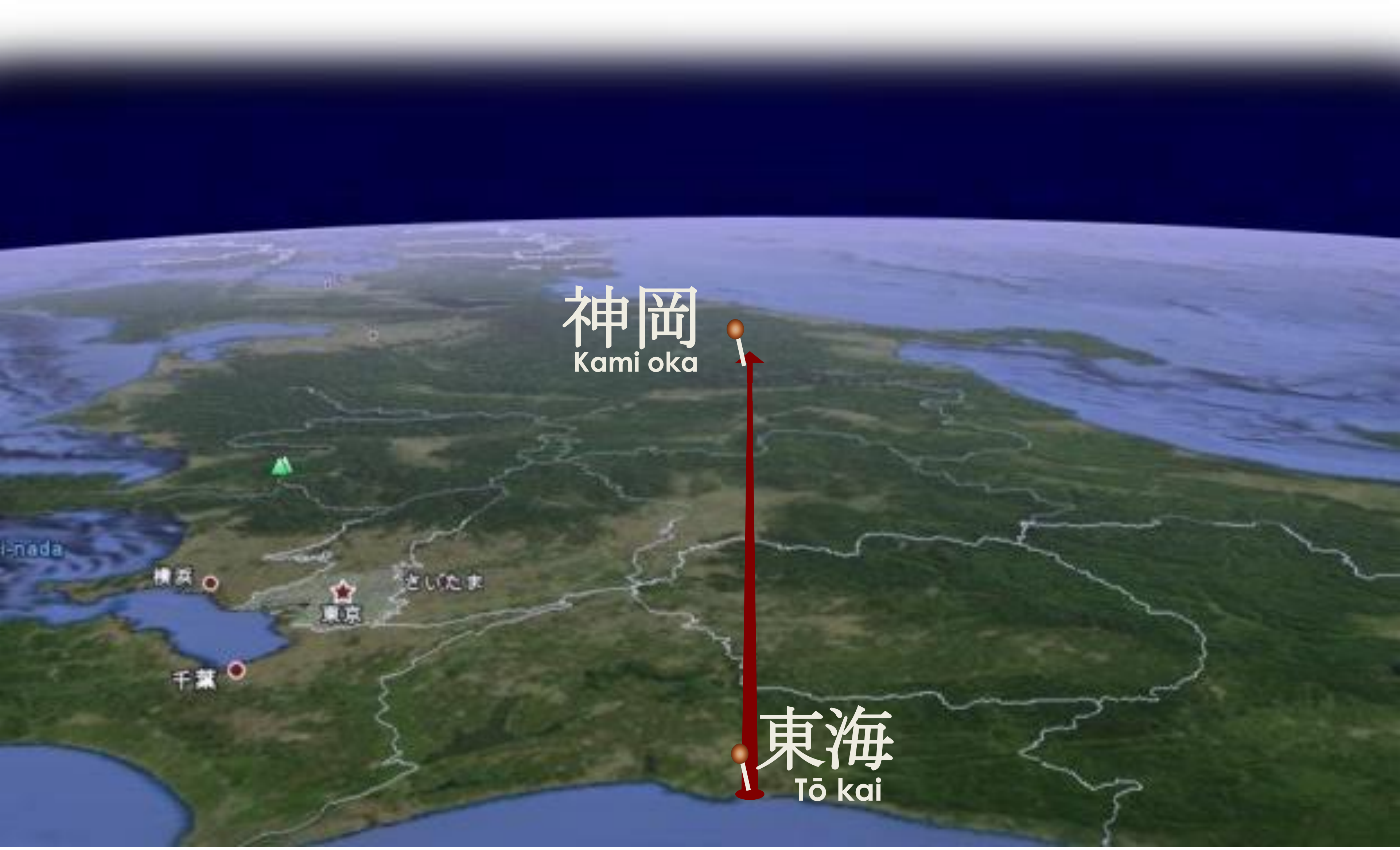
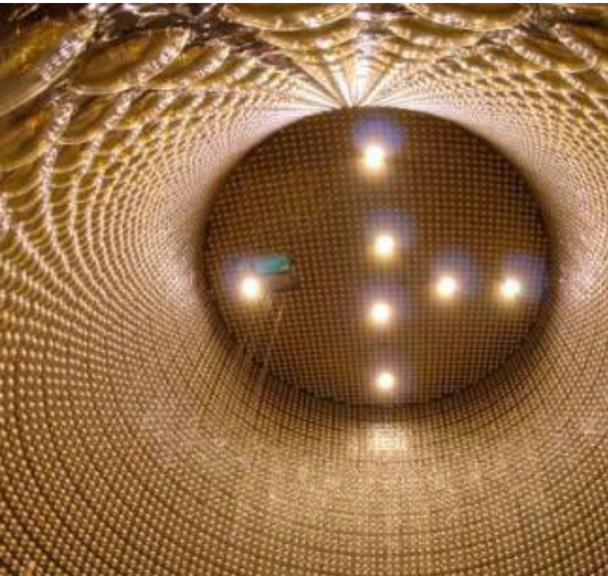
T2K, T2K upgrades and HyperK





Idea of T2K was born 1999-2001 hep-ex/0106019 combining:

-- existing SuperKamiokande detector (50kton W.Č., 22.5 kton fiducial)

-- JAERI-KEK Japanese Proton Accelerator Research Complex (JPARC) at TOKAI including a high power, 0.75MW/30GeV Proton Synchrotron neutrino beam from pion decay $\pi^+ \rightarrow \mu^+ \nu_\mu$

-- baseline 295 km ➔ neutrino energy for first maximum is ~650 MeV achievable by pion-decay beam at 2.5 degrees off-axis

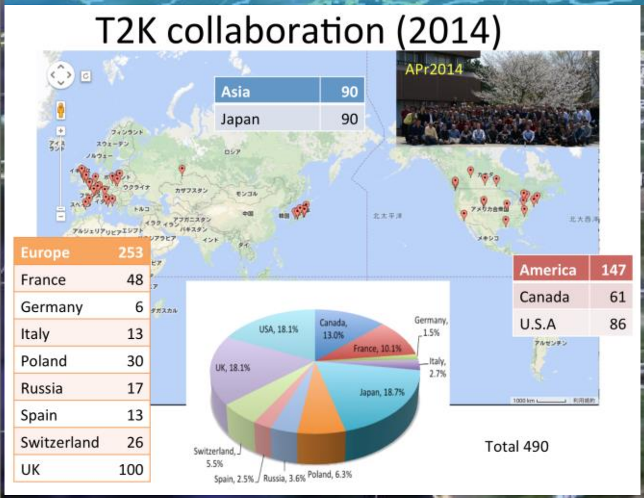
T2K Long Baseline Neutrino Oscillation Experiment

Attack fundamental questions of nature, eg,

How matter (us) was created in the Universe

What is the ultimate law to govern extreme microscopic world

through exploring most elusive elementally particle called "neutrino"



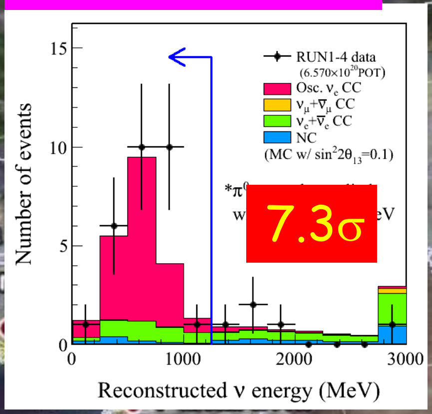
40m$^\phi$x40m^H

50kt Water Cherenkov det.

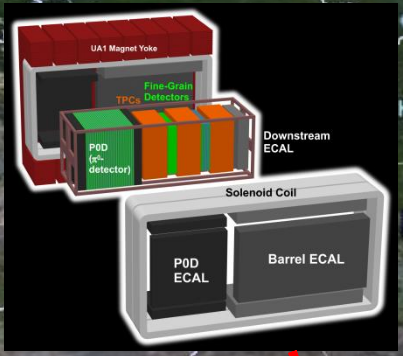
Muon neutrino beam

295km

Discovery of appearance of electron neutrino



Near neutrino detect



- T2K collaboration ~500 collaborators from 59 institutions, 11 countries
- Funded in FY2004, Started measurements in 2010
- First discovery of ν_e appearance in ν_μ beam
- Best measurement of ν_μ disappearance
- Opens the door for CP violation measurements
  - Could be the key to matter in the universe!

Pointer 36° 23'41.59" N 139° 11'54.71" E elev 665 m Streaming 100%

Swiss contributions to T2K

- Collaboraton
  - University of Bern (Prof. A.Ereditato)
  - University of Geneva (Prof. A.Blondel)
  - ETH Zurich (Prof. A. Rubbia)
  - 24 scientists + engineers & technicians (34 total) + 8 PhD students + 5 PhD thesis
- Contributions
  - Responsibility on UA1 magnet
  - Tracking detector TPC
  - Essential NA61 measurement for T2K at CERN
- Total contributions since 2005:
  - 3.1 MCHF (FORCE/FLARE/SINERGIA) for hardware, common fund, maintenance
  - Adding manpower and travel: over 10MCHF (SNF, ETHZ, University funds and foundations)

DPNC UNIVERSITÉ DE GENÈVE

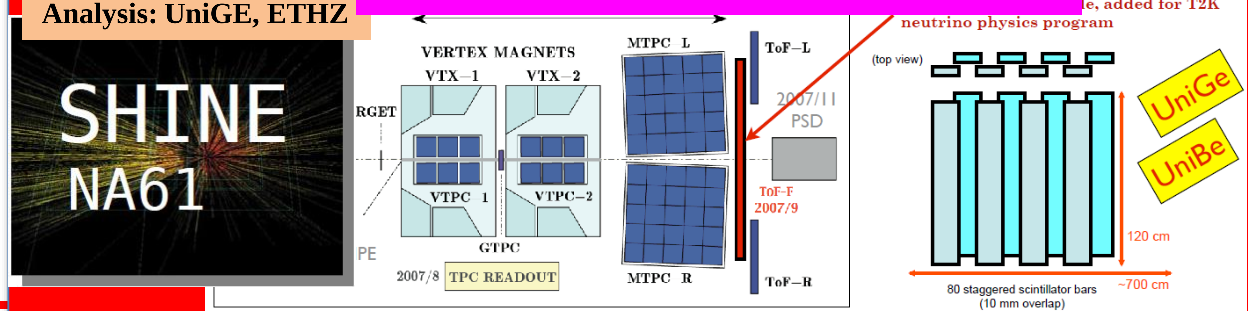
ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich

LABORATORIUM FÜR HOCHENERGIEPHYSIK LHEP UNIVERSITÄT BERN

Refurbishment, transport, installation, commissioning, operation of UA1 magnet donated from CERN

Contributions to near detector TPC

Critical input data for T2K from experiment at CERN

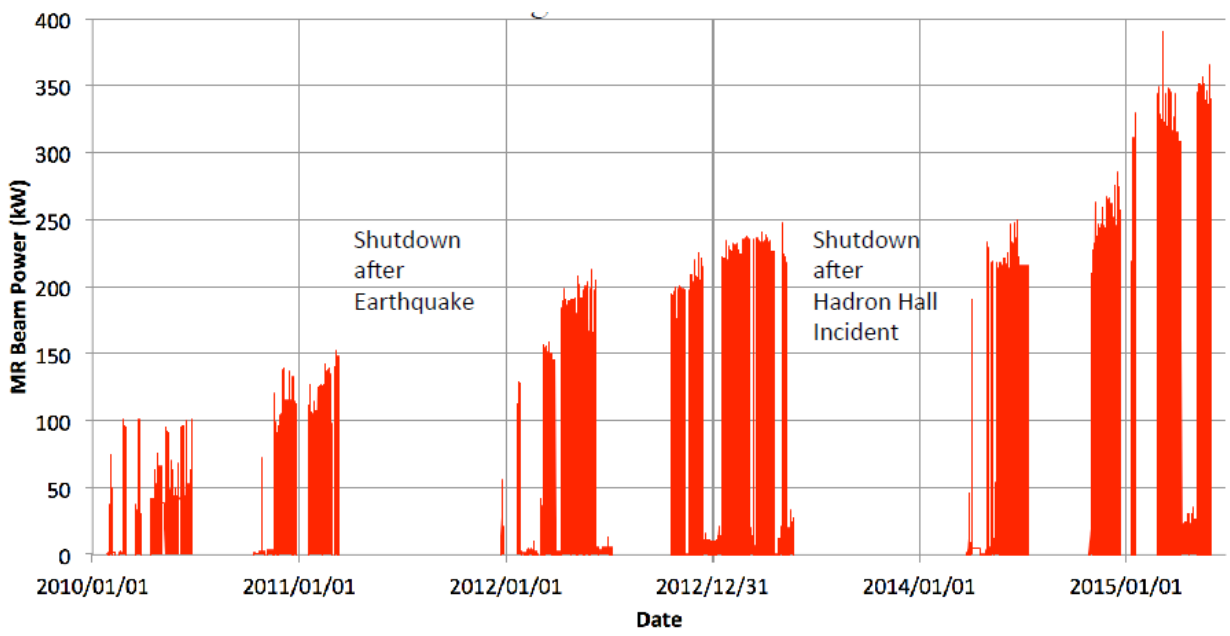


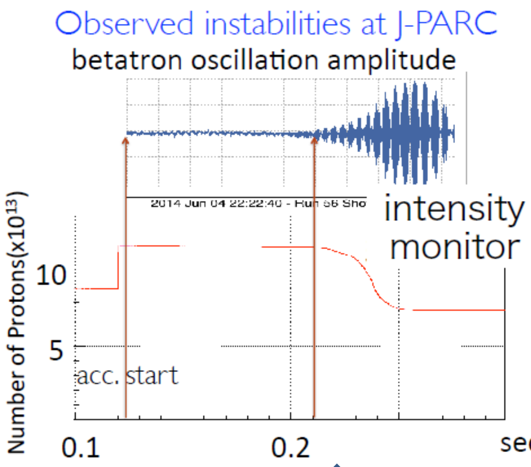
Neutrino source: off axis neutrino beam with peak at 650 MeV.

-- quasi-elastic dominates, well suited for Water Cherenkov detector

-- kinematics assures precise energy reconstruction

Beam power has raised regularly, operations suffered from big earthquake and shutdown





improvements: increased linac energy, intra-bunch feed-back system

achieved 365kW

intensity limited by instabilities

next steps: double rep.rate with new power supplies, fast kickers and higher gradient RF

improve loss controls further with more feedbacks

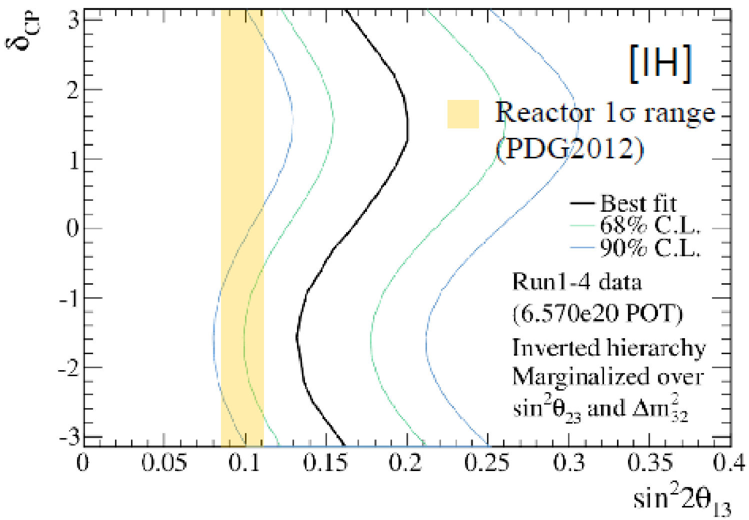
Power upgrade plan of MR

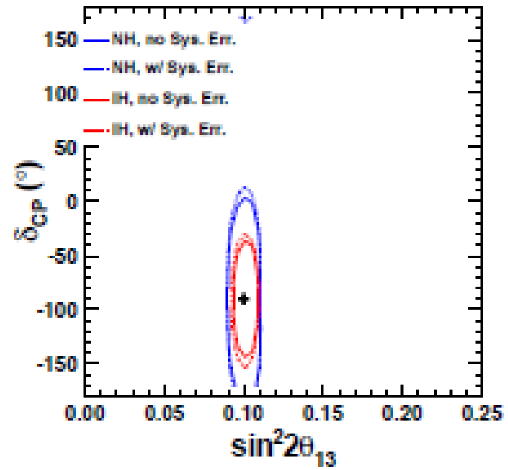
FX: The high rep. rate scheme is adopted to achieve the design beam intensity, 750 kW.
Rep. rate will be increased from ~ 0.4 Hz to ~1 Hz by replacing magnet PS's and RF cavities.
SX: After replacement of stainless steel ducts to titanium ducts to reduce residual radiation dose, 50 kW operation for users will be started. Beam power will be gradually increased toward 100 kW carefully watching the residual activity. Local shields will also be installed if necessary.

JFY	2014	2015	2016	2017	2018	2019
Event	Li. current 30 -> 50 mA		New PS Buildings			
FX [kW] (study/trial) SX [kW] (study/trial)	240-320 -	>320 24~50	~400 >50	>400 50~100	~750 ~100	>750 100
Period of magnet PS New magnet PS	2.48 s R&D	Low cost R&D		Mass production	1.3 s	
Present RF system High gradient rf system	Manufacture, installation & test					
Ring collimators	Back to JFY2012 (2kW)	Add. colli. C,D	Add. colli. E,F			
Injection system FX system	Kicker PS improvement, Septa manufacture /test Kicker PS improvement, LF & HF septa manufacture /test					
SX collimator / Local shields			Local shields			
Ti ducts and SX devices with Ti chamber	Beam ducts	ESS				

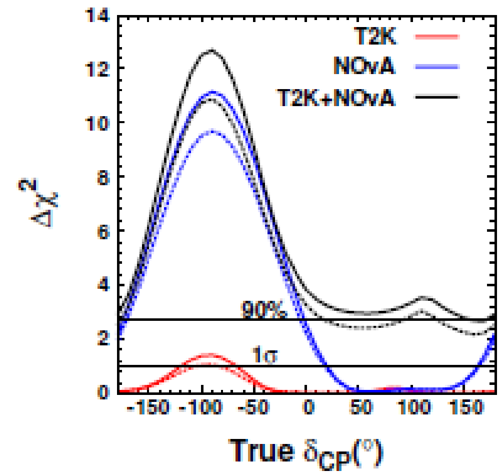
Expect O(1MW by 2019)
original beam request:
5 yrs @750kW

T2K will run at least until the original request is fulfilled... or more.
This will be discussed in an international workshop on neutrino strategy in Japan (4-6 Aug'15)





(d) 50% ν-, 50% $\bar{\nu}$-mode, with ultimate reactor constraint.



(a) 1:0 T2K, 1:1 NOνA ν:$\bar{\nu}$, NH

present observation of $\nu_\mu \rightarrow \nu_e$ favours negative value of δ_{CP} (thanks to a bit of luck)

If this is true this will be demonstrated with T2K full exposure with 50% antineutrino

and many other precise measurements. ➔ **The backbone of the neutrino program.**
T2K + NOvA will determine the mass hierarchy at more than 90%
NB with improvements to the proton accelerator, contemplate 2-3x nominal T2K by 2025 (above curves should be redone).
NBB Together with ORCA, PINGU, JUNO in early 2020's **MH will be known by 2025.**

Upgrade path and Swiss plans

2015-2018

Upgrades to T2K:

-- Accelerator double rep rate → O(1MW) on target

-- Gadolinium loading of SuperK

-- Wagasci and **BabyMIND** to measure H2O/Scintillator cross-section (2016)

-- NA61 improved long target results or measurements

-- ND280 upgrade

2018-2024

HyperK construction → far detector is increased to >500kton fiducial

-- one of the two pillars of the Japan particle physics community road map.

-- classified in 27 priority projects in Japan

  -- not ready for approval in 2014

  -- CDR review end 2015, proposal in 2016, approval 2017/8

-- AB member of International Steering Group ISG (4 non japanese)

-- CDR in preparation (near detectors, electronics/trigger, reviewing)

-- characterization of photodetectors, definition of electronics (Bravar, UNIGE)

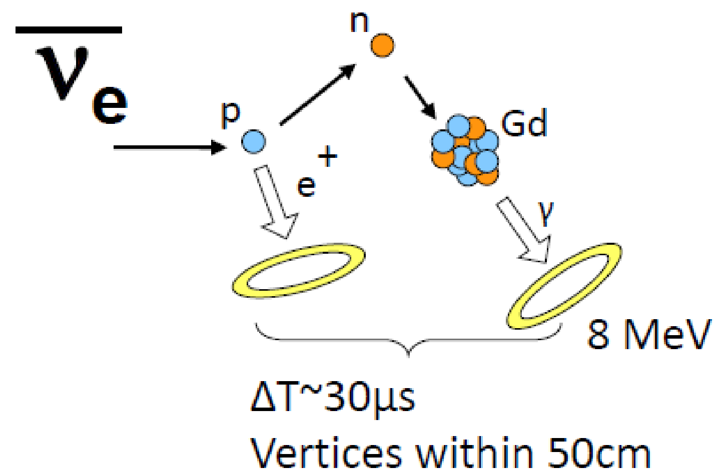
-- «intelligent data filter/trigger» (Ariga, UNIBE)

→ aim at major contribution in electronics and trigger

SK and T2K upgrades

1. Gadolinium-loaded SuperK

=> high efficiency for $\bar{\nu}$e



especially for the search for SN relic $\bar{\nu}$
also improvement on tagging/rejection
of interactions producing a neutron $\bar{\nu}$ vs ν

Expected date 2017/8 (same time as accelerator upgrade)

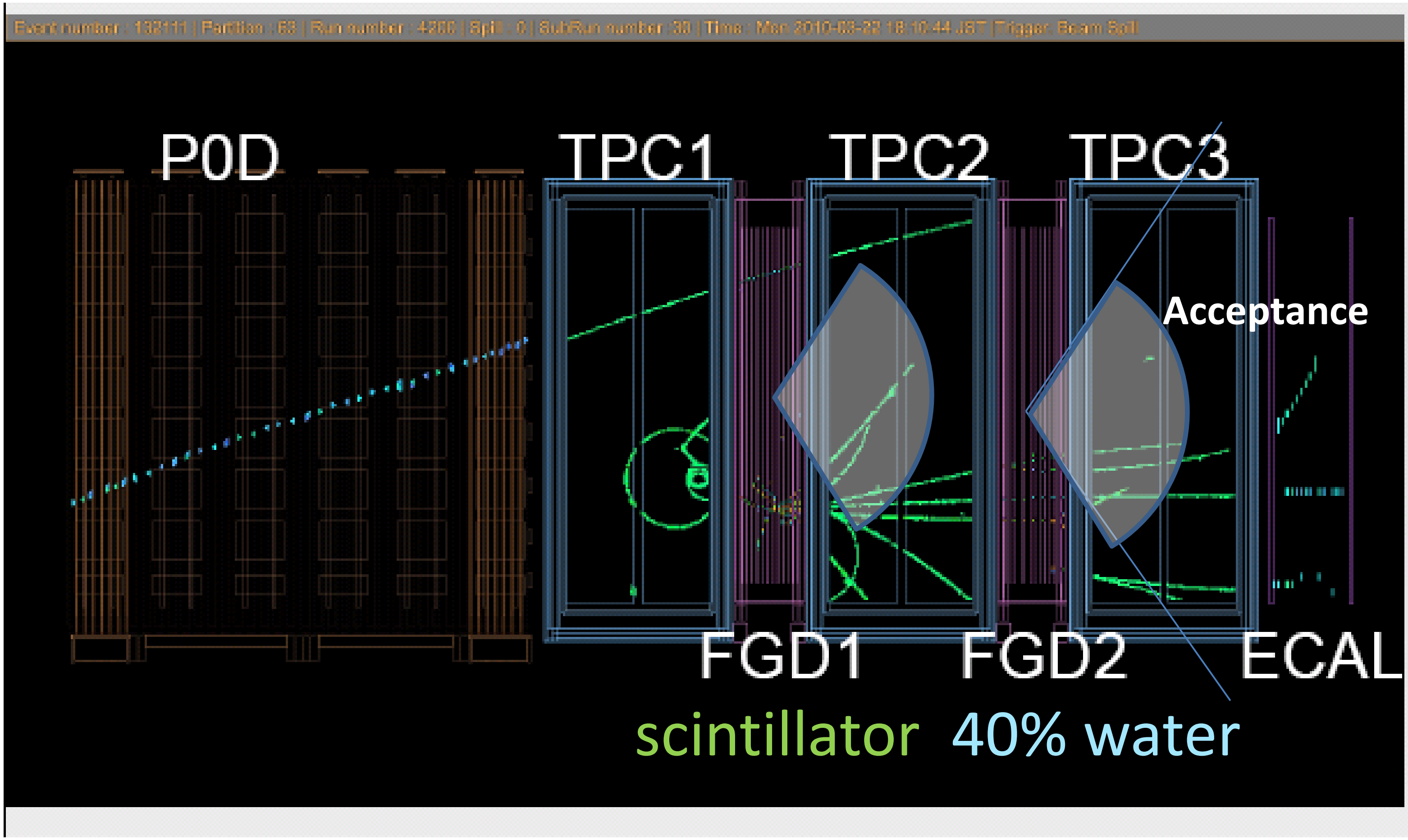
2. ND280 detector upgrade

Now have sufficient experience to understand limitations of ND280 as built mainly:

- -- angular acceptance of momentum measurement has large hole at 90°
- -- ND280 targets are mostly scintillator and far detector is water
- -- time resolution of ECAL is not sufficient to associate photons to events
- -- this will reduce Far/Near systematics to ~3-4% level or better

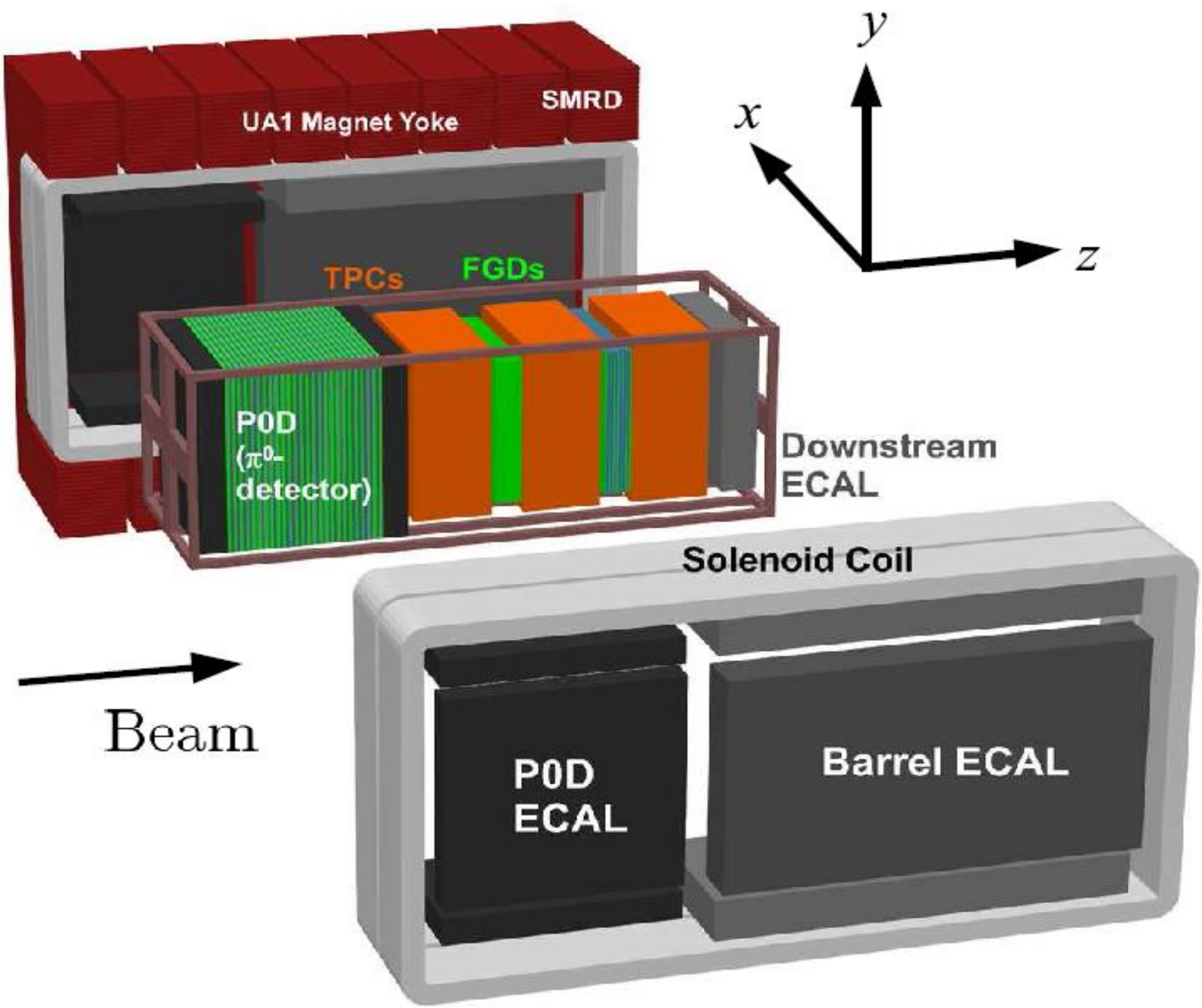
We have taken the lead on this.

ND 280 upgrades

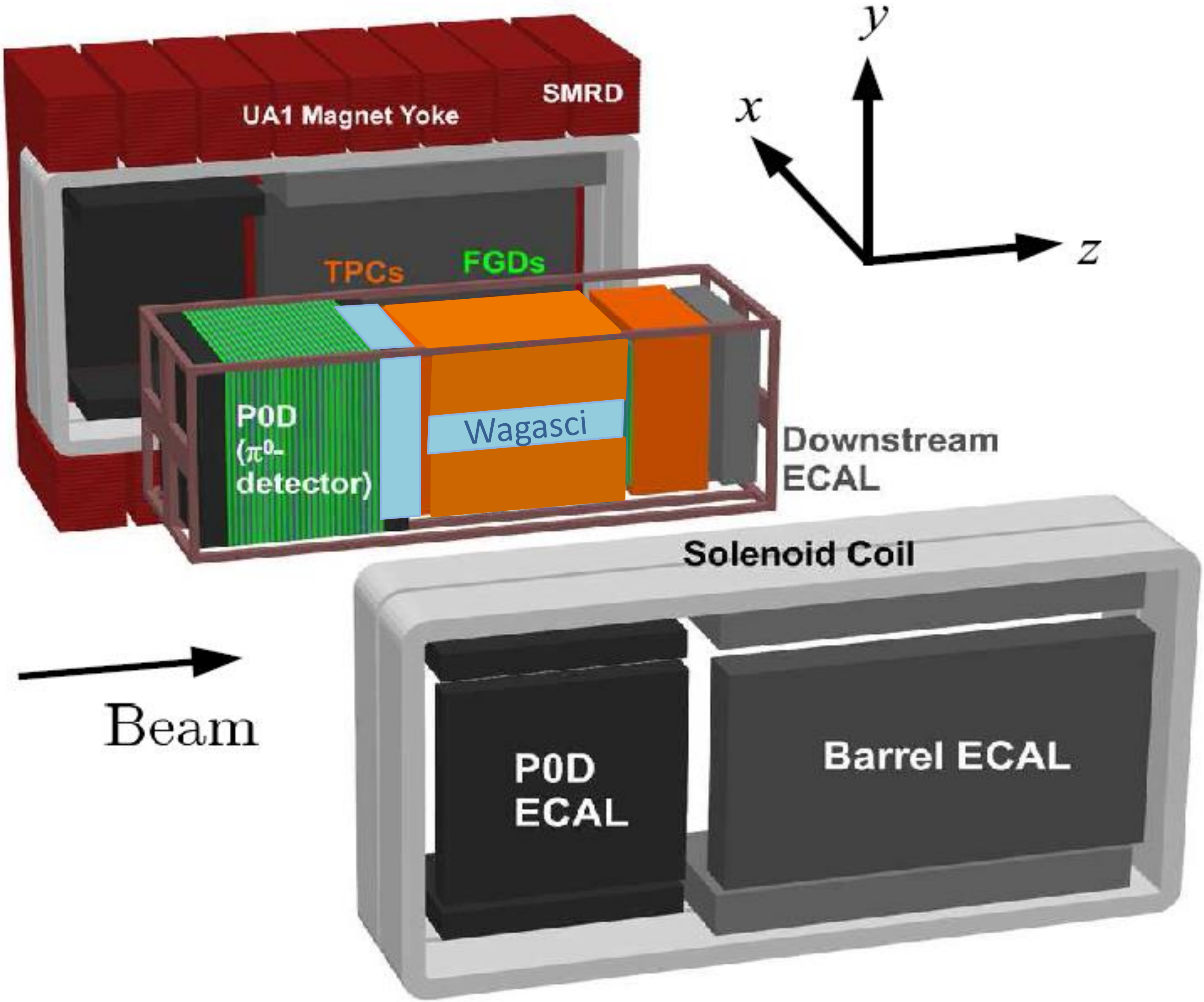


aim of upgrade: full angular acceptance, 80% water in target

reduce systematics on predicted SK numberof events to ~3% (from 8%)

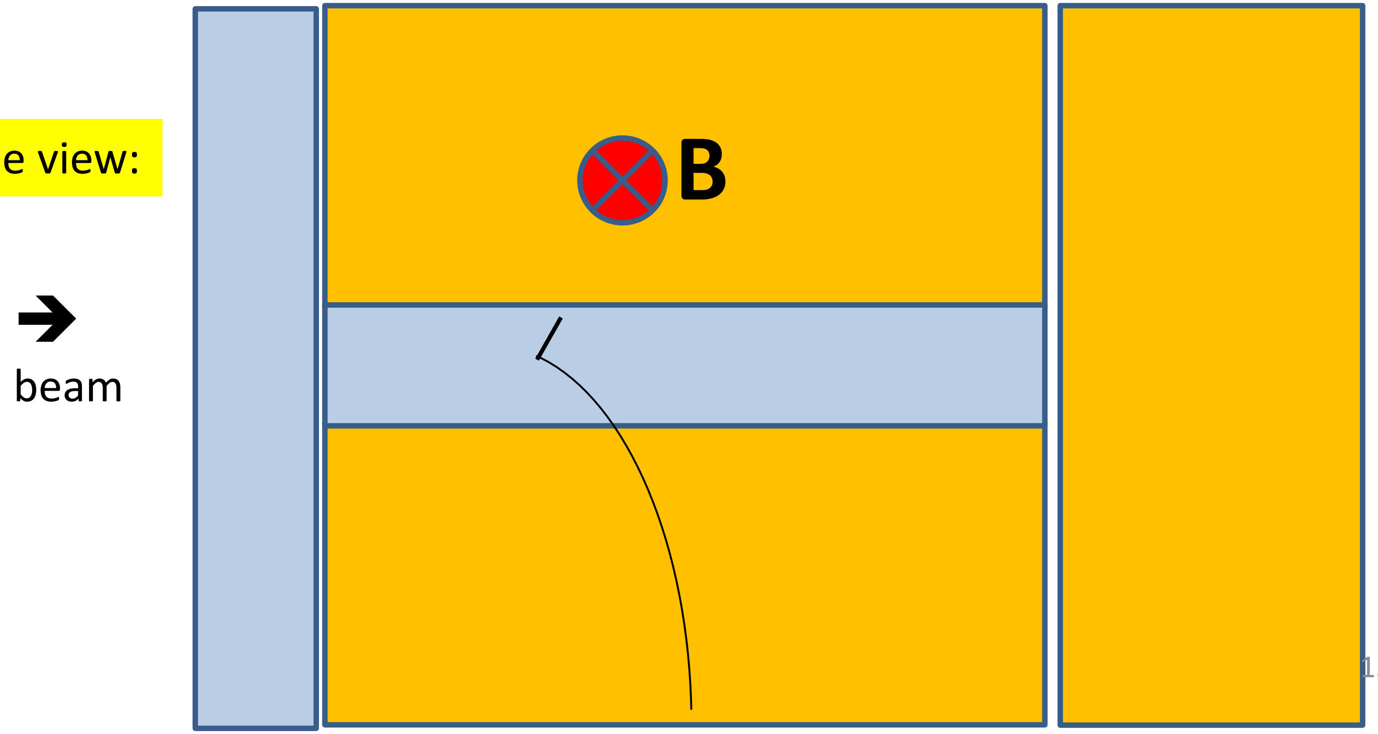

UA1 Magnet Yoke
SMRD
y
x
z
TPCs
FGDs
P0D
(π0-
detector)
Downstream
ECAL
Solenoid Coil
Beam
P0D
ECAL
Barrel ECAL

example:


UA1 Magnet Yoke
SMRD
TPCs
FGDs
P0D
(π⁰-
detector)
Wagasci
Downstream
ECAL
Solenoid Coil
Beam
P0D
ECAL
Barrel ECAL
x
y
z

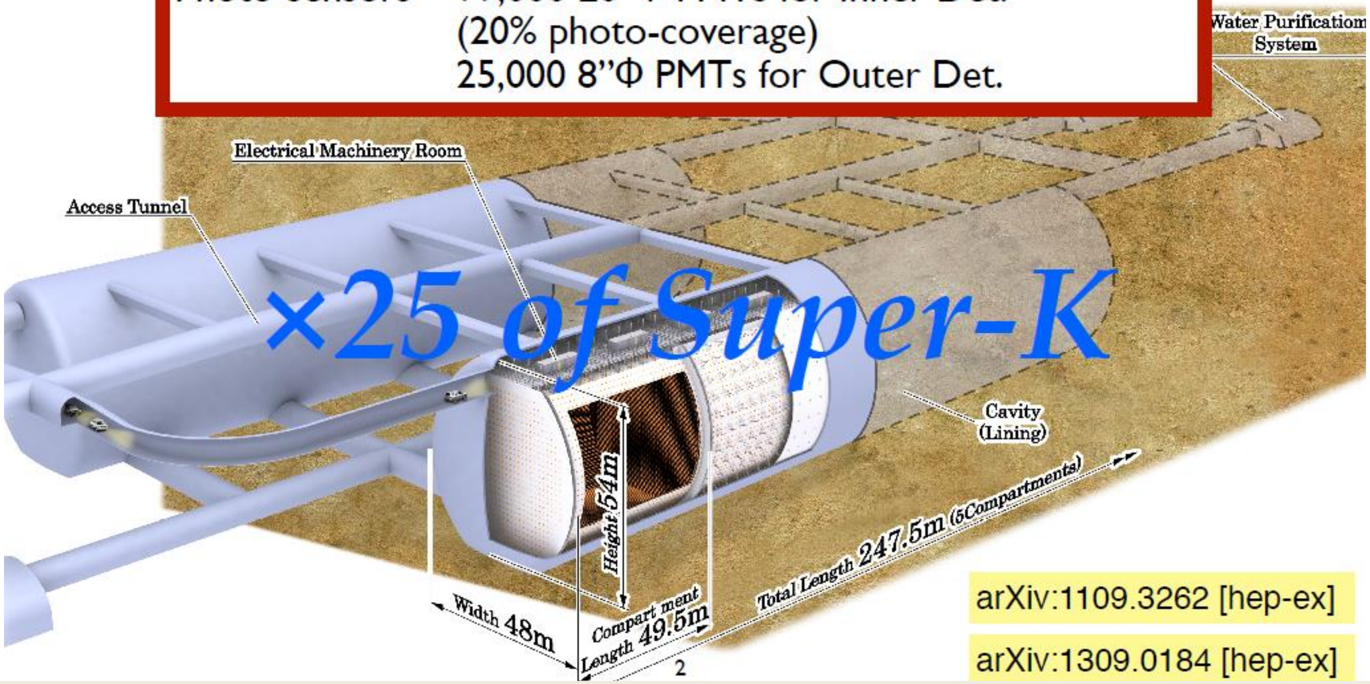
ND280 - upgrade
suggested reconfiguration
TPCs 1 and 2 rotated around
B field
Or prefer new TPCs

side view:



Hyper-K Overview

Total Volume	0.99 Megaton
Inner Volume	0.74 Mton
Fiducial Volume	0.56 Mton (0.056 Mton × 10 compartments)
Outer Volume	0.2 Megaton
Photo-sensors	99,000 20"Φ PMTs for Inner Det. (20% photo-coverage) 25,000 8"Φ PMTs for Outer Det.



This is why we are here!

CPviolation, mass hierarchy, proton decay, supernovae neutrinos; etc...
Top of the list in Japan science projects (with ILC)
LBL Physics potential published in Prog. Theor. Exp. Phys. (2015) 053C02
A.B. is member of HyperK Steering group and Swiss rep in IBR

Third Hyper-Kamiokande EU meeting

27-28 April 2015
CERN

Search

Europe/Zurich timezone

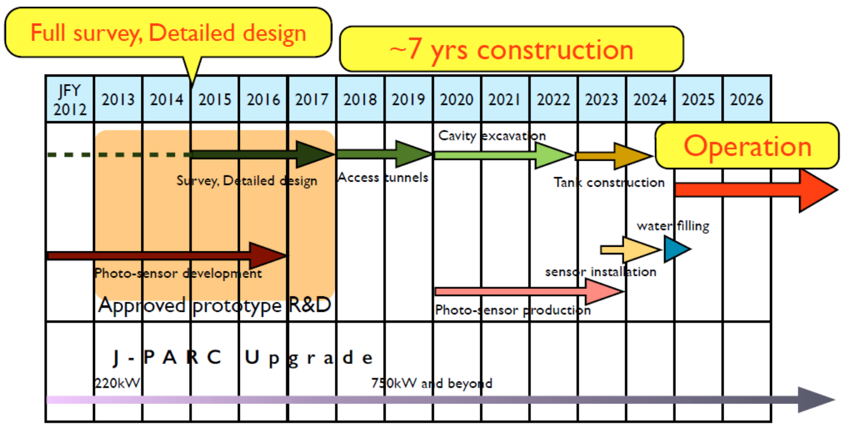
- Overview
- Timetable

- Meeting to discuss the European effort in the Hyper-Kamiokande experiment.
- Open to anyone who has interests in Hyper-K, or is planning to join Hyper-K, or is contributing.

Swiss : Di Luise, Periale (ETHZ), Ariga, Ereditato, Pistillo (UNIBE),
Blondel, Bravar, Noah, Haegel, Ravonel, Scantamburlo (UNIGE) (speakers)

Status of HyperK

Notional Timeline



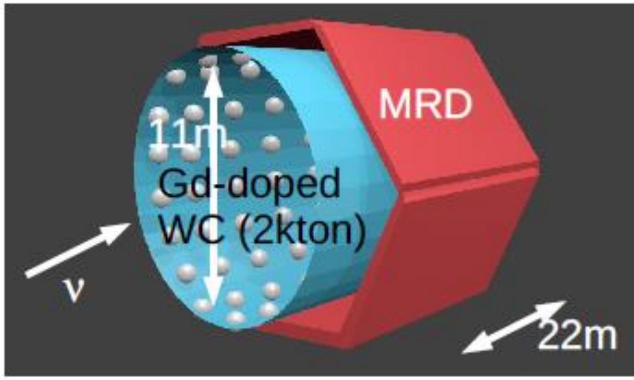
Operation in 2025

<u>LOI submitted</u> to JPARC PAC April 2014
(signed by Bern, ETHZ, UNIGE,
A.B. is SC member and IBR rep)
Top particle physics project in Japan with ILC
Classified by MEXT within 27 top priority projects

-- Scientific case recognized, must improve intl participation, organization, cost estimate.
HyperK collaboration Kick-off meeting 31 January 2015. MOU between KEK and Uni Tokyo.
CDR in preparation for Oct2015.

-- Swiss participation under discussion within HyperK-EU and Swiss groups
- -- upgrade of T2K ND system (as discussed)
- -- Major responsibility in HyperK readout electronics and DAQ
- -- studies of magnetization of near detector →
- -- meanwhile, contributions to CDR

Prepare R&D/prototype/measurements proposal for CERN neutrino platform

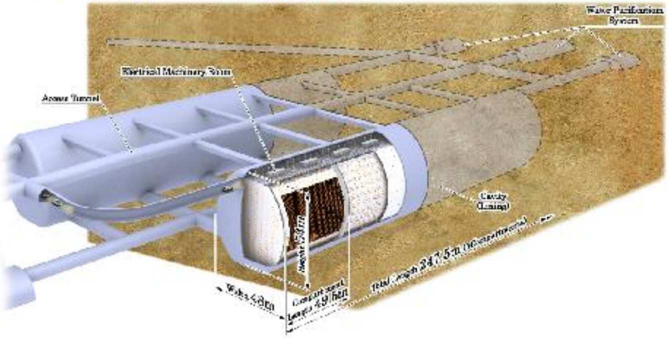


1. Excavating a cavern for > 500 kton fiducial

Rock in Kamioka is of excellent cavity, gneiss and migmatite
large span vertical cylinder caverns offer better cost/volume ratio

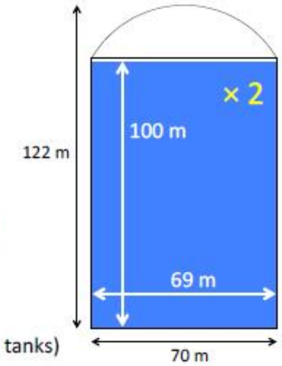
Proposed to study 4 cases

baseline design



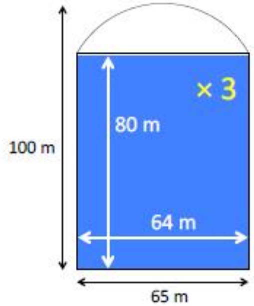
Case 1

- Water tank size
  - Depth : 100 m, Diameter : 69 m
- Water volume (2 tanks)
  - Total : 747.9 kt
  - Fiducial : 568.7 kt
- Excavation volume (2 caverns)
  - 868000 m³ 72% of current one
- ID surface area (2 tanks)
  - 52800 m² 53% of current one
- Number of ID photodetectors (2 tanks)



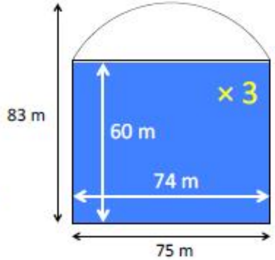
Case 2

- Water tank size
  - Depth : 80 m, Diameter : 64 m
- Water volume (3 tanks)
  - Total : 772.1 kt
  - Fiducial : 565.2 kt
- Excavation volume (3 caverns)
  - 915000 m³ 76% of current one
- ID surface area (3 tanks)
  - 60300 m² 61% of current one
- Number of ID photodetectors (3 tanks)
  - 38.0 k 38% of current one



Case 3

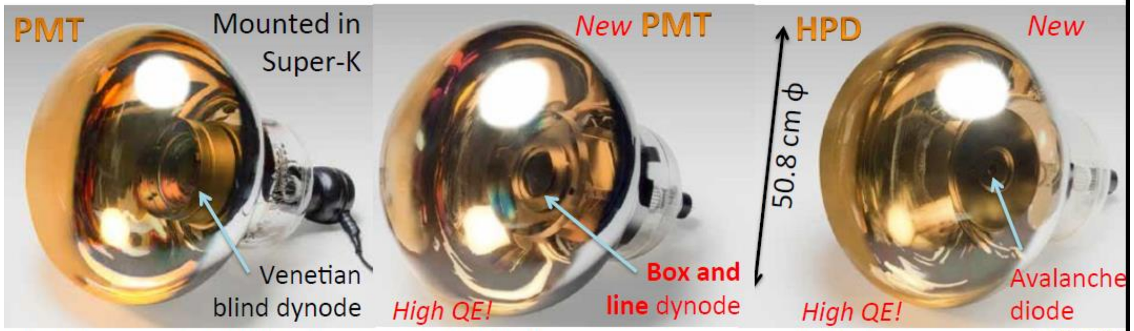
- Water tank size
  - Depth : 60 m, Diameter : 74 m
- Water volume (3 tanks)
  - Total : 774.2 kt
  - Fiducial : 561.0 kt
- Excavation volume (3 caverns)
  - 968000 m³ 81% of current one
- ID surface area (3 tanks)
  - 60200 m² 61% of current one
- Number of ID photodetectors (3 tanks)
  - 38.0 k 38% of current one



2. Producing 40’000 high Q.E. 20’ PMTs

By Hamamatsu Photonics K.K.

- New 50 cm Φ photodetectors developed for HK.



Model R3600 (Used for 2-30 yrs) R12860 R12850 † still in R&D

Hamamatsu new plant for mass production

New detectors offer higher Q.E. by typically 50%.
Presently investigating noise and time resolution of various options and calculating consequences for physics.

Optimizing PMT coverage for physics; possibly staging.

To realize mass production for HK, Hamamatsu built a new large plant and PMT division is moving in it.

- Automated transportation, test facility, earthquake-resistant, …

We have to determine PD for HK 2 years before mass production.

- Design for 0.5 year, equipment for 0.5-1 year, startup for 0.5-1 year

- Around 6 years for mass production.

Some physics

HYPERK , δ_{CP}=0, and NH

	Signal ($\nu_\mu \to \nu_e$ CC)	Wrong sign appearance	$\nu_\mu/\bar{\nu}_\mu$ CC	beam $\nu_e/\bar{\nu}_e$ contamination	NC
ν	3,016	28	11	523	172
$\bar{\nu}$	2,110	396	9	618	265

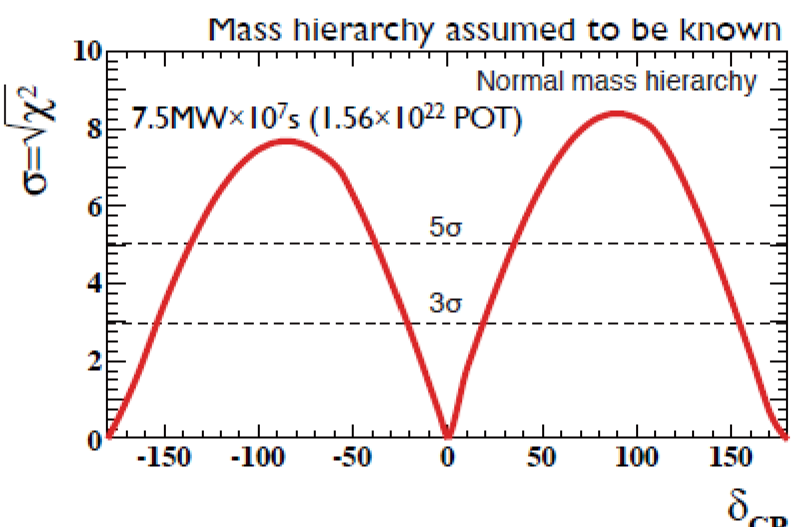
750 kW x10yrs

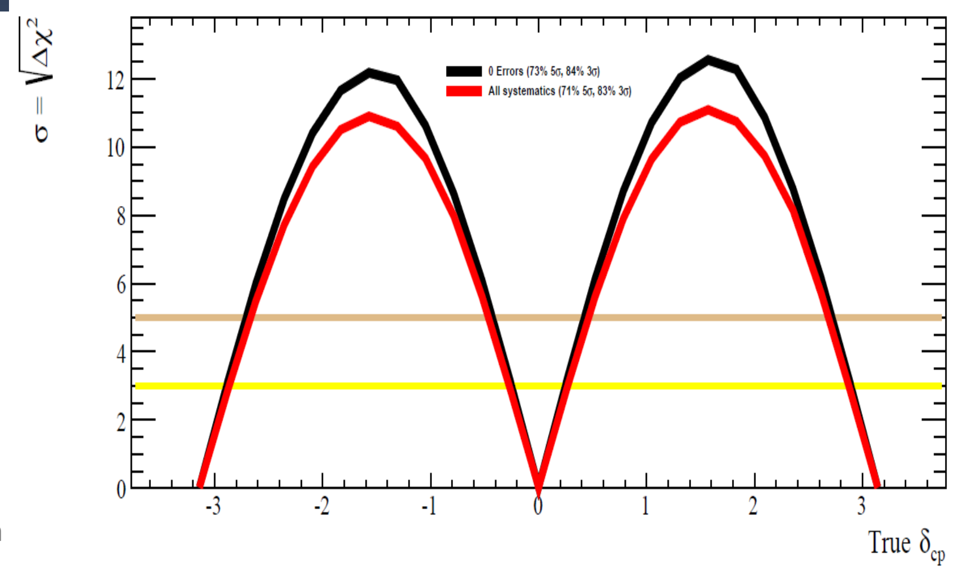
~5-10 years

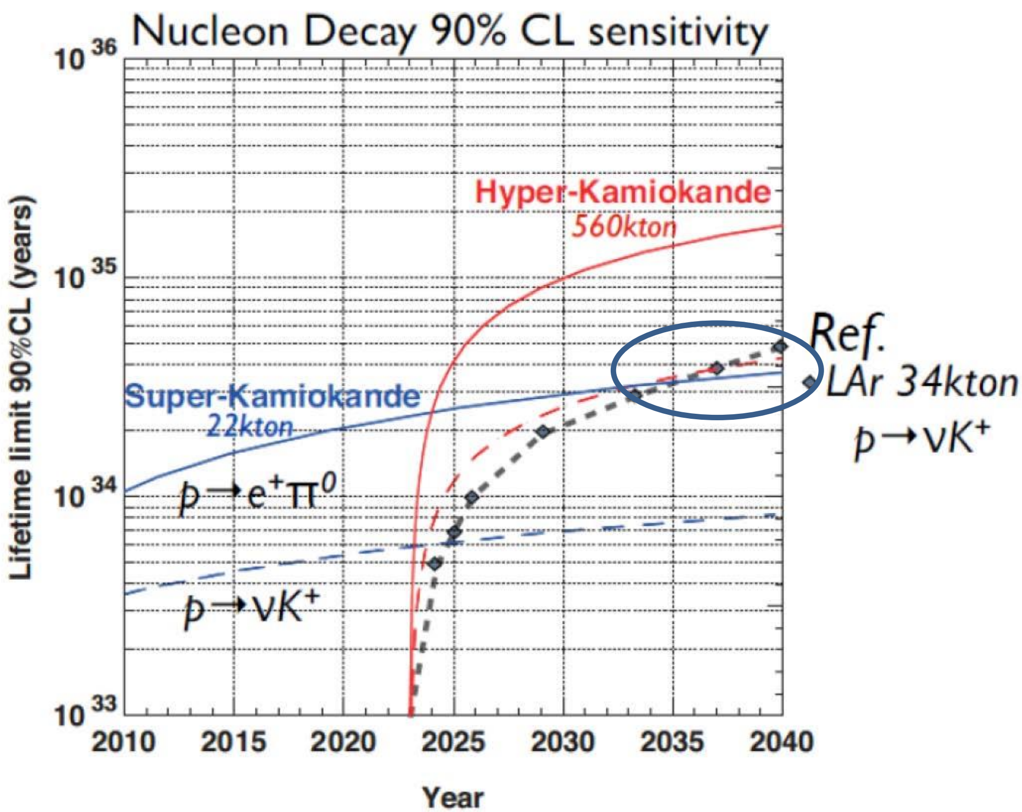
ELBNF 40KT

Run Mode	Signal Events δ_{CP} $-\pi/2$	0	$\pi/2$	Background Events ν_μ NC	ν_μ CC	ν_e Beam	ν_τ CC
Neutrino	1068	864	649	72	83	182	55
Antineutrino	166	213	231	41	42	107	33

Dominant error:
(anti) ν_e/ν_μ x-sections
as measureable:
56% 5σ ,76% 3σ
If use th calculations
(71% 5σ, 83% 3σ)





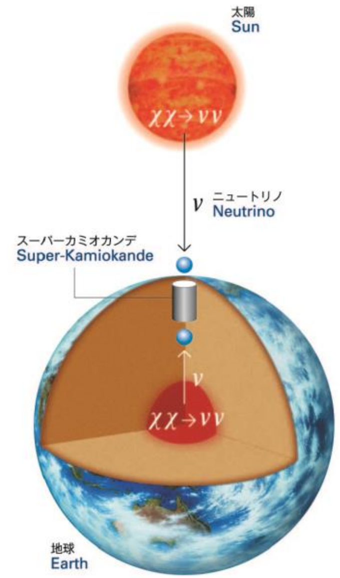


HyperK will push all existing limits (from SK) by factor 10-20

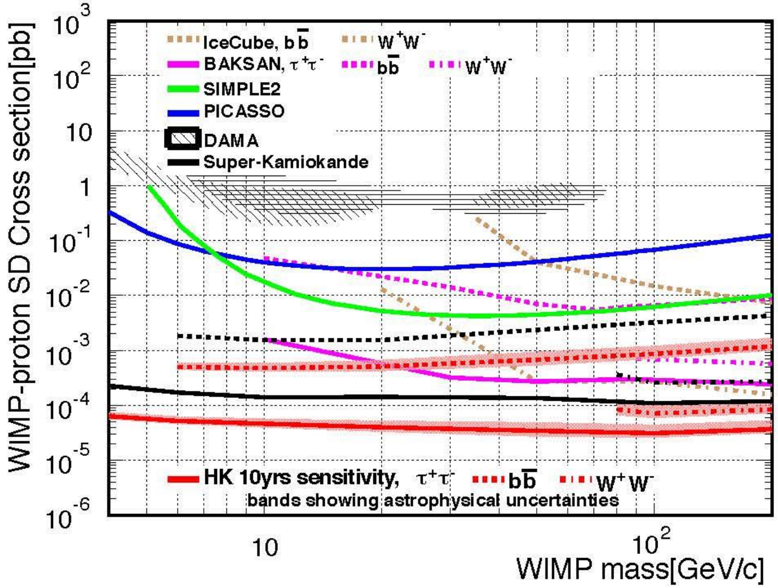
DUNE smaller; competitive for p → K+ν where efficiency of LArg pays off.

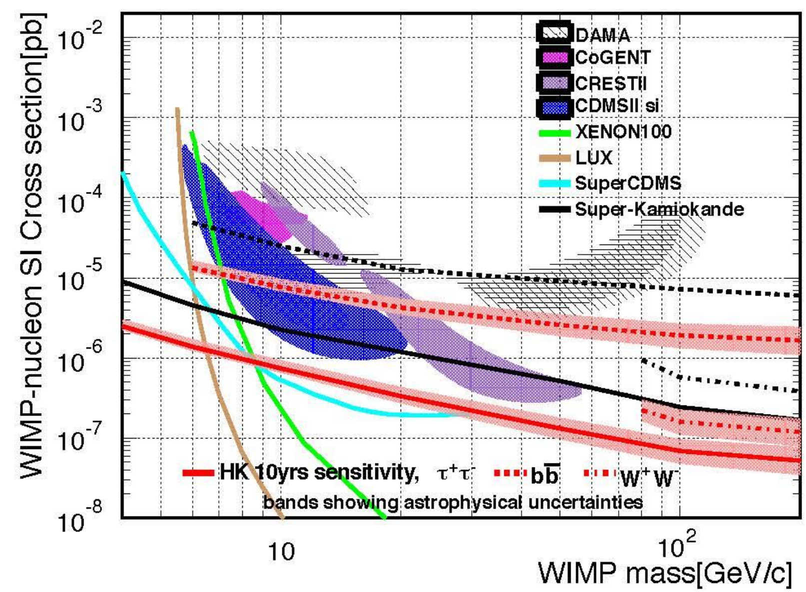
Based on arXiv:1501.03918 by ICFA Neutrino Panel

WIMP annihilation at Sun



SK updated results recently presented by Nakahata-san at Neutel 2015
HK sensitivity by far the best Spin Dependent (SD) and very competitive in the SI low WIMP mass region





Astrophysical neutrinos

SUPERNOVAE

Mainly $\bar{\nu}_e$ from $\bar{\nu}_e\, p \rightarrow e^+\, n$

- Burst from galactic center (10 kpc)
  170,000 – 260,000 ν's
- Burst from Andromeda Galaxy
  30 – 50 ν's
- Supernova relic ν
  890 in 10 years

SOLAR NEUTRINOS

- ^{8}B ν from Sun
  200 ν's/day @ 7 MeV threshold

Allows detailed day/night studies

CONCLUSIONS

The T2K/NA61 program is extremely successful with great synergy between swiss groups → discovery of $\nu_\mu \rightarrow \nu_e$ oscillation!

JPARC accelerator improvements and prospects are now impressive.
Experiment will run another factor 9 (approved) or more over present exposure
→ determination of mass hierarchy and even first evidence for CPV are possible
Upgrade of near detector very well justified and being organized (we lead)

HyperK is an upgrade by a further factor 25. It is highly placed on Japan road map.
Swiss groups (UNIGE, UNIBE) are well engaged in the preparation of the CDR and look forward to major contribution to electronics, DAQ, trigger
Unlike T2K vs SK, this implies full participation to beam and non-accelerator program

HYPERK is a highly competitive for the study of neutrino oscillations (discovery of CPV)
\+ unparalleled program for proton decay, supernovae observations (near and relic) and other astrophysical sources.

DUNE and HyperK are certainly complementary and match differently the competence of the swiss neutrino groups

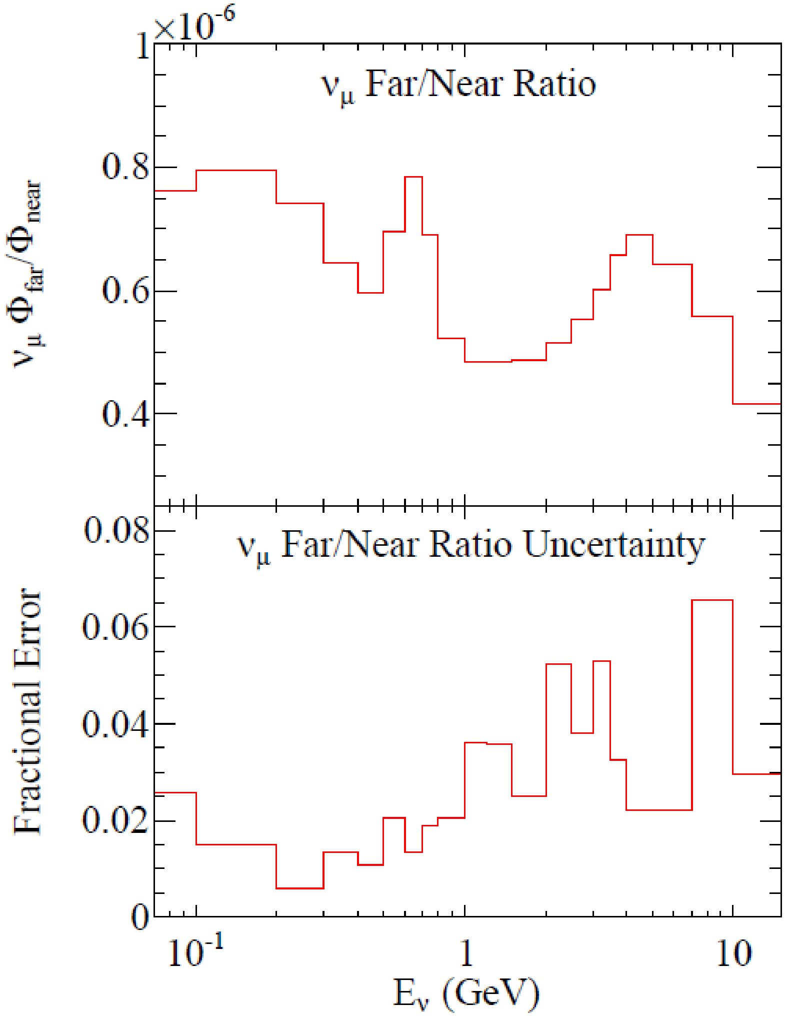
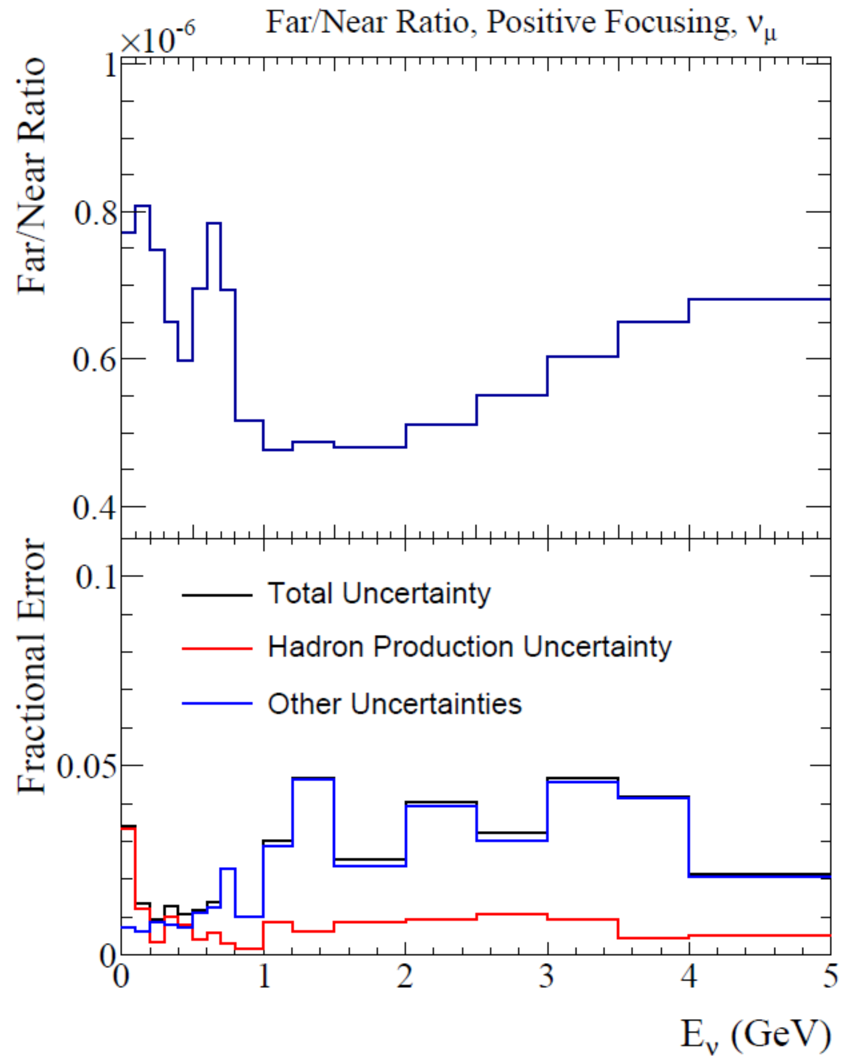


FIG. 45: The far/near ratio for the ν_μ flux prediction (top) and the uncertainty on the ratio (bottom).

2012 with 2007 NA61 data



2015 version with 2009 NA61 data

NA61 performance can be further improved, see Silvestro's talk tomorrow

What is missing?

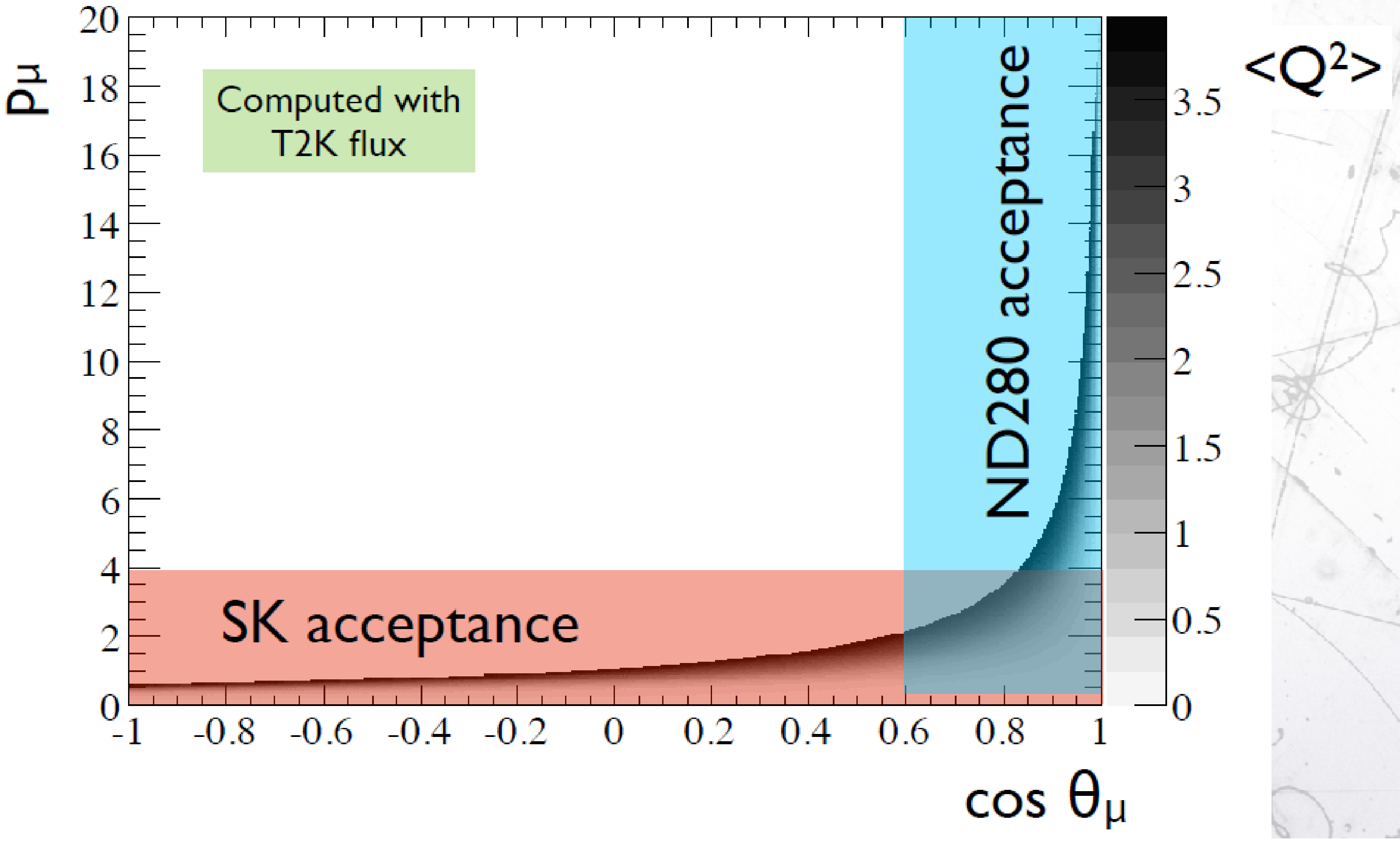
Present systematics in prediction of number of far detector events is presently of order 8.8%.

Neutrino beam mode $\nu_\mu \to \nu_e$ uncertainties:

Error source [%]	$\sin^2 2\theta_{13} = 0.1$	$\sin^2 2\theta_{13} = 0$
Beam flux and near detector	2.9	4.8
(w/o ND280 constraint)	(25.9)	(21.7)
ν interaction (external data)	7.5	6.8
Far detector and FSI+SI+PN	3.5	7.3
Total	8.8	11.1
	signal	background

11% uncertainty on 15% background is 1.7% of signal -- small compared with 8.8% on signal (this is dominated by intrinsic beam ν_e)

➔ **In this particular beam, Water Cherenkov is well suited** to do the $\nu_\mu \to \nu_e$ oscillation measurements



Federico Sanchez

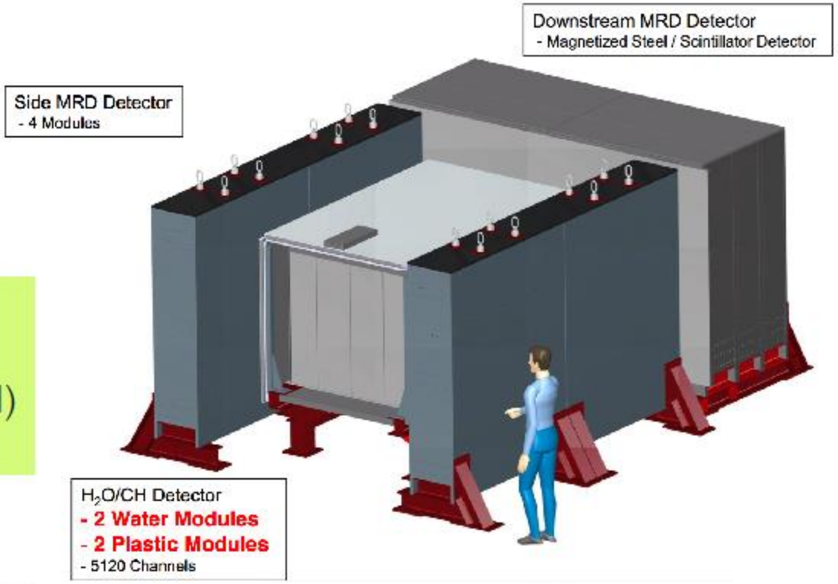
3% precision H_2O / CH x-section ratio

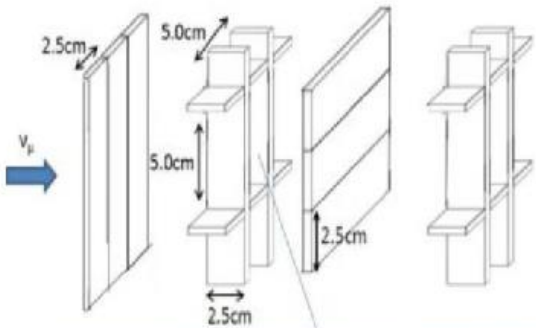
Wagasci

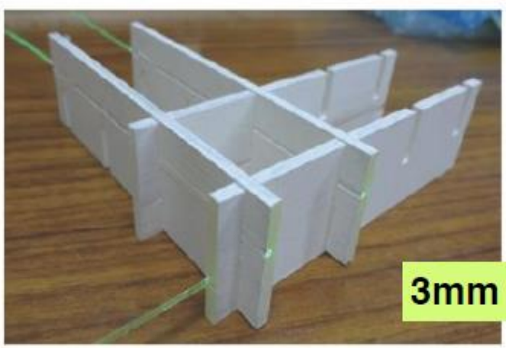
Wagasci collaboration

'The B2 experiment'

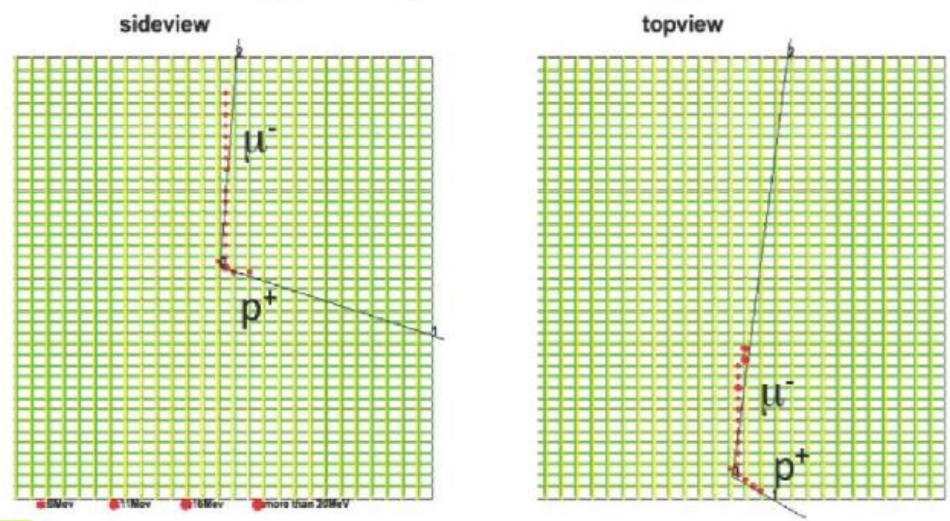
- 3D scintillator grid filled with water
- Side MRDs and end MRD (magnetized)
- Excellent phase space coverage







3mm thick



See talk on Tuesday