the JUNO Small PMT system

NEPTUNE Workshop

Napoli - July 2018

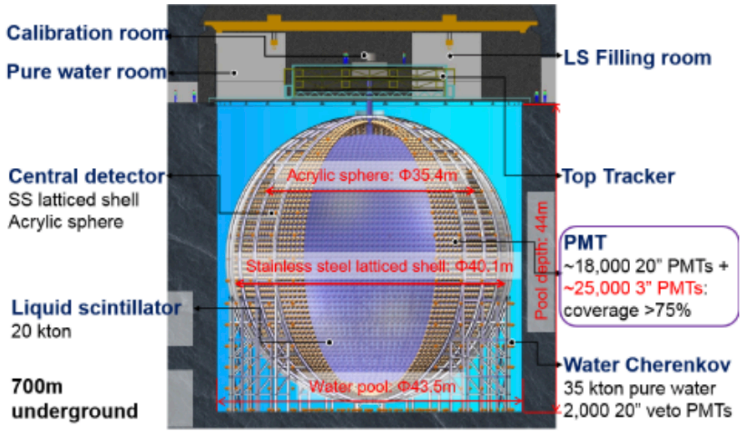
Cedric CERNA

on behalf of the JUNO collaboration

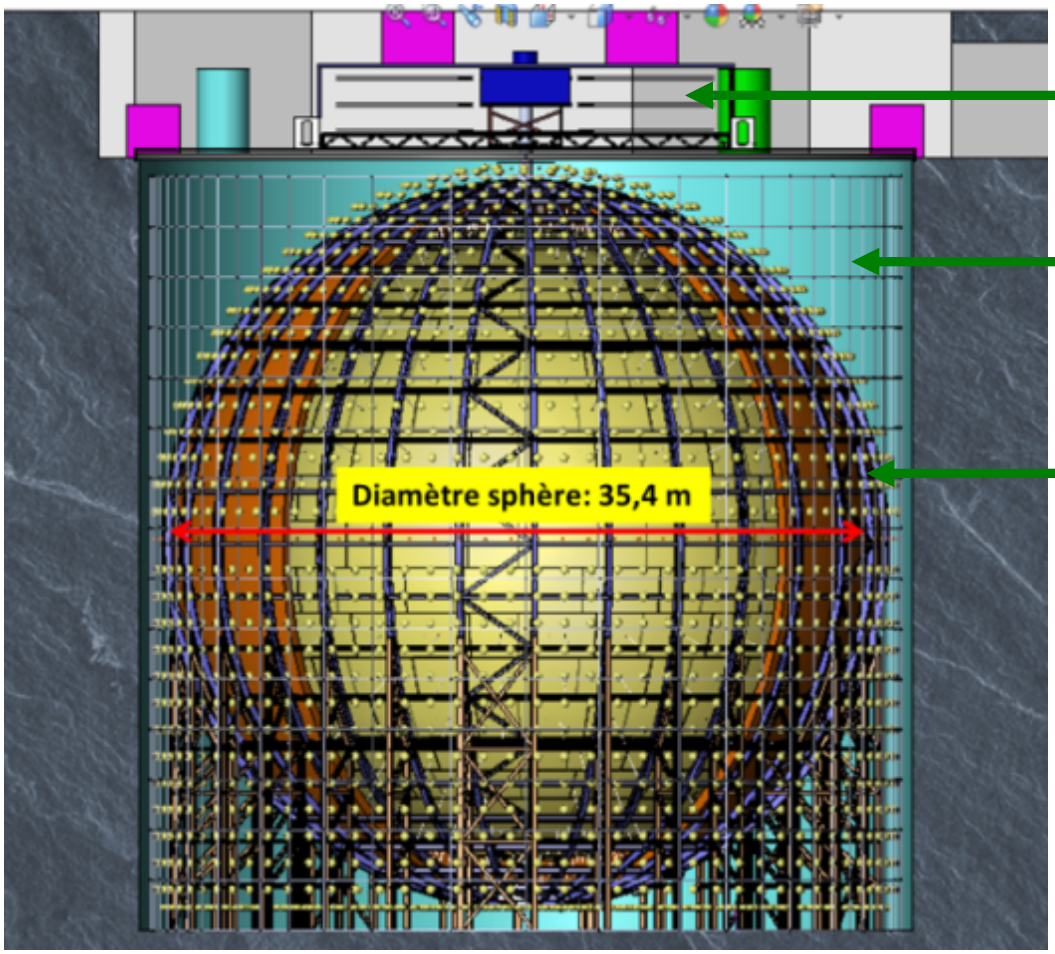
JUNO

Jiangmen Underground Neutrino Observatory

- **Multipurpose neutrino experiment**
- **Primary goal:**
  - **neutrino mass hierarchy**
  - **precise measurement of neutrino oscillation parameters…**
- **Energy resolution:** $3\%/\sqrt{E}$



JUNO



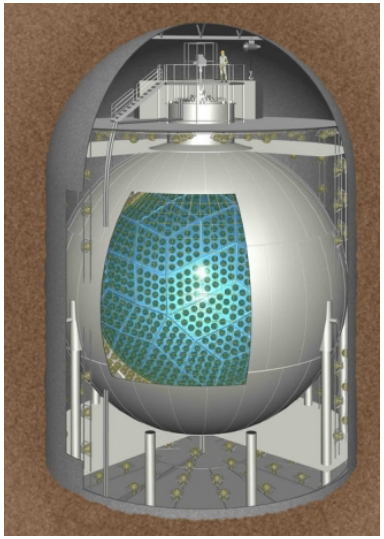
Top Tracker (veto à muons)

Cherenkov pure water tank
(2000 PMT 20'', D=43m)

Central Detector

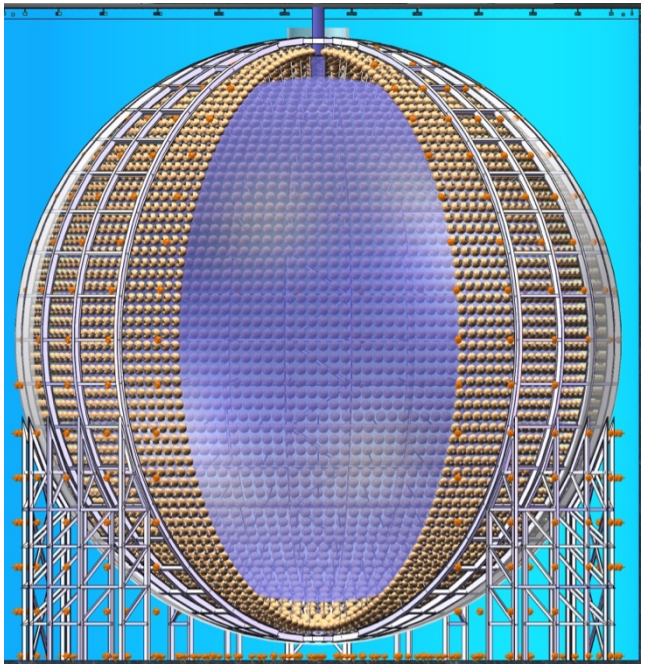
- 20 000 tons liquid scintillator (D=35,4m)
- Acrylic sphere
- 18000 PMT 20'' (LPMT)
- **25000 PM 3'' (SPMT)**

JUNO photomultipliers



Kamland
1,000 t
1,325 x 17’’+ 544 x 20’’
32%
6% /√E

Borexino
300t
2,200 x 8’’
34%
5% /√E



JUNO
20,000 t
- **18,000 x 20’’**

75% coverage
>1200 PE/MeV → 3% /√E

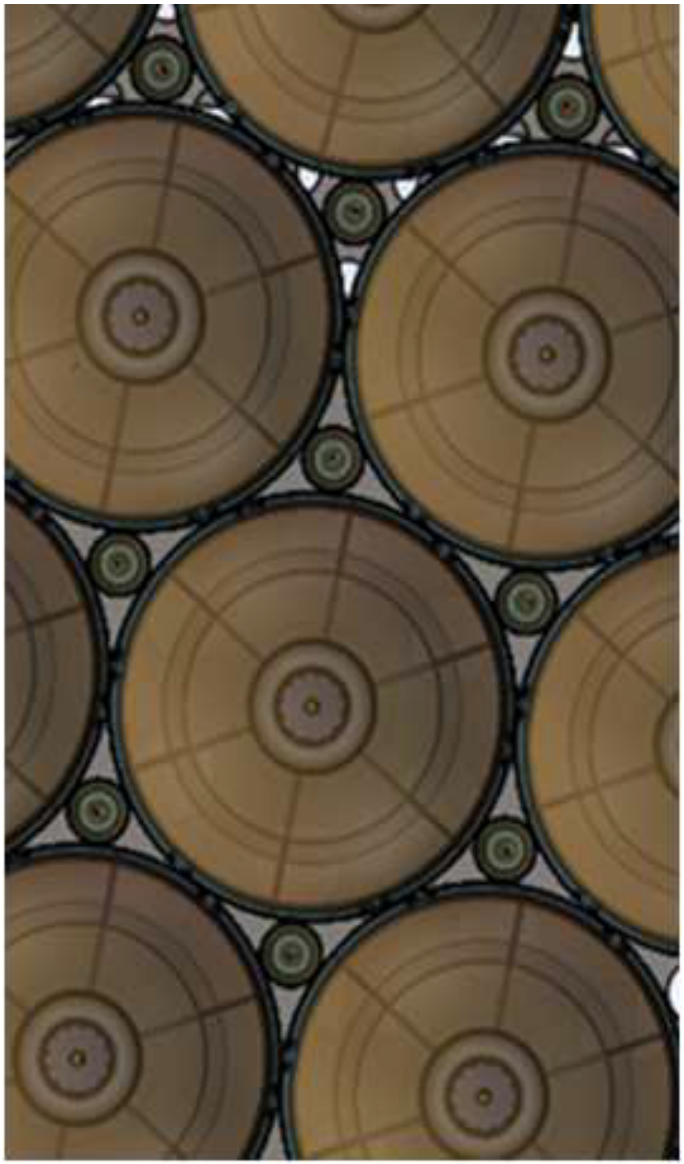
20’’	
NNVT	**Hamamatsu**
13,000 MCP	5,000 Dynode
DE = QE x CE 27%	
Gain 1E7	
SPE Resol. ~30%	
TTS 5.1ns	**1.2ns**

Cf. Wei WANG talk

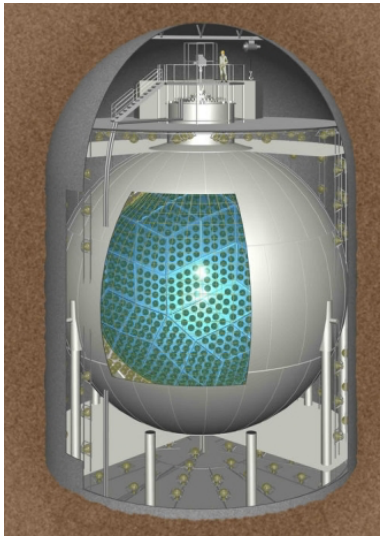
cerna@cenbg.in2p3.fr

Stereo-calorimetry

Stereo-calorimetry



JUNO photomultipliers



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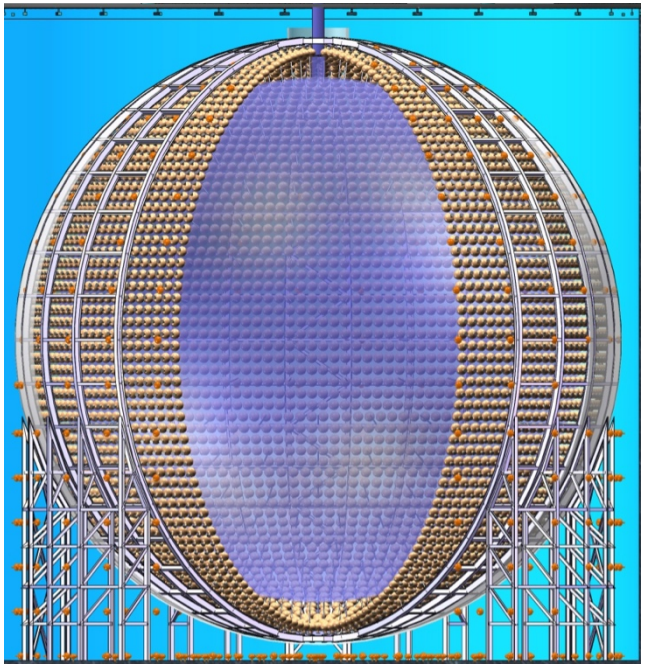
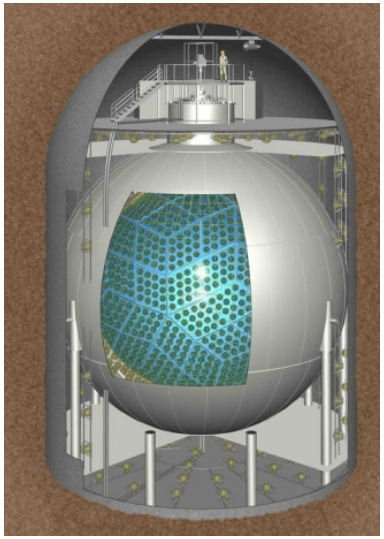


JUNO
20,000 t

- **18,000 x 20’’**
  - **75% coverage**
  - **1200 PE/MeV**
  - **3% /√E**
- **25,000 x 3’’**
  - **35 PE/MeV**
  - **+3% coverage**

JUNO photomultipliers



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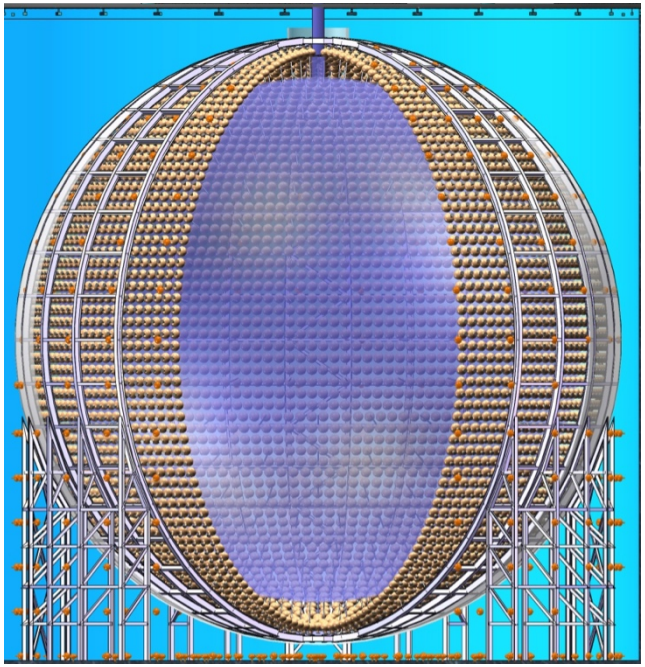


JUNO
20,000 t
- **18,000 x 20''**

75% coverage
3% /√E
- **25,000 x 3''**

20'' NNVT	20'' Hamamatsu
13,000	5,000
TTS 5.1ns	**TTS 1.2ns**
	3''
	25,000
	TTS < 2.5ns

+11% of good timing photocathode

Small PMT (SPMT) system

- **Complete the physics program with good timing & SPE counting**

SPMT physics program

Cf. Bedrich ROSKOVEC talk

Cf. Marco GRASSI talk

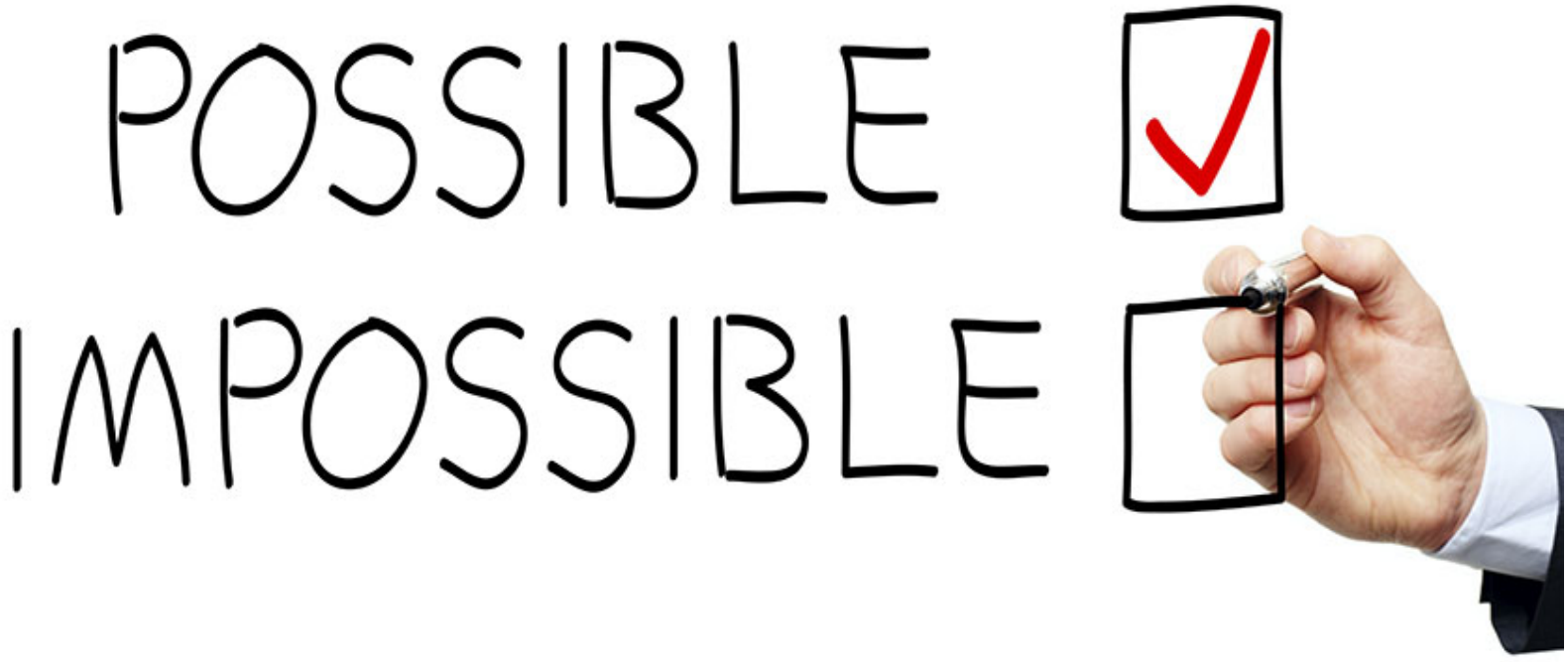
1. High precision calorimetry
   Improve response systematics within IBD physics aid to achieve ≤3% resolution at 1MeV

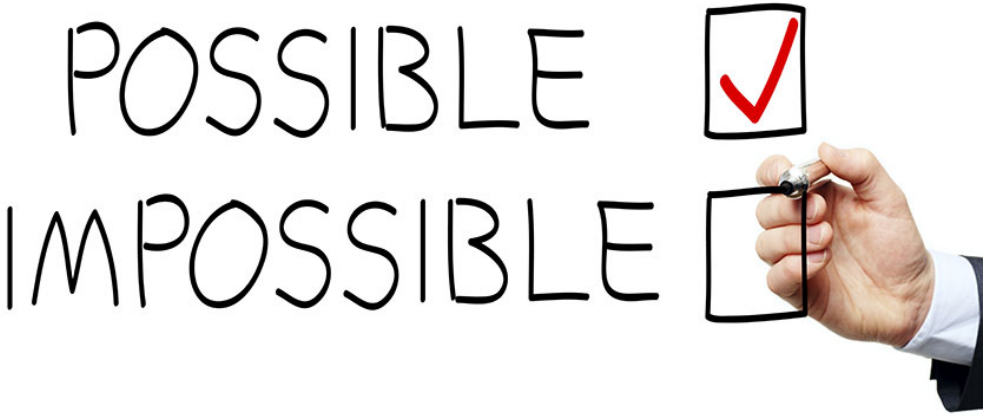
2. Physics: Standalone measurement of solar parameters
   Ensure accurate physics results and validate energy scale

3. Improve inner-detector μ-reconstruction resolution
   Aide $^{12}B/^{9}Li/^{8}He$ tagging/vetoing

4. High rate SN pile-up (if very near)
   Minimise bias in absolute rate & energy spectrum

5. Complementary readout info: time resolution, dynamic range & trigger


POSSIBLE
IMPOSSIBLE



feasibility

25,000 channels → meet industry

The smart path....

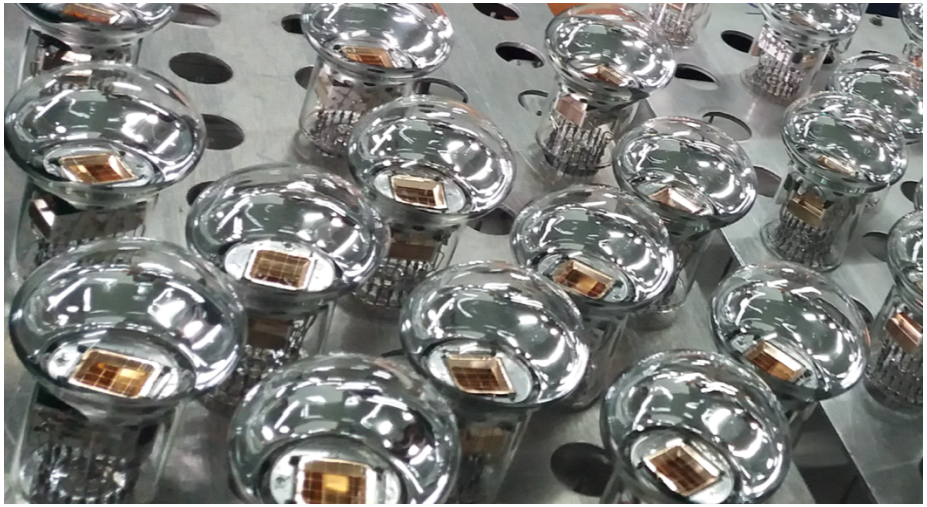
3'' PMT

Cf. Nan LI talk

- custom made for JUNO

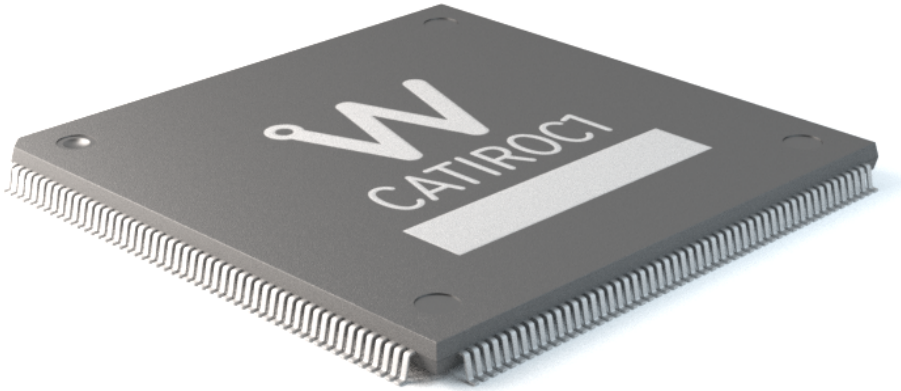
TTS optimization

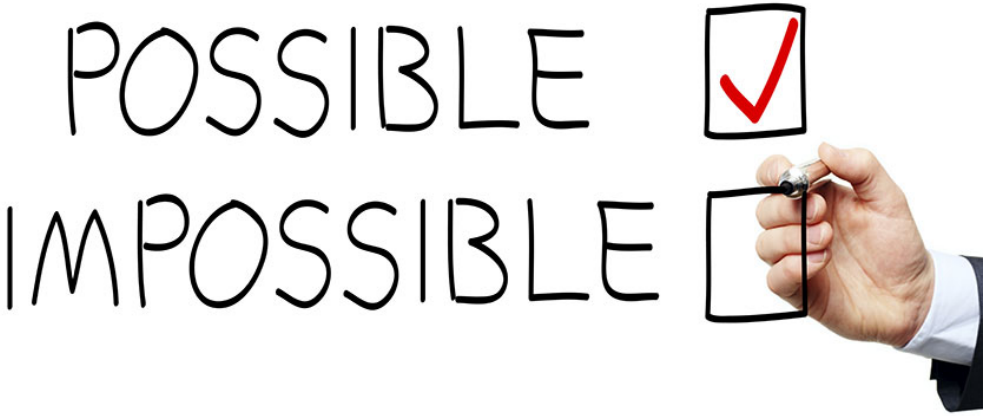
- **Existing** in industry now
- **Affordable**
- Good single photon counting system



Readout ASIC

- **Existing** in lab *or industry*
- **Affordable**
- Charge & time / Multi-channel
- SPE readout system

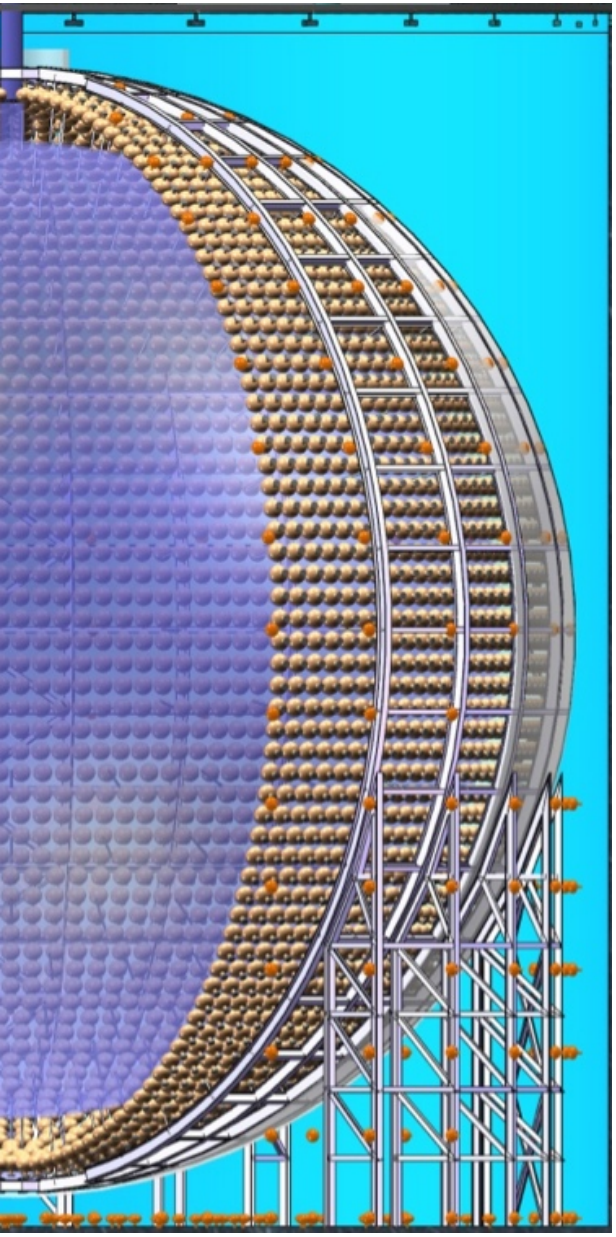




design

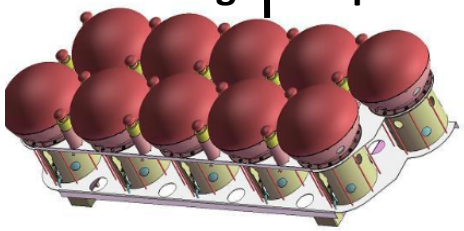
easy to produce
easy to integrate
easy to install

Example : Installation



>45m

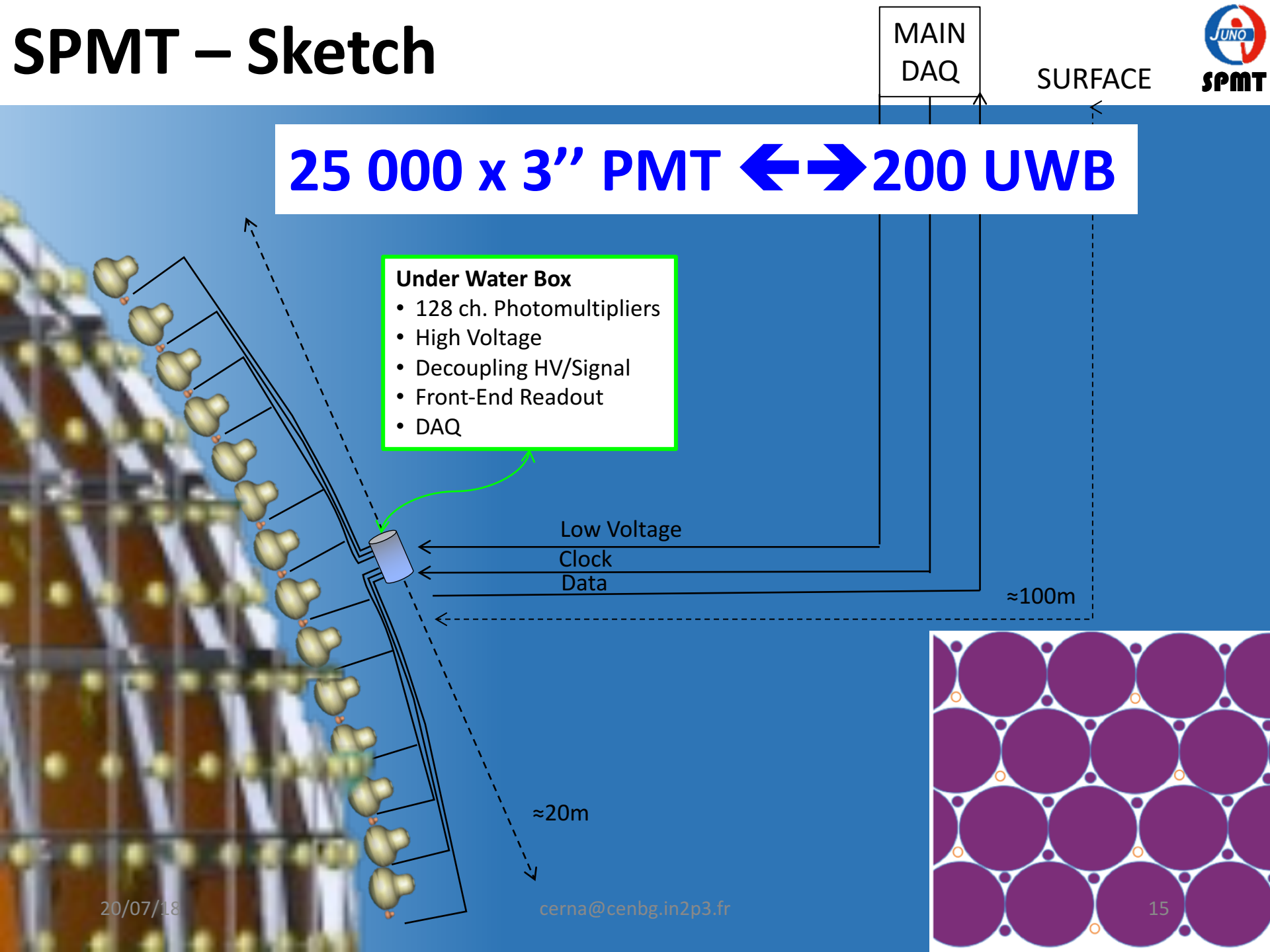
Integration panels



Lifted from top

All constrains should be included in the design!!!

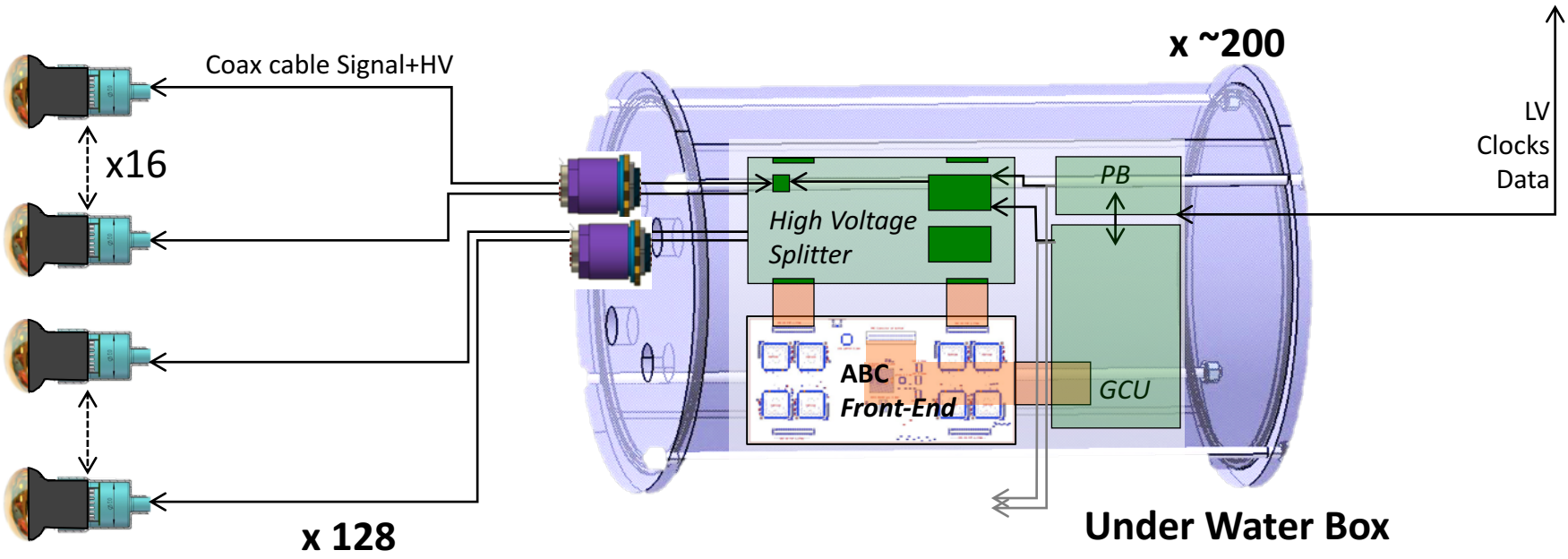
SPMT – Sketch


MAIN DAQ
SURFACE
25 000 x 3” PMT ←→200 UWB
Under Water Box
• 128 ch. Photomultipliers
• High Voltage
• Decoupling HV/Signal
• Front-End Readout
• DAQ
Low Voltage
Clock
Data
≈100m
≈20m

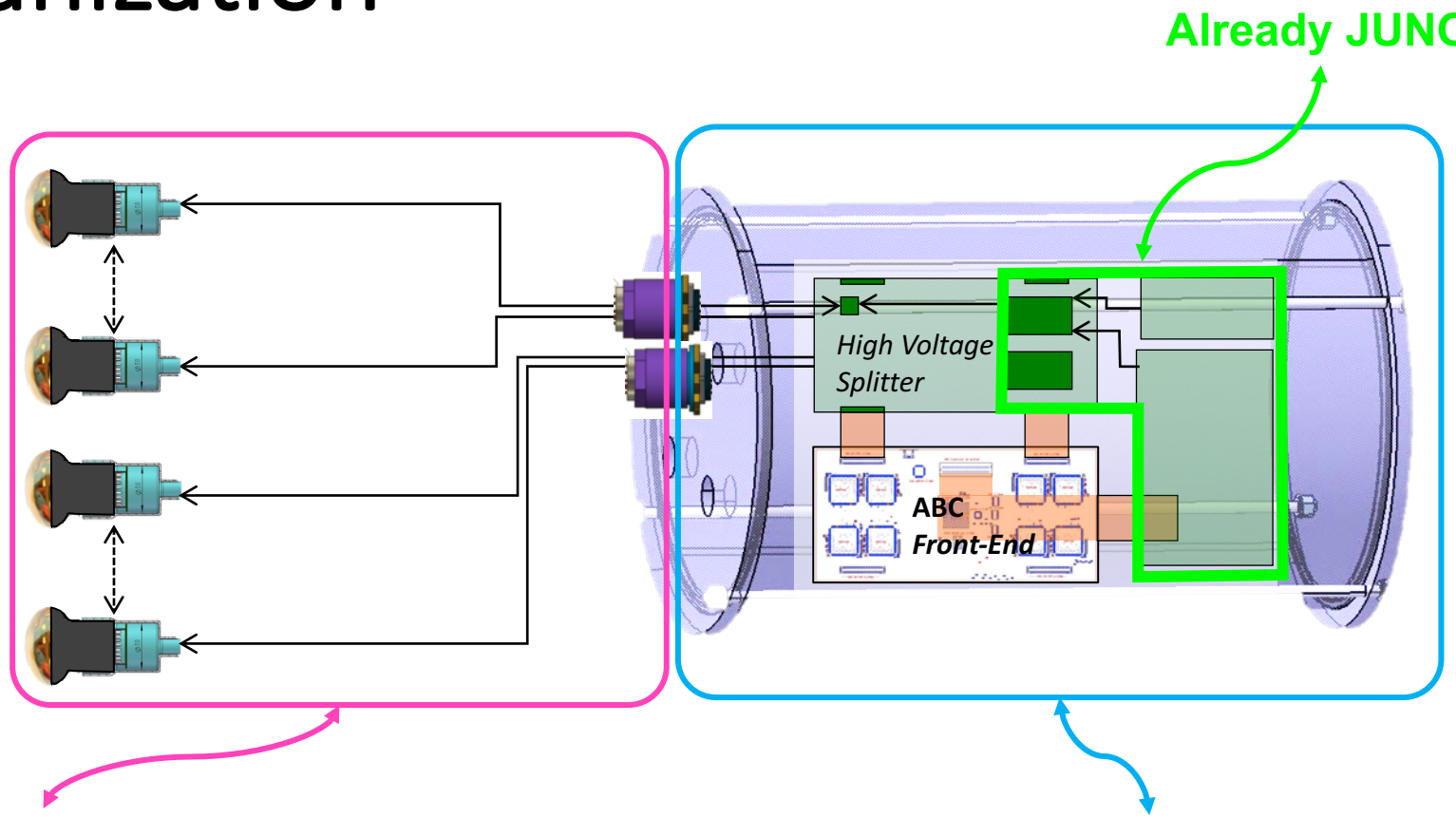
System schematics

our construction brick

- 3" PMT
- High Voltage divider
- Potting
- Cable
- Connector
- Under Water Box
- ABC board
- Splitter board



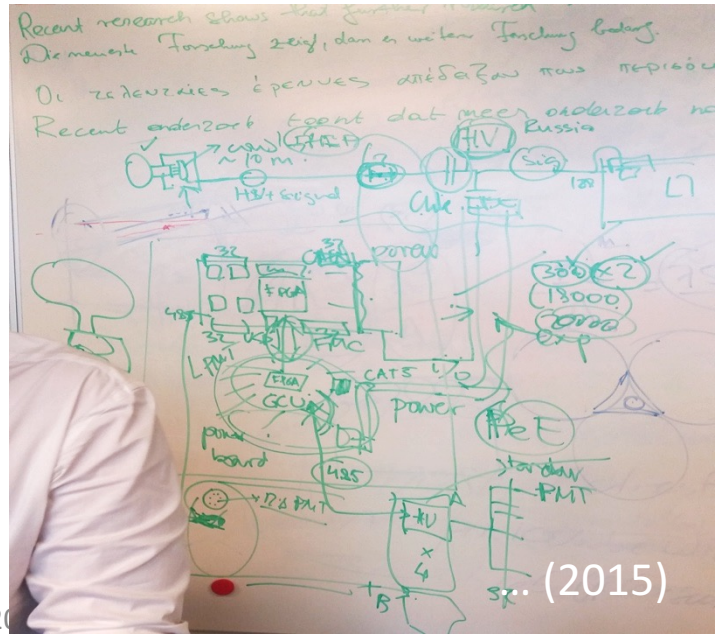
Organization

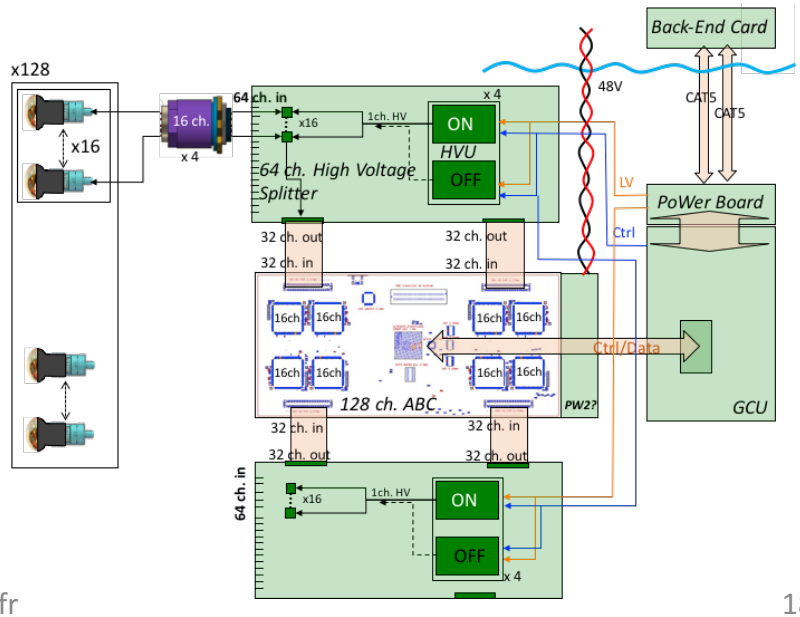


PMT instrumentation and UWB + Electronics are produced at different time, tested separately, and then installed together in JUNO → **underwater connector**

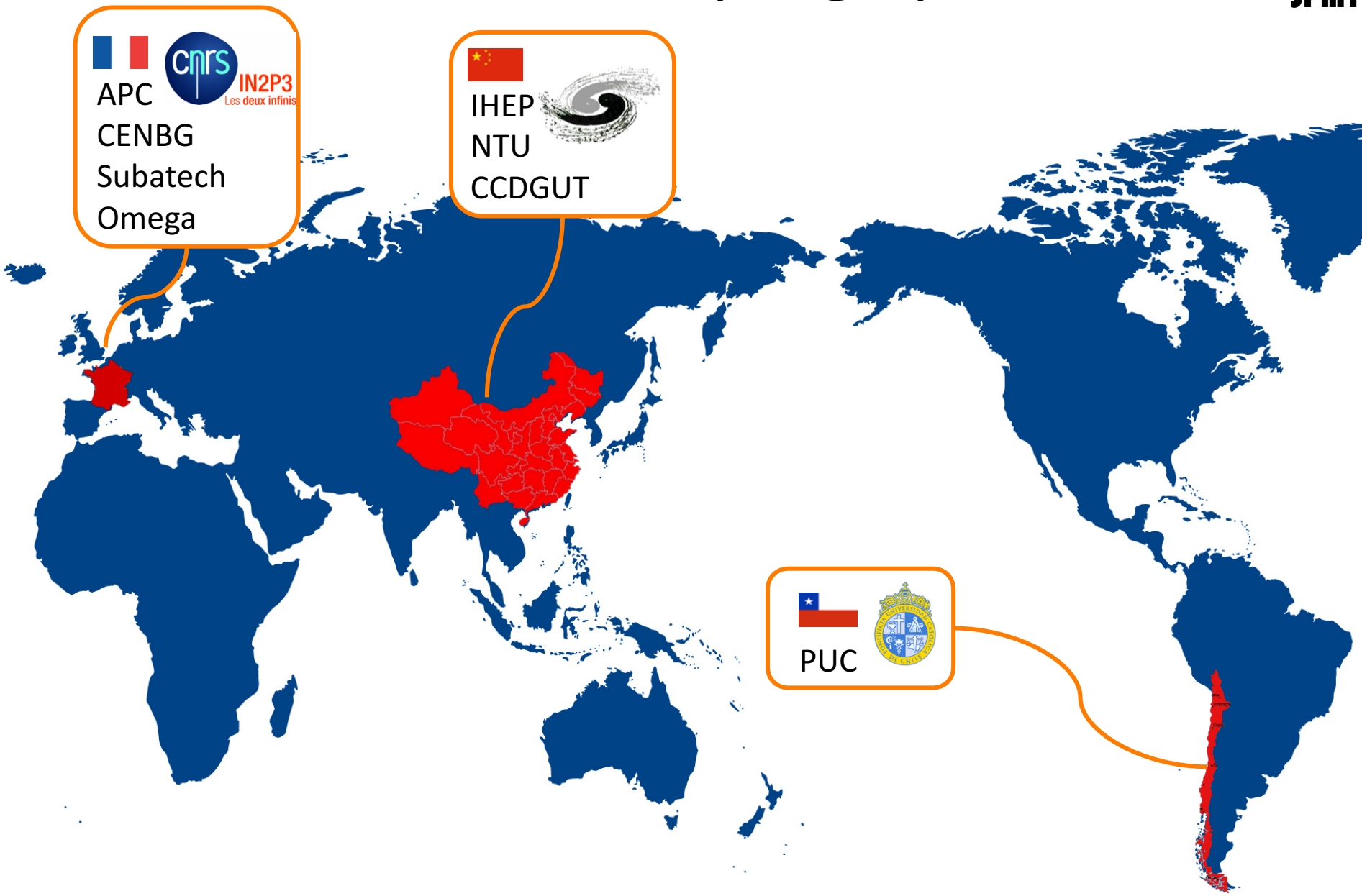
JUNO - SPMT : a fast development

earliest idea 2014 → earliest design 2015 → JUNO Review 2016 → JUNO Approval 2016 → Studies [2016-19] Beginning of production 2018





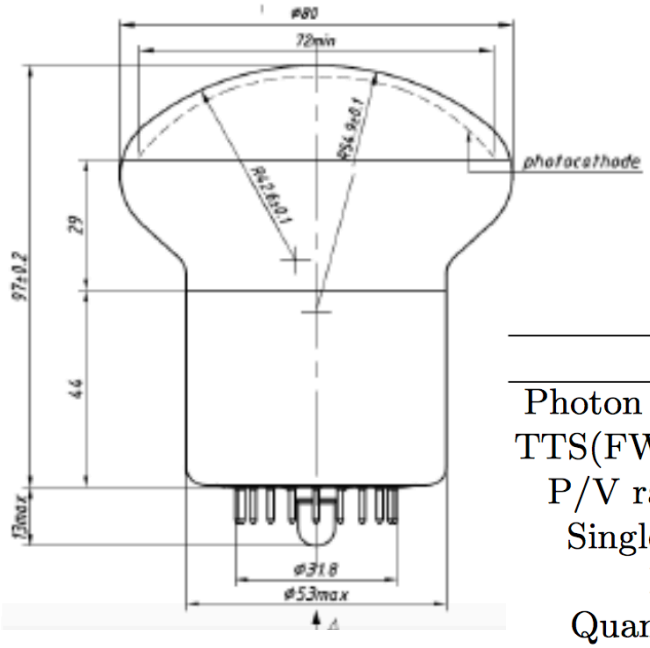
SPMT a never sleeping system



3’’ photomultipliers

Cf. Nan LI talk

July 16 → May 17	• Close work with Hamamatsu, ETEL, HZC, NNVT • Requirements, products, production, prototypes, testing
May 17	Biding at IHEP → HZC to produce 25,000 + 1,000 photomultipliers XP72B22
November 17	Production Readiness Review at HZC
January 18	Production kickoff



Parameters	HZC’s response
Photon detection efficiency@420 nm	24%
TTS(FWHM) of single photoelectron	<5ns
P/V ratio of single photoelectron	3
Single photoelectron resolution	35%
Dark rate @ 0.25 PE	1,000 Hz
Quantum efficiency uniformity	<30% in Φ60 mm
Pre/after pulse charge ratio	<5%/<15%
Nonlinearity	<10%@1-100 PE
Radioactivity	^{238}U<400 ppb, ^{232}Th<400 ppb, ^{40}K<200 ppb

Photomultipliers

Cf. Nan LI talk

- Mass testing of 26,000 photomultipliers is an industrial issue

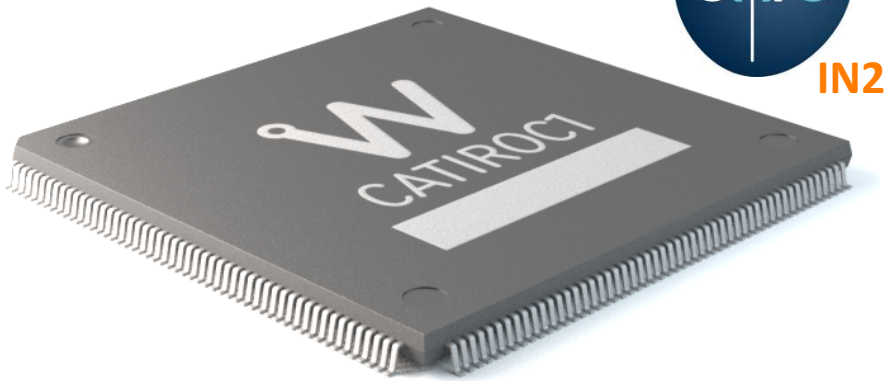
➢ **HZC produce and test 100% of performances under JUNO supervision**

→ 10% random internally fully tested by JUNO ➢ **Good agreement**

CATIROC readout ASIC

- developed at Omega laboratory (Paris)
- **charge and time** measurements
- **trigger-less system**

- **16 input** channels
- **pre-amplifier for each channel**
- programmable **trigger threshold** (common to all channels)
- output handled by a FPGA

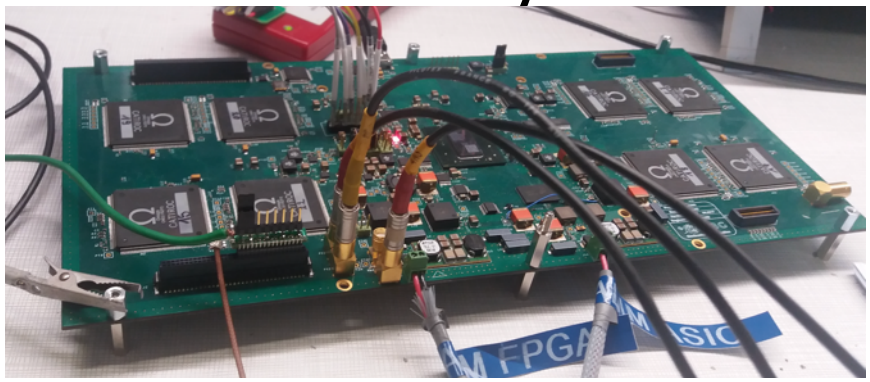


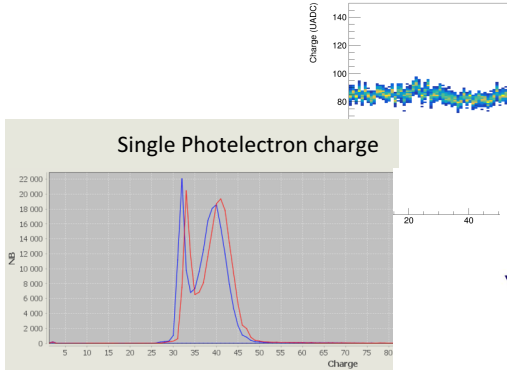
IN2P3

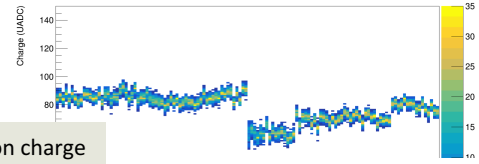
Linearity
Time resolution
Dead time less (SuperNovae)

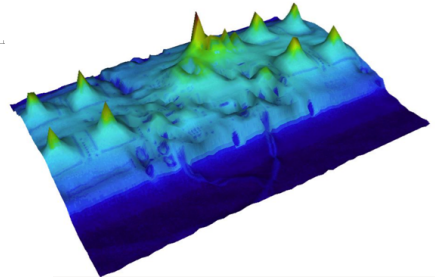
Cf. Anatael
CABRERA talk

Asic Battery Card front-end board





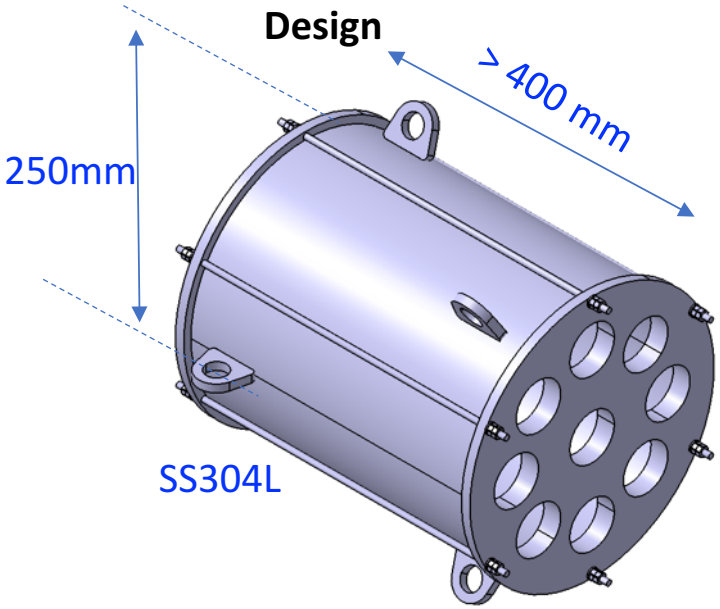




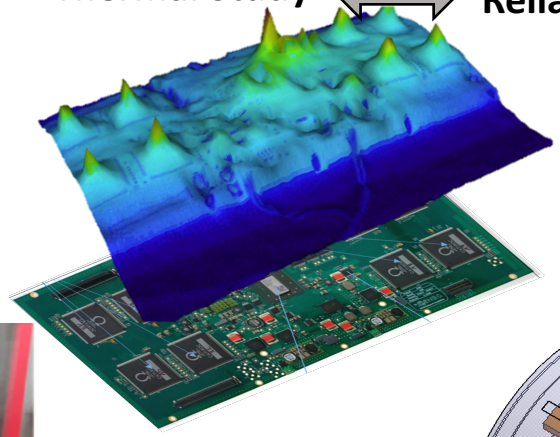
Goal : **CATIROC Production in 2019**

➢ **ABC Production in 2019**

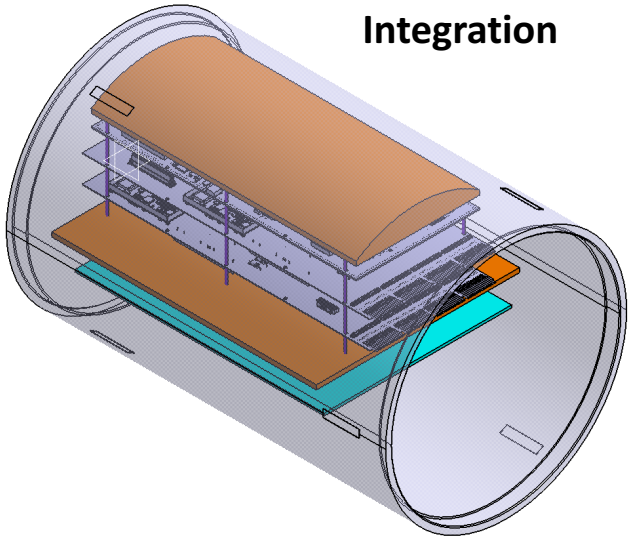
Under Water Box



Thermal Study ⟺ Reliability



Integration



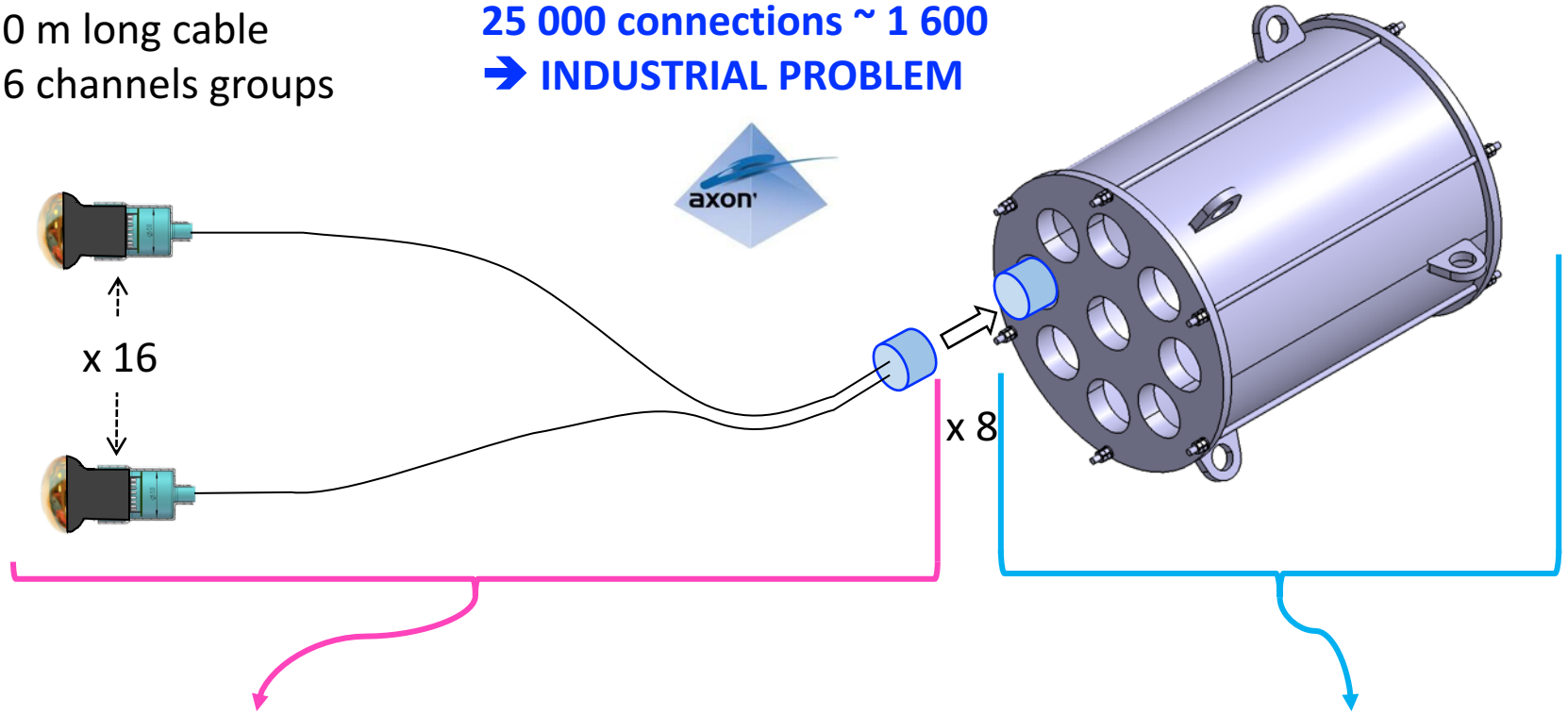
a@cenbg.in2p3.fr

Cable and Connectivity
→ a central key feature for JUNO SPMT production and installation

Specifications

- Ultra Pure Water compatibility / [0 - 5] Mpa
- Production-Storage-Installation environment
- < 1.5 kV / 50 Ω
- 10 m long cable
- 16 channels groups

25 000 connections ~ 1 600
→ INDUSTRIAL PROBLEM



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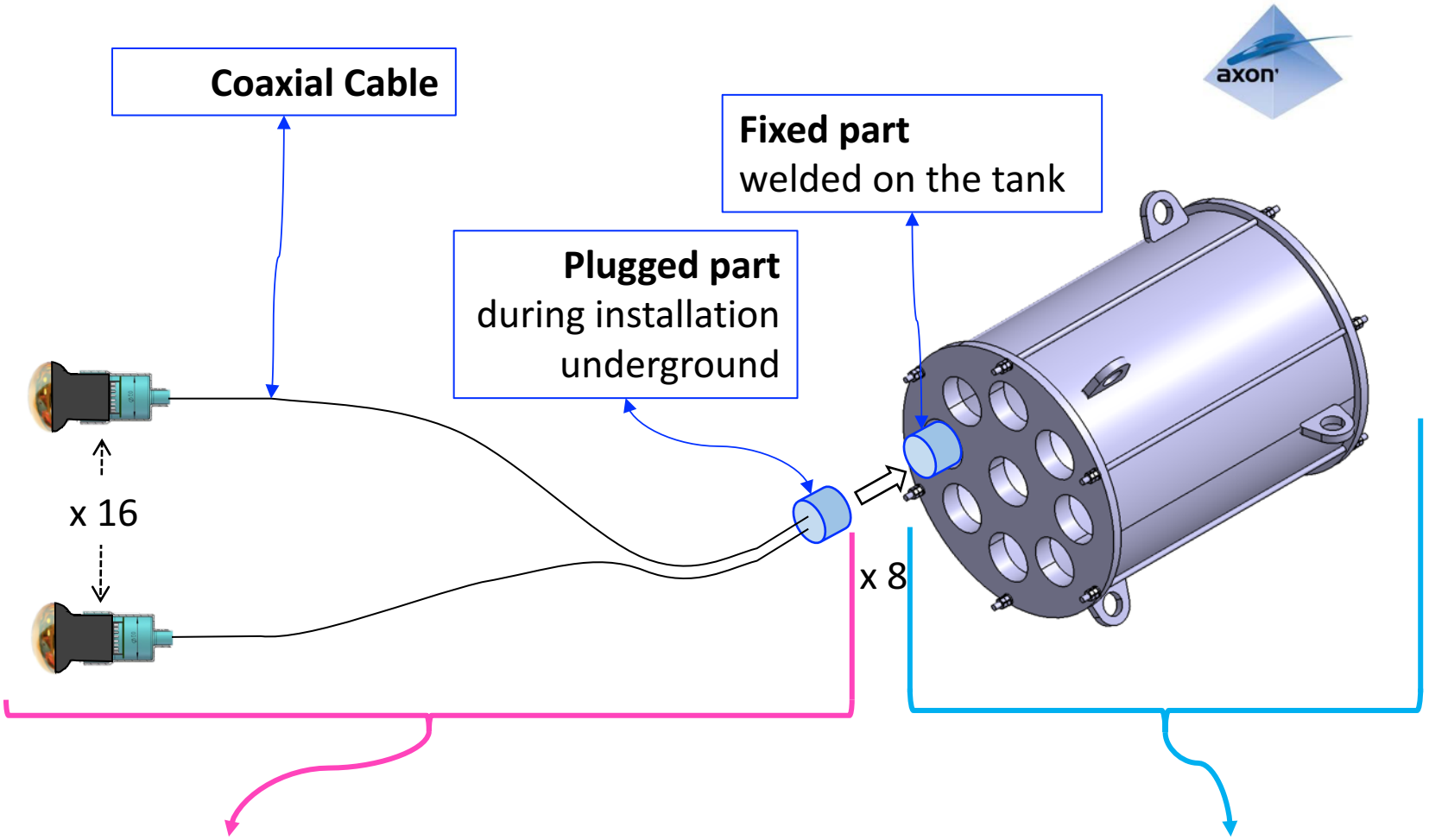

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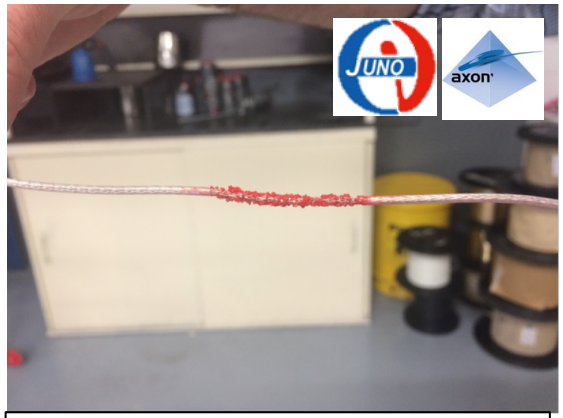
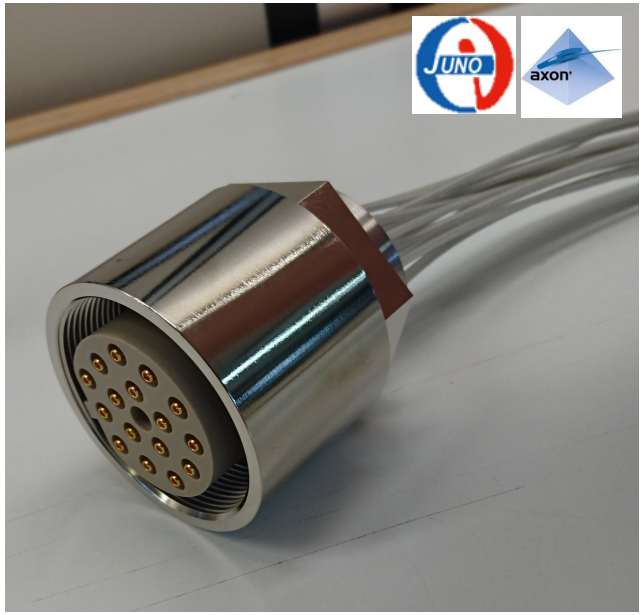
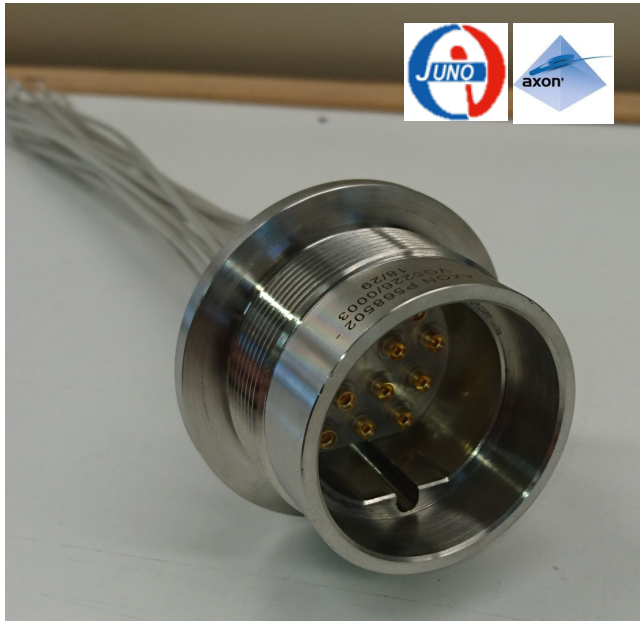
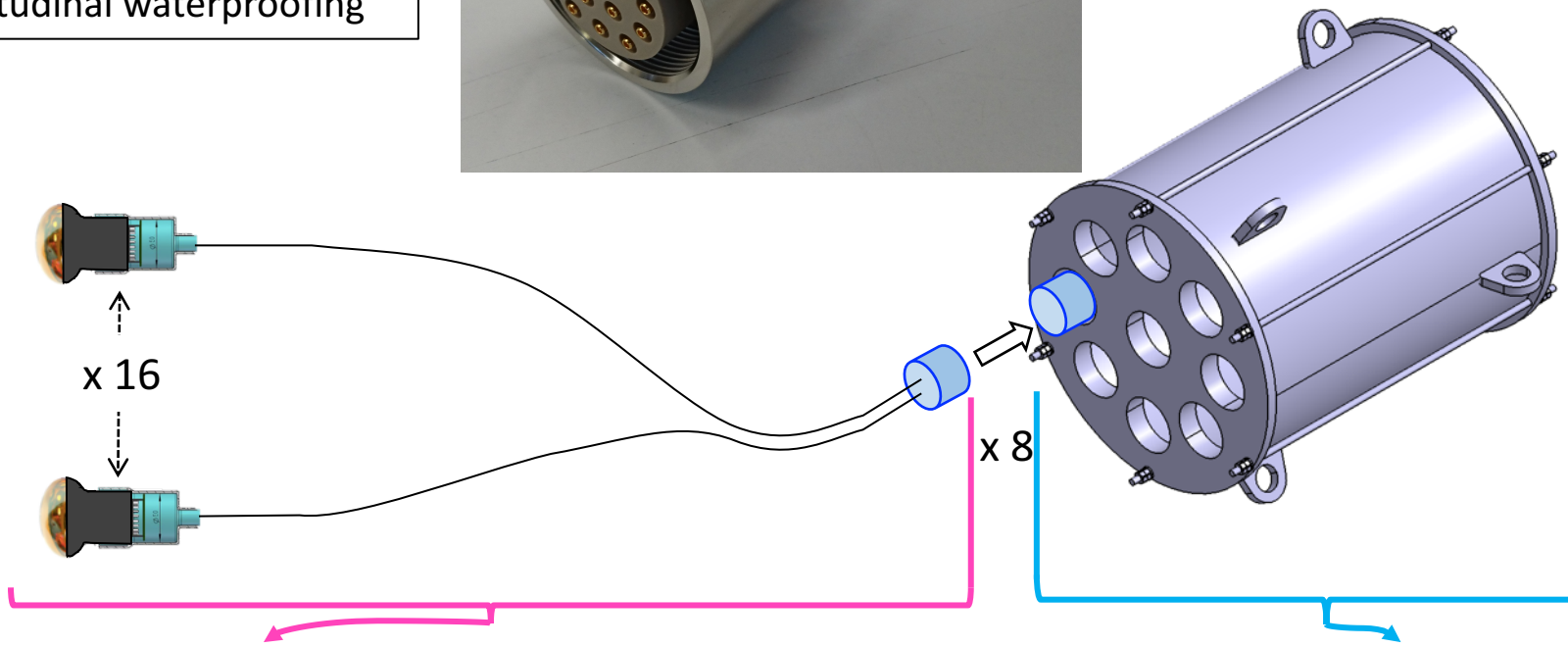


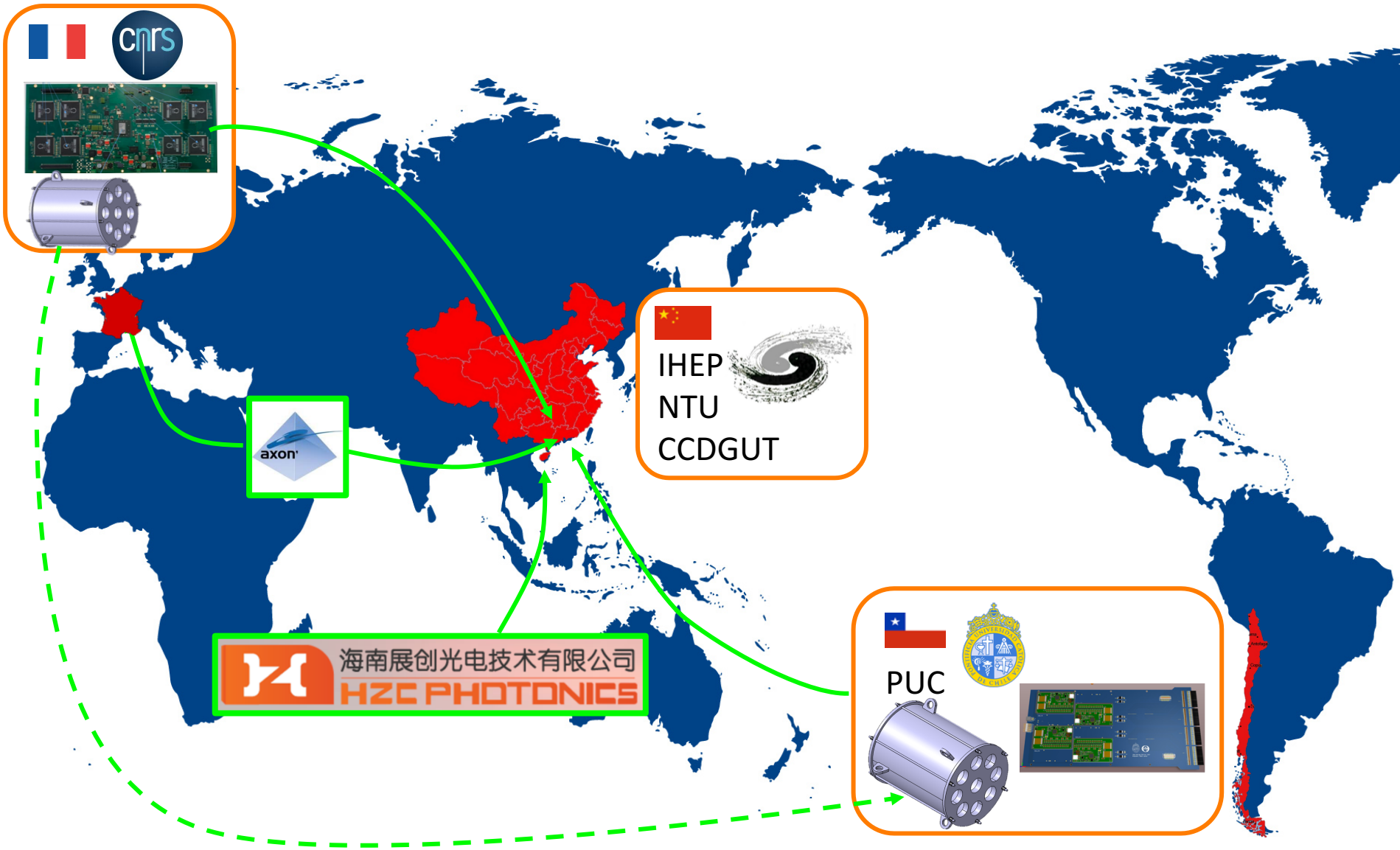
Coaxial RG178
HPDE jacket
Longitudinal waterproofing



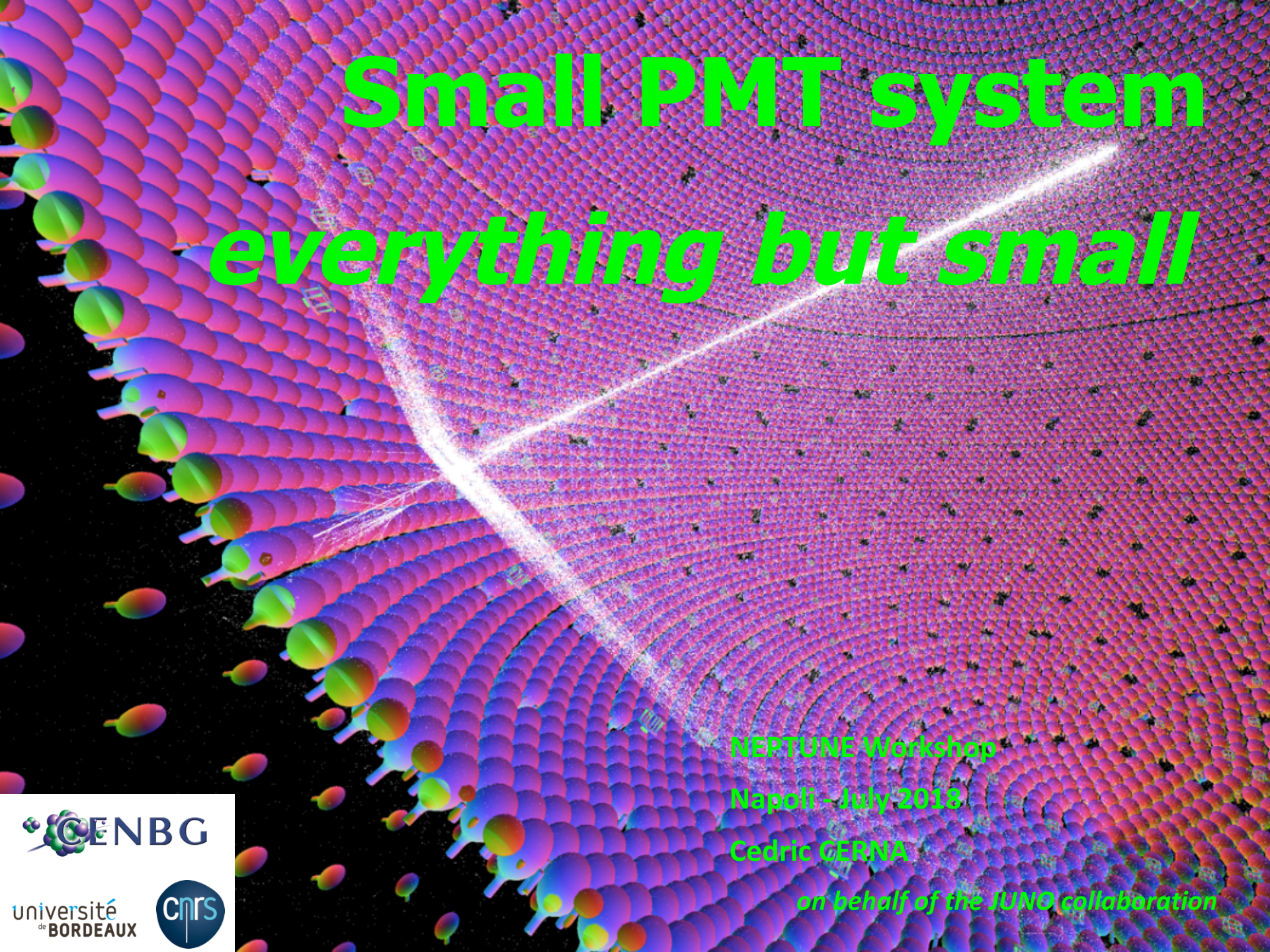




JUNO - SPMT a smart producing system



SPMT a smart producing system



Small PMT system

everything but small

NEPTUNE Workshop

Napoli - July 2018

Cedric CERNA

on behalf of the JUNO collaboration

CENBG

université de BORDEAUX

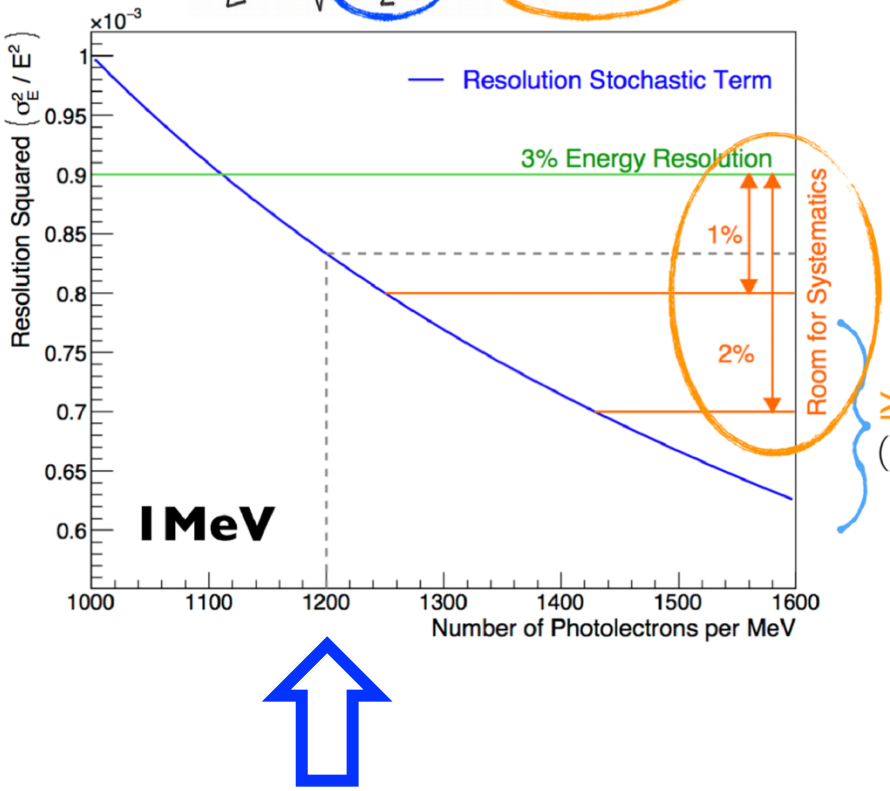
cnrs

SPARE

Challenging calorimetry systematic control

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

≤3% @ 1MeV



But not sufficient

≥2%
(previous experiments)

Lot of light is needed

- **20'' PMT photon range [10^{-1} - 10]**

Nonlinearity contributes to non-uniformity
→ deterioration of the energy resolution

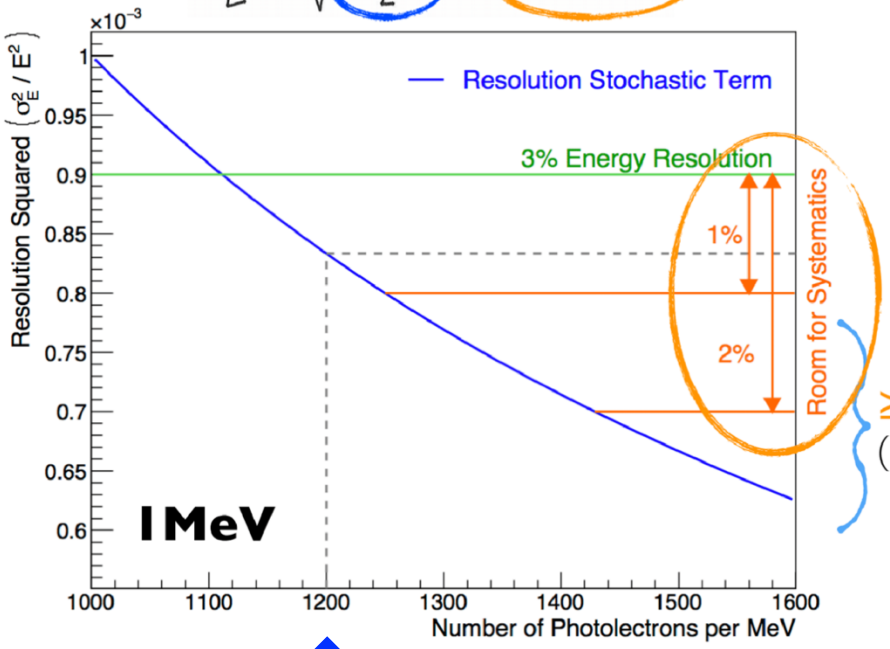
RISK of non-linearity mixing : LY & quenching, propagation, detection, reconstruction
RISK of converting a vertex difference in a charge mis-reconstruction

CHALLENGE: calibrate the nonlinear response to sub-percent level

Challenging calorimetry systematic control

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

≤3% @ 1MeV



But not sufficient

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Lot of light is needed

➢ **20'' PMT photon range [10^{-1} - 10]**

Nonlinearity contributes to non-uniformity

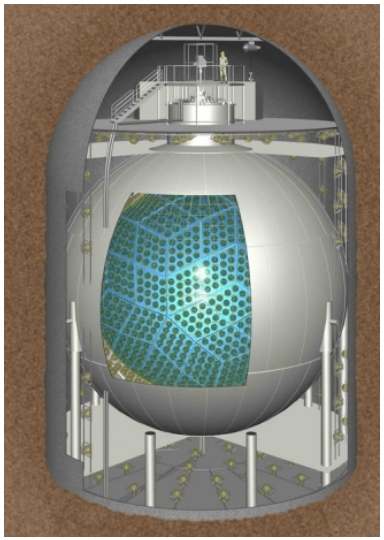
→ deterioration of the energy resolution

CHALLENGE: calibrate the non linear response to sub-percent level

SOLUTION:

- ✓ **Look at the same events with another dynamic range**
- ✓ **Interleave in JUNO another detector always in the SPE dynamic range**

JUNO photomultipliers



Kamland
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32%
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Borexino
300t
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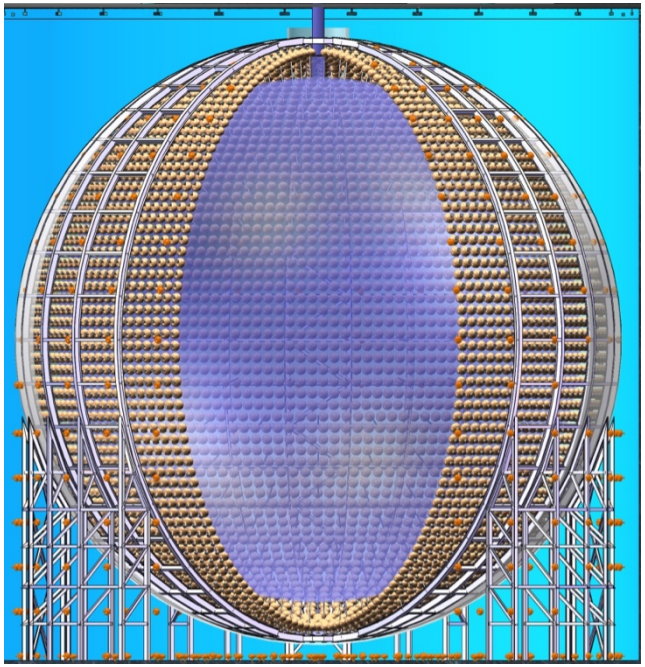
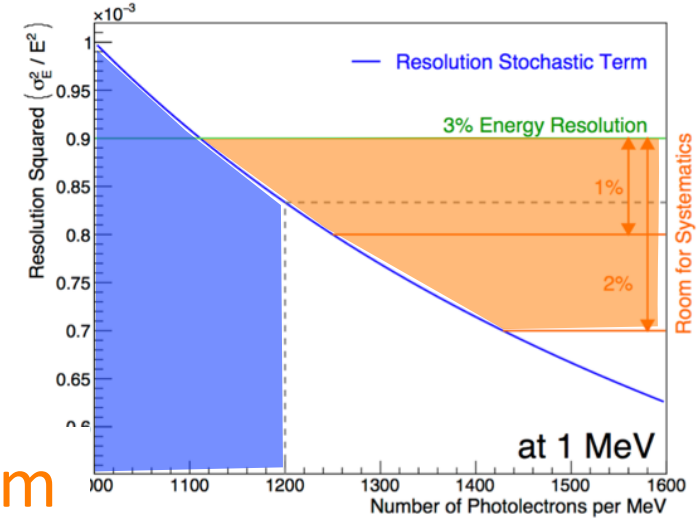


JUNO
20,000 t
➢ **18,000 x 20’’**
75% coverage
1200 PE/MeV
3% /√E
➢ **25,000 x 3’’**
35 PE/MeV
+3% coverage



The *misnamed* **Small PMT (SPMT)** system