NUFACT16,
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PACIFIC NEUTRINOS

Towards a high precision measurement of CP violation in the neutrino sector ?

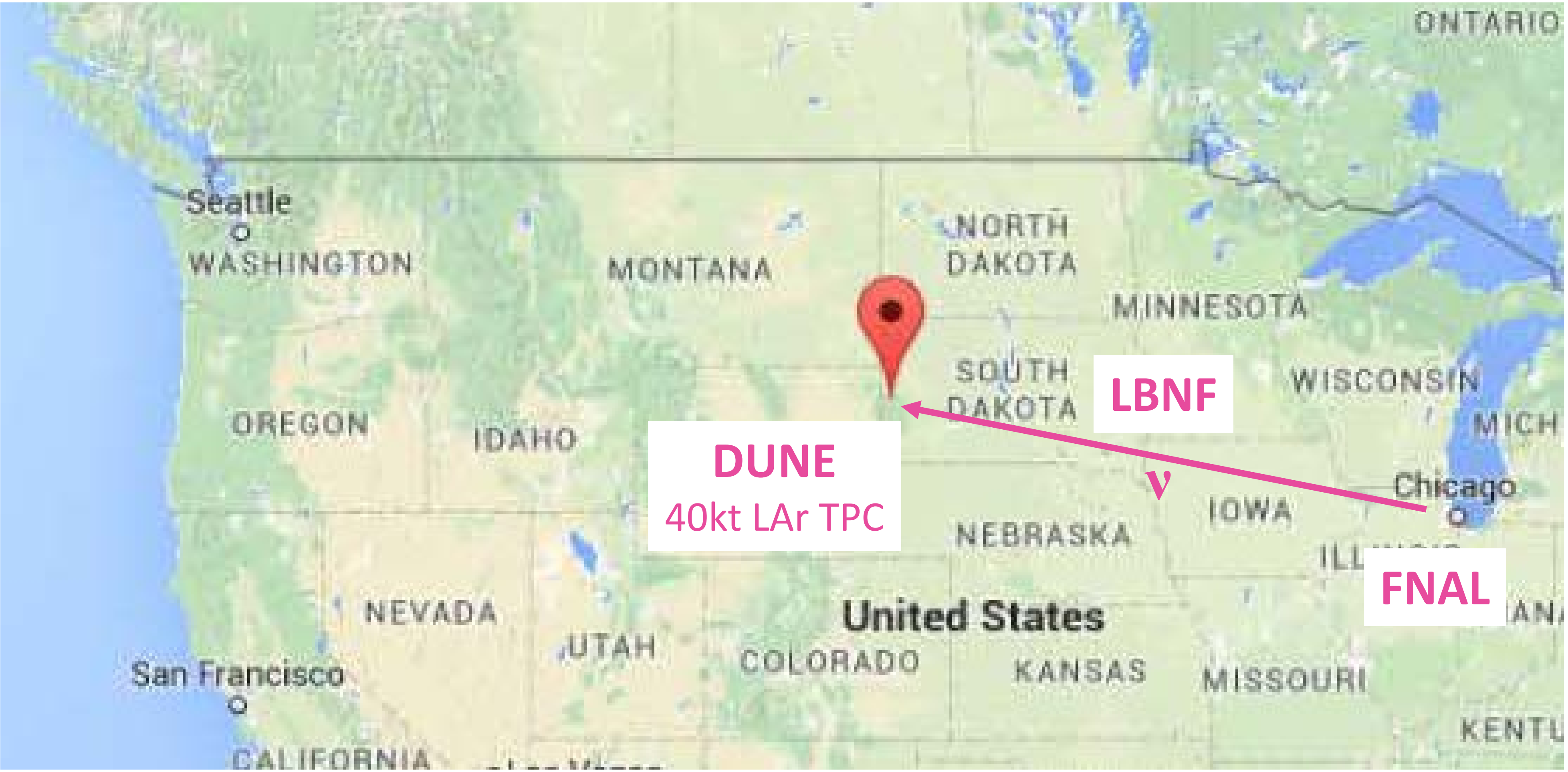
1. **An outstanding triangular conjunction**
2. **Semi-quantitative investigation of its potential**
3. **Short term study and possible roadmap towards a project**

Plots and numbers based on:
LBNO studies (arXiv:1412.0593 [hep-ph]) and KM3NeT/ORCA LOI (arXiv:1601.0745 [astro-ph.IM])
(See also pioneering work from Jürgen Brunner: arXiv:1304.6230 [hep-ph])

NB: all estimations are orders of magnitudes to be checked with detailed simulations

AN OUTSTANDING TRIANGULAR CONJUNCTION : input 1

Establishment of FNAL as a long term worldwide neutrino facility



LBNF

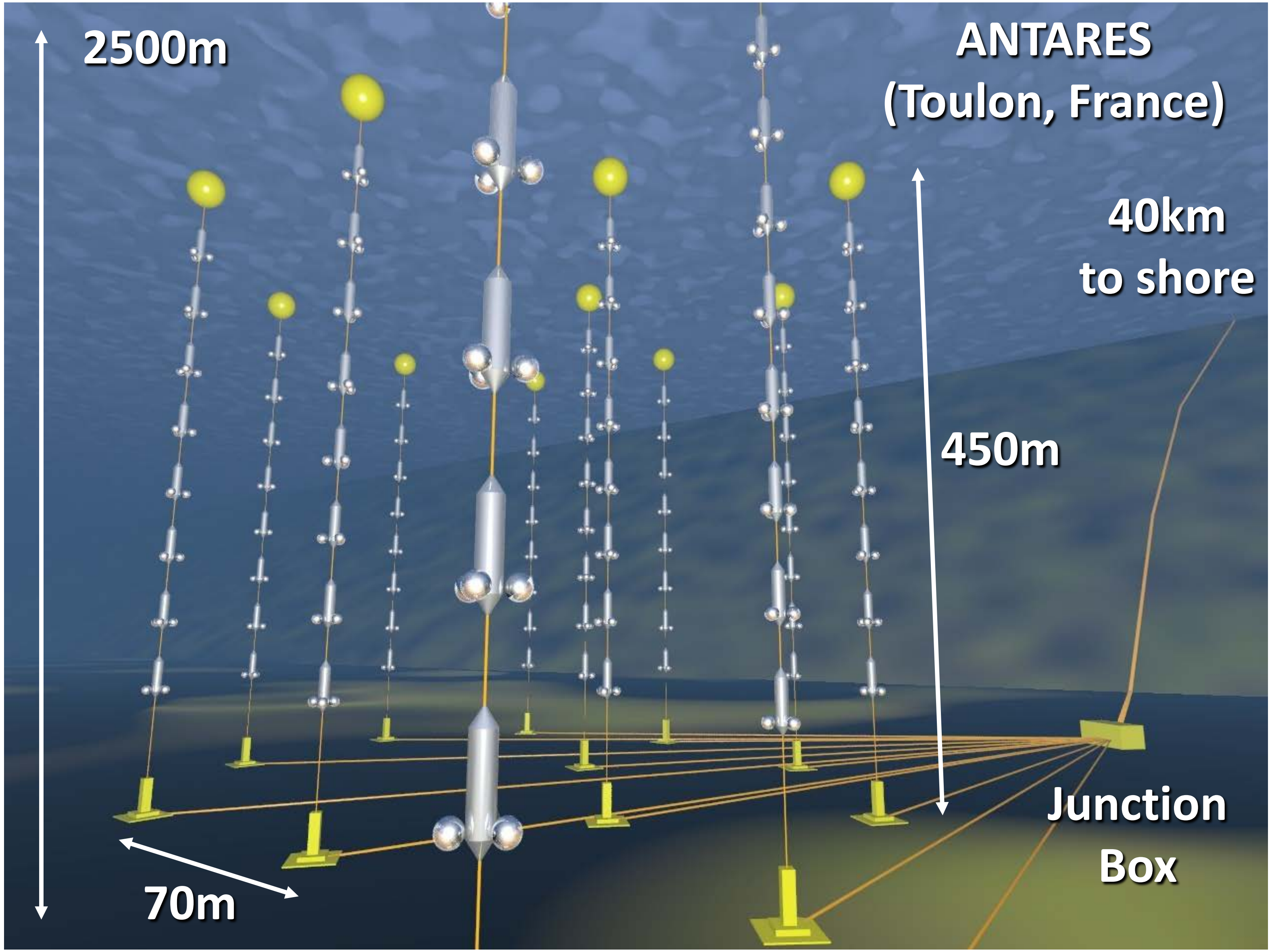
DUNE
40kt LAr TPC

FNAL

A facility to be exploited during decades in regard of the o(1G$) investment

AN OUTSTANDING TRIANGULAR CONJUNCTION : input 2

Deep sea instrumentation is reaching maturity for low-E neutrinos



ANTARES :

First deep sea ν telescope

- 900 Optical Modules distributed on 12 lines
- Optimized for measurement of single long muon tracks ($E_\nu > 20$ GeV)
- Successfully operated for 10 years → *proof of long term reliability of deep sea optical instrumentation*

AN OUTSTANDING TRIANGULAR CONJUNCTION : input 2 cont'd

Deep sea instrumentation is reaching maturity for low-E neutrinos

ANTARES

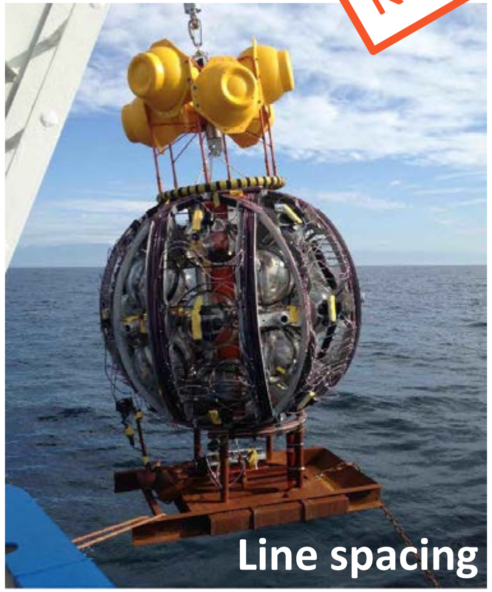
KM3NeT

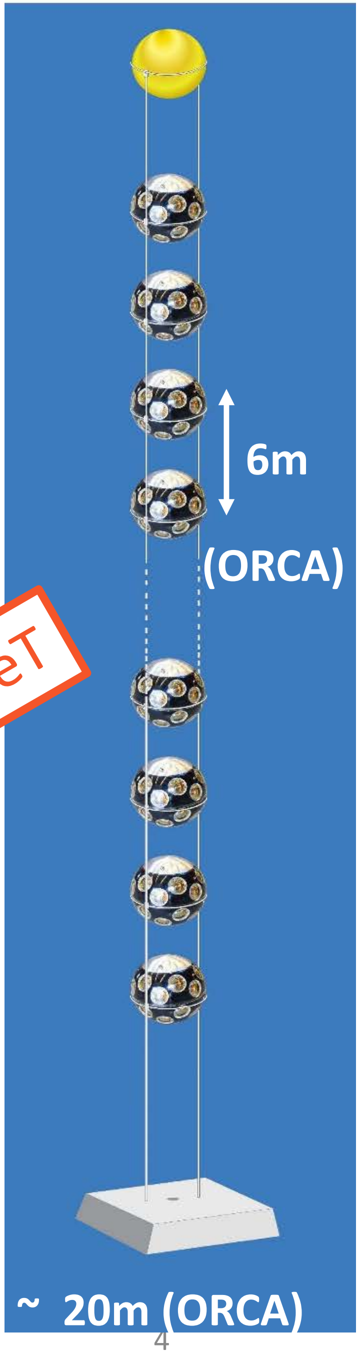
KM3NeT:

Ongoing final validation of a finer grain deep sea optical instrumentation suitable for few GeV ν's

- Multi-PMT Optical Modules with full integrated control and R/O electronics (modular design with each OM acting as independent ethernet hub)
- Compact Launching Modules for simplified deployments
- Cost reduced by factor 3, dominated by OMs: ~10k€/OM
- High granularity option (ORCA layout) allows shower pattern reconstruction of few GeV neutrinos.

KM3NeT

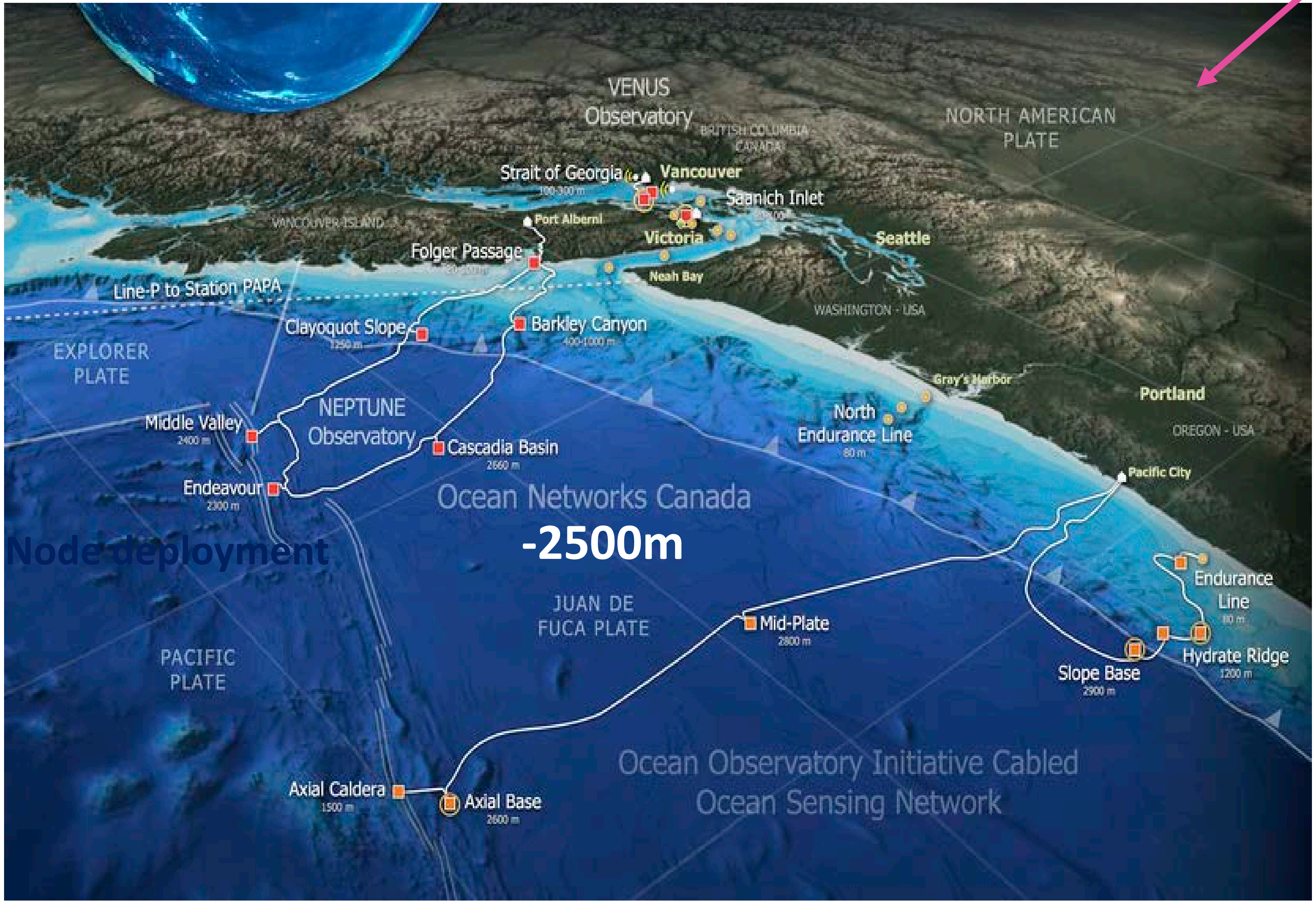




Line spacing ~ 20m (ORCA)

AN OUTSTANDING TRIANGULAR CONJUNCTION : input 3

Development of the NEPTUNE (Canada) and OOI (US) deep sea cabled observatories for environmental sciences



OFF SHORE OF VANCOUVER/SEATTLE:

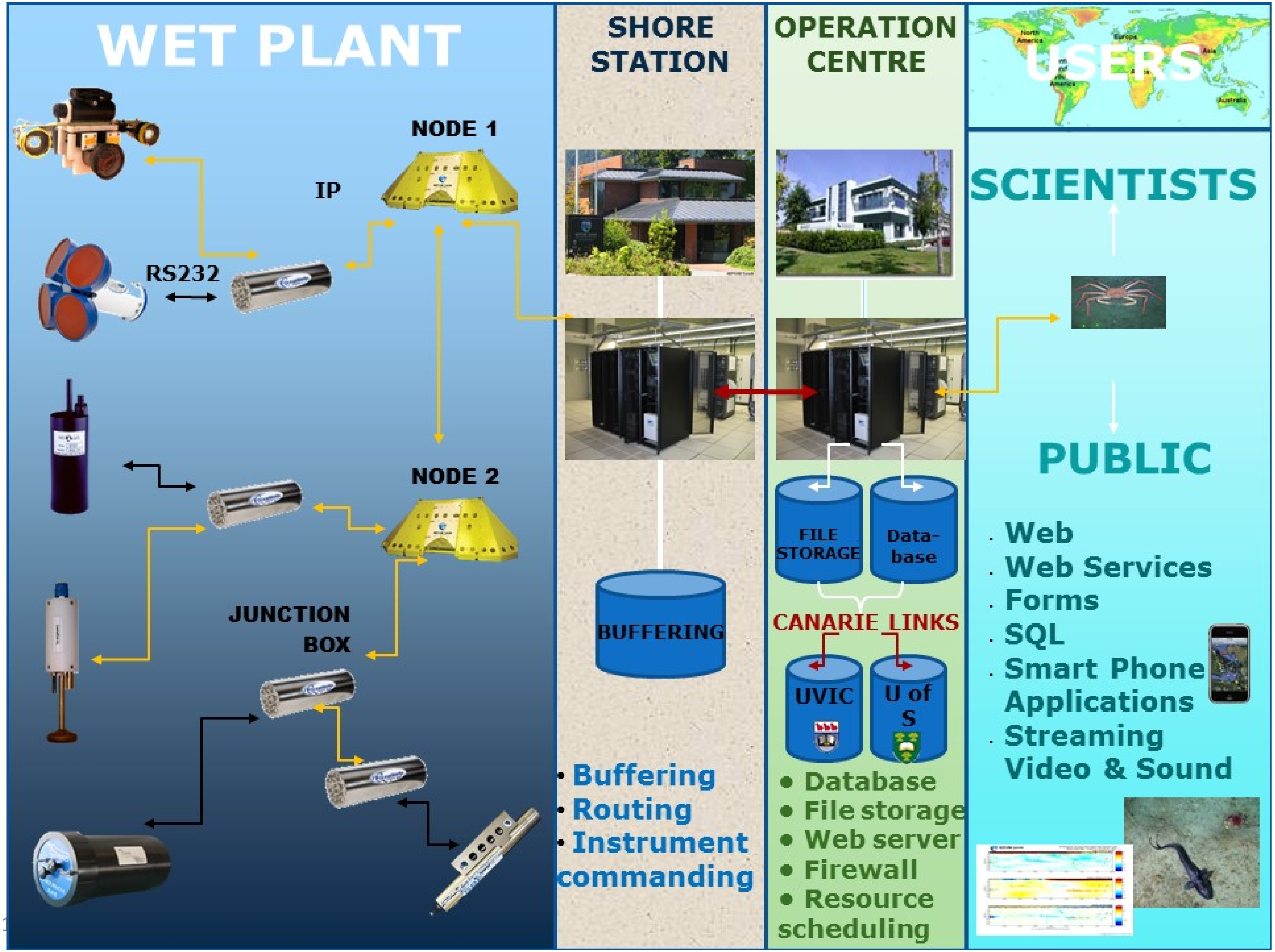
World-wide unique
permanent observatories
of the deep sea
at a depth similar to the
ANTARES neutrino telescope

NEPTUNE/OOI:

Unique deep sea infrastructure and logistics providing :

- instruments and operation tools
- electric power and large data flow
- with components similar to KM3NeT

Node deployment



WET PLANT

SHORE STATION

BUFFERING

- Buffering
- Routing
- Instrument commanding

OPERATION CENTRE

FILE STORAGE

Data-base

CANARIE LINKS

UVIC

U of S

- Database
- File storage
- Web server
- Firewall
- Resource scheduling

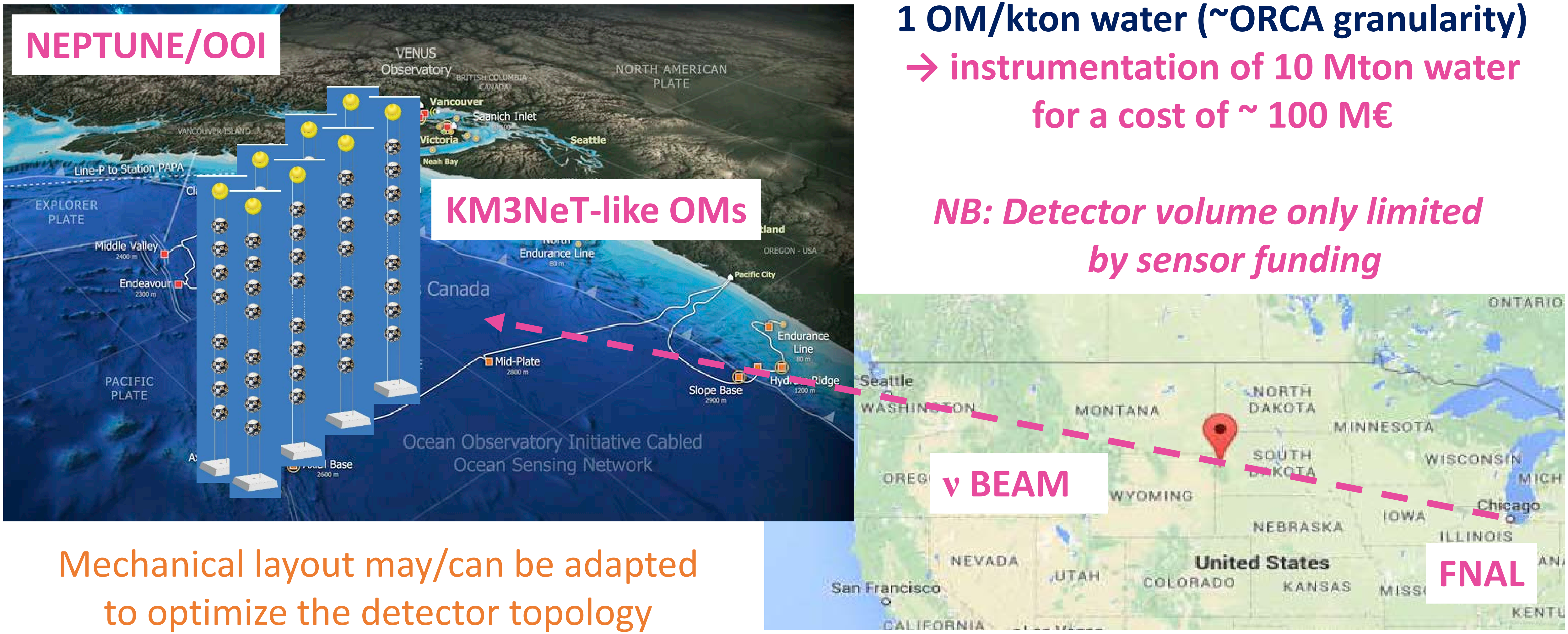
USERS

SCIENTISTS

PUBLIC

- Web
- Web Services
- Forms
- SQL
- Smart Phone Applications
- Streaming Video & Sound

EXPLOITING THE CONJUNCTION (1+2+3):
Fermilab neutrino beam into the Pacific ("PACIFIC neutrinos")

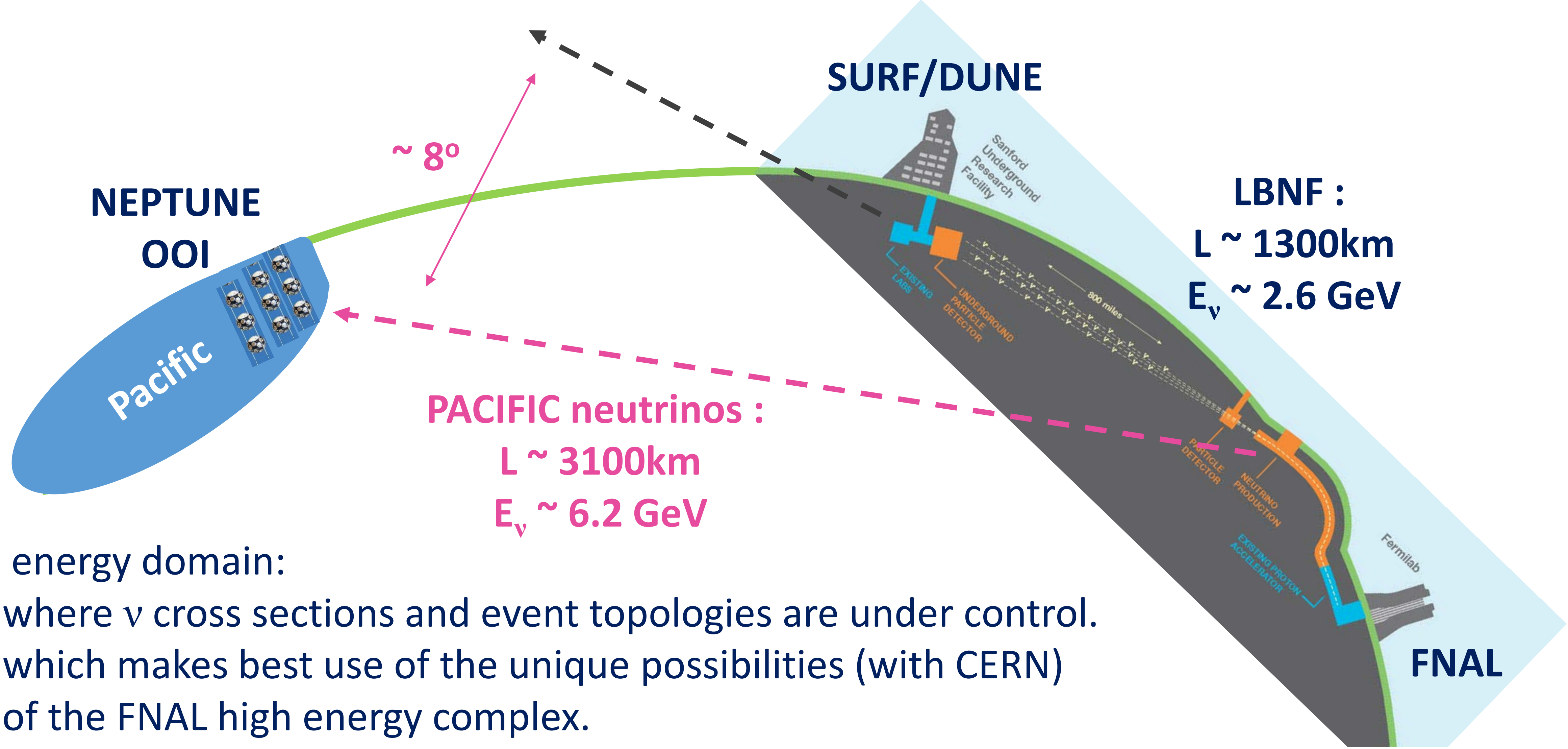


1 OM/kton water (~ORCA granularity)
→ instrumentation of 10 Mton water for a cost of ~ 100 M€

NB: Detector volume only limited by sensor funding

Mechanical layout may/can be adapted to optimize the detector topology

NB: NOT THE SAME BEAM AS LBNF !



SURF/DUNE

~ 8°

NEPTUNE
OOI

LBNF :
L ~ 1300km
E_ν ~ 2.6 GeV

PACIFIC neutrinos :
L ~ 3100km
E_ν ~ 6.2 GeV

FNAL

An energy domain:

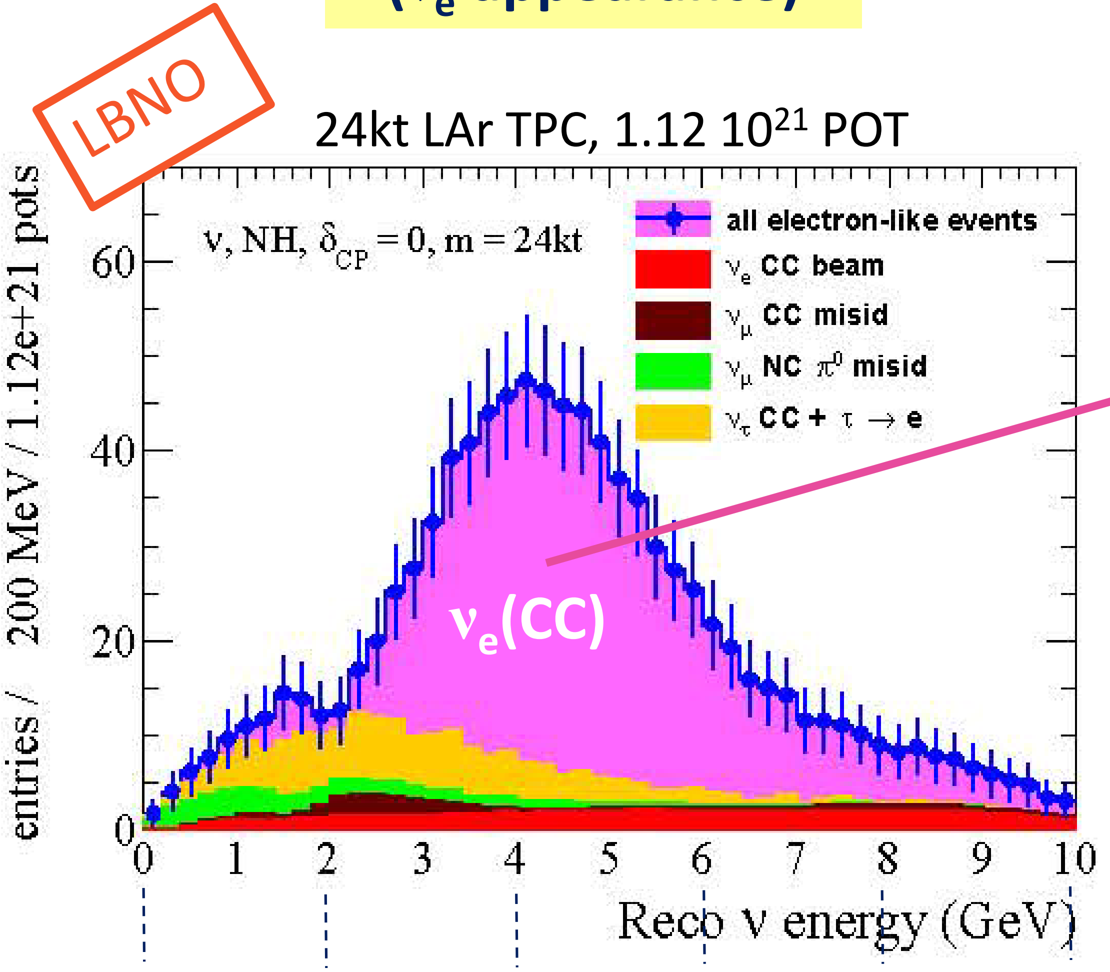
- where ν cross sections and event topologies are under control.
- which makes best use of the unique possibilities (with CERN) of the FNAL high energy complex.

NB: the large (extensible) size of the detector would not require multi-MW beam operation

EXPECTED SIGNAL (ν_e appearance)

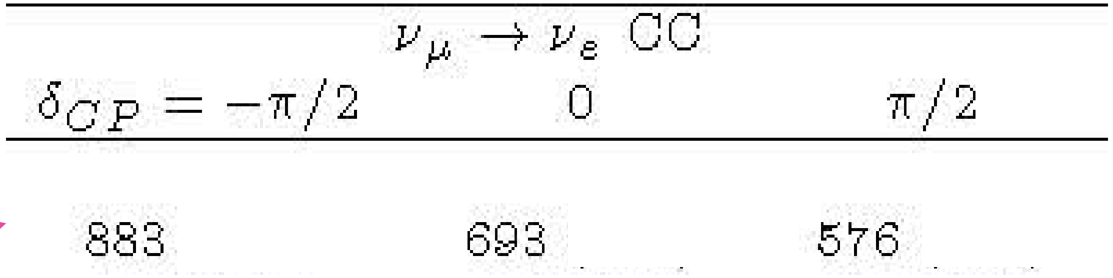
Extrapolated from LBNO study (L = 2300 km) the studied configuration closest to PACIFIC neutrinos

Show case with neutrinos and Normal Hierarchy only



P'c ν : 0 3 6 9 12 15

ν_e appearance



	$\nu_\mu \to \nu_e$ CC	
$\delta_{CP} = -\pi/2$	0	$\pi/2$
883	693	576

LBNO → PACIFIC ν's

#evts x ~ 100 ! *for same #POTs*

(10000/24) x $(2300/3100)^2$ x (3100/2300) x 120/400

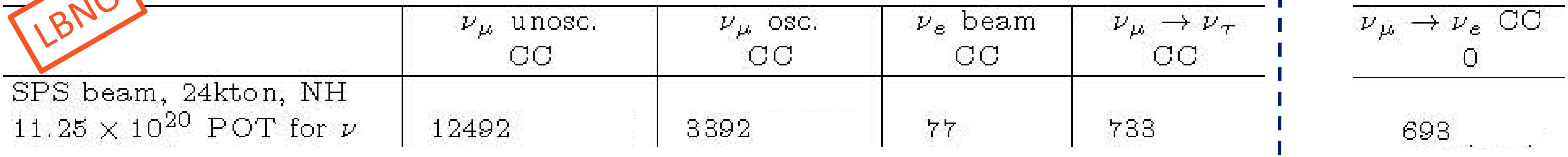
size angular dispersion $\sigma_\nu(E)$ E_{p_beam}

Δ(#evts) = o(20 kevts) for $\Delta(\delta_{CP})$= 180°

→ statistical precision of o(1°) on δ_{CP}

BACKGROUND LEVELS

$\#NC_{tot} \sim \#CC_{\mu}$



LBNO

	ν_μ unosc. CC	ν_μ osc. CC	ν_e beam CC	$\nu_\mu \to \nu_\tau$ CC	$\nu_\mu \to \nu_e$ CC 0
SPS beam, 24kton, NH 11.25×10^{20} POT for ν	12492	3392	77	733	693

Background/Signal :
(before any suppression)

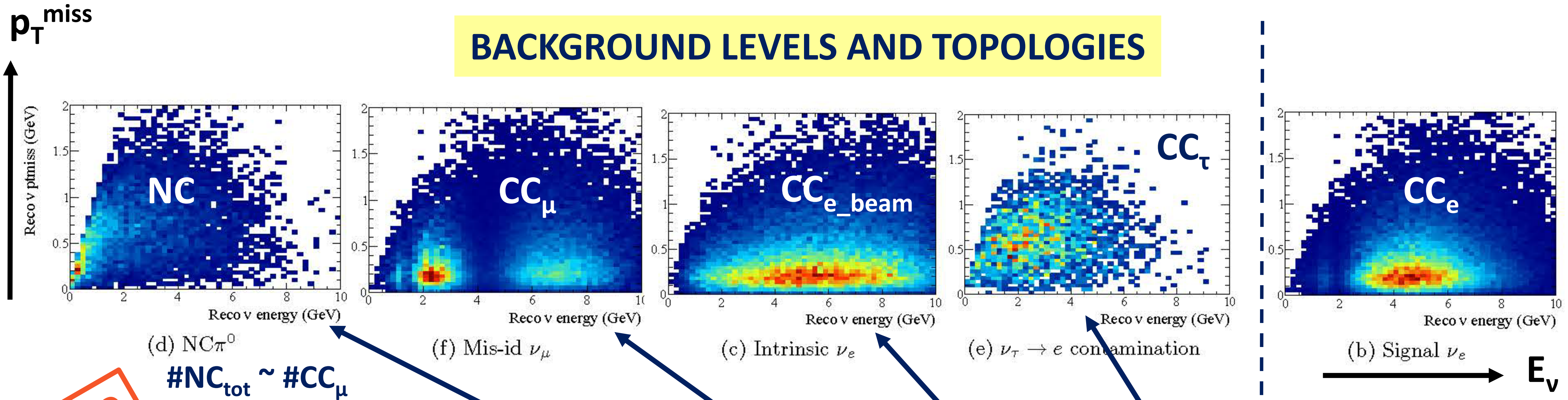
10
$CC_{\mu} + NC_{tot}$

0.1
CC_{e_beam}

1 - 0.2
CC_{τ} - $CC_{\tau \to e}$

Signal

BACKGROUND LEVELS AND TOPOLOGIES



(d) NCπ^0 (f) Mis-id ν_μ (c) Intrinsic ν_e (e) $\nu_\tau \to e$ contamination (b) Signal ν_e

#NC_{tot} ~ #CC_μ

LBNO

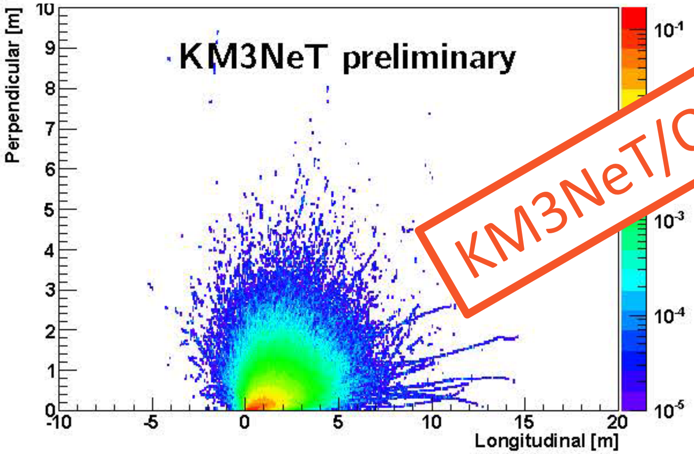
	ν_μ unosc. CC	ν_μ osc. CC	ν_e beam CC	$\nu_\mu \to \nu_\tau$ CC	$\nu_\mu \to \nu_e$ CC 0
SPS beam, 24kton, NH 11.25×10^{20} POT for ν	12492	3392	77	733	693

Background/Signal : **(before any suppression)**	**10** $CC_\mu + NC_{tot}$	**0.1** CC_{e_beam}	**1 - 0.2** CC_τ - $CC_{\tau \to e}$	**Signal**
Suppression criteria :	μ veto (CC_μ) P_T^{miss} (NC) low E	irreducible high E	H & μ vetos P_T^{miss} low E	

BACKGROUND SUPPRESSION

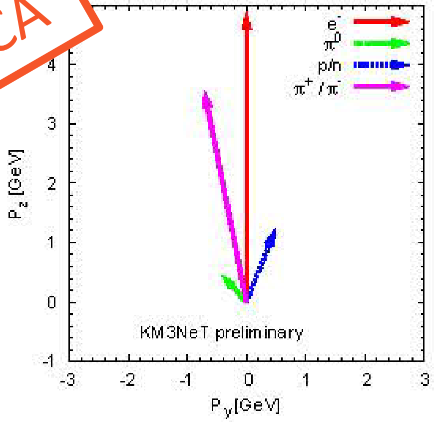
Key issue: OM granularity needed to achieve the required BG suppression from Cerenkov emission measurement

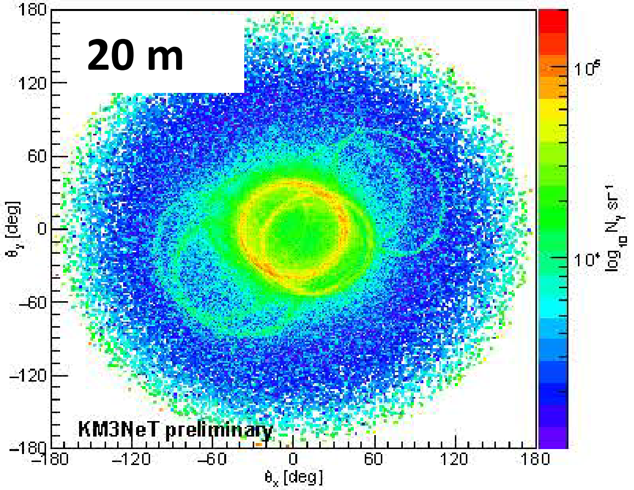
5 GeV had showers (cumulated)

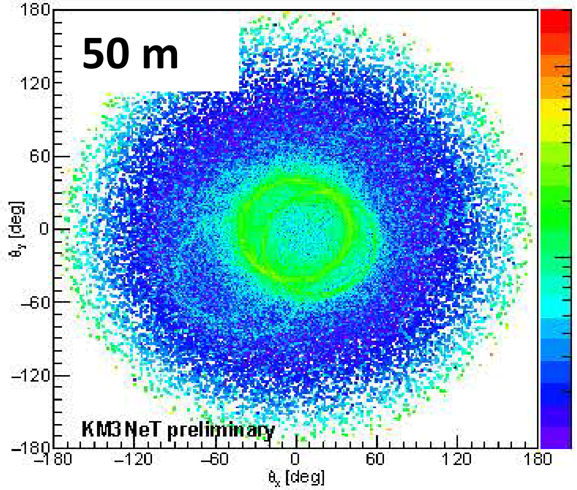


KM3NeT/ORCA

10 GeV ν_e CC







Cerenkov emission
from hadronic showers is
concentrated on a few meters

Cerenkov ring patterns are maintained on the full light absorption range (~60m)
thanks to large light scattering length in water
→ ORCA-like granularity should allow signal/background separation

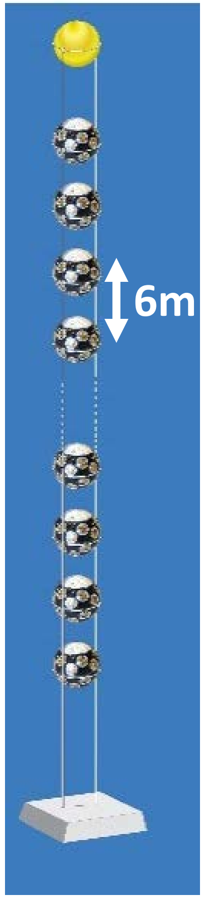
NB1: Very large event samples allow using statistical suppression methods

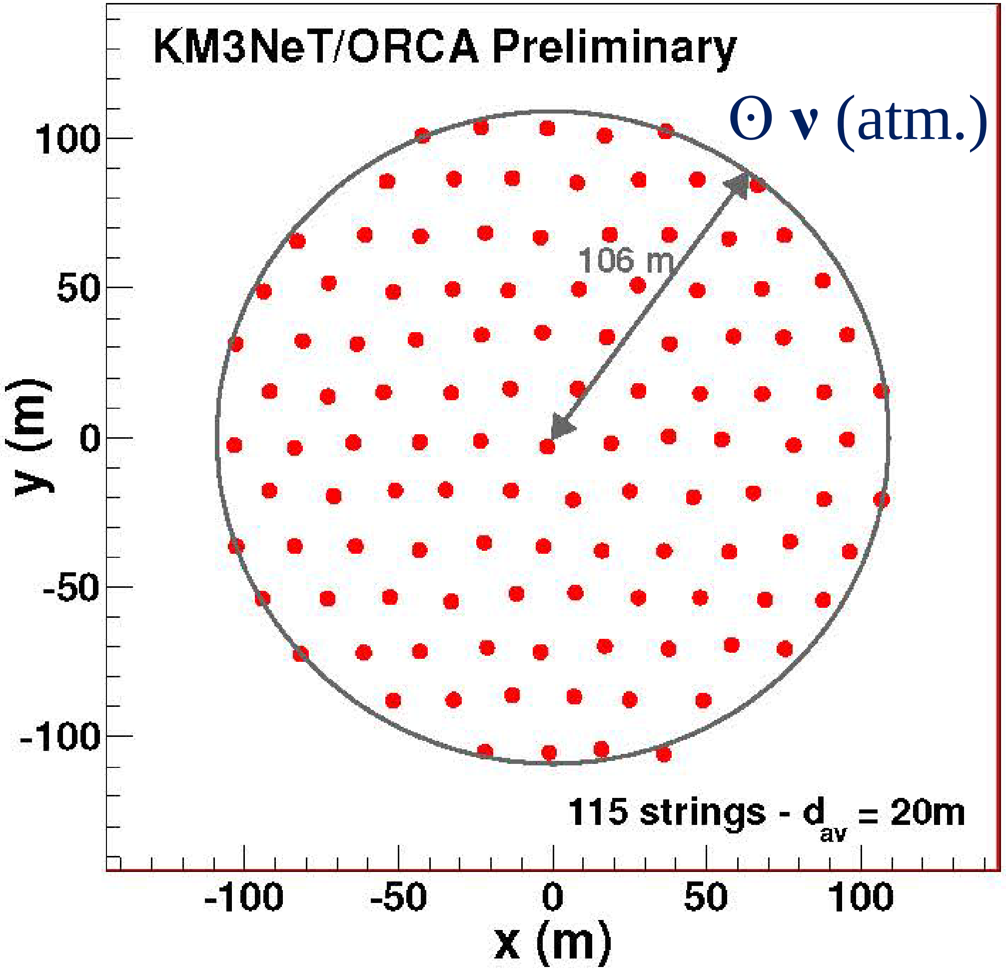
NB2: Background suppression must be controlled with high precision
to benefit from the full statistical precision of the signal sample.

DETECTOR LAYOUT

ORCA

ν_e(CC) : dV_{int} ~ 1m, dE_ν/E_ν ~ 20%, $d\theta_e$ ~ 5°, $d\theta_{had}$ < 20°

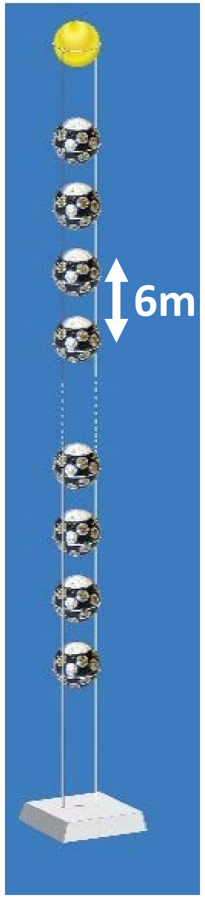


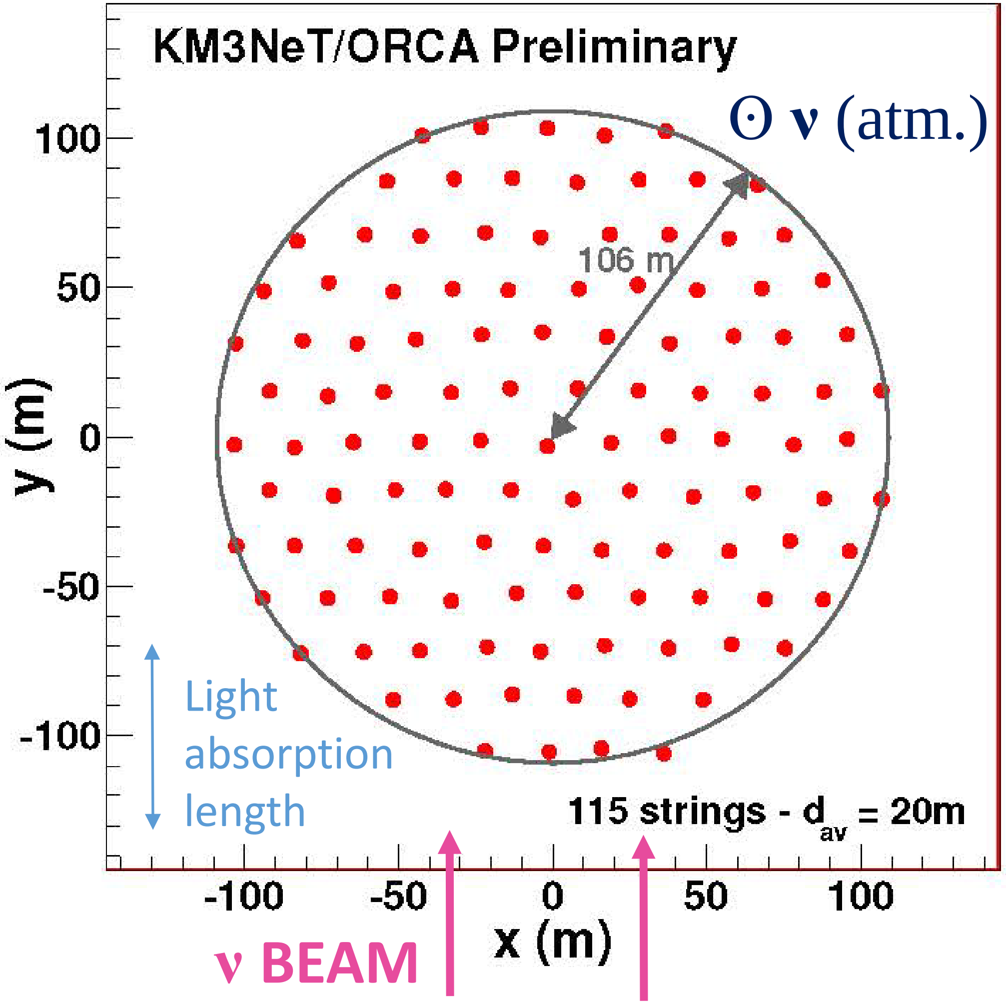


DETECTOR LAYOUT

ORCA → PACIFIC neutrinos

ν_e(CC) : $dV_{int} \sim 1m$, $dE_\nu/E_\nu \sim 20\%$, $d\theta_e \sim 5^\circ$, $d\theta_{had} < 20^\circ$

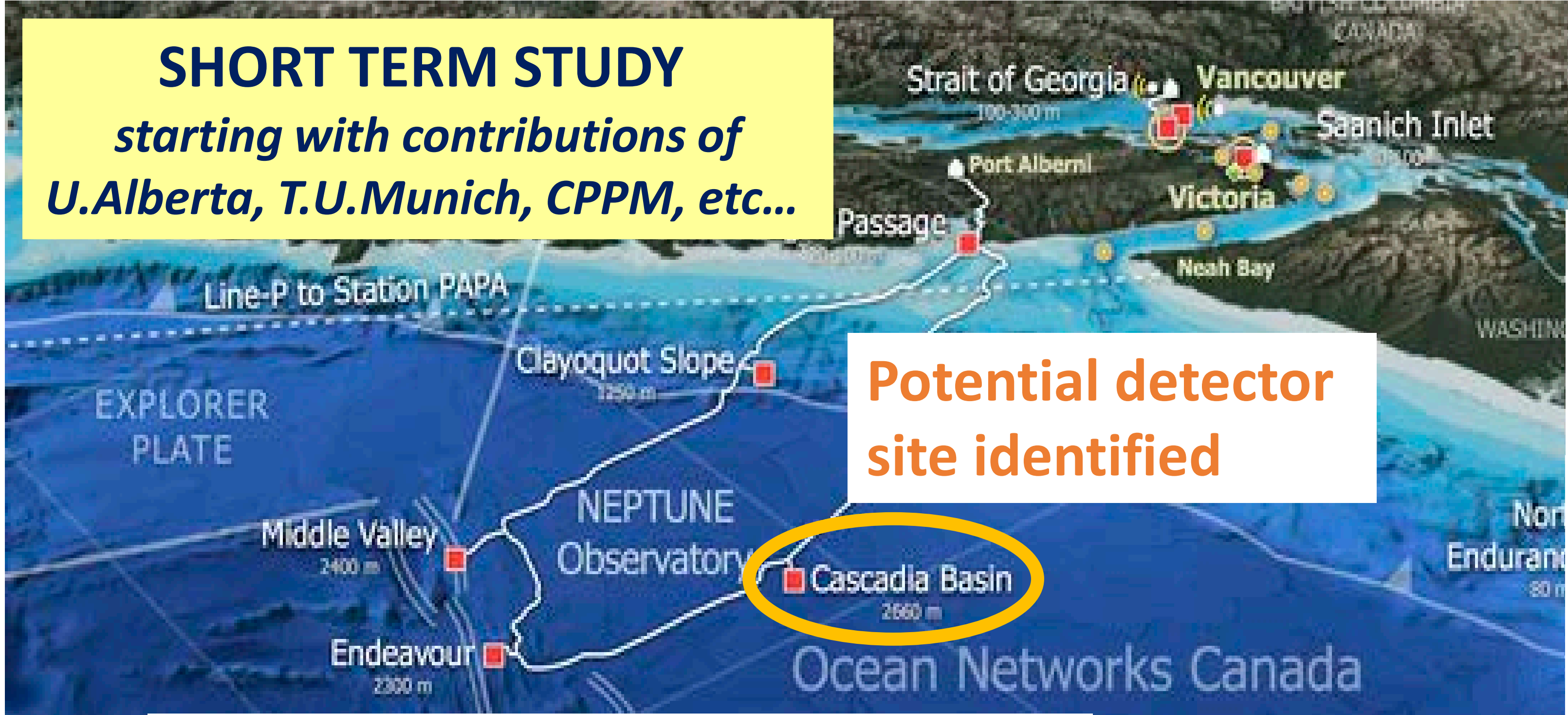




- **With an horizontal beam, staggered lines would provide an effective instrumentation granularity of ~6m in both transverse directions on a depth corresponding to light absorption. It might be necessary to reduce the OM vertical spacing to increase Cerenkov ring pattern efficiency.**
- **Beam timing fully suppresses atmospheric muon background**
  → much relaxed reconstruction cuts
  → improved sensitivity to event patterns
- **Beam direction allows more efficient reconstruction algorithms and kinematical constraints (PT balance)**
- **Optional core with denser instrumentation could allow reaching the 2nd oscillation peak**

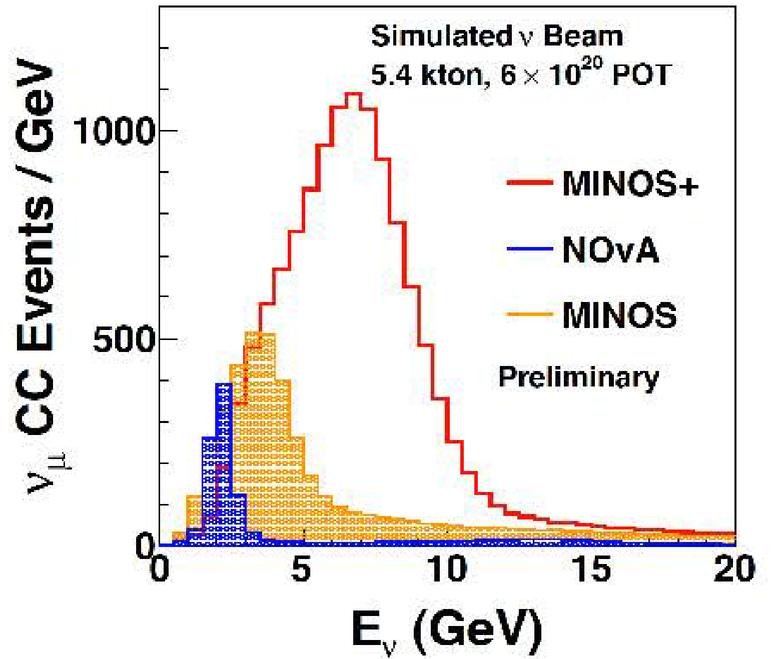
SHORT TERM STUDY

starting with contributions of
U.Alberta, T.U.Munich, CPPM, etc…



Potential detector site identified

Beam parameters extrapolated from MINOS+ (NUMI medium energy tune)

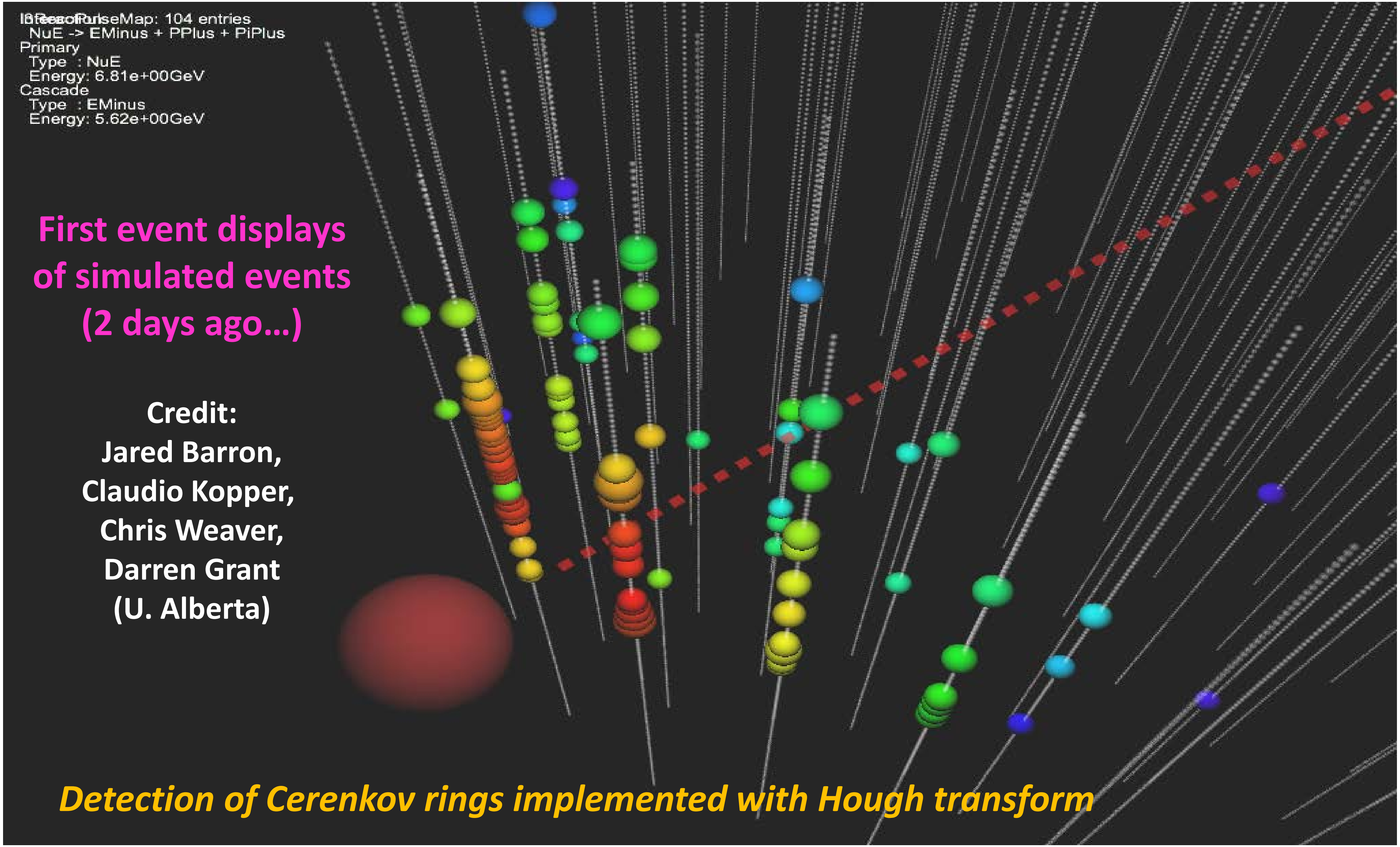


Simulation of an array of 20000 OMs with:

- **20m horizontal spacing**
- **1m vertical spacing**

→ 8 Mton sensitive volume

Key issue: optimize granularity and ν pattern reconstruction for signal extraction



First event displays of simulated events (2 days ago…)

Credit:
Jared Barron,
Claudio Kopper,
Chris Weaver,
Darren Grant
(U. Alberta)

Detection of Cerenkov rings implemented with Hough transform

POSSIBLE ROADMAP TOWARDS A PROJECT

Providing the short term study outcome remains promising, mid-term actions involving small teams with minor investments could be performed in parallel:

- **Design the optimal detector and beam (ν/anti-ν) configuration for CP violation measurement.**
- **Investigate and quantify complementary physics reach (ν_τ, DM, astro, etc…).**
- **Get acquainted with corresponding technologies within the KM3NeT/ORCA project offshore of Toulon/France (several lines already funded).**
- **Perform deep sea site quality studies in collaboration with NEPTUNE/OOI.**
- **In LBNF design, implement flexibility to later build a new beam towards a (slightly) different direction without interfering with LBNF operation.**

OUTLOOK

Deep sea instrumentation with multi-PM optical modules is reaching maturity and may provide the optimal compromise between detector size and instrumentation granularity for the long term future of long baseline neutrino physics

North America offers the geographical opportunity and the institutional synergies necessary for a concrete implementation of such a project