Backgrounds for ν_e appearance at T2K using a water Cherenkov detector 2 km away from the neutrino source

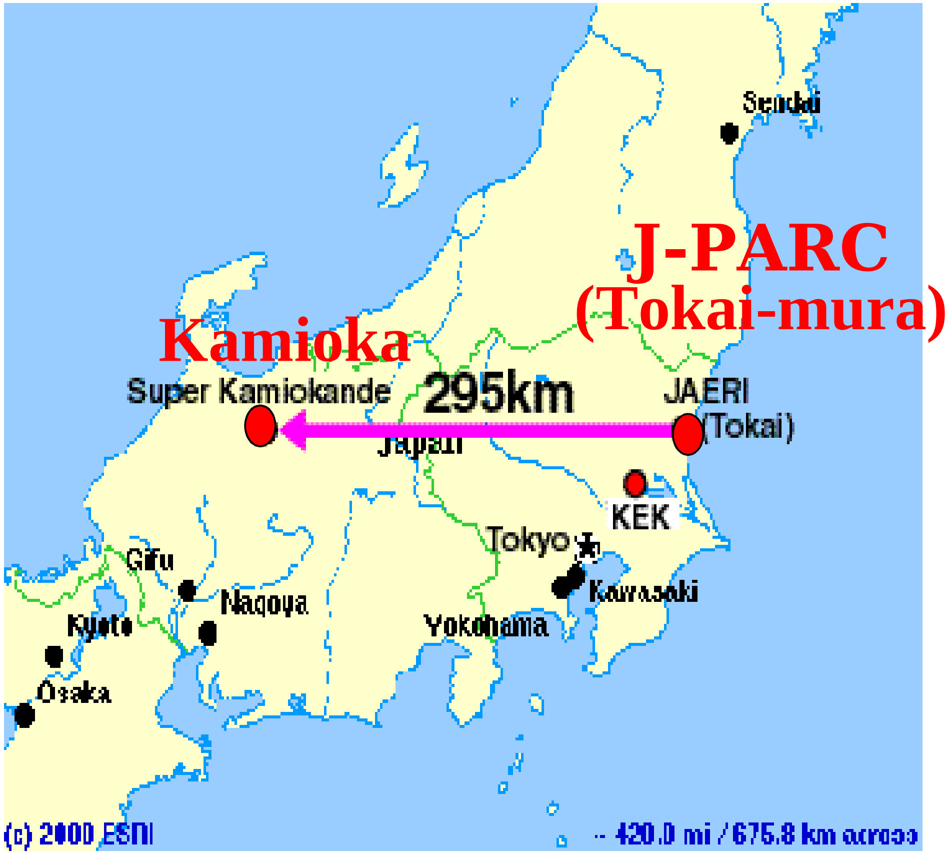
Maximilien Fechner
CEA Saclay DAPNIA/SPP

OUTLINE

- T2K & Intermediate detector project
- Neutrino fluxes at different positions
- 2KM water Cherenkov detector & ν_e appearance analysis
- Outlook : Phase II

T2K

Already explained in great details by previous speaker...



- JPARC : 40 GeV PS
0.75 MW for phase I
4 MW for phase II

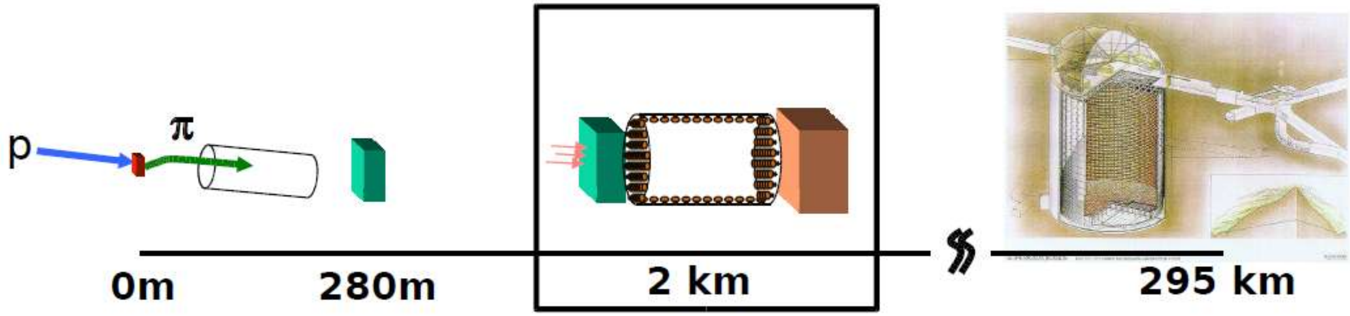
- ~2.5° off axis with respect to SK

- Peak ν energy : ~700 MeV

- ~2,200 ν_μ interactions/yr at SK for OA 2.5°

GOALS : measure θ_{13} (ν_e appearance) and θ_{23} & Δm^2_{23} (ν_μ disappearance)

Intermediate detector project for T2K



A project to build a detector complex 1.8 km away from the neutrino source for T2K is under study. We will measure backgrounds for ν_e appearance before oscillation.

Detectors : Liquid Argon TPC, Water Cherenkov, Muon Ranger

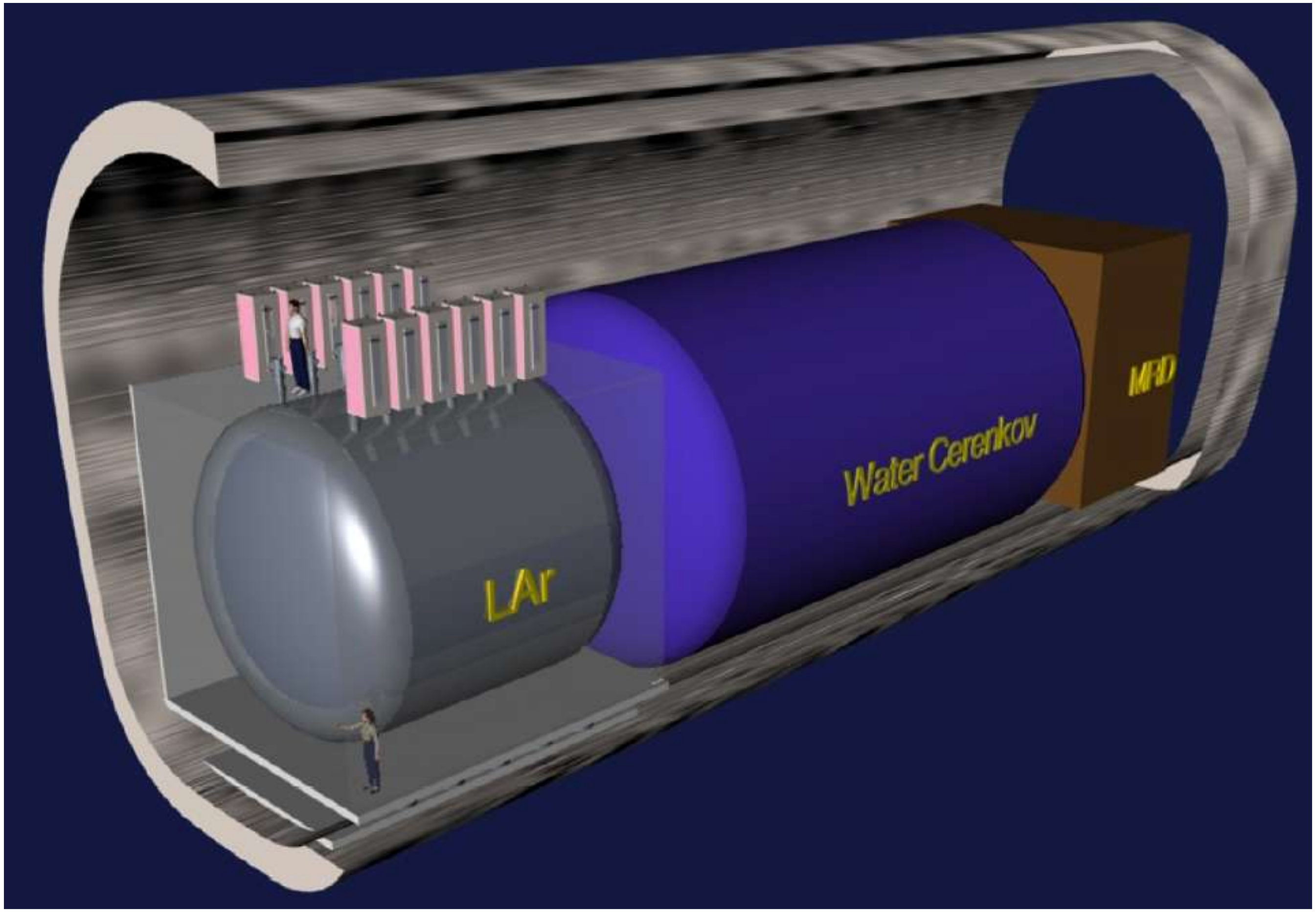
- Measure energy spectrum and interactions with almost the same ν beam as SK (detector hall 57m underground to be at same off-axis angle)
- Water Cherenkov : measurement of interactions on water with same algorithms/techniques as SK-> minimize systematics in prediction @SK
- Fine grained lAr for very good CCQE/nonQE distinction + exclusive cross sections measurements -> see A. Meregaglia's talk (WG2)

In this talk I will focus on the water Cherenkov detector

2KM Detector Configuration

The 2KM detector is made of three sub-systems.

ν Direction



Muon Ranger:
Measure high energy tail of neutrino spectrum.

Liquid Argon Detector:
exclusive final states
frozen water target

Water Cherenkov Detector:
Same detector technology as SK
~ 1 interaction/spill/1kton

T2K-2KM working group

27 institutions, ~90 people

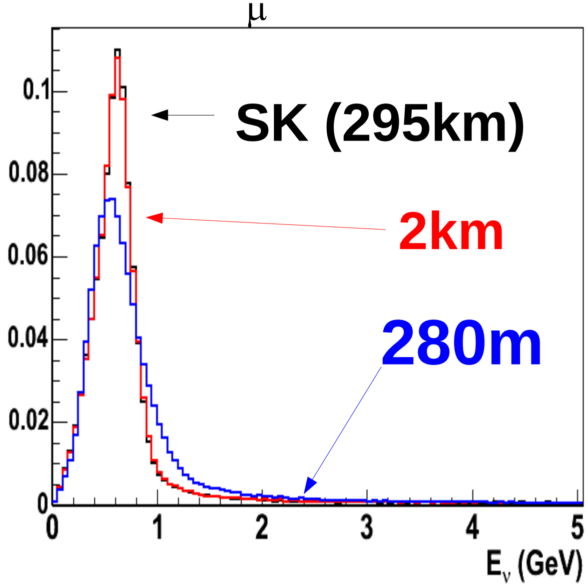
Boston University (USA) : E. Kearns, M. Litos, J. Raaf, J. Stone, L.R. Sulak
CEA Saclay (France) : J. Bouchez, C. Cavata, M. Fechner, L. Mosca, F. Pierre, M. Zito
CIEMAT (Spain) : I. Gil-Botella, P. Ladron de Guevara, L. Romero
Columbia University (USA): E. Aprile, K. Giboni, K.Ni, M. Yamashita
Duke University (USA) : K. Scholberg, N. Tanimoto, C.W. Walter
ETHZ (Switzerland) : W. Bachmann, A. Badertscher, M. Baer, Y. Ge, M. La!ranchi, 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 : 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
Universita 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

Neutrino spectra at different positions

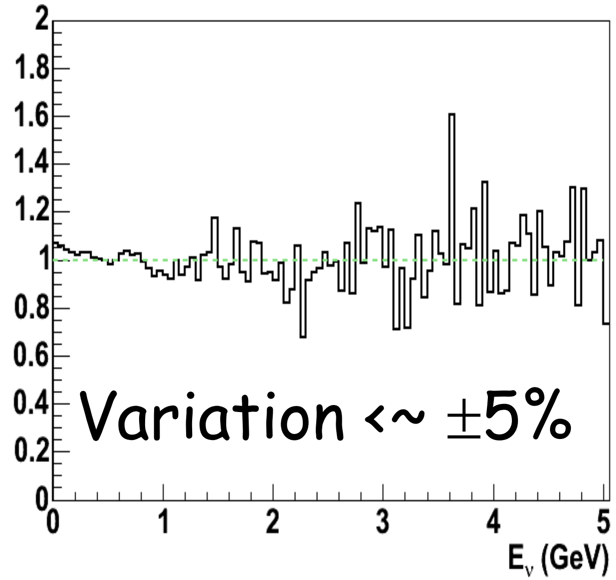
[all off-axis] (2.5°)

From T2K beam MC

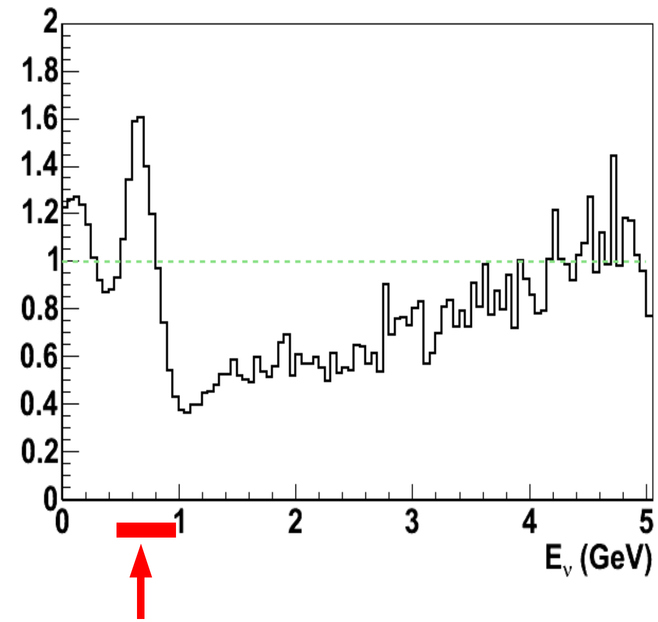
ν_μ flux



SK/2km



SK/280m



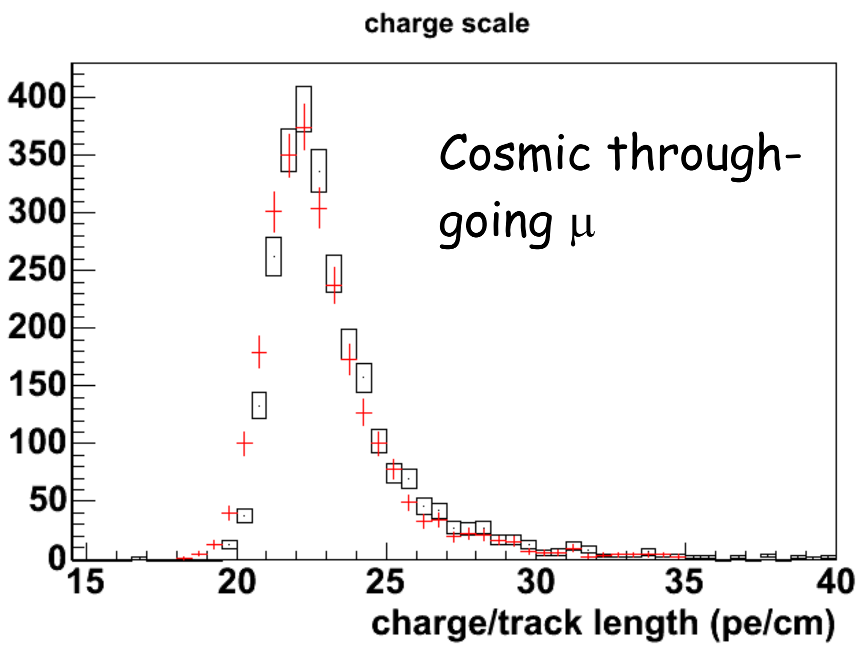
Largest difference at peak (location of μ disappearance and e appearance signal)

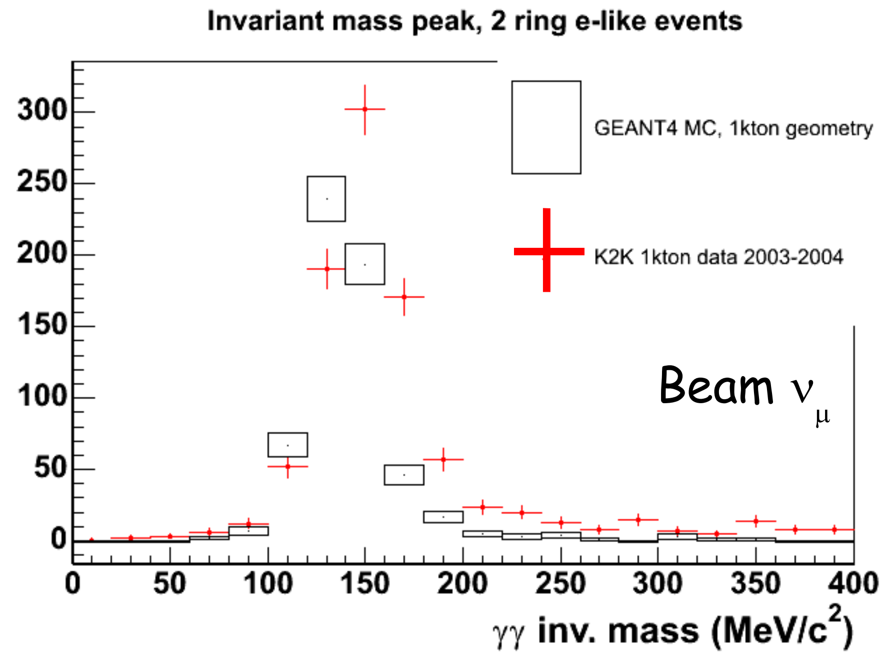
At 280m : neutrino source not point like, significant spectral differences

Neutrino spectra at SK and 2km are almost the same : needed Monte Carlo corrections will be far less important

Water Cherenkov detector simulation

- New GEANT4 simulation, able to simulate several water Cherenkov geometries *(K2K 1kton, 2KM detector)* (as well as liq Ar & μ ranger)
- Water scattering lengths, reflections,... tuned using K2K 1kt data (beam and cosmics)

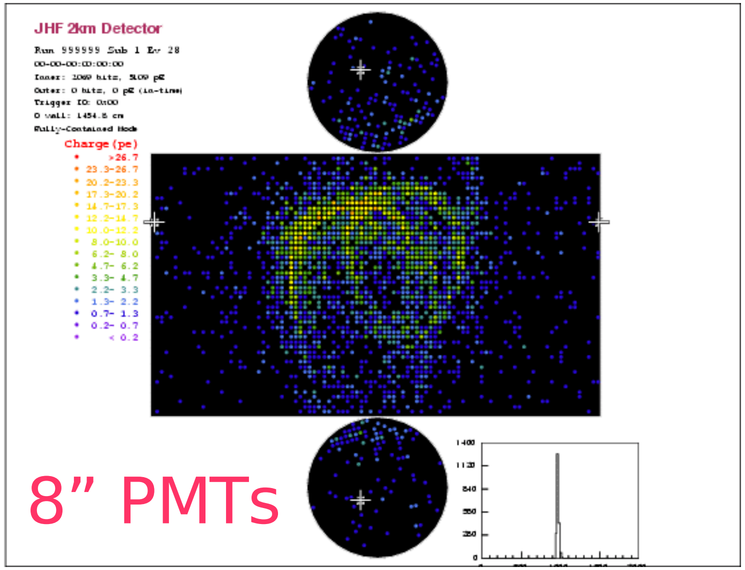




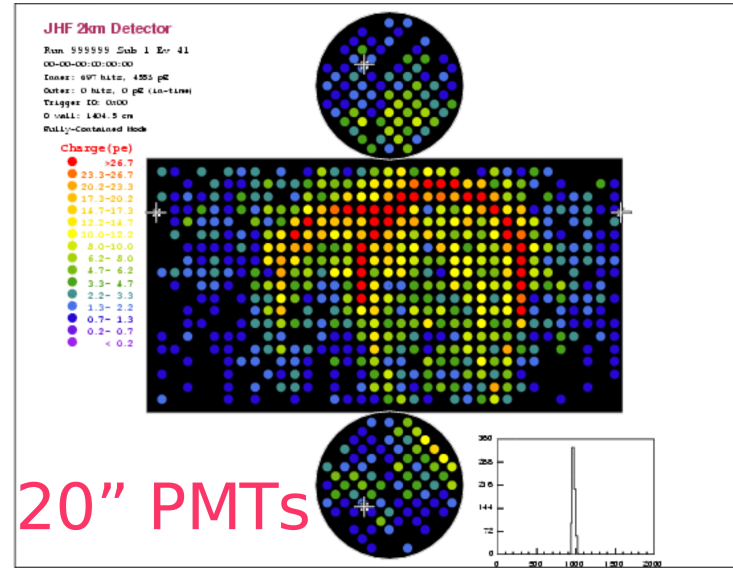
→ **Simulator suitable for reliable studies of the 2KM detector**

- Test 20” & 8” PMT sizes for 2KM
- SK/1Kton software was adapted to the 2KM geometry

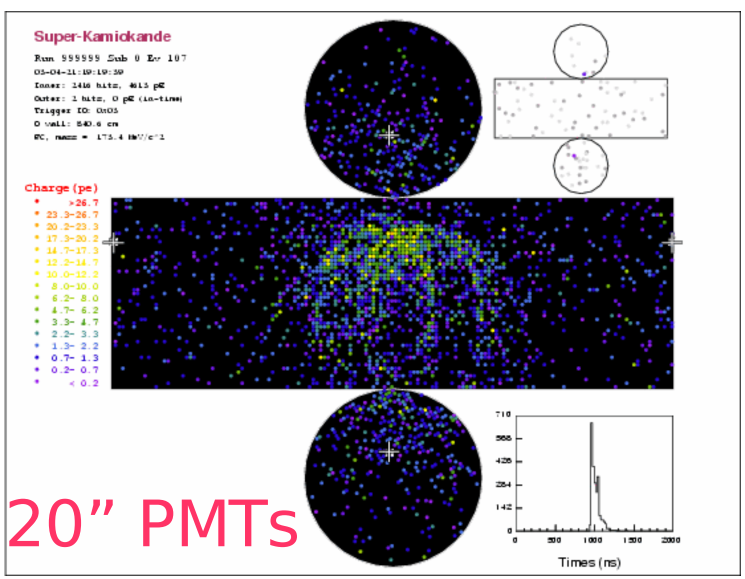
2KM : 5660 PMTs



2KM : 841 PMTs



SK : 11146 PMTs



Studies show that 5660 8” PMTs best match SK performance :

- Ring counting
- Particle ID
- Fid. Vol. Determination
- e/π^0 separation

ν_e appearance with 2KM for phase I

GOAL : Estimate ν_e appearance *background @ SK by extrapolation of the measurement @ 2km*

We have just seen that beam & detector differences are small

USE SIMPLE SCALING TECHNIQUE WITH NO MC CORRECTIONS

Analysis strategy :

- Get event spectra from official beam simulator & ν interaction MC @ SK and 2km
- Simulate T2K beam events @ SK with official SK det. sim.
- Using a dedicated GEANT4 simulator for the 2km complex simulate T2K beam events @ 2km in water Cherenkov det.
- Apply reconstruction & standard analysis cuts : similar algorithms & cuts at both detectors
- Extrapolate measured background from 2KM to SK with *simple scaling method*

In this talk : 5yrs T2K operation with 40 GeV PS, OA2.5°, 10^{21} POT/yr

ν_e appearance analysis strategy

Main sources of background for ν_e appearance at T2K :

1. **NC π^0 production** most serious BG
2. **Intrinsic beam ν_e background**
3. **CC ν_μ mis-ID**

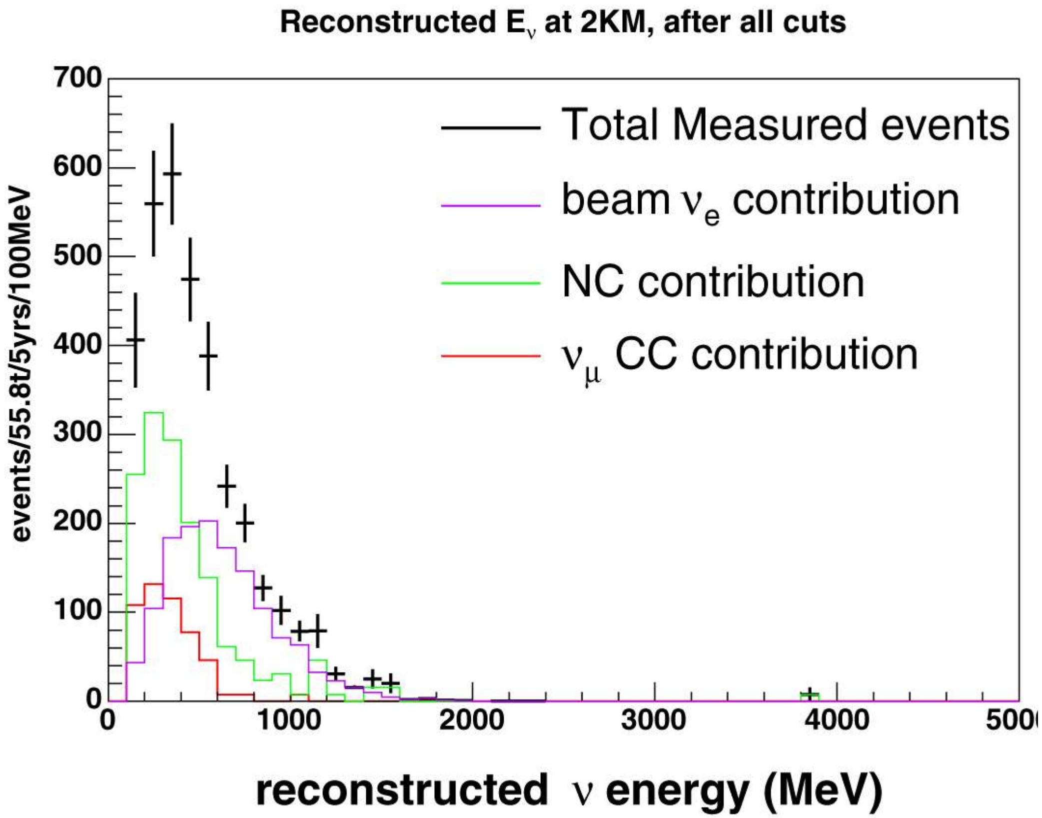
Cuts and analysis:

- fully contained in FV (55.8t)
- visible energy > 100 MeV
- Single-ring
- e-like
- No decay e-
- 0.35 < rec. E < 0.85 GeV
- Cos $\theta_{\nu e}$ < 0.9 (remove coherent π^0)
- $M_{\gamma\gamma}$ < 95 MeV
- log-likelihood difference < 150.0

→ **Select *CCQE* ν_e *events, with 1 ring, e-like & special* π^0 *fitter cuts***

The same selection criteria are used at SK and 2KM

Measured Events at 2KM



ν_e appearance background measurement :

Simulate 5yrs 2KM data &
Apply same analysis cuts as at SK
~1800 events total

	NC	beam ν_e	CC-ν_μ
1) FCFV, E_{vis} >100 MeV	53847	10997	325969
2) 1-ring e-like	10843	5454	10604
3) no decay-e	10187	4575	2009
4) 0.35 GeV < $E_{\nu e}^{rec}$ <0.85 GeV	3476	1409	649
5) e/π^0separation	641	879	216

Other important event samples :

- 2 ring e-like NC π^0 events ~ 20,000 events
- 1 ring μ-like events ~ 300,000 events (~230,000 CCQE)

Background estimates

Simple scaling :

$$N^i_{sk} = N^i_{2km} \; (M_{sk}/M_{2km})(L_{sk}/L_{2km})^2(\epsilon^i_{sk}/\epsilon^i_{2km})$$

No beam MC correction **Not used, assume = 1**

For ν_μ mis-ID, also multiply by the 'survival' probability

With preliminary, simple & conservative estimate of the systematics

- Beam F/N ~ 4%, Fiducial volume ~ 4%, Energy scale ~ 3%,
- Analysis systematics < 7.0% (conservative) for each channel

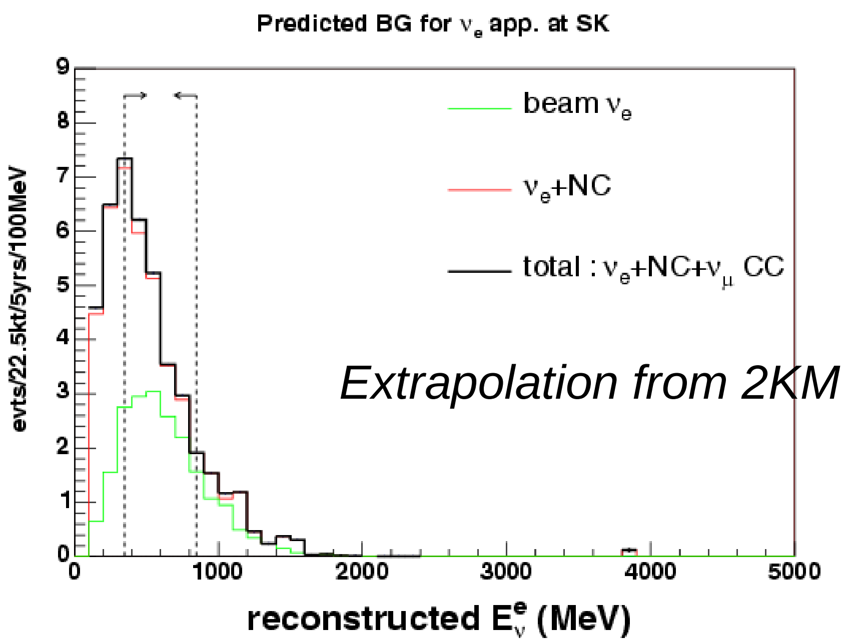
still under study

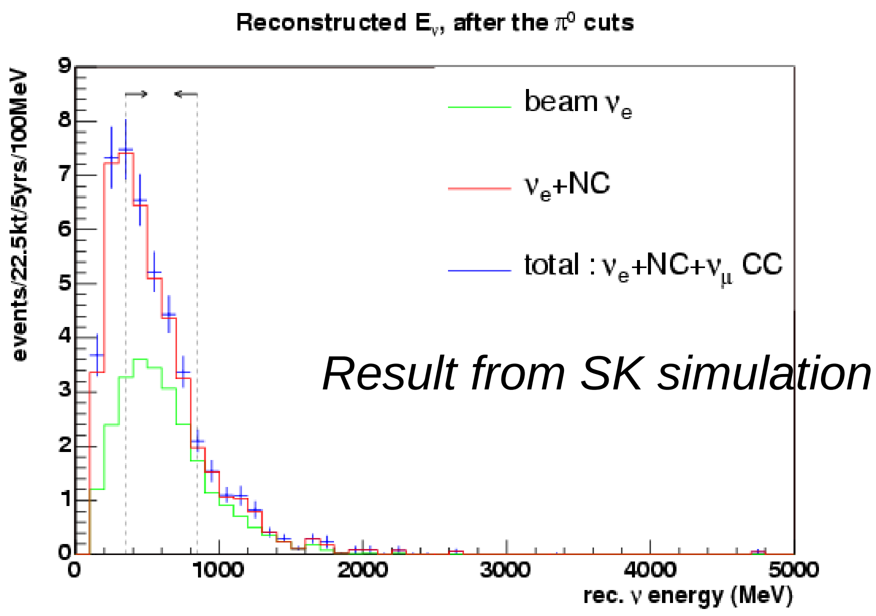
Total background from SK MC = 24.4

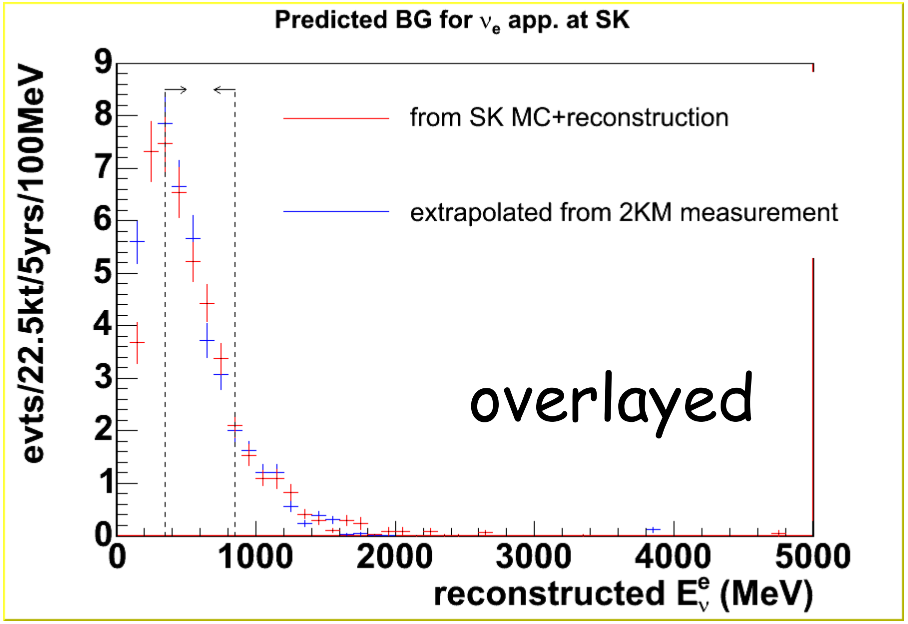
Extrapolated background from 2KM = 25.6 ± 1.8 (7.0%)

→ *Total uncertainty better than goal of 10% for phase I*

Background at SK for ν_e appearance





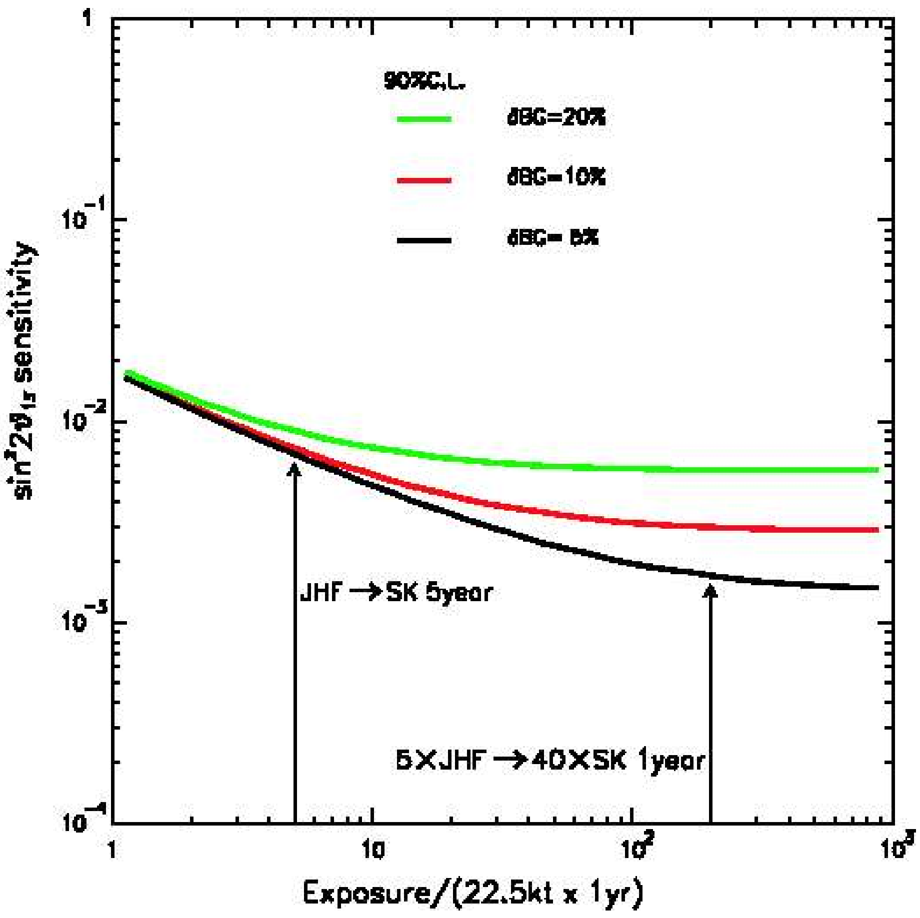


Shapes within the signal window as well as rates are well predicted with this method

What about phase II ?

T2K phase II : with HyperK Mt detector (see other talks in this session), 4 MW proton beam power

→ present systs have to be lowered in order to benefit from the gain in statistics



- Simple scaling method no longer sufficient :
- Need to take into account far /near differences
- 2KM much less sensitive to beam MC fine-tuning than closer detector

Example : remaining far/near differences for high-precision phase II study

Shape of the spectrum around the peak is caused by :

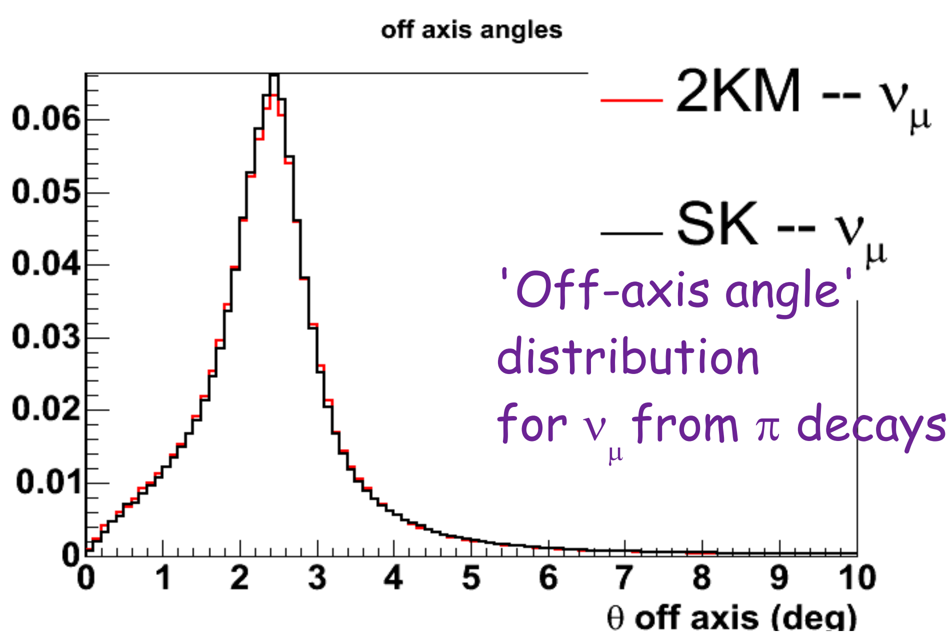
@ 295 km :

- *Energy resolution*
- *Pion beam divergence*

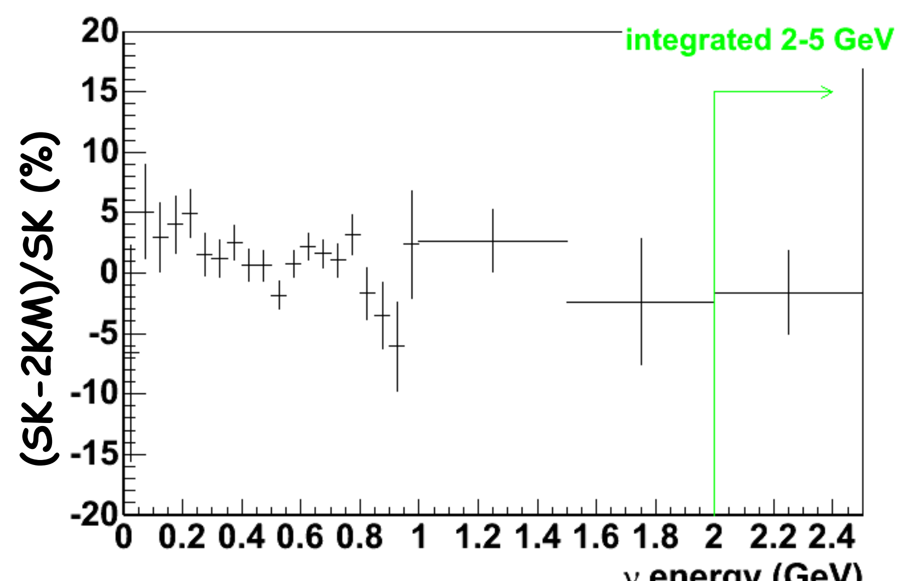
@ near detector :

- *Energy resolution*
- *Pion beam divergence* **[main effect]**
- *Pion decay point [decay tunnel **not** point-like]*
- *Position of the interaction in the detector [detector **not** point-like]*

→ **@ 2KM those effects are small, F/N variations <~ ±5%**



'Zoom' on the N/F ratio



• Spectral differences between 2KM & SK come from the proximity of the ν source & the finite size of the detector

• @ ***2KM*** , similar orders of magnitude (estimated with simple geometry)

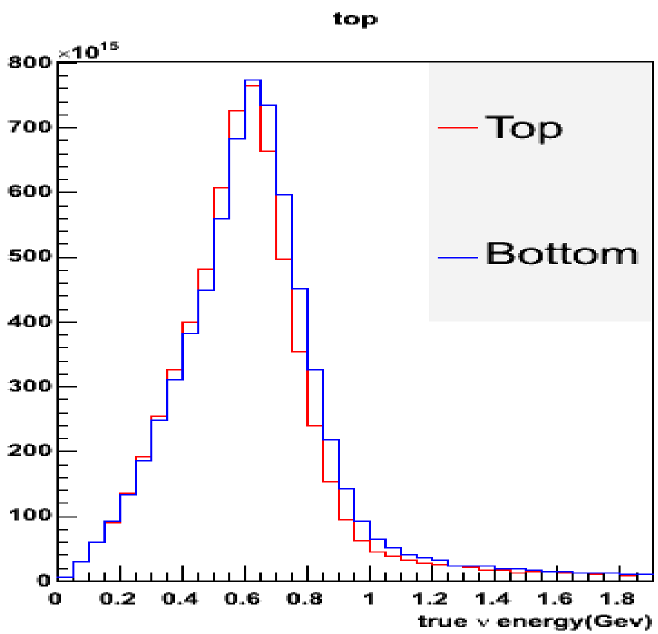
130m long decay tunnel seen from 2km :

→ max. off-axis angle variation of ~5.5 mrad

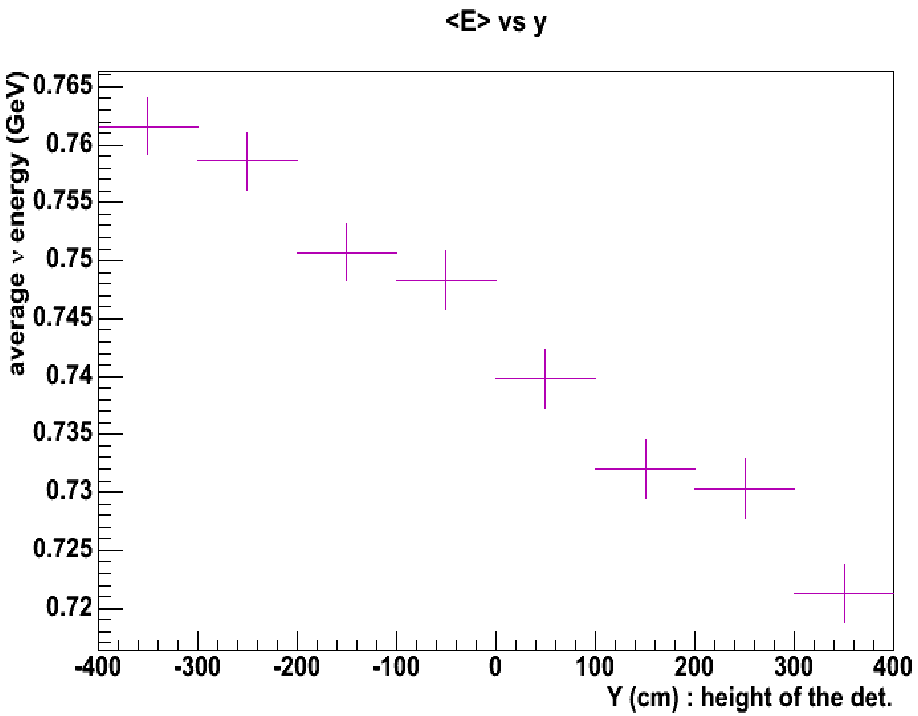
~8m wide detector :

→ max. off-axis angle variation of ~4.6 mrad (~ 0.3 degrees)

At 2KM with high statistics it is possible to measure the variation of the mean neutrino energy vs the vertical position in the detector



@ 2km



Variation ~3% over the 4.5m wide Fid. Vol

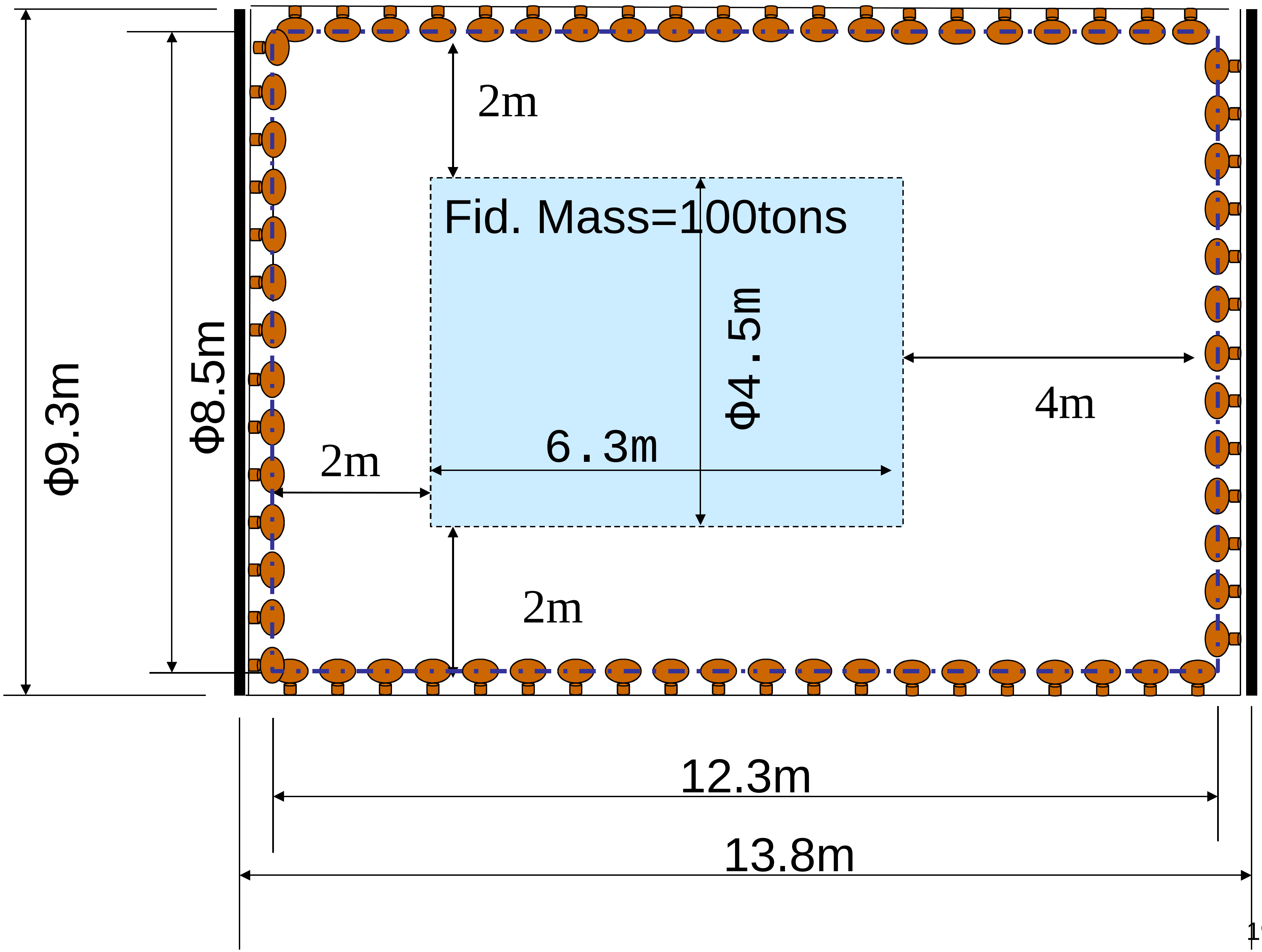
Conclusion

- Intermediate detector complex for T2K with liquid Argon TPC, water Cherenkov detector & MRD highly desirable for phase I

- Studies show that a water Cherenkov detector optimized to minimize systematics errors will predict the ν_e background at Super-K to less than the needed 10% even relying only on simple scaling of mass and distance

Thank you !

2KM water Cherenkov geometry



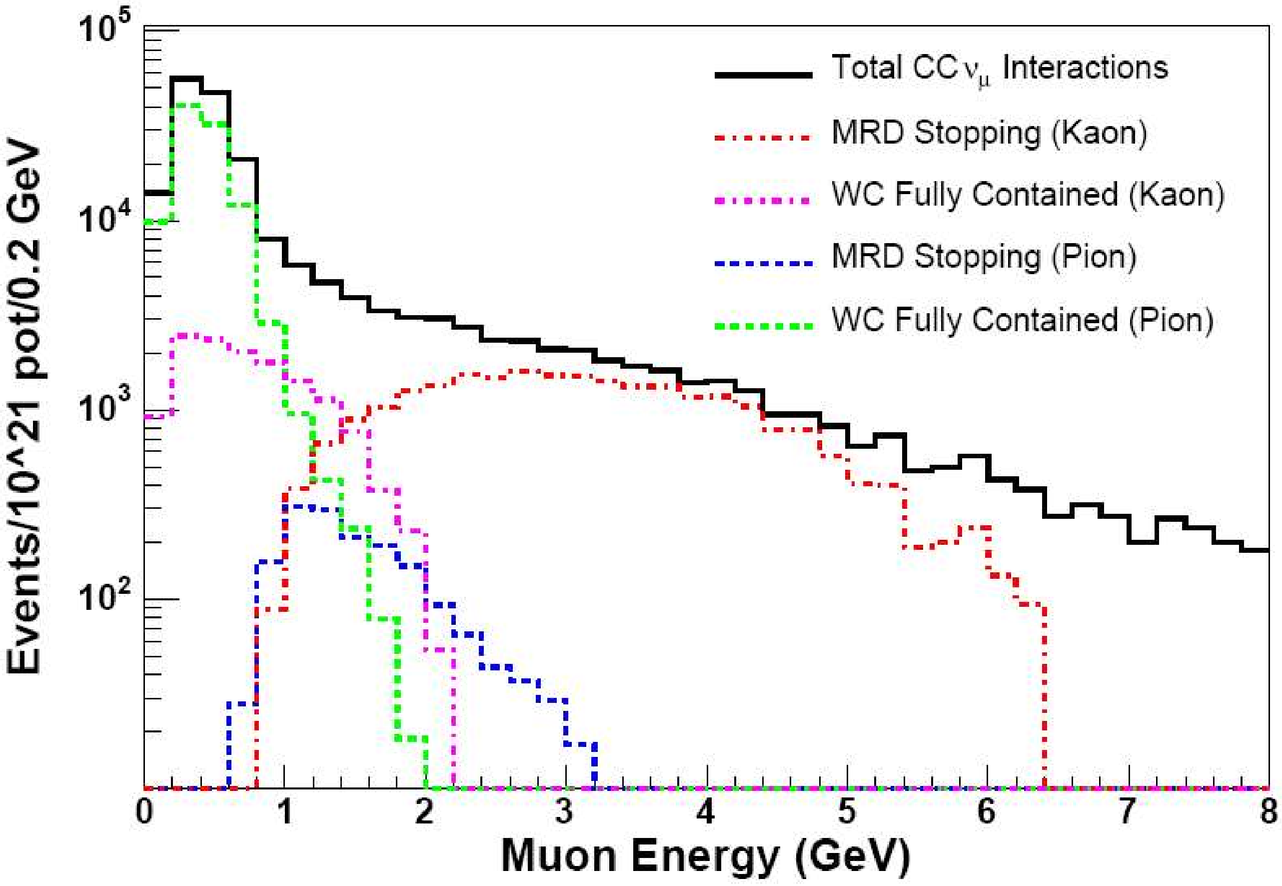
What Liquid Argon Adds

- Particles below Cherenkov threshold are visible, especially protons.
- Independent measure of off-axis flux and non-QE/QE event ratio.
- Exclusive measurement of NC and intrinsic electron neutrino background. Excellent PID will allow these to be separately measured.
- Study the same classes of events in LAr and WC to better understand the systematics of the WC reconstruction and SK extrapolation.
- High statistics neutrino interaction studies with bubble chamber accuracy.

See A. Meregaglia's talk on the T2K-2KM LAr TPC project (WG2)

Why Muon Range Detector

Measure high energy tail of the neutrino spectrum which is source of NC BG and sensitive to the electron neutrino BG.



For Example: Constrain the kaon produced neutrino flux which also produces a large fraction of the intrinsic electron neutrino background.