Swiss participation in future long baseline neutrino experiments

CHIPP Meeting, USI Lugano, August 22, 2016

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v2

Neutrino physics in Switzerland

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Neutrino white paper

14 November 2015

Experimental neutrino physics: Switzerland in the global context, a white paper

Editors: L. Baudis, A. Blondel, A. Ereditato, T. Montaruli, A. Rubbia, N. Serra

As far as the financial investments in R&D and detector construction **for the period 2016-2020** are concerned, we define priorities such that:

A) first priority for Swiss funding, notably FLARE, should be given to the approved WA105 and SBN projects.
B) The Swiss involvement in DUNE will be developed in the coming years within the international context. A coherent Swiss DUNE proposal for FLARE will be eventually submitted.
C) The evolution of the Hyper-K project might also lead to a proposal to be submitted to FLARE, which will propose upgrades of the T2K experiment and participation to the Hyper-K construction.
D) After approval by CERN and pending more precise timescales, SHiP will also request support from FLARE.
E) The evolution of a ton-scale double beta decay experiment might also lead to a proposal to be submitted to FLARE.

Focused on long baseline programme

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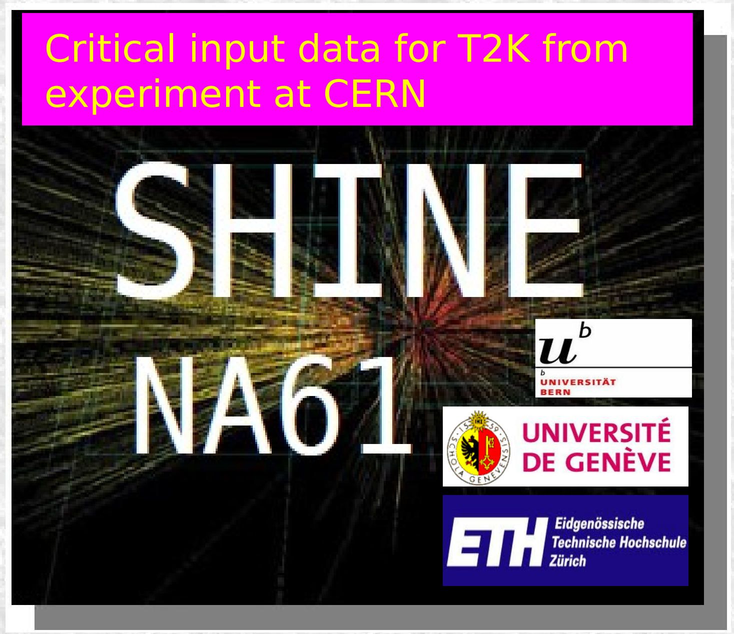
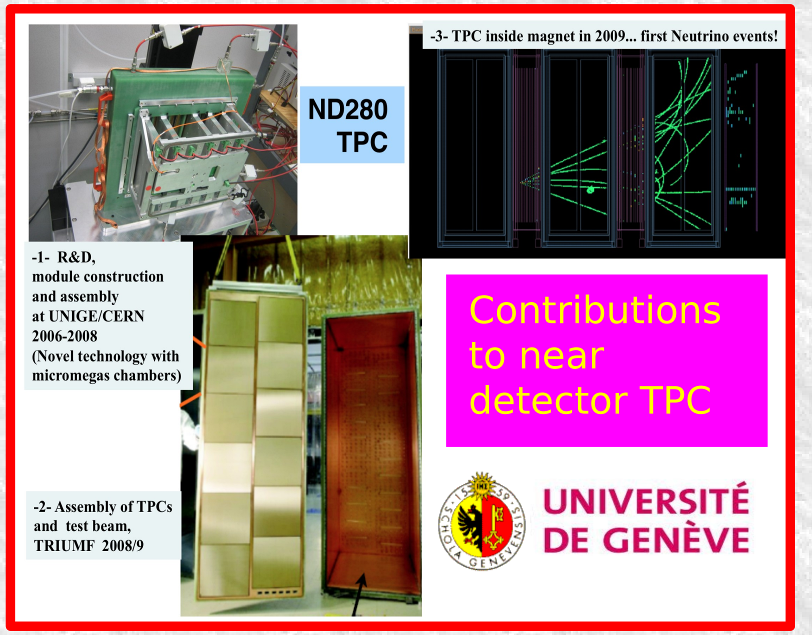
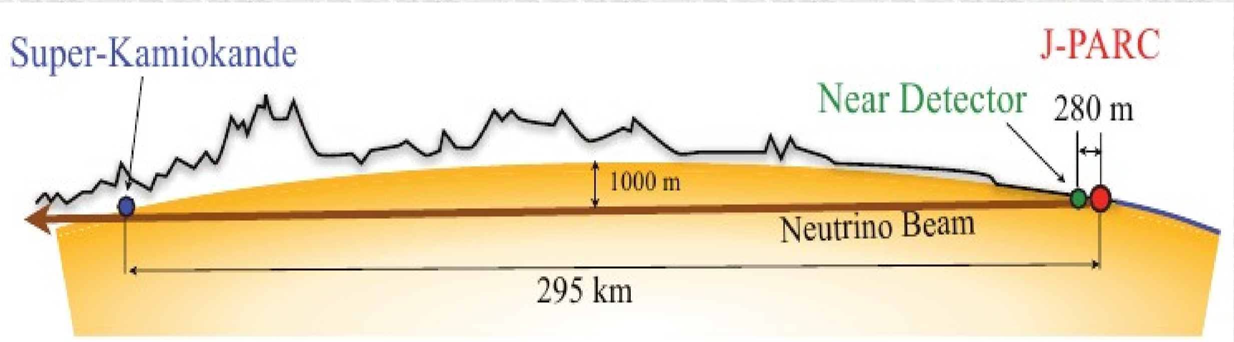
The running T2K experiment

- A coherent strategy among Swiss groups defined in 2006 has enabled significant and very visible contributions to the T2K experiment:

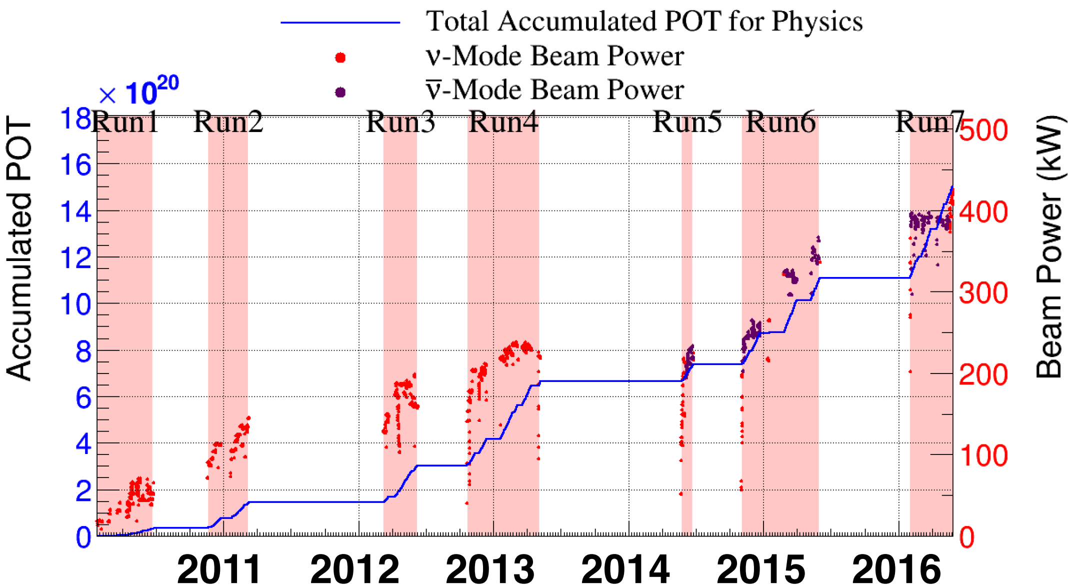






Study of muon neutrino and antineutrino disappearance

Search for electron neutrino and antineutrino appearance in accelerator beam

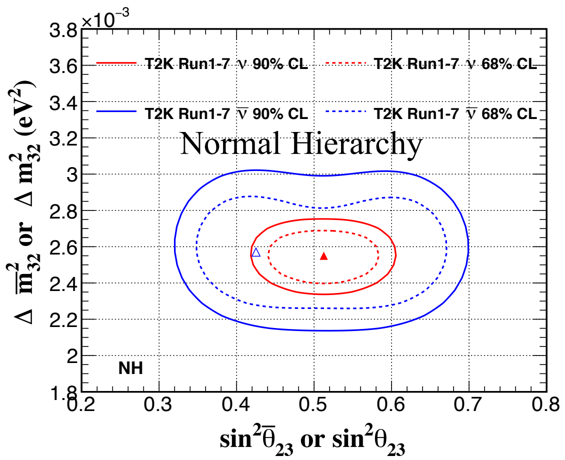


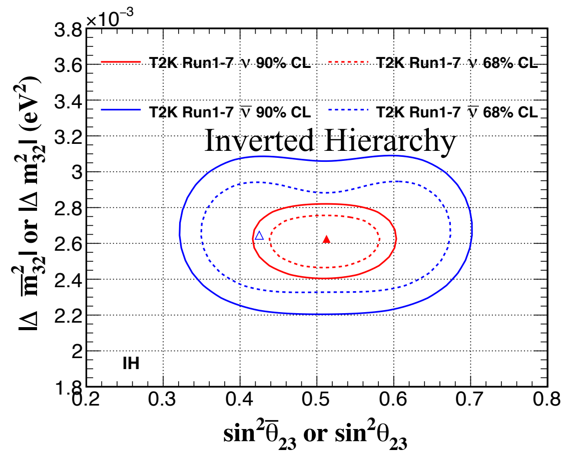
Beam power record : 400 kW

Total POT = 1.5 x 10^{21} pots

Main results of T2K

Study of muon neutrino and antineutrino disappearance





$\Delta\bar{m}^2_{32} = [2.16, 3.02]\times10^{-3} eV^2 (NH)$ at 90% CL

$\sin^2\bar{\theta}_{23} = [0.32, 0.70] (NH)$ at 90% CL

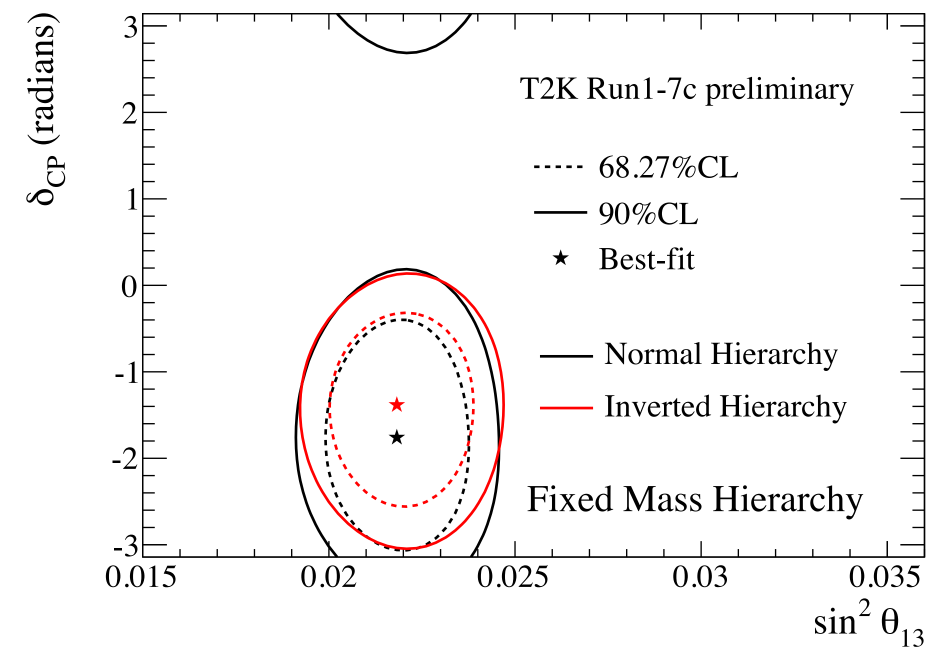
$\Delta m^2_{32} = [2.34, 2.75]\times10^{-3} eV^2 (NH)$ at 90% CL

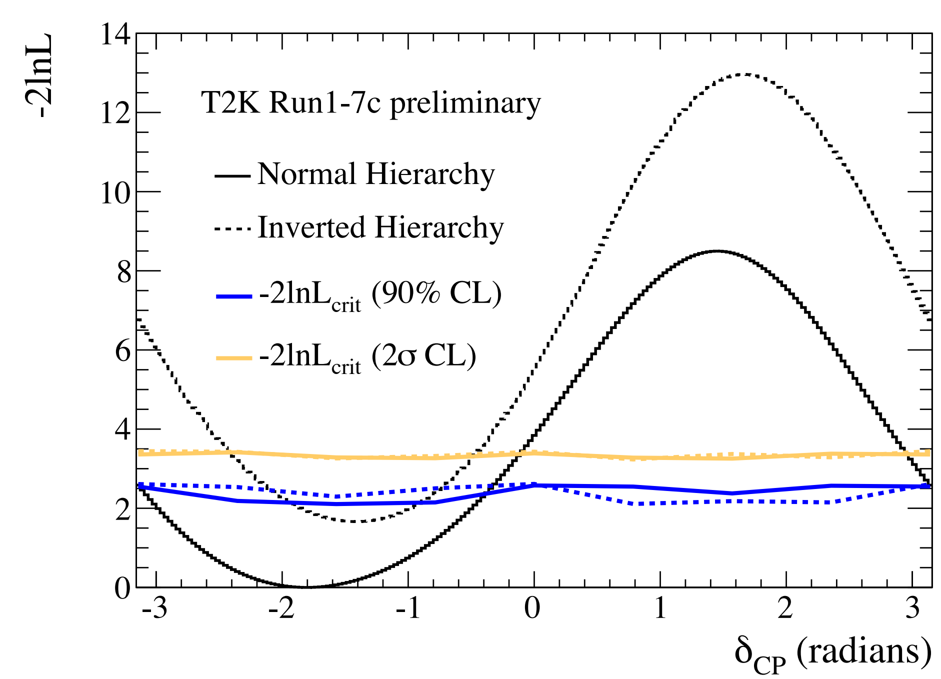
$\sin^2\theta_{23} = [0.42, 0.61] (NH)$ at 90% CL

No hint for CPT violation

Search for electron neutrino and antineutrino appearance

T2K Result with Reactor Constraint
$(\sin^2 2\theta_{13} = 0.085 \pm 0.005)$





Consistency between reactors and T2K

Combined result within 3 neutrino flavours prefers the $\delta_{CP} \approx -\pi/2$ region and normal hierarchy

$$\delta_{cp} = [-3.13, -0.39](NH), [-2.09, -0.74]\ (IH) \text{ at } 90\%\ CL$$

D. Sgalaberna, Diss. ETHZ No. 23350 (2015)

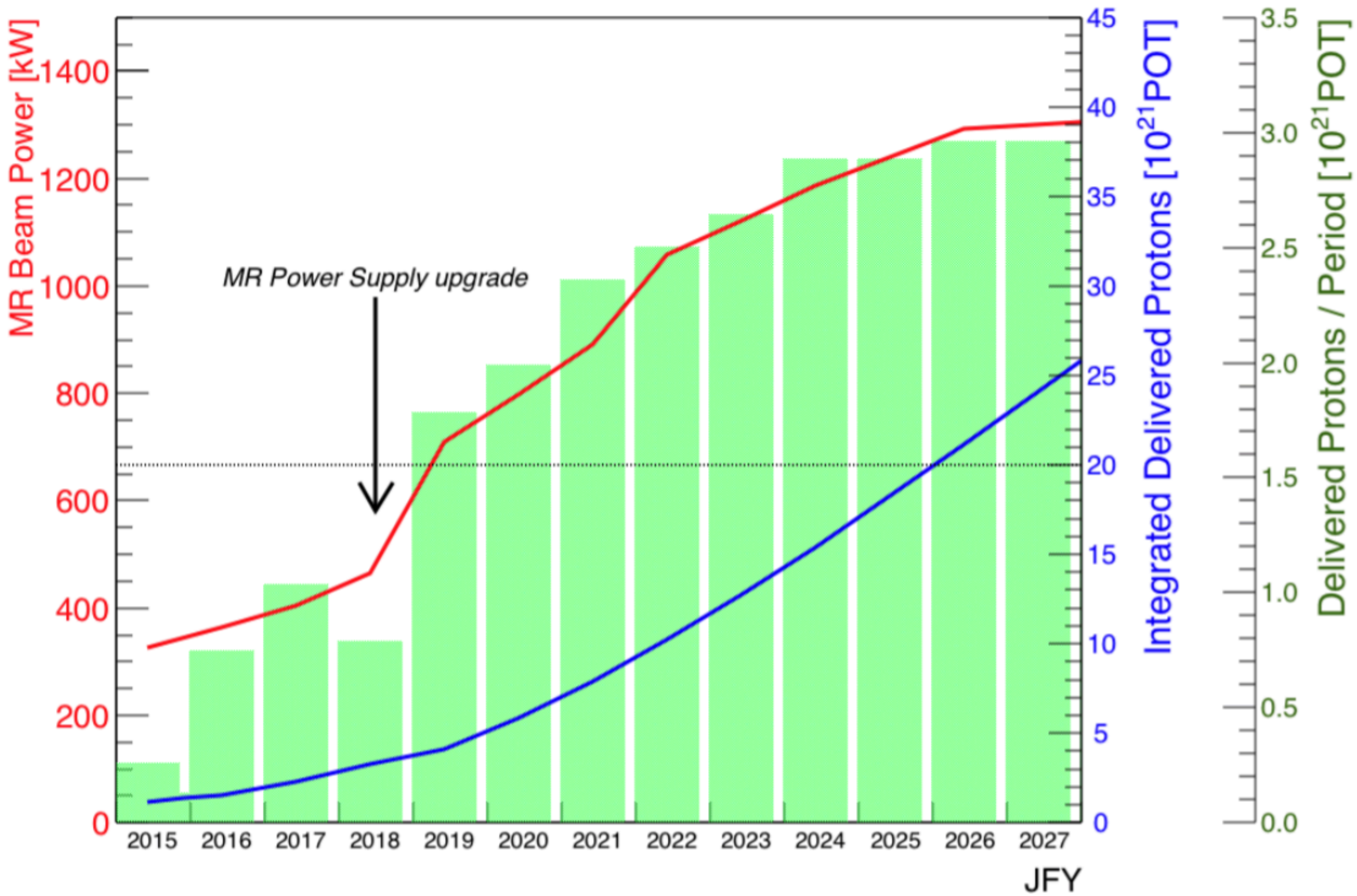
Long term prospects for T2K

- *T2K accumulated statistics in 5 years (2011-2016) is 1.5x10^{21} pots*

  Record beam power 400kW

- *Approved T2K statistics is 7.8x10^{21} pots which is x5 more than presently accumulated*
- *Thanks to proton beam power upgrade ($50M for new magnet power supplies), **expect to reach 750 kW and T2K approved goal by year 2020***

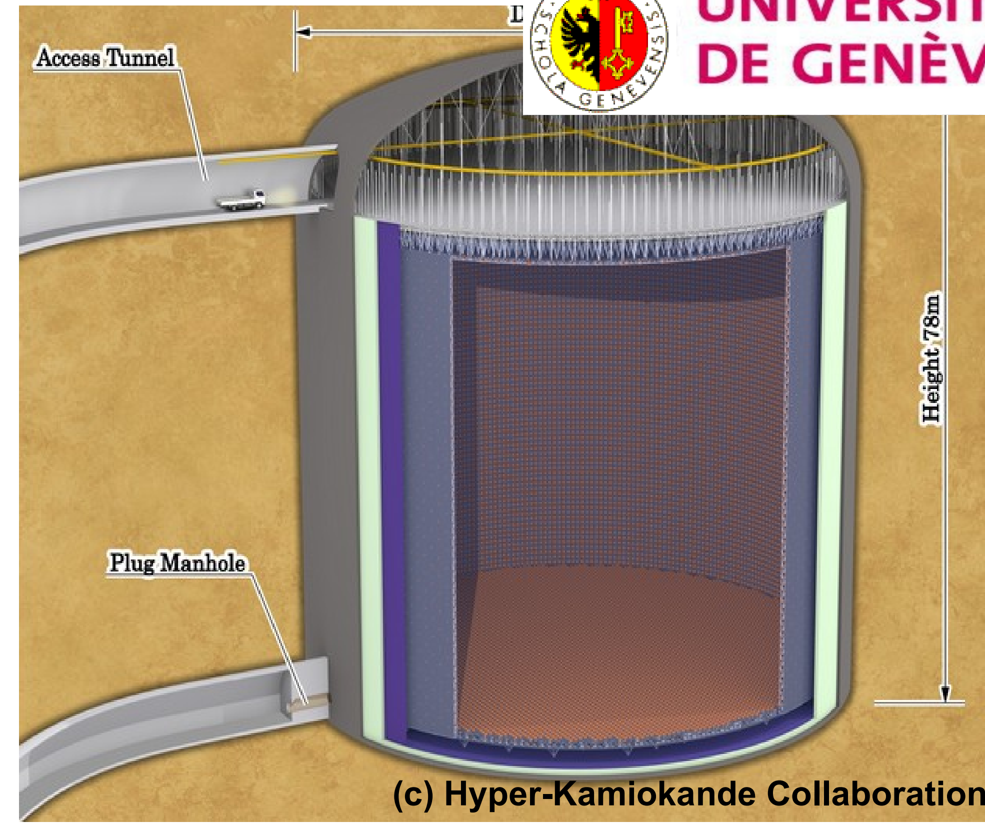
JPARC neutrino beam power forecast



- ***New proposal T2K-II**: assume that JPARC MR accelerator will continue to be upgraded beyond 2020 to reach **1.3MW by 2026**; then extend T2K statistics to 20x10^{21} pots by 2026*

⇒ *T2K-II aims at reaching 3σ sensitivity for special case δ_{CP}=-90º*

HyperKamiokande



Now similar to LAGUNA-LBNO WC design

New design for HK submitted last March:

Significant reduction for the cost of the project
→ 2 vertical tanks and mass from 1Mton to 0.52Mton (fiducial 190 kton per tank)
Staging (first tank ≈ 2026, second tank ≈ 2033)

New assumption of JPARC beam power:

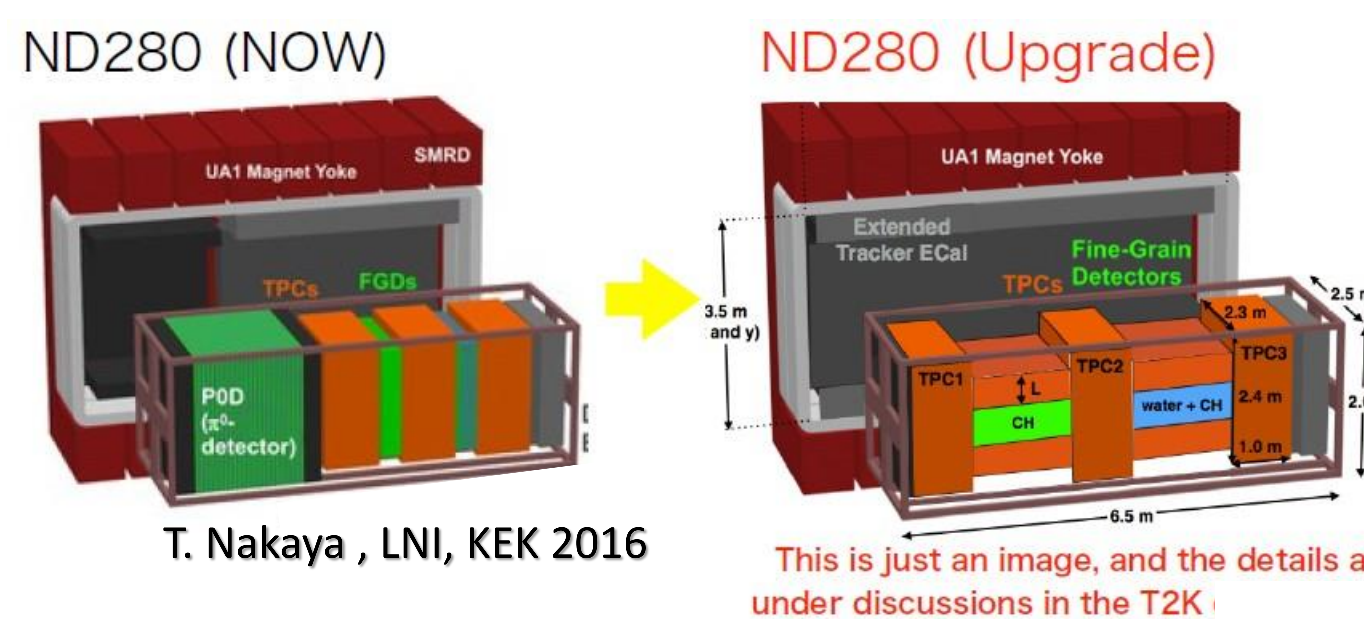
Continuous beam upgrade at JPARC
Reach 750 kW by 2020 and 1.3 MW by 2026 (?)

Near detector ND280 upgrade:

Reduction of systematic errors

New Intermediate detector @ 1.2km:

New infrastructure outside J-PARC
New kton-scale WC detector
@ ≈120m depth
Two options: NuPRISM / TITUS

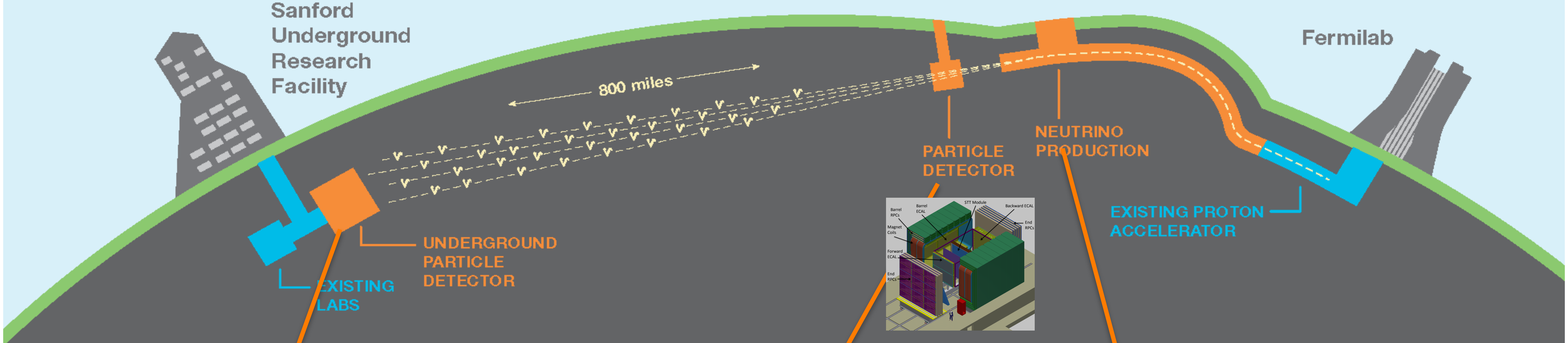


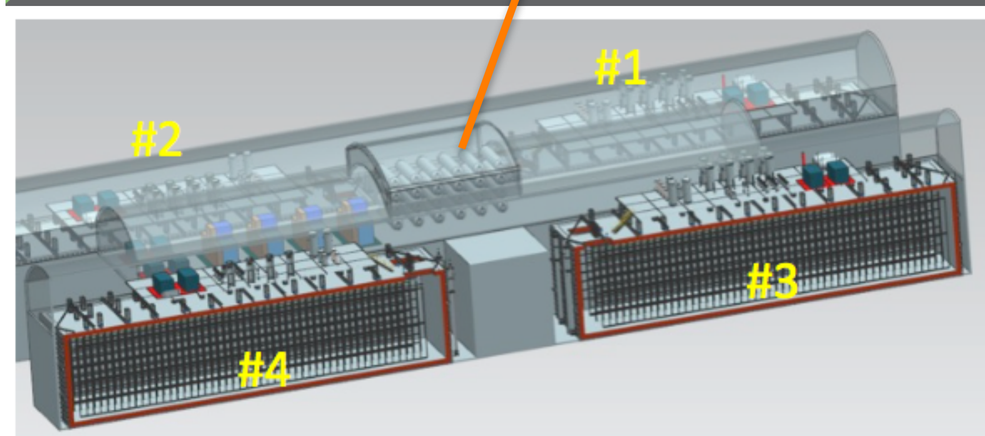
⇒ *Covers 60% of CP phase space at >5σ in 10 years @ 1.3MW*
(*For δ_{CP}=-90º: 8σ C.L. and precision measurement of ≈±20º*)

DUNE/LBNF

≈890 members, ≈160 institutions from 29 countries; US deeply intertwined with CERN

"Long-Baseline Neutrino Facility (LBNF) and Deep Underground Neutrino Experiment (DUNE) Conceptual Design Report Volume 2: The Physics Program for DUNE at LBNF" (arXiv:1512.06148)





high precision near detector complex

Wide band, high purity ν_μ beam with peak flux at 2.5 GeV operating at $\sim$1.2 MW and upgradeable

- four identical cryostats deep underground
- staged approach to four independent 10 kt LAr detector modules
- Single-phase and double-phase readout under consideration

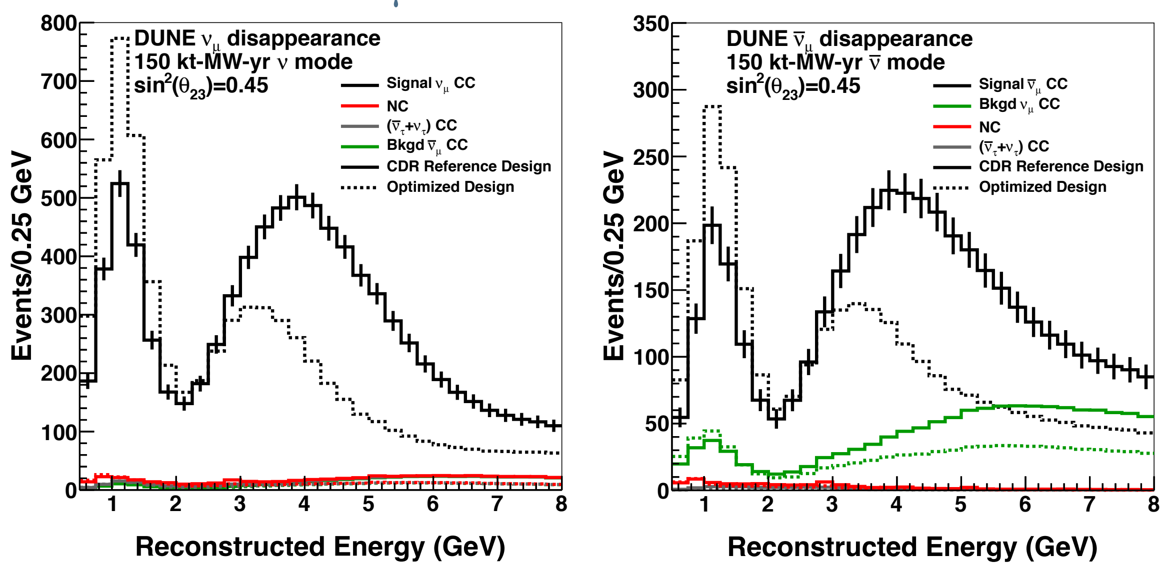
Present MI beam power 650kW and 700kW in 2017

DUNE long baseline oscillations

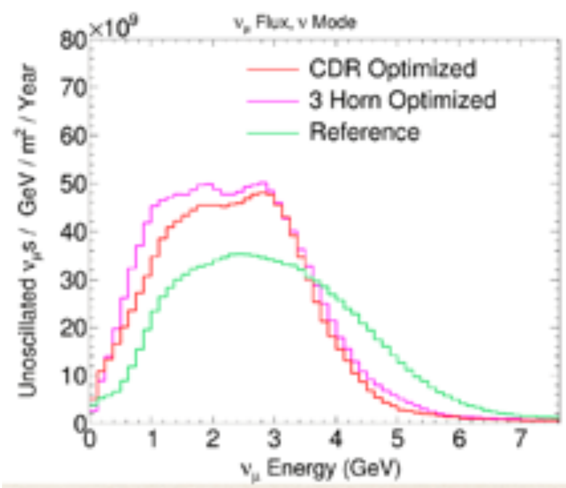
- ***Measure neutrino spectra at 1300 km in a wide-band beam***

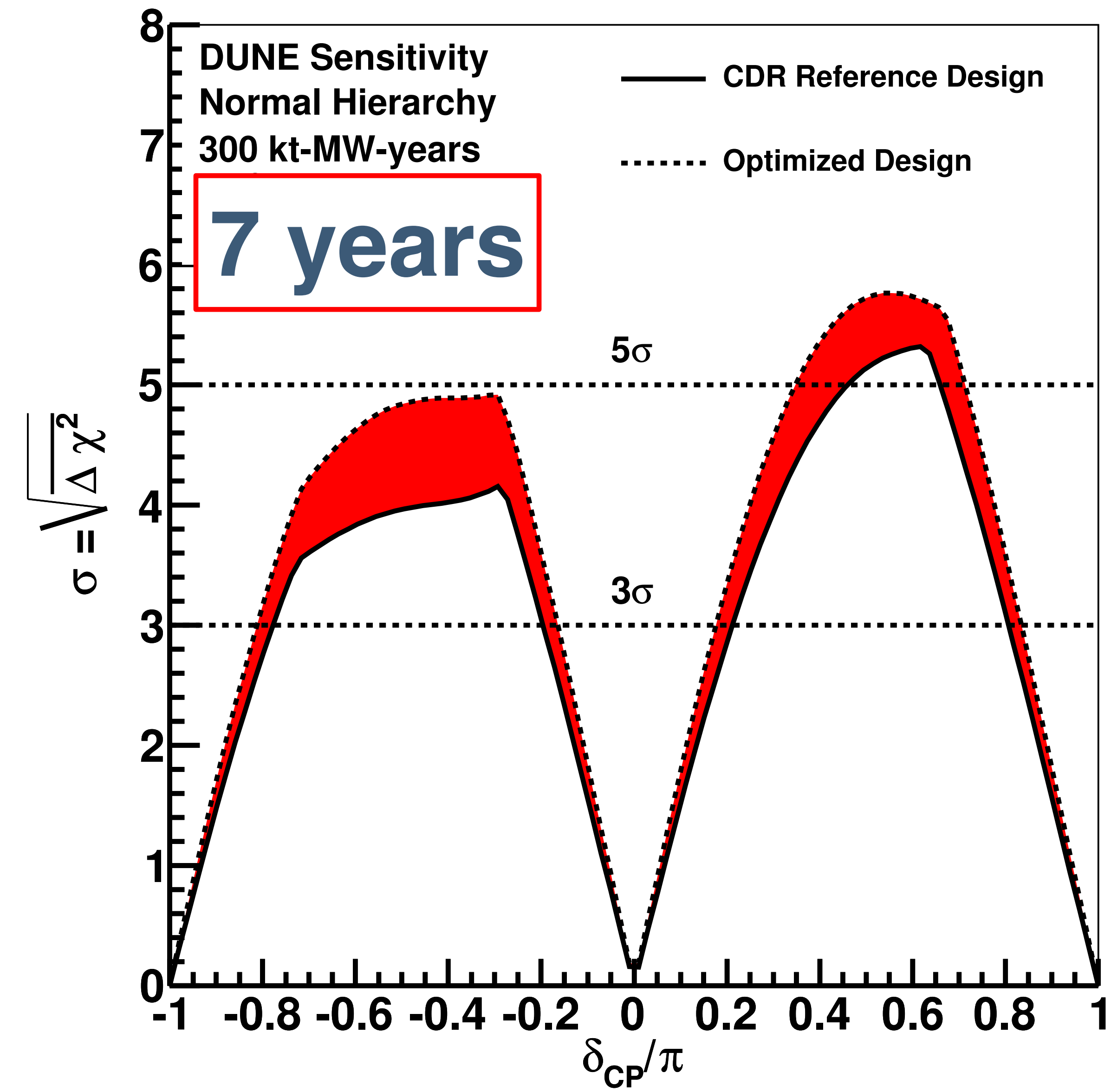
Determine MH and θ_{23} octant, discover CPV, test 3 flavour paradigm and search for non-standard interactions in a single experiment

ν_μ disappearance



Optimised neutrino beam profile to cover 1st&2nd oscillation maxima



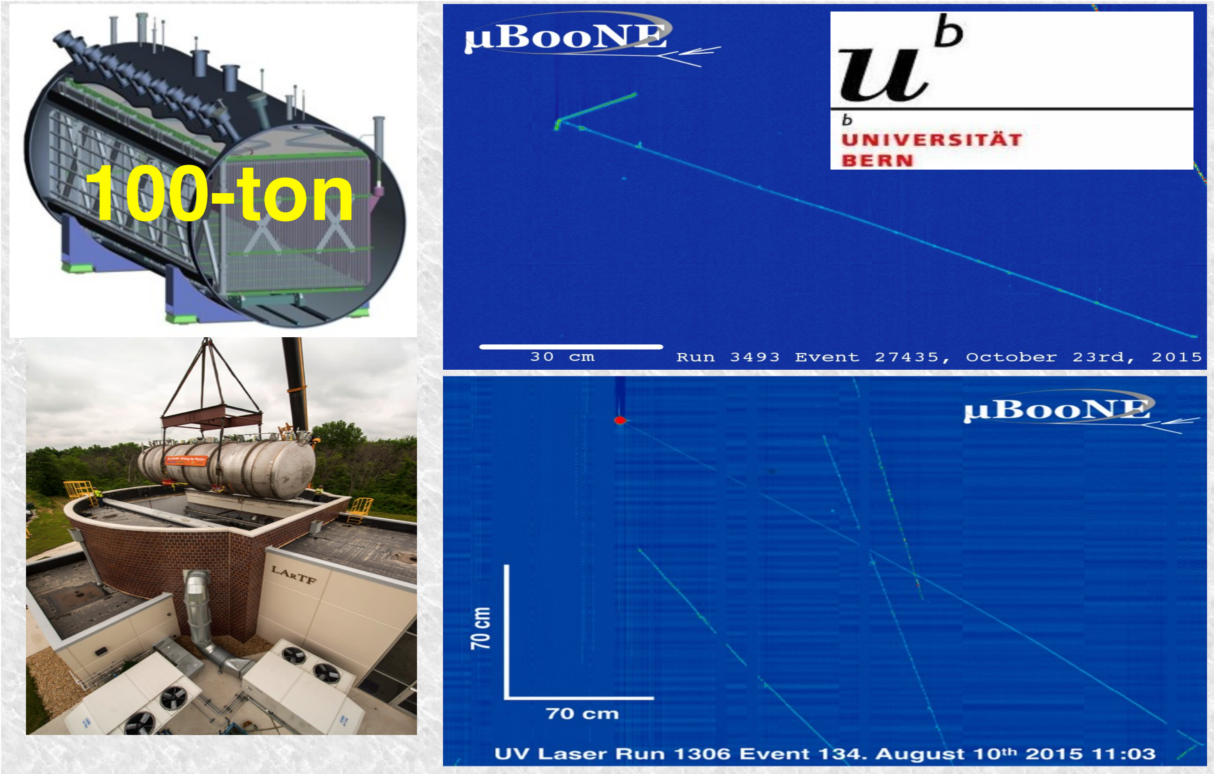


⇒ *Covers 50% of CP phase space at >5σ in <u>12 years</u> @ 1.2MW For δ_{CP}=-90º: ≈8σ C.L. and precision measurement of ≈±10º* *(better than HK)*

Towards the DUNE detector

Short Baseline SBN@FNAL:

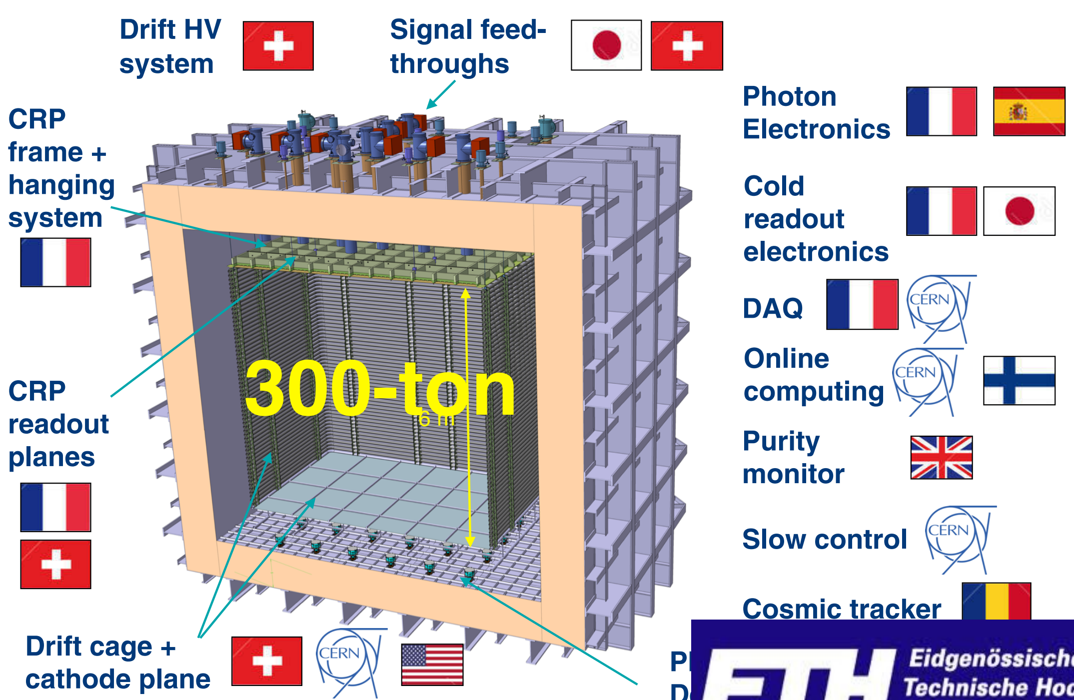
- *MicroBooNE running since Nov 2015 with excellent Booster neutrino beam performance → physics exploitation*
- *SBND near detector under construction to start data taking in 2018 to improve systematic errors and perform cross-section measurements*
- *Neutrino event reconstruction in LAr TPCs*



WA105/ProtoDUNE-DP @ CERN Platform

- *Innovative "dual phase" technology*
- *Construction and test of full-scale far detector components*
- *Precise calibration and calorimetry*
- *Major CERN infrastructure investment with new large extension of the CERN North Area and charged particle beams*
- ***Data taking in 2018 (constrained by LS2)***

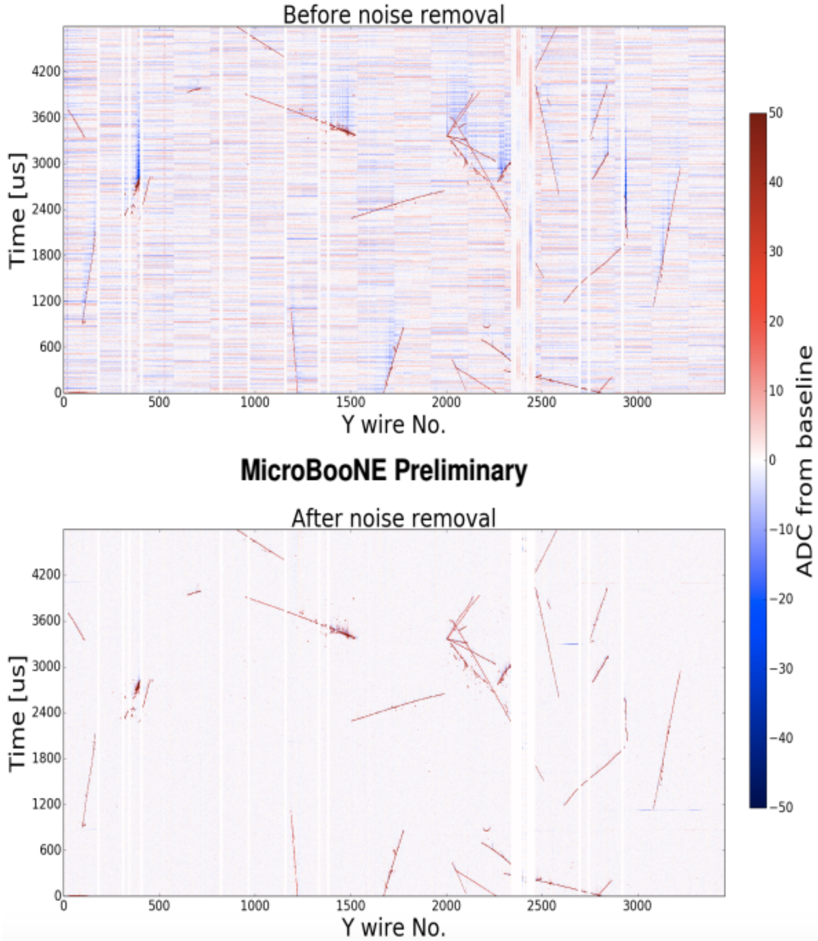
Dual phase protoDUNE (WA105/NP02)



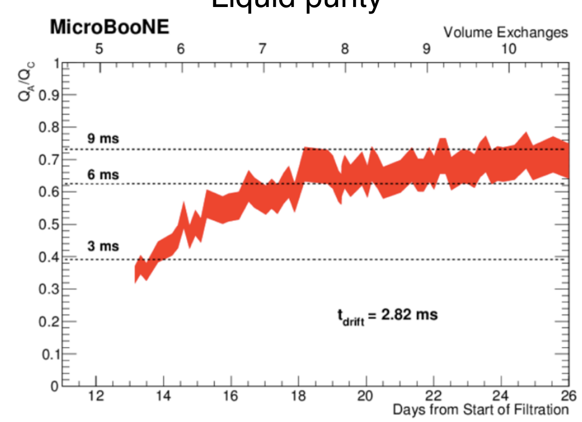
➡Critical path for the realisation of 10 kton FD modules at SURF, South Dakota

MicroBooNE status

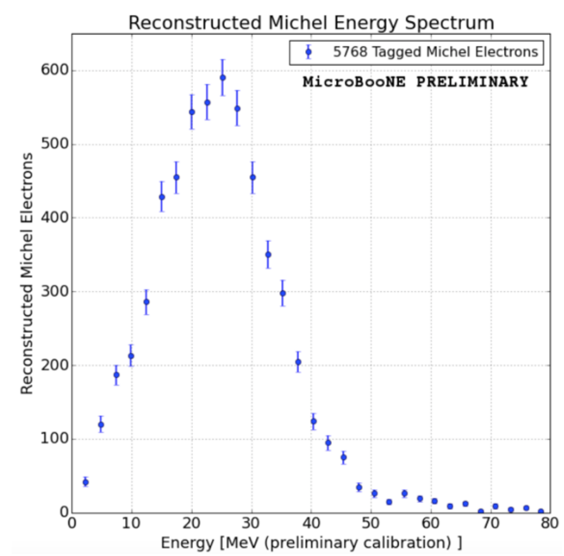
- Collected 3.4E20 POT good quality beam data (expected 2E20 for the first year !)
- 14 public notes with early results



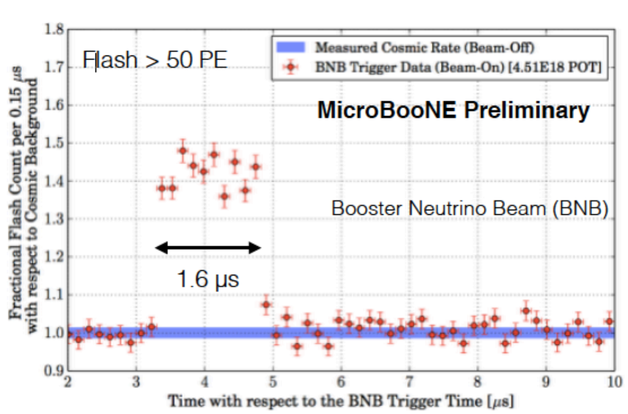
Liquid purity

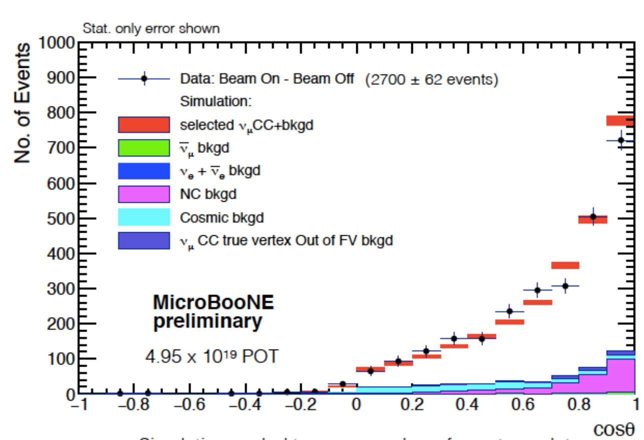


Michel electron reconstruction



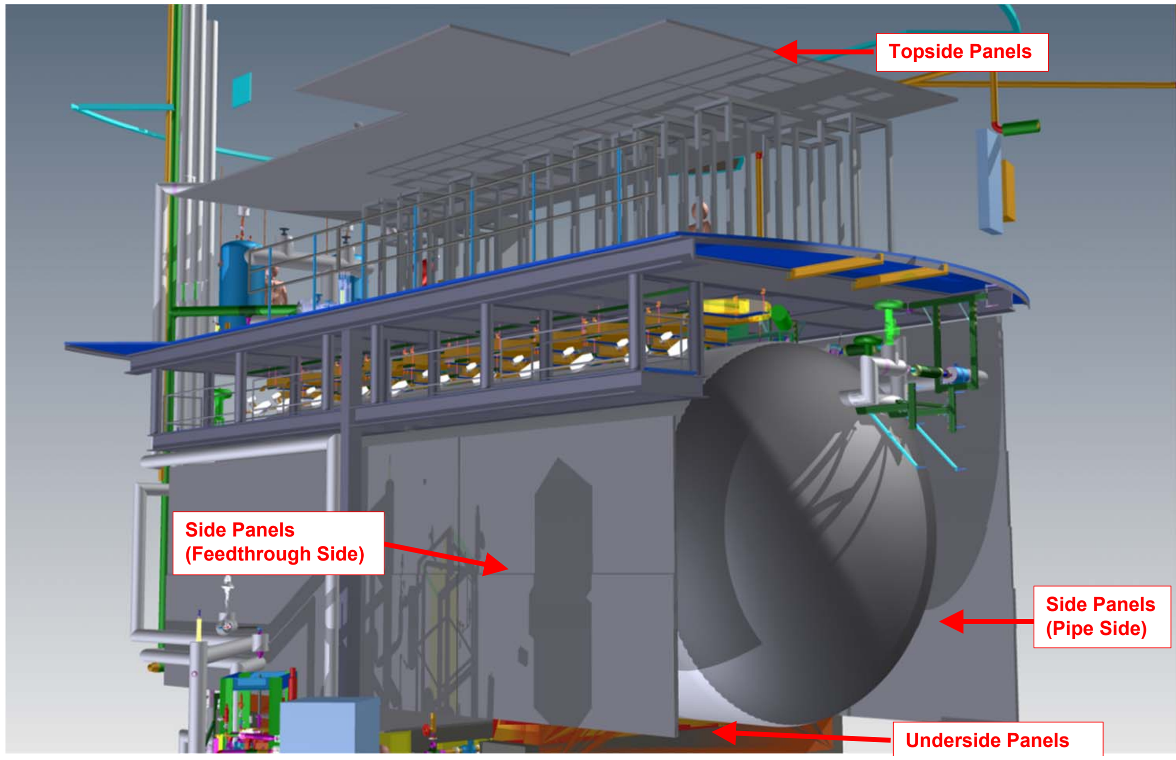
Automated identification of neutrinos and first differential distributions:

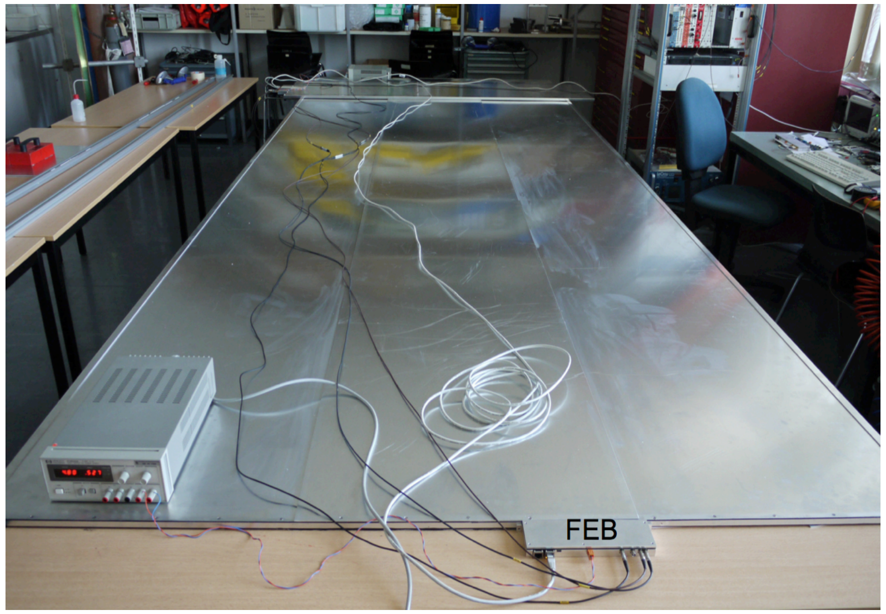




νμ CC

Cosmic ray tagging system being installed now !
All panels (150 m²) designed and produced in Bern



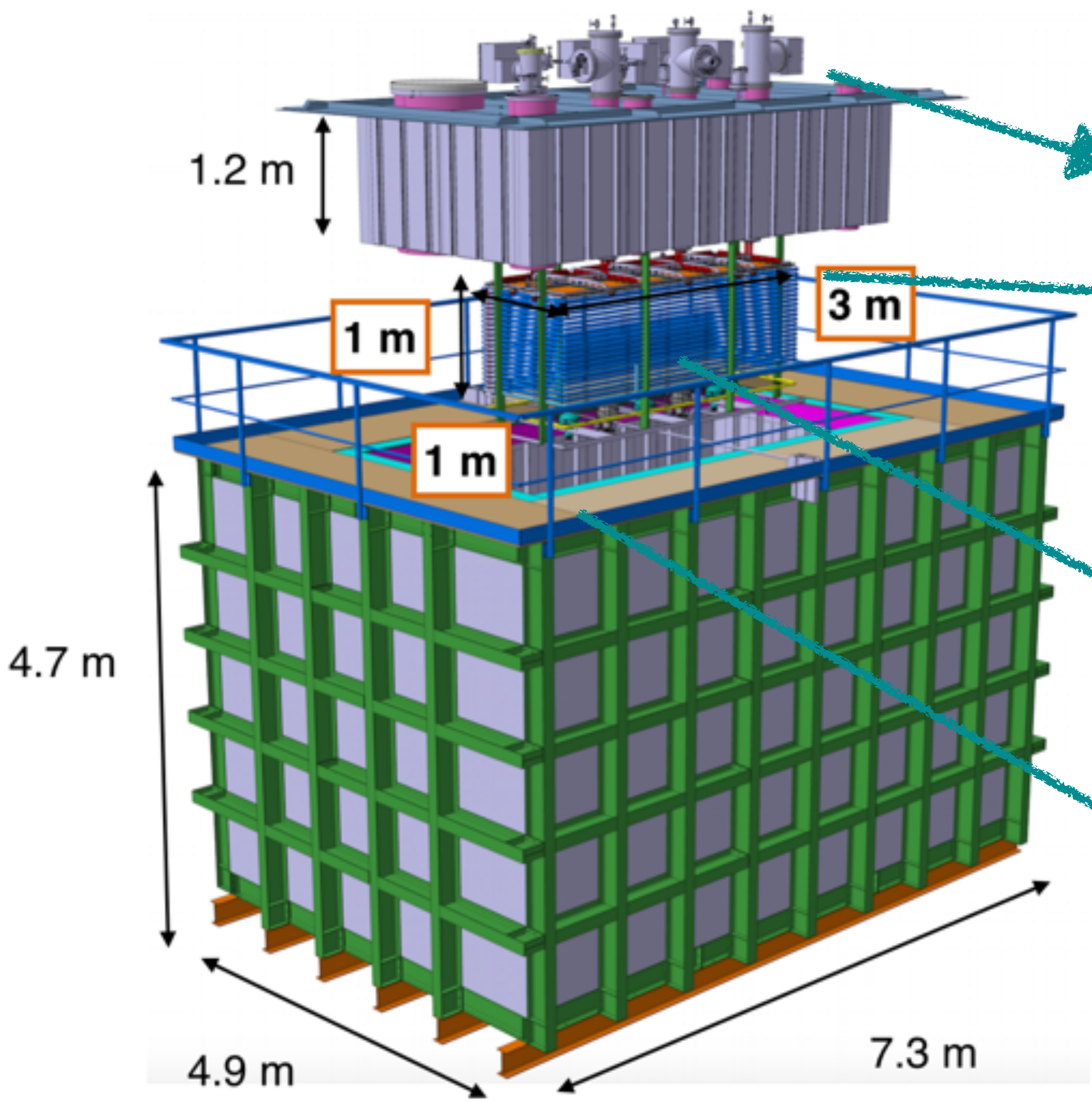


Also used for WA105/ProtoDUNE-DP

WA105 3x1x1 status

First 10-ton scale test of Dual Phase technology prior to ProtoDUNE-DP

First GTT membrane cryostat



Cryogenic operation: October 2016 (on schedule)

Financial resources and requests

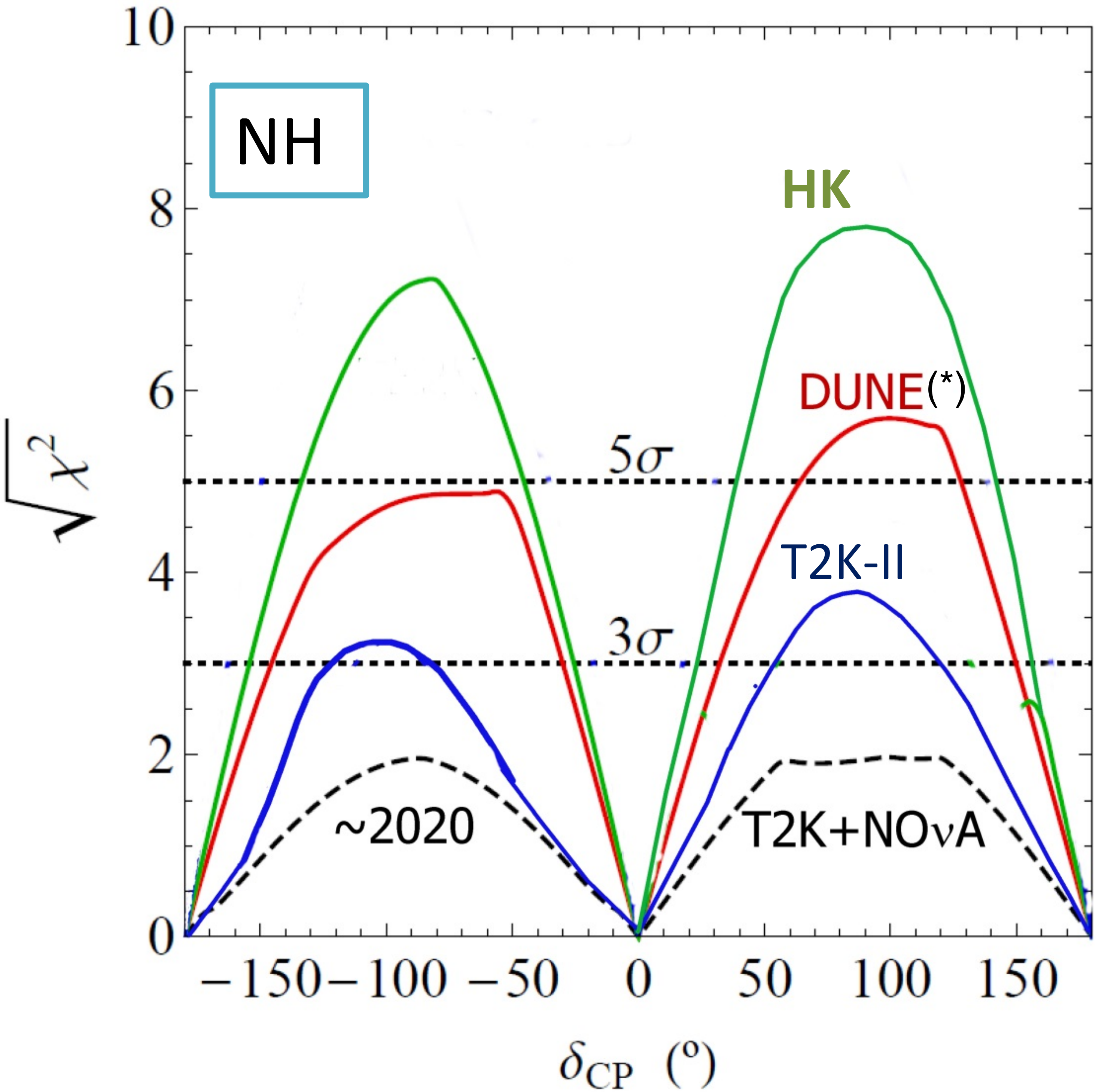
Table compiled from the CHIPP Tables 10.08.2018:

		2013	2014	2015	2016	2017	2018	2019	2020
Neutrino	SBN	0	0	325	125	945	615	315	90
Neutrino	NA61/T2K/NP05	132	132	216	214	450	550	600	600
Neutrino	WA105/ProtoDUNE	331	382	290	576	650	700	200	50
Neutrino	**TOTAL**	463	514	831	915				

- *Steady increase of FLARE funding for neutrino pillar during the period 2013-2016; still below the guideline of ≈1.3MCHF/year*
- *Since no FLARE call is foreseen in 2018, SBN and WA105 intend to submit two requests in November 2016 to cover the total of expenditures for 2017 & 2018.*
- *The WA105/ProtoDUNE-DP detector must be constructed before and commissioned in spring 2018 due to the constraints from LHC LS2 → no delay is possible.*
- *The NA61/T2K/NP05 requests beyond 2018 are to be considered in the context of the succession of Prof. Blondel.*
- *We anticipate that DUNE construction funds will be requested in 2018 and beyond.*

Paths towards a CPV discovery

M. Mezzetto @ Neutrino 2016



(*) DUNE CPV sensitivity for 12 years @1.2MW is similar to that shown for HyperK

T2K & NOvA around 2020:
T2K 8x10^{21} pots (now 1.5x10^{21})
NOvA 3+3 years

T2K-II by 2026 (?):
20x10^{21} pots with 1.3MW J-PARC beam and reduction of systematic errors

DUNE (2026→):
7 years of running (*)
1.2 MW for MI proton beam
40kton far detector
2% systematic uncertainties

HyperKamiokande (2026→):
10 years of running
1.3 MW for JPARC proton beam
40% PMT coverage
3% systematic uncertainties

Summary

- Neutrinos – and flavour oscillations – are an exciting field and provide so far the only evidence for physics beyond the Standard Model *("at the moment we know more about the Higgs than we do about neutrinos" – Ian Shipsey, concluding talk at ICHEP2016)*

- A major scientific success of the Swiss groups of Bern, ETHZ and Geneva has been achieved in T2K over several years – producing discoveries, new measurements, and a large number of theses.

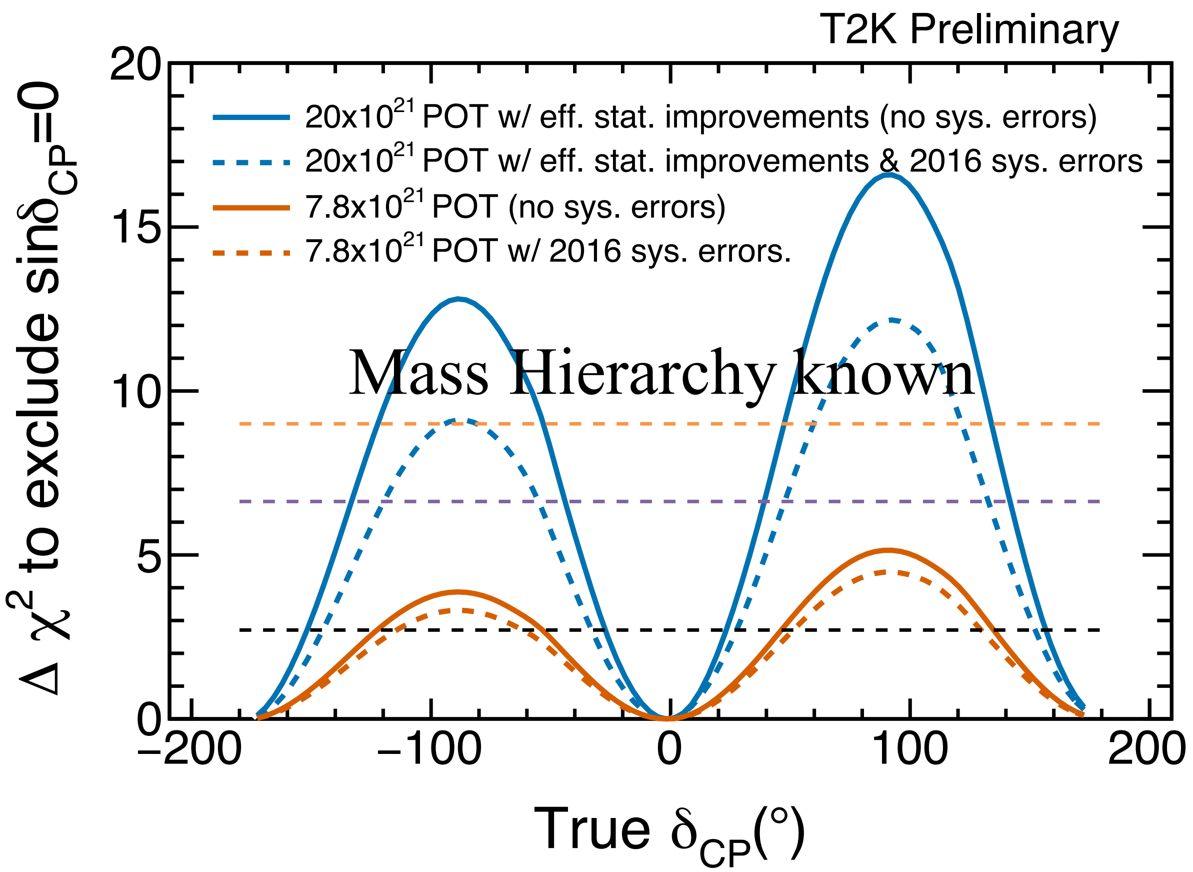
- A strong Swiss visibility in the T2K international project was possible thanks to a coherent effort among Swiss PIs. In 2006, we had the choice between T2K and NOvA and there was a decision to focus on one project.

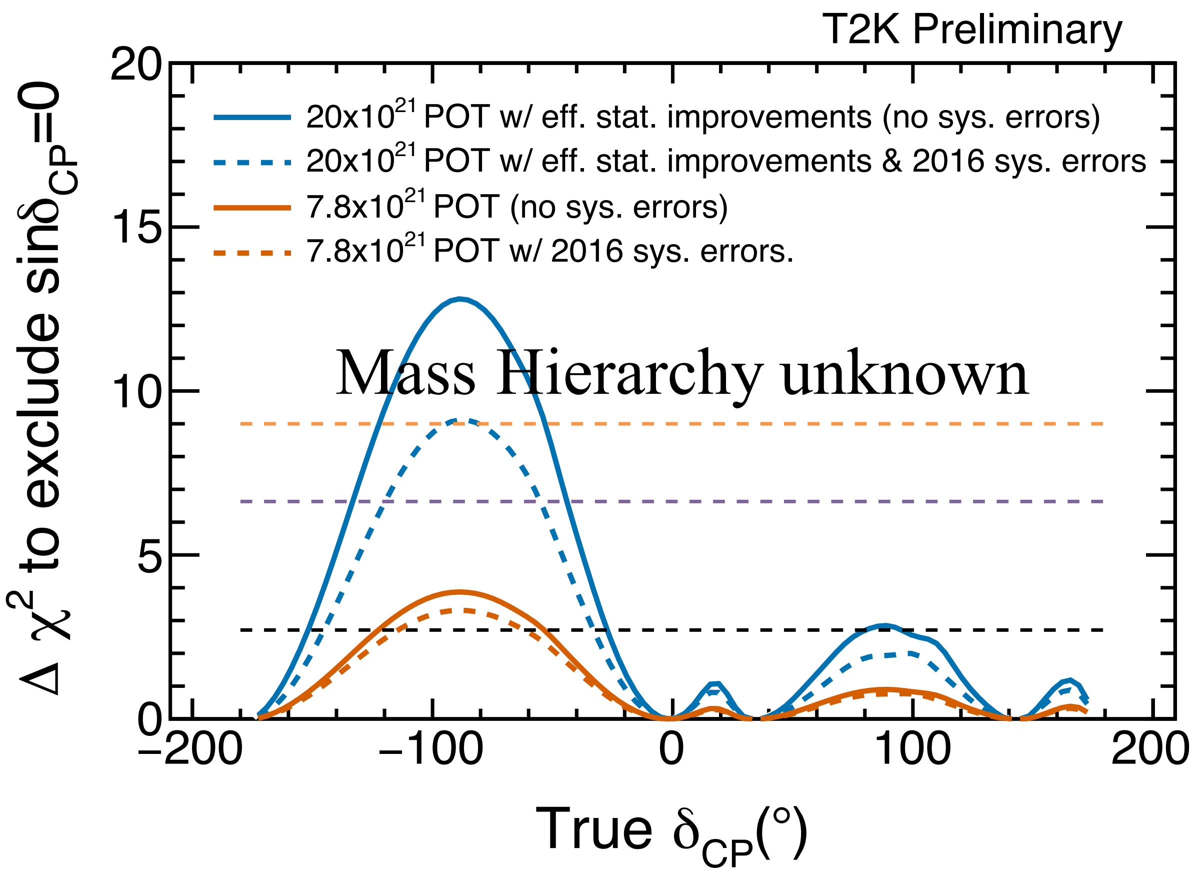
- A coherent Swiss plan was presented in the white paper and its implementation will allow to maintain this strong visibility coupled to scientific, technical and managerial leadership.

- The Swiss groups already play a crucial role and are currently very active on physics studies, detector R&D and collaboration management of future long baseline programmes. A further strengthening & consolidation with the groups of Basel, UniGE, and possibly others is recommended.

Backup

Physics potential of T2K-II





Assumes that favoured NH will hold

Needs reduction of systematic errors to reach 3σ sensitivity for special case of δ_{CP}=-90°

LBL science discovery potential

Rapidly reach scientifically interesting sensitivities

Physics milestone	Exposure kt · MW · year (reference beam)	Exposure kt · MW · year (optimized beam)
1° θ_{23} resolution ($\theta_{23} = 42^\circ$)	70	45
CPV at 3σ ($\delta_{\rm CP} = +\pi/2$)	70	60
CPV at 3σ ($\delta_{\rm CP} = -\pi/2$)	160	100
CPV at 5σ ($\delta_{\rm CP} = +\pi/2$)	280	210
MH at 5σ (worst point)	400	230
10° resolution ($\delta_{\rm CP} = 0$)	450	290
CPV at 5σ ($\delta_{\rm CP} = -\pi/2$)	525	320
CPV at 5σ 50% of $\delta_{\rm CP}$	810	550
Reactor θ_{13} resolution ($\sin^2 2\theta_{13} = 0.084 \pm 0.003$)	1200	850
CPV at 3σ 75% of $\delta_{\rm CP}$	1320	850

5σ CPV Discovery

Exposure is critical to cover the full science exploitation!

What if δ_{CP} = -π/2 (or close to) ?

A) First presented at ICHEP, T2K data – when combined within a full framework of 3 ordinary neutrinos and with neutrino reactor experiments – prefer the $\delta_{CP} \approx -\pi/2$ region. The CP-conserving cases ($\sin \delta_{CP} = 0$) lie outside the 90% confidence interval of T2K which is $\delta_{CP} \in [-3.13; -0.39]$ ($[-2.09 ; -0.74]$) for the normal (inverted) mass ordering. What are the consequence for DUNE?

- *A statistical fluctuation of the T2K data cannot be excluded (e.g. 750 GeV @LHC.).*
- *DUNE is a next generation experiment designed to unequivocally discover CP-violation and determine the mass ordering within a single experiment. The sensitivity to CPV of the present generation T2K and NOvA is much less due to limitations in their designs. For example, T2K sensitivity to CPV depends critically on the combination of several very different measurements, such as those from accelerator and reactor experiments, and on the actual value of the CP phase.*
- *Only DUNE will provide a definitive and irrefutable discovery of CP violation with a confidence level of at least 5 sigmas (e.g. discovery of the Higgs boson) over a large faction of the possible CP phase values.*

What if δ_{CP} = -π/2 (or close to) ?

B) T2K and NOvA approved plans include an increase their present statistics until 2020, and T2K has proposed an extension until 2026 (T2K-II) to accumulate x10 the statistics obtained in the last 5 years. If Nature has indeed chosen $\delta_{CP} = -\pi/2$, what are the consequences for DUNE?

- *If $\delta_{CP} = -\pi/2$, there is a chance that global neutrino fits establish CPV at a 3σ C.L. before the start of DUNE. If $\delta_{CP} = -\pi/2$, DUNE will also benefit and will quickly reach a 3σ C.L. in 3 years. DUNE will provide the definitive 5σ C.L. discovery of CPV in 7 years.*

- *DUNE will not only exclude $\delta_{CP}=0$ or π with 5σ C.L., it will also measure the value of δ_{CP} phase with a precision of $\pm 10^{o}$. Such a precision is fundamental. It will be for instance possible to tell whether CPV is maximal or not - a critical information for phenomenologists and theoretical model builders.*

- *DUNE, unlike T2K and NOvA and the proposed HK, will be the only experiment to operate in an "on-axis" configuration with a wide-band neutrino beam. DUNE can uniquely study how oscillations depend on the neutrino energy. This allows exploring if the neutrinos and antineutrinos oscillation asymmetry is consistent with the one predicted by a complex phase of the Pontecorvo–Maki–Nakagawa–Sakata matrix, thereby enhancing our understanding of the origin of the phenomenon.*