Roganova Tatiana
for OPERA collaboration

Joint Research on “Neutrino Oscillation on CNGS beam”

(Present Status of Russian participation in OPERA experiment)

Skobeltsyn Institute of Nuclear Physics
Moscow State University

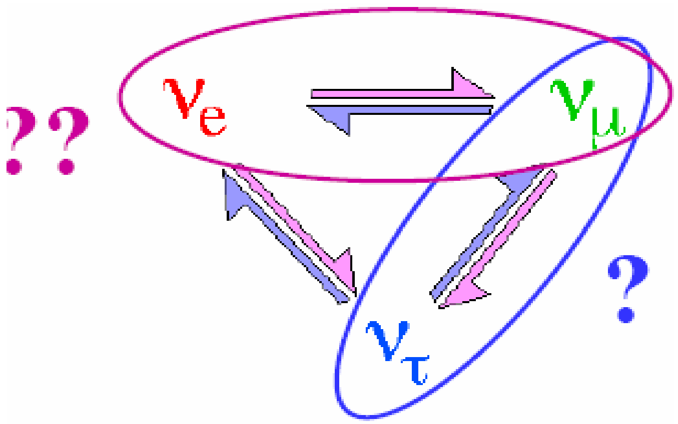
CONTENTS

1 Introduction

The OPERA experiment currently in construction in Hall C of the Gran Sasso laboratory, aims to conclusively reveal in the appearance mode the oscillation of ν_μ into ν_τ using the dedicated high energy neutrino beam from CERN to Gran Sasso (CNGS).

Besides this main stream of analysis, an extension of the search for θ_{13} mixing angle beyond the CHOOZ limit can be achieved by OPERA.

Physics motivation



- Provide unambiguous evidence for $\nu_\mu \rightarrow \nu_\tau$ oscillations in the atmospheric neutrino region ($\Delta m^2 = 1.5\text{–}3.0 \times 10^{-3}\ eV^2$) through the appearance of ν_τ in a pure ν_μ beam
- Search for the sub-leading $\nu_\mu \rightarrow \nu_e$ oscillations (θ_{13})

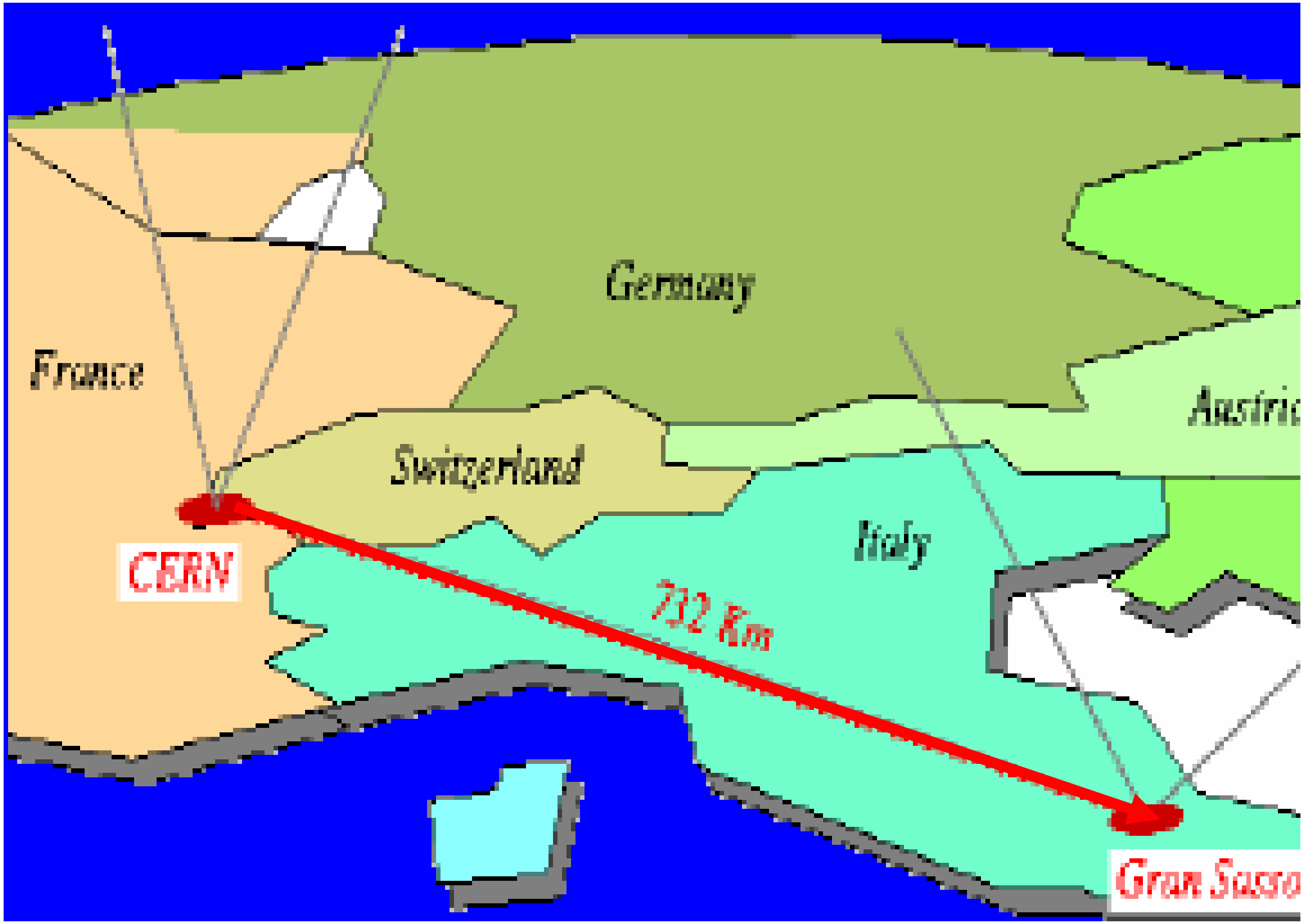
2 The CNGS beam line

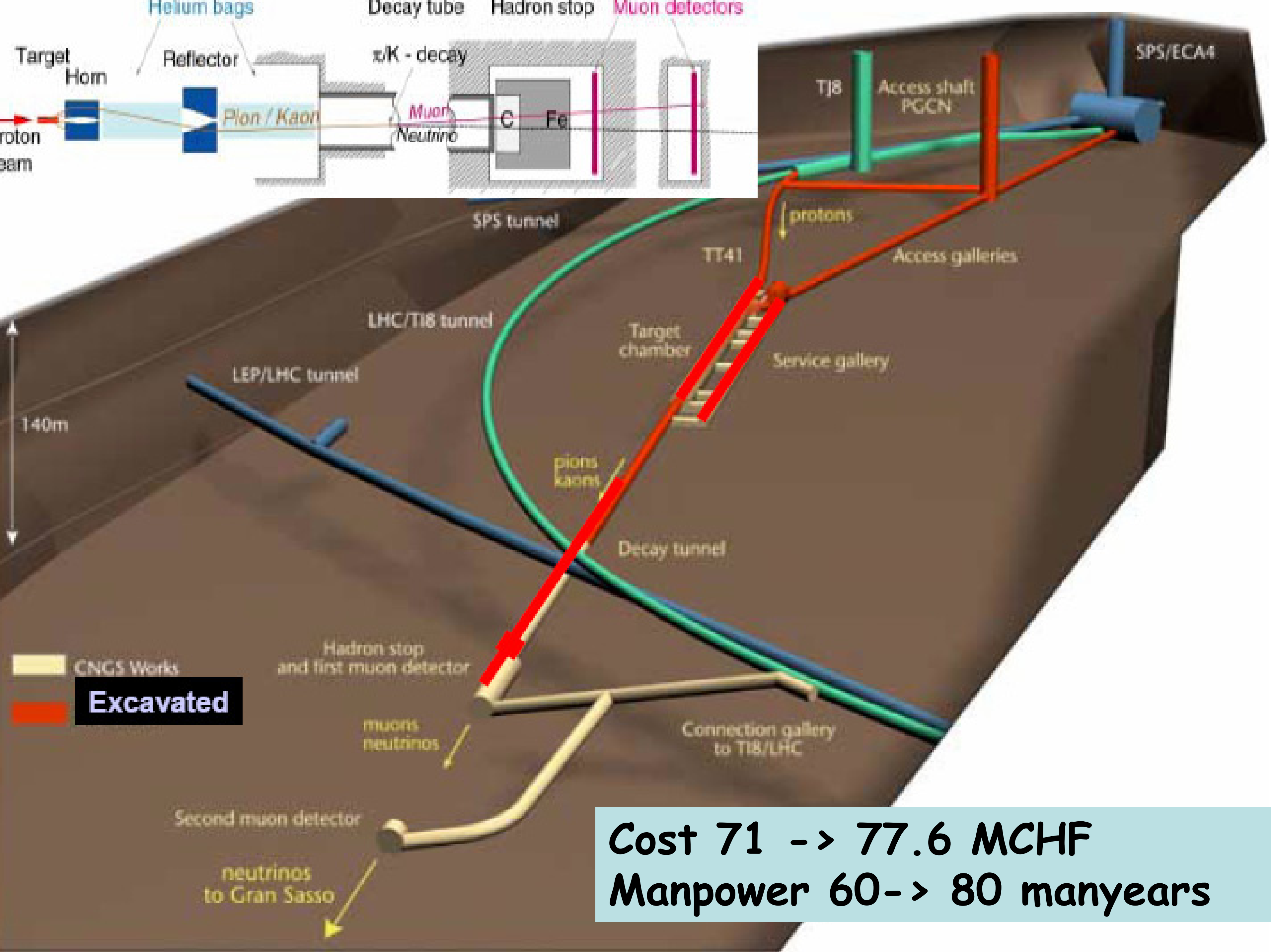
The ν_μ CNGS beam between CERN and the Gran Sasso laboratory (730 km) entered in operation in May 2006. It has been optimized for ν_τ appearance oscillations with a mean neutrino energy of 17 GeV.

During one year, in a mode where the use of the SPS is shared with LHC and fixed target operations, it is expected that 4.5×10^{19} protons on target (pot) can be delivered, assuming 200 days of operation.

In the 1.8 ktons OPERA detector, the corresponding ν_μ flux will lead to about 46 events per day with a contamination of 2.1% $\bar{\nu}_\mu$, 0.8% ν_e and less than 0.05% of $\bar{\nu}_e$.

If the $\nu_\mu \rightarrow \nu_\tau$ oscillation hypothesis is confirmed, the number of τ's produced via charged current interactions at the Gran Sasso is about 20/kton/year for $\Delta m^2 = 2.5 \times 10^{-3} eV^2$ at full mixing.


Germany
France
Austria
Switzerland
Italy
CERN
732 Km
Gran Sasso



Cost 71 -> 77.6 MCHF
Manpower 60-> 80 manyears

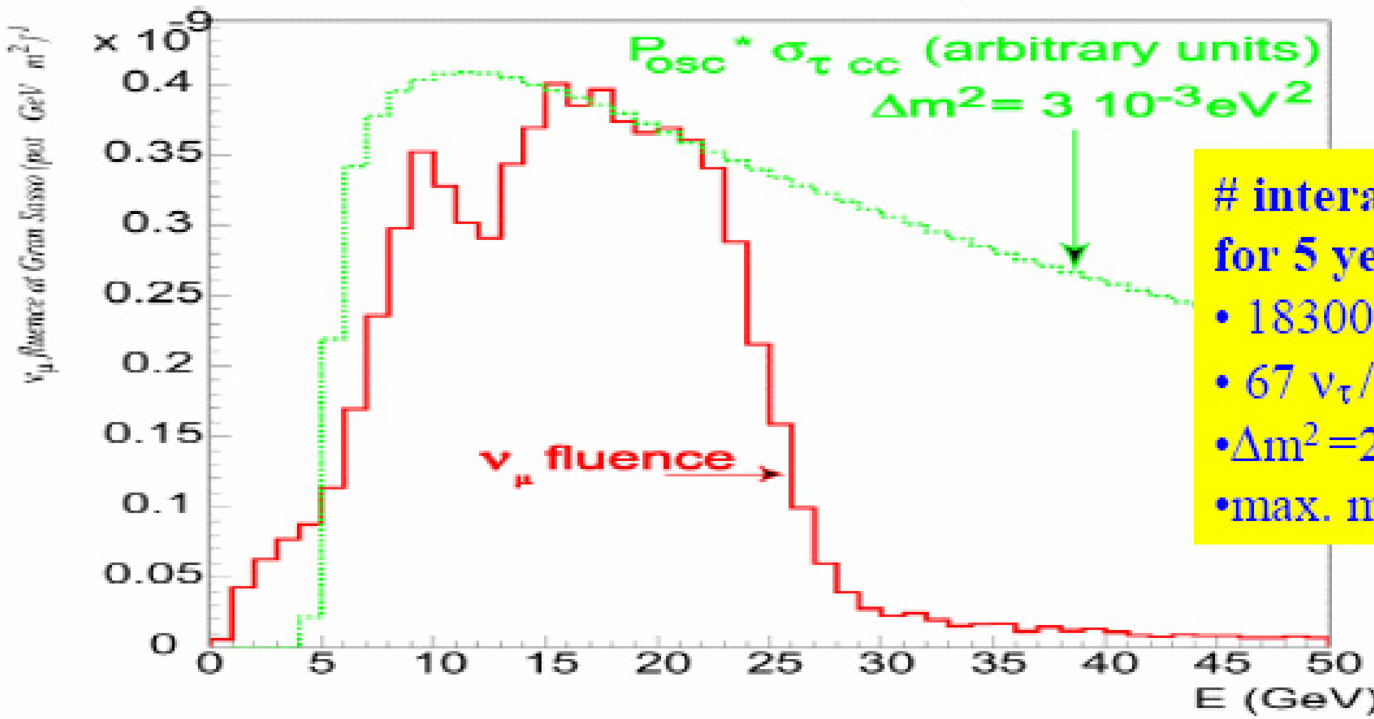
CNGS beam optimized for appearance

Shared SPS operation

200 days/year

4.5×10^{19} pot / year

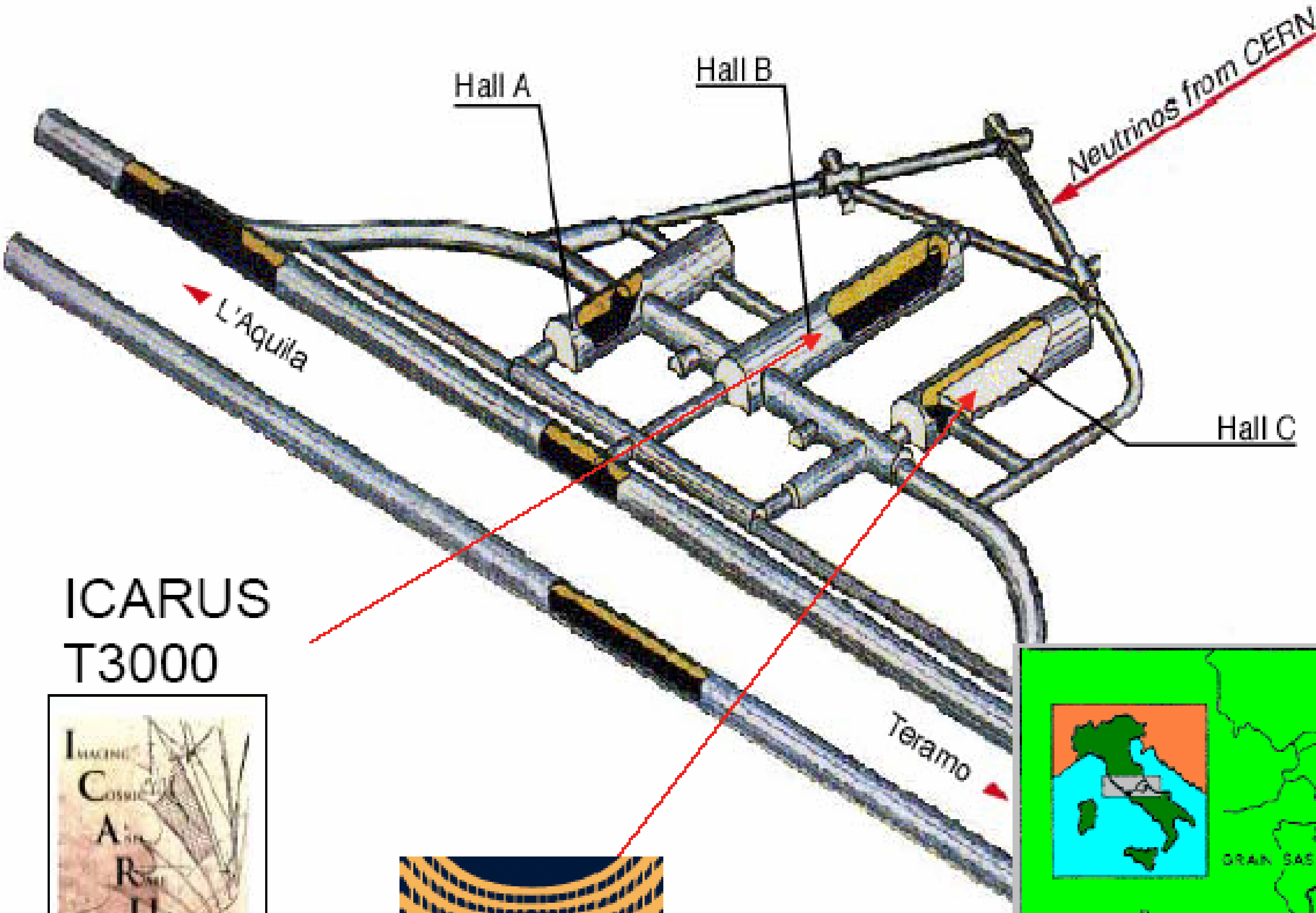
$<E>_\nu$ (GeV)	17
$(\nu_e + \bar{\nu}_e) / \nu_\mu$	0.87 %
$\bar{\nu}_\mu / \nu_\mu$	2.1 %
ν_τ prompt	negligible



 # interactions ν for 5 years :

- 18300 NC+CC / kt
- 67 ν_τ / kt
- $\Delta m^2 = 2.4 \times 10^{-3}\ eV^2$
- max. mixing

LNGS Laboratory and the 2 detectors



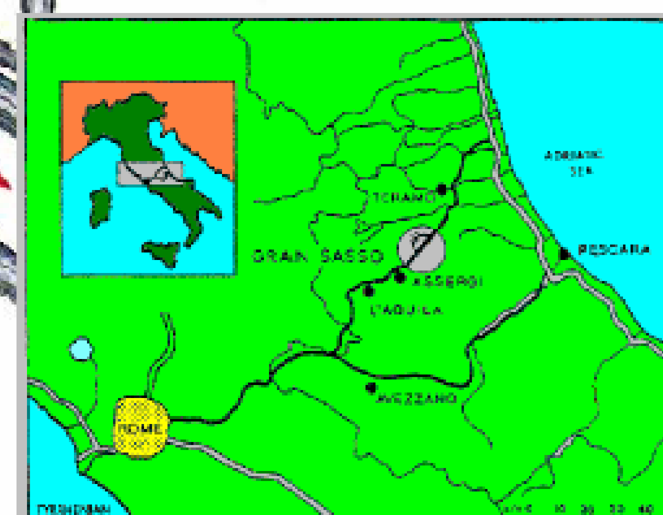


Table 1.

ν_μ events in the 1.8 ktons OPERA detector per day with improved proton beam

Event type	number
NC	10.96
CC (DIS)	31.42
CC (QE + RES)	4.07
Total	46.45

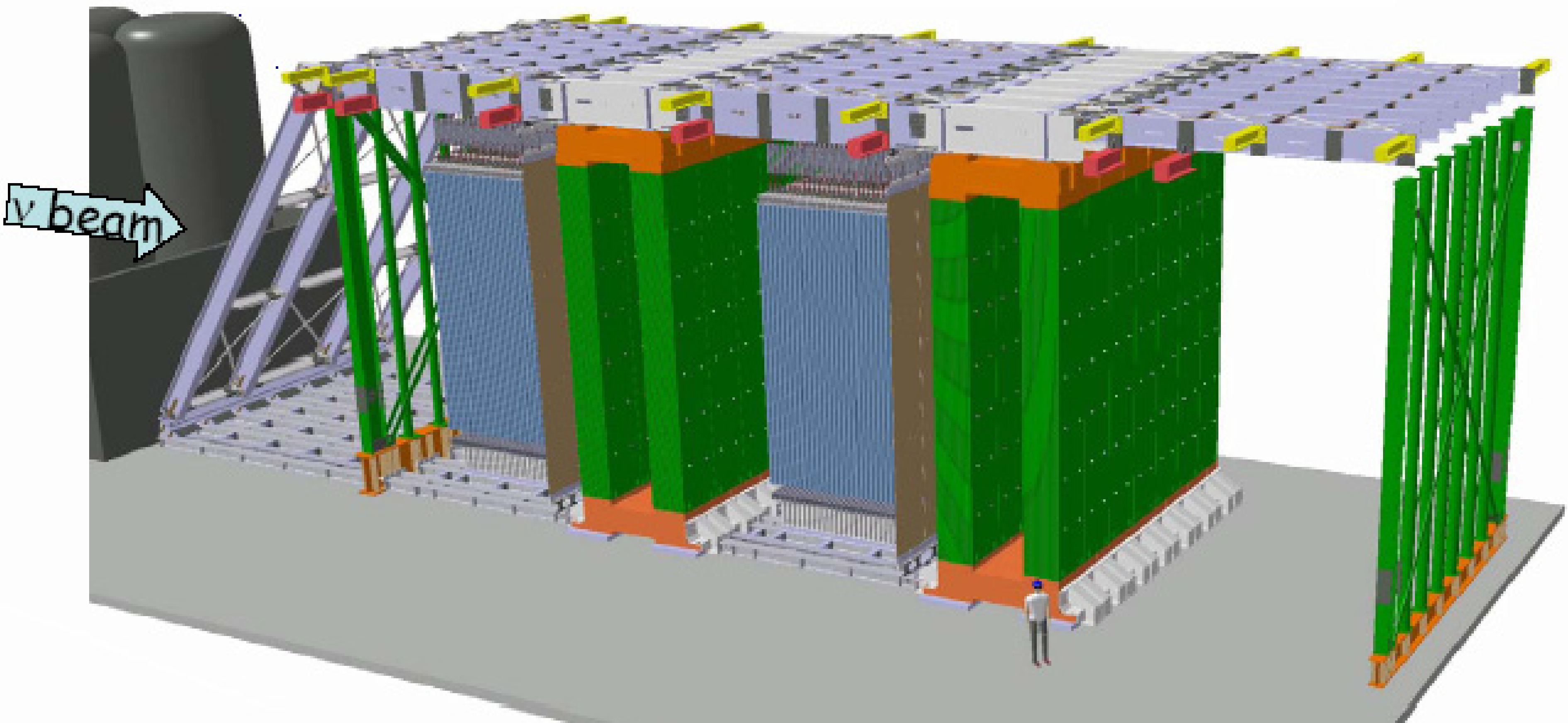
3 The OPERA experiment

3.1 The detector structure

The main purpose that has driven the detector design is to observe the trajectories of the τ and of its decay products in thin layers of emulsion.

The OPERA detector consists of 2 identical "super modules" (SM). Each SM has a target section and a muon spectrometer. The spectrometers measure the charge and the momentum of crossing muons by means of a dipolar magnet providing a 1.6 T magnetic flux density transverse to the neutrino beam axis, equipped with drift tubes for precise measurements and RPC chambers for pattern recognition.

Schematic view of the OPERA



Hybrid Detector:

- Two supermodules - Target Mass 1766 tons
- 2 x [31 Target Walls and Target Trackers]
- 2 Magnetic spectrometers with RPC & Drift tubes
- 206,336 Emulsion Cloud Chamber (ECC) bricks (Pb/Emulsion)

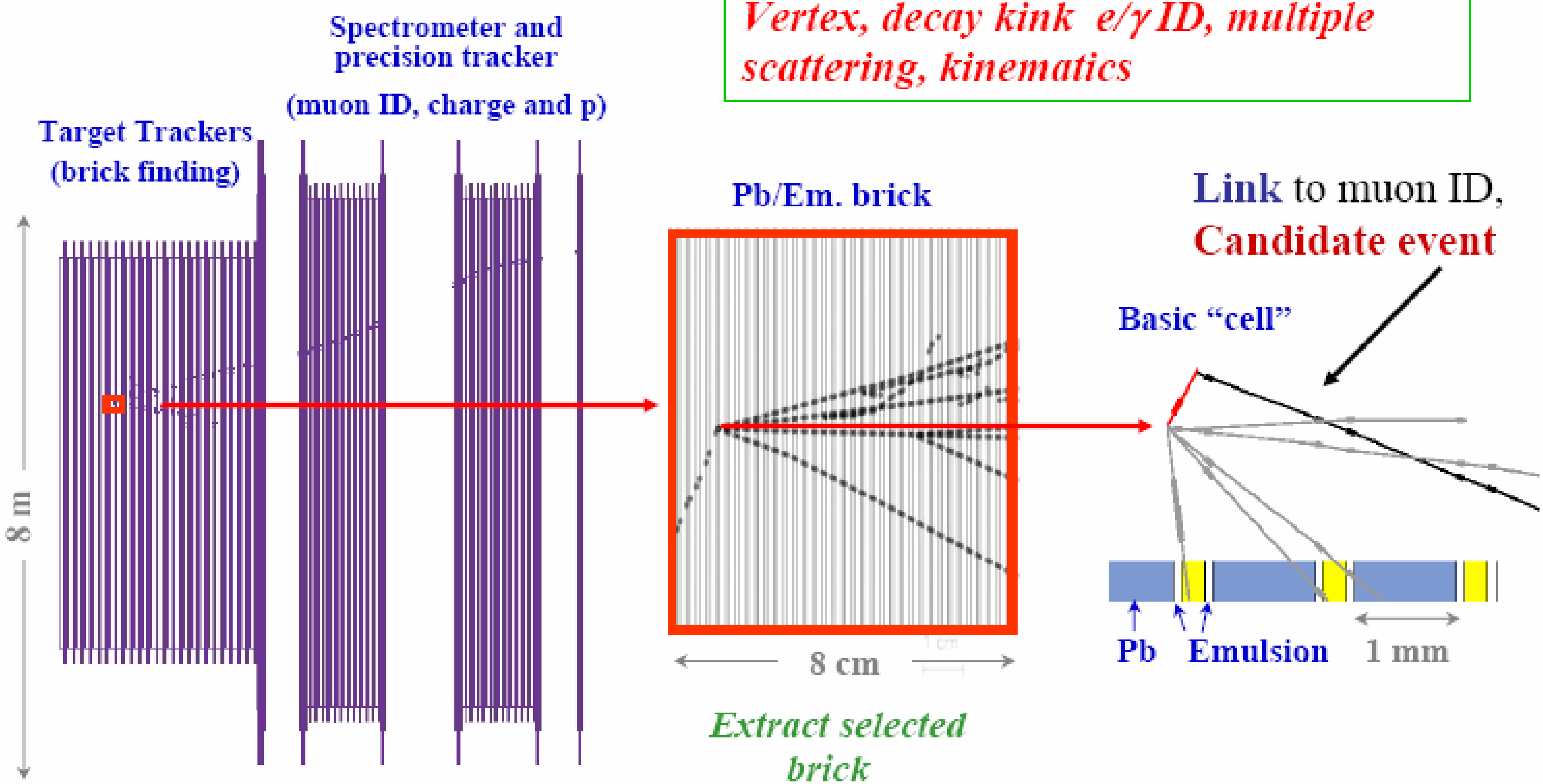
Electronic detector task

- ***trigger*** *and* ***location*** *of neutrino interactions*
- ***muon*** *identification and momentum/charge measurement*

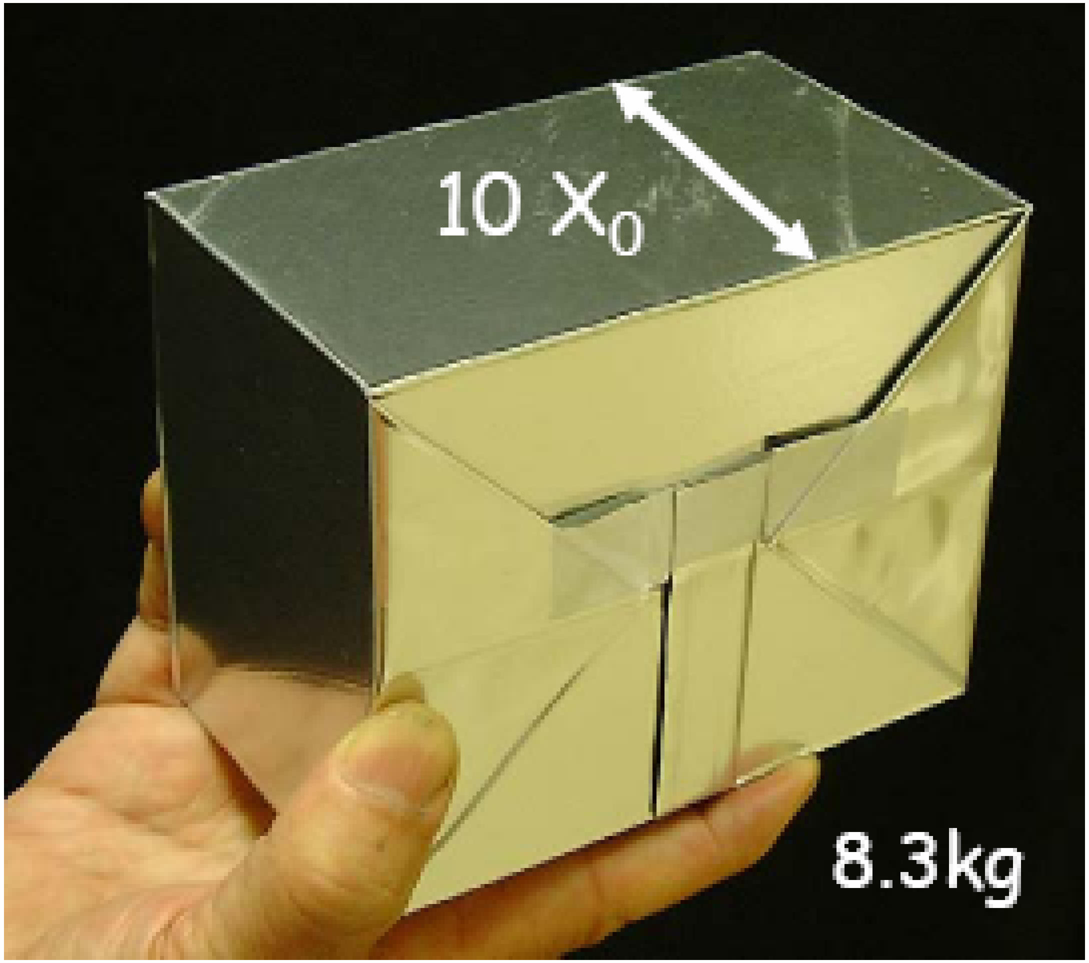
Electronic detectors:

ECC emulsion analysis:

Vertex, decay kink e/γ ID, multiple scattering, kinematics

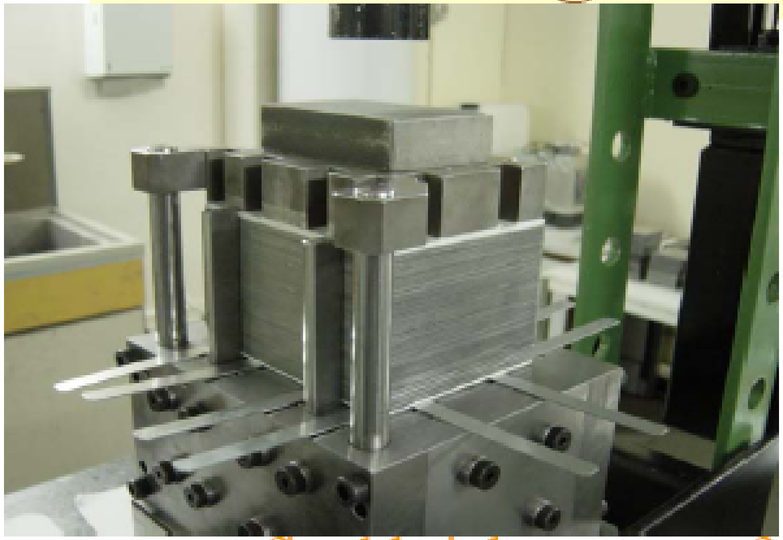


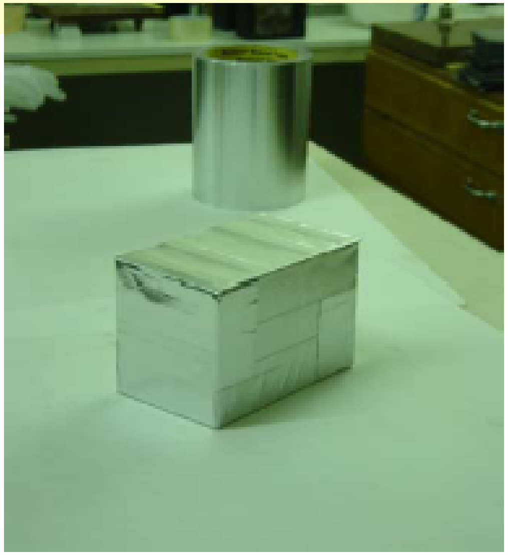
The basic unit : the « brick »



10.2 x 12.7 x 7.5 cm^3

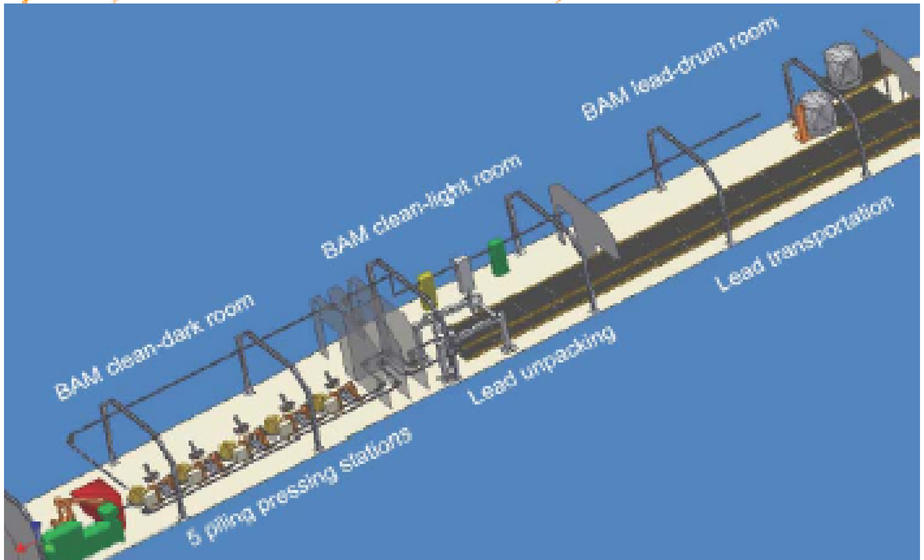
Building the brick: packing process



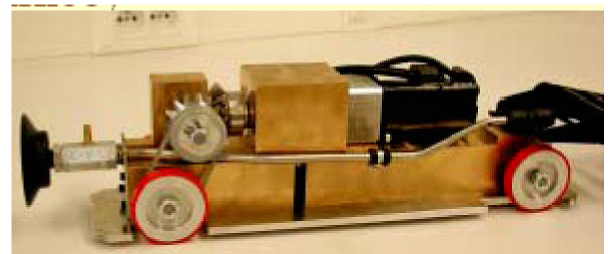


- final bricks successfully used in test beam exposures
- mechanical properties measured to be within specs
- *Brick assembling machine fully commissioned by Dec 05*

BAM Lay-out fully defined



The targets are in total composed of 206336 bricks that will be installed by an automatic manipulator system into 62 walls containing 64 rows of 52 bricks and separated from each other by modules of electronic trackers.



The robotised "Ferrari" for insertion/extraction of bricks with vacuum grip by Venturi valve

"Carousel" brick dispensing and storage system

Before being assembled into bricks, all the films, produced by the Fuji company, will be <u>refreshed</u> to erase preexisting tracks occurred during the production and the storage phases.

The candidate bricks will be daily removed by the manipulator system for subsequent analysis. It takes about 3 hours to change 50 bricks.

The analysis of the emulsion films are performed using automatic scanning.
The present routine scanning speed is around 1 – 5 cm2/hr depending on the scanning conditions and hardware.
A speed of 20 – 40 cm2/hr will be reached with new systems presently under test at Nagoya and in european laboratories.

4 Physics performances ($\nu_\mu \rightarrow \nu_\tau$ search)

The channels investigated by OPERA are the τ decays into electron, μ or a single charged hadron.

They are classified in 2 categories, long and short decays, depending on the location of the tau decay vertex.

In the long decay category the τ does not decay in the lead plate where it is produced and its track can be entirely reconstructed in one film.

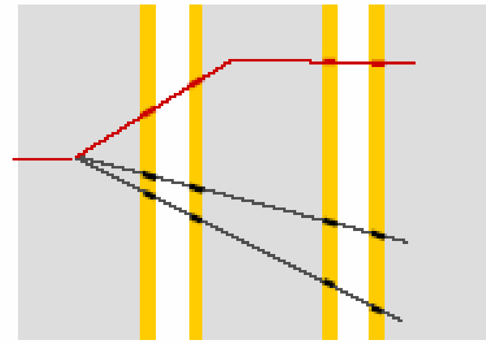
The τ candidate events are selected on the basis of the existence of a kink angle between the τ and the daughter tracks ($\theta_{kink} > 20$ mrad).

In the short decay category the τ decays in the lead plate where it is produced.

These events are selected on the basis of the impact parameter of the τ daughter track with respect to the interaction vertex (IP > 5-20 μm). This category is used only for the electron and muon channels.

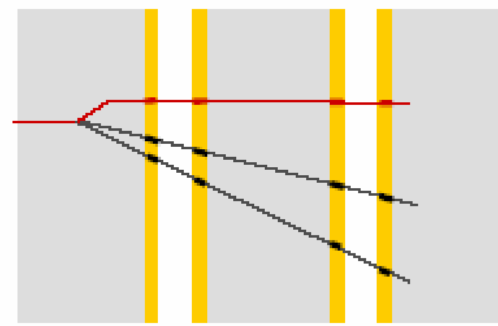
$\nu_\mu \to \nu_\tau$ search
exploited τ decay channels

$\tau \to$ **e** " long decays "
$\tau \to$ μ " long decays "
$\tau \to$ **h** " long decays "
$\varepsilon \cdot BR = 2.8\text{-}3.5\%$



kink angle $\theta_{kink} > 20$ mrad

$\tau \to$ **e** " short decays "
$\tau \to$ μ " short decays "
$\varepsilon \cdot BR = 0.7\text{-}1\%$



impact parameter I.P. > 5 to 20 μm

Recently added: $\tau \to$ **3h long and short decays**

Main backgrounds:

- charm decays
- large angle μ scattering
- hadron reinteractions

Table 2.

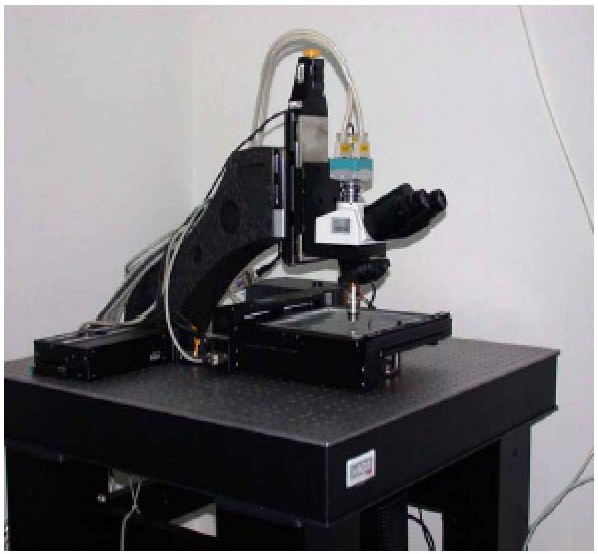
Summary of the expected numbers of τ events in 5 years for different Δm2 compatible with the Super Kamiokande results with the expected background per decay channel. The numbers have been computed using the nominal design flux (numbers in parenthesis) and a flux increased by 50% corresponding to 3.38 × 1020 pot

channel	signal for Δm^2 (10^{-3}eV^2)			Bkg
	1.3	2.0	3.0	
$\tau \to e$	1.8 (1.2)	4.1 (2.7)	9.2 (6.1)	0.31 (0.21)
$\tau \to \mu$	1.4 (0.9)	3.4 (2.3)	7.6 (5.1)	0.33 (0.22)
$\tau \to h$	1.5 (1.0)	3.5 (2.3)	7.8 (5.2)	0.42 (0.28)
Total	4.7 (3.1)	11.0 (7.3)	24.6 (16.4)	1.06 (0.71)

5 Automatic scanning

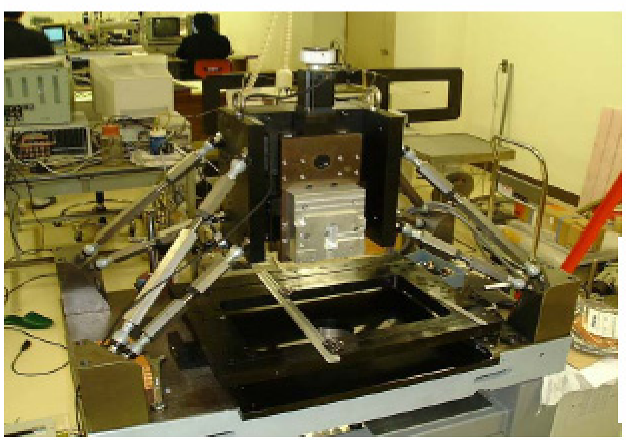
Development of automatic scanning in Japan and in Europe

"Sysal" system in Salerno R&D in Bari, Bern, Bologna, Lyon, Münster, Napoli, Roma, Salerno



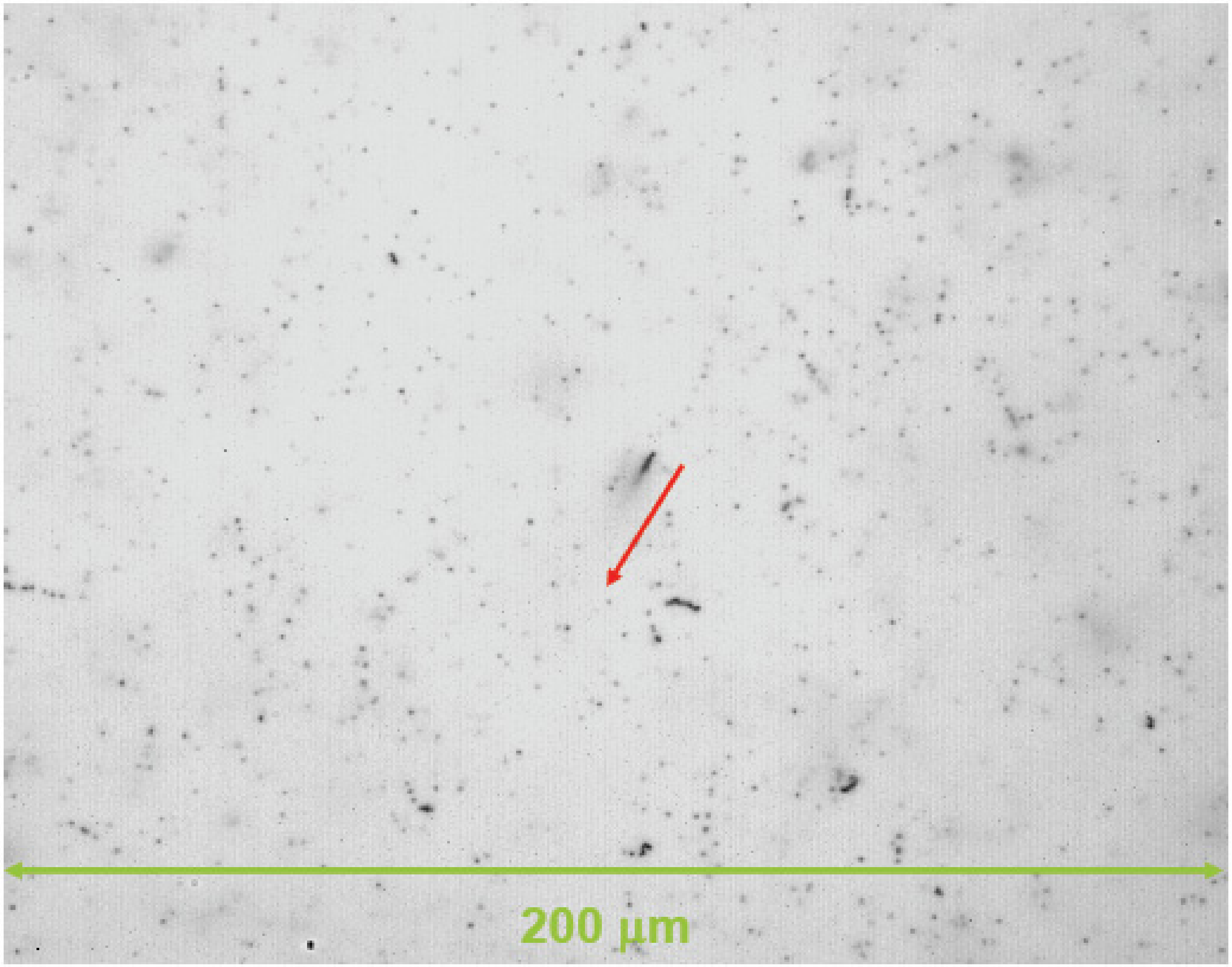
- Real time analysis: several tens of bricks extracted/day
- About 1500 cm^2 to be scanned/day
- High speed (20 cm^2/h) fully automatic scanning systems (one order of magnitude faster than previous generation)
- independent R&D in Europe and Japan based on different approaches
- First prototype developed and tuned in Europe
- Successfully running since Summer 2004 with high efficiency (>90%), high purity (~2 tracks/ cm^2 /angle) and design speed

2 mrad accuracy at small incident angles

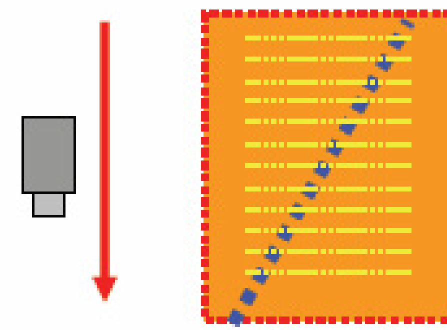


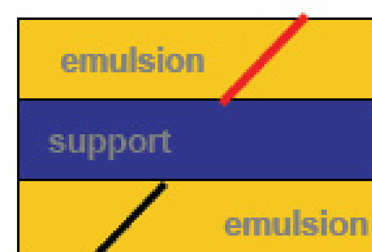
- Fast CCD camera (3 k frames/sec)
- Continuous movement of the X-Y stage

Video sequence of a track in emulsion
(Large angle track)



20 images
different focus plane
1 layer
40 µm emulsion

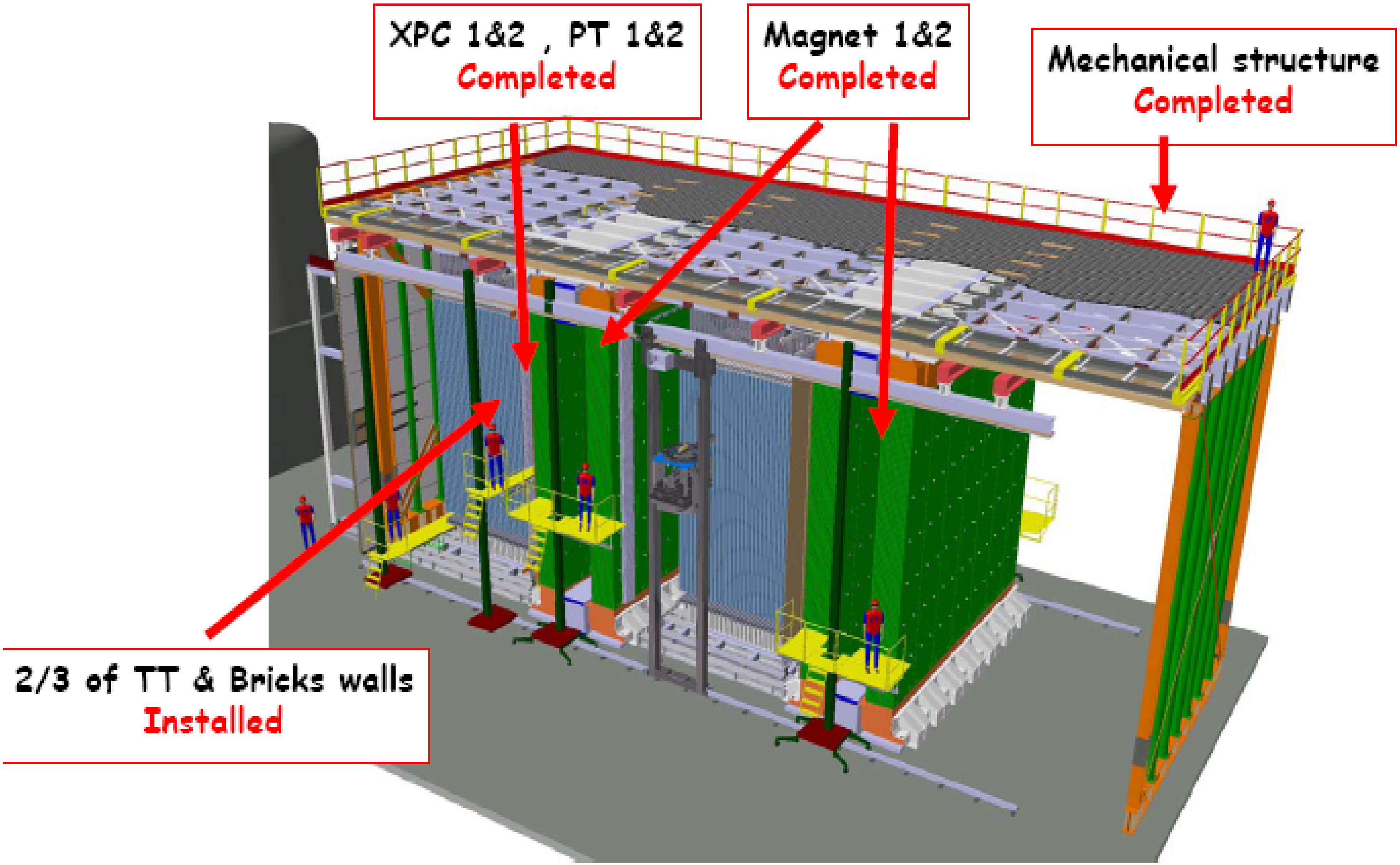




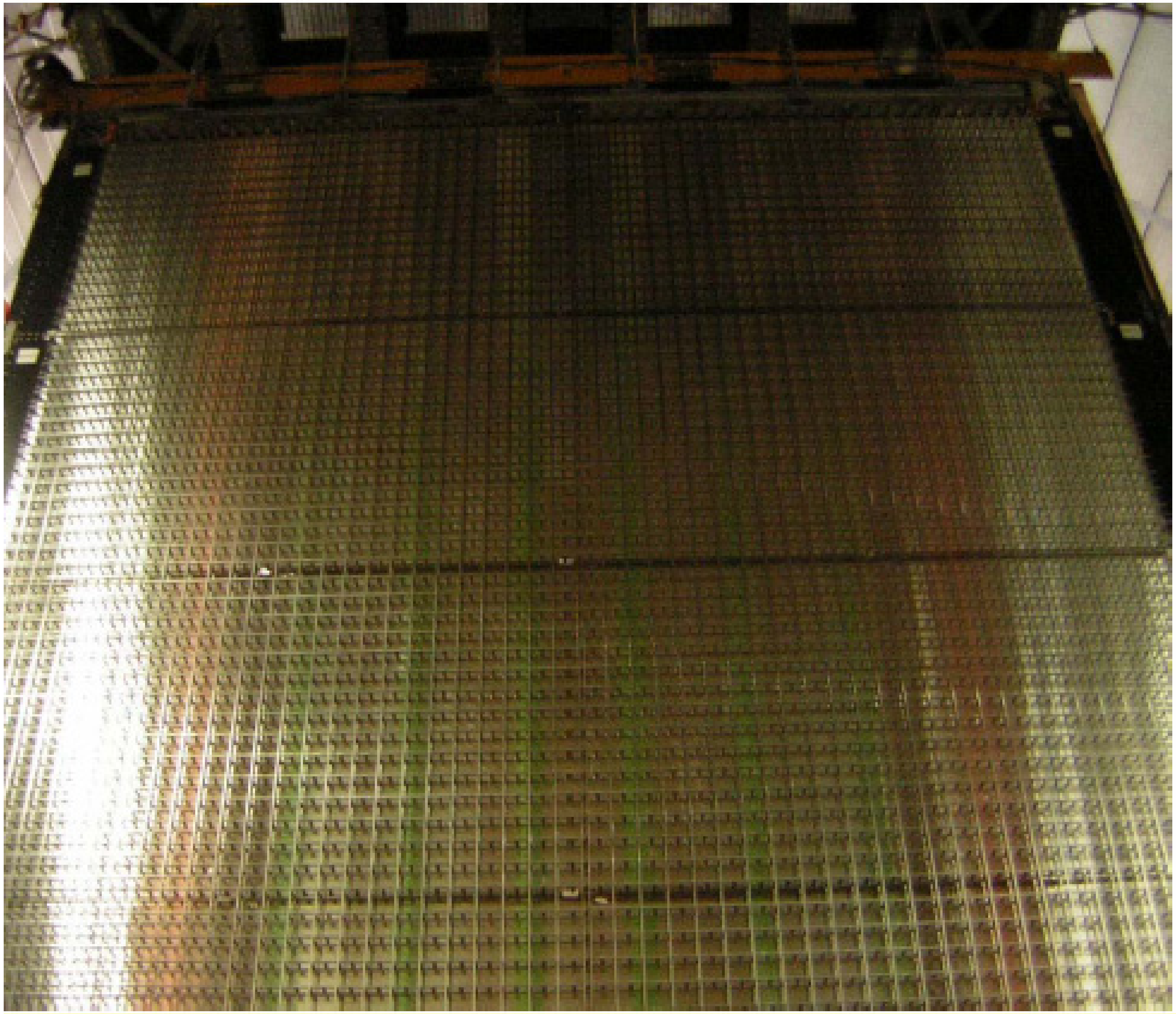
@ OPERA will collect of the order of 25-30 τ appearance events in 5 years with negligible background

@ Δm^2 ~2.5 10-3 eV^2 permitting a determination of Δm^2 with a precision of 10%

Status of the installation



Brick wall installation



first brick wall installed in Hall C: side view

First Wall installed - May 2005
End of installation for SM1 Oct 05

$\nu_\mu \rightarrow \nu_\tau$ *sensitivity*

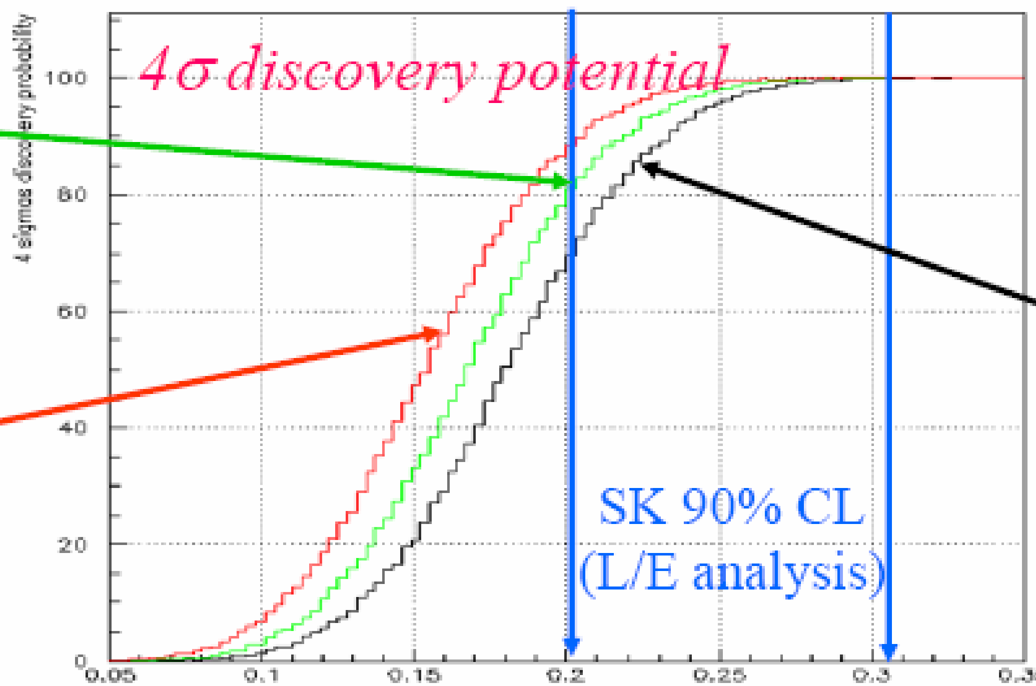
full mixing, 5 years run @ 4.5 x10^{19} pot / year

	signal (Δm^2=1.9x10^{-3}eV^2)	signal (Δm^2=2.4 x10^{-3}eV^2)	signal (Δm^2=3.0x10^{-3}eV^2)	BKGD
OPERA 1.8 kton fiducial	6.6	10.5	16.4	0.7
+ brick finding + 3 prong decay	8.0	12.8	19.9	1.0
Background reduction	8.0	12.8	19.9	0.8

OPERA with background reduction

Discovery potential ranging from 80% to 100%

Opera, half background

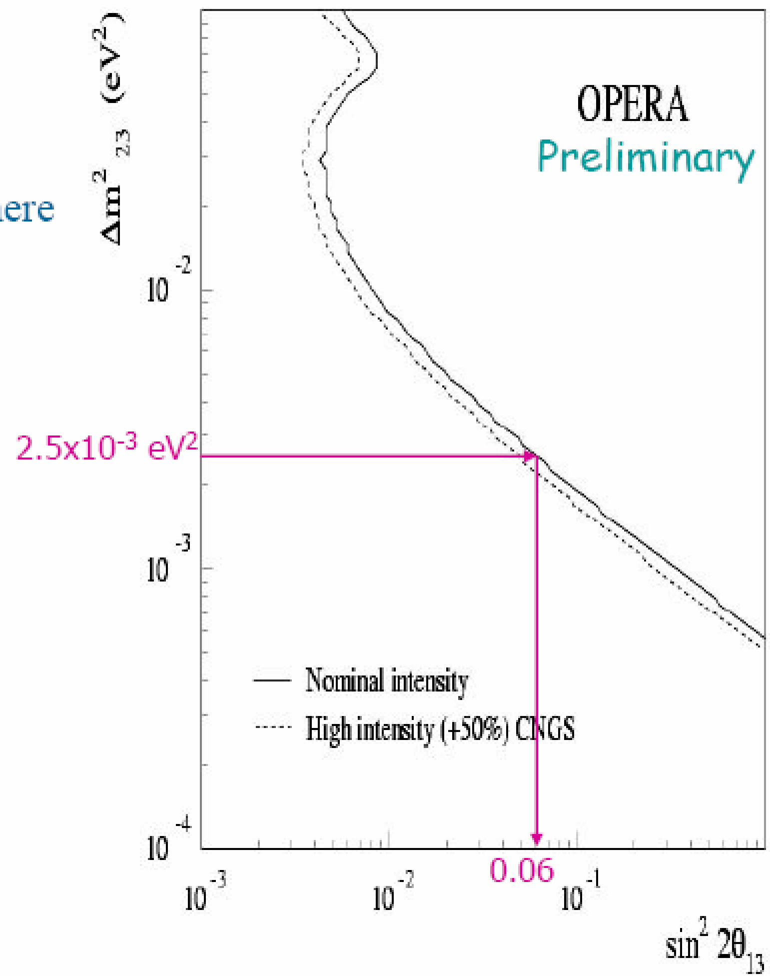


Opera nominal

$\nu_\mu \rightarrow \nu_e$ *study*

Background:

- ν_e beam contamination
- ν_μ NC and ν_μ CC with μ mis-id where π^0's are identified as electrons
- $\tau \rightarrow e$ from $\nu_\mu \rightarrow \nu_\tau$ oscillations



Limits at 90% CL for

$\Delta m^2 = 2.5 \times 10^{-3}$ eV^2 full mixing

	$\sin^2 2\theta_{13}$	θ_{13}
CHOOZ	**<0.14**	**11^0**
OPERA	**<0.06**	**7.1^0**

OPERA

COLLABORATION

Russian participation

6

Belgium
IIHE(ULB-VUB) Brussels

China
IHEP Beijing, Shandong

Croatia
Zagreb

France
LAPP Annecy, IPNL Lyon, LAL Orsay, IRES Strasbourg

Germany
Berlin, Hagen, Hamburg, Münster, Rostock

Israel
Technion Haifa

Italy
Bari, Bologna, LNF Frascati, L'Aquila, Naples, Padova, Rome, Salerno

Japan
Aichi, Toho, Kobe, Nagoya, Utsunomiya

Russia
INR Moscow, ITEP Moscow, JINR Dubna, Obninsk

additional manpower **INR Moscow, SINP MSU Moscow, LPI Moscow**

+3 groups (25 physicists)

Switzerland
Bern, Neuchâtel

Turkey
METU Ankara

34 groups
~ 170 physicists

ABOUT POSSIBLE PARTICIPATION OF RUSSIAN RESEARCHERS IN THE INTERNATIONAL EXPERIMENT "OPERA"

WITHIN THE FRAMEWORK OF THE ITALIAN – RUSSIAN COLLABORATION PROGRAMME.

The INR team intends to participate in following OPERA activity:

- due to the long and considerable experience in the field of the experimental and computing methods of the cosmic rays physics the INR can give a contribution to the definition and optimization of conditions of the brick exposition in cosmic rays flux by means of simulations;
- with physicists and technicians a providing for the data taking during the brick exposition. The INR can also take upon oneself the responsibility for an assurance of the experiment with required manpower;
- in a phase of putting in operation of the prototype, which has been installed in LNGS already, with technical personnel;
- in a phase of run the INR contributes with personnel (physicists and technicians) to provide the routine procedures.

The Skobeltsyn Institute of Nuclear Physics (SINP MSU) and the Lebedev Physical Institute (LPI) can contribute in emulsion development and film scanning:

▪ Search and analysis of neutrino interactions will be carried out with Completely Automated Measuring System (PAVICOM), constructed in Physical Lebedev Institute. It enables to process huge amount of experimental data and to rise essentially the event statistics. At PAVICOM there is made in complete automation regime:
- search and digitizing of charged particles tracks within detector body;
- identification and tracing of the tracks with a computer;
- systematization and data primary processing.

▪ Methodical measurements of distortion in emulsion layers for the search and precision measurements of event kinematics. Our methodical program sets as a purpose to investigate the possibility of usage of alpha-particles from a radioactive source for measurements of distortion in emulsion layers. The value of optical corrections for coordinates and angles as depending on physical properties of diluted emulsion will be obtained.

▪ Participation in experimental work on mounting and dismounting of the chamber, participation in emulsion procession.

▪ Staff qualification:
1) the experience of emulsion scanning in semi automation regime (experiments MUBEE, RUNJOB, EMU-5);
2) the experience of automated emulsion scanning (PAVICOM);
3) the experience of software maintenance for track searching, identification and tracing of tracks.

Assumed structure of experimental group:

INR		
1	N. Agafonova	junior researcher
2	V. Boyarkin	post-graduate
3	E. Dobrynina	junior researcher
4	R. Enikeev	researcher
5	A. Malgin	senior researcher
6	V. Ryasny	senior researcher
7	O. Ryazhskaya	leading researcher
8	V. Yakushev	researcher
9	V. Fomin	engineer
10	V.A. Kuznetsov	leading engineer
11	V.V. Kuznetsov	engineer
12	V. Korchagin	leading engineer
13	V. Los	engineer
14	O. Ochkas	engineer
15	L. Shapovalov	engineer
16	V. Talochkin	leading engineer
17	A. Yarosh	engineer
18	L. Chernishov	technician

SINP MSU		
1	A. Anochina	researcher
2	V. Galkin	senior researcher
3	D. Oshuev	researcher
4	P. Publichenko	leading programmer
5	V. Petruchin	programmer
6	T. Roganova	leading researcher
7	G. Sazhina	engineer

LPI		
1	V. Tsarev	leading researcher
2	N. Starkov	senior researcher
3	A. Aleksandrov	researcher
4	N. Poluhina	senior researcher
5	G. Orlova	researcher
6	I. Apacheva	junior researcher
7	L. Goncharova	junior researcher

The visits of the russian personnel in LNGS can be paid partially by russian side according to the Programme of the Italian – Russian collaboration. The Coordinator of the Programme is prof. Matveev. The responsible persons are

INR	- prof. Ryazhskaya O.
SINP MSU	- prof. Roganova T.
LPI	- prof. Lebedev A.

Programme coordinator	A. Matveev
Director of INR	A. Matveev
Director of SINP MSU	M. Panasjuk
Director of LPI	A. Lebedev

The INR team :

©can give a contribution to the definition and optimization of conditions of the brick exposition in cosmic rays flux by means of simulations;

©the data taking during the brick exposition;

©the responsibility for an assurance of the experiment with required manpower;

The Skobeltsyn Institute of Nuclear Physics (SINP MSU) and the Lebedev Physical Institute (LPI) :

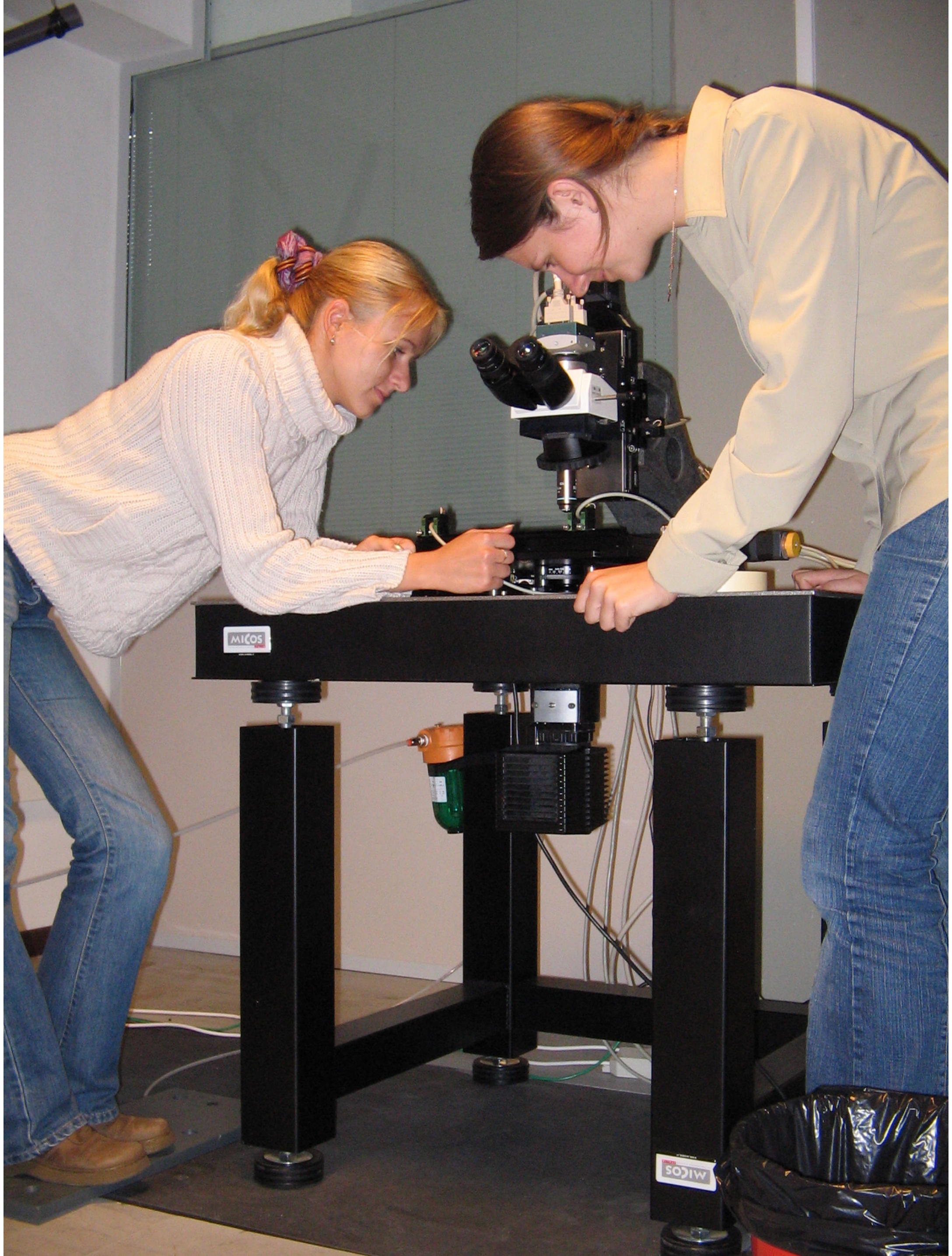
©can contribute in emulsion development;

film scanning;

©data primary processing;

©participation in experimental work on mounting and dismounting of the chamber;

©participation in emulsion procession.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NOTES

7 Conclusions

The $\nu\tau$ appearance is still an important missing piece of the neutrino oscillation puzzle .

The OPERA detector is designed to study this subject and its performances has been estimated with the foreseen CNGS flux.

Grazie tante per vostro attenzione.