T2KLAr: a liquid Argon TPC for the T2K neutrino experiment

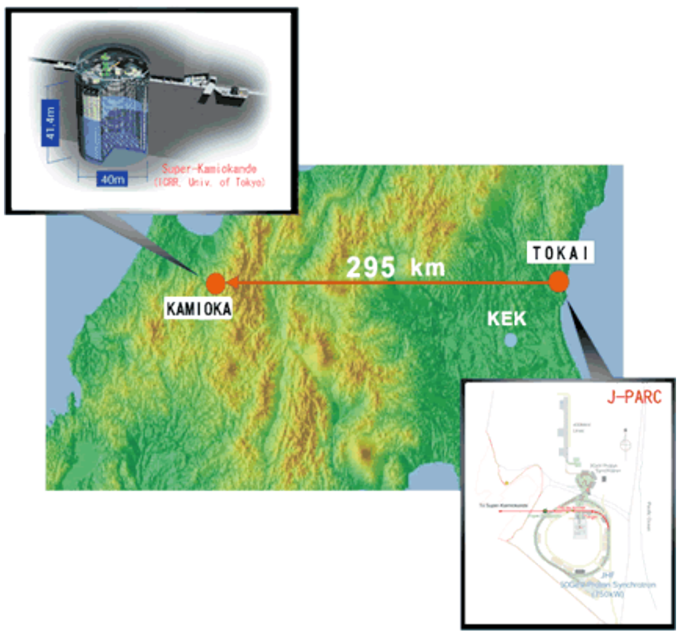
Presented by Anselmo Meregaglia (ETH Zürich)

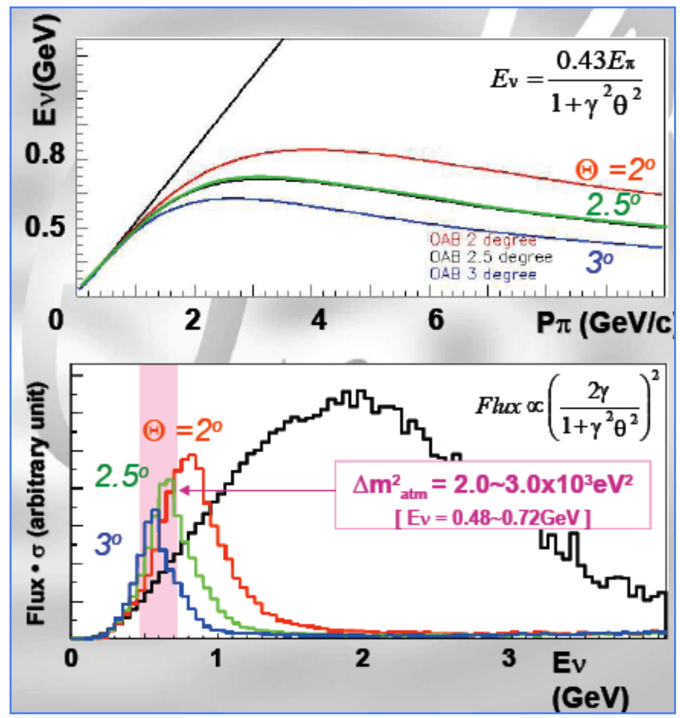
NuFact05

T2K overview

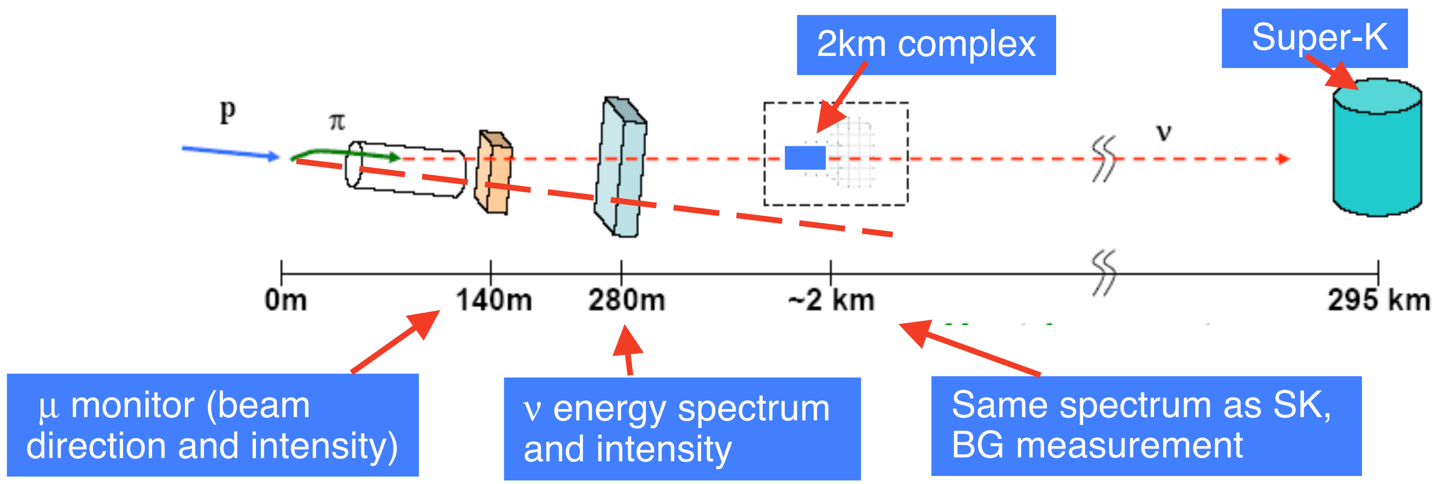
The first Super Beam: off-axis T2K, from Tokai to SK

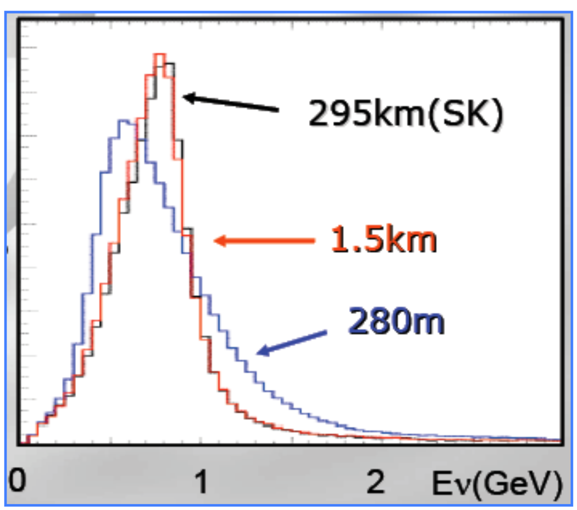
- Low E_ν (less than 1 GeV) Super Beam: 10^{21} p.o.t/year.
- Off axis by 2.5°.
- 0.75 MW from a 50 GeV proton synchrotron. Foreseen upgrade to 4 MW.





T2K detectors





Importance of near detectors: **main systematic error** in K2K comes from difference in near/far spectra.

EoI from 27 groups (EU, Japan, USA) for a detector complex at 2km has been submitted to NuSAG panel.

T2K-2km working group (27 institutes, 92 members)

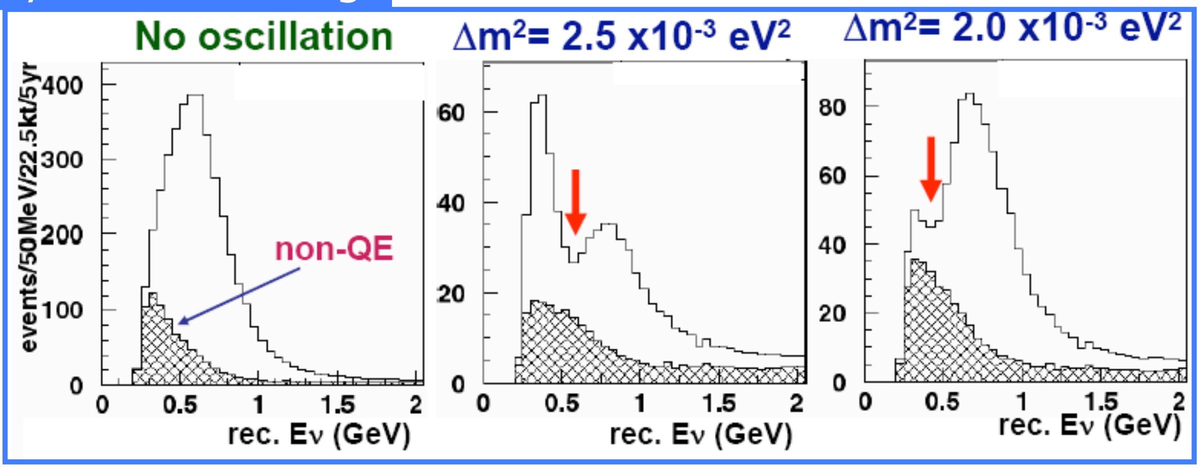
Boston University (USA):	E. Kearns, M. Litos, J. Raaf, J. Stone, L.R. Sulak
CEA Saclay (France):	J. Bouchez, C. Cavata, M. Fechner, L. Mosca, F. Pierre, M. Zito
CIEMAT (Spain):	I. Gil-Botella, P. Ladron de Guevara, L. Romero
Columbia University (USA):	E. Aprile, K. Giboni, K.Ni, M. Yamashita
Duke University (USA):	K. Scholberg, N. Tanimoto, C.W. Walter
ETHZ (Switzerland):	W. Bachmann, A. Badertscher, M. Baer, Y. Ge, M. Laffranchi, A. Meregaglia, M. Messina, G. Natterer, A. Rubbia
ICRR University of Tokyo (Japan):	I. Higuchi, Y. Itow, T. Kajita, K. Kaneyuki, Y. Koshi, M. Miura ,S. Moriyama, N. Nakahata, S. Nakayama, T. Namba, K. Okumura, Y. Obayashi, C. Saji, M. Shiozawa, Y. Suzuki, Y. Takeuchi
INFN Napoli (Italy):	A. Ereditato
INFN Frascati (Italy):	G. Mannocchi
LNGS (Italy):	O. Palamara
Louisiana State University (USA):	S. Dazeley, S. Hatakeyama, R. McNeil, W. Metcalf, R. Svoboda
L'Aquila University (Italy):	F. Cavanna, G. Piano-Mortari
Niewodniczanski Institute Krakow (Poland):	A. Szelc, A. Zalewska
RAS (Russia):	A. Butkevich, S.P. Mikheyev
Silesia University Katowice (Poland):	J. Holeczek, J. Kisiel
Soltan Institute Warszawa (Poland):	P. Przewlocki, E. Rondio
University of California, Irvine (USA):	D. Casper, J. Dunmore, S. Mine, H.W. Sobel, W.R. Kropp, M.B. Smy, M.R. Vagins
University of California, Los Angeles (USA):	D. Cline, M. Felcini, B. Lisowski, C. Matthey, S. Otwinowski
IN2P3 IPN-Lyon (France) :	D. Autiero, Y. Declais, J. Marteau
Universidad de Granada (Spain):	A. Bueno, S. Navas-Concha
University of Sheffield (UK):	P.K. Lightfoot, N. Spooner
Universit`a di Torino (Italy) :	P. Picchi
University of Valencia (Spain):	J.J. Cadenas
University of Washington, Seattle (USA):	H. Berns, R. Gran, J. Wilkes
Warsaw University (Poland):	D. Kielczewska
Wroclaw University (Poland):	J. Sobczyk
Yale University (USA):	A. Curioni, B.T. Fleming

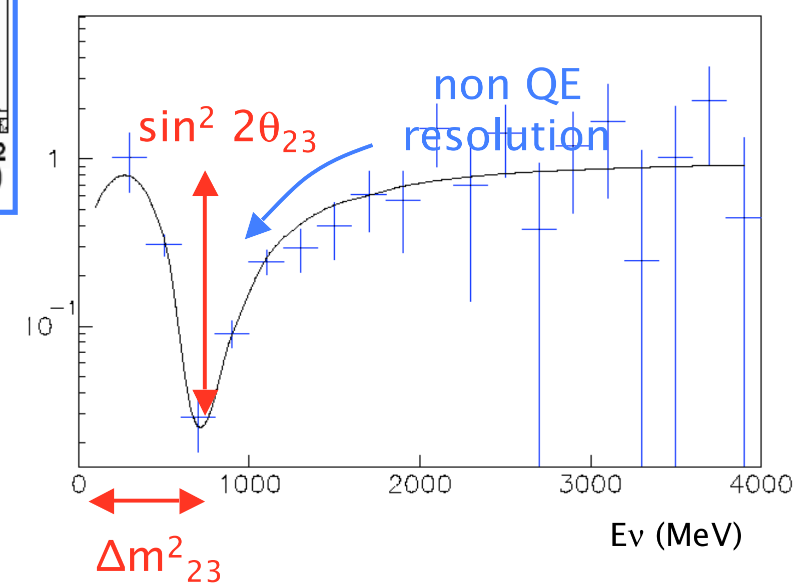
T2K physics

T2K ν_μ disappearance

assume $\theta_{23} = \pi/4$
5 years of running

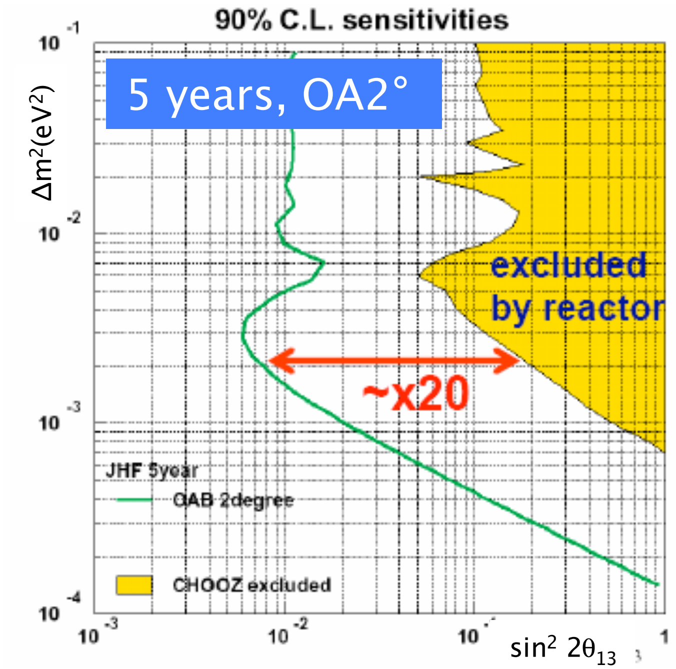
$$P(\nu_\mu \to \nu_x) \sim \cos^4\theta_{13} \sin^2\theta_{23} \sin^2(\Delta m^2_{23} L/4E_\nu)$$





A good QE/nQE measurement is fundamental to reduce systematic errors: in K2K its contribution to the systematics was 20%.

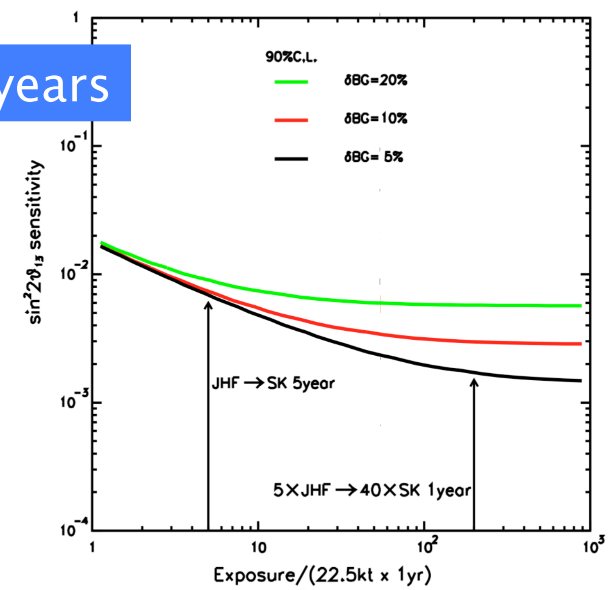
T2K ν_e appearance: measurement of θ_{13}



$\Delta m^2 = 3\times10^{-3}$ eV^2 and $\sin^2 2\theta_{13} = 0.1$

5 years

	νμC.C.	%	νμN.C.	%	Beam νe	%	Osc'd νe	%
Generated	10713.6		4080.3		292.1		301.6	
1R e-like	[illegible]	0.1	[illegible]	6.1	68.4	23.4	203.7	67.5
e/π⁰ sep.	3.5	0.03	23.0	0.6	21.9	7.5	152.2	50.4
.4 <Eν<1.2	1.8	0.02	9.3	0.2	11.1	3.8	123.2	40.8



Background:

Beam ν_e : ν_e/ν_μ flux ~ 0.2% at peak.

NC π^0 production : 2 rings merged to 1 ring.

Very different systematics: measure them separately.

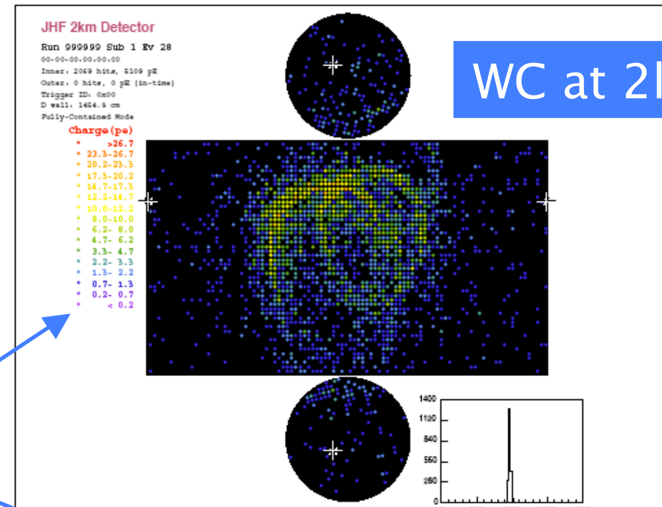
2km complex

Motivation for a 2km complex

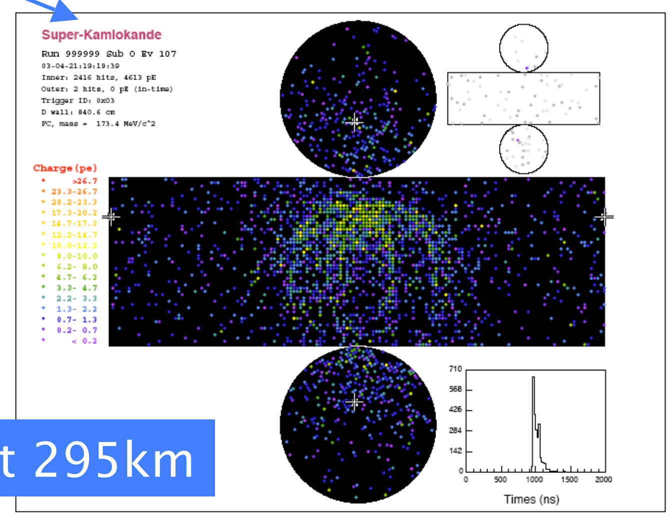
- The high statistics disappearance measurement will require a precise control of all sources of systematic errors (e.g.$N(E_\nu)$=flux(E_ν)*cross-section(E_ν), reconstruction in SK, ...).
- The high-sensitivity exploratory appearance search requires a control of all sources of background in SuperK at a level $<<10^{-2}$.
- A signal excess would require a cross-check with a WC detector at 2 km and the ultimate θ_{13} sensitivity will improve with a 2 km WC detector. $\Rightarrow$ **1 kton near Water Cerenkov detector would be an important asset for T2K**.
- **1 kton WC detector would profit if operated in conjunction with a muon ranger and a 100 ton fine grained detector**, able to reconstruct recoiling protons, low momentum hadrons, asymmetric decays of π^0, etc., in an unbiased way.

Why 2km WC?

- Same target as far detector.
- Same flux as far detector.
- Same event reconstruction as far detector $\Rightarrow$ **minimize systematics in prediction at far detector.**
- High statistics: ~ 1 interaction per spill per kton.
- Low cost/ton, well known technology.



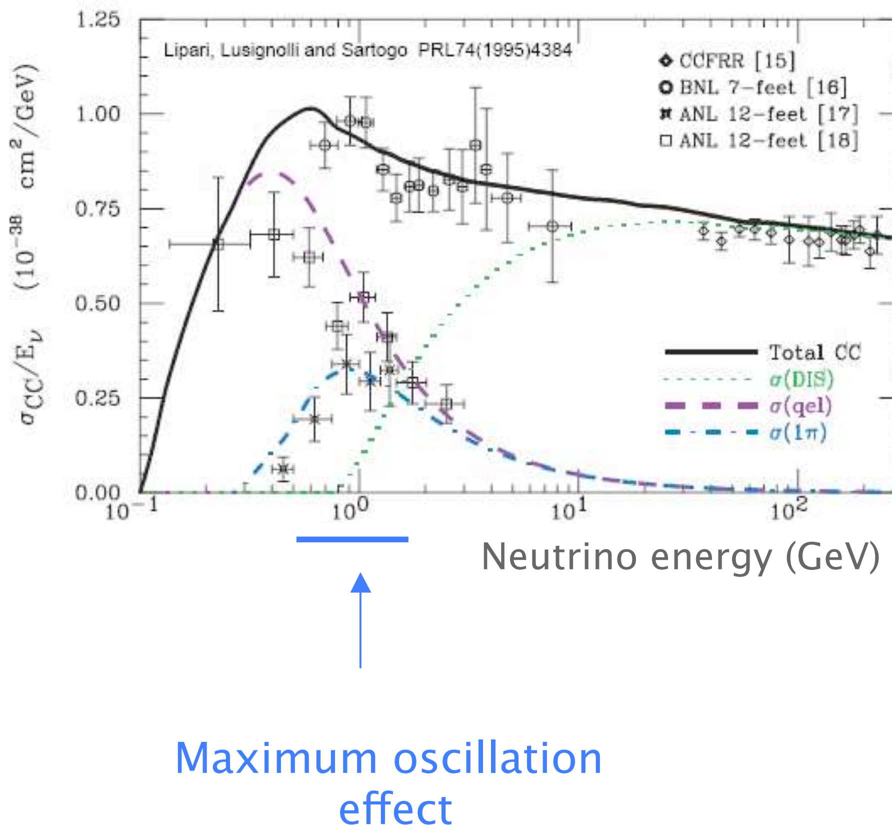
WC at 2km



SK at 295km

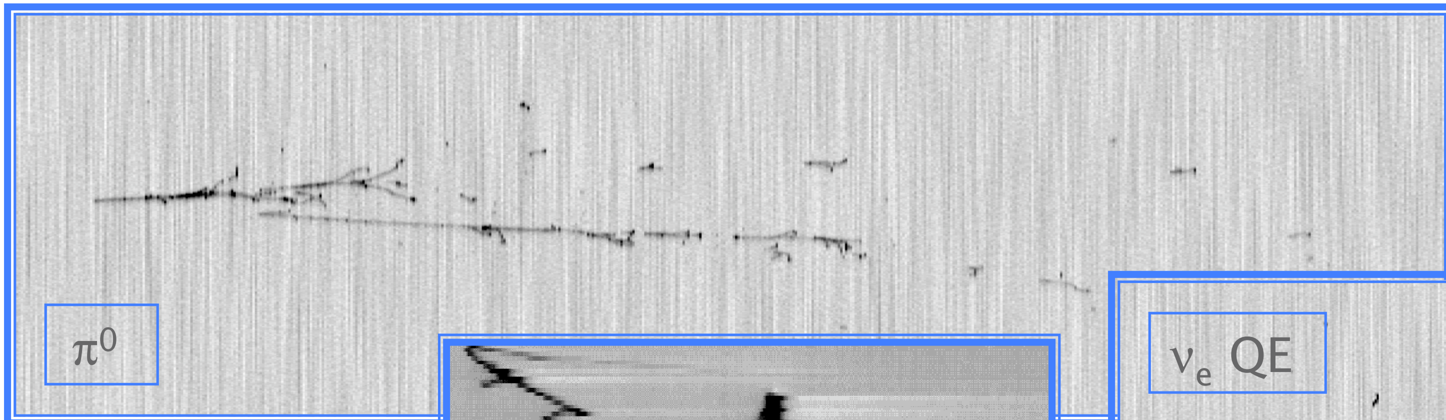
Why 2km LAr TPC?

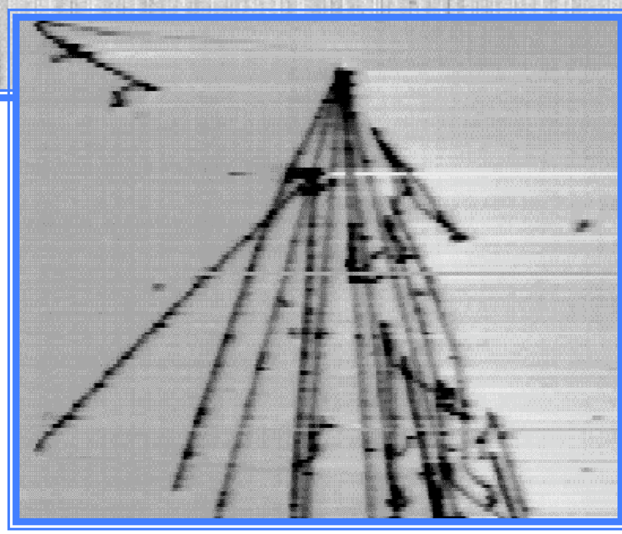
- Fully active, homogeneous, high-resolution device ⇒ **high statistics neutrino interaction studies with bubble chamber accuracy** .
- Reconstruction of low momentum hadrons (below Cherenkov threshold), especially recoiling protons.
- Independent measurement of off-axis flux and QE/nonQE event ratio.
- Exclusive measurement of νNC events with clean π^0 identification for an independent determination of systematic errors on the NC/CC ratio.
- Measurement of the intrinsic ν_eCC background.
- Collection of a large statistical sample of neutrino interactions in the GeV region for the study of the quasi-elastic, deep-inelastic and resonance modelling and of nuclear effects.



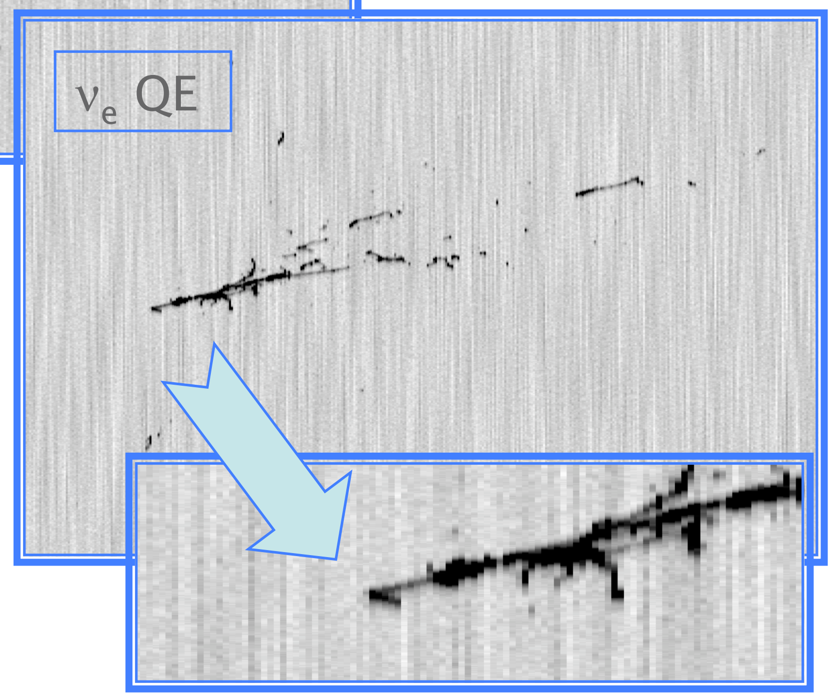
Examples of LAr TPC high resolution imaging

High granularity: Sampling = 0.02 X_0

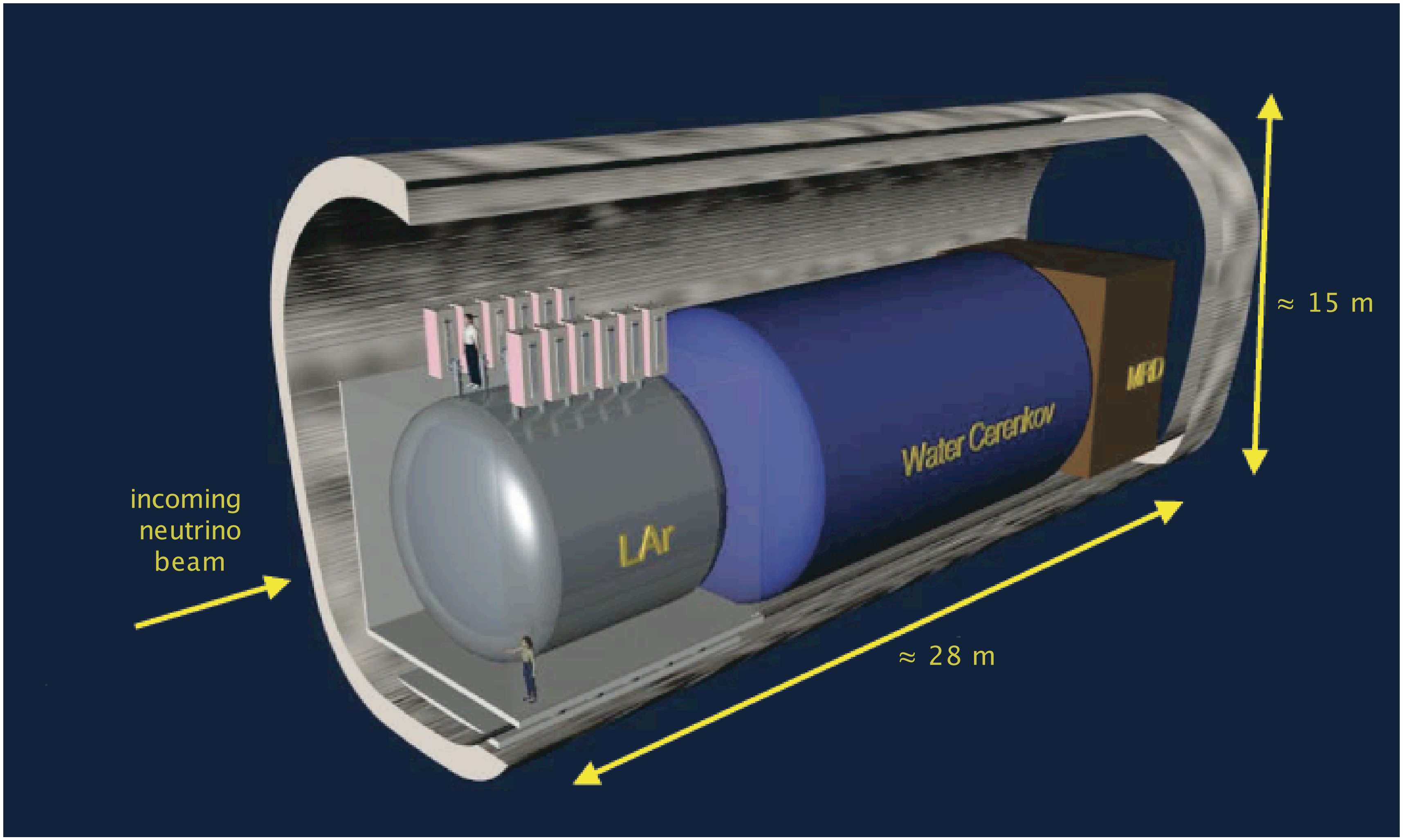




Real neutrino in ICARUS

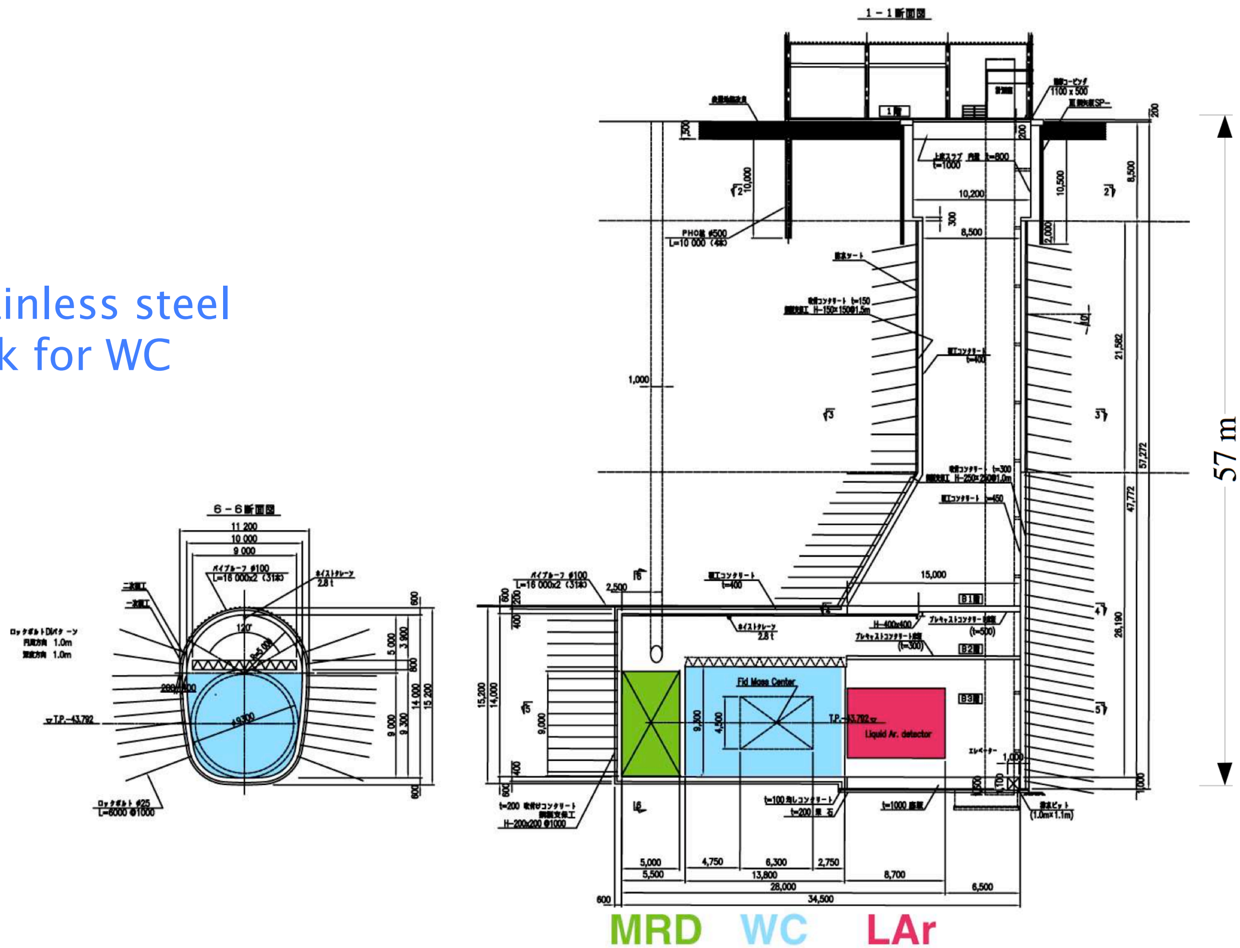


Artistic view of LAr integration in 2km underground site



2km detector hall

No stainless steel tank for WC

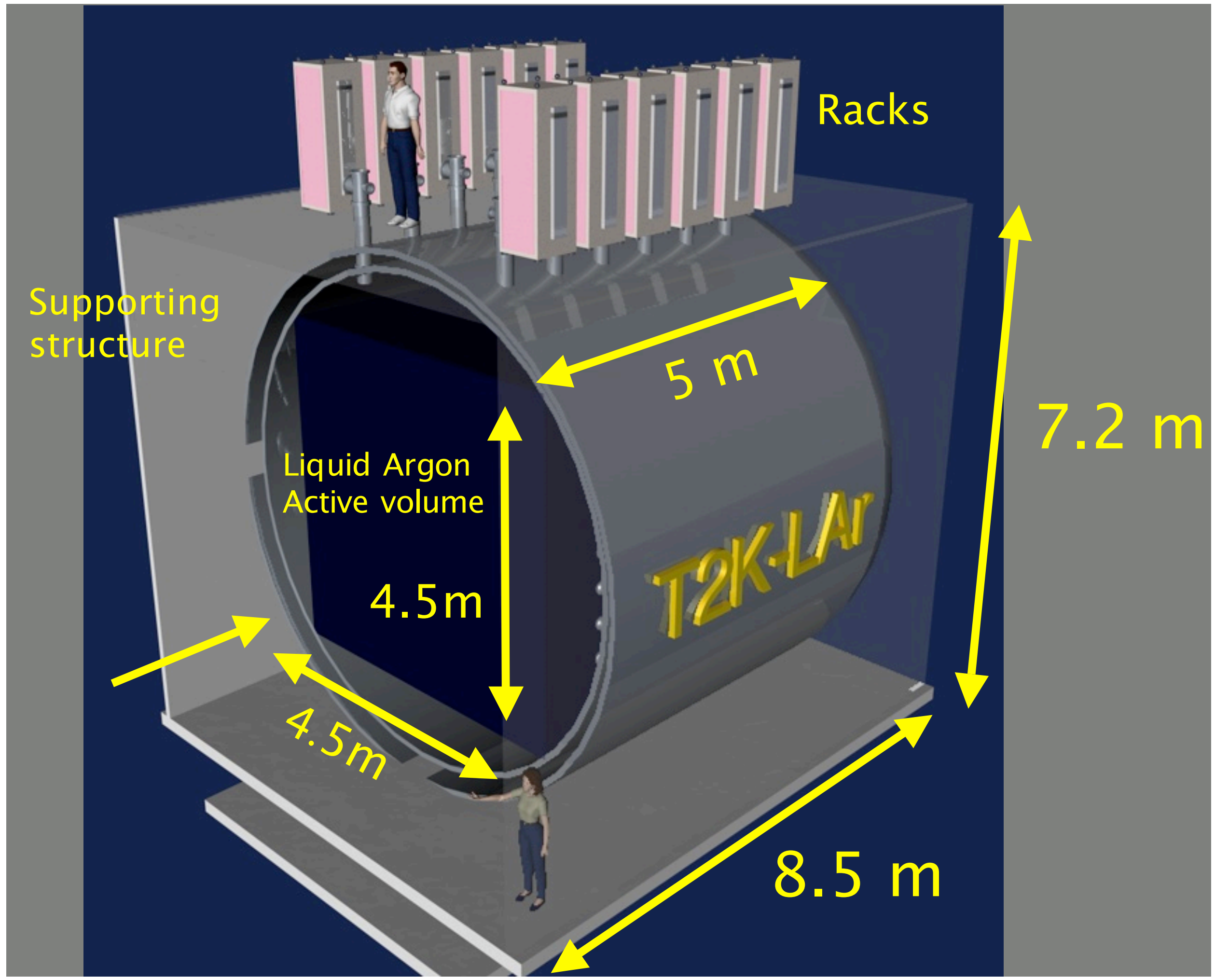


ν direction

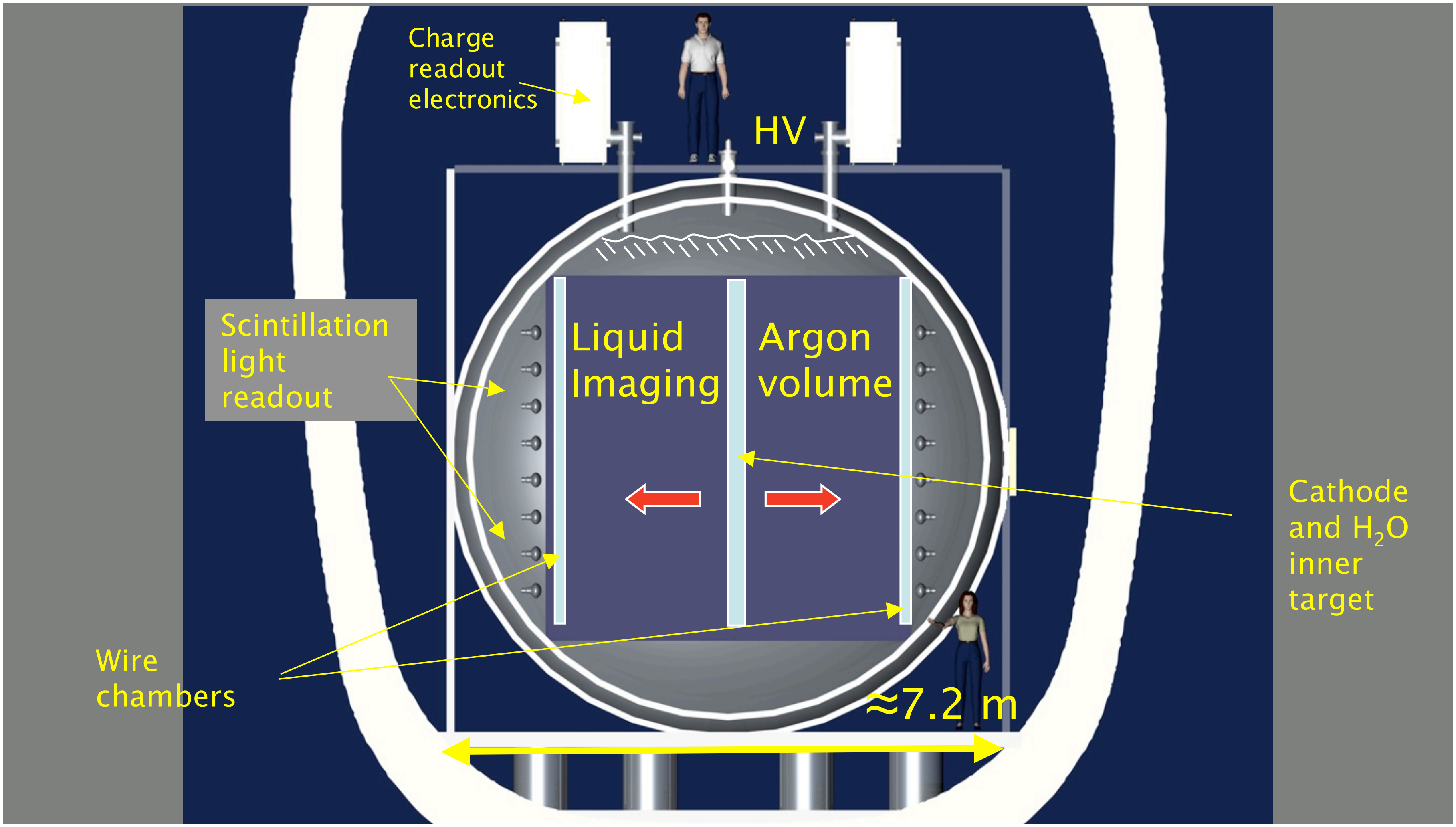
Artistic view of LAr detector (open endcap)

Number of interactions per 10^{21} p.o.t. on a 100 ton detector

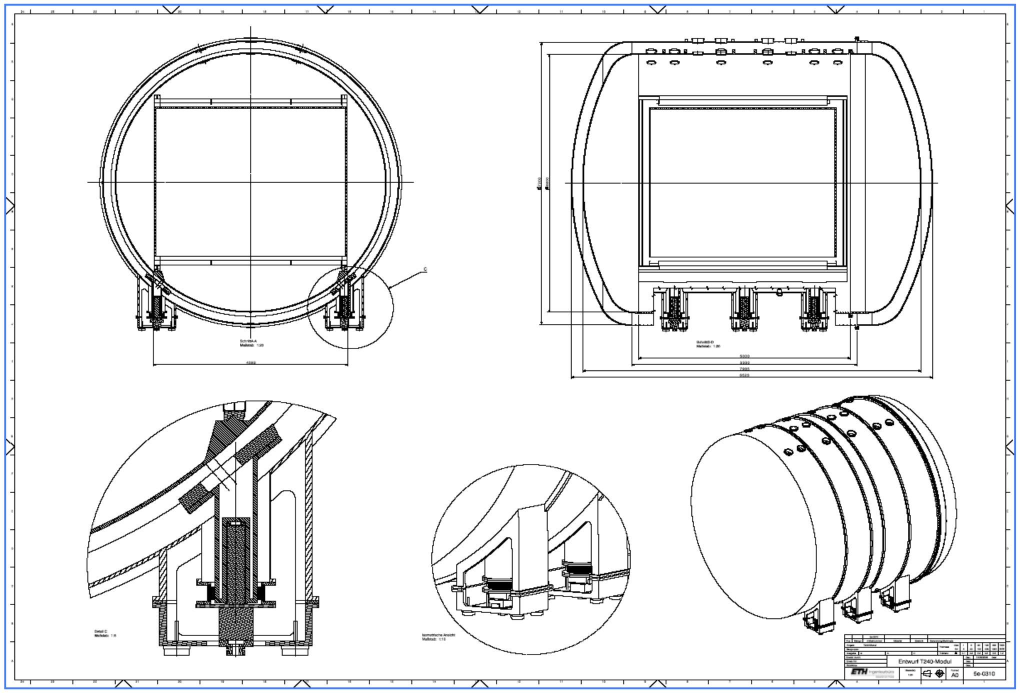
Flavour	CC (QE)	NC	TOT
ν_μ	190763 (121859)	26253	217016
$\bar{\nu}_\mu$	8023 (2764)	2063	10086
ν_e	3704 (1372)	725	4429
$\bar{\nu}_e$	372 (96)	100	472

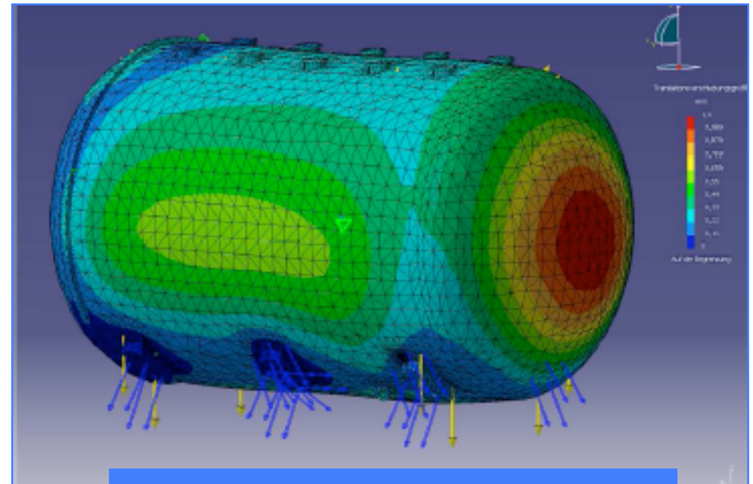


Artistic view of LAr detector (front)



Engineering studies ongoing...



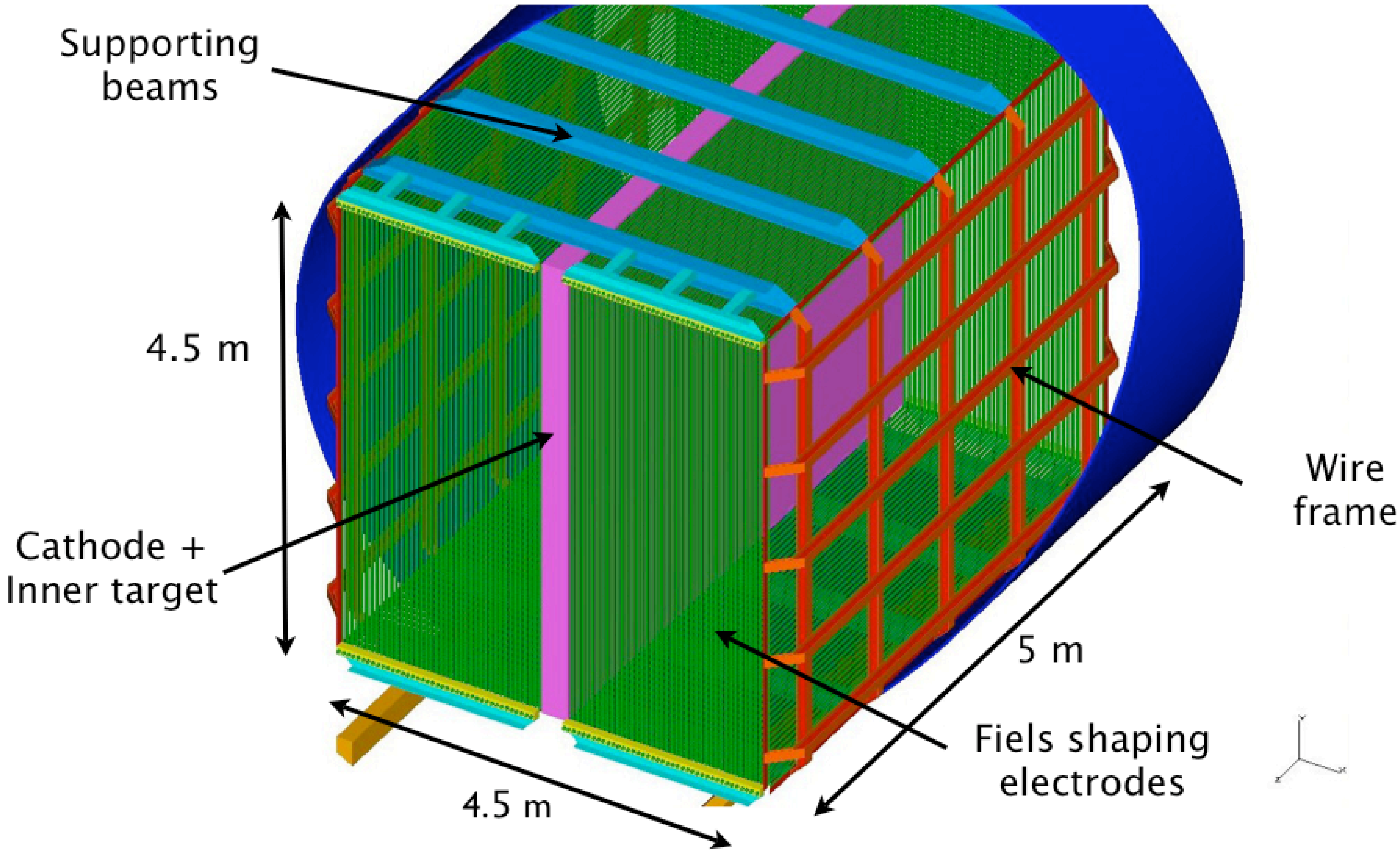


Finite element analysis

thermal Insulation	multi-layer super–insulation in vacuum
surface heat input	$1\ W/m^3$
total surface heat input	100 W
(accidental loss of vacuum)	(4 kW)
supporting feet	custom designed
heat input per supporting foot	< 50 W
number of supporting feet	6
total heat input through supporting feet	300 W
signal cables diameter	0.25 mm
length signal cables	0.75 m
number signal cables twisted pairs	10000
total heat input through cables	100 W
total heat input	500 W

Thermal analysis

Chamber overview



T2KLAr: detector performance

LAr detector performance: neutrino energy reconstruction

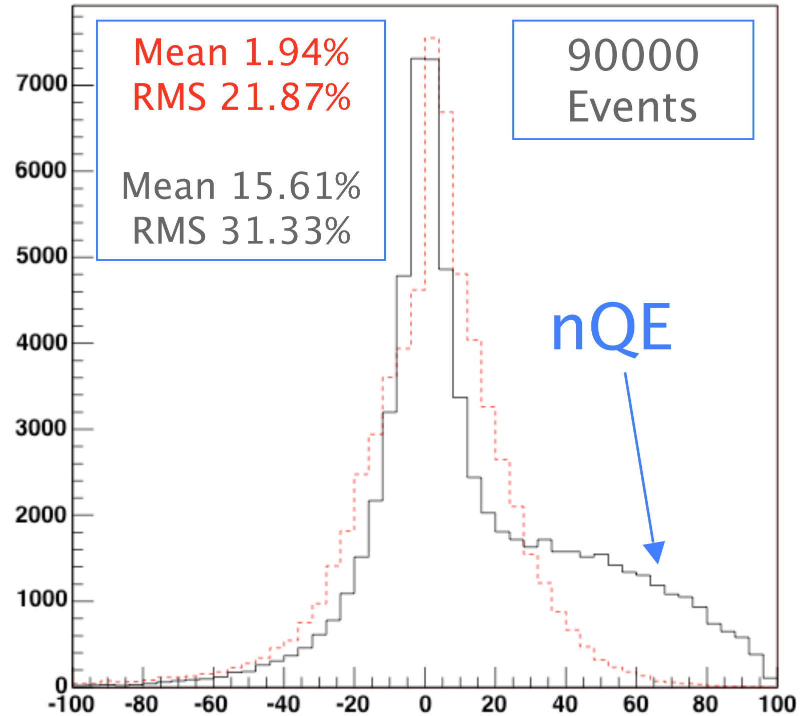
—— μ stand alone reconstruction

$$E_\nu^{rec} = \frac{m_N E_\mu - m_\mu^2/2}{m_N - E_\mu + p_\mu \cos\theta_\mu}$$

------ complete reconstruction

$$E_\nu^{rec} = \left|p_\nu^{rec}\right| = \sqrt{\left(\sum p_x\right)^2 + \left(\sum p_y\right)^2 + \left(\sum p_z\right)^2}$$

Cut on E_{vis} < 1250 MeV



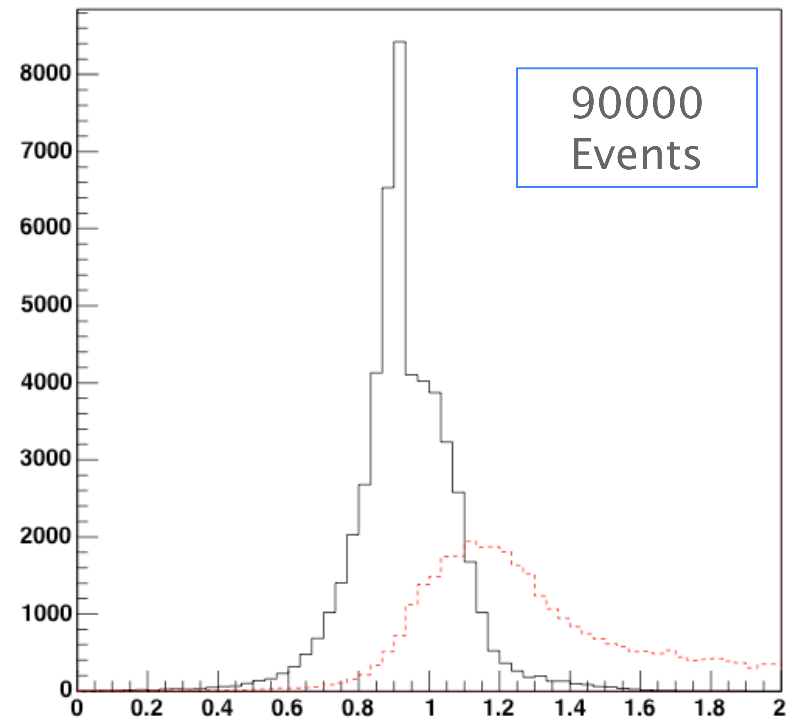
$(E_\nu^{MC} - E_{vis}) / E_\nu^{MC}$ (%)

LAr detector performance: QE/nQE measurement

$$Q^2 = 4E_\nu E_\mu \sin^2 \theta/2$$

$$\boxed{W^2 + Q^2 = 2M\nu + M^2}$$

$$\nu = E_{had} - M = E_\nu - E_\mu$$



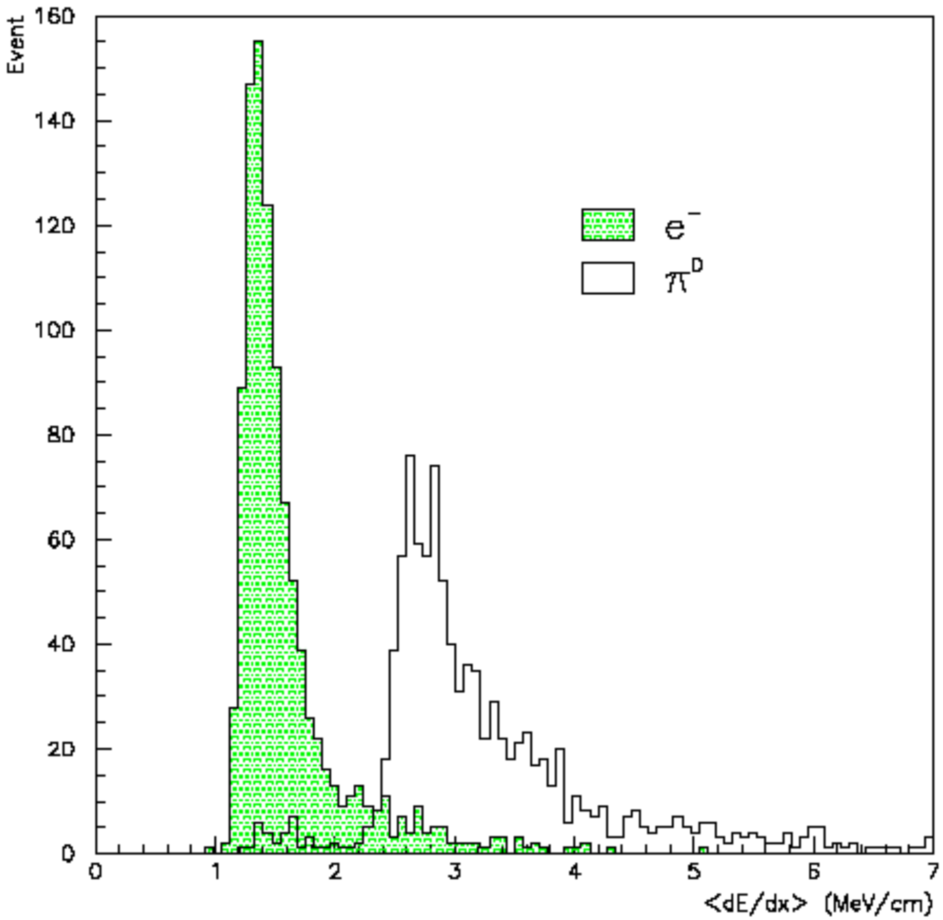
Invariant Mass (GeV/c^2)

—— QE interactions (51596 Events)

- - - - - non-QE interactions (38404 Events)

LAr detector performance: e/π^0 separation

Sampling : 0.02 X_0



dE/dx cut efficiency:

Energy (GeV)	π^0 efficiency (%)	$< dE/dx >_{cut}$ (MeV/cm)
0.25	6.5	2.13
0.5	5.5	2.19
1	3.7	2.21
2	2.7	2.10

When vertex known, combine with probability to convert within 1 cm:
$\Rightarrow$ 5.4%

$$\lambda_{pair} = 18 \text{ cm}$$

Combined, aim at:
$\Rightarrow$ **0.2% π^0 efficiency by imaging for 90% electron efficiency**

T2KLAr: inner target

Motivation for an inner target

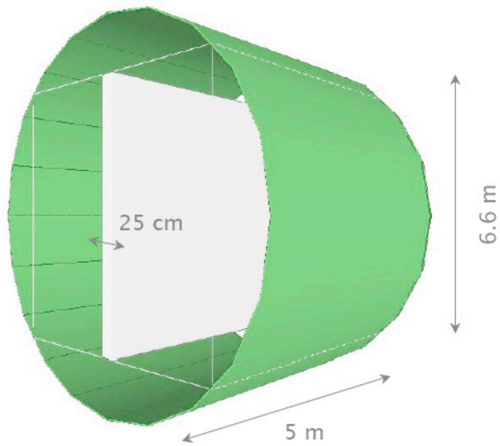
- It is expected that the knowledge of the neutrino cross sections and nuclear effects will improve in the following years thanks to new measurements (K2K, Minerva, …), however, extrapolation between argon and water targets might still be plagued by uncertainties, which could affect the goal of precision measurements at T2K.

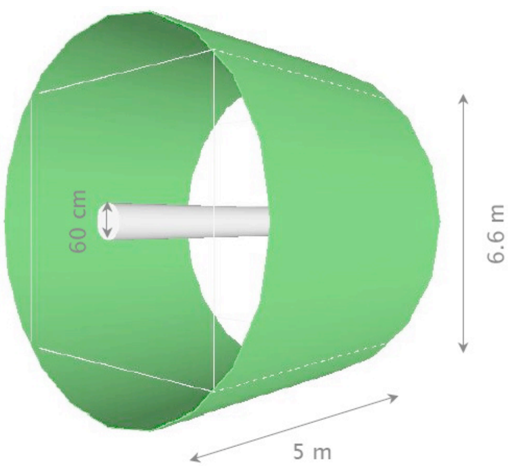
- The “straight-forward” solution is to insert an additional target within the 100 ton LAr detector. This approach (embedded target) is supported by the kinematics of the events (low energy, large angle products, etc.).

Issues for an inner target

- The additional target medium must not enter into contact with the Argon otherwise contamination is possible. The additional medium is therefore contained in a specially located steel structure.
- The inner target geometry is chosen in order to have the best performance taking into account real engineering problems. It should be as small as possible in order to minimize the “dead region”.
- For symmetry, simplicity and to disturb the least the E-field, we locate the steel structure at the cathode which divides the volume into two equivalent volumes. It is placed along the axis of the beam, centred in the middle. In addition the length is equivalent to the total length of the chamber (5m).
- The volume will be evacuated and filled during or after the liquid argon filling phase.

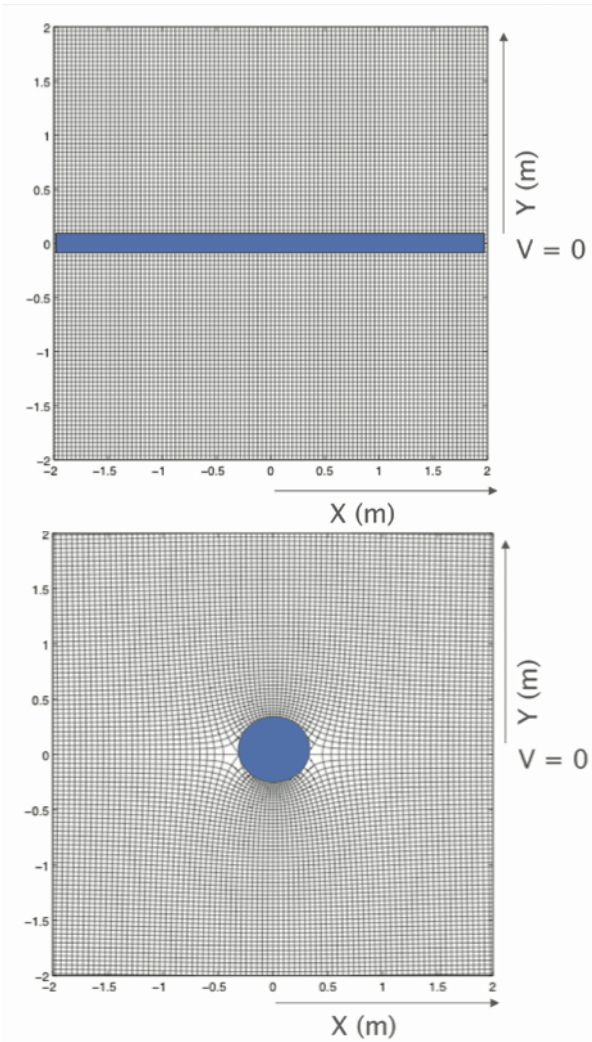
Possible geometries



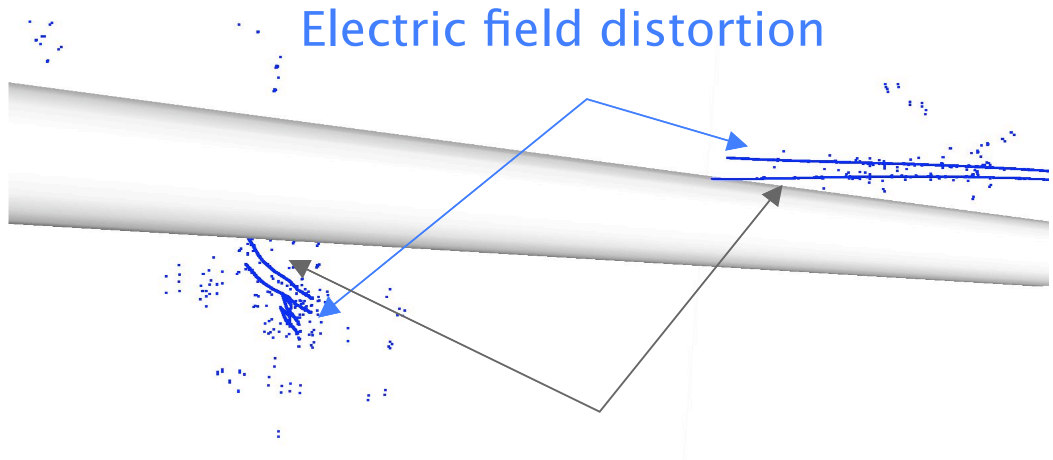


geometry	parallel planes	cylinder
length	5 m	5 m
height	4.67 m	–
width	25 cm	–
radius	–	30 cm
outer material	stainless steel 304L	stainless steel 304L
thickness	2 mm	2 mm
inner material	water (ice)	water (ice)
inner material density	0.92 g/cm^3	0.92 g/cm^3
mass	5.37 ton	1.3 ton

Electric field distortion



Parallel planes geometry does not distort the electric field whereas cylindrical geometry does.

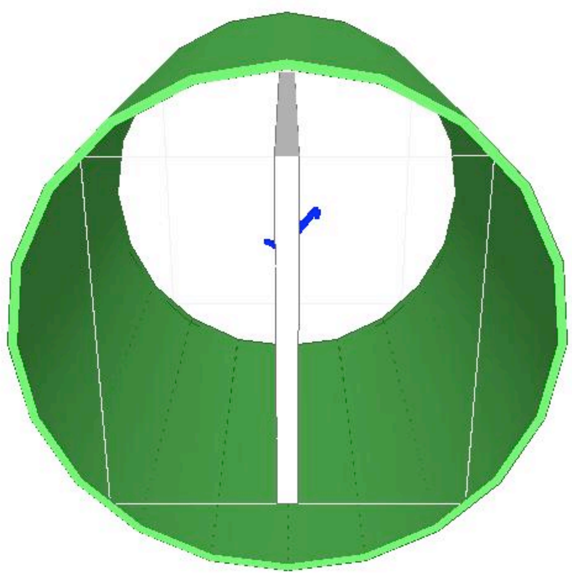


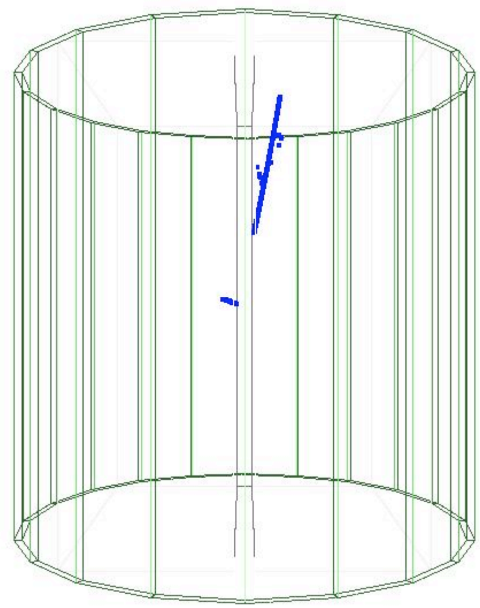
Reconstruction performance

Particles are considered “reconstructed” if their momentum is above the following cuts when entering the LAr volume:

- 310 MeV/c for protons (50 MeV of kinetic energy).
- 53.8 MeV/c for charged pions (10 MeV of kinetic energy).

QE event.
Recoil proton
momentum = 660 MeV/c





Reconstruction performance

mass	2.69 ton	5.37 ton	10.74 ton
width	12.5 cm	25 cm	50 cm
QE protons	50%	30%	19%
QE full rec.	36%	22%	14%
QE per 10^{21} pot	1178	1440	1832
nonQE protons	32%	22%	16%
nonQE π^+	94%	85%	71%
nonQE π^0	95%	85%	76%
nonQE full rec.	27%	17%	9%
nonQE per 10^{21} pot	500	630	670

Comments on geometry

- A final decision concerning the geometry will be taken after performing a detailed mechanical simulation and laboratory tests of freezing.
- A larger number of “usable” events is expected choosing the parallel planes configuration, because of the larger surface with respect to the cylindrical configuration at equal volumes.
- To have the same amount of mass we would have choosing a parallel planes configuration 25 cm wide (5.37 ton) we would need a cylinder with a diameter equal to 1.2 m.
- The parallel planes configuration is also favoured by the fact that it does not distort the electric field.
- Since the number of “usable” events does not scale with volume (i.e. it increases much more slowly) an inner target that minimizes the non-active volume is more likely to be chosen.

T2KLAr: conclusions

Status/outlook

- A 2km facility has been proposed: at this distance, almost the same neutrino flux is measured as that seen at SuperK 295 km away.
- The flux would be measured with both a 1 kton water Cherenkov detector which has been optimized to match SuperK resolution, and a 100 ton fiducial volume liquid argon TPC which would provide fine grain imaging and low particle detection thresholds for a precise study of neutrino interactions at the relevant energies.
- The combination of a detector made with the same target as SuperK, with almost the same detector response, and an extremely fine grained tracking chamber sited in the off-axis beam, would allow for a prediction of the events seen at SuperK with very little correction other than that of geometric acceptance.
- Dedicated simulation tools for T2KLAr geometry have been developed to assess detector performance, and some results (e.g. e/π^0 separation, events reconstruction, events in inner target, …) are already available.
- Physics items to be studied next are

1) Prediction of ν_μ events at SK.
2) Prediction of ν_e events and π^0 background at SK.

Conclusion

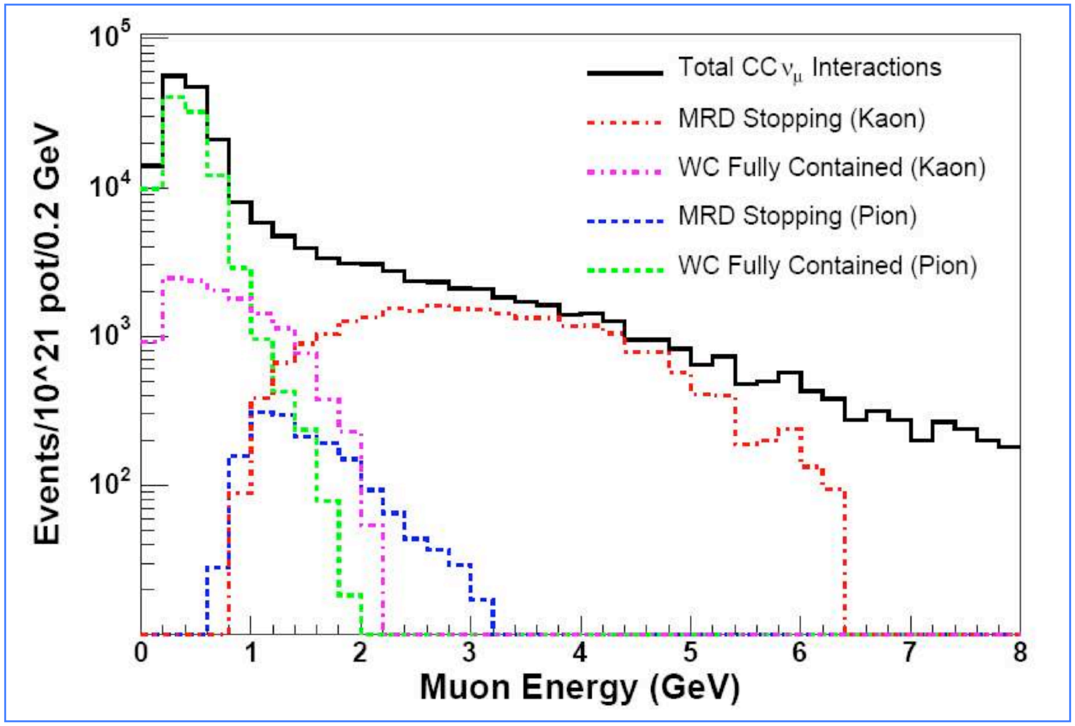
The 2km facility is the most straight-forward and cost-effective method to reach the best possible sensitivity in θ_{13} , Δm^2 and θ_{23} by characterizing the beam with the same flux and target as SuperK.

The End

Backup

Why 2km MRD?

- Measure high energy tail of the neutrino spectrum which is source of NC BG.



Time scale

Three-year construction schedule