Light detection In DRD2

LIDINE 2025
22/10/2025

Miguel Ángel García Peris
On behalf of the DRD2 collaboration

The big questions

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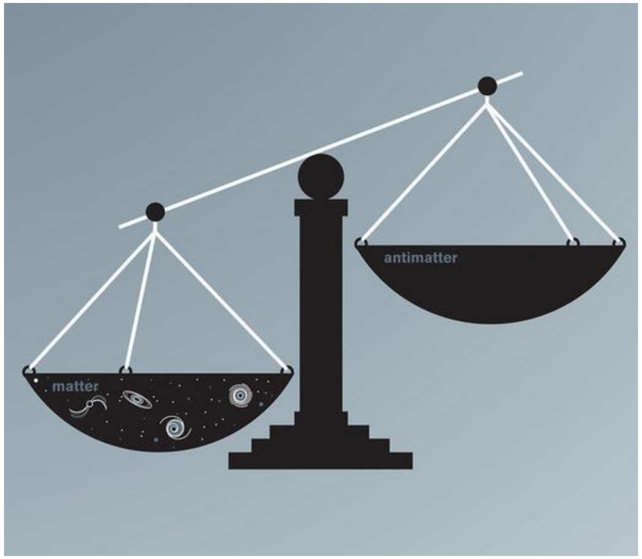

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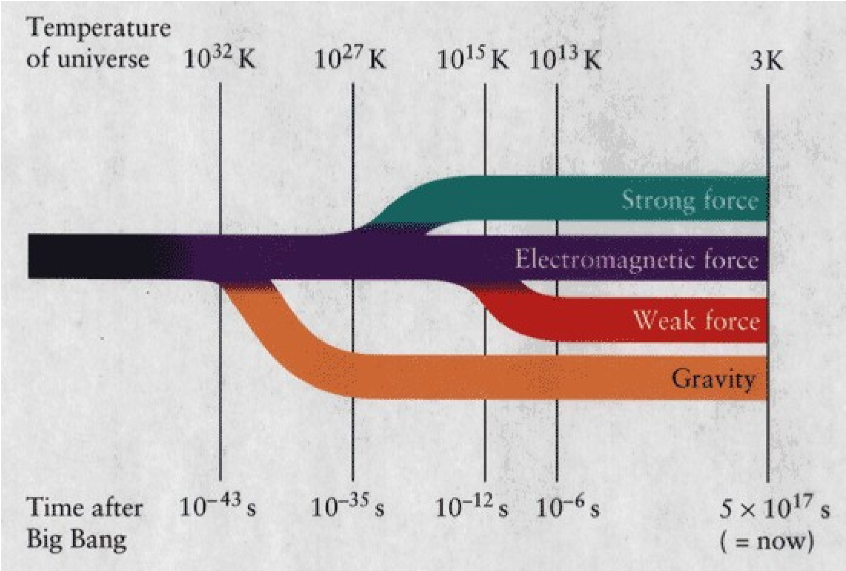

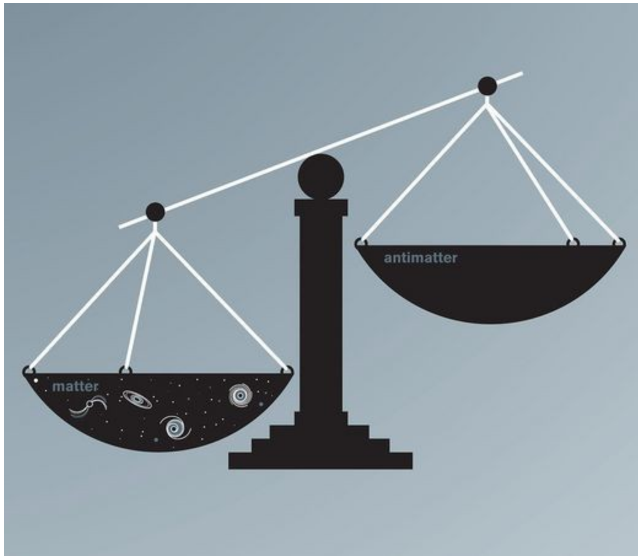

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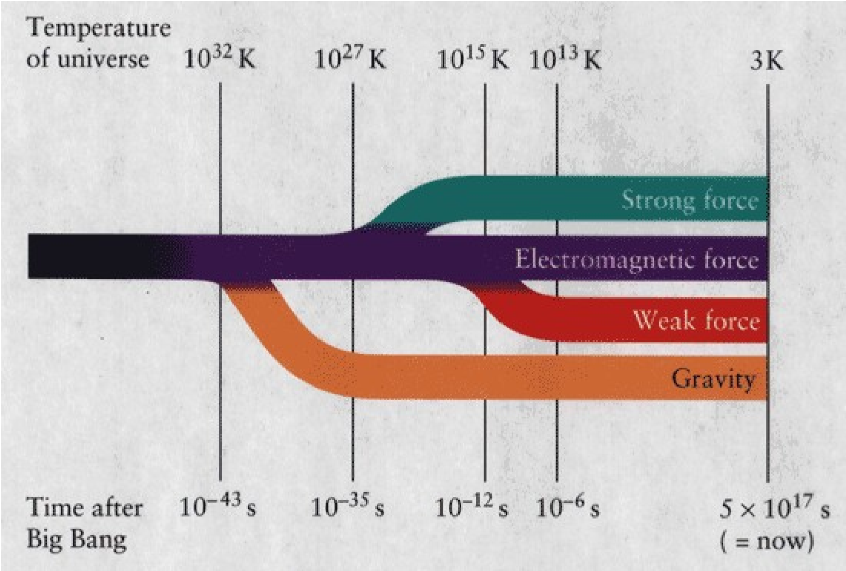

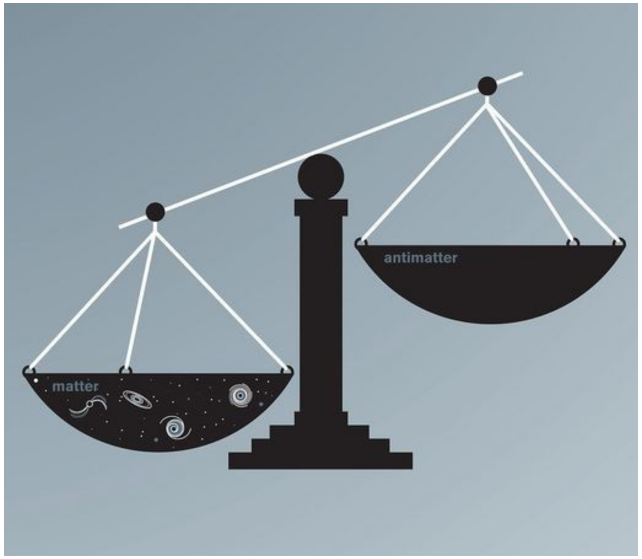

Neutrinos dark matter, and more

What is dark matter?

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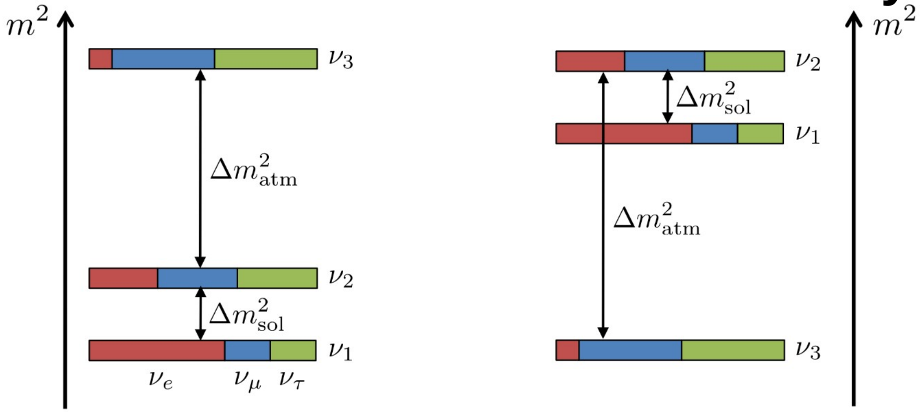
What is neutrinos’ mass and **hierarchy**?



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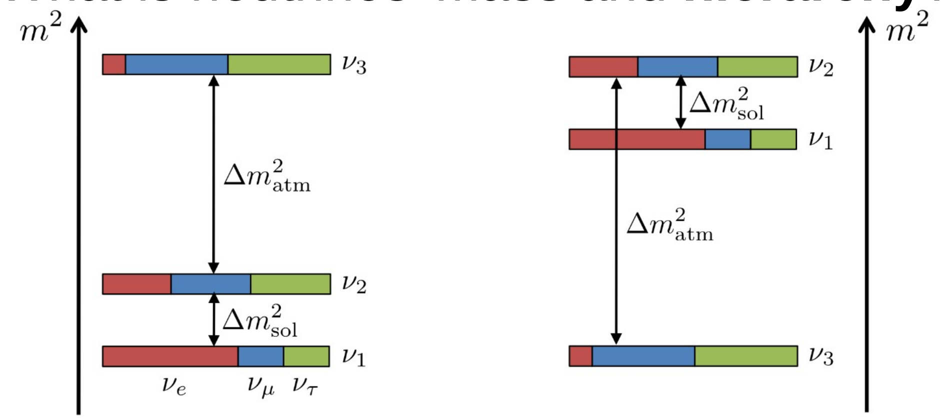

Are they **Dirac or Majorana** particles?

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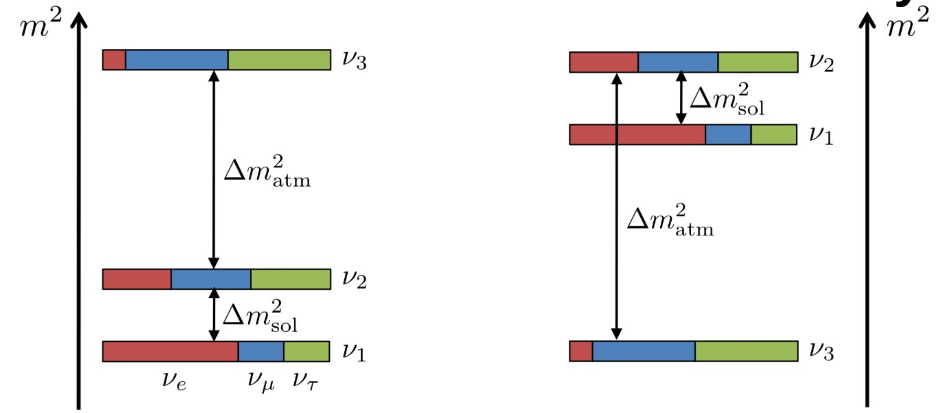

Insert your big question here

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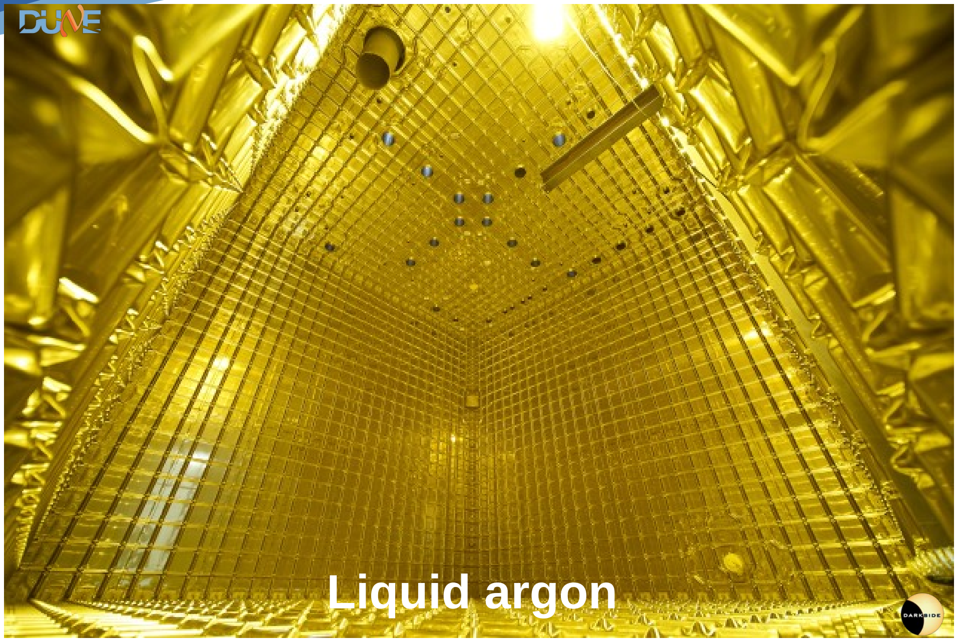
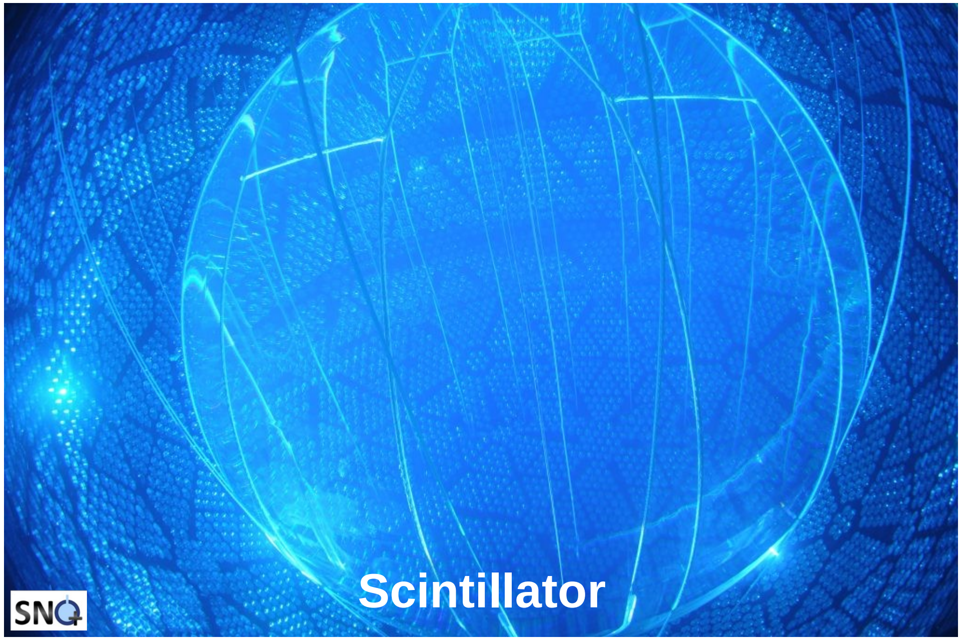
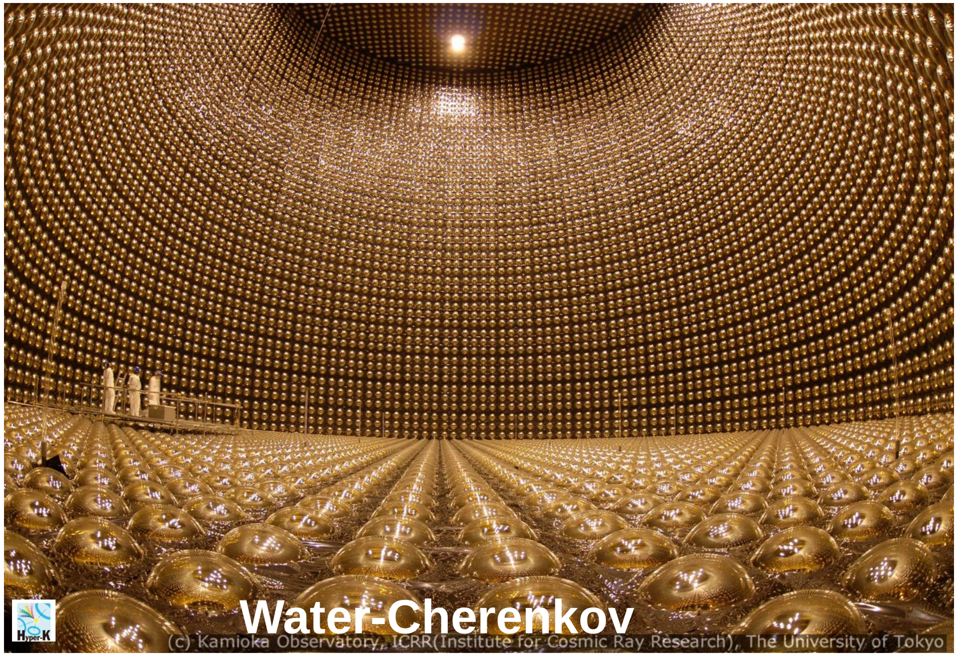
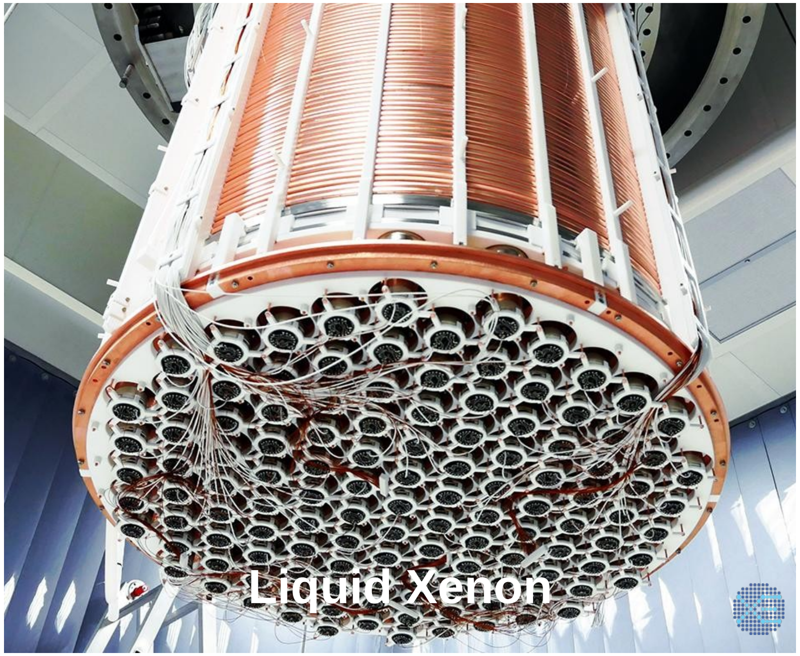




Liquid detectors

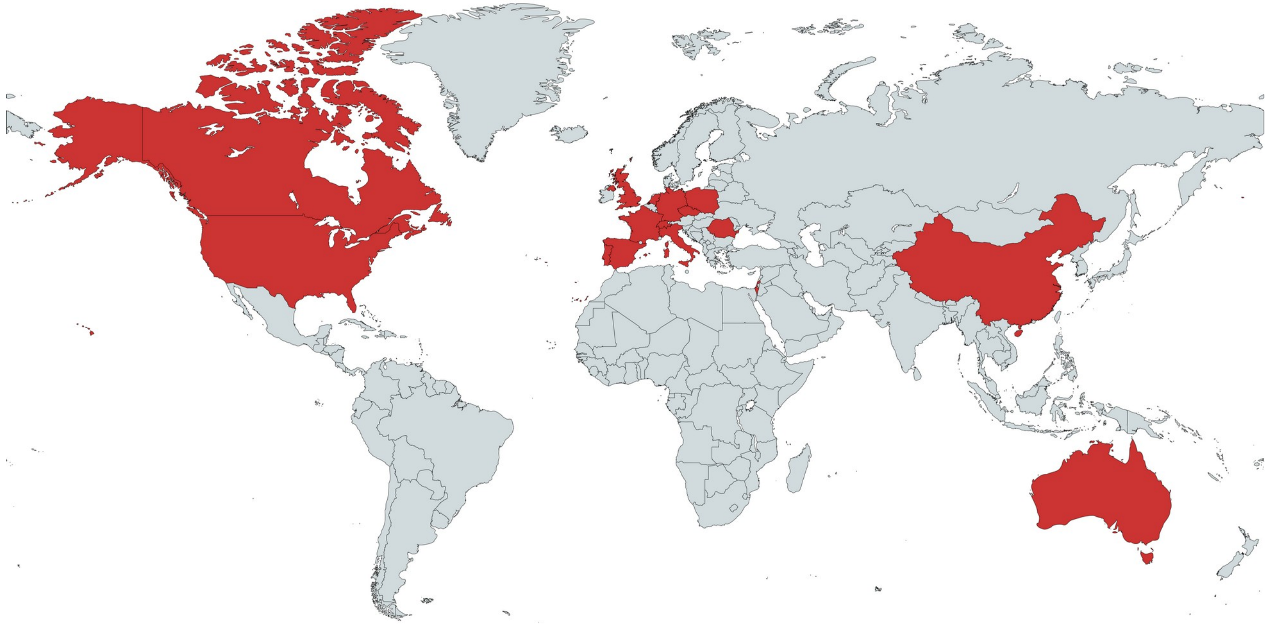




DRD2 Collaboration

- R&D collaboration focused on liquid detectors (see webpage here).
- **We aim to optimize the R&D process** for the next generation of HEP experiments:
  - Information exchange.
  - Eliminate work-duplication.
  - Facilities sharing.
  - Merge R&D proposals.
  - PhD/postdoc training.
  - Tools exchange.

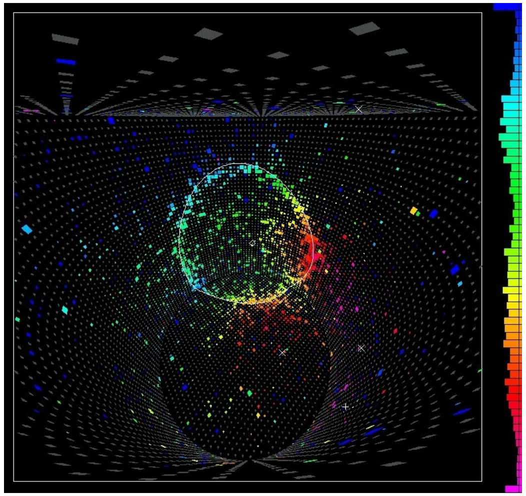
- 85 institutions from more than 17 countries.
- More than 200 collaborators.



Liquid detectors technologies

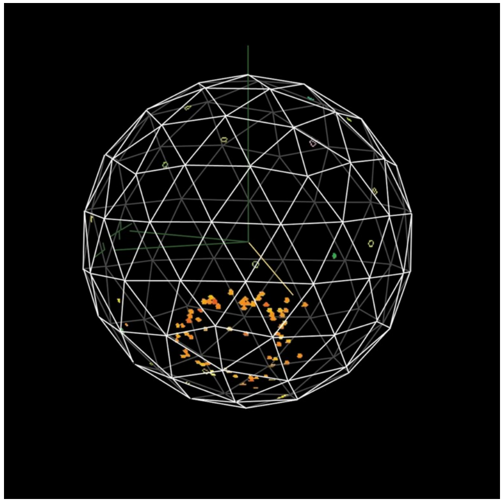
Water Cherenkov

- Well-established technology.
- Cherenkov light.
- Large-area photon detectors with some granularity (multiPMTs).
- Gd doping to increase neutron sensitivity.



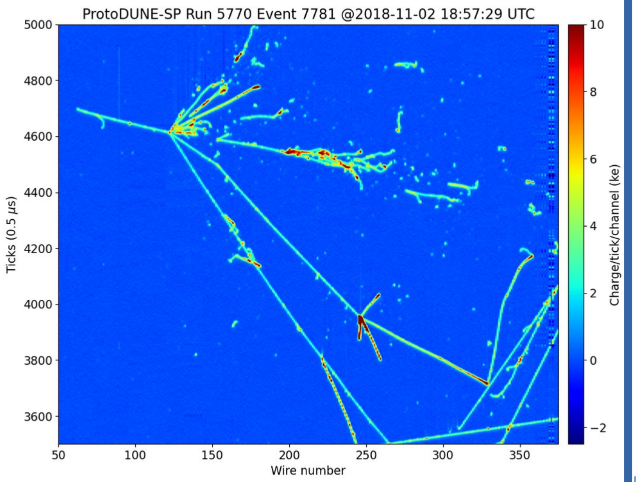
Scintillators

- Established technology.
- Scintillation light (visible).
- Hybrid development for dual (Cherenkov + scintillation).
- Isotope loading ($0\nu\beta\beta$).



Noble elements

- More recent technology.
- Mostly Argon and Xenon.
- VUV scintillation light (128 and 178 nm).
- Energy depositions shared between charge, light and phonons.



DRD2 Collaboration

WP1
Charge Readout
- 1.1 Pixels & charge+light
- 1.2 Charge-to-light, electroluminescence & amplification
- Ion detection

WP2
Light Readout
- 2.1 Increased sensor quantum efficiency
- 2.2 Higher efficiency WLS and collection
- Improved sensors for LS & WC

WP3
Target Properties
- 3.1 Target properties and isotope loading of LS & WC
- 3.2 Target properties and isotope loading of noble elements

WP4
Scaling-up Challenges
- 4.1 Radiopurity & background mitigation
- 4.2 Detector and target procurement/production & purification
- 4.3 Large-area readouts
- Material properties

DRD2 Collaboration

See R. Santorelli talk on Friday!

WP1 Charge Readout	WP2 Light Readout	WP3 Target Properties	WP4 Scaling-up Challenges
1.1 Pixels & charge+light	2.1 Increased sensor quantum efficiency	3.1 Target properties and isotope loading of LS & WC	4.1 Radiopurity & background mitigation
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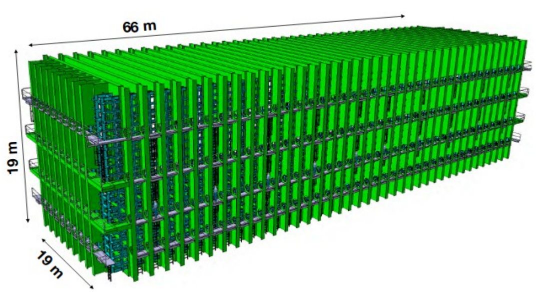
Physics needs

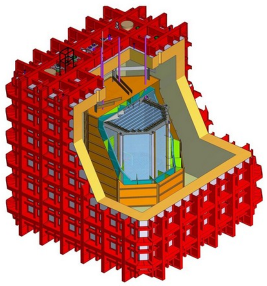
Neutrinos

- **Push energy thresholds down** to ≤ 1 MeV to enhance neutrino physics.
- Unambiguous readout.
- **Reduce background rates.**
- **Scalability.**



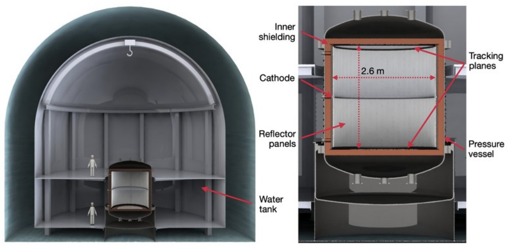
Dark Matter

- **Push energy thresholds down** to ≤ 1 MeV / 10 eV / 1 keV to enable low mass DM / 1 GeV DM / WIMPS
- **Reduce background rates.**
- **Scalability.**



0νββ

- **Improve energy resolution** to sub-% FWHM.
- **Reduce background rates.**
- **Scalability.**



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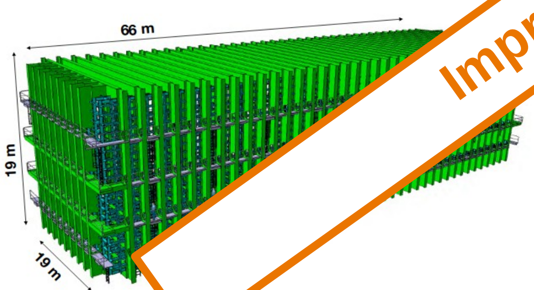

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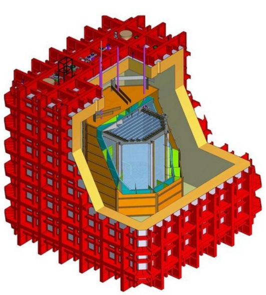

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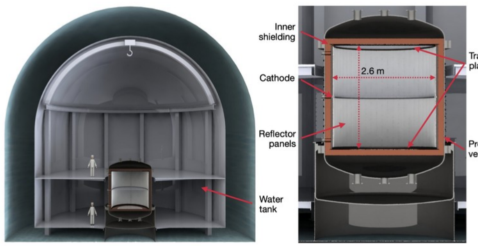
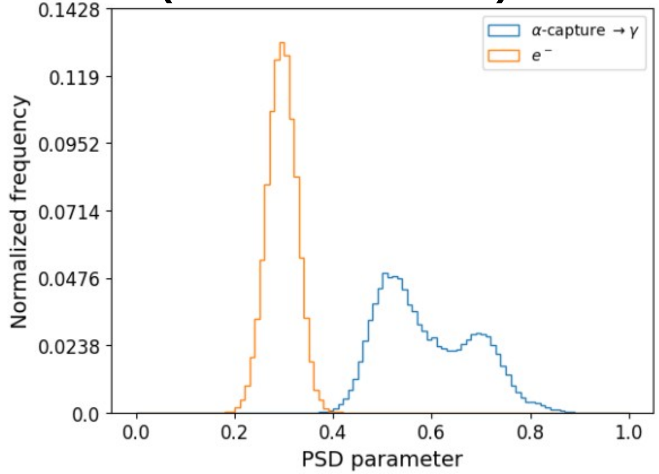


Improving light readout can address all of these!

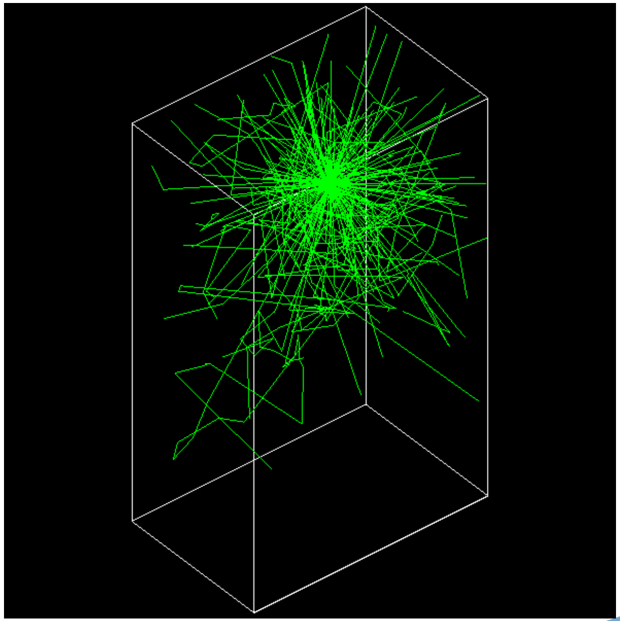
Light? Light!

- Light is produced in detectors by energy depositions of charged particles.
- Light signals provide:
  - Timing (event reconstruction)
  - Calorimetry
  - PID
- To exploit light information we need to:
  - Understand **light production** mechanisms
  - Understand **light propagation/simulation**
  - **Efficiently collect and detect light.**

Pulse-shape discrimination
Alphas-electrons
(arXiv:2507.15459)



Photon propagation



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Complicated in noble elements!

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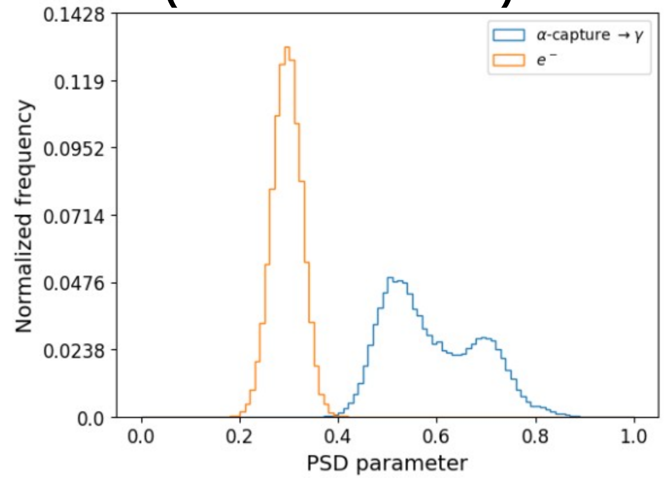
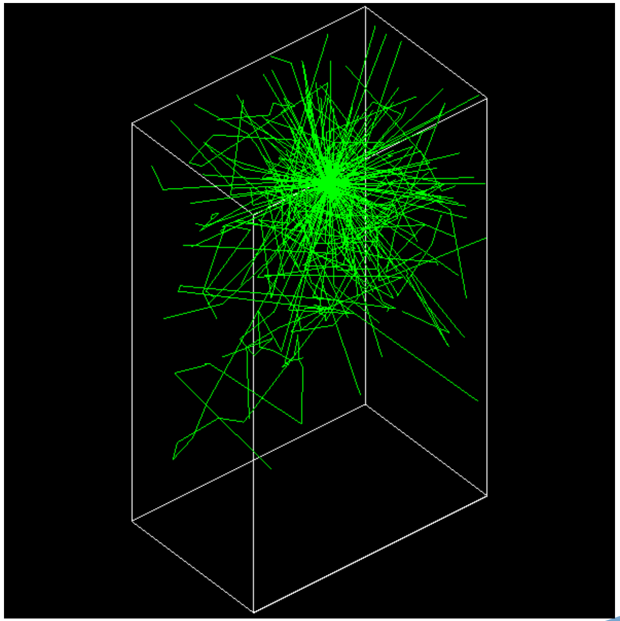


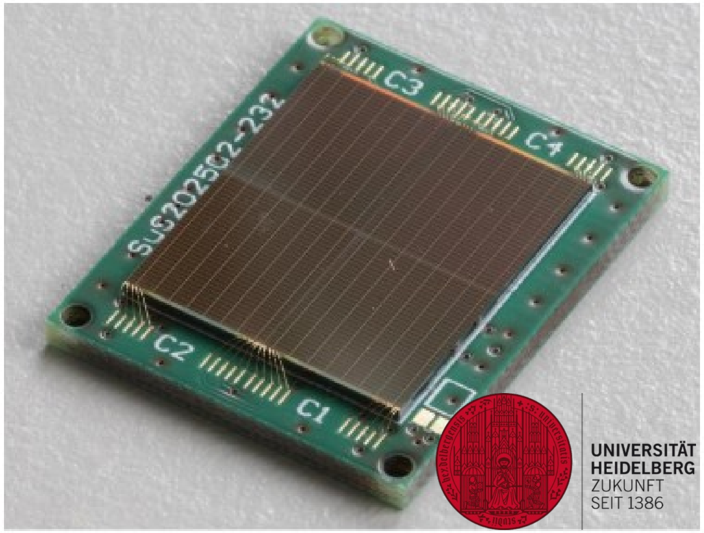
Photon propagation



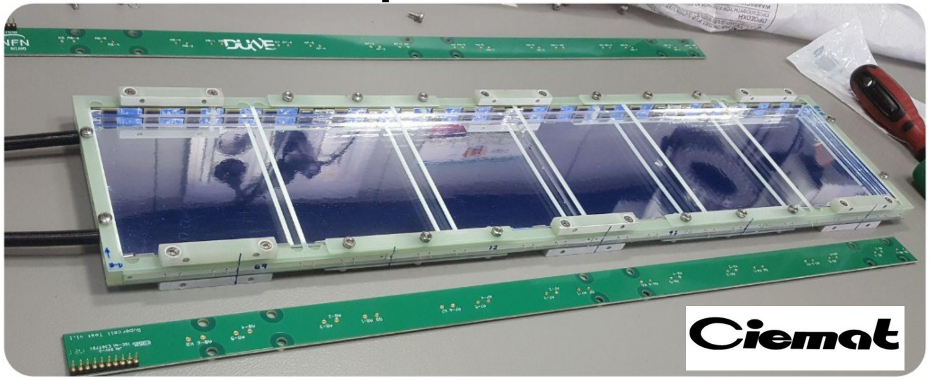
Improving light readout

- Three different layers for improvement (mostly focused on Si SPADs):
  - Light readout itself.
  - Photon detection efficiency / collection.
  - Light production.

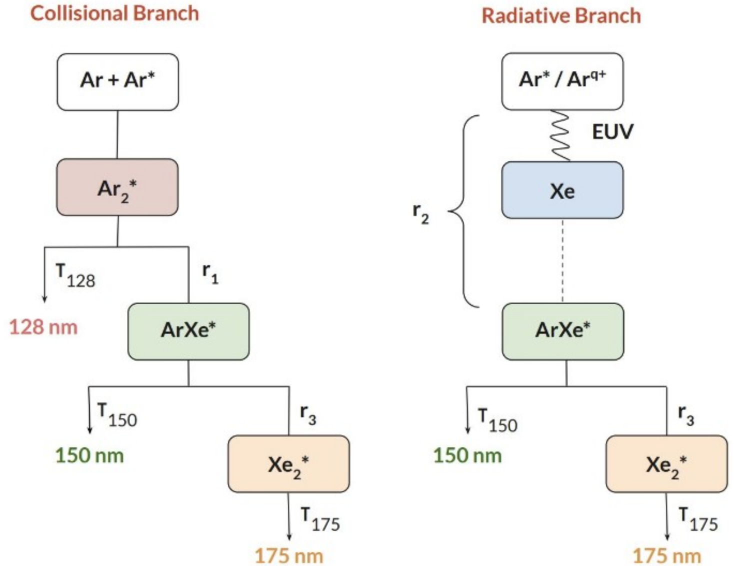
Digital Photon module



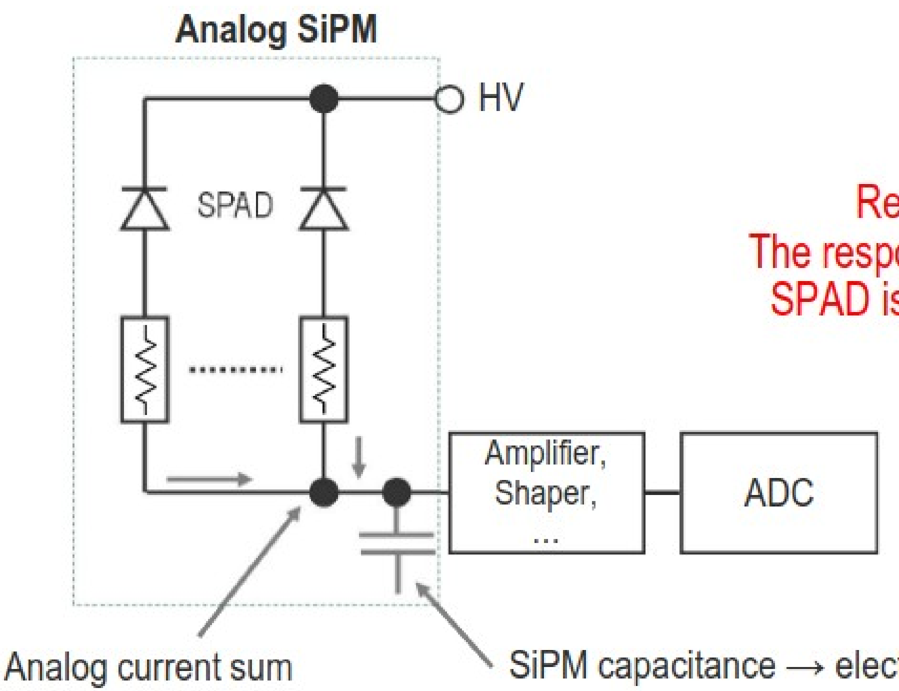
X-Arapuca module



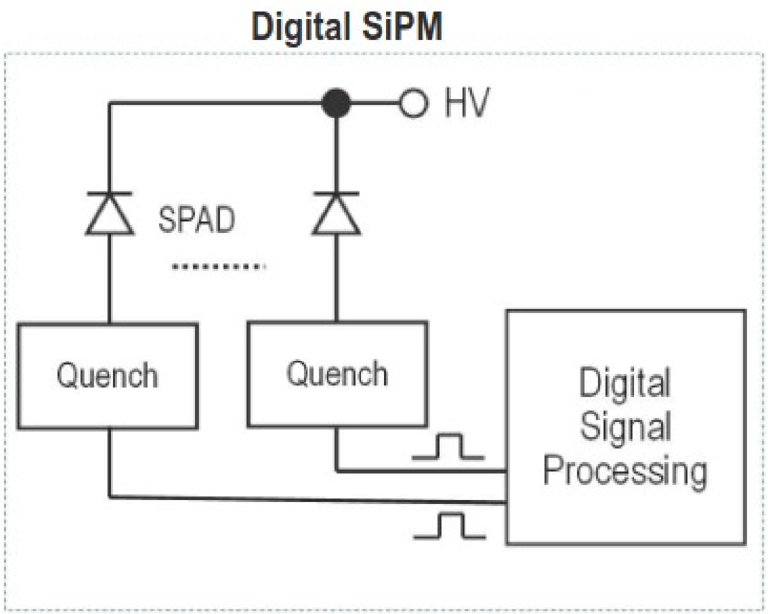
Light production in Ar+Xe



Photon to Digital Converters

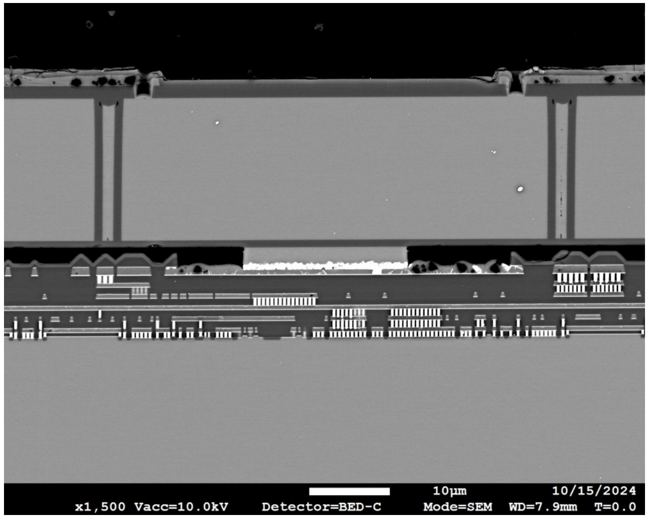


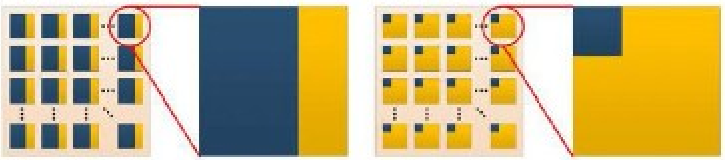
Recall:
The response of the
SPAD is Boolean



3D bonding

The SPAD-readout connection is the complicated part. Ideally, we aim for a '3D' architecture to maximize coverage →



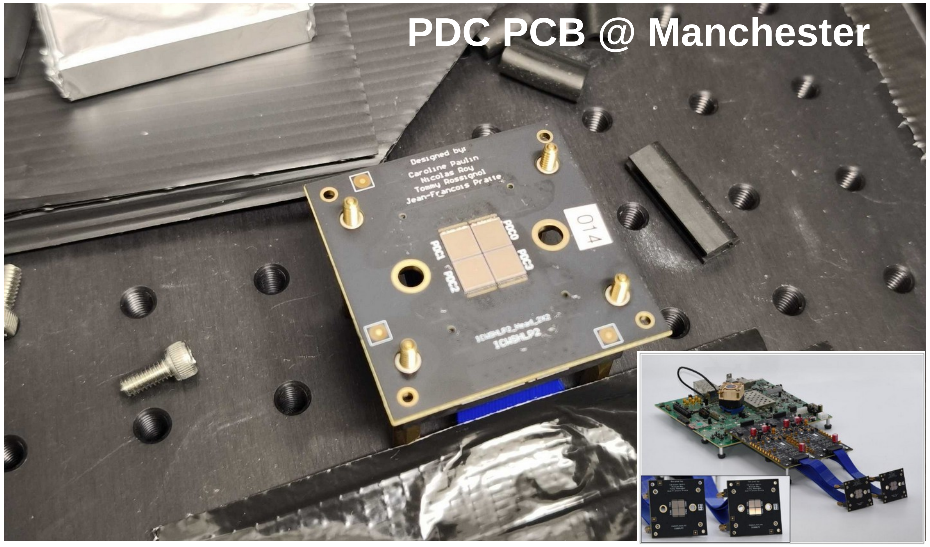


in 2D: loosing sensitive area

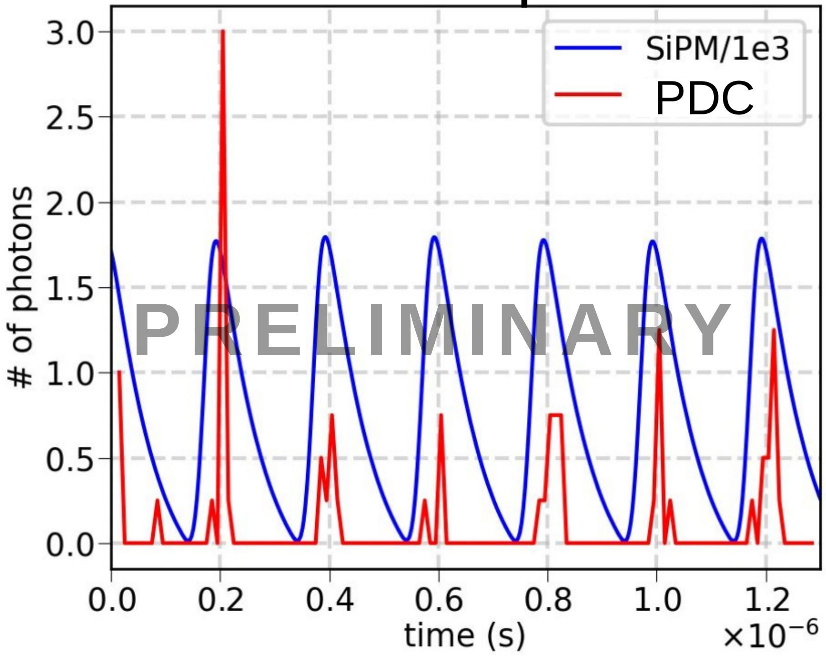
PDCs (enhanced light readout)

Université de Sherbrooke — MANCHESTER 1824 The University of Manchester

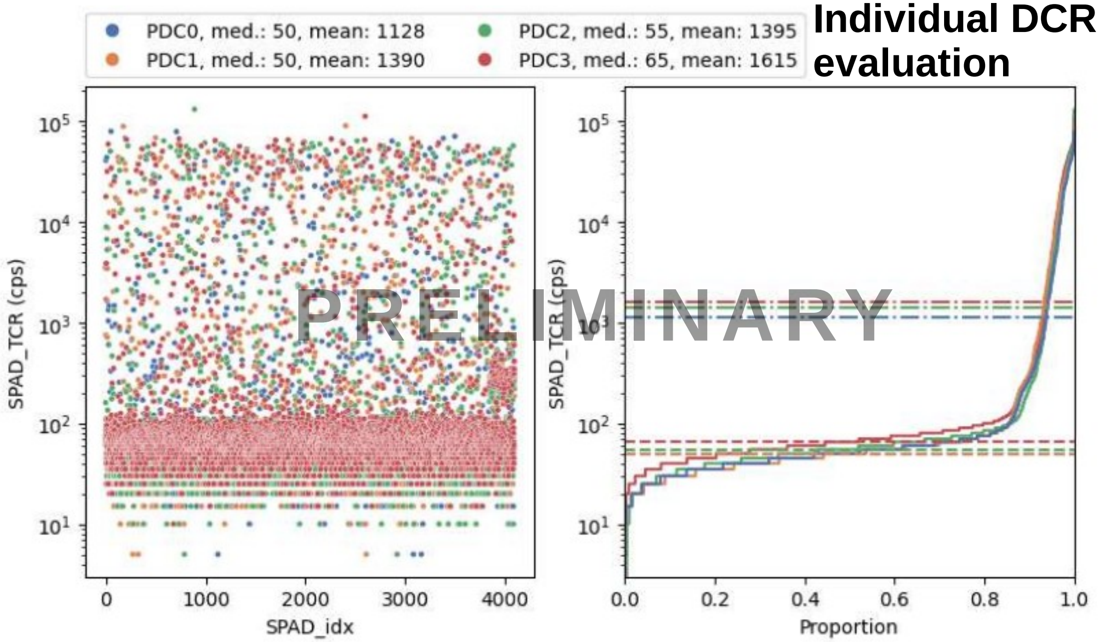
- Unambiguous photon count.
- Single pe resolution across the whole dynamic range.
- Enhanced time resolution.
- Individual DCR evaluation and masking.



SiPM vs PDC comparison

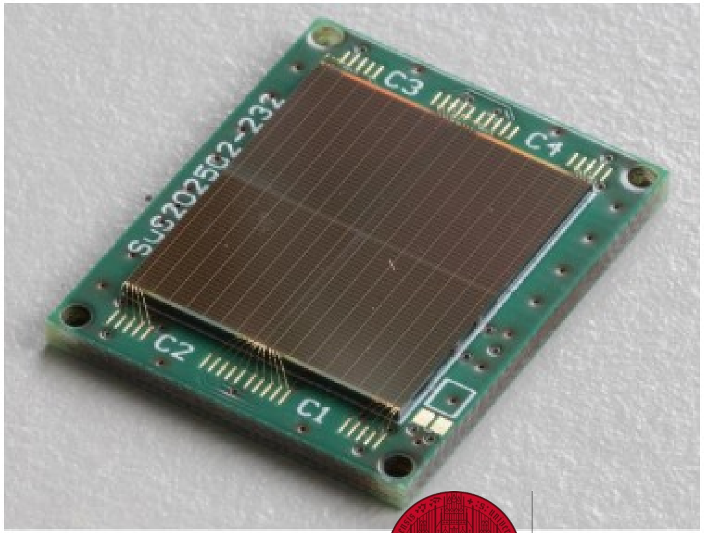


Individual DCR evaluation



PDCs (enhanced light readout)

- Heidelberg and Sherbrooke Universities are spearheading this front.
- Trying to achieve digital multi-chip modules alongside different industrial partners.
- Developing test-kits to share with collaborators.
- Readout suited for Low Level Experiments.



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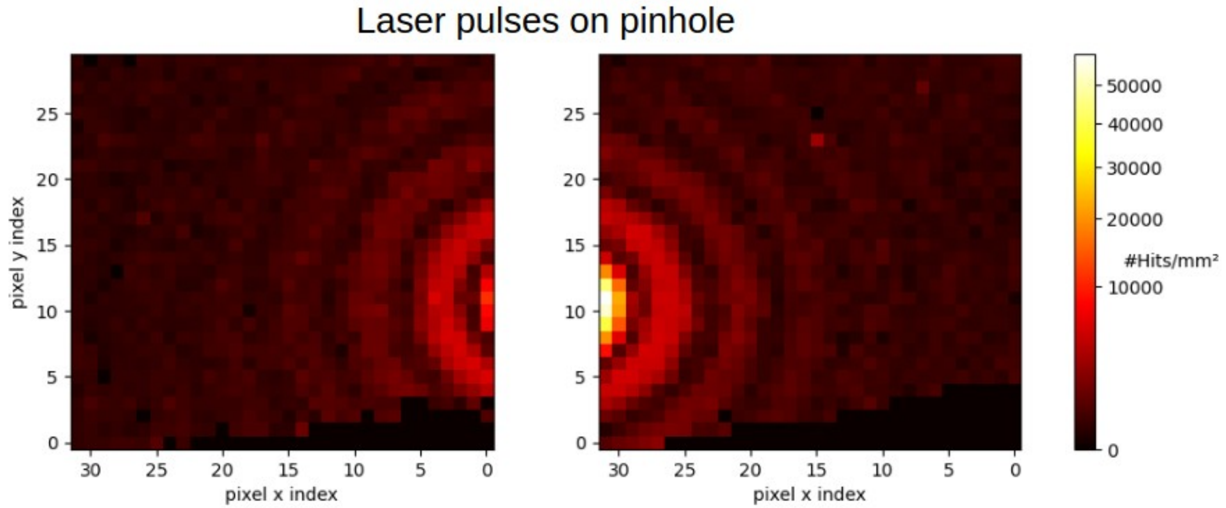
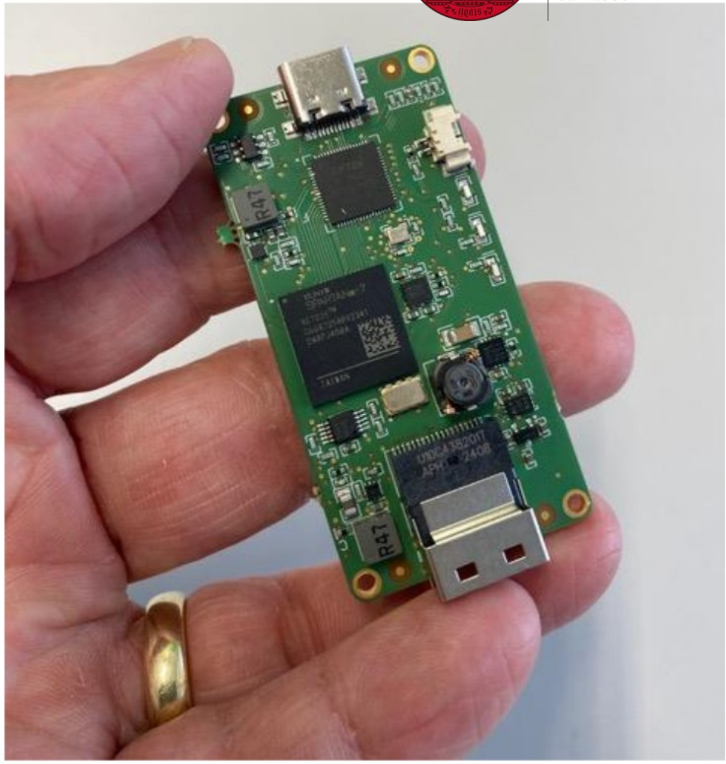
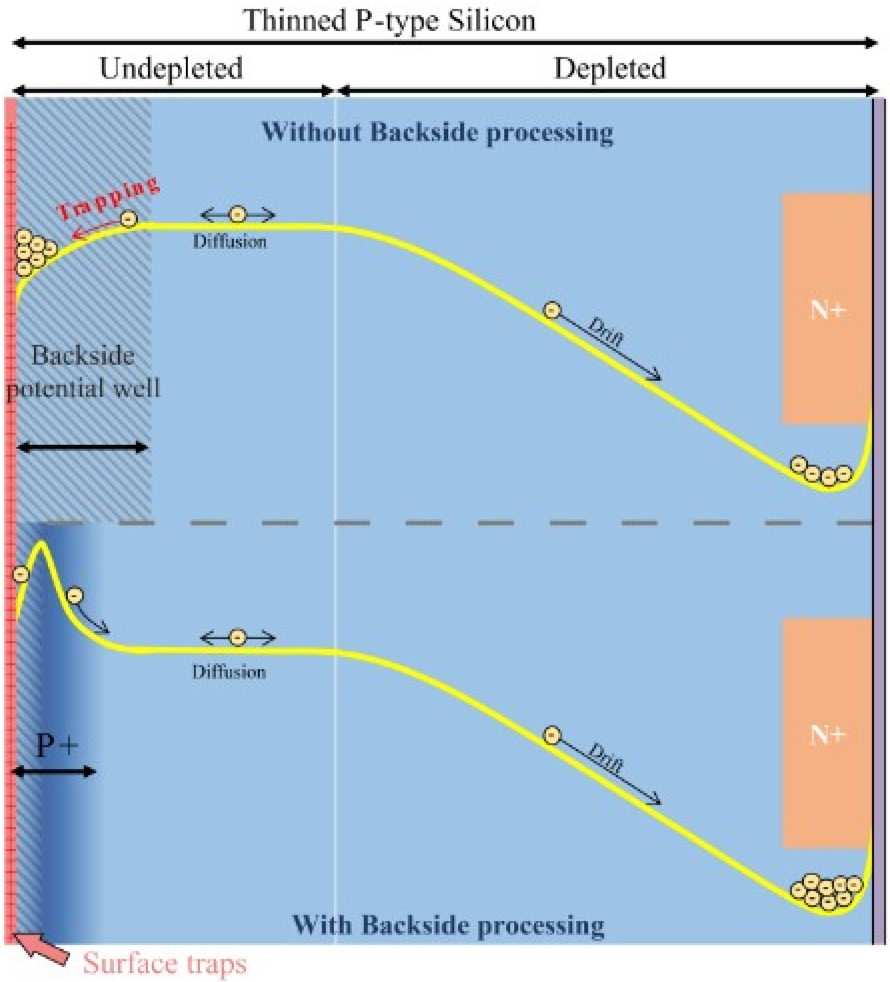




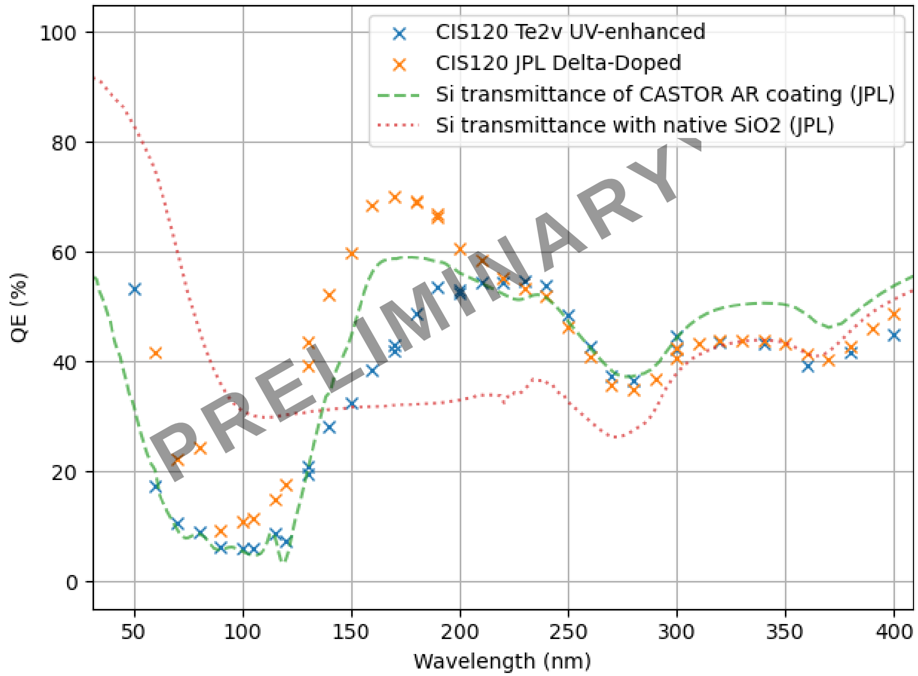
Improving VUV sensitivity

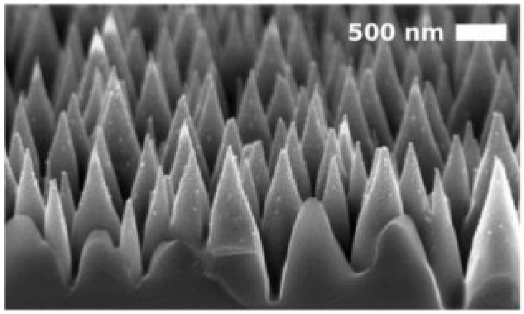
- Noble element scintillate in the VUV (128 nm argon, 178 nm xenon).
- VUV photo detection is complicated in Si due to
  - High reflectance on Si surface (high n_{Si}).
  - Shallow absorption depth.

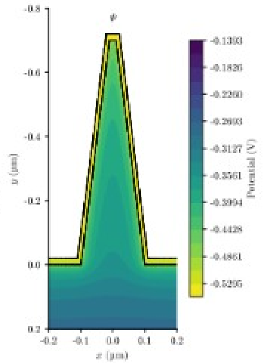


Enhanced VUV sensitivity

- Different passivation strategies are being explored
  - Dopant implants
  - Black silicon
  - Graphene to reduce reflectivity of Si

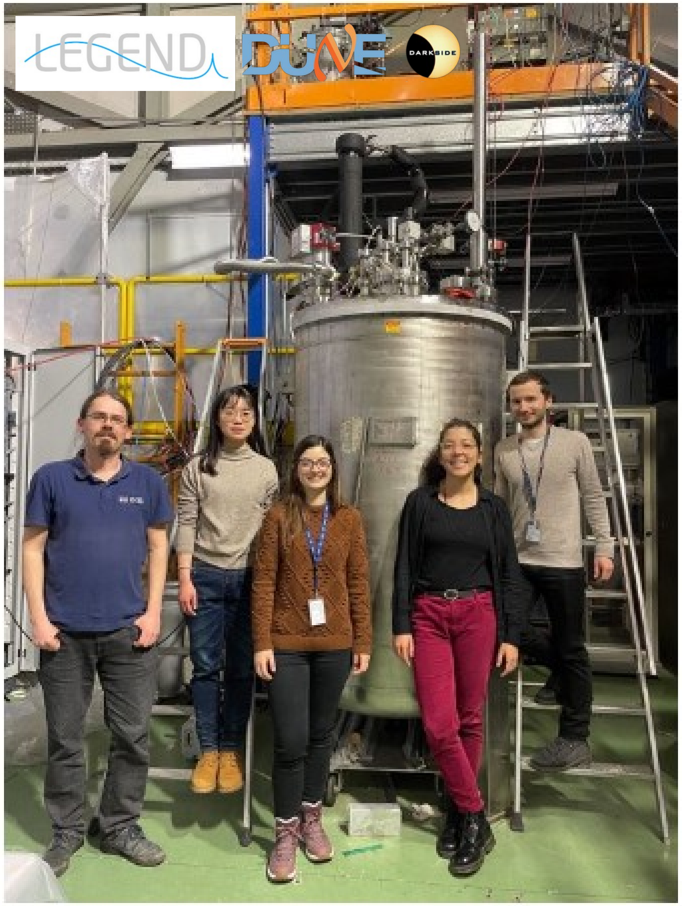


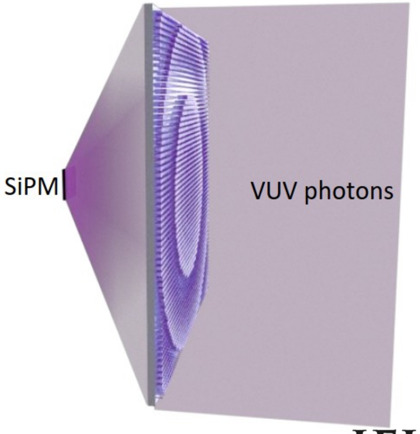


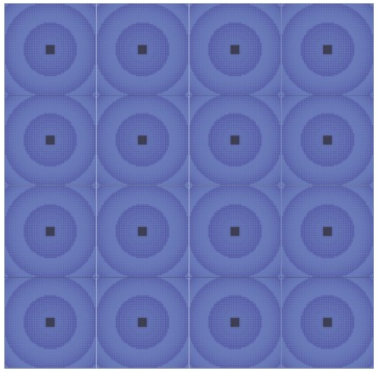


WLS and collection

- Activities ongoing to characterize different WLS:
  - PEN at Neutrino Platform (link), →
  - PVN, PTP, tPB… (see N. Canci talk later!)
  - POWER readout proposal for DUNE (see F. di Capua talk later!)
- Different aspects of large are readouts studied:
  - X-ARAPUCA absolute PDE measurements at CIEMAT.
  - Reflectivity measurements at IFIC (see J. Soto talk tomorrow).
- First studies of metalesenses and metasurfaces in VUV ongoing.







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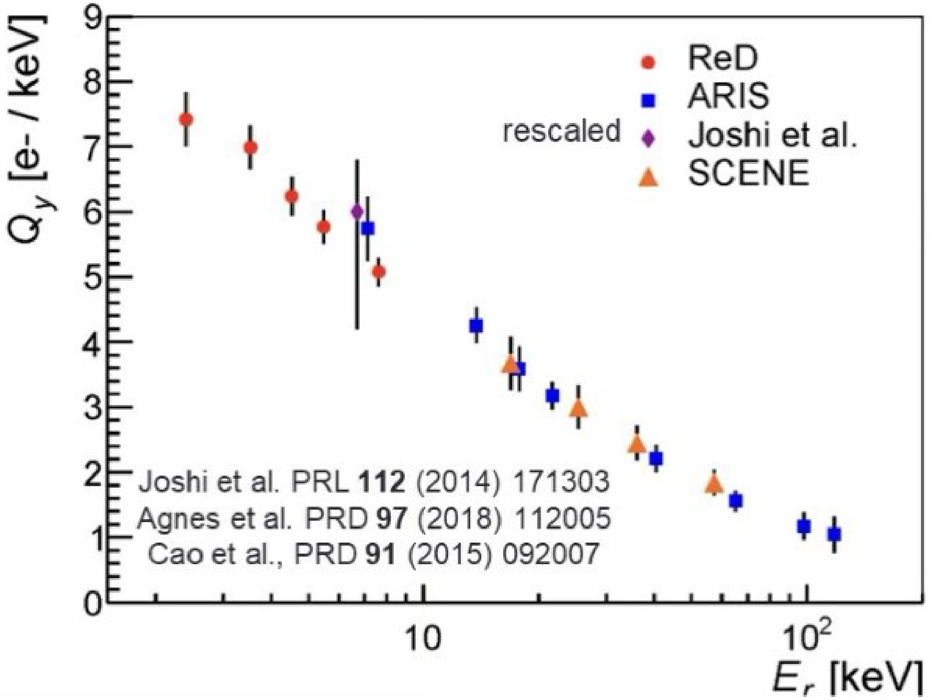
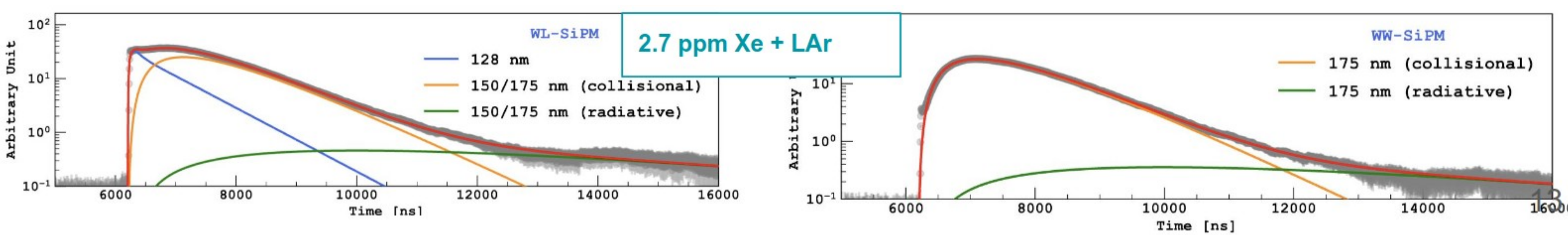
Target properties

- Different efforts trying to characterize NL response at very low energies:
  - BLEND.
  - ReD (see L. Pandola talk).
- Characterizing properties of doped NL ongoing:
  - Scintillation profile.
  - Thermodynamic properties.

Sensitivity to 2 KeV nuclear recoils achieved





Charge Readout

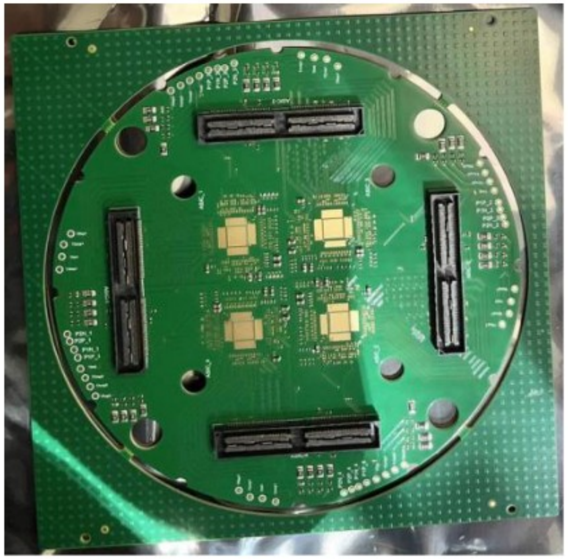
- Ionization charge is one of the two handles to obtain information from noble element detectors.
- Charge readout is a **well-understood** process.
- Traditional approaches lead to
  - **Reconstruction ambiguities**
  - **High energy floor.**
- Large charge readouts **leave little space for light readouts**, (3-15)% coverage.

PROTODUNE-HD

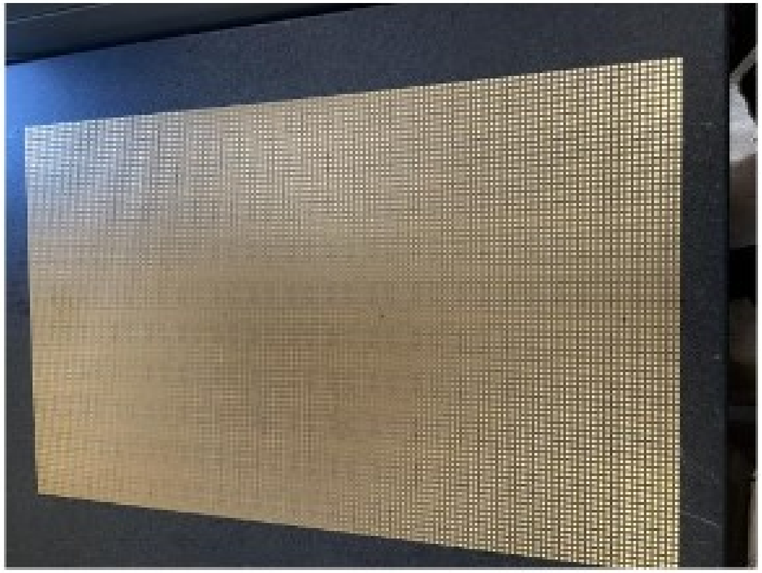
Enhanced charge readout

- Pixelated readouts overcome the problems of traditional readouts:
  - Unambiguous readout.
  - Energy resolution.
  - Spatial resolution.
- Significant progress in the last years → mid-scale tests foreseen in the next years.
- However… they still doesn't give room for light readout).

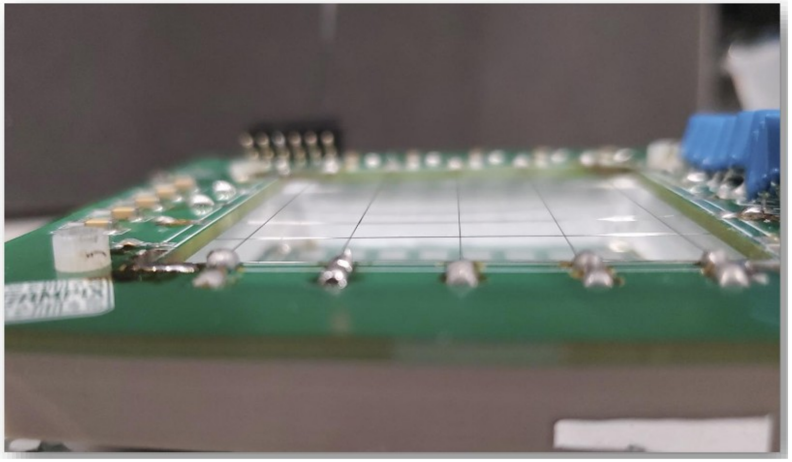
Q-Pix



LArPix

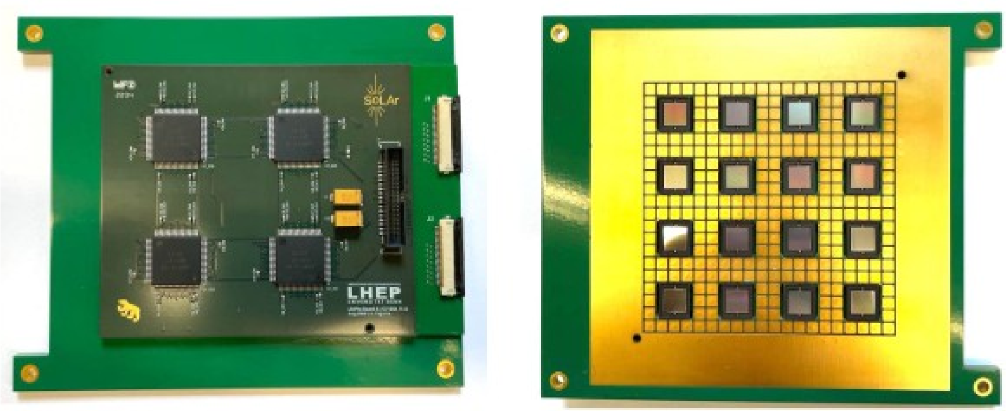


GAMPix



Charge + Light

SoLAr

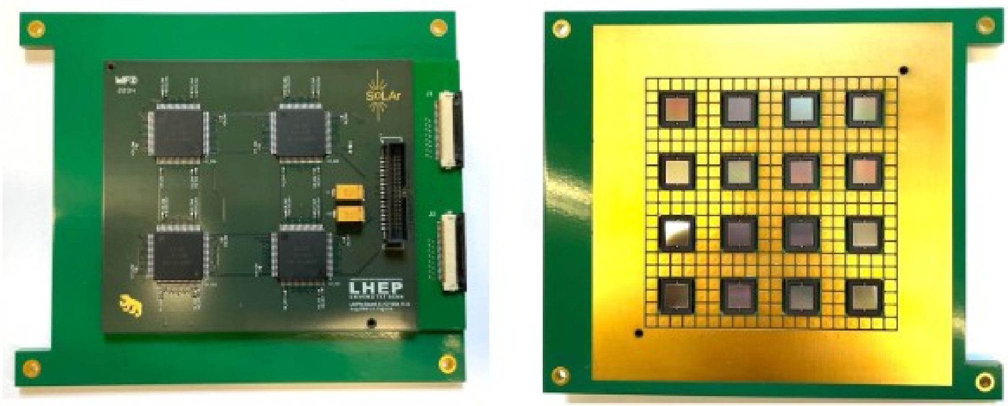


- Can we integrate light and charge readout in a single plane?
  - SoLAr has made significant progress in the last years and a mid-scale test is expected in the next years.

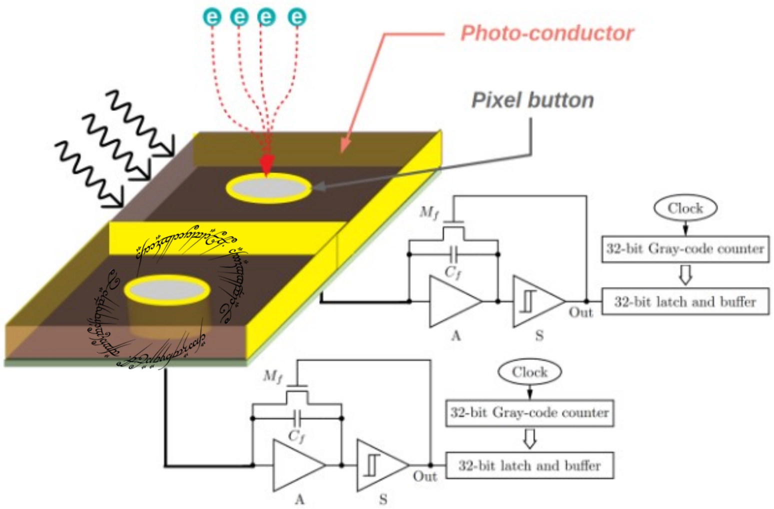
Charge + Light

- Can we integrate light and charge readout in a single plane?
  - SoLAr has made significant progress in the last years and a mid-scale test is expected in the next years.
- Can we integrate light and charge readout in a single pixel? Can we make **the One Pixel to detect them all**?
- It may be possible!
  - ASe is a promising material for VUV detection.
  - First integrated chip developed in UTA.

SoLAr



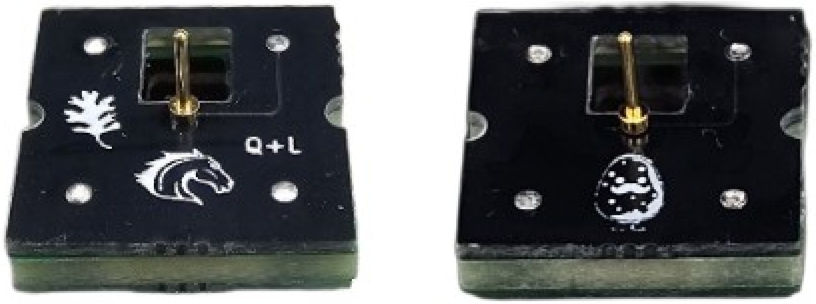
Multimodality pixels



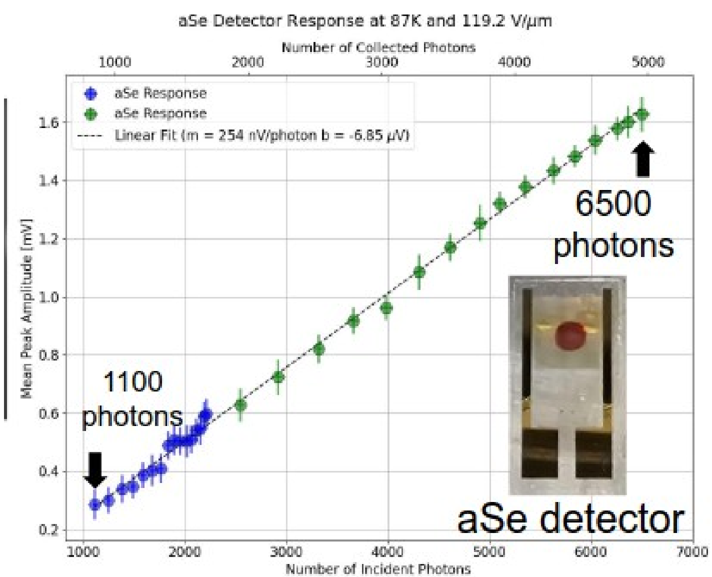
arXiv:2207.11127

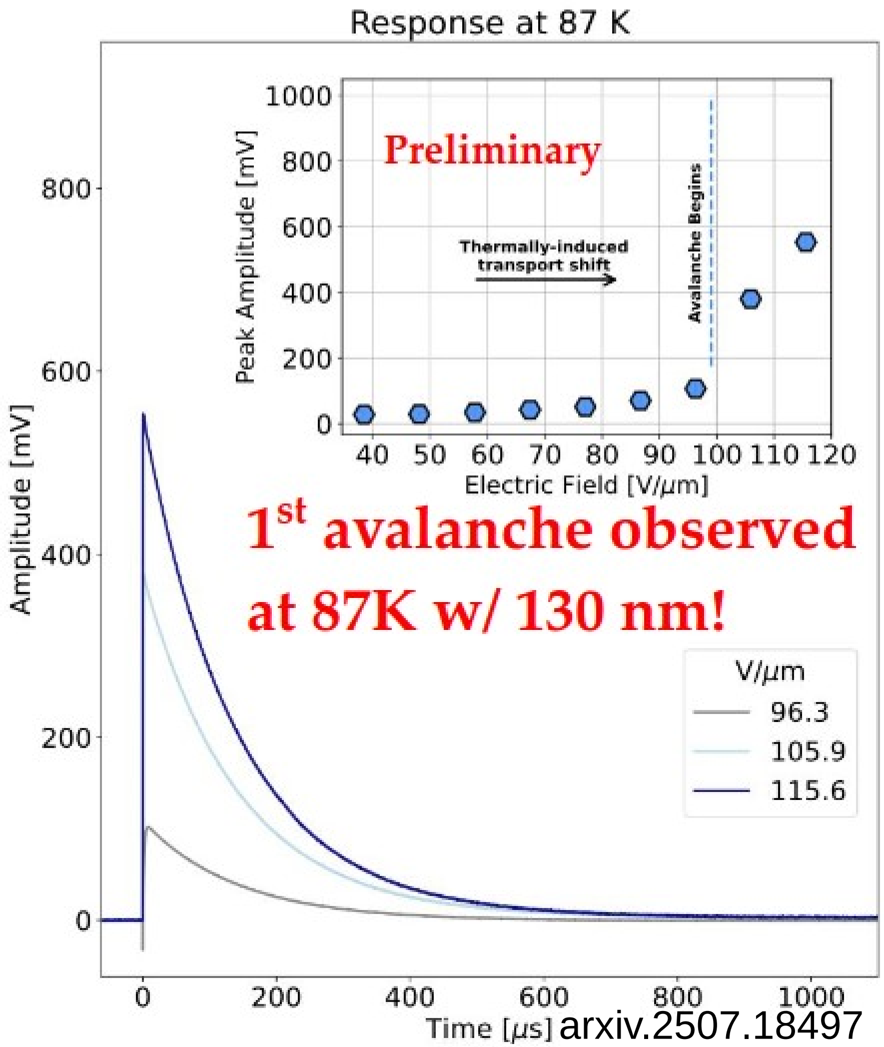
ASe

- ASe is a novel material with response to VUV in cryogenic temperature.
- UTA leading the study of different geometries and detector concepts.
- Significant progress and promising results in the past months.



Multimodality pixels

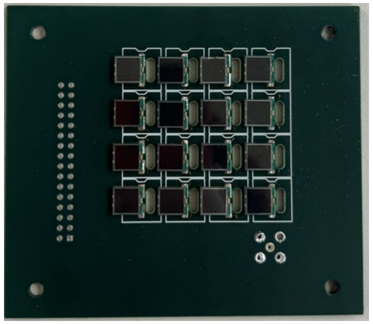




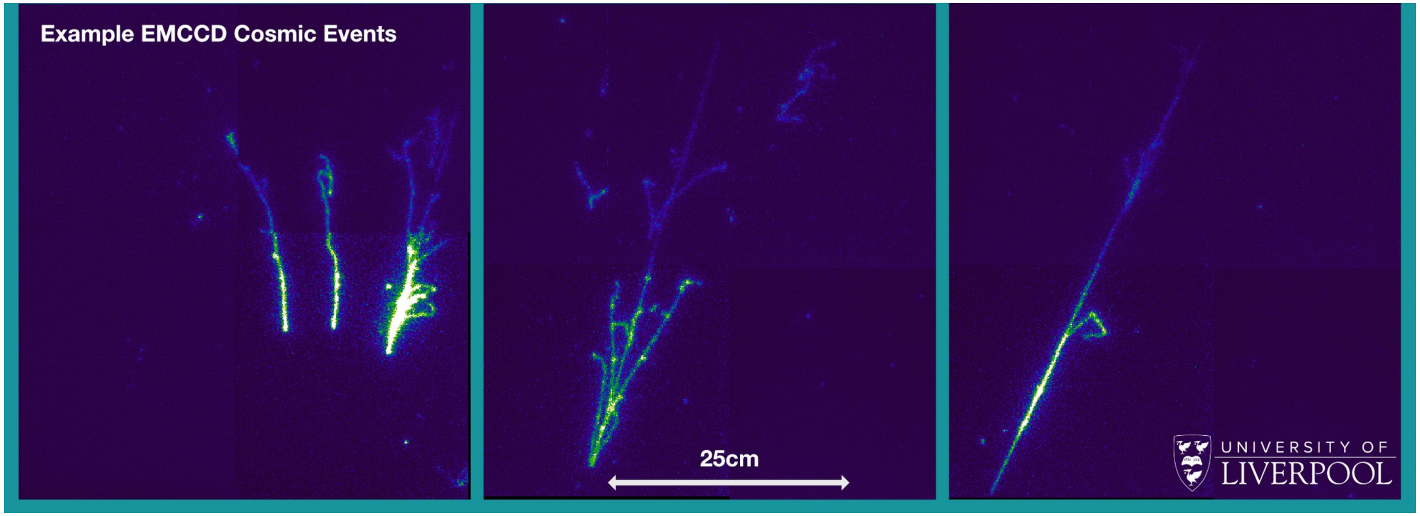
arxiv.2507.18497

Charge to Light

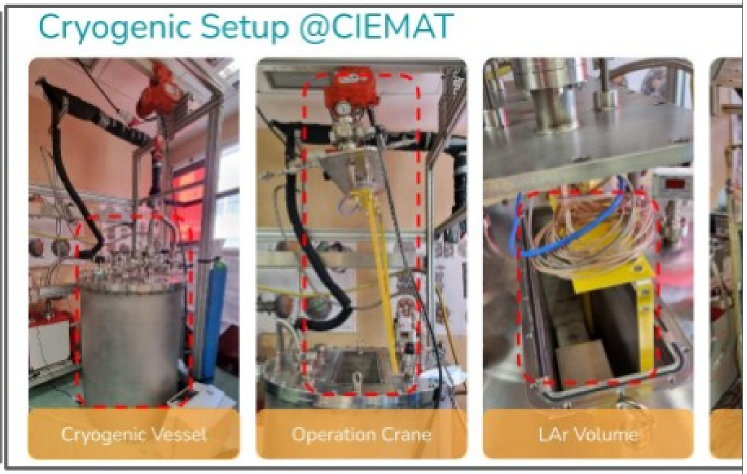
- Ongoing efforts to improve tracking and calorimetry with cameras and SiPMs.
  - A dense tracking plane prototype being developed at Manchester for NEXT.
  - Ariadne moving forward to the TimePix4 camera model.
- Aiming for a joint workshop theoreticians-experimentalist to improve electron transport models.



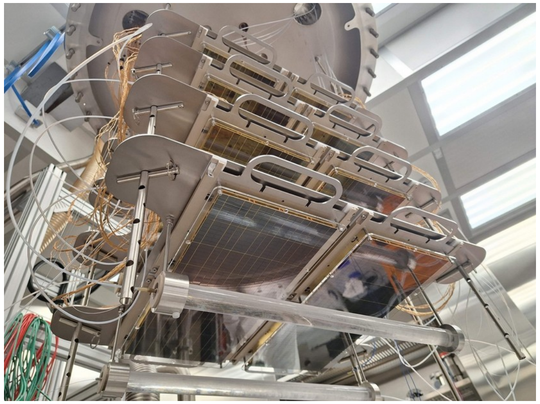
ARIADNE event displays



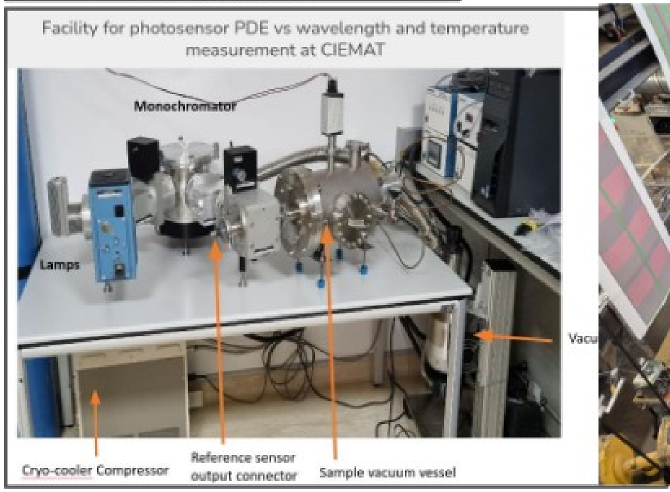
Network of facilities

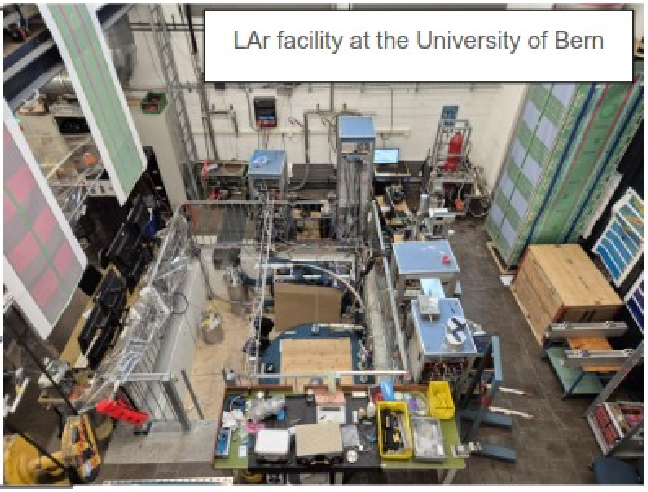


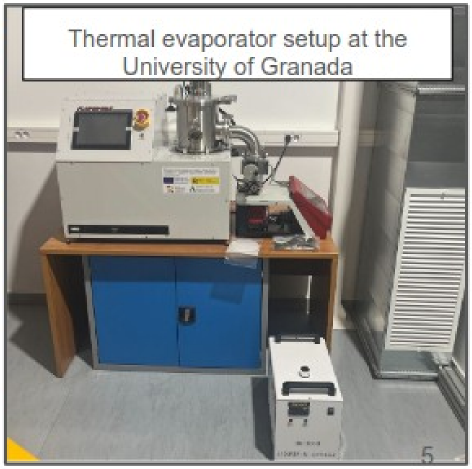
PDU testing unit Naples (see D.Rudik later and G. Mateucci yesterday)



We've prepared a network of experimental facilities that we share to speed-up testing and evaluation of systematic uncertainties.







Summary

- Noble element detectors are at the forefront of HEP.
- Improving VUV photo-detection is critical for the next generation of experiments.
- DRD2 is a collaborative effort trying to address these questions.
- Different approaches are considered and small collaborations under the umbrella of DRD2 have been moving forward through this past year.
- We expect this collaborative effort to increase in the coming years (exponentially?).

Get involved!

Contacts

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- Roxanne Guenette (University of Manchester)

Collaboration Board Chair

- Walter Bonivento (INFN Cagliari)

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2. Industry Connections & Technology transfer: Lucia Consiglio (INFN) & Jesper Skottfelt (Open University)
3. Training and Outreach: Patricia Sanchez-Lucas (University of Granada) & Benjamin Tam (University of Oxford)

Backup