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Future Outlook

Nufact2017, Uppsala, 25-30 September 2017

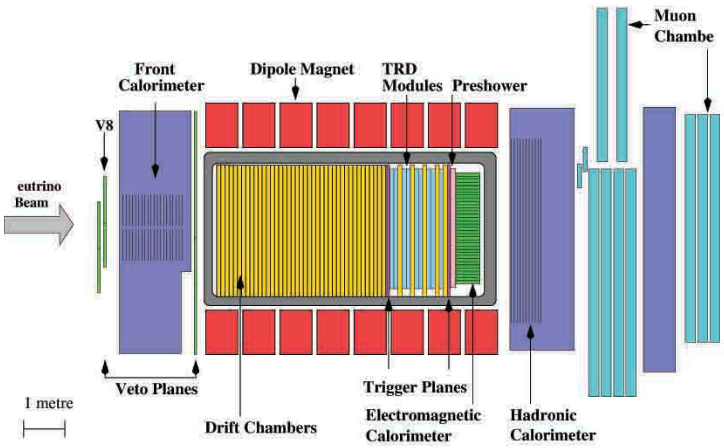
Apologies ...

... my record as crystal ball reader is just very poor

a) I worked full time in the 90's in the Nomad experiment at CERN looking for $\nu_\mu - \nu_\tau$ oscillations at $\delta m^2 > 10$ eV^2.

However:

- At the time no guideline about the best strategy: scan $\sin^2 2\theta$ at $\delta m^2 > 10$ eV^2 or scan δm^2 at $\sin^2 2\theta > 0.1$
- An entire generation of european neutrino physicists had been trained in Nomad and Chorus
- The Nomad result on QE cross section convinced the community that this cross section was not just a problem of fitting m_A
- Nomad (refurbished) and its "competitor" SK are now working together as close and far detector of T2K respectively
- … not to mention Feldman-Cousins

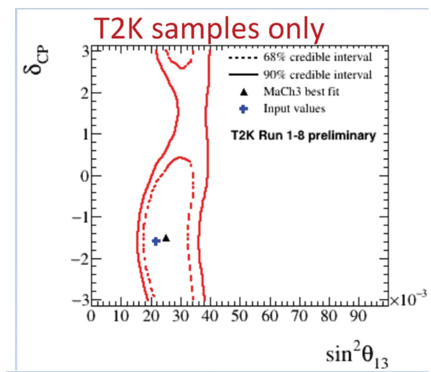


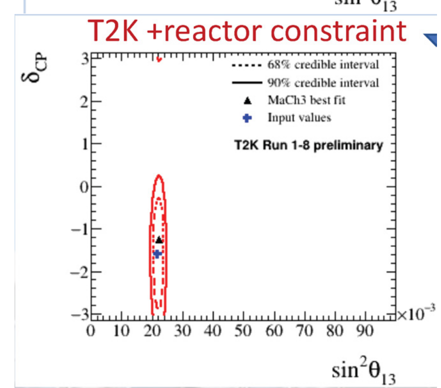
… and

b) At Nufact ‘01 I presented performances of a SuperBeam configuration, arguing that to address leptonic CP violation was needed a setup where a WC detector 20 times bigger of SK integrated a 4MW beam for 10 years.

At Nufact ‘17 T2K presents a 2σ indication of CP violation having integrated roughly 500 times less ν interactions (in terms of detector mass x run time x beam power). Btw T2K had been presented at Nufact ’01 too, it was the 2nd or 3rd T2K presentation at an international conference.

T2K sensitivity
Talk by p. Ddunne





What was missing (in the computation)?

- θ_{13} happened to be maximal, in the allowed range (killing neutrino factories and beta beams)
- T2K fits maximal values of δ_{CP}
- At high θ_{13} reactors can measure its value at the percent level increasing very much the discovery power of accelerator experiments like T2K

What lesson can we take?

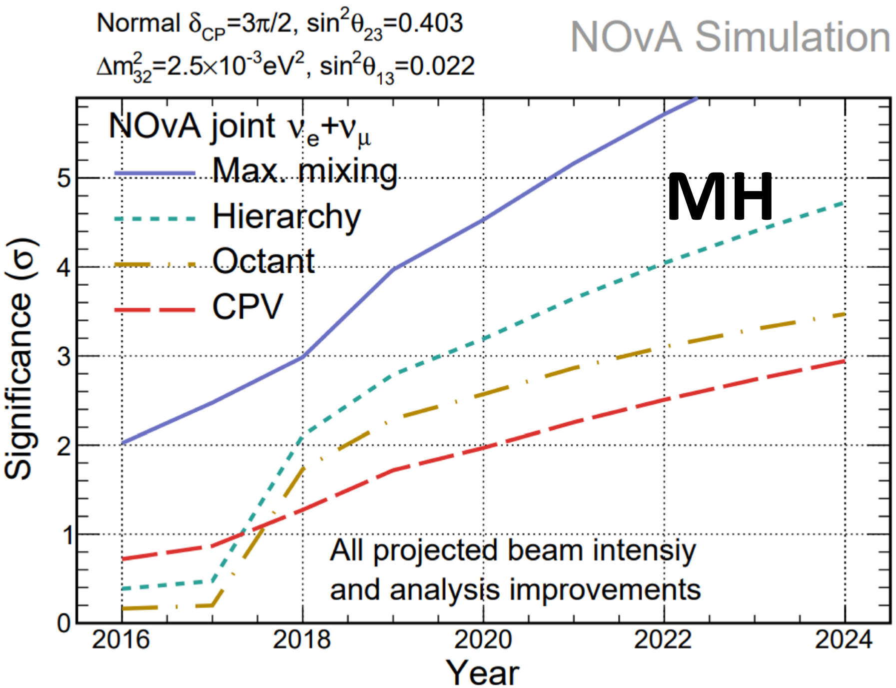
- The parameters measured by neutrino experiments can significantly change their strategy
- Sinergies between different experiments can be very powerful

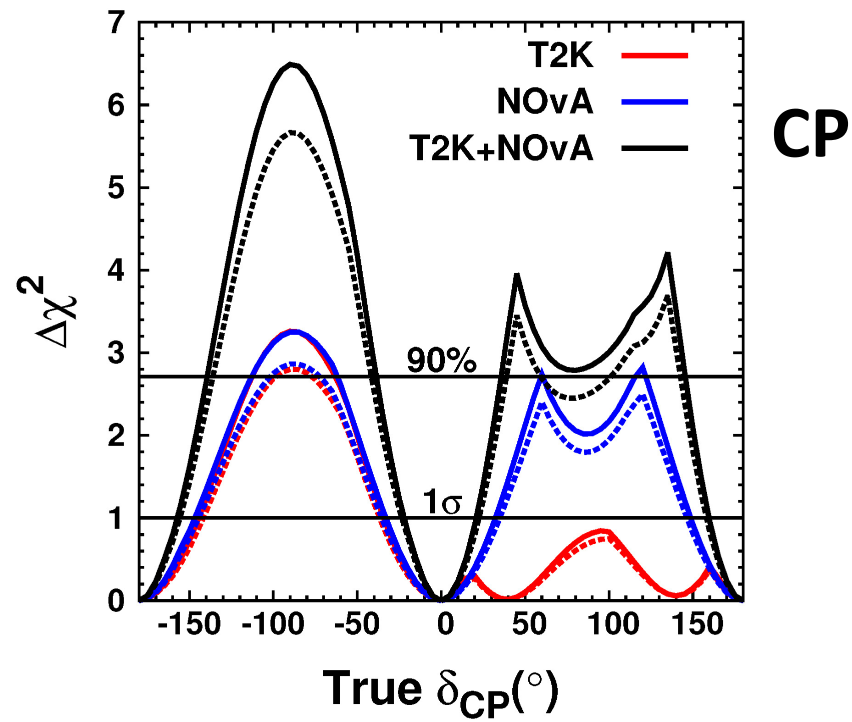
Is something similar going to happen?

Let's take seriously T2K best fit at $\delta_{CP}=-\pi/2$

PTEP 2015 (2015) 4, 043C01 (both T2K and Nova improved detection efficiency in the meantime, SK also contributes)

From … presentation





By 2020-21 MH could be decided at 3σ and CPC excluded at 3σ

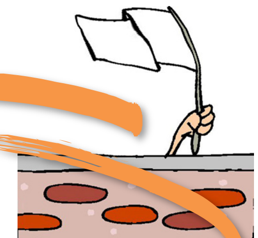
Focus on δ_{CP} precision rather than CPV discovery (MH precision doesn't matter)

Short term: Sterile Neutrinos

Short Baseline at FNAL
- LAr1ND
- MicroBooNE
- Icarus

Long Baseline
- Daya Bay
- T2K
- Nova

DAR ν beams
- JSNS^2
- Isodar (?)



Sterile Neutrinos

Cosmology

ν generators
- CeSOX
- Katrin
- Best (?)

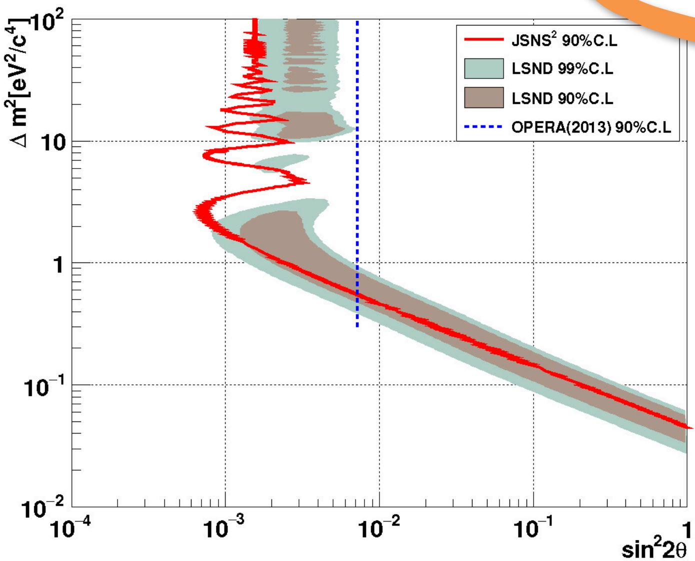
Reactors
- DANSS
- NEOS
- nuLat
- Neutrino4
- PROSPECT
- SoLid
- Chandler
- Stereo

Check of LSND

π DAR

- JSNS^2

Excess of $\overline{\nu}_e$-like events in a ν beam from π decays at rest



JSNS^2 TDR: arXiv:1705.08629
90%CL sensitivity for 1MW x 3 years x 1 detector

Third generation Long Baseline Experiments

The three liquids gigantic detectors are under way:

- Liquid scintillator: **Juno** and **SNO+** are in construction
- Water**: Hyper-Kamiokande** selected as top project by Mext.   And also **IceCube Gen 2 , Km3net/Orca**
- Liquid Argon: **Dune** is approved and partially funded

Such a big effort and investment by thousands of physicists and several major funding agencies is the right recognition of the splendid results and great perspectives of neutrino physics

Schedules

Talk by M. Sorel

Project timeline

2017
Far Site Construction Begins

2018
ProtoDUNEs at CERN

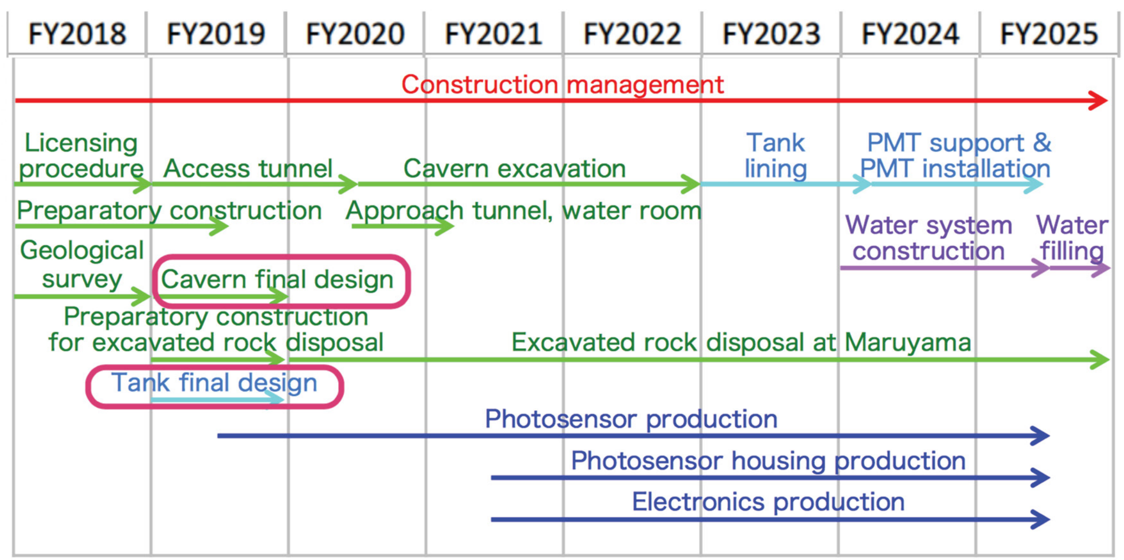
2021
Far Detector Installation Begins

2024
Physics Data Begins

2026
Neutrino Beam and Near Detector Available

Talk by E. O' Sullivan

HK construction timeline



Data taking expected in 2026

Complementarity

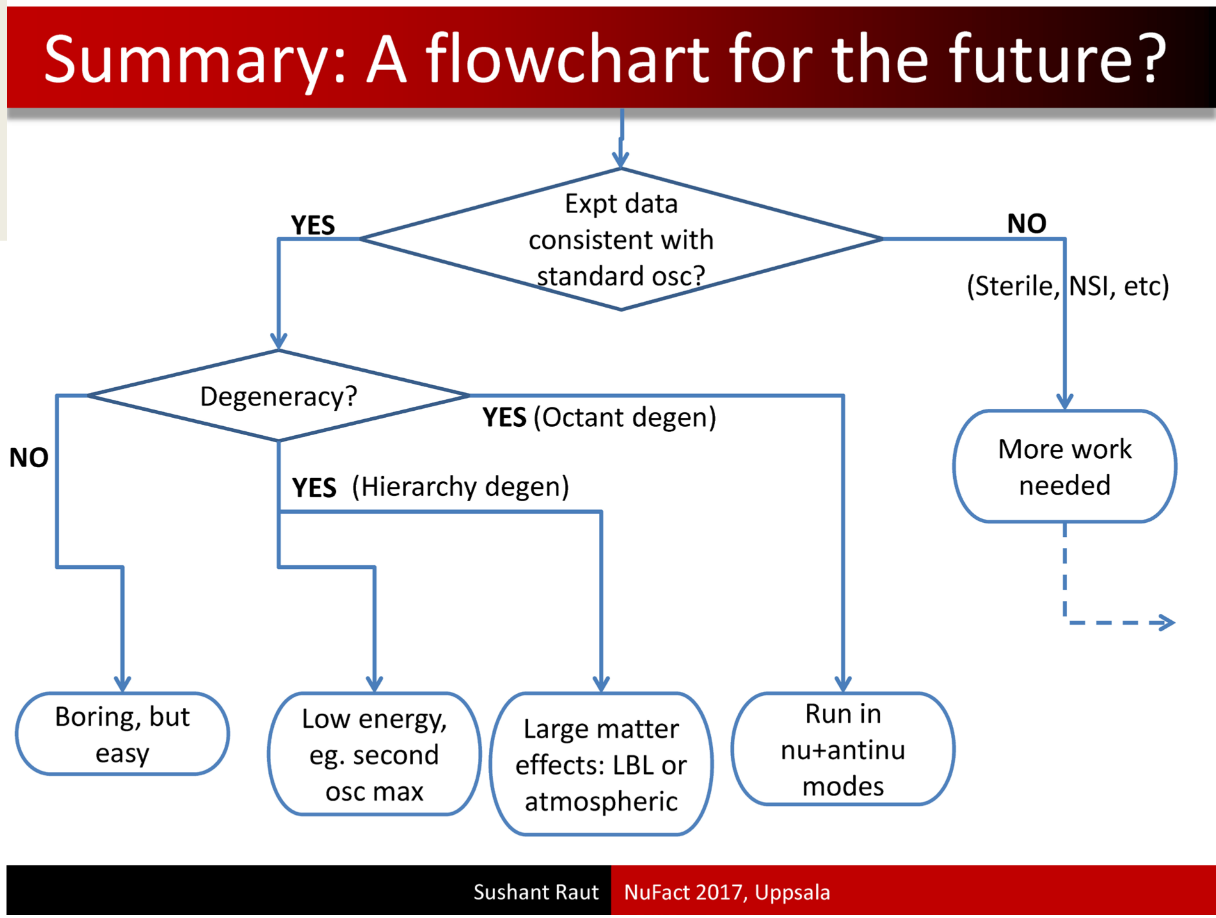
- HK and Dune nicely complement their physics reach in neutrino oscillations (see f.i. arXiv:1501.03918)
- Juno can improve their sensitivity in precisely measuring solar parameters while HK and Dune can measure Δm_{ee}^2 for Juno
- The three liquids really complement each other in detecting SN neutrinos, proton decays, solar neutrinos, indirect DM searches, …

Complementarity

To fully exploit the physics potential of your experiment you have to wish all the best to your «competitors», the flow chart here below illustrates a real case at best.

Couldn't we follow the example of gravitational waves and form joint collaborations a la Ligo/Virgo?

Talk by S. Raut

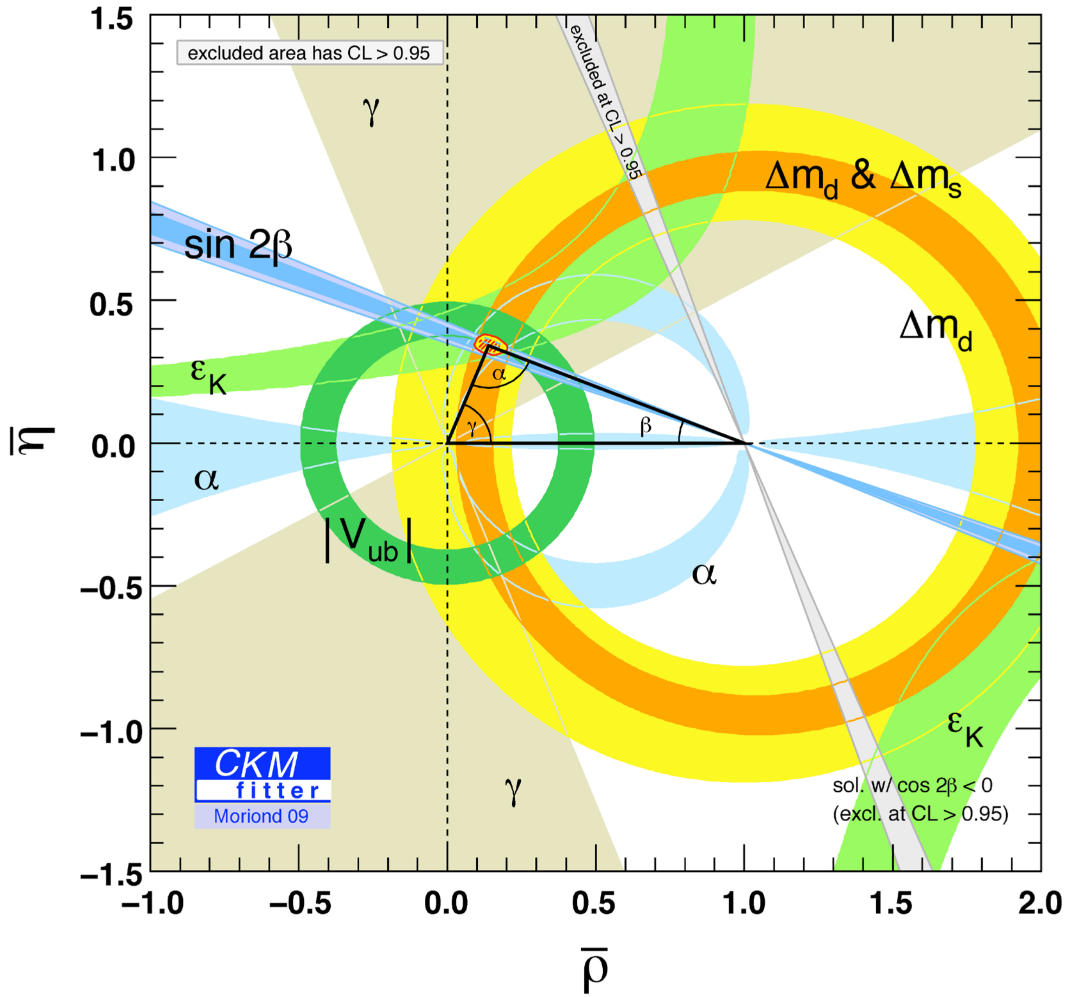


What Next

From André DE GOUVÊA opening talk

Ultimate Goal: Not Measure Parameters but Test the Formalism (Over-Constrain Parameter Space)

What we ultimately want to achieve:



We need to do this in the lepton sector!

HOW?

From Alain Blondel «Concluding Remarks» talk at Nufact '16

Questions:

1. Will we want a neutrino factory after , say 10 years of operation of DUNE + HYPERK?

other phrasing:

How many years of running DUNE + HyperK will it take to match a neutrino factory?

2. Does neutrino factory bring qualitatively different discovery potential?

Example:

Testing Unitarity for the existence of mixing with other states (e.g. RH/sterile neutrinos)

-- N_ν @ LEP tests unitarity at Ecm=90 GeV

-- different from test at eV scale because of possible intermediate scale of RH m asses.

What Next

I'm afraid I don't have clear answers to André and Alain questions, but we can formulate some general considerations:

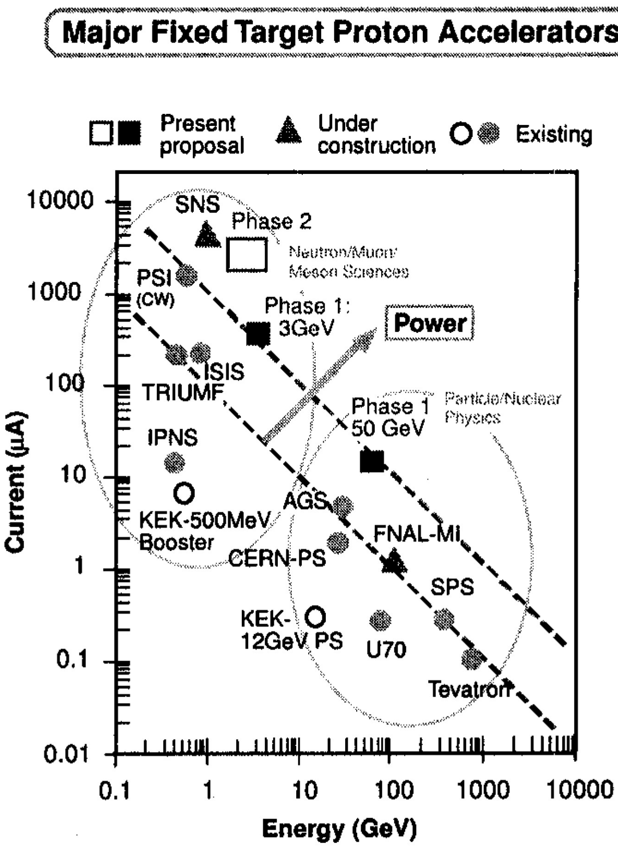
After Dune and HK, detectors can't be improved very much and any significant progress of sensitivities can only be achieved through neutrino beams

So we are back to the main focus (and great merit) of this conference serie: bring together theorists, neutrino physicists and accelerator experts

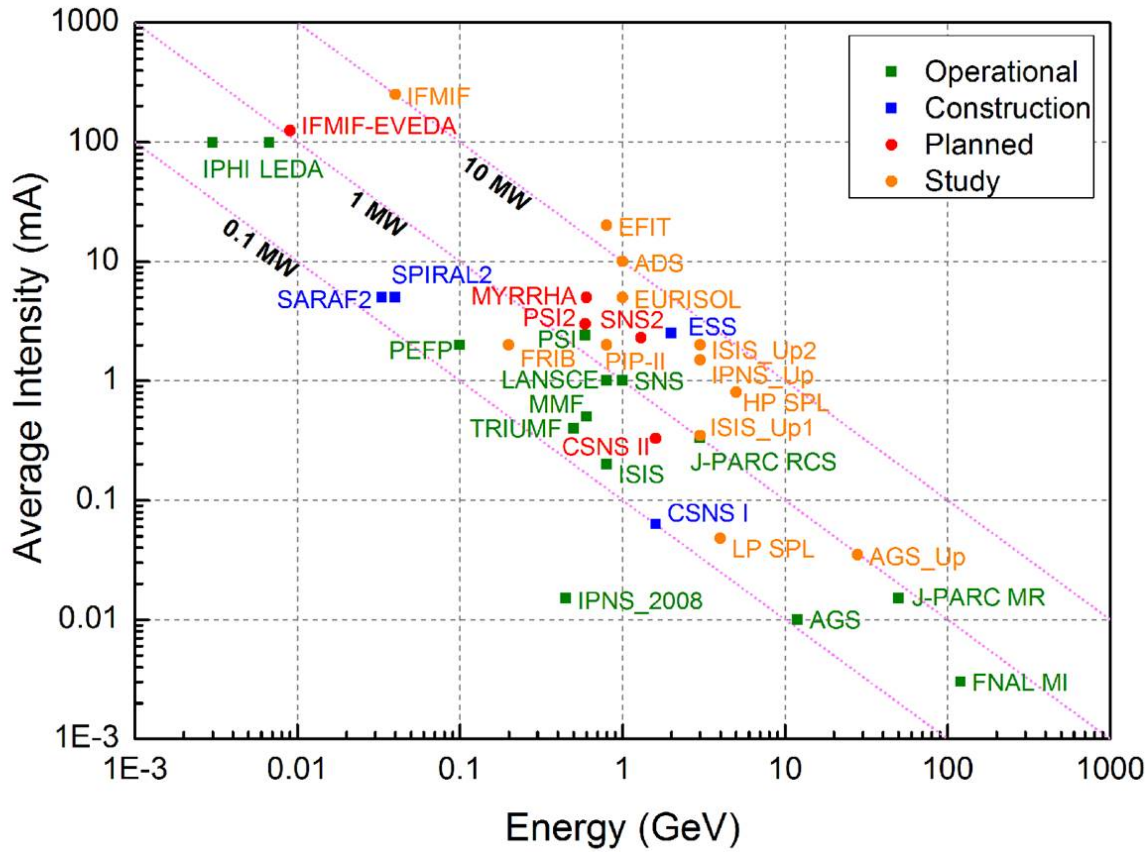
Statistics: ESSnuSB, IOTA, KEKB proton linac
Systematics: Moment, DAEdALUS, Neutrino Factory, Beta Beams (nuSTORM, Enubet in the short time)

Proton drivers

Year 2000



Year 2017, Talk of C. Plostinar

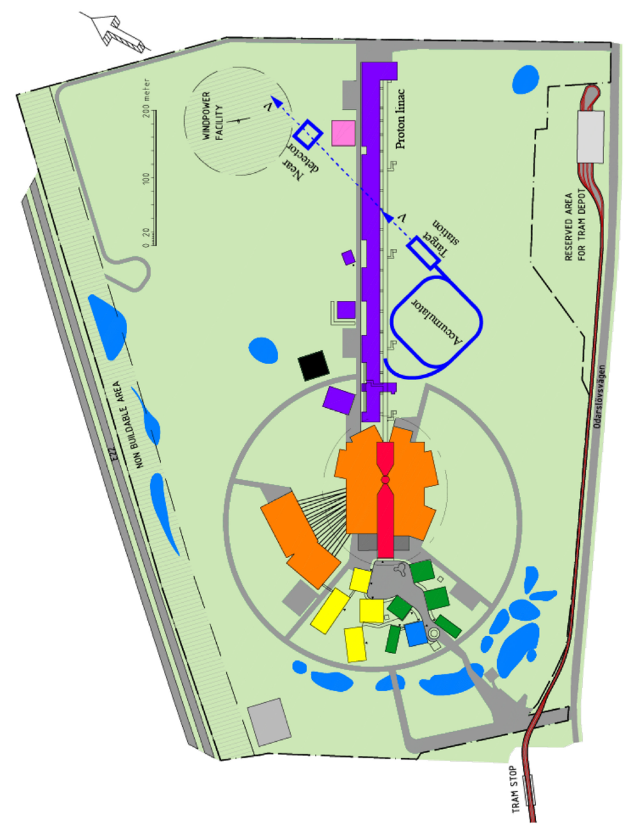


ESSnuSB

Talk by M. Dracos

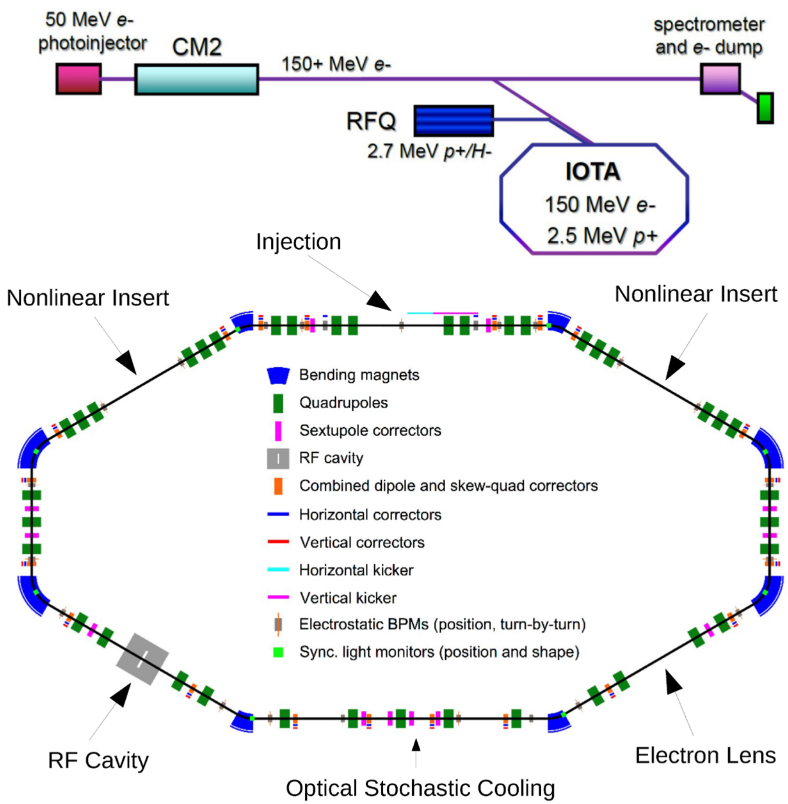
How to add a neutrino facility?

- The neutron program must not be affected and if possible synergetic modifications.
- Linac modifications: double the rate (14 Hz → 28 Hz), from 4% duty cycle to 8%.
- Accumulator (C~400 m) needed to compress to few μs the 2.86 ms proton pulses, affordable by the magnetic horn (350 kA, power consumption, Joule effect)
  - H^- source (instead of protons),
  - space charge problems to be solved.
- ~300 MeV neutrinos.
- Target station (studied in EUROν).
- Underground detector (studied in LAGUNA).
- Short pulses (~μs) will also allow DAR experiments (as those proposed for SNS) using the neutron target.

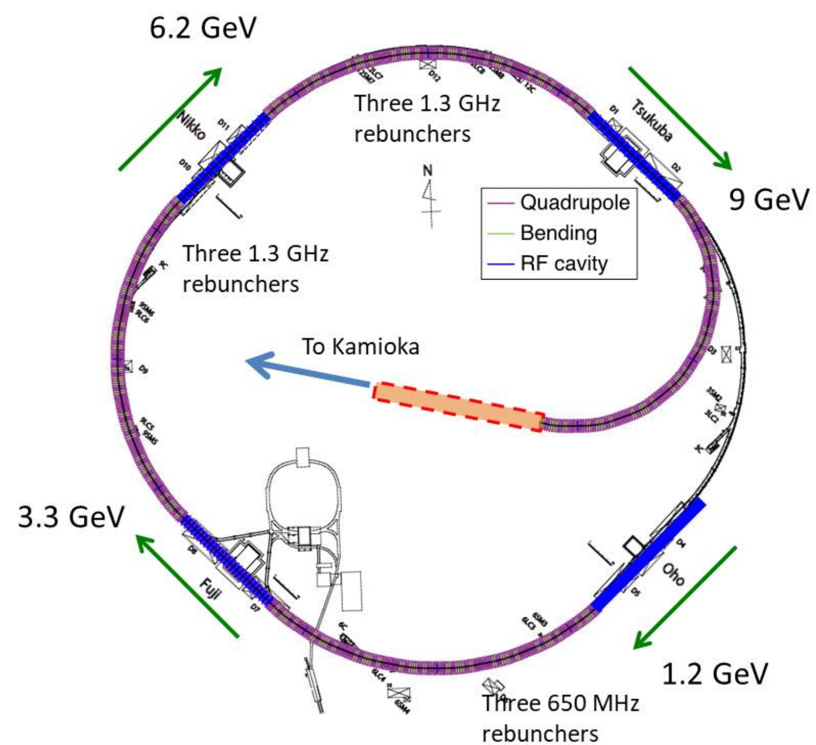


Long term R&D

IOTA at FNAL, talk by B. Freemire



9 GeV proton Linac at KEKB aiming at 9 MW, Moruta et al. JPS Conf. Proceedings. 8, 011013 (2015)



Systematics

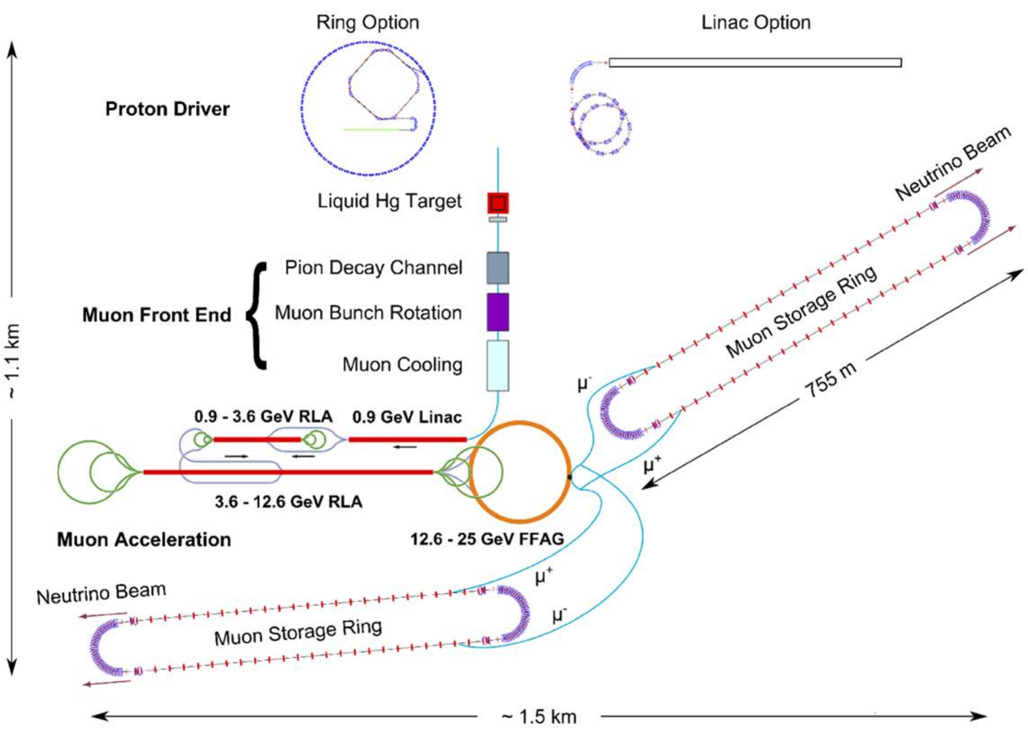
Talk on systematics by D. Hadley

- The ultimate (optimistic) goal of HK and Dune is 3% systematics
- It's the value where statistical error equal systematics

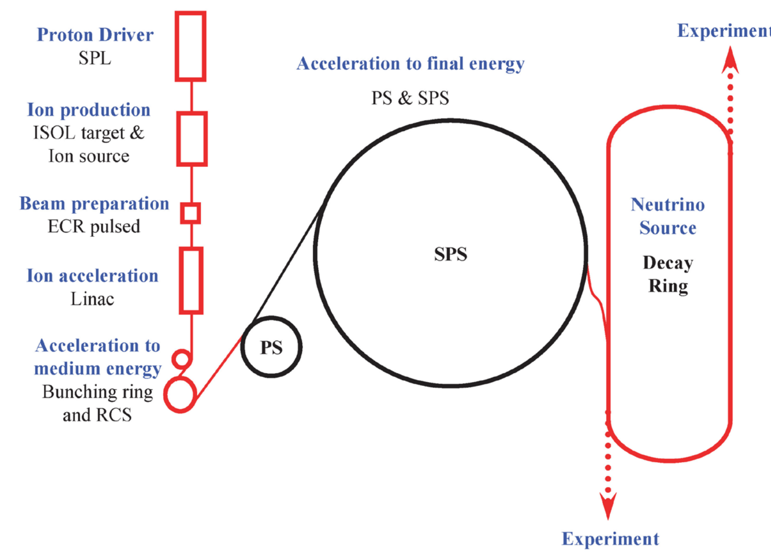
Experiment	$\nu_e + \bar{\nu}_e$	$1/\sqrt{N}$	Ref.
T2K (current)	74 + 7	12% + 40%	2.2×10^{21} POT
NOvA (current)	33	17%	FERMILAB-PUB-17-065-ND
NOvA (projected)	110 + 50	10% + 14%	arXiv:1409.7469 [hep-ex]
T2K-I (projected)	150 + 50	8% + 14%	7.8×10^{21} POT, arXiv:1409.7469 [hep-ex]
T2K-II	470 + 130	5% + 9%	20×10^{21} POT, arXiv1607.08004 [hep-ex]
Hyper-K	2900 + 2700	2% + 2%	10 yrs 2-tank staged KEK Preprint 2016-21
DUNE	1200 + 350	3% + 5%	3.5+3.5 yrs x 40kt @ 1.07 MW arXiv:1512.06148 [physics.ins-det]

- A further generation of ν experiments will require 1% systematic errors (3 times better!)
- This is almost impossible with conventional ν beams due their (well known) **intrinsic** limitations

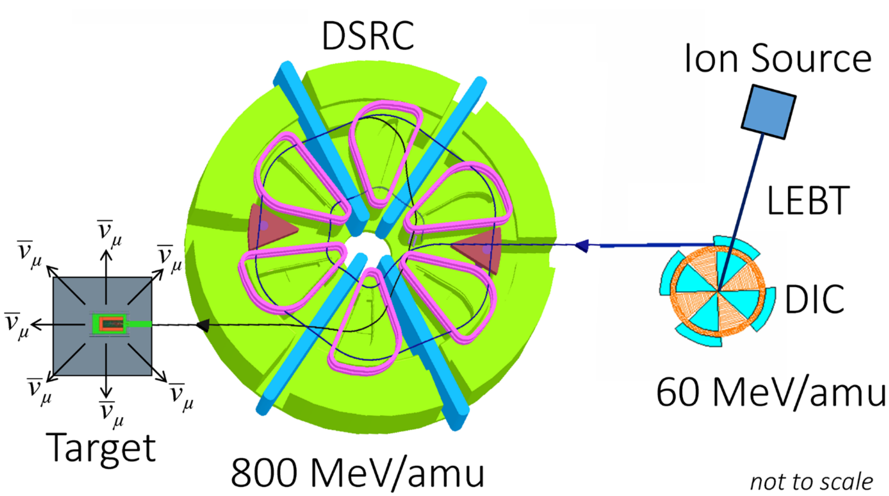
New concepts for neutrino beams are not for tomorrow, but the R&D should be fully supported since today

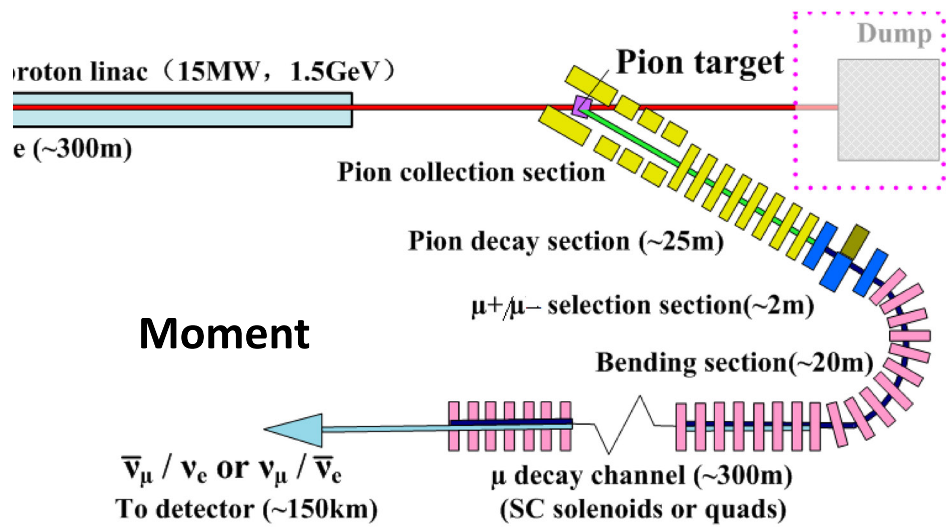


Beta Beam



DAEdALUS





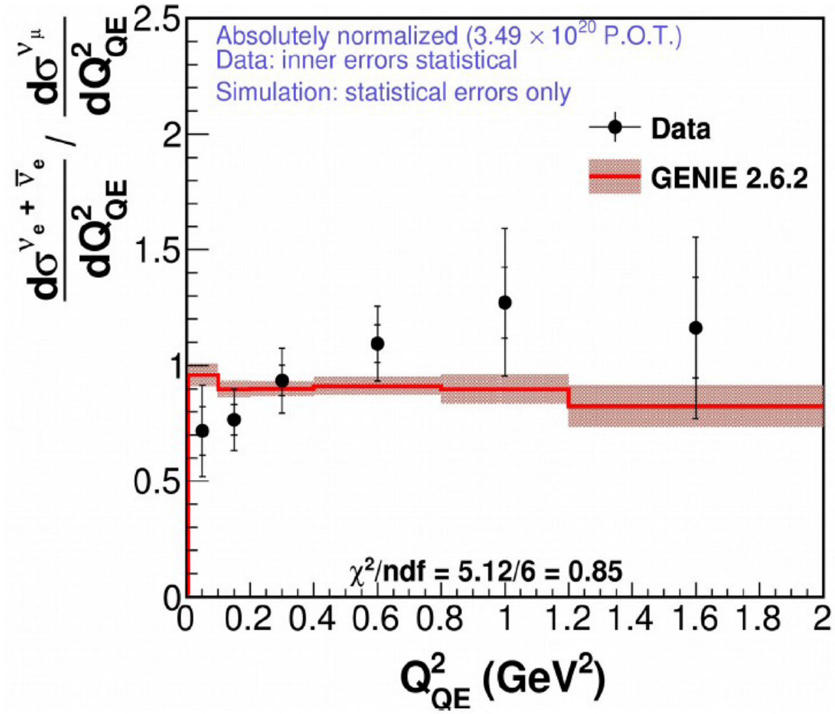
… in the meantime ν_e cross sections

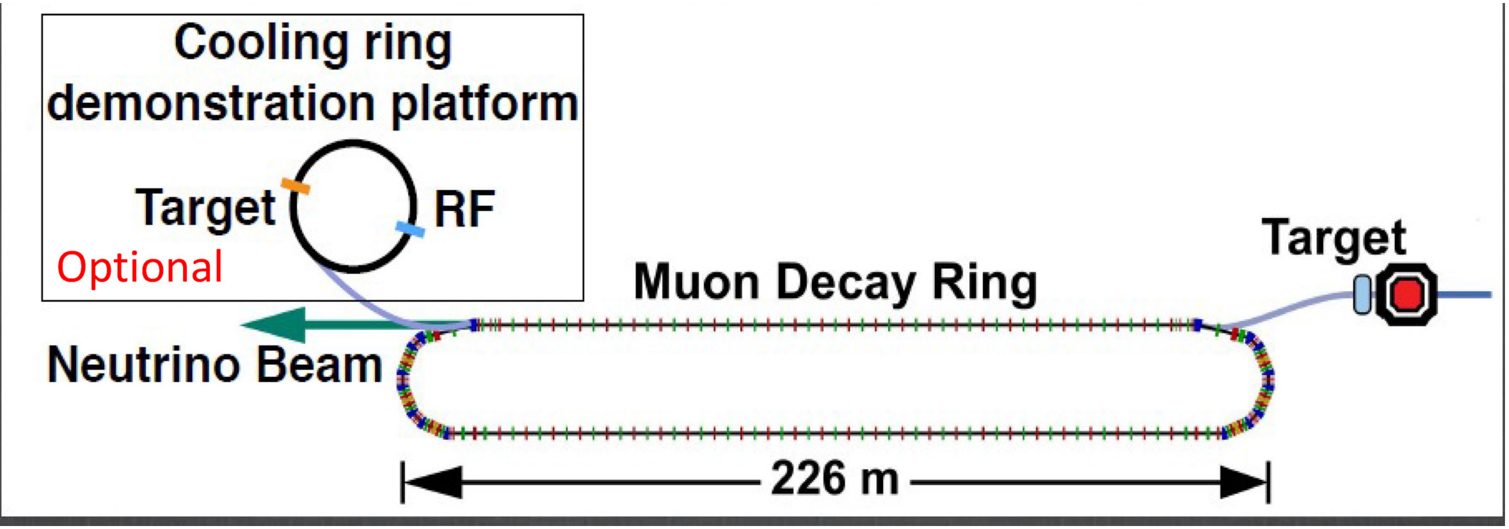
Early stages of a ν factory like nuSTORM or tagged ν beams a la ENUBET (funded by an ERC consolidator grant, talk by F. Pupilli) could measure ν_e cross section at 1%

This cross section is difficult at close detectors because

- Well known flux-xsec degeneracy at conventional neutrino beams
- Low ν_e fluxes at close detectors
- Large γ backgrounds from ν interactions around the close detectors

J. Pasternak talk about nuSTORM





nuSTORM,
Talk by J. Pasternak

ENUBET,
Talk by F. Pupilli

Systematics on the ν_e flux

Positron tagging eliminates the most important contributions. Assessing in detail the **viability of the 1% systematics** on the flux is one of the final goals of ENUBET. Full analysis is being setup profiting from a **detailed simulation** of the beamline, the tagger and inputs from **test beams**.

Source of uncertainty	Estimate
statistical error	<1% (10^4 ν_e^{CC})
kaon production yield	irrelevant (positron tag)
number of integrated PoT	irrelevant (positron tag)
secondary transport efficiency	irrelevant (positron tag)
branching ratios	negligible + only enter in bkg estimation
3-body kinematics and mass	<0.1%
phase space at the entrance	to be checked with low intensity pion runs
ν_e from μ-decay	constrain μ from K by the tagger and μ from π by low intensity runs
e/π separation	being checked directly at test beams

Congratulations to the organizers of this XIX edition of Nufact