About
Measuring Leptonic CP Violation
before Retiring

I analyze the current approaches world wide to the measurement. Politics and socioeconomic aspects are important. But Feasibility, Scientific Return, Willingness & Push, and Scientific Policy are crucial. Currently I see only one project with which I could hardly achieve the title.

Luis Labarga, University Autónoma Madrid
I.F.I.C., Valencia, October 22nd 2014

The title I was drafting/trying was ...

Next generation

long base line Neutrino and

Nucleon decay experiment:

what for ?

what ? where ? when ?

when ? what ? where ?

where ? when ? what ?

.....

is there a rationale ?

Goals in Neutrino physics

take for instance:

A Perspective on Neutrino Physics
By Members of the Spanish Neutrino Physics Community

3. Strategic experiments

... the following questions should be answered:

1. Is lepton number violated?
2. Is there CP violation in the lepton sector?
3. What is the neutrino mass ordering, normal or inverted?
4. How many additional degrees of freedom are required by the νSM, and what are they?
5. Is there a new physics scale associated to such additional degrees of freedom? What is this scale?
6. Why is the mixing pattern of leptons so different from quark's

... key experiments are needed to search for them.

$2\beta 0\nu$ type experiments provide extremely valuable information but might not give definite answers (within reasonable time & mass scales). They are large, yet affordable experiments.

- I find them worth
- they are very difficult, however the push of one or a few good physicists might bring the success

NιbιNN will ***(must !)*** **definitely answer** at least 2 & 3. This is a warranty breakthrough in Science.
But, is the needed monster, world-wide experiment worth ?

- undoubtedly **yes** → **go** for it !

- however, the project (as a whole) is huge and we are humans, thus there is much more room to screw it up in the way ... and convert it in a non-sense (relatively) ... and loose the opportunity

A wonderful history/story of related scientific success:

pre-pre-NNN experiments (IBM, Kamiokande, ...)

- started in the search for proton decay,
- but became wonderful neutrino telescopes

because of that, funding came for pre-NNN (Super-Kamiokande)

- to make perfect machines to learn Fundamental Science from Atmospheric Neutrinos
- and Solar Neutrinos
- and ...

the corresponding pre-NlblNN (K2K ... T2K)

- confirmed in a controlled way the discoveries above
- about to discover, just confirmation though, of large θ_{13}

... no prejudices, lots of common sense in scientific policy, lots of Science ...

Needed: No prejudices, Lots of common sense in scientific policy, Lots of Science

We are talking about an extremely expensive experiment, ≈ 750 M€, paid by the tax payers; only the above will be finally accepted ... by all of us

It must tackle in a timely way **all that only this** type of experiment **can** tackle:

- Neutrino Mass Hierarchy,
- CP Violation in the lepton sector,
- Proton Decay
- Atmospheric and Solar Neutrino Physics
- Neutrino Astrophysics
- Neutrino-induced dark matter searches

If it doesn't, if it only pursues one or two of them, one would have to pay twice for the same physics ... but nobody will be providing the needed funding

LBNO: text-book example of a non-fundable project

What was LAGUNA ?

some sort of first "European approach"
[main funding from E.U., 1.7 M€]
towards next generation liquid [Mt-like]
p-decay and neutrino experiment

➔ The goal was the Feasibility Study of the seven candidate sites:

- CUPP @ Pyhäsalmi mine, Finland
- IUS @ Boulby mine, UK
- SUNLAB @ Sieroszowice mine, Poland
- IFIN-HH @ Unirea mine, Romania
- LSM @ Frejus tunnel, France
- New-Site @ CNGS beam halo, Italy
- *LSC @ Canfranc RW tunnel, Spain*

to host any of 3 considered detectors

- Liquid-Scintillator: ~ 0.05 Mt
- Liquid-Argon TPC: ~ 0.1 Mt
- *Water-Cherenkov: ~ 1 Mt*

a lot of work by LL here

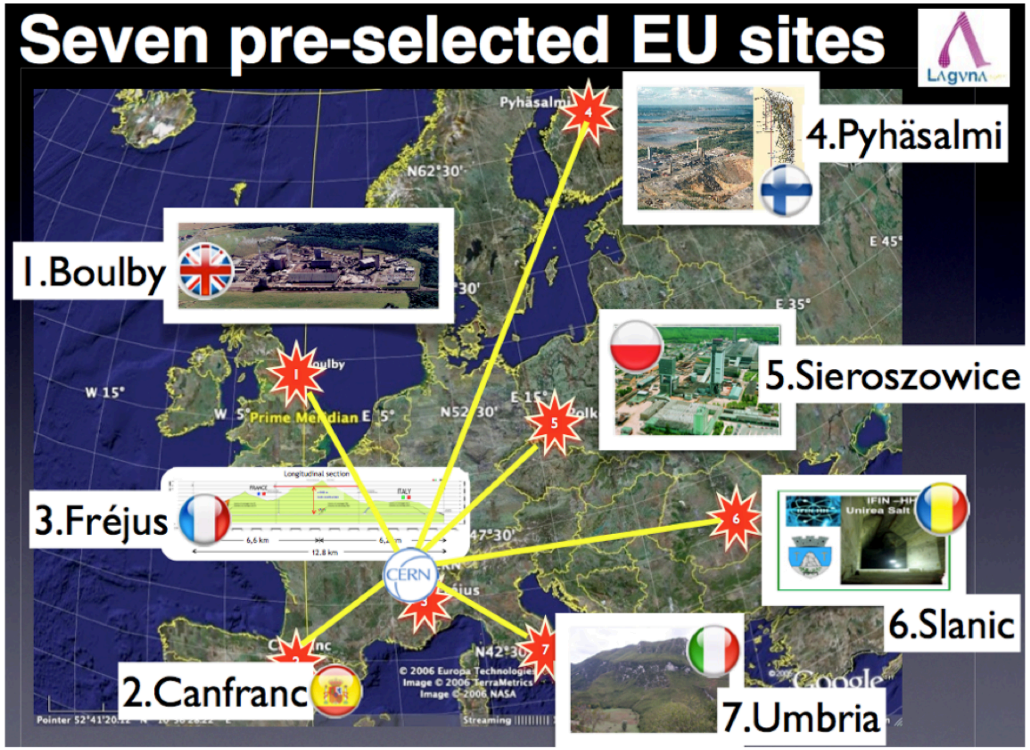
having in mind a possible new ν beam from CERN, and that the value of θ_{13} might be known within a not too distant future … [now it is known…]

LAGUNA-LBNO
E.U.-FP7 LAGUNA-LBNO-284518
Document Of Work
July 14th , 2011

time passes

θ_{13} **is large**

decision is taken



LBNO,
Expression of Interest
SPSC-EOI-007
June 28th, 2012

Europe has thus *a priori* the benefit of more flexibility in choice of beam, baseline, and detector technology. Recognising the challenge of investigating all these options we will focus on two combinations and compare them to an option based on the existing infrastructure.

this was a clear a priori mistake for LAGUNA;
why was it committed ?

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

SPSC-EOI-007

Expression of Interest

for a very long baseline neutrino oscillation experiment

(LBNO) (Dated: June 28, 2012)

(CN2PY). The beam will be aimed at a next generation deep-underground neutrino observatory comprising a double phase liquid argon (LAr) detector and a magnetized iron calorimeter, located at the Pyhäsalmi (Finland) mine at a distance of 2300 km.

. . . . . .

niques. An initial 20 kton LAr fiducial volume, as considered here, comparable to the fiducial mass of SuperKamiokande and NOvA, offers a new insight and an increase in sensitivity reach for many physics channels. A magnetized iron calorimeter with muon momentum and charge determination collects an

. . . . . .

the δ_{CP} violating phase from global fits of all available data. With an exposure of 2.25×10^{20} p.o.t. from the SPS at 400 GeV, a conclusive determination ($> 5\sigma$ C.L.) of the neutrino mass hierarchy is possible for *any* value of δ_{CP}. Although limited by statistics in the initial configuration, the L/E method also yields a clean measurement of the CP-violating phase. With 1×10^{21} p.o.t., the existence of CP-violation (CPV) can be demonstrated at the 90%C.L. for $\sim$ 60% of the δ_{CP} parameter space. This CPV-sensitivity is achievable in ~12 years at the upgraded SPS. It improves further with the

Expectations for determining M.H. at LBNO

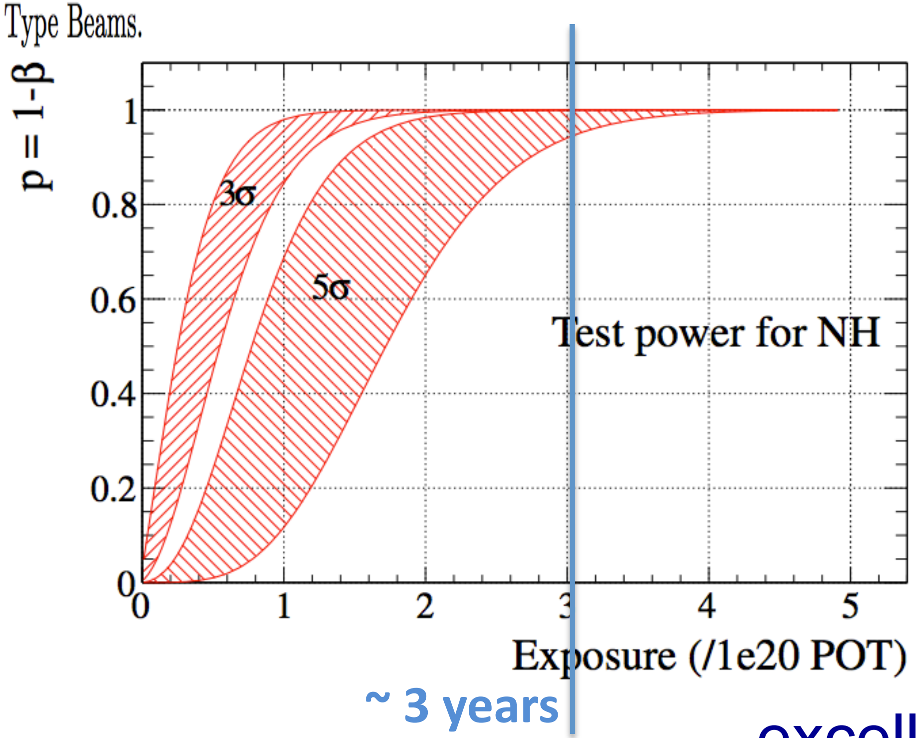
LAGUNA-LBNO, JHEP 05 (2014) 094

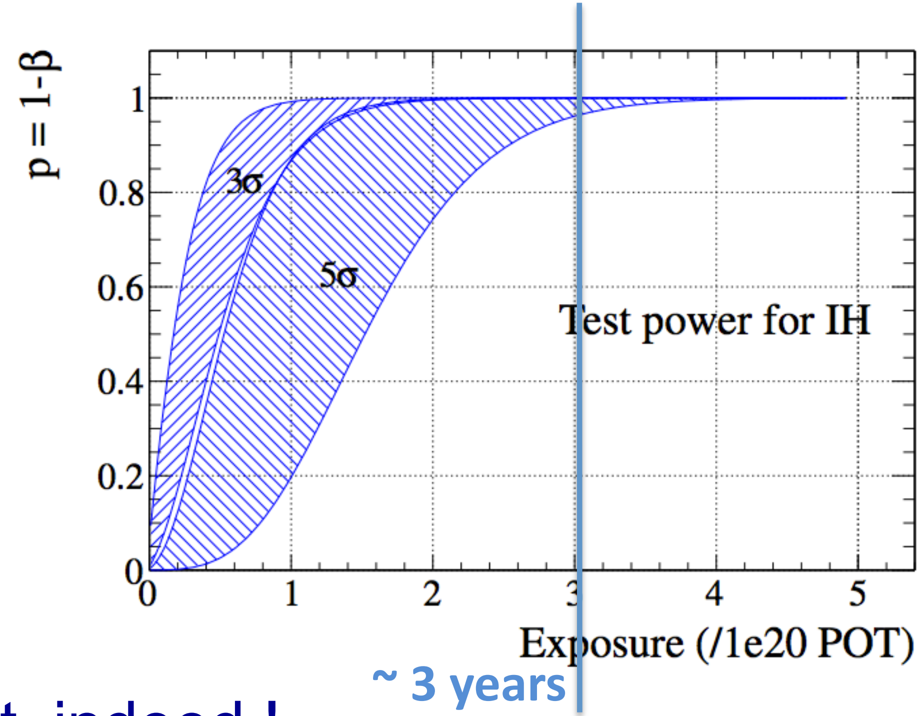
	CNGS	RECORD	LBNO
$E_{\rm SPS}$ [GeV]	400	400	400
Bunch spacing [ns]	5	5	5
$I_{\rm bunch}$ [$\times 10^{10}$]	1.05	1.3	1.7
$N_{\rm bunches}$	4200	4200	4200
$I_{\rm SPS}$ [$\times 10^{13}$]	4.4	5.3	7.0
$I_{\rm PS}$ [$\times 10^{13}$]	2.3	3.0	4.0
PS cycle length [s]	1.2	1.2	1.2/2.4
SPS cycle length [s]	6.0	6.0	6.0/7.2
$E_{\rm PS}$ [GeV/c]	14	14	14
Beam power [kW]	470	565	747/622

Table 1: Present, All-time Record, and Possible Future SPS Parameters for Neutrino Type Beams.

Parameter	SPS beam	HP-PS beam
$E_{\rm beam}[GeV]$	400	$50 \div 75$
$I_{\rm beam}[ppp]$	7×10^{13}	$2.5 \div 1.7 \times 10^{14}$
Cycle length [s]	6	1
$P_{\rm beam}[MW]$	0.750	2
$\rm POT_{year}$ [10^{21}]	$0.10 \div 0.14$	$3.46 \div 2.35$

Table 2: Key parameters of the assumed LBNO proton beam from the SPS and HP-PS [29].





excellent, indeed !

However: expectations for measuring CPV at LBNO

LAGUNA-LBNO, JHEP 05 (2014) 094

	CNGS	RECORD	LBNO
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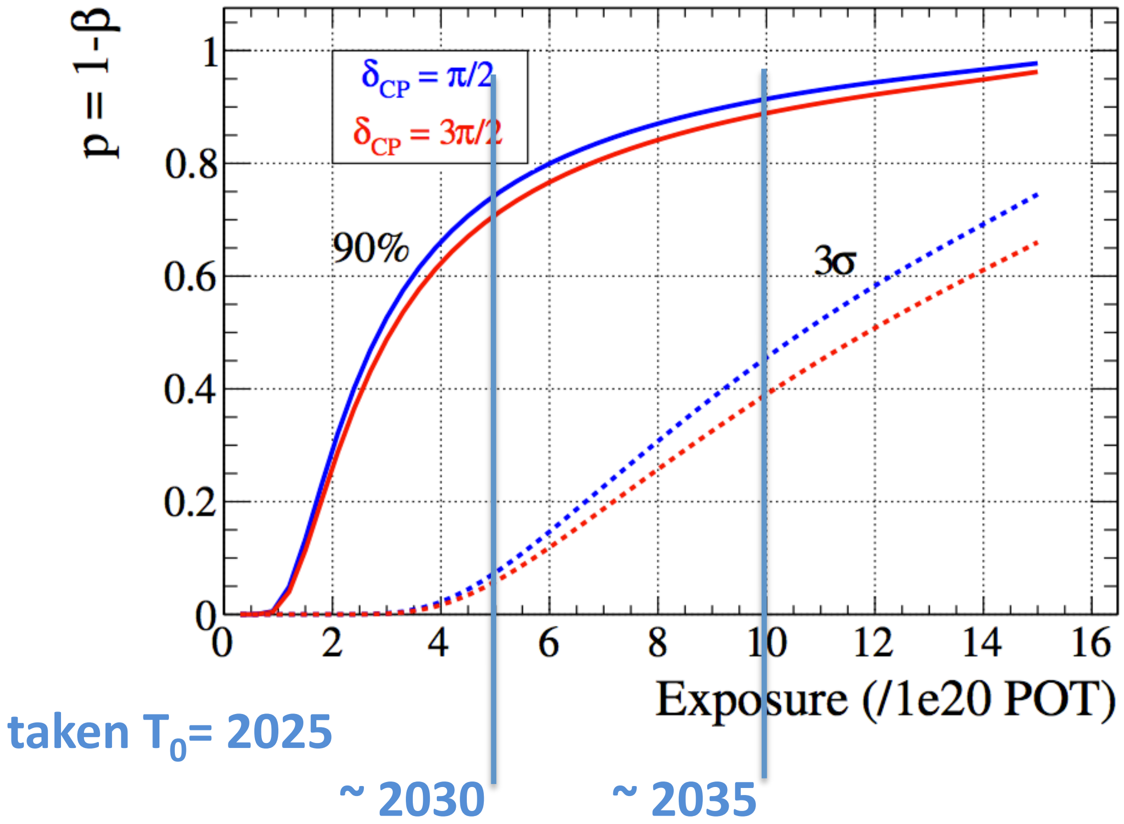

no funding agency will fund this, I guess

(however we are humans)

Helsinki, 18.12.2012

TEM/2908/30.01.06/2012

Prof. Dr. Andrè Rubbia
Institute of Particle Physics
ETH Zürich
HPK F 23
CH-8093 Zürich, Switzerland

Dear Professor Rubbia,

Thank you for your letter of 20th November 2012 regarding the creation of a pan-European deep-underground LAGUNA Observatory at Pyhäsalmi.

We have followed preliminary preparations of the LAGUNA project with great interest. The Finnish stakeholders have kept us well informed of the different aspects of the project during all these years.

The LAGUNA project is of great scientific interest and value at the global level, and in Finland we are pleased that our researcher community has been active in the project since the very beginning. After thorough consideration between the relevant ministries, we have, however, reached the conclusion that Finland cannot commit herself to host the Laguna, mainly because of the very heavy costs involved and a limited national scientific community in the country in this area. We have identified the need to upgrade our scientific infrastructures as one of the most urgent science policy actions, and we are painfully aware that in the coming years we will hardly be able to finance even the most highly prioritized infrastructures due to stringent public budgets ahead of us.

Yours sincerely,

Jukka Gustafsson
Minister of Education and Science

Jan Vapaavuori
Minister of Economic Affairs

DG/2013/263

12 September 2013

MEMORANDUM

To : S. Bertolucci, S. Lettow, S. Myers

From : R. Heuer

cc : M. Nessi

Subject : **CERN Neutrino Project**

Following the events of the last few months and in line with the approved European Strategy, an initial project is starting at CERN, with the aim to provide an effective platform for future neutrino research activities at CERN and/or outside CERN.

The proposal SPSC-P-347 (ICARUS-NESSiE) and the expression of interest SPSC-E-007 (LAGUNA) have been conditionally approved by the August 2013 CERN Research Board with the CERN code WA104 and WA105 respectively. Conditionally implies that at this moment in time the construction of a short-baseline neutrino beam is not granted and the focus is mainly on detector technology development and qualification in test beams.

The initial LOI for a CENF neutrino facility should proceed towards concluding the detailed studies in early 2014, to allow a timely implementation, in case a positive decision would be taken in this direction.

The on going discussions and R&D plans with the US and the Japanese Colleagues should continue, in view of presenting to the CERN management a plan towards a major Intensity Frontier Facility, according to the European Strategy decision.

A CERN project is now created with the aim to foster collaboration with all partners mentioned above and to create an effective research platform, supported by CERN, for a future neutrino research activity involving European partners.

The above-mentioned CERN project will be coordinated Marzio Nessi, as CERN project coordinator who reports directly to the CERN Directorate.

*****

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-SPSC-2014-013
SPSC-TDR-004
March 31st, 2014

LBNO-DEMO

Large-scale neutrino detector demonstrators for phased performance assessment in view of a long-baseline oscillation experiment

The LBNO-DEMO (WA105) Collaboration

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LAPP, Université de Savoie, CNRS/IN2P3, Annecy-le-Vieux, France

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Institut de Fisica d'Altes Energies (IFAE), Bellaterra (Barcelona), Spain

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Faculty of Physics, University of Bucharest, Bucharest, Romania

I. Efthymiopoulos and M. Nessi
CERN, Geneva, Switzerland

R. Asfandiyarov, A. Blondel, A. Bravar, F. Cadoux, A. Haesler, Y. Karadzhov, A. Korzenev, C. Martin, E. Noah, M. Ravonel, M. Rayner, and E. Scantamburlo
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R. Bayes and F.J.P. Soler
University of Glasgow, Glasgow, United Kingdom

G.A. Nuijten
Rockplan Ltd., Helsinki, Finland

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Department of Physics, University of Jyväskylä, Finland

M. Campanelli
Dept. of Physics and Astronomy, University College London, London, United Kingdom

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Horia Hulubei National Institute of R&D for Physics and Nuclear Engineering - IFIN-HH, Magurele, Romania

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I. Karpikov, A. Khotjantsev, Y. Kudenko, A. Mefodiev, O. Mineev, T. Ovsiannikova, and N. Yershov
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T. Enqvist and P. Kuusiniemi
University of Oulu, Oulu, Finland

C. De La Taille, F. Dulucq, and G. Martin-Chassard
OMEGA Ecole Polytechnique/CNRS-IN2P3, route de Saclay, Palaiseau, France

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UPMC, Université Paris Diderot, CNRS/IN2P3, Laboratoire de Physique Nucléaire et de Hautes Energies (LPNHE), Paris, France

L. Agostino, M. Buizza-Avanzini, J. Dawson, D. Franco, P. Gorodetzky, D. Kryn, T. Patzak, A. Tonazzo, and F. Vannucci
APC, AstroParticule et Cosmologie, Université Paris Diderot, CNRS/IN2P3, CEA/Irfu, Observatoire de Paris, Sorbonne Paris Cité, 10, rue Alice Domon et Léonie Duquet, 75205 Paris Cedex 13, France

O. Bésida, S. Bolognesi, A. Delbart, S. Emery, V. Galymov, E. Mazzucato, G. Vasseur, and M. Zito
IRFU, CEA Saclay, Gif-sur-Yvette, France

M. Bogomilov, R. Tsenov, and G. Vankova-Kirilova
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M. Friend, T. Hasegawa, T. Nakadaira, K. Sakashita, and L. Zambelli
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F. Bay, C. Cantini, P. Crivelli, L. Epprecht, A. Gendotti, S. Di Luise, S. Horikawa, S. Murphy, K. Nikolics, L. Periale, C. Regenfus, A. Rubbia*, D. Sgalaberna, T. Viant, and S. Wu
ETH Zurich, Institute for Particle Physics, Zurich, Switzerland

F. Sergiampietri
ETH Zurich, Institute for Particle Physics, Zurich, Switzerland and INFN-Sezione di Pisa, Italy

another generation of
experimental neutrino physics
lost in Europe !

European Strategy for Particle Physics
Adopted by the CERN Council
https://europeanstrategygroup.web.cern.ch/EuropeanStrategyGroup/
5th Open Hyper-K Collaboration meeting

Vancouver, Canada, 20-22 July 2014

T. Nakada
EPFL-LPHE
Lausanne, Switzerland
Last Scientific Secretary for Strategy Session of CERN
Chairing Strategy Group and Preparatory Group

To conclude

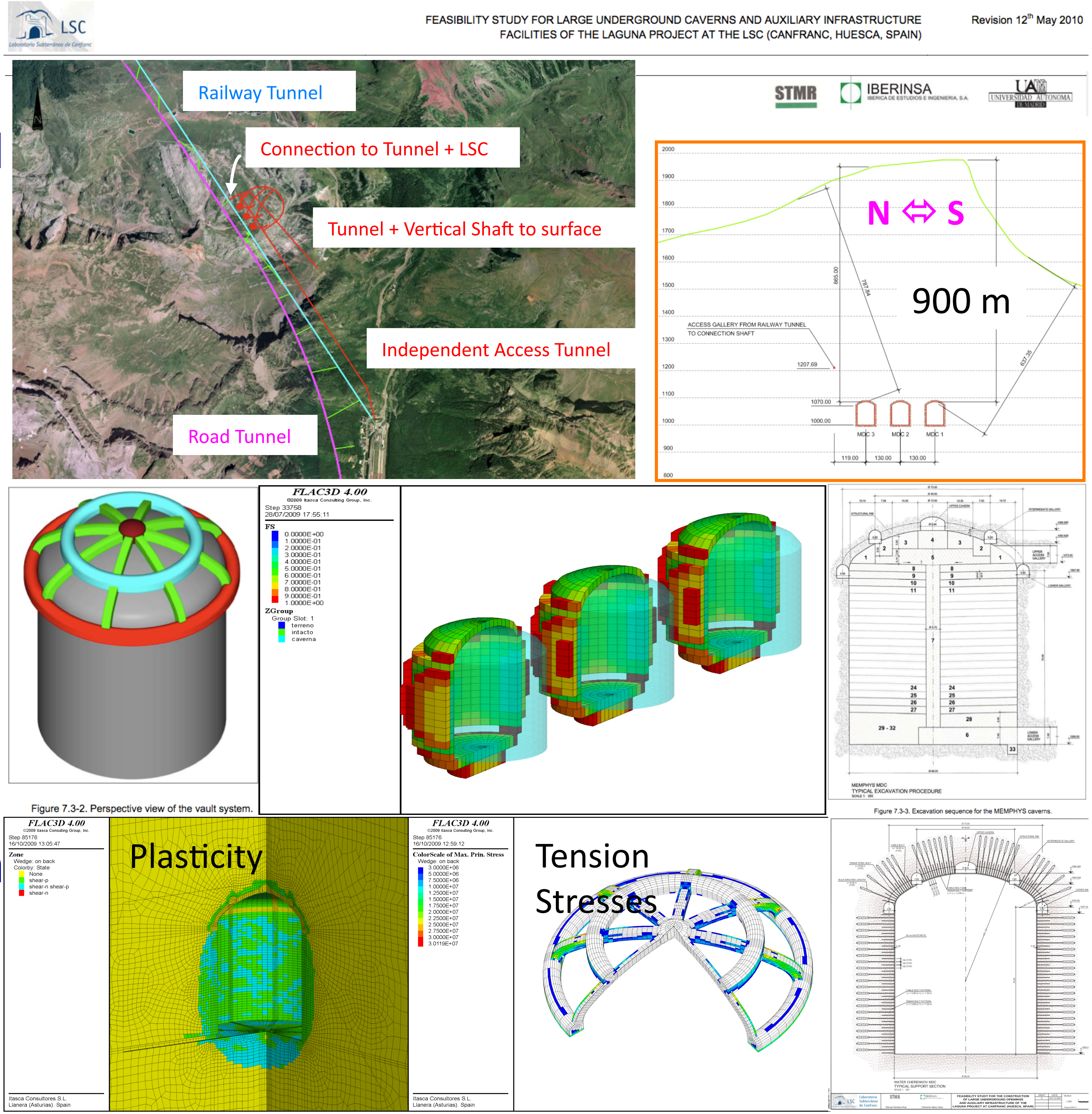
- The current European Strategy does not envisage construction of a long baseline neutrino beam experimental facility
- It, however, foresees CERN to construct infrastructure for detector R&D
- Its implementation, CERN neutrino platform, is in place now
- Detector funding will primarily come from the national funding agencies
- CERN contribution could be possible for accelerator related items, in-kind.
- For detector contribution from CERN, participation of CERN research physicists in the project needed.

Note that it could have not been the case.

For instance:
a ~ 500 kt f.v. W.C. detector

@ Canfranc
(or LNGS)

with a ~700 kW CNGS-like beam from CERN



European Strategy for Particle Physics

CERN Council Open Symposium on

European Strategy for Particle Physics

10 – 12 September 2012, Kraków, Poland

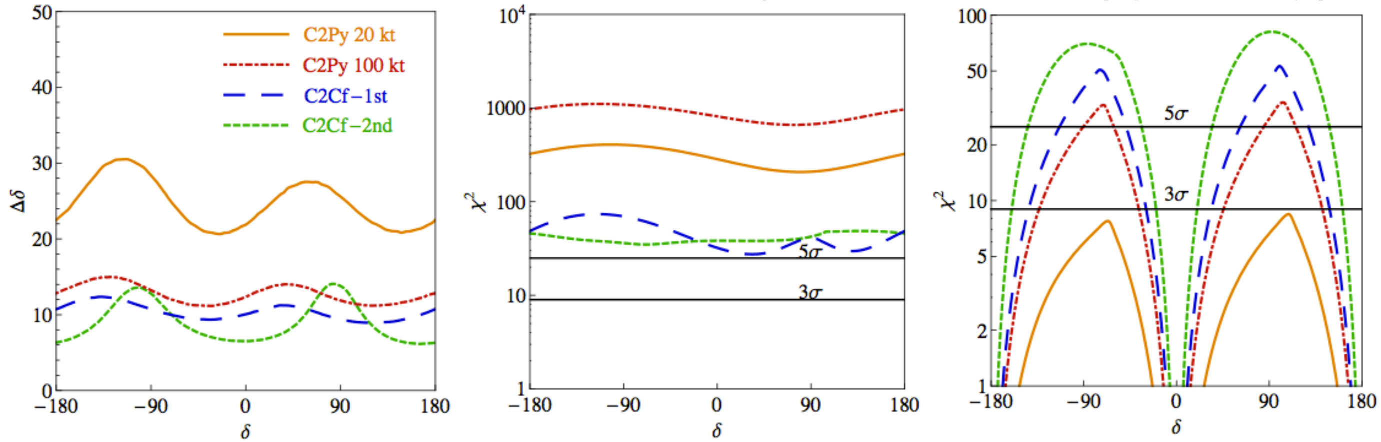
AGH UST, IFJ PAN, The M. Smoluchowski Scientific Consortium, Kraków

Foundation for the AGH University of Science and Technology

Contribution ID : 24

A realistic next-generation nucleon decay and neutrino experiment capable to probe leptonic CP violation

Primary authors : FERNANDEZ MARTINEZ, Enrique () ; LABARGA, Luis (Departam.de Fisica Teorica)



Next Generation Accelerator Neutrino Projects - Long and Short Baseline

Marco Zito, IRFU/SPP CEA-Saclay

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

*: if mass hierachy is known

an excellent experiment to pursue !

crossing the Atlantic:

Building for Discovery

Strategic Plan for U.S. Particle Physics in the Global Context

Report of the Particle Physics Project Prioritization Panel (P5)

HEPAP
22 May 2014

S. Ritz

2014 P5 Report Building for Discovery

U.S. Department of Energy
and the
National Science Foundation

Professor Andrew Lankford
Chair, HEPAP
University of California at Irvine
4129H Frederick Reines Hall
Irvine, CA 92697

Dear Professor Lankford:

Much has changed since the last long-range planning document for high energy physics was endorsed by HEPAP (the Particle Physics Project Prioritization Panel (P5) report, submitted in 2008). It is therefore an opportune time to revisit this guidance to the DOE and the NSF. To that end, we ask that you constitute a new P5 panel to develop an updated strategic plan for U.S. high energy physics that can be executed over a 10 year timescale, in the context of a 20-year global vision for the field.

.....

We would appreciate the committee's preliminary comments by March 1, 2014 and a final report by May 1, 2014. We understand this is a difficult task; however your considerations on these issues will be an essential input to planning at both the DOE and NSF.

Sincerely,

Patricia M. Dehmer
Acting Director, Office of Science
U.S. Department of Energy

Dr. F. Fleming Crim
Assistant Director
Directorate for Mathematical and Physical Sciences
National Science Foundation

Recommendation 12: In collaboration with international partners, develop a coherent short- and long-baseline neutrino program hosted at Fermilab.

we set as the goal a mean sensitivity to CP violation[2] of better than 3σ (corresponding to 99.8% confidence level for a detected signal) over more than 75% of the range of possible values of the unknown CP-violating phase δ_{CP}.

The minimum requirements to proceed are the identified capability to reach an exposure of at least 120 kt*MW*yr by the 2035 timeframe, the far detector situated underground with cavern space for expansion to at least 40 kt LAr fiducial volume, and 1.2 MW beam power upgradable to multi-megawatt power. The experiment should have the demonstrated capability to search for supernova (SN) bursts and for proton decay, providing a significant improvement in discovery sensitivity over current searches for the proton lifetime.

Key preparatory activities will converge over the next few years: in addition to the international reformulation described above, PIP-II design and project definition will be nearing completion, as will the necessary refurbishments to the Sanford Underground Research Facility. Together, these will set the stage for the facility to move from the preparatory to the construction phase around 2018. The peak in LBNF construction will occur after HL-LHC peak construction.

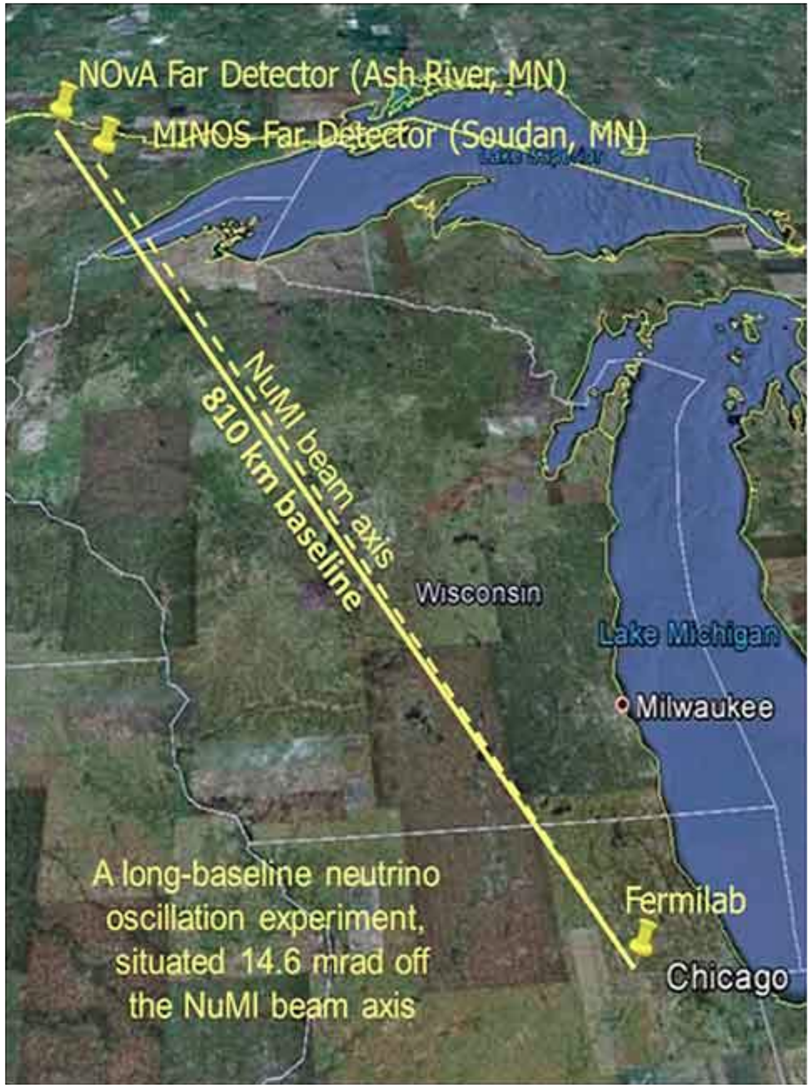
Recommendation 13: Form a new international collaboration to design and execute a highly capable Long-Baseline Neutrino Facility (LBNF) hosted by the U.S. To proceed, a project plan and identified resources must exist to meet the minimum requirements in the text. LBNF is the highest-priority large project in its timeframe.

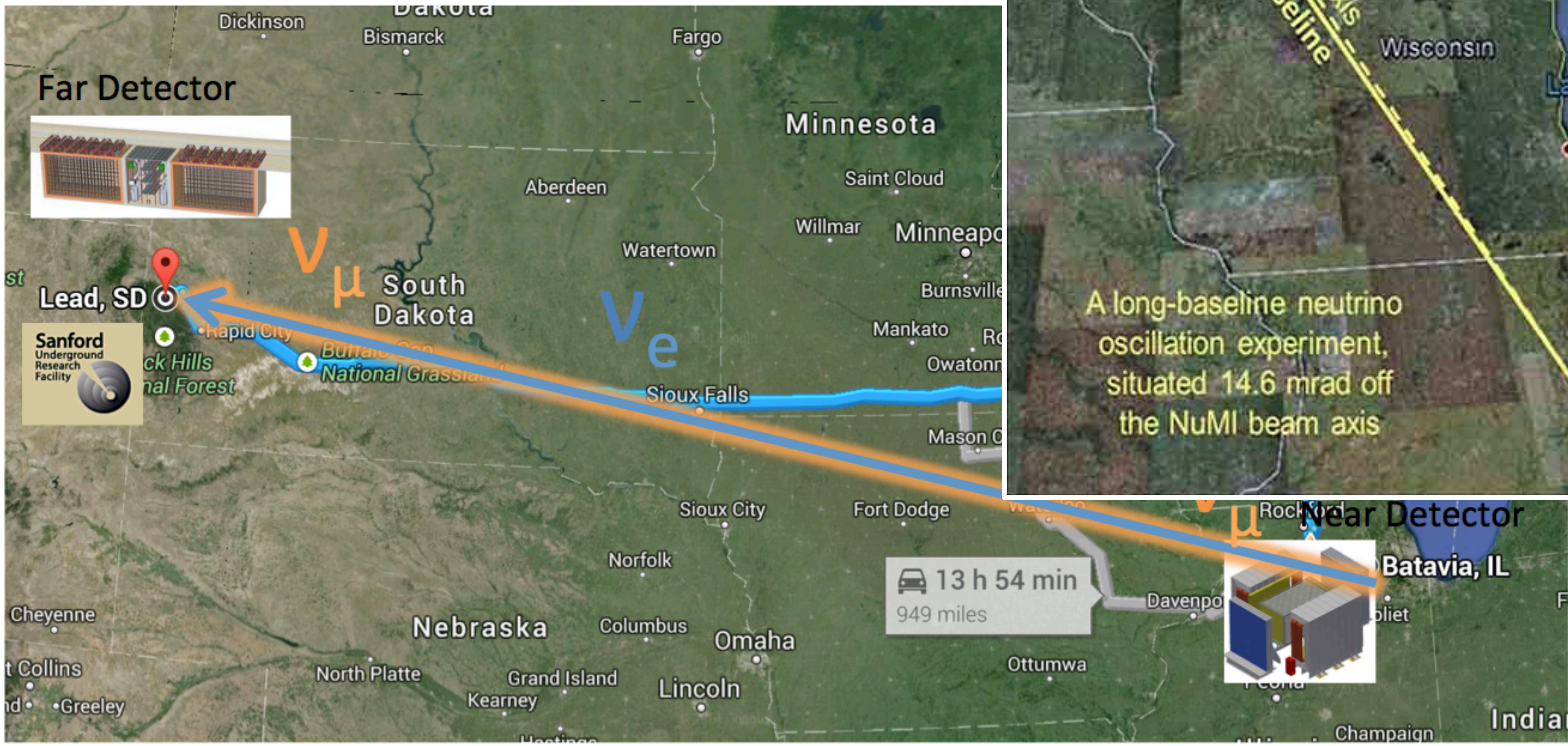
Recommendation 14: Upgrade the Fermilab proton accelerator complex to produce higher intensity beams. R&D for the Proton Improvement Plan II (PIP-II) should proceed immediately, followed by construction, to provide proton beams of >1 MW by the time of first operation of the new long-baseline neutrino facility.

I like NOvA (in its context)

I do not like LBNE (it its context)

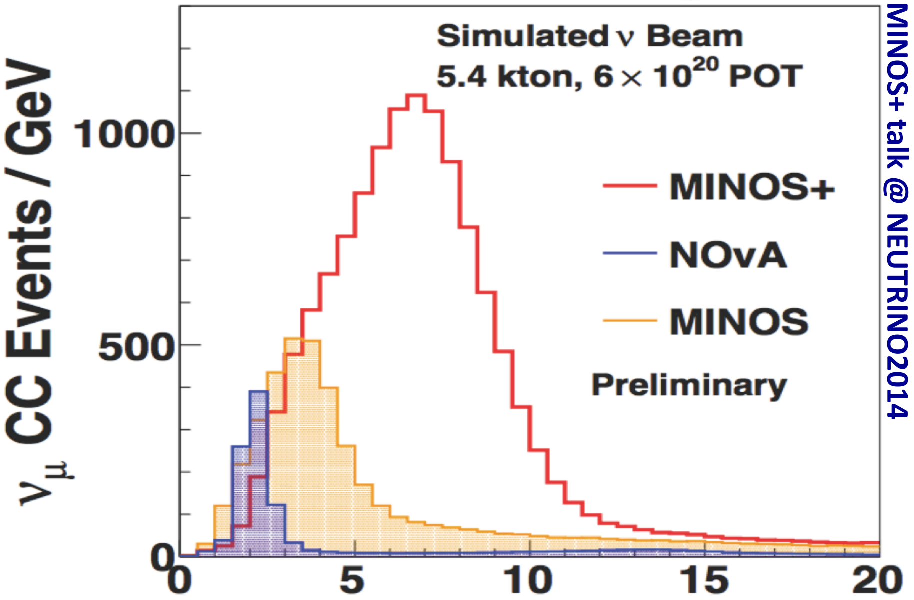
- why LArg ?
- **why** Sanford is a must ?
  - originally LBNE FD was planned on surface !
  - It implies a **new** beam line !





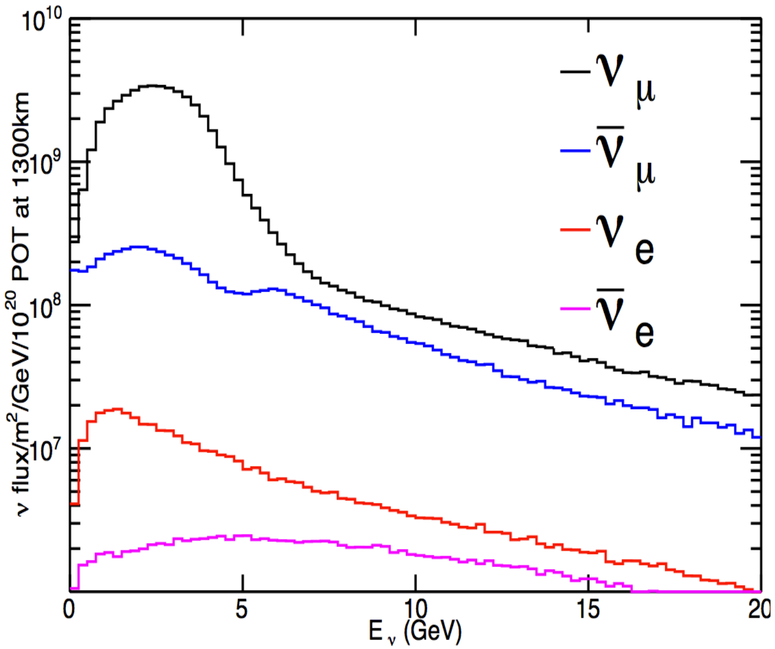
some different would be a ~200 kt WC at second maxima in an off-axis beam …

Beam to Minnesota



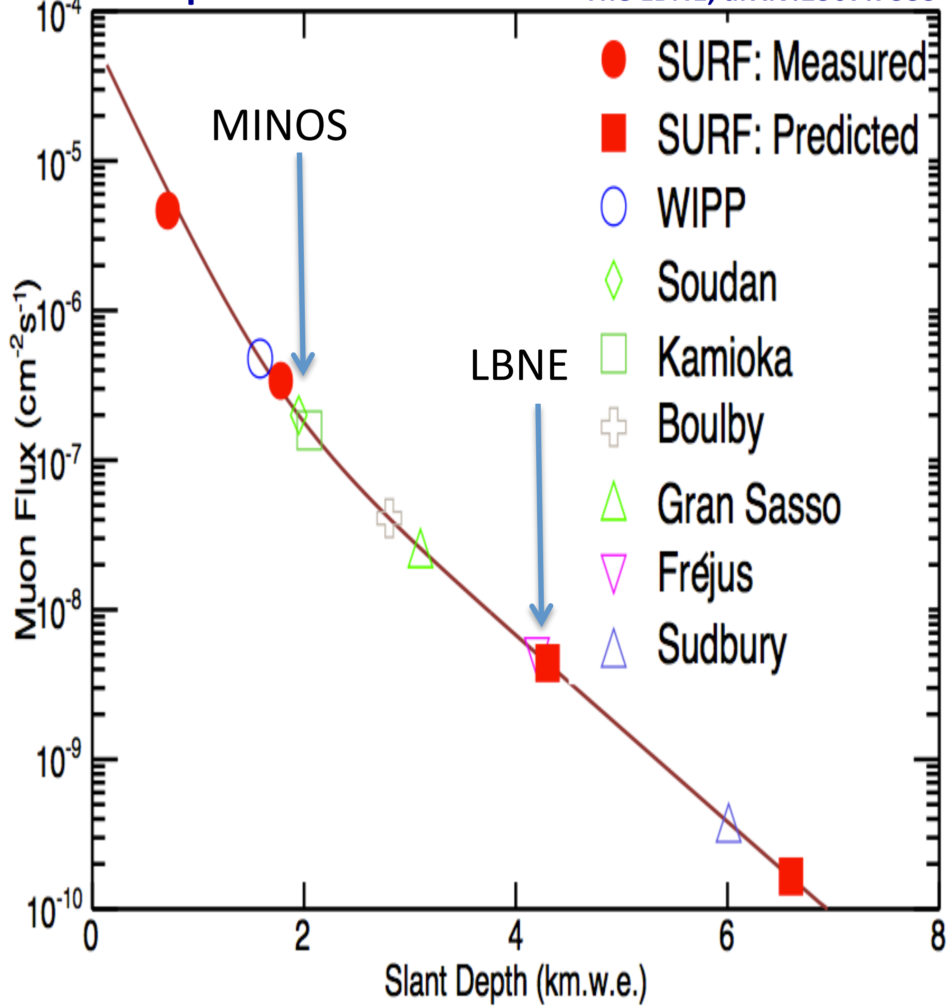
A. Sousa, U. Cincinnati,
MINOS+ talk @ NEUTRINO2014

Beam to South Dakota

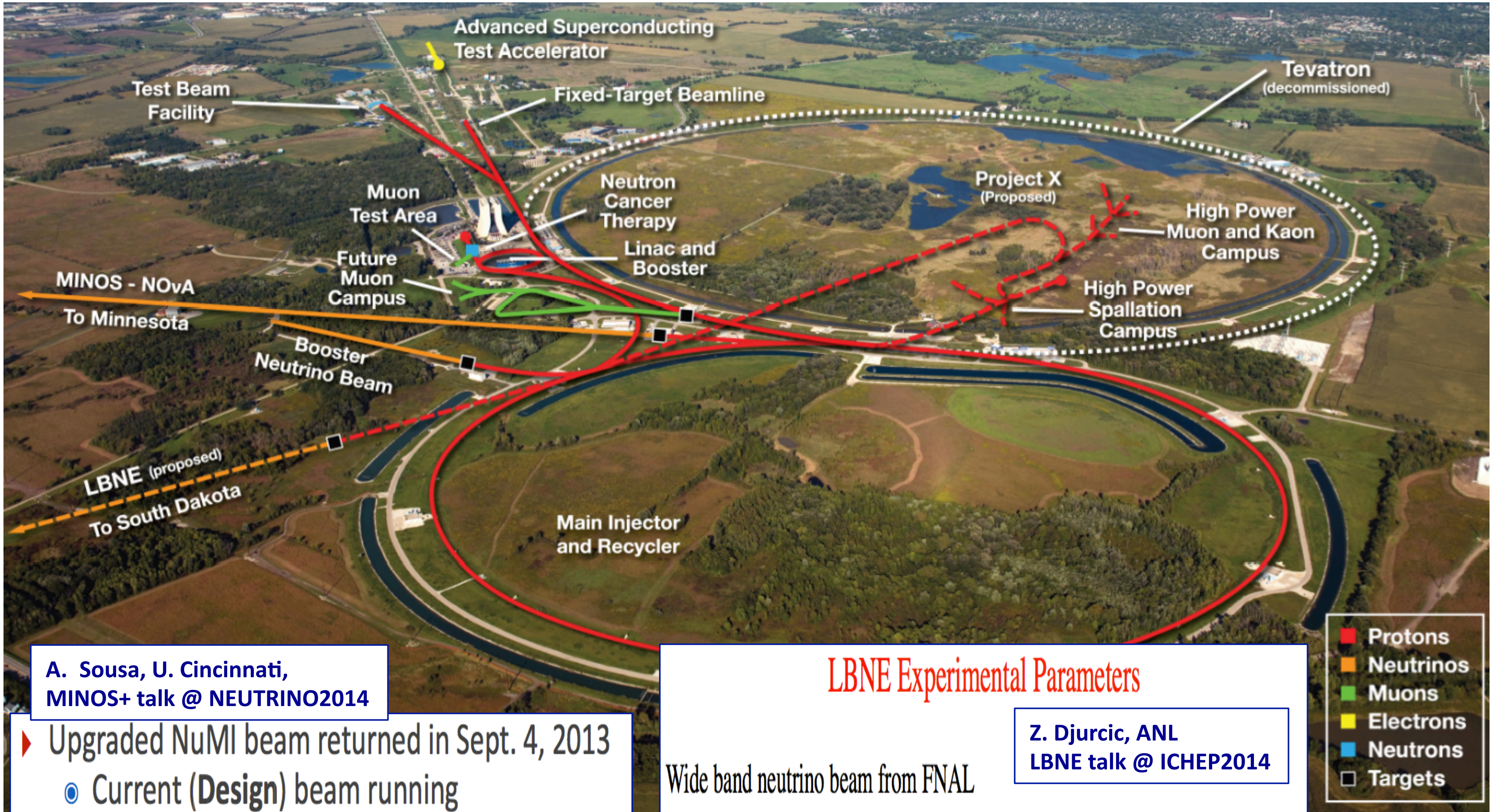


Depths

The LBNE, arXiv:1307.7335



FERMILAB accelerator complex, proposals included



A. Sousa, U. Cincinnati,
MINOS+ talk @ NEUTRINO2014

- Upgraded NuMI beam returned in Sept. 4, 2013
  - Current (**Design**) beam running
  - 2.4×10^{13} (**5×10^{13}**) protons/pulse
  - 280 kW (**700 kW**) beam power
    500 kW end 2014 ?
  - Beam spill every 1.7 s (**1.33 s**)

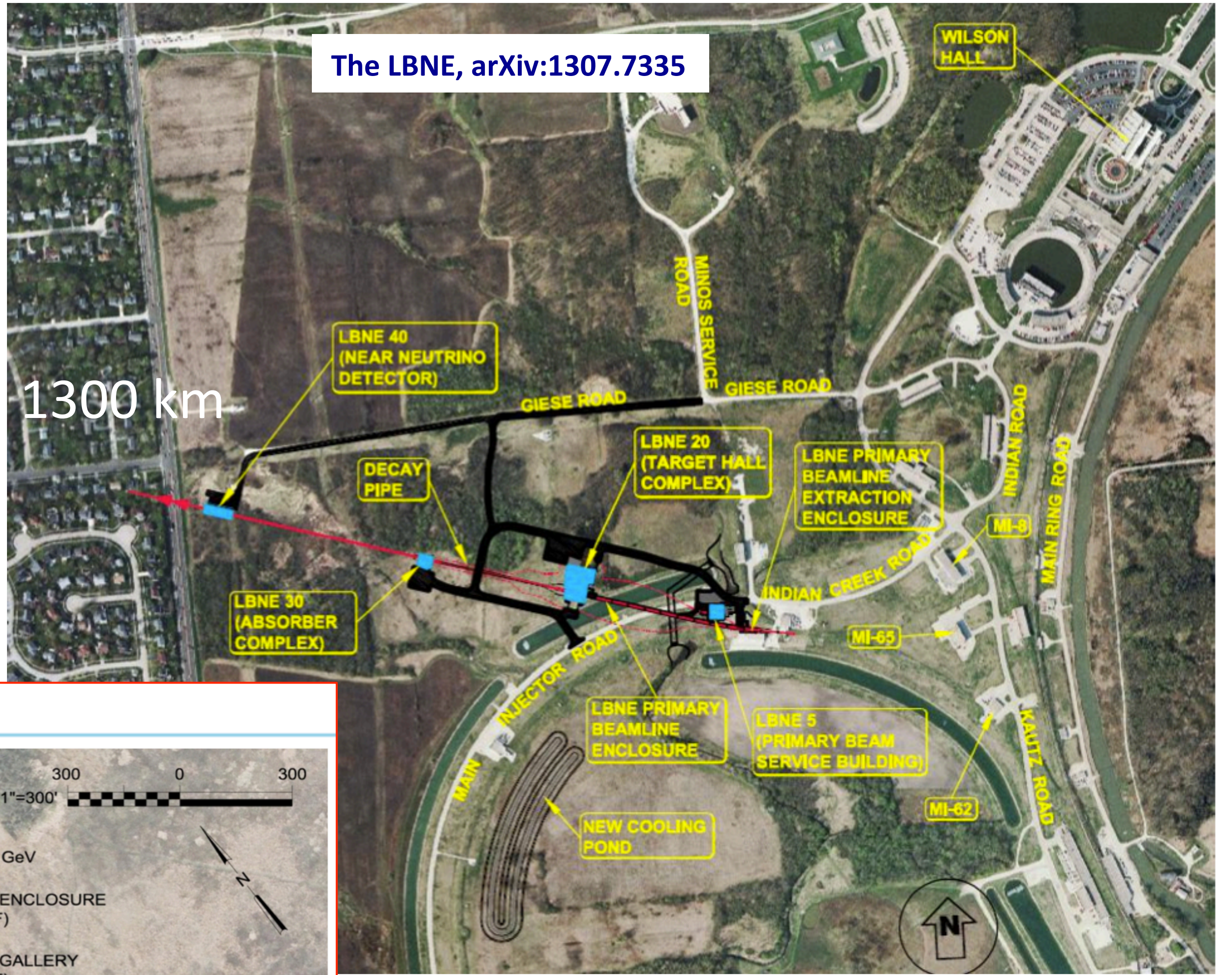
LBNE Experimental Parameters

Z. Djurcic, ANL
LBNE talk @ ICHEP2014

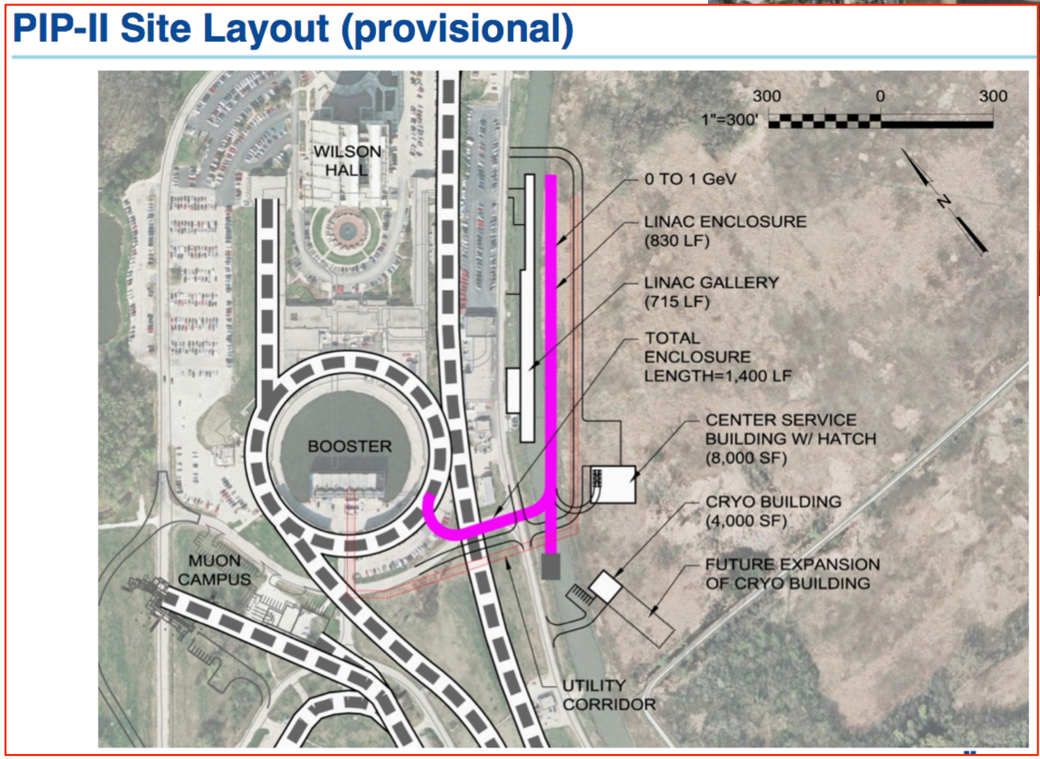
Wide band neutrino beam from FNAL

- protons: 60-120 GeV, 1.2 MW; upgradable to 2.3 MW
- 10 μs pulses every 1.0 to 1.33 sec depending on proton energy&power.
- Neutrinos: sign selected, horn focused, 0.5 - 5 GeV
- 1300 km through the Earth to Sanford Underground Research Facility.

LBNE requires a **new** neutrino beam line



S. Brice, FNAL, PIP-II talk @ ICHEP2014



and a **new** proton source !

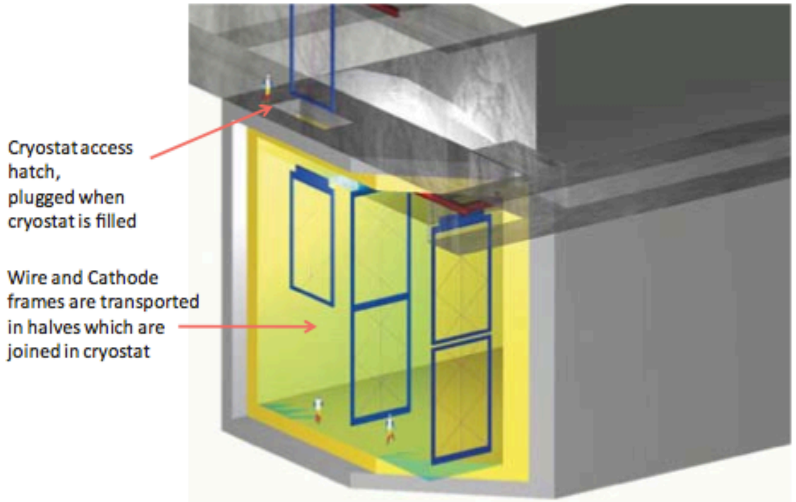
(also necessary for other physics programs at FNAL)

20121022_LBNE_CDRvol4-LArFarDetector_LBNE-doc-4892-v12

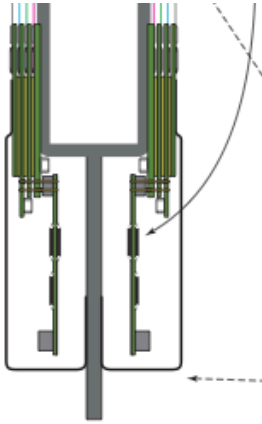
Table 1–3: LAr-FD Principal Parameters

Parameter	Value
Total Active (Fiducial) Mass	13.5 (10) kton
Number of Detector Modules (Cryostats)	2
Drift Cell Configuration within Module	3 wide × 2 high × 10 long drift cells
Drift Cell Dimensions	2 × 2.3 m wide (drift) × 7 m high × 2.5 m long
Detector Module Dimensions	13.9 m wide × 14 m high × 25.3 m long
Anode Wire Spacing	∼5 mm
Wire Planes (Orientation from vertical)	Grid (0°), Induction 1 (45°), Induction 2 (-45°), Collection (0°)
Drift Electric Field	500 V/cm
Maximum Drift Time	1.4 ms

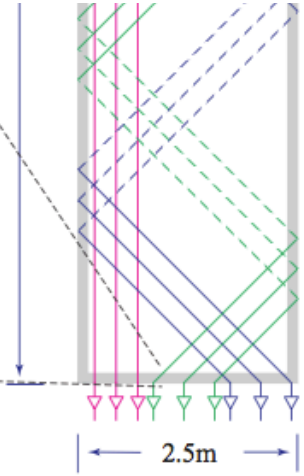
installation of APAs inside the crypstat



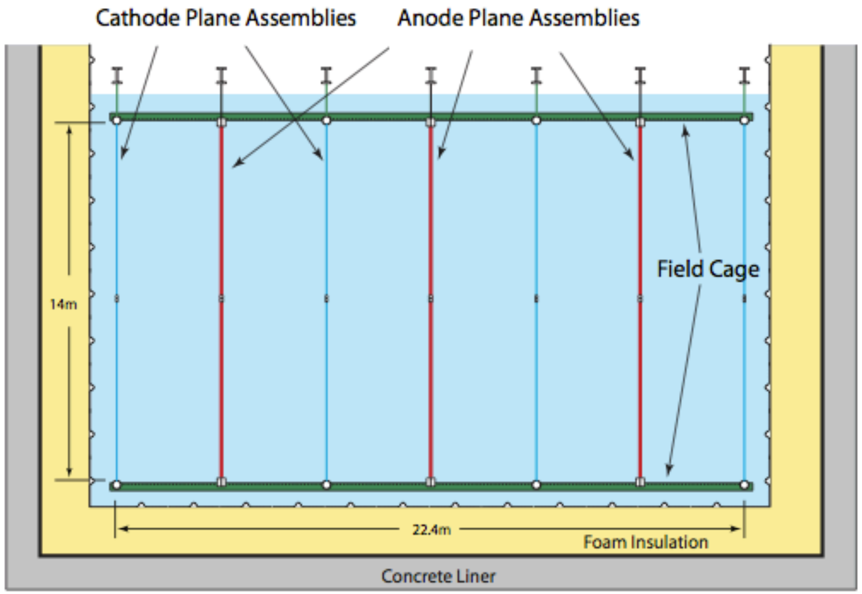
The 34 Kt fid. vol. LBNF far detector is based on the ICARUS technique/ experiment



detail cross section of the electronics enclosures



concept of the APAs, and wire wrapping arrangement



cross section view of the TPC componets inside the cryostat however *ICARUS* technique/experiment is not an example for a rapid building, commissioning and successfully running detector !

- start in ~1985
- first physics paper ~2012 [neutrino velocity]
- only two physics measurements [neutrino velocity, search for LSND anomaly]

amazing !

The Final Report of the Subcommittee on Future Projects of High Energy Physics[1]

S. Asai (Univ. of Tokyo), M. Hazumi (KEK), K. Hanagaki (Osaka Univ., *Secretary*),
J. Hisano (Nagoya Univ.), T. Iijima (Nagoya Univ.), K. Inoue (Tohoku Univ.), K. Ishii (KEK),
T. Kobayashi (KEK), M. Kuriki (Hiroshima Univ.), T. Mori (Univ. of Tokyo, *Chair*),
T. Moroi (Univ. of Tokyo), H. Murayama (Univ. of Tokyo/U.C. Berkeley),
T. Nakaya (Kyoto Univ.), M. Nojiri (KEK), T. Nomura (KEK, *Secretary*), Y. Ohnishi (KEK),
Y. Tabuchi (KEK), Y. Ushiroda (KEK), S. Yamashita (Univ. of Tokyo)

February 11, 2012

The committee makes the following recommendations concerning large-scale projects, which comprise the core of future high energy physics research in Japan.

- **Should a new particle such as a Higgs boson with a mass below approximately 1 TeV be confirmed at LHC, Japan should take the leadership role in an early realization of an e^+e^- linear collider.** In particular, if the particle is light, experiments at low collision energy should be started at the earliest possible time. In parallel, continuous studies on new physics should be pursued for both LHC and the upgraded LHC version. Should the energy scale of new particles/physics be higher, accelerator R&D should be strengthened in order to realize the necessary collision energy.
- **Should the neutrino mixing angle θ_{13} be confirmed as large, Japan should aim to realize a large-scale neutrino detector through international cooperation, accompanied by the necessary reinforcement of accelerator intensity, so allowing studies on CP symmetry through neutrino oscillations.** This new large-scale neutrino detector should have sufficient sensitivity to allow the search for proton decays, which would be direct evidence of Grand Unified Theories.

It is expected that the Committee on Future Projects, which includes the High Energy Physics Committee members as its core, should be able to swiftly and flexibly update the strategies for these key, large-scale projects according to newly obtained knowledge from LHC and other sources.

提　言

第22期学術の大型研究計画に関する

マスタープラン

（マスタープラン2014）

SCIENCE COUNCIL OF JAPAN

日本学術会議

平成２６年（２０１４年）２月２８日

日　本　学　術　会　議

The **Science Council of Japan** has selected Hyper-Kamiokande as a top priority project in the **Japanese Master Plan of Large Research Projects** (27 chosen out of 192 in all science area)

http://www.scj.go.jp/ja/info/kohyo/pdf/kohyo-22-t188-1.pdf

No.	Scien-tific Field No.	Project Name	Project Summary	Scientific Significance	Social Value	Project Duration	Financial Requirement (1billion yen)	Implementing Institution, or Affiliation of Proposer
85	23-2	Nucleon decay and neutrino oscillation experiment with an advanced large detector	The project aims to construct a one million ton-scale water Cherenkov detector, Hyper-Kamiokande, to succeed Super-Kamiokande and to perform world-leading neutrino and nucleon decay research in conjunction with the J-PARC accelerator facility.	The project will explore CP violation (matter-antimatter asymmetry) in neutrinos in order to help understand the evolution of the universe. Additionally, with the world's best nucleon decay searches it also aims to establish the unification of elementary particles and their forces.	Addressing profound questions concerning the elementary structure and evolution of the universe appeals directly to the inherent intellectual curiosity mankind harbors for comprehension of its origins and future. Additionally, dramatic advances in neutrino research with a world-leading project in Japan represent society's dreams for a rich program in basic science.	2015 to 2038	Total:1,880 Construction of Hyper-Kamiokande 800, Operating cost of Hyper-Kamiokande 450, Operating cost of J-PARC 600, Neutrino monitor 30	Lead by the Institute for Cosmic Ray Research, University of Tokyo and the High Energy Accelerator Research Organization. Participation from domestic and foreign universities and research institutions is anticipated.

T. Nakaya (Kyoto U.), Comments from the Hyper-K group

Neutrino Summit Meeting, **Fermilab 21, 22 July**

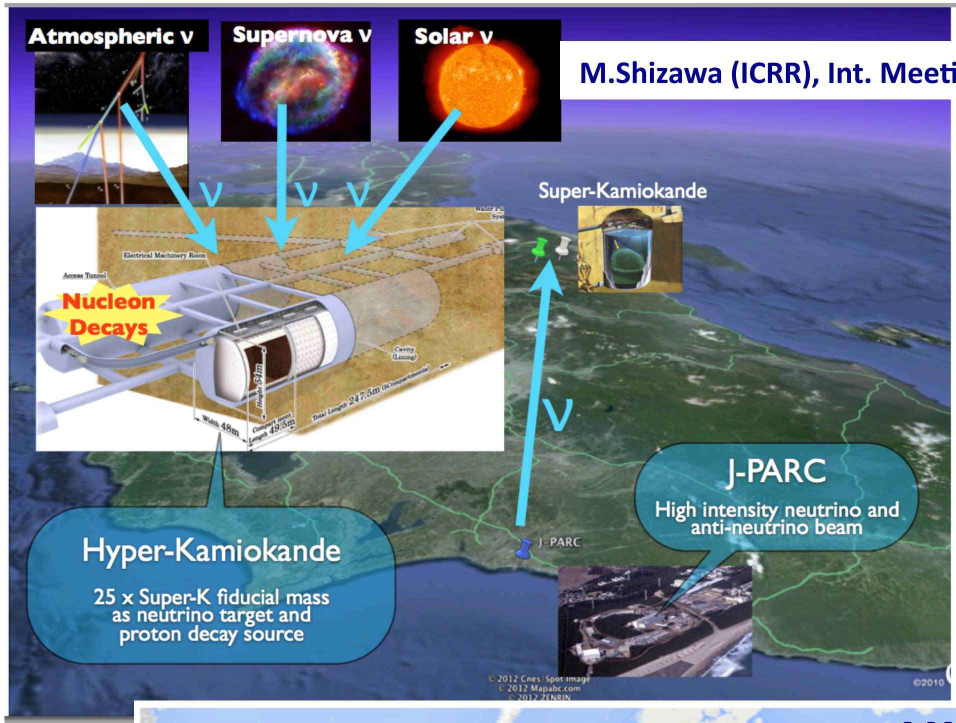
MEXT Roadmap 2014 draft is released

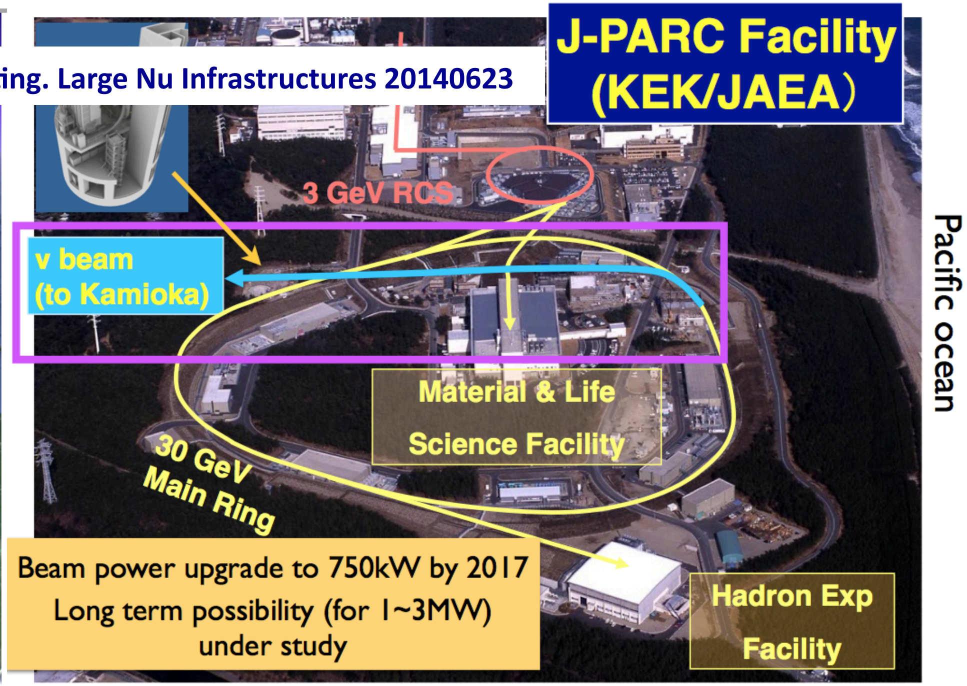
- The recent MEXT roadmap recommends funding 10 of the 27 immediately.
- Hyper-K not among those ten recommended for urgent funding.
- Hyper-K is also being asked to improve
  - International participation
  - Organization
  - Cost estimate
- Next revision of roadmap in 2017. Time to address above items.
- Does not delay HK operations. Budget request was planned for 2017 anyway.

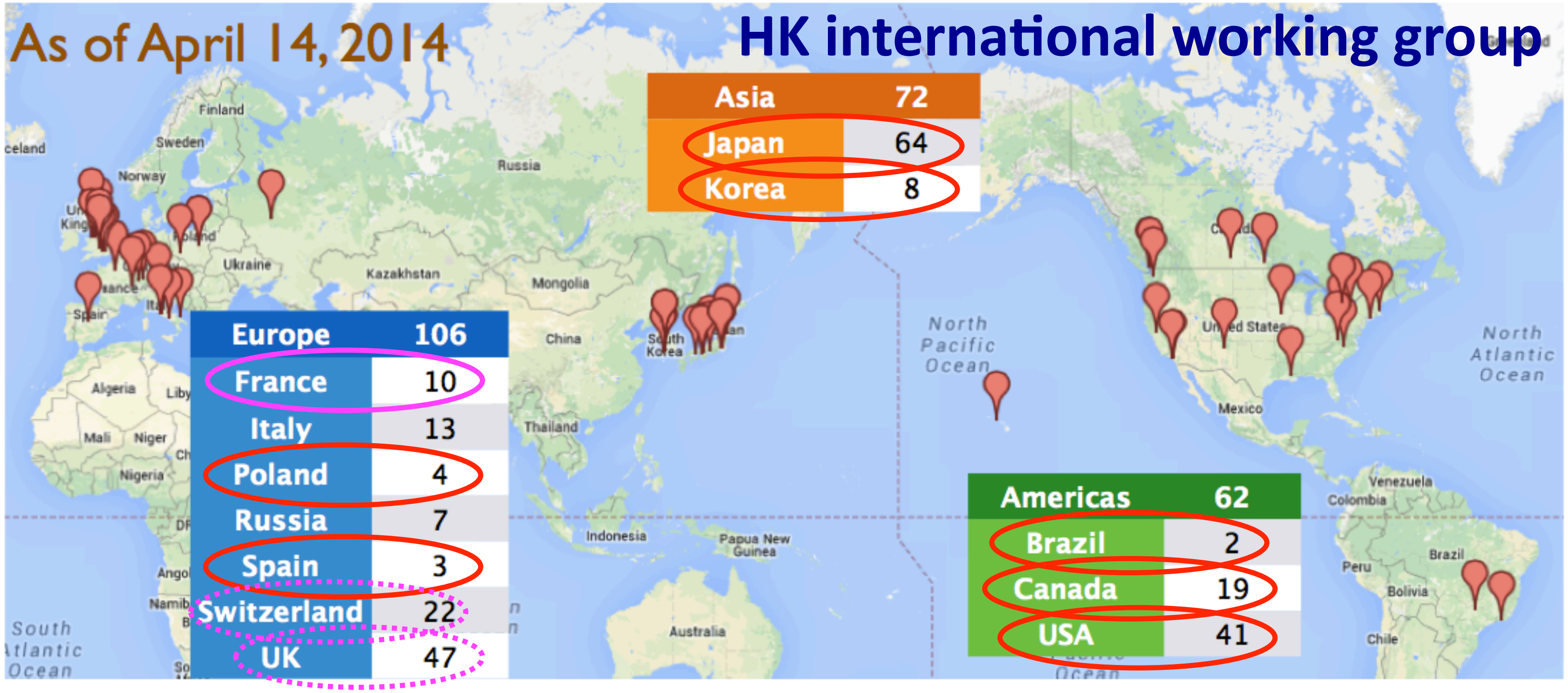
Strategy toward the approval of the Hyper-K projects in Japan

1. Make a proposal with the realistic design, reliable budget plan, solid organization and visible international contributions.
2. Negotiation with MEXT. It will be accelerating with the proposal.
3. Discussions with KEK and ICRR managements.
4. Have a campaign of Hyper-K physics seminars in the major Japanese universities and institutes for more outreach.
   1. In each country, the similar campaign is desired.
5. Continuous endorsements of Hyper-K in the Japanese communities (HEP and CRC) with moderate supports from Nuclear Physics, Astronomy, J-PARC community, etc..
6. Endorsements of Hyper-K in the world-wide neutrino community.
7. Submit the budget request in 201X (X=6,7?)

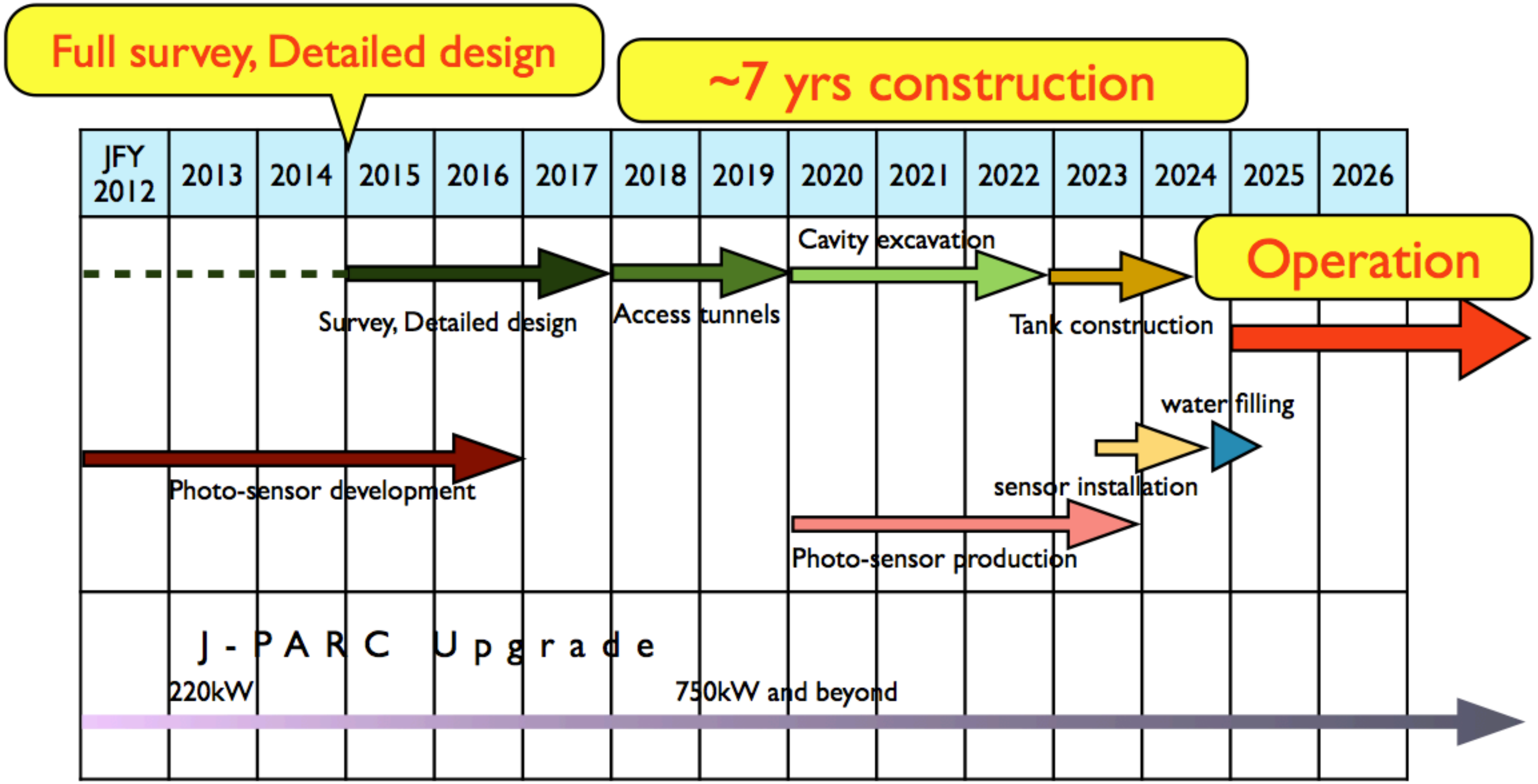
M.Shizawa (ICRR), Int. Meeting. Large Nu Infrastructures 20140623







Notional timeline



-2015 Full survey, Detailed design (3 years)

-2018 Excavation start (7 years)

-2025 Start operation

Hyper-Kamiokande vs. LBNE

20140720_R.Wendel-ICRR HKom5

	Hyper-K	LBNE
Fiducial Vol.	560 kton	34 kton
Eff. Area	22,000 m^2	800 m^2
Protons	1.8×10^{35}	9.4×10^{33}
Neutrons	1.5×10^{35}	9.4×10^{33}
Fully Contained e-like	267,600	13,600
Fully Contained μ-like	281,900	20,200
Partially Contained μ-like	62,200	6,600
Upward-Going μ	31,400	***

mass is key

Hyper-Kamiokande vs. LBNE

20140720_R.Wendel-ICRR HKom5

	Hyper-K	LBNE
σ_{mom} e / μ	5.6% /3.6%	2.4% / 3%
σ_{dir} e / μ	3.0° / 1.8°	1° / 1°
σ_{E} Had. Sys.	***	30/ √E %
σ_{dir} Had Sys.	***	10°
ν CC Purity :		
FC e-like	94.2 %	97.8 %
FC μ-like	95.7 %	99.7 %
PC μ-like	98.7 %	99.6 %

- LBNE can tag protons as well as Kaons, both of which are (mostly) invisible at HK
- LBNE has very good PID to separate hadrons from leptons and create very pure analysis samples

mass is key

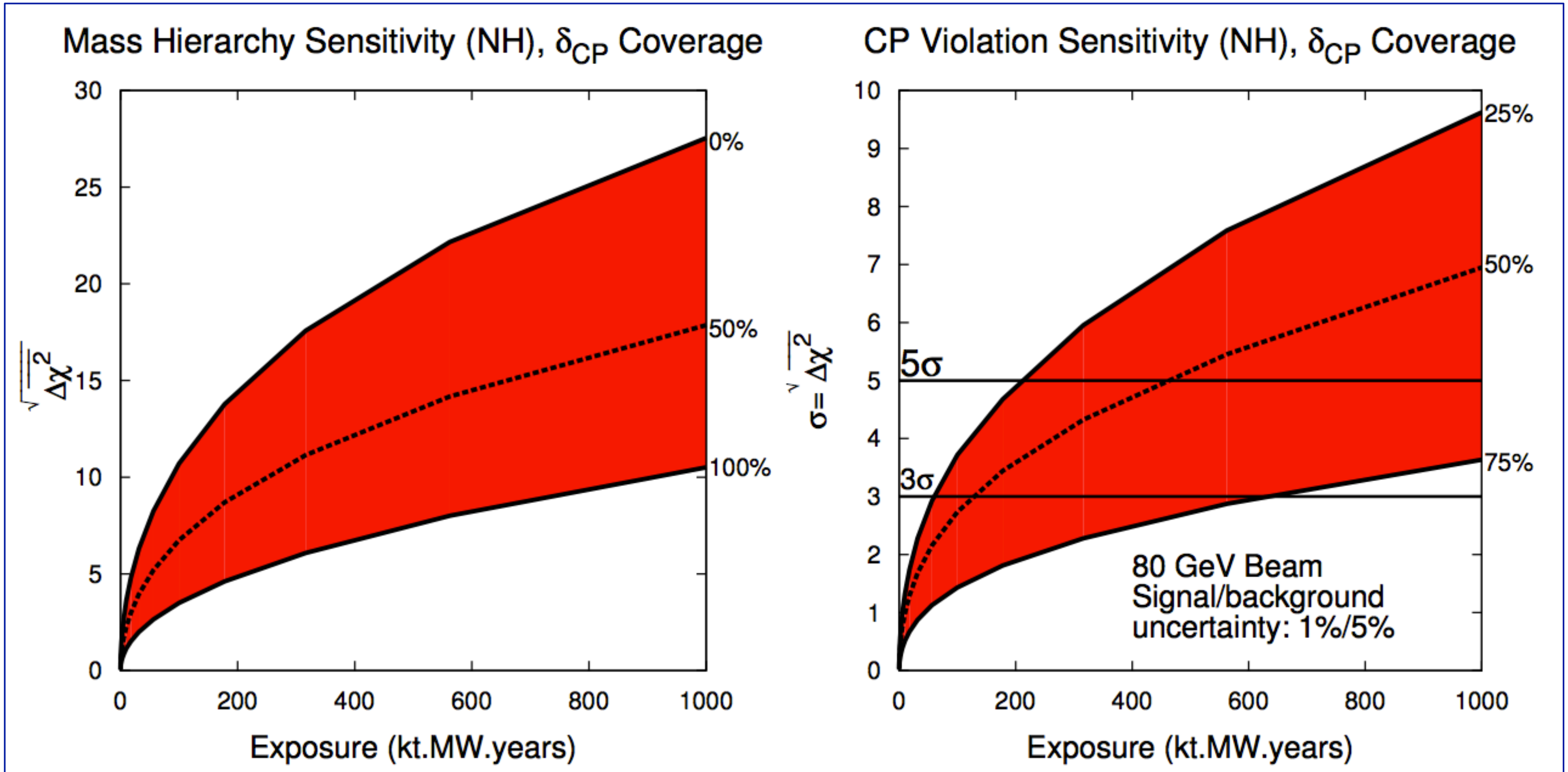


Figure 4.16: The minimum significance with which the mass hierarchy (left) and CP violation (right) can be resolved as a function of exposure in detector mass (kiloton) × beam power (MW) × time (years), for true NH. The red band represents the fraction of δ_{CP} values for which the sensitivity can be achieved with at least the minimal significance on the y-axis.

The LBNE, arXiv:1307.7335

Using the current understanding of DOE funding profiles, we outline one plausible long-term timeline that integrates evolution of LBNE detector mass with development of the Fermilab accelerator complex (i.e., PIP-II) and contributions from non-DOE partners. Implicit in this timeline is an assumption that agreements with new partners be put in place on a timescale of three years (by 2017). In this scenario, the milestones that bear on the physics are as follows:

1. LBNE begins operation in 2025 with a 1.2−MW beam and a 15−kt far detector. (In such a scenario, a significant fraction of the far detector mass might be provided in the form of a standalone LArTPC module developed, funded, and constructed by international partners.)

2. Data are recorded for five years, for a net exposure of $90\,\mathrm{kt} \cdot \mathrm{MW} \cdot \mathrm{year}$.

3. In 2030, the LBNE far detector mass is increased to 34 kt, and proton beam power is increased to 2.3 MW.

4. By 2035, after five years of additional running, a net exposure of $490\,\mathrm{kt} \cdot \mathrm{MW} \cdot \mathrm{year}$ is attained.

The LBNE, arXiv:1307.7335

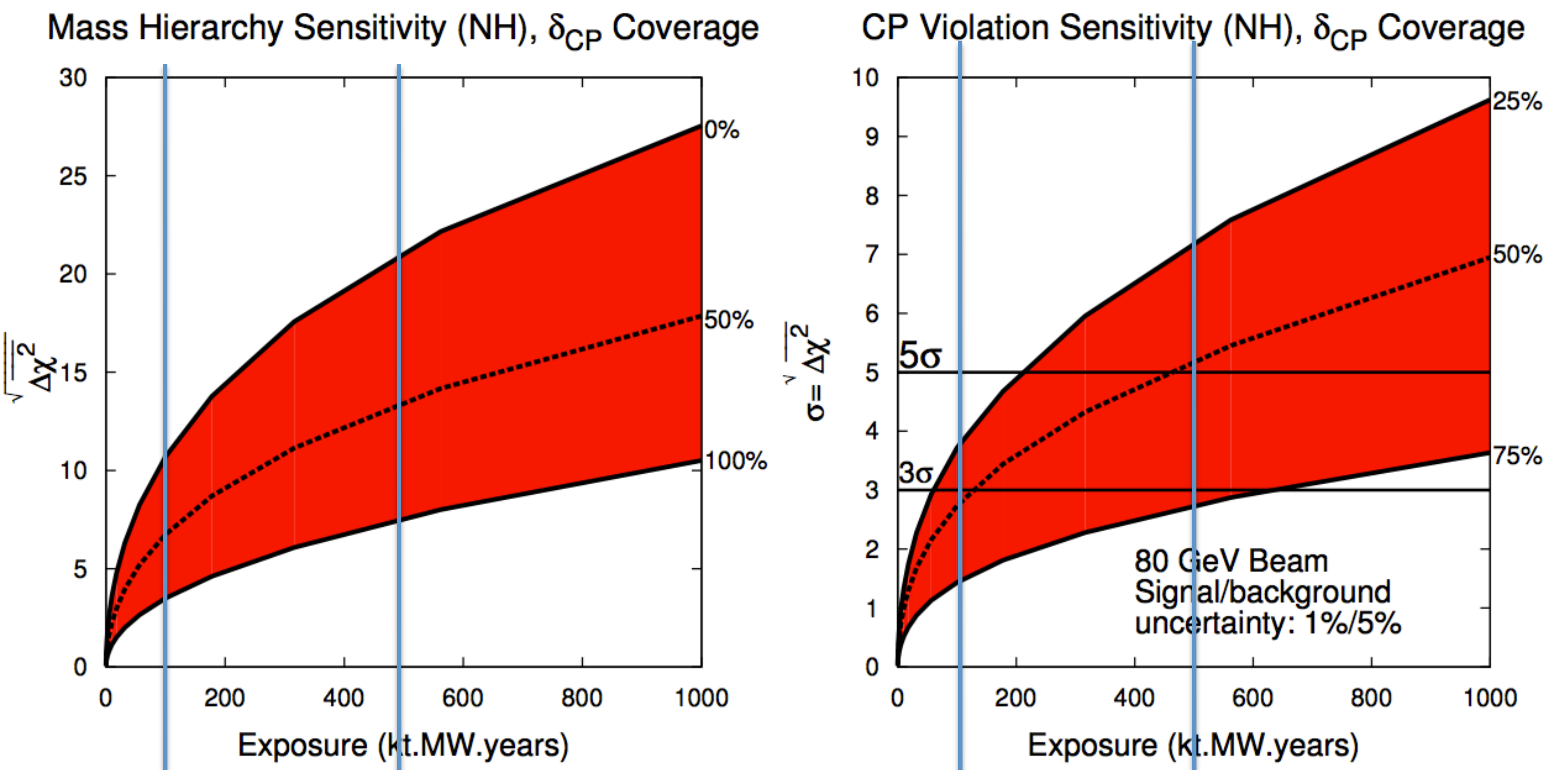


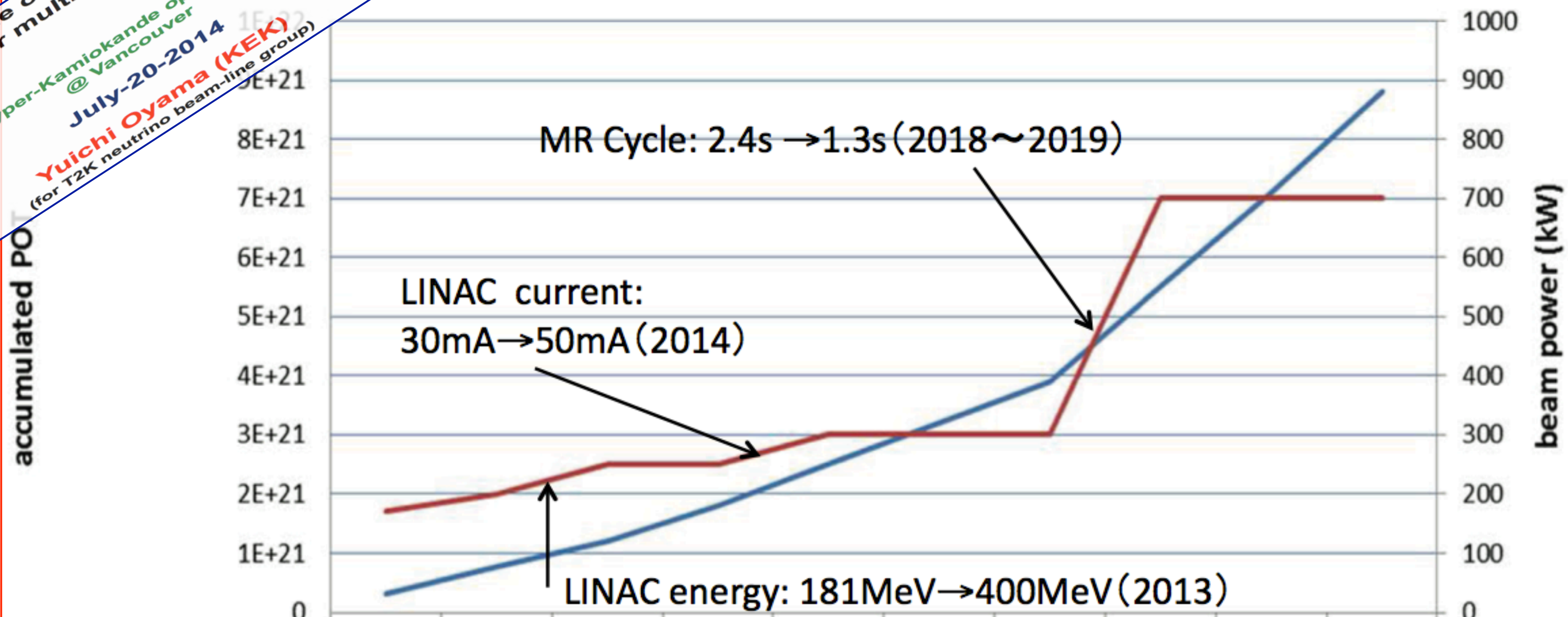
Figure 4.16: The minimum significance with which the mass hierarchy (left) and CP violation (right) can be resolved as a function of exposure in detector mass (kiloton) × beam power (MW) × time (years), for true NH. The red band represents the fraction of δ_{CP} values for which the sensitivity can be achieved with at least the minimal significance on the y-axis.

The LBNE, arXiv:1307.7335

~ 2030 ~ 2035 T_0= 2025 ~ 2030 ~ 2035

[15 Kton • 1.2 MW • 5 years] + [34 Kton • 2.3 MW • 5 years]

Future Improvements for higher beam power

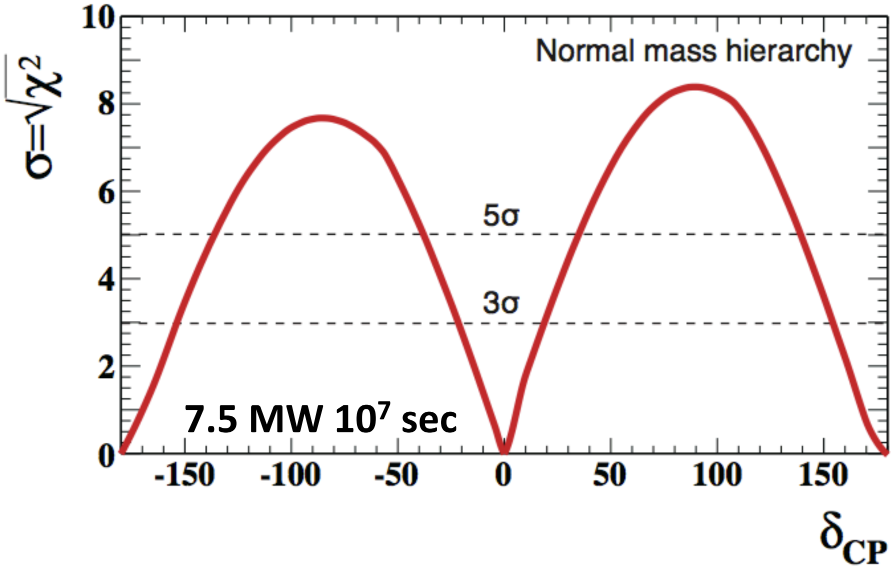


	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
accumulated POT	3.1E+20	7.8E+20	1.2E+21	1.8E+21	2.50E+21	3.20E+21	3.90E+21	5.50E+21	7.10E+21	8.80E+21
beam power	170	200	250	250	300	300	300	700	700	700

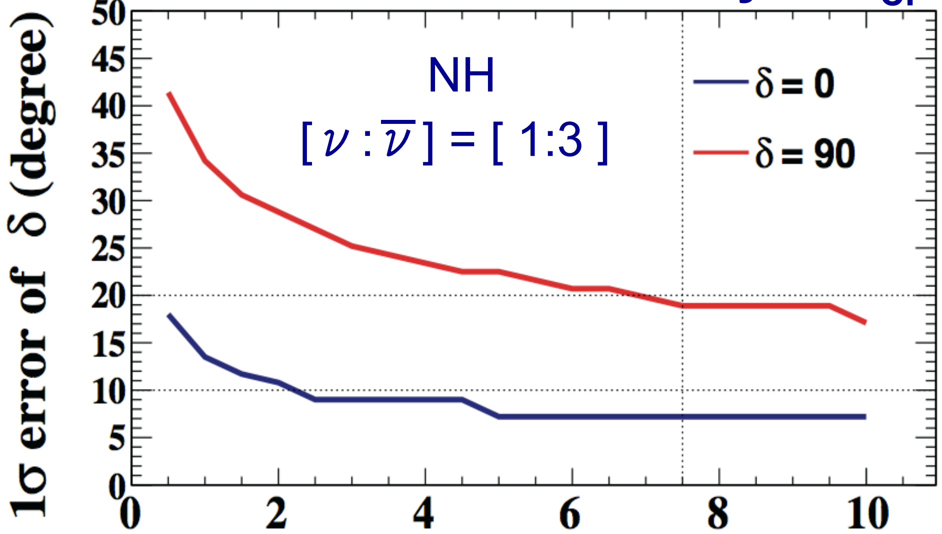
● **Present expected beam parameters for ~700kW will be ~1.3sec Main Ring cycle and ~2.0×10^{14} ppp (proton per pulse).**

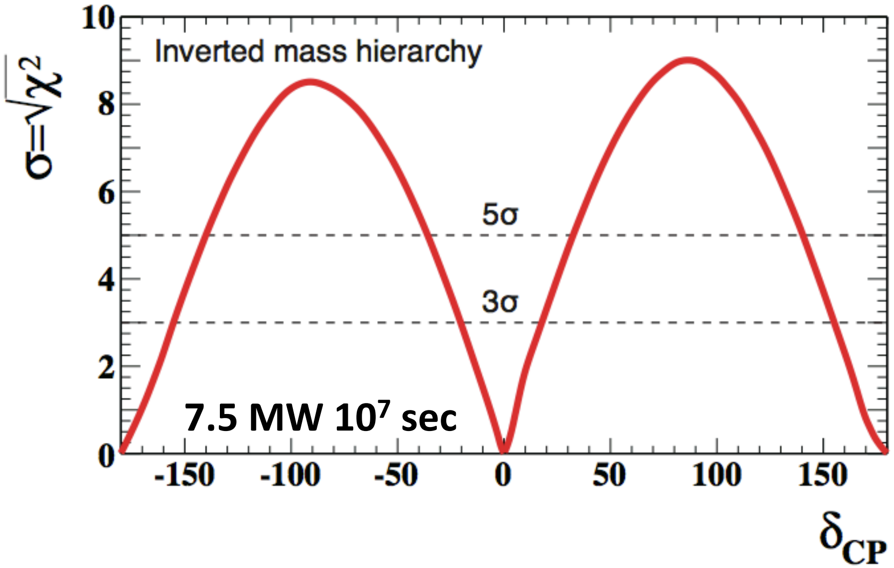
~ 700 kW beam scheduled for **~ 2018**

Expectations for measuring CPV at T2-HK

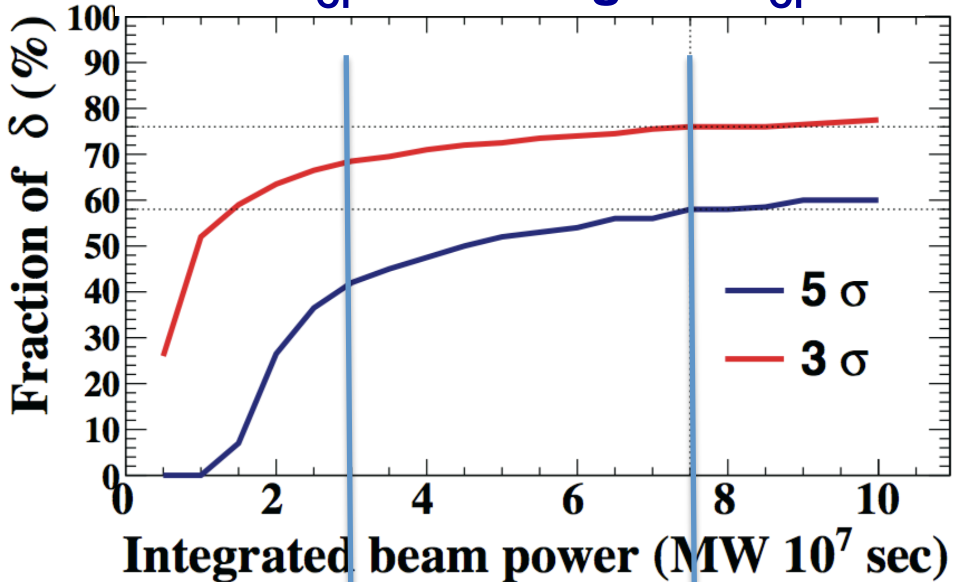


1σ uncertainty of δ_{CP}





% of δ_{CP} excluding $\sin\delta_{CP} = 0$



~ 2028 ~ 2033 T_0= 2025

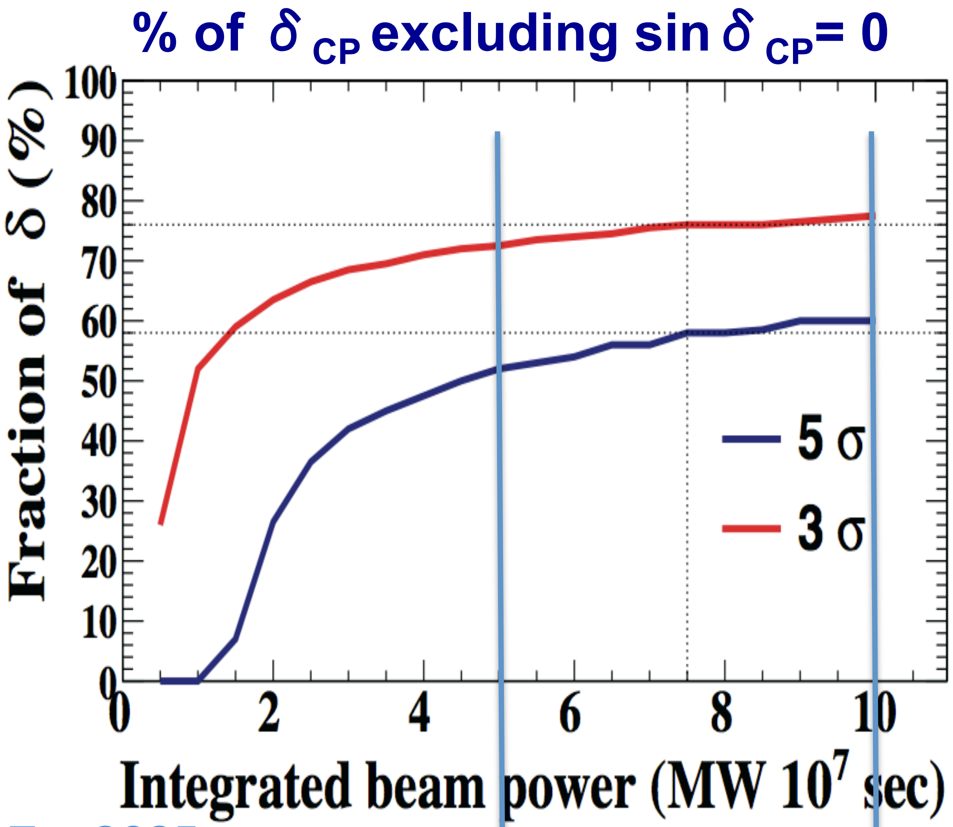
overwhelming observation in ~ 3 y. (2028)

detailed measurement in ~ 8 y. (2033)

measuring CPV: T2-HK vs. LBNE

HK-wg 20140414, JPARC-PAC-2014

The LBNE, arXiv:1307.7335

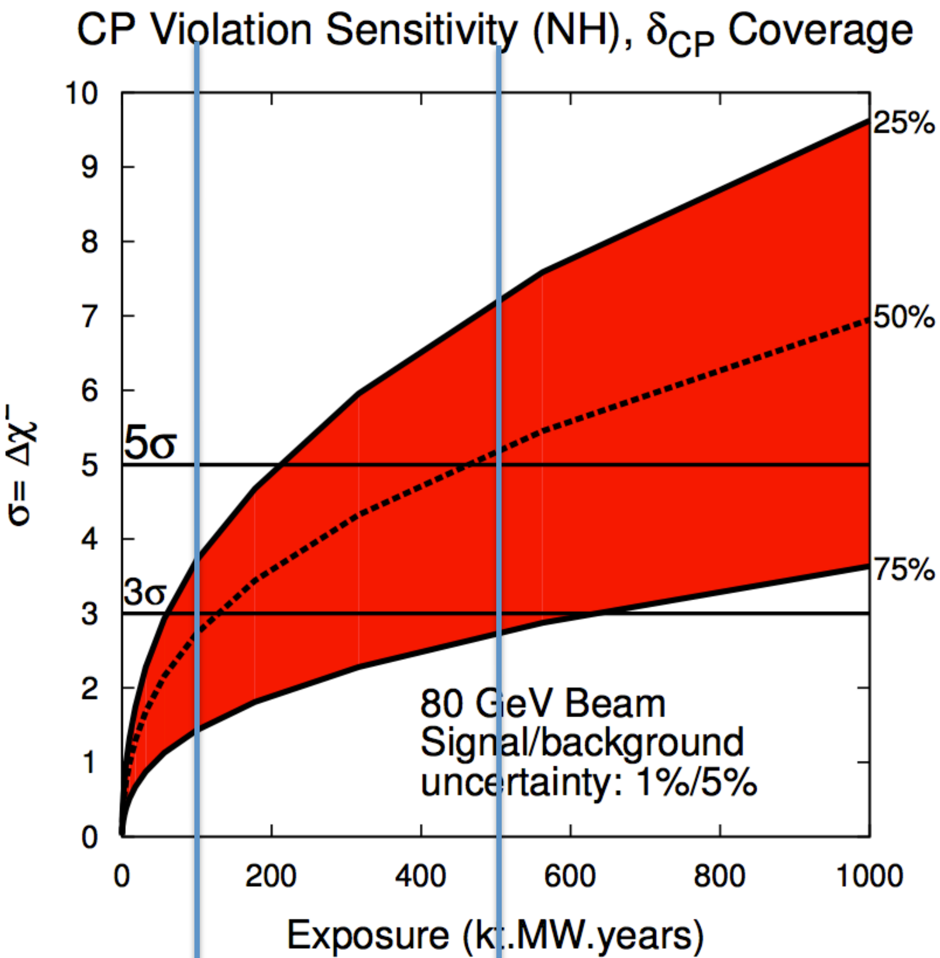


T_0= 2025

~ 2030

~ 2035

700 kW beam along whole period



~ 2030

~ 2035

LBNE/F strategy

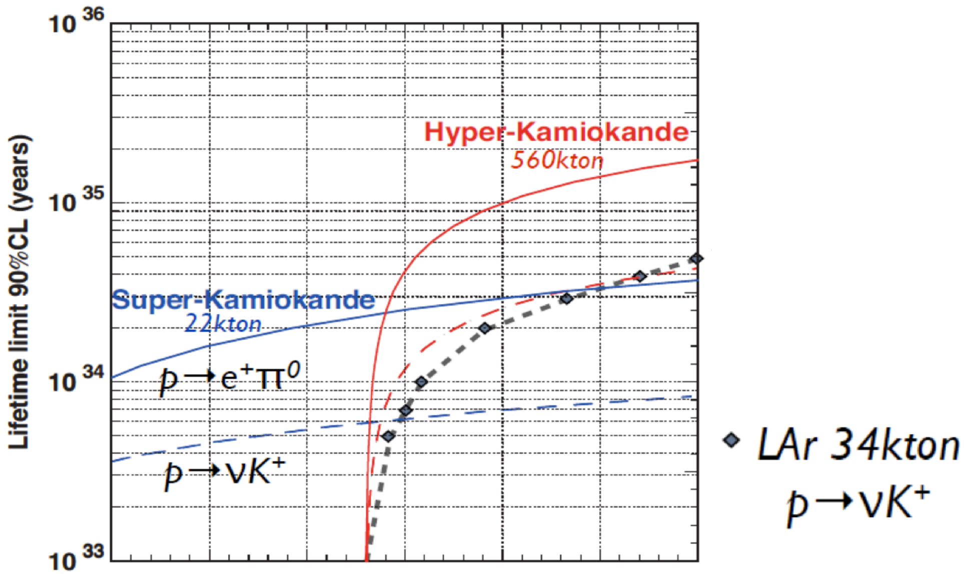
expectations around nucleon decay: HK vs. LBNF

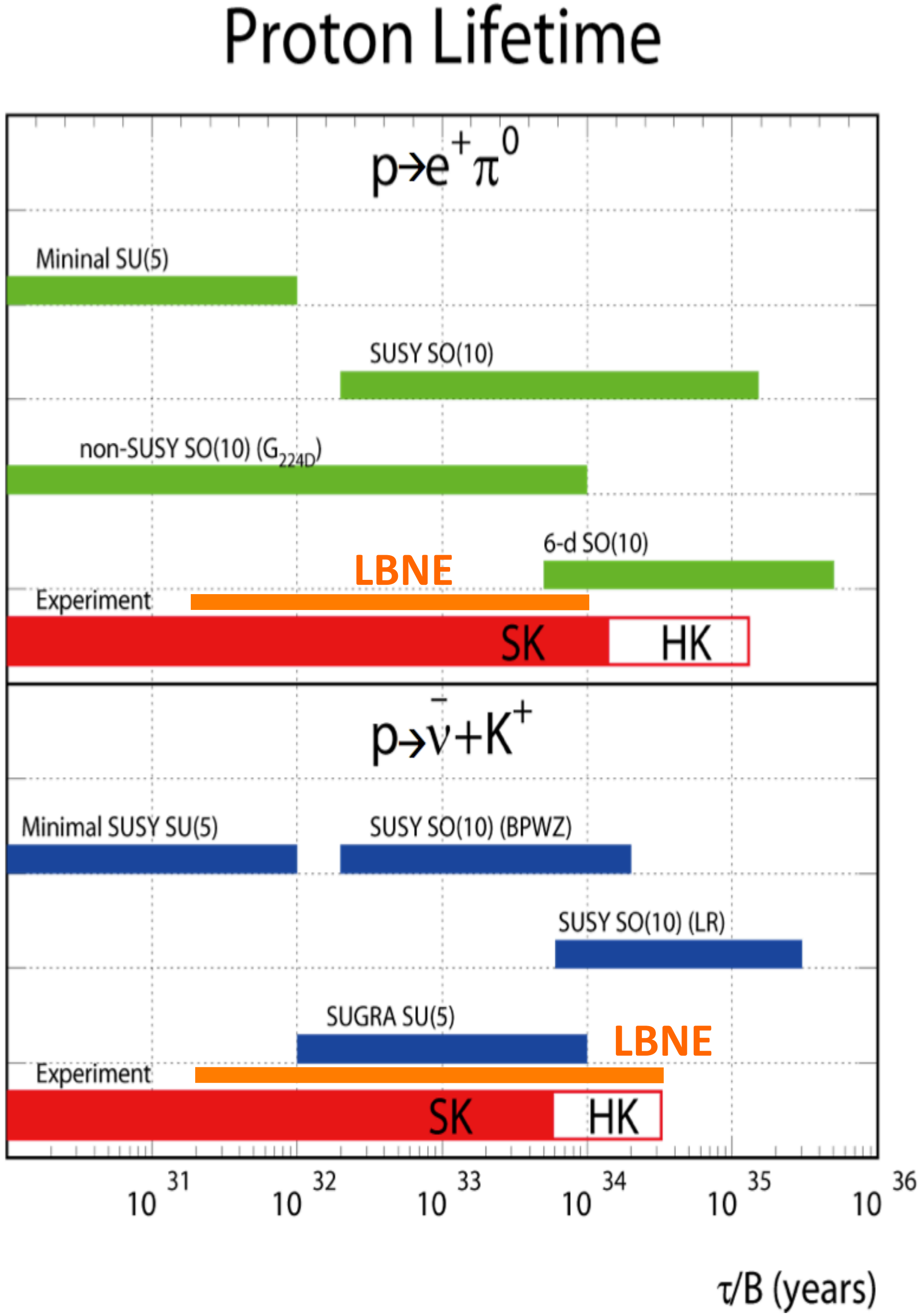
$p \rightarrow e^{+}\pi^{0}$

	Hyper-K	LBNF
Signal ε	45%	45%
BG / Mton yr	1.6	~1
10yr. Sens. 90%	1.3×10^{35} yr	$\sim 10^{34}$

$p \rightarrow \bar{\nu} K^{+}$

	Hyper-K	LBNE
Signal ε	7.6 - 37%	97%
BG / Mton yr	1.8 - 2556	< 1
10yr. Sens. 90%	3.2×10^{34} ⟷	3.3×10^{34}





expected signal from a Supernova 10Kpc away (≈ galactic center)

20140720_E.OSullivan-Duke_HKom5

HK:
- 560 kT of water
- 19 % photocoverage
- SK II response
- In SNOwGLoBES: wc100kt15prct (multiplied by 5.6 for HK FV)

Dominant Reaction

$\bar{\nu}_e + p \rightarrow e^+ + n$ **IBD**

Other Reactions

$\nu_x + e^- \rightarrow \nu_x + e^-$ **ES**

$\nu_e + {}^{16}\mathrm{O} \rightarrow e^- + {}^{16}\mathrm{F}^{(*)}$ **CC**

$\bar{\nu}_e + {}^{16}\mathrm{O} \rightarrow e^+ + {}^{16}\mathrm{N}^{(*)}$ **CC**

$\nu_x + {}^{16}\mathrm{O} \rightarrow \nu_x + {}^{16}\mathrm{O}^*$ **NC**

LBNF:
- 34 kT of argon
- In SNOwGLoBES: ar17kt (multiplied by 2 for LBNF 34 kT FV)

Dominant Reaction

$\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$ **CC**

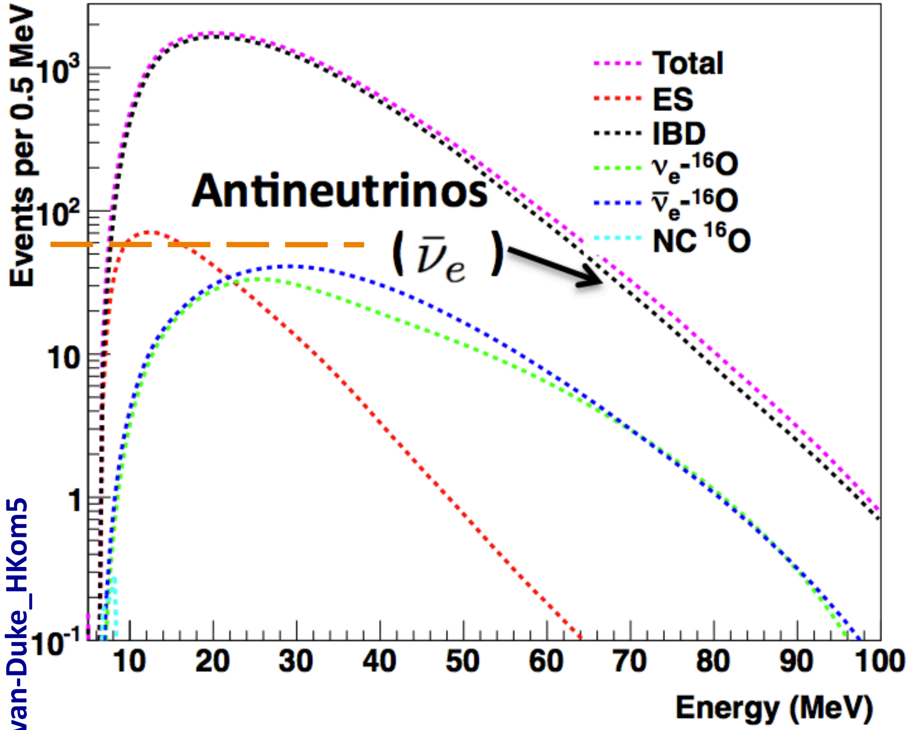
Other Reactions

$\nu_x + e^- \rightarrow \nu_x + e^-$ **ES**

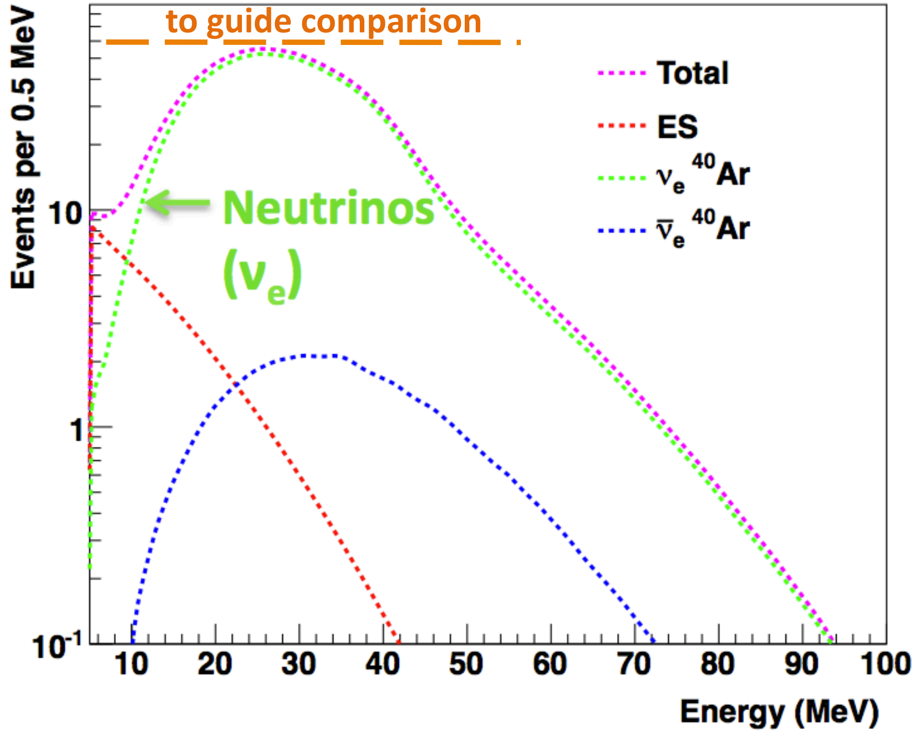
$\bar{\nu}_e + {}^{40}\mathrm{Ar} \rightarrow e^+ + {}^{40}\mathrm{Cl}^*$ **CC**

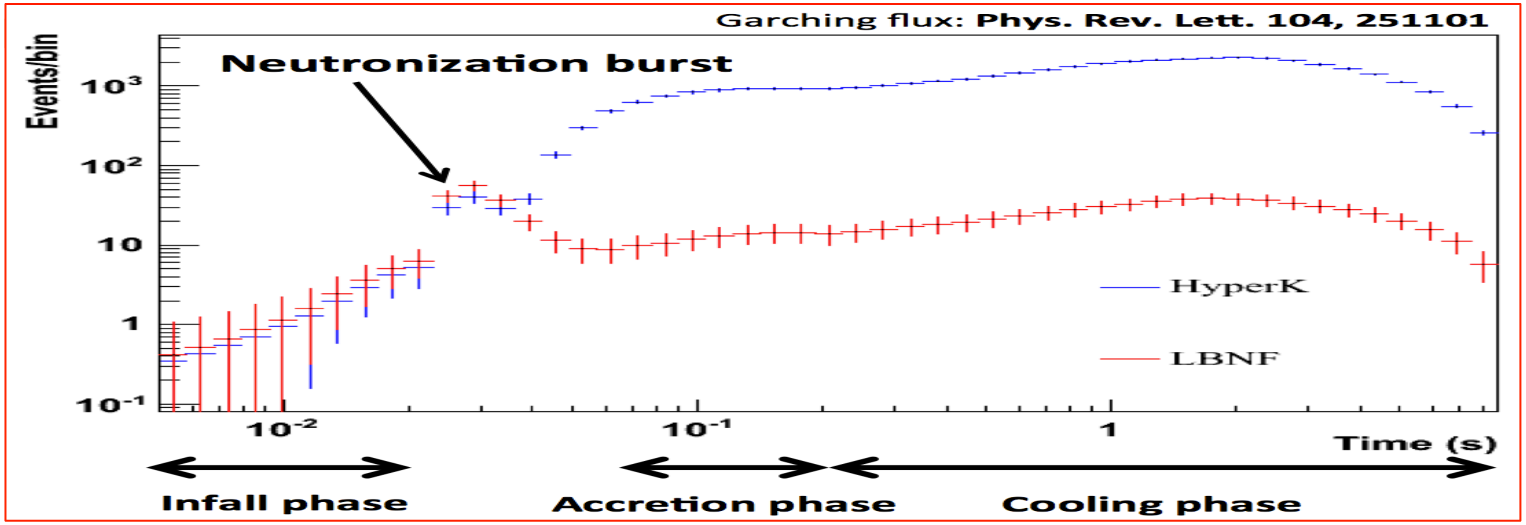
expected signal from a Supernova 10Kpc away (≈ galactic center)

Flux: gvkm[1] Detector:HK-like
PRL 103:071101, 2009



Flux: gvkm Detector: LBNF

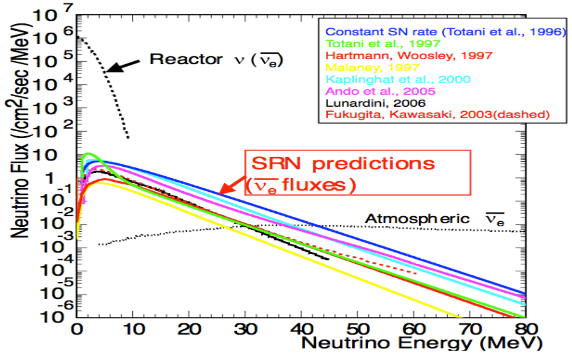


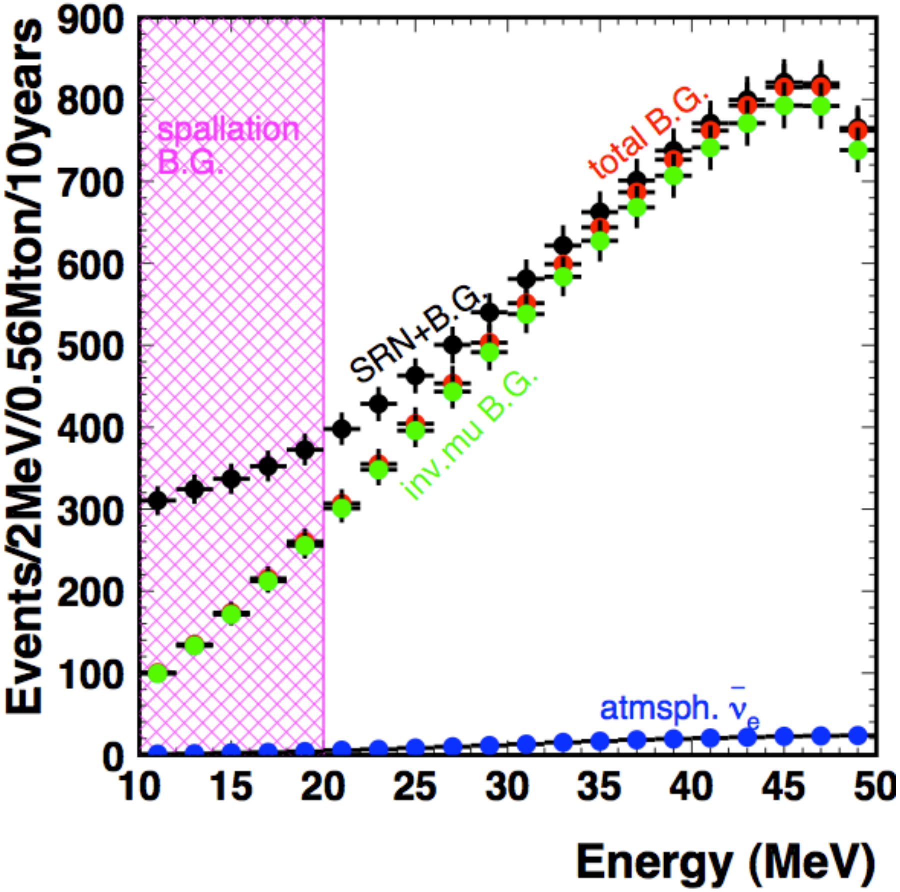


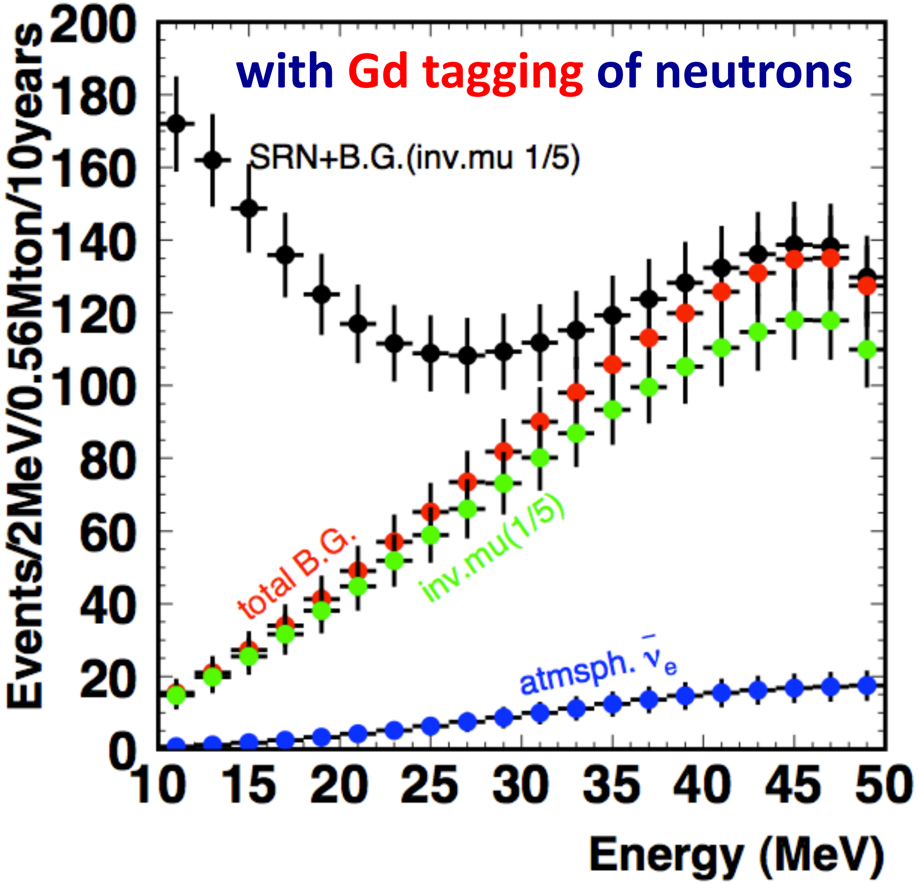
20140720_E.OSullivan-Duke_HKom5

Diffuse Supernova Neutrino Background [DSNB]
or Supernova Relic Neutrino [SRN]

Hyper-Kamiokande LOI arXiv:1109.3262







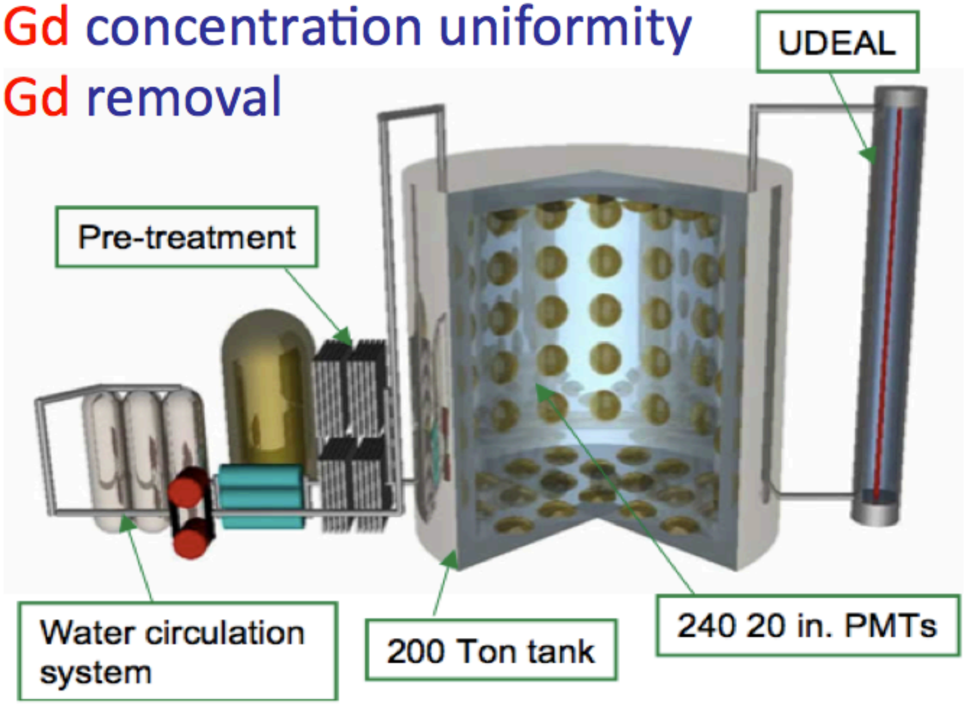
LBNE: basically **no signal** because of low statistics

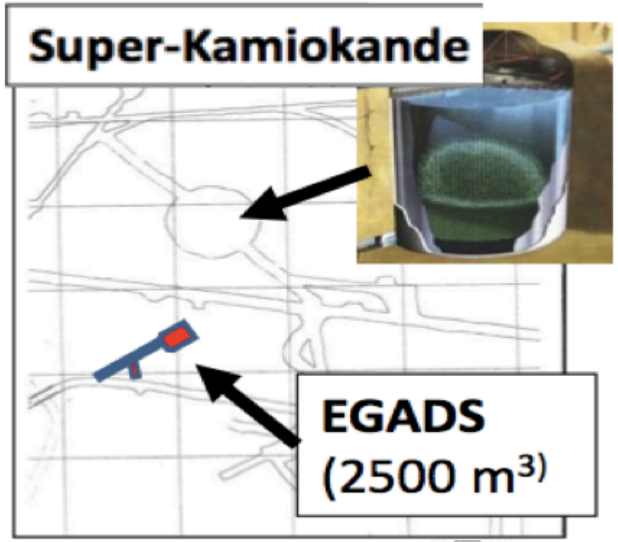
EGADS

Evaluating Gadolinium's
Action on Detector Systems

Facility for testing the effect of Gd in water-Cherenkov detectors:

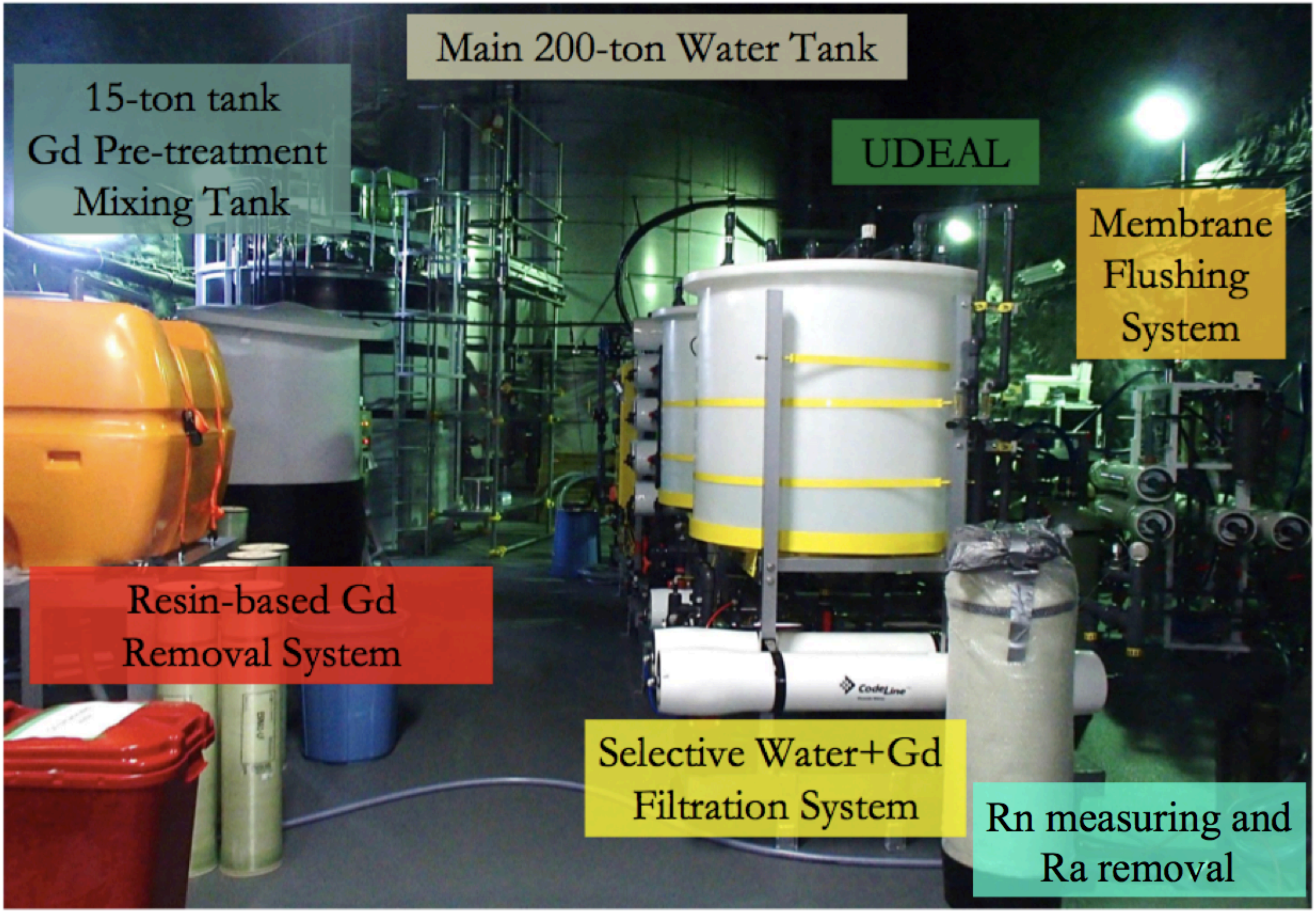
- Selective filtration for Gd water
- $Gd_2(SO_4)_3$ "cleaning" and dissolving
- water transparency monitoring
- Gd concentration uniformity
- Gd removal



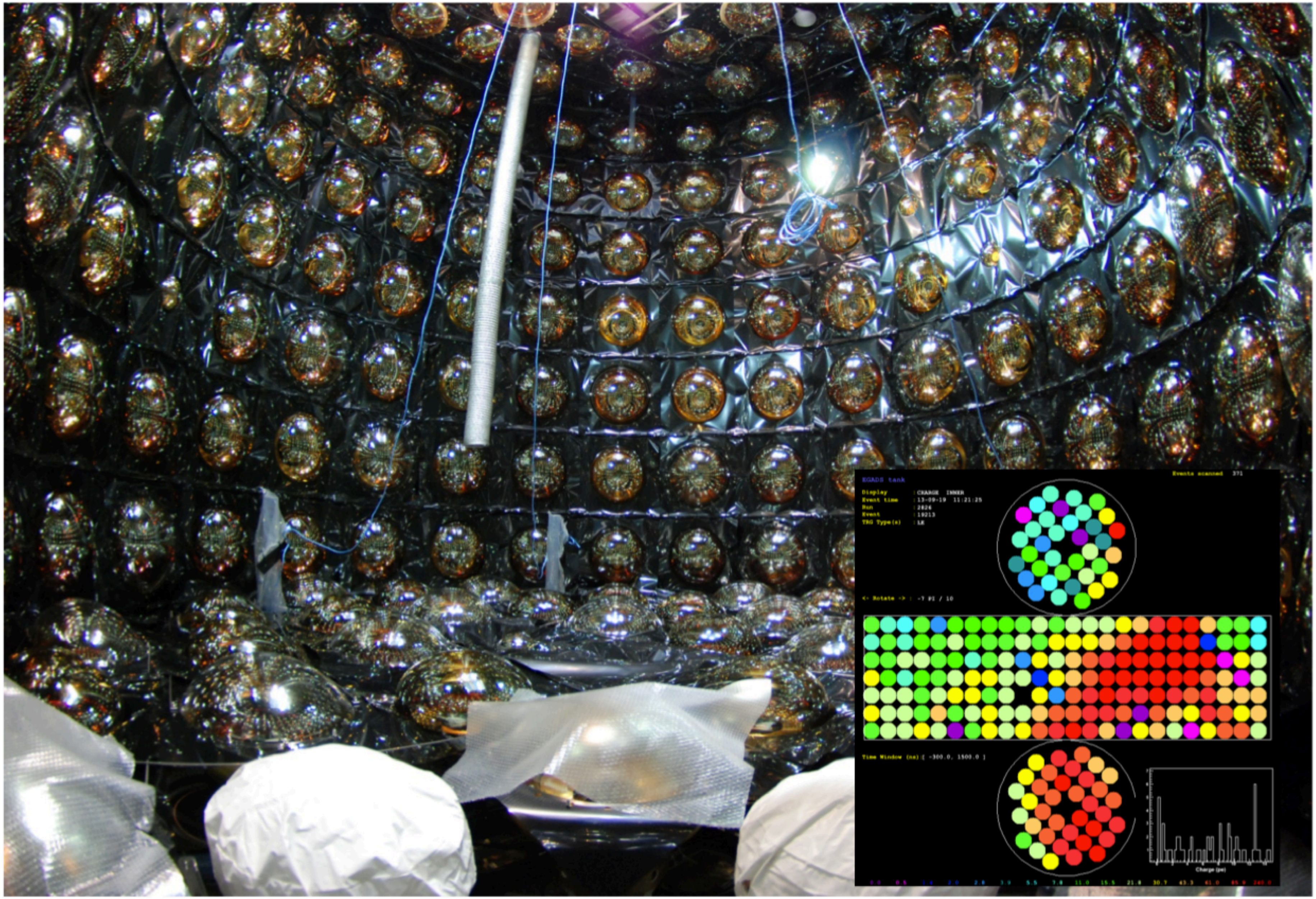


Last summer it became an actual detector, instrumented with 240 PMTs

EGADS hall


Main 200-ton Water Tank
15-ton tank
Gd Pre-treatment
Mixing Tank
UDEAL
Membrane
Flushing
System
Resin-based Gd
Removal System
Selective Water+Gd
Filtration System
Rn measuring and
Ra removal

EGADS tank fully instrumented... and already taking data

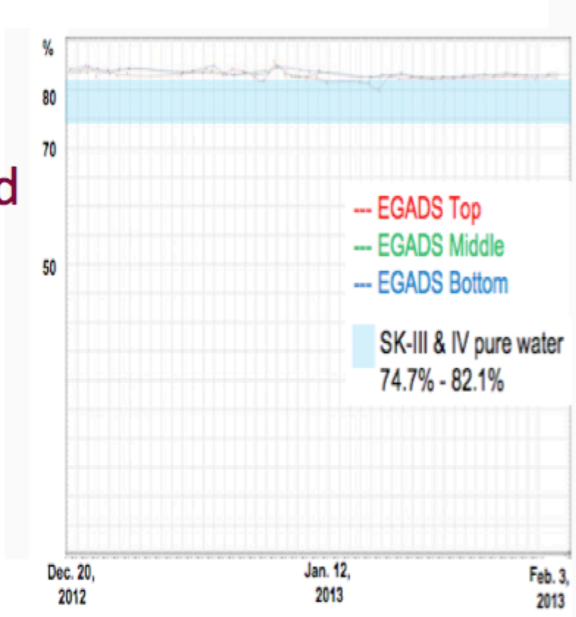


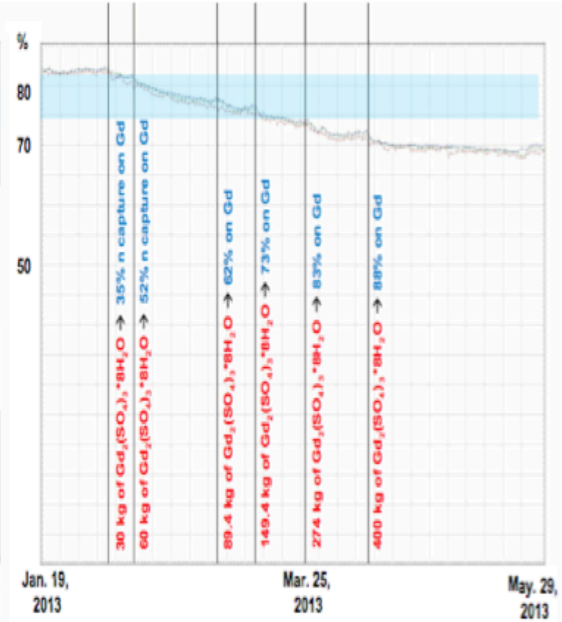
Water transparency measurement with UDEAL

Non-instrumented EAGDS

For pure water, transparency was very stable and very good quality

Good behavior when introducing Gd, < 15% drop



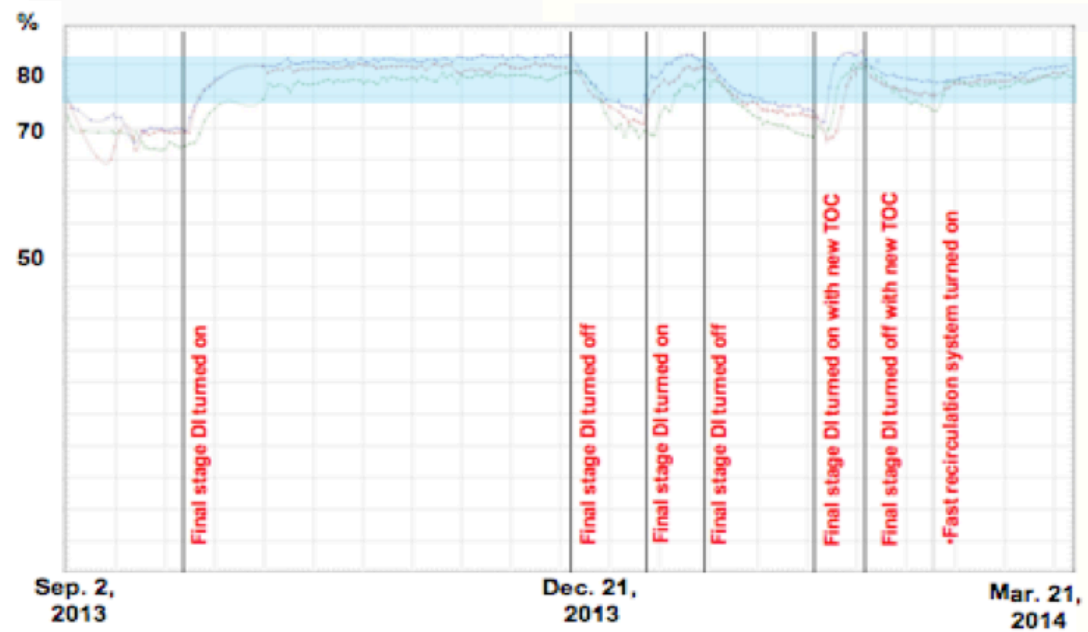


Instrumented EAGDS

For pure water, transparency was not so good quality

Became worse during the procedure of adding Gd, when changing the water level

After investigation, we found that there was a bad material

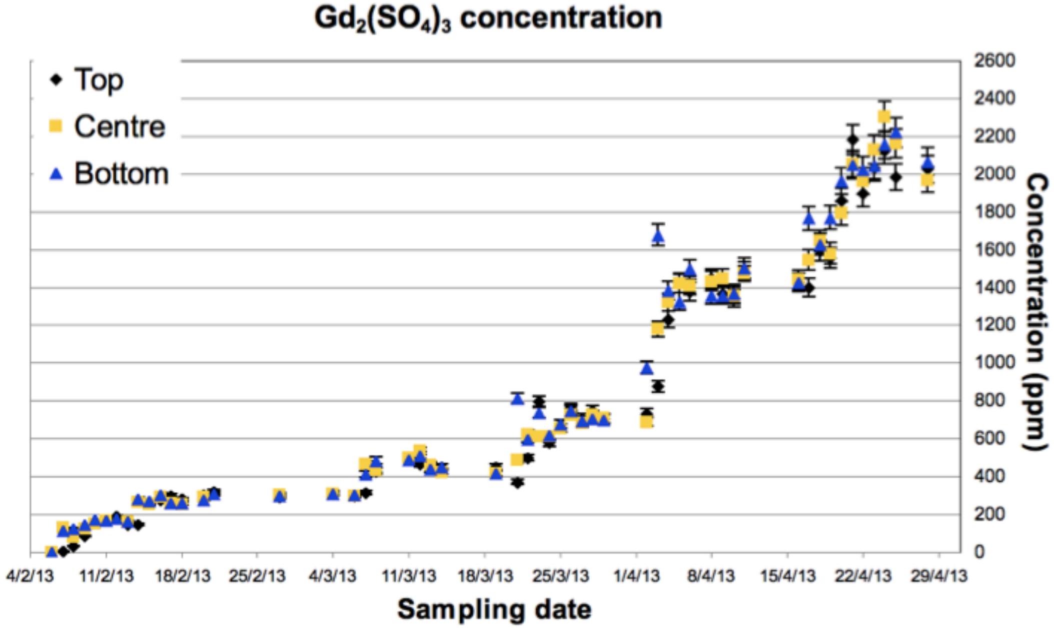


Gd concentration measurement with AAS

Non-instrumented EAGDS

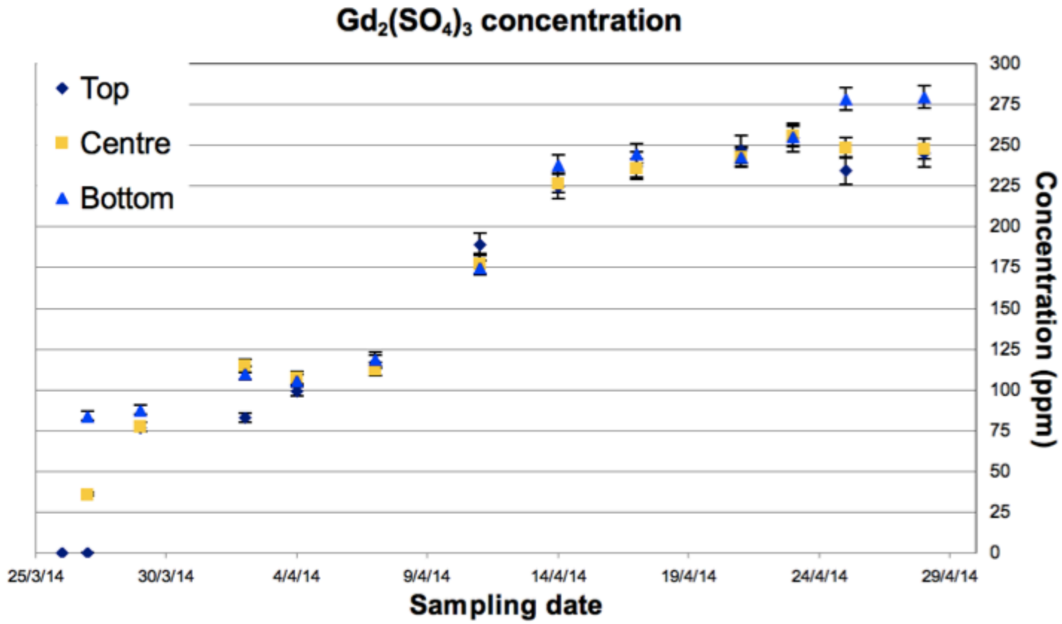
Concentration becomes rapidly uniform along the whole volume of the detector after each Gd insertion

$Gd_2(SO_4)_3$ remains homogenously dissolved



Instrumented EAGDS

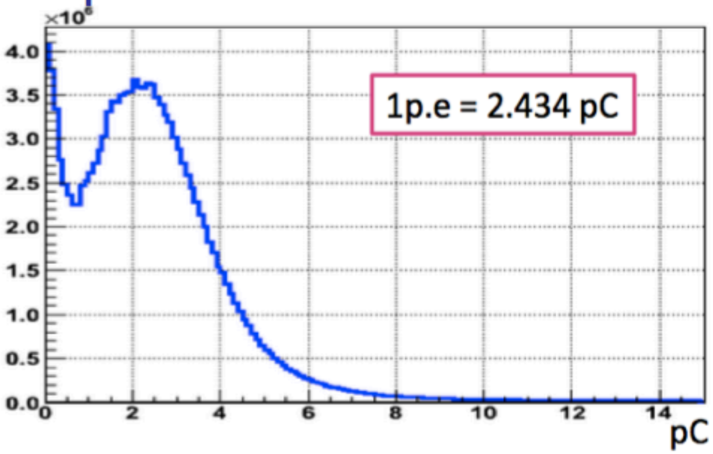
No major effect in uniformity and stability of Gd concentration once the PMTs were installed



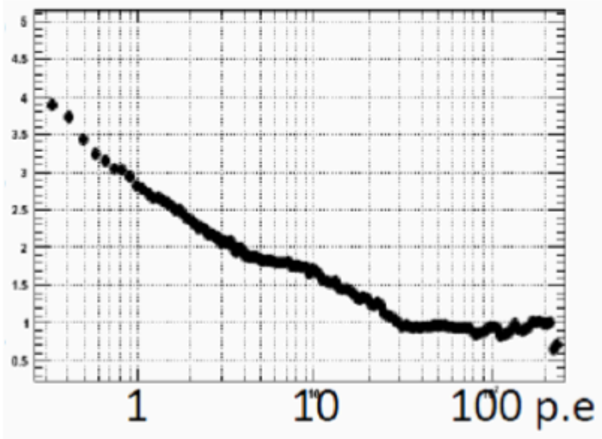
EGADS calibrations

All calibrations show stable and reliable performance of the detector

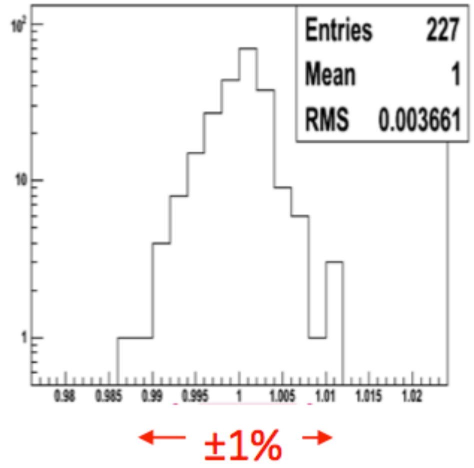
- 1photo-electron



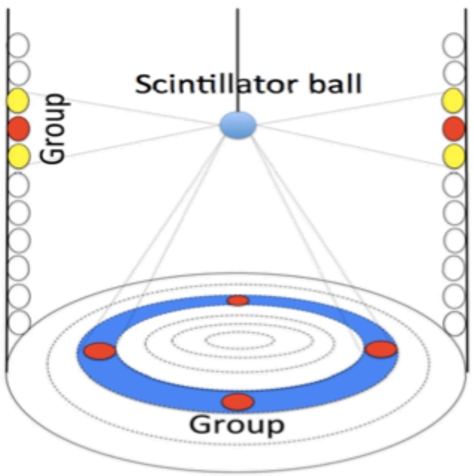
- Timing resolution

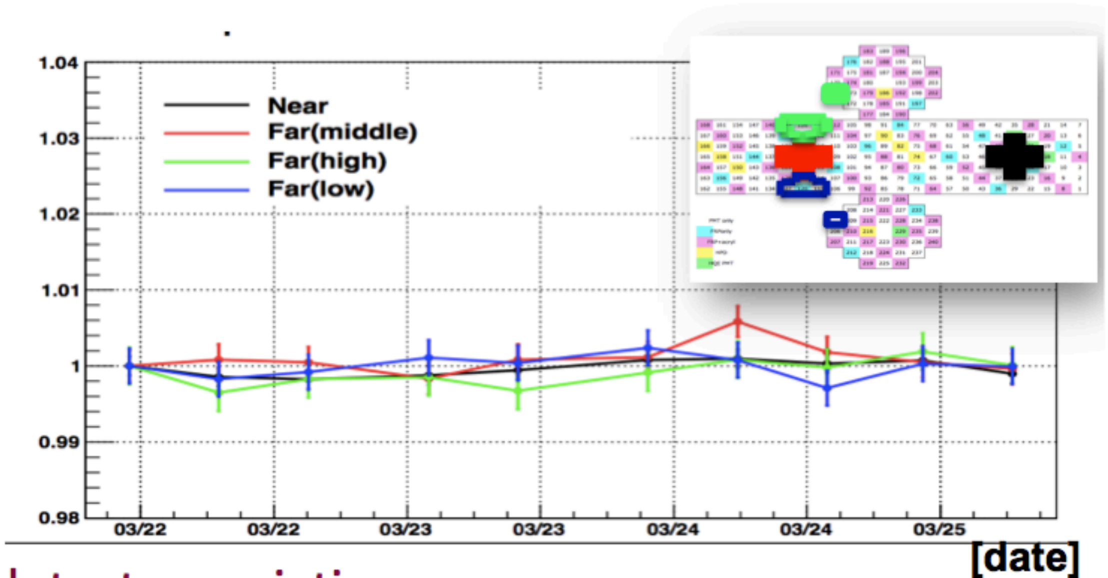


- PMT Q uniformity



- auto-Xe lamp





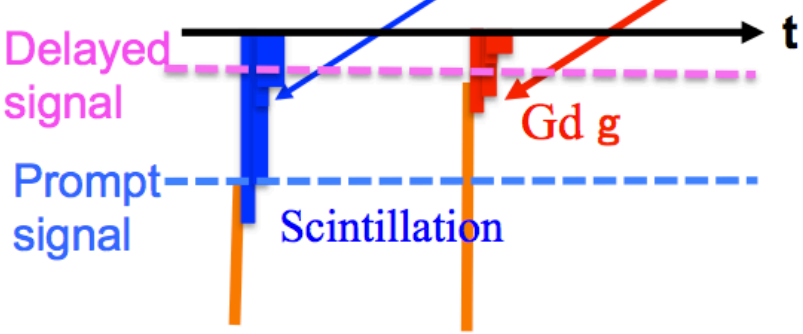
Precise monitoring of the detector variations

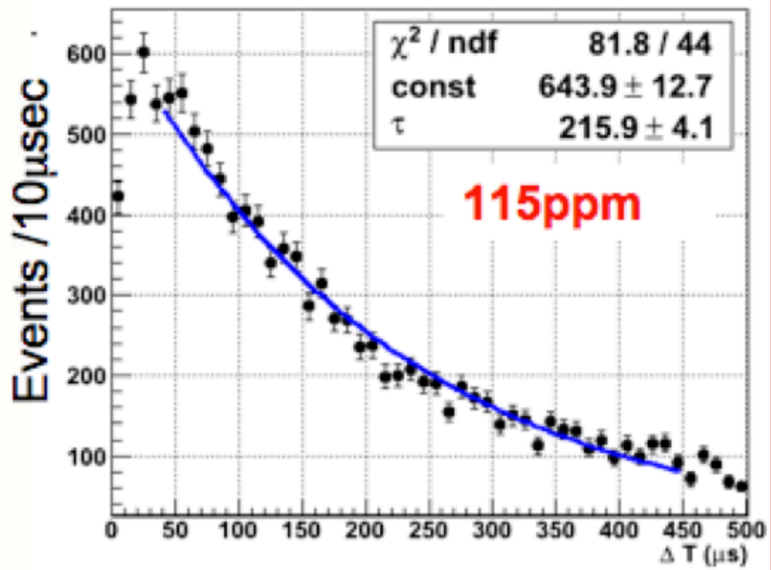
- Am - Be source

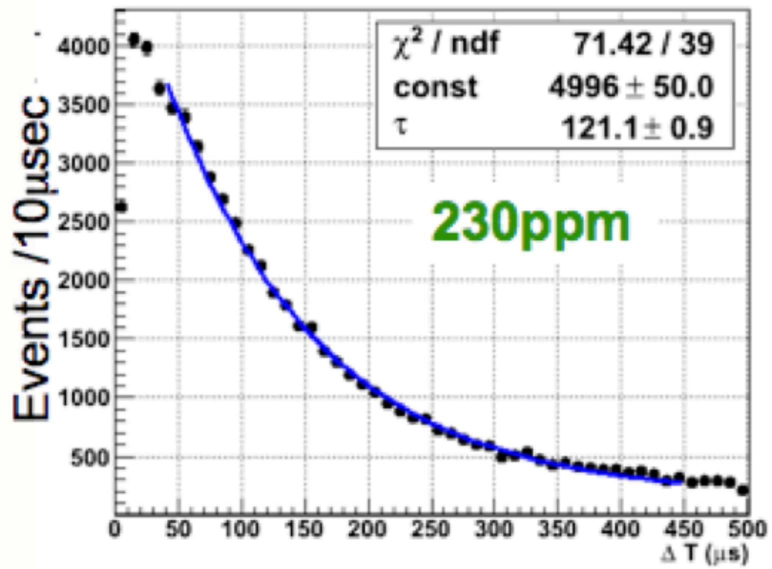
Used to test detector performance and check Gd neutron capture efficiency

$^{241}Am \rightarrow {}^{237}Np + a$

$^{9}Be + a \rightarrow {}^{12}C + g(4.4MeV) + n$







neutron capture delay after prompt signal depends on Gd concentration as expected from Monte Carlo simulations

$Gd_2(SO_4)_3$	Data [ms]	MC [ms]
115ppm	215.6 ± 4.1	221.8 ± 2.3
230ppm	121.1 ± 0.9	124.8 ± 2.1

Mass Hierarchy discrimination with atmospheric neutrinos at SK+Gd

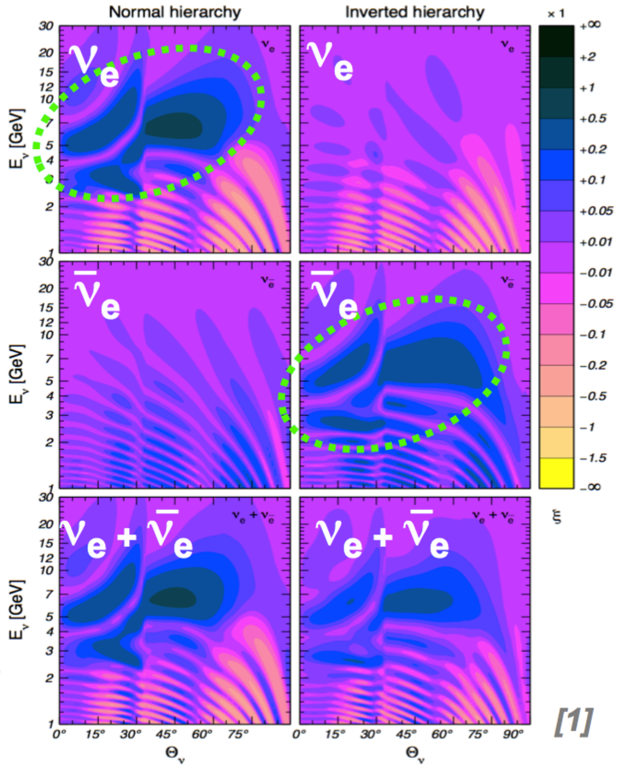
Pablo Fernández, Luis Labarga
UAM

ν oscillations through Earth

"Eventogram"

relative flux of upwards atmospheric neutrinos and anti-neutrinos as a function of their energy, zenith angle and νMH

→try to use the resonance enhancement from earth's core and mantle



[1]

Conclusions

- This analysis show that neutron tagging can also help at the GeV scale for distinguishing between neutrinos and anti-neutrinos. This increases the sensitivity of SK to the neutrino mass hierarchy.
- However, the mass hierarchy is very sensitive to the octant of θ_{23}. This analysis is done assuming we know precisely θ_{23} for each of the three possible scenario
- **HK+Gd will definitely solve MH after 5 years of running**

  extremely preliminary
- Room for improvement:
  - extend analysis to multi-ring events as well
  - include other variables to enhance neutrino-antineutrino separation

Conclusions & Remarks

Europe could be in the race for leptonic CPV and proton decay, but it is not

LBNE seems designed mainly to become complementary to Japan regardless of measuring CPV: LArg, low mass, new beam ... it will never be competitive (I guess)

Hyper-Kamiokande is the only experiment ~fulfilling ~all the requirements of any new Mega-Project: there is Science, there is beam, there is a Laboratory, the technology is there ... the only thing that is not yet there is the full support of a large enough international community

Thus,
if you want to know how CP is violated in the lepton sector, you'd better work (within your field) for Hyper-Kamiokande

Additional material

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Expression of Interest
for a very long baseline neutrino oscillation experiment
(LBNO)

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(Dated: June 28, 2012)

Building for Discovery

Strategic Plan for U.S. Particle Physics in the Global Context

Report of the Particle Physics Project Prioritization Panel (P5)

HEPAP
22 May 2014
S. Ritz

2014 P5 Report Building for Discovery

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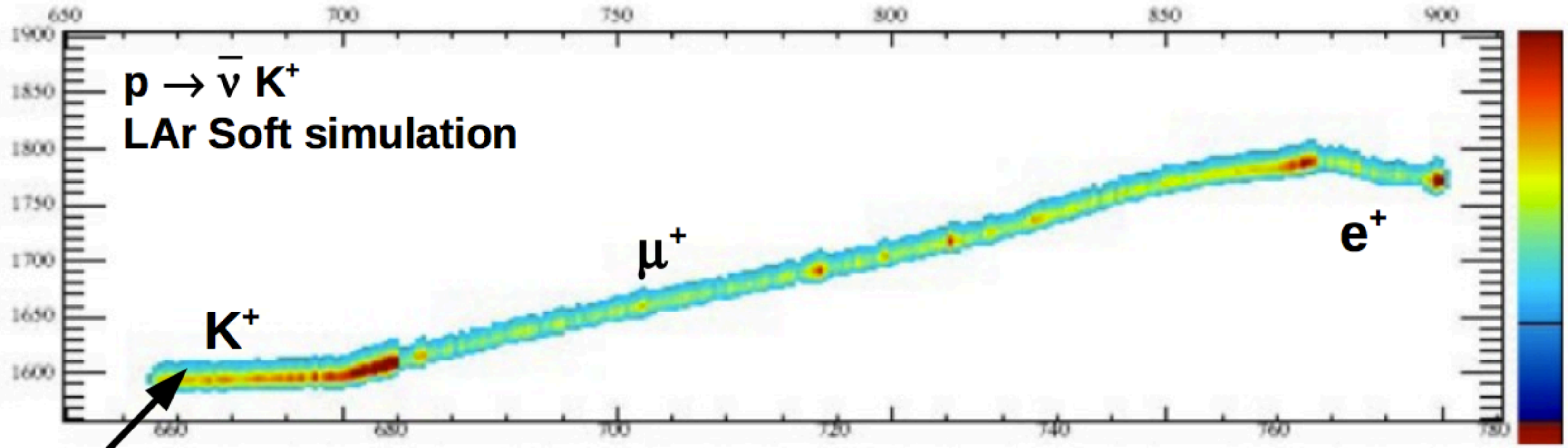
$p \to \bar{\nu} K^+$



Below Cherenkov threshold in Water

Hyper-K analysis is based on three methods of searching the kaon's decay producits

	Hyper-K	LBNE
Signal ε	7.6 - 37%	**97%**
BG / Mton yr	1.8 - 2556	**< 1**
10yr. Sens. 90%	3.2×10^{34} ⟷	$\mathbf{3.3 \times 10^{34}}$

- LBNE exhibits good sensitivity to decay modes with a Kaon present
  - Significant advantage over water Cherenkov detectors

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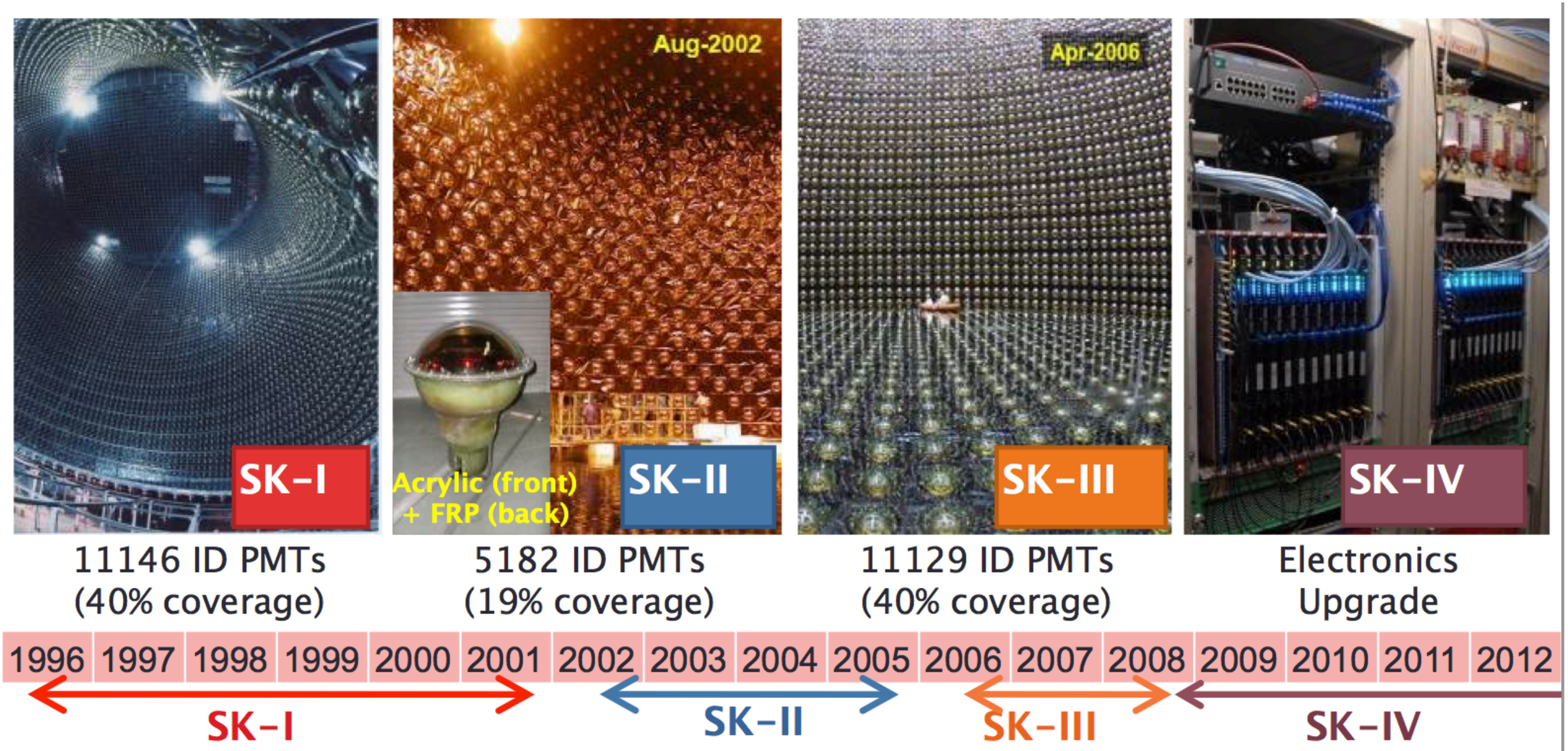
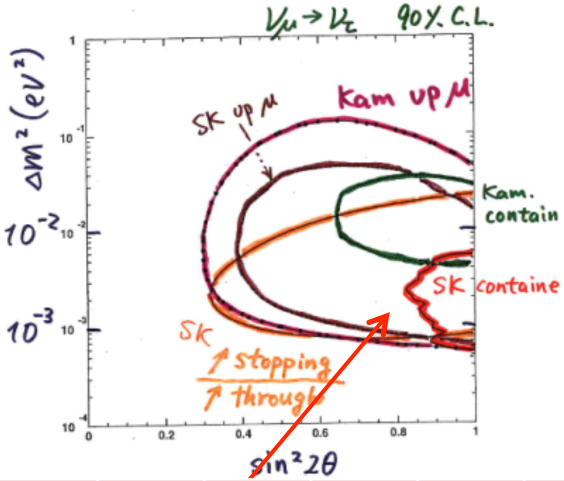
history of Super-Kamiokande

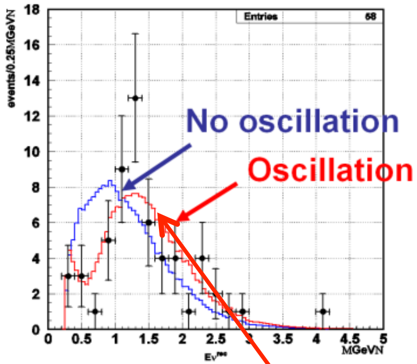


physics achievements with Super-Kamiokande

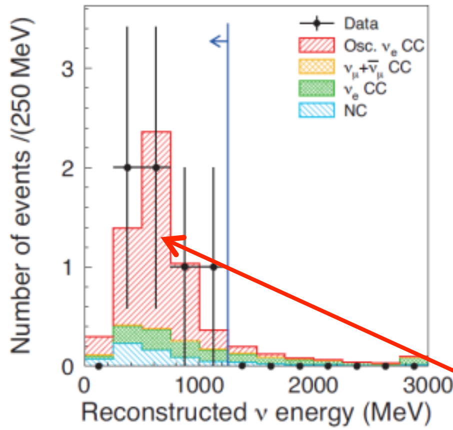
Atmospheric ν oscillations



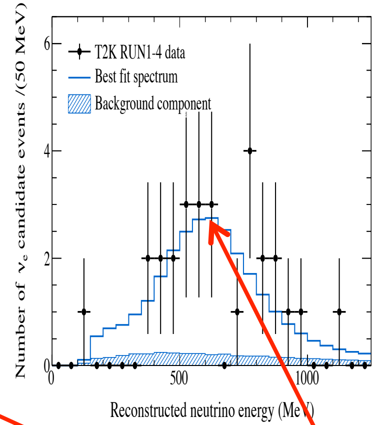
K2K confirmed atmospheric osc. by long baseline ν



indication θ_{13} by T2K

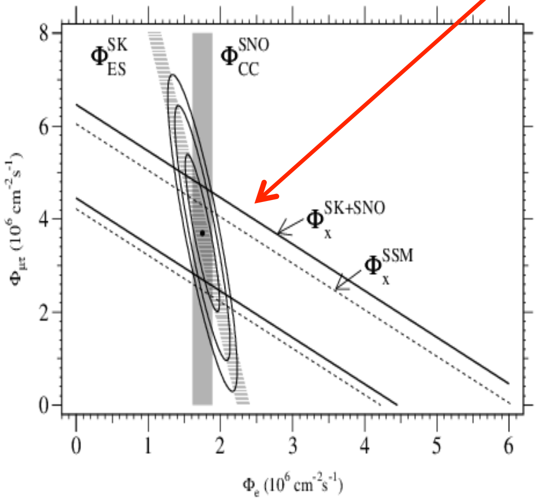


observation θ_{13} by T2K

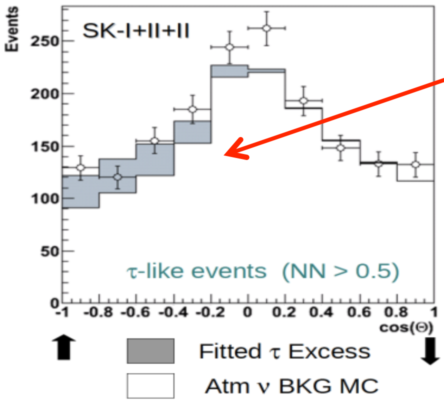


96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13

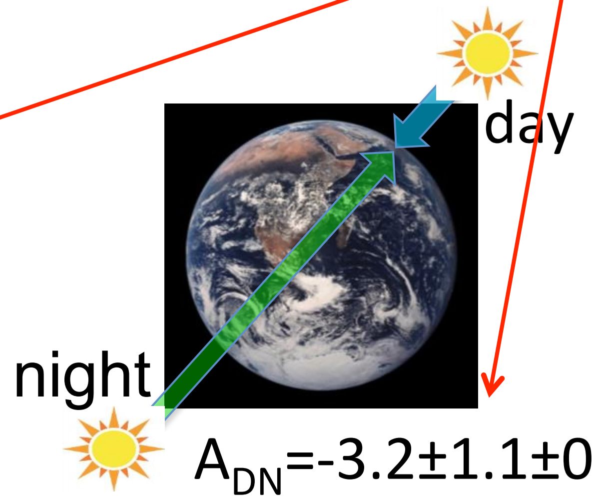
Solar ν oscillations



ν_τ appearance in atmospheric ν



Solar day/night asymmetry



A_{DN}=-3.2±1.1±0.5 %

Antineutrino tagging will have a profound impact in experimental neutrino physics.

Remarkably, SK will be in the position of **discovering** the Difusse Supernova Neutrino Background, and the next generation will measure its energy spectrum: the red-shifted sum of the contribution of supernova neutrino from every epoch of the Universe

In addition

– precise measurement of the solar elements in the leptonic mixing matrix from nuclear reactor electron antineutrinos,
– a much increased sensitivity to the neutrino MH from atmospheric neutrinos and antineutrinos traversing the earth before interacting in SK
– increase the sensitivity for proton decay searches
– others coming along the learning curve

Elastic $\nu + e \rightarrow \nu + e$ ← << 1 GeV

Quasi-elastic

CC:

$\nu_l n \rightarrow l^- p$

$\bar{\nu}_l p \rightarrow l^+ n$ (IBD)

← < 1 GeV

main interactions

~ 1 GeV ↓

Single-meson *CC:*

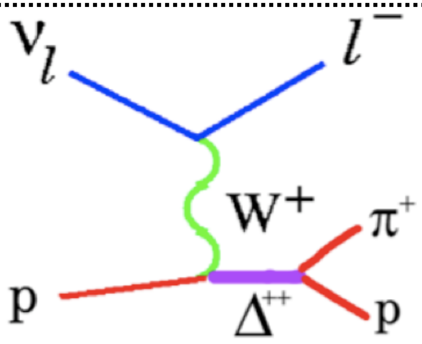
a) $\nu N \rightarrow l\, N^*,\ N^* \rightarrow m N'$

N, N': nucleons

N: baryon resonance*

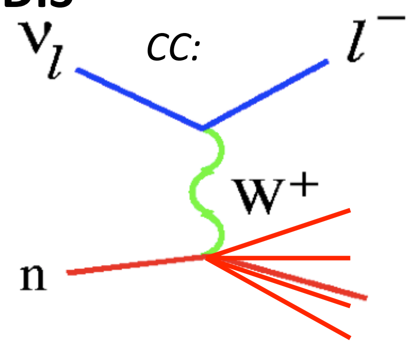
m: meson (π's, also K, η)

b) coherent π production: $\nu\, ^{16}O \rightarrow l\, \pi\, ^{16}O$

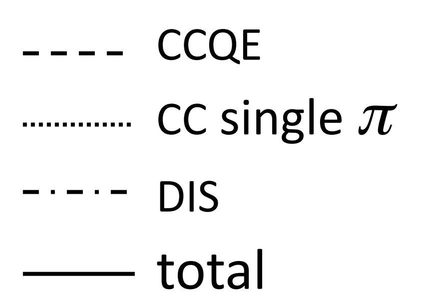


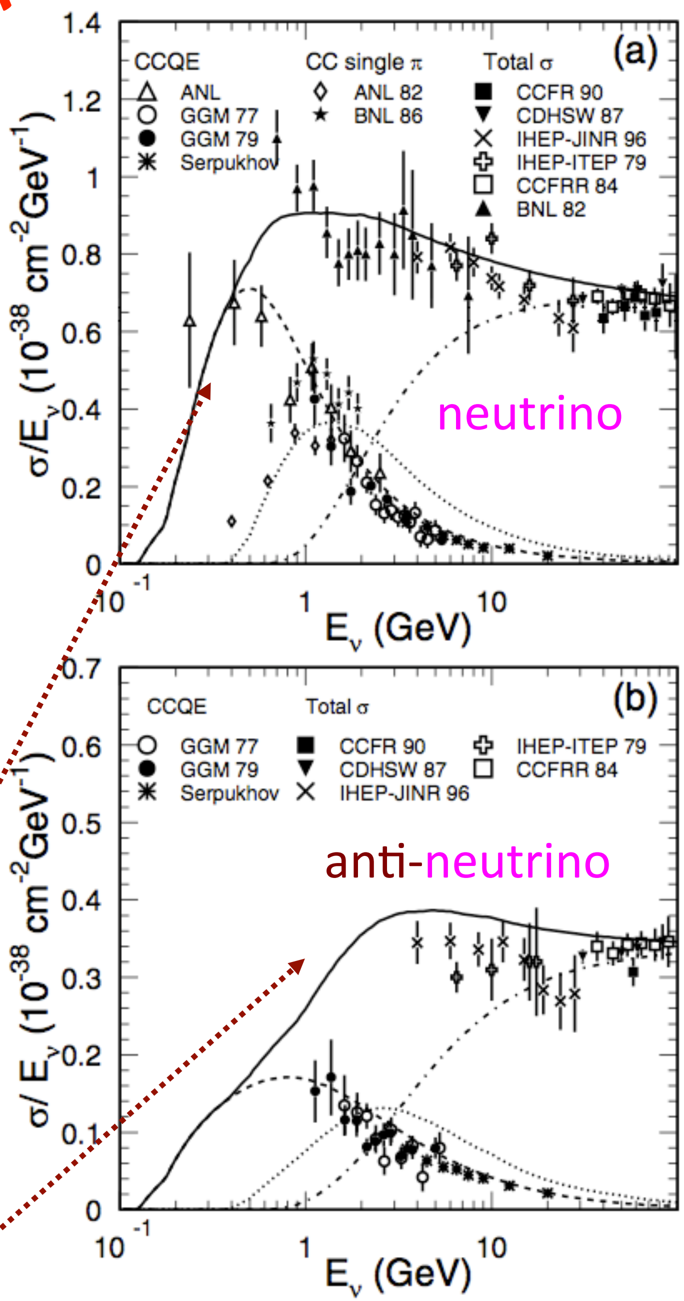
DIS

CC:



← High Energy





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