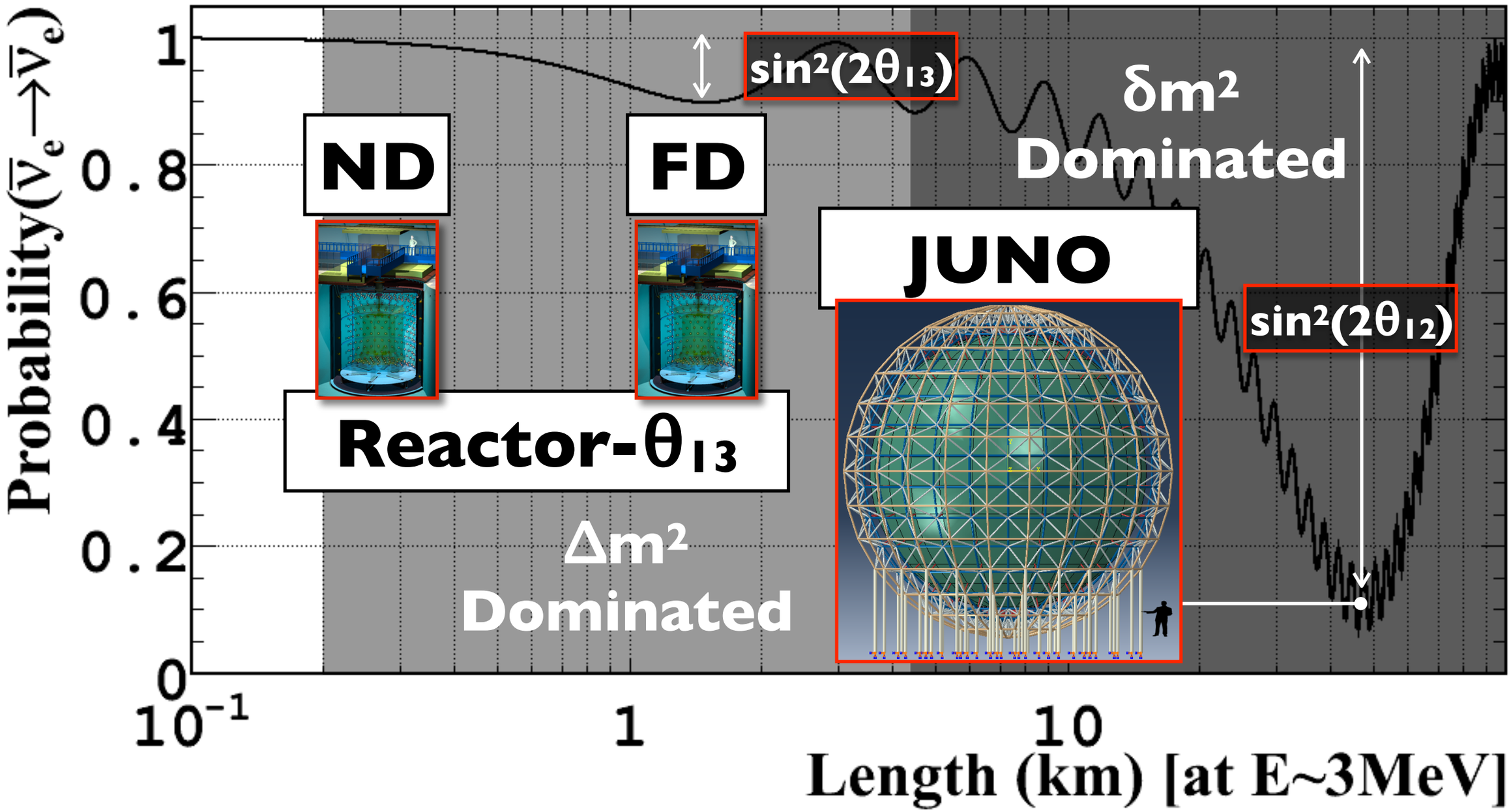
JUNO

(Physics @ IN2P3/CNRS)

CSI-IN2P3

IN2P3/CNRS — June 2018

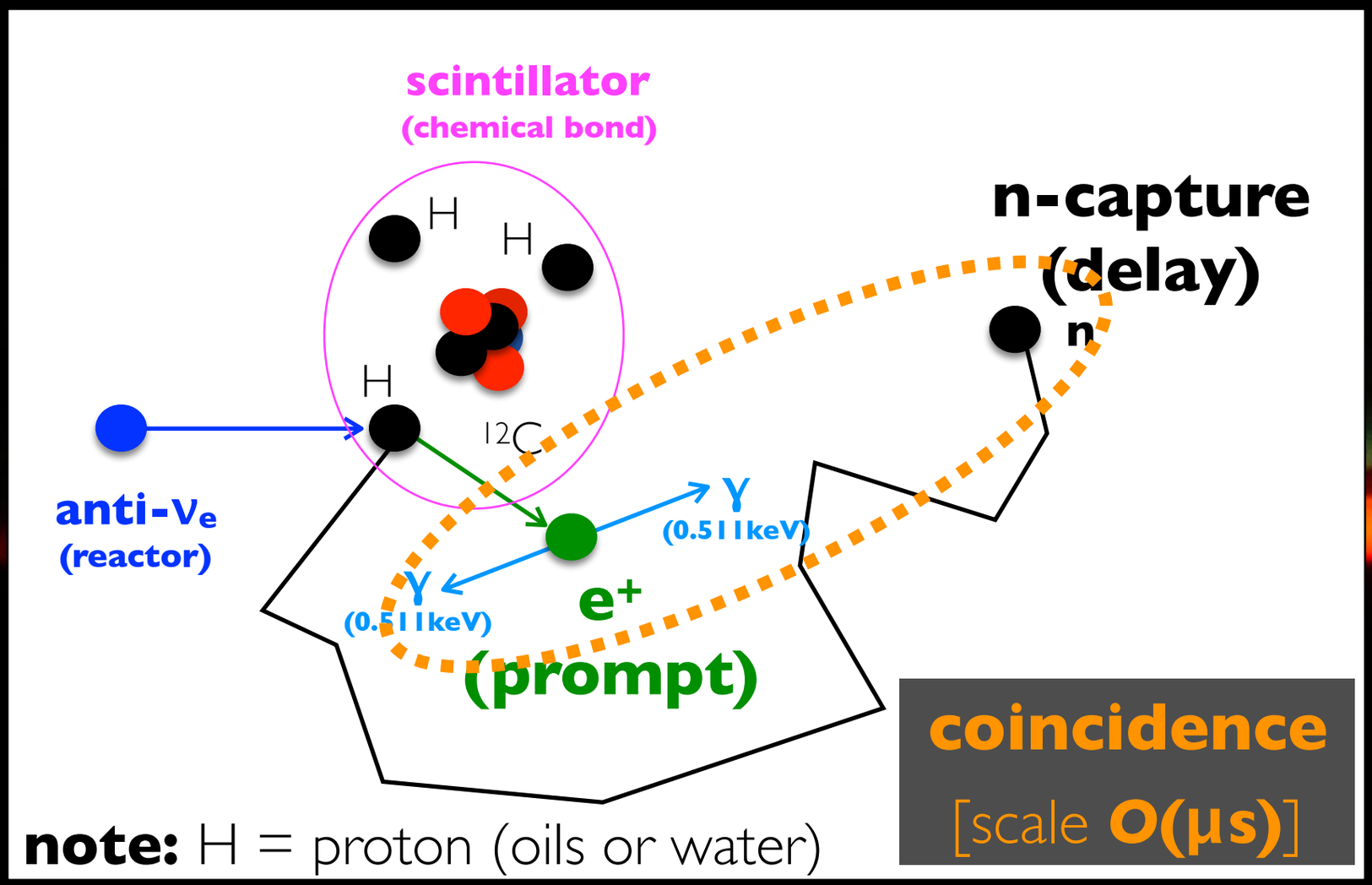
a long story short…



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

inverse-β decay (IBD) interaction…

IBD: anti-ν_e + p → e^+ + n



IBD detection art…

n-H (**native**)

n-C (**native oil**)

—

n-Cd (doped)

n-Gd (doped)

n-Li (doped)

—

^{3}He (different technology)

no e+ PID implies

e^+ ≈ BG (γ ≈ e^- ≈ α ≈ p-recoil)

DoubleChooz

(status review)

CSI requested: review main results

APC⊕CENBG⊕SUBATECH

Anatael Cabrera

CNRS / IN2P3 @ APC (Paris)

DC's LNCA laboratory…

Near Lab
<L>≈410m
~30ν day^{-1} ton^{-1}
~120 mwe

Far Lab
<L>≈1050m
~6ν day^{-1} ton^{-1}
~300 mwe

Chooz Reactors
Power: 8.5GW^{thermal} ⇒ ~10^{21}ν/s
(2x N4 reactor)

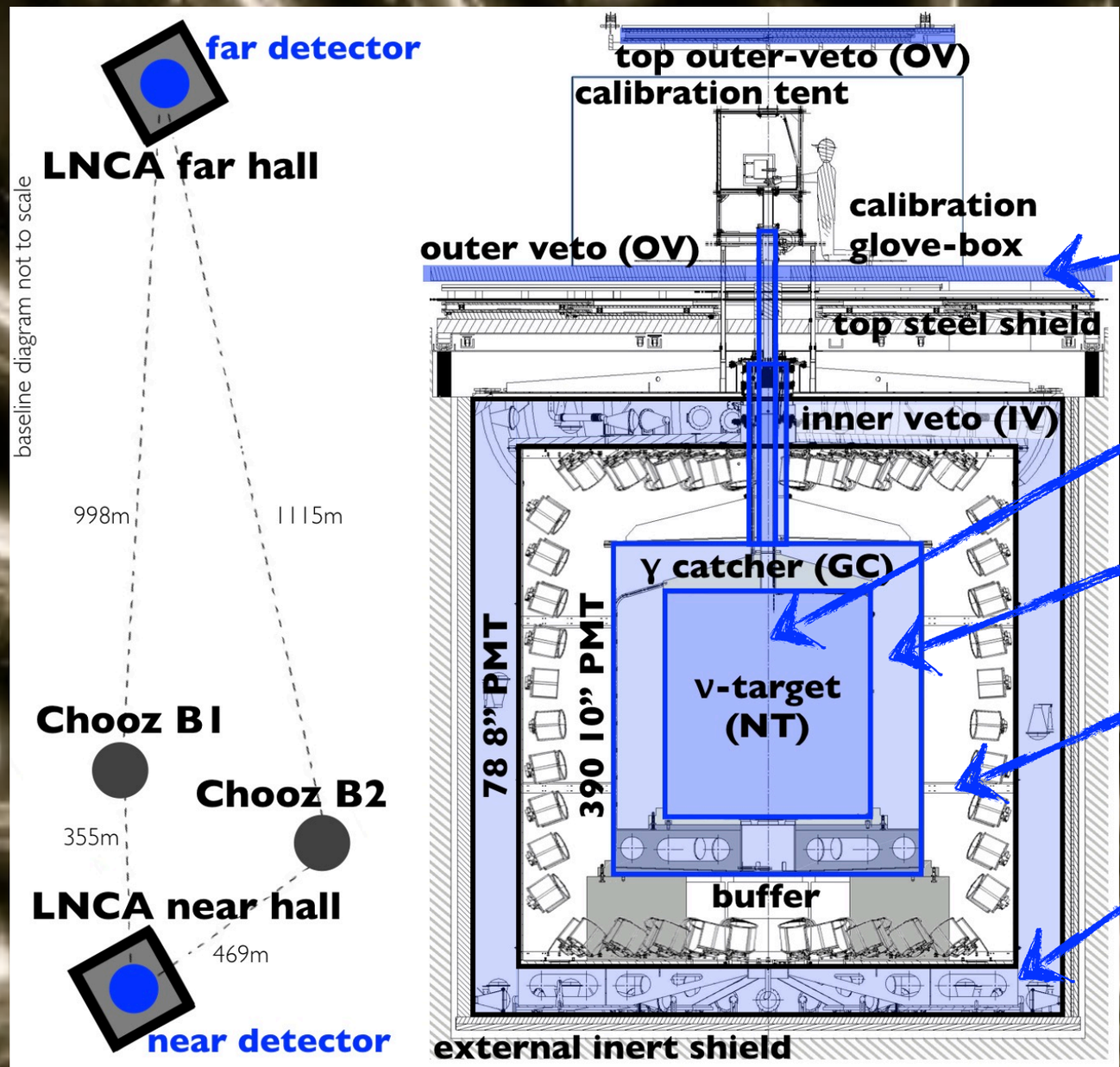
only latest on…

- detection

- physics (new)

detection highlights…

DC a θ_{13}-LAND…



Outer μ-Veto (OV)
plastics-scintillator: strips (→tracking)

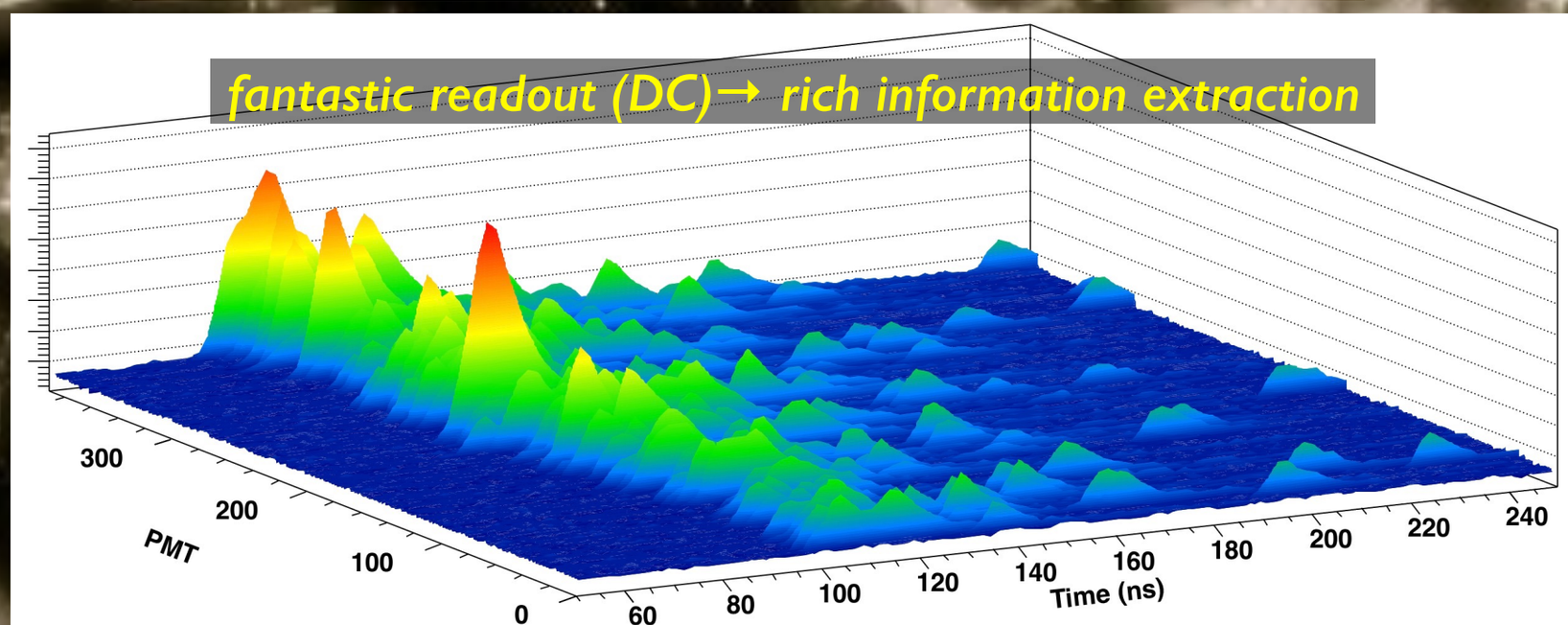
ν-Target (NT)
~10m³ Liquid-Scintillator + Gd (0.1%)

γ-Catcher (GC)
~20m³ Liquid-Scintillation

Light Buffer
~100m³ oil (no scintillation)

Inner μ-Veto (IV)
~90m³ Liquid-Scintillator

Inert γ-Shield
15cm steel [FD] / 1m water [ND]



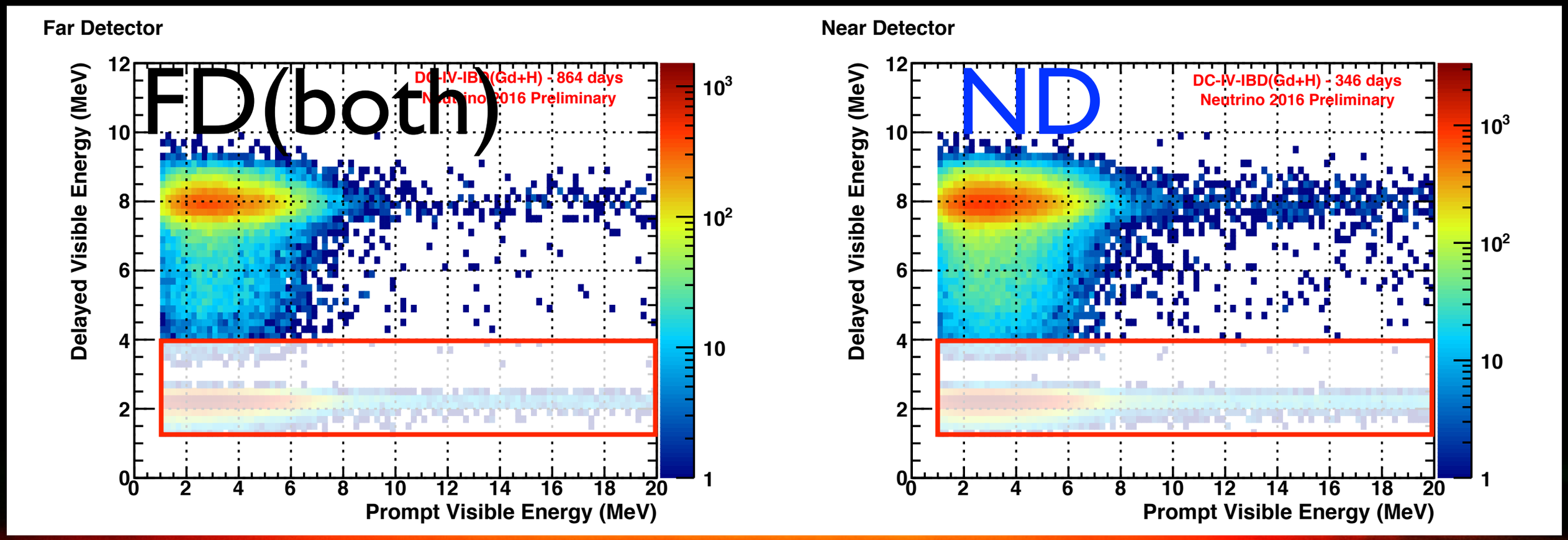
Liquid Scintillator
⊕
10" PMTs
⊕
FADC readout
⊕
offline reconstruction
(time,charge,position,PS,multiplicity,etc)

novel IBD detection…

Total neutron-Capture

(H-n⊕C-n⊕Gd-n)

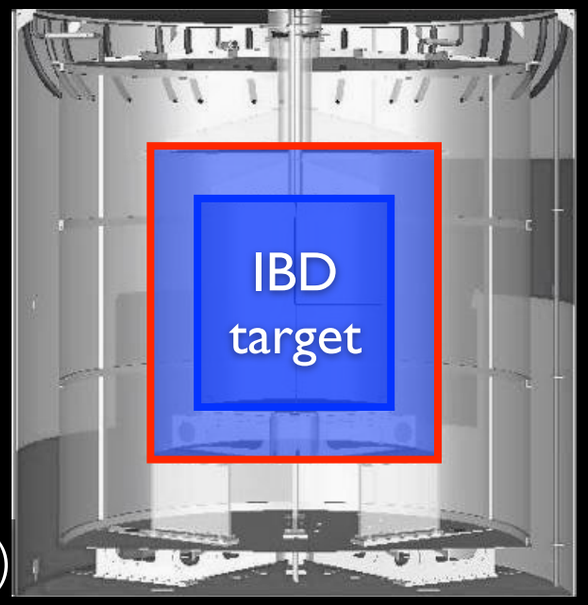
larger single-θ_{13}-target...



IBD(Gd)

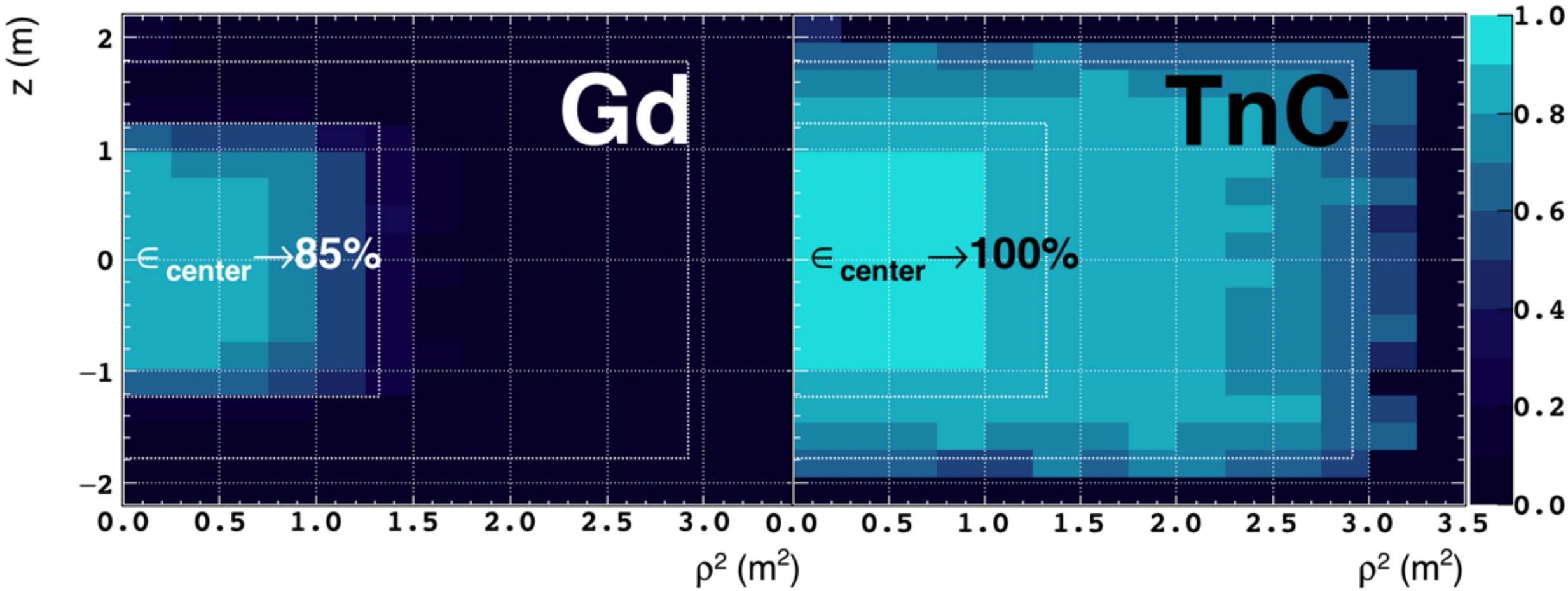
target: ~8t (smallest θ13 target)

IBD(Gd⊕H⊕C)



target: ~30t (large θ13 single detector target)

TnC major detection improvement…

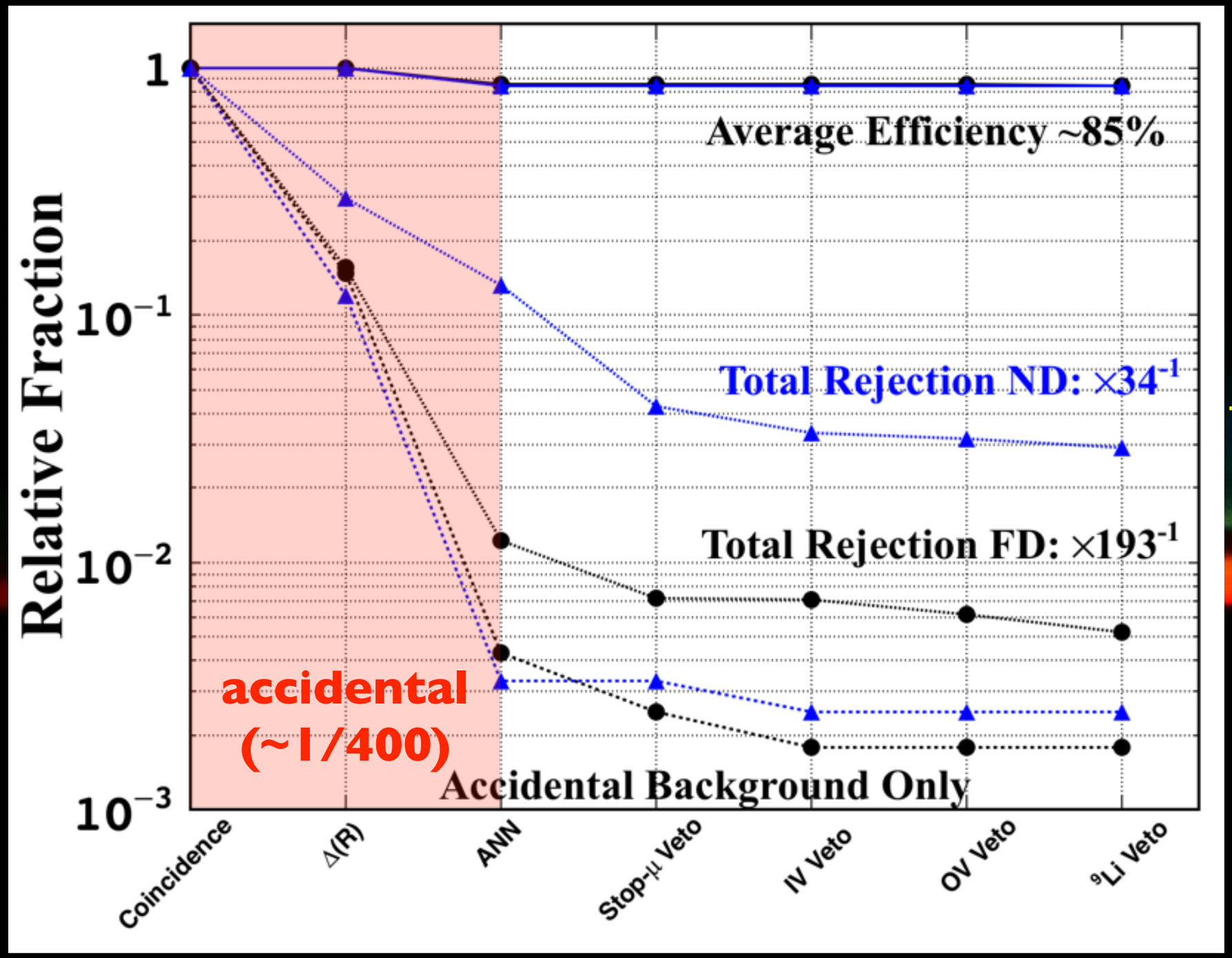


higher efficiency per volume (→100%)

higher efficiency total (increase fiducial volume ~x3)
[major reduction of statistical and background systematics]

lower efficiency detection systematics
[dominant systematics: **poor GC proton#→ not measured**]

powerful active BG rejection…



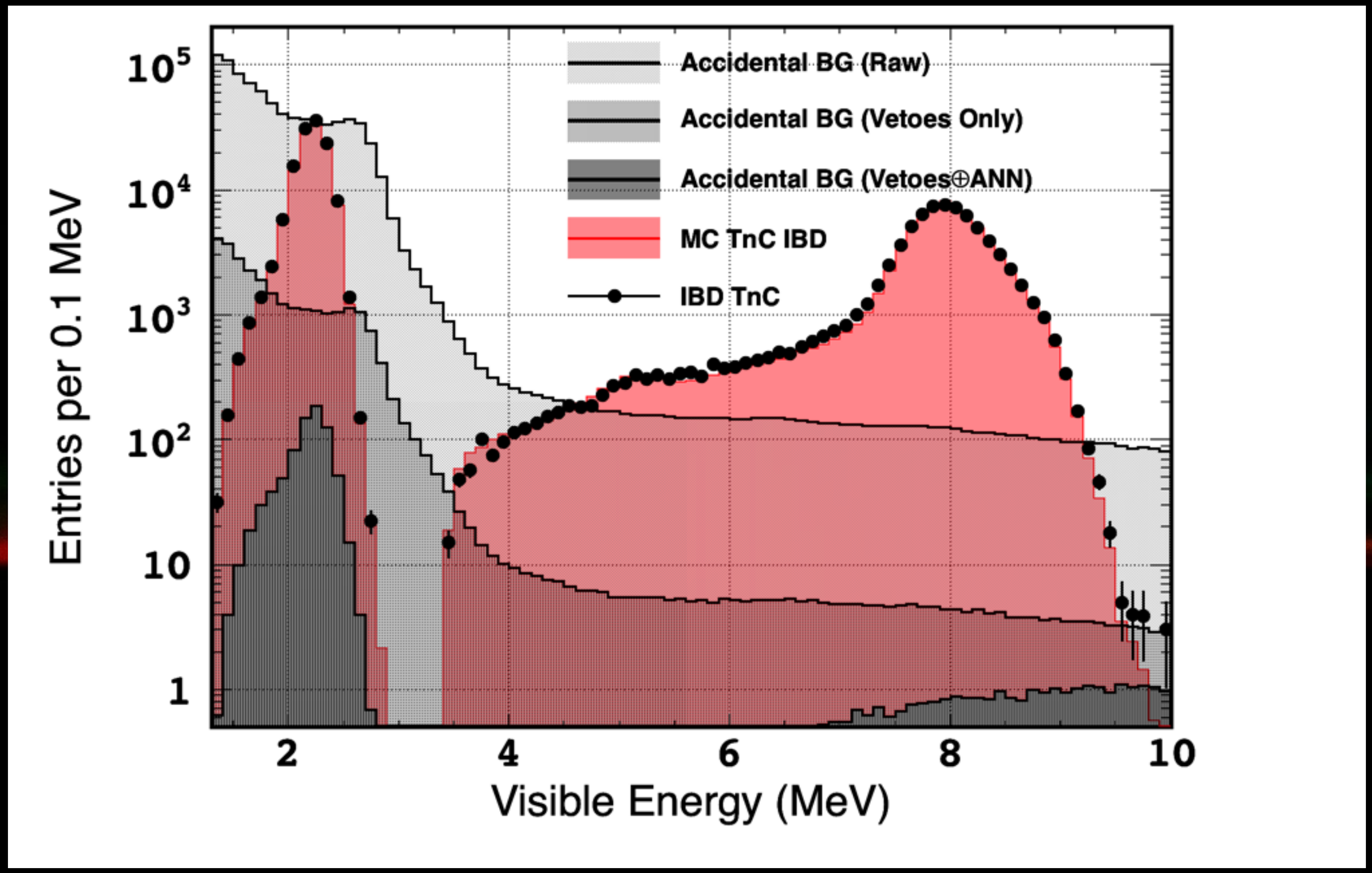
→ **ND cosmogenic dominated**
(overburden ~100mwe)

→ **FD cosmogenic dominated**
(overburden ~300mwe)

↑
coincidence
(~1/375 singles)

powerful veto system
(multi-layer detector articulation)

stunning BG (active) rejection…

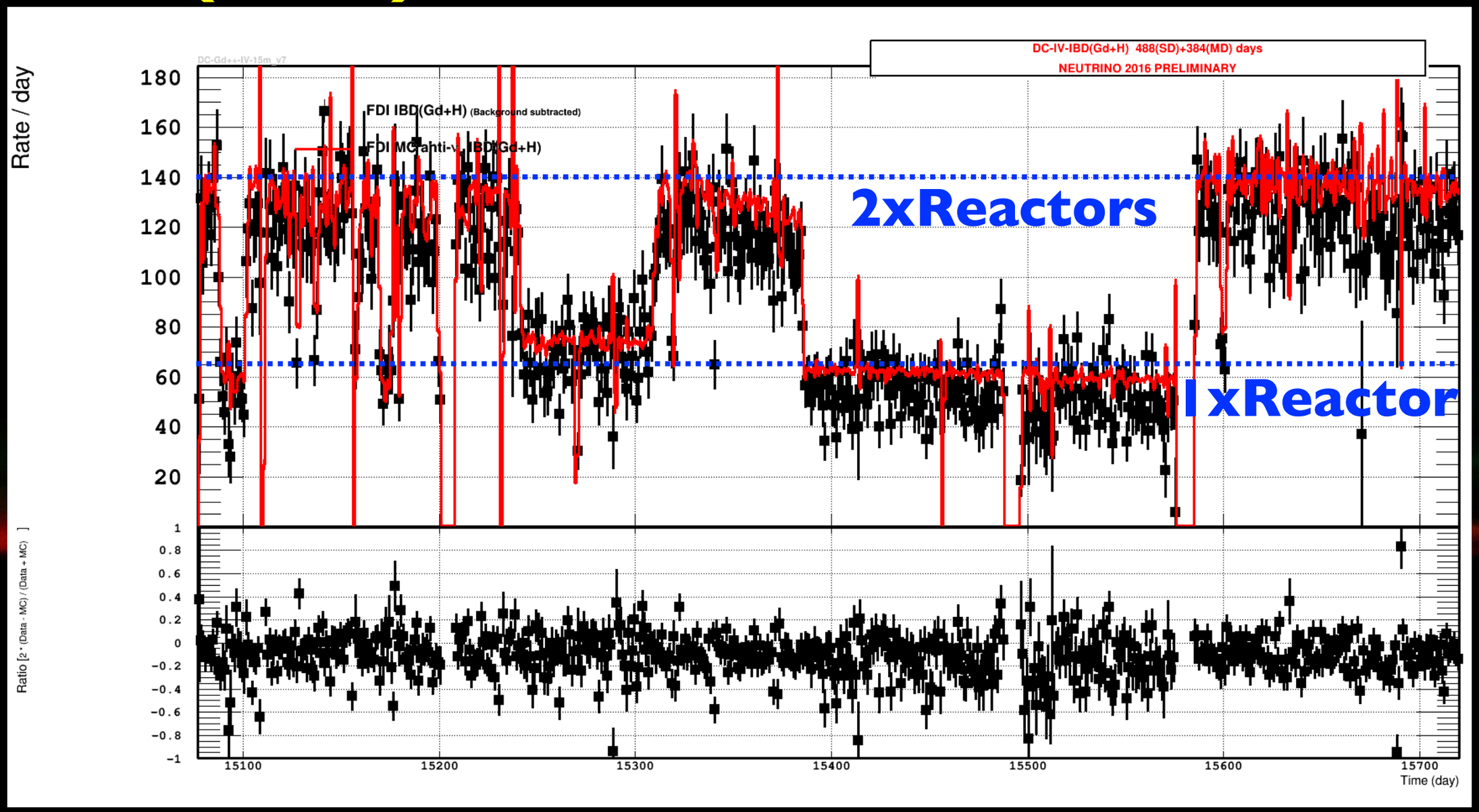


dig into BG to recover the H-n peak

(several orders of magnitude)

IBD(TnC) vs time…

IBD(TnC)



≲140day^{-1}@ FD (≲50day^{-1}@ FD)

≲1000day^{-1}@ ND (≲300day^{-1}@ ND)

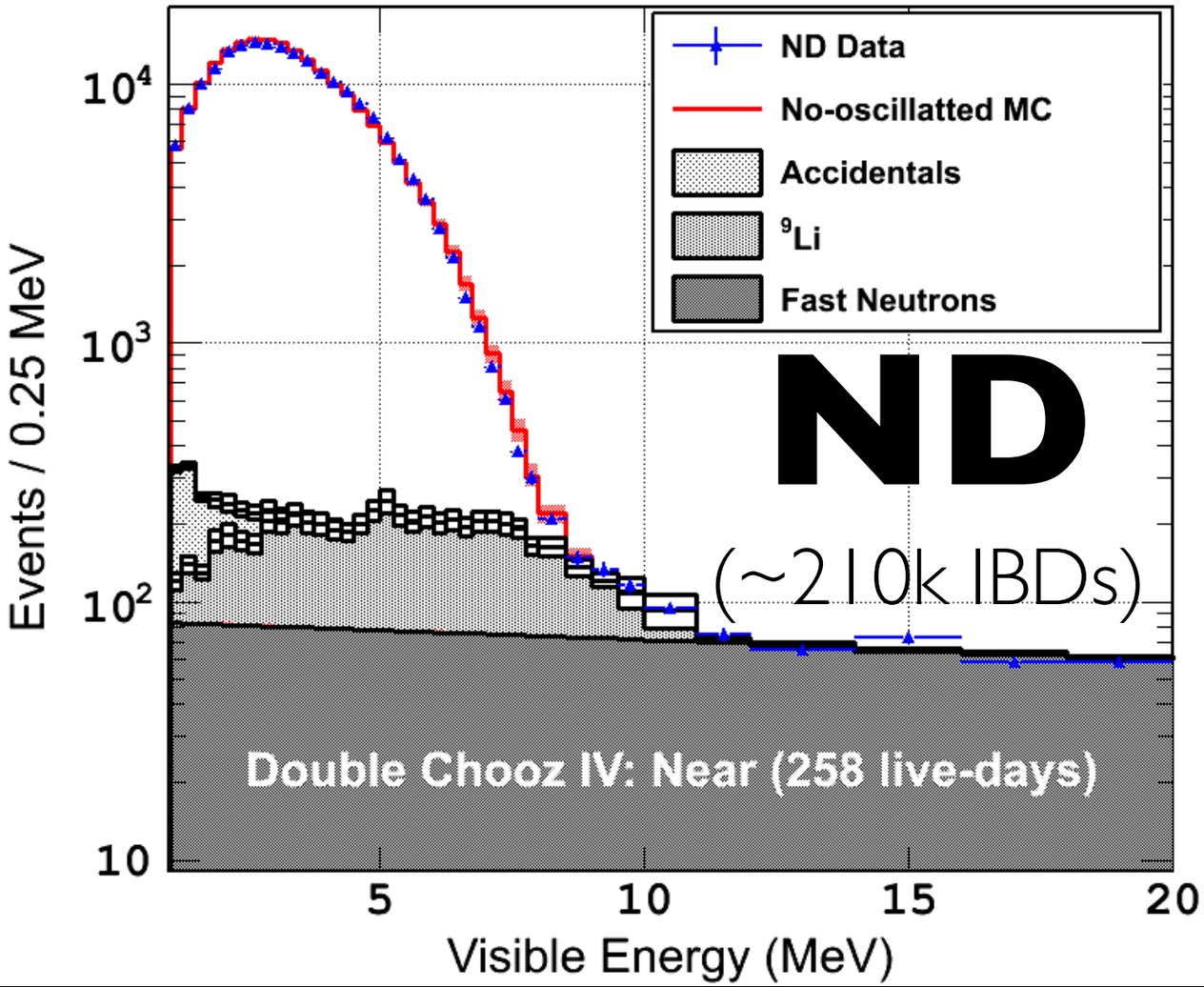
⇒≲0.3%^{stat} final DC

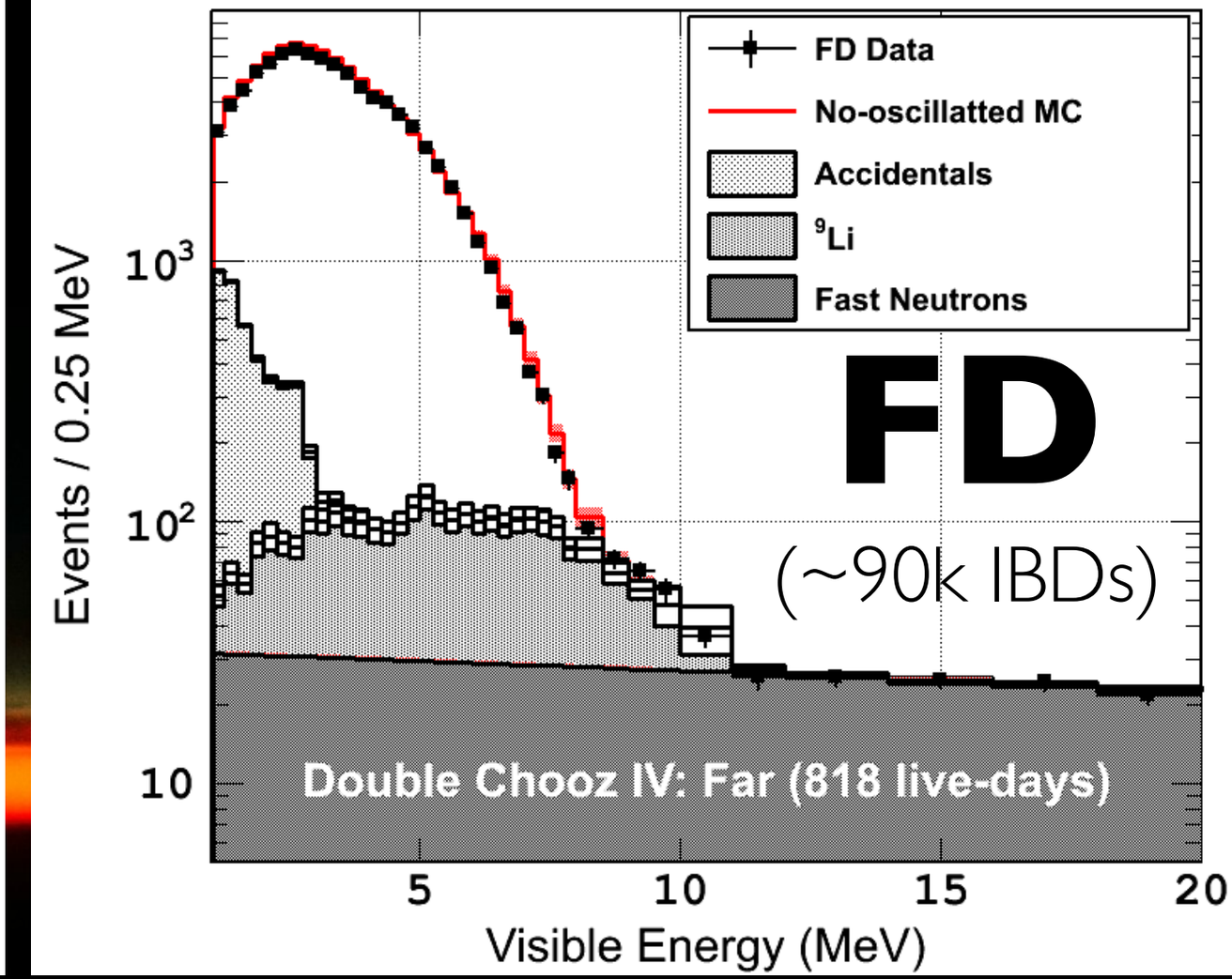
DC stopped data taking…

April 2011 — Dec.2017
(dismantling soon)

physics highlights…

each single-detector (SD) spectra…





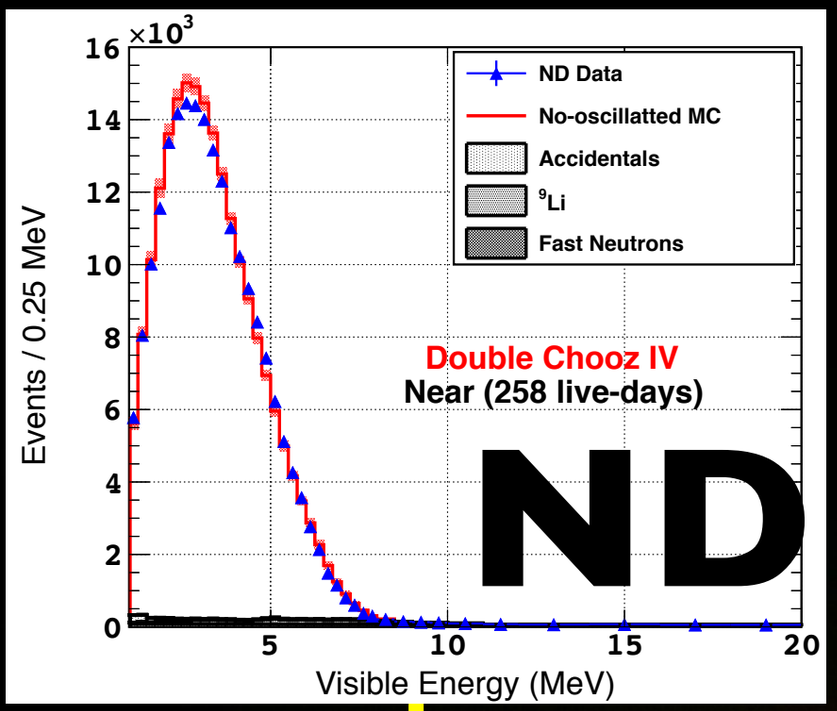
well understood spectra signal & BG

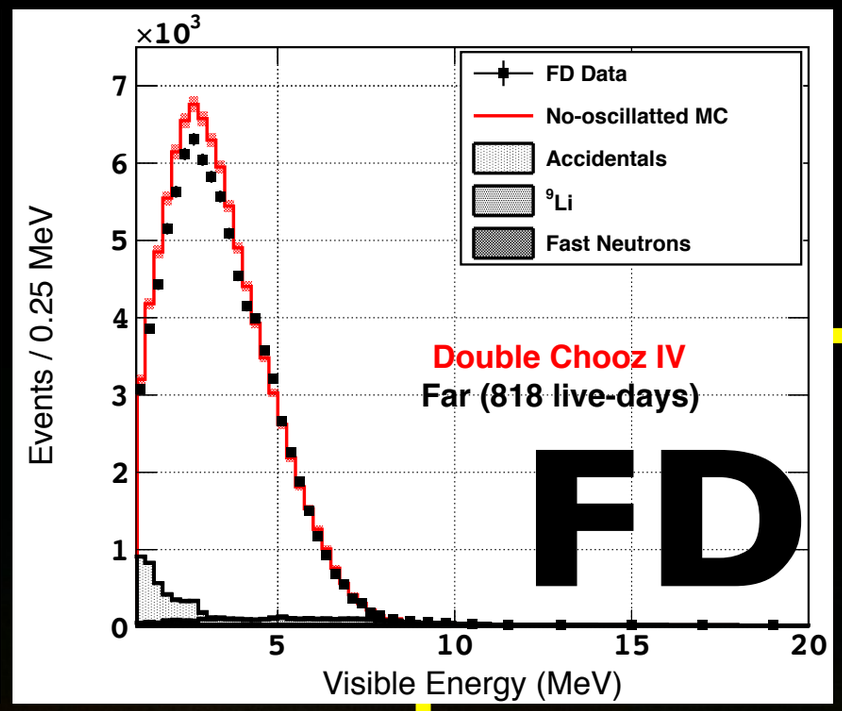
(reactor model external→scrutinise)

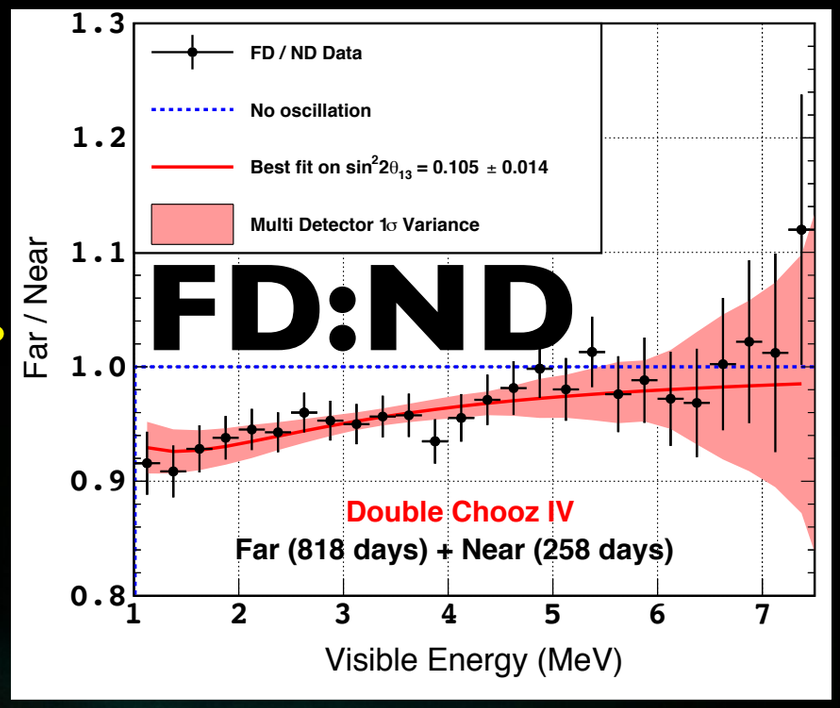
multi-detector (MD) combination

(physics extraction)

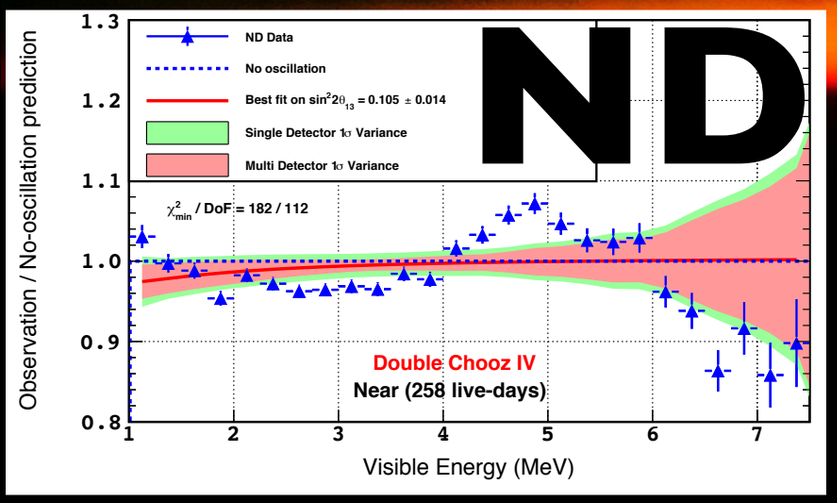
multi-detector θ13 fit extraction…

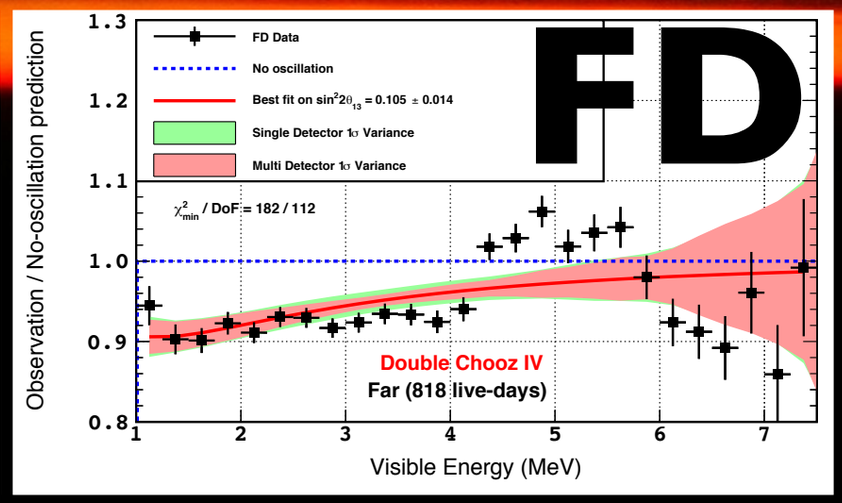






direct data to MC ratio





inter-detector ratio
(reactor model cancellation)

sin2(2θ13)=0.105±0.014
X2/DoF: 182/112

(sensitivity 0.014)

"common" (correlated) effects cancel
(MC reactor model distorsion → poor X^2)

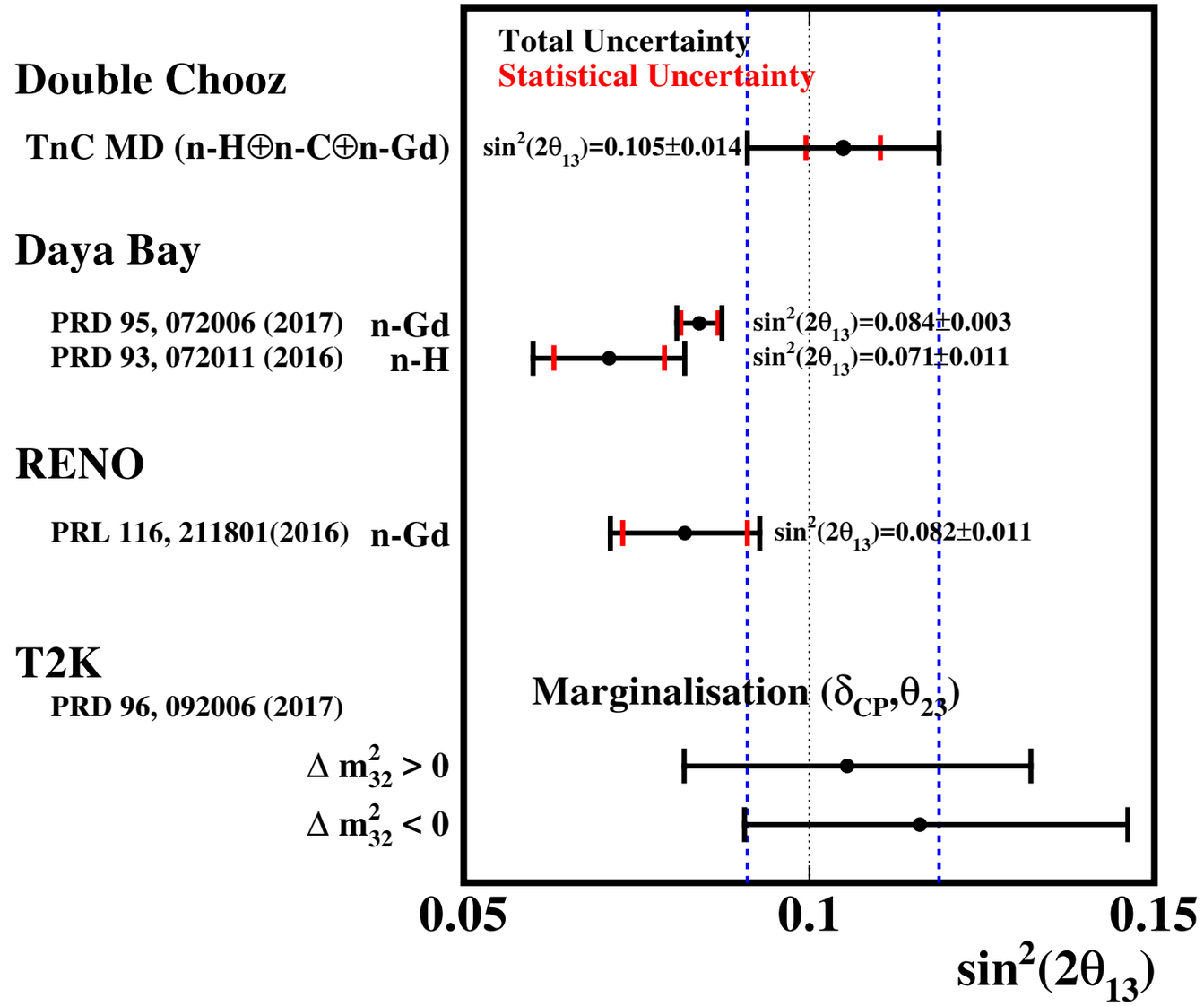
DC compared to the world knowledge…

Uncertainty	Fit Output	Correlation
Statistics	0.0054 (5.0%)	–
Reactor Flux	0.0081 (7.6%)	1.1
Detection	0.0073 (6.8%)	1.2
Energy	0.0018 (1.7%)	4.0
Background	0.0018 (1.7%)	2.4
$\lvert\Delta m^2_{ee}\rvert$	0.0018 (1.7%)	1.0
Correlation	0.0065 (6.1%)	–
Total	0.0141 (13.3%)	

reactor systematics
(**FD-I with no ND**)

detection systematics
(**poor proton# GC**)

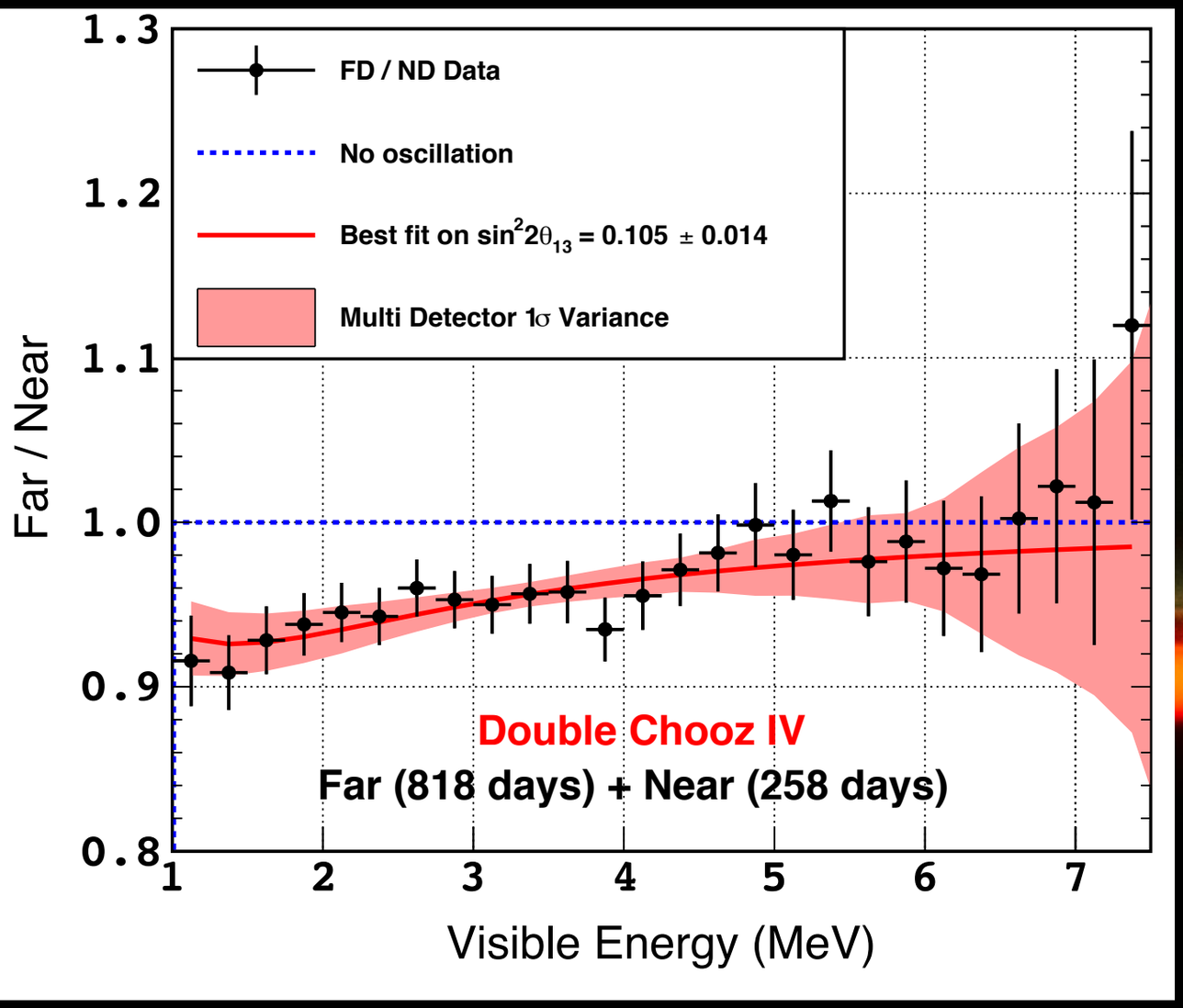
energy systematics
(via correlation)

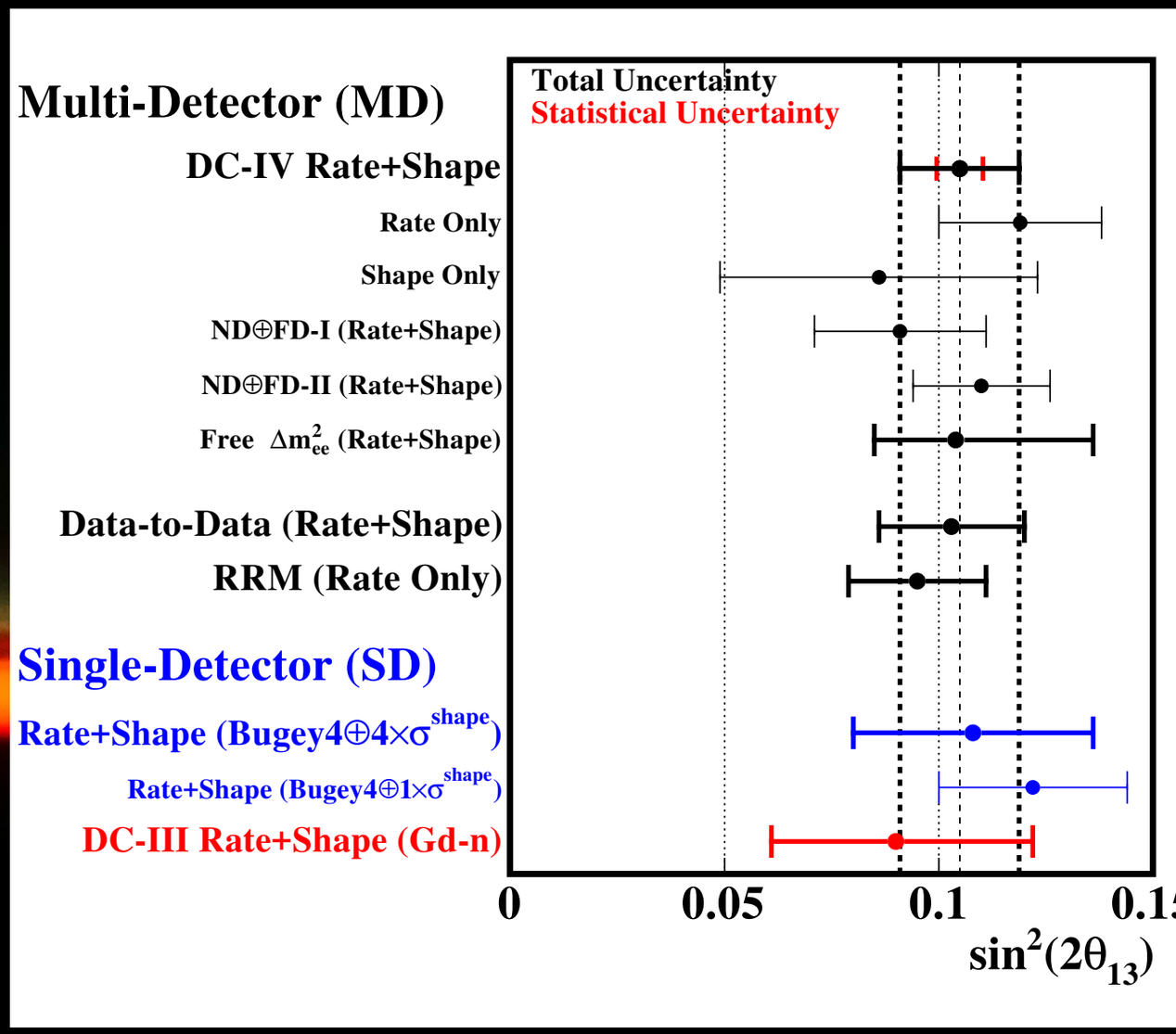


DC prefers a higher [up to ≤2σ]
(DYB & RENO higher @ Neutrino-2018)

systematics effect?
(statistics deviation not impossible but disfavoured)

DC internal multi-fit θ13 extraction…

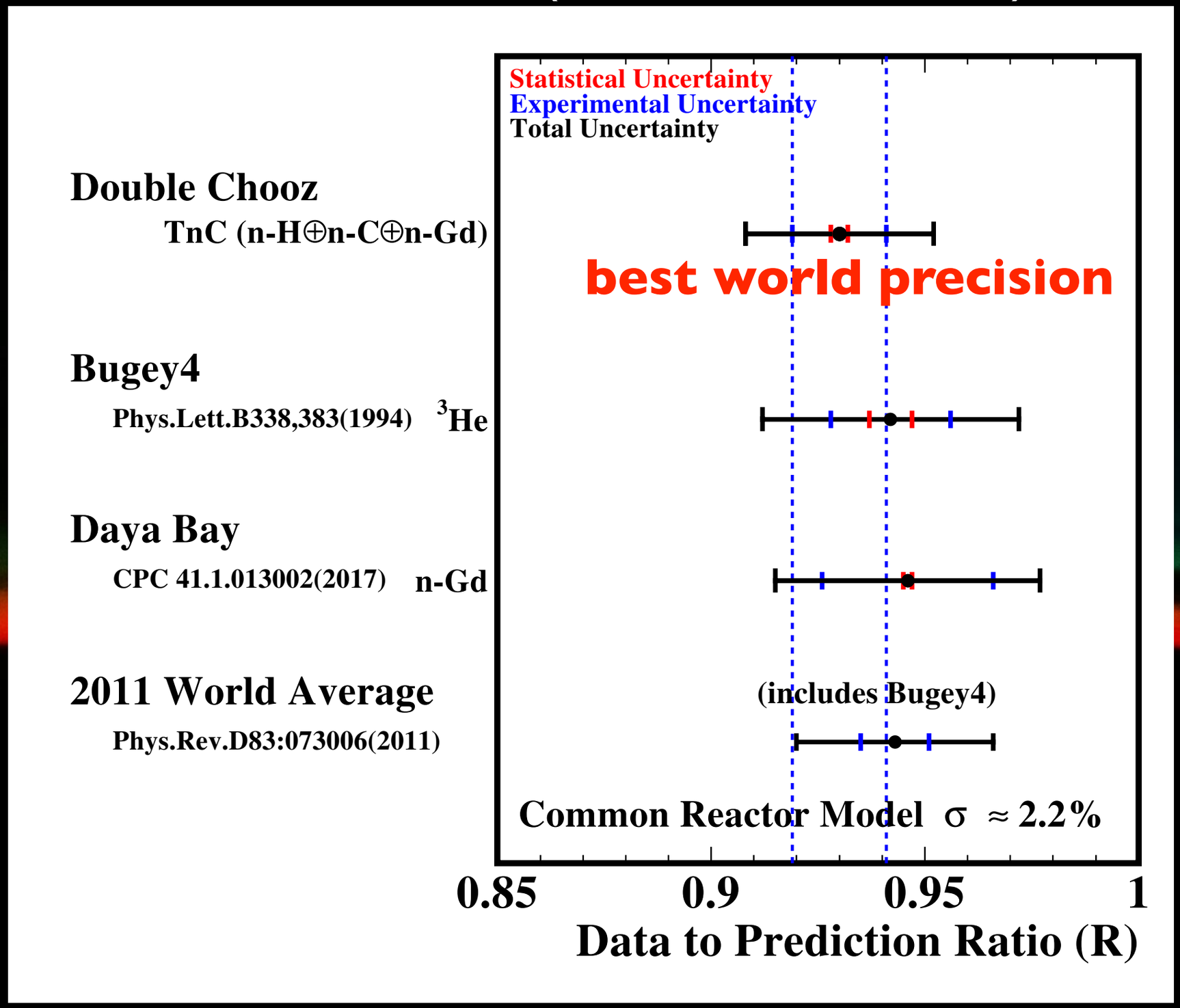




coherent & consistent multiple θ13

(internal validation of precision⊕accuracy)

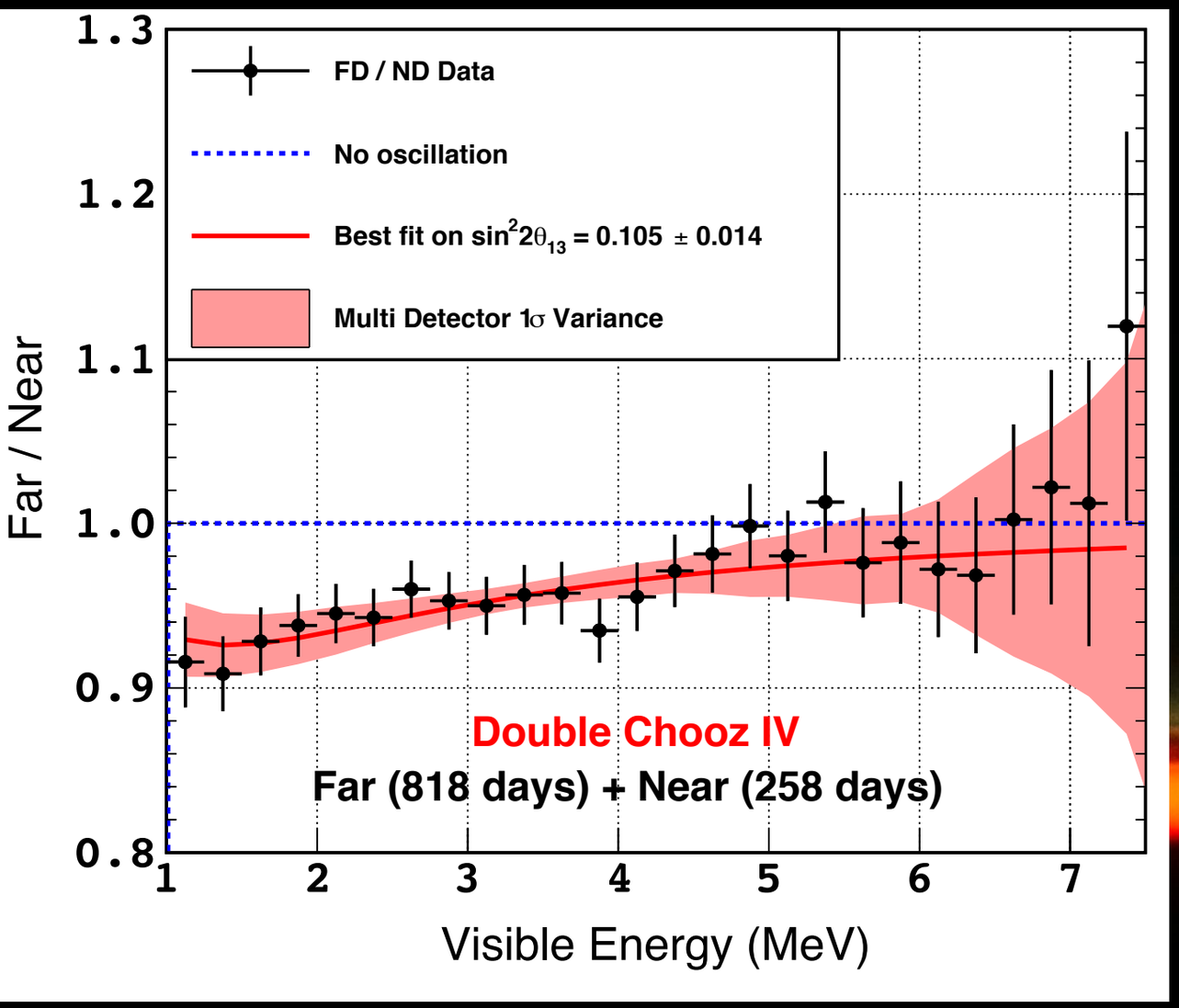
our ND rate (normalisation) validation…

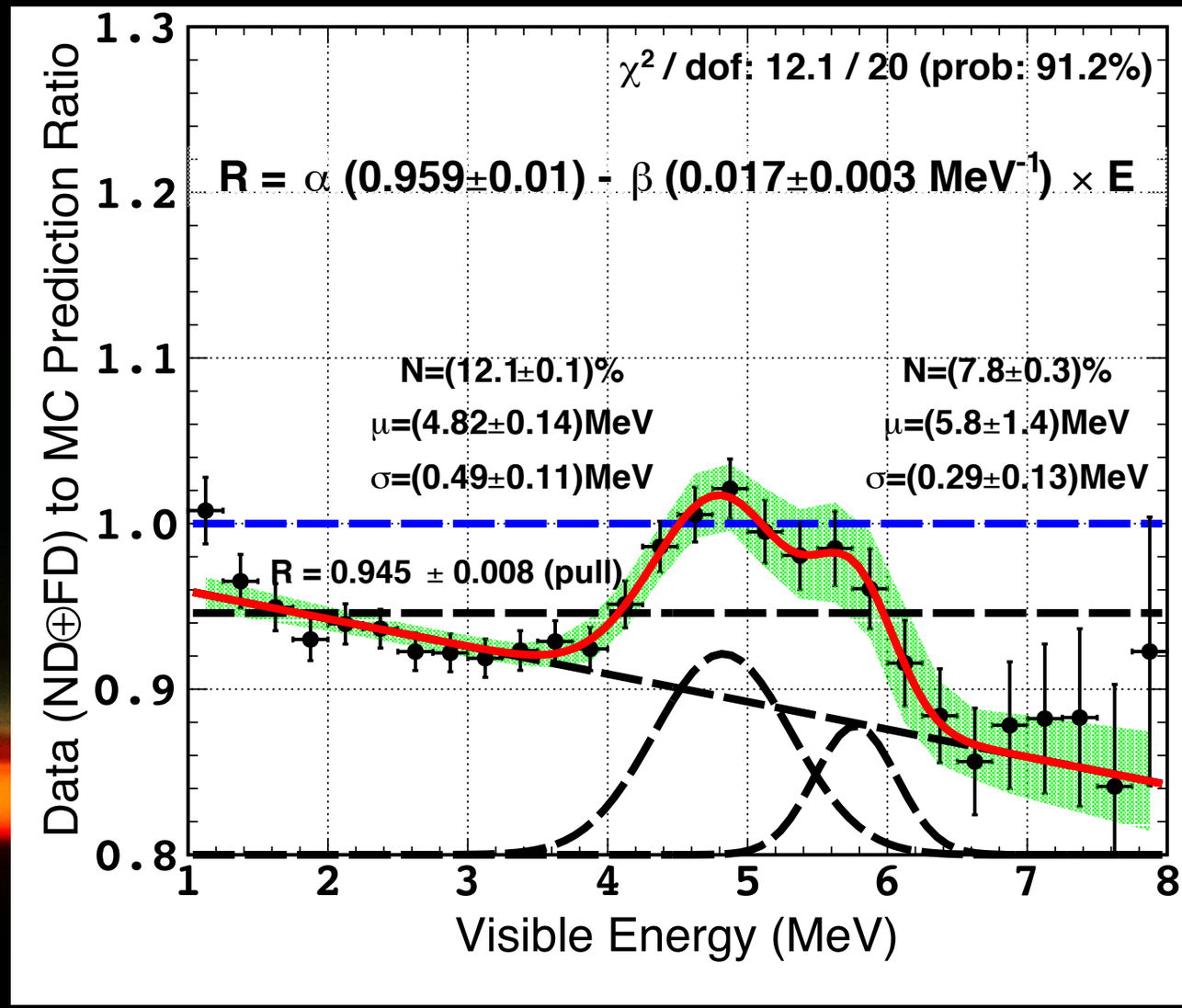


ND normalisation→ impact θ13

(excellent agreement with Bugey4 et al)

exploiting ND⊕FD⊕reactor model behaviour…





uncorrelated ratio
(ND:FD difference→θ_{13})

correlated ratio
(FD⊕ND common distorsion)

complementary views of our data
(high precision distorsion characterisation)

Reactor-θ_{13}

(combining results)

Daya Bay⊕Double Chooz⊕RENO

0th discussion/planning→@ Neutrino-2016, London (UK)

1st workshop→ October 2016 (Seoul, South Korea)
(systematics, results consistency)

2nd workshop→ June 2017 (Paris, France)
(further θ_{13} systematics consistency)

3rd workshop→ end 2018 (Hong Kong, China)

(likely) most precise input to θ_{13} for several decades...

Anatael Cabrera (CNRS-IN2P3 & APC)

our big loss (Dec.2017)…

Hervé de Kerret

Double Chooz collaboration

Brazil

CBPF
UNICAMP

France

APC (IN2P3)
CEA/IRFU:
- **SPP**
- **SPhN**
- **SEDI**
- **SIS**
- **SENAC**

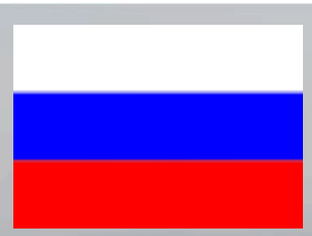
CENBG (IN2P3)
LNCA (IN2P3/CEA)
Subatech (IN2P3)

Germany

EKU Tübingen
MPIK Heidelberg
RWTH Aachen
TU München

Japan

Tohoku U.
Tokyo Inst. Tech.
Tokyo Metro. U.
Tokyo U. Science
Kitasato U.
Kobe U.



Russia

INR RAS
RRC Kurchatov

Spain

CIEMAT-Madrid

USA

Alabama U.
ANL
Chicago U.
Drexel U.
Hawaii U.
Notre Dame U.
Virginia Tech.

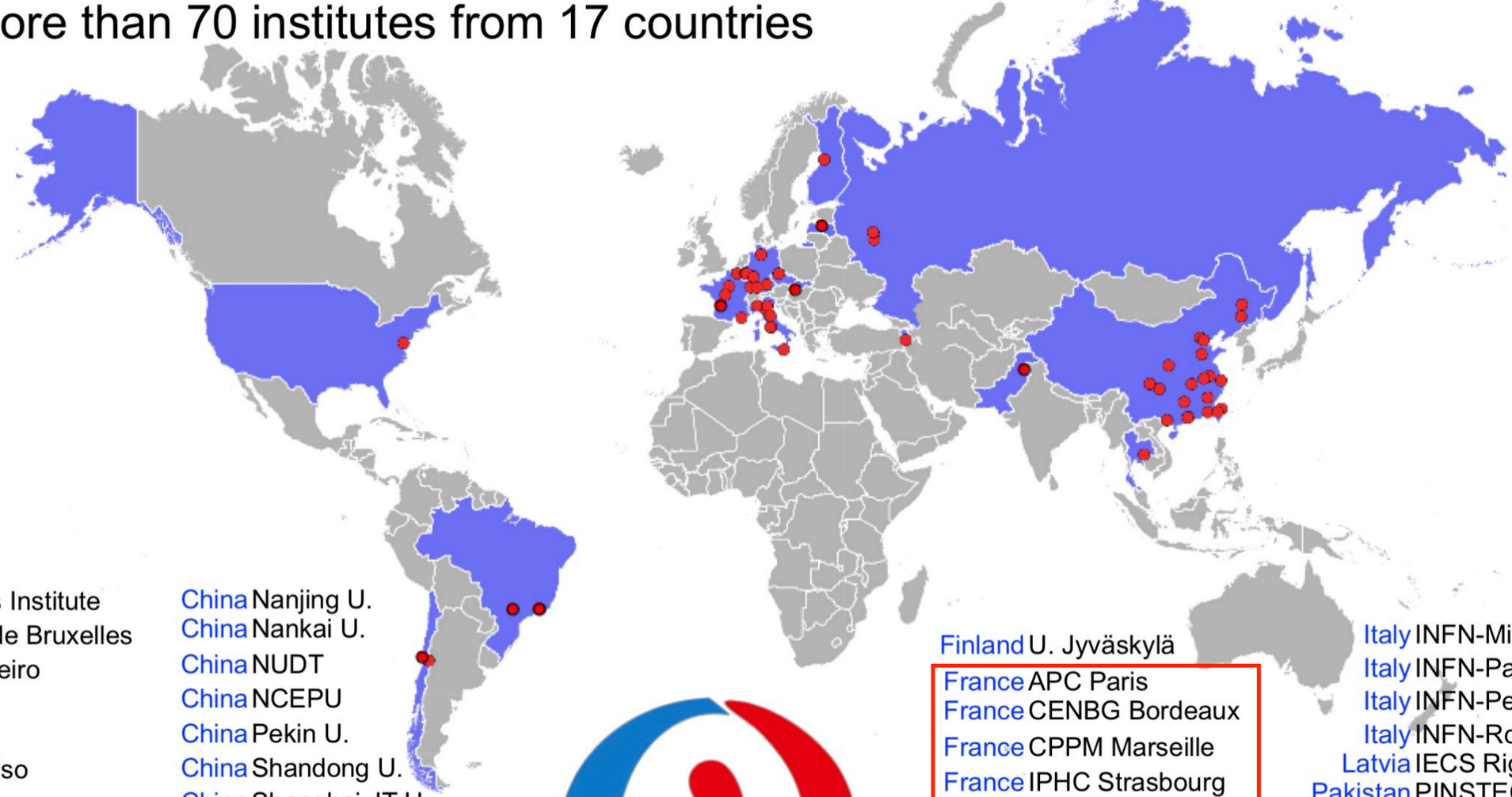
Spokesperson:
A. Cabrera (IN2P3/CNRS)

Project Manager:
Ch. Veyssière (CEA)

97 scientists 25 institutions (Americas, Asia, Europe)

web: doublechooz.in2p3.fr

More than 70 institutes from 17 countries



Armenia Yerevan Physics Institute
Belgium Université libre de Bruxelles
Brazil PUC Rio de Janeiro
Brazil UE Londrina
Chile PCUC
Chile UTFSM Valparaiso
China BISEE
China Beijing Normal U.
China CAGS
China ChongQing University
China CIAE
China DGUT
China ECUST
China Guangxi U.
China Harbin Institute of Technology
China IHEP
China IMP-CAS
China Jilin U.
China Jinan U.

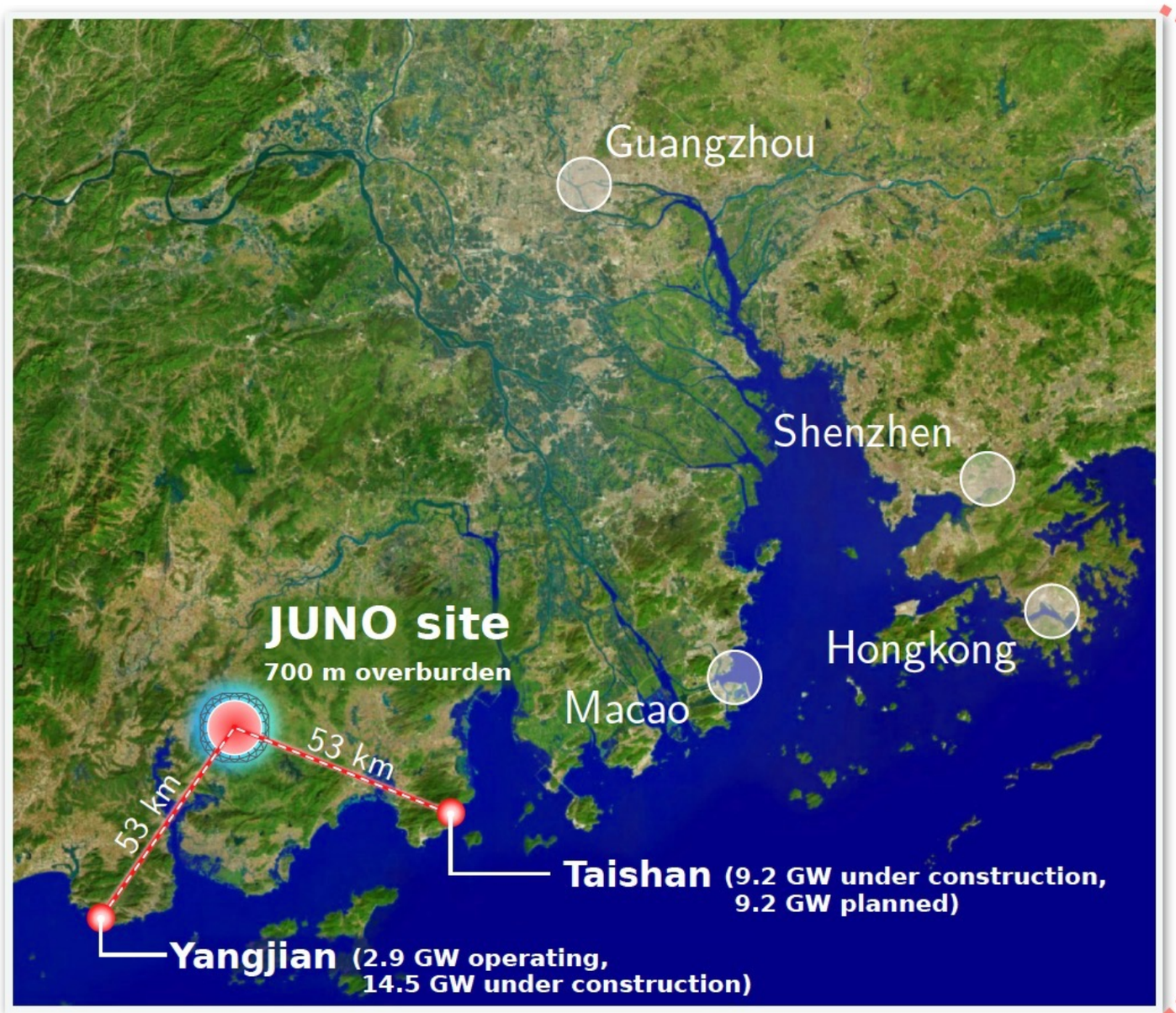
China Nanjing U.
China Nankai U.
China NUDT
China NCEPU
China Pekin U.
China Shandong U.
China Shanghai JT U.
China SYSU
China Tsinghua U.
China UCAS
China USTC
China U. of South China
China Wu Yi U.
China Wuhan U.
China Xi'an JT U.
China Xiamen University
China Zhengzhou U.
Czech R. Charles U. Prague

Finland U. Jyväskylä
France APC Paris
France CENBG Bordeaux
France CPPM Marseille
France IPHC Strasbourg
France Subatech Nantes
Germany ZEA FZ Julich
Germany RWTH Aachen U.
Germany TUM
Germany U. Hamburg
Germany IKP-2 FZ Jülich
Germany U. Mainz
Germany U. Tuebingen
Italy INFN Catania
Italy INFN di Frascati
Italy INFN-Ferrara
Italy INFN-Milano

Italy INFN-Milano Bicocca
Italy INFN-Padova
Italy INFN-Perugia
Italy INFN-Roma 3
Latvia IECS Riga
Pakistan PINSTECH Islamabad
Russia INR Moscow
Russia JINR
Russia MSU
Slovakia U. Bratislava FMPICU
Taiwan National Chiao-Tung U.
Taiwan National Taiwan U.
Taiwan National United U.
Thailand NARIT
Thailand PPRLCU Bangkok
Thailand SUT
USA UMD1
USA UMD2

the JUNO collaboration…

JUNO location…

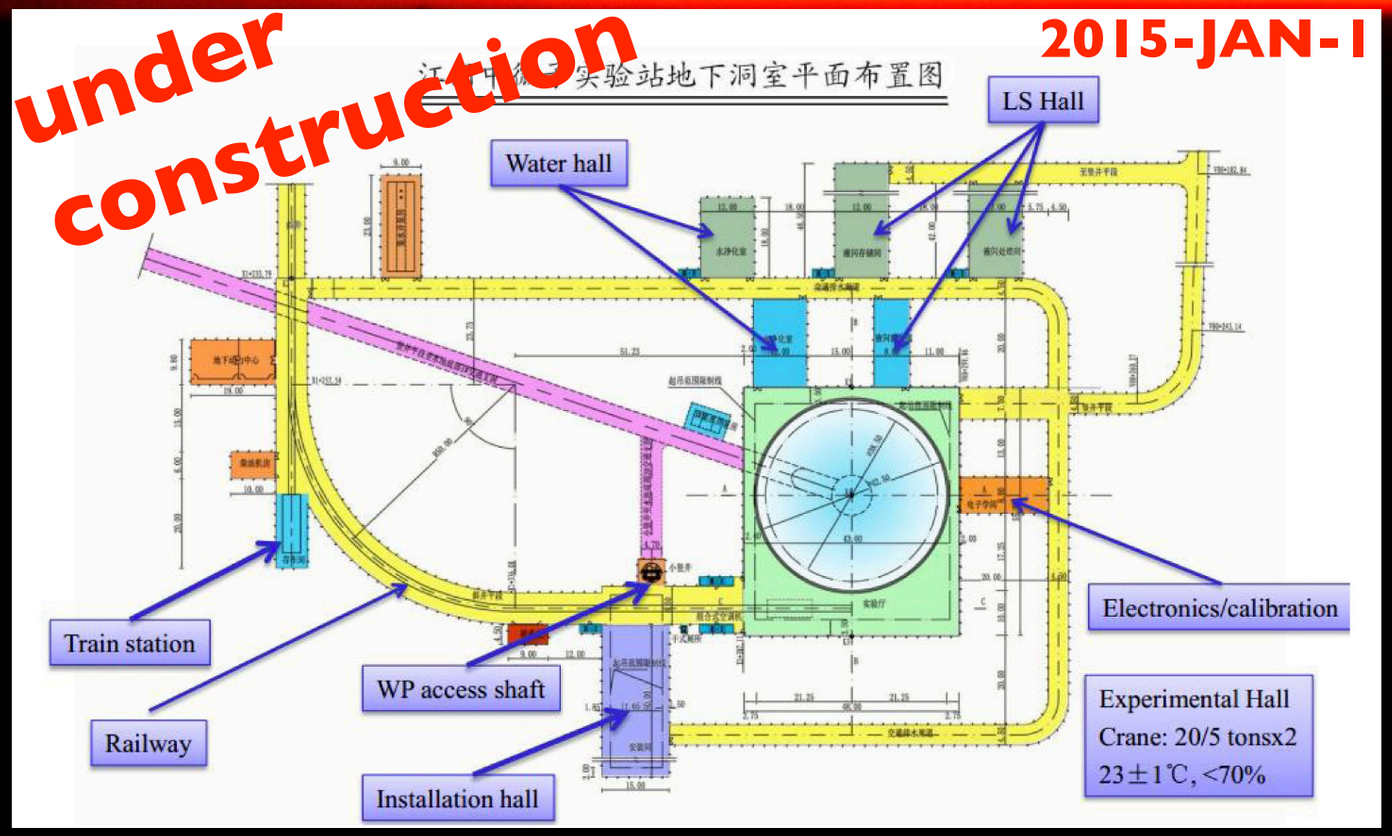


simplistic schedule: **data-taking aim to start by ~2021**

the JUNO laboratories…

on surface facilities

- construction support
- running



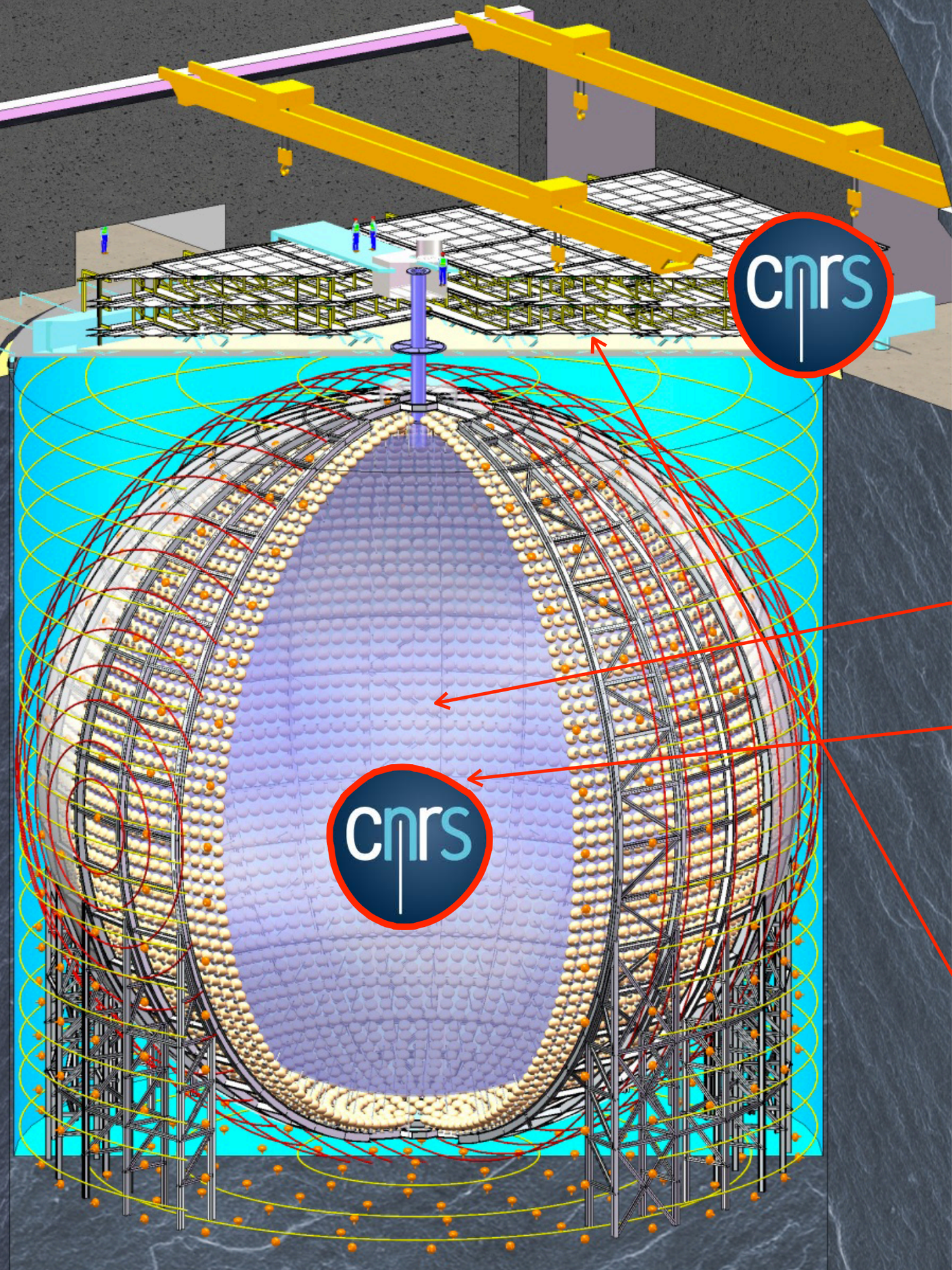
schedule driver

(delay ≳ 1 year)

- detector cavity
- underground facilities

underground cavity

our (huge) detector…



Underground Laboratory:

- ~700m overburden→ **~3μ/s**
- **~53km baseline** to reactors

Neutrino Detector:

- **~20k ton liquid scintillator** [acrylic 12cm surrounding]
- **~18k 20" PMT** (implosion mask)
- **25k 3" PMT**(stereo-calorimetry)
- compensation coils: Earth B(field)
- **high radio-purity** control

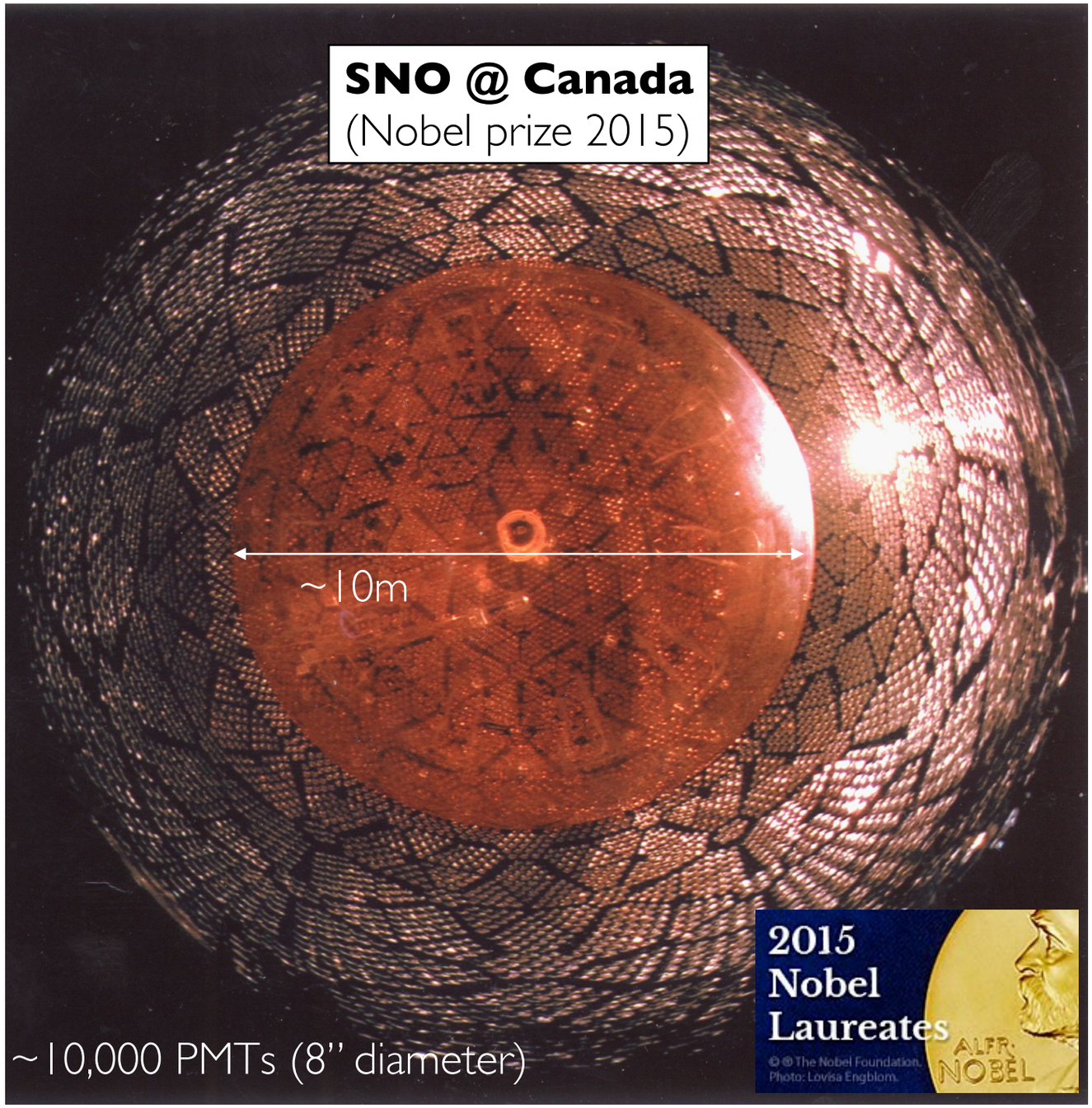
Calibration Articulation(s):

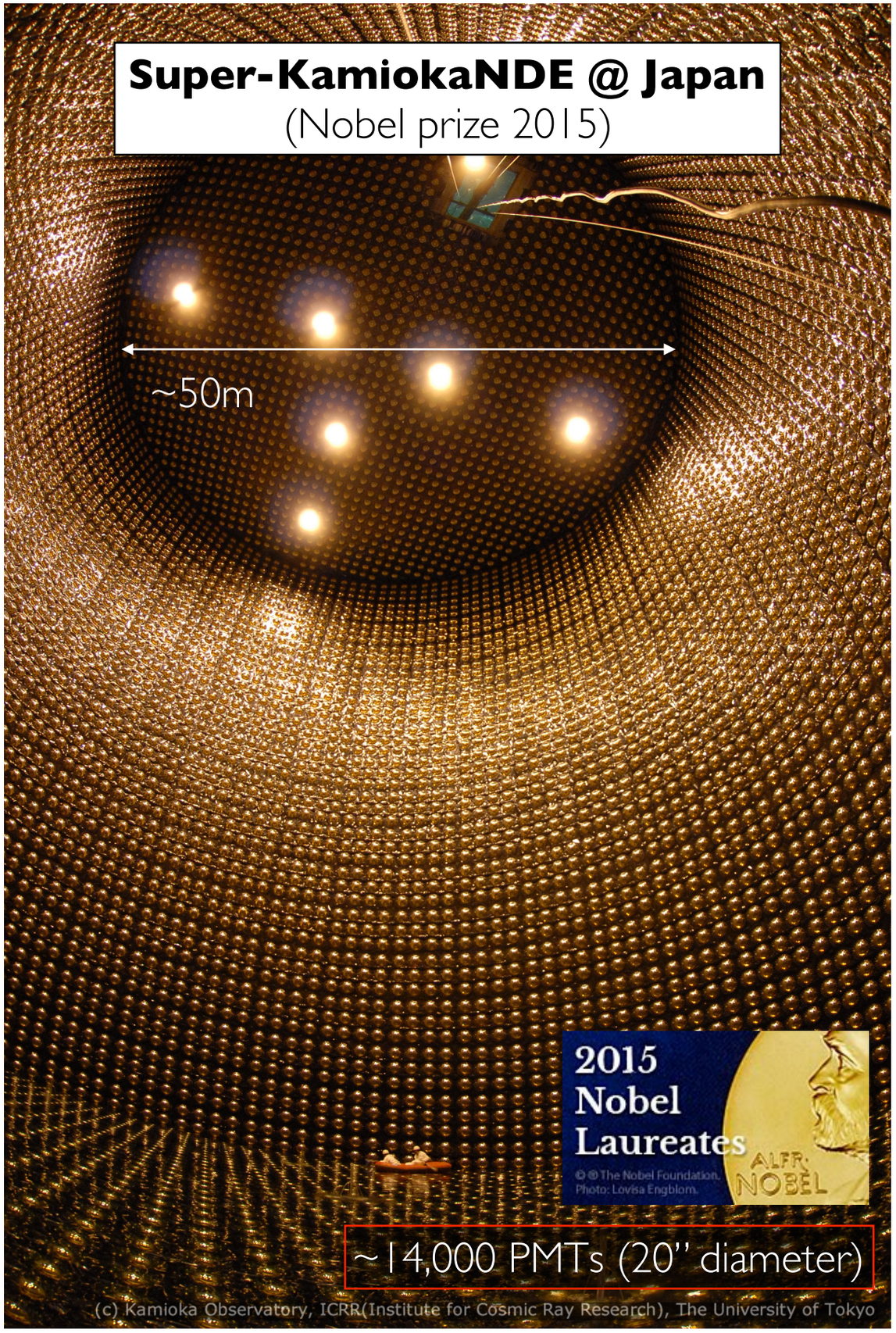
- access chimney
- calibration deploy system(s) [box]

Veto Detector(s):

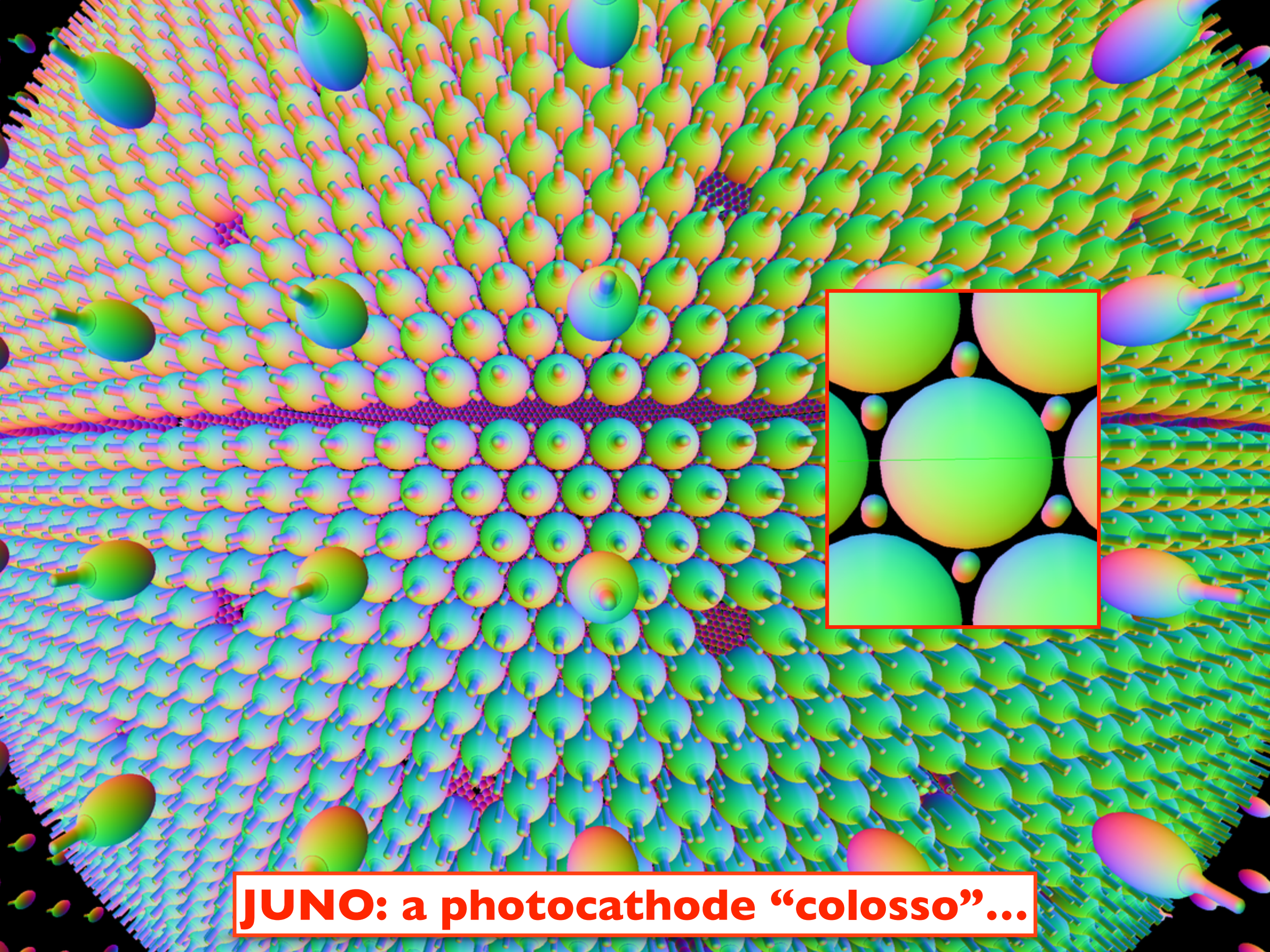
- **water-Cherenkov** (4π μ's)
  →≳2m rock-γ's shield (inert)
- **top-tracker** (multi-layer & top)

the JUNO detector (famous predecessors)…



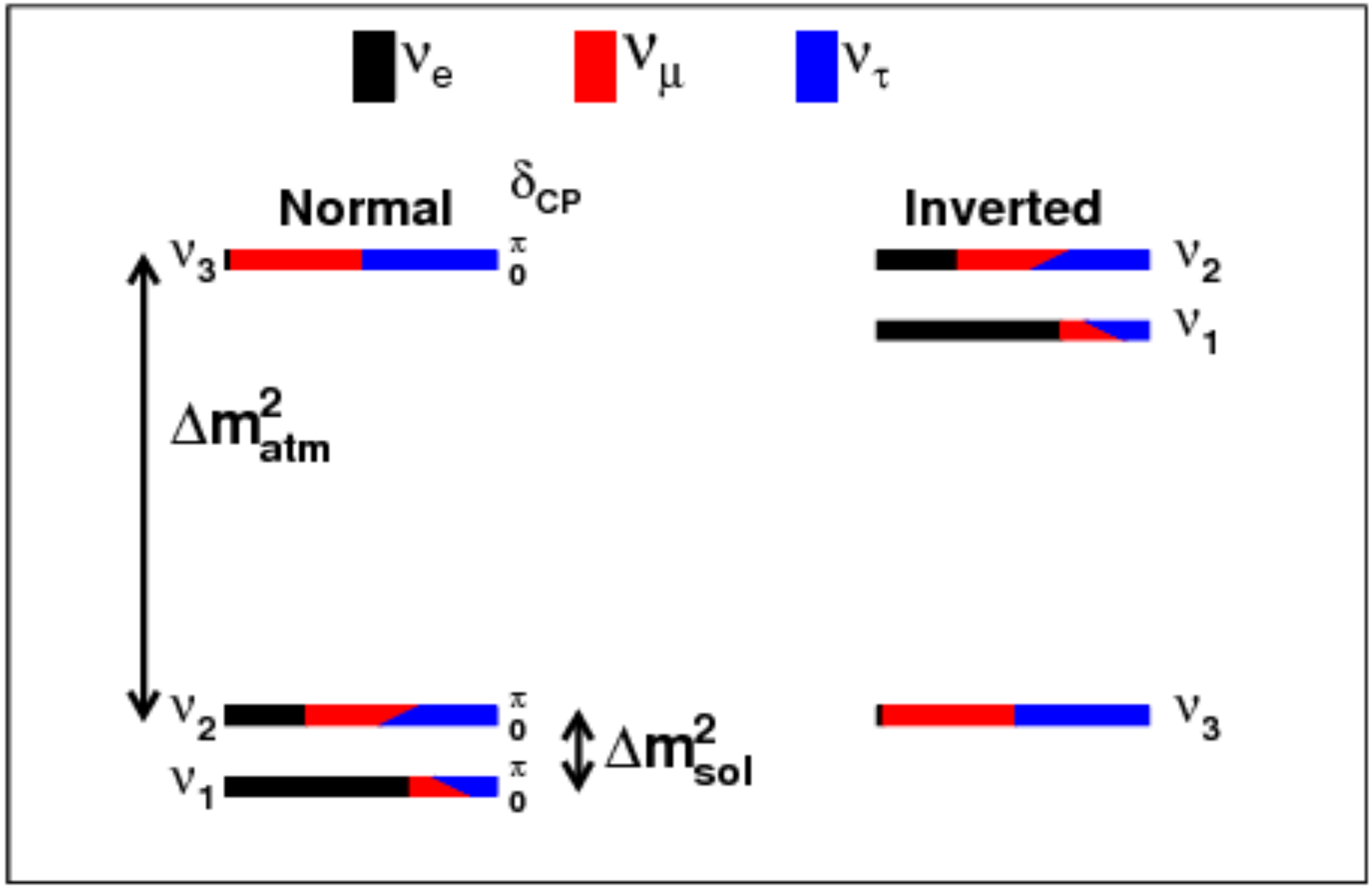


JUNO can be regarded as a hybrid of both…
(filled with liquid-scintillator→ **MUCH more light**)



JUNO: a photocathode “colosso”...

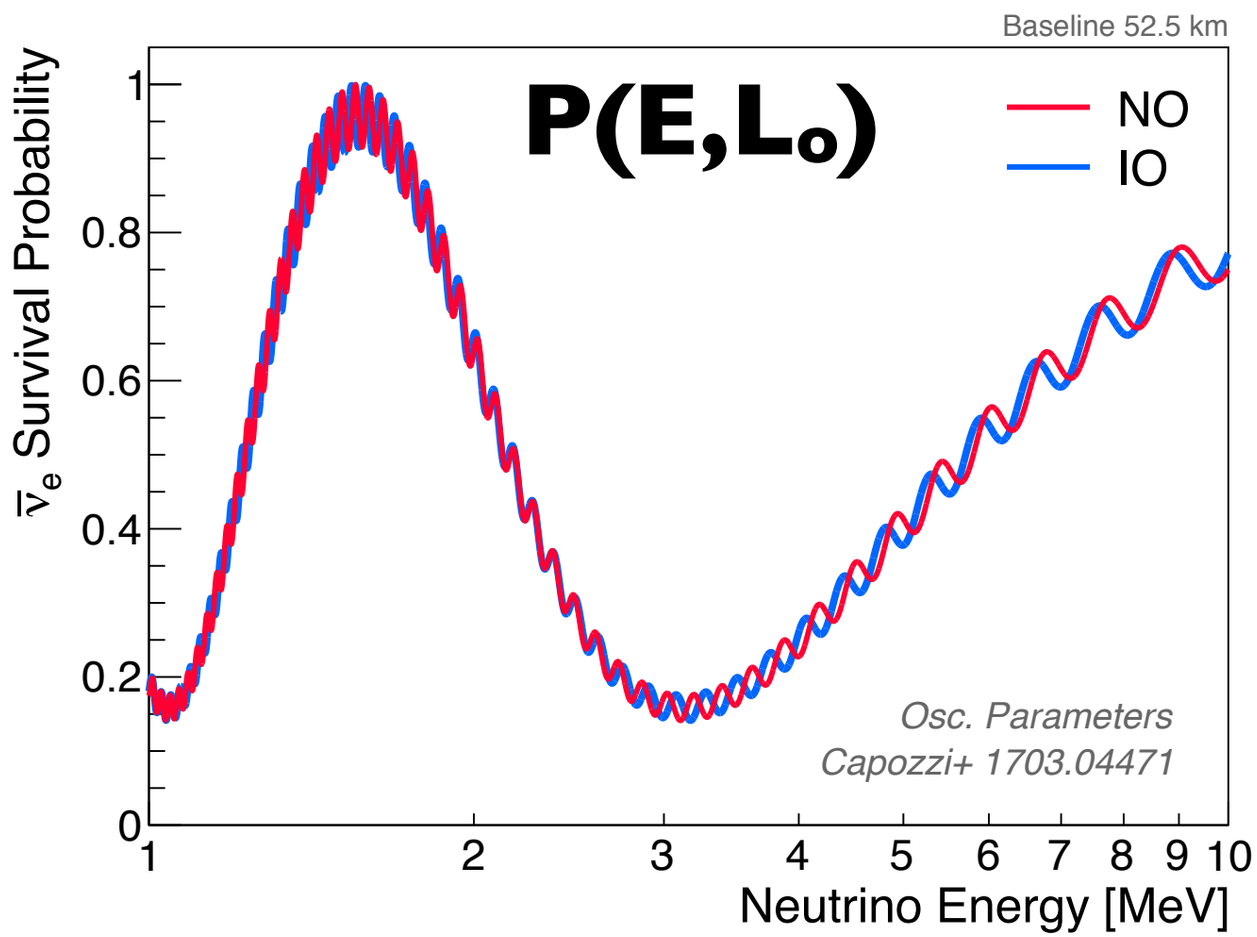
(atmospheric) **Mass** Hierarchy/**Ordering**…

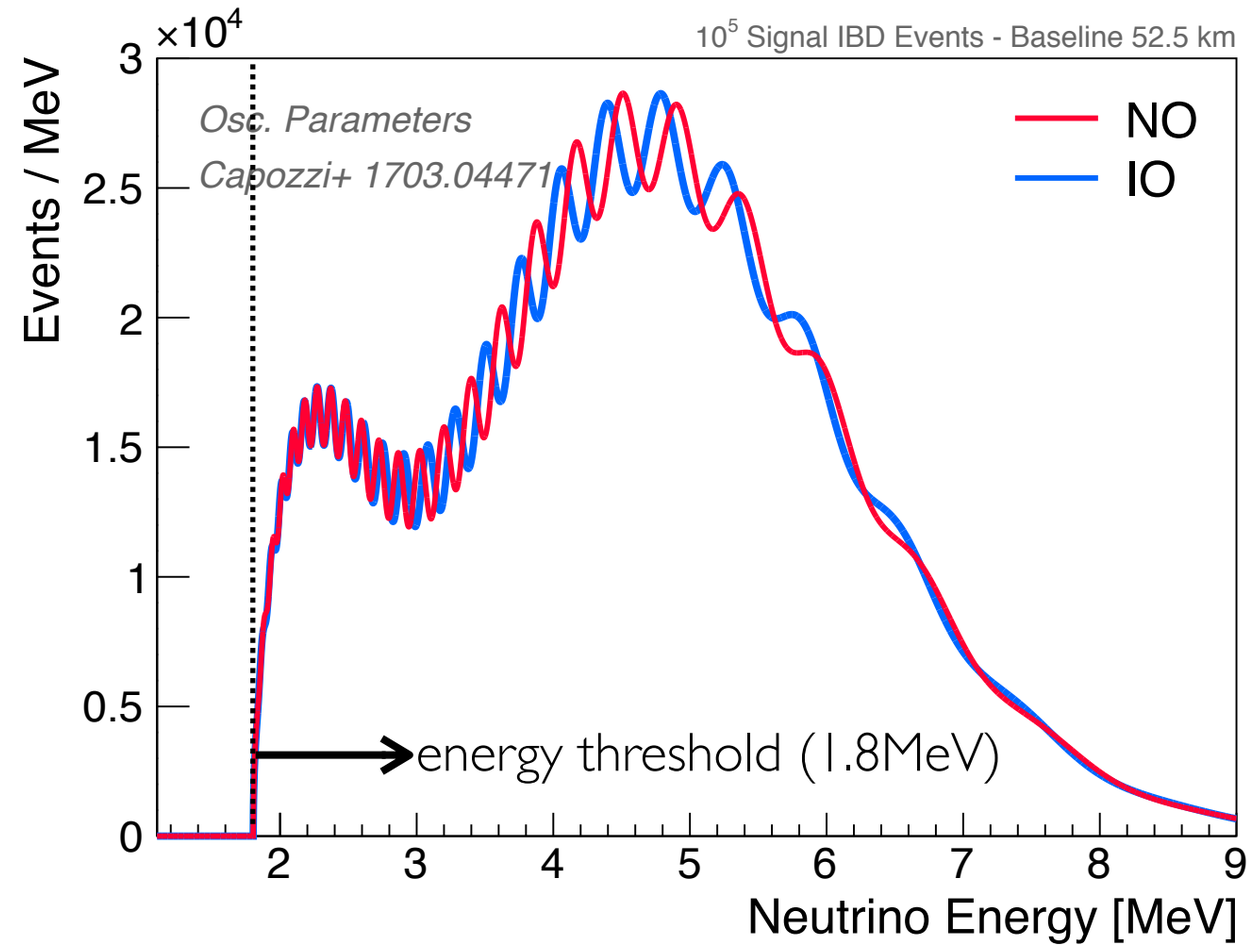


solar data: $+\delta m^2 \rightarrow m_1 < m_2$ [matter effects]

atmospheric data: ≈vacuum! [$\pm\Delta m^2$]

the JUNO observables…





neutrino oscillations
(flux modulation)

spectral distorsion
(a perfect detector)

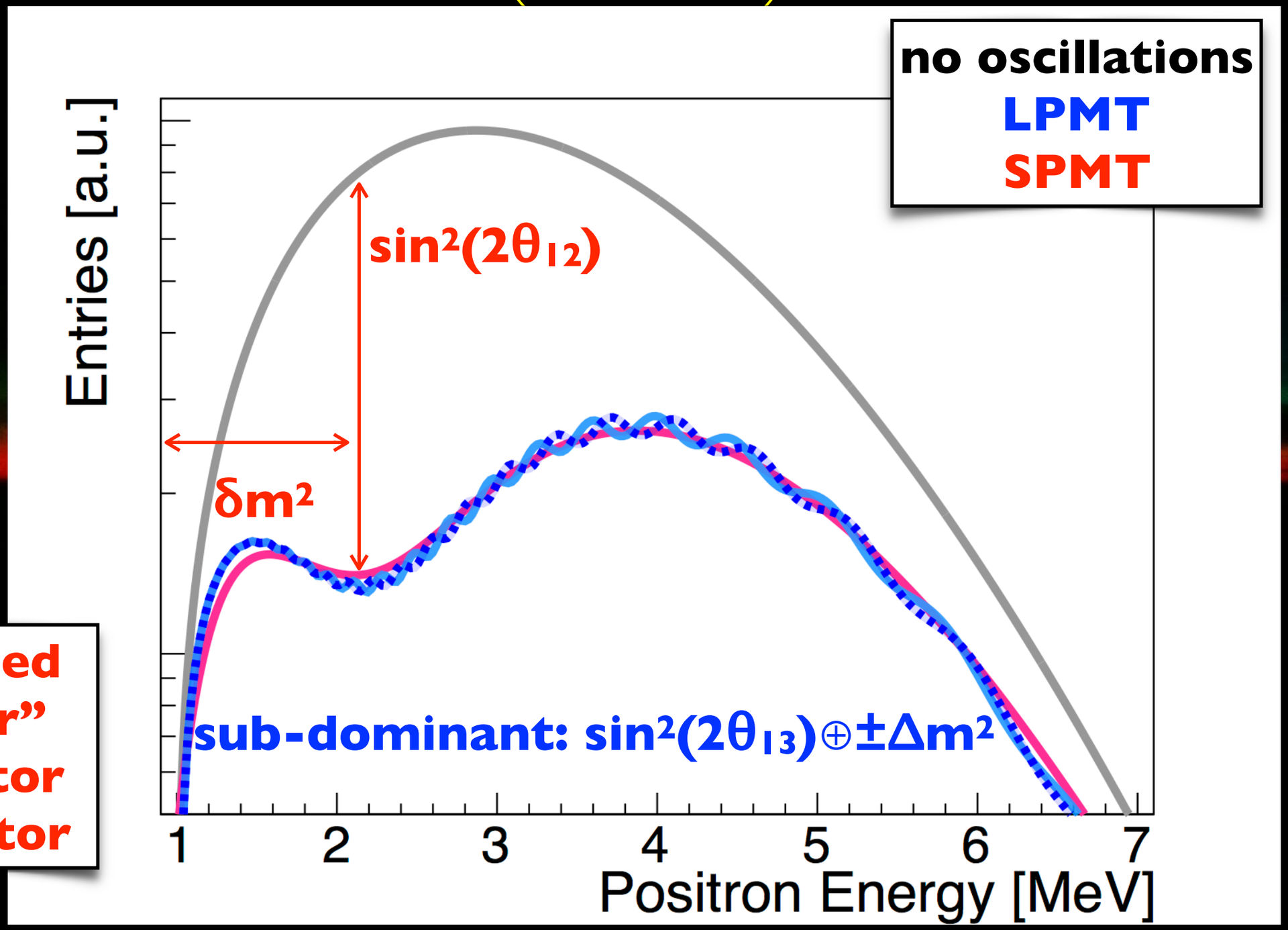
$$\textbf{Spectrum}(E_\nu) \approx \textbf{P}(E_\nu,\textbf{Lo}) \times \Phi(E_\nu) \times \sigma(E_\nu)$$

[trivial energy relation: $E_{e+} \approx E_\nu$ **- cost**]

JUNO's experiment rationale…

2 oscillations modes simultaneously

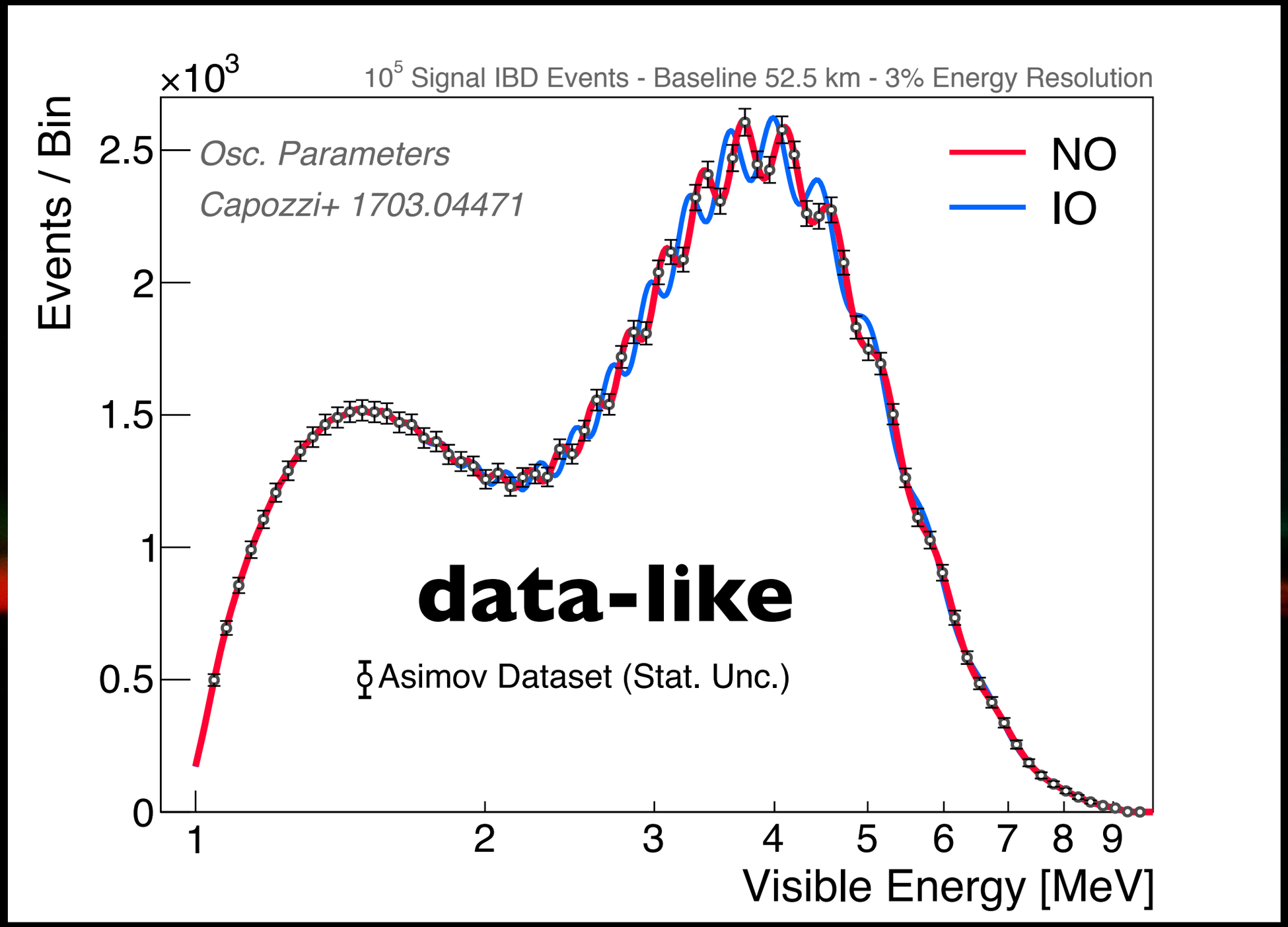
(first time)



no need "near" monitor detector

sensitivity: $\theta_{12} \oplus \theta_{13} \oplus \delta m^2 \oplus \pm \Delta m^2$

JUNO spectrum in more detail…



rich physics programme

$\theta_{12} \oplus \delta m^2 \oplus \pm\Delta m^2$ & info θ_{13}

mass ordering now…

NO favoured to ~2σ

(SK⊕NOvA→**matter effects**)

vacuum

(JUNO)

unique!

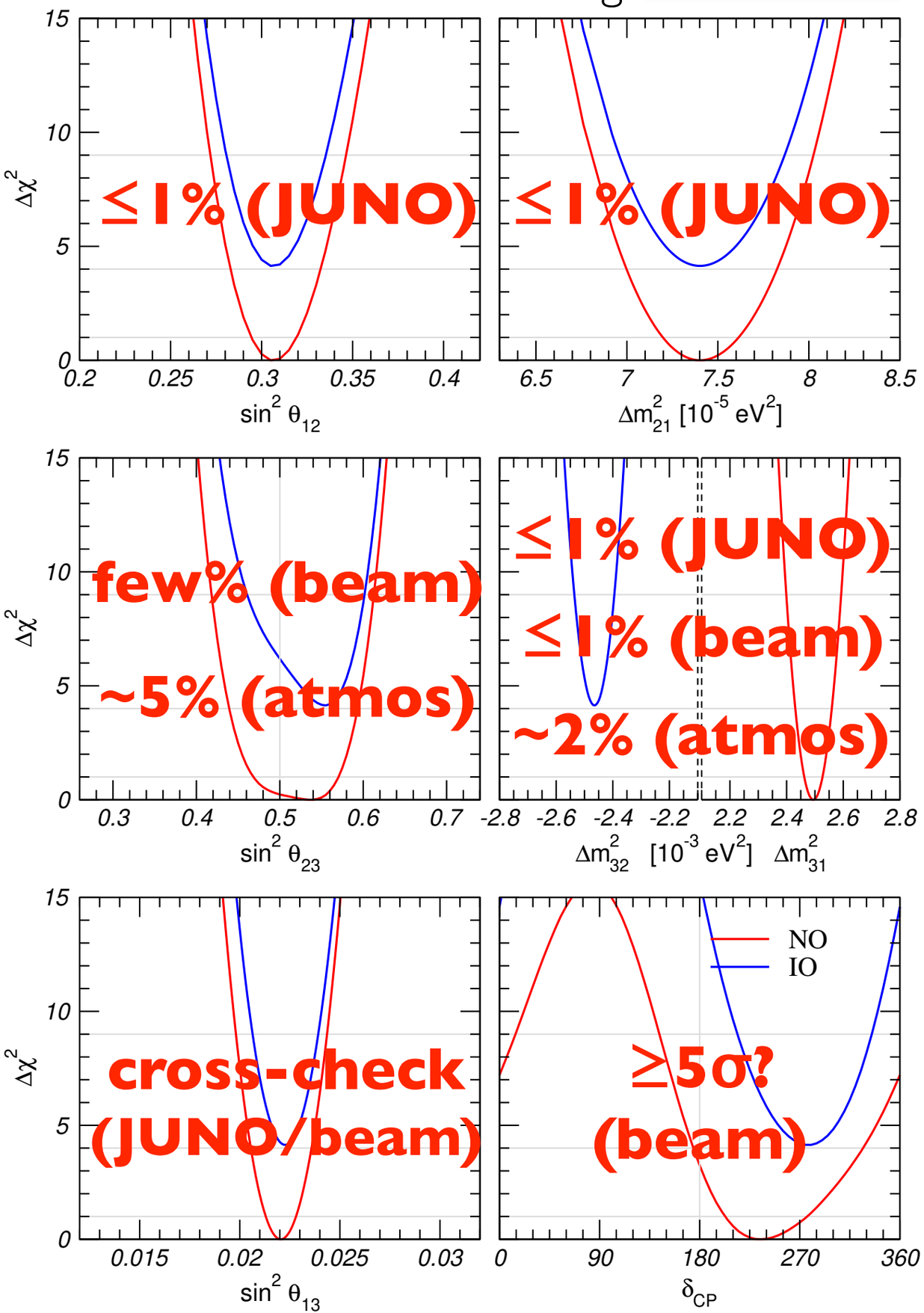
matter

(DUNE & ORCA/PINGU)

global knowledge prospect…

Normal/Inverted Ordering

NuFIT 3.2 (2018)



θ13 terms:

- **θ_{13}: reactor-θ_{13}**

reactor-θ_{13}=DC⊕DYB⊕RENO

JUNO: a cross-check (like DC now)

JUNO (~~solar~~) terms:

- **θ_{12}:** JUNO [now: solar]
- **δm^2:** JUNO [now: KamLAND]

?? (~~atmospheric~~) terms:

- **θ_{23}:** beam⊕atmos
- **Δm^2:** JUNO⊕beam⊕atmos
- **sign[Δm^2]:** JUNO⊕beam⊕atmos

beam = **DUNE⊕HK**

atmos = **ORCA⊕PINGU**

CPV term: beam* (directly)

JUNO expected numbers…

Neutrino Physics with JUNO

Fengpeng An[1], Guangpeng An[2], Qi An[3], Vito Antonelli[4], Eric Baussan[5], John Beacom[6], Leonid Bezrukov[7], Simon Blyth[8], Riccardo Brugnera[9], Margherita Buizza Avanzini[10], Jose Busto[11], Anatael Cabrera[12], Hao Cai[13], Xiao Cai[2], Antonio Cammi[14,15], Guofu Cao[2], Jun Cao*[2], Yun Chang[16], Shaomin Chen[17], Shenjian Chen[18], Yixue Chen[19], Davide Chiesa[14,20], Massimiliano Clemenza[14,20], Barbara Clerbaux[21], Janet Conrad[22], Davide D'Angelo[4], Hervé De Kerret[12], Zhi Deng[17], Ziyan Deng[2], Yayun Ding[2], Zelimir Djurcic[23], Damien Dornic[11], Marcos Dracos[5], Olivier Drapier[10], Stefano Dusini[24],

2015

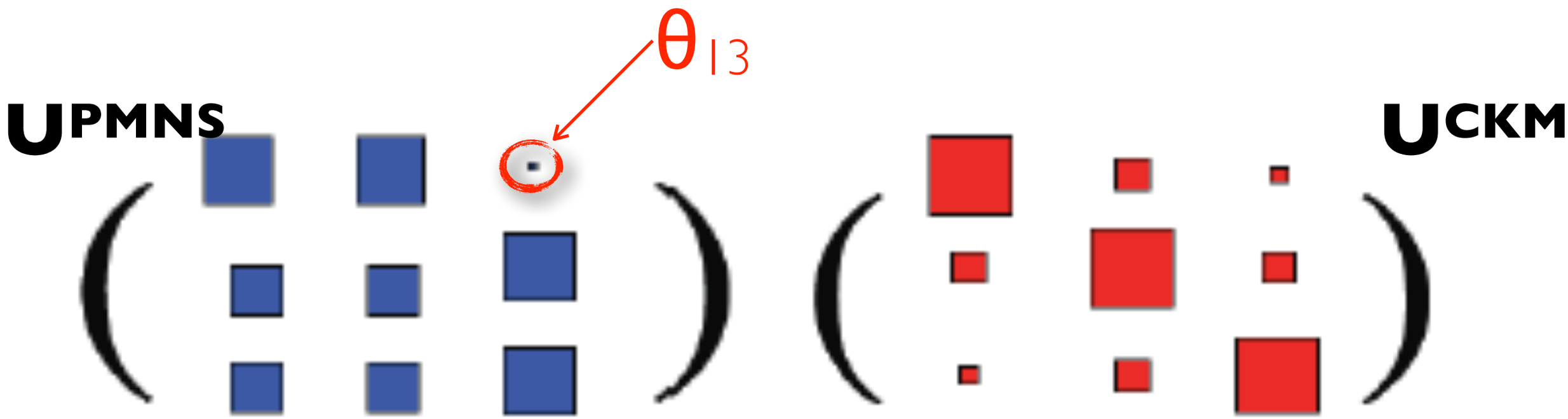
	Precision Now	Precision JUNO
θ_{13}	3.5% (reactor-θ_{13})	15% (cross-check)
θ_{12}	4.0% (Solar)	~0.7%
Δm^2	1.5% (several)	~0.5%
δm^2	2.2% (KamLAND)	~0.5%
MH	>80% Normal Hierarchy favoured	up to ~4σ (Δm^2dependence)

Barbara Ricci[53], Markus Robens[31], Aldo Romani[58], Xiangdong Ruan[49], Xichao Ruan[35], Giuseppe Salamanna[55], Mike Shaevitz[63], Valery Sinev [7], Chiara Sirignano[9], Monica Sisti[14,20], Oleg Smirnov[30], Michael Soiron[64], Achim Stahl[64], Luca Stanco[24], Jochen Steinmann[64], Xilei Sun[2], Yongjie Sun[3], Dmitriy Taichenachev[30], Jian Tang[45], Igor Tkachev[7], Wladyslaw Trzaska[65], Stefan van Waasen[31], Cristina Volpe[12], Vit Vorobel[43], Lucia Votano[59], Chung-Hsiang Wang[16], Guoli Wang[37], Hao Wang[32], Meng Wang[36], Ruiguang Wang[2], Siguang Wang[54], Wei Wang[45], Yi Wang[17], Yi Wang[27], Yifang Wang[2], Zhe Wang[17], Zheng Wang[2], Zhigang Wang[2], Zhimin Wang[2], Wei Wei[2], Liangjian Wen[2], Christopher Wiebusch[64], Björn Wonsak[34], Qun Wu[36], Claudia Elisabeth Wulz[39], Michael Wurm[66], ong Xing[‡2], Jilei Xu[2], Baojun Yan[2], Char i Yang[41], Yifan Yang[21], Yu Yao[31], Ugur Yegin[31], Frederic Yermia[28], Zhengyun You[28], Boxiang Yu[2], Chunxu Yu[69], Zeyuan Yu[2], Sandra Zavatarelli[70], Liang Zhan[2], Chao Zhang[60], Hong-Hao Zhang[45],

arXiv:1507.

arXiv:1507.0561

a (tough) BIG question…



⇒ ~maximal mixing ⇒ ~minimal mixing

PMNS meets unitarity?

(beyond standard model→ only 3 families?)

the CNRS contributions…

Anatael Cabrera (CNRS-IN2P3 & APC)

JUNO @ CNRS/IN2P3…

CNRS

IN2P3 direction

JUNO national coordination
(Jacques MARTINO)

SPMT@IN2P3
coordination
(Anatael CABRERA)

TT@IN2P3
coordination
(Marcos DRACOS)

SPMT-Team@IN2P3
[4 laboratories: ~25scientists]
APC+CENBG+CPPM+SUBATECH

IBD physics/calorimetry
supernova & cosmo-BG

OMEGA laboratory
(μ-electronics)

CC-IN2P3
(computing)

TT-Team@IN2P3
[2 laboratories: ~6scientists]
CENBG+IPHC

μ-reco⊕cosmo-BG

JUNO-IN2P3 = 6 laboratories⊕universities (behind)

the "ROC" ASIC family…


SPMT
(stereo-calorimetry)

our fast genesis…

the idea
(2014 late)

Anatael+Stefano
(SPMT team: 0)

→ ~3months

the 1st design
(2015 early)

Anatael+Stefano
(SPMT team: 0)

→ ~6months

JUNO review
(2015 mid)

Anatael et al
(SPMT team: ~5)

→ ~15motnhs

JUNO approval
(2016 early)

SPMT team: ~10

→ **collaboration**
(2016 late)

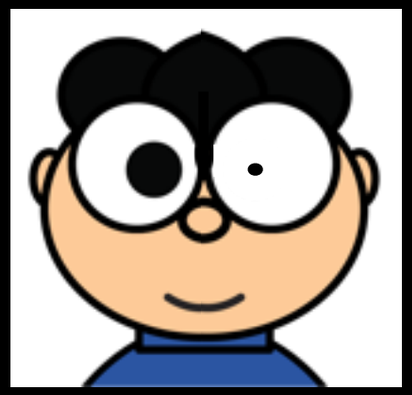
SPMT team: ~30

→ **consider JUNO only SPMT**

JUNO
(mono)

25k PMTs⊕readout
(huge system)

JUNO
(stereo)



our (international) team…

20 laboratories (9 countries) so far…

Armenia
- Yerevan Physics Institute (Yerevan)

Brasil
- FABC (Sao Paulo)
- PUC (Rio de Janeiro)

Belgium
- UBL (Brussels)

Chile
- PUC (Santiago) **(project/physics coordination)**

China
- IHEP (Beijing) **(project/physics coordination)**
- SYSU (Guangzhou)

France
- APC (Paris) **(project/physics coordination)**
- CENBG (Bordeaux) **(technical coordination)**
- CPPM (Marseille)
- LLR (Paris)
- OMEGA (Paris)
- SUBATECH (Nantes)

Italy
- Padova-INFN (Padova)

Russia
- Moscow State University (Moscow)
- Institute of Nuclear Research & Russian Academy of Science (Moscow)

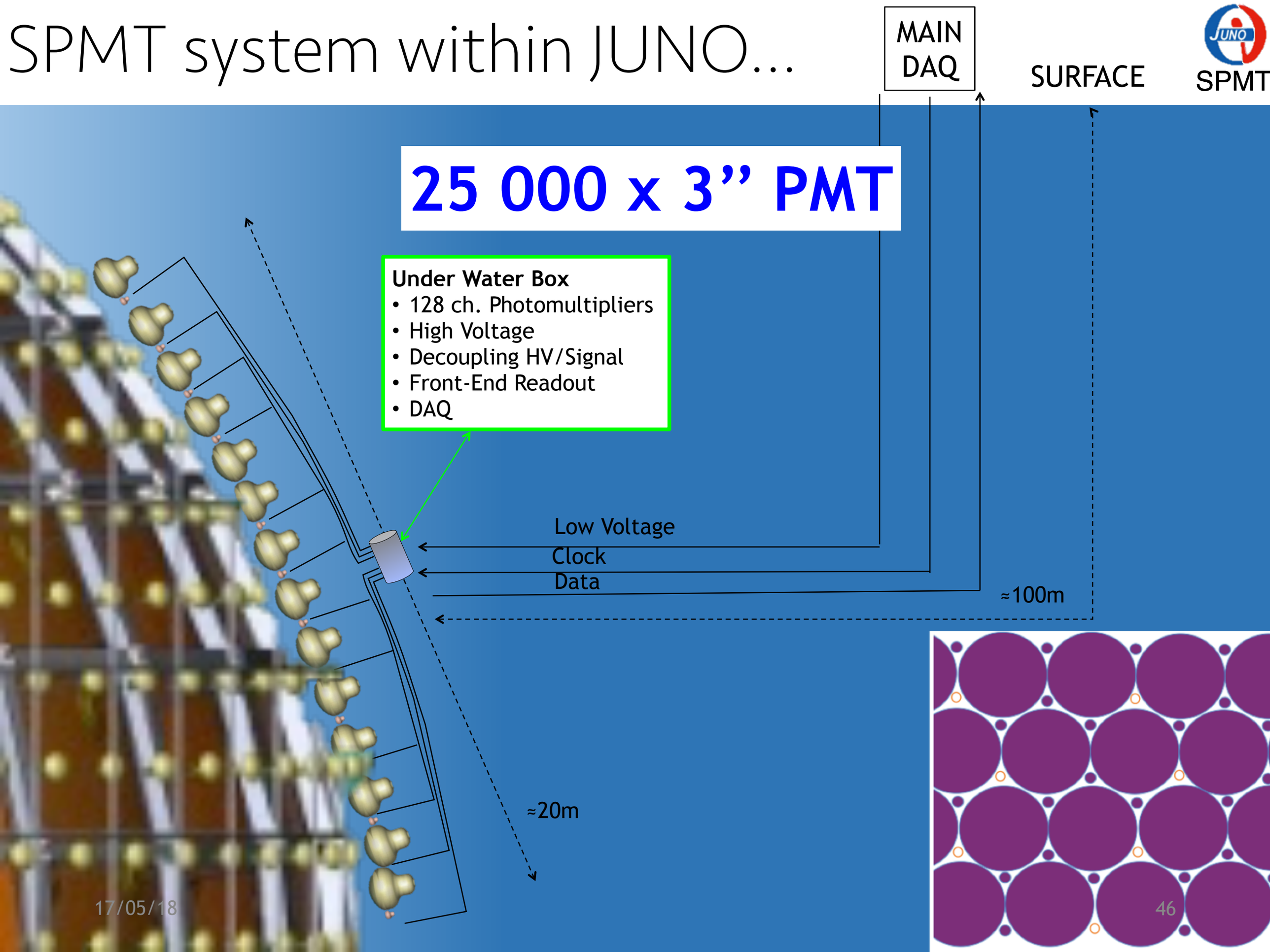
Taiwan
- National Taiwan University NTU (Taipei)
- National Chiao Tung University NCTU (Hsinchu)
- National United University NUU (Miaoli)

technical coordination: C.Cerna

internal coordination
- **physics:** F. Perrot (+INFN)
- **DAQ:** M. Settimo
- **electronics:** A.Cabrera

L2 project management: A.Cabrera (+2)

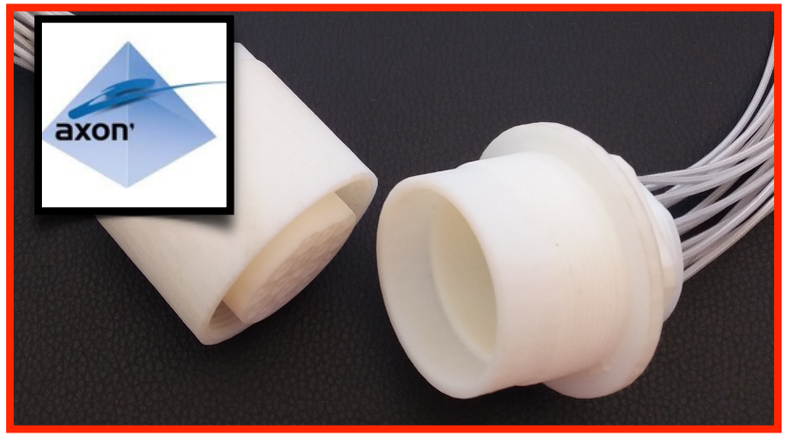
SPMT system within JUNO...



the SPMT ingredients…

3” PMT
(industrial)

PMT HW
(same LPMT)



connectivity
(industrial)

underwater housing
(academic)

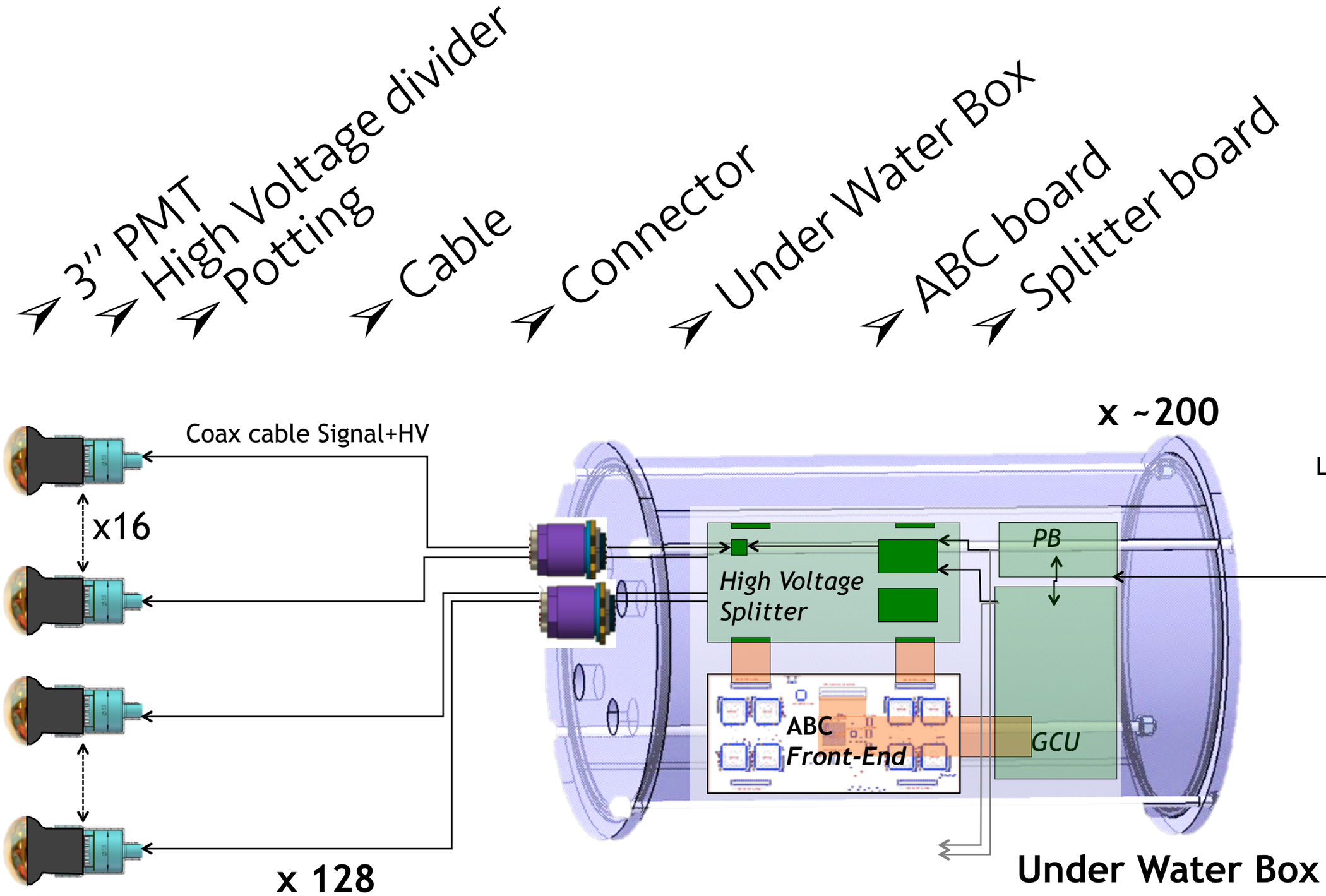
electronics
(academic)

design:
- simple
- high reliability
- industry-driven
- installation*
- recycle JUNO

System schematics

our construction brick

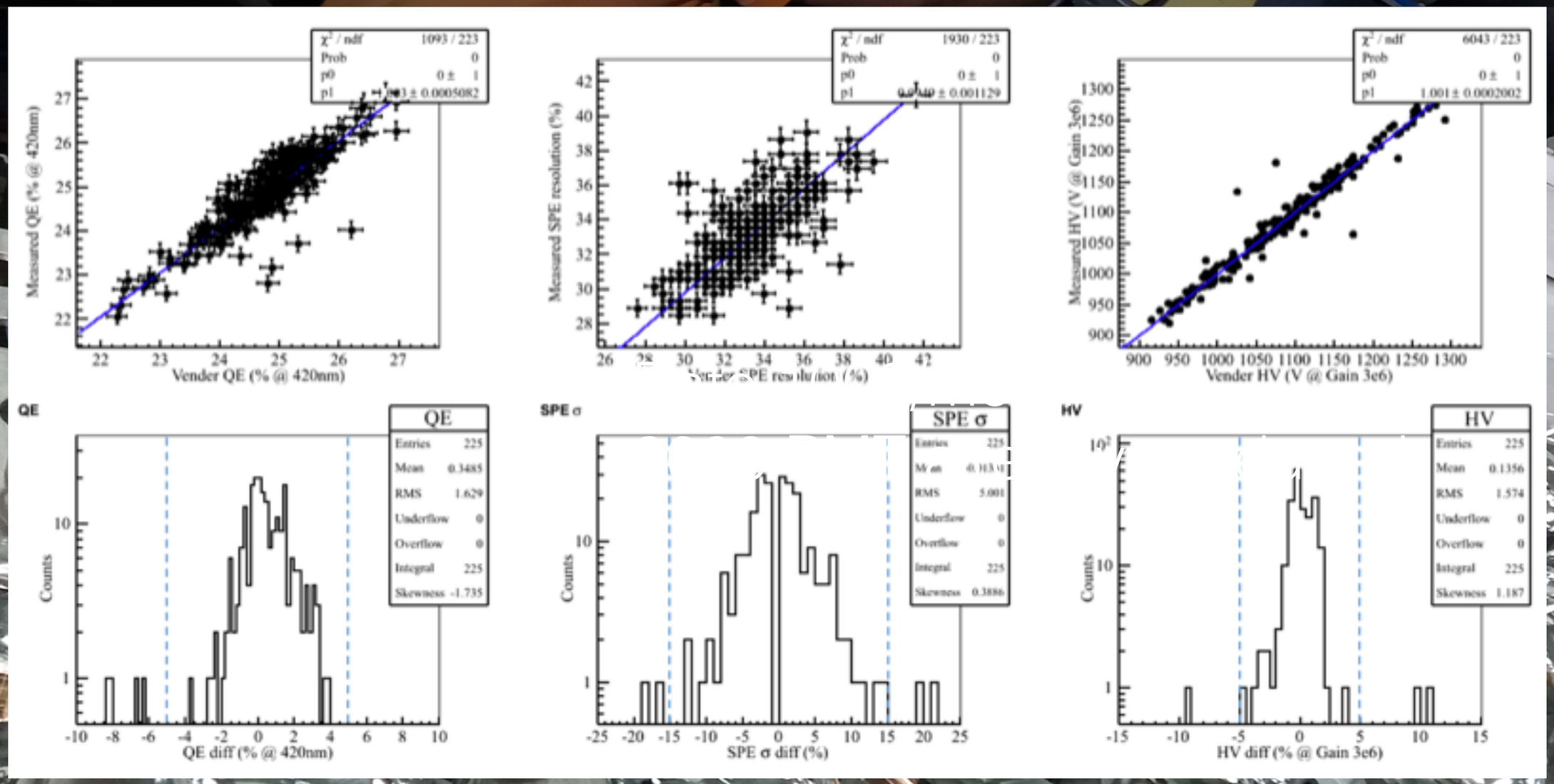
SPMT



PMT production & testing (industry)status …

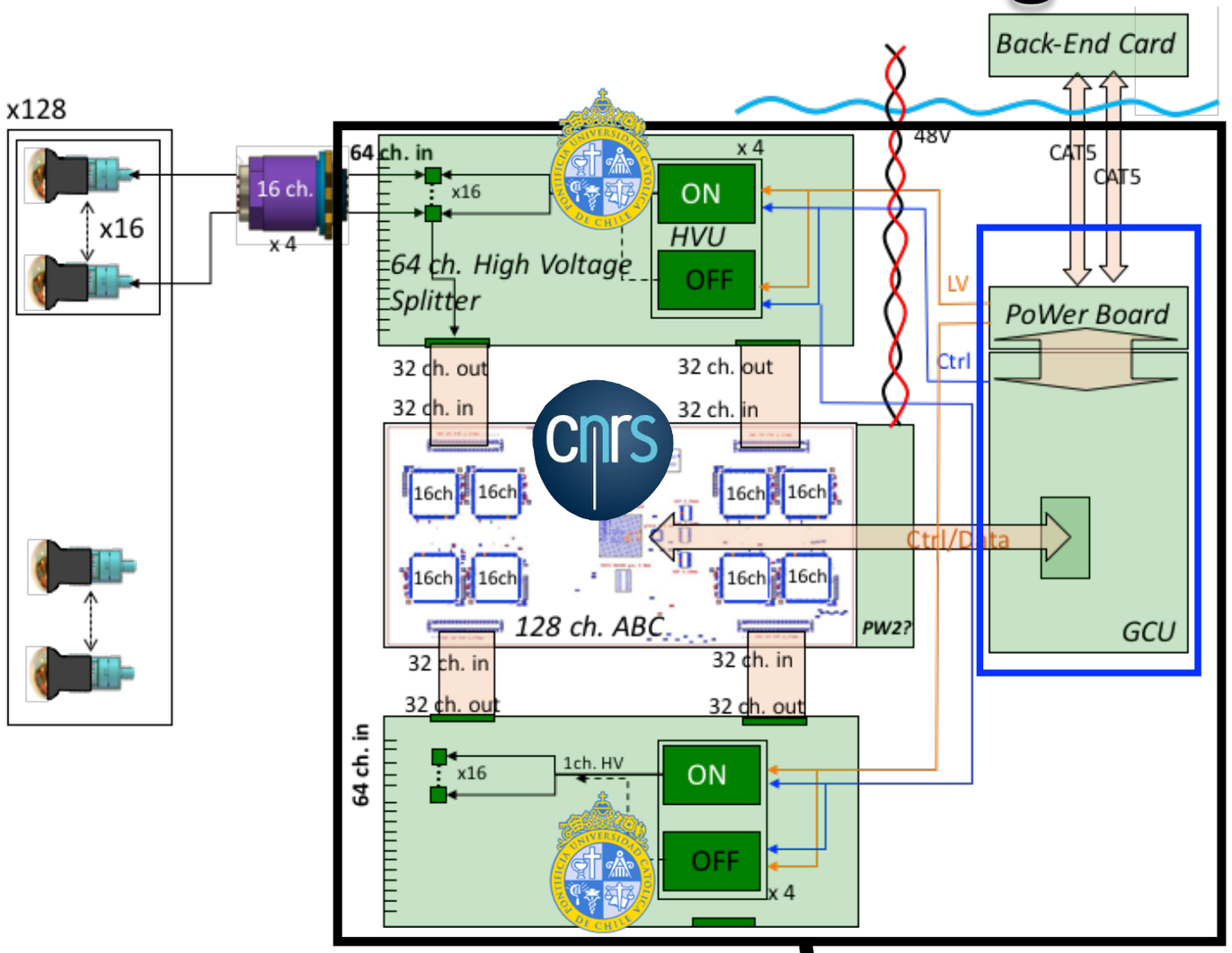
26,000 3” PMTs production & testing

(@HZC→ company personnel ⊕ JUNO supervision)



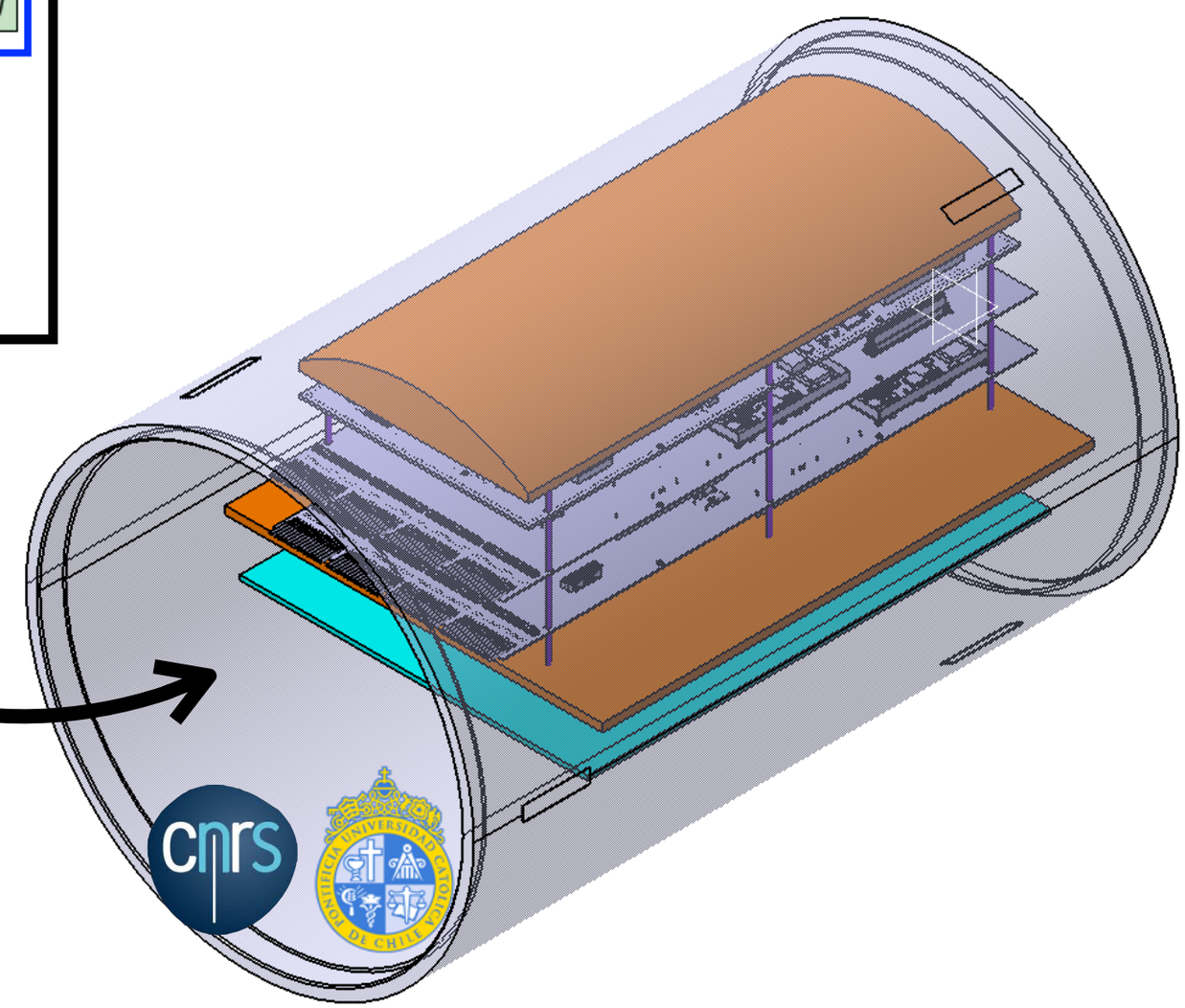
1 k PMT/month→ ~6k PMTs done!

the readout goes (folded) under-water…

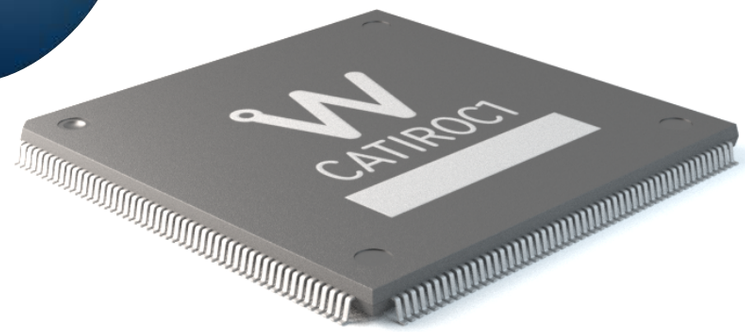


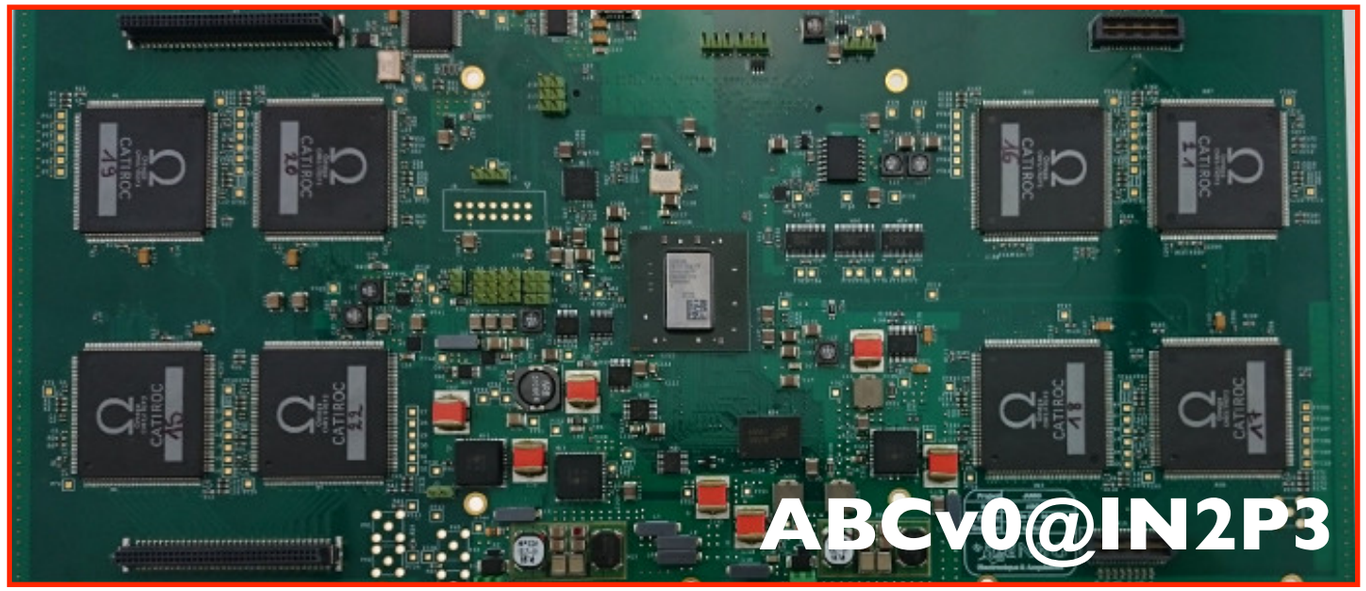
JUNO common
(SPMT⊕LPMT readout)

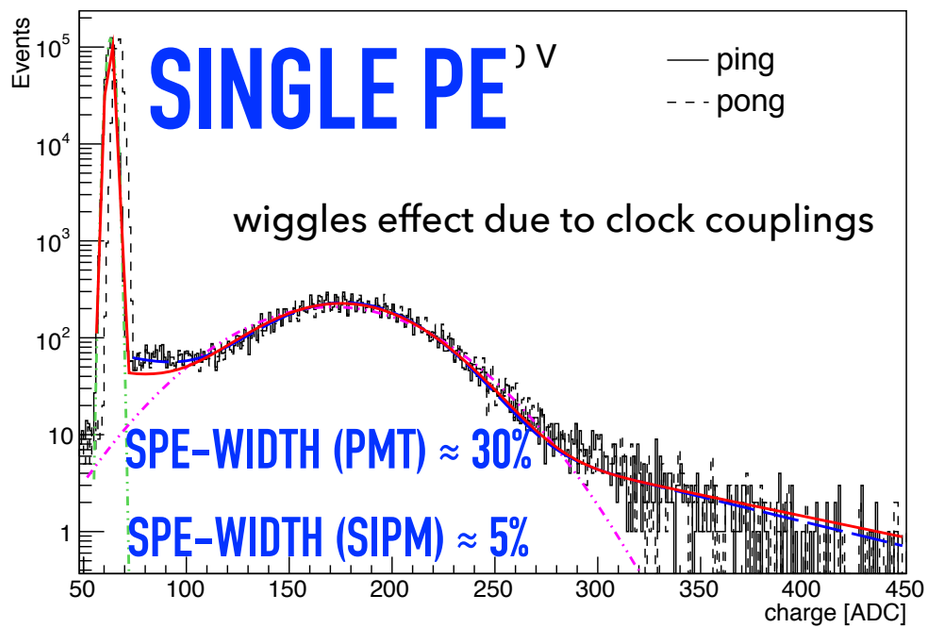
underwater box

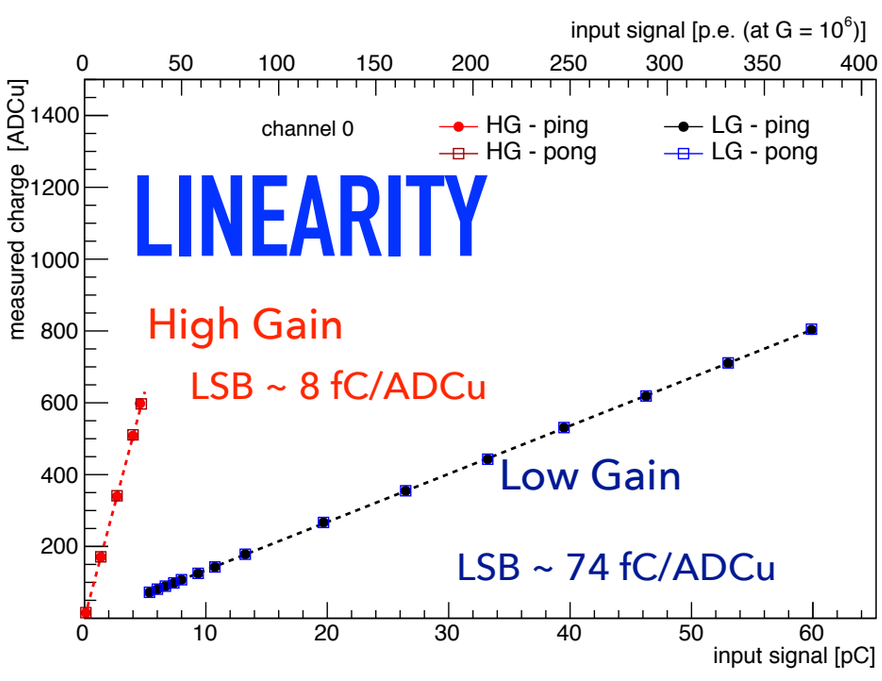


SPMT core readout electronics…









NOVEL SUPERNOVA READOUT → ≲10M/S

Anatael Cabrera (CNRS-IN2P3 & APC)

the ABC team (+ a few others)…

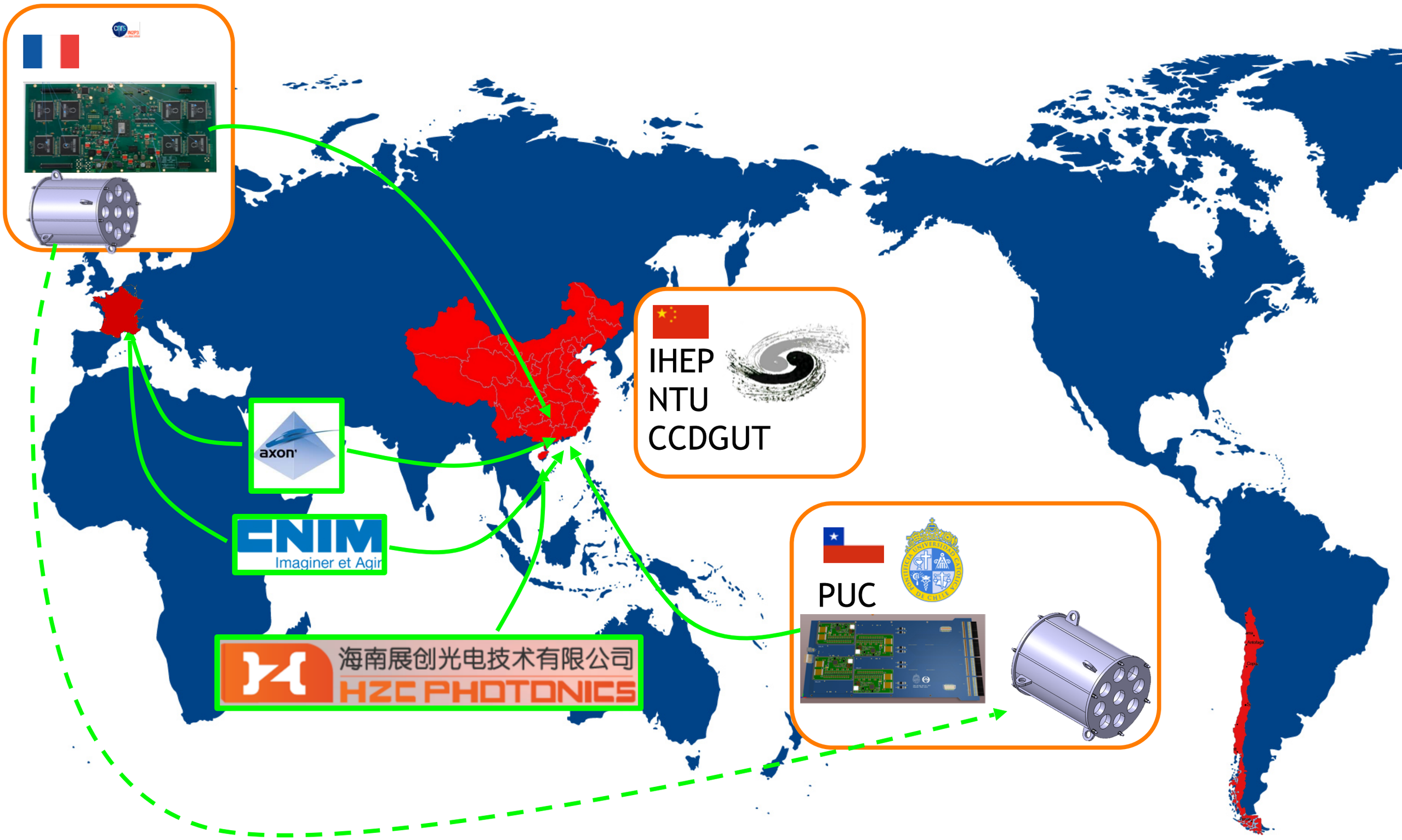
external ABC readiness review

(March 2018)

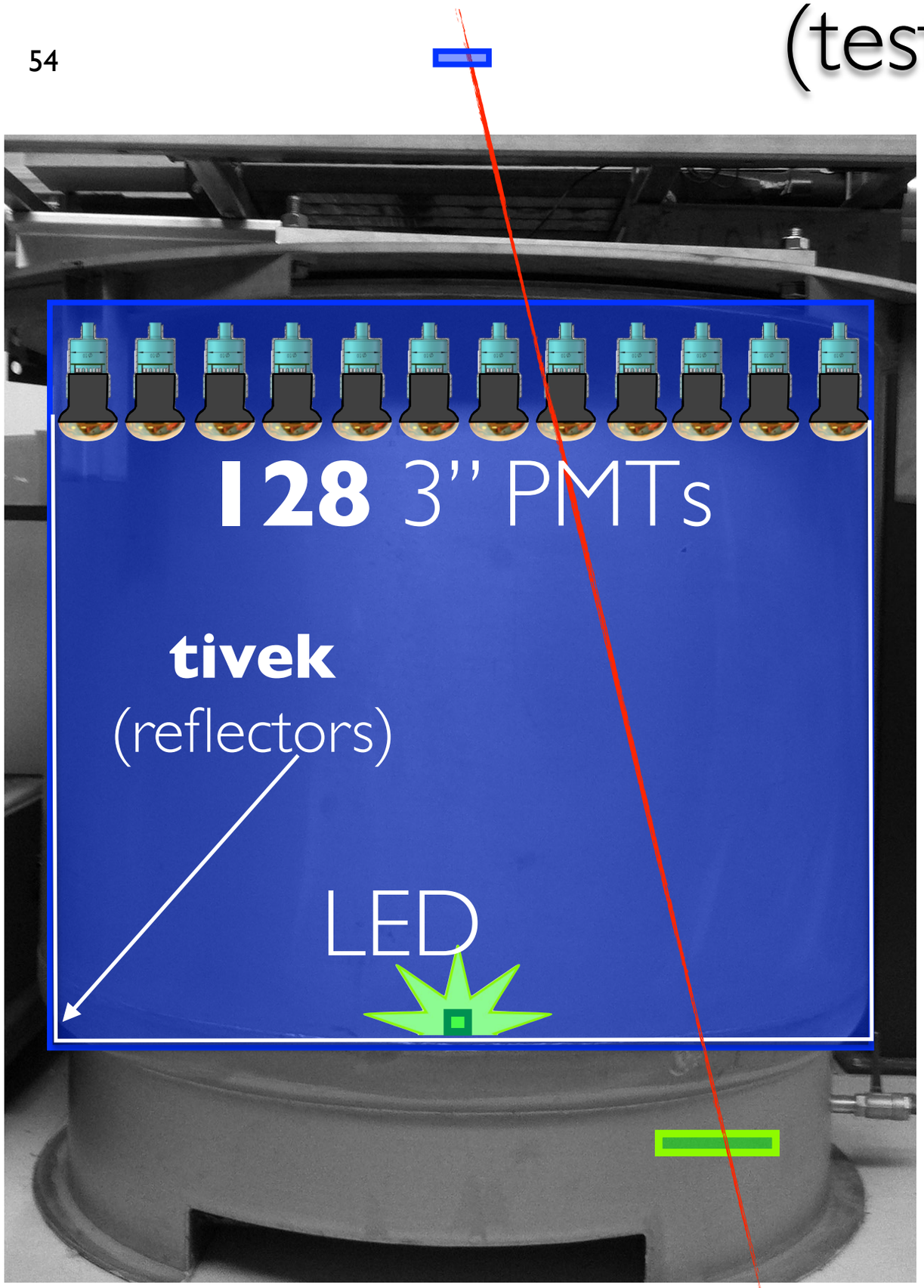
Anatael Cabrera (CNRS-IN2P3 & APC)

shipping to JUNO site…

SPMT



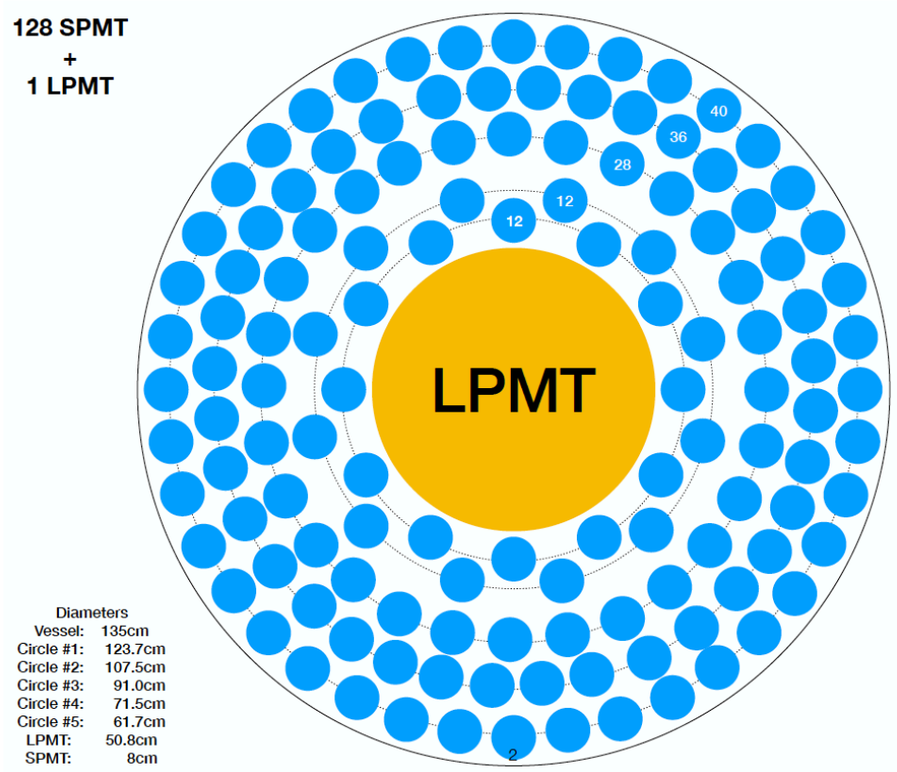
(test before) JINO @ IN2P3…



Φ=135cm M≤1.4tons

JINO (prototype) goals…

- **full system integration**
- **electronics/DAQ validation**
  - ABC card performance
  - multi-card synchronisation
- **supernova** high rate test/optimisation
- **stereo-calorimetry** data validation
- **pre-installation full system**



Anatael Cabrera (CNRS-IN2P3 & APC)

The JUNO Top Tracker

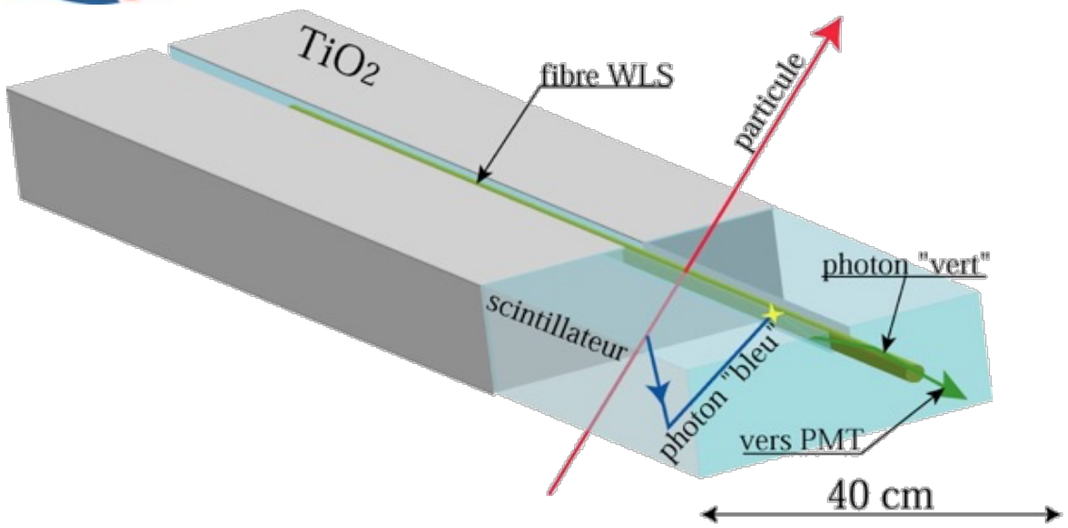
IPHC, CENBG, LLR (2014-17), OMEGA,
LNF (INFN, CAEN), JINR, ULB, IHEP

(IN2P3 in kind contribution for 3.2 M€)

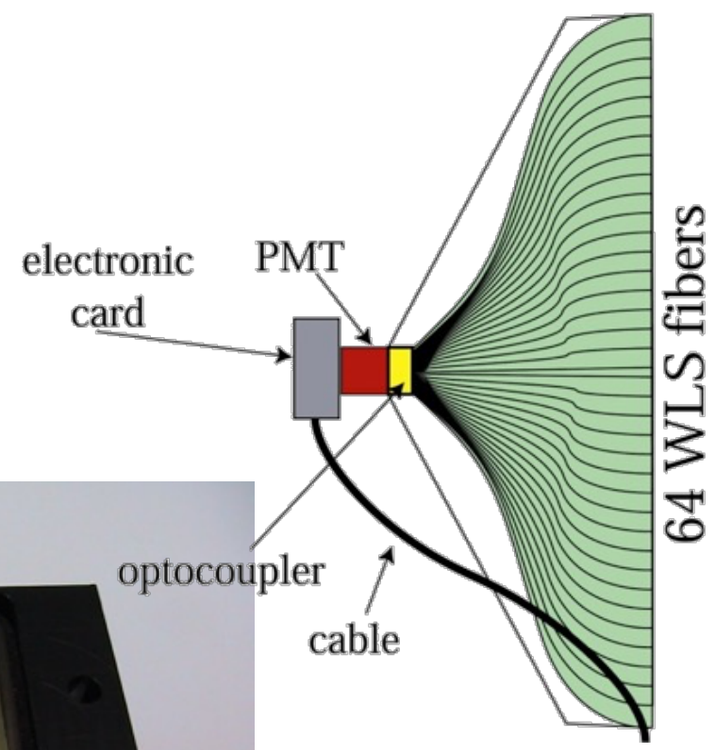
IN2P3 responsibilities:

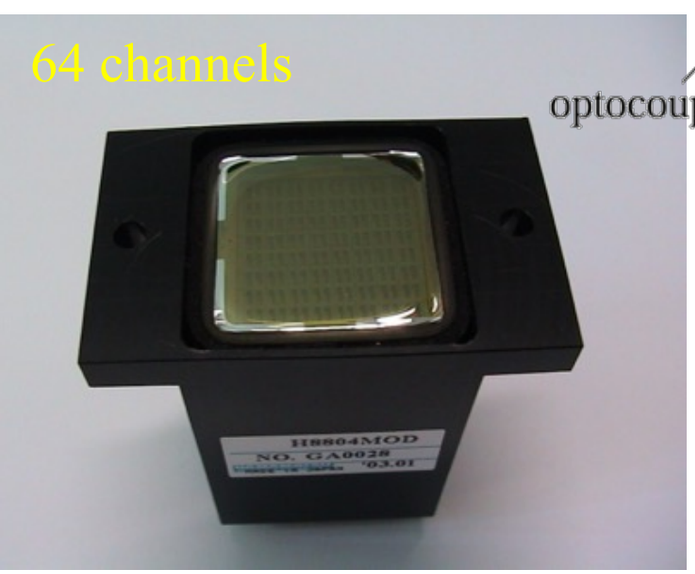
- Project Leader (L2): M. Dracos (IPHC)
- Technical coordinator: J. Wurtz (IPHC)
- Software coordinator: C. Jollet (CENBG)

JUNO Top Tracker

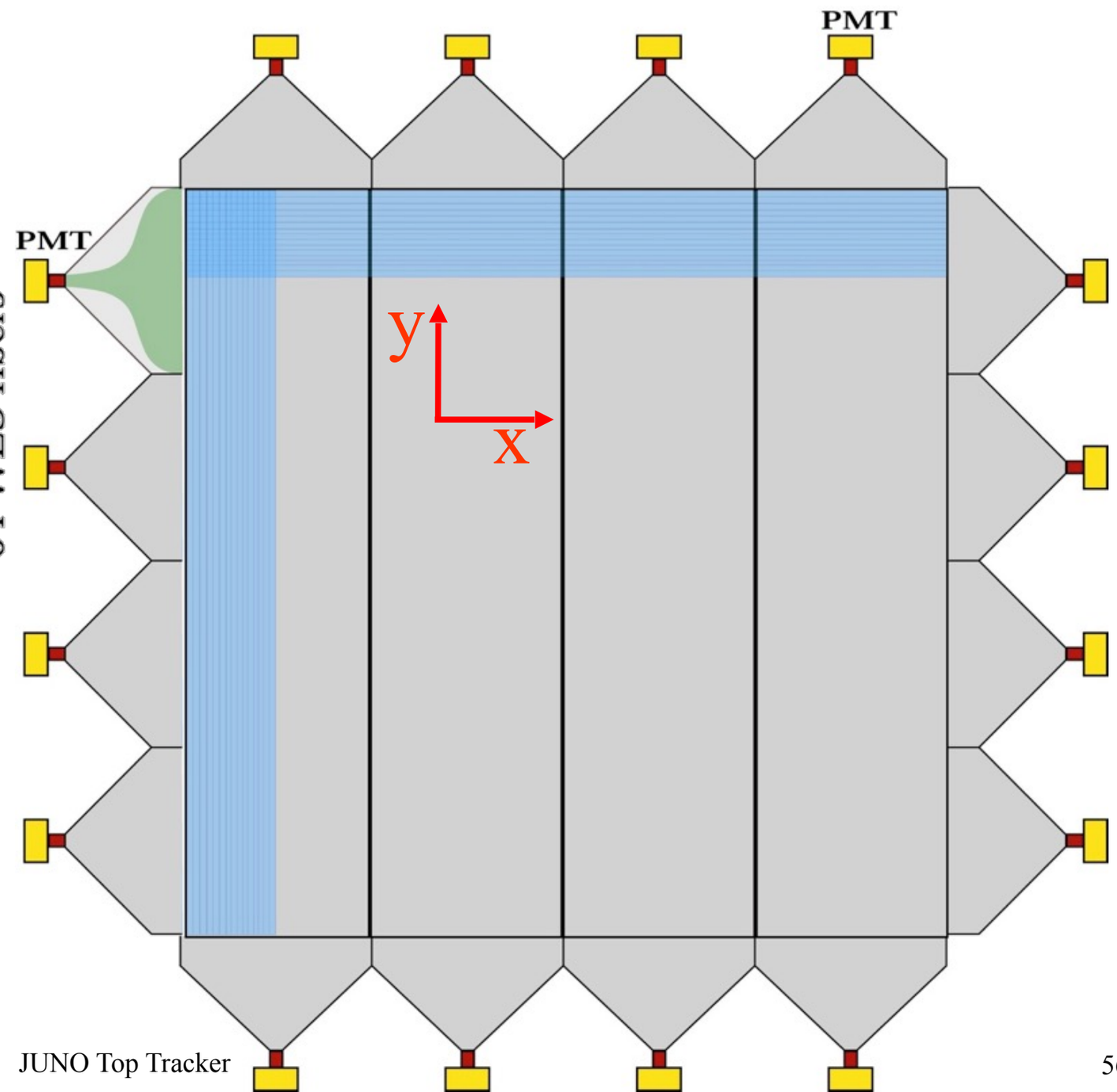


- 62 walls (496 modules)
- 6.8x6.8 m² sensitive area/wall
- 64 k channel in total

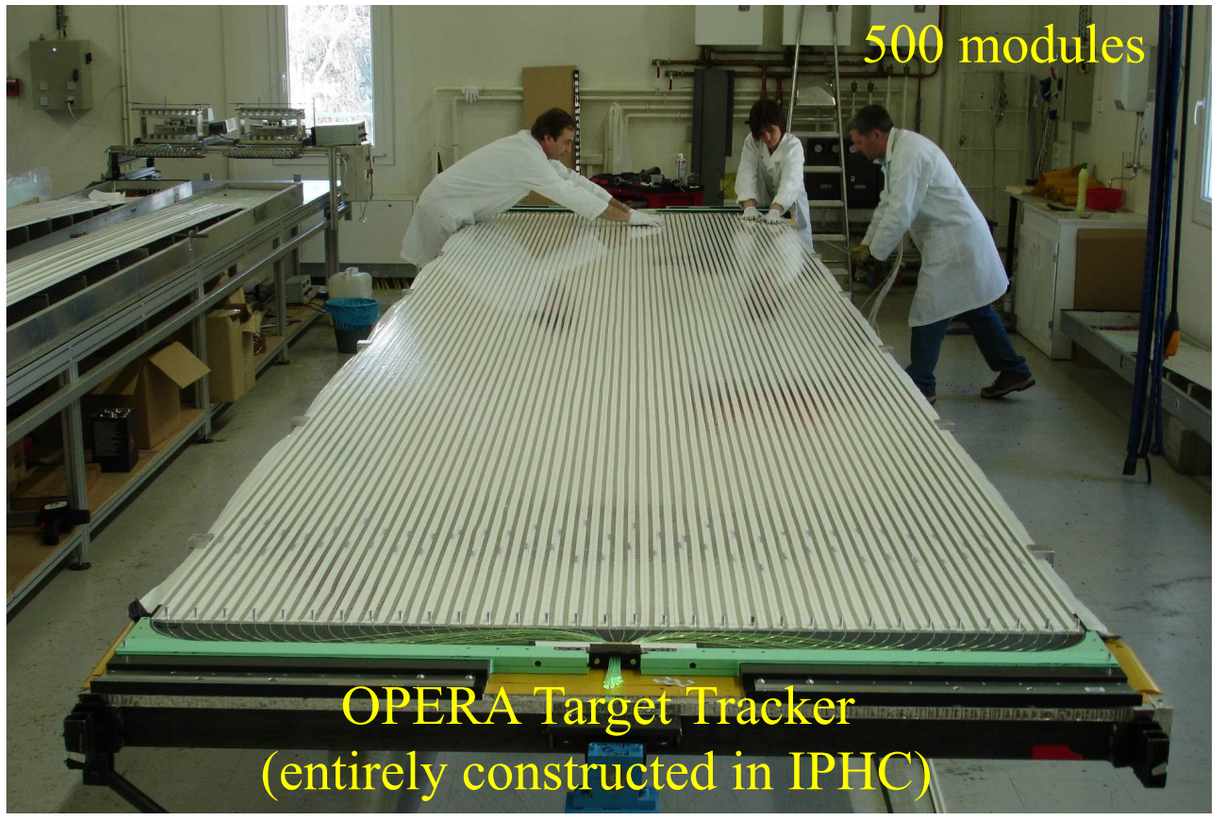




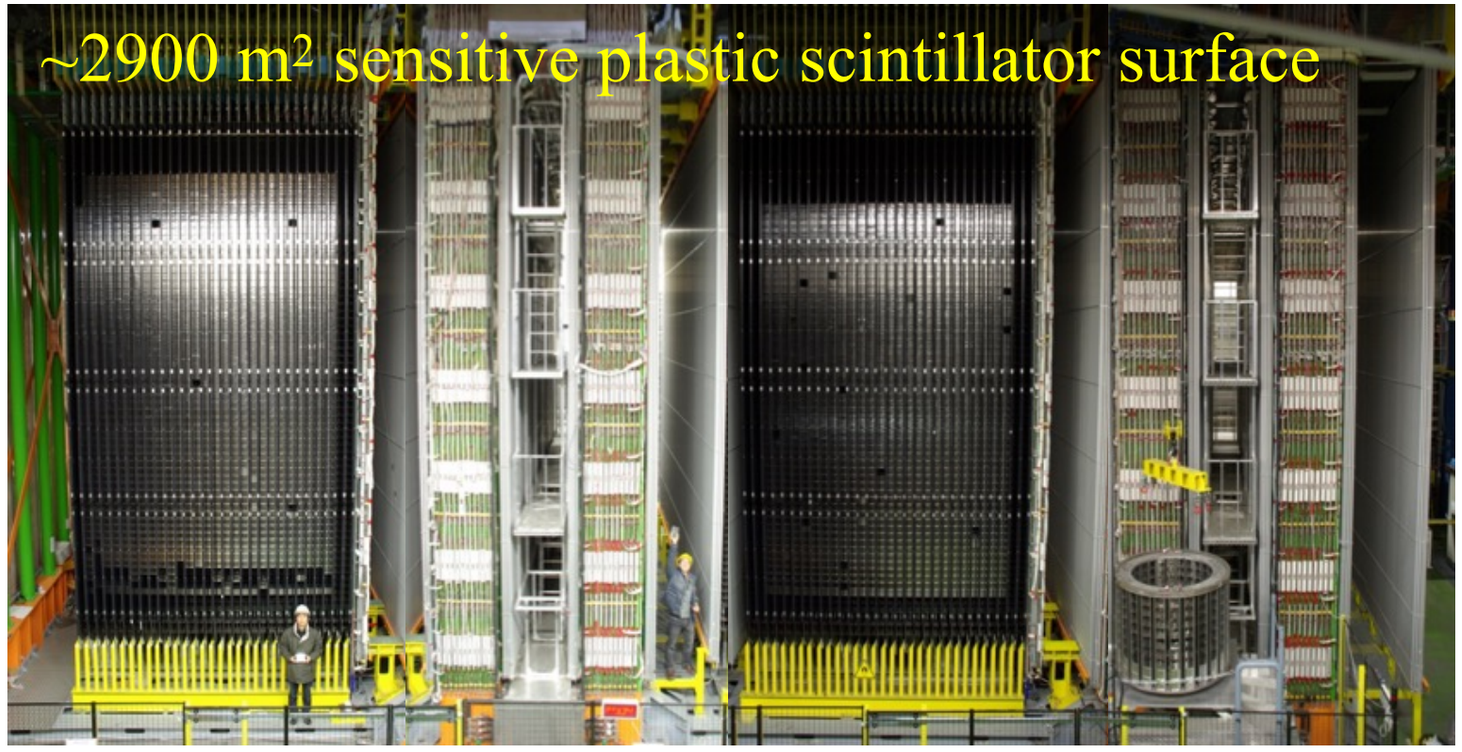
Hamamatsu MA-PMT (3x3 cm²)



OPERA Target Tracker



The TT has been packed into 7 containers and shipped from the underground lab of Gran Sasso to China in 2017.

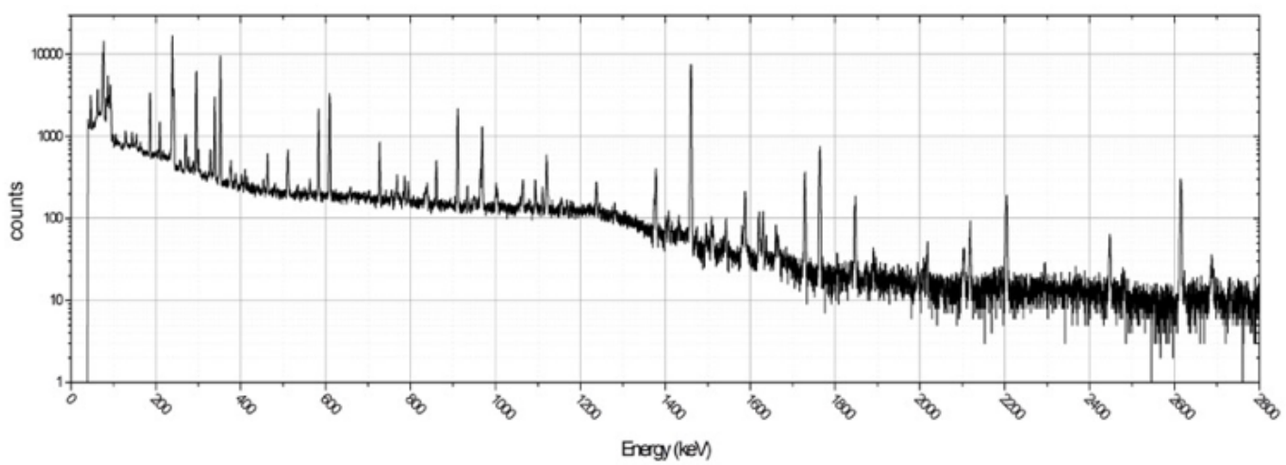


JUNO Top Tracker

Estimation of the TT DAQ Rate

(mainly due to rock radioactivity)

- The sample with label 2702 is extracted from underground between -633 m and -638 m, few meters above the bottom of the water pool.
- Measurement realised by CENBG - Bordeaux using a Ge detector.



JUNO site	Bq/kg	ppm
^{40}K	1340 +/- 50	5
^{238}U	110 +/- 10	9
^{232}Th	105 +/- 10	25

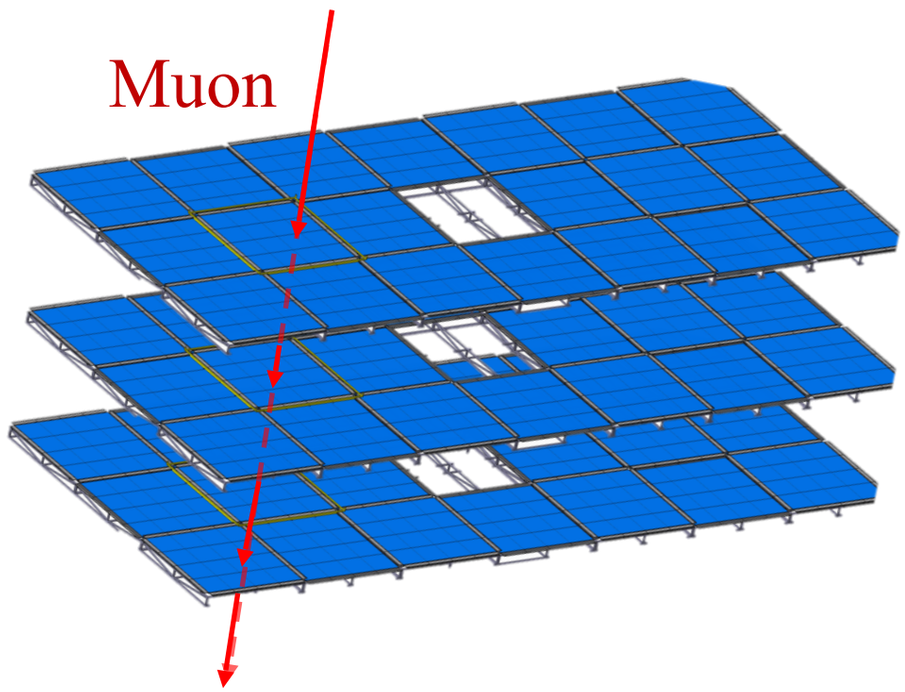
GS (just for comparison):

^{40}K 26 ± 2 Bq/kg
^{238}U 1.8 ± 1 Bq/kg
^{232}Th 1.5 ± 1 Bq/kg

much higher radioactivity than in GS!
New electronics needed

Top Tracker rate and triggering

- All TT software already introduced in the JUNO framework
- Rate simulations done by LLR and IPHC (CENBG)



Trigger Strategy:

Level 1:

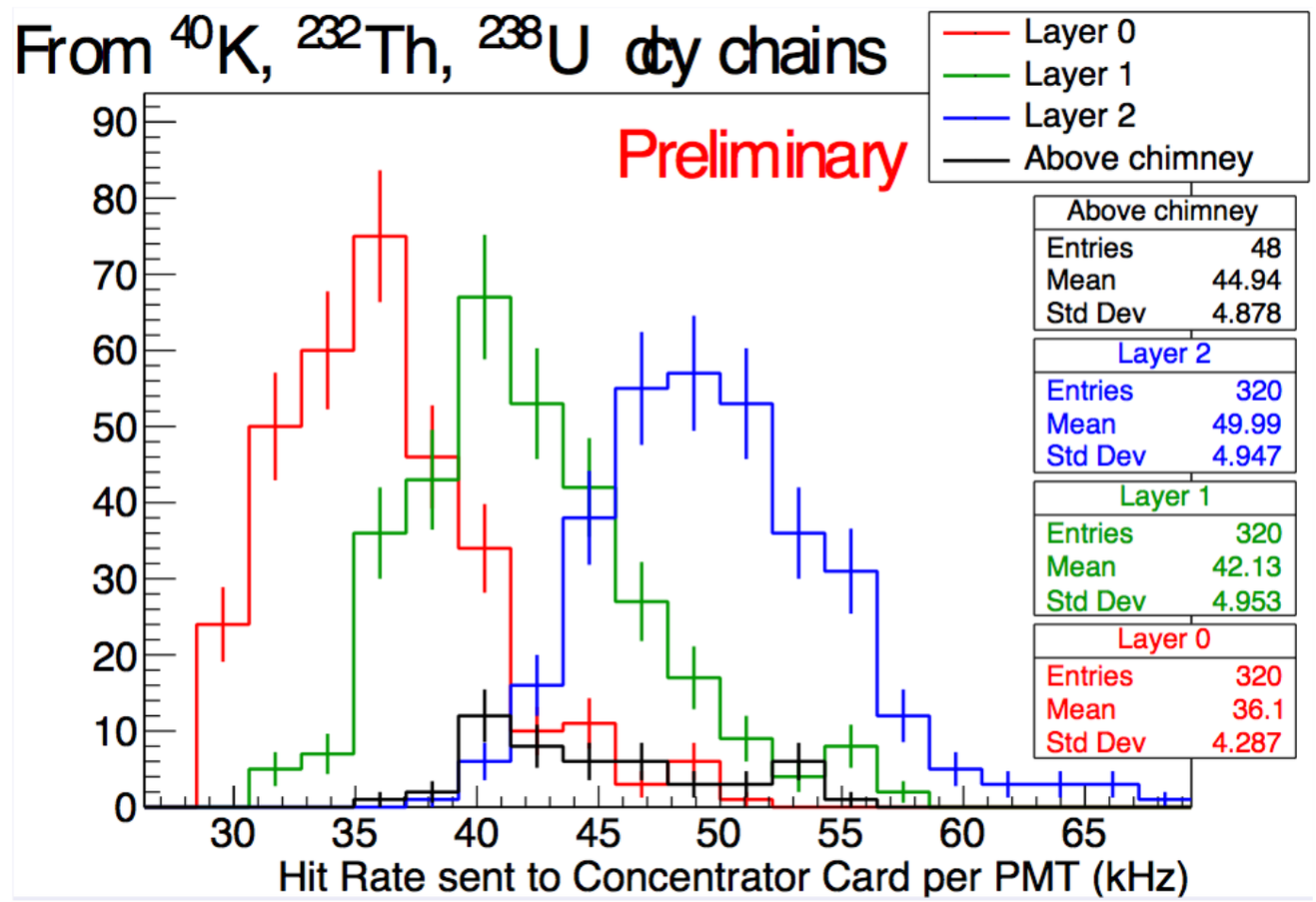
- Wall level (Square of 6.7x6.7m²)
- 64*16 Channels
- Counting rate: 50 kHz/PMT
- L1 trigger selection needed (~10 kHz/wall)

Level 2 (online if needed):

- Global level for track alignment

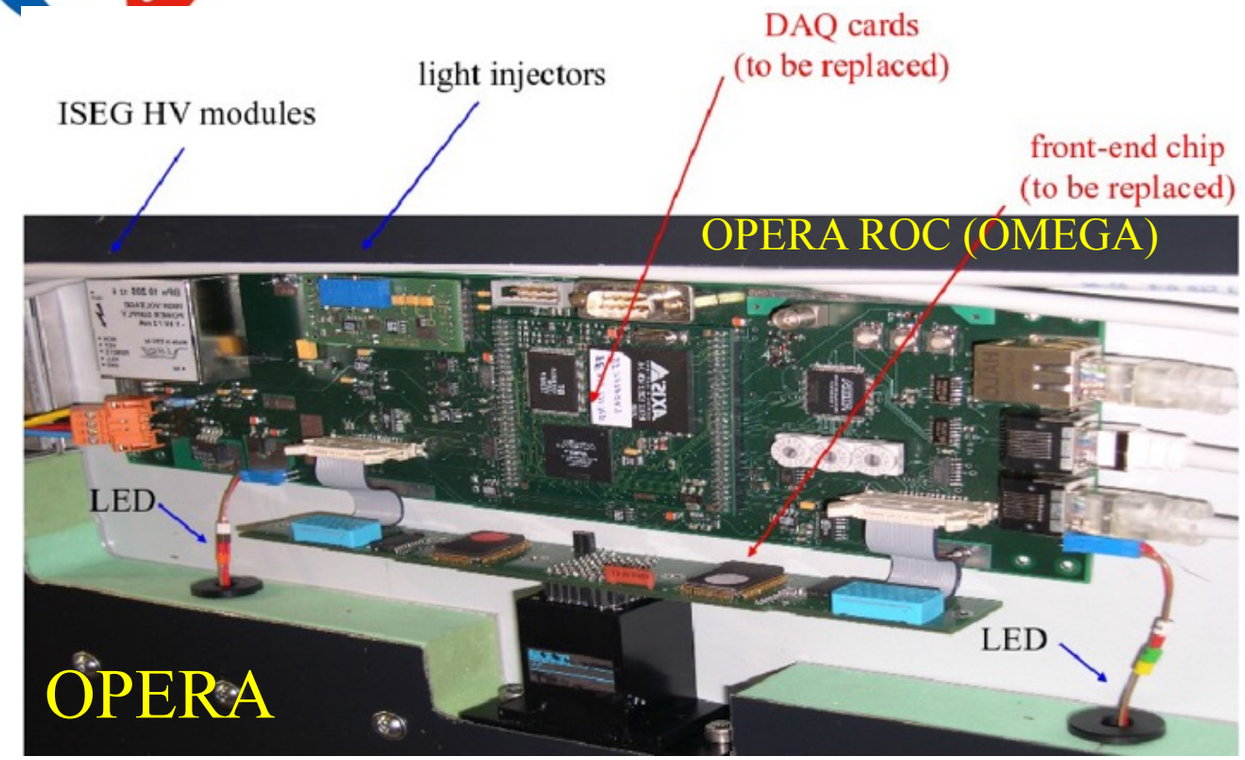
Expected rate:

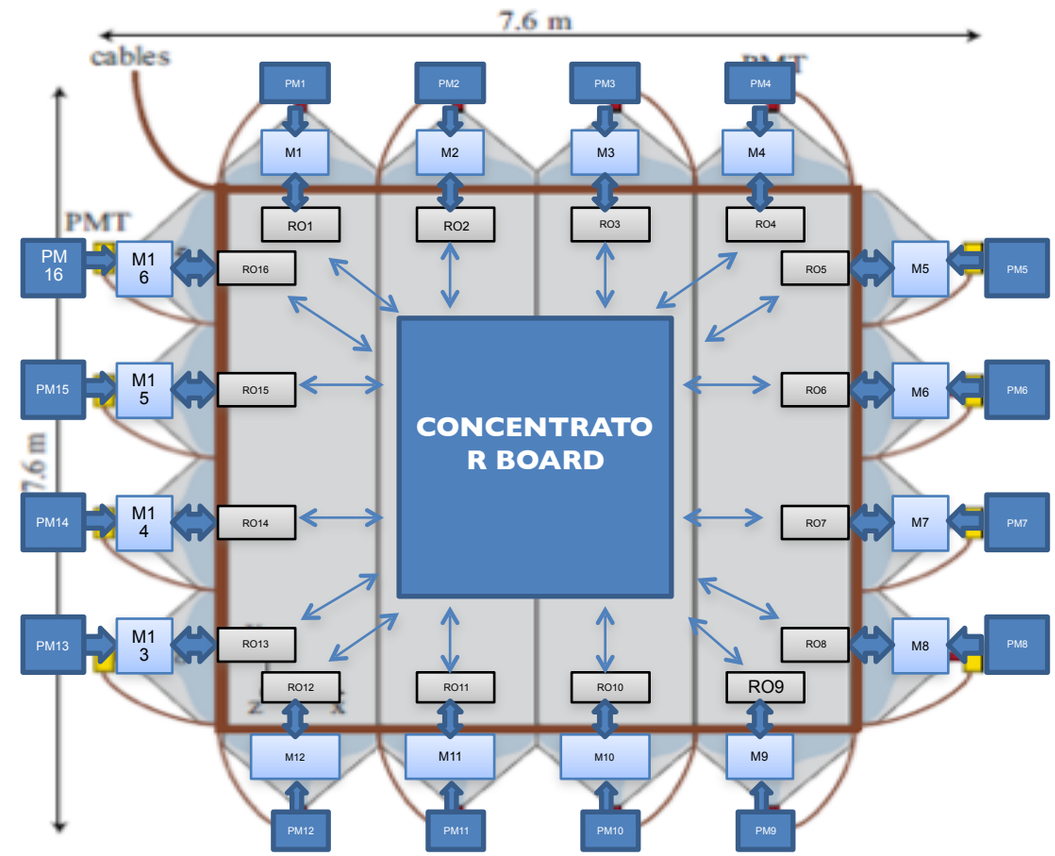
•The event rate per channel is 30x higher in JUNO site compared to Gran Sasso Laboratory due to rock radioactivity.



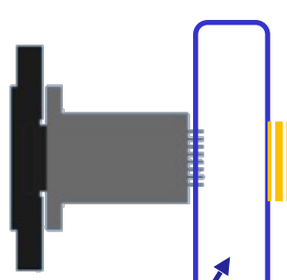
- Coincidences based on 3 aligned points can drastically reduced the rate and can be done offline (~25 Hz)

TT new Electronics





new electronics



front end boards
with MAROC3 chip
(996)

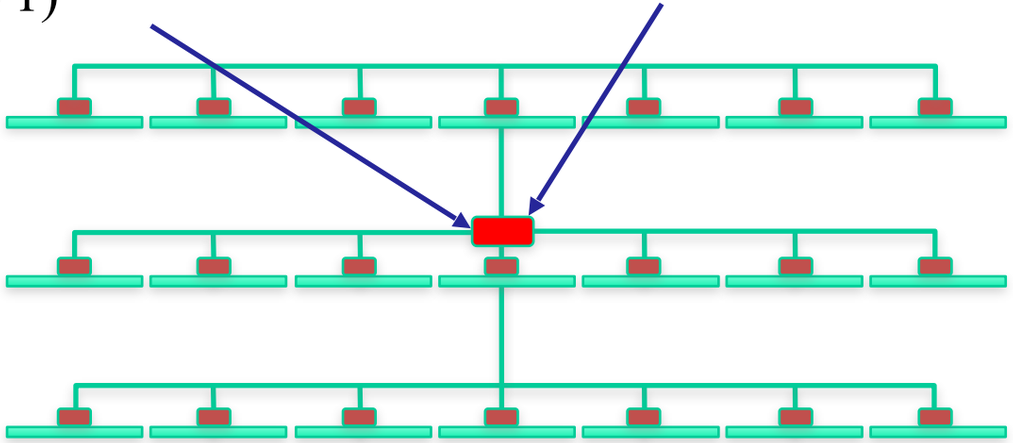
R/O boards
(996)

concentrators,
one per TT wall
(16 PMTs)
(63)

- Time stamps data
- LV1 trigger
- Sends multi-ROB events to the DAQ

local x-y
trigger
(LV1)

global trigger
(LV2, if needed)

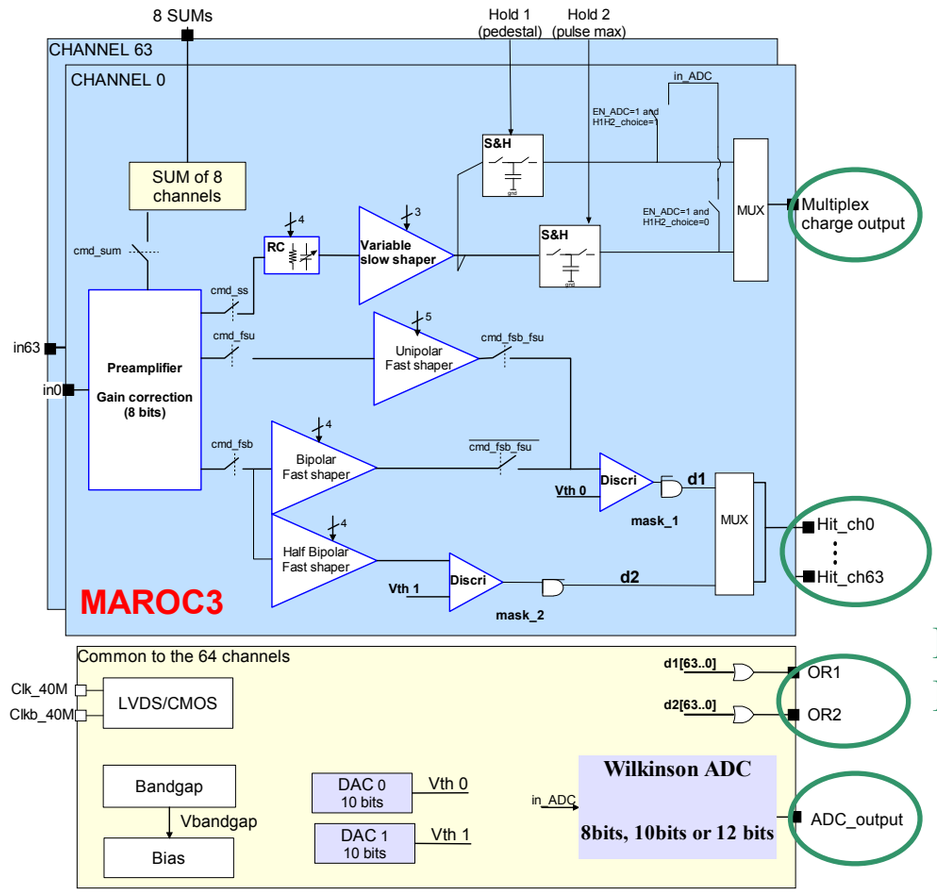


LV2 feedback to the sensors
in less than 1 μs

Front End Board

Successful running the chip two times faster than recommended (80 MHz) to decrease the dead time!

MAROC3



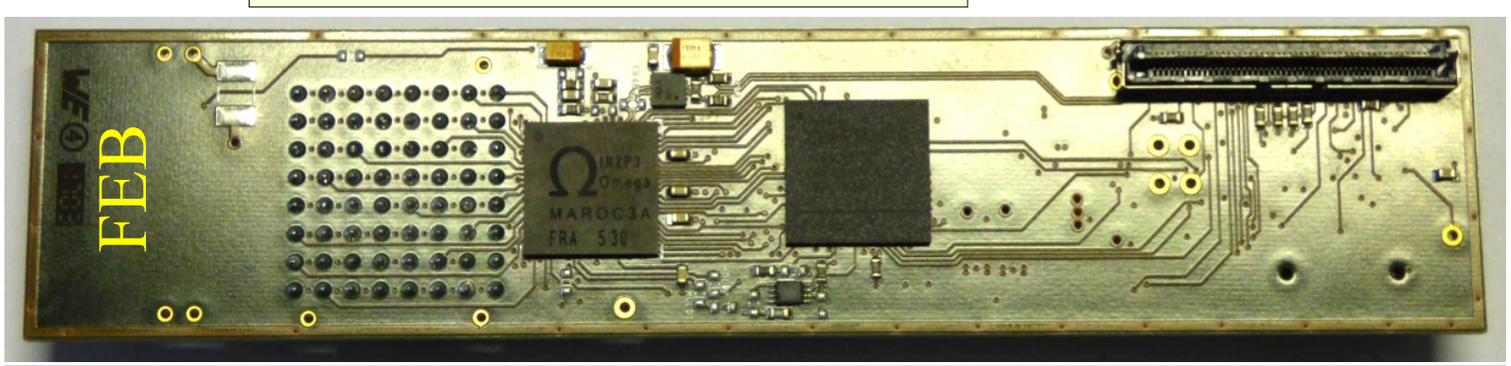
Out_Q :
Multiplex charge output for analog reading on ROB

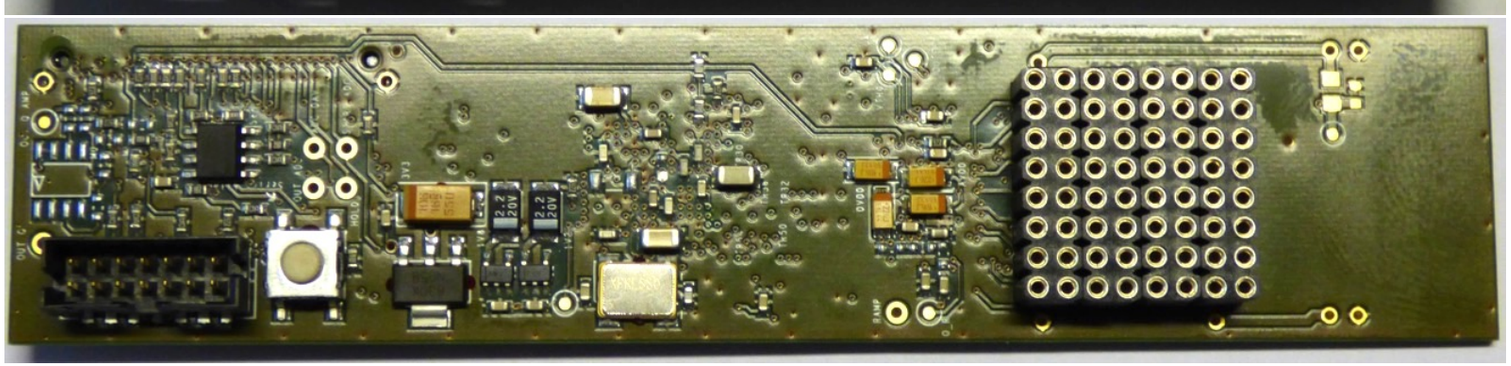
64 triggers continuously active

Fast OR trigger propagated to the concentrators for time-stamping and LV1 trigger selection

Out_ADC :
Wilkinson internal ADC output

FEB

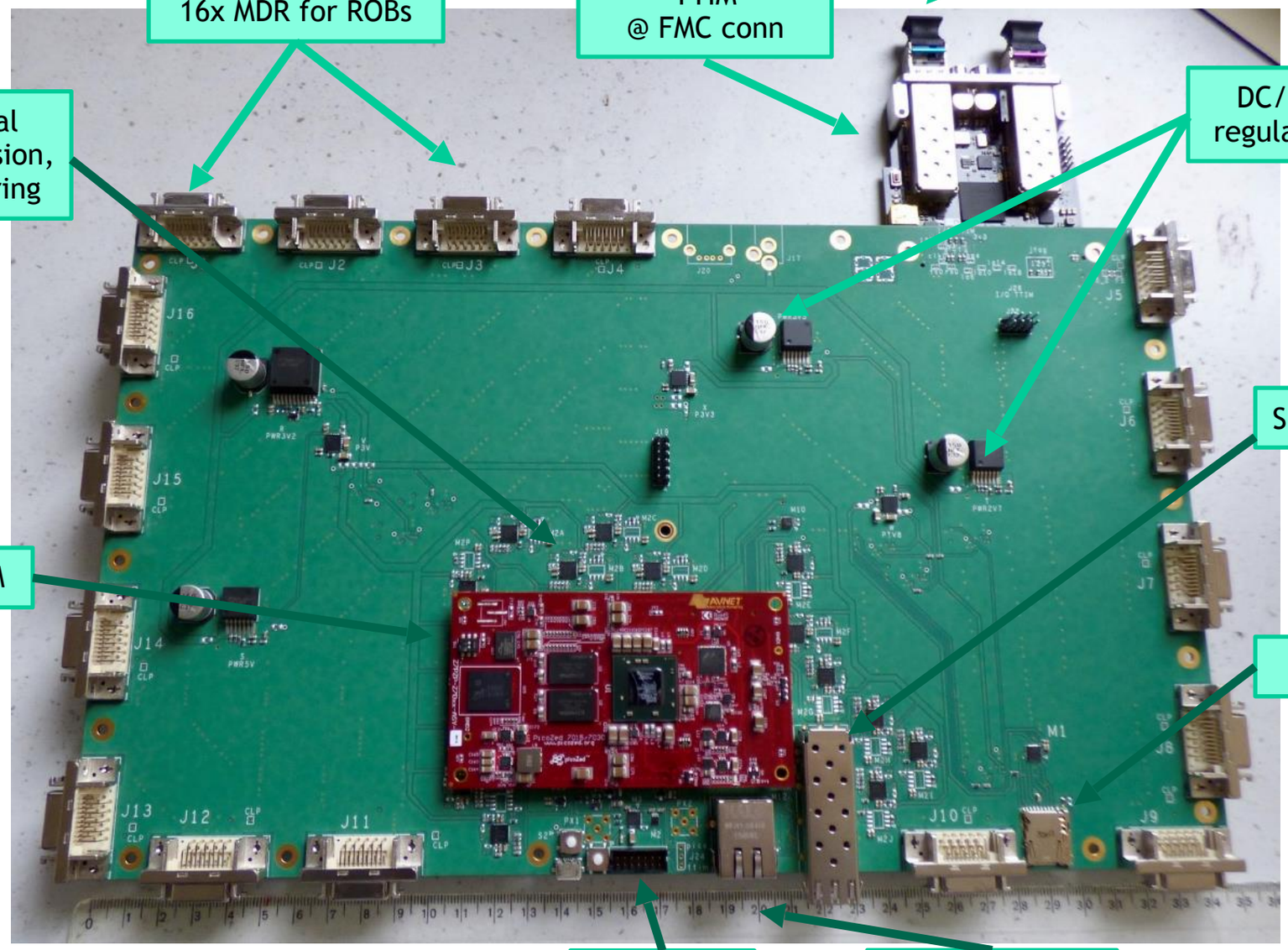




- Ready for production (mounting in IPHC during 2019): 1200 boards.
- Maroc 3A BGA encapsulation → ongoing (1500 chips).
- Power consumption: 2 W.

Concentrators in the DAQ chain

- **Acquiring information from ROB**
  - Hits in coincidence
  - Charge
- **Reset and programming of the FE ASIC**
- **Acceptance of interesting events**
  - Timestamp with approximately 1ns time resolution for each event coming from the ROB
- **Veto of background noise**
  - We aim to reduce the background radioactivity noise to approximately 10 kHz / wall
- **Misc. requirements (optional)**
  - periodic/random triggers for detector study
  - Data throttling in case of extreme noise rates
    - Commissioning study



- 2 boards have been assembled
- tests ongoing

Complete electronic chain

Concentrator card (IPHC)

10 m cable (real conditions)

MAROC3 (OMEGA)

MA-PMT

Front End Board (IPHC)

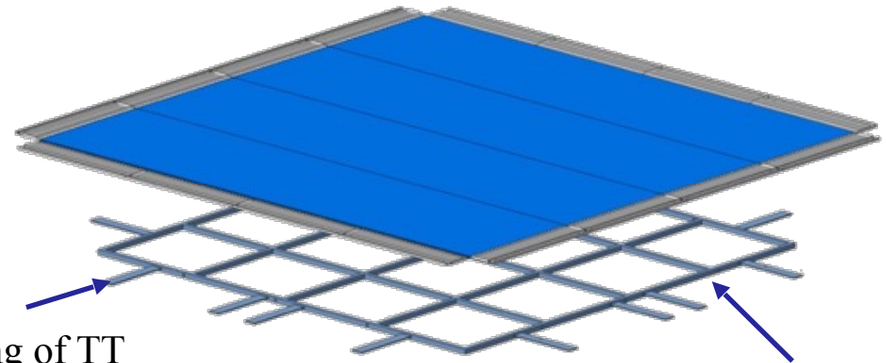
Timing (Tsinghua)

Read-Out Board (INFN/CAEN)

To equip soon the TT prototype in Strasbourg:

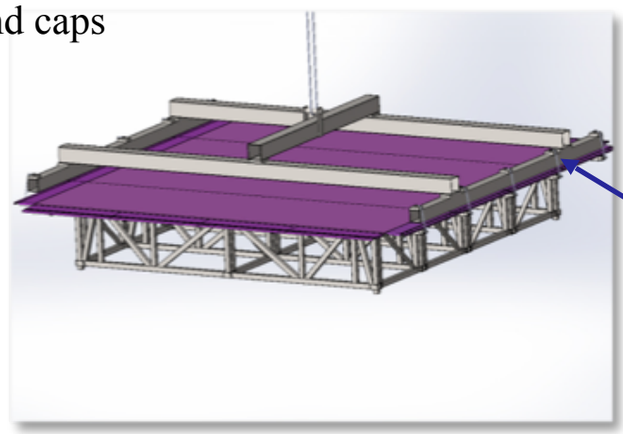
- test the whole electronic chain
- start preparing the online software
- prepare trigger strategy
- test the calibration system

Top Tracker mounting
(during CD filling)

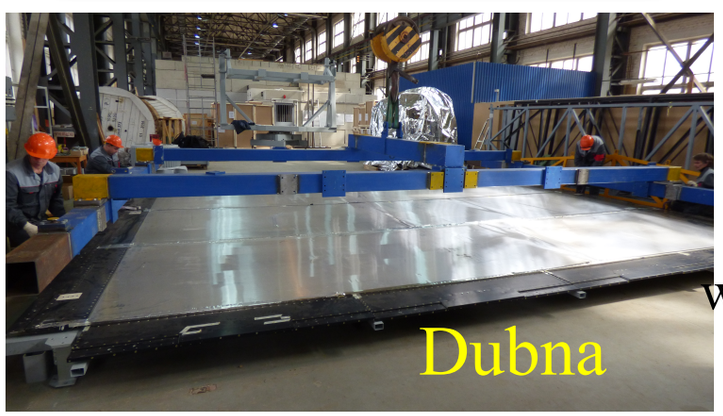


used for positioning of TT end caps

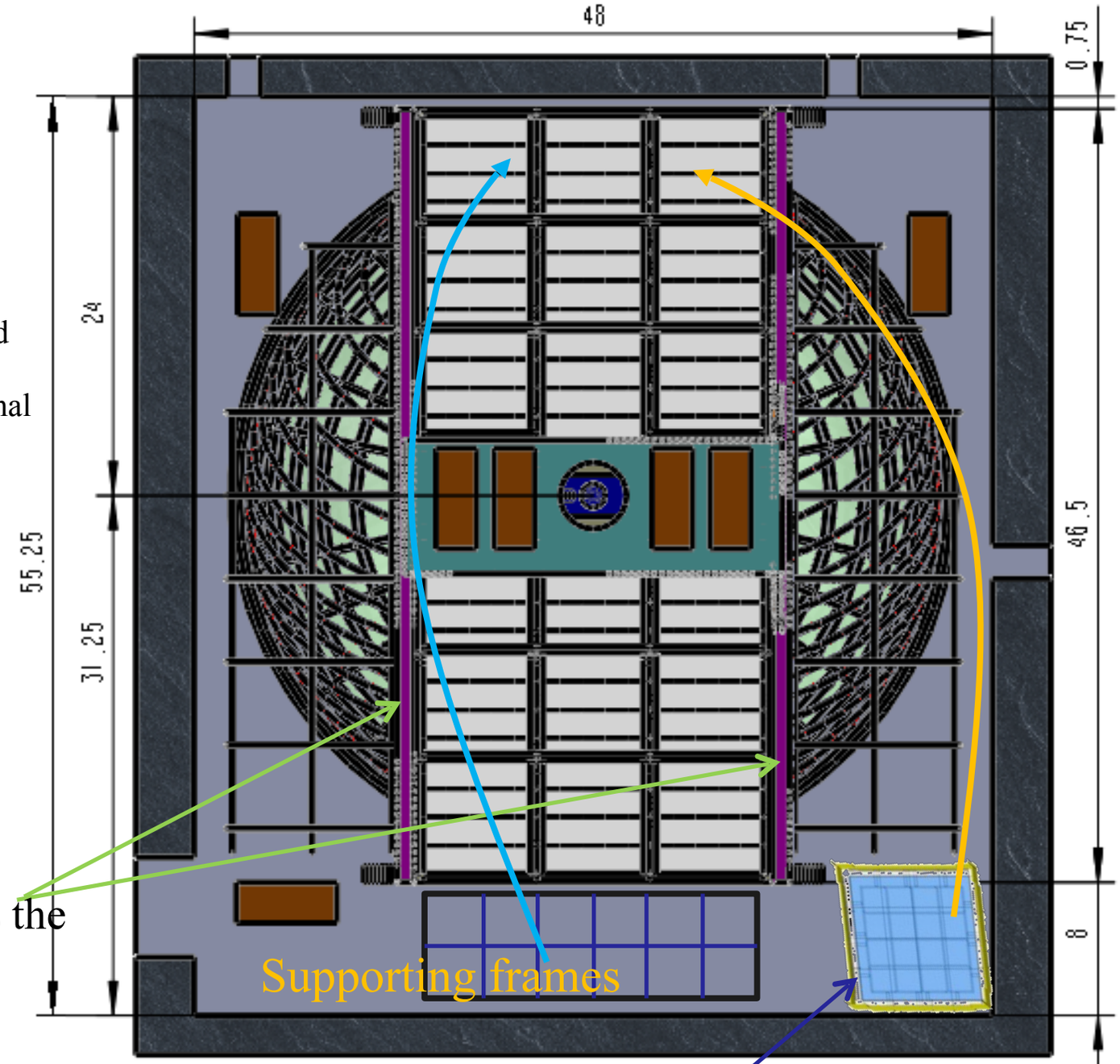
supporting frame used during mounting and remaining after for final mounting



auxiliary frame used during mounting and transportation (same for all walls)



walk paths to access the TT electronics



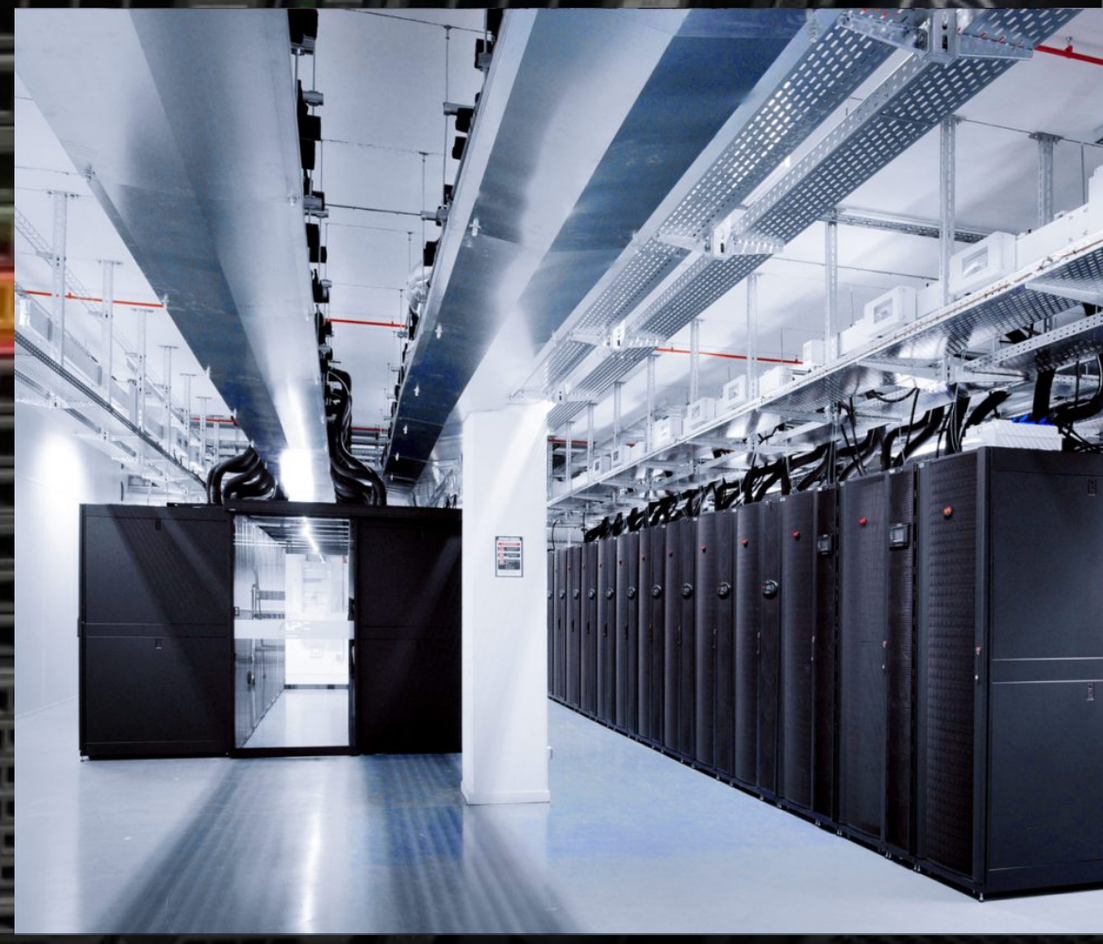
area to mount the TT walls

~6 months in total for mounting the TT

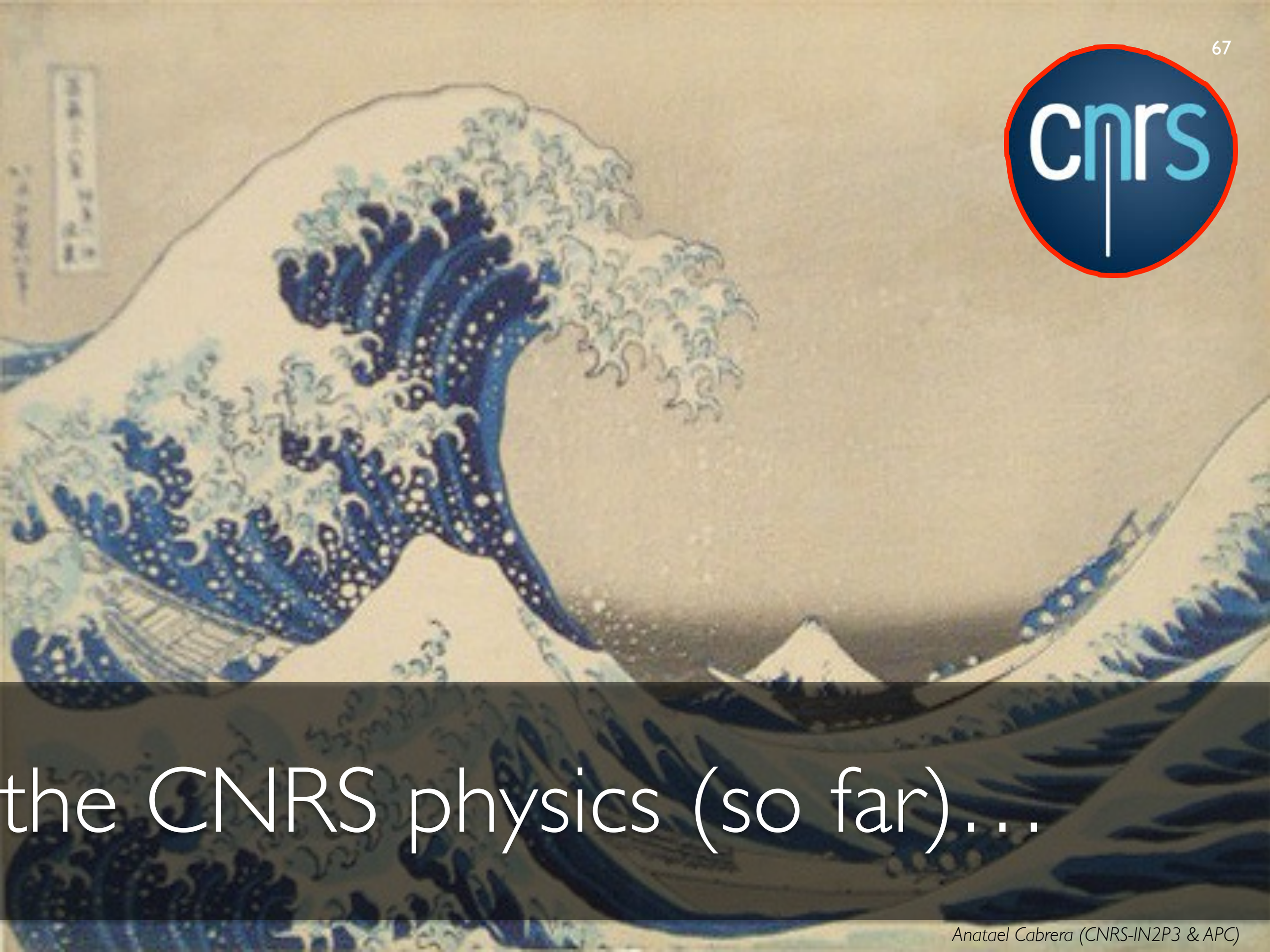
Top Tracker Schedule

- **During 2018**: The BGA encapsulation of the MAROC3 chips (OMEGA) is under realisation, after which all 1500 chips will have to be tested.
- **End 2018**:
  - The Front End and Concentrator Boards R&D have to be finished.
  - Complete prototype electronics chain to equip the muon telescope already built at IPHC in order to test the whole system and prepare the online software.
- **2019**: production of the 80 Concentrator cards under the responsibility of the INFN.
- **During 2019**: start the design of the Trigger card.
- **2019-2020**: production of the 1200 Front End Boards.
- **2020**: test of the Front End Boards.
- **Beginning of 2021**: preparation of cables and of all remaining systems.
- **TT installation**: should take place during the filling and commissioning of the Central Detector:
  - **March 2021**: TT supporting structure (IHEP)
  - **April-October 2021**: TT installation and commissioning.

powerful computing…
(expert support)



(FADC data experience)



the CNRS physics (so far)…

Anatael Cabrera (CNRS-IN2P3 & APC)

main physics channels…

central detector (→SPMT)

- **IBD precision calorimetry** (LPMT⊕SPMT)
  - →mass ordering/hierarchy measurement
- **IBD δm^2-θ_{12} measurement**
- **supernova** core-collapse detection
- radiogenic⊕cosmogenic(μ) **backgrounds**

veto systems (→TT)

- high precision **μ-tracking**
- cosmogenic(μ) **background** (synergy with LPMT⊕SPMT)

Stereo Calorimetry

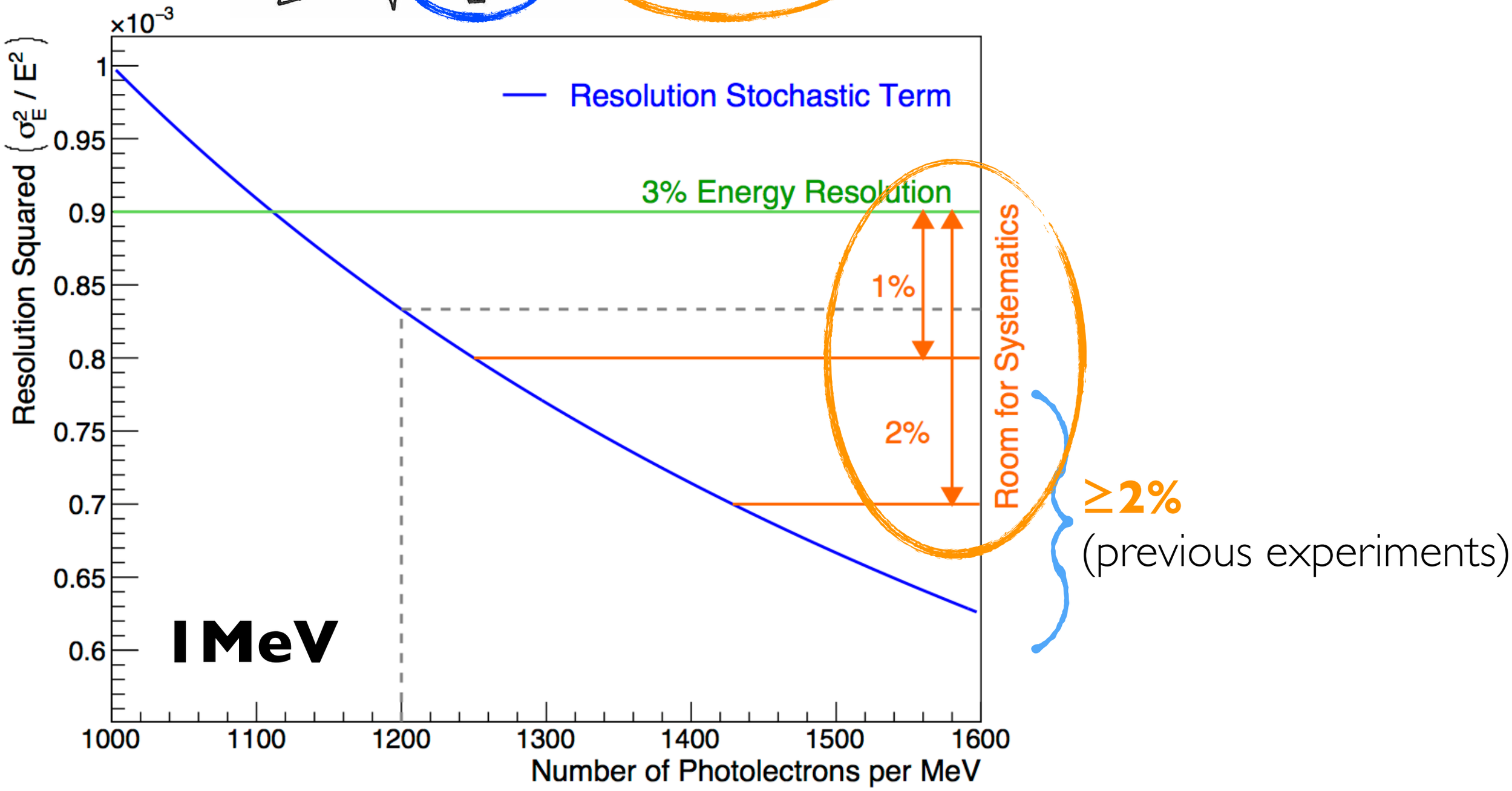
(basic logic)

JUNO calorimetry condition…

lot of light is a necessary but not sufficient condition

$$\frac{\sigma(E)}{E} = \sqrt{\frac{\sigma^2_{STOCH}}{E} + \sigma^2_{NON-STOCH}(E)}$$

≤3% @ 1MeV

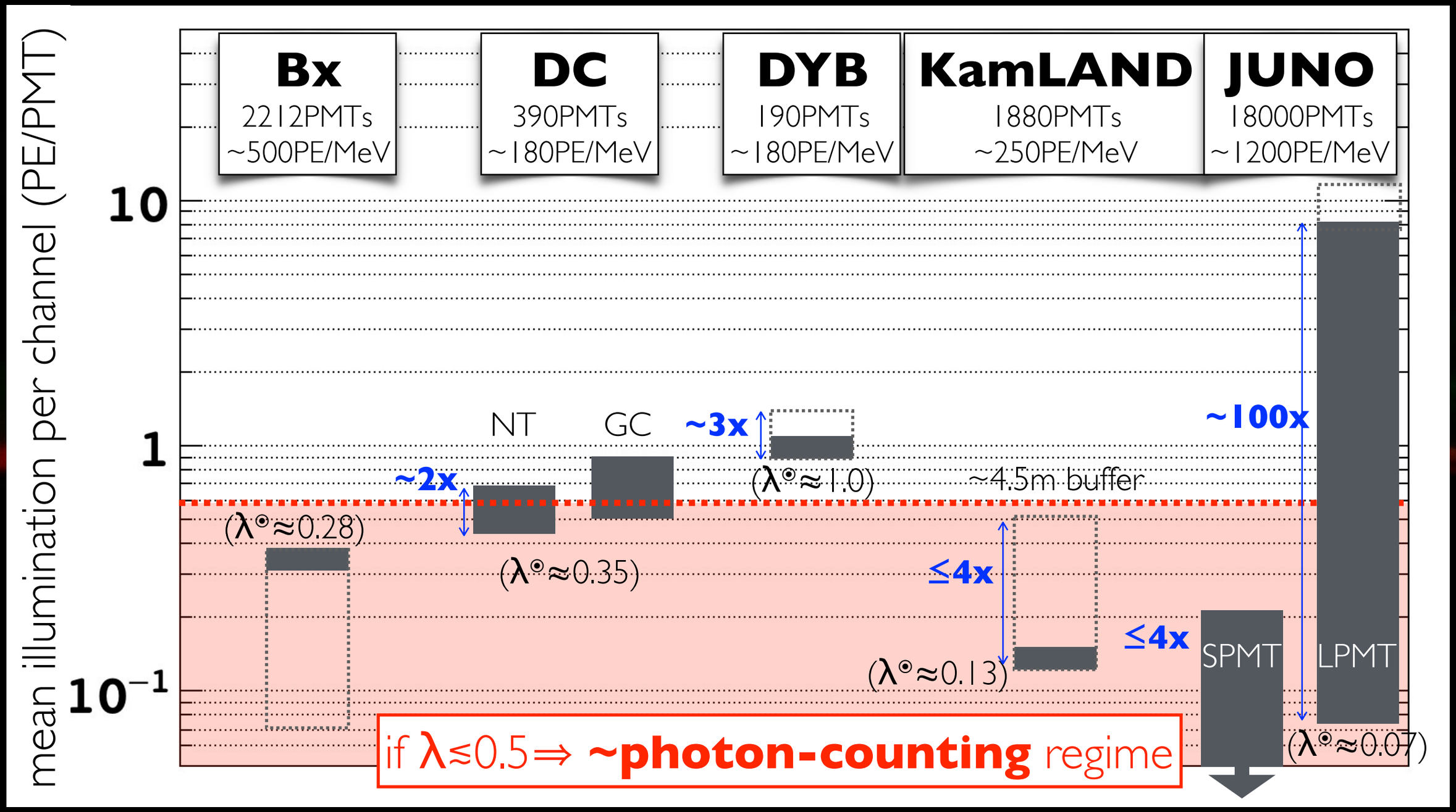


challenging calorimetry systematics control

the JUNO challenge…

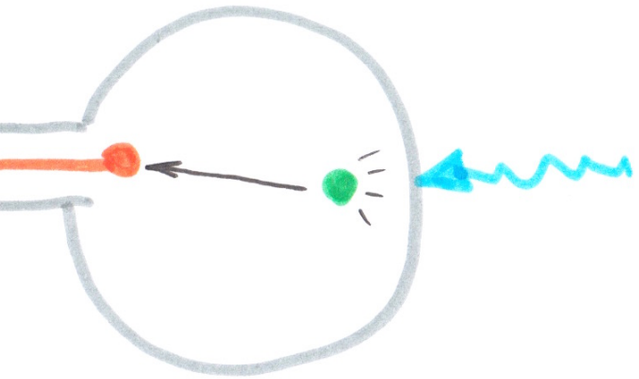
@1MeV

$\lambda^{\odot}$ = mean illumination per channel @ center



LARGEST dynamic range in calorimetry (channel-wise) [⇒ **uniformity⊕linearity⊕stability**]

Photon-Counting vs Charge-Integration…

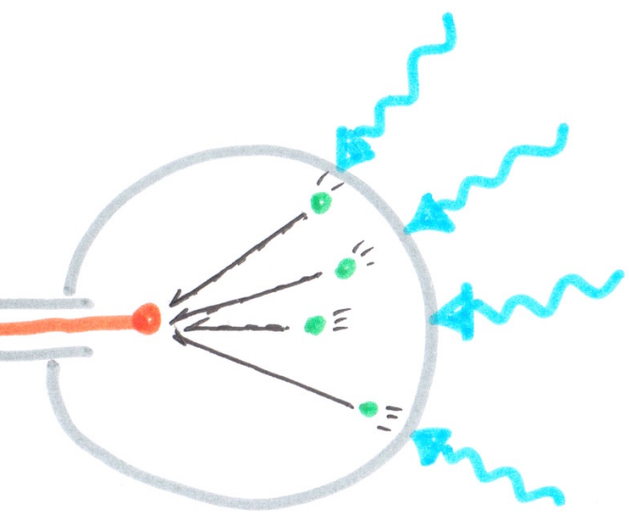


Photon-Counting

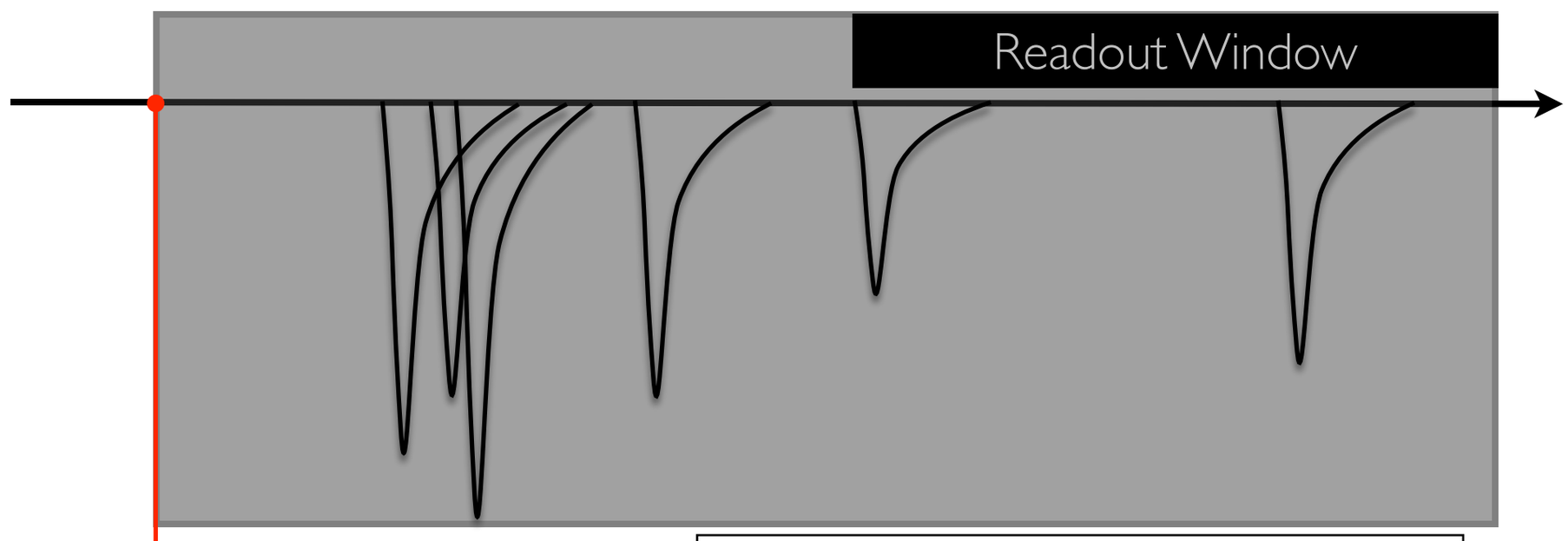
• ***1 hit=1 PE→no reconstruction*** *(no gain needed!)*

zero dynamic range (non-linearity→0)

time-stamp (self-trigger)
(pulse @ threshold→ discriminator)



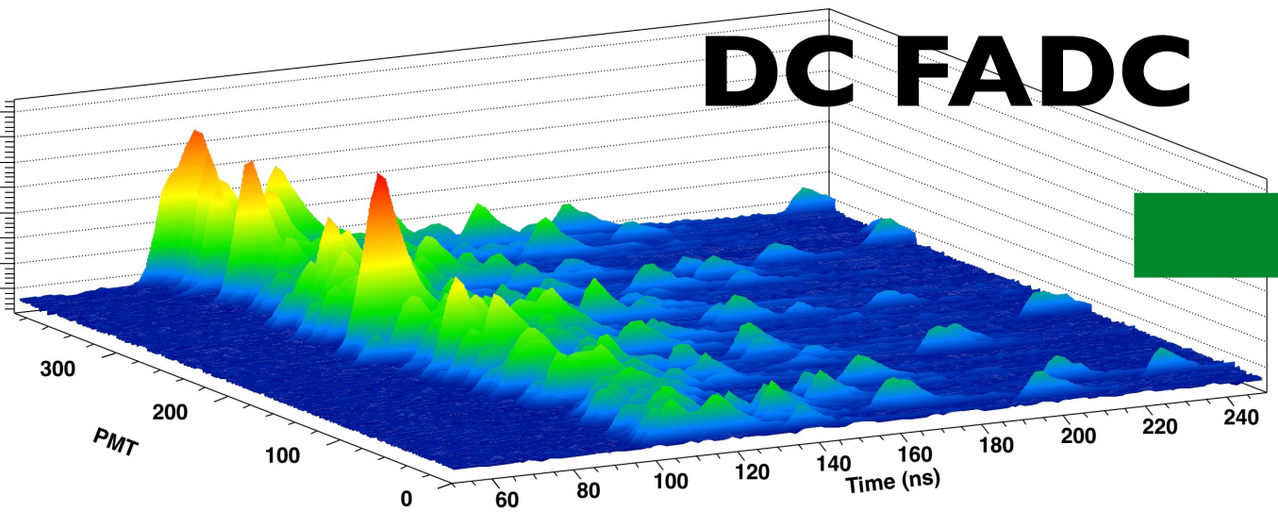
Charge Integral



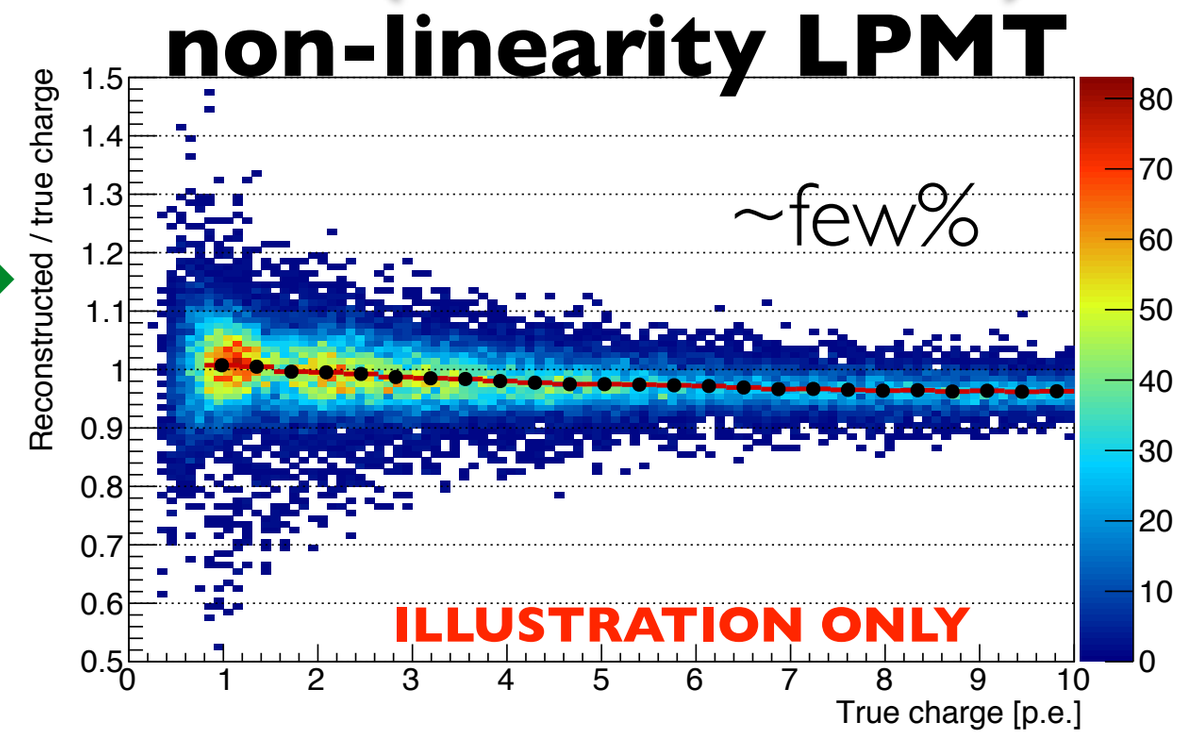
• ***1 hit≠1 PE→reconstruction is a must! [calibration/reconstruction]***

time-stamp (global trigger)
(readout-window sampled, example @ start)

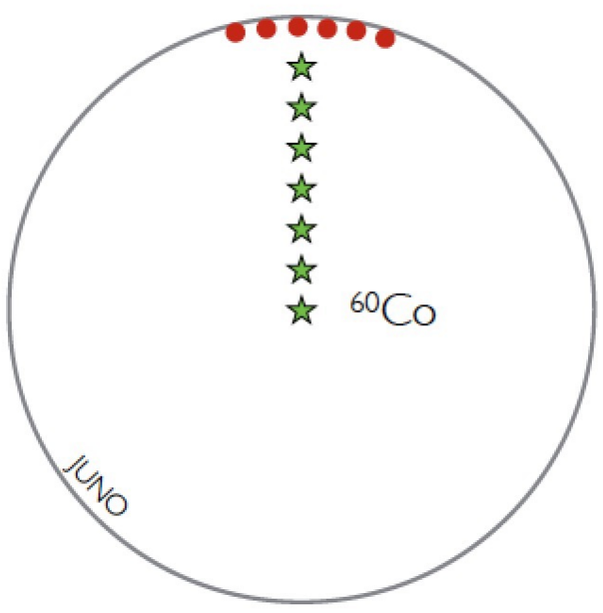
energy reconstruction bias (illustration)…

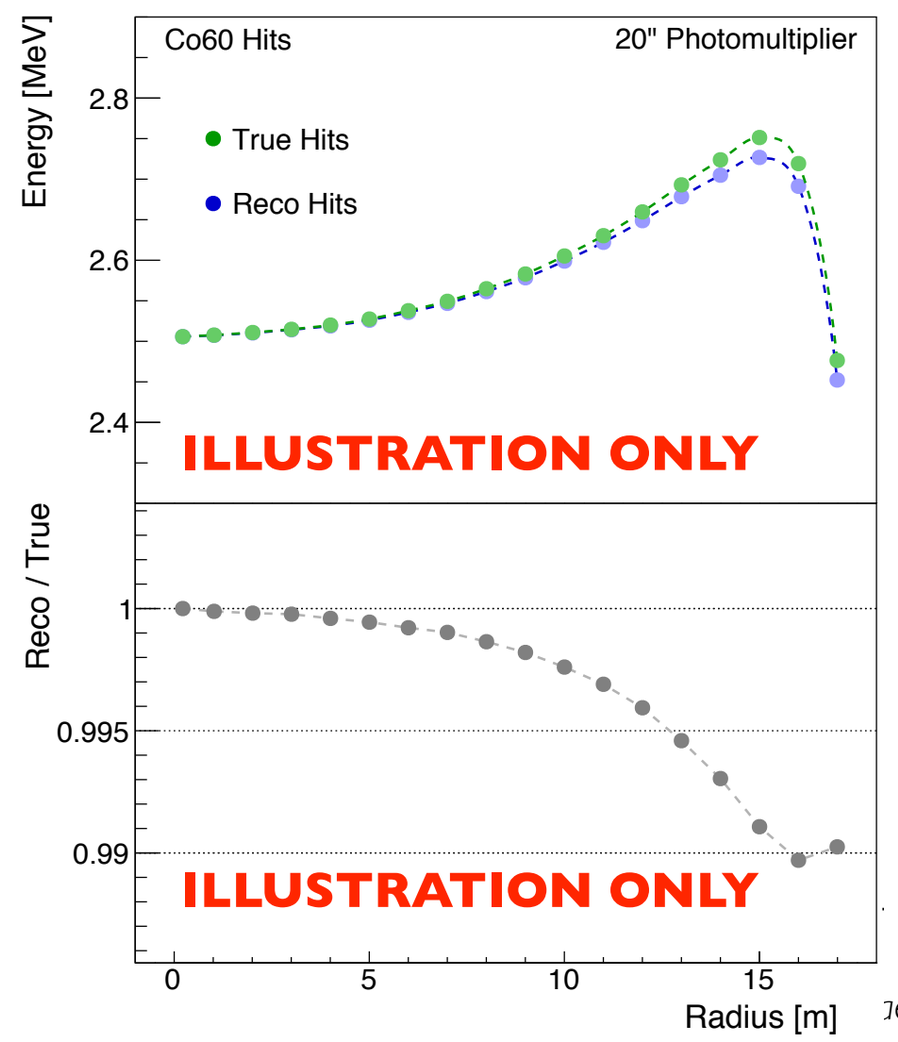


realistic pulse reco (QI)



calibration mimicking





non-linearity
(channel-wise)

non-uniformity
(position-wise)
[QI regime variations]

worsens resolution
(full detector)

LPMT⊕SPMT complementarity systems…

LPMT: collect light (25x)
(excellent stochastic resolution)

SPMT: less light & linear
(dynamic range→0)

LPMT Response:

$R_{stability}$

$R_{uniformity}$

$R_{linearity}$ →**most delicate**

(complex?)

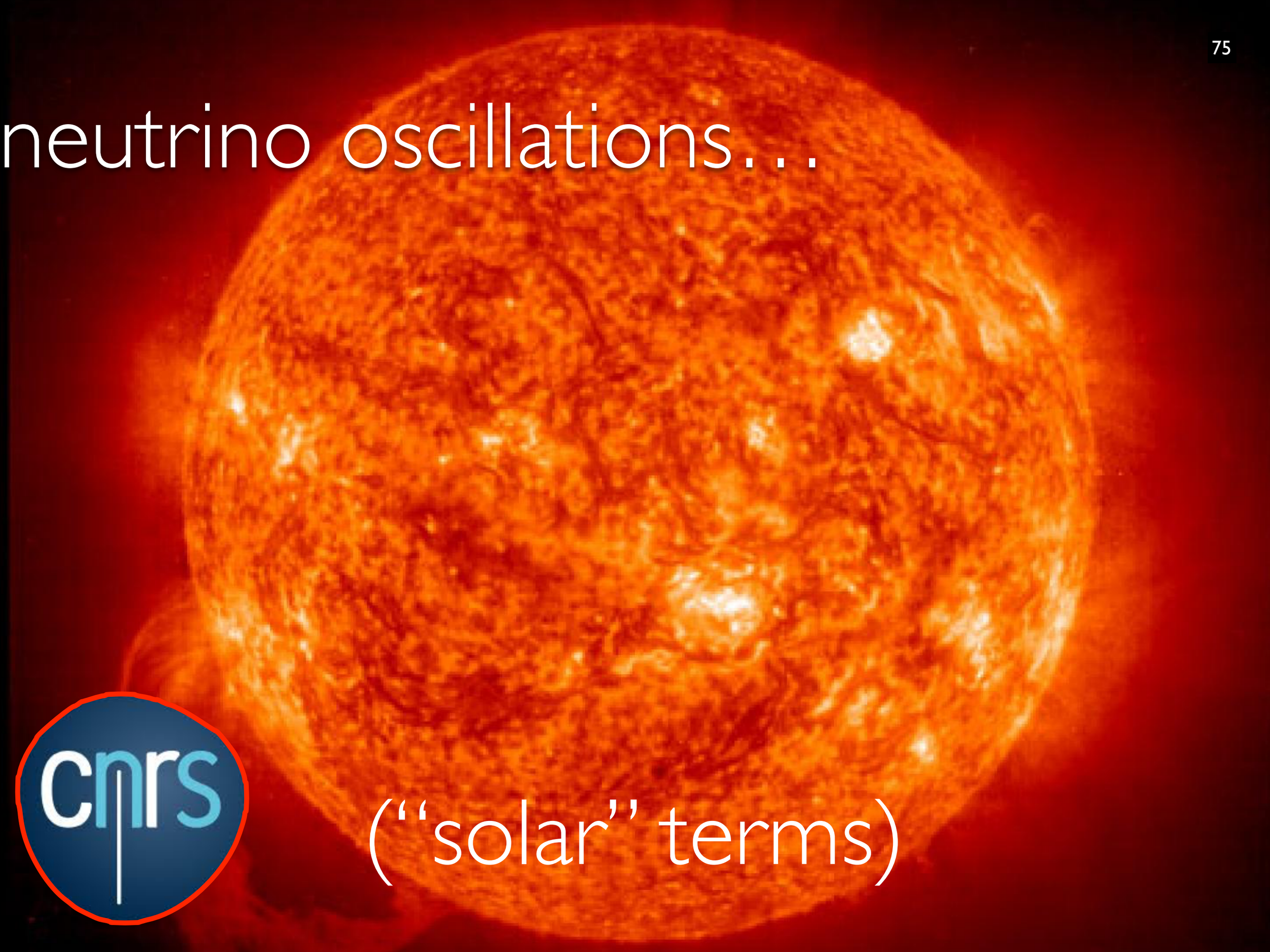
SPMT Response:

$R_{stability}$

$R_{uniformity}$

(much simpler)

neutrino oscillations…

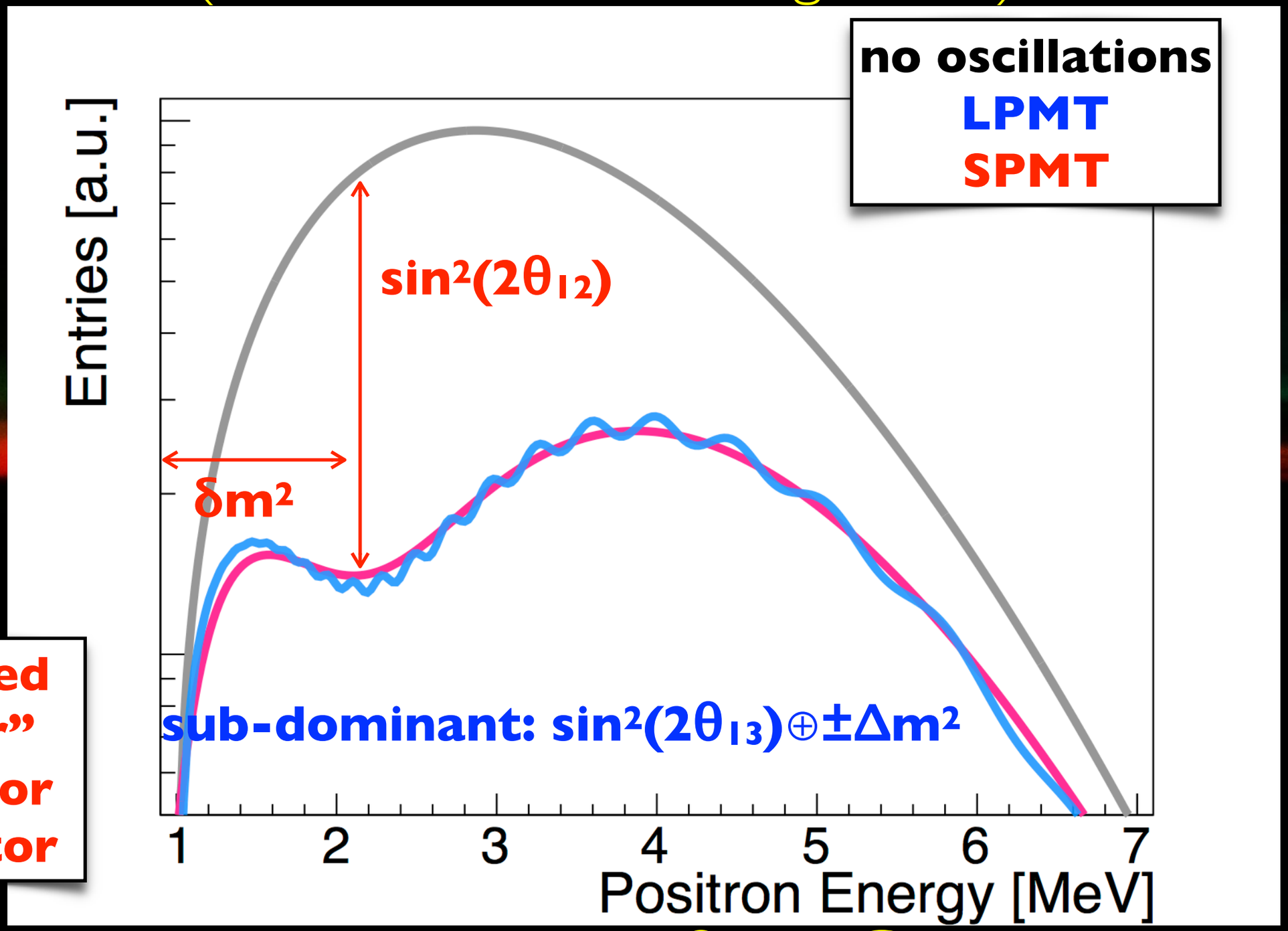


("solar" terms)

IBD oscillation with the SPMT…

SPMT only see 1 oscillation mode

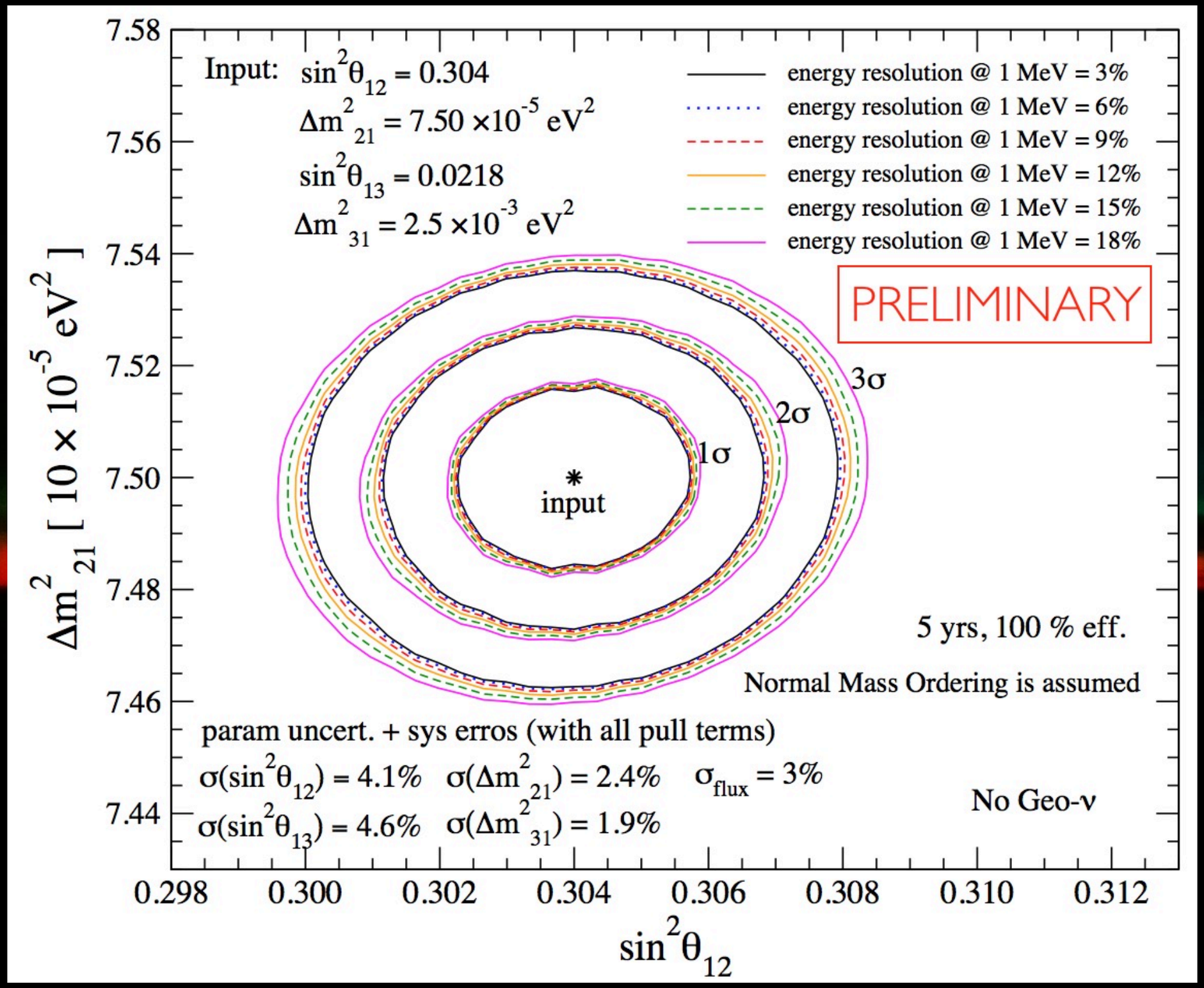
(fast oscillation is averaged out)



no need "near" monitor detector

sensitivity: $\theta_{12} \oplus \delta m^2$

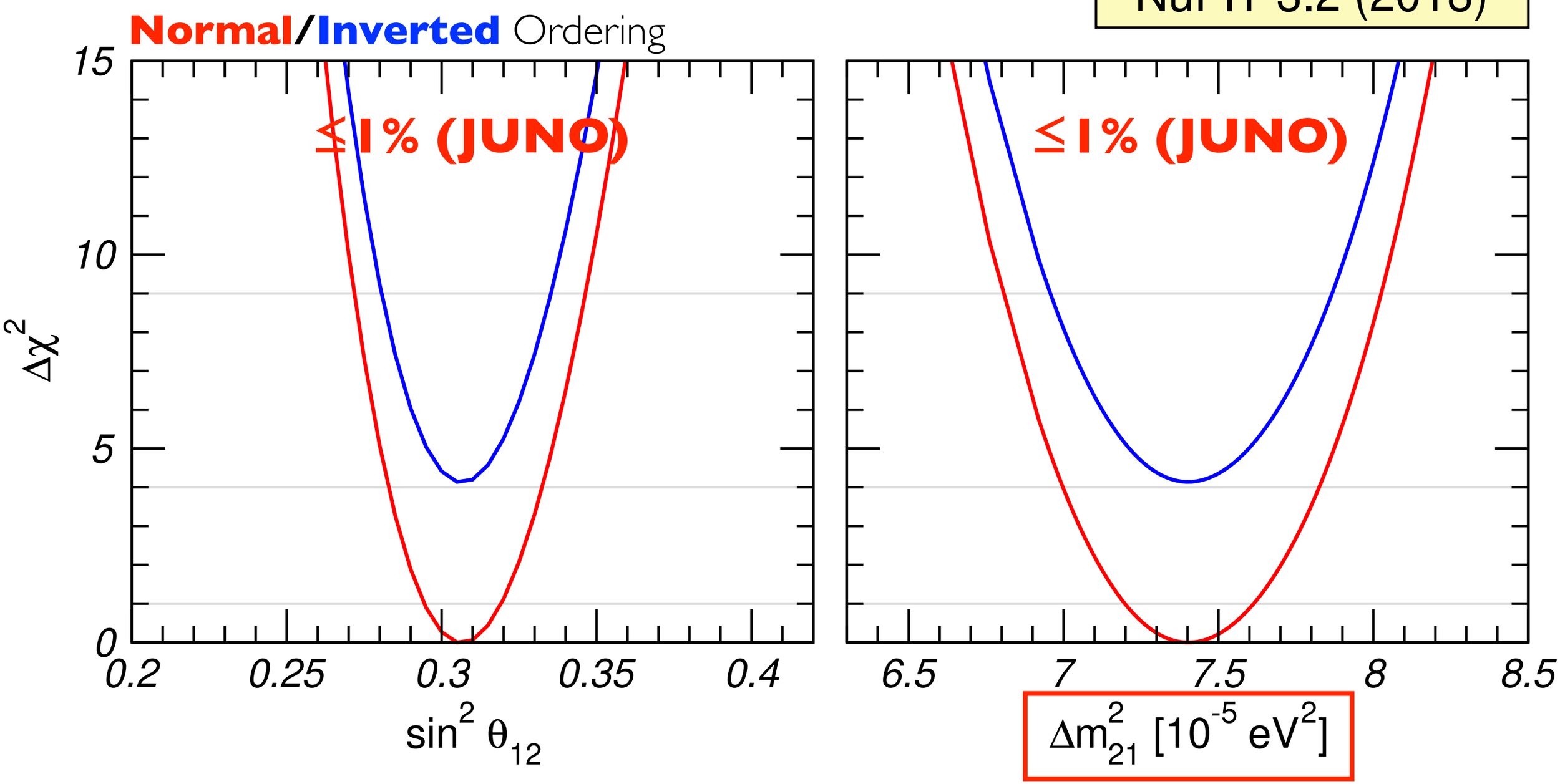
JUNO internal redundancy on θ_{12}-δm^2…



SPMT⊕LPMT comparable precision

no cross-check to JUNO (except JUNO)…

NuFIT 3.2 (2018)

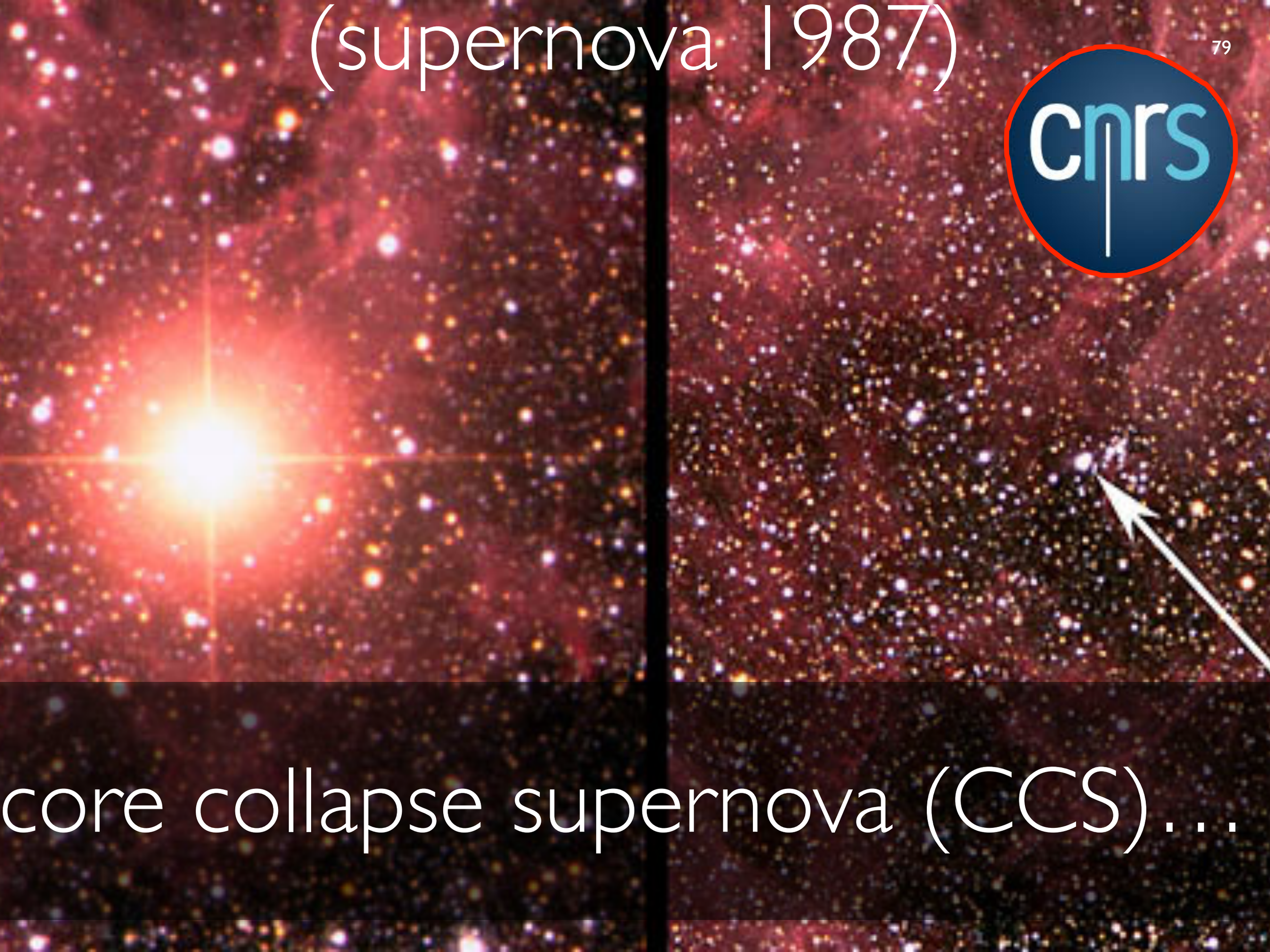


~rate systematics (common)

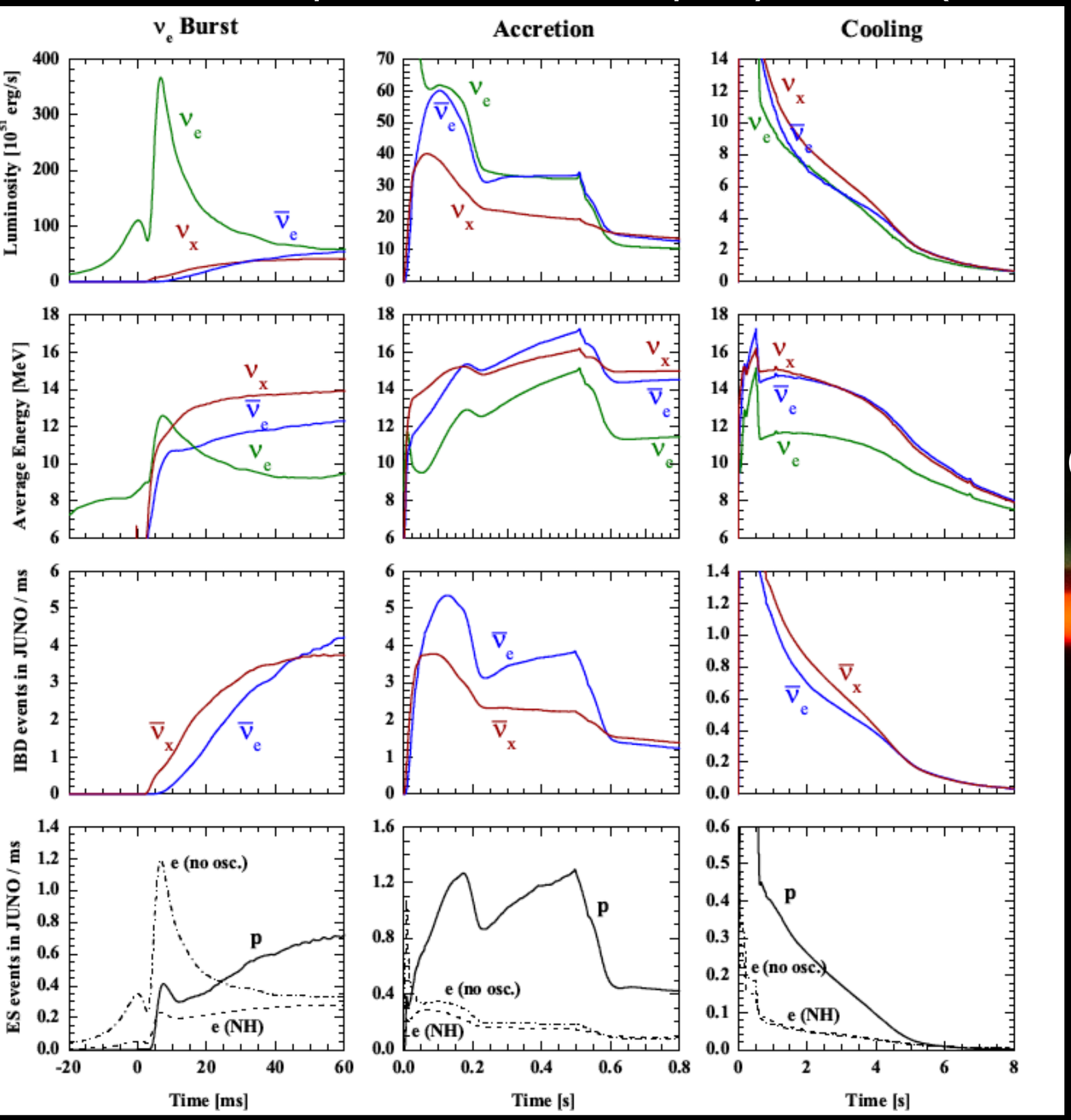
~shape systematics (different SPMT LPMT)

SPMT⊕LPMT internal cross-check

(→ robust result validation)


(supernova 1987)
core collapse supernova (CCS)...

CCS spectacular physics (astro/particle/nuclear)…



rate vs time

energy vs time

IBD only

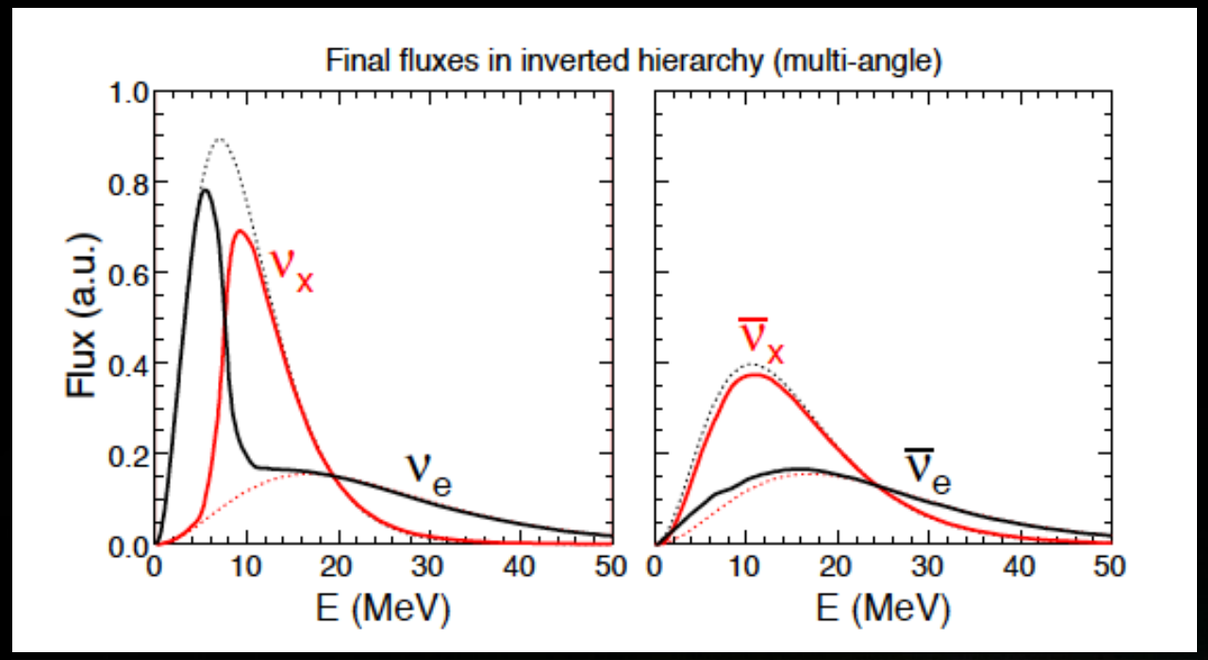
($\nu_e + p \rightarrow n + e^+$)

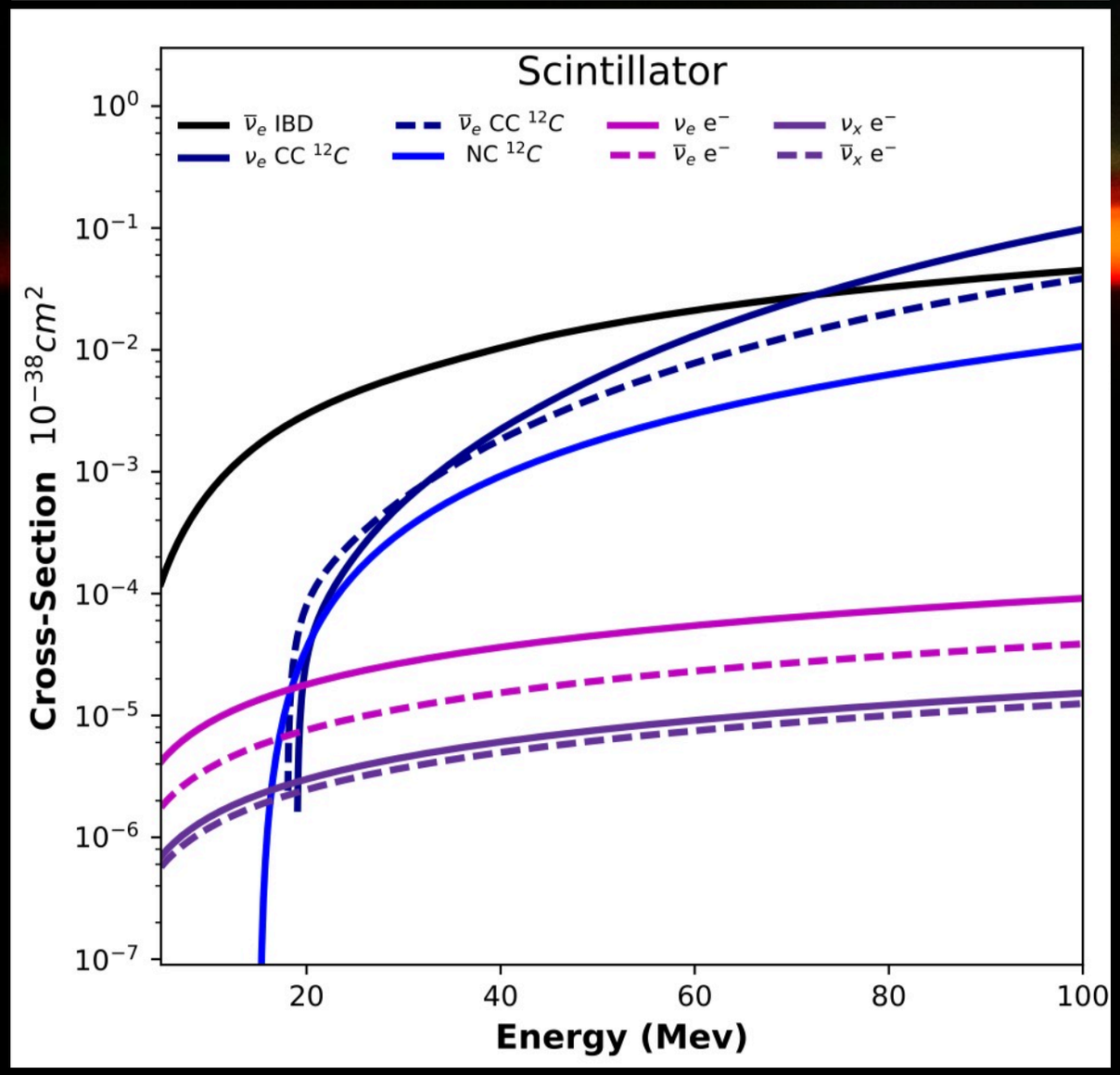
elastic scattering

($\nu_e + e \rightarrow \nu_e + e$)

(unique astrophysics probe)

CCS challenges…

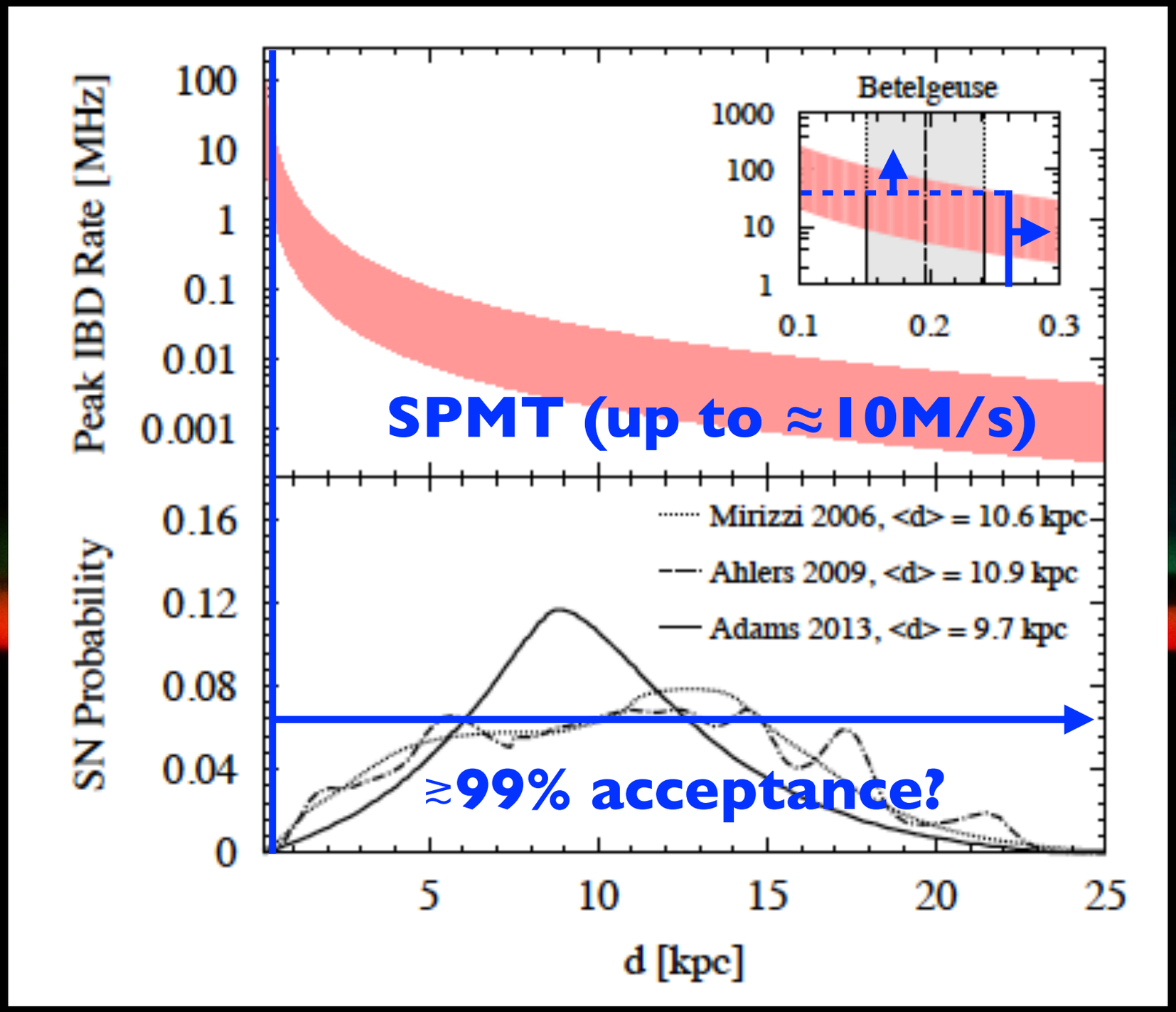




CCS particle physics
(ν-ν interaction)

multi-interactions
(disentangle information)

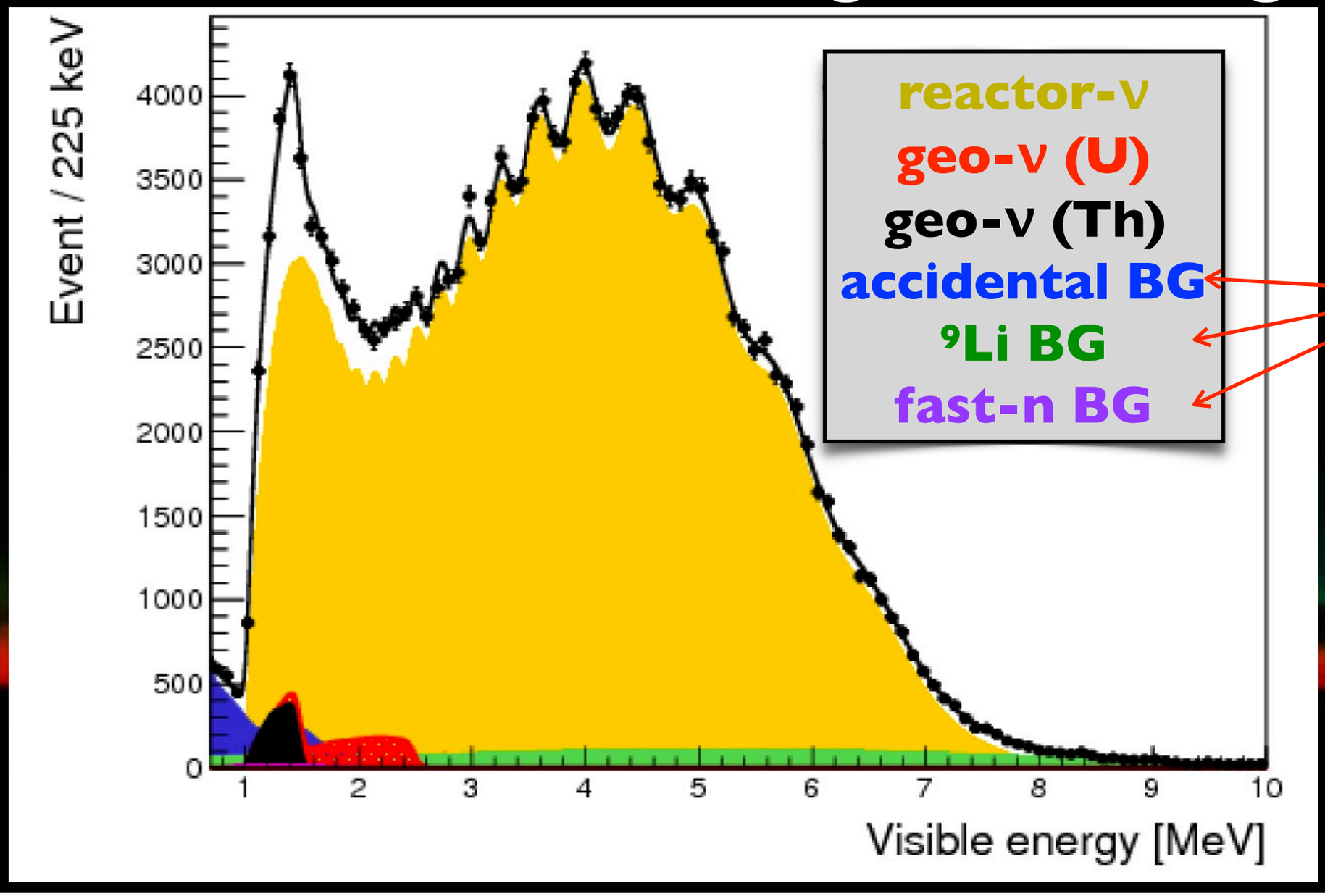
ensure we get it (almost) all…



unbiased measurement

(high rate ⊕ deadtime monitor)

JUNO challenge: the background…



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				

radio-purity control…

Low background expertise at IN2P3

✓ CENBG and CPPM laboratories have a long expertize in low background techniques related to ββ0ν experiments (NEMO3/SuperNEMO)

✓ Existing facilities in France have been used to perform ultra-low gamma and Radon spectrometry measurements for JUNO since 2016

CENBG detectors @ LSM / PRISNA

Underground labs with 4800 / 6 m.w.e.

Low background HPGe detectors

Sensitivities :

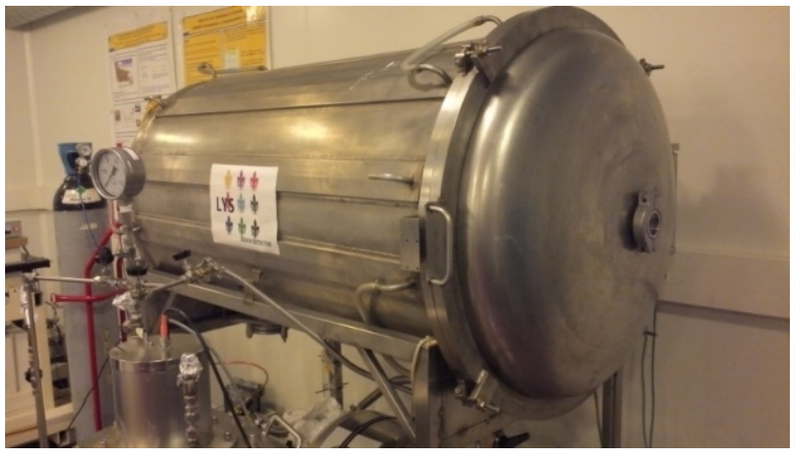
~ 0.5 mBq/kg for ^{226}Ra @ LSM

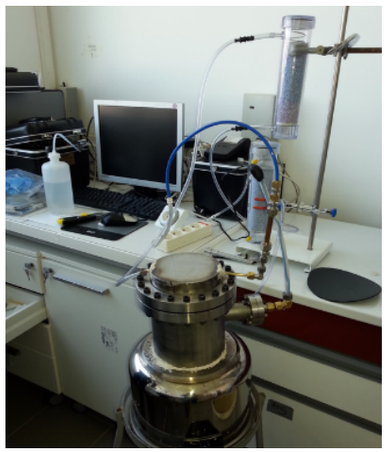
~ 50 mBq/kg for ^{226}Ra @ PRISNA

Radon facilities (CENBG & CPPM)

A Rn chamber of 710 L for large volume coupled to sensitive Radon detectors

Setup to measure the Rn diffusion length





Sensitivity ~ 20 Rn atoms/s/m^2

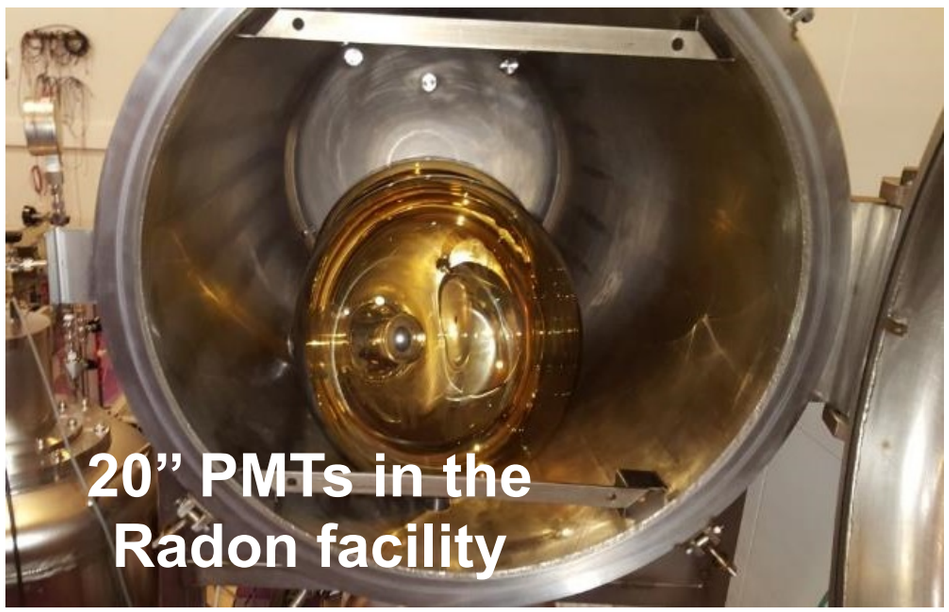
(unique in JUNO collaboration)

Highlights on material selection since 2016

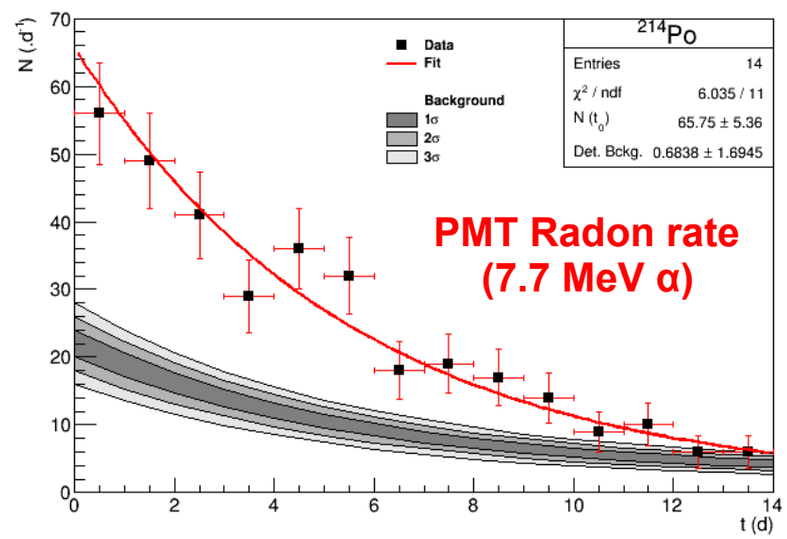
✓ Qualification of the 20” and 3” PMT glass by gamma spectrometry and Radon emanation measurements performed in France

→ radiopurity of the PMT glass fulfill the JUNO requirements

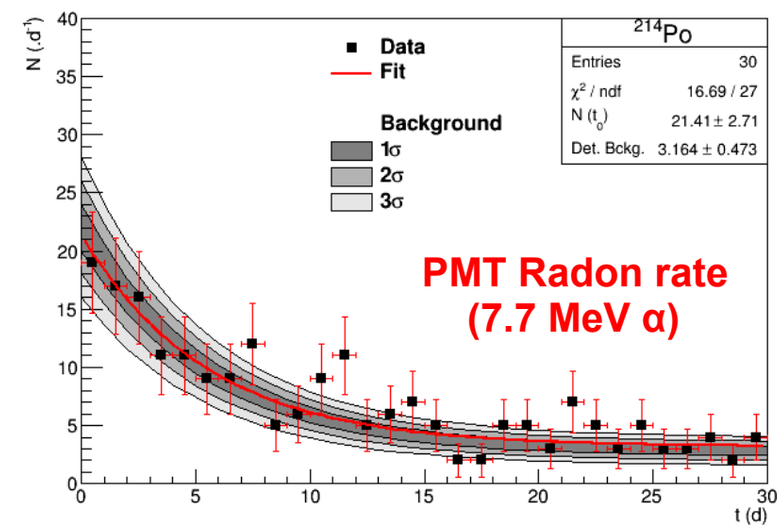
→ radon emanation rate well below the JUNO requirements (< 0.2 Bq/m³)



PMT not OK → rejected



PMTs OK → accepted



✓ Qualification of the stainless steel to be used for PMT support structure at a level of 1 mBq/kg (critical measurement only achieved at LSM)

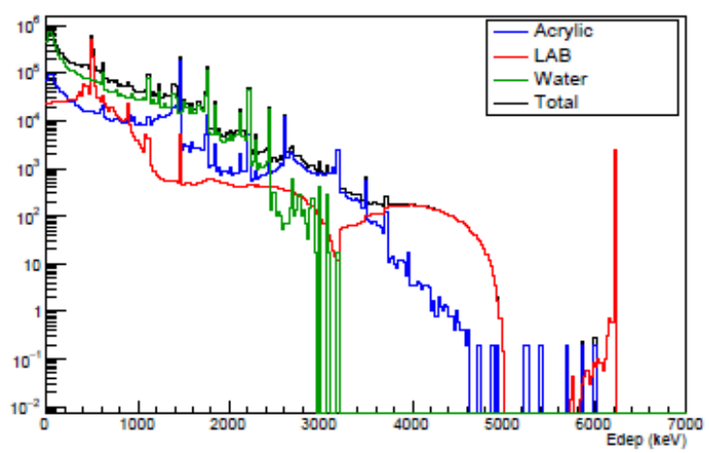
✓ Ongoing qualification of the Radon diffusion lenght through the Polyethylen liner to be used as a Radon barrier for the JUNO water pool (critical measurement)

Future implication in accidental background

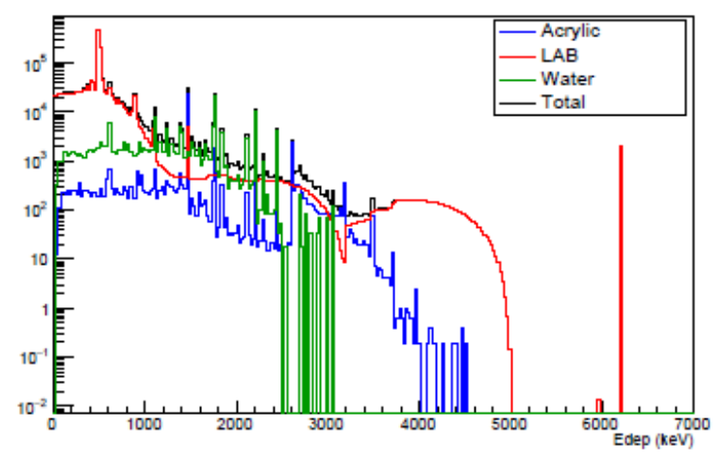
- ✓ IN2P3 labs have already performed critical radiopurity measurements within the JUNO collaboration and will continue to use its expertize in term of low background techniques in the next 2 years during the construction

- ✓ Preliminary GEANT4 Monte-Carlo simulations have been performed to evaluate the impact of the radioactivity of the JUNO materials already measured on the physics cases in JUNO (such as solar oscillation parameter study)

rate: 100/day (default)
No fiducial volume cut:

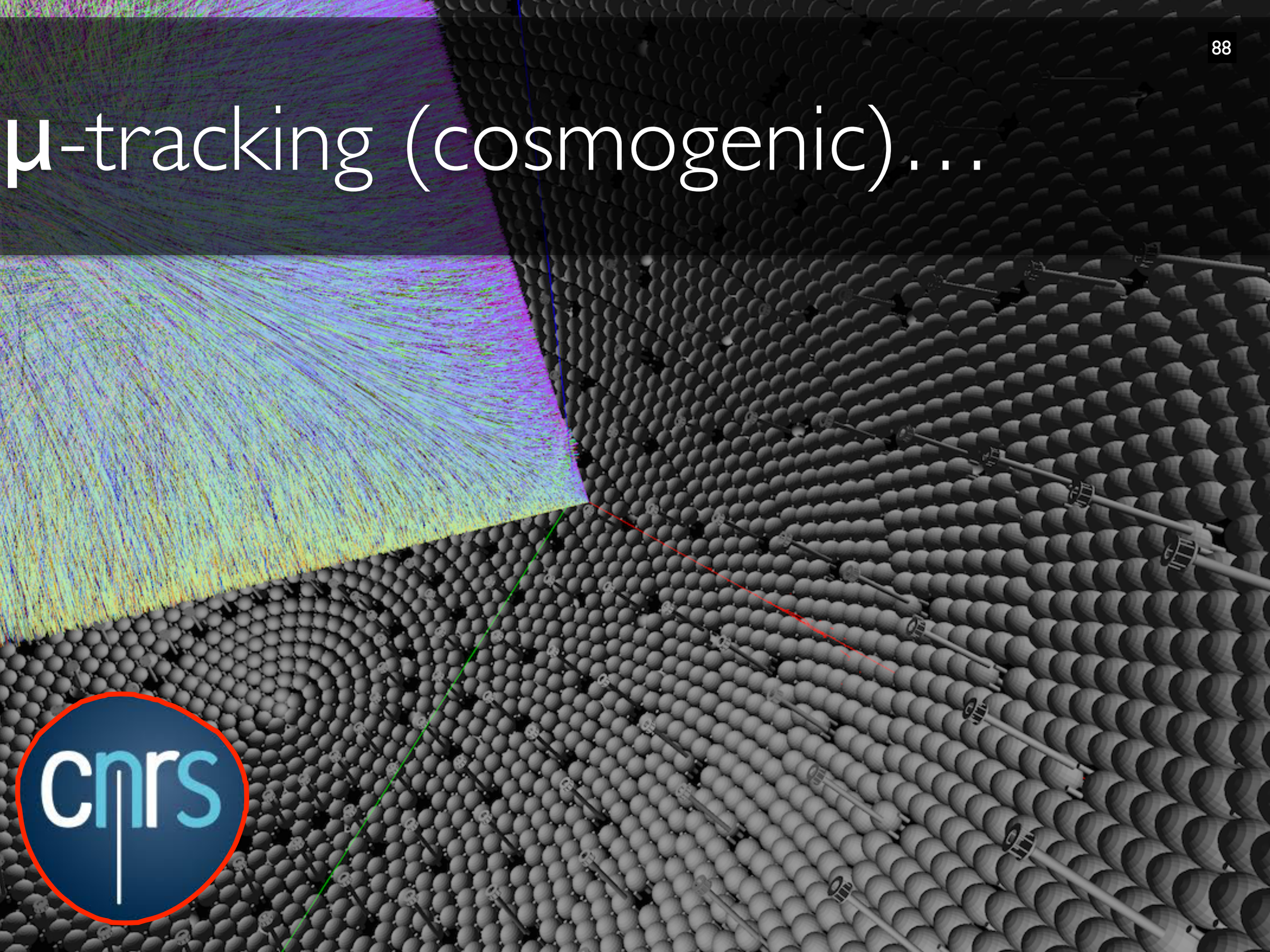


rate: 1.1/day
17.2 m fiductial volume cut:

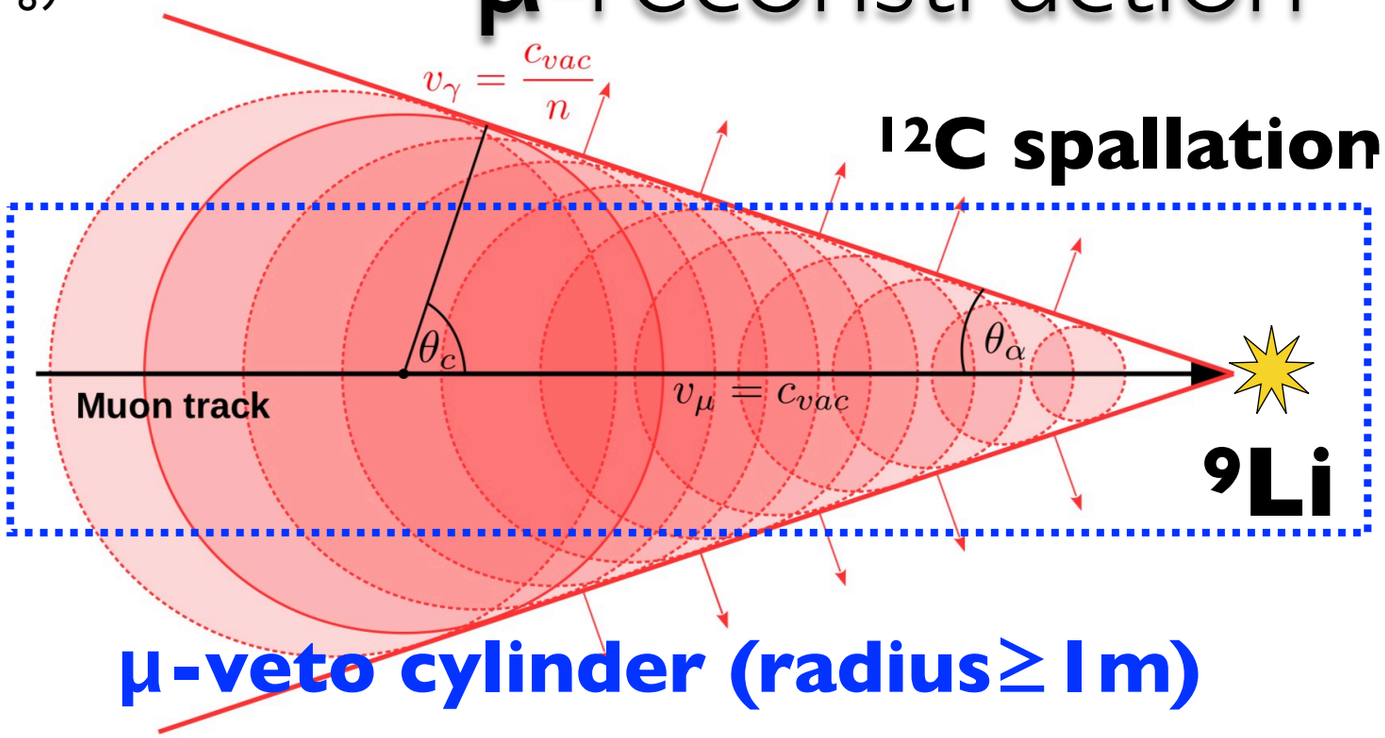


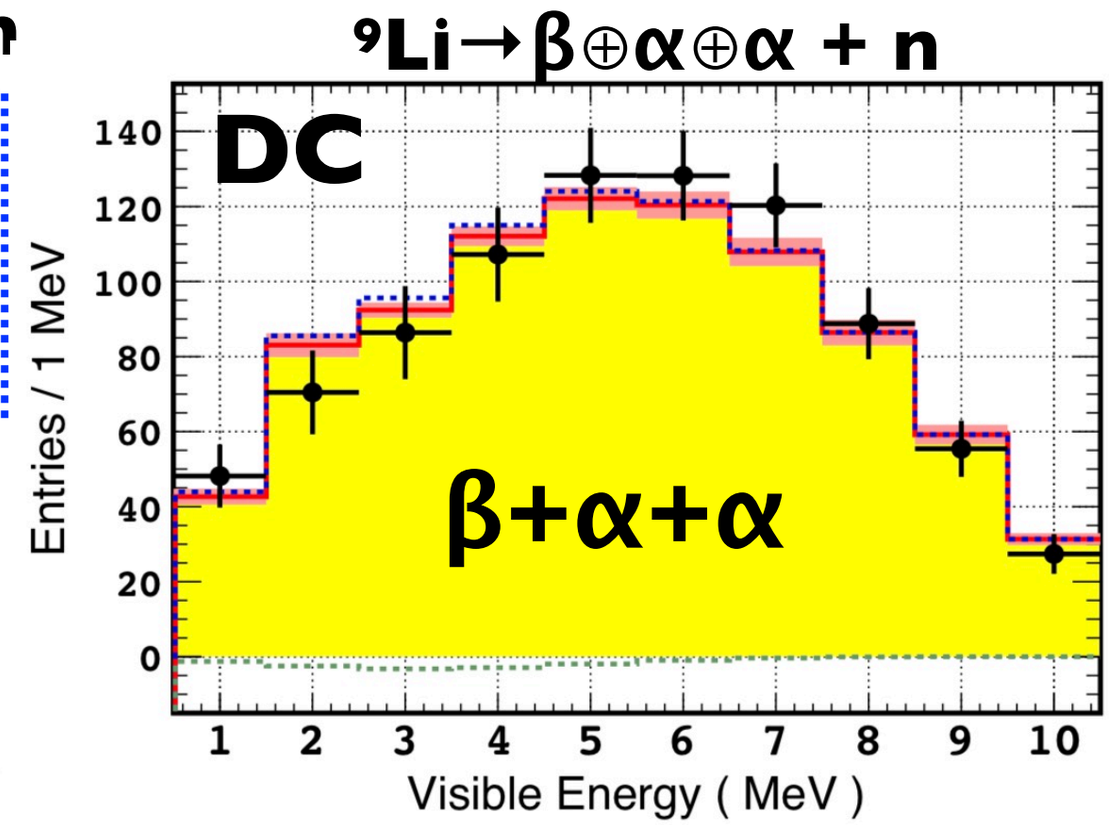
→ detailed Monte-Carlo simulations using JUNO software are planned in order to better describe the accidental background energy spectrum

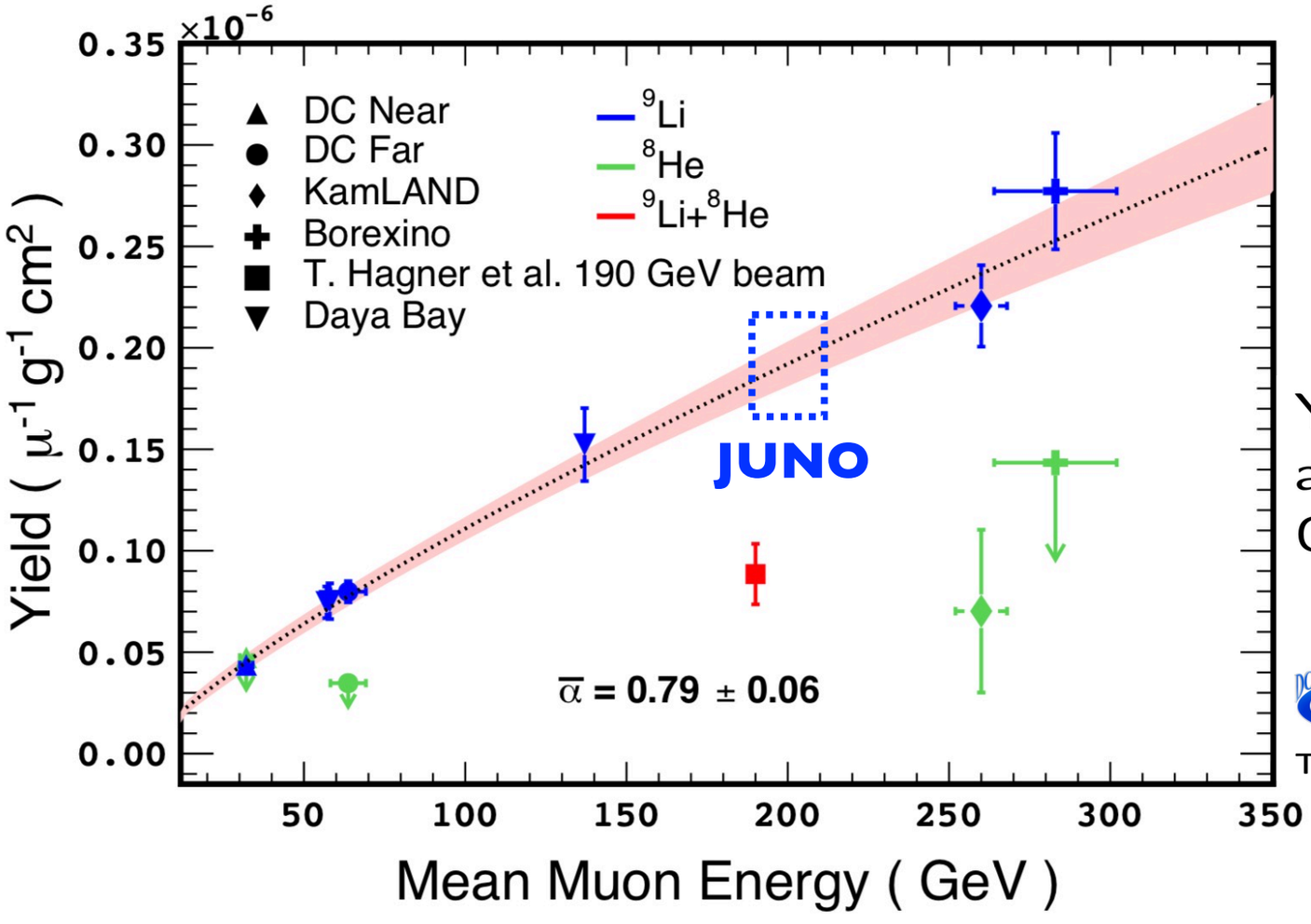
μ-tracking (cosmogenic)…



μ-reconstruction→cosmogenic vetoing…





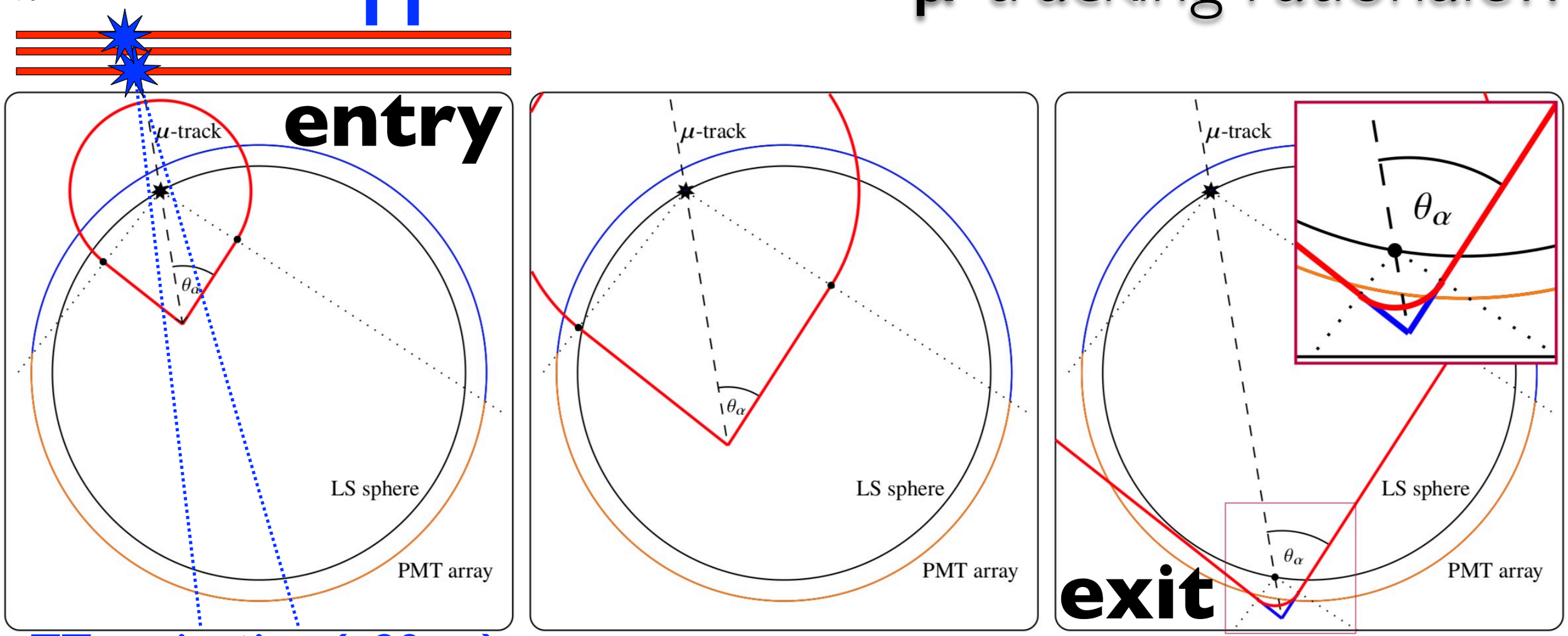


Yields and production rates of ^{9}Li and ^{8}He measured with the Double Chooz near and far detectors

arXiv:1802.08048v1

The Double Chooz Collaboration

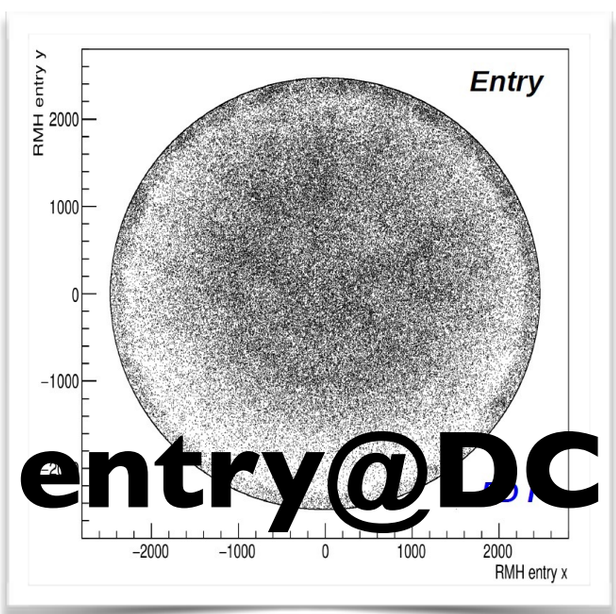
μ-tracking rationale…

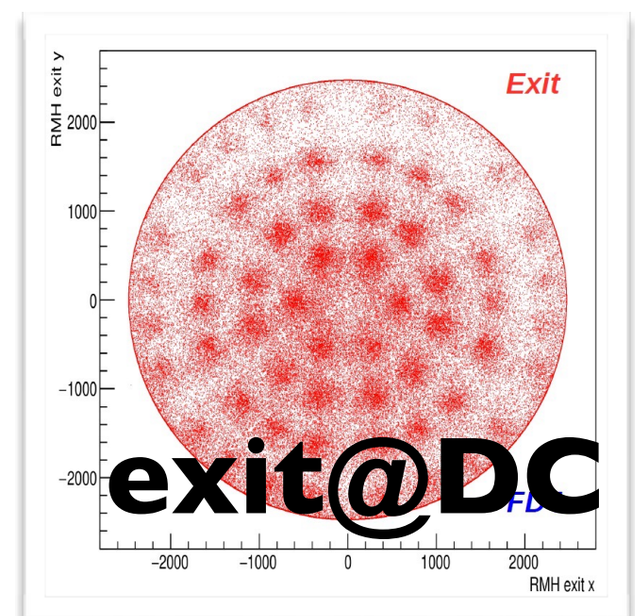


TT projection (~20cm)

propagation

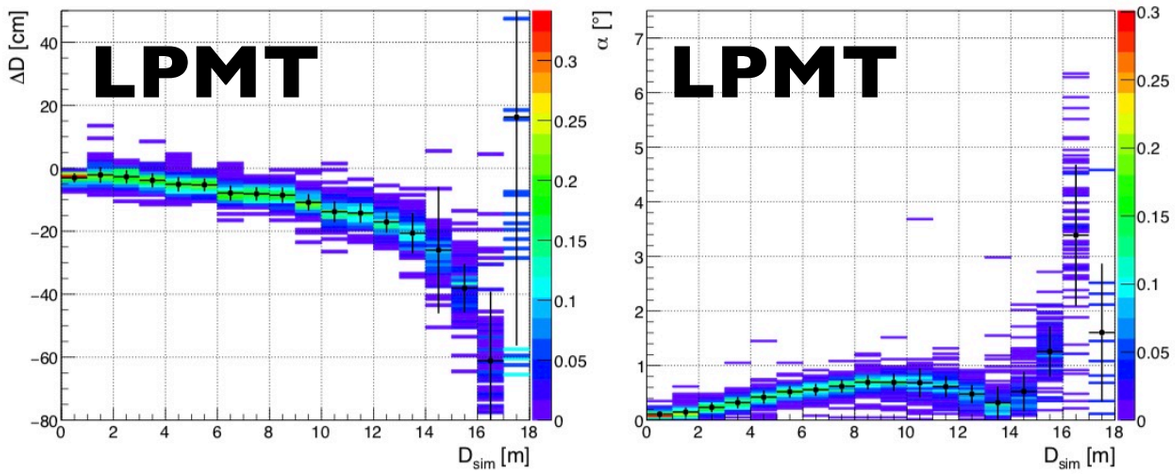
(straight extrapolation)



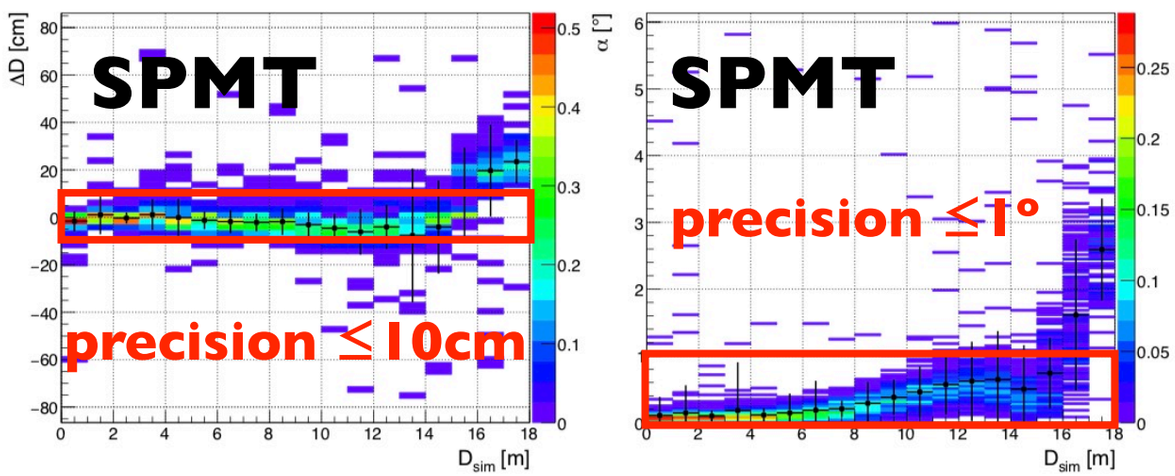


μ-reco accuracy…

space resolution | **angular resolution**

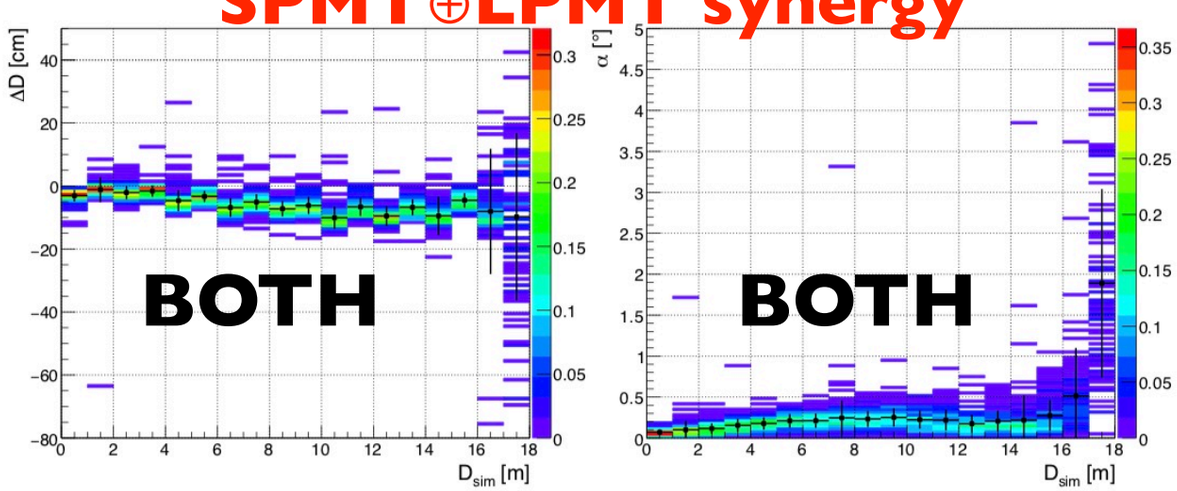


detector radius



(c) SPMT ΔD (d) SPMT α

SPMT⊕LPMT synergy



(e) LPMT+SPMT ΔD (f) LPMT+SPMT α

Muon reconstruction with a geometrical model in JUNO

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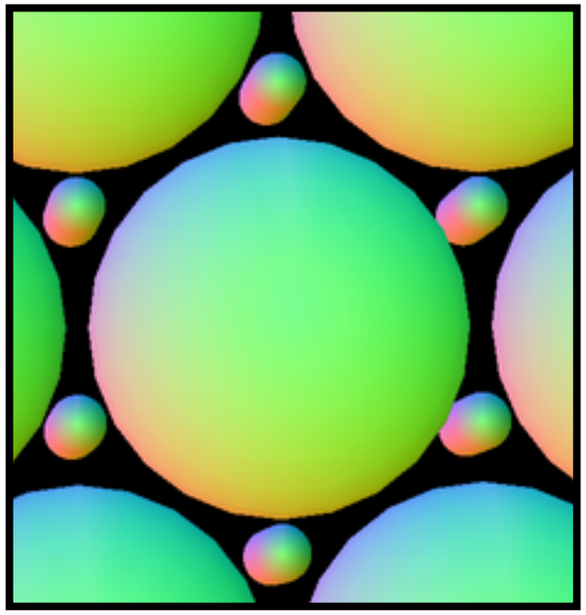
[a] *Forschungszentrum Jülich IKP, Wilhelm-Johnen-Strasse, D-52428 Jülich, Germany*

[b] *III. Physikalisches Institut B, RWTH Aachen University, Aachen, Germany*

E-mail: c.genster@fz-juelich.de

2018 JINST 13 T03003



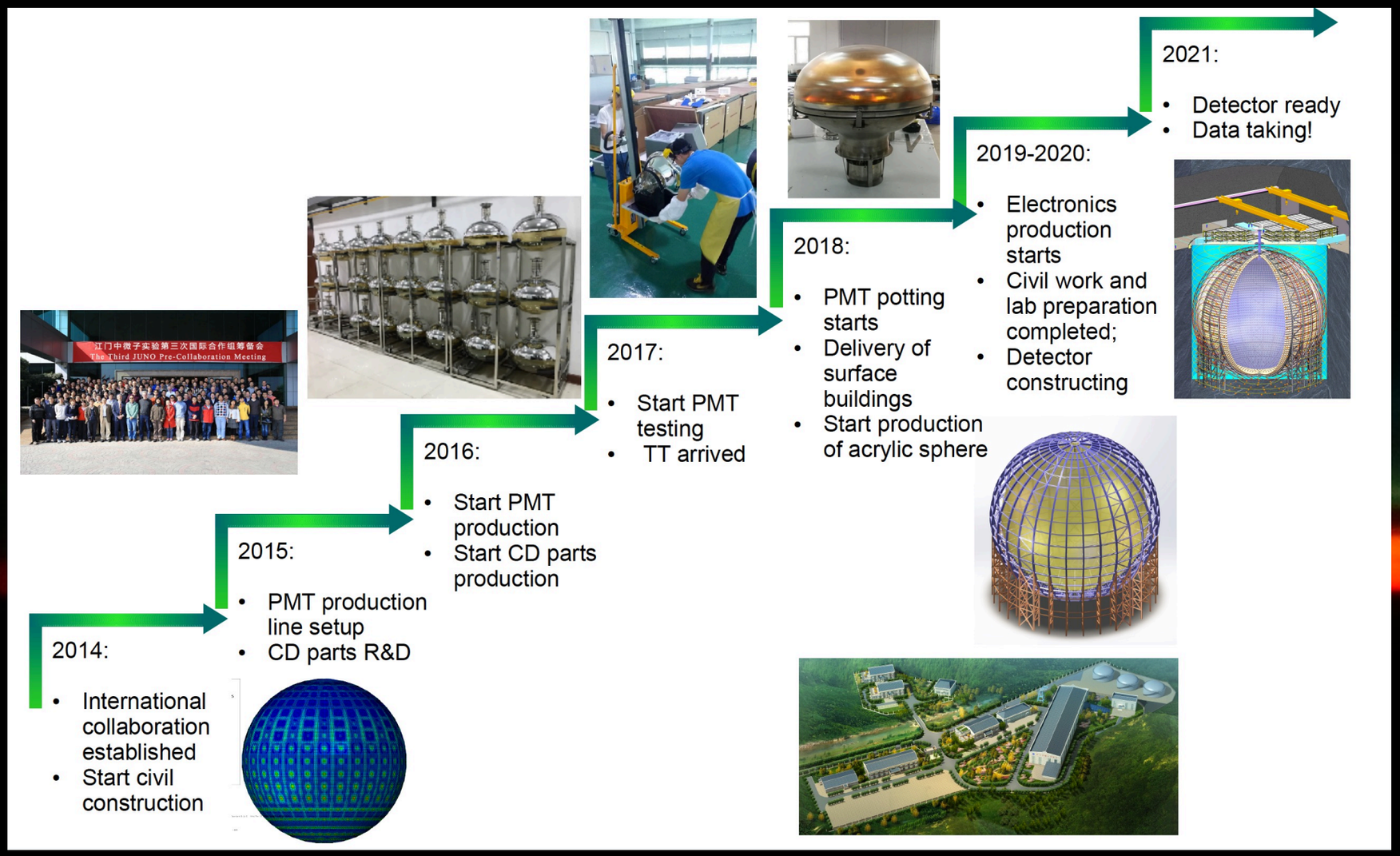
- **more PMT density**
- **excellent timing (RMS)**
- **enough light**
- **better triangulation**

further improve with TT input (~20cm projection: not yet)

excellent SPMT⊕TT synergy…

the organisation (details)…

the JUNO schedule…



2018:

- Continuation of the underground laboratory civil construction.
- JUNO surface building infrastructure delivery.
- PMT potting starts.
- Completion of all preparation operations and start of all elements production.

2019:

- Underground laboratory completion.
- Start of JUNO detector construction.
- SPMT and LPMT electronics production and assembly.

2020:

- Continuation of detector construction.
- SPMT and LPMT electronics installation.

2021:

- Completion of CD detector construction.
- Filling of CD and water-veto detectors.
- Construction of top support detector structure (needed for TT).
- Installation of TT system.
- Start data-taking and commissioning.

highest priority

- HW prototype / readiness completion ≤2018
- HW full production (early 2019) & assembly (within 2019)
- **neutrino detector construction starts end-2019** (TT installation ≥late 2021)

Anatael Cabrera (CNRS-IN2P3 & APC)

JUNO experiment

- ultimate reactor-ν experiment and well beyond…
- world neutrino oscillation physics (CP-Violation experiments support)
- physics programme beyond oscillations (supernova, etc)

CNRS within JUNO

- key hardware contributions: **SPMT** & **Top-Tracker**
- **strong physics programme** — leading role (even with limited resources)

questions…?

obrigado…
ありがとう…
merci…
danke…
고맙습니다…
Спасибо…
gracias…
grazie…
谢谢…
hvala…
thank you…

anatael@in2p3.fr