Status and results from OPERA experiment

Luca Scotto Lavina
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LHEP Bern University

on behalf of the OPERA swiss groups (Bern and ETHZ)

The present OPERA Collaboration:
170 physicists, 33 institutions in 12 countries

Belgium
IIHE-ULB Brussels

Croatia
IRB Zagreb

France
LAPP Annecy
IPNL Lyon
IPHC Strasbourg

Germany
Hamburg
Münster
Rostock

Israel
Technion Haifa

Italy
Bari
Bologna
LNF Frascati
L'Aquila,
LNGS
Napoli
Padova
Roma
Salerno

Japan
Aichi
Toho
Kobe
Nagoya
Utsunomiya

Korea
Jinju

Russia
INR RAS Moscow
LPI RAS Moscow
ITEP Moscow
SINP MSU Moscow
JINR Dubna

Switzerland
Bern
ETH Zurich

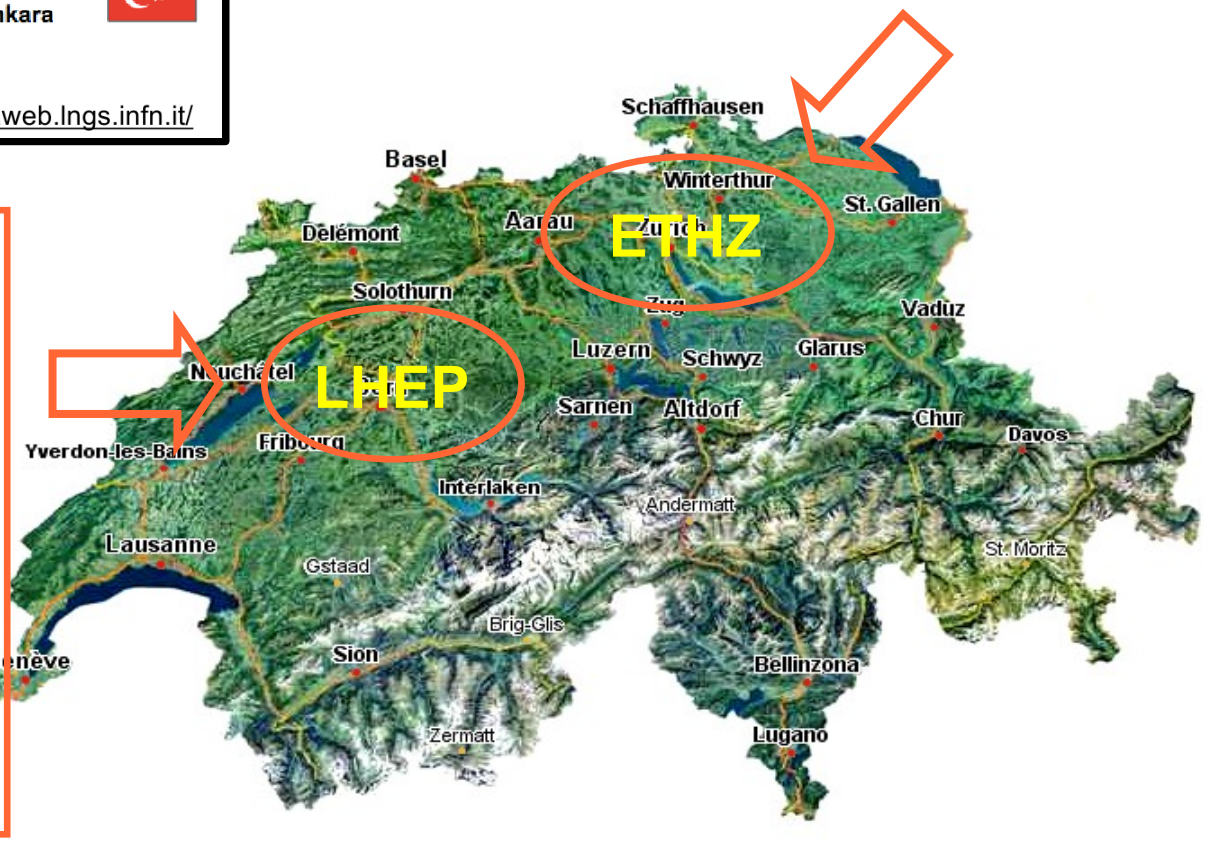
Tunisia
CNSTN Tunis

Turkey
METU Ankara

OPERA: CERN CNGS1 and LNGS experiment http://operaweb.lngs.infn.it/

OPERA in Switzerland:
2 institutions, 19 physicists

A. Badertscher
C. Lazzaro
A. Rubbia
T. Strauss



A. Ariga
T. Ariga
A. Bendhabi
A. Ereditato
J. Knüsel
F. Juget
J. Kawada
I. Kreslo
G. Lutter
F. Meisel
U. Moser
C. Pistillo
K. Pretzl
L. Scotto Lavina
J.L. Vuilleumier

Activities of swiss groups in OPERA

Past activities

- Conceptual design
- Proposal
- CNGS beam design and optimization
- Construction of the Target Tracker
- Lead production monitoring
- Development of European microscopes
- Emulsion film robot
- Test beams
- Physics analysis

…

Present activities

Common for all scanning labs:
- Decay search
- Kinematic analysis

Unique to Swiss group:
- Study of hadron background for tau
- Gamma detection, energy estimation, π_0 reconstruction
- Electron ID, energy estimation
- MC studies on tau and charm
- Low momentum muon ID
- Development of 3D display for event analysis
- ECC analysis and event reconstruction

Emulsion scanning

The largest scanning team in Europe:
- 20 physicists
- ~35% brick european scanning load at LHEP
- ~75% european scanning load for BG studies at LHEP

Responsibilities of the Swiss researchers

A. Ereditato (spokesperson)

Education

PhD thesis in progress:
- J. Knüsel (LHEP):
  low momentum muon identification
- C. Lazzaro (ETHZ):
  determination of the CNGS neutrino energy spectrum from CC events reconstructed with the electronic detectors
- F. Meisel (LHEP):
  electron and gamma reconstruction in OPERA experiment
- T. Strauss (ETHZ):
  neutrino induced charmed particle decays

OPERA: first direct detection of neutrino oscillations in appearance mode

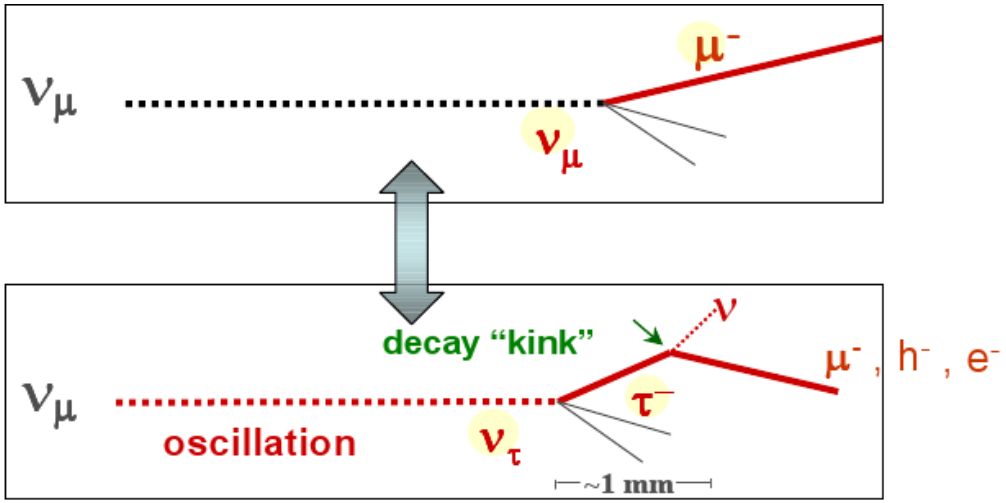
following the Super- Kamiokande discovery of oscillations with atmospheric neutrinos and the confirmation obtained with solar neutrinos and accelerator beams. Important, missing tile in the oscillation picture.

The PMNS 3-flavor oscillation formalism predicts:

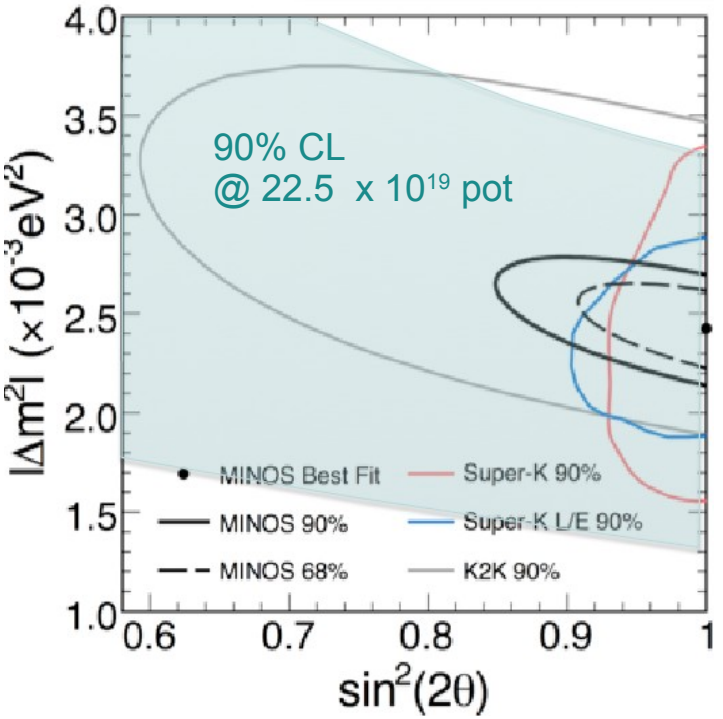
$$P(\nu_\mu \rightarrow \nu_\tau) \sim \sin^2 2\theta_{23} \cos^4 \theta_{13} \sin^2(\Delta m^2_{23} L/4E)$$

Requirements:

1) long baseline, 2) high neutrino energy, 3) high beam intensity, 4) detect short lived τ's



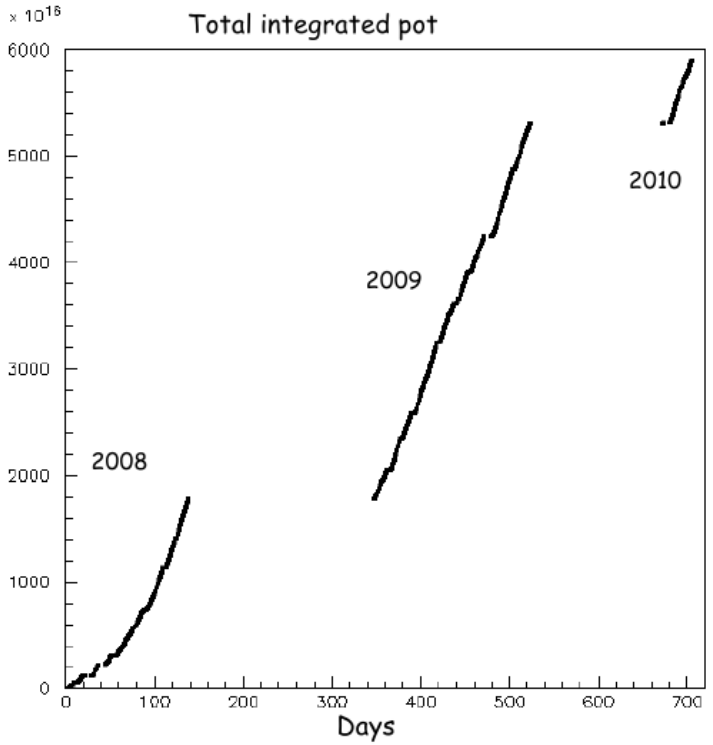
plus 3-prong decay modes



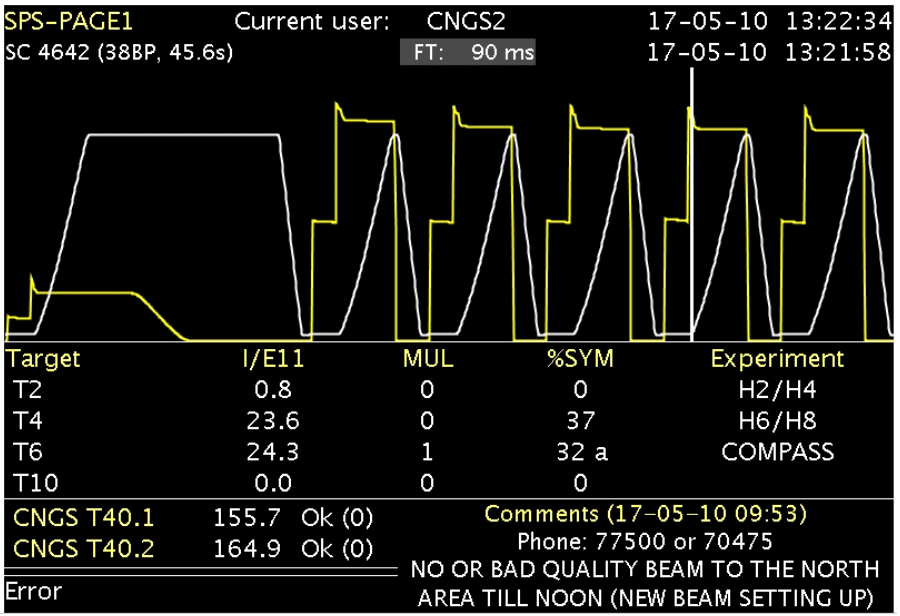
The CNGS neutrino beam

< E >	17 GeV
L	730 km
$(\nu_e + \bar{\nu}_e) / \nu_\mu$ (CC)	0.87%
$\nu_\mu / \bar{\nu}_\mu$ (CC)	2.1%
ν_τ prompt	negligible

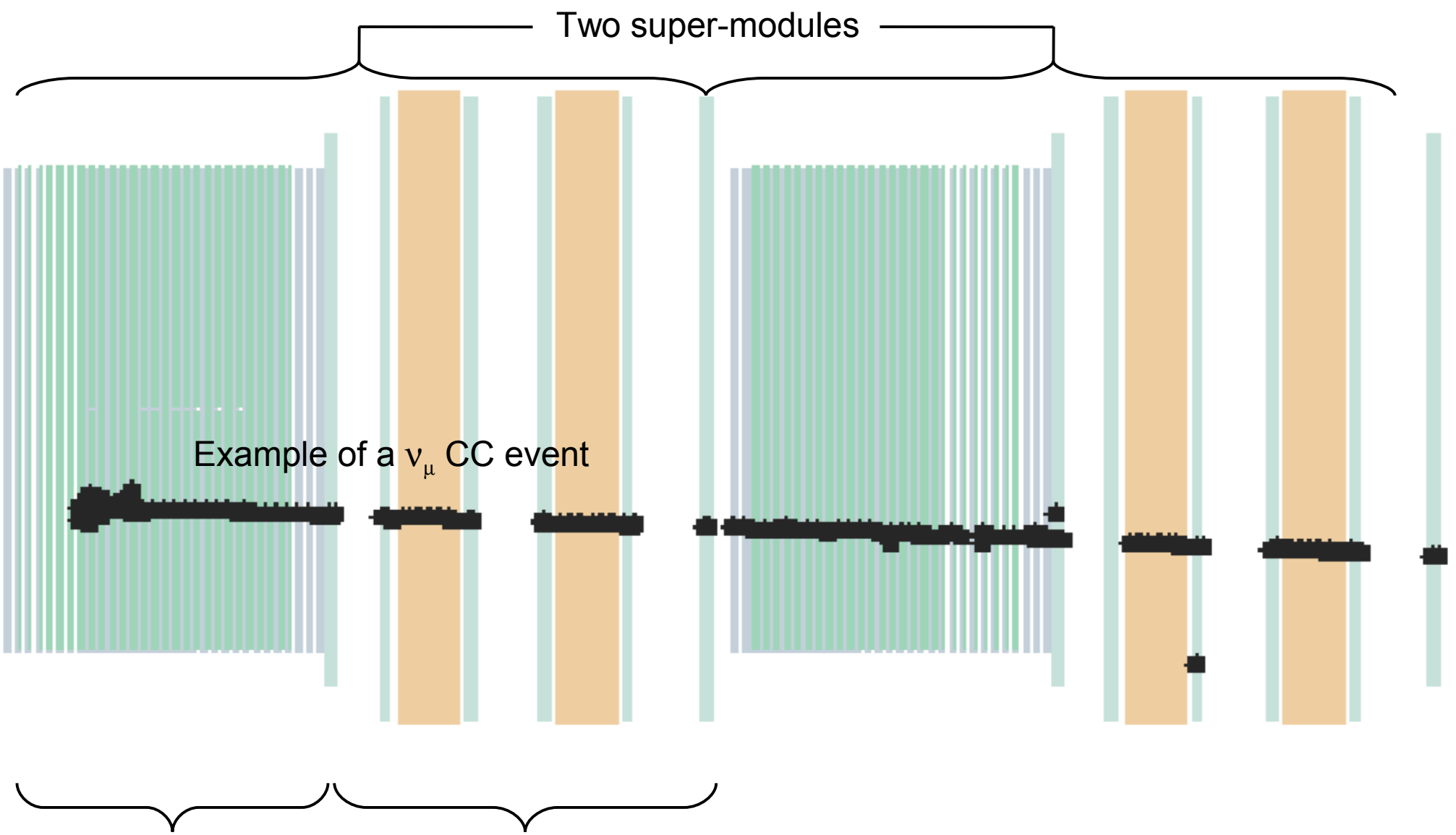
Run	Cumulated pot
2008	1.78×10^{19}
2009	3.52×10^{19}
2010	2×10^{19} (Aug 2010, 50% of run), goal = 4.25×10^{19}
2011	minimum goal > 4.5×10^{19} (as in the proposal)
2012	no beam by CNGS?
2013	?



Typical cycles: CNGS + FT (tests)

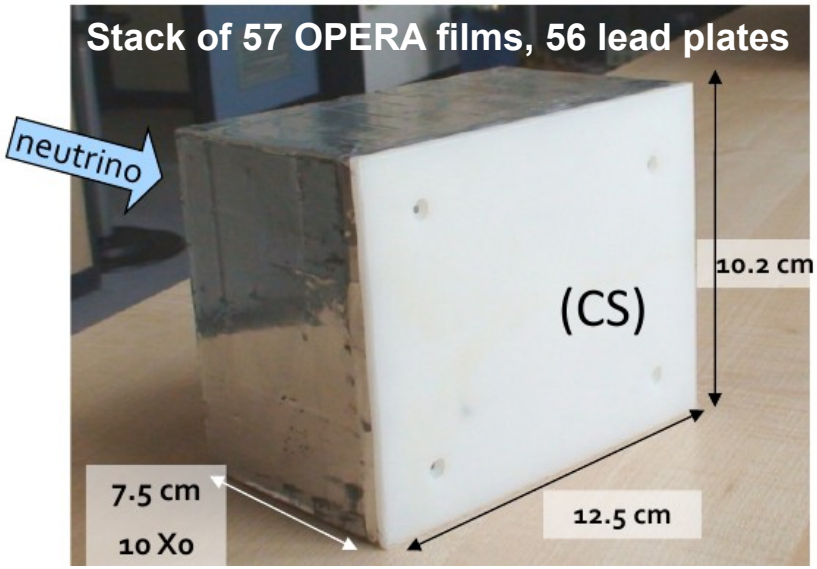


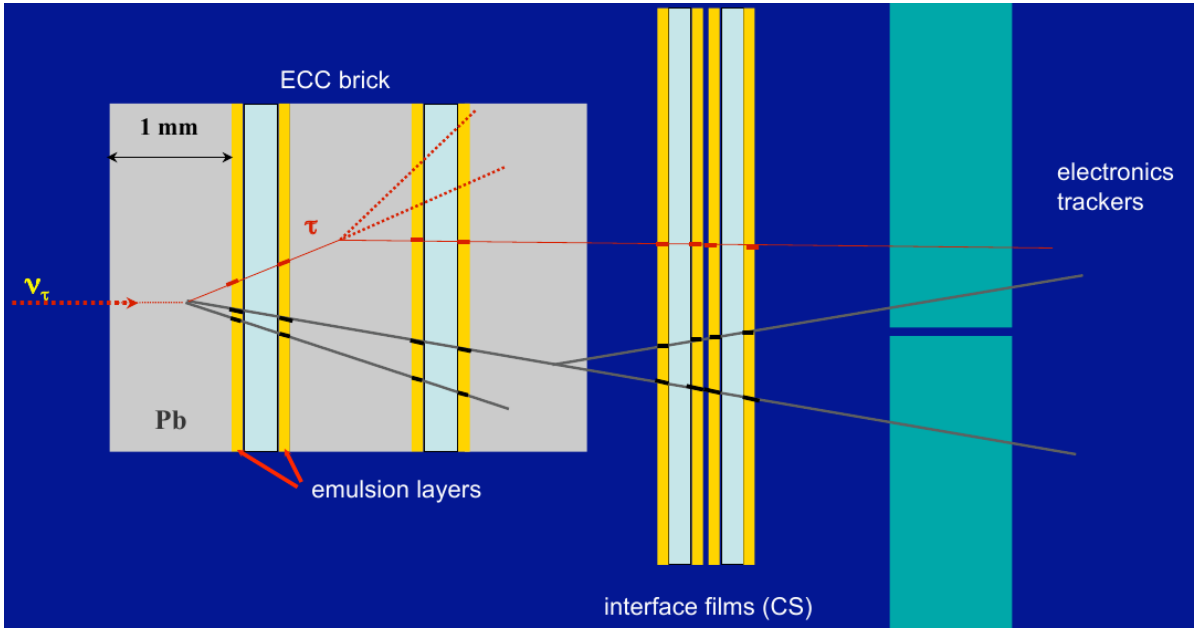
OPERA detector, 150000 ECC 1.25 kton target

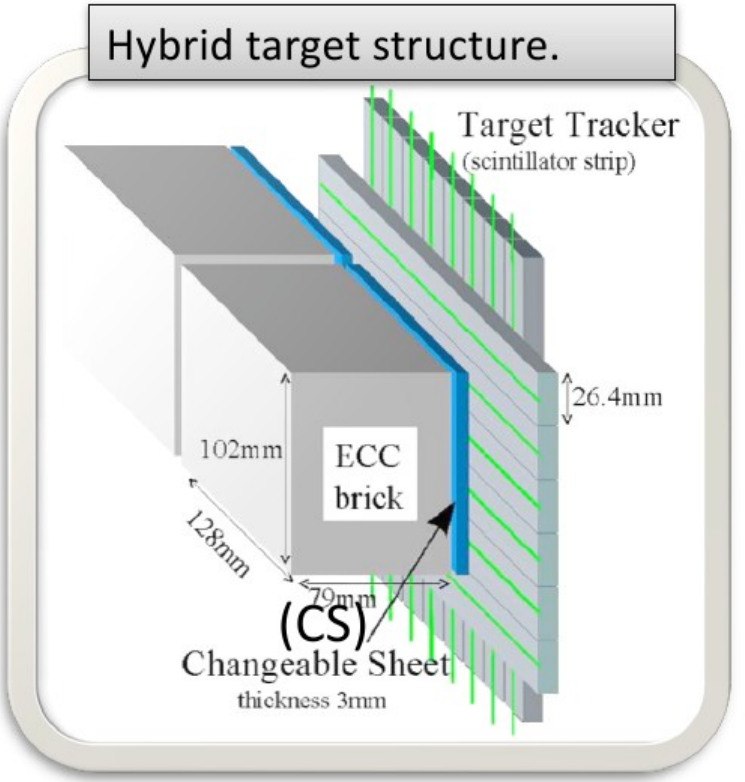


~3100 m.w.e., ~1 cosmic μ / m^2 / hour

The heart of the experiment: the ECC target bricks







Improvement of muon tracking in TT:
C. Lazzaro, ETHZ, PhD thesis

Parallel analyisis of ECC bricks

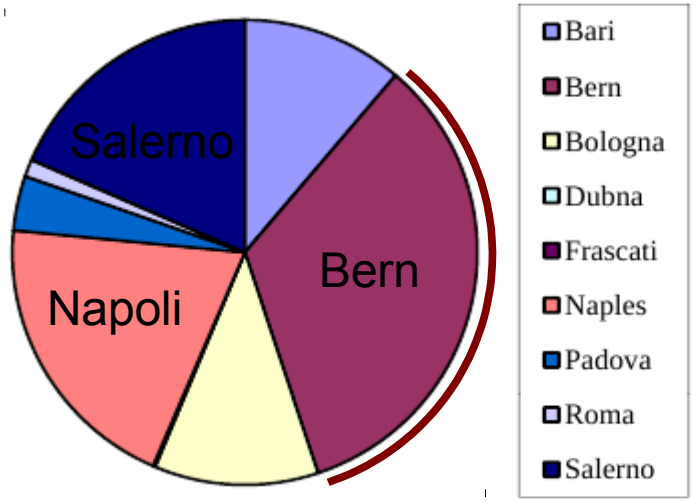
Validated bricks are sent to the scanning labs

2 scanning stations share the **CS** scanning load:

- Nagoya (J)
- LNGS (I)

11 scanning labs share the **brick** scanning load:

- Nagoya (J)
- LHEP Bern (CH)
- Napoli, Bari, Salerno, Bologna, Padova, Roma, Frascati (IT)
- Dubna (Ru)
- Ankara (Tu)



<u>Swiss scanning station scanned the highest number of bricks in Europe</u>

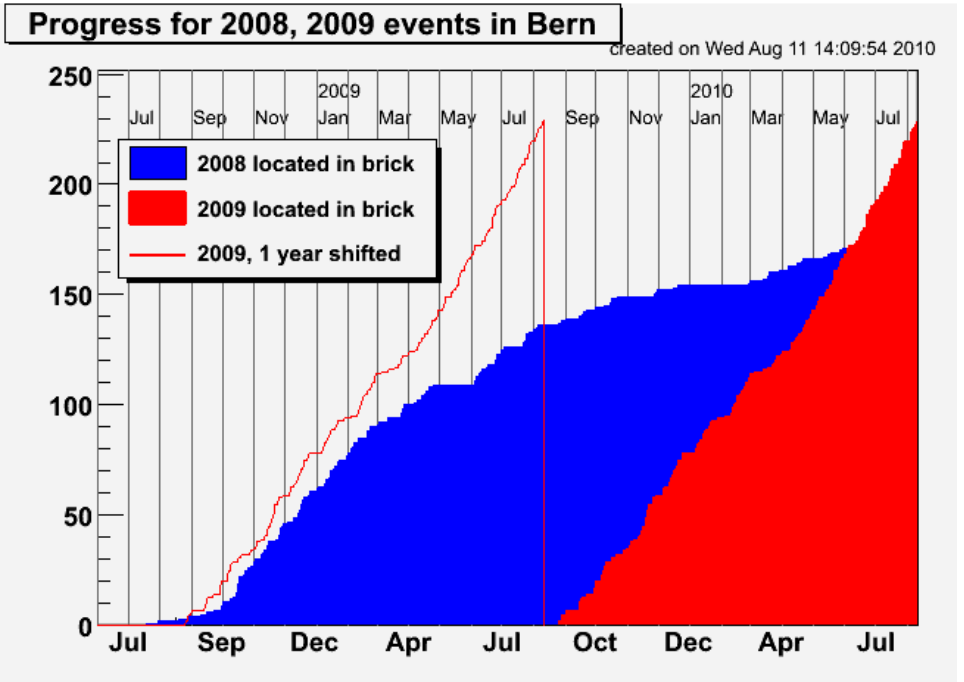
The Swiss scanning station in LHEP Bern

Largest scanning group in Europe
19 physicists (Bern + ETHZ)

5 microscopes with full-automatic plate changer
+1 in construction

Capability to scan more than 15 bricks/week

...and many efforts to improve the scanning speed even more!



Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

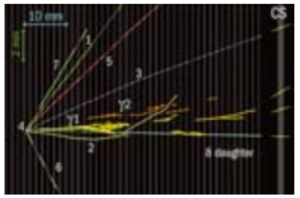
Observation of a first ν_τ candidate event in the OPERA experiment in the CNGS beam

CERN COURIER

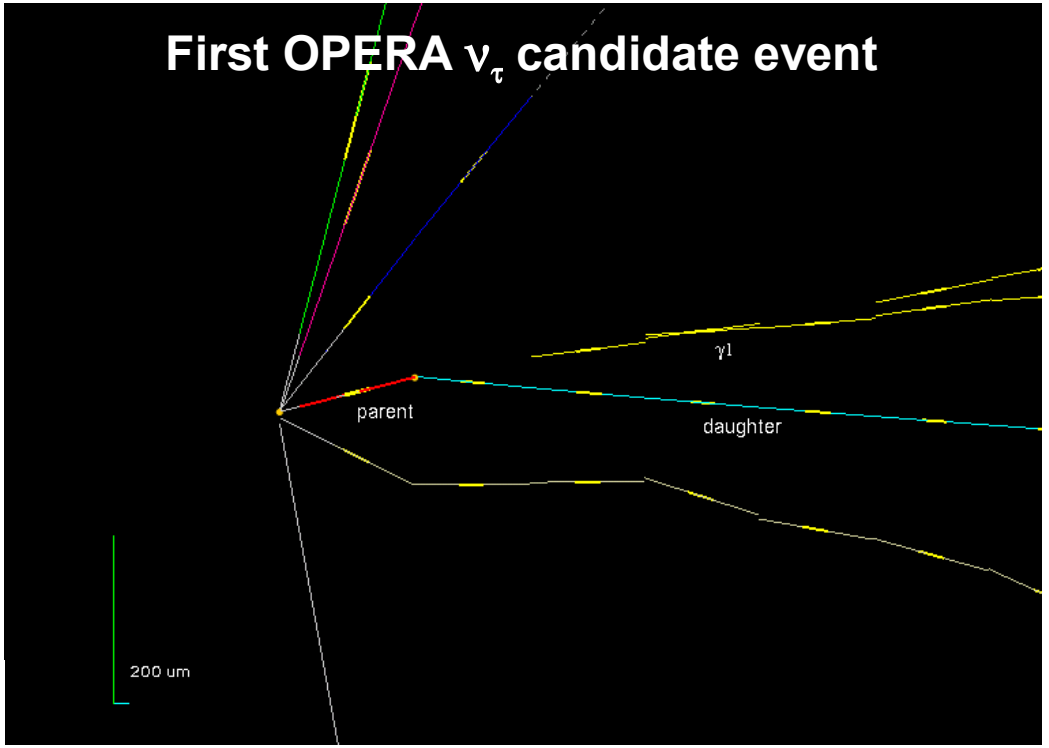
Jul 20, 2010

OPERA catches its first tau-neutrino

The OPERA collaboration has announced the observation of the first candidate tau-neutrino (ν_τ) in the muon-neutrino (ν_μ) beam sent through the Earth from CERN to the INFN's Gran Sasso Laboratory 730 km away. The result is an important final piece in a puzzle that has challenged science for almost half a century.



Longitudinal view



The Bulletin

Neutrino oscillations make their first appearance in OPERA

1400 metres underground in the INFN Gran Sasso Laboratory, the Opera experiment has just observed its first candidate for neutrino oscillation – the phenomenon that confirms that neutrinos have mass. It is the first time that an experiment has observed the direct appearance of the new type of neutrinos produced in the oscillation. Opera uses a dedicated beam produced at CERN's Super Proton Synchrotron (SPS).

symmetrybreaking

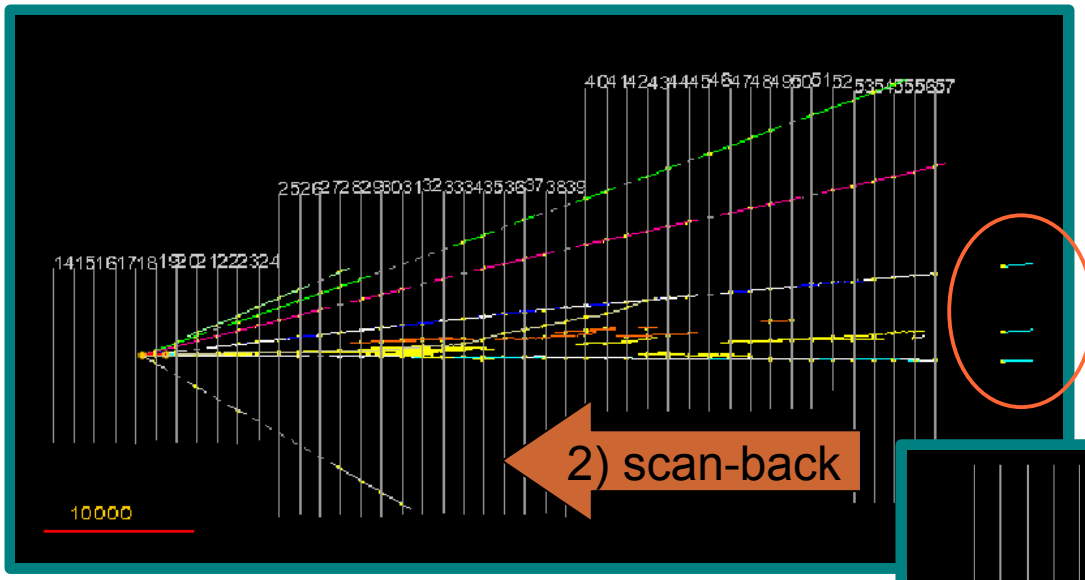
extra dimensions of particle physics

A joint Fermilab/SLAC publication

OPERA catches its first tau neutrino

May 31, 2010 | 6:49 am

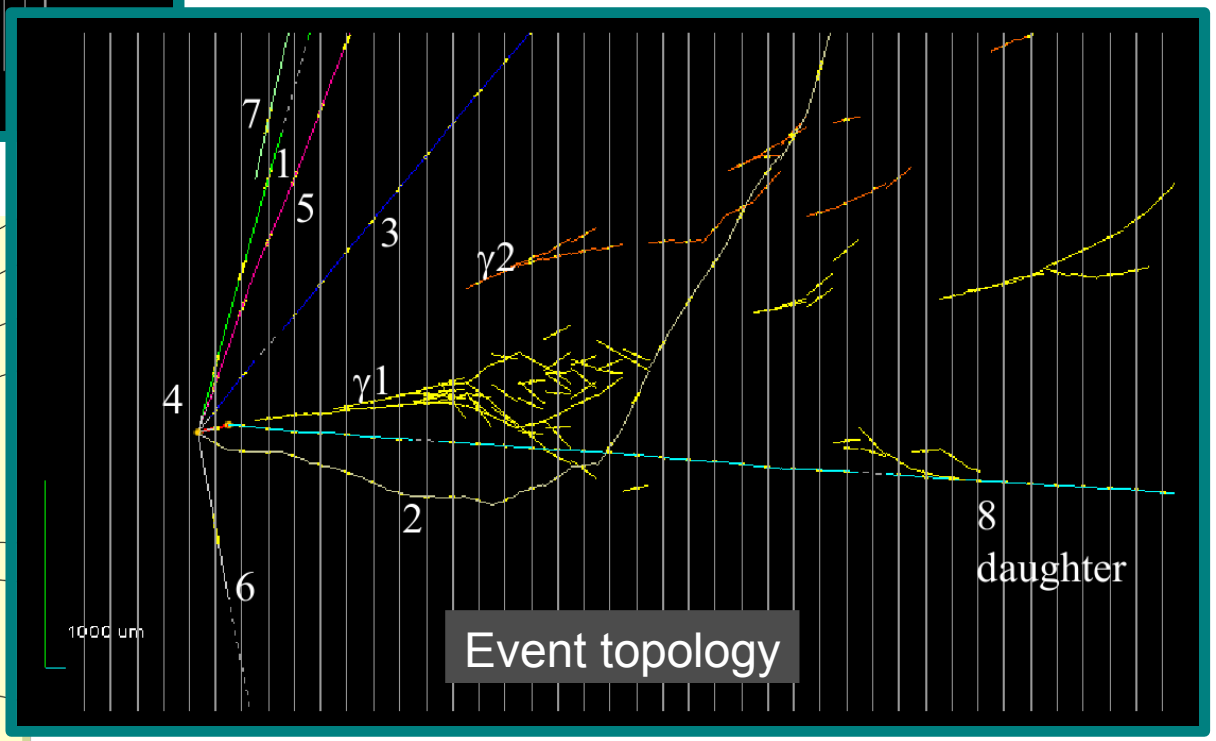
From CS to vertex location

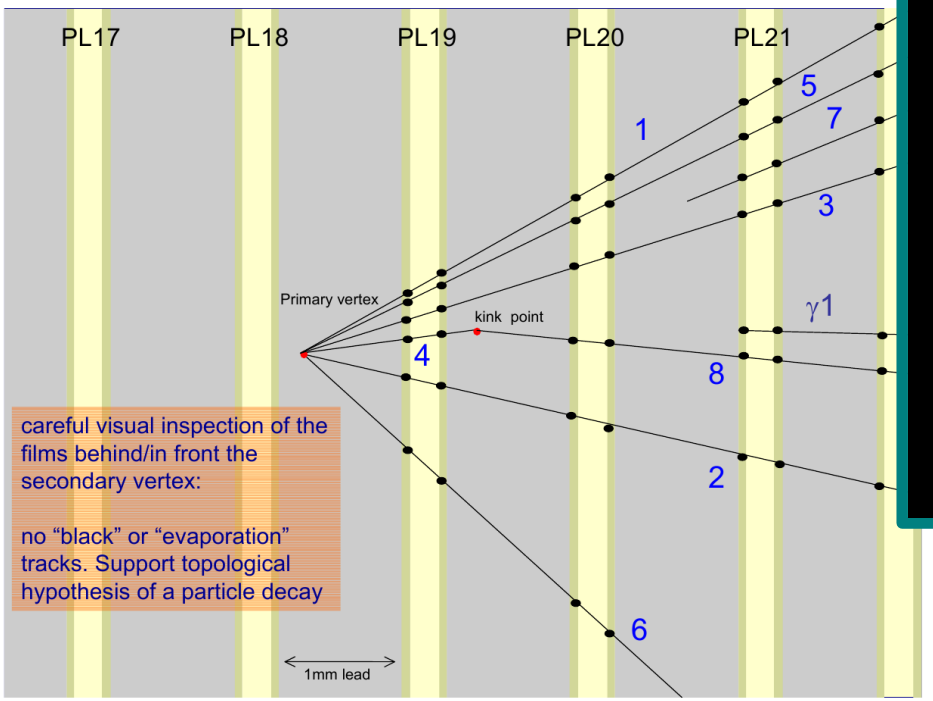


3) Large area scanning

1) CS predictions

2) scan-back

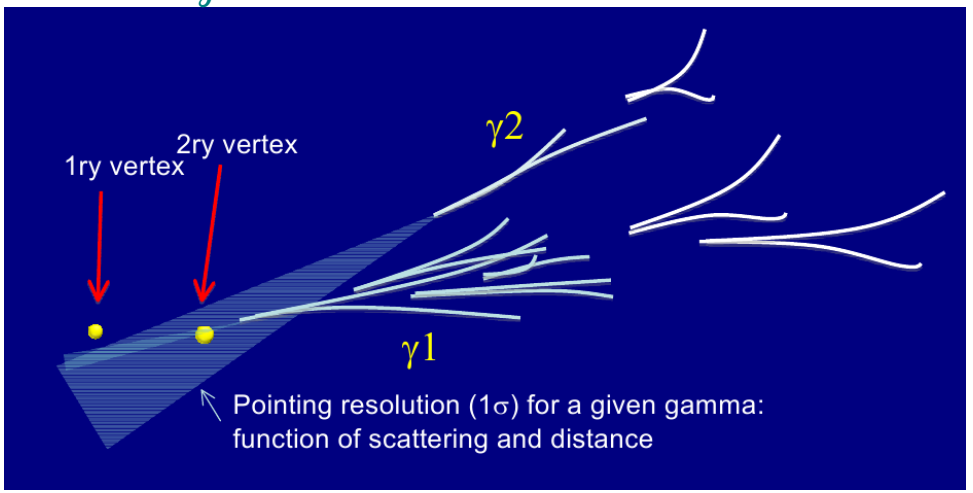




4) Full reconstruction of vertices and gammas

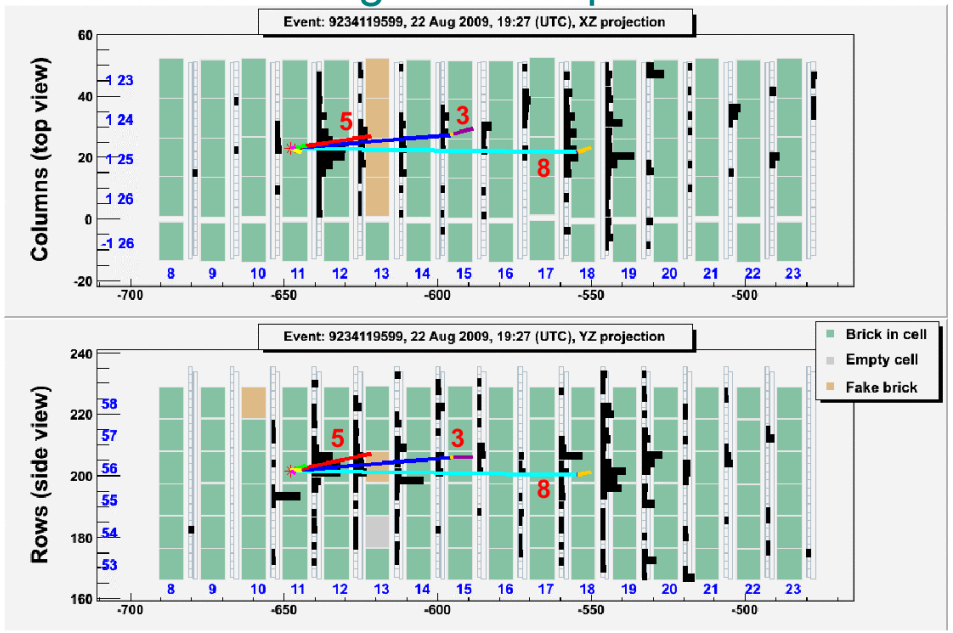
Very careful measurements of the candidate

γ attachment to the vertices



Electron and gamma reconstruction:
F. Meisel, LHEP, PhD Thesis

Following down all particles



Low energies particle identification (π/μ):
J. Knüsel, LHEP, PhD Thesis

Kinematic analysis

10 years old criteria (@Proposal) → Blind analysis

- kink occurring within 2 lead plates downstream of the primary vertex
- kink angle larger than 20 mrad
- daughter momentum higher than 2 GeV/c
- decay Pt higher than 600 MeV/c, 300 MeV/c if ≥ 1 gamma pointing to the decay vertex
- missing Pt at primary vertex lower than 1 GeV/c
- azimuthal angle between the resulting hadron momentum direction and the parent track direction larger than $\pi/2$ rad

VARIABLE	AVERAGE
kink (mrad)	**41 ± 2**
decay length (μm)	**1335 ± 35**
P daughter (GeV/c)	**$12\ ^{+6}_{-3}$**
Pt daughter (MeV/c)	**$470\ ^{+230}_{-120}$**
missing Pt (MeV/c)	**$570\ ^{+320}_{-170}$**
ϕ (deg)	**173 ± 2**

Event nature and invariant mass reconstruction

π^o mass	ρ mass
120 ± 20 ± 35 MeV	$640\ ^{+125}_{-80}\ ^{+100}_{-90}$ MeV

Background sources

Charmed particle decay from ν_μ interactions
~ 10^{-5}/CC

Evaluation is based on the study of charm events in a region where no τ signal is present.

Very nice data/MC agreement

Expected background for 1-prong hadron channel

= 0.007±0.004 (syst) events

Prompt ν_τ	~ 10^{-7}/CC
Charm from ν_e	~ 10^{-6}/CC
Double charm	~ 10^{-6}/CC

negligible

Hadron interactions

~ 10^{-5}/CC

Two possible methods:
1) using state-of-the-art of simulations
2) measurement by using OPERA data

So far, simulation by using FLUKA:

kink probabilities integrated over the ν_μ NC hadronic spectrum yield a BG probability of:

(1.9 ± 0.1) x 10^{-4} kinks/NC (2 mm Pb)

Expected background for 1-prong hadron channel

= 0.011 events (50% error)

0.018 ± 0.007 (syst) events 1-prong hadron

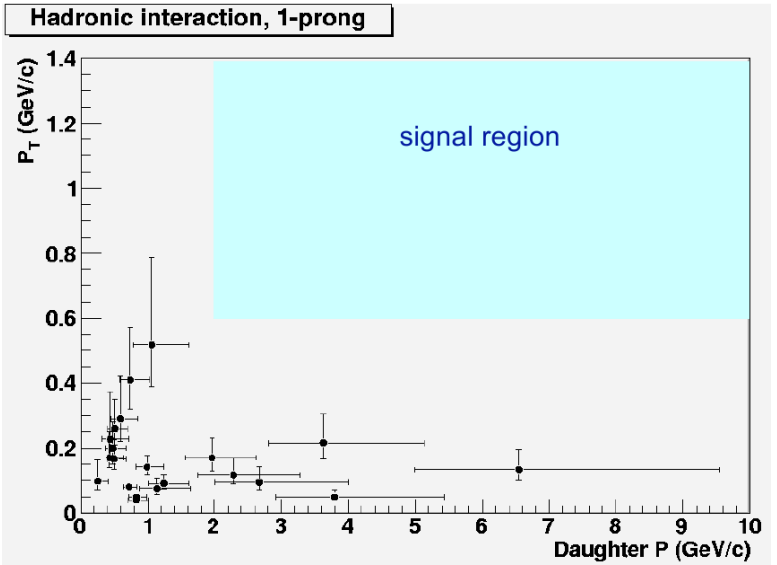
0.045 ± 0.020 (syst) events total BG

Measuring hadron interaction BG with OPERA events

The aim is however to measure the background rate with OPERA data directly, by following down hadrons

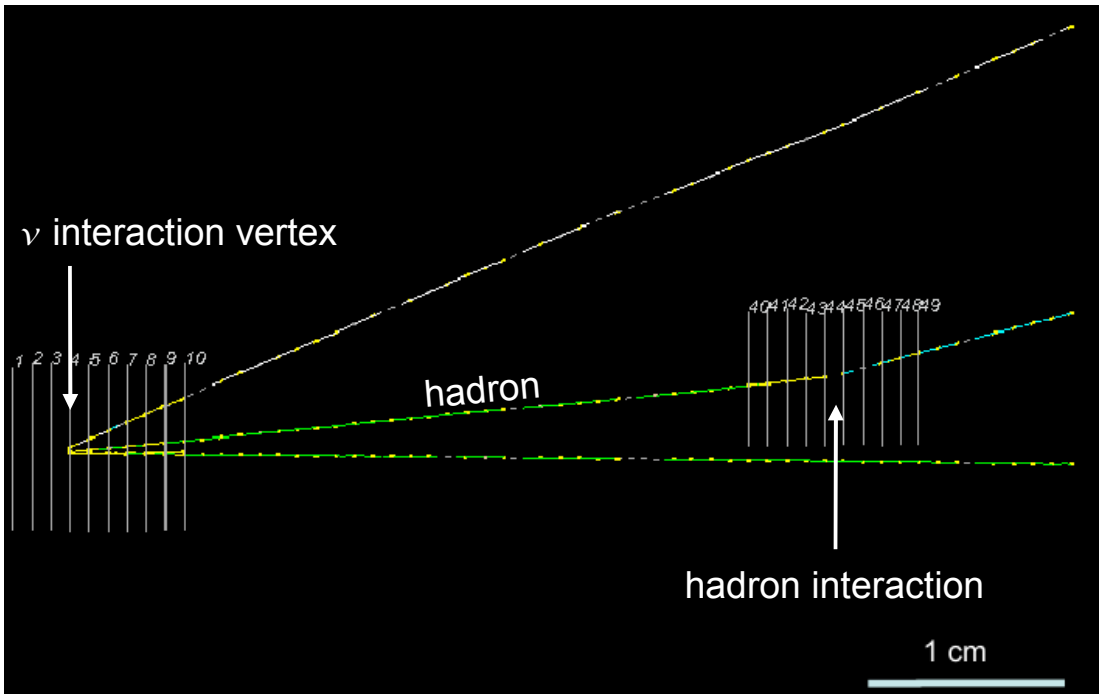
It needs a huge scanning effort!

LHEP scanning station is leading the analysis



9 meters equivalent scanned so far

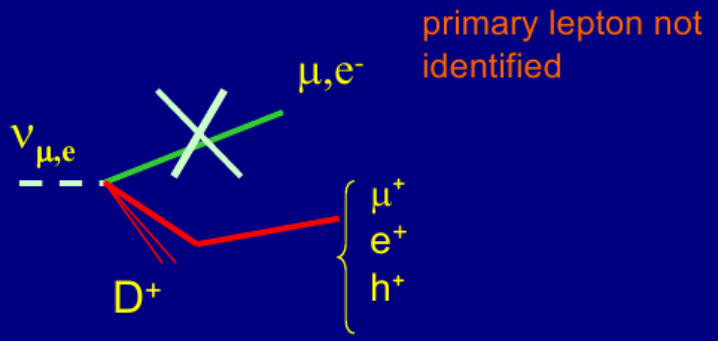
Goal: ~100 m will fully validate (eventually replace) the MC information



75% of total scanning load among the whole Collaboration is afforded by LHEP scanning station

Charm background

Charmed particles have similar decay topologies to the τ



- charm production in CC events represents a background source to all tau decay channels

- this background can be suppressed by identifying the primary lepton
→ ~ 95% muon ID

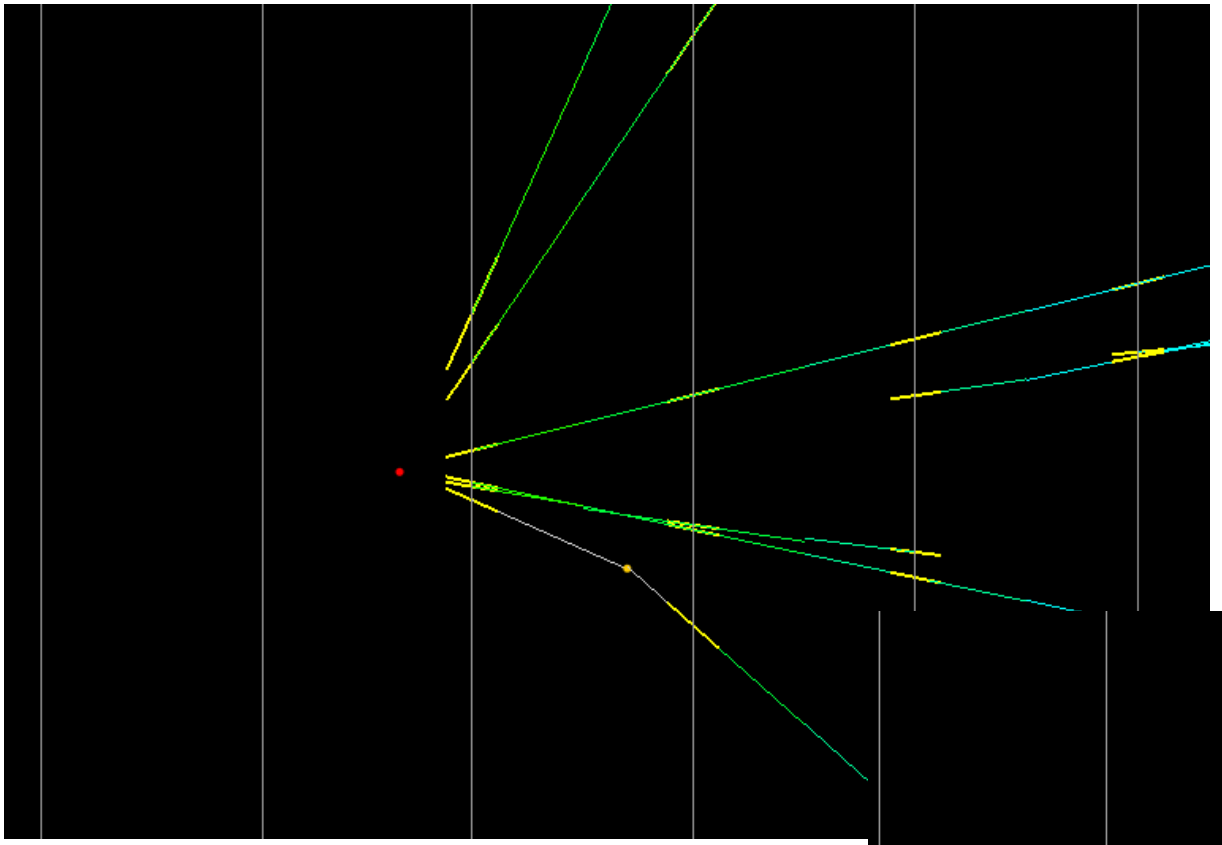
20 charm candidate events selected by the kinematical cuts,
3 of them with 1-prong kink topology.

Expected: 16.0 ± 2.9 out of which 0.80 ± 0.22 with kink topology

Expected BG: ~2 events (loose cuts: work in progress to reduce BG)

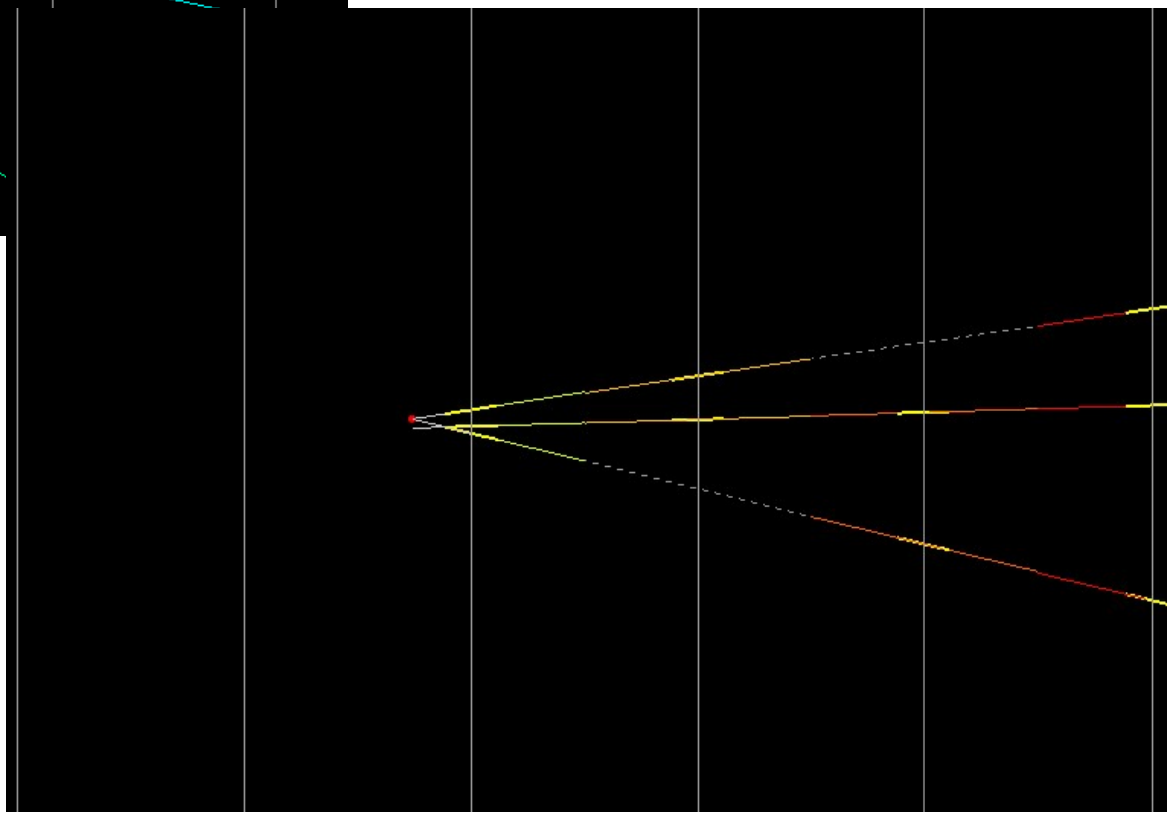
Study of charm contamination and its rejection: *T. Strauss, ETHZ, PhD Thesis*

Example of charm events

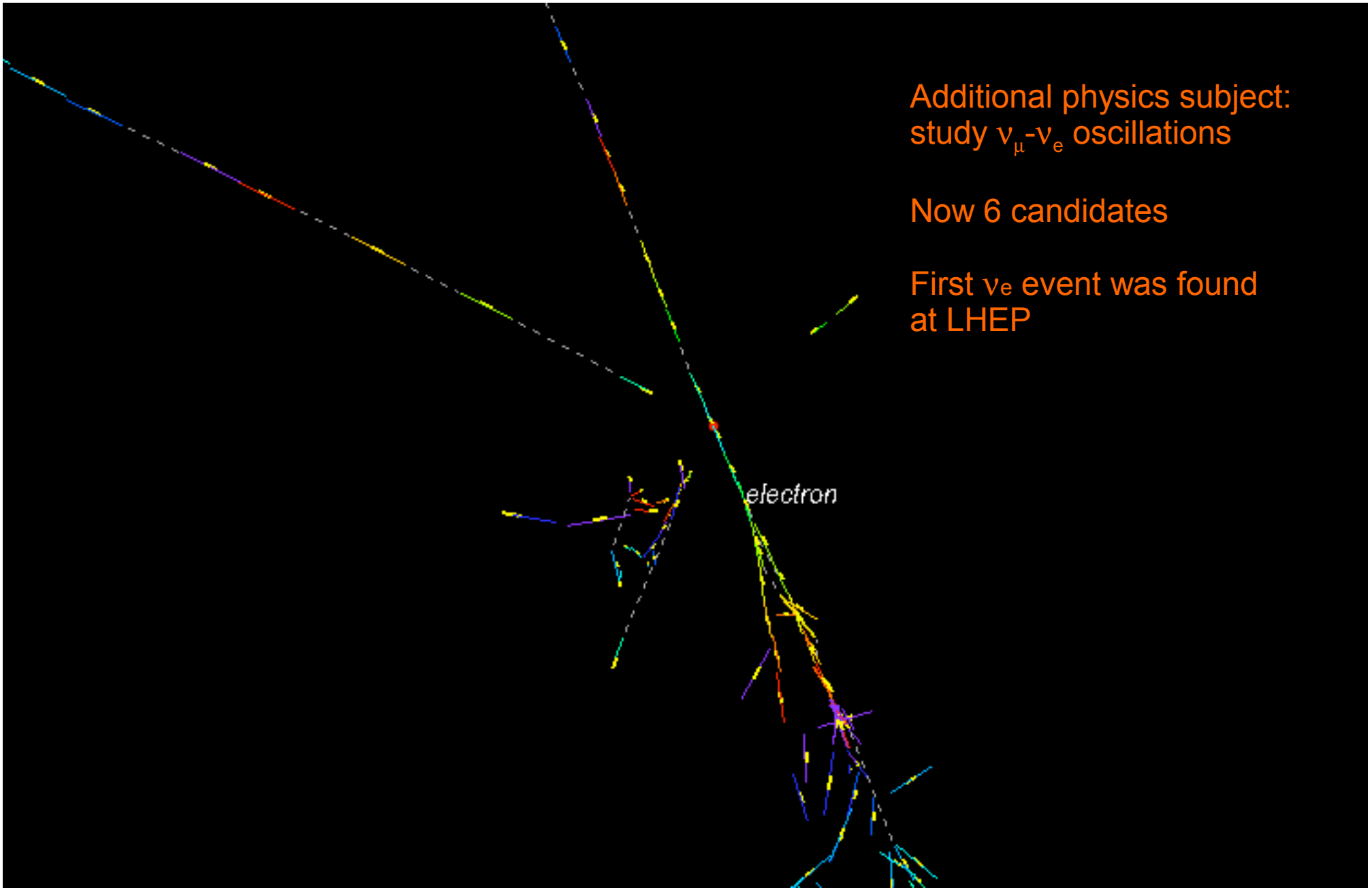


Long decay

Short decay



ν_e candidate event



Additional physics subject: study ν_μ-ν_e oscillations

Now 6 candidates

First ν_e event was found at LHEP

OPERA status

OPERA collected so far about 2 x 10^{19} pot events (August 2010)

• One muonless event showing a τ ➔ 1-prong hadron decay topology has been detected and studied in detail. It passes all kinematical cuts required to reduce the physics background. It is the first ν_τ candidate event in OPERA.

This is reported in:

N. Agafonova et al. [OPERA Collaboration], Phys. Lett. B691 (2010) 138 [arXiv:1006.1623 [hep-ex]]

At the time of the published paper, about 35% of 2008-2009 statistics was analysed. This would comport:

• By considering the 1-prong hadron channel only, the probability to observe 1 event due to a background fluctuation is 1.8%, for a statistical significance of 2.36 σ on the measurement of a first ν_τ candidate event in OPERA.

• If one considers all decay modes included in the search, the probability to observe 1 event for a background fluctuation is 4.5%. This corresponds to a significance of 2.01 σ.

Conclusions

The OPERA experiment is taking data in the CNGS beam

OPERA collected so far about **2 x 10^{19} pot events (August 2010)**

The analysis of 2008-2009 data is still in progress. The goal is to finish it within the end of 2010 (as it was planned).

The observation of **1 ν_τ candidate event** is the proof of a continuous and hard work and it is an important step towards the discovery of neutrino oscillation in direct appearance mode

The full evaluation of total efficiencies is ongoing

To meet this goal we require to successfully **complete data taking in the CNGS beam** and perform the analysis of the full data sample

In addition to the **seminal and proposal work**, to the **key managerial duties** and to the qualitative and quantitative role in the OPERA Collaboration, **swiss groups** have a very active role in the **OPERA analysis** and are also contributing to the **~35% of the european brick scanning load** and to the **75% of the whole scanning load for the evaluation of the hadron background**

Backup slides

Event statistics

Events collected by 2008-2009 run **5391**

Brick tagging efficiency times vertex location efficiency: ~60%

Total found neutrino vertices:
1921
This is ~60% of the total 2008-2009 run statistics

Events for which "decay search" was completed: **1088 (187 NC)**

This is ~35% of the total 2008-2009 run statistics,
corresponding to **1.85×10^{19} pot**

With the above statistics, and for $\Delta m^2_{23} = 2.5 \times 10^{-3}$ eV^2 and full mixing, OPERA expects:

~0.5 ν_τ events

OPERA expected performance (Proposal)

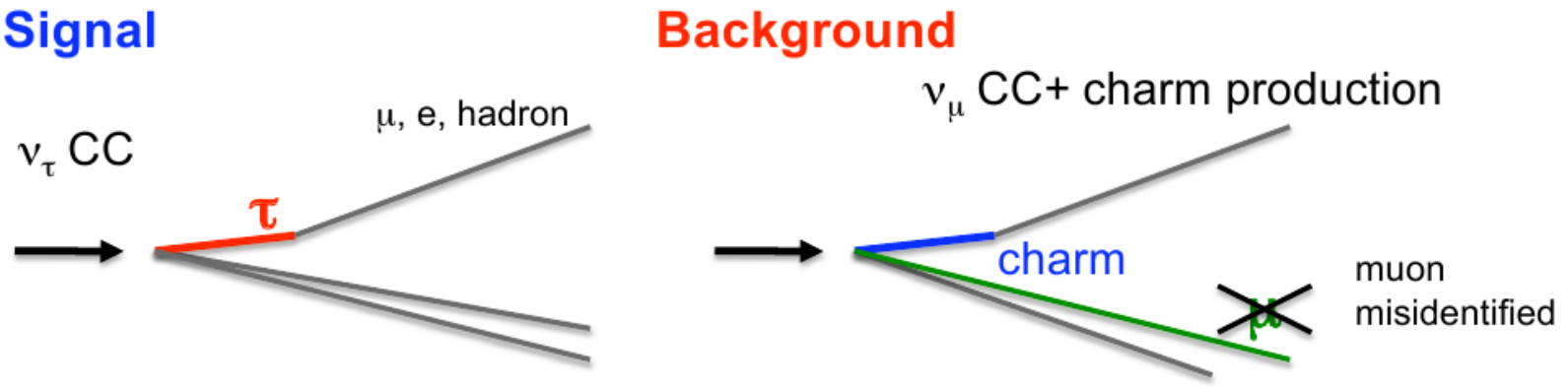
τ decay channel	B.R. (%)	Signal $\Delta m^2 = 2.5 \times 10^{-3}$ eV^2	Background
$\tau \rightarrow \mu$	17.7	2.9	0.17
$\tau \rightarrow e$	17.8	3.5	0.17
$\tau \rightarrow h$	49.5	3.1	0.24
$\tau \rightarrow 3h$	15.0	0.9	0.17
Total		10.4	0.75

Main background sources:

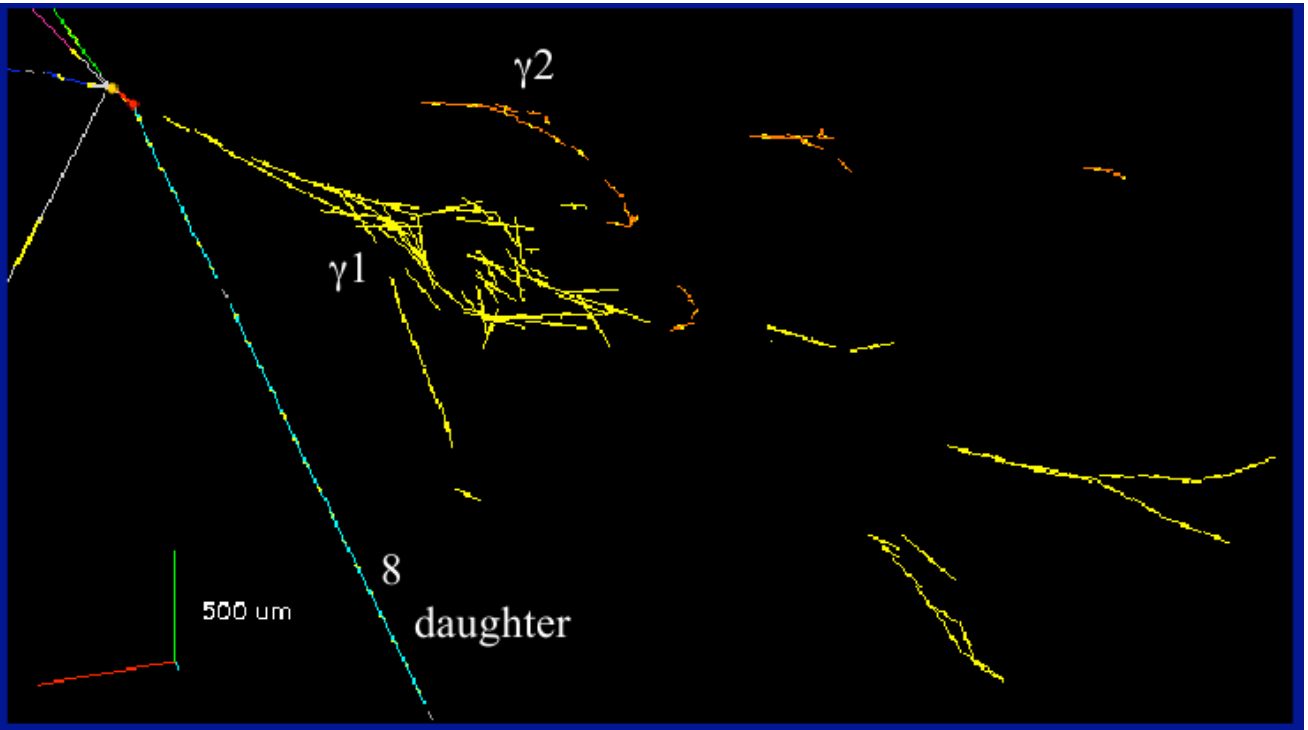
- Production and decay of charmed particles
- Hadron reinteractions
- Large angle muon scattering

Assume 22.5×10^{19} pot

Example: charm BG to tau decays



γ detection

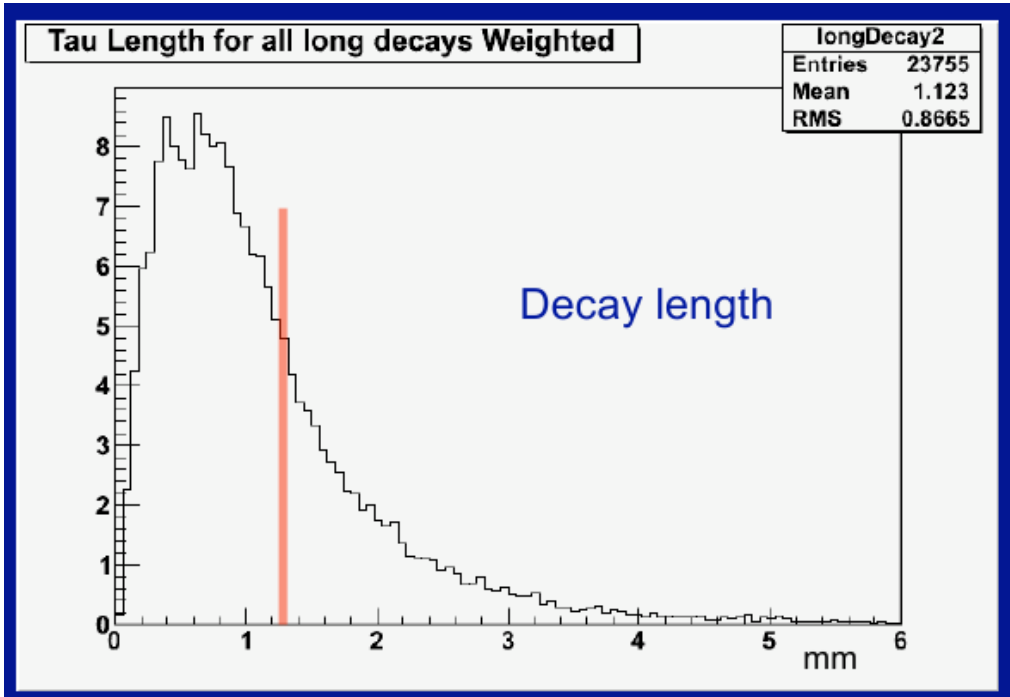


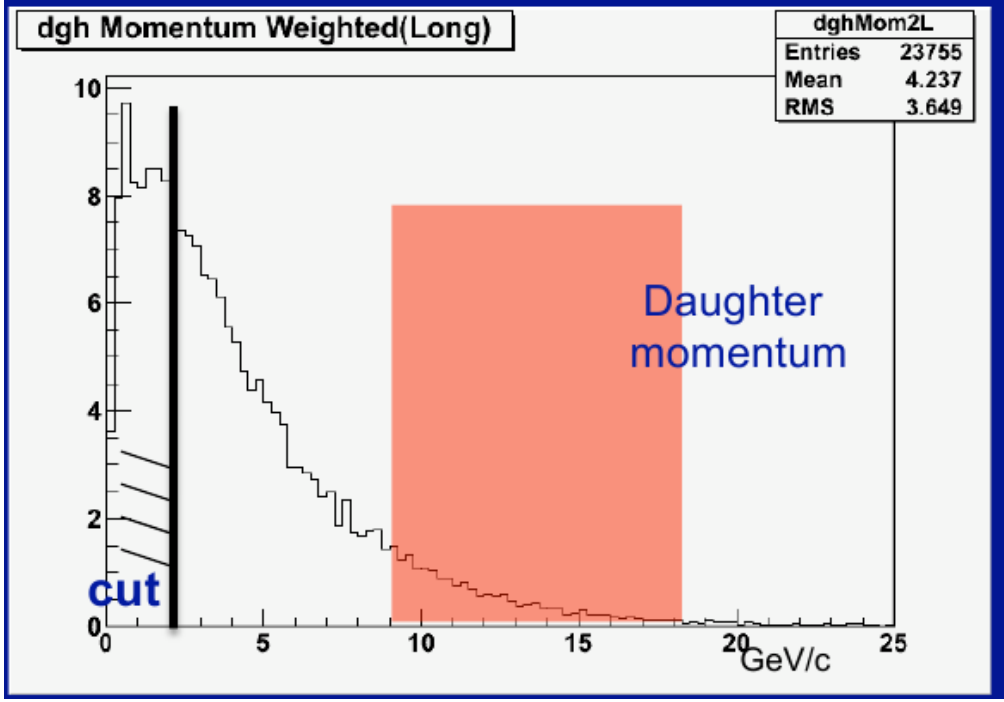
- total radiation length downstream the vertices: 6.5 X_0
- gamma search performed in the whole scanned volume
- careful visual scanning checks

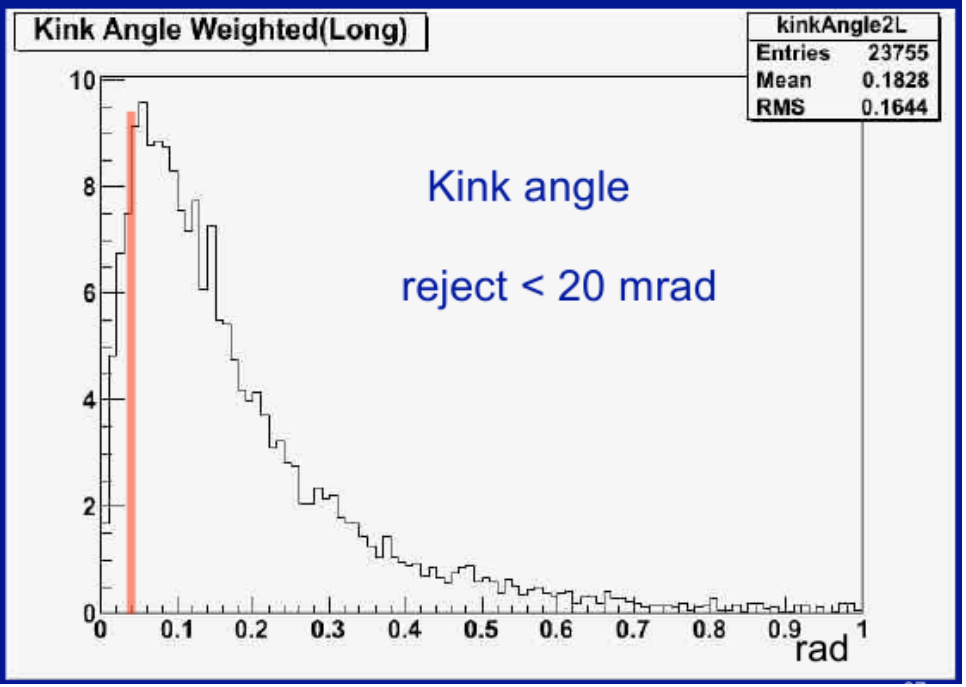
	Distance from 2ry vertex (mm)	Energy (GeV)
1st γ	2.2	5.6 ± 1.0 ± 1.7
2nd γ	12.6	1.2 ± 0.4 ± 0.4

Features of the decay topology

red bands: values for the “interesting” event with uncertainties

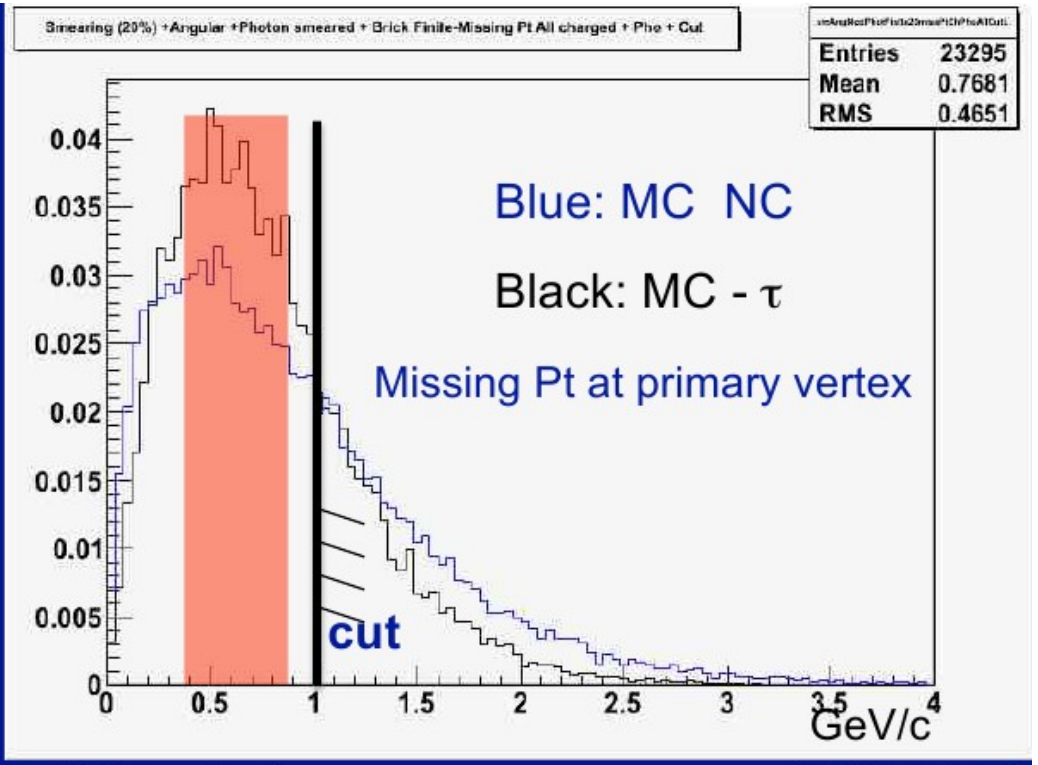




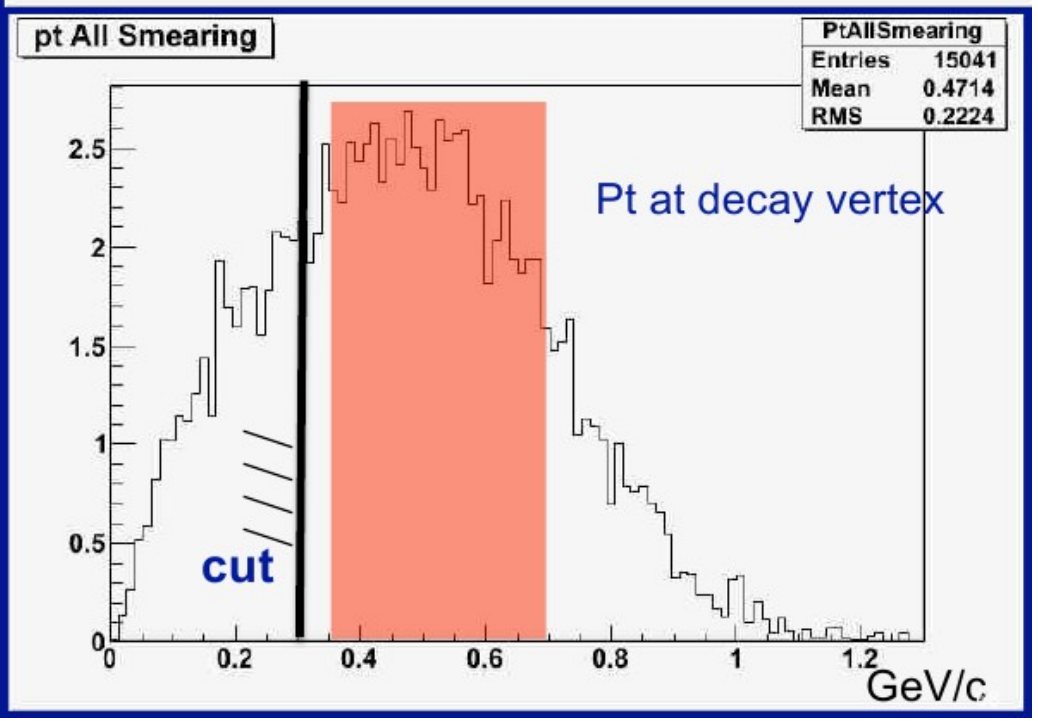


Kinematical cuts to be passed

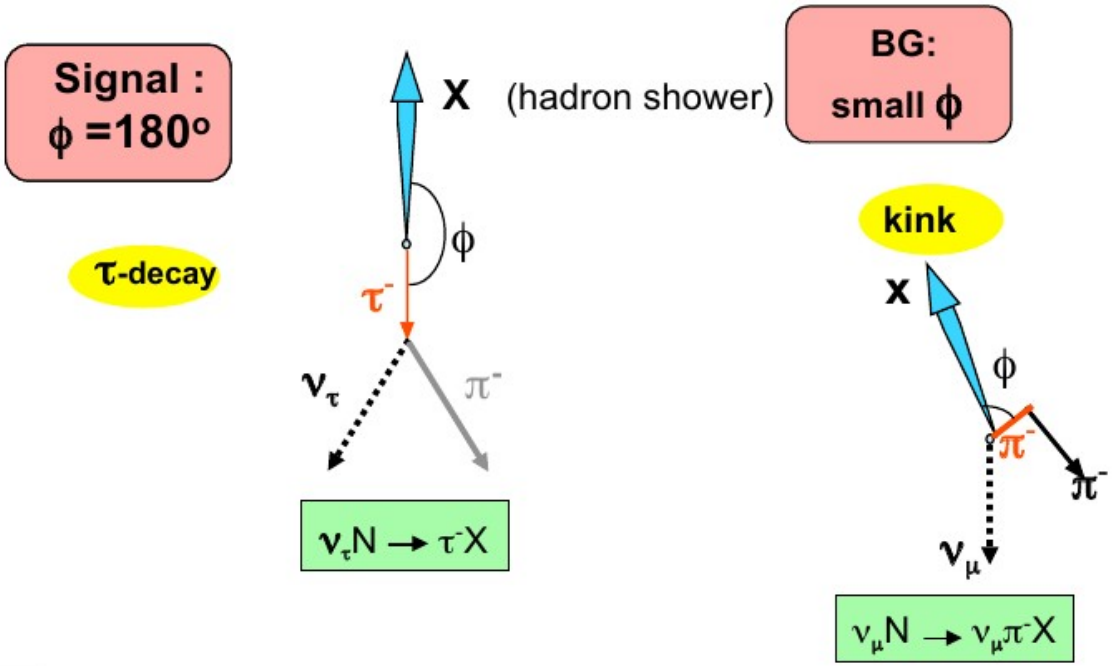
Reject NC events with larger missing Pt (neutrino)

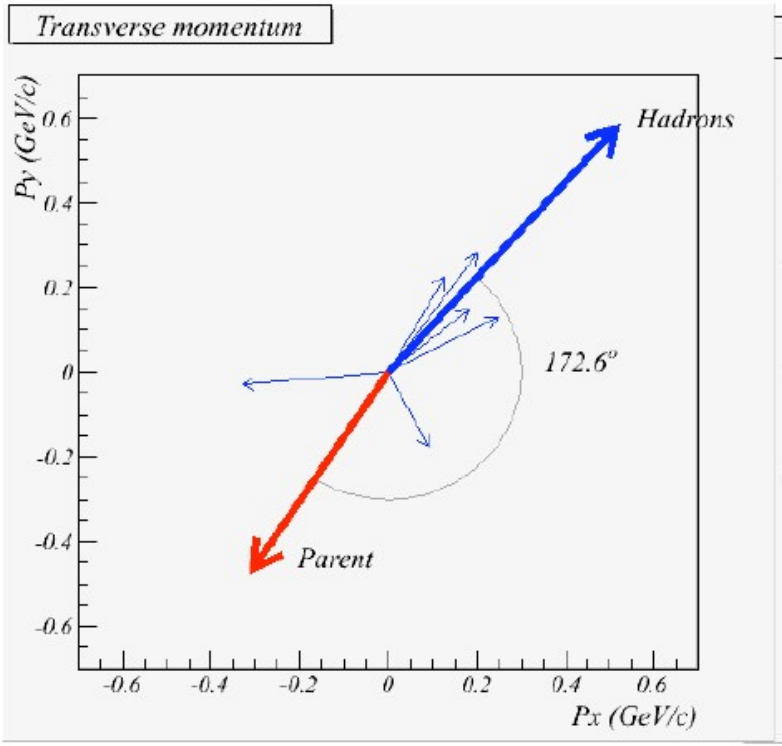


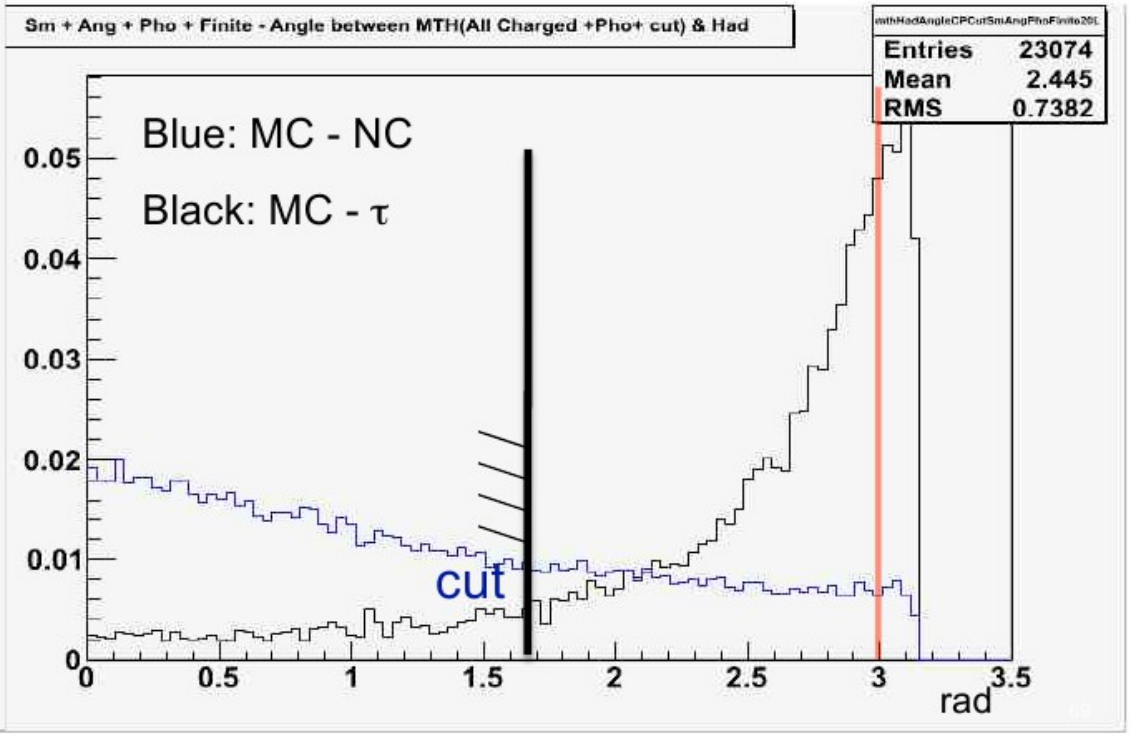
Reject hadron interactions



Azimuthal angle between the resulting hadron momentum direction and the parent track direction

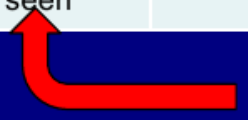






Event tracks' features

TRACK NUMBER	PID	Probability	MEASUREMENT 1			MEASUREMENT 2		
			tan Θ_X	tan Θ_Y	P (GeV/c)	tan Θ_X	tan Θ_Y	P (GeV/c)
1	HADRON range in Pb/em=4.1/1.2cm	Prob(μ)≈10^{-3}	0.177	0.368	0.77 [0.66,0.93]	0.175	0.357	0,80 [0.65,1.05]
2	PROTON	range, scattering and dE/dx	-0.646	-0.001	0.60 [0.55,0.65]	-0.653	0.001	
3	HADRON	interaction seen	0.105	0.113	2.16 [1.80,2.69]	0.110	0.113	1,71 [1.42,2.15]
4 (PARENT)			-0.023	0.026		-0.030	0.018	
5	HADRON: range in Pb/em=9.5/2.8cm	Prob(μ)≈10^{-3}	0.165	0.275	1.33 [1.13,1.61]	0.149	0.259	1,23 [0.98,1.64]
6	HADRON: range in Pb/emul=1.6/0.5 cm	Prob(μ)≈10^{-3}				0.334	-0.584	0,36 [0.27,0.54]
7	From a prompt neutral particle		0.430	0.419	0.34 [0.22,0.69]	0.445	0.419	0.58 [0.39,1.16]
8 (DAUGHTER)	HADRON	interaction seen	-0.004	-0.008	12 [9,18]	-0.009	-0.020	



muonless event (favored hypothesis)

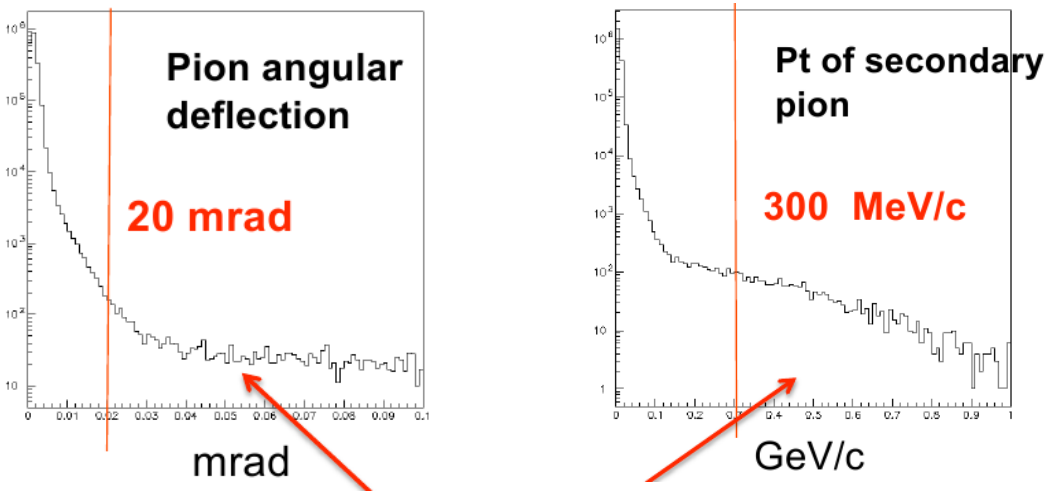
Simulation of the reinteraction BG

- Background evaluation by using state-of-the-art FLUKA code, upgrade of the Proposal simulations.
- 160 million events (0.5-15 GeV/c) of π^+,π^- ,K^+,K^-,p impinging 1 mm of lead, equivalent to 160 km of hadronic track length.
- Kink probabilities evaluated by applying the same cuts as for the tau analysis.

kink probabilities integrated over the ν_μ NC hadronic spectrum yield a BG probability of:

$(1.9 \pm 0.1) \times 10^{-4}$ kinks/NC (2 mm Pb)

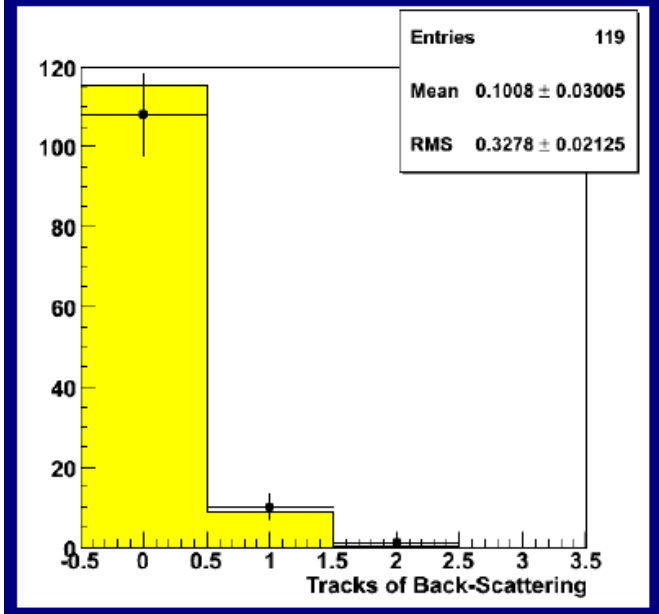
Typical scattering distributions for : 5 GeV π^+

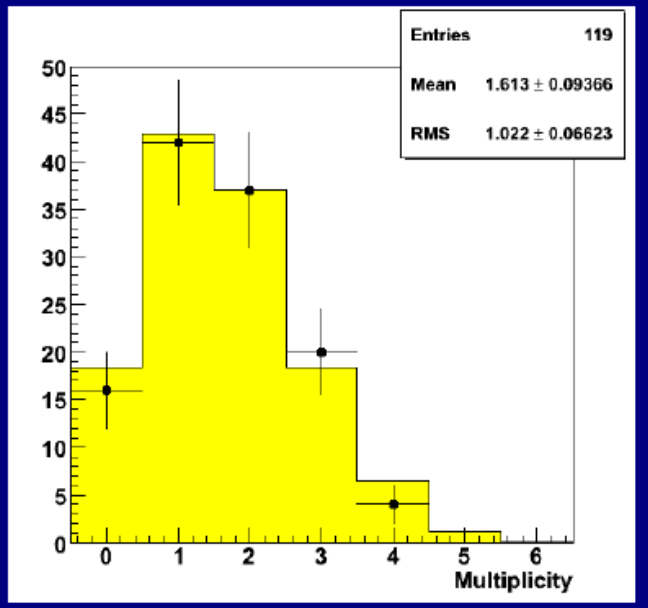


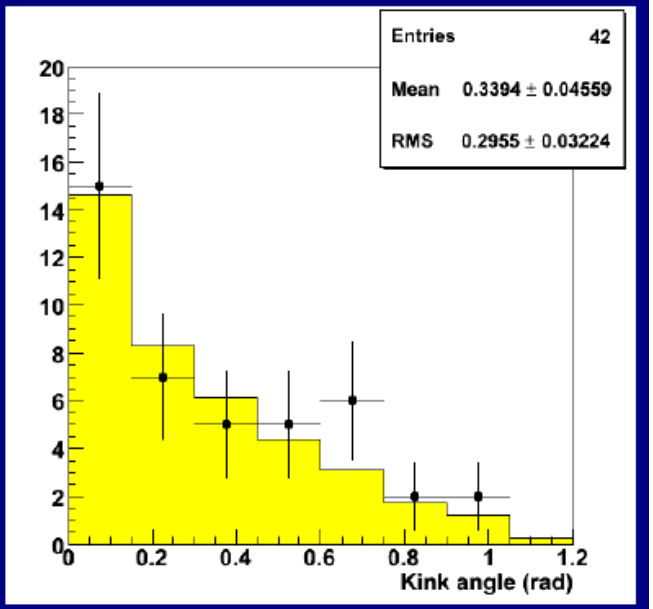
Tails of the distributions

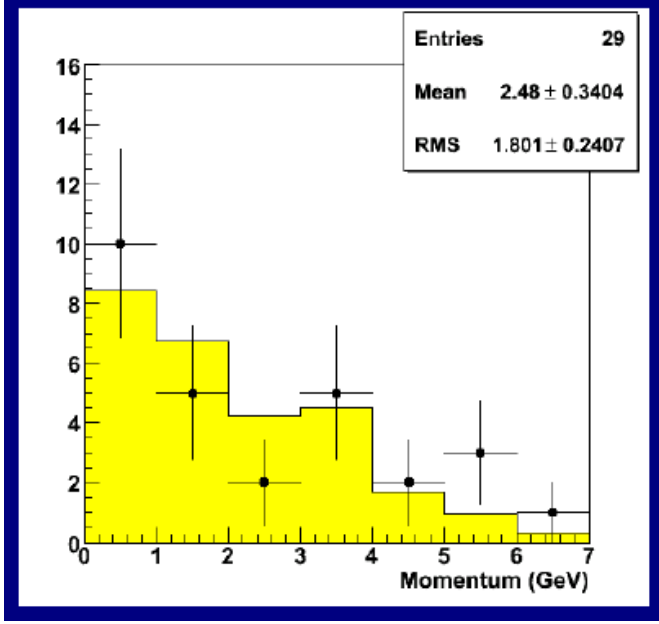
DATA/MC comparison: good agreement in normalization and shape

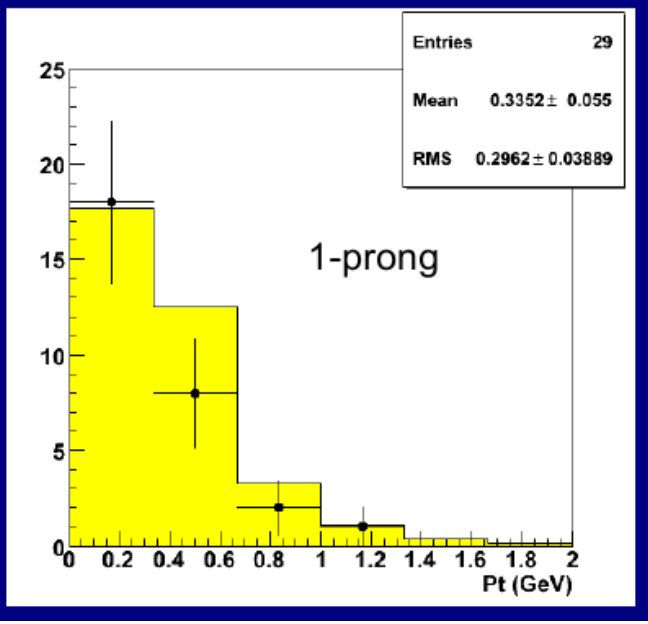
Beam Test 4GeV pion 18 times track length(20m) of tau search.

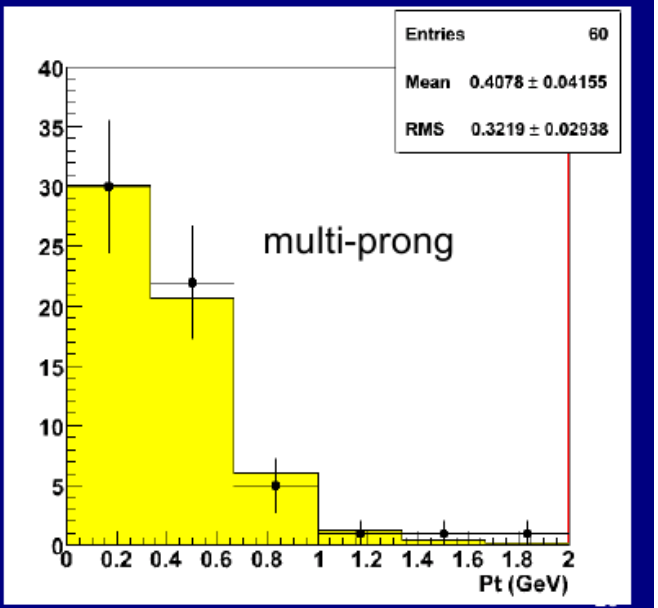












Main kinematical cuts for charm events:

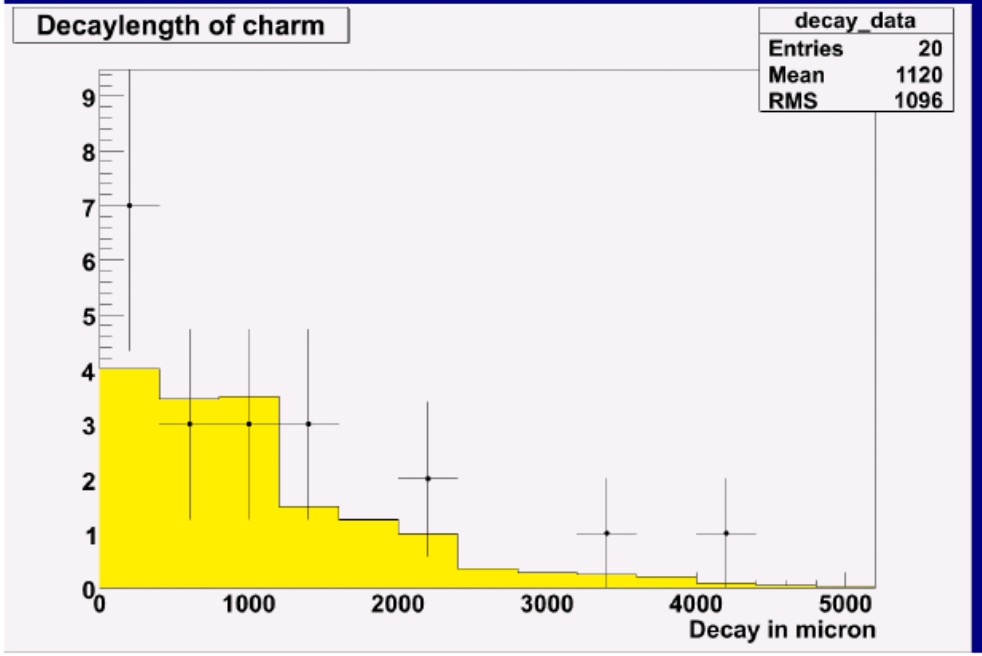
- P daughter >2.5 GeV/c, kink Pt > 0.5 GeV/c (for kink events)
- looser cuts for multi-prong events

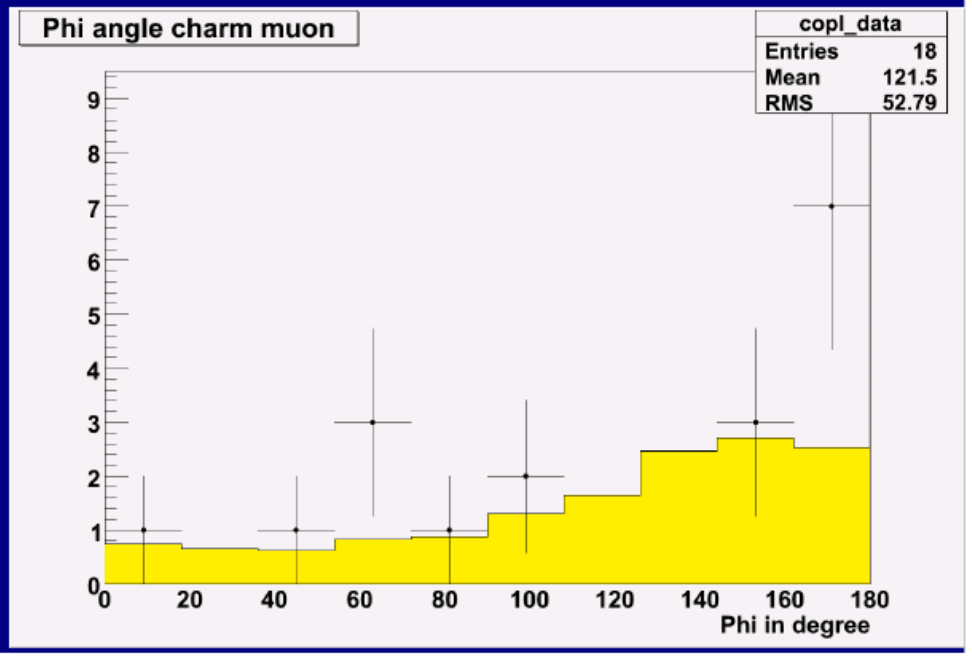
20 charm candidate events selected by the kinematical cuts,
3 of them with 1-prong kink topology.

Expected: 16.0 ± 2.9 out of which 0.80 ± 0.22 with kink topology

Expected BG: ~2 events (loose cuts: work in progress to reduce BG)

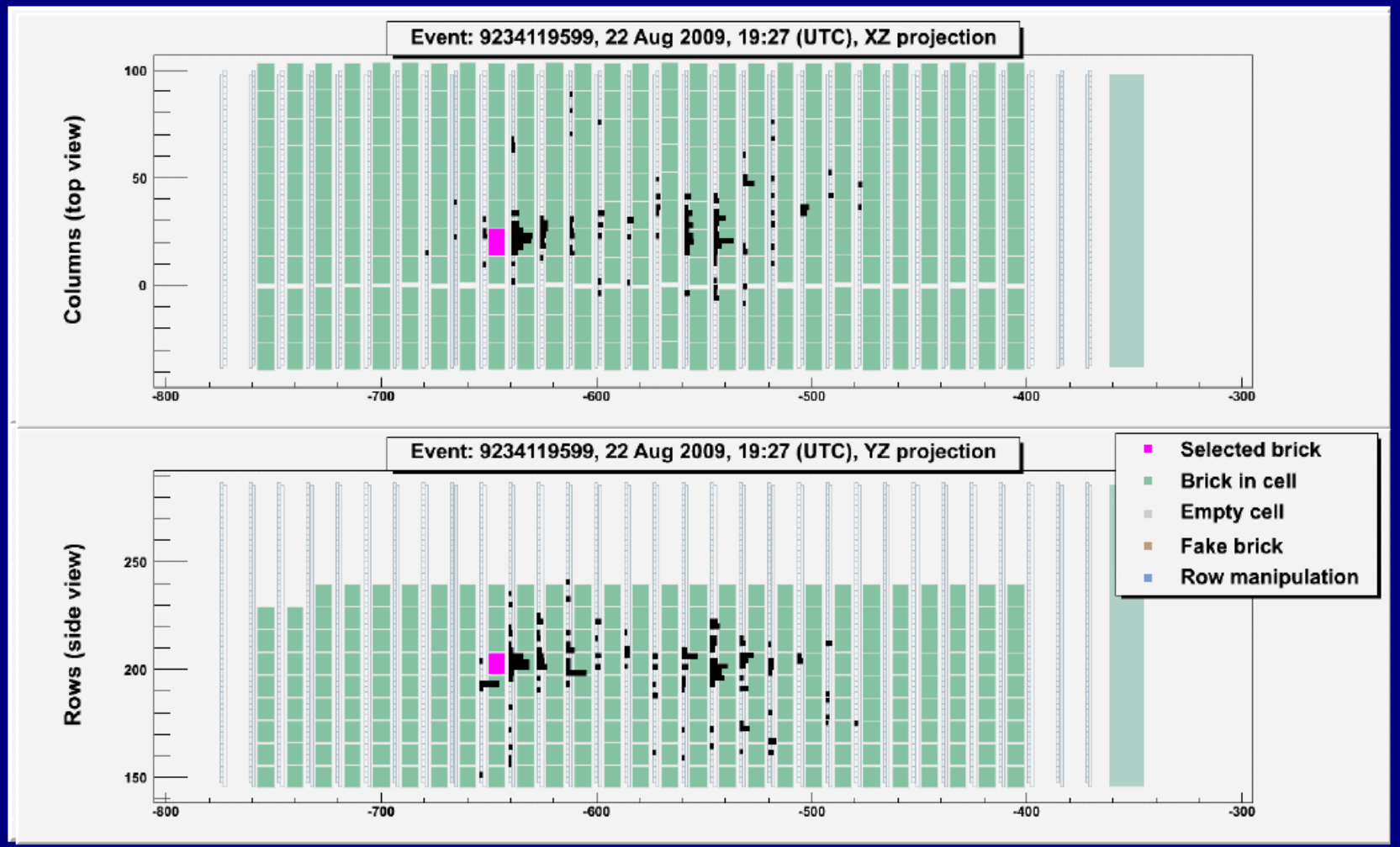
Examples of distributions:





A very interesting event: brick extraction

Muonless event 9234119599, taken on 22 August 2009, 19:27 (as seen by the electronic detectors)



ν_e interaction event