Design and Performance of ECC-MECC

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Nufact08, Valencia
July 3rd, 2008
A bit of history

- CP violation in the leptonic sector
  - $\nu_e \rightarrow \nu_\mu$ is the most sensitive ("golden") channel

- In the $(\theta_{13}, \delta)$ parameters plane, a single experimental measurement cannot solve some ambiguities (intrinsic degeneracy, $\Delta m^2$ sign degeneracy, $\theta_{23}$ octant symmetry degeneracy)

- The combination with the $\nu_e \rightarrow \nu_\tau$ ("silver") channel is able to solve the intrinsic degeneracy at the neutrino factory

- Then the use of an Emulsion Cloud Chamber (ECC) was considered

- Performances of a magnetized ECC detector is under study:
The golden and the silver channel

\[ \Delta \theta = \theta_{13} - \bar{\theta}_{13} \]

\[ \nu_e \rightarrow \nu_\mu \left( \bar{\nu}_e \rightarrow \bar{\nu}_\mu \right) \]
\[ P_{e\mu}^\pm (\bar{\theta}_{13}, \delta) = P_{e\mu}^\pm (\theta_{13}, \delta) \]

\[ \nu_e \rightarrow \nu_\tau \left( \bar{\nu}_e \rightarrow \bar{\nu}_\tau \right) \]
\[ P_{e\tau}^\pm (\bar{\theta}_{13}, \delta) = P_{e\tau}^\pm (\theta_{13}, \delta) \]
**Detection of \( \tau \) decay: emulsion cloud chamber**

The Emulsion Cloud Chamber (ECC):
- emulsion films (trackers) interleaved by lead plates (passive)
- capable at the same time of large mass (kton) and high spatial resolution (< 1 micron) in a modular structure

Topological and kinematics measurements:
- Neutrino interaction vertex and decay topology reconstruction
- Measurement of hadrons momenta by Coulomb Multiple Scattering
- \( dE/dx \) for \( \pi/\mu \) separation at the end of their range
- Electron identification and energy measurement
Hybrid detectors, OPERA

Nuclear emulsions used in the past in cosmic rays. After that, hybrid detectors were successfully used in the last two decades.

**CHORUS** experiment: 2000 neutrino interactions with charm production. Few events, compared with the electronic detectors, but very low BG contamination (F. Di Capua talk in this session).

**DONUT**: the use of the ECC and the first $\nu_\tau$ direct observation.

The present: the **OPERA** experiment (A. Cazes talk in this session).

The basic unit: the ECC (**"brick"**)
"silver" muons signal and its background

The signal: $\tau \rightarrow \mu$ decay

Dominating background

Punch-through or decay in flight of hadrons

Taus from oscillated antineutrino

Anti-neutrino induced charm-production

Charge misidentification: $1-3 \times 10^{-3}$

(M. Guler et al. [OPERA Collaboration], CERN-SPSC-2001-025)
OPERA-like detector: 1 Kton target located 732 km from the beam source

- 5 years data taking

- Scan all events with a negative (wrong sign) $\mu$: 
  - “silver” ~ 30 events and “golden” ~ 310
  - $\bar{\nu}_\mu$ with misidentified charge: ~ 2200
  - Charm background: ~ 80 events
  - $\nu$ NC with punch-through or decaying h: ~ 4800

- ~ $8 \times 10^3$ events in 5 years

- 5 kton ECC detector feasible
Detected events

Sensitivity with $\theta_{13}$

Below 3° the silver channel contributes very little in disentangling the intrinsic degeneracy
The use of a magnetized ECC (MECC)

An ideal detector exploiting a Neutrino Factory should, with high accuracy:

- Identify and measure the charge of the muon ("golden" channel)
- Identify and measure the charge of the electron ("platinum" channel)
- The identification of tau decays ("silver" channel) can take advantage of additional requests if we want to recognize with high accuracy all the tau decays
- Identify the complete topology and measure the kinematics of an event in order to increase the signal/background ratio

The MECC could fulfill all the requirements for such ideal detector
Assumption: accuracy of film by film alignment = 10 micron (conservative)

The geometry of the MECC is being optimized:

- Muon energy from 1 GeV to 10 GeV
- Spacer thickness from 2 cm to 5 cm
- Magnetic field: 0.25 T, 0.5 T, 1.0 T
- TT resolution
Emulsions do not have time resolution. The MECC needs a time stamp, then TT is mandatory

- Scanning is not driven by the electronic detectors
- Matching is done after event location

CC/NC classification with MECC-TT match

For 2.5cm TT segmentation case
- 15GeV CC = 122 events/brick
- 15GeV NC = 198 events/brick
- 40GeV CC = 97 events/brick
- 40GeV NC = 151 events/brick

A conservative number could be 100 events per brick
Performances with a MECC

Muon momentum resolution as a function of the momentum for different spacer thicknesses

B=0.25 T
B=0.5 T
B=1.0 T
Charge misidentification as a function of the momentum for minimum ionizing particles (left panel) and electrons (right panel), assuming a 3 cm spacer thickness and a 0.5 T magnetic field.
A first test of an emulsion spectrometer exposed to a pion beam has been performed on Dec 7, 2005 in a KEK-PS T1 pion beam (C. Fukushima, M. Kimura, S. Ogawa, H. Shibuya, G. Takahashi, T. Hara and K. Kodama, paper in preparation)
A first test beam for MECC

- Different stack were exposed:
  - Different support used (40 μm polystyrene or 200 μm acrylic plate)
  - 2 GeV π+ [no magnet] 3000/cm² as reference beam
  - 1 T magnetic field
  - Different beams: 0.5 GeV, 1. GeV and 2. GeV, each with 1000/cm² π+ (π-)

![Graph 1](image1.jpg)
![Graph 2](image2.jpg)
The achieved momentum resolution is $\Delta p/p \sim 0.14\%$, but:

- alignment among the elements of the spectrometer is much more accurate (a few microns with respect to about ten microns)

- on the other hand, the smaller number of spacers (2 with respect to 4 of the proposed MECC) and the thinner spacers (1.5 cm with respect to 3 cm of the proposed MECC) determine a worsening of the resolution.
The search for the tau

\( \tau \rightarrow \mu \ (\sim 17\%) \)

Performances similar to the OPERA case (the muon measurement is similar in both detectors).

Improvements:
- background from scattering, although not dominant, much smaller than in the OPERA case (a factor 40)

\( \tau \rightarrow n\bar{h} + n\pi^0 \ (\sim 64\%) \)

The magnetic field enables the ECC to measure the hadrons charge.

The main background is:
- anti-neutrino charm production (\sim 50\%)
- hadron interactions (\sim 50\%)

Improvements:
- the MECC momentum resolution is better than the ECC one (\sim 20\% \rightarrow \sim 10\%): better kinematics analysis
- kinematics analysis improved
- background from hadron interaction decreases by a factor 2 (only negative hadrons may contribute to the background)
The search for the electron: \( \tau \rightarrow e \) and the “platinum” \((\bar{\nu}_\mu \rightarrow \bar{\nu}_e)\) channel

\( \tau \rightarrow e \) (~17%)

The magnetic field enables the ECC to measure the electrons charge.
The main background is:
- anti-neutrino charm production as in the muonic case
Possible drawback:
- the electron ID is worse than the muon one (to be studied)
Improvements:
- the \( p_t \) cut at the 2ry vtx can be lowered from 250 MeV to 100 MeV
  (meson decays are not an issue)
- The MECC momentum resolution is better than the ECC one
  (~20% \( \rightarrow \) ~10%): better kinematical analysis

The platinum channel

There are not yet detailed available studies, but it is easy to make a rough estimation.
An OPERA-like detector at L=3000 km \((\theta_{13} = 5^\circ, \delta = 90^\circ)\) would collect:
- \( \nu_e \) with the wrong electron charge: \( \sim 10^4 \)
- \( \bar{\nu}_e \) from the oscillation: \( \sim 10^2 \)
The kinematical cuts should be able to improve the signal/background by a factor 100 (to be studied)
Conclusions

- A hybrid detector for the study of CP violation in the leptonic sector by means of the "silver" channel is feasible.
- The OPERA experiment with the same technology successfully demonstrated it during the (short) 2007 run and the run starting just now will demonstrate to handle thousands of events. The scanning load for a neutrino factory is feasible already now.
- Very preliminary estimation of the performances of emulsion detectors in magnetic fields look very promising both for the extension of the silver channel and perhaps for the platinum channel study.
- Detailed studies will continue and test measurements are planned.