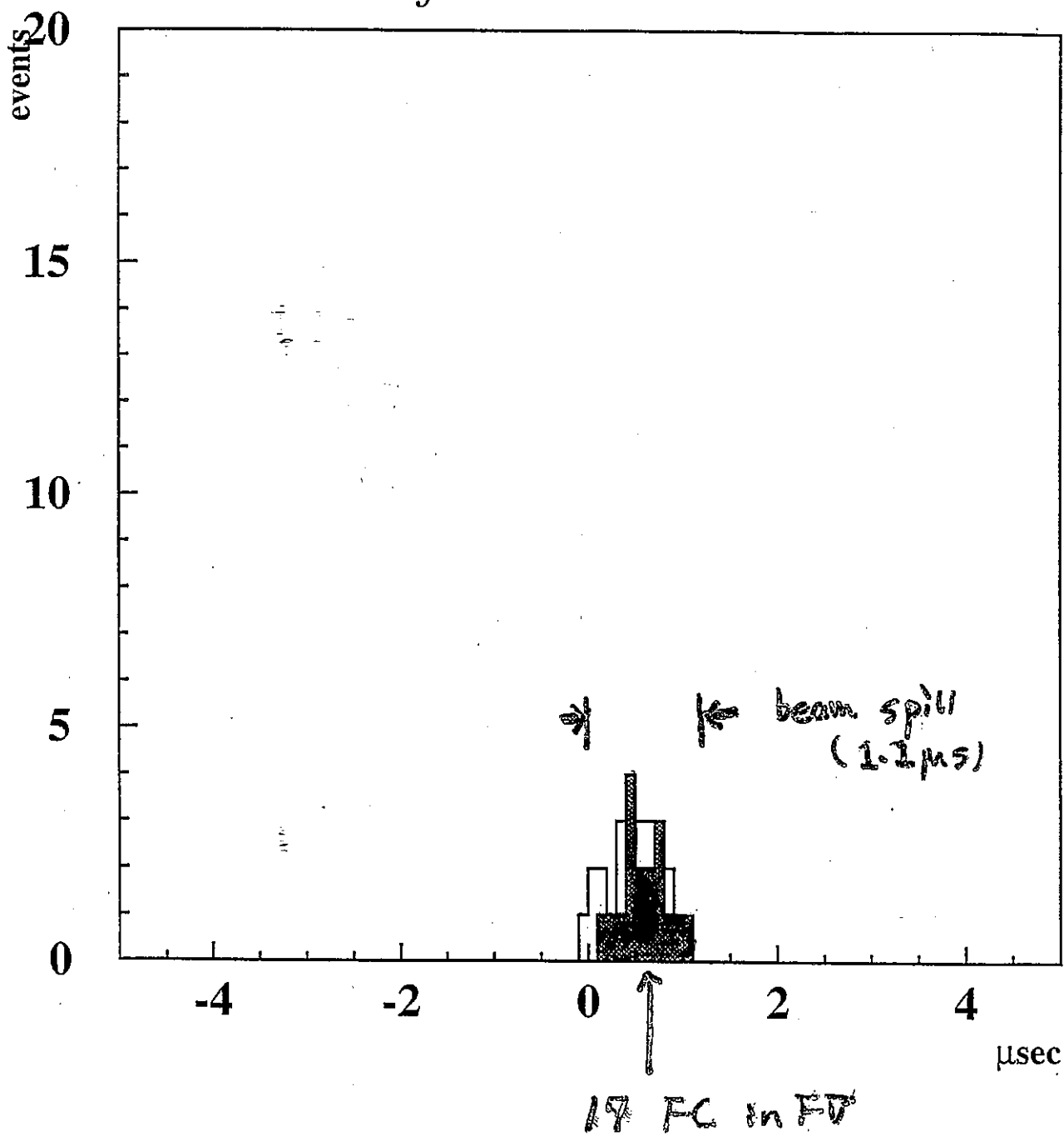
```

    graph TD
      A[decay electron cut] --> B[200 pe ≤ Q ≤ 50000 pe]
      B --> C[Nhit in ODclst. < 10 (FC)]
      C --> D[candidate in ΔT = 0 ~ 1.1 μs]
      D --> E[fiducial cut (Dwall > 2m)]
      E --> F[ ]
  
```

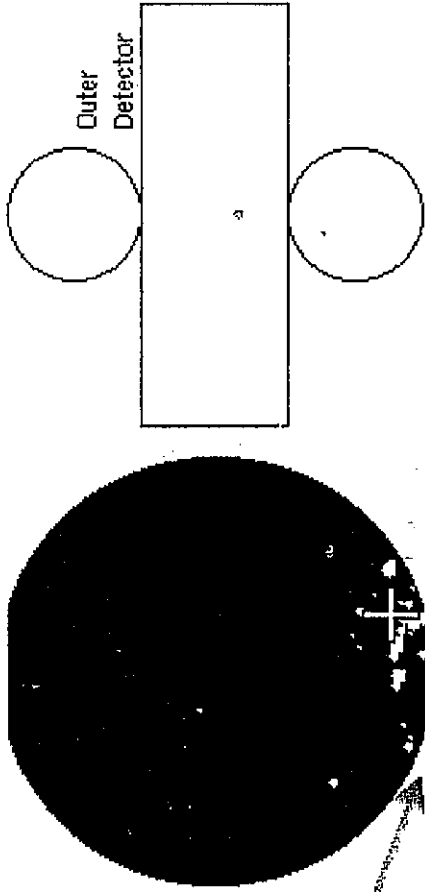
1999 JUN ~ 2000 MAR
 Δt of F.C. candidates



Δt of F.C. candidates

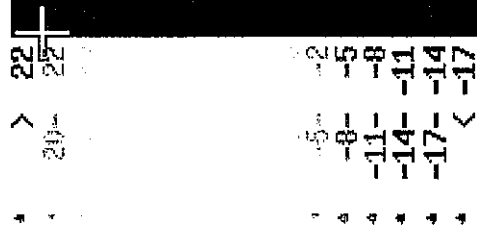


Super-Kamiokande
 Run 7436 Event 1405412
 99-06-19:18:42:4
 Inner: 516 hits, 1018 E
 Outer: 2 hits, 2 PE (in-time)

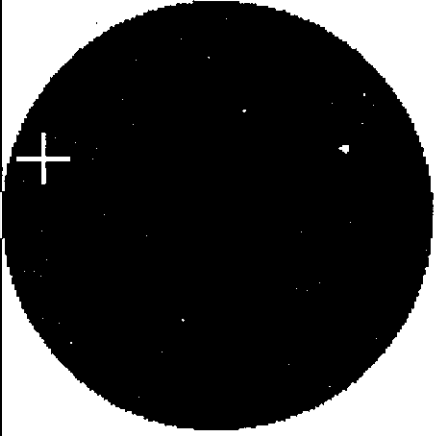
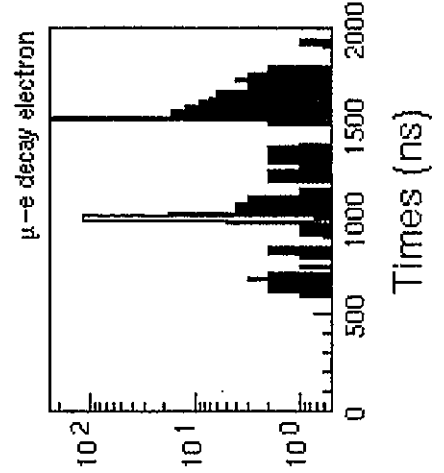
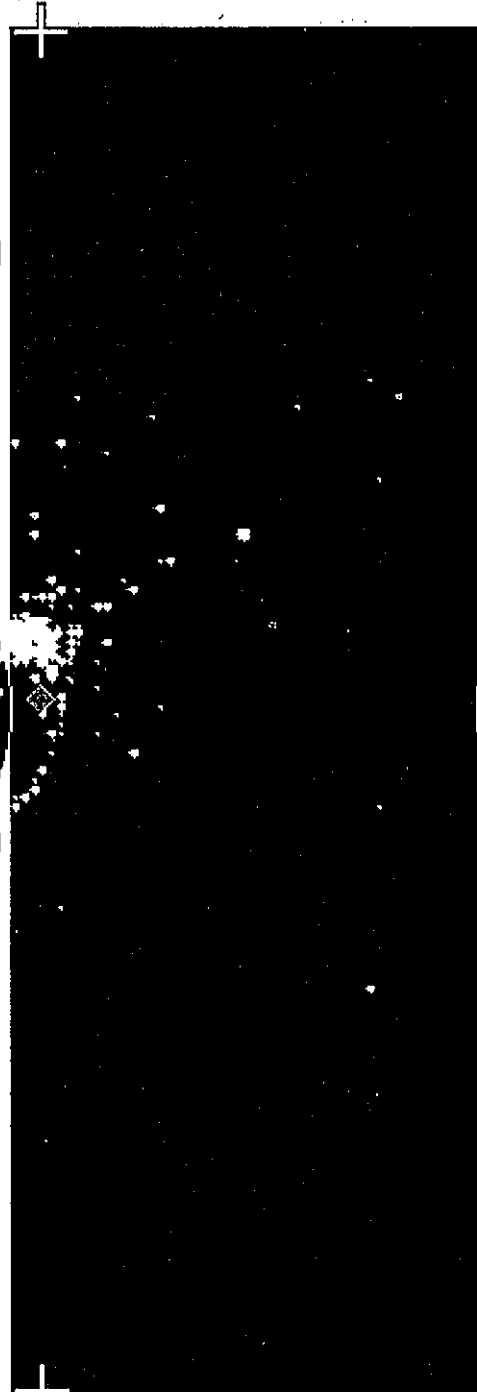


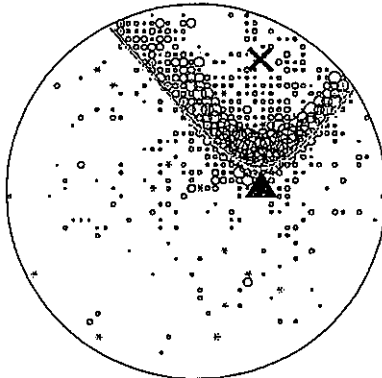
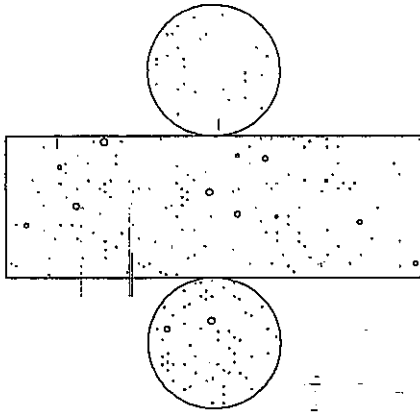
K2K beam direction
 marked by diamond

Resid(ns)

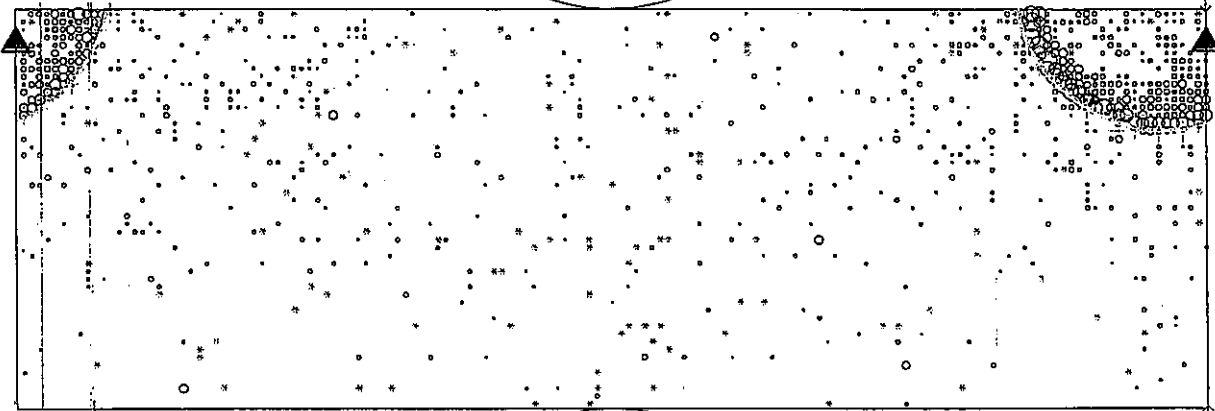


FIRST K2K EVENT
in SUPER-K

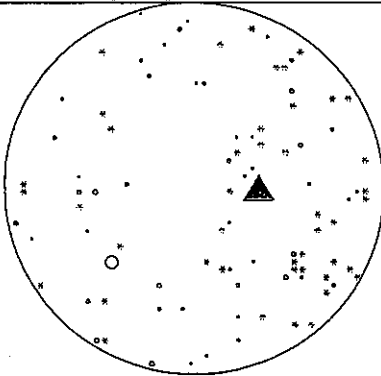




★ Super Kamiokande ★
 NUM 1
 RUN 8356
 SUBRUN 327
 EVENT 44038364
 DATE 2000-Feb-20
 TIME 10:12:30
 TOT PE: 5680.6
 MAX PE: 85.1
 NMHIT : 1285
 ANT-PE: 22.7
 ANT-MX: 1.9
 NMHITA: 27

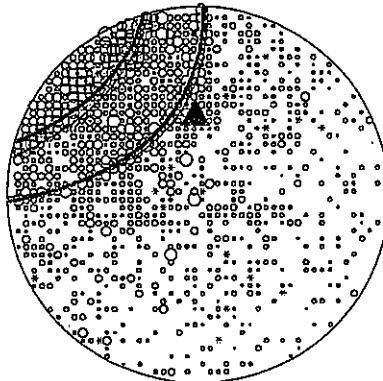
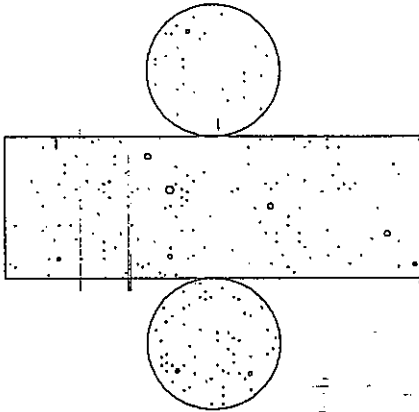


90/00/00:NoYet:NoYet
 90/00/00:NoYet:NoYet
 90/00/00:NoYet:NoYet
 90/00/00:NoYet:NoYet
 90/00/00:NoYet:NoYet
 **/04/29:;R= 1:NoYet
 R Z PHI
 5.79: 15.01: 1.51:0
 CANG : RTOT : AMOM : I
 41.6: 3103: 588:
 V= 0.966:-0.005: 0..



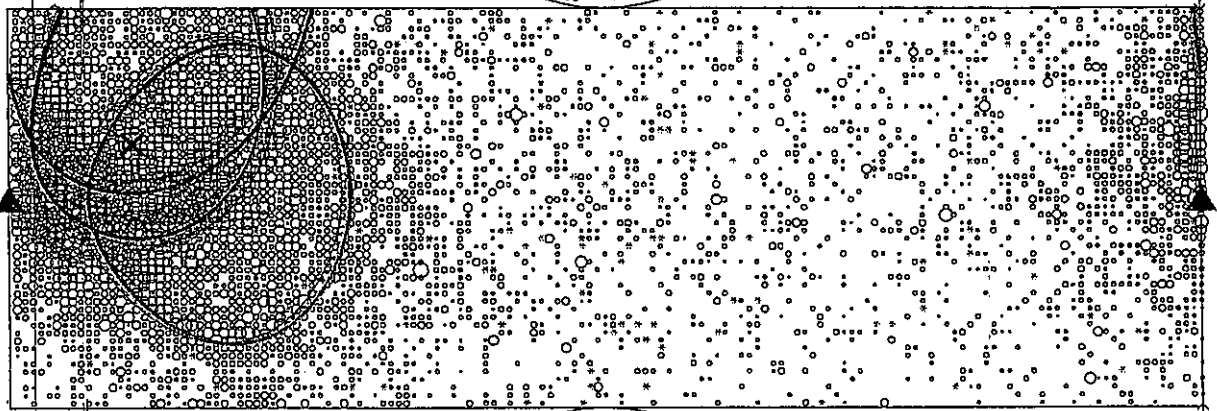
RunMODE: NORMAL
 TRG ID : 00000111
 T diff.: 0.896E+05u
 FEVSK : 81002803
 nOD YK/LW: 1/ 1
 BAD ch.: masked
 SUB EV : 0/ 1
 Dec-e: 1(0/ 1/ 0
 CT16: 5.28433e12
 RN: 4424SP: 1718
 GPSDIF: 0.60101u
 NHITAC: 1

Comnt;

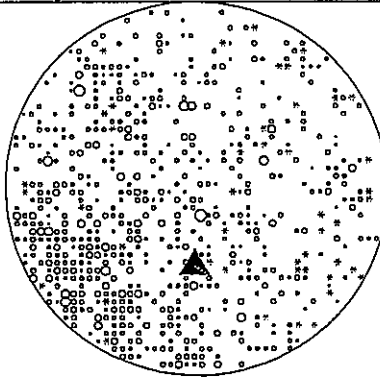


★ Super Kamiokande ★

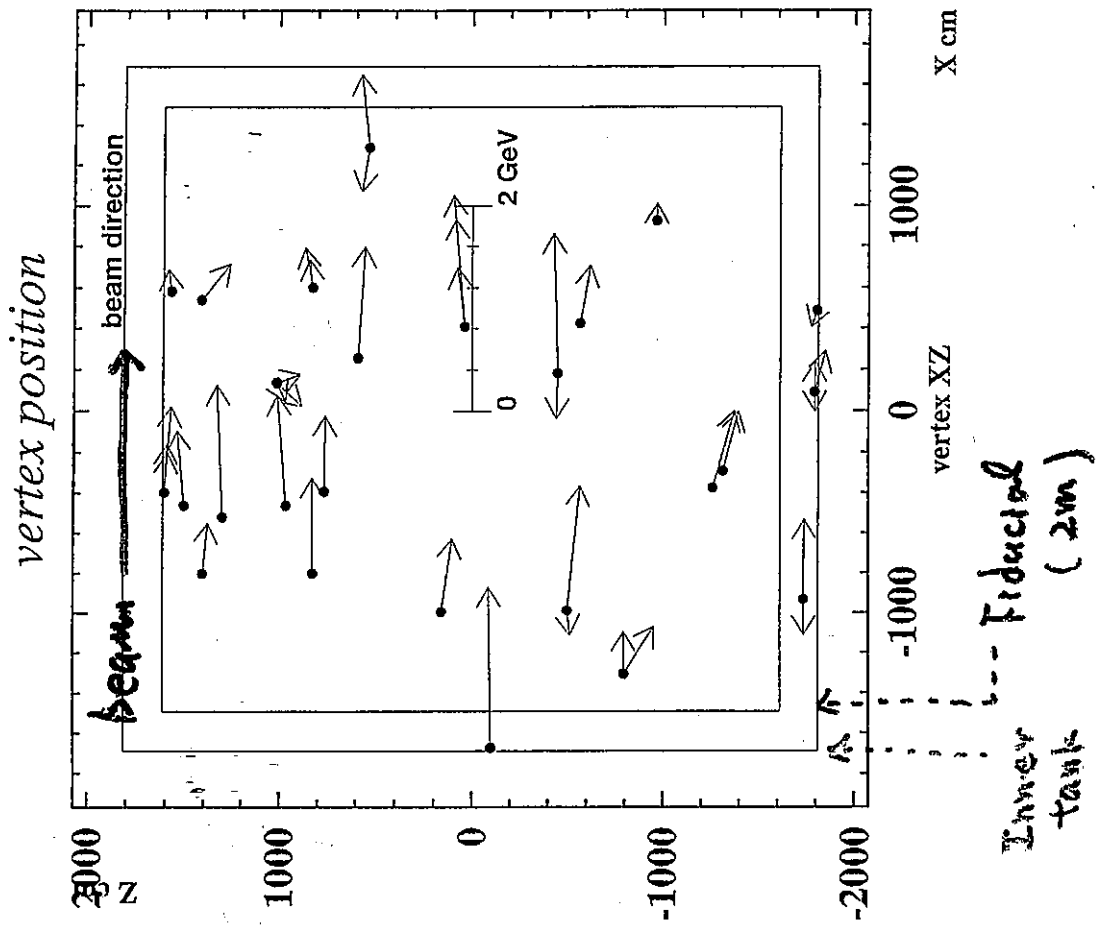
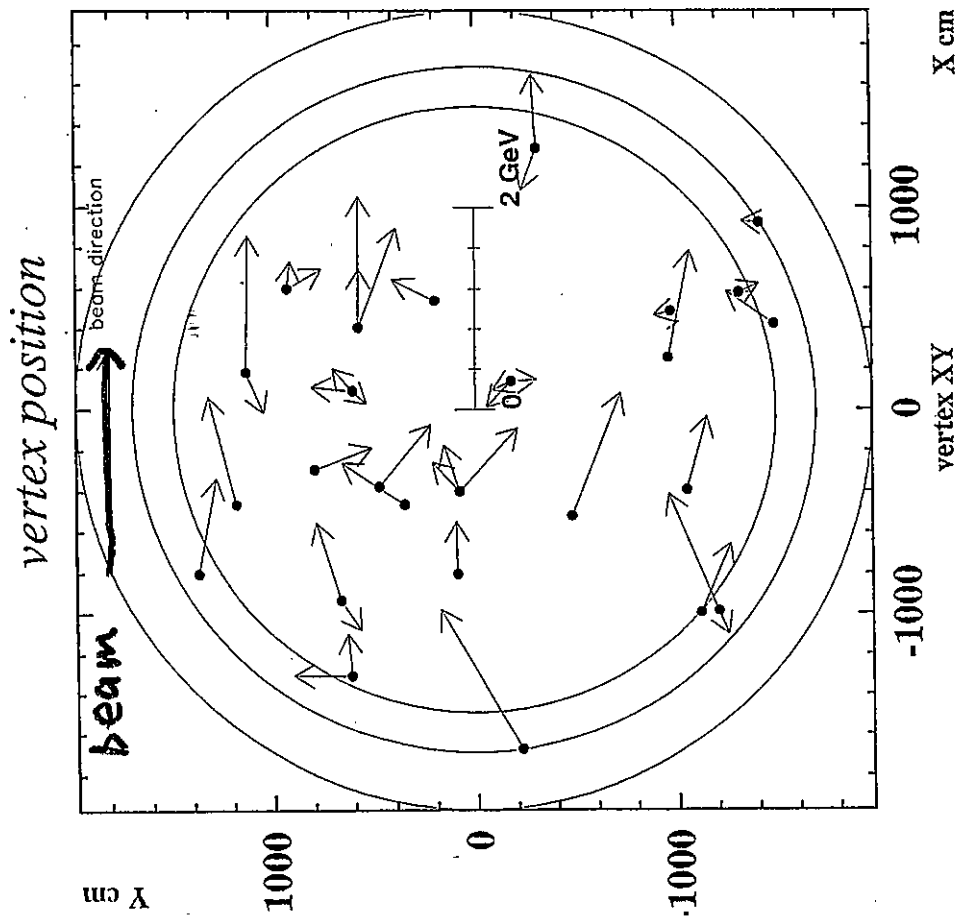
NUM 1
 RUN 8418
 SUBRUN 206
 EVENT 27699738
 DATE 2000-Mar- 7
 TIME 2:17:47
 TOT PE: 26322.4
 MAX PE: 68.3
 NMHIT : 5446
 ANT-PE: 12.9
 ANT-MX: 1.9
 NMHITA: 20



90/00/00:NoYet:NoYet
 90/00/00:NoYet:NoYet
 90/00/00:NoYet:NoYet
 90/00/00:NoYet:NoYet
 **/04/28;;R= 3:NoYet
 R Z PHI
 7.03: 0.40:-0.04:0
 CANG: RTOT: AMOM
 42.3: 6514: 1222: 1
 V= 0.493:-0.765: 0.
 44.0: 6245: 1173: .
 V= 0.216:-0.975: 0.
 38.0: 1949: 371: .
 V= 0.363:-0.570: 0.
 Comnt;



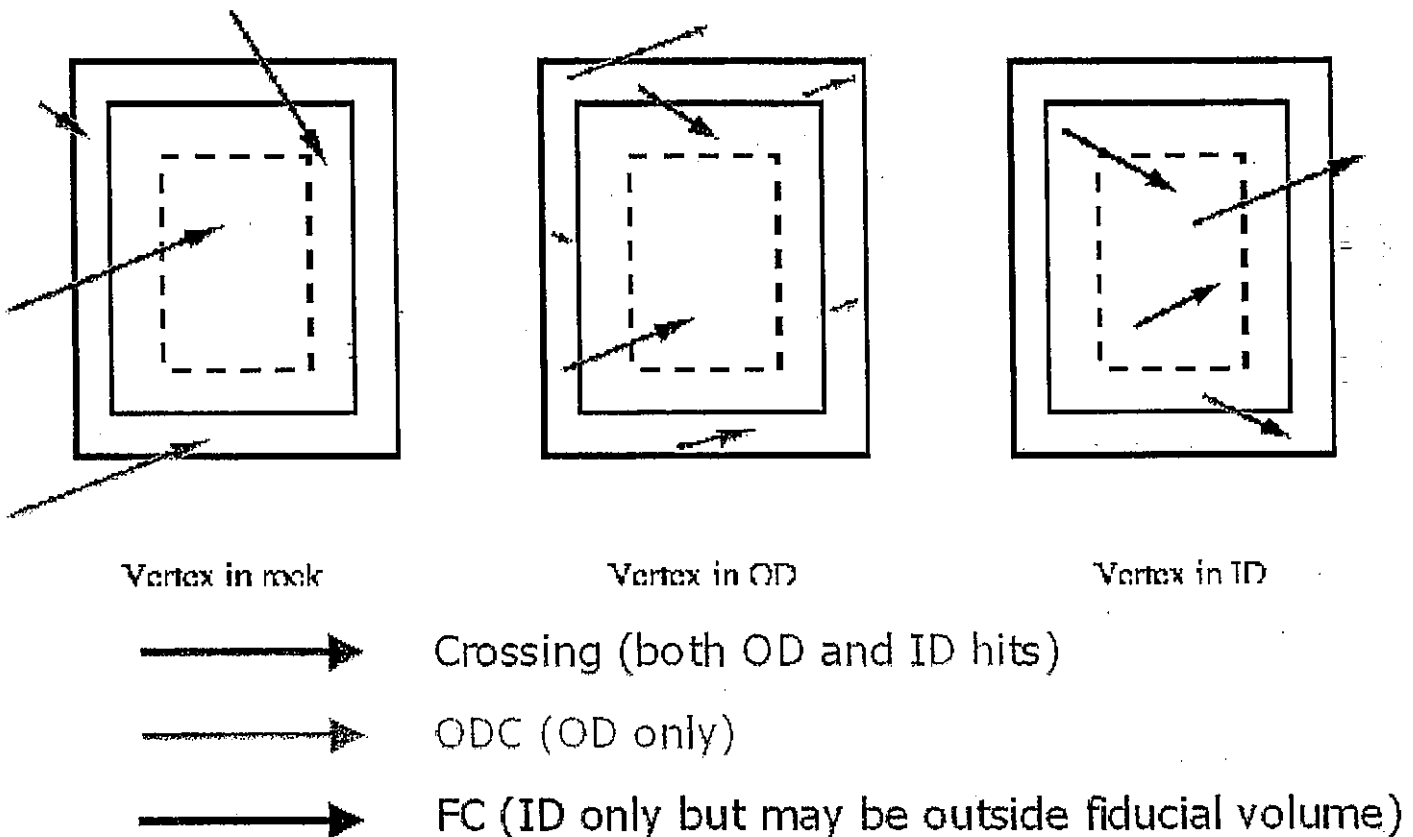
RunMODE: NORMAL
 TRG ID : 00000111
 T diff.: 0.641E+05u
 FEVSK : 81002803
 nOD YK/LW: 1/ 1
 BAD ch.: masked
 SUB EV : 0/ 1
 Dec-e: 1(1/ 0/ 0
 CT16: 5.61947e12
 RN: 4508SP: 796
 GPSDIF: 0.49402u
 NHITAC: 1



K2K beam-induced events in Super-K

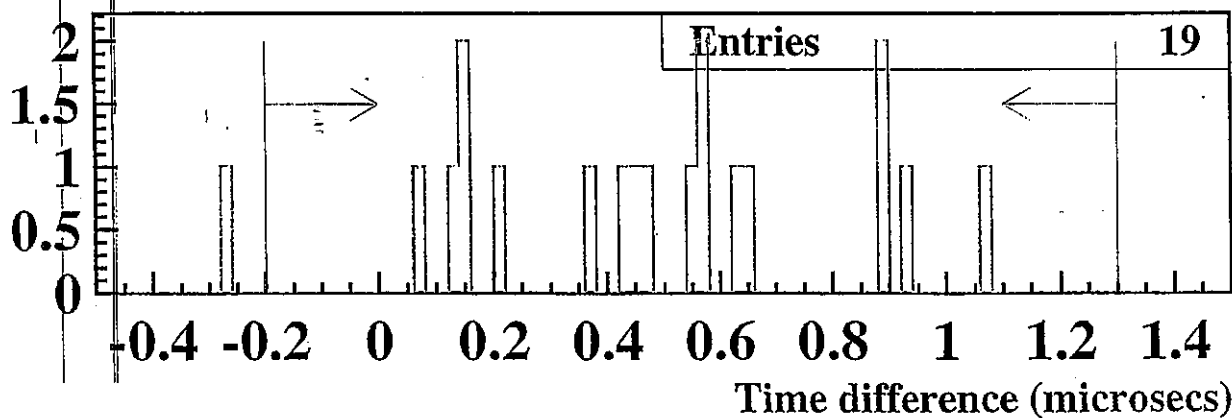
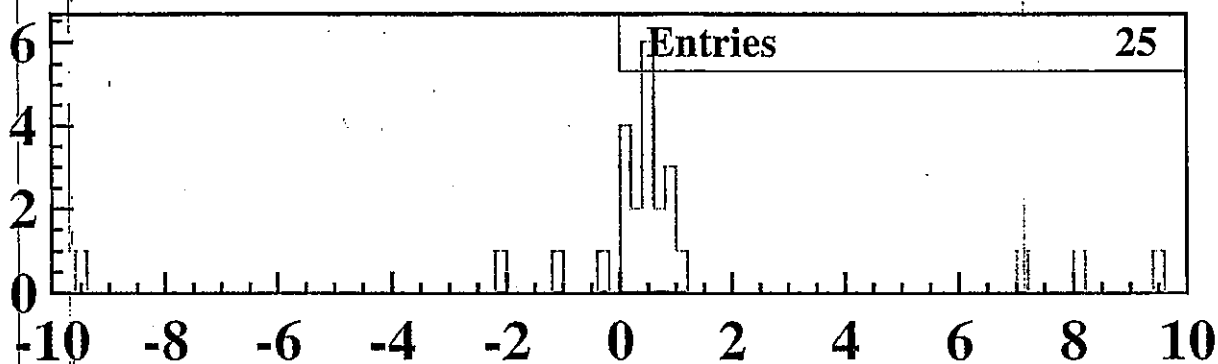
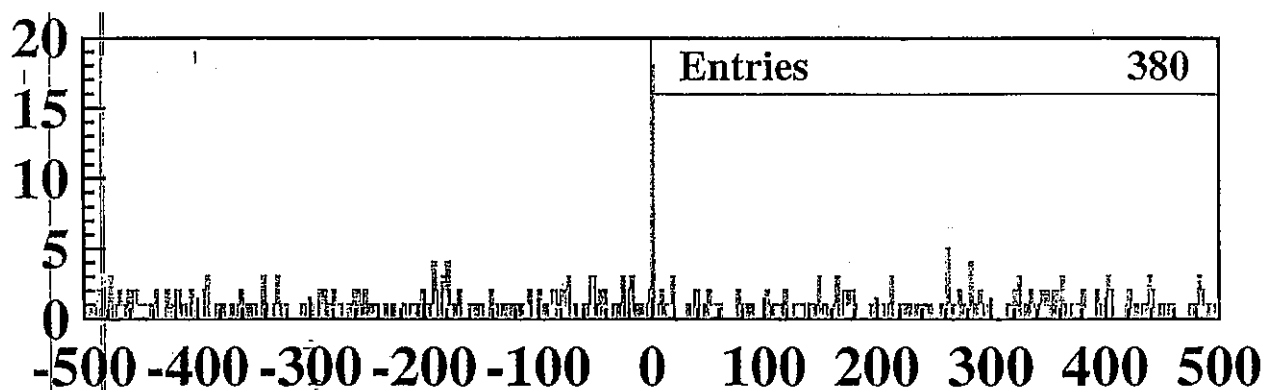
Definitions for K2K events in Super-K

- **Not** the same as Super-K FC and PC definitions
- Fully contained (significant light in ID only)
 - passes decay-e cut
 - $200 < Q_{TOT}^{ID} < 50,000$ photo-electrons
 - OD cluster size ≤ 9 hit PMTs
- OD events (light in ID + OD)
 - OD cluster size > 9 hit PMTs
 - Two categories:
 - Crossing events: $Q_{TOT}^{ID} \geq 180$
 - ODC (OD-Contained): $Q_{TOT}^{ID} < 180$



OD events } crossing contained

June 1999-March 2000



Super-Kamiokande

Run 7447 Sub 86 EV 4677921

99-06-24:05:00:36

Inner: 587 hits, 1545 pE

Outer: 19 hits, 9 pE (in-time)

Trigger ID: 0x07

D wall: 30.4 cm

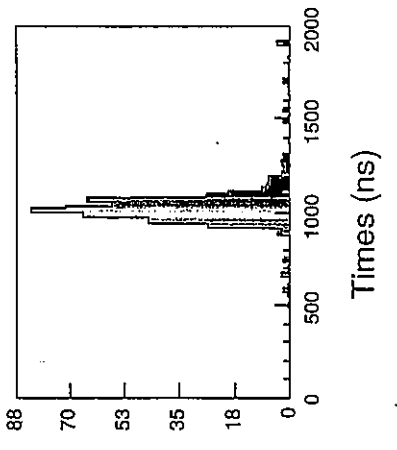
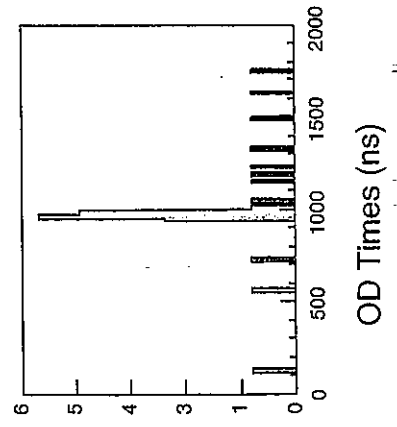
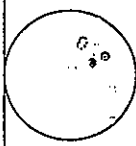
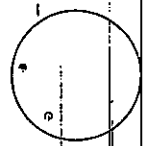
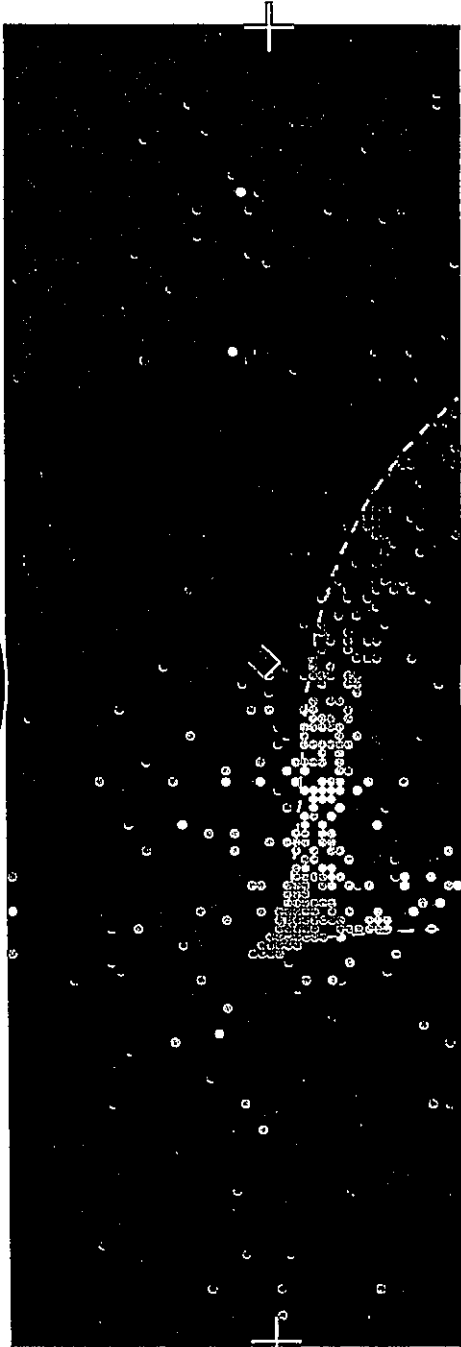
Partially-Contained Mode

SK: 930168036.60339270 KEK: 930168036.60338380

Time difference: 0.890 usec

Time (ns)

- < 899
- 899-915
- 915-931
- 931-947
- 947-963
- 963-979
- 979-995
- 995-1011
- 1011-1027
- 1027-1043
- 1043-1059
- 1059-1075
- 1075-1091
- 1091-1107
- 1107-1123
- >1123



Super-Kamiokande

Run 7426 Sub 60 Ev 3255713

99-06-14:17:43:21

Inner: 58 hits, 59 pE

Outer: 41 hits, 77 pE (in-time)

Trigger ID: 0x08

D wall: 1690.0 cm

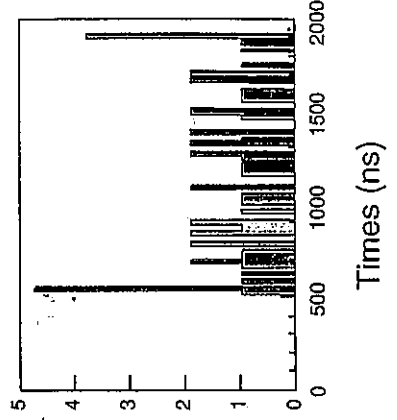
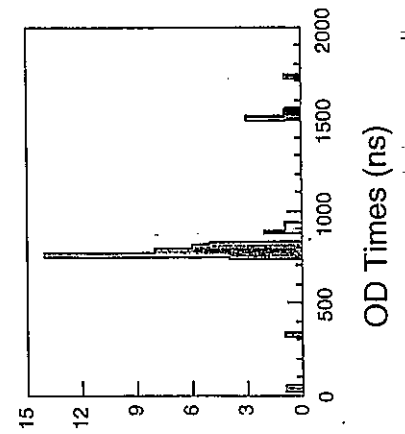
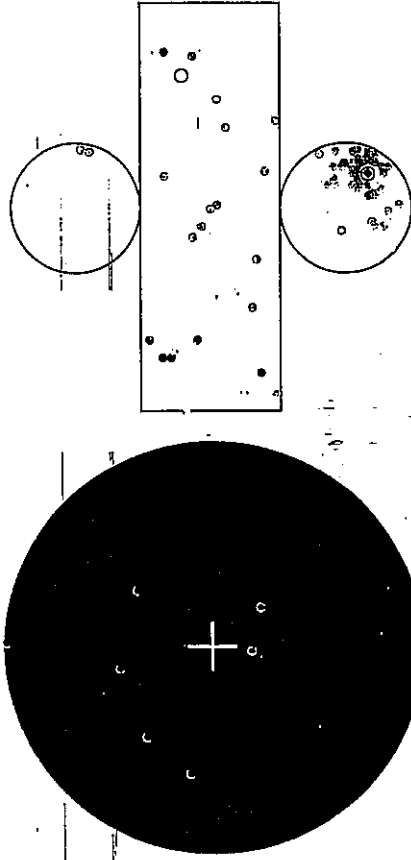
Partially-Contained Mode

SK: 929349801.33141204 KEK: 929349801.33140738

Time difference: 0.466 usec

Time (ns)

- * < 731
- * 731-763
- * 763-795
- * 795-827
- * 827-859
- * 859-891
- * 891-923
- * 923-955
- * 955-987
- * 987-1019
- * 1019-1051
- * 1051-1083
- * 1083-1115
- * 1115-1147
- * 1147-1179
- * >1179



SK event summary

Period : Jun 1999 - March 2000

Sk live POT : 16.64 E 18

○ Fully contained		26
<u>22.5 kt fiducial</u>		<u>17</u>
1- ring	10	
9 μ like		
1 e like		
m-ring	7	
Out of fiducial		9
○ OD crossing	(0.17 B.G. expected)	10
Exiting		4
Entering		6
○ OD contained	(0.37 B.G. expected)	8

Results for June 1999 - March 2000 period

Number of ODC events found: 8

Number of crossing events found: 10 (6 entering, 4 exiting)

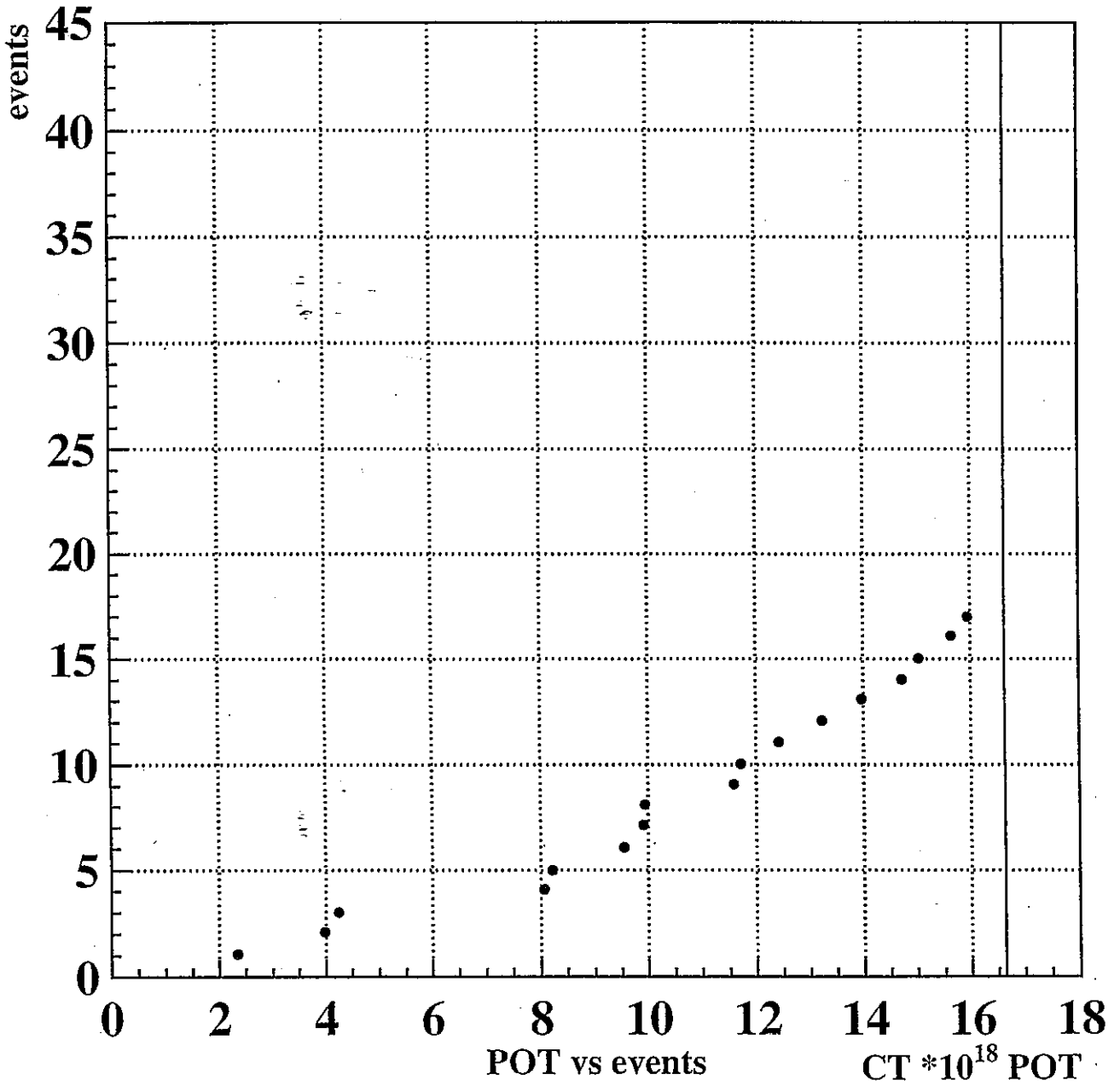
Total number of OD events found: 18

Expected mean number of background events
in -0.2 to 1.3 microsec window: 0.54 (0.17 crossing, 0.37 ODC)

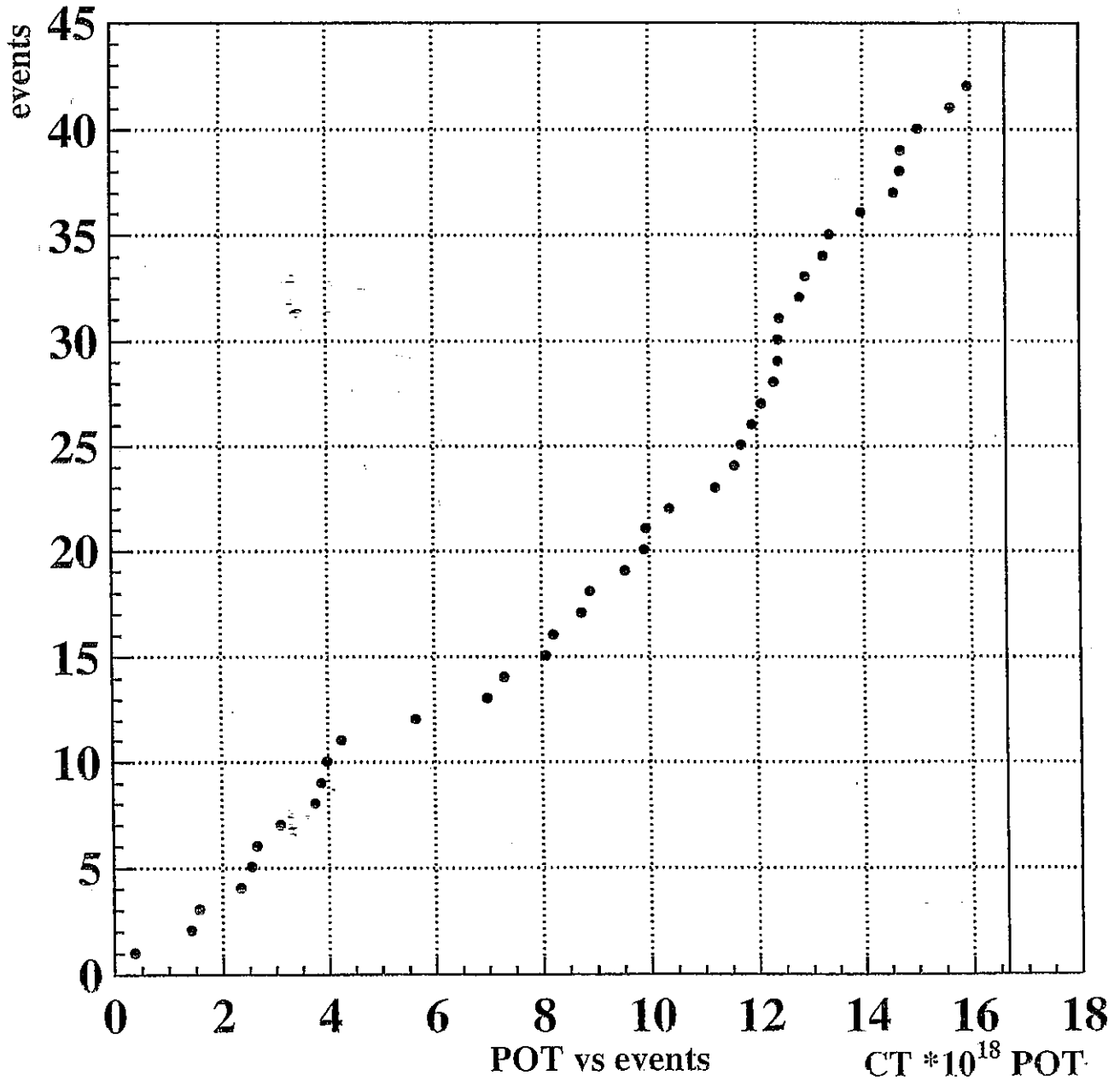
Predicted numbers of OD events:

	No osc	$\Delta m^2=0.003$	$\Delta m^2=0.005$	$\Delta m^2=0.00$
ODC	21.8 ± 8.3	14.5	9.5	7.7
Crossing	10.4 ± 3.8	7.9	5.2	3.6

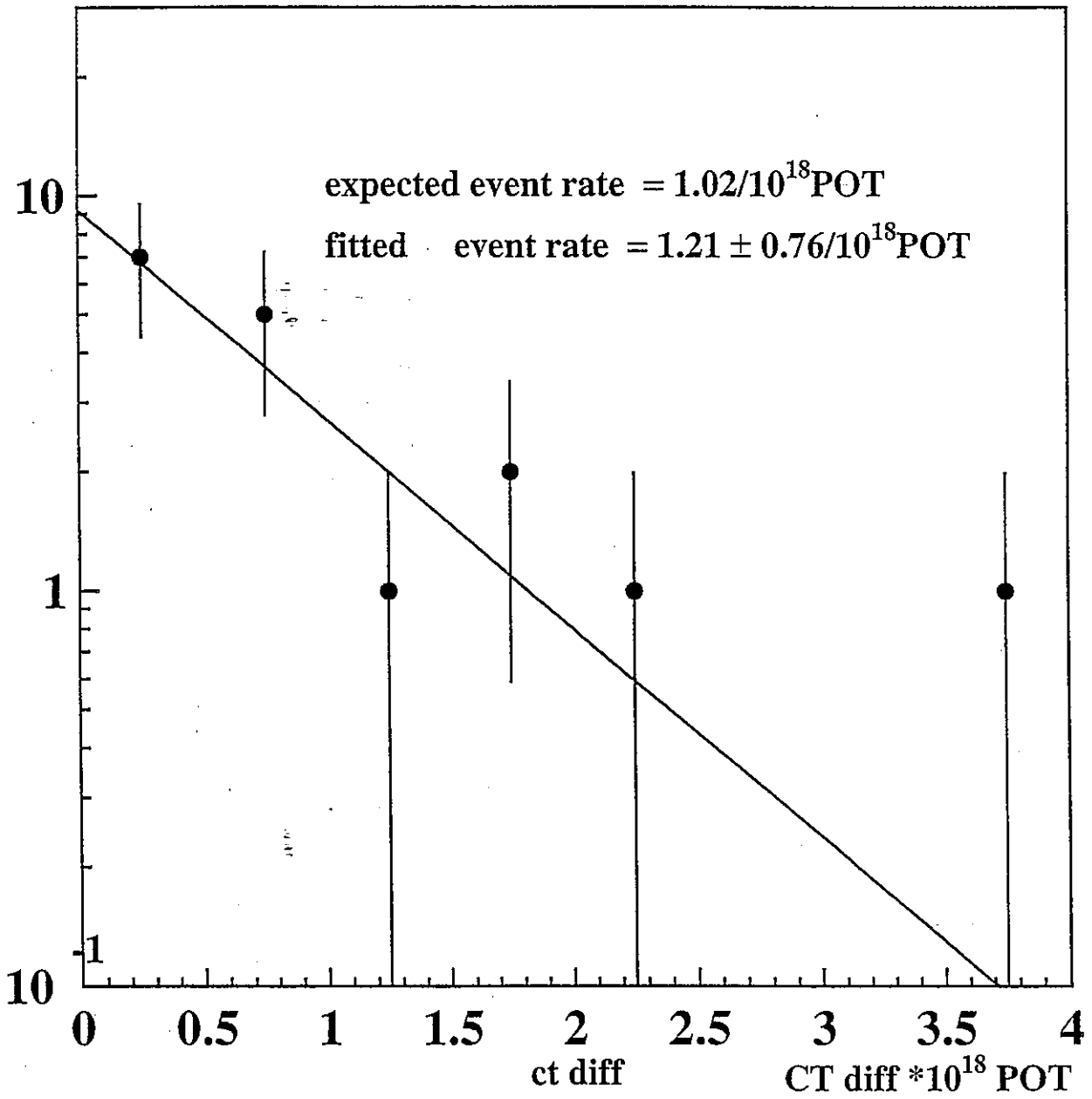
FC 22.5kt



ALL



FC 22.5kt



SK observed vs. expected

	Obs.		Null Osc.		Expected	
	Count	Rate	Count	Rate	Count	Rate
FC 22.5kt	17	29.2 ^{+3.5} _{-3.3}	19.3 ^{+2.5} _{-2.4}	12.9 ^{+1.6} _{-1.6}	10.8 ^{+1.4} _{-1.3}	$\Delta m^2 (\times 10^{-3} \text{eV}^2)$ 5.4 ± 0.4
I-ring	10	17.6 \pm 2.5	10.4 \pm 1.7	6.8 \pm 1.1	6.2 \pm 1.0	
μ -like	9	15.8 \pm 2.0	9.0 \pm 1.5	5.4 \pm 0.9	4.9 \pm 0.8	
e-like	1	1.7 \pm 0.3	1.5 \pm 0.3	1.4 \pm 0.3	1.3 \pm 0.3	
multi ring	7	11.6 \pm 2.0	8.8 \pm 1.6	6.1 \pm 1.1	4.6 \pm 0.8	
FC Out of EV	9	12.4 \pm 2.5	3.1 \pm 1.7	5.5 \pm 1.1	4.8 \pm 1.0	
OD contained	8	21.8 \pm 8.3	14.5	9.5	7.7	
Crossing	10	10.4 \pm 3.8	7.9	5.2	3.6	

Systematic errors

(For expected number of FC events in Fid. Vol. deduced from 1 kton)

■ 1 kton - SK correlated error on the detection efficiency : 1 kton SK
 residual

● σ_{MC} ($\pm 30\%$)

1 kton	SK	residual
-4.1%	-3.3%	+0.8%
+4.8%	+3.9%	-0.9%

● Spectrum uncertainty

1 kton	SK	residual
-2.4%	-1.1%	+1.3%
+3.4%	+1.6%	-1.7%

■ 1 kton

● Fiducial volume $\pm 6\%$

● Multi-event ambiguity $\pm 3\%$

■ SK (Fiducial volume, MC statistics) $\pm 3\%$

■ CT normalization $\pm 1\%$

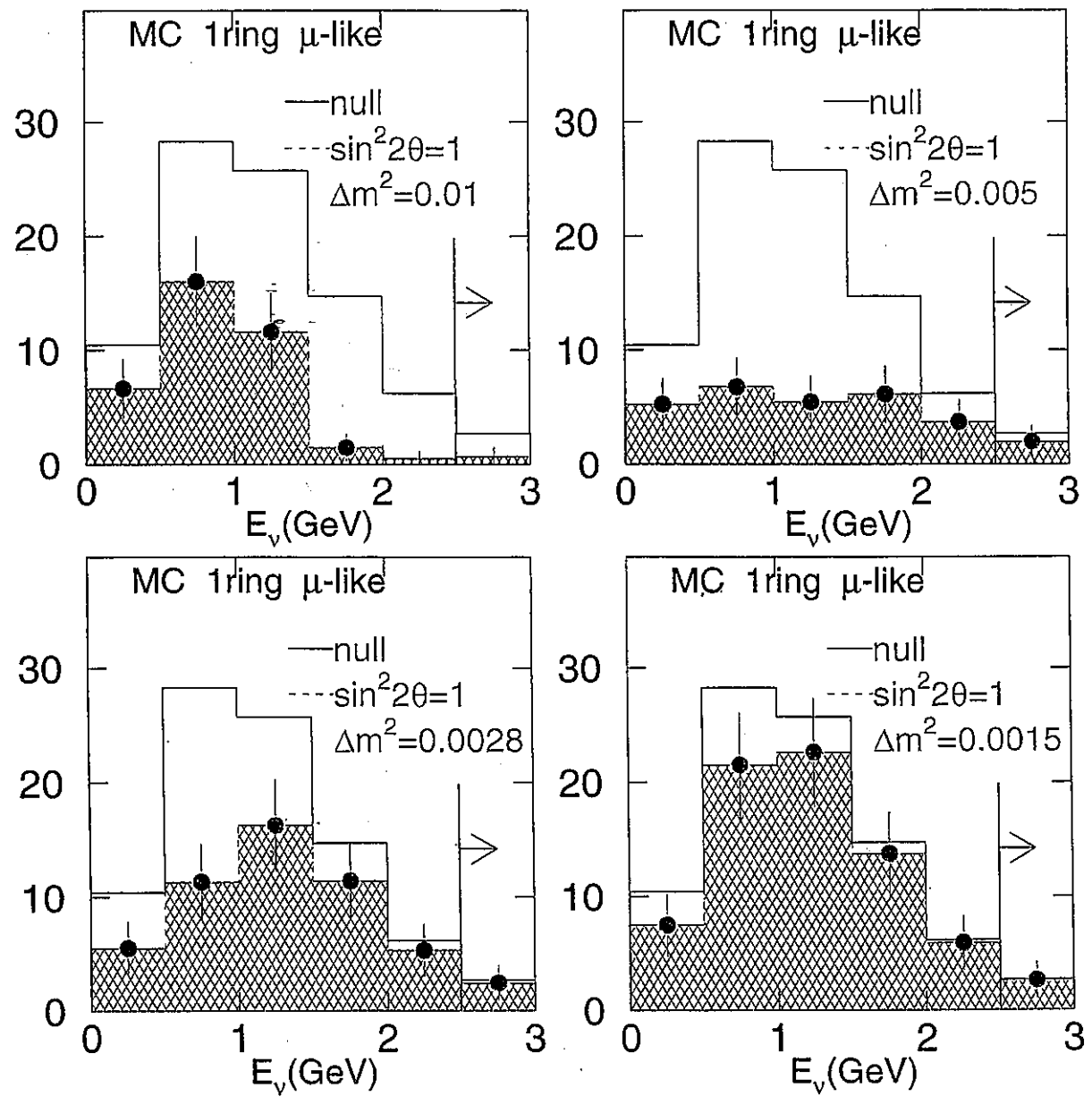
■ Near/far ratio $+5.8\%$
 -7.4%

■ $N_{SK}^{expected}$

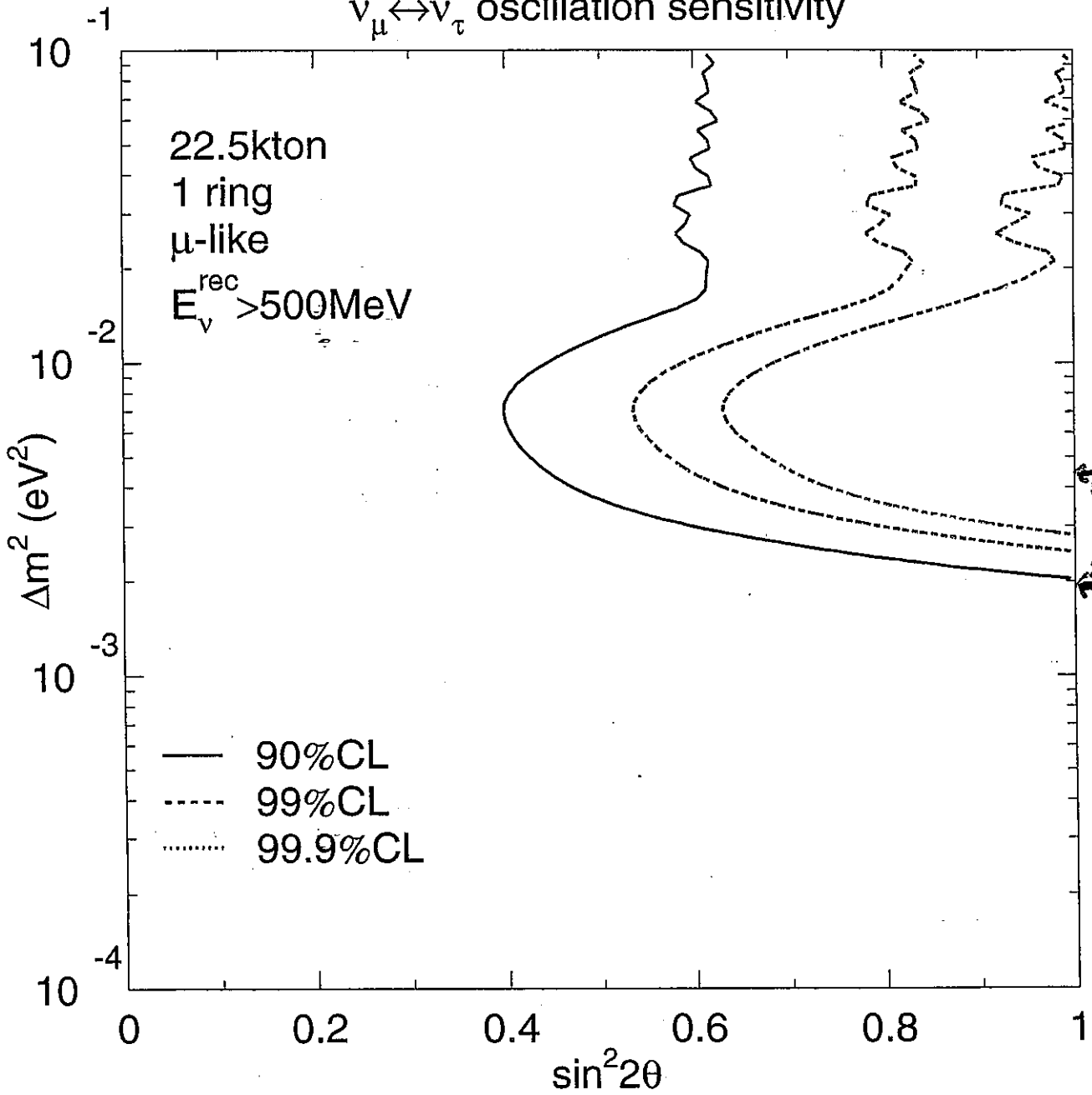
$\sim \pm 10\%$ ($\sim \pm 15\%$ in 99 runs)

Total 210 ν interaction @ 10^{20} pot
 (88 1-R FC)

Reconstructed Neutrino Energy (MC)



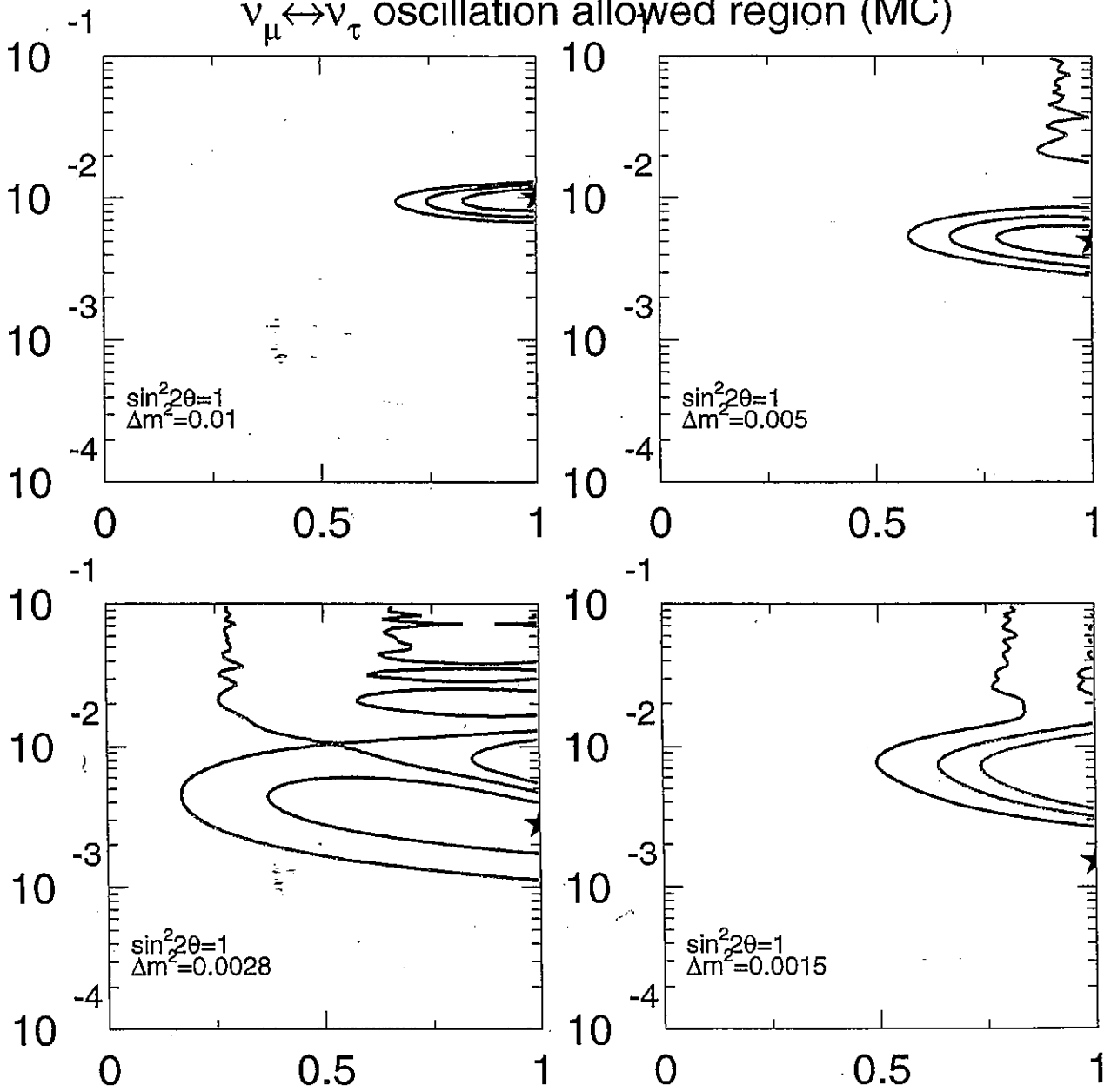
$\nu_\mu \leftrightarrow \nu_\tau$ oscillation sensitivity

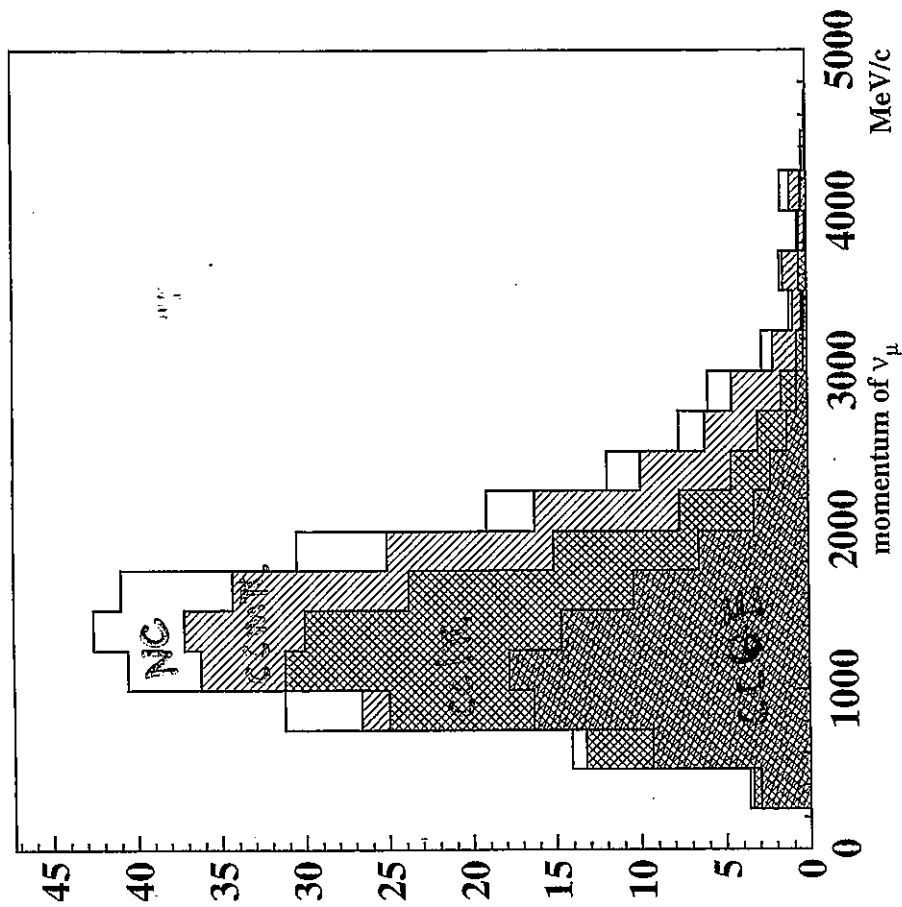


SK 90%CL
@ 990 days

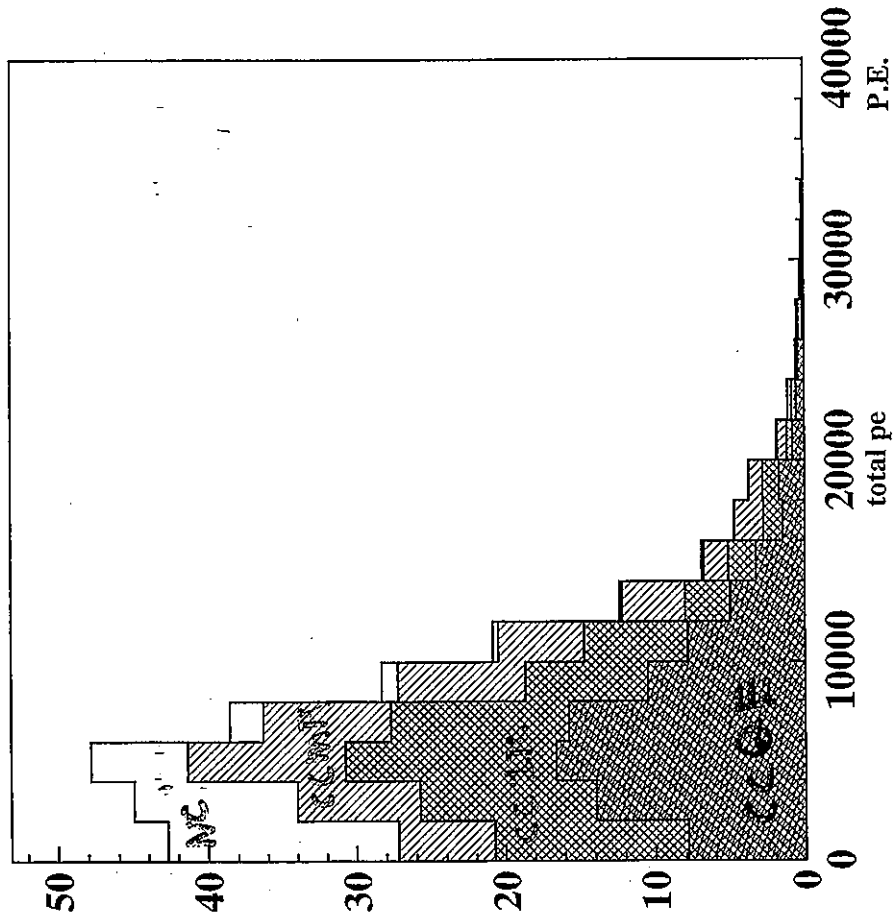
W/ 2.1% total
@ 100% pot

$\nu_\mu \leftrightarrow \nu_\tau$ oscillation allowed region (MC)





E_ν @ SK



P.E. @ SK

Summary

① K2K results (Jun 1999 ~ Mar 2000)

- Total POT (Apr 1999 - Nov 1999) \Rightarrow **16.6E18**
- ν beam is well measured by 3 front detectors
- Number of FC events in 22.5kt at SK

expected $29.2^{+3.5}_{-3.3}$
observed 17

\Rightarrow deficit (?) is 2σ level, need more data !

② future

- more 2 month data are coming (May, Jun 00)
in next ICHEP
- More study in spectrum, ν interaction in FD
- Next beam \rightarrow beginning of next year