Experimental program on the CERN-Gran Sasso neutrino beam-line

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CERN

New Hera in Neutrino Physics
Tokyo Metropolitan University
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Some remarks:

- Mandatory to investigate existing indications:
  Solar, LSND and Atmospheric (K/SK).

- NGS beam from CERN to Gran Sasso:
  detect the source of the atmospheric ~~anomaly;~~ evidence for ν_μ oscillation!
  international facility: CERN experience with neutrino beams + GS unique site and infrastructures.

- Future scenario: 1999 K2K beam (KEK to SK). Low energy, only ν_μ- ν_x (SK confirmation ?).
  200~~3~~2 NUMI beam: high energy, conventional detector.
  2003 NGS beam: high energy, broad range of proposed experimental techniques. Unique opportunity for ν_μ- ν_τ appearance.

⇩

NGS-Gran Sasso: high discovery potential

CERN - European Laboratory for Particle Physics
INFN - Istituto Nazionale di Fisica Nucleare

CERN 98-??
INFN/AE-98/05

The CERN Neutrino beam to Gran Sasso (NGS)

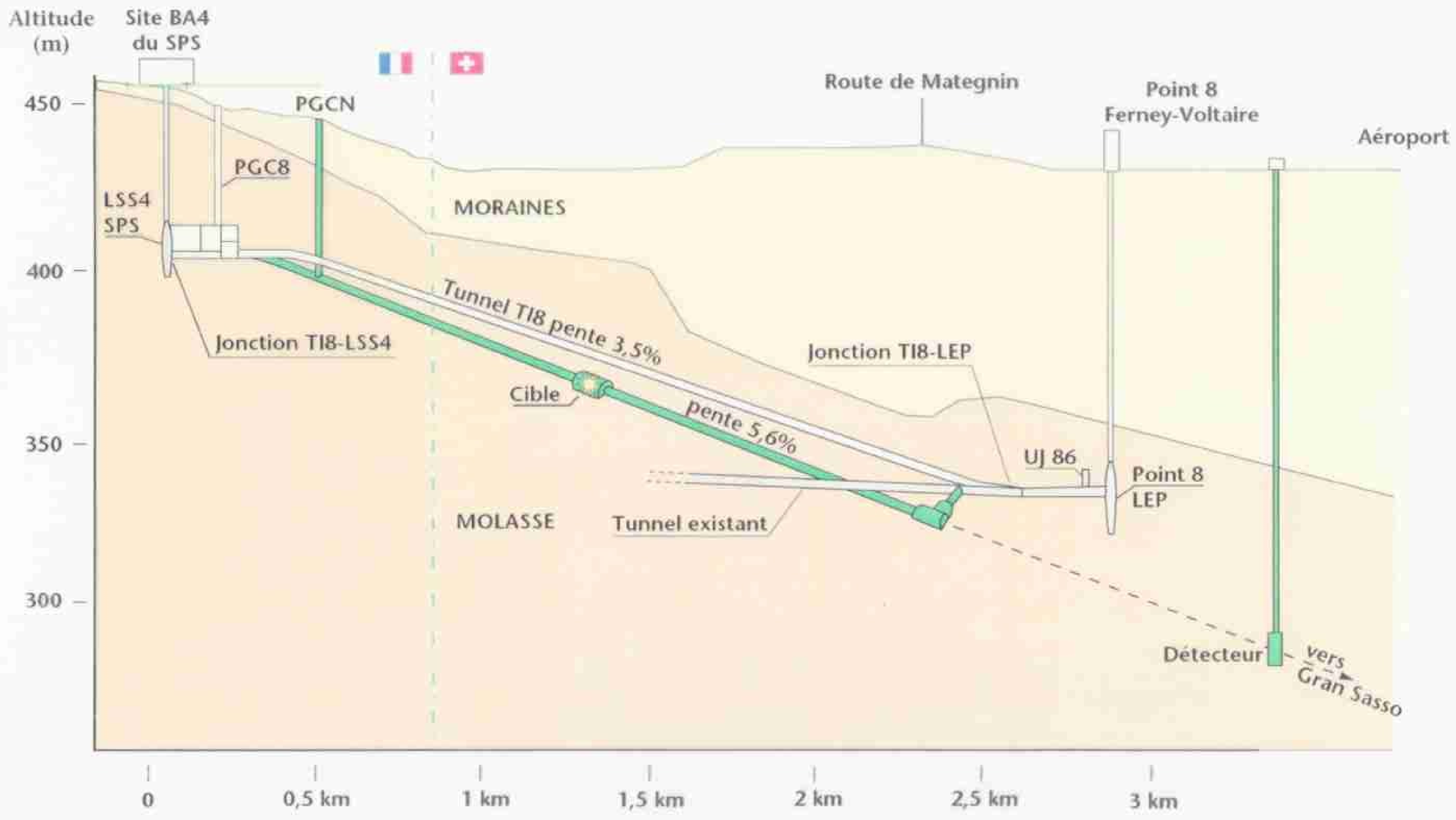
Conceptual Technical Design

DRAFT

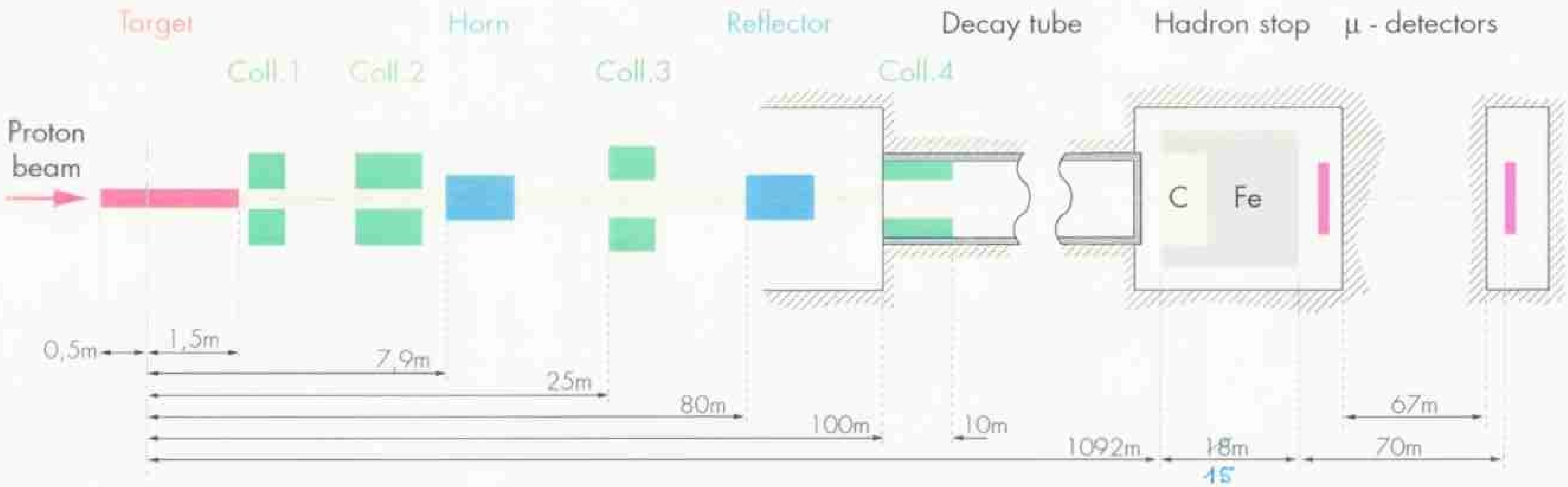
G. Acquistapace, J. L. Baldy, A. E. Ball, P. Bonnal, M. Buhler-Broglin, F. Carminati, E. Cennini, K. Elsener, A. Ereditato, V. Falaleev, P. Faugeras, A. Ferrari, L. Foa, G. Fortuna, A. L. Grant, L. Henny, A. Hilaire, K. Hübner, R. Genand, J. Inigo-Golfin, K. H. Kissler, L.A. Lopez-Hernandez, J.M. Maugain, M. Mayoud, P. Migliozzi, V. Palladino, I. M. Papadopoulos, S. Péraire, F. Pietropaolo, S. Rangod, J.P. Revol, J. Roche, P. Sala, C. Sanelli, G. R. Stevenson, B. Tomat, E. Tsesmelis, R. Valbuena, H. Vincke, E. Weisse, M. Wilhelmsson

Abstract

The conceptual design of a new neutrino facility at CERN is presented. Starting with 400 GeV/c protons from the Super Proton Synchrotron (SPS), a neutrino beam is produced which is directed towards the Gran Sasso Laboratory in Italy, 732 km away from CERN, where large, complex detectors will allow long-baseline experiments searching for neutrino oscillation phenomena to be performed. At approximately 2 km from the new CERN neutrino production target an underground experimental area is envisaged for a short-baseline experiment.

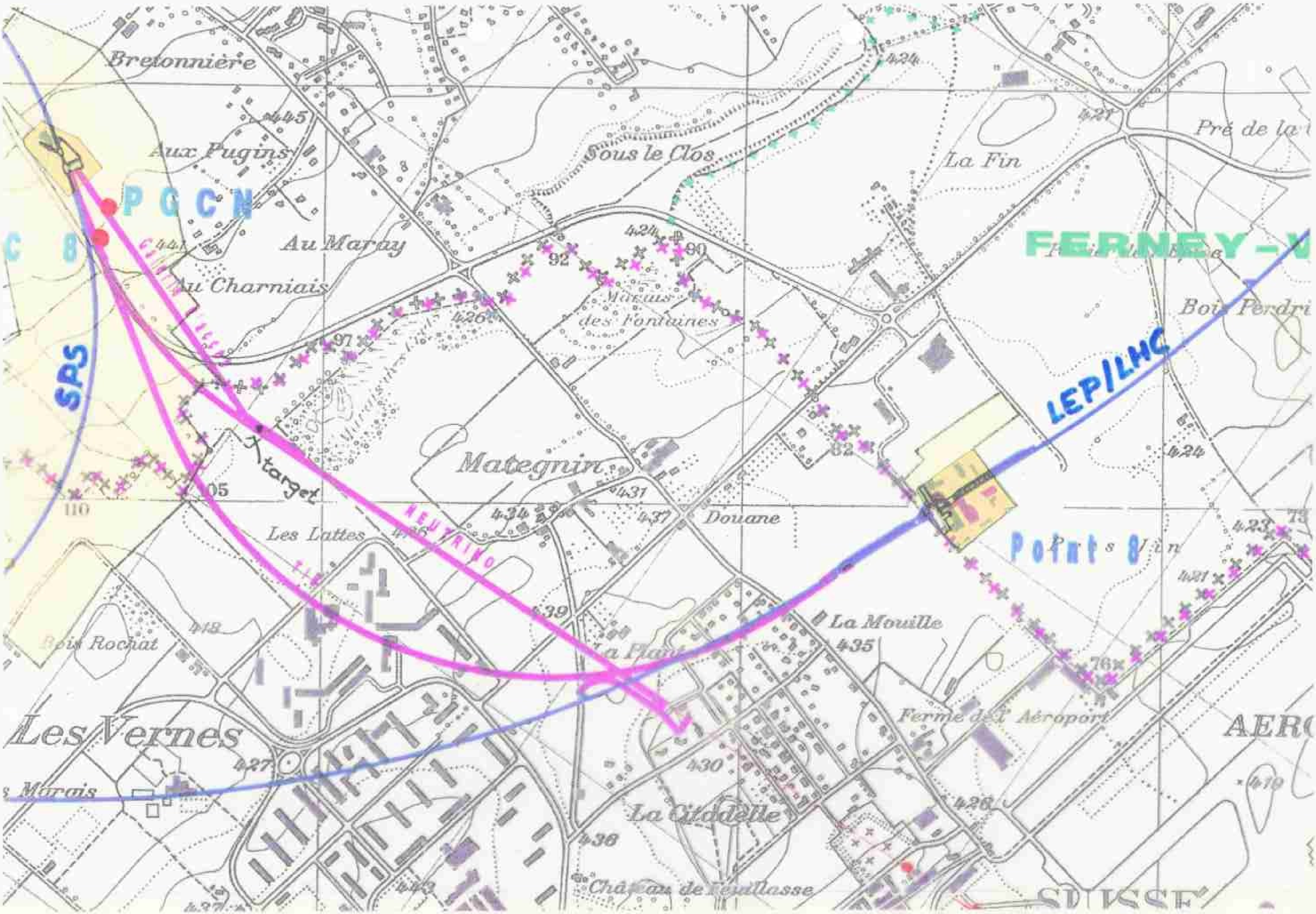

Altitude (m)
Site BA4 du SPS
450
400
350
300
PGCN
PGC8
LSS4 SPS
MORAINES
Route de Mategnin
Point 8 Ferney-Voltaire
Aéroport
Tunnel TI8 pente 3,5%
Jonction TI8-LSS4
Cible
pente 5,6%
Jonction TI8-LEP
UJ 86
Point 8 LEP
MOLASSE
Tunnel existant
Détecteur
vers Gran Sasso
0
0,5 km
1 km
1,5 km
2 km
2,5 km
3 km

Schematic layout of secondary Beam Line



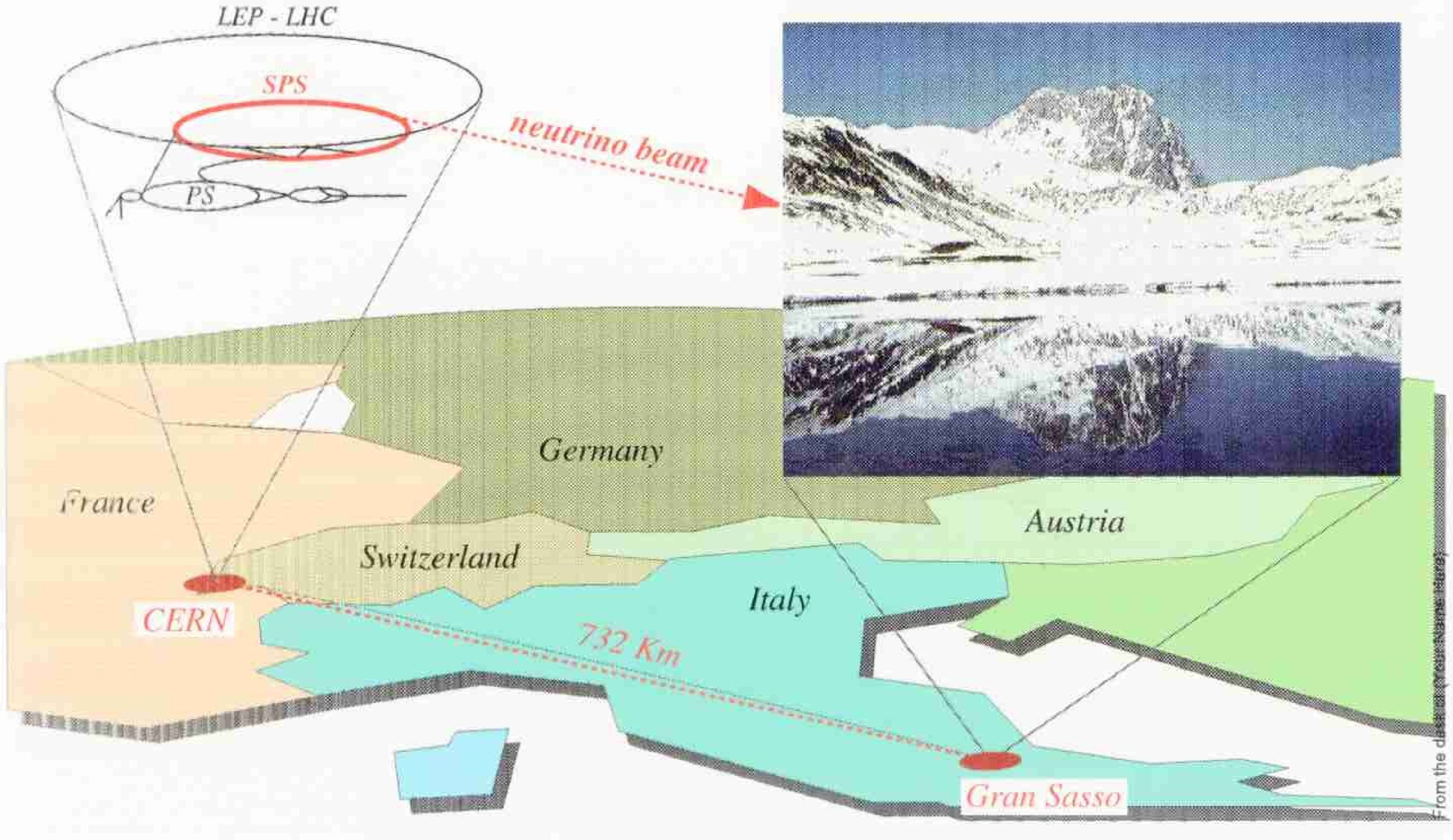
Target:
- Carbon
- 11 rods
- rod length 10cm
- rod diameter 3mm
- rod spacing 9cm

Decay tube:
- inner diameter 2,45m
- vacuum 1 Torr



Bretonnière
Aux Pugins
P G C N
C 8
Au Maray
Au Charniais
SPS
Sous le Clos
La Fin
Pré de la
FERNEY-V
Marais des Fontaines
Bois Perdri
LEP/LHC
target
Mategnin
Douane
Les Lattes
NEUTRINO
Point 8
La Mouille
Bois Rochat
Les Vernes
Ferme de l'Aéroport
AER
La Citadelle
Château de Feuillasse
SUISSE

CERN to Gran Sasso Neutrino Beam



Characteristics the NGS project

- Beam layout determined by geography of CERN and Gran Sasso;
- Designed as a facility (driven by physics requirements):
  - presently optimized for high ν energy to search for ν_τ appearance;
  - other configurations not excluded (low energy beam for disappearance);
  - near position (SLB/monitor) foreseen but decoupled from NGS project.
- Exploits experience of the CERN-WANF:
  - reliability; conservative design whenever possible.
- Exploits existing CERN facilities:
  - SPS complex: high intensity, high energy proton beam;
  - civil engineering works for the LHC transfer lines.
- No interference with LEP/LHC and fixed target program.

NGS reference beam: neutrino fluxes and event rates

- Assuming $E_p = 400$ GeV and $2.9\ 10^{19}$ pot/year (200 days, 50% efficiency):

	LBL detector (732 km)		SBL detector (1.8 Km)
ν_μ flux [m^{-2}/pot]	$4.39\ 10^{-9}$		$1.09\ 10^{-3}$
<E ν_μ> [GeV]	26.7		24.1
ν_μ CC evts/pot/ton	$4.73\ 10^{-20}$		$1.06\ 10^{-14}$
ν_μ CC evts/year/ton	1.40	$<\sigma_\tau/\sigma_\mu> \sim 0.50$	$3.13\ 10^{+5}$
ν_e/ν_μ	0.8 %		0.9 %
$\bar{\nu}_\mu/\nu_\mu$	2.2 %		2.0 %
$\bar{\nu}_e/\nu_\mu$	0.08 %		0.07 %

- Full simulation of the neutrino beam performed by four independent methods (FLUKA 97 and 97.5 stand-alone, GEANT 321, accelerated tracking):
  - common input: hadrons production in the target from FLUKA 97.5;
  - detailed description of the material in the decay line (50 % flux reduction).
- Agreement within few percent.
- Optimization underway: constant p_t focussing, larger acceptance, less material
  - improvement of 20 -30 % at reach! (MAXIMIZE ν_τ evts!)

Possible experiments on the NGS

- Short Baseline
  - TOSCA
- Long Baseline
  - AquaRich
  - NICE
  - NOE
  - ICARUS
  - OPERA

TOSCA aim

Oscillation search in $\nu_\mu - \nu_\tau$ channel

- push sensitivity to the limit
- emphasise small mixing
- improve towards lower Δm^2
- unique signature for τ

Combination of CHORUS and NOMAD techniques

- topological signature
- kinematical event analysis

Improve flux x mass x efficiency

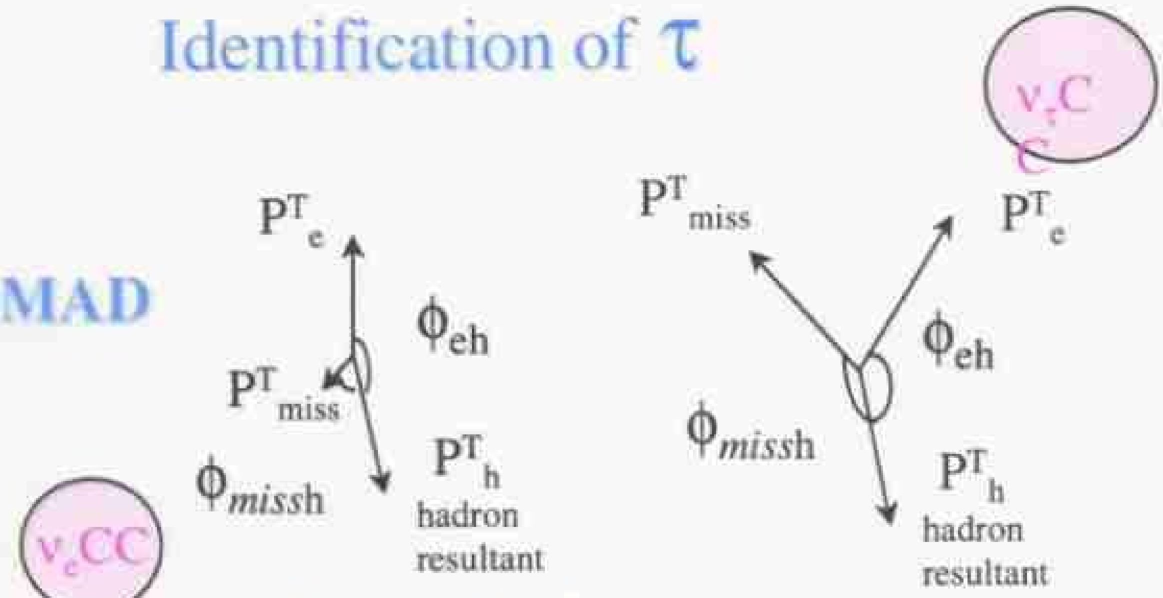
- advanced beam studies
- segmented target
- inside magnetic field

Credible design, i.e. proven technology

Present experiments

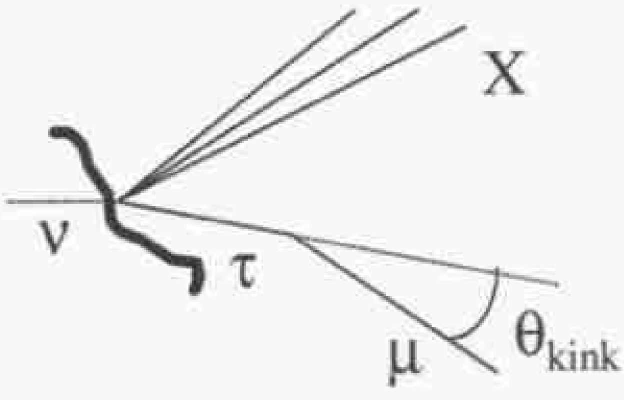
Identification of τ

NOMAD



kinematical signature

CHORUS

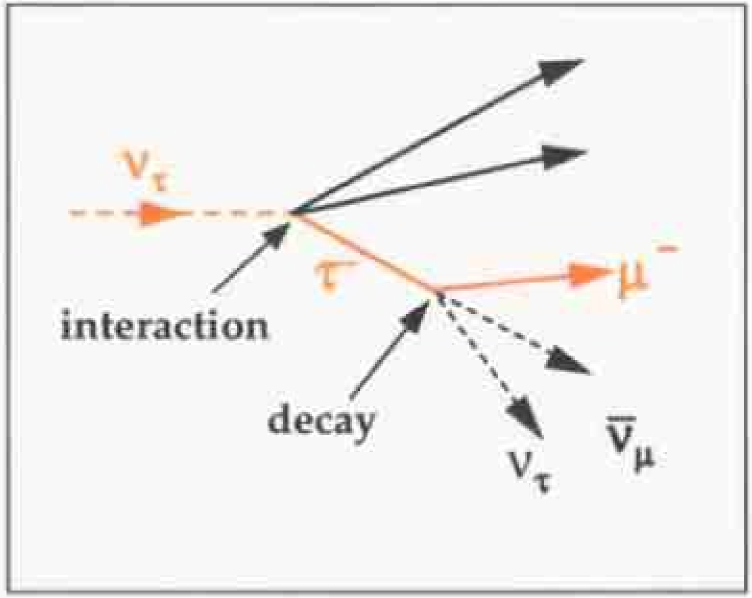


topological signature

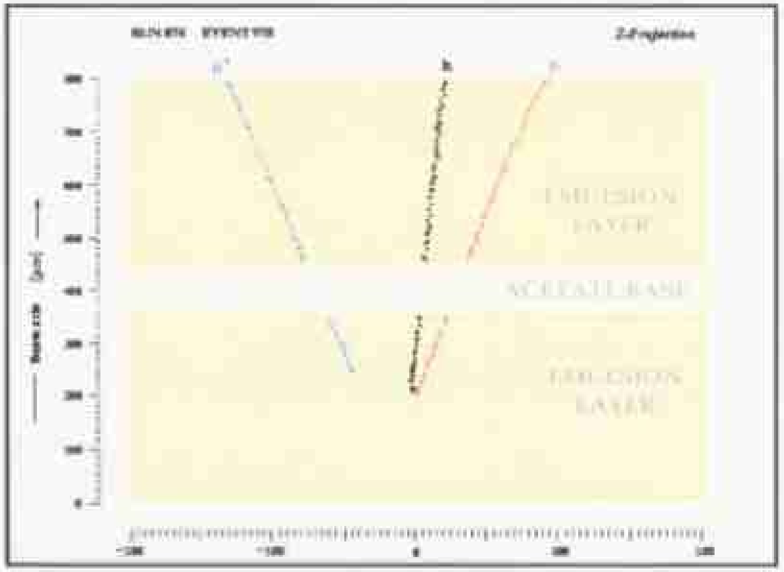
Decay "signature" in CHORUS

(emulsion target)

Expected muonic τ decay



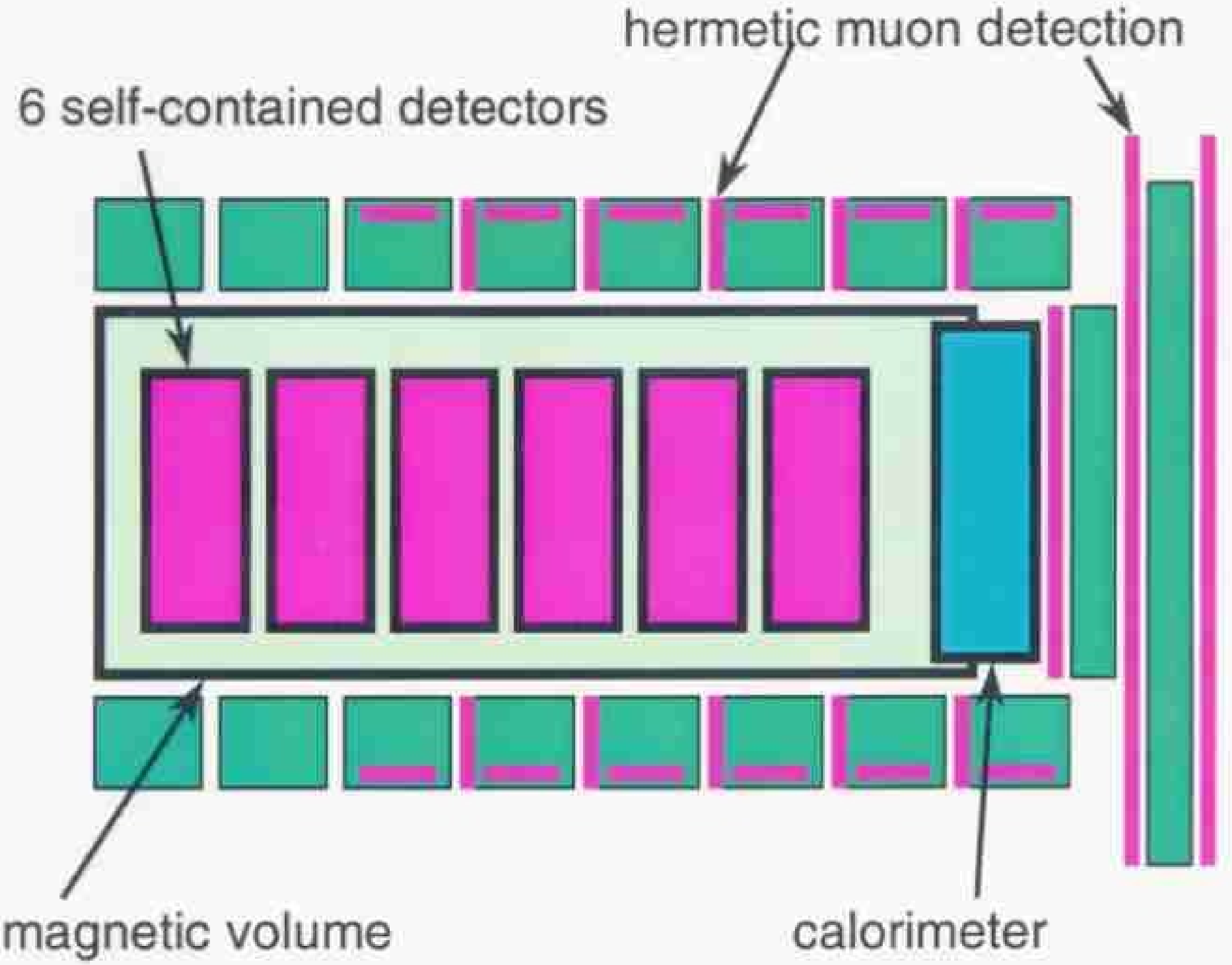
Observed charm decay



(units in μm)

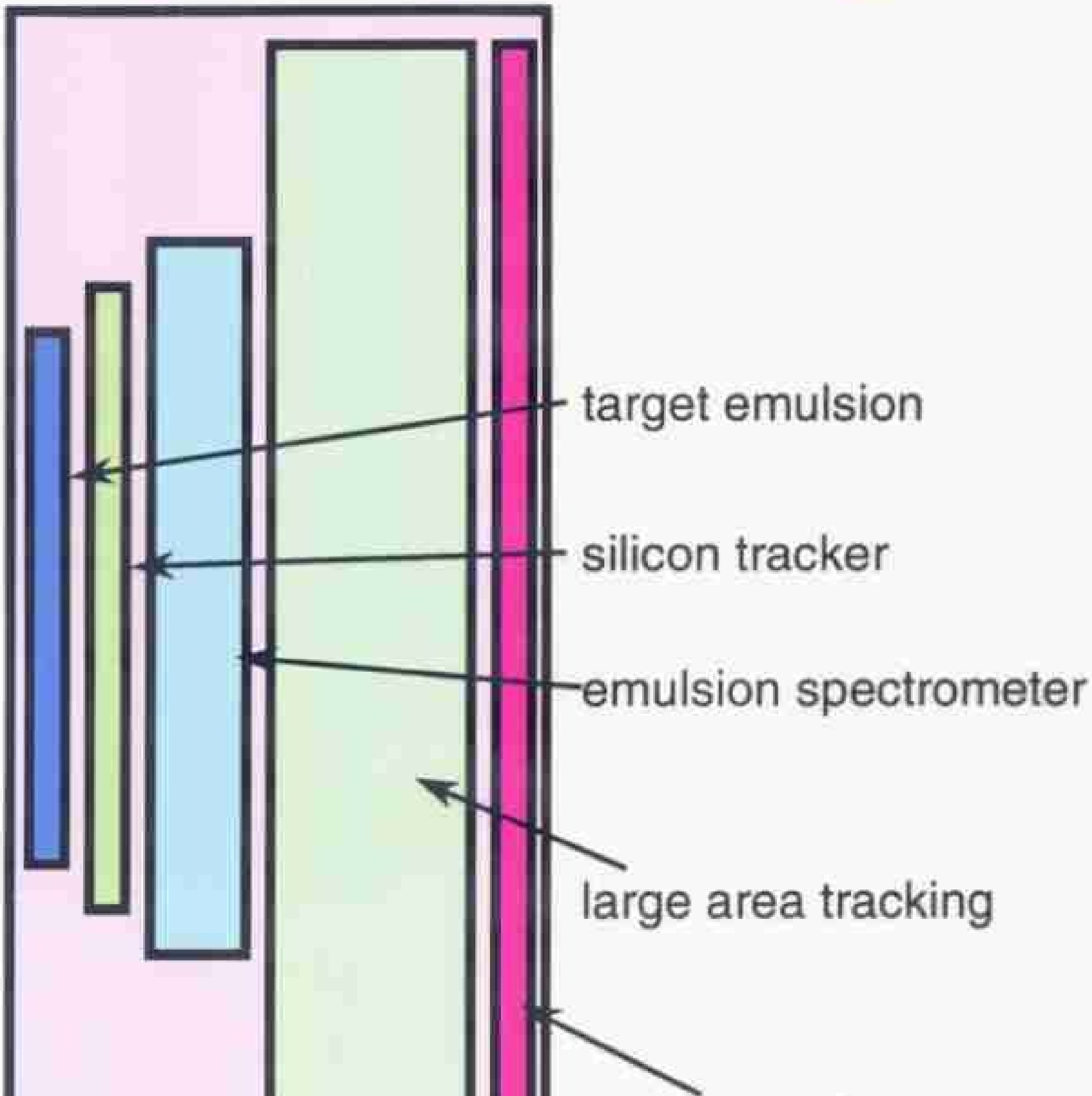
TOSCA detector

Segmented target, tracking and calorimetry
Common muon detection



TOSCA module

target, tracking and e.m. energy



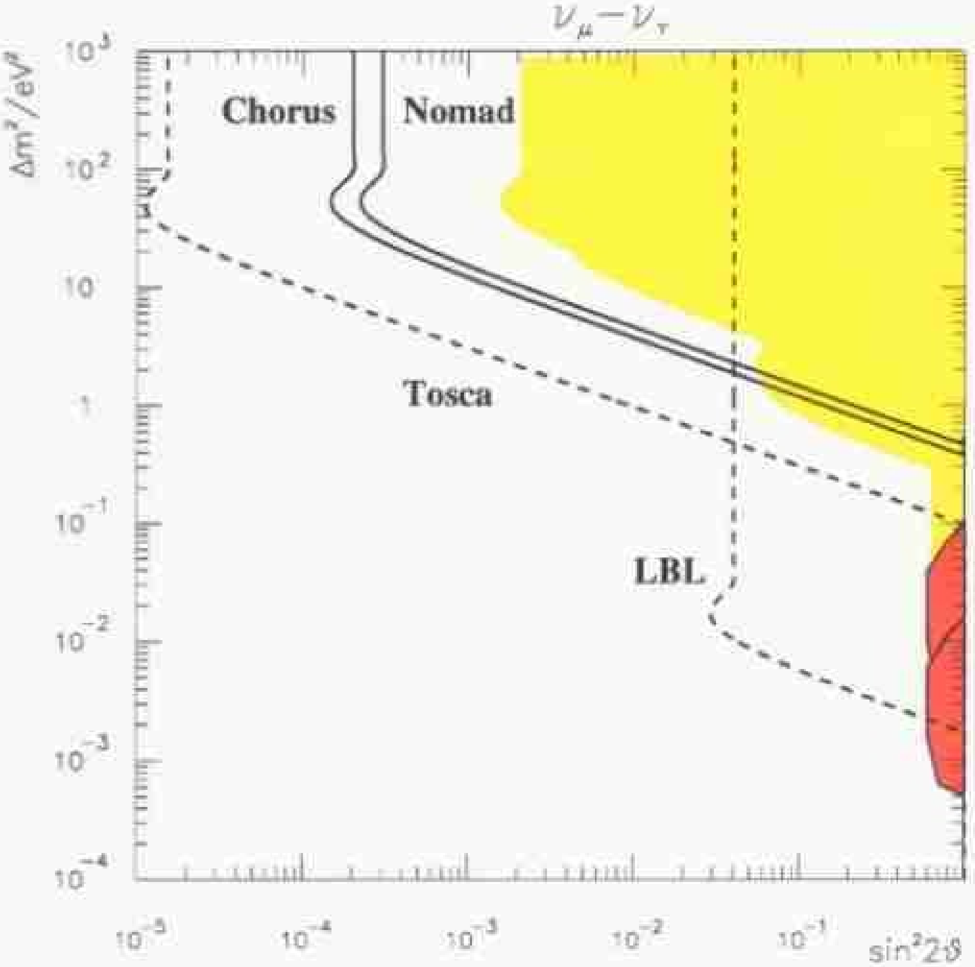
Sensitivity and Background

background in terms of 10^{-7} of CC events
sensitivity: efficiency x Br x cross-section ratio

decay		Charm			
channel	ε	μ	e	prompt	W.K
muon	0.037	1.7	0.3	0.7	
electron	0.009	0.4	0.07	0.17	
hadron	0.068	2.4	0.4	1.1	9.2
kin. reduction:		30x			23x
efficiency for kin. cuts 55%					
Sum	0.070	0.2	-	0.7	0.4

limit at $\sin^2 2\theta < 1.5 \times 10^{-5}$ (1 event background)
at full mixing $\Delta m^2 < 0.1$ eV^2

Projected for mu-tau channel



- **AquaRich:** 125 kton water RICH detector (outside the cavern).
  ν_μ disappearance with low energy beam (<10 GeV).
  Kinematical selection for ν_μ-ν_τ with high energy beam (~20 GeV) under study.

- **NICE:** 10 kton isotropic iron/scintillator calorimeter.
  ν_μ disappearance with low energy beam (<5 GeV) and $2 \cdot 10^{20}$ pot.

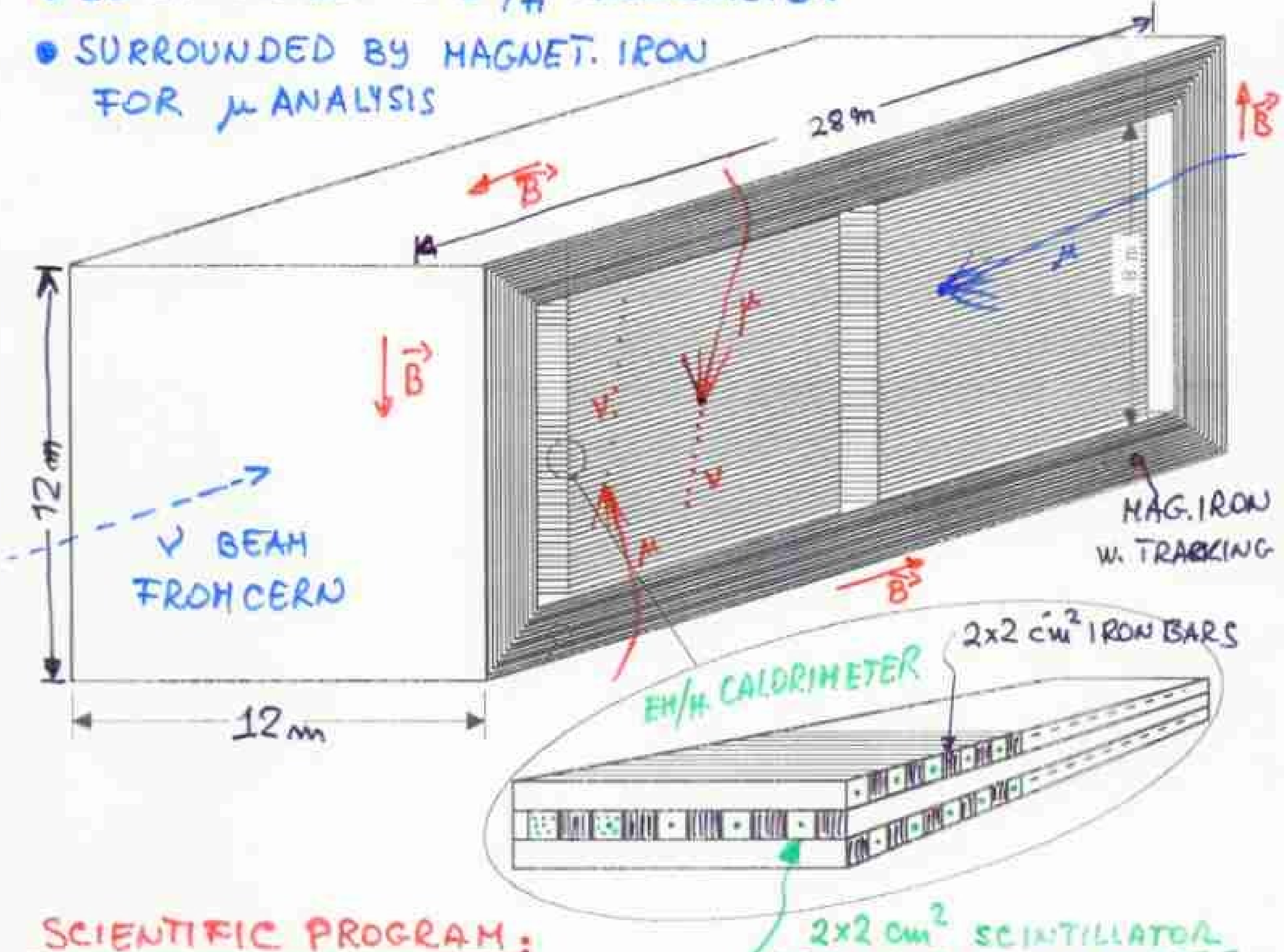
- **NOE:** 7 kton iron/scintillator calorimeter + TRD.
  ν_μ disappearance (near detector needed) and ν_μ-ν_τ appearance (electron channel).
  10-15 GeV beam and $1.5 \cdot 10^{20}$ pot.

- **ICARUS:** Liquid Ar TPC; approved experiment: start with 0.6 kton detector.
  ν_μ-ν_τ and ν_μ-ν_e appearance with kinematical selection.
  High energy beam (>20 GeV). $2 \cdot 10^{20}$ pot for a 1.8 kton detector.

- **OPERA:** < 1 kton emulsion/lead target.
  Direct τ-decay detection for ν_μ-ν_τ appearance.
  High energy beam (>20 GeV) and $2.5 \cdot 10^{20}$ pot.

NICE: EXPERIMENT FOR BOTH { NGS ν BEAM / ATMOSPHERIC ν

- 10 KT ISOTROPIC EM/H CALORIMETER
- SURROUNDED BY MAGNET. IRON FOR μ ANALYSIS



SCIENTIFIC PROGRAM:

- ATMOSPH. ν: GOOD RESOL. FOR MEASUR. ON EV. BY EV. BASIS E_ν AND L SO:

  L/E DISTR. OF $\phi(\nu_\mu)$ WITH $\sin(\frac{L}{E}\Delta m^2)$ PATTERN →

- H.E. BEAM:
  - DISAPPEARENCE TEST WITH NC/CC DOWN TO FEW × 10^{-3} IN Δm^2
  - STATISTICAL APPEARENCE? INCREASE OF NC TO BE STUDIED

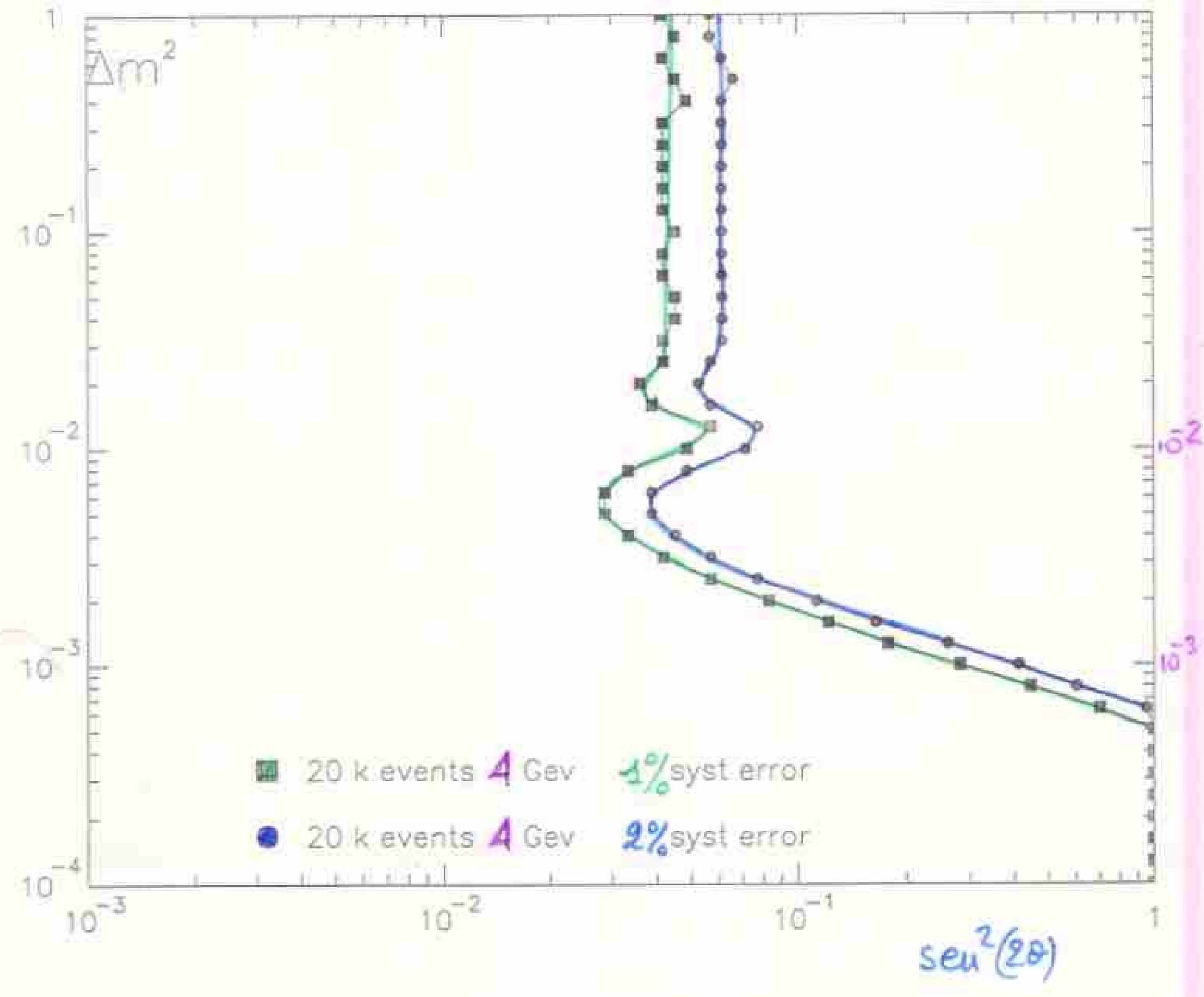
- L.E. BEAM:
  - DISAPPEARENCE TEST WITH NC/CC BELOW 10^{-3} IN Δm^2 (NEAR DETEC. NEEDED)

CROSS CECKS BETWEEN VARIOUS RESULTS FOR OTHER THEORETICAL SCHEMES OF OSCILLATIONS

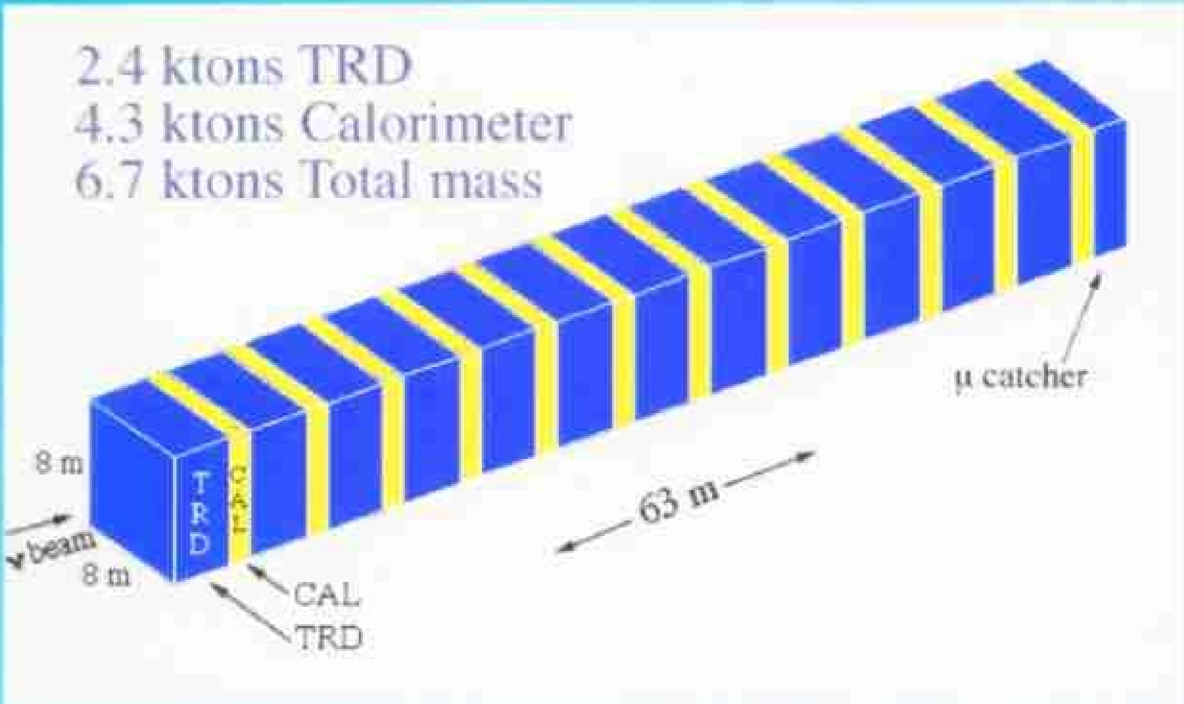
LOW ENERGY BEAM

INT.: 100 ev/KT/ 10^{19} POT

EXP.: 40 KT×y



The LBL NOE detector at Gran Sasso



Basic Module (BM):

TRD+CAL subdetectors:
e, μ, π, E_μ, E_e, E_π

12 BM: 7kton NOE detector

ν_μ- ν_τ appearance search (NOE)

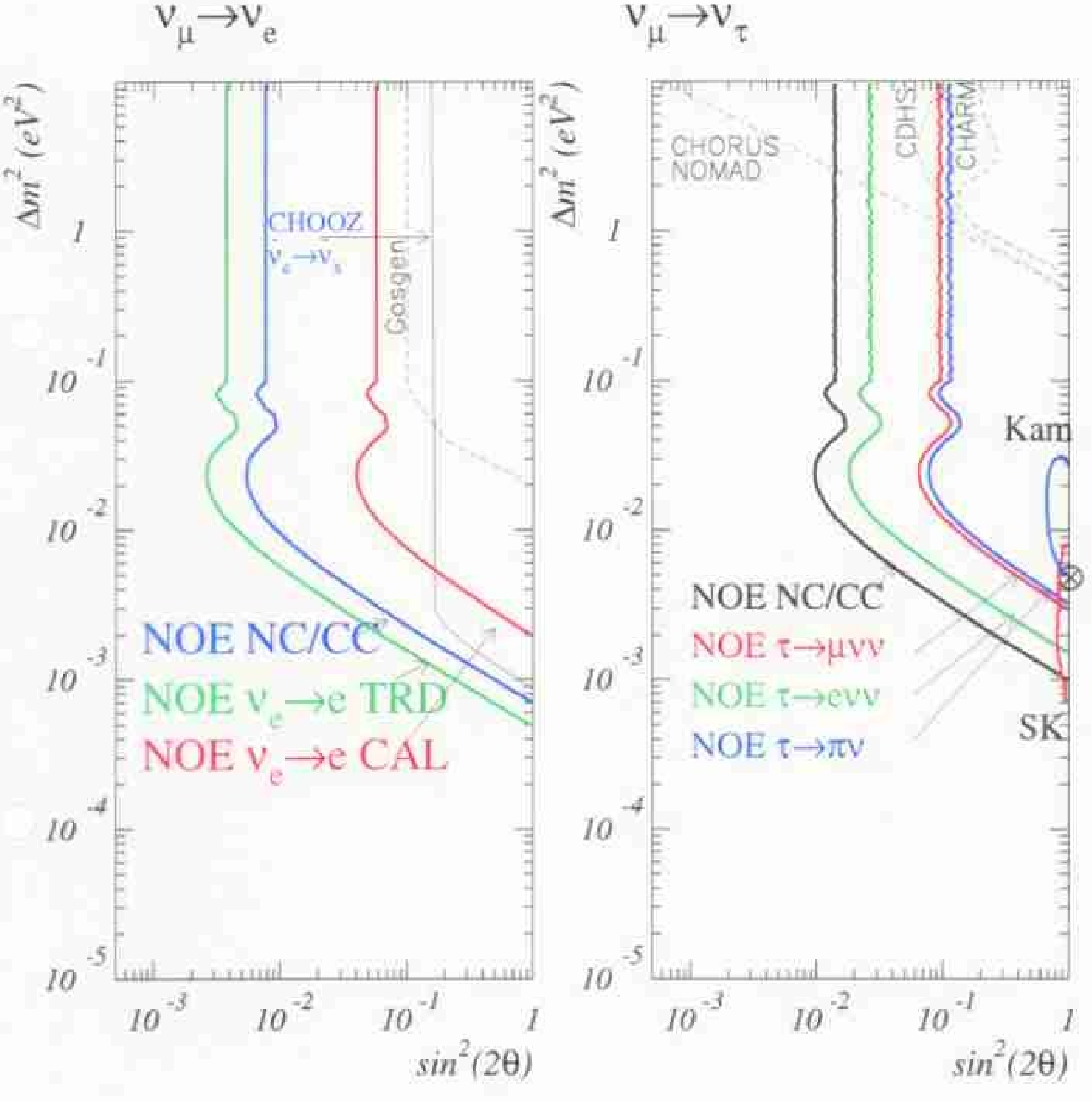
Exploit classical kinematical cuts:

1) missing pt;
2) angular correlation between decay prong and shower.

$\tau \rightarrow \mu$: (cal+TRD)	40 k ν_μ CC events $\rightarrow$	~130 BG events
$\tau \rightarrow e$: (TRD)	12 k ν_μ CC events $\rightarrow$ π^0 background	~20 BG events
	140 ν_e CC events (contamination)	

⇓

ν_μ- ν_τ as an excess beyond statistics



$\nu_\mu \rightarrow \nu_e$
$\nu_\mu \rightarrow \nu_\tau$
$\Delta m^2\ (eV^2)$
CHOOZ
$\nu_e \rightarrow \nu_x$
Gosgen
NOE NC/CC
NOE $\nu_e \rightarrow$ e TRD
NOE $\nu_e \rightarrow$ e CAL
CHORUS
NOMAD
CDHS
CHARM
Kam
SK
NOE NC/CC
NOE $\tau \rightarrow \mu\nu\nu$
NOE $\tau \rightarrow e\nu\nu$
NOE $\tau \rightarrow \pi\nu$
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
$\sin^2(2\theta)$

The ICARUS project

CERN - ICGF(CNR) - LNF - L'Aquila - Padova - Pavia - Pisa - UCLA

*** Approved by INFN and by the GranSasso Advisory Committee**

*** Funded by INFN**

- **A large liquid Ar volume**
  - Three dimensional imaging - Time Projection Chamber.
- **To be run at the Laboratori Nazionali del Gran Sasso.**
- **Three stage program**
  - $\approx$ 3 tons detector: $\leftarrow$ working at CERN
    - For feasibility studies.
  - $\approx$ 600 tons detector: $\leftarrow$ approved !
    - For R&D and quality physics.
  - $\approx$ 5000 tons detector (8 • 600 ton ?):
    - For proton decay and neutrino study.

The LAr Image Chamber
(An electronic "Bubble Chamber")

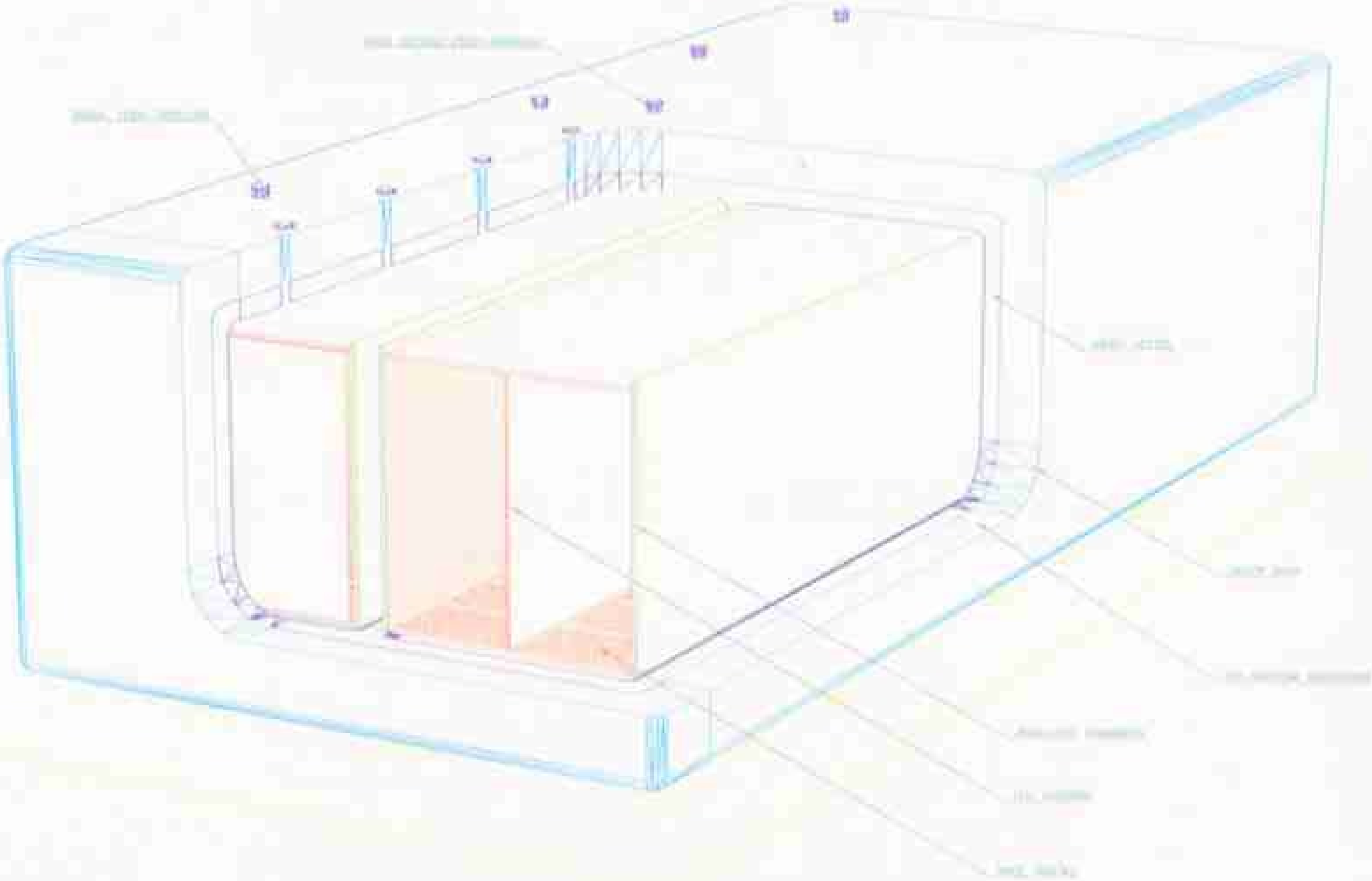
Characteristics

• Large sensitive volume	BC
• Detector = Target	BC
• Continous sensitivity	
• Self triggering capability.	
• dE/dx measurement.	
• dE/dx vs. range for particle identification.	
• Energy measurement.	BC
• High spatial granularity.	BC
• High energy resolution.	

NEW DETECTOR → ..... NEW PHYSICS?

ICARUS → { p decay, solar ν, atm. ν (long-baseline) }

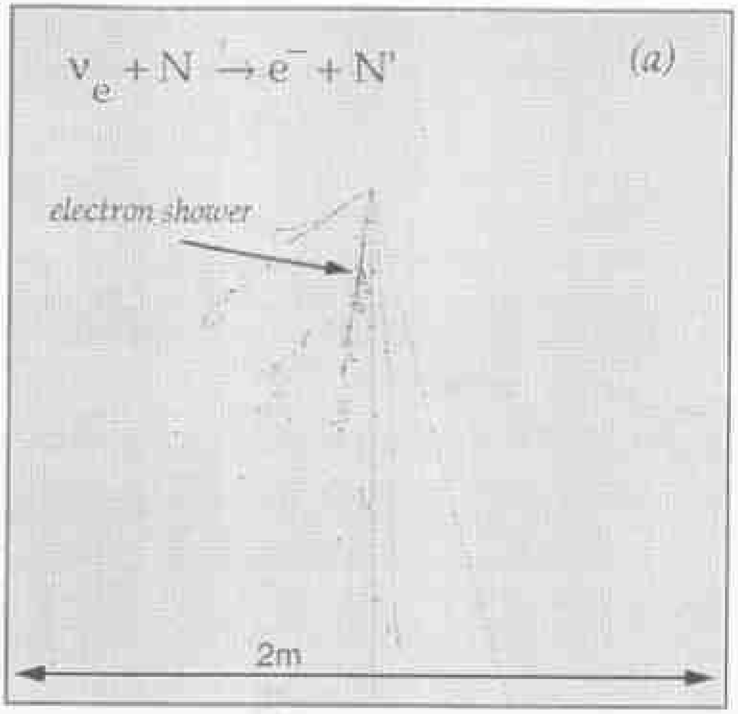
The first ICARUS 600 ton module



Built and tested in Pavia (1998-2000)
Operational at Gran Sasso (Hall C) in 2000
Data taking 2000!

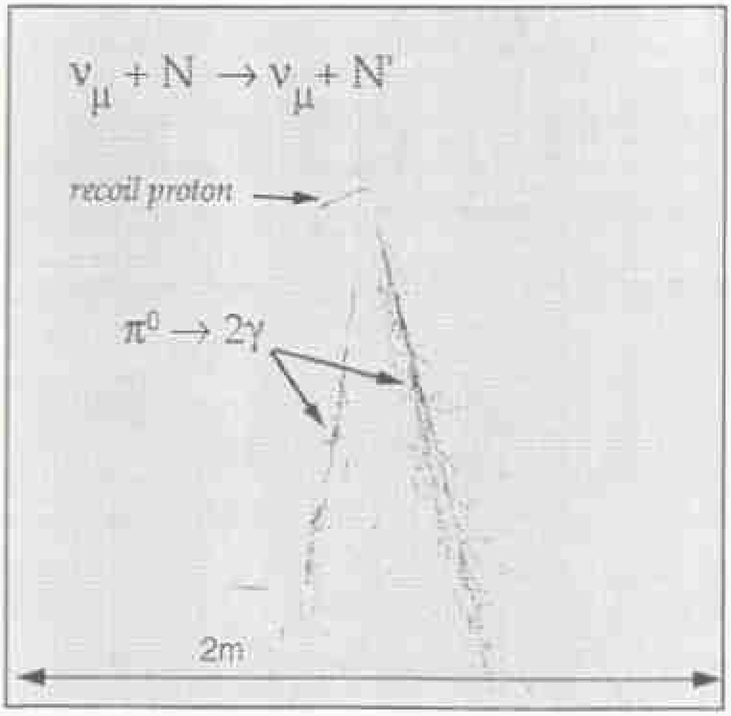
3 modules (1.8 kton) by 2002 (beam to G.S.)

π⁰ REJECTION BY ICARUS (MC)



electron shower

Simulated ν_e charged-current event in the liquid argon. The electron shower is spectacular and easy to recognize.

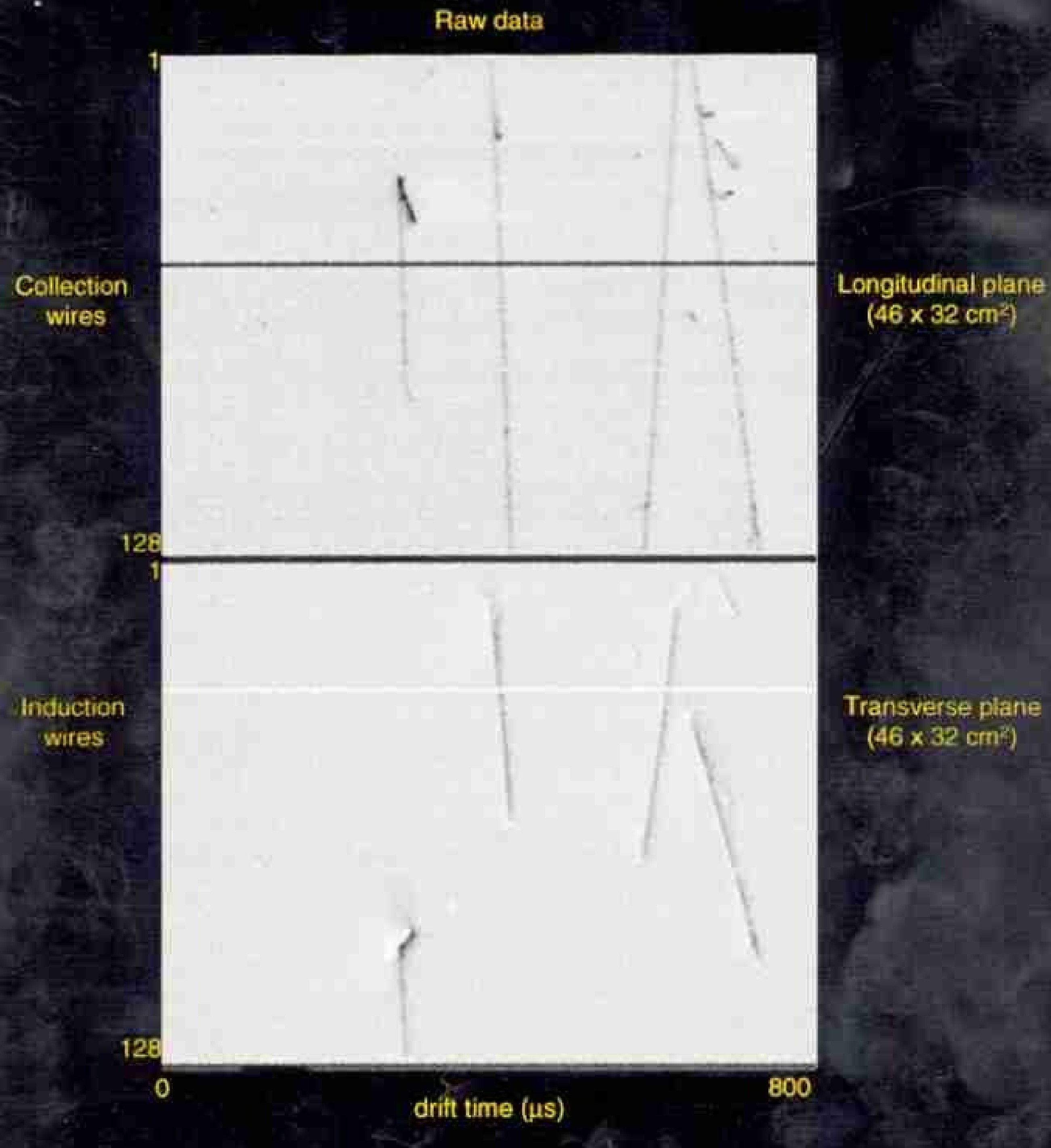


π_0

(ASYMMETRIC DALITZ PAIRS REQUIRE MORE CARE)

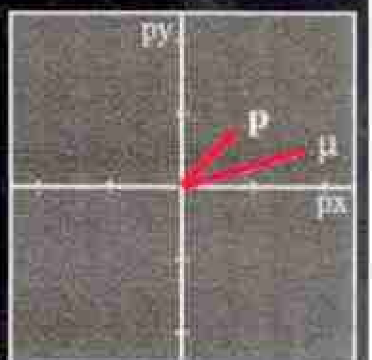
Neutral-current ν_μ interaction producing an energetic π^0. The two separated photon showers are clearly visible.

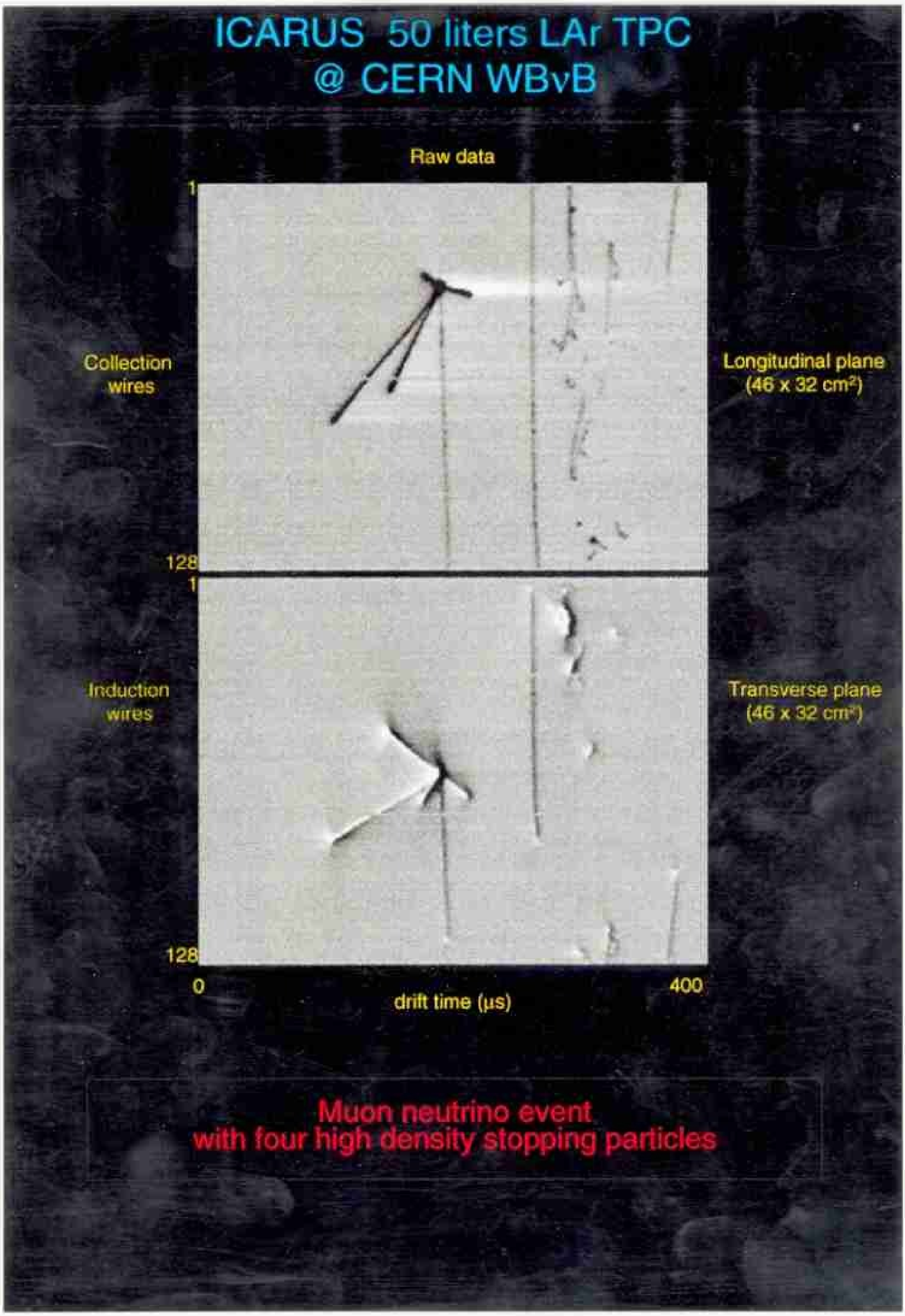
ICARUS 50 liters LAr TPC
@ CERN WBνB



Q.E. muon neutrino interaction with unbalanced proton

	μ	p	
px	-0.426	+0.274	GeV
py	+0.121	+0.163	GeV
pz	22.910	+0.145	GeV




ICARUS 50 liters LAr TPC
@ CERN WBνB
Raw data
1
Collection
wires
Longitudinal plane
(46 x 32 cm²)
128
1
Induction
wires
Transverse plane
(46 x 32 cm²)
128
0
400
drift time (μs)
Muon neutrino event
with four high density stopping particles

$\nu_\mu \leftrightarrow \nu_\tau$ SENSITIVITY WITH ICARUS

- $P_{\nu_\mu \to \nu_\tau} = \dfrac{2.3}{N_{\nu_\mu CC} \cdot \sigma_\tau/\sigma_\mu \cdot BR \cdot \varepsilon_\tau}$ @ 90% CL (NO BGD)

- $N_{\mu CC} = 16000$ evts ($1.5 \cdot 10^{20}$ pot $\cdot$ 2 kTons)
  5 years 4 modules

- USE ONLY THE $\tau \to e\nu\nu$ DECAY CHANNEL (17%) *

- $N_{eCC} \simeq 100$ evts (BEAM CONTAMINATION)

- KINEMATIC CUTS → $\varepsilon_\tau \simeq 50\%$
  → ν_{eCC} REJECTION $\simeq 99\%$

- $\sigma_\tau/\sigma_\mu \simeq 0.50$; $E_\nu = 20$ GeV

⇓

$\Delta m^2 \leq 1.5 \cdot 10^{-3}\, eV^2$
$\sin^2(2\theta) \leq 5 \cdot 10^{-3}$ @ 90% CL

* ALL OTHER CHANNELS CAN BE USED TO IMPROVE THE SENSITIVITY (UNDER STUDY)

Searches for neutrino oscillations with ICARUS

- The search for oscillations is based on the particle identification capabilities of ICARUS and on the kinematical reconstruction of the events:

- for the $\nu_\mu \leftrightarrow \nu_x$ disappearance search, we rely on the external muon detector and on the reconstruction of the jet energy in the TPC; the measured energy spectrum at the 'far' position is compared to that of the 'near' position; NEED "NEAR" POSITION & LARGE MASS!

- for the $\nu_\mu \leftrightarrow \nu_e$ appearance search, the analysis is based on the straightforward identification of the electron and the reconstruction of the jet energy; the measured energy spectrum is compared to the one expected from the ν_e contamination calculated from the knowledge of the beam.

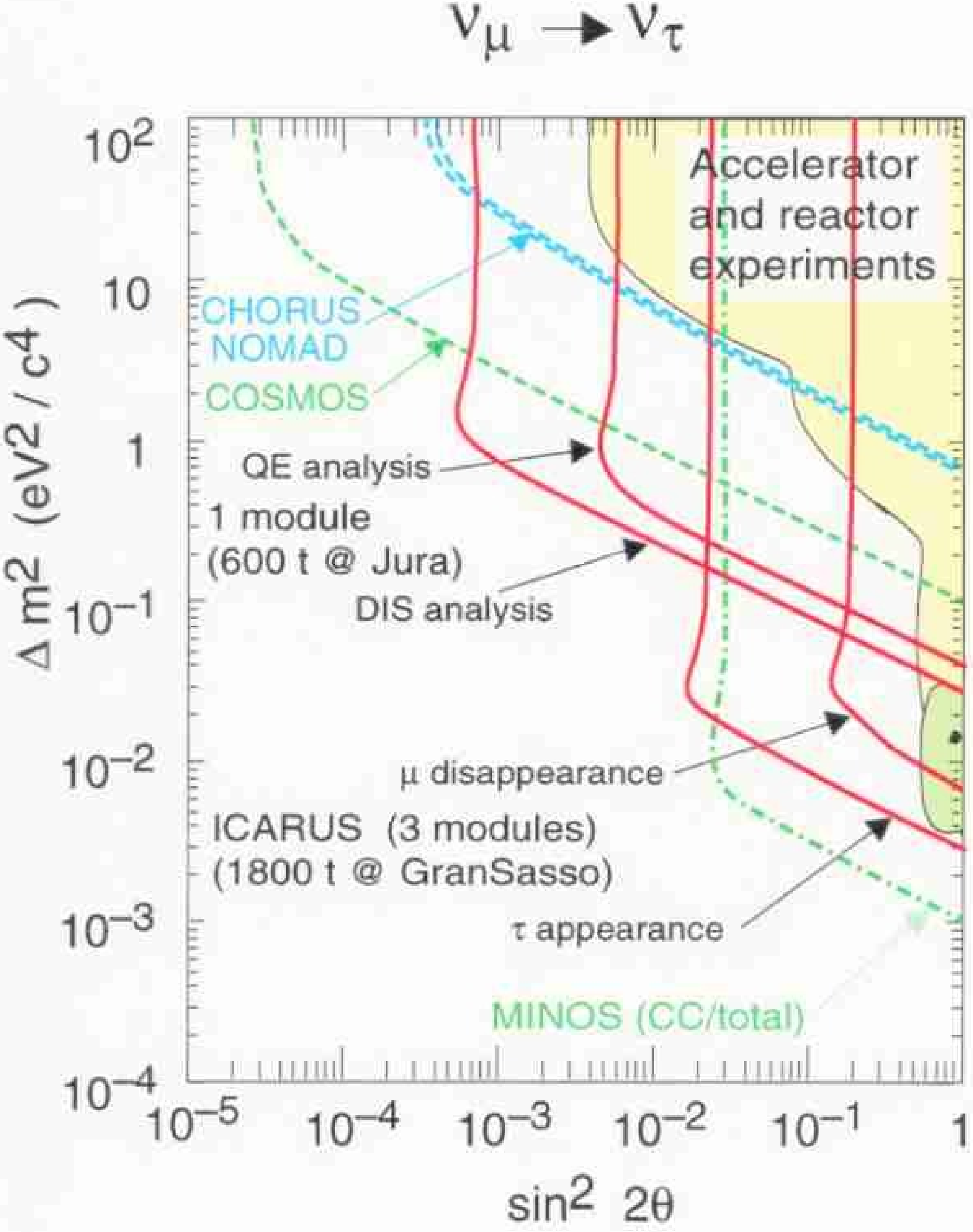
- for the $\nu_\mu \leftrightarrow \nu_\tau$ appearance search, the analysis is based on the *kinematical* suppression of the background using similar techniques to those of the NOMAD experiment. While in NOMAD a rejection of a factor 10^4 is needed in order to achieve a zero-background limit, in our case we only require a rejection of a factor 100 to 1000 in order to extract the oscillation signal predicted by the theoretical prejudice.

$\nu_\mu - \nu_\tau$: Tau identification with ICARUS (I)

- Given the excellent particle identification and measurement in the ICARUS LAr TPC, all decay modes of the tau lepton are accessible ($\tau \rightarrow e\nu\nu$, $\tau \rightarrow \pi\nu$, $\tau \rightarrow \rho\nu$, $\tau \rightarrow \pi\pi\pi\nu$); BUT SPECIALLY $\tau \rightarrow e\nu\nu$! BR=18%
- The identification of the tau lepton by means of kinematical selection is complicated by irreducible backgrounds produced by:
  - potential losses of final-state particles (detector acceptance, neutrons, low momentum particles);
  - tails in the Fermi momentum of bound nucleons;
  - nuclear effects (rescattering, absorption, etc.);
- There is essentially no loss of final-state particles since the detector is fully sensitive, has full angular acceptance and large containment, and has high granularity (3 mm wire pitch) which allows one to detect very well small range tracks (the detection and measurement threshold for proton is typically 60 MeV of kinetic energy). } GOOD WITH ICARUS

BACKGROUND ESTIMATE TO $\tau \rightarrow e\nu\nu$: ~2 EVENTS/2×10^{20} pot /1.8 kton

Two neutrinos oscillation 90%C.L. sensitivity



The OPERA emulsion detector for a long-baseline neutrino oscillation experiment

LNGS-LOI 8/97 and SPSC 97-24/I218

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S.Buontempo, A.Cocco, V.Cuomo, N.D'Ambrosio, G.De Lellis, A.Ereditato, G.Fiorillo, R.Listone, M.Messina, P.Migliozzi, S.Sorrentino, P.Strolin, V.Tioukov
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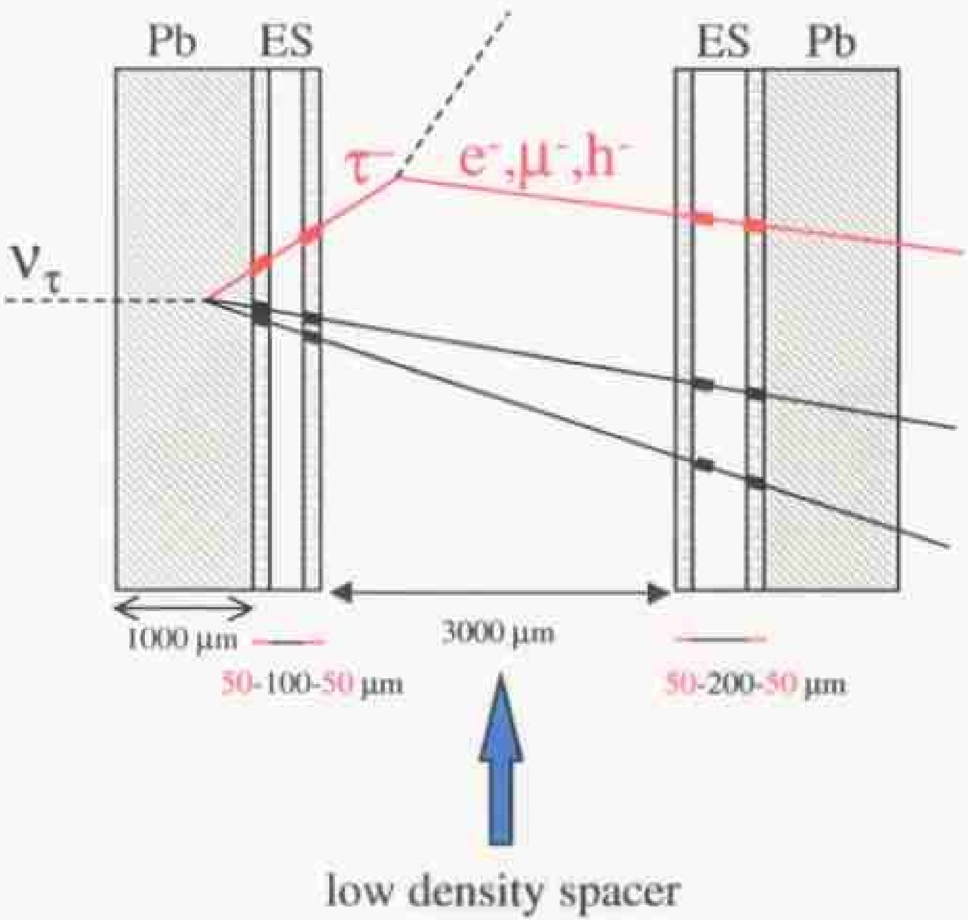
Utsunomiya Univ., Japan

The OPERA concept



- reject (short) τ decays in metal plates
- thin lead plates :
  1 mm < $\gamma c\tau$ → $\varepsilon_\tau \sim 0.5$
- two emulsion sheets (ES) for tracking, light spacer
- each ES :
  - 50 µm emulsion layers on both sides of 100 (200) µm plastic base
  - 2 high quality track segments in space (µm granularity) ~5 mrad ang res
- decay topology (kink angle) detection in space
- use decays in Pb for checks and specific studies

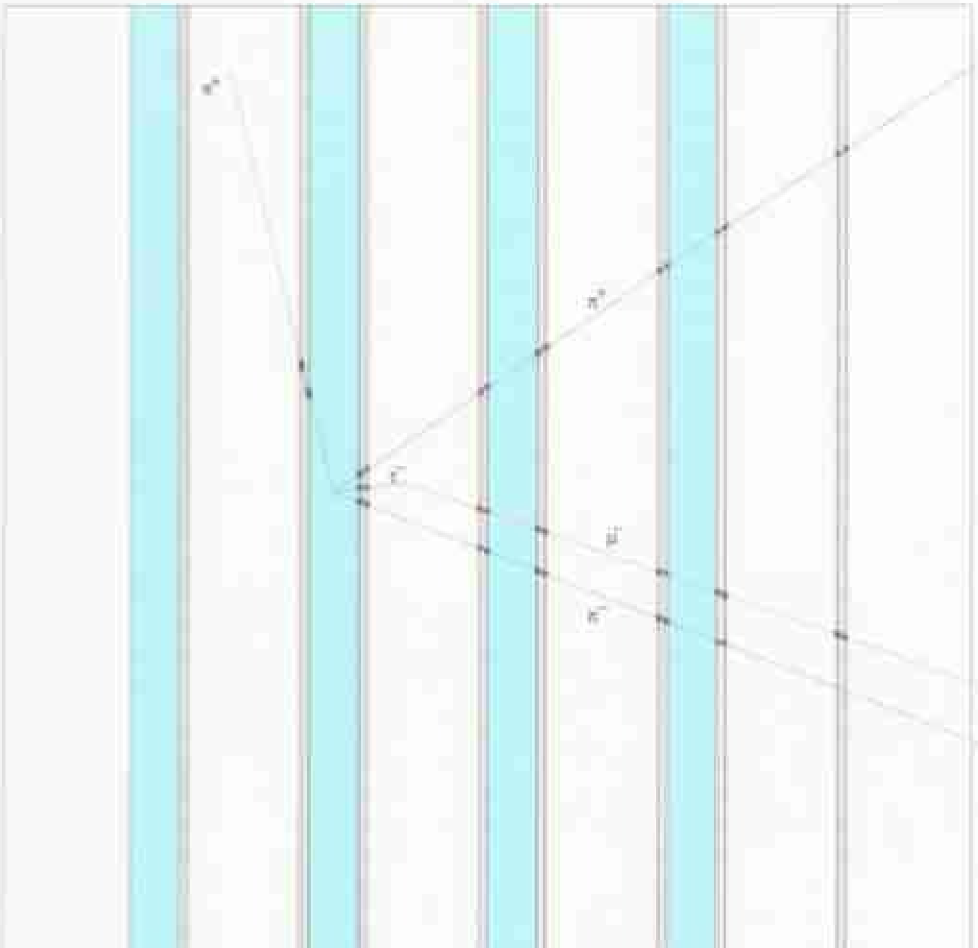


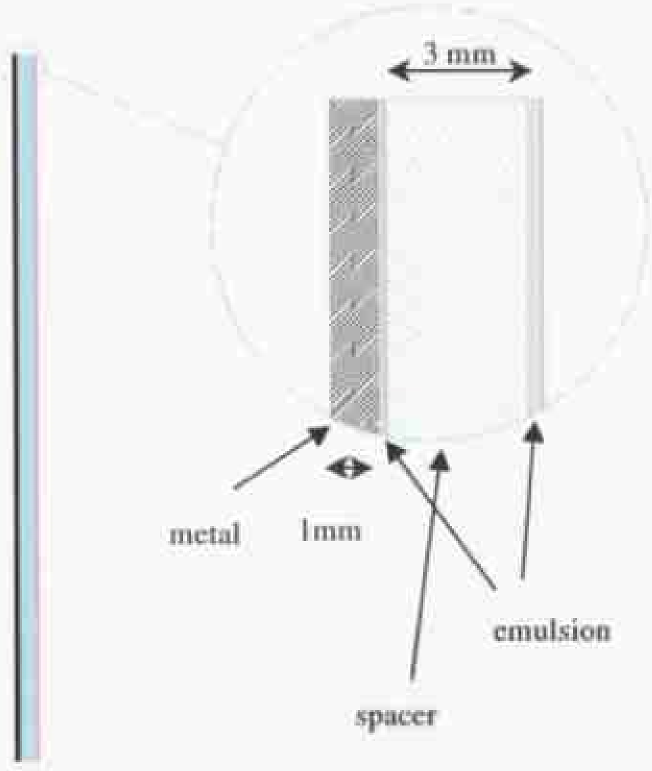
Figure 14: Detail of the vertex region of the event shown in the previous Figure.

The detector

Preliminary design

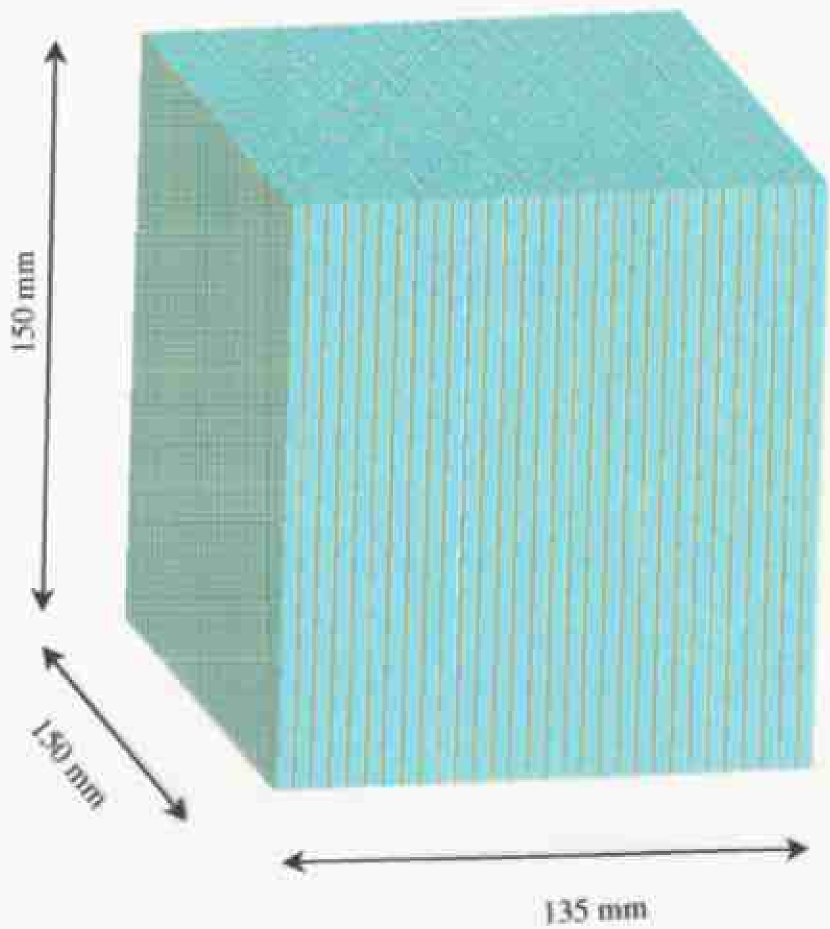
- **Lead-emulsion target**
  - element: 1 mm Pb, ES, 3 mm gap, ES
  - brick: stack of 30 elements (~ 13 cm thick, 15 x 15 cm^2 X-sect.)
  - module: 18 x 18 bricks (~ 2.8 x 2.8 m^2)
  - electronic detector planes following each module (~ 5 cm thick)
  - 300 modules: ~ 750 ton, subdivided into 10 identical supermodules
  - overall target dimensions ~ 3.5 x 3.5 x 40 m^3 (x 2)
- **Muon detection**
  - tracking in the target (electronic detectors)
  - magnetised iron μ-spectrometer downstream: sign of charge (momentum)
- **Calorimetry**
  - in the target: Pb (each module ~ 5 X_0) + electronic det. (RPC, straws,...)
- **$\Delta p/p$** ~ 10-20 % at 1-30 GeV/c from multiple scattering in emulsion

Cell



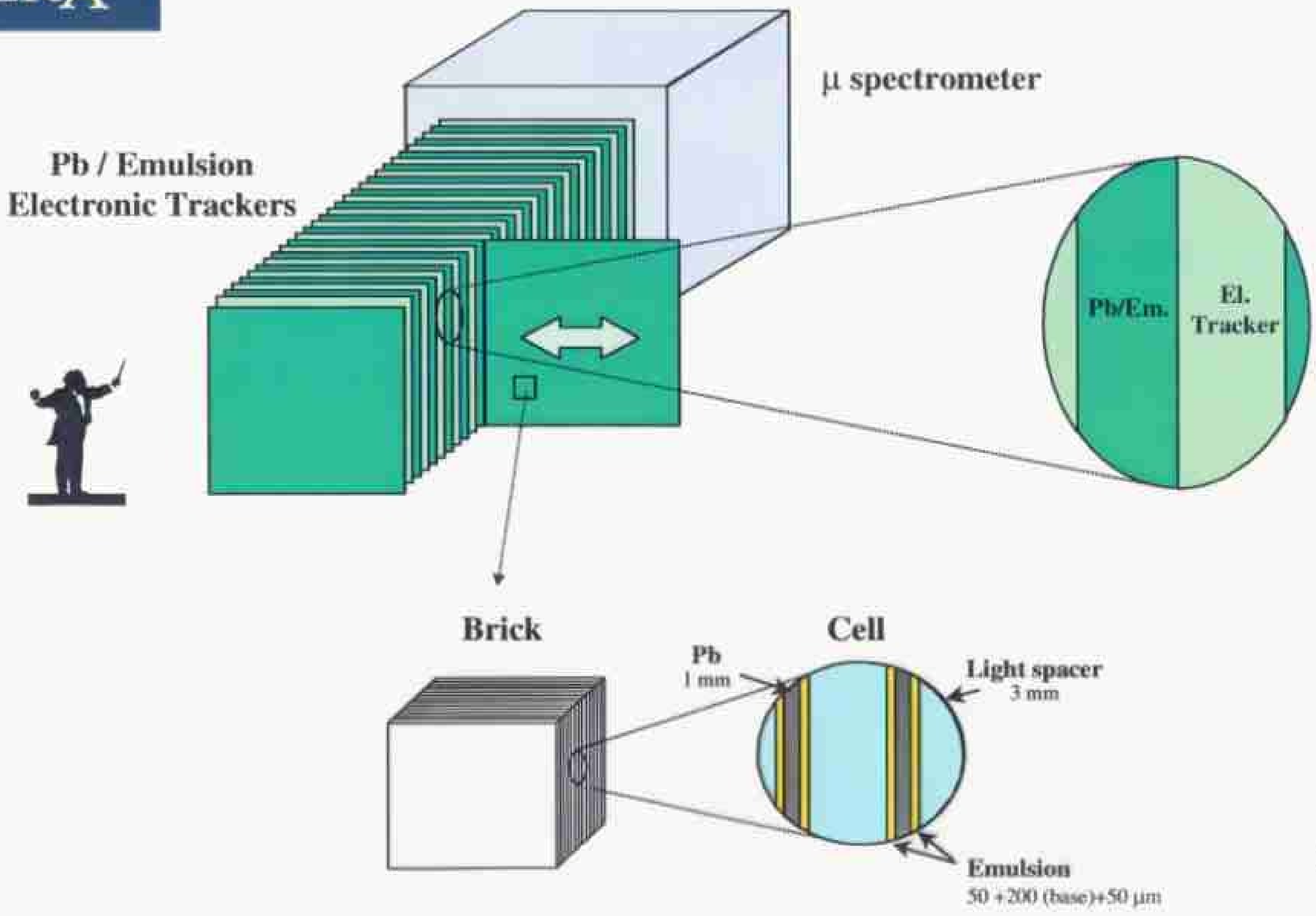
Brick

(30 cells)

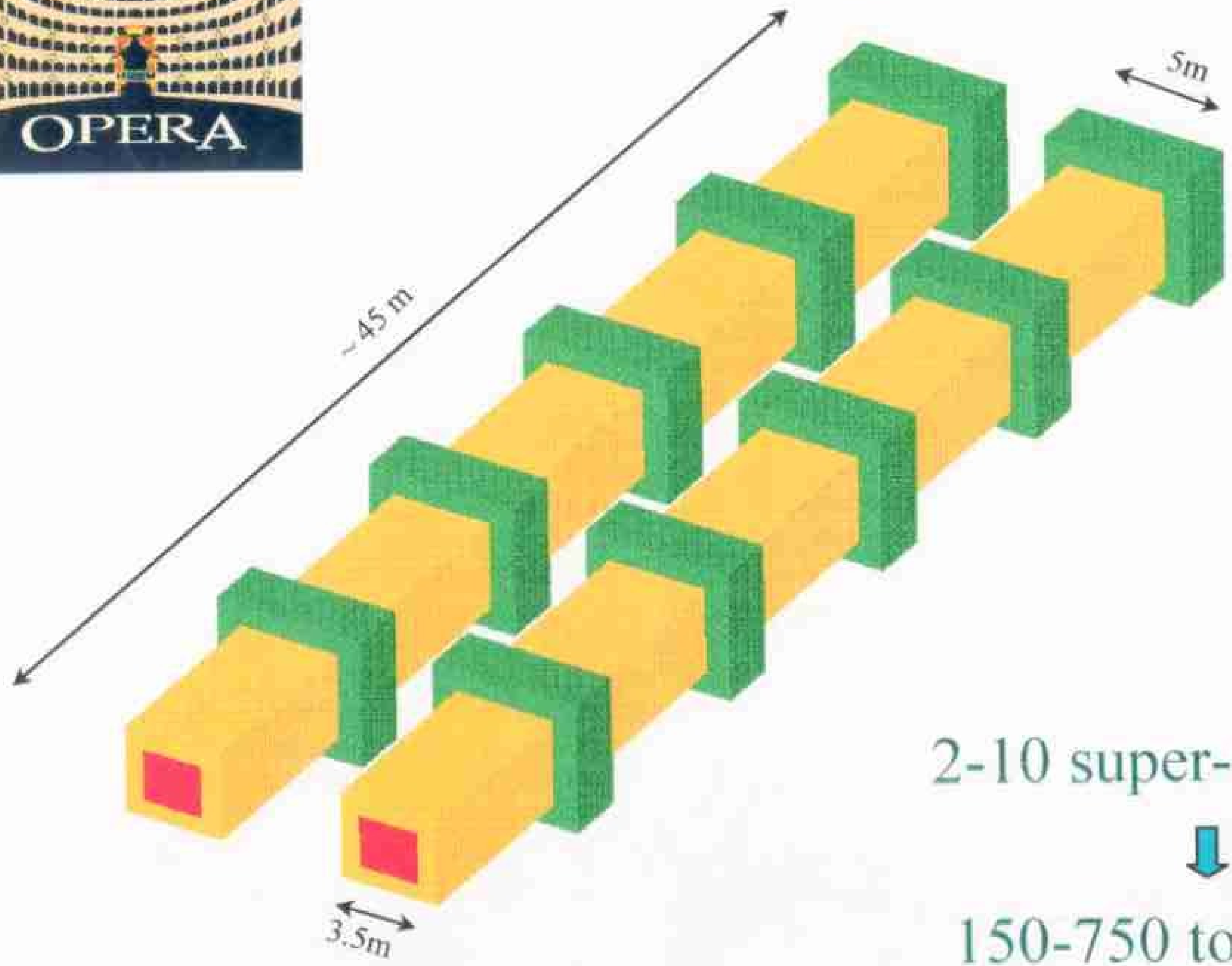


INFN ISTITUTO NAZIONALE DI FISICA NUCLEARE
SEZIONE DI NAPOLI

An OPERA supermodule



OPERA



2-10 super-modules

⇓

150-750 ton target

τ detection efficiency

- Decays outside Pb (1 mm) → $\varepsilon_{gap} \sim 0.50$
  (ε_{gap} depends on beam features)
- Kink finding efficiency ε_{kink} → 0.87 ($\tau \rightarrow \mu$), 0.84 ($\tau \rightarrow e$), 0.89 ($\tau \rightarrow h$)

  determined by the angular cuts:
  (resolution) ⇒ $20 < \theta_{kink} < 500$ mrad ⇐ (scanning & bg rejection)
- BR $\tau \rightarrow \mu, e, h$ → 0.174 , 0.178 , 0.498
- Fiducial cuts & alignment → $\varepsilon_{geom} \sim 0.93$

Total efficiency for the 1-prong channels: **0.36**
(3π channel under study)

OPERA at Gran Sasso

- Possible design: **~750 ton , 2.0 x 10^{20} pot** (4 years)

  → **~13000** ν_μ CC+NC events

- Discovery potential: small bg, a few events are meaningful:

  @ Super K. ($\Delta m^2 = 5 \times 10^{-3}$ eV^2) → **~ 50** events (<1 b.g.)

  $\Delta m^2 = 2.5 \cdot 10^{-3}$ eV^2 => ~ 15 events (")

- Negative search: $\Delta m^2 < 10^{-3}$ eV^2 ; $\sin^2 2\theta_{\mu\tau} < 2.5 \times 10^{-3}$

  → covers ν_{atm} (Super Kamiokande)

- Modular structure: scalable detector mass (~150-750 t)

↓

High sensitivity ν_μ-ν_τ search

↓

explore the atmospheric neutrino signal

Summary

- NGS:
  - the project is FEASIBLE and the civil engineering is finalized;
  - the neutrino beam is competitive for ν_τ appearance search but there is still room for optimization;
  - the design is flexible for future configurations;
  - the cost is 71MCHF;
  - If timely approved by contributors, it could be available for physics in 2003.
- Experiments:
  - five proposals/LOI have been submitted to and are reviewed by the Gran Sasso Scientific Committee; one is already approved (ICARUS);
  - the choice of the alternative techniques is not yet known;
  - next meeting of the Gran Sasso Scientific Committee on June 22nd 1998.