Collaboration of the Czech Republic in Neutrino Physics

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Neutrino oscillations

Reactor neutrino experiments
CZ – Daya Bay in CN
FR – Double Chooz in FR
Near future: CZ+FR in JUNO CN

Accelerator neutrino experiments
CZ – NOvA in US
FR – T2K in JP
Future: CZ+FR in DUNE (US),
       FR in HyperKamiokande (JP), CZ not (yet?)

Direct measurement of electron antineutrino mass
CZ+FR - KATRIN in GE

Neutrino-less double beta decay
– will be covered at next talk
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Reactor neutrino experiments

CZ – Daya Bay in CN
FR – Double Chooz in FR

Main result of Daya Bay and Double Chooz is measurement of smallest mixing angle $\theta_{13}$

Near future: CZ+FR in JUNO CN

The goal of JUNO is to decide on ordering of neutrino masses and improve precision of mixing angles and mass splits.
Daya Bay Collaboration

~230 collaborators from 41 institutions:

Europe (2)
- Charles University
- JINR Dubna

Asia (23)
- Beijing Normal Univ.
- CNGPG
- CIAE
- Chongqing Univ.
- Dongguan Polytechnic
- ECUST
- Nanjing Univ.
- Nankai Univ.
- NCEPU
- NUDT
- Shandong Univ.
- Shanghai Jiao Tong Univ.
- Shenzhen Univ.
- Tsinghua Univ.
- USTC
- Xi’an Jiaotong Univ.
- Zhongshan Univ.
- Chinese Univ. of Hong Kong
- Univ. of Hong Kong
- National Chiao Tung Univ.
- National Taiwan Univ.
- National United Univ.

North America (15)
- Brookhaven Nat’l Lab
- Illinois Institute of Technology
- Iowa State
- Lawrence Berkeley Nat’l Lab
- Princeton
- Siena College
- Temple Univ.
- UC Berkeley
- Univ. of Cincinnati
- Univ. of Houston
- UIUC
- Univ. of Wisconsin
- Virginia Tech
- William & Mary
- Yale

South America (1)
- Catholic Univ. of Chile
The most important results are precise values of mixing angle $\theta_{13}$ and neutrino mass split $\Delta m_{32}$

$\sin^2 2\theta_{13}$

There are many other Daya Bay results (also important)

Absolute measurement of reactor antineutrino flux and spectrum
Seasonal variations of cosmic muons signal
Cosmogenic production of neutrons
Searches for sterile neutrinos
Searches for time variation of neutrino signals
JUNO – future reactor neutrino oscillation experiment

- Jiangmen Underground Neutrino Observatory
- a multi-purpose neutrino experiment,
- approved in Feb. 2013,
- ~ 300 M$,

- Neutrino source: 10 nuclear reactors (Yangjiang+Taishan: 26.6-35.7 GWth),
- baseline: 53 km,
- overburden: ~700 m.

Measurement of the antineutrino spectrum allows to determine precisely four oscillation parameters:

\[
\begin{align*}
\sin^2 2\theta_{12} & \quad \Delta m_{21}^2 & \quad \sin^2 2\theta_{13} & \quad |\Delta m_{ee}^2|
\end{align*}
\]
JUNO collaboration
71 institutions 550 collaborators

- Asia – Armenia, China 30, Pakistan, Taiwan 3, Thailand
- Europa – Belgium, Czech R., Finland, France 5, Germany 7, Italy 8, Russia 3, Slovakia
- America – Brazil 2, Chile 2, USA 2

France – APC Paris, CENBG Bordeaux, CPPM Marseille, IPHC Strasbourg, Subatech Nantes
Low background measurements, Veto/Top Tracker construction, Small PMTs and others

Schedule

2014: International collaboration established

2015: PMT production line manufacturing

2016: Start PMT and detector production

2017: Start PMT testing

2018: PMT potting

2019: Start building central detector and LS filling

Beginning of next decade: start data taking

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JUNO Physics Program

- Reactor neutrinos
  - Mass Hierarchy
    - needed energy resolution ~3% @ 1 MeV,
    - energy scale uncertainty <1%
  - Precision measurements of oscillation parameters
- Supernovae neutrinos
- Geoneutrinos
- Solar neutrinos
- Atmospheric neutrinos
- Exotic searches


Charles University contribution
3 senior scientists, 2 doctoral students, 1 master student

- System for calibration of the Cerenkov detector PMTs
- LS investigation – precise evaluation of composition, nonlinearity
- Physics – neutrino hierarchy, supernova neutrinos, geo-neutrinos

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Neutrino oscillations
Accelerator neutrino experiments
CZ – NOvA in US
FR – T2K in JP

Major result of NOvA and T2K is the appearance of electron neutrino in muon neutrino beam.

Future: CZ+FR in DUNE (US), FR in HyperKamiokande JP, CZ not(yet?)

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NOvA experiment

- Detectors located at FNAL (ND, 330 t), in Minnesota 810 km away (FD, 14 kt) plastic structure filled with liquid scintillator
- Beam power \( \sim 730 \text{ kW} \), off-axis 2 GeV \( \nu_\mu \) beam
- \( \sim 240 \) collaborators from 50 institutions of 7 countries
- Czech institutions:

  Latest results: New Constraints on oscillation parameters from \( \nu_e \) and \( \nu_\mu \) disappearance in the NOvA experiment *Phys. Rev. D, 98, 032012 (2018)*

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Czech institutions at NOvA

- Computing capacities delivery
  - MC production for NOvA, DUNE
  - Inst. of Phys. Farm delivered 25% offsite capacities in 2018 (P. Vokac)

- NOvA operations
  - NearDet bad parts replacements (P. Filip)
  - TestBeam commissioning (P. Filip, K. Soustruznik)
  - HV source for NOvA testbeam (I. Polak, J. Zuklin)
  - NOvA remote control room Prague, CTU (P. Vokac)

- Statistical methods
  - Mathematicians from CTU
  - Reconstruction methods for machine learning
  - CNN networks for NOvA calibration
Czech institutions at NOvA #2

- NOvA DAQ software
  - Dashboard online alarm watch (K. Soustruznik)
  - Downtime logger (K.S.)
  - Internal DAQ message rate analysis (K.S.)

- NOvA data analysis
  - NOvA Multimuon Seasonal Variation analysis (P. Filip)
  - Systematics study for electron neutrino group (T. Nosek)
  - Sterile neutrino data analysis (T. Nosek)

No French member institutions at NOvA
DUNE – Collaboration

Armenia, Brazil, Bulgaria, Canada, CERN, Chile, China, Colombia, **Czech Republic (11)**, Spain, Finland, **France (24)**, Greece, India, Iran, Italy, Japan, Madagascar, Mexico, The Netherlands, Paraguay, Peru, Poland, Portugal, Romania, Russia, South Korea, Sweden, Switzerland, Turkey, UK, Ukraine, USA

- **Czech Republic – 3 institutions (FZU, CTU, UK)**
  - Members of **Single Phase Photon Detection Consortium**
  - Members of **Computing Consortium** - computing capacities
  - Measurement SiPMs for the first Far Detector module light system.
  - Installation, commissioning, operation and data analysis of **Single ProtoDUNE prototype** at CERN Neutrino Platform (beam exposure in Fall 2018)

- **France – 6 institutions**
  - Involved in **Dual Phase TPC Electronics and Photon Detection system**
  - Participation in **Dual Phase ProtoDUNE prototype**.
- Approximately 40 kt fiducial mass liquid-argon TPC Far Detector.
- Located at SURF’s – depth of 1478 m, with 1300 km baseline.
- Hybrid Near Detector located 575 m from neutrino source.
- Wide-band neutrino beam (~ GeV range).
- Physics topics: CPV, supernova neutrinos, proton decay, and more
Direct measurement of electron antineutrino mass

KATRIN - Karlsruhe Tritium Neutrino Experiment at KIT
direct β-spectroscopic search for $m(\nu_e)$

Present limit: $m(\nu_e) < 2$ eV

KATRIN aim: sensitivity of $m(\nu_e) = 0.24$ eV

150 researches from 24 institutions,
FR: IRFU, CEA Universite Paris Saclay

Czech participant: Nuclear Physics Institute of the Czech Acad. Sci., Řež near Prague NPI

Plans (2019-2023)

- **NPI**: Production of the solid and gaseous sources with their characterization
- **KIT**: Measurement and data analysis
KATRIN setup with 3 electrostatic spectrometers

- High resolution: 0.9 eV
- High luminosity: 19% of 4π
- \( T_2 \) injection of 40 g/day, 4.7 Ci/s
- 1000 measurement days
- High stability of key parameters
  \( \pm 3 \text{ ppm for } 18\text{ kV voltage} \)

Calibration & monitoring sources of monoenergetic electrons based on \(^{83}\text{Rb} \rightarrow ^{83}\text{mKr} \rightarrow ^{83}\text{Kr}\) have been developed at NPI

- Solid electron source implanted in graphite
- Gaseous electron source in zeolite
- \(^{83}\text{Rb}\) target for \(^{83}\text{Rb}\) production at NPI cyclotron
Neutrino oscillations and direct measurement of neutrino mass

CZ Institutions:
Academy of Sciences (Inst. of Physics, Nuclear Physics Inst., Inst. of Informatics)
Charles University
Czech Technical University

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There are opportunities to collaborate on physics programme with French partners within JUNO, DUNE and KATRIN experiments.