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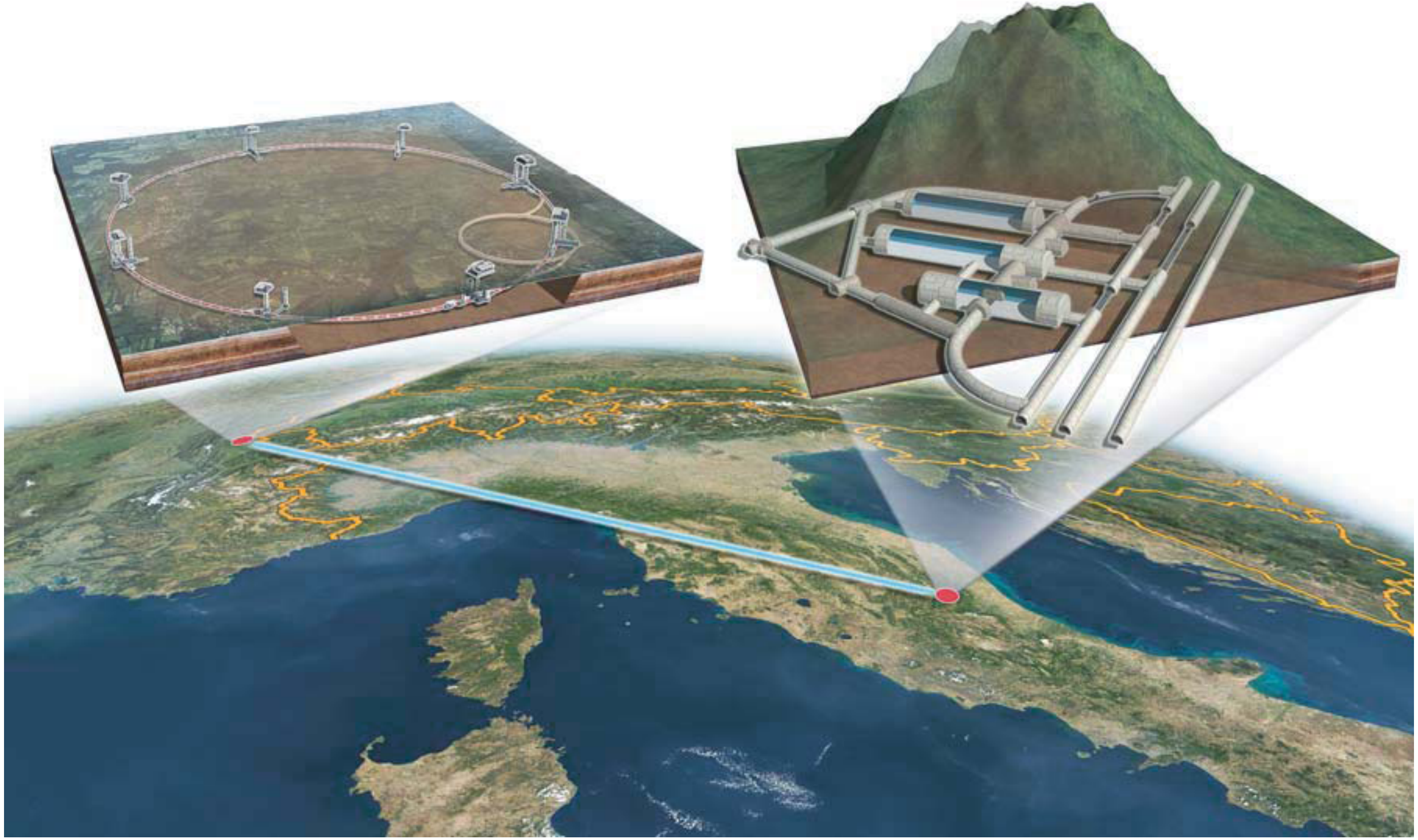
A new, very massive modular Liquid Argon Imaging Chamber to detect low energy off-axis neutrinos from the CNGS beam (Project MODULAr)



CERN – May 11, 2009

Neutrino oscillations

- *strong evidence for neutrino flavor changing transitions: existence of a mass term $m_\nu \neq 0$ and an interaction violating lepton flavor number*
- *cosmological arguments: to build up the today's dominance of matter over antimatter in non-equilibrium conditions the strong CP violation in the quark sector must be extended also to leptons*
- *neutrino oscillations have been observed in the solar and atmosph. ν's: corresponding parameters θ_{12},$|\Delta m_{12}^2|$ and θ_{23},$|\Delta m_{23}^2|$ have been measured*
- *a third subleading $\nu_\mu \rightarrow \nu_e$ driven by θ_{13} mixing angle - link between solar/atmosph. ν oscillations has not been detected yet: a $\theta_{13} \neq 0$ will allow ordering the ν masses and the determination of CP violation phase δ_{CP}*
- *present limit $\sin^2 2\theta_{13} \leq 0.14$ at 90% C.L.,$|\Delta m_{23}^2|=2.5\times10^{-3}$ eV^2 (CHOOZ) $\nu_\mu \rightarrow \nu_e$ hard to be measured in ν_μ beam: $\leq$10% effect at the osc. maximum!*
- *Double Chooz, Reno, Daya-Bay reactor experiments: addressed to explore θ_{13} down to 0.01*

ν oscillations at accelerators: toward θ_{13} and δ_{CP}

- *first generation long baseline experiments: K2K L=250 km baseline, NuMI and CNGS with L~ 730 km with conventional ν beams, 170 KWatt on target*
- *present detectors: SK 22.5 kt W-Cherenkov, MINOS 5.4 kt Iron-Scintillator calorimeter and ICARUS ~ 600t liquid Argon TPC (LAr-TPC); OPERA emulsion detector for ν_τ appearance*
- *measurement of θ_{13} and δ_{CP} in $\nu_\mu \rightarrow \nu_e$ requires major improvements both in beams and detectors: high intensity pure ν beams, L/E$_\nu$ tuned to Δm_{23}^2, well defined energy spectrum (present beams: intrinsic ν_e mainly from μ and K decay):*

  ν-Factories: ν's from decay of accelerated μ's

  β-Beams: ν's from decay of accelerated radioactive ions, just one flavor beam!
- *"ultimate" massive detectors to measure ν_e-CC (electrons!) rejecting ν-NC (π^0's)*

  100 kt LAr-TPC GLACIER, 50 kt L-Scint. LENA,~1 Mt W-Cherenkov MEMPHIS

  USA and Japan: two similar projects, UNO and HyperK
- *2nd generation experiments at improved conventional beams, ≥ 1 MW power*

  T2K: present SK detector but a new 0.7 GeV ν_μ beam from 50 GeV/c RCS, 0.7 MW, L=295 km

  NOVA project, 20 kt L-Scint, L~820 km, 2 GeV ν_μ beam, 6.5×10^{20} pot/y at 120 GeV/c.

MODULAr proposal: ν physics with/without accelerator, search for p-decay

- a new LAr-TPC Imaging underground detector made of several identical units 5 kt fid. mass each, 20 kt LAr-TPC detector as a first step
- a new experimental area LNGS-B tailored to MODULAr detector, 10 km Off-Axis the main lab, away from the protected area of the National Park, ~1.2 km of eq. water depth for p-decay and cosmic ν searches
- a neutrino beam derived from the existing CNGS facility, eventually with an increased intensity; a nearly optimal ν_μ beam in few GeV energy range for $\nu_\mu \rightarrow \nu_e$ searches can be realized with relatively modest changes.

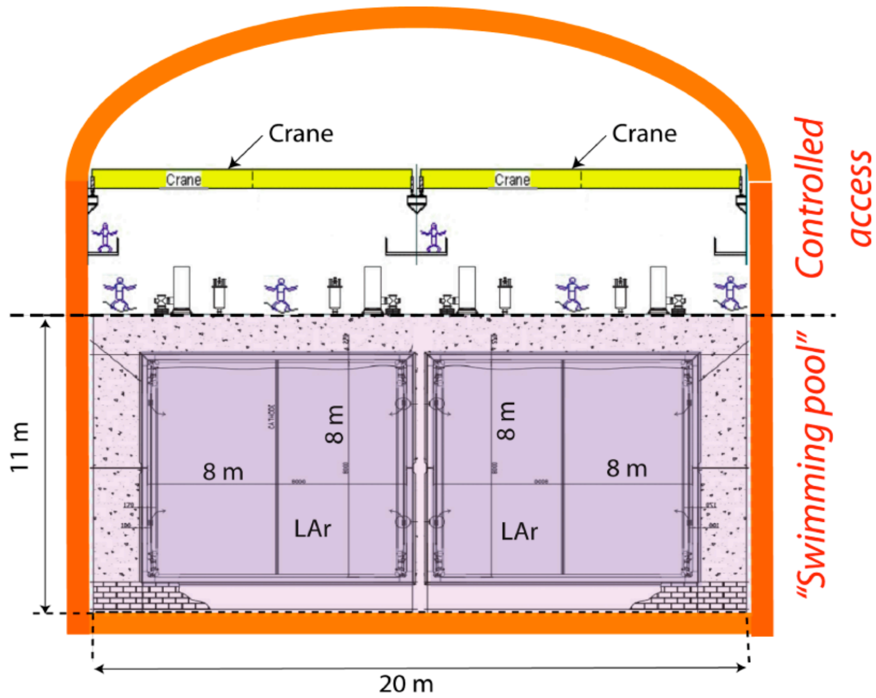
HOWEVER the new underground lab is an additional but not necessary feature of the project for θ_{13} and δ_{CP} measurements with CNGS beam.

MODULAr can be located in a swimming pool at surface inside the LNGS external lab, 7 km Off-Axis, largely reducing the effort of excavation and the need of infrastructures.

from ICARUS-T600 to multi-kton LAr detector: a modular approach!

MODULAr will be initially composed by 4 identical modules:

- $8 \times 8\ m^2$ cross section, 60 m of length
- LAr active mass: 5370 ton
- 4 m electron drift
- 3-D imaging similar to T600 but 6 mm wire pitch
- scintillation light detection with PMTs



this layout is valid both at shallow-depth and on surface

On surface: cosmic muons are easily recognized and efficiently rejected because of their different direction/topology w.r.t. CNGS genuine events!

- collected c-ray event rate: < 1 μ/ $2m^2$ in 2.7 ms full drift window per 5kt module, perfectly sustainable by present ICARUS-T600 DAQ
- ν event trigger: coincidence of CNGS-early-warning p-extraction and PMT signal < 0.5 spurious μ event/spill per module.

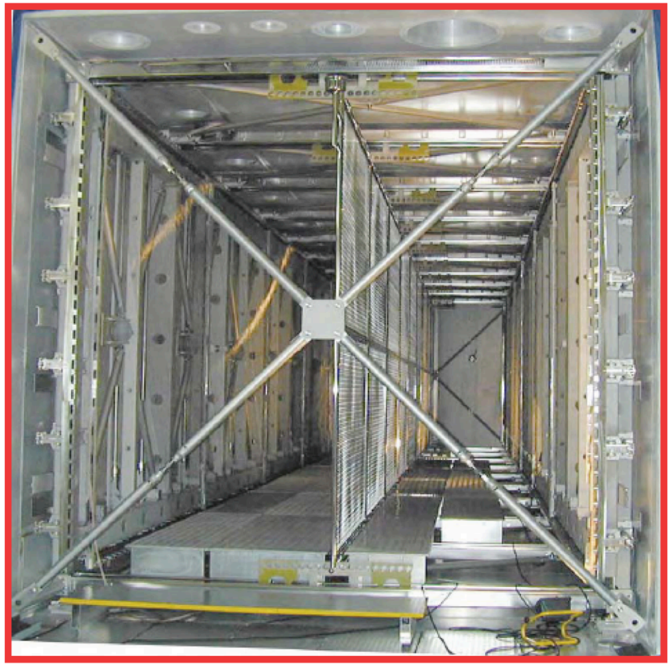
The MODULAr detector inherits all the achievements of ICARUS-T600

- mechanical structure and LAr, N_2 supply and refrigeration
- well established/tested wiring technique used for T600, but wire length ~30 m
- impurity level : <0.1ppb, H.V.: -200 kV cathode biased (E_{drift} = 0.5 kV/cm)
- 8" PMT's + Wl.s. for prompt (ns) VUV scintillation light, up to 20% Q.E.
- electronics for 1 module: 50000 chs., new improved design w.r.t. T600 front-end

MODULAr: ICARUS-T600 scaled up by only 2.66!

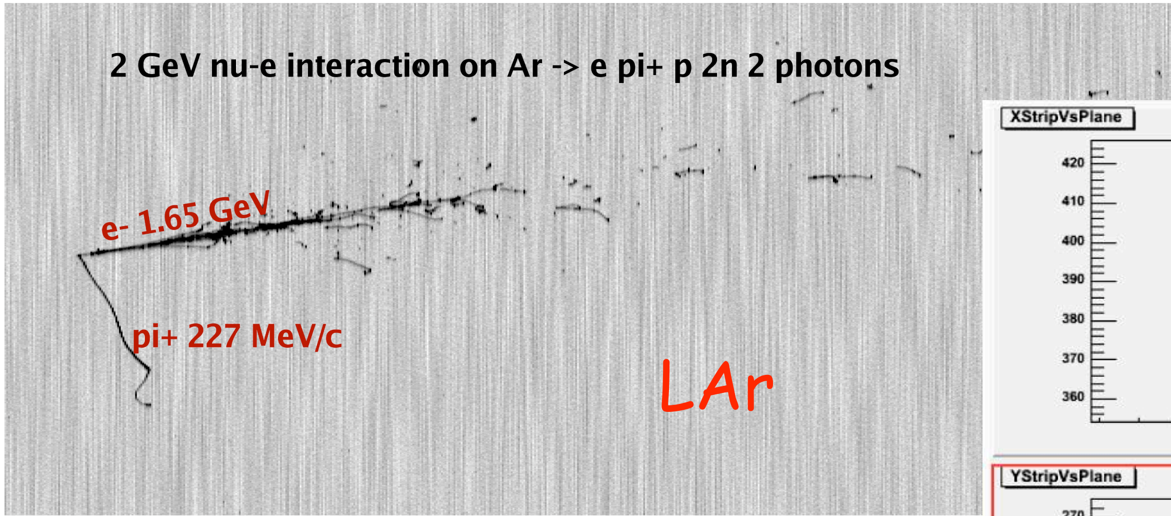
Limited R&D test?
- air evacuation by flushing pure Argon gas
- insulation by expanded Perlite
- 4m electron drift

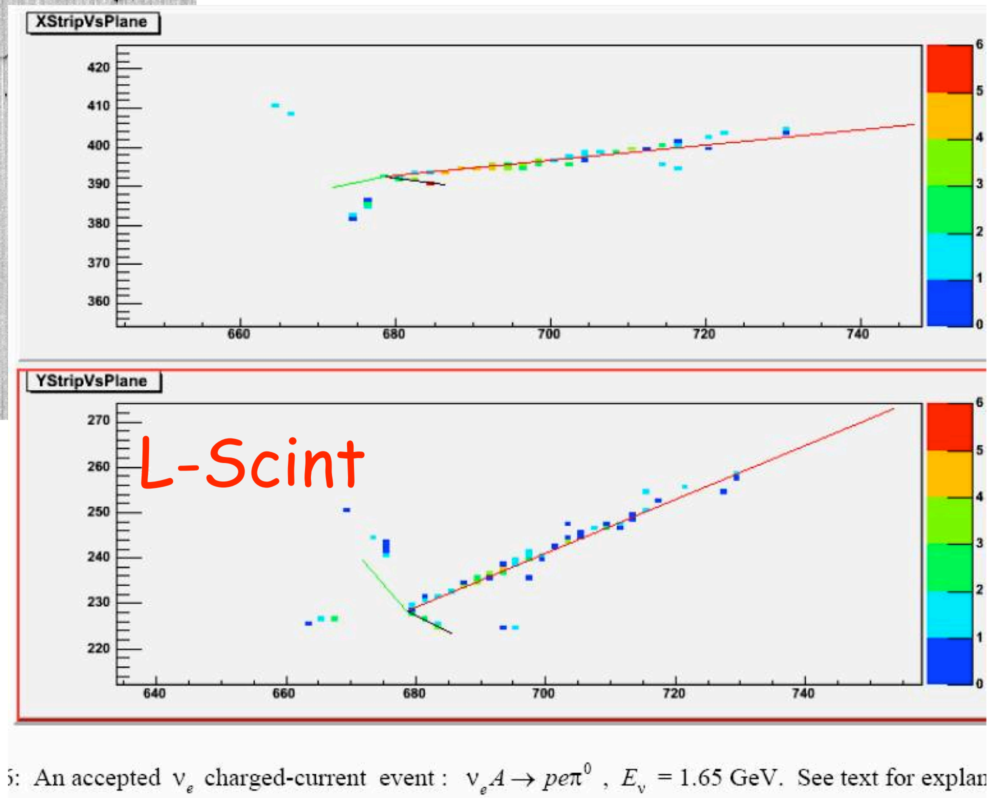
MODULAr: 8 x 8 m^2

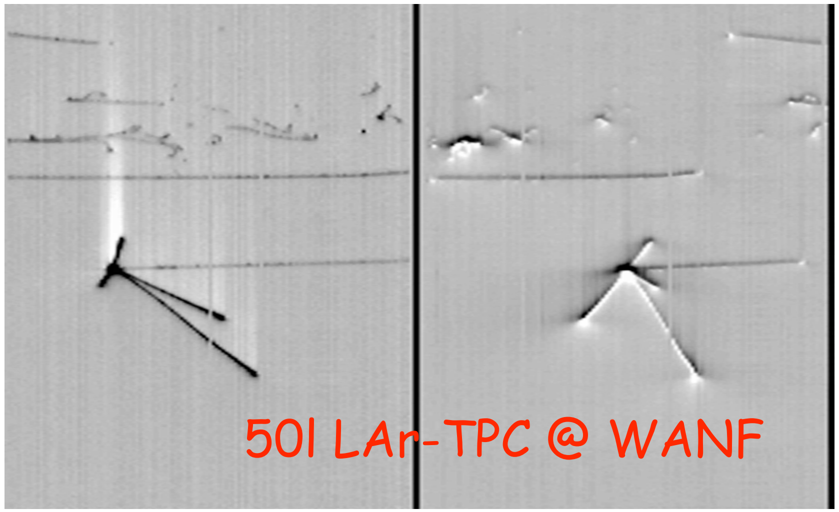


ICARUS: 3 x 3 m^2

LAr-TPC imaging: a key of $\nu_\mu \rightarrow \nu_e$ event observation





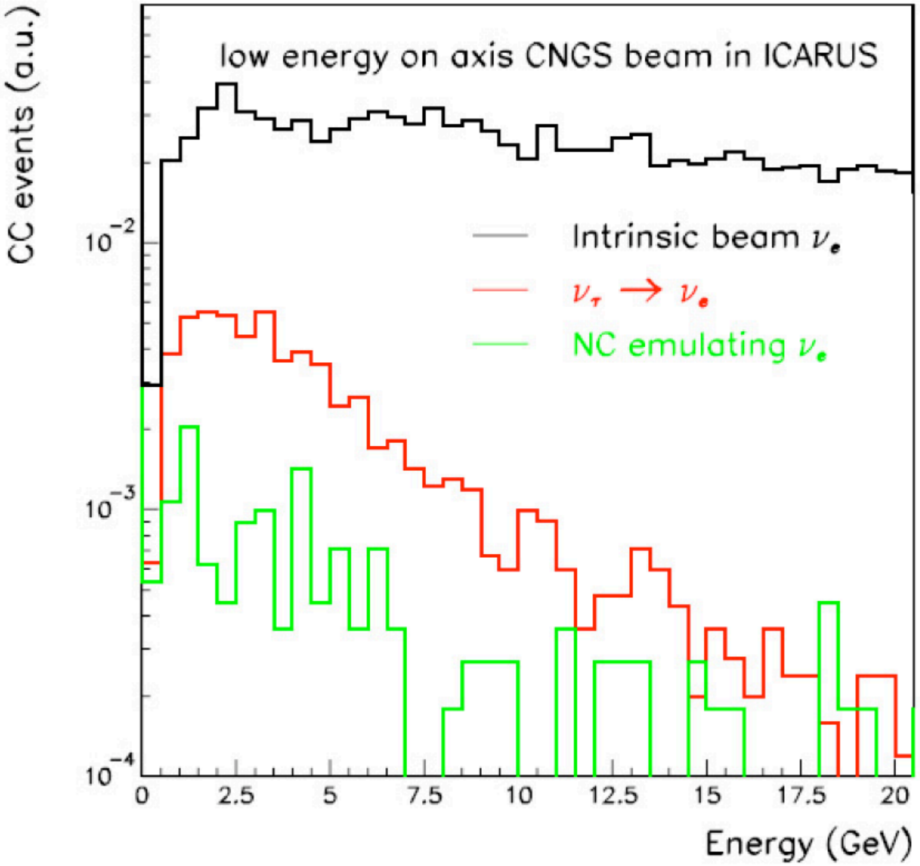


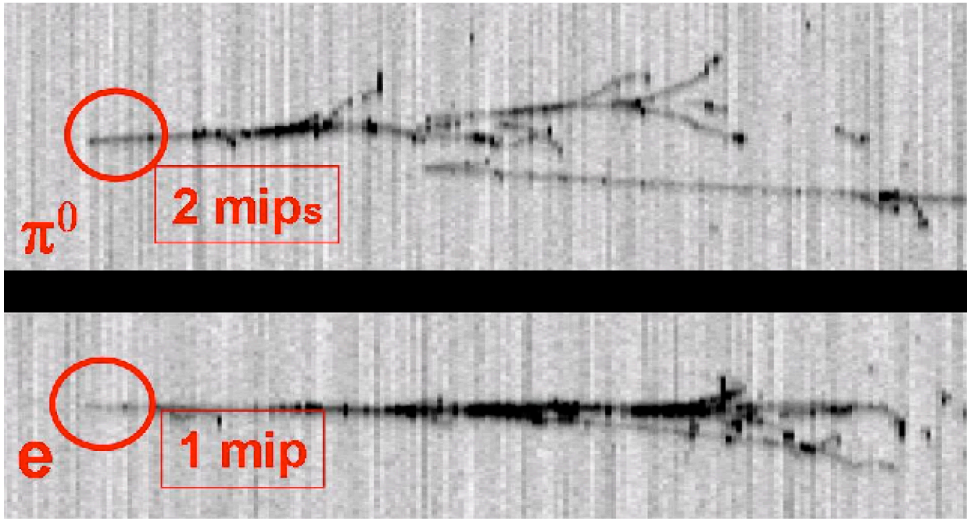
ν_e detection in L-Scint/W-Cherenkov limited by π^0 NC background!

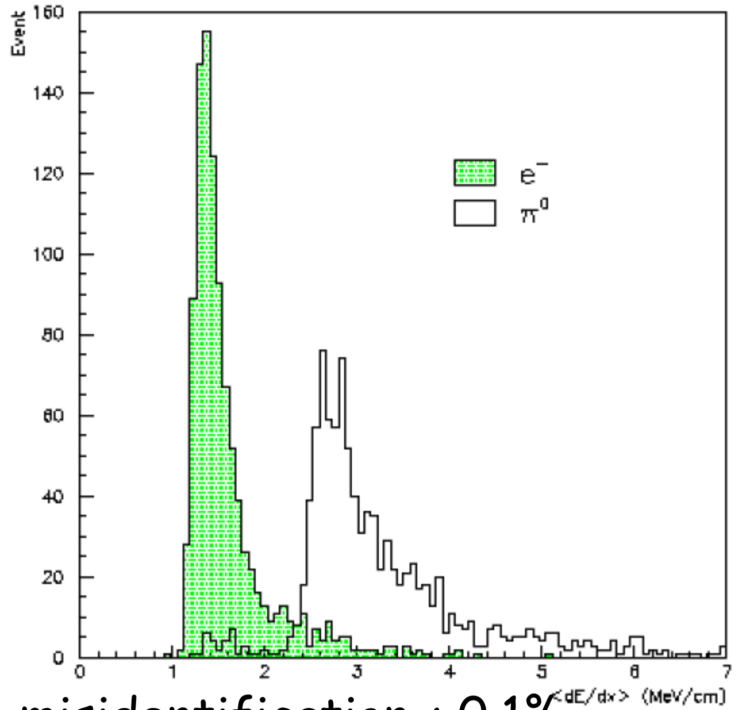
NOvA: ν_e detection efficiency ~24% due to poor νNC/ν_eCC separation

NC π^0 background in LAr suppressed by:

- topology (γ conversion from vertex)
- reconstruction of π^0 mass
- electron/photon separation (dE/dx)







Residual misidentification < 0.1%
Electron identification eff. = 90%

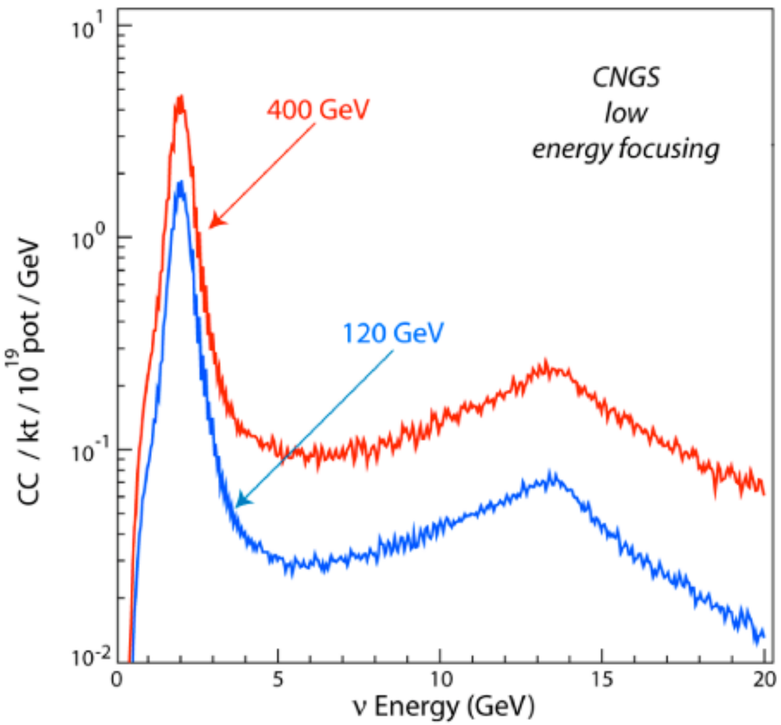
Much higher discovery potential of LAr w.r.t. L-Scint./W-Cherenkov detectors:
5 kton LAr detector ~20 kton of L-Scint

a new CNGS off-axis neutrino beam facility

- present CNGS: 4.5×10^{19} pot/y in shared mode, 55%efficiency for accelerator complex operation
- SPS requirement for the new CNGS: 512 kW beam power at 400 GeV, 1.2×10^{20} pot/y achievable without major upgrade (1.4×10^{20} pot/y for 200 days full efficiency dedicated operation)
- further upgrades by increasing p-beam intensity delivered by PS/SPS (up to 4.3×10^{20} pot/y, 1.6 MW)
- E_p = 400 GeV~3.3x120 GeV (NOνA); meson production scales almost linearly with E_p.

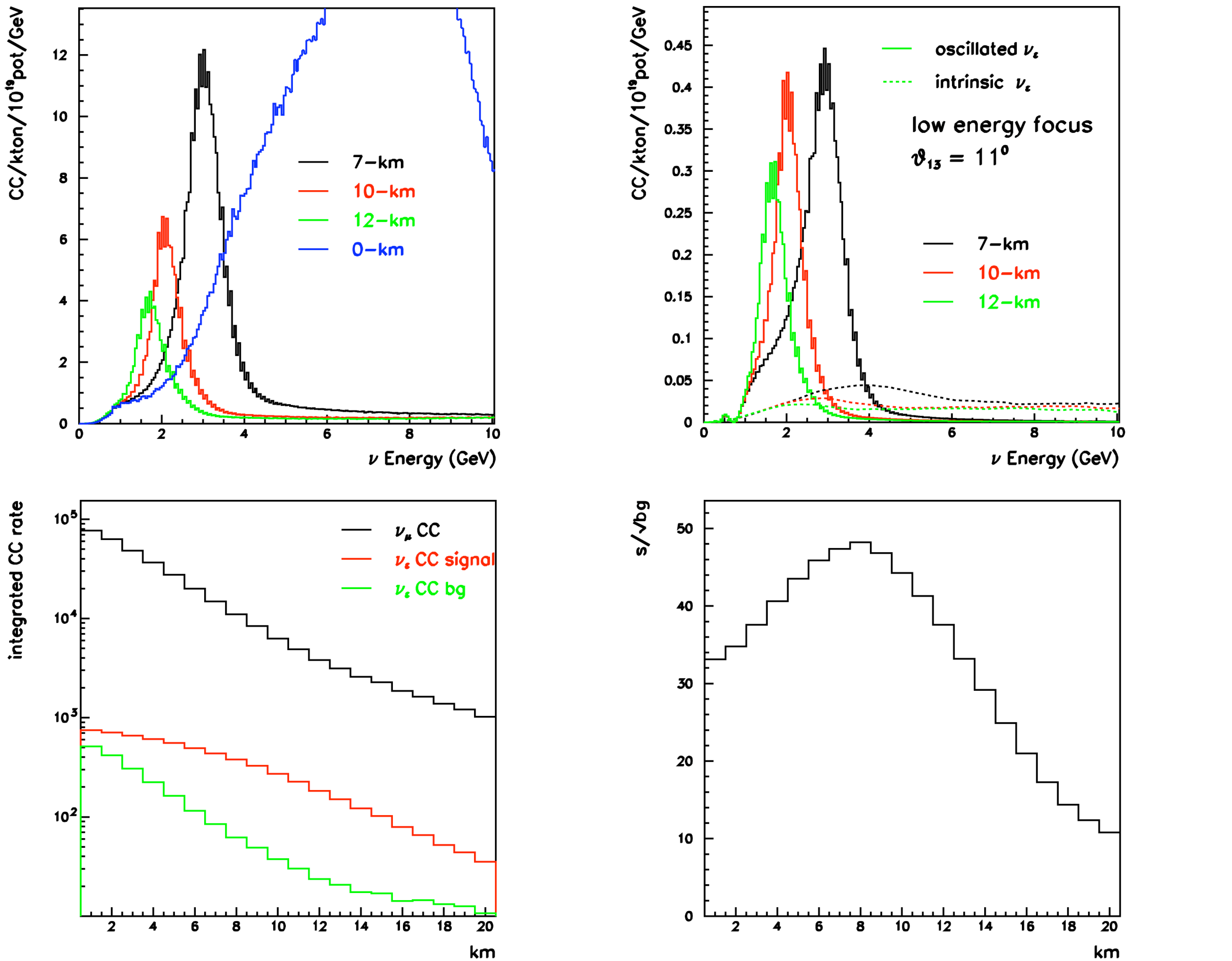
new target/optics optimized for low energy, 7 km Off-Axis ν beam:

- target: 1 m long graphite
- horn: 20 cm from target, NUMI-ME-like (3m long) 200 kA current
- reflector: same position, inner conductor redesigned for 15 GeV focus, 200 kA.



MODULAr (CNGS, 400 GeV) 1.2×10^{20} pot/y ~ NOνA (NUMI, 120 GeV) 6.5×10^{20} pot/y!

Off-axis neutrino beam: Sensitivity S/√backg vs. Off-axis distance

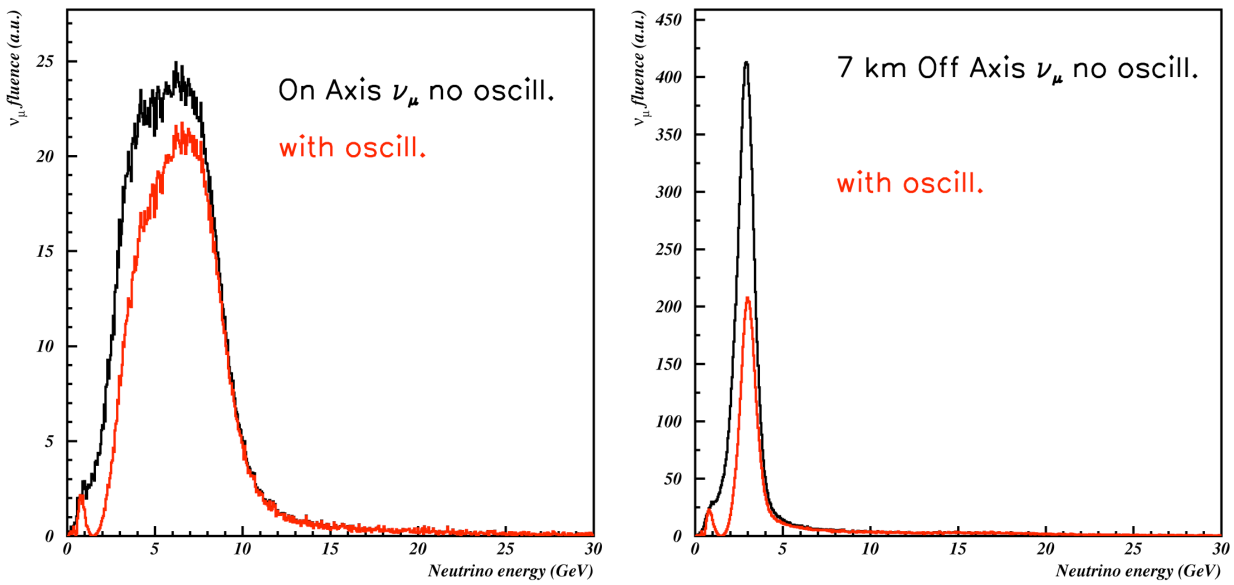


MODULAR: a two FAR detector experiment

the simultaneous use of two FAR detectors ICARUS-T600 On-Axis and MODULAr Off-Axis allows for a precise combined measurement of incoming ν's - via ν cross-sections: the two FAR detectors see the target/beam-optics within ~ same small angular acceptance (not in the case of conventional NEAR-FAR detector exp.)

- On-Axis ν_μ beam - E_ν~7 GeV- scarsely sensitive to $\nu_\mu \to \nu_\tau$:

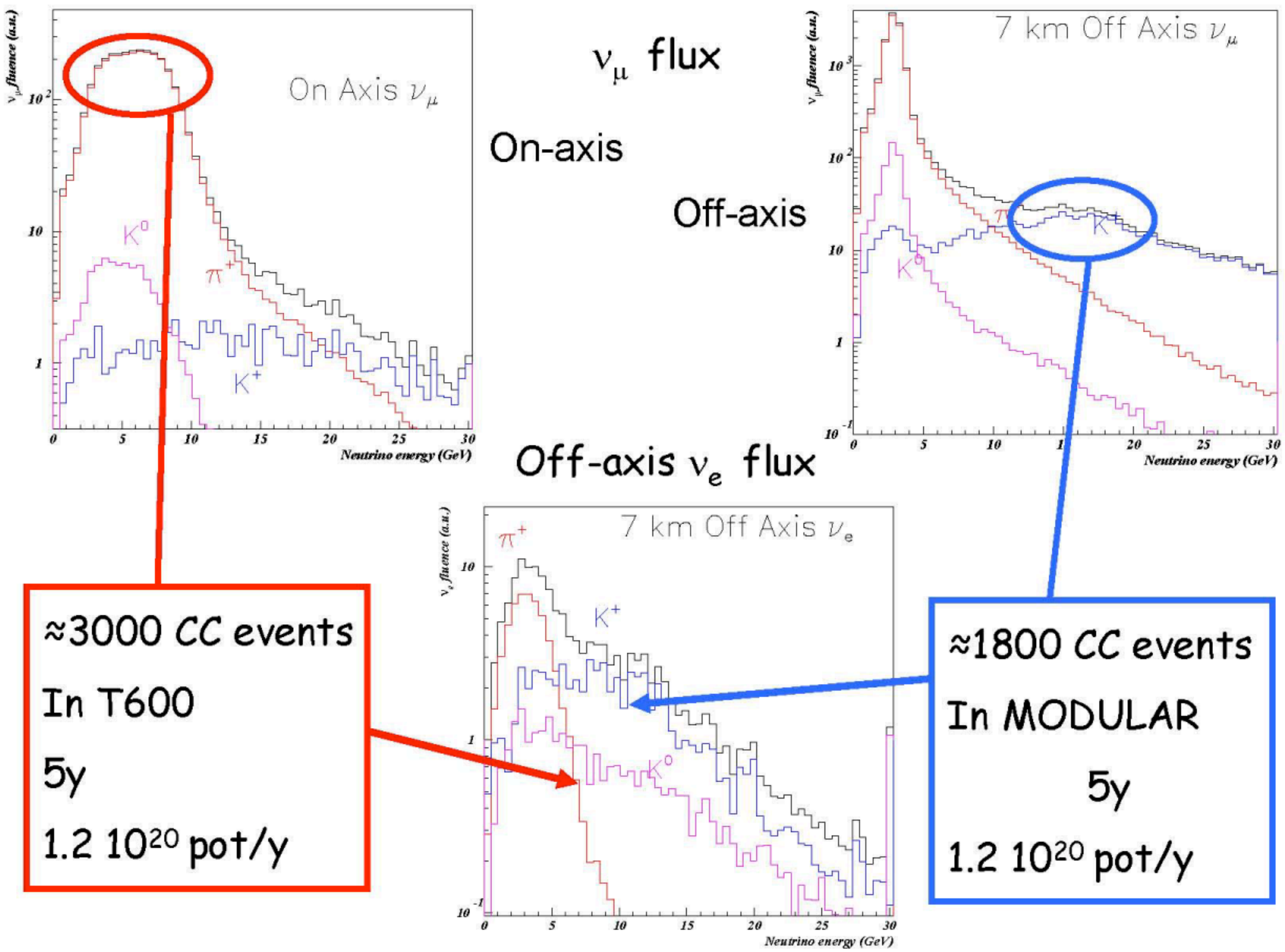
Measurement of ν_μ flux after the correction for Δm_{23}^2 driven oscillations



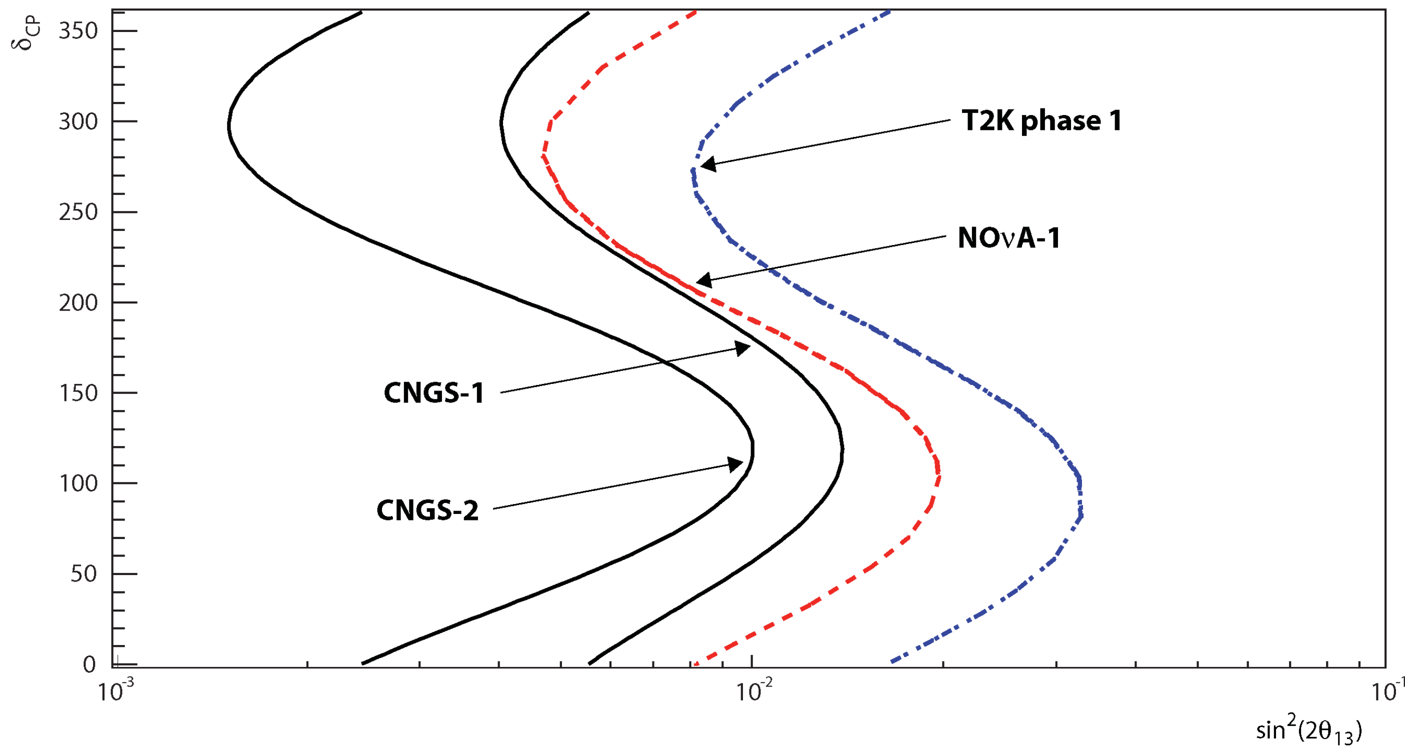
On $\to$ Off -Axis transformation is straightforward:

the lower energy Off-Axis ν beam is a result of well-known ``Jacobian-peak'' in the two body π,K decay kinematics

- the 0.5% ν_e beam contamination: from measurement of On-Axis ν_μ (2-10 GeV: $\pi^+ \rightarrow \mu^+ \rightarrow \nu_e$) and Off-Axis ν_μ ($E_\nu \geq 10$ GeV: $K^+ \rightarrow \nu_e$)



3σ MODULAr sensitivity to θ_{13} and δ_{CP}



CNGS-1: 1.2×10^{20} pot/y
CNGS-2: 4.3×10^{20} pot/y
$\Delta m_{23}^2 = 2.5\times10^{-3}eV^2$
normal mass hierarchy

GLoBES calculation:
5 % beam systematics
$\Delta E/E$ = 15 %

Rates for 20 kt mass, 5 y
and 1.2×10^{20} pot/y
$\sin^2(2\theta_{13}) = 0.1$

	ν_μ CC	bg	signal	$S/\sqrt{bg}$
MODULAr	13000	70	390	47
NOνA (20kt)		19.5	142	32
T2K		23	103	23