EXPERIMENTAL ν PHYSICS AT THE MUON COLLIDER COMPLEX

PETER FISHER / MIT

11 NOV. 1996

- FRONT END
- RECIRCULATING LINACS
- COLLIDER
- STORAGE RING?

BOOSTER

BOONE - EXPLORE REGION
OF LSND PARAMETER SPACE

$\langle E_\nu \rangle \sim 1.5$ GeV {R. STEFANSKI, H. WHITE}

$L \sim 0.5 - 2$ KM

- OTHER PHYSICS {R. TAYLOR}
  - QUASI-ELASTIC
  - CHARM PHYSICS
  - STRUCTURE FUNCTIONS

MOVE TO MUON COLLIDER
FIRST END FOR HIGHER
STATISTICS?

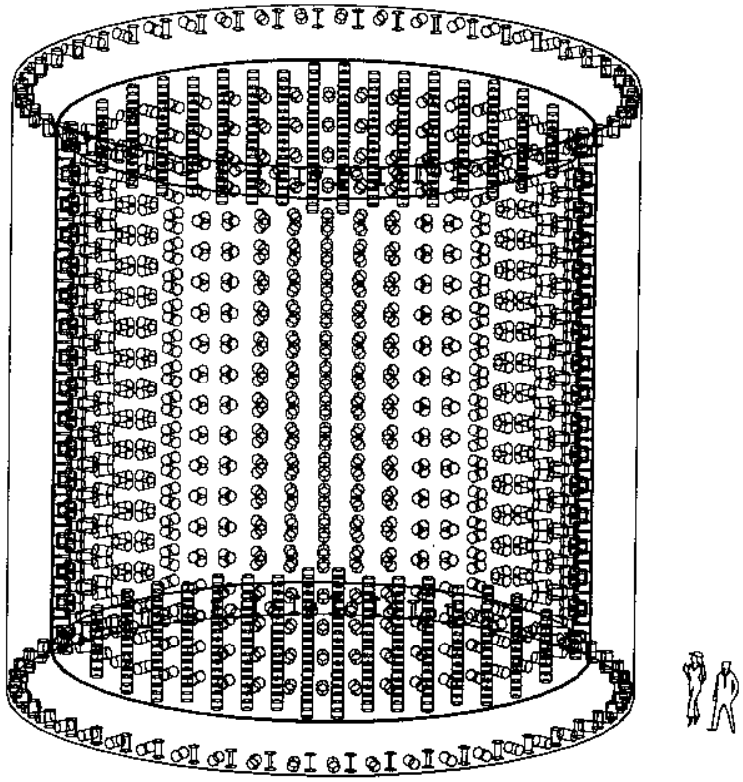


Figure 16: Schematic of the proposed detector.

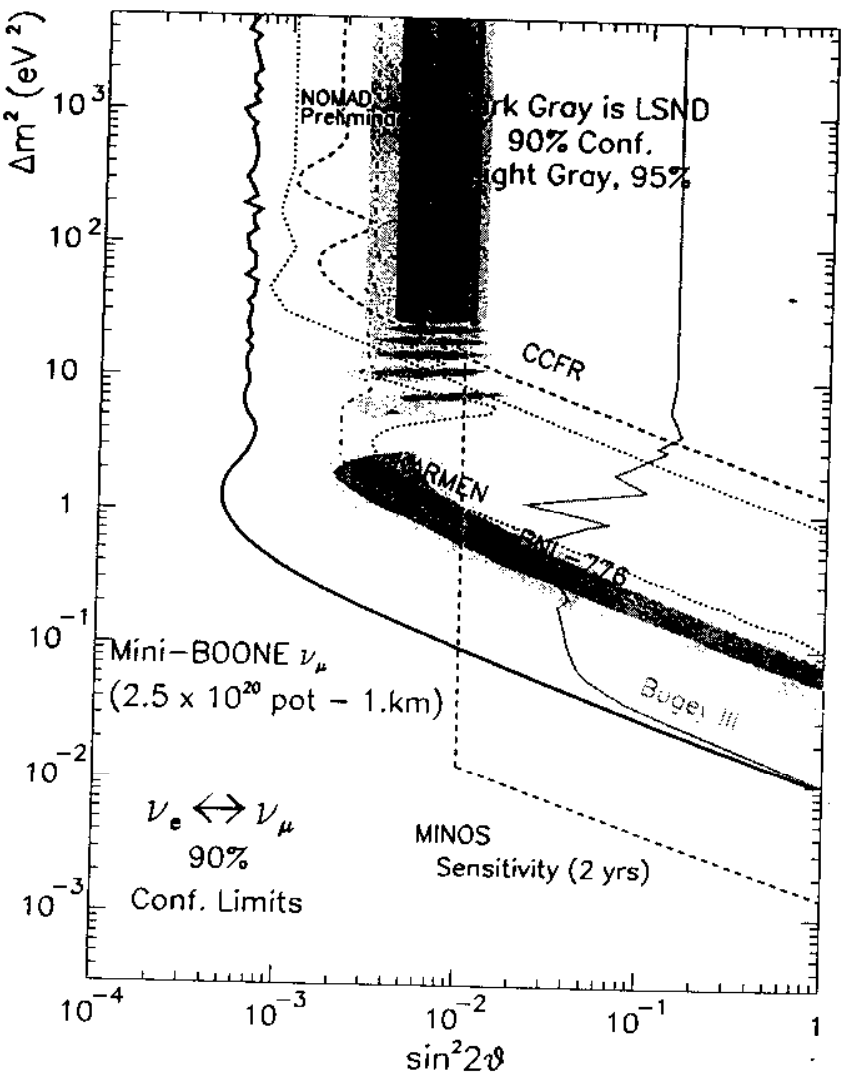
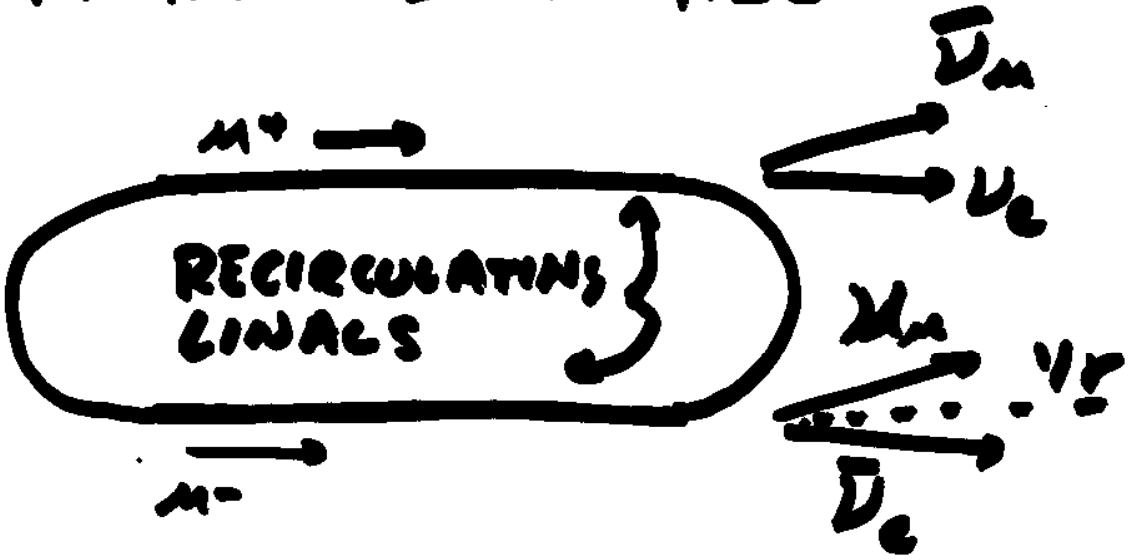


Figure 1: 90% C.L. limit expected for MiniBooNE for $\nu_\mu \to \nu_e$ appearance after one year of running, including 10% systematic error, if LSND signal is not observed (solid line). Summary of results from past experiments and expectations for the future MINOS experiment are also shown.

HIGHER ENERGIES



- HIGH, KNOWN PURITY
- SMALL BEAM SIZE, → $\frac{10\,cm}{m}$ @ 250 GeV
- HIGH INTENSITY

  ~ $\times 10^5$ DIS ν_μ ev/yr/kg TARGET

  ➡ PILE UP IN SAMPLING CALORIMETER!

K. MALFARANO

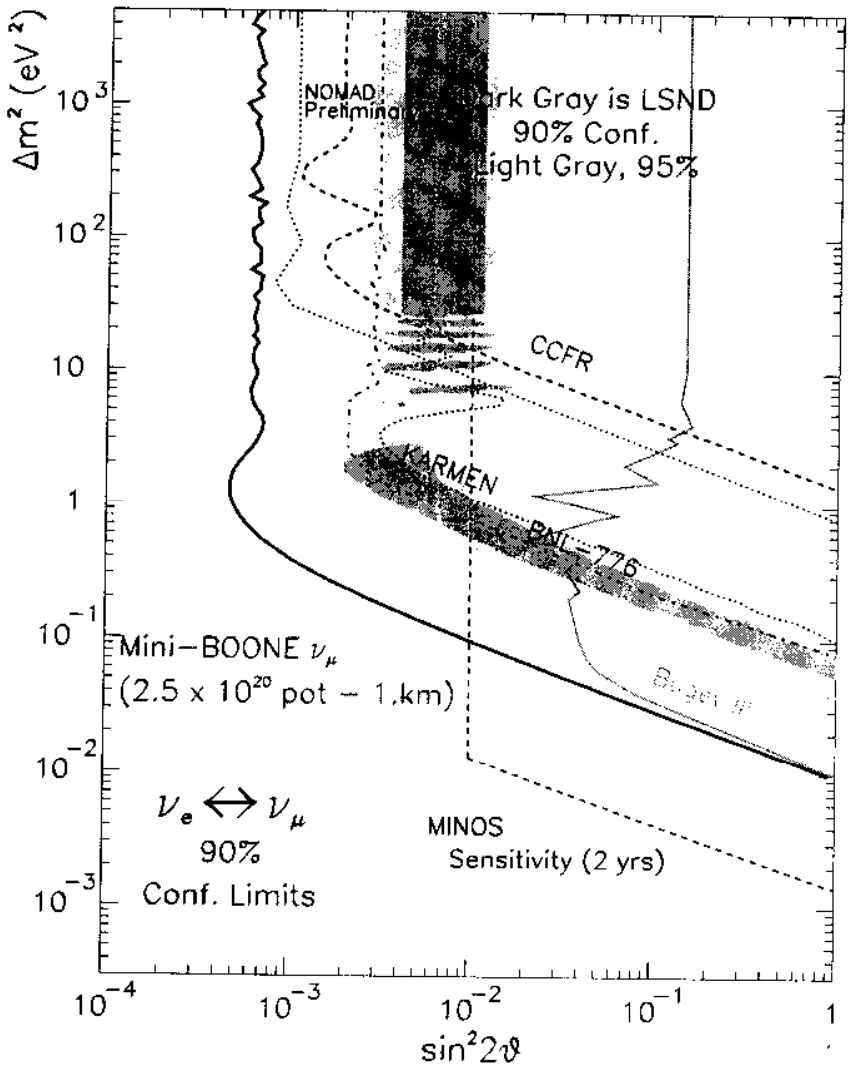


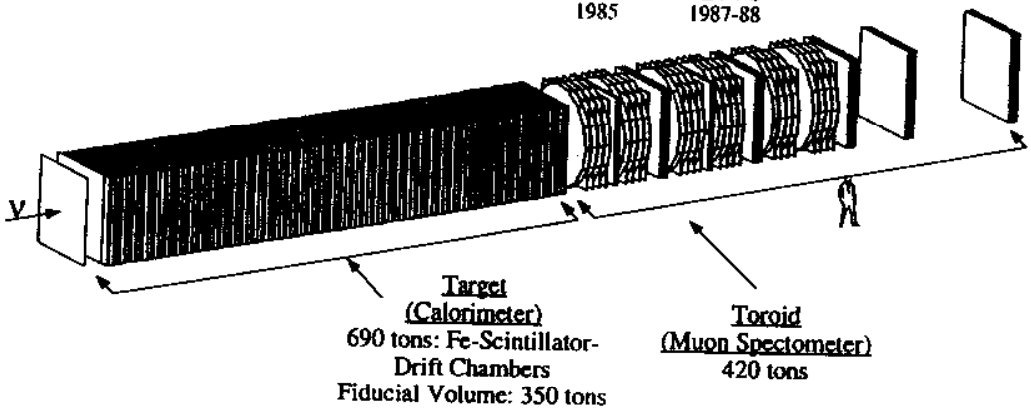
Figure 1: 90% C.L. limit expected for MiniBooNE for $\nu_\mu \to \nu_e$ appearance after one year of running, including 10% systematic error, if LSND signal is not observed (solid line). Summary of results from past experiments and expectations for the future MINOS experiment are also shown.

Too Many Neutrinos?

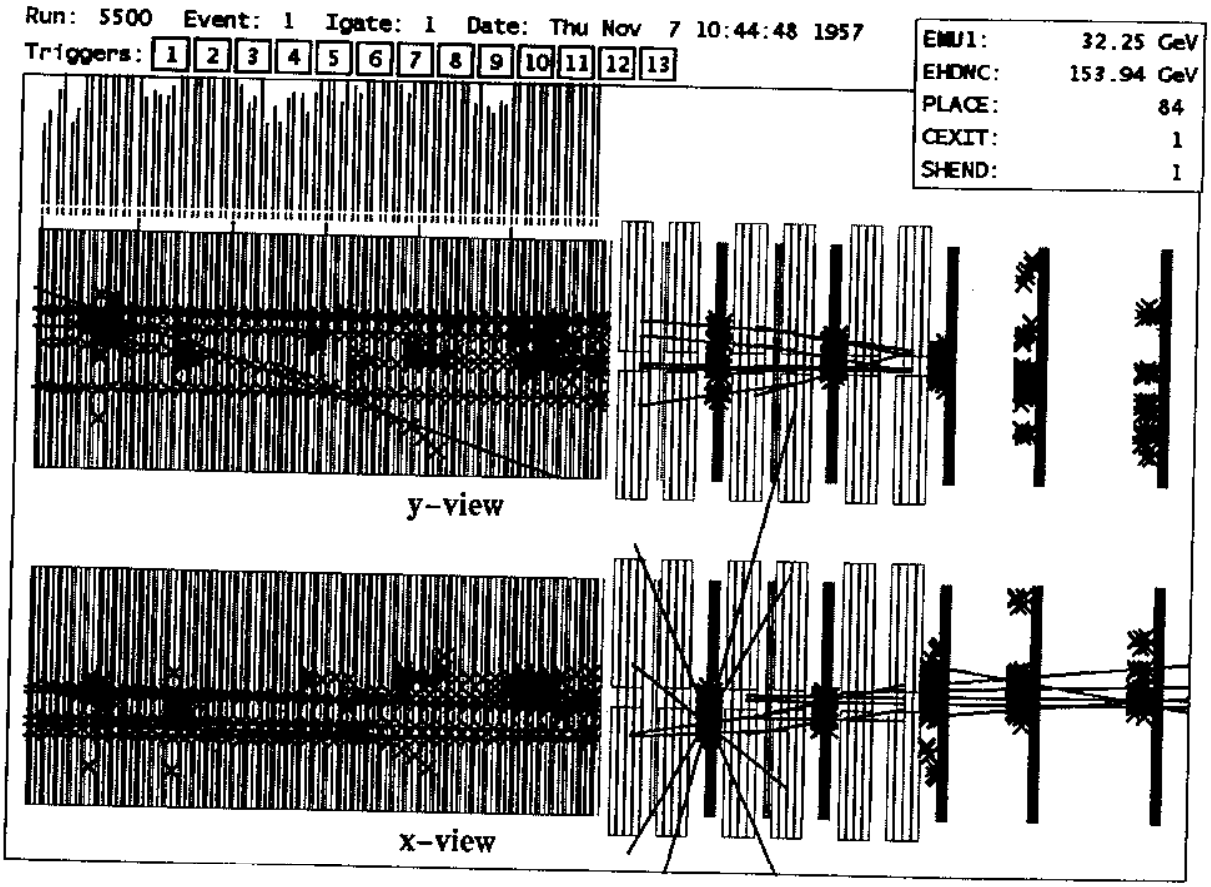
CCFR (Columbia-Chicago-Fermilab-Rochester)

LAB-E Detector - Fermilab E744 and E770

1985 1987-88



NuTeV: 600 m downstream of RLA3, one turn



D. HARRIS

Where and When

- Shielding requires about 2.2m/GeV
  - ▷ this is still short...
- Beam *still* contained within 1 meter [1]

	Collider			
	50 GeV	100 GeV	175 GeV	250 GeV
Baseline	120 m	250 m	450 m	600 m
50% ν's within	15 cm	15 cm	15 cm	15 cm
90% ν's within	35 cm	40 cm	40 cm	40 cm
10^6 DIS ν_μ Events/kg/yr (10 cm)	0.18	0.35	0.60	0.90

	Recirculating Linacs		
	RLA1	RLA2	RLA3
Baseline	25 m	200 m	600 m
50% ν's within	25 cm	30 cm	25 cm
90% ν's within	75 cm	75 cm	60 cm
10^6 DIS ν_μ Events/kg/yr (10 cm)	0.035	0.10	0.32

- Target can be tiny (or statistics large)
- Peak frequency of pulses: 300 kHz-1.5 MHz; easy!
- Sneaky reason to like RLAs:
  - ▷ if collider is down 10% of time, can increase statistics by factor of 2–5

[1] MC joint project with D.A. Harris

OSCILLATION PHYSICS (μ^- BEAM)

- $\nu_\mu \rightarrow \nu_e N \rightarrow X e^+$

  $\bar{\nu}_e \rightarrow \bar{\nu}_\mu N \rightarrow X \mu^-$

  ➡ WRONG SIGN LEPTON IN FINAL STATE

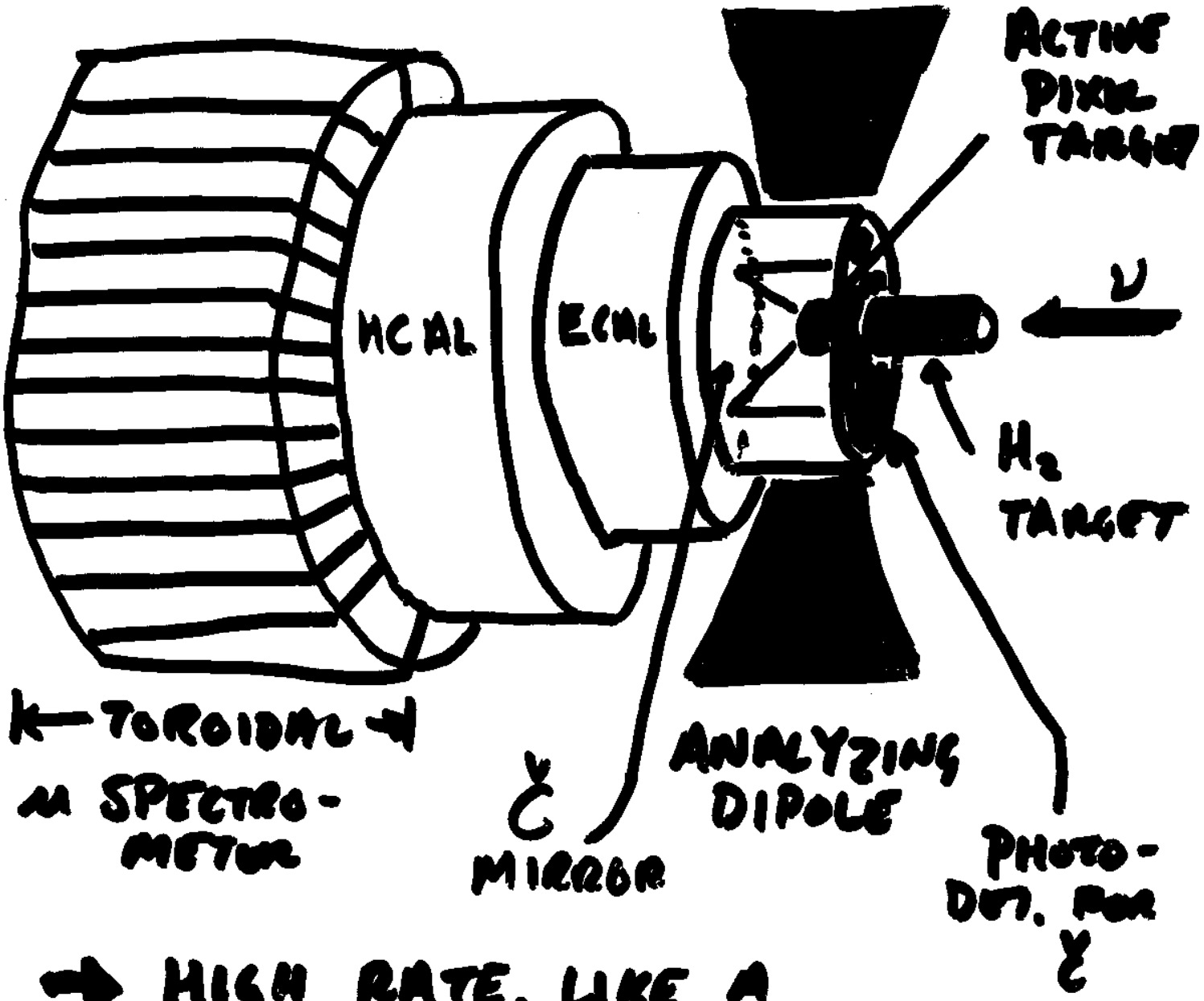
  ➡ FLAVOR CONTENT PRECISELY CALCULABLE

  ➡ NEED MAGNETIC DETECTOR

- HIGH STATISTICS

  ➡ LOW $\sin^2 2\theta$ ($\sim 10^{-5}$ FOR LARGE Δm^2)

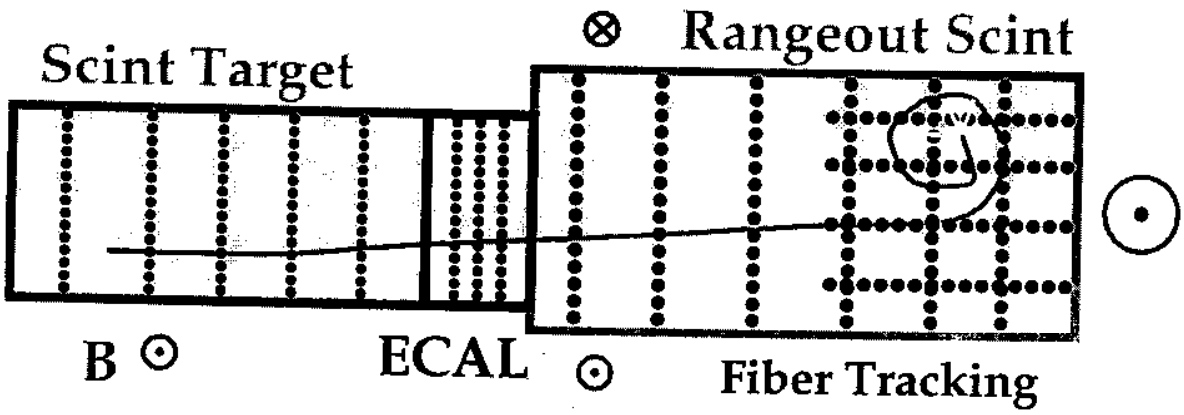
DETECTOR CONCEPTS (BRUCE KING)



→ HIGH RATE, LIKE A FIXED TARGET DET.

Tabletop

$\nu_e \to \nu_\mu$ appearance



- So small, it fits in a truck, and can be moved to optimize L/E vs rate
- Backgrounds?
  - ▷ Require single muon scintillation, track (charge), through calorimeter, watch for decay of muon in back tank
  - ▷ Veto DIS (too much scintillation light, tracks)
  - ▷ NC single π^- production (low σ, π^- capture before decay, decay in flight gives kink in tracker, initial angle, etc.)
  - ▷ Pileup? Veto inefficiency for cosmics?
- $\overline{\nu}_\mu \to \overline{\nu}_e$ also, but not as clean (single π^0)
- OK, you could make this a "real" experiment too, 1km away, 2m×2m×2m tank, and get a million events with good oscillation probability at $\Delta m^2 \sim 1$ eV^2, but would that be as much fun?

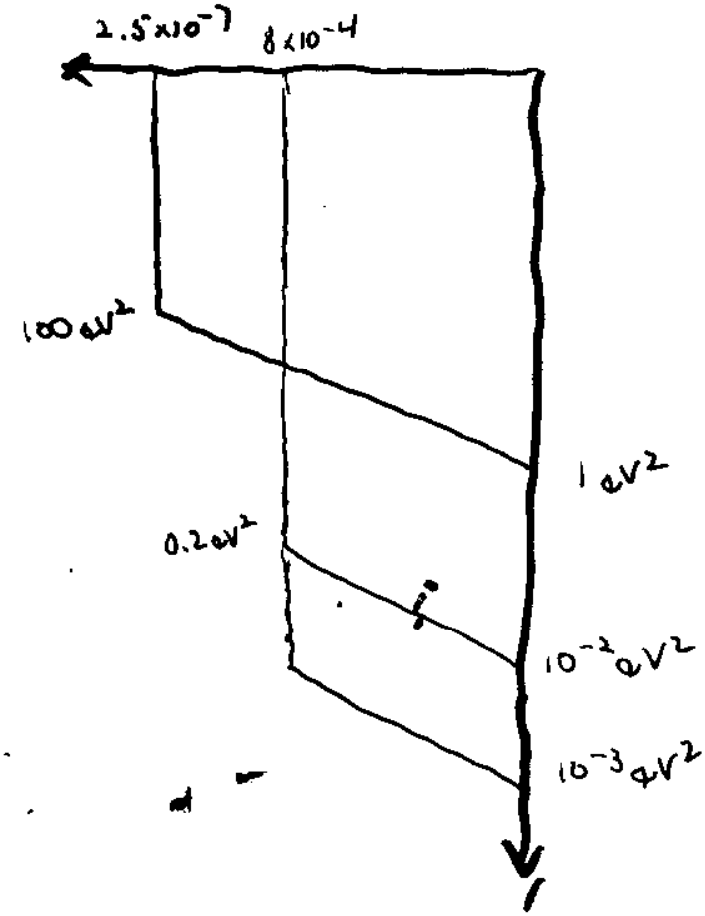
$\nu_e \rightarrow \nu_\mu$
RLA1

Assume Dedicated RLA1 gives ×40

25m, 40kg

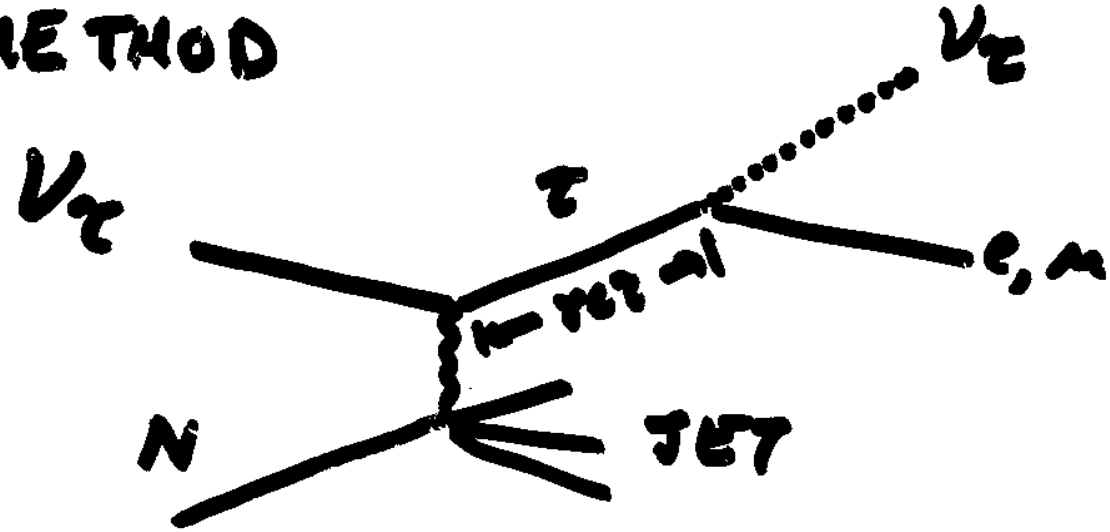
10km, 400kg

100km, 40 ton



ν_τ APPEARANCE

- $\nu_e \to \nu_\tau$ <u>NEW</u>
  $\nu_\mu \to \nu_\tau$
- METHOD



- USE $\not{p}_T$ TO REJECT CC EV.
  ($\not{p}_T$ TENDS TO RECOIL AGAINST LEPTON
- τ LIFETIME PROVIDES ADDITIONAL HANDLE
  - Si + TARGET
  - EMULSION (REAY)

ADDITIONAL INFORMATION

$\tau_\tau \sim 300$ fs, $\gamma \sim 15$ (@ SPS)

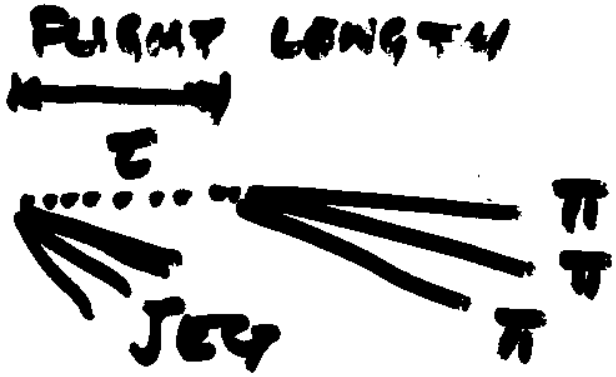
$\rightarrow \gamma c \tau \sim 1.5$ mm

➡ USE VERTEX INFORMATION TO DETECT τ IN ACTIVE TARGET

(1)

IMPACT PARAMETER 90μ

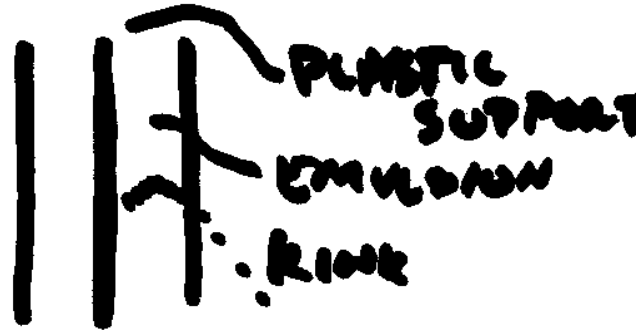
(2)



LIFETIME

SI + TARGET

- LOW Z, HIGH DENSITY MATERIAL
- TRACKER SANDWICHED, 7m
- SYSTEM'S W/ 10's m^2 Si POSSIBLE

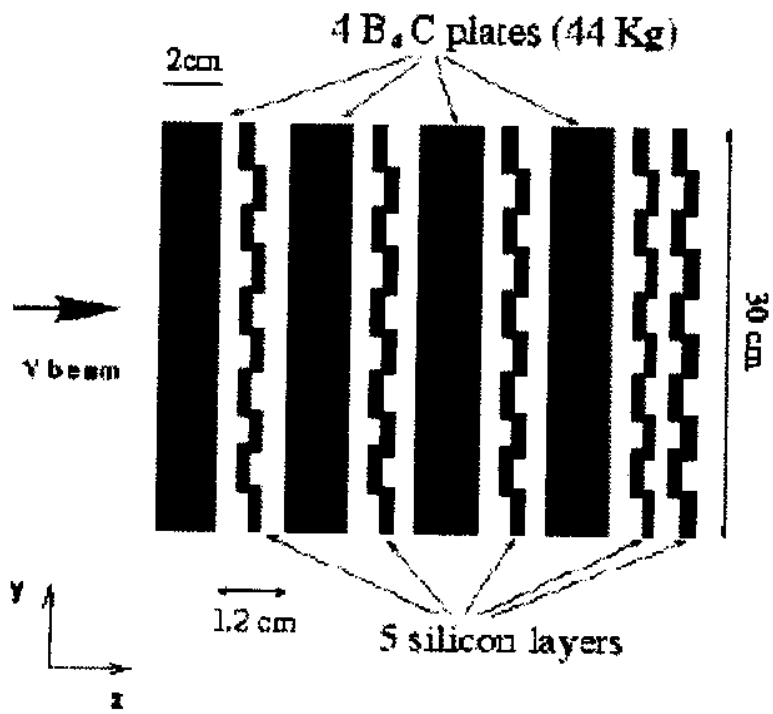


EMULSION (REAY)

- SEE KINK, VERTEX
- NEW SCAN METHOD
  FULL SCAN OF STACK + ELECTRONIC DETECTOR
- "EMULSION CLOUD CHAMBER"
  ECC MATERIAL → 1 KT
  ACTIVE TARGET MAY BE POSSIBLE.

NOMAD STAR PROTOTYPE

- 44 Kg → ~ 30K CC EVENTS
  0.5 m³ Si IN 1992
- ϵ_τ = 3% → 10%

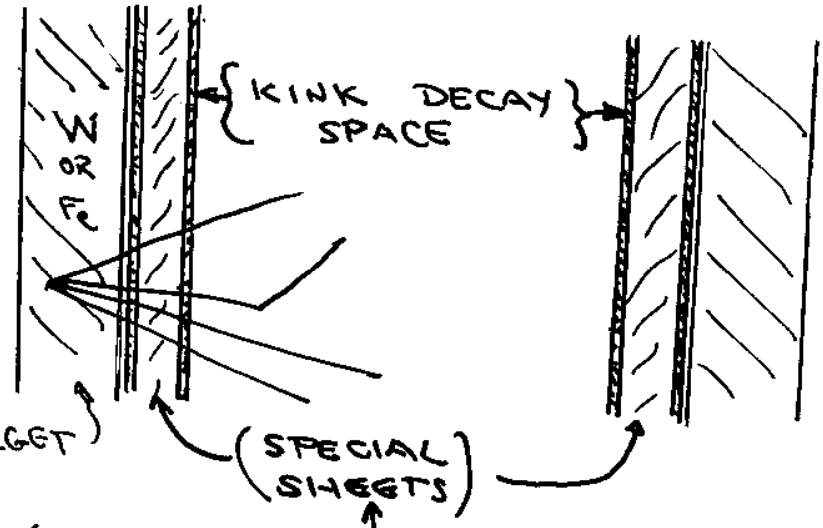


- INSTALLED, RUNNING NOW
  - 1 YR. CONSTRUCTION
  - $300 K

ECC TARGET

(EMULSION CLOUD CHAMBER)

NOT TO SCALE!



(50μ Em → 300μ PLASTIC → 50μ E.

LOWER DENSITY Ag GIVES 3-5% EMULSION BY WEIGHT, AND SPECIAL SHEET EMULSION PIXEL TRACKERS LOOK ONLY FOR STRAIGHT TRACK SEGMENTS, BUT NO VERTEX OR KINK INFO.

100 TONS NOW POSSIBLE.

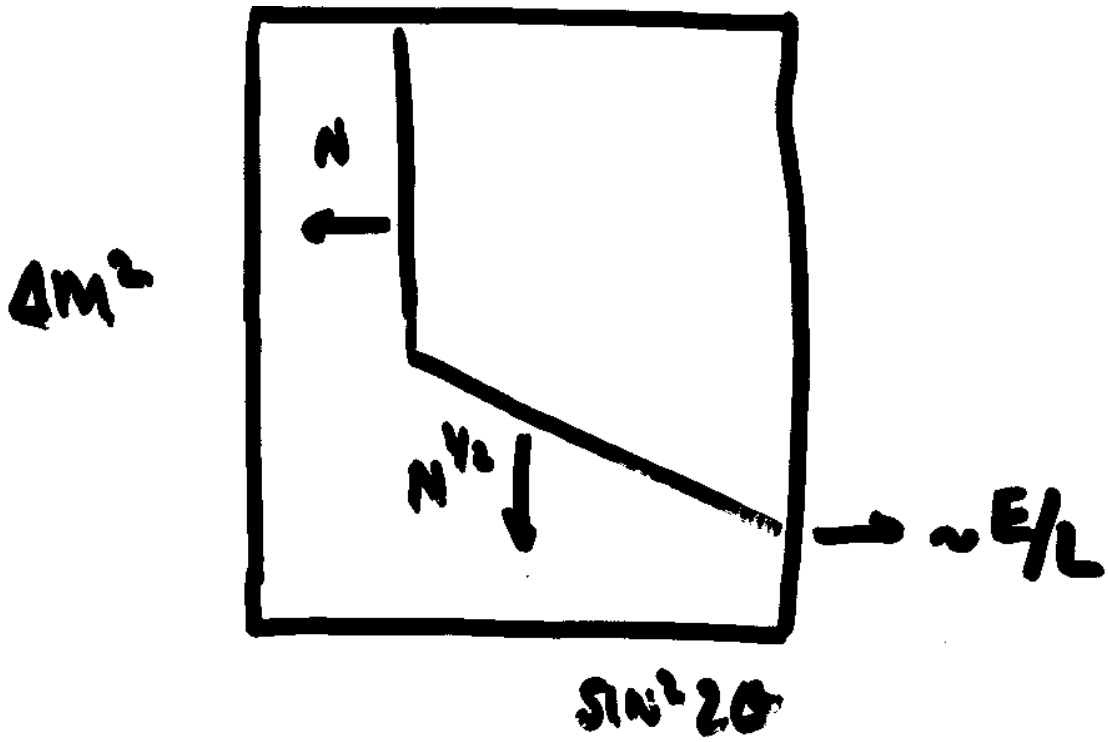
BUT CONSIDER,

X-RAY FILM BY ABOVE MANUAL TECHNIQUE ≈ $1000/SHEET, BUT CAN PURCHASE X-RAY FILM FOR $160/SHEET.

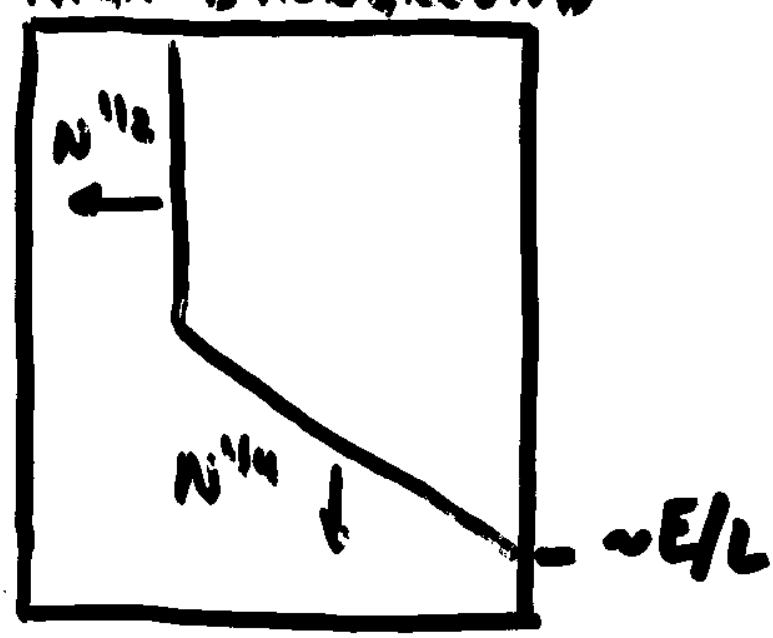
.... MAYBE? ....

STATISTICS OF ν DET. (M. GOODMAN)

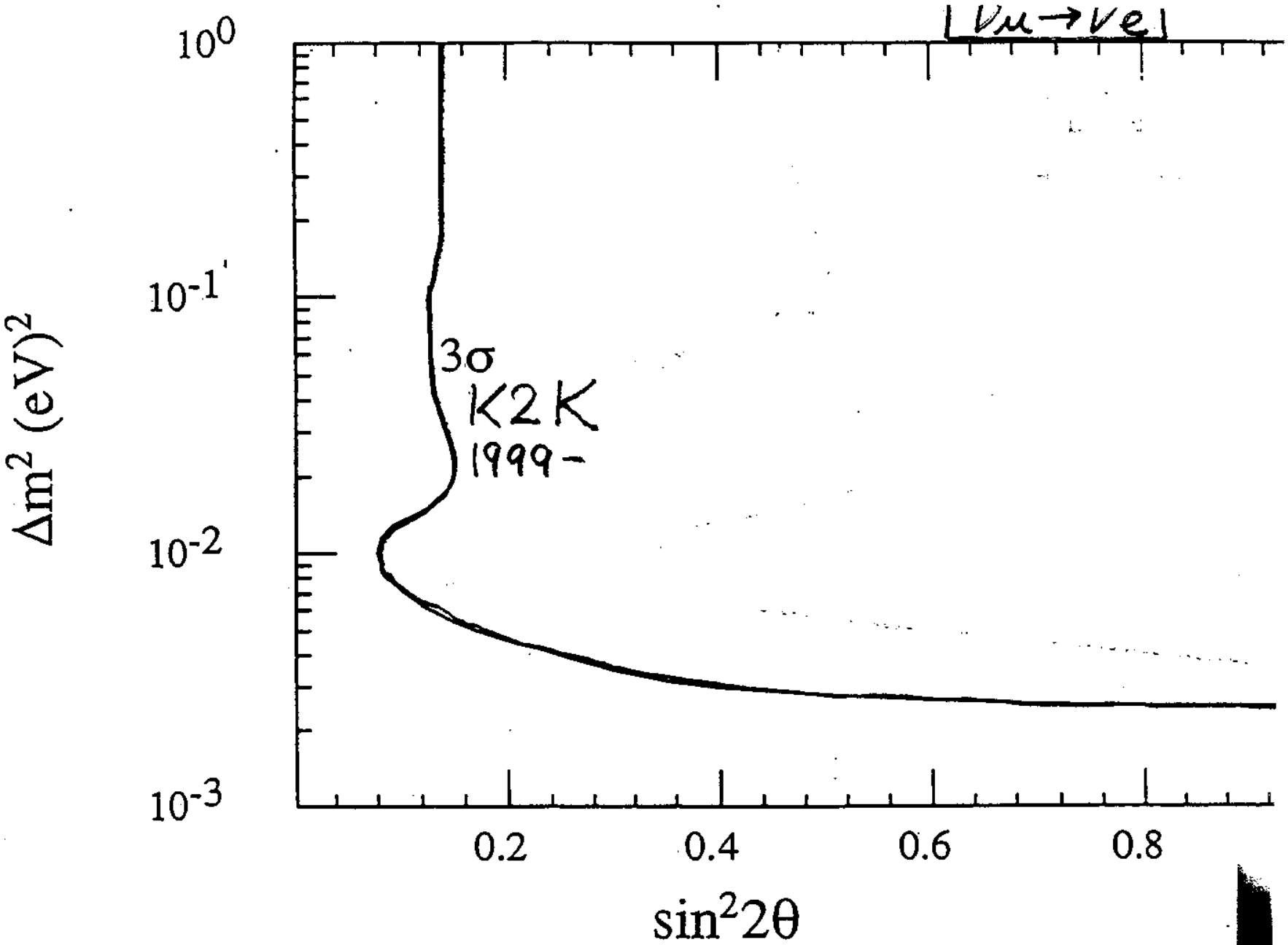
ZERO - LOW BACKGROUND



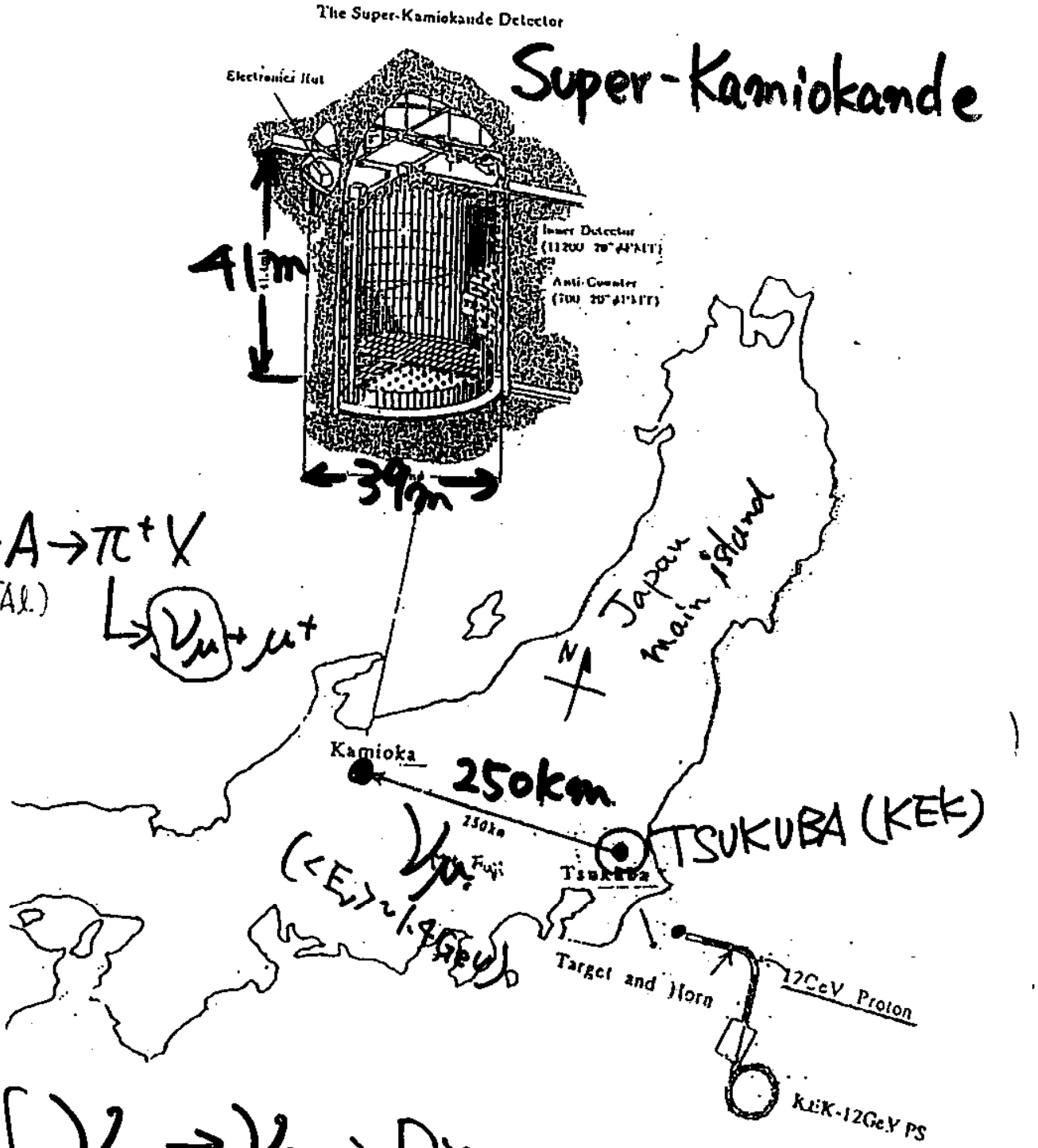
HIGH BACKGROUND



$\Rightarrow$ LONG BASELINE, WORK TO ELIMINATE BG.


$\nu_\mu \to \nu_e$
10^0
10^{-1}
10^{-2}
10^{-3}
Δm^2 (eV)^2
3σ
K2K
1999 -
0.2
0.4
0.6
0.8
$\sin^2 2\theta$

Overview



$p + A \to \pi^+ X$
(Al.)
$\hookrightarrow \nu_\mu + \mu^+$

ν_μ
$(\langle E_\nu \rangle \sim 1.2\,\mathrm{GeV})$

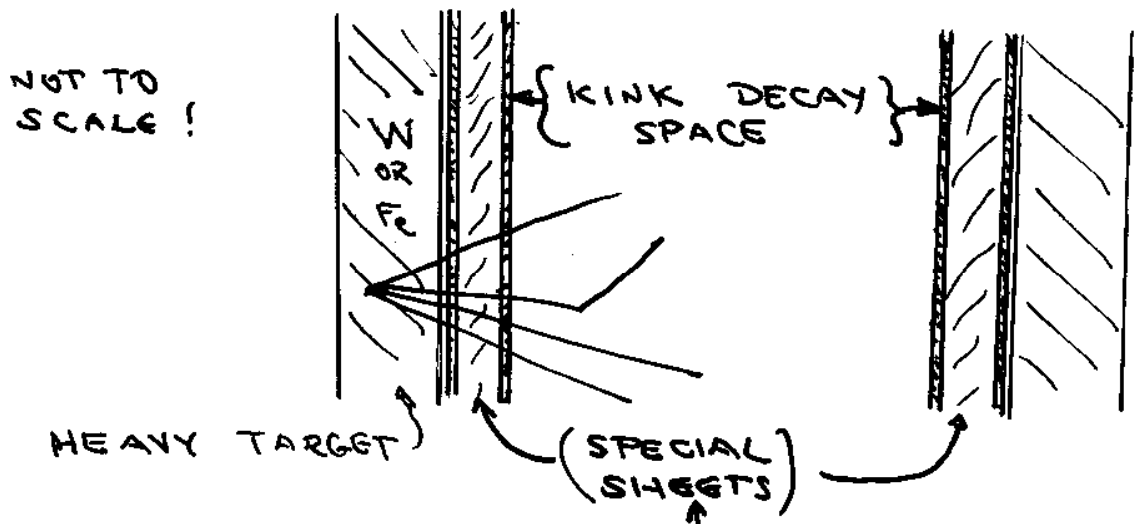
$\nu_\mu \to \nu_\tau$: Disappearance
($\because \nu_\tau \to \tau$ $E_{th} \sim 3.5\,\mathrm{GeV}$)

$\nu_\mu \to \nu_e$: Appearance

Probe both.

ECC TARGET

(EMULSION CLOUD CHAMBER)



(50μ Em → 300μ PLASTIC → 50μ Em

LOWER DENSITY Ag GIVES 3-5% EMULSION BY WEIGHT, AND SPECIAL SHEET EMULSION PIXEL TRACKERS LOOK ONLY FOR STRAIGHT TRACK SEGMENTS, BUT NO VERTEX OR KINK INFO.

100 TONS NOW POSSIBLE.

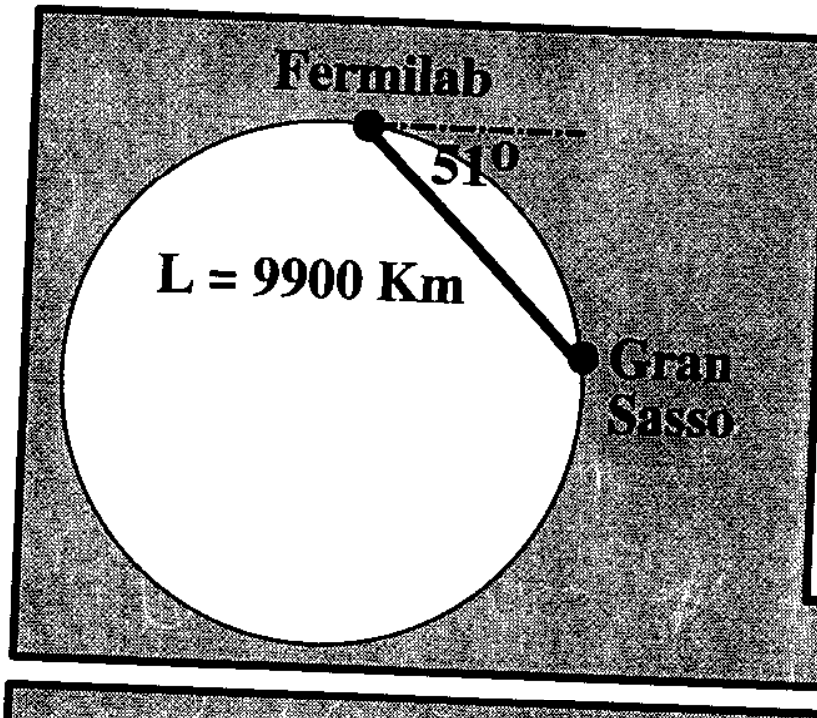
BUT CONSIDER,

X-RAY FILM BY ABOVE MANUAL TECHNIQUE ≈ $1000/SHEET, BUT CAN PURCHASE X-RAY FILM FOR $160/SHEET.

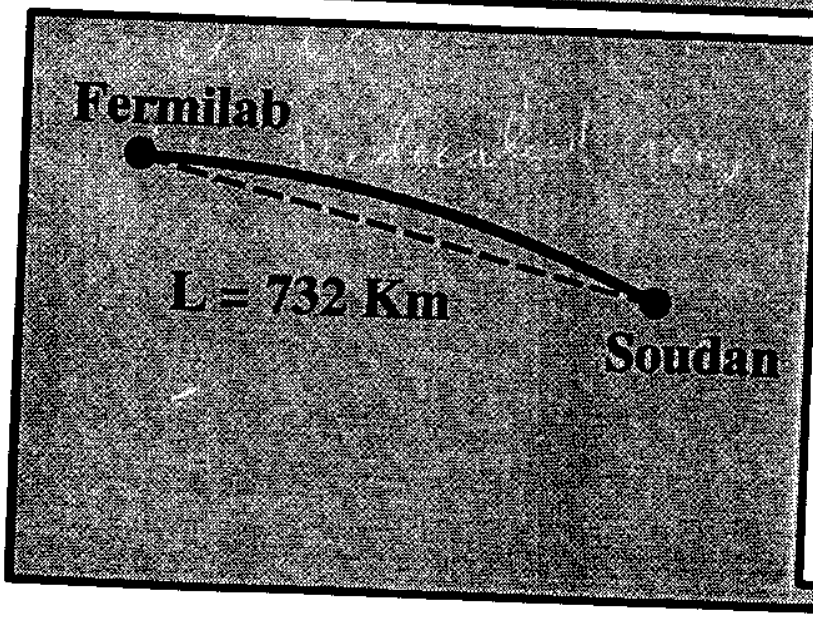
.... MAYBE ? ....

Options

- Will consider long baseline (Fermilab -> Soudan) and very long baseline (Fermilab -> Gran Sasso) scenarios.



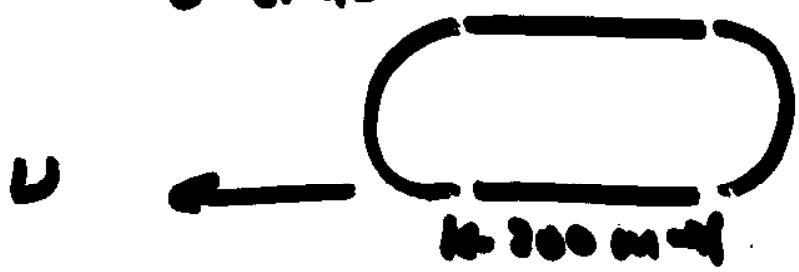
E_ν (GeV)	L/E Km/GeV
10	990
20	495
30	330
40	71
50	20



E_ν (GeV)	L/E Km/GeV
10	73.2
20	36.6
30	24.4
40	18.3
50	14.6

LONG BASELINE

- $\frac{L}{E} \sim 10^{-4}$ FOR ATMOSPHERIC ν
- K2K, FIRST LONG BASELINE (T. KOBAYASHI)
- S. GEER μ STORAGE RING



⇒ FILL RING AND LET THEM ALL DECAY

GET 1/4 OF DECAYS

- ANGLE RING TO AIM AT REMOTE DETECTOR

Osc. physics μ^- beam

~~$\nu_\mu \to \nu_e$~~
~~$\bar{\nu}_e \to \bar{\nu}_\mu$~~ } ~~Wrong sign lepton in final~~

~~→ Much cleaner experiments,~~

$\nu_\mu \not\to \nu_e N \to X e^+$
$\bar{\nu}_e \not\to \bar{\nu}_\mu N \to \mu^- X$ } Wrong sign lepton in final state.

→ Mixed, ~~&~~ beam, but well known (or calculable) flavor content

→ High statistics ~~flux~~.

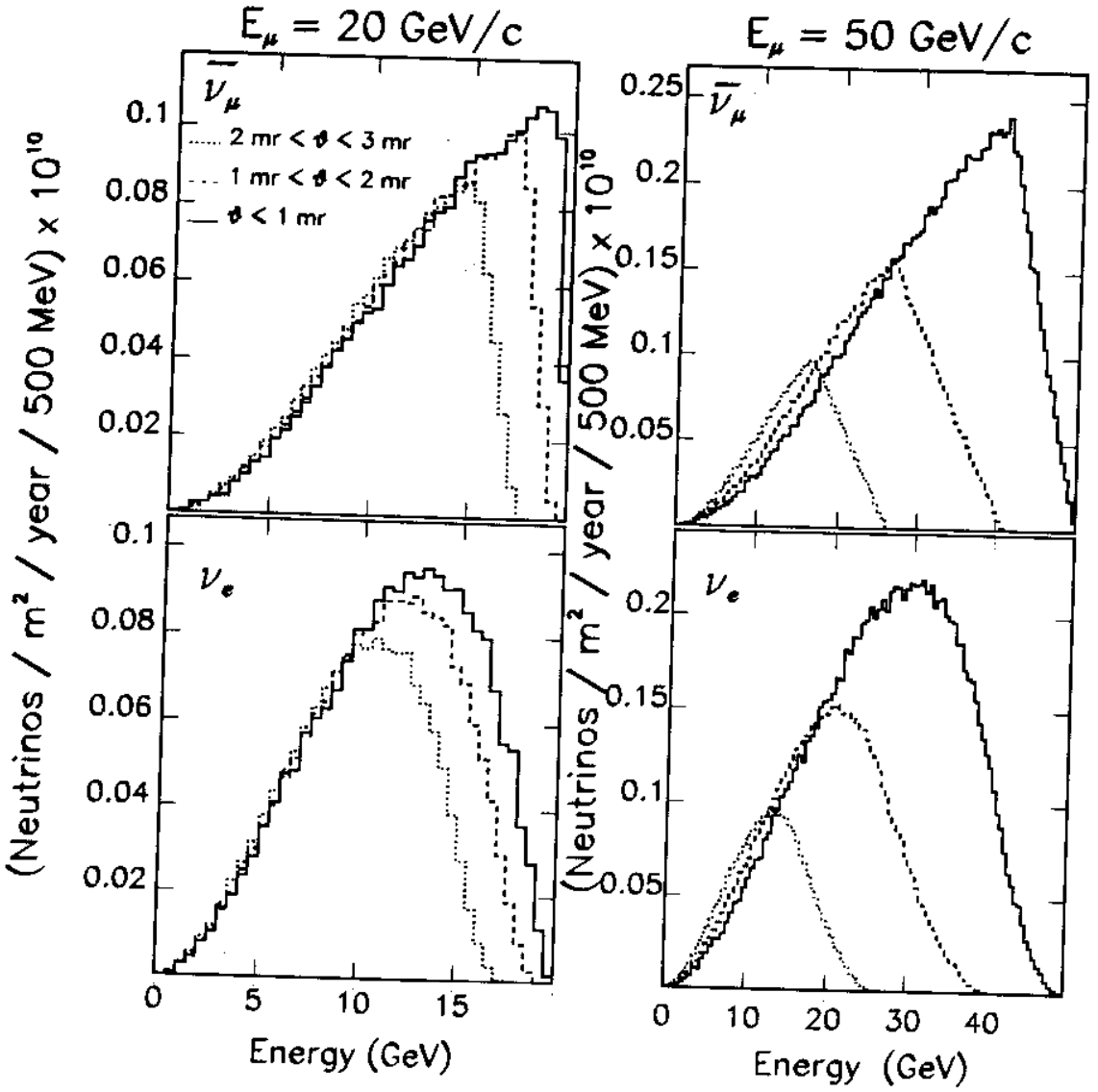
$\sin^2 2\theta \sim 10^{-5}$ for large Δm^2

→ Magnetic detector

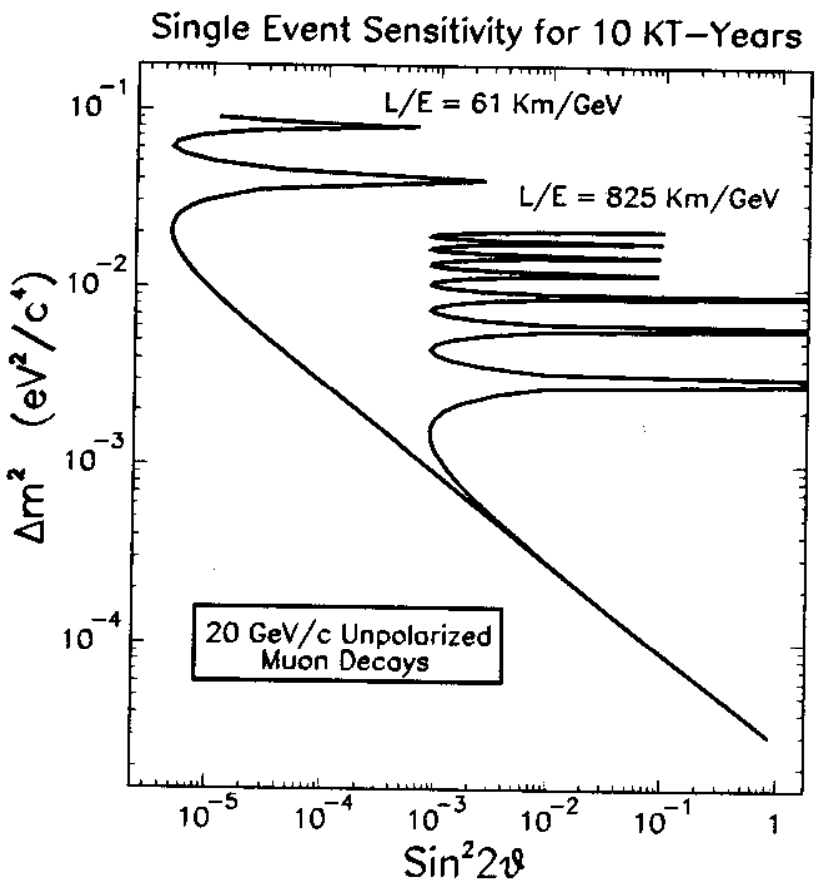
Angular Dependence of Neutrino Energy Distributions

- **Fluxes in Europe (L = 9900 Km)**

Unpolarized μ^+ Decay



Sensitivity in the (Δm^2,$\sin^2 2\theta$)–Plane for a $\nu_e \rightarrow \nu_\mu$ Appearance Experiment



- **20 GeV un-polarized μ^+ beam**
- **Fix L/E at their average values for Soudan (L/E = 61 Km/GeV) & Gran Sasso(L/E = 825 km/GeV)**

M. GOODMAN

	Accelerator	$\langle E_\nu \rangle$ (GeV)	η	10 KT 2-year N	L (km)	P_{min}	$(2P_{min})$ $(\sin^2 2\theta)$	$\frac{\sqrt{P_{min}}}{1.27}$ $(\Delta m^2_\mu$
	NUMI/MINOS	15	.3	60,000	732	.00763	.015	.0014
Snider	$E_A = 250$	125	.85	$7.3\ 10^8$	732	.00010	.0002	.00
	100	50	.6	$7.3\ 10^7$	732	.00040	.0008	.001
	50	25	.4	$7.3\ 10^6$	732	.0016	.003	.001
	20	10	.2	$7.3\ 10^5$	732	.0067	.013	.000
	10	5	0	$7.3\ 10^4$	732	.032	.06	.000
GS	$E_A = 250$	125	.85	$4\ 10^6$	9900	.00135	.003	.000
	100	50	.6	$4\ 10^5$	9900	.0054	.010	.000
	50	25	.4	$4\ 10^4$	9900	.0216	.04	.000
	20	10	.2	$4\ 10^3$	9900	.0906	.2	.0002
	10	5	0	400	9900	.427	.8	.0002

Long baseline - ~~[illegible]~~

K2K $\frac{L}{E} \sim 10^3$ -

(3)

- μ Storage ring angled to point at desired detector.
- ~~[illegible]~~ $\nu_\mu / \bar{\nu}_e \rightarrow$ few $\times 10^{-5}$ Δm^2 possible

(0) Beam comp.

(1) Appearance expt, Magn. det.

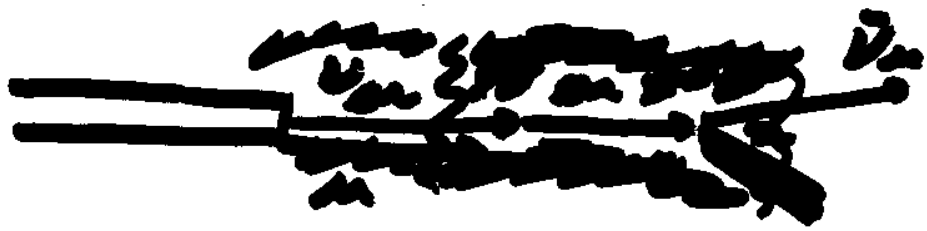
(2) Cerulean watch

(3) Dedicated ring.

NEXT STEPS

- WHAT OTHER WAYS CAN WE EXPLOIT 1ST HIGH ENERGY PURE $\bar{\nu}_e$ BEAM

- HOW PURE ARE BEAMS?



DET.

- FURTHER STUDY OF CHARM BG W/ EMULSION, Si FOR τ ID

- PUSH STORAGE RING, LONG BASELINE DESIGN

CONCLUSIONS

- μ DECAY SOURCE
  - ⇒ KNOWN BEAM COMPOSITION
- μ STORAGE RING + LONG BASELINE
  - ⇒ EARLY PROGRAM WILL ADDRESS ν ATMO.
- HIGH ENERGY, VERY HIGH INTENSITY BEAMS
  - ⇒ ν_τ PHYSICS

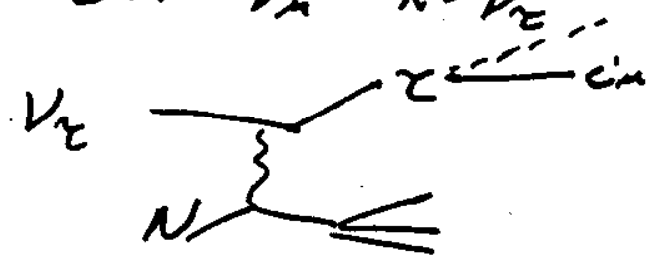
~~ν_τ appearance~~

~~ν~~

ν_τ appearance

~~o Use $\not{p}_T$ to~~

~~$\nu_\mu \to \nu_\tau$~~



- Use $\not{p}_T$ to reject cc events ($\not{p}_T$ tends to recoil against lepton)
- τ lifetime provides additional information

→ detector choice
- emulsion
- Si - Target.