FOURTEENTH LOMONOSOV CONFERENCE ON

ELEMENTARY PARTICLE PHYSICS

Moscow, 19 - 25 August, 2009

Neutrino physics with OPERA

A. Bertolin (INFN - Padova)
on behalf of the OPERA Collaboration

- the OPERA physics goal
- the CNGS beam
- the OPERA detector
- analysis in the electronic detectors
- analysis in the emulsions
- a few interesting events
- summary and outlook

The OPERA Collaboration
150 physicists, 34 institutions in 12 countries

Belgium

Bulgaria

Croatia

France

Germany

Israel
Technion

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

Japan
Aichi
Toho
Kobe
Nagoya
Utsunomiya

Korea
Jinju

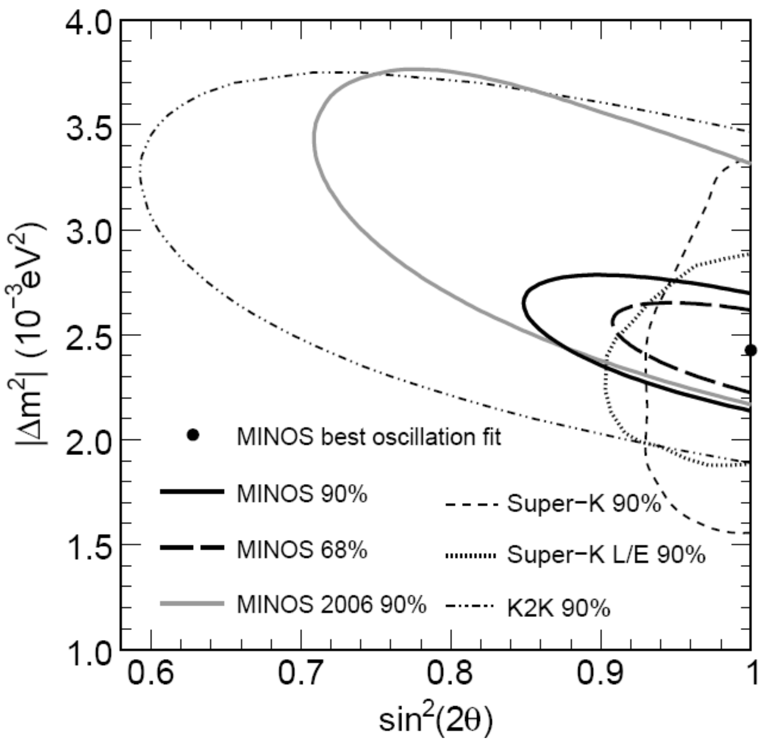
Russia
INR RAS Moscow
NPI RAS Moscow
ITEP Moscow
SINP MSU Moscow
JINR Dubna
Obninsk

Switzerland
Bern
ETH Zurich

Turkey
METU Ankara

http://operaweb.web.cern.ch/operaweb/index.shtml

• the OPERA physics goal



• Super-K (1998): atmospheric neutrino anomaly can be explained in terms of neutrino oscillations

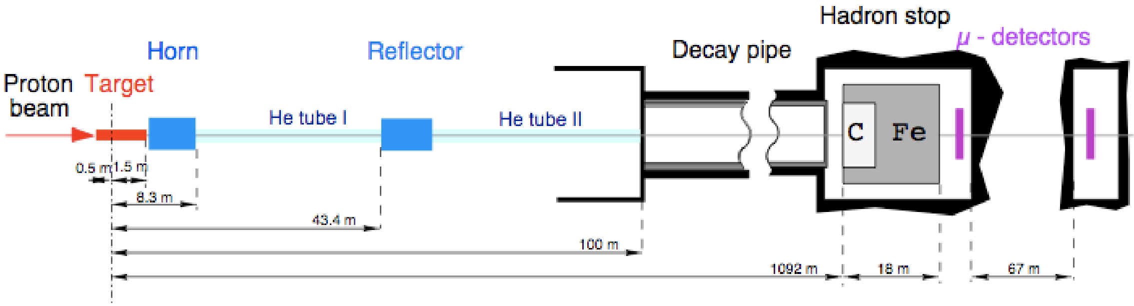
• CHOOZ: $\nu_\mu \rightarrow \nu_e$ oscillations excluded as dominant process responsible for atmospheric neutrino disappearance

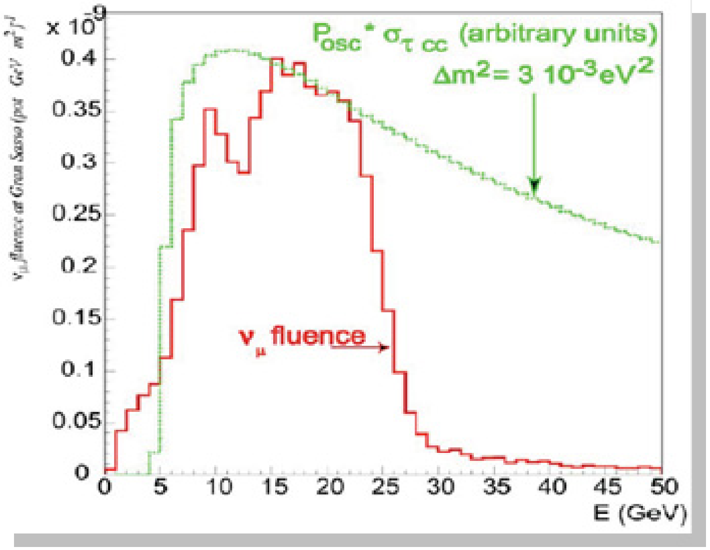
• Super-K ν_μ disappearance signal confirmed by K2K and MINOS

$\Rightarrow \nu_\mu \rightarrow \nu_\tau$ oscillation ?

direct observation of ν_τ appearance from ν_μ oscillation still missing: primary goal of the OPERA experiment

• the CNGS (CERN Neutrino To Gran Sasso) beam





- 400 GeV protons on a graphite target
- 1 km decay tunnel
- ν_μ beam, <E> ~ 17.9 GeV *(Nuclear Physics B 189 (2009) 263)*

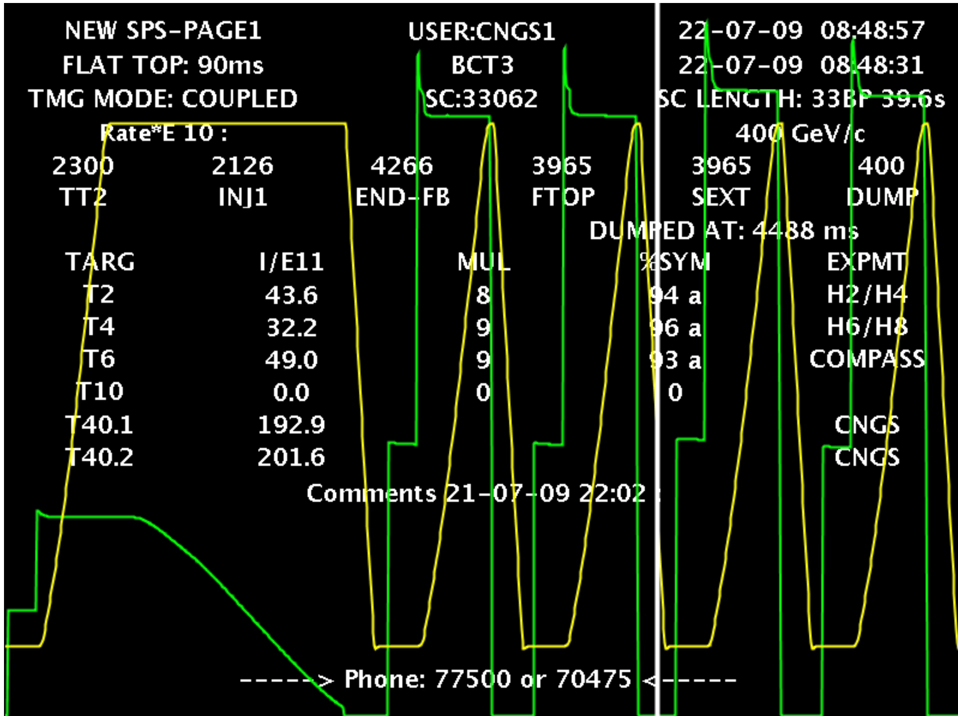
$< E_{\nu_\mu} >$	17 GeV
L(CERN,OPERA)	730 km
L/E	43 km/GeV
$(\nu_e + \overline{\nu}_e) / \nu_\mu$	0.87%
$\overline{\nu}_\mu / \nu_\mu$	4%
ν_τ prompt	negligible

in 5 years of running (200 days / year), 4.5 10^{19} p.o.t. / year (expected intensity), 1.3 kton target (reached) the expected number of produced events is: *(New Journal of Physics 8 (2006) 303 + 1.3 / 1.7 kton)*

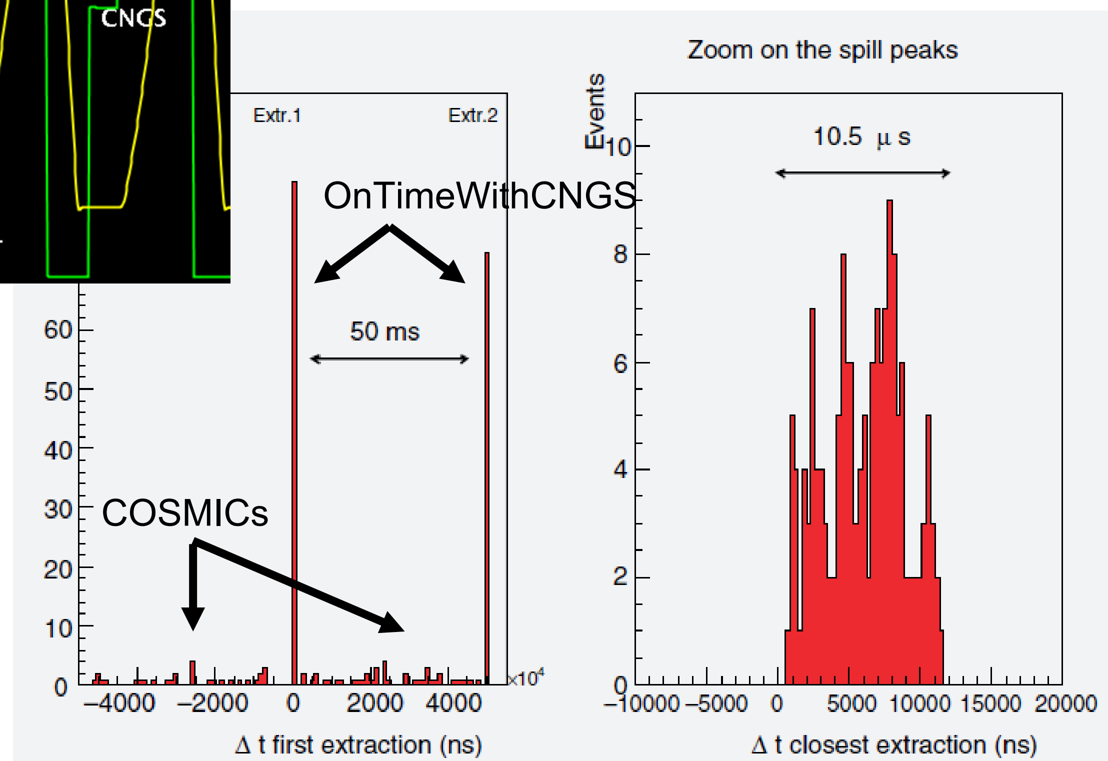
~ 22000 $\overline{\nu}_\mu$ CC + NC

~ 70 - 150 ν_τ CC events (Δm^2= 2 - 3 10^{-3} eV^2 and $\sin^2 2\theta_{23} = 1$

• the CNGS (CERN Neutrino To Gran Sasso) beam

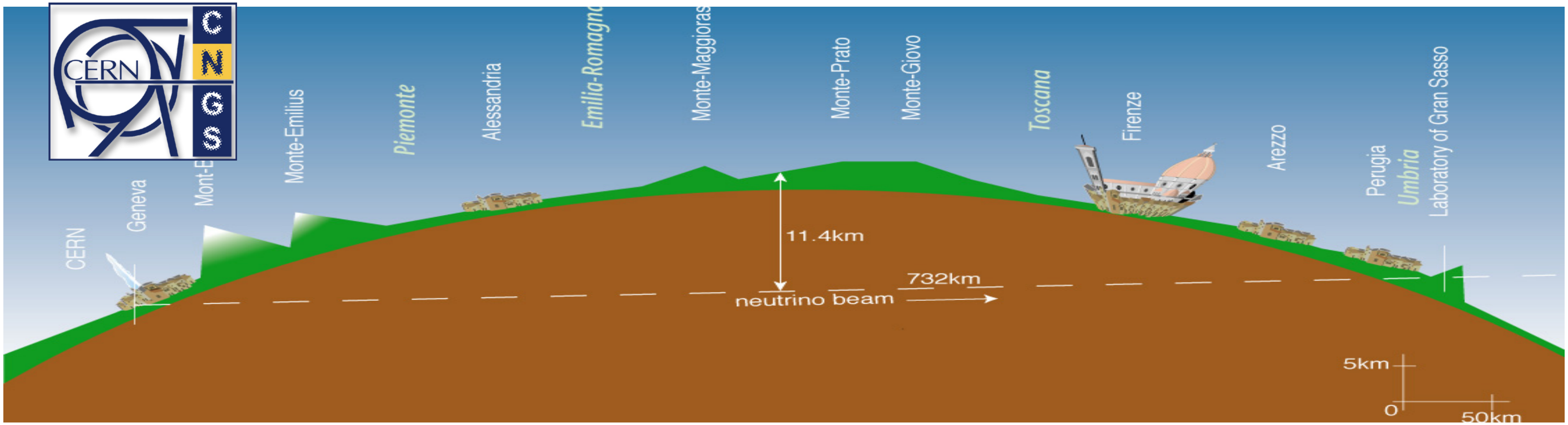


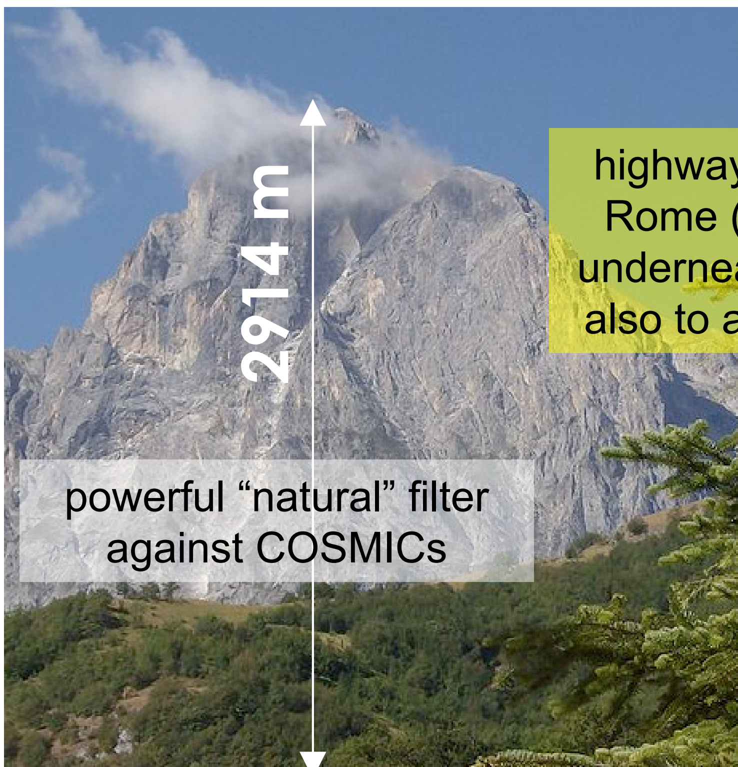
- pulsed ν beam
- 3 (default) to 4 CNGS cycles per SPS supercycle
- each CNGS cycle has two shots, 50 ms apart, each shot lasts 10.5 μs

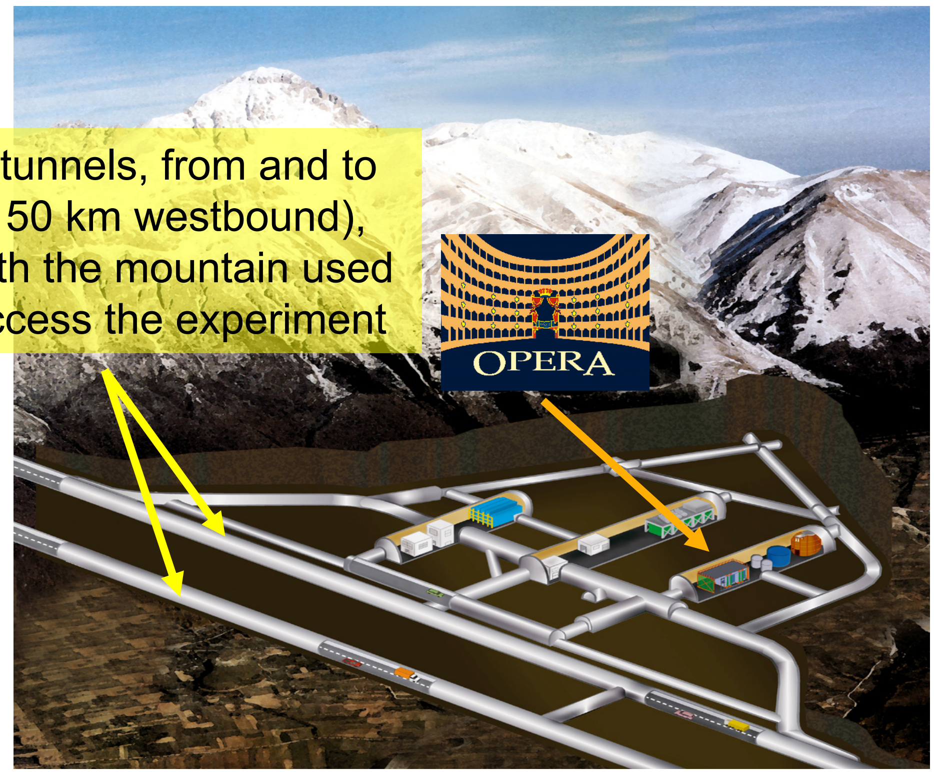


can find out if the recorded events are in time coincidence with the ν beam, on an event by event basis: OnTimeWithCNGS events, the remaining ones are COSMICs

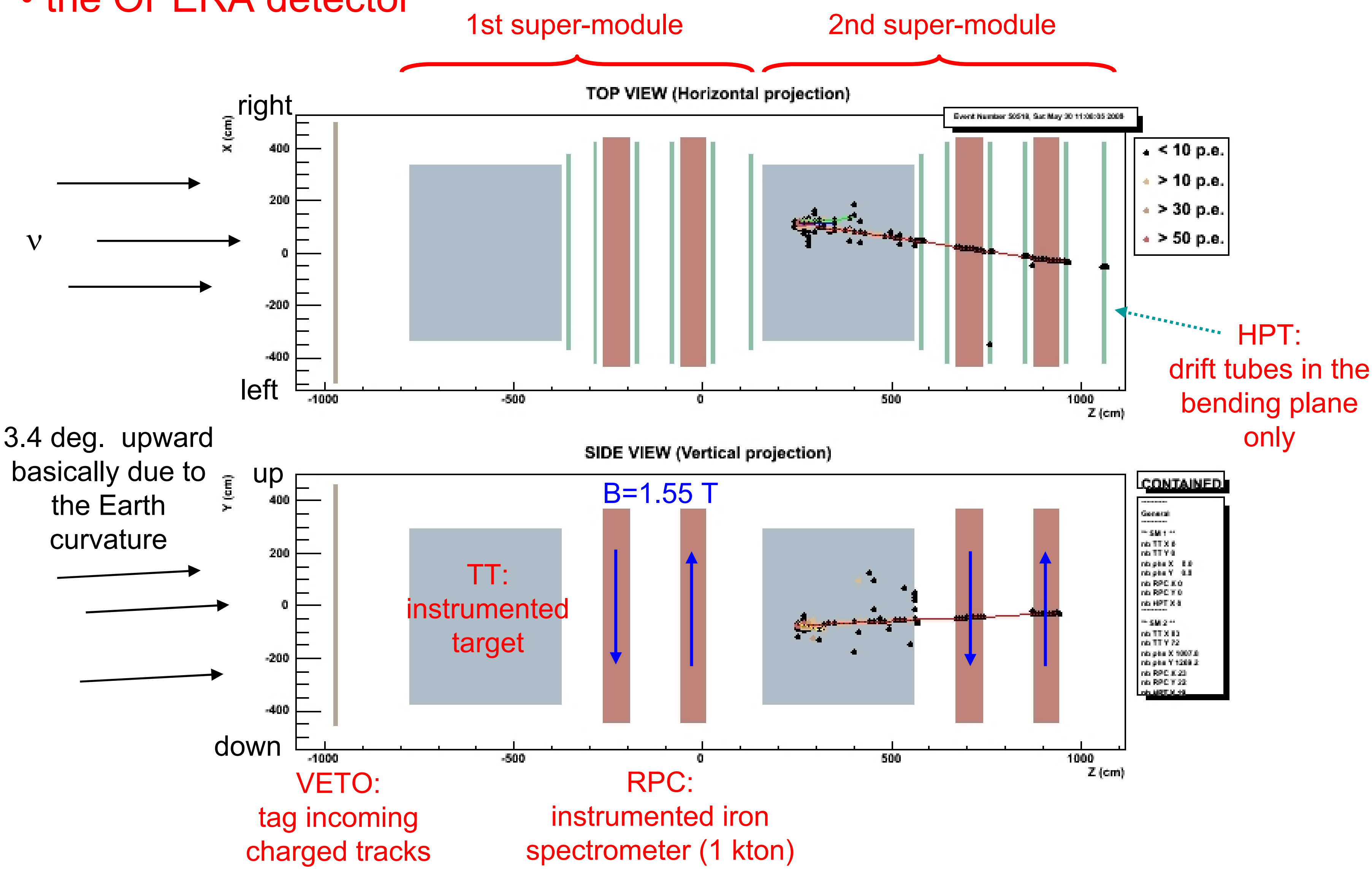
- the CNGS (CERN Neutrino To Gran Sasso) beam







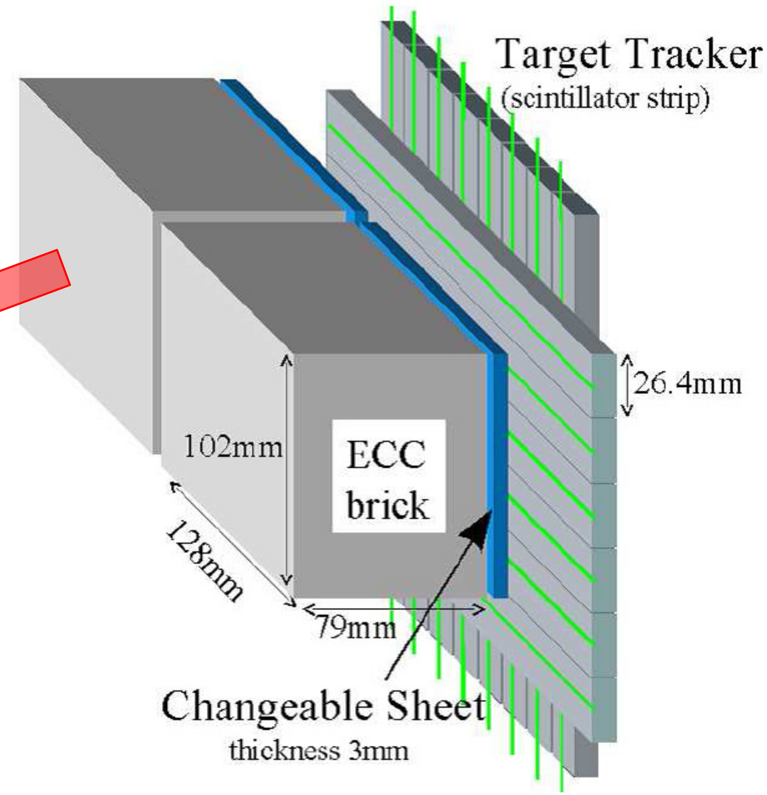
• the OPERA detector

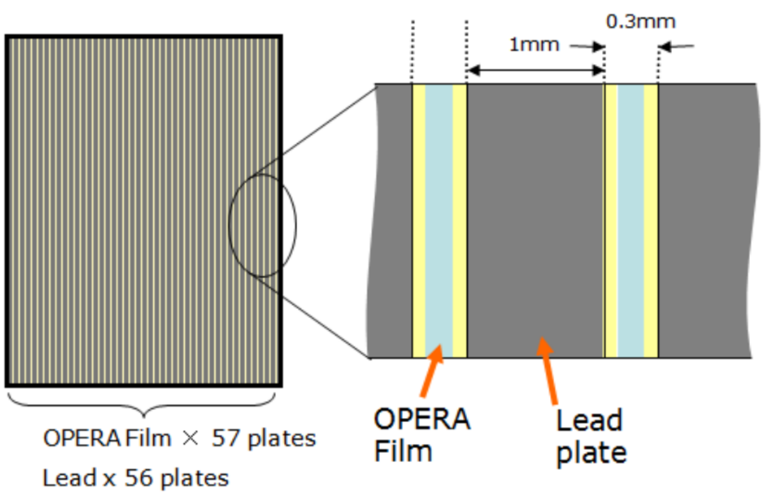


RPC + HPT: identification and momentum measurement of penetrating particles

• the OPERA detector: the instrumented target

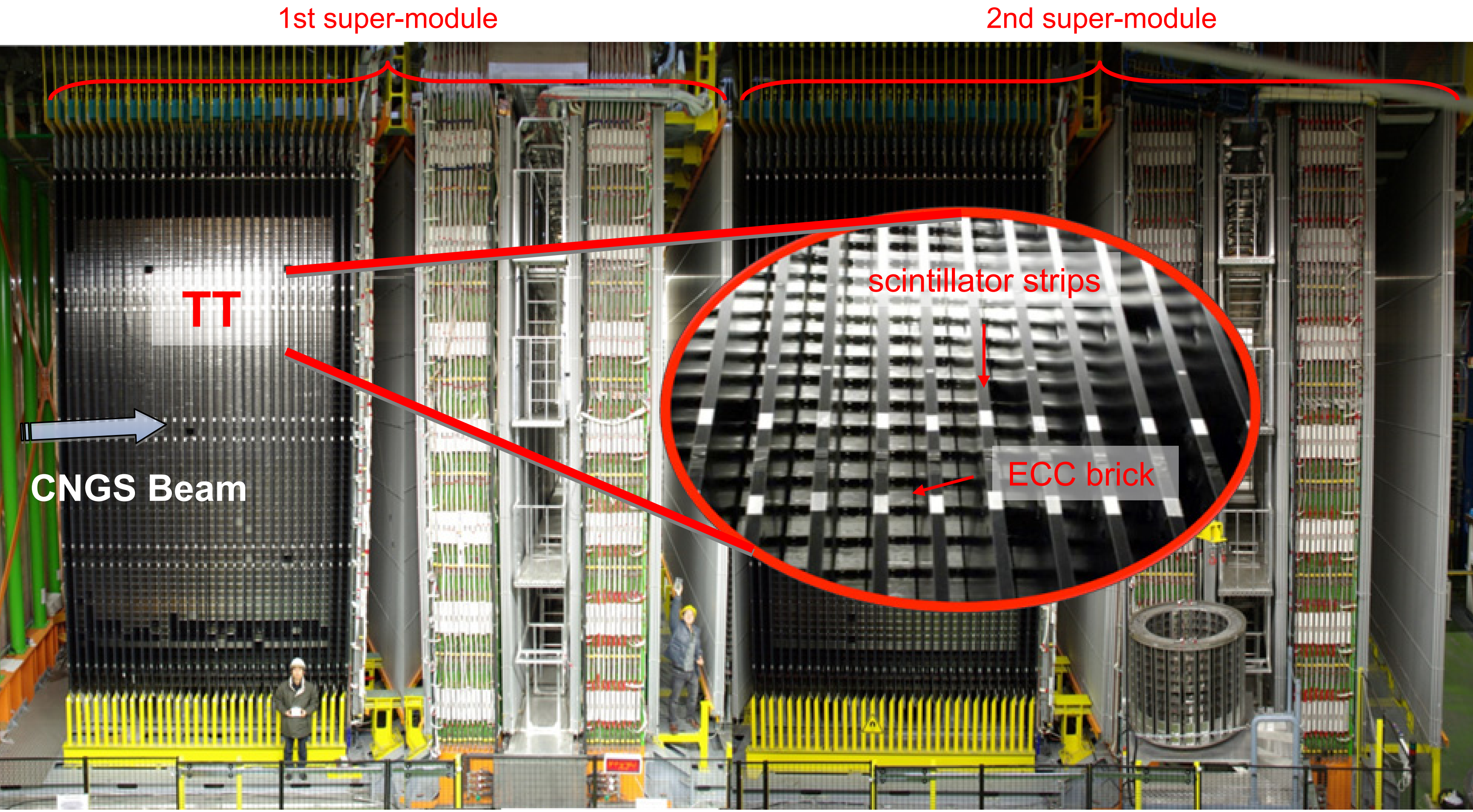
• “passive” material: 75000 ECC bricks arranged in 31 walls in each super-module
• active material: 31 walls of horizontal / vertical crossed scintillator strips: Target Tracker
• TT data, combined with RPC and HPT data, are used to locate the brick containing the primary vertex
• each ECC brick: 57 OPERA films and 56 lead plates + changeable sheet (2 OPERA films), downstream





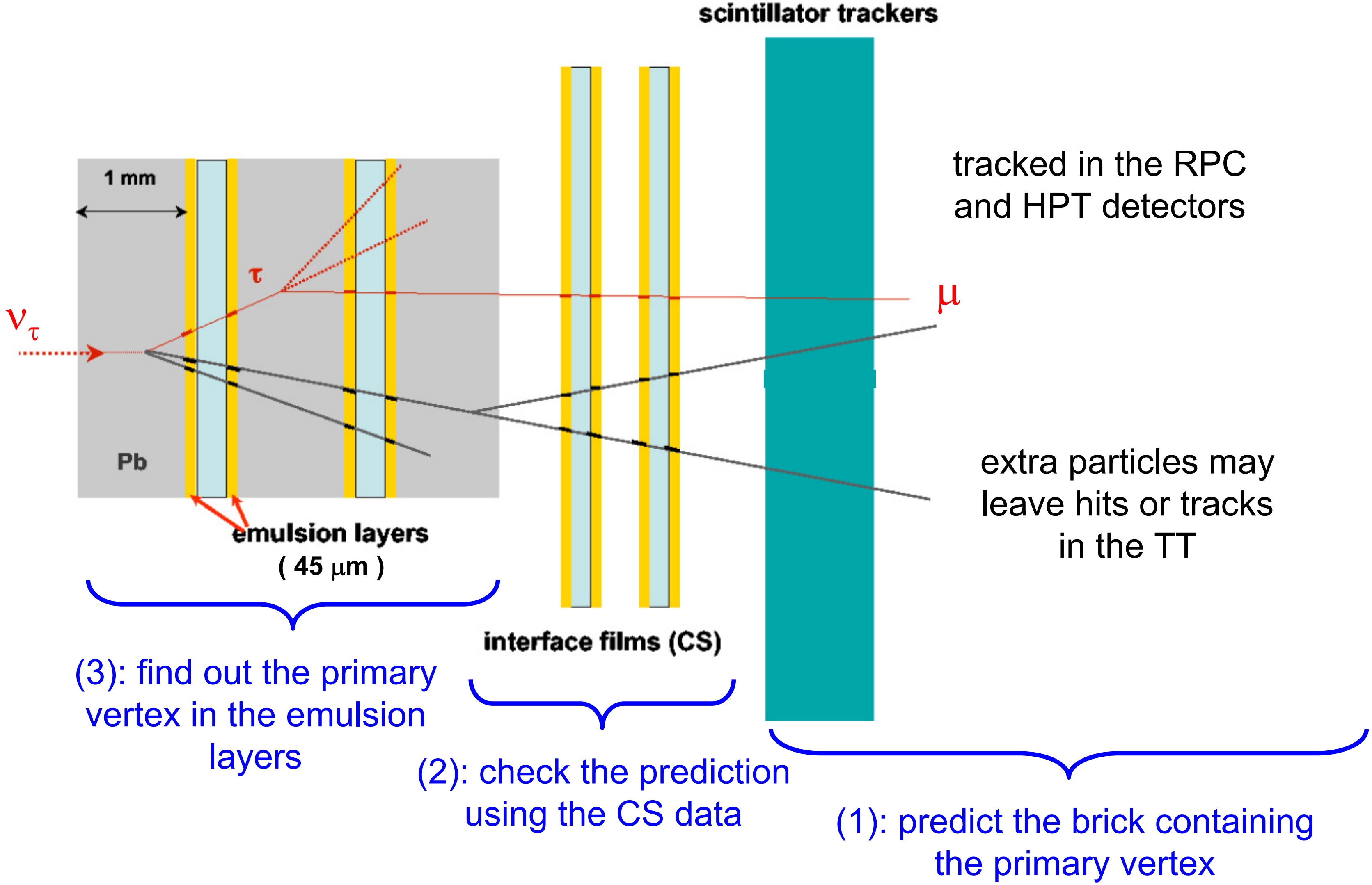
• 0.3 mm OPERA Film plate: 44 μm emulsion + 212 μm plastic base + 44 μm emulsion

• the OPERA detector: the instrumented target



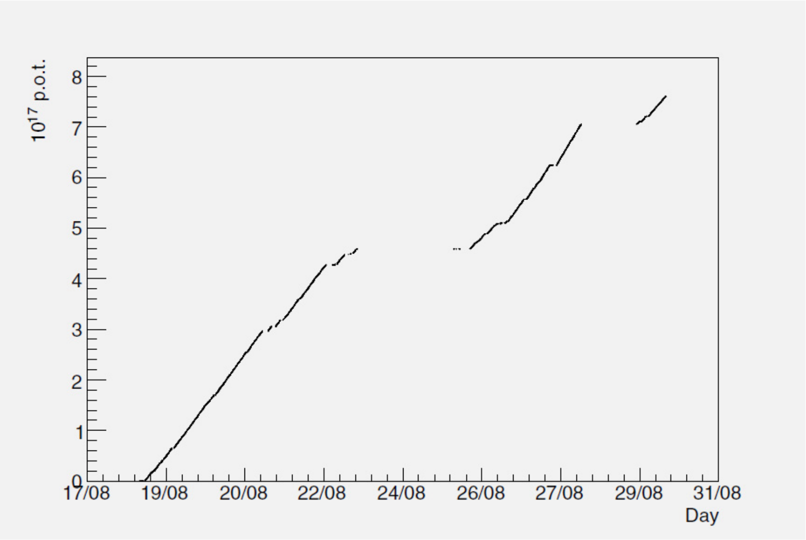
• the OPERA detector: a hybrid detector

$c\tau(\tau) = 87.11\ \mu m$



electronic detectors are used to tag in real time the brick containing the primary vertex, high resolution tracking O(few μm) is performed later on in the emulsion layers of the tagged brick: hybrid detector

• 2006 run (empty target)

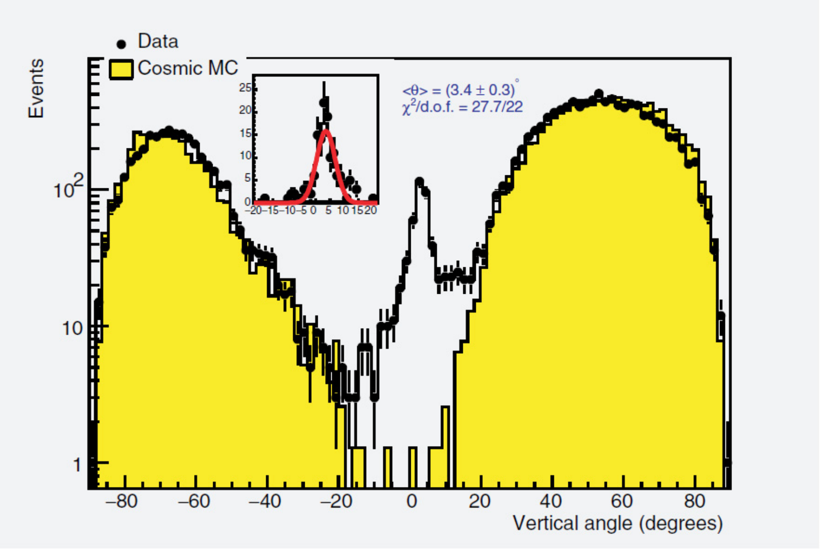


• overall ~ 10 days of running

• 7.6 10^{17} p.o.t.

• empty target

analysis in the electronic detectors:

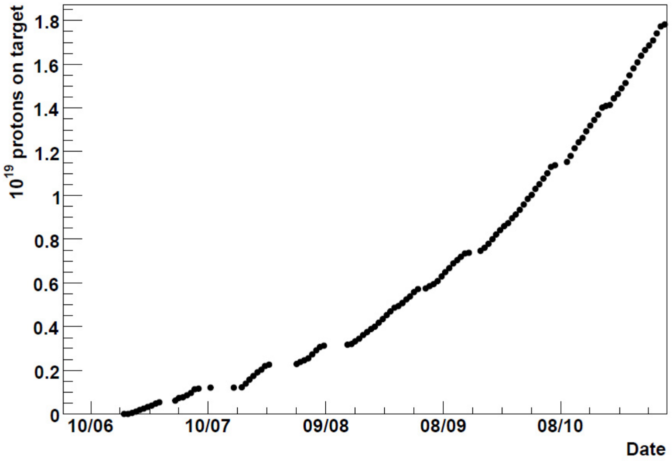


• useful mostly for the electronic detectors
• could see the peak at 3.4 deg. (exp. 3.3) due to beam induced μ tracks on top of the COSMICs background
• all COSMICs gone requiring the OnTimeWithCNGS tag (see insert)

• 2007 run (target half filled)

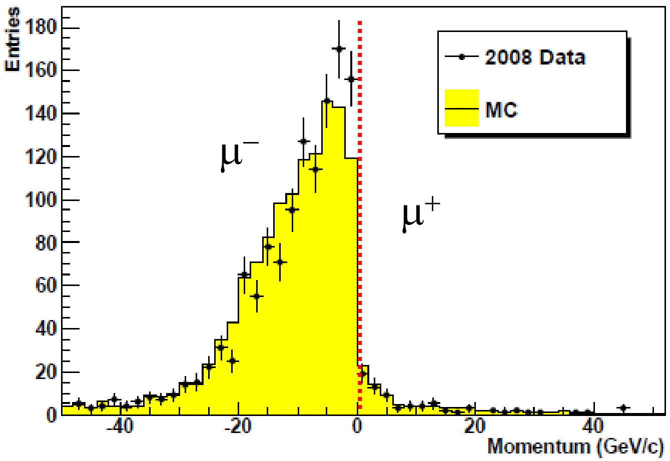
• CNGS operation started on September 2007 at rather low intensity
• unfortunately, due to a fault of the CNGS facility, the physics run lasted only a few days
• 0.082 10^{19} p.o.t. were accumulated (~ 3.6 effective nominal days of running)
• 465 OnTimeWithCNGS events recorded, 35 occurring in the target region

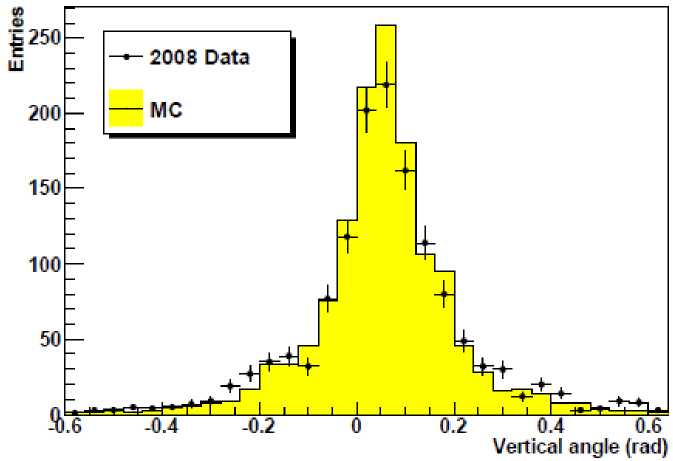
• 2008 run (target almost fully filled)



• June – November period
• got about 1.8 10^{19} p.o.t.
(nominal: 4.5 10^{19} p.o.t. / year)
• 10100 OnTimeWithCNGS events, 1663 automatically classified as occurring in the target region

<u>analysis in the electronic detectors:</u>





• mostly μ^-, μ^+ due to the $\bar{\nu}_\mu$ contamination of the CNGS beam

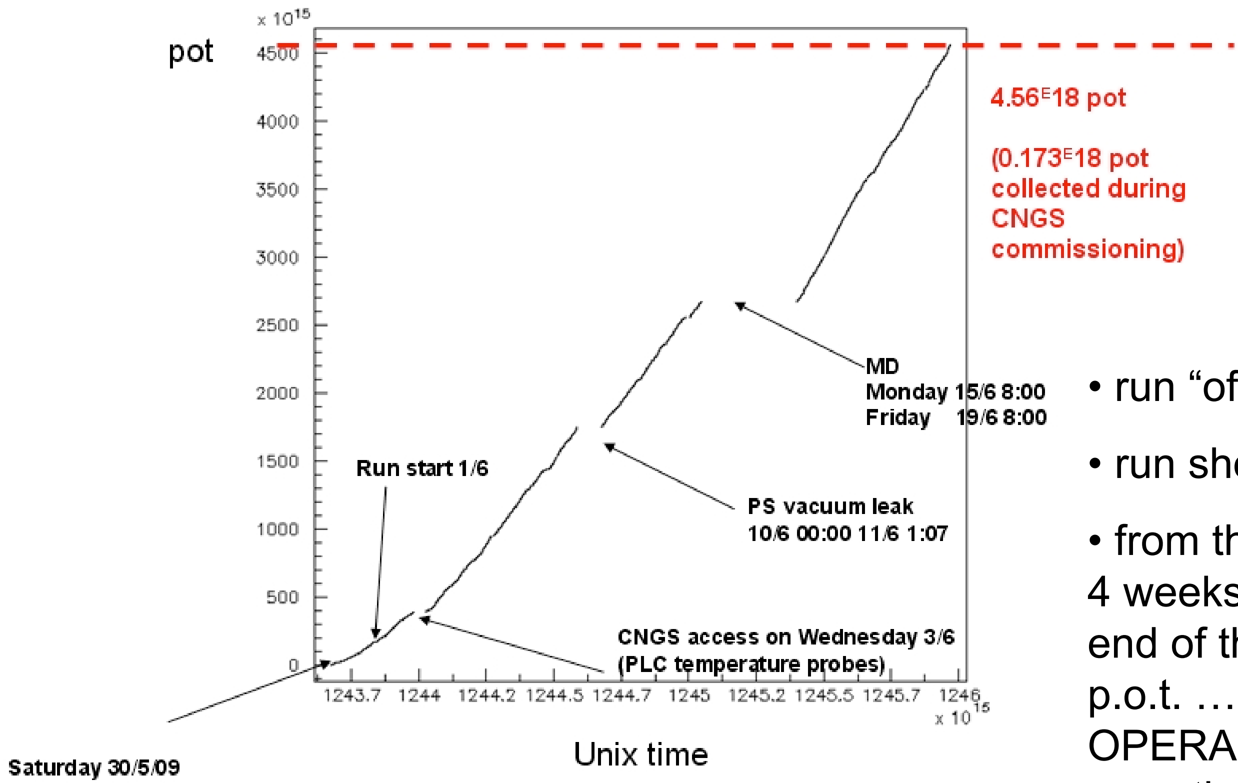
• vertical beam tilt consistent with expectations

• ongoing 2009 run (target fully filled)

• run start was delayed by a quake that occurred in L'Aquila region on April the 6th (306 killed, 1600 injured)

• the effect in the underground lab. was dumped by a factor of 5 so no damage occurred to the OPERA detector

Pot collected up to Friday 26/6



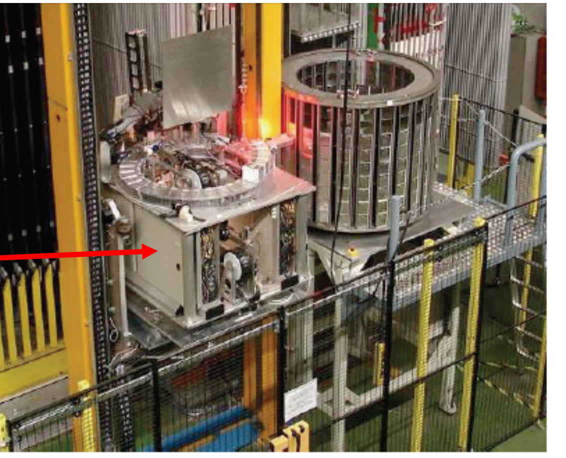
• run "officially" started on June the 1rst

• run should last 153 days

• from the performances seen in the first 4 weeks of running one expects at the end of the run 3.2 10^{19} p.o.t. < 4.5 10^{19} p.o.t. … to reach quickly its physics goal OPERA relies on CERN support to have soon the CNGS running at nominal intensity

• analysis in the emulsions

Intensity (pot/year) 4.5×10^{19}	
Events/year	4370
CS/year	5680
Bricks/year	3600
BMS	6000
CS marking	8000
CS development	9000
CS scanning	9000
Brick marking	6000
Brick development	6000
Brick scanning	6000



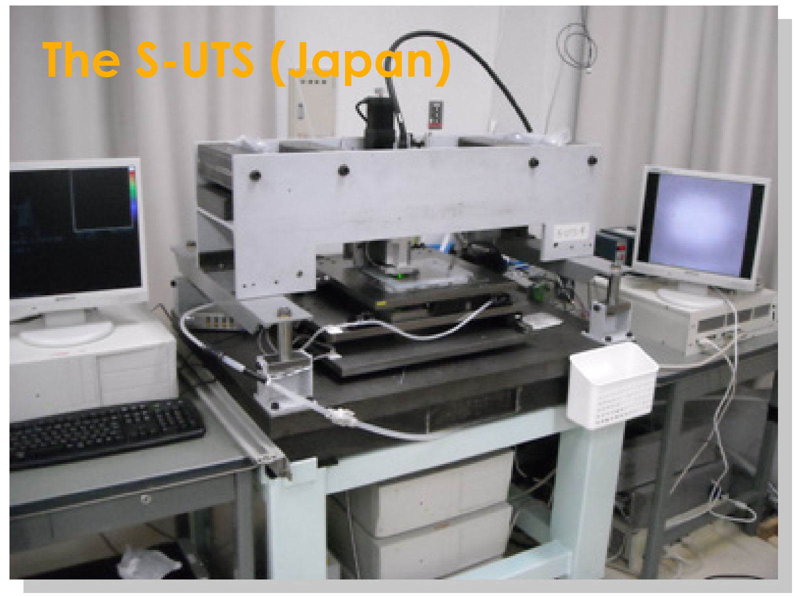
expected performances with the present infrastructures

- reconstruction of ele. det. data
- automatic selection of events in the target
- brick finding: identify the brick containing the primary vertex
- BMS: robot to extract the identified brick from the detector
- CS marking (X ray mark for alignment), development and scanning: to have a confirmation of the brick finding step
- brick marking (as for CS), development and scanning: to investigate in detail the primary vertex properties

• analysis in the emulsions

- performed in Europe and Japan
- based on the tomographic acquisition of emulsion layers
- as automated as possible
- scanning speed ~ 20 (Europe) / 75 (Japan) cm^2 / h
- ~ 30 bricks daily extracted → thousands of cm^2 / day

customized commercial optics and mechanics



custom made hardware

numbers in this page are up to mid July 09

• analysis in the emulsions

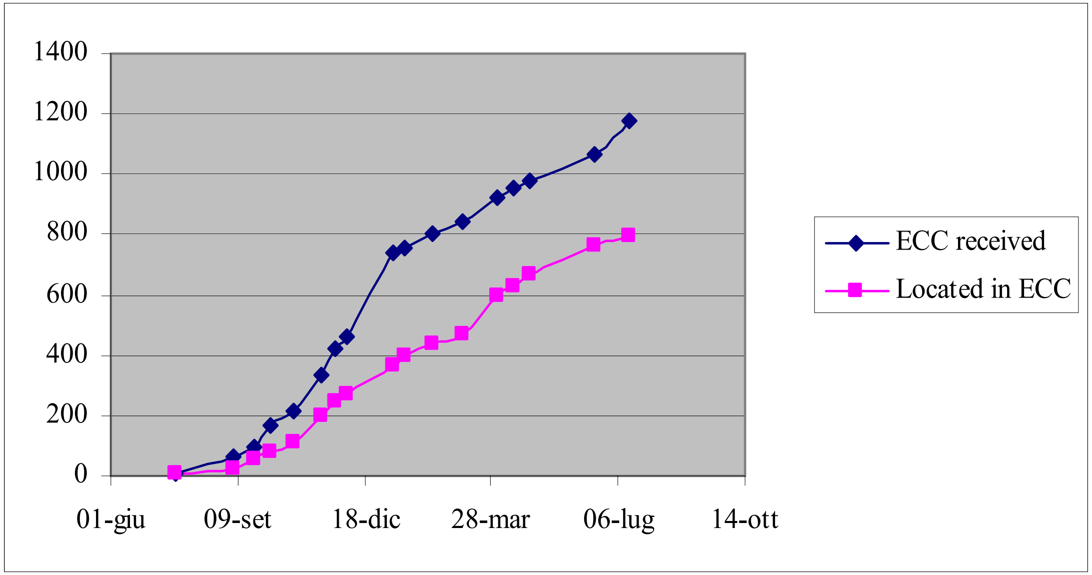
	NC	CC	Totat
bricks received in the labs	218	959	1177
scanning started	195	895	1090
CS to brick connected	178	849	1027
vertices located in the brick	119	678	797
passing through	12	46	58
vertices in the dead material	4	17	21

→ ECC received (bricks received in the labs)

→ best scenario, located in ECC (vertices located in the brick)

→ wrong wall of bricks (passing through)

→ can not be used (vertices in the dead material)

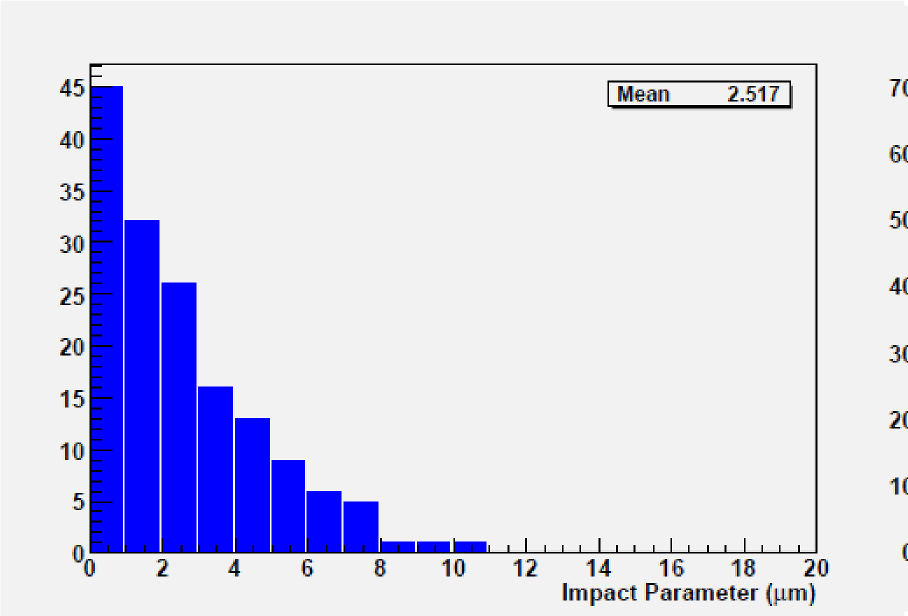


• CC: 678 / 849 ≈ 80 %

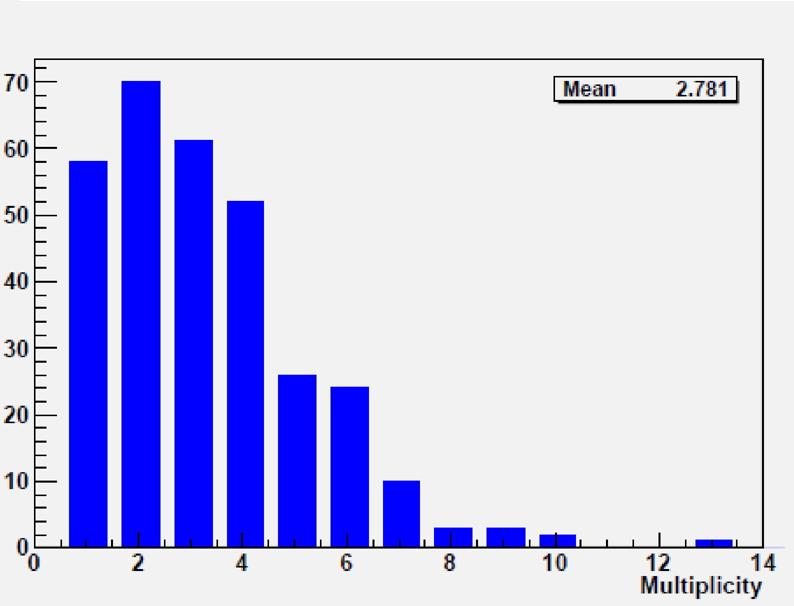
• NC: 119 / 178 ≈ 67 %

⇒ NC events harder to locate … not too surprising … but the more events we have the better we will learn how to locate them

- analysis in the emulsions



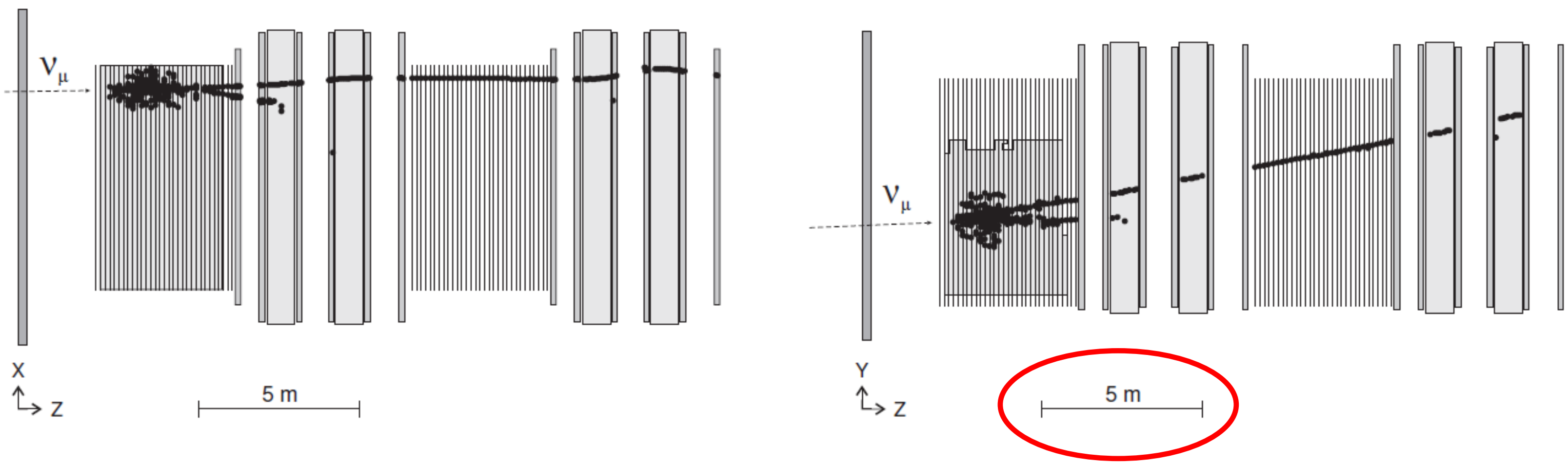
impact parameter of the μ track in CC events w.r.t. the primary vertex



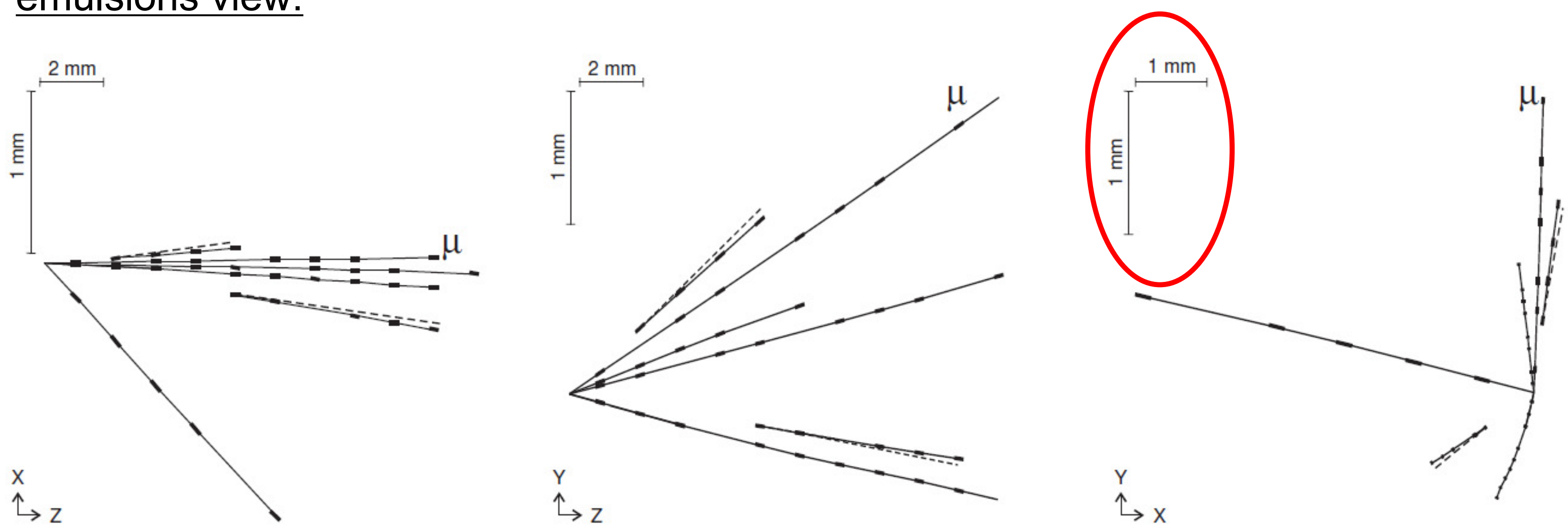
charged track multiplicity distribution

• analysis in the emulsions: a CC event

electronic detectors view:



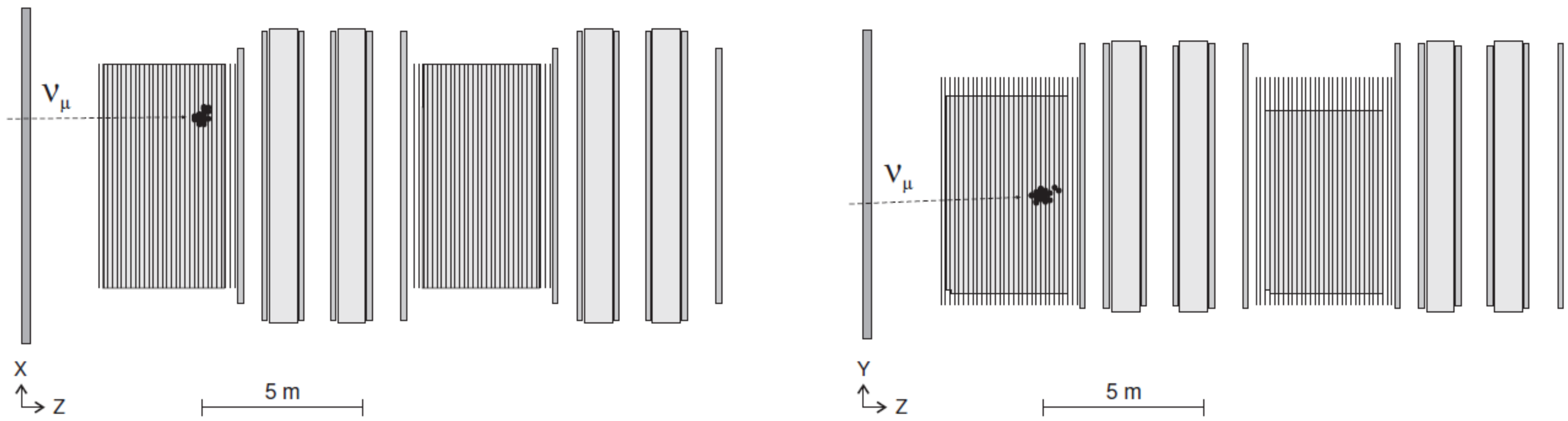
emulsions view:



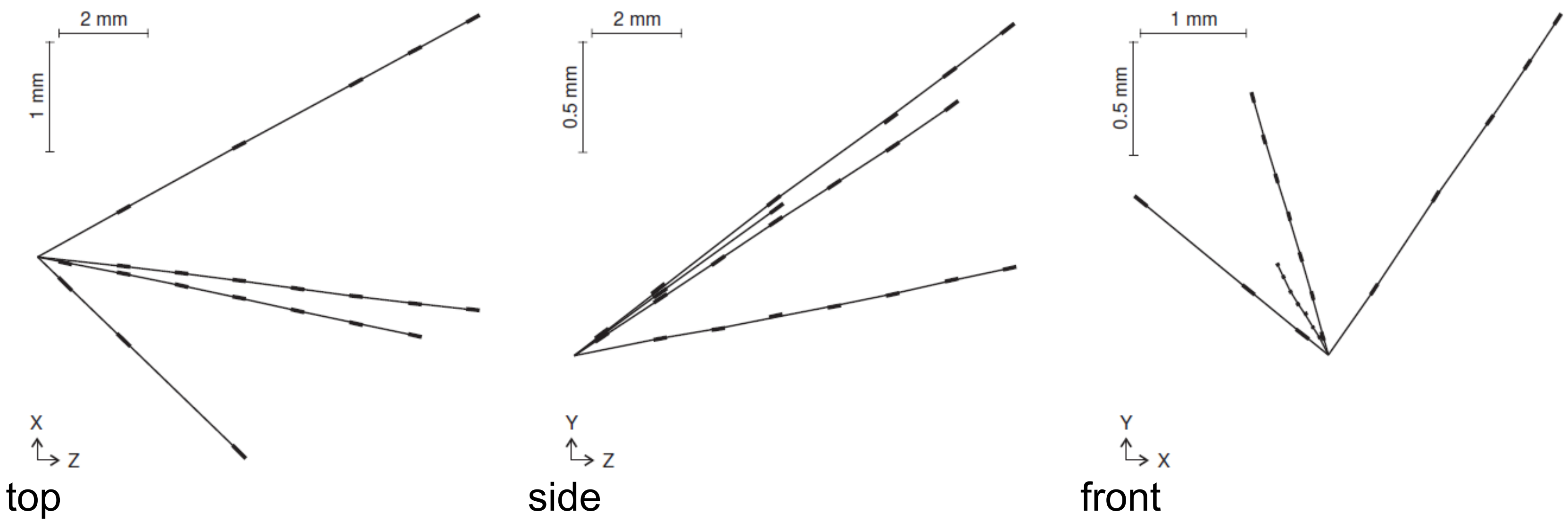
top side front

• analysis in the emulsions: a NC event

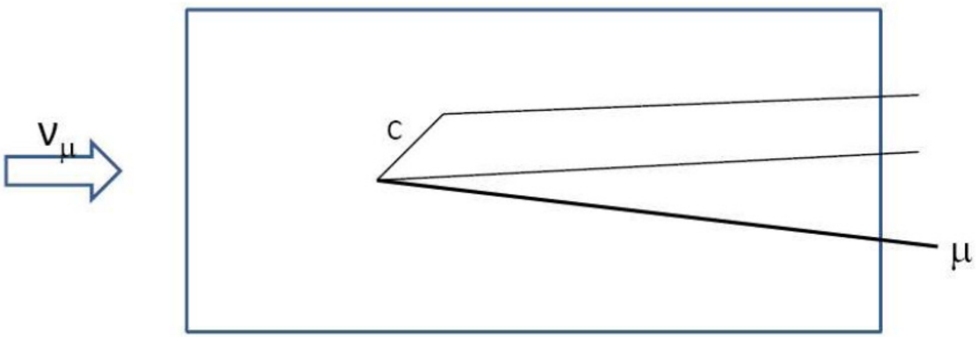
electronic detectors view:



emulsions view:



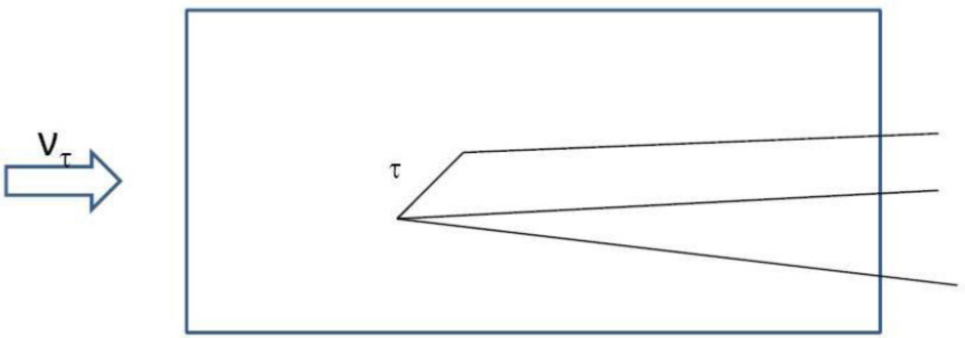
• analysis in the emulsions: more interesting topologies



• charm can only be produced in CC interactions

⇒ μ in the final state

⇒ charmed hadron giving a secondary vertex



• τ leptons can only be produced in CC interaction

⇒ τ decay secondary vertex

- $\tau \to \mu$ X 17.4 % BR
- $\tau \to$ e X 17.8 % BR
- $\tau \to$ h X 48.7 % BR
- $\tau \to$ 3 h X 14.6 % BR

⇒ >= 1 tracks from the primary vertex

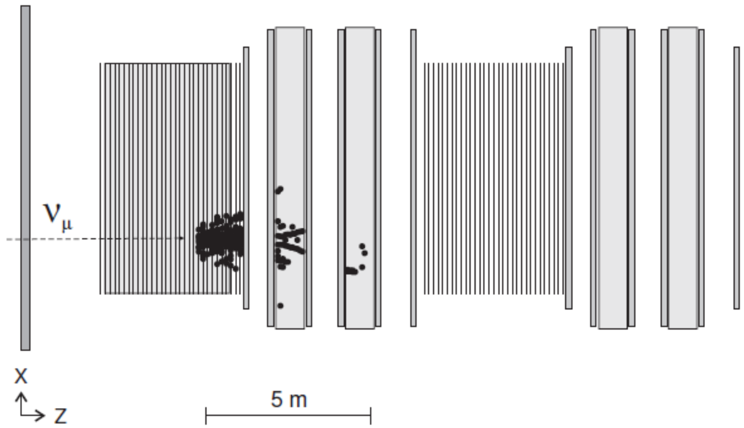
• charm is an interesting signal by itself

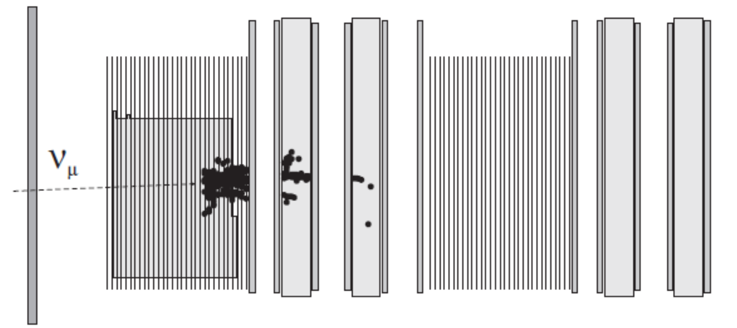
• if you miss a μ in a charm event you have a τ

⇒ good understanding of charm production is mandatory for / before τ measurements

• analysis in the emulsions: charm event from kink

electronic detectors view:

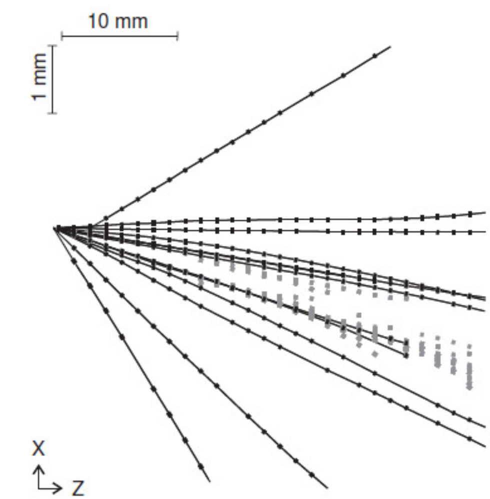




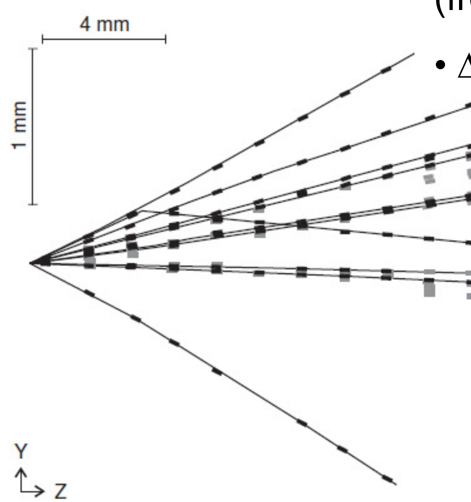
Y
Z

- track from the primary vertex with a kink
- flight length of the primary is 3247 μm
- 610 < p_t (daughter) < 1140 MeV/c @ 90 % CL (from MS)
- $\Delta\phi$ (charm,μ) $\approx$ 165°

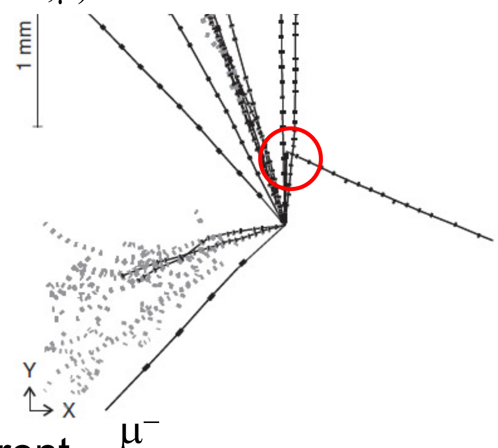
emulsions view:



top



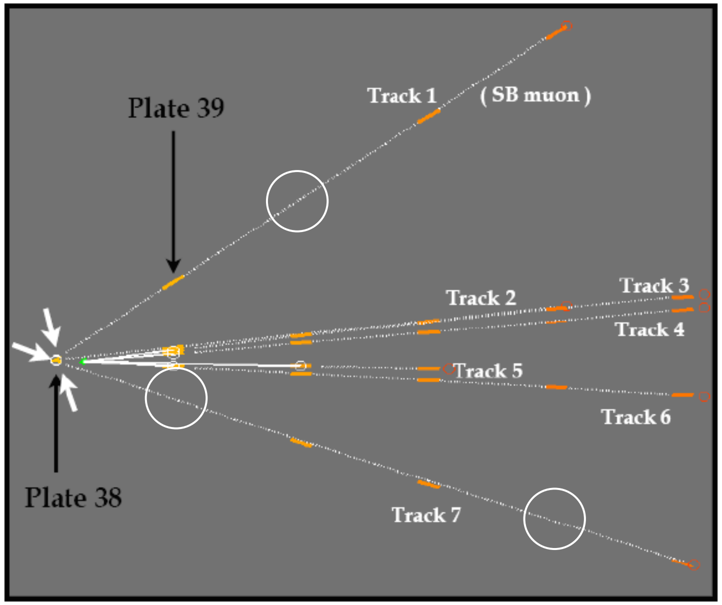
side



front

• analysis in the emulsions: charm event from secondary vertex

positions and impact parameters are in μm



VERTEX 1

	Impact Parameter
Track 1	1,36
Track 2	0,88
Track 7	0,51

X	66716,60
Y	49892,8
Z	90,9

VERTEX 2

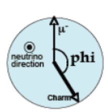
	Impact Parameter
Track 3	1,13
Track 4	1,81
Track 5	1,99
Track 6	1,39

X	66710,10
Y	49899
Z	403,9

	Tx	Ty	Impact Parameter	Momentum (GeV/c)
Track 1	0,006	0,073	1,36	
Track 2	-0,420	0,438	0,88	$0,4^{+0,34}_{-0,12}$
Track 7	0,267	-0,206	0,51	$0,8^{+0,79}_{-0,26}$

	Tx	Ty	Impact Parameter	Momentum (GeV/c)
Track 3	0,046	-0,036	1,13	$3,3^{+3,3}_{-1,2}$
Track 4	0,052	0,056	1,81	$1,2^{+0,9}_{-0,4}$
Track 5	-0,065	-0,013	1,99	$6,8^{+11,7}_{-2,6}$
Track 6	0,222	0,082	1,39	$0,8^{+0,8}_{-0,28}$

Tx	Ty	Flight Length (μm)	phi	minimum mass (GeV/c²)
-0,0207	0,0198	313,1	173,2°	1,7



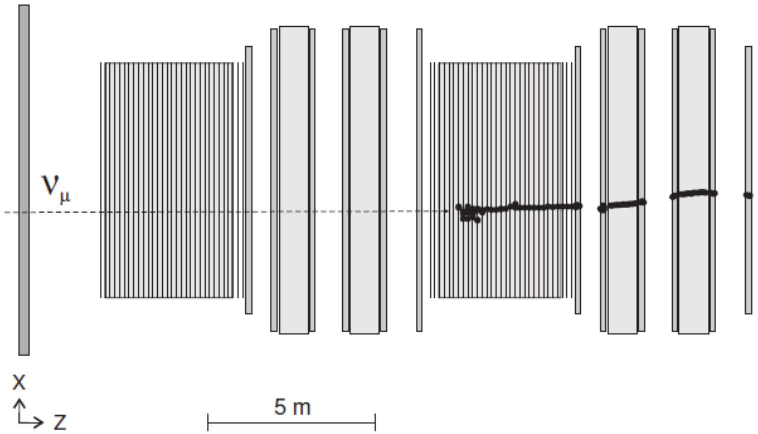
fitted tracks: white

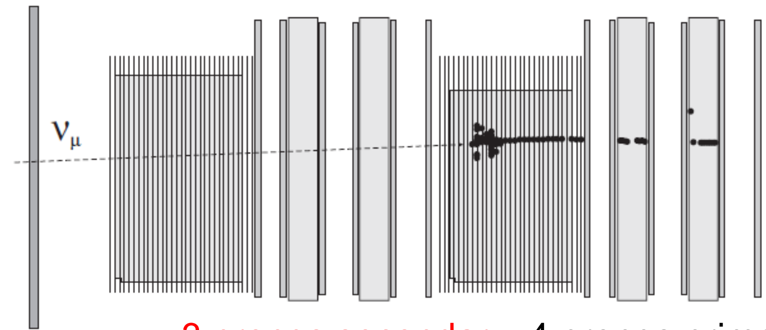
emulsion micro-track: orange

⇒ can handle also events with missing micro-track

• analysis in the emulsions: charm event from secondary vertex

electronic detectors view:

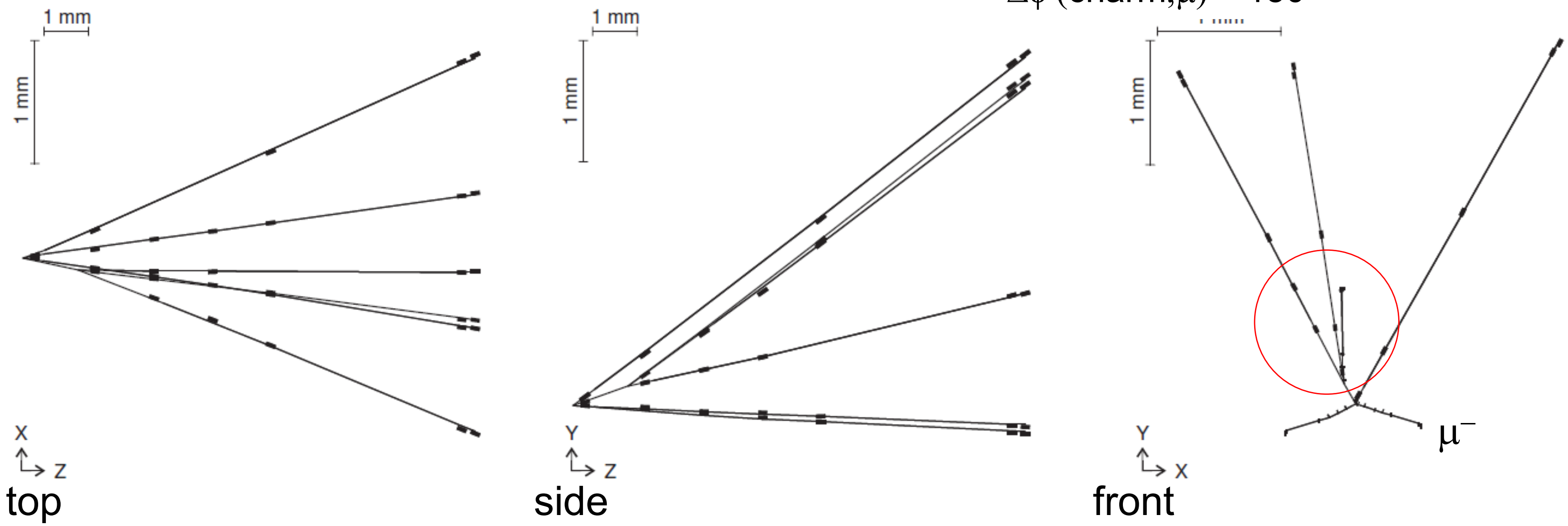




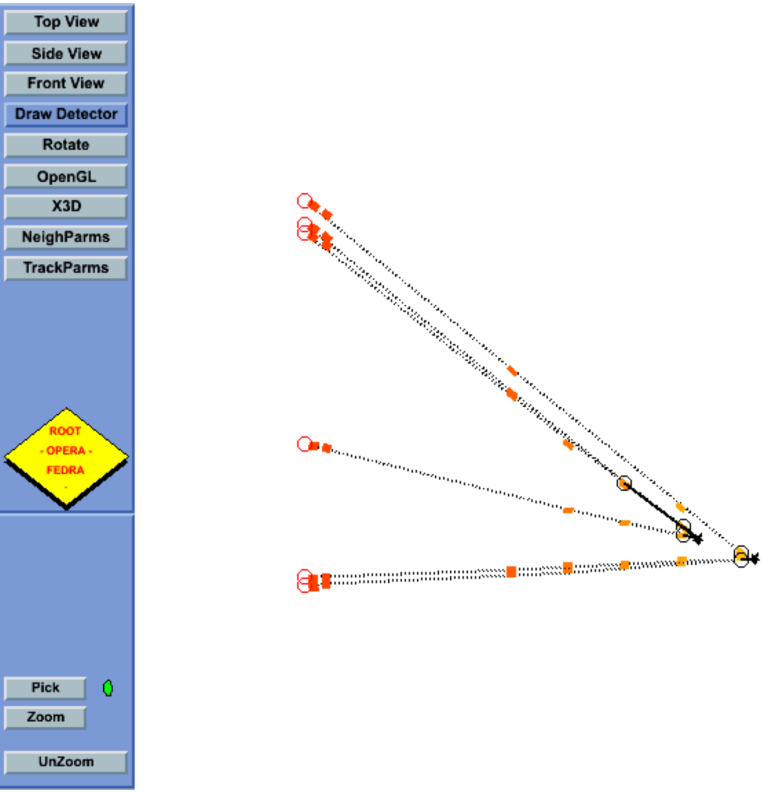
Y
Z

- 3 prongs secondary, 4 prongs primary vertex
- secondary 1150 μm away from the primary
- charmed parent seen in 1 emulsion layer !
- $\Delta\phi$ (charm,μ) ≈ 150°

emulsions view:



• summary and outlook



• electronic detectors are fully operational and doing well

• all steps of the emulsion analysis have been successfully validated

• events are being regularly analyzed up to the primary vertex

• interesting charm events have been identified

• … of course looking for τ !

• as statistic is a key point in order to reach the OPERA physics goal, OPERA relies on the CERN support to have soon the CNGS running at nominal intensity
(from 3 to 4 CNGS cycles per supercycle whenever possible is a way to solve this problem already in place)