Experimental neutrino physics from the Finnish perspective

Timo Enqvist
University of Oulu

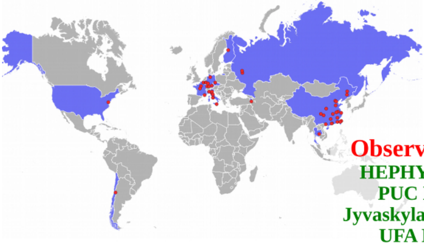
Experimental neutrino physics from the Finnish perspective

Outline

- JUNO
  - Jiangmen Underground Neutrino Observatory
  - ν–MH, reactor neutrinos
- DUNE
  - Deep Underground Neutrino Experiment
  - δ_{CP}, long baseline neutrino beam (Fermilab – Sanford)
  - LBNE + WA104 + WA105 [<=LAGUNA-LBNO]
- Large collaborations in JUNO and DUNE
  - Oulu (JUNO) and Jyväskylä (DUNE)
- THEIA
  - large water-based liquid scintillator experiment
  - proto-collaboration

Experimental neutrino physics from the Finnish perspective

The JUNO Collaboration



Asia (31)

BNU
CAGS
CQ U
CIAE
DGUT
ECUST
Guangxi U
HIT
IHEP
Jilin U
Jinan U.

Nanjing U
Nankai U
Natl. CT U
Natl. Taiwan U
Natl. United U
NCEPU
Pekin U
Shandong U
Shanghai JTU
Sichuan U
SUT

SYSU
Tsinghua
UCAS
USTC
U. of S. China
Wuhan U
Wuyi U
Xiamen U
Xi'an JTU

Observers (7):

HEPHY Vienna
PUC Brazil
Jyvaskyla U. Finlan
UFA Brazil
CENBG France
UTFSM Chile
IMP CAS China

America (4) PCUC – BISEE Chile
Maryland U.- 2 groups

Europe (27)

France (5)
APC Paris
CPPM Marseille
IPHC Strasbourg
LLR Paris
Subatech Nantes
Finland (1)
U Oulu
Czech (1)
Charles U

Italy (8)
INFN Catania
INFN-Frascati
INFN-Ferrara
INFN-Milano
INFN-Bicocca
INFN-Padova
INFN-Perugia
INFN-Roma 3
Russia (3)
JINR
INR Moscow
MSU

Germany (7)
FZ Julich
RWTH Aachen
TUM
U Hamburg
IKP FZI Jülich
U Mainz
U Tuebingen
Belgium (1)
ULB
Amenia (1)
YPI

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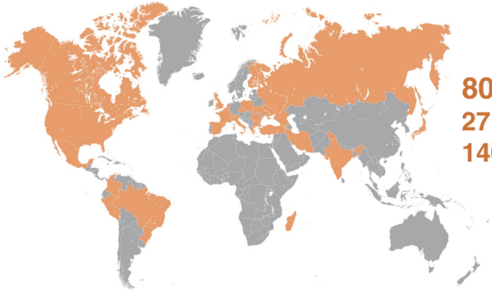
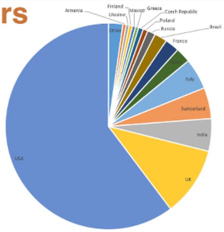
The DUNE Collaboration



805 Collaborators
27 Nations
146 institutions

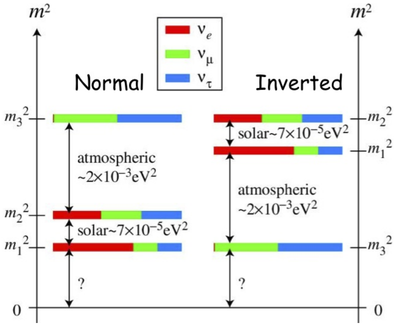


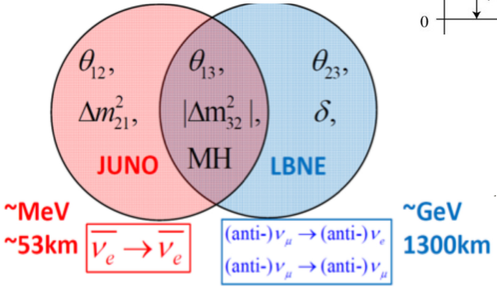
Armenia Yerevan Inst. for Theoretical Physics and Modeling
Belgium Univ. de Liege
Brazil Univ. Federal do ABC; Univ. Federal de Alfenas em Poços de Caldas; Univ. de Campinas; Univ. Estadual de Feira de Santana; Univ. Federal de Goias; Observatorio Nacional
Bulgaria Univ. of Sofia
Canada York University
Colombia Univ. del Atlantico
Czech Republic Charles University, Prague; Czech Technical University, Prague; Institute of Physics ASCR, Prague
France Lab. d'Annecy-le-Vieux de Phys. des Particules; Inst. de Physique Nucleaire de Lyon; APC-Paris; CEA/Saclay
Finland Jyväskylä
Greece Athens
India Aligarh Muslim University; Banaras Hindu University; Bhabha Atomic Research Center; Univ. of Delhi; Indian Inst. of Technology, Guwahati; Harish-Chandra Research Institute; Indian Inst. of Technology, Hyderabad; Univ. of Hyderabad; Univ. of Jammu; Jawaharlal Nehru University; Koneru Lakshmaiah; Univ. of Lucknow; Panjab University; Punjab Agri. University; Variable Energy Cyclotron Centre
Iran Inst. for Research in Fundamental Sciences
Italy Lab. Nazionali del Gran Sasso, Assergi; Univ. di Catania; Gran Sasso Science Institute; Univ. di Milano; INFN Sezione di Milano Bicocca; INFN Sezione di Napoli; Univ. of Padova; Univ. of Pavia, INFN Sezione di Pavia; CNI Pisa; Univ. di Pisa
Japan KEK; Kavli IPMU, Univ. of Tokyo
Madagascar Univ. of Antananarivo
Mexico Univ. de Colima; CINVESTAV
Netherlands NIKHEF
Peru PUCP
Poland Inst. of Nuclear Physics, Krakow; National Centre for Nuclear Research, Warsaw; Univ. of Warsaw; Wroclaw University
Romania Horia Hulubei National Institute
Russia Inst. for Nuclear Research, Moscow
Spain Inst. de Fisica d'Altas Energias, Barcelona; CIEMAT; Inst. de Fisica Corpuscular, Madrid
Switzerland Univ. of Bern; CERN; ETH Zurich
Turkey TUBITAK Space Technologies Research Institute
Ukraine Kyiv National University
United Kingdom Univ. of Cambridge; Univ. of Durham; Univ. of Huddersfield; Imperial College of Science, Tech. & Medicine; Lancaster University; Univ. of Liverpool; University College London; Univ. of Manchester; Univ. of Oxford; STFC Rutherford Appleton Laboratory; Univ. of Sheffield; Univ. of Sussex; Univ. of Warwick
USA Univ. of Alabama; Argonne National Lab; Boston University; Brookhaven National Lab; Univ. of California, Berkeley; Univ. of California, Davis; Univ. of California, Irvine; Univ. of California, Los Angeles; California Inst. of Technology; Univ. of Chicago; Univ. of Cincinnati; Univ. of Colorado; Colorado State University; Columbia University; Cornell University; Dakota State University; Drexel University; Duke University; Fermi National Accelerator Lab; Univ. of Hawaii; Univ. of Houston; Idaho State University; Illinois Institute of Technology; Indiana University; Iowa State University; Kansas State University; Lawrence Berkeley National Lab; Los Alamos National Lab; Louisiana State University; Univ. of Maryland; Massachusetts Institute of Technology; Michigan State University; Univ. of Minnesota; Univ. of Minnesota (Duluth); Univ. of New Mexico; Northwestern University; Univ. of Notre Dame; Ohio State University; Oregon State University; Pacific Northwest National Lab; Univ. of Pennsylvania; Pennsylvania State University; Univ. of Pittsburgh; Princeton University; Univ. of Puerto Rico; Univ. of Rochester; SLAC National Accelerator Lab; Univ. of South Carolina; Univ. of South Dakota; South Dakota School of Mines and Technology; South Dakota Science And Technology Authority; South Dakota State University; Southern Methodist University; Stanford University; Stony Brook University; Syracuse University; Univ. of Tennessee; Univ. of Texas at Arlington; Univ. of Texas at Austin; Tufts University; Virginia Tech; Wichita State University; College of William and Mary; Univ. of Wisconsin; Yale University

Experimental neutrino physics from the Finnish perspective

Physics motivations

- The main physics goals
  - JUNO: ν-mass hierarchy
  - DUNE: CP-violation (δ_{CP})
- Multipurpose experiments
  - detailed ν properties
  - SNν, DSNB, Solar-ν
  - search for proton decay





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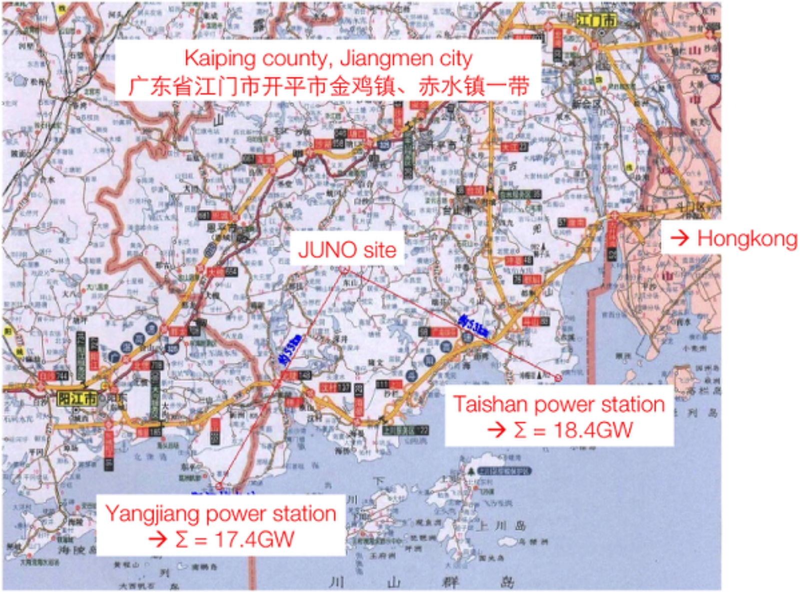
JUNO – the site



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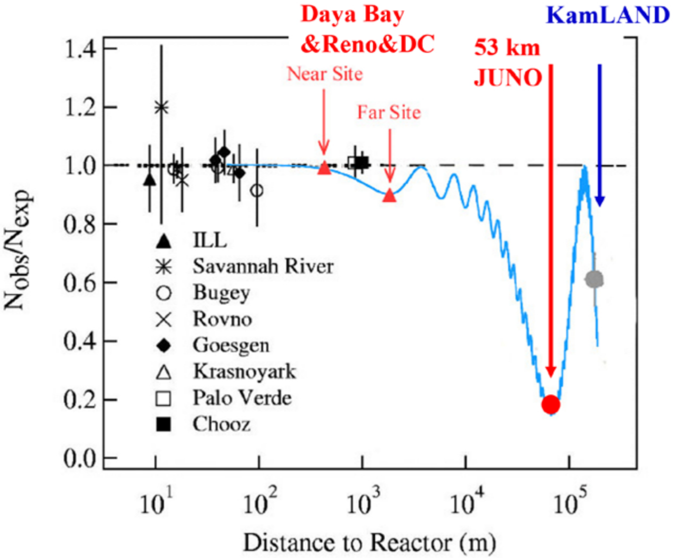
JUNO – the distance



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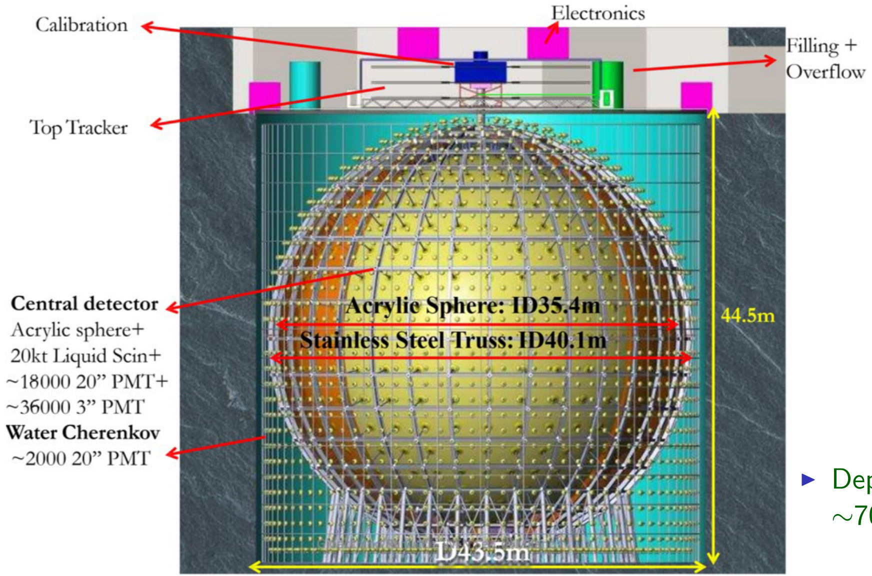
JUNO – the detector



- Depth ~700 m

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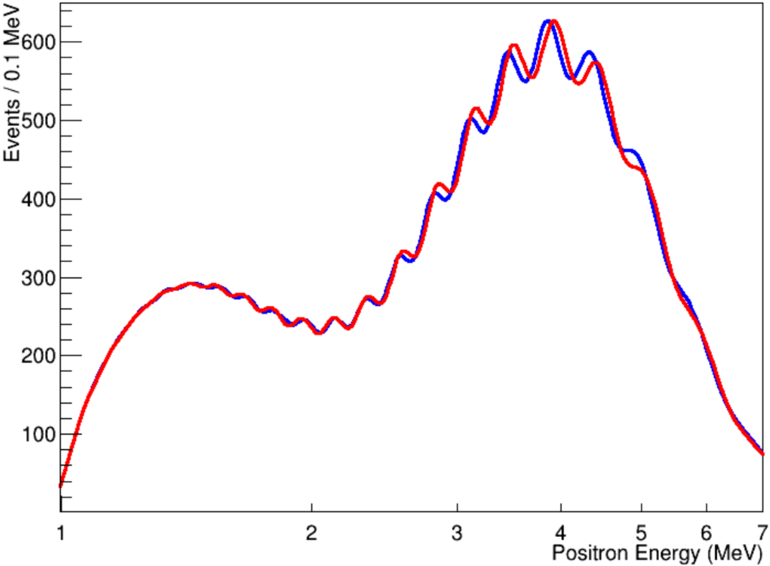
JUNO

- Determination of ν–MH
  - significance 3–4σ in six years
- The main challence: 3% energy resolution
  - 18000 20-inch and (up to) 36000 3-inch PMTs
    $\Longrightarrow$ 78% PMT coverage
- Civil construction work on-going
  - vertical shaft and decline ($\sim$half done)
- Start of data taking at the end of 2020

- Finnish contribution: determination of the ^{14}C concentration in the liquid scintillator (LAB = Linear Alkylbenzene)
  - upper limit 10^{-17} (to avoid pile-up pulses)

Experimental neutrino physics from the Finnish perspective

JUNO – MH determination



Experimental neutrino physics from the Finnish perspective

JUNO – supernova neutrinos

J. Phys. G: Nucl. Part. Phys. **43** (2016) 030401 Technical Report

Table 10. Numbers of neutrino events in JUNO for a SN at a typical distance of 10 kpc, where ν collectively stands for neutrinos and antineutrinos of all three flavors and their contributions are summed over. Three representative values of the average neutrino energy $\langle E_\nu \rangle = 12$, 14 and 16 MeV are taken for illustration, where in each case the same average energy is assumed for all flavors and neutrino flavor conversions are not considered. For the elastic neutrino–proton scattering, a threshold of 0.2 MeV for the proton recoil energy is chosen.

Channel	Type	Events for different $\langle E_\nu \rangle$ values		
		12 MeV	14 MeV	16 MeV
$\overline{\nu}_e + p \rightarrow e^+ + n$	CC	4.3×10^3	5.0×10^3	5.7×10^3
$\nu + p \rightarrow \nu + p$	NC	0.6×10^3	1.2×10^3	2.0×10^3
$\nu + e \rightarrow \nu + e$	ES	3.6×10^2	3.6×10^2	3.6×10^2
$\nu + {}^{12}C \rightarrow \nu + {}^{12}C^*$	NC	1.7×10^2	3.2×10^2	5.2×10^2
$\nu_e + {}^{12}C \rightarrow e^- + {}^{12}N$	CC	0.5×10^2	0.9×10^2	1.6×10^2
$\overline{\nu}_e + {}^{12}C \rightarrow e^+ + {}^{12}B$	CC	0.6×10^2	1.1×10^2	1.6×10^2

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JUNO – diffuse supernova neutrino background

J. Phys. G: Nucl. Part. Phys. **43** (2016) 030401 Technical Report

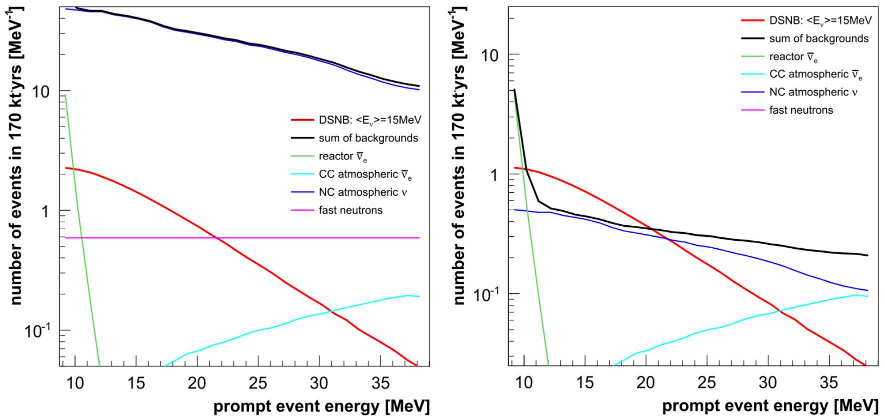

Figure 39. Prompt DSNB signal ($\langle E_{\bar{\nu}_e} \rangle = 15$ MeV), $\Phi = \Phi_0$) and background spectra before (*left*) and after (*right*) the application of pulse-shape discrimination. The DSNB signal dominates all backgrounds for a large fraction of the observation window from 11 to 30 MeV.

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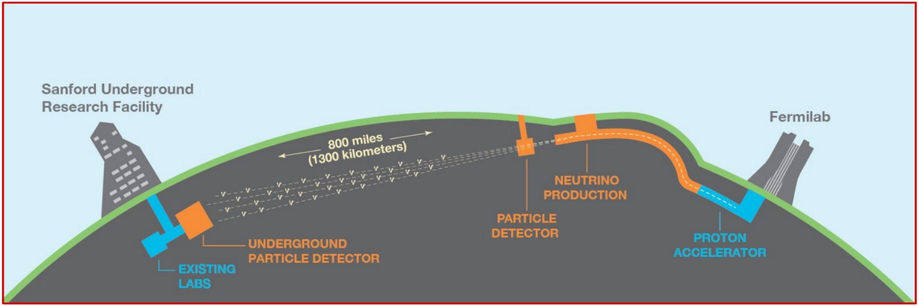
DUNE – the concept



- Sanford Underground Research Facility (SURF)
  - Homestake mine
  - Lead, South Dakota
  - far detector, 4×10 kT LAr-TPC, 1400 m (4000 mwe)
- Fermilab
  - neutrino beam
  - near detector

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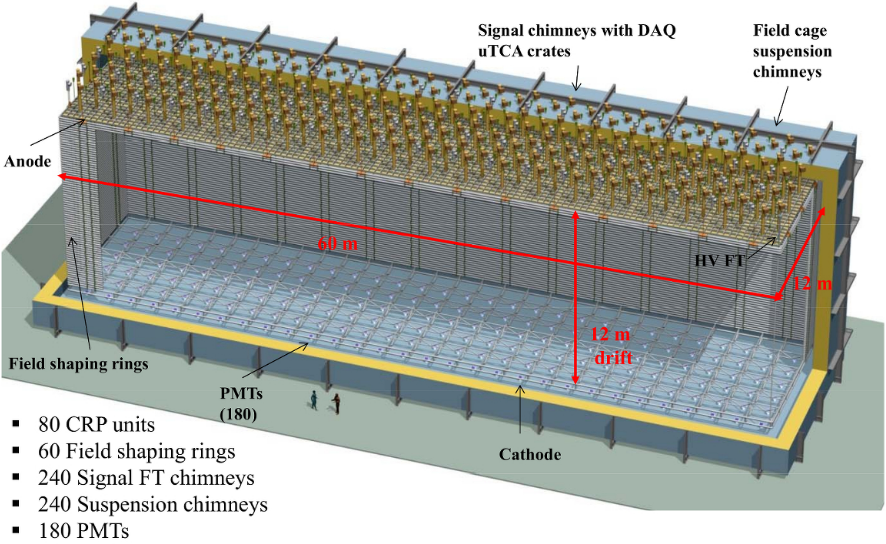
DUNE – the far detector (1/4)



Experimental neutrino physics from the Finnish perspective

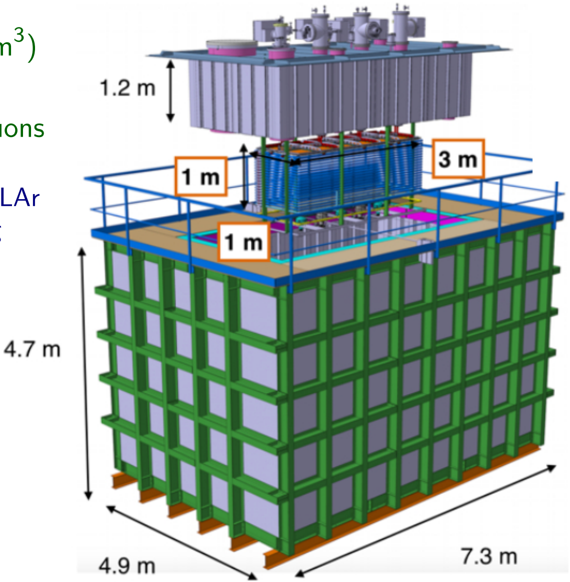
DUNE – ProtoDUNE

- Construction and testing of two 300 tons ($6\times6\times6$ m^3) LAr-TPC detectors at CERN (neutrino platform)
  - single phase (liquid only)
  - dual phase (liquid and gas)
  $\Longrightarrow$ WA105 Demonstrator ($3\times1\times1$ m^3) and
  WA105 Prototype ($6\times6\times6$ m^3) = Dual-Phase ProtoDUNE
- To demonstrate the LAr technology in large scale
  - drift of 6 m (half of the full detector)
  - LAr purity (100 ppt O_2)
- New building and beam-line at CERN
  - charged particles
- Data taking during 2018
  - before the long shut down
- Finnish contribution: on-line computing
  - tracking algorithm, event reconstruction, particle id

Experimental neutrino physics from the Finnish perspective

ProtoDUNE – the first stage

- WA105 Proto ($3 \times 1 \times 1$ m^3)
  - 4.2 tons
- Test with cosmic-ray muons in 2017
  - filling and cooling of LAr start in the beginning of 2017



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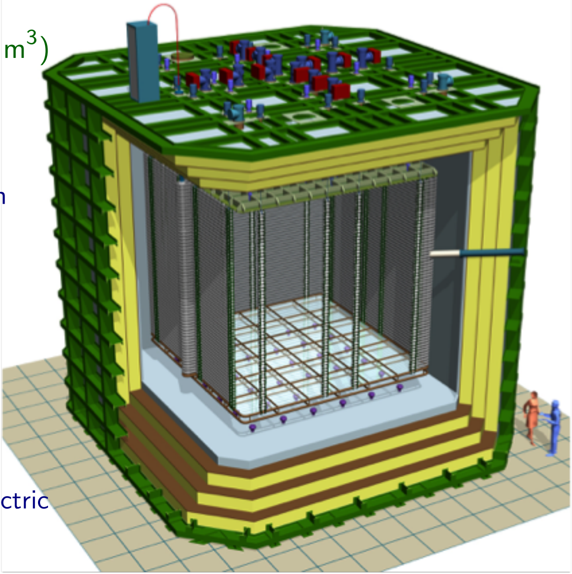
ProtoDUNE – the second stage

- WA105 Demo (6×6×6 m^3)
  - 300 tons
- Schedule
  - 2017: Gryostat and detector construction
  - Jan 2018: Start gryogenic operation
  - Spring 2018: Start taking data (charged-particle beam)
- e^- drift slow: $\mathcal{O}$(ms)
  - very pure LAr
  - high and uniform electric field (∼2 kV/cm)



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THEIA

- Water-based liquid scintillation detector
  - ∼90:10 Water:LS
- Size 50–100 kton
- To combine
  - directionality of water Cherenkov detectors
  - low-energy threshold of liquid scintillators
- Proto-collaboration forming (US initiative)
- On-going R&D work, for example,
  - separation of WC and LS light
  - purification (of water)
- Physics
  - long baseline
  - astroparticle physics
  - double-beta decay

Experimental neutrino physics from the Finnish perspective

Conclusions

- Finnish contribution in two large neutrino experiments
  - JUNO – 20 kton liquid scintillator & reactor-νs
  - DUNE – 40 kton LAr experiment & long baseline
- In JUNO civil construction work started
  - data taking expected at the end of 2020
  - six years of data taking for MH determination
  - detector lifetime 20–30 years for versatile astroparticle physics program
- DUNE is at the prototype stage
  - single-phase and dual-phase technologies tested at CERN in large scale
  - dual-phase 300-ton detector to be tested in 2018
- THEIA
  - water-based liquid scintillation detector – a new concept to realize next-generation large-size neutrino detector
  - proto-collaboration is forming