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A compact electron calibration source using laser wakefield acceleration technology

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Solar Neutrinos at DUNE

SoLAr: Solar Neutrinos in Liquid Argon

Submitted to the Proceedings of the US Community Study on the Future of Particle Physics (Snowmass 2021)

ABSTRACT

SoLAr is a new concept for a liquid-argon neutrino detector technology to extend the sensitivities of these devices to the MeV energy range - expanding the physics reach of these next-generation detectors to include solar neutrinos. We propose this novel concept to significantly improve the precision on solar neutrino mixing parameters and to observe the “hep branch” of the proton-proton fusion chain. The SoLAr detector will achieve flavour-tagging of solar neutrinos in liquid argon. The SoLAr technology will be based on the concept of monolithic light-charge pixel-based readout, which addresses the main requirements for such a detector: a low energy threshold with excellent energy resolution (≈ 7%) and background rejection through pulse-shape discrimination.

The SoLAr concept is also timely as a possible technology choice for the DUNE “Module of Opportunity”, which could serve as a next-generation multipurpose observatory for neutrinos from the MeV to the GeV range. The goal of SoLAr is to observe solar neutrinos in a 10-ton-scale detector and to demonstrate that the required background suppression and energy resolution can be achieved. SoLAr will pave the way for a precise measurement of the 8B flux, an improved precision on solar neutrino mixing parameters, and ultimately lead to the first observation of hep neutrinos in the DUNE Module of Opportunity.

Low-Energy Physics and Calibration at DUNE

Identification and reconstruction of low-energy electrons in the ProtoDUNE-SP detector

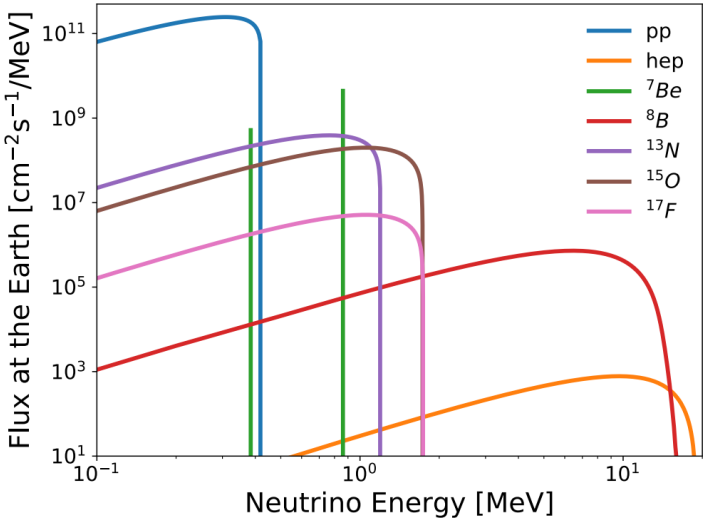
arXiv:2211.01166v2

ABSTRACT

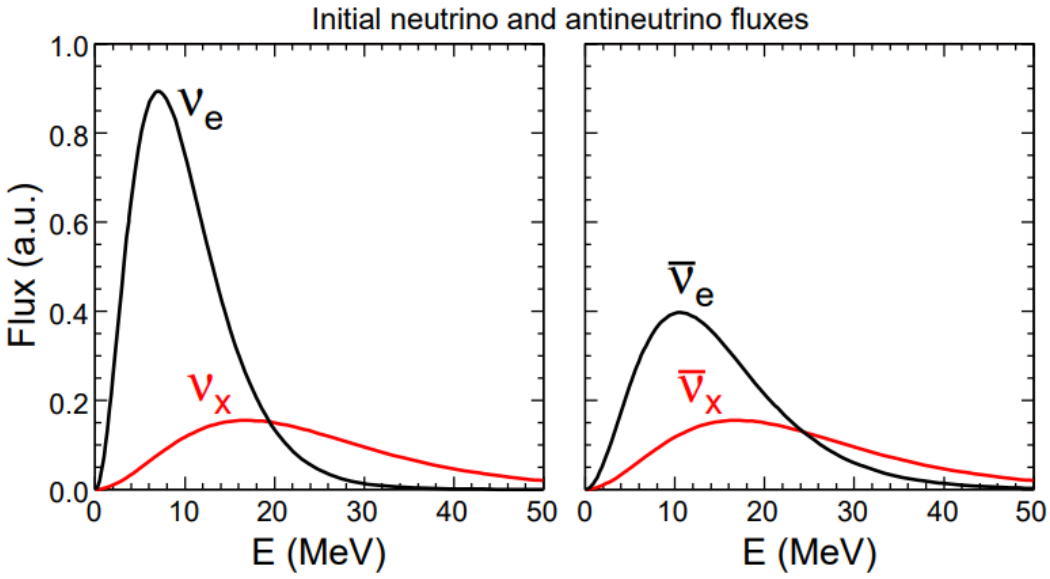
Measurements of electrons from *νe* interactions are crucial for the Deep Underground Neutrino Experiment (DUNE) neutrino oscillation program, as well as searches for physics beyond the standard model, supernova neutrino detection, and solar neutrino measurements. This article describes the selection and reconstruction of low-energy (Michel) electrons in the ProtoDUNE-SP detector. ProtoDUNE-SP is one of the prototypes for the DUNE far detector, built and operated at CERN as a charged particle test beam experiment. A sample of low-energy electrons produced by the decay of cosmic muons is selected with a purity of 95%. This sample is used to calibrate the low-energy electron energy scale with two techniques. An electron energy calibration based on a cosmic ray muon sample uses calibration constants derived from measured and simulated cosmic ray muon events. Another calibration technique makes use of the theoretically well-understood Michel electron energy spectrum to convert reconstructed charge to electron energy. In addition, the effects of detector response to low-energy electron energy scale and its resolution, including readout electronics threshold effects, are quantified. Finally, the relation between the theoretical and reconstructed low-energy electron energy spectrum is derived, and the energy resolution is characterized. The low-energy electron selection presented here accounts for about 75% of the total electron-deposited energy. After the addition of missing energy using a Monte Carlo simulation, the energy resolution improves from about 40% to 25% at 50 MeV. These results are used to validate the expected capabilities of the DUNE far detector to reconstruct low-energy electrons.

MeV energy search for Solar and SN neutrinos

arXiv: 1611.09867

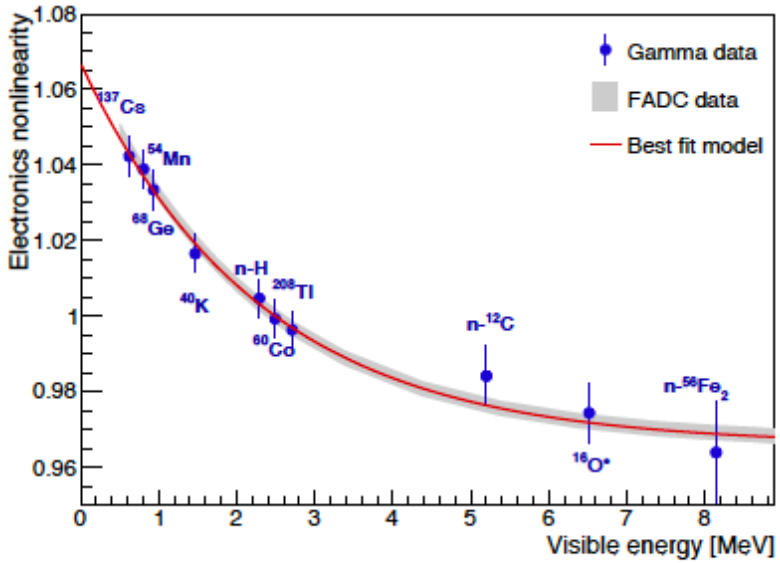


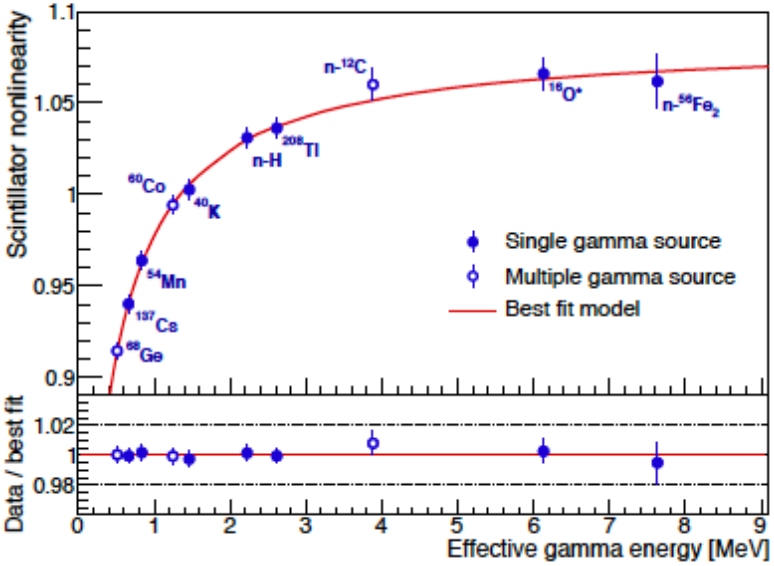
Fogli, Lisi, Marrone, Mirizzi,
arXiv: 0707.1998



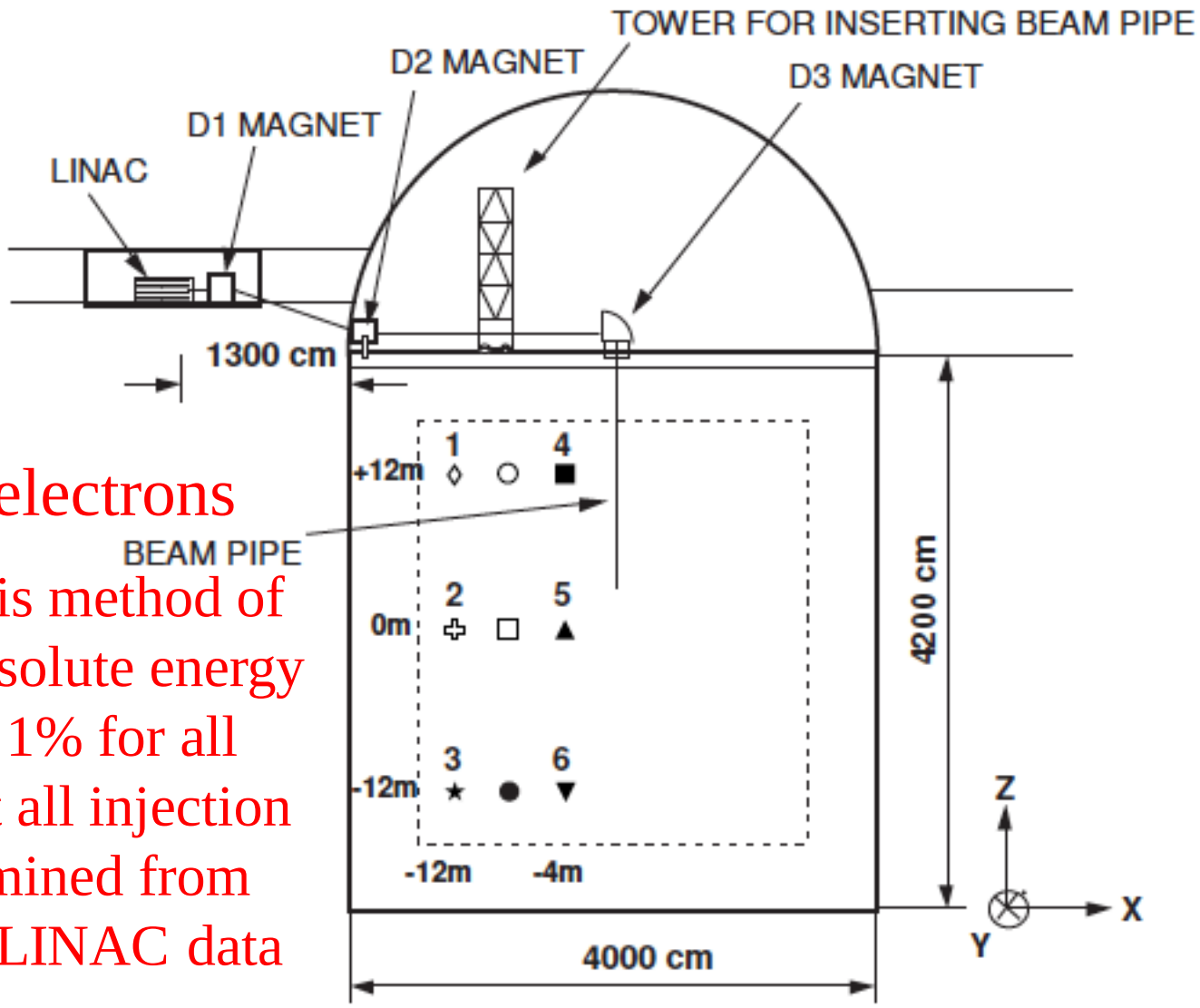
Both solar and SN neutrinos may be detected in 10-30 MeV energy range at DUNE.

Energy calibration at Daya Bay





LINAC at Super-K



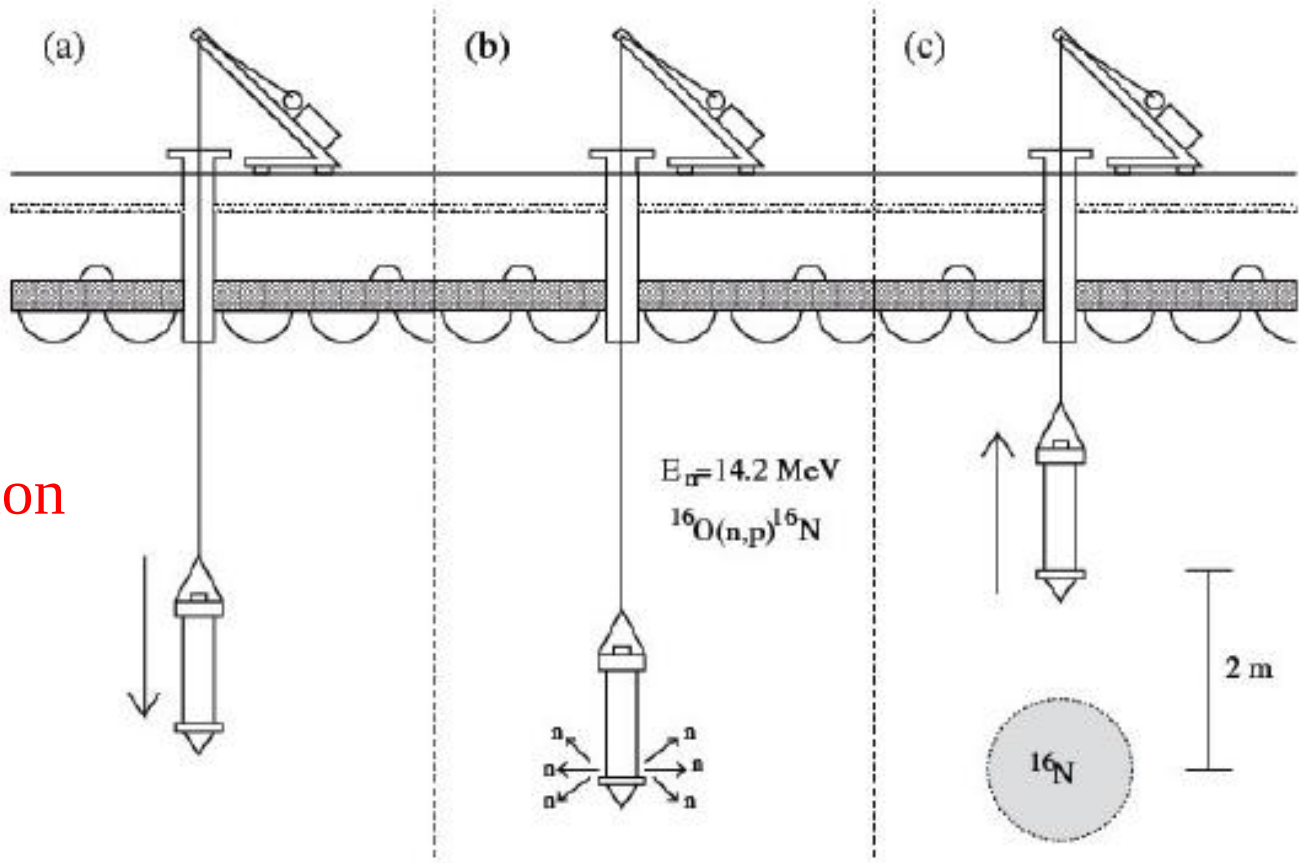
4.6 -15.8 MeV

Monoenergetic electrons

The accuracy of this method of determining the absolute energy scale is better than 1% for all LINAC energies at all injection positions, as determined from comparison of the LINAC data to MC simulation.

DT calibration at Super-K

The energy scale from DT calibration data and MC simulation is around 0.5%.



$$^{3}\mathrm{H} + {}^{2}\mathrm{H} \rightarrow {}^{4}\mathrm{He} + n \textbf{(14.2 MeV)}$$

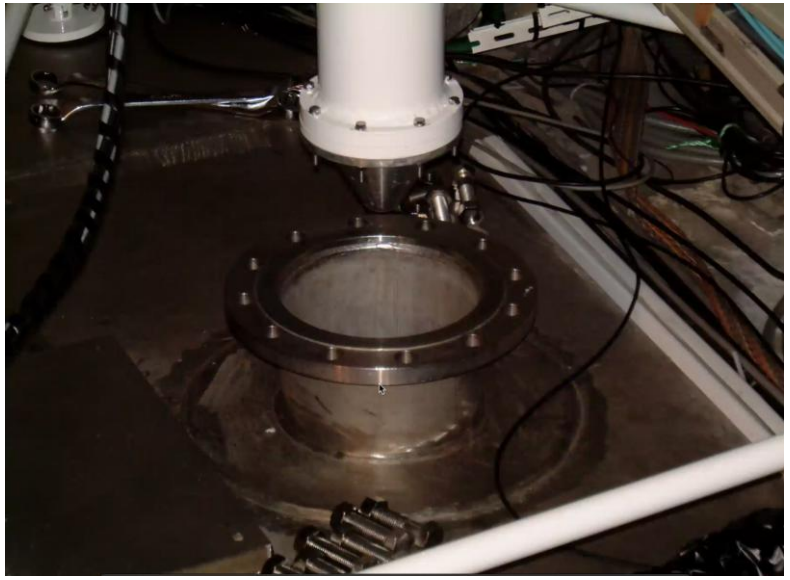
$$^{16}\mathrm{O} + n \rightarrow {}^{16}\mathrm{N} + p.$$

^{16}N → 6.1 MeV γ, 4.3 MeV β, 10.41 MeV β

$T_{1/2}$ ~ 7.13s

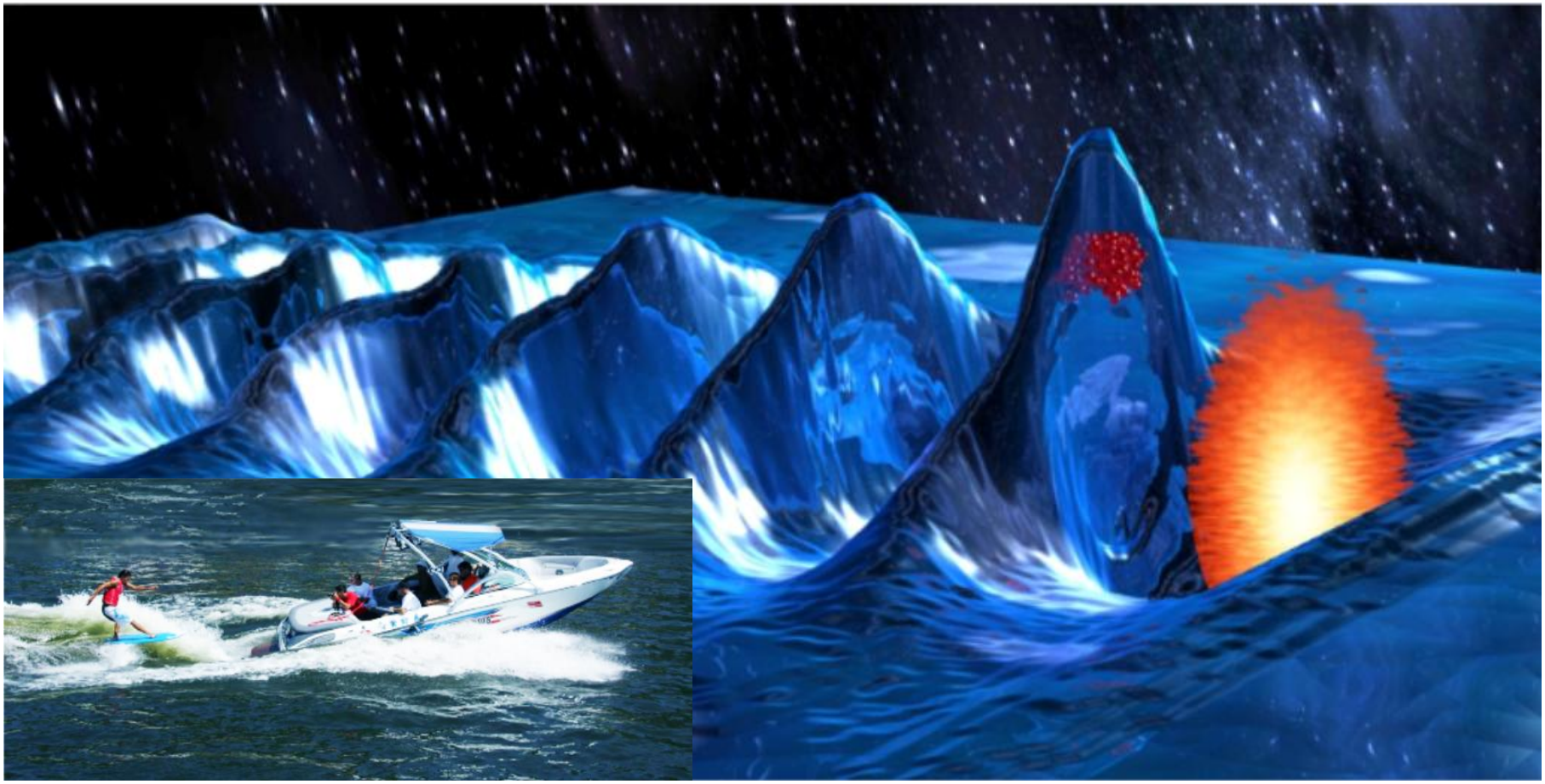
Why electron calibration source?

- Natural radioactive sources and electron accelerators are used for neutrino detector calibration purposes.
- **Limitation for radioactive source**
  - Usually broad beta spectrum
  - NO timing information
  - Limited energy end-point
- **Limitation for electron accelerators**
  - Quite large size and expensive
  - Radiation background contamination



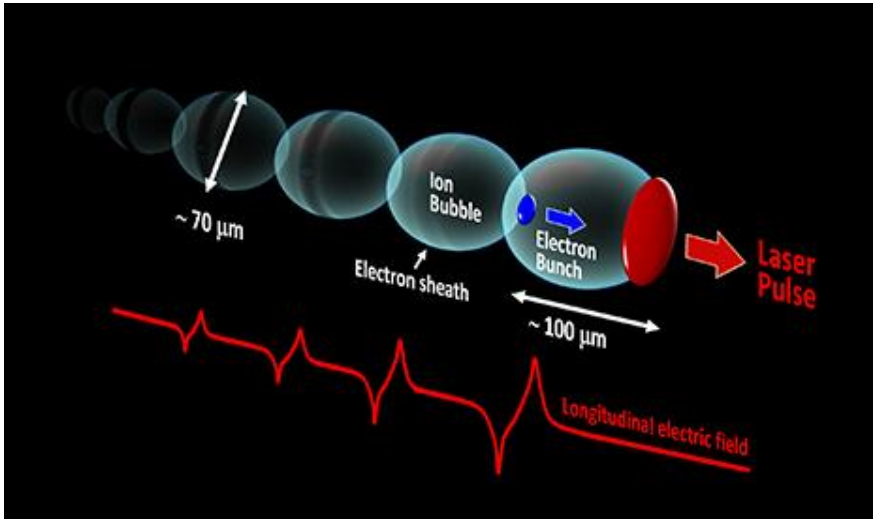
Accelerators based on laser wakefield

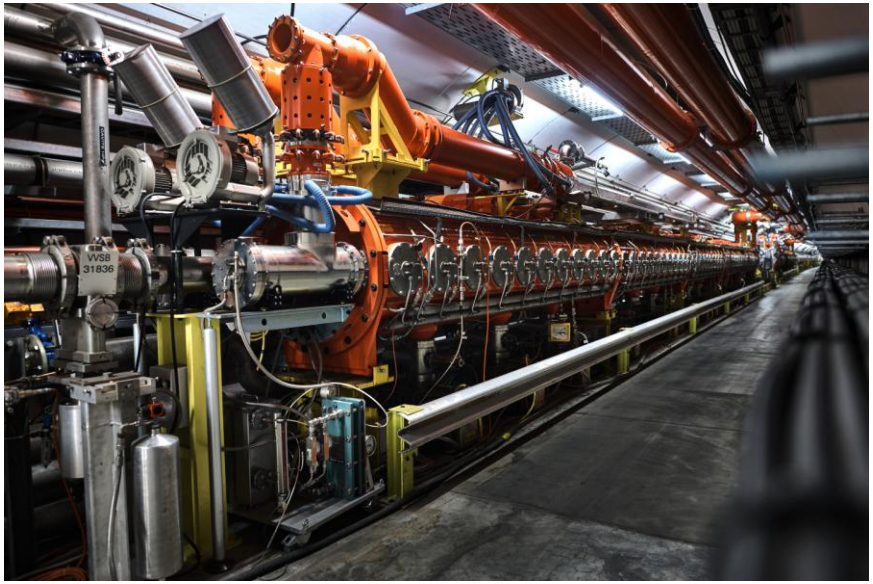
Accelerator based laser wakefield is a revolutionary technology, especially for the accelerator-based research and applications.



Advantage of accelerators based on laser wakefield

- **Extreme high acceleration gradient**
  - Acceleration gradient over 100GV/m，3-4 order of magnitude higher than traditional accelerator approach。
- **Extreme small accelerator size**
  - The accelerator can be made as small as 10-1000 μm size。





Status on accelerator based on laser wakefield

Many breakthroughs have been achieved on the technology of accelerator development based on laser wakefiled. It has a huge potential for the next generation high energy particle accelerators, free electron laser, advanced synchrotron radiation light, advanced radiotherapy，etc.

Advantage of using accelerators based on laser wakefield as electron calibration source

High acceleration gradient and compact size

Beam electron intensity (charges) are tunable (fC~nC charges)

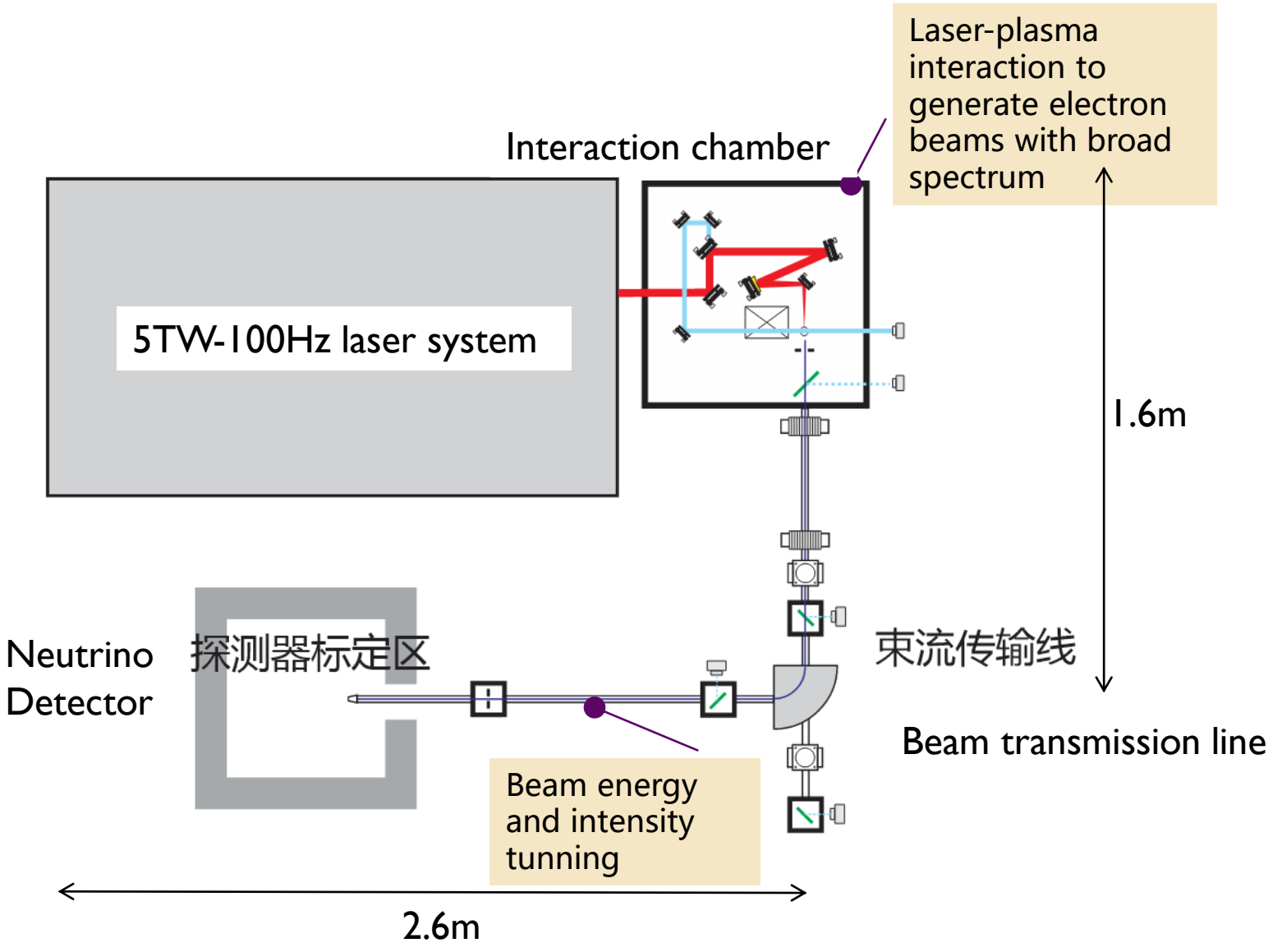
fs laser and electron beam

Desktop and portable electron calibration device

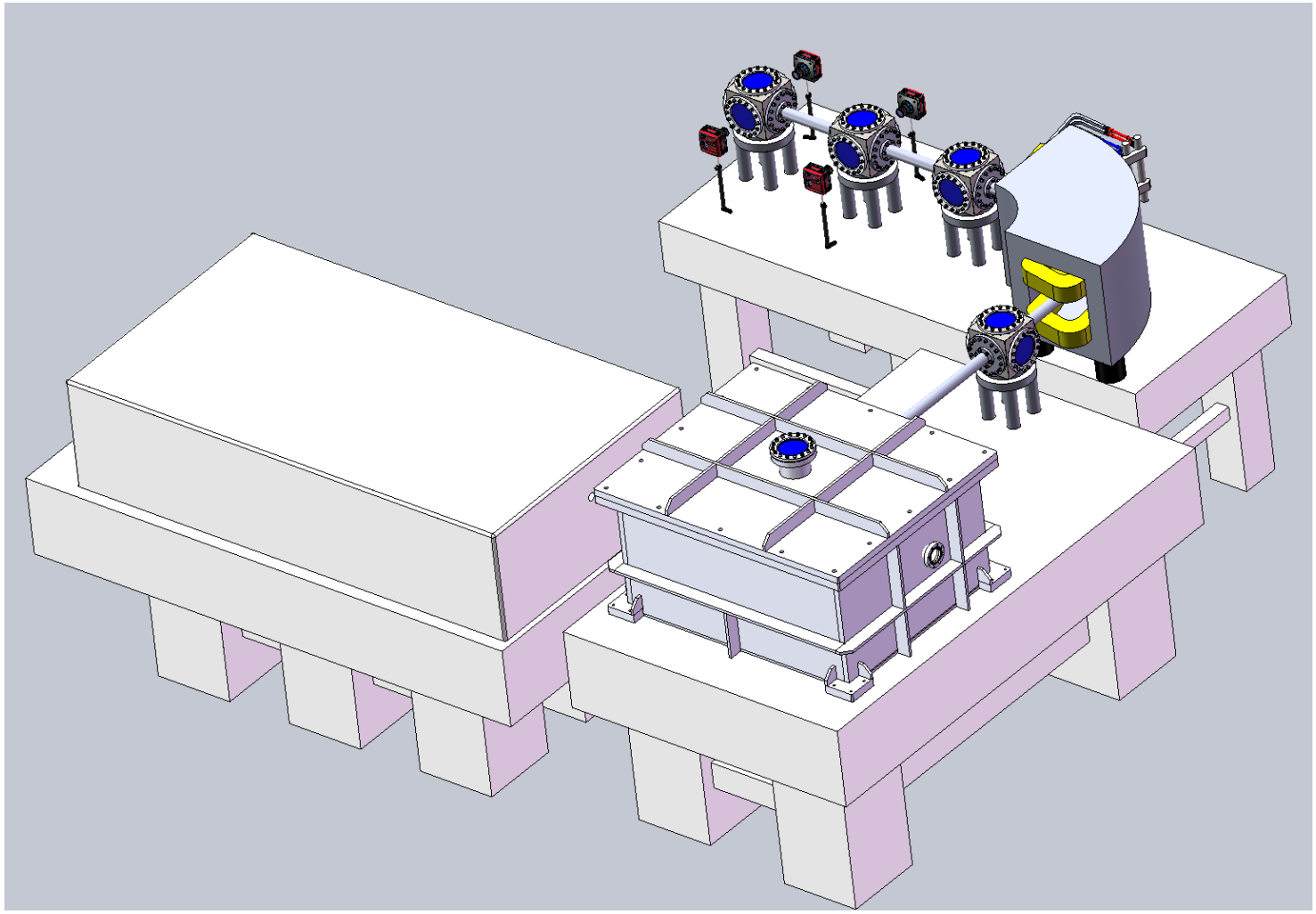
Very low radiation background

Fs timing resolution

Electron calibration source driven by accelerators based on laser wakefield



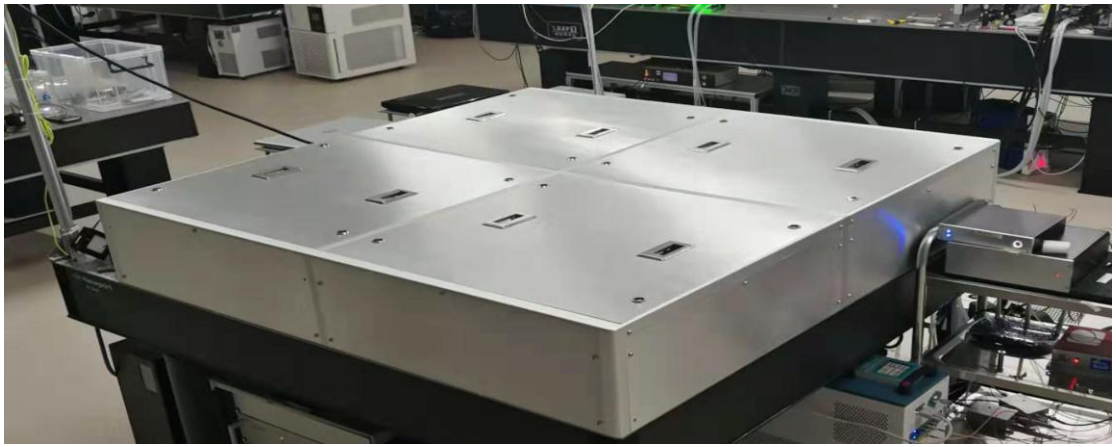
Electron calibration source driven by accelerators based on laser wakefield

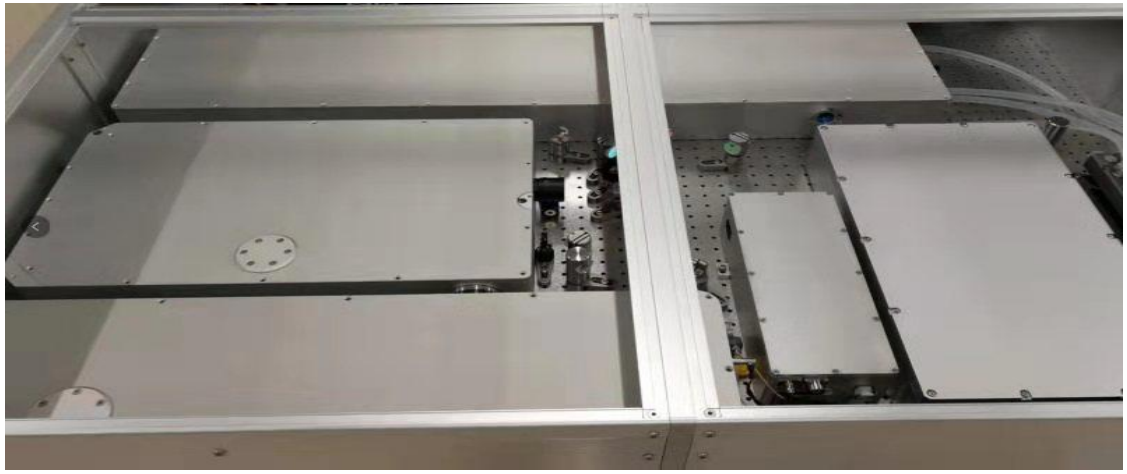


Industrial Laser system

Laser system

- Improved stability
- Reduced size
- Modular
- Temperature and humidity monitor





Typical Parameters

	parameters	Designed values
Laser system	Center wavelength	800nm
	Peak power	5TW
	Pulse width	30fs
	Repetition frequency	10~100Hz
Electron calibration system	Electron energy	1~30MeV tunable
	Energy instability	<1%
	Energy resolution	<1%
	Electron charge per beam	Single electron to 10fC
	Repetition frequency	Same as laser

Plan in this year

1. Build a test device to get the electron beam
2. Measure the beam parameter to justify the idea
3. Submit a proposal to the funding agency to support to build a movable compact calibration source
4. ???

Thanks !