Neutrino PLATFORM

LAPP Annecy-le-vieux, March 9th 2018

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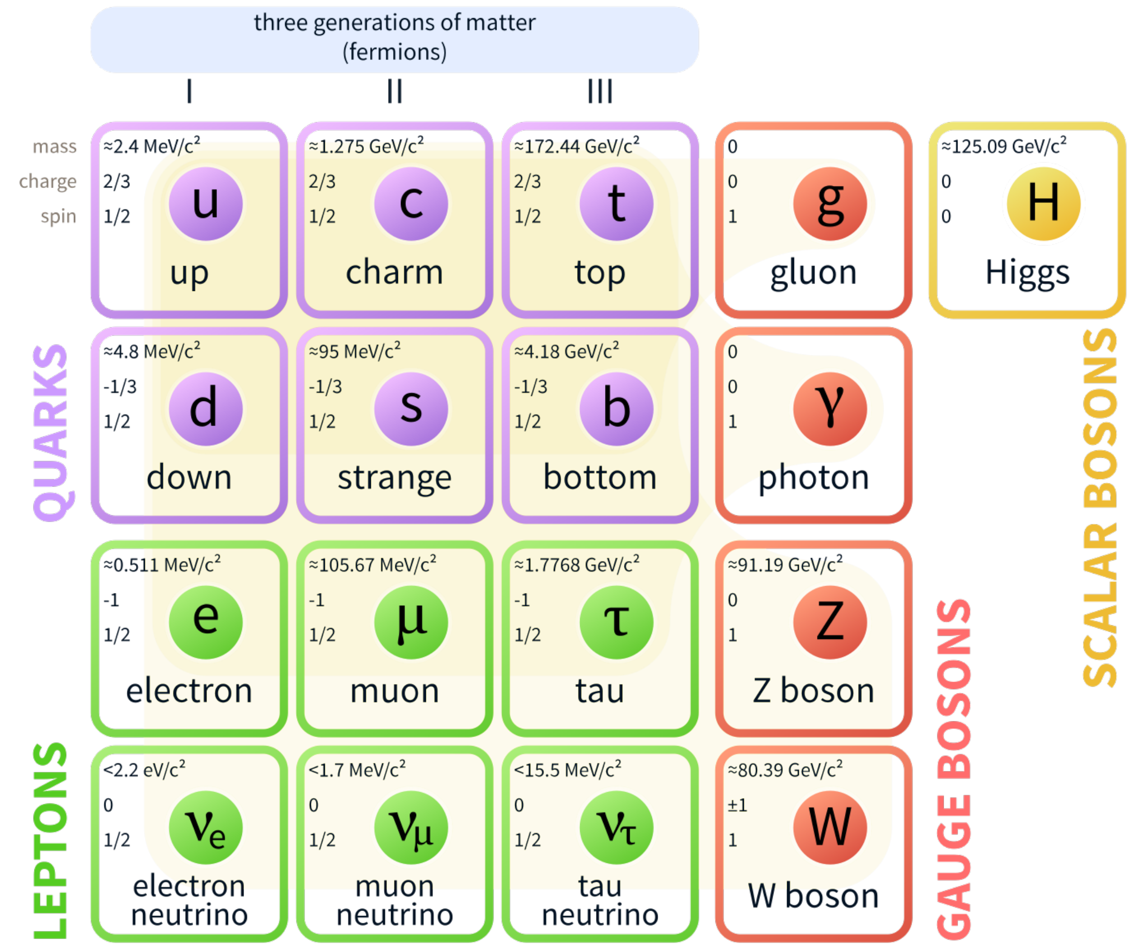
THE CERN NEUTRINO PLATFORM

OVERVIEW

- Introduction: neutrinos and oscillations
- The CERN Neutrino Platform
  - Near detector activities
  - DUNE/protoDUNE activities
- Conclusions

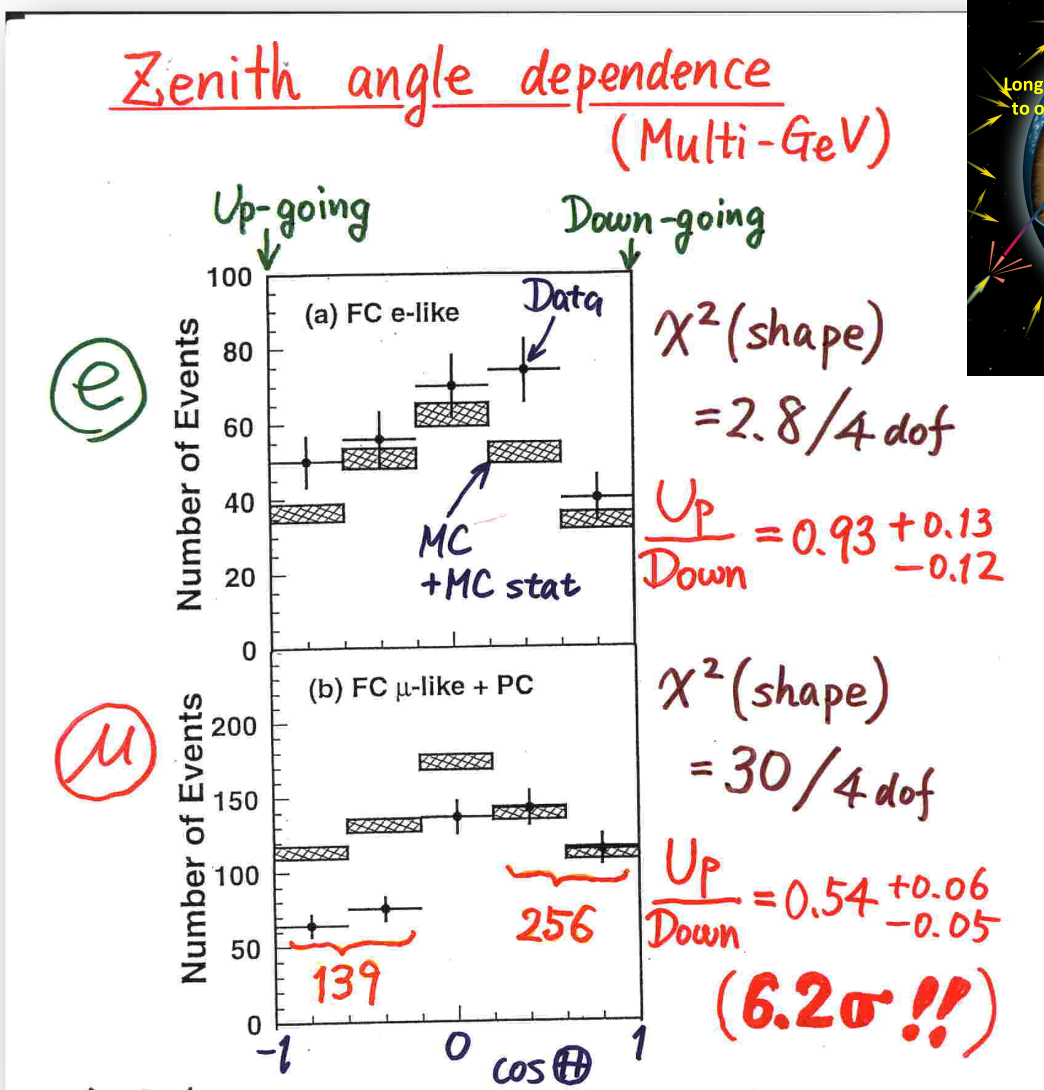
INTRODUCTION

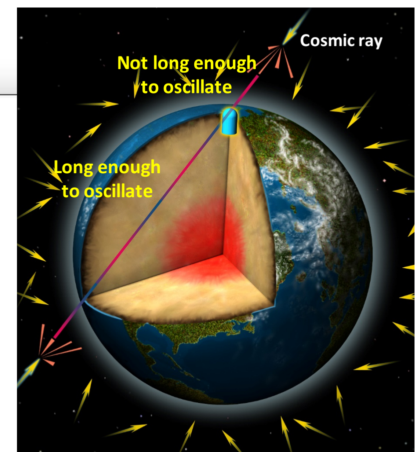
- 3 “standard” neutrino flavours
- **weakly interacting** ($\sigma_{\nu\text{->}N}/E_\nu \approx 10^{-38}$ cm^2/GeV)
  1 GeV neutrino mean free path in lead ≈ 10^{11} m.
- Standard Model states:
  - massless
  - lepton flavour conservation



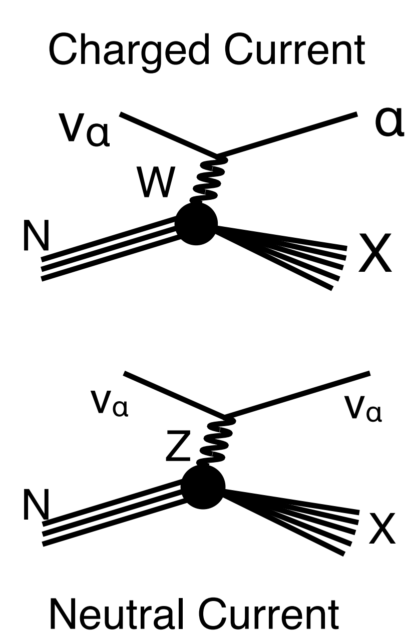
NEUTRINO OSCILLATIONS DISCOVERY

Super-Kamiokande (1998)



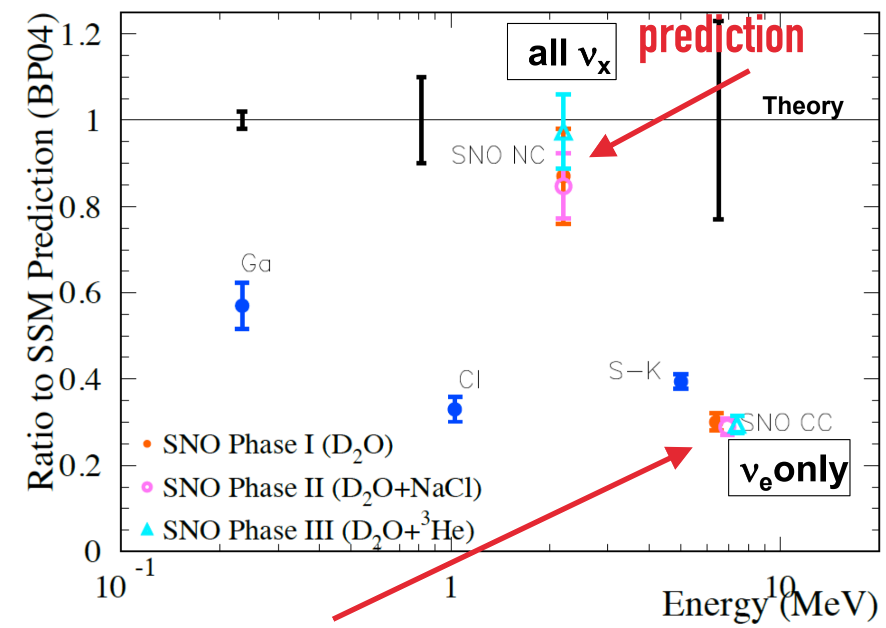


Presented at Neutrino Conference in 1998

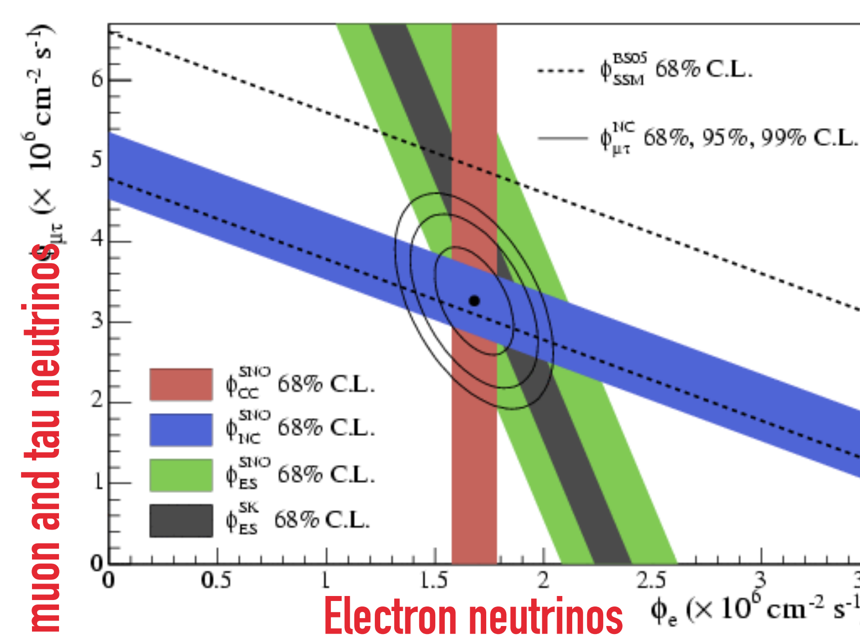


SNO (2000)

Neutral currents in agreement with the prediction



electron neutrinos are only ~1/3 of the total



3 NEUTRINO OSCILLATIONS

$c_{ij} = \cos\theta_{ij}$

$s_{ij} = \sin\theta_{ij}$

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \begin{pmatrix}1 & 0 & 0\\ 0 & c_{23} & s_{23}\\ 0 & -s_{23} & c_{23}\end{pmatrix}\begin{pmatrix}c_{13} & 0 & s_{13}e^{-i\delta}\\ 0 & 1 & 0\\ -s_{13}e^{+i\delta} & 0 & c_{13}\end{pmatrix}\begin{pmatrix}c_{12} & s_{12} & 0\\ -s_{12} & c_{12} & 0\\ 0 & 0 & 1\end{pmatrix}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

atmospheric, accelerator | **accelerator, reactor** | **solar, reactor**

3 Flavour states

3 mixing angles, 2 squared mass difference, 1 complex phase (δ_{CP})

3 Mass states
$m_1 \neq m_2 \neq m_3$

more than15 years of experimental efforts

Parameters		Experiment	signal
$\lvert\Delta m_{21}\rvert^2 = \lvert m^2_2 - m^2_1\rvert$	ϑ_{12}	solar and reactor	$P(\nu_e \to \nu_{\mu,\tau})$
$\lvert\Delta m_{32}\rvert^2 = \lvert m^2_3 - m^2_2\rvert$	ϑ_{23}	atmospheric and accelerator	$P(\nu_\mu \to \nu_\mu)$ & $P(\nu_\mu \to \nu_\tau)$
	ϑ_{13}	reactor and accelerator	$P(\nu_\mu \to \nu_e)$ & $P(\bar{\nu}_e \to \bar{\nu}_e)$
	δ_{CP}	accelerator	$P(\nu_\mu \to \nu_e)$

NEUTRINO OSCILLATION : WHAT DO WE MEASURE

- Neutrinos can change flavour while flying.
- dis/appearance probabilities depend on the neutrino energy E and distance L
- **Oscillations** give access to the Δm^2

Accelerator experiments

- $$P(\nu_\mu \to \nu_\mu) \sim 1 - \left(\cos^4\theta_{13}\sin^2 2\theta_{23} + \sin^2 2\theta_{13}\sin^2\theta_{23}\right)\sin^2 \Delta m^2_{31}\frac{L}{4E}$$

- $$\begin{aligned} P(\nu_\mu \to \nu_e) \sim\ & \sin^2 2\theta_{13} \times \sin^2\theta_{23} \times \frac{\sin^2[(1-x)\Delta]}{(1-x)^2} \\ & -\alpha\sin\delta \times \sin 2\theta_{12}\sin 2\theta_{13}\sin 2\theta_{23} \times \sin\Delta\frac{\sin[x\Delta]}{x}\frac{\sin[(1-x)\Delta]}{(1-x)} \\ & +\alpha\cos\delta \times \sin 2\theta_{12}\sin 2\theta_{13}\sin 2\theta_{23} \times \cos\Delta\frac{\sin[x\Delta]}{x}\frac{\sin[(1-x)\Delta]}{(1-x)} \\ & +\mathcal{O}(\alpha^2) \end{aligned}$$

matter effects

$$\alpha = \left|\frac{\Delta m^2_{21}}{\Delta m^2_{31}}\right| \sim \frac{1}{30} \qquad \Delta \equiv \frac{\Delta m^2_{31}L}{4E} \qquad x \equiv \frac{2\sqrt{2}G_F N_e E}{\Delta m^2_{31}}$$

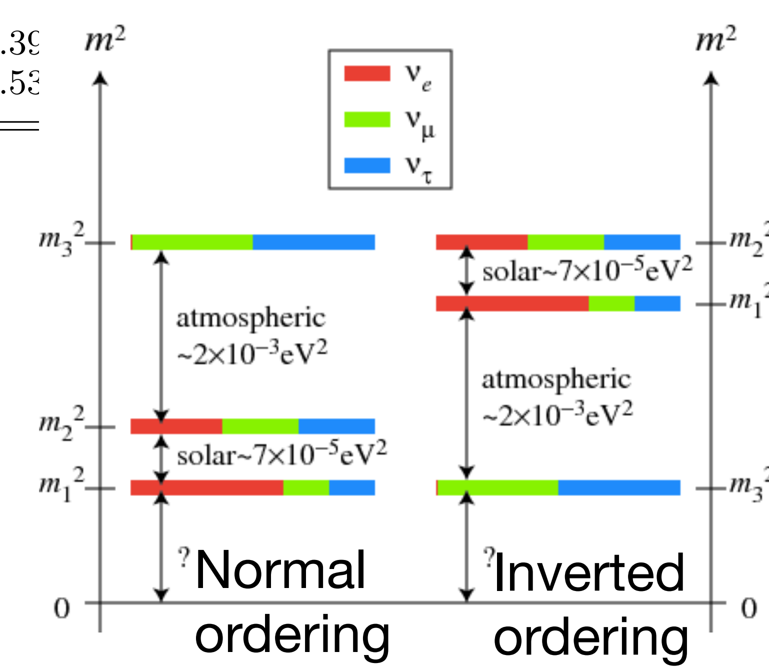
M. Freund, Phys.Rev. D64 (2001) 053003

THE KNOWNS AND THE UNKNOWNS

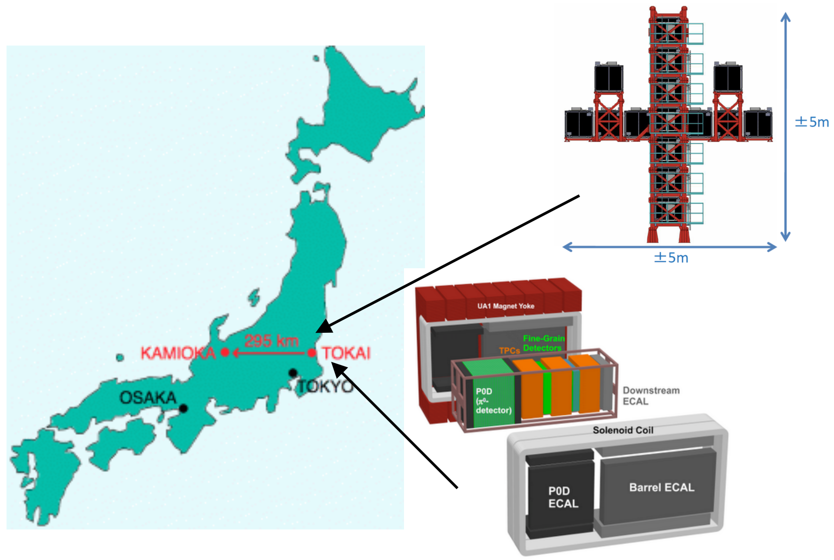
from NuFit 2016

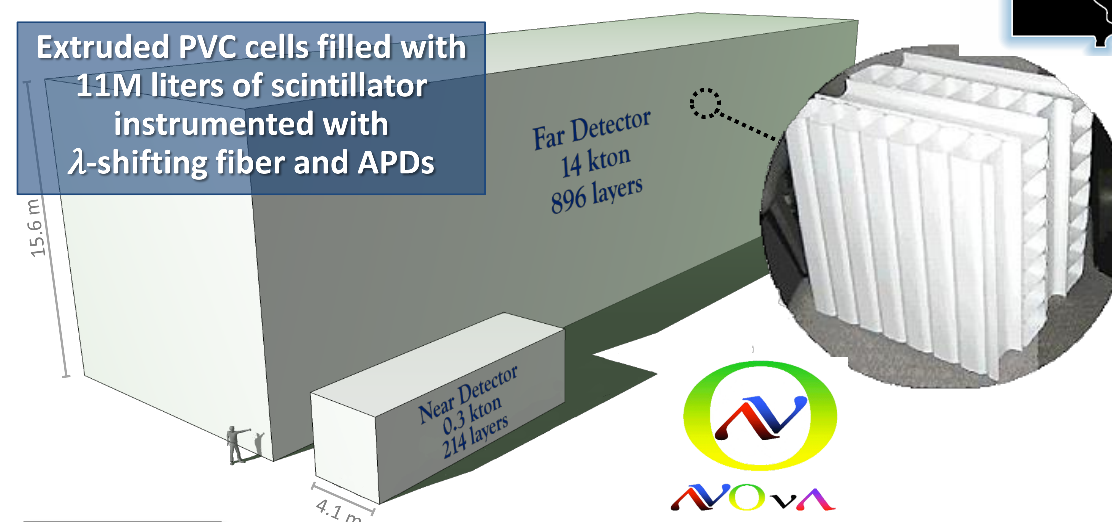
NuFIT 3.2 (2018)

		Normal Ordering (best fit)		Inverted Ordering ($\Delta\chi^2 = 4.14$)		Any Ordering
		bfp $\pm 1\sigma$	3σ range	bfp $\pm 1\sigma$	3σ range	3σ range
	$\sin^2\theta_{12}$	$0.307^{+0.013}_{-0.012}$	$0.272 \to 0.346$	$0.307^{+0.013}_{-0.012}$	$0.272 \to 0.346$	$0.272 \to 0.346$
	$\theta_{12}/^\circ$	$33.62^{+0.78}_{-0.76}$	$31.42 \to 36.05$	$33.62^{+0.78}_{-0.76}$	$31.43 \to 36.06$	$31.42 \to 36.05$
	$\sin^2\theta_{23}$	$0.538^{+0.033}_{-0.069}$	$0.418 \to 0.613$	$0.554^{+0.023}_{-0.033}$	$0.435 \to 0.616$	$0.418 \to 0.613$
octant	$\theta_{23}/^\circ$	$47.2^{+1.9}_{-3.9}$	$40.3 \to 51.5$	$48.1^{+1.4}_{-1.9}$	$41.3 \to 51.7$	$40.3 \to 51.5$
	$\sin^2\theta_{13}$	$0.02206^{+0.00075}_{-0.00075}$	$0.01981 \to 0.02436$	$0.02227^{+0.00074}_{-0.00074}$	$0.02006 \to 0.02452$	$0.01981 \to 0.02436$
	$\theta_{13}/^\circ$	$8.54^{+0.15}_{-0.15}$	$8.09 \to 8.98$	$8.58^{+0.14}_{-0.14}$	$8.14 \to 9.01$	$8.09 \to 8.98$
CPV	$\delta_{CP}/^\circ$	234^{+43}_{-31}	$144 \to 374$	278^{+26}_{-29}	$192 \to 354$	$144 \to 374$
	$\frac{\Delta m^2_{21}}{10^{-5}\ \mathrm{eV}^2}$	$7.40^{+0.21}_{-0.20}$	$6.80 \to 8.02$	$7.40^{+0.21}_{-0.20}$	$6.80 \to 8.02$	$6.80 \to 8.02$
Mass ordering	$\frac{\Delta m^2_{3\ell}}{10^{-3}\ \mathrm{eV}^2}$	$+2.494^{+0.033}_{-0.031}$	$+2.399 \to +2.593$	$-2.465^{+0.032}_{-0.031}$	$-2.562 \to -2.369$	[+2.39 / −2.53

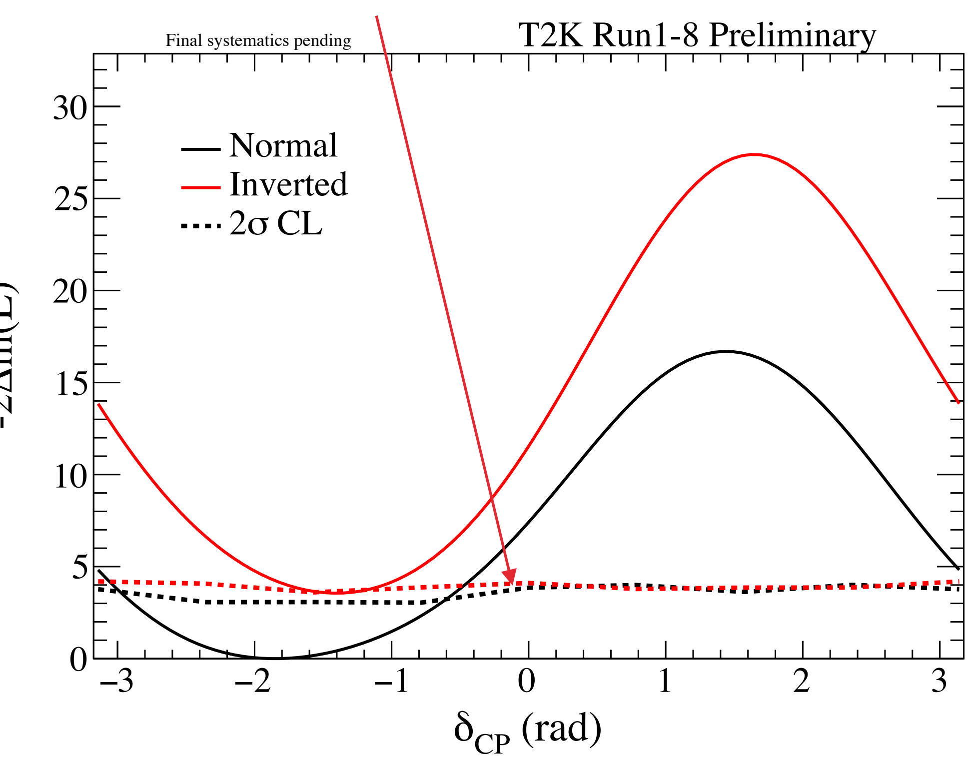


OSCILLATIONS: STATE OF THE ART MEASUREMENTS



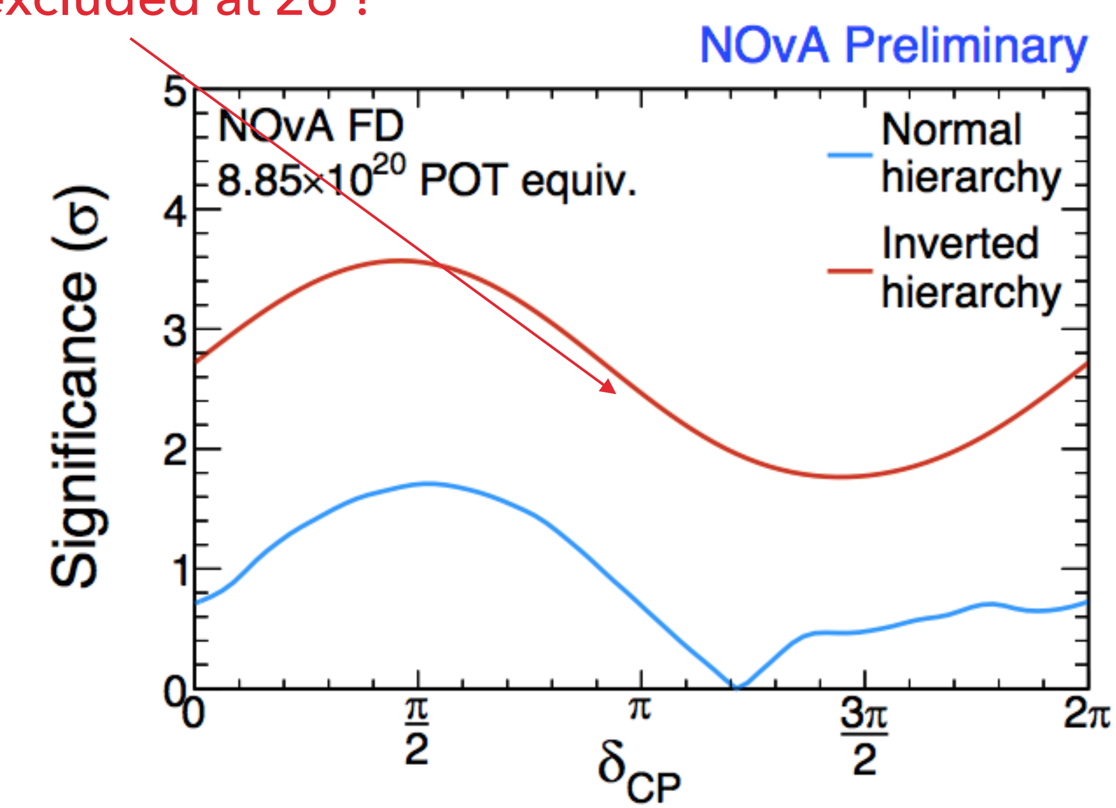


δCP = 0 excluded at 2σ !



Results [presented at KEK](#) last summer

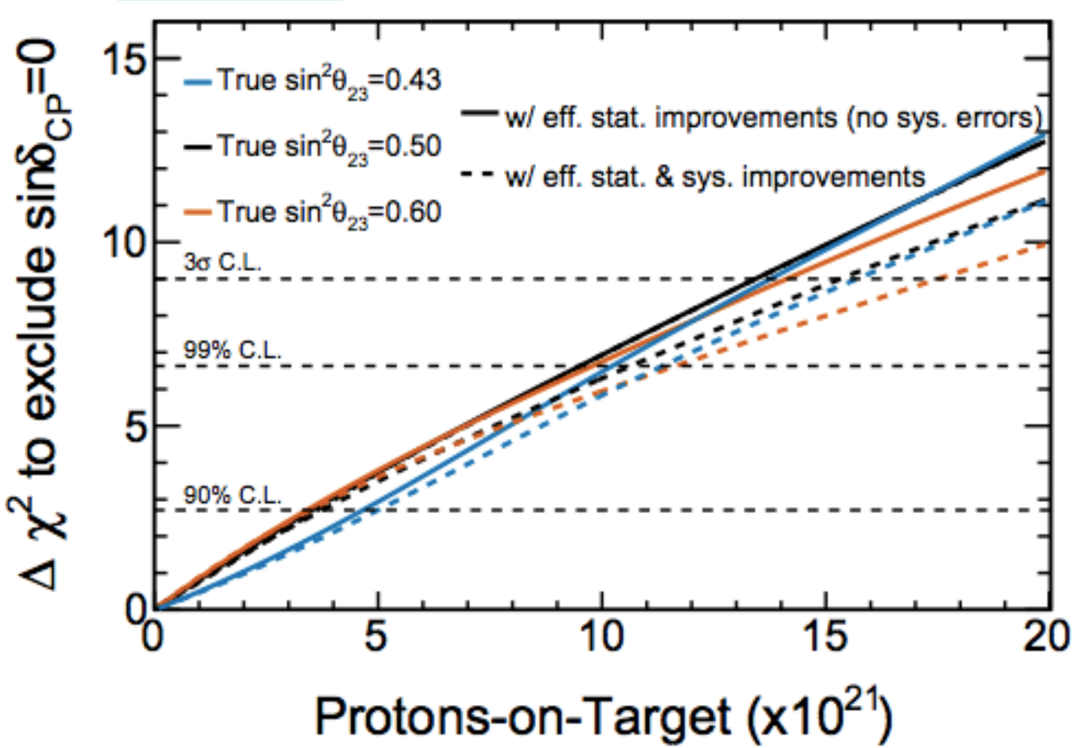
IH excluded at 2σ !



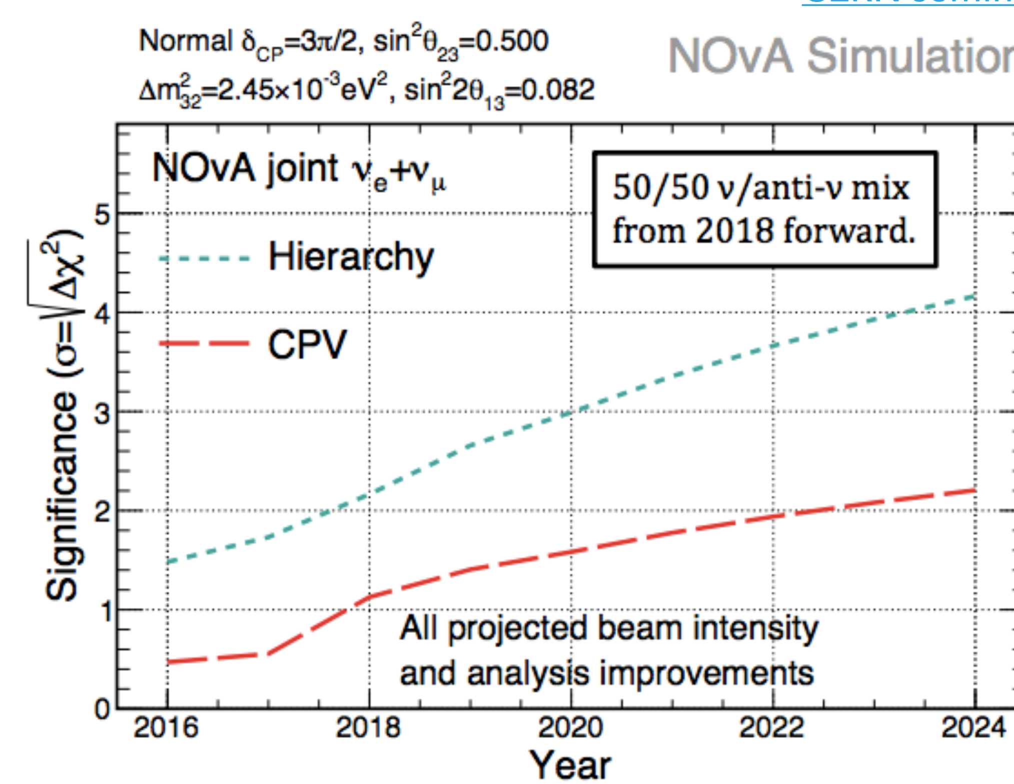
OSCILLATIONS: PERSPECTIVES

- T2K and NOvA have already some sensitivities to dCP and the MH with only part of the foreseen final statistics
- Effort to combine of the results to further enhance the physics potential of the current experiments are on-going
- Extension of the current T2K data taking (a.k.a. T2K-II) is also foreseen
  - upgrade of the ND280 near detector

arXiv:1607.08004



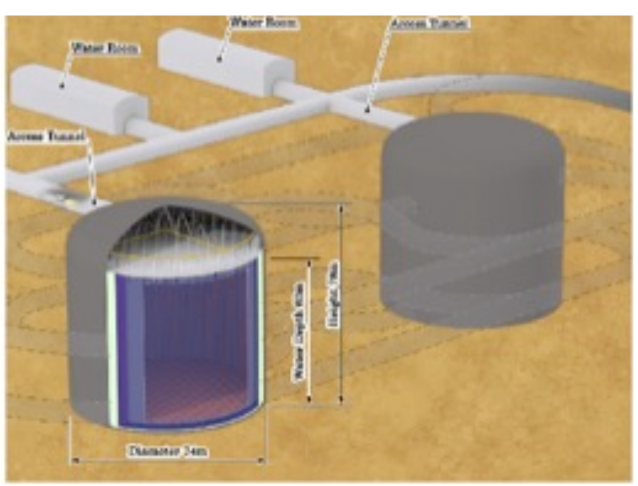
CERN seminar

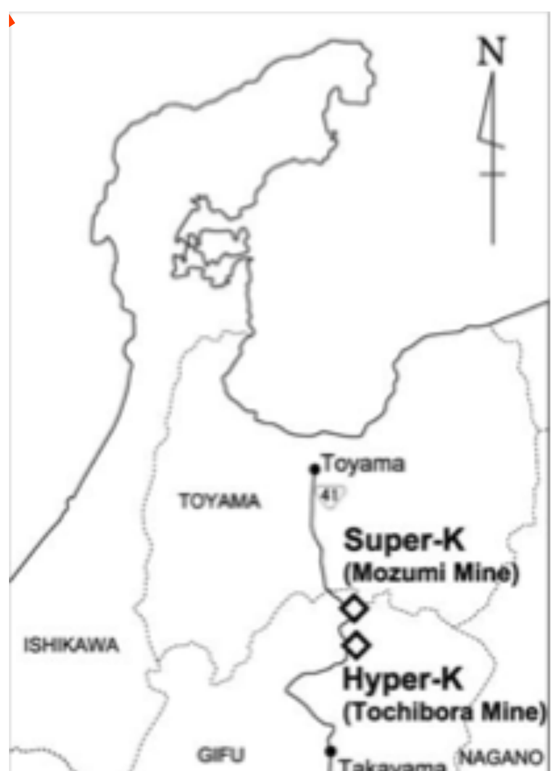


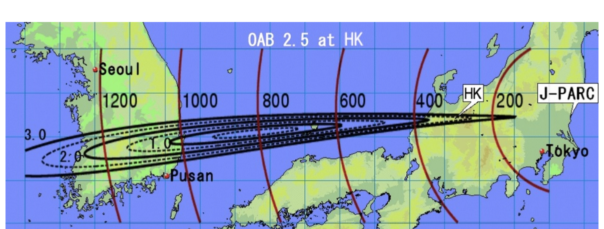
FUTURE LONG BASELINE EXPERIMENTS

TOKAY-TO-HYPER-KAMIOKANDE

- 2 water Cherenkov of ~260 ton each
- Tochibora (Japan),~1750mwe
- Off-axis beam from Tokai (1.3 MW)
- baseline ~**300km** (1100km if T2HKK)
- <E_ν> ~**0.6GeV**

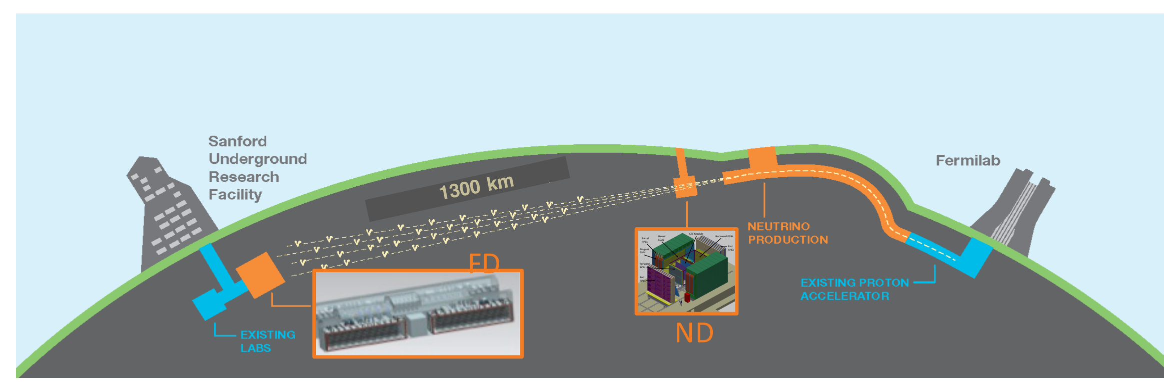


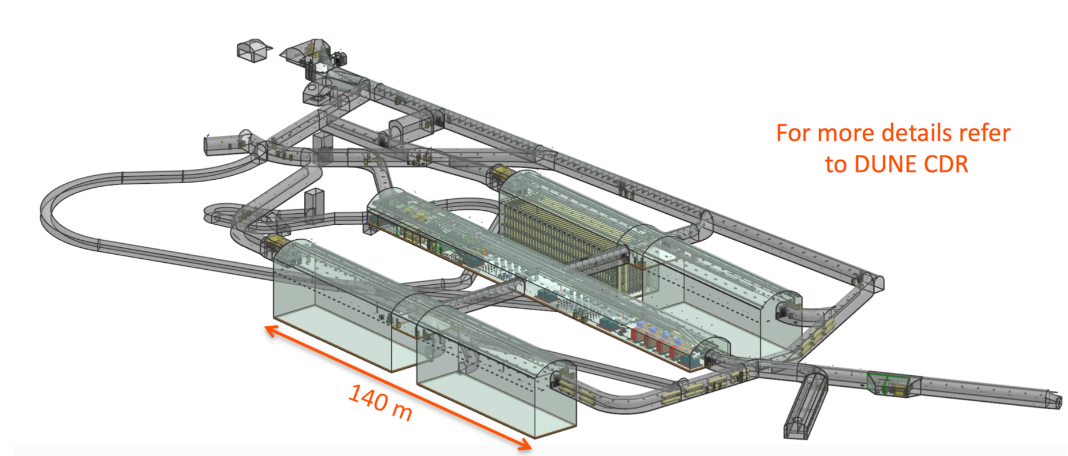




DUNE

- 4 modules Liquid Ar-TPC ~10kton each
- SURF, Homestake mine (US) ~2400mwe
- On-axis beam from Fermilab (1.2-2.4 MW)
- baseline ~**1300km**
- <E_ν> ~**3GeV**

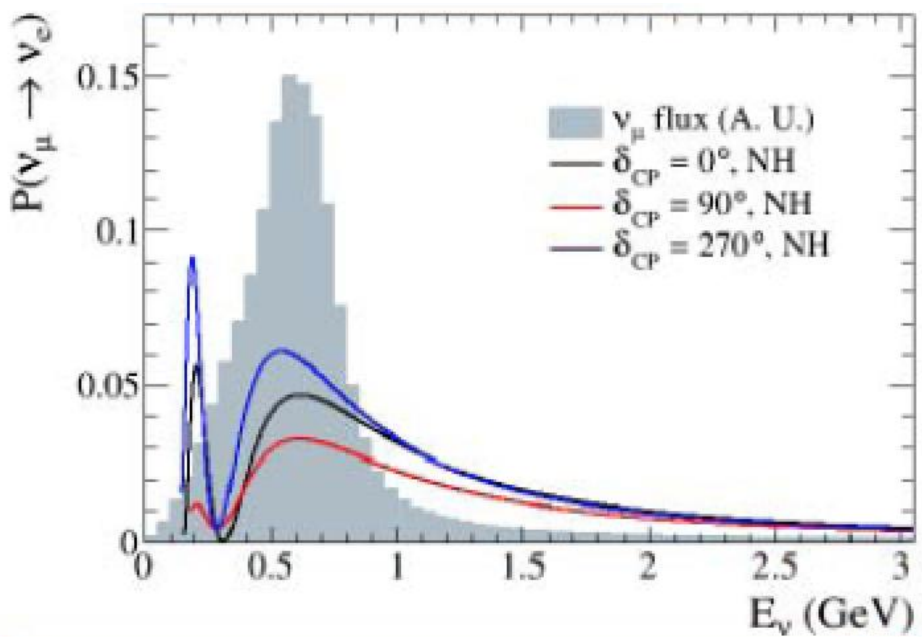




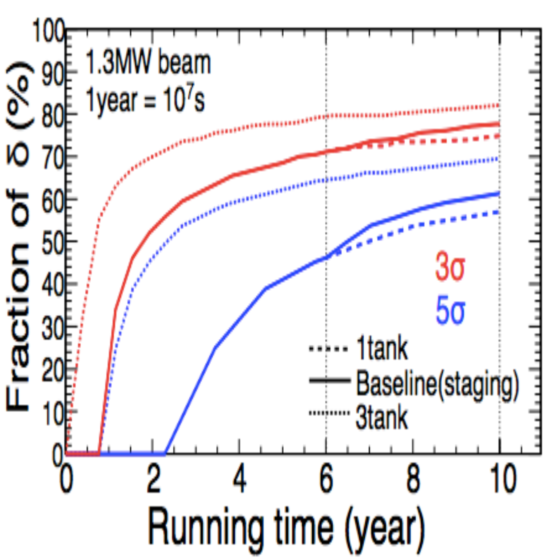
For more details refer to DUNE CDR

FUTURE LONG BASELINE EXPERIMENT

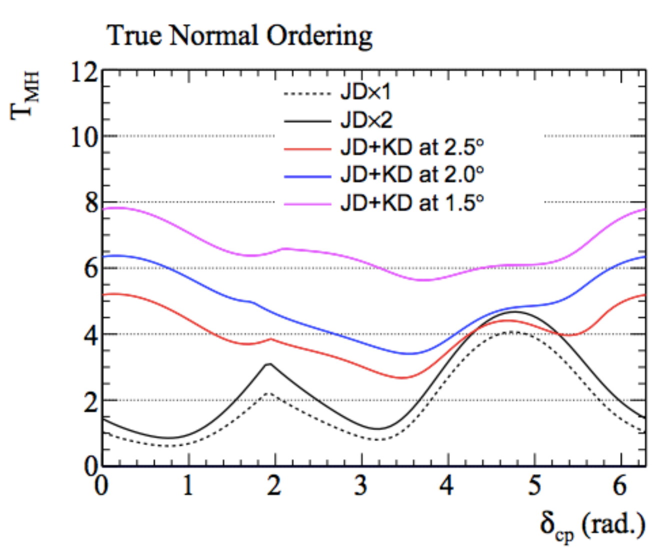
TOKAI-TO-HYPER-KAMIOKANDE



CP violation sensitivity

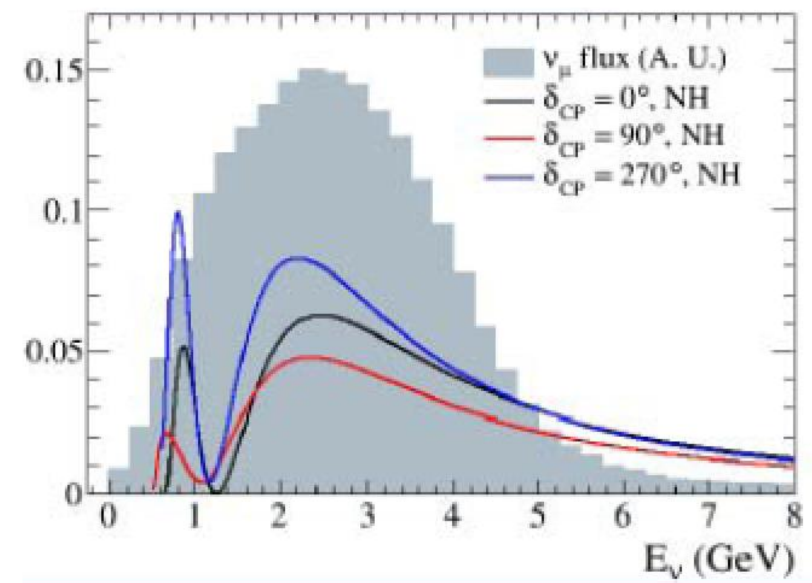


Mass ordering sensitivity

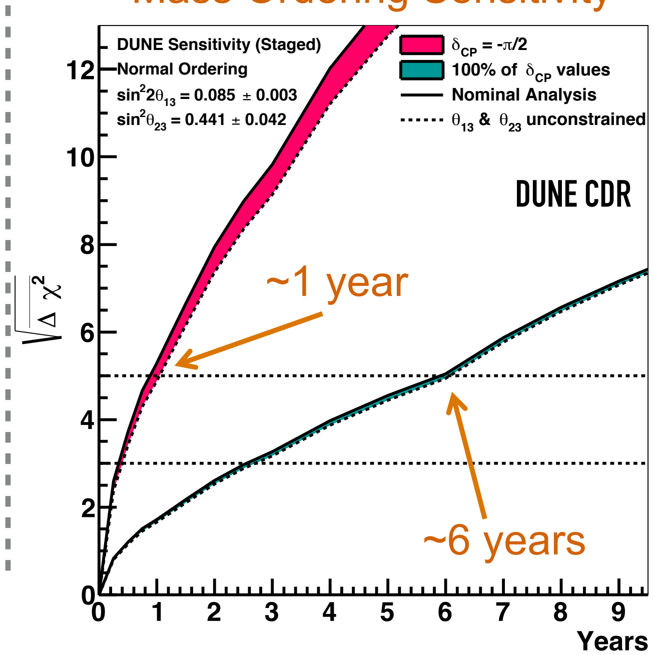


arXiv:1611.06118

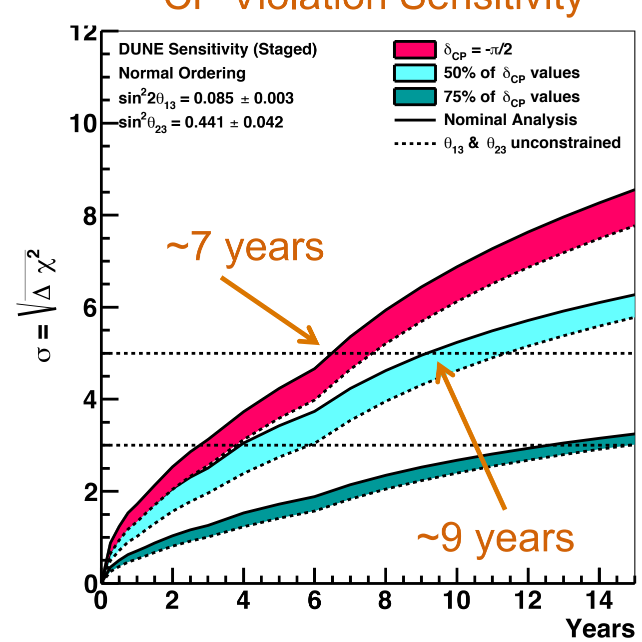
DUNE



Mass Ordering Sensitivity



CP Violation Sensitivity

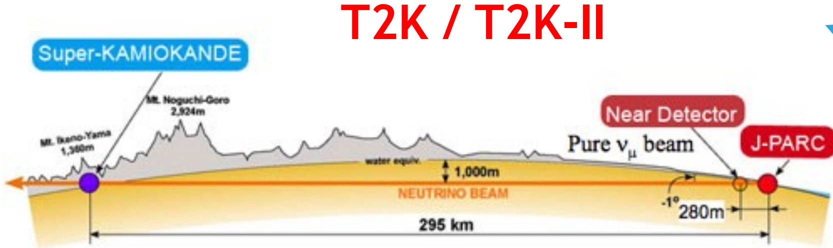


THE CERN NEUTRINO PLATFORM

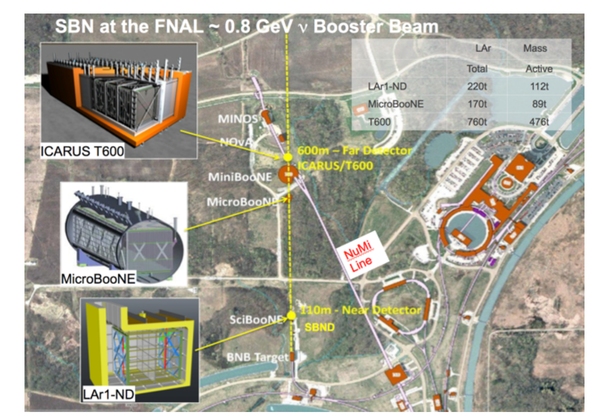
The Mandate: European Strategy for Particle Physics (2013)

"Rapid progress in neutrino oscillation physics, with significant European involvement, has established a strong scientific case for a long-baseline neutrino programme exploring CP violation and the mass hierarchy in the neutrino sector. CERN should develop a neutrino program to ***pave the way*** *for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan."*

T2K / T2K-II



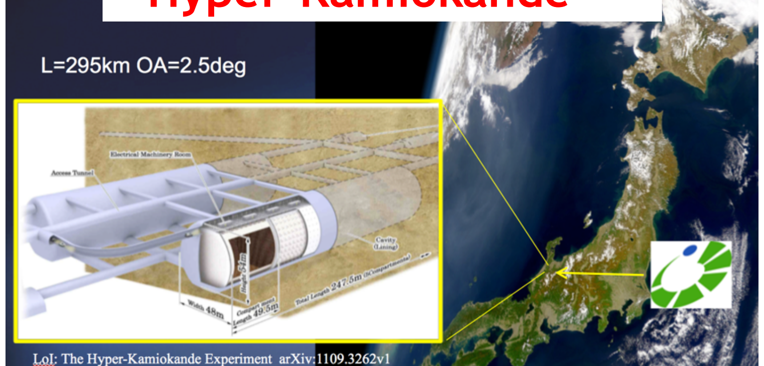
SBN (short baseline)



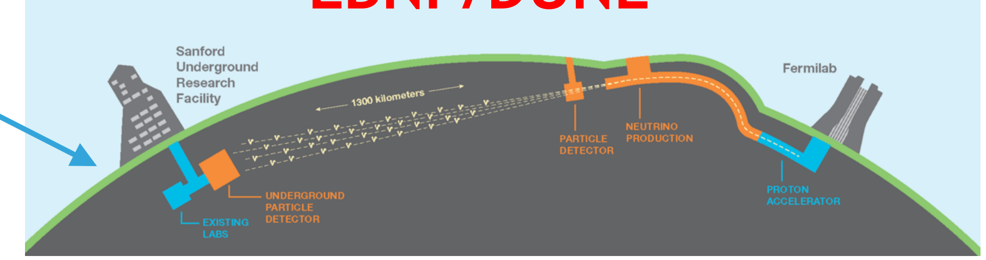
Neutrino PLATFORM

http://cenf.web.cern.ch/

Hyper-Kamiokande

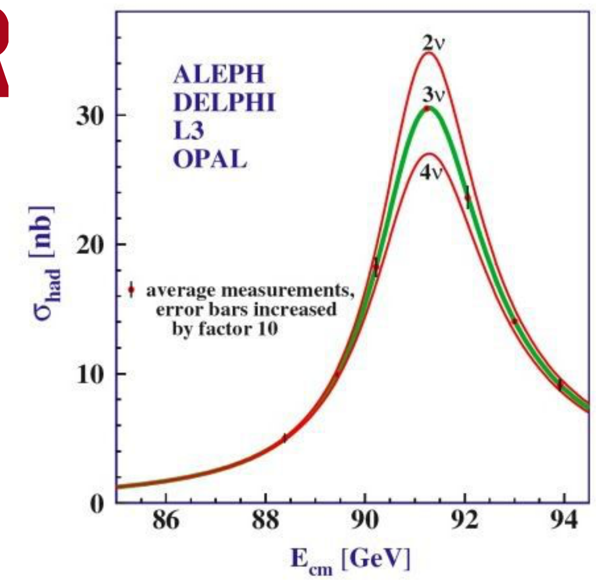


LBNF/DUNE



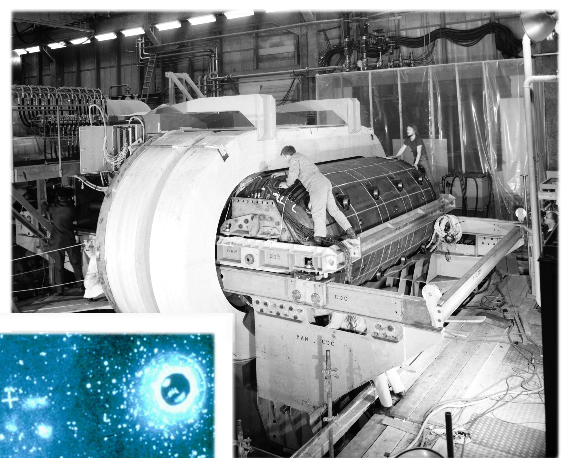
INTRODUCTION : NEUTRINOS ET CER

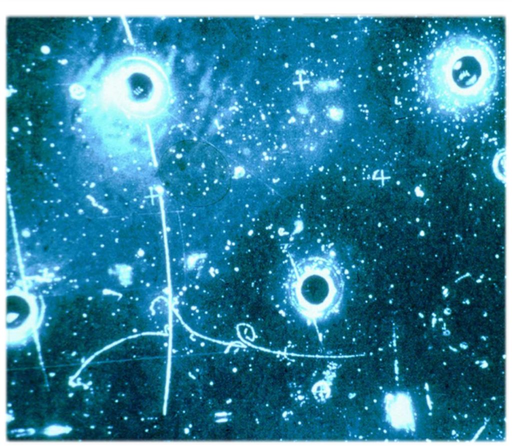
width of Z boson



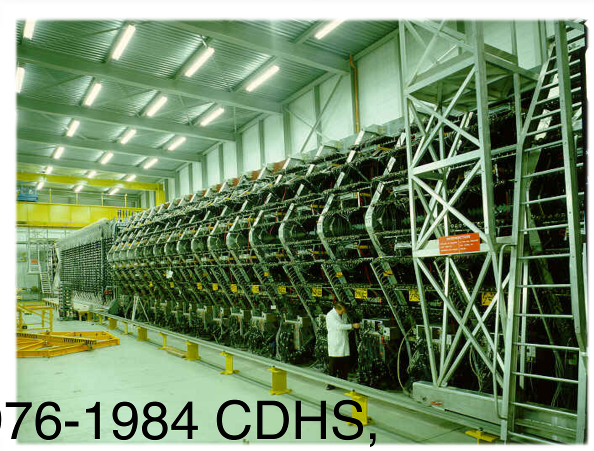
1970-1979 Gargamelle

Discovery of neutral currents



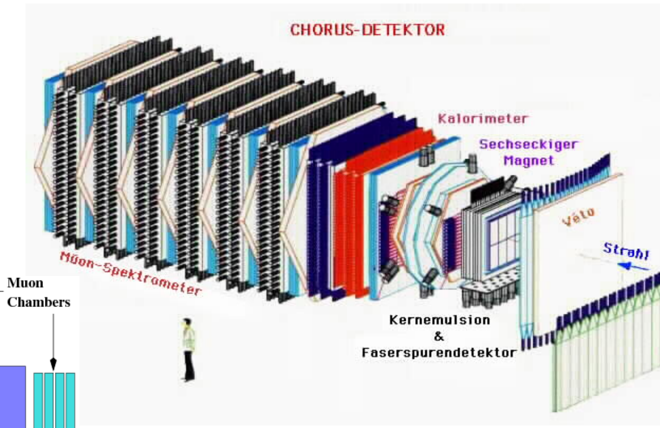


BEBC 1960-1984

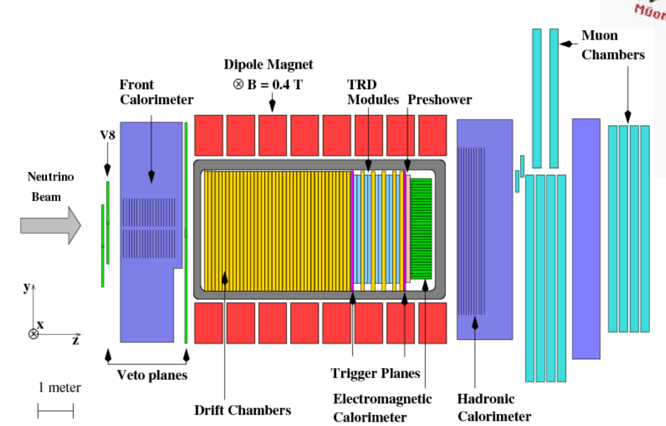


1976-1984 CDHS,
deep inelastic interactions

CHORUS 1994-1997



NOMAD 1995-1998



ICARUS
2010-2012

OPERA
2009-2012

THE CERN NEUTRINO PLATFORM

- **Assist** the various groups in their R&D phase in the short and medium term and give **coherence** to a fragmented European Neutrino Community
- Provide a charged particle test beam **infrastructure** for tests and R&D
- Bring R&D programs to the level of **technology demonstrators** in view of major construction activities
- Continue **neutrino beam R&D**, as possible basis for further collaborations
- Support the **short and long baseline activities** (infrastructure & detectors)
- Be a partner in the physics exploitation

NP reacts on **input from the community**

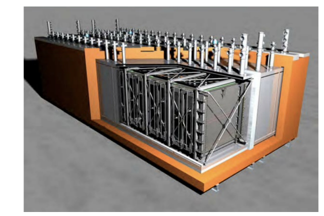
> **100** institutes participate to the NP (MoU)

Neutrino Platform part of the CERN Medium Term Plan (since 2015)

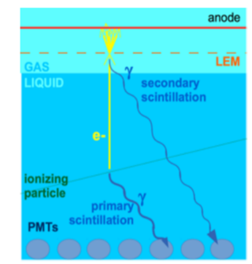
THE NP CURRENT PROJECTS

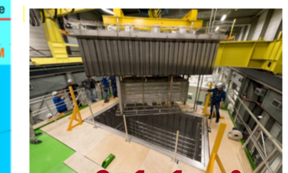
- **NP01** (WA104/ICARUS) : far detector for the US Short Baseline program

ICARUS



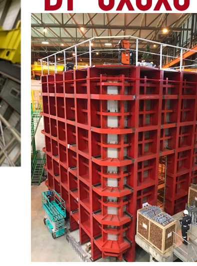
- **NP02** (protoDUNE-DP WA105): demonstrator + engineering prototype for a Double phase (LAr+GAr) TPC





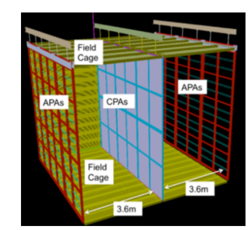
3x1x1 m^3

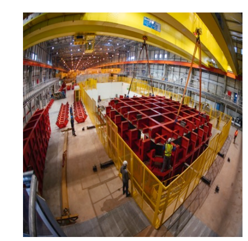
DP 6x6x6 m^3



- **NP03:** generic R&D framework

- **NP04** (protoDUNE-SP): engineering prototype for a LAr TPC





SP 6x6x6 m^3

- **NP05** (Baby MIND): a magnetised muon spectrometer for the WAGASCI experiment in Japan

Baby MIND

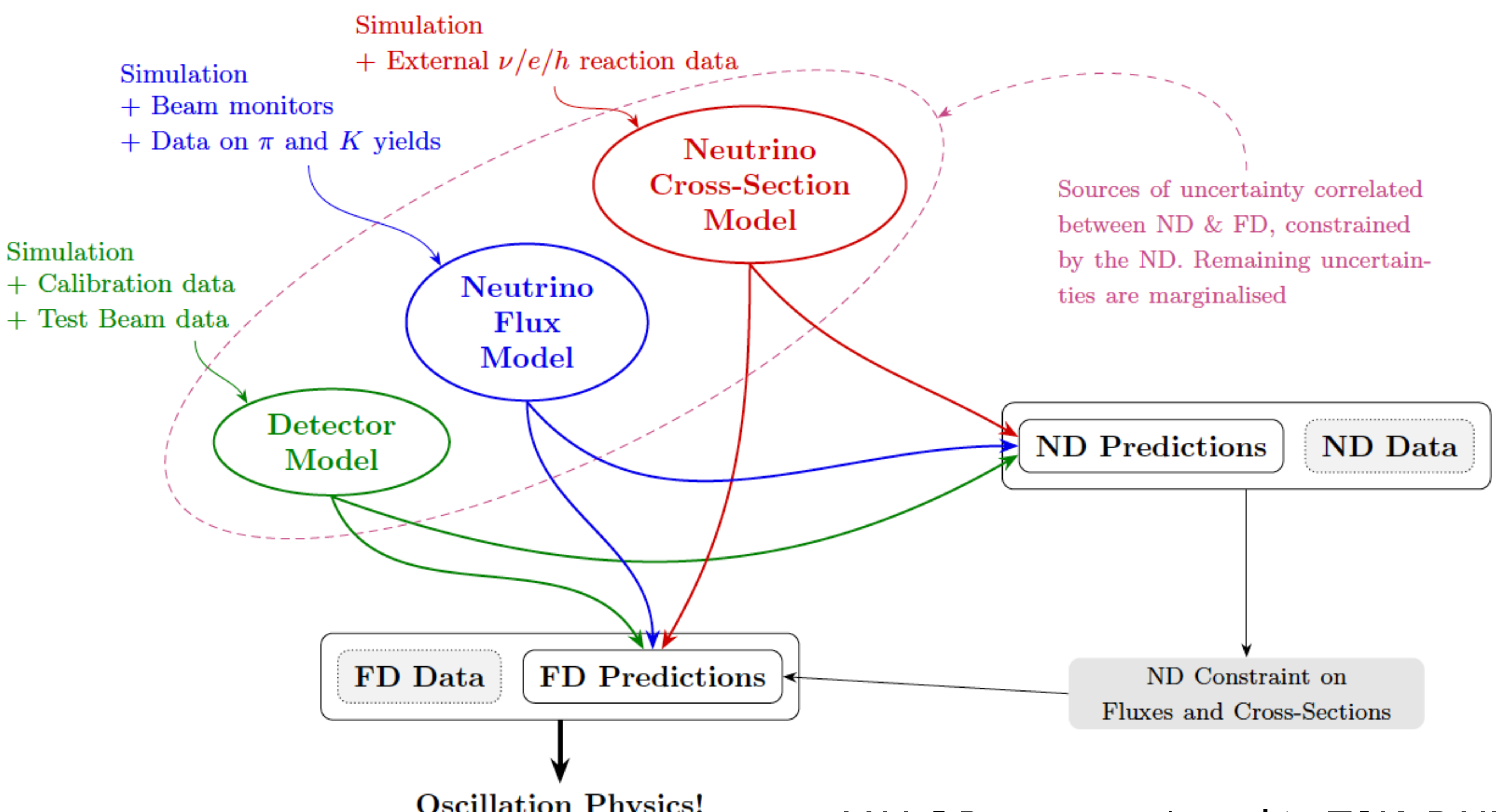
+

- Near detector studies for T2K and DUNE
- Performance study and requirement assessment of neutrino near detectors
- Participation in the design and construction of the DUNE cryostats
- Active participation in FNAL-SBN and DUNE programs

CERN AND THE NEAR DETECTOR EFFORTS

THE ROLE OF THE NEAR DETECTORS

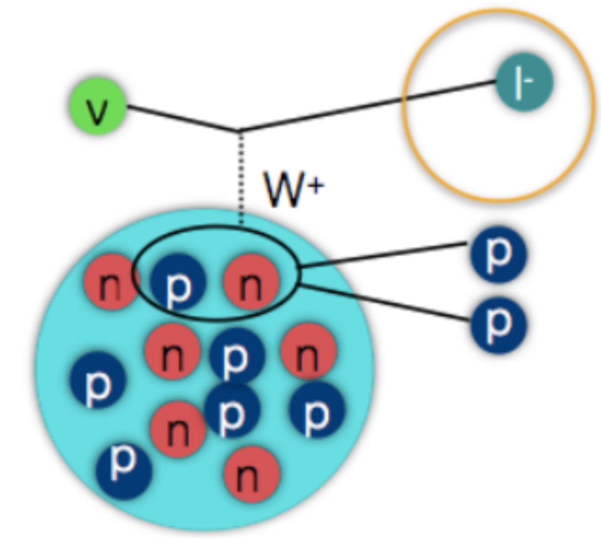
- Crucial detectors to **characterise** the **neutrino flux** before oscillation occurs
- **Provide constrains** to flux and cross-section **systematics**



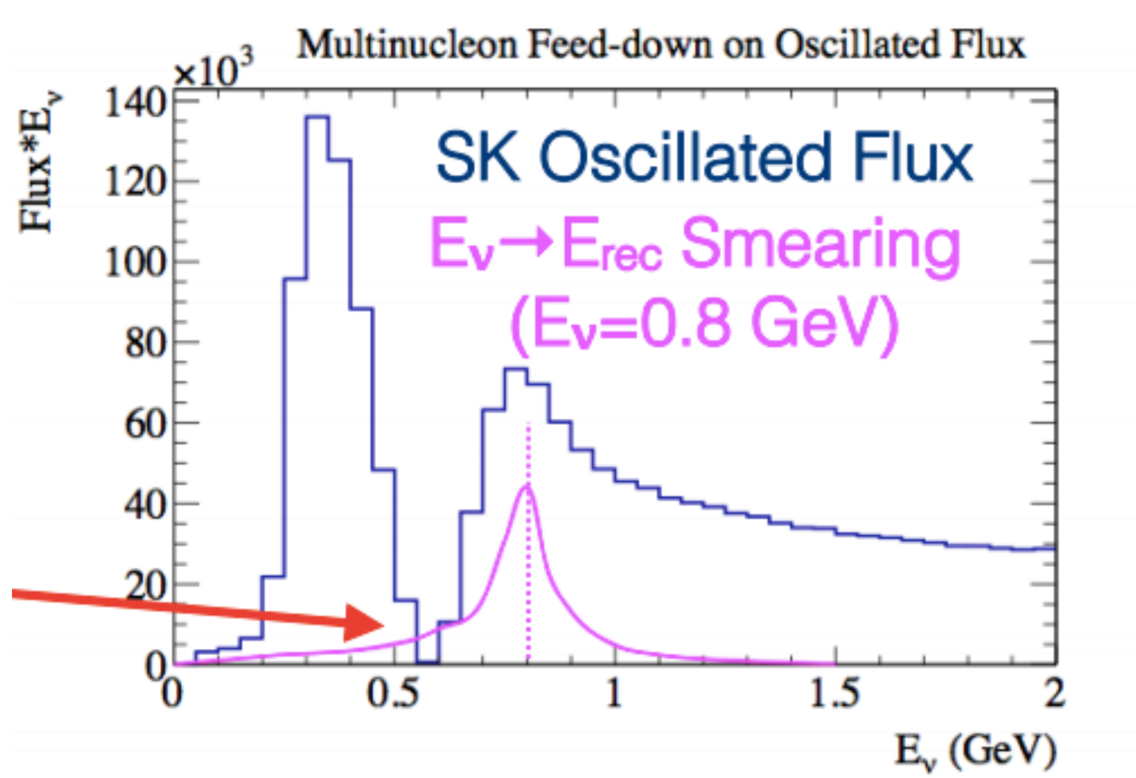
VALOR strategy (used in T2K, DUNE, SBN..)

THE ROLE OF THE NEAR DETECTORS

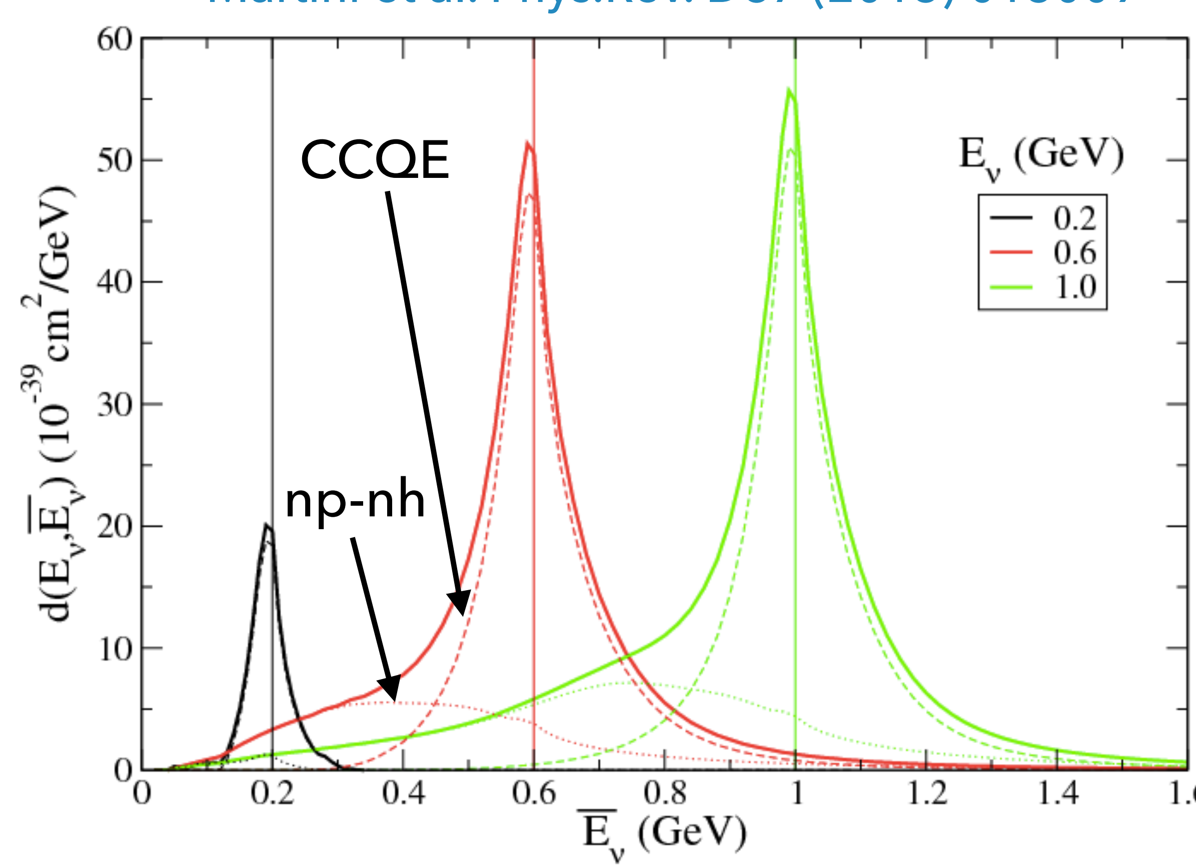
- Near detectors can **give a handle** to master **nuclear effects** which are becoming one of the dominant sources of uncertainties in the oscillation analyses



- Bias in the reconstructed energy translates in bias in the oscillation parameters

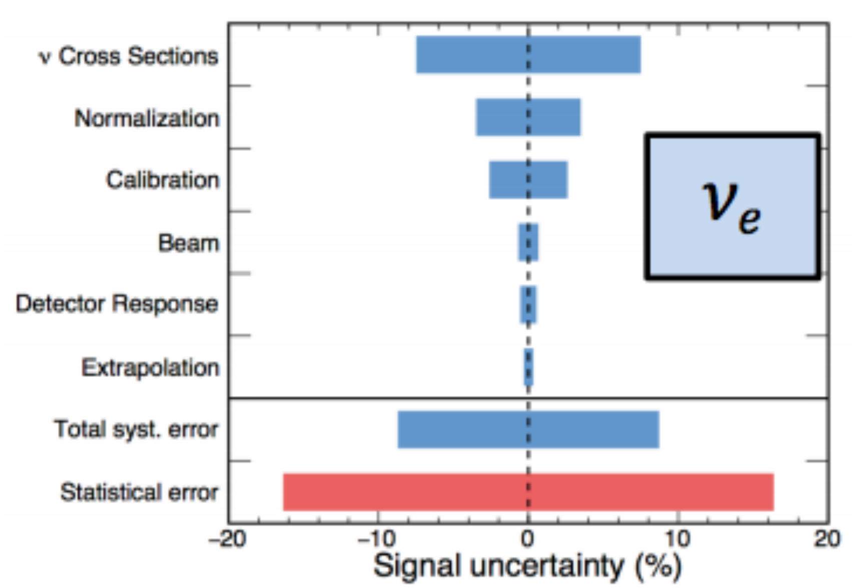


Martini et al. Phys.Rev. D87 (2013) 013009

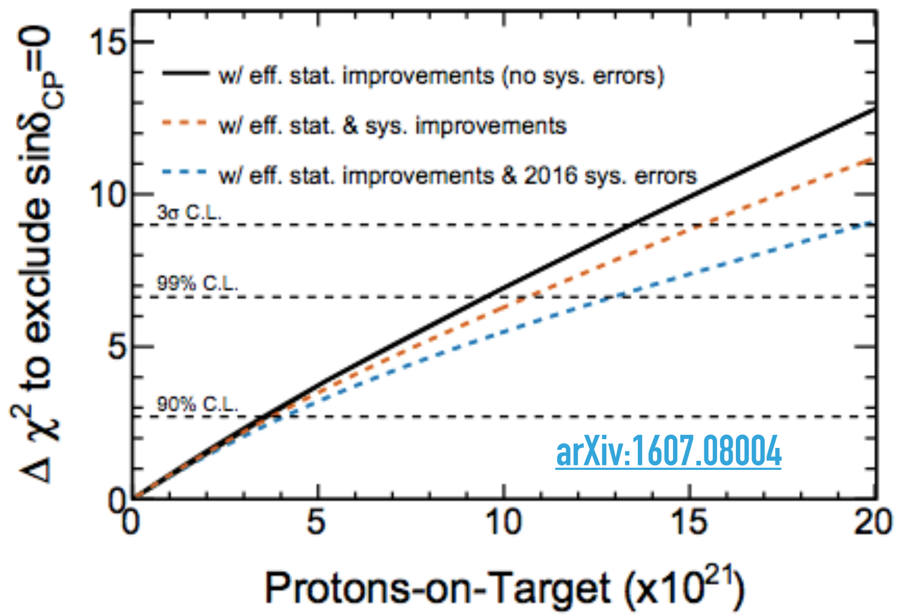


OSCILLATIONS: IMPACT OF THE SYSTEMATICS

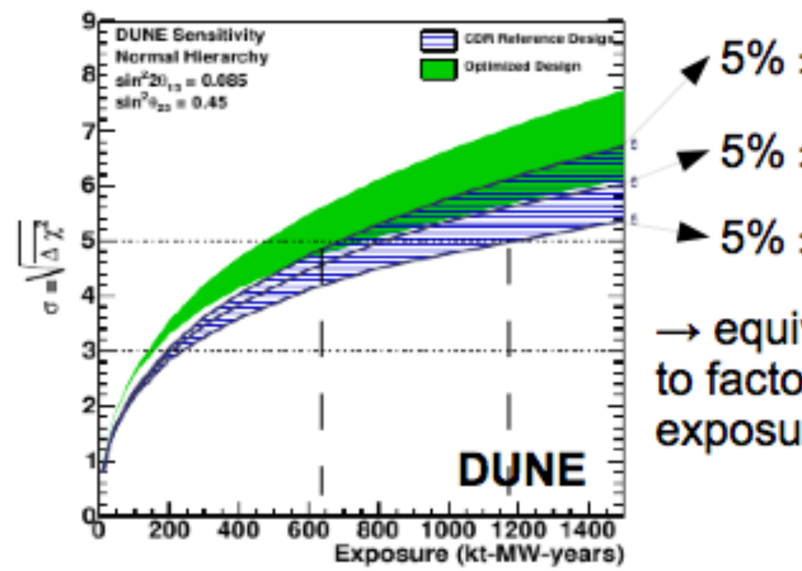
NOvA



T2K-II



from DUNE CDR



- The control of the systematics uncertainties is crucial for both current and future LBN experiments
- Neutrino cross section is the dominant source
- Importance of Near Detector measurements : better sensitivity , shorter exposure time

THE CENF-ND FORUM

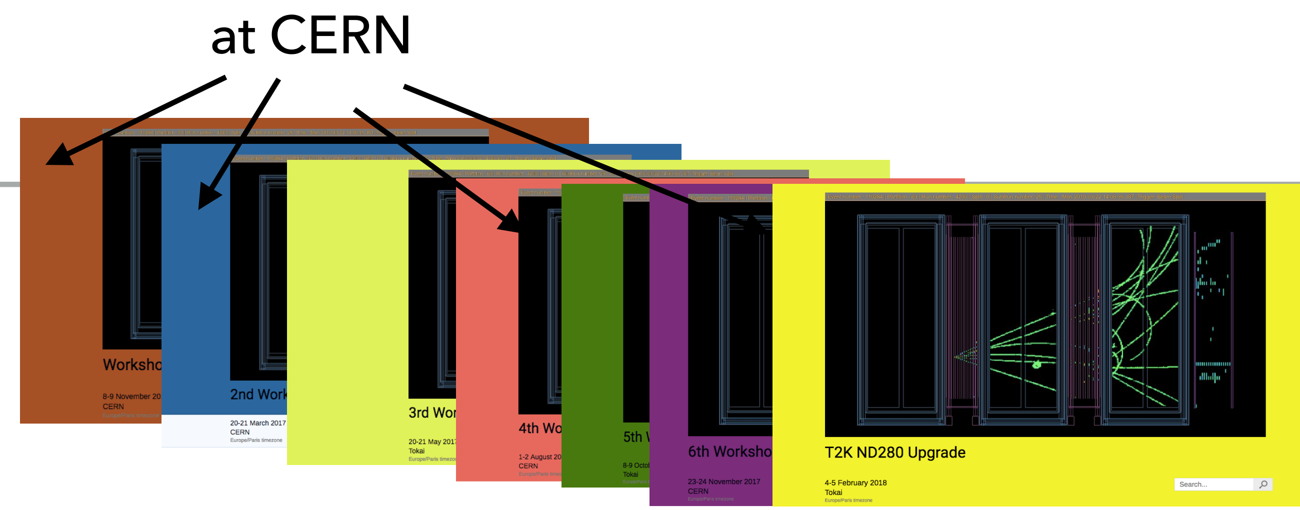
https://twiki.cern.ch/twiki/bin/view/CENF/NearDetector

TWiki > CENF Web > NearDetector (2017-06-01, StefaniaBordoni) Edit Attach PDF

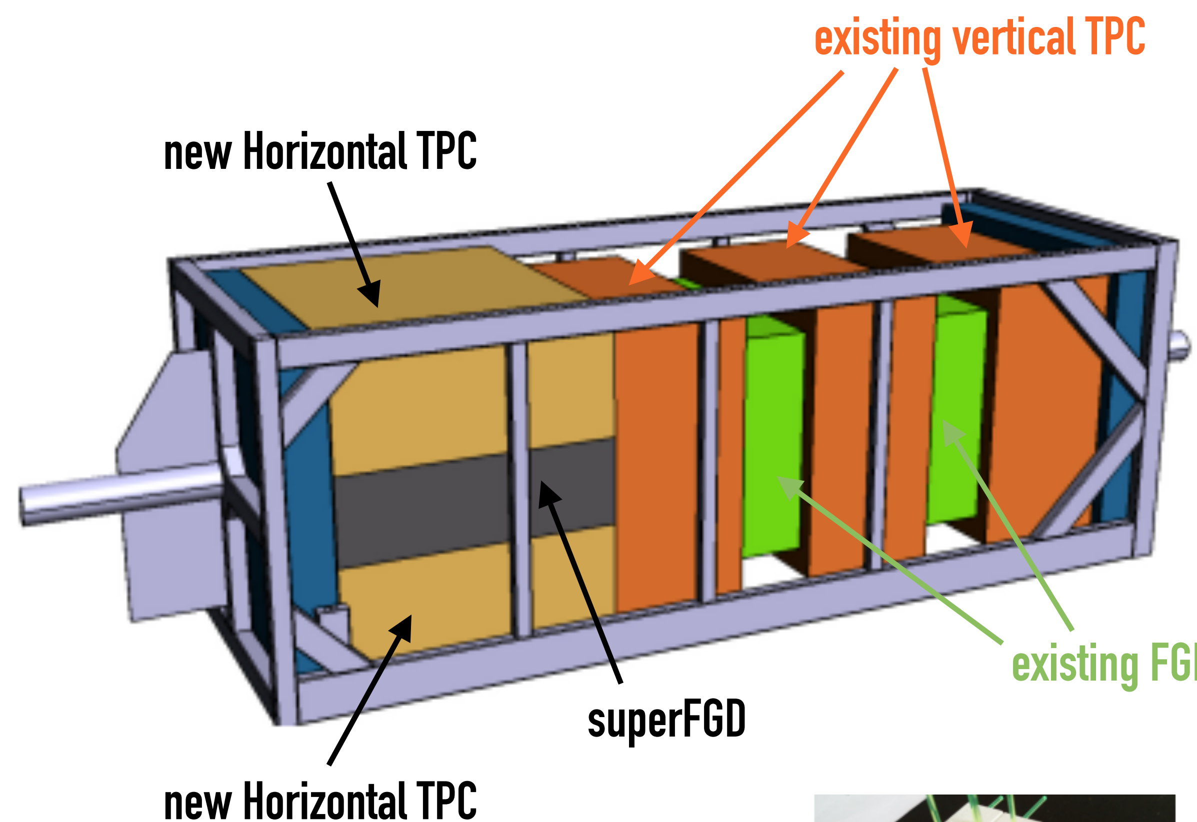
A collaborative effort toward the design of a Near Detector for the new generation of neutrino oscillation LBL experiment

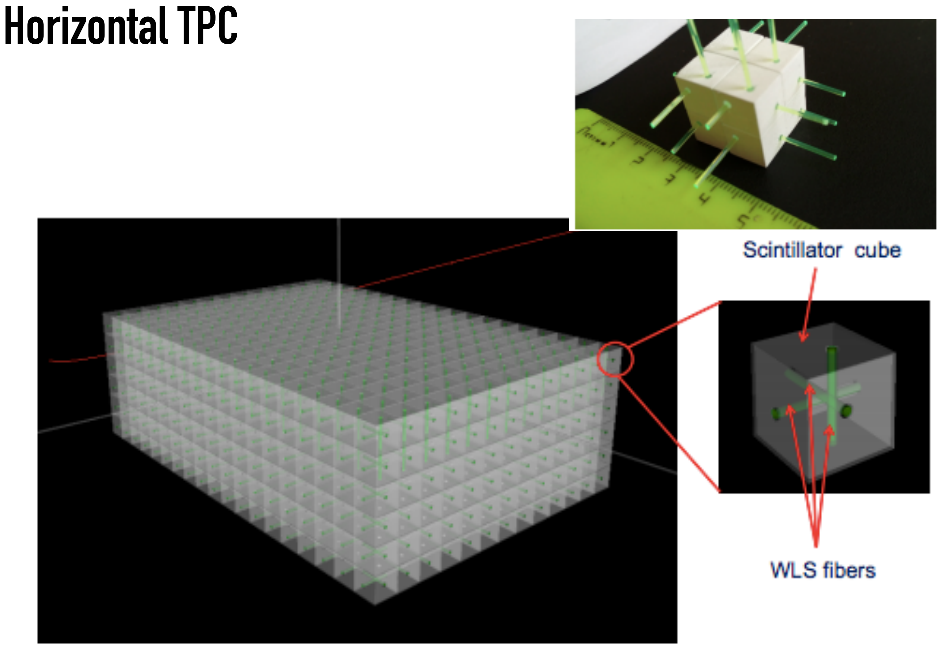
- Hub to **provide support** to the ongoing efforts of the LBN collaborations, strength the European support, **attract new institutes**, endorse participation from Japanese and American Institutes.
- **Steering group** (S.B., P.Sala, A.Weber, M. Zito) + **5 WGs** (flux, cross-section, R&D..) in close collaboration with existing frameworks and groups
- Activity started in July 2017, **more than 100 participants**
- Video meetings, Workshop at CERN and visiting are being organised

THE ND280 UPGRADE



- Proposal for an upgrade of the existing ND280 detector (at T2K)
  - 2 new horizontal TPCs with resistive MM
  - New target: 1cm^3 cubes with 3D readout (superFGD)
  - ToF around the TPCs
- HPTPC for ν cross-section measurements
- Several workshops at CERN, EoI and proposal submitted to the CERN SPSC to be a project of the Neutrino Platform
- Test beam at CERN this summer !



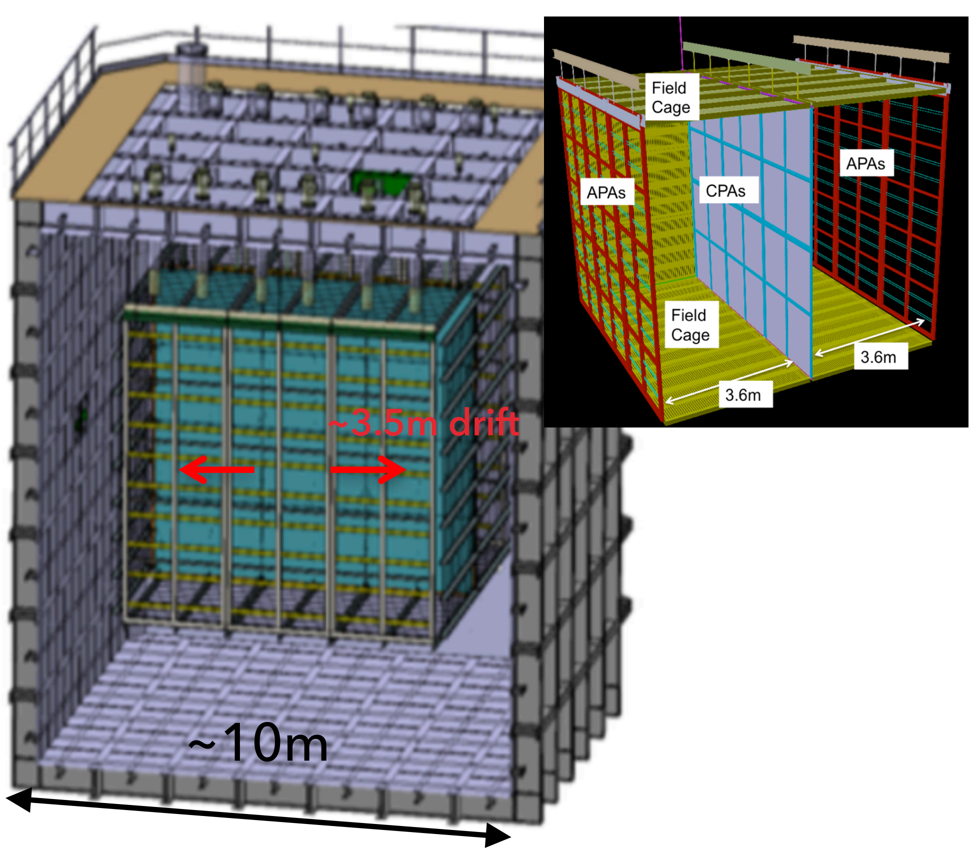


CERN AND DUNE

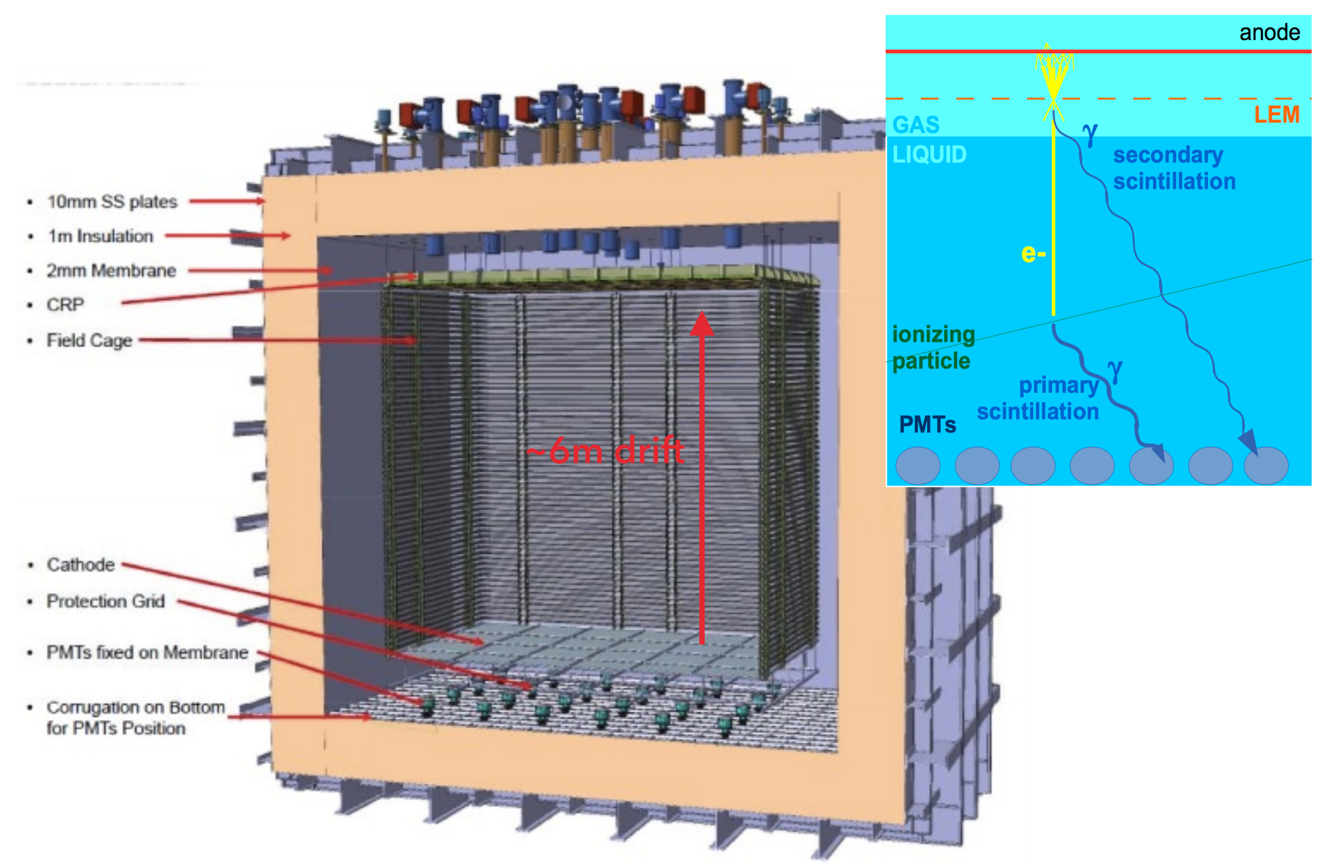
THE CERN NEUTRINO PLATFORM AND DUNE

- Large effort on the preparation of the DUNE experiment
  - Design, construction and operation of the cryostats and cryogenics system
  - New facility with dedicated tertiary H2 and H4 beam lines (VLE from SPS)
  - Construction of the prototype detectors

protoDUNE Single Phase (SP)



protoDUNE Double Phase (DP)



NORTH AREA EXTENSION (EHN1)

14 April 2016

beneficial occupancy in September 2016

NORTH AREA EXTENSION (EHN1)

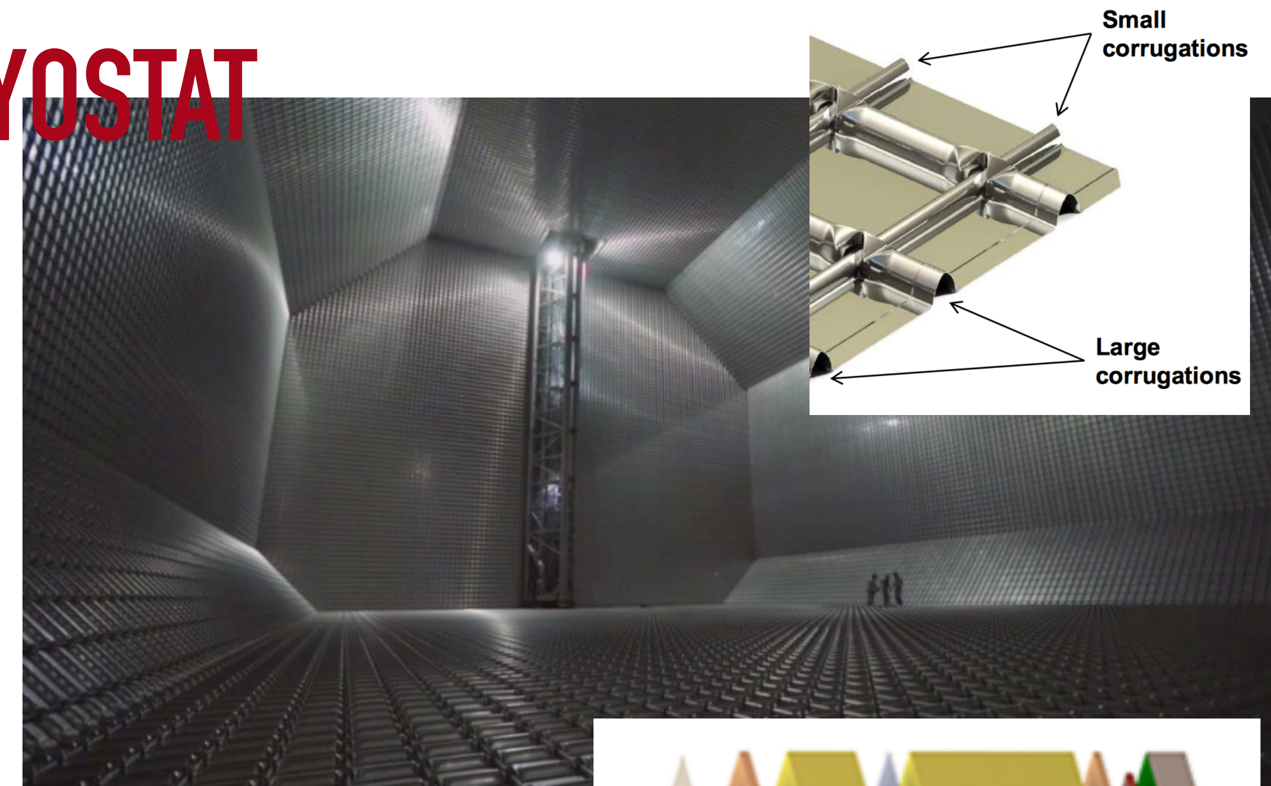
Now !

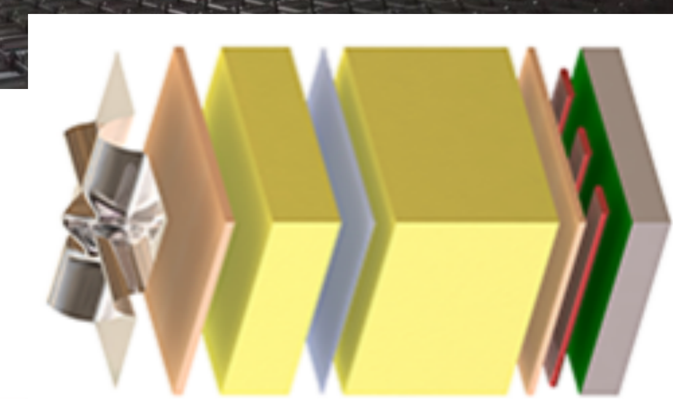
beneficial occupancy in September 2016

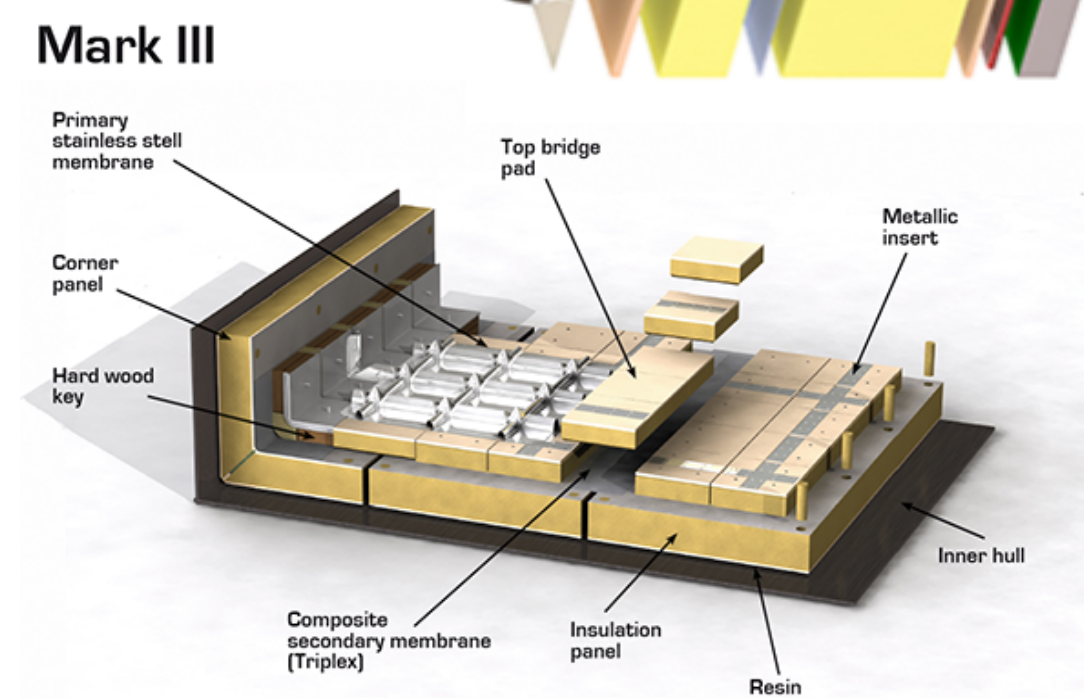
A "NEW" TECHNOLOGY FOR THE CRYOSTAT

- Technology from GTT (France) used for LNG transportation and storage
  - primary membrane in contact with the liquified gas, flexible and elastic
  - Passive thermal insulation: in between and directly connected to the primary membrane and the hull.
  - Hull: the warm structure, sustains and support the entire system.

- Technology adapted to particle physics experiments requirements
  - structure (dimensions, openings, LAr, ..)
  - More stringent requirement on heat input (5-7 W/m^2) -> 79 cm thick insulation

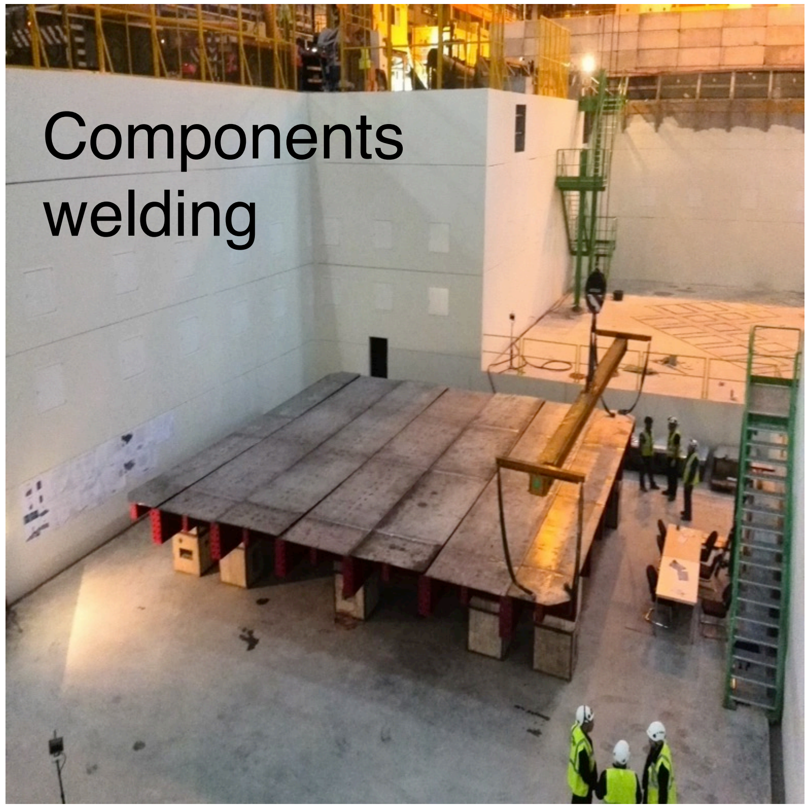






A "NEW" TECHNOLOGY FOR THE CRYOSTAT

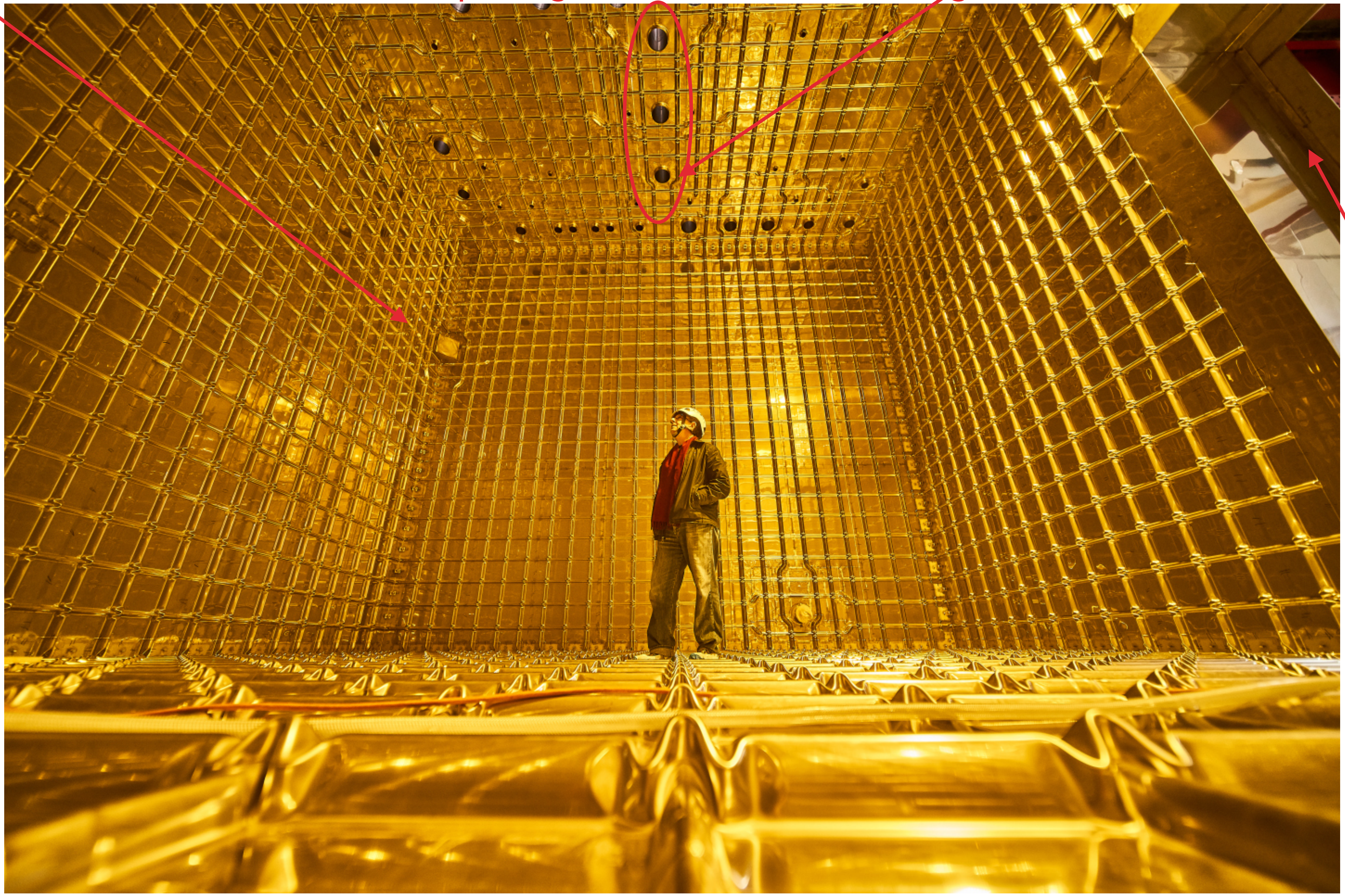
- Construction of the protoDUNE cryostats



A "NEW" TECHNOLOGY FOR THE CRYOSTATS

Beam entrance

Openings from inside (feedthrough)



Temporary Construction Opening (TCO)

Focusing on protoDUNE-SP (arbitrary choice)

- DP protoDUNE goal is to validate the alternative technology on large scale
- Strong synergies between SP and DP for cryogenics, HV feedthrough, field cage reconstruction and data analyses
- Complementarity of the two technologies

SINGLE PHASE

Pro

- demonstrated functioning underground for years
- sensing electrodes are simple wires
- stable thermodynamic conditions of the detector
- no need of HV in gas

Cons

- signal to noise limited by the electronics and wire length
- very different induction and collection view signals

DUAL PHASE

Pro

- signal amplification during just before signal formation
- electronic noise less important with respect to the SP
- completely analogous signals on the views
- possibly fewer electronic channels for the same volume
- accessible electronics

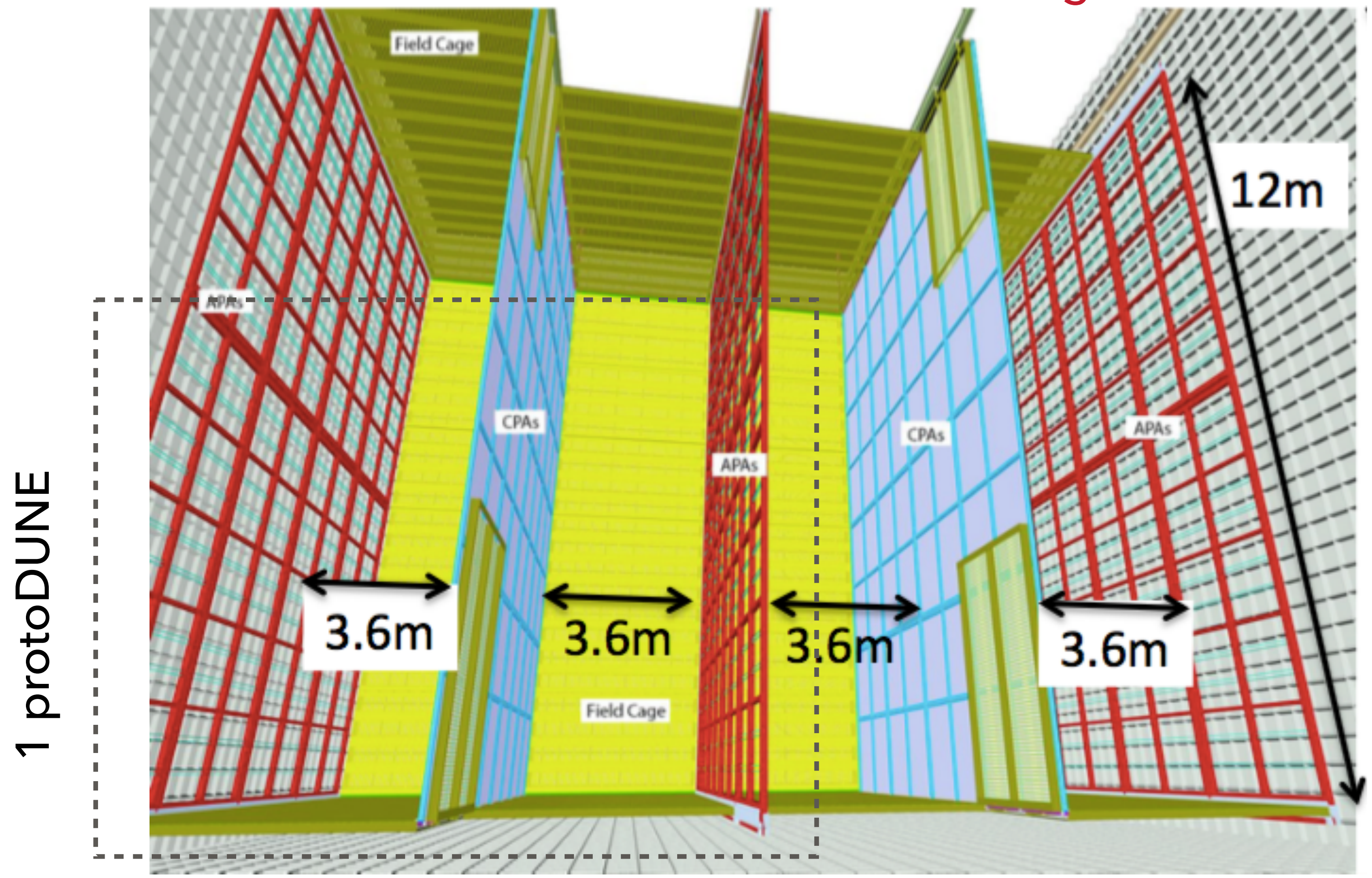
Cons

- stability and uniformity of the charge amplification
- generally larger HV needed

PROTODUNE-SP: WHY?

- real engineering prototype for the first module of the DUNE far detector
- protoDUNE-SP ~1/20 of the final FD module
- modular design: each detector part already on the size for the DUNE module

DUNE far detector SP design

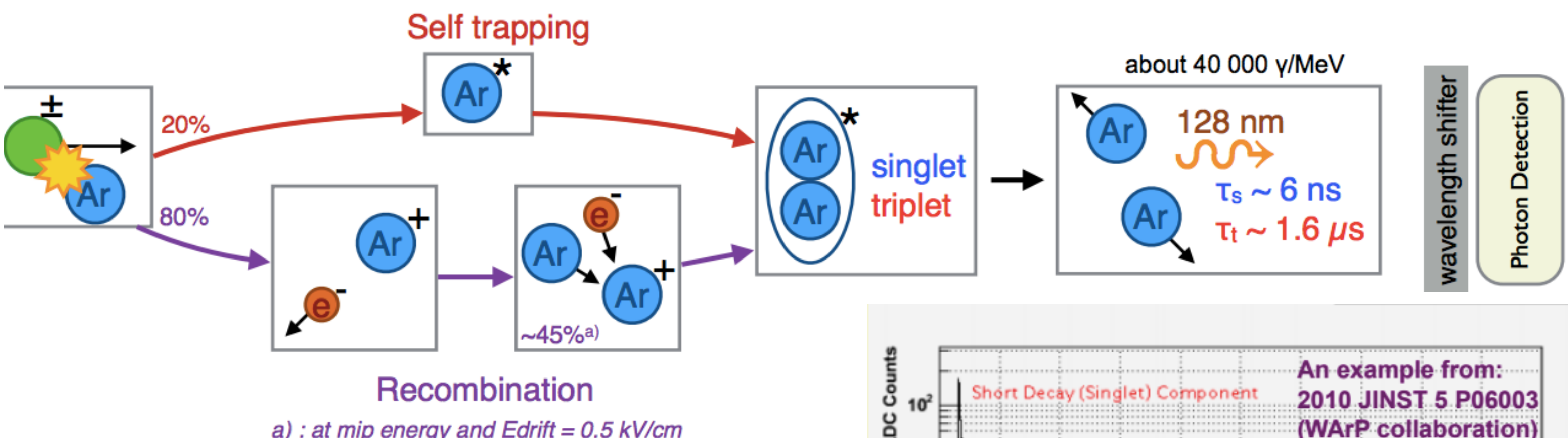


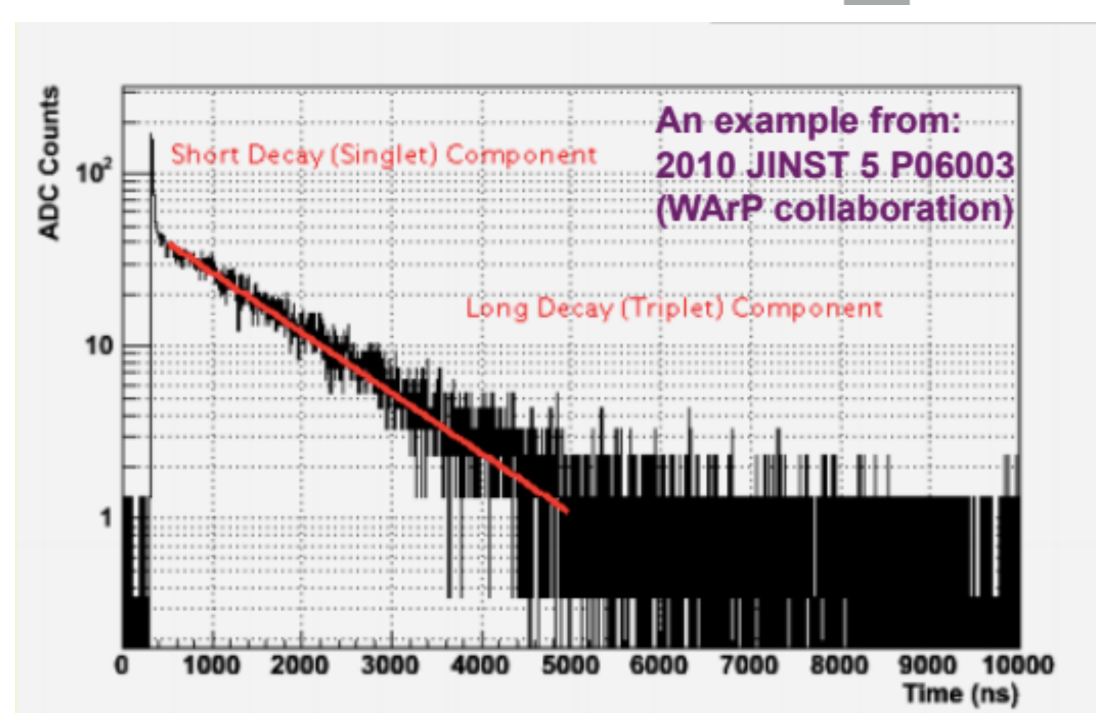
- beginning of installation of 1st FD module in y 2022
- data taking starting in y 2026

LAR TPC : HOW DOES IT WORK

When a charged particle pass through the detector

1. scintillation light from the desexcitation of the Ar excimers



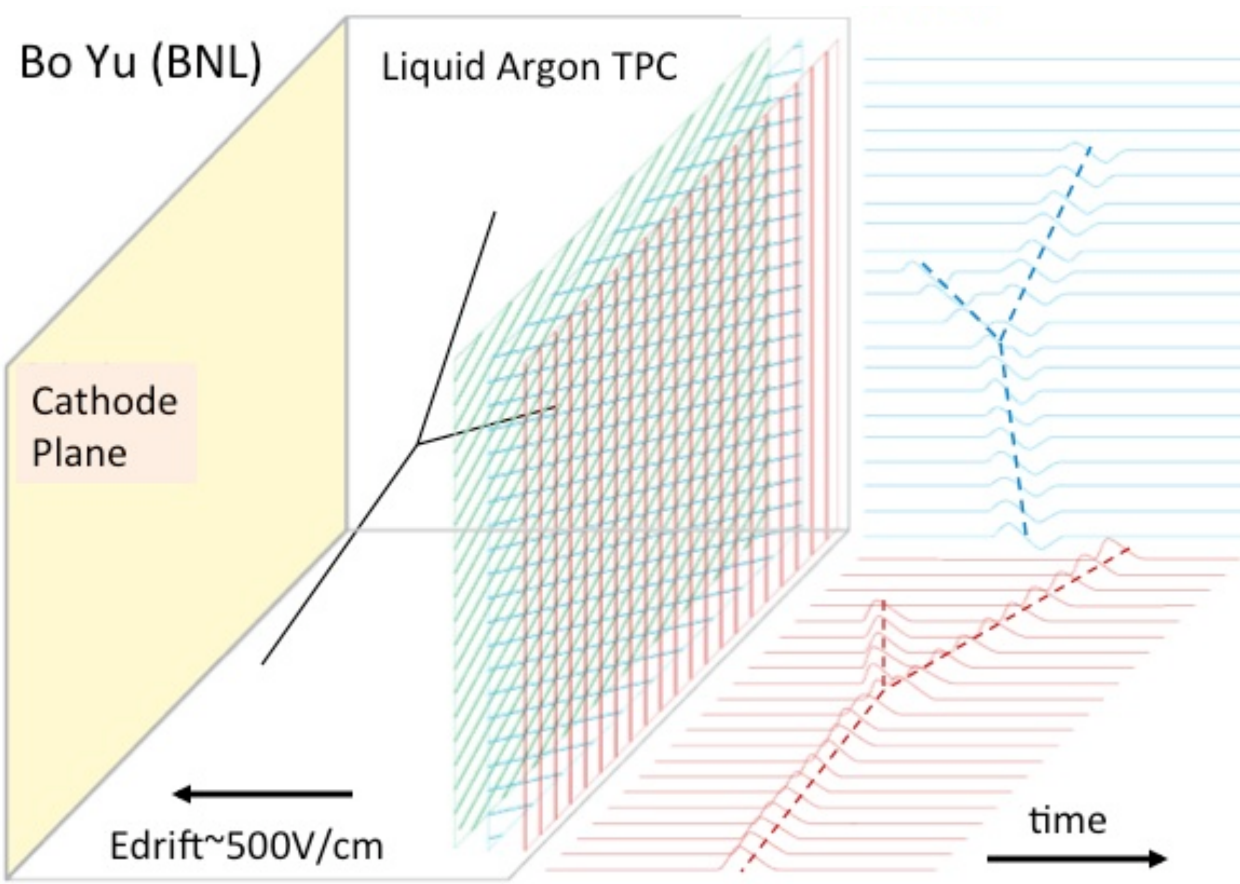


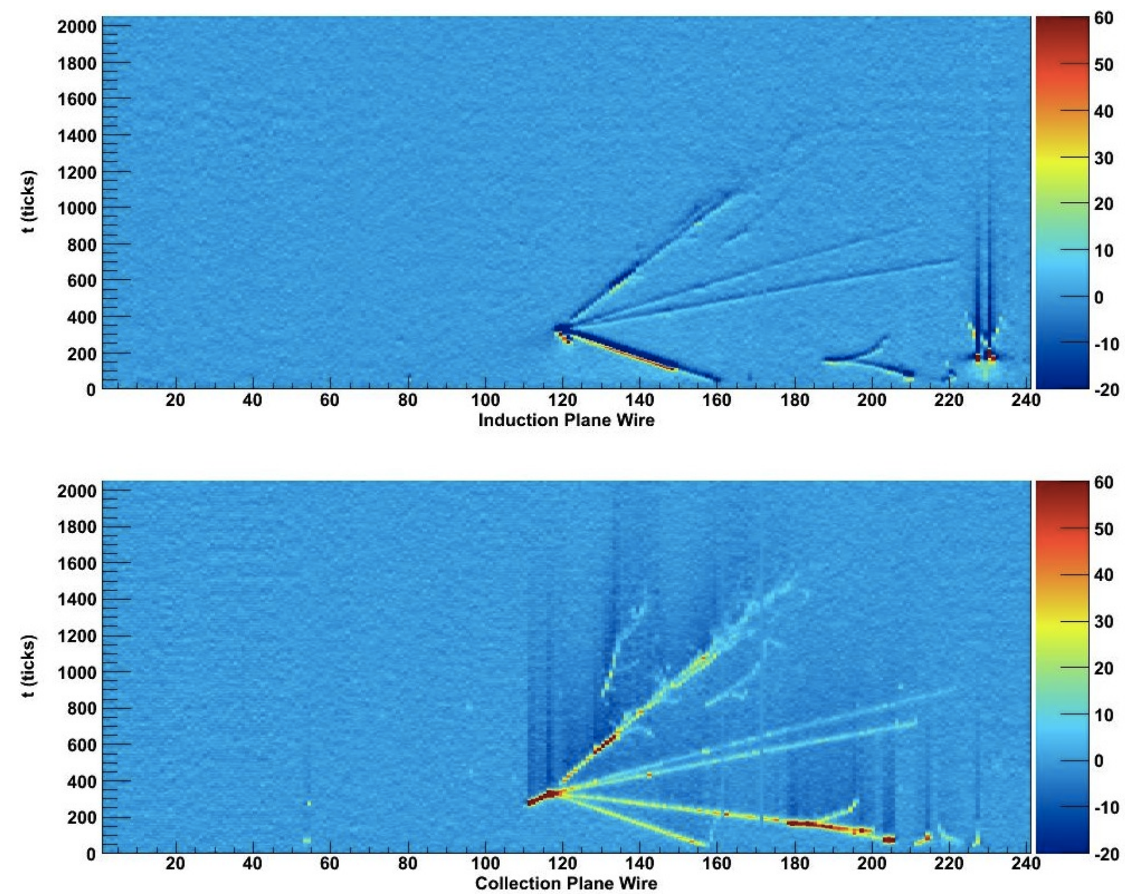
LAR TPC : HOW DOES IT WORK

2D image of the event

When a charged particle pass through the detector:

1. scintillation light from the desexcitation of the Ar excimers
2. Ar ionisation, free electrons drift towards the anode (nominal Efield = 500V/cm)



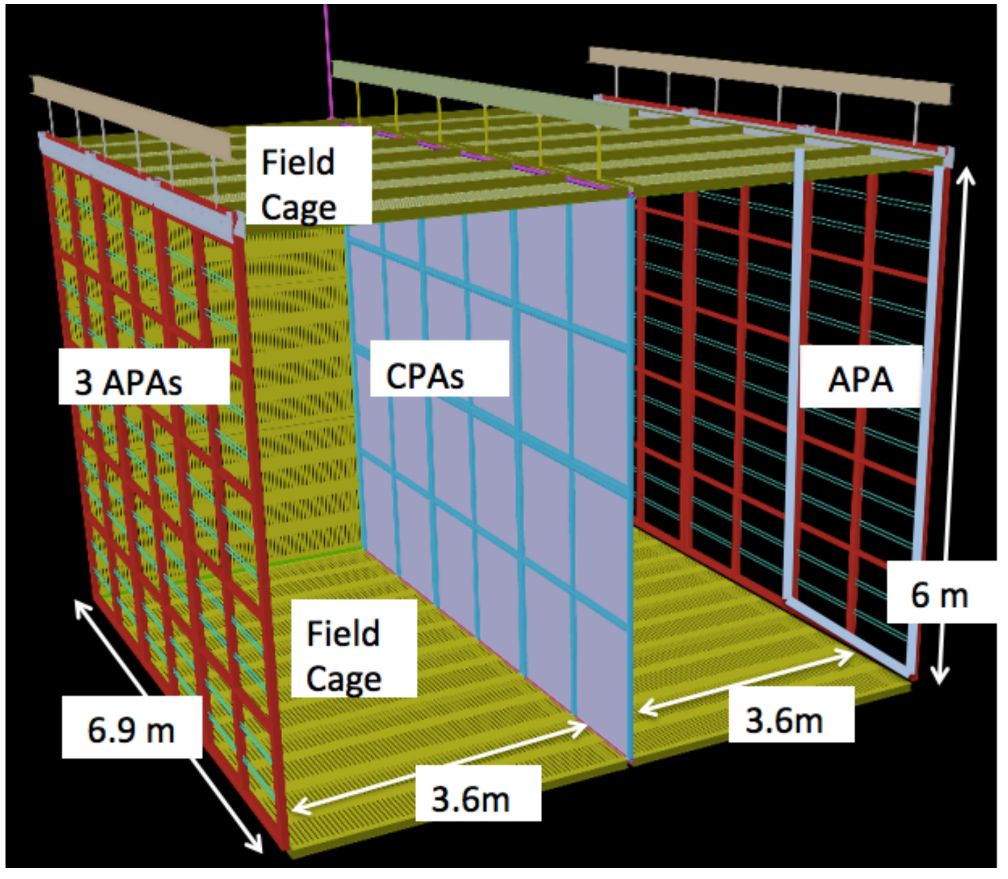


PROTODUNE-SP DESIGN

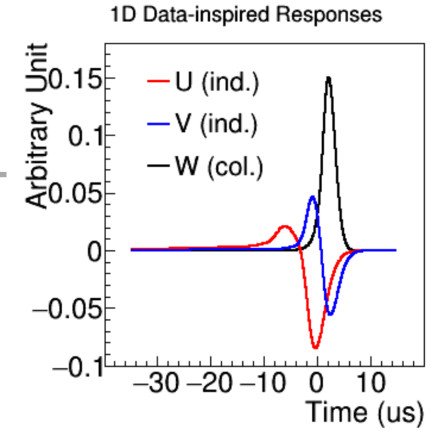
LAr TPC à la ICARUS :

- cathode in the middle, anode planes on the two sides
- Anodes: 2 planes of wires at 35.7° (induction) + 1 plane of vertical wires (collection) + 1 grid plane
- light read by plastic scintillator bars coupled with SiPM

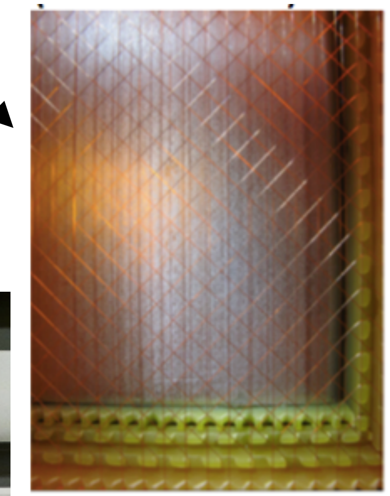
protoDUNE-SP



- ~ 800 tons of LAr
- The biggest LAr TPC at today



wire frame detail (35 tons)



PROTODUNE–SP: ANODE PLANES

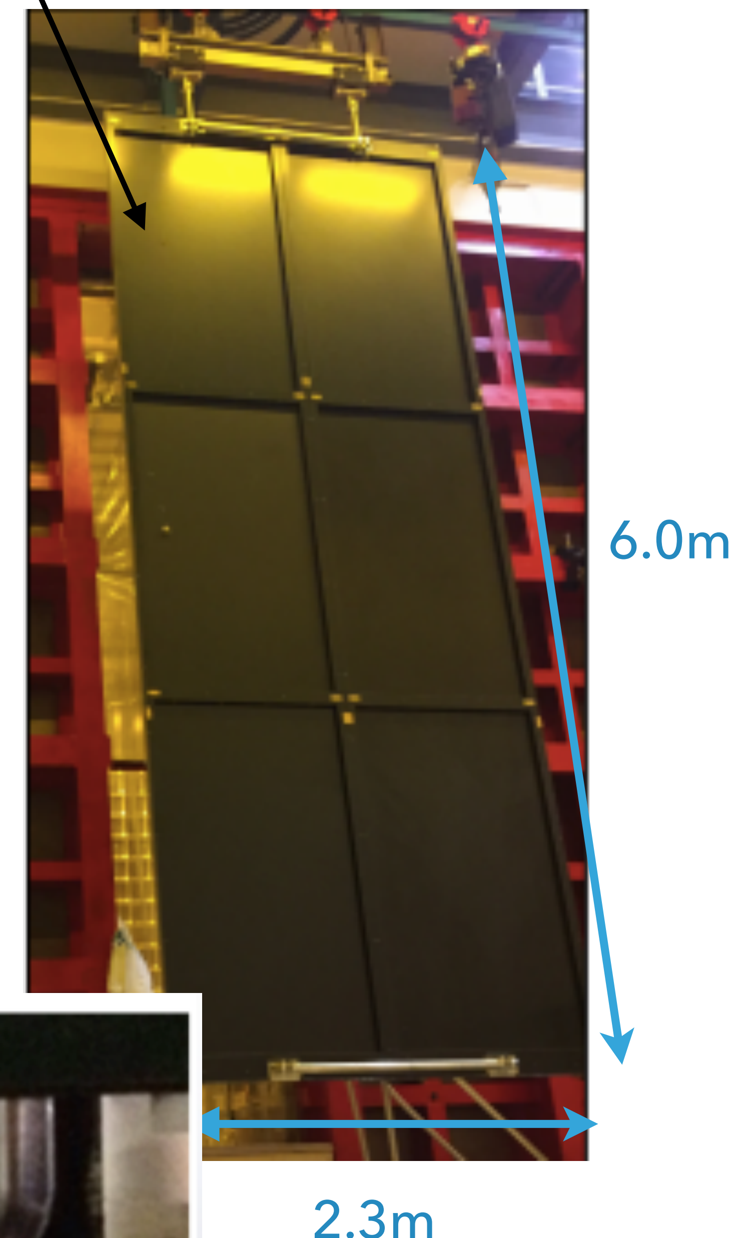
Function	no.	pitch [mm]	orientation	potential [V]
Collection (x)	960	4.79	vertical	820
Induction (V)	800	4.67	35.7° - wrapped	0
Induction (U)	800	4.67	35.7° - wrapped	-370
Grid	960	4.5	vertical	- 665

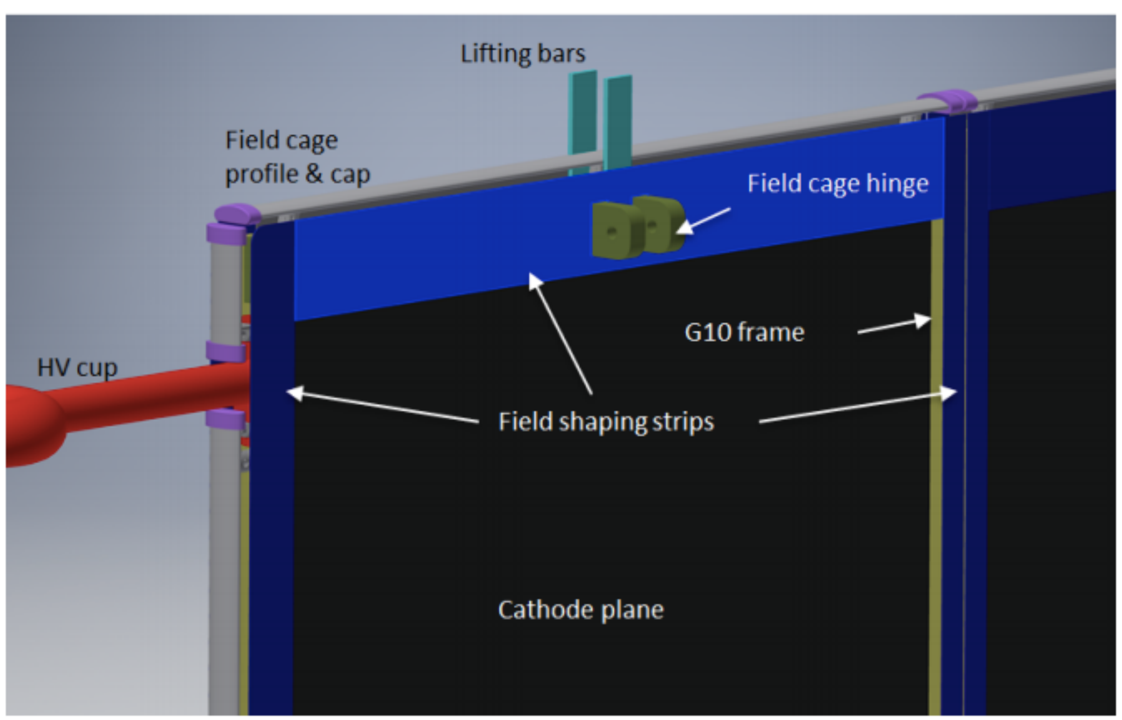
- No signal amplification
- Use of Cold Electronics to reduce the noise
- Tests in cold very successful

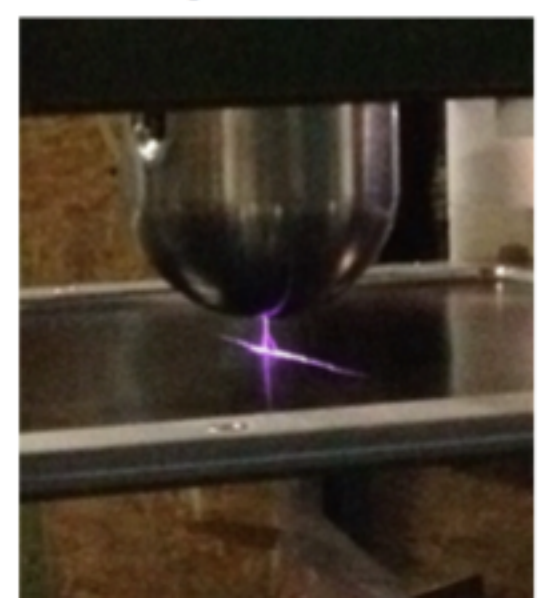
PROTODUNE-SP: CATHODE PLANE

- 3mm thick FR4 panels laminated on both side with resistive Kapton
- Bias voltage -180kV
- No electric connection across CPA columns to prevent damages in case of HV discharges
- Edges of the CPA populated with the same profile as the field cage. No need of a special design for such crucial part

1 of the 3 CPA module being assembled in the protoDUNE-SP clean room

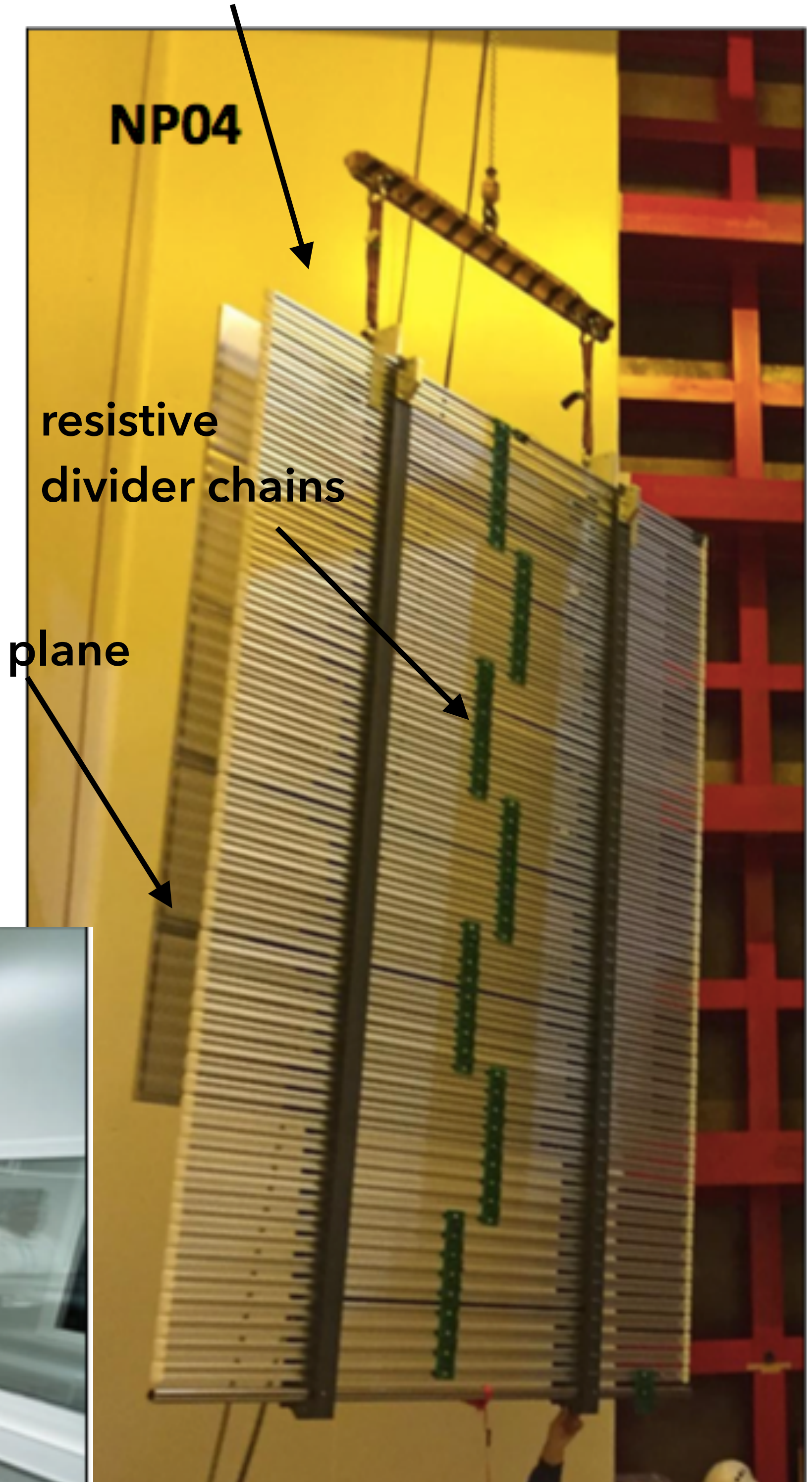


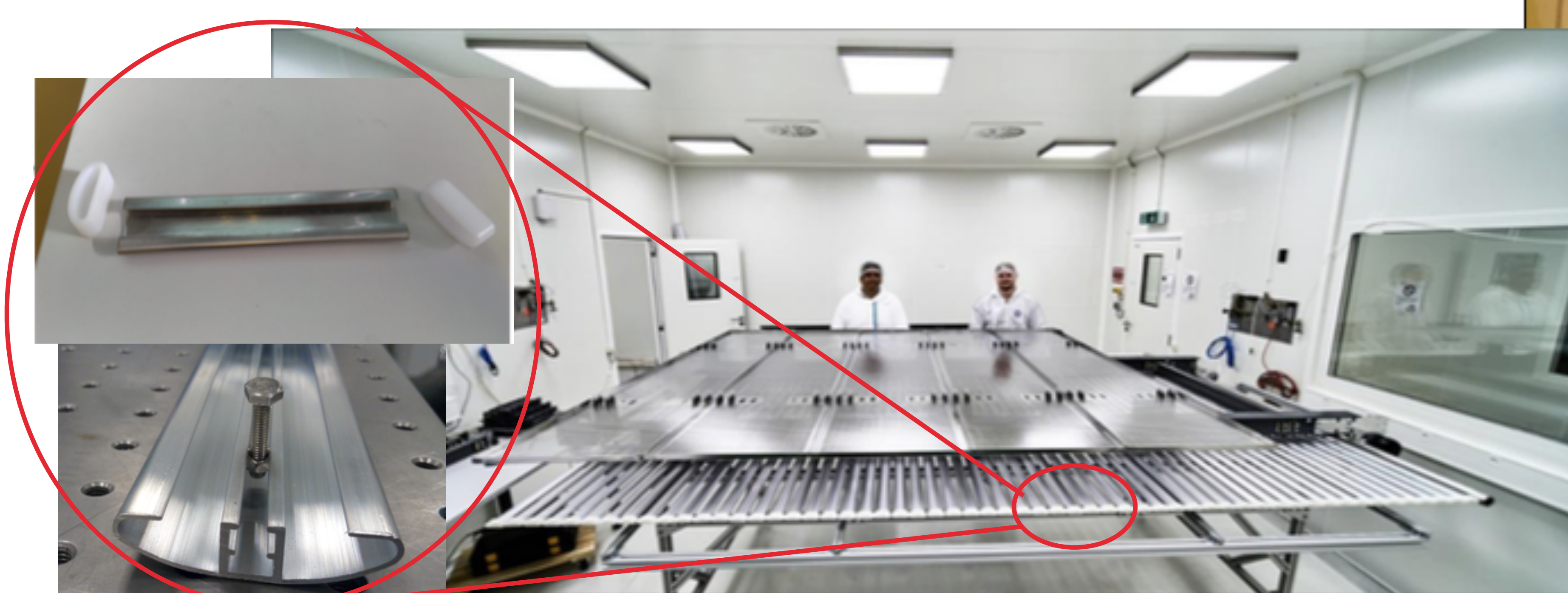




PROTODUNE-SP: FIELD CAGE

- Surround all the TPC volume maximising the active region
- providing a uniform drift field (500V/cm)
  - parallel rounded aluminium profiles with plastic cups
  - resistive divider chains interconnecting the profiles
  - on top/bottom modules equipped with ground planes in SS with holes for LAr circulation



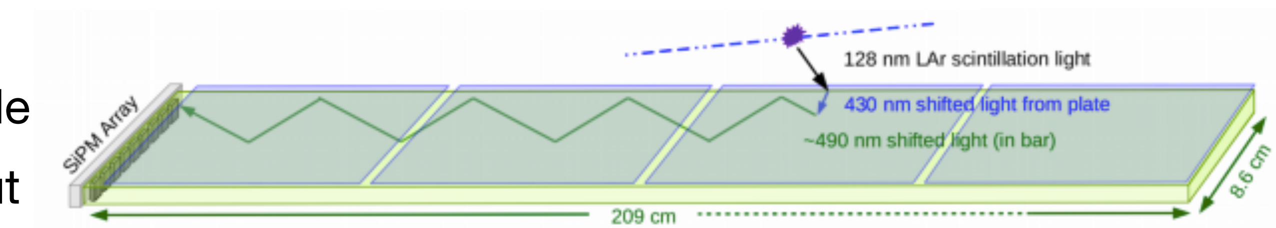


PROTODUNE-SP: PHOTOSENSORS

- 10 PhotoDetection systems per APA
- Plastic scintillator bars with wavelength shifter + SiPM

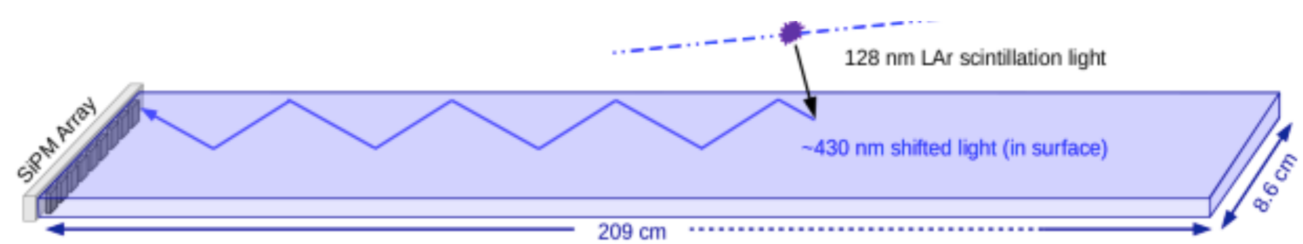
Double shift light guide

- wavelength-shifting plates + wavelength-shifting light guide
- Transport shifted light via total internal reflection to readout (SiPM array)



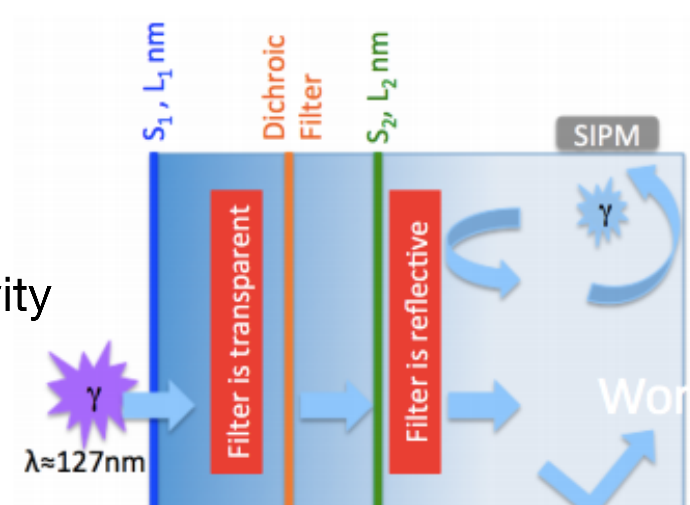
Dip-coated light guide

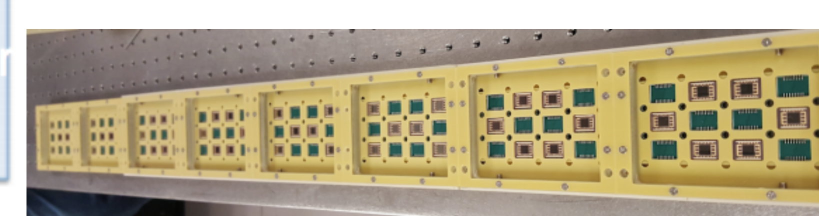
- Acrylic dip-coated with TPB+acrylic+toluene solution



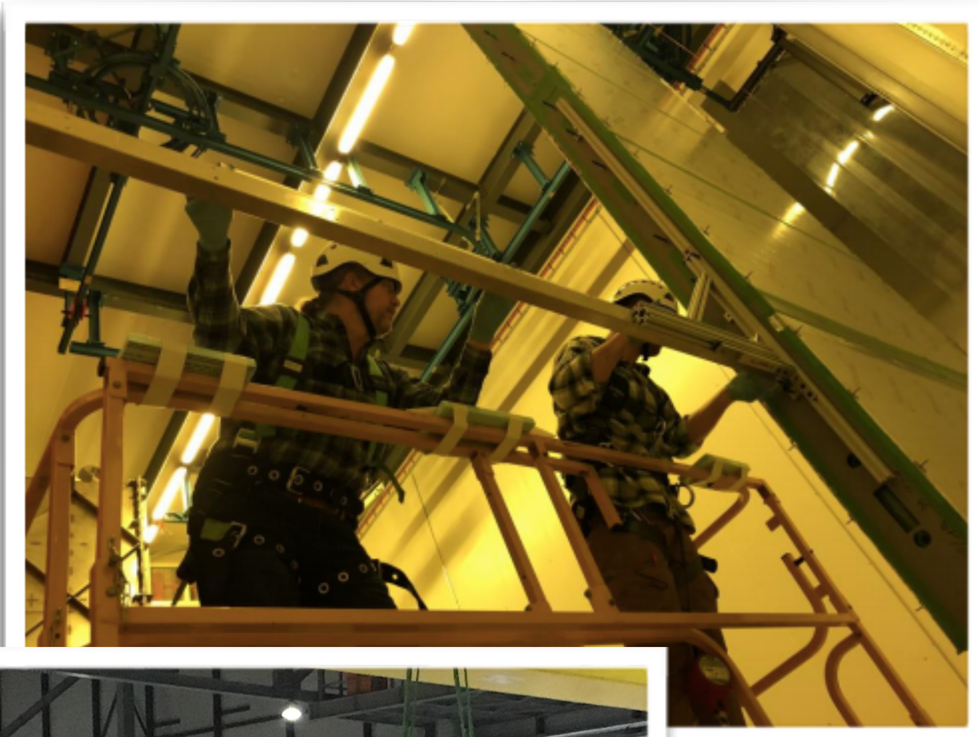
ARAPUCA

- light trapped inside box with high internal reflectivity
- combination of wavelength shifters and a dichroic optical filter





SOME PICTURES

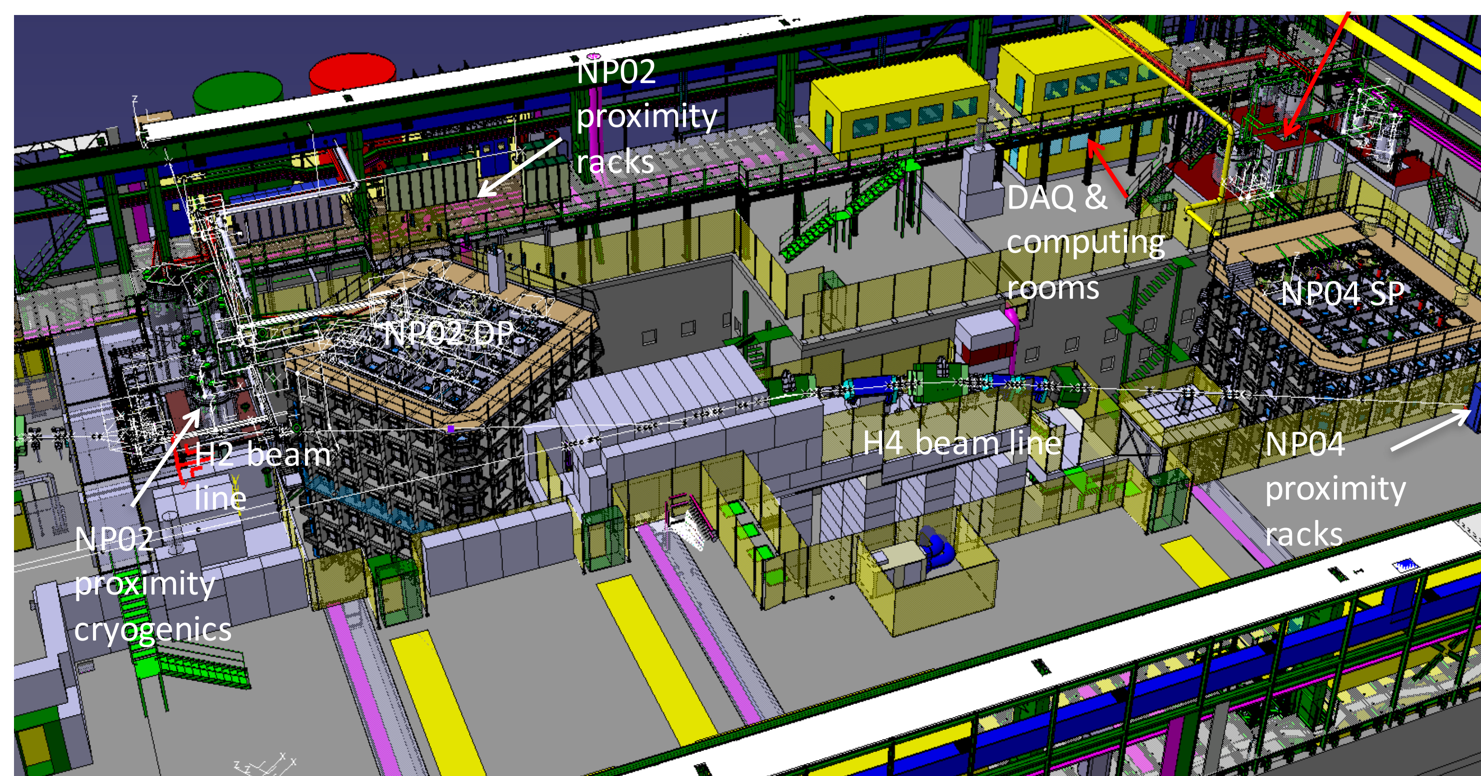


SOME PICTURES

PROTODUNE-SP: SCHEDULE AND TEST BEAM

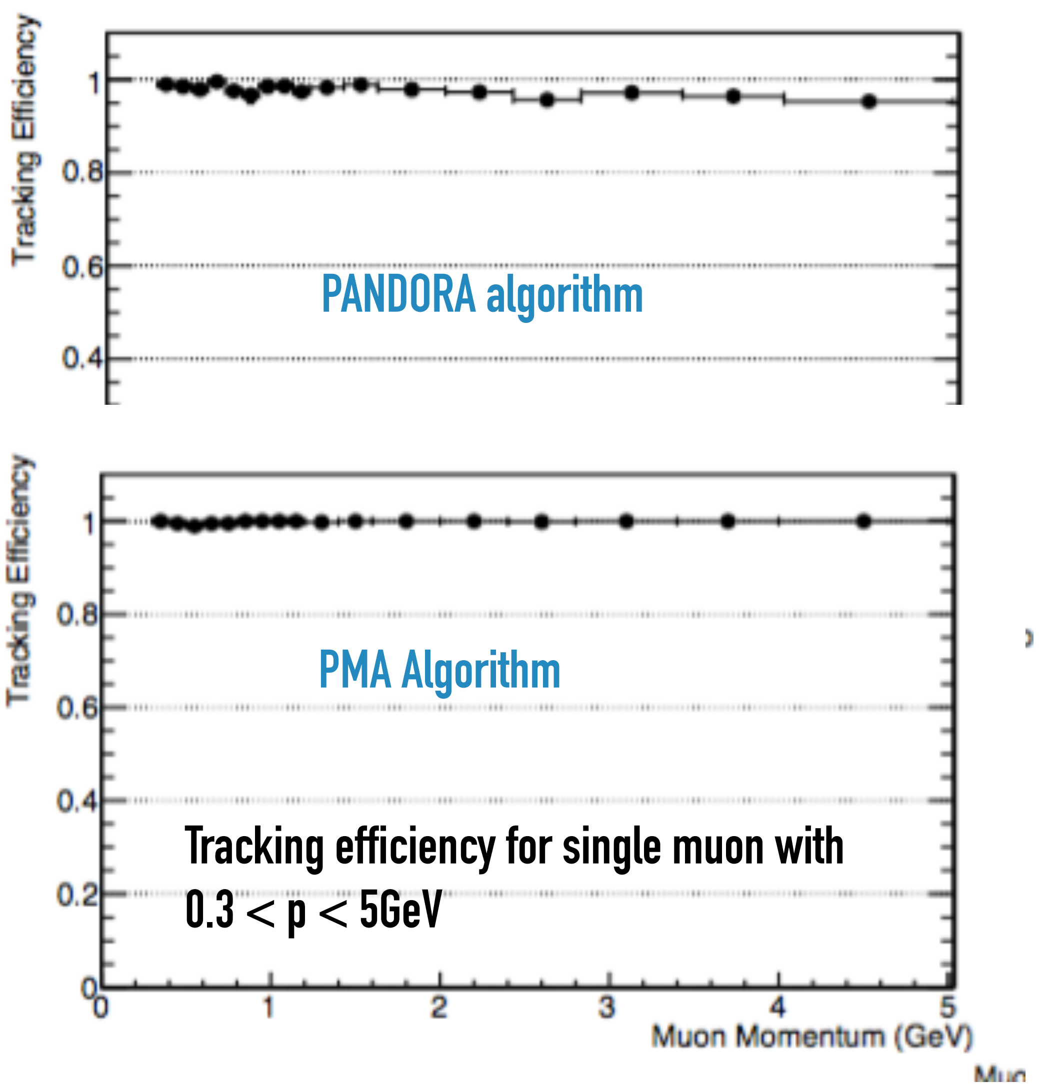
- Very tight schedule since the beginning but we are managing!
- 4th APA arrived at CERN, cathode planes installed in the cryostat, field cage end-walls already partially installed. Next week closing the first volume of the TPC.
- All detectors element inside the cryostat by end of April. Then TSO closed and access through the manhole
- June to August : purge, cool down + filling (7-8 weeks) , commissioning (1-2 weeks) and cosmic rays runs

- 7 weeks of beam from the H4 line, alternated with cosmic runs
- electron and hadron beams from 1 to 7 GeV/c

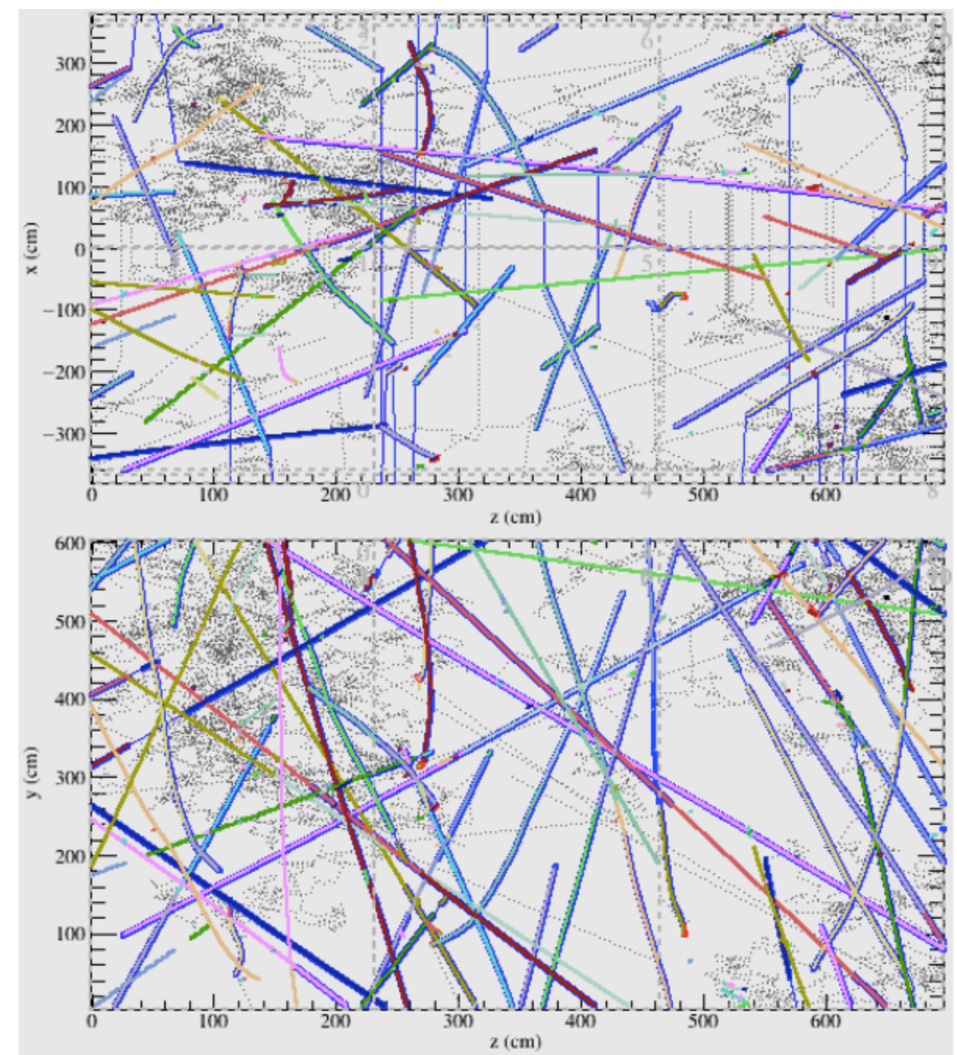


PROTODUNE-SP: RECONSTRUCTION

- protoDUNE is a test bed also for the event reconstruction in LAr
- very challenging because on surface: large cosmic ray background

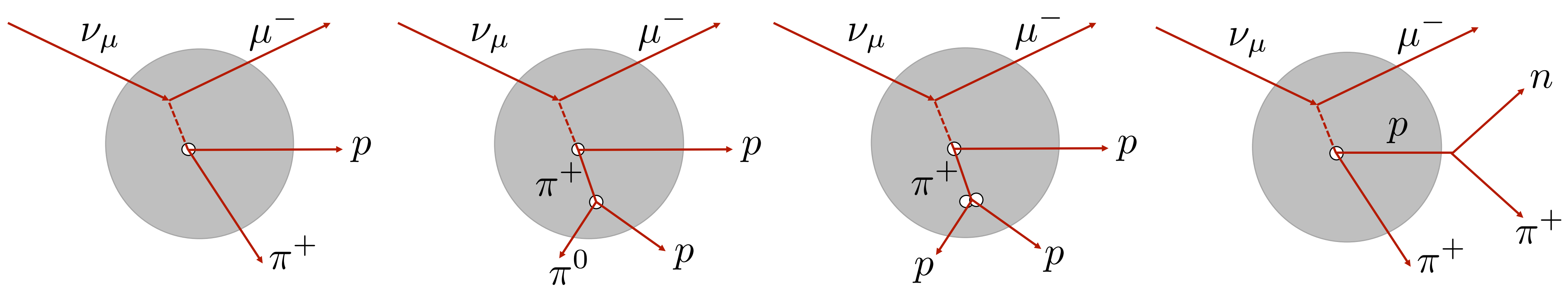


Reconstruction of cosmic rays with PMA algorithm



PROTODUNE-SP: PHYSICS MEASUREMENTS

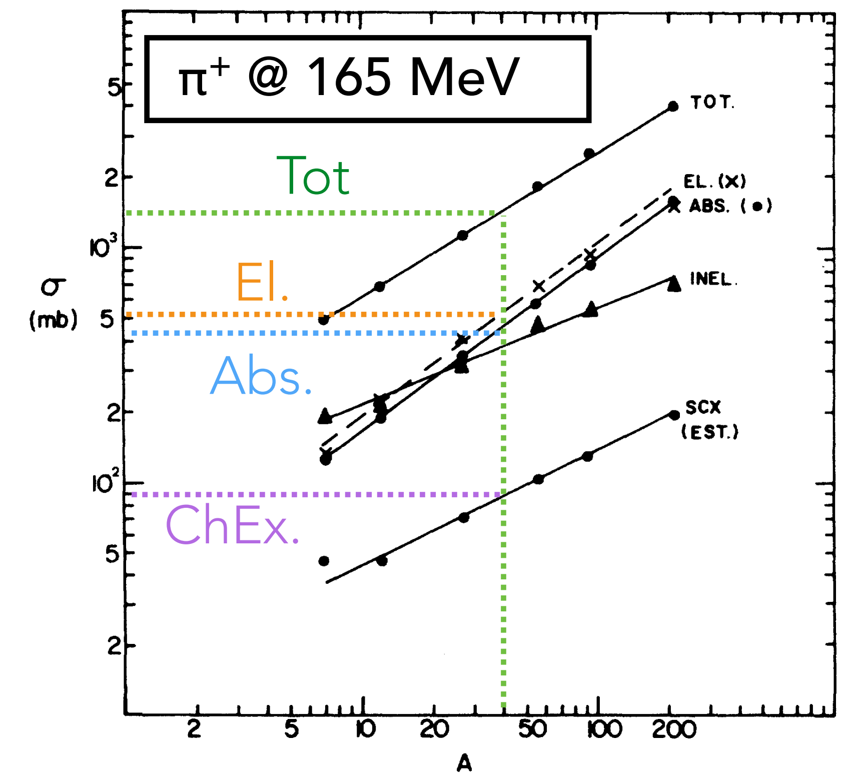
- ProtoDUNE-SP will provide the chance to validate on data the reconstruction algorithm performances
  - energy scale (em /had showers)
  - e-gamma separation
  - **cross-section measurements**
  - …

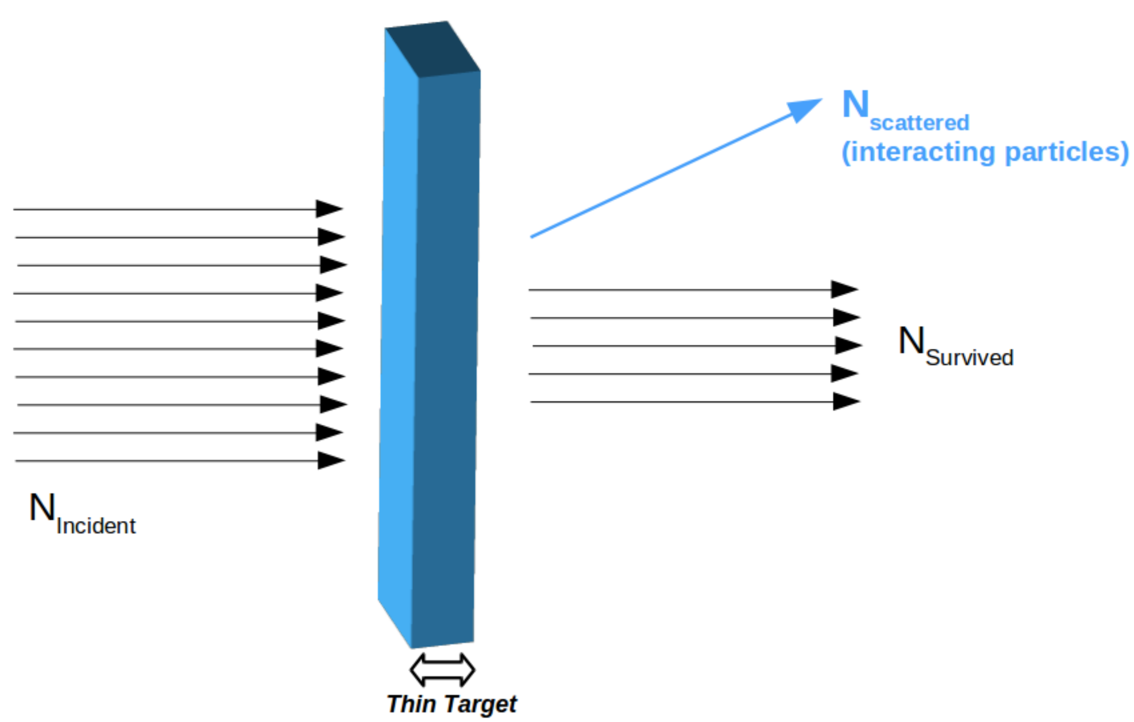


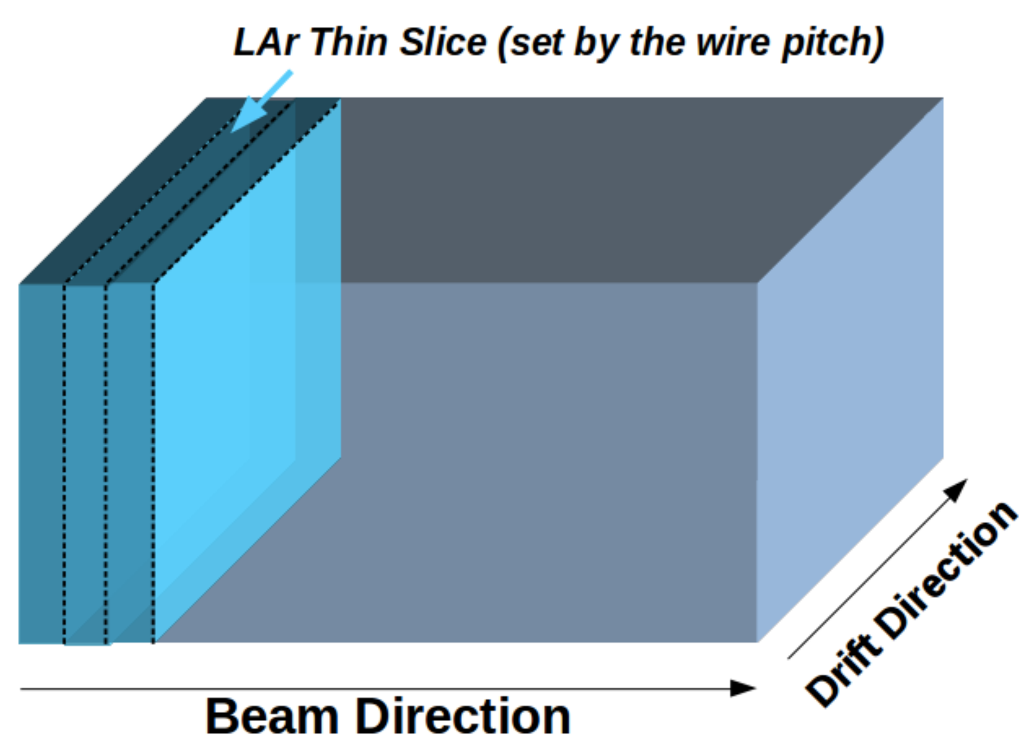
- The knowledge of π-Ar interactions are key to control systematics for DUNE
- Measurements of interest for the entire LAr community (e.g. SBN)

PROTODUNE-SP: PHYSICS MEASUREMENTS

- Almost no existing measurement of π-Ar cross-section
  - LArIAT recent measurement for Pion momentum range 0.2-1.2 GeV
  - Previous estimation from extrapolation from other nuclei (at very low p)
- ProtoDUNE aim to reproduce the measurement, enlarge the range, do a similar measurements for protons





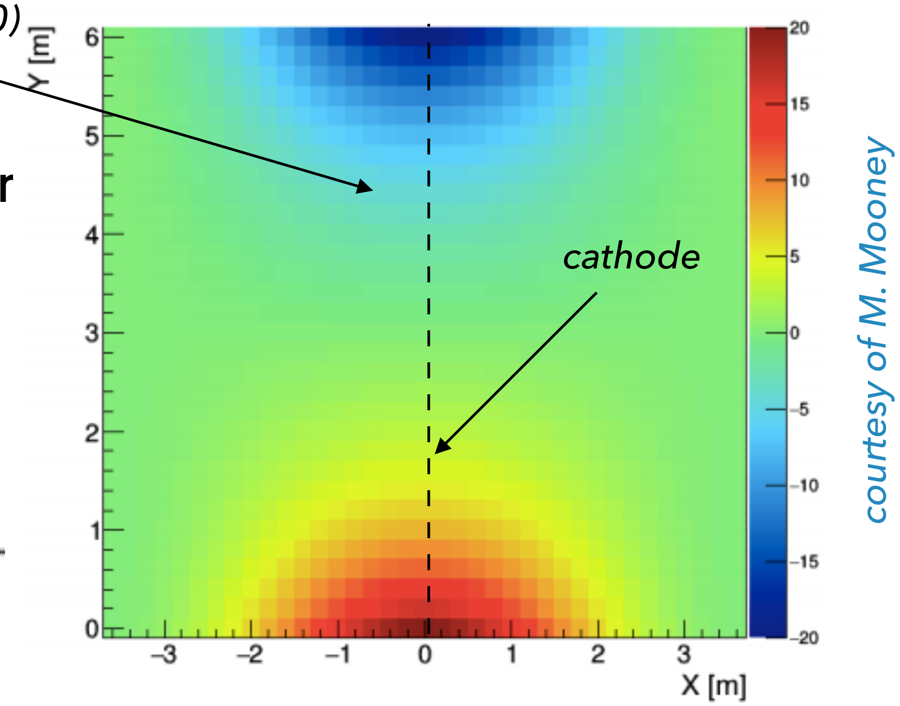


PROTODUNE-SP: PHYSICS MEASUREMENTS

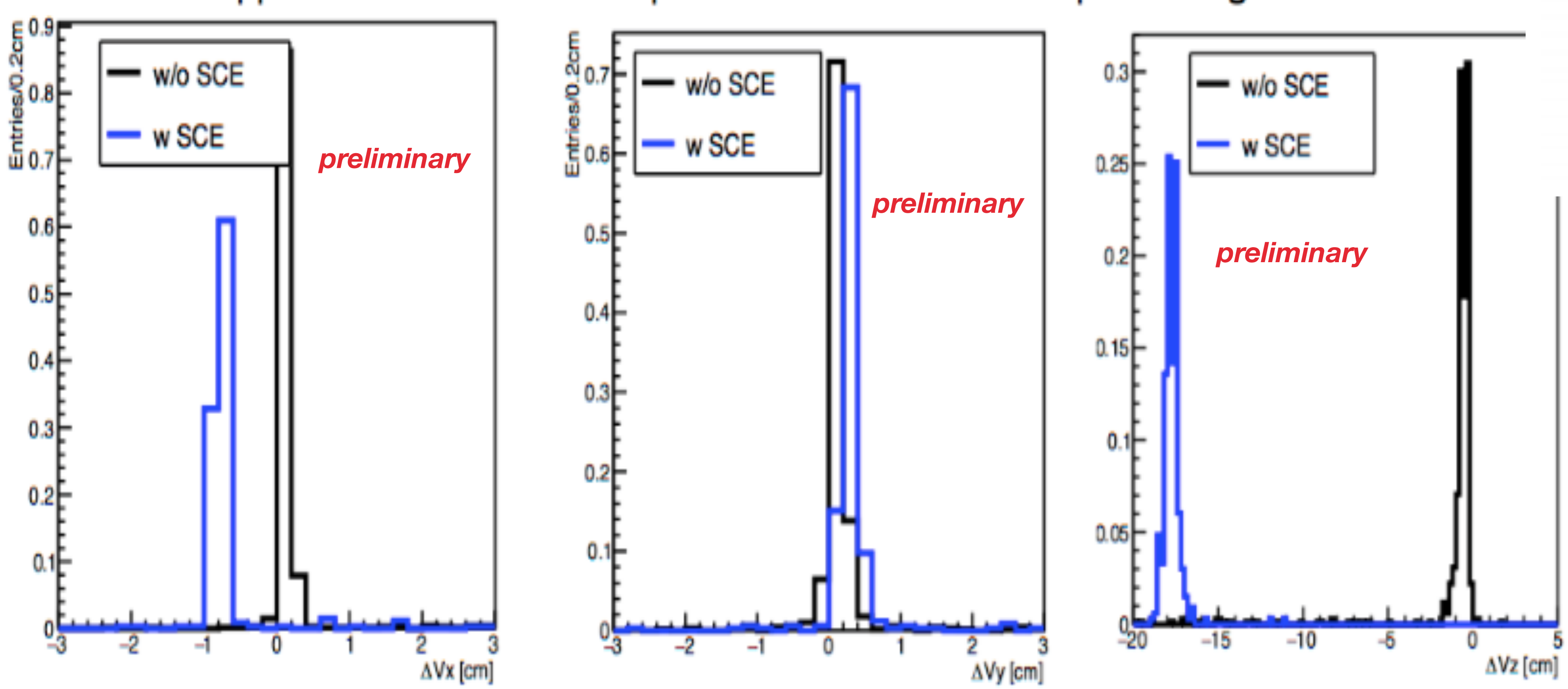
- Analysis in preparation : challenges due to cosmic-rays background and space charge effect

beam entrance around here (Z=0)

SCE simulation for protoDUNE-SP



Apparent shift of the beam particle vertex due to the space charge effect

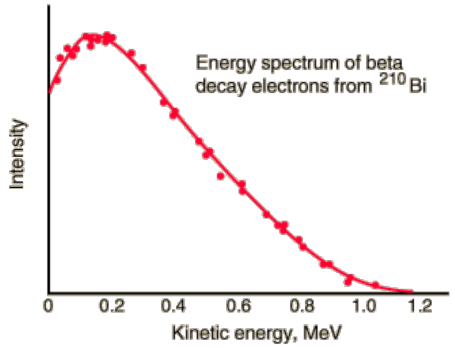


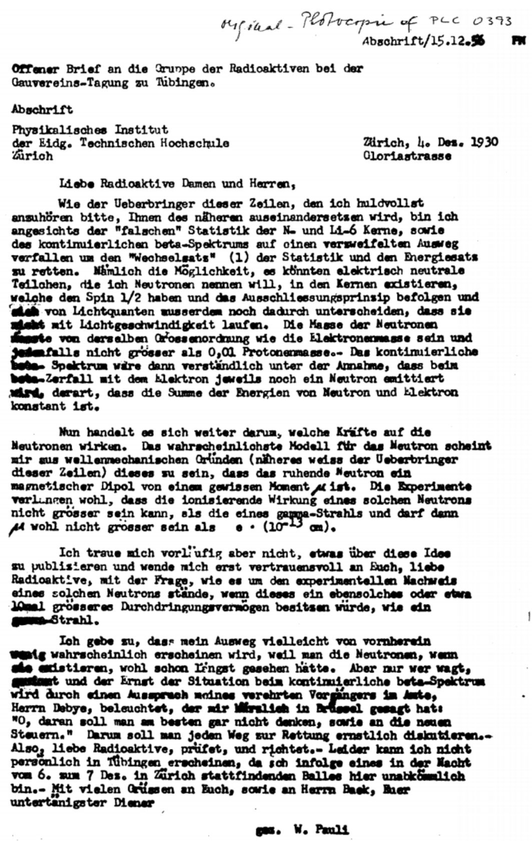
CONCLUSIONS

- A new generation of long baseline oscillation experiments is being to have definitive measurements of the still unknown PMNS parameters
- The control of the systematics uncertainties is crucial : the new experiments need to carefully design their detectors to address the main sources of errors
- CERN has established in 2016 a new program to support the LBN activities, and strength the European effort
- In only 2 years the CERN Neutrino Platform has accomplished big achievements and attracted more than 100 institutes

SUPPLEMENTARY

INTRODUCTION




Original - Photocopie of PLC 0393
Abschrift/15.12.56 PM

Offener Brief an die Gruppe der Radioaktiven bei der Gauvereins-Tagung zu Tübingen.

Abschrift

Physikalisches Institut
der Eidg. Technischen Hochschule
Zürich

Zürich, 4. Des. 1930
Gloriastrasse

Liebe Radioaktive Damen und Herren,

Wie der Ueberbringer dieser Zeilen, den ich huldvollst anzuhören bitte, Ihnen des näheren auseinandersetzen wird, bin ich angesichts der "falschen" Statistik der N- und Li-6 Kerne, sowie des kontinuierlichen beta-Spektrums auf einen verzweifelten Ausweg verfallen um den "Wechselsatz" (1) der Statistik und den Energiesatz zu retten. Nämlich die Möglichkeit, es könnten elektrisch neutrale Teilchen, die ich Neutronen nennen will, in den Kernen existieren, welche den Spin 1/2 haben und das Ausschliessungsprinzip befolgen und sich von Lichtquanten ausserdem noch dadurch unterscheiden, dass sie nicht mit Lichtgeschwindigkeit laufen. Die Masse der Neutronen müsste von derselben Grossenordnung wie die Elektronenmasse sein und jedenfalls nicht grösser als 0,01 Protonenmasse.- Das kontinuierliche beta- Spektrum wäre dann verständlich unter der Annahme, dass beim beta-Zerfall mit dem Elektron jeweils noch ein Neutron emittiert wird, derart, dass die Summe der Energien von Neutron und Elektron konstant ist.

Nun handelt es sich weiter darum, welche Kräfte auf die Neutronen wirken. Das wahrscheinlichste Modell für das Neutron scheint mir aus wellenmechanischen Gründen (näheres weiss der Ueberbringer dieser Zeilen) dieses zu sein, dass das ruhende Neutron ein magnetischer Dipol von einem gewissen Moment μ ist. Die Experimente verlangen wohl, dass die ionisierende Wirkung eines solchen Neutrons nicht grösser sein kann, als die eines gamma-Strahls und darf dann μ wohl nicht grösser sein als e · (10^{-13} cm).

Ich traue mich vorläufig aber nicht, etwas über diese Idee zu publizieren und wende mich erst vertrauensvoll an Euch, liebe Radioaktive, mit der Frage, wie es um den experimentellen Nachweis eines solchen Neutrons stände, wenn dieses ein ebensolches oder etwa 10mal grösseres Durchdringungsvermögen besitzen würde, wie ein gamma-Strahl.

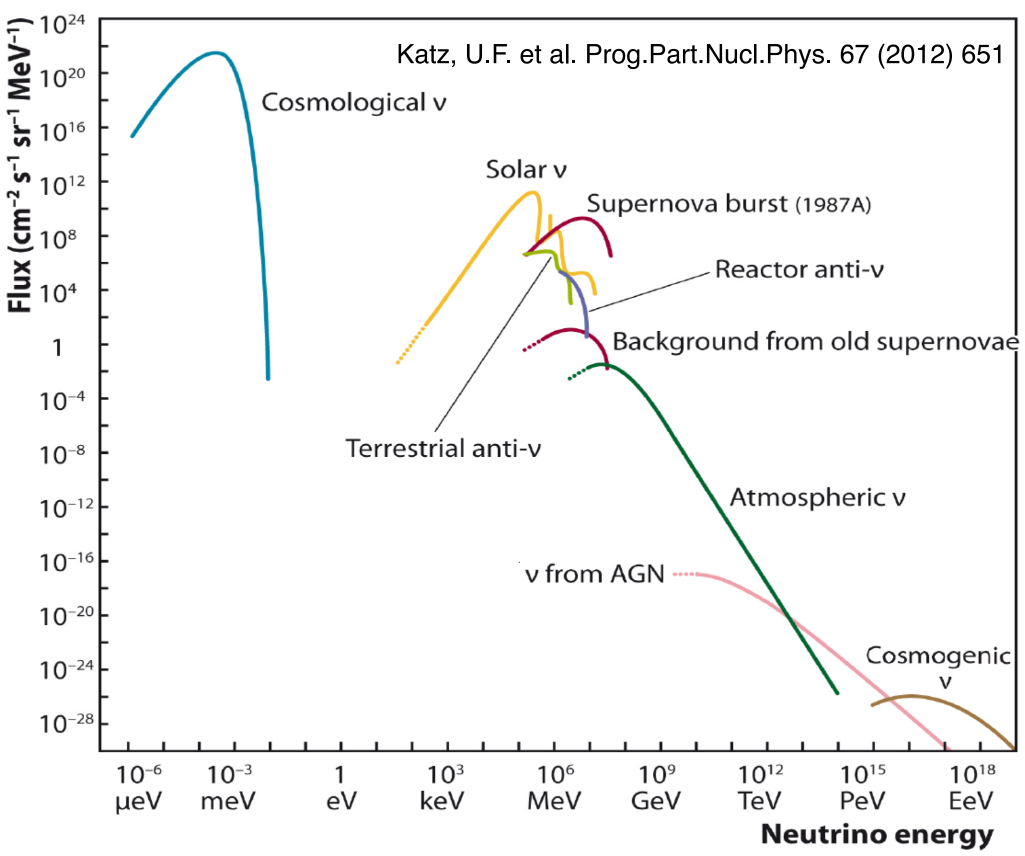
Ich gebe zu, dass mein Ausweg vielleicht von vornherein wenig wahrscheinlich erscheinen wird, weil man die Neutronen, wenn sie existieren, wohl schon längst gesehen hätte. Aber nur wer wagt, gewinnt und der Ernst der Situation beim kontinuierliche beta-Spektrum wird durch einen Ausspruch meines verehrten Vorgängers im Amte, Herrn Debye, beleuchtet, der mir mündlich in Brüssel gesagt hat: "O, daran soll man am besten gar nicht denken, sowie an die neuen Steuern." Darum soll man jeden Weg zur Rettung ernstlich diskutieren.- Also, liebe Radioaktive, prüfet, und richtet.- Leider kann ich nicht persönlich in Tübingen erscheinen, da ich infolge eines in der Nacht vom 6. zum 7 Dez. in Zürich stattfindenden Balles hier unabkömmlich bin.- Mit vielen Grüssen an Euch, sowie an Herrn Back, Euer untertänigster Diener

gez. W. Pauli

- Postulated by Pauli as “desperate remedy” to explain the continuum spectrum of the ß decay (1930)
- Discovered only in 1956 by Reines and Cowan

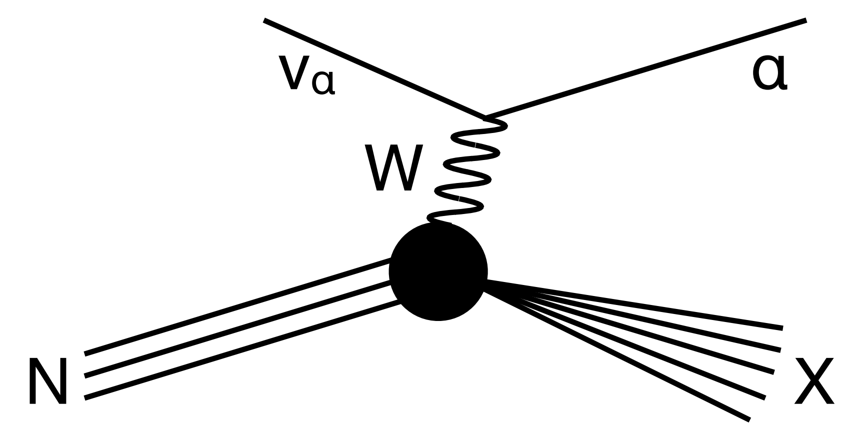

1995

- Second most abundant particle in the Universe
- Natural and artificial sources covering an energy spectra over 20 orders of magnitude

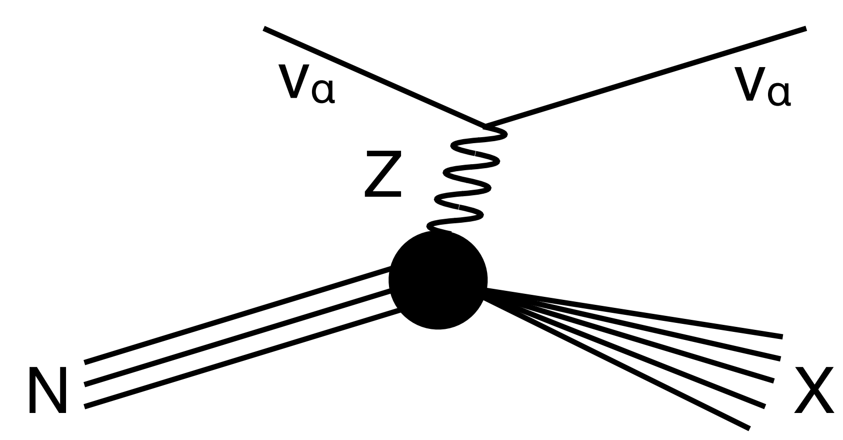


INTRODUCTION

- Charged current (CC) interactions
  - Out-coming lepton bring information about the neutrino flavour
  - Threshold of the interaction given by the lepton mass ($E_{\nu\mu}$ > 110 MeV, $E_{\nu\tau}$ >3.5 GeV)



- Neutral current (NC) interactions
  - No information about the neutrino flavour
  - much less measurements available



INTRODUCTION

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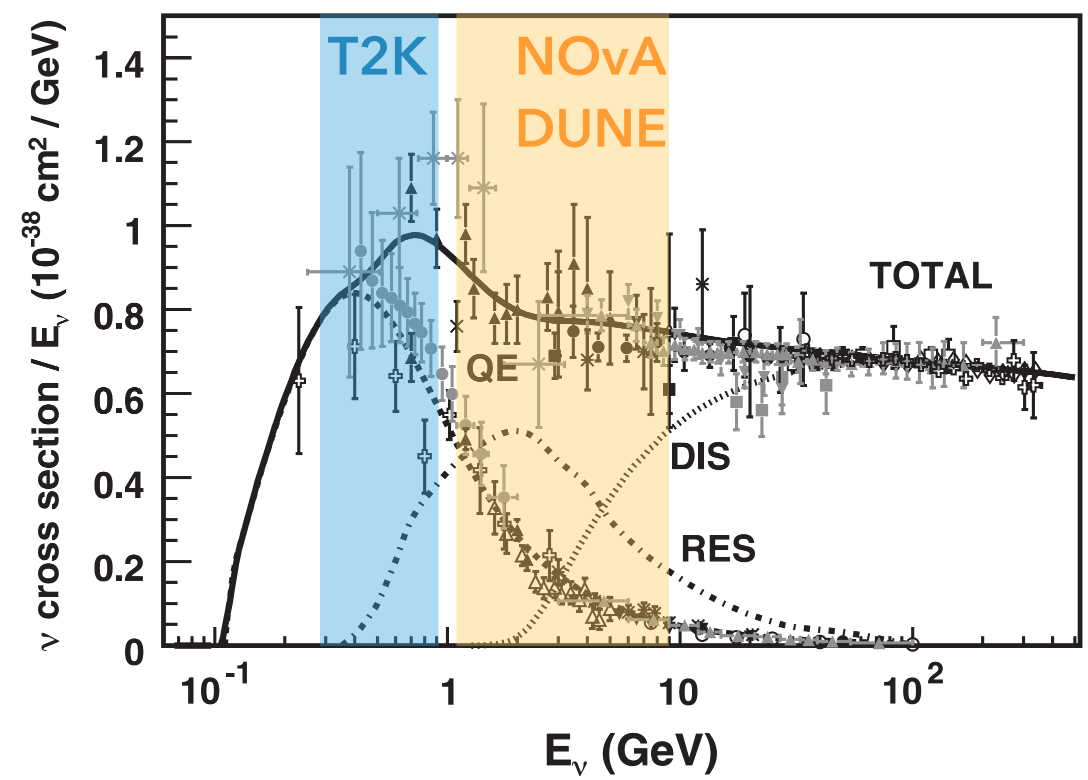
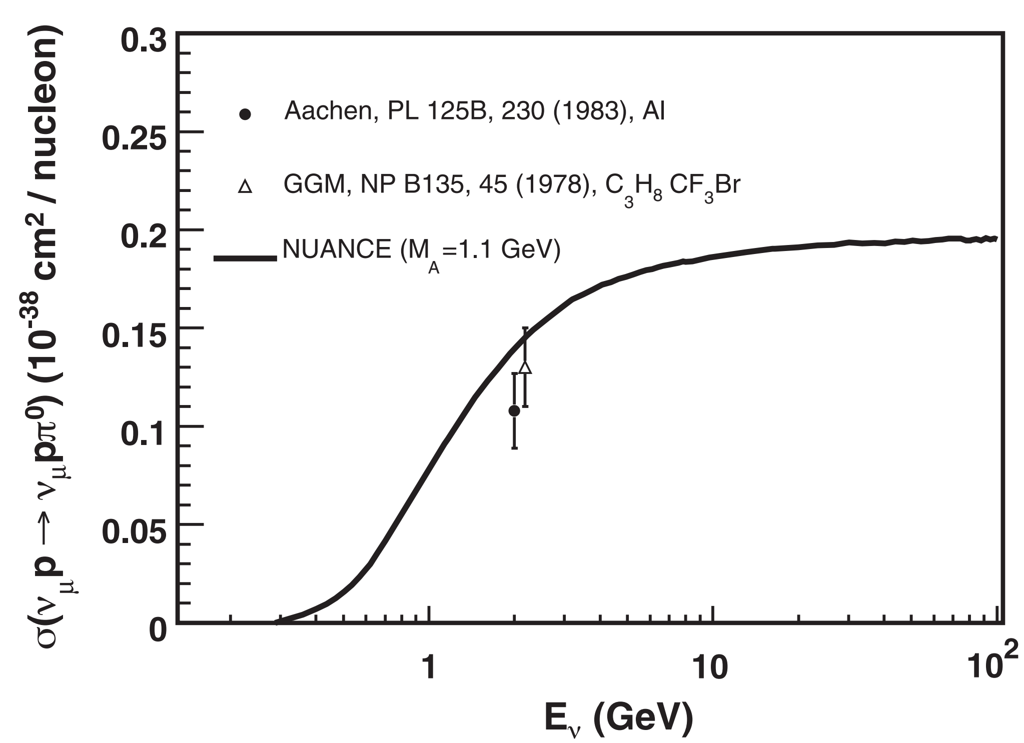
  - Out-coming lepton bring information about the neutrino flavour
  - Threshold of the interaction given by the lepton mass ($E_{\nu\mu}$ > 110 MeV, $E_{\nu\tau}$ >3.5 GeV)



- Neutral current (NC) interactions
  - No information about the neutrino flavour
  - much less measurements available



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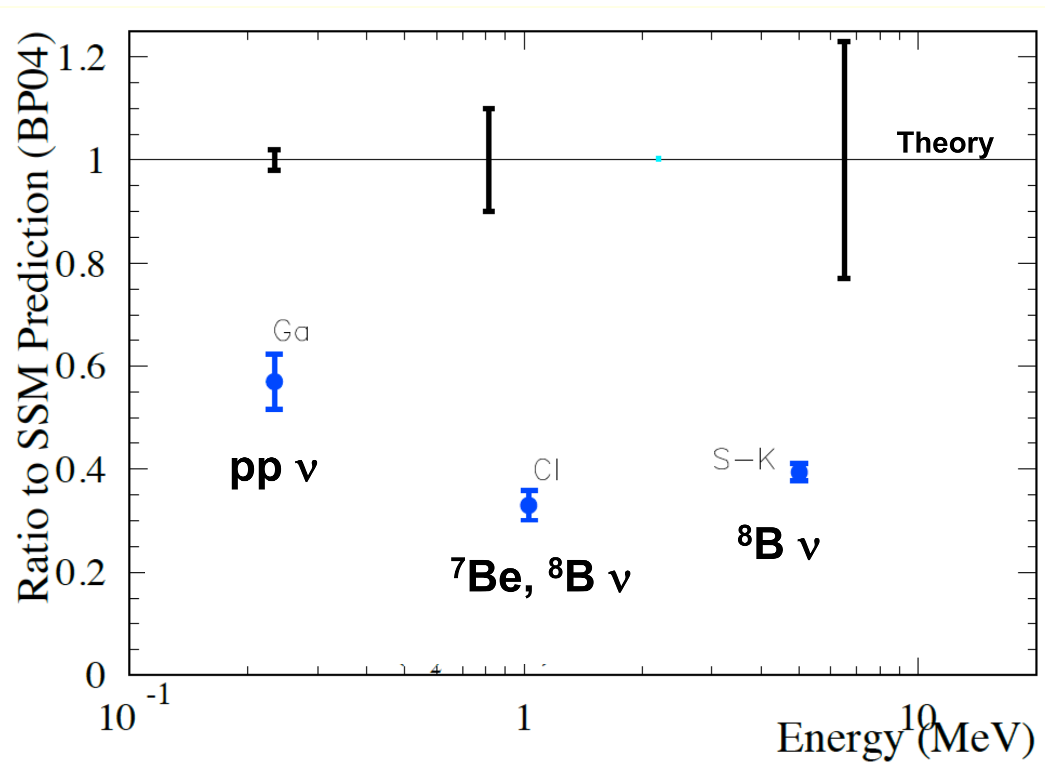
NEUTRINO OSCILLATIONS DISCOVERY

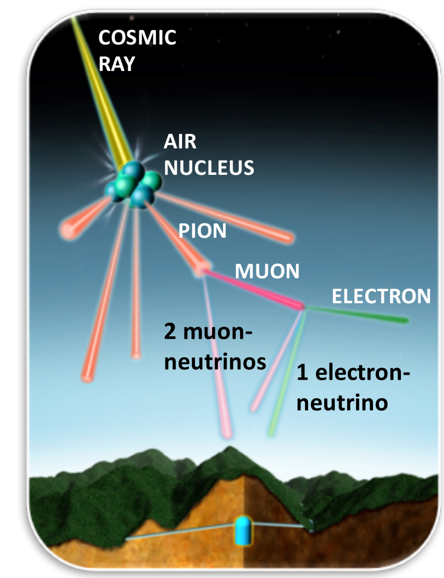
The solar problem

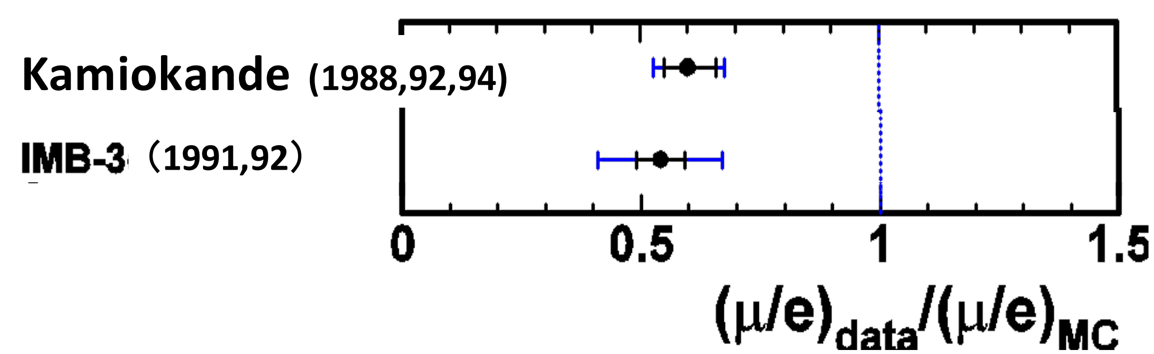


- clear deficit wrt SSM prediction
- About 2/3 of ν_e are missing!

The atmospheric anomaly

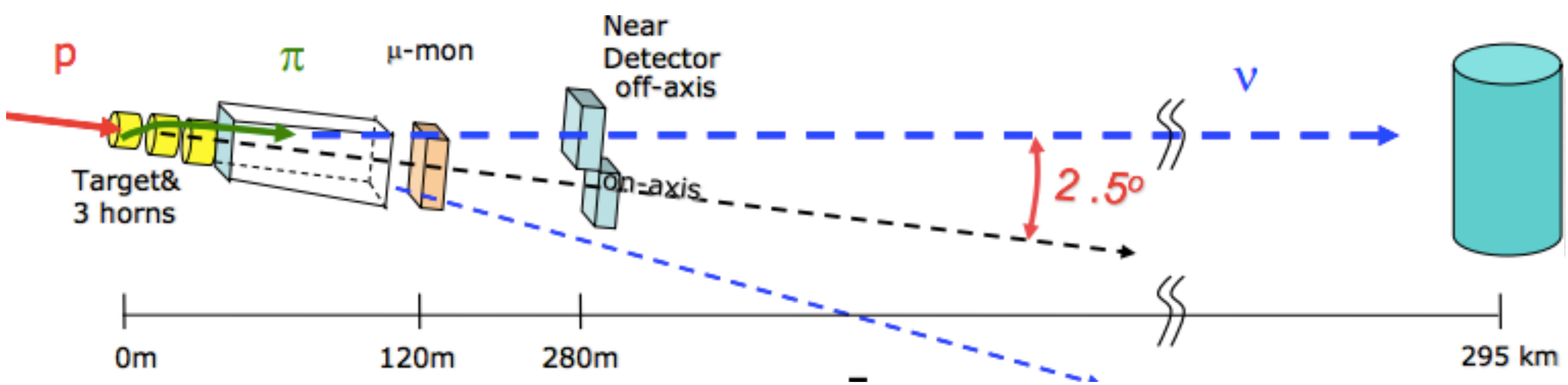
$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$
$$\downarrow$$
$$e^+ + \nu_e + \bar{\nu}_\mu$$





- ratio expected 2:1 but observed ~1
- missing 1/2 of ν_μ !

LONG BASELINE EXPERIMENTS PRINCIPLE

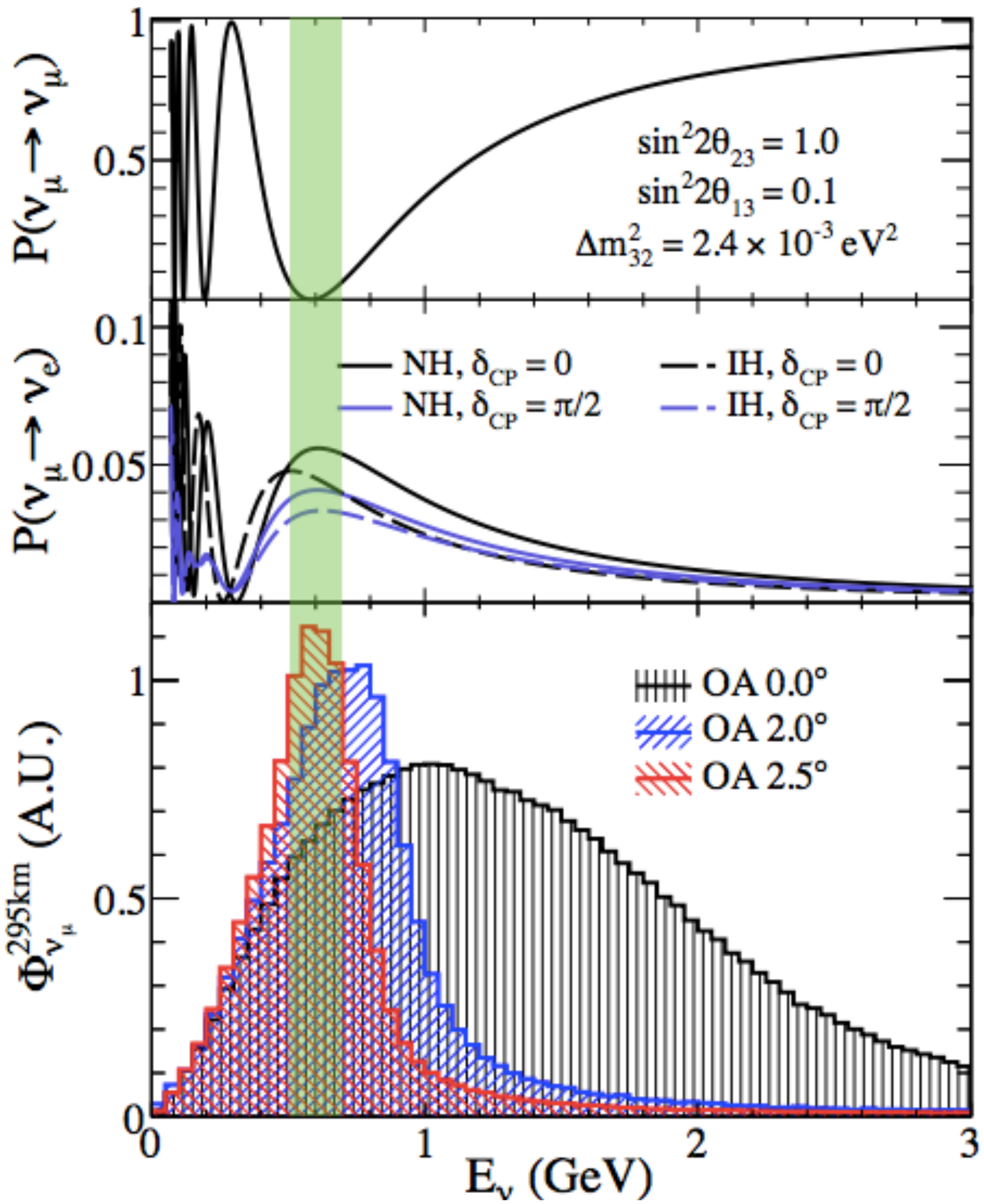


cartoon for T2K experiment

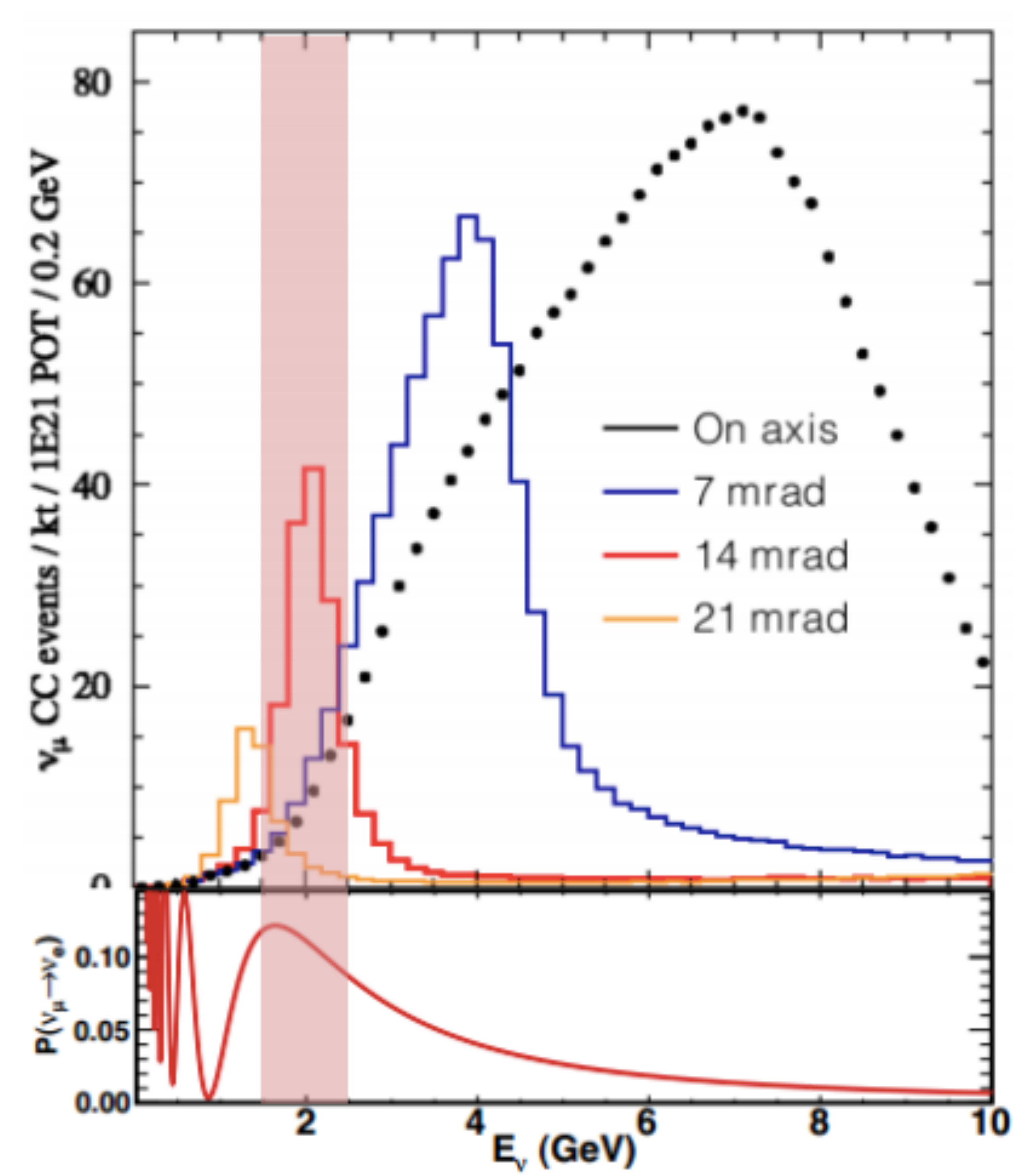
- Protons colliding on a fix target
- Production of secondary hadrons (π, K), focussed on the decay line by magnetic horns
- Decay of the hadrons in the decay volume
- Stop all remaining particles with a dump, muons can be used to monitoring purpose
- Neutrinos are the only remaining particles : Near detector (before oscillation occurs), Far Detector at best L/E to maximise the oscillation probability

T2K AND NOVA FLUX

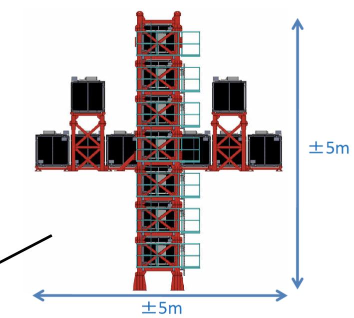
T2K

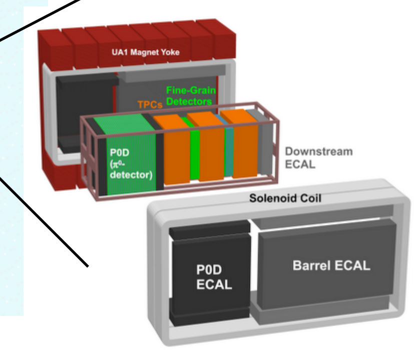


NOvA



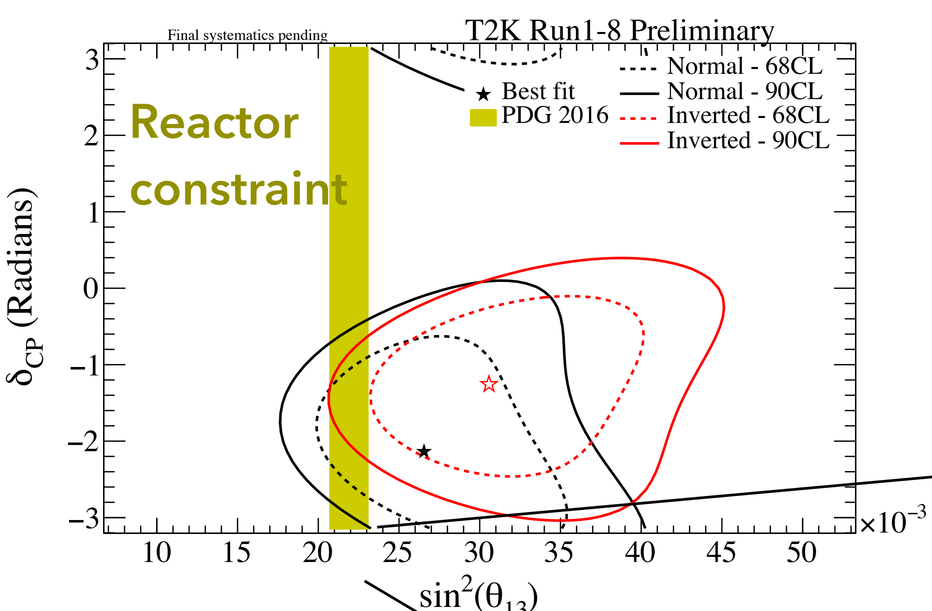
OSCILLATIONS: STATE OF THE ART MEASUREMENTS

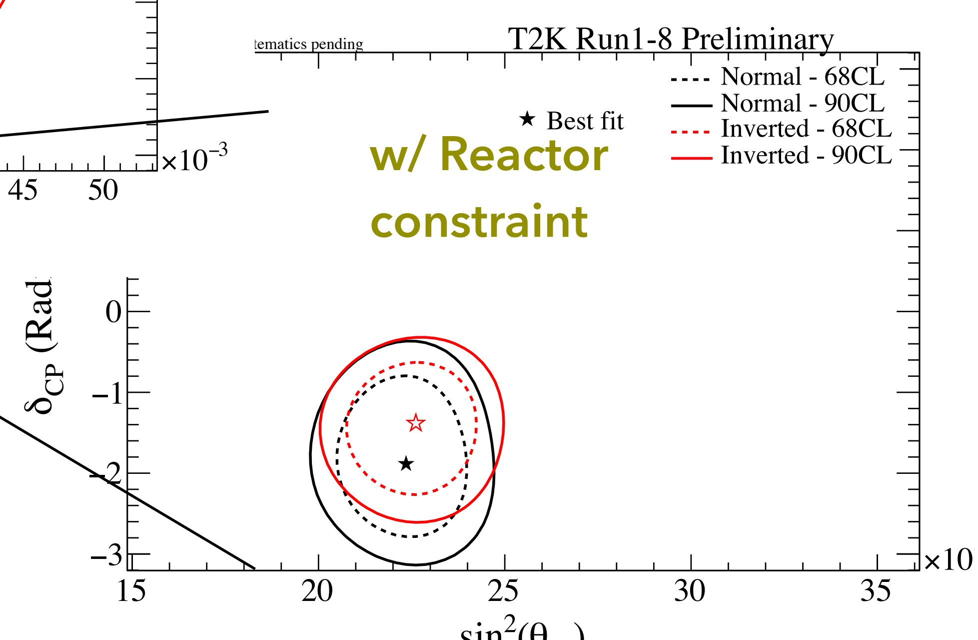




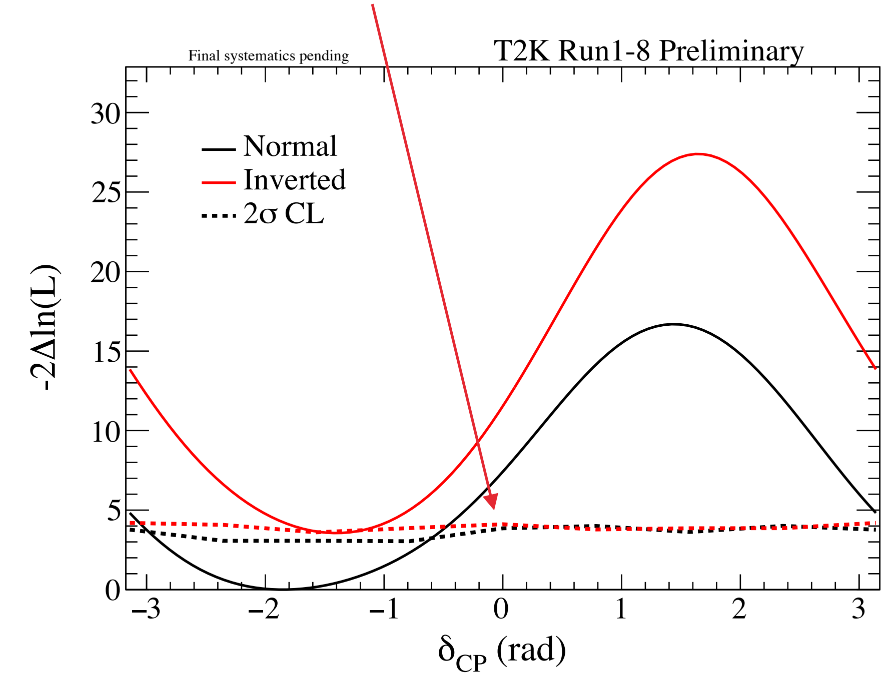
Far detector: Super-Kamiokande
40kt water Cherenkov detector, located off-axis

Near detectors:
INGRID: on-axis
ND280: off-axis magnetised (0.2 T) composite detector tracker (FGD+FGD) surrounded by calorimeter + muon range detector





δCP = 0 excluded at 2σ !



Results presented at KEK last summer

NEUTRINO BEAMS

A few comparative parameters

	LBNF/DUNE	T2K2/HyperK
Beam energy	120 GeV	30 GeV
Beam cycle	1.2 s	1.16 s
Spill length	10 µs	4.1 µs
Protons/spill	7.5×10^{13}	3.2×10^{14}
Beam rms radius	~2.7 mm	4.2 mm
Maximum beam power to date	0.7 MW (NuMI/NoVA)	0.46 MW (T2K)
Approved upgrade beam power	1.2 MW	1.3 MW

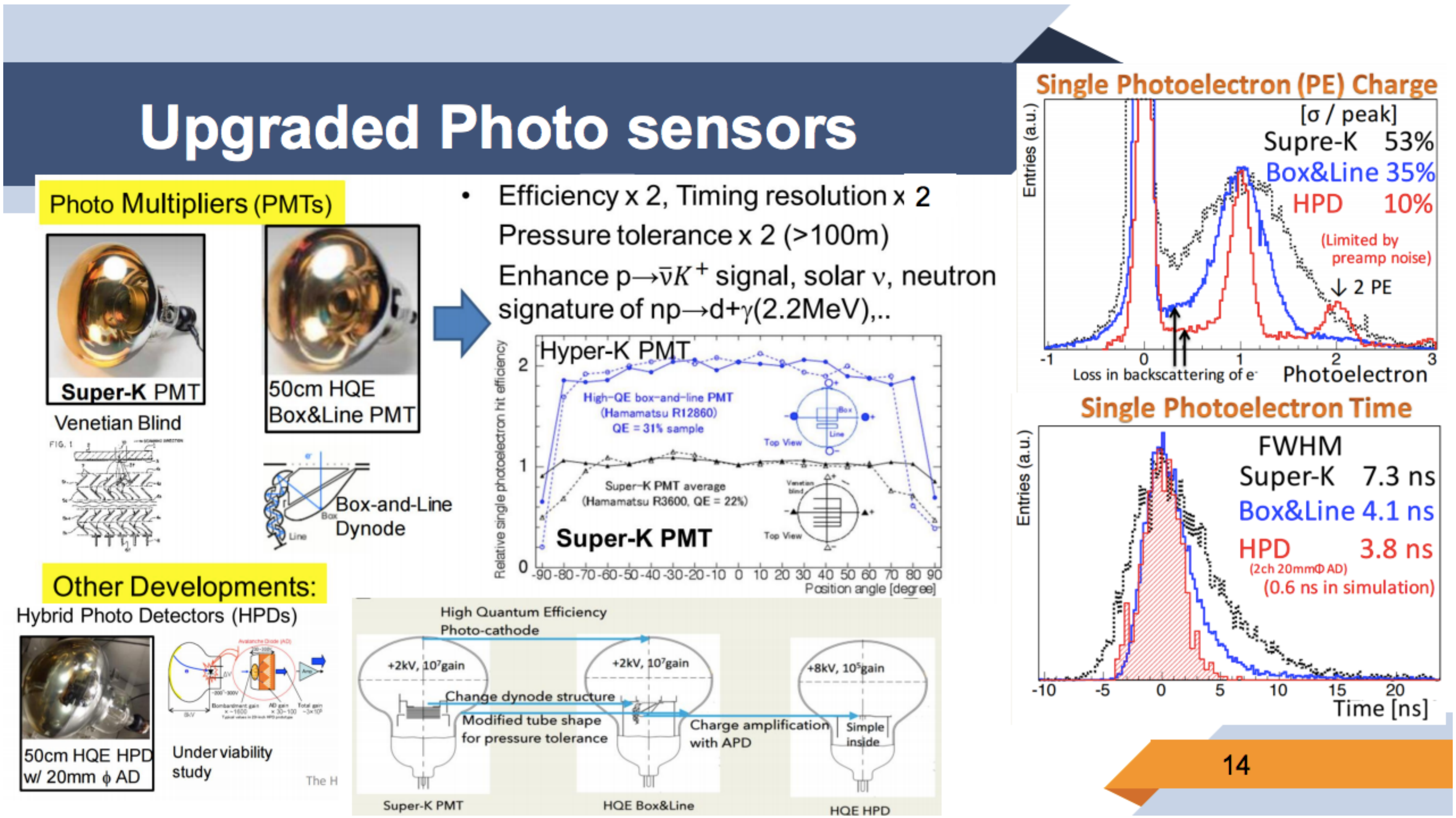
presented at CENF-WG1

Chris Densham 4

T2-HK PHYSICS POTENTIAL

		HK (1 tank)
LBL (1.3MW×10years)	δ precision	7°-23°
	CPV coverage (3/5σ)	76%/57%
	$\sin^2\theta_{23}$ error (for 0.5)	±0.017
ATM+LBL (10 years)	MH determination	3-7σ
	Octant determination (3σ)	$\lvert\theta_{23}-45°\rvert>2°$
Proton Decay (20 years)	$e^+\pi^0$ (3σ)	1×10^{35}
	$\bar{\nu}K$ (3σ)	3×10^{34}
Solar (10 years)	Day/Night (from 0/from KL)	8σ/4σ
	Upturn	>3σ
Supernova	Burst (10kpc)	52k-79k
	Relic	3σ(5σ) in 5(15) years

NEW PHOTOSENSORS FOR HK



WHY LIQUID ARGON?

	Water	He	Ne	Ar	Kr	Xe
Boiling Point [K] @ 1atm	373	4.2	27.1	87.3	120.0	165.0
Density [g/cm^3]	1	0.125	1.2	1.4	2.4	3.0
Radiation Length [cm]	36.1	755.2	24.0	14.0	4.9	2.8
Scintillation [γ /MeV]	-	19,000	30,000	40,000	25,000	42,000
dE/dx [MeV/cm]	1.9		1.4	2.1	3.0	3.8
Scintillation λ [nm]		80	78	128	150	175

Noble liquids are good neutrino targets:

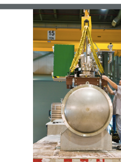
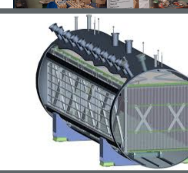
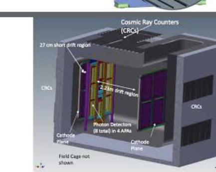
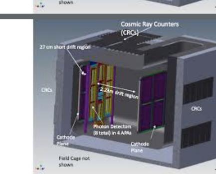
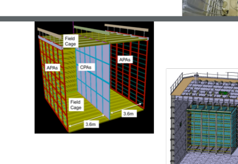
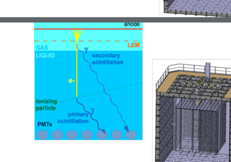
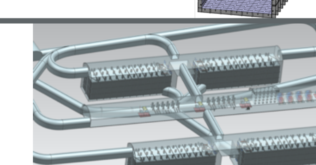
– if purified, long drifts are possible → large detectors

– high light yield → triggering and calorimetry (dark matter experiments)

- Argon is abundant (~1% of the atmosphere)
- Liquid argon is cheap: $ 2/L vs $ 3000 /L for Xe or $ 500 / L for N

NON EXHAUSTIVE COMPILATION OF LAR EXPERIMENTS

a.m. = active mass

Detector	Operation	Mass (tons)	Max. drift d.	
ArgoNeuT / LArIAT	2008-2009 / 2015- oggi	0.77	47cm	
ICARUS	2010 - 2013	2x375 (476a.m.)	1.5m	
MicroBooNE	2015-today	170 (89a.m.)	2.5m	
35tons	2015-2016	35	2.2m	
SBND	>2018	112 am	4m	
WA105	2017	50	1m	
ProtoDUNE-SP	fall 2018	770	3.6m	
ProtoDUNE-DP	fall 2018	770	6m	
DUNE	>2026	4x 17ktons	6m (12m DP)	

APA DESIGN SPEC

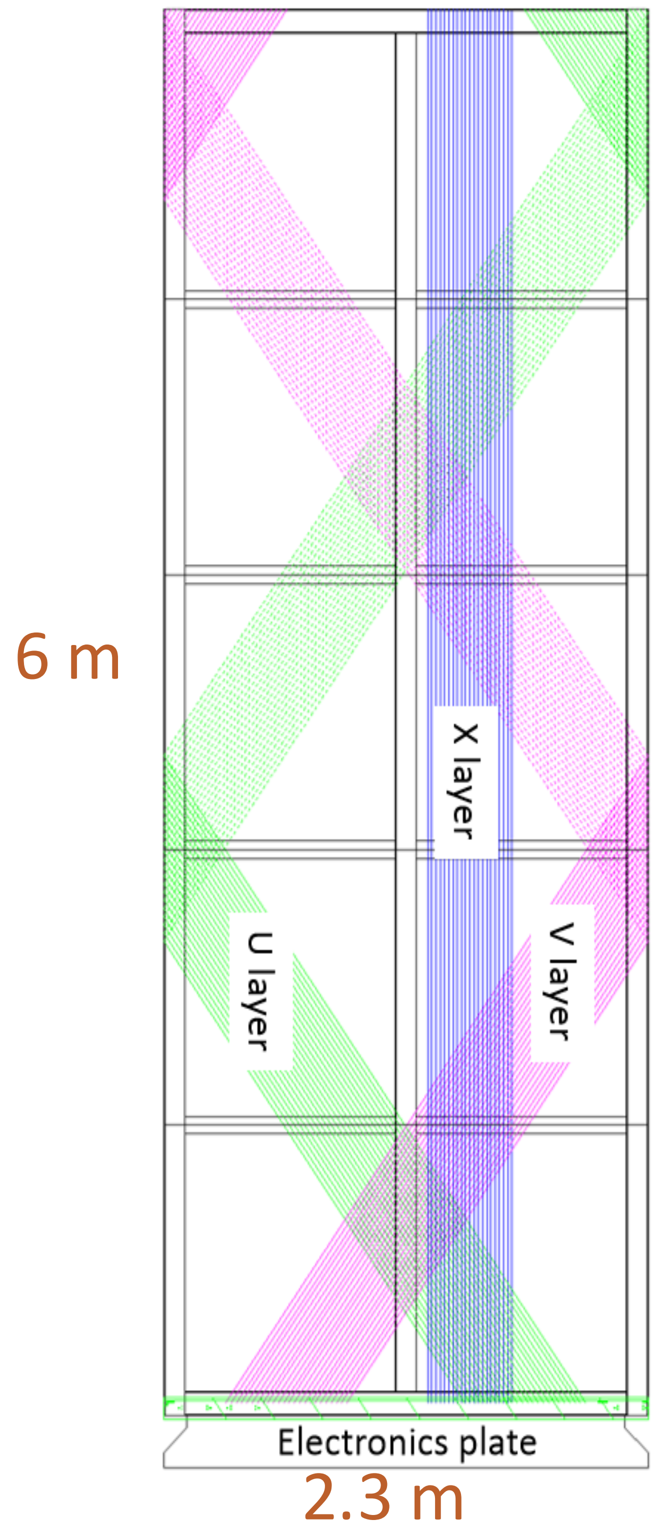
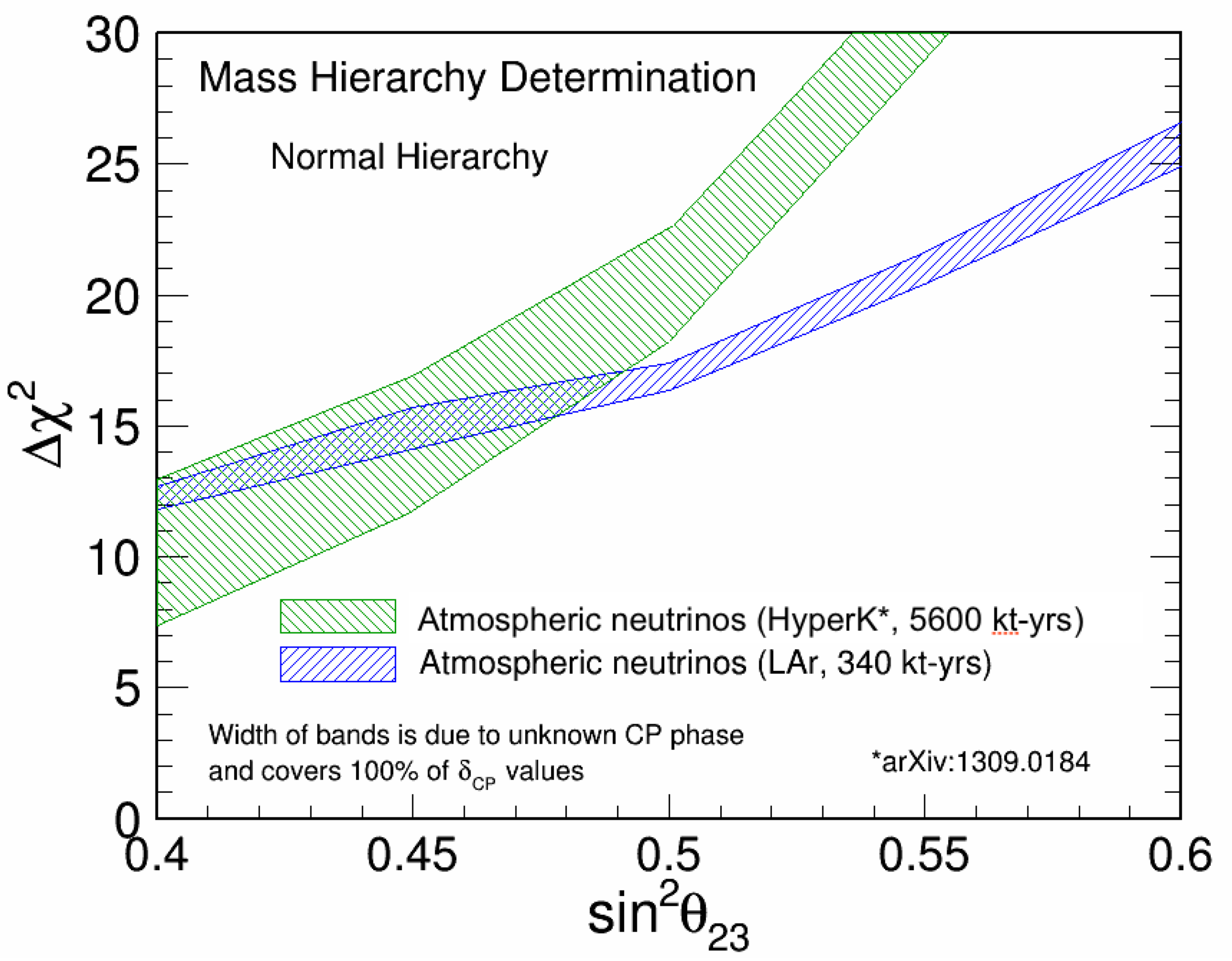


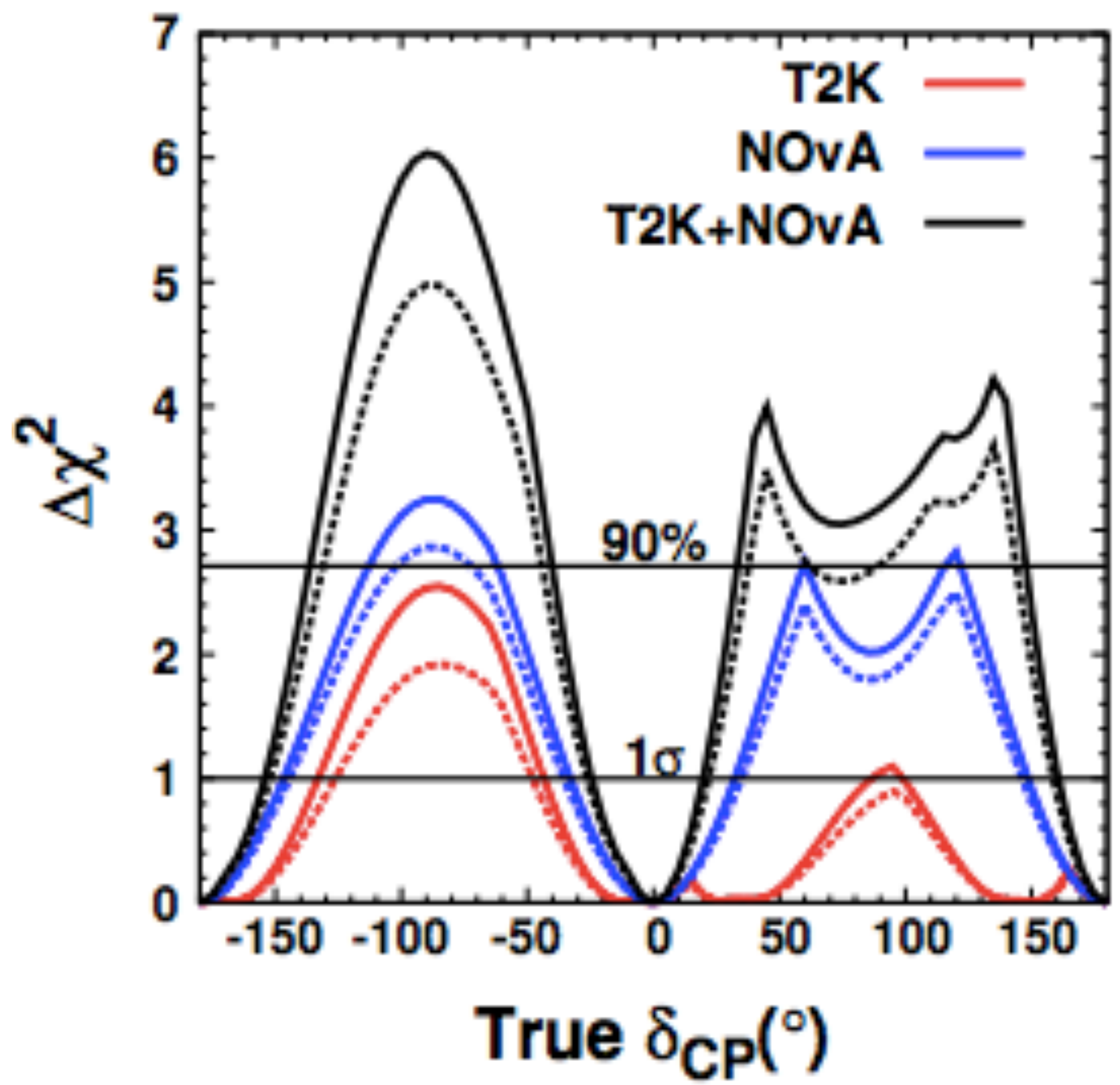
Table 2.3: APA design parameters

Parameter	Value
Active Height	5.984 m
Active Width	2.300 m
Wire Pitch (U,V)	4.669 mm
Wire Pitch (X,G)	4.790 mm
Wire Position Tolerance	0.5 mm
Wire Plane Spacing	4.75 mm
Wire Angle (w.r.t. vertical) (U,V)	35.7°
Wire Angle (w.r.t. vertical) (X,G)	0°
Number Wires / APA	960 (X), 960 (G), 800 (U), 800 (V)
Number Electronic Channels / APA	2560
Wire Tension	5.0 N
Wire Material	Beryllium Copper
Wire Diameter	150 μm
Wire Resistivity	7.68 $\mu\Omega$-cm @ 20° C
Wire Resistance/m	4.4 Ω/m @ 20° C
Frame Planarity	5 mm
Photon Detector Slots	10

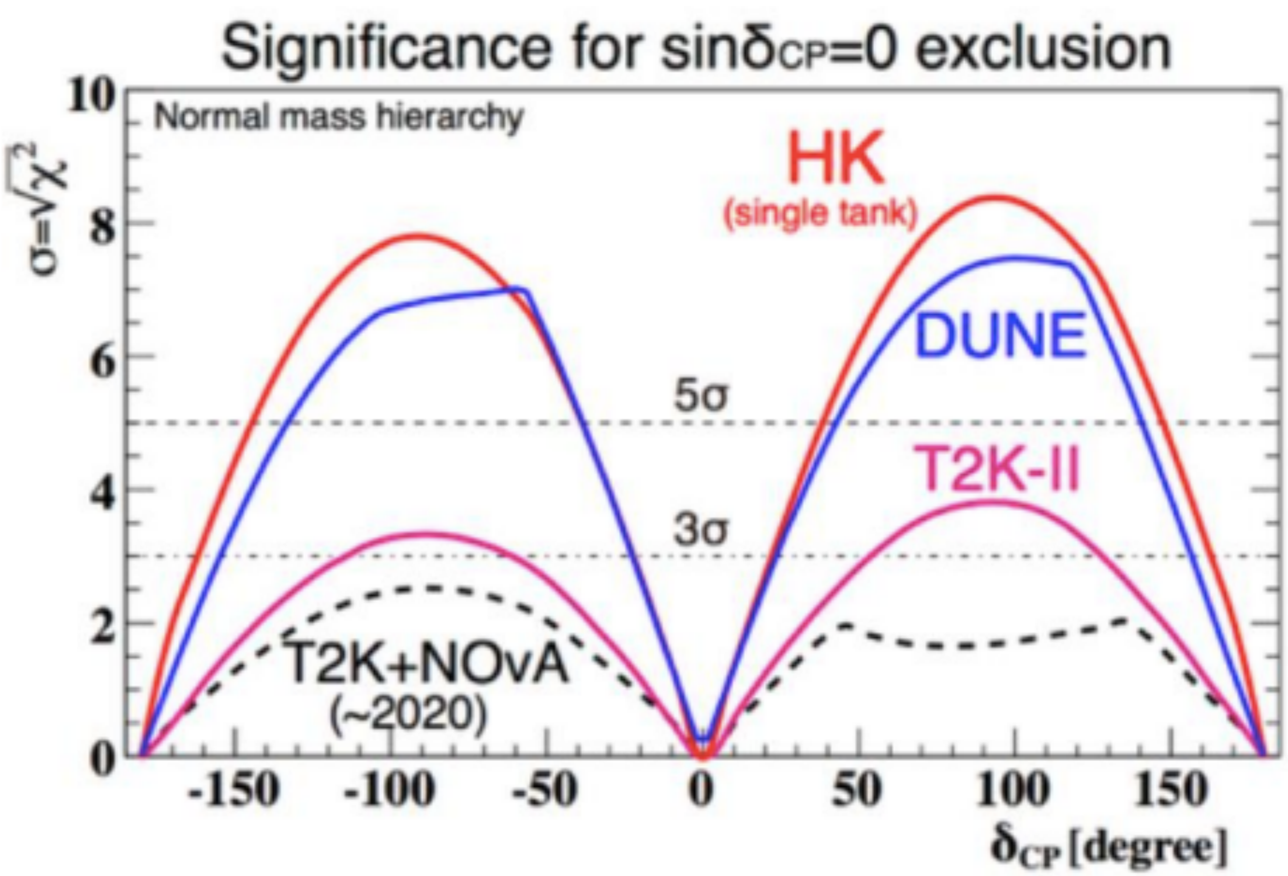
DUNE VS HK : MH SENSITIVITY (ATM. NU)

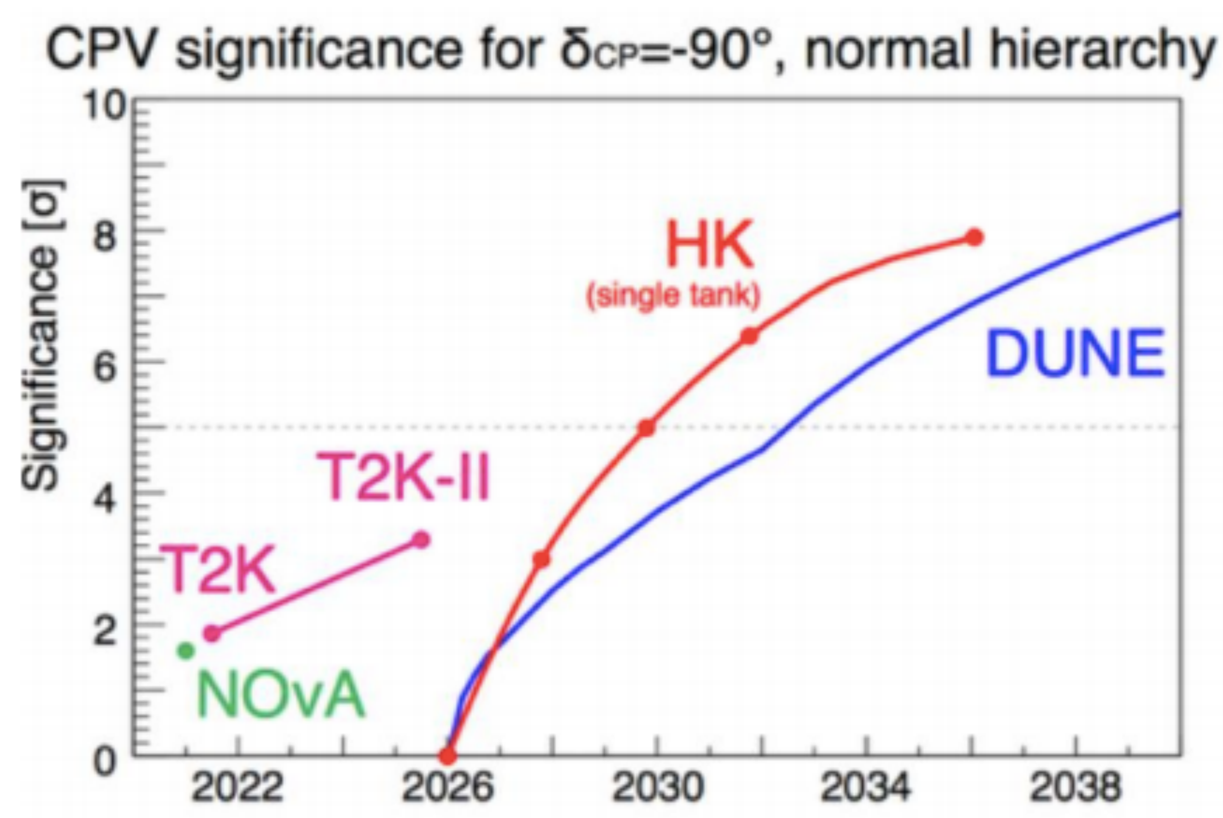


T2K + NOVA


T2K
NOvA
T2K+NOvA
90%
1σ
$\Delta\chi^2$
True δ_{CP}(°)
0
1
2
3
4
5
6
7
-150
-100
-50
0
50
100
150

T2HK DCP SENSITIVITY

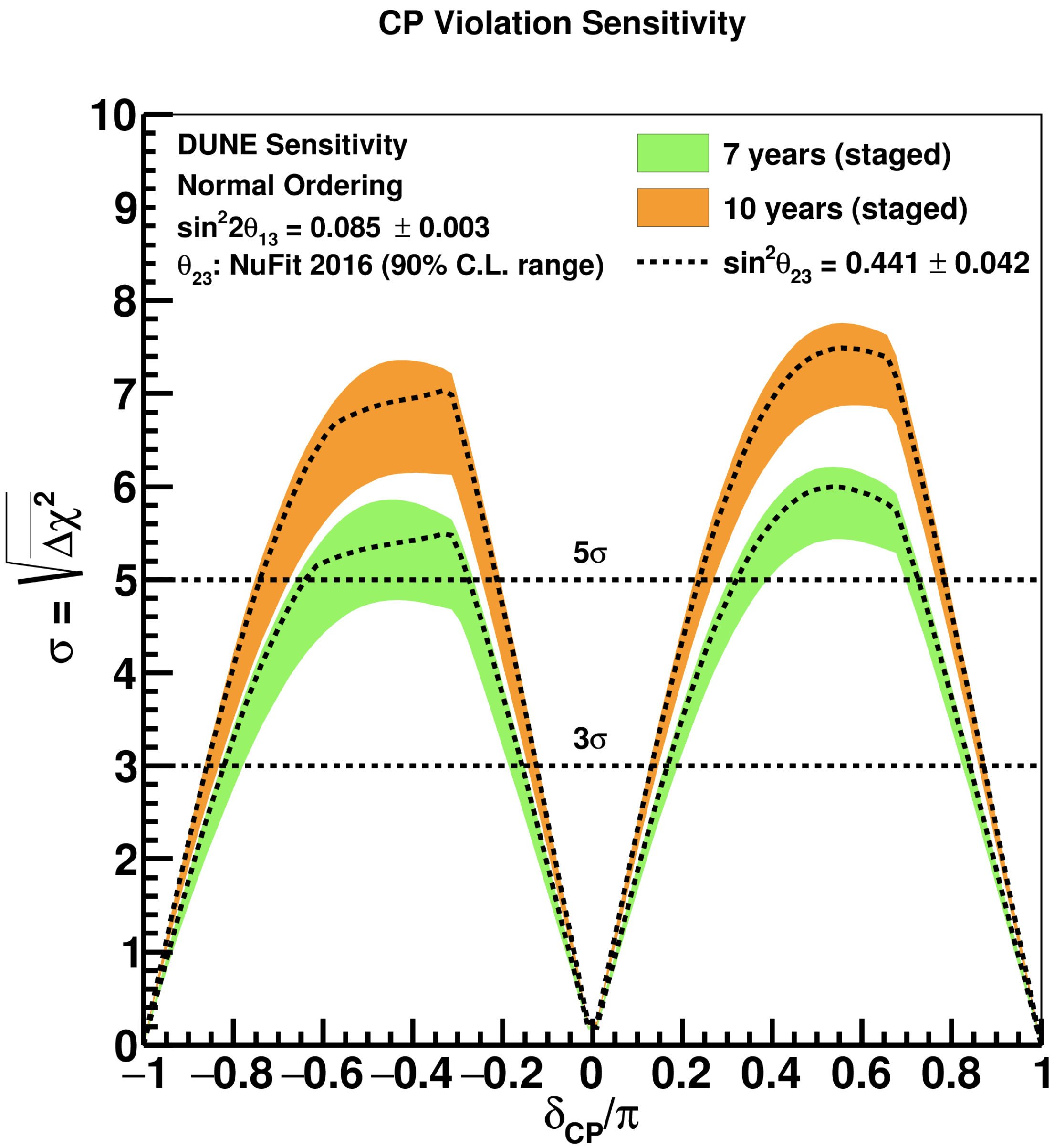


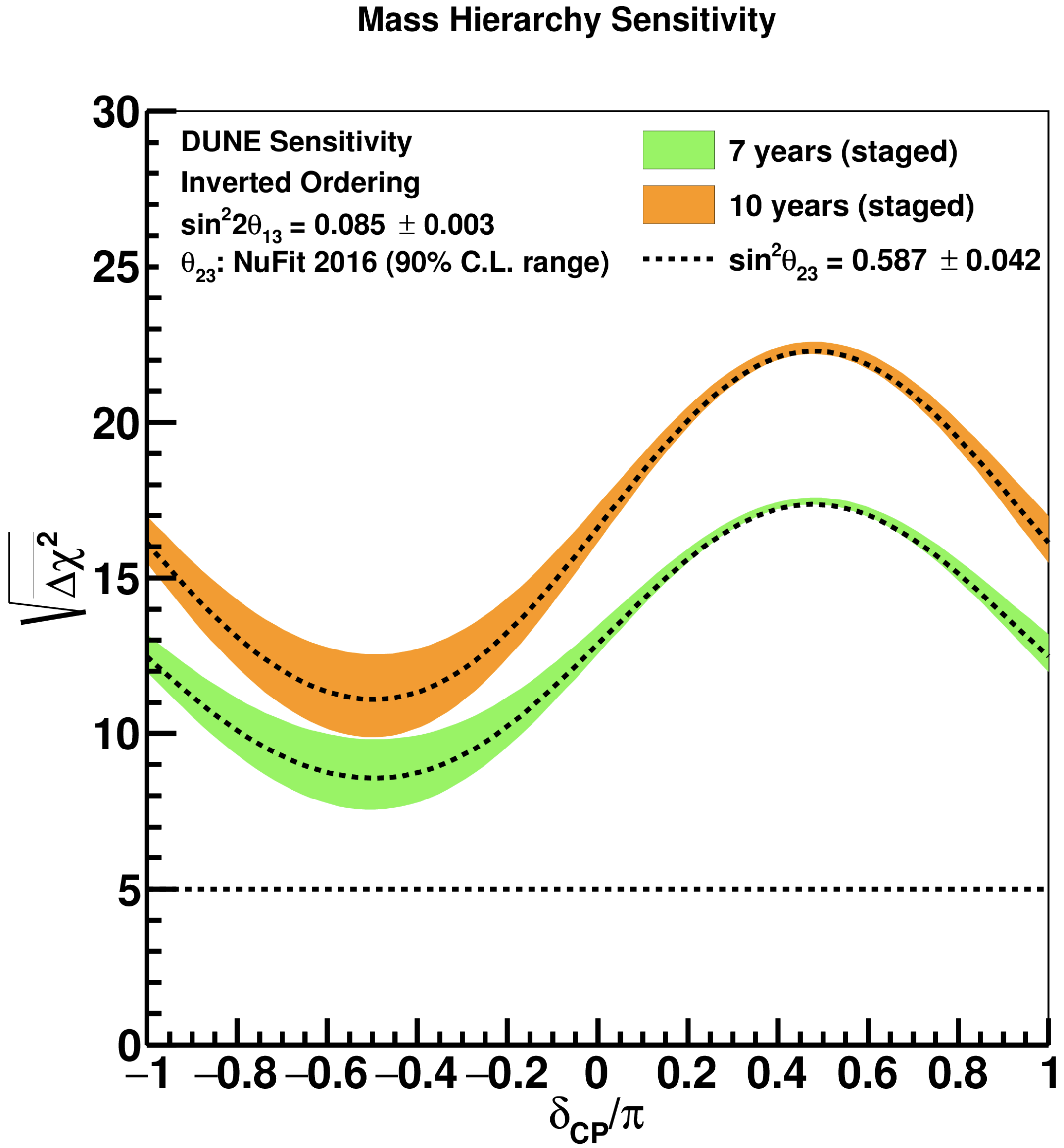


DUNE SENSITIVITY

STAGED APPROACH:

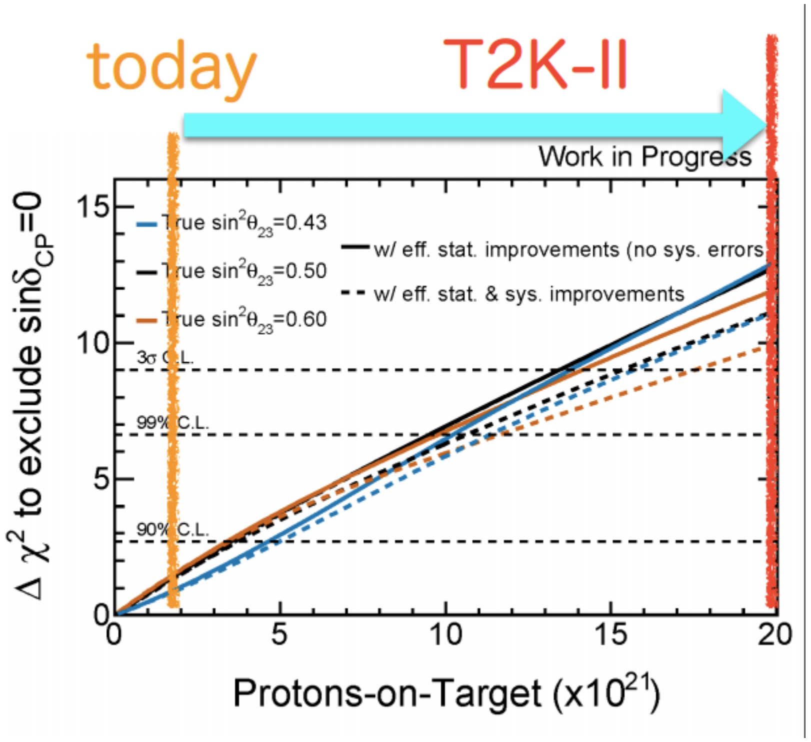
Y_1 (2026) 20kt FD @ 1.07 MW
Y_2 (2027) 30kt FD @ 1.07 MW
Y_3 (2029) 40kt FD @ 1.07 MW
Y_7 (2032) 40kt FD @ 2.14 MW





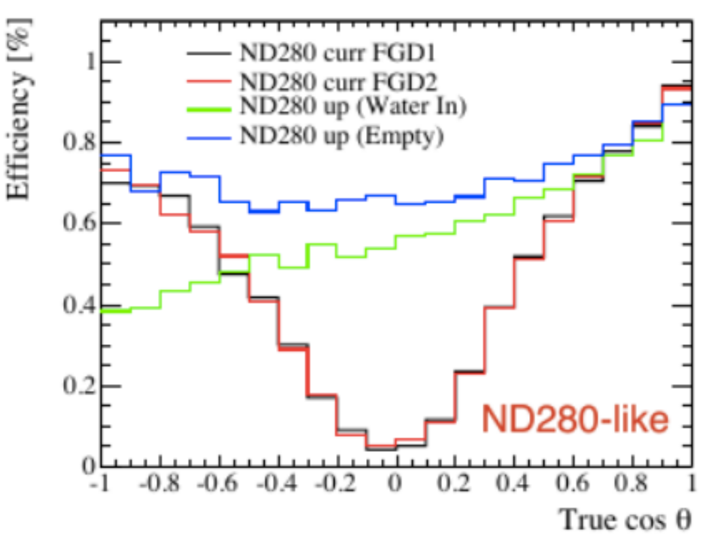
EOI 15

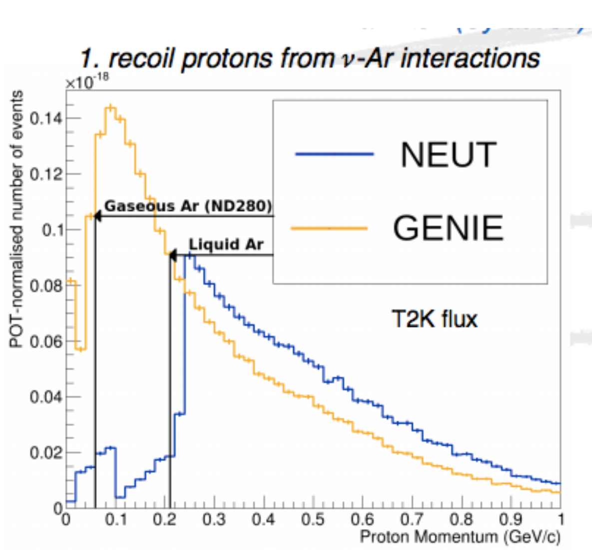
- Expression of Interest on ND based on gas TPCs signed by 190 people. **Project in evaluation to be part of the Neutrino Platform**
- 2 main axis :
  - AtmP-TPC for ND280 upgrade (**T2K-II** ~ y **2020**)
  - HighP-TPC for cross-section studies
- CERN contribution foreseen for gas system, TPC readout (MM), test-beams, physics studies
- 4 workshop organised. Detailed proposal in January



AtmP-TPC :

Large improvement of the ND280 acceptance → more similar acceptance to SK



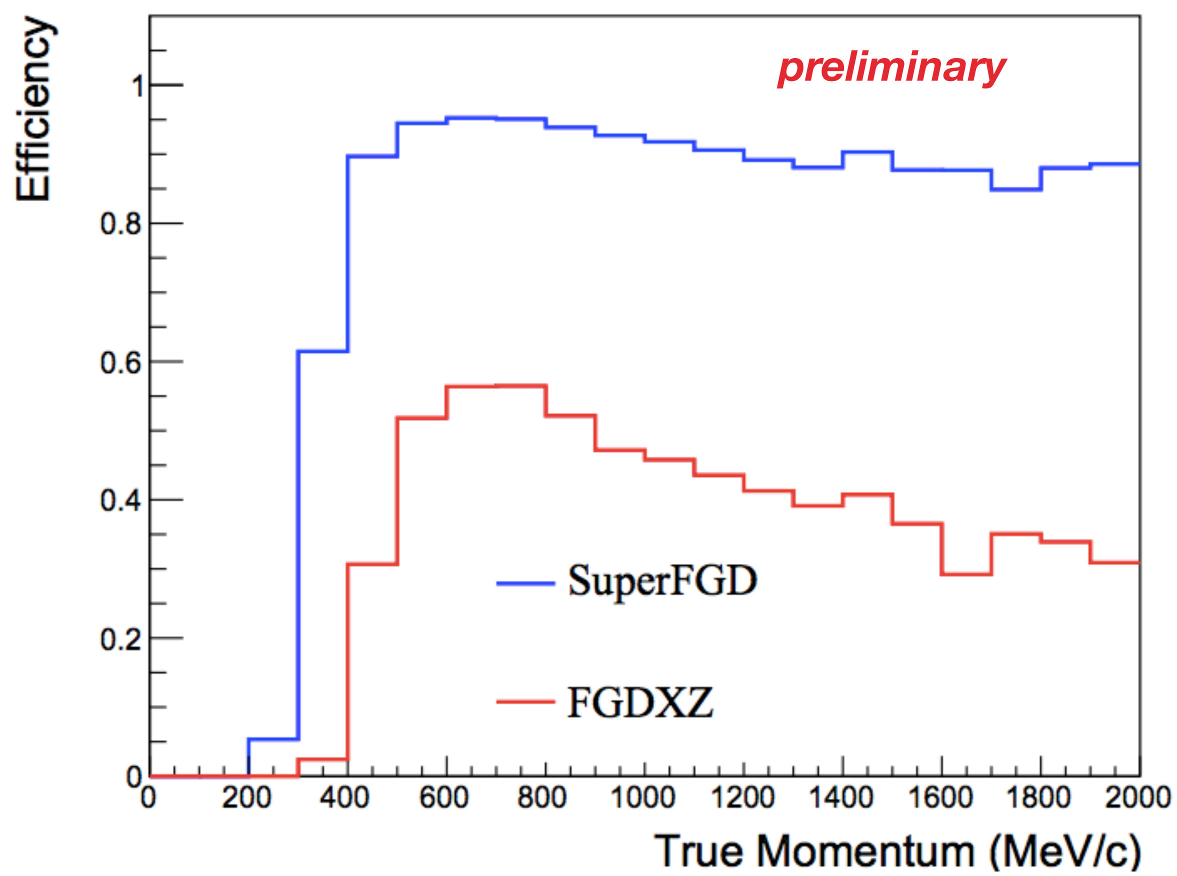


HighP-TPC :

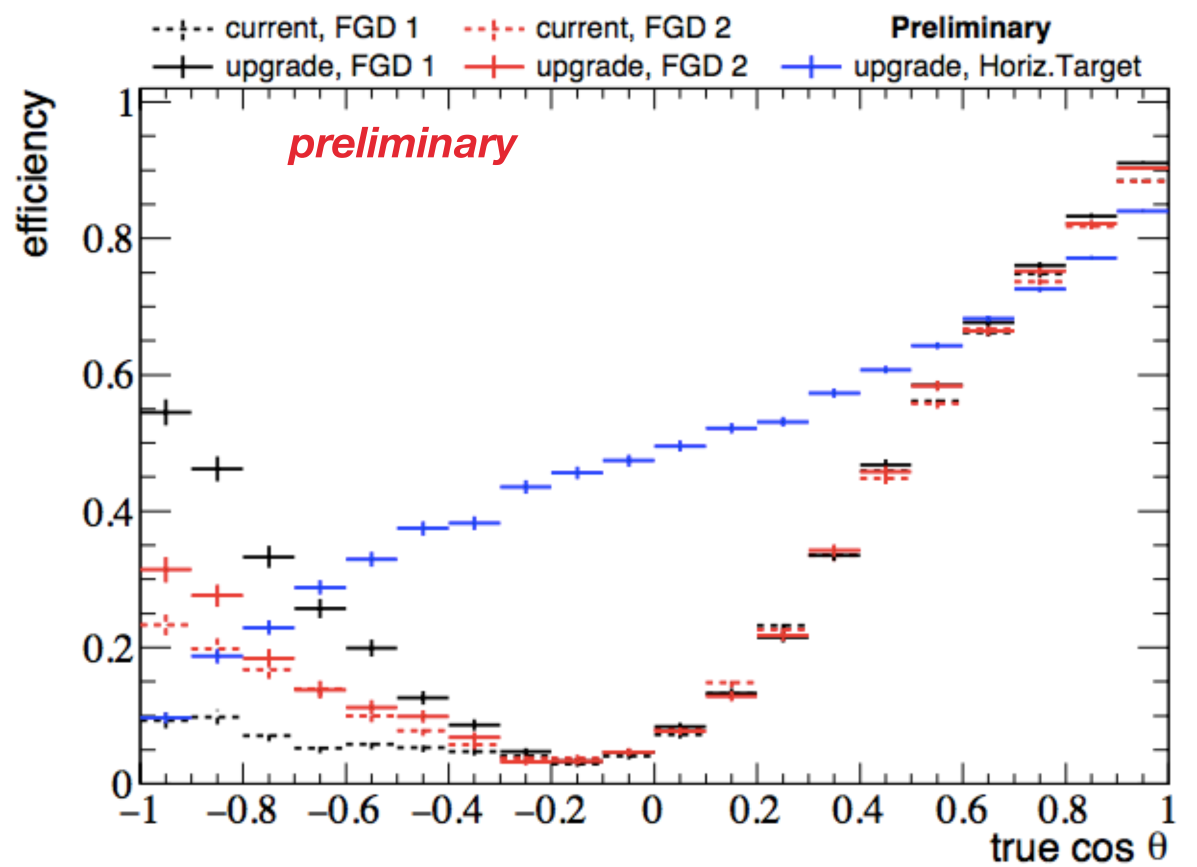
Lower detection threshold → improve MC generators

THE ND280 UPGRADE

Reconstruction efficiency for proton stopping in the target

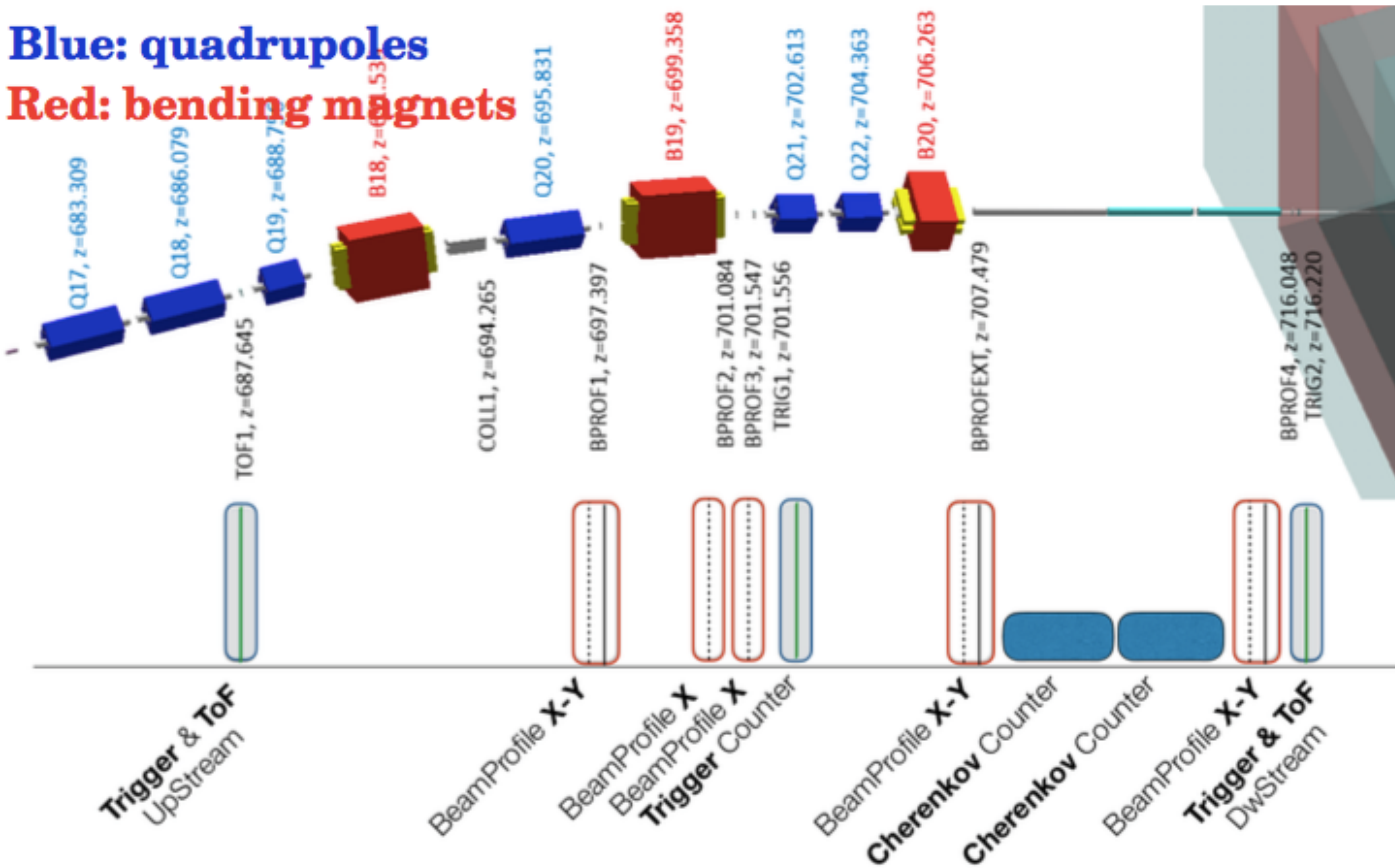


Selection efficiency for ν_μCC interactions in the ND280 configurations

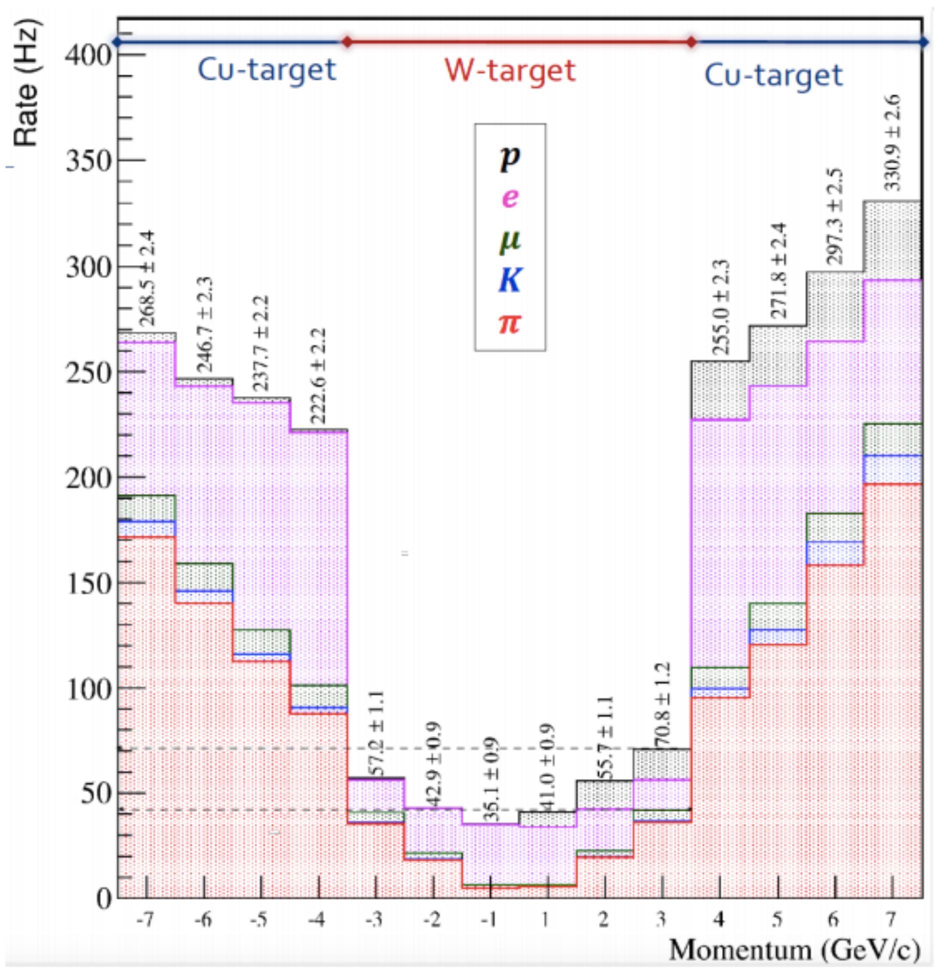


- lower detection threshold → **better sensitivity to nuclear effects**
- Enhance the acceptance

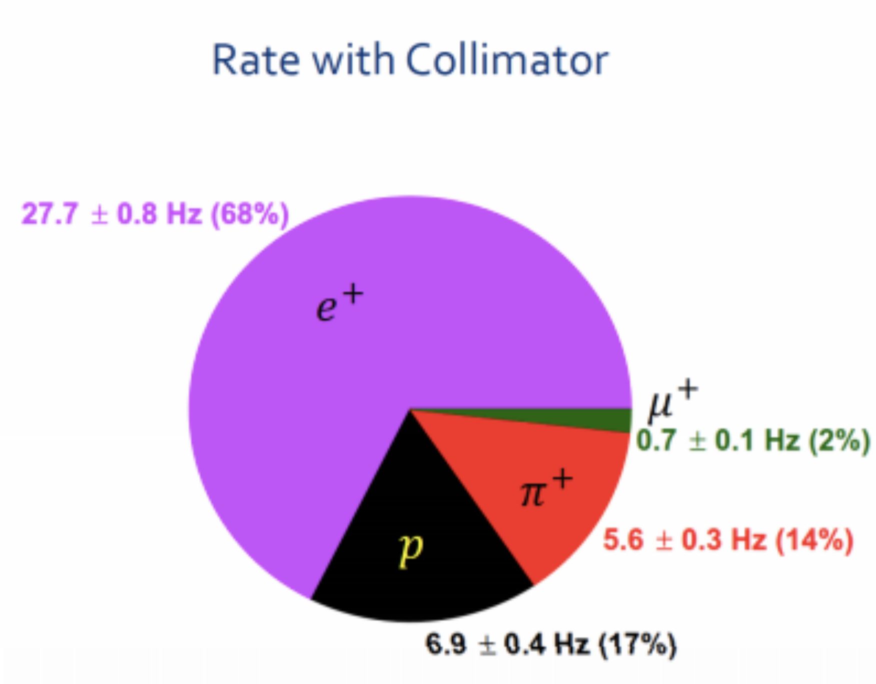
NP-04 BEAM LINE



PROTODUNE-SP BEAM TESTS



1 GEV/C



Data collection goal with 25Hz trigger rate and 3000 spill per day

- > 500k pions events per momentum setting
- > 100k protons per momentum setting
- > 900k electron events in total