Other Future Long Baseline Projects

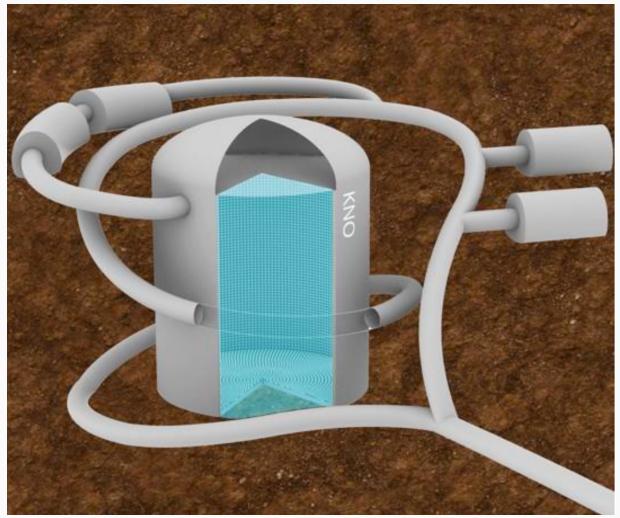
Alfons Weber
JGU Mainz & FNAL
Milano, June 18th, 2024

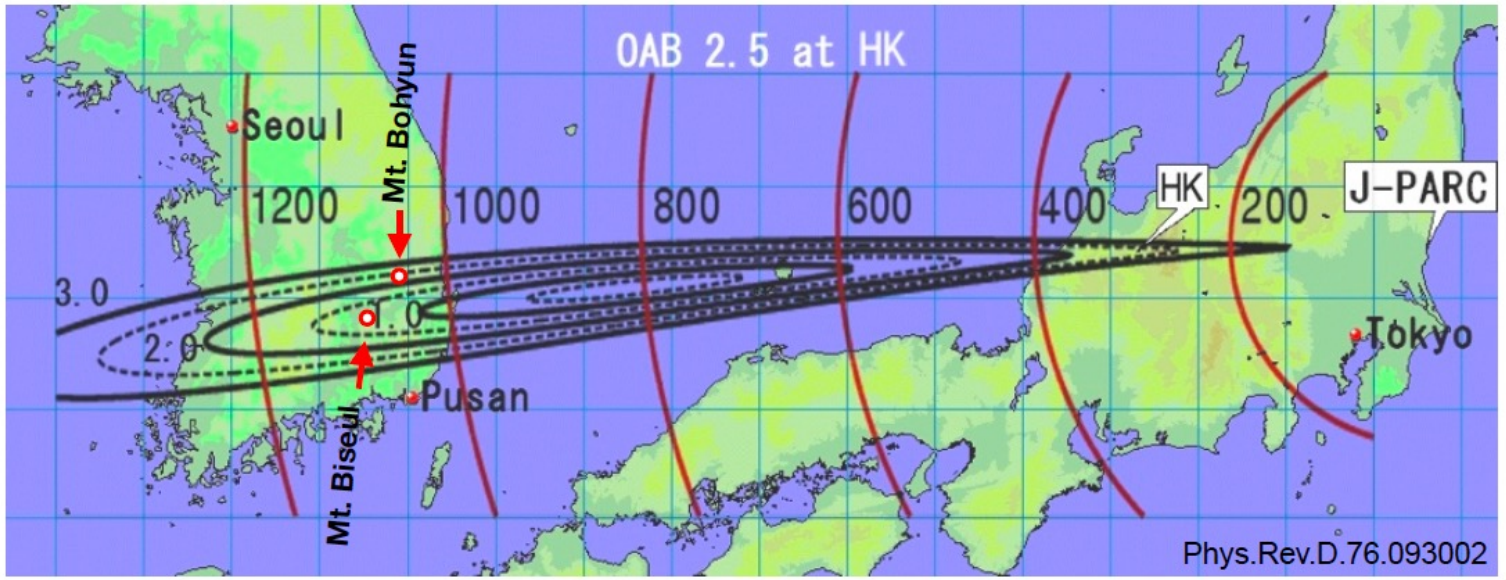
Motivation

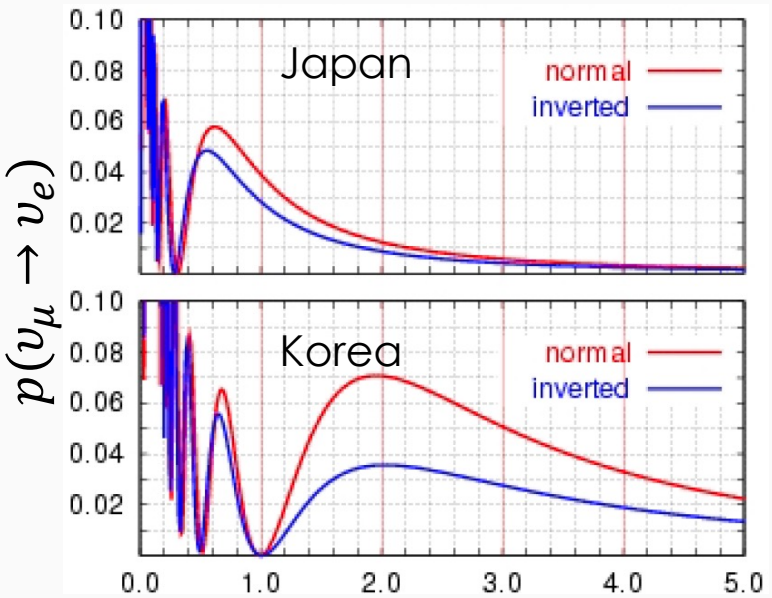
- Precision neutrino observatories under construction
  - HyperK (water Cherenkov detector)
  - DUNE (liquid argon TPC)
- Physics program
  - Neutrino oscillations (mixing angles, mass ordering, leptonic CPV)
  - Solar neutrinos
  - Supernova neutrinos
  - Baryon number violation
  - …
- Opportunity to explore additional/improved physics
  - Korea Neutrino Observatory
  - Theia

Korea Neutrino Observatory (KNO)

- The detector formerly known as T2HKK
  - Water Cherenkov Detector
  - Similar size to HyperK, significantly more overburden
- Physics
  - Mass ordering & 2nd oscillation maximum
  - Non-standard interactions, (diffuse) supernova, proton decay







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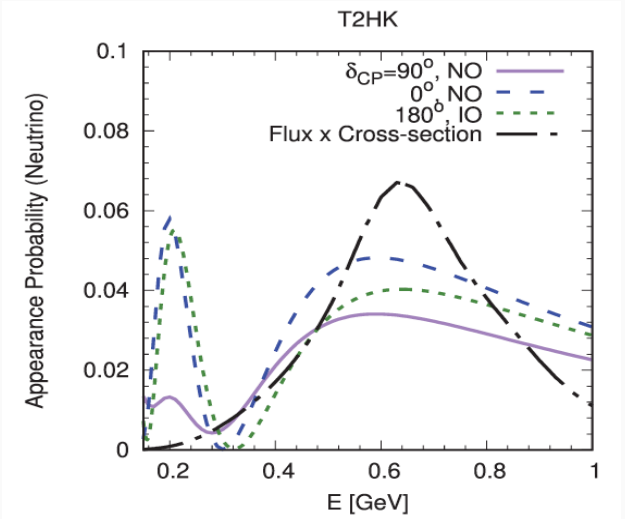
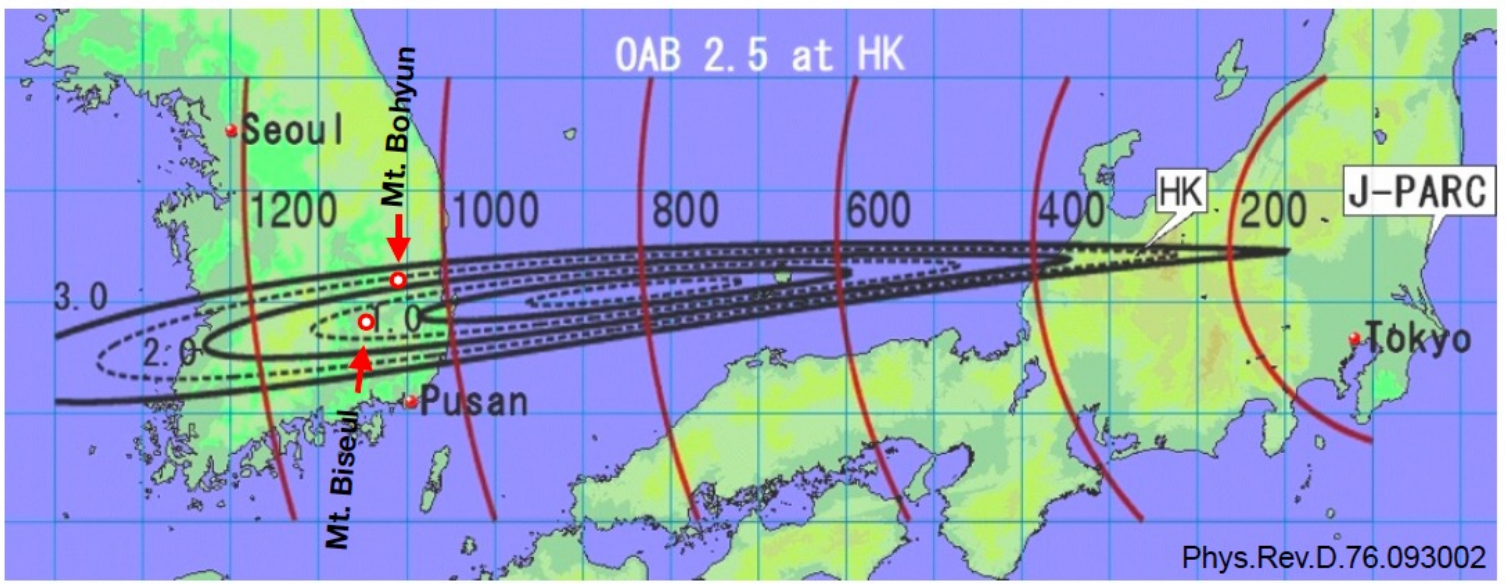
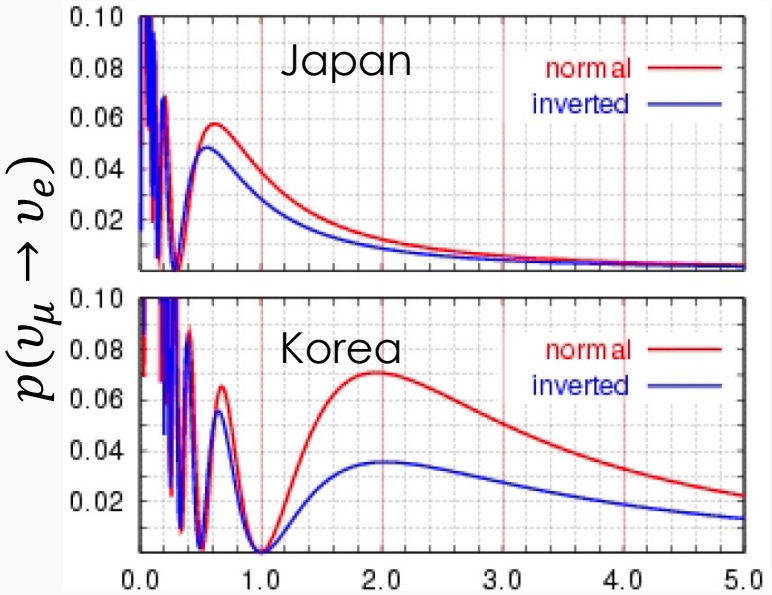
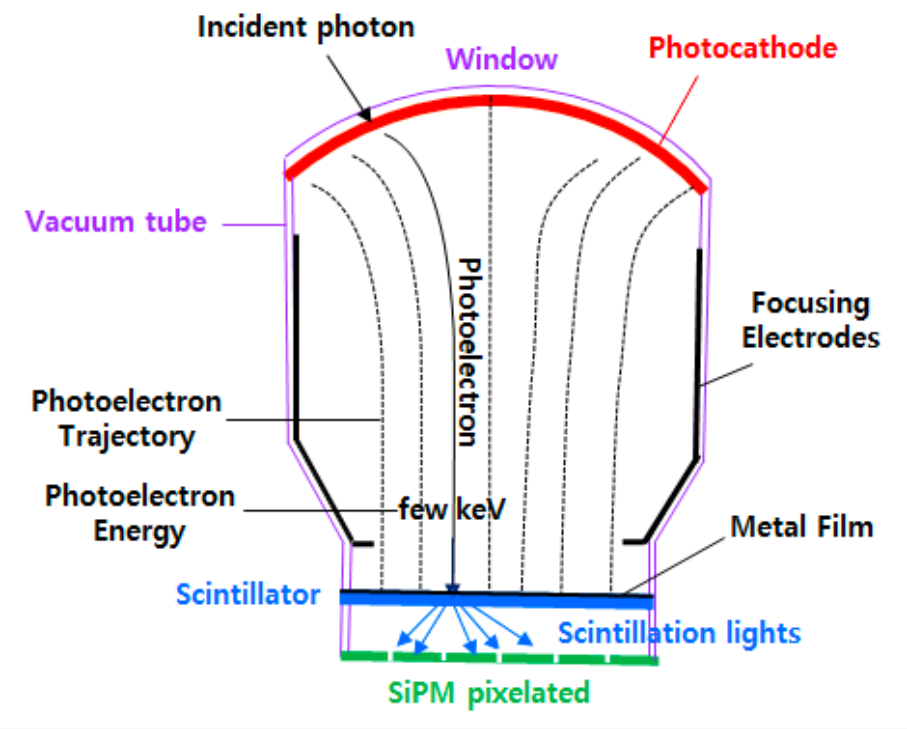


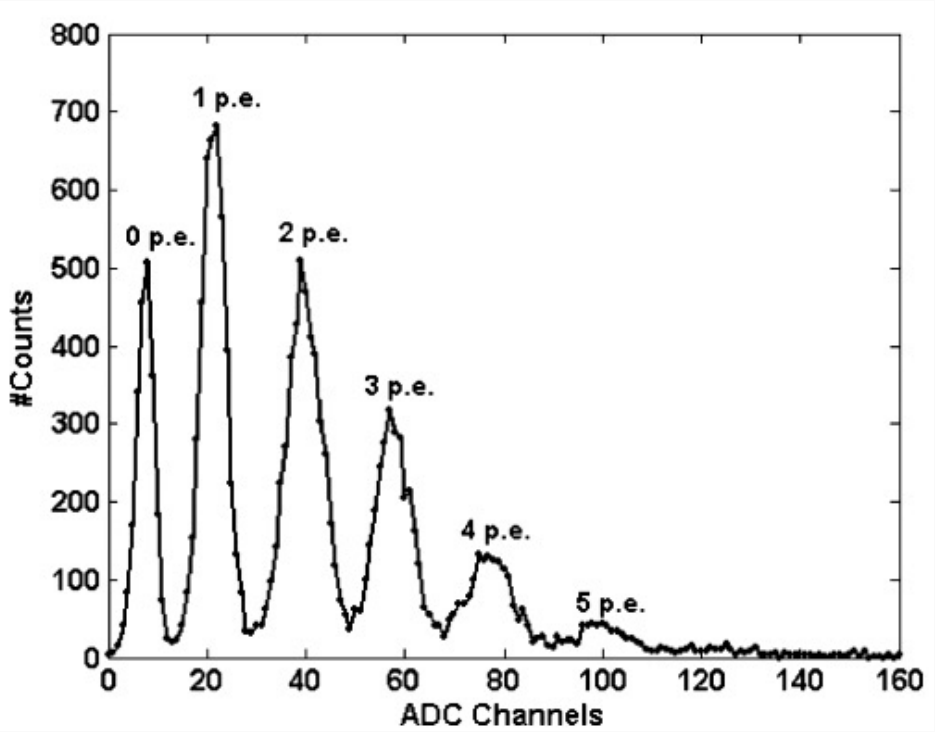




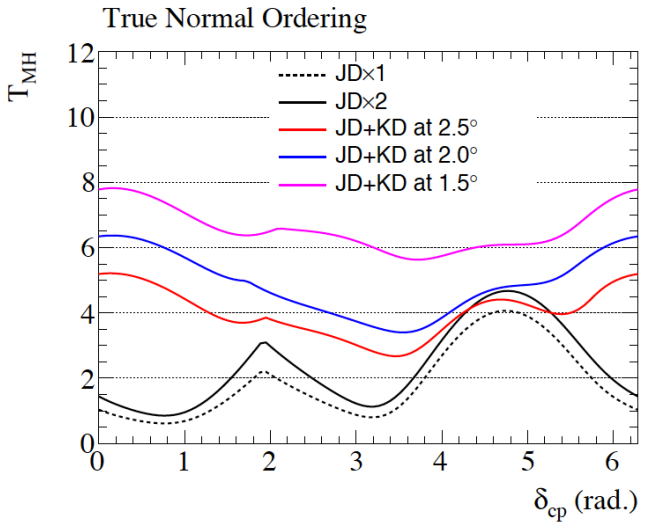
KNO Detector Technology

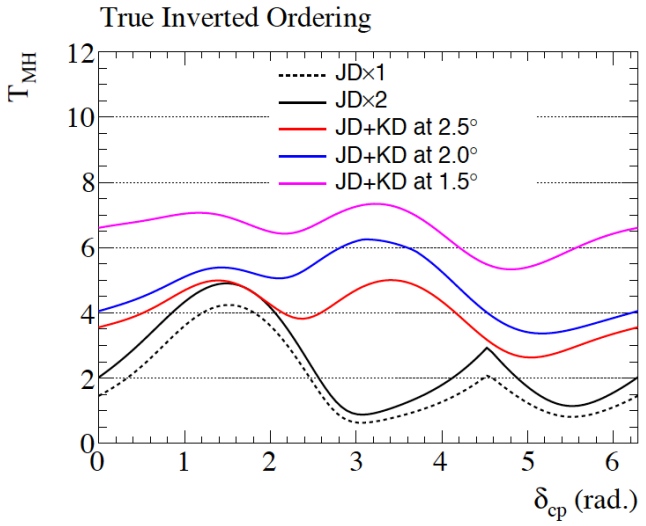
- Potential to use novel detector technology
- Hybrid Silicon Photon Multiplier Tubes
  - PE resolution of SiPM
  - Area of large PMT

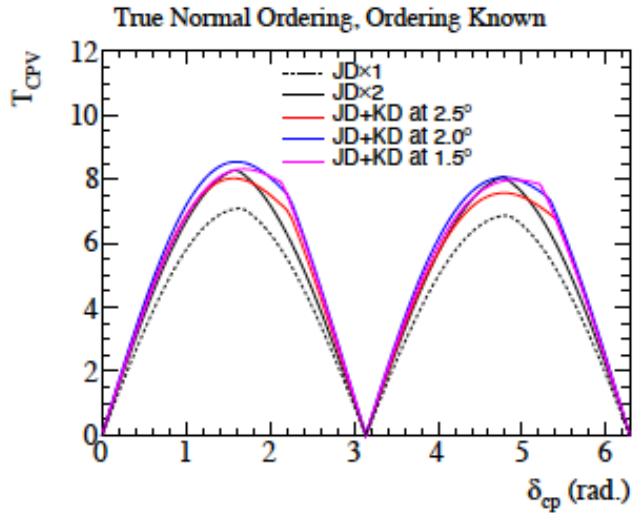


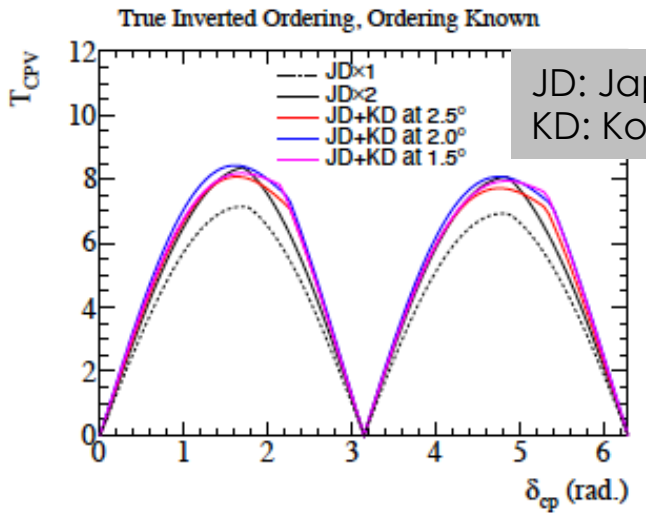


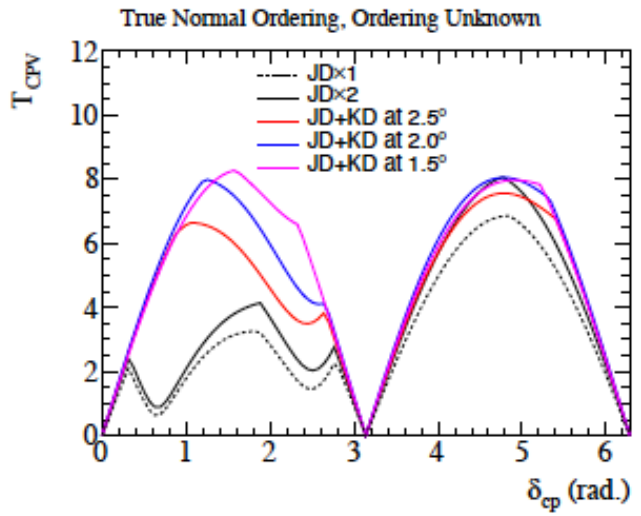
KNO Physics Potential

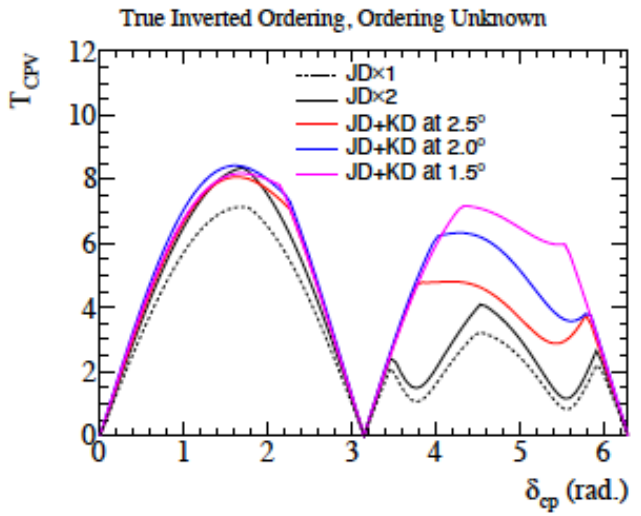








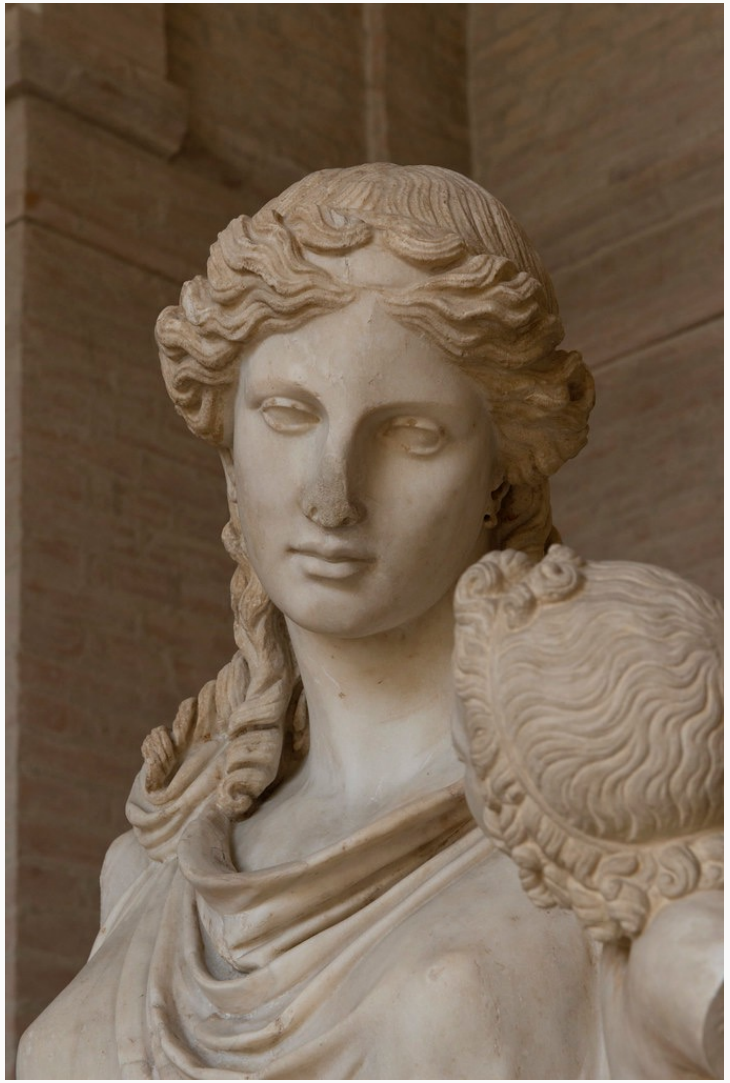


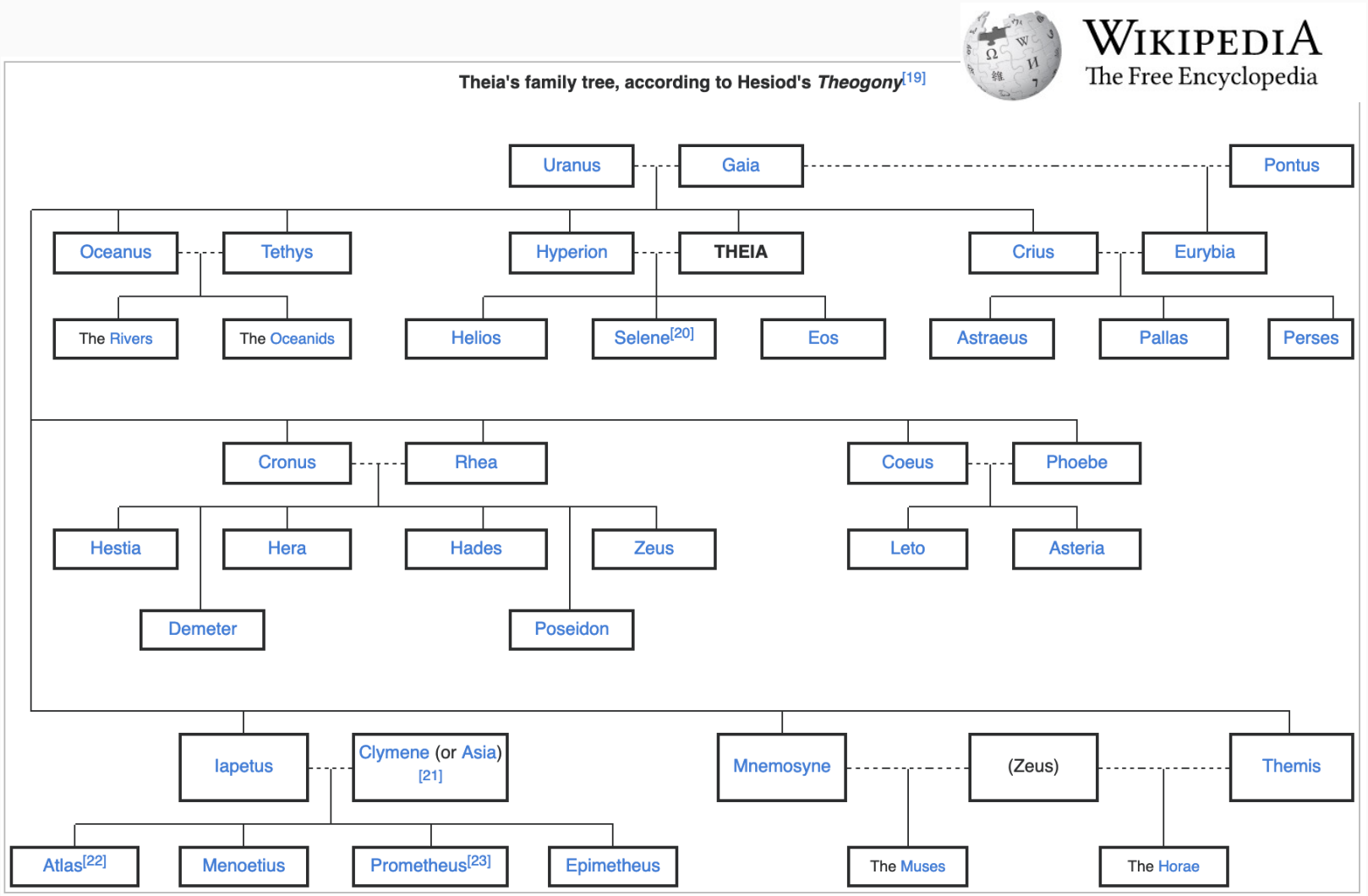


JD: Japanese det.
KD: Korean det.

arXiv:1611.06118

Theia — The Goddess of Glittery Things



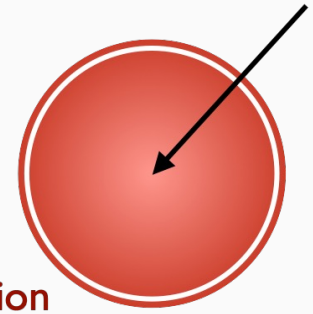


The Light

Cherenkov

- Cherenkov topology: directional sensitivity, particle ID
- Optical transparency: scaling

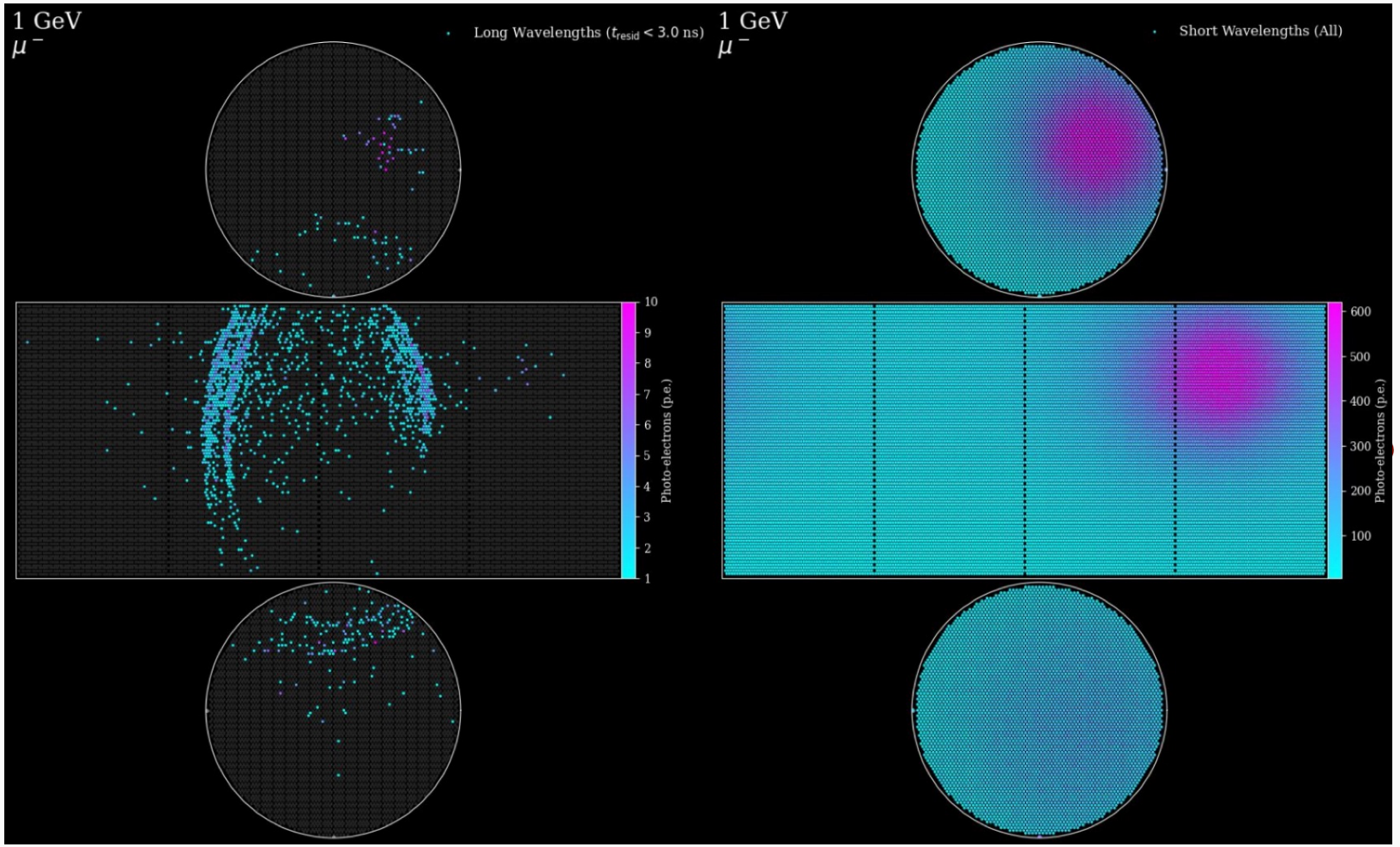
Scintillation



- High light yield: threshold, resolution
- Pulse shape discrimination: Particle ID
- Radiopure

The Light

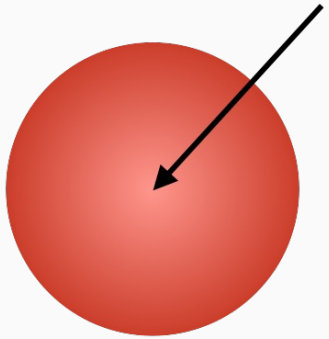
Cherenkov **Scintillation**

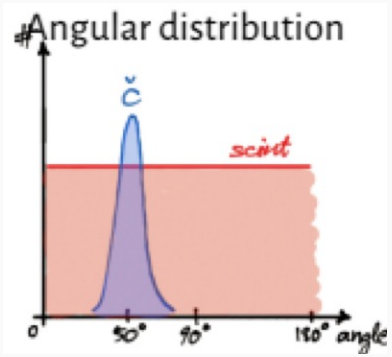


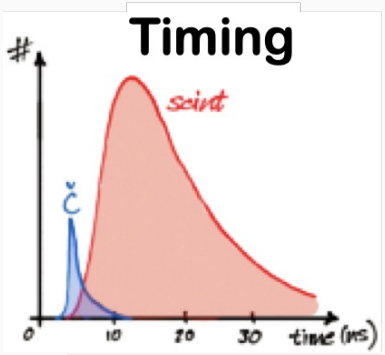
Light Patterns

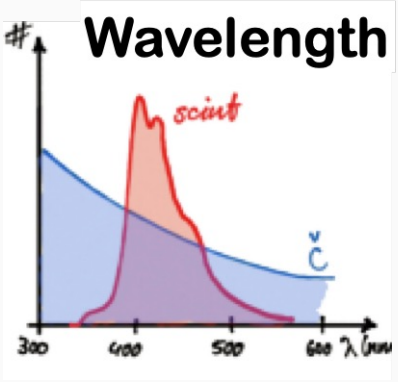
Cherenkov

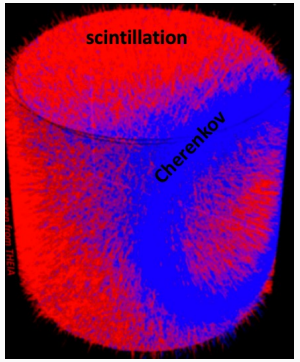
Scintillation



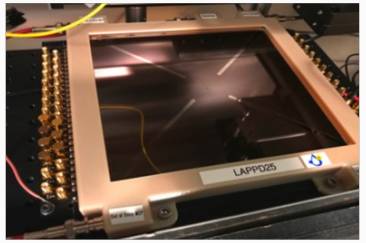






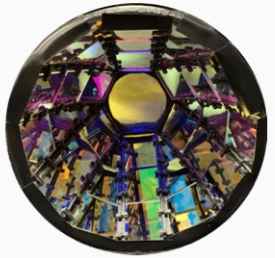


Poster
Tue: 545

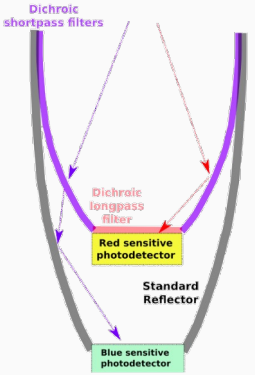


B.W.Adams et al. NIM A Volume 795, 1 (2015)

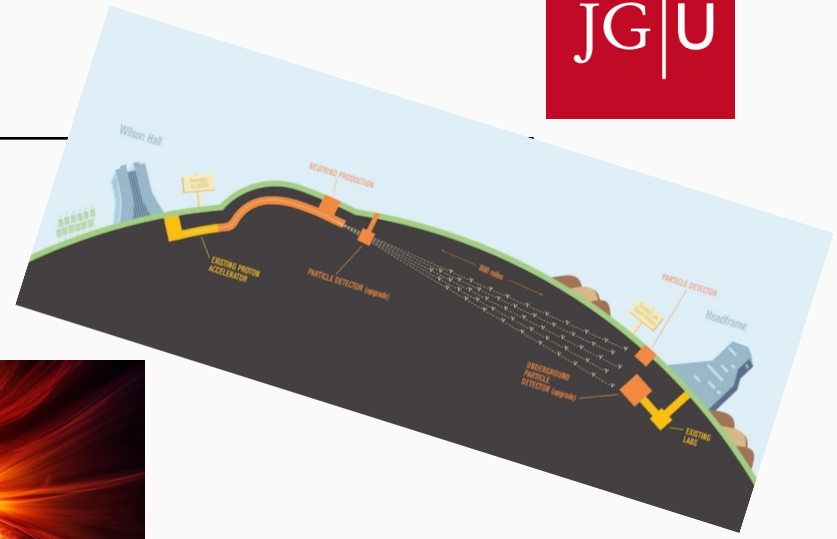
LAPPD



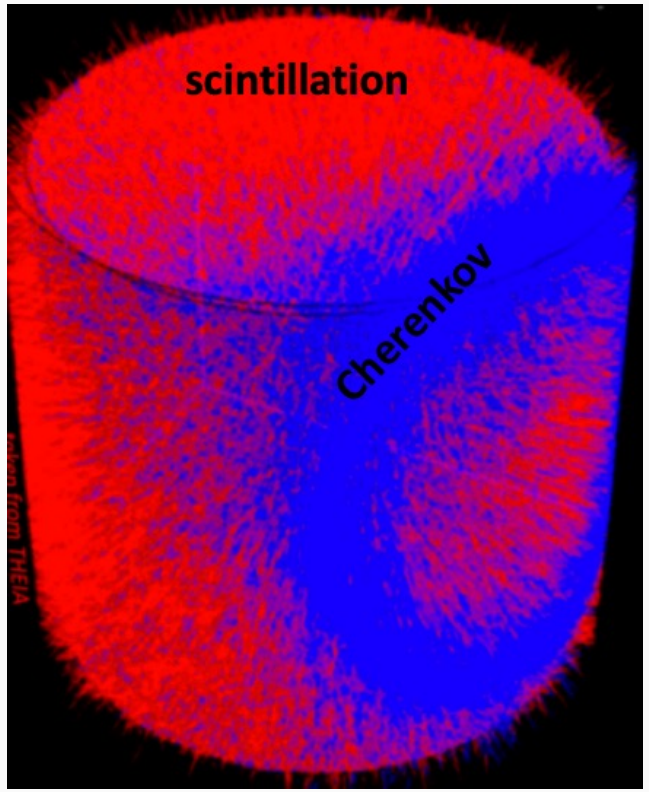
T. Kaptanoglu et al.
Phys. Rev. D 101, 072002 (2020)



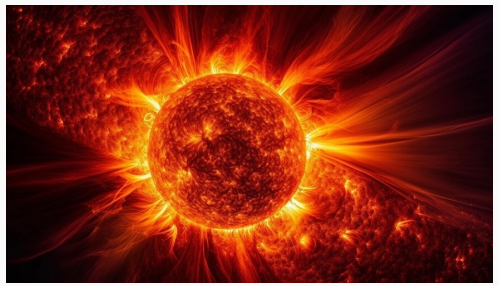
Physics Potential



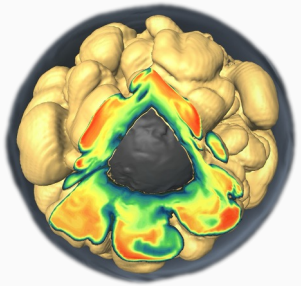
- Long baseline oscillations



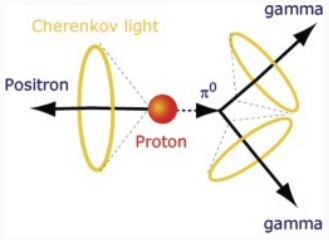
- Solar neutrinos



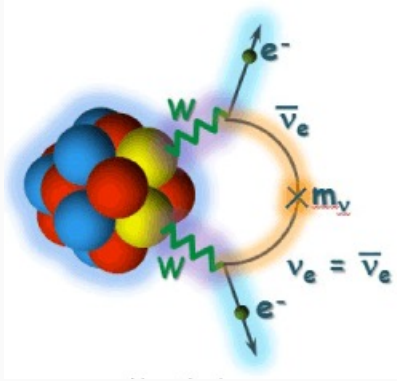
- SN neutrinos



- Diffuse SN background



- Baryon number violation



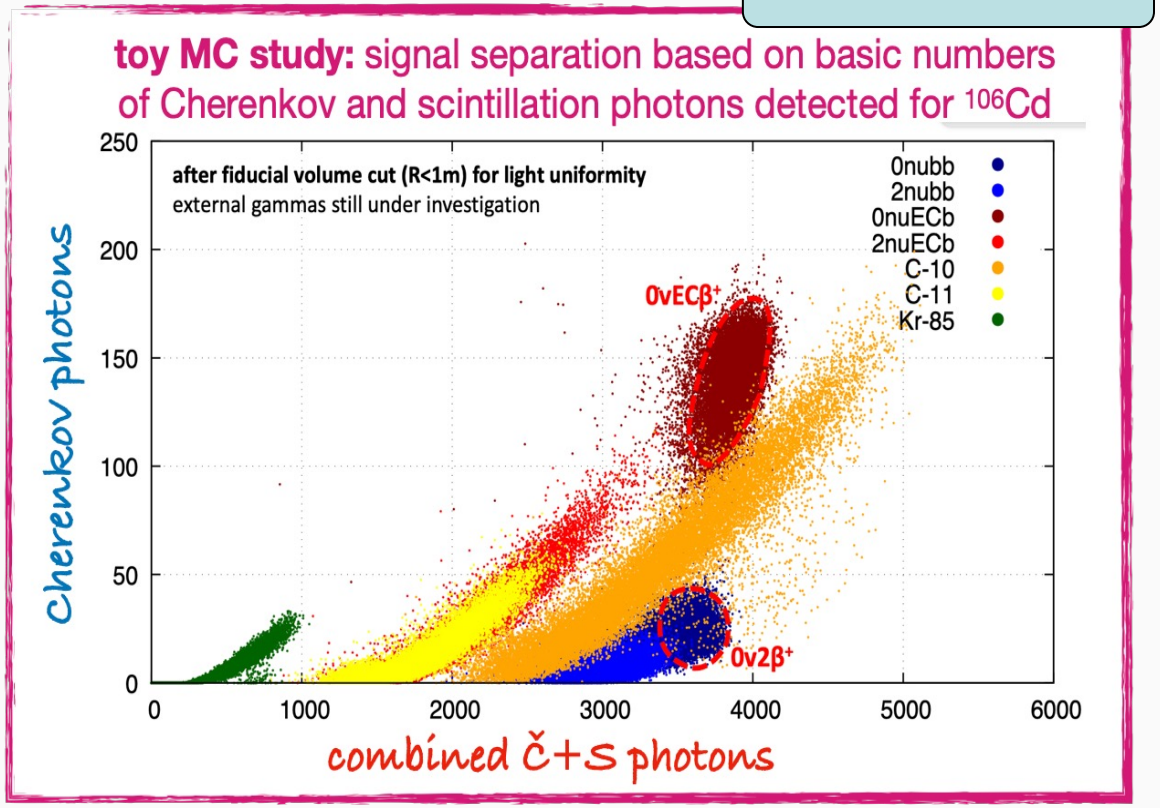
- Neutrino-less double beta decay

Why Hybrid?

- Scintillation
  - Excellent energy reconstruction
- Cherenkov
  - Directional information
- Relative sharing used for PID

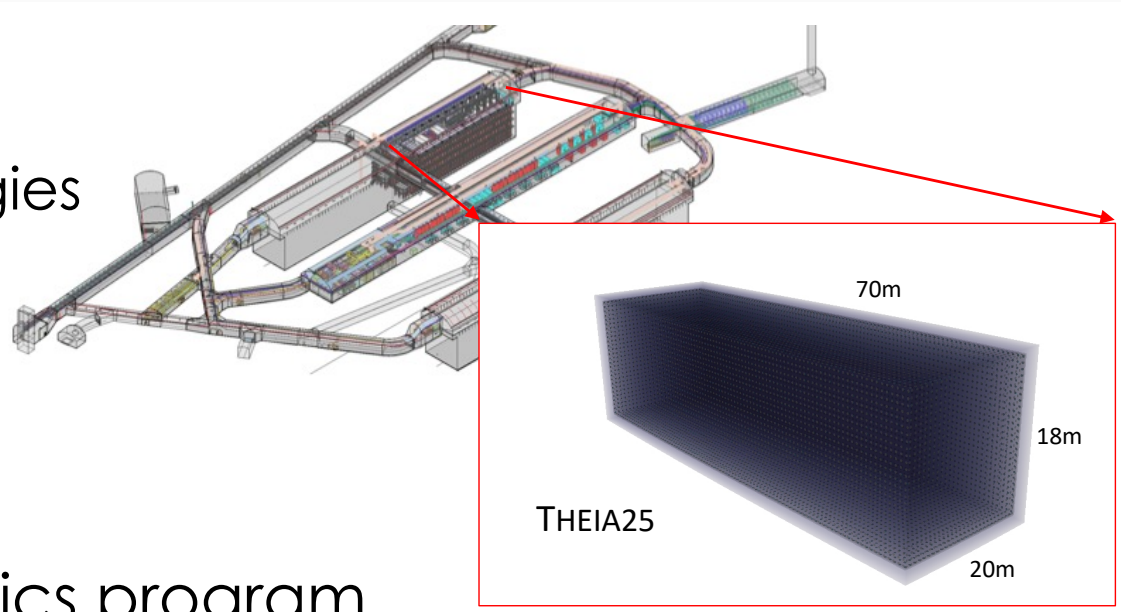
- Example:
  Double beta decay
  - Signal and BG have different Cherenkov fraction

Kai Loo @JGU Mainz



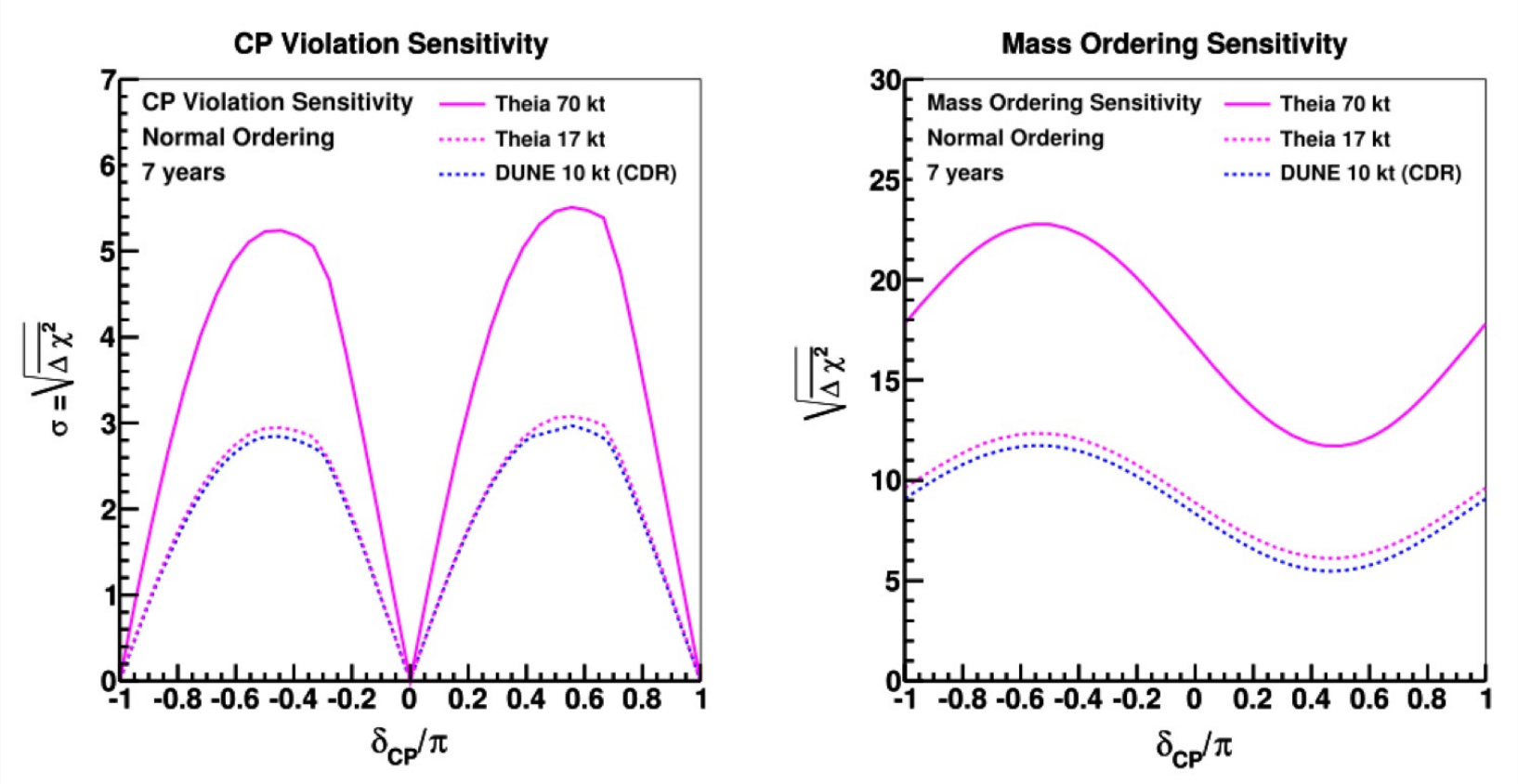
A 4th DUNE Far Detector

- DUNE Program (talk by Chris Marshall)
  - Start with 2 far detector modules
  - P5 supported DUNE Phase II: design and construction of FD3, improved ND and R&D for FD4
  - 3rd will be improved LAr technology
  - 4th more ambitious designs (pixel or optical r/o) including non-LAr technologies 'module of opportunity'
- Requirements
  - Provide similar or better long baseline oscillation sensitivity
- Theia is one opportunity to extend physics program



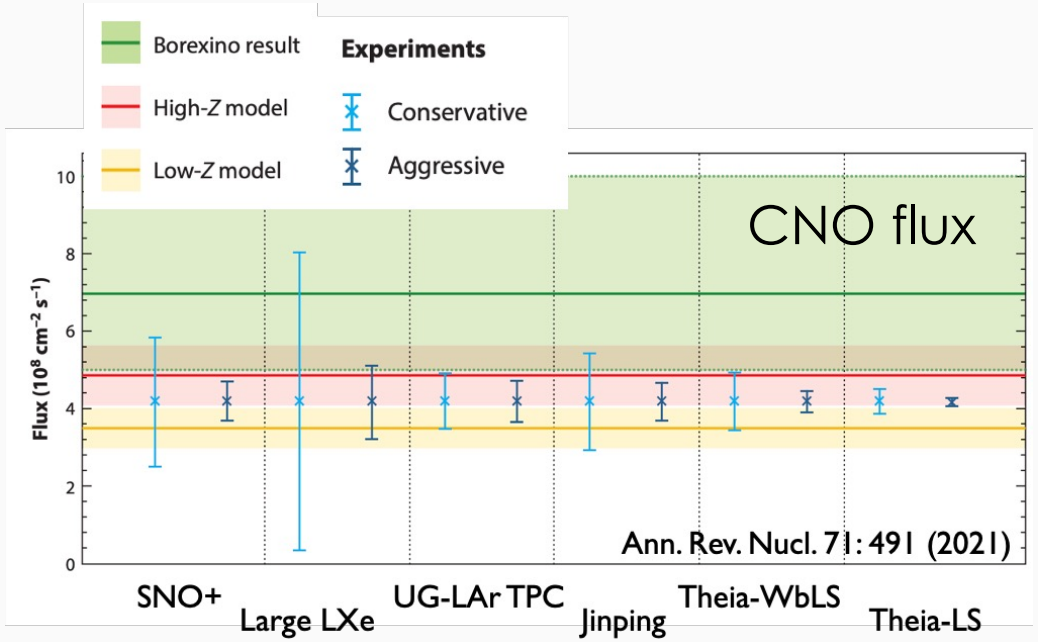
Oscillation Sensitivity

- Similar sensitivity for neutrino oscillation program as LAr
  - 17 kt Theia (Cherenkov only & equiv. ND) ⇔ 10 kt LAr

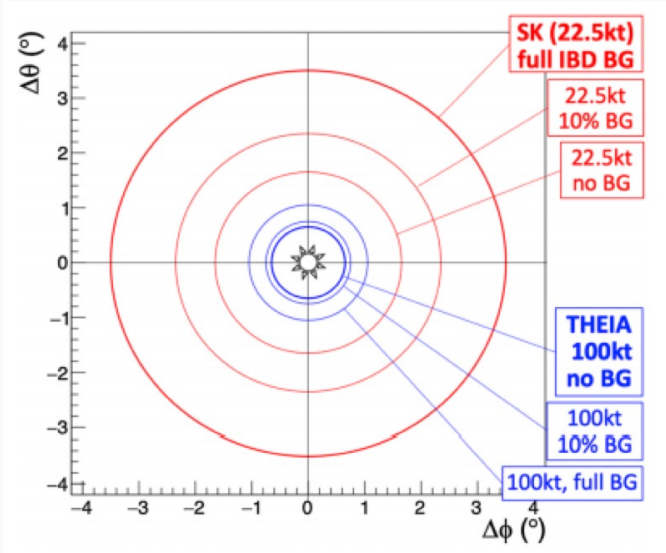


Additional Physics (examples)

- Solar Neutrinos
  - BG: natural radioactivity
  - unique low-E, directional
  - PID from scintillator time profile, quenching, Ch/S ratio



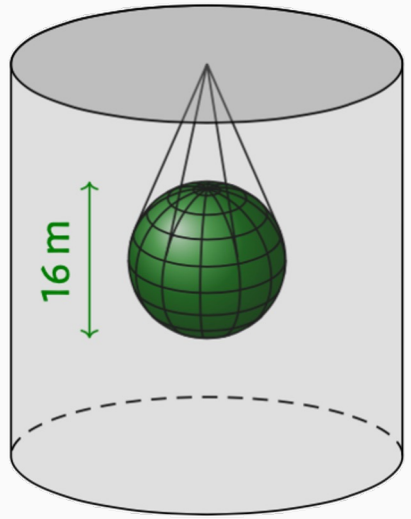
- Supernova
  - ~90% IBD
  - ES ⇒ pointing accuracy < 1°
  - Mono-E γ from NC
    Flavour-resolved neutrino spectra
  - Pre-supernova ν sensitivity (Si-burning)
  - Enhanced CC sensitivity with Li doping



Physics Program

poster
Fri: 578, 596

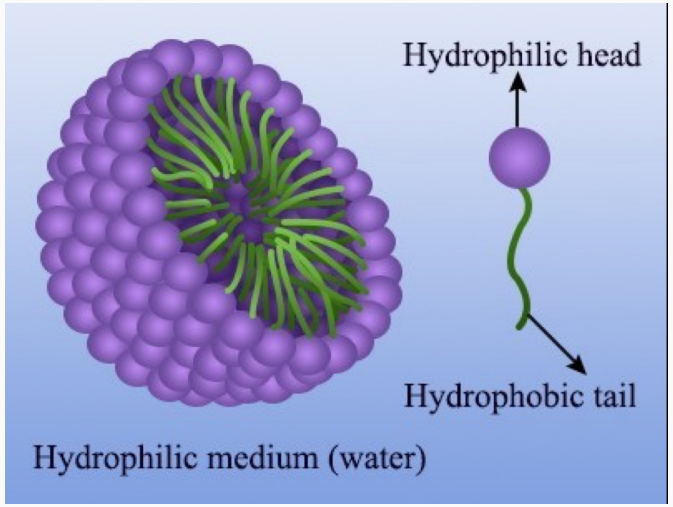
Primary physics goal	Reach	Exposure/assumptions
Long-baseline oscillations	>5σ for 30% of δ_{CP}	524kt-MW-year
Nucleon decay $p \to \bar{\nu} K^+$	T>3.8 x 10^{34} year	800 kt-year
Supernova burst	<1(2)° pointing 20K(5K) events	100(25)kt, 10kpc SN
Diffuse Supernova Neutrino	5σ	125kt-year
CNO neutrinos	<5(10)%	300(62.5)kt-year
Geoneutrinos	< 7 %	25 kt-year
$0\nu\nu\beta$	$T_{1/2}$ > 1.1 x 10^{28} year (90%C.L.)	800 kt-year (Multi-tonne loaded LS in suspended vessel search)



Snowmass white paper arXiv:2202.12839 and ref. therein

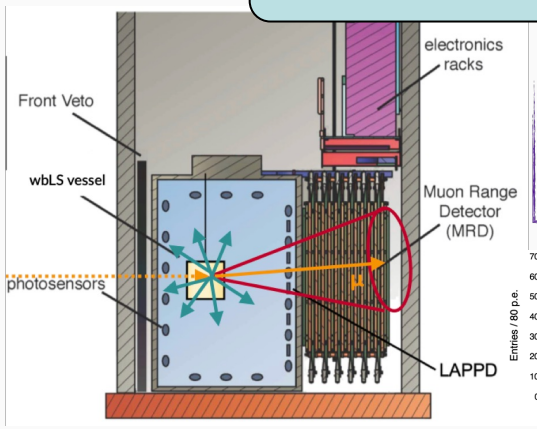
Scintillator Technology

- Scintillator can be tuned depending on the physics that is targeted. (see talks on Saturday)
  - Novel concepts of light sensors and light detection techniques for neutrino physics by Ettore Segreto
  - Novel Liquid Technologies by Minfang Yeh
- Hybrid scintillator (could be water based)
  - Tune light level
  - Make it slow
  - Loading, double beta isotopes, …
- Active R&D Program



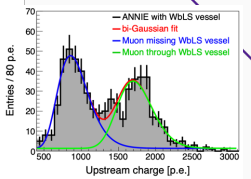
R&D Activities

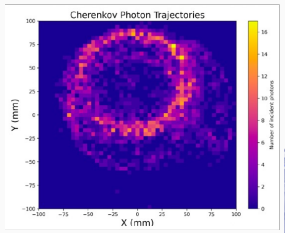
Tue: 467
Fri: 481, 518, 553



ANNIE: 365 kg

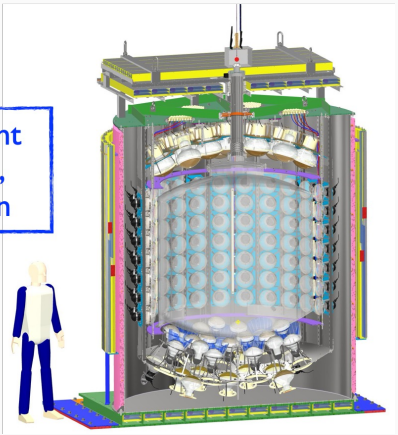
High-energy event reconstruction, neutrino detection



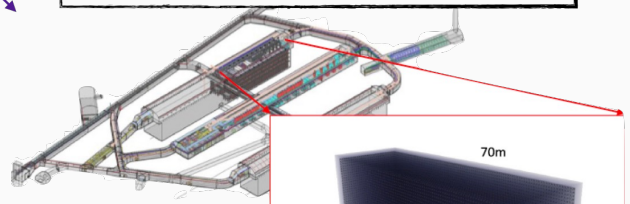


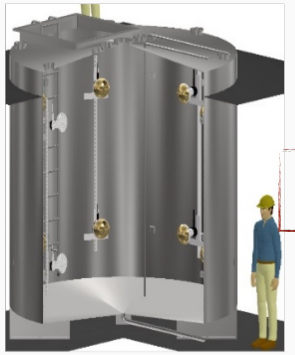
Eos: 20 ton

Low-energy event reconstruction, model validation



Building on a broad program of bench-top scale development





BNL: 1- and 30-ton

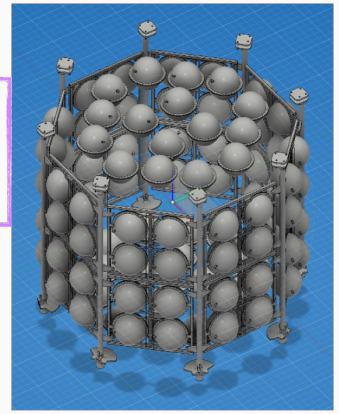
Deployment, purification, recirculation, transparency

NuDot: 1 ton

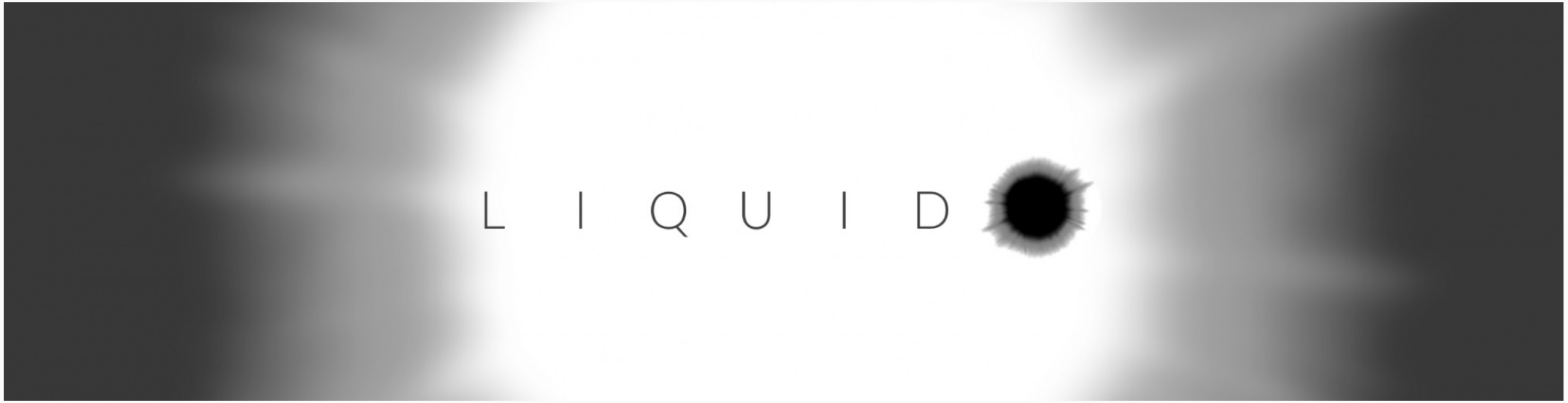
Isotope loading, NLDBD topology

BUTTON: 30 ton

Underground deployment, low bkg verification



Near Detector



A precision near detector for liquid scintillator or Cherenkov far detectors

- Same target as far detector
- potentially different technology
- High spatial resolution

LiquidO Technology

- Use same target as Far Detector, but make it opaque
  - Scattering, not absorption

LiquidO Technology

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LiquidO Technology

- Use same target as Far Detector, but make it opaque
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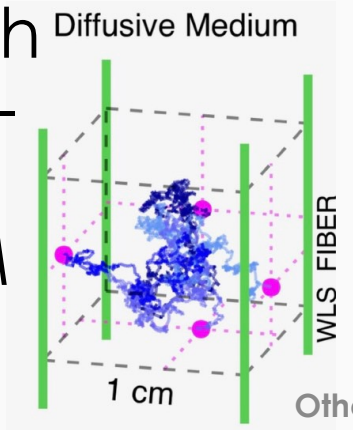
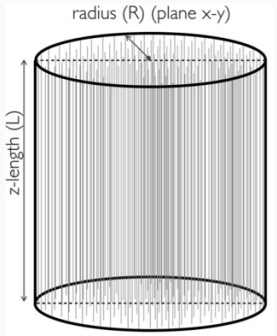
- Light is stochastically confined
- Readout with wavelength-shifting fibre array & SiPM





LiquidO Technology

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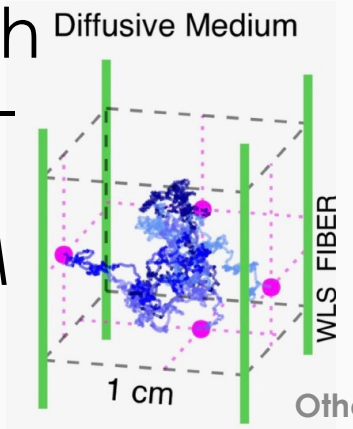
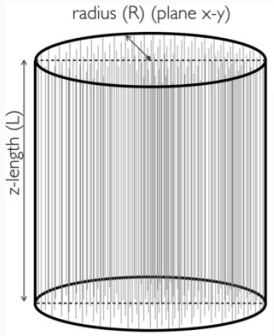
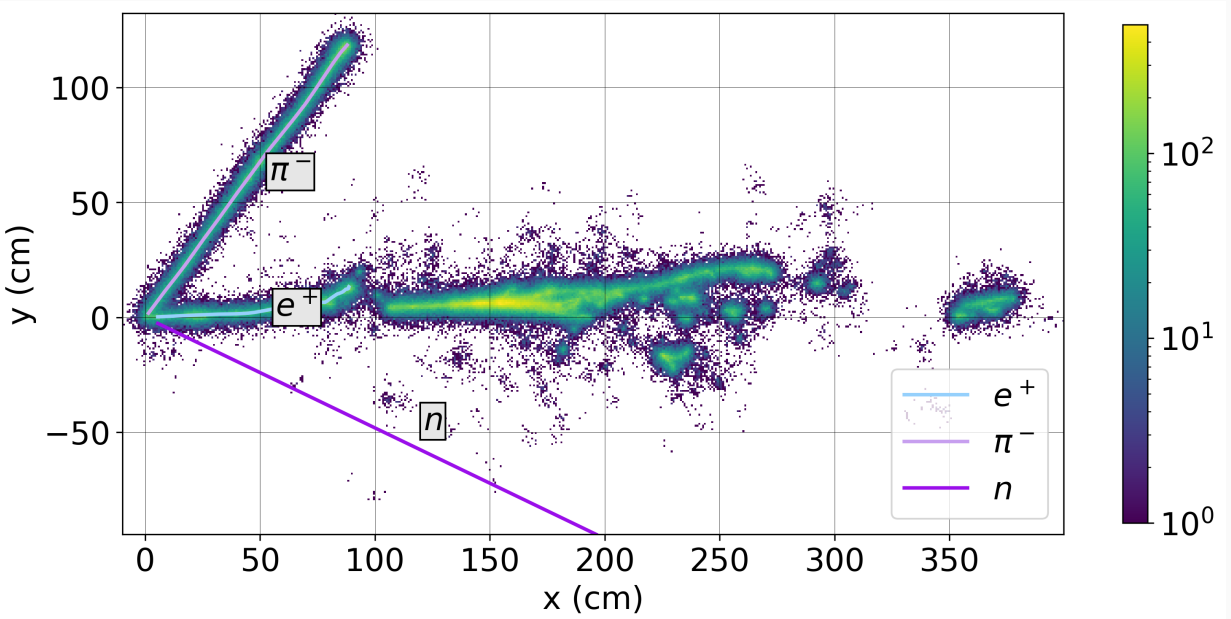
- Readout with wavelength-shifting fibre array & SiPM





- High resolution O(1 mm)
  - detailed image of interaction



doi:10.5281/zenodo.7645759

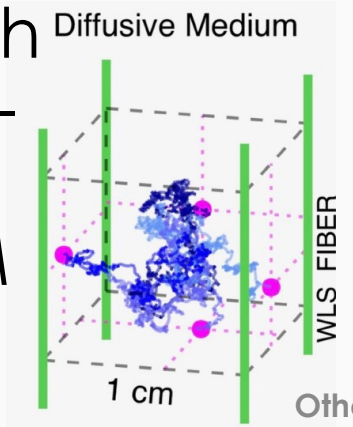
LiquidO Technology

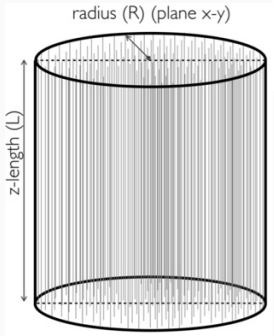
Poster
Tue: 393
Fri: 328, 579, 612, 635

- Use same target as Far Detector, but make it opaque
  - Scattering, not absorption



- Light is stochastically confined
- Readout with wavelength-shifting fibre array & SiPM





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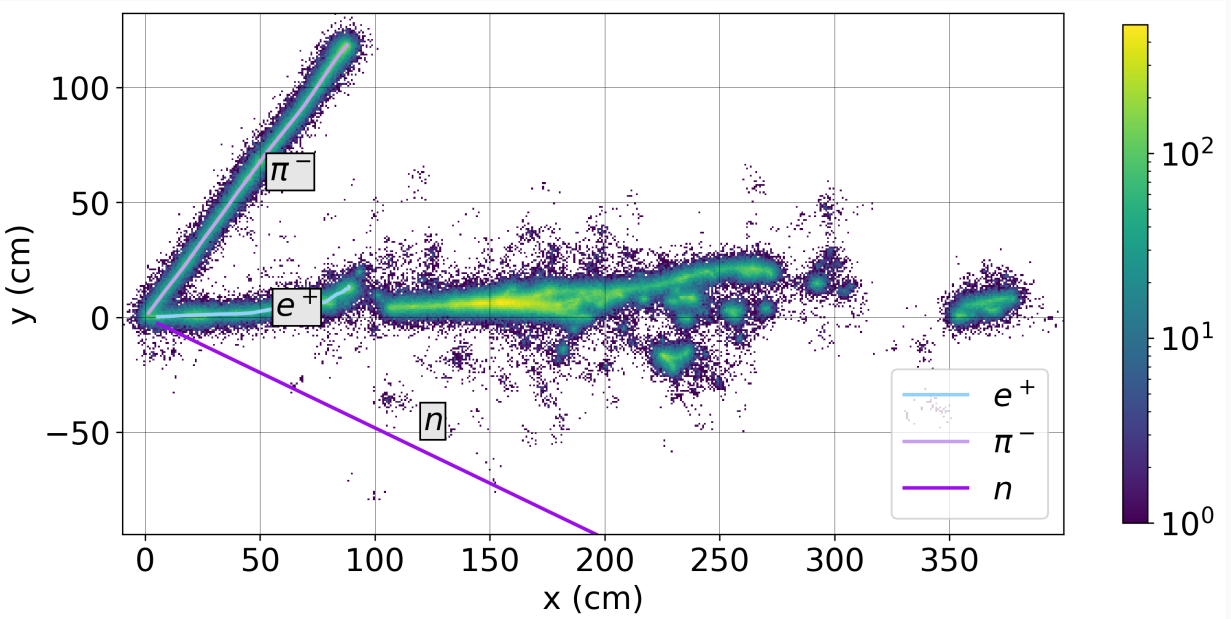

doi:10.5281/zenodo.7645759

- Could also be used as a Far Detector

List of Posters

#	Title	Author	Day
328	CLOUD: the first reactor antineutrino experiment using the novel LiquidO detection technology	D Navas (Ciemat)	Fri
393	Simulations of the LiquidO-based CLOUD Inner Detector	S Wakely (JGU Mainz)	Tue
467	The Science of the Accelerator Neutrino Neutron Interaction Experiment	F Lemmons (SDSM)	Fri
481	First Neutrinos on Large Picosecond Photodetectors in ANNIE	A Weinstein, M Wetstein (Iowa State U)	Fri
518	Deployment of water-based liquid scintillator in ANNIE	A Augusthy, N Göhlke (JGU Mainz)	Fri
545	Scintillation and Cherenkov Light Separation in Novel Liquid Scintillators for Large Scale Neutrino Detectors	J Steiger, M Lu (TU Munich)	Tue
553	Initial Look at Event Reconstruction in ANNIE	J He (UC Davis)	Fri
578	The broad physics Program of Theia	L Lebanowski (UC Berkeley)	Fri
579	Simulation of CLOUD, the first LiquidO reactor neutrino experiment	C Girard-Carillo (JGU Mainz)	Fri
596	Technology and reconstruction development for Theia	T Kaptanoglu (UC Berkeley)	Fri
612	Deep Learning Event Reconstruction Techniques for the CLOUD LiquidO Based Experiment	G Wendel (Penn State)	Fri
635	The SuperChooz project: a LiquidO-based neutrino oscillation experiment	R Gazzini (IJCLab)	Fri

is linked to poster

Summary and Conclusion

- Ideas/proposals to expand the physics reach of future LBL facilities
  - Korea Neutrino Observatory
  - Theia@DUNE
- Extract additional physics to fully exploit the massive investment
  - Solar neutrinos
  - Supernova & Diffuse SN background
  - (neutrino-less) double beta decay
  - Baryon number violation
- Active R&D program & supporting community
  - Photon Detectors
  - Hybrid & opaque scintillators
  - Scaling up
- Let's realise the potential!