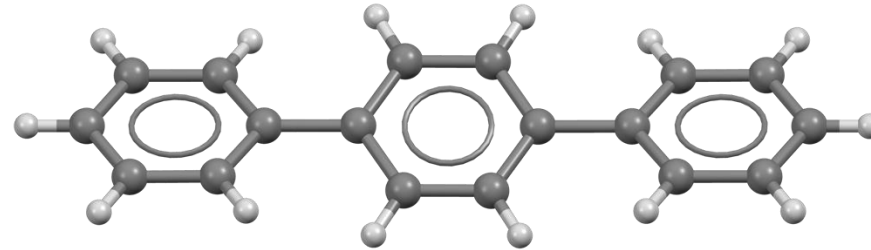


Stato delle facility di deposizione del p-Terphenyl (Napoli e Pavia)

F. Di Capua on behalf of Napoli Group
Frascati, Meeting Annuale DUNE Italia
10/11/2025

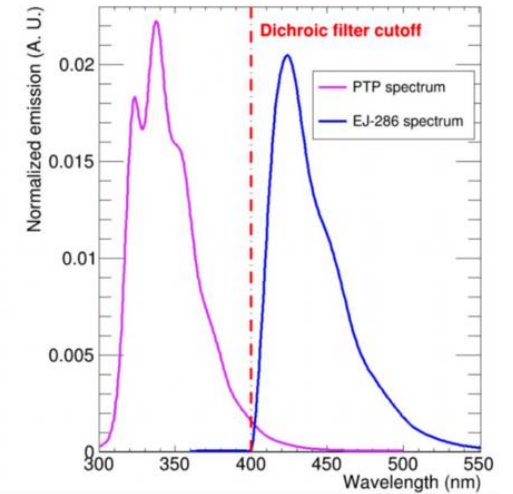
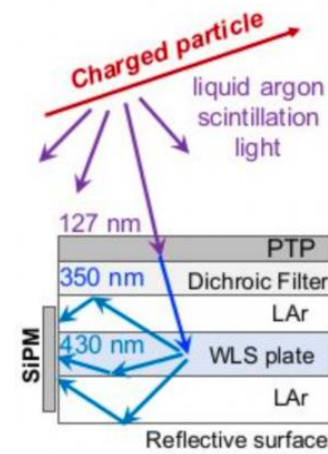


Outlines

- **WLS Vacuum Deposition Design**
- **Description of the evaporation system**
- **Installation of systems in Napoli and Pavia**
- **WLS Coating Process**
- **Evaluation and characterization of the WLS coated substrates**
- **Conclusions**

WLS deposition of the optical substrates

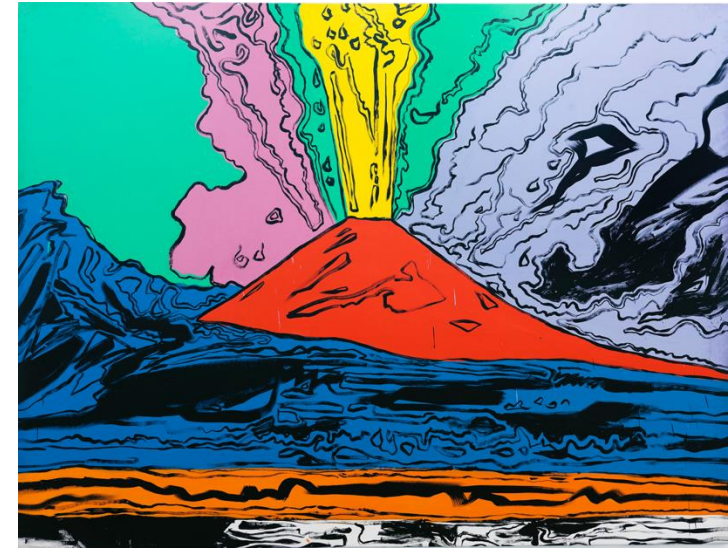
- In the X-ARAPUCA photon detection system, the external surface of the optical substrate coated with PTP used as wavelength-shifting material
- A thin film of PTP (200-500 $\mu\text{g}/\text{cm}^2$) deposited on the external surface of the optical windows to convert 128 nm VUV to 350 nm visible light and achieve high photon conversion yield
- Evaporation systems designed and constructed for the deposition of PTP onto surfaces of optical windows
 - European site for PTP coating on optical substrates (for DUNE Vertical Drift Far Detector) hosted in **Naples and Pavia**
 - Evaporation of filters of XA-VD Modules for cathode (320 double sides) and membrane (320+32 single side),
 - 24 substrates for module + spares, **on overall 16600 substrates**



WLS Vacuum deposition design

Evaporation chamber designed considering the following parameters:

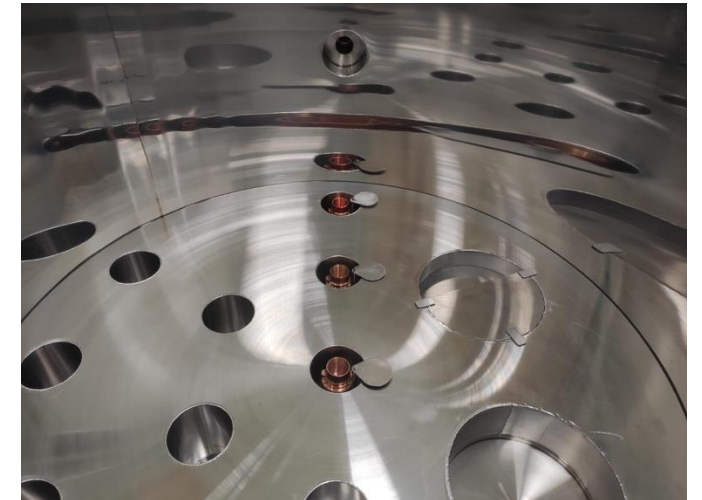
- Size/dimensions and shape of the chamber
- Uniformity of the coating
- Vacuum level
- Number of samples and/or materials deposited per cycle
- Cylindrical symmetry chambers widest used to ensure higher uniformity
- Height of the chamber impacting on the uniformity and on the number of evaporation sources
- Transverse dimensions important requirement for hosting the number and the size of parts to be coated
- Relevant time (order of hours) requested for large evaporators to reach the vacuum level matching the required mean free path allowing for the evaporated molecules to coat the substrate



Vacuum
Evaporation
System for
Ultra
Violet
Optics

Napoli Evaporation System Overview

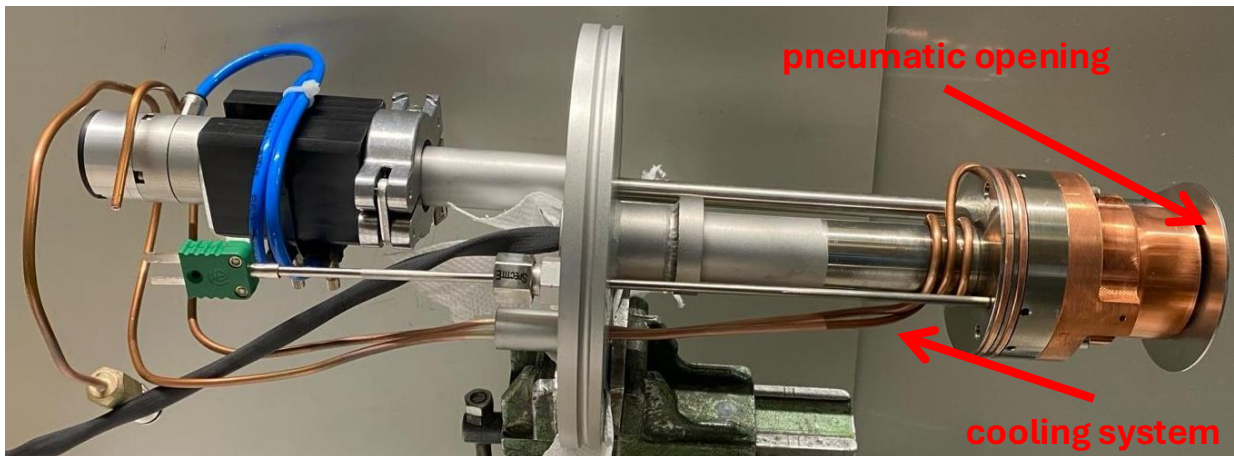
- Stainless Steel cylindrical vacuum chamber:
 - 120 cm diameter - 70 cm height
 - Electropolished inner parts
 - Removable dome flange
- Helium leak test performed with leak rate $<10^{-10}$ mbar/l/s
- Motor with rotating feedthrough and disk holder
- Three (3) crucibles+control units
- Thickness measurement unit
- Pumping system (designed to have a vacuum level of the order of $\sim 5 \times 10^{-5}$ mbar in ~ 1 h)
 - Primary dry pump (40 m³/h)
 - Turbopump (2300 l/s)
- Evaporation system hosted in a ISO-6 Clean Room



Crucibles and Control System

Knudsen cells

- About 30 cm³ volume/each
- Stainless steel body on DN 100 ISO-K flange
- Copper crucible designed to host fused silica crucibles for high purity coatings
- 1000 W heating modules
- Working temperature at ~230-250°C (maximum temperature 500°C)
- Electro-pneumatic opening and cooling system



Integrated control system including:

- Pump system control
- Vacuum monitoring
- Crucible temperature controls
- Pneumatic caps for opening/closing crucibles
- Disk motor switch and speed regulator
- Thickness monitoring

Deployment of Substrates

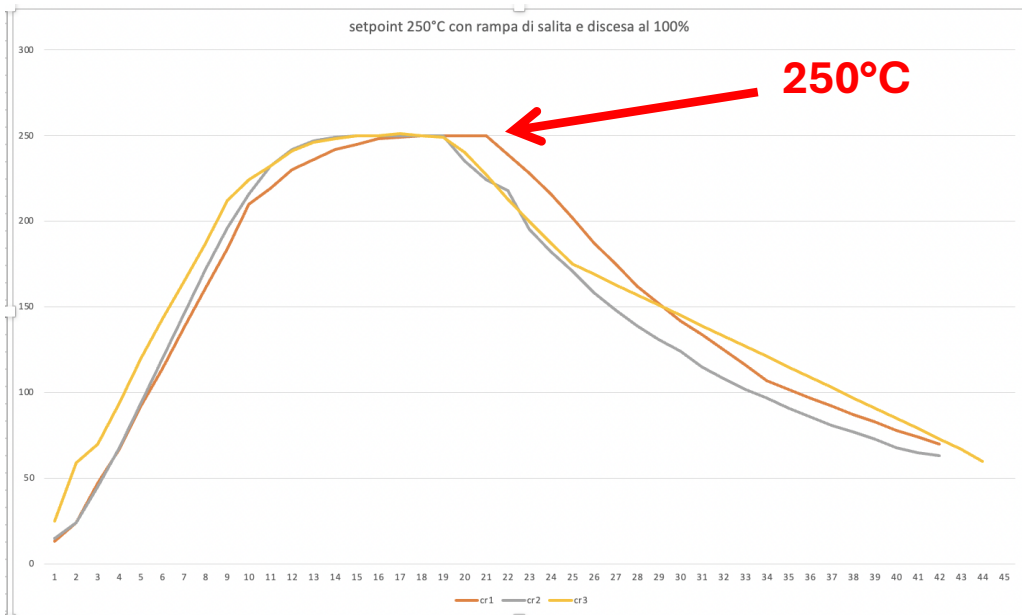
Substrate positioning system designed to facilitate efficient handling, precise placement, and stable support of coated parts

- **Full removable dome with crane:**
allowing safe and convenient access to the chamber for installation, cleaning, and maintenance
- **Dome holding structure:**
securing the dome during operation, ensuring stability to withstand mechanical loads and unloads
- **Dedicated substrate supporting frame with slots for substrates:**
frame to precisely holding multiple samples or substrates simultaneously, ensuring uniform treatment and repeatability of production batches
- **Versatile interface:**
system offering adaptability to accommodate various holders and support frames, enabling flexibility for different substrate sizes, shapes and configurations



Evaporation System Installation

- Installation and test of the pumping system and vacuum tightness
- Installation and test of the Knudsen Cells:
 - PID controlled temperature
 - Set point stability of the temperature checked
- Finalization of tests for some additional controls and small hardware adjustment
- Commissioning already started
- First evaporation expected soon for fine tuning of parameters of the process
- Coating of the optical substrates foreseen for the beginning of 2026



Vacuum Evaporation Operations

Phases of operations

• Preparation

- Mounting of the filters on a proper holder
- Weighting of the reference samples
- Mounting of the holder on the dome flange



• Coating

- Vacuum phase till $\sim 5 \times 10^{-5} - 5 \times 10^{-6}$ mbar
- Starting and monitoring of the evaporation
- End of coating, breaking of the vacuum and back filling with gaseous nitrogen
- Opening of the flange and removal of the coated filters and samples



• Quality Control

- Visual inspection of the coatings and samples
- Placement of the filters in appropriate shipping boxes
- Quality check of the reference samples

Characterization of Coatings

- Visual check of the overall deposition process
- Further Check of 10% of coated samples for each evaporation process:
- **Measurement of mass densities** with precision scale ($O(10^{-5} \text{ g})$)
- **Conversion yield test:** spectrofluorimeter measurements compared wrt a reference sample
- **Adhesion test:** controlled-slow immersion of samples/substrates in liquid nitrogen
- **Photo-conversion test:** measurement of the conversion efficiency by illuminating the reference samples with UV light



Low Temperature Test

Detailed and controlled procedure to ensure integrity of the coatings under cryogenic conditions

- **Adhesion Test:**

adhesion test for the coated samples using a controlled low-speed motorized system moving at ≤ 5 mm/min to evaluate the bonding of the PTP to the substrate

- **Immersion in cryostat:**

samples immersed for ~ 60 minutes in a cryostat filled with liquid nitrogen (~ 77 K) to assess thermal, mechanical, and structural stability

- **Extraction Handling:**

after dipping, substrates carefully extracted into a nitrogen gas-saturated ambient environment to prevent moisture-induced damage or degradation of the coating or substrate during warming



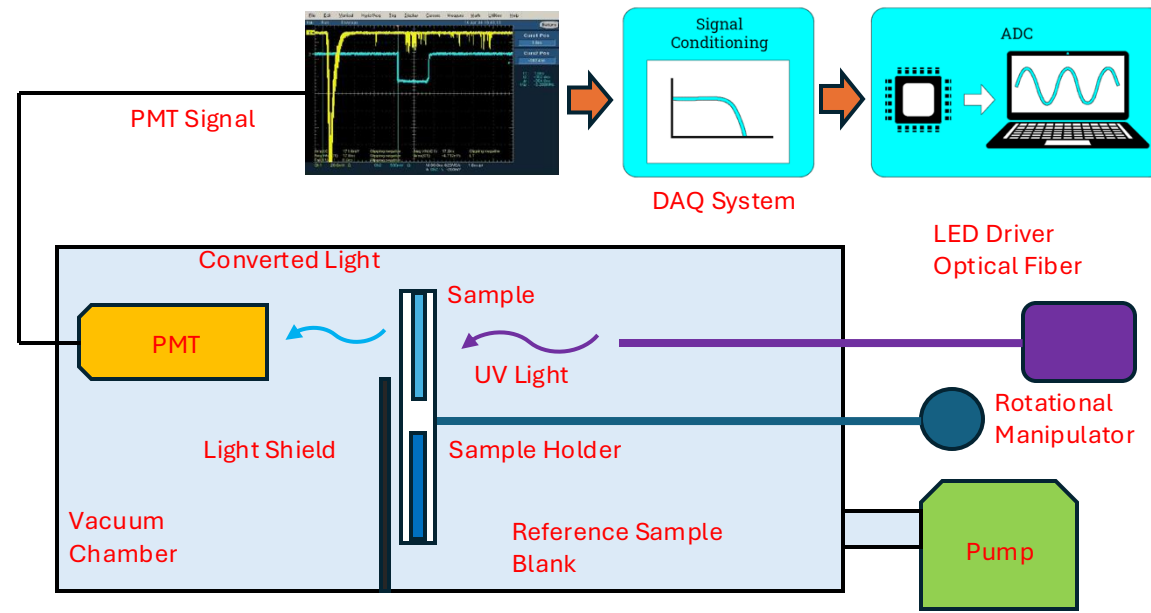
Conversion Efficiency Measurements

Systematic procedure to measure the photon conversion efficiency (PCE) of coated samples and evaluate the effect of immersion in liquid nitrogen (LN)

Controlled environment setup to characterize PCE of coated samples using a PMT and UV illumination

Measurement of relative photon conversion efficiency in comparison with blank, reference samples, same sample before and after the LN dipping

Concept Design of the PCE System



Evaporation Station in Pavia

- **Setup of the pTP deposition facility:**

- Installation of the evaporator: chamber and evaporation cells in an advanced phase of construction – delivery expected in January 2026.
- Production of approximately 20% of the pTP coatings for the DUNE FD.

- **Characterization of coating uniformity:**

- Ongoing setup of a dedicated UV optical system operating under vacuum to characterize a subset of depositions.

- **Initial evaporation tests:**

- Material samples (pTP) for initial evaporation tests have already been purchased.
- Tests to be planned in collaboration with the Naples group.

- **Additional PDS activities** include the characterization of alternative wavelength shifters and light detector prototypes, mainly in collaboration with the Milano-Bicocca group.

Conclusions (1)

- Large evaporation system (**VESUVIO**) designed, constructed and installed at INFN-Naples for PTP coating of optical filters substrates of the PDS devices of FD-VD of DUNE experiment
- Another fully equivalent system will be delivered to INFN-Pavia at the beginning of 2026
- Evaporation system designed to host (quite) large parts, have the flexibility for coating different materials (glass, quartz, scintillation bars, acrylic, metals, alloys, phototodosensors, etc.) and allow 2 complete deposition cycles per day
- Commissioning of the coating station already started, finalization of tests for some additional controls ongoing, fine tuning of the parameters for the process expected soon
- INFN RDA for **two technician service** for one year has been placed, order is going to be processed by local administration
- At the beginning of 2026, the training of the technicians will be a crucial phase to ensure the accuracy and the successful outcome of the process

Conclusions (2)

- Complementary quality controls and characterization of the coatings through several methods (measurement of mass densities, adhesion test in LN, photo-conversion yield measurements) will be performed
- Some set-ups already designed, constructed and/or ready for operations, other systems in progress
- Important collaboration with Chemical Department and CNR-SPIN
- Dedicated vacuum evaporation systems are an integral part of LAr detector preparation, used to apply WLS layers precisely and ensure optimal light collection and timing for neutrino physics experiments and rare events search
- Proper evaporation and handling procedures are essential for maximizing the stability and conversion efficiency of the coatings enhancing the overall photon detection system performance in large liquid argon detectors
- **And now.....as already mentioned in other contexts.....**

...Amma Faticà



Back-up

Conversion Efficiency Measurements

Systematic procedure to measure the photon conversion efficiency (PCE) of coated samples and evaluate the effect of immersion in liquid nitrogen (LN)

Controlled environment setup to characterize PCE of coated samples using a PMT and UV illumination

Measurement of relative photon conversion efficiency in comparison with blank, reference samples, same sample before and after the LN dipping

Process to ensure reproducible measurements of photon conversion efficiency and photodetector performance:

- **PMT Stabilization:** (~15 minutes) to ensure stable gain and minimal noise, after powering on the PMT
- **Chamber Evacuation:** to $\sim 10^{-2}$ mbar to reduce moisture and prevent contamination potentially affecting optical measurements
- **Single Electron Response (SER) Acquisition and PMT Gain Tuning:** calibration of the PMT gain to optimize sensitivity and ensure accurate photon counting
- **Sample Illumination:** illumination of samples with 260 nm UV light from an LED driver to convert UV photons into visible photons
- **Signal Acquisition:** intensity or count of converted photons recorded by the PMT, capturing the quantitative photon output from each sample
- **Relative Efficiency Measurement:** photon conversion efficiency calculated by comparing the signals from coated samples with blank/reference samples and by comparing the same sample's performance before and after LN dipping

Concept Design of the PCE System

