R&D on liquid argon detectors

dr hab. Marcin Kuźniak, prof. CAMK PAN
(Group 1 – SiPM systems for astroparticle and medical physics)

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 952480

Dark Wave

European Funds Smart Growth

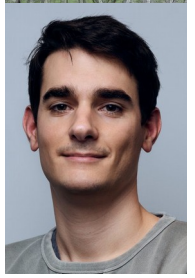
Republic of Poland

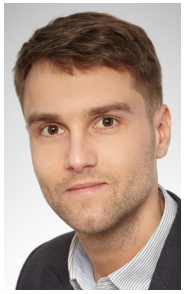
FNP Foundation for Polish Science

European Union European Regional Development Fund

Group 1 profile

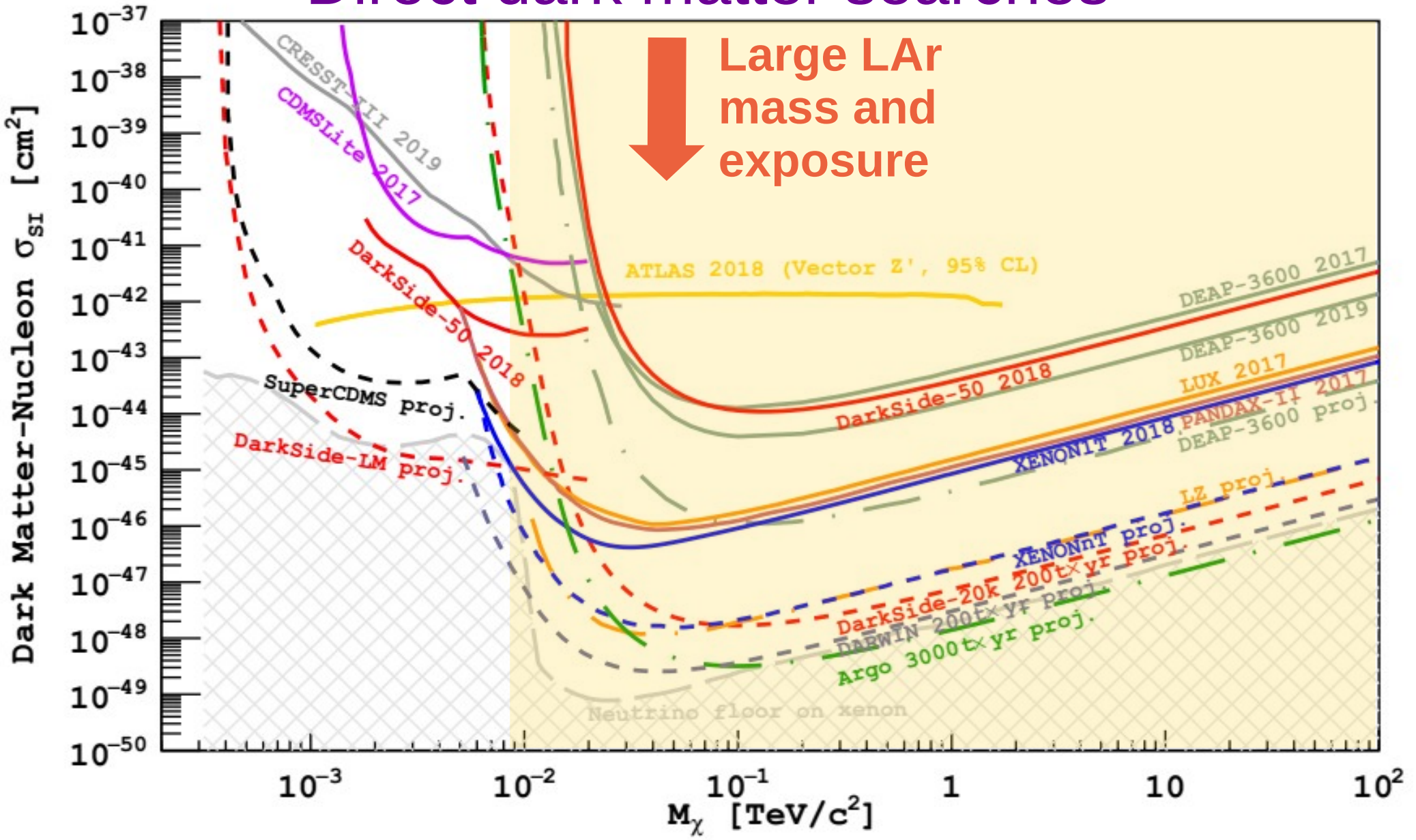







- Group members:
  - **Leader** Marcin Kuźniak
  - **2 PhD students:**
    - Sarthak Choudhary
      - Pulse shape discrimination analysis + light collection optimization
    - Theo Hugues (cotutelle GeoPlant/CAMK and APC Paris)
      - DEAP-3600 physics data analysis
      - Annual modulation analysis for DarkSide-50
  - **2 Postdocs:**
    - Michał Olszewski
      - Monte Carlo simulations
    - Marek Walczak
      - SiPM analysis software development, analysis and testing
  - **Visiting scientist:** Andre Cortez
  - **Support from technicians and an engineer**
- Access to electronics, chemistry and cryogenic (cleanroom) lab at CEZAMAT
- Cooperation agreement with the University of Warsaw, Chemistry Department

Direct dark matter searches

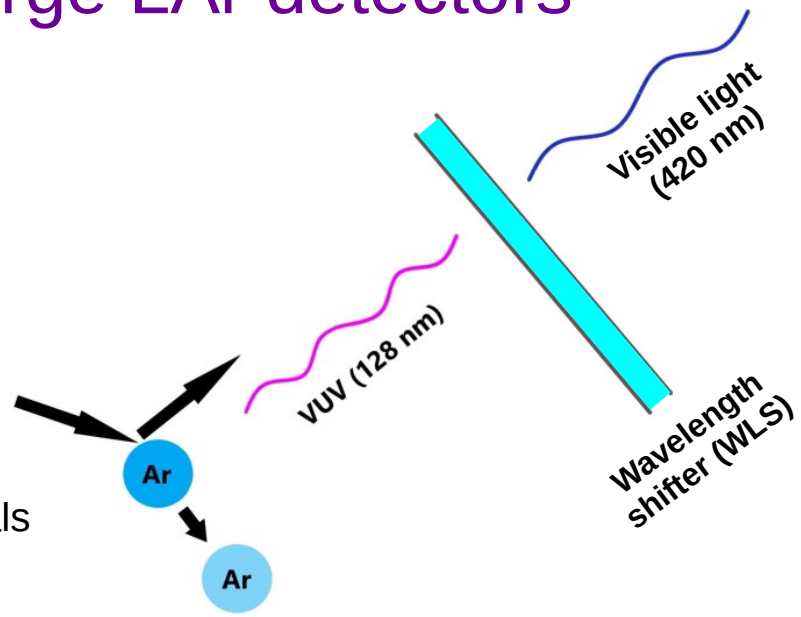


- Current detectors (DEAP) have several tons of liquid argon (LAr)
- Scale-up x100 needed for ARGO, with the ultimate senstitivty to the “neutrino floor”
- Roadmap in place for global consolidation of efforts and R&D

Our specialty:
light collection/detection in large LAr detectors

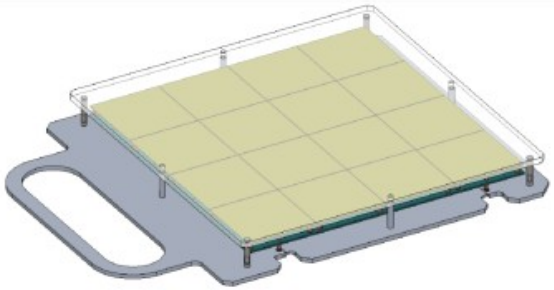
Next generation detectors will have 100- 10000 m² of surface area

- **Light collection**
  - Wavelength shifter (WLS) materials
    - Liquid argon scintillates at 128 nm (VUV)
    - Proposed a new scalable material (PEN)
    - Developed concept for new wavelength shifting materials for background mitigation
  - Reflector and optics configuration/optimization
    - Photosensitive surface is expensive



- **... and light detection**
  - SiPM: new cutting edge devices, DarkSide-20k is the first experiment to use them on that scale
  - Collaboration with DarkSide-20k:

    Veto SiPM system: analysis, testing and development



20cm x 20cm SiPM array

Common challenge not only for dark matter, but also:

- Accelerator neutrino (**DUNE, FLArE**, Hyper-K)
- Neutrinoless double beta decay (**LEGEND**)
- Astrophysical neutrino (KM3NeT)

R&D at AstroCeNT

- Identified suitable PEN grade for WLS
  - Approved for DarkSide-20k veto
  - Panels for DarkSide-20k designed, cryotested for stability

Eur. Phys. J. C 79, 291 (2019)
Instruments 5, 4 (2021)
Eur. Phys. J. C 81, 1099 (2021)

- Synthesis of purified PEN

LIDINE 2023 proceedings

- Industrialized analytic code for light yield optmization and design studies

J. Phys.: Conf. Ser. 2156, 012236 (2021)

- PEDOT:PSS-based transparent electrodes, light and charge collection with WLS-FAT-GEM

Eur. Phys. J. C 81, 609 (2021)

- Slow WLS (pyrene-doped PS) for surface background rejection
- TPB-doped polystyrene for applications in water

Nucl. Instrum. Methods Phys. Res. A 968, 163631 (2020)
JINST 16, P12029 (2021)
Nucl. Instrum. Methods Phys. Res. A 1034, 166683 (2022)

- DarkSide-20k veto SiPM testing

Front. Phys. 11, 1181400 (2023)

Synergies

DS-20k, LEGEND, DUNE
- Identified suitable PEN grade for WLS
  - Approved for DarkSide-20k veto
  - Panels for DarkSide-20k designed, cryotested for stability

ARGO, DUNE
- Synthesis of purified PEN

DS-20k, ARGO, DUNE, FLArE
- Industrialized analytic code for light yield optmization and design studies

DS-LM? NEXT? DUNE? FLArE?
- PEDOT:PSS-based transparent electrodes, light and charge collection with WLS-FAT-GEM

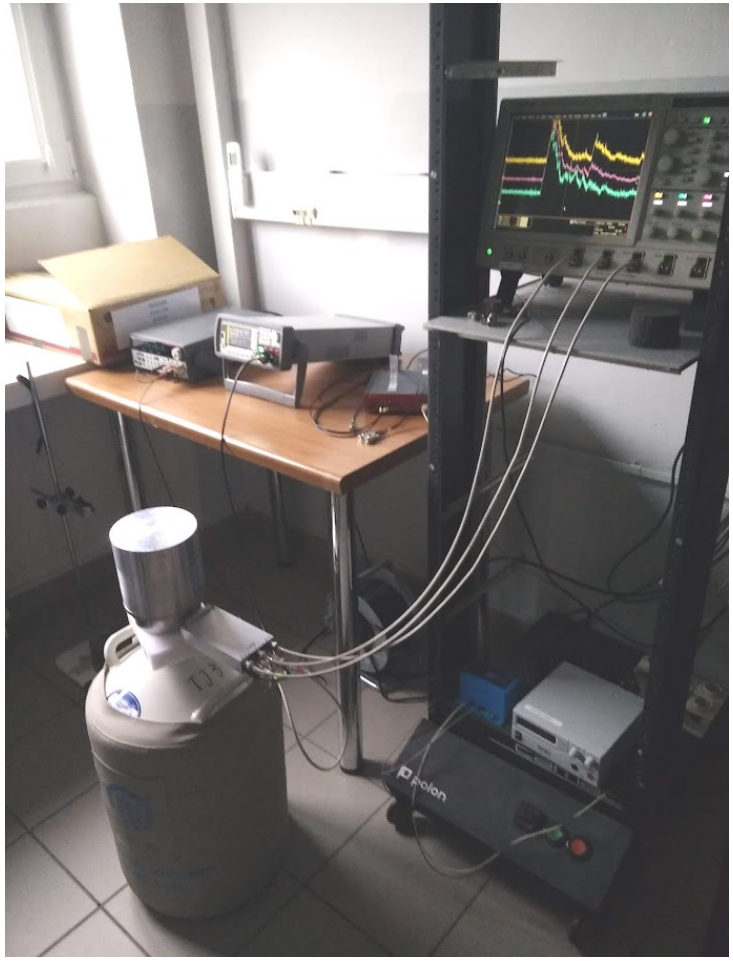
DEAP-3600
- Slow WLS (pyrene-doped PS) for surface background rejection

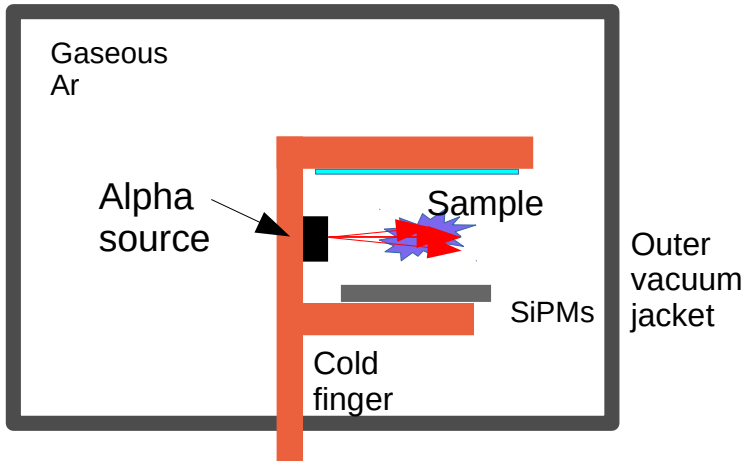
KM3NeT, Hyper-K?
- TPB-doped polystyrene for applications in water

DS-20k
- DarkSide-20k veto SiPM testing

Test stand @ AstroCeNT for quality control

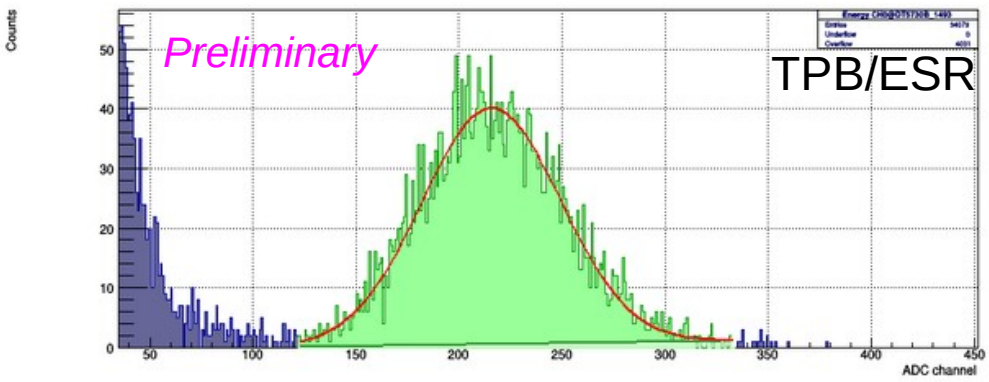
- DarkSide-20k to use ~300 m2 of PEN as the WLS in the veto
- WLSE of various PEN grades, including samples of the same grade varies
- WLSE depends on the excitation wavelength AND temperature
- Developed an alpha-excited gaseous Ar cell with a cryogenic stage
- Recently successfully commissioned an alpha-excited gaseous Ar cell with a cryogenic stage for PEN WLS quality control

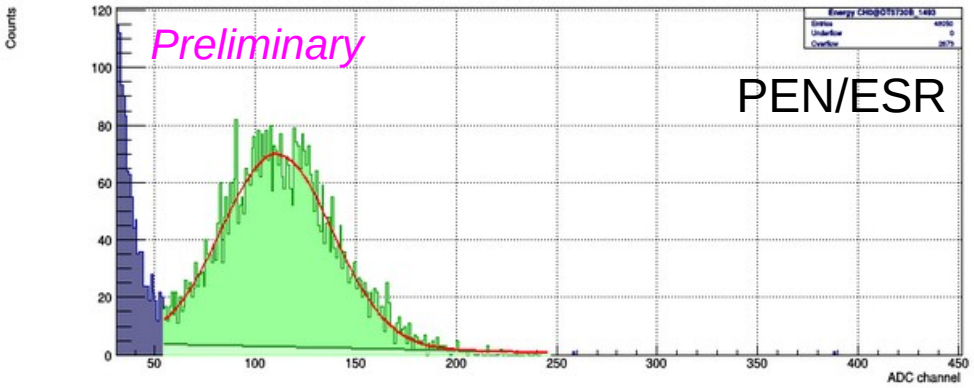




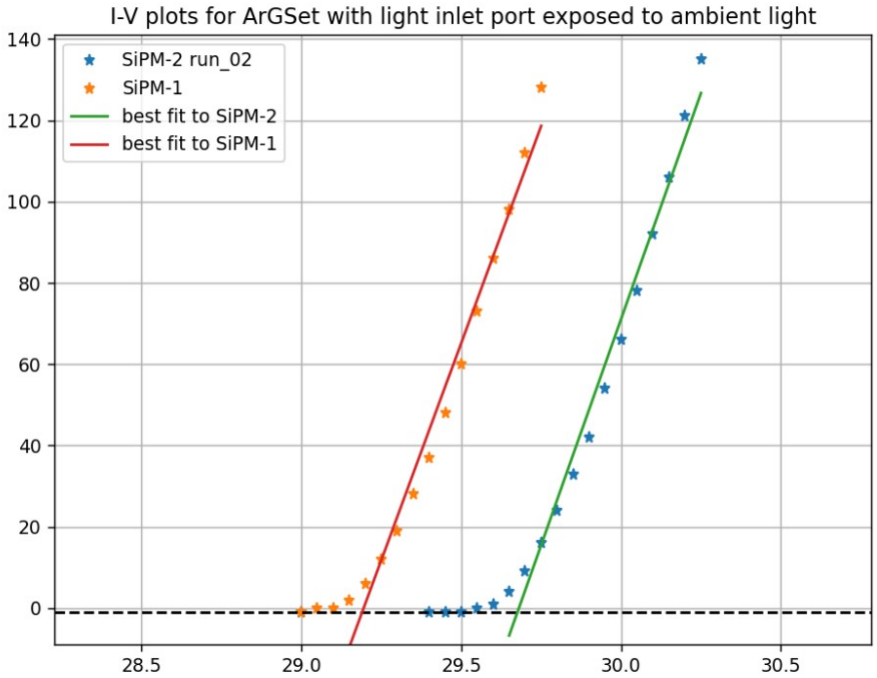
Next steps:

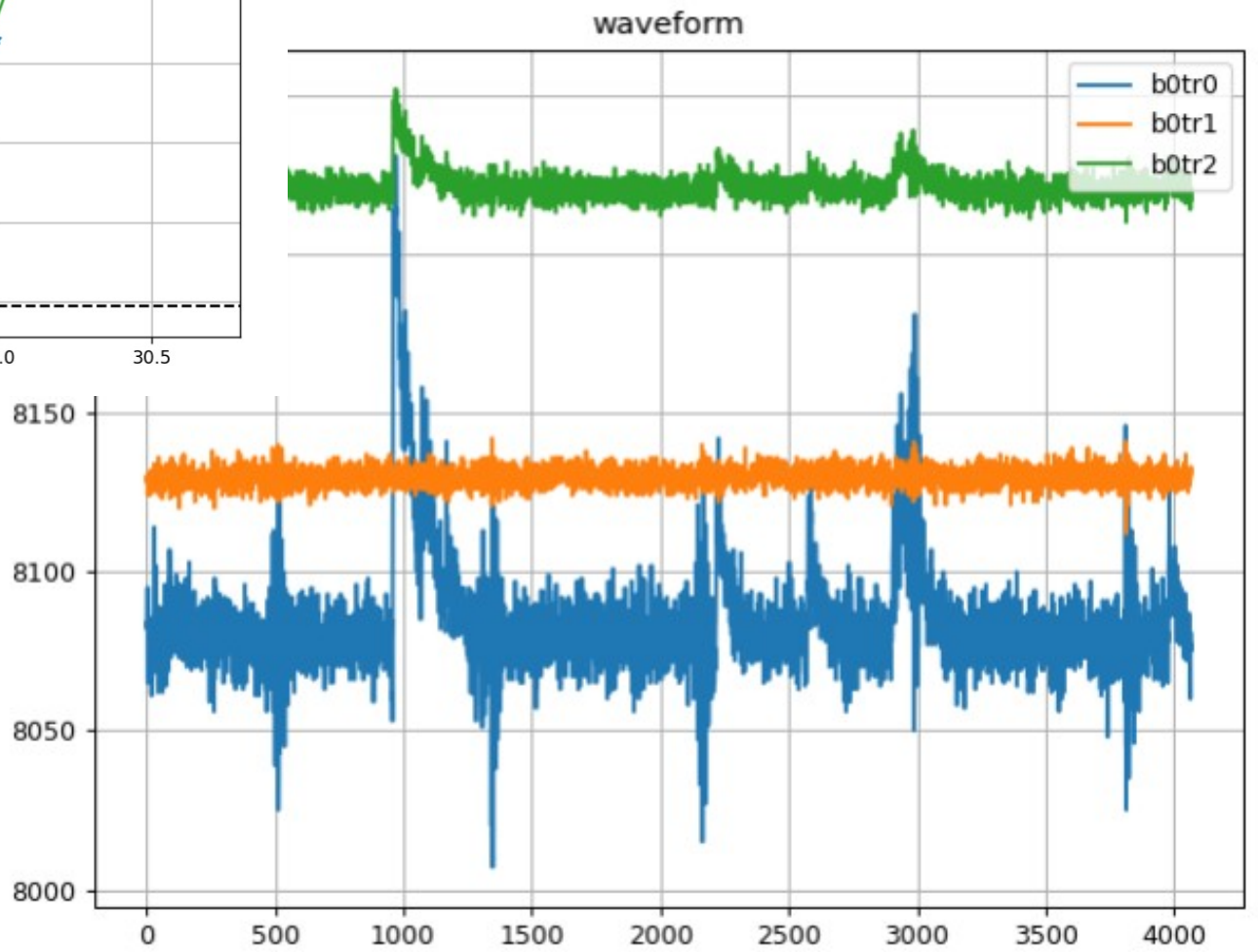
- QC for DarkSide-20k
- New materials
- Add a nanosecond-pulsed VUV source
- Gaseous TPC configuration





Ongoing calibration work

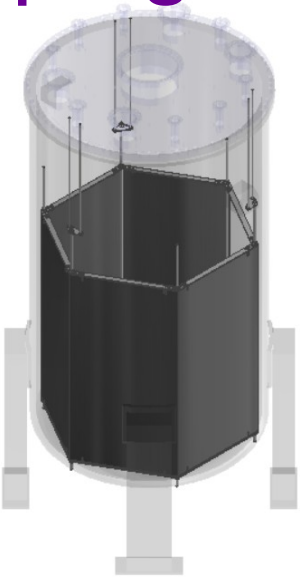


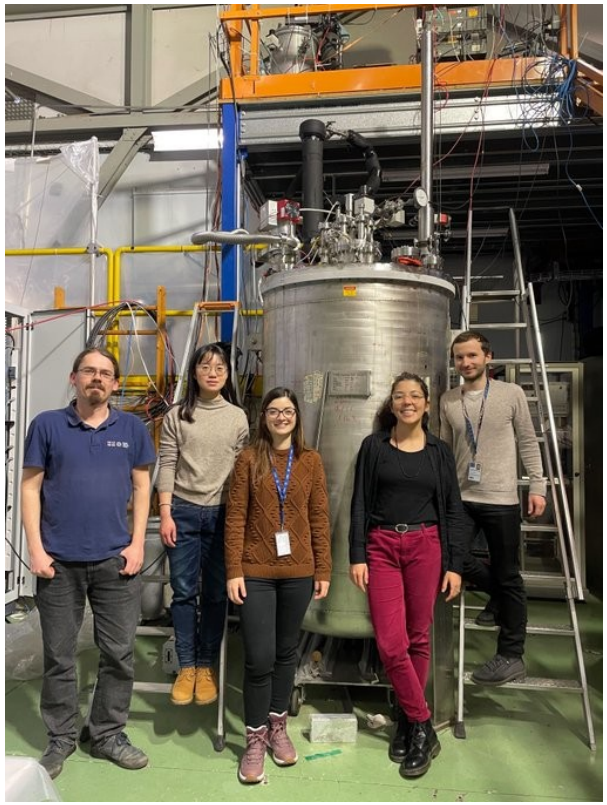


S. Choudhary
G. Nieradka
A. Cortez

General purpose WLS reflector campaign

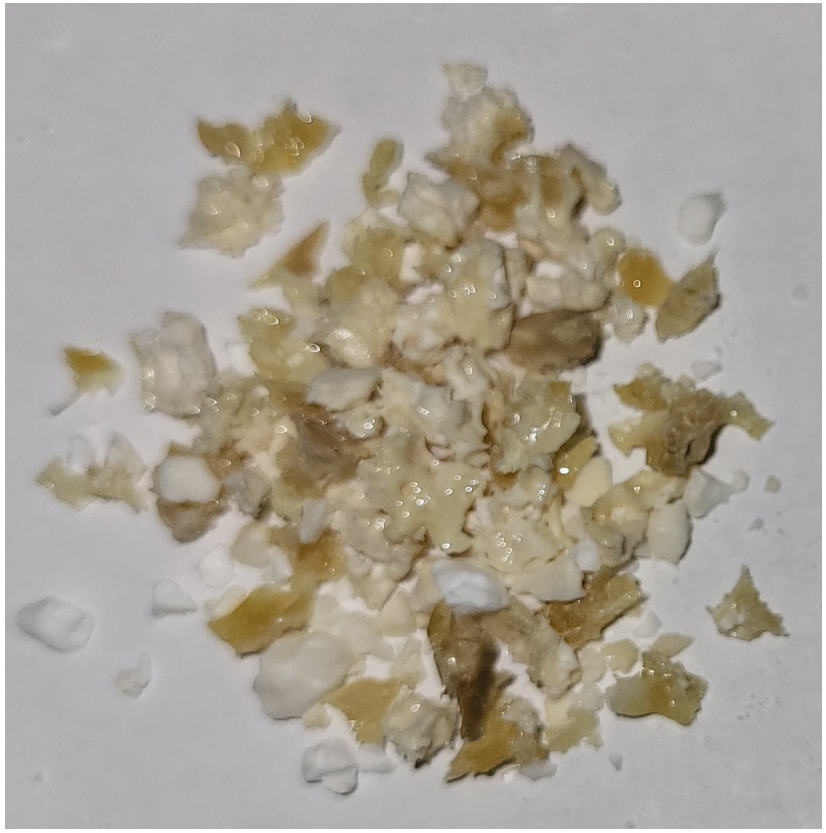
- Jointly with TUM, Uni Zurich, NIKHEF, Uni Edinburgh and CERN
  - Groups from LEGEND, DUNE and DarkSide-20k
- Most promising combination of reflector (ESR) and PEN identified with table-top measurements (Zurich, TUM, Astrocent)
- Large scale LAr test completed at CERN in February to demonstrate light yield and light yield **stability over 2 weeks** long run with an alpha source inside:
  - 1 m tall aluminum cage lined with ESR/PEN (LAr gap inbetween)
  - Viewed by 2 PMTs from the top (Vis and VUV)
  - Analysis currently ongoing

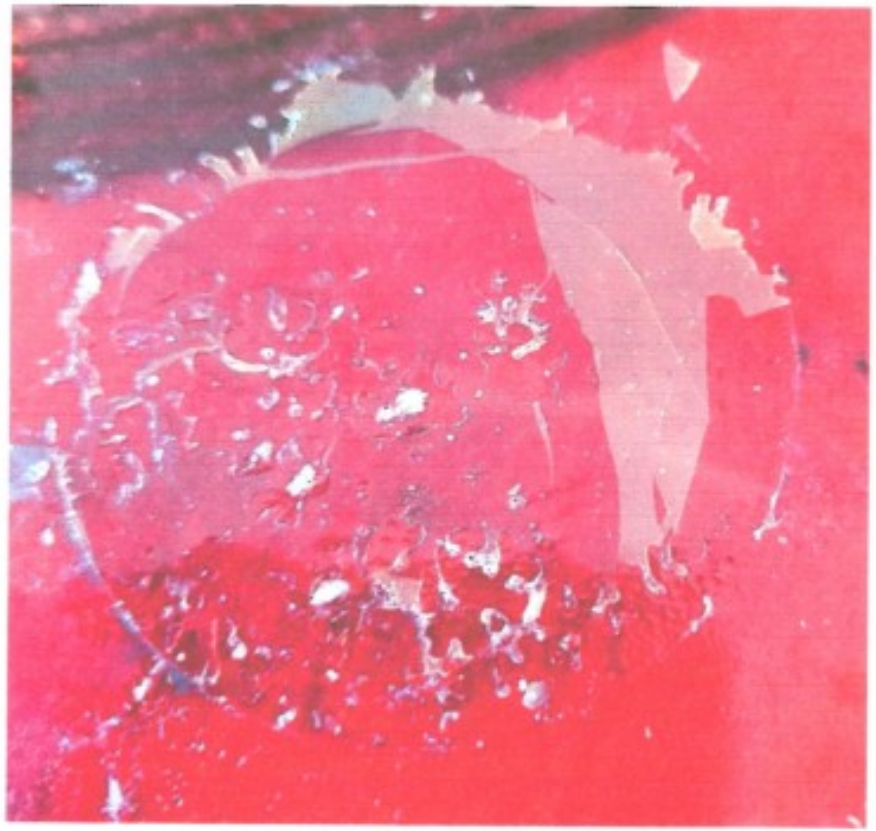




Custom synthesis

- In collaboration with Sławomir Pawłowski (Łukasiewicz Research Network – Institute of Industrial Chemistry in Warsaw)
- Starting from affordable and abundantly available base chemical
- Controlled conditions: no exposure to light, purified base chemicals
- After synthesis pressed into foils (>7kg is the threshold for drawing foils)

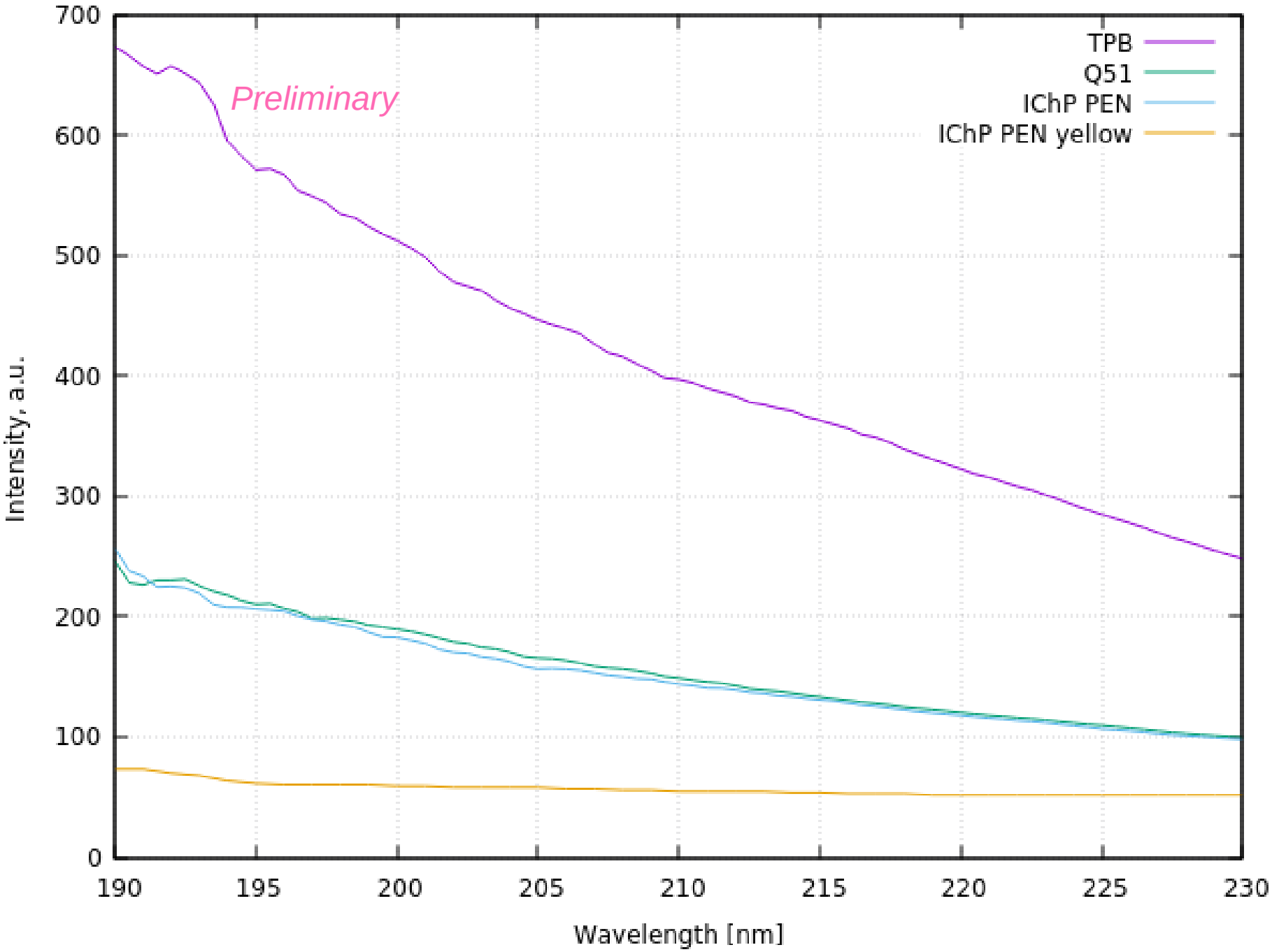




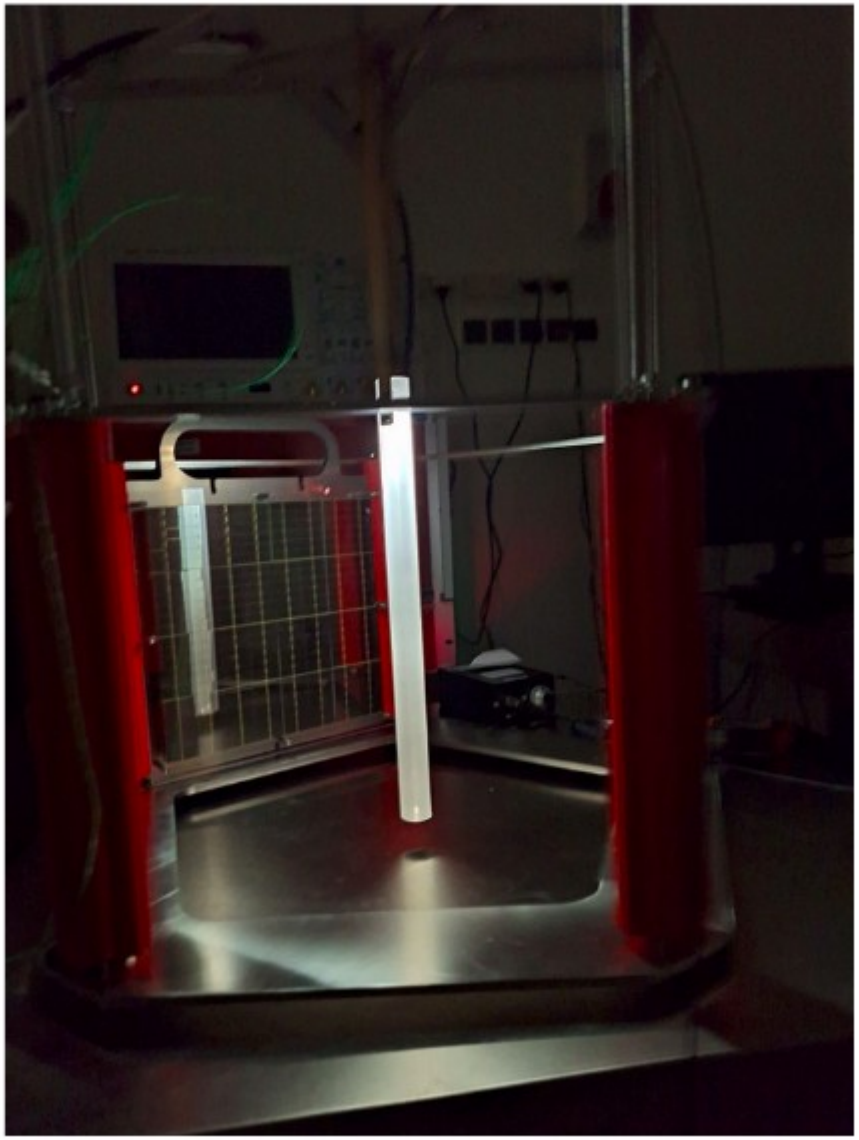
At first mixed results and visible yellow tint of the product (effect of temperature and impurities)

Custom synthesis II

- After multiple iterations and improvements, in last weeks finally clean white product!
- High crystallinity results in white color; becomes translucent when heated up and cooled down
- Next step: press into foils and compare with commercial PEN
- Might be useful in the current form as a diffuse WLS reflector
- Synthesis is scalable. Working on acquiring dedicated funds.


Preliminary
TPB
Q51
IChP PEN
IChP PEN yellow
Intensity, a.u.
Wavelength [nm]
0
100
200
300
400
500
600
700
190
195
200
205
210
215
220
225
230

DS-20k veto SiPM module testing

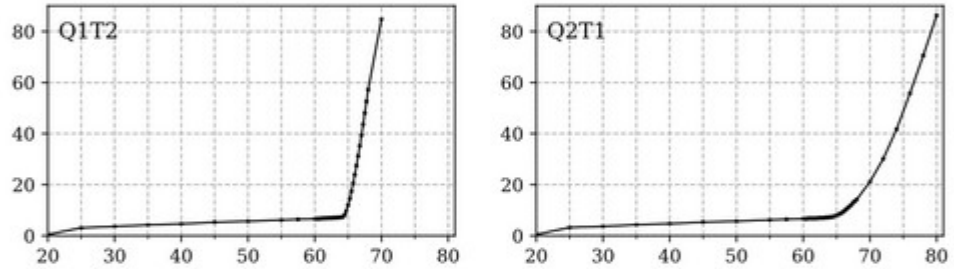


- ISO-7 class cleanroom in CEZAMAT laboratory
- Allows tests of 5 (10) units per cooldown
- CAEN power supplies and VX2740 digitizer

Slide courtesy M. Walczak

DS-20k veto SiPM module testing

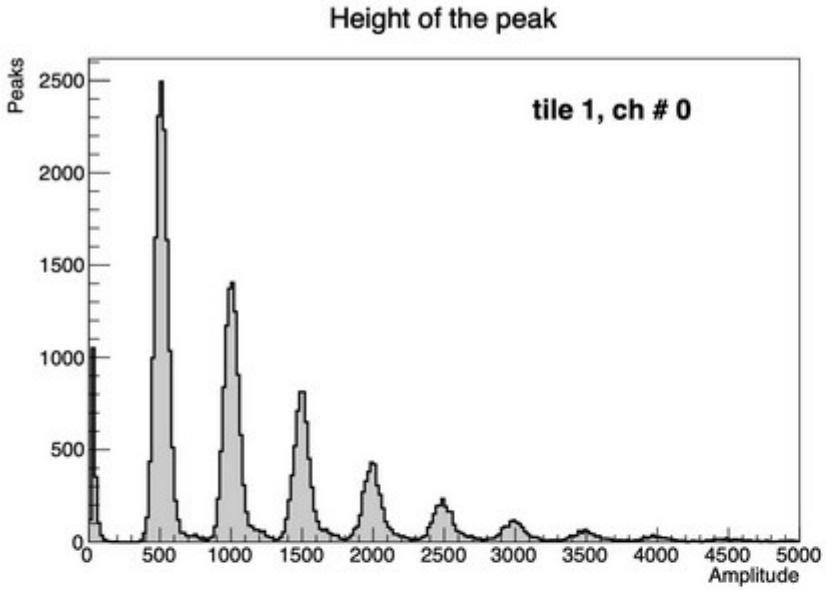
- Setup commissioning during Alice's Hammer (Edinburgh) visit (11 - 15 Sep 2023)
- First data successfully taken at warm:
- vPDU2 Warm test @ AstroCeNT - IV Curves

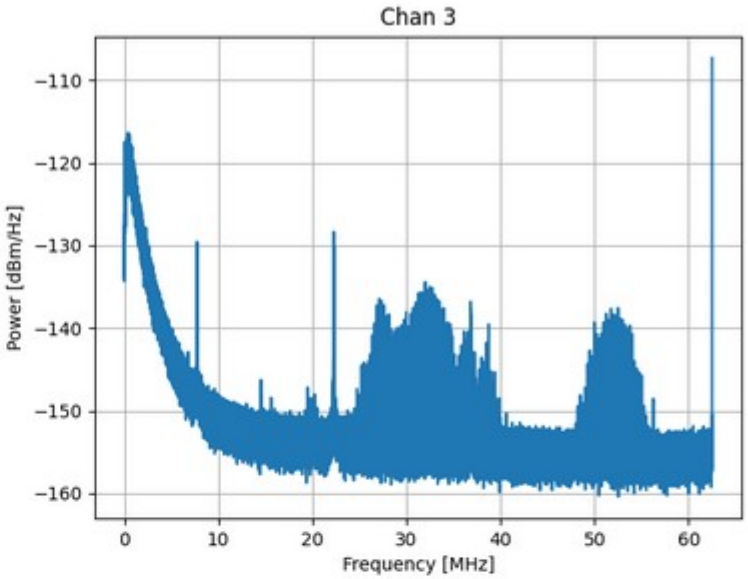


- vPDU workshop 18 - 19 Sep 2023
- Participants from INFN, University of Warwick, Edinburgh, Lancaster, and Royal Holloway University of London
- Discussions on the schedule, technical details of the setups and list of required tests

Slide courtesy M. Walczak

DS-20k veto SiPM module testing





	Bias_V	SNR	1peAmp_mV	DN_Hz_per_mm2	CDA	rms_mV	DiCT_prob	SNRError
Q1T1	68	9,727	15,246	0,155	0,071	1,512	0,393	0,022
Q1T2	68	11,289	15,484	0,173	0,076	1,340	0,362	0,024

- Results obtained for vPDU2 in Warsaw are consistent with earlier test run at INFN Napoli
- We carried out full training for PhD students
- Setup is now fully operational and ready for full scale testing

Slide courtesy M. Walczak

Data analysis

- In addition to SiPM event reconstruction for DS-20k (M. Walczak) ...

- **Joint DarkSide-50 annual modulation analysis with APC**
  - T. Hugues
  - M. Kimura, M. Wada (Group 4)

- **Continued analysis effort on DEAP-3600 dark matter search**
  - Pulse shape discrimination
    - S. Choudhary
    - M. Gupta, P. Gawron (Group 5)
  - Boosted dark matter analysis
    - T. Hugues, V. Ivanyan, M. Walczak
    - S. Trojanowski (Group 6, theory support)

New collaboration

DRD2 collaboration (Detector R&D, Task Force 2: Liquid Detectors) is forming:

- Proposal submitted and approved by ECFA and CERN
- Kick-off meetings and MoU drafting to start early next year
- Flexible platform to collaborate on multiple topics of common interest for AstroCeNT and APC

Grants

Completed

- European Commission Horizon 2020 Twinning, "**DarkWave: Novel technologies for dark matter search and frontier astroparticle physics experiments**"
  - **900 kEUR budget**
  - Consortium of CAMK (coordinating institution), APC/CNRS, GSSI, INFN and TUM
  - Training, travel, short and long-term exchange support **for all AstroCeNT groups**
  - Enables key contributions to DarkSide-20k, Virgo, Einstein telescope:
    - Measurement campaigns
    - Study visits
    - Workshops and meetings
    - Up to 10% for equipment
  - Admin. coordination / communication by Y. Hoika

https://darkwave.astrocent.pl

Ongoing

- M. Kuźniak, 2.1 MPLN/ 3 yr, Search for dark matter with liquid argon detectors, **OPUS, NCN**

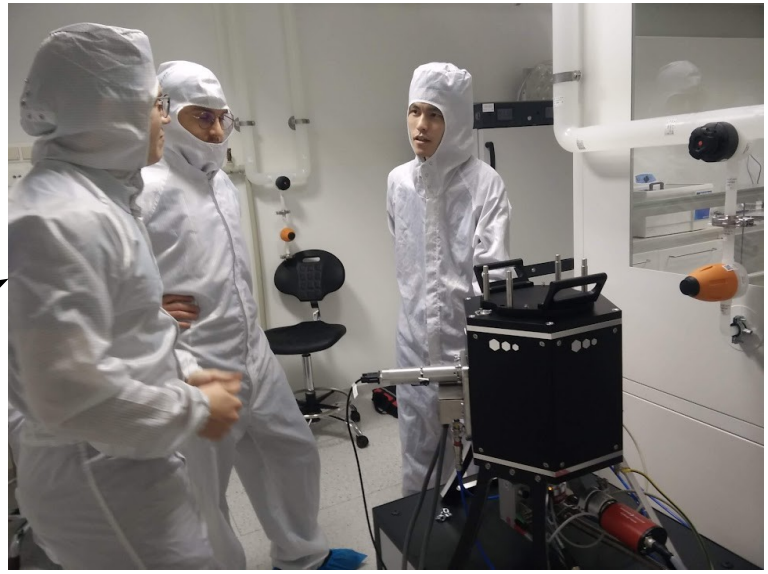
Submitted

- 3 proposals from Andre Cortez (NCN Sonata, FNP First Team, MSCA PF)

Summary

- Active on DEAP-3600 and DarkSide-20k data analysis

- New hardware capabilities:
  - vPDU cryogenic test setup
  - Access to UV/Vis/NIR spectrophotometer
  - Cryogenic gaseous Ar cell for WLS characterization
  - Thin film deposition: spray gun, **10” spin-coater** and **10” vacuum evaporator**
  - Recently received funding for a cryogenic optical characterization facility with a nanosecond pulsed VUV light source



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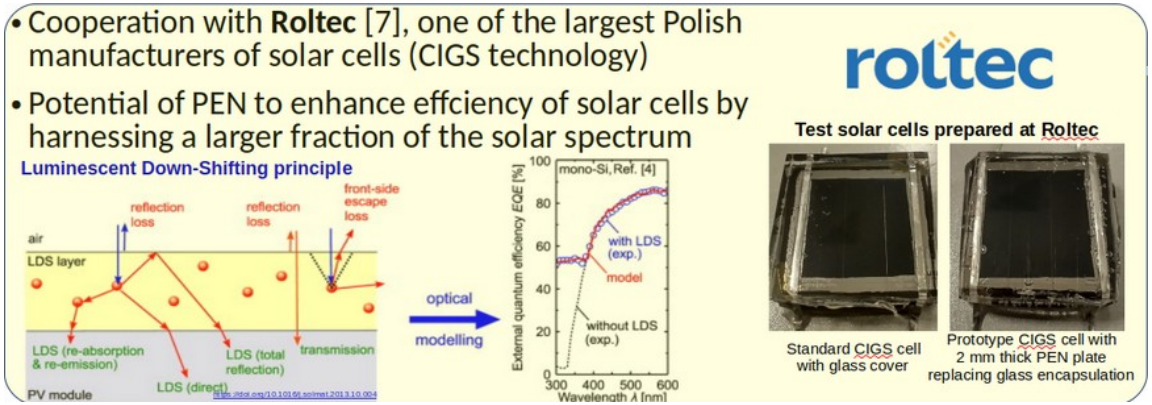
- Continued R&D on several fronts:
  - Scalable and/or specialized wavelength shifters
  - New scheme for light and charge collection: WLS FAT GEMs
  - SiPM testing

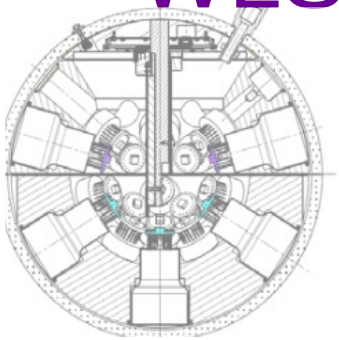
- Potential for broader (grant) applications: photovoltaics, organic / flexible photosensors

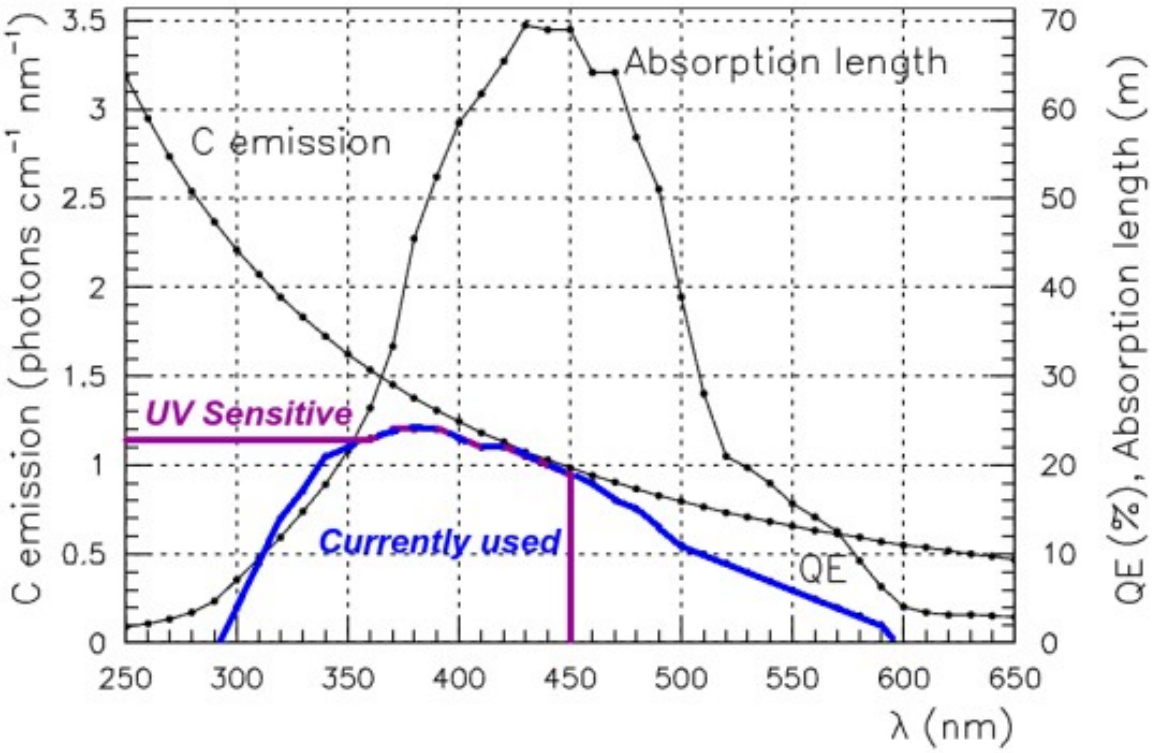
- Major efforts in 2024 at AstroCeNT:
  - DarkSide-20k veto SiPM testing campaign
  - PEN QC for DarkSide-20k
  - Gaseous TPC assembly and commissioning
  - Nanosecond-pulsed VUV source procurement
  - Teaming and industry grant preparation



Thank you!

WLS synergy with KM3NeT@APC



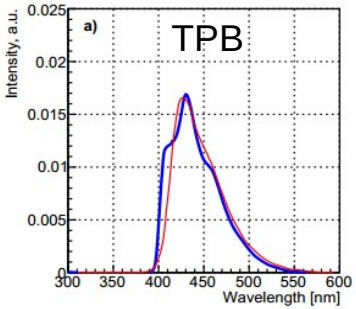


Requirements:

- WLS has to be on the outside of glass spheres:
  - Seawater compatible!
  - Good adhesion to glass
  - ... or completely decoupled from glass
- Purple or blue emission
- Good long term stability (~10 years?)
  - Mechanical & chemical
- Scalability

Development of TPB-doped polystyrene coatings

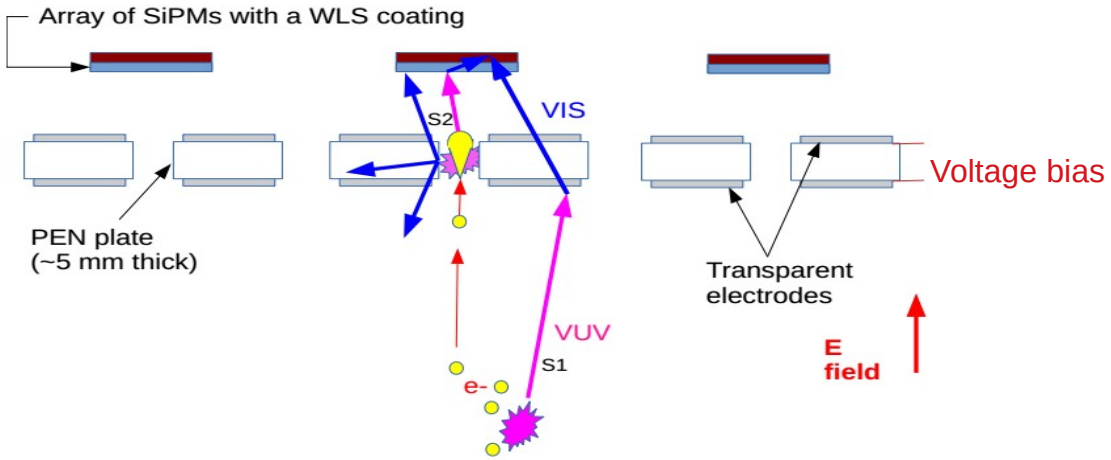
- The first batch of coated glass samples tested



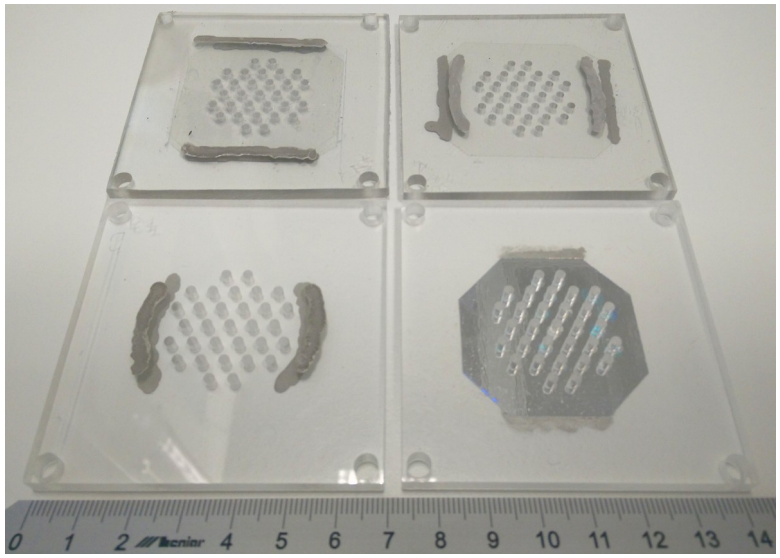
WLS GEM detector

Proposed & prototyped a new type of detector for simultaneous charge and light detection

(GEM: gaseous electron multiplier)



PEN wavelength shifting tiles



Spray coated polymeric (PEDOT:PSS) transparent electrodes

- own technique!
- successful proof-of-principle tests in gaseous Xe and Ar

Expecting **tripled** light collection & better scalability w.r.t. wire grid TPCs

Proposed (Kuźniak), fabrictated (Sworobowicz), optically characterized (Nieradka) and simulated (Turkoglu) at AstroCeNT.

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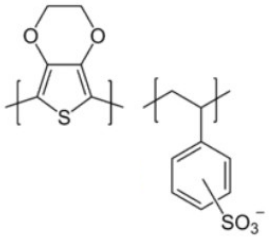
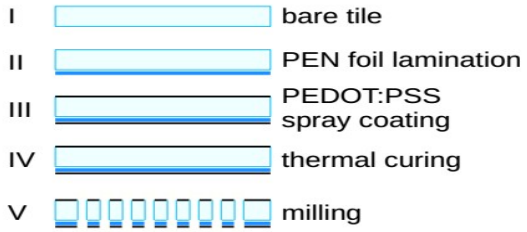
IGFAE
Instituto Galego de Física de Altas Enerxías

Transparent electrode production

- PEDOT:PSS conductive polymer, deposited from solution



- Can give very transparent coatings:
  - Substantially diluted
  - Airbrushed
  - Thickness in range of O(10) nm



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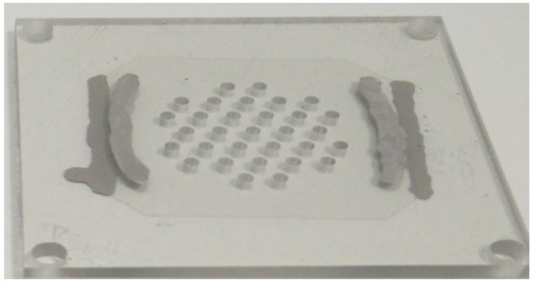
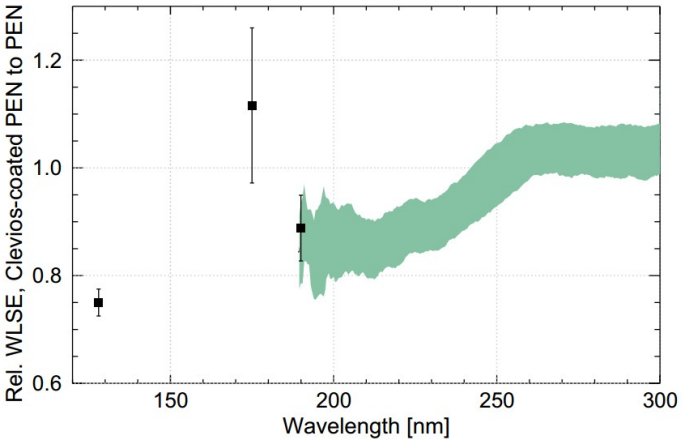
POLITECHNIKA WARSZAWSKA



- Optical properties
  - 95 – 99% transmission (visible)
  - Low refractive index
  - Low haze
  - Tunable conductivity
  - VUV transmission



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