Integrated Program on Accelerator Neutrino Experiments in Europe

and first results from the CNGS neutrino beam

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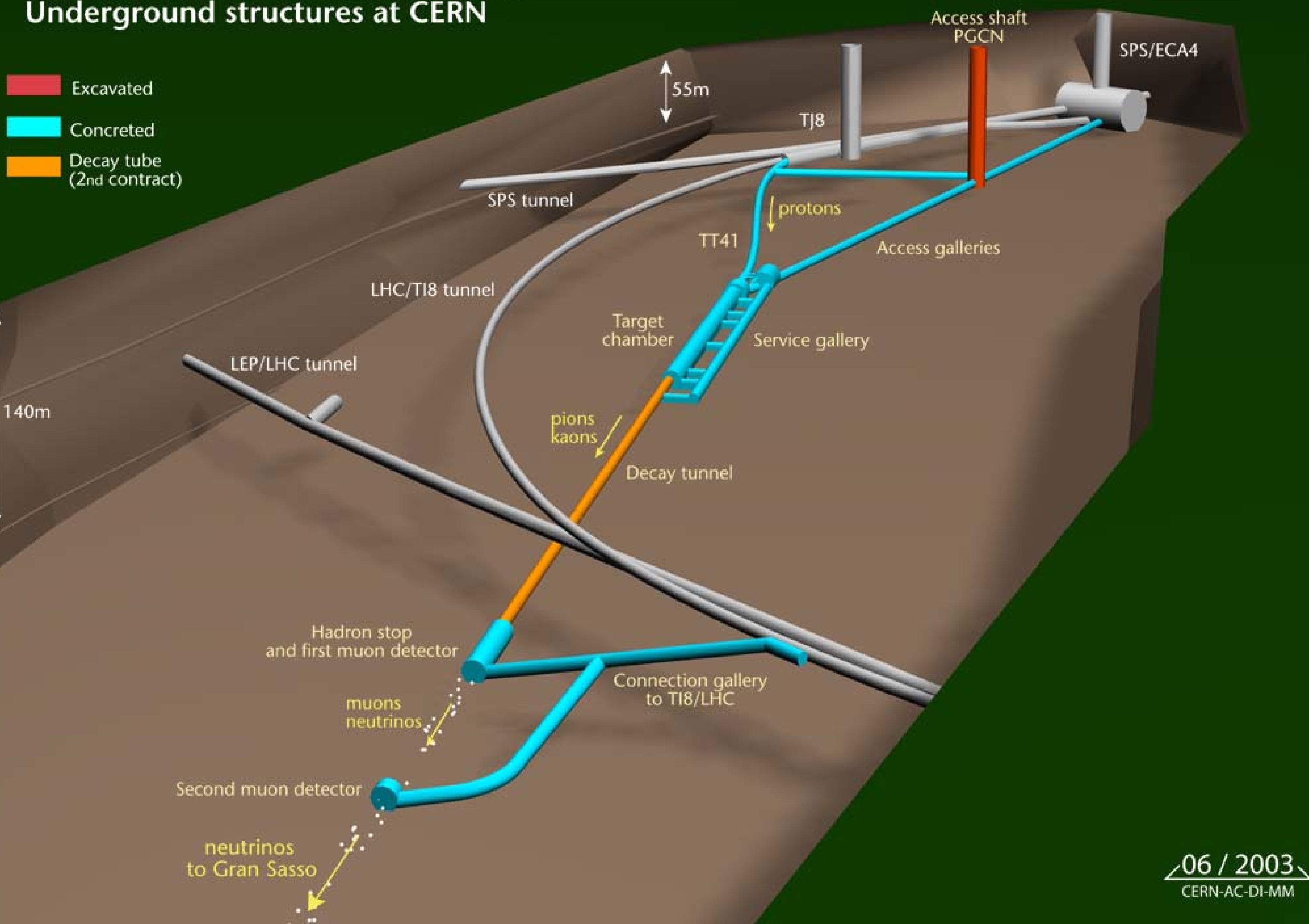
on behalf of the OPERA collaboration

Neutrino Frontiers, Minneapolis 2008

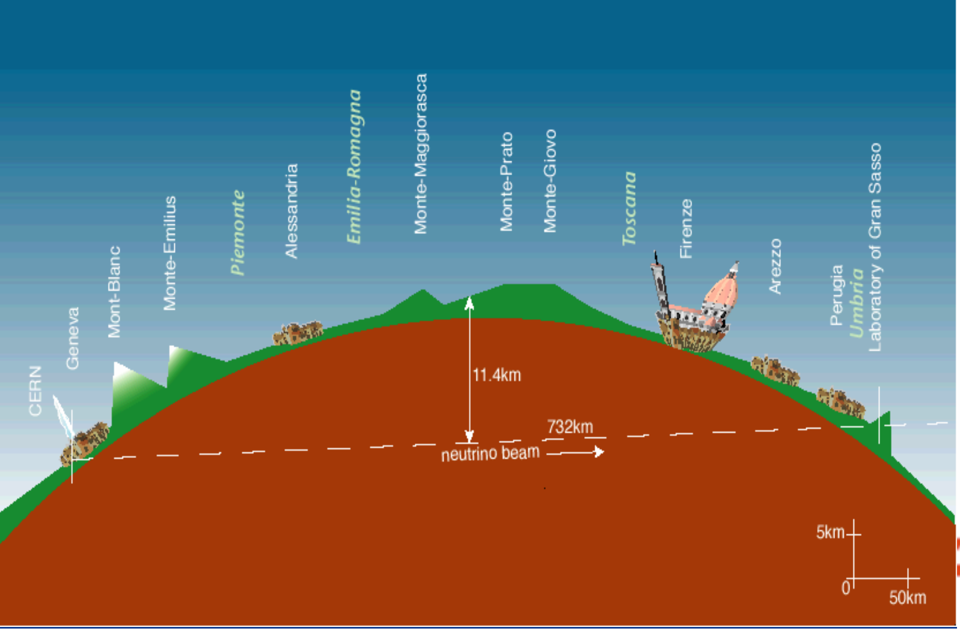
Overview

- Actual beams and experiments
  - CNGS neutrino beam and Gran Sasso actual experiments
    - OPERA – construction completed, data taking now
    - ICARUS
- Next generation facilities actively discussed now
  - Super beam
  - Beta beam
  - Neutrino factory

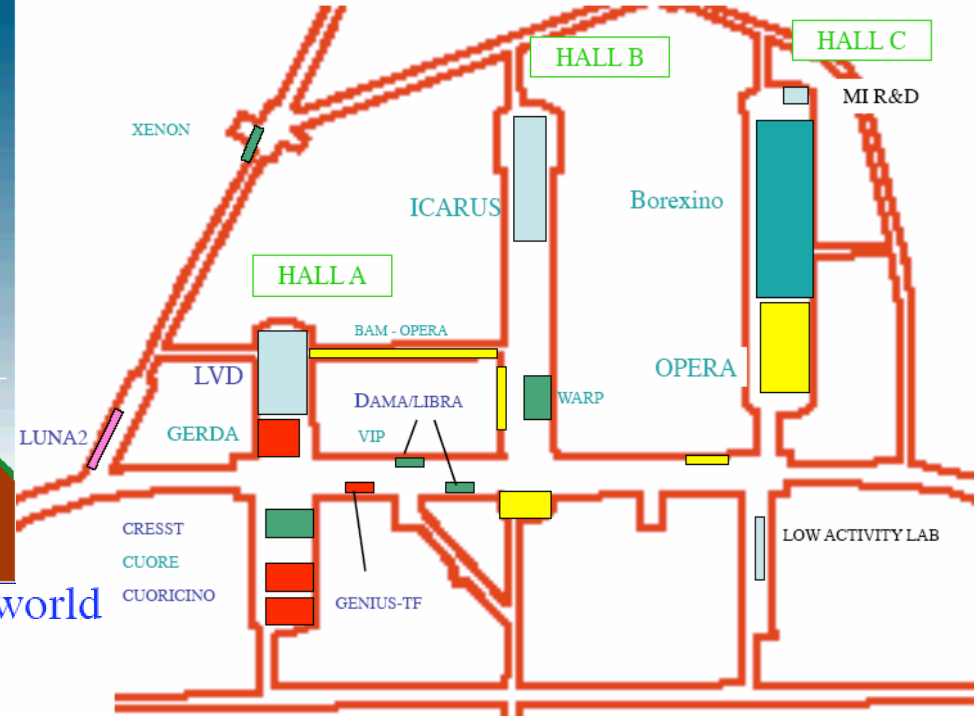
CERN NEUTRINOS TO GRAN SASSO
Underground structures at CERN



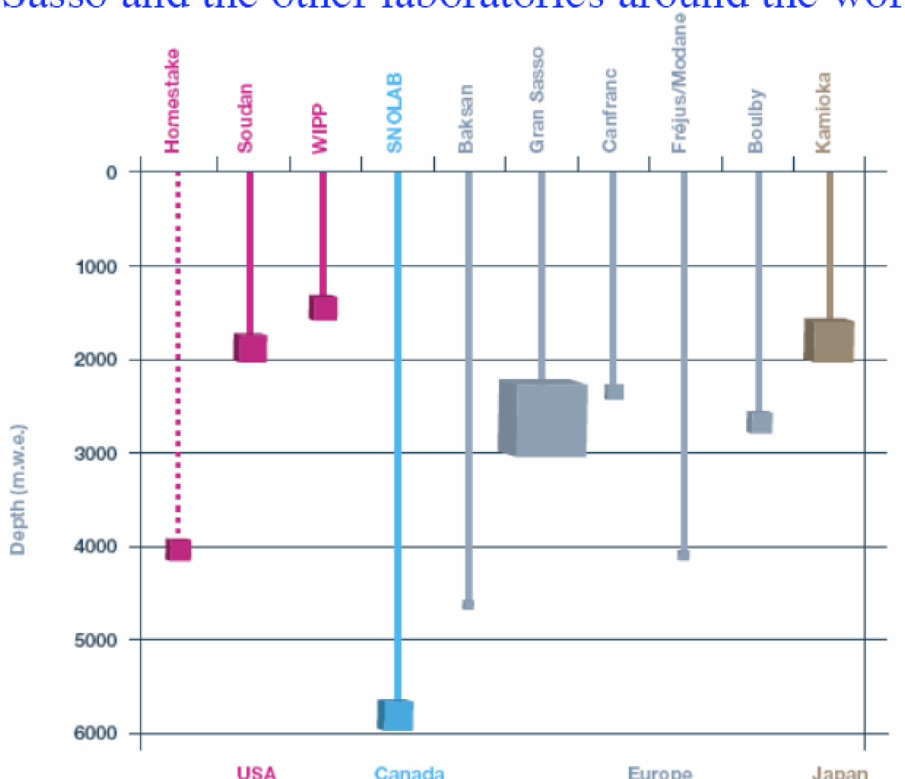
06 / 2003
CERN-AC-DI-MM



Occupancy



Gran Sasso and the other laboratories around the world



LNGS – largest underground laboratory (18000 m^2)
1400 m rock shielding,
Cosmic μ reduction 10^{-6} wrt surface

3 experimental halls
4 large experiments:

- LVD
- ICARUS
- BOREXINO
- OPERA

CNGS ν_τ appearance potential

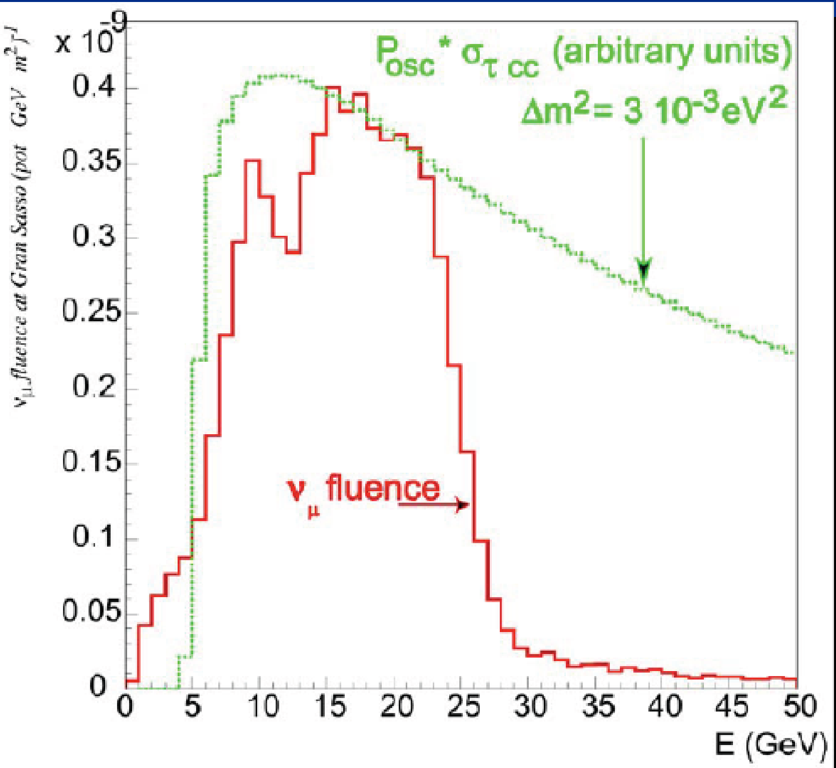
- **The beam is optimized for ν_τ appearance in the atmospheric oscillation region. The present best fit is now:**

  $\Delta m_{23}^2 = (2.43 \pm 0.13) \times 10^{-3}\ eV^2$

  $\sin^2 2\theta_{23} = 1.0$

- **Although the maximum of oscillation probability at 730 km is at about 1.5 GeV, the ν_τ CC cross section and the production threshold of 3.5 GeV should be taken into account**

$<E\nu_\mu>$	17 Gev
$(\nu_e - \bar{\nu}_e) / \nu_\mu$	0.87%
$\bar{\nu}_\mu / \nu_\mu$	4 %
ν_τ prompt	negligible
p.o.t/year	4.5×10^{19}
ν_μ CC/kton/year	~2900
ν_τ CC/kton/year	~16

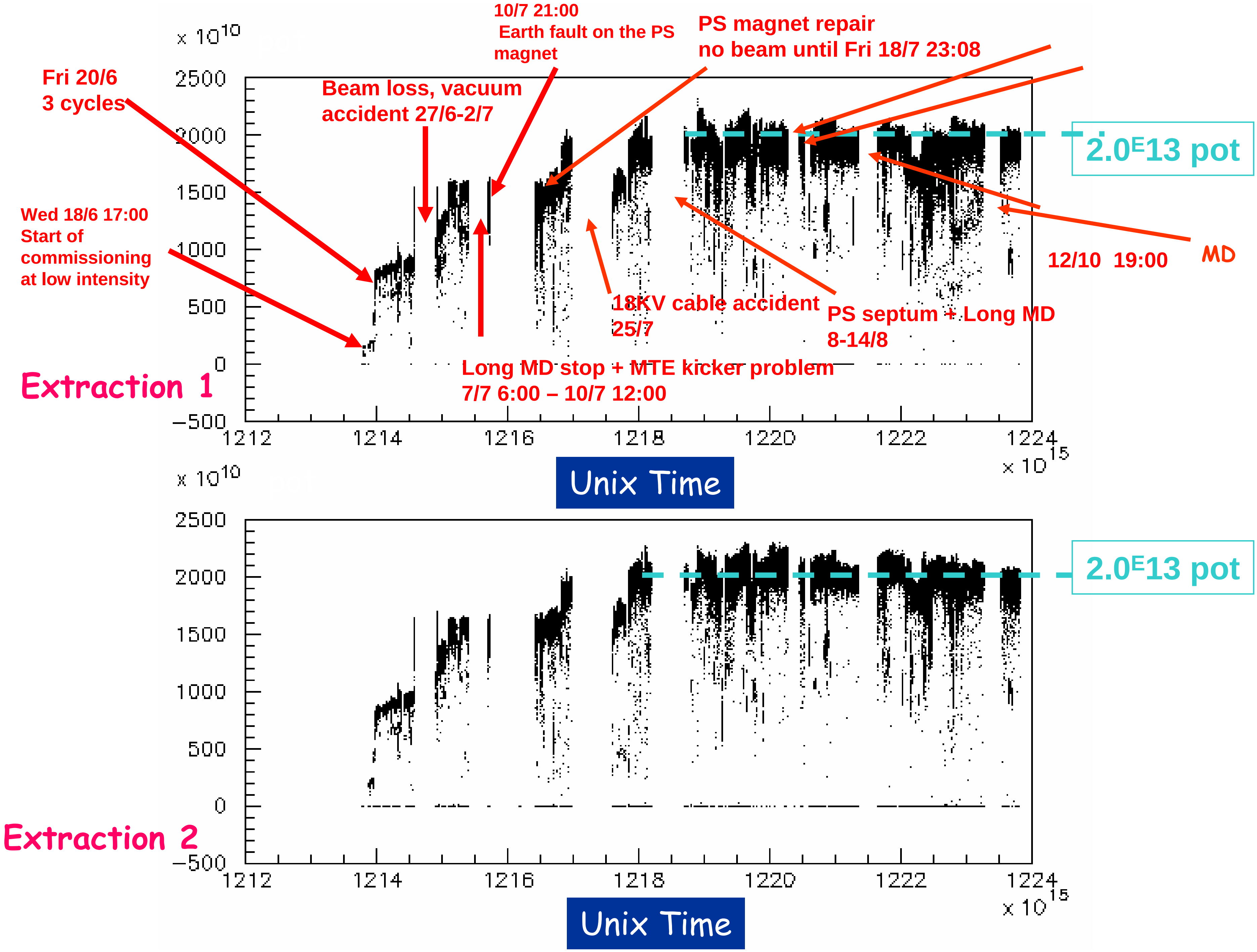


CNGS beam in 2006-2008

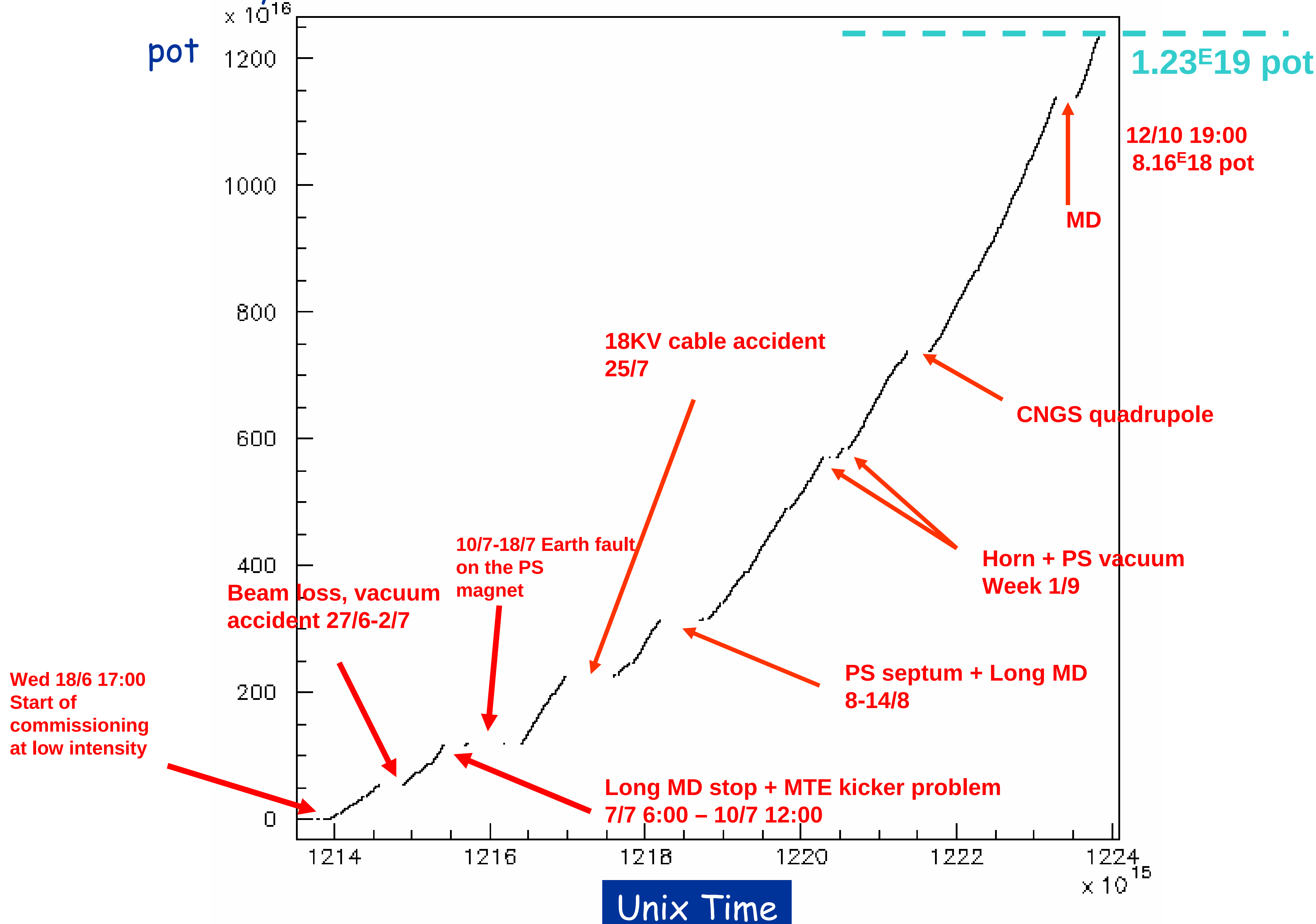
- 2006 CNGS commissioning run **($8.5x10^{17}$ pot)**
  - Stopped due to the leak in reflector cooling
- 2007 run 6 weeks, **($7.9x10^{17}$ pot)**
  - Stopped for radiation damages in ventilation electronics

In June 2008 CNGS modifications finished

- Since 18-Jun-2008 first production run
  - First milestone of **1.0E19 POTs** reached on 1 October 2008 with some delay in respect to schedule
  - In the last 2 weeks: 5/6 super-cycles with average intensity of about 3.6E17 POT/day is tested. With this intensity the scheduled for this run values is likely to be approached


10/7 21:00
Earth fault on the PS magnet
PS magnet repair
no beam until Fri 18/7 23:08
Fri 20/6
3 cycles
Beam loss, vacuum accident 27/6-2/7
2.0E13 pot
Wed 18/6 17:00
Start of commissioning at low intensity
12/10 19:00
MD
18KV cable accident
25/7
PS septum + Long MD
8-14/8
Long MD stop + MTE kicker problem
7/7 6:00 – 10/7 12:00
Extraction 1
x 10^10
2500
2000
1500
1000
500
0
−500
1212
1214
1216
1218
1220
1222
1224
x 10^15
Unix Time
x 10^10
2.0E13 pot
Extraction 2
Unix Time

CNGS integrated intensity: $1.23^{E}19$ pot up to Sunday 12/10 at 19:00, collected in 107 effective beam days



Monitoring CNGS with LVD

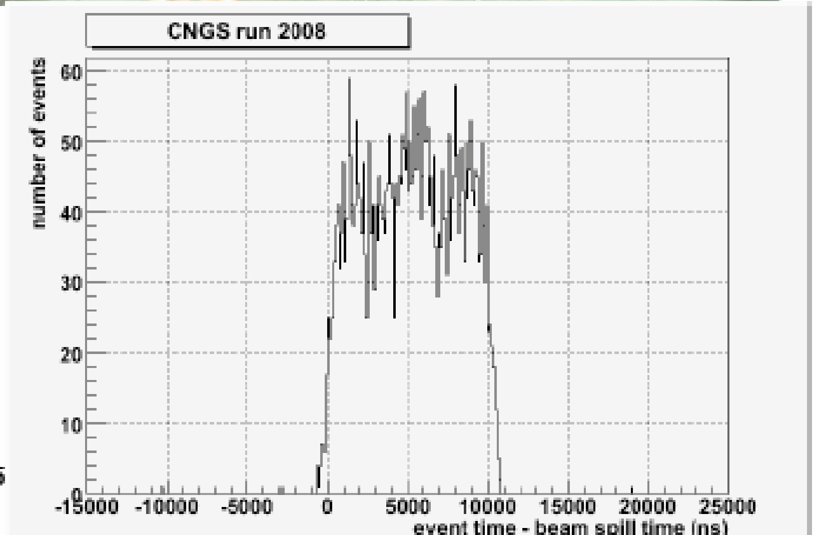
Eur. Phys. J. C 52, 849– 855 (2007)

- main LVD topic: search for stellar collapse, but useful CNGS monitoring

- ν_μ CC interaction in the rock up-stream LVD (78%)
- ν_μ CC (17%)and neutral current NC (5%) inside LVD

- 7.422×10^{-16} events per p.o.t. ~ 167 events/day at the nominal intensity 4.5×10^{19} p.o.t./y

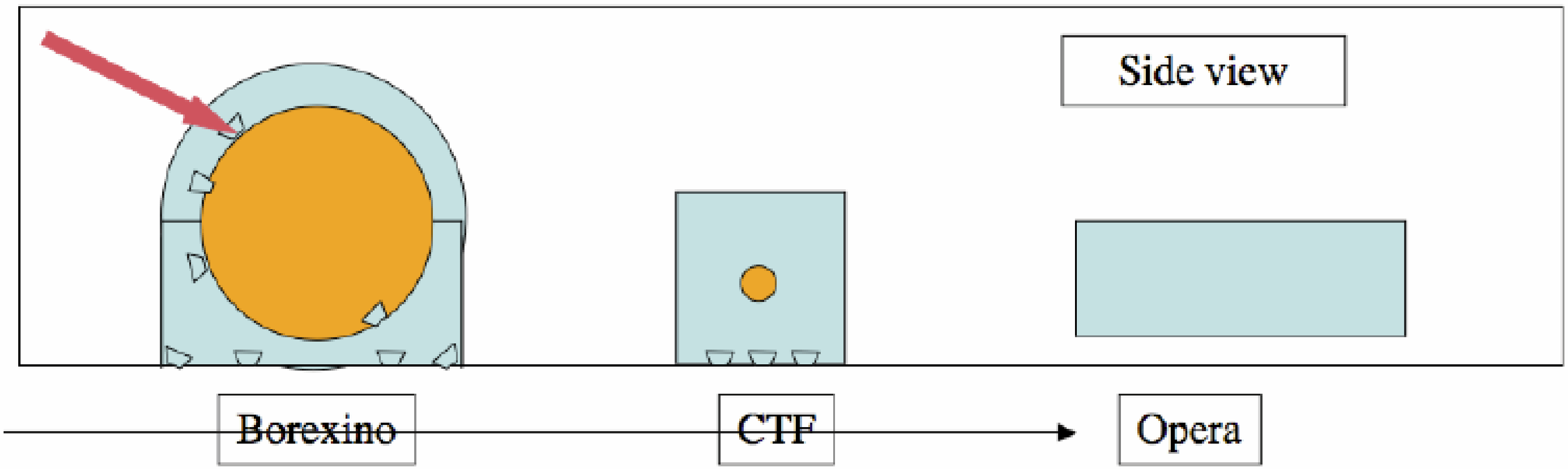
- 4538 events detected up to now during the 2008 run (4240 expected)



thanks to M Selvi LVD collab

Monitoring CNGS with Borexino

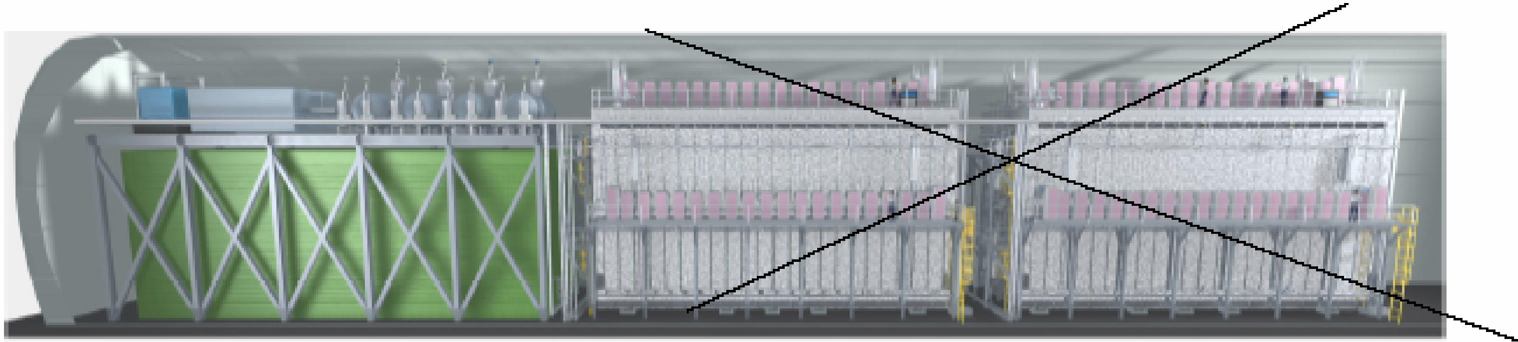
Borexino (dedicated to solar neutrinos) is just in front of OPERA, total mass for muon detection ~ 3.3 kT, mainly water used for shielding



muons generated		Det eff.	Final rate[ev/day]
inside the det. (CC+NC)	48	~98%*	47
in the rocks	271	~99%	268
Total rate	319		**315 [ev/day]**
Cosmic muon rate bk in the CNGS gate			2 ev/day

ICARUS T600 Imaging Cosmic and Rare Underground Signals

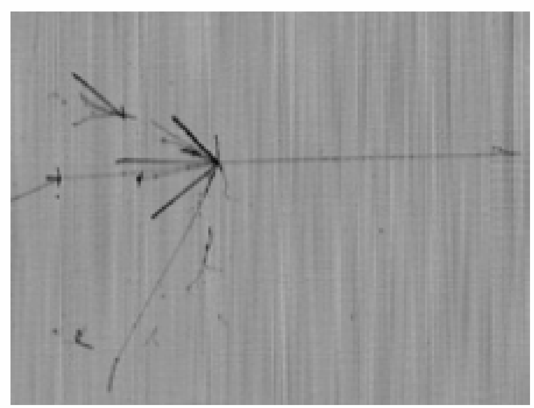
First Unit T600 | T1200 | T1200



Liquid Argon TPC (-176 °C)

(cancelled)

- Wide physics program , but now statistics limited
  - ν_τ and ν_e appearance on CNGS
  - atmospheric neutrinos
  - supernova neutrinos
  - solar neutrinos
  - proton decay



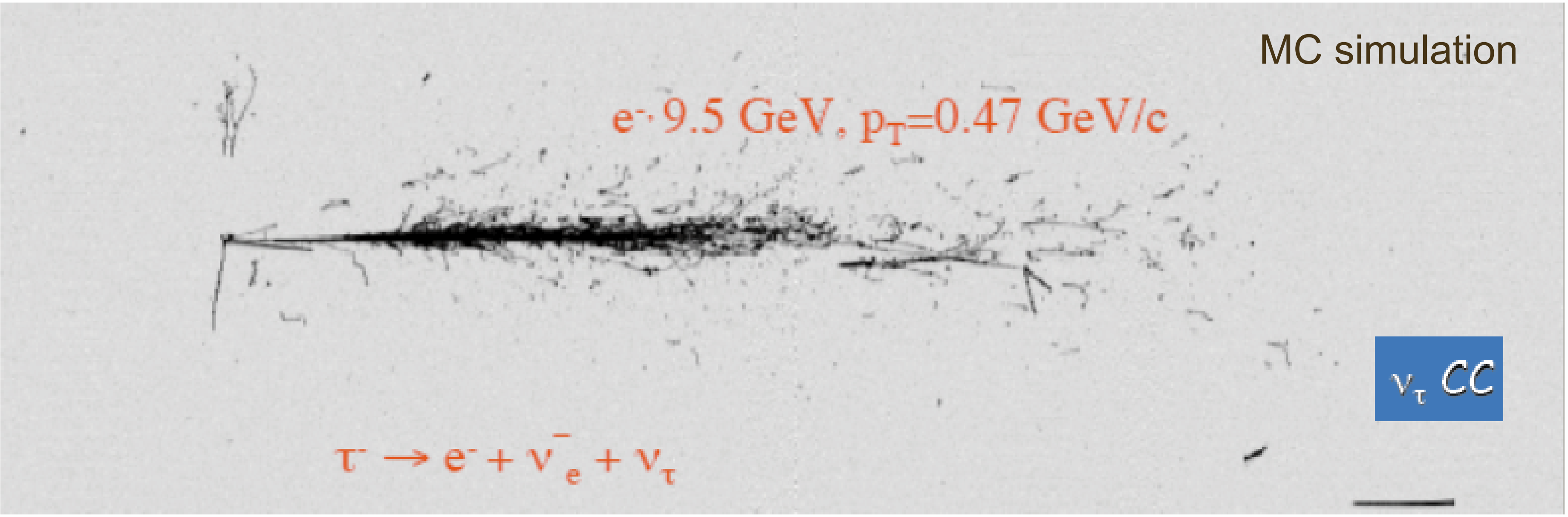
17 m

INFN

ICARUS T600

τ search based on **kinematical criteria**

main reaction: ν_τ + Ar -> τ + jet (gold candidate is the τ electron decay)



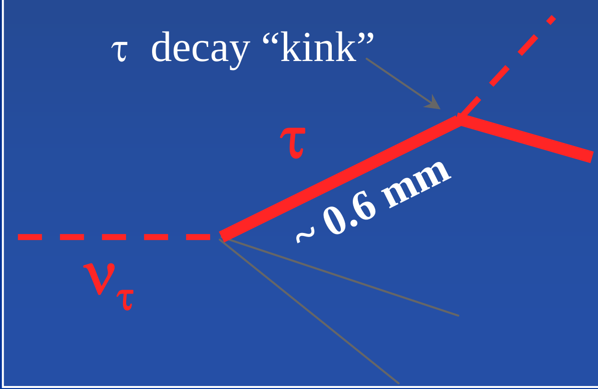
in 5 years running ~ 2 events and 0.1 events as background

The main importance of this detector is in the technological developments for future large mass liquid Argon detectors.

OPERA ≡ Oscillation Project with Emulsion tRacking Apparatus

Primary goal of OPERA:

direct observation of τ leptons produced in ν_τ^{CC} interactions



Detector resolution must be *O(1μm)*, *O(1mrad)*

$$N_\tau = N_A M_D \int \phi_{\nu_\mu}(E) P_{\nu_\mu \to \nu_\tau}(E, \Delta m^2) \sigma_{\nu_\tau}^{CC}(E) \varepsilon(E) dE$$

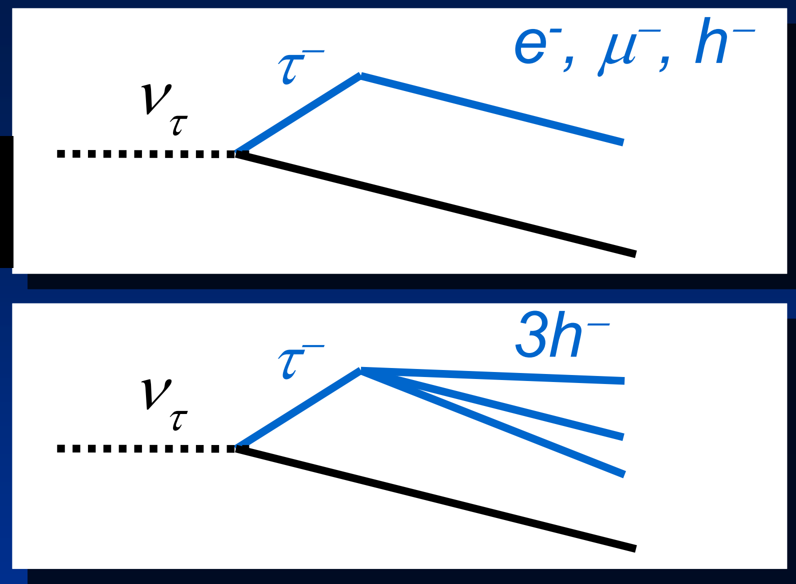
Target mass must be *O(1 kton)* for $\Delta m^2 = O(10^{-3}\ eV^2)$

ECC concept adopted

Detection principle

$\nu_\mu \xrightarrow{\text{oscillation}} \nu_\tau \xrightarrow{\text{CC interaction}} \tau + X$

τ decay
(~10[-13] s ; cτ~87 μm)



$\tau \rightarrow e \quad (17.8\%)$

$\tau \rightarrow \mu \quad (17.4\%)$

$\tau \rightarrow h \quad (49.5\%)$

$\tau \rightarrow 3h \quad (15.2\%)$

- **The detection of the τ lepton requires an identification of a “kink” or “trident” topology**
- **The detector must fulfil the following requests:**

1. Large mass due to small CC cross section (lead target)

2. Micrometric and milliradian resolution to observe the kink (photographic emulsions)

3. Select neutrino interactions (electronic detectors)

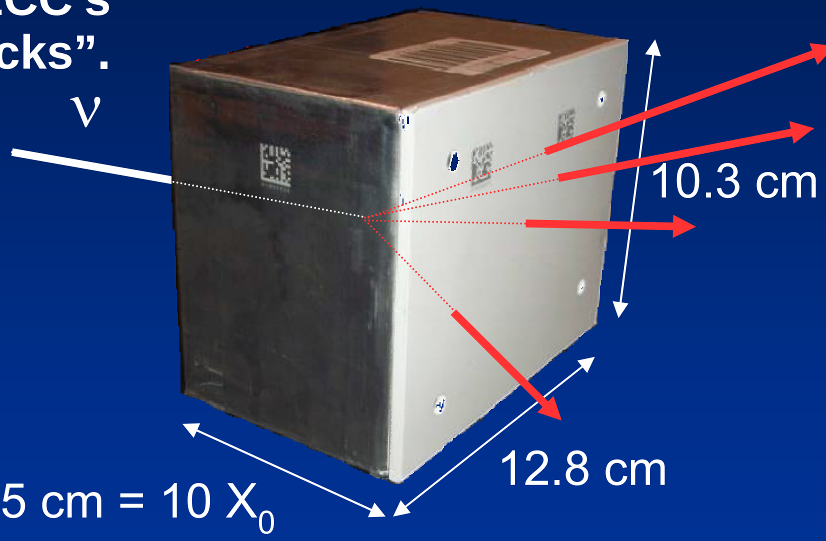
4. Identify muons and their charge to reduce charm background (precision tracker and spectrometer)

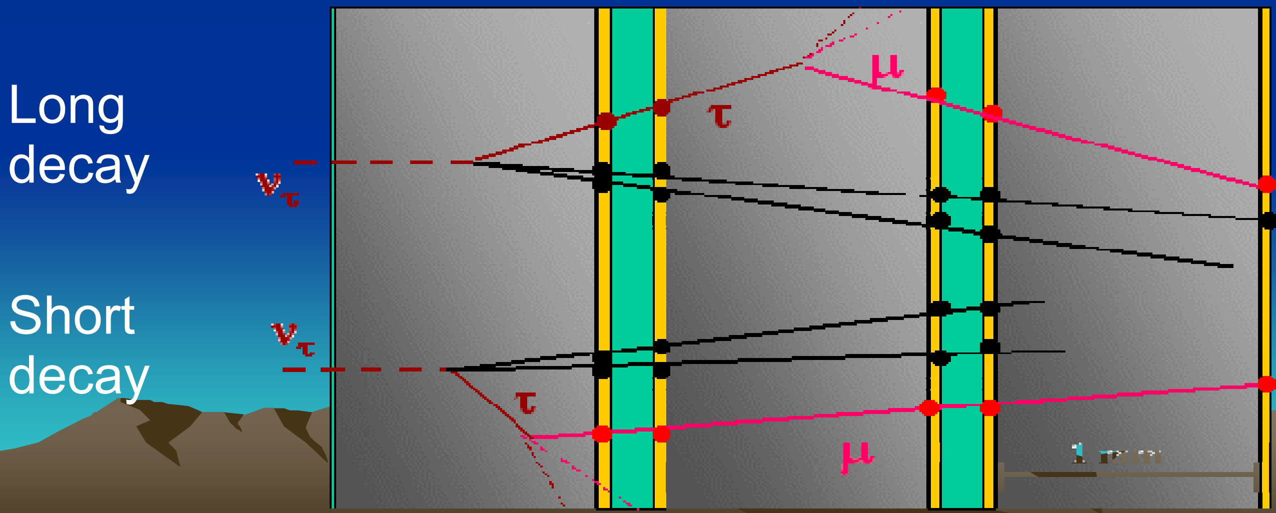
τ identification

- The target is divided in about 152000 ECC's (Emulsion Cloud Chamber), so called “bricks”. Each brick weights 8.3 kg

- One brick is made by a sandwich of:

  56 (1mm) Pb sheets
  57 (300μm) FUJI emulsion layers
  2 (300μm) changeable sheets





OPERA layout

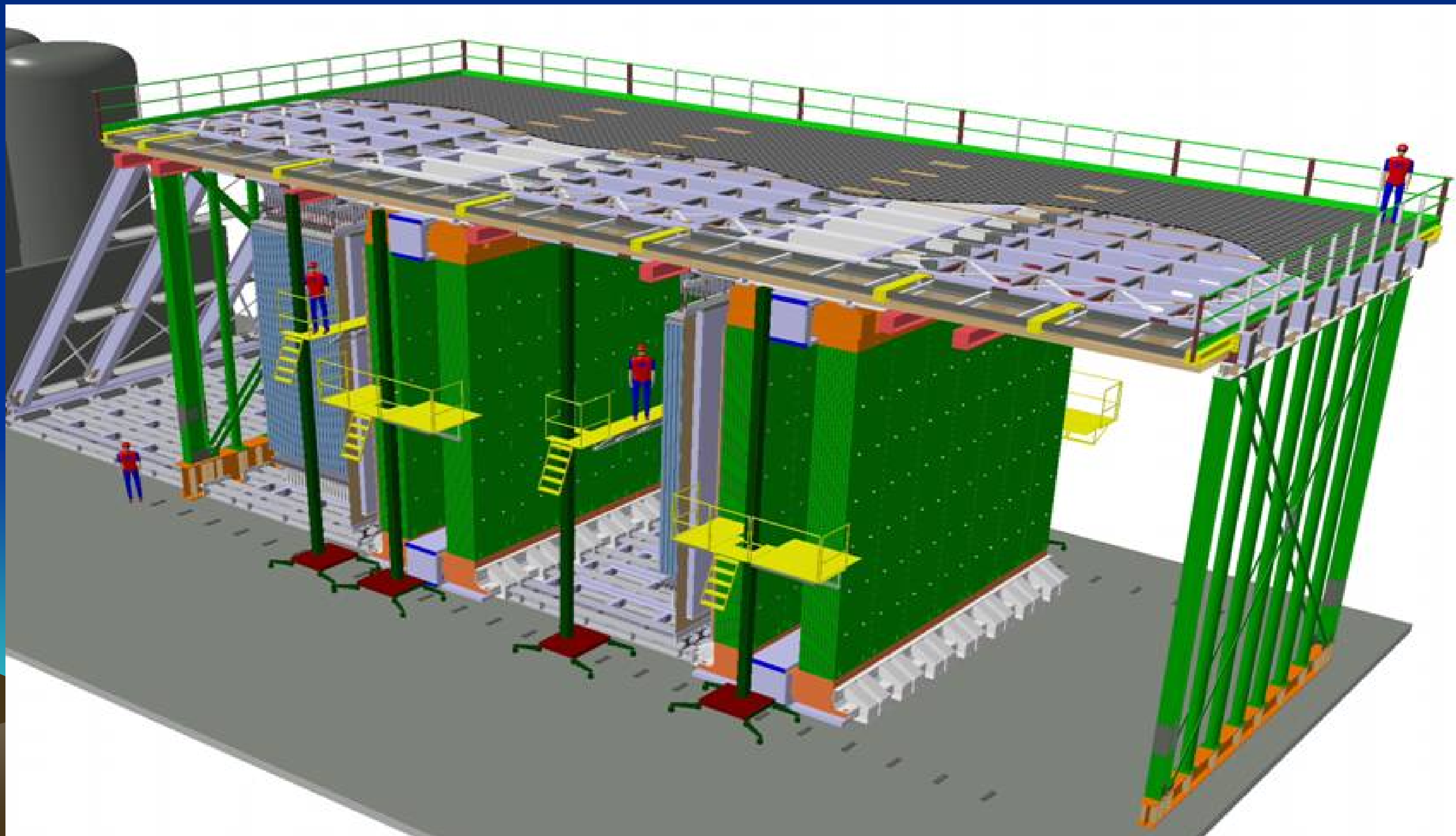
Hybrid detector (electronic + emulsions) with a modular structure:

2 supermodules = 2*(31 walls + 1 spectrometer)

↳ 31 walls = 31*(56*64 bricks + 2 scintillator tracker planes)

The total target mass = 1.35 Kton

ν_τ



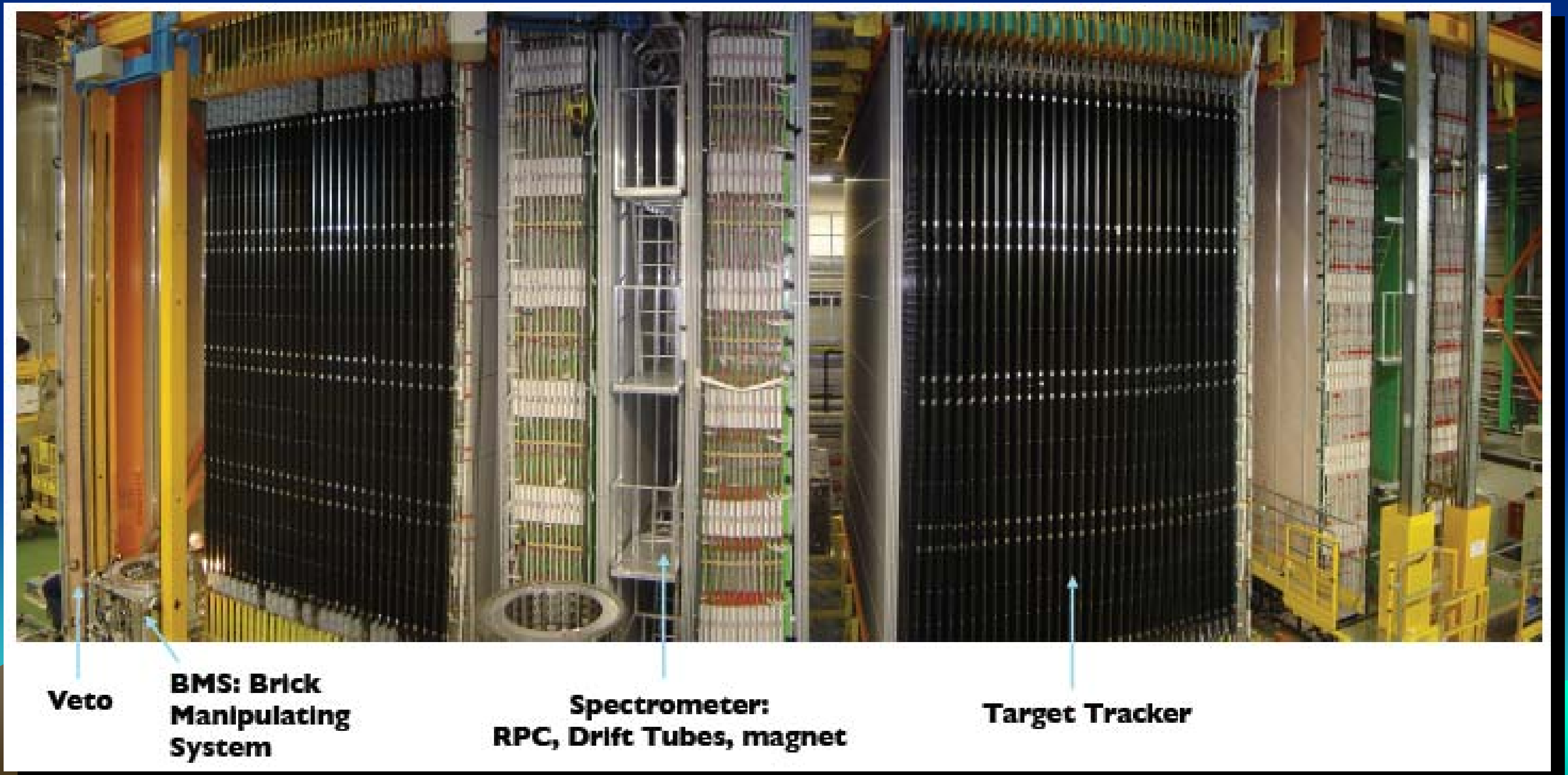
The OPERA electronic detectors

Target Tracker

- Made of plastic scintillation strips with wavelength shifting fibers
- p.e/mip > 5
- Detection efficiency: 99 %
- Brick finding efficiency: ~80 %

Muon spectrometer

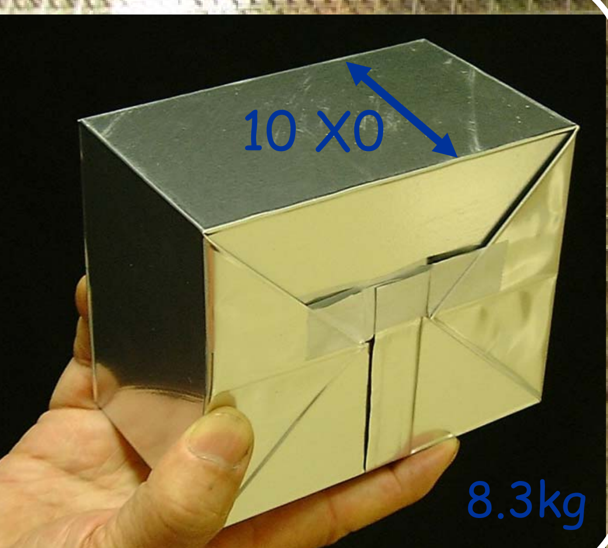
- RPC and drift tubes in 1.5T magnet
- charge miss id (<25 GeV/c): <1%
- ΔP/P (<50GeV/c) ~ 20%
- μ id (with TT) ~ 95%



Emulsion/lead target

- Brick filling is finished in July 2008
- 146621 bricks with ~ 8 millions of nuclear emulsions plates

Bricks assembling was technologically challenging
The small mechanical industry installed underground and worked in the red-light dark room



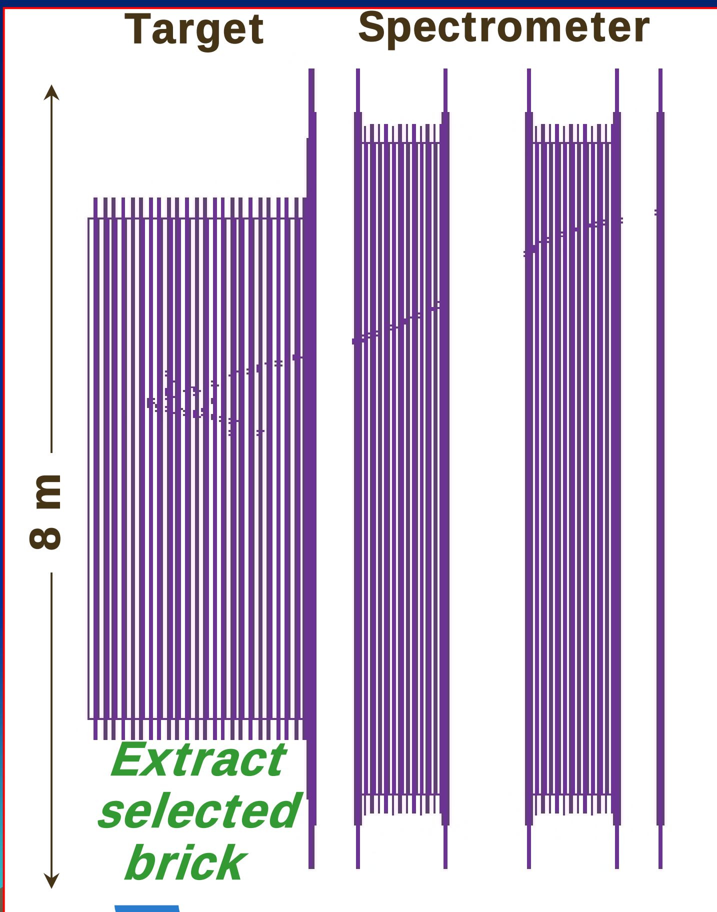
10.2 x 12.7 x 7.5 cm

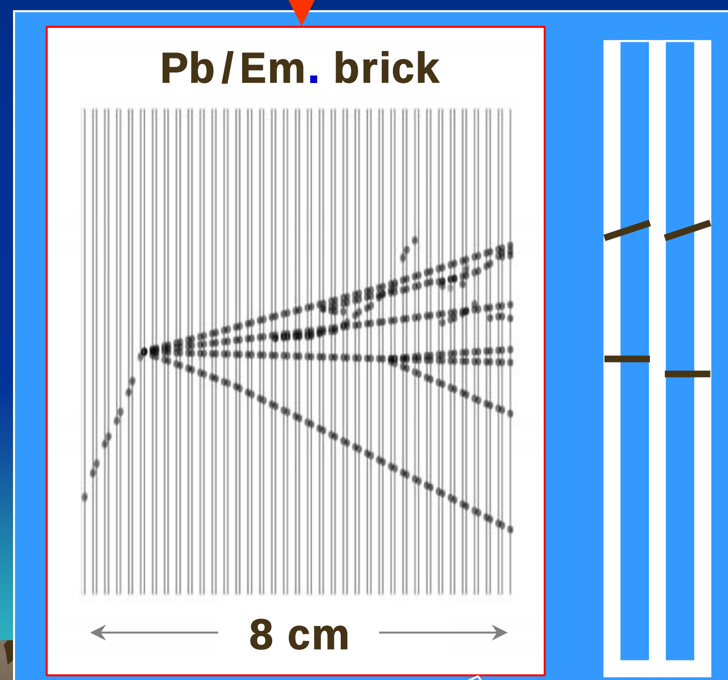
Target Tracker: trigger and localize the ν interaction (Brick Finding)

Spectrometer: measure μ ID, charge and momentum

ECC: Once individuated the candidate brick will be extracted developed and scanned

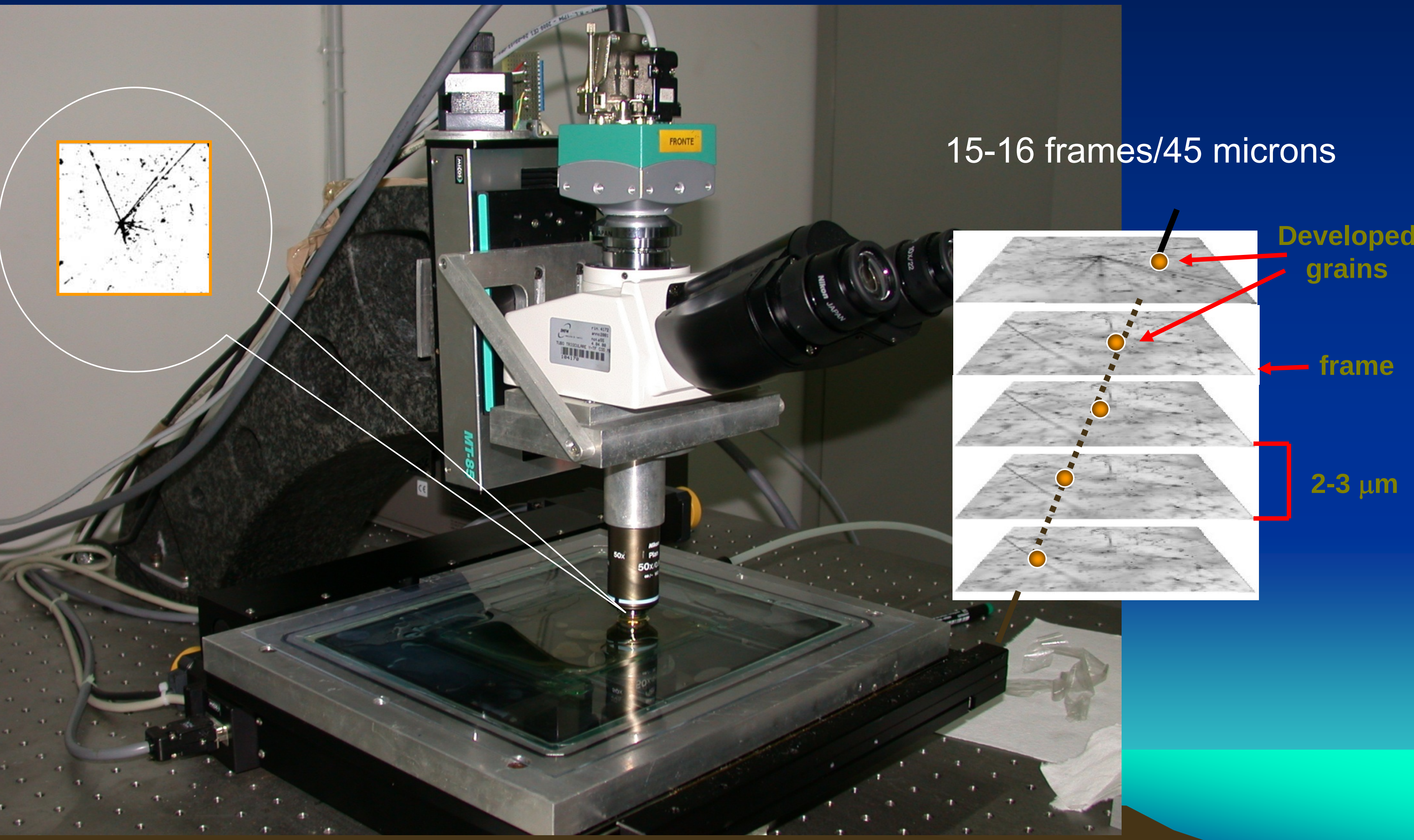
CSD: Changeable Sheet Doublet – interface emulsions between TT and brick



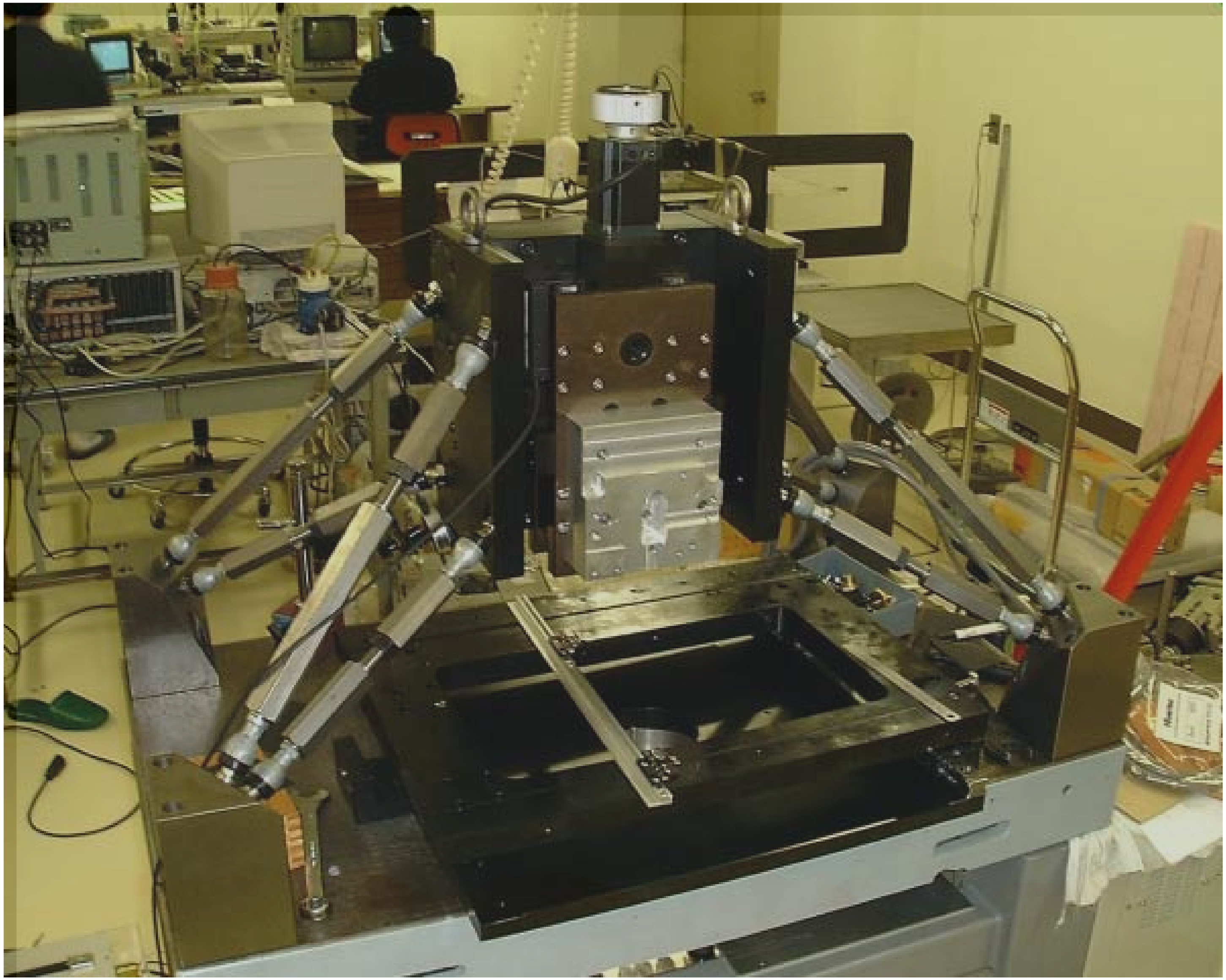


The automatic emulsion scanning

The European Scanning System. About 30 of them installed in the European labs



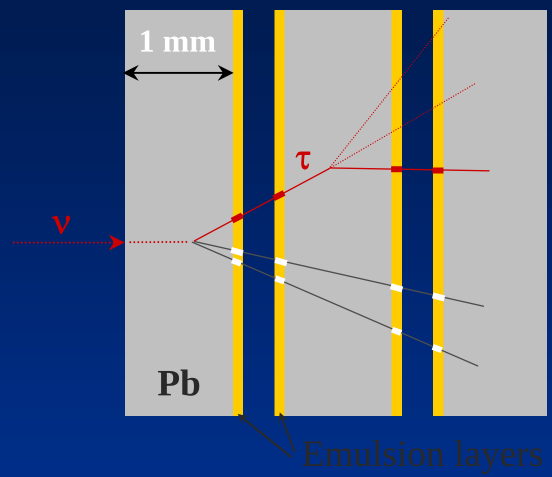
UTS, S-UTS automatic microscopes generation (Japan)



S-UTS:

- Up to 90 cm^2/hour scanning performance
- High speed CCD Camera (3 KHz)
- Objective lens moved by piezo-element
- Dedicated hardware for the reconstruction algorithms

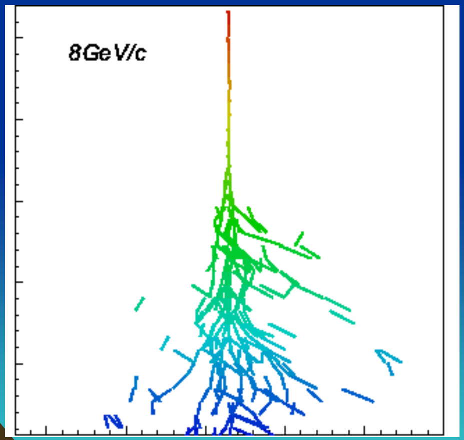
OPERA emulsion target



- Based on the concept of the Emulsion Cloud Chamber (**ECC**)
- **56 Pb sheets 1mm + 57 emulsion plates**
- Solves the problem of compatibility of large mass for neutrino interactions + high space resolution in a completely **modular** scheme

ECC are almost stand-alone detectors:

- Neutrino interaction vertex and kink **topology** reconstruction
- Measurement of the **momenta** of hadrons by multiple scattering
- **dE/dx** pion/muon separation at low energy
- **Electron identification** and measurement of the energy of the electrons and photons



ECC Technique validated by the direct observation of ν_τ:
DONUT 2000

Expected signal and background

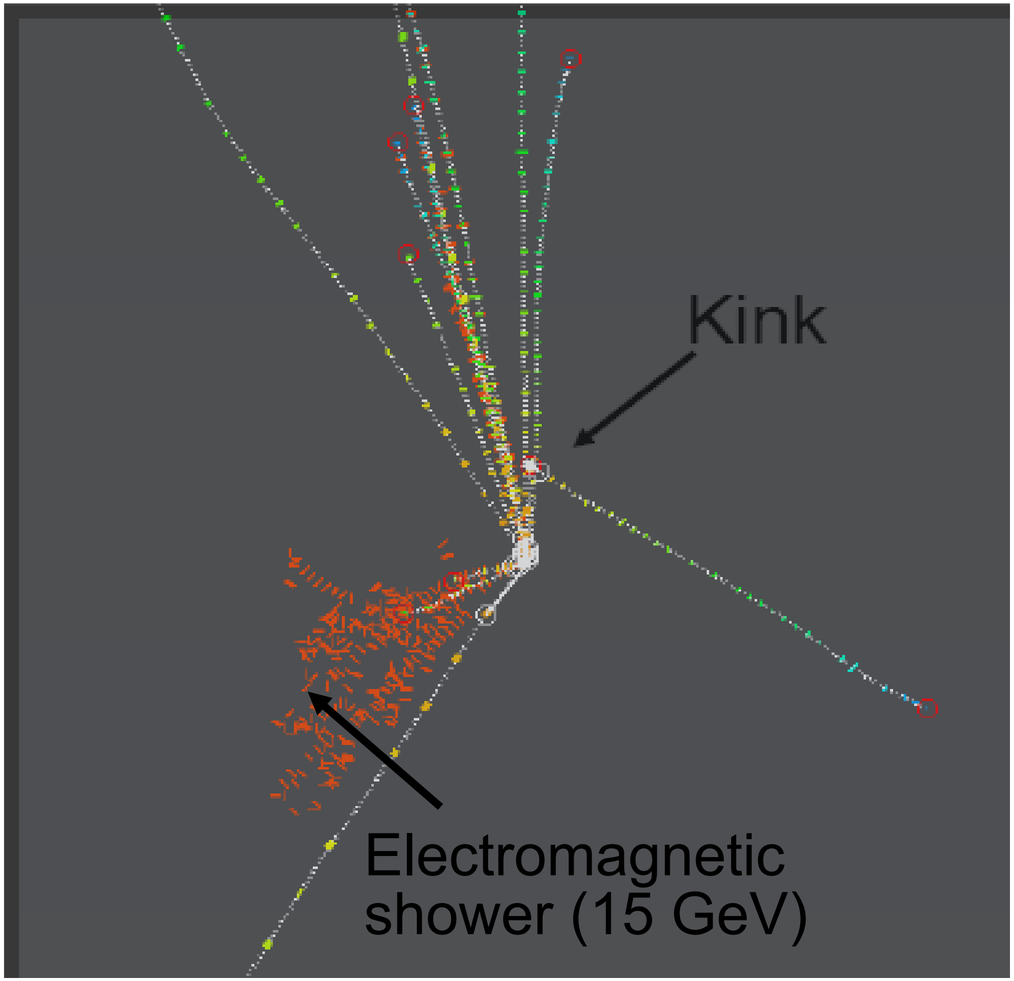
Full mixing after 5 years run at $4.5x10^{19}$ pot / year
Efficiency before τ identification: $\varepsilon_{trigger}$ x ε_{brick} x ε_{geom} x $\varepsilon_{vertex\ location}$
99% x 80% x 94% x 90%

τ decay channels	ε(%)	BR(%)	Signal $\Delta m^2 = 2.5 \times 10^{-3}\ eV^2$	Signal $\Delta m^2 = 3.0 \times 10^{-3}\ eV^2$	Background
$\tau \to \mu$	17.5	17.7	2.9	4.2	0.17
$\tau \to e$	20.8	17.8	3.5	5.0	0.17
$\tau \to h$	5.8	49.5	3.1	4.4	0.24
$\tau \to 3h$	6.3	15	0.9	1.3	0.17
ALL	$\varepsilon \times BR = 10.6\%$		**10.4**	**14.9**	**0.75**

Background sources:
.Charm production and decays
.Hadron re-interactions in lead
.Large-angle muon scattering in lead

Occurs if primary muon is not detected and possible wrong charge measurement of secondary muon. **Muon ID is very crucial issue for the experiment!**

2007 Run: a charm candidate !



Trk	TX	TY	IP	Momentum(GeV)	Comment
1	0.005	0.036	3.30	$1.7^{+0.5}_{-0.3}$	
2	0.005	0.139	1.01	-	parent
3	0.002	0.064	6.64	>20.0	SB
4	-0.021	0.064	7.15	$2.1^{+0.7}_{-0.4}$	SB
5	-0.029	0.046	2.83	>8.4	SB
6	-0.031	0.064	7.32	$2.4^{+0.8}_{-0.5}$	SB
7	-0.076	0.068	4.19	$1.8^{+1.6}_{-0.6}$	SB
8	-0.089	0.141	6.88	$2.5^{+1.4}_{-0.7}$	
9	-0.183	0.106	5.39	$0.7^{+0.2}_{-0.1}$	
10	-0.297	-0.143	19.17	$0.7^{+0.3}_{-0.1}$	
11	-0.067	0.008	7.26	$3.5^{+3.6}_{-1.2}$	e-pair
12	-0.069	0.005	16.80	$2.0^{+3.1}_{-0.8}$	e-pair

Secondary Vertex

Daughter momentum = $3.9^{+1.7}_{-0.9}$

θ kink = 0.204 rad

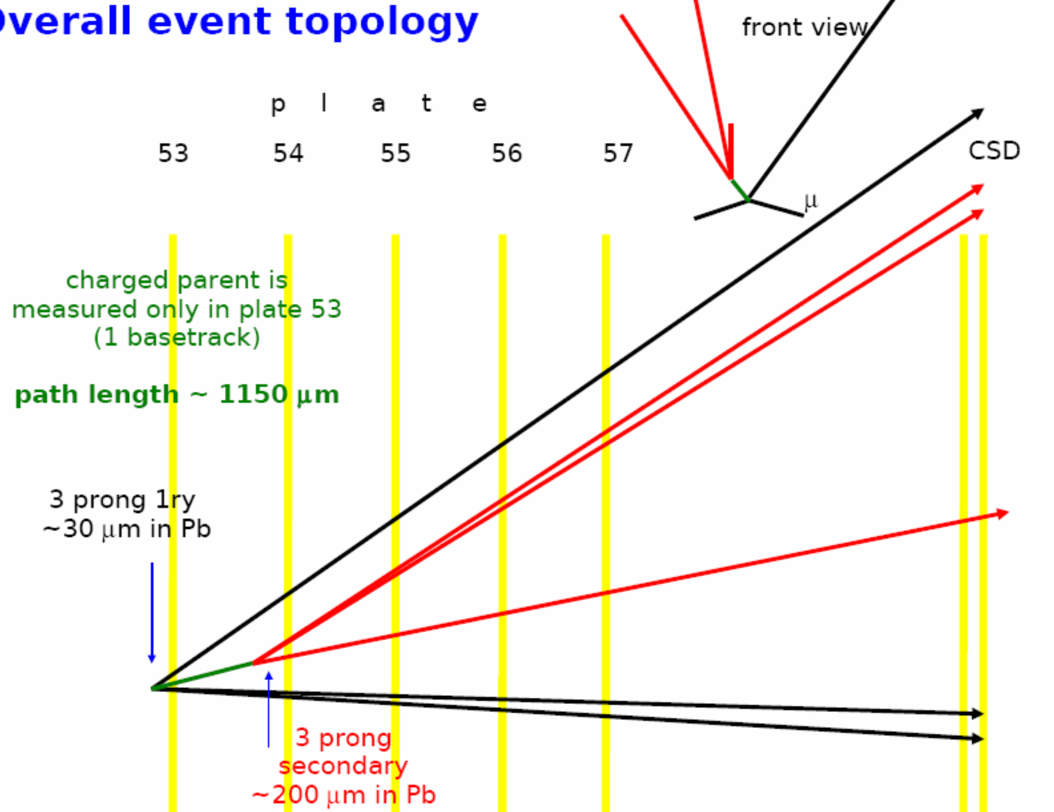
Flight length = 3247 μm

P_t = 796 MeV

P_t^{MIN} = 606 MeV (90% C.L.)

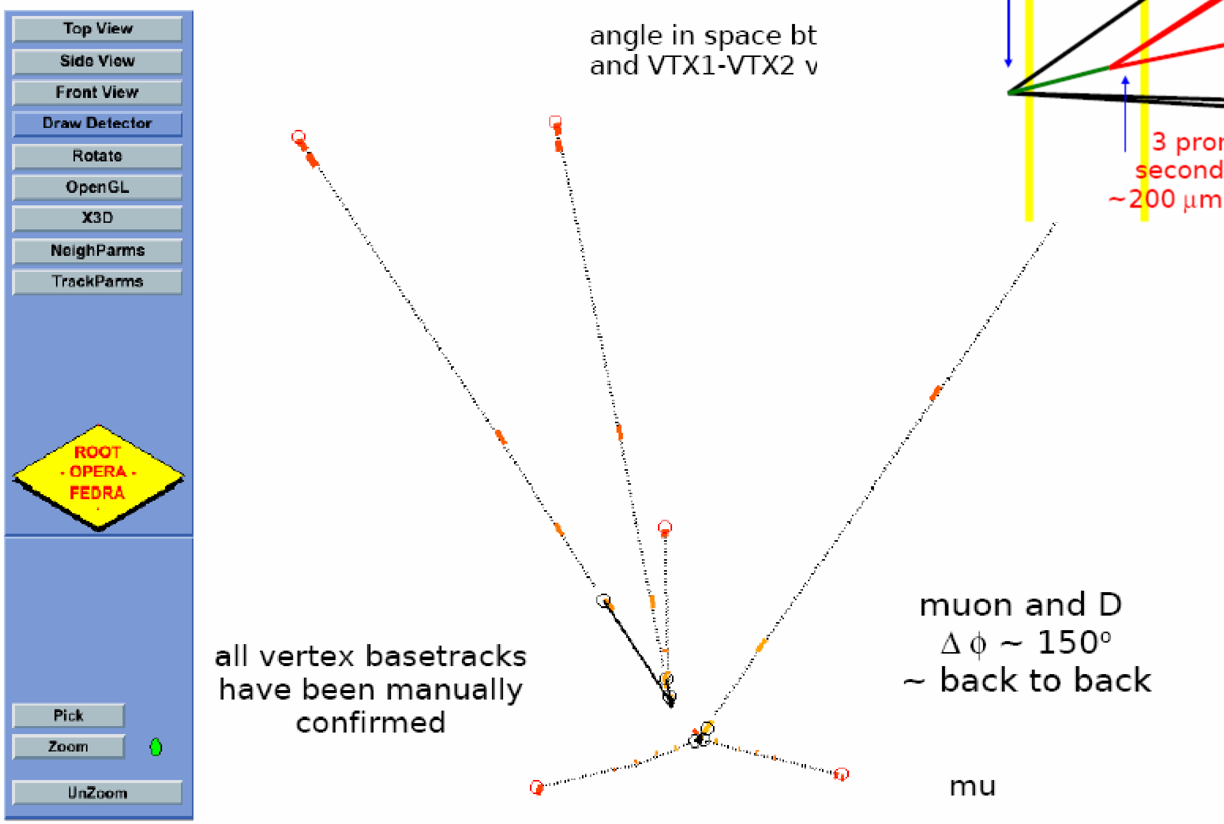
2008 Run: Example of another charm event

Overall event topology



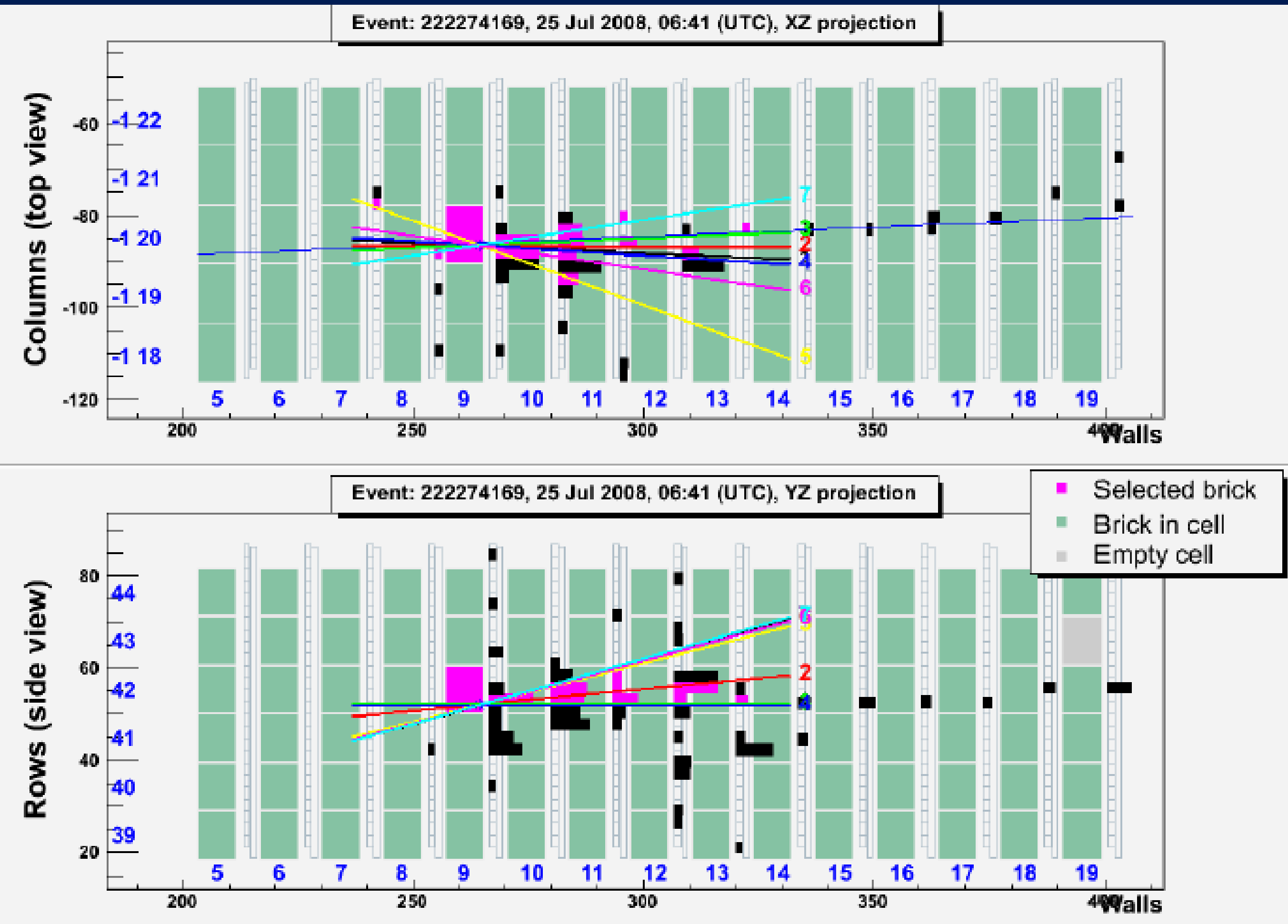
event CC 222274169, bri

front view



D+ - favored topology
(preliminary)

How this event looks like in the electronic detectors:
Tracks found in the emulsion brick are superimposed to the target tracker hits



Brick finding information: Super module 2

	BrickId	Wall	Side	Column	Row	Prob	CS x	CS y
brick 1:	1127653	9	-1	20	42	0.82	-1.0	-1.0
brick 2:	1127679	9	-1	20	41	0.11	-1.0	-1.0
brick 3:	1127757	10	-1	20	42	0.06	-1.0	-1.0

Muon track parameters: Mu-
Momentum: 4.666 GeV/c
Angle XZ (rad): 0.041+/-1.571
Angle YZ (rad): N/A

2007 Run

- We expected 32±6 interaction events in bricks, divided in 75% CC and 25% NC
- We found 38 events, divided in 29 CC (76%) and 9 NC (24%)
- The 38 events were shared in Europe (19) and Japan (19)
- Here is reported the status of the European bricks:

All events	19
Events confirmed in the Csd	18
Events not confirmed in the Csd	1
Events located in the bricks	15
Interactions in dead material	2
Analysis in progress	1

← Muon passed between two bricks

2008 OPERA Run schedule

- Started since June 18th
- Almost 20 weeks of beam are provided for the OPERA experiment
- Expected beam performance for the 2008 run:

Number of days	123
Efficiency	80%
Intensity (p.o.t./extraction)	$2x10^{13}$
Cycles per super cycle	3
Super cycle duration	48s (50%) + 42s (50%)
Integrated p.o.t.	$2.28x10^{19}$
Interactions rate (per week)	~120

- Expected interactions are:

~ 2200 ν_μ interactions
~ 10 ν_τ CC $\rightarrow$ 1 event considering efficiency

Observation of the 1st τ event ??

RUN 2008 status

OPERA is taking data now!

- Slow start with **1.0×10^{19}** achieved the 1st Oct with a delay with respect to schedule
- Since 6-Oct – high duty cycle was implemented (all SPS protons send to CNGS in this period)
- With the new rate the scheduled numbers can be achieved by the end of the run
- The total number of pot delivered so far (19-Oct-08) is **1.40×10^{19}**. This corresponds to 7827 on time events and 1329 candidate interactions in OPERA bricks
- Most of the candidate bricks have been extracted
- Emulsion scanning and reconstruction becoming the major task now

Summary of the OPERA status

- The OPERA detector is essentially completed and it is now massive with 1.3 kton of lead-emulsion target
- Emulsion scanning laboratories and infrastructures are operational
- In 2007: first CNGS neutrino run:
  - Test and tuning of electronic detectors, brick finding algorithms and scanning strategy
  - Validation of reconstruction software and analysis tools
  - 38 neutrino events collected
  - The concept of the OPERA detector has been successfully validated!
- Now: run 2008 started since June 18th, 123 days of data taking
  - So far collected 1.4x10^{19} p.o.t. and 1329 candidate interactions in the emulsion target

Future: possible CNGS improvements

In respect to the nominal intensity of 4.6×10^{19} pot/year

- Near future (actually present) almost x2 due to modification of the duty cycle and the beam sharing (probably will not be possible when LHC restart)
- After 2016 – possible SPS upgrade and up to x5 increase of CNGS intensity

M. Meddahi, E. Shaposhnikova CERN-AB-2007-013 PAF

Table 7: Protons on target per year [$\times 10^{19}$] for 200 days of operation with 80% machine availability

		SPS cycle length	6 s		4.8 s	
		Injection momentum	14 GeV/c		26 GeV/c	
		Beam sharing / Max SPS intensity @ 400GeV [$\times 10^{13}$]	0.45	0.85	0.45	0.85
"short term" multi-turn extraction ecc	Present injectors + machines' improvement	4.8 – "Nominal CNGS"	5	9.4		
		5.7- "Max. SPS"	5.9	11.1		
after 2016	Future injectors + SPS RF upgrade	7 – "Ultimate CNGS"			9	17.1
	Future injectors + new SPS RF system + CNGS new equipment design	10 – "Max. PS2"			12.9	24.5

Units 10^{19} pot

factor ~ 5 possible

Next generation experiments

- Motivation: to develop a precision tools for neutrino mixing study sensible to:
  - Theta 13 determination
  - Leptonic CP violation
  - Neutrino mass hierarchy
  - Quantitative theory improvements

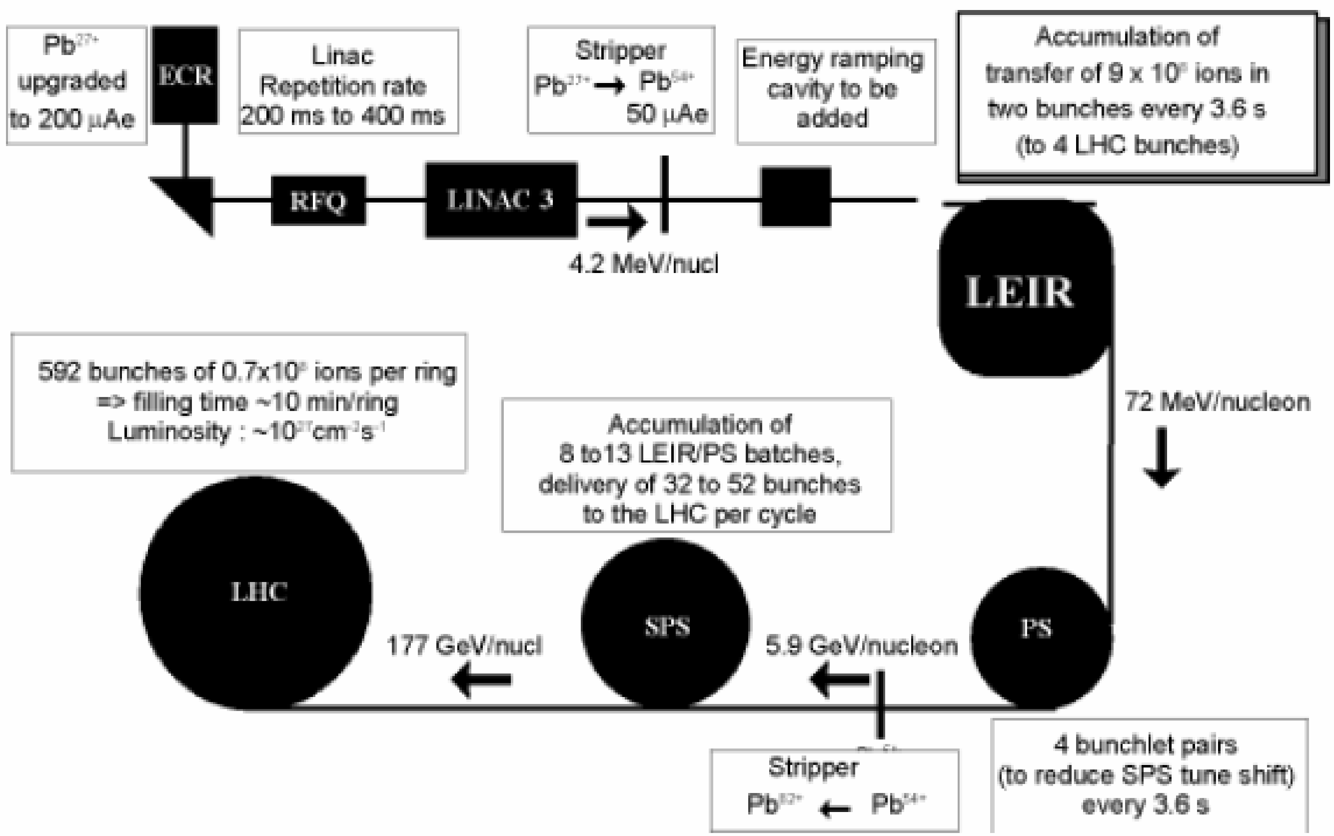
- Neutrino sources under discussion
  - Super beam (high pot, PI, K decay)
  - Neutrino factory   (high pot, Muons decay)
  - Beta beam (Ions beam storage, beta-decay)

General requirements

- For the beam source:
  - Very high intensity
  - Very low intrinsic background (possibly monochromatic ν beam)
  - Control of the systematics
- For the detectors:
  - Huge active mass 0.1-1 Mton
  - Charge ID (magnetic field when possible)
- Detector candidats:
  - Water or liquid scintillator
  - Liquid argon (ICARUS-like – Modular project)
  - Magnetized Iron with plastic scintillator or with emulsion

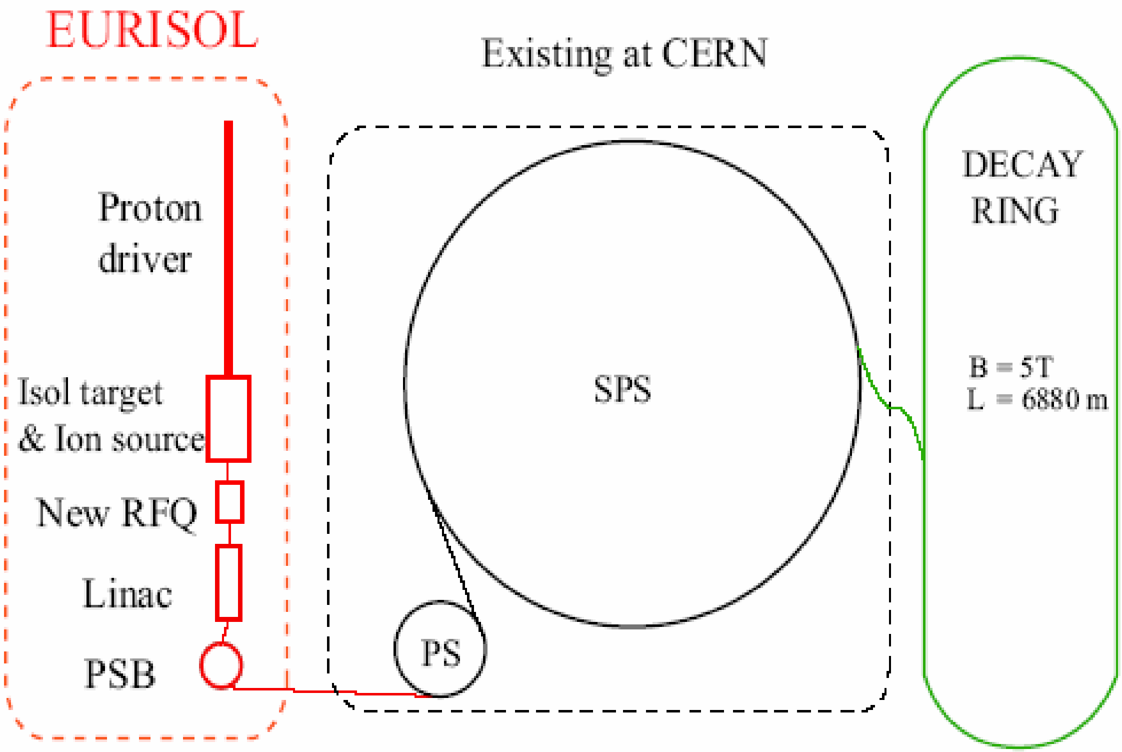
CERN can be a good place for the beta-beam

A beta beam facility would share many features (and much equipment) with the heavy ion programme at LHC.



Beta beam: P. Zucchelli: Phys. Lett. B532:166, 2002

see M. Lindroos et al., http://beta-beam.web.ch/beta-beam



- 1 ISOL target to produce He^6, 100 μA, $\Rightarrow 2.9 \cdot 10^{18}$ ion decays/straight session/year. $\Rightarrow \overline{\nu}_e$.
- 1 ISOL target to produce Ne^{18}, 100 μA, $\Rightarrow 1.1 \cdot 10^{18}$ ion decays/straight session/year. $\Rightarrow \nu_e$.

Low energy & short baseline beta beam

SPS can accelerate $^6\mathrm{He}$ up to $\gamma = 150$ $\Rightarrow$ baseline up to 300 km. Frejus is the only realistic possibility to accomodate a Megaton detector, 130 km away from CERN. The CERN-Frejus scenario, not necessarely the optimal one, is for $\gamma = 100$ and $L = 130$ km.

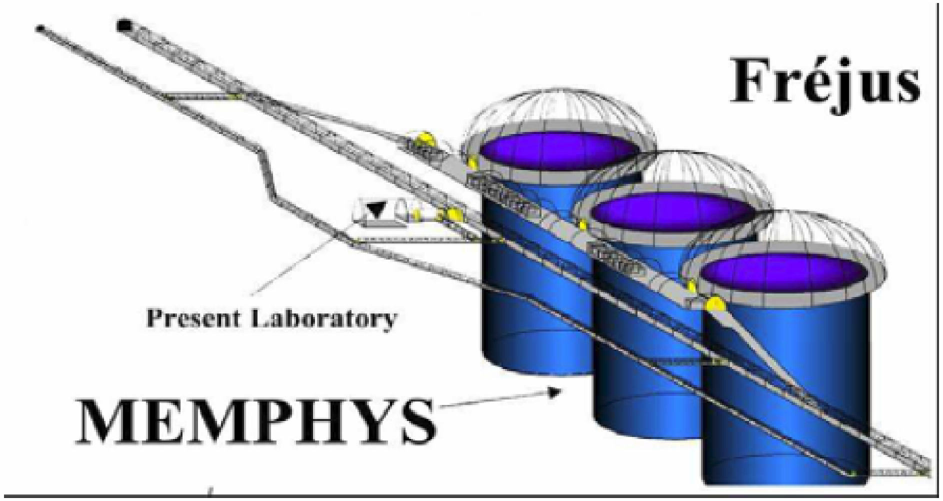
- Absolutely negligible matter effects: the cleanest possible environment for direct leptonic CP violation and θ_{13} searches.
- Almost all the events are quasi elastics.
- Reasonable energy shape information.
- Degeneracies don't influence θ_{13} and LCPV discovery potential.

On the other hand

- Mass hierarchy cannot be directly measured. A not trivial sensitivity on $\mathrm{sign}(\Delta m^2_{23})$ can however been recovered combining accelerator neutrino signals with the atmospherics' (see the following).
- Small cross sections, loosely known and with important influence of nuclear effects.

- Beta beam can have the same energy spectrum as SPL superbeam
- both beams can fire to the same detector (LCPV searches)
- plus atmospherics: degeneracy removal:
  (Campagne, Maltoni, Mezzetto Shweitz, JHEP 0704 (2007)

The Memphys detector (hep-ex/0607026)



At a depth of 4800 m.w.e at the Frejus tunnel.
It's possible to excavate up to five shafts of about 250,000 m^3 each (ϕ = 65 m, full height=80 m).

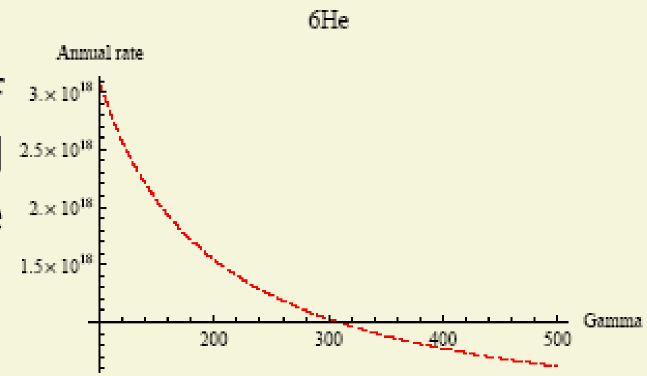
Fiducial of 3 shafts: 440 kton.

30% coverage by using 12" PMT's from Photonis, 81k per shaft (equivalent in photostatistics to SK)

High energy beta-beam option can be possible with SPS upgrade to 1 Tev (*γ =300)*
In this case existing LNGS laboratory can be used to accommodate
Iron-RPC 40 kton detector (Domini et.al. EPJC(2006))

J. Burguet-Castell et al., Nucl. Phys. B **695**, 217 (2004), Nucl. Phys. B 725, 306 (2005)
F. Terranova et al., EPJC 38 (2004) 69. A. Donini et al., EPJC 48 (2006) 787.
P. Huber, M. Lindner, M. Rolinec and W. Winter, Phys. Rev. D 73,053002, 2006
S. Agarwalla, S. Choubey, A. Raychaudhuri, Nucl. Phys. B **771** (2007) 1
D. Meloni, O. Mena, C. Orme, S. Palomares-Ruiz and S. Pascoli, arXiv:0802.0255 [hep-ph].
W. Winter, arXiv:0804.4000 [hep-ph].

- Need a proton machine of 1 TeV energy (LHC cannot be used at such high fluxes), only possible candidate: SPS+: an upgrade of SPS studied in view of a possible energy upgrade of LHC.
- Assume the same ion decay rates of the SPS option. Requiring an improved decay ring configuration, otherwhile decay rates scale inversely to the ion γ

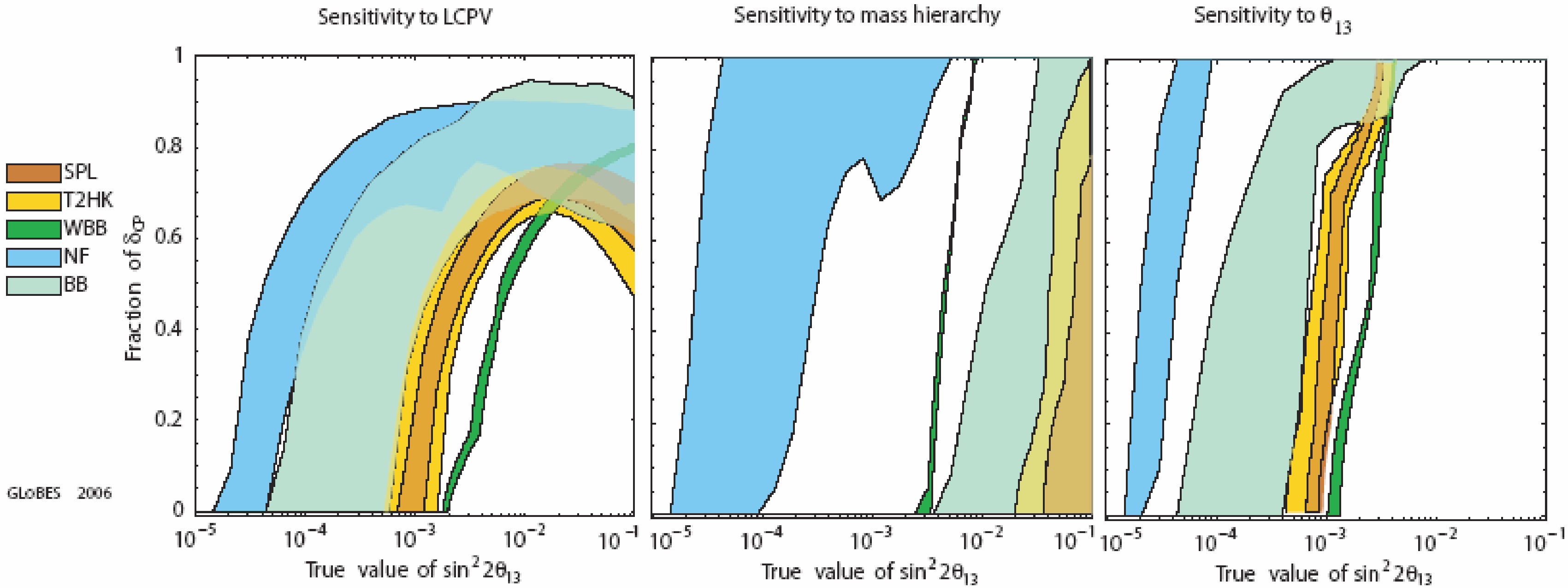


- The decay ring length rises linearly with $\gamma \rightarrow$ high energy Beta Beams require developments of high field, big aperture, radiation hard superconducting magnets to keep short the decay ring.

Beta Beams vs Neutrino Factory

Comparison made within the International Scoping Study (ISS) framework, arXiv:0710.4947 [hep-ph]. (Not including $^8\mathrm{B}\,/^8\mathrm{Li}\,\beta$B)

Line widths reflect different possible assumptions about machin configurations, neutrino fluxes, detector performances, systematic errors.



EUROnu and the IDS-NF

K.Long Oct-2008

- EUROnu *is* the European contribution to the IDS-NF

EURONu

SB

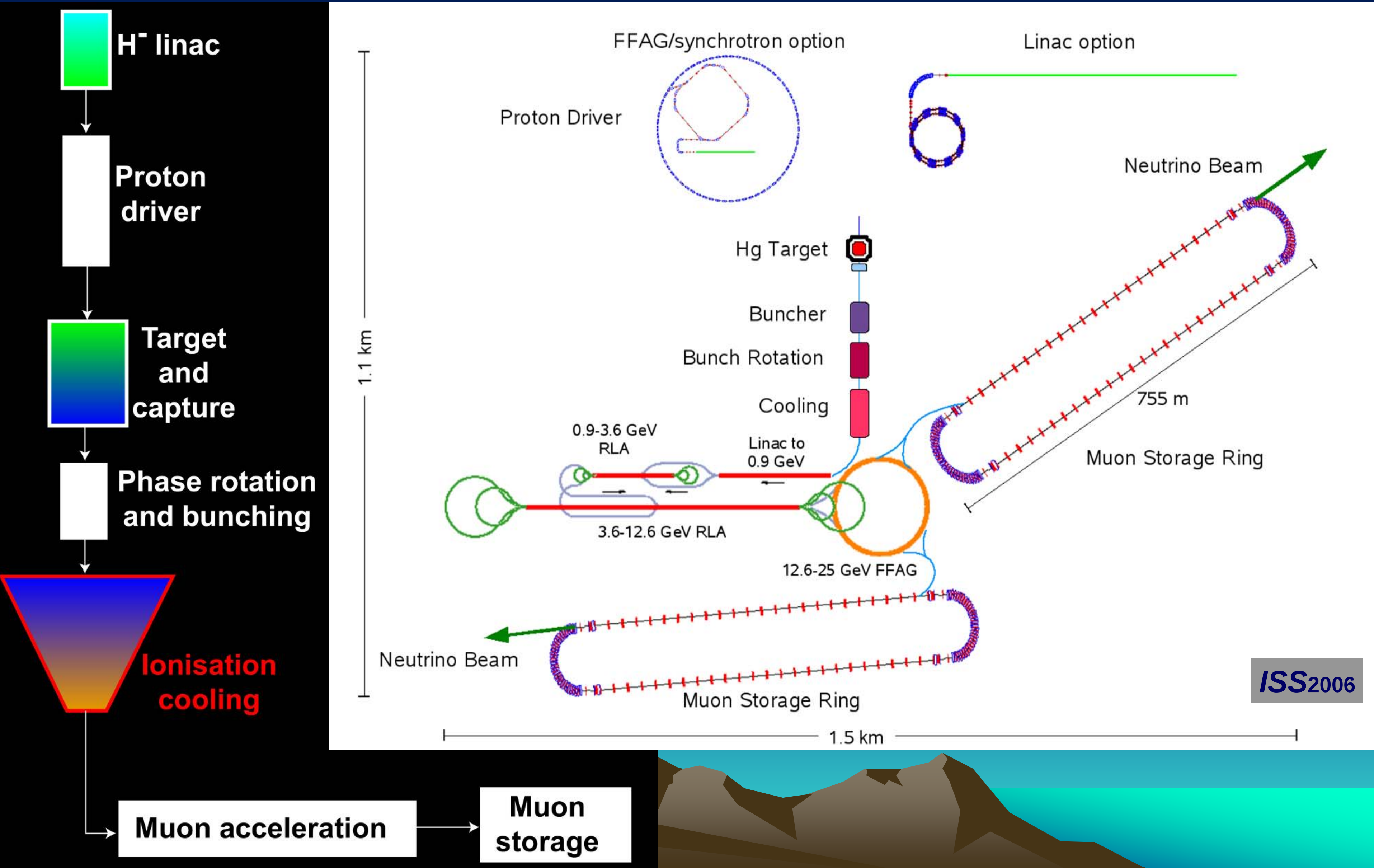
BB

NF

IDS-NF

- **The Americas**
  - **Canada**
  - **USA**
- **Asia**
  - **Japan**
  - **India**
  - **(in the future: China …)**
- **Europe**
  - **EURONu**

IDS-NF baseline accelerator design



EUROnu: goals

- Produce ‘CDR’ for:
  - Super-beam
    - Consider SPL → Frejus
  - Beta-beam
  - Neutrino Factory
    - EUROnu coordinates/provides European contributions to IDS-NF
- ‘CDR’ implies:
  - Physics performance of *costed* scenario
  - Conceived as input to cost/performance comparison required at CERN Council Strategy Group 2012 decision point