European Strategy for Particle Physics
CERN Council

„Europejska Strategia Fizyki Czastek - sprawozdanie z Otwartego Sympozjum w Krakowie"

część II - neutrina i astrofizyka cząstek

Ewa Rondio (NCBJ)

Warszawa 19.10.2012

General issues

1. European particle physics is founded on strong national institutes, universities and laboratories and the CERN Organization; *Europe should maintain and strengthen its central position in particle physics.*

2. Increased globalization, concentration and scale of particle physics make a well coordinated strategy in Europe paramount; *this strategy will be defined and updated by CERN Council as outlined below.*

Scientific activities

3. The LHC will be the energy frontier machine for the foreseeable future, maintaining European leadership in the field; *the highest priority is to fully exploit the physics potential of the LHC, resources for completion of the initial programme have to be secured such that machine and experiments can operate optimally at their design performance.* A subsequent major luminosity upgrade (SLHC), motivated by physics results and operation experience, will be enabled by focussed R&D; *to this end, R&D for machine and detectors has to be vigorously pursued now and centrally organized towards a luminosity upgrade by around 2015.*

4. In order to be in the position to push the energy and luminosity frontier even further it is vital to strengthen the advanced accelerator R&D programme; *a coordinated programme should be intensified, to develop the CLIC technology and high performance magnets for future accelerators, and to play a significant role in the study and development of a high-intensity neutrino facility.*

5. It is fundamental to complement the results of the LHC with measurements at a linear collider. In the energy range of 0.5 to 1 TeV, the ILC, based on superconducting technology, will provide a unique scientific opportunity at the precision frontier; *there should be a strong well-coordinated European activity, including CERN, through the Global Design Effort, for its design and technical preparation towards the construction decision, to be ready for a new assessment by Council around 2010.*

6. Studies of the scientific case for future neutrino facilities and the R&D into associated technologies are required to be in a position to define the optimal neutrino programme based on the information available in around 2012; *Council will play an active role in promoting a coordinated European participation in a global neutrino programme.*

7. A range of very important non-accelerator experiments take place at the overlap between particle and astroparticle physics exploring otherwise inaccessible phenomena; *Council will seek to work with ApPEC to develop a coordinated strategy in these areas of mutual interest.*

Physics of Neutrinos

Convener: D. Wark, E. Fernandez Martinez (Scientific Secretary)]

10:50 **Phenomenology of Neutrino Oscillations and Current Situation** *15'*
Speaker: Pilar Hernandez (University of Valencia)
11:05 **Neutrino Mass Measurements** *10'*
Speaker: Hamish Robertson (University of Washington)
11:15 **Next Generation Accelerator Neutrino Projects – Long and Short Baseline** *25'*
Speaker: Marco Zito (IRFU-Centre d'Etudes de Saclay)
11:40 **Longer-term Accelerator and Future Reactor Neutrino Projects** *20'*
Speaker: Caren Hagner (Hamburg University)

12:00 **Discussion** *1h0'*

Astroparticle Physics, Gravitation and Cosmology

Convener: C. De Clercq, Pierre Brun (Scientific Secretary)

09:00 **European Astroparticle Physics: Status and Vision** *25′*

Speaker: Christian Spiering (DESY)

09:25 **Summary of Activities in Regions Beyond Europe** *25′*

Speaker: Stavros Katsanevas (CNRS/IN2P3)

09:50 **Discussion** *30′*

Why do we care about neutrinos?

- We are all thrilled and enthusiastic about the Higgs boson discovery
- ...but still no sign of new physics
- The clearest signal of physics beyond the SM is given by the neutrino masses:
- Either new right-handed states (no SM charge, who ordered them ?) or Majorana masses and lepton number violation
- Neutrinos might be our best window on GUT physics

Why are neutrinos so much lighter ?

Neutral vs charged hierarchy ?

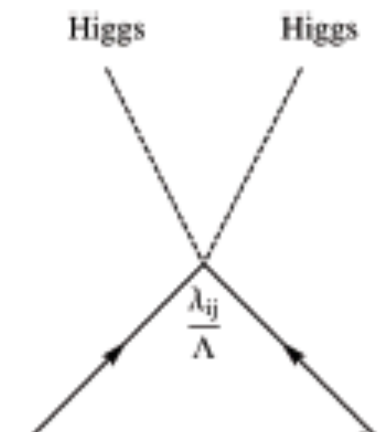
Neutrinos have tiny masses -> a new physics scale

$$-\mathcal{L}_{\text{Majorana}} = \bar{\nu}_L m_\nu \nu_L^c + h.c. \;\leftrightarrow \bar{L}\tilde{\Phi}\;\alpha\;\tilde{\Phi}L^c + h.c.$$

Weinberg

$$[\alpha] = -1$$

$$m_\nu \sim \lambda \frac{v^2}{\Lambda}$$



Why so different mixing ?

CKM

$$|V|_{\rm CKM} = \begin{pmatrix} 0.97427 \pm 0.00015 & 0.22534 \pm 0.0065 & (3.51 \pm 0.15) \times 10^{-3} \\ 0.2252 \pm 0.00065 & 0.97344 \pm 0.00016 & (41.2^{+1.1}_{-5}) \times 10^{-3} \\ (8.67^{+0.29}_{-0.31}) \times 10^{-3} & (40.4^{+1.1}_{-0.5}) \times 10^{-3} & 0.999146^{+0.000021}_{-0.000046} \end{pmatrix}$$

Is CP violated in neutrino sector ?

PMNS

$$|U|_{\rm LEP(3\sigma)} = \begin{pmatrix} 0.795 \to 0.841 & 0.517 \to 0.584 & 0.141 \to 0.179 \\ 0.213 \to 0.543 & 0.425 \to 0.728 & 0.575 \to 0.802 \\ 0.213 \to 0.541 & 0.411 \to 0.720 & 0.576 \to 0.802 \end{pmatrix}$$

- The next step: discovery of the CP violation phase δ and mass hierarchy, precise measurement of θ_{23}
- In the end, we would like to explore PMNS to the same level of accuracy as CKM
- This calls for a complete set of precision measurements

Summary of neutrino phenomenology talk at the symphosium

Obs 1: Neutrinos add at least as many parameters as quarks to the puzzle, but with features that might hint to a new physics scale

Obs 2:We still don't know what the νSM is

Obs 3: The existence of a new physics scale in νSM whether related or not to the EW scale would have clear implications for the hierarchy problem and EWSB

Obs 4: The observation of neutrinoless double beta decay would be the discovery of such a new physics scale !

Obs 5: Predicting the matter-antimatter asymmetry in the Universe would be a major achievement of the νSM

Two key ingredients: Leptonic CP violation
Lepton number violation

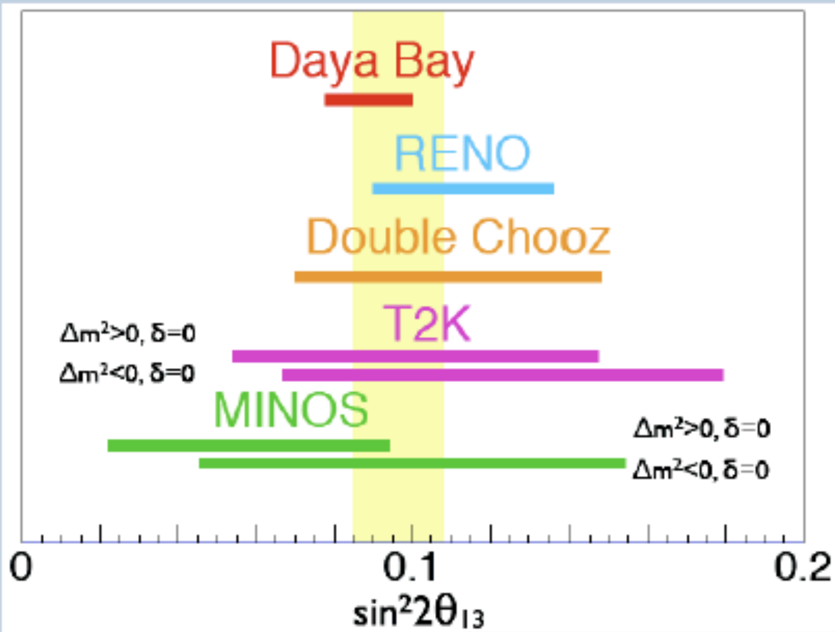
Obs 6: Mass Hierarchy essential for reconstructing the underlying model of neutrino masses & predictions for other observables

Jakie odkrycia w sektorze neutrin moga zmienić zasadniczo nasza wiedzę?

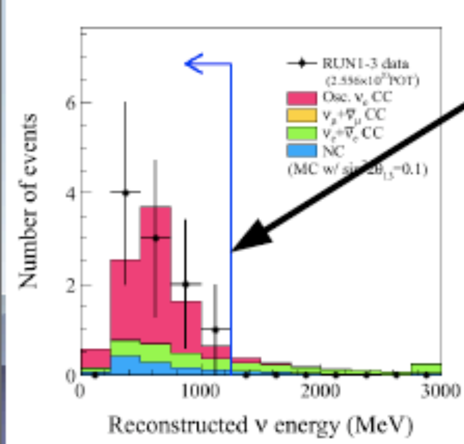
- Obserwaja odwróconej hierarchii mas dla aktywnych neutrin
- **Łamanie CP w oscylacjach neutrin**
- Łamanie unitarności dla macierzy mieszania neutrin
- Określenie absolutnej skali mas dla neutrin
- Obserwacja bezneutrinowego rozpadu beta = = demonstracja łamania liczby fermionowej
- **Odkrycie neutrina sterylnego**

Progress since the last strategy plan

The θ_{13} revolution

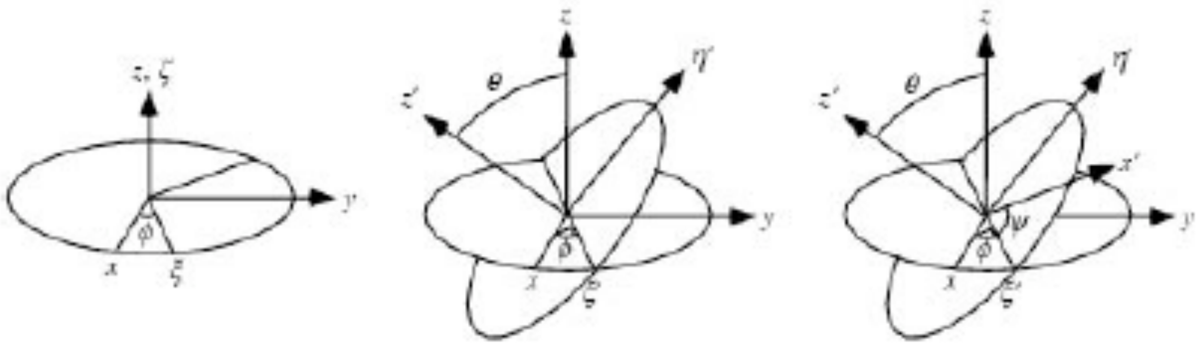


- Good agreement between the experiments
- This angle is sizable : $\theta_{13} \sim 9°$
- We can proceed with the next steps

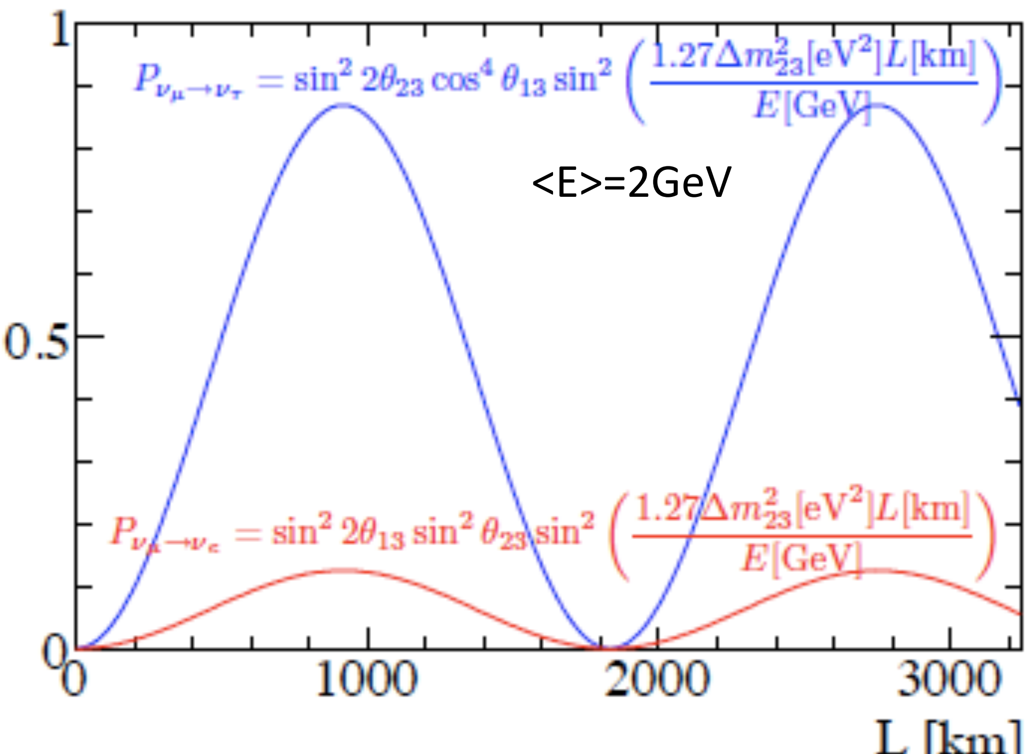


- T2K signal: 10 ev (2.7 exp. background)
- $\nu_\mu \rightarrow \nu_e$: main channel for CPV exploration
- First clean appearance experiment
- Large European effort

Neutrino mixing



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



$$\nu_\alpha = U^{ij} \cdot \nu_j$$

Sector 1-2 → Solar and reactor

Sector 2-3 → Atmospheric and accelerator

CP violation

$$P(\nu_\alpha \to \nu_\beta) = \delta_{\alpha\beta} - 4\sum_{i>j} \mathrm{Re}\left(U^*_{\alpha i} U_{\beta i} U_{\alpha j} U^*_{\beta j}\right) \sin^2 \Delta_{ij}$$
$$\pm 2\sum_{i>j} \mathrm{Im}\left(U^*_{\alpha i} U_{\beta i} U_{\alpha j} U^*_{\beta j}\right) \sin 2\Delta_{ij}$$

$$\Delta_{ij} \equiv \frac{1.27\Delta m^2_{ij} L}{E_\nu}$$

- for neutrinos
+ for antineutrinos

CP violation can be observed only in appearance experiments because :

$$\mathrm{Im}\left(U^*_{\alpha i} U_{\beta i} U_{\alpha j} U^*_{\beta j}\right) = 0$$
$$\text{for} \quad \alpha = \beta$$

How to measure CP violating phase δ

In vacuum the shift in oscil. prob. due to δ is:

$$\Delta P_\delta(\nu_\mu \to \nu_e) \approx 0.9 \cdot \sin 2\vartheta_{13} \cdot \sin\Delta_{sol} \cdot \sin\Delta_{atm} \cdot (\cos\delta \cos\Delta_{atm} \mp \sin\delta \sin\Delta_{atm})$$

- for ν

+ for $\bar{\nu}$

$$\Delta_{atm} = \frac{1.27\,\Delta m_{32}^2 L}{E}$$

$$\Delta_{sol} = \frac{1.27\,\Delta m_{12}^2 L}{E}$$

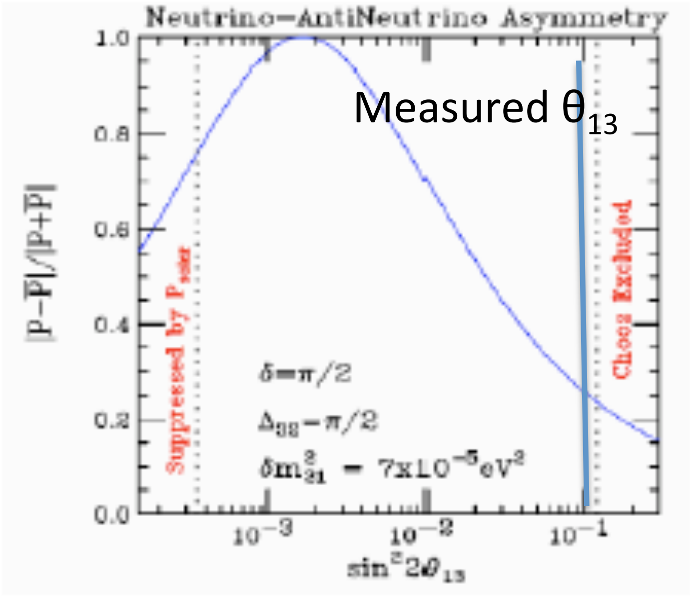
Asymmetry:

$$\frac{\left|P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e)\right|}{P(\nu_\mu \to \nu_e) + P(\bar{\nu}_\mu \to \bar{\nu}_e)}$$

$\sim \sin 2\vartheta_{13}$

measures δ

(if CP is violated through δ)



from „Nova" proposal

$\nu_\mu \rightarrow \nu_e$ with matter effects

$\Delta_{12} << \Delta_{13}$

$$P(\nu_\mu \rightarrow \nu_e) =$$

$$4 s_{23}^2 s_{13}^2 c_{13}^2 \sin^2 \Delta_{13}$$

$$+8 s_{12} s_{23} s_{13} c_{13}^2 (c_{12} c_{23} \cos\delta - s_{12} s_{23} s_{13}) \sin\Delta_{13} \sin\Delta_{12} \cos\Delta_{23}$$

$$-8 s_{12} s_{23} s_{13} c_{12} c_{23} c_{13}^2 \sin\delta \sin\Delta_{13} \sin\Delta_{12} \sin\Delta_{23}$$

CP violation

$$+4 s_{12}^2 c_{13}^2 (c_{12}^2 c_{23}^2 + s_{23}^2 s_{13}^2 c_{13}^2 - 2 s_{12} s_{23} s_{13} c_{12} c_{23} \cos\delta) \sin^2 \Delta_{12}$$

solar

$$-8 s_{13}^2 s_{23}^2 c_{13}^2 (1 - 2 s_{13}^2) \frac{\alpha L}{4E} \sin\Delta_{13} \cos\Delta_{23}$$

matter effects

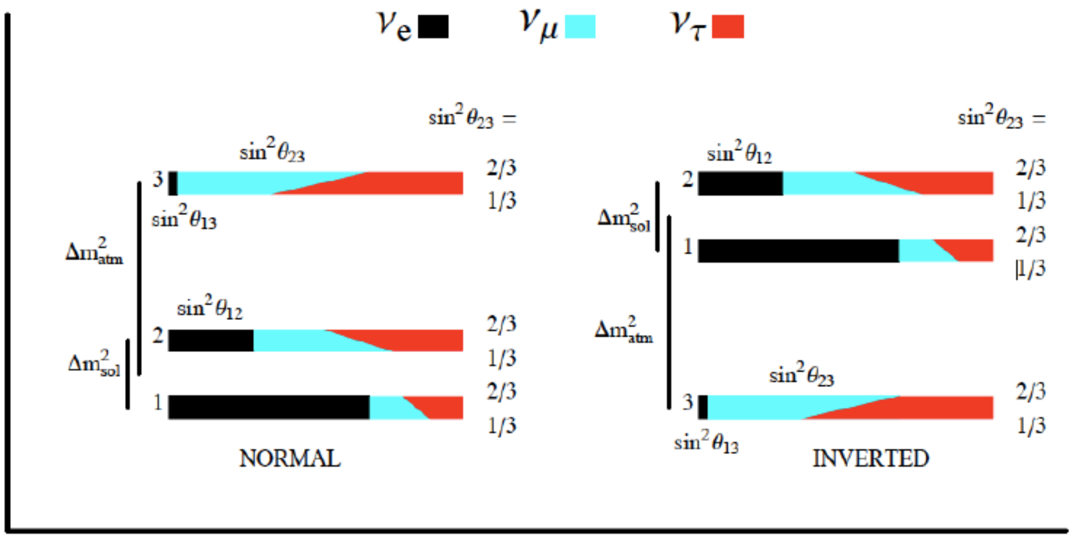
where:

$$s_{ij} \equiv \sin\vartheta_{ij}, \quad c_{ij} \equiv \cos\vartheta_{ij}$$

$$\Delta_{ij} \equiv \frac{1.27 \Delta m_{ij}^2 L}{E_\nu} \qquad \alpha = 2\sqrt{2} G_F n_e E$$

matter effects

s_{12} large is a good news!



But we don't know if $m_2 < m_3$ or $m_3 < m_2$

Determination of mass hierarchy

How to measure $\text{sgn}(\Delta m^2_{32})$

Matter effects: due to a difference in interactions of $\nu\ (\bar{\nu})$ of different flavors with electrons:

$$\Delta V = \sqrt{2}\, G_F n_e$$

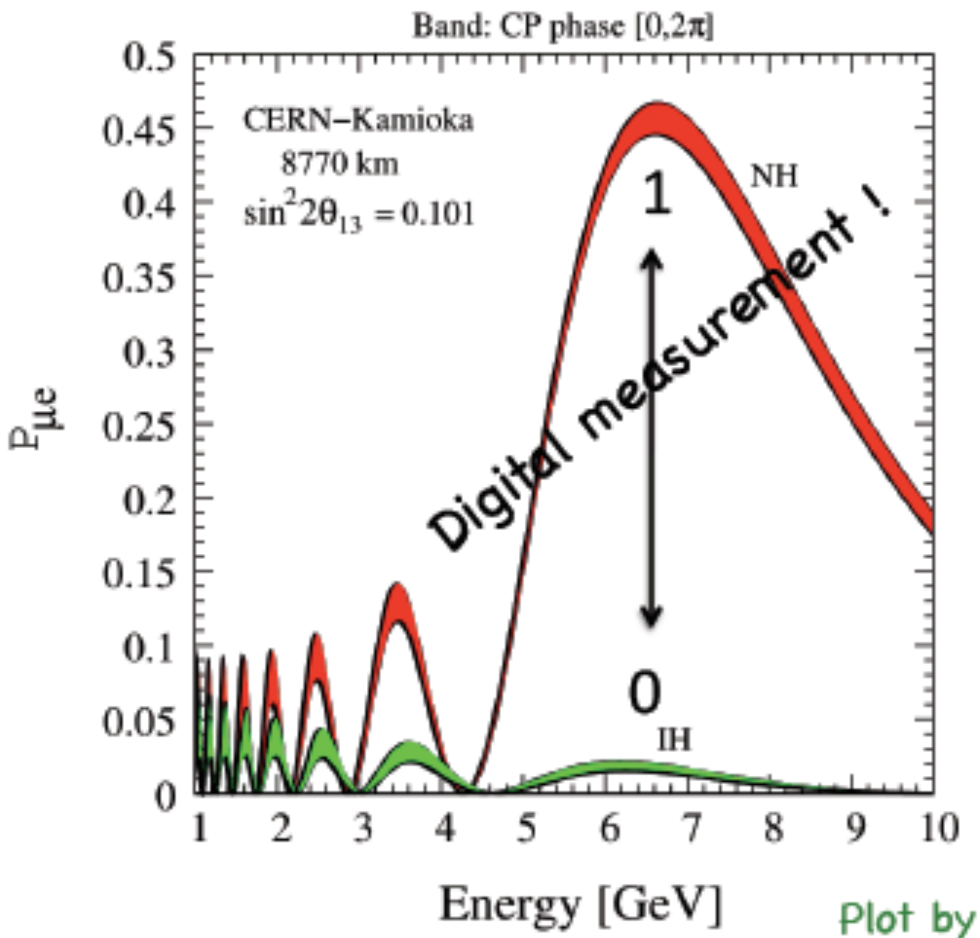
$$\delta m^2 \Longrightarrow \delta m^2 \pm \frac{2E(\Delta V)}{\cos 2\vartheta}$$

different sign for ν and $\bar{\nu}$

Good news: matter effects are sensitive to $\text{sgn}(\Delta m^2_{32})$

- First question: mass hierarchy

for some experimental configurations it can be 0-1 measurement



Plot by S. Agarwalla

$$E_{res} \equiv \frac{\Delta m^2_{31}\cos 2\theta_{13}}{2\sqrt{2}G_F n_e},$$

$$n_e(L)L|_{L_{max}} = \frac{\pi}{\sqrt{2}G_F \tan 2\theta_{13}}$$

Spectacular MSW effect at O(6GeV) and very long baselines: no need for spectral info nor two channels

$\nu_\mu \rightarrow \nu_e$ with matter effects

$P(\nu_\mu \rightarrow \nu_e) =$

$\Delta_{12} << \Delta_{13}$

$4s_{23}^2 s_{13}^2 c_{13}^2 \sin^2 \Delta_{13}$

$+8s_{12}s_{23}s_{13}c_{13}^2 (c_{12}c_{23}\cos\delta - s_{12}s_{23}s_{13}) \sin\Delta_{13} \sin\Delta_{12} \cos\Delta_{23}$

$-8s_{12}s_{23}s_{13}c_{12}c_{23}c_{13}^2 \sin\delta \sin\Delta_{13} \sin\Delta_{12} \sin\Delta_{23}$ CP violation

$+4s_{12}^2 c_{13}^2 (c_{12}^2 c_{23}^2 + s_{23}^2 s_{13}^2 c_{13}^2 - 2s_{12}s_{23}s_{13}c_{12}c_{23}\cos\delta) \sin^2 \Delta_{12}$ solar

$-8s_{13}^2 s_{23}^2 c_{13}^2 (1-2s_{13}^2) \frac{\alpha L}{4E} \sin\Delta_{13} \cos\Delta_{23}$ matter effects

where:

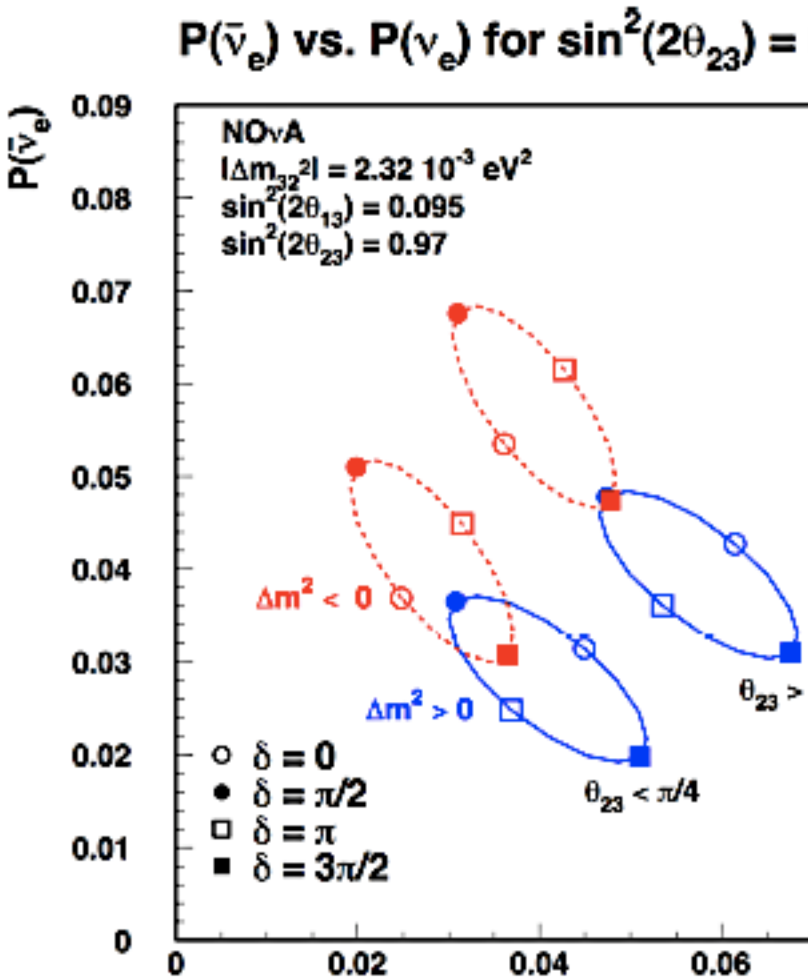
$s_{ij} \equiv \sin\vartheta_{ij}, \quad c_{ij} \equiv \cos\vartheta_{ij}$

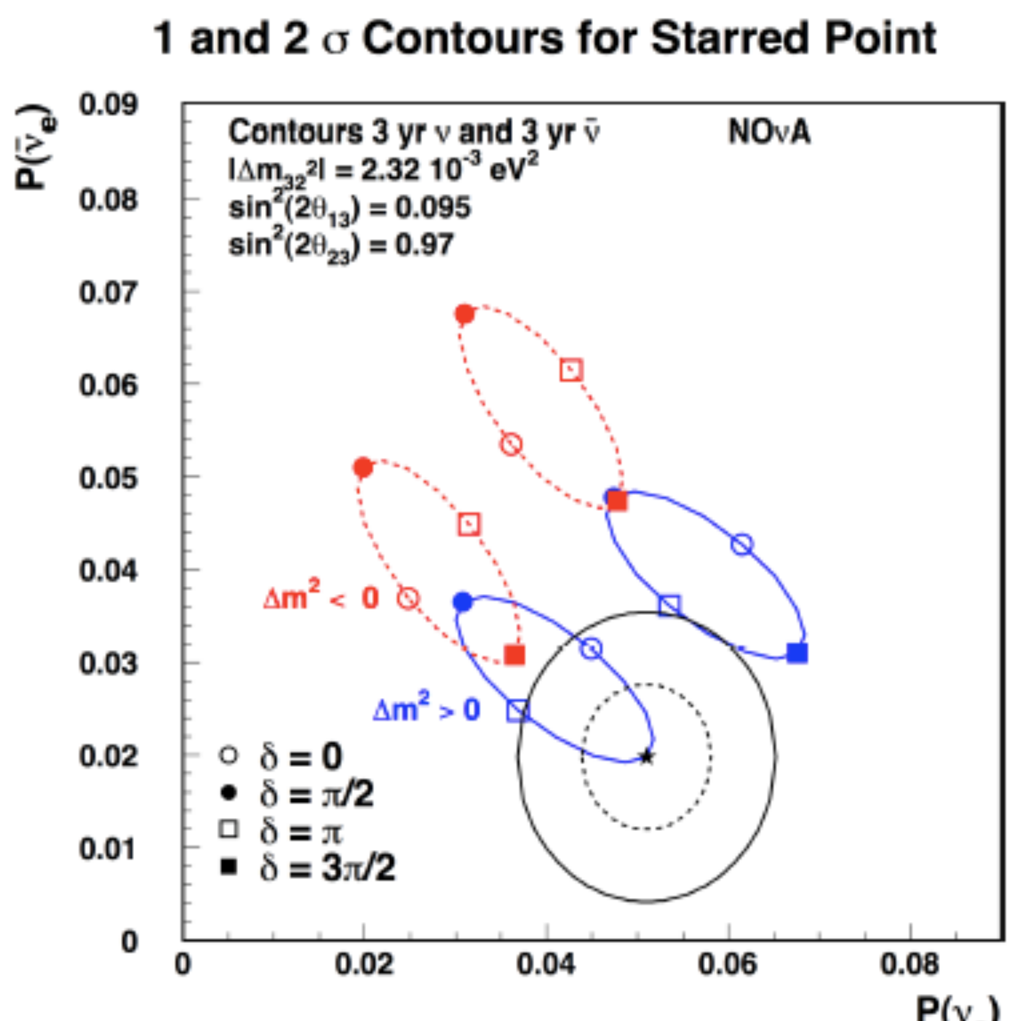
$\Delta_{ij} \equiv \frac{1.27\Delta m_{ij}^2 L}{E_\nu}$ $\alpha = 2\sqrt{2} G_F n_e E$

matter effects

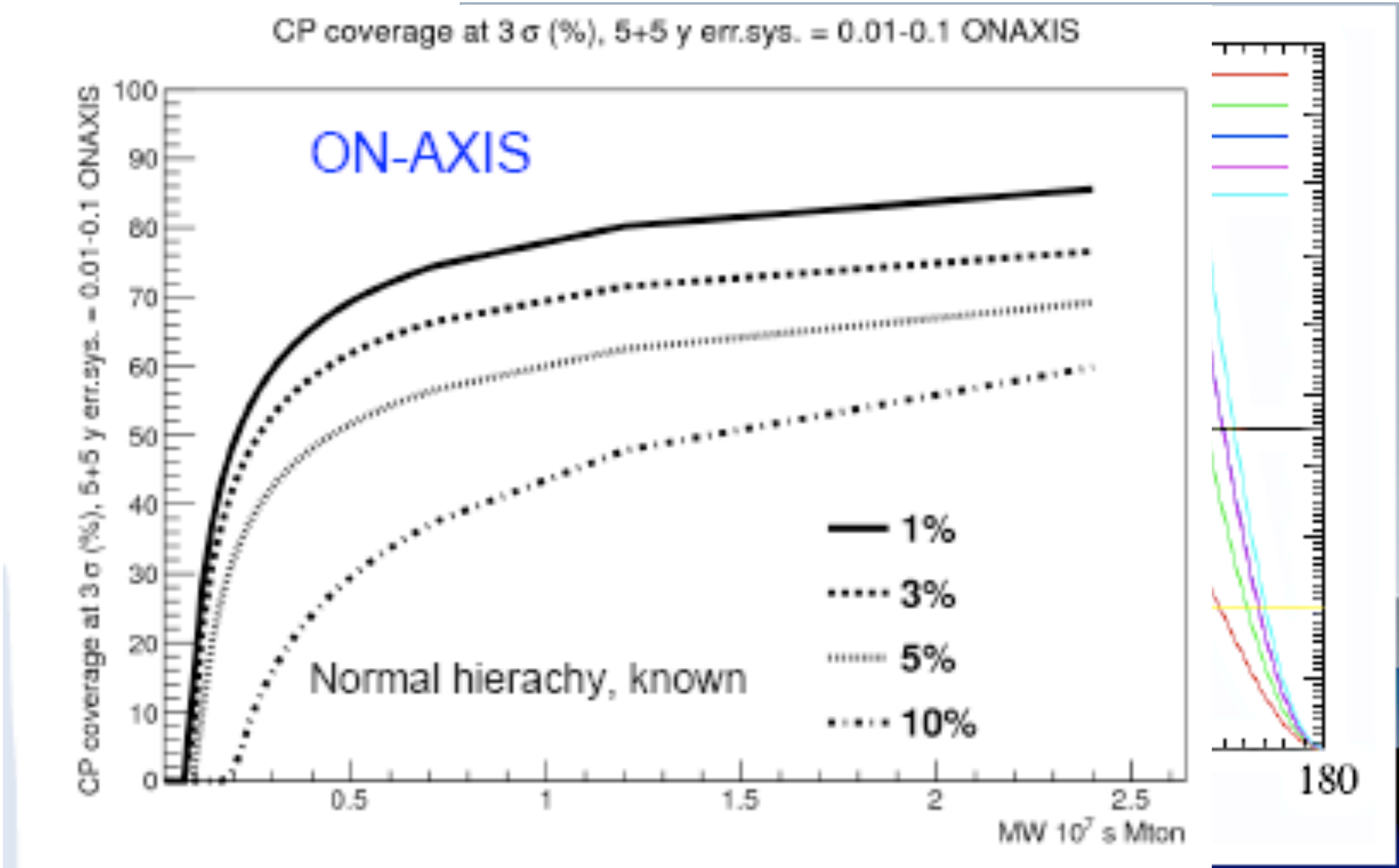
s_{12} large is a good news!

How measurements can be translated to CP parameters and MH





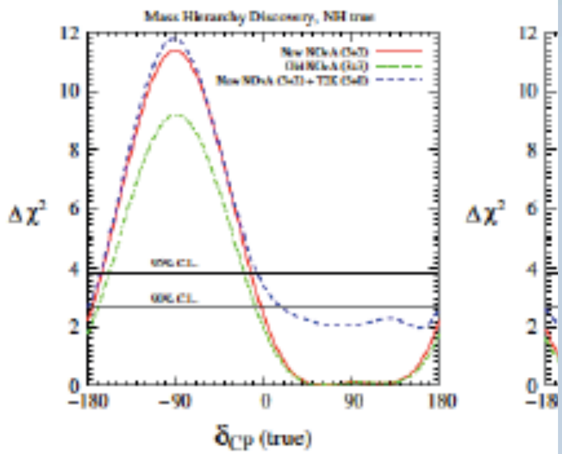
How to quantify: how well given experiment can deal with CP+MH?



Long baseline : the consensus

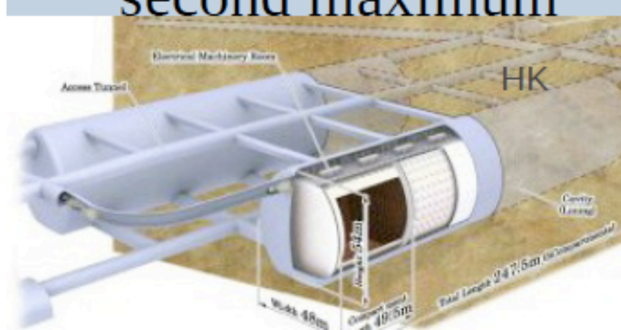
- The currently approved/running experiments (T2K, N0vA) will not be able to fully explore the PMNS matrix

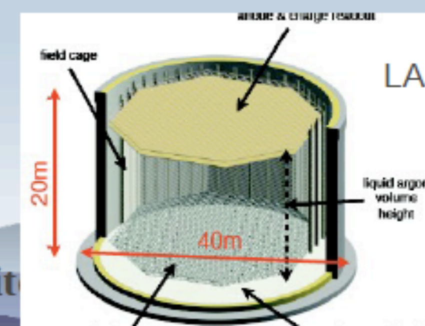
First experiments in



The two strategies towards CP violation

- Short baseline (~100-300 km), lower energy (<1 GeV), narrow beam, large Water Cherenkov (~500 kT). Concentrates on $\nu/\bar{\nu}$ asymmetry, “counting” experiment.
- Longer baseline (>1000 km), higher energy (>1 GeV), wide beam, Liquid Argon TPC. All final states accessible, E/L oscillation pattern and second maximum





LAGUN

Contribution ID74

LAGUNA-LBNO

LAGUNA-LBNO : reach and plans

- All transitions (ν_e ν_μ ν_τ) in neutrino/antineutrino mode in a single experiment, with wide L/E range
- Clean and direct matter effects for a conclusive mass hierarchy and CP violation sensitivity
- Proton decay and astrophysical reach (SN)
- Clear upgrade path. Baseline adopted by the Neutrino Factory/Euronu studies
- Call to CERN to support design of the beam and detector R/D

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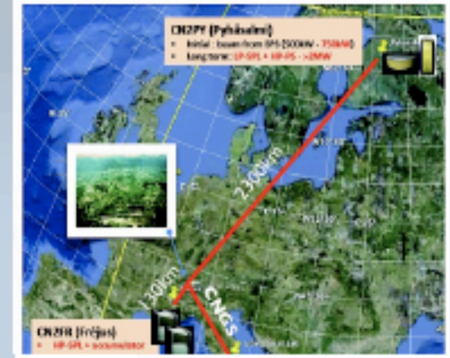
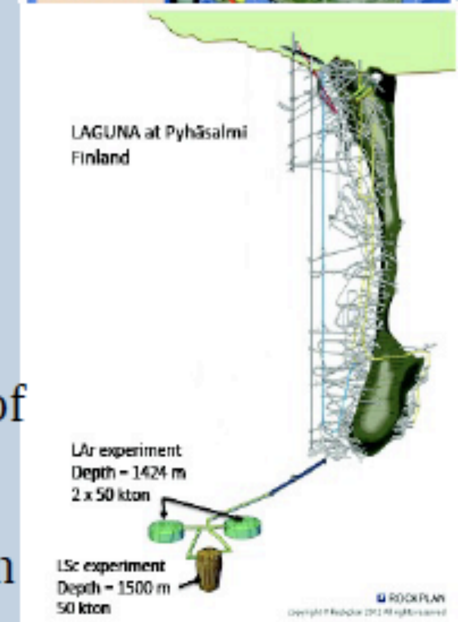
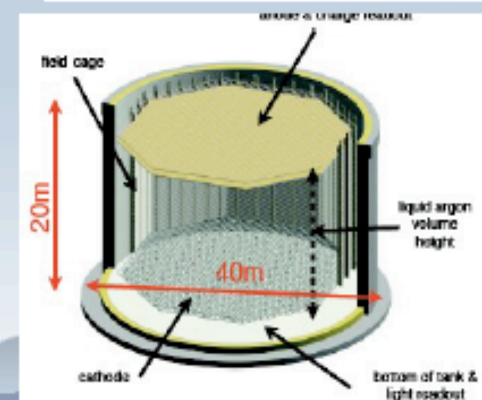


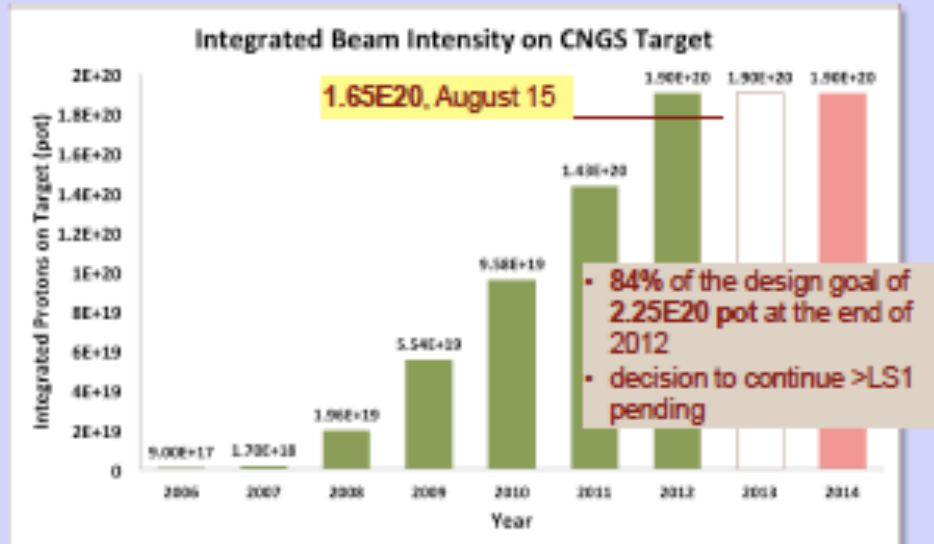




Future ν-beams at CERN - The potential !

Present :

- CNGS : successful operation for five years
- SPS a key asset for CERN
  - **510 kW** nominal beam power today
    - 4.8 10^{13} prot @ 400 GeV, 6s cycle
  - operation at ~**365kW**, 4.5÷4.7 10^{19} pot/y achieved
    - Limitations due to beam losses in PS and SPS, beam sharing with FT experiments and LHC



Future-I :

- Sub-MW conventional ν-beams from SPS
  - Short-baseline beam in the SPS North Area – SBL2NA
  - (very)Long-baseline beam to a far LAGUNA detector in the Pyhasalmi mine in Finland, 2300km – CN2PY
  - SPS operation following upgrades (>LS2) up to **750 kW**, 7.0 10^{13} prot @ 400 GeV, 6s cycle

Future-II (>2025?) :

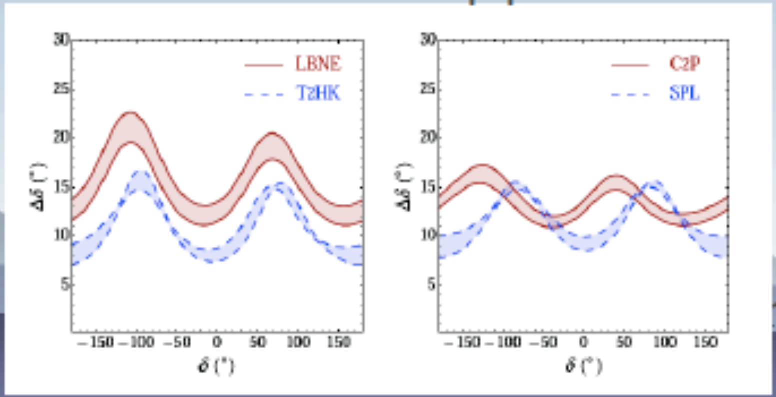
- High-power upgrades with new accelerators
  - High-power (2MW) upgrade of the Long-baseline CN2PY beam: LP-SPL + HP-PS
  - New Medium-baseline beam (130km) using a **β**-beam (1MW) or a Super-beam (4MW)
  - A Neutrino Factory (4MW) for a Long-baseline ν-beam to the Pyhasalmi site

Long baseline projects

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	No	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

*: if mass hierachy is known

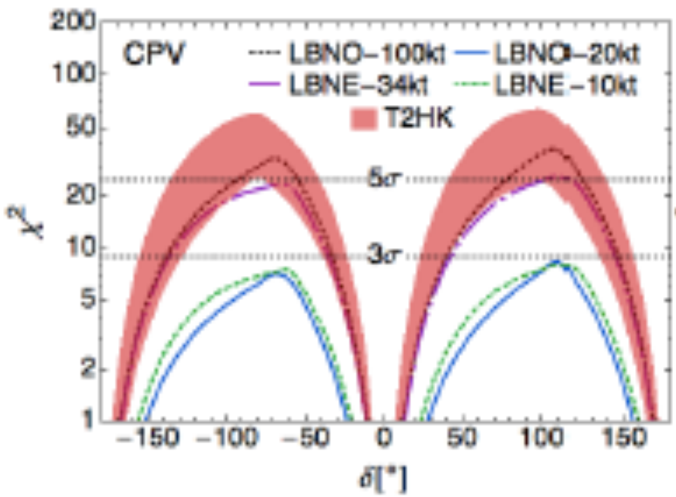
P. Coloma et al.hep-ph:1203.5651

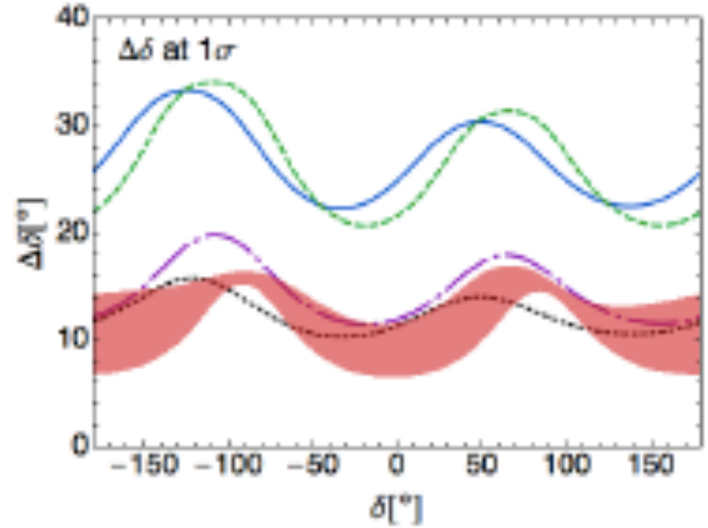


T2HK: 4MW, 500 kt
LBNE: 0.8 MW,33 kt
C2P=LBNO : 0.8 MW, 100 kt

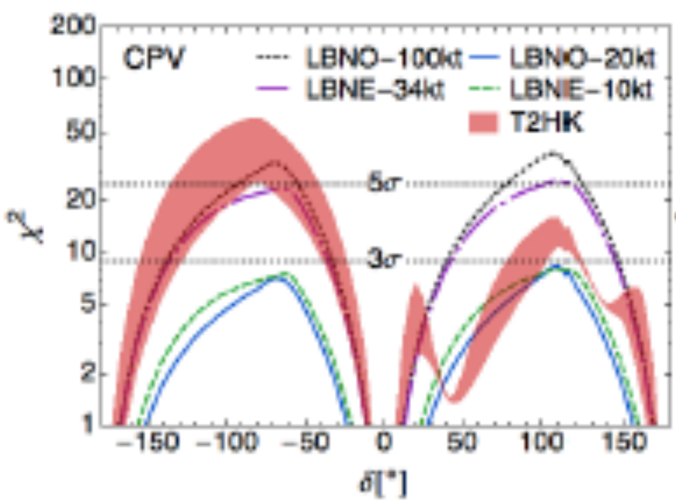
20 years from now with conventional beams....

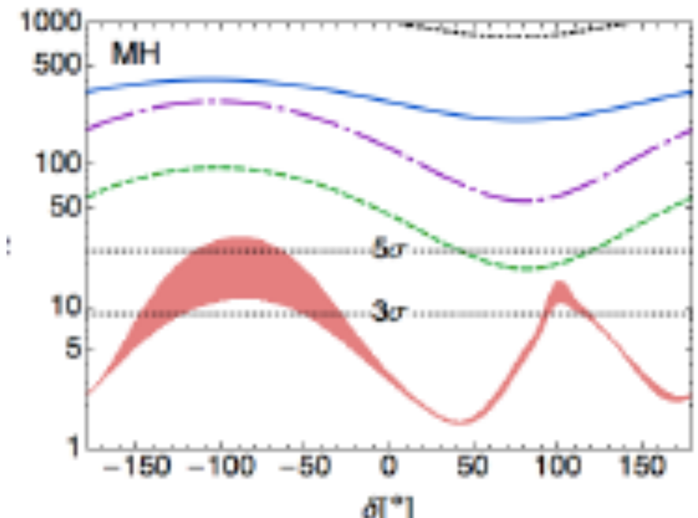
Hierarchy known





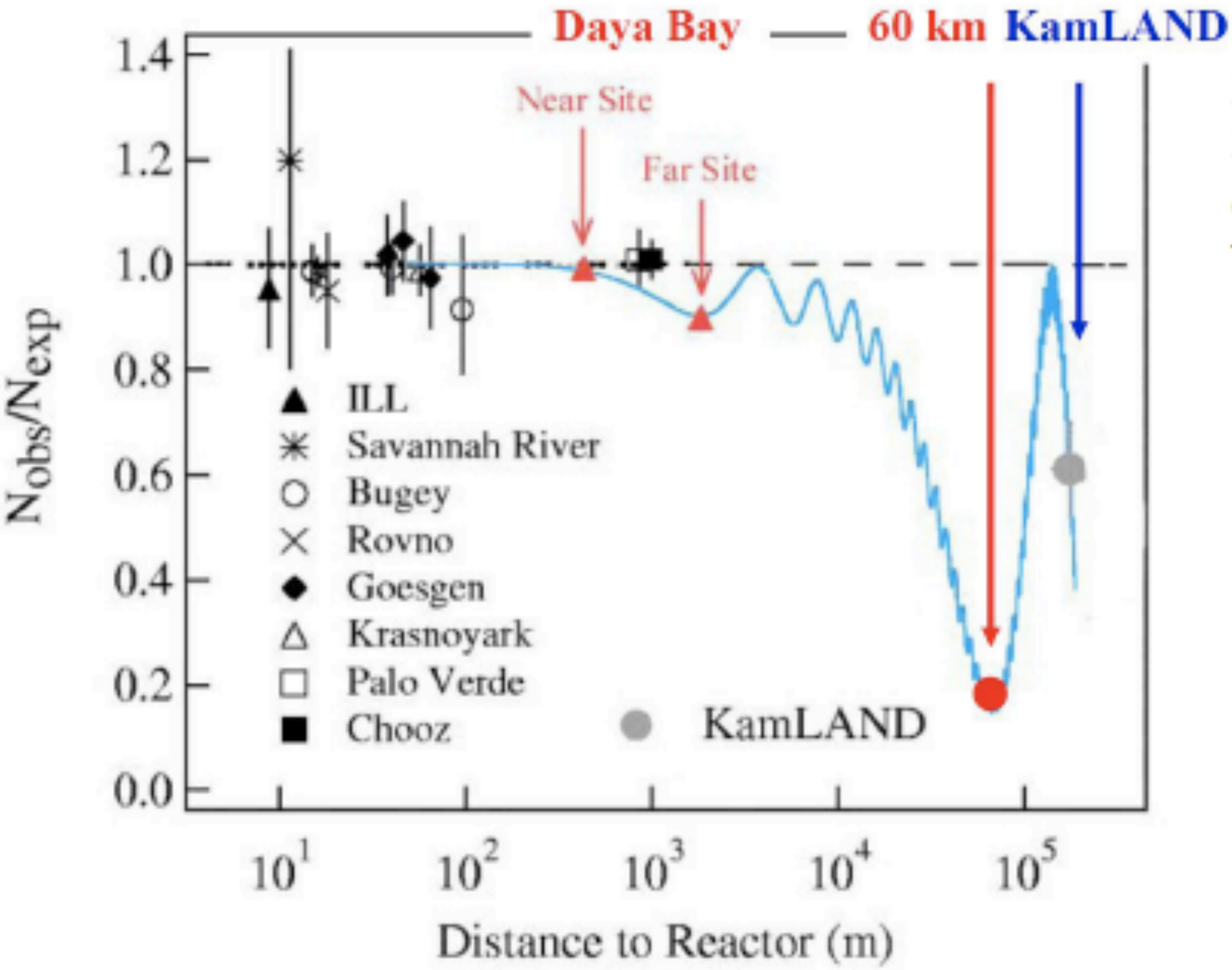
Hierarchy not known



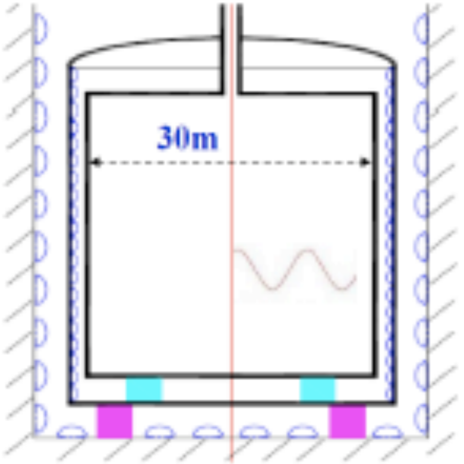


Mass Hierarchy in Future Reactor Experiments

J. Cao at νTURN2012 workshop: Daya Bay 2 Experiment



20kt Liquid Scintillator
3%/√E energy resolution
overburden: > 1000mwe
Thermal power 35GW
15000 PMTs 20"

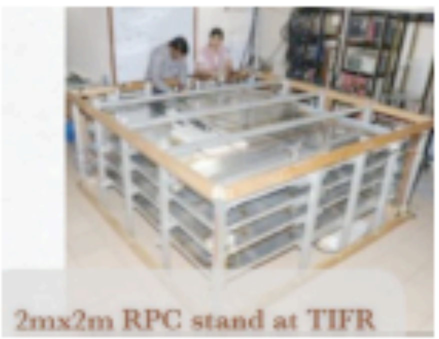


No CP effects here

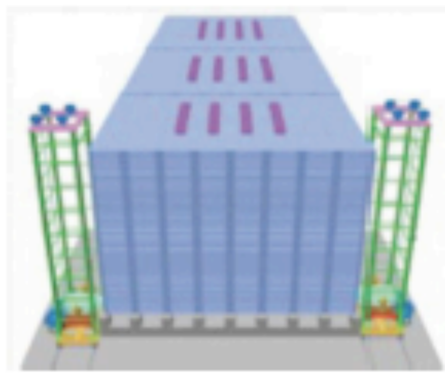
Atmospheric Neutrinos: ICAL @ INO

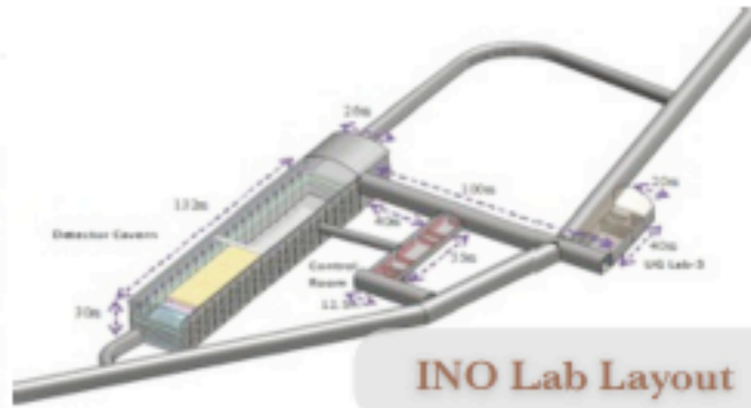
50kt magnetized iron calorimeter using glass RPCs (ICAL),
Underground Lab INO in Tamil Nadu (India)

Mass hierarchy results possible before 2025, but < 3σ
even with most optimistic assumptions on energy and angular resolution of ICAL
(10% and 10º, respectively)



2mx2m RPC stand at TIFR





INO Lab Layout

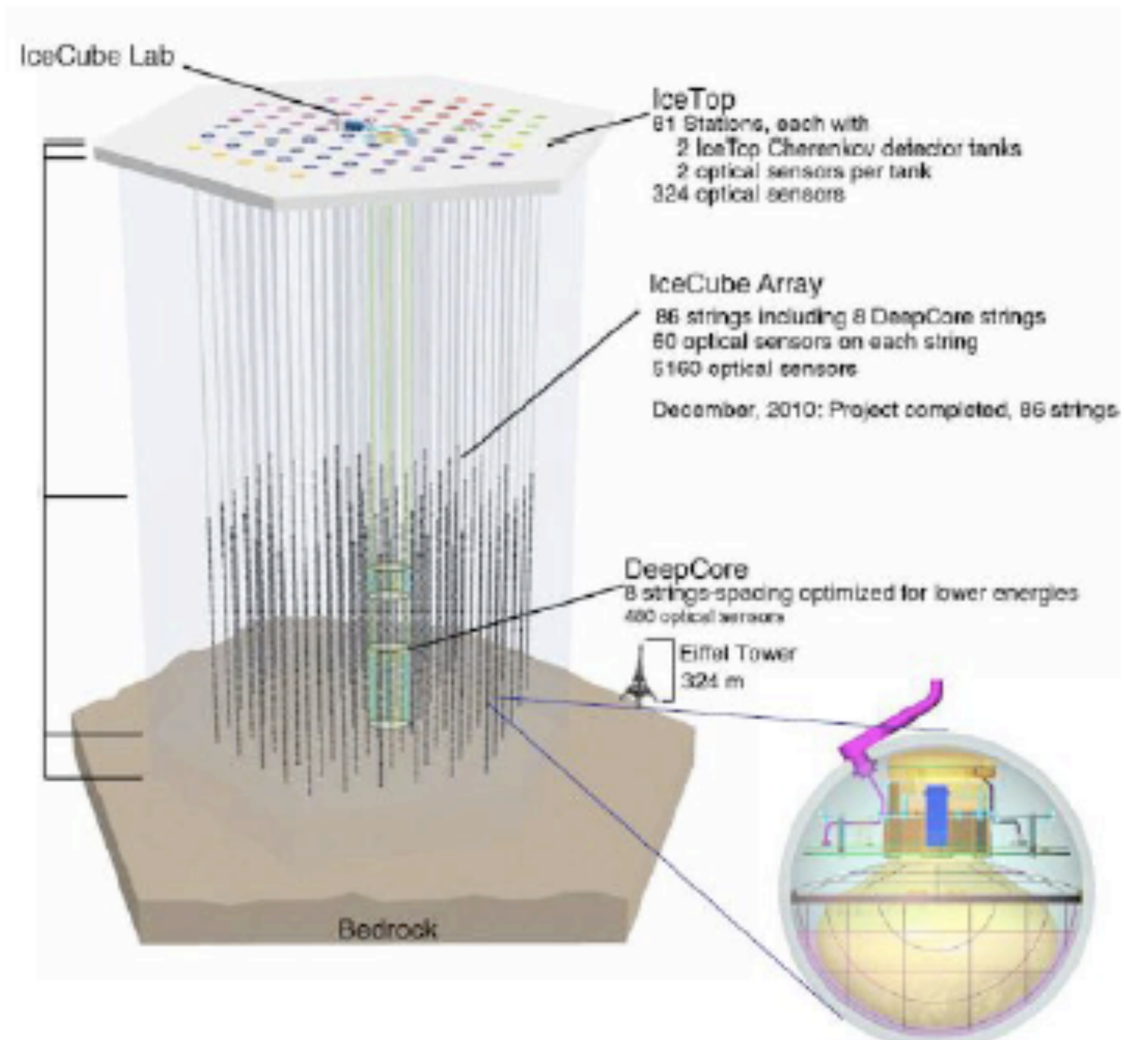
Comment from Input#11 Conclusions from NUTURN2012 workshop @ LNGS:
"It is worth mentioning that a proposal similar to ICAL@INO has been put forward in 1999 at LNGS (MONOLITH) since the Gran Sasso Laboratories are able to host high density detectors up to masses of 100 kton in a single experimental hall. However, the granularity of the detector should be significantly better than ICAL@INO to reach conclusive (>3 σ) sensitivities on the mass pattern."

Atmospheric Neutrinos: PINGU

PINGU @ Icecube:

- add 20 strings in DeepCore region
- lower energy threshold: 1 GeV (DeepCore 10GeV)

Timeline:
2012 LOI
2013 proposal



Mass Hierarchy with PINGU

Akhmedov, Smirnov, Razzaque (arxiv:1205.7071)

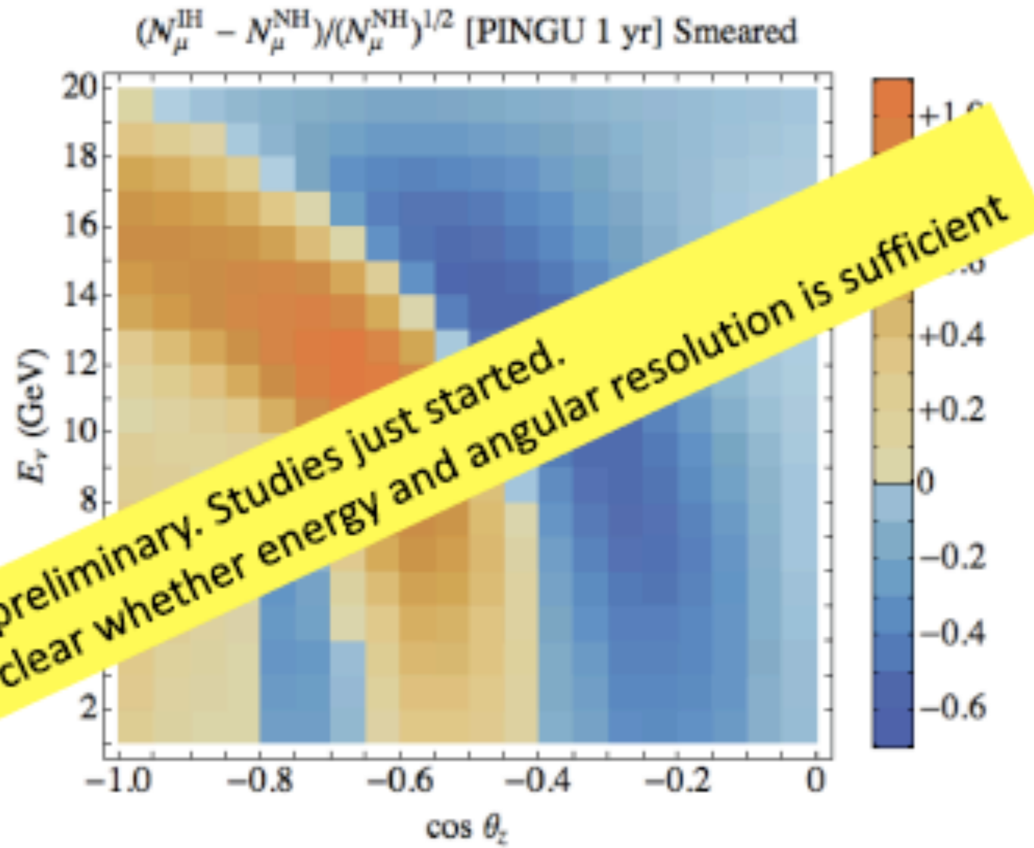
"Preliminar estimation: (After 5 years of PINGU 20 operation)
Significance of the determination of the hierarchy can range from 4σ to 11σ
(without taking into account parameter degeneracies),
depending on the accuracy of reconstruction of the neutrino energy and zenith angle."

One example: 5years

$$\sigma_E = 0.3E_\nu \text{ and } \sigma_\theta = \sqrt{m_p/E_\nu}.$$

f = 10% (uncorrelated syst. Errors)
Total Significance: 7.1σ

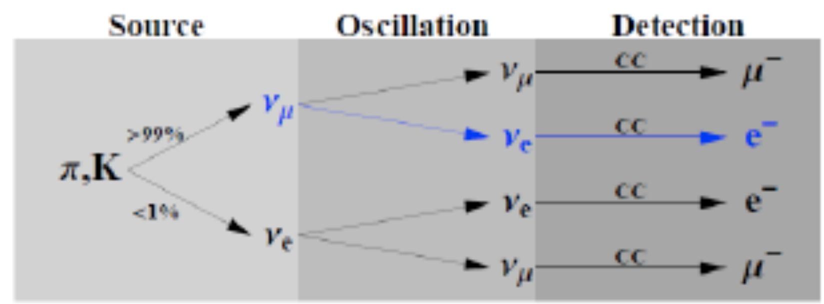
Similar method could be used by KM3NeT:
ORCA feasibility study
(input #42)



Long term strategy….

Superbeam, Betabeam and Neutrino Factory

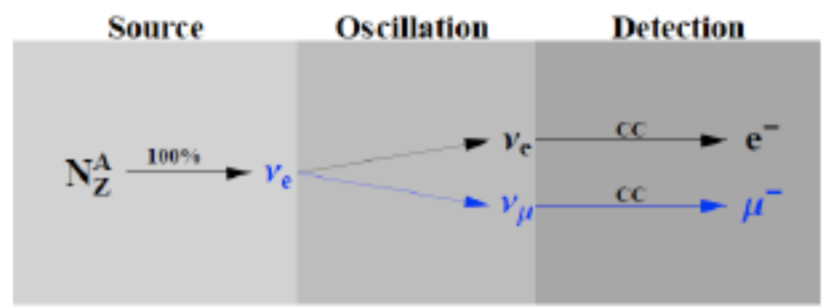
Superbeam:
dominantly (99%) ν_μ
ν_e „contamination“



Betabeam:

$${}^{6}He \rightarrow {}^{6}Li + e^- + \bar{\nu}_e$$

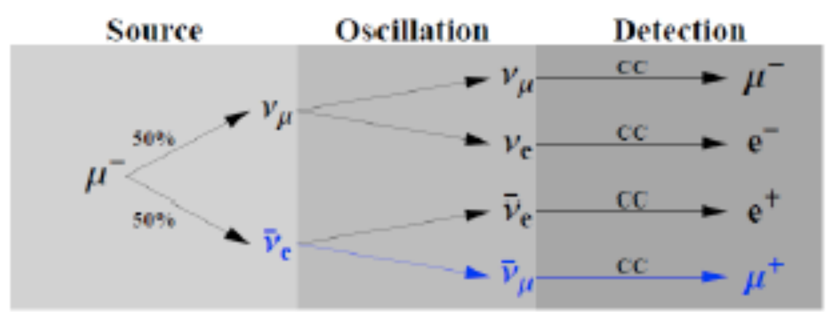
$${}^{18}Ne \rightarrow {}^{18}F + e^+ + \nu_e$$



Neutrino Factory:

$$\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$$

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



EUROnu Study: Precision of CP phase

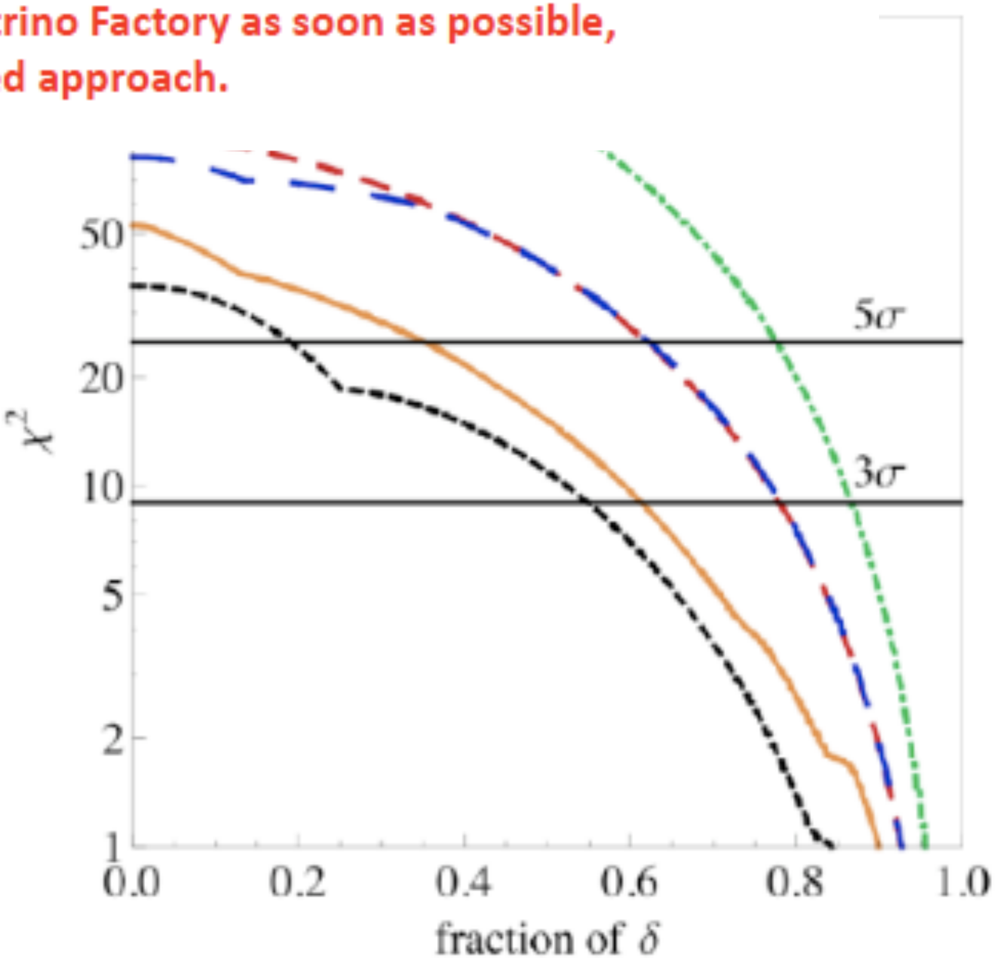
BB100: Beta [...]
γ=100, 1.3(3. [...]
500kt Water [...]
@Frejus (130[...]

As a result, the recommendation of EUROnu is the construction and operation of a 10 GeV Neutrino Factory as soon as possible, implemented using a staged approach.

SPL-1st: Super Beam @ 1st oscill. max.
4MW (SPL),
500kt Water Cherenkov (MEMPHYS),
@Frejus

SPL-2nd: Super Beam @ 2nd oscill. max.
4MW (SPL),
500kt Water Cherenkov (MEMPHYS),
@Canfranc (660km)

LENF: Low Energy Neutrino Factory
E_ν = 10GeV, $1.4\cdot10^{21}$ decays/y,
100kt MIND (magnetized iron detector),
@2000km



(after 10 years of measurement)

The Muon Accelerator Program (MAP) in US

Input #135

„A Staged Muon-Based Neutrino and Collider Physics Program“

unique in ability to span both the Energy and Intensity Frontiers

- Entry point: νSTORM facility proposed at Fermilab
- Neutrino Factory (stored muon beam)
- „Higgs Factory“ Muon Collider
  uniquely precise measurements of the 126GeV boson
- Energy-frontier Muon Collider
  unique measurements of Terascale physics
  (both for precision and discovery reach)

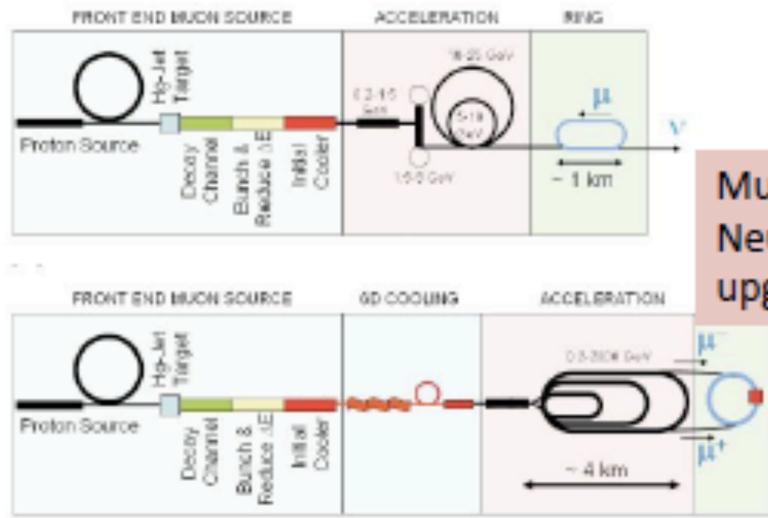
Important milestone needed: MICE @ RAL in UK
demonstrate muon ionization cooling, detailed validation of simulation codes by measurements

Ingredients for a muon-facility staging plan

vSTORM

a)

c)

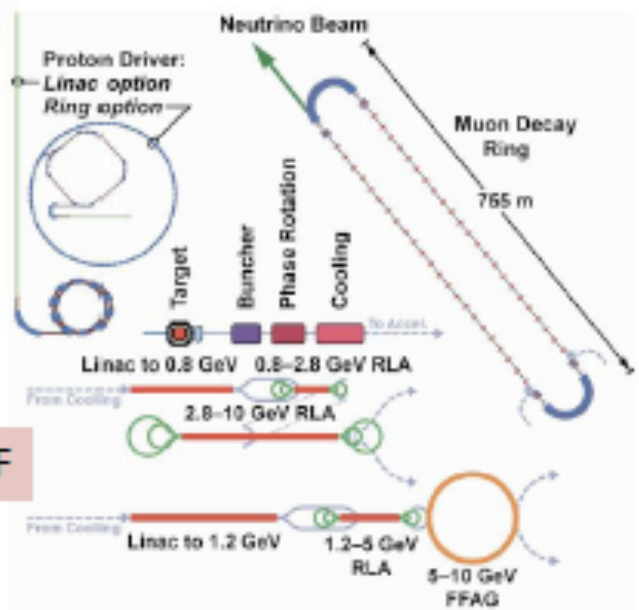


NEUTRINO FACTORY

Muon Collider as Neutrino Factory upgrade

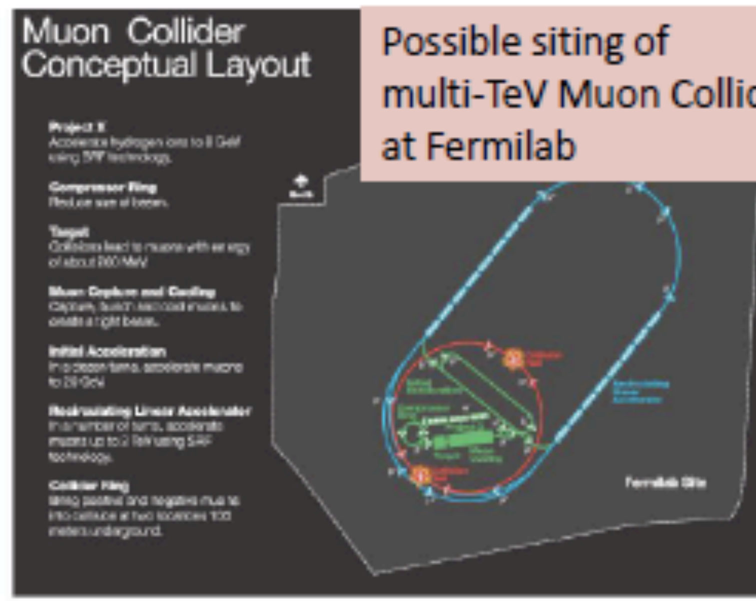
MUON COLLIDER

b)



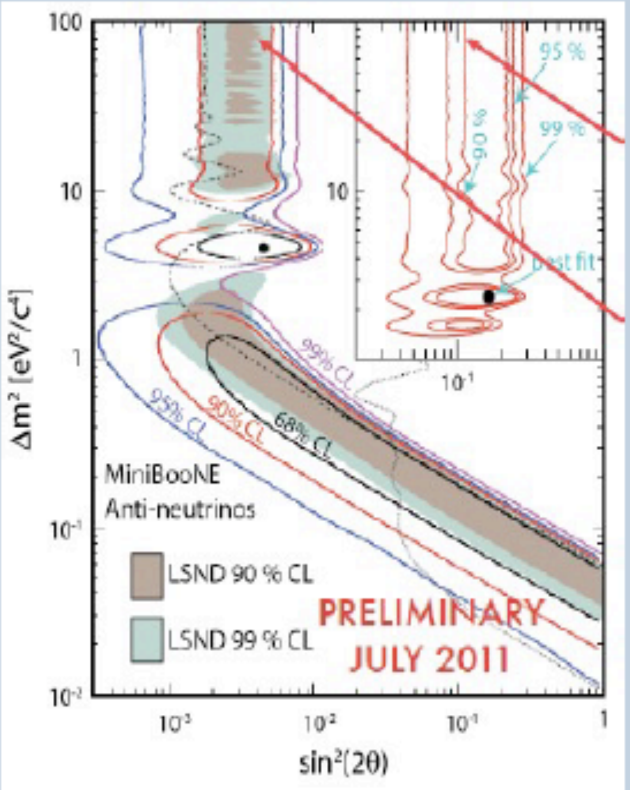
IDS-NF

d)

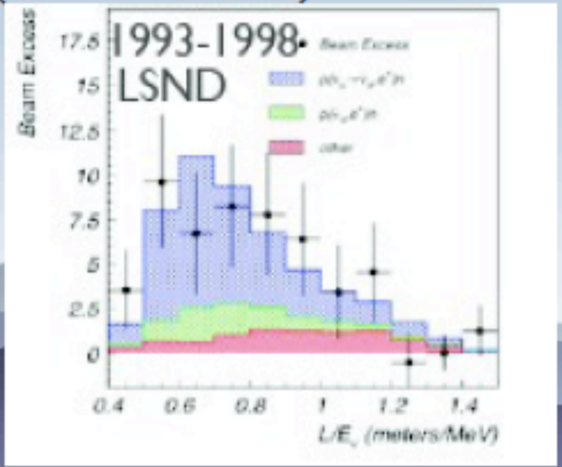


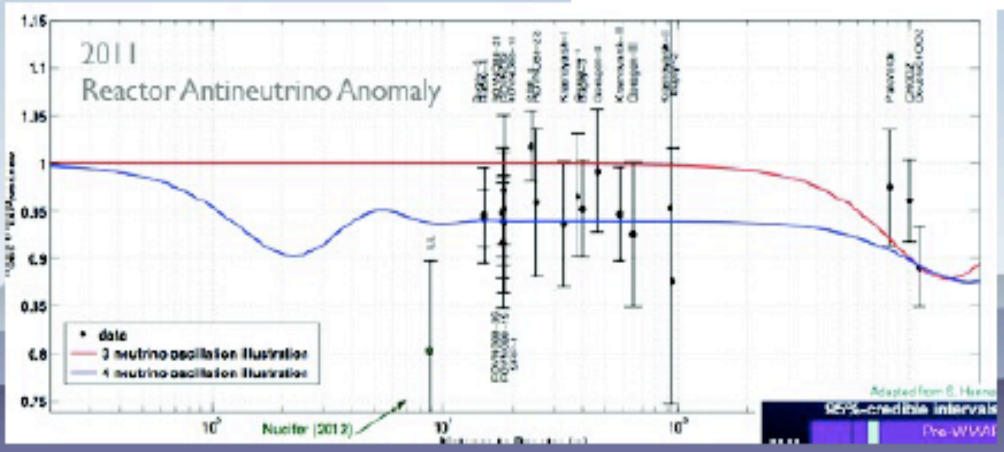
Possible siting of multi-TeV Muon Collider at Fermilab

Neutrino anomalies



- There are hints of possible new states beyond the three observed neutrinos:
- LSND anomaly in ν_μ -> ν_e channel
- The neutrino deficit in reactor fluxes
- Is there a new ν with $\Delta m^2 \sim 1$ eV^2 ?
- Many experimental approaches: reactor exp., strong sources close to an existing det. (CeLAND ...)

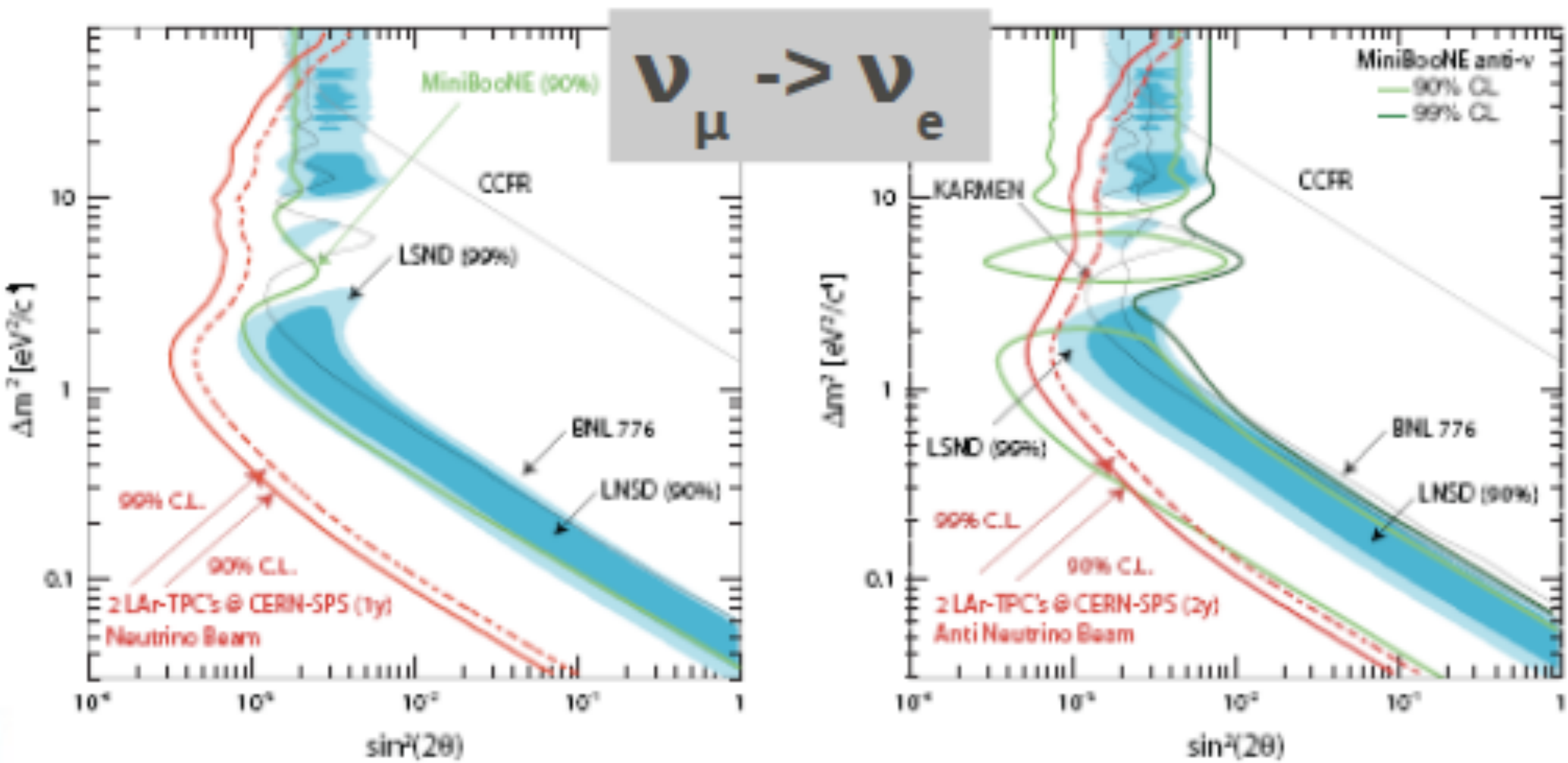




Contribution ID38

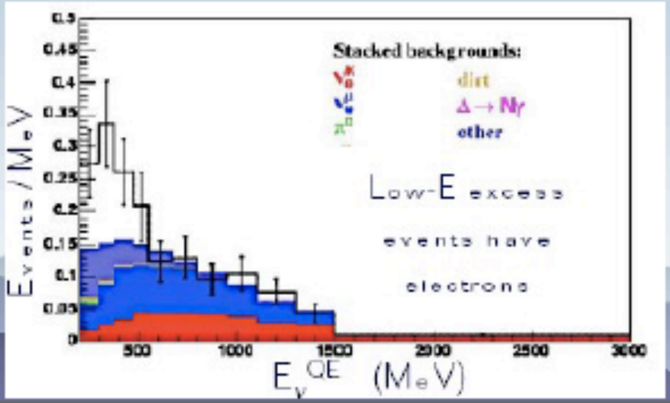
SPSC-P-347 (Icarus-Nessie)

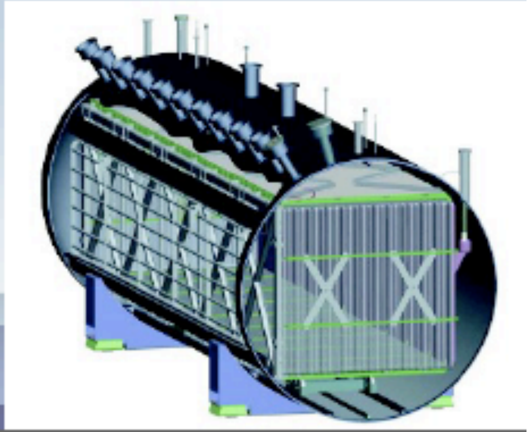
- Proposal (SPSC-P-347, 150 authors) of a comprehensive search for new neutrino states around $\Delta m^2 \sim 1eV^2$ using a SPS 110 GeV proton beam in the NA



MICROBooNE

- 70 ton Liquid Argon detector under construction (completion end 2013) on the Booster neutrino beam line at FNAL
- Same baseline as MiniBooNE : 500 m, E=0.7 GeV
- Study of the low energy excess of MiniBooNe: electron or photons ? 5 (e) or 4 (γ) σ possible in 2-3 years
- Possible construction of 1 kton Liquid Argon TPC (LAr1) to investigate the MiniBoone antineutrino anomaly

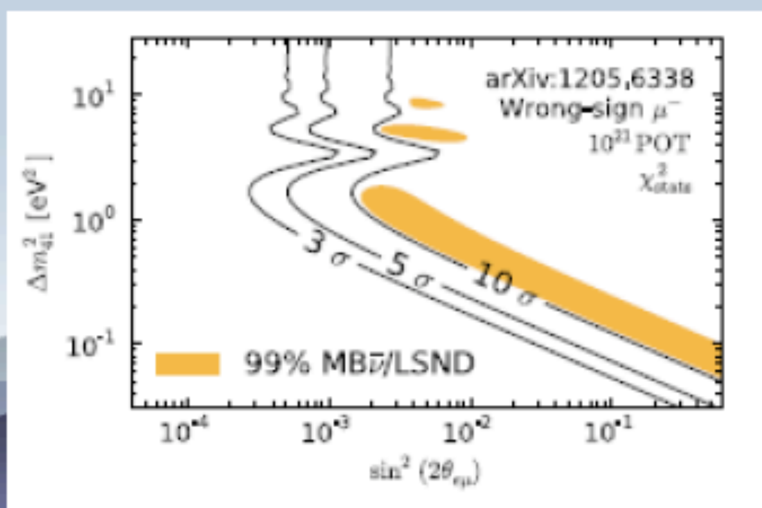


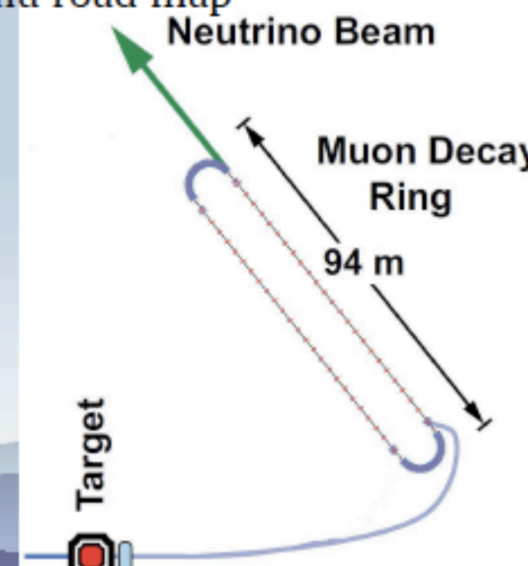


Contribution ID108

νSTORM

- LOI submitted to FNAL PAC
- Use a muon decay ring to produce with $\mu \to e\, \nu_\mu\, \bar{\nu}_e$ a precisely known beam aimed at a magnetized iron detector to
- Investigate the LSND signal in the T conjugated mode $\nu_e \to \nu_\mu$ at 10 σ
- Study ν_e and ν_μ disappearance
- And precisely (1%) measure ν_μ and ν_e cross-sections
- Accelerator R/D towards the Neutrino Factory, on the EUROnu road map





Test of sterile neutrino scenarios

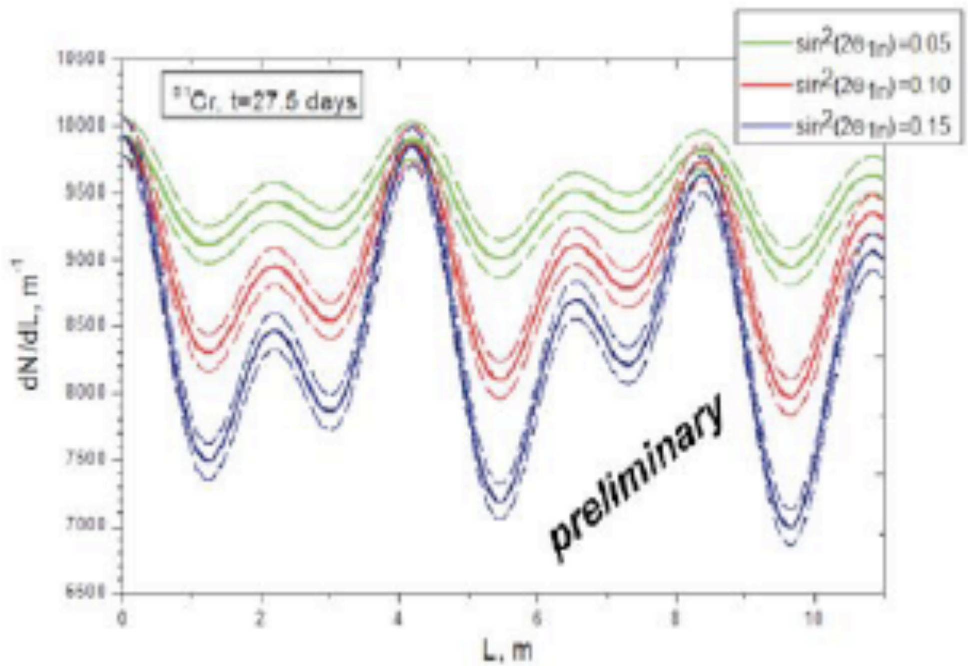
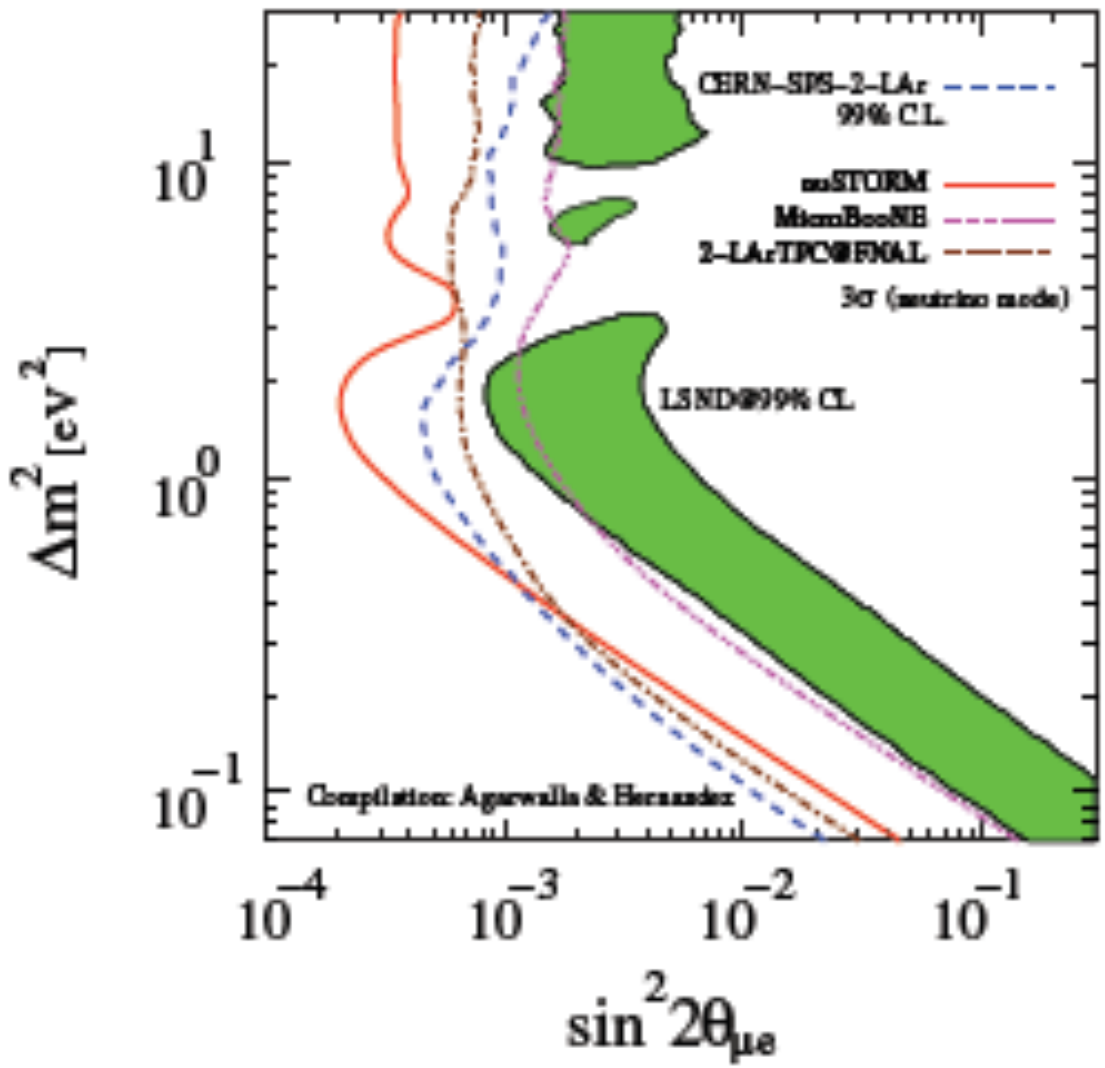


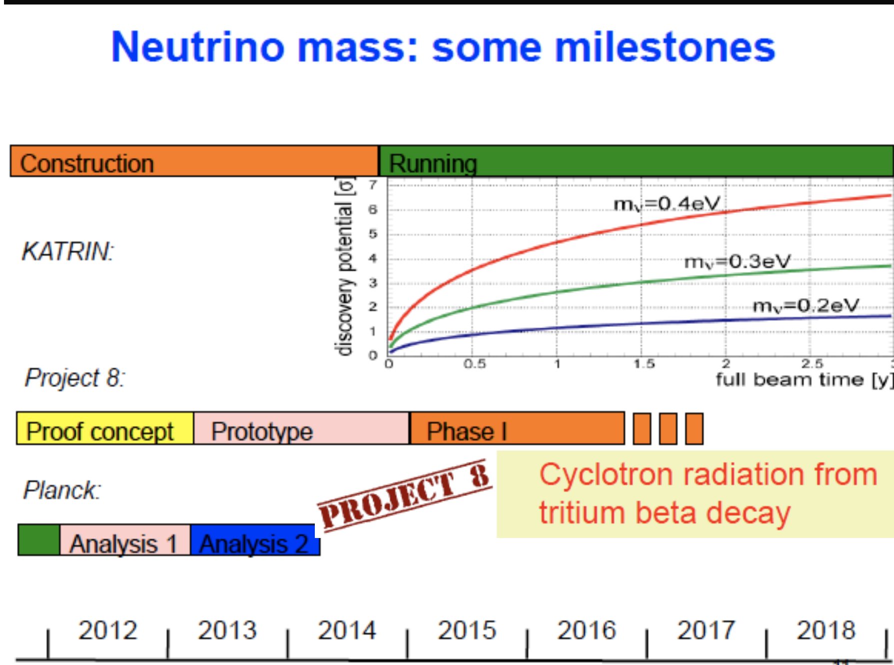
Fig. 8. Oscillometry curves for the case of three active and two sterile neutrinos in the (3+2) scenario with mass parameters proposed in [6]. In the figure top (green), middle (red) and bottom (blue) curves correspond to $\sin^2(2\theta_{1n}) = 0.05; 0.10; 0.15$, respectively, with n=4, 5. The dashed lines indicate the statistical uncertainties (1σ). Input parameters are $(T_e)_{th}$ = 200 keV. R_0 = 11 m, exposure - 27.5 days, ^{51}Cr-source intensity – 5 MCi. The background from solar neutrinos is taken from the BOREXINO experiment [26] as 0.5 events/day·t.

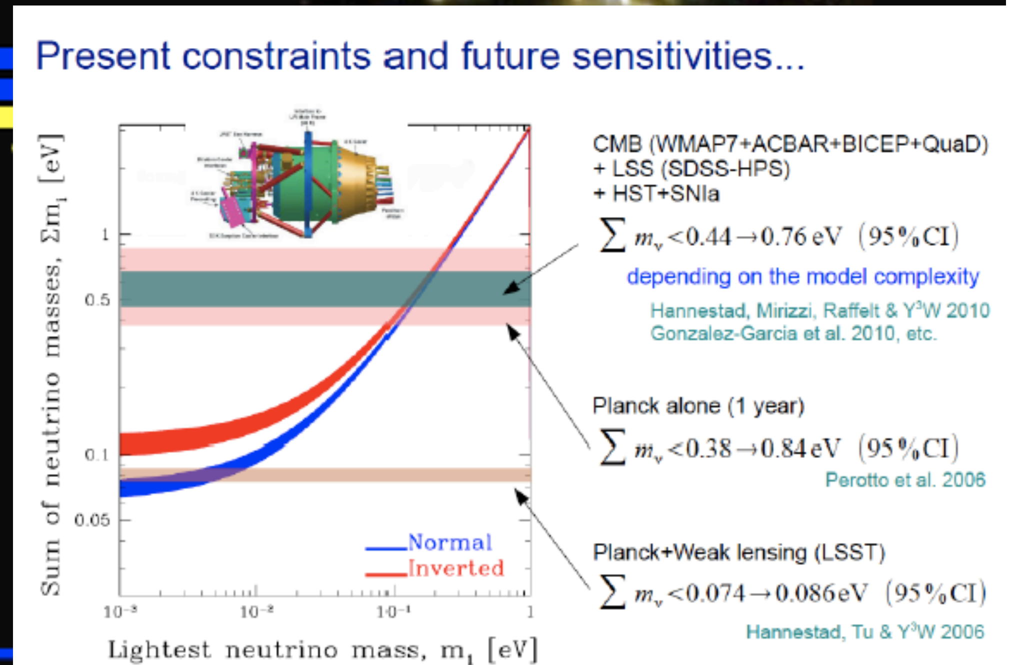
Testing neutrino anomalies…
….. in few years



- conventional beams – CERN, FNAL
- nuStorm
- Reactor fluxes
- Atmospheric (Icecube, SK, LBL …)
- Oscillations inside detector
- (Borexino, SNO+, strong source, ??)

Neutrino Mass Measurements





Particle Physics — Cosmology

What is the neutrino mass scale?

Hamish Robertson, ESPP12, Kracow, Sept. 11, 2012

Summary of the ν session

- ν mass and mixings confirmed by many experiments and remain, with dark matter, the only present evidence of beyond the Standard Model physics.
- As the highest priority we should determine the unknown oscillation parameters and look for surprises. CP violation and the ν mass hierarchy could be keys to the matter/antimatter asymmetry of the Universe.
- A large and effective European community exists in this area.
- Long baselines are optimal for determining the mass hierarchy, real advantage of the CERN → Pyhăsalmi baseline and, to a lesser extent, LBNE.
- The CERN → Pyhăsalmi baseline is also near optimal for a Neutrino Factory.
- Shorter (~hundreds of kilometres) baselines with huge detectors would allow very high statistics measurements more helpful for CP violation, particularly if hierarchy is known. This is the case of T2HK (also European alternatives such as CERN → Frejus, CERN → Canfranc, or ESS-based ν beam)
- For best performance and synergy an experiment of each category is needed → Coherence with efforts in other regions. Coordination and cooperation with our international colleagues mandatory.
- Anomalies in a range of phenomena at lower energies perhaps point to sterile neutrinos, and a proposed experiment at CERN would be highly competitive.
- More sophisticated future projects, which EUROnu has concluded should be a Neutrino Factory, necessary to achieve the desired sensitivity to the CP phase and probe new physics.
- R&D including projects such as MICE and nuStorm (which may also offer a definitive test for sterile neutrinos) should be supported.
- Experiments in absolute neutrino mass, especially in neutrinoless double-beta decay, are also a top priority.
- Hadron production, neutrino cross-section, and other support measurements will be essential to reach the neutrino oscillation sensitivity goals.

Astropaticles, underground experiments

- Tutaj troche inna rola stategii, a także sympozjum
- **ApPEC** przygotowuje własną strategię

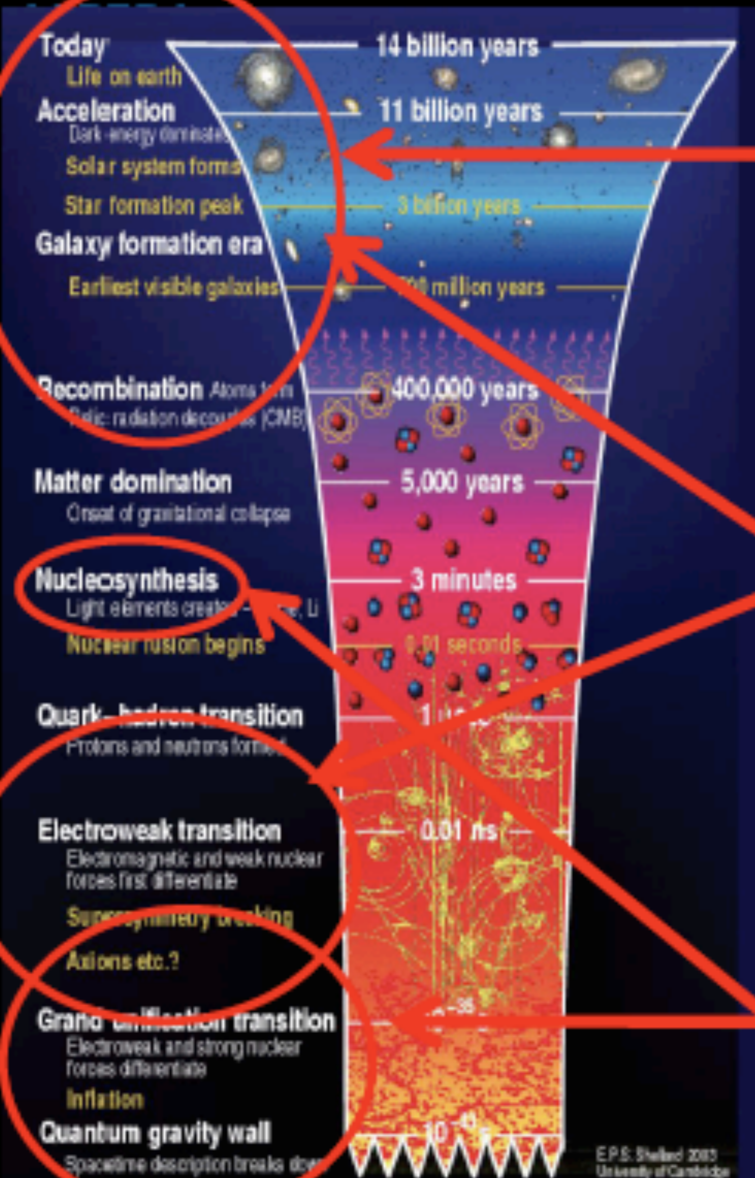
  taki dokument już powstał
- Ten dokument stanowi input do

European Strategy for Particle Physics
CERN Council

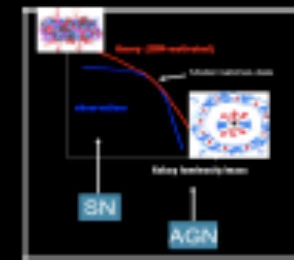
- Przedstawiciel ApPEC uczestniczy

  w pracach grupy strategicznej

The 3 themes (6 topics) of Astroparticle Physics
(APIF definition)



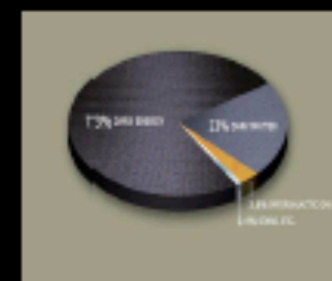
Understand cosmic accelerators and their role in the formation of cosmic structures. Probe for new particles (e.g. dark matter) or violations of fundamental laws



V. High energy cosmic messengers (γ, ν, CR)

VI. Gravitational waves

What is the Universe made of?



III. Nature of dark matter

IV. Nature of dark energy

Probe matter and interactions at the smallest scales or highest energies beyond these of accelerators, through rare decays.

I. Neutrino mass

II. Proton lifetime and neutrino properties

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda}\mathcal{L}_5 + \frac{1}{\Lambda^2}\mathcal{L}_6 + \cdots$$

3 unities…

1

Overview ASPERA Roadmap

Three catego

- Medium s
- Large scal
- Very large

ApPEC ASPERA Astroparticle Physics for Europe

Large scale, mid of decade

ApPEC ASPERA Astroparticle Physics for Europe

Very large scale, 2020 horizon

LAGUNA-type infrastructure including beam would fall in this category (see the talks of next session)

- Next generation Dark Energy surveys
  - LSST at ground
  - EUCLID in space
- Next generation graviational wave antennas
  - Einstein Telescope ET underground
  - eLISA/NGO in space
    - Somewhere between category 2 and 3

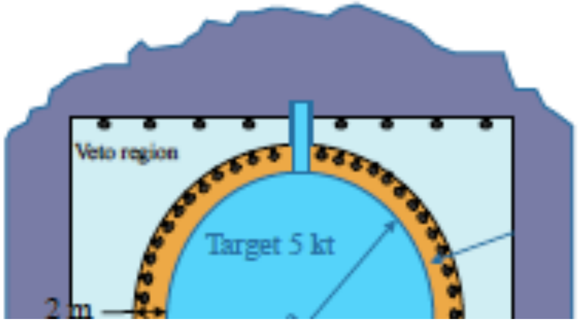
Physics case

Neutrino Astrophysics, Neutrino Physics and Search for Proton Decay with Deep Underground Detectors

- **Proton decay**
  - Test further classes of SUSY models w
- **Galactic Supernova**
  - Bonanza for astrophysics and particle physics
  - Incredibly detailed information on early SN phase and explosion mechanism
- **Solar neutrinos: details of solar model with percent accuracy**
  - Metallicity problem ← ν from CNO cycle → burning of heavy stars
  - Time variations on the 10^{-3} level
  - Transition vacuum/matter oscillations
- **Geoneutrinos**
  - What generates the heat of the Earth (about 30-50% due to U/Th decays).
  - How much U, how much Th? Crust, mantel? (Reactor inside Earth?)
- **Diffuse background of past Supernova**
  - „average“ SN spectrum, star formation rate, „failed“ supernova
- **Indirect dark matter search**
- Oscillation physics: see talks of Hernandez, Zito and Hagner, …

Large Underground Neutrino Detectors: Community Input

- #11 Conclusions of NUTURN Workshop, May 2012
- # 24: Realistic next-generation nucleon decay and neutrino expt. Capable to probe leptonic CP violation
- **# 45: Neutrino and Astroparticle Physics Program of JINR and Russian Institutes : Baksan LSc 5-50 kt**
  - 5 kt option: geo-neutrinos, solar neutrinos, SN neutrinos
  - 50 kt option: full LENA program



- #70: LENA
- #74 LAGUNA-LBNO: CN2PY (Cern to Pyhäsalmi): an opportunity of particle and astroparticle neutrino and GUT physics
- #86 Hyper-Kamiokande

ApPEC ASPERA Astroparticle Physics for Europe

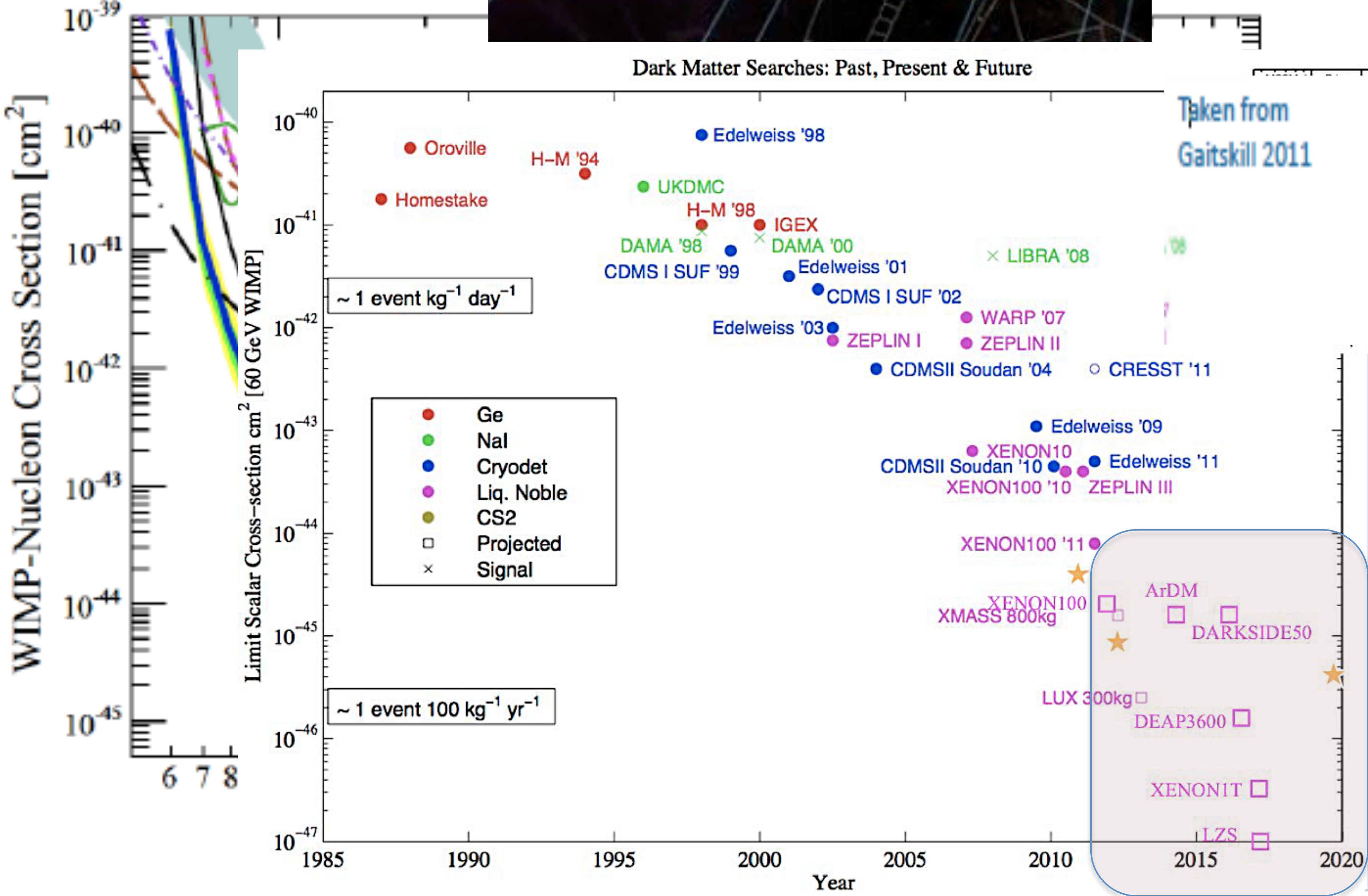
Recommendation: large underground detectors

- program with neutrino beams must be flanked by a strong astroparticle program to justify the high investment. It is important to note that the astroparticle physics topics will be the decision driver for a good part of the community and that therefore the astroparticle physics potential of different options should be considered when examining the overall coherence of a global program. There is an opportunity for a common program on both accelerator based neutrino physics and astro-particle physics that will have more impact than the sum of its parts. We recommend therefore that:

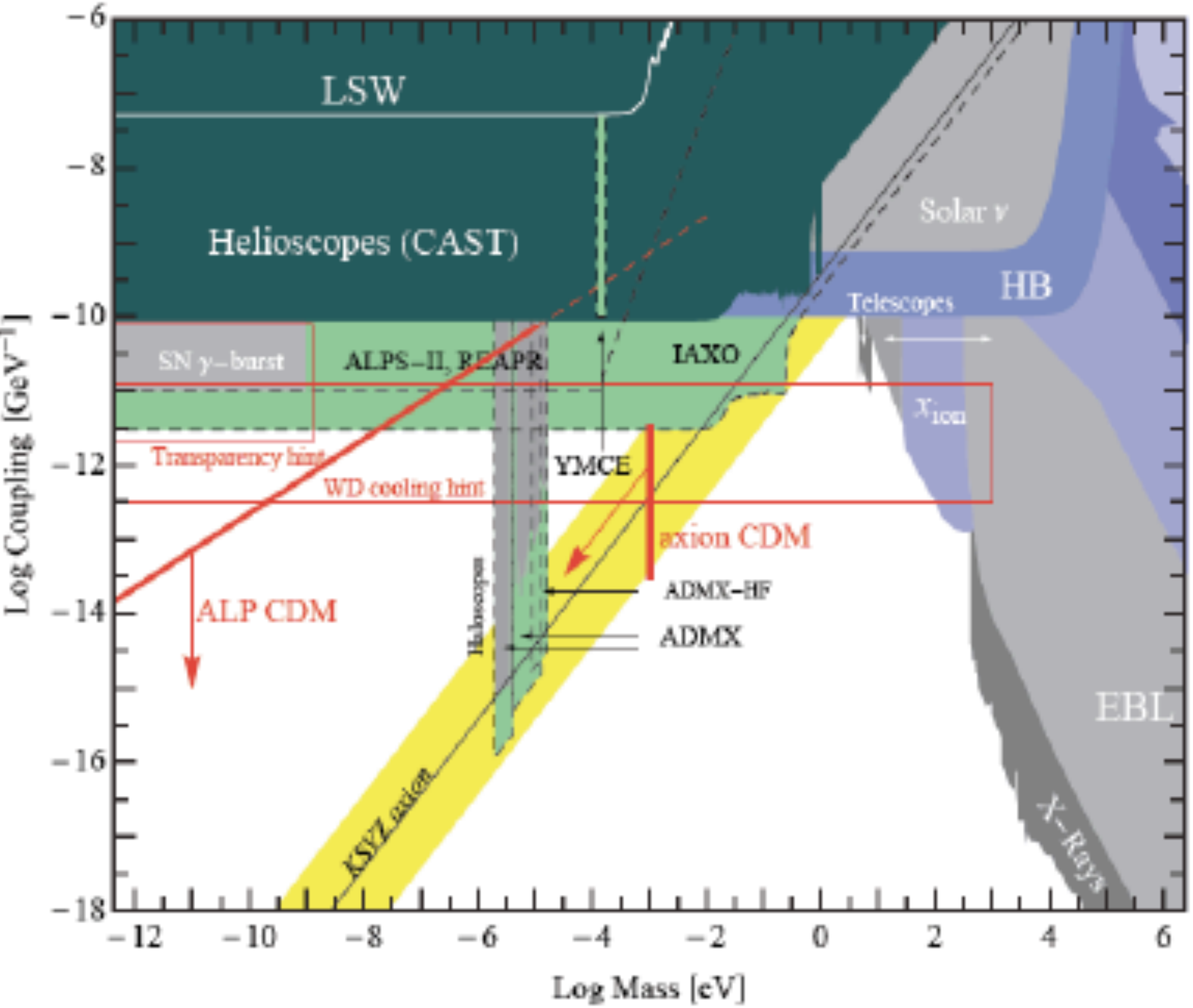
- CERN and the national agencies, as well as ApPEC, should support a vigorous R&D program on neutrino detectors (e.g. liquid argon) and beam design studies (e.g. a neutrino beam to Pyhäsalmi), in anticipation of a critical decision in 2015.
- ApPEC supports the astroparticle physics program that will profit from the synergy with the accelerator-based program (e.g. a liquid scintillation detector in Pyhäsalmi) as well as medium scale astroparticle physics detectors (including feasibility studies for high-density infills of high-energy neutrino telescopes) which can in principle determine the neutrino mass hierarchy and other neutrino parameters.
- **Given the obvious worldwide interest and the high project costs, it is recommended that CERN, together with key European agencies and ApPEC, enter into discussions with their US and Asian counterparts in order to develop a coherent international strategy for this field, including relevant astroparticle physics issues.**

Snapshot Summer 2012

Dark Matter Searches



Parameter space for axions or axion-like particles



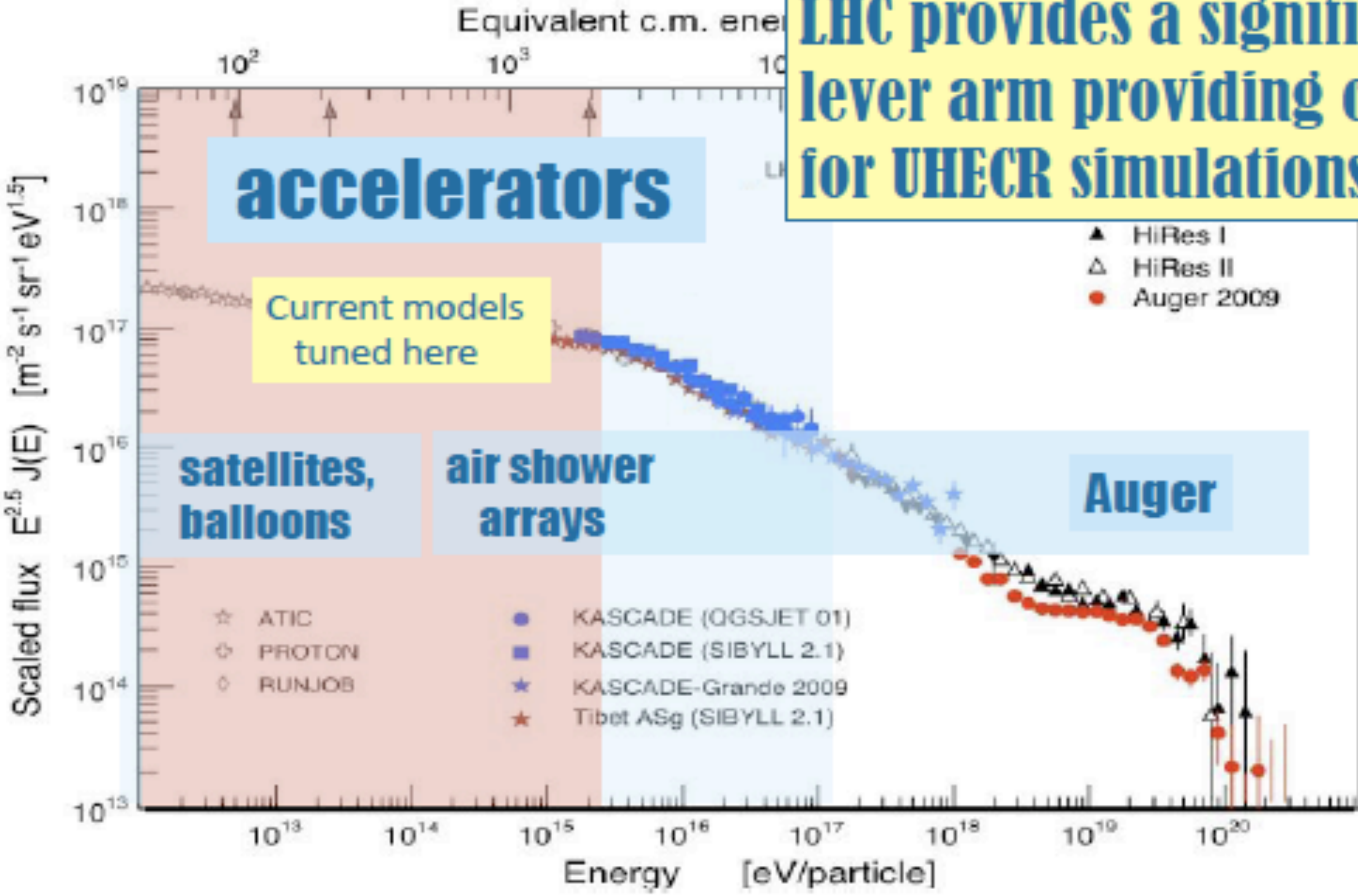
- Experimentally excluded
- Astronomy constraints
- Cosmology constraints
- Sensitivity of planned experiments

IAXO: CAST follow-up

10T magnets, 16m
low-BG/threshold X-ray detectors

50-100 M€

Cosmic Rays and LHC



LHC provides a significant lever arm providing constraints for UHECR simulations !

R. Engel (KIT)

- Establishing an „Astroparticle Physics Forum“ at CERN would intensify co-operation and synergies.

APpEC - summary

- **Dark Matter:**
  - close synergy "direct – indirect – LHC"
  - Direct measurements: → ... → DARWIN, EURECA
- **Double Beta Decay**
  - Cover inverted hierarchy region
  - Phased approach to one-ton detector(s)
- **Nu astronomy and p-decay**
  - Combines fundamental discovery physics and precision physics
  - Combines astro- and particle physics
- **High energy Universe**
  - LHC ↔ air showers
  - Indirect dark matter search
  - Test of fundamental principles

- **Need global approach** (the higher the cost, the more urgent)
- **Install "Astroparticle Physics Forum" at CERN**
- **Closer cooperation between CERN and ApPEC**

ASPERA

Dark Matter I, Direct detection
30 projects distributed worldwide

From Masaki Yamasita

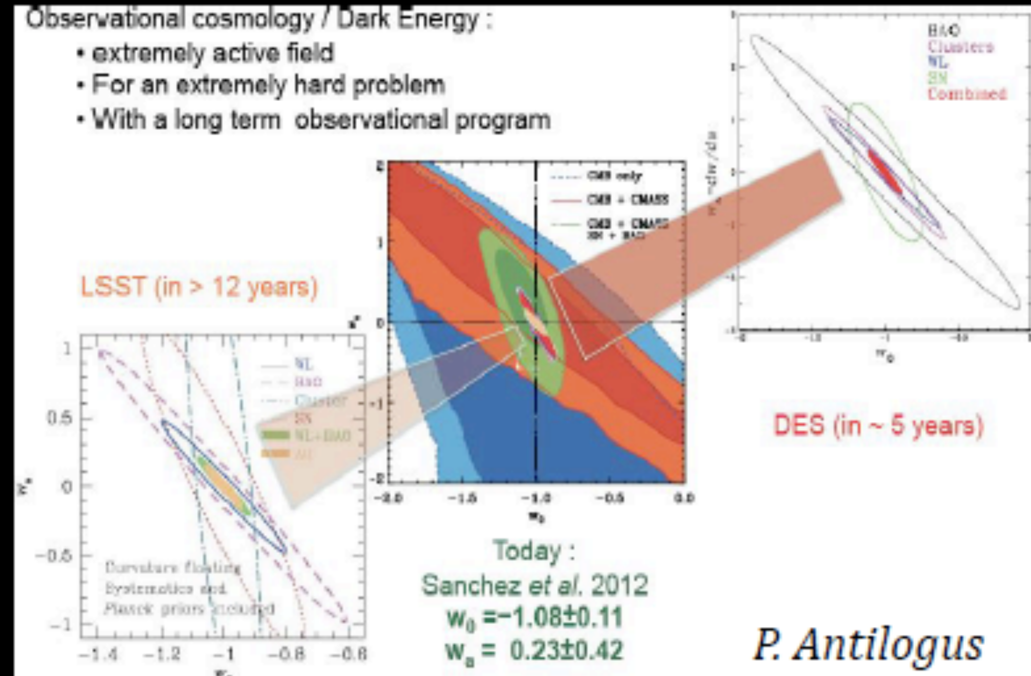
ASPERA

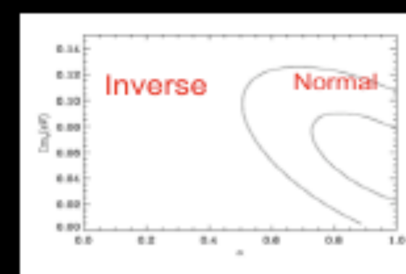
Dark Energy III

The communities and agencies have converged to large sky surveys (FoM > 800) with telescopes (first light 2020) :

•on ground **(LSST, NSF/DOE, 8.4m)**
and
• in space **(EUCLID, ESA, 1.2m)**

• LSST and EUCLID are complementary in systematics (superior spectroscopy vs absence of atmospheric distortion) they are both approved.



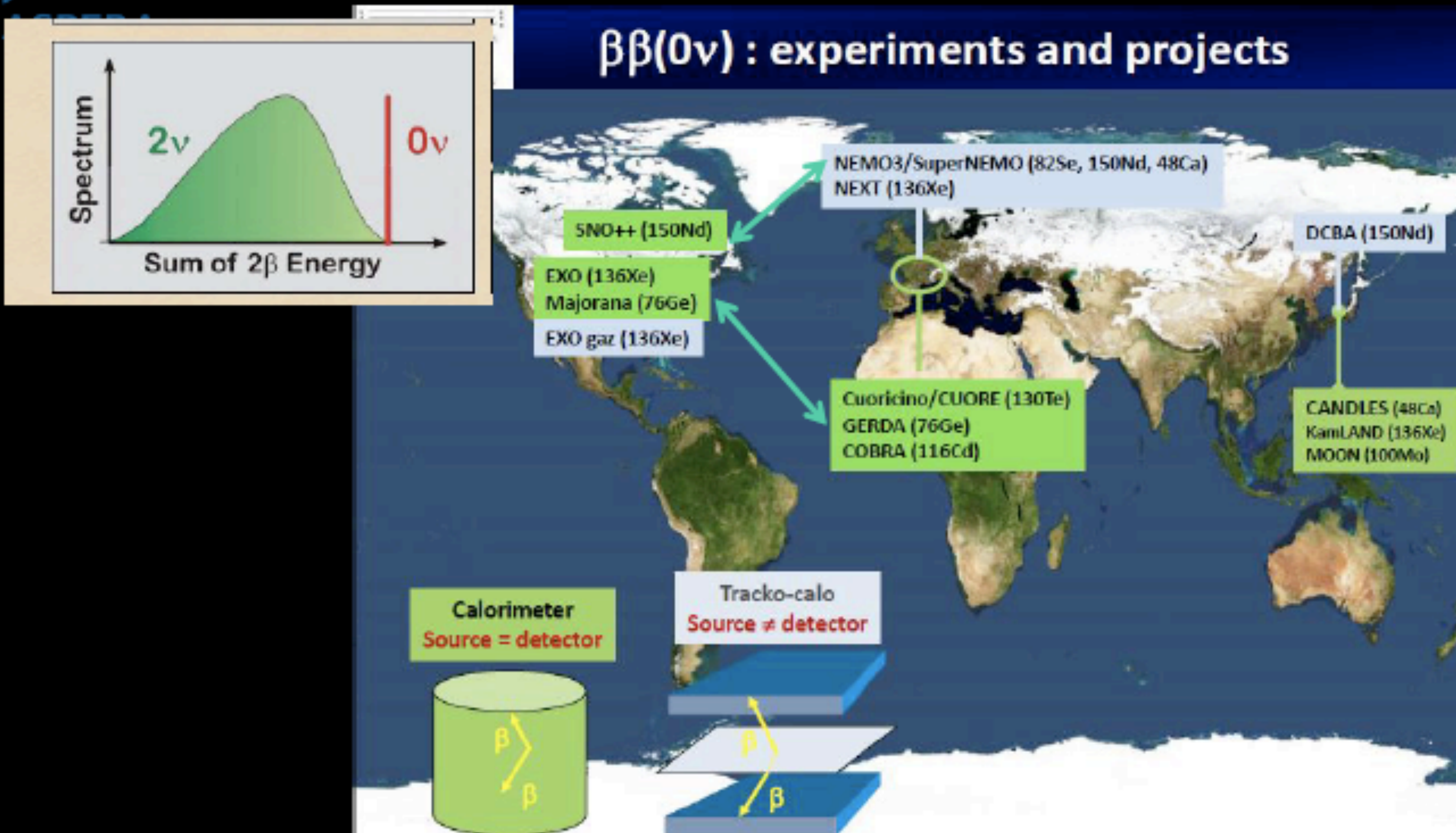


LSST/Euclid will be sensitive to the neutrino mass hierarchy (2022)

From the global coordination point of view:

- *The field has finally a clear long term program with complementary aspects*
- *The data management of e.g. the LSST is challenging and could be scaled in LHC units*
- *An interesting issue, under discussion is the issue of data-availability and exchange between LSST and EUCLID, and of course the rest of the world…*

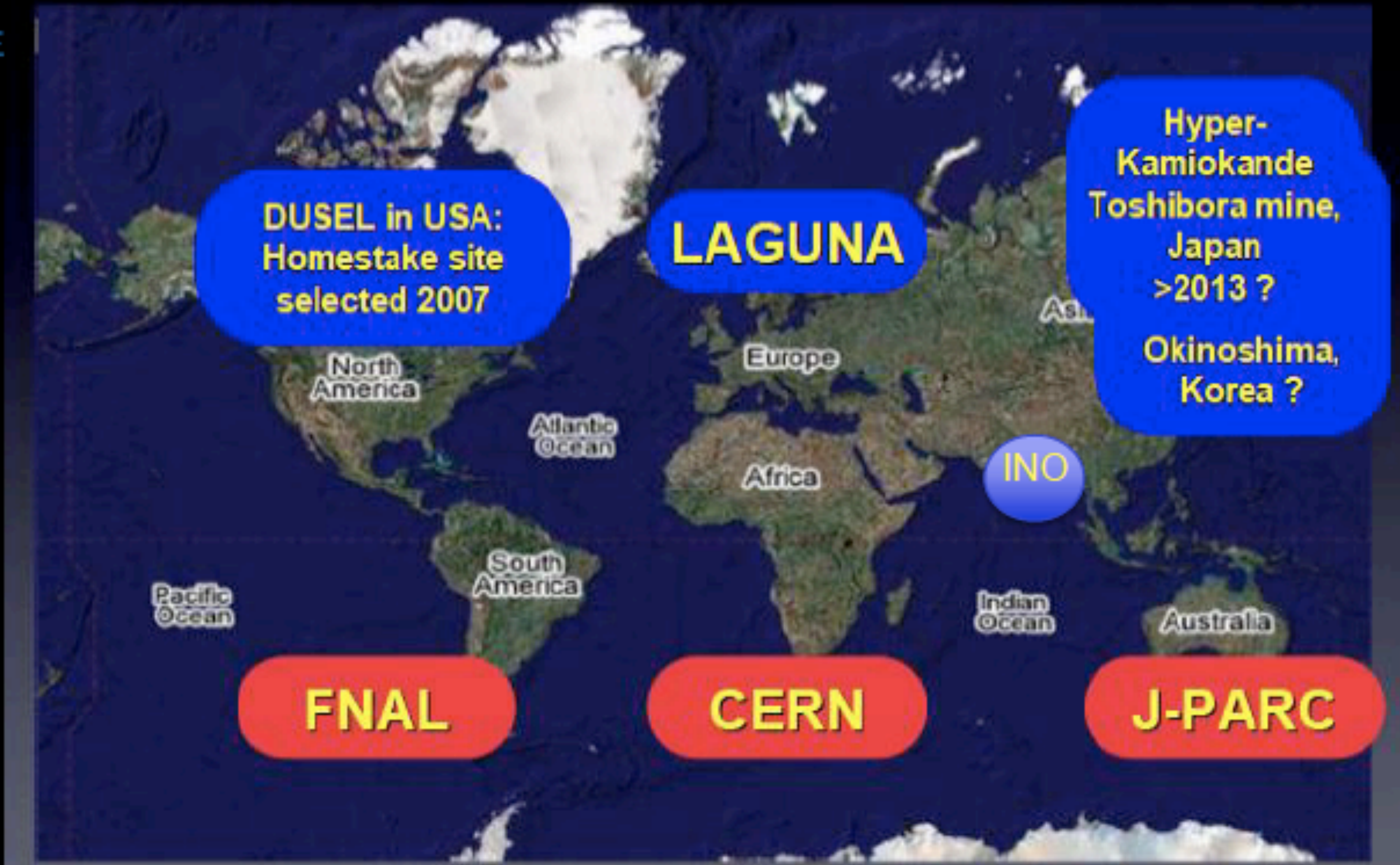
Probing the neutrino mass I, Testing the Majorana nature of neutrinos through the detection neutrinoless double beta decays (which would also provide information about their masses).



Healthy competition among projects is the rule in the investigation of neutrinoless double beta decay. However, global-scale coordination and avoidance of duplication would be beneficial, especially for the procurement of crystals and scarce enriched isotopes (Ge, Nd, Ca). A future generation experiments, using target masses of approximately one ton of isotope, will certainly need international coordination.

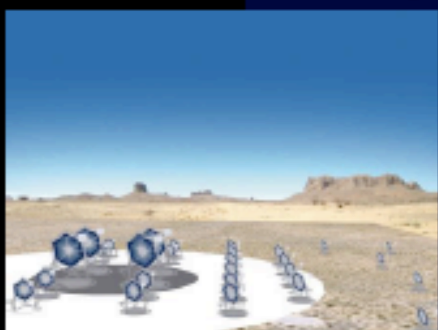
Proton decay I,

"megaton" scale projects for proton decay and neutrino physics



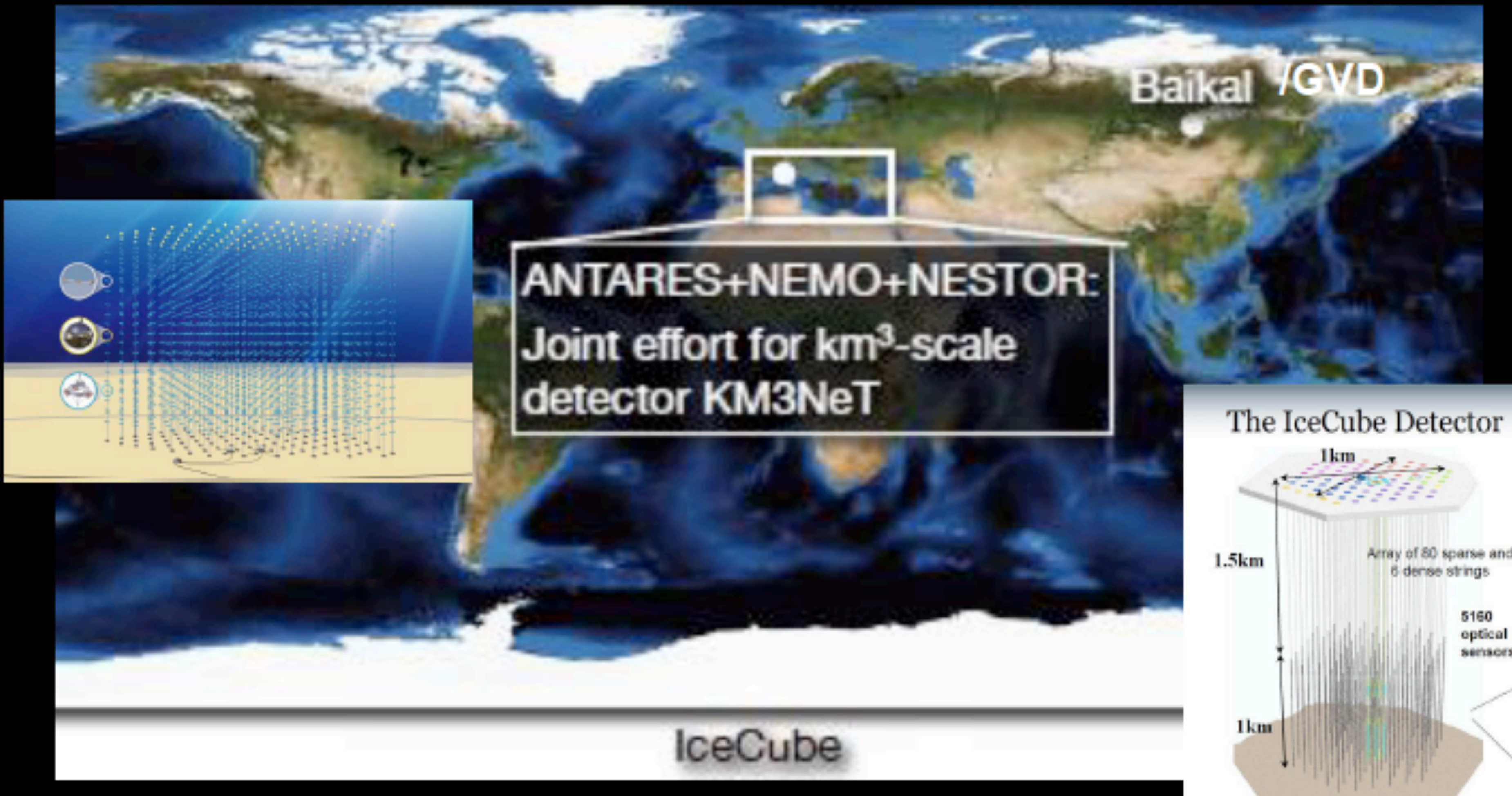
The current surface option for LBNE (+15% to go underground) does not have an astroparticle physics program (see talk by K. Hagner). LAGUNA is covered by S. Spiering. Will not also cover INO and DayaBay II.

High Energy Universe II
High energy gamma ray telescopes



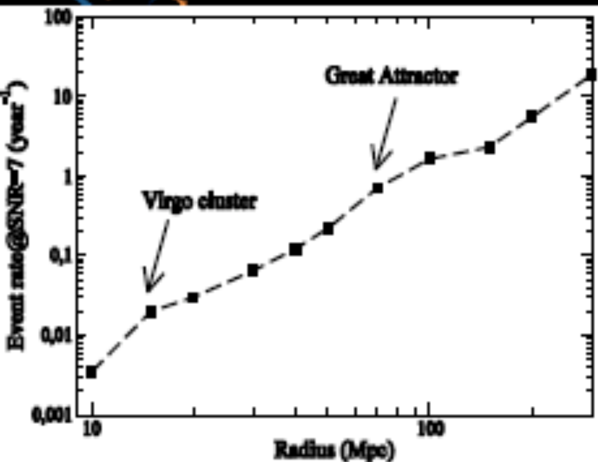
Good convergence. In the domain of TeV gamma-ray astrophysics the **Cherenkov Telescope Array (CTA)** is a worldwide priority project. The ambitious time schedule for technical design and prototype development of CTA, as well as the selection of the site(s), is aiming at a start of construction by the middle of the decade. LHASSO in Tibet will have a complementary coverage. Also MACE for lower energies in India?

High energy Universe IV, HE Neutrino telescopes



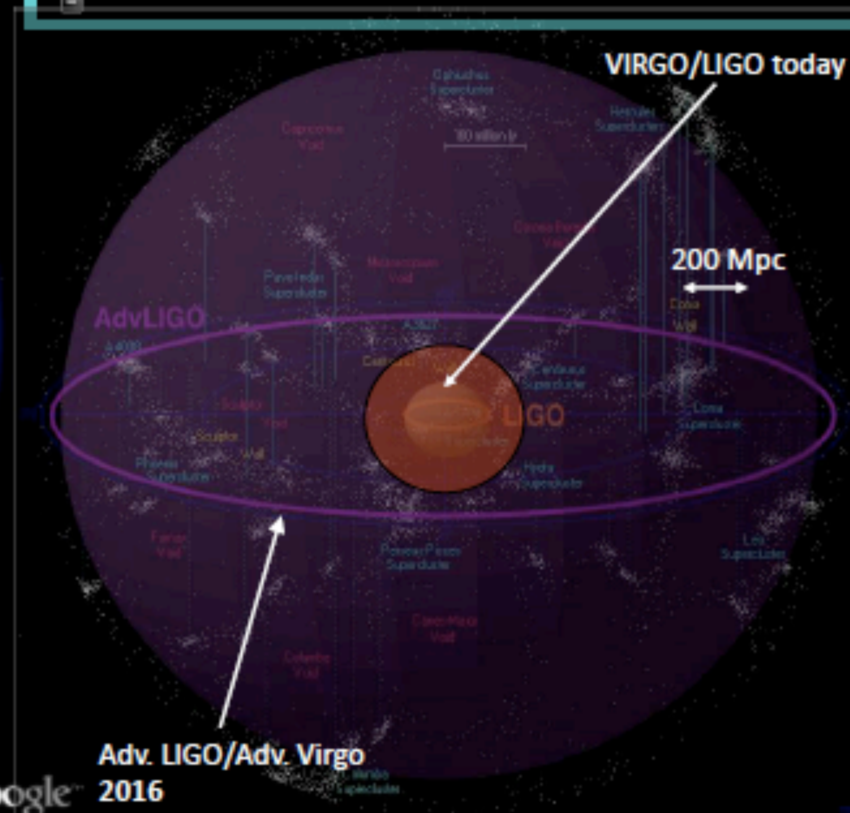
See talk by C. Spiering. Nothern Hemisphere projects and IceCube move through coordination towards a future Global Neutrino Observatory
First exemple PINGU-ORCA

High Energy Universe XII, GW: a first detection by 2017-18?



An inspiring example: World network of gravitational wave antennas:

- ✓ **Sensitivity increase**
- ✓ **Source direction determination**
- ✓ **Polarizations measurement**



Astroparticle physics, gravitation and cosmology - session summary

- **Large variety of exciting experiments and physics topics** - APP community size has grown fast in recent 5 years: in Europe now ~ 2000 scientists
- **The following synergies were identified :**
  - LHC searches for new particles and direct/indirect searches for dark matter , axions
  - Specific models may relate $0\nu\beta\beta$ measurements (low E) and LHC results (high E)
  - Sterile neutrinos and dark matter
  - HE cosmic rays and LHC measurements, eg AUGER and LHC cross sections
  - Next LBL neutrino detector should have capabilities for astroparticle physics to justifty investment ; therefore it should go underground
- **On the role of CERN:**
  - There should be a closer collaboration between ApPEC and CERN, eg exchange of information
  - The CERN convention allows research in the field of cosmic rays
- **Organisation of APP projects:**
  - Present planning stops around 2020 (with exceptions): wait for results for next phases
  - Global planning is needed on worldwide scale
  - APP is in between astrophysics, cosmology and particle physics – which community decides on core business of given project?
  - CERN, national agencies and ApPEC should support R&D program on neutrino detectors & beam design studies

- Concrete physics cases for both long and short baseline neutrino programme can be made. In principle, many of the technology seems to exist for those (i.e. more D than R needed). Long baseline facilities might be a concrete example of coordination between PP and APP.
- Projects to deepen our knowledge in Standard Model are being proposed
- Lets start the discussion, if anytime left….

To conclude I

T. Nakada (

- If we can do everything in everyplace at anytime, we do not need strategy.
- We can do (almost) everything only if we exploit fully the four dimensional space-time → strategy
- Scientific case is a crucial input for setting up the strategy, however…
  - Obviously there is not enough resources.
  - Many non-scientific (political, social, economical, etc.) factors.
  - But also importance for different scientific cases are neither uniquely nor objectively defined: different scientific tastes.
- As nature shows, difference is also strength: but we need compromises, concessions, patience, and determination to reach a strategy!