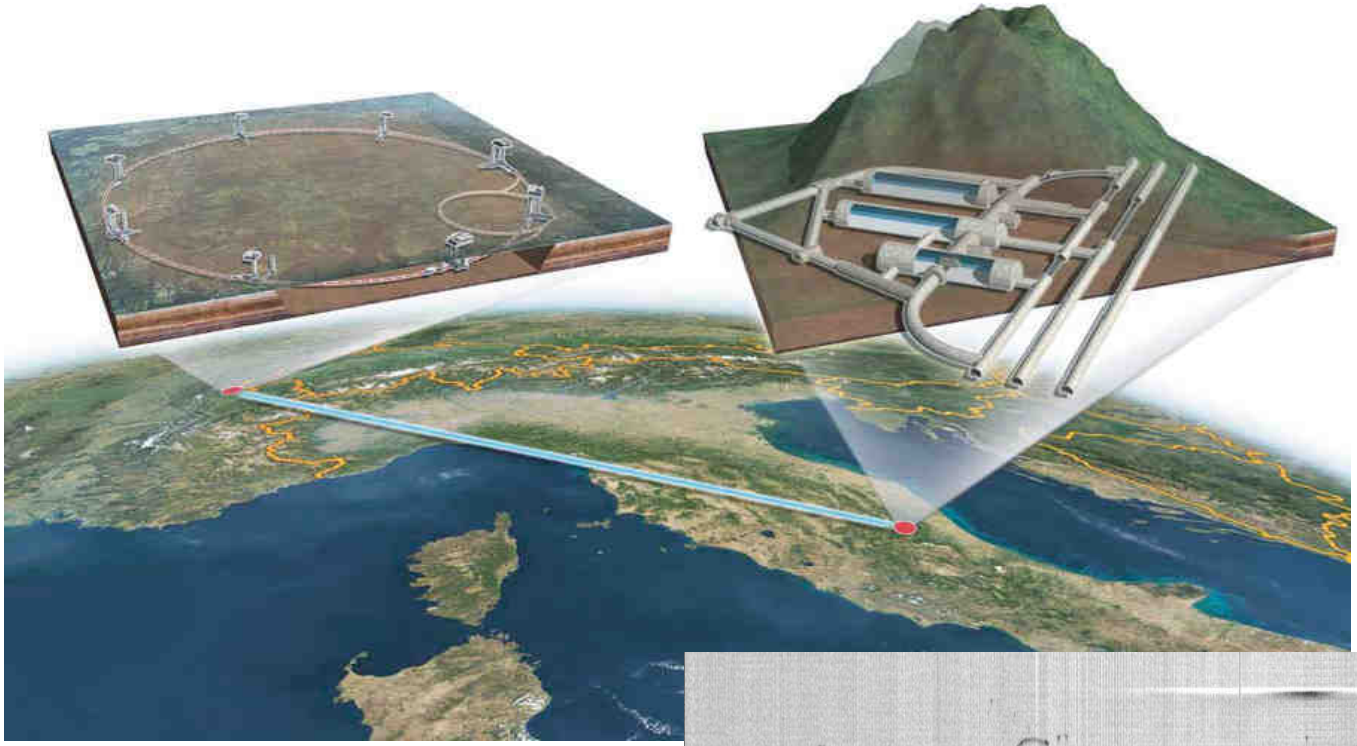
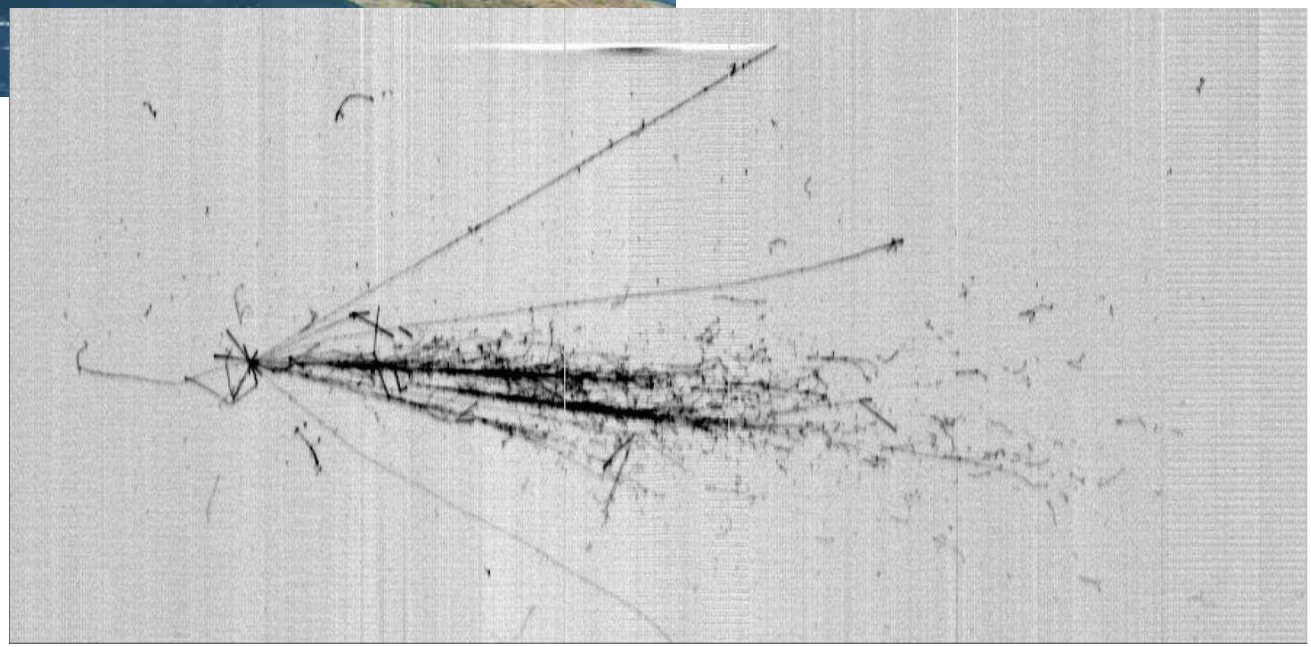
NEUTRINOS FROM ICARUS





C. Farnese
For the ICARUS Collaboration

Vulcano Workshop 2012
1 June 2012

The ICARUS Collaboration

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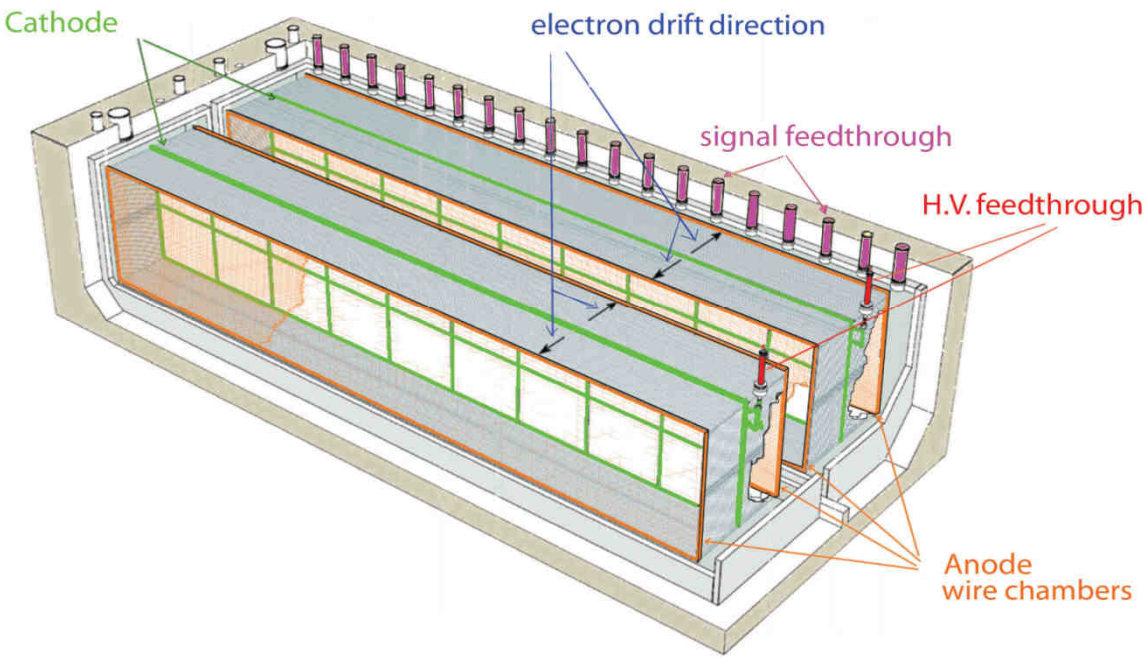
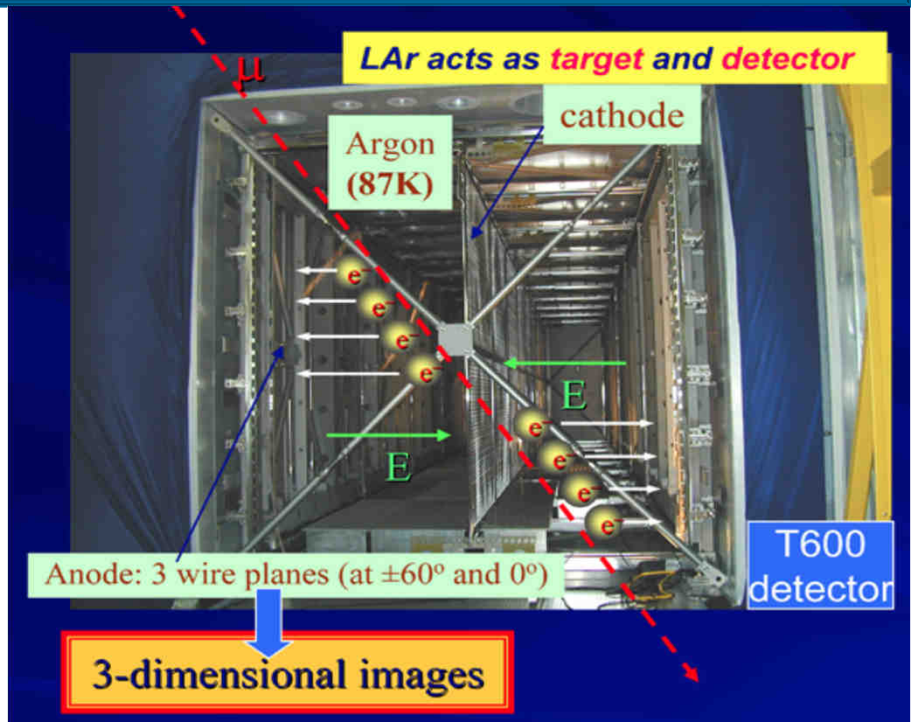
The ICARUS T600 detector



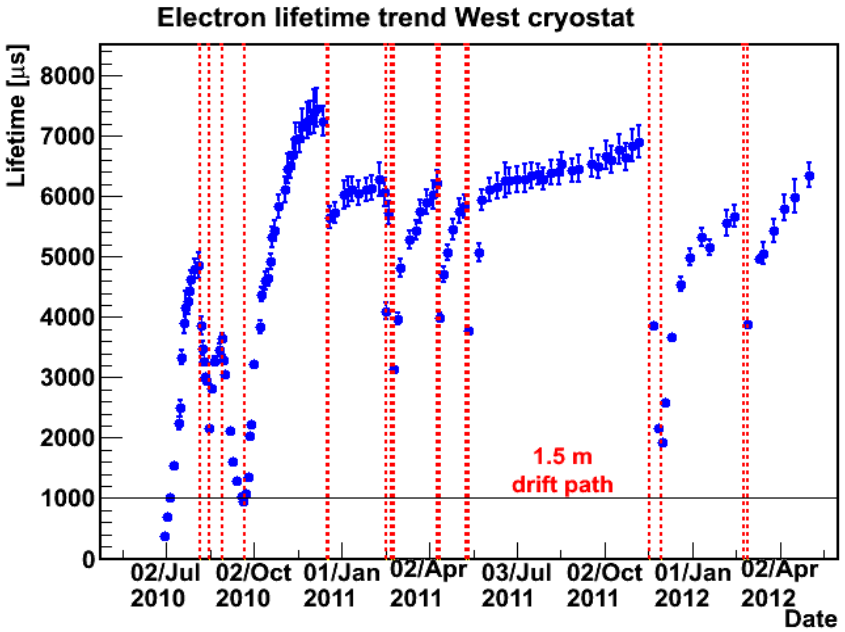


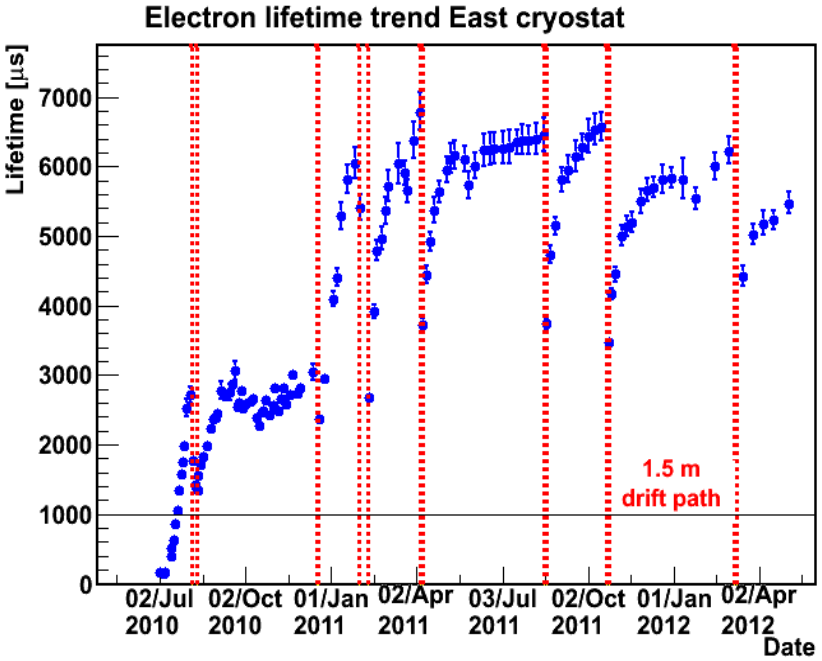
- Two identical modules
  - 3.6 x 3.9 x 19.6 ≈ 275 m^3 each
  - Liquid Ar active mass: ≈ 476 t
  - Drift length = 1.5 m (1 ms)
  - HV = -75 kV E = 0.5 kV/cm
  - v-drift = 1.55 mm/μs

- 4 wire chambers:
  - 2 chambers per module
  - 3 readout wire planes per chamber, wires at 0,±60°
  - ≈ 54000 wires, 3 mm pitch, 3 mm plane spacing
- 20+54 PMTs , 8" Ø, for scintillation light detection:
  - VUV sensitive (128nm) with wave shifter (TPB)

Taking data in LNGS hall B

LAr purification





Key feature: LAr purity from electro-negative molecules (O_2, H_2O,CO_2).

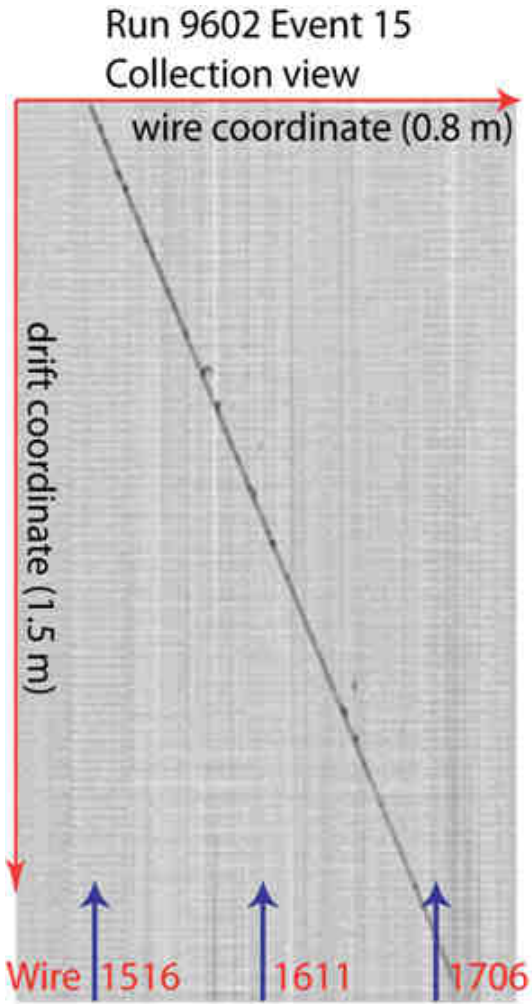
LAr continuously filtered, e^- life-time measured by charge attenuation study on cosmic μ track

τ_{ele} > 5ms

(~60 ppt $[O_2]_{eq}$)

corresponding to 17% max. charge attenuation at 1.5m

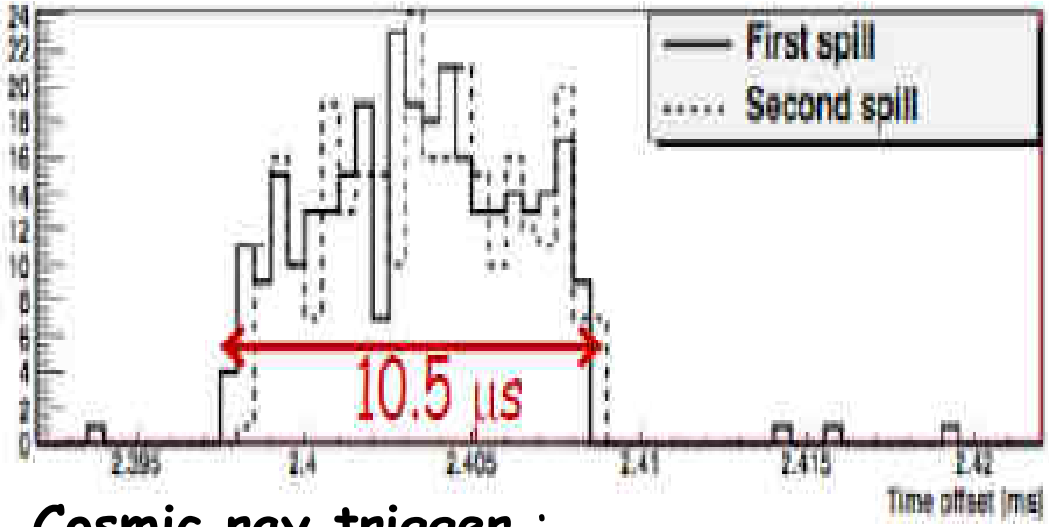
These results would allow operation at larger drift distances.



Trigger

CNGS trigger :

- CNGS "Early Warning" signal sent 80 ms before the SPS p extraction. It contains the predicted extraction time of the 2 spills → opens a 60 μs wide gate.
- Photomultiplier sum signal for each chamber in coincidence with the beam gate



- 2.40 ms offset value in agreement with 2.44 ms ν tof (40 μs fiber transit time from external lab to Hall B).
- Spill duration reproduced (10.5μs)

1 mHz event rate , ≈ 80 events/day

Cosmic ray trigger :

- Photomultiplier sum signal, requiring coincidence of two adjacent chambers (50% cathode transparency)
- Globally 36 mHz trigger rate achieved: ~130 cosmic events/h

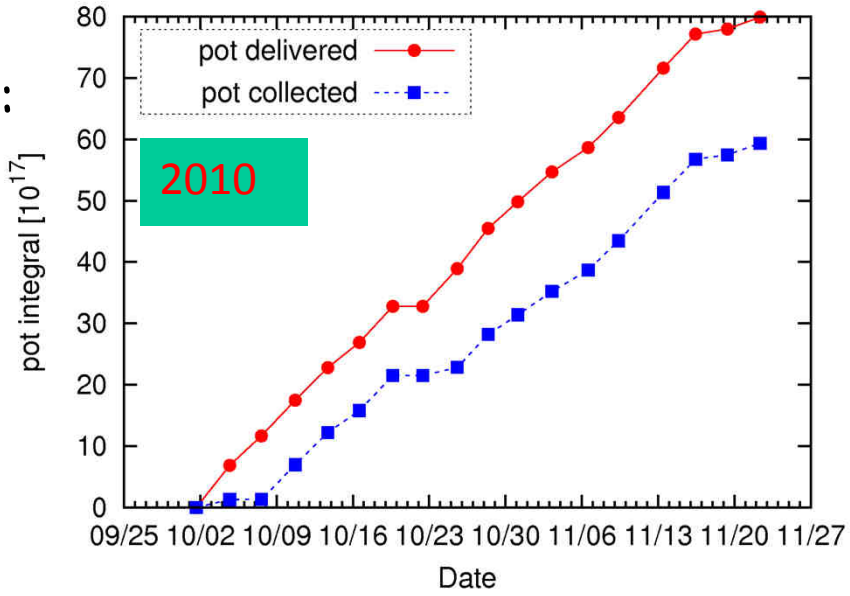
SuperDedalus : New trigger system based on charge deposition on TPC wires: DR-slw algorithm implemented in a new SuperDedalus chip (FPGA), installed and used to improve trigger efficiency for CNGS events at low energy (i.e. below 500 MeV)

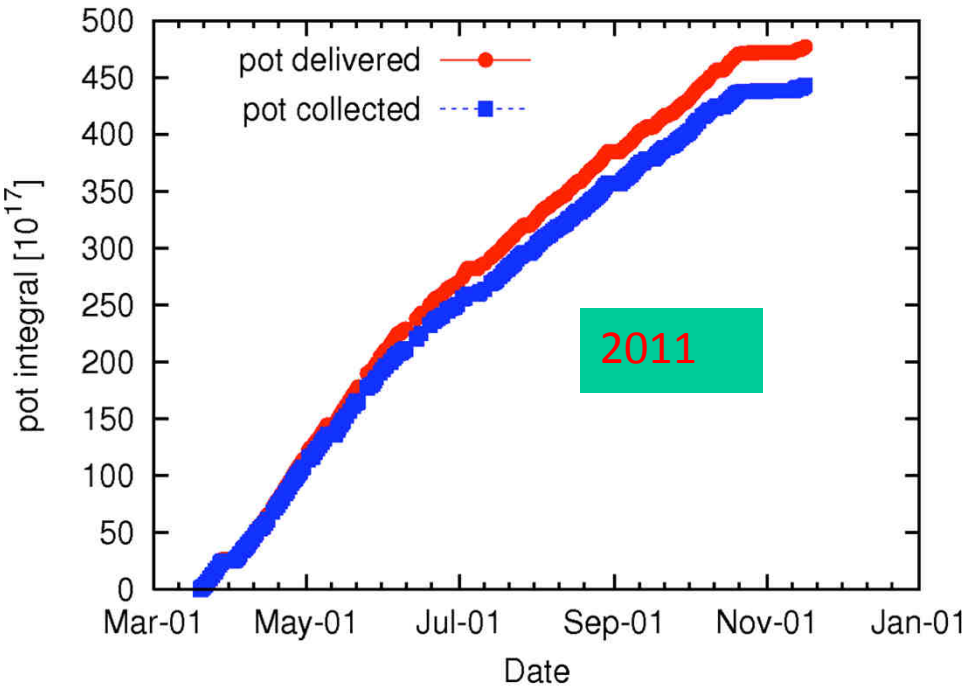
ICARUS T600 physics potential

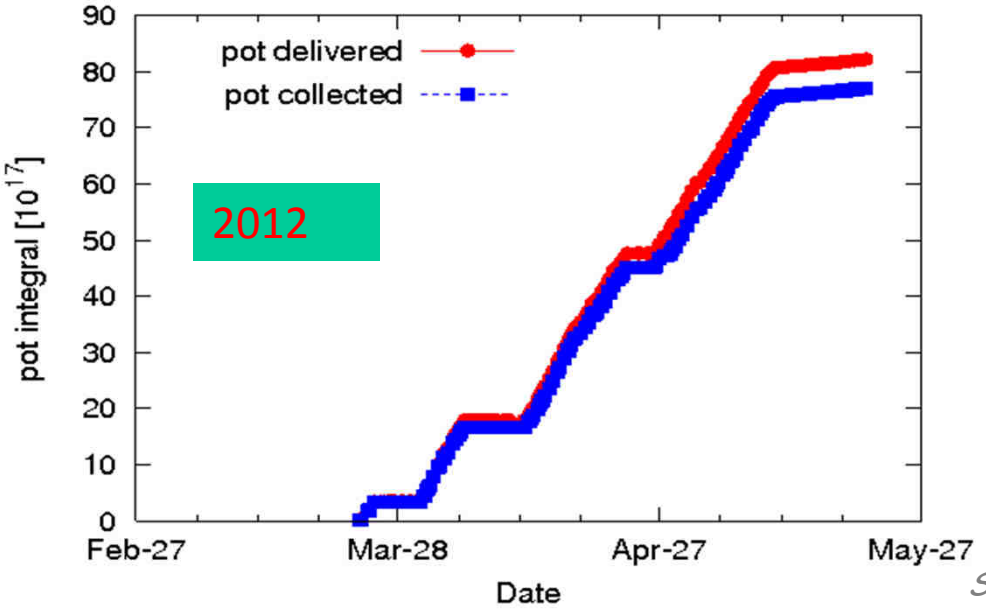
- T600 is a major milestone towards the realization of a much more massive multikton LAr detector, but it offers also some interesting physics in itself. The unique imaging capability of ICARUS, its spatial/calorimetric resolutions, and e/π^0 separation allow "to see" events in a new way
- The detector is collecting "bubble chamber like" CNGS events: for 10^{20} pot
  - CC event expected ≈ 2800 ev
  - NC event expected ≈ 900 ev
  - Muons from upstream GS rock ≈ 12000 ev (≈ 8200 on TPC front face)
  - Intrinsic beam ν_e CC ≈ 26 ev
  - $\nu_\mu \Rightarrow \nu_\tau$ detecting τ decay with kinematical criteria (~2 event $\tau \rightarrow e$) .
  - $\nu_\mu \Rightarrow \nu_e$ (θ_{13}) from e-like CC events excess at E < 20GeV (~5 events CC)
  - Search for sterile neutrinos in LSND parameter space, with e-like CC events excess at E>10GeV .
- The T600 is also collecting simultaneously "self triggered" events:
  - ≈ 100 ev/year of atmospheric ν CC interactions.
  - Proton decay with 3×10^{32} nucleons , zero bckg. in some of the channels

CNGS neutrino runs

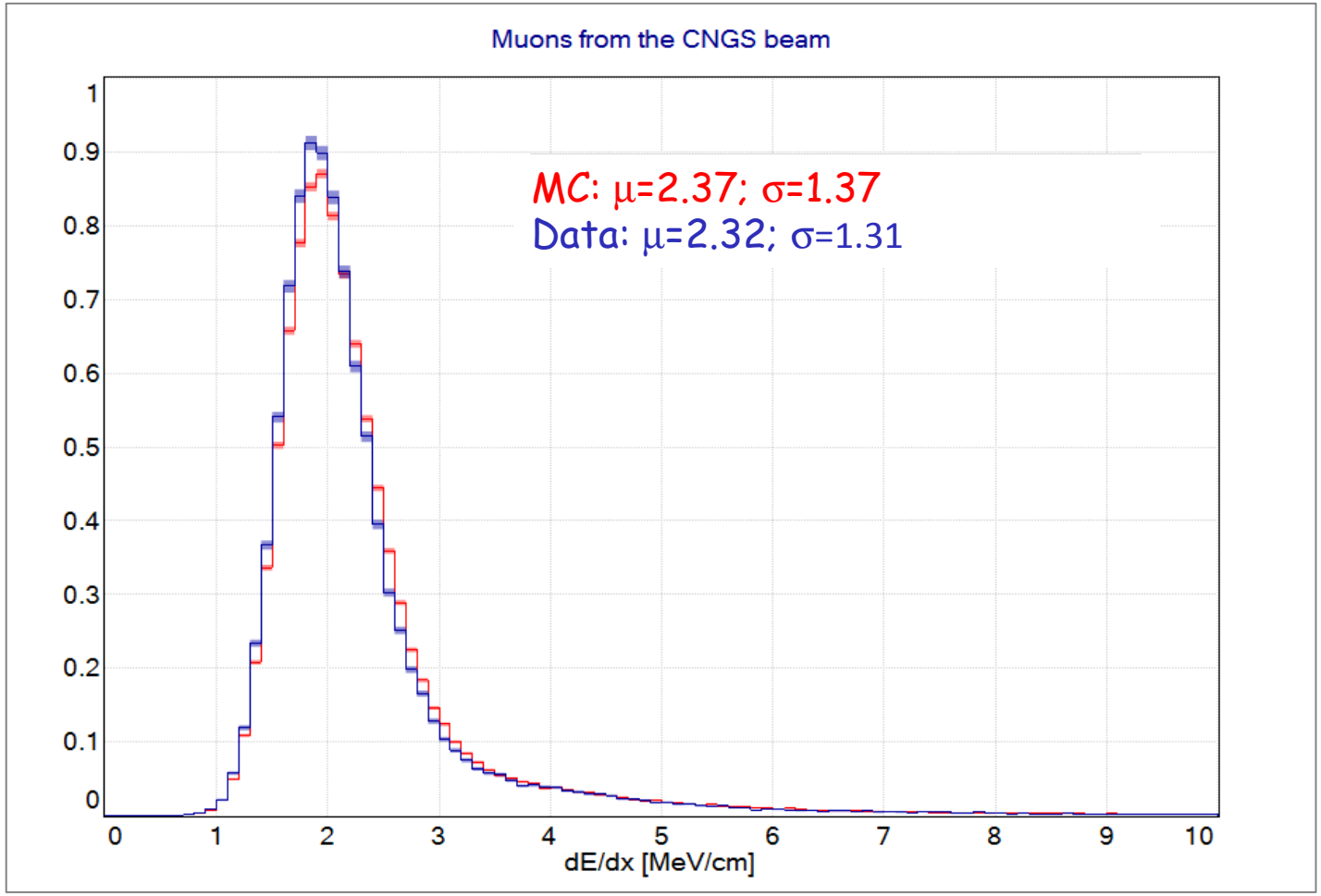
- ICARUS fully operational since Oct. 1st 2010: 5.8 10^{18} pot collected in 2010.
- 2011 CNGS run: Mar. 19th to Nov. 14th
  - 4.44(4.78) x 10^{19} pot collected (delivered): 93% detector live-time
  - Expected ~1280 CC and ~395 NC events
- March 23rd 2012: new CNGS events, 7.7 x 10^{18} pot collected.







Calibration with CNGS muons



dE/dx distribution for real and MC muon tracks from CNGS events

Tracks reconstructed in 3D. δ rays and showers rejected.

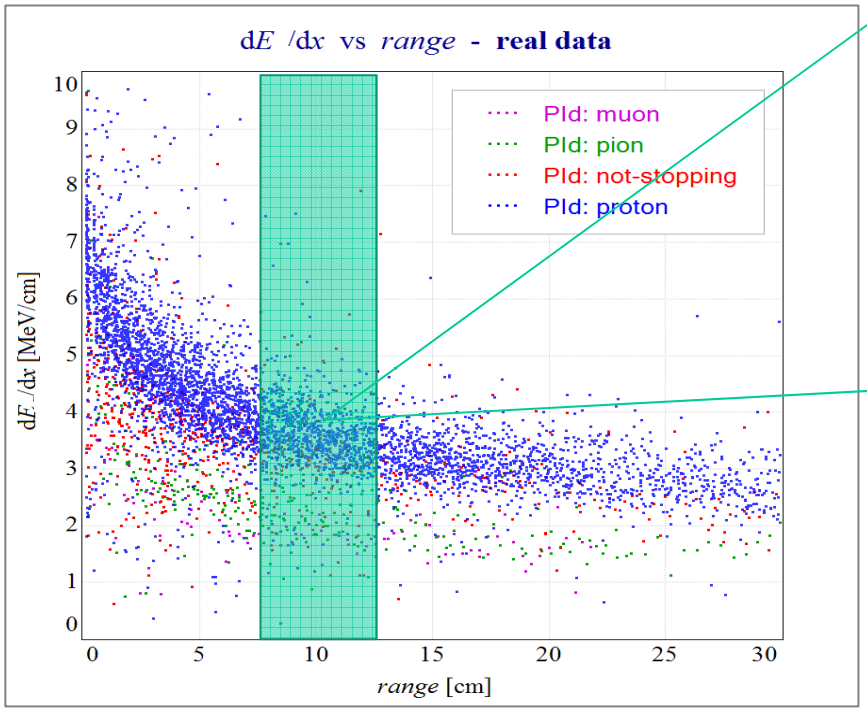
Same reconstruction on MC muons with CNGS spectrum.

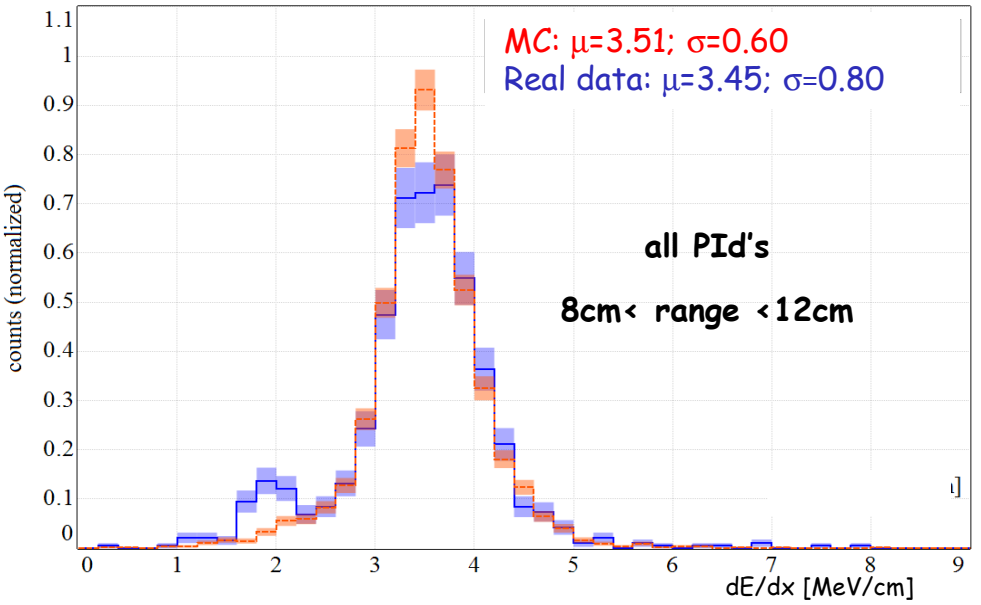
Very nice agreement (~ 2-3%) – still possible small different conditions of data and MC (noise patterns and their effects on δ ray selection).

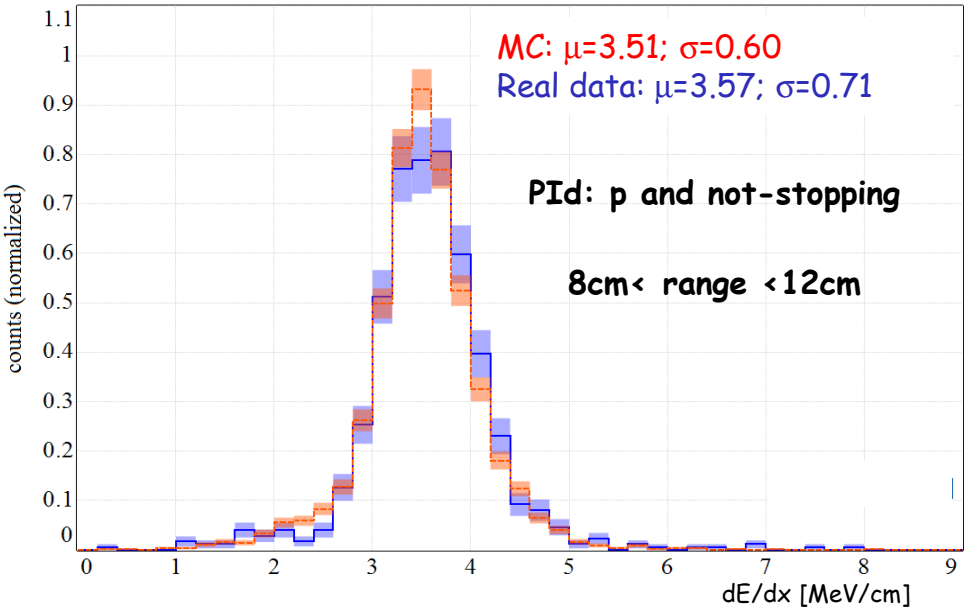
Study of stopping tracks

- Deposited dE/dx vs residual range
- No quenching corr. for dE estimation
- Residual range between 8 and 12 cm

- Good agreement between Data and MC
- π clearly separated from protons
- MC: only protons are considered

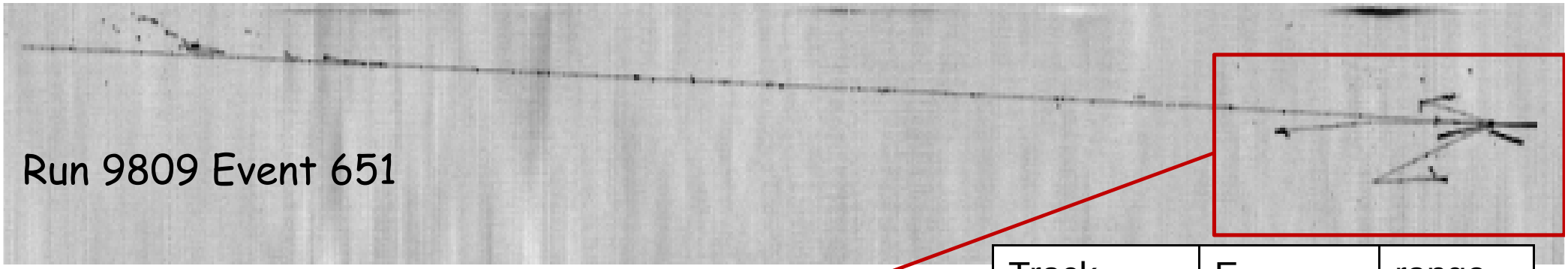


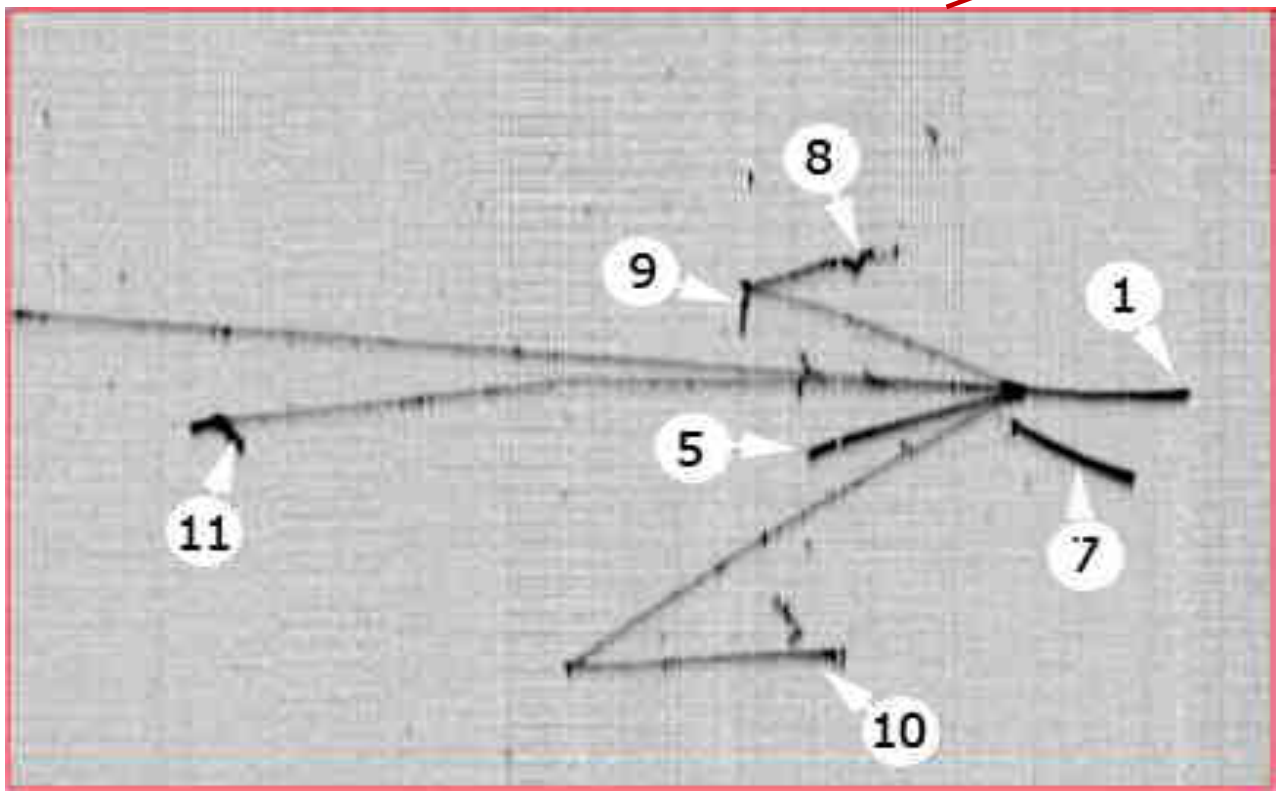




Methods for identification of non-stopping particles are under development

ν_μ CC CNGS event: reconstruction of stopping tracks

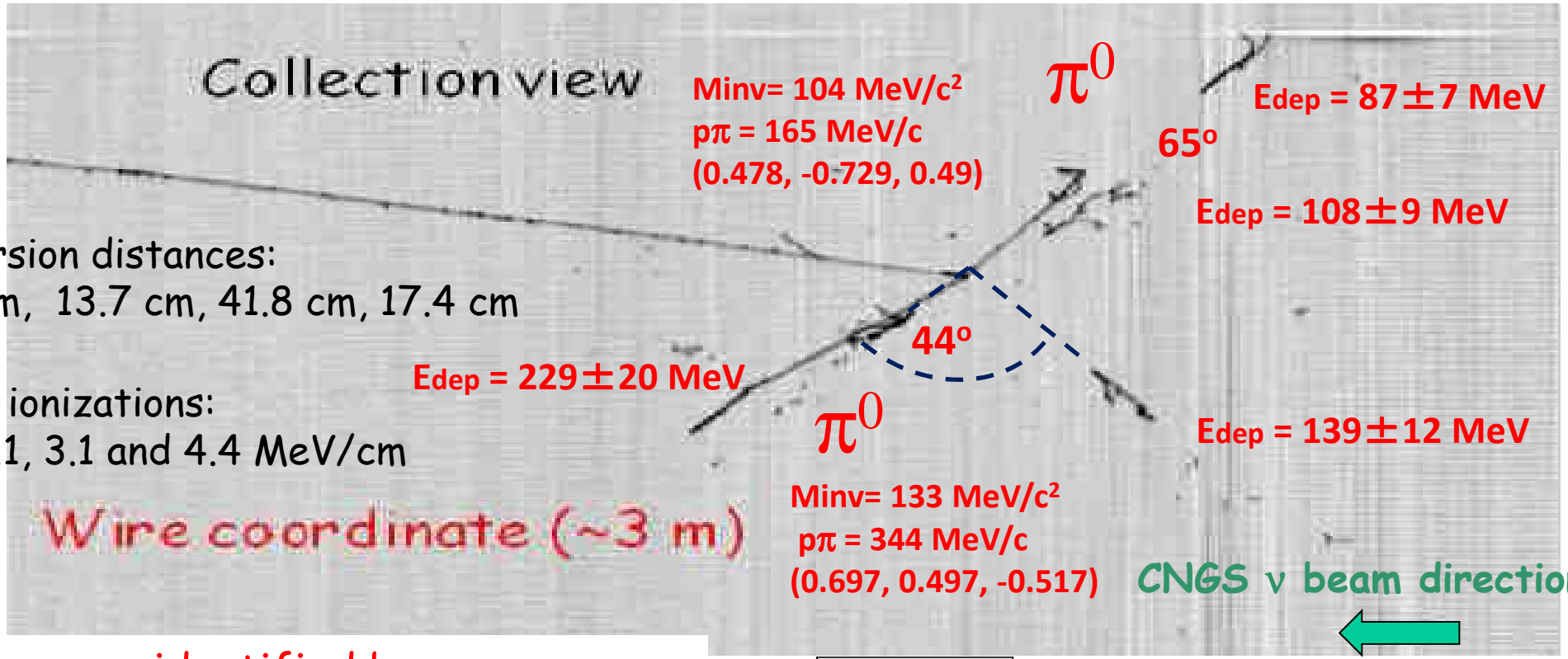




Track	E_{dep} [MeV]	range [cm]
1(p)	185±16	15
5(p)	192±16	20
7(p)	142±12	17
8(π)	94±8	12
9(p)	26±2	4
10(p)	141±12	23
11(p)	123±10	6

6 protons, 1 pion decays at rest

π^0 reconstruction in CNGS event



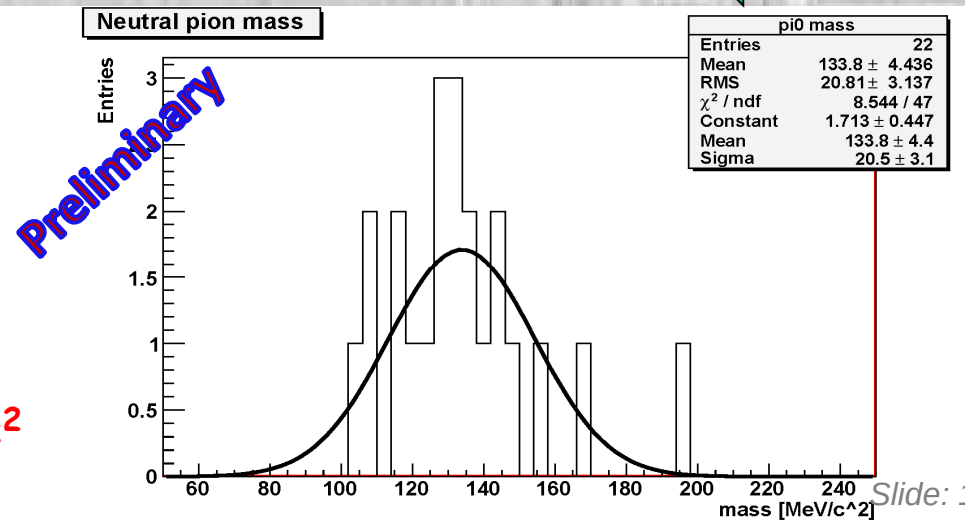
Conversion distances:
71.2 cm, 13.7 cm, 41.8 cm, 17.4 cm

Initial ionizations:
5.1, 6.1, 3.1 and 4.4 MeV/cm

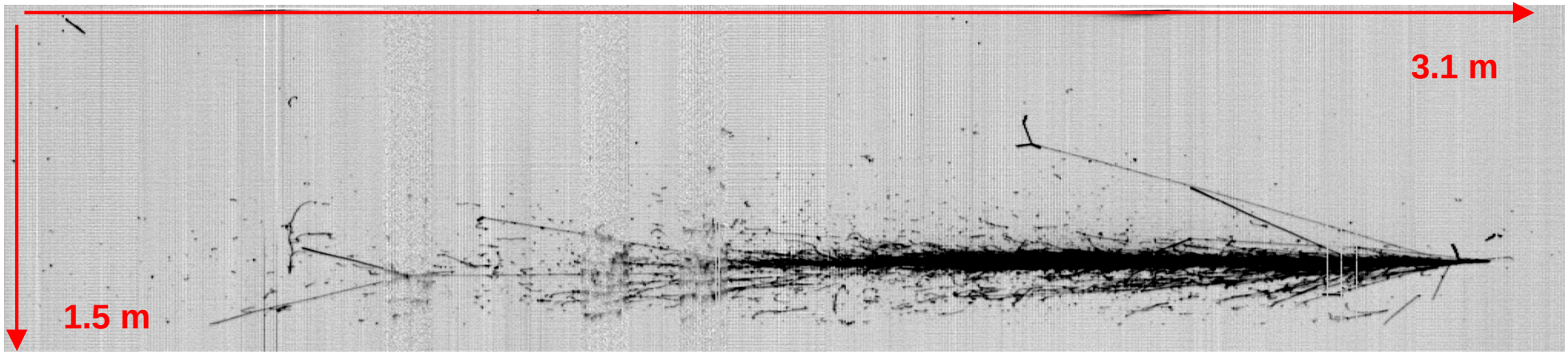
π^0-showers identified by

- 2γ conversion separated from primary vertex
- Reconstruction of $\gamma\gamma$ invariant mass
- Ionization in the first segment of showers (1 mip or 2 mips)

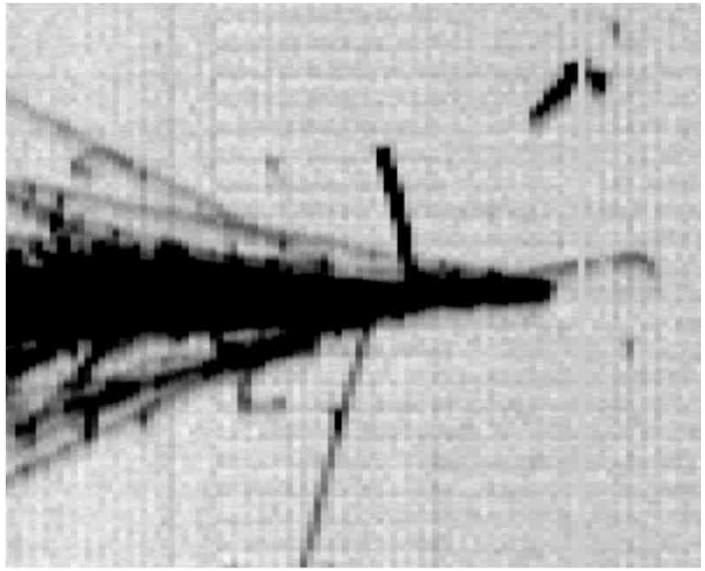
Mean: 133.8 ± 4.4(stat) ± 4 (syst) MeV/c²
σ = 20.5 MeV

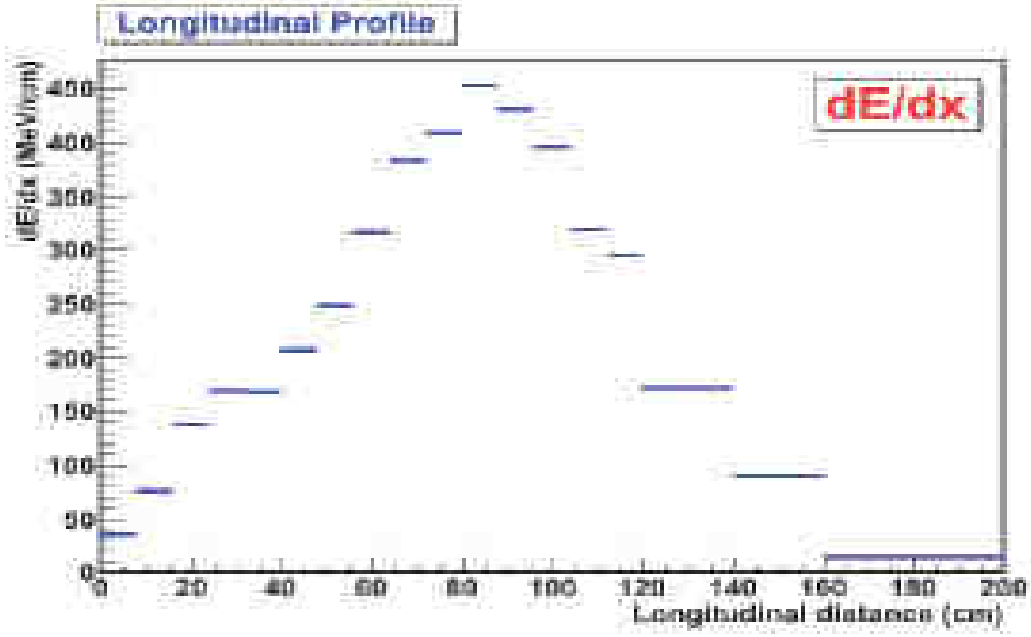


Electron event candidate

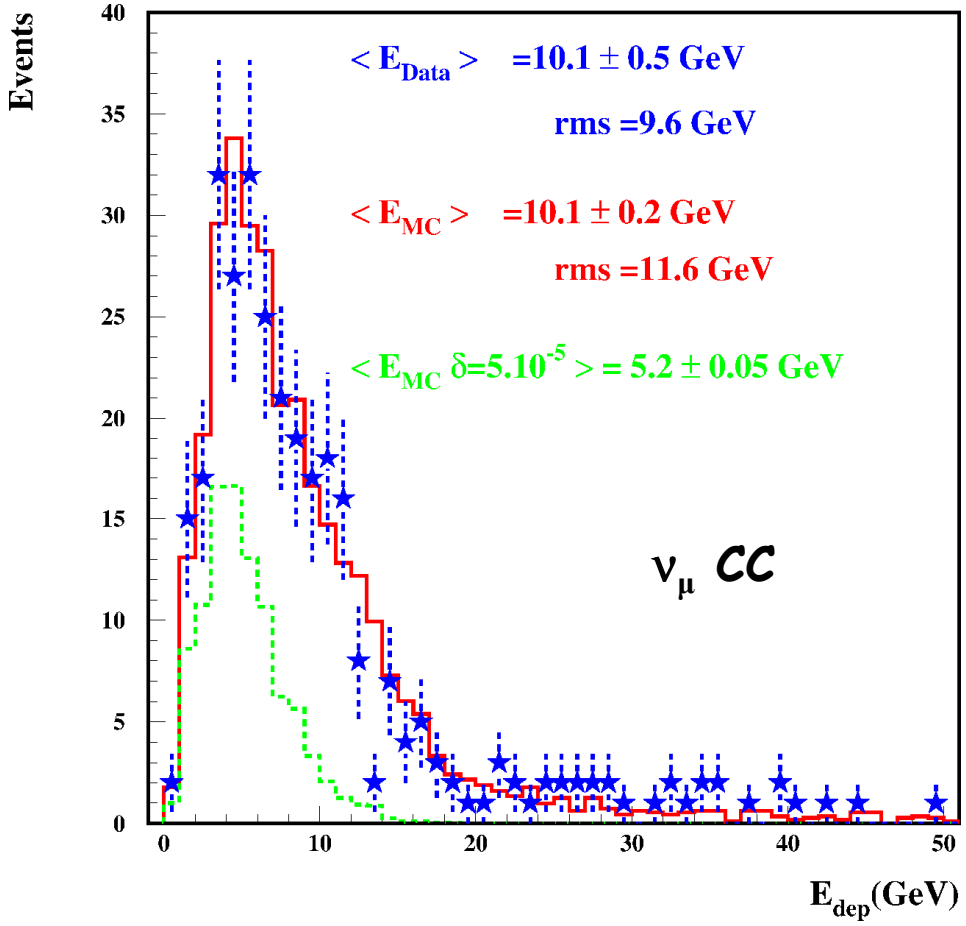


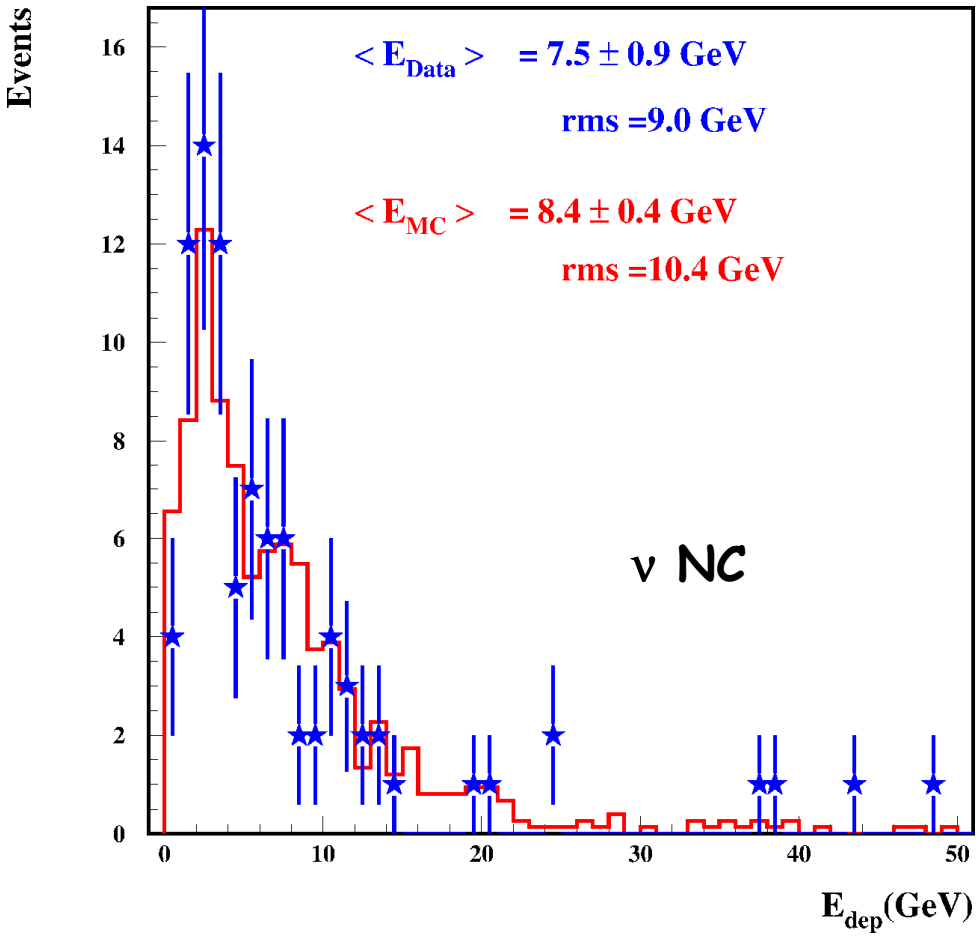
- A ν_eCC candidate from 2010 run. This event has *45 GeV energy* with a single powerful *37 GeV e.m. shower* at vertex with a longitudinal profile peaking at the expected position (~88 cm).





Total energy deposition in CNGS ν events

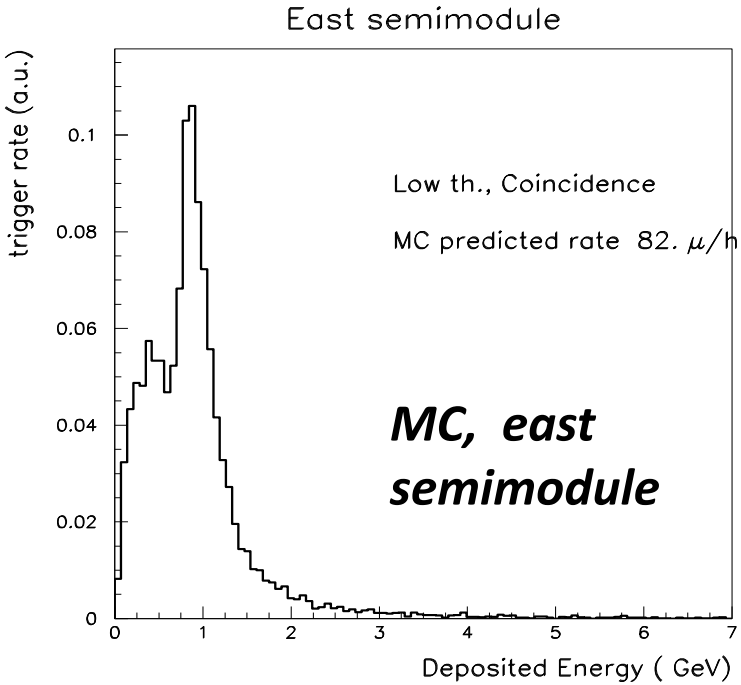




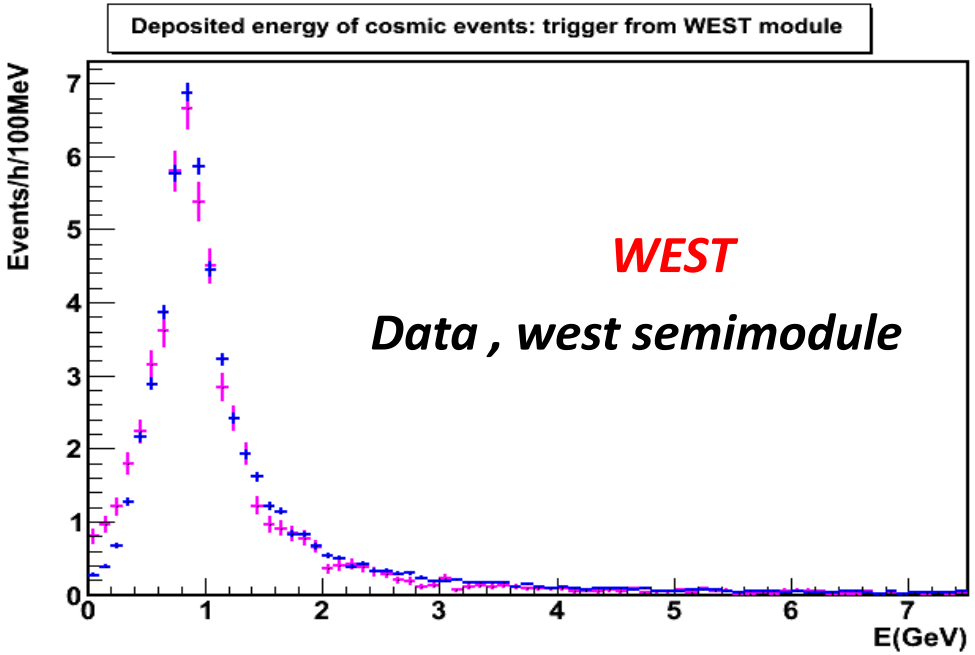
- Comparison of the predicted (full MC) and detected deposited energy spectrum from NC and CC events on 2010 statistics and a subset of the 2011 statistics.
- Used for the "superluminal" neutrino searches.

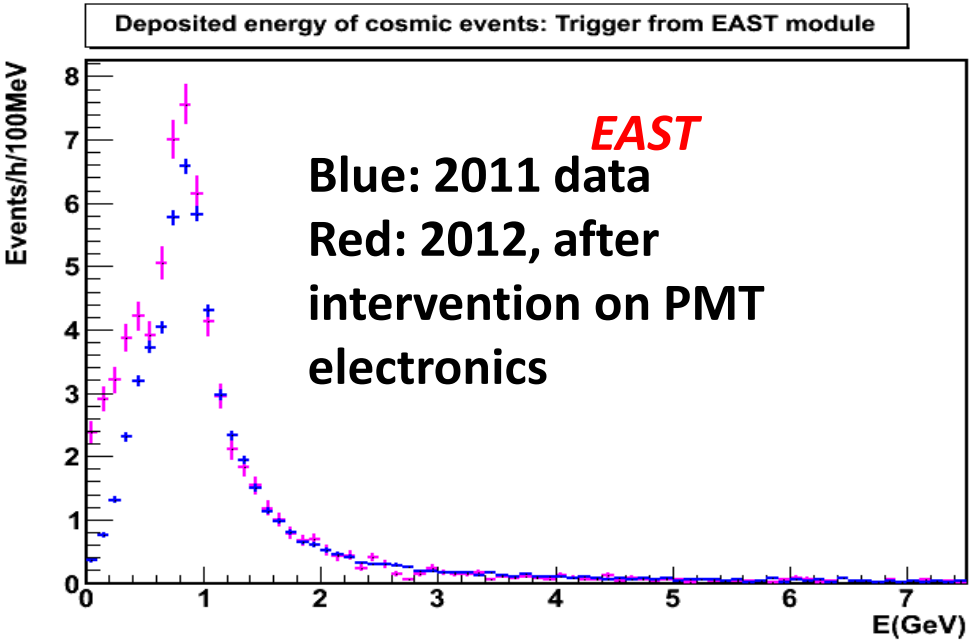
C-ray spectrum

- CR data automatically filtered
- Good agreement of energy spectrum with MC expectation. (MC simulation includes light collection/trigger conditions)



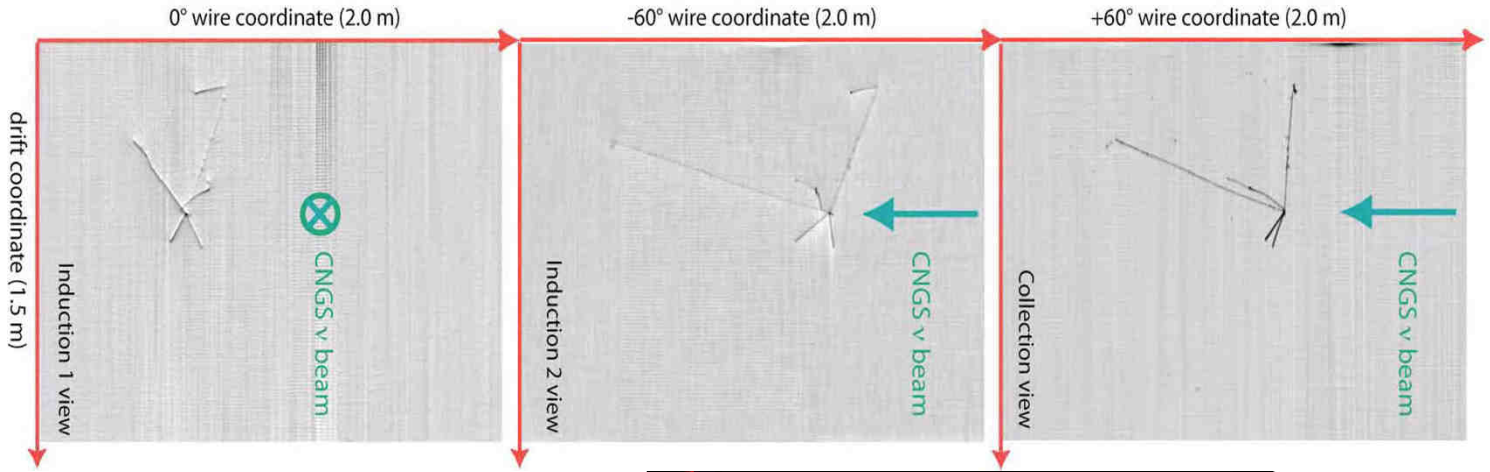
- 2012: 30% improvement w.r.t. 2011 trigger rate thanks to new PMT's HV biasing signal readout: signal amplitude increased → *efficiency at low energy increased*





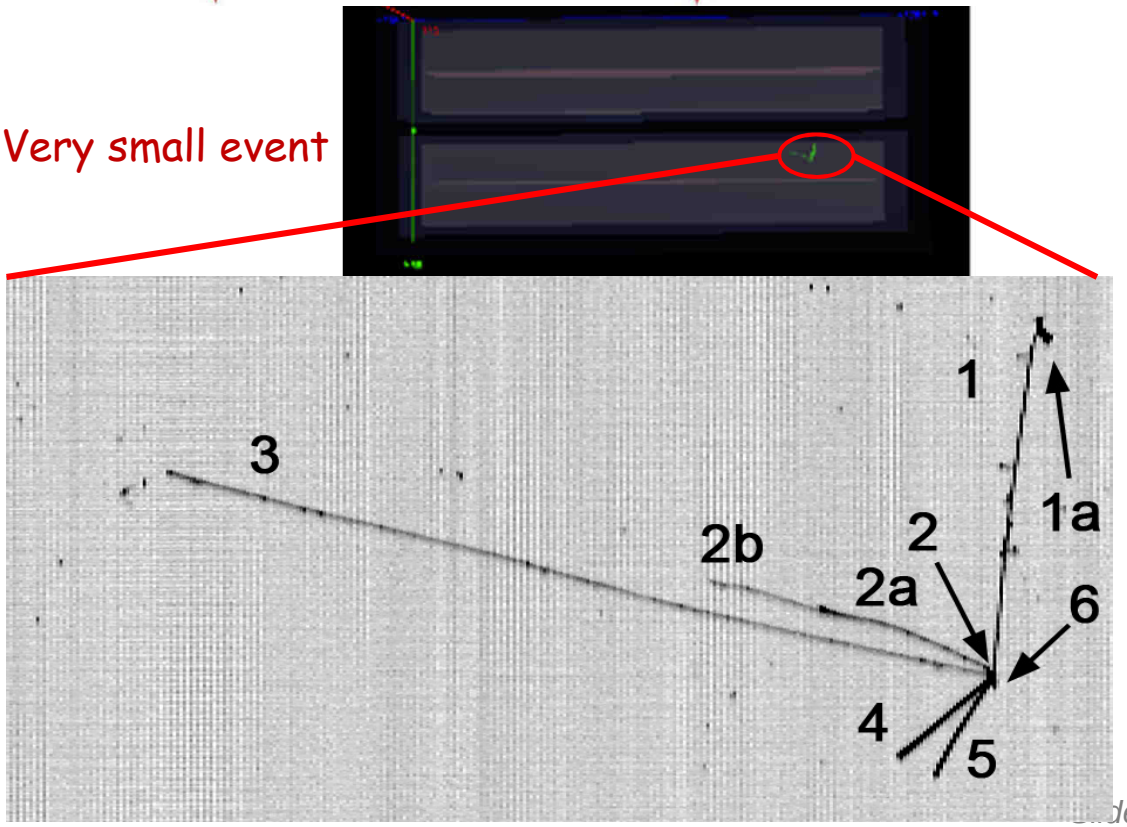
Atmospheric ν candidate

- Total visible energy:887 MeV
- Out-of-time wrt CNGS spill, 35^0 angle w.r.t. beam direction.



Track	E_k [MeV]	Range [cm]
1 (π, decays in flight)	136.1	55.77
2 (π)	26	3.3
2a (μ)	79.1	17.8
2b (e)	24.1	10.4
3 (μ)	231.6	99.1
4 (p)	168	19.2
5 (p)	152	16.3
6 (?) (merged with vtx)		2.9

Very small event

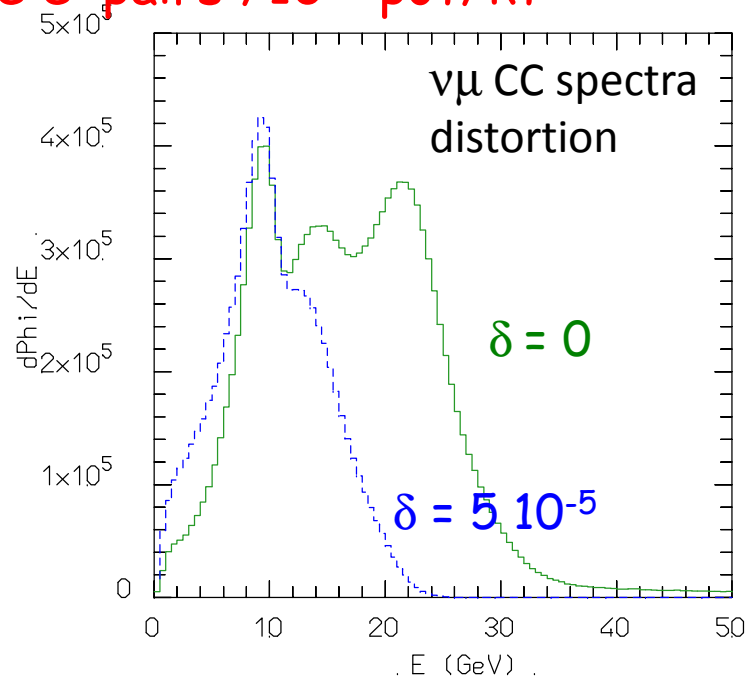


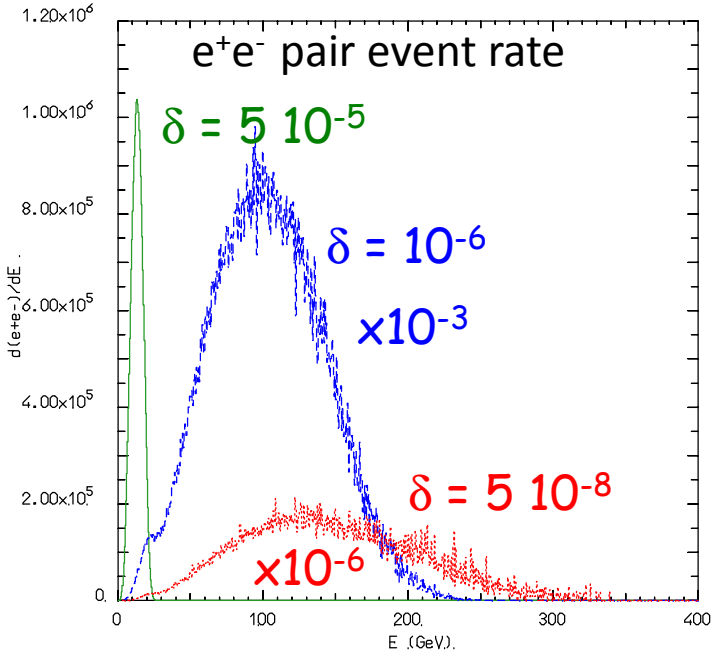
Search for superluminal ν's radiative processes in ICARUS

http://dx.doi.org/10.1016/j.physletb.2012.04.014
Phys.Lett.B711. (2012) 270-275

- Cohen and Glashow [Phys. Rev. Lett., 107 (2011) 181803] argued that superluminal ν should loose energy mainly via e^+e^- bremsstrahlung, on average $0.78 \cdot E_\nu$ energy loss/emission
- Full FLUKA simulation of the process kinematics, folded in the CNGS beam, studied as a function of $\delta = (v_\nu^2 - c^2)/c^2$

  For $\delta = 5\ 10^{-5}$ (OPERA first claim):
  - full ν event suppression for E > 30 GeV
  - ~10^7 e^+e^- pairs /10^{19} pot/kt





Search for superluminal ν's radiative processes in ICARUS

Expected ν event rate and e^+e^- pair production spectra for 10^{19} pot*kt of ICARUS exposure and different δ values

δ	CC (all flavours)	NC (all flavours)	CC>60 GeV $(\nu_\mu + \bar{\nu}_\mu)$	e^+e^-
0	644	203	57	0
$5 \cdot 10^{-8}$	644	203	57	27
$5 \cdot 10^{-7}$	643	203	56	$2.1 \cdot 10^4$
$5 \cdot 10^{-6}$	594	188	8.5	$7.2 \cdot 10^5$
$5 \cdot 10^{-5}$	203	85	$< 10^{-6}$	$1.1 \cdot 10^7$

- Effects searched in 6.7 10^{18} pot·kt ICARUS exposure (2010/11) toCNGS
  - No spectrum suppression found in both NC , CC data (~ 400 events)
  - No e^+e^- pair bremsstrahlung event candidate found

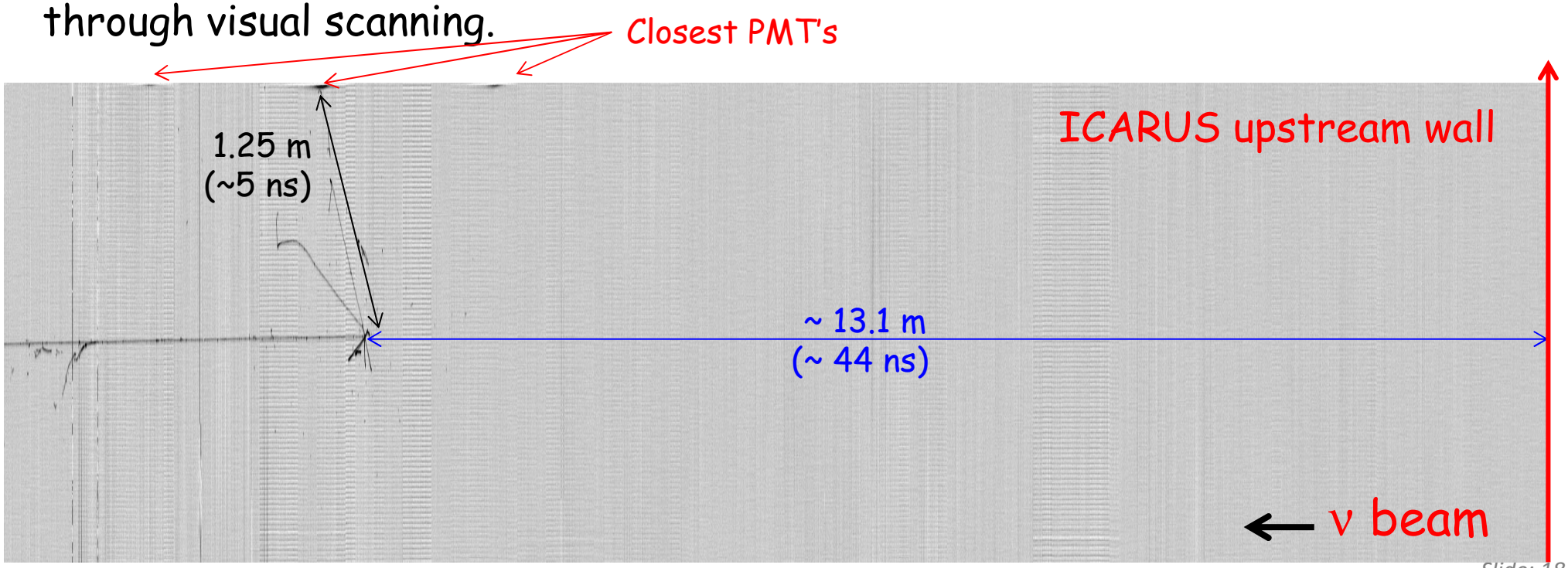
- The lack of pair in CNGS ICARUS 2010/2011 data, sets the limit:

$$\delta = (v_\nu^2 - c^2)/c^2 < 2.5\ 10^{-8}\ 90\%\ CL$$

- comparable to the SuperK limit $\delta < 1.4\ 10^{-8}$, somewhat larger than the lower energy velocity constraint $\delta < 4\ 10^{-9}$ from SN1987A.

Neutrino time of flight with 2011 bunched beam

- Bunched beam: 4 bunches/spill, 3 ns FWHM, 524 ns separation
- From October 31st to Nov. 5th ICARUS observed 7 bunched-beam events
- Timing from ICARUS PMT readout equipped with an independent DAQ
- Reference point : upstream wall of active volume -> corrections needed:
  - the position of interaction vertex along 18 m of detector length
  - the distance of event vertex from closest PMT
- Both corrections precisely (~1ns) deduced from event topology in LAr-TPC through visual scanning.

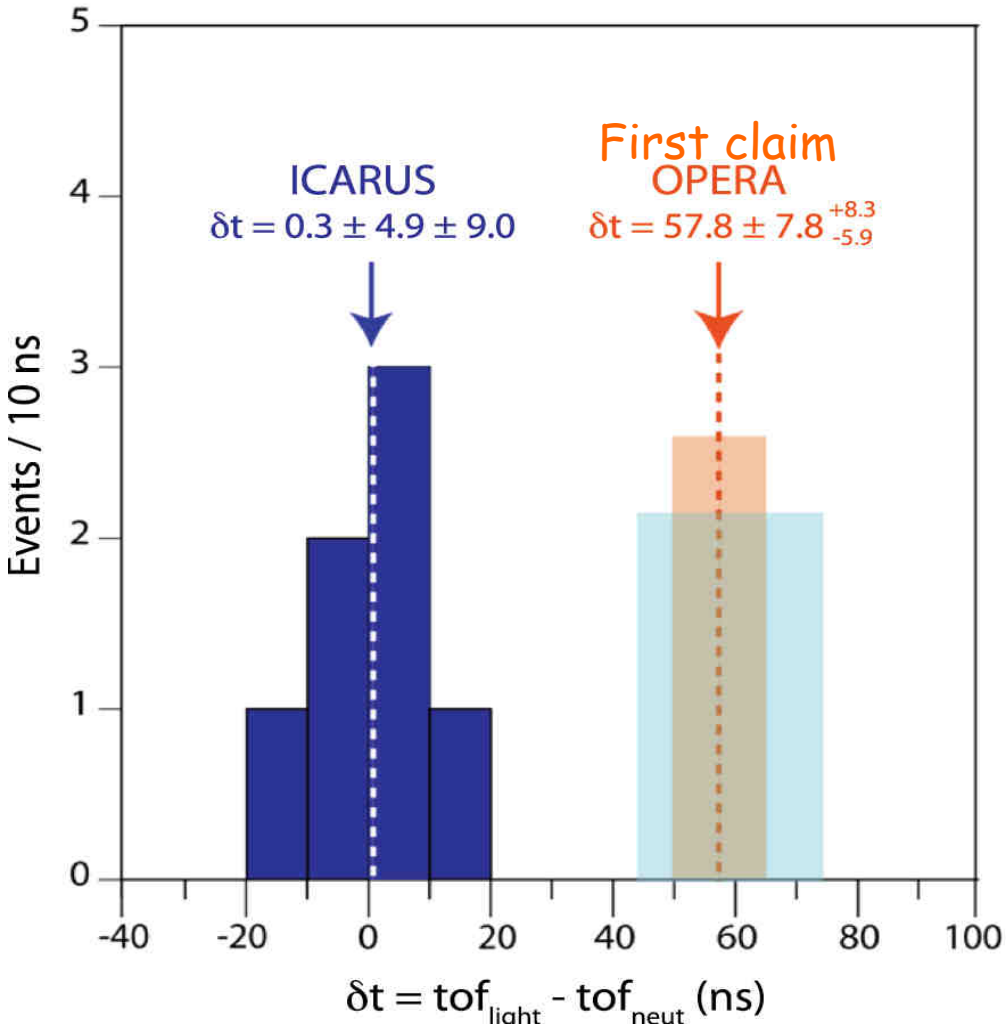


Neutrino time of flight result

http://dx.doi.org/10.1016/j.physletb.2012.05.033(PhysLettB)

- All fixed delays/propagation times calibrated
- Baseline estimation relies on existing available geodesy data (OPERA/LNGS)
- Variable corrections to GPS from OPERA/CERN recipe

- The average $\delta t = tof_c - tof_\nu$ for the 7 events is +0.3 ns ± 4.9 ns (stat) ±9 ns (syst)
- ν velocity compatible with speed of light



Presently analyzing data with the new bunched beam run,
Common effort LNGS and CERN , involving Borexino, LVD, Opera, Icarus

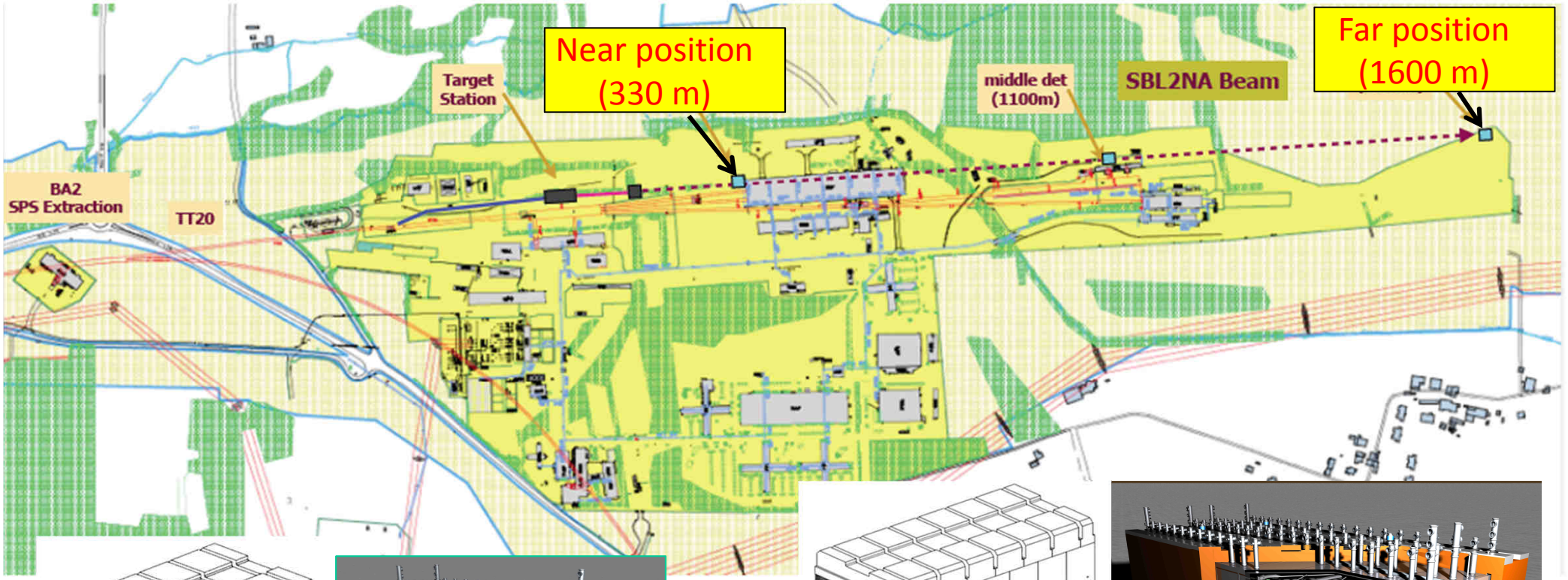
ICARUS after CNGS2: a new approach to sterile ν at CERN/SPS

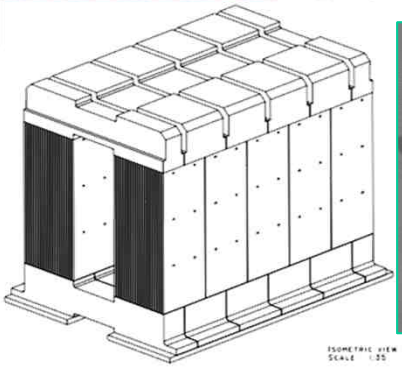
The experimental "anomalies" found by LSND/Miniboone (observation of electron *excess* in a anti-ν_μ beam from accelerators) and by the reactor neutrino experiments (apparent *disappearance signal* in the anti-ν_e events) might be due to the presence of "sterile" neutrino

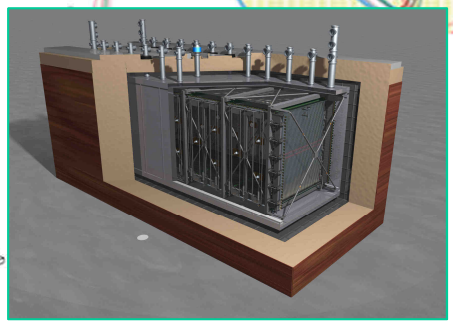
- The LAr-TPC is the viable device to solve these "anomalies" thanks to
  - detection capability of genuine ν_e events
  - energy resolution/detector granularity largely adequate for E<3GeV
  - high level of rejection of associated background events (π^0).
- A novel experimental search based on two strictly identical LAr-TPC detector + 2 magnetic spectrometers at 330 m and 1600 m from the p target is proposed at CERN – SPS
- Neutrino beam produced by a 100 GeV proton beam fast extracted from SPS will be centred at ~2 GeV
- Anti-neutrino beam by inverting the current of the horn

➢ *Technical proposal: "Search for "anomalies" from neutrino and anti-neutrino oscillations at $\Delta m^2 \approx 1eV^2$ with muon spectrometers and large LAr-TPC imaging detectors" (SPSC-P-347) of March 15th, 2012.*

New Neutrino Facility in the CERN North Area

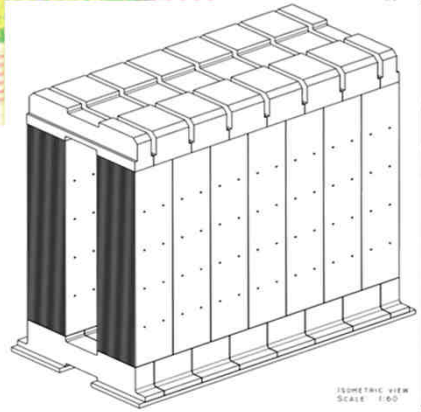


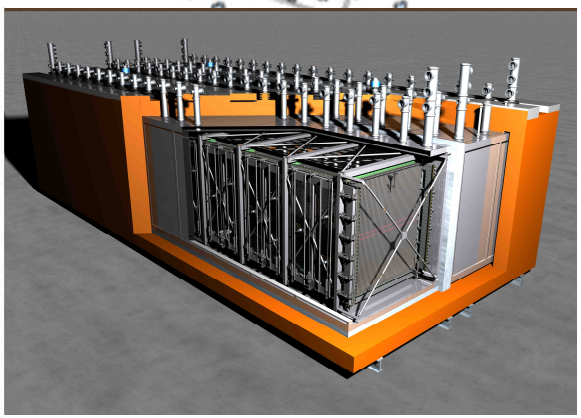




NEAR

New detector T150
identical to ICARUS
but of smaller size





FAR

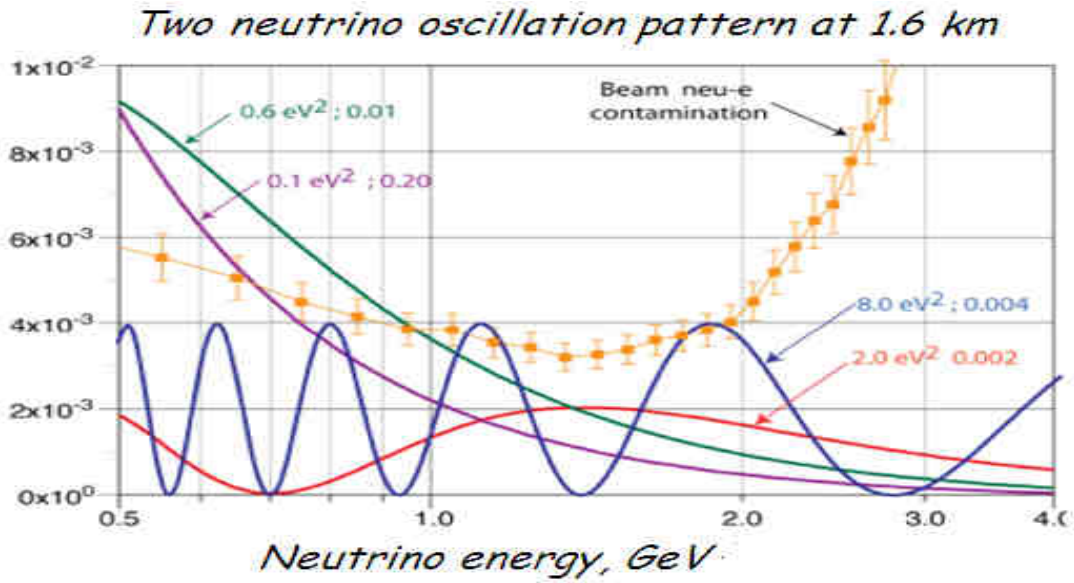
T600 moved from LNGS to
CERN with new insulation

Unique features of the CERN beam

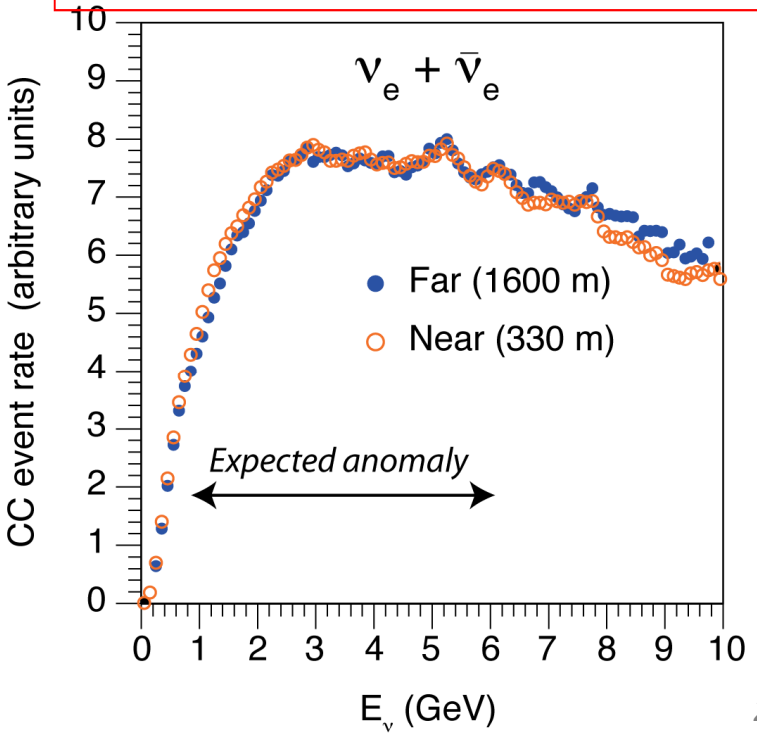
- The present proposal is a search for spectral differences of electron like specific signatures in two identical detectors but at two different neutrino decay distances.

➢ *In absence of oscillations*, apart some beam related small spatial corrections, the two ν_e intrinsic spectra are a precise copy of each other, independently of the specific experimental event signatures and without any Monte Carlo comparison.

o Therefore an exact, observed proportionality between the two ν_e spectra implies directly the absence of neutrino oscillations over the measured interval of L/E.



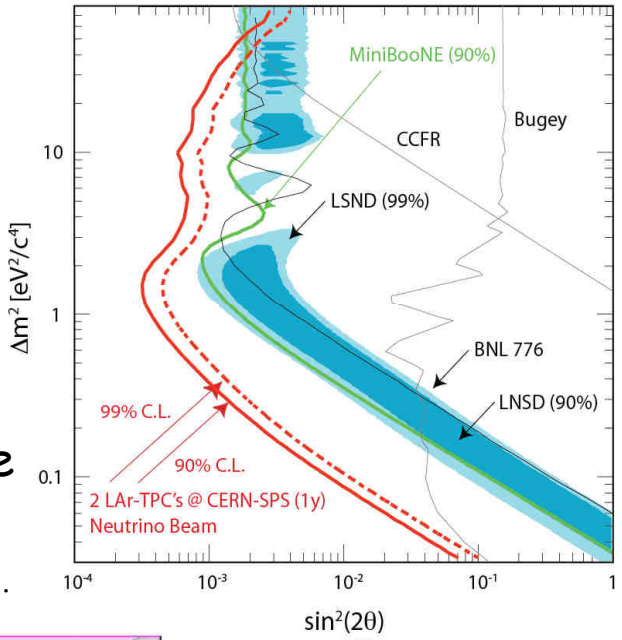
Precise identity of intrinsic ν-e events in the near and far positions

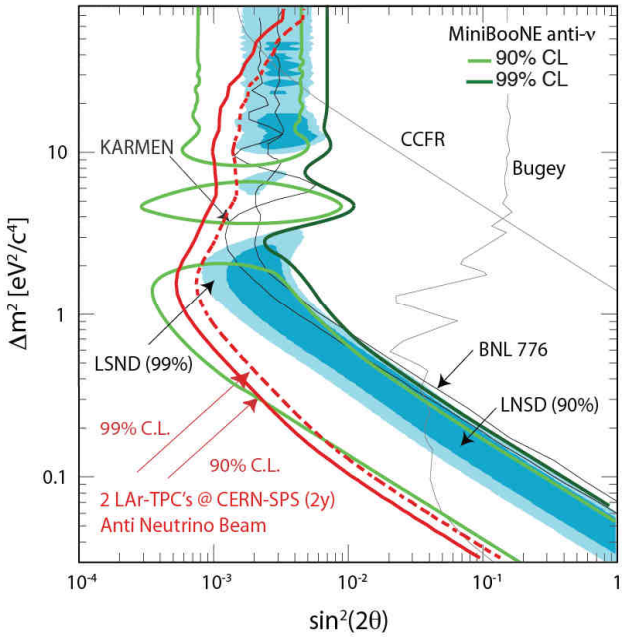


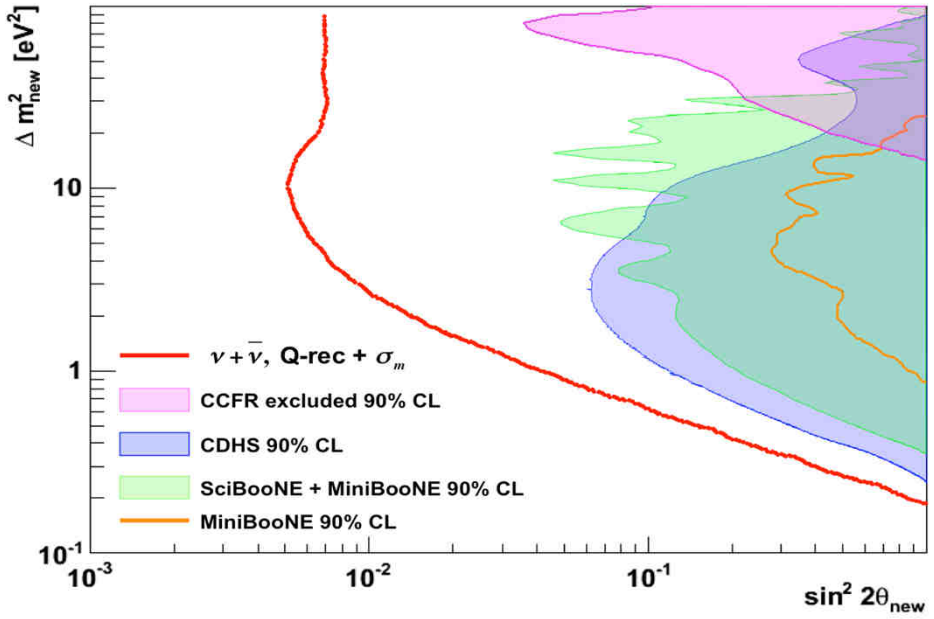
Physics program

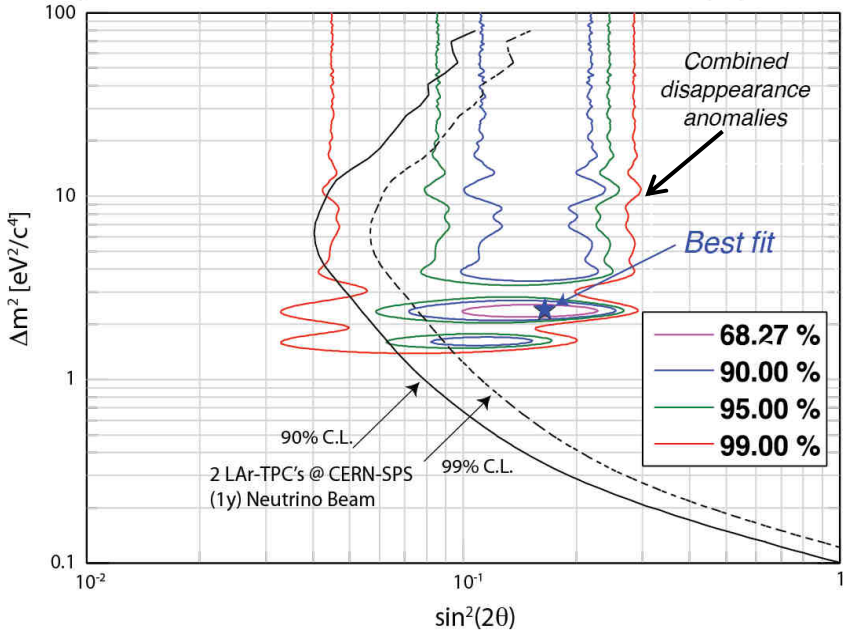
Full exploration of LNSD $\nu_\mu \rightarrow \nu_e$ allowed region both with ν_μ and anti-ν_μ beam.
Expected sensitivity at neutrino beam (top left) for 4.5×10^{19} pot and twice as much for anti-neutrino (top right) .

- Search for a possible oscillatory disappearance in the ν_μ (bottom left) and in the initial ν_e signals (bottom right).









- *ICARUS T600 LAr-TPC is taking data @LNGS with CNGS beam searching for $\nu_\mu \rightarrow \nu_\tau$ and $\nu_\mu \rightarrow \nu_e$ oscillations as well as for athmospheric νs and proton decay.*
- *Its unique imaging capability, spatial/calorimetric resolutions, and e/π^0 separation allow to reconstruct/identify events in a new way, w.r.t. previous/current experiments:*

  a major milestone towards a much more massive LAr detector.
- *A novel search using 2 LAr TPCs and 2 magnetic spectrometers @CERN-SPS is proposed after the ICARUS T600 exploitation at LNGS to solve LSND/MiniBooNe/reactor neutrino anomalies.*

Thank you !