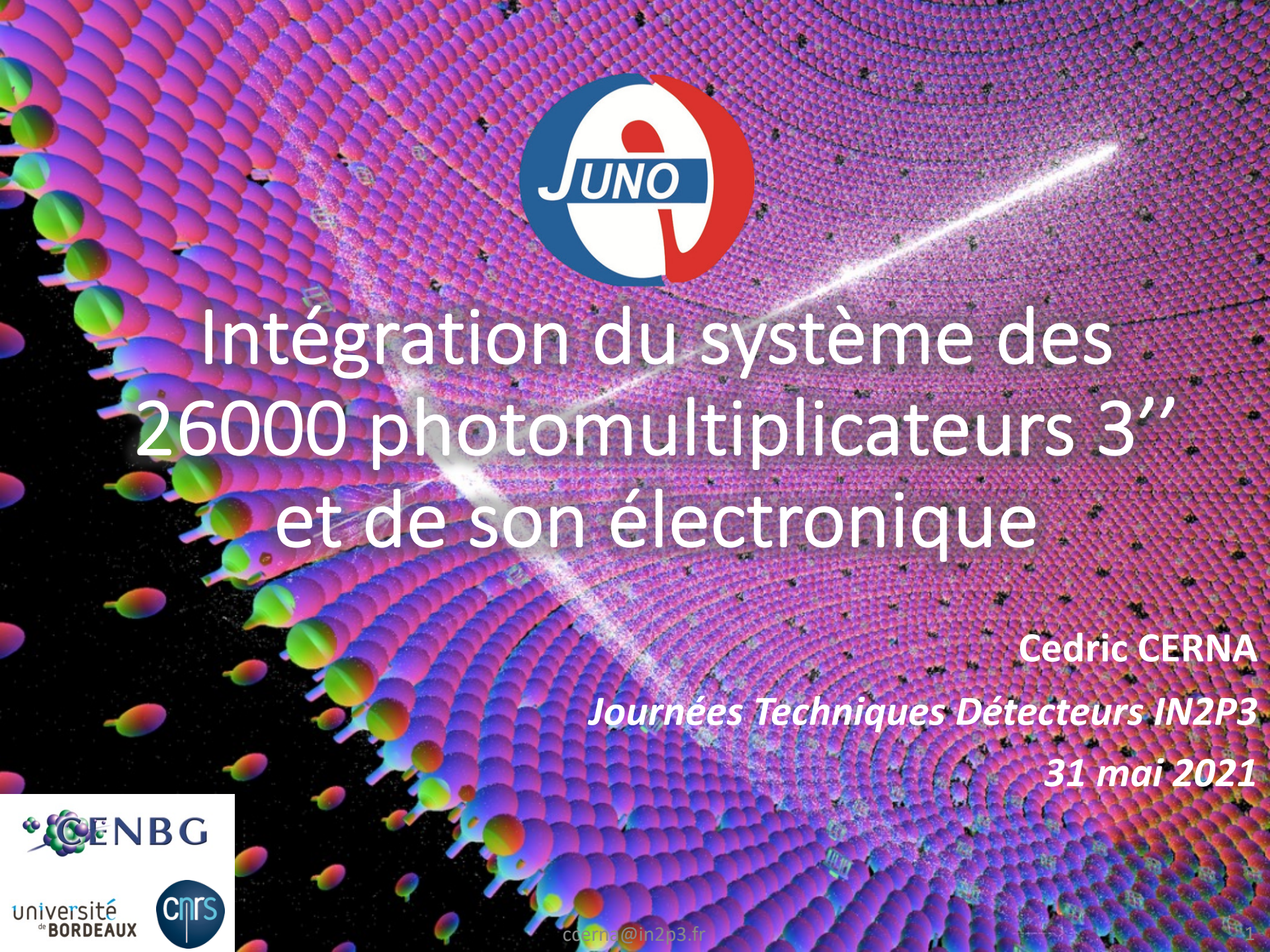


Intégration du système des 26000 photomultiplicateurs 3'' et de son électronique

Cedric CERNA

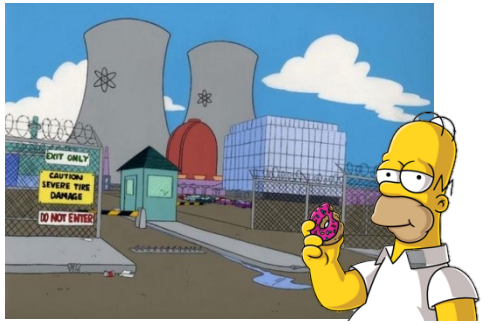
Journées Techniques Détecteurs IN2P3

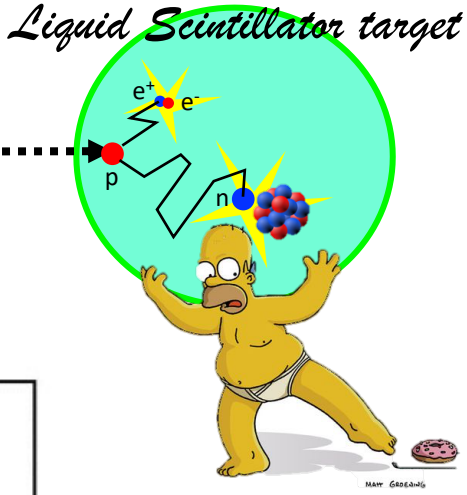
31 mai 2021

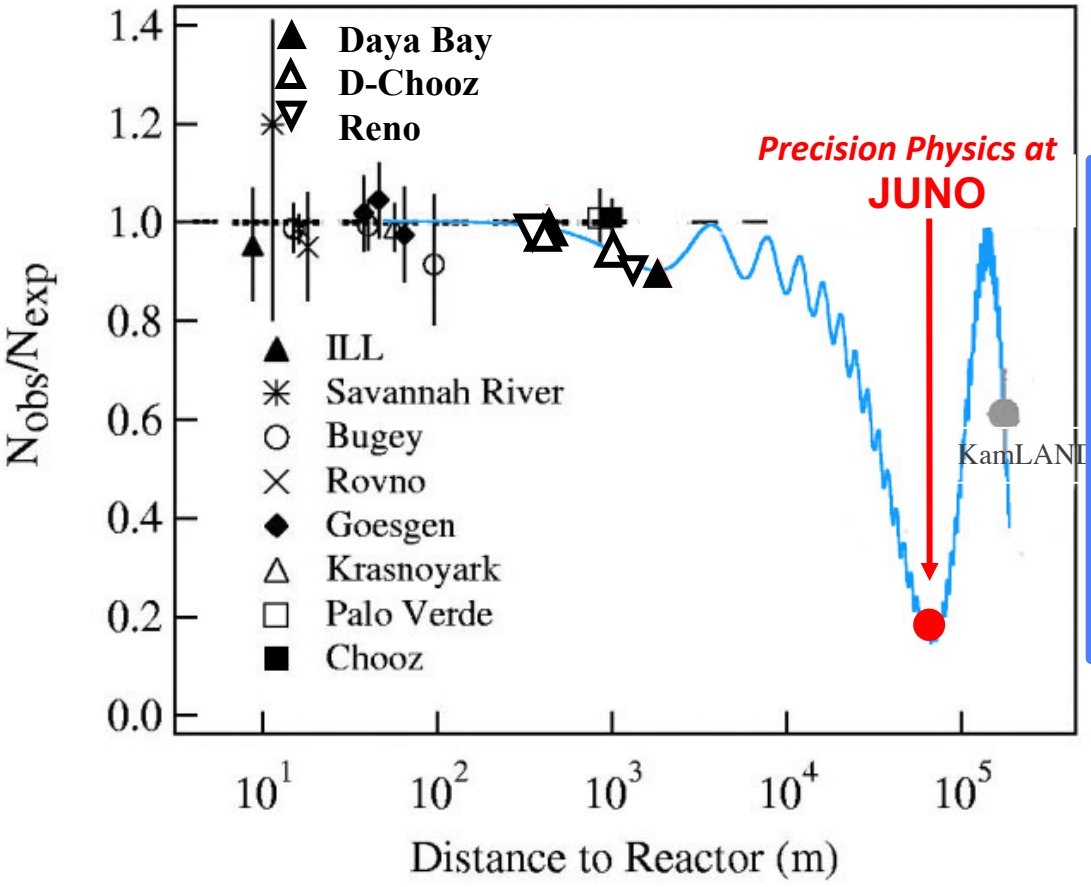
CENBG
université de BORDEAUX
cnrs

ccerna@in2p3.fr

L'expérience JUNO



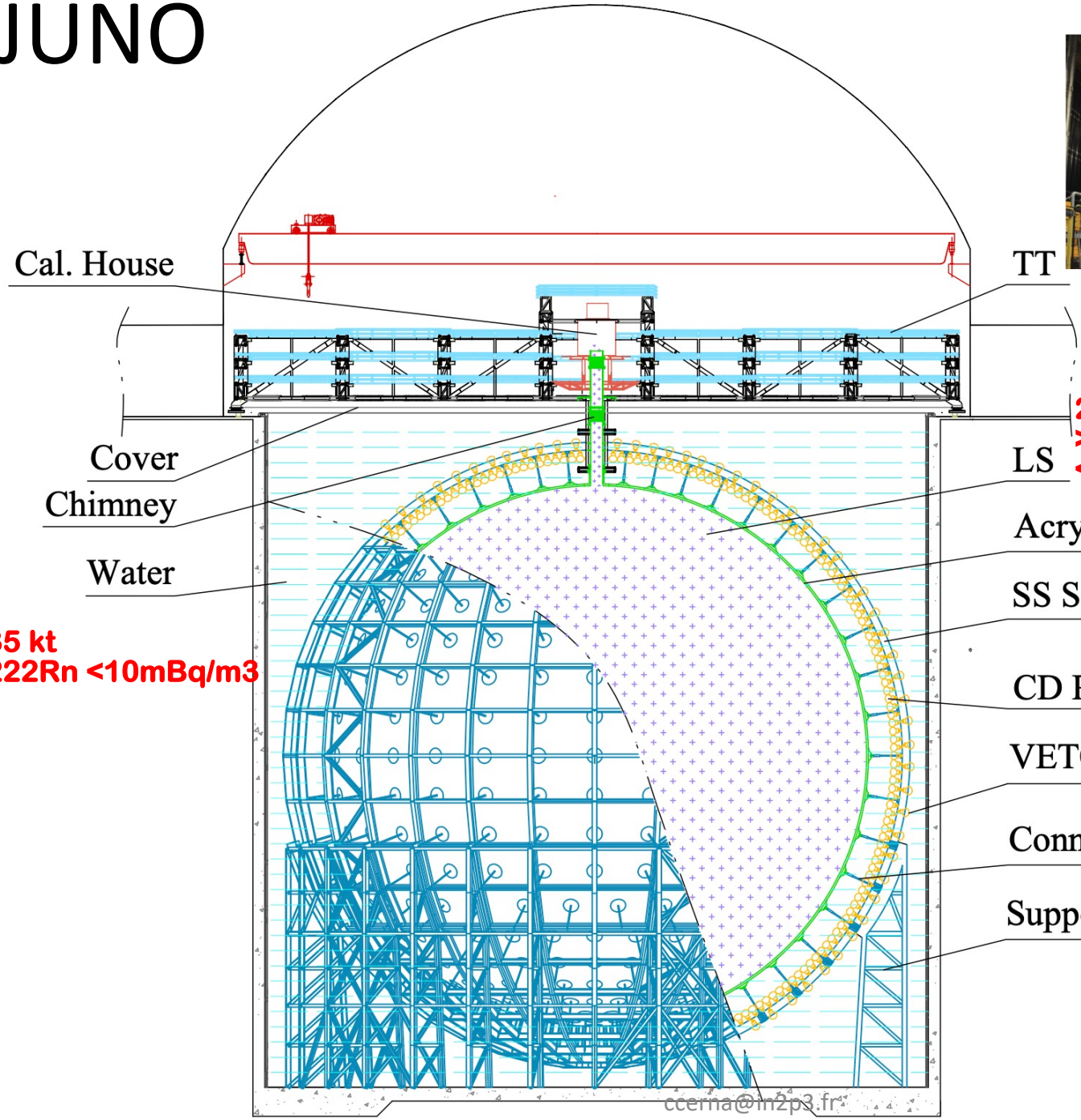




CHALLENGES INTRUMENTAUX

- Cible de scintillateur liquide énorme
- Collection de photons gigantesque
- Excellente Calibration
- Contrôle des bruits de fond
  - Cosmiques
  - Radiopureté

JUNO



20 kt
>20m attenuation length
<10^{-15} g/g U/Th

35.4 m.ø
>96% transp.
<0.5 ppt U/Th

35 kt
222Rn <10mBq/m3

18 000 PMT 20''
25 600 PMT 3''

2 000 PMT 20''

Le challenge instrumental de JUNO

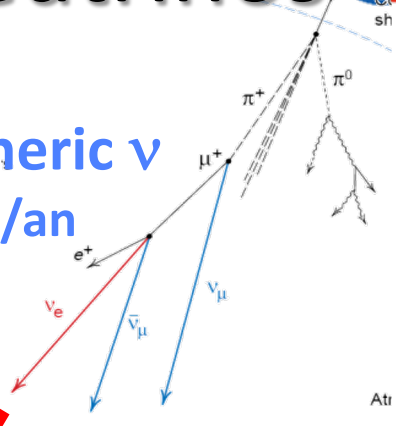
Energy Resolution	6% @ 1MeV	**3.02% @ 1MeV**
LS mass	~1 kt	**20 kt**
LS Attenuation/Diameter	15m / 16m	**>20m / 35m**
Photocathode Coverage	32%	**75%**
QE x CE	25% x 60%	**> 40% x 60%**
Photon collection	250 p.e./MeV	**1345 p.e./MeV**

Un observatoire à neutrinos

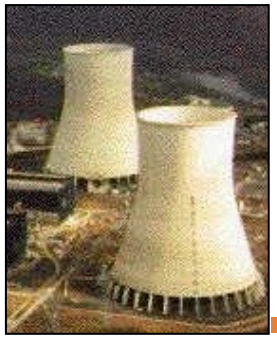
Supernova ν @10 kpc
~ 5k IBD + ~ 2k νp
10s

Solar ν
Centaines/an

Atmospheric ν
centaines /an



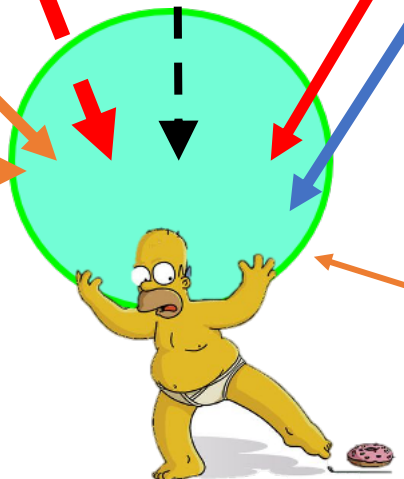
700 m
1800 m.w.e.

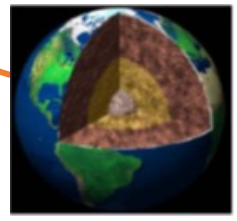


36 GW, 53 km

reactor ν ~ 60/jour

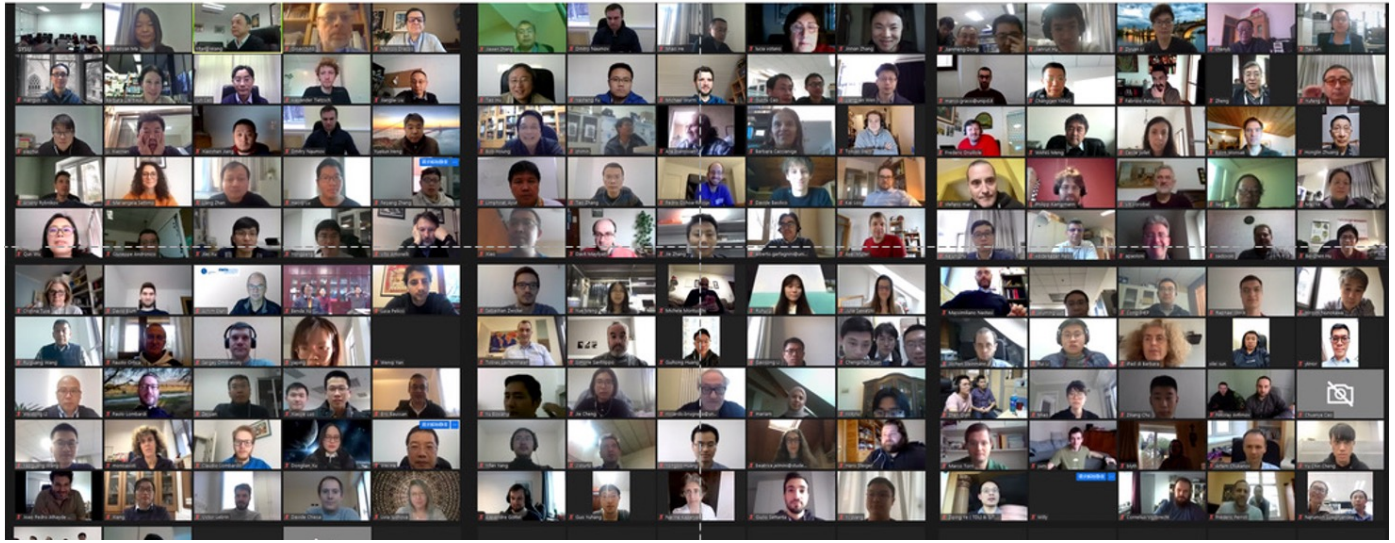
Cosmic muons
~ 300k/day





Geo-neutrinos
~ 400/an

JUNO Physics and Detector
JUNO Collaboration • Angel Abusleme (Chile U., Catolica) et al. (Apr 6, 2021)
e-Print: 2104.02565 [hep-ex]

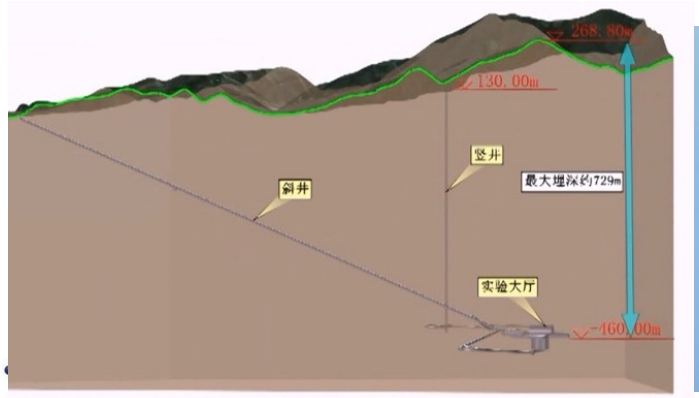


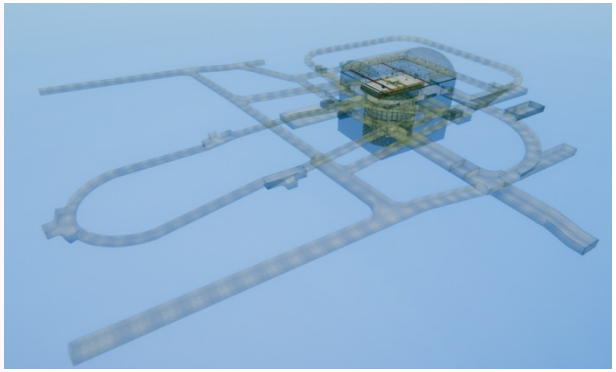
16 countries 77 institutions 618 members

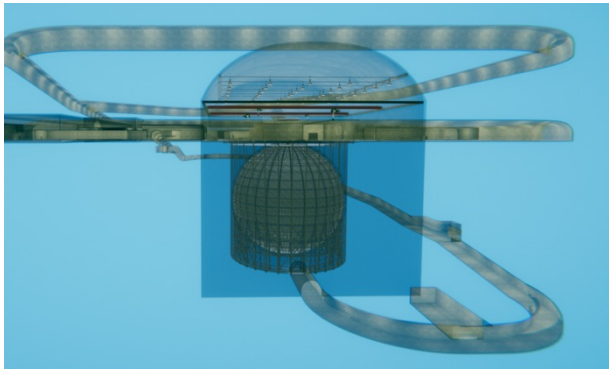
Armenia	Yerevan Physics Institute	China	IMP-CAS	Germany	U. Mainz
Belgium	Universite libre de Bruxelles	China	SYSU	Germany	U. Tuebingen
Brazil	PUC	China	Tsinghua U.	Italy	INFN Catania
Brazil	UEL	China	UCAS	Italy	INFN di Frascati
Chile	PCUC	China	USTC	Italy	INFN-Ferrara
Chile	UTFSM	China	U. of South China	Italy	INFN-Milano
China	BISEE	China	Wu Yi U.	Italy	INFN-Milano Bicocca
China	Beijing Normal U.	China	Wuhan U.	Italy	INFN-Padova
China	CAGS	China	Xi'an JT U.	Italy	INFN-Perugia
China	ChongQing University	China	Xiamen University	Italy	INFN-Roma 3
China	CIAE	China	Zhengzhou U.	Latvia	IECS
China	DGUT	China	NUDT	Pakistan	PINSTECH (PAEC)
China	ECUST	China	CUG-Beijing	Russia	INR Moscow
China	Guangxi U.	China	ECUT-Nanchang City	Russia	JINR
China	Harbin Institute of Technology	Czech	Charles U.	Russia	MSU
China	IHEP	Finland	University of Jyvaskyla	Slovakia	FMPICU
China	Jilin U.	France	LAL Orsay	Taiwan-China	National Chiao-Tung U.
China	Jinan U.	France	CENBG Bordeaux	Taiwan-China	National Taiwan U.
China	Nanjing U.	France	CPPM Marseille	Taiwan-China	National United U.
China	Nankai U.	France	IPHC Strasbourg	Thailand	NARIT
China	NCEPU	France	Subatech Nantes	Thailand	PPRLCU
China	Pekin U.	Germany	FZJ-ZEA	Thailand	SUT
China	Shandong U.	Germany	RWTH Aachen U.	USA	UMD1
China	Shanghai JT U.	Germany	TUM	USA	UMD2
China	IGG-Beijing	Germany	U. Hamburg	USA	UC Irvine
China	IGG-Wuhan	Germany	FZJ-IKP		

Le laboratoire JUNO en surface

Le laboratoire JUNO souterrain







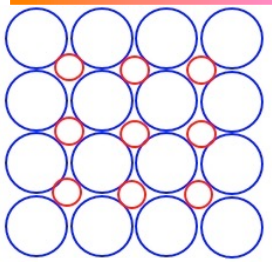
La plateforme d'installation

Production des photomultiplicateurs 20’’

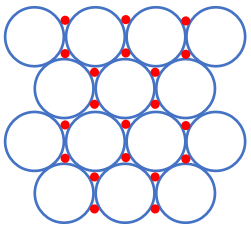
Pré-assemblage de l’acrylique

2 systèmes de détection entrelacés

2012 | 2014 | 2016 | 2018 | 2021



20’’+8’’



20’’+3’’

Approuvé dans JUNO

Début des productions

Livraison pour intégration

- Très peu de temps de développement pour s’insérer dans un design déjà existant

JUNO photomultiplicateurs

Small PMT (SPMT)

- **Contrôler/désintriquer les systématiques**
- **Soutien au programme de physique**

Large PMT system
- **18 000 x 20''**

75% de couverture
>1345 PE/MeV → 3% /√E

20'' NNVT	20'' Hamamatsu
13 000	5 000
TTS 5.1ns	TTS 1.2ns

Small PMT system
- **25,600 PMTs 3''**

40 PE/MeV

+3% de couverture MAIS en mode Photo-Electron Unique SPE

+11% de photocathode à bon timing

3'' HZC
25,600
TTS 1.5ns

Design

- easy to produce
- easy to integrate
- easy to install

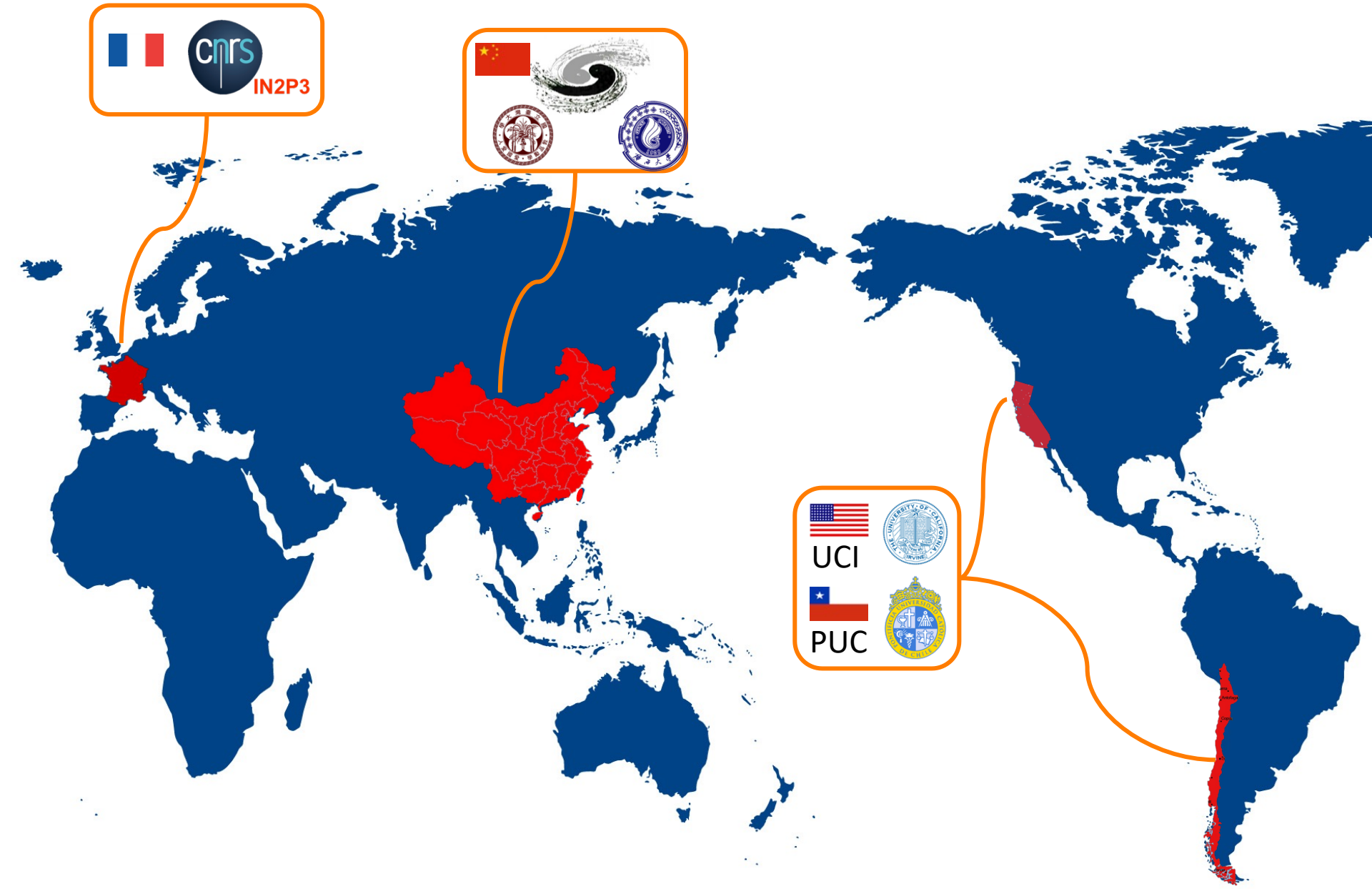
Industrie

26,000 channels

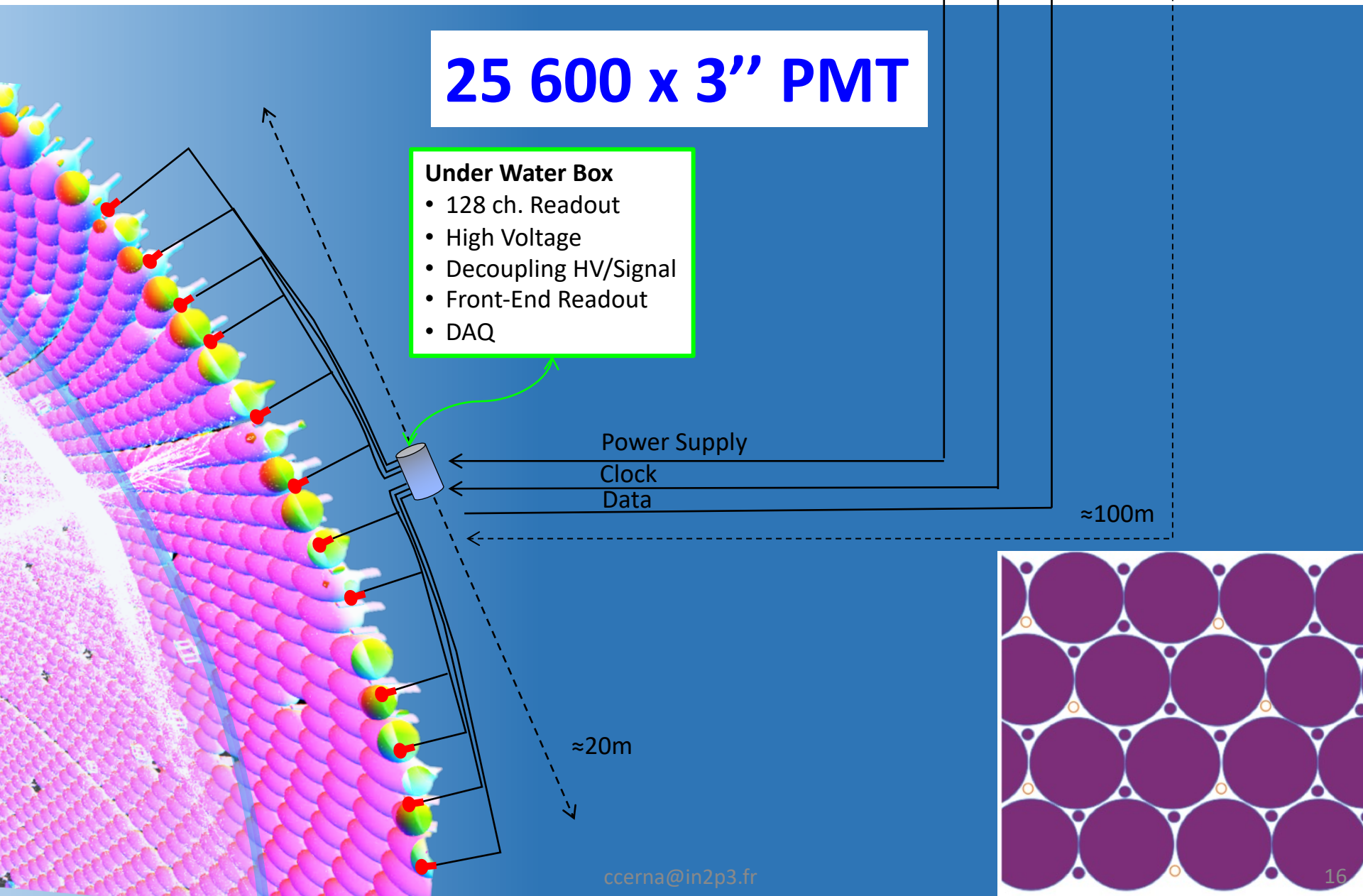
- Photomultipliers
- Readout electronics
- Cabling

Consortium/Experience

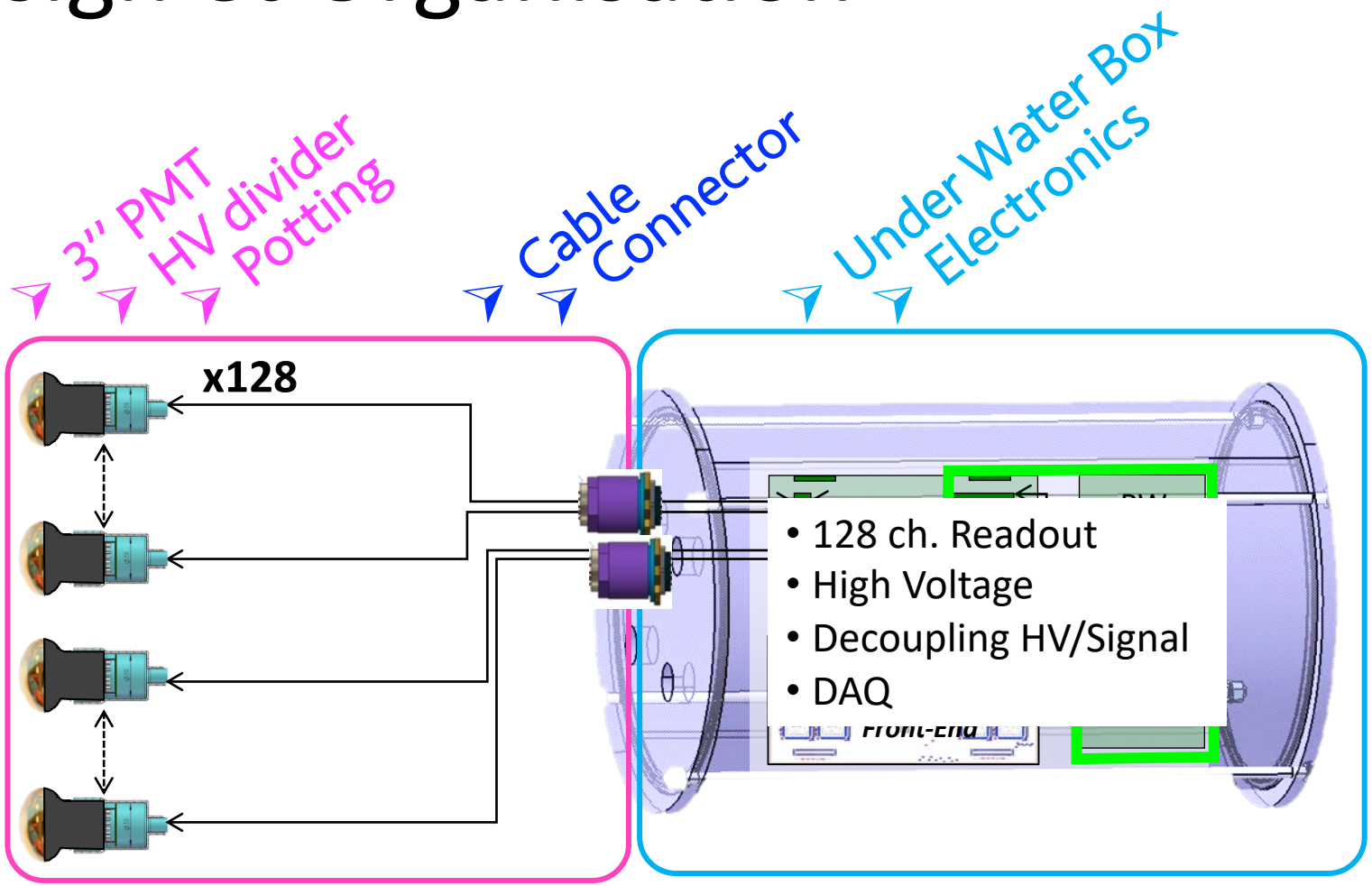
SPMT un système qui ne dort jamais



SPMT : Choix de Design

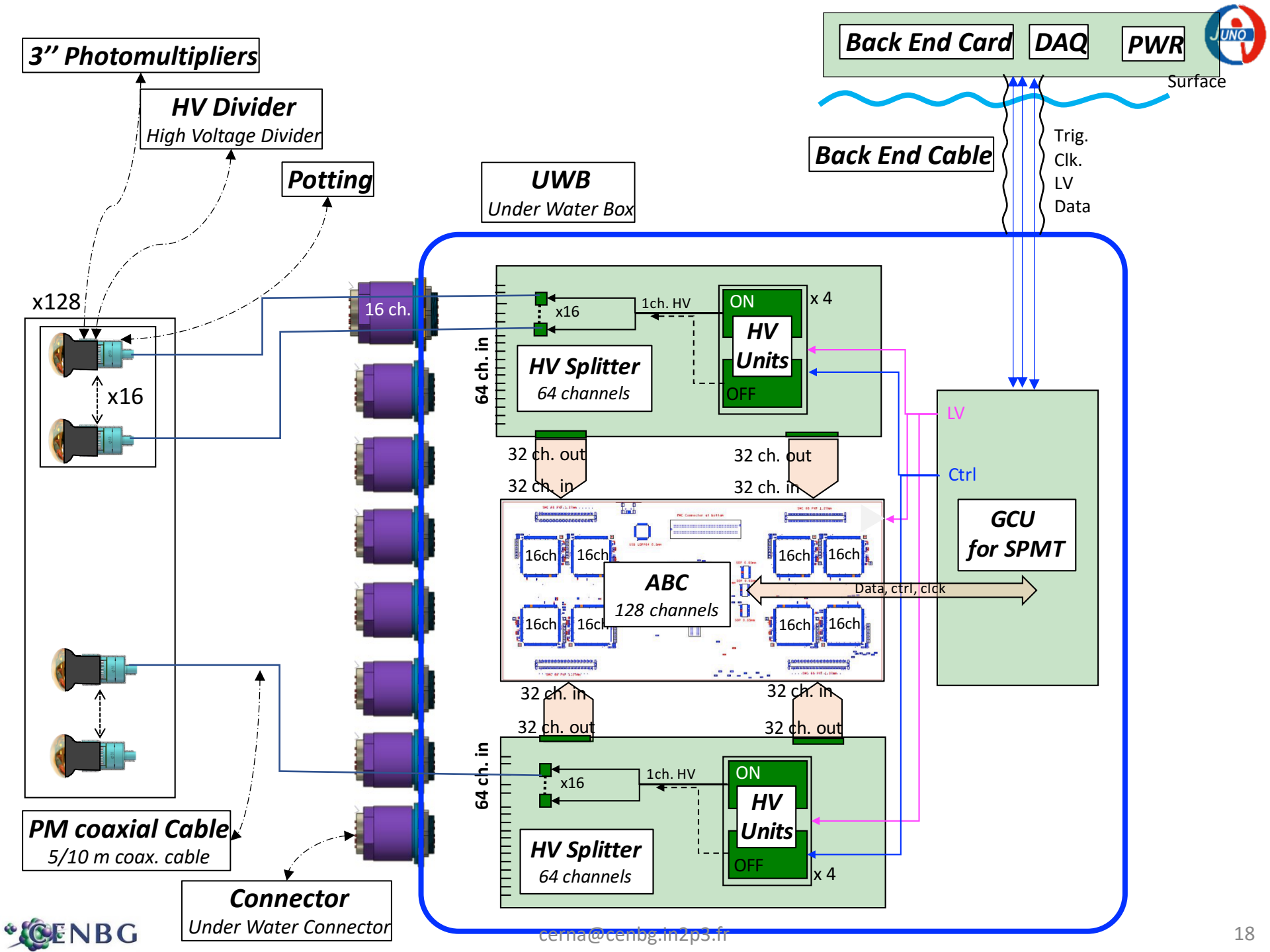


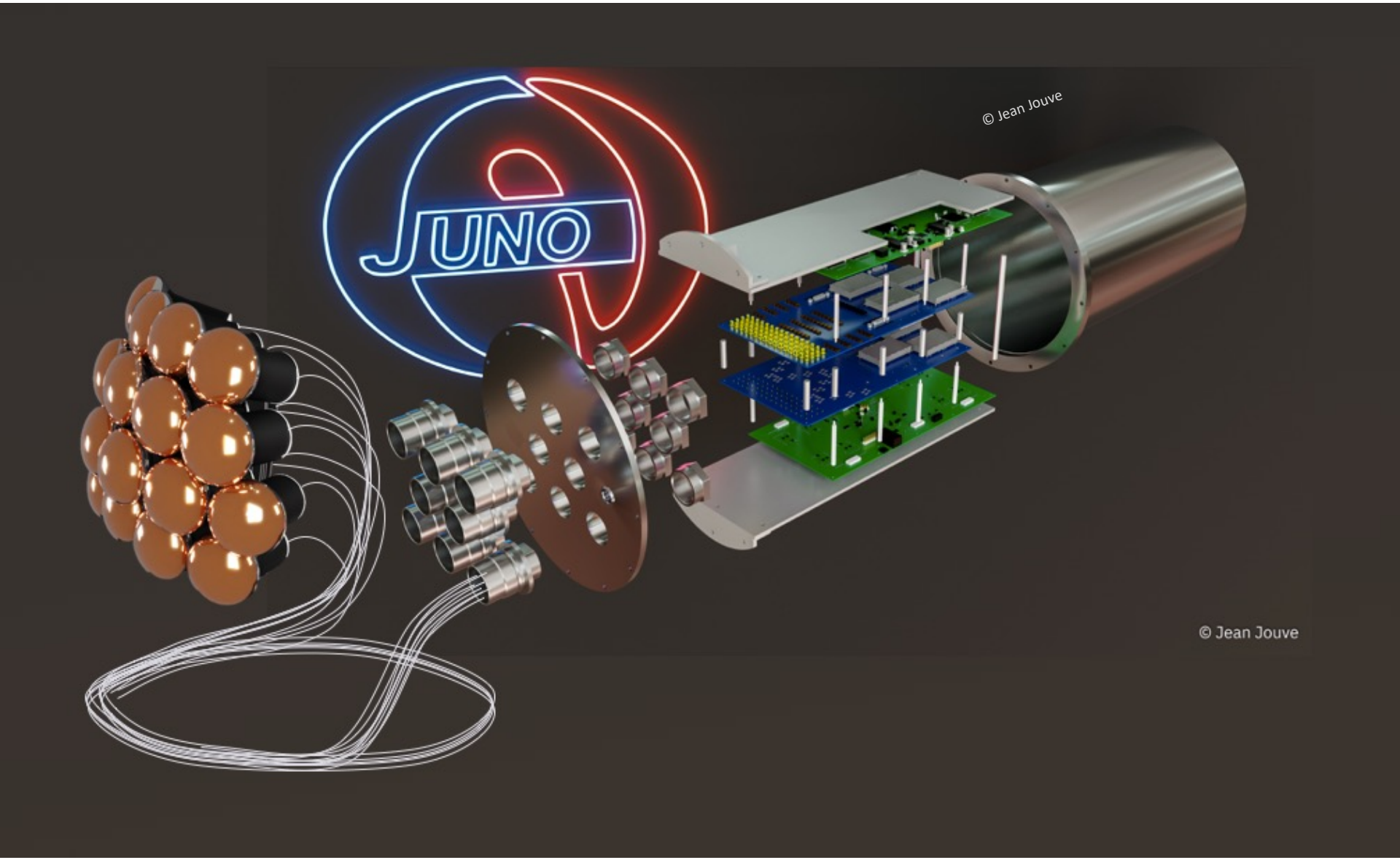
Design et Organisation



x 200 = 25,600 channels

PMT instrumentation et UWB + Electronique sont conçus et produits en décallage temporal, testés séparéments puis installés ensemble sur JUNO


3'' Photomultipliers
HV Divider
High Voltage Divider
Potting
x128
x16
PM coaxial Cable
5/10 m coax. cable
Connector
Under Water Connector
UWB
Under Water Box
16 ch.
64 ch. in
x16
1ch. HV
ON
HV Units
OFF
x 4
HV Splitter
64 channels
32 ch. out
32 ch. in
16ch
ABC
128 channels
Back End Card
DAQ
PWR
Surface
Back End Cable
Trig.
Clk.
LV
Data
LV
Ctrl
GCU
for SPMT
Data, ctrl, clck

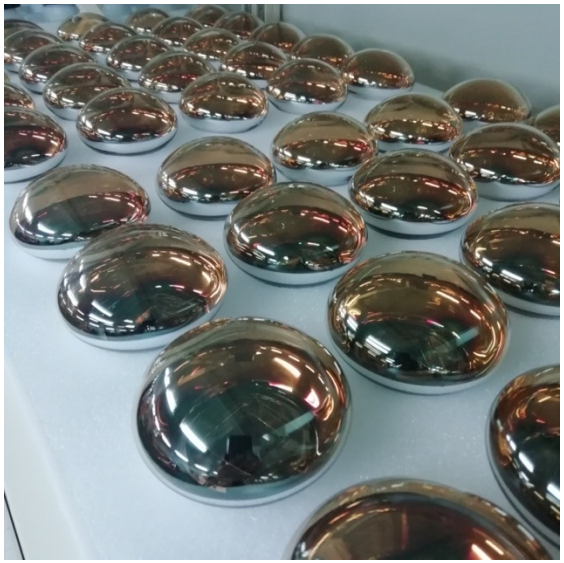

JUNO
© Jean Jouve
© Jean Jouve

Chapitre 1
Les Grands Problème d'abord

- 26 000 Photomultiplicateurs 3''
- 26 000 voies de lecture électronique

3’’ photomultiplicateurs

2017	Contrat → **XP72B22**
Janvier 2018	Production kickoff → 1 000 PMT/mois
Janvier 2020	**26 000 photomultiplicateurs produits**



Parameters	HZC XP72B22 Performance
Photon detection efficiency@420 nm	24%
TTS (FWHM) of single photoelectron	<5 ns
P/V ratio of single photoelectron	3
Single photoelectron resolution	35%
Dark rate @ 0.25 p.e.	1,000 Hz
Quantum efficiency non-uniformity	<11% in Φ60 mm
Pre/after pulse charge ratio	<5%/<15%
Nonlinearity	<10%@1-100 p.e.
Radioactivity	^{238}U<400 ppb, ^{232}Th<400 ppb, ^{40}K<200 ppb

Caractérisation et vérification

26000 photomultiplicateurs, un problème industriel

- **Fait à HZC sous supervision de JUNO**
- 100% testé chez le fabricant → 10% vérifié aléatoirement par JUNO
- 100% recette par JUNO (acceptance)

Mass production and characterization of 3-inch PMTs for the JUNO experiment

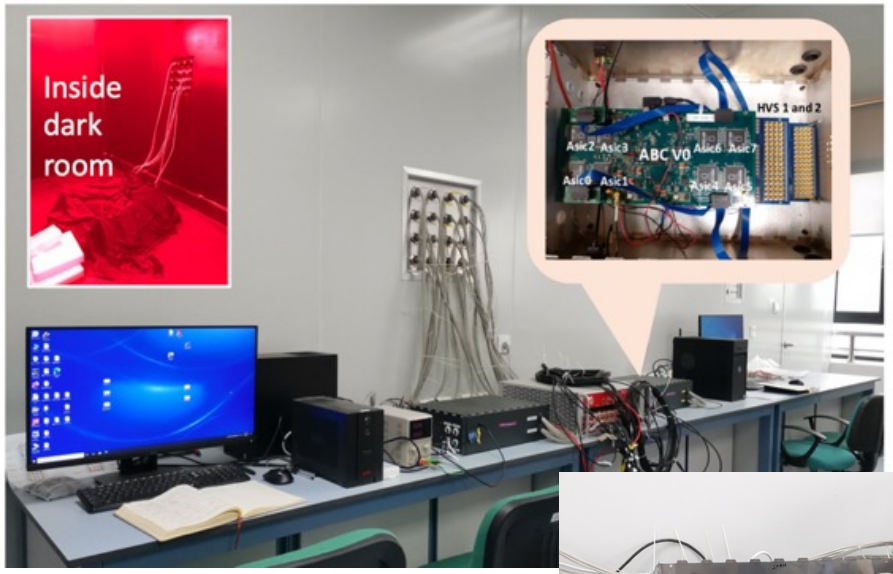
Chuanya Cao[1], Jilei Xu[*1], Miao He[11], Angel Abusleme[2], Mathieu Bongrand[3], Clément Bordereau[4,5], Anatael Cabrera[6], Agustin Campeny[2], Cédric Cerna[4], Haoqiang Chen[7], Po-An Chen[5], Gérard Claverie[4], Selma Conforti Di Lorenzo[8], Christophe De La Taille[8], Frédéric Druillole[4], Amélie Fournier[4], Xiaofei Gu[7], Michael Haacke[2], Yang Han[14], Patrick Hellmuth[4], Yuekun Heng[1], Rafael Herrera[2], Yee Hsiung[5], Bei-Zhen Hu[5], Yongbo Huang[9], Cédric Huss[4], Ignacio Jeria[2], Xiaoping Jing[1], Cécile Jollet[4], Victor Lebrin[3], Frédéric Lefèvre[3], Hongwei Li[10], Nan Li[1], Hongbang Liu[9], Xiwen Liu[9], Bayarto Lubsandorzhiev[11], Anselmo Meregaglia[4], Diana Navas-Nicolas[6], Juan Pedro Ochoa-Ricoux[12,2], Frédéric Perrot[4], Rebin Karaparambil Rajan[3], Abdel Rebii[4], Bo[illegible] Roskovec[12], Cayetano Santos[14], Mariangela Settimo[3], Giancarlo [illegible], Guill[illegible]an Royen[3], Benoit Viaud[3], Pablo Walker[2], Chung-Hsiang Wang[13], Z[illegible] Wang[1], Yu Wu[1], Hangkun Xu[1], Meihang Xu[1], Chengfeng Yang[9], Jie [illegible], Frédéric [illegible][3], and Xuantong Zhang[1]

[1]*Institute [illegible]*
[2]*Pontificia [illegible] de Santiago, Chile*
[3]*SUBATECH, [illegible] CNRS-IN2P3, Nantes, France*
[4]*Univ. Bordeaux, CNRS, [illegible], F-33170 Gradignan, France*
[5]*Department [illegible] Taiwan University, Taipei*
[6]*Laboratoire des [illegible]ne Joliot-Curie, Paris, France*
[7]*School of Physics [illegible] Zhengzhou University, Zhengzhou, China*
[8]*OMI[illegible] Ecole [illegible]nique-CNRS/IN2P3, Paris, France*
[9]*[illegible] University, Nanning, China*
[10]*Hai[illegible] Zhanchi Photonics Technology Co., Ltd, Chengmai, China*
[11]*Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, Russia*
[12]*Department of Physics and Astronomy, University of California, Irvine, California, USA*
[13]*National United University, Miao-Li*
[14]*Astro-Particle Physics Laboratory, CNRS/CEA/Paris7/Observatoire de Paris, Paris, France*

2020-11-26

Published in Nucl.Instrum.Meth.A 1005 (2021) 165347

Gaungxi Acceptance testing system

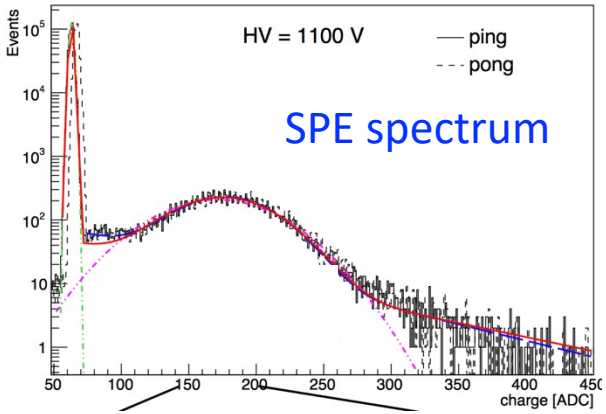


Bancs de test électronique @in2p3

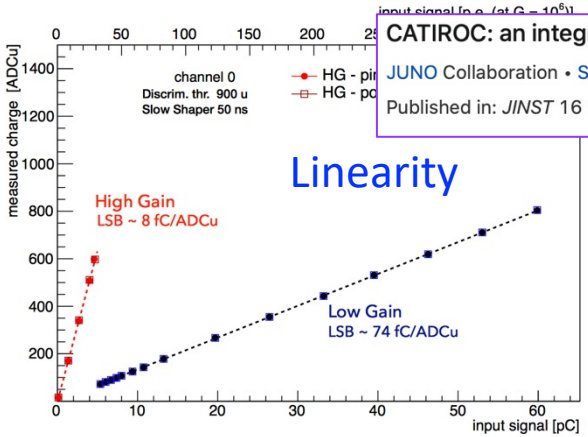
Readout: L'ASIC CATIROC

En mode Single Photo-electron on a seulement besoin de mesurer la charge et le temps

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

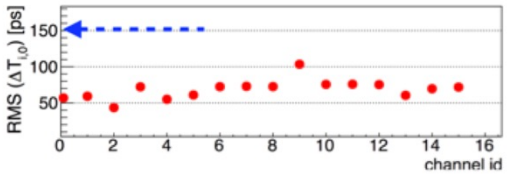


SPE spectrum



Linearity

Time resolution <200 ps



CATIROC: an integrated chip for neutrino experiments using photomultiplier tubes

JUNO Collaboration • Selma Conforti (Ec. Polytech., OMEGA) et al. (Nov 27, 2020)

Published in: *JINST* 16 (2021) 05, P05010 • e-Print: 2012.01565 [physics.ins-det]

CATIROC: an integrated chip for neutrino experiments using photomultiplier tubes

Selma Conforti[a,*] Mariangela Settimo[b,*] Cayetano Santos[c] Clément Bordereau[d] Anatael Cabrera[e,f] Stéphane Callier[a] Cédric Cerna[d] Christophe De La Taille[a] Frédéric Druillole[d] Frédéric Dulucq[a] Victor Lebrin[b] Frédéric Lefèvre[b] Gisèle Martin-Chassard[a] Frédéric Perrot[d] Abdel Rebii[d] Louis-Marie Rigalleau[b] Nathalie Seguin-Moreau[a]
on behalf of JUNO collaboration

[a] *OMEGA, Ecole Polytechnique-CNRS/IN2P3, Paris, France*
[b] *SUBATECH, IMT Atlantique, Université de Nantes, CNRS-IN2P3, Nantes, France*
[c] *Astro-Particle Physics Laboratory, CNRS/CEA/Paris7/Observatoire de Paris, Paris, France*
[d] *Univ. Bordeaux, CNRS, CENBG, UMR 5797, F-33170 Gradignan, France*
[e] *IJCLab, Université Paris-Saclay, CNRS/IN2P3, 91405 Orsay, France*
[f] *LNCA Underground Laboratory, IN2P3/CNRS - CEA, Chooz, France*

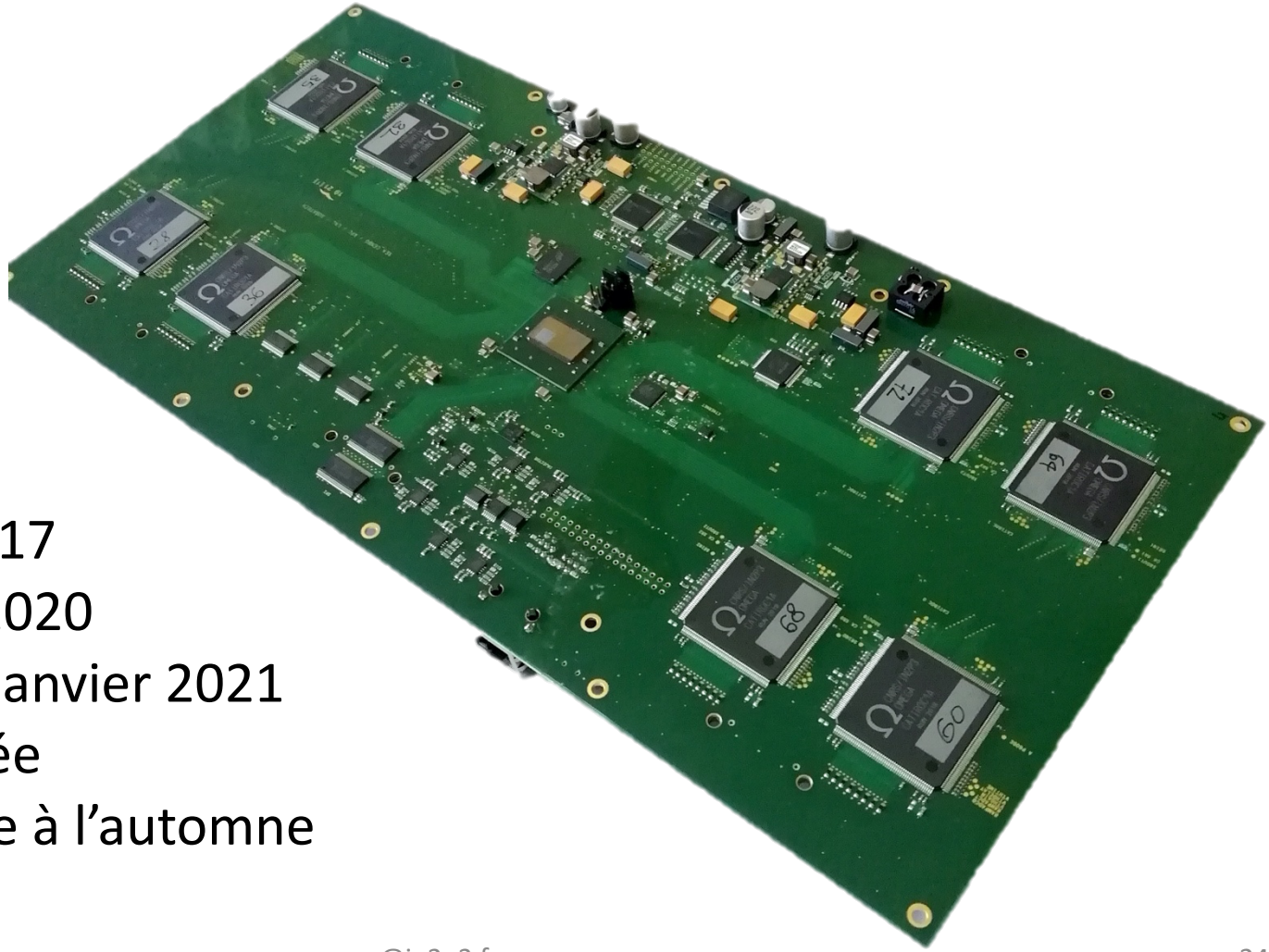
E-mail: conforti@omega.in2p3.fr, settimo@subatech.in2p3.fr

Abstract: An ASIC (Application Specific Integrated Chip) named CATIROC (Charge And Time Integrated Read Out Chip) has been developed for the next-generation neutrino experiments using a large number of photomultiplier tubes (PMTs). Each CATIROC provides the time and the charge measurements for 16 configurable input channels operating in auto-trigger mode. Originally designed for the light emission in water Cherenkov detectors, we show in this paper that its use can be extended to liquid-scintillator based experiments. The ~ 26000 3-inch PMTs of the JUNO experiment, under construction in China, is a case in point. This paper describes the features of CATIROC with a special attention to the most critical points for its application to the time profile of the light emission in liquid scintillators. The achieved performances in both charge and time measurements can be inputs for future high-precision experiments making use of PMTs or other photo-sensitive detectors.

La carte de lecture front-end ABC

- Le livrable français sur SPMT

- 8 ASICs CATIROC = 8*16= 128 channels
- FPGA K7
- DDR3 1GB
- FirmWare IPBUS



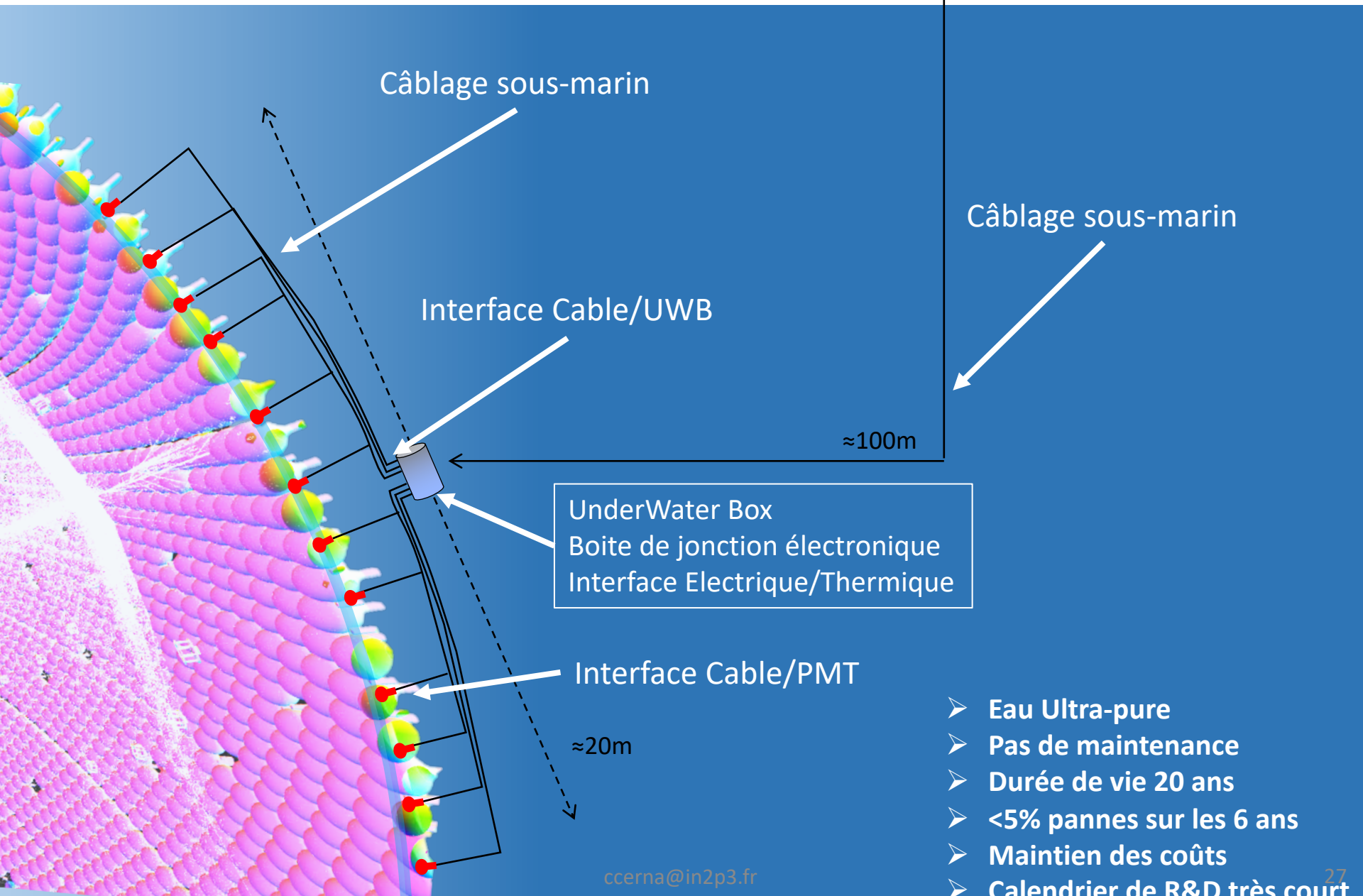
- 1er prototype 2017
- 3ème Prototype 2020
- Pré-production Janvier 2021
- Production lancée
- Livrable en Chine à l'automne

Le système électronique SPMT

Chapitre 2
Tous les autres problèmes qui peuvent faire échouer ce projet

- Interfaces
- Câblage
- Fiabilité

SPMT – Design

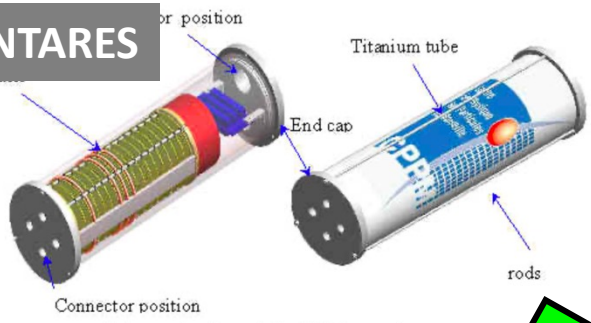


- **Eau Ultra-pure**
- **Pas de maintenance**
- **Durée de vie 20 ans**
- **<5% pannes sur les 6 ans**
- **Maintien des coûts**
- **Calendrier de R&D très court**

L'Under-Water Box

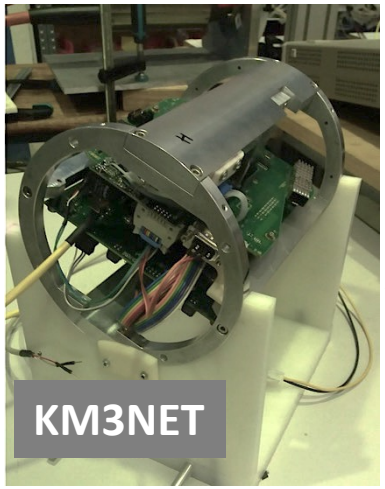
- Interface électronique
  - Interface électrique
  - Interface Mécanique
  - Interface Thermique

ANTARES



Schematic view of the LCM container


JUNO-SPMT
1er Proto @CENBG
2017


KM3NET

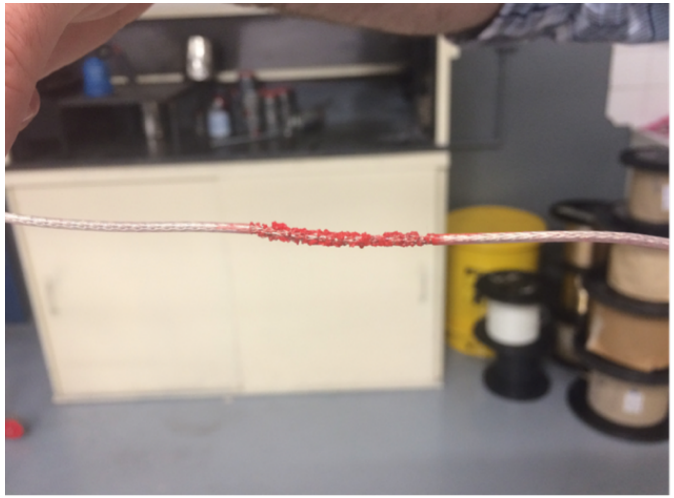

JUNO-SPMT
Maquette electrique/Thermique
IHEP 2021


JUNO-SPMT
Pre-production @Shanghai
2021

Cable RF sous-marin

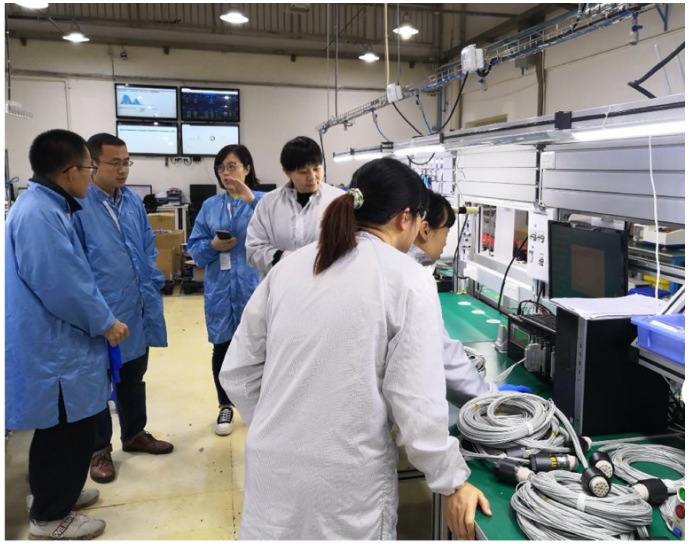
Axon Custom RG178

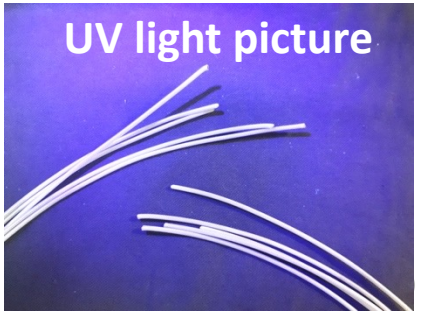
- Jacket HDPE 2.1mm diam.
- Anti-water blocking system
- 50 Ohms / RF
- Attenuation 1.6 dB/m @ 1GHz
  - → 11% de perte de charge sur un SPE
- 1600 VDC garantie
- 200 km de câble produit pour JUNO SPMT



R&D Axon France et CENBG

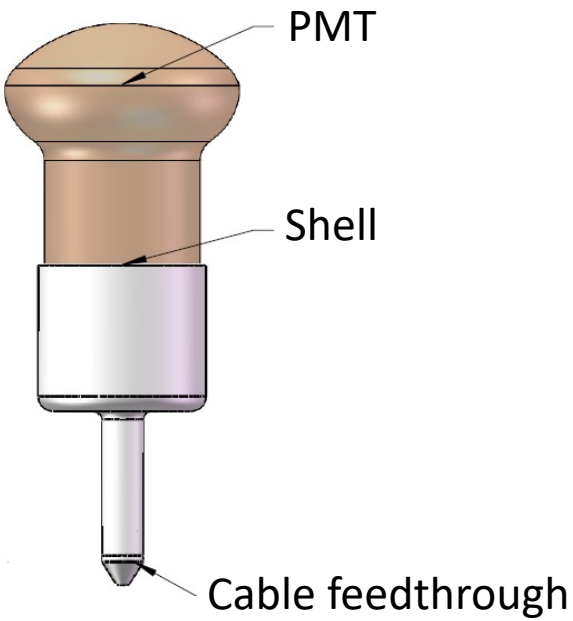
Production Axon China et IHEP

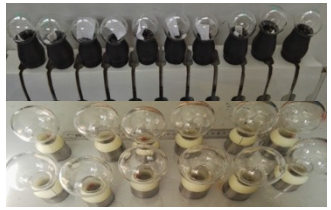


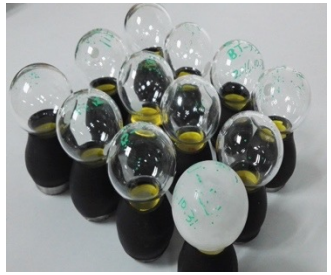


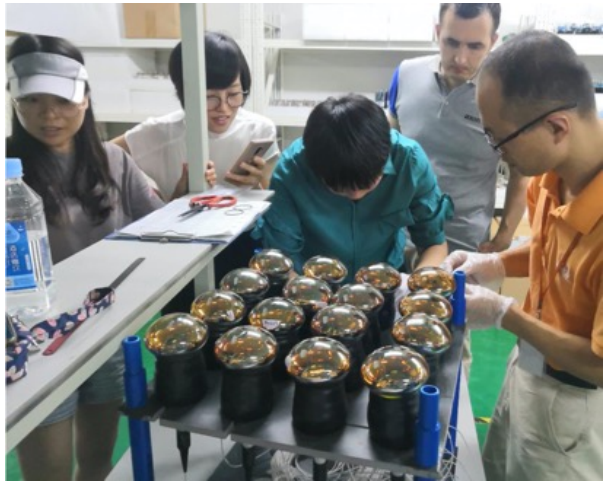
Interface Photomultiplicateur/Câble

Développement IHEP









- **Double sealing design**
  - outer layer: Butyl tape
    low pressure injection
  - Inner layer: potting sealant

- **sealants:**
  -Base sealing: polyurethane
  -Cable sealing: epoxy;

- **shell:**
  - ABS material: high strength, compatible, well adhesive, easy injection, cheap;
  - integrated structure;
  - injection molding process;

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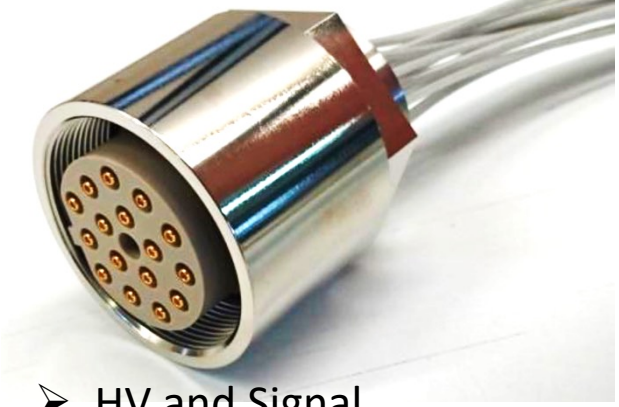
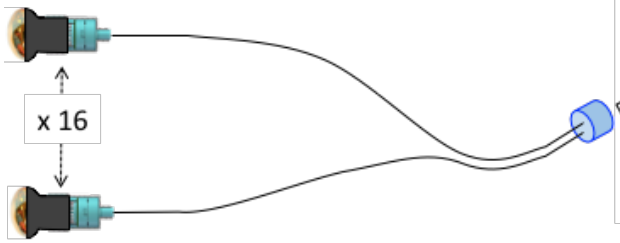
Interface Câble – Boite sous-marine

Connector axon'



- HV and Signal
- Under Pure Water
- Connecteur PE surmoulé sur le câble
- 16 channels
- 1600 VDC



- **R&D Axon France + CENBG**
- **Production Axon China + IHEP**
  - **1650 paires de connecteurs**

Tests de vieillissement accéléré @CENBG

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SPMT dans JUNO

Un système complexe

Très peu de temps de développement pour s'insérer dans un design déjà existant

- **Un consortium « agile »**
- **Un design initial très orienté par l'intégration**
- **Un appuis industriel très fort**
- **Beaucoup d'expérience académique**