Experimental Neutrino Physics in Brazil

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BRASIL-JINR FORUM

Outline

- Physics Challenges
  - History and facts
  - The context of neutrino experiments in the frontier of Physics
- Experiments
  - Where are the Brazilians researchers/institutions within this scenario ?
- Conclusion

Neutrino: a building block

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin =1/2

Flavor	Mass GeV/c^2	Electric charge
ν_L lightest neutrino*	$(0-0.13)\times10^{-9}$	0
e electron	0.000511	–1
ν_M middle neutrino*	$(0.009-0.13)\times10^{-9}$	0
μ muon	0.106	–1
ν_H heaviest neutrino*	$(0.04-0.14)\times10^{-9}$	0
τ tau	1.777	–1

Quarks spin =1/2

Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.002	2/3
d down	0.005	–1/3
c charm	1.3	2/3
s strange	0.1	–1/3
t top	173	2/3
b bottom	4.2	–1/3

The three types of neutrinos in the standard model are the lightest particles with a non-zero mass ever discovered. The upper limit on the mass of the heaviest neutrino is still more than 4 million times lighter than the electron, the next lightest particle.

Neutrinos: some facts

- **Neutrinos are super abundant.** Neutrinos are the second most abundant particle in the universe.
  - If we were to take a snapshot, we'd see that every cubic centimeter has approximately 1,000 photons and 300 neutrinos.
  - The nuclear fusion reactions in the Sun sends 65 billion neutrinos per second per square centimeter to Earth, they are crossing us all the time.
- **Neutrinos are almost massless.** The three types of neutrinos in the standard model are the lightest particles with a non-zero mass ever discovered. The upper limit on the mass of the heaviest neutrino is still more than 4 million times lighter than the electron, the next lightest particle.
- **Neutrinos may have altered the course of the universe.** Why we have predominance of matter over antimatter? Cosmologists think that at the start of the universe there were equal parts of matter and antimatter.
  - Neutrino interactions may have tipped this delicate balance, enabling the formation of galaxies, stars and planets like our own Earth.
- **Neutrinos are the key particle in the heavy-element forges of the universe:** neutrinos dissipate more than 99 percent of a supernova's energy. Supernovae eject heavy elements to the cosmos in a recycling matter mechanism.
  - "Core collapse" supernovae end as either a black hole or a neutron star. Neutrinos are key particles to understand how supernovae explode and tell us more about other astronomical objects like active galactic nuclei.

Do they deserve a careful and comprehensive study ???

Neutrinos: historical remark

APRIL 1, 1941 PHYSICAL REVIEW VOLUME 59

Neutrino Theory of Stellar Collapse

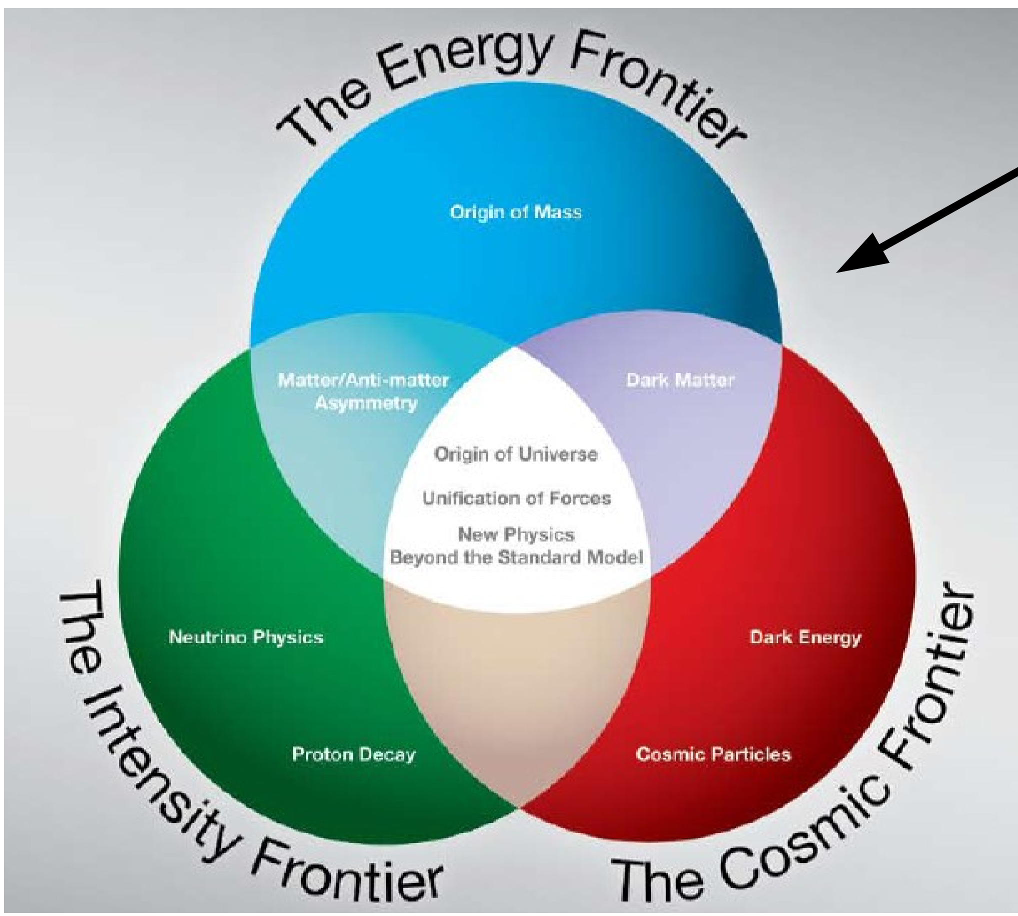
G. GAMOW, *George Washington University, Washington, D. C.*
M. SCHOENBERG,* *University of São Paulo, São Paulo, Brazil*

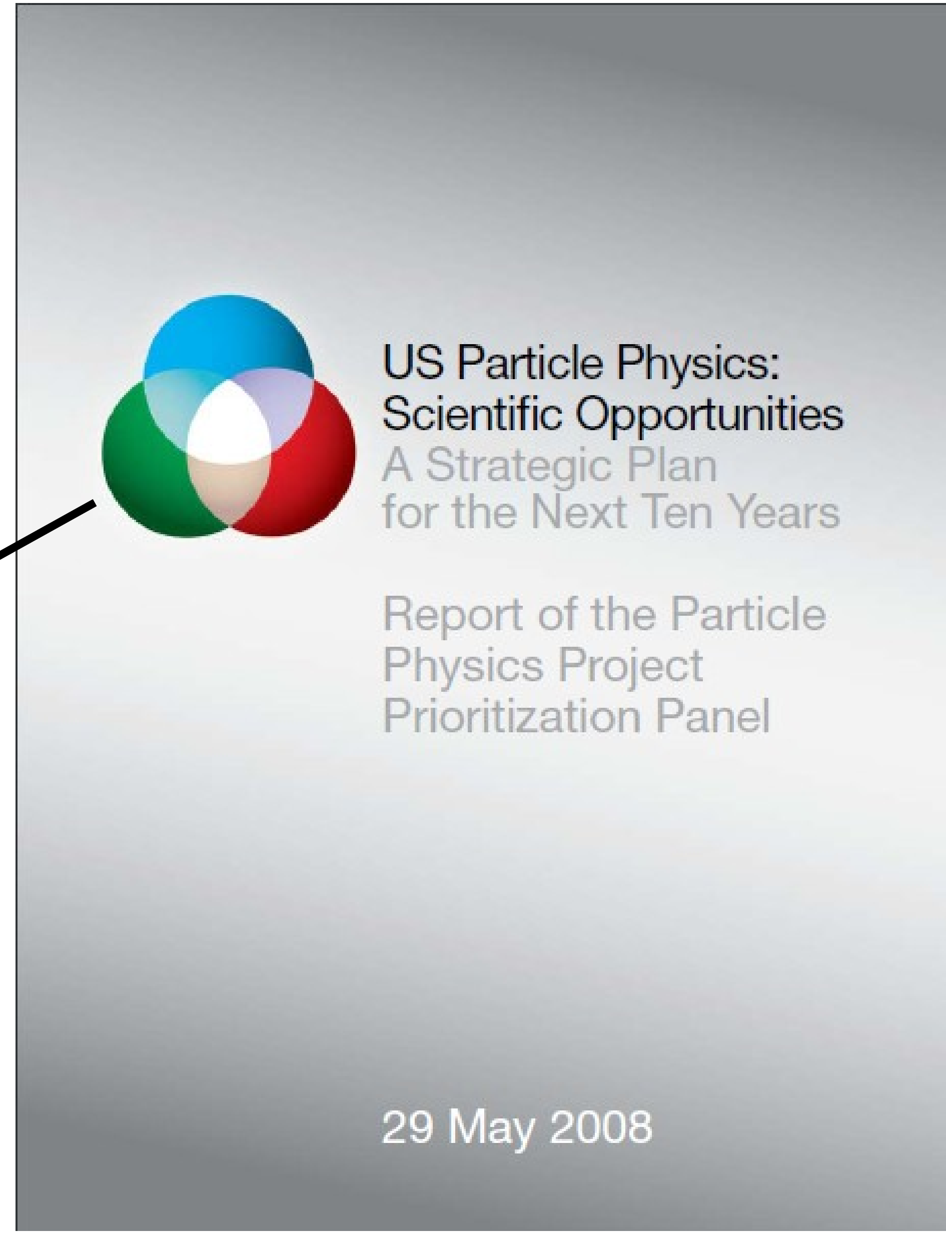
(Received February 6, 1941)

At the very high temperatures and densities which must exist in the interior of contracting stars during the later stages of their evolution, one must expect a special type of nuclear processes accompanied by *the emission of a large number of neutrinos*. These neutrinos penetrating almost without difficulty the body of the star, must carry away very large amounts of energy and prevent the central temperature from rising above a certain limit. This must cause *a rapid contraction of the stellar body* ultimately resulting in a *catastrophic collapse*. It is shown that energy losses through the neutrinos produced in reactions between free electrons and oxygen nuclei can cause a complete collapse of the star within the time period of half an hour. Although the main energy losses in such collapses are due to neutrino emission which escapes direct observation, the heating of the body of a collapsing star must necessarily lead to the *rapid expansion of the outer layers* and the *tremendous increase of luminosity*. It is suggested that stellar collapses of this kind are responsible for the phenomena of *novae* and *supernovae*, the difference between the two being probably due to the difference of their masses.

Physics Challenges

http://science.energy.gov/~/media/hep/pdf/files/pdfs/p5_report_06022008.pdf





Physics Challenges

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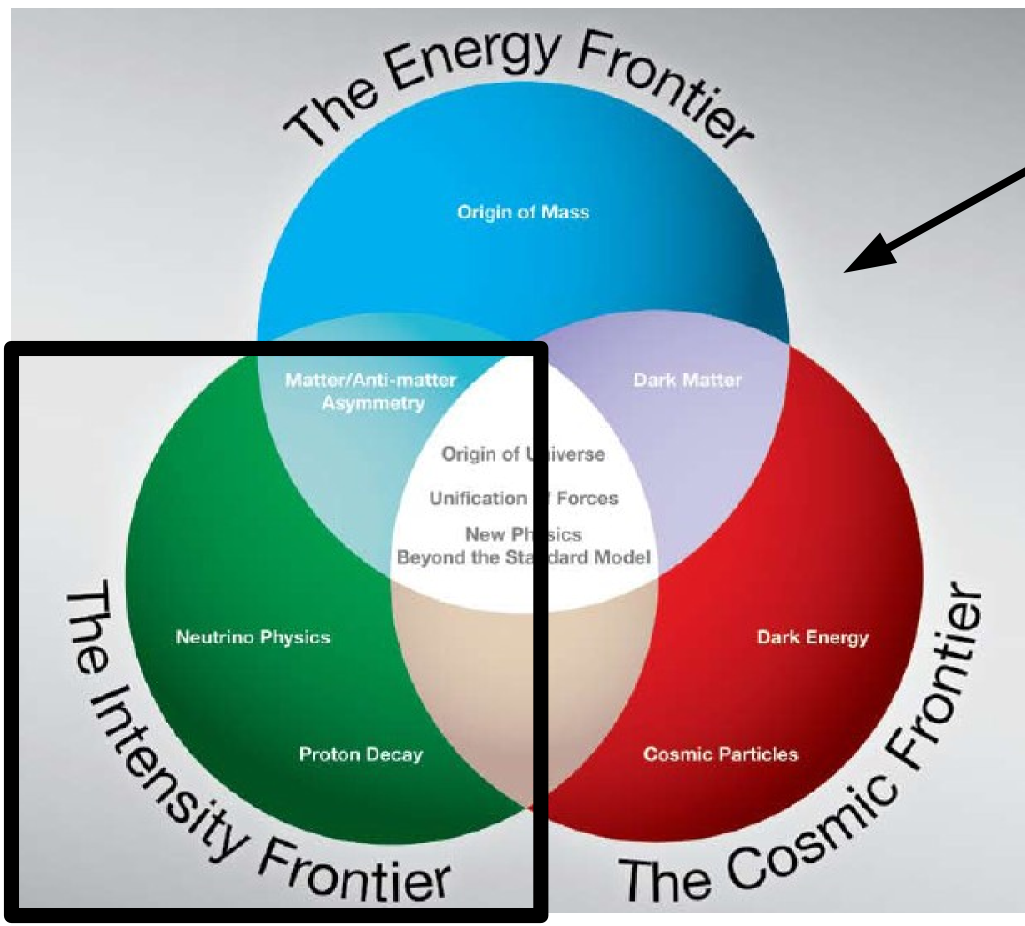
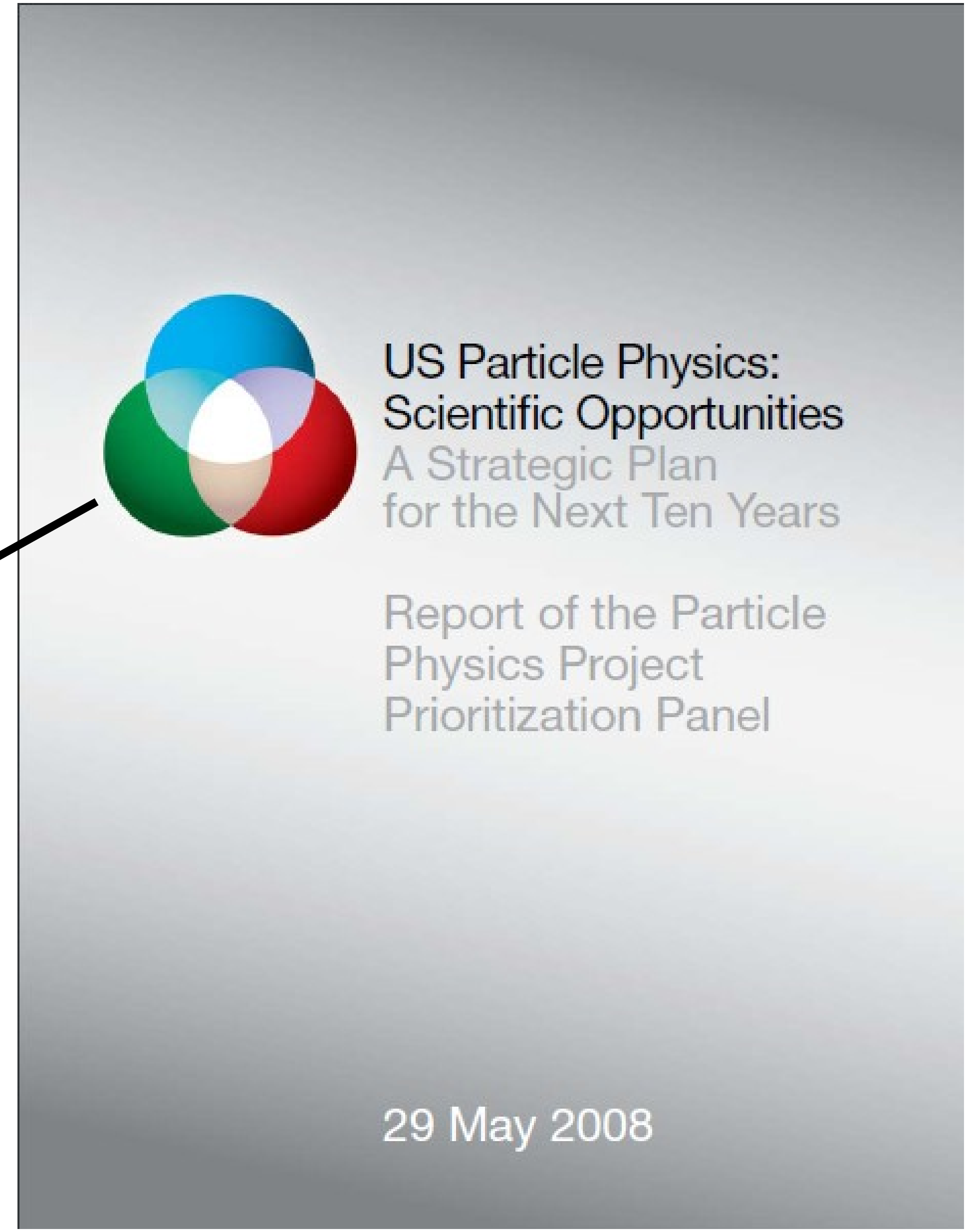




Physics Challenges: P5 report (2008)

- **The Intensity Frontier**
  - *"Measurements of the mass and other properties of neutrinos are fundamental to understanding physics beyond the Standard Model and have profound consequences for the understanding of the evolution of the universe."* (PG. 3)
  - *"Recent striking discoveries make the study of the properties of neutrinos a vitally important area of research. Measurements of the properties of neutrinos are fundamental to understanding physics beyond the Standard Model and have profound consequences for the evolution of the universe. The latest developments in accelerator and detector technology make possible promising new scientific opportunities in neutrino science as well as in experiments to measure rare processes."* (PG. 10)

The panel recommends a world-class neutrino program as a core component of the US program (PG. 3)

Physics Challenges: P5 report (2014)

Building for Discovery

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

Report of the Particle Physics Project Prioritization Panel (P5)

Download a PDF of the report. *Download the report summary.* *Visit the P5 community portal.*

The P5 report recommends a prioritized and time-ordered list of experiments to address the five science Drivers optimally. These opportunities are at the small, medium, and large investment scales that, together, produce a continuous flow of major scientific results throughout a twenty-year timeframe.

- Large projects, in time order, include the Muon g-2 and Muon-to-electron Conversion (Mu2e) experiments at Fermilab, strong collaboration in the high-luminosity upgrades to the Large Hadron Collider (HL-LHC), and a U.S.-hosted Long Baseline Neutrino Facility (LBNF) that receives the world's highest intensity neutrino beam from an improved accelerator complex (PIP-II) at Fermilab.

Small changes in yearly budgets have large impacts on the timeline and capability of the U.S. particle physics program. A very large return on investment is ensured by the relatively small increment in funding between the constrained budget scenarios given in the P5 charge:

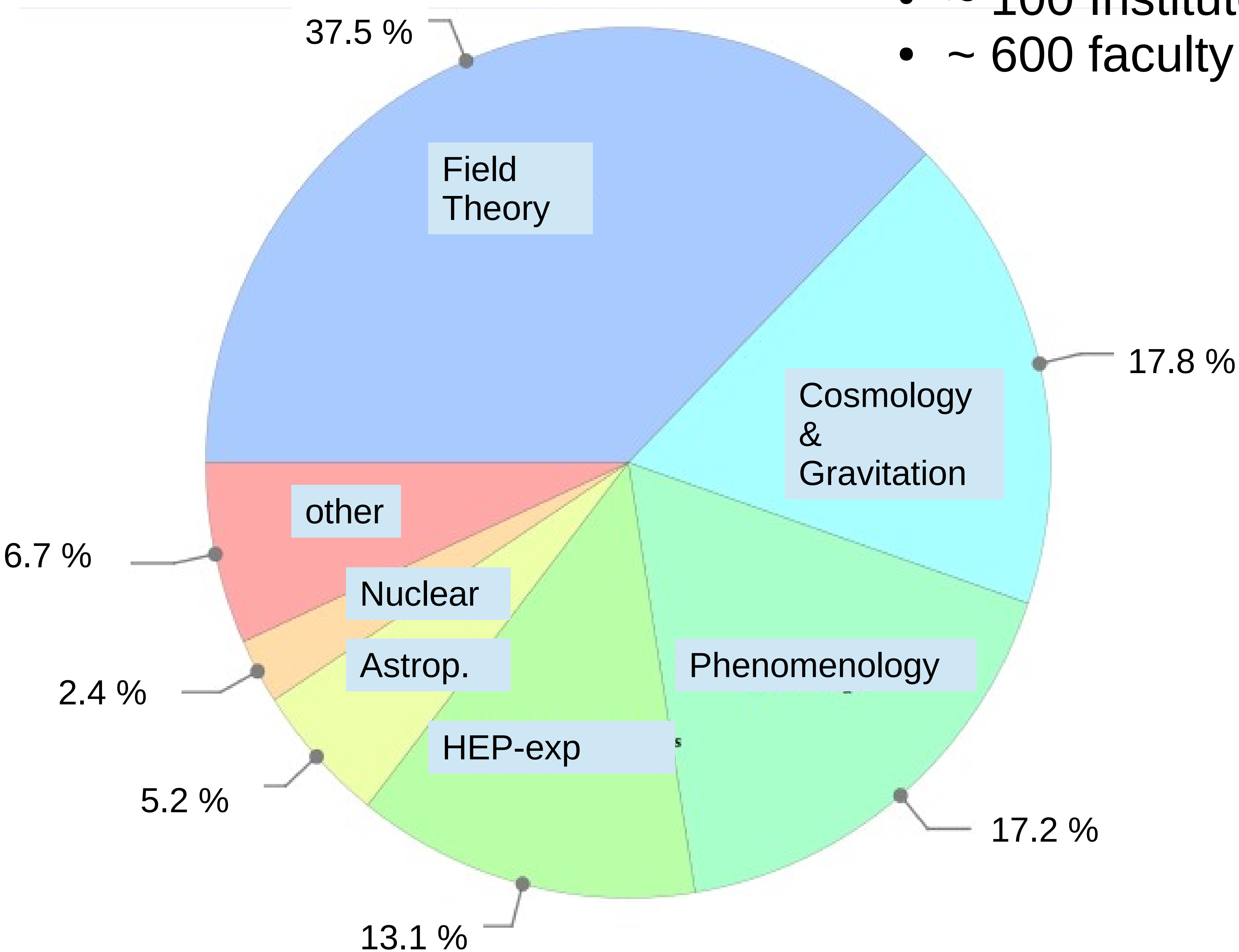
- A small limited-time funding increment to ensure support of the Dark Energy Spectroscopic Instrument (DESI) would yield scientific returns with high impact.
- World-leading accelerator and instrumentation development research would be retained.
- U.S. research capability would be maintained, including a

Physics Challenges: scientific motivations

- Neutrino Physics is one of the most active field in the advanced frontier of "Big Science"
- Offers an unique opportunity to stay tuned with technological and scientific progress in worldwide scale
  - **For sure Brazilian physicists/scientists are interested to be part of it.**

Figures about BR-HEP

- ~ 100 Institutes
- ~ 600 faculty

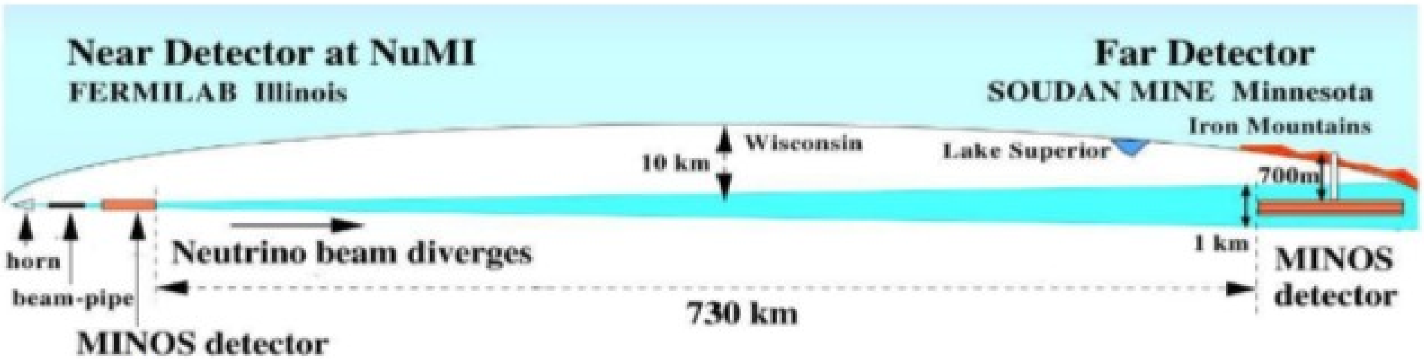


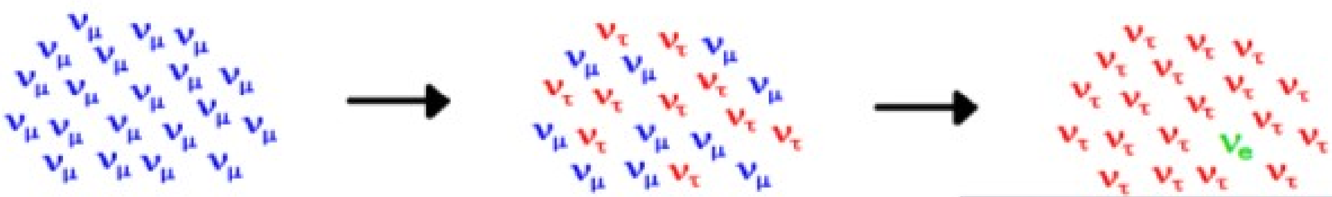
Figures about BR-HEP: by subarea

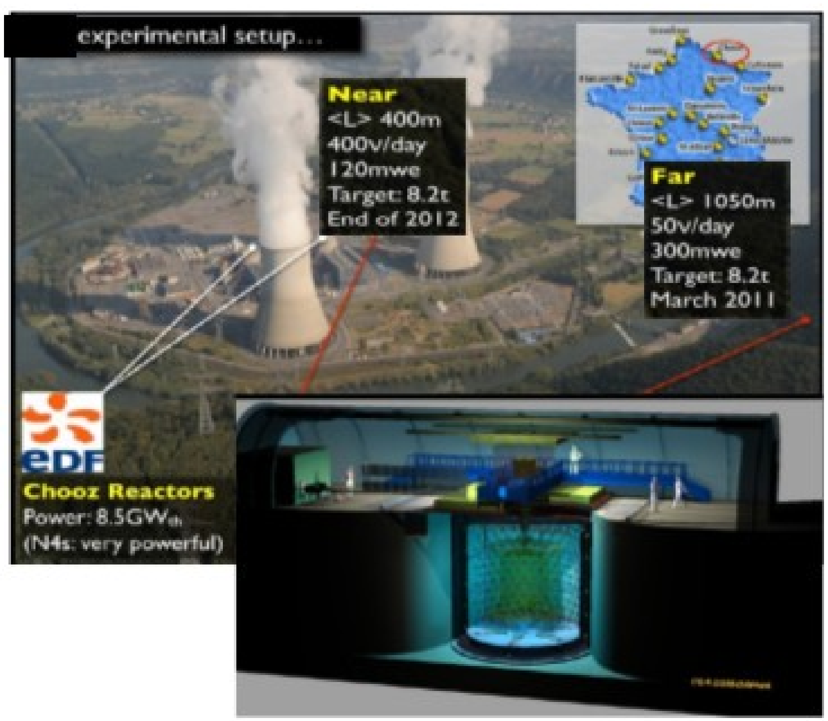
- hep-exp
  - 5800 papers
  - 242 technological products
  - 211 supervision works in progress
  - 1080 concluded
- cosmology
  - 3000 papers
  - 308 technological products
  - 318 supervision works in progress
  - 1352 concluded
- Particle Physics
  - 3900 papers
  - 218 technological products
  - 259 supervision works in progress
  - 1379 concluded
- Field Theory
  - 6800 papers
  - 375 technological products
  - 534 supervision works in progress
  - 3476 concluded

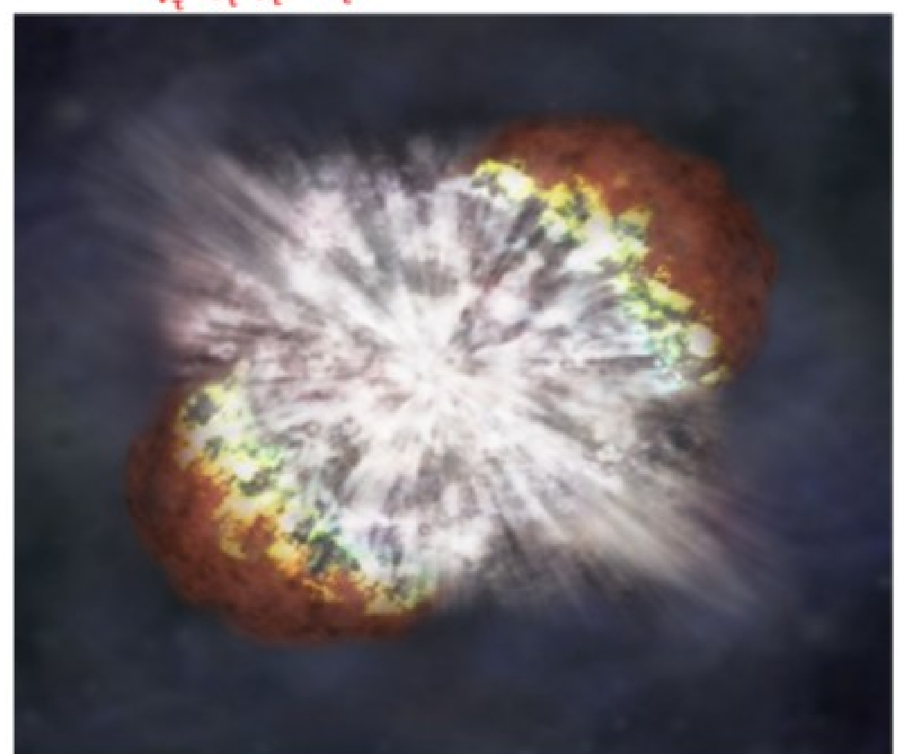
- Lattes data base (from CNPq)
- Sampled from ENFPC (2013)
- Caution: there are “ contaminations”

Neutrino experiments: some examples









Where ? : Experiments with BR teams

- **Neutrino Properties:**
  - ***oscillations***
    - DUNE
    - Double Chooz
    - NOvA
    - MINOS
      - MINOS+
- **Neutrino Interactions:**
  - ***nuclear scattering and NSI***
    - DUNE
    - MINERVA
    - CONNIE

- **Astrophysical Neutrinos**
    - DUNE
    - LVD
      - Xenon
    - Pierre Auger Observatory
- **Neutrino Applied Physics**
    - Neutrinos-ANGRA
- **Special Remark: ANDES**

Most of Brazilian neutrino scientists have joined DUNE collaboration:
1) a more efficient participation
2) a very attractive experiment

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What ? : activities from BR teams

- R&D
  - Detectors development, integration, prototype tests
- Experiment construction
  - installation, commissioning
- Monitoring
  - Data analysis for detector characterization
    - performance and systematics studies
- Data Analysis
- Management
  - Scientific boards and task leading
  - Administrative boards and tasks

Experiments: Double Chooz

Experiments: Double Chooz

The Double Chooz Collaboration

Univ. of Alabama, ANL,
Univ. of Chicago, Columbia,
U.C. Davis, Drexel Univ.,
Kansas State, Illinois Inst. Tech.,
LLNL, Notre Dame, SNL,
Univ. of Tennessee

CBPF, UNICAMP, UFABC

Hiroshima Inst. Tech.,
Kobe Univ., Miyagi Univ.,
Niigata Univ., Tohoku Univ.,
Tohoku Gakuin Univ.,
Tokyo Metro. Univ.,
Tokyo Inst. Tech.

APC Univ. of Paris,
SUBATECH (Nantes)
DAPNIA CEA/Saclay
Strasbourg

Aachen Univ., Hamburg Univ.,
MPIK Heidelberg, T.U. München,
E.K. Univ. Tubingen,

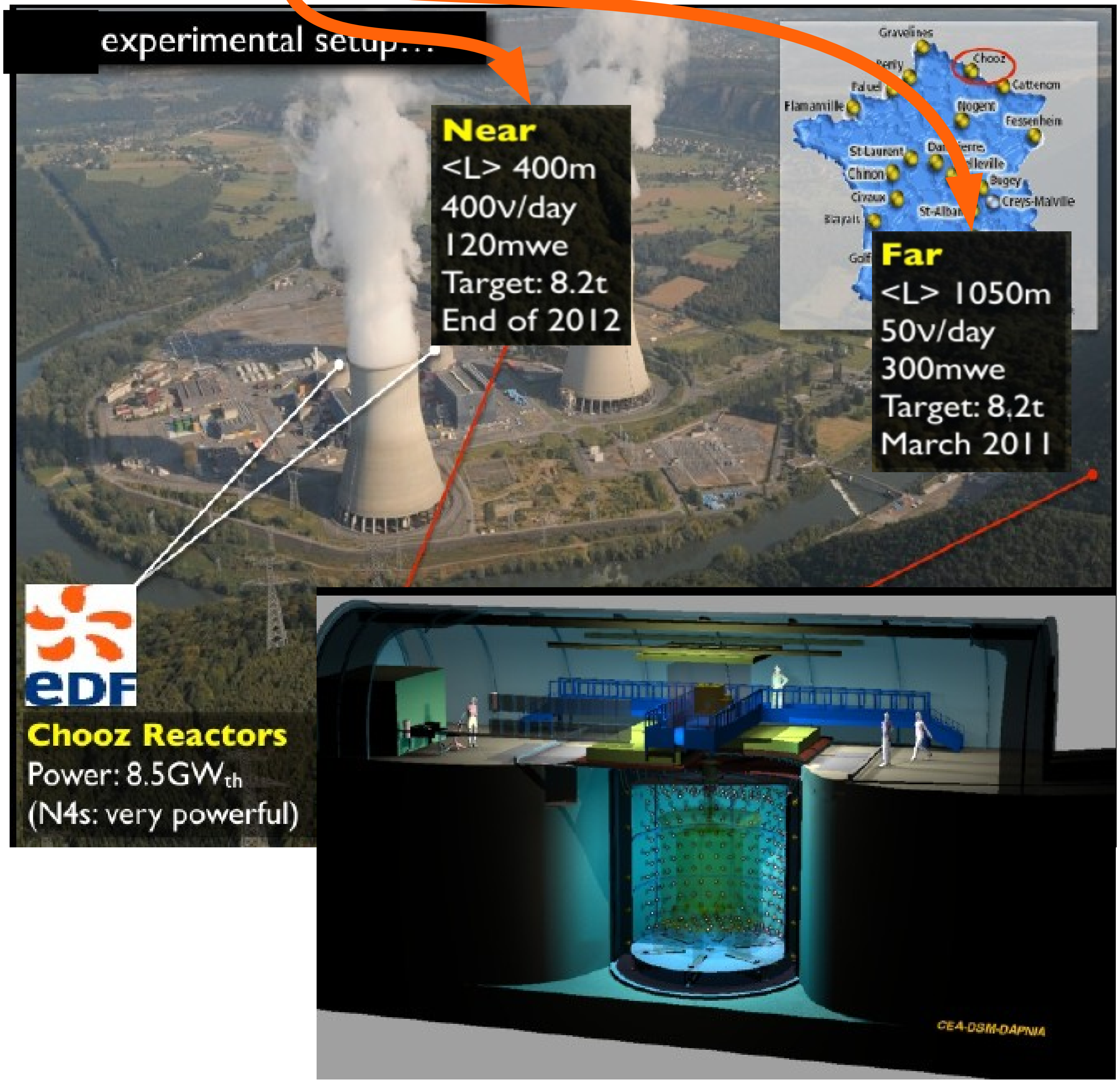
INR-RAS, IPC-RAS,
RRC Kurchatov

CIEMAT Madrid

Univ of Sussex

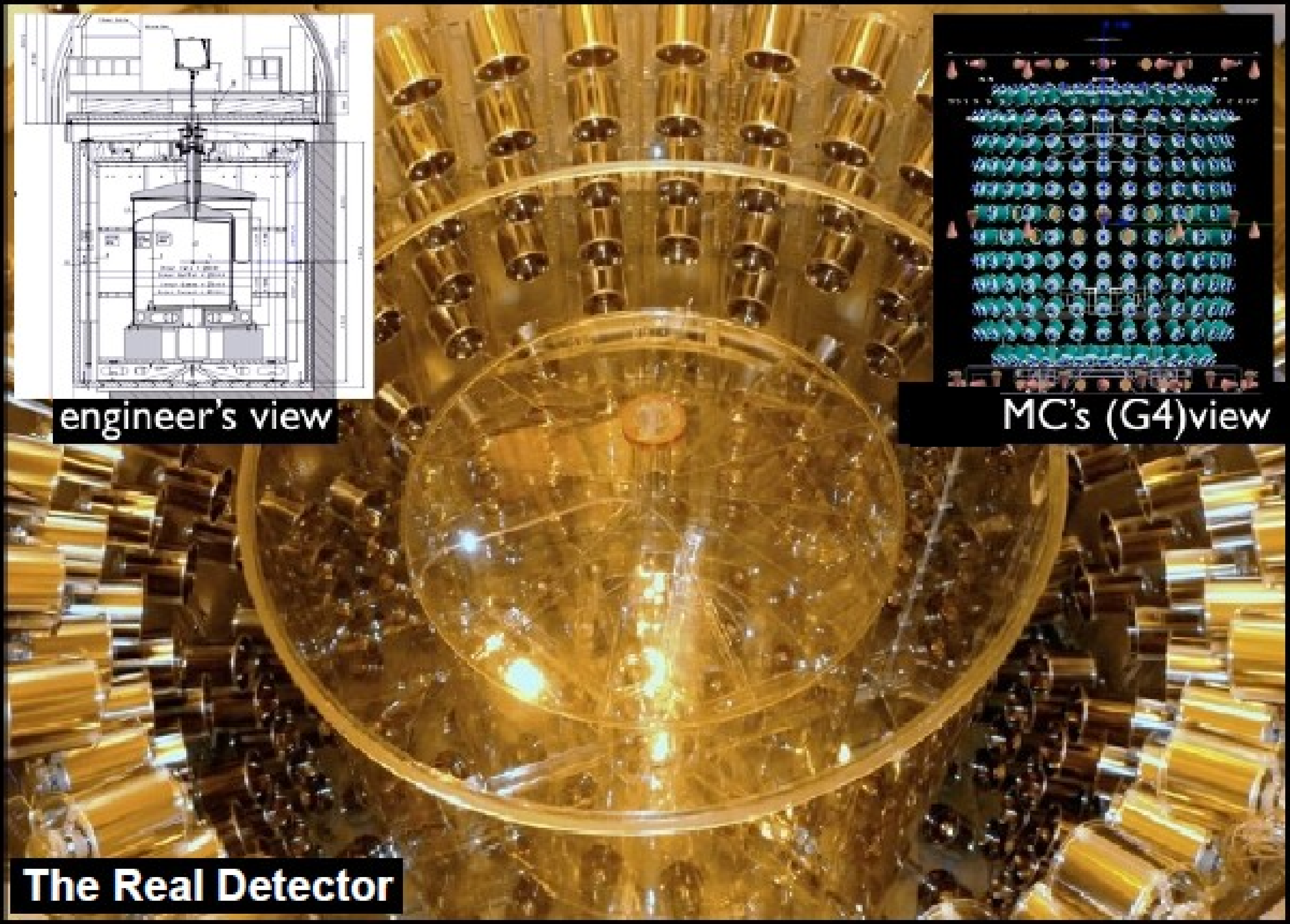
Experiments: Double Chooz

- To look for non-zero values of θ_{13}
  - Strong requirements to reduce the previous sistematics limitations from Chooz results
  - Identical detector placed in different distances is a solution
    - main sistematics and uncertainties are canceled



Experiments: Double Chooz

Detector Layout



Double Chooz main backgrounds

Systematic uncertainties on rate

Preliminary

Source		Uncertainty w.r.t. signal (previous analysis)	
Statistics		**1.1%** (1.6%)	
Flux		**1.7%**	
Detector	Energy response	**0.3%** (1.7%)	**1.0%** (2.1%)
	E_{delay} containment	0.7%	
	Gd fraction	0.3%	
	Δt cut	0.5%	
	Spill in/out	0.3%	
	Trigger efficiency	<0.1%	
	Target H	0.3%	
Background	Accidental	<0.1%	**1.6%** (3.0%)
	Fast neutron + stop μ	**0.5%** (0.9%)	
	^{9}Li	**1.4%** (2.8%)	

Further constraint by a fit to spectrum

Double Chooz: error budget

Systematic uncertainties on rate

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Further constraint by a fit to spectrum

Double Chooz Brazilian contribution: Muon Electronics

- VME 6U Board waveform digitizer

  + time stamp
- 30 units produced

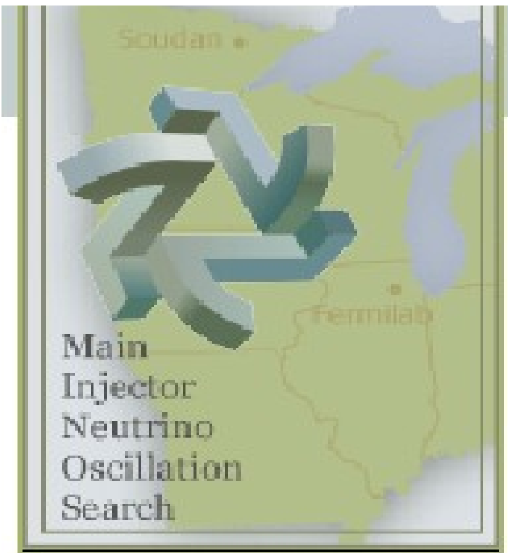
  and tested.

- Full crate installed

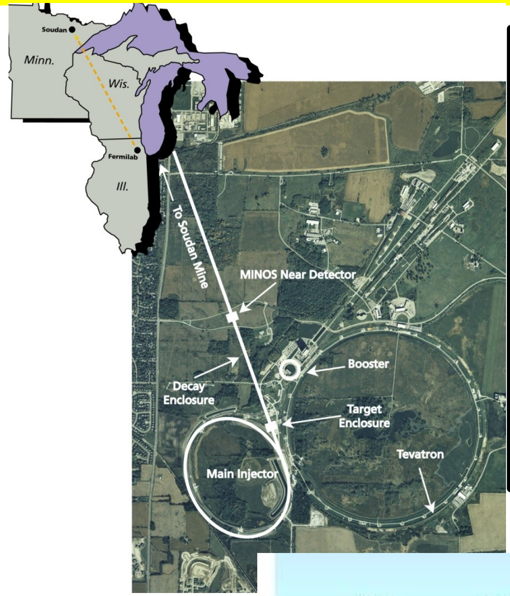
  @ FD

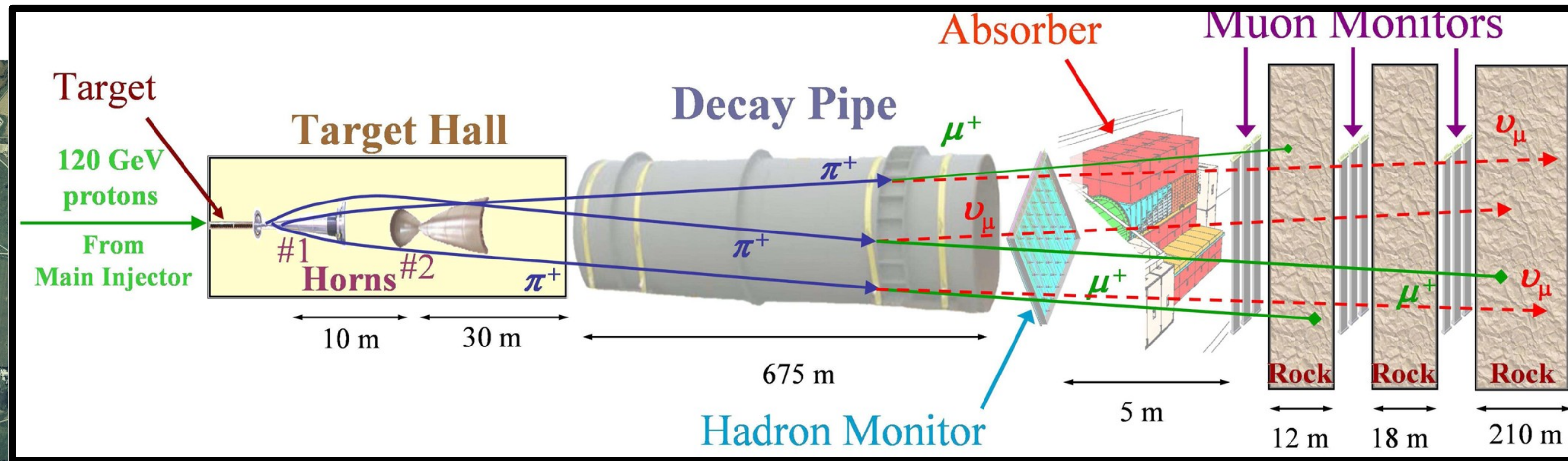
Double Chooz: results

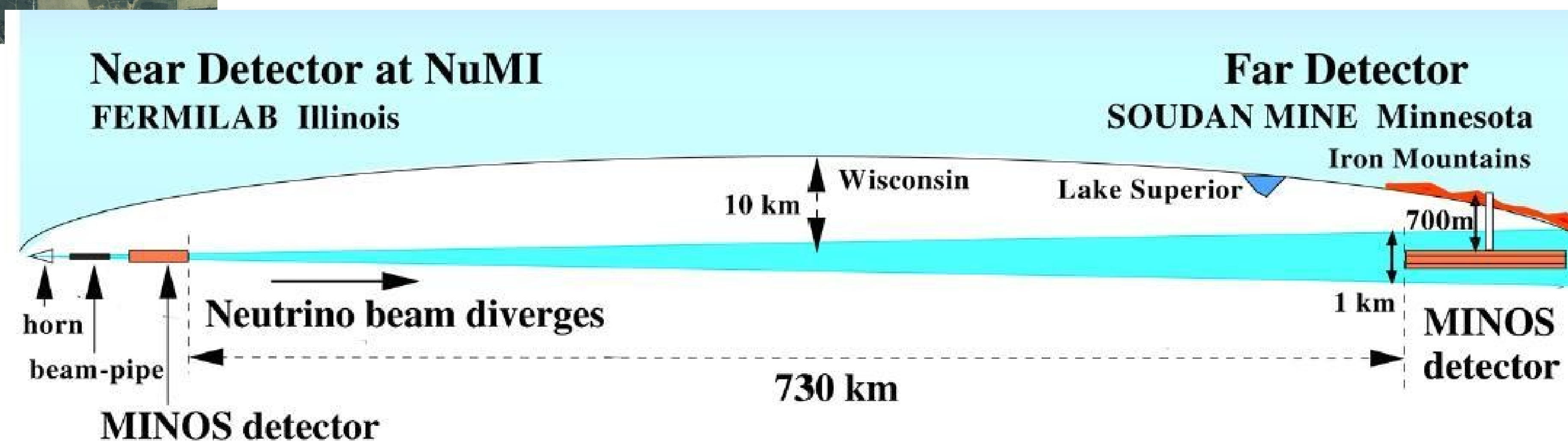
Experiments: MINOS

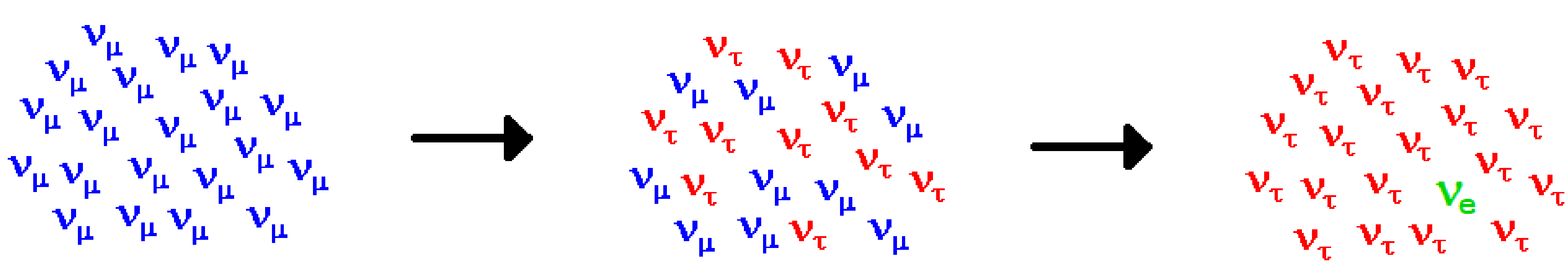


Experiments: MINOS

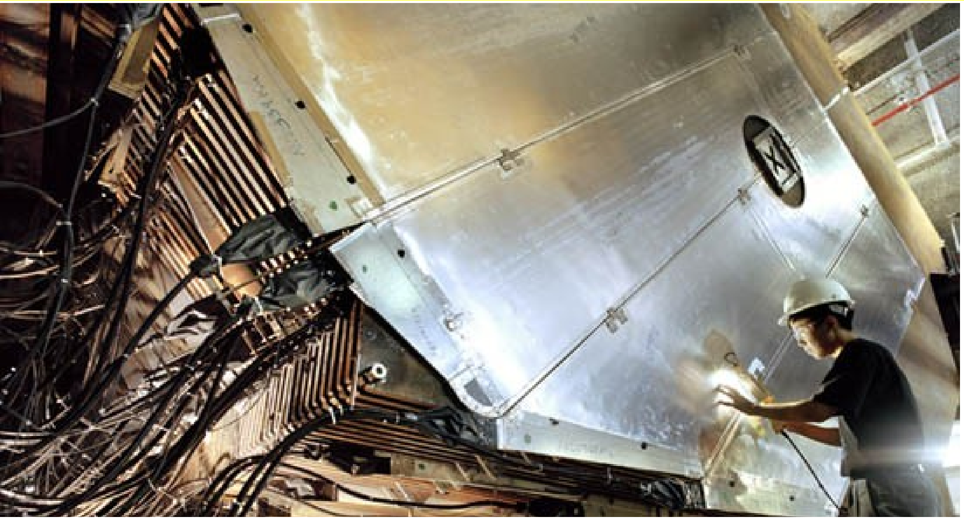


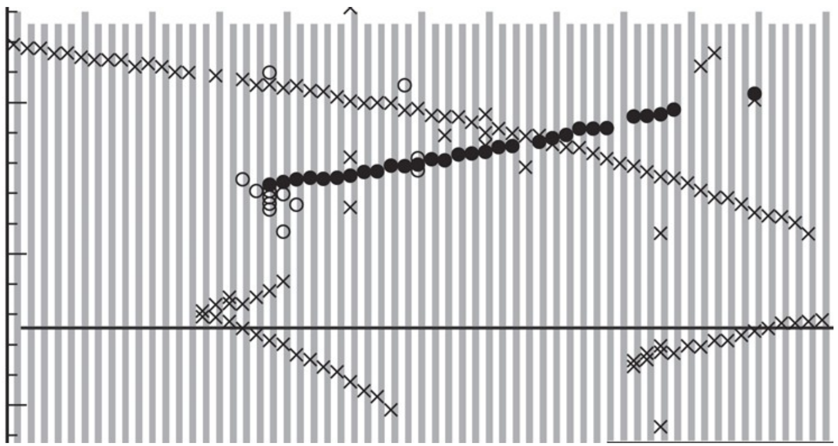


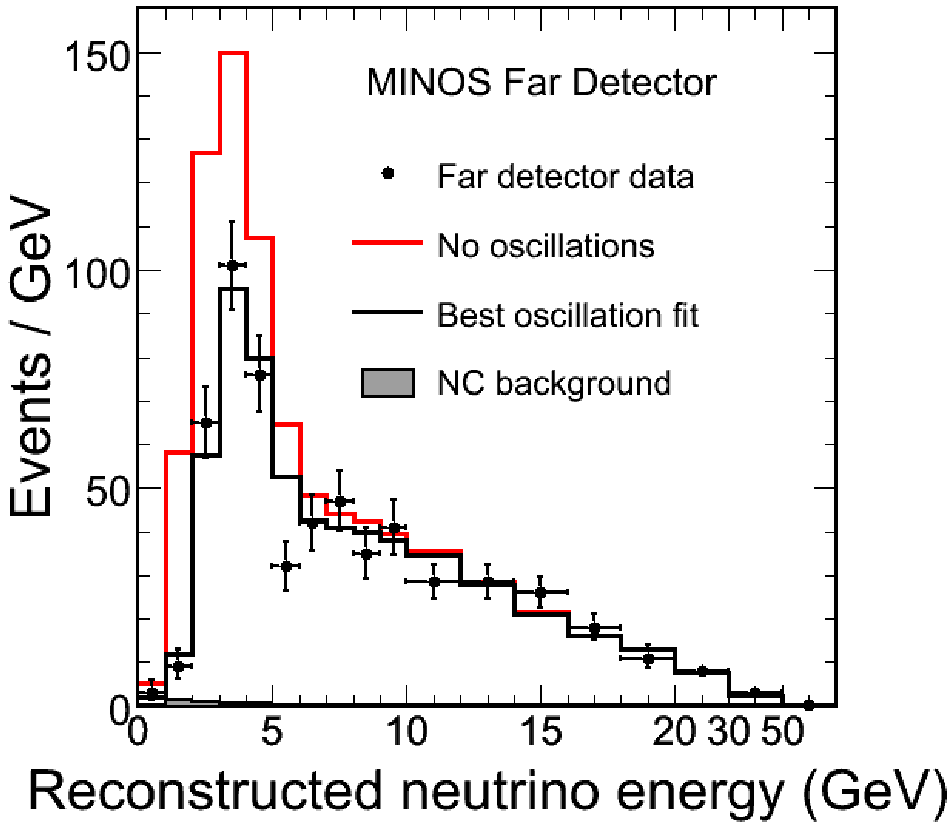




Experiments: MINOS





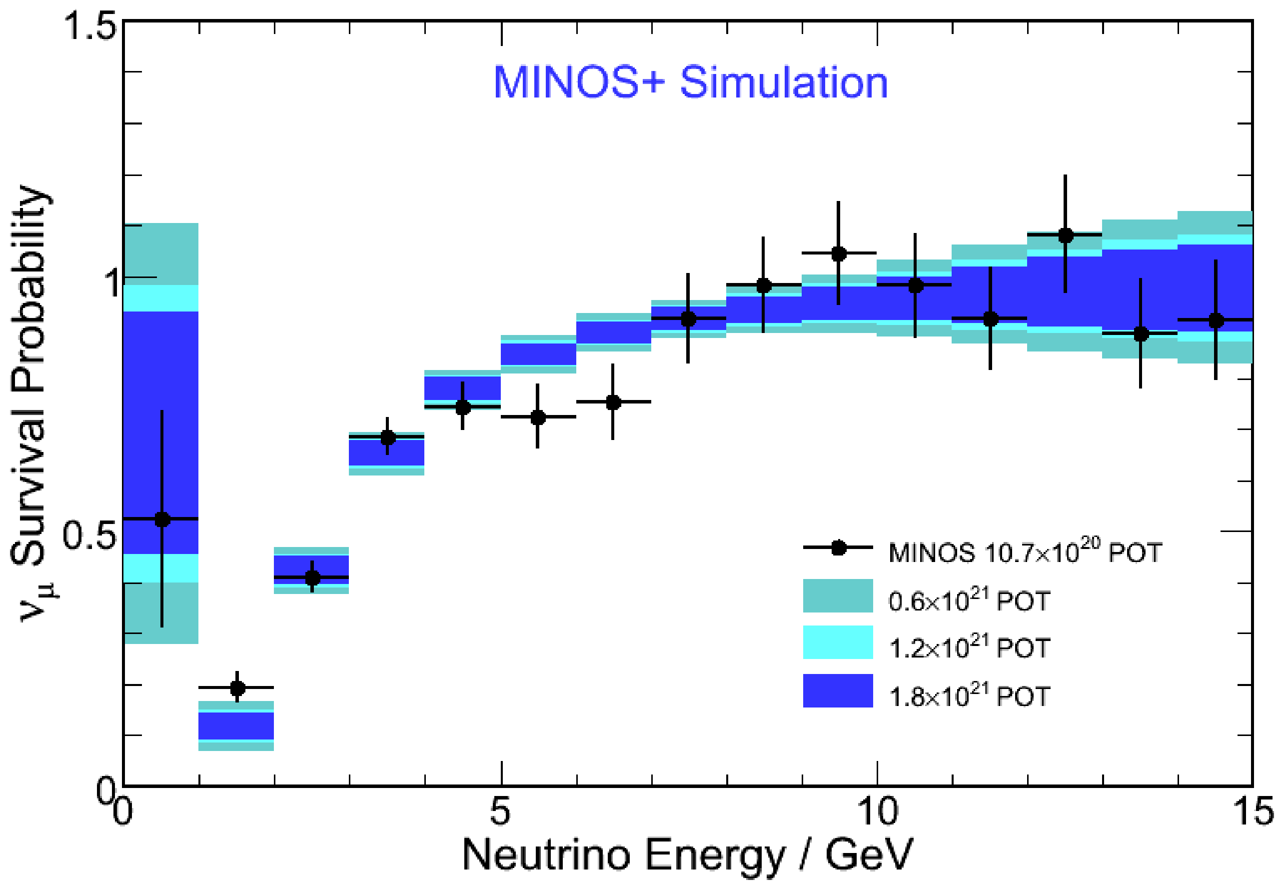


- The detectors are made of steel plates interleaved with scintillators
- We identify the neutrinos through the trajectory of the particles they generate
- The number of muon neutrinos measured in the detector is far less than expected based on the near detector if there was no oscillation

Statistical precision in MINOS+

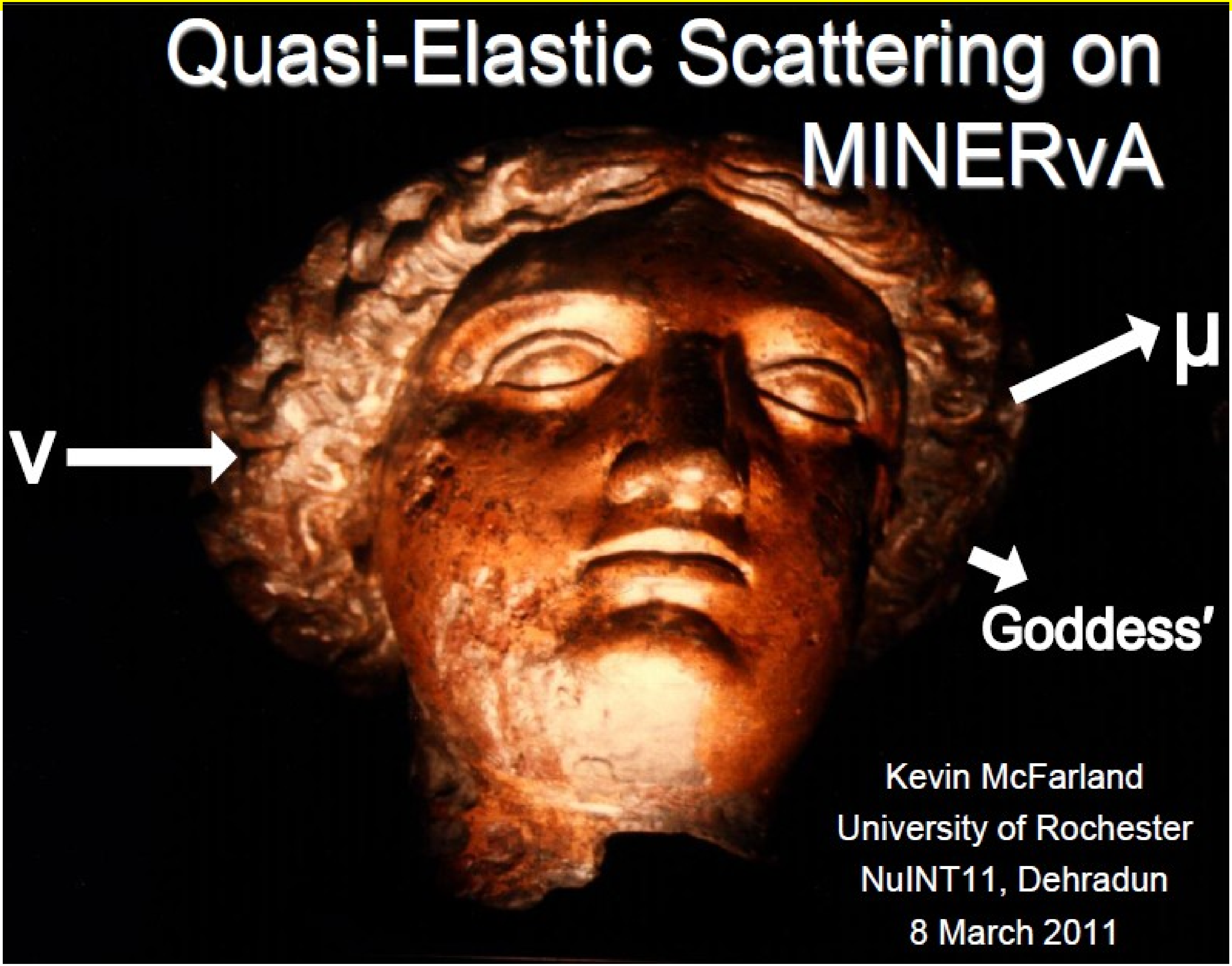
Significant improvement in statistical precision in the 4-10 GeV region

Over 3000 CC events per year in that interval



A unique high-statistics experiment with charge-sign measurement in an previously unexplored region

Experiments: MINERVA



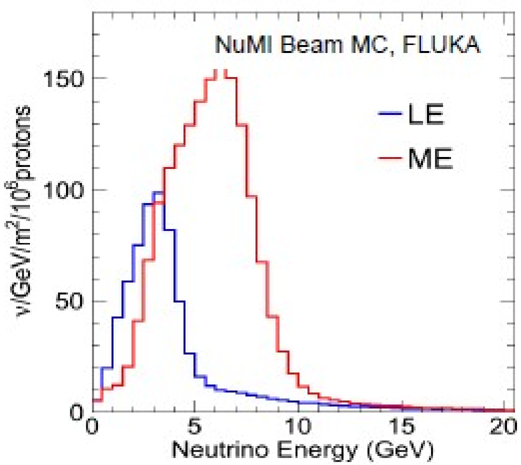
Experiments: MINERVA

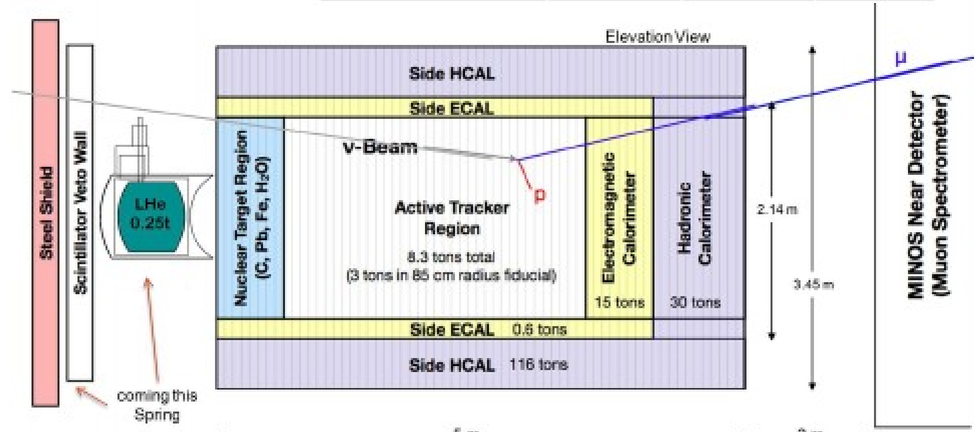
Goals for (Quasi)-Elastic Scattering at MINERvA

- MINERvA was designed in large part to map out features of quasi-elastic cross-sections at moderate energies across a wide range of Q^2
  - Broad range of energies, target nuclei

Fiducial CCQE Interactions/1.2E20 POT

Target	LE ν_μ	LE $\bar{\nu}_\mu$	Mass
Scint. (CH)	58.0K	34.1K	6.4t
Helium	2.6K	1.3K	0.25t
Graphite (C)	1.5K	0.8K	0.17t
Water (H_2O)	3.2K	2.2K	0.4t
Iron (Fe)	9.5K	4.3K	0.97t
Lead	11.4K	3.7K	0.98t





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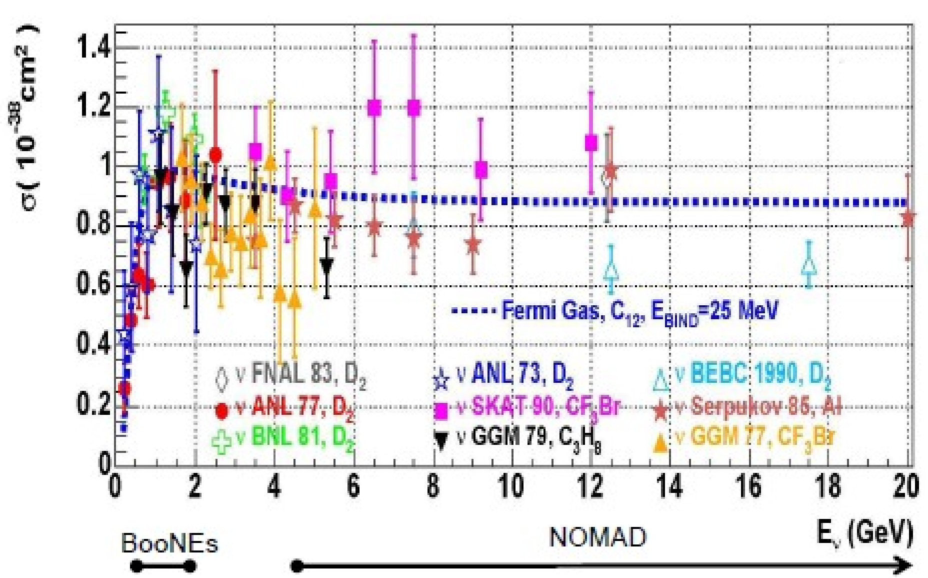
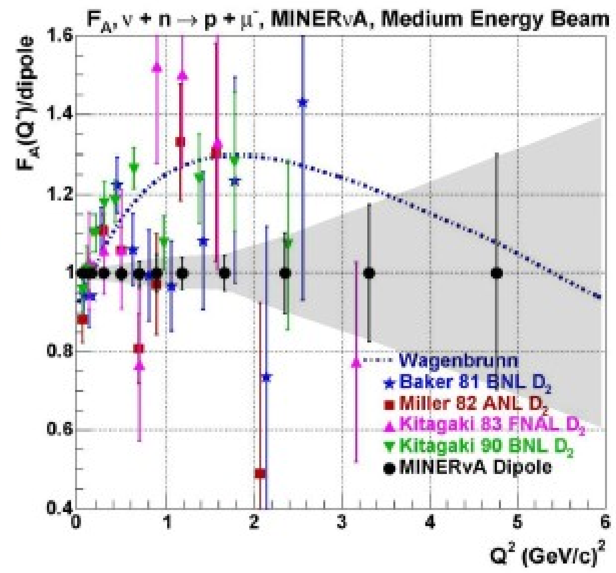
Experiments: MINERVA

MINERvA's Prospects

- To illustrate our aspirations, here are our design-era simulation results for measurements with our full low energy data set.





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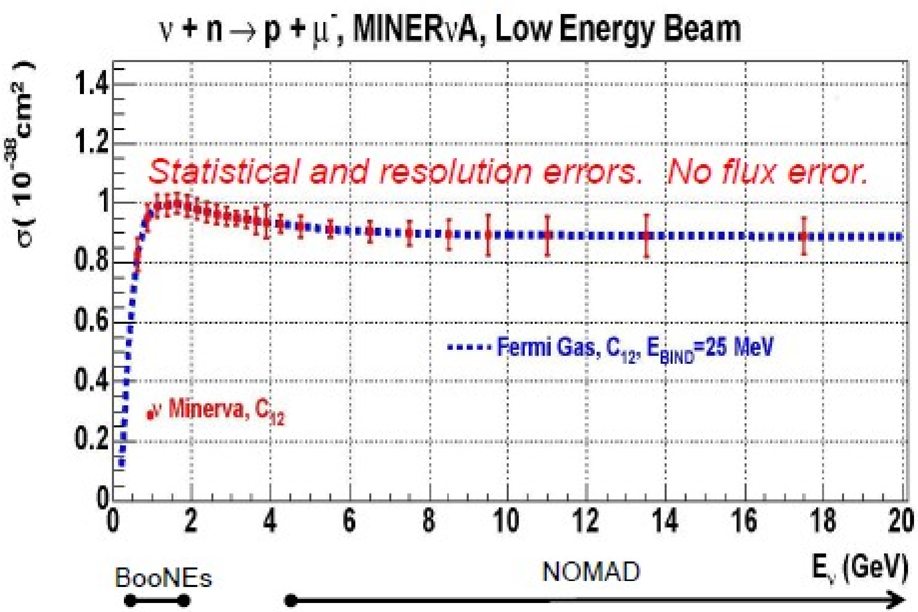

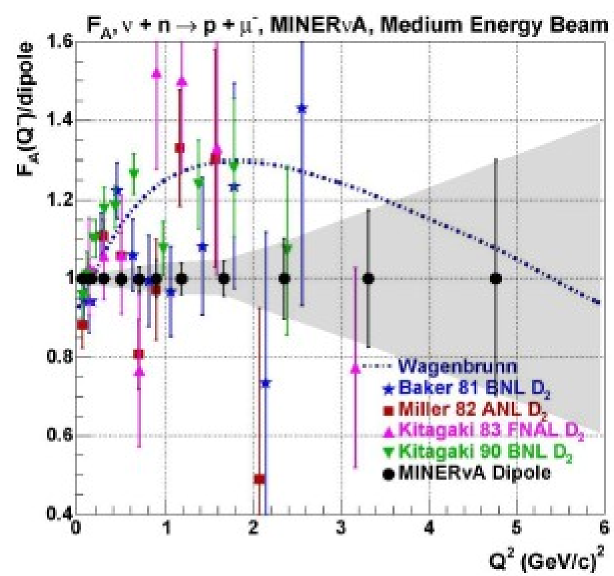

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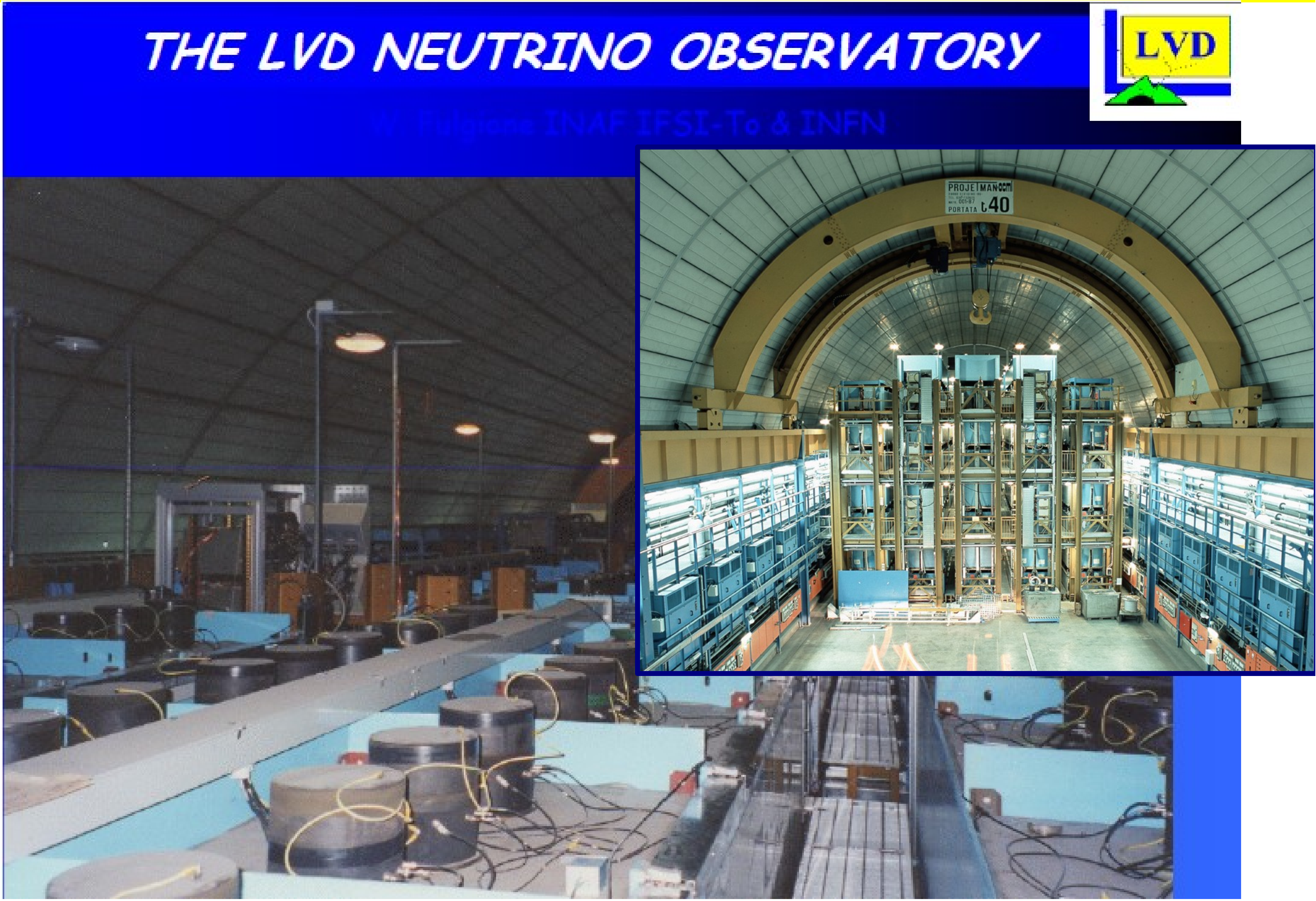
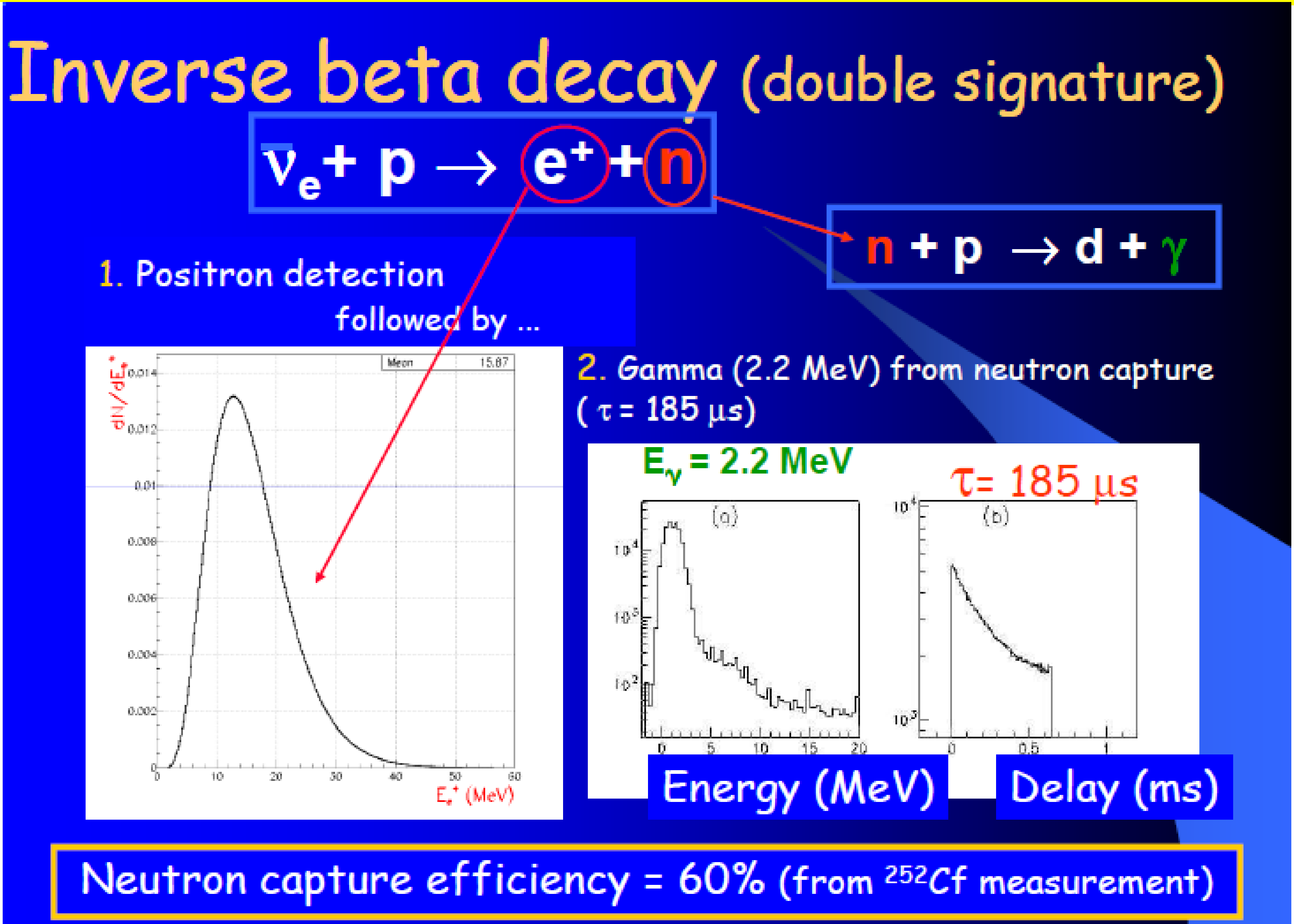
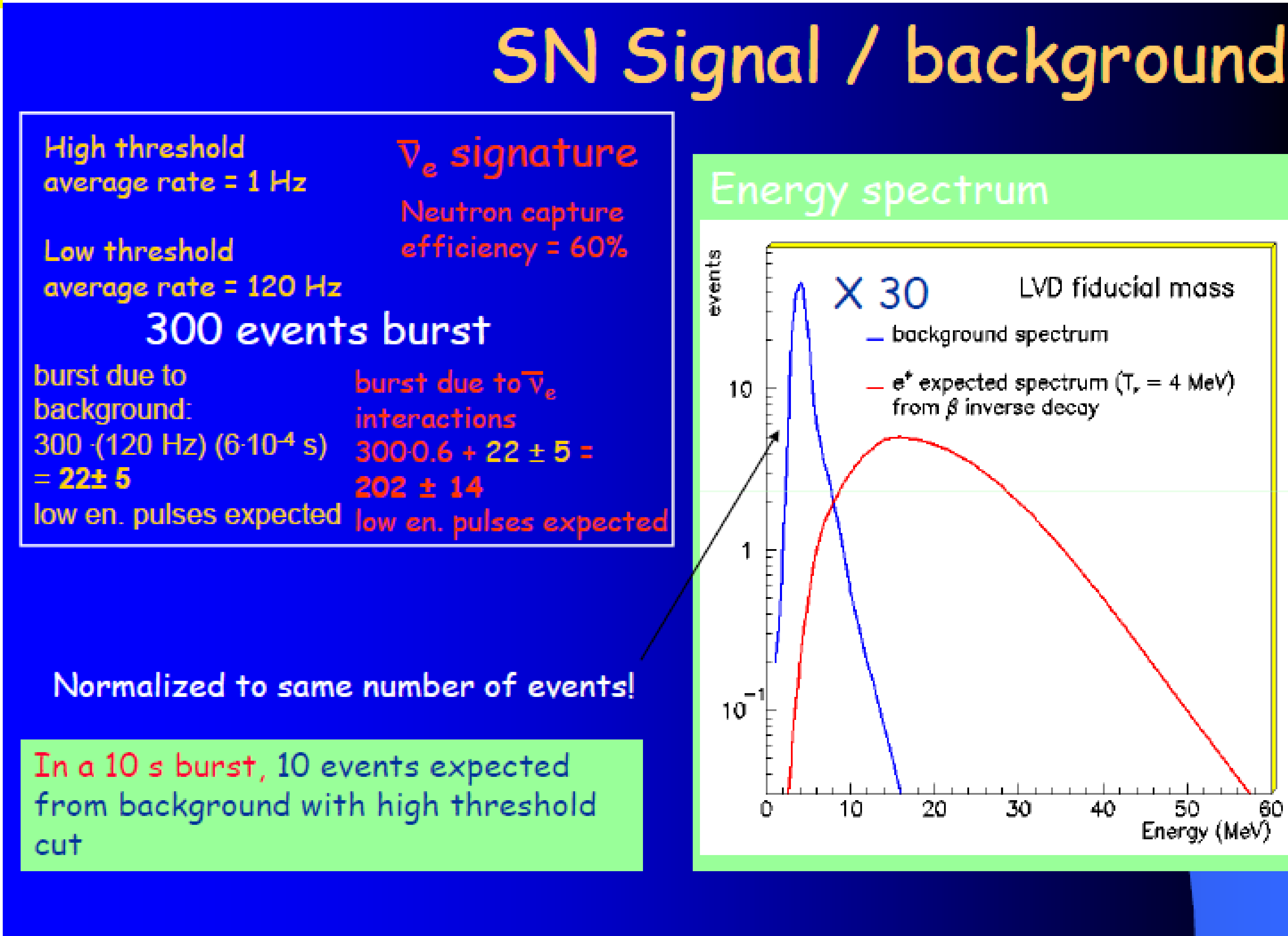
Experiments: **L**arge **V**olume **D**etector **- LVD**



Experiments: Large **V**olume **D**etector **- LVD**



Experiments: Large Volume Detector - LVD



Experiments: Large Volume Detector - LVD

Conclusions from LVD (presentation in 20 years of SN1987A - Hawaii - Feb/2007)

Leaving to a further study the detailed time structure, the energy spectrum, the flavor content and the topological distribution of signals inside the detector,
LVD is able to identify (at 90 % c.l.) on-line neutrino bursts from gravitational stellar collapses occurring in the whole Galaxy ($D \leq 20$ kpc).

Such a sensitivity is preserved *even if the detector is running with only one third of its total mass in operation, with a severe noise rejection factor (1 fake event every 100 year).*

LVD has been monitoring the Galaxy since 1992, for ~ 5000 days and with a duty cycle > 90%.
Since 2001 is running in the final configuration, M_{act} always > 600 tons and duty cycle > 99.5%

$\longrightarrow$ *R < 0.18 event/year 90% c.l.*

Gd loaded scintillator in the future?

Experiments: Pierre Auger Observatory

Experiments: Pierre Auger Observatory

The Auger Collaboration

Participating Countries

Argentina
Australia
Bolivia*
Brazil
Czech Republic
France
Germany
Italy
Mexico
Netherlands
Poland
Portugal
Slovenia
Spain
United Kingdom
USA
Vietnam*

**Associate*

17 countries, 63 Institutions, 369 Collaborators

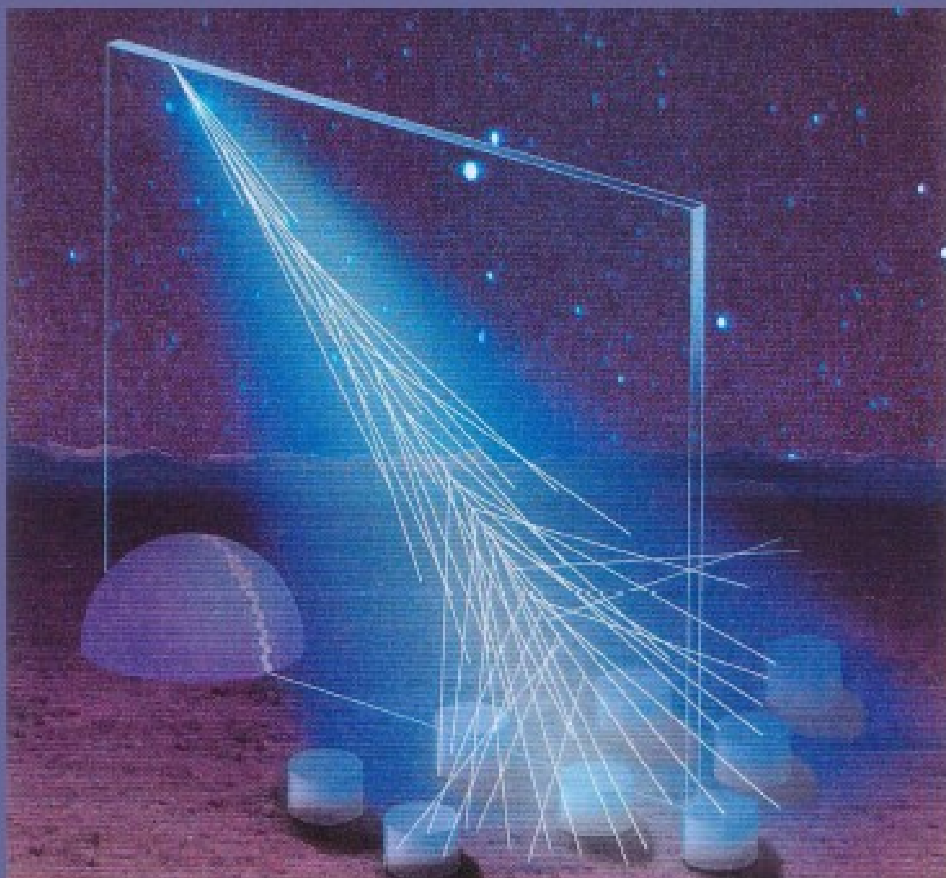
07-Oct-2009 e.k. iwara 09 7

Experiments: Pierre Auger Observatory

The Hybrid Design

Surface detector array + Air fluorescence detectors

A unique and powerful design



- Nearly calorimetric energy calibration of the fluorescence detector transferred to the event gathering power of the surface array.
- A complementary set of mass sensitive shower parameters.
- Different measurement techniques force understanding of systematic uncertainties
- Determination of the angular and core position resolutions

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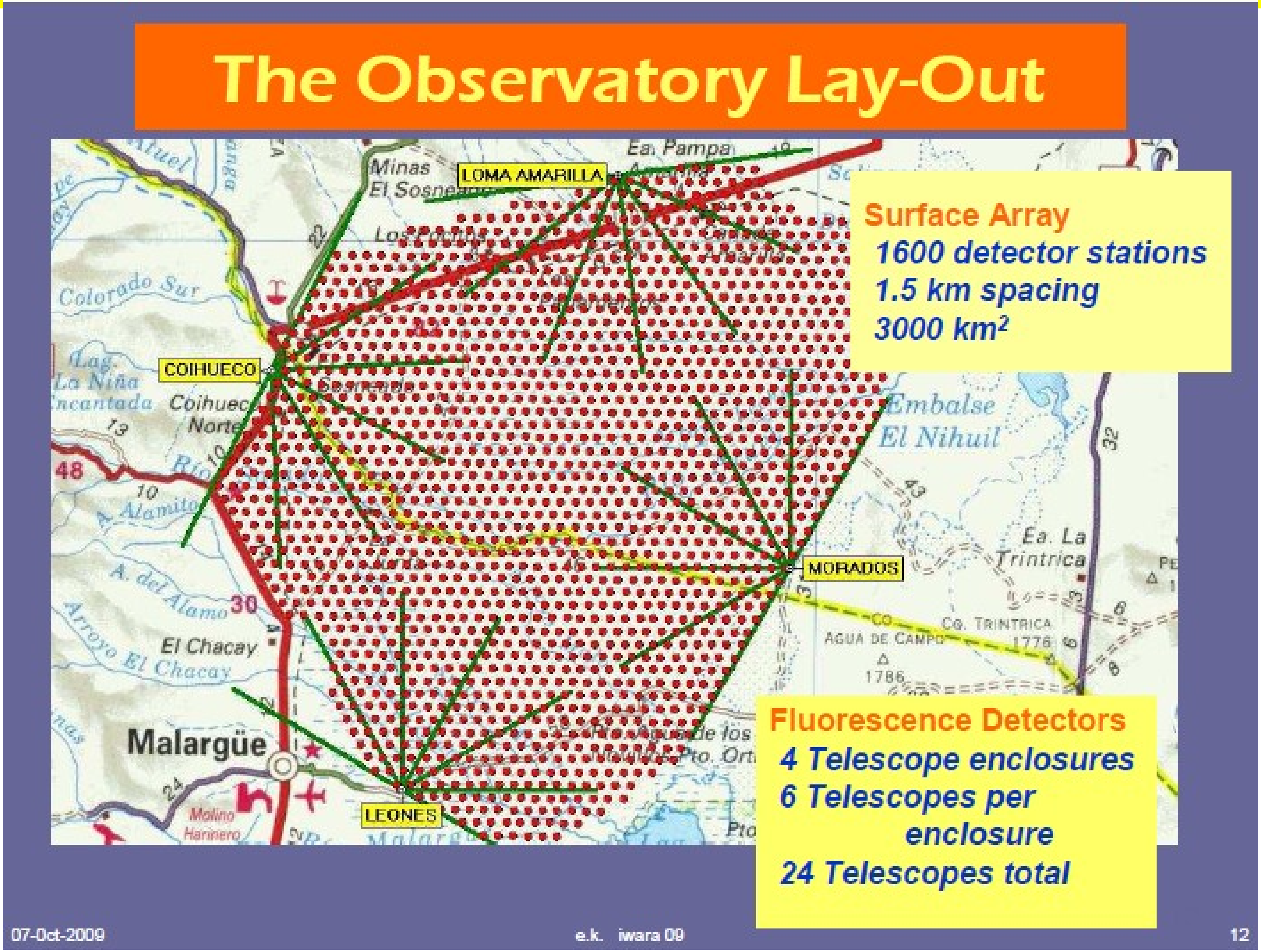
Experiments: Pierre Auger Observatory



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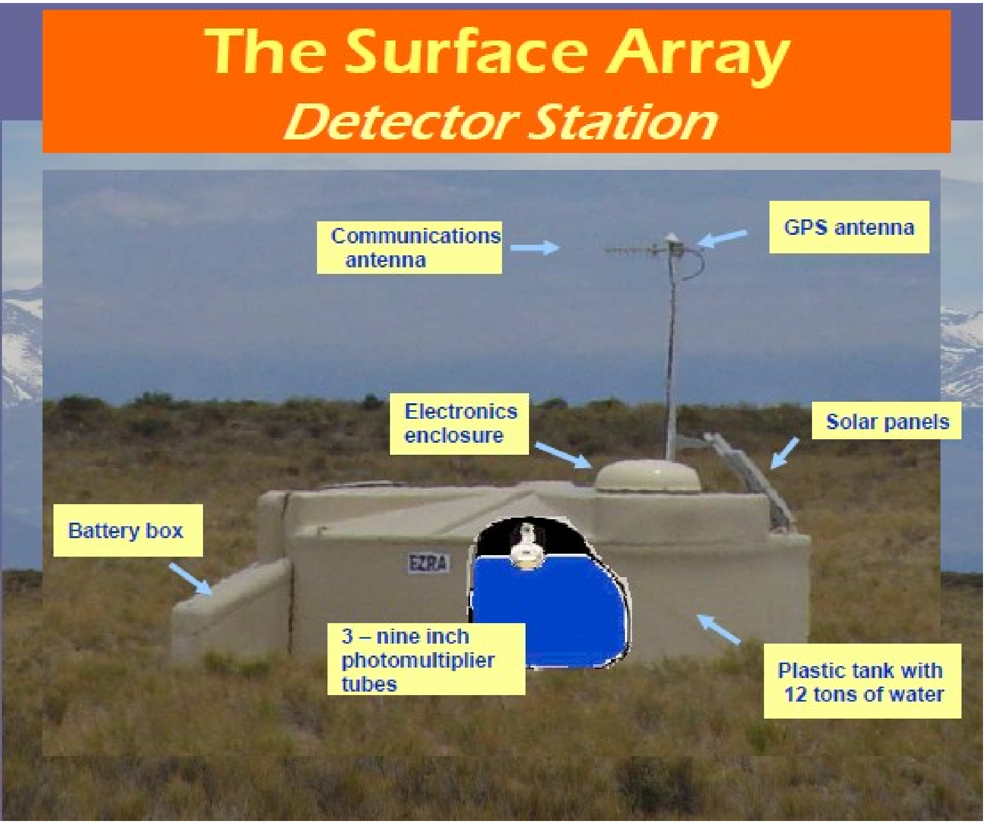
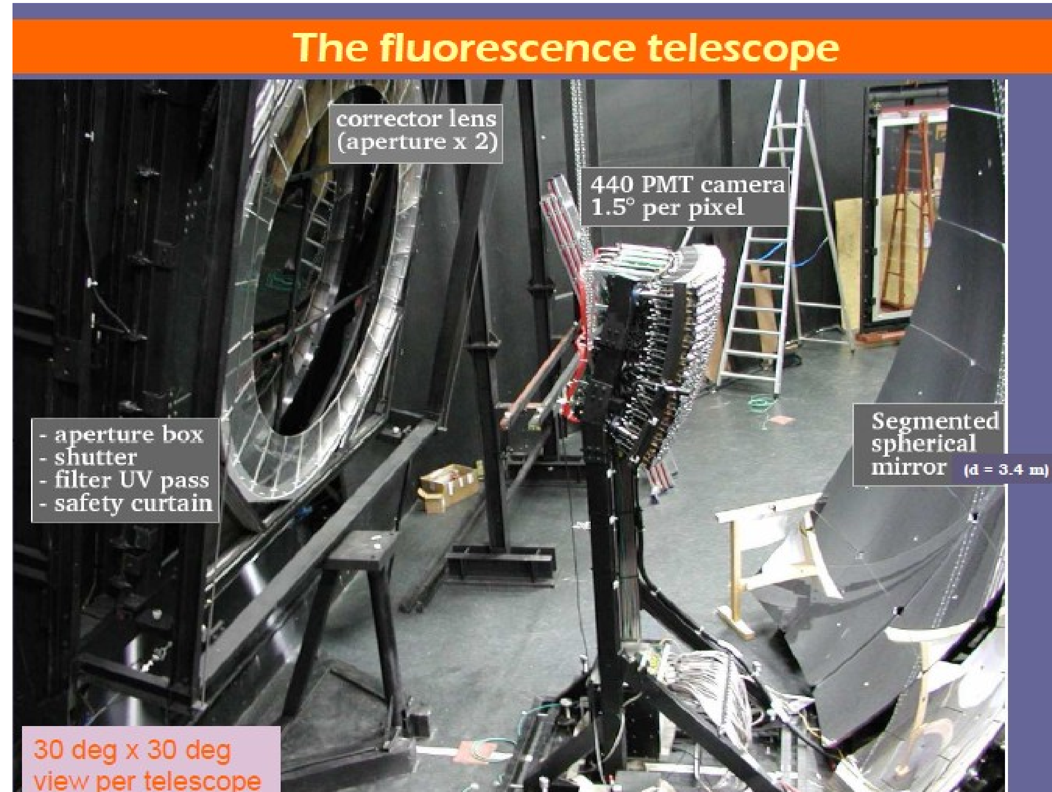
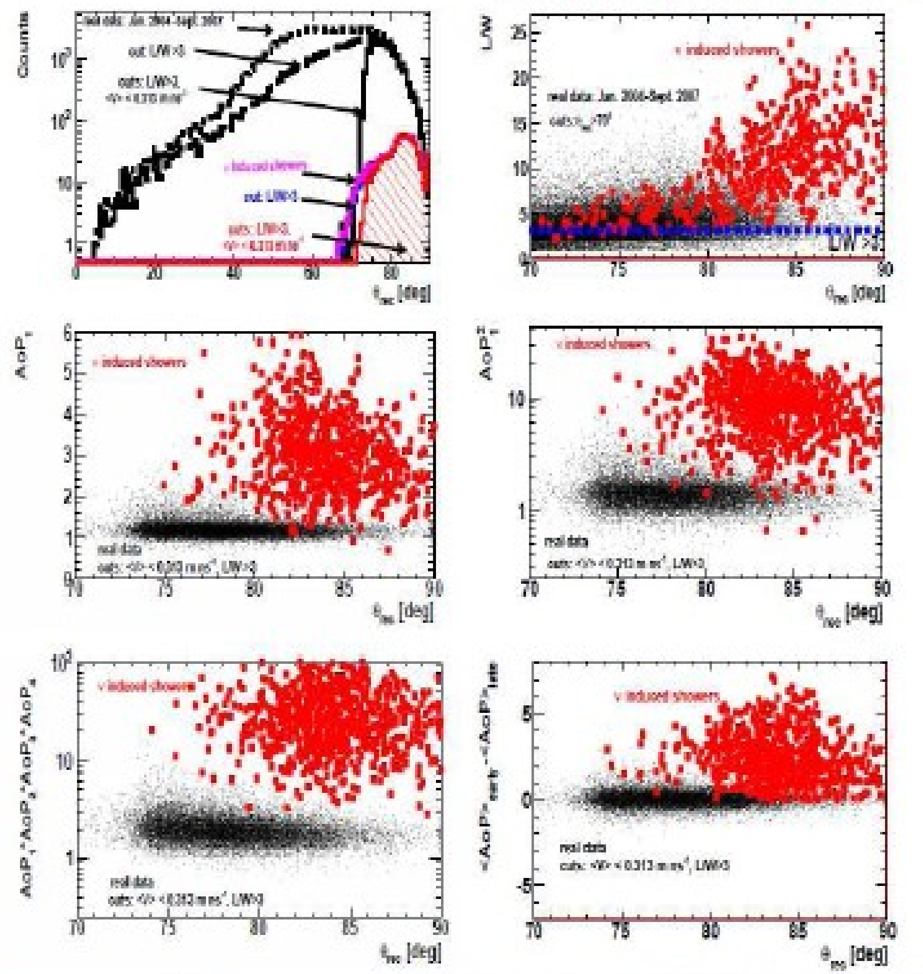
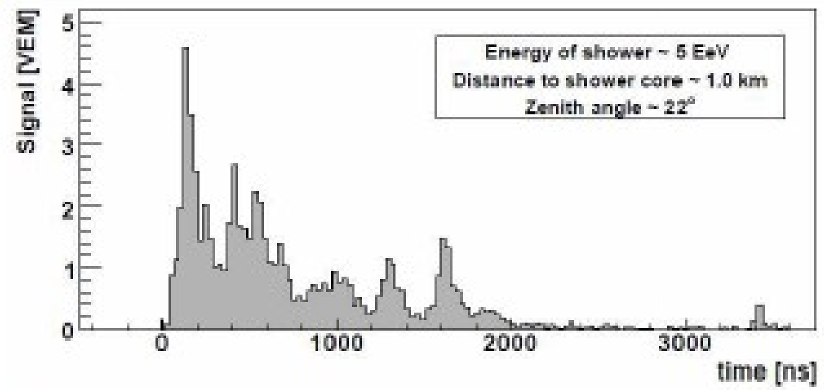


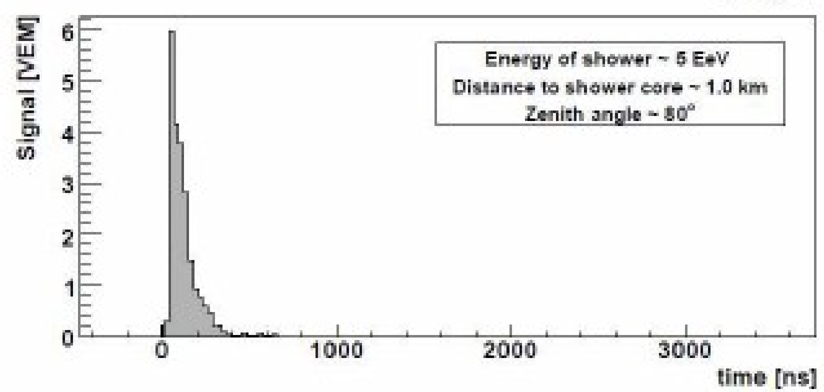


Neutrinos in Auger



Very inclined (and young!) showers are strong candidates to have been triggered by neutrinos



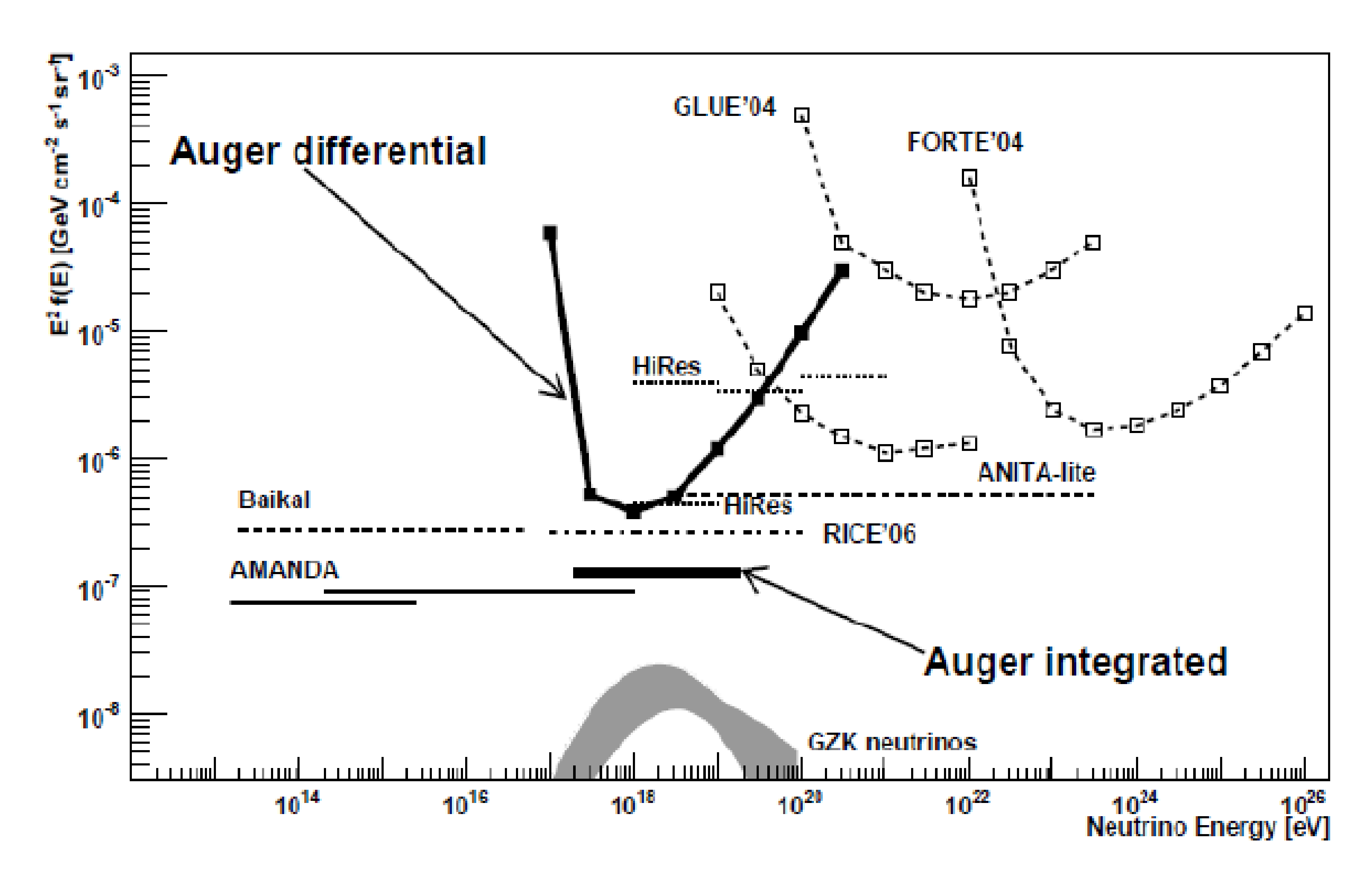


Tau-neutrinos can interact on Earth producing up-going taus that can induces EM showers

07-Oct-2009 e.k. iwara 09 46

Experiments: Pierre Auger Observatory

Neutrinos in Auger



Tau-neutrinos coming soon...

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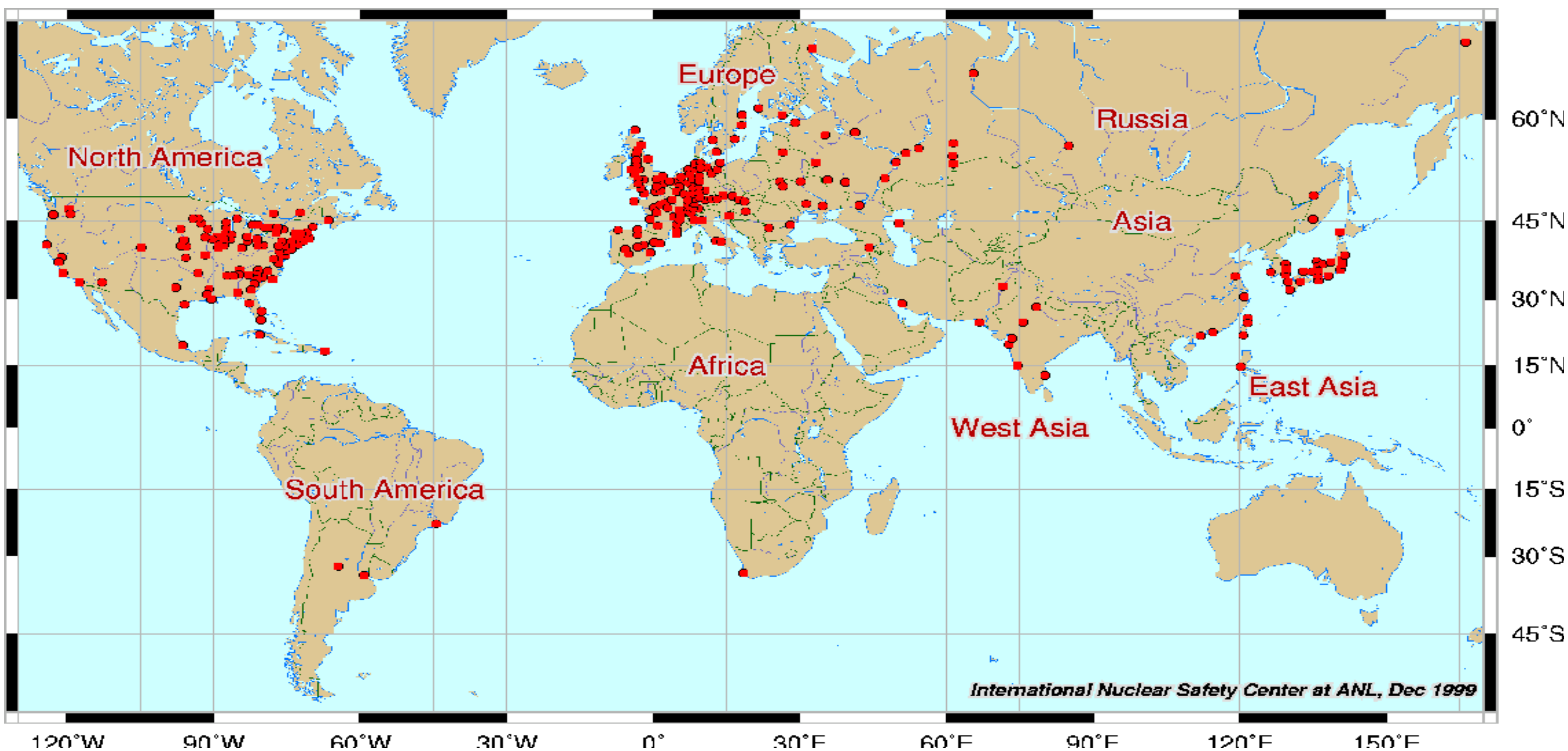
Experiments: Neutrinos-ANGRA

World map of nuclear reactors



Experiments: Neutrinos-ANGRA

Neutrinos & Non-proliferation

IAEA.org
International Atomic Energy Agency

- ~ 438 reactors worldwide:
  The International Atomic Energy Agency - IAEA
  inspects nuclear installations under safeguards
- ~200kg plutonium produced in each fuel cycle (~ 1.5 years)
  ~90 tons of Plutonium produced every year worldwide
- IAEA is the verification authority of the Non Proliferation Treaty (NPT). IAEA has to keep track of all this material.

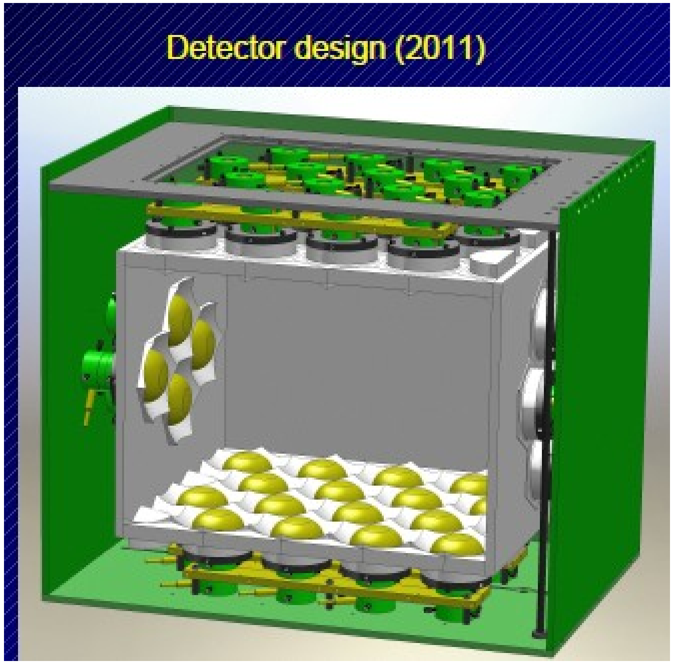
Experiments: Neutrinos-ANGRA

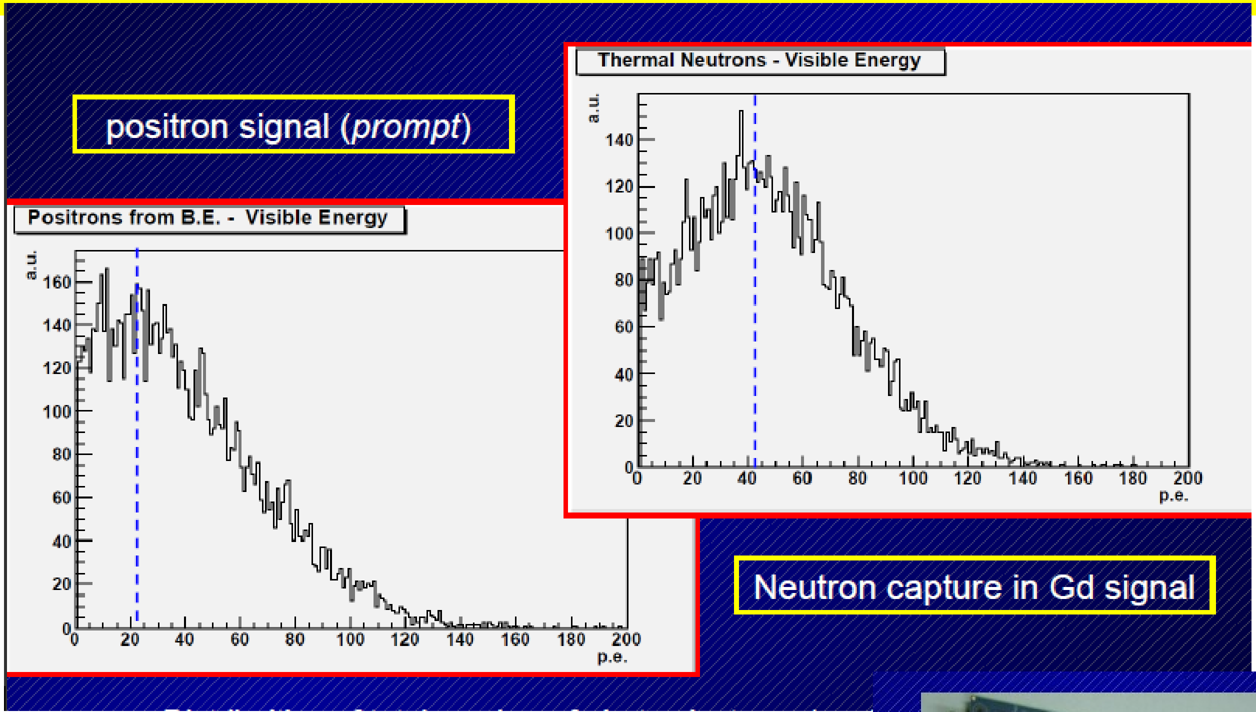
NEUTRINOS ANGRA Project

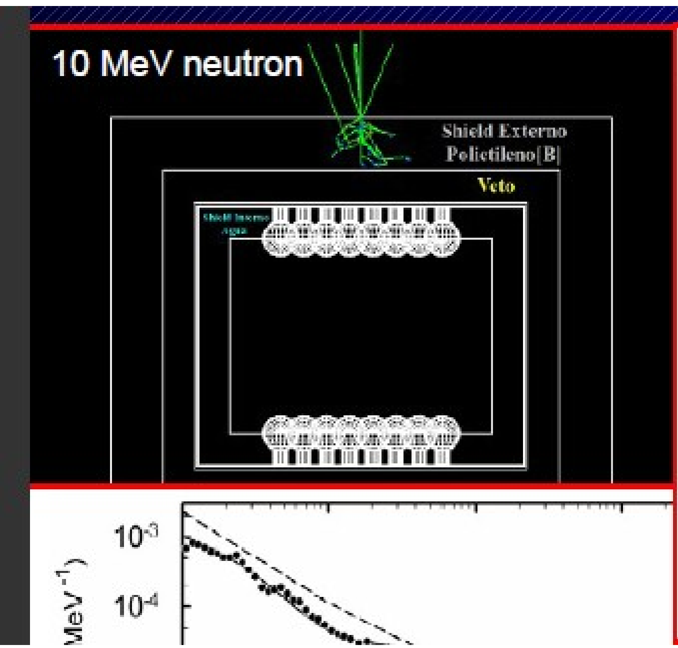
23/09/2008

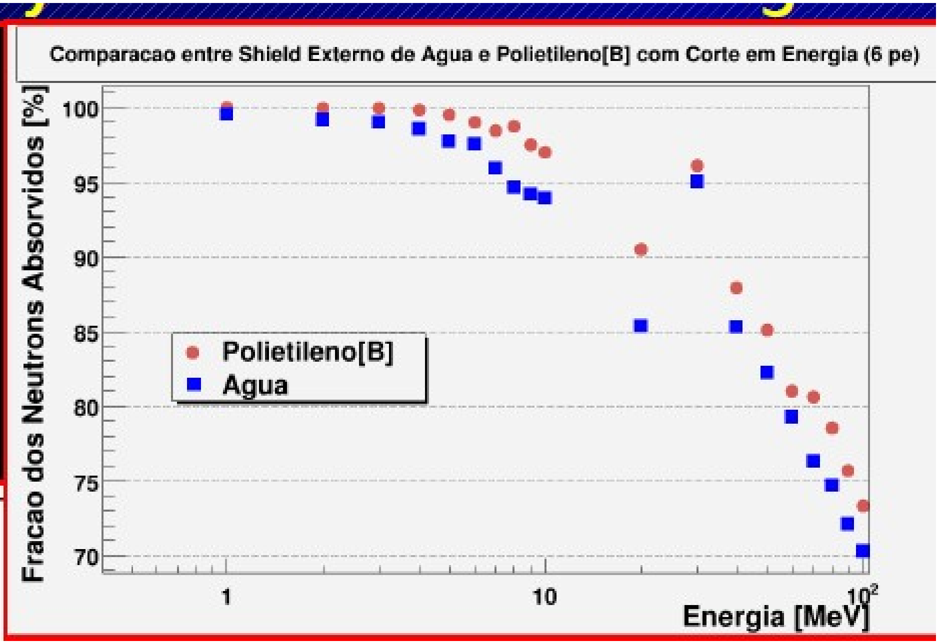
conteiner: 1st laboratory in Angra

Experiments: Neutrinos-ANGRA

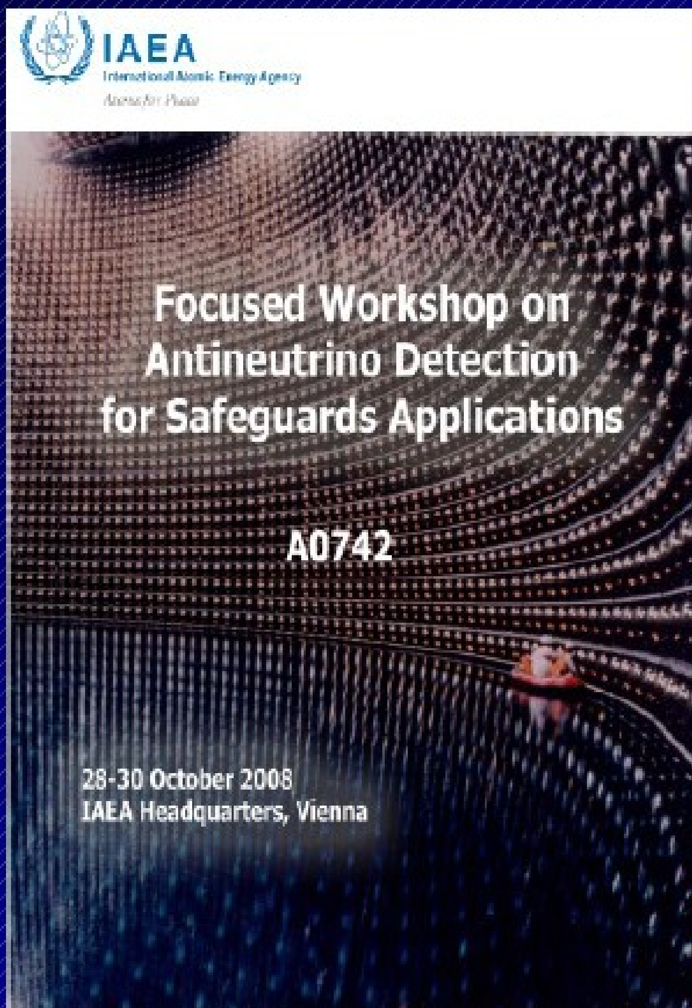








Expert´s Workshop by IAEA in Vienna (2008)



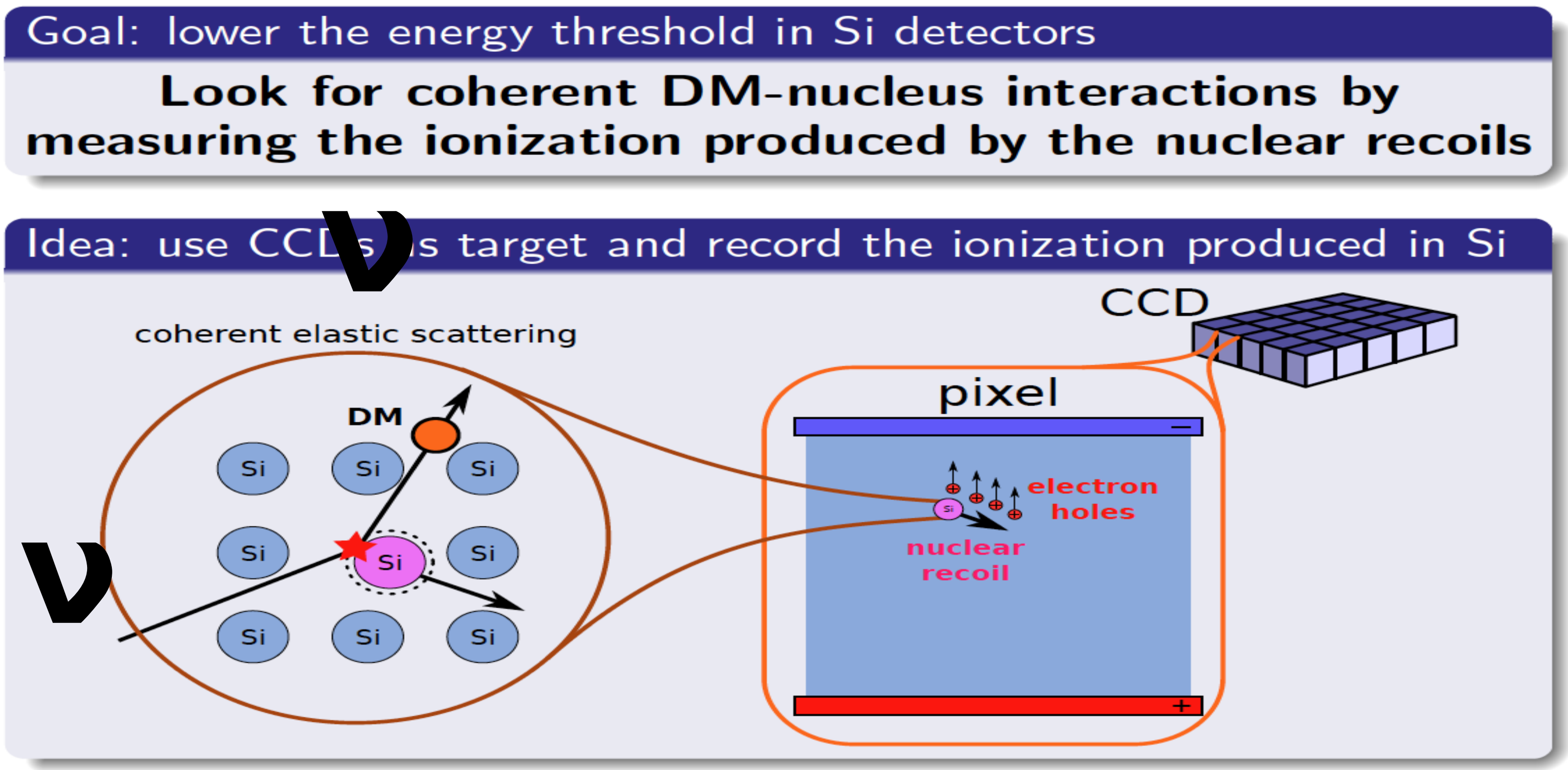
Agenda

Focused Workshop on Antineutrino Detection for Safeguards Applications, 28-30 October 2008

Tuesday, 28 October	A0742
09:00 – 09:45	Introductory Talk for Agency Personnel on Neutrinos (A. Bernstein. LLNL, USA)
10:00 – 10:15	Welcoming Address (M. Zendel, Acting Director SGTS, IAEA)
10:15 – 10:45	Introduction of participants (all) • Objectives of meeting (J. Whichello, IAEA) • Elect Chairperson and rapporteur
10:45 – 11:00	Coffee Break
11:00 – 11:20	IAEA Safeguards Presentation (A. Monteith, SGTS, IAEA)
11:20 – 11:50	Antineutrino Flux from a Research and Isotope Producing Facility - A Case Study for Determining Detector Requirements (G. Jonkmans / R. Didsbury, AECL, Canada)
11:50 – 12:20	The Nucifer Neutrino Detector for Thermal Power Measurement and Non Proliferation (Th. Lasserre, CEA, France)
12:20 – 13:15	Lunch
13:15 – 13:50	Reactor Neutrino Spectra and Nuclear Reactor Simulations for Unveiling Diversion Scenarios (D. Lhuillier, CEA, France / M. Fallot, Subatech, France)
13:50 – 14:25	Direction-Sensitive Monitoring of Nuclear Power Plants (R. de Meijer, Stichting EARTH foundation)
14:25 – 15:00	Finnish know-how, Infrastructure and Activities Relevant to the Development of Antineutrino Detection Technologies for Safeguards Purposes (W. Trzaska, Univ. of Jyväskylä, Finland)
15:00 – 15:15	Coffee Break
15:15 – 15:50	The Angra Neutrino Project: Present Status (J dos Anjos, CBPF, Brazil)
15:50 – 16:25	Study of Neutrino Detection from Joyo Fast Research Reactor (F. Suekane, Tohoku Univ., Japan)

81

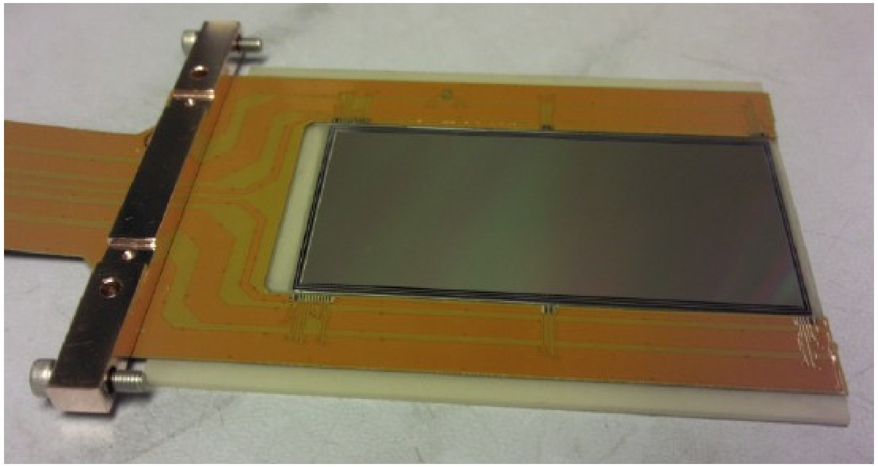
Coherent Neutrino Nucleus Interaction Experiment (CONNIE)

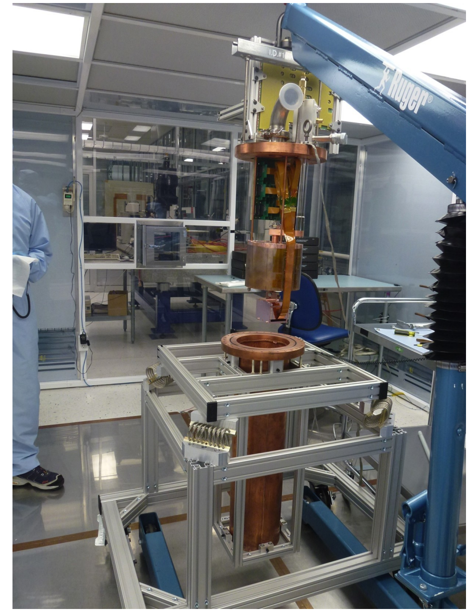


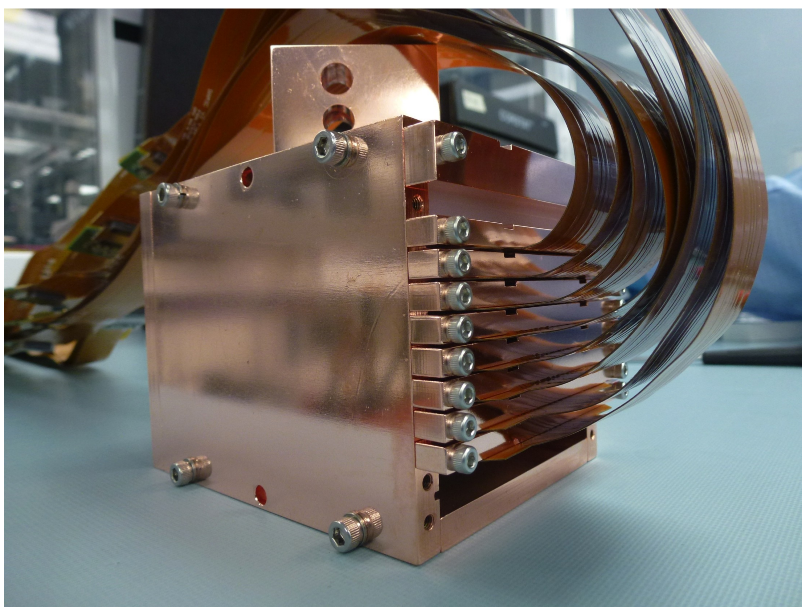
Using the technology developed for DM searches with CCDs. Low noise (~7.2eV RMS) and low background packages currently under test at SNOLAB.

Vacuum vessell

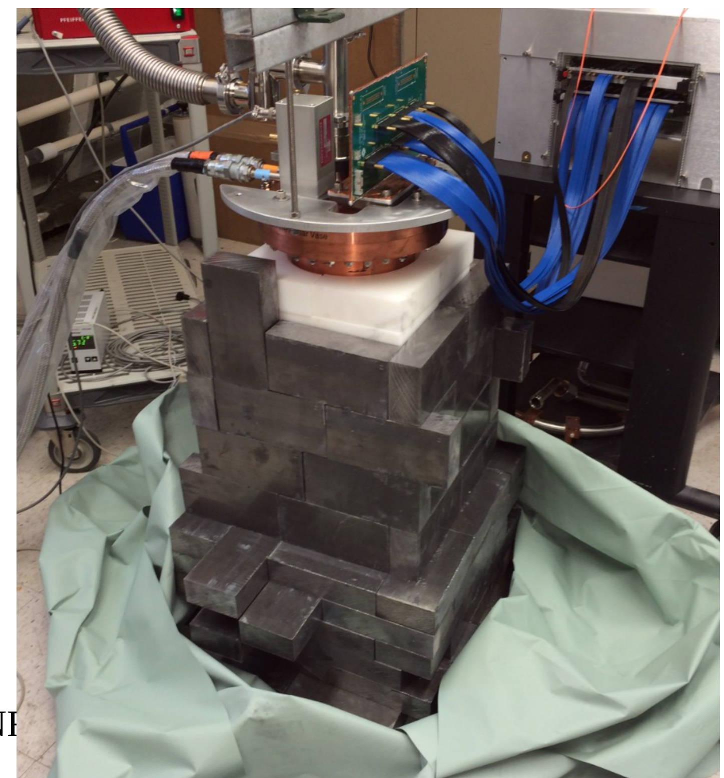
CCD in low background package







Array of CCD in cold box to Operate at -150C



1/5 of the lead and poly shield being tested at FNAL (Jan-2014)

To be installed in the site of the Angra Neutrino Project.
Next to a large reactor, close Rio de Janerio.

Now studying shield design, with a few tests at FNAL. Installation at Reactor soon (months away).

Future Perspective (in the past...)

Double Chooz group + **MINOS group**

↓

LBNE : joint effort

October/2012

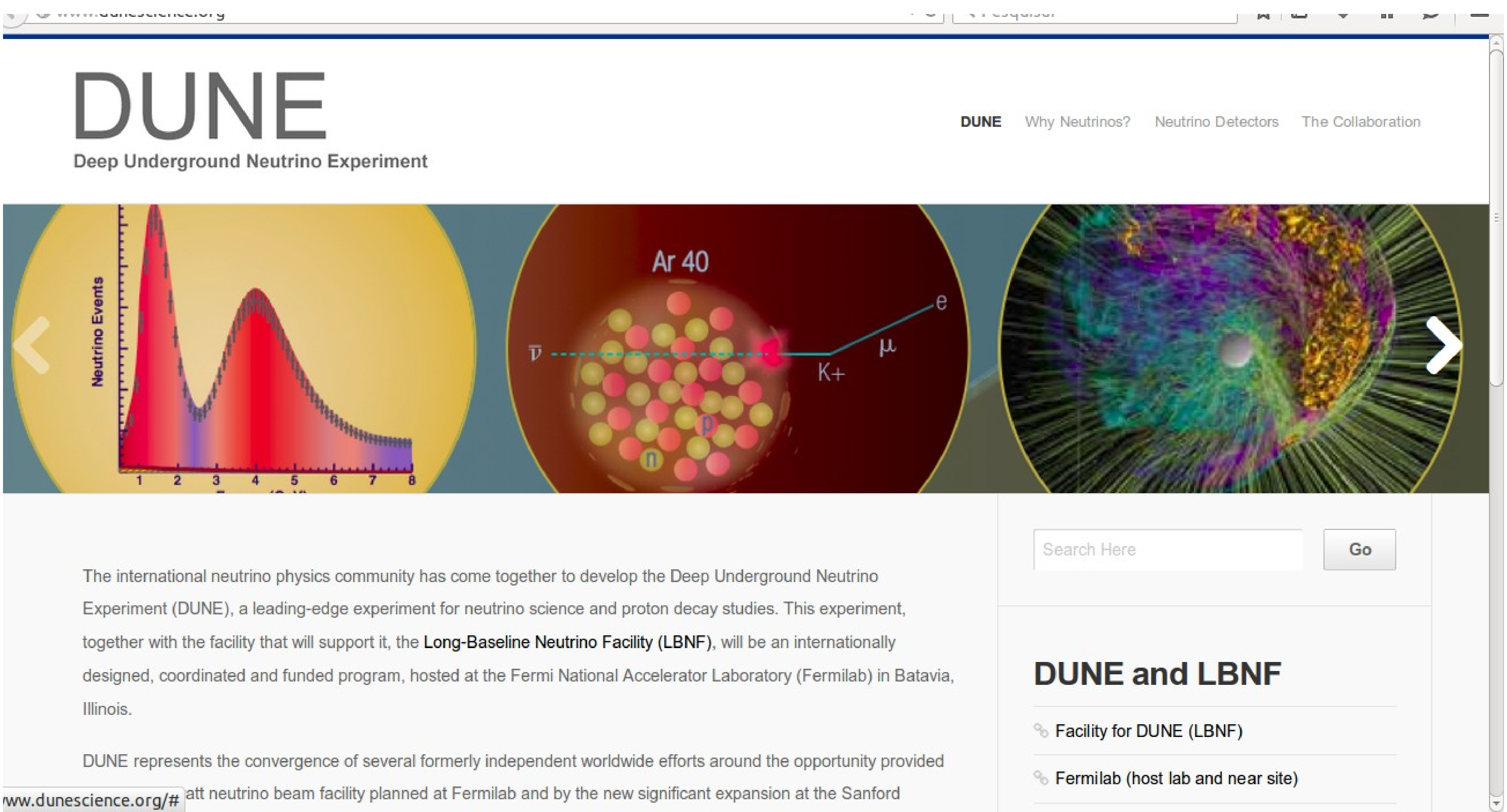
RENAFAE meeting

Current Situation

Double Chooz group + **MINOS group**

DUNE : joint effort

Deep Underground Neutrino Experiment: DUNE



http://www.dunescience.org/

DUNE motivations

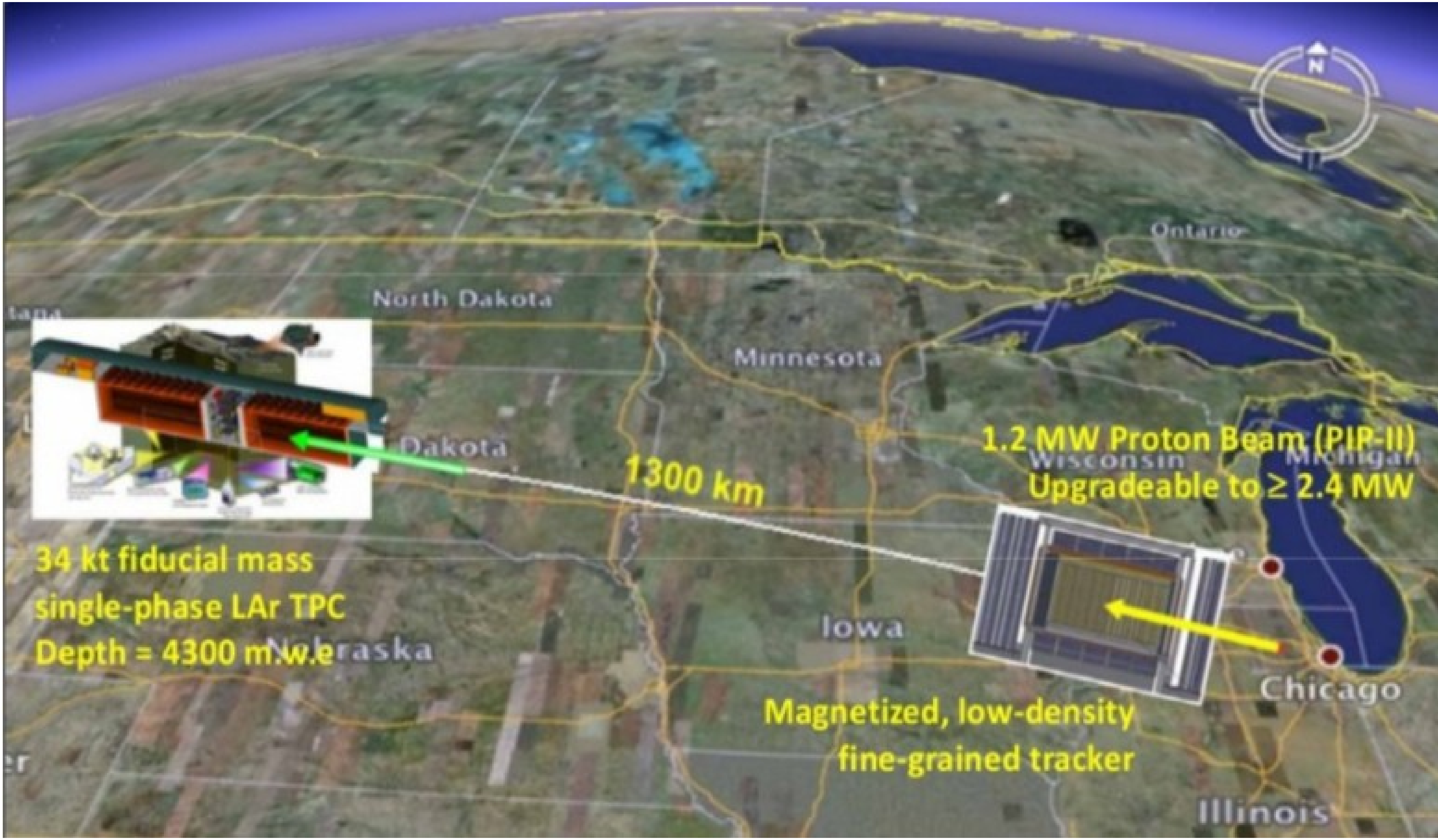
- Standard Model
  - Remarkably accurate description of the elementary particles/interactions
    - But … is incomplete
- Results from the last decade
  - 3 known types of neutrinos have nonzero mass, mix with one another and oscillate between generations
    - ➔ **implies physics beyond the Standard Model.**
- Remarkable progress has been made in this decade to understand the new phenomena of neutrino oscillations
  - We have all the ingredients for a scientifically well motivated and comprehensive program of measurements of neutrino oscillations and fundamental symmetries using leptons.

… a more fundamental underlying theory must exist …

DUNE motivations

- The Long-Baseline Neutrino Experiment Collaboration (DUNE) :
  - Experiment that will fully characterize neutrino oscillation phenomenology using a high-purity ν_μ beam, operated in both beam polarities (particle/antiparticle)
- Main Goals:
  - Measure full oscillation patterns in multiple channels, precisely constraining mixing angles and mass differences.
  - Search for CP violation both by measuring the CKM phase δCP and by explicitly observing differences in ν_μ / ν_μ-bar oscillations.
  - Cleanly separate matter effects from CP-violating effects
    - determine the ordering of the three neutrino mass eigenstates

Experiments: DUNE design



DUNE collaboration

The first DUNE Collaboration meeting, April 16-18, 2015 at Fermilab. Photo: R. Hahn

The DUNE Science Collaboration, established in January 2015, is currently made up of about 750 scientists from nearly 150 institutions in 23 countries. The collaboration works closely with the LBNF Project to ensure the coordinated development of facilities and detectors that will enable the ambitious physics program.

Deep Underground Neutrino Experiment: DUNE concepts

Studies already done: a complete, practical and achievable configuration for the experiment:

- Neutrino source
  - Fermilab
- Far Detector site:
  - Sanford Underground Research Facility (SURF) in the former Homestake gold mine in Lead, South Dakota
- Development of technical designs:
  - neutrino beam
  - far detector and near detector
  - all of the civil engineering for the facilities at Fermilab and SURF required to support the program

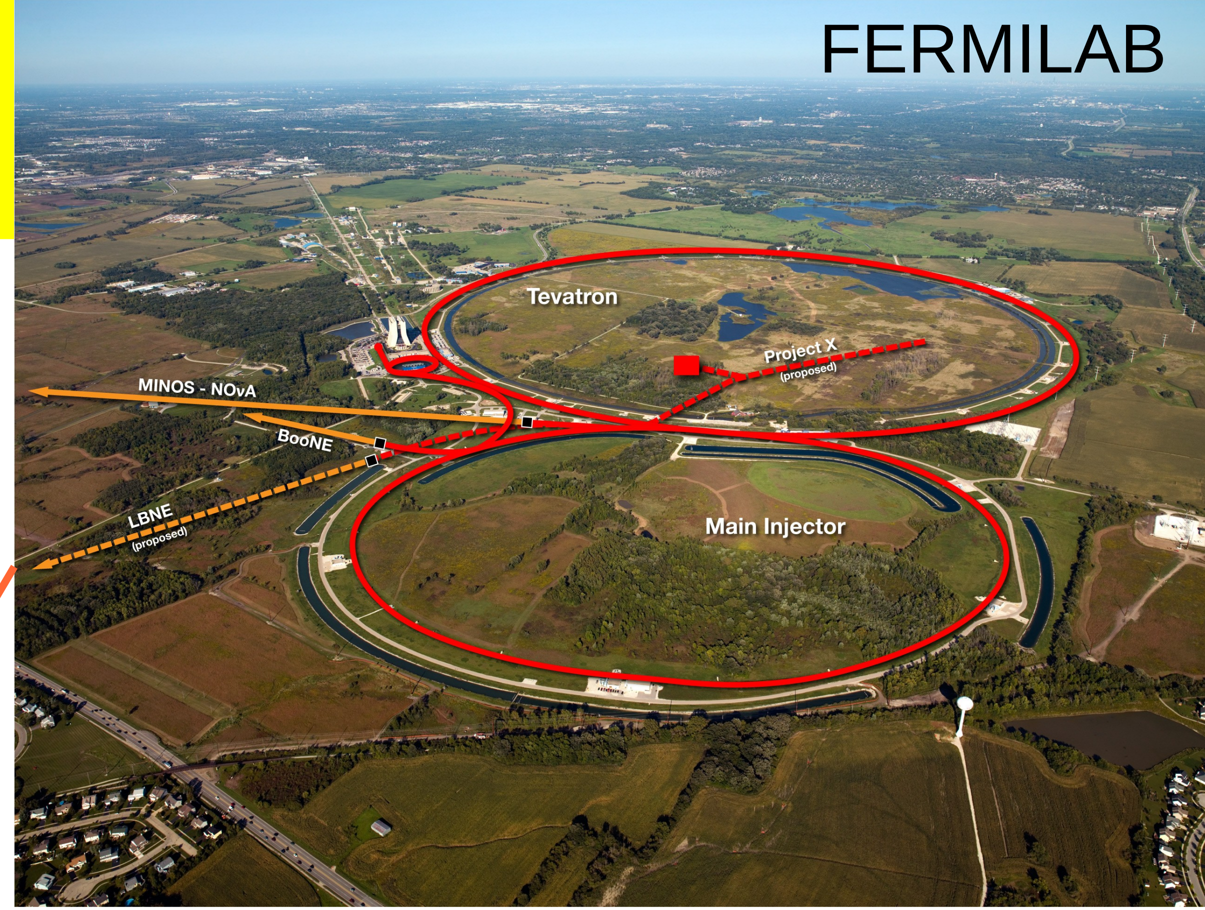
DUNE key elements

- the right baseline
- highly capable detector
  - high statistics measurements
  - efficient measure of complex final states
  - Clean separation of signal/background
- beam:
  - High power
  - broad-band
  - High-purity
  - sign-selected neutrino beam
- highly capable near detector
  - precise measurements of flux spectra of all neutrino species in the beam
  - Precise measurements of cross-sections relevant for the oscillation physics

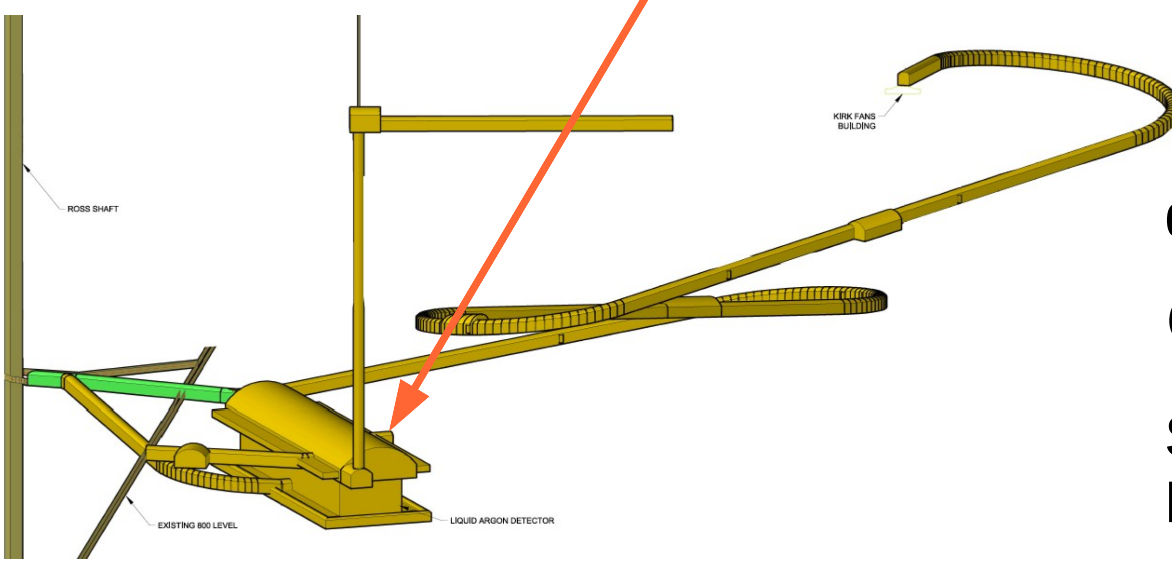
DUNE:
beam and baseline

MINOS

700 km



1300 km



depth of 1480 m ≈ 4300 (mwe)

@SURF/Homestake

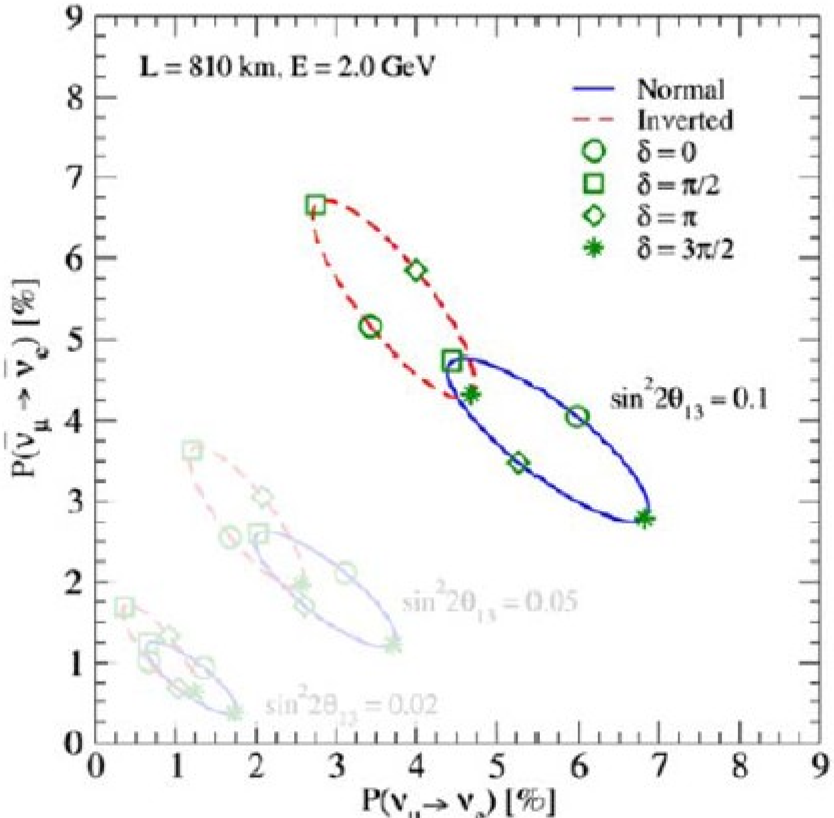
Sanford Underground Laboratory
Lead, South Dakota

DUNE: beam and baseline

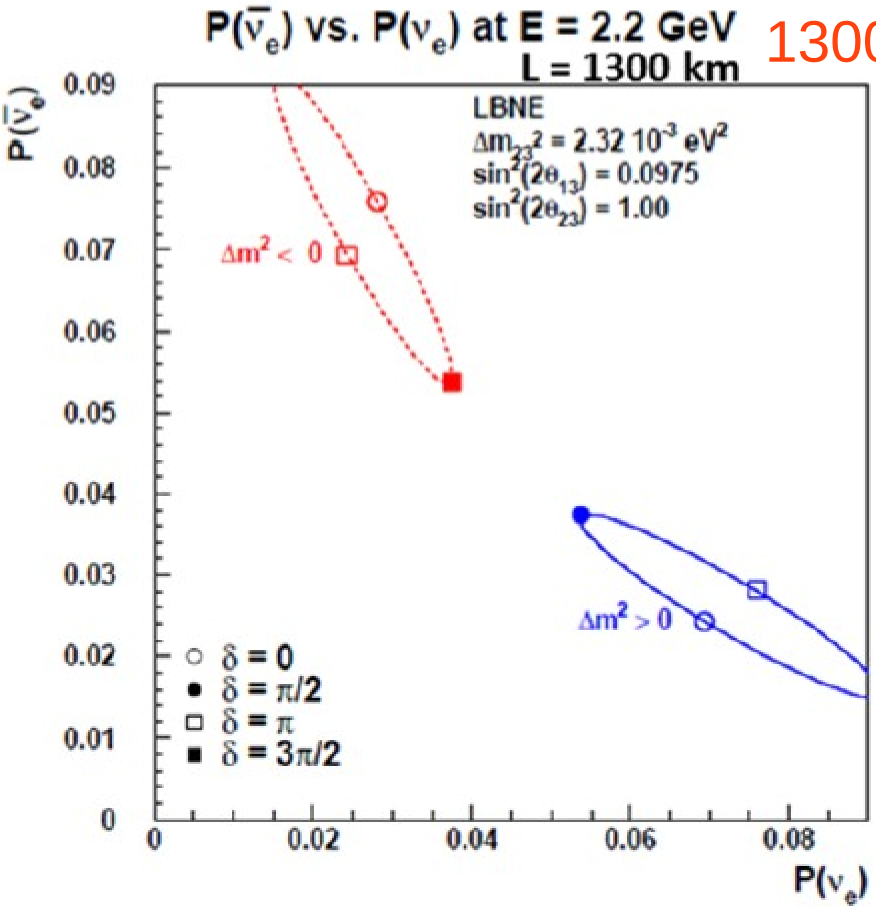
- The baseline should be long enough to cleanly separate the oscillation asymmetry between ν_μ / ν_μ-bar — due to the (non-CP-violating) matter effect from that due to true CP violation.

- Too short baseline => fundamental ambiguities between these two effects.

800 km



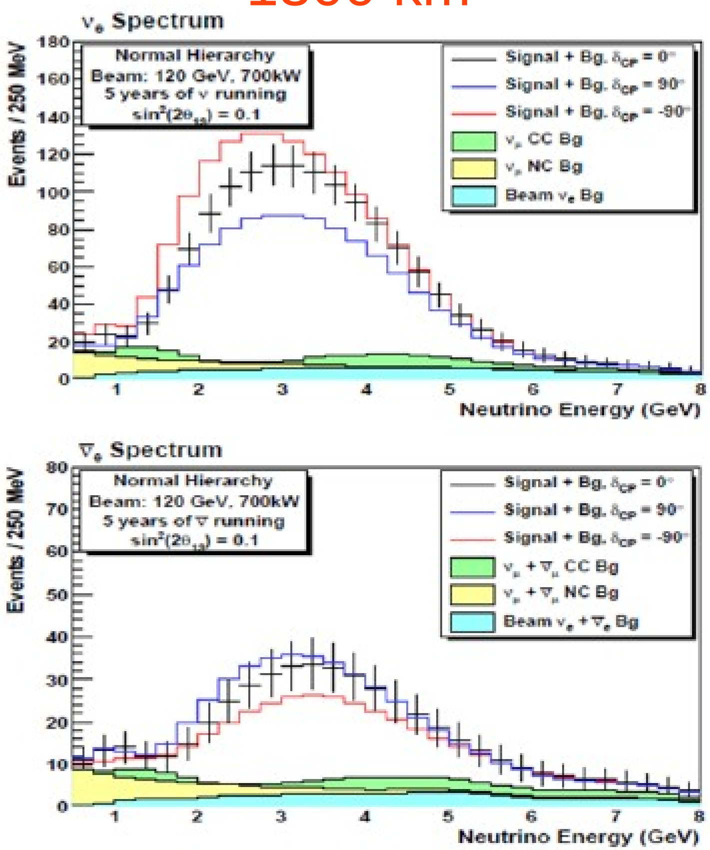
1300 km



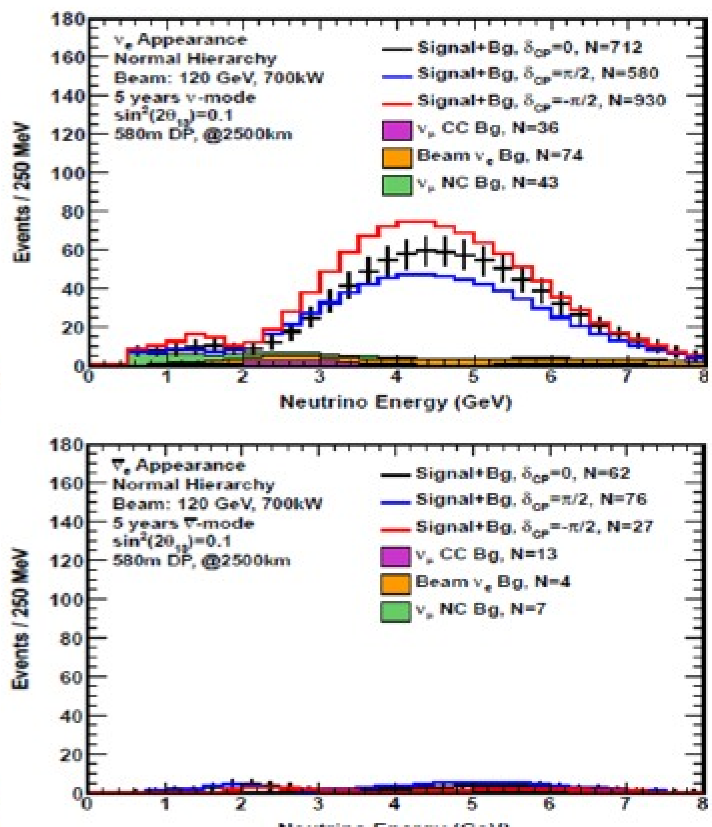
DUNE: beam and baseline

- Too long baseline: asymmetry due to the matter effect can become so large
  - Full suppression the flux of ν (ν_μ-bar) in the case of the normal (inverted) mass hierarchy.

1300 km

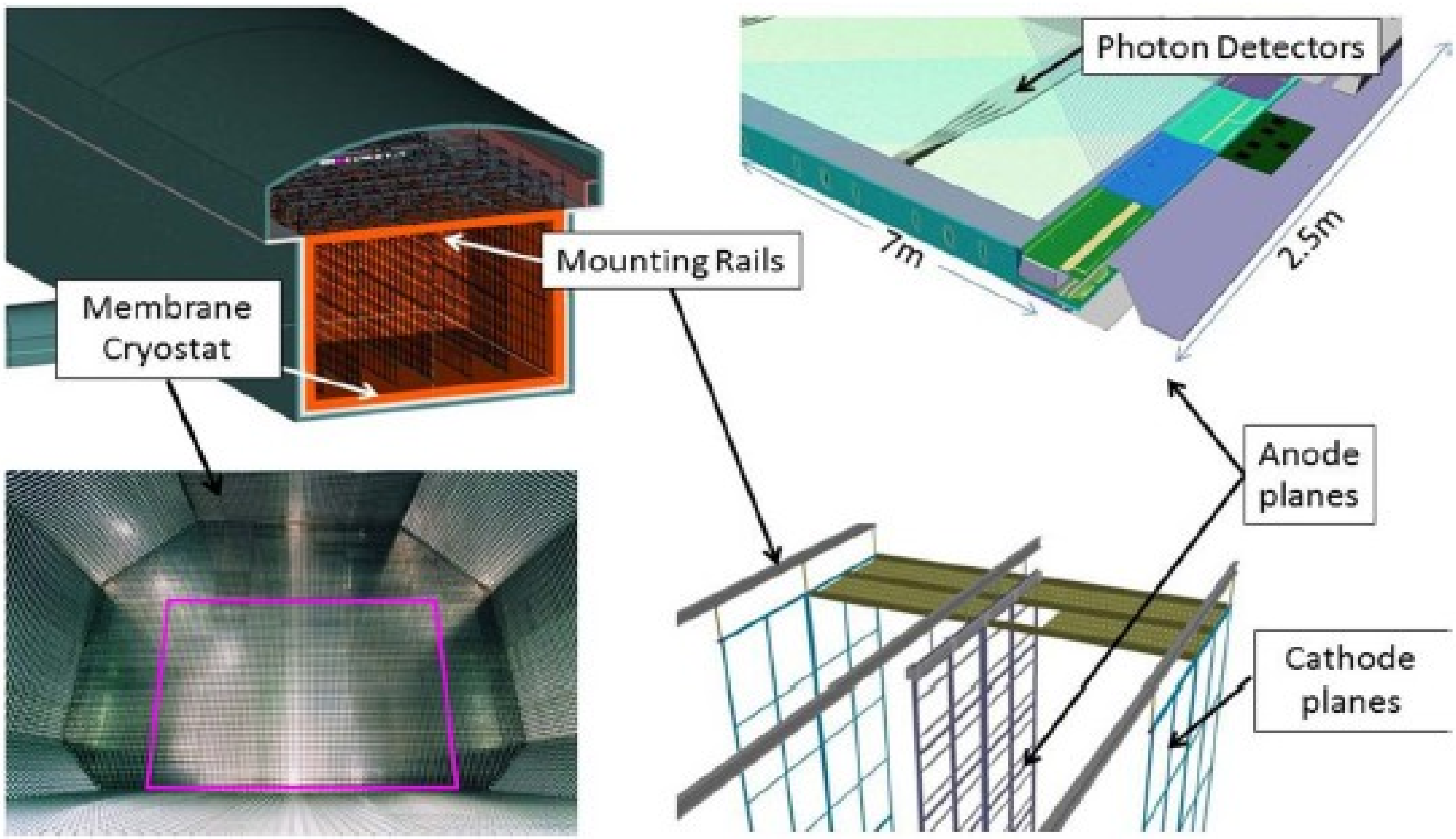


2500 km



DUNE: highly capable Far-Detector

Main design elements of the DUNE LAr TPC far detector. Upper left is an isometric cut-away drawing of the LAr TPC in it membrane cryostat, with alternating vertical anode and cathode planes. Lower left is a membrane cryostat in a liquefied natural gas tanker. The pink rectangle indicates roughly the cross-section size of the DUNE cryostat. Upper right is a conceptual design of one anode plane assembly module. Lower right shows the design for the mounting rail system that will support the anode and cathode planes.

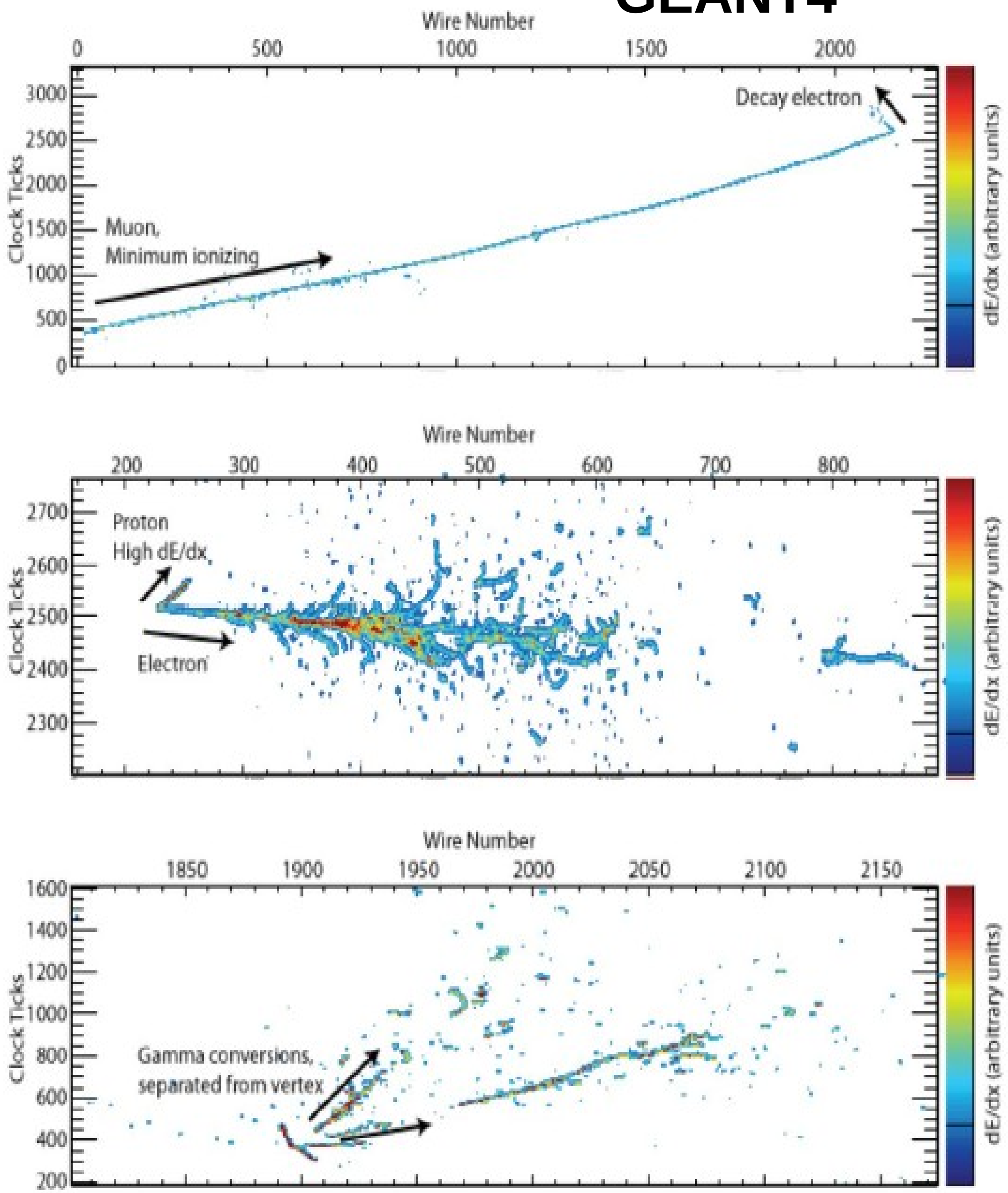


DUNE: highly capable Far-Detector

GEANT4

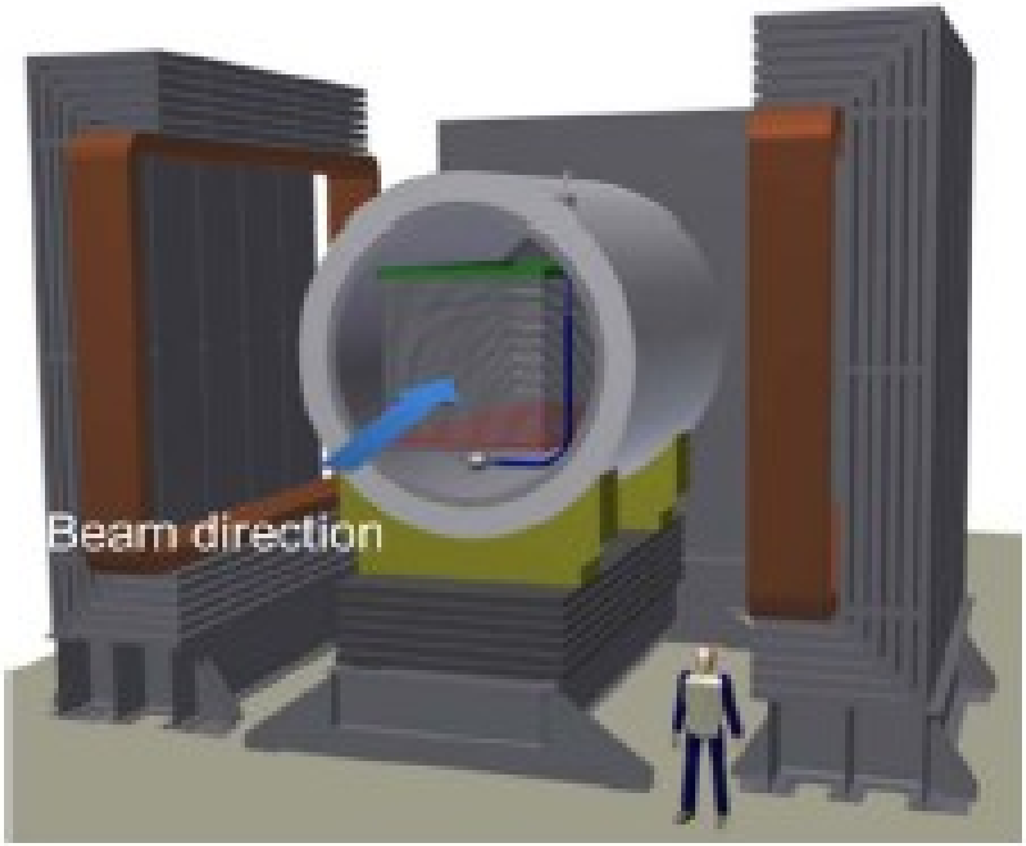
Liquid Argon (LAr) TPC:

- fiducial mass = 34 kton
- low-rate, large-volume, high-precision
  particle physics experiment
  - excellent 3D resolution
- Event topologies and kinematics:
  - *Particle identification:*
    - electrons, muons, photons, kaons, pions and protons



DUNE: high precision Near-Detector

Magnetized LAr TPC Near Detector

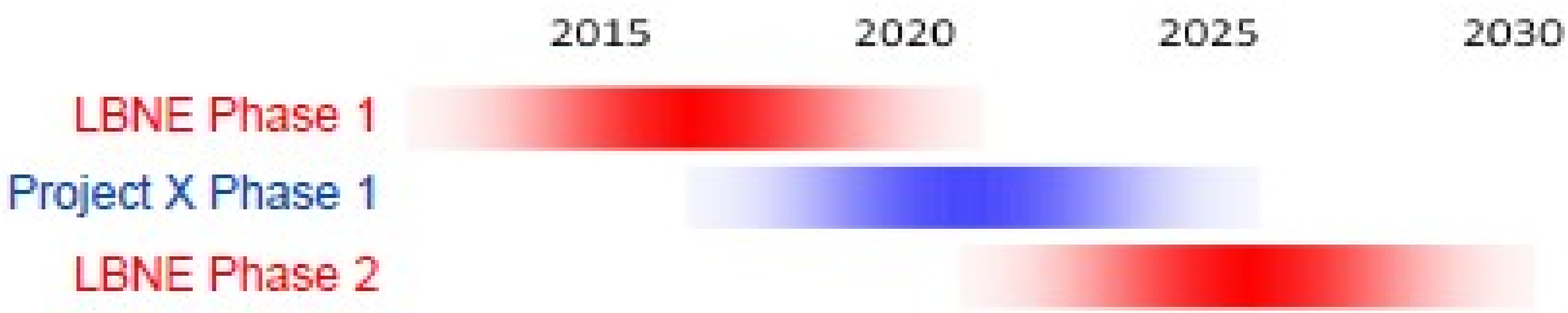


Sunfor Underground Research Facility - SURF: existing laboratory

Corridor 1480 m depth

LUX experiment

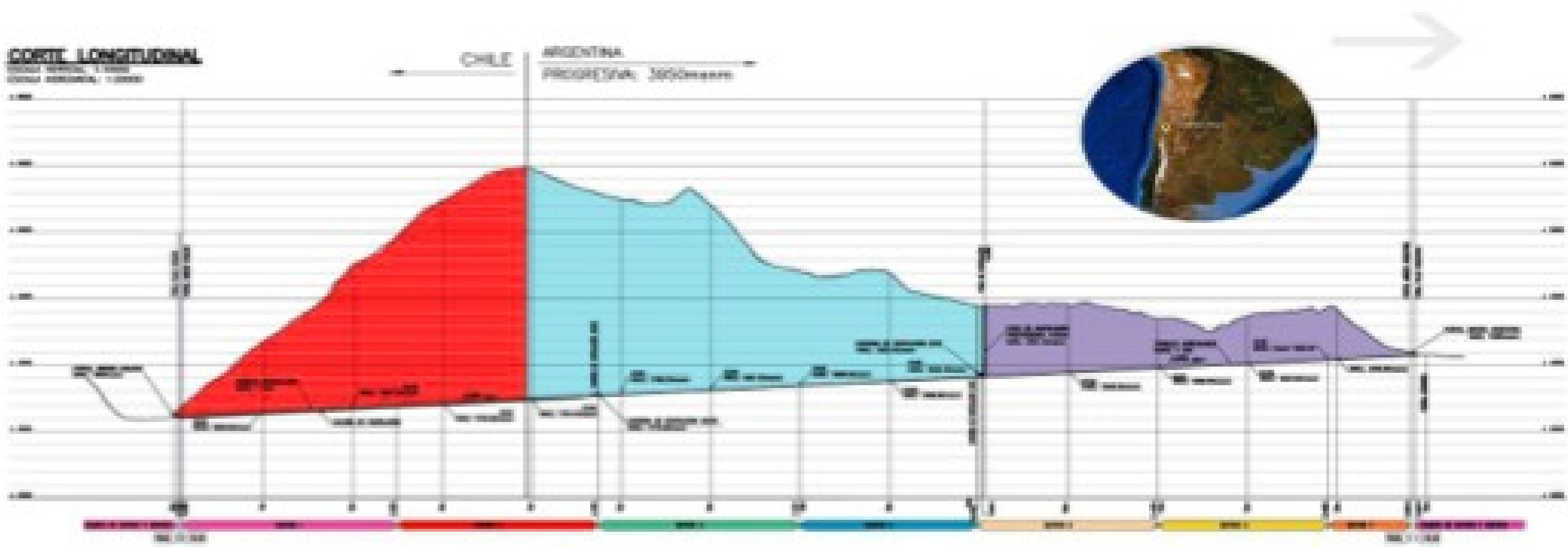
DUNE time-line



Future Perspectives:

ANDES

The first deep underground laboratory of the Southern hemisphere.



Agua Negra Deep Experiment Site

A Latin American project in the Agua Negra tunnel

Future Perspectives: ANDES

- Experimental facility in the tunnel connecting Argentina-Chile
  - Underground Physics
    - SN Neuttrinos
    - Geoneutrinos
    - Double-beta decay
    - Dark matter
- CLES: Centro Latino Americano de Estudos Subterraneos
  - A CERN-like consortium to manage the laboratory and drive the activities on all related fields in LA.

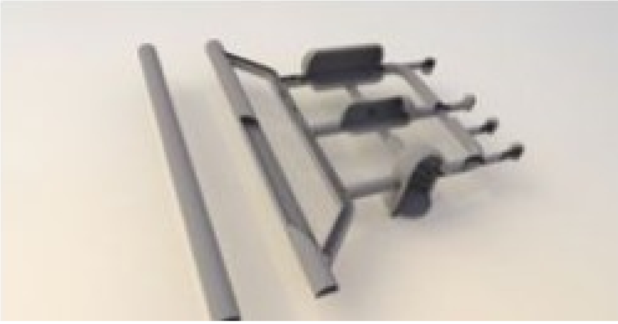
Future Perspectives: ANDES

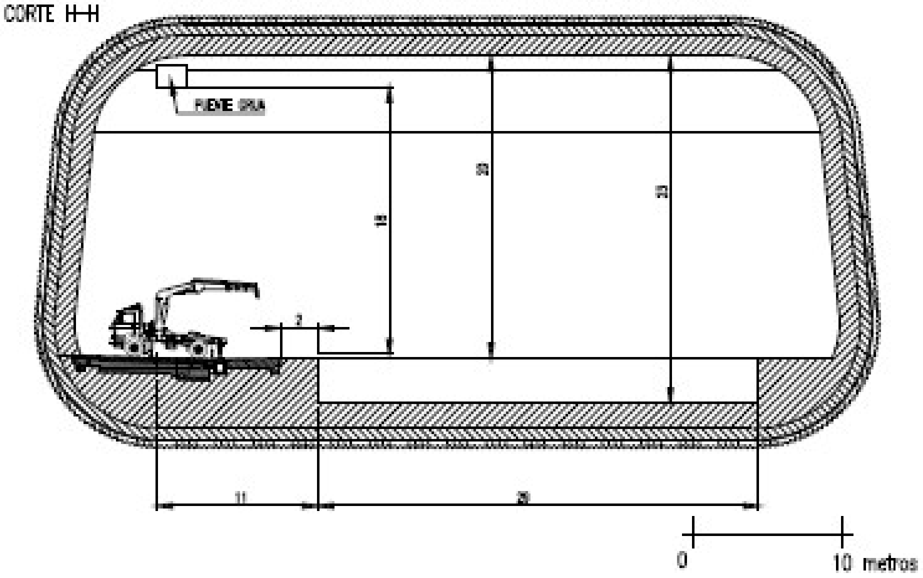
Future Perspectives: ANDES

Proposal for the ANDES laboratory

Located at km 3.5-5

- Main hall
  - $(21\times23\times50)\,m^3$
- Secundary hall
  - $(16\times14\times40)\,m^3$
- Offices and small laboratories
  - 3 halls of $100\,m^2$
- Low radiation pit
  - $\varnothing 9\,m$, $9\,m$ tall
- Large experimental pit
  - $\varnothing 30\,m$, $30\,m$ tall





Civil work cost estimated $< 2\%$ of tunnel cost

- + Laboratory equipment
- + 2 support laboratories
- + Experiments

Conclusions:

- **Brazilian group of experimental neutrino physics is participating in major experiments in frontier studies of neutrino properties**
- **The Brazilian scientific community has an unique opportunity to stay tuned with development of new technologies and their applications**
    - **even in a broader scope than experimental particle physics.**
- **Close contact of Brazilians teams with the current experimental efforts enables a stronger interaction with the phenomenological and theoretical groups in our country**
    - **deepest and faster feedback in both directions.**

Conclusions: DUNE

Significant opportunity for new collaborators (Brazilian group has grabbed it!) :

- **Collaboration on the design and construction:**
  - **far detector**
  - **near detector**
  - **neutrino beam**
- **Interest in the advanced state of LAr-TPC**
  - **Any member country in the collaboration will work together to develop and implement the best possible configuration**
- **Collaboration on the any aspect of the near detector/beam:**
  - **major step in advancing this science**
- **Excellent opportunity to participate in a cutting-edge program of measurements of neutrino oscillations and fundamental symmetries using leptons.**

The End

Thank you very much for the attention

Спасибо вам большое за внимание