The SBND Photon Detection System

LIDINE 23

Rodrigo Alvarez*,

on behalf of the SBND collaboration

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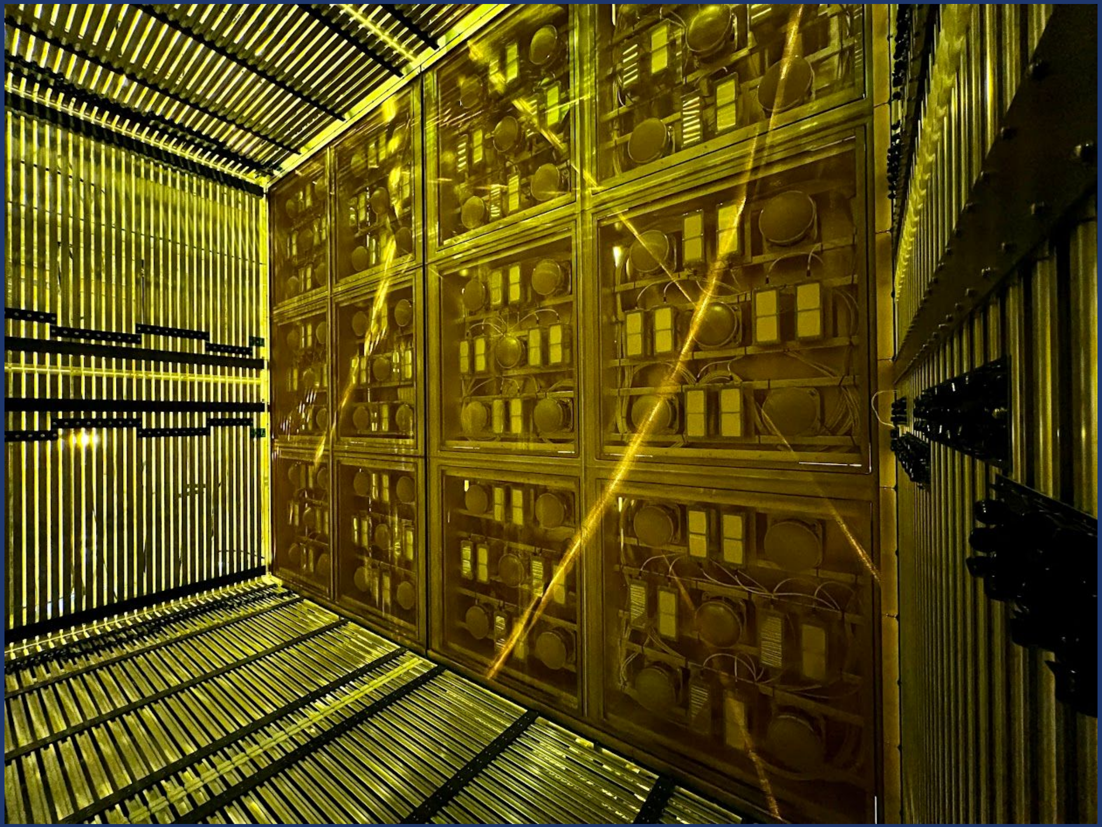
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

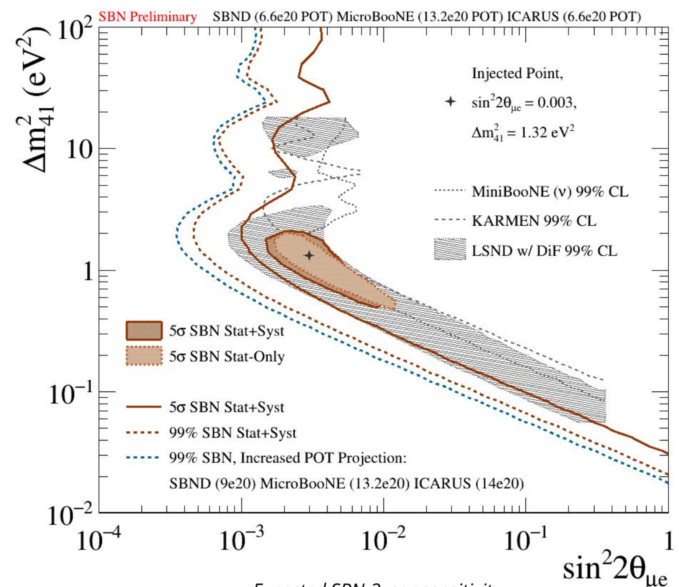


Short-Baseline Neutrino program

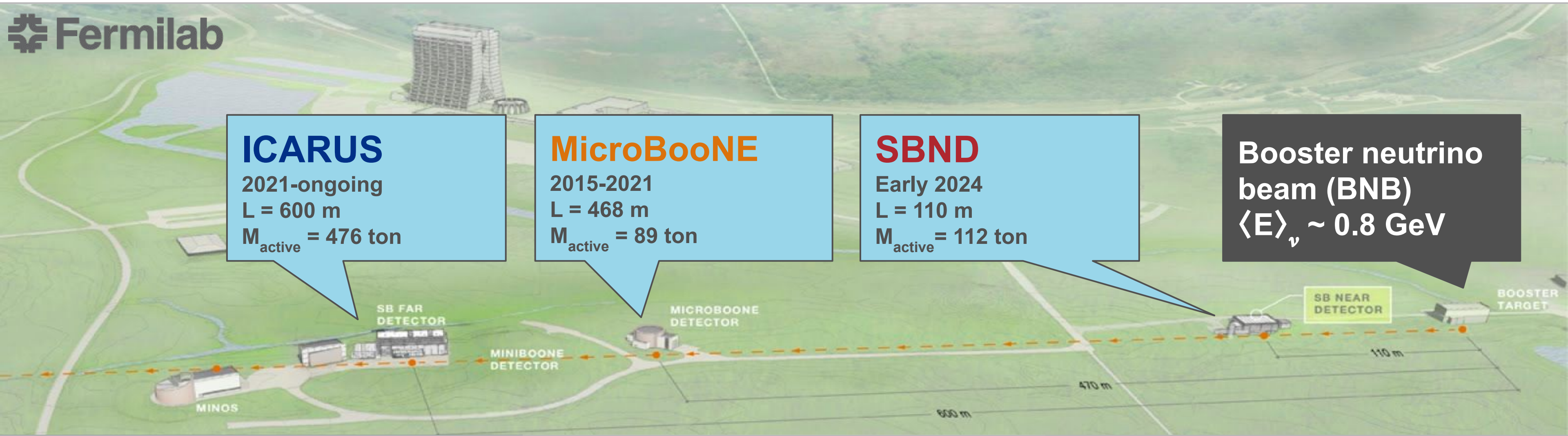
- ➔ Located in Fermilab (Illinois), consists of 3 LArTPC experiments:

  ICARUS, **MicroBooNE**, **SBND**

- ➔ Has a rich physics program:
  - ◆ Searches for light sterile neutrinos and other BSM particles (heavy neutral leptons, light dark matter) …
  - ◆ Highest neutrino-Argon interaction statistics
  - ◆ Research & Development in new technologies

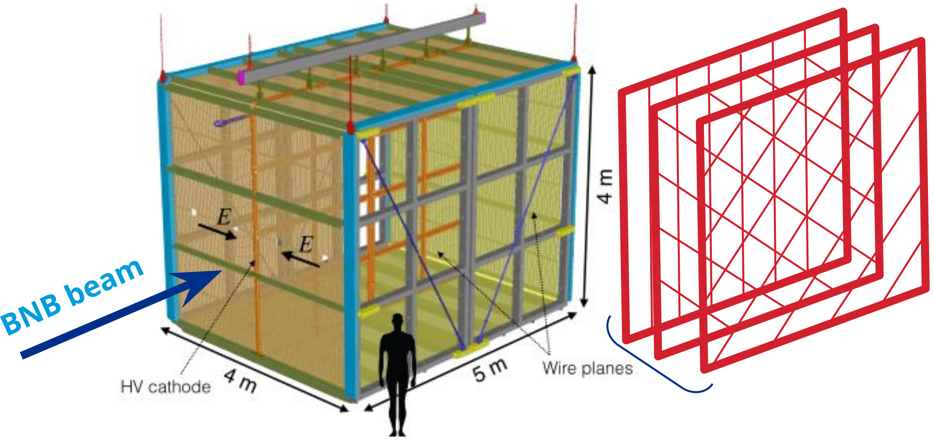


Expected SBN-3year sensitivity to a light sterile neutrino.



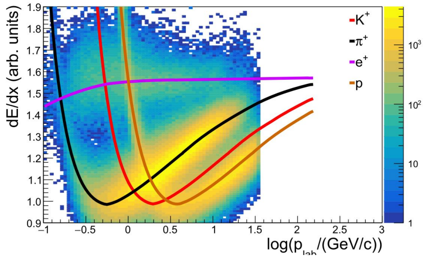
SBND: the Short-Baseline Near Detector

As a LArTPC, SBND has 3 main subsystems

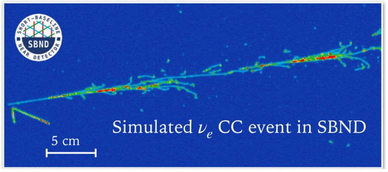


2 TPC volumes

- ➔ **Cathode in the middle separates in two TPCs the active volume: 2x5x4 m^3 each**
- ➔ **Wire pitch of 3mm, for a total ~11,000 wires**
- ➔ **mm level resolution of the event, precise calorimetry & particle ID (Bethe-Bloch equation)**
- ➔ **Continuous LAr purifying system to prevent charge (and light) loss (2m drift).**



SPS. Eur. Phys. J. C 82, 322 (2022).



SBND simulation

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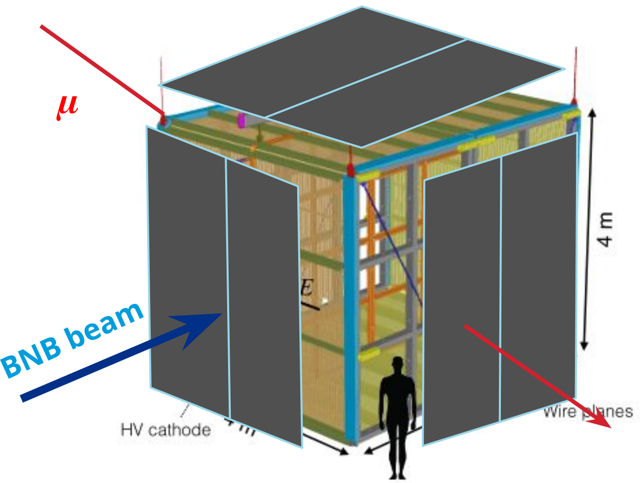

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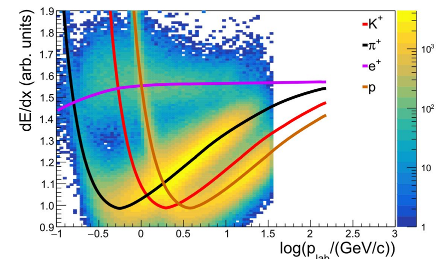

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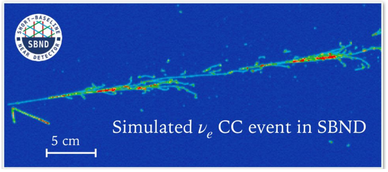
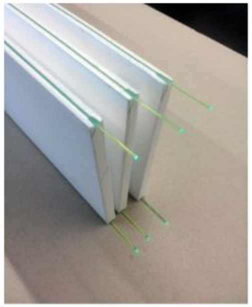


SBND simulation

Cosmic Ray Tagger system (CRT)

- ➔ **CRT walls surround the cryostat with ~4π coverage. They are composed of scintillator panels with SiPMs on the sides.**
- ➔ **Provides discrimination to backgrounds from cosmic rays.**
- ➔ **Precise timing (ns) and topology of the event allows for selection of calibration samples.**



CRT scintillator strip with wavelength shifting fibres in each side

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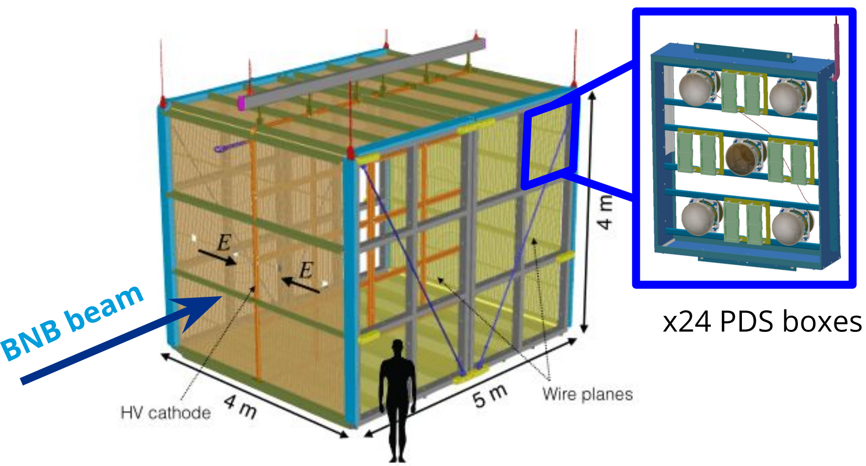

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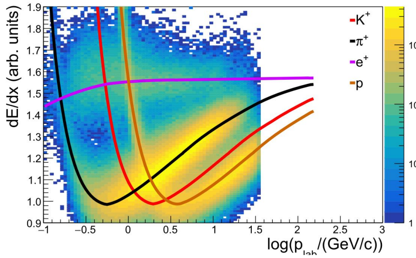

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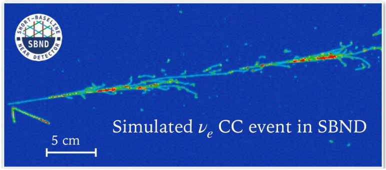

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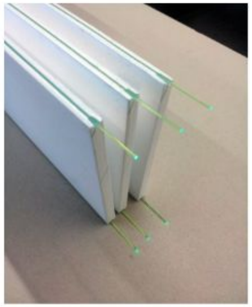


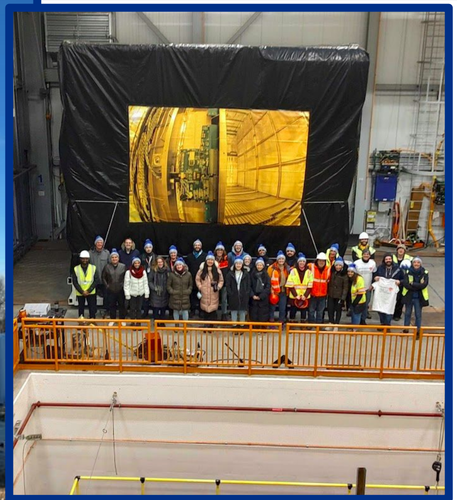
CRT scintillator strip with wavelength shifting fibres in each side

Photon Detection system (PDS)

- ➔ Composed by 192 XARAPUCAs and 120 PMTs.
- ➔ Provides triggering, particle ID, complementary energy reconstruction, background rejection...
- ➔ Sensitive to both VUV, produced by Ar_2 (direct) and visible light, produced by the TPB coated foils in the cathode plane.
- ➔ Nano second-level resolution allows for new physics searches (longlived massive particles).

SBND PDS boxes behind anode wire planes

SBND installation status



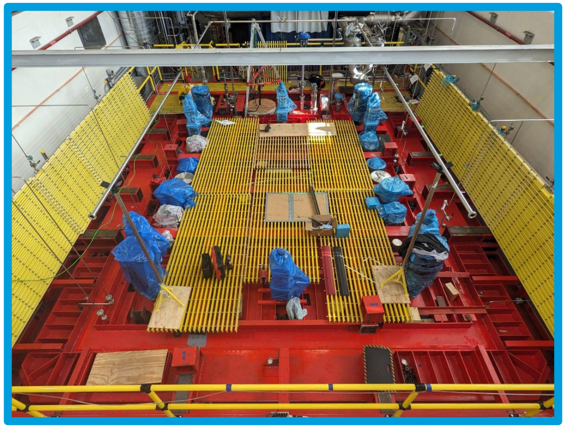
TPC moved to SBN-ND
December 1, 2022

Detector placed into the cryostat,

April 25, 2023

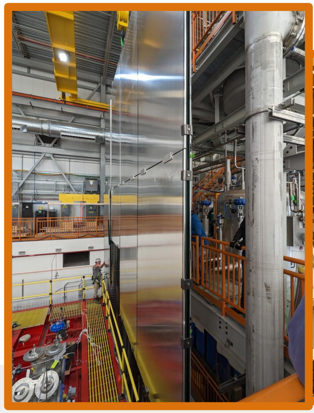
HV feedthrough installed and cryostat closed

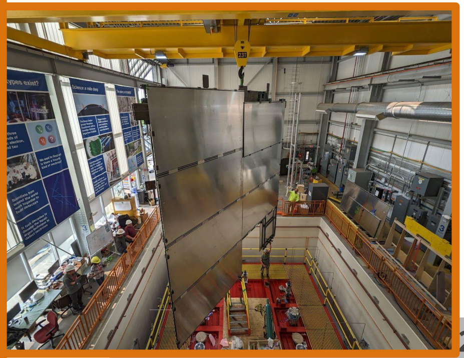
July 20, 2023



First CRT wall installed

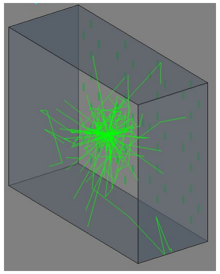
May 18, 2023





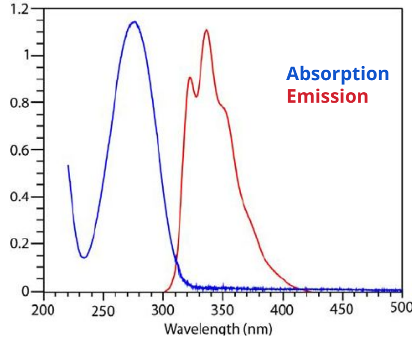
Light production in SBND

VUV Light



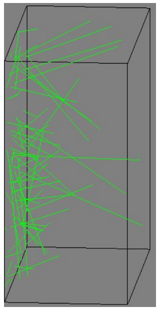
- Directly produced in LAr volume
- Rayleigh scattering length ~1 m
- TPB & P-Terphenyl (pTP) coating of PDS sensors

pTP absorption & emission spectra



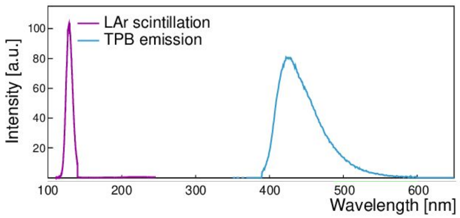
Nuclear Science Symposium (pp. 2228-2233), 2008

Visible Light



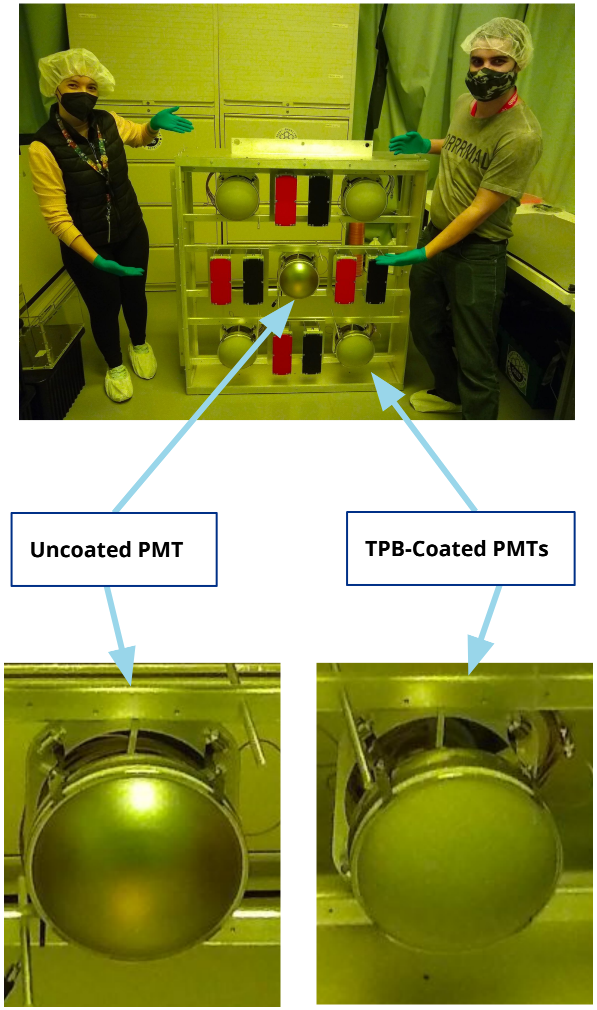
- Re-emitted by TPB foils in the cathode plane
- Rayleigh scattering length ~20 m

TPB emission spectra



Eur.Phys.J.C 82 (2022) 5, 442

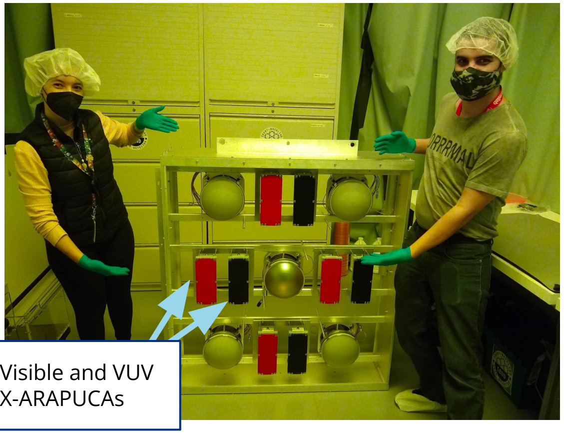
PDS: Photomultiplier Tubes



Left & right: uncoated and coated PMTs installed in PDS Box

- ➔ 120 total 8” Hamamatsu R5912 PMTs
  - ◆ 96 TPB coated PMTs (VUV +visible light)
  - ◆ 24 uncoated PMTs (visible only)
- ➔ 500 MHz CAEN readout.
- ➔ PMT system already tested and characterized by [CCM experiment]
- ➔ Used for trigger building.

PDS: X-ARAPUCAs

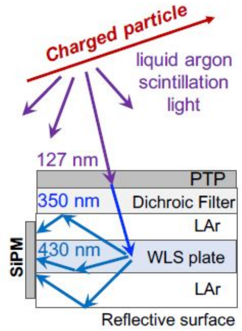


Visible and VUV X-ARAPUCAs

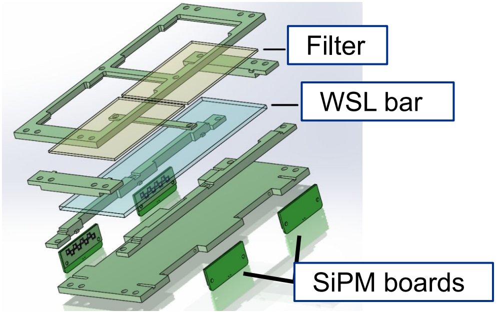
SiPMs	WLS Bar	Filter	Modules in SBND
SensL MICROFC-30050-SMT	Eljen 286	pTP coated 400 nm cutoff	88
SensL MICROFC-30050-SMT	Eljen 280	450 nm cutoff	88
HPK 6050-VE	Glass to power B.	pTP coated 400 nm cutoff	6
HPK-VE 6050-VE	Glass to power G.	450 nm cutoff	6
HPK 6050-HS (↓bias,↑PDE)	Glass to power B.	pTP coated 400 nm cutoff	2
HPK-HS 6050-HS (↓bias,↑PDE)	Glass to power G.	450 nm cutoff	2

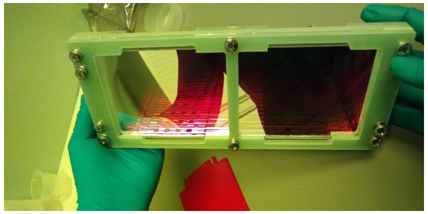
SBND X-ARAPAPUCA configurations

- ➔ **New scalable technology under development.**
- ➔ **Photons get trapped inside the module, increasing collection area. Side SiPMs collect the photons.**
- ➔ **Cut-offs allow for light source discrimination (450nm filter lets only visible light through)**
- ➔ **CAEN readouts: 14-bit 5 MHz and 12-bit 62.5 MHz**
- ➔ **Important R&D for future experiments (DUNE PDS is only X-ARAPUCA based).**



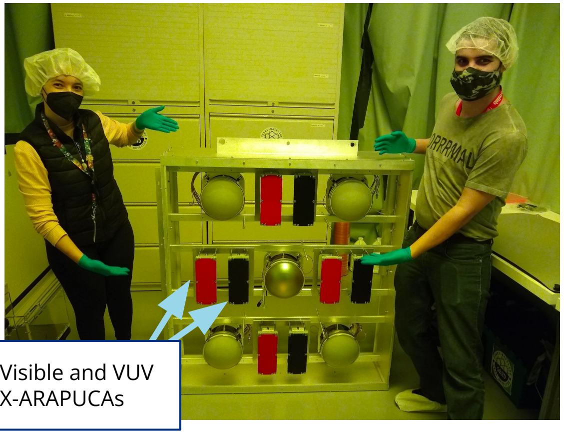
X-ARAPUCA operating principle. Nucl. Instrum. Meth. A, 985 (2021)





Left: SBND X-ARAPUCA mechanical scheme. Right: mounted module

PDS: X-ARAPUCAs



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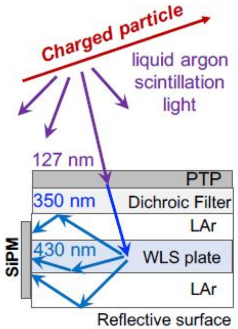
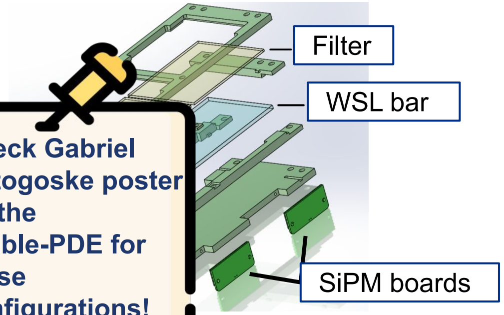
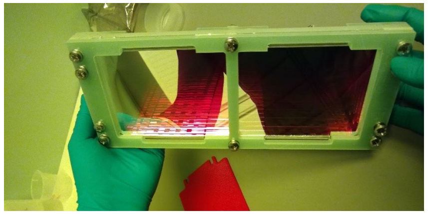


X-ARAPUCA operating principle. Nucl. Instrum. Meth. A, 985 (2021)

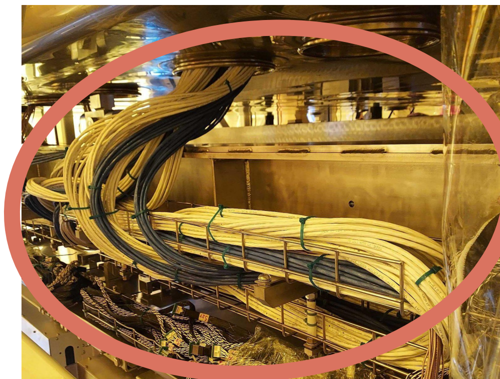
Check Gabriel Botogoske poster on the visible-PDE for these configurations!

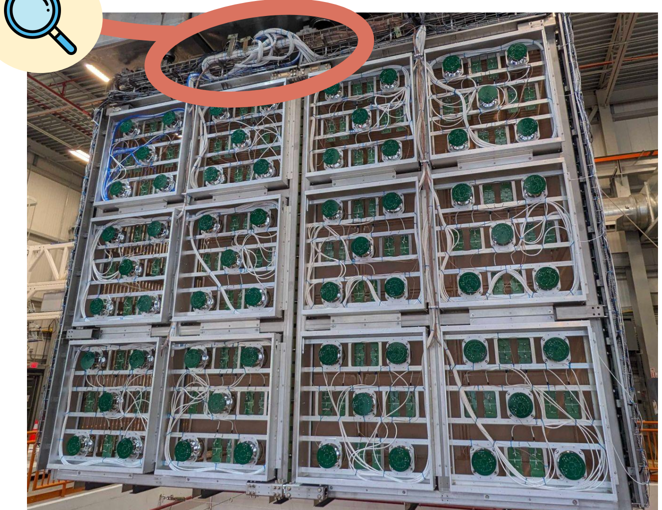




Left: SBND X-ARAPUCA mechanical scheme. Right: mounted module

Latest PDS status

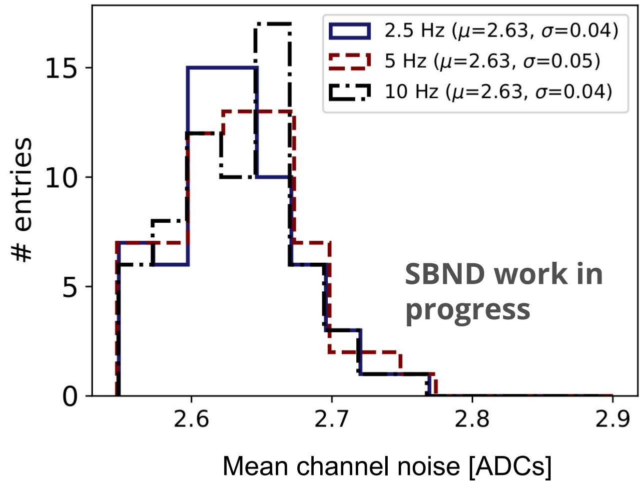


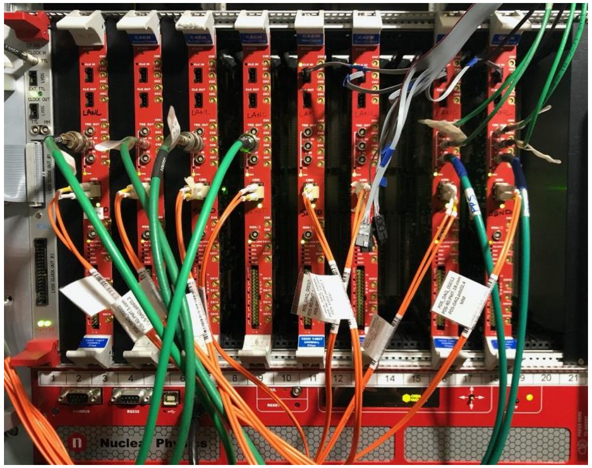


- ➔ **PDS cabling of each box to the top side of the detector.**
- ➔ **Cold-warm connection through flanges at the top of the cryostat.**
- ➔ **QA/QC tests performed at different stages.**

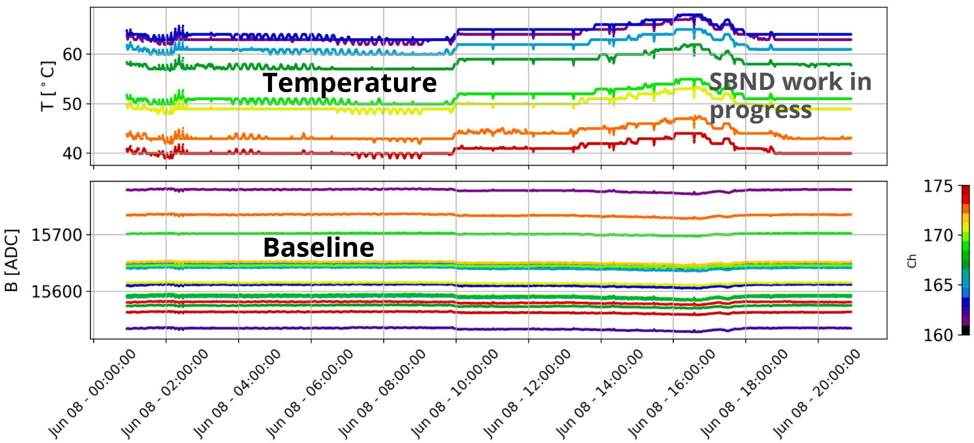
PDS commissioning

- PDS commissioning started on warm side. CAEN V1730 digitizers tests performed (no PMTs connected):
  - Pedestal noise check for different trigger rates
  - Quantifying the impact of temperature on baseline level.
  - Checking synchronization between trigger and PDS channels.
  - Testing PMTs high voltage power supply.



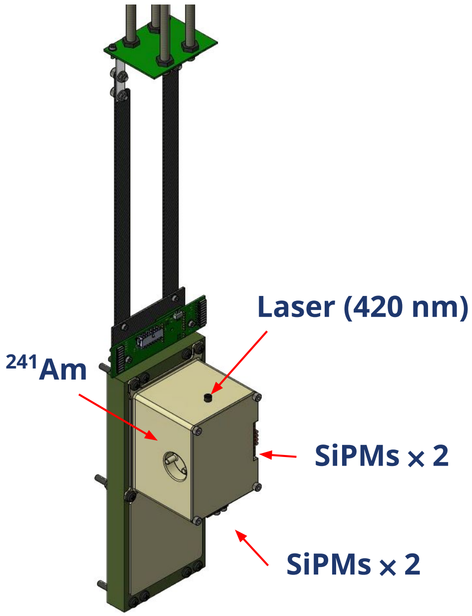


PMT CAEN boards



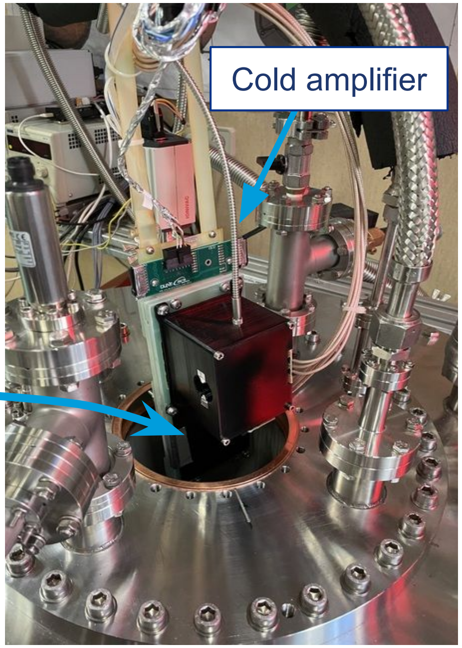
X-ARAPUCA PDE measurement

- ➔ **Setup developed by CIEMAT neutrino group to measure the photon detection efficiency (PDE) of 6 out of the 8 X-ARAPUCA configurations**
- ➔ **X-ARAPUCA modules tested in LAr, external Hamamatsu VUV4 SiPMs provide a reference of the light yield (purity independent measurement).**



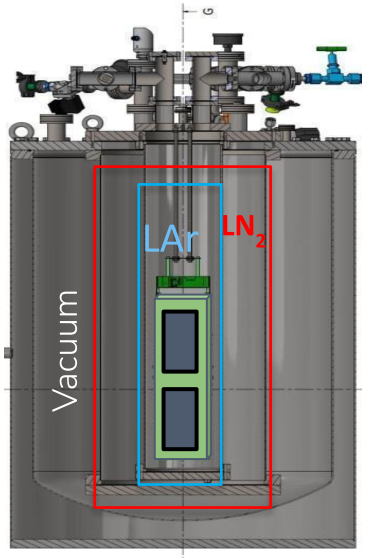
The setup includes:

- SiPM pairs in front of each light source as reference sensors performing flux calibration.
- Both VUV and visible light sources.
- Opaque box that guarantees reduced backgrounds from cosmic rays
- Inner vessel **filled** with **LAr** (cooled with LN2).
- A complete SBND-XARAPUCA module.
- XARAPUCA amplification in cold and warm.



LAr vessel (18 L)
∅ 16,2 cm x h 93,3 cm

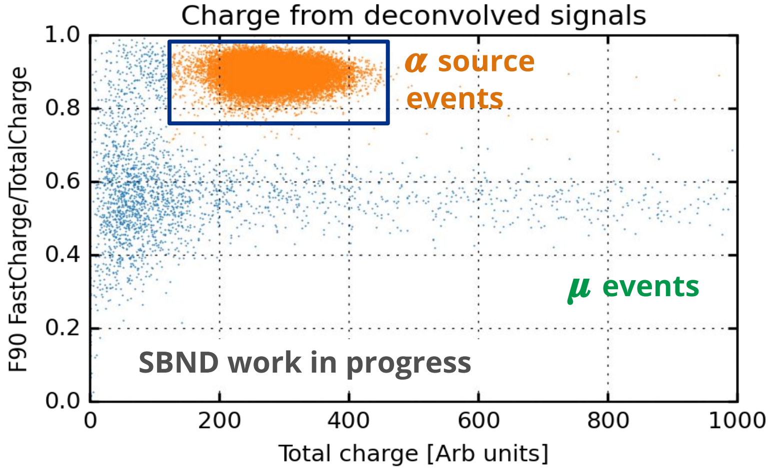
LN_2 vessel (100 L) ∅ 35,2 cm x h 94,5 cm

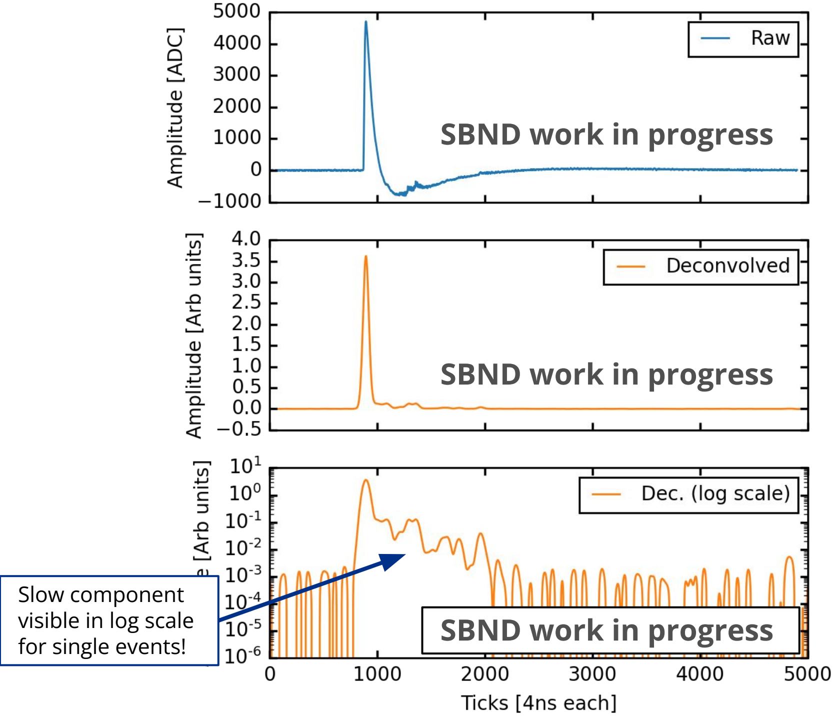


Vessels system scheme

VUV X-ARAPUCA PDE

- ➔ **Deconvolution of X-ARAPUCA signals performed to reconstruct charge from the slow component due to undershoot (AC-coupled readouts).**
- ➔ **Fast/slow ratio used to select alpha source events**
- ➔ **From X-ARAPUCA and reference sensors charge ratio, we can estimate the PDE value.**





Hamamatsu XA

OV [V]	PDE [%]
3.5	1.49 ± 0.21
4.5	1.77 ± 0.25
6	2.25 ± 0.32

SensL XA

OV [V]	PDE [%]
2	2.37 ± 0.37
2.5	2.59 ± 0.42
3	2.73 ± 0.42

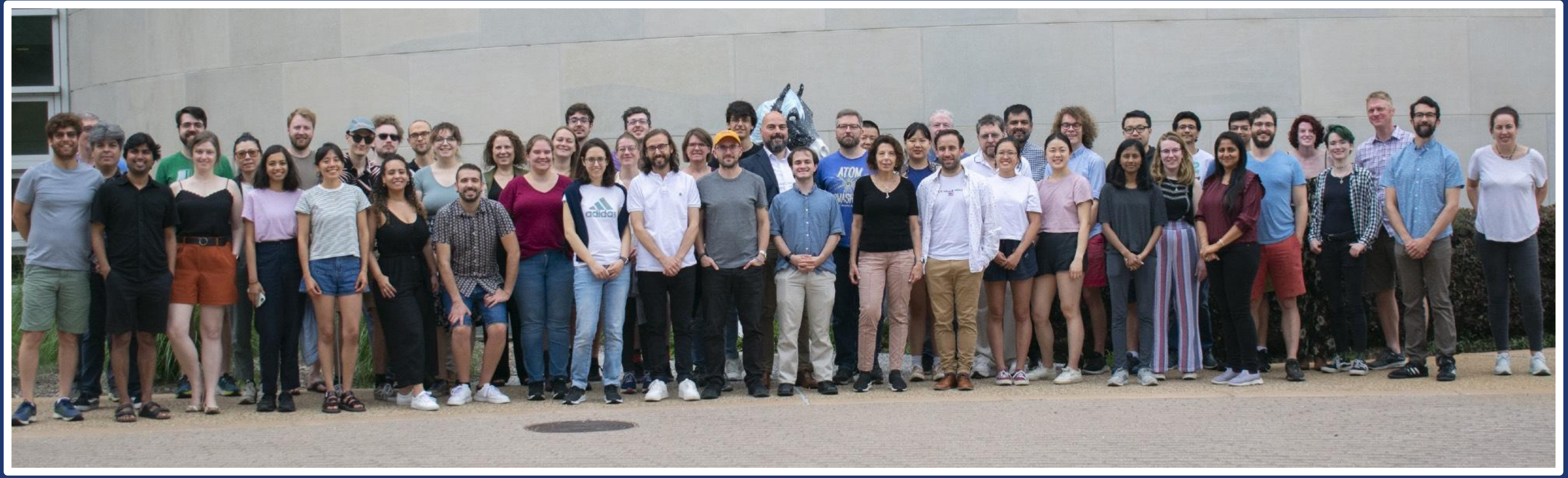
- Preliminary results, main uncertainty comes from the reference SiPMs PDE efficiency* (~14%).
- PDE to visible light challenging due to dichroic filter transmittance dependance on incident angle.

*JINST 17(04), 2022

Conclusions

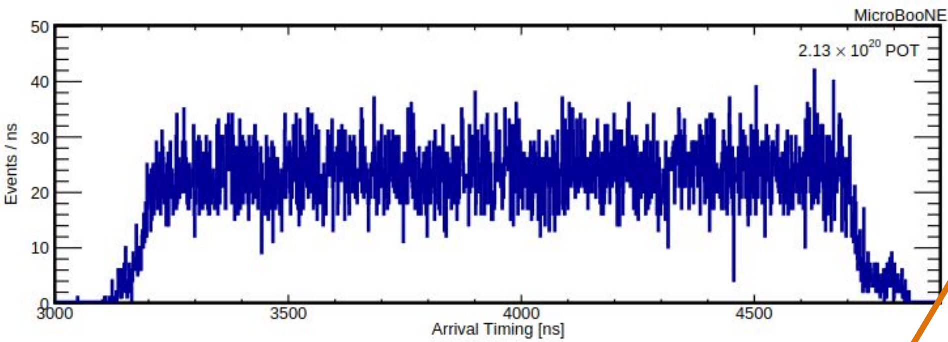
- ➔ SBND PDS plays a key role for the experiment: triggering, background rejection, but also nanosecond timing resolution opens new opportunities and searches.
- ➔ The unique design of the PDS allows for new analyses and provides crucial information for future LArTPCs such as DUNE.
- ➔ Installation of cold side electronics has been completed. Warm side commissioning already under way. Start of operations in early 2024.
- ➔ First results on the PDE of SBND X-ARAPUCAs, based on measurements performed at CIEMAT lab, are presented.
- ➔ SBND detector will be taking data in the near future, stay tuned!

Thank you for your attention!

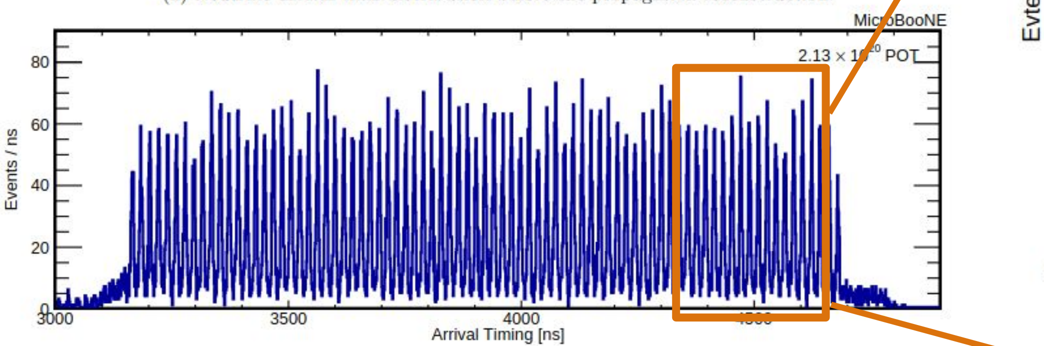


Massive long-lived particle searches

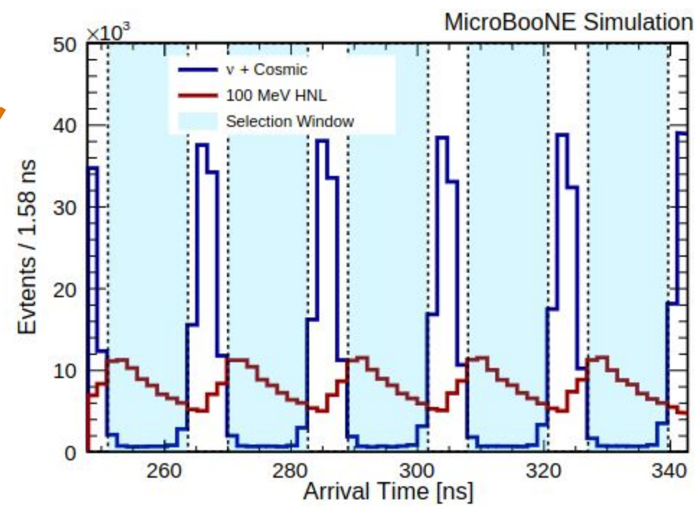
Decays out of the expected neutrino windows can hint new BSM particles in our detectors!



(a) Neutrino arrival time distribution before the propagation reconstruction.



(b) Neutrino arrival time distribution after the propagation reconstruction.



(b) When the timing resolution can resolve the BNB substructure, each gap between the 81 bunches can be used to estimate the sensitivity to HNL.

[arXiv:2304.02076](https://arxiv.org/abs/2304.02076)

PDE in a nutshell

For both VUV and visible light, we can compute the PDE efficiency by comparing XA response with VUV calibrated SiPMs for the same light source:

From data

Our estimation (MC, analytical …) = R_{Geo}

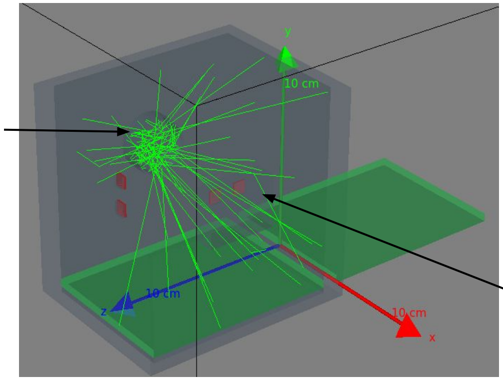
$$Measured\ Ratio: \quad R_{meas} = \frac{PE_{XA}}{PE_{SiPM}} = \frac{Photons_{XA}}{Photons_{SiPM}} \times \frac{PDE_{XA}}{PDE_{SiPM}}$$

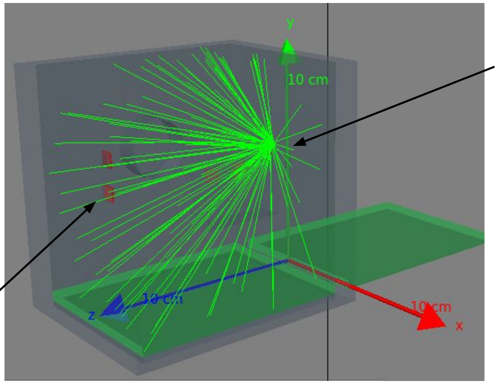
$$R_{meas} = R_{Geo} \times \frac{PDE_{XA}}{PDE_{SiPM}}$$

$$PDE_{XA} = \frac{R_{meas}}{R_{Geo}} \times PDE_{SiPM}$$

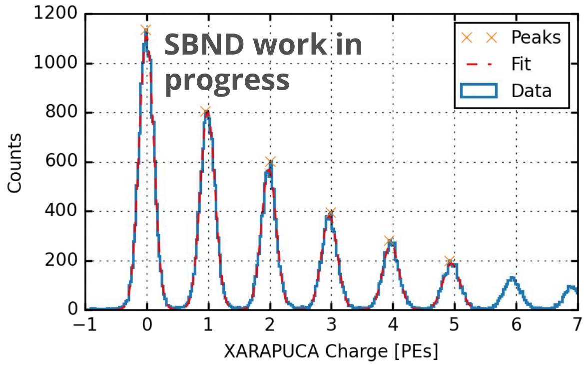
Reference sensor, known ~14% for 127nm light (https://arxiv.org/pdf/2202.02977.pdf)

G4 simulations of the setup

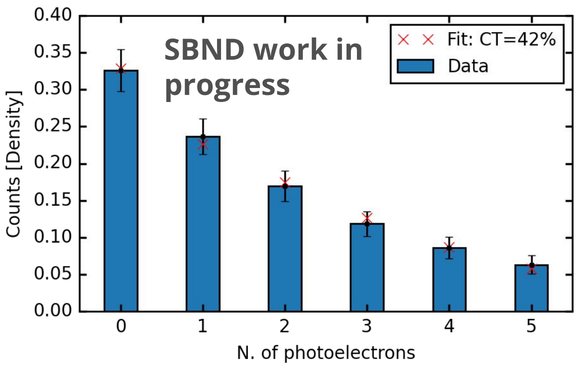




Calibration & crosstalk: Vinogradov fit



- Based on analytical approach, modeling the CT as a binomial convolved with a Poisson distribution (using calibration data runs).
- Results show good agreement with reference values for the VUV4 SiPMs (arxiv: 02977).
- Only spectra with clear pedestal and at least 4 consecutive peaks considered for the fits.



$$f(n;\mu,p) = \frac{e^{-\mu}}{n!}\sum_{i=0}^{n} B_{i,n}[\mu\cdot(1-p)]^i \cdot p^{n-i}$$

$$B_{i,k} = \begin{cases} 1 & \text{when } i=0 \text{ and } k=0 \\ 0 & \text{when } i=0 \text{ and } k>0 \\ \frac{k!(k-1)!}{i!(i-1)!(k-i)!} & \text{otherwise} \end{cases}$$

SensL XA

OV	Crosstalk value(%)	Error	Relative (%)
3.5	20.47	0.36	1.75
4.5	29.45	0.76	2.58
6	42.40	1.52	3.59

Hamamatsu XA

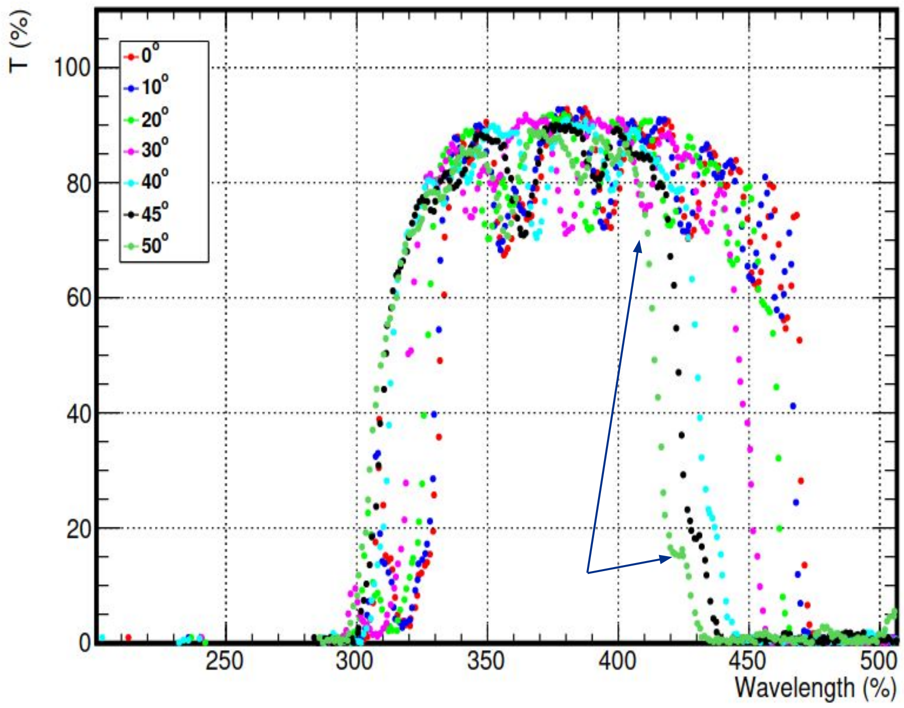
OV	Crosstalk value(%)	Error	Relative (%)
2	6.16	0.33	5.30
2.5	7.11	0.49	6.85
3	9.56	0.48	4.99

Reference SiPMs

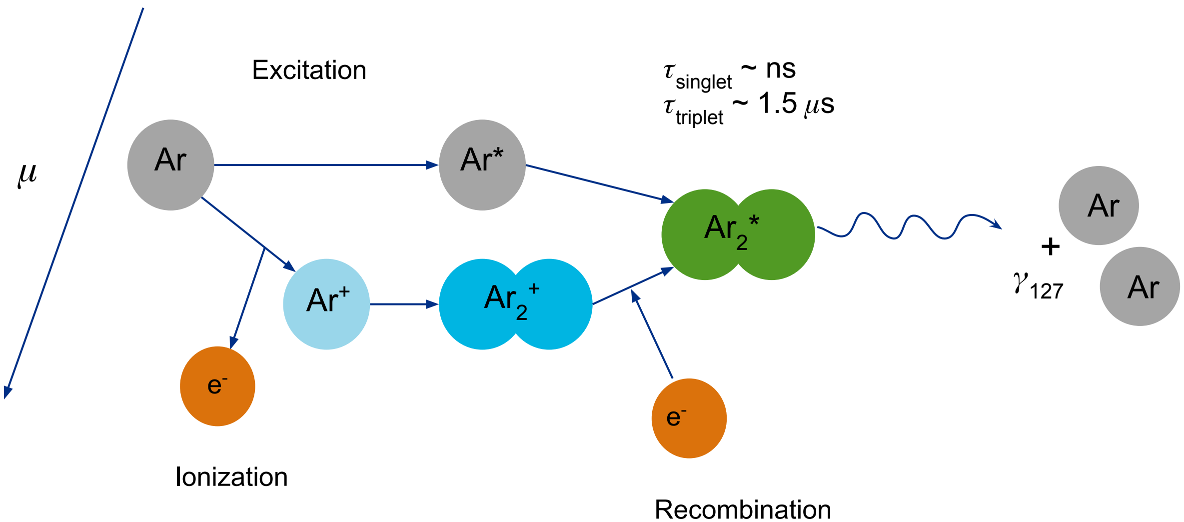
OV	Crosstalk value(%)	Error	Relative (%)
3.00	10.02	0.08	0.75
4.00	14.84	0.29	1.63
5.00	23.81	0.98	2.82

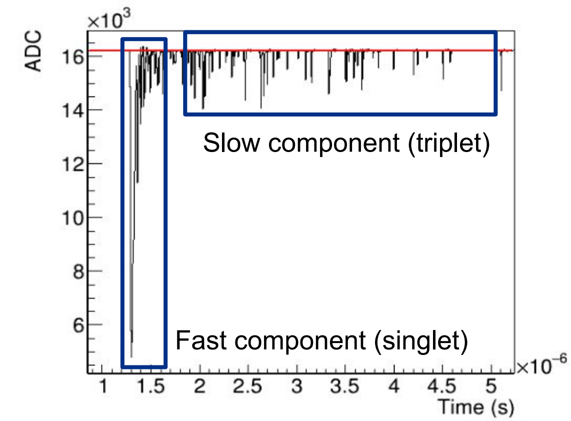
Visible filters transmittance

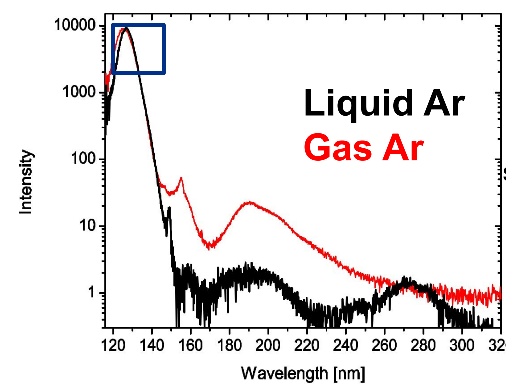
SBND VIS filter transmittance for different
incident angles in air, measured at CIEMAT



Liquid argon scintillation light







Emission spectra of argon

EPL (2010), *91*(6), 62002

LArTPCs working principle

- ➔ Charged particles produce ionization electrons and scintillation photons inside the TPC.
- ➔ Photon sensors measure the interaction time t_0 with ns precision.
- ➔ Electric field drifts e^- towards anode plane.
- ➔ Wire planes(or other readouts) detect the e^- producing 3D mm-level resolution images.