

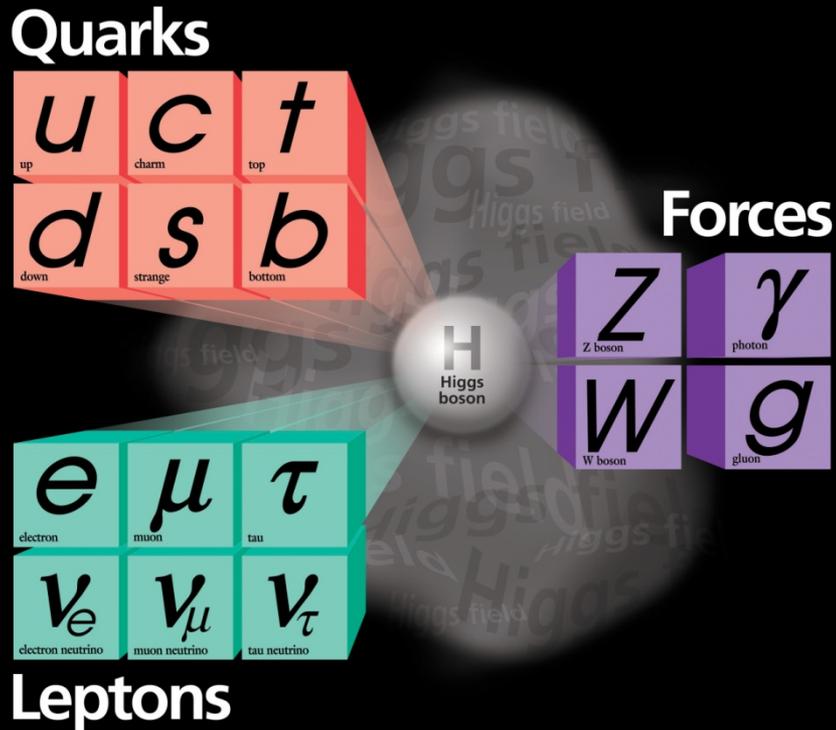
Neutrinos @ CERN

The Liverpool neutrino programme:
Opportunities at CERN



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The Standard Model of Particle Physics



- **Matter particles** (fermions: quarks, leptons: three families)
- **Force carriers** (bosons for electroweak, strong interactions)
- **Higgs**
- **Neutrino mass and flavour oscillations NOT included**

Brief history

- **Beta decay:** (nucleus) \rightarrow (another nucleus) + electron
 - 2-body decay: E and P conservation \Rightarrow **monoenergetic electron**
- **1927: Chadwick:** continuous electron spectrum
 - Energy non-conservation?
- **1930: Pauli:** neutrino: light, non-interacting
 - Bet a case of Champagne that it would never be discovered
- **1956: discovery of electron-neutrino (1995 Nobel)**
 - Pauli paid up
- **1962: discovery of muon-neutrino (1998 Nobel)**
- **1968: first detection of solar neutrinos (2002 Nobel)**
- **1987: Supernova 1987A (2002 Nobel)**
- **2000: discovery of the tau-neutrino**
- **2002: establishment of neutrino oscillations**
- **2011: T2K: first evidence of electron-neutrino appearance**
- **2013: 7 sigma non-zero θ_{13} , electron-neutrino appearance**

Neutrinos: discovery potential

- **Matter dominance** (Sakharov conditions)
 - B or L violation (Majorana neutrinos?)
 - CP Violation (see below)
 - Out of thermal equilibrium universe
- **CPV in quarks: known, too small by 10^{10}**
- **CPV in neutrinos require:**
 - Majorana (**SNO+**)
 - Large θ_{13} (found; **T2K**)
 - CPV in three known neutrino mixing (**LBNE, HK**)

Neutrinos at CERN and at Liverpool

- 1963: invention of the magnetic horn for neutrino beam production
- 1973: discovery of Neutral Currents
- Many experiments over 50 years

- The **Liverpool neutrino group**, since 2003
- Current experiment: **T2K** (Japan)
- Future experiments:
 - **LBNE** (Fermilab, USA)
 - **SNO+** (Canada)
 - **Hyper-Kamiokande** (Japan)

Opportunities for activities at CERN

- **LBNE: DoE CD1 (\$860M)**
 - Requires more \$ for full program (few \$100M) outside USA
 - Community-building globally
- CERN-FNAL coordination / UK key role
- EU/USA i.e. CERN/FNAL immediate joint program:
 - **LAr TPC R&D**
 - Infrastructure (cryo, UHV, Ar recirc/purif, high power proton beams and targets, magnets etc)

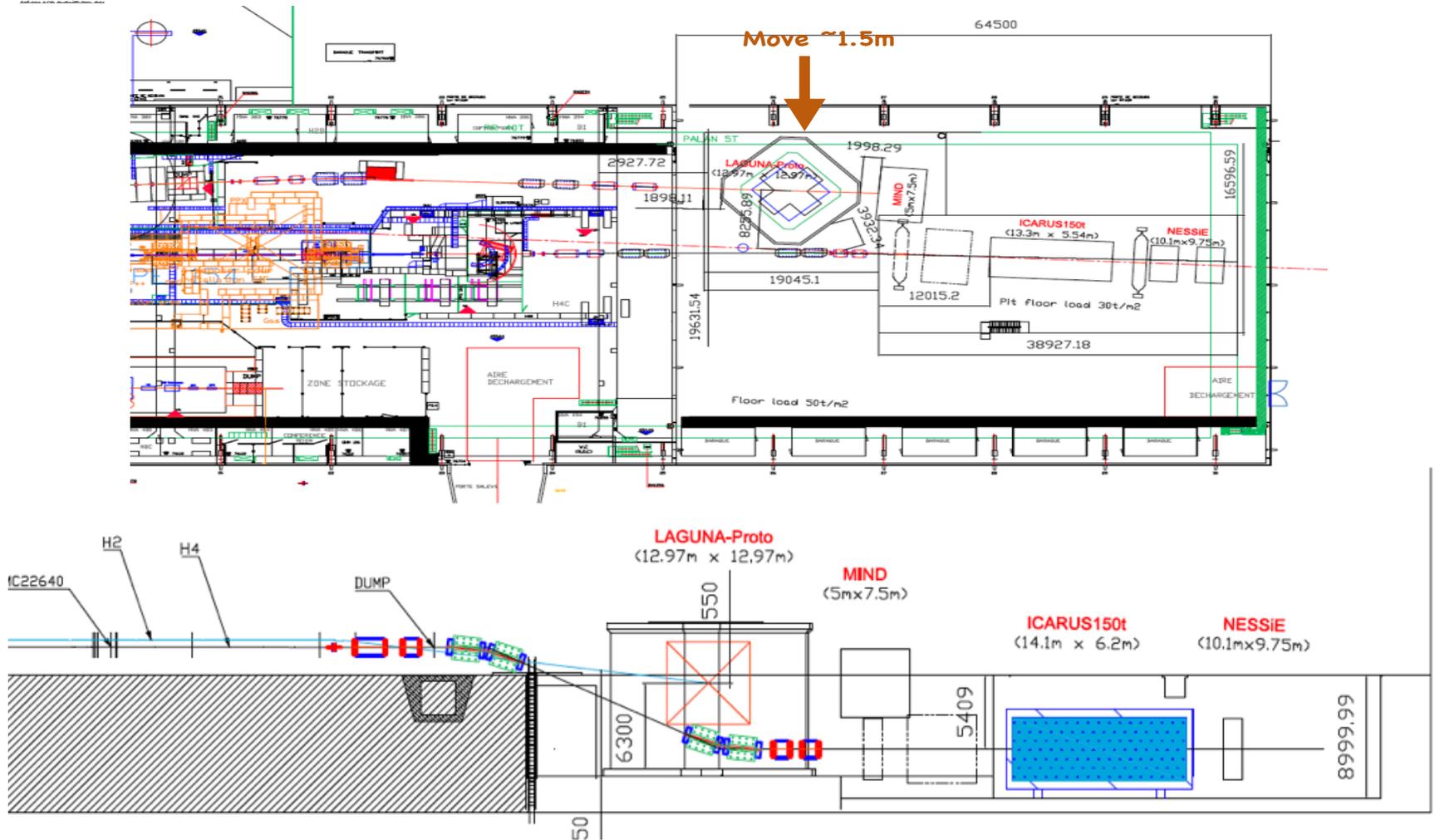
CERN, WA104, WA105

- CERN Neutrino Facility (RB approved)
 - WA104: R&D around ICARUS
 - WA105: LAGUNA demo & LBNE test
 - Neutrino beam for short baseline - option
- Liverpool position:
 - LAGUNA / double phase
 - LBNE test organisation
 - Future UK LBNE construction bid; DL
 - Positioning for possible neutrino program

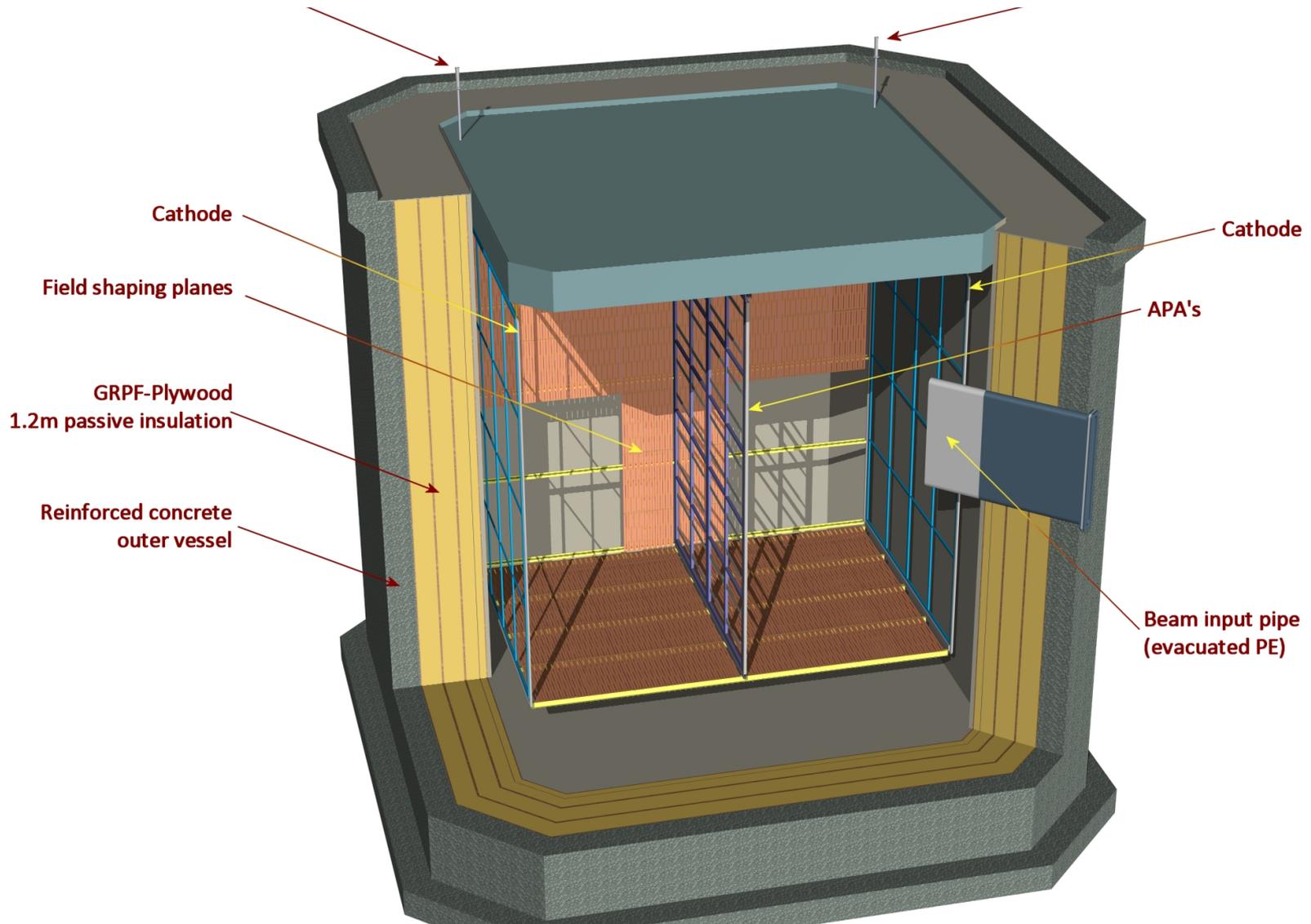
Planned Facility in the NA



CERN EHN1 integration

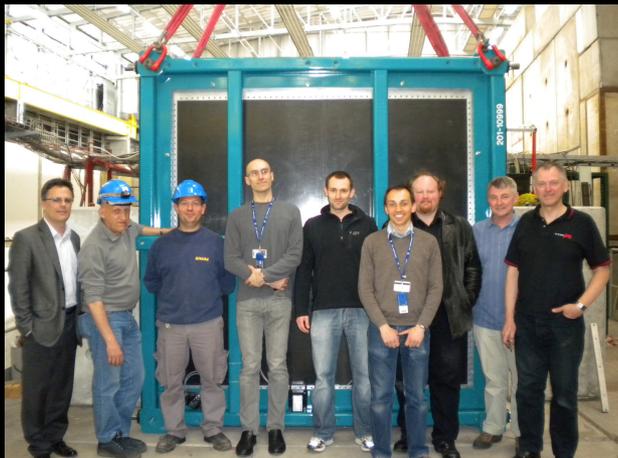


LBNE cell in WA105 cryostat



Applications

T2K module at CERN, 2009



Reactor monitor, 2014



Special Nuclear Materials screening, MODES-SNM



Summary

- Key roles in the development of the future CERN neutrino program, and the CERN/FNAL developing collaboration
- Physicists already engaged
- Ample potential for accelerator & engineering projects
- Promising future for science and applications