MINOS
A Long Baseline Neutrino Oscillation Experiment

UCL, RAL, Oxford, Sussex ~30 PEOPLE

MainInjectorNeutrinoOscillationSearch at FNAL

- Preview
  - **Introduction to ν oscillations & MINOS**
  - **MINOS Physics analysis procedures**
  - **MINOS Detector**
    - ⇒**description of detector** (*recent progress*)
    - ⇒**electronics design** (*trigger challenges*)

    (UK CONTRIBUTION)

    PHOTO DETECTORS
  - **Conclusion**
    - ⇒**Interesting Physics**
    - ⇒**A lot to do!**

Introduction

- **What can we learn about m_ν from oscillations?**
  3 flavour neutrino mixing: (mass eigenstate ≠ weak)

$$\Rightarrow P(\nu(t)\rightarrow\nu_\alpha)=|\langle \nu_\alpha \mid \nu(t)\rangle|^2$$
$$= 1-2c_1^2s_1^2c_3^2[1-\cos(E_1-E_2)t]$$
$$-2c_1^2s_1^2s_3^2[1-\cos(E_1-E_3)t]$$
$$-2s_1^4s_3^2c_3^2[1-\cos(E_2-E_3)t]$$

- **Mass Eigenstates have energy eigenvalue:**

$$\Rightarrow E_i^2 = p^2 + m_i^2 \text{ \& for } p>>m_i$$
$$E_i = p + (m_i^2/2p) \quad \text{so}$$

$$\boxed{E_i - E_j = (m_i^2 - m_j^2)/2p}$$

- **Learn about Δm_{ij}^2, difference between m_ν^2s**
- **Δm^2 ~ 10^{-4} eV^2 accessible this way: improvement over 10eV from tritium decay (*direct measurement*)**
- **No ν_R in weak interaction**
- **In Standard Model νs are massless**
- **If $m_\nu \neq 0$, simple extension adds ν_R singlet**
- **If ν_R ν_L are Dirac neutrinos ν_R neutrinos sterile: Cosmological complications.**

Introduction

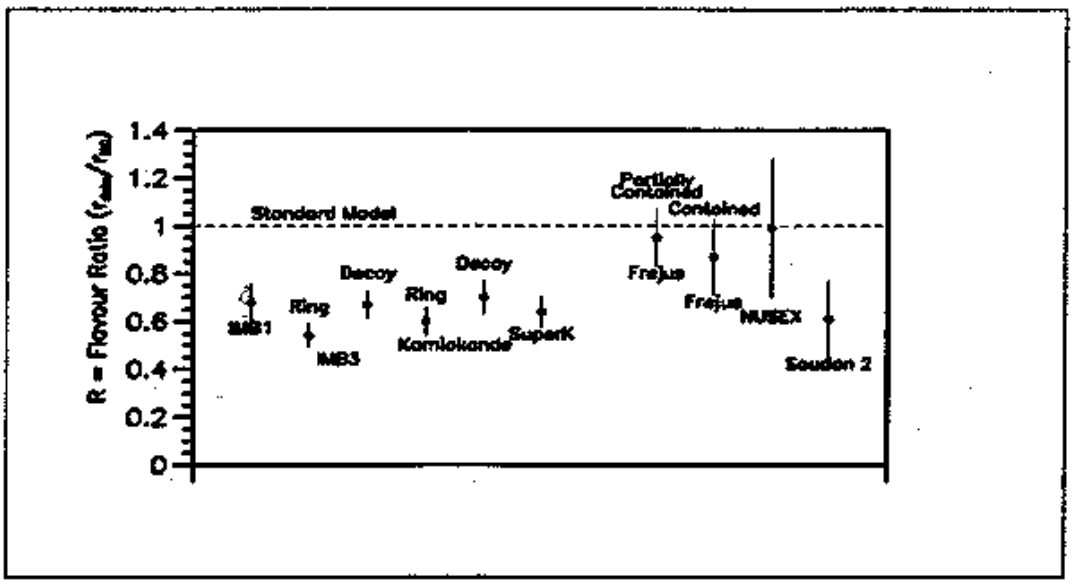
- **Long baseline neutrino oscillation experiments :**
  - **Final neutrino flavour is measured**
  - **Initial neutrino flavour is known/measured** (& FLUX)
  - **Distance between initial and final allows neutrino to oscillate - depends on E_ν**

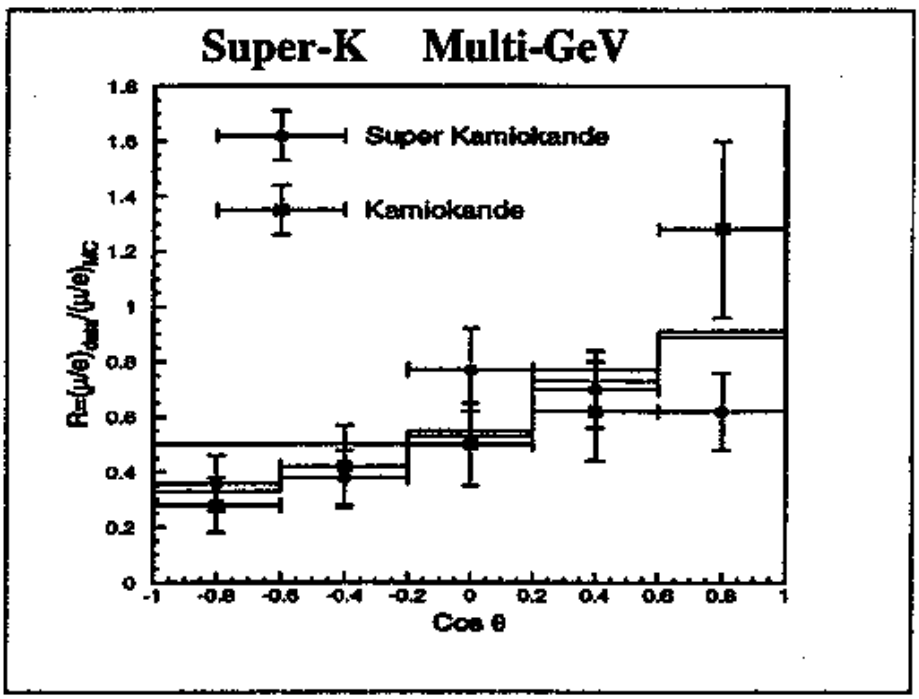
$$P(\alpha \rightarrow \beta) = \sin^2 2\theta \, \sin^2(1.27 \, \Delta m^2 L/E)$$

- **Because of E_ν dependence, many experiments fit the bill even when baseline is 'short'.**

TYPE	BASELINE	ENERGY	Δm^2
Solar	10^8 km SNO	0.1-10 MeV	10^{-5} eV^2
Atmospheric	10^4 or 10 km SOUDAN SUPER-K	0.1-10 GeV	10^{-2} eV^2
Reactor	0.1 - 10 km CHOOZ SANONOFRE	1-10 MeV	10^{-3} eV^2
Accelerator	1 and 10^3km CHORUS NOMAD LNSD KARMEN	10 GeV	10^{-2} &10 eV^2

ATMOSPHERIC NEUTRINO EXPERIMENTS





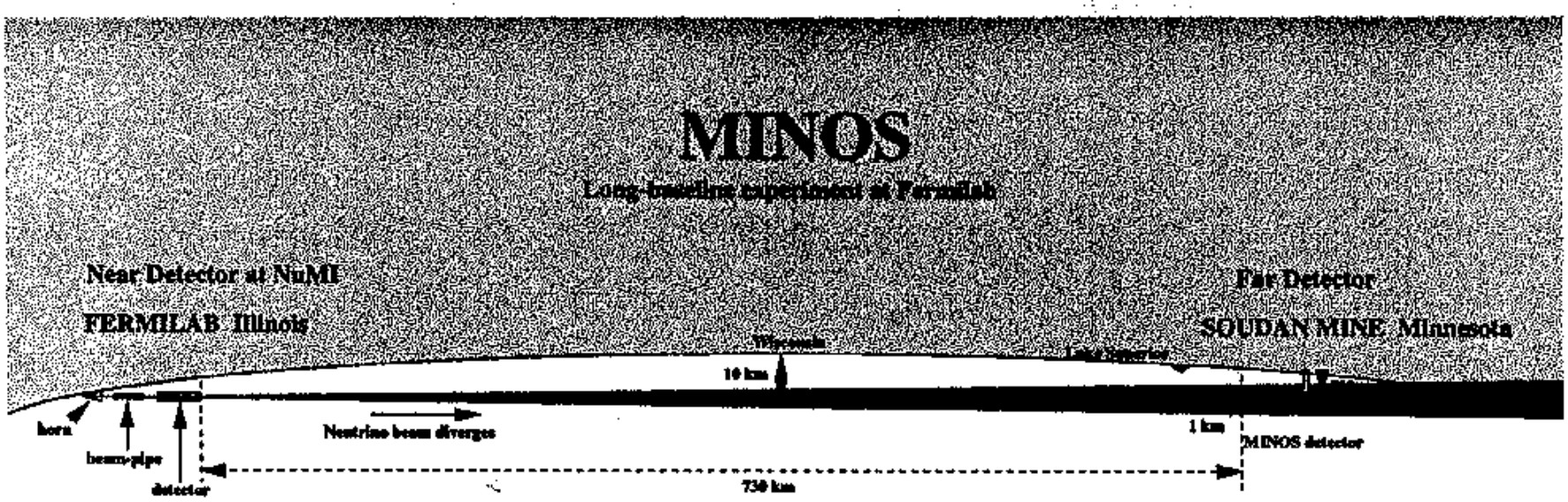
- **Angular distribution used to determine** Δm^2

Introduction

- **MINOS is a *long baseline* experiment.**
- **Notable Characteristics:**
  - **⇒Near Station at FNAL (1 Kton)**
  - **⇒Far Station in Minnesota (~7-8 Kton)**
  - **⇒720 km baseline**
  - **⇒Mean neutrino energy ≤ 10GeV (> m_τ)**
  - **⇒Wide band/narrow band beam**
  - **⇒Iron/solid scintillator calorimeter**

- **Neutrinos from protons from Main Injector**
- **Planned turn on : 2001**
- **2 year run should produce ~40-50k events**
- **sensitivity**
  - **⇒ $\sin^2 2\theta \sim 0.01$,**
  - **⇒ $\Delta m^2 \sim 10^{-3} - 10^{-4}$ eV^2**
  - **(*includes region suggested by SuperKamiokande.*)**
- **Status**
  - **⇒ FNAL stage I approval**
  - **⇒ DoE approval to continue**

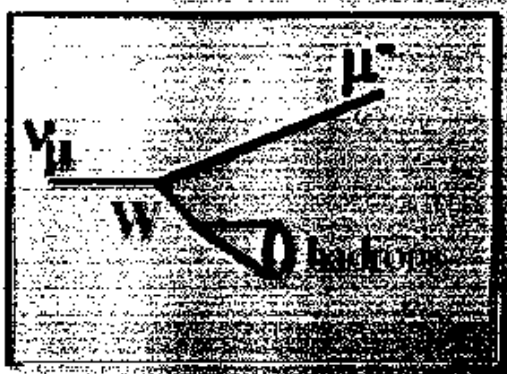
$5.5 M
BEAM ENGINEERING
STUDIES
from CONGRESS !


MINOS
Long-baseline experiment at Fermilab
Near Detector at NuMI
FERMILAB Illinois
Far Detector
SOUDAN MINE Minnesota
10 km
horn
beam-pipe
detector
Neutrino beam diverges
1 km
MINOS detector
730 km

- **MINOS....**

  ⇒ Analysis Issues

  - **Events with identifiable muon classified as "CC *like*"**



charged current ν_μ interaction

  - Events classified as [illegible] observed

Neutral current ν_μ interaction — Looks very different to CC

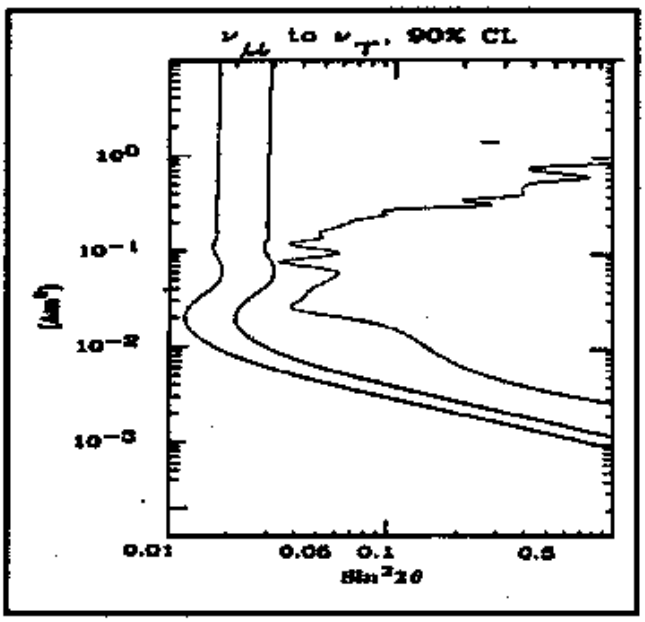
  - **Overlap for low momentum muons!!**

Analysis Procedures

- **Several different near-far comparisons yield evidence of oscillations but most sensitive and robust is T" test**

$$T'' = \left(\frac{N_{cc}}{N_{tot}}\right)_{Near} / \left(\frac{N_{cc}}{N_{tot}}\right)_{Far}$$

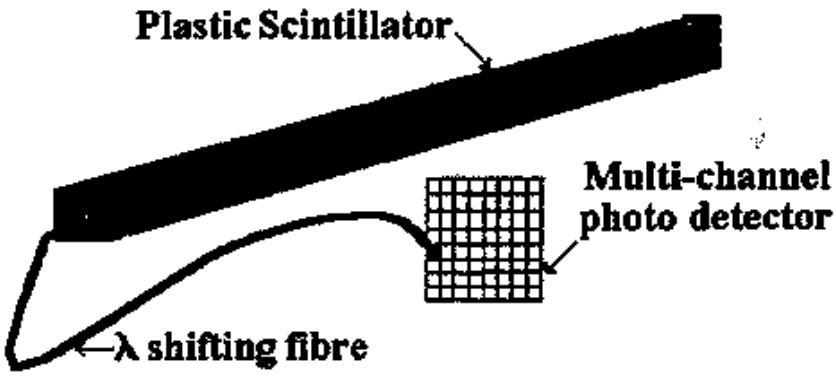
- **Ncc refers to events with an identified μ**
- **All νs in near detector are μ-like**
- **In far detector νs can be ν_e (no μ), ν_μ or ν_τ (83% no μ)**
- **Any oscillation will result in a *decrease* in Ncc in far detector**



- **more sensitivity at low Δm^2 can be achieved with electron identification**

MINOS Detector

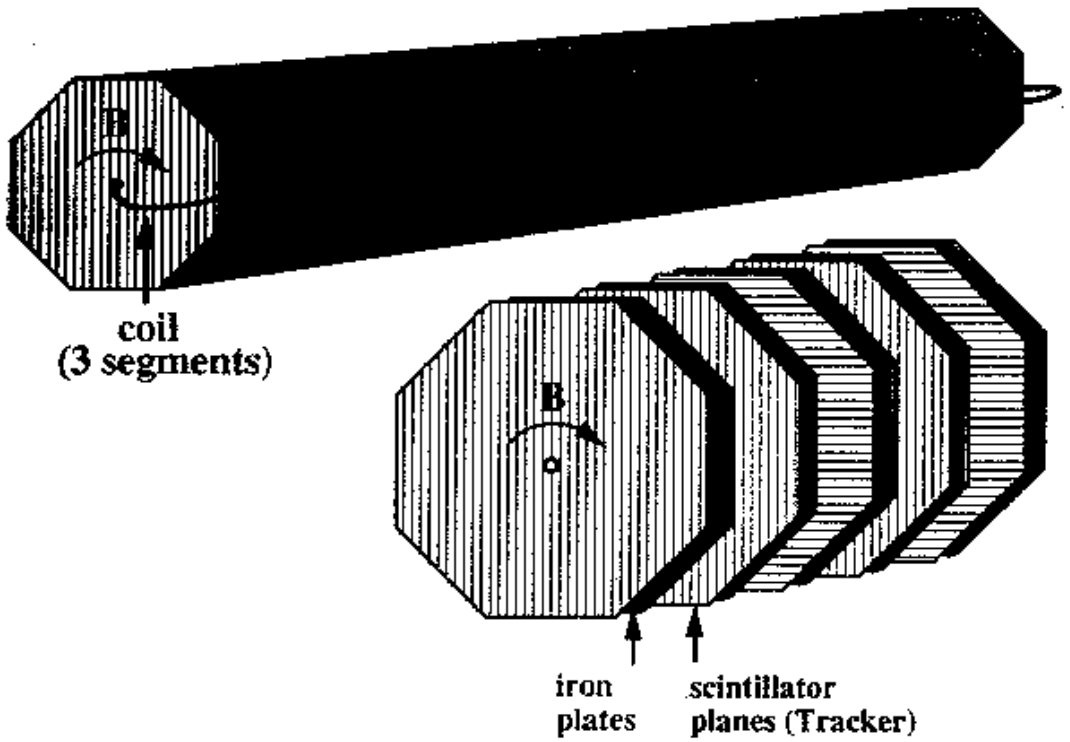
- **Active Detector decision has been made**
- **Technology will be solid scintillator with wavelength shifting fiber**
  - **Good energy resolution**
  - **Ease of distributed construction**
  - **Low running costs**
  - **Timing information (*up/down muons*)**
  - **Make use of CDF/D0 technical advances**



MINOS Detector

Far Detector

- ~7KT Steel Calorimeter (*with upgrade possibly*) $32 M for detector + contingency
- 40 - 400Kchannels
- <B> = 1.5T (Magnetized Iron)
- 600 layers of 1 inch magnetized Fe plates
- Below 700m of greenstone



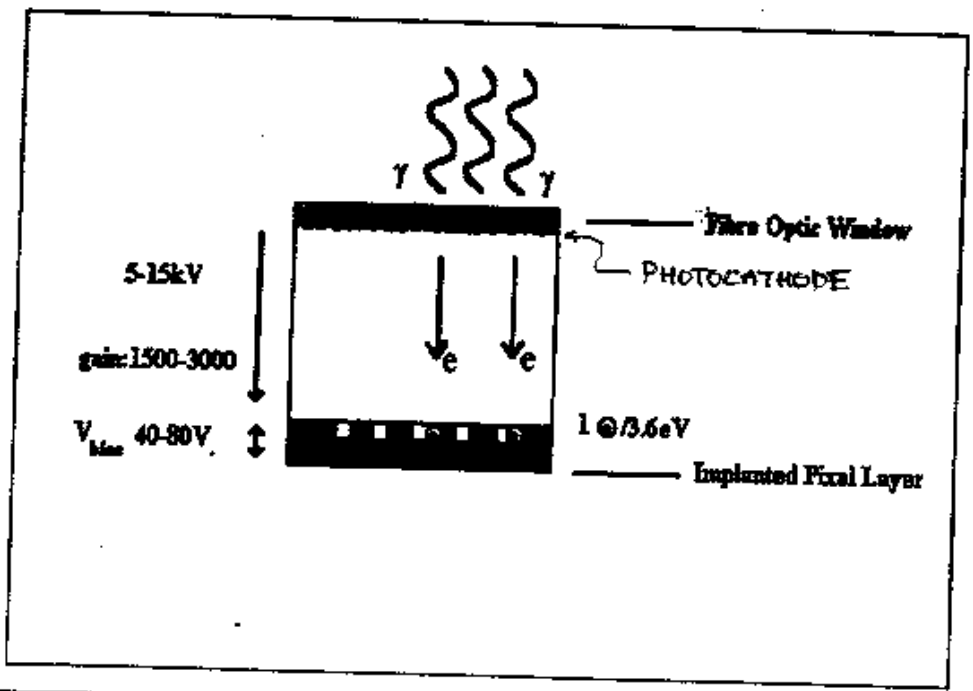
Near Detector

- 1KT
- 8m of Fe length
- 30m below ground

Photodetectors

- Two possible photodetectors available
- Both multi-channel devices
  - ⇒ Hammamatsu
    - Large signal (no preamp)
    - 14 stages of metal channel plate
    - More expensive: x8 multiplexing
    - Pixel to Pixel variations (factor 1-5)

  - ⇒ DEP Hybrid Photodiode
    - Small signal (needs preamp, no base)
    - No internal structure
    - Completely uniform over silicon face



PROPOSED UK CONTRIBUTION

Electronics Design

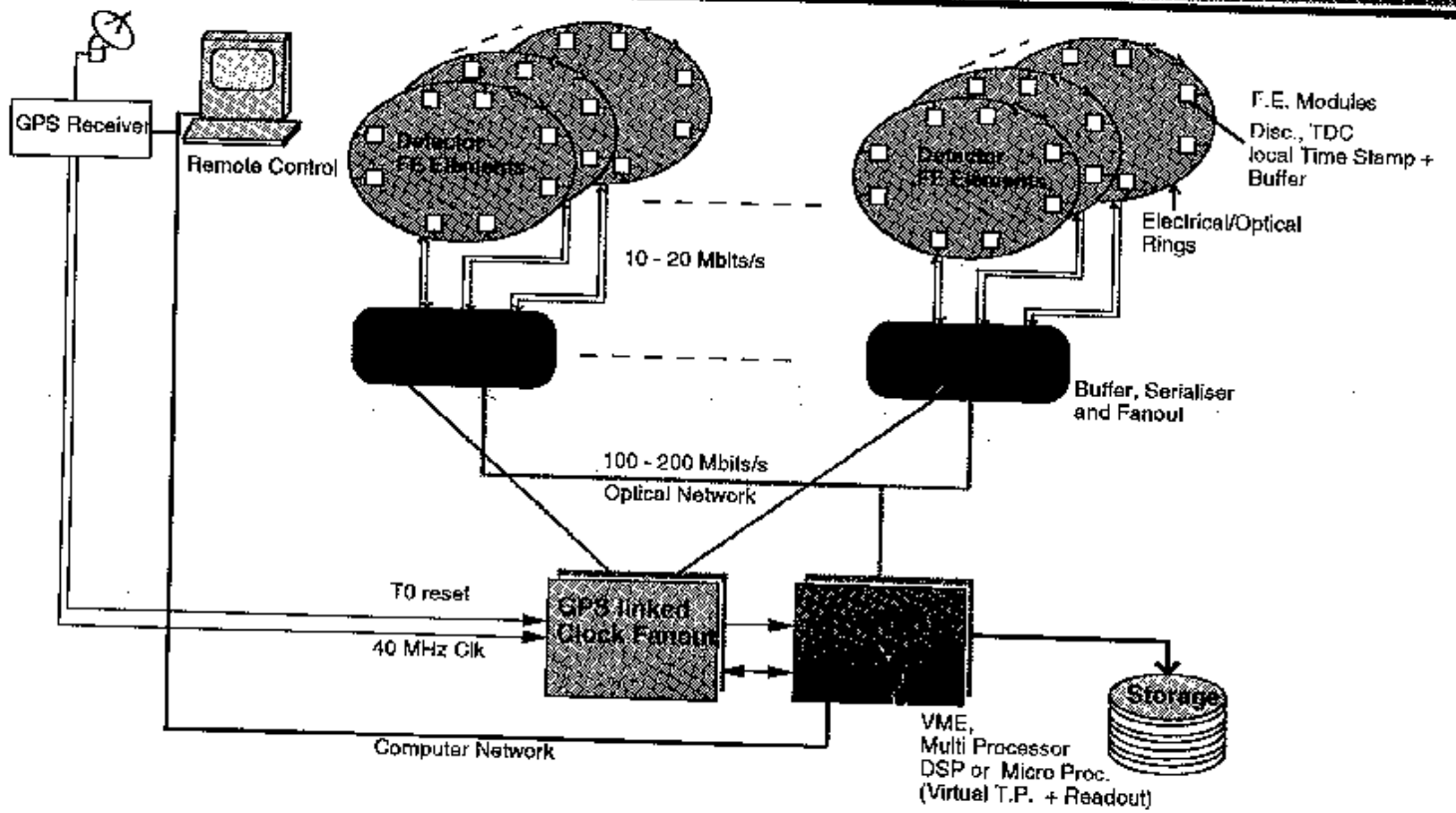
- **Near and Far detectors present very different environments**
  - ⇒ ***very*** **high rate in near detector (~80evts/spill)**
  - ⇒ **low rate in far detector (~1 evt/20minutes)**

- **100ns timing reduces overlap < 0.1% (near)**
  - ⇒ **overlapping events will bias event spectra**
  - ⇒ **essentially no overlap in far detector**

- **Very diverse event shapes:**
  - ⇒ **nc events short and fat (relatively)**
  - ⇒ **cc(μ) events long and thin**

- **Beam spill very long ~1ms :**
  - ⇒ **system must be self-triggering**
  - ⇒ **time stamp necessary to identify event parts**

- **One approach:**
  - ⇒ **detector is continually** ~~**live**~~ obsly
  - ⇒ **all trigger intelligence done in processors**


GPS Receiver
Remote Control
Detector
FE Elements
Detector
FE Elements
F.E. Modules
Disc., TDC
local Time Stamp +
Buffer
Electrical/Optical
Rings
10 - 20 Mbits/s
Buffer, Serialiser
and Fanout
100 - 200 Mbits/s
Optical Network
T0 reset
40 MHz Clk
GPS linked
Clock Fanout
Storage
VME,
Multi Processor
DSP or Micro Proc.
(Virtual T.P. + Readout)
Computer Network