Status and perspectives of OPERA in the CNGS beam

Antonio Ereditato

Albert Einstein Center for Fundamental Physics

LHEP, Bern University

OPERA's goal: establish detection of neutrino oscillations in appearance mode

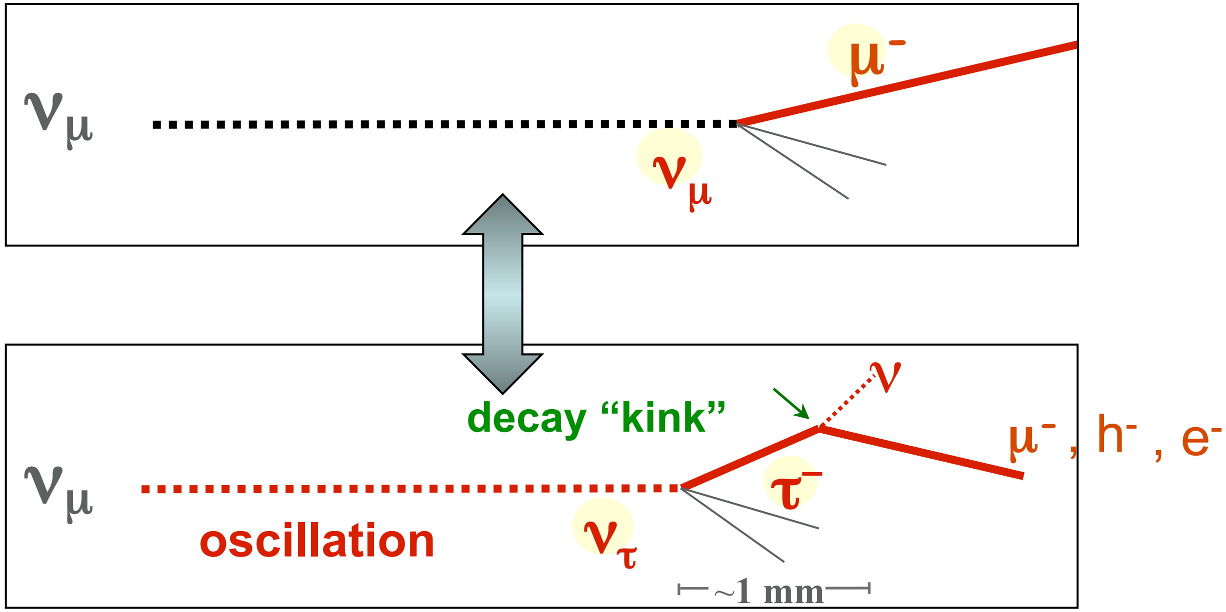
following the Super- Kamiokande discovery of oscillations with atmospheric neutrinos and the confirmation obtained with solar neutrinos and accelerator beams. Important, missing tile in the oscillation picture.

The PMNS 3-flavor oscillation formalism predicts:

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

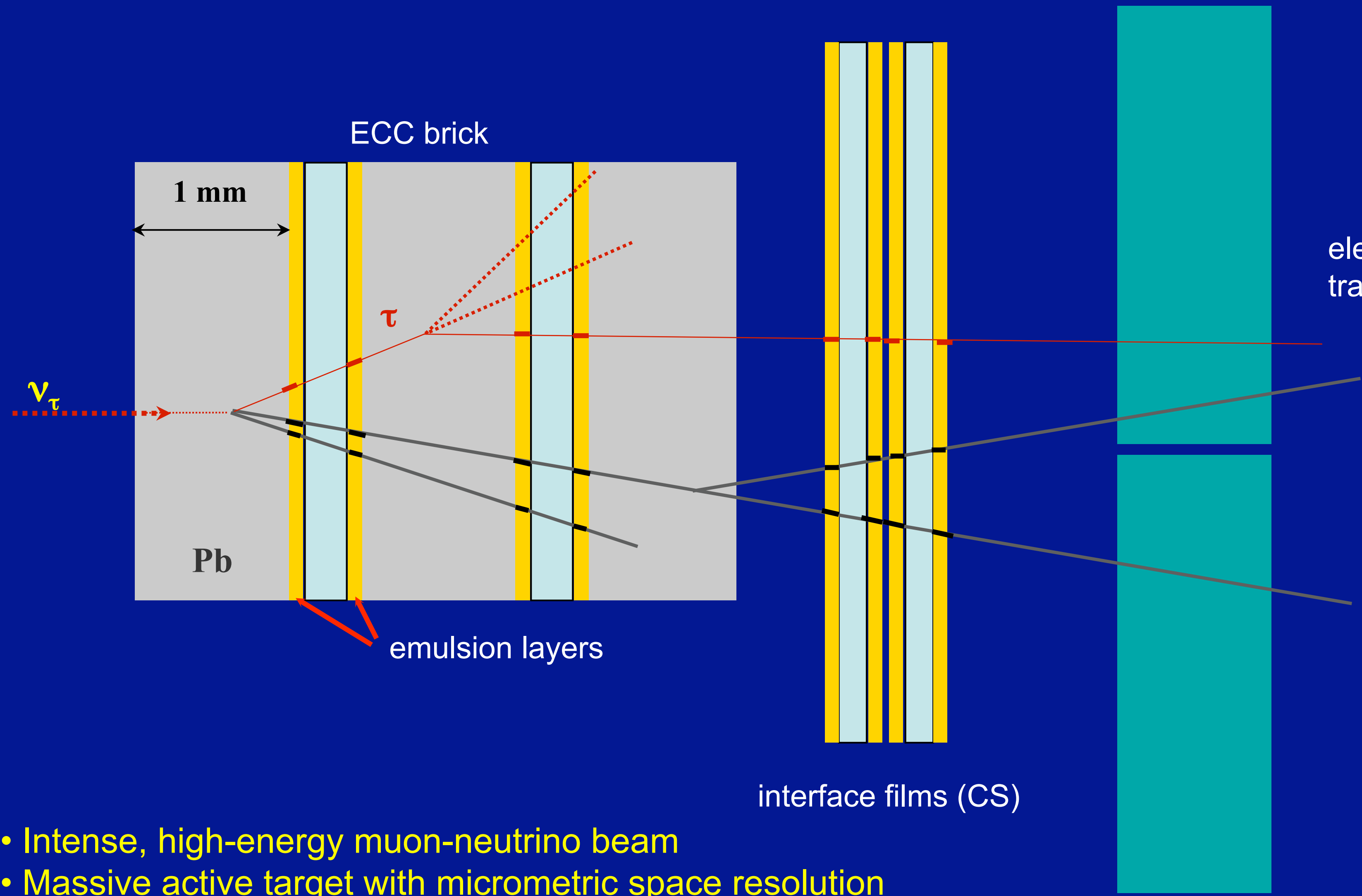
Requirements:

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



plus 3-prong decay modes

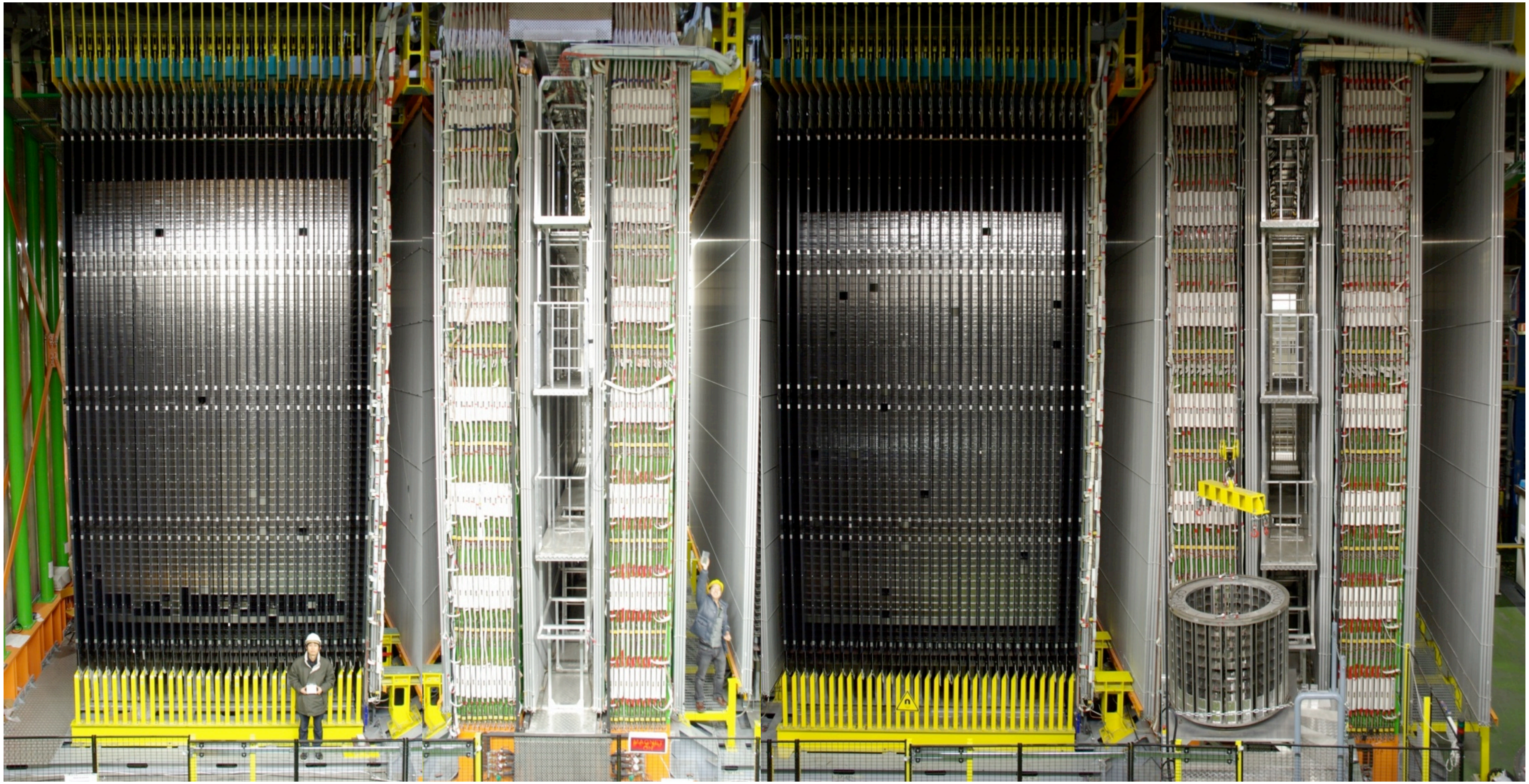
THE PRINCIPLE OF THE EXPERIMENT: ECC + ELECTRONIC DETECTORS



- Intense, high-energy muon-neutrino beam
- Massive active target with micrometric space resolution
- Detect tau-lepton production and decay
- Use electronic detectors to provide “time resolution” to the emulsions and preselect the interaction region

THE IMPLEMENTATION OF THE PRINCIPLE

SM1 SM2

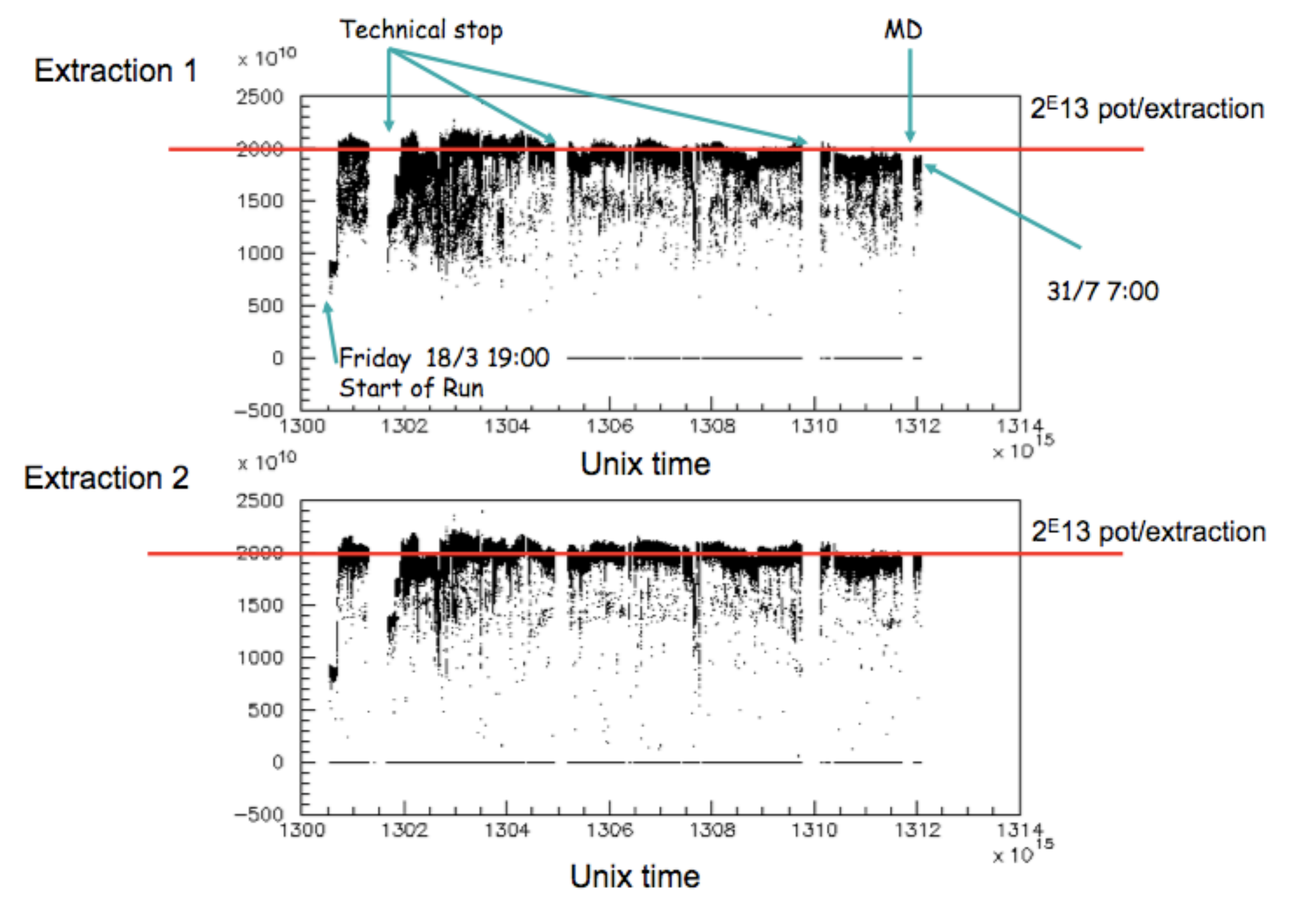


Target area Muon spectrometer

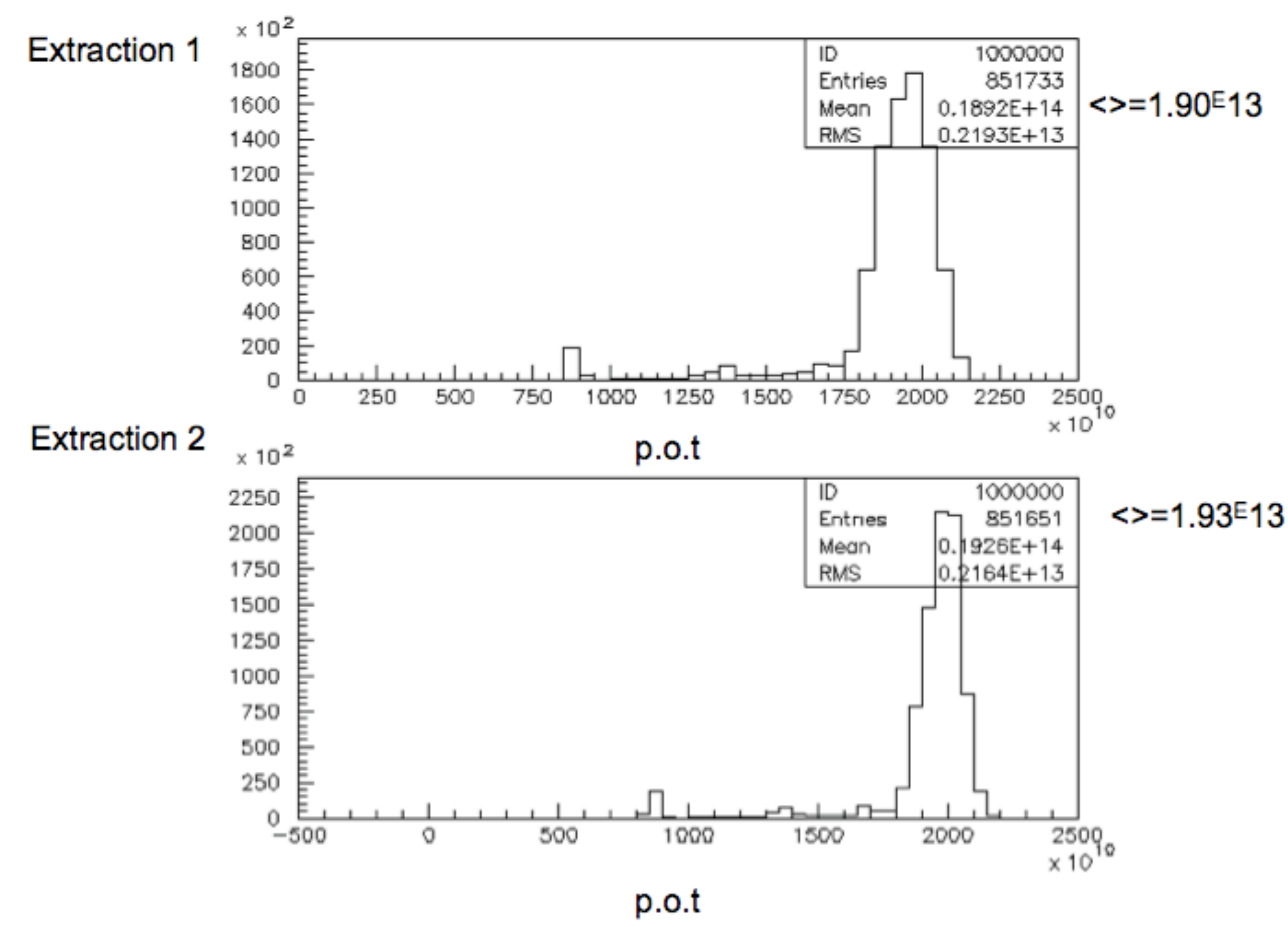
plus a series of large infrastructure for brick manipulation, film development, scanning,…

CNGS BEAM

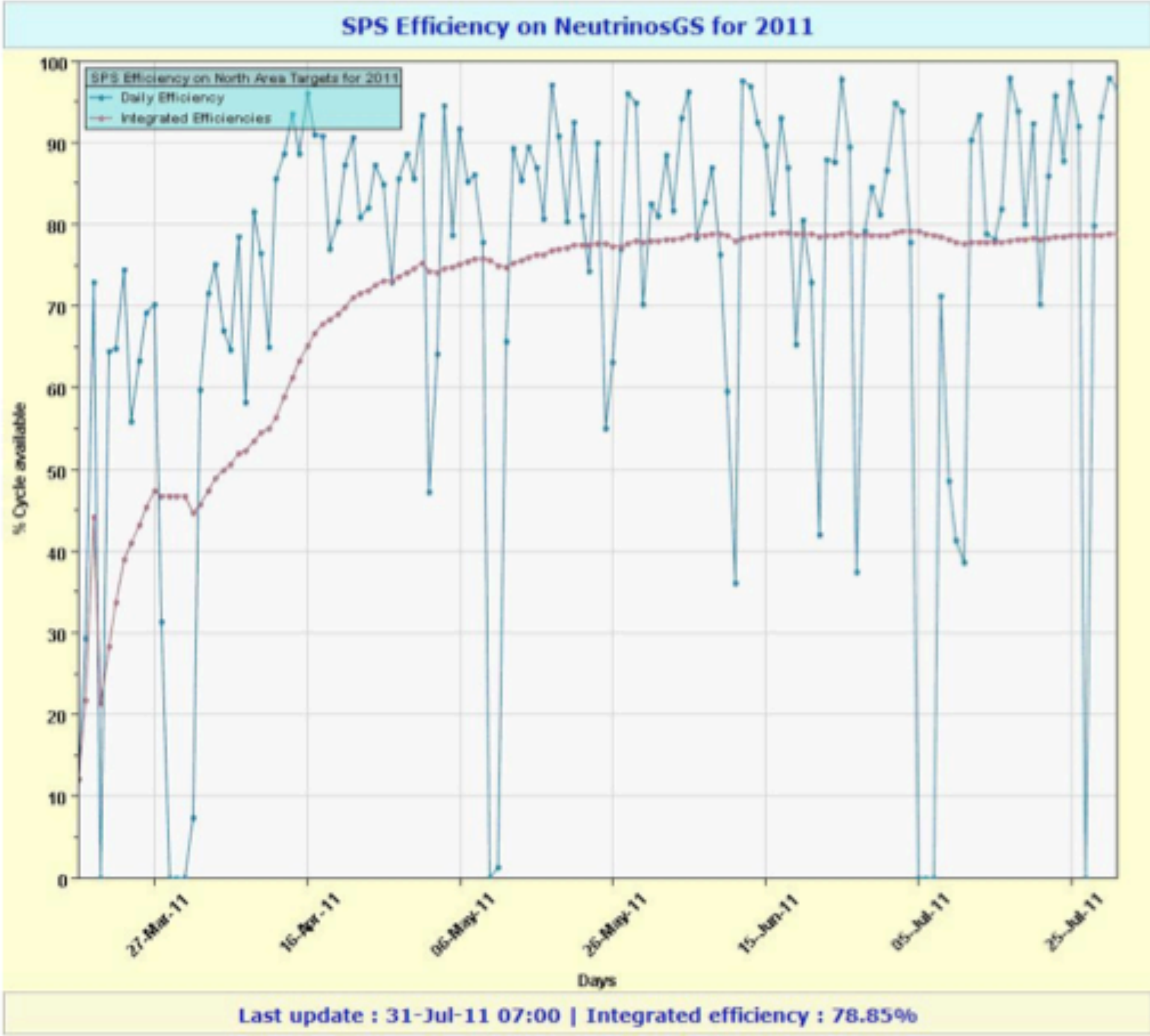
2011 run



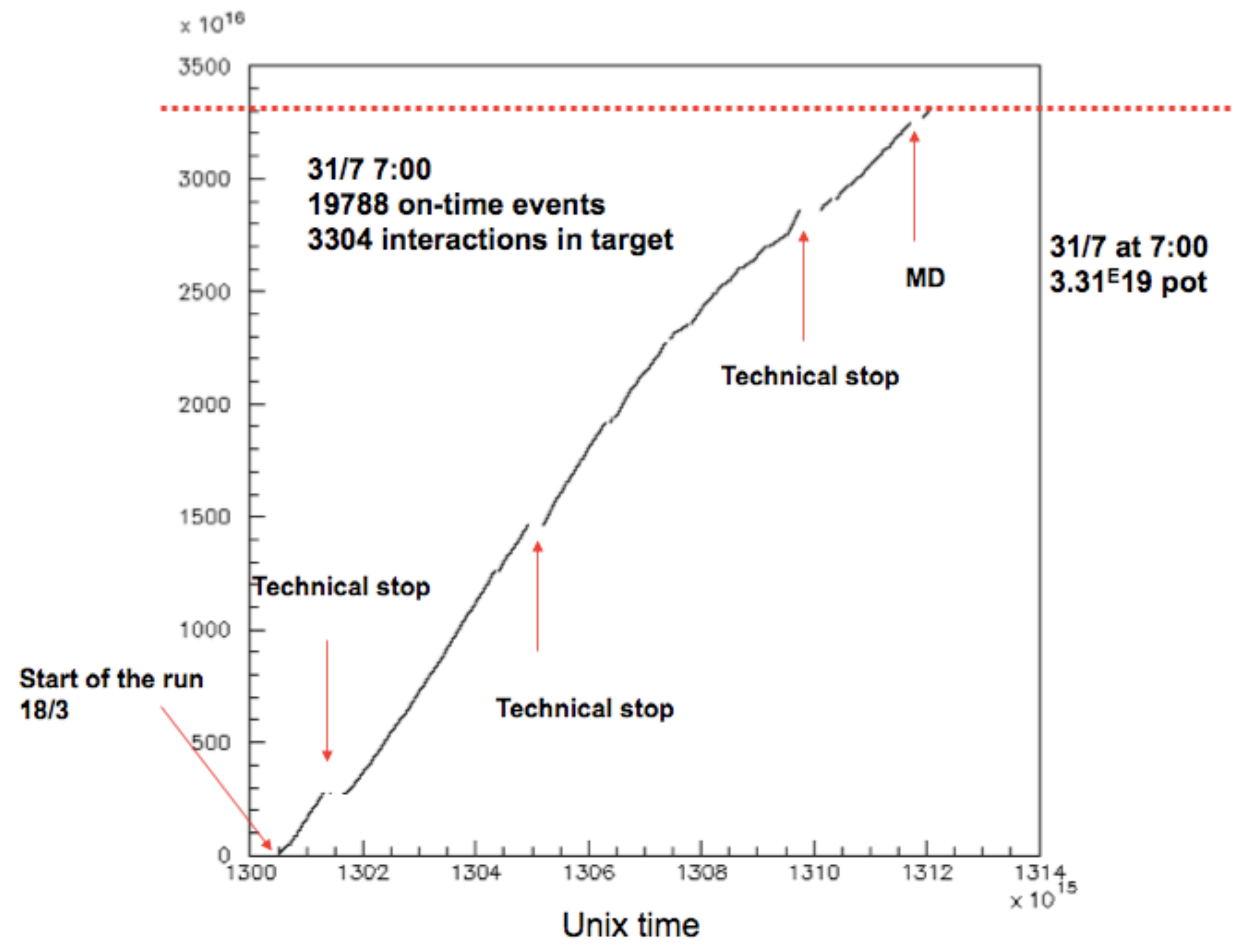
Extraction 1
Technical stop
MD
x 10^10
2500
2000
1500
1000
500
0
−500
2^E13 pot/extraction
31/7 7:00
Friday 18/3 19:00
Start of Run
1300
1302
1304
1306
1308
1310
1312
1314
x 10^15
Unix time
Extraction 2
x 10^10
2500
2000
1500
1000
500
0
−500
2^E13 pot/extraction
1300
1302
1304
1306
1308
1310
1312
1314
x 10^15
Unix time



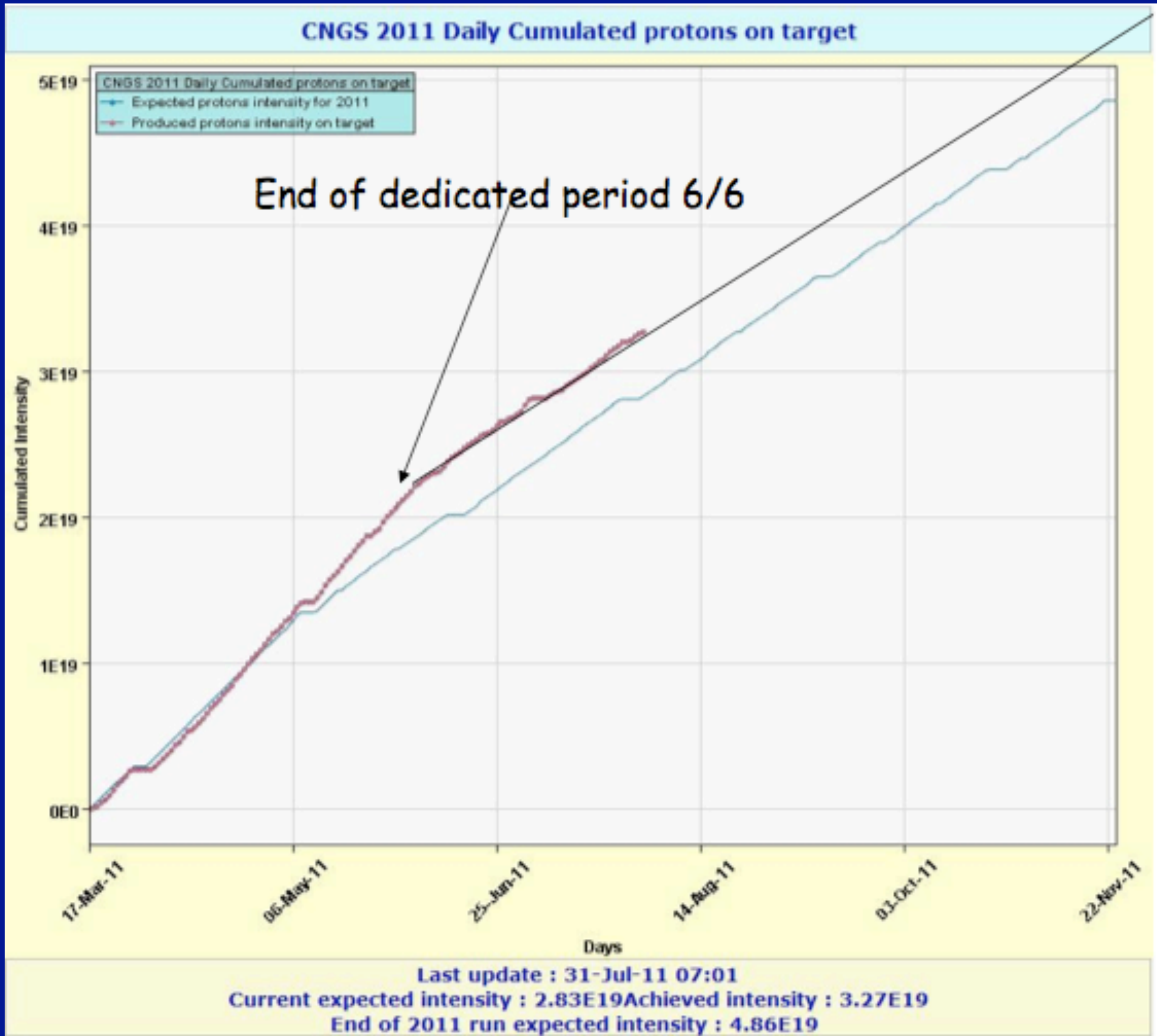
Extraction 1
x 10^2
ID 1000000
Entries 851733
Mean 0.1892E+14
RMS 0.2193E+13
<>=1.90E13
x 10^10
p.o.t
Extraction 2
x 10^2
ID 1000000
Entries 851651
Mean 0.1926E+14
RMS 0.2164E+13
<>=1.93E13
x 10^10
p.o.t



Average efficiency for 2011 78.85%

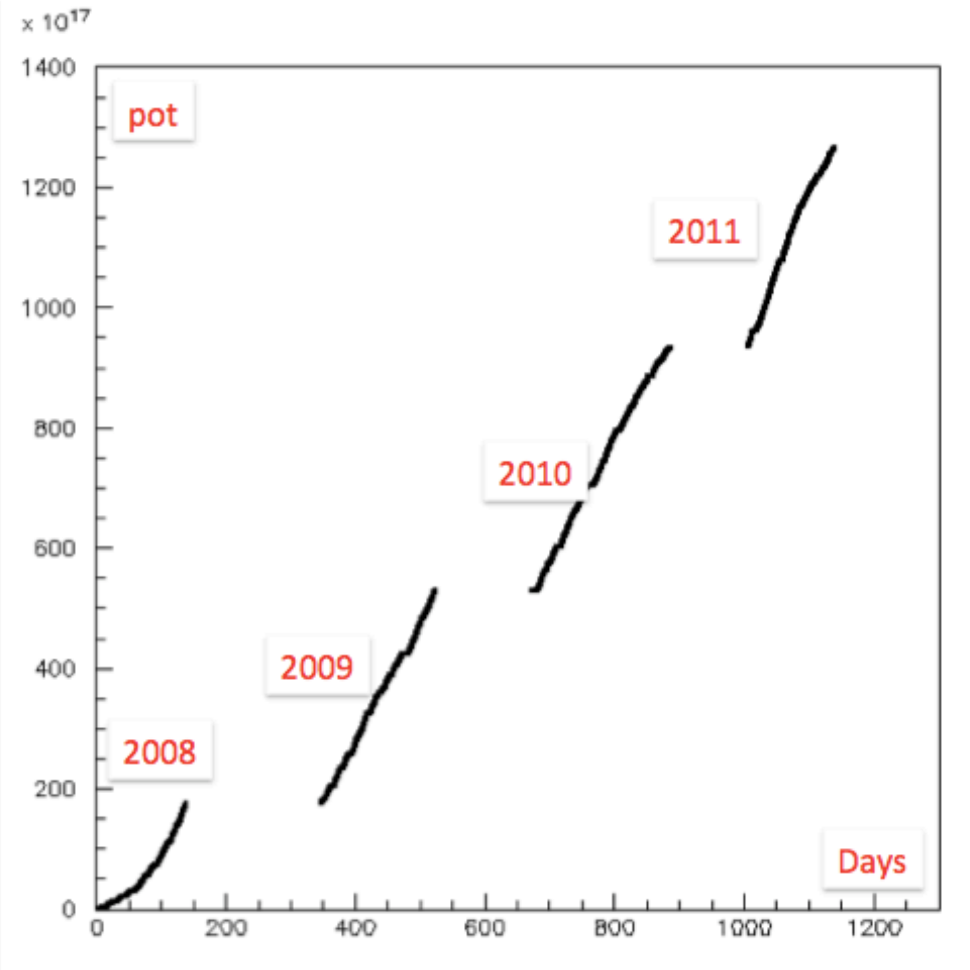


x 10^16
3500
3000
2500
2000
1500
1000
500
0
1300
1302
1304
1306
1308
1310
1312
1314
x 10^15
Unix time
31/7 7:00
19788 on-time events
3304 interactions in target
31/7 at 7:00
3.31E19 pot
MD
Technical stop
Technical stop
Technical stop
Start of the run
18/3


CNGS 2011 Daily Cumulated protons on target
CNGS 2011 Daily Cumulated protons on target
Expected protons intensity for 2011
Produced protons intensity on target
End of dedicated period 6/6
Cumulated Intensity
5E19
4E19
3E19
2E19
1E19
0E0
17-Mar-11
06-May-11
25-Jun-11
14-Aug-11
03-Oct-11
22-Nov-11
Days
Last update : 31-Jul-11 07:01
Current expected intensity : 2.83E19Achieved intensity : 3.27E19
End of 2011 run expected intensity : 4.86E19

CNGS vs OPERA

Year	Beam days	Protons on target (pot)	SPS Eff.	Events in the bricks
2008	123	1.78×10^{19}	61%	1698
2009	155	3.52×10^{19}	70%	3693
2010	187	4.04×10^{19}	81%	4248
2011	Ongoing (223)	3.31×10^{19}	79%	3304



Goal of the experiment: 22.5×10^{19} pot

2010: close to nominal year (4.5×10^{19} pot)

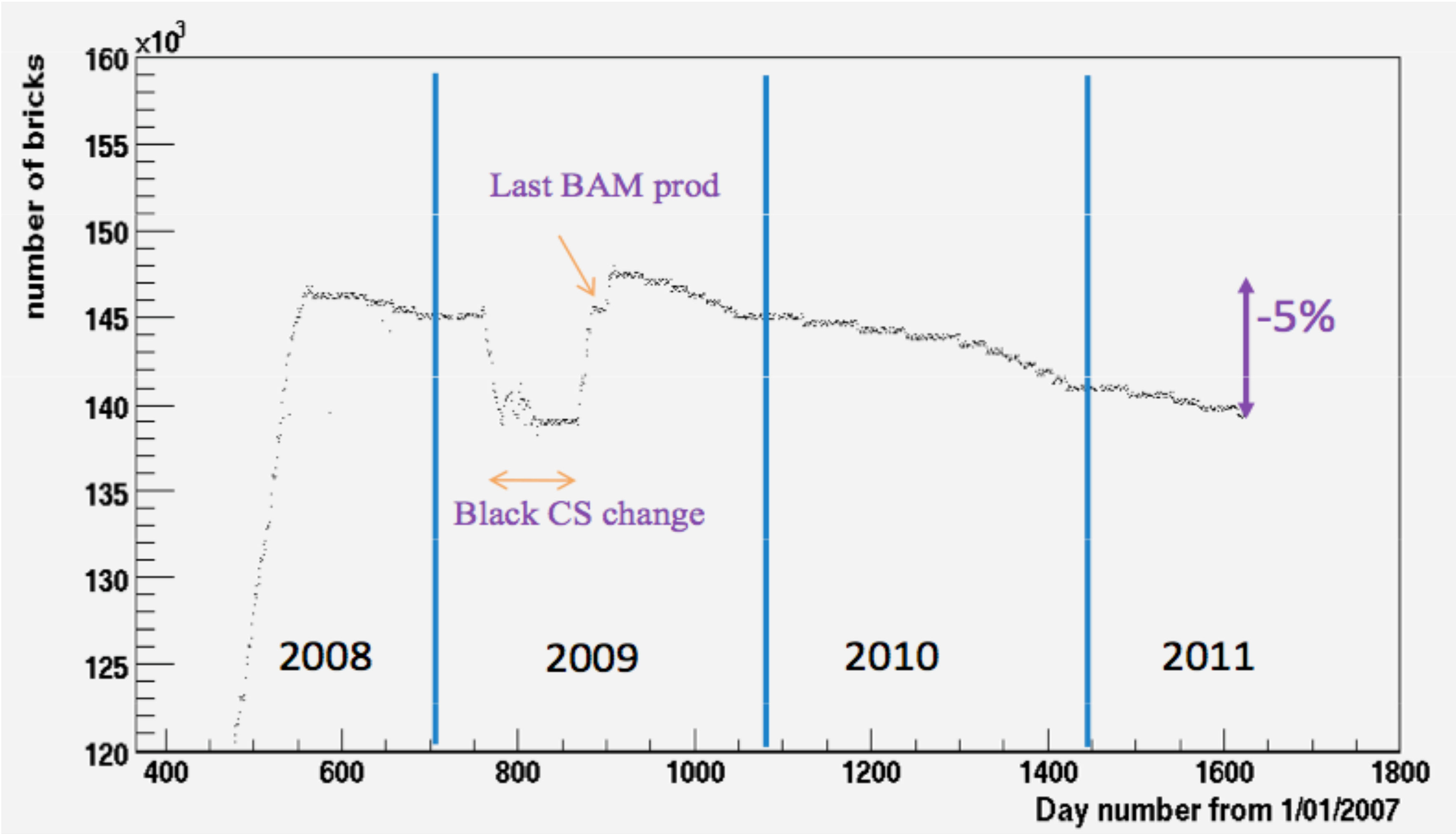
2011: hit record performance ?
(expect ~5×10^{19} pot for 223 days)
Dedicated mode (no other fixed target) from 18 March to 7 June.

Until now (2008-2011): 12.65×10^{19} pot

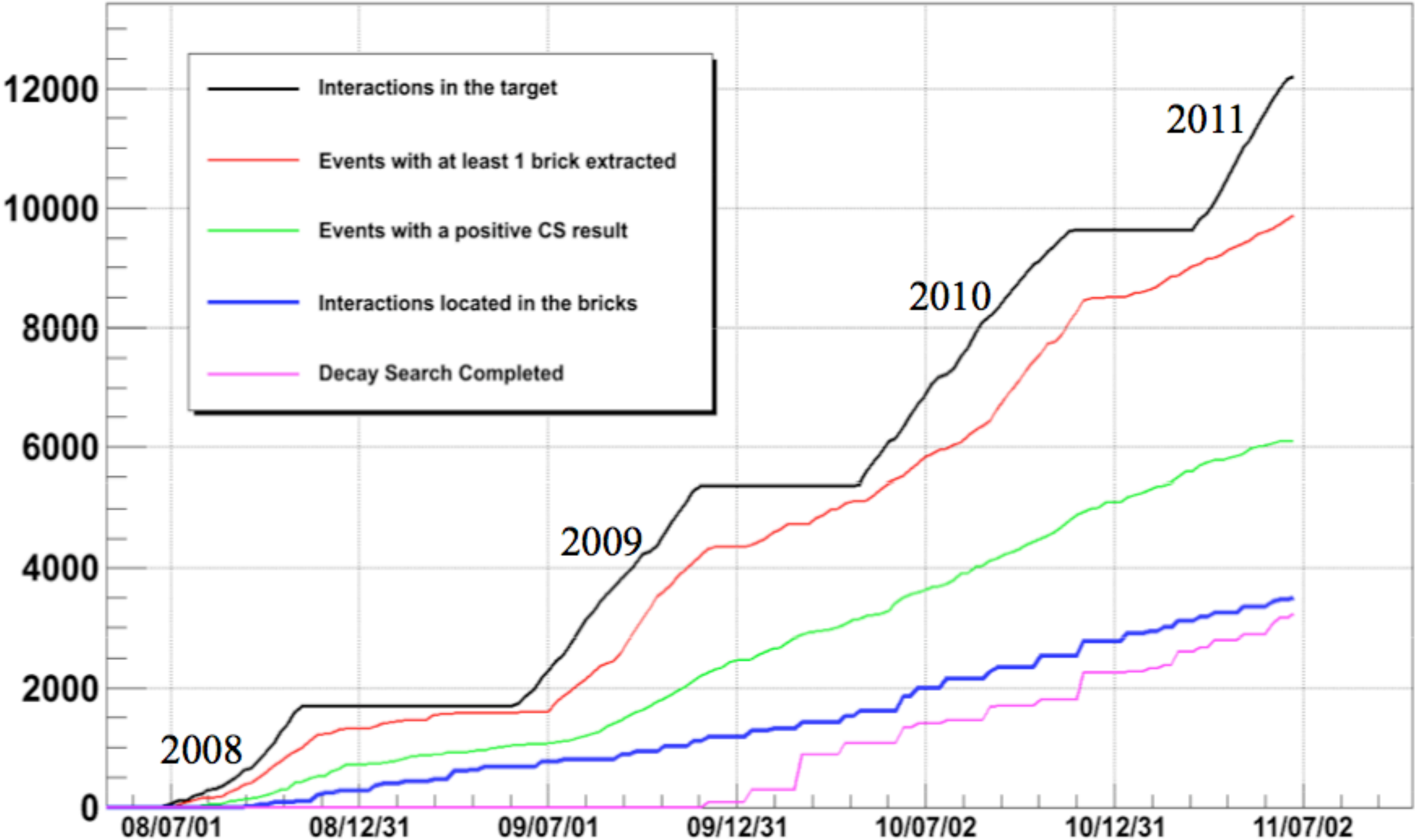
Aim at high-intensity runs in 2012 as well, with a dedicated running period

GLOBAL EXPERIMENTAL FEATURES

Evolution of the OPERA target with time



OPERA analysis performance plot



3513 interactions located in the bricks,
3232 “decay searched” events

PERFORMANCE OF THE ELECTRONIC DETECTORS

N. Agafonova et al 2011 New J. Phys. 13 053051

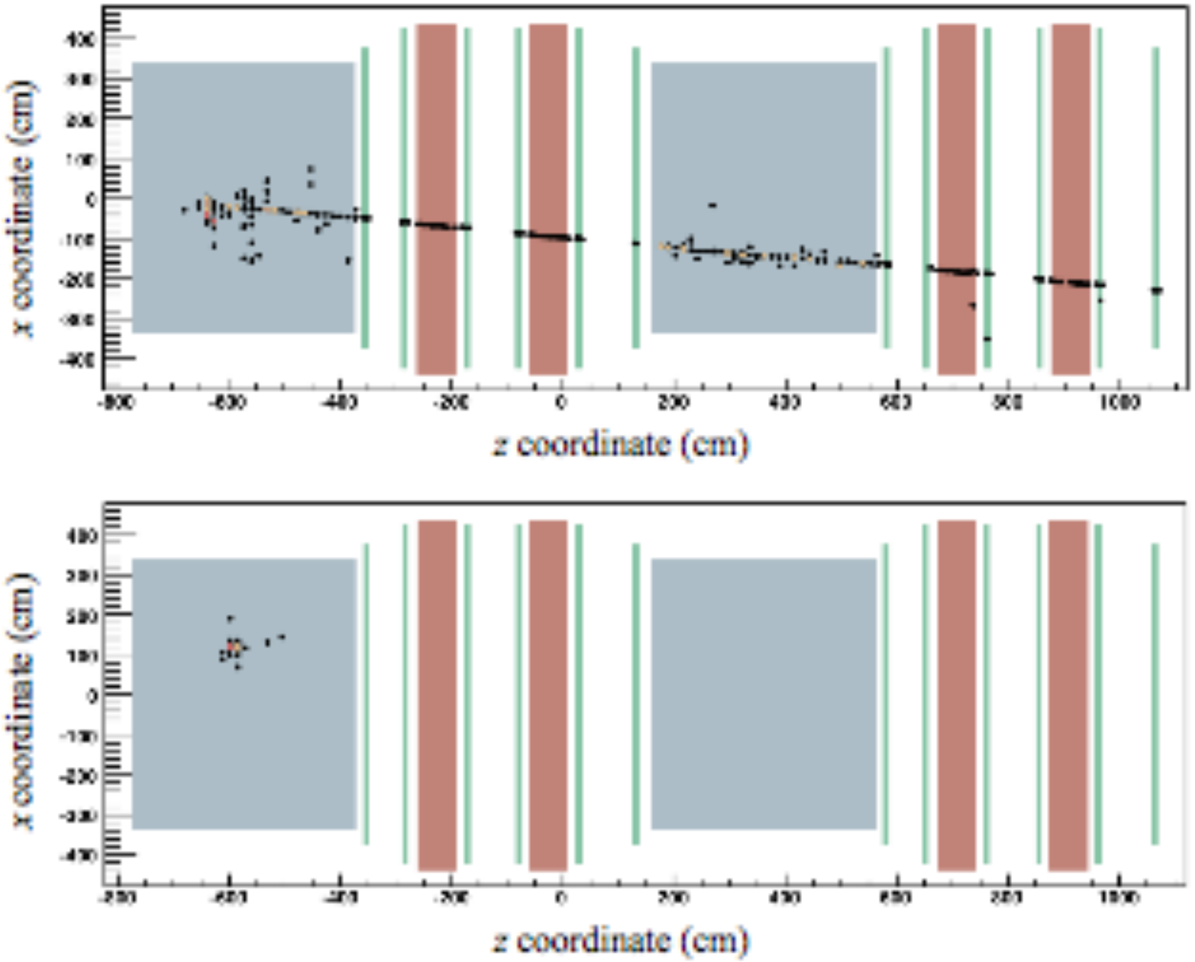


Figure 2. Examples of CC (top) and NC (bottom) events as seen in one projection view of the OPERA EDs. In this view, the two SMs can be recognized: for each of these, the target is followed by the muon spectrometer.

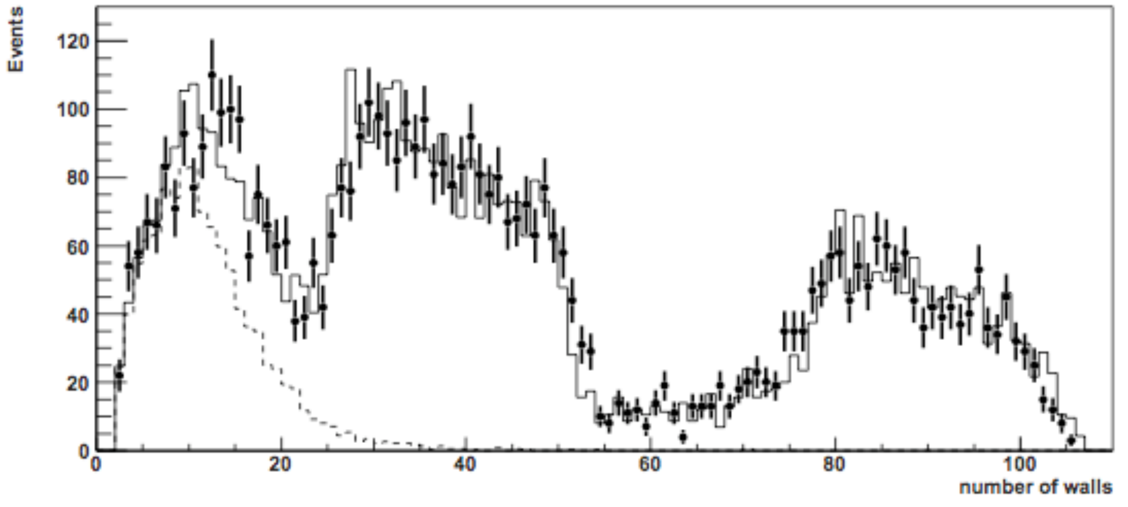


Figure 4. Number of hit walls for data (dots with error bars) and MC (solid line) contained events. The first bump is mainly due to NC events (dashed line), whereas the second and third ones originate from CC events crossing one and two SMs, respectively. The MC distribution has been normalized to data.

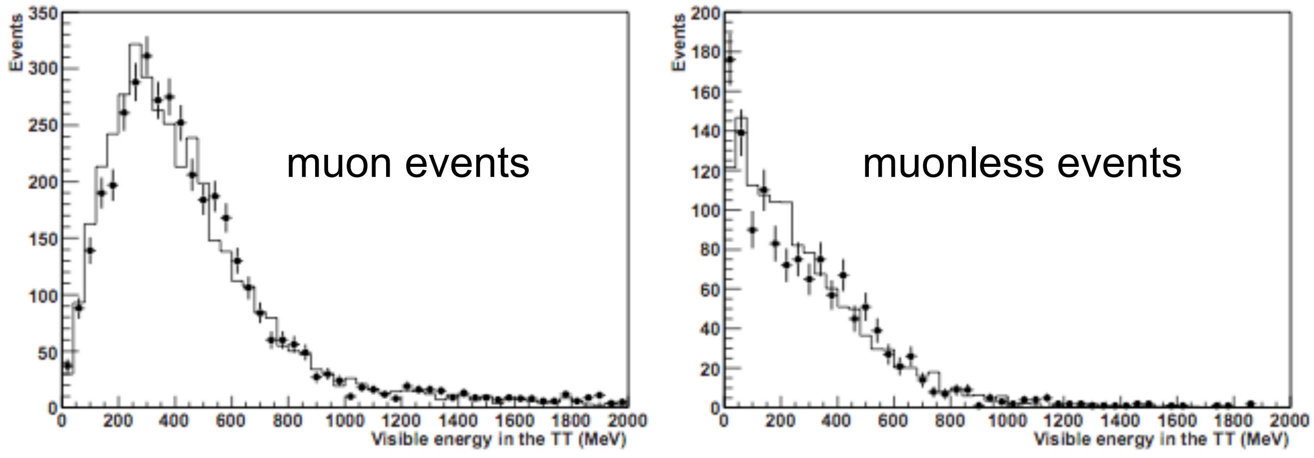


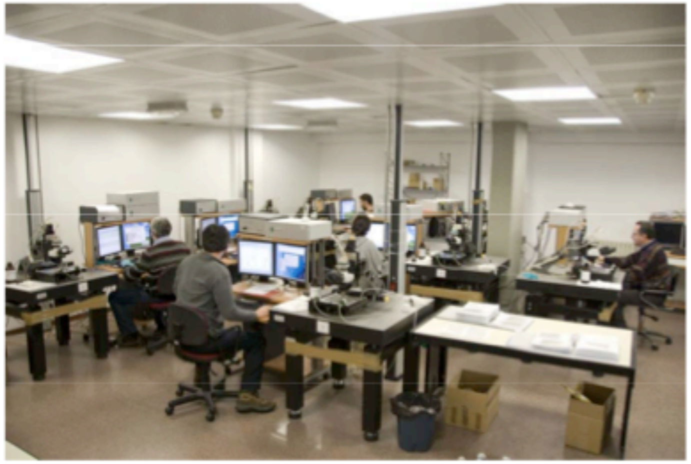
Figure 9. Energy deposit in the TT for events with at least one reconstructed muon (left) and events with no muon (right). Dots with error bars correspond to data and solid lines to MC. MC distributions are normalized to data.

NEWS FROM THE DATA ANALYSIS

- continuously improving scanning performance
- full simulation of emulsion data, scanning and event selection
- improved knowledge of detection efficiencies
- BG reduction
- one ν_τ candidate event: in agreement with expectations
- 2008-2009 CNGS data statistics published

examples →

Changeable Sheet scanning



LNGS: 11 microscopes, 220 cm^2/h

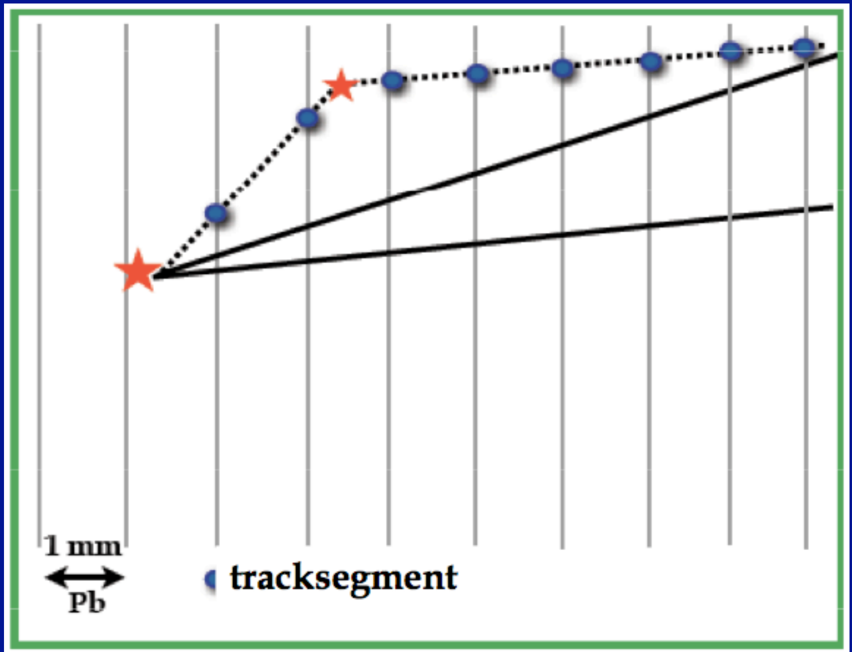
Nagoya: 5 S-UTS, 220 cm^2/h

1'000'000 cm^2 analyzed so far

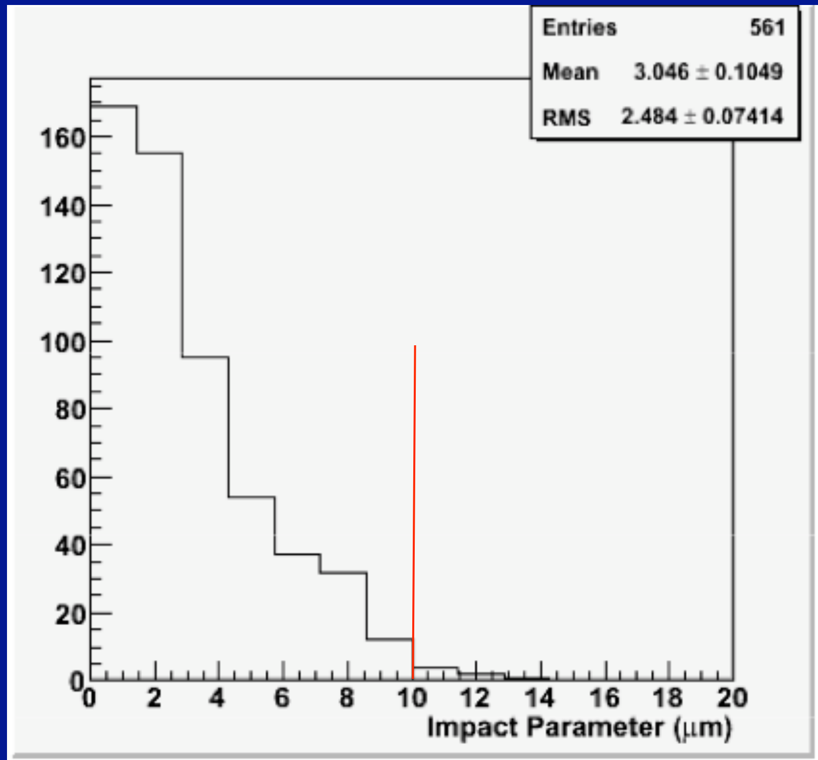
Improvements in the CS analysis: neutrino interaction vertex pre-validated by the CS tracks →

Transverse accuracy: 0.3 mm
Longitudinal accuracy: 3 mm

Decay topology detection

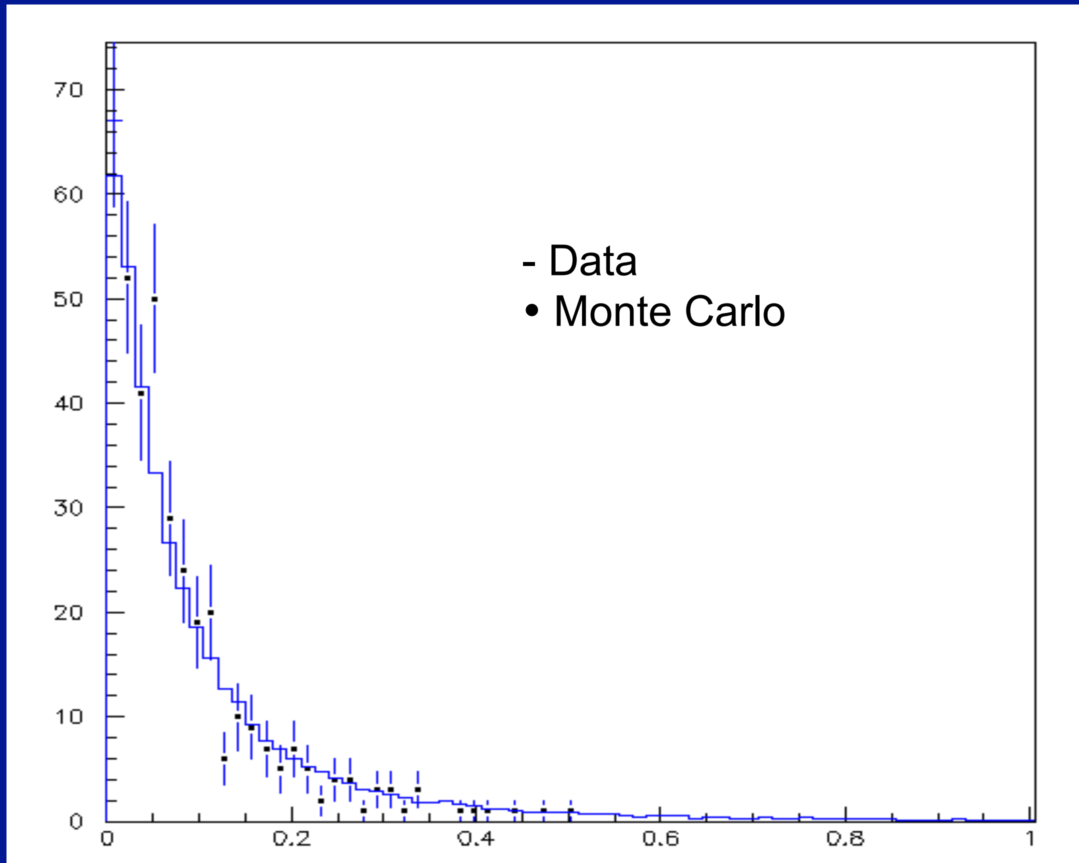


Impact parameter distribution as measured with data



Events with IP>10 μm are visually inspected: possible decay topology

Muon angular distribution as measured in the bricks



Track slope (rad)

Good agreement in the angular distribution of muon tracks

Soft muon measurement

(arXiv:1106.6211v1)

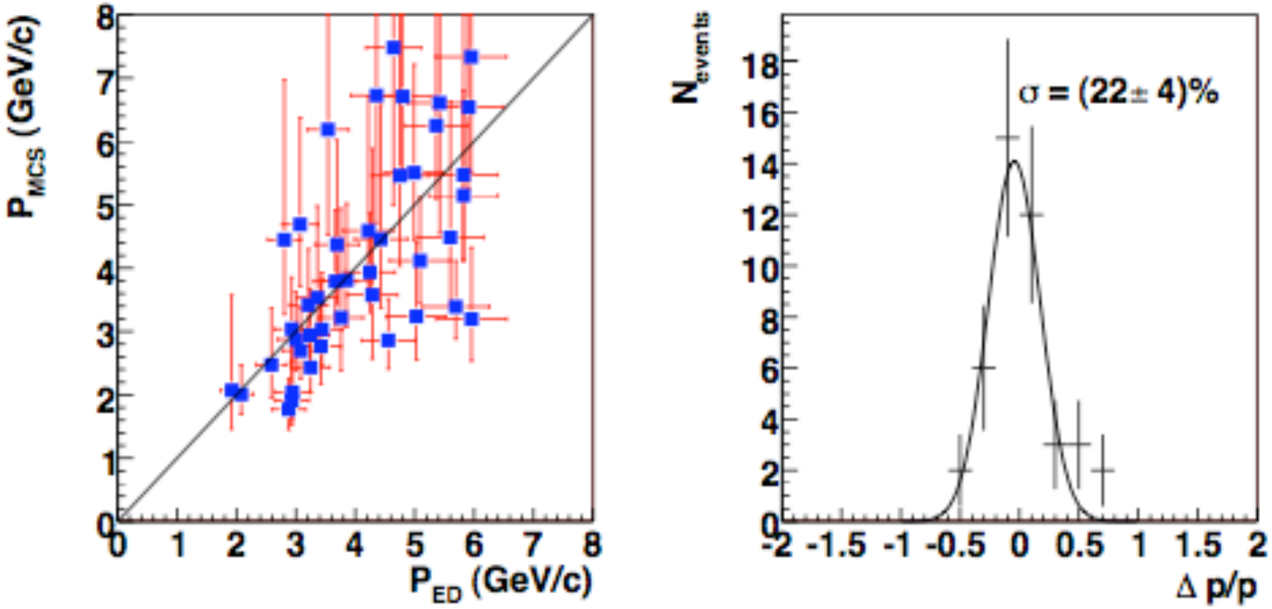
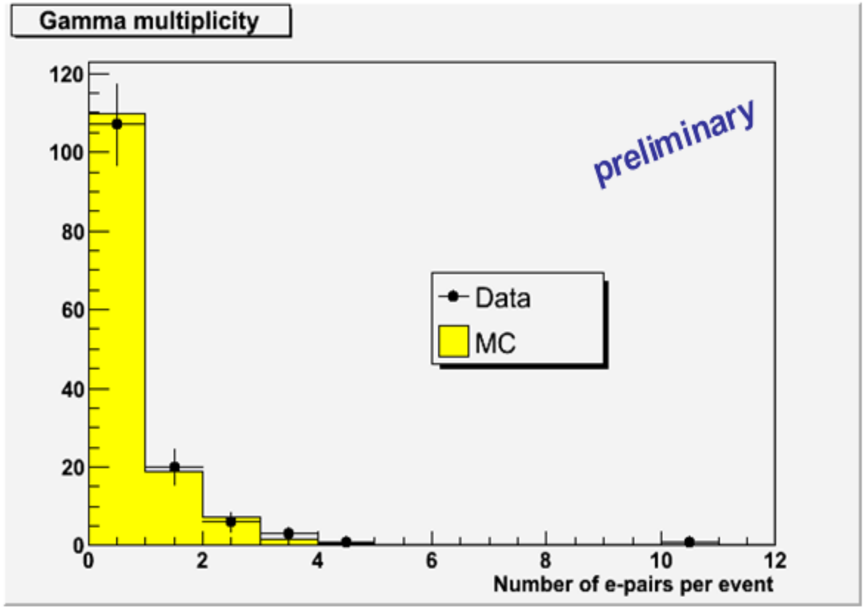


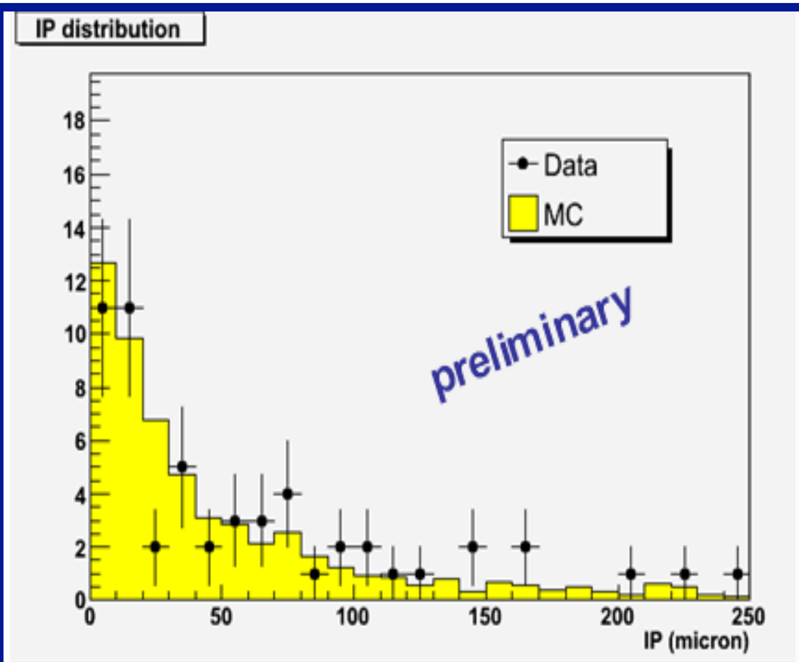
Figure 14: Left: Muon momenta measured by MCS (P_{MCS}) as a function of the momenta obtained from the electronic detectors (P_{ED}). The error bars correspond to the 68% confidence level range. Right: The relative difference between the two measurements with respect to the electronic detector measurement.

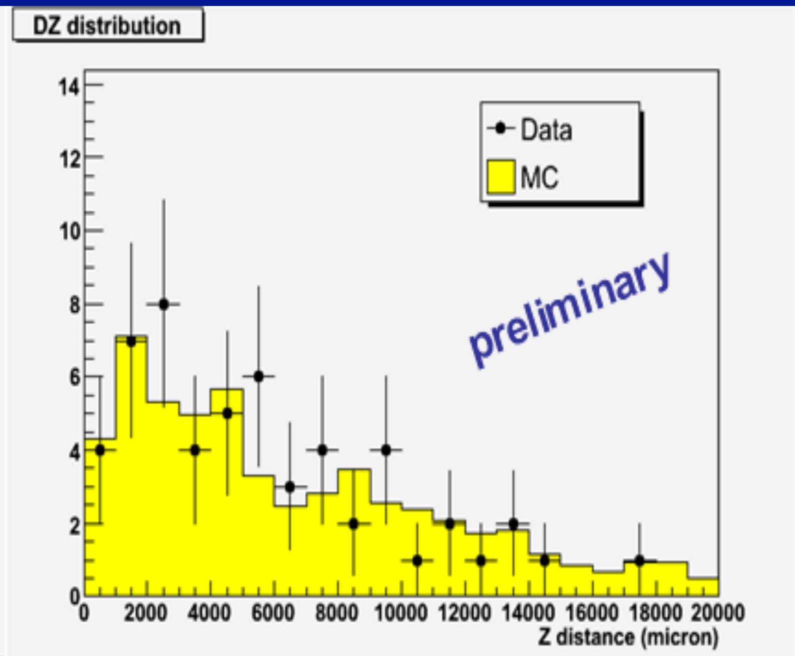
γ reconstruction



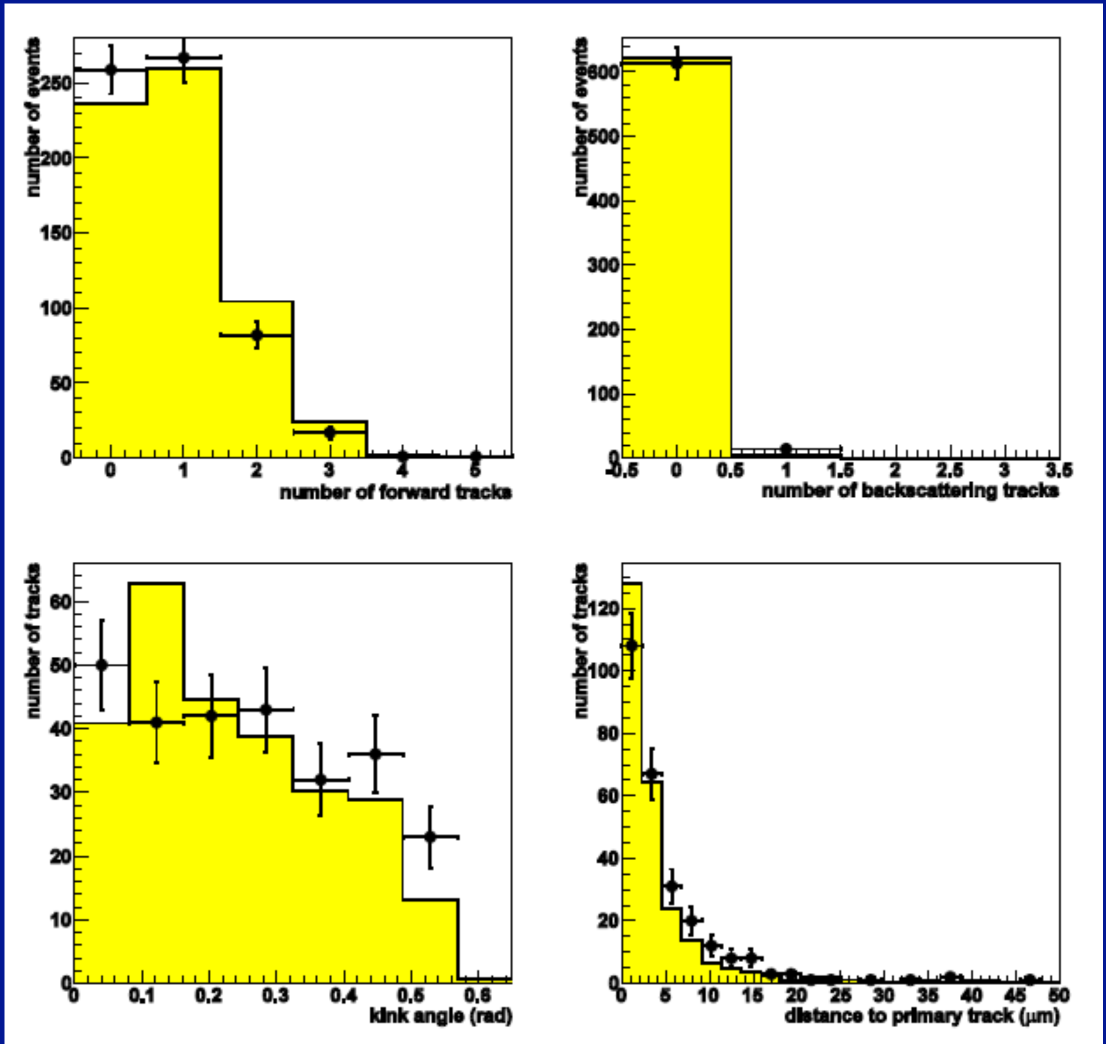
Comparison data/MC for the Gamma multiplicity in ν_μ CC+NC events

Volume scan of 20 plates downstream the vertex for a surface of 1 cm^2





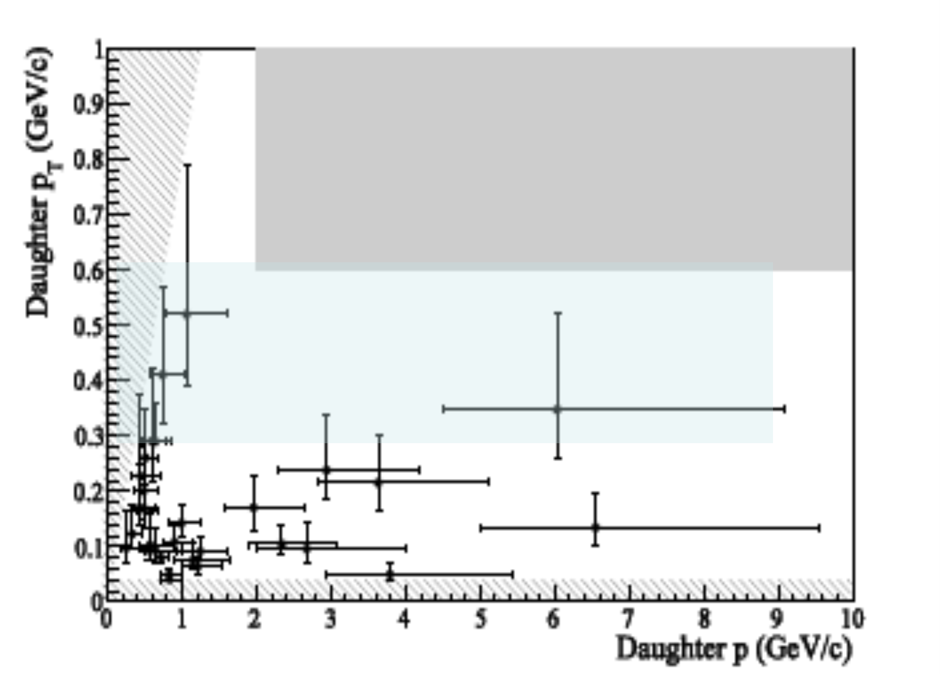
Hadron reinteraction BG



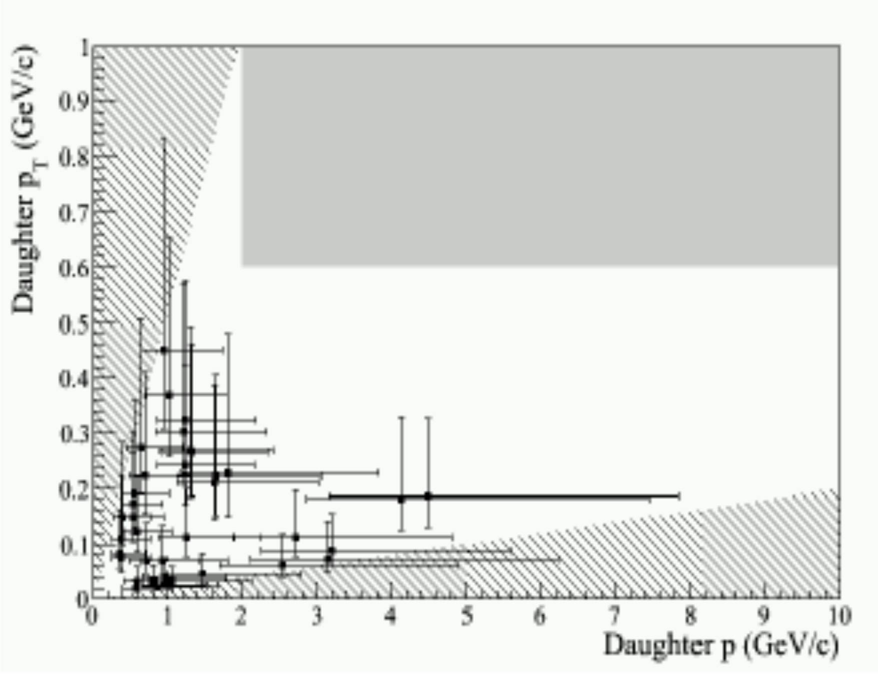
Increased number of interactions from test-beam data (4 GeV negative pions) to cross-check simulations (x10 statistics w.r.t. first oscillation paper: ~200 m of hadronic tracks)

Pion interaction studies

Hadronic tracks in neutrino interactions with kink topology far from the primary vertex



Hadronic interactions in test beam brick



14 m of tracks: equivalent to 2300 NC events

No events in the signal region

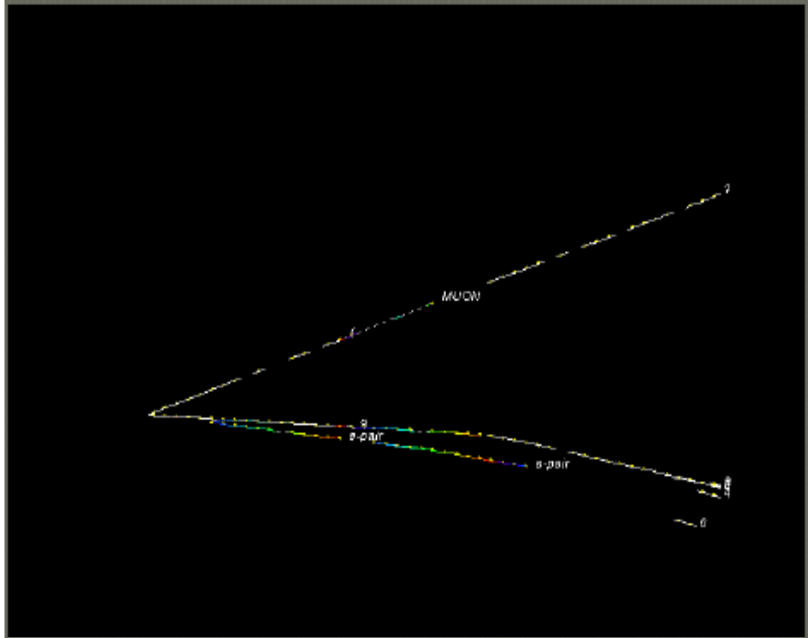
10 events in reference region (Pt > 200 MeV/c): 10.8 expected by updated simulations

Systematic track follow-down for candidate events: search for muons

- Charm
- Hadronic interactions in ν_μ CC with misidentified μ ($\tau \to h$ channel)
- Hadronic interactions in ν_μ CC and NC ($\tau \to \mu$ channel)

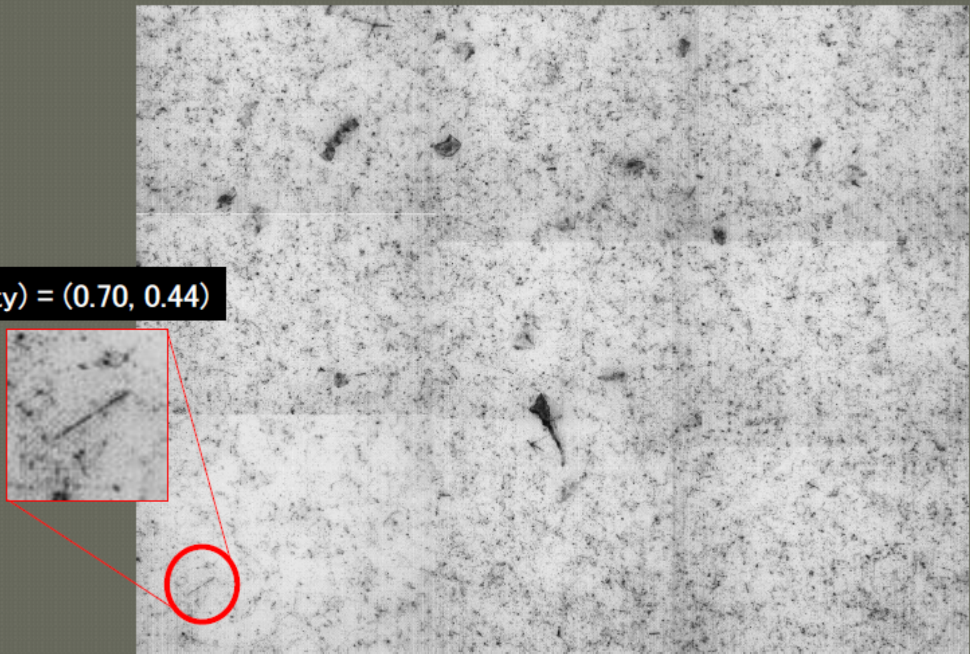
- Momentum range correlation: tested for the first ν_τ candidate event
- Misidentified muons from charm events: 3.28 % (was 5%)
- Factor 100 reduction of the BG for the $\tau \to \mu$ channel: golden channel!

Search for highly ionizing fragments (indication of interaction rather than decay)



Hadron interaction at pl37 ⇔ pl38
Kink angle = 0.144 rad.
Pt = 0.265 GeV/c

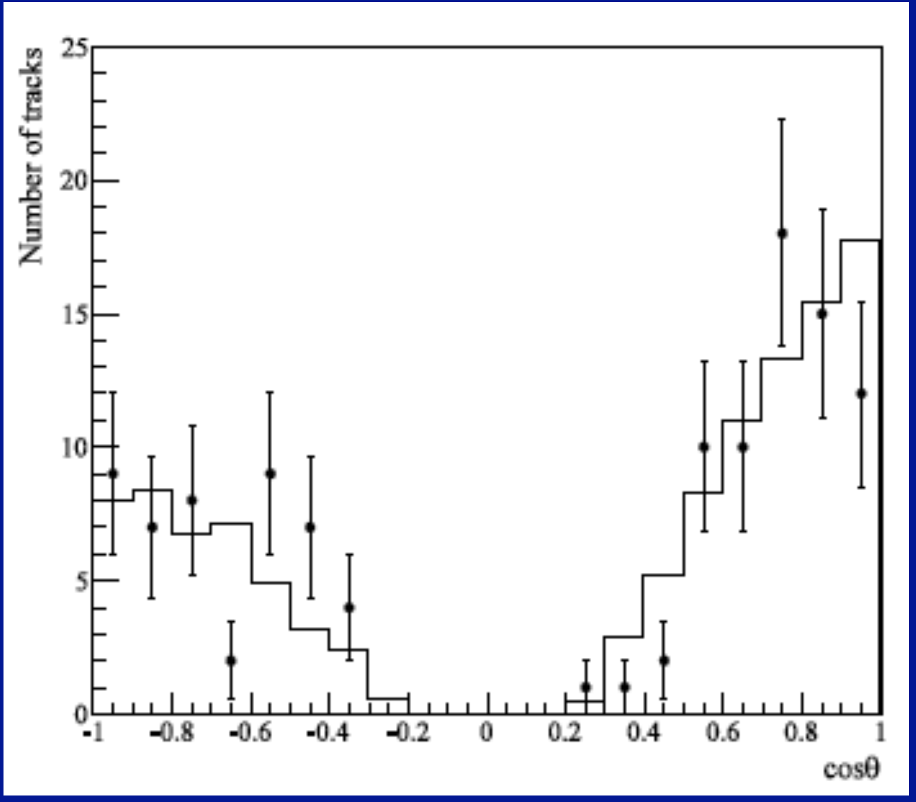
Interaction position
z = 477micron



Down stream of interaction point

- Specific tool and procedure set up and applied
- Validation on the test-beam sample of hadronic interactions
- Search on the first tau candidate → no associated fragments found

Simulation of highly ionizing fragments



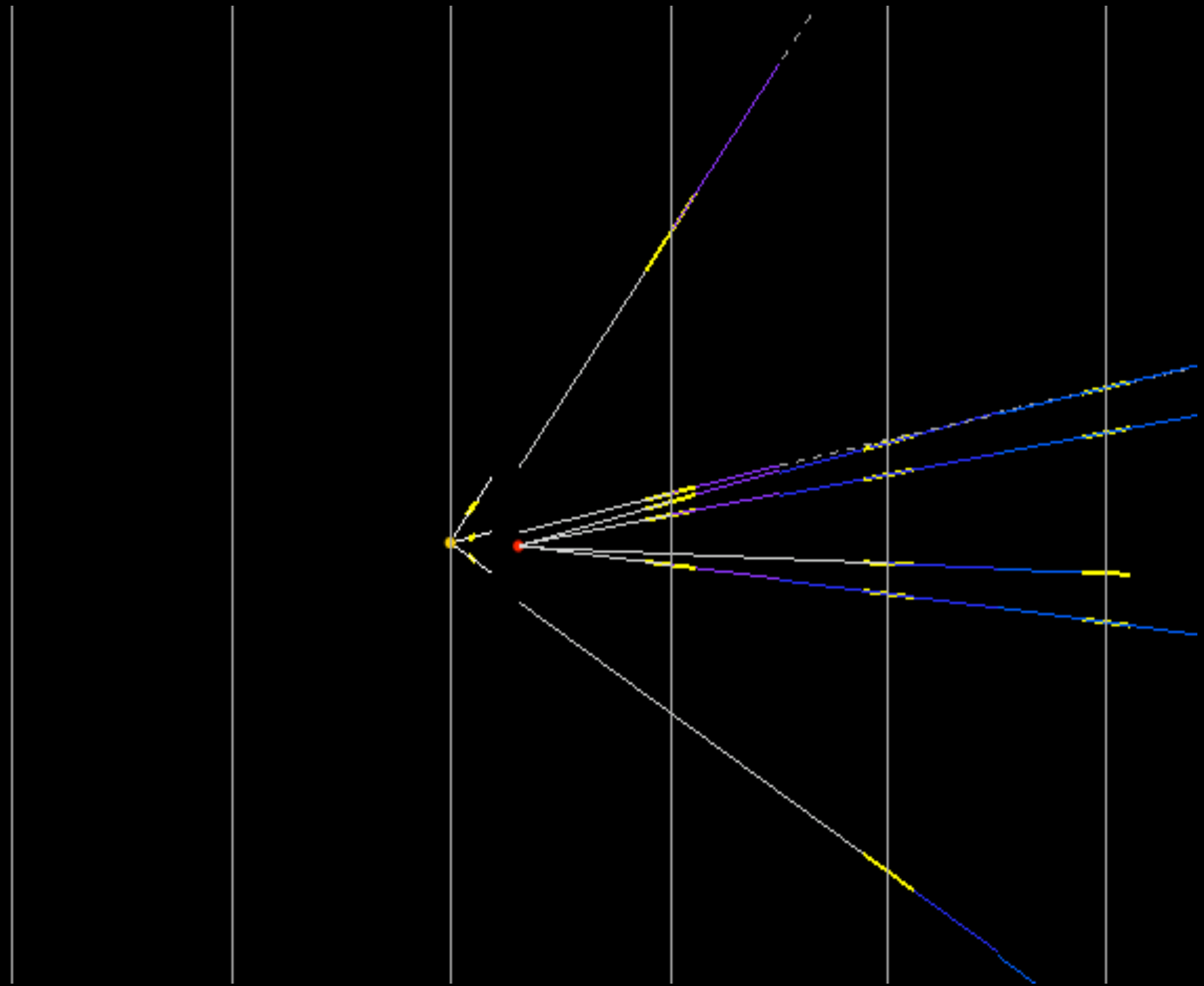
Study of 64 interactions of 8 GeV π-

→ Highly ionizing tracks detection in 57±7% of the cases (Fluka: 53%)

Forward-backward asymmetry: 0.75 ± 0.15 (Fluka: 0.71)

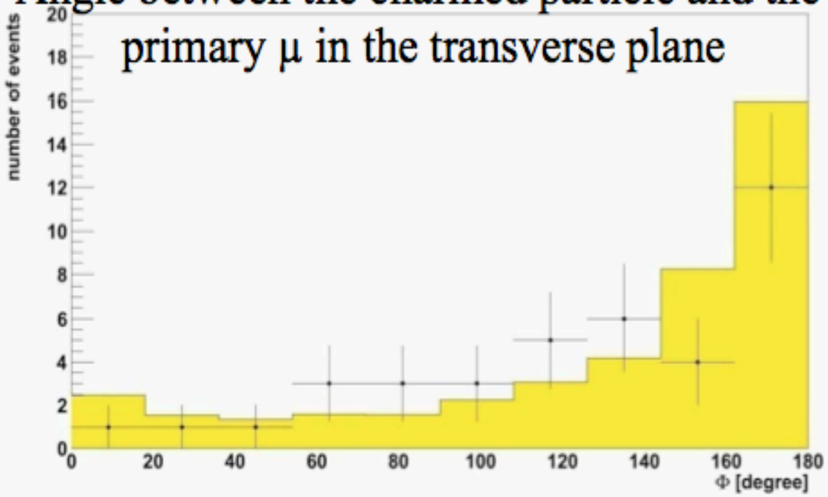
Charm events (2008-2009 data sample)

D^0 candidate event

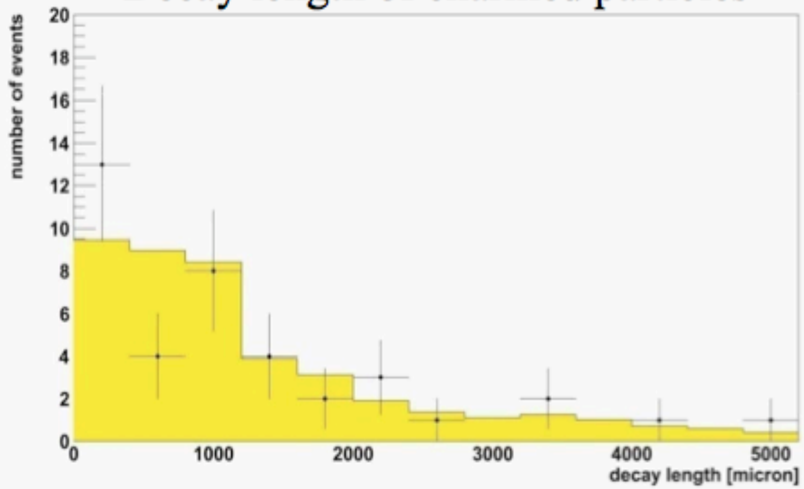


Topology	Observed events	Expected events		
		Charm	Background	Total
Charged 1-prong	13	15.9	1.9	17.8
Neutral 2-prong	18	15.7	0.8	16.5
Charged 3-prong	5	5.5	0.3	5.8
Neutral 4-prong	3	2.0	<0.1	2.1
Total	39	39.1±7.5	3.0±0.9	42.2±8.3

Angle between the charmed particle and the primary μ in the transverse plane



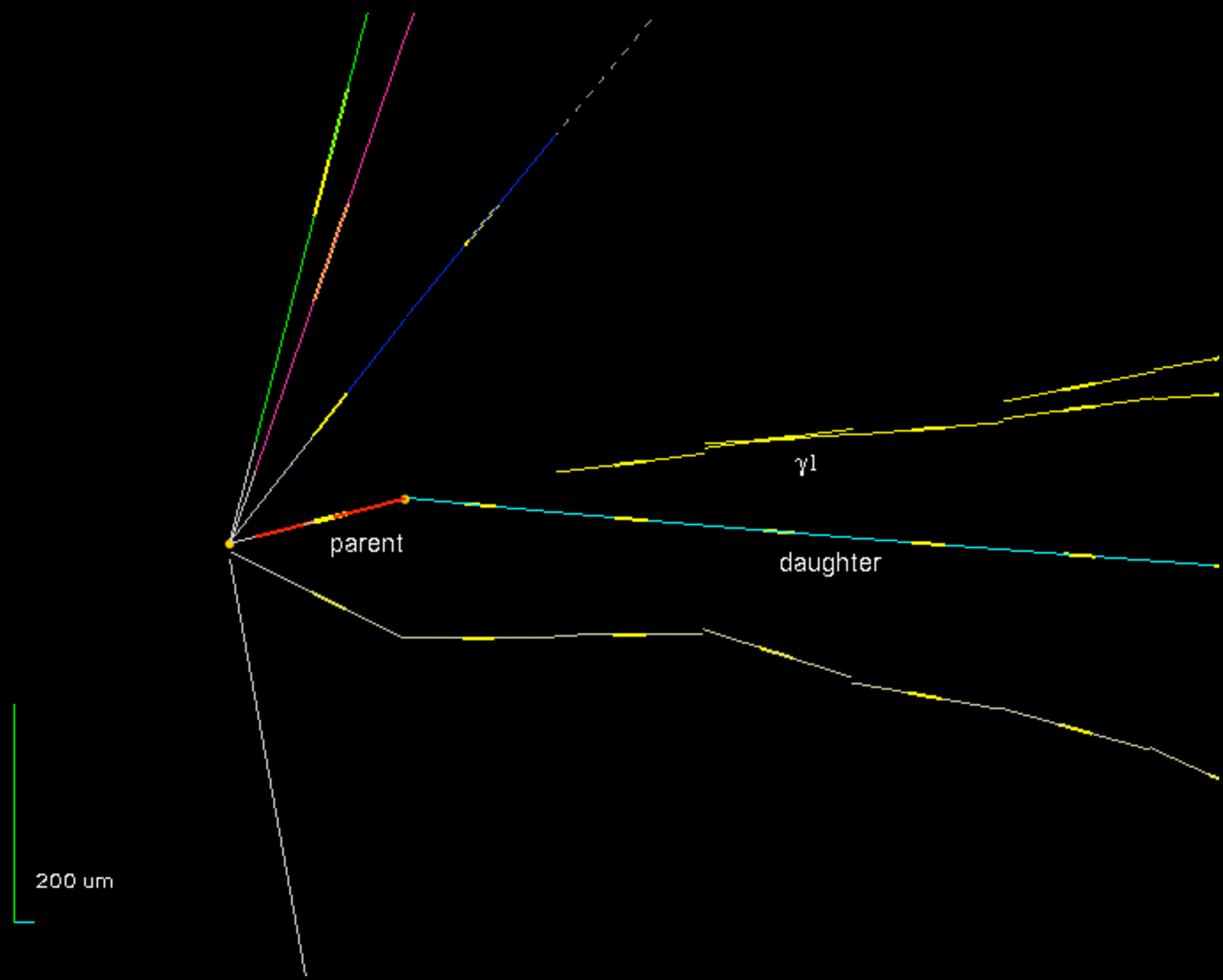
Decay length of charmed particles



NEW OSCILLATION ANALYSIS

arXiv:1107.2594
submitted to PLB

First ν_τ candidate event



Data

	0mu	1mu	All
Events predicted by the electronic detector	1503	3752	5255
Interactions located in ECC	519	2280	2799
Located in dead material	54	245	299
Decay search performed	494	2244	2738

- 92% of the expected sample that could be decay searched

- location efficiency of the interaction vertex:
74% for CC and 48% for NC

Backgrounds

- Production and decay of charmed particles
- Hadron re-interactions
- Large angle μ scattering

Decay channel	Number of background events for:							
	22.5×10^{19} p.o.t.				Analysed sample			
	Charm	Hadron	Muon	Total	Charm	Hadron	Muon	Total
$\tau\rightarrow\mu$	0.025	0.00	0.07	0.09 ± 0.04	0.00	0.00	0.02	0.02 ± 0.01
$\tau\rightarrow e$	0.22	0	0	0.22 ± 0.05	0.05	0	0	0.05 ± 0.01
$\tau\rightarrow h$	0.14	0.11	0	0.24 ± 0.06	0.03	0.02	0	0.05 ± 0.01
$\tau\rightarrow 3h$	0.18	0	0	0.18 ± 0.04	0.04	0	0	0.04 ± 0.01
Total	0.55	0.11	0.07	0.73 ± 0.15	0.12	0.02	0.02	0.16 ± 0.03

- Charm production cross-section increased (last CHORUS data)
- Fragmentation fraction into D^+ increased from 10% to 22%
- Improvements due to the track follow-down
- Significant reduction of the background in the $\tau\rightarrow\mu$ channel

arXiv:1107.0613v1

Signal

Decay channel	Number of signal events expected for	
	22.5×10^{19} p.o.t.	Analysed sample
$\tau \rightarrow \mu$	1.79	0.39
$\tau \rightarrow e$	2.89	0.63
$\tau \rightarrow h$	2.25	0.49
$\tau \rightarrow 3h$	0.71	0.15
Total	7.63	1.65

1 ν_τ candidate event observed in the hadronic decay mode, with a BG of 0.05 ± 0.01 events (0.49 ± 0.12 expected signal events)

For standard oscillation parameter values this corresponds to 95% probability that the event is not due to a BG fluctuation.

Considering all decay modes:
expected 1.65 ± 0.41 events, BG = 0.16 ± 0.03 events.
Probability of BG fluctuation: 15%

WORK IN PROGRESS

(e.g. 2010 data sample)

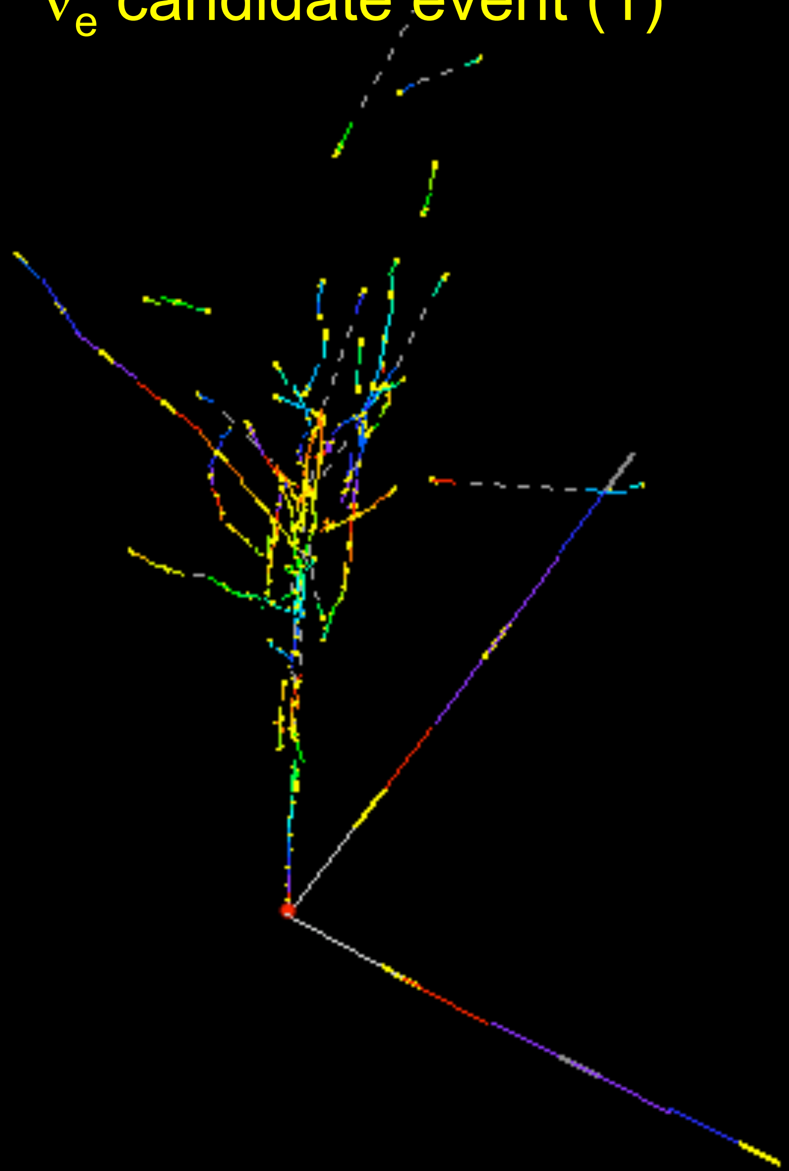
	0mu	1mu	All
Events predicted by the electronic detector	1165	2747	3912
Extracted CS	1146	2700	3846
CS Scanned	1043	2517	3560
Found in CS	479	1420	1909
Interactions located in ECC	156	558	714
Decay search	113	381	494

- Set up an aggressive scanning/analysis strategy

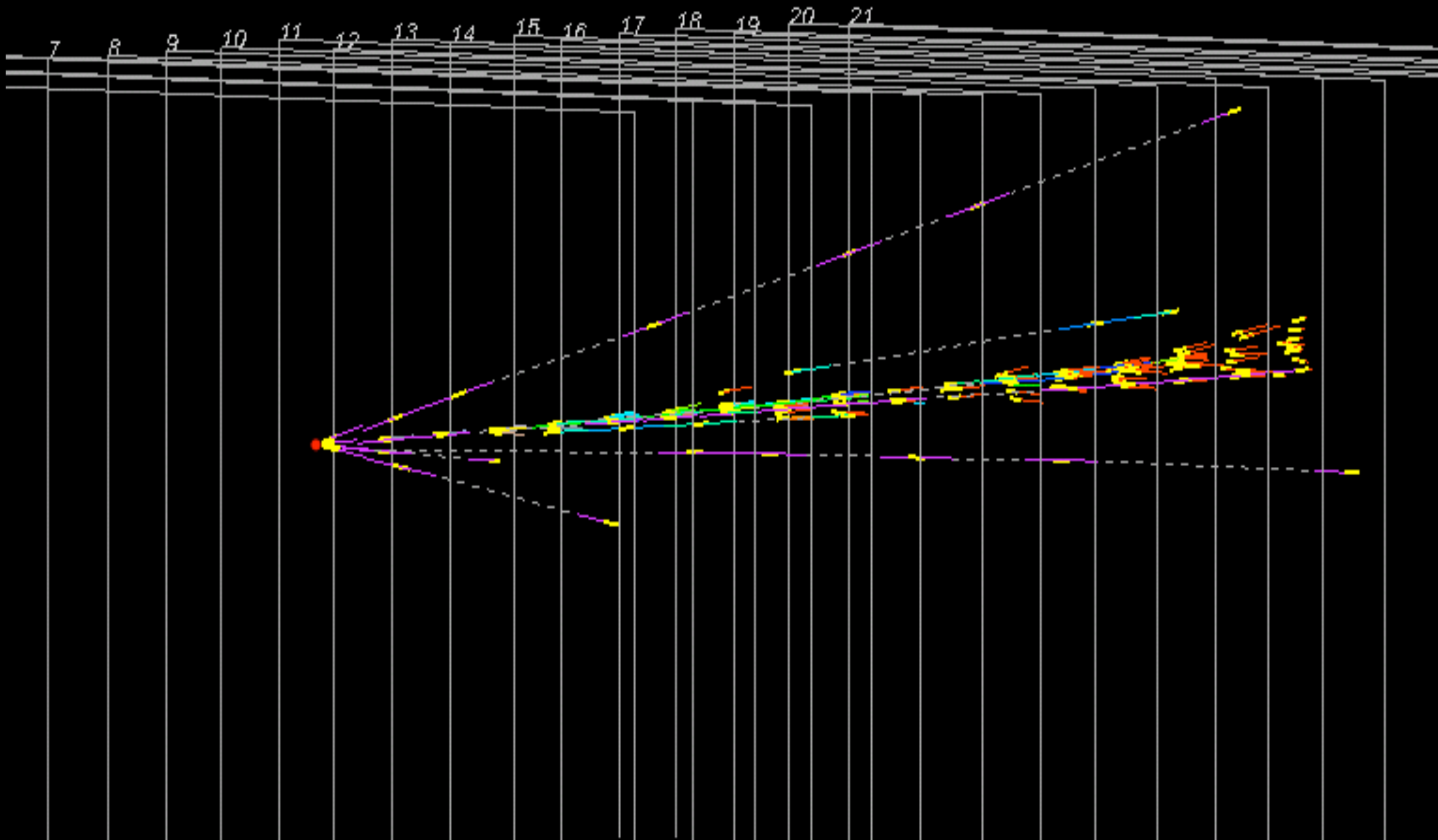
- Goal: report at NEUTRINO 2012 on the full 2008-2009-2010 (+part of 2011) statistics

another example: ν_e EVENTS

ν_e candidate event (1)



ν_e candidate event (3)



- So far detected 14 ν_e candidates during the scan back procedure

- Developing dedicated analyses to increase the detection efficiency

- Estimation of BG in progress: prompt ν_e beam component and γ conversion contamination

- ν_μ-ν_e oscillation analysis in progress

MID-LONG TERM STRATEGY OF OPERA

Memo recently sent to the SPSC:

The OPERA Collaboration looks forward to the successful completion of the CNGS 2011 run, with the aim of securing an integrated number of p.o.t. close, or hopefully exceeding, the nominal figure of 4.5×10^{19} p.o.t/year. This would perfectly match the high efficiency that OPERA reached for the various detectors and facilities after several years of continuously improving operation.

We strongly request CERN and the CNGS team to make sure that the 2012 run will be at least as good as the 2011 run, hopefully with a period of dedicated mode operation as like this year. Our goal is to collect by the end of 2012 a total statistics (2008-2012) as close as possible to the goal of the experiment, namely 22.5×10^{19} p.o.t.

By summer 2012 we will be in position of making a statement about the longer term strategy on the basis of the potential availability of a CNGS beam in 2013 and/or 2014, and of the support provided by the funding agencies. In any case, we will keep the detector and the facilities operational during the CERN accelerator shut-down as required for the handling of the bricks hit by CNGS neutrinos collected up to 2012.

As a general remark, we stress our continued commitment to a successful achievement of our main physics goal, the statistically significant observation of direct appearance $\nu_\mu - \nu_\tau$ flavor transition, as well as of the study of the sub-leading ν_μ-ν_e oscillation.

Thank you for your attention