Status and perspective of AP in Spain: neutrinos

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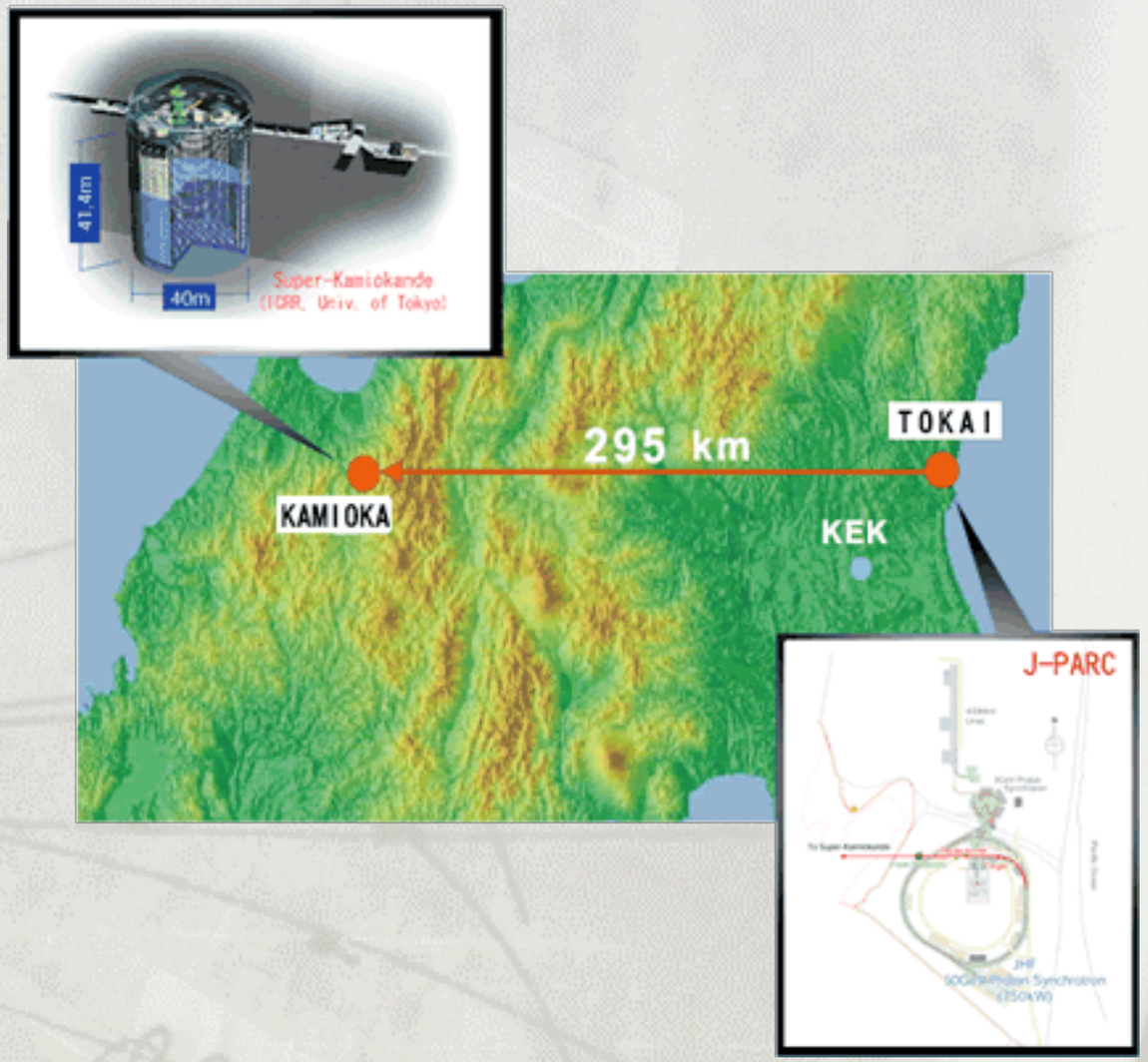
Outlook

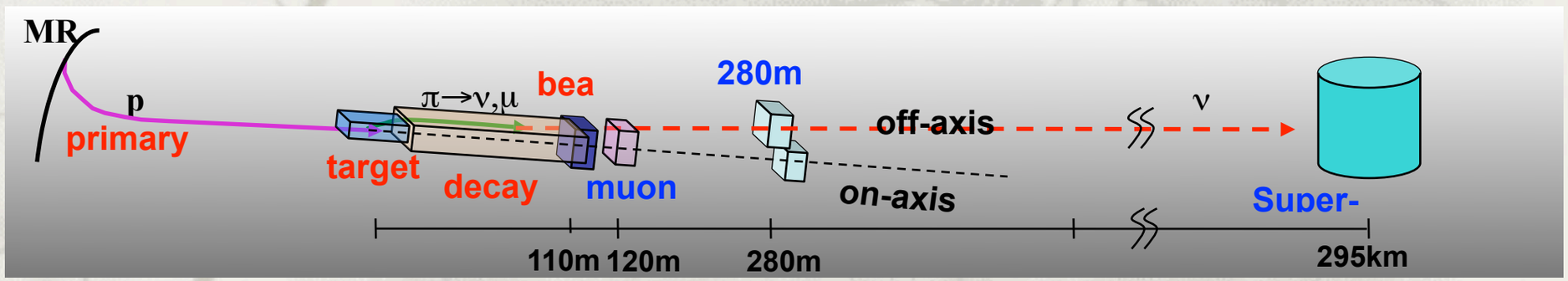
- Oscillation physics:
  - Present: Double Chooz, T2K.
  - Future: LBNO,LBNE,HK,Steriles,…
- Double beta decay:
  - Present: NEXT
  - Future: SuperNEXT,…
- Neutrino astrophysics:
  - Present: Antares
  - Future: K3NeT

Present : θ_{13}

T2K

- $\upsilon_\mu \rightarrow \upsilon_e$ & $\upsilon_\mu \rightarrow \upsilon_\mu$ from high intensity accelerator.
- E_υ ~ 600 MeV.
- Oscillation distance: 295km.
- Off-axis technique → narrow energy spectrum.



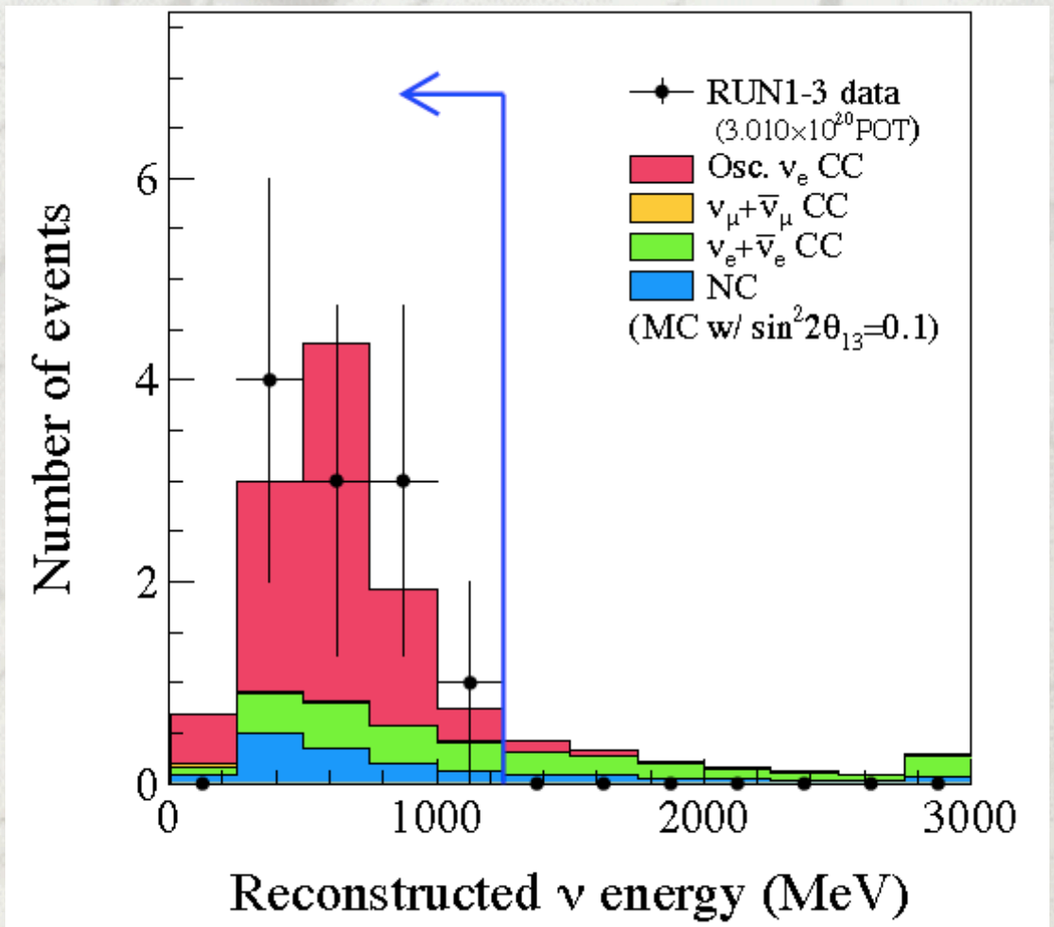


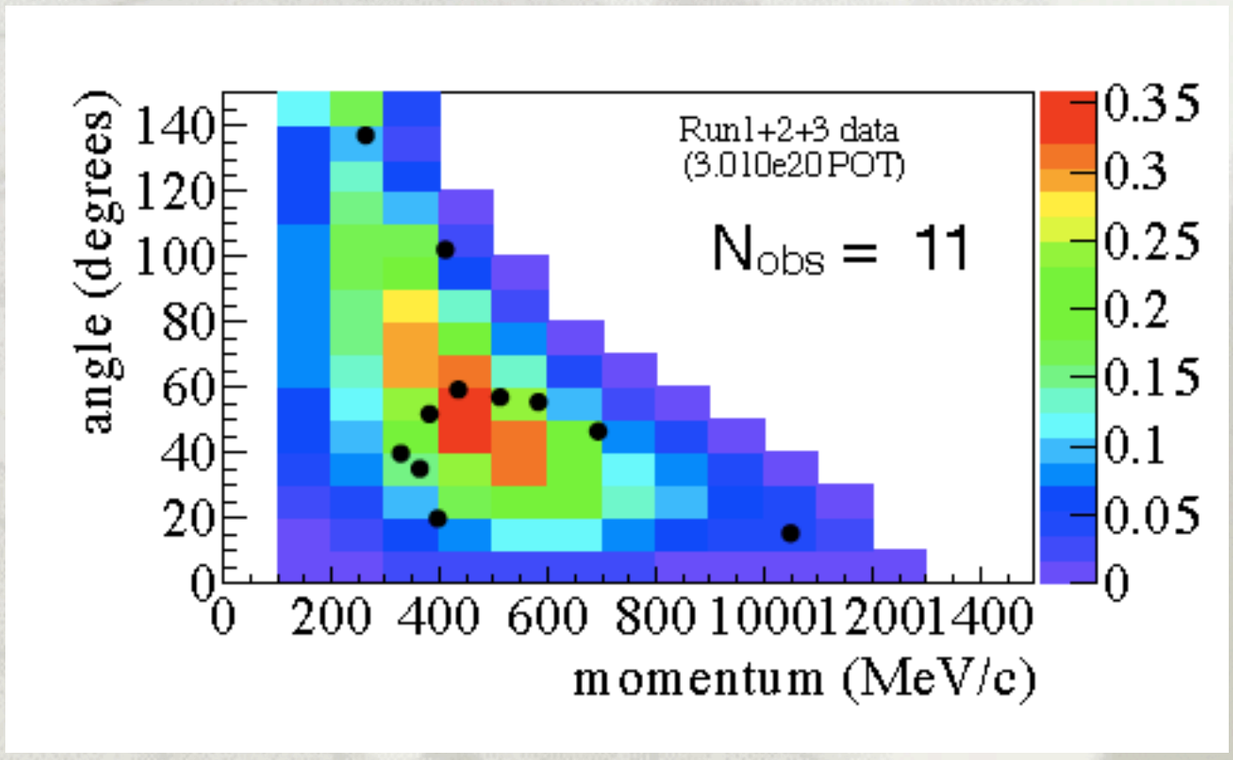
- *Spanish groups (IFAE & IFIC) contributed to the construction & operation of the near detector:*
  - *Magnet construction: water cooling and slow control.*
  - *TPC construction: calibration, testing, electronics, DAQ*
  - *Reconstruction software: TPC and global.*
- *and data analysis:*
  - *Neutrino flux determination: muon and electron neutrinos.*
  - *Neutrino-Nucleus cross-sections: CCQE, NC, pion production, etc...*
  - *Oscillation physics:*
    - *Muon neutrino disappearance.*
    - *Sterile neutrinos.*

ν_e signal in T2K

- 11 ν_e candidate events are selected over a predicted background of 3.2 (mainly electron neutrinos in the beam and neutral pions in Neutral currents, common to all accelerator approaches).
- The probability to observe 11 or more events with the predicted background for θ_{13}=0 is 0.08 % (equivalent to 3.2 σ)

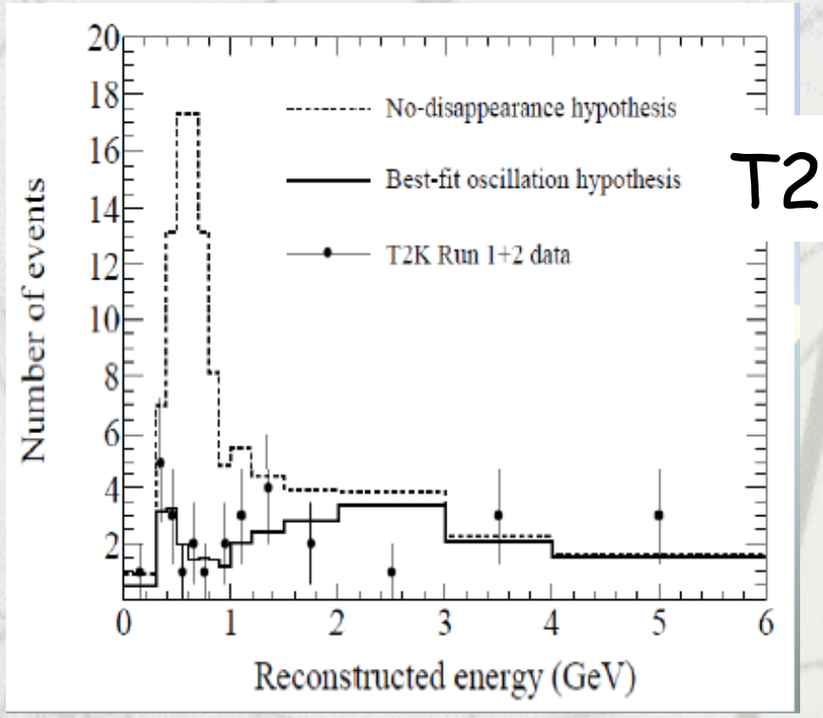
~4% of full T2K exposure



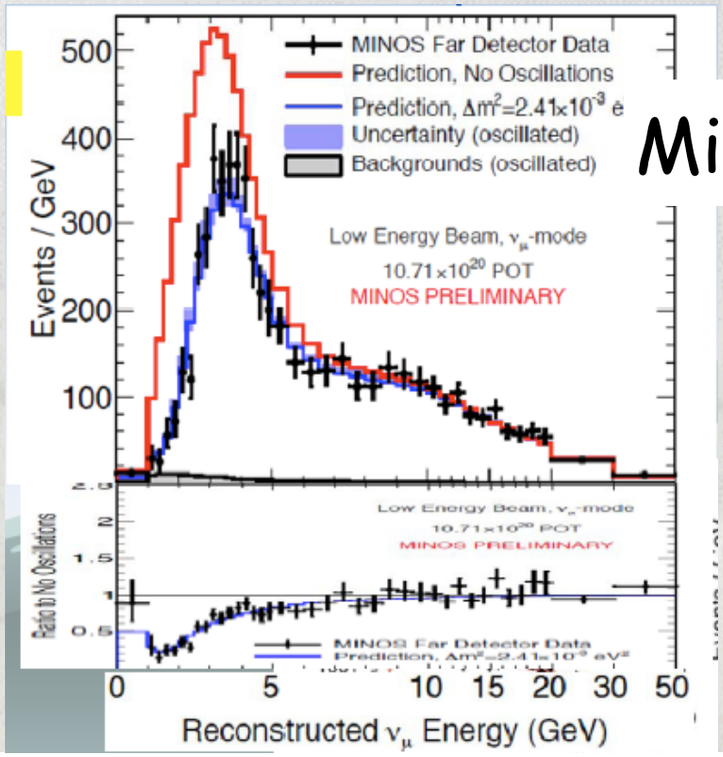


The fit uses the information on the momentum-angle plane.

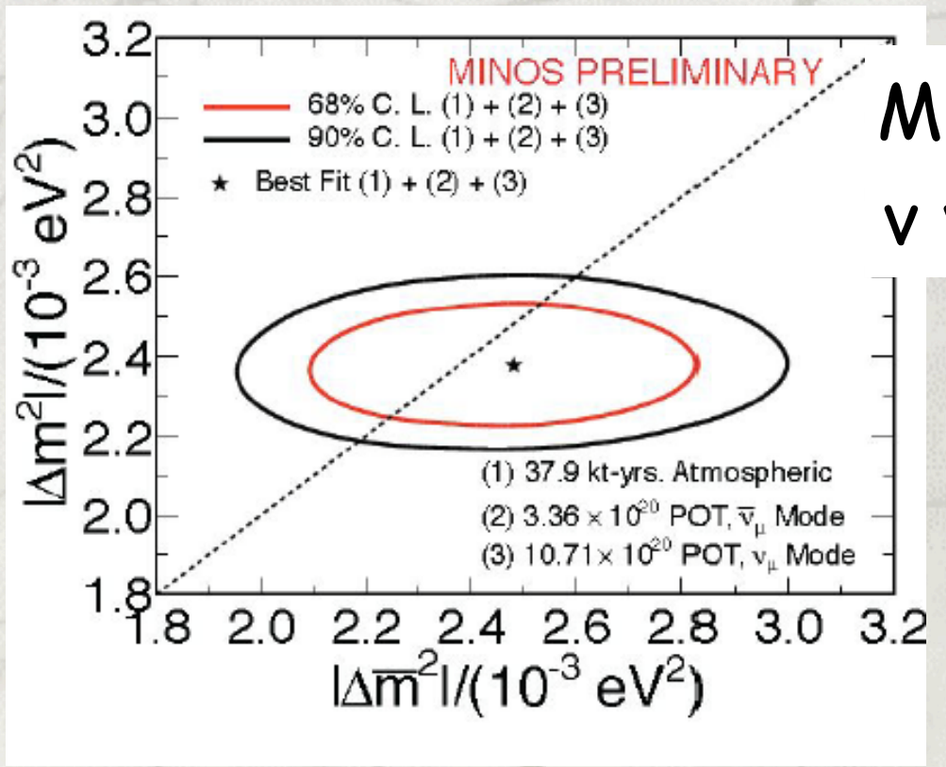
ν_μ disappearance



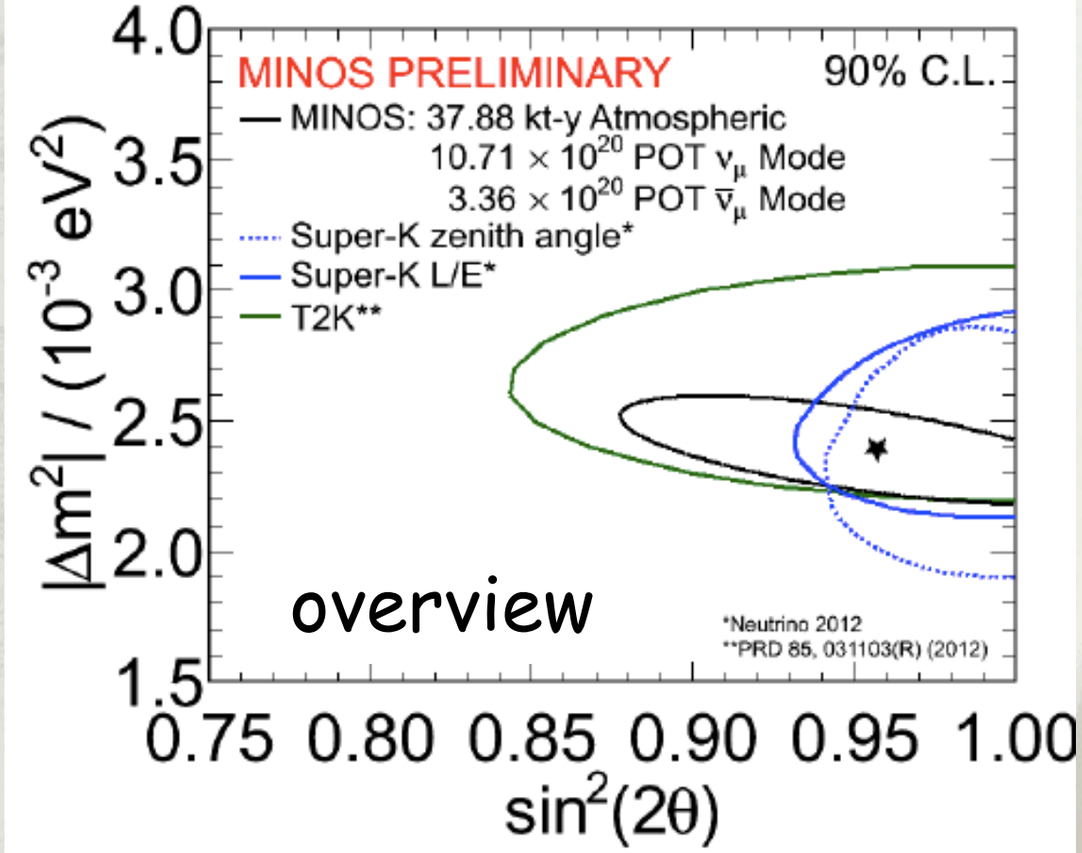
T2K



Minos



Minos
ν vs $\bar{\nu}$



θ_{23} is also important to improve θ_{13} results.

Double Chooz

Spanish contribution

DETECTOR MECHANICS

- Design and construction of special tools for acrylics installation
- Design, construction and assembly of PMT mechanical supports
- Installation of PMTs in the detectors

ELECTRONICS

- Design, tests, production and installation of PMT HV splitters

ONLINE SYSTEM

- DAQ Event Builder development

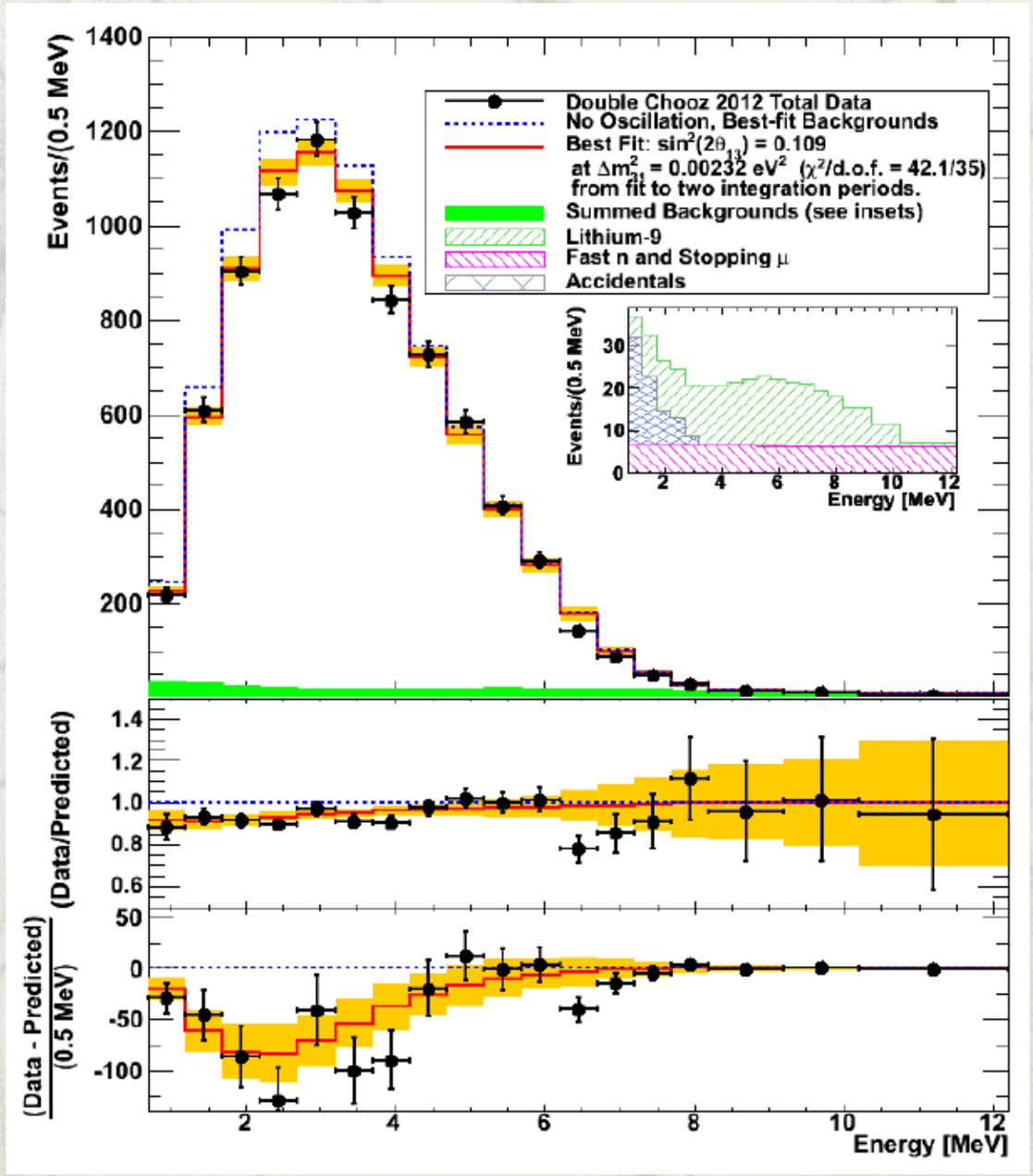
PHOTODETECTION SYSTEM

- PMT functionality tests
- PMT characterization under magnetic field
- Design, tests, production and assembly of PMT magnetic shields
- PMT light noise characterization

SIMULATION, DATA RECONSTR. AND PHYSICS ANALYSIS

- Detector simulation software
- Data reconstruction algorithms
- Background simulation and analysis
- Neutrino selection
- Analysis tools for sys. and sensit. estimation
- Coordination of the European cluster
- Convenor of the Gd analysis

Double Chooz



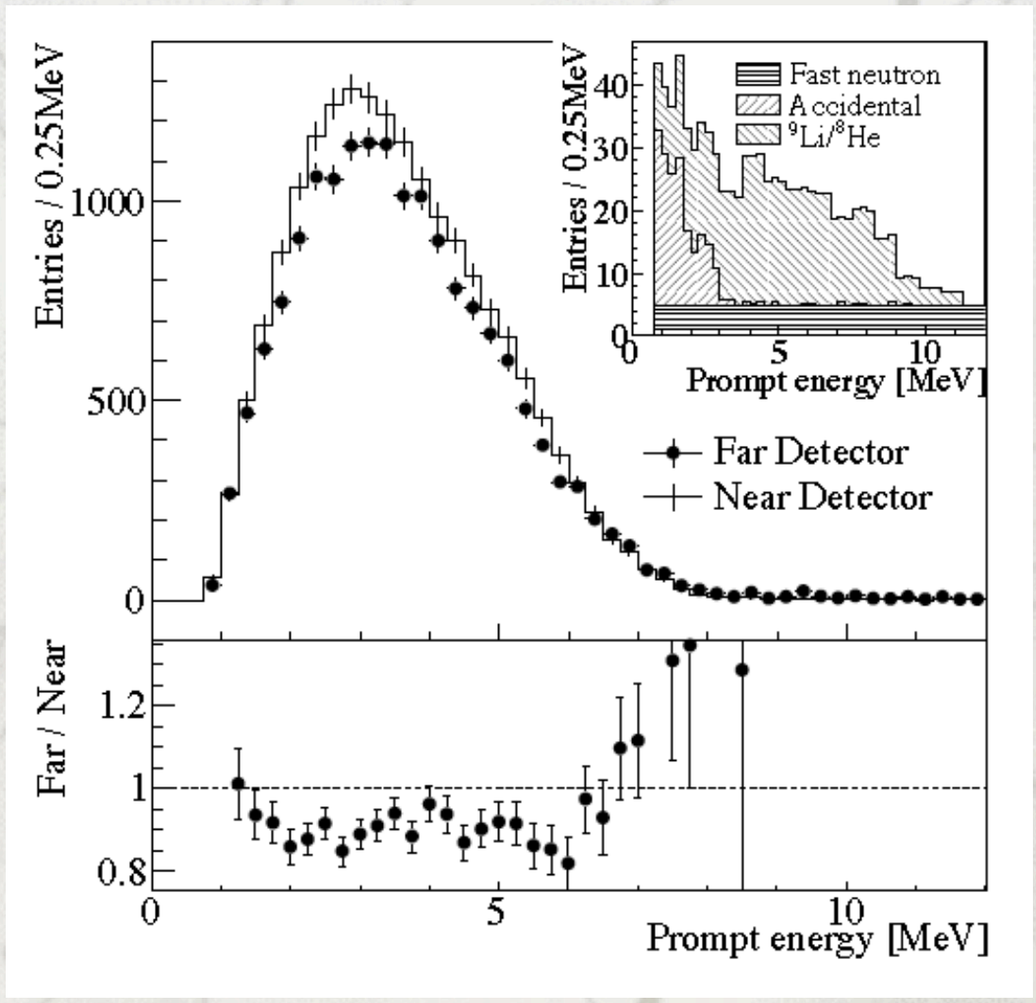
Source		Uncertainty w.r.t. signal	
Statistics		1.1%	
Flux		1.7%	
Detector	Energy response	0.3%	1.0%
	E_{delay} containment	0.7%	
	Gd fraction	0.3%	
	Δt cut	0.5%	
	Spill in/out	0.3%	
	Trigger efficiency	<0.1%	
	Target H	0.3%	
Background	Accidental	<0.1%	1.6%
	Fast-n + stop μ	0.5%	
	^{9}Li	1.4%	

- rate and shape analysis.
- Null oscillation rejected at the 99.8% CL. (2.9 σ)

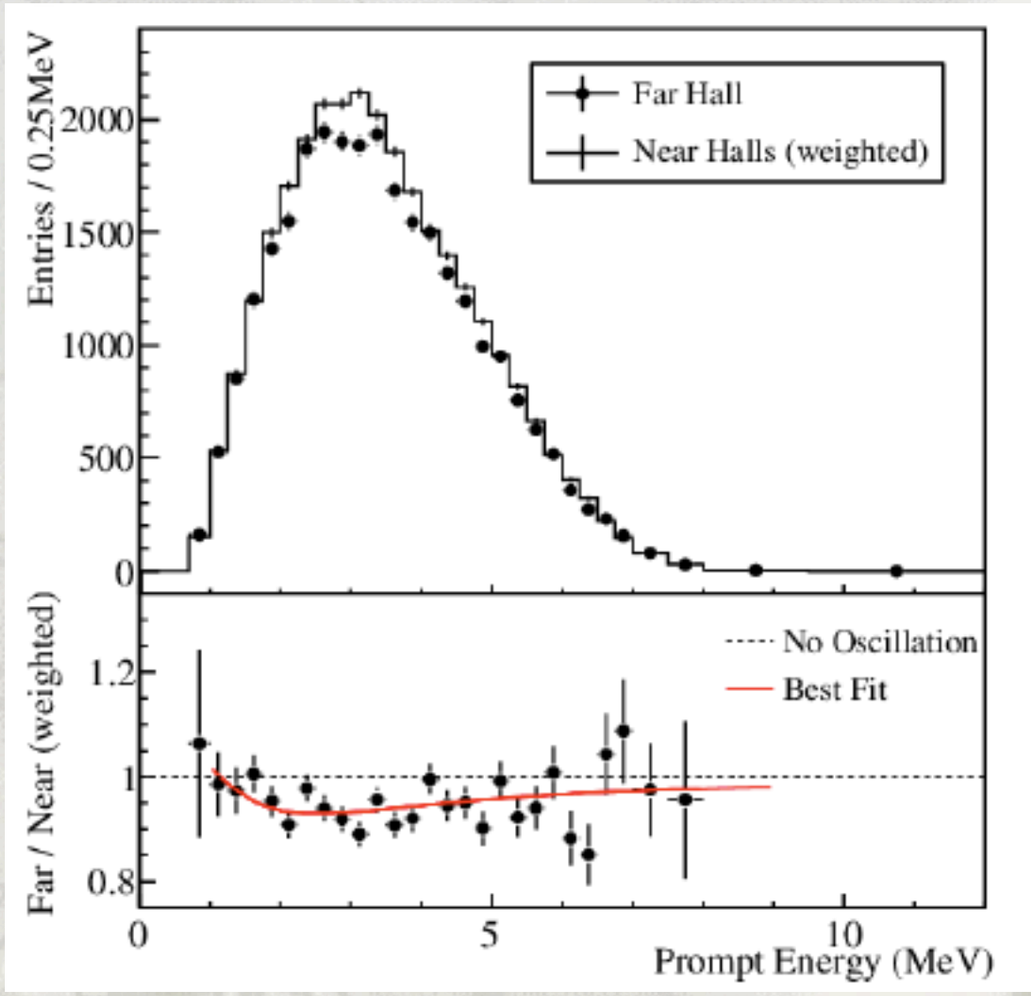
$$\sin^2 2\theta_{13} = 0.109 \pm 0.030\ (\text{stat}) \pm 0.025\ (\text{syst})$$

Double Chooz in the media

Daya Bay & RENO results

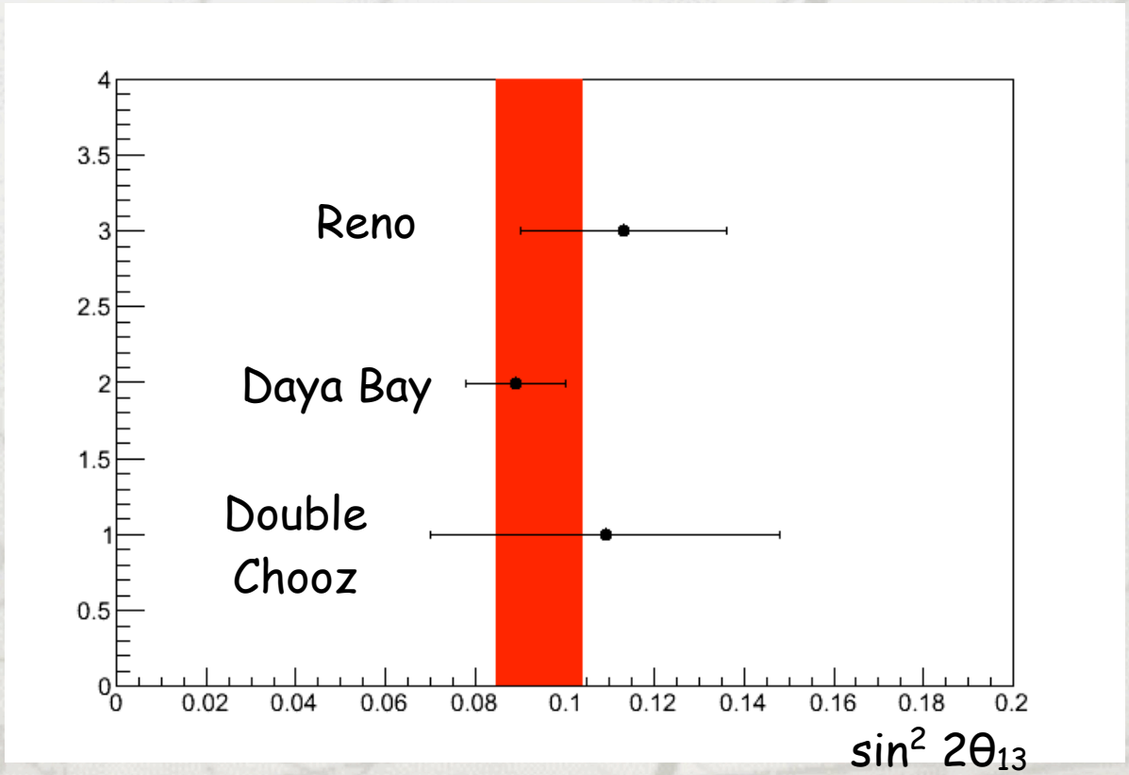


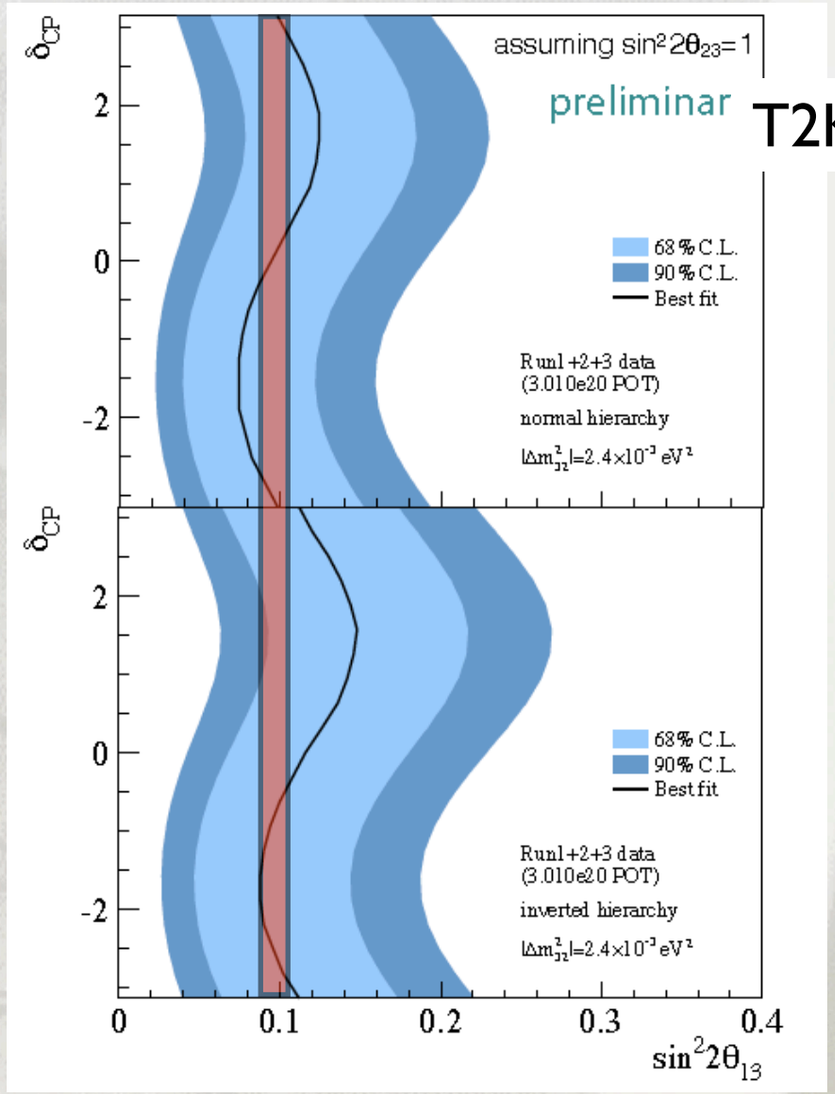
$\sin^2 2\theta_{13} = 0.113 \pm 0.013\ (stat) \pm 0.019\ (syst)$



$\sin^2 2\theta_{13} = 0.089 \pm 0.010\ (stat) \pm 0.005\ (syst)$

Overview picture





Combination reactor data assuming no correlations:

$\sin^2 2\theta_{13} = 0.0945 \pm 0.0097$ (9.7σ effect)

The mixing angle θ_{13} is getting under control but the potential of running experiments is not exhausted:

- shape + rate in DayaBay and Reno.
- near detector in Double Chooz
- Beam power & systematics in T2K & new NoVa.

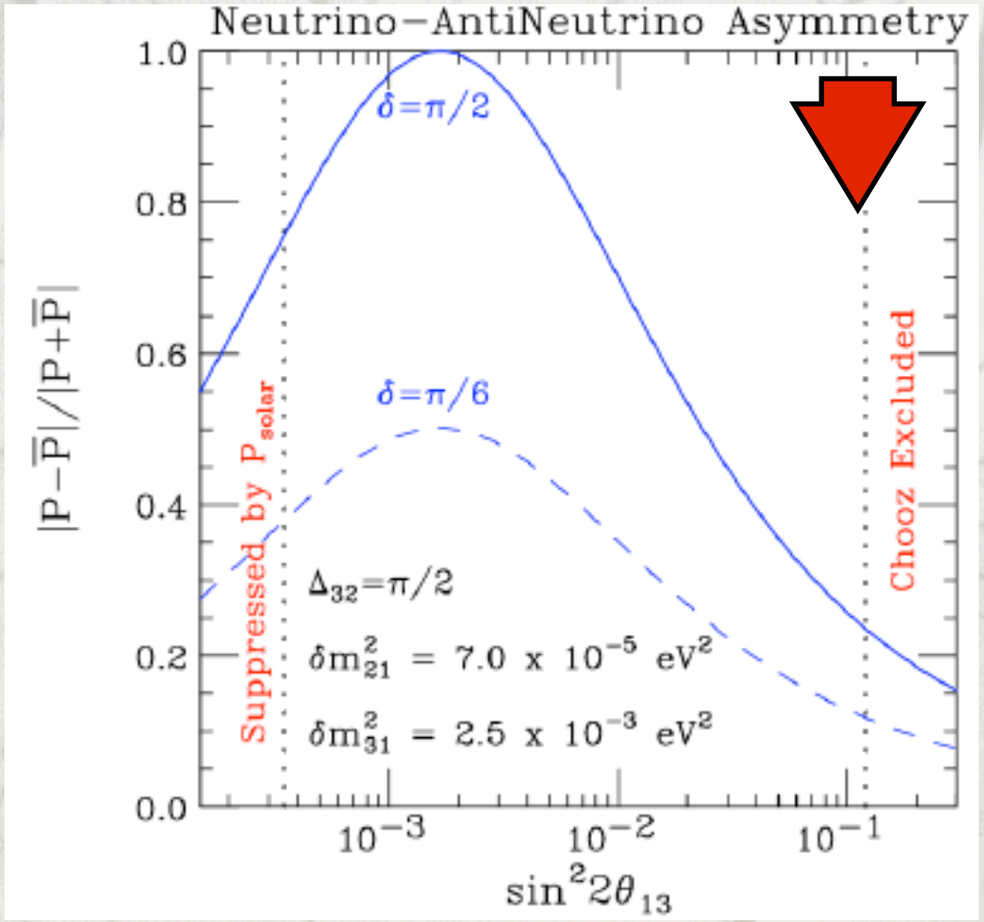
Reactors are unique due to clean signature!

Future of current Spanish activities

- T2K will be running in a first phase until the nominal POT is obtained: 7.8×10^{21} (3.01×10^{20} until summer). This implies running beyond 2015.
  - Continuation will depend on Nova performance and future results.
- Double-Chooz is installing the near detector and it will start operation in April 2014. This will be followed by at least two years of operation (~2016).

Future:
mass hierarchy, CP violation & steriles

Common agreement



- The actual experiments (T2K+NOVA+Reactors) cannot fully explore the PNMS matrix.
- We need a new facility.
- The facility is a conventional beam of very high intensity.
- Systematic errors are critical:
  - Excellent flux prediction with hadro-production experiments.
  - Neutrino-Nucleus cross-sections systematics with "ad-hoc" or "near site" experiments.

… and disagrements

- Short baseline (~100-300 km):
  - lower energy (<1GeV)
  - narrow beam
  - large Water Cherenkov(~500 kT)
  - Concentrates on $\nu/\bar{\nu}$ asymmetry, "counting" experiment.

- Longer baseline (>1000 km):
  - higher energy (>1GeV)
  - wide band beam
  - Liquid Argon TPC. All final states accessible.
  - E/L oscillation pattern and second maximum

Contributions to the CERN strategy meeting.

Long Base Line

Both are related also to strong astroparticle physics program: proton decay, SN, atmospheric ν

Cern to Pyhäsalmi (Finland) (LBNO) ID74

- Base line: 2300 km.
- 50kT+50kT liquid Argon + 50 kT Iron sampling calorimenter. Phase I 20kT.
- upgraded SPS (700 kW) neutrino beam.
- Include LENA for solar and SN neutrinos.

Fermilab to Homesteak (LBNE) ID150

- Base line: 1300 km.
- 10kT liquid Argon with a second fase of 35kT.
- up to 2.3 MW (Project-X) neutrino beam.

synergies

EUROnu recommendation

construction and operation of a 10 GeV Neutrino Factory as soon as possible, implemented using the staged approach.

Contributions to the CERN strategy meeting.

Short Base Line

T2HK (Japan) ID86

- Base line: 295 km.
- 500kT water Cerenkov.
- JPARC (750 kW) off-axis neutrino beam.
- Option: Tokai to Okinoshima (650km) and LiqAr detector.

ID 82 and 24

- CERN to Canfranc or base on ESS facility (Lund, Sweden).
- 400kT water Cerenkov (Menphis)
- ESS: 5 MW
- SPS: 800kW SPL: 4MW.

Performance

- There is strong discussion inside the community. The common feeling is that short base line are better for CP and long base lines for hierarchy.
  - But!, both measurements are critical and complementary due to degeneracies.
- The different proposals are staged and it is difficult to evaluate medium and long term prospects at once.

Performance

Project	Beam power MW	Fiducial Mass kt	Baseline km	MH	CPV 90%CL, (3σ)	Physics starts	Astrophysical program
LBNO	0.8	20->100	2300	Excellent	71 (44)	2023	Yes
T2HK	0.75	500	295	Little	86 (74)*	2023	Yes
LBNE	0.7	10	1300	OK	69 (43)	2022	No
Lund	5	440	365	Some	86 (70)	>2019	Yes
CERN-Canfranc	0.8-4	440	650	Some	80-88(80)	>2020	Yes

M.Zito Cracow meeting

L.Alvarez-Ruso et al.

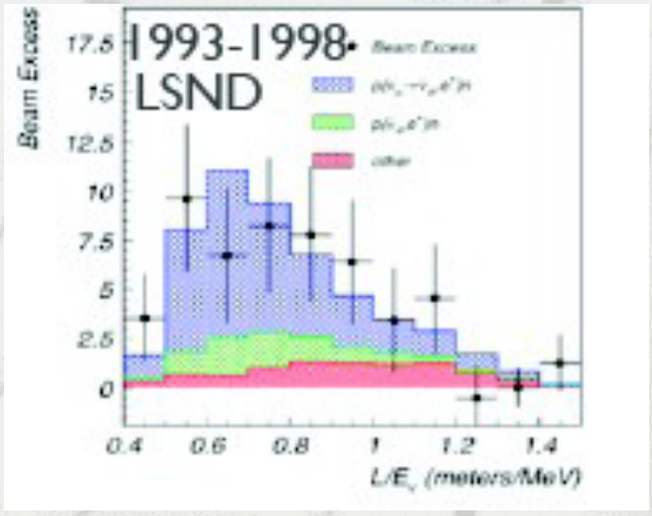
"Perspectiva en física de neutrinos"

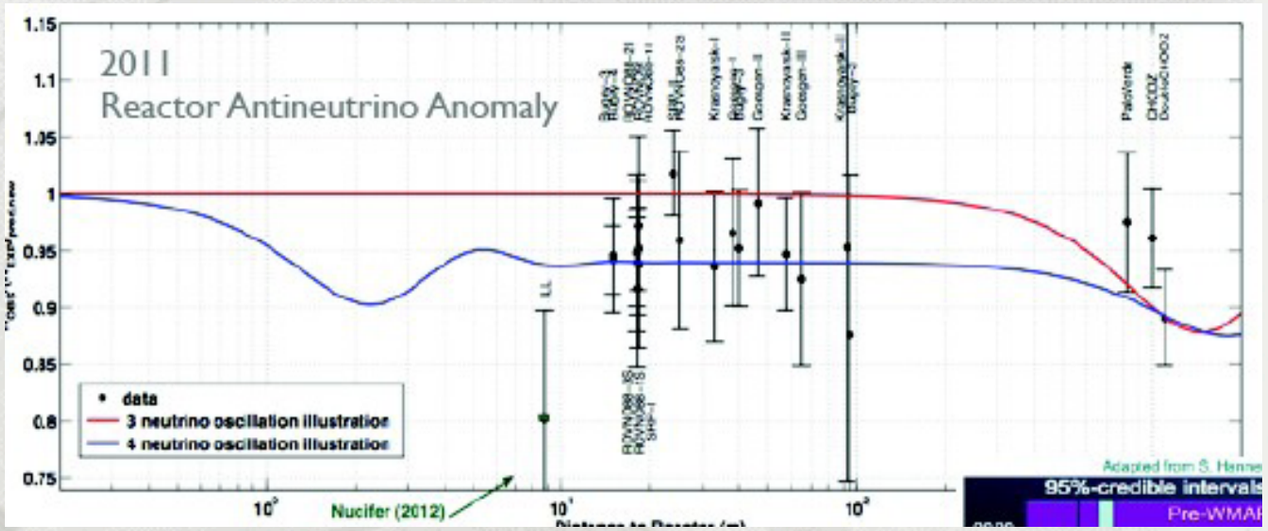
Experimento	Distancia	Tiempo	Espectro	$\Delta\delta(^\circ)$	Rango CP
NOVA+T2K	290/810 km	+10y	<2-3 σ		-
LBNE (10kton)	1300 km	$\sim$ 10y+10y	$\sim 5\sigma$	$< 33^\circ$	-
LBNO (20kton)	2300 km	$\sim$ 10y+10y	$>5\sigma$	$< 34^\circ$	-
T2HK	290 km	$\sim$ 10y+10y	$\sim 4\sigma$	$< 15^\circ$	$\sim$ [50%-70%]
LBNE (34kton)	1300 km	?+10y	$\gg 5\sigma$	$< 20^\circ$	$\sim 56\%$
LBNO (100kton)	2300 km	?+10y	$\gg 5\sigma$	$< 15^\circ$	$\sim 59\%$
SPL	130/630 km	?+10y	-/3σ	$\leq 16^\circ/26^\circ$	$\sim 55\%/\sim 70\%$
ESS	400 km	?+10y	$3-4\sigma$	$< 20^\circ$	$\sim 70\%$
LENF	2300 km	?+10y	$> 5\sigma$	$\leq 7^\circ$	~ 85 %

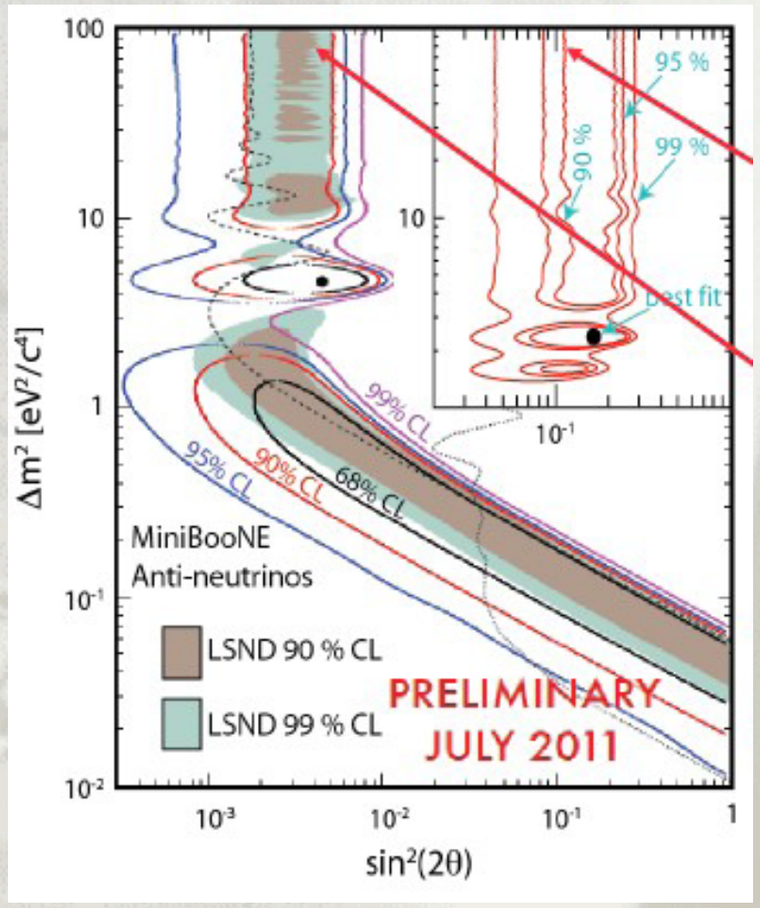
Beam power, target mass & staging strategy are not always taken consistently.

F.Sánchez RENATA meeting, 26th November 2012

Steriles







- LSND & MiniBoone: $\nu_\mu \rightarrow \nu_e$
- Deficit in reactor experiments & Gallium anomaly.
- Cosmology (3+1).
- Many approaches:
  - accelerator neutrinos.
  - reactor neutrinos.
  - strong ν sources close to detectors (CLAND)

Steriles

Icarus-Nessi — CERN

- Search for neutrinos with Δm~1 MeV.
- Two LiqAr (600T and 150T) detectors at CERN.
- SPS 110 GeV proton beam.

NuStorm — FNAL

- Search for neutrinos with Δm~1 MeV, ν_μ $\nu_e \rightarrow \nu_\mu$
- Magnetized iron detector.
- Neutrinos from muon accumulator ring.

MicroBoone — FNAL

- 170 t LiqAr detectors.
- Boone in FNAL.
- MiniBoone excess and anti-ν anomaly.

CeLAND — GranSasso, Kamioka, etc..

- Strong ν_e source (^{144}Ce) in the center of Kamland. (also Borexino,SNO,etc…)
- Use the detector to look for the sinusiodal oscillation pattern.

- Proposals (Nucifer) to measure the reactor spectrum very close to production for reactor anomaly.

Saclay, …

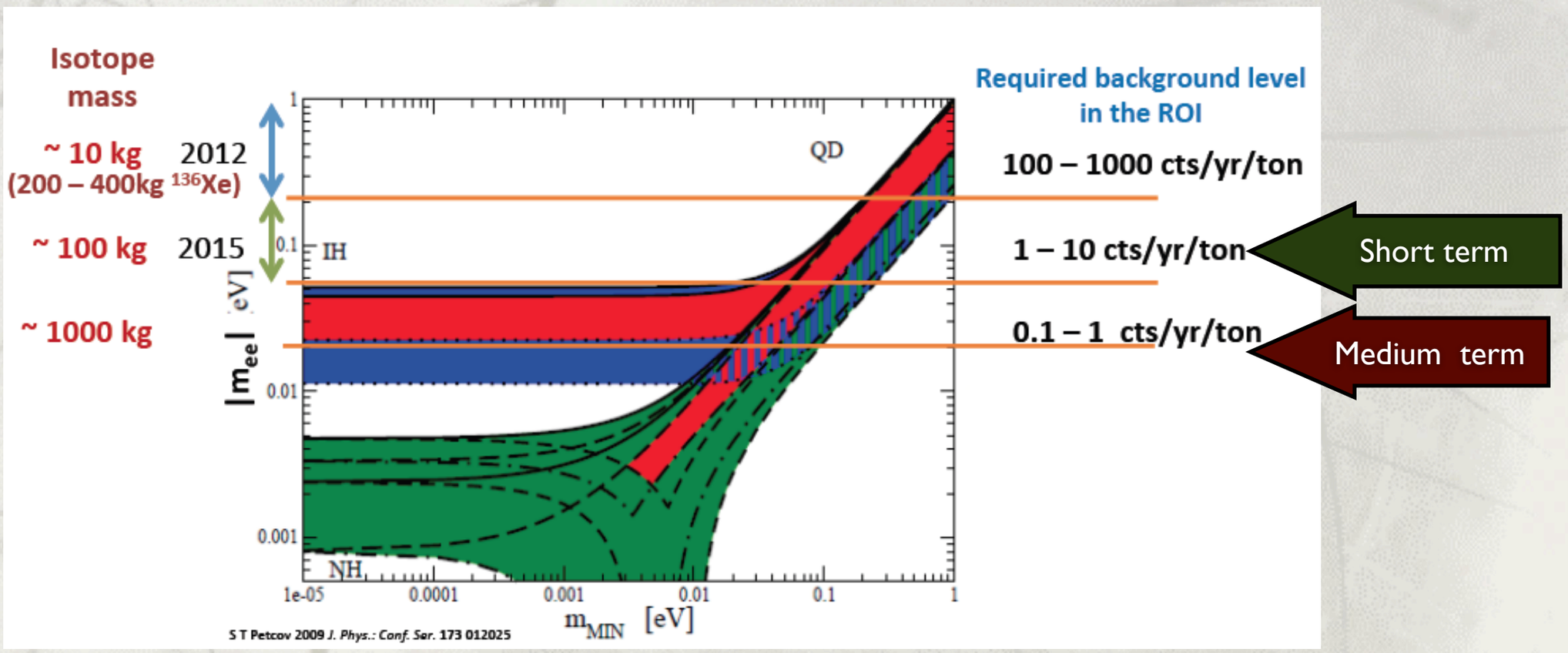
Some considerations

- Spanish groups has experience & infrastructure in:
  - Liquid Argon: Ciemat & Univ.Granada.
  - Liquid Scintillators: Ciemat.
  - TPC and gas detectors: IFAE & IFIC & Univ. Zaragoza with T2K, NEXT & MicroPattern detectors.
  - Member of groups with experience in XENON.
  - Experience in SuperKamiokande: UAM.
- Spanish experimental groups has shown strong interest in the LiqAr development but we still have concerns about the physics potential of LBNO.
- We are in a good position to make a serious contribution to the new generation of experiments and we have to. But!, what ?:
  - We will try to organize an spanish workshop to bring the different positions to converge.

Double-Beta decay & the neutrino mass nature

Neutrino mass nature

- The Majorana nature of neutrinos is the door to new physics:
  - The lepton number is not a conserved symmetry.
  - It provides a measurement of absolute neutrino mass and the scale of new physics.



Next

NEXT Collaboration

UAM (Madrid) • U. Girona • IFIC (Valencia) • U. Santiago • U.P. Valencia • U. Zaragoza

LBNL • Texas A&M • Iowa State

U. Coimbra • U. Aveiro

http://next.ific.uv.es/

JINR (Dubna)

UAN (Bogotá)

NEXT in Papers

Technical design report (detector design, background model)

•V.~Alvarez *et al.* [NEXT Collaboration], "NEXT-100 Technical Design Report (TDR): Executive Summary," JINST 7, T06001 (2012). arXiv:1202.0721 [physics.ins-det].

Design of SiPM plane, coating with TPB, PMTs

•V.~Alvarez, *et al.* [NEXT Collaboration], "SiPMs coated with TPB : coating protocol and characterization for NEXT," JINST {\bf 7}, P02010 (2012). arXiv:1201.2018 [physics.ins-det].

•V.~Alvarez, *et al.* [NEXT Collaboration], "Design and characterization of the SiPM tracking system of the NEXT-100 demonstrator," arXiv:1206.6199 [physics.ins-det].

•V.~Alvarez *et al.* [NEXT Collaboration], "In-situ calibration of a PMT inside a scintillation detector by means of primary scintillation detection," arXiv:1211.4409 [physics.ins-det].

Radiopurity

•V.~Alvarez *et al.* [NEXT Collaboration], "Radiopurity control in the NEXT-100 double beta decay experiment: procedures and initial measurements,". arXiv:1211.3961 [physics.ins-det].

Alpha particles in NEXT-DEMO

•V.~Alvarez, *et al.* [NEXT Collaboration], "Ionization and scintillation response of high-pressure xenon gas to alpha particles," arXiv:1211.4508 [physics.ins-det.

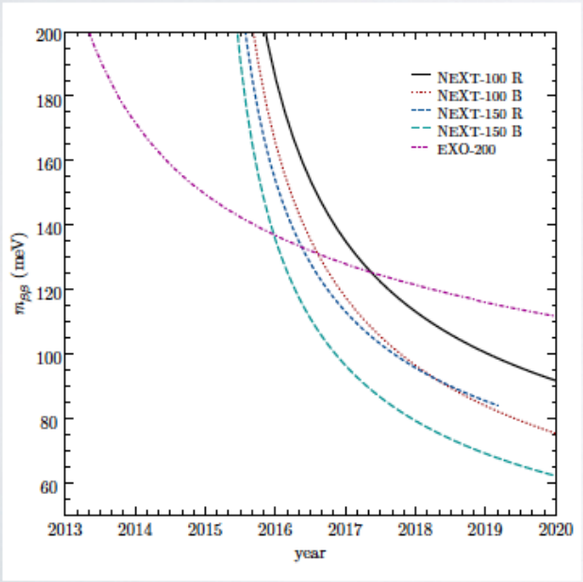
NEXT-DEMO & NEXT-DBDM: Energy resolution and topology

•V.~Alvarez, *et al.* [NEXT Collaboration], "Near-Intrinsic Energy Resolution for 30 to 662 keV Gamma Rays in a High Pressure Xenon Electroluminescent TPC," arXiv:1211.4474 [physics.ins-det].

•V.~Alvarez *et al.* [NEXT Collaboration], "Initial results of NEXT-DEMO, a large-scale prototype of the NEXT-100 experiment," arXiv:1211.4838 [physics.ins-det].

NEXT PHYSICS CASE

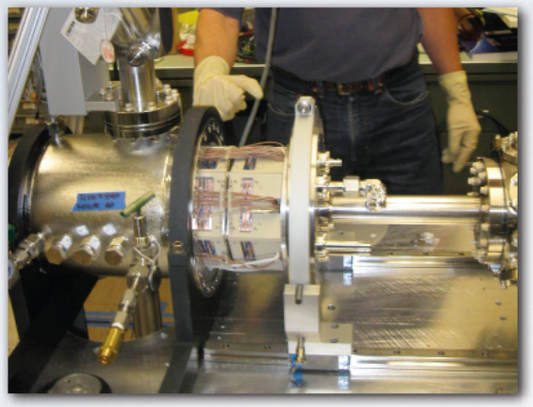
•J.~J.~Gomez-Cadenas, J.~Martin-Albo and F.~Monrabal, "NEXT, high-pressure xenon gas experiments for ultimate sensitivity to Majorana neutrinos" arXiv:1210.0341 [physics.ins-det].



- EXO already dominated by backgrounds.
- NEXT can overtake EXO very quickly and improve its sensitivity.
- The technology can be extrapolated to large masses.
- The physics case is excellent.

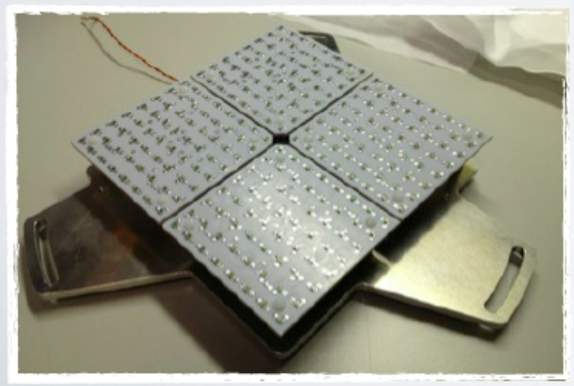
Next

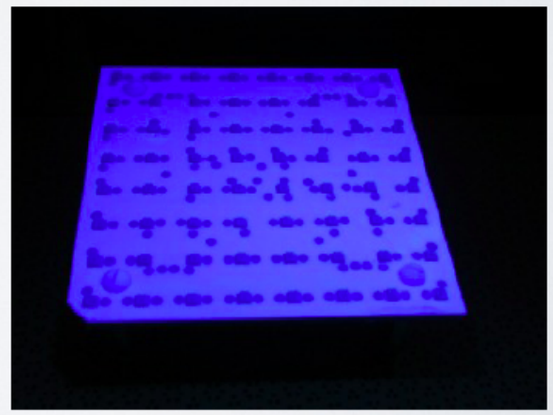
NEXT: EL Prototypes



•V.~Alvarez, *et al.* [NEXT Collaboration], "Near-Intrinsic Energy Resolution for 30 to 662 keV Gamma Rays in a High Pressure Xenon Electroluminescent TPC," arXiv:1211.4474 [physics.ins-det].

•V.~Alvarez *et al.* [NEXT Collaboration], ``Initial results of NEXT-DEMO, a large-scale prototype of the NEXT-100 experiment," arXiv:1211.4838 [physics.ins-det].

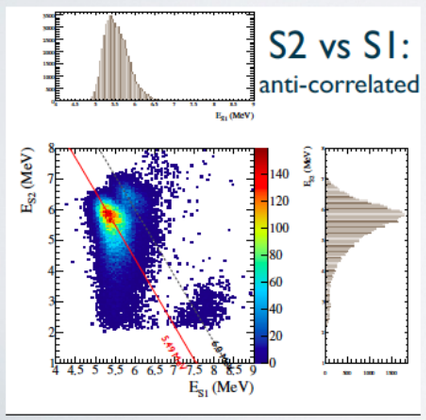




New results from DEMO

Alpha particles

•V.~Alvarez, *et al.* [NEXT Collaboration], "Ionization and scintillation response of high-pressure xenon gas to alpha particles," arXiv:1211.4508 [physics.ins-det].

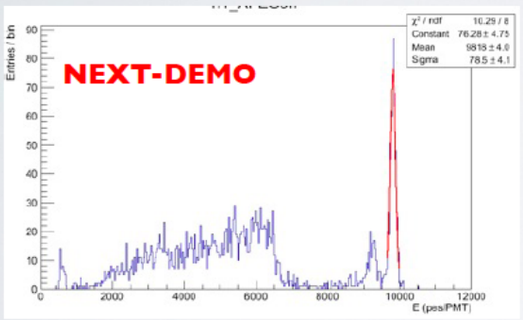


• First measurement of alpha S1-S2 anticorrelation in gas

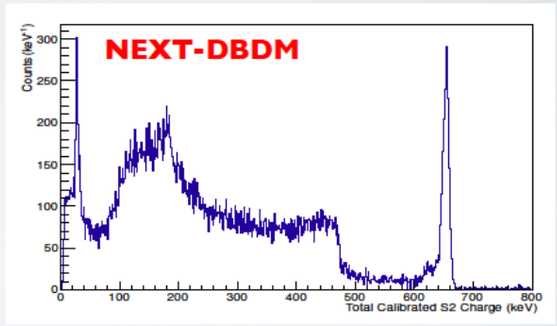
Energy resolution and tracking

•V.~Alvarez *et al.* [NEXT Collaboration], ``Initial results of NEXT-DEMO, a large-scale prototype of the NEXT-100 experiment," arXiv:1211.4838 [physics.ins-det].

•V.~Alvarez, *et al.* [NEXT Collaboration], "Near-Intrinsic Energy Resolution for 30 to 662 keV Gamma Rays in a High Pressure Xenon Electroluminescent TPC," arXiv:1211.4474 [physics.ins-det].



• 511 keV in full fiducial region. Achieves 0.77% FWHM in full fiducial (improves NEXT target of 1% FWHM)

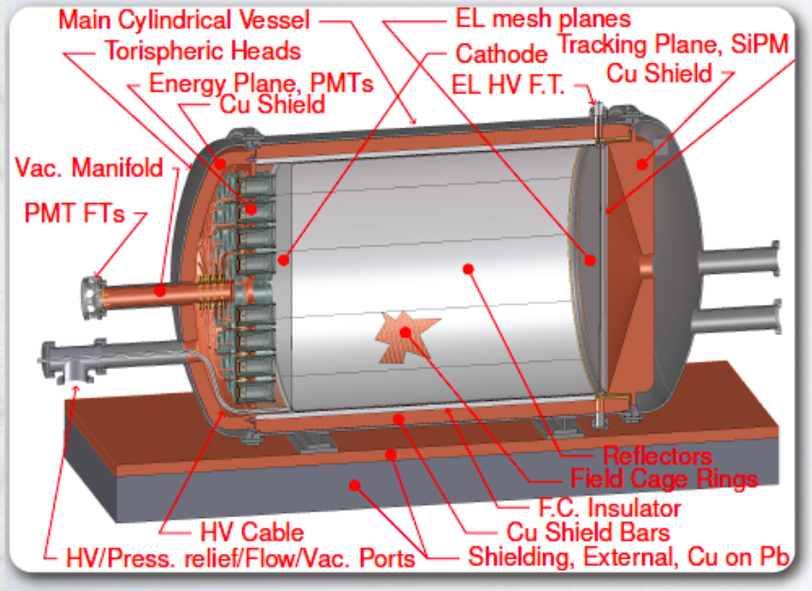


• 660 keV electrons in central region. Achieves near intrinsic resolution in a large EL system: 0.5 % at Qbb

TDR and radiopurity

Technical design report (detector design, background model)

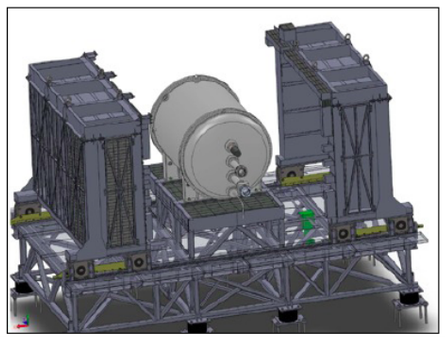
- **V.~Alvarez *et al.* [NEXT Collaboration],**
  "NEXT-100 Technical Design Report (TDR): Executive Summary,"
  JINST 7, T06001 (2012).
  arXiv:1202.0721 [physics.ins-det].
- **V.~Alvarez *et al.* [NEXT Collaboration],**
  "Radiopurity control in the NEXT-100 double beta decay experiment: procedures and initial measurements,"
  [arXiv:1211.3961 [physics.ins-det]].



- **A High Pressure Gas Xenon TPC.**
- **Can hold 100 kg of Xenon at 10 bar of 150 kg at 15 bar.**
- **Drift field 300 V/cm**
- **Made of radiopure components**

Next

NEXT: Status



- **Pressure Vessel under construction.**
- **Seismic pedestal and lead castle under construction.**
- **Infrastructures including gas system will be ready by Q3 2013.**
- **Sensors already purchased and being tested.**
- **Radiopurity campaign very advanced.**

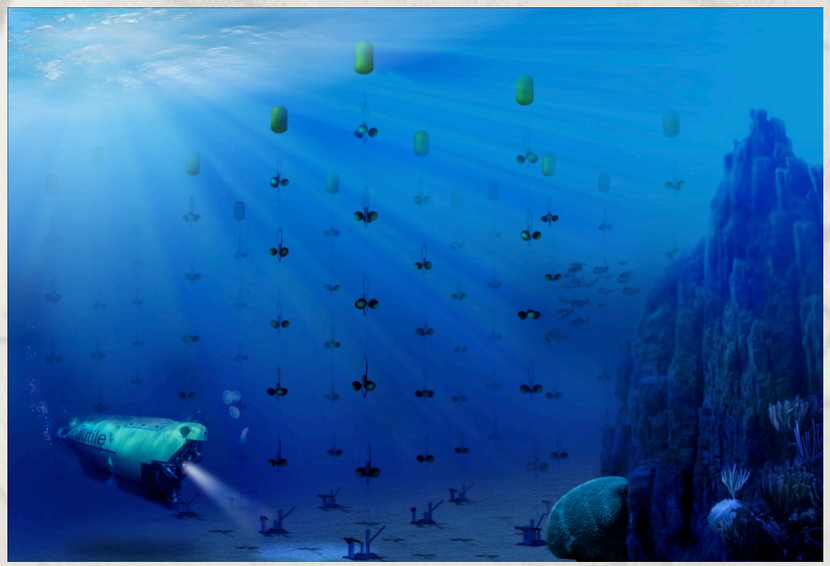
NEXT: Status

- **The EL grid for NEXT compared with that of LUX**

- **Field cage will be built at Texas A&M.**
- **Mechanics of Energy plane: LBNL/ANL.**
- **Tracking plane: IFIC/ Fermilab.**
- **Proposal to DOE from USA groups (including Fermilab and Argonne National Laboratory).**
- **Ready to start in 2014.**

- **NEXT has proven its technological choices and started construction of the detector according to schedule.**

Astroneutrinos

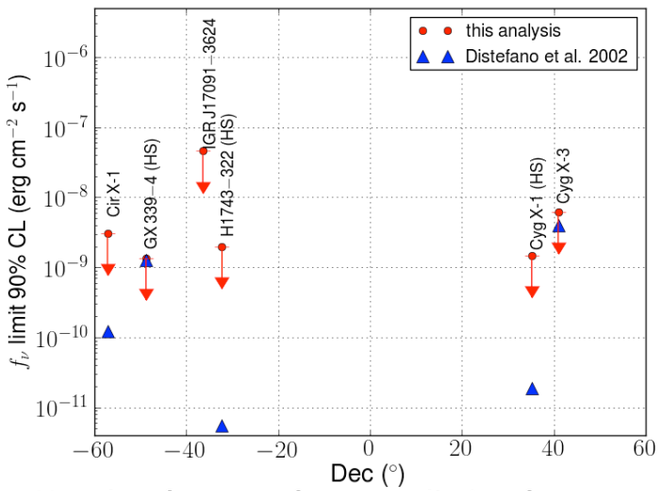


ANTARES/KM3NeT

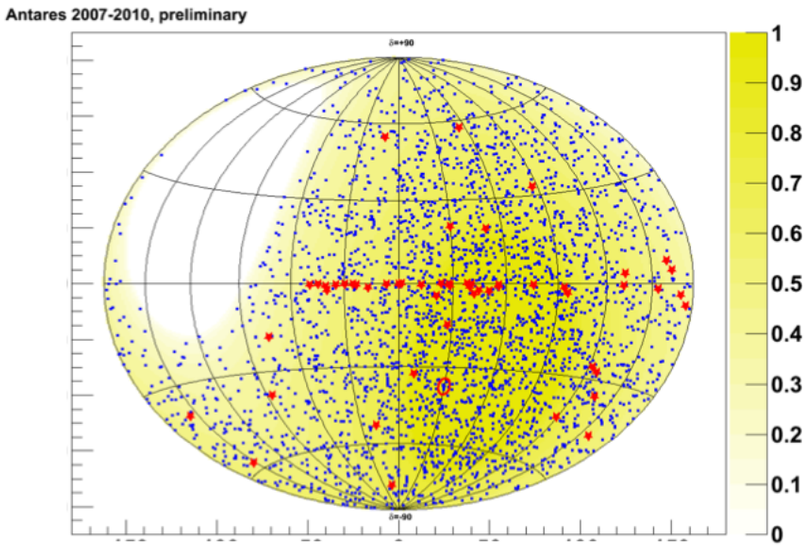
ANTARES:

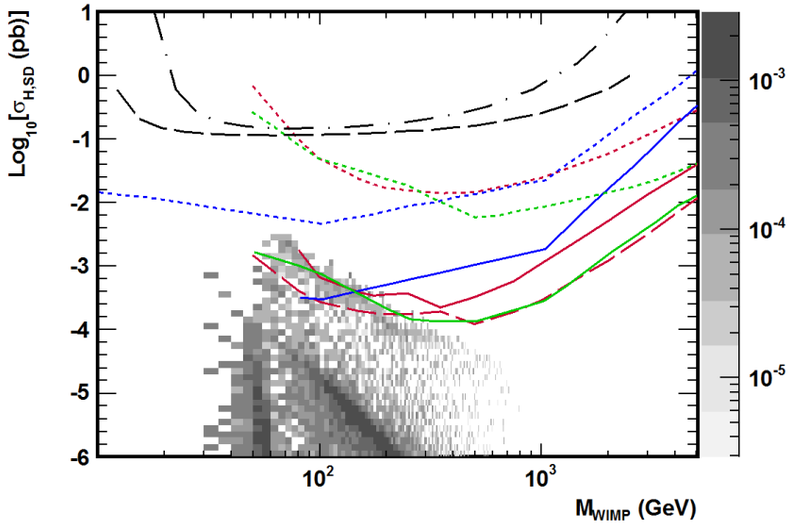
- Scientific Issues:
  - Taking data since **6 years**. Several thousands neutrinos recorded.
  - "Feasibility" of a underwater neutrino telescope is not anymore an issue. The question is now size.
  - No signal observed, but:
    - **Best limits** on the Southern sky on neutrino **point-sources.**
    - **Best limits** to date on **magnetic monopoles and nuclearites**.
    - Competitive **limits on dark matter** searches (e.g. spin-dependent WIMP-nucleon cross-sections).
    - **Lively multimessenger program** (VIRGO-LIGO gravitational waves, optical, gamma-ray and X-ray, Fermi, Rossi, Tarot, Rotse).
    - Measurement of atmospheric neutrino oscillations and others.
    - More than 30 papers published.
- Future:
  - **Data taking approved until end of 2014** (by then a major review will take place). Collaboration wishes at least until end 2016.
  - Last news (and rumours) from IceCube could extend ANTARES life.
  - It is a testbench for KM3NeT equipment.
- Spain:
  - **High visibility and high impact** of the Spanish groups in the collaboration.
  - **Leading role** in several systems (optical beacons, acoustics) and analysis (point sources and dark matter searches).

Some ANTARES results

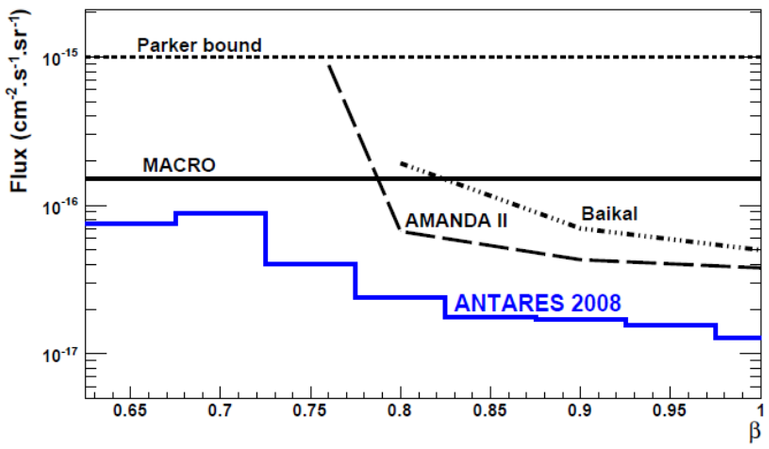


Not that far away from prediction from Galactic flaring objects, e.g. μ-quasars (preliminary)

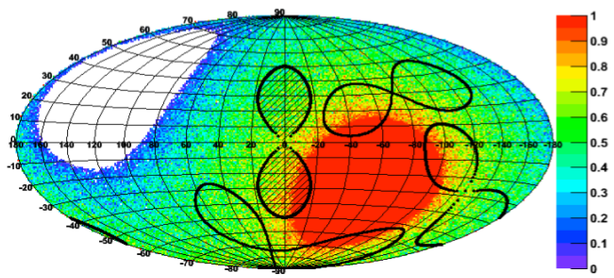




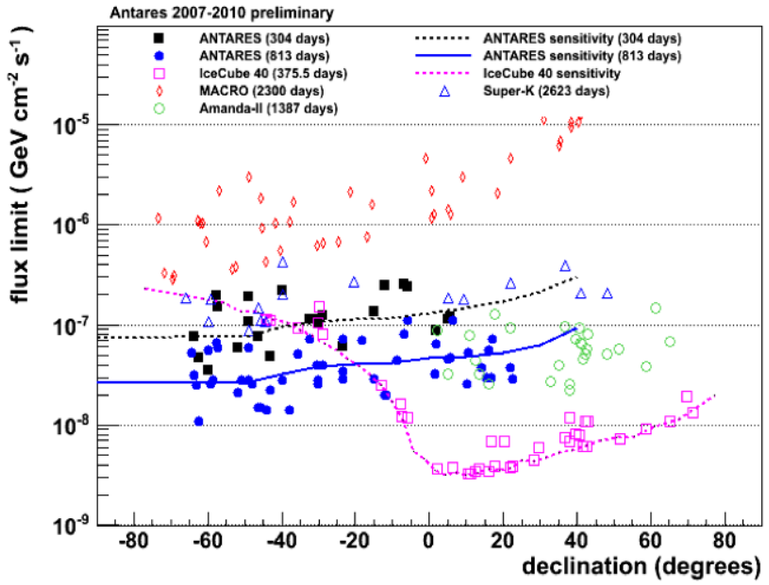
Indirect search for dark matter. Very competitive limits (good visibility of the Galactic Centre



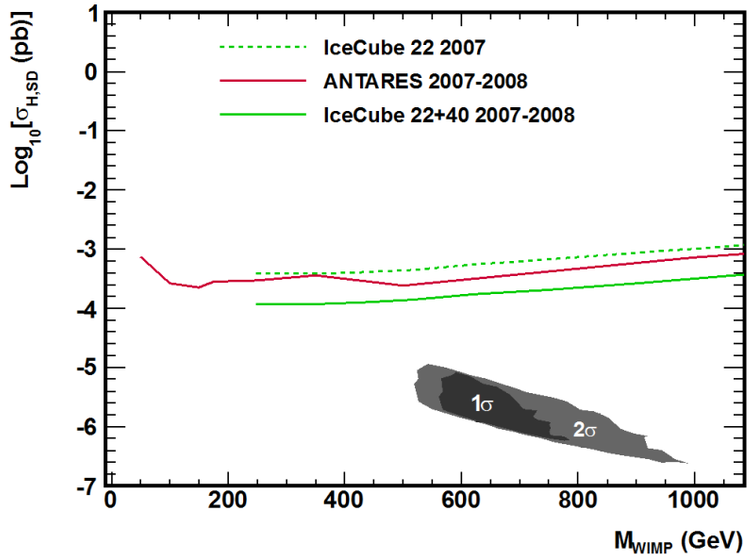
Best world limits on magnetic monopoles

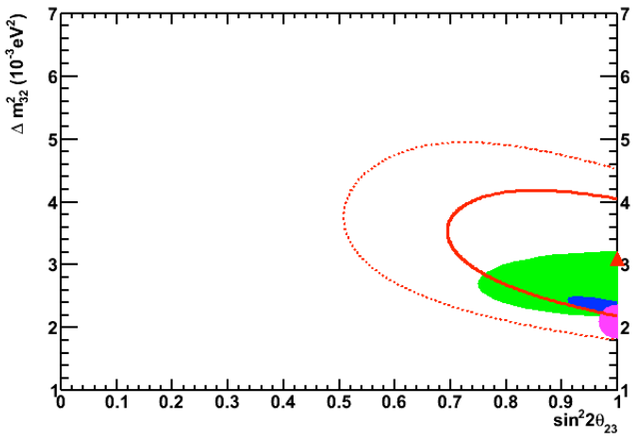


Results on Fermi Bubbles coming soon



Best upper limits for point sources in the Southern sky





Measurement of neutrino oscillations

ANTARES/KM3NeT

KM3NeT:

- Highlights:
  - **Design Study** and **Preparatory Phase** have **finished** (funded by EU's FP VI and VII).
  - Goal: **More than 5 km^3** (~200 M€). Looking towards the inner part of the Galaxy. An order of magnitude more sensitive than IceCube.
  - Funding: **40 M€ available** for the period 2013-2015 (first km^3!)
  - But perhaps an initial detour: **ORCA** →Measurement of the **neutrino mass hierarchy** using atmospheric neutrinos. Under study.
  - An MoU is almost ready for a **First Phase.**

- Spain:
  - **Actively participated** in D.S. and P.P. (CSIC, UVEG, UPV, UB, UC) mainly thanks to E.U. funding.
  - Dim prospects for the Spanish participation in the upcoming MoU.

SuperKamiokande

- Universidad Autonoma de Madrid is very active in ***Super-Kamiokande***; it is fully involved in R&D on ***n***eutron tagging to identify the matter/anti-matter nature of the interacting ν , this is key for measuring *relic* or *nearby* Core Collapse *S*upernovae and *N*uclear *R*eactor ν s and a must in next generation ν experiments. The radio-purity campaign is carried out in the LSC.

- UAM aims to learn about the Majorana nature of the ν with the NEXT experiment at LSC; our main responsibility is the radio-purity program

- UAM pursues a realistic next generation **p**roton-decay and ν experiment capable to probe leptonic CP**V**. We lead in **LAGUNA** a thorough Feasibility Study for the LSC to host it.

- Working in the search of the most promising option, and contributing to it: for the time being **T2-HK** (no physics case in the current approaches in Europe)

in extreme survival mode; funding for the above has been denied by Ministry in the last two Calls;

Final review

- Double beta decay has a clear project and roadmap with the NEXT experiment for the next decade (?).

- Neutrino astrophysics has a clear short term plan (Antares) until 2014 with options until 2016.

  - Long term plan (KM3Net) is more in the air but with strong interest from Spanish groups in Antares (now financed via EU grants).

- Neutrino oscillation has a clear short term plan: Double-Chooz and T2K will run until 2016/17. T2K might extend the running depending on the physics potential.

- Long term plan is more confusing: many projects with several stages and not 100% overlapping physic cases and timings makes the decision complex.

  - Spanish groups are in a good position to take an important role if we can find a suitable project for all of us.

- Oscillation physics are large projects with strong astroparticle physics component.

Backup

Oscillations with 3 ν's

Mass eigenstates != flavor eigenstates

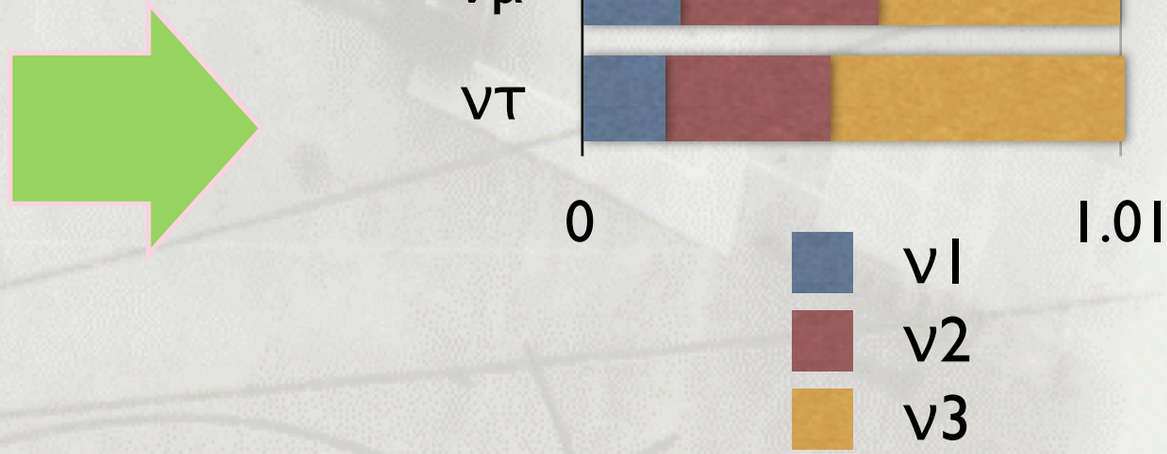
$$U_{PNMS} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta_{CP}} \\ 0 & 1 & 0 \\ -\sin\theta_{13}e^{i\delta_{CP}} & 0 & \cos\theta_{13} \end{pmatrix} \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$\begin{pmatrix} \nu_e & \nu_\mu & \nu_\tau \end{pmatrix} = U_{PNMS} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

- With 3ν, there are 3 angles and 1 imaginary phase (δ).
- The phase allows for CP violation similar to the quark sector.
- There are also 2 values of Δm^2, traditionally Δm^2_{12} &Δm^2_{31} with their signs.
- Oscillations are not sensitive to absolute mass.

Oscillations with 3 ν's

$$\begin{pmatrix} \nu_e & \nu_\mu & \nu_\tau \end{pmatrix} = U_{PNMS} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$



- Hierarchy:
  - associate the mass of the lepton state to that that contains the larger fraction of mass eigenstate: ν_e to ν_1 ν_μ to ν_2 ν_τ to ν_3.
  - normal hierarchy is define when the neutrinos follow the lepton partner mass ordering.
  - No theoretical prejudicies, normal is not more plausible than inverted!

We knew in 2011

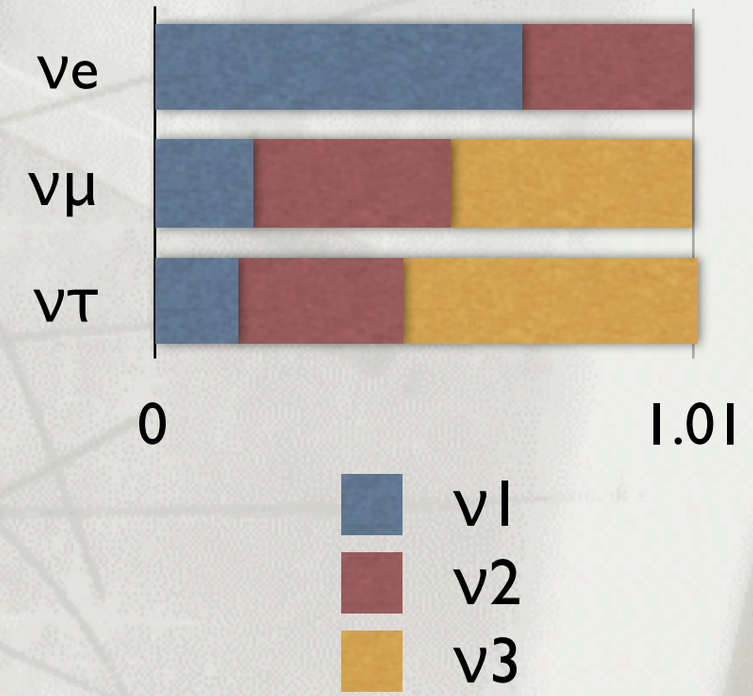
$$\Delta m^2_{12} = 7.59^{+0.2}_{-0.18} \times 10^{-5} eV^2$$

$$|\Delta m^2_{23}| = 2.45 \pm 0.09 \times 10^{-3} eV^2$$

$$\theta_{12} = 33.97^o \, ^{+1.04^o}_{-0.93^o}$$

$$\theta_{23} = 45.57^o \, ^{+3.45^o}_{-3.44^o}$$

$$\theta_{13} < 9.45^o (90\% C.L.)$$



hep-ph 1103.0734 v2

- Most urgent: values of δ_{CP}, θ_{13}, absolute mass scale.

θ_{13}: accelerators vs reactors

Accelerator

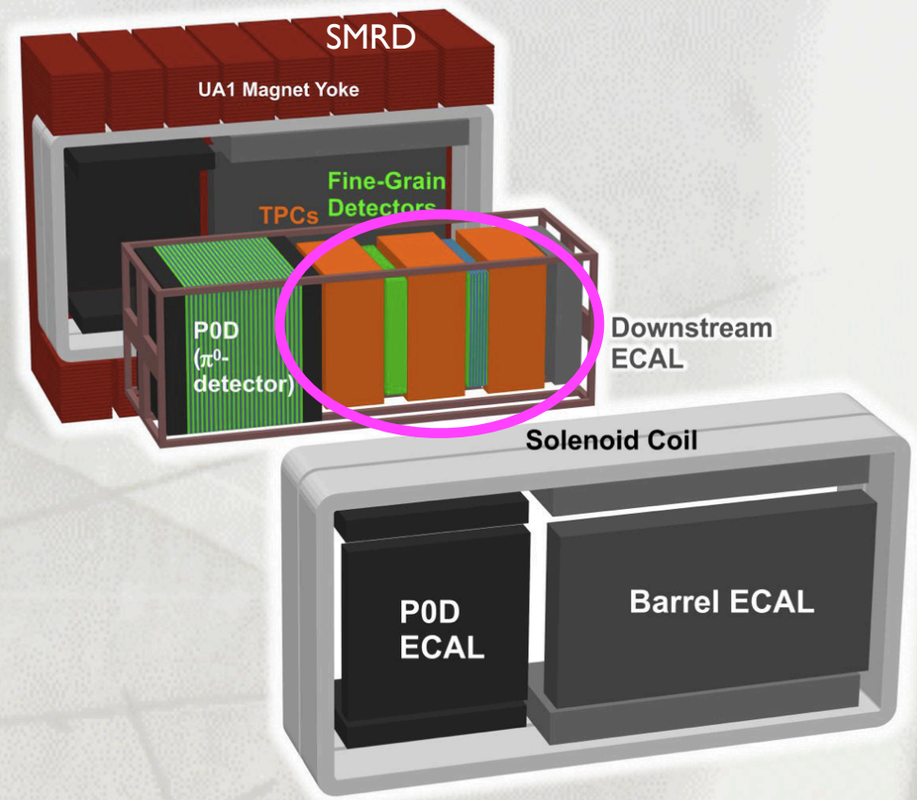
- Appearance experiment.
- Oscillation depends on θ_{13},θ_{23}, signΔm^2, δ_{CP} and matter effects:
  - degeneracies.
    - possible signΔm^2 &δ_{CP}
- Multipurpose: several oscillation (θ_{23}, steriles) and non-oscillation physics.
- Experimental challenges:
  - beam intensity, flavor composition and flux extrapolation.
  - νN interaction cross-sections.

Reactor

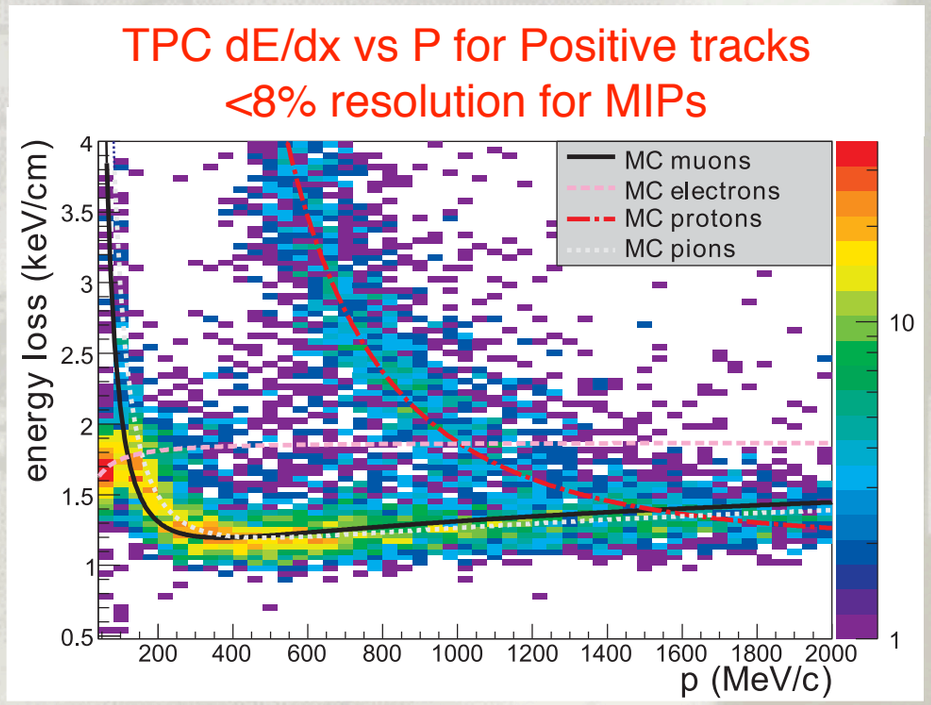
- Disappearance experiment.
- Oscillation depends on θ_{13}.
  - No degeneracies except for θ_{23} obtained from accelerators.
- No access to signΔm^2 & δ_{CP}: disappearance is like 2 ν oscillation where CP violation phase can factorize.
- Experimental challenges:
  - backgrounds
  - flux systematic uncertainties.

T2K: Off-axis ND280

- Set of detector installed inside the ex-UA1/NOMAD magnet providing a 0.2 T magnetic field.
- Measure ν_μ and ν_e spectra before the oscillation
- Measure cross-sections for backgrounds to oscillation
- Dedicated π^0 detector (POD), EM calorimeter to identify e/γ(ECAL), side muon range detector for high angle μ (SMRD)



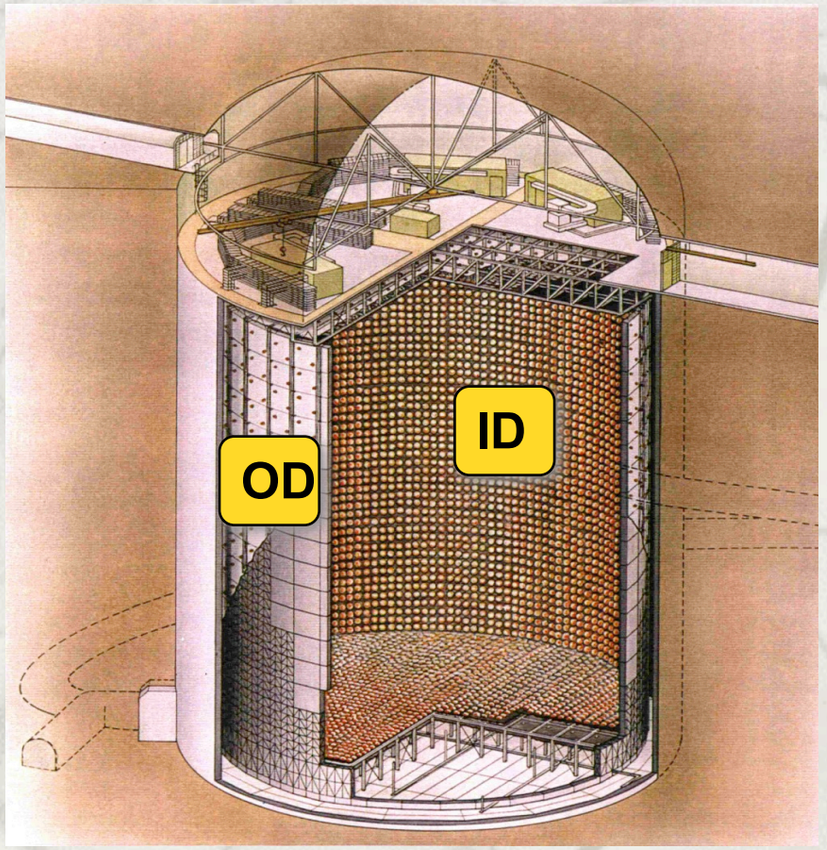
- The Tracker:
  - 2 fine grained detectors (FGD)
    - Active target for neutrino interactions (carbon and water)
    - 1.6 ton of Fiducial Volume
  - 3 time projection chambers (TPC)*
    - Instrumented with MicroMEGAS detectors
    - Reconstruct momentum and charge of the particles produced in ν interactions
    - PID capabilities measuring dE/dx in the gas

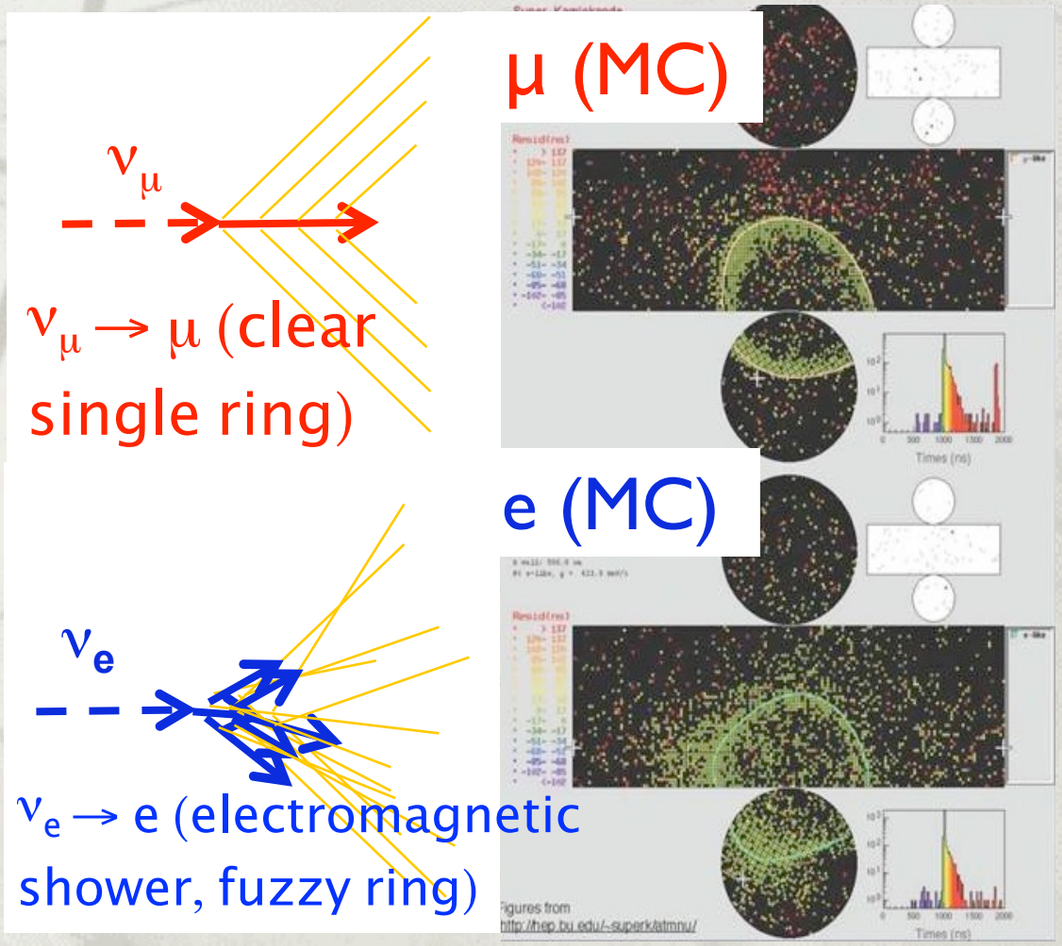


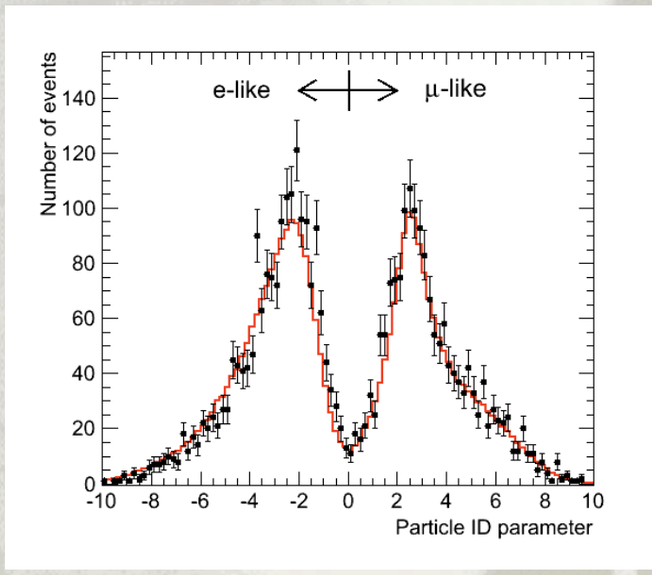
*NIM, A **637** (2011) pp. 25-46

T2K far Detector: Super-Kamiokande

- 50 kton water Cherenkov detector (22.5 kton Fiducial Volume)
- Optically divided between an inner detector (ID) and an outer detector (OD)
  - 11129 20-inch Hamamatsu PMTs for the inner detector
- 1000 meters underground in the Kamioka mine (295 km from JPARC)
- Very good PID capabilities: probability of a muon reconstructed as an electron of 1%

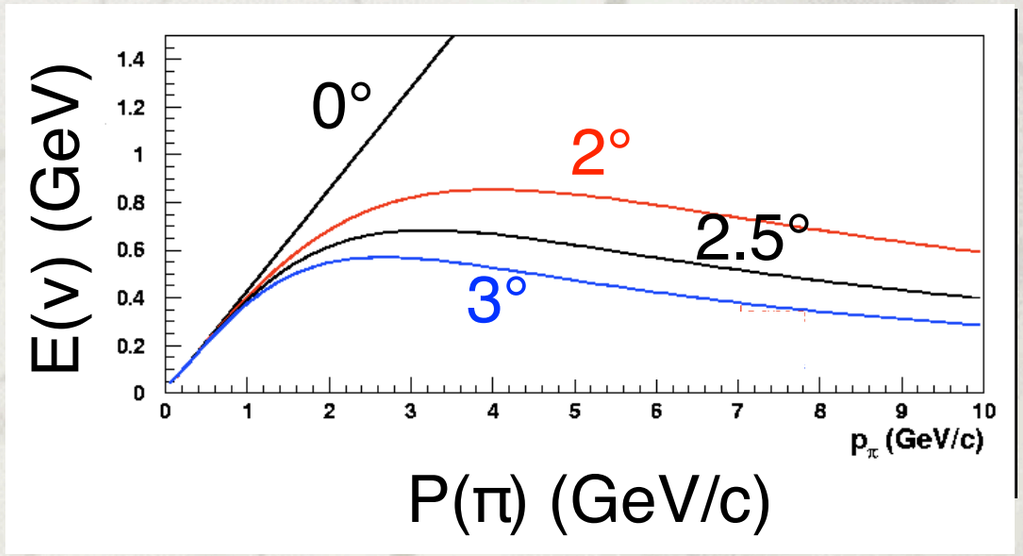


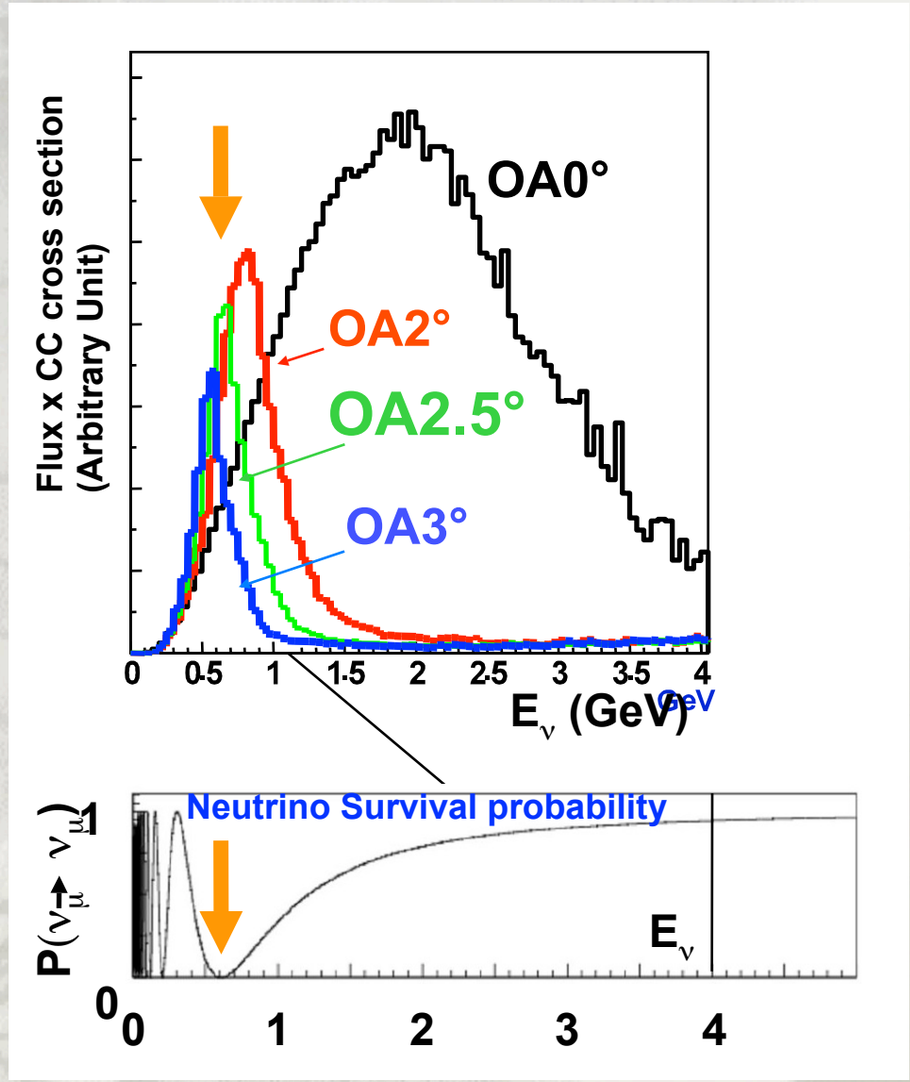




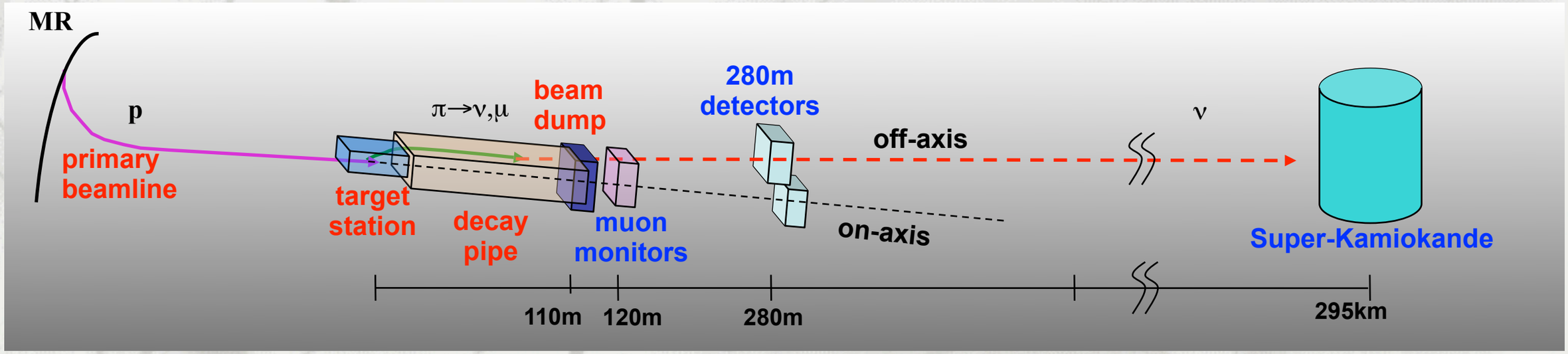
T2K: off-axis

- T2K is the first long baseline experiment using off-axis technique
- Reduced dependence of E_ν from E_π
  - Intense beam where the oscillation effect is maximum (~0.6 GeV)
  - Enhance the CCQE sample, reducing the high energy tails of the beam → reduce the backgrounds to oscillation signal

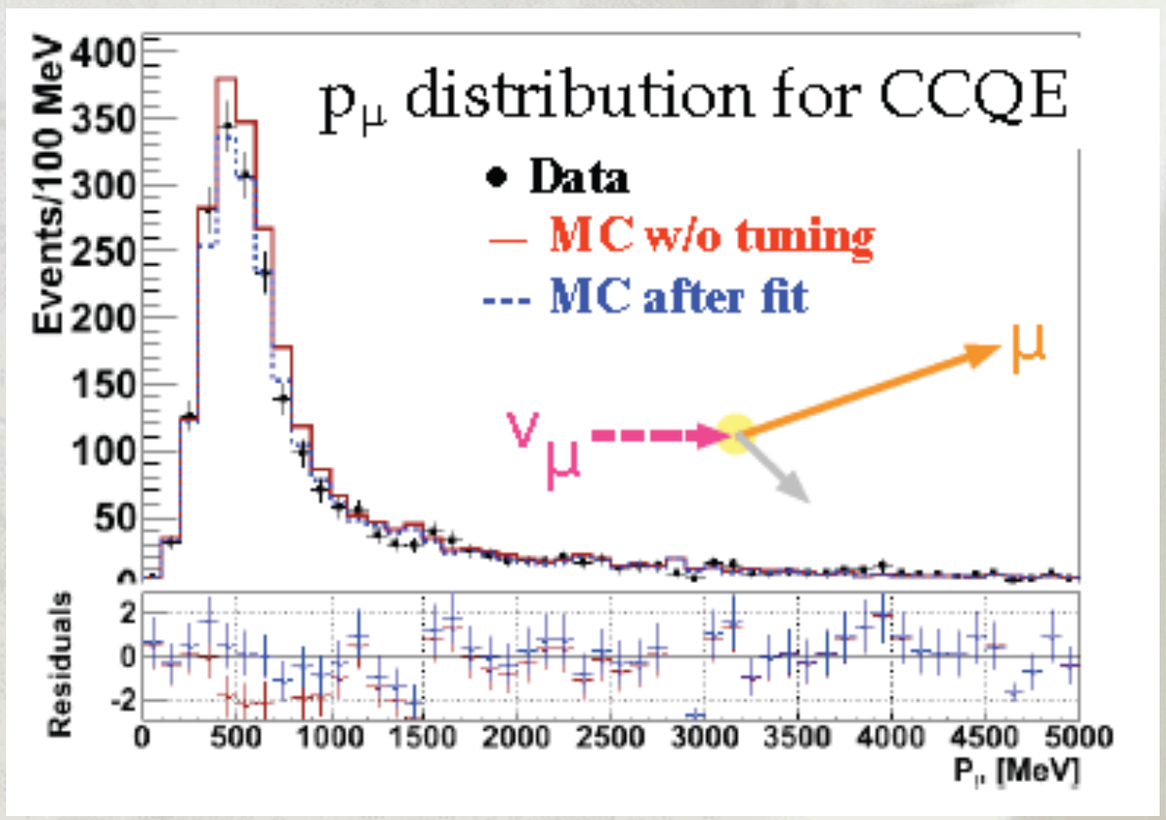




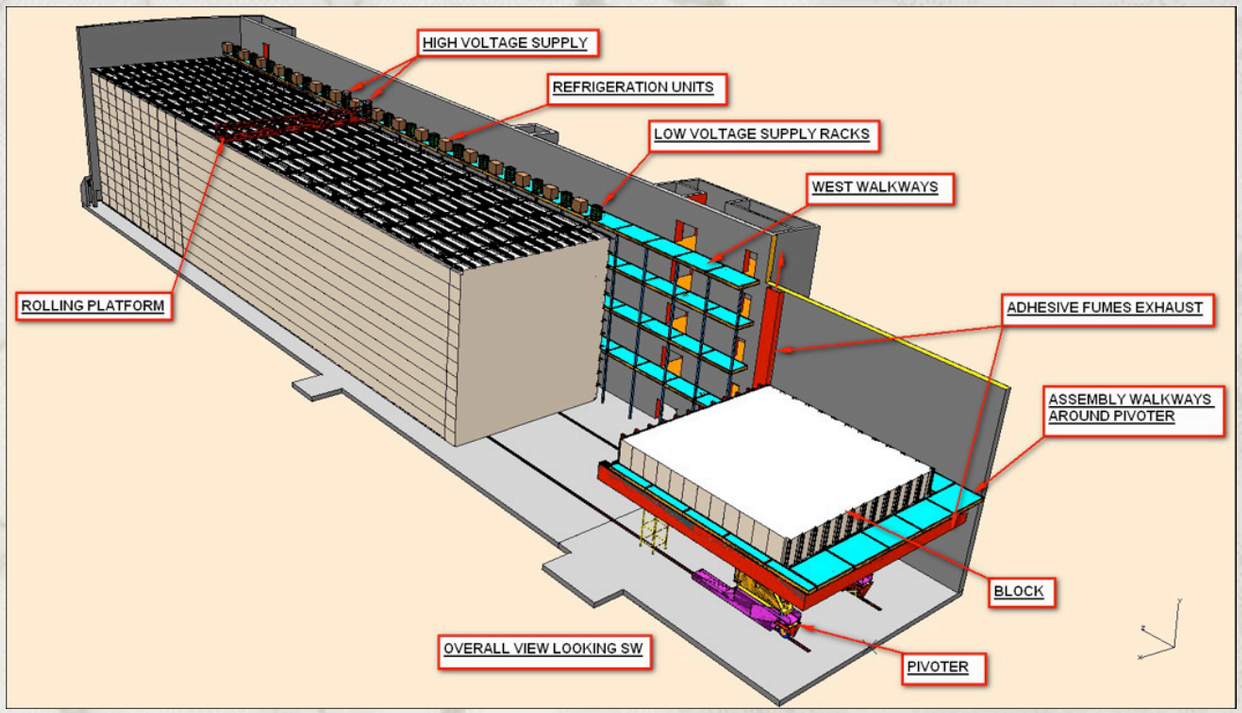
T2K (acc. neutrinos) concept



- Near detector complex monitors:
  - beam stability and direction.
  - measures neutrino flux to check and calibrate predictions.

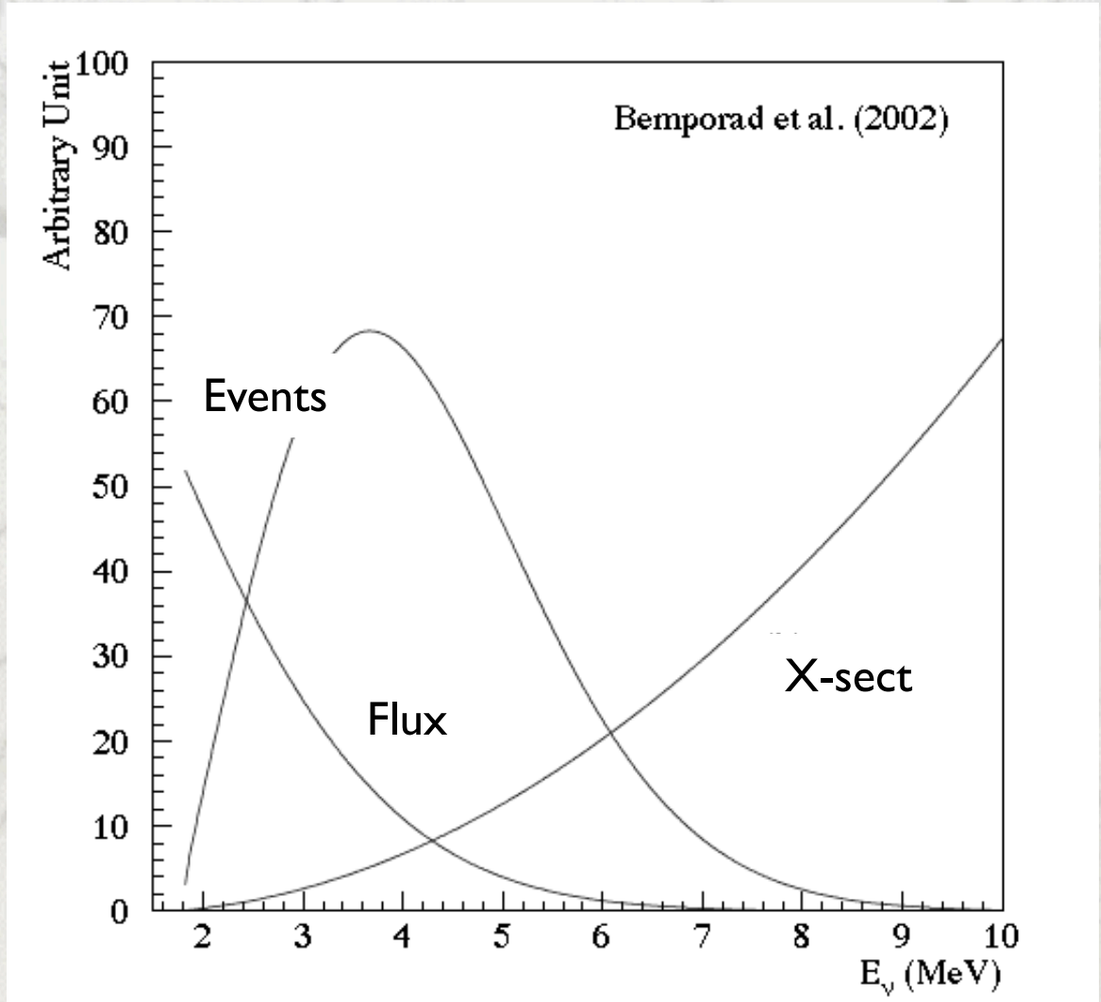


Nova

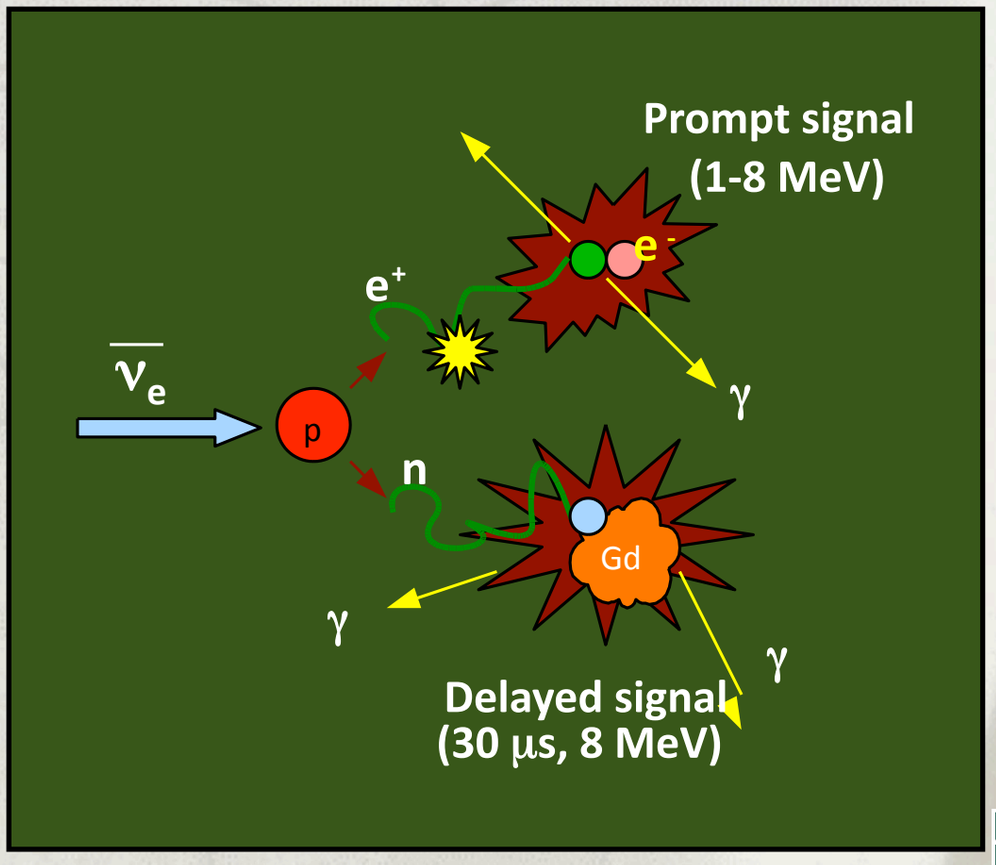


- 15000 Ton detector at 800 km: long base line, starts to be sensitive to matter effects.
- Off-axis technique.
- High intensity Numi beam (400 kW).
- Expected in 2013

Reactor principle

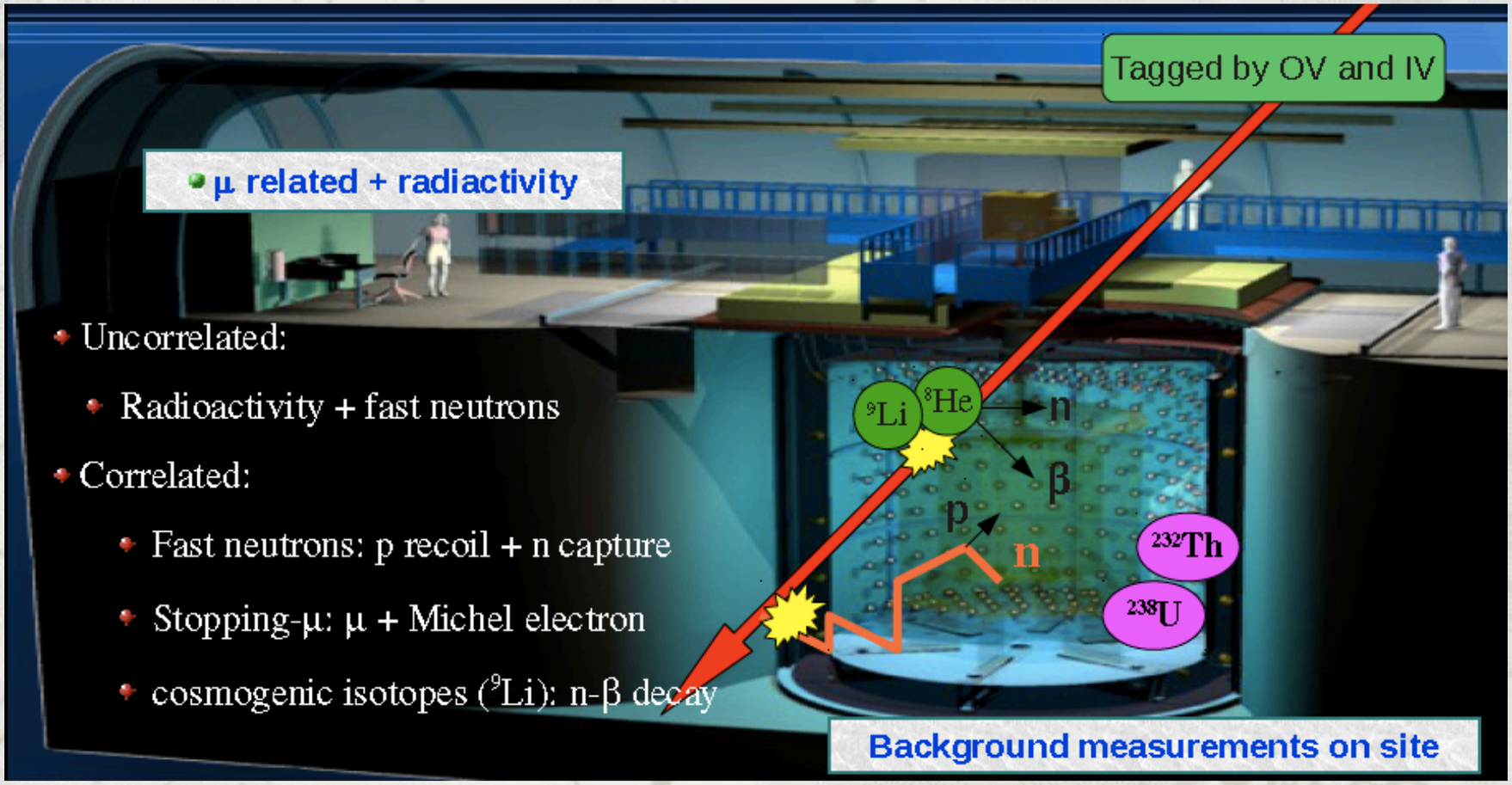


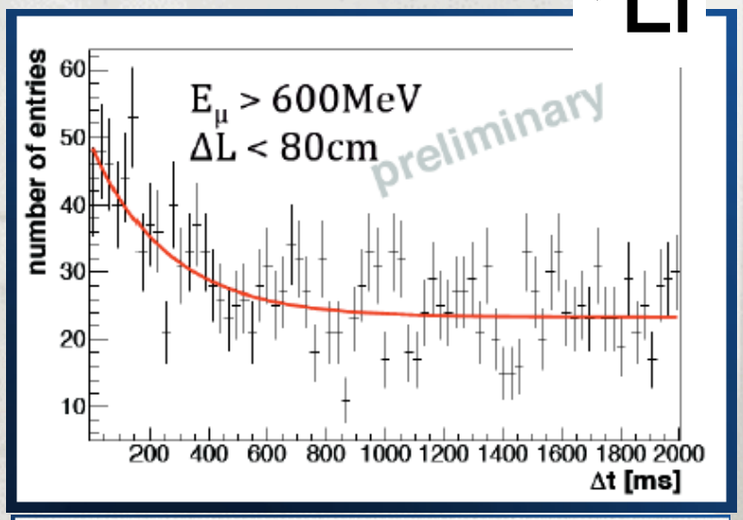
- Prompt photons from e^+ annihilation:
  - $E_{VIS} \sim E_\nu - (M_n - M_p) + m_e$
- Delayed photons from **n** capture:
  - on H : t ~200 s, E~2 MeV
  - on Gd: t ~30 s, E ~8 MeV

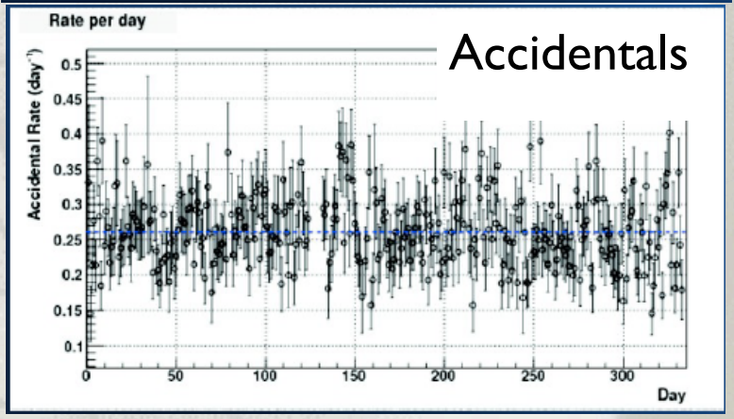


Reactor principle

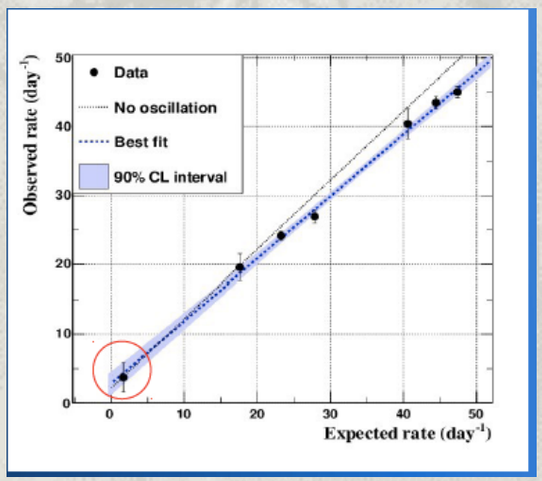
- Main source of systematics is the background determination.







Double-Chooz examples.



Reactor On/Off validations

Accelerator search

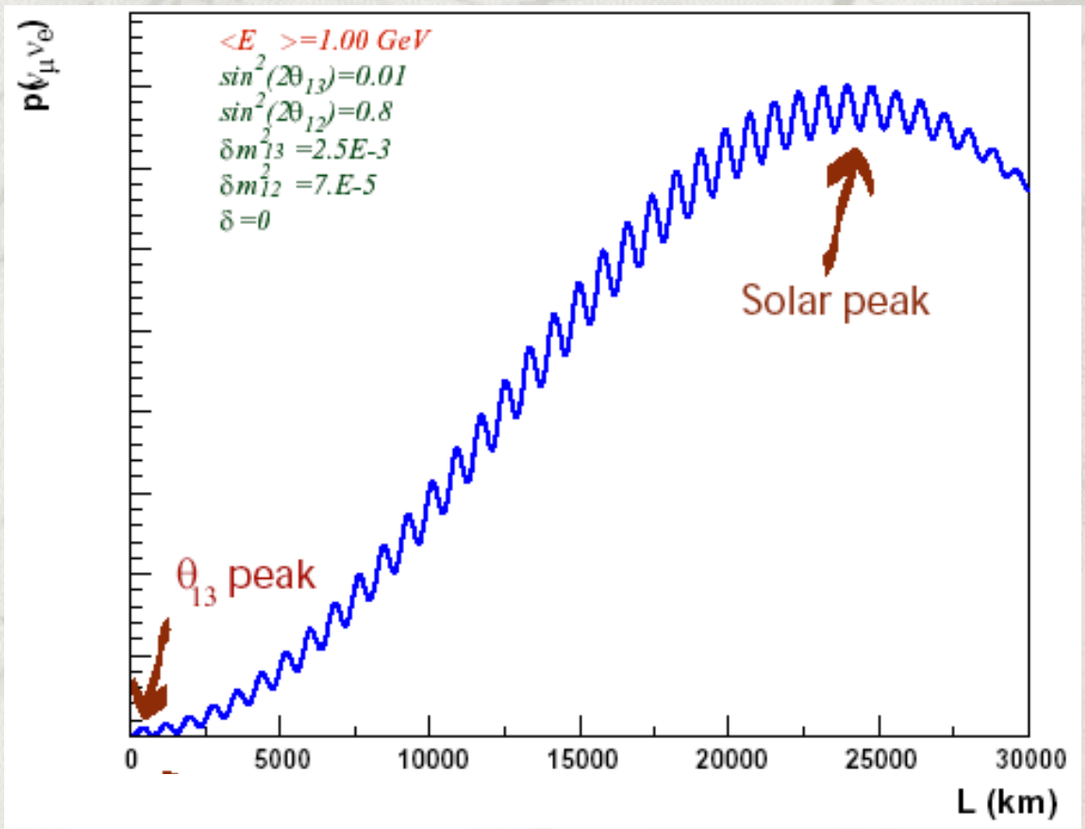
$$P_{\nu_\mu,\nu_e} = \sin^2\theta_{23}\sin^2 2\theta_{13}\sin^2\frac{\Delta m^2_{31}L}{4E}$$ θ13 peak

$$+\cos^2\theta_{23}\cos^2\theta_{13}\sin^2\theta_{12}\sin^2\frac{\Delta m^2_{21}L}{4E}$$ Solar peak

$$+8\cos^2\theta_{13}\sin\theta_{13}\sin\theta_{23}\cos\theta_{23}\sin\theta_{12}\cos\theta_{12}\sin\frac{\Delta m^2_{31}L}{4E}\sin\frac{\Delta m^2_{12}L}{4E}\cos(\frac{\Delta m^2_{32}L}{4E}\delta_{CP})$$

$$-2\sin^2\theta_{12}\sin^2\theta_{23}\sin^2 2\theta_{13}\sin\frac{\Delta m^2_{21}L}{4E}\sin\frac{\Delta m^2_{31}L}{4E}\cos\frac{\Delta m^2_{32}L}{4E}$$

$$+4\cos^2\theta_{13}\sin^2\theta_{12}\sin\theta_{13}\sin\theta_{23}(\sin\theta_{23}\sin\theta_{13}\sin\theta_{12}-2\cos\theta_{12}\cos\theta_{23}\cos\delta_{CP})\sin^2\frac{\Delta m^2_{21}L}{4E}$$

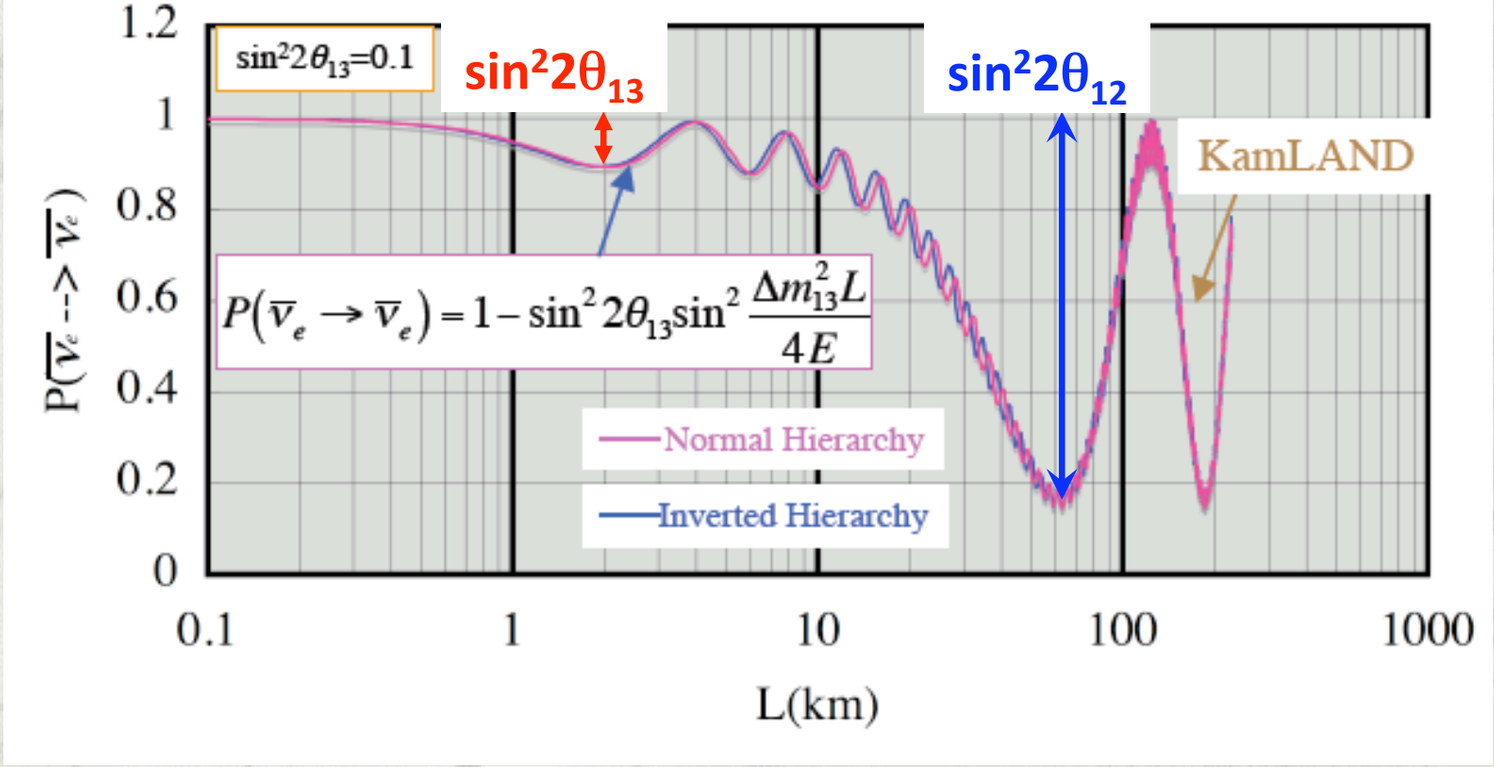


- $\nu_\mu \longrightarrow \nu_e$ compites with the (inverse) solar oscillation.
- decoupled by the L/E value.

Reactor principle

Clean measurement

$$P_{ee} \approx 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m_{13}^2 L}{4E_\nu}\right) - \cos^4\theta_{13} \sin^2 2\theta_{12} \sin^2\left(\frac{\Delta m_{21}^2 L}{4E_\nu}\right)$$



- $\nu_\mu \longrightarrow \nu_e$ compites with the solar oscillation.
- decoupled by the L/E value.

a year after !

Global fits to all data

hep-ph 1103.0734 v2

C.Gonzalez-Garcia ICHEP 2012

$$\Delta m^2_{12} = 7.59^{+0.2}_{-0.18} \times 10^{-5} eV^2 \qquad 7.5 \pm 0.19 \times 10^{-5} eV^2$$

$$|\Delta m^2_{23}| = 2.45 \pm 0.09 \times 10^{-3} eV^2 \qquad 2.45^{+0.067}_{-0.071} \times 10^{-3} eV^2$$

$$\theta_{12} = 33.97^o\ ^{+1.04^o}_{-0.93^o} \qquad 32.4^o \pm 0.8^o$$

$$\theta_{23} = 45.57^o\ ^{+3.45^o}_{-3.44^o} \qquad 40.4^o\ ^{+0.8^o}_{-1.8^o}$$

The error depends on the central value

$$\theta_{13} < 9.45^o (90\% C.L.) \qquad 8.7^o \pm 0.45^o$$

The mean values depend on the fit assumptions and models!!!

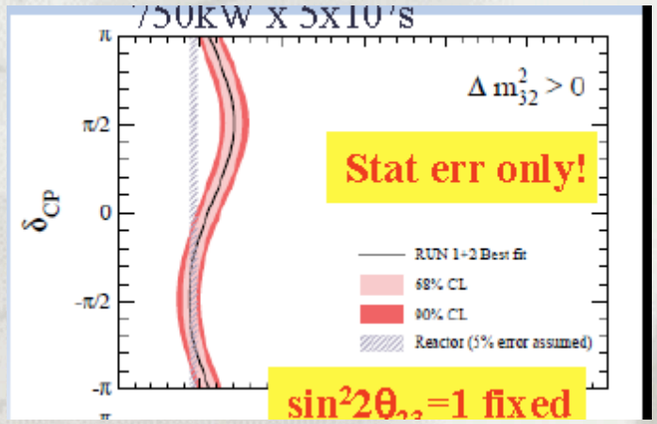
It does not contain the latest values presented in this talk.

What's next?

- Reactor experiments will be improving the results… Systematics of Daya Bay are very small (<$\frac{1}{2}$ of the actual combined error, we might expect errors of the order of 0.005 or better).

- T2K will be improving the results.

- Nova will start next year with a longer base line to measure matter effects and the neutrino hierarchy.



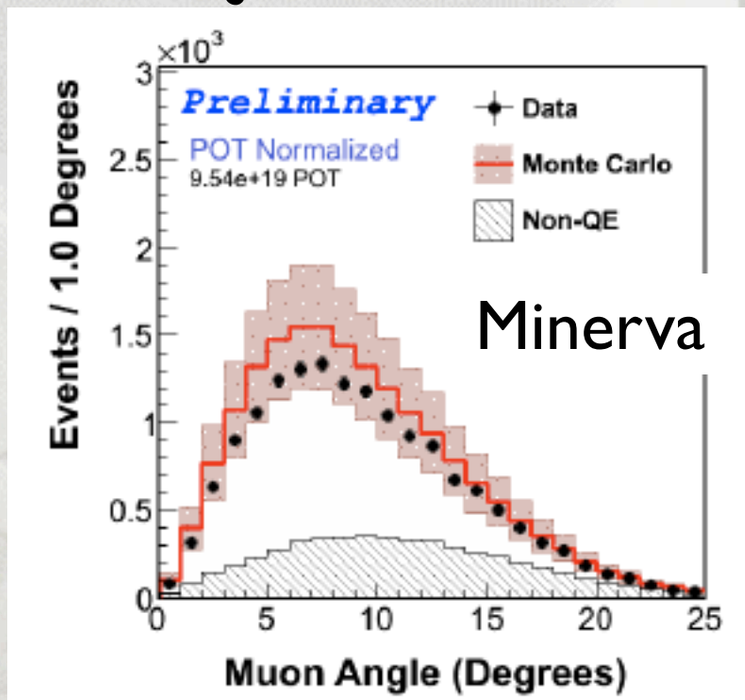
- We might be close to this measurement with serious implications in the search of double beta decays.

- The road is open to search for CP violation.

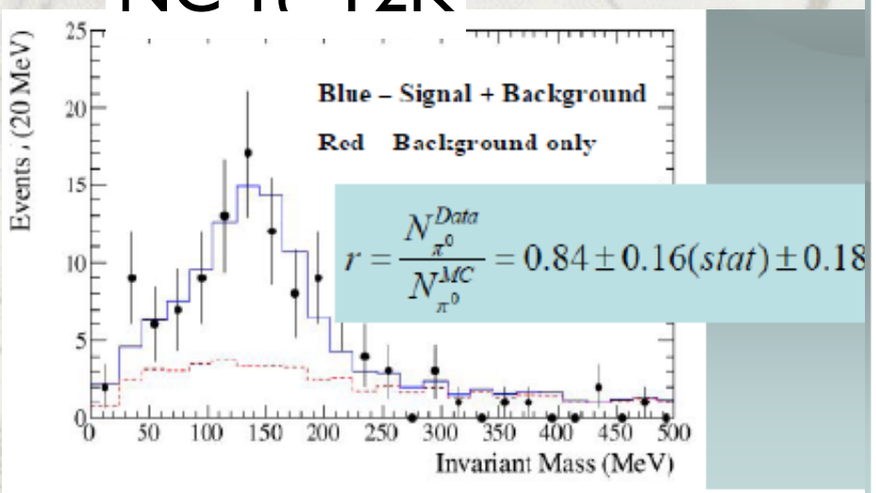
- With hierarchy measurement and very precise reactor and accelerator neutrinos, and a bit of luck (maximal CP violation) we might be able to say something about the CP phase in few years, but this is very unlikely and/or not very precise.

Booming industry

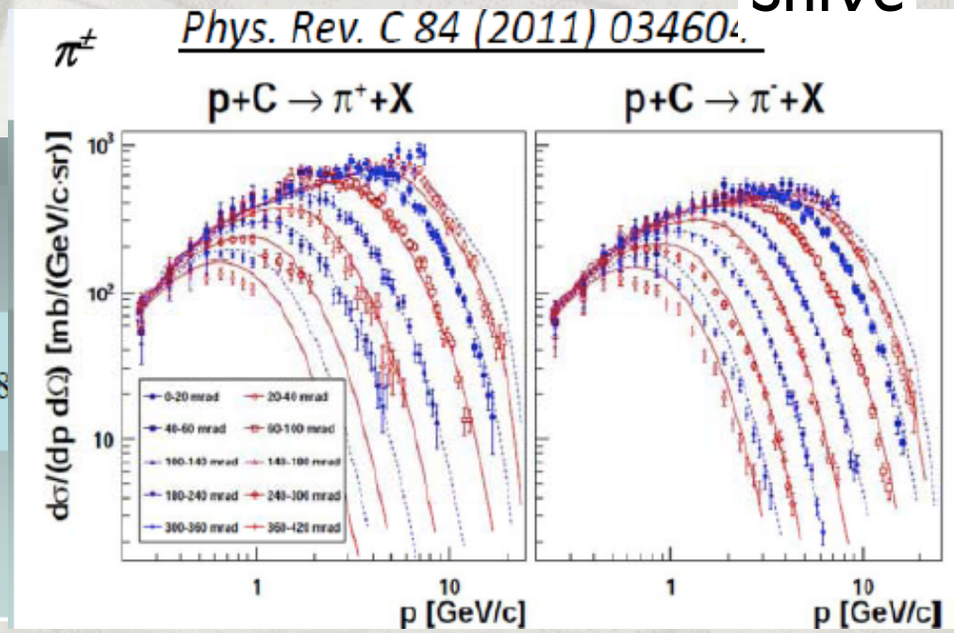
- The needs of the oscillation experiments in accelerator experiments boomed the field of neutrino cross-section and flux calculations.
- Neutrino-Nucleus cross section is very active theoretical and experimental field: Minerva, SciBoone, MiniBoone, MicroBoone, T2K ND280, etc...
- Flux calculations are supported now by hadro-production experiments like Shine at CERN.

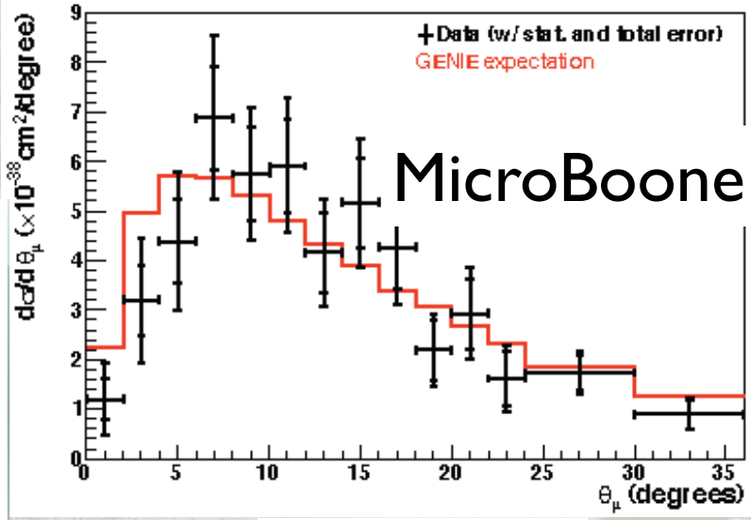


NC π^0 T2K



Shive





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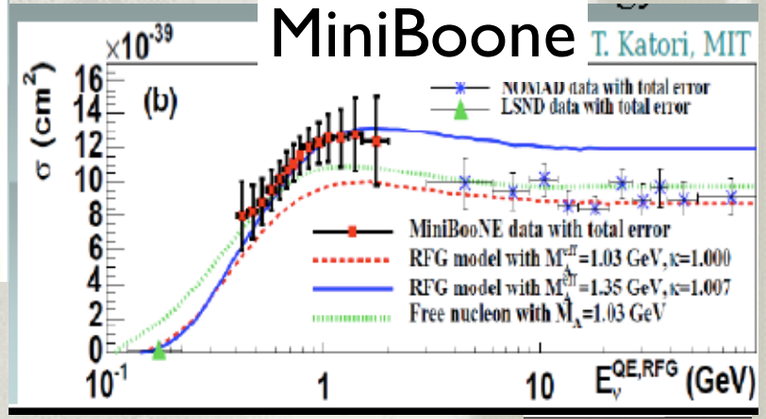

Poster A.WILCZEK