JUNO

(a ν-oscillations factory)

WIN-2017 Conference

Irvine, California (USA) — June 2017

on behalf of the JUNO collaboration

Anatael Cabrera

CNRS / IN2P3 @ APC (Paris)

JUNO Collaboration…

EUROPE

APC Paris
Charles University Prague
CPPM Marseille
FZ Julich
IKP FZI Julich
INFN Catania
INFN Frascati
INFN Ferrara
INFN Milano-Bicocca
INFN Milano
INFN Padova
INFN Perugia
INFN Roma3
INR Moscow
IPHC Strasbourg
JINR Dubna
LLR Paris
MSU
RWTH Aachen
Subatech Nantes
TUM Munich
University of Hambourg
University of Mainz
University of Oulu
University of Tuebingen
Yerevan Physics Institute
Université libre de Bruxelles

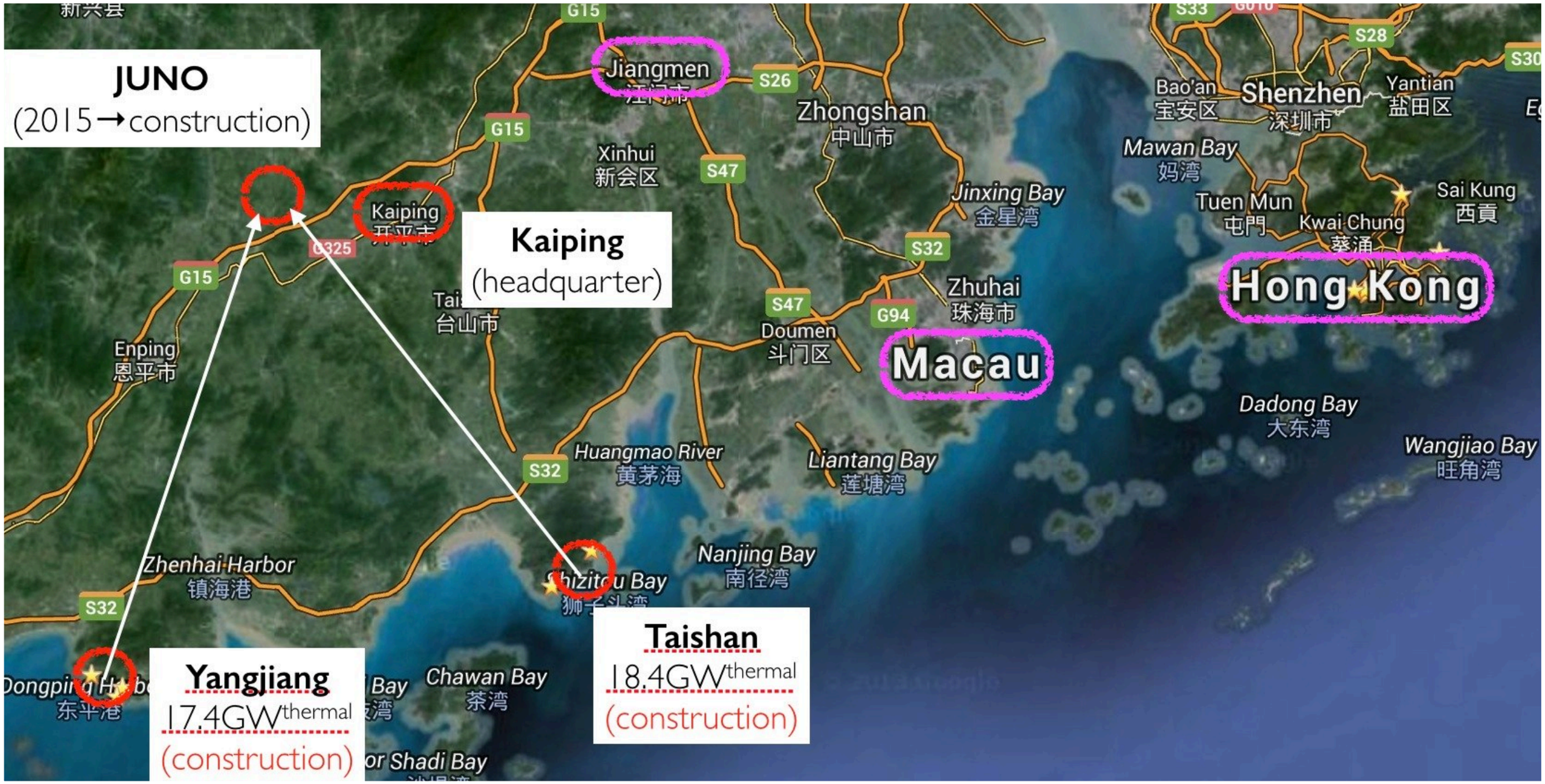
America

PCUC Chile
BISEE Chile
UMD1 USA
UMD2 USA

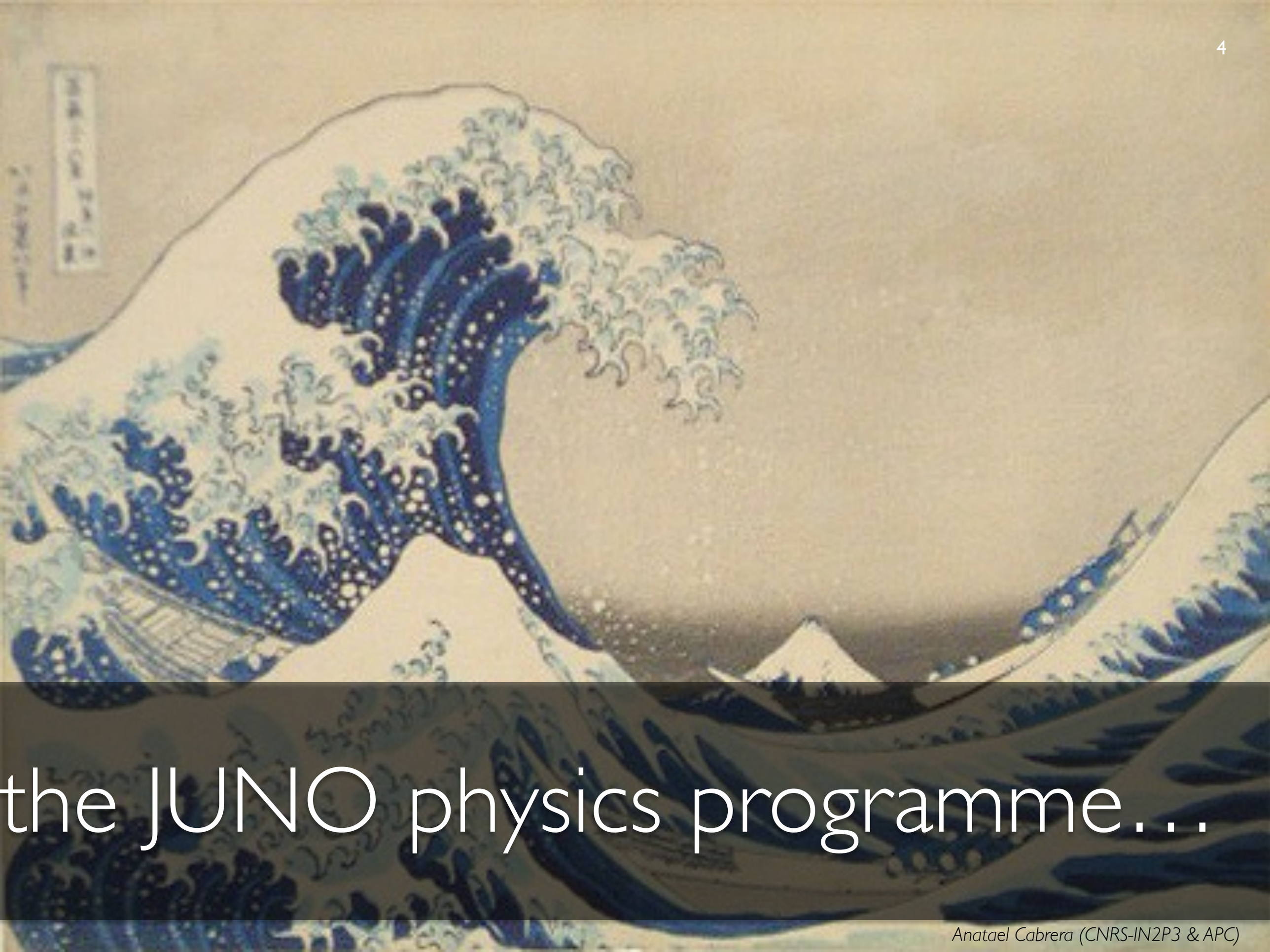
ASIA

Beijing Normal University
CAGS
ChongOing University
CIAE
DGUT
ECUST
Guangxi University
Harbin Institute of Technology
IHEP
Jilin University
Jinan University
Nanjing University
Nankay University
Natl. Chiao-Tung University
Natl. Taiwan University
Natl. United University
NCEPU
Pekin University
Shandong University
Shanghai JT University
Sichuan University
SUT
SYSU
Tsinghua University
UCAS
USTC
University of South China
Wu Yi University
Wuhan University
Xi'an University
Xiamen University

JUNO location…



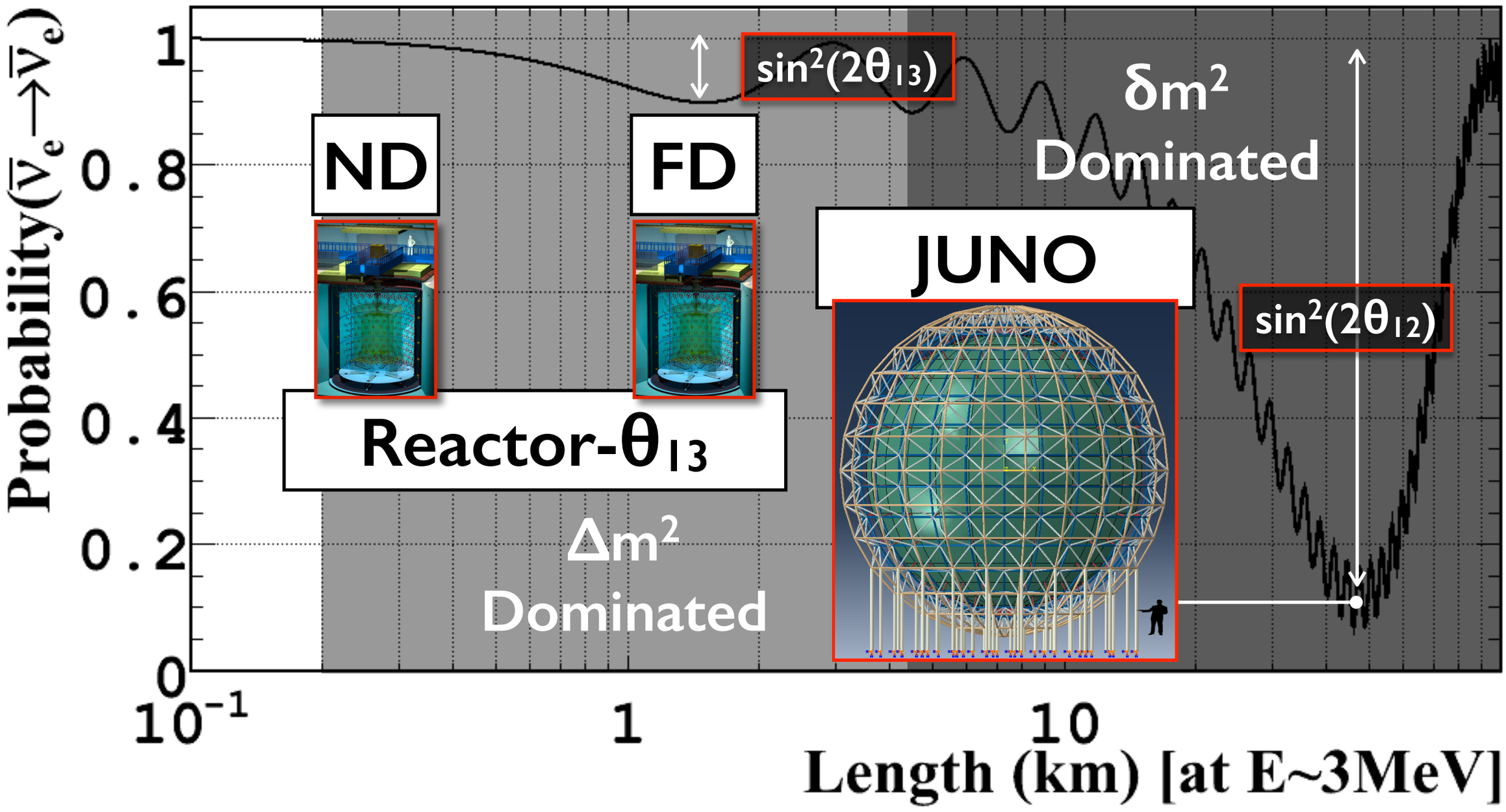
simplistic schedule: **data-taking starts by 2021**



the JUNO physics programme…

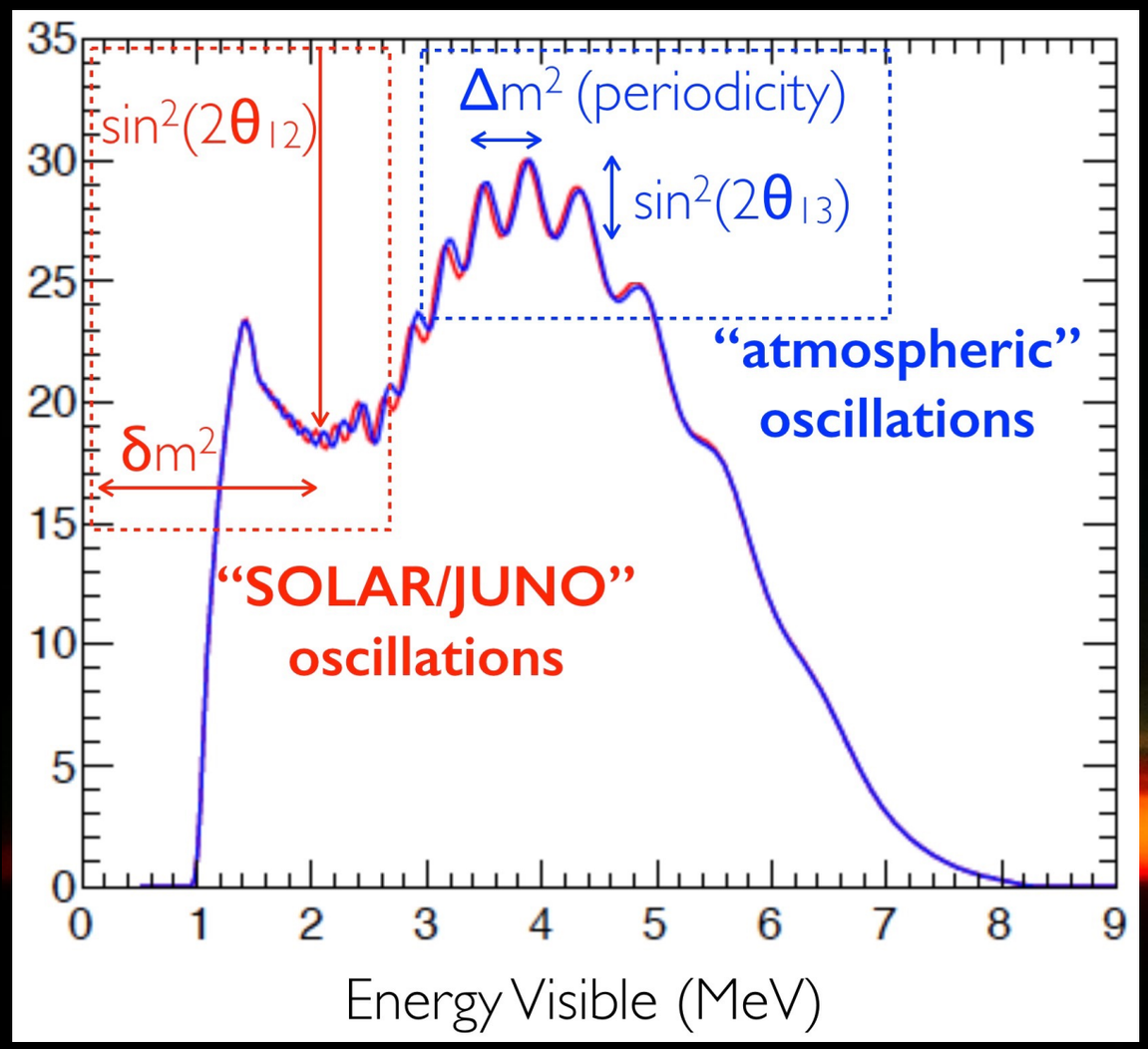
Anatael Cabrera (CNRS-IN2P3 & APC)

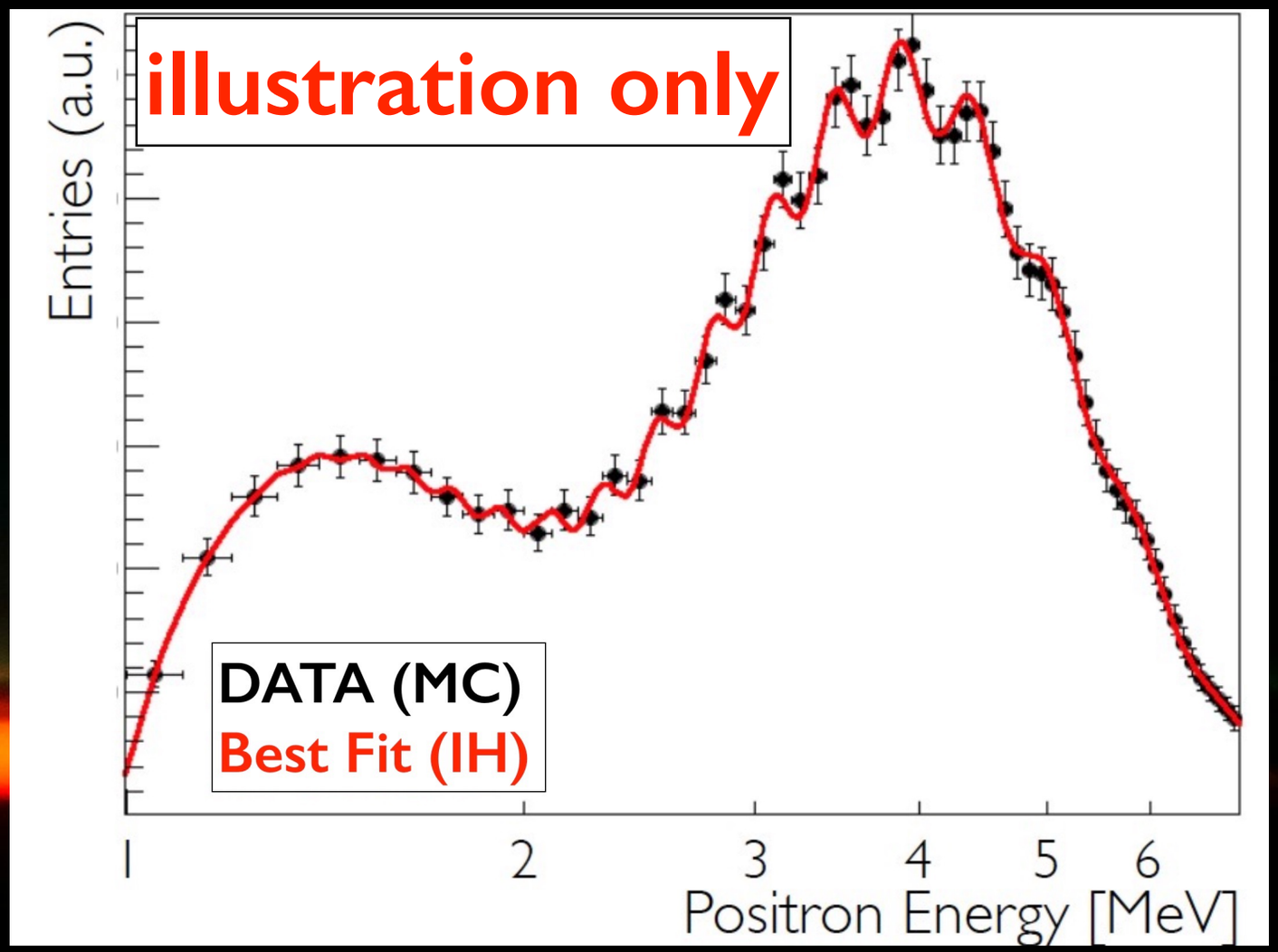
a long story short…



JUNO sensitive to <u>both oscillations</u>→ first time!

JUNO spectrum in more detail…



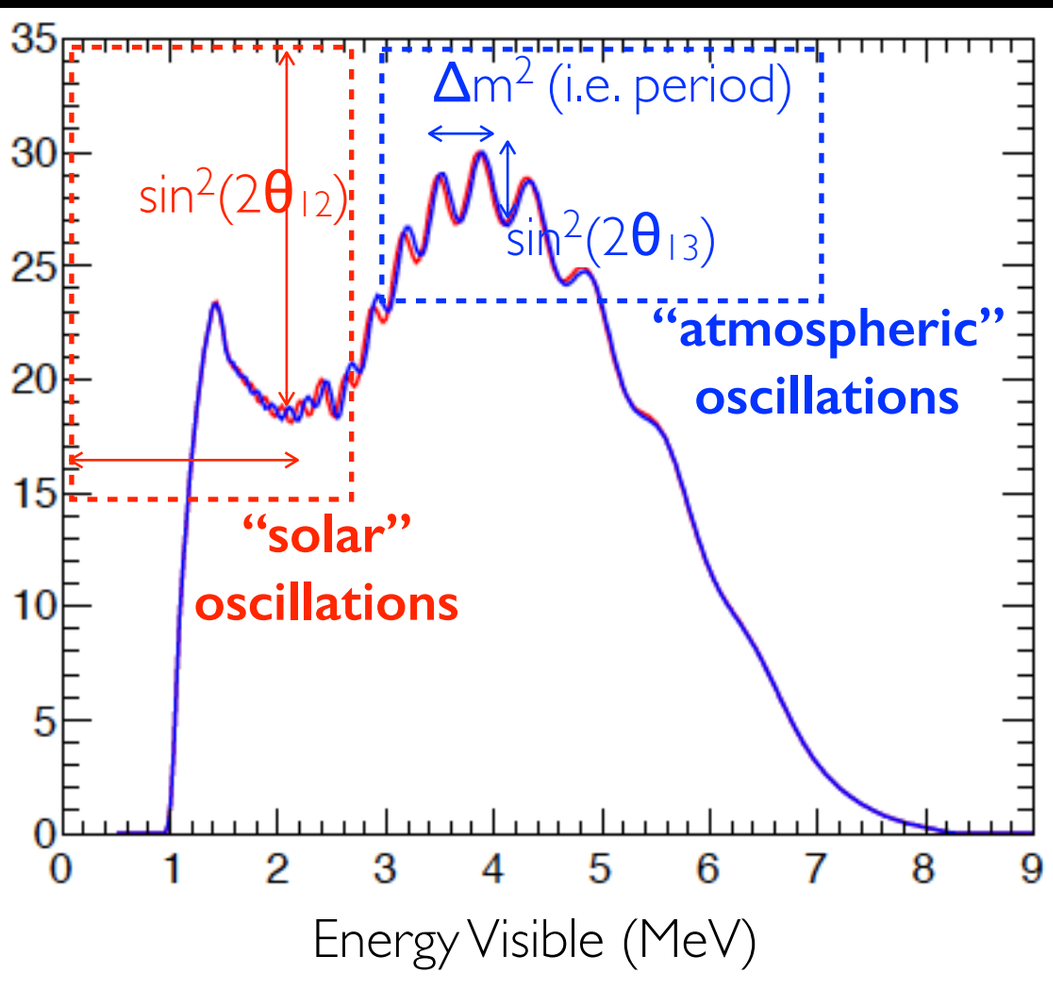


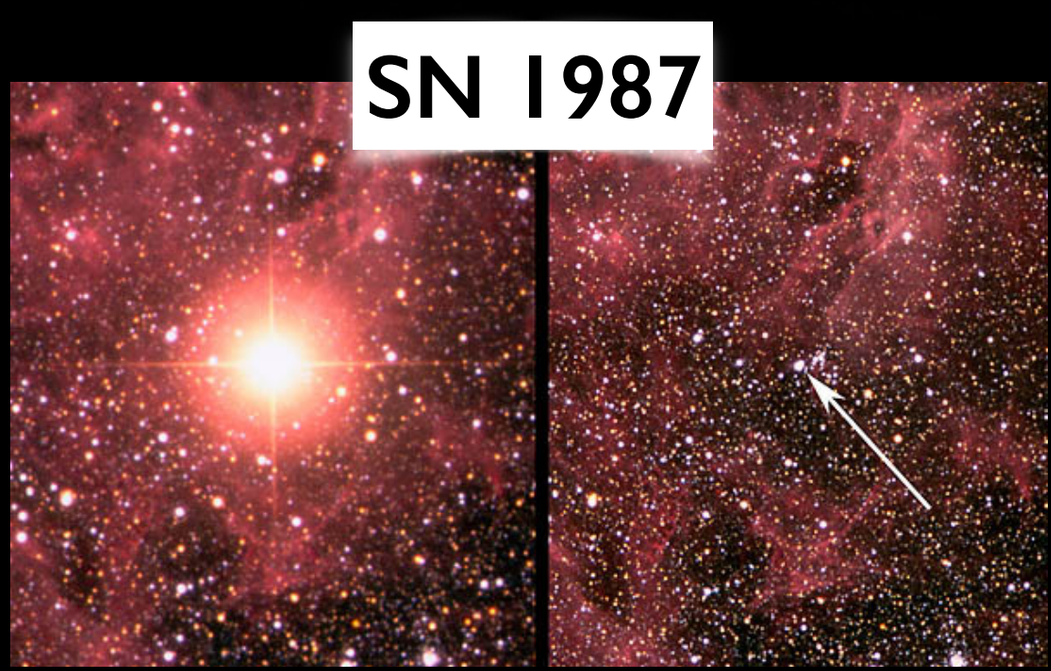
the rationale

data-like (challenging)

elegant ⊕ rich physics ($\theta_{12} \oplus \theta_{13} \oplus \delta m^2 \oplus \pm\Delta m^2$)

what to do with the largest LS detector in the world?



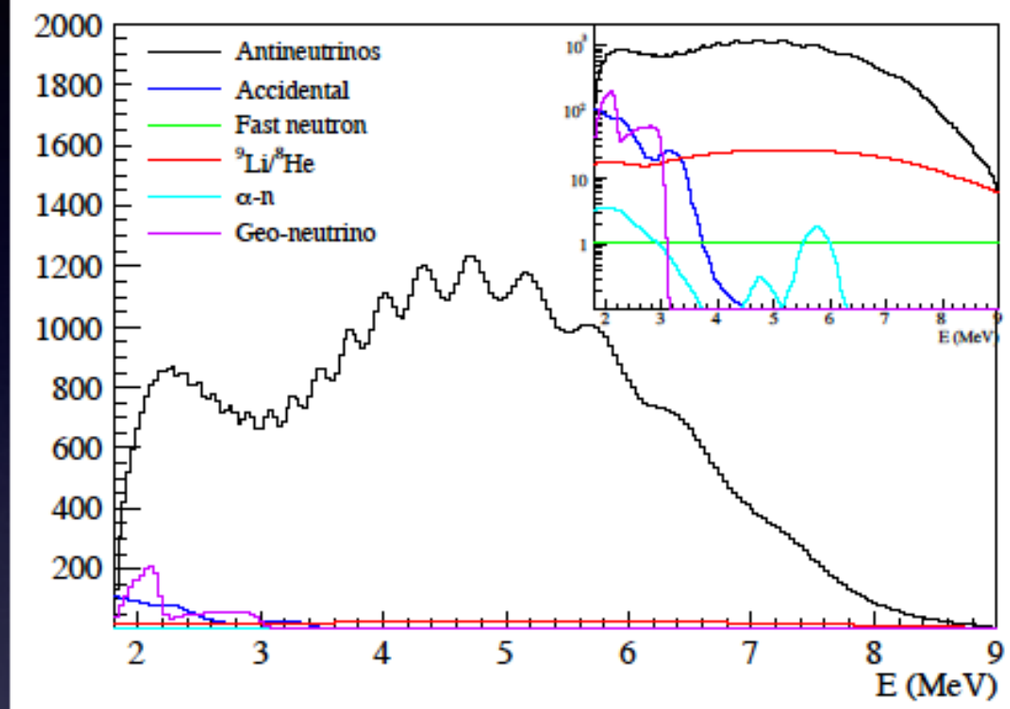


- (**reactor-ν**) **unique solar⊕atmospheric vacuum-oscillations fit**
- (**reactor-ν**) **mass hierarchy (atmospheric)**…
  - subdominant (θ13 modulated) spectral distorsion
    - driven by Δm^2(atmospheric)
  - **vacuum effect**→ no via matter enhance effects
    - no θ_{23}-octant or δ_{CP} ambiguities
    - **complementarity to NOνA,ORCA⊕PINGU,DUNE**
- (**reactor-ν**) **solar δm2 & θ12 highest precision**…
  - needed for CP-violation (**Jarlskog Invariant**)→ **ambiguities!**
  - **complementarity to T2K⊕NOνA & DUNE**
  - test: Solar (MSW) vs KamLAND (complex baseline)
- (**supernova-ν**) unique capabilities (size & observation: IBD, ν_e, ν_x)
- (**proton-decay**) unique capabilities (size & unique channels)
  - proton fraction larger in scintillator than water (up to ~2x)
- (**geo-ν**) observation (reactor-ν large BG)→ aid geo-physics
- other physics…
  - solar-ν, non-standard-interaction (different phase-space), etc

IBD selection & backgrounds…

Applying the different selection cuts, the signal rate will be 60 events/day and the background will be 3.8 events/day.

Antineutrino signal spectra and five kinds of main background

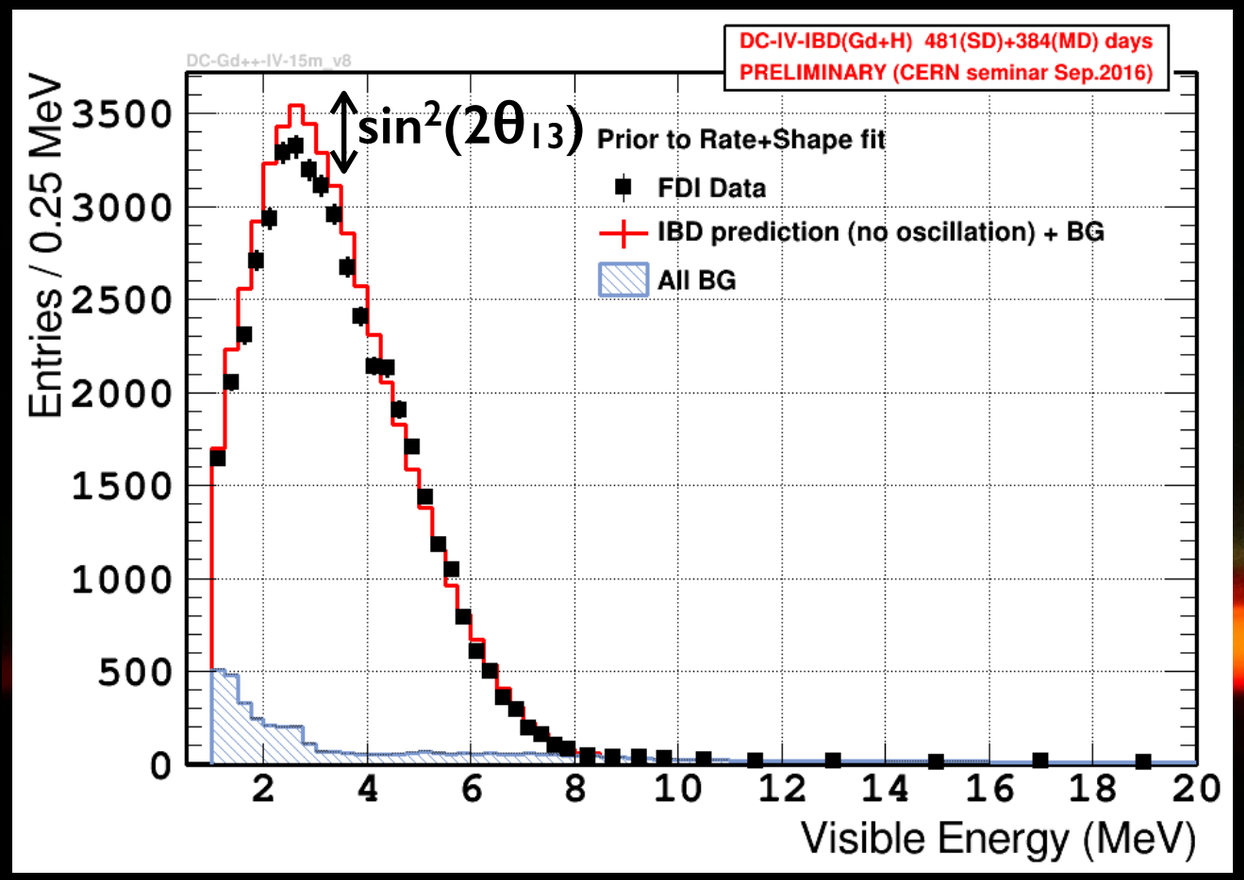


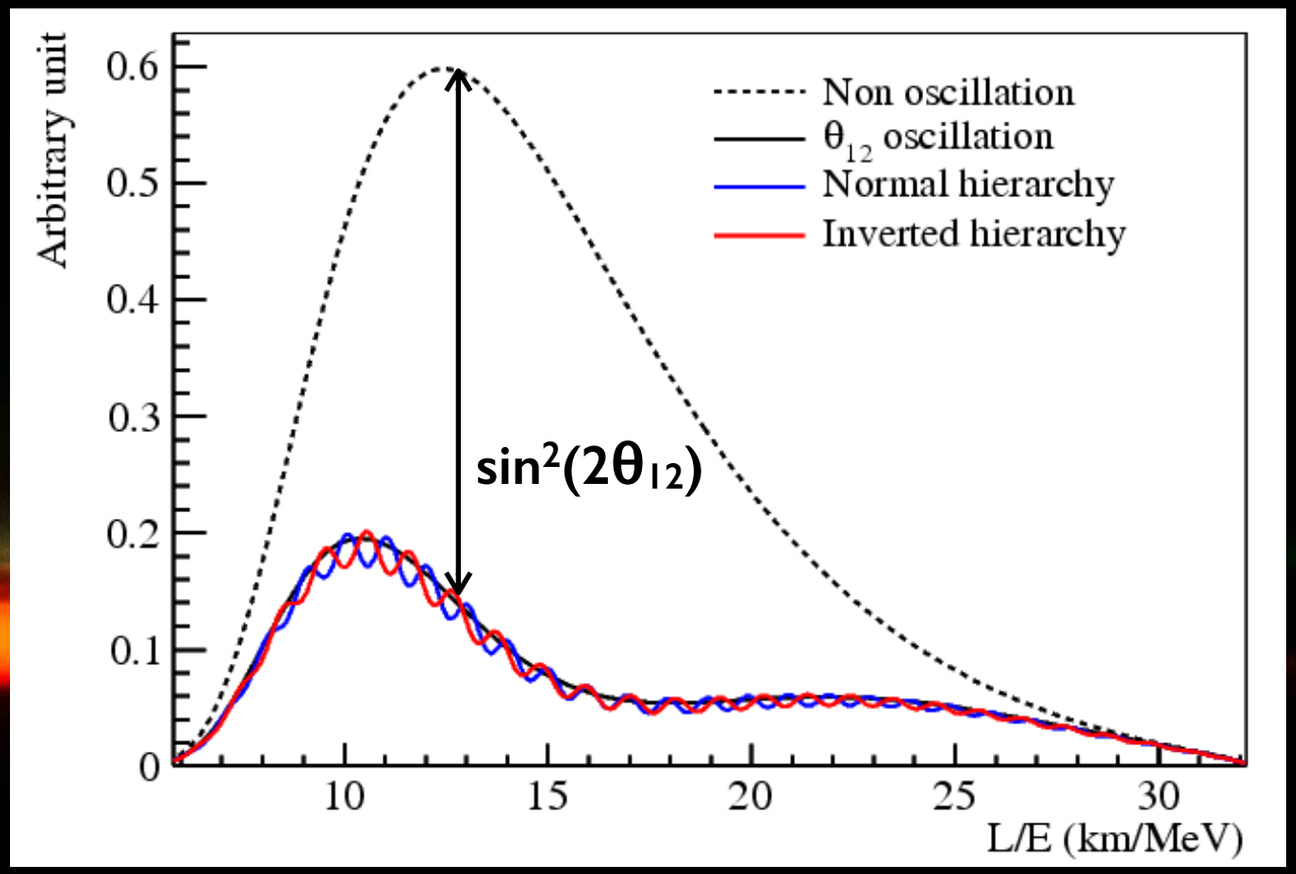
Efficiency, signal and background rates after each selection criterion

Selection	IBD efficiency	IBD	Geo-νs	Accidental	^{9}Li/^{8}He	Fast n	(α, n)
-	-	83	1.5	$\sim 5.7 \times 10^4$	84	-	-
Fiducial volume	91.8%	76	1.4	410	77	0.1	0.05
Energy cut	97.8%	73	1.3		71		
Time cut	99.1%						
Vertex cut	98.7%			1.1			
Muon veto	83%	60	1.1	0.9	1.6		
Combined	73%	60	3.8				

single-detector experiments…

(a priori) like **KamLAND**→ no need for near-detector



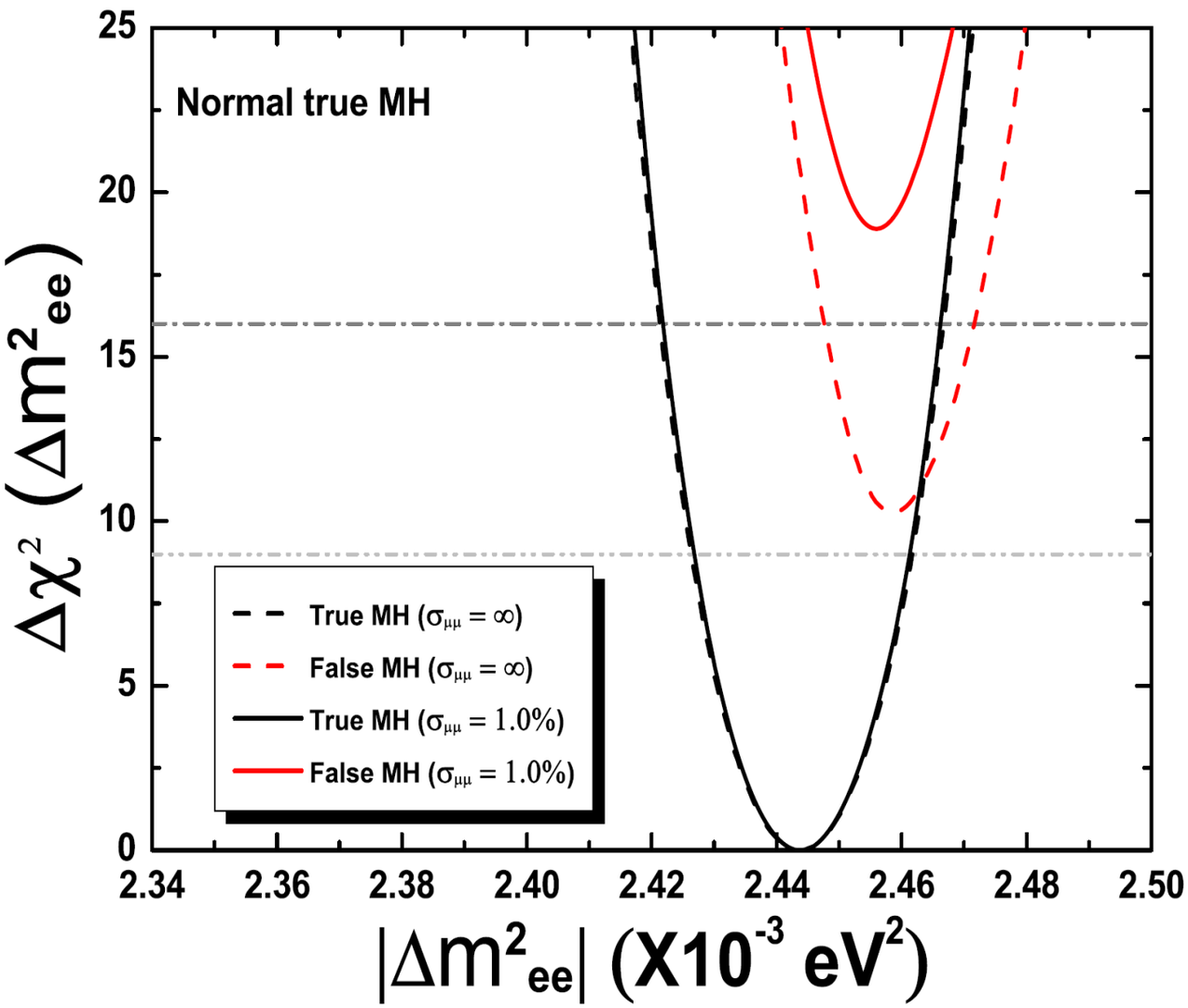


Double Chooz
(FD only)
1σ[sin2(2θ13)] ↔ δ(flux)

JUNO
(one detector only)

fundamental physics (ν oscillations)→ strongly affected by δ(flux) uncertainties

Mass Hierarchy significance…



- ~3σ→ spectral measurement with no Δm^2 external constrain
- ~4σ→ external Δm^2 measured to ~1% error (ν_μ disappearance with ν-beam off-axis)
  - Δm^2 @~1% by T2K+NOvA
  - combined analysis [1312.1477]

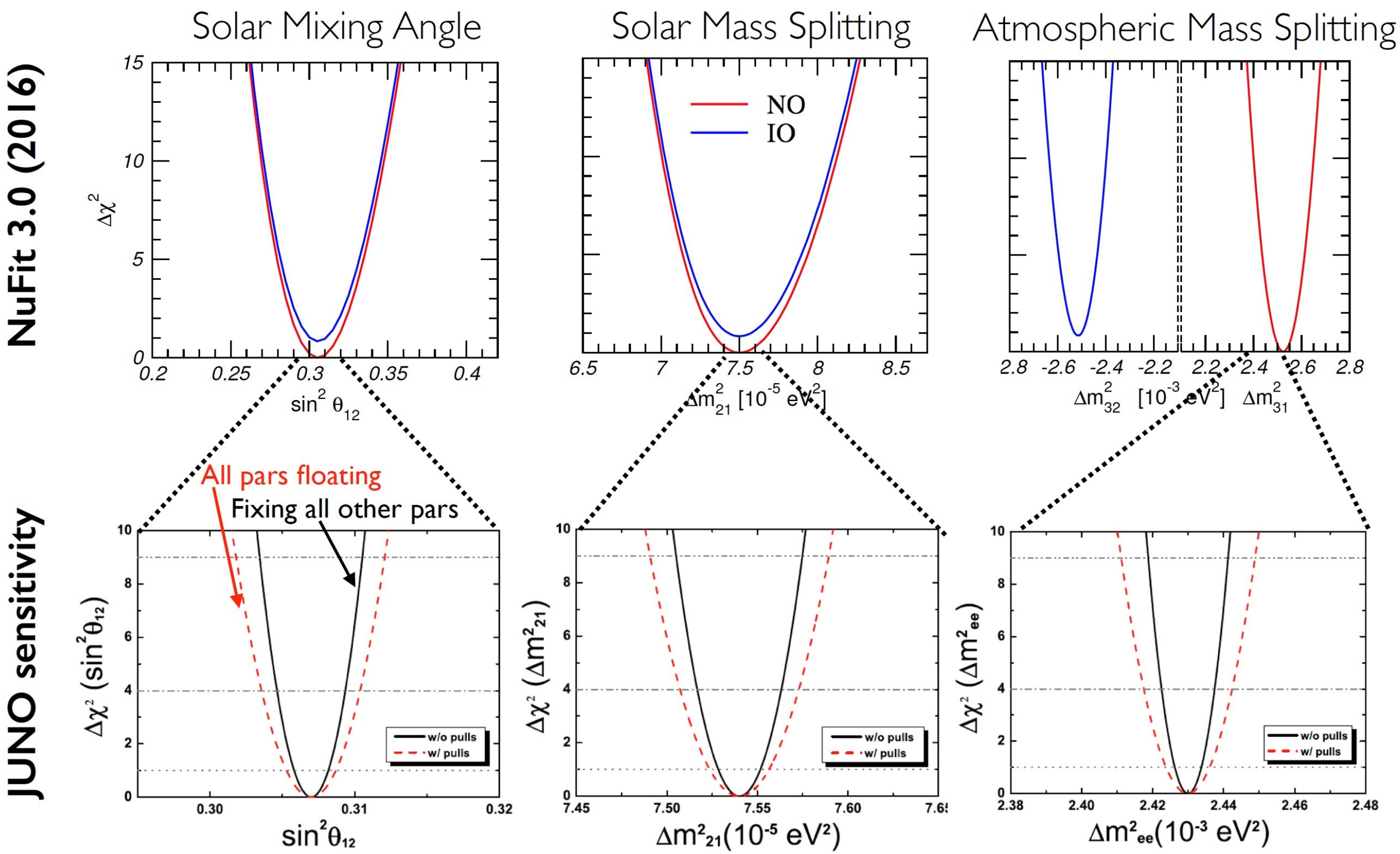
ingredients…

✓Realistic reactor distributions considered

✓20kt valid target mass ⊕ 36GW reactor power ⊕ 6-years data

✓3% energy resolution ⊕ ~1% energy scale uncertainty assumed

JUNO high precision oscillations…

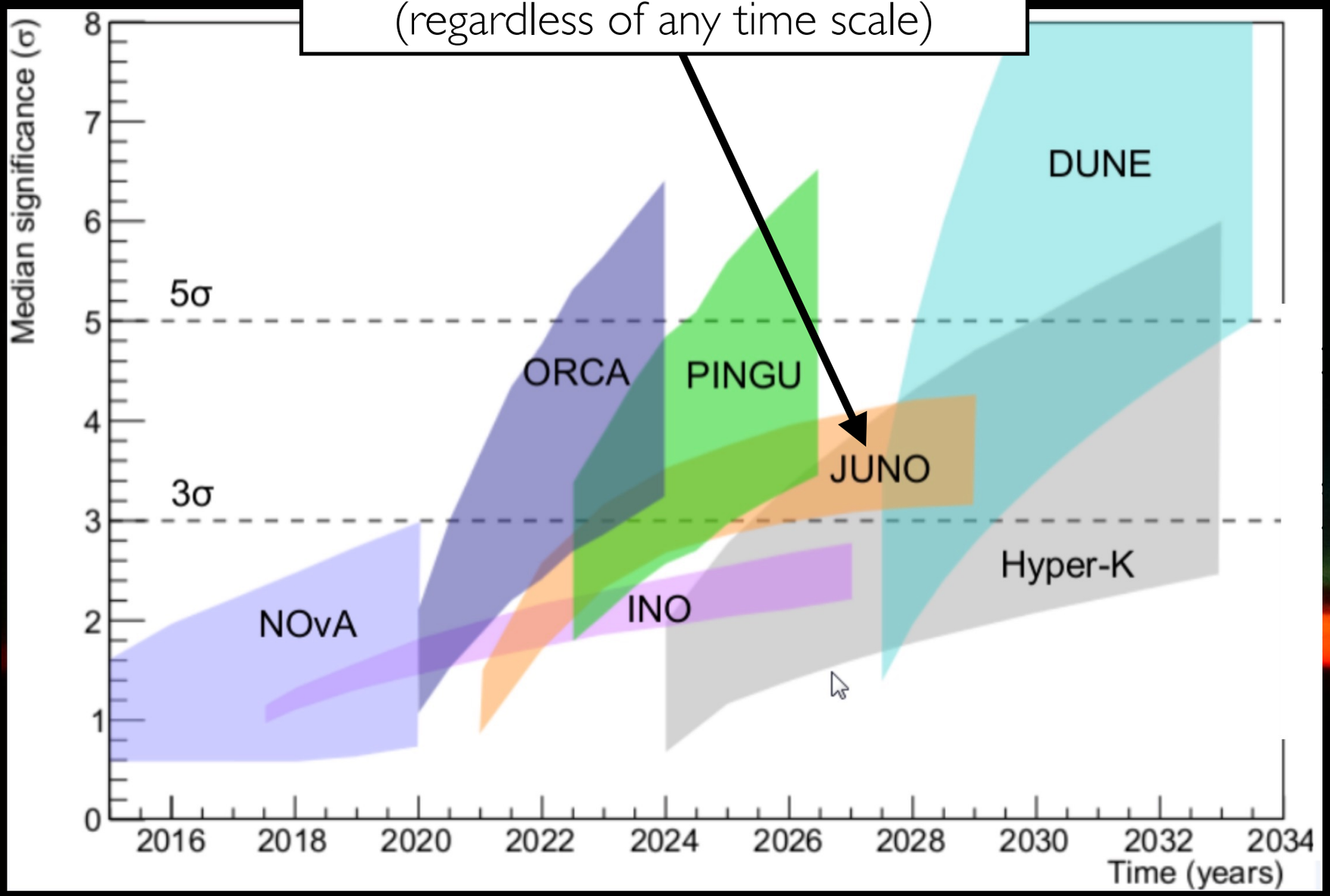


$\sin^2(\theta_{12})$: 0.54%

Δm^2_{21}: 0.24%

Δm^2_{ee}: 0.27%

don't forget…



JUNO = others
(nice!)

but

JUNO ≠ others
(breakthrough?)

2β0ν interplay

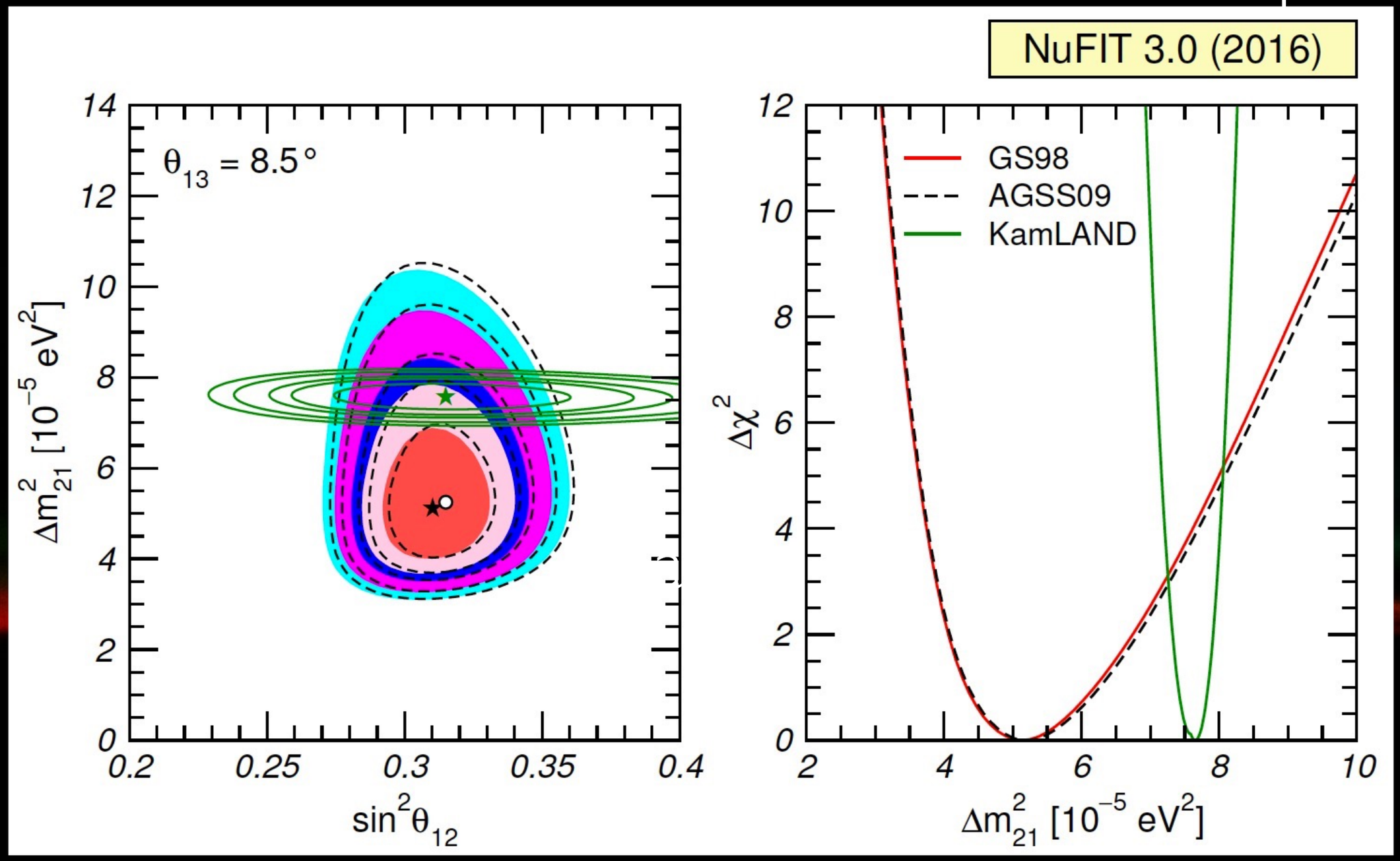
JUNO: huge amount of neutrino physics since early 2020's…

- **ν oscillation:** complementary & necessary for **high precision δ(CP)** [complementary]
  expected world leading knowledge in **δm^2**, **$\pm\Delta m^2$**, **θ_{12}** and unique **θ_{13} validation**
- **beyond ν oscillation:** study other sources (supernova, geo-neutrino, proton-decay, etc)

into today's panorama…
(an appetiser)

Anatael Cabrera (CNRS-IN2P3 & APC)

KamLAND vs SOLAR discrepancy…

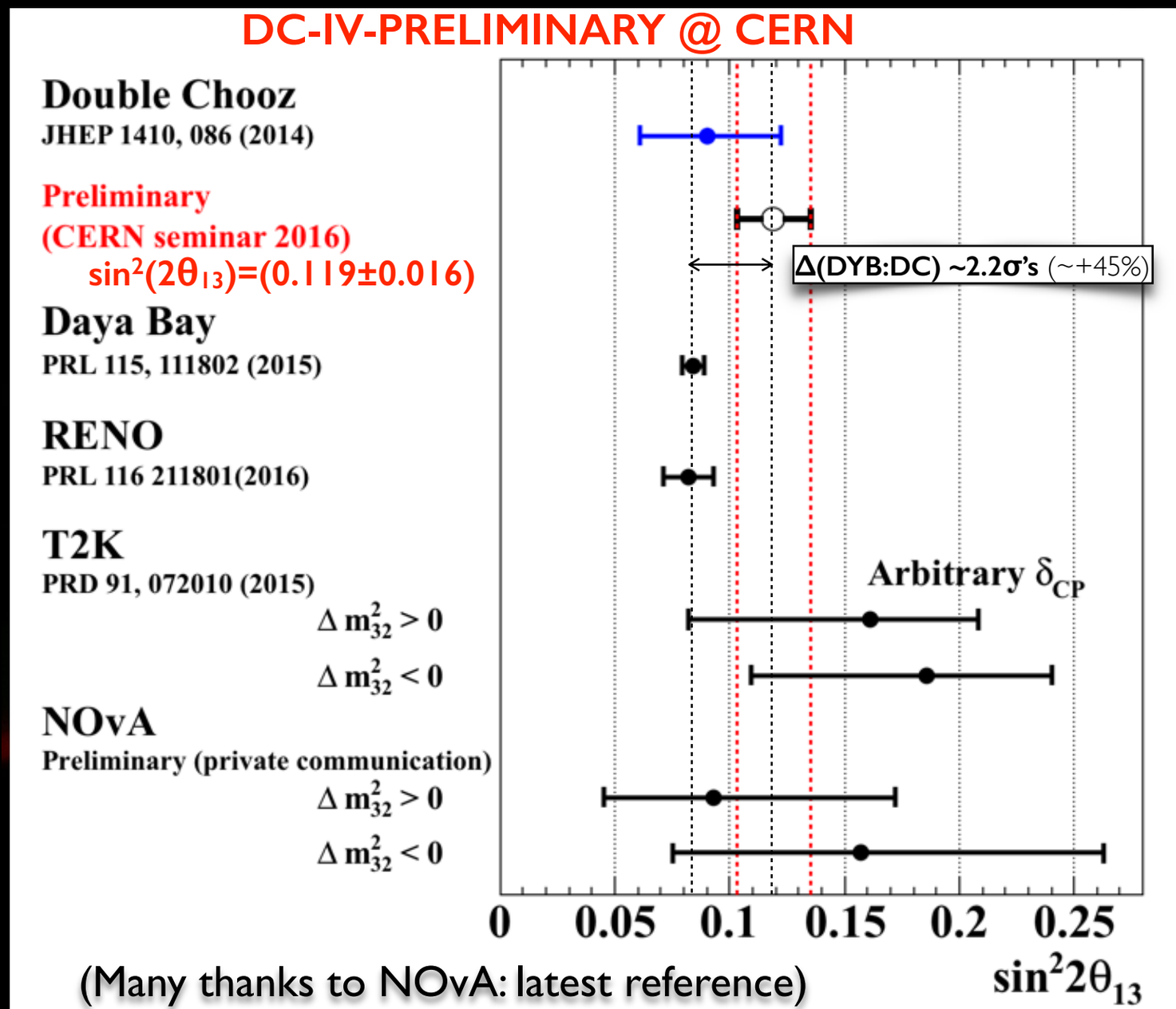


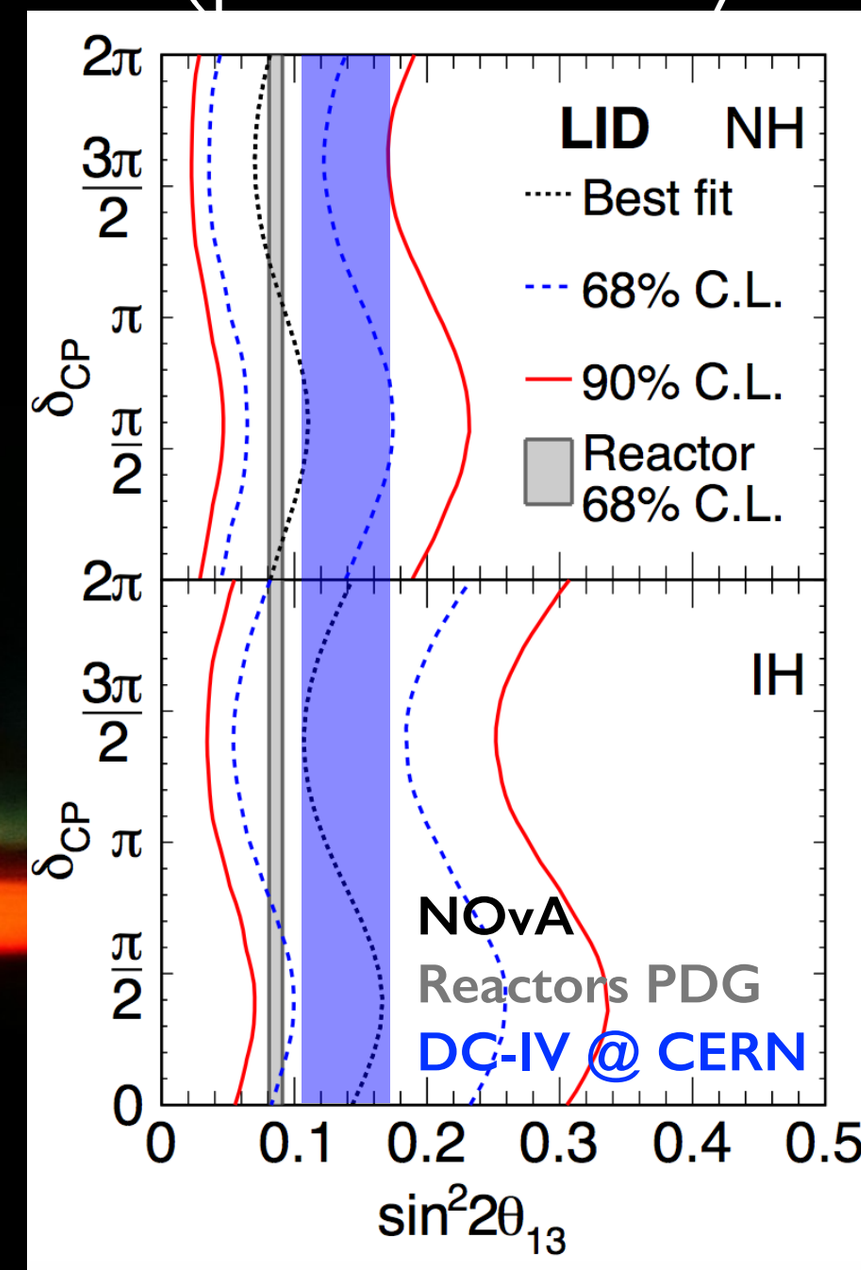
solar-ν physics vs reactor-ν physics?

(an experimental feature: i.e. bias?)

JUNO measurement of $\sin^2(2\theta_{12}) \oplus \delta m^2$ (unique!)

DC-IV @ CERN (preliminary…





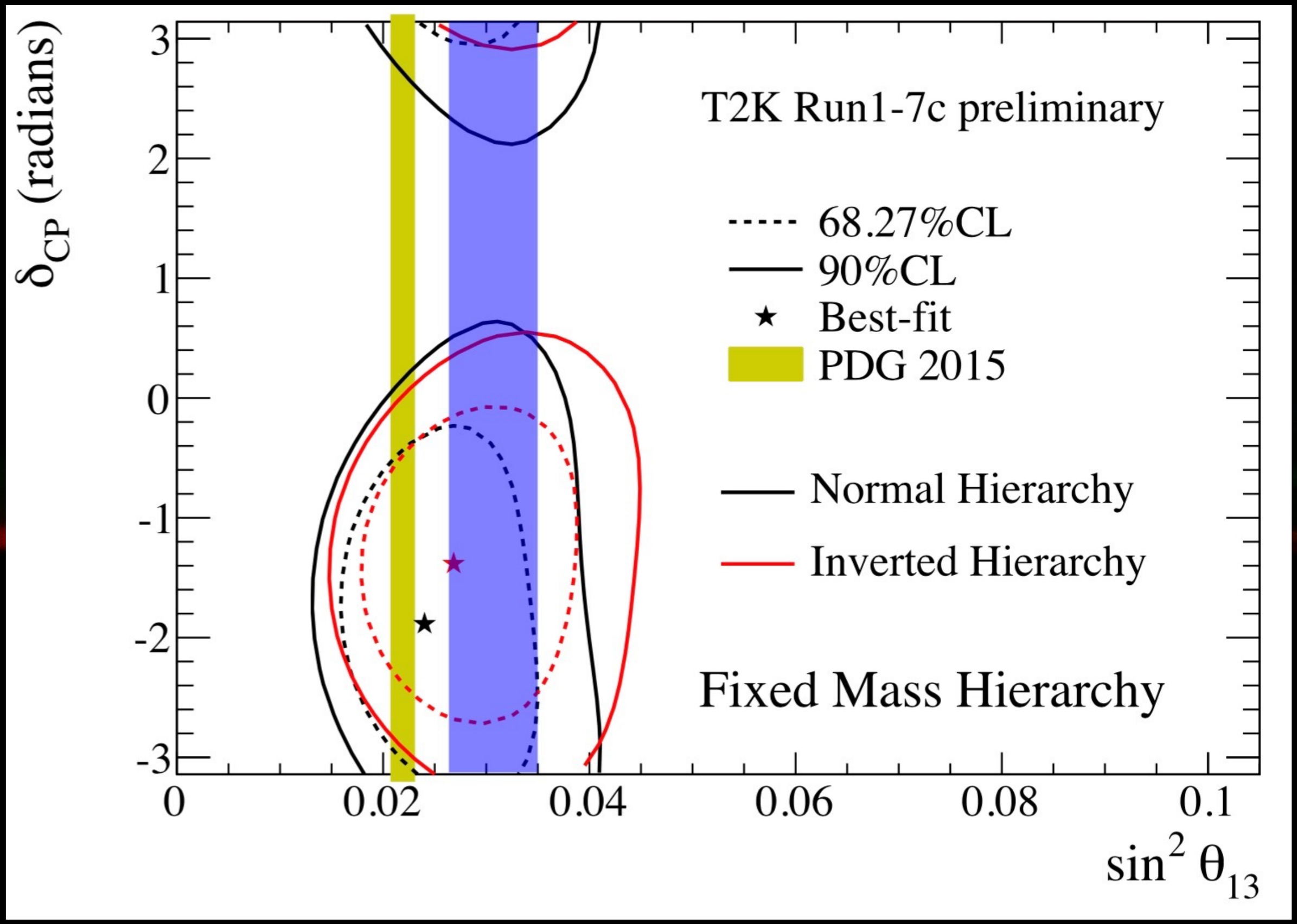
Example: NOvA

DC vs DYB discrepancy unresolved?

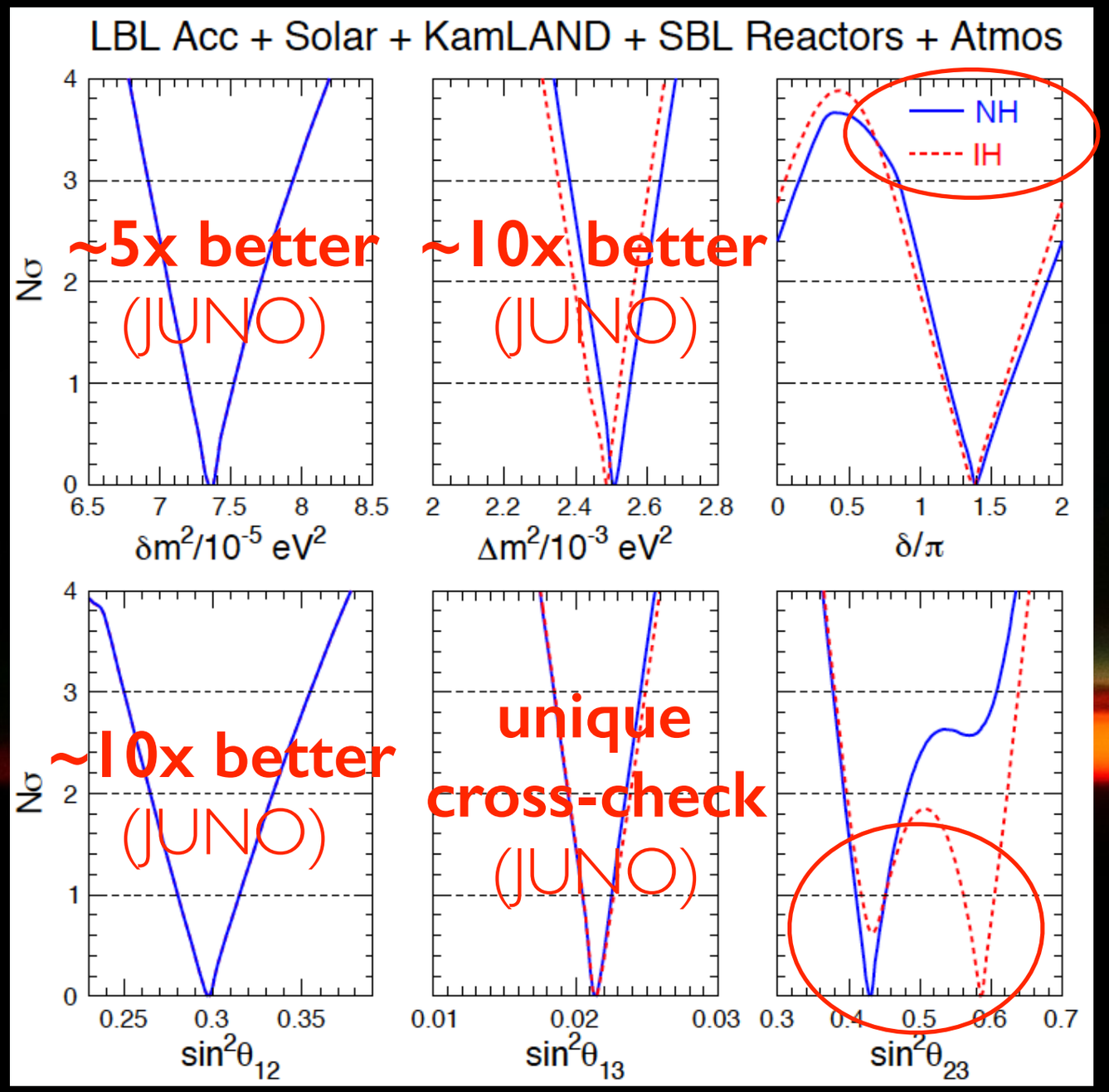
(beam use this as input to tackle key unknowns(θ_{23},δ_{CP})→ richer physics)

beyond **reactor-θ_{13}** (DYB⊕DC⊕RENO)→ **only JUNO might be able to help!**

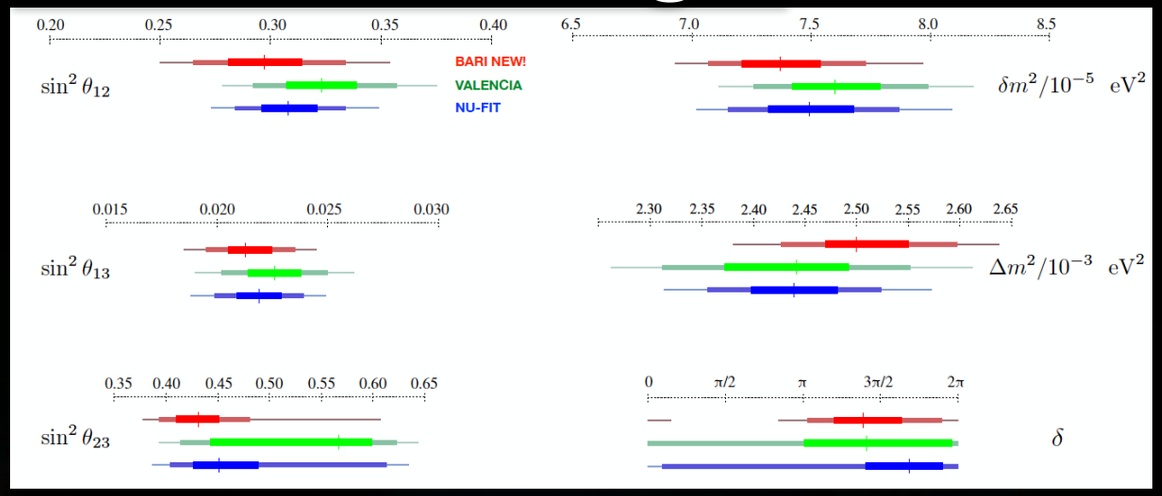
also against the latest T2K (ICHEP-2016)



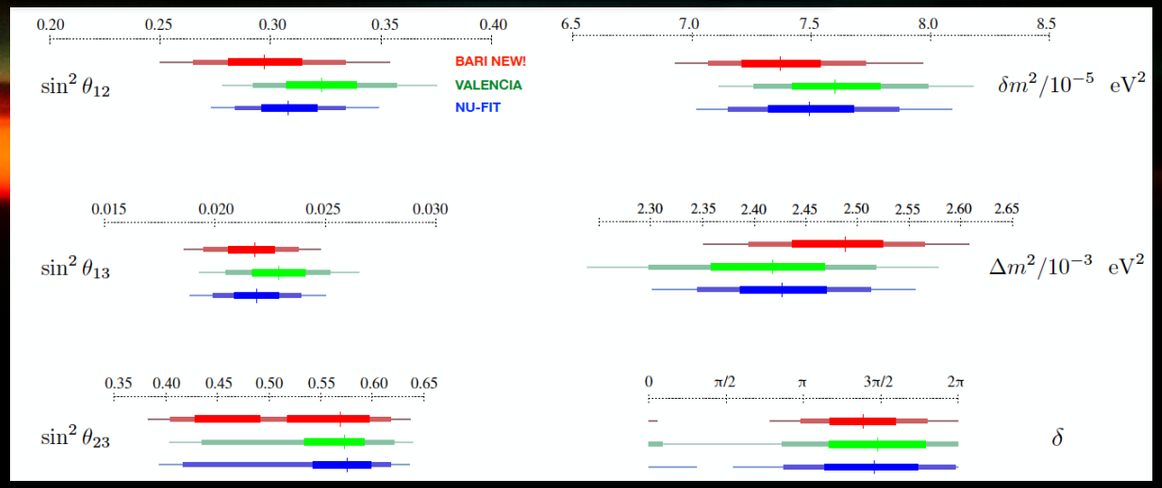
(*Marrone et al* @ NEUTRINO-16) 3ν oscillation status…



normal ordering…



inverted ordering…



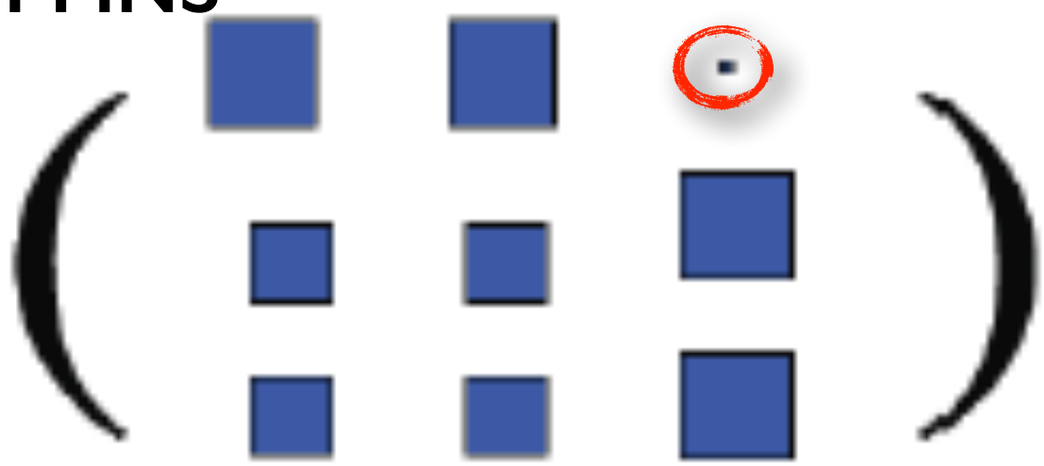
oscillation parameters: θ_{12}, $\pm\Delta m^2$, $\pm\delta m^2$, θ_{13}, θ_{23}, δ(CP)

⇒ improve **world precision knowledge** towards **δ(CP)**

BARI - NPB908 (2016) 218-234 VALENCIA - PRD90 (2014) 9, 093006 NU-FIT JHEP 11 (2014) 052 (www.nu-fit.org)

a (tough) BIG question…

U^{PMNS}



⇒ ~maximal mixing

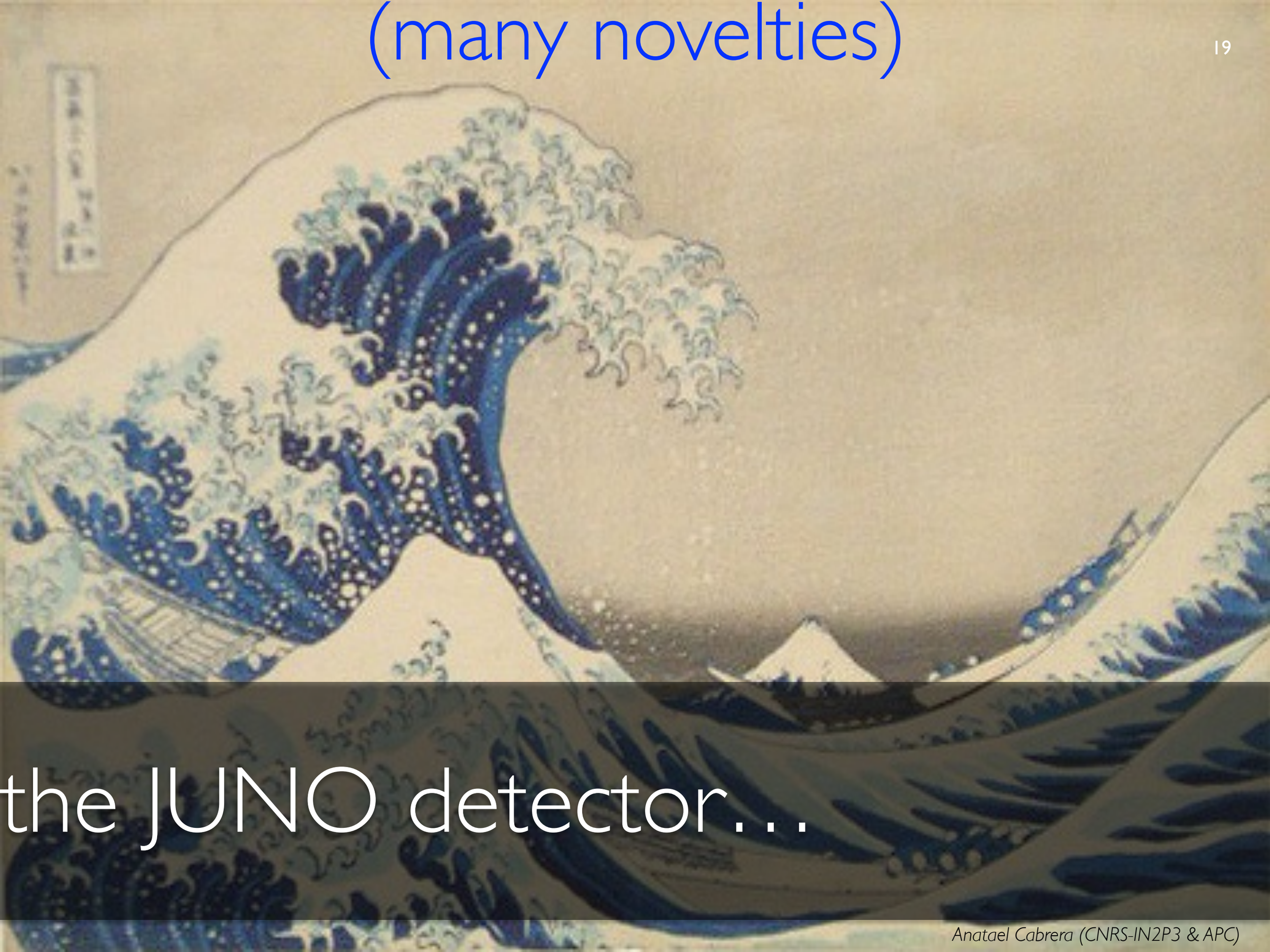
U^{CKM}

⇒ ~minimal mixing

PMNS meets unitarity?

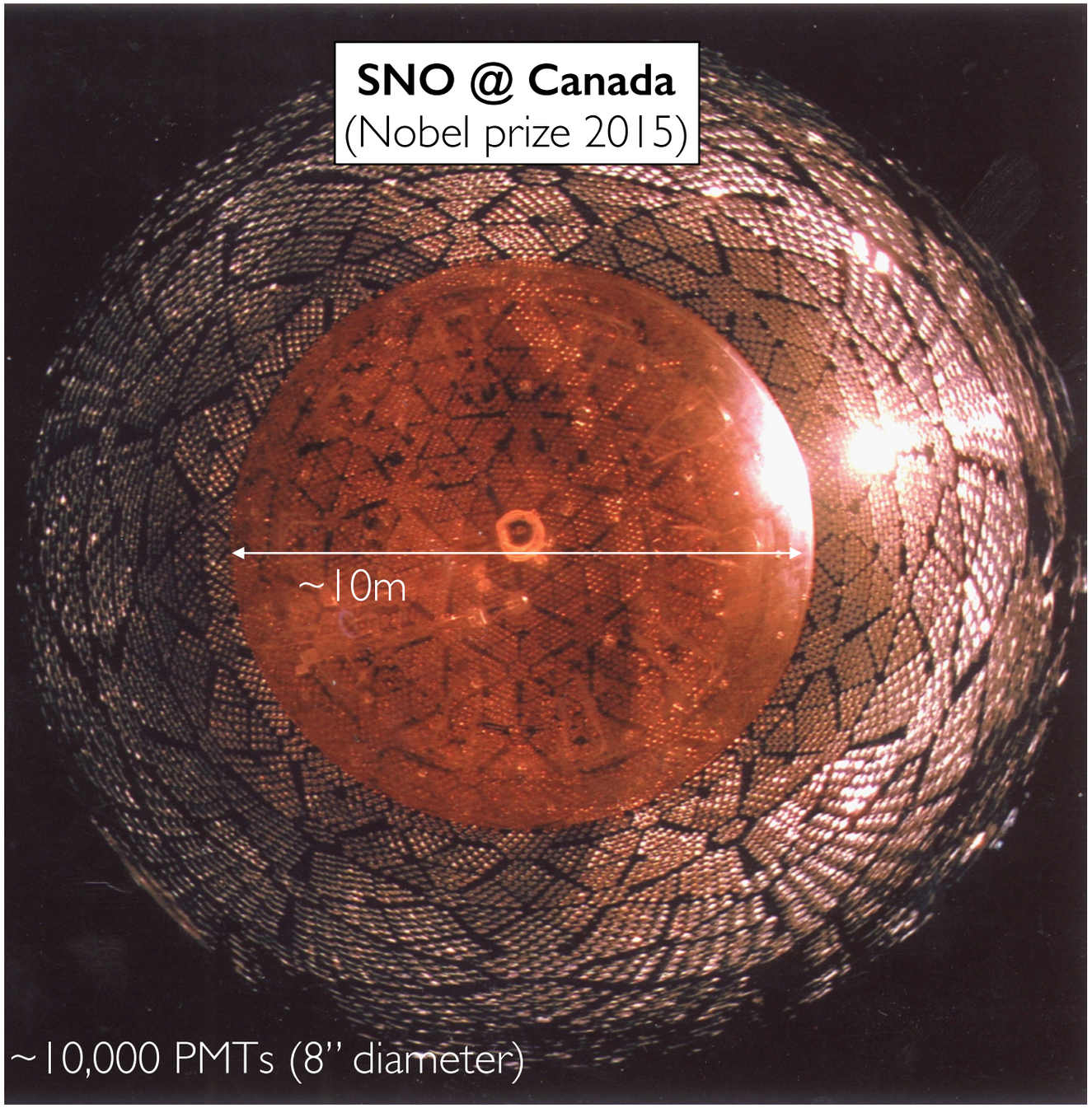
(beyond standard model→ only 3 families?)

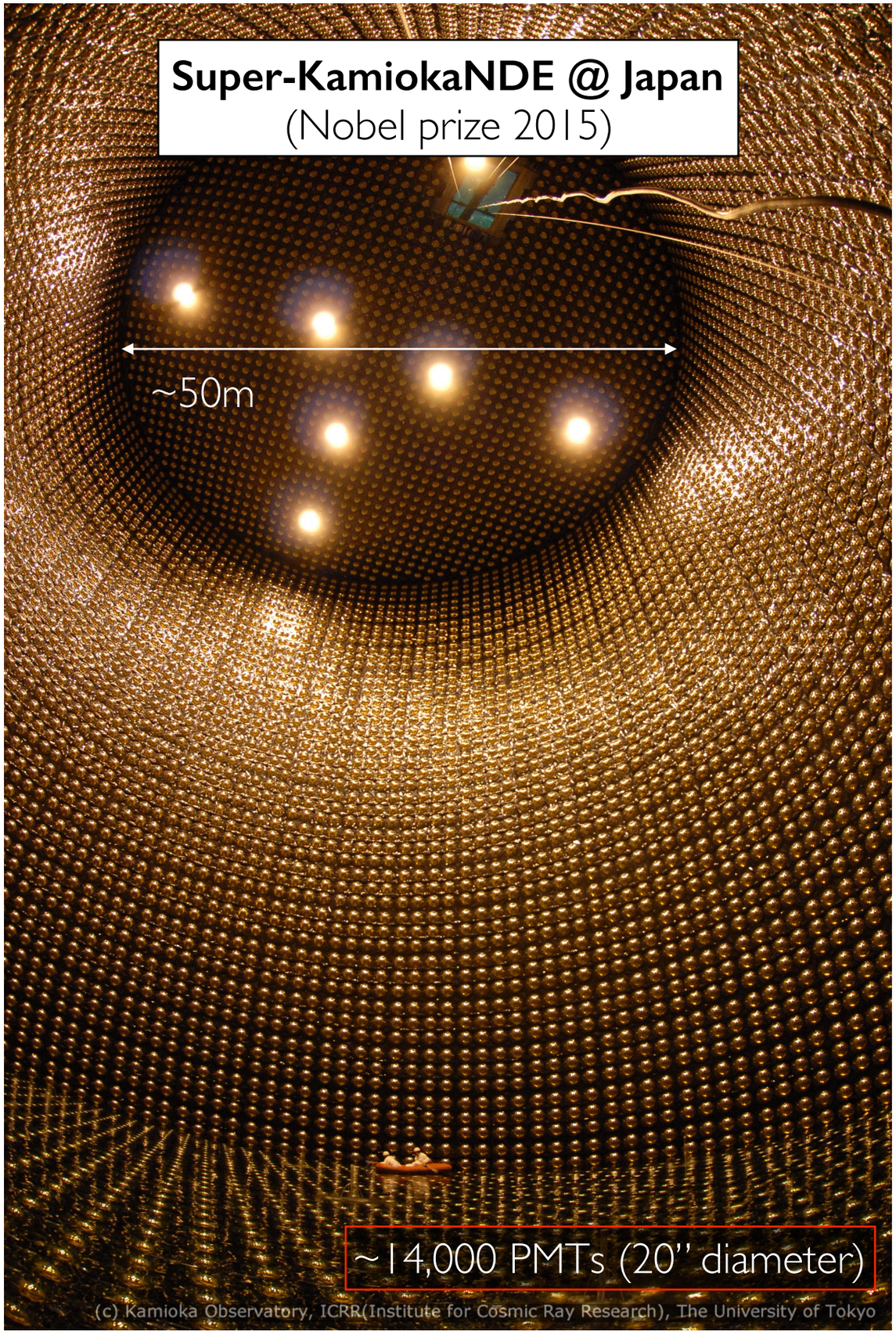
(many novelties)



the JUNO detector…

the JUNO detector (predecessors)…



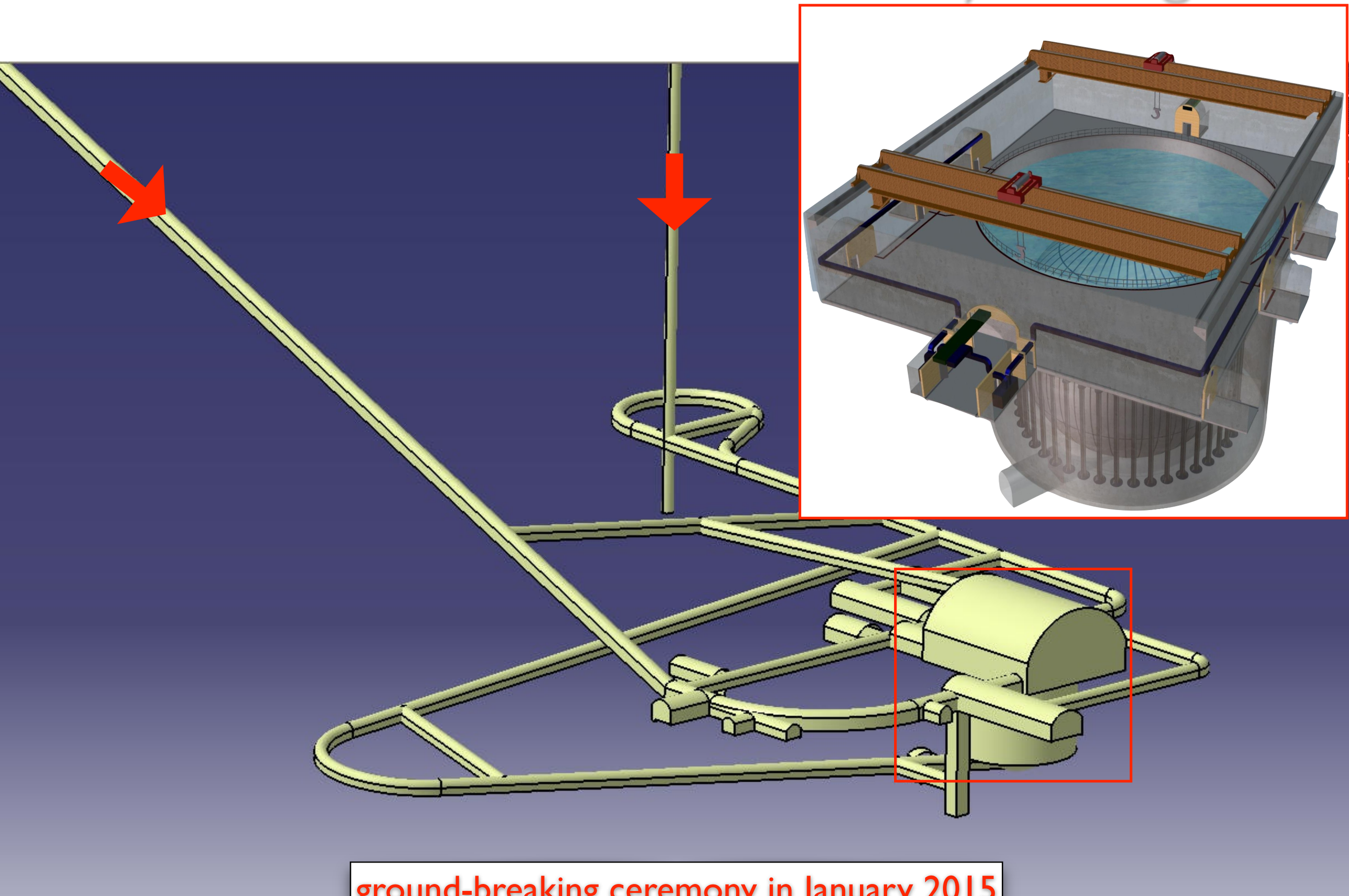


JUNO can be regarded as a hybrid of both…
(filled with liquid-scintillator→ **~100x more light**)

underground lab status…

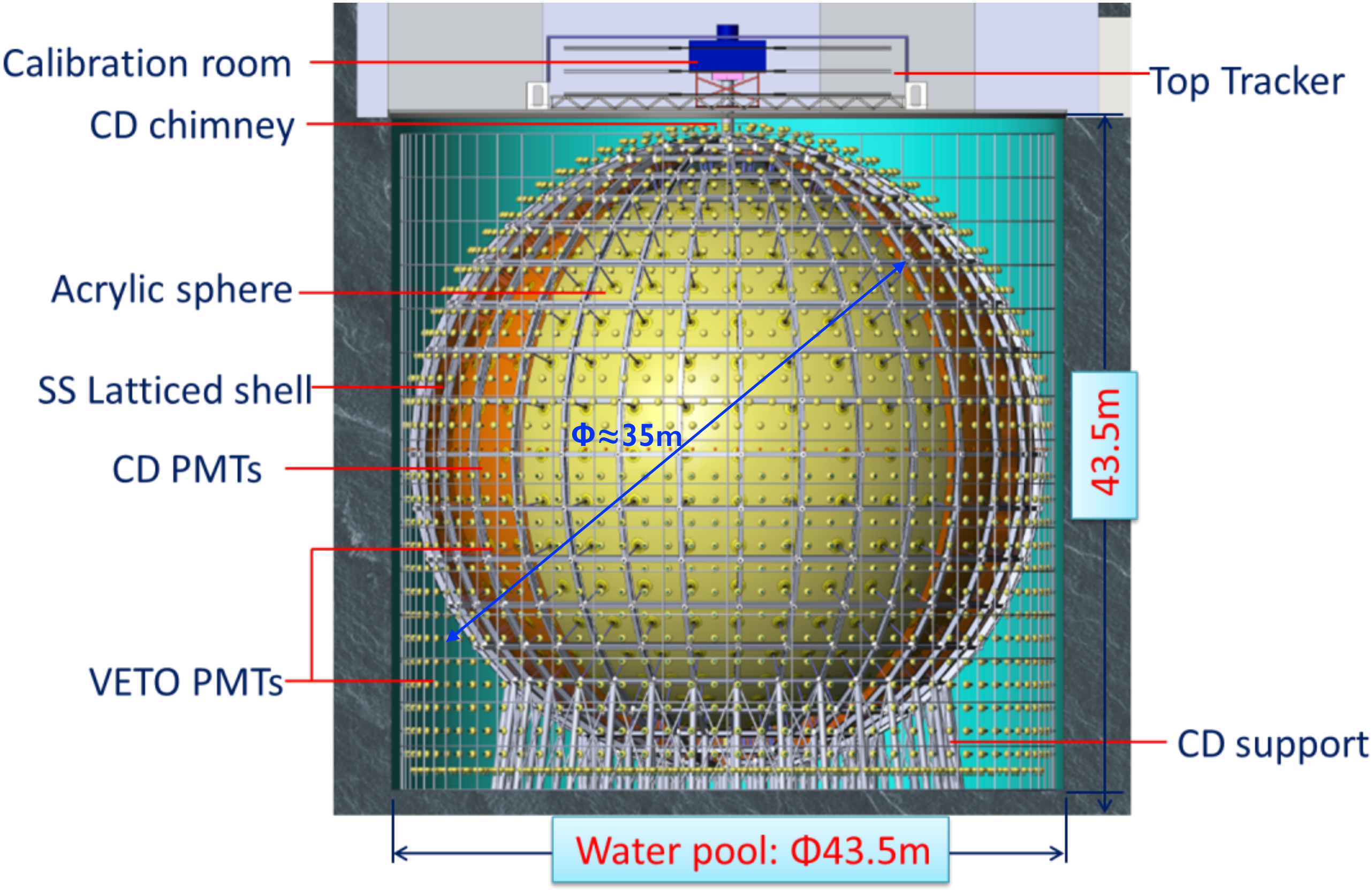
digging…

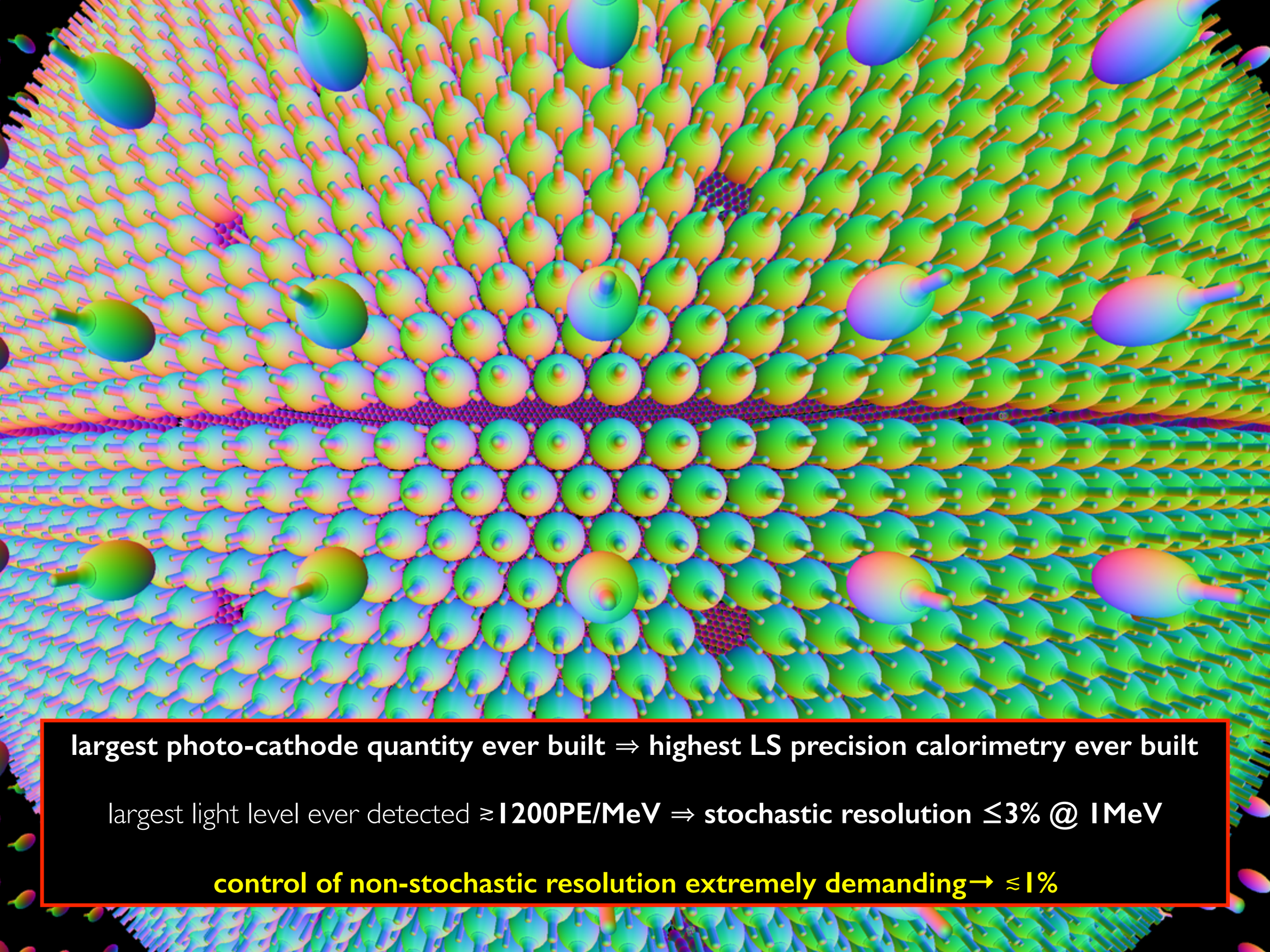
new laboratory underground



ground-breaking ceremony in January 2015

the JUNO detector…

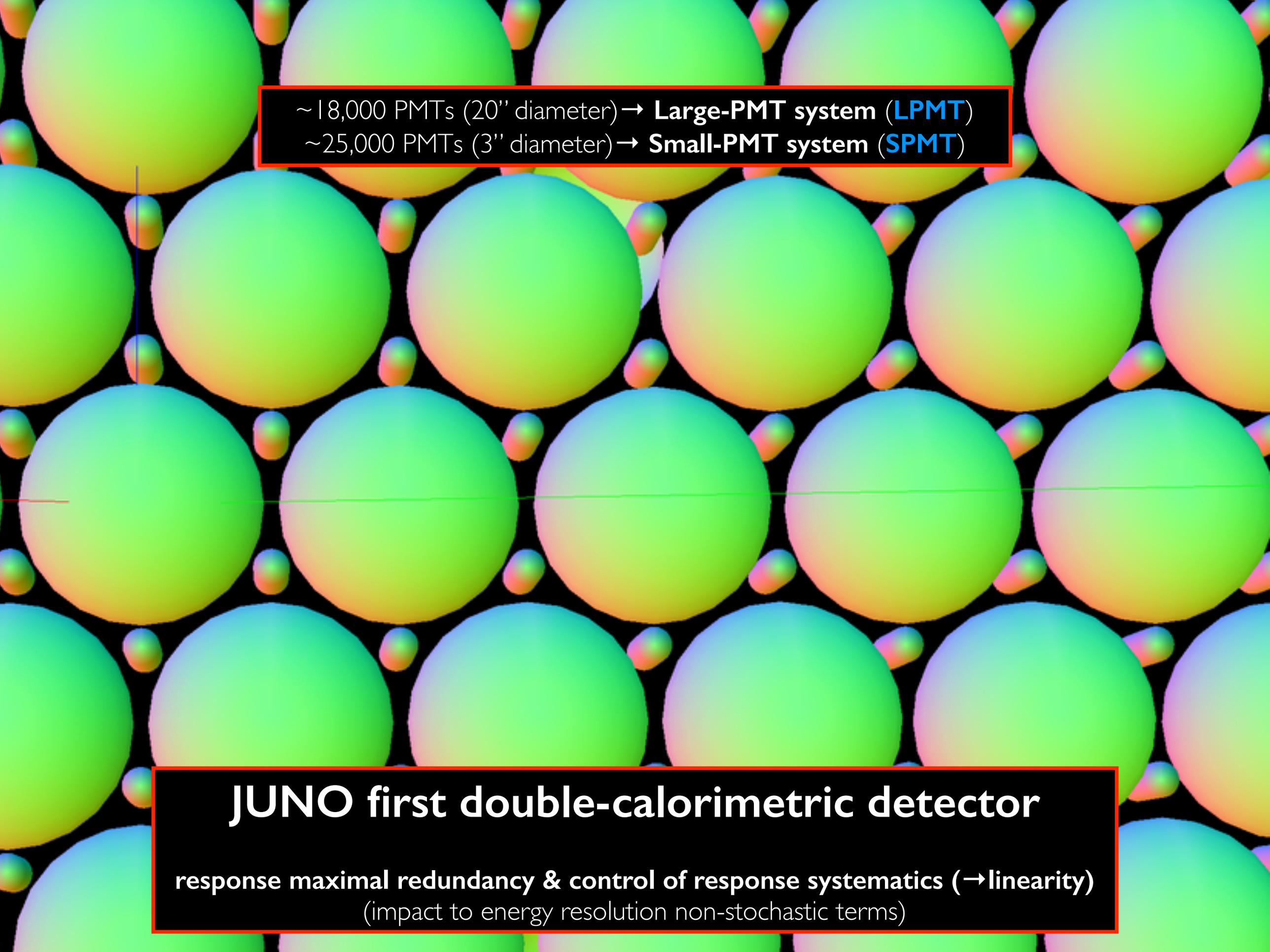




largest photo-cathode quantity ever built ⇒ highest LS precision calorimetry ever built

largest light level ever detected ≳**1200PE/MeV ⇒ stochastic resolution ≲3% @ 1MeV**

control of non-stochastic resolution extremely demanding→ ≲1%

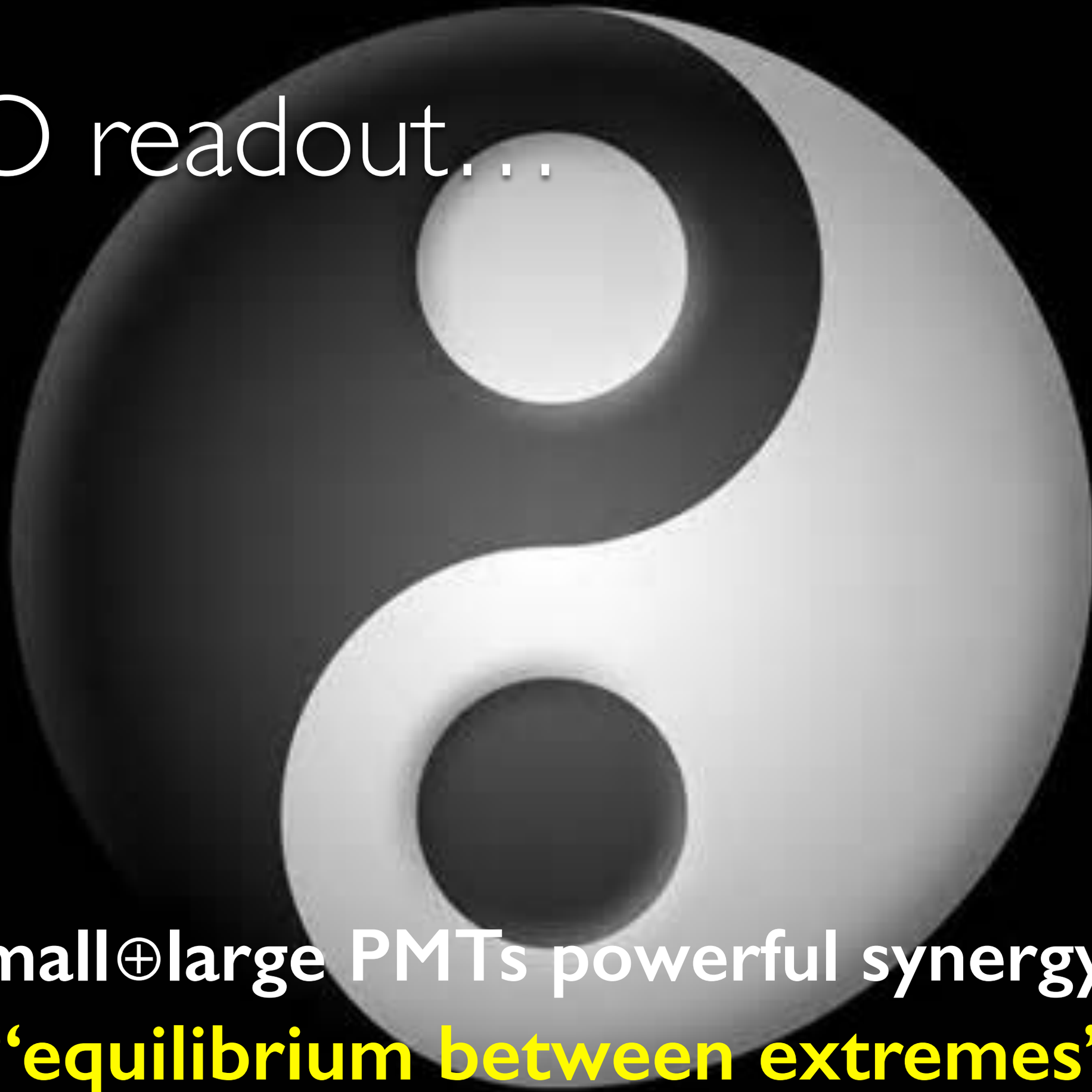


~18,000 PMTs (20'' diameter) → **Large-PMT system** (**LPMT**)
~25,000 PMTs (3'' diameter) → **Small-PMT system** (**SPMT**)

JUNO first double-calorimetric detector

response maximal redundancy & control of response systematics (→linearity)
(impact to energy resolution non-stochastic terms)

JUNO readout…



— small⊕large PMTs powerful synergy —

(“equilibrium between extremes”)

latest JUNO highlights…

Anatael Cabrera (CNRS-IN2P3 & APC)

excellent progress on all fronts…

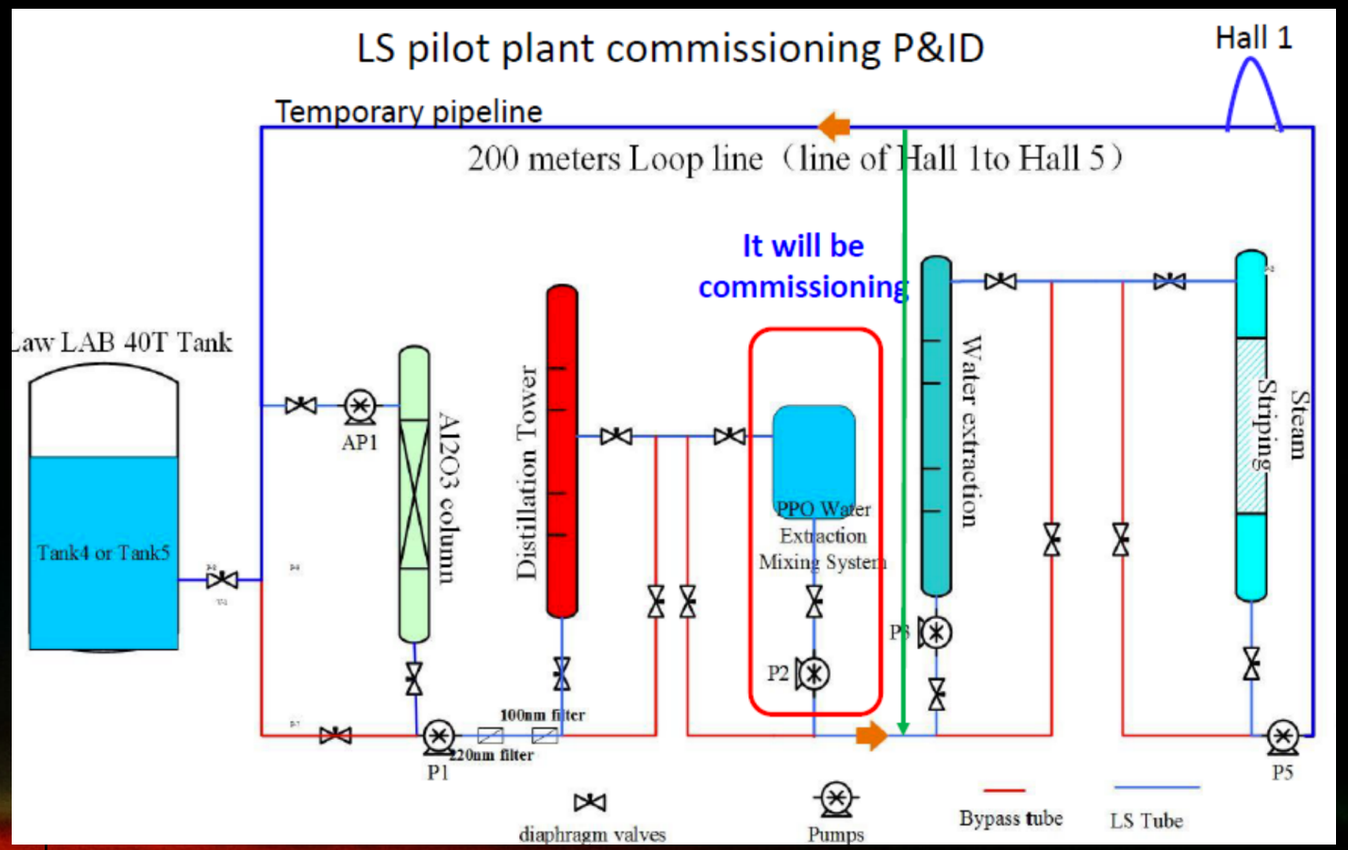
- **underground (~700m) laboratory civil construction**
- **surface laboratory**
- **central detector & μ (veto) detectors**
- **detector installation & integration**
- **<u>liquid scintillator</u> (transparency)**
- **<u>readout</u>**
- **<u>double calorimetric system</u>**
- **calibration (sources & deployment)**
- **<u>detector prototype</u> (validate dynamics/performance)**

JUNO LS stunning transparency…

Liquid Scintillator Purification Plants
composed of…

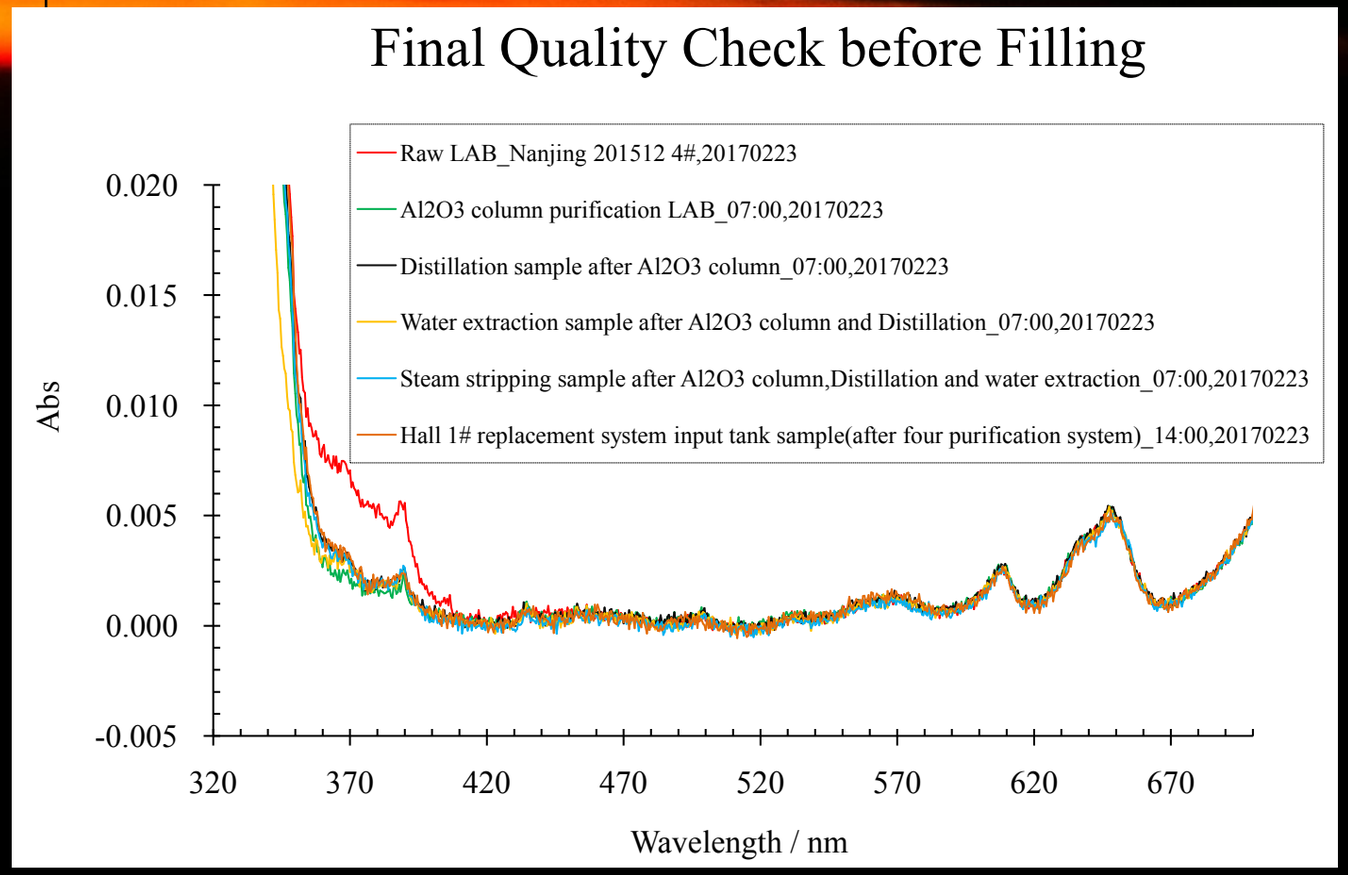
- AL_2O_3 Column
- Distillation Tower
- Water Extraction
- Steam Stripping

- very accurate cleaning of all the parts

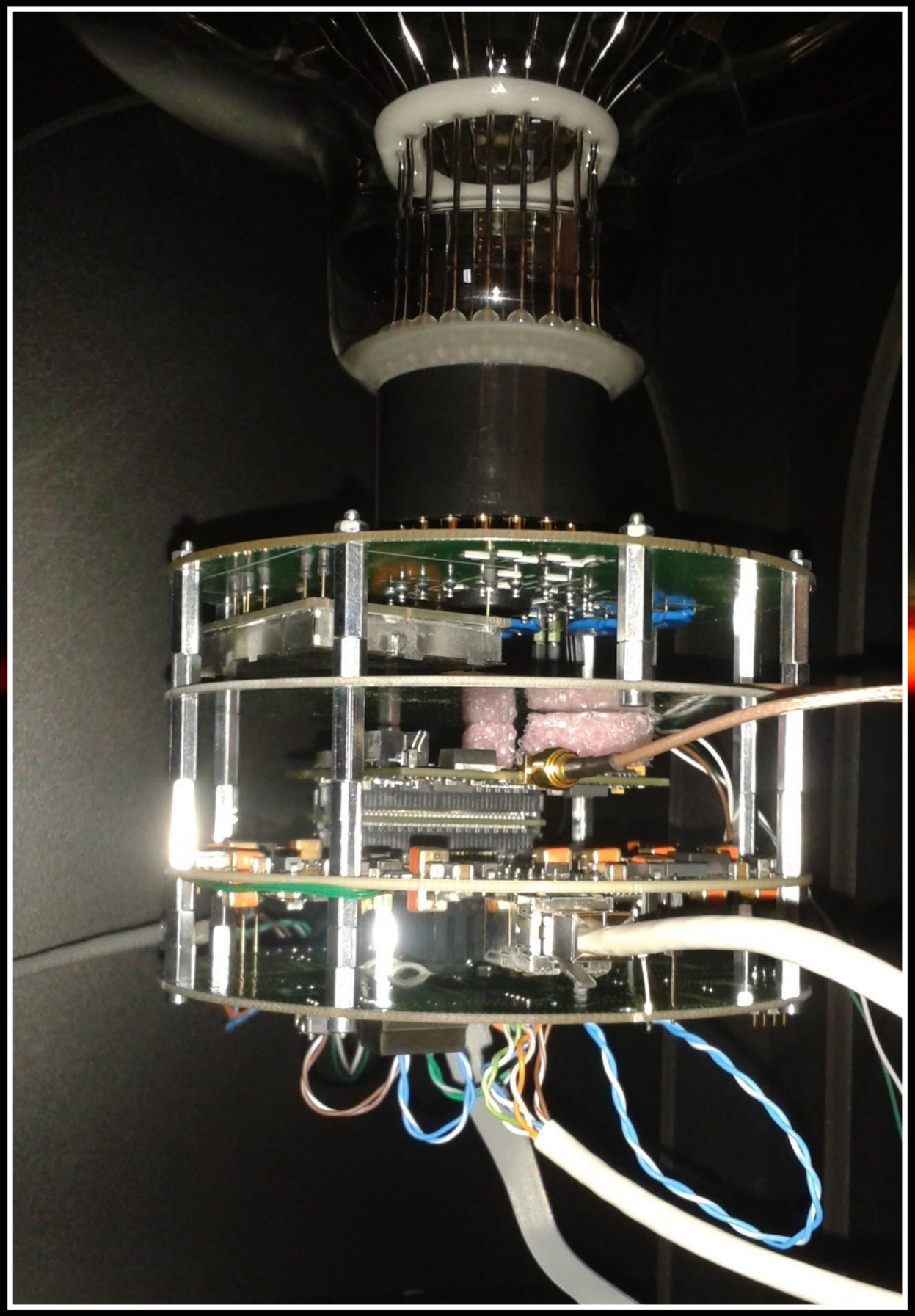


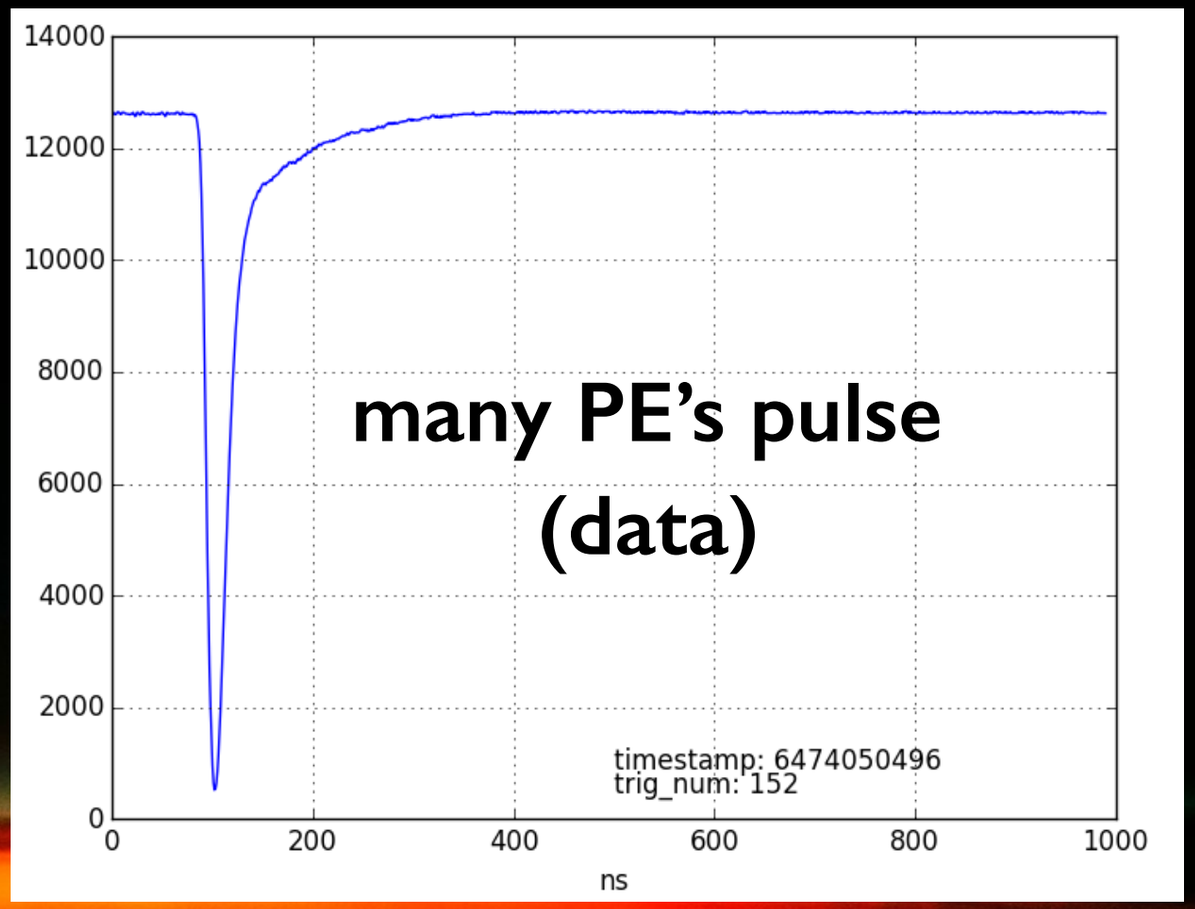
validation @ Daya Bay detector (Hall-1)

- 23rd-FEB to 7th-MARCH: purified 20 m^3 Liquid Scintillator (LAB+PPO) through the 4 subsystem: **clear improvement of the absorption spectra**.
- **attenuation length: ~20.5m→ ~25.1m**
- **JUNO goal ≥20m [feasible]**



large PMT new readout (1GHz FADC based)…



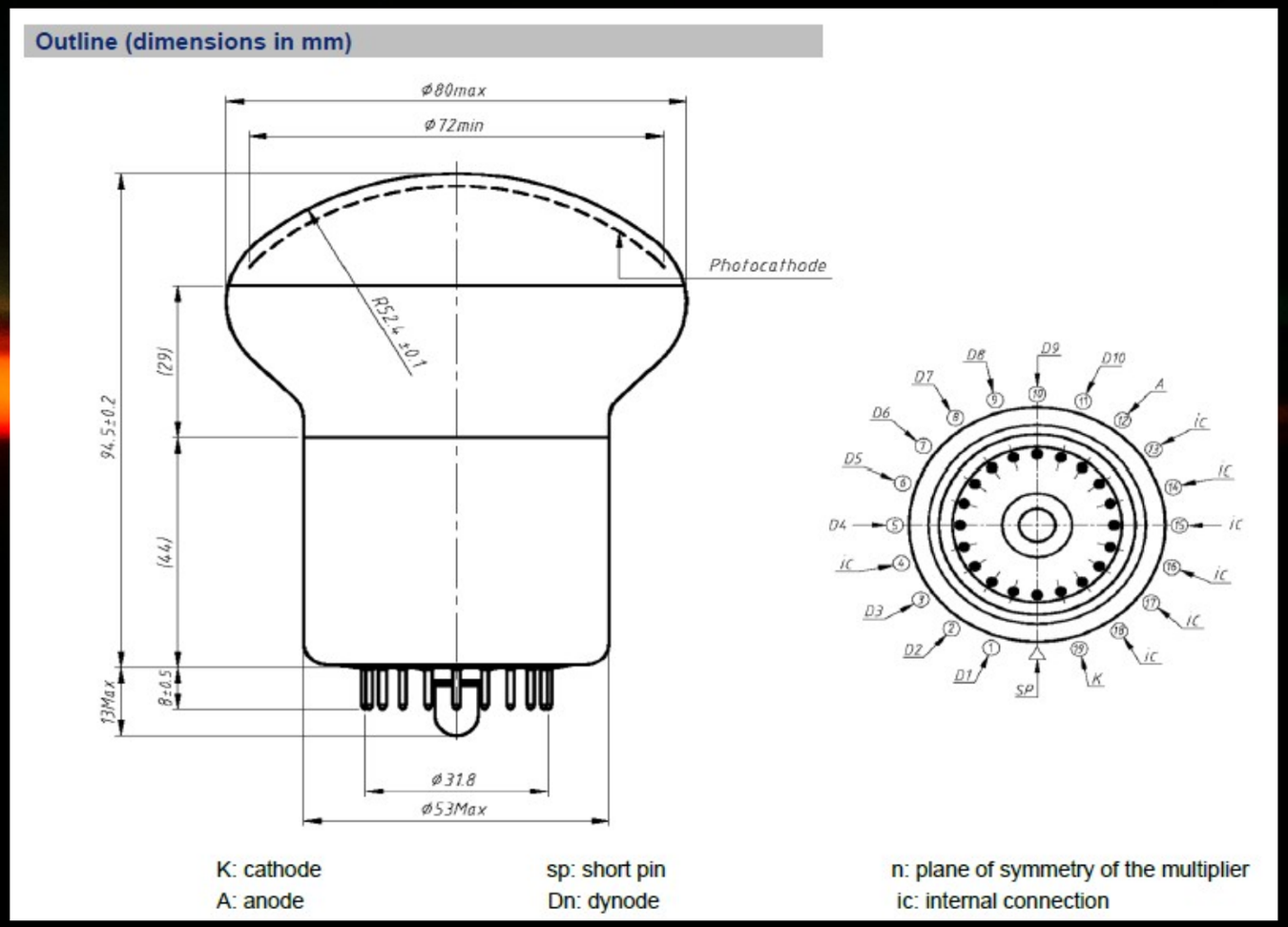


1st prototype demonstration…

- **analogue front-end**…
  - → baseline, noise, no ringing/overshoot, etc
- **digital front-end**…
  - → FADC sampling, data handling
- **connectivity (underwater-surface)**…
  - → cabling, interfaces, etc
- **digital back-end**…
  - → DAQ, clock, data-collection, etc

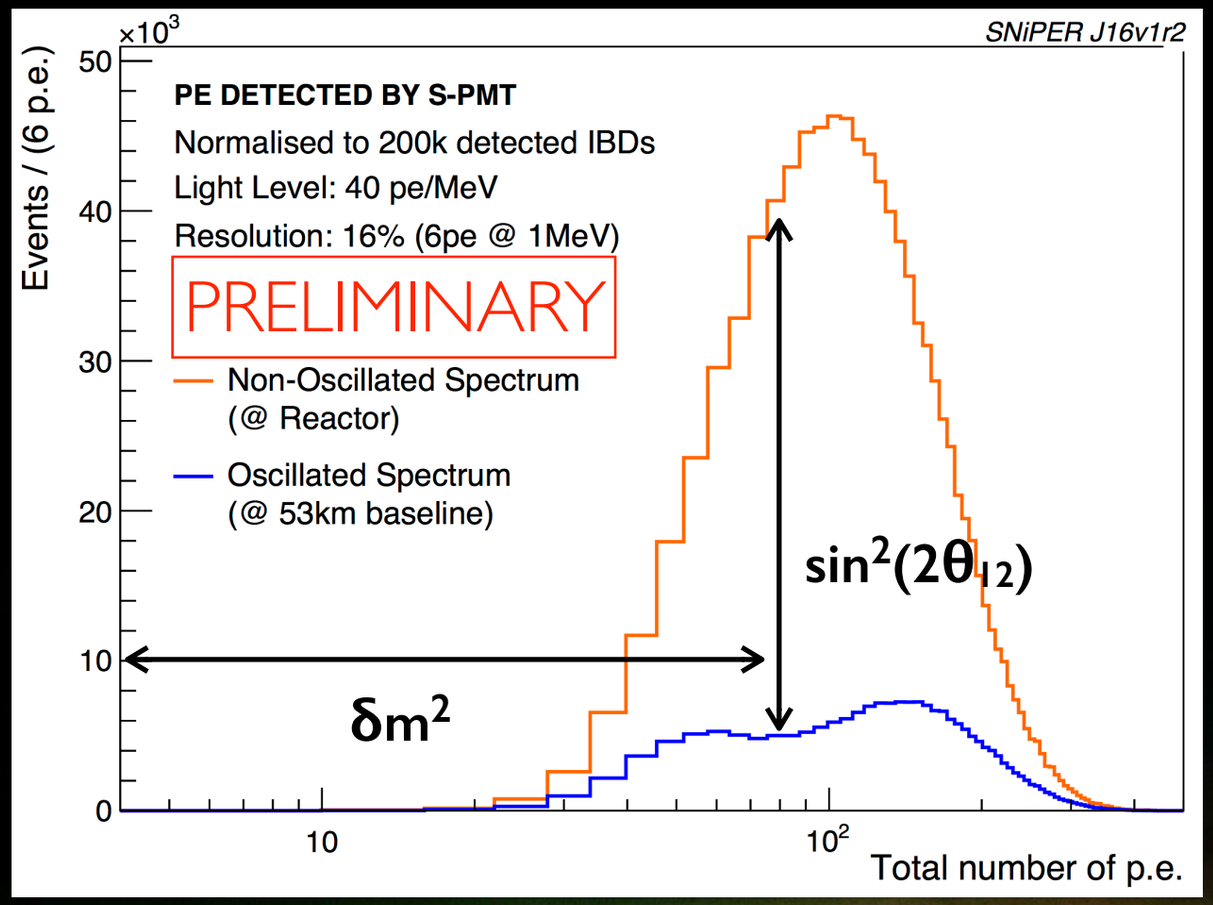
double calorimetry 3” PMT system…

26,000 XP72B20 3” PMTs ordered to HZC-Photonics (China) [8th MAY 2017]



new development with improved TTS (based on KM3Net design)

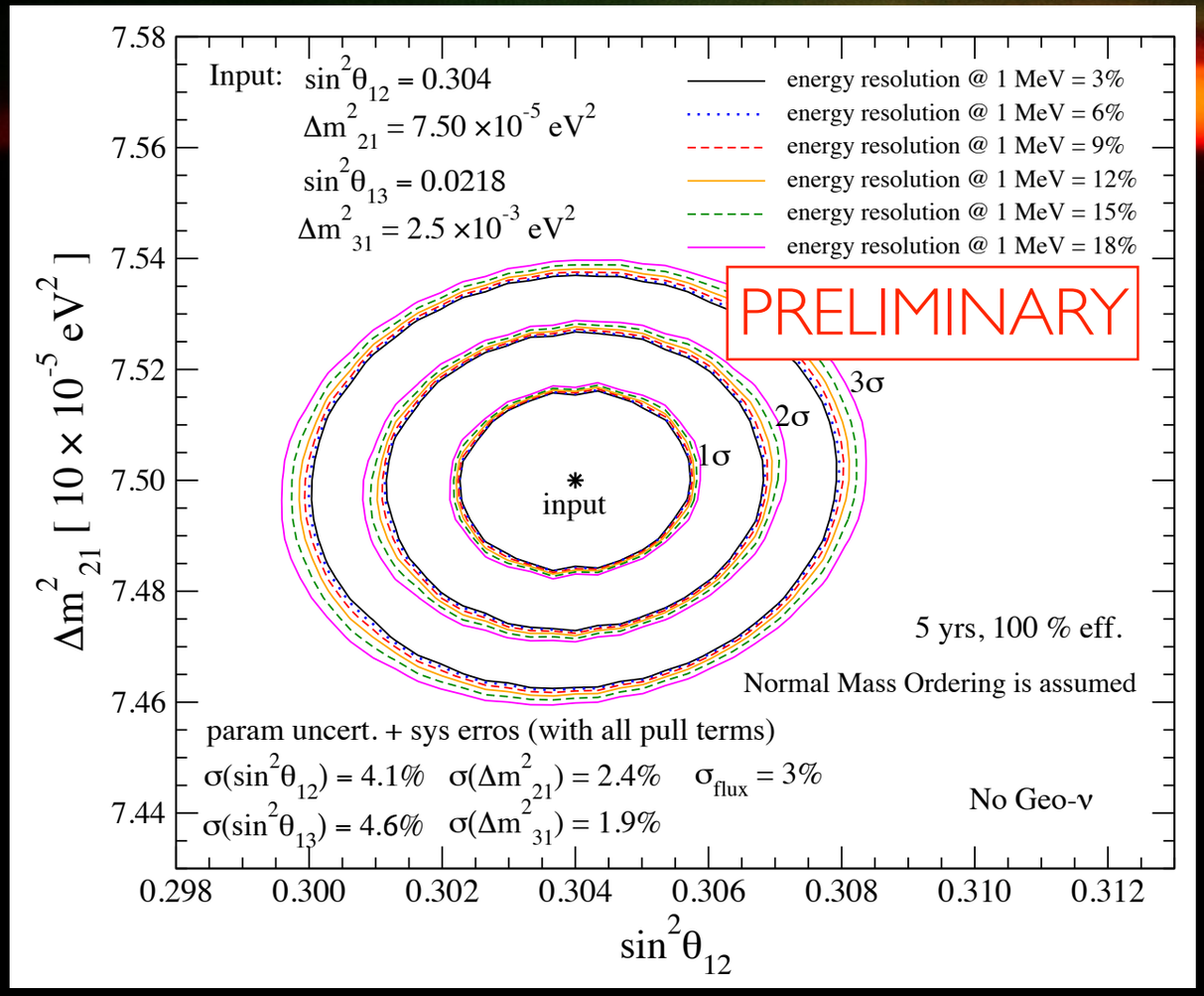
precision & redundancy…



2 measurements $\theta_{12} \oplus \delta m^2$ Rate⊕Shape

[shape-only $\theta_{13} \oplus \pm \Delta m^2$]

- 20'' PMT readout: resolution ~3%@1MeV
- 3'' PMT readout: resolution ≤15%@1MeV



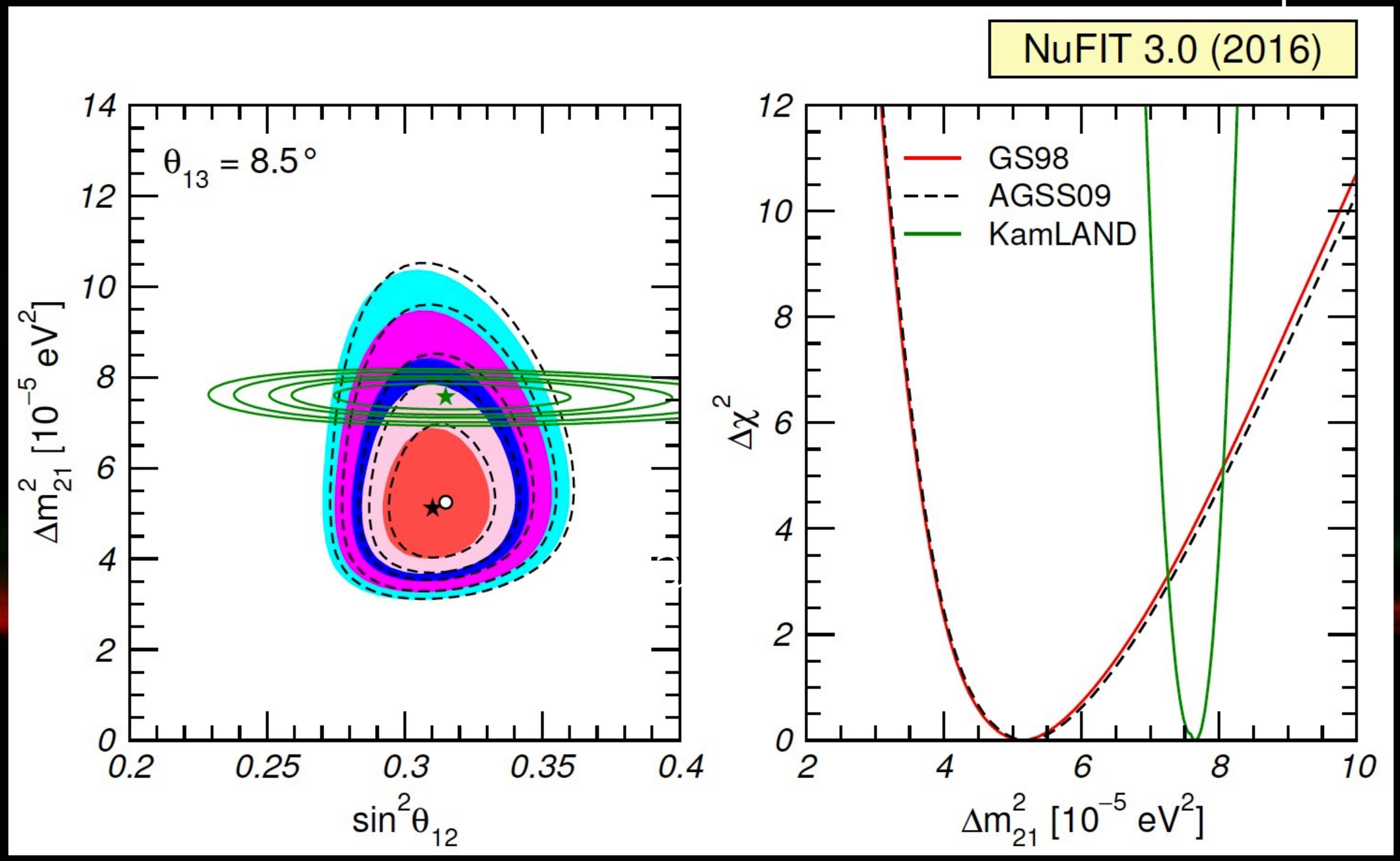
- 20'' PMT → 1 measurement
- 3'' PMT → 1 measurement

(not independent, **same detector**)

unique JUNO self-redundancy articulation (a must for high precision ≤1%)

NOTE: no JUNO competitor envisaged (unfortunately)

KamLAND vs SOLAR discrepancy…



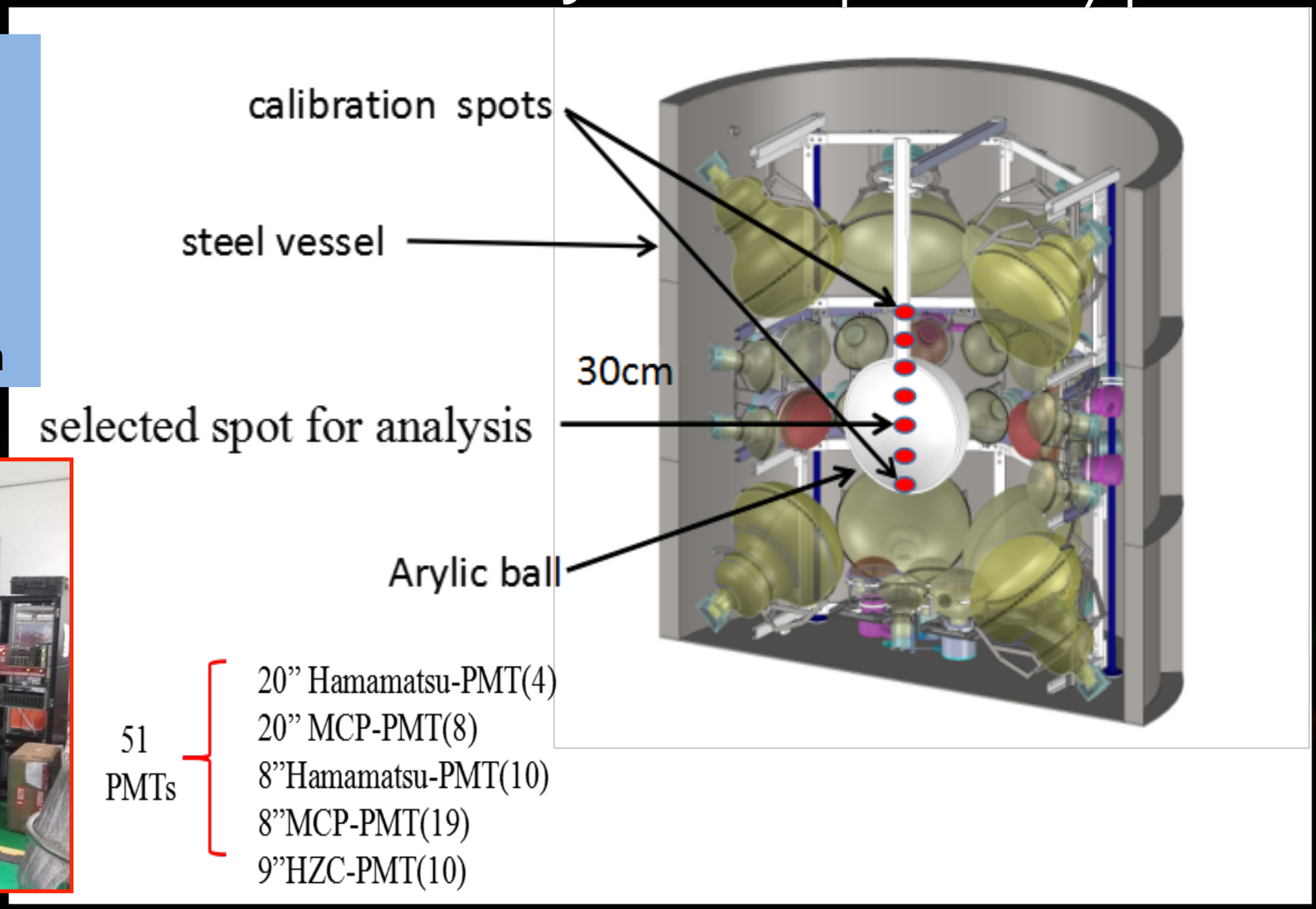
solar-ν physics vs reactor-ν physics?

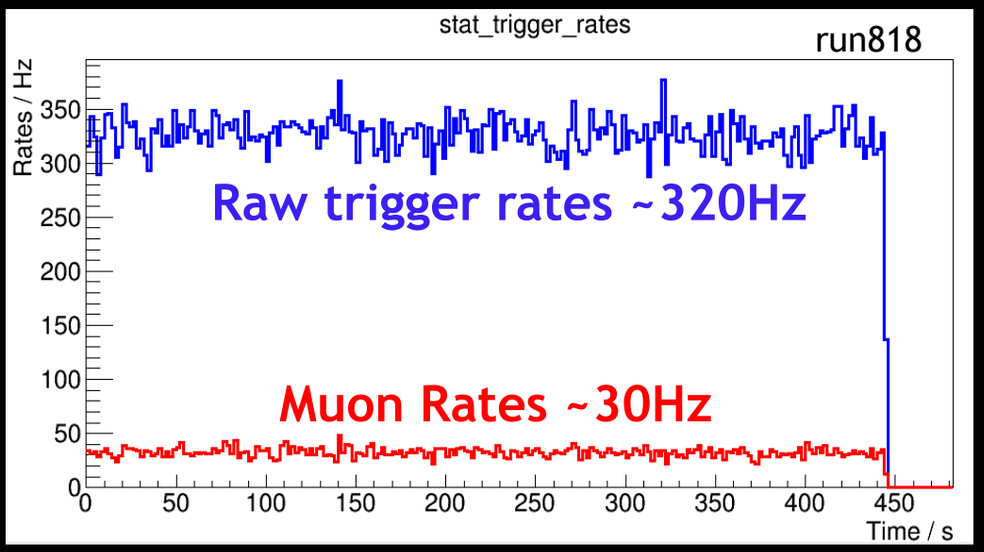
(an experimental feature: i.e. bias?)

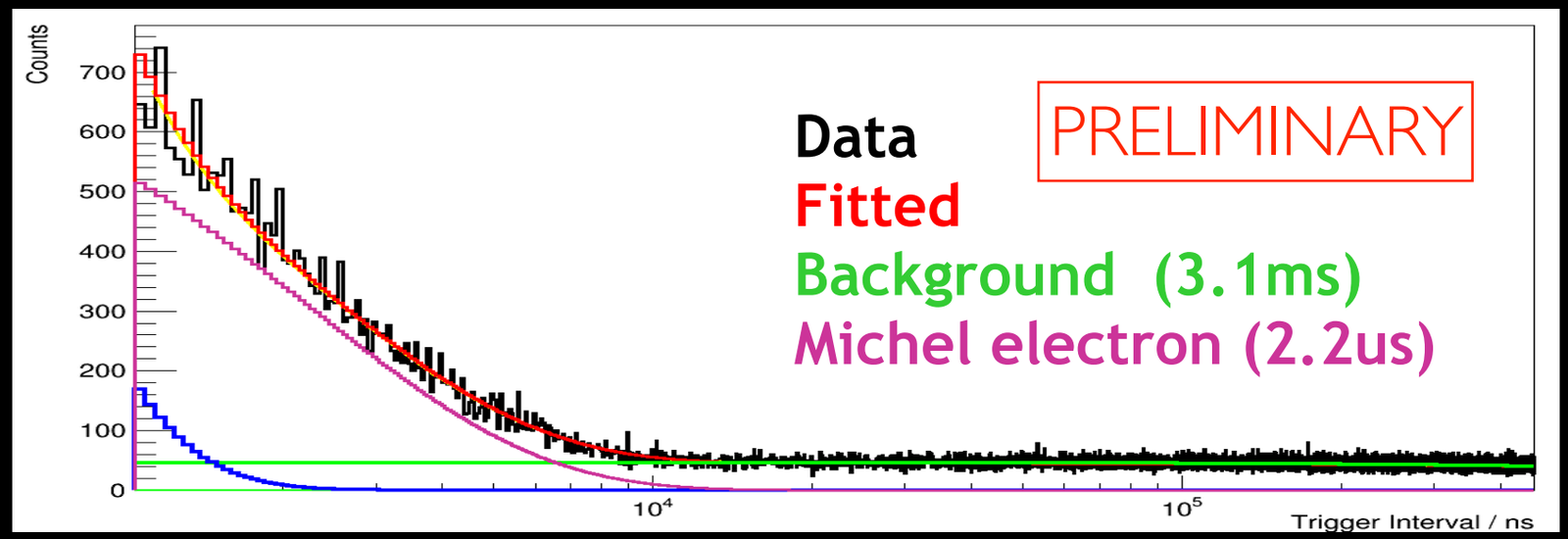
JUNO measurement of $\sin^2(2\theta_{12}) \oplus \delta m^2$ (unique!)

JUNO prototype…

Detector running continuously
PMT bench test
PMT potting
Supporting/Installation
1GHz Electronics + DAQ
Water system study
Detector calibration and simulation







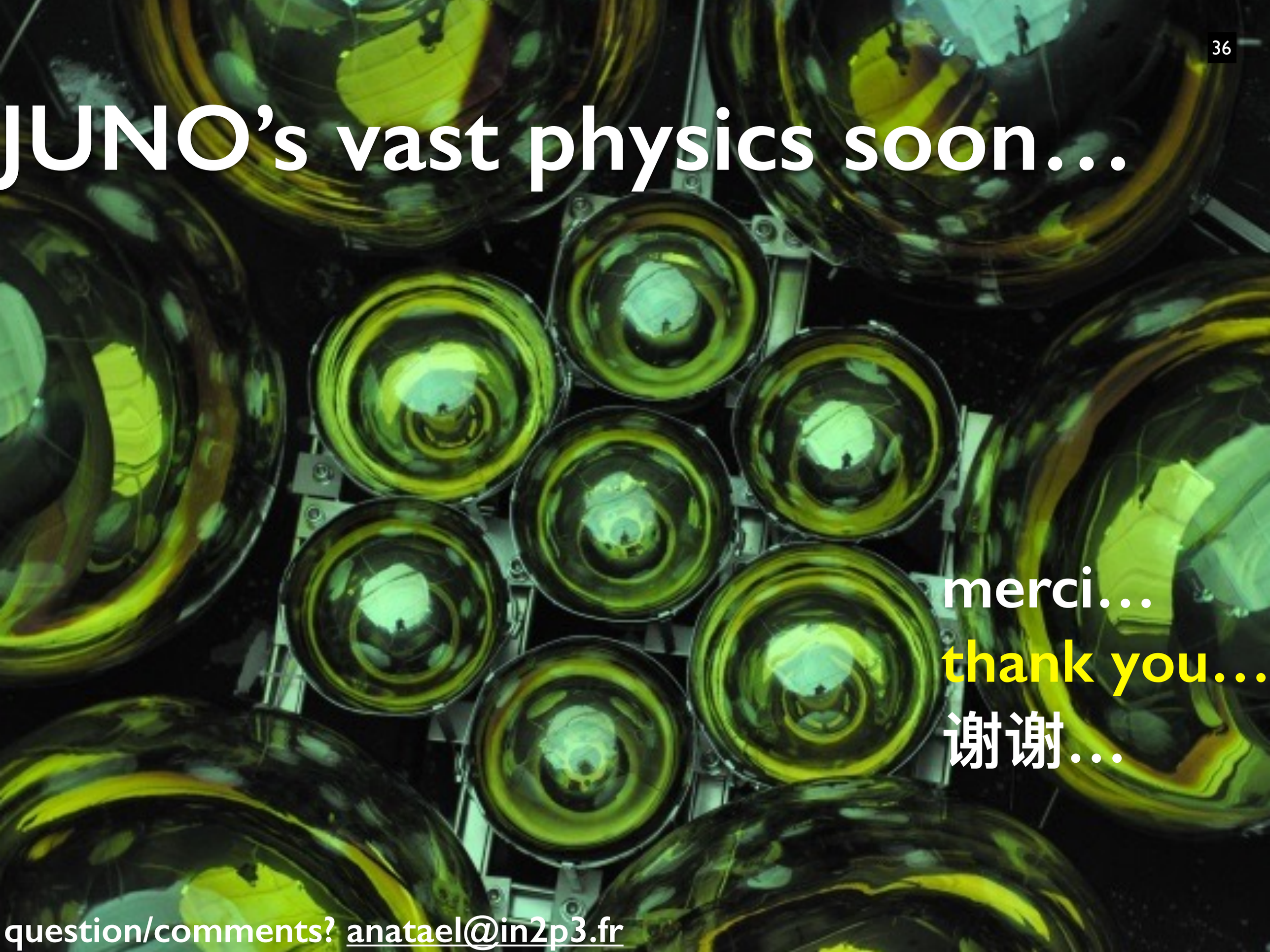
what to remember?

- **JUNO: a world reference in neutrino oscillation…**
  - several unique measurements: **(θ_{12}, δm^2, $\pm\Delta m^2$, θ_{13}** [not just Mass Hierarchy]…
  - no δ(CP) and θ_{23}-octant nuisance [both unknown]→ clean input to beam [DUNE⊕HK]
    - similar to the **critical reactor-θ_{13} & T2K⊕NOvA interplay**
  - up to 20years of copious physics with reactor-ν and beyond (geo-ν, supernova-ν, etc)

- **double calorimetric detector for maximal precision…**
  - improved LS detector design with exquisite transparency
  - very challenging design (high precision calorimetry) with latest state of the art technology

- **latest status…**
  - much progress — technical developments (all within schedule)
  - laboratory civil construction delay due to unexpected underground water (under control)
  - trying to address a priori all critical issues (including the challenging systematics)

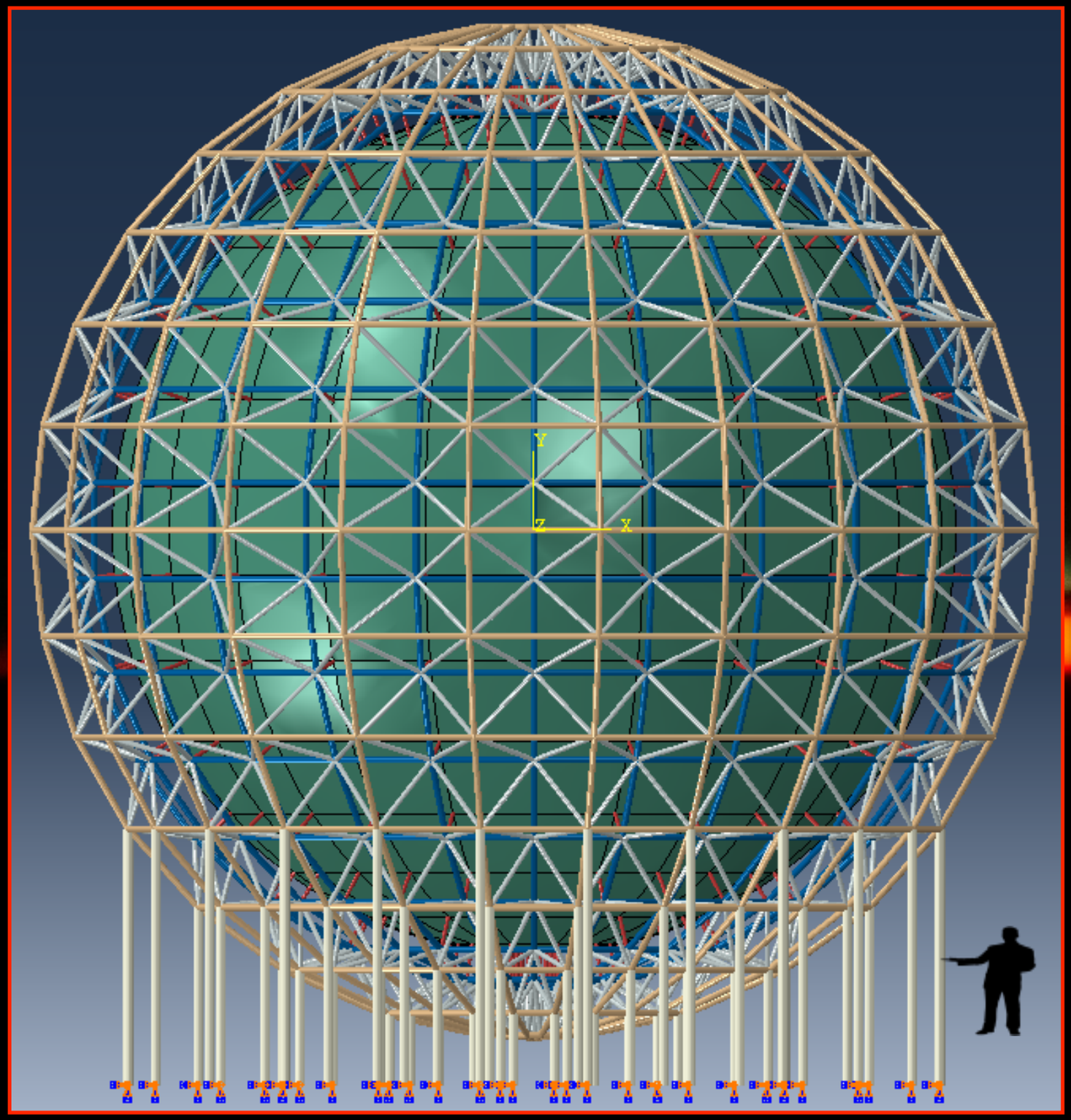
JUNO's vast physics soon…



merci…
thank you…
谢谢…

question/comments? anatael@in2p3.fr

JUNO neutrino detector system…



~SuperKamiokaNDE
~20x KamLAND or SNO
~600x DC or ~300 DYB

- JUNO detector major requirement (MH)
  - **high precision calorimetry**
    - highest light yield: **~1.2kPE/MeV**
    - systematics control (transparency)
  - **must be large** (reactors @ ~50km)
    - →over-designed for all other physics
- ~20kt spherical liquid scintillator detector
  - ~1.5m of buffer (isolation + optics)
  - **~18k 20" PMTs** (~80% photo-coverage)
  - **~25k 3" PMTs (calorimetry control)**
  - excellent μ-tracking→**^{9}Li+^{8}He rejection**
- cylindrical water pool system (surrounding)
  - shield (radioactivity + fast-n moderator)
  - muon active veto (Water-Cherenkov)
- top-tracker detector systems (→OPERA)
  - stopping-muons & fast-neutrons
  - critical complementarity to ν-detector
- input (BX, DB, DC, KamLAND, SuperK, etc)