Journée du LabEx P2IO 2022

30 November 2022 to 1 December 2022
Institut Pascal

BSM-Nu

Neutrinos: a door to physics Beyond the Standard Model (2020 – 2024)

Sara Bolognesi – CEA / IRFU / DPhP
Andrea Giuliani – CNRS / IJCLab / A2C

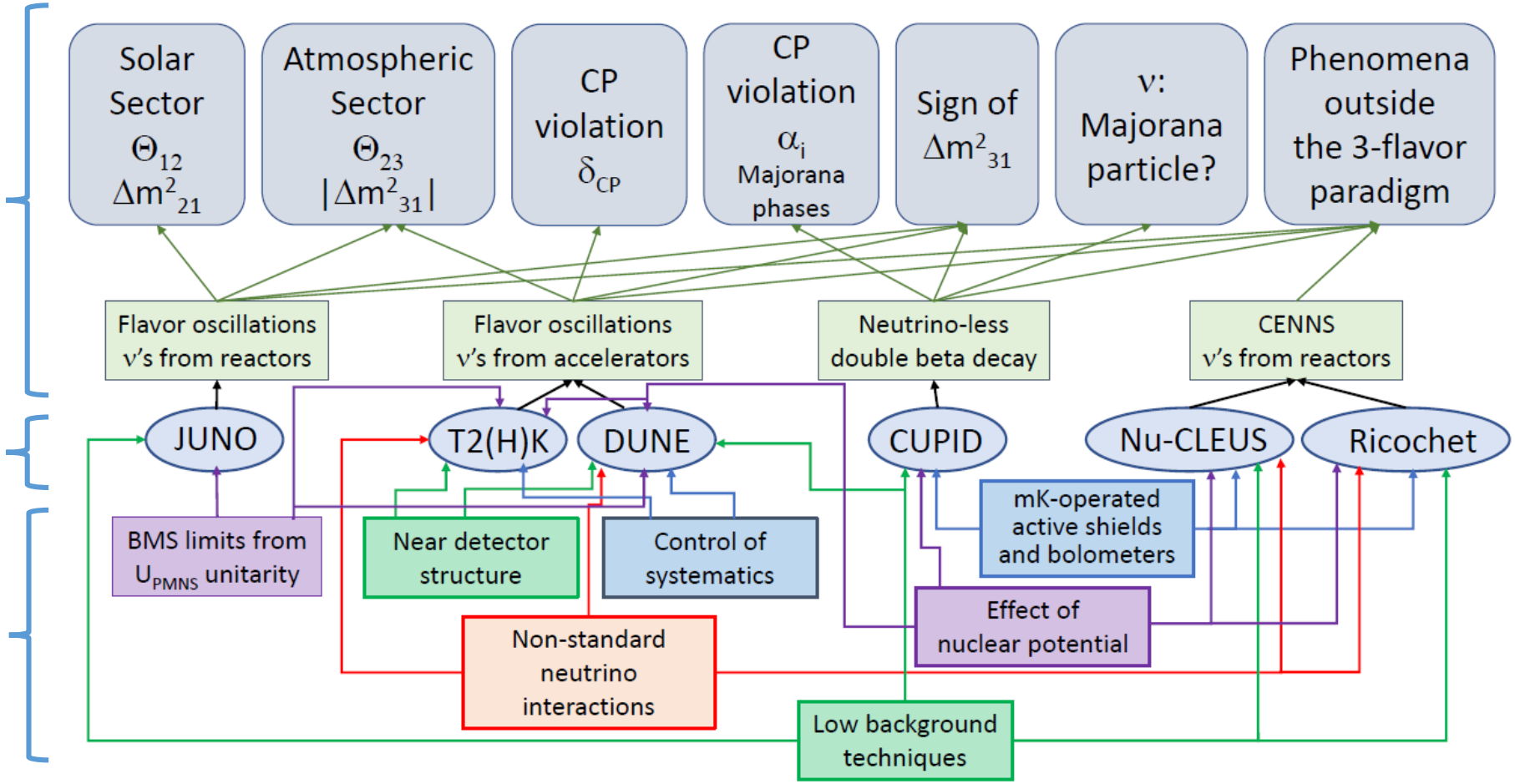
BSM-Nu in a nutshell

Involved laboratories: **CEA IRFU (DPhP, DPhN, DEDIP, DIS); CEA IPhT; IJCLab: (A2C, HEP); LLR**

Physics cases

Experiments

Common topics



BSM-Nu in a nutshell

Work package structure

WP 2

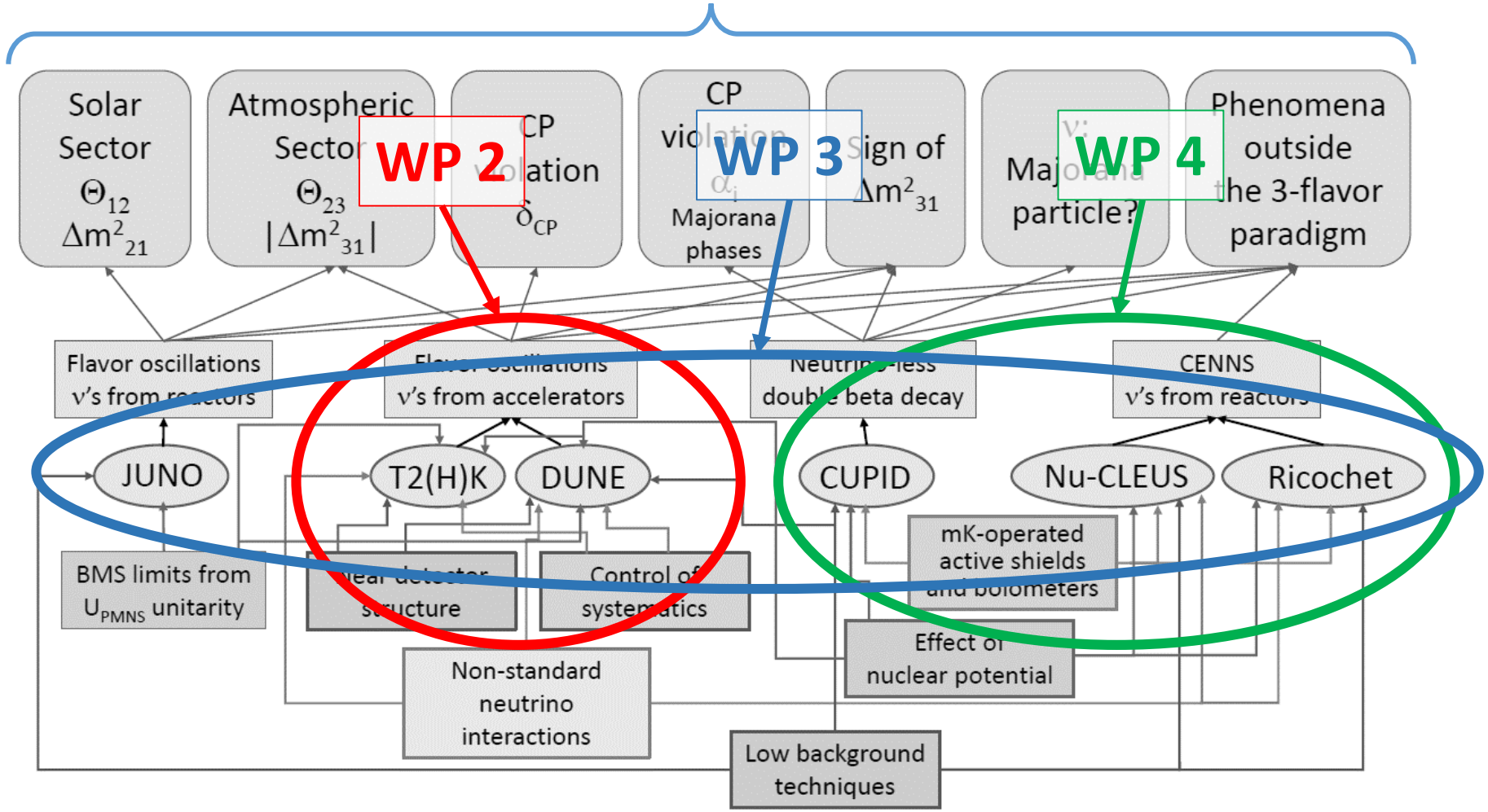
Neutrino-nucleus scattering and near-detector design for long baseline experiments

WP 3

Combination of experiments

WP4

Low-background bolometers for CEνNS and 0νββ



General objectives of BSM-Nu

Main objective → **federate all the actors of neutrino physics inside the P2IO perimeter**
→ Most effective coping with challenges of:

① **Physics** – comprehensive view of neutrino physics beyond sectorial views dominated by Standard Model assumptions

② **Precision** – control of **systematic uncertainties** by combining their measurements from different experiments and discussing together analysis strategies

③ **Detector advancement** – mutualizing R&D to **improve devices** and **develop new concepts** with a view to points ① and ②

④ **Critical mass** – **team building** inside the P2IO neutrino community

- Enlargement of the neutrino physics community
- Education of a new generation of physicists with a comprehensive view of the neutrino field

WP-specific objectives

WP2

- Develop nuclear physics models of **exclusive final states** of **neutrino-nucleus interactions**
- Develop a **new optimized analysis framework** for oscillation analysis using the new capabilities of next generation of **near detectors**
- Develop and characterize **innovative resistive Micromegas technology** for TPCs

WP3

- Sensitivity studies on **JUNO in combination with other experiments** for **PMNS unitarity** and **mass hierarchy**

→ impact on **0νββ phase space**

- Sensitivity studies on **Non-Standard-Interactions (NSI)** using LBL → impact on **CEvNS phase space**
- ~~Specific WP on NSI~~ ← **budget cut at the start of the project**

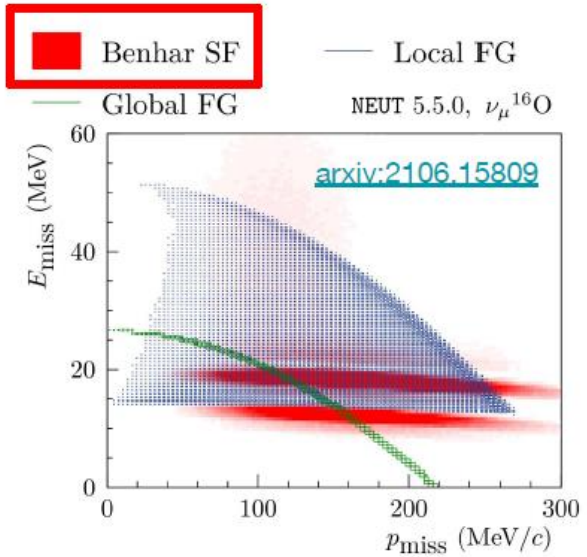
WP4

- Final analysis of the **CUPID-Mo 0νββ experiment**
- ~~Protocol for enriched $Li_2{}^{100}MoO_4$ crystal production~~ ← war against Ukraine
- Low-threshold prototypes based on **superconductive transition edge sensors** (TES)
- **Innovative bolometers for CEvNS and 0νββ** with a view to active background control
- Develop **vetos** operated at **millikelvin temperatures** for the mitigation of the external γ background

WP2 – Results

Main challenge: to cope with the **Precision Era** in neutrino oscillation experiments
→ Uncertainties on neutrino interactions must be reduced

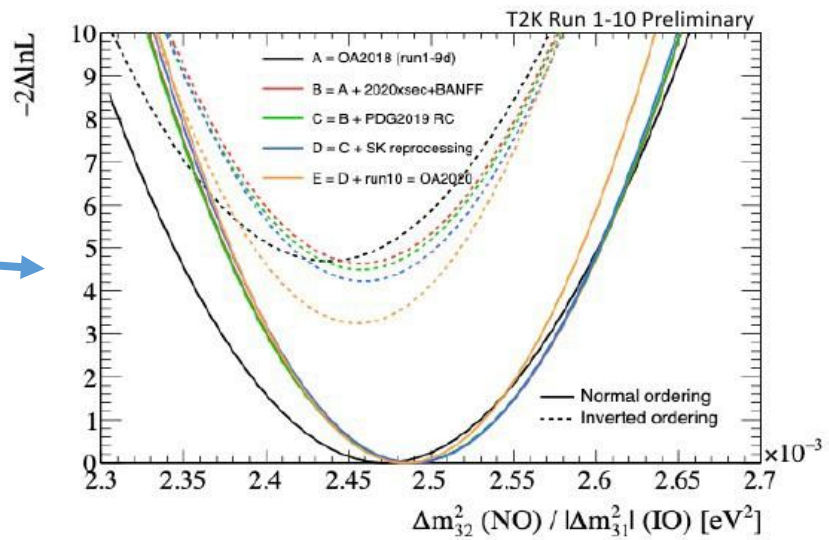
- More sophisticated detectors → upgraded ND280 – T2K (reconstruction of low-momentum protons and neutrons)
- More sophisticated models



Improvement in **nuclear models** with **increased predictivity for exclusive final state**: moving from relativistic Fermi Gas to Spectral Function
→ Full set of new uncertainties for Spectral Function tuned to neutrino cross-section measurements worldwide

Leading role of BSM-Nu PhD Jafar Chakrani [LLR]

Implementation of the **new model in T2K analysis**
→ 30% improved precision of Δm_{32}^2 measurement



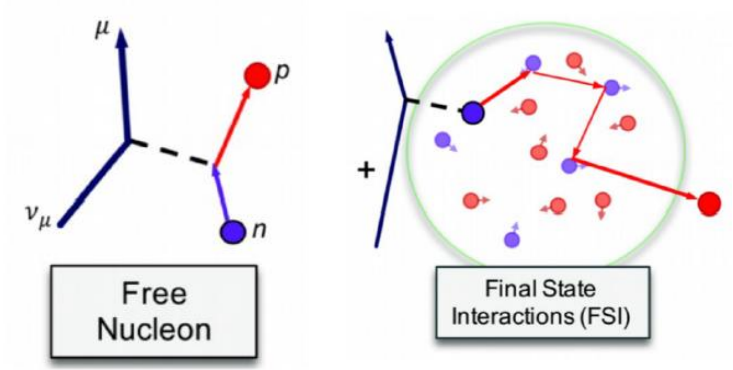
Detailed evaluation of the **sensitivity of the new generation of near detectors** with the new model

PoS NuFact2021 (2022) 235
Phys.Rev.D 105 (2022) 3, 032010

WP2 – Results

Improvement of nuclear model for **final state re-interactions of protons and neutrons with nucleus**
→ Introducing a much more sophisticated treatment (INCL code from IRFU/DPhN) into neutrino simulations

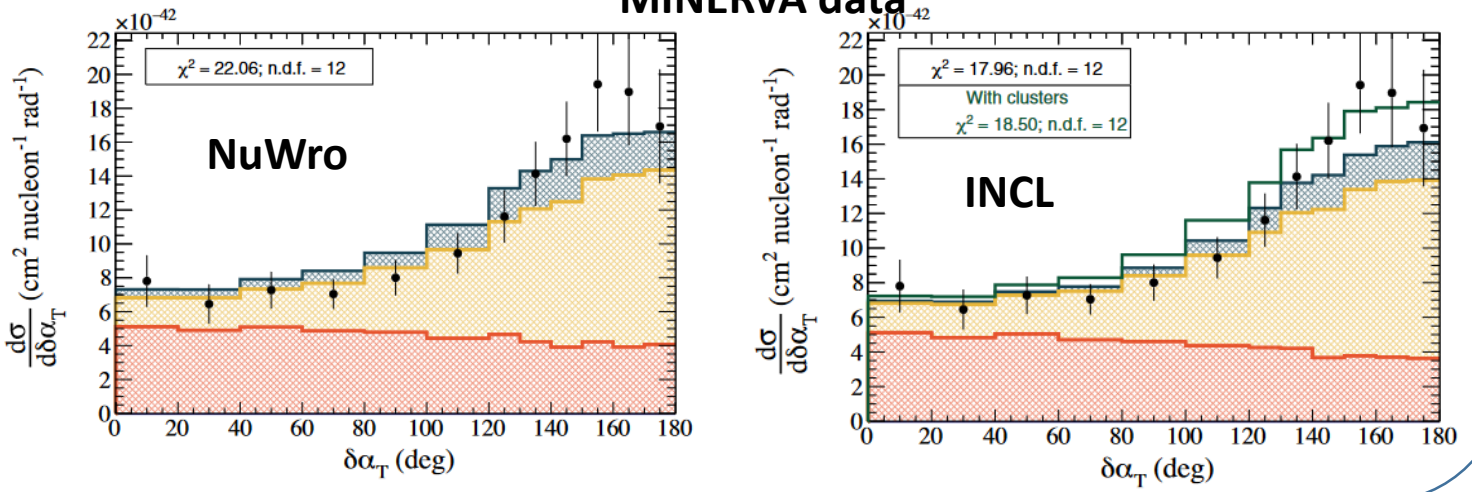
↳ production of nuclear clusters (d,α) in the final state



Leading role of BSM-Nu
PhD Anna Ershova [CEA/DPhP]

Phys.Rev.D 106 (2022) 3, 032009

MINERvA data



New framework for analysis of **exclusive final states at the near detector** for the oscillation analysis: **GUNDAM**
→ Now became the standard framework at T2K and being ported to DUNE and HK

DPhP → LLR

GUNDAM – *Generic fitter for Upgraded Near Detector Analysis Methods*

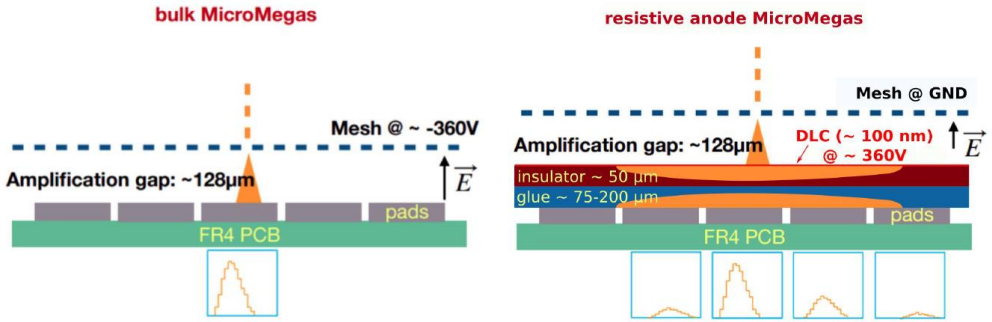
New fitter under validation on T2K OA data

Sensitivity studies done using the new SF systematics parameterisation, T2K present MC + ND280Up MC

WP2 – Results

Prototypes of **resistive Micromegas** with cosmics and in 3 test beams

→ first complete characterization of resistive effects with data



Leading role of BSM-Nu
Postdoc David Henaff [CEA/DPhP]
PhD Anna Ershova [CEA/DPhP]

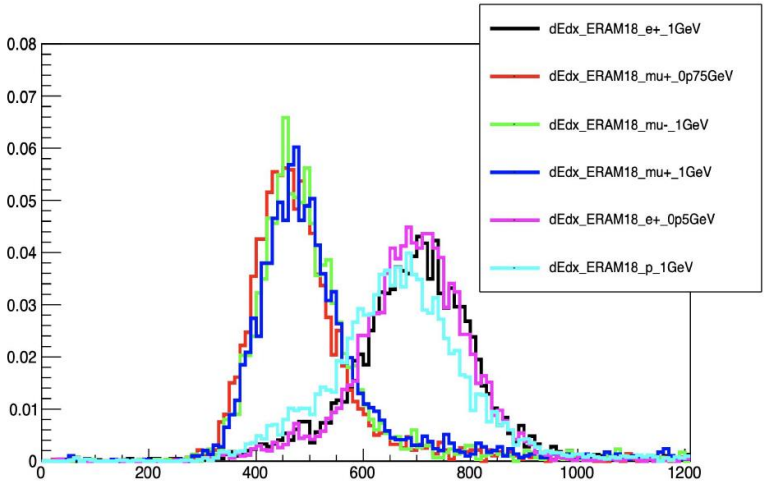
Resistive layer → better space resolution with lower number of pads

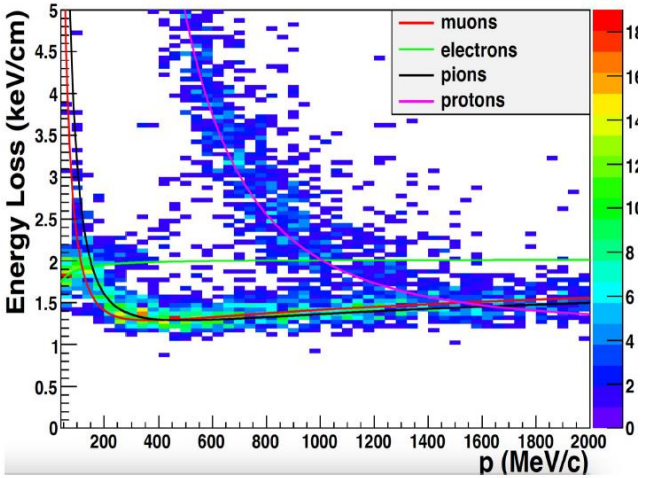
Nucl.Instrum.Meth.A 1025 (2022) 166109

Further **characterization with dedicated X-rays test bench** and development of **complete simulation of resistive effects**

Several test beams at CERN – dE/dX resolution within ND280 upgrade requirements

Space resolution better than previous technology by a factor 2-3

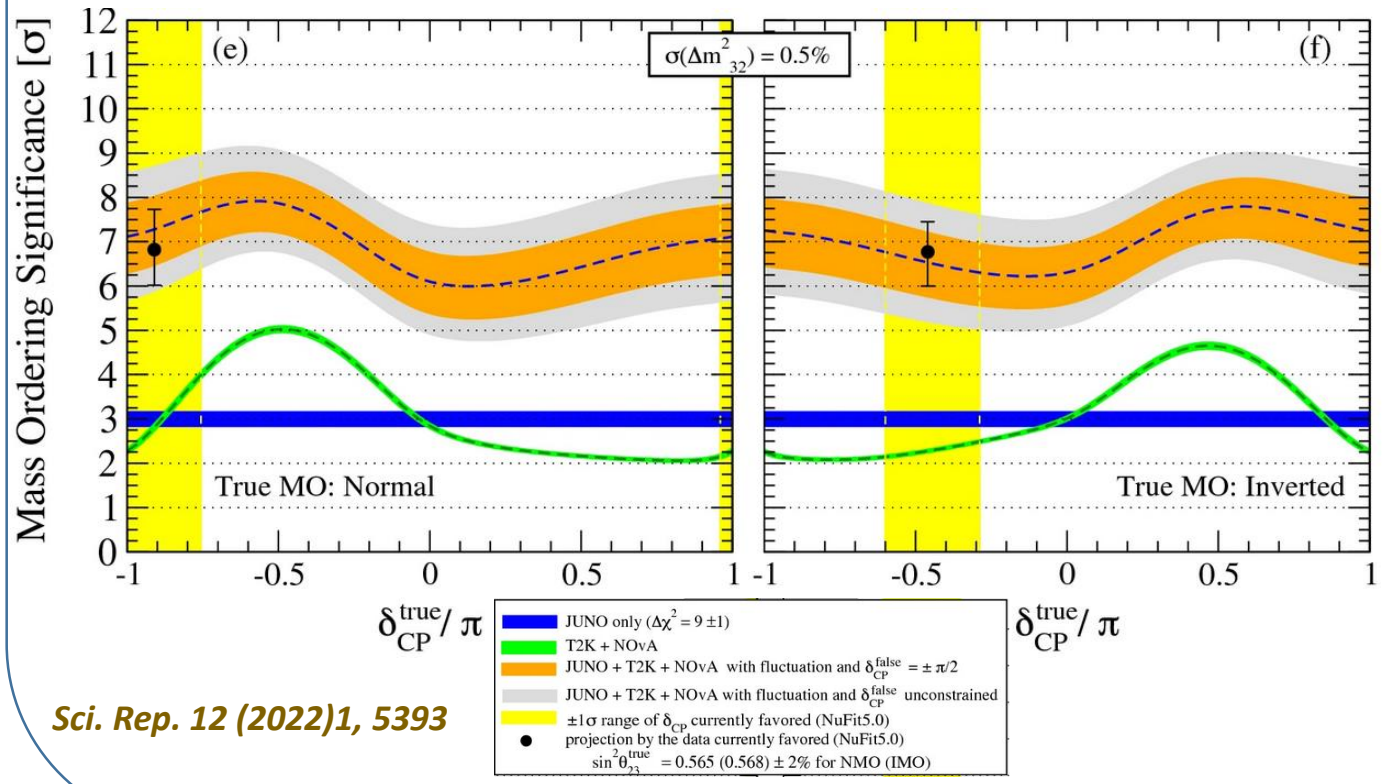




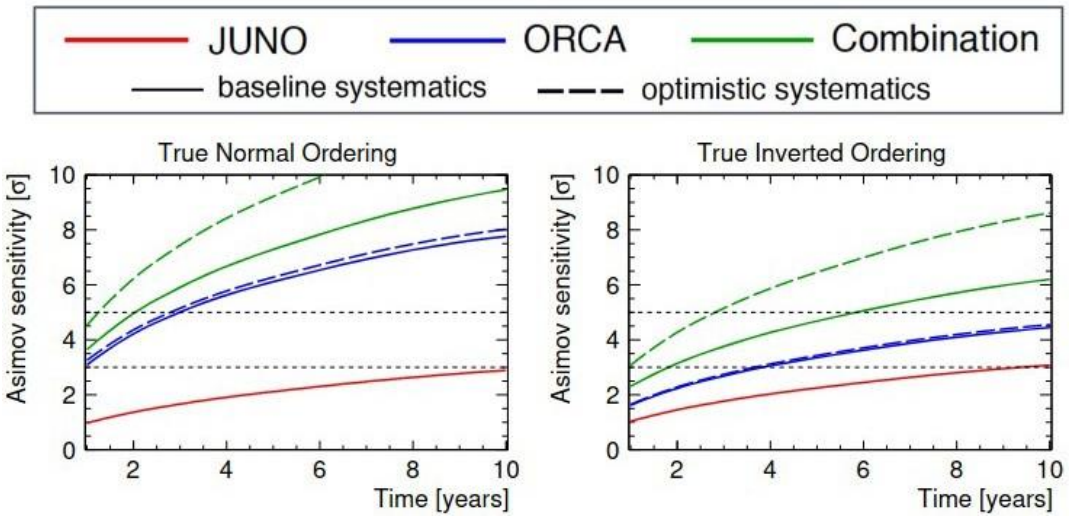
WP3 – Results

Milestone paper: crucial role of Δm^2(atmospheric) precision for **early Mass Ordering determination when combining LBL and JUNO sensitivities**

→ same concept used in ORCA+JUNO combination, also with contribution from P2IO members.



Sci. Rep. 12 (2022)1, 5393



JHEP 03 (2022) 055

WP3 – Results

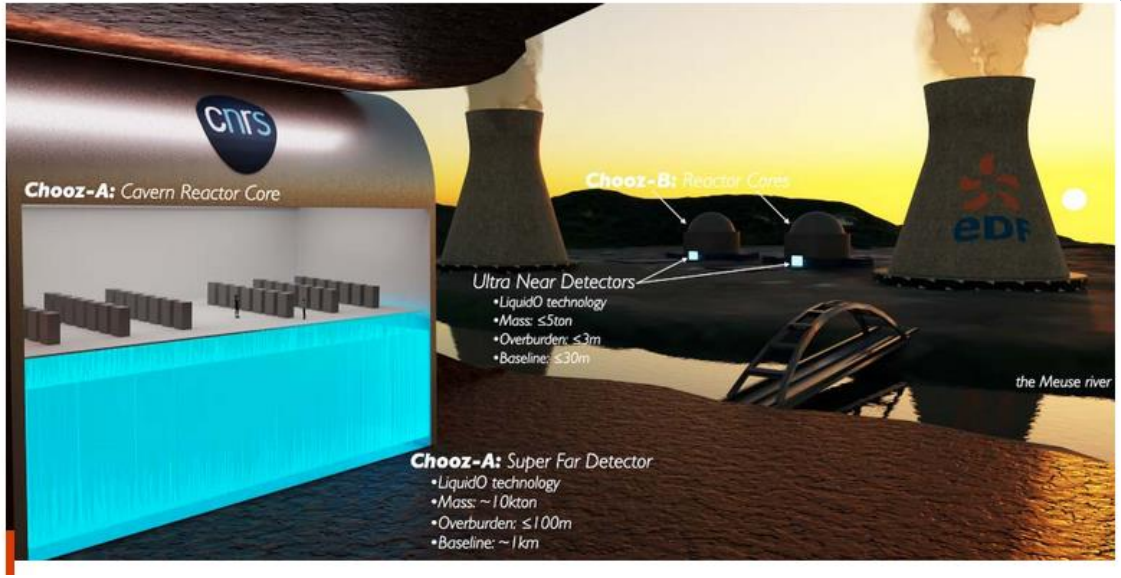
The P2IO BSM-Nu collaborators led the **per-mille precision measurement of θ_{12}, δm^2, and Δm^2 studies** within the **JUNO** collaboration.

Postdoc Diana Navas [IJCLab]

Chinese Phys. C 46 (2022) 123001

Leading role in the launch of the **new SuperChooz proposed experiment**, based in France (feasibility studies ongoing).

- measure θ_{13} and Δm^2 (reactor neutrinos) and θ_{12} and δm^2 (solar neutrino) to the sub-percent precision
- unique validation of the JUNO experiment results
- synergic information boosting the sensitivity of HyperKamiokande and DUNE
- unique exploration of the completeness of the SM via the effective manifestations of possible unitarity or CPT violation(s).

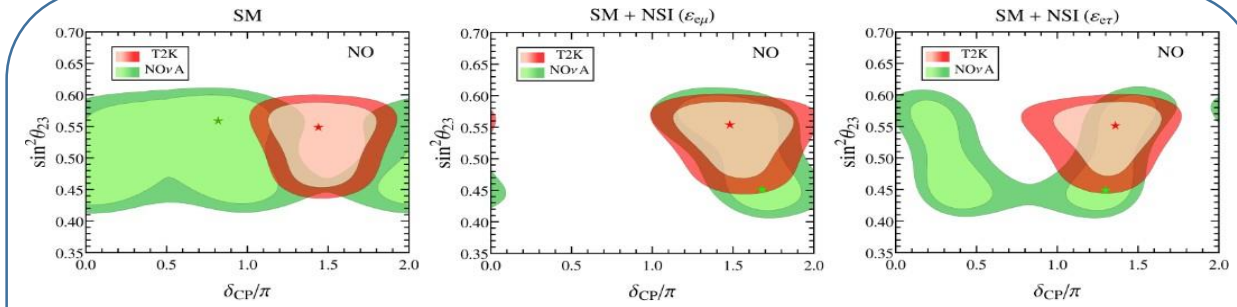


WP3 – Results

Study of the **impact of various New Physis scenarios** (NSI, deviation from unitarity of the PMNS matrix) on long-baseline oscillation experiments and on CEvNS.

The BSMNu team has

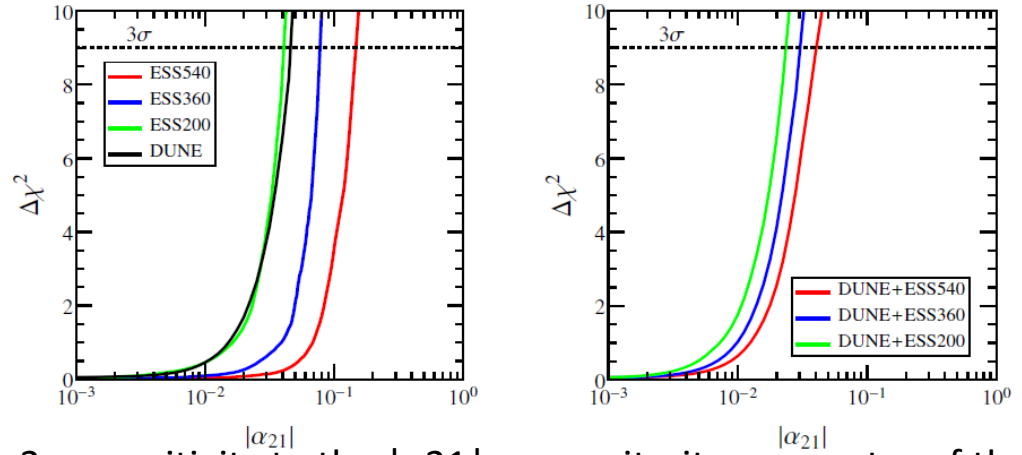
- demonstrated quantitatively how **NSI could reconcile** recent **T2K and NOVA** oscillation results
- evaluated the **sensitivity of ESSnuSB to CP violation** in presence of deviations from unitarity of the PMNS matrix
- evaluated the **combined sensitivity of DUNE and ESSnuSB** to **the non-unitarity parameters** *Phys. Rev. D 106, 075016*



T2K/NOvA tension Reconciling by introducing NSI

Phys. Rev. Lett. 126, 051802

arXiv:2208.11771 [hep-ph]



3 σ sensitivity to the |a21| non-unitarity parameter of the combination DUNE + ESSnuSB is 0.040, 0.030 and 0.022 for L = 540, 360 and 200 km (current 3 σ bound: 0.025)

Leading role:
Postdoc Sabya Sachi Chatterjee [CEA/IPhT]

WP4 – Results

Crucial contribution to the data taking of the **CUPID-Mo experiment** at LSM (March 2019 – July 2020)
→ funding experiment maintenance in 2020

Analysis of the **CUPID-Mo full statistics**, with the following results:

- new **world leading limit** on the half-life of $0\nu\beta\beta$ of ^{100}Mo
- CUPID-Mo background model
- measurement of $2\nu\beta\beta$ on ^{100}Ru excited states
- best worldwide limits on various ^{100}Mo 2β processes

arXiv:2207.09577v1 [nucl-ex]

Measurement of $2\beta2\nu$ on ^{100}Ru excited states

$T_{1/2}^{2\nu\to0_1^+} = (7.5 \pm 0.8\ (\text{stat.})\ ^{+0.4}_{-0.3}\ (\text{syst.})) \times 10^{20}$ yr

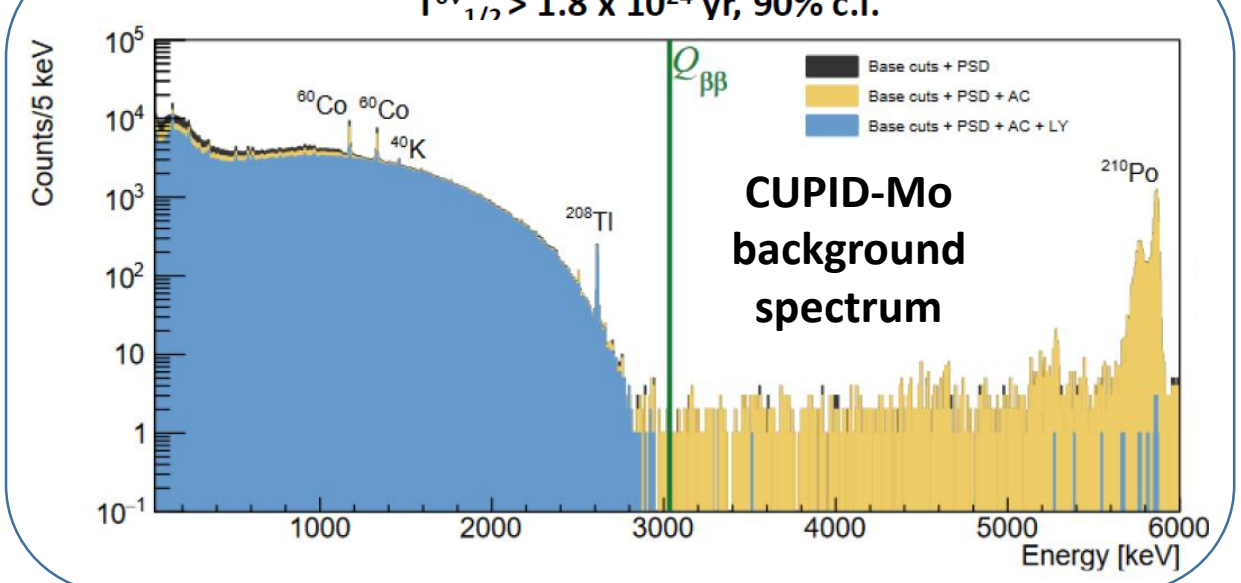
Best worldwide limits on various processes

$T_{1/2}^{2\nu\to2_1^+} > 4.4 \times 10^{21}$ yr (90% c.i.)

$T_{1/2}^{0\nu\to0_1^+} > 1.2 \times 10^{23}$ yr (90% c.i.)

$T_{1/2}^{0\nu\to2_1^+} > 2.1 \times 10^{23}$ yr (90% c.i.)

$T^{0\nu}_{1/2} > 1.8 \times 10^{24}$ yr, 90% c.i.

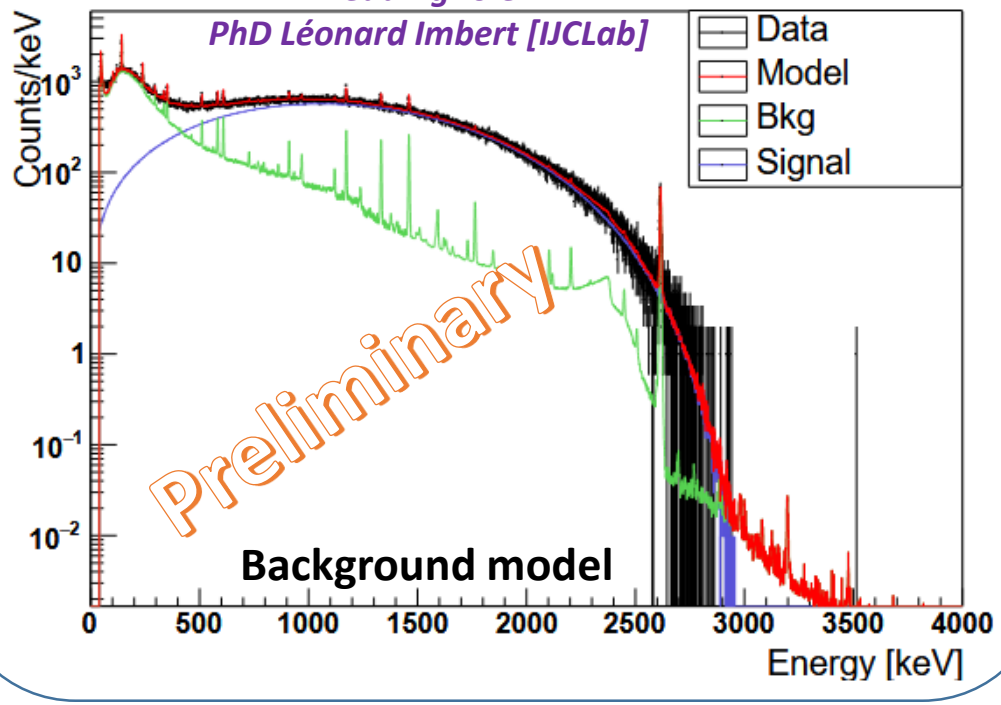


Phys. Rev. Lett. 126 (2021) 181802

Eur.Phys.J.C **82 (2022) 11, 1033**

Leading role:

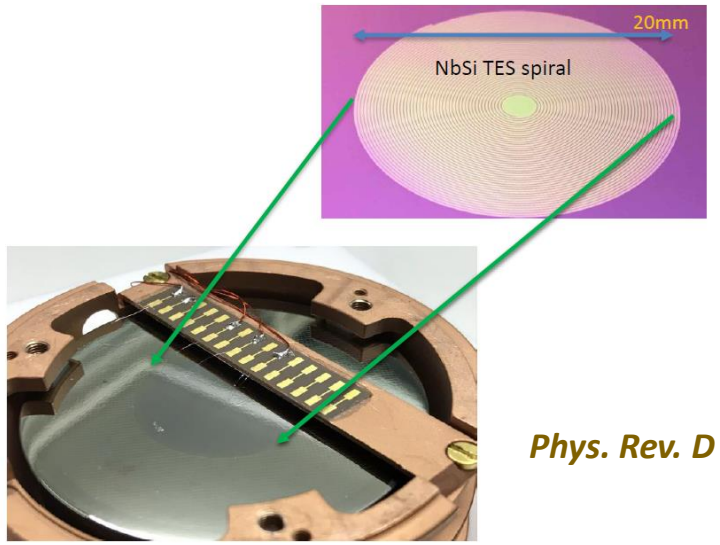
PhD Léonard Imbert [IJCLab]



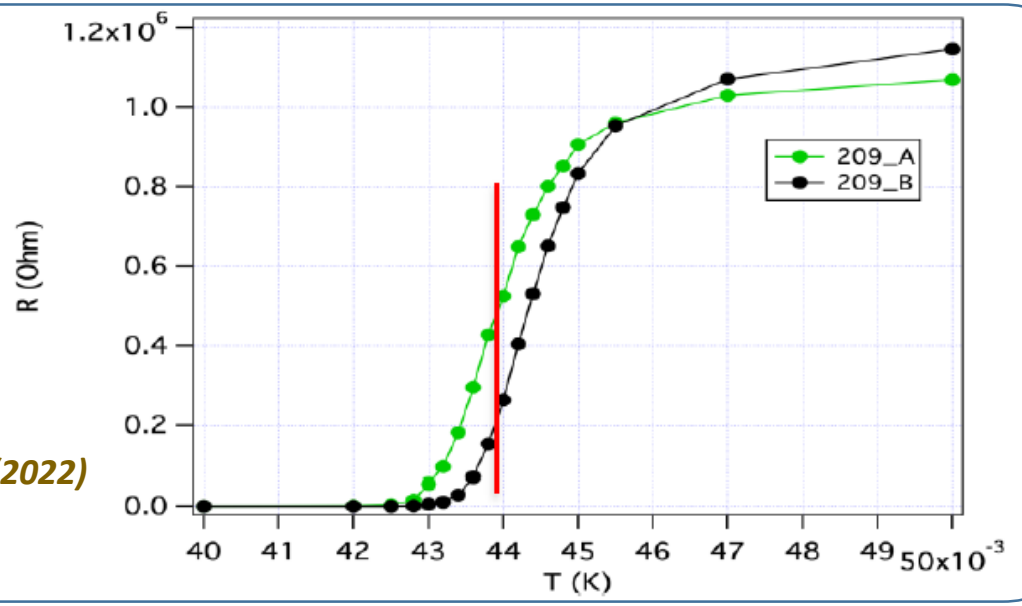
WP4 – Results

Development of **low-threshold Ge detectors** equipped with TES
→ using high normal-state impedance NbSi TESs in meander/spiral configuration, preliminary results:

- 200 g Ge detector mass, 500 eV threshold
- 35 g Ge detector mass, 250 eV threshold



Phys. Rev. D 106, 062004 (2022)



Development of a **new detector concept** (in connection with the ANR CRYOSEL) with Ge absorber and NbSi TES (application to CEvNS but also low-mass dark matter)
→ separate three classes of events: [1] nuclear recoils – [2] electron recoils – [3] non-radiogenic "heat-only" events

WP4 – Results

Vetos in the millikelvin experimental space

- Establishment of a **veto structure for the NUCLEUS CEvNS experiment** using Ge ionization detectors
- Progress in the development of a **scintillator-based veto for 0νββ experiment** (in connection with the BINGO project) with bolometric light read-out the veto material

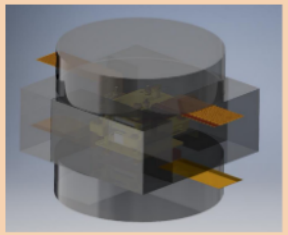
  → initially foreseen $ZnWO_4$ was changed to BGO as a consequence of the Ukraine war

  → main veto concepts (threshold and surface radioactivity rejection) were proved

Postdoc Anastasiia Zolotarova [CEA/DPhP]

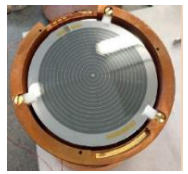
Ge ionization detectors (EDELWEISS-like) → **NUCLEUS internal veto**

Final configuration:

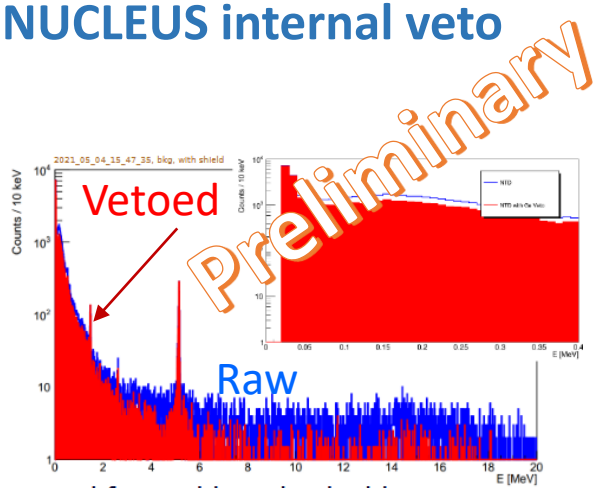


- 2 cylinders (ϕ = 100 mm, h = 25 mm)
- 4 paralleled-shaped (50 mm x 74.5 mm x 25 mm)

Bottom

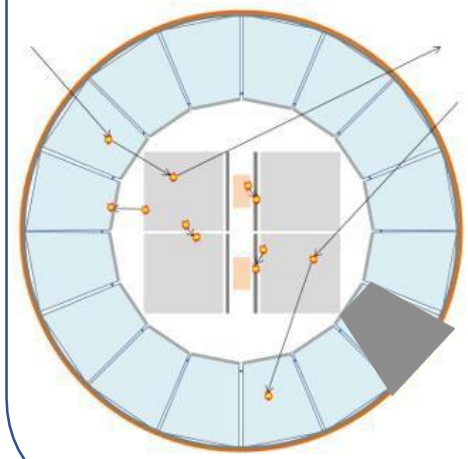


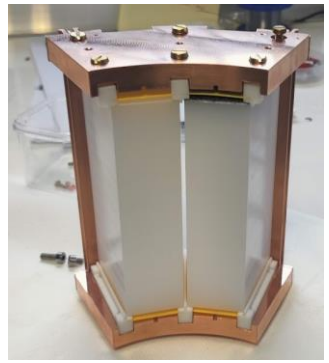
Top



- Corrected for accidental coincidences:
- Veto rejection (full range)~ 23% (> 0.8%)
- Veto rejection (0-100 keV)~ 11%

BGO scintillators → **BINGO internal veto**
CUPID-1T candidate





First prototype tested successfully above ground

Read-out by Neganov-Luke bolometric Ge light detectors

Publications and talks

Papers

Nucl.Instrum.Meth.A 1025 (2022) 166109
PoS NuFact2021 (2022) 235
Phys.Rev.D 105 (2022) 3, 032010
Phys.Rev.D 106 (2022) 3, 032009

Sci. Rep. 12 (2022)1, 5393
JHEP 03 (2022) 055
Chinese Phys. C 46 (2022) 123001
arXiv:2201.10412 (NuFact 2021 proceedings)
Phys. Rev. D106 (2022) 075016
arXiv:2208.11771 (submitted to JHEP)

Phys. Rev. Lett. 126, 181802
Eur.Phys.J.C 82 (2022) 11, 1033
Phys. Rev. D 106, 062004 (2022)
arXiv:2207.09577 [nucl-ex] (submitted to PRC)

Several others in preparation

Talks

- A Ershova, INPC2022 September 2022- Sensitivity of the T2K Near Detector Upgrade to constrain CCQE uncertainties in the Spectral Function model
- J.Chakrani, Niels Bohr Institute Summer school July 2022 - Nuisances in the fit: the nuclear model uncertainties in the new era of Spectral Function
- A.Ershova, NuSTEC seminar April 2022 - Simulations and cascades: using INCL to boost nuclear models for neutrino interactions Final State Interaction effects with NuWro and INCL
- J.Chakrani, NuFact 2021 - Parametrising CCQE uncertainties in the Spectral Function model for neutrino oscillation analyses
- J.Chakrani IRN meeting November 2021 - Improved near detectors and nuclear models for present and future neutrino oscillation experiments
- Diana Navas, NuFact 2021, September 2021 - Neutrino Oscillation physics in JUNO
- Diana Navas, NOW 2022, September 2022 - Prospects of Neutrino Oscillation Physics in JUNO
- Sabya Chatterjee, NuFact 2021, September 2021 - Resolving the NOvA and T2K tension in the presence of neutrino non-standard interactions
- Sabya Chatterjee, IRN meeting, December 2021 - Resolving the NOvA and T2K tension in the presence of neutrino non-standard interactions
- Sabya Chatterjee, Planck 2022, July 2022 - Exploring the New Physics at the Neutrino facilities of the European Spallation Source
- Sabya Chatterjee, PASCOS 2022, June 2022 - Resolving the NOvA and T2K tension in the presence of neutrino non-standard interactions
- A. Zolotarova, NEUTRINO2022, June 2022 - CUPID and its demonstrators: scintillating bolometers for $0\nu\beta\beta$ search
- L.Imbert. 20th Lomonosov Conference on Elementary Particle Physics, Aug 2021 - CUPID-Mo: A World Leading Limit on Neutrinoless Double Beta Decay of 100Mo

Training and education

WP1

Recruitment of 2 students (**Jafar Chakrani** [LLR], **Anna Ershova** [CEA/DPhP]) and 1 postdoc (**David Henaff** [CEA/DPhP])

- Training on nuclear physics problems and near detector analysis and design for present and next generation of LBL experiments
- Training on TPC technology in real life: R&D, characterization with data taking, production and assembly

WP2

Recruitment of 2 postdocs (**Diana Navas** [IJCLab/HEP] and **Sabya Chatterjee** [CEA/IPhT])

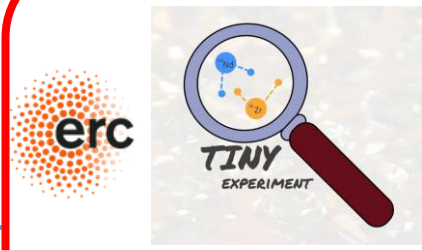
- Training a theory postdoc (S. Chatterjee) to operate in an experimental environment (eg, realistic systematics)

WP3

Recruitment of 1 student (**Léonard Imbert** [IJCLab/A2C) and **1 postdoc** (**Anastasiia Zolotarova** [CEA/DPhP])

- The student (L. Imbert) was trained in data analysis and background simulation in bolometric detectors

Many few-author papers !



ERC Starting Grant Project TINY Start on September 1st, 2023

Structuring role

WP2

- for the first time a nuclear physics model developed at DPhN ported into neutrino physics
- GUNDAM tool originally developed at DPhP → now expertise moved at LLR
- reflection and discussion about Δm^2 precision prospects (important for MH determination when combined to other experiments) → WP2

WP3

- establishing discussion, comparison and combinations between reactor and accelerator experiments and between experimentalists and theorists
- enlarging the horizon of P2IO community to ESS and SuperChooz
- constraints of the $0\nu\beta\beta$ and CEvNS parameter spaces → WP3

WP4

- reinforcing connections among the bolometric groups inside the project (CEA/IRFU - CUPID and NUCLEUS groups; IJCLab – CUPID, RICOCHET and EDELWEISS groups)
- sharing methods between dark matter detectors and CEvNS detectors
- transfering methods from low-threshold Ge bolometer to light detectors for 0nbb application (specifically, for the scintillation veto readout)
- transfering methods from large mass dark matter detectors to veto detectors for CEvNS

WP2 – Plans and prospects

Work planned

- Study of final state interactions (FSI) with INCL model for neutrons in antineutrino interactions
- Resistive Micromegas characterization: full model of gas gain, resistive charge spread and electronics response

Prospects

- Implementation of improved FSI model in ND data analysis: parametrization of uncertainties and comparison to worldwide neutrino-nucelus cross-section results
- Implementation of neutrino-nucleus interactions in INCL
  (new thesis subjects shared betweeh DPhP and DPhN in preparation for next years)
- Further R&D for TPCs with resistive technology for readout and field cage for hadroproduction measurements for neutrino flux constraints (ERC submitted for evaluation)

WP3 – Plans and prospects

Work planned

- New DualCalorimetry analysis in JUNO using both large (20”) and small (3”) PMT readout systems is under preparation for the ultimate control of neutrino energy bias and possible systematics to the neutrino oscillation parameters. The DualCalorimetry JUNO detector design is pioneered by the IJCLab team participating to the BSMNu project, being explored experimentally with the JINO prototype. Leading scientists is the postdoc hired by BSMNu Diana Navas.
- SuperChooz: several publications in preparation for the full physics programme with both reactor and solar neutrinos. Preparation with an expert scientist on sabbatical leave at IJCLab (Prof. Mark Chen; Queen’s University) and Prof. Hiroshi Nunokawa (coming to IJCLab in Nov 2022). New CLOUD experiment starting from 1 Dec 2022 funded by EU-EIC and UKRI.
- Study of the possibility to constrain more general non-standard neutrino interactions at the ESS.
- Study of a possible explanation of the LSND and MiniBooNE anomalies involving a heavy decaying sterile neutrino.

Prospects

- Establish open new physics scenarios at neutrino oscillation and non-oscillation experiments, in connection with the future experimental programme.
- Establish ultimate achievable precision on all the PMNS parameters and on PMNS unitarity constraints with present and planned oscillation experiments

WP4 – Plans and prospects

Work planned

- Complete the CUPID-Mo analysis with new results on $2\nu\beta\beta$, Majoron emission and other exotic rare decays.
- Fabrication of advanced prototypes based on a new Ge bolometer concept capable of identifying three classes of events: nuclear recoils, electron recoils, parasitic “heat-only” events due to micro-cracks relaxation in the crystal target and detector elements in contact with them. Application to CEvNS and dark matter search.
- Fabrication and test of scintillating veto elements, operated in the vicinity of detectors, for double beta decay experiments.
- Development of innovative light detectors based on the Neganov-Luke effect to mitigate the random coincidence pile-up and read out the veto scintillating elements.

Prospects

- Establish mature innovative experimental approaches to increase the reach and the sensitivities of future experiments on $0\nu2\beta$ (in particular CUPID- 1T) and on CEvNS (both with Ge and CaWO4 targets)

Meetings and dissemination

Web site →

Home

BSM-Nu: a door to physics Beyond the Standard Model (2020-2024)

BSM Nu project

- **BSM Nu physics:**
  - General
  - Near Detectors and nuclear physics
  - Combination of experiments and PMNS precision physics
  - Bolometers for 0nubb search and CEnNS scattering
- **Organization:**
  - Official documentation
  - Continuous reporting
  - Calendar and internal meetings

Internal Meetings

- Internal meeting 13 Jan 2020
- Internal meeting 13 March 2020
- Internal meeting 22 May 2020
- Internal meeting 22 June 2020
- Internal meeting 29 Oct 2020
- Internal meeting 4 Dec 2020
- Internal meeting 19 July 2021
- Internal meeting 8 October 2021
- Internal meeting 11 February 2022
- Internal meeting 30 September 2022

Workshops

- Feb 2021: P2IO BSMNu first workshop
- April 2022: P2IO BSMNu second workshop
- April 2023, May 2024, October 2025 (conclusions)

Seminars

3 seminars in P2IO laboratories

- BSM physics with neutrinos - LLR – Jan 2021 - *Andre de Gouvea* (Northwestern U.)
- Bolometers for neutrino physics – IRFU – Dec 2022 – *Anastasiia Zolotarova* (IRFU)
- Nuclear physics for neutrino experiments – IJCLab – Apr 2023 - *TbA*

Zoom meeting
(Pandemic)

Near Detectors for Long Baseline | Nuclear Physics for Neutrino

09:00	**T2HK and DUNE strategy for Near Detectors**	*Davide Sgalaberna* 09:00 - 09:20
	Measuring protons and neutrons	*Stephen DOLAN* 09:30 - 09:50
10:00	**TPC with resistive Micromegas**	*Claudio Giganti* 10:00 - 10:20
	Brew your own coffee	10:30 - 11:00
11:00	**Nuclear models for LBL and 0nbb: synergies**	*Marco Martini* 11:00 - 11:20
	Nuclear models for inclusive and semi-inclusive neutrino interactions in Carbon, Oxygen and Argon	*Maria Barbaro* 11:30 - 11:50
12:00	**Measurement strategies for the 0nbb matrix elements**	*Francesco Cappuzzello* 12:00 - 12:20
	Synergy between nuclear physics in CEvNS experiments and long-baseline oscillation experiments	*Vishvas Pandey* 12:30 - 12:50

New Developments in Neutrino | PMNS and BSM Phyiscs in

09:00	**Experimental review of new ideas and their applications: double beta decay**	*Giovanni Benato* 09:00 - 09:20
	Experimental review of new ideas and their applications: CEnNS and dark matter	*Victoria Wagner et al.* 09:30 - 09:50
10:00	**Bolometric advanced technologies for background mitigation**	*Stefano Pirro* 10:00 - 10:20
	Brew your own coffee	10:30 - 11:00
11:00	**Limits on New Physics from present 0nuBB results**	*Frank Deppisch* 11:00 - 11:20
	NSIs and their impact on the determination of neutrino parameters	*Michele Maltoni* 11:30 - 11:50
12:00	**Results of combination JUNO+T2K+NOVA**	*Joao Coelho* 12:00 - 12:20
	Unitarity Test in Neutrino Oscillations	*Nunokawa Hiroshi* 12:30 - 12:50

P2IO BSM-Nu second workshop

11 April 2022
IJCLab (Orsay)

Bolometers | Combination of experiments and | Near detectors of long-baseline

Welcome and introduction
100/-1-A900 - Auditorium Joliot Curie, IJCLab (Orsay) 09:30 - 10:00

10:00
Role of near detectors in present and future long-baseline experiments *Ciro Riccio*
100/-1-A900 - Auditorium Joliot Curie, IJCLab (Orsay) 10:00 - 10:35

ND280 upgrade design and resistive Micromegas *David Henaff*
100/-1-A900 - Auditorium Joliot Curie, IJCLab (Orsay) 10:35 - 11:05

11:00
New constraints on nuclear models from ND280 upgrade *Jaafar Chakrani*
100/-1-A900 - Auditorium Joliot Curie, IJCLab (Orsay) 11:05 - 11:30

New nuclear models to exploit the capabilities of new near detectors *Anna Ershova*
100/-1-A900 - Auditorium Joliot Curie, IJCLab (Orsay) 11:30 - 11:55

12:00
Lunch
100/-1-A900 - Auditorium Joliot Curie, IJCLab (Orsay) 12:00 - 13:00

13:00
Bolometric detection of CENNS: concept, status and prospects *Julien Billard*
100/-1-A900 - Auditorium Joliot Curie, IJCLab (Orsay) 13:00 - 13:30

Background studies for CUPID-Mo and CUPID 0νββ experiments *Leonard Imbert*
100/-1-A900 - Auditorium Joliot Curie, IJCLab (Orsay) 13:30 - 14:00

14:00
Status of CUPID and its demonstrator *Anastasiia Zolotarova*
100/-1-A900 - Auditorium Joliot Curie, IJCLab (Orsay) 14:00 - 14:30

Cryogenic active shielding for double beta decay experiments *Giovanni Benato*
100/-1-A900 - Auditorium Joliot Curie, IJCLab (Orsay) 14:30 - 15:00

15:00
Break
100/-1-A900 - Auditorium Joliot Curie, IJCLab (Orsay) 15:00 - 15:30

Why is the neutrino mass important? *Francesco Vissani*
ZOOM 15:30 - 16:05

16:00
Neutrino Mass Order Detecting by the Next Generation of Experiments and their Synergies *Anatael Cabrera*
ZOOM 16:05 - 16:40

Precision oscillation physics with JUNO *Diana NAVAS NICOLAS*
100/-1-A900 - Auditorium Joliot Curie, IJCLab (Orsay) 16:40 - 17:05

17:00
NSI in combination of long baseline experiments *Sabya Sachi Chatterjee*
100/-1-A900 - Auditorium Joliot Curie, IJCLab (Orsay) 17:05 - 17:30

Use of resources

Status of recruitments

- DPhN student recruited: Anna Ershova (A.Letourneau, S.Bolognesi, start date Nov 2020)
- LLR student recruited: Jafaar Chakrani (M.Buizza Avanzini, start date Oct 2020)
- IJC student recruited: Leonard Imbert, (P.Loaiza, A.Giuliani start date Oct 2020)
- IPhT postdoc recruited: Sabya Chatterjee (S.Lavignac, start date October 2021)
- DPhP postdoc recruited: Anastasia Zolotorova (C.Nones, start date Oct 2021)
- DPhP postdoc recruited: David Henaff (G.Eurin, start date Dec 2021)
- IJC-Lab postdoc recruited: Diana Navas (A.Cabrera, start date Feb 2022)
- Hiroshi Nunokawa is back in IJCLab soon and we will continue working in Unitarity, as part of the inter-experiment synergy effort
- Mark Chen (SNO+ spokesperson) on sabbatical “LiquidO” in IJCLab. We are envisaging one/few seminars with him in end of 2022
- Visit of ABLA (nuclear de-excitation model) experts
- Call open: CEvNS student???

Hardware purchase

- The cooling-He purchase for the CUPID-Mo experiment in Spring 2020 allowed to produce the best $0\nu\beta\beta$ results on Mo up to date, presented at Neutrino2020 international conference
- New crystals for VETO in bolometric experiments ($0\nu\beta\beta$ and CEvNS)
- New computer for the control of the front end electronics and the DAQ for the $0\nu\beta\beta$ bolometers tested in a dilution refrigerator at IJCLab
- Upgrade of test bench for resistive Micromegas modules