Review of the past and present work

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Introduction

> 10 yr experience
in experimental neutrino physics

1989 - 1992	$\beta\beta$ R&D with a scintillator spectrometer
1992 - 1999	DBA $\beta\beta$ experiment at Gran Sasso
1999 - present	MINOS neutrino oscillation experiment

Neutrino Oscillations

- Suggested by Bruno Pontecorvo. Neutrinos can mix IF $m_\nu \neq 0$. Can probe physics beyond the Standard Model

$$\mathbf{P}(\alpha \longrightarrow \beta) = \mathbf{Sin}^2 2\theta\ \mathbf{Sin}^2(\mathbf{1.27}\ \Delta\mathbf{m}^2\ \frac{L}{E}\ )$$

- In a 3-neutrino mixing framework:

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

- Oscillation experiments constrain U_{li}
- Oscillation hypothesis has been plausible explanation of anomalies observed in solar and atmospheric neutrino experiments over > 30 yr: radiochemistry (Homestake, SAGE, GALLEX), real time (SuperK, Soudan-II, MACRO, SNO)
- and finally...

Neutrino Oscillations

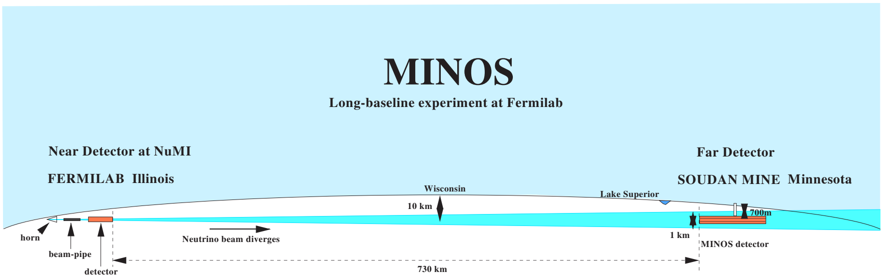
- In 1998 SuperK announces Evidence for Oscillation in atmospheric neutrinos consistent with $\nu_\mu \rightarrow \nu_\tau$
- Recent analysis: $\Delta m^2_{atm} = (1.6 - 4) \times 10^{-3} eV^2$, $sin^2 2\theta > 0.92$, at 90% C.L.
- Solar neutrinos: 2001 (SuperK + SNO), 2002 SNO (with neutral current measurements)
- SNO: Using NC, ES, and CC the non-electron component is found to be > 0 at > 5σ. Data consistent with oscillations to *active* neutrinos
- There's LSND though but MiniBOONe should sort it out soon
- The solar data favour to LMA and $\Delta m^2_{solar} \approx 5 \times 10^{-5} eV^2$
- Short term: KamLAND and Borexino will shed more light on the solution (LMA, LOW, SMA)

Some Conclusions

- Very exciting time
- Neutrinos most probaly oscillate $\Rightarrow$ have mass but still lots of things to do in the near and more distant future:
- Measure mixing matrix elements
- Measure Δm^2s
- Hierarchy (sign of Δm^2)
- CP violation
- Absolute mass scale
- Neutrino nature (Majorana vs Dirac)
- ....

Overview of MINOS

- The idea: Use a controlled accelerator neutrino beam to reduce uncertainties in atmospheric measurements
- Not just confirmation of oscillations. Will measure Δm^2, $sin^2 2\theta$ with unprecedent ($\sim$ 10%) accuracy
- Crucial for this measurement: Use TWO detectors, *Near* and *Far* to measure beam *before* and *after* mixing

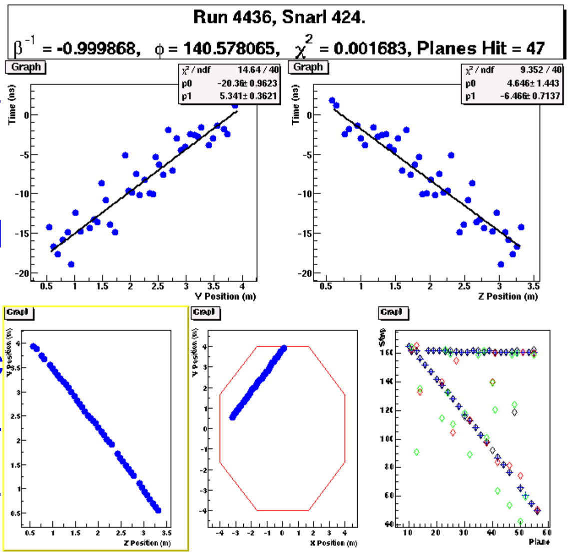


- ν_μ beam from protons at Main Injector, adjustable E_ν to match low Δm^2
- 5.4 kT FarDet and $\sim$ 1 kT NearDet
- B-field for muon momentum, $\frac{\Delta p}{p} \approx 12\%$
- 1” steel planes, plastic scintillator strips + WLS fiber
- Hamamatsu M16/M64 PMTs, optical 8-fold multiplexing

Overview of MINOS

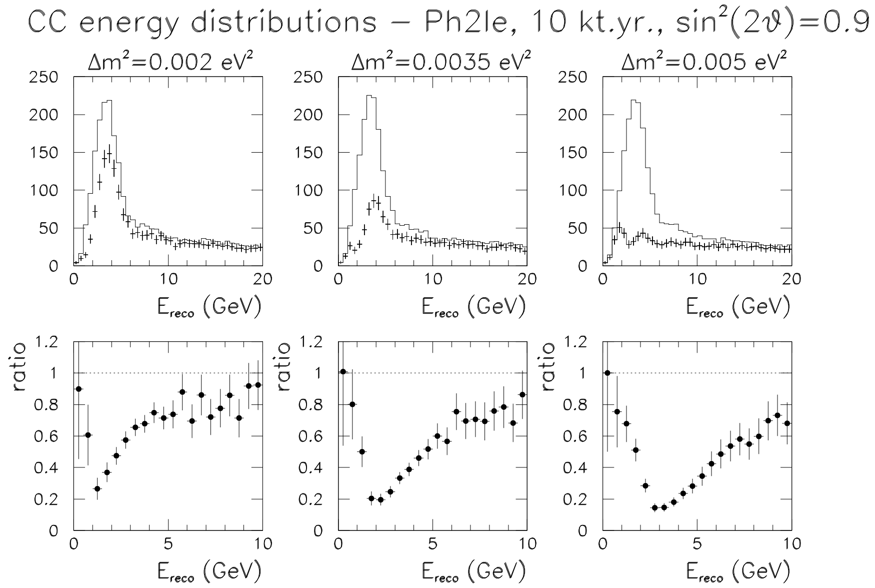
- Installation at Soudan is going well
- First SM installed and *magnetized* $\sim$ 50% of SM2 installed

- Data taking alongside with Installation
- First upward muons from ν interactions
- Installation will be completed by summer'03
- $\sim 10kT \times yr$ of atmospheric ν data *with magnetic field* before beam turn-on in December'04



MINOS Calibration

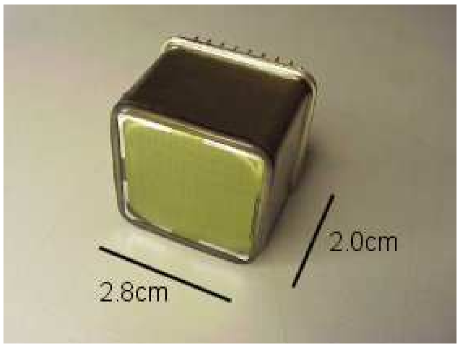
- How we measure the oscillations:
  - Measure ν spectrum with NearDet
  - Extrapolate it for FarDet
  - Measure the difference

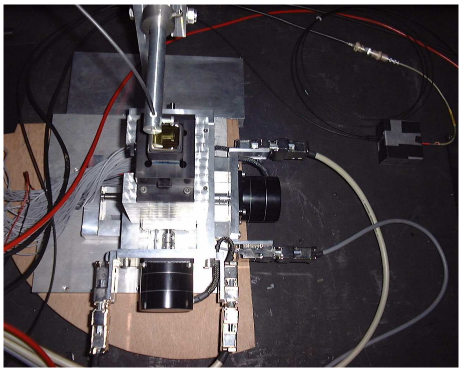


- Conclusion: systematics/calibration are crucial
- 3 steps of calibration:
  - Light Injection System
  - Muons
  - Calibration Detector (my main work concentrated here)

Past and Present Work

- NearDet $\Rightarrow$ high rates $\Rightarrow$ no multiplexing $\Rightarrow$ M64s instead of M16s suggested
- Started with characterizing M64s





- Study of linearity, gain, QE$\times$CE, xtalk etc., resulted in collaboration's approval of M64s in 2000
- Studied photoelectron counting using low light M16/M64 PMT spectra
- The developed technique is used now for gain calibration in MINOS detectors

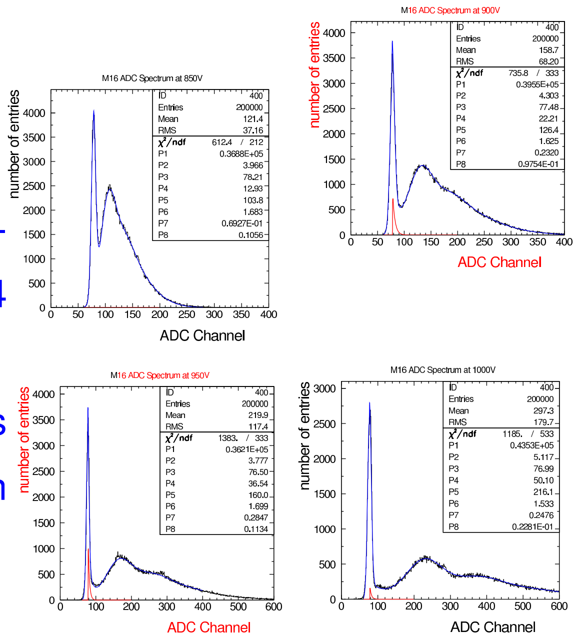
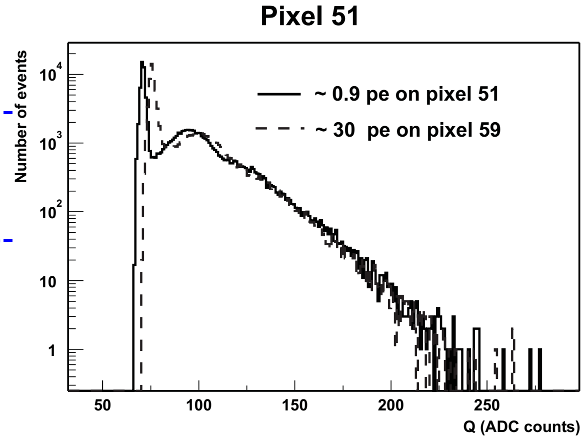


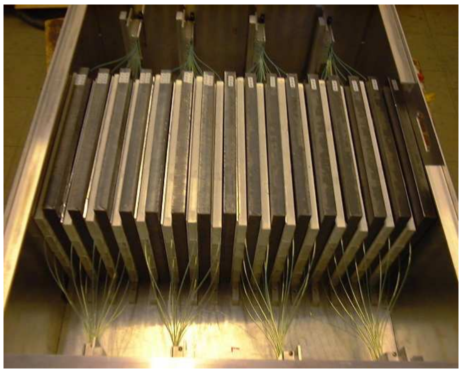
Figure 1: The charge spectra for an M16 for a low light level

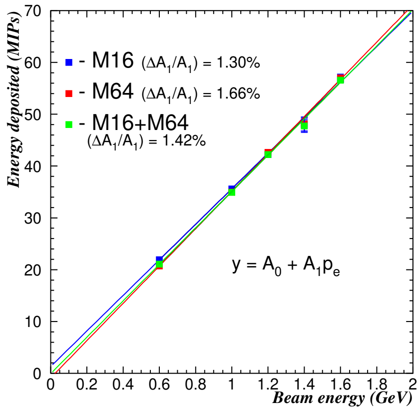
Past and Present Work

- Pioneered the work on non-optical xtalk in M64s
- Analysed the origin and potential danger for MINOS



Mini-module test beam at 2000



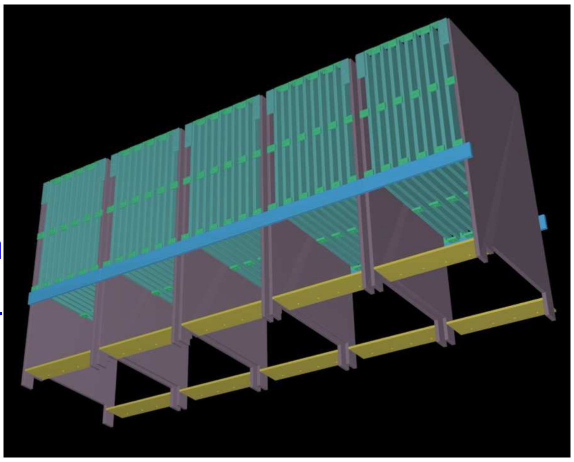


- Important exercise before real CalDet programme
- Commissioning: beam, calorimeter, LI, electronics, DAQ
- Wrote GEANT based MC code, Analysed electromagnetic shower data, comparison showed good agreement, checked that LI calibration idea works

Past and Present Work

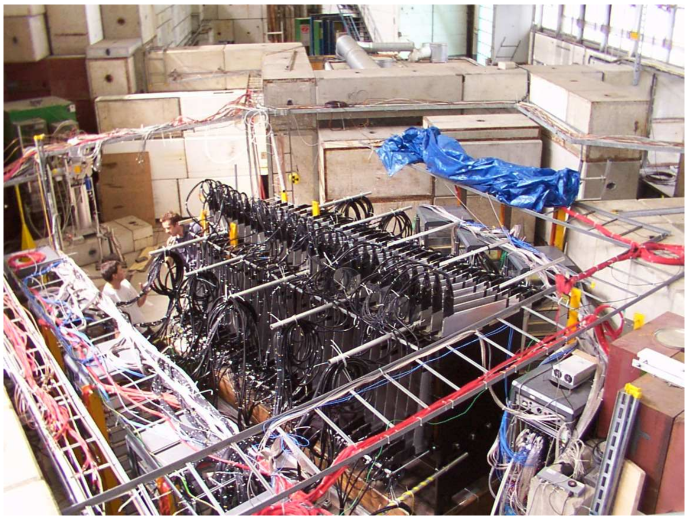
Calibration Detector @ CERN PS

- Converts Muon Energy Unit into the hadron and electron energy in Test Beam
- Both FarDet and NearDet are too big to be directly calibrated
- Exposed to a beam of e, p, π, μ of known energies
- 3 year programme (2001 - 2003) in T11 ($p_{max} = 3.6GeV$) and T7 ($p_{max} = 10GeV$) to cover MINOS E_ν range
- Calibrate out Near/Far differences in readout
- Test and sharpen pattern recognition algorithms



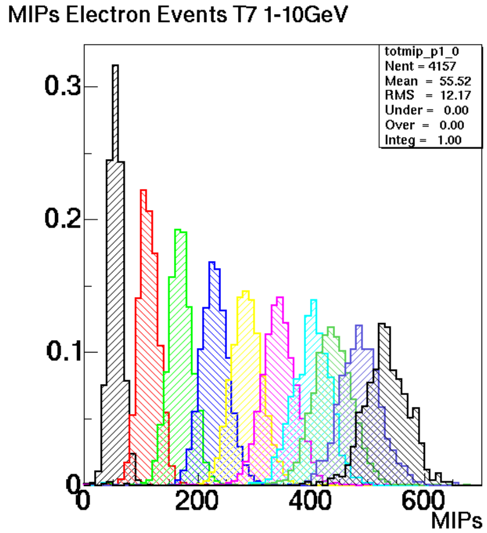
- 60 1m$\times$1m MINOS modules
- X, Y, Z readout
- Particle ID: ToF, Cerenkov
- Hadron measurement with $p_{hadr} < 10GeV$ is of general interest (GEANT)

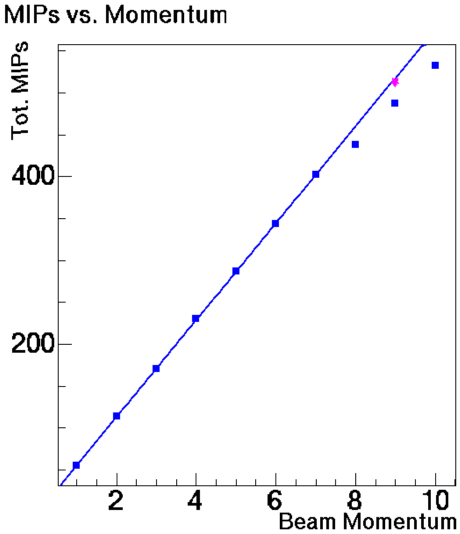
Past and Present Work



- As scintillator hardware coordinator I have led the commissioning of the detector
- Successfully built and commissioned
  - In 2001: T11(3.6 GeV) with Far electronics
  - In 2002: T11 with Far and Near/Far for several planes; T7(10 GeV) with Far
- Collected unprecedent ammount of high quality data
- Analysis in progress

Past and Present Work

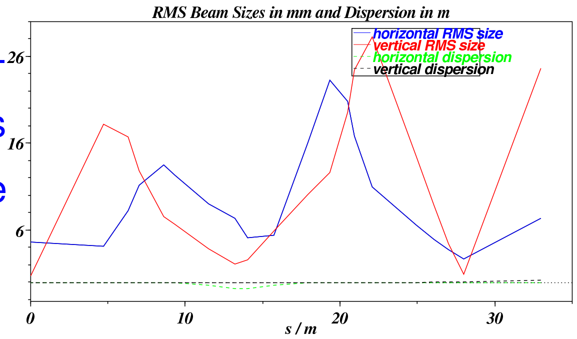


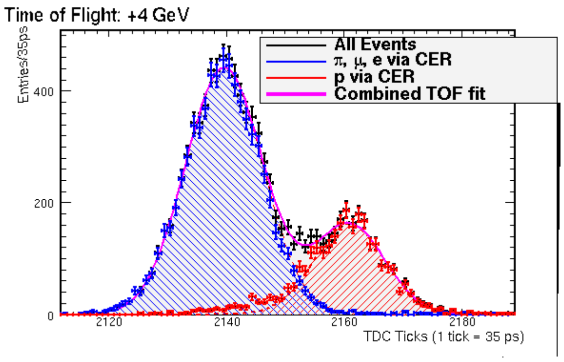


- first MEU/GeV constants in use, $\frac{\Delta E}{E}$, linearity, e/π,...

Other responsabilities

- "Beam Operation": Calculate beamline magnet settings using beam transport routine (MAD)



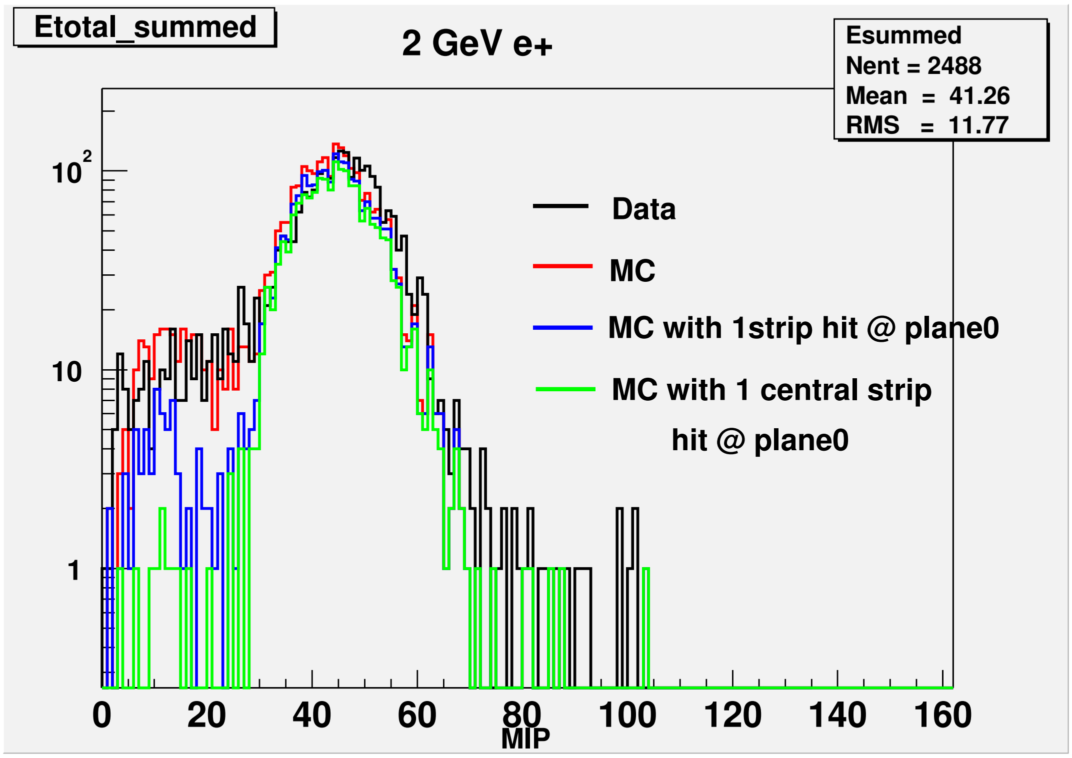


- "Beam Detectors": Cerenkov (efficiency studies, optimization etc...)

Past and Present Work

CalDet Monte Carlo

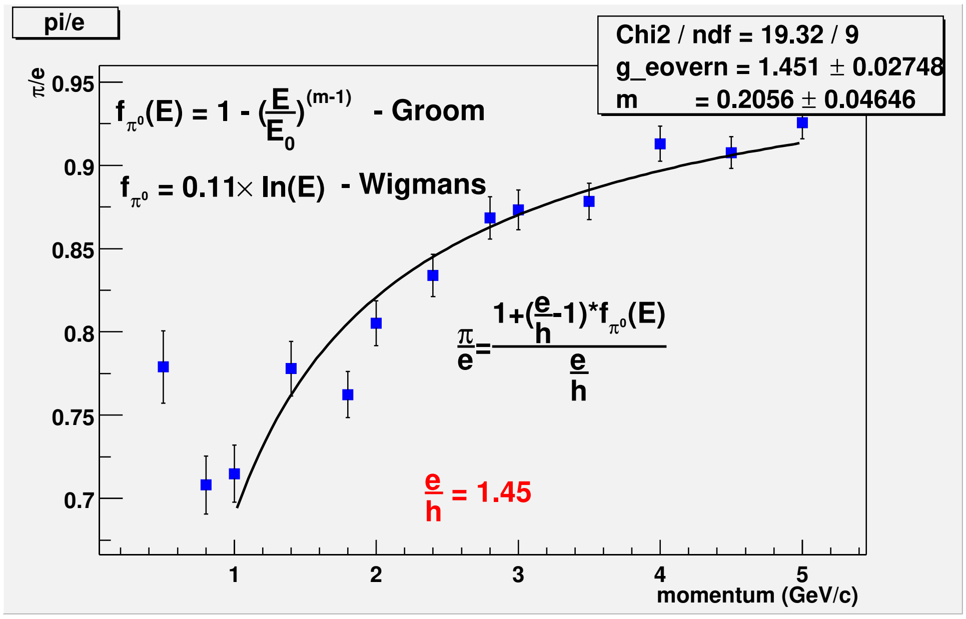
- Pioneered MC simulations for CalDet
- Simulations included Birks' saturation in scintillator, light attenuation in fibers, PMT response simulation...
- Included some beam elements to simulate scraping observed in data
- Very good agreement for electrons, for hadrons work in progress. Incorporating CalDet MC into "official" MINOS MC



Present and Future Work

Short-term

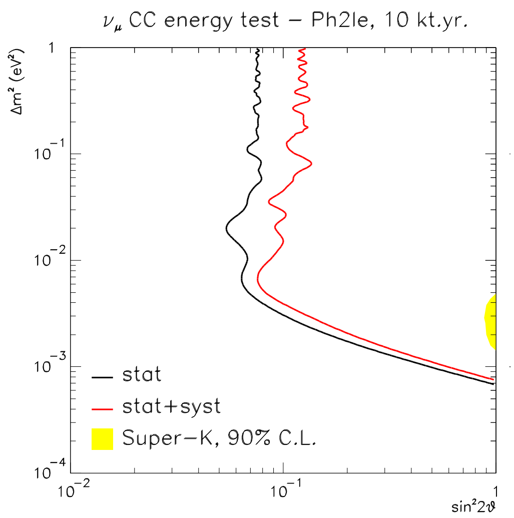
- 2003: Test beam in NearDet configuration. New hardware (single readout with reflector, electronics...) I will be responsible for commissioning again
- Currently working on:
  - Accurate beam simiulation
  - $\pi \longrightarrow \mu\nu_\mu$ kinematics and transport through beam optics to disentangle π and μ samples
- CalDet Data analysis. Using data to parameterize the detector response in MC simulations, feed back to GEANT (*not just for MINOS*). Some work started but it is at very early stage

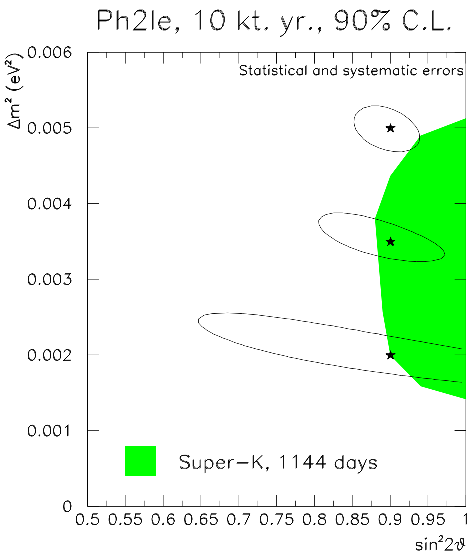


Future Work

Long-term

- NuMI beam is expected with certainty in January 2005
- Apply information/experience from CalDet to understand NearDet response and extrapolate it to the Far site
- Would concentrate on CC events analysis - the most sensitive measurement of oscillation parameters
  - But also most vulnerable to systematic effects
  - ν Spectra different at Near and Far (kinematics + *pion divergence from primary target*)
  - Statistics should be fine, but systematcis must be understood and its error kept low
  - Main players here are Calibration (major UK contirbution) and hadron production experiment





$\beta\beta$decay. A New Initiative

Why $0\nu\beta\beta$ decay?

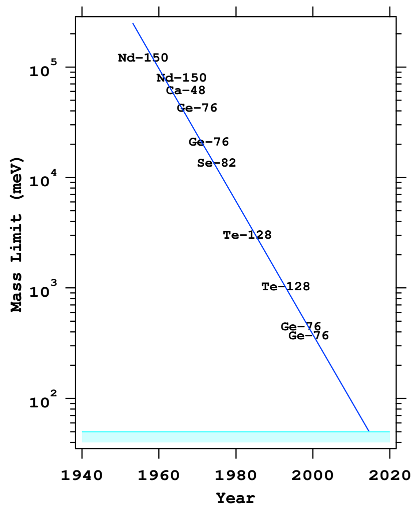
- $\Delta L \neq 0$

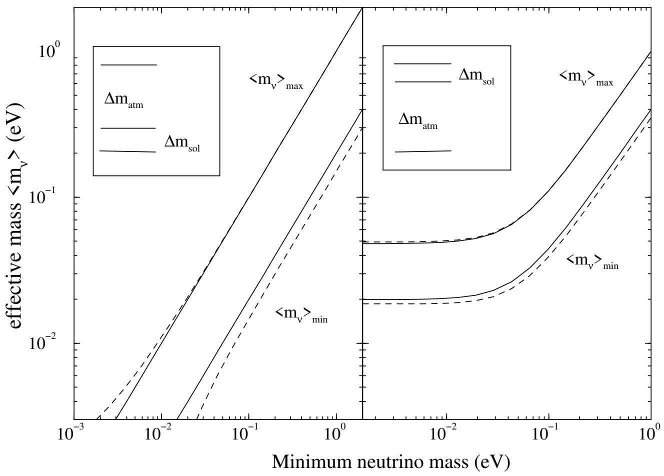
$$(Z, A) \rightarrow (Z+2, A) + e_1^- + e_2^- \qquad \Delta L = 2\ (!)$$

- Nature of neutrino. Majorana ($\nu \equiv \tilde{\nu}$) or Dirac ($\nu \neq \tilde{\nu}$).
  Theorists seem to prefer Majorana (see-saw)

- Oscillation experiments measure Δm^2, not m_{abs}

- From oscillations
  $\Delta m^2_{atm} \sim 2.5 \times 10^{-3} eV^2 \Rightarrow m_{scale} \sim 0.05 eV$. Current sensitivity $\sim 0.35 - 1.0 eV$ Very hopeful!





$\beta\beta$decay. A New Initiative

Statement of Interest in a future double beta decay experiment

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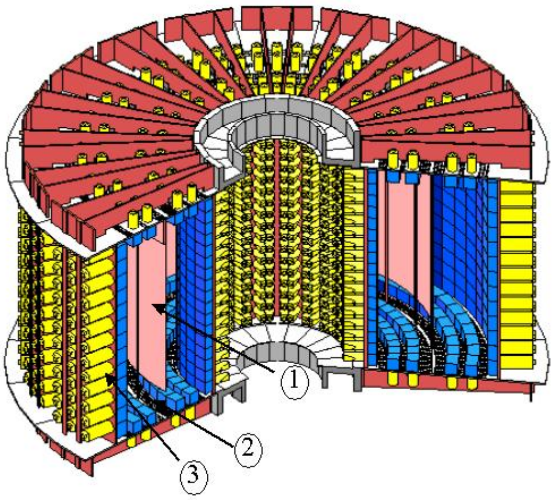
University College London

November 22, 2002

The following proposal, being submitted to the PPRP in January 2003, could represent the beginning of a larger programme of double beta decay involvement for the UK. It outlines an opportunity to take part in the analysis of data being taken presently in the NEMO-III double beta decay experiment. Furthermore, it outlines a plan to initiate, on a small scale, a programme of R&D relevant to the next generation SuperNEMO proposal, and the real possibility to be intellectually involved with design and goals of this future experiment. It is expected that a new generation of double beta decay experiments, which will push the presently reachable limits on the Majorana neutrino mass by an order of magnitude, will start to be built in about 2008-2010. The generic cost of such an experiment is expected to be of order 20M, for which the UK could expect to contribute 25-50% depending on manpower and contributions from other collaborating countries.

NEMO experiment @ Frejus



- Will measure *several* isotopes (important because of NME uncertainties)
- First experiment to have *zero* BG from radioactivity
- Best sensitivity to $< m_\nu^M > \sim 0.1 - 0.4 eV$ for a few isotopes by 2007
- If BG(radioactivity) = 0 feasible, SuperNEMO ($\sim$ 100 kg) can push $< m_\nu^M >$ to $\leq 0.05 eV$