CNGS (CERN Neutrino to Gran Sasso)

400GeV/c proton beam
4.5×10^{19} pot/year in shared mode

Average $\nu_\mu$ energy = 17GeV

$\nu_\mu : \bar{\nu}_\mu : \nu_e : \bar{\nu}_e = 1 : 2 \times 10^{-2} : 8 \times 10^{-3} : 5 \times 10^{-4}$

2600 $\nu_\mu$ CC events/kton/year
22 $\nu_\tau$ CC events/kton/year

assuming $\sin^2 2\theta = 1$, $\delta m^2 = 3 \times 10^{-3}$eV^2

First beam to Gran Sasso in May 2006
Turkey

Bern, Neuchâtel
Switzerland

INR Moscow, ITEP Moscow, JINR Dubna, Dubna
Russia

Aichi, Toho, Kobe, Nagoya, Utsunomiya
Japan

Bari, Bologna, INFN-Frascati, L'Avigliana, LNF, Naples, Padova, Rome, Salerno
Italy

Technion Haifa
Israel

Bremen, Hamburg, Munster, Rostock
Germany

LAPP Annecy, IN2P3 Lyon, LAL Orsay, IRSN Saclay
France

Zagreb University
Croatia

IHEP Beijing, Shandong
China

Sofia University
Bulgaria

IHEE (ULB-VUB) Brussels
Belgium
OPERAS is an emulsion experiment similar to DONUT

$\nu_\tau$ CC event is identified by detecting $\tau$ decay vertex

$F.L. = 280 \mu m$
$\theta_{kin} = 0.090 rad$
$P_t = 414^{+144}_{-81} \text{ MeV/c}$
$P = 4.6^{+1.6}_{-0.9} \text{ GeV/c}$

DONUT $\nu_\tau$ CC event

Closeup view near the neutrino interaction

Electron ID in emulsion
$\mu$ ID in emulsion and in electronic detector
Momentum measurement in emulsion
to reject backgrounds
Detector in Gran Sasso

Exposed Emulsion for Analysis

Scan station in Europe

Scan station in Japan

Analysis begins when the beam

(≈) emulsion DAQ outside of Gran Sasso
Emulsion Brick for OPERA

57 emulsion sheets and 56 lead plates are vacuum packed.

Use 200k bricks.
rolled and ready for prototype mass production (25t)

10t Bolden Pb + 0.6t Britannia Pb

Lead Production (Germany)

Low radiation lead
Delivery at LCGS: June 2004
Full size proto built by ILMA

Brick Loading Test

OPERA Target Wall (Italy)
First TT Vertical Plane

OPERA Target Tracker (France)
Decay analysis is no problem

Enough experience from DONUT and CHORUS physics analysis

DONUT

Observation of tau neutrino interactions


4 $\nu_\tau$ CC events among 203 $\nu$ interactions

$\rightarrow$ 7 $\nu_\tau$ CC now

CHORUS $\sim 140 k \nu$ interactions now

Measurement of $D^0$ production in neutrino charged-current interactions


283 $D^0$ decays among $\sim 25 k \nu_\mu$ CC events

Measurement of $\Lambda^+$ production in neutrino charged-current interactions


338 $\Lambda^+$ candidates among $\sim 50 k \nu_\mu$ CC events

Determination of the semi-leptonic branching fraction of charm hadrons produced in neutrino charged-current interactions


956 charm candidates among $\sim 56 k \nu_\mu$ CC events

Improvements in OPERA

- S-UTS (faster emulsion DAQ) $1 cm^2/h \rightarrow > 20 cm^2/h$

- $dE/dx$ (i.e. $\beta$) measurement (low momentum $\mu$ ID)

- Better electron ID and energy measurement $\leftarrow$ clean emulsion by refresh + Pb instead of H
Emulsion Scanning Station in F-Lab (Japan)
S-UTS (new emulsion DAQ system)

UTS (current system) runs at 1cm²/h
→ S-UTS is designed to run at 20cm²/h or faster

- Ultra High Speed Camera
  - Up to 3k frames per second.
  → Max 100 views/sec

- Image taking by follow shot
  - No go-stop operation to avoid a mechanical bottleneck.
Ultra High Speed CCD Camera for S-UTS

- 3k frames/sec
- 512(H) × 504(V) pixels
- Digital output via LVDS, 1.3 Gbyte/sec

real time processing
S-UTS camera image consists of 32 readout channels
averaged on 29 sheets along a track

Test at KEK N

(number 2002)

Pulse height (dE/dx) in emulsion

Emulsion sheet

number of tracks

number of tracks

1 GeV/c

p and n

positive hadrons

1.2 GeV/c

de/dx (or p) in emulsion is a measurable quantity in automated scan (Track selector)
High pulse height graph has $p/p$ consistent with

Low pulse height graph has $p/p$ consistent with

$1/p\text{p}(\text{MeV}/c) = 0.00105$

$1/p\text{p}(\text{MeV}/c) = 0.00086$

$\frac{p\text{p}}{\text{MeV}/c} = 0.009$

$\frac{p\text{p}}{\text{MeV}/c} = 0.004$

$\text{Expected value for} p$

$\text{Expected value for} \pi^+$
Further reduction of charm Bc

$\text{d}E/\text{d}x \leftarrow \text{measurement in emulsion}$

Low momentum $l$ (Range $\geq 4\gamma_{\text{INT}}$)

High momentum $l$ (Range $\geq 4\gamma_{\text{INT}}$)

Identification
Energy loss measurement by multiple scattering

\[ E \sim E_0 \]

- Like energy loss \[ \rightarrow \]
- Like energy loss

\[ E \sim E_0 \]

Efficiency: 90%, miss-id ~ 5%
Electron energy measurement by counting track segments in a horn

$E_{\text{electron}} \propto \# \text{ of track segments}$

$\Delta \theta_{\text{beam}} < 250 \text{ mrad}$

68% of shower tracks are contained @ 4GeV

Test @ CERN PS (May 2001)
Random background

interaction are seen.

Tracks segments from

at random volume

Estimation of background

~ 1 track/mm²
$E_{\text{electron}} \propto \# \text{ of segments}$

**2 GeV**

- DATA (B.G.)
- DATA (shower)
- MC (shower) + DATA (B.G.)

$N_{\text{SEG}} = 51 \pm 14$

**4 GeV**

$N_{\text{SEG}} = 94 \pm 18$
These performances can be improved in lower BE condition!

\[ \frac{E}{A} \sim \frac{0.4}{A} \text{ few GeV} \]

Energy measurement

\[ \text{Eff. } \sim 90\%, \text{ mis-id probability } \sim 5\% \]

Identification

\[ \text{Our data from tests are well understood and reproduced by Monte Carlo.} \]

(2) Cascade shower detection

\[ \begin{cases} \text{Energy loss difference between electrons and pions} \\ \text{Energy loss measurement by multiple scattering} \end{cases} \]

\[ \begin{align*}
E_{\text{rel}}(z) & \sim E_0 \\
E_{\text{rel}}(z) & \sim \frac{E_0}{\sqrt{z}}
\end{align*} \]

... using...
Refreshable Emulsion

Trajectory of a charged particle
~35 grains/100 micron

Refresh (3 days in 30°C and 98% RH)

~ 8 grains/100 μm remains
Refresh Facility in Tono Mine

Cosmic ray shielding

Room#1 1/50 of a ground level (115m.w.e.)
Room#2 1/400 of ground level (220m.w.e.)

Emulsion delivery to Gran Sasso begins in Aug. 2003
CERN PS and SPS is down in 2005

CERN is dot in OPERA

Rehearsal must be done!

Emulsion analysis chain for event location must be ready before having Real events!

It is not the case for CHORUS nor

Well organized analysis procedure

CNGS dedicated mode will acceptable

Event location begins when beam is on

Quasi-online event location

Ultra fast emulsion DAG by S-UTS

Larger area must be scanned

DONUT, CHORUS, 0.5mmp fiber tracker

OPERA 2.6cm with strips

Poor resolution of a tracking detector

Decay analysis is no problem but event location is a hard job...
Nagoya

Scan station development facility

Tono Mine

Fresh facility

Brick packing

as of a real brick

similar Bg condition will be feasible

close to our scan station and refresh facility

Exposure to TGF

Event location rehearsal using KEk PS
Mini OPERA setup

Expoze > 100 bricks for event location reconstruction.

Emulsion brick wall (3x3)

Beam
DONUT Scintillation Fiber Tracker reused in Mini OPERA

500μm fibers

fiber plane (2 layers)

G10 plate

paper honeycomb plate

fiber plane (4 layers)

YZZY plate

U plate

distances between plates are flexible

640mm × 640 mm

{5 YZZY plates
2 U plates

I.I. (max 30Hz)
Mini OPERA setup (07-Jun-2003)
Ultra low density exposure > 10 beam over 100cm²

(1) General scan to pick up all tracks

(2) Scan back picked up tracks

(3) Find a vertex

Cosmic ray

Know the truth by SF

Rehearsal scheme
Mini OPERA Schedule

2003 Jun
Submit Proposal to KEK

2004 Feb
PS Beam Line Study at KEK
Ready in KEK

2004 Oct
PS KEK' PS Slow Extraction

2006 May
1st Beam to Gran Sasso

2006 May
Tuning and Improving Event Location

2006 May
Full Running of Event Location Rehearsal

2006 May
Begin Event Location Rehearsal
The ICARUS Collaboration
Run 308 Event 160 Collection View

Hadronic Interaction

Examples of events: "electronic" bubble chamber (I)
Run 308 Event 332 Collection View

Run 308 Event 7 Collection View

Cosmic Ray Showers (1600)

Electronics bubble chamber (II)
High sensitivity to signal: oscillation parameters determination

(low) backgrounds measured in situ (control samples)

Several decay channels exploited (golden channel = electron)

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<td>BG</td>
<td>2.0 × 10^{-3} GeV^2</td>
<td>3.0 × 10^{-3} GeV^2</td>
<td>2.2 × 10^{-3} GeV^2</td>
<td>1.6 × 10^{-3} GeV^2</td>
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Super-Kamiokande: (2.25 × 10^{79} p.o.t.)

5 year ČNNGS shared running

(2.35 Kton active LAr, 1.5 Kton fiducial)

7600+2 x 71200 modules
vt detection by kinematical analyses
3000+ LAr Tpc

ICARUS

Rehearsal for event location using mini-OPERA at KEK

S-UTS
de/\xi is a measurable quantity \( \rightarrow \) low momentum ID to kilo charm BG
refracted emulsion \( \rightarrow \) low noise \( \rightarrow \) better in electron ID and energy measurement
t decay vertex detection

OPERA

Long baseline vt appearance experiments in Gran Sasso run from the 1st day

CNGS 1st beam in May 2006

Summary