ECFA R&D: liquid detectors

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The physics of liquid detectors

Science covered

Neutrinos

Dark Matter

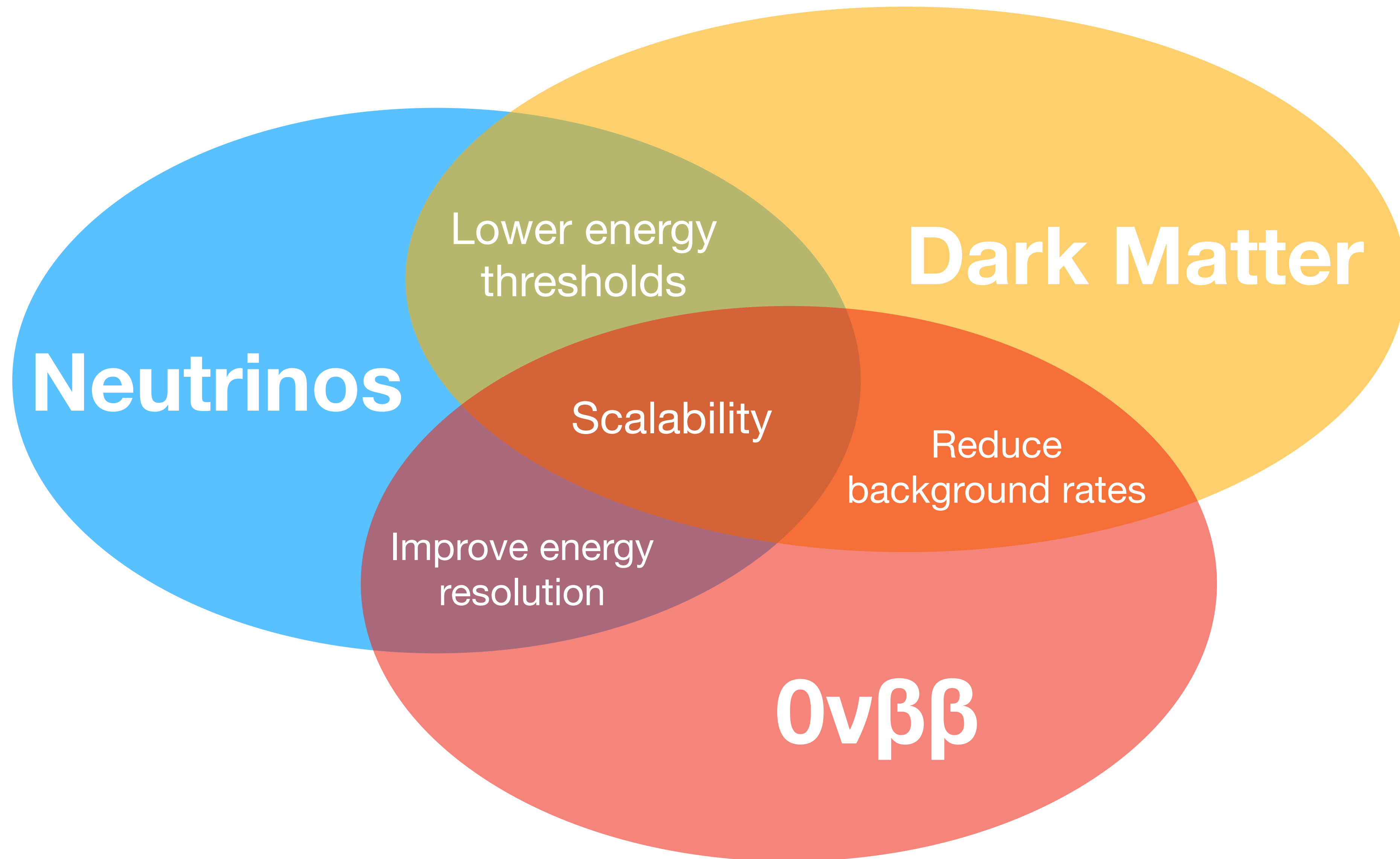Liquid scintillator

Noble liquid

0νββ

...

Water Cherenkov

Detector technologies

Physics challenges

Neutrinos

Dark Matter

0νββ

Lower energy thresholds

Scalability

Reduce background rates

Improve energy resolution

R&D in liquid detectors

Charge Readout Conveners	Light Readout Conveners	Target Properties Conveners	Scaling-up Challenges Conveners
Pixels & charge+light Group leaders	Increased sensor quantum efficiency Group leaders	Target properties and isotope loading of LS & WC Group leaders	Radiopurity & background mitigation Group leaders
Charge-to-light, electroluminescence & amplification Group leaders	Higher efficiency WLS and collection Group leaders		Detector and target procurement/production & purification Group leaders
Ion detection Group leaders	Improved sensors for LS & WC Group leaders	Target properties and isotope loading of noble elements Group leaders	Large-area readouts Group leaders
			Material properties Group leaders

Dark matter with liquid detectors

Argon

DarkSide-50

DEAP-3600

Previous/current liquid detectors

Neon
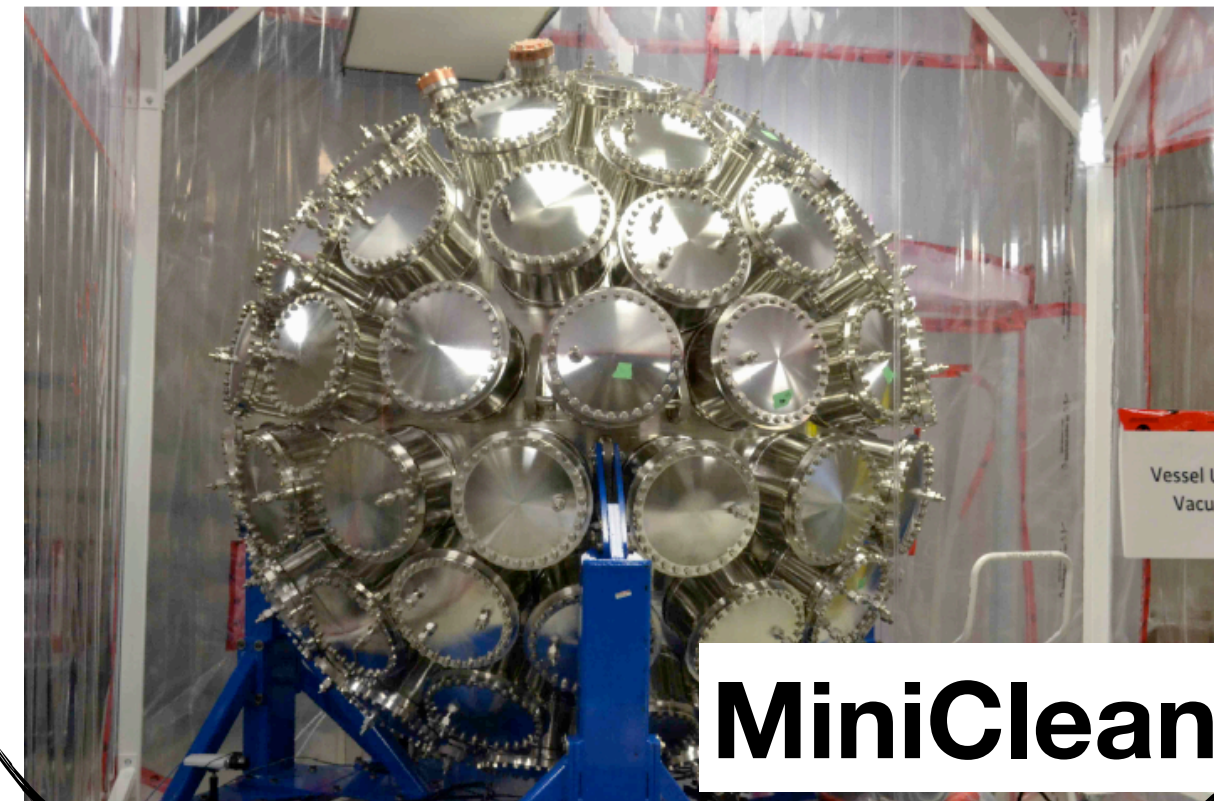
MiniClean

Xenon

XENONnT

LZ

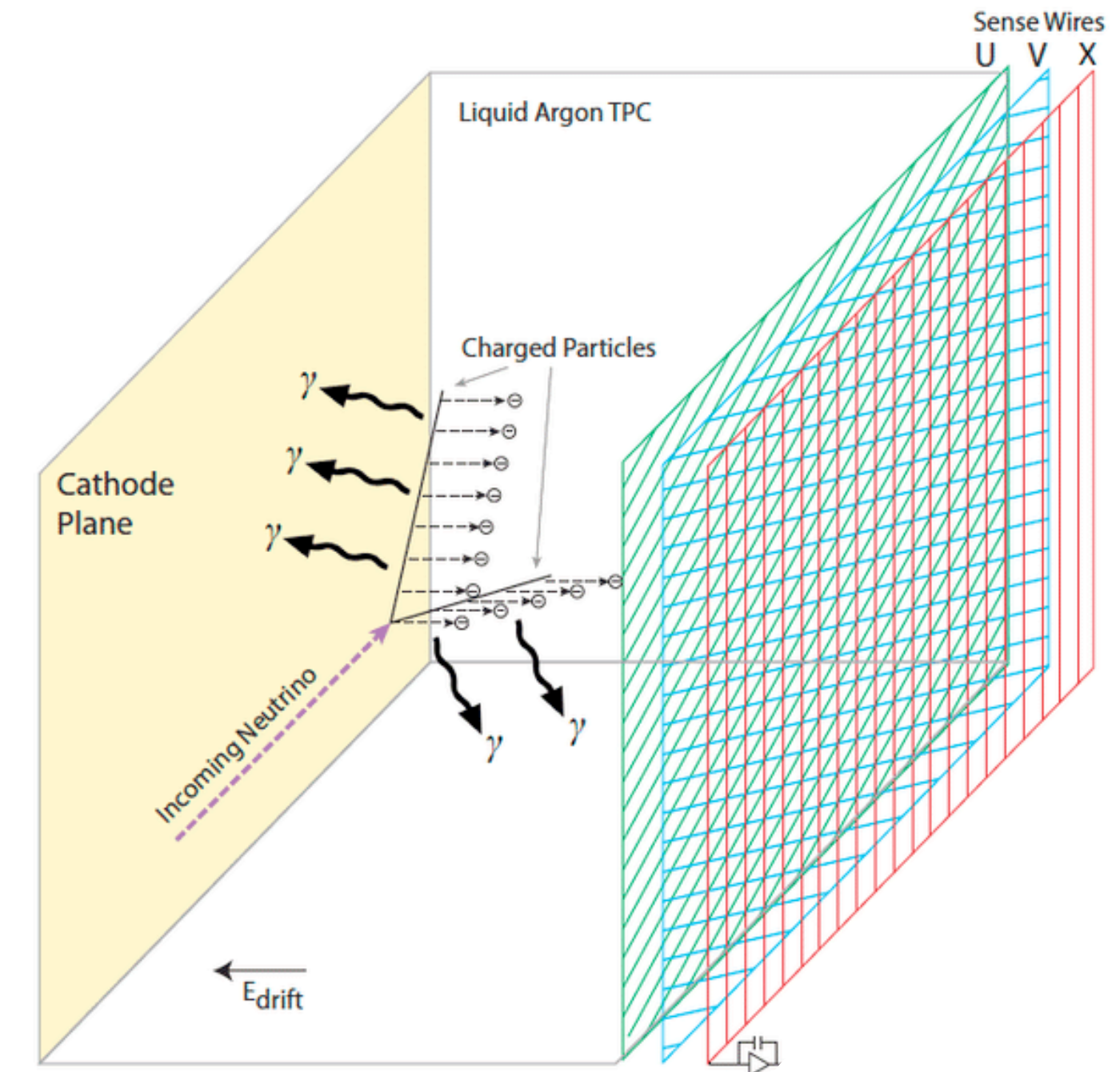# Next generation DM liquid detectors
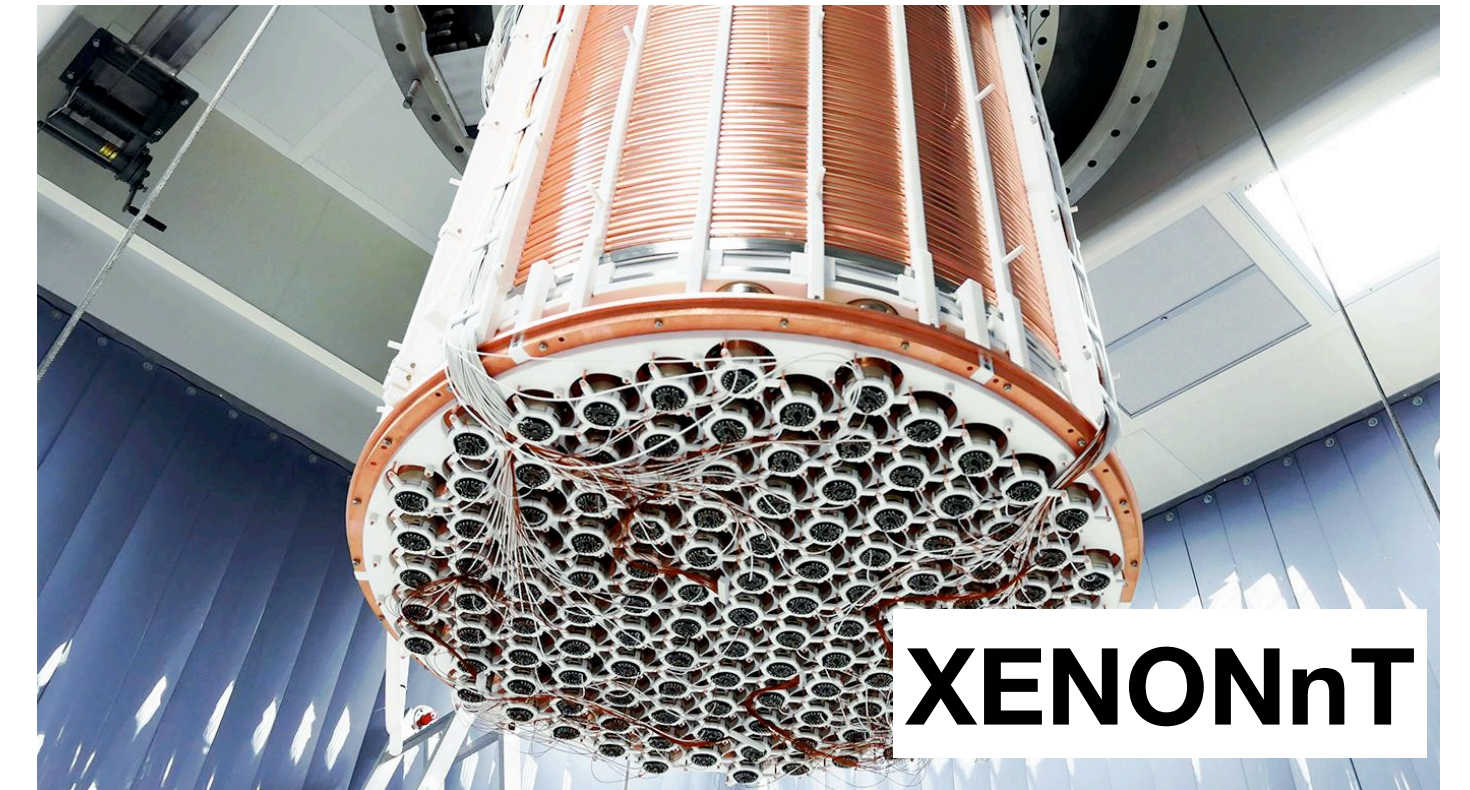
Dark Matter noble liquid TPCs
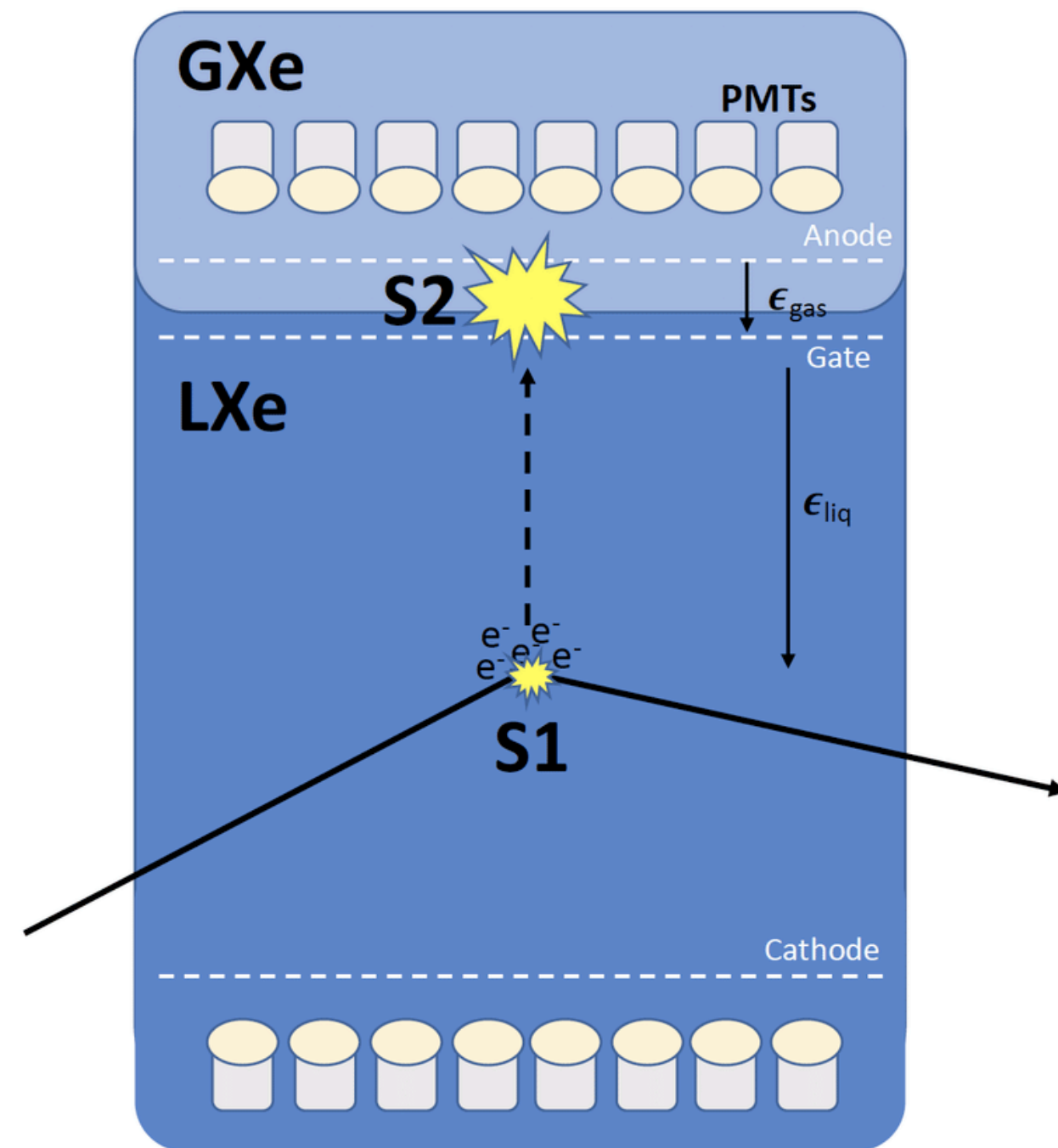
- LAr or LXe
- Dual-phase
- O (100) tonne
- Readout light

Direct dark matter detection

Neutrinos LArTPCs

- LAr only
- Single phase
- kT scale
- Readout charge

Indirect dark sector access

Future detectors challenges

Move from $\mathcal{O}$(1-100) tonne to kT scale

- Long drift distances
- Large active masses
- Readout large areas

Target materials

- Radiopurity & background mitigation
- Purification
- Procurement

Readouts

- Noise
- Many channels
- High data rate
- Assembly/testing facilities

Target materials
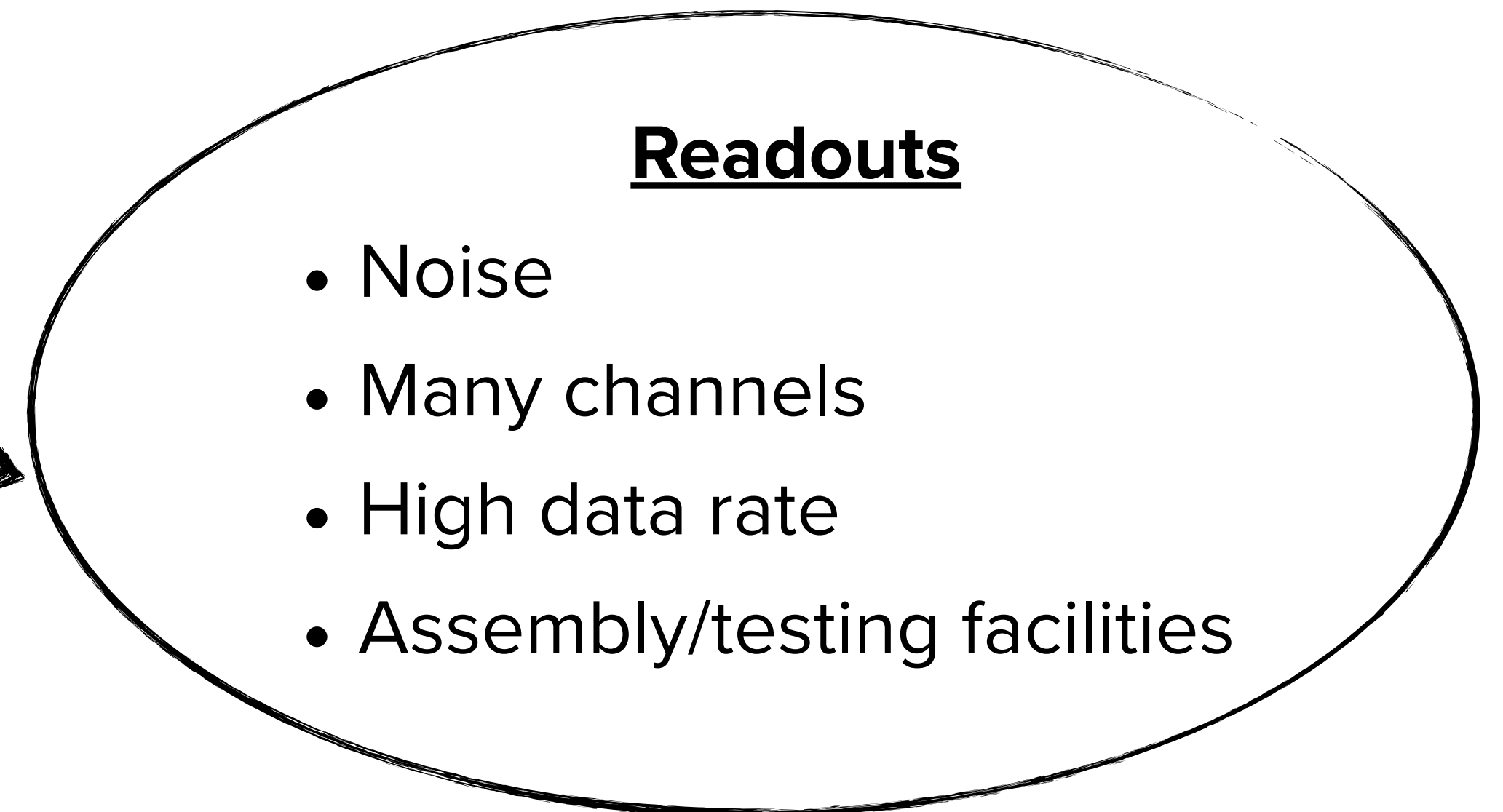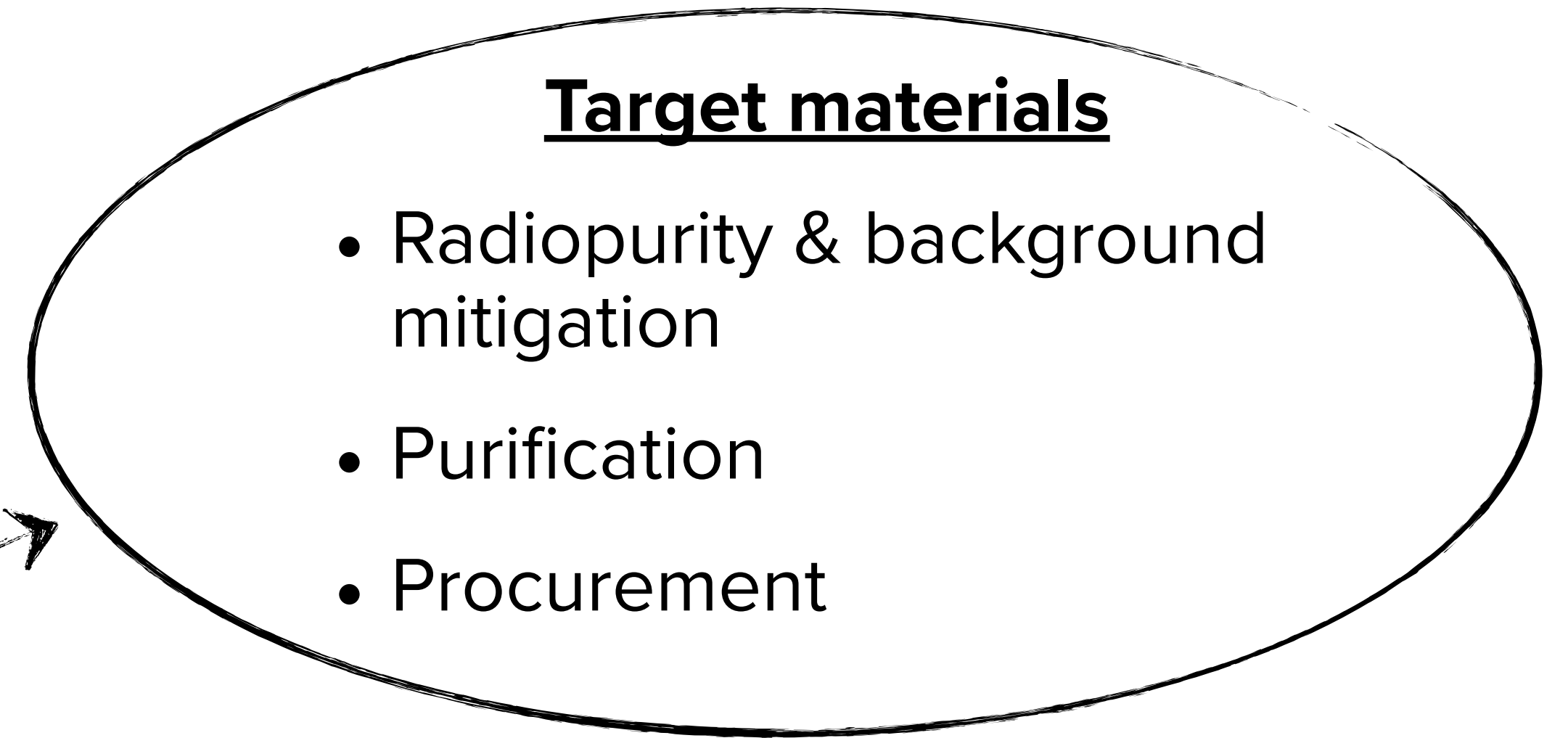
- **Traces of radioactivity** can be a dominant background

- **Extract/purify/transport** large quantities of LAr

- **Electron-lifetime** measurement

- **Light yield enhancement** via doping

- Understand **noble liquid response**

→
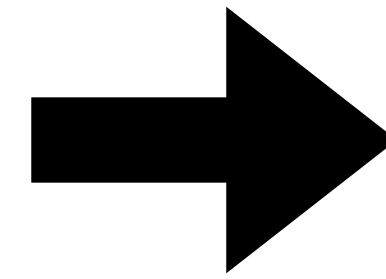
- More sensitive **assay methods**

- Material **selection and treatment**

- **In-situ laser beam**

- Set-up **small scale testing facilities**

Light collection

- **LAr/LXe VUV scintillation** challenging
  - ‣ Quantum efficiency (QE) in VUV range
  - ‣ Wavelength shifting (WLS) in large detectors

- **Light yield** enhancement

- Necessity to cover **huge surfaces** with photodetectors
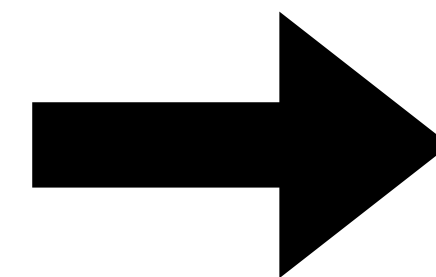 - ‣ Up to $\mathcal{O}(1000\ m^2)$

- **High voltage environment**
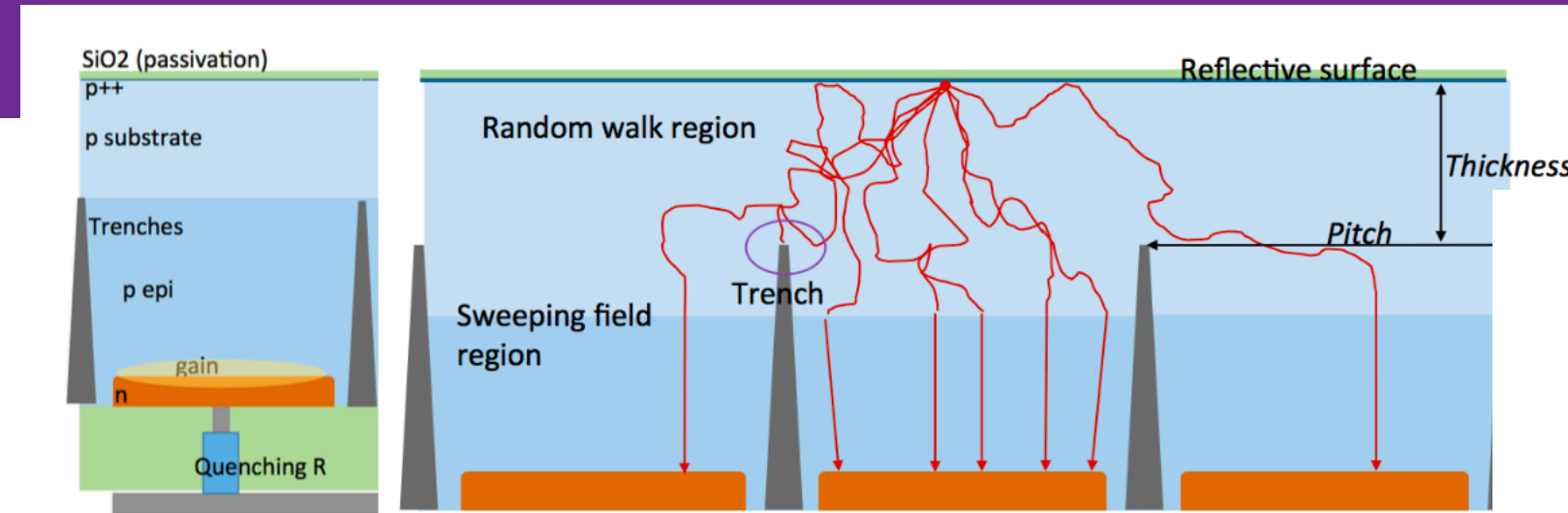
Increase QE in VUV range
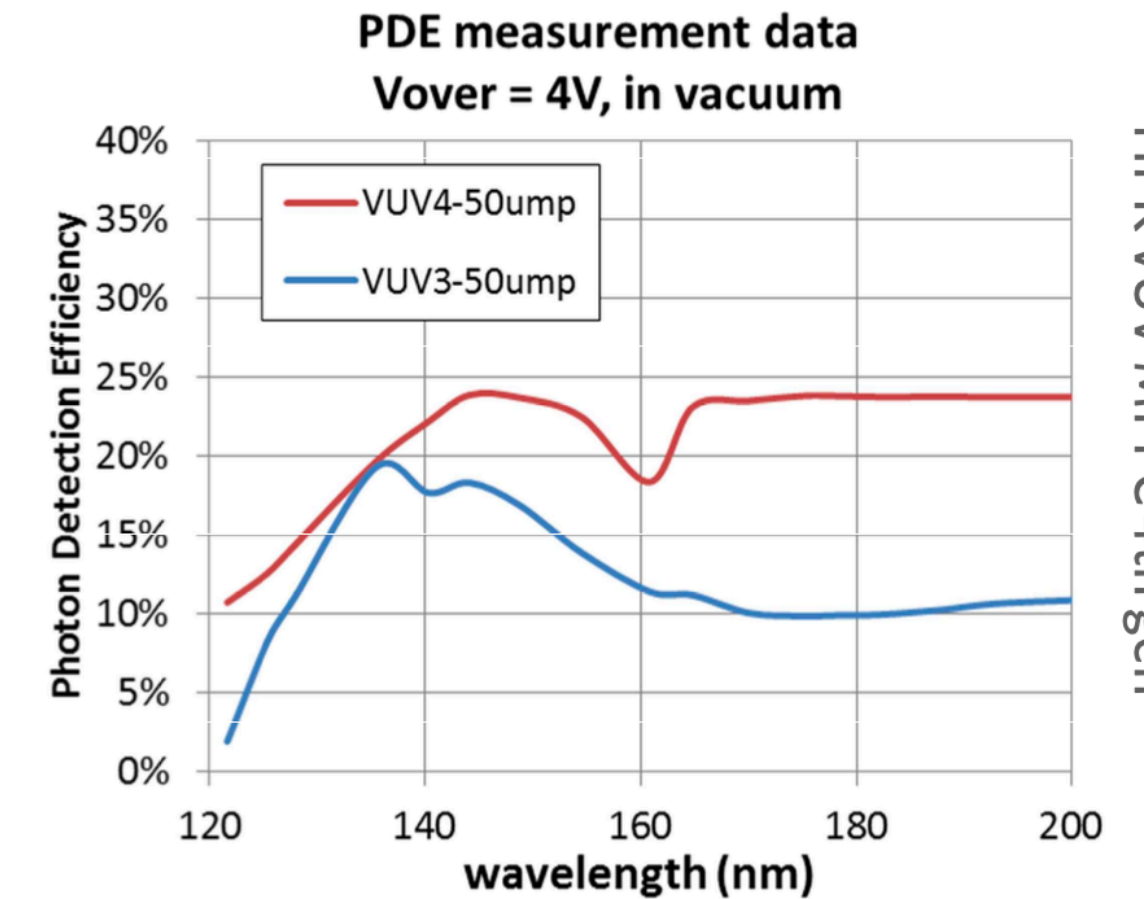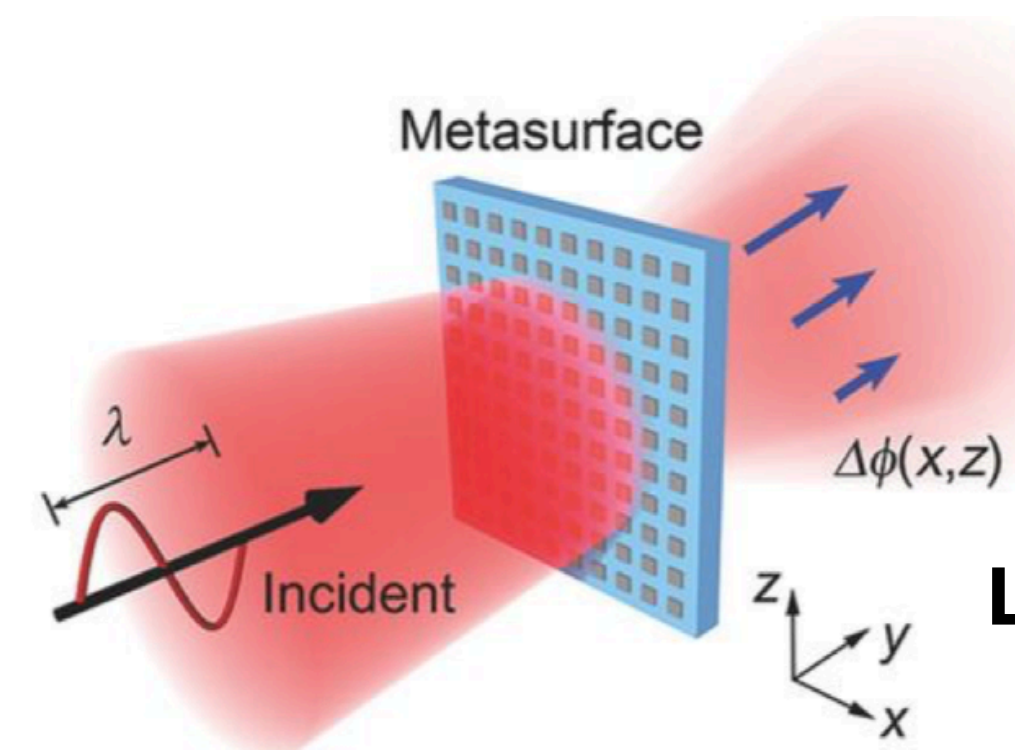
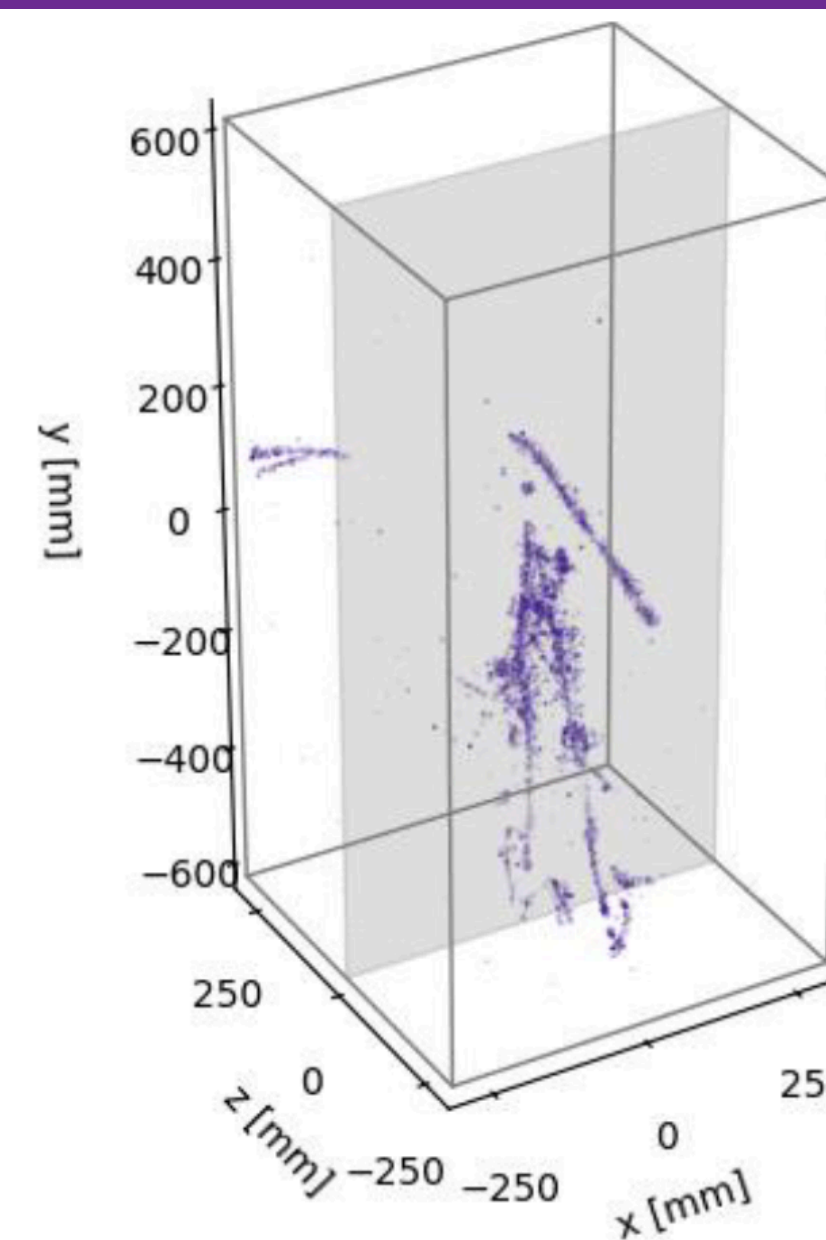**Light collectors/concentrators**

Power/signal over fibre

And more!

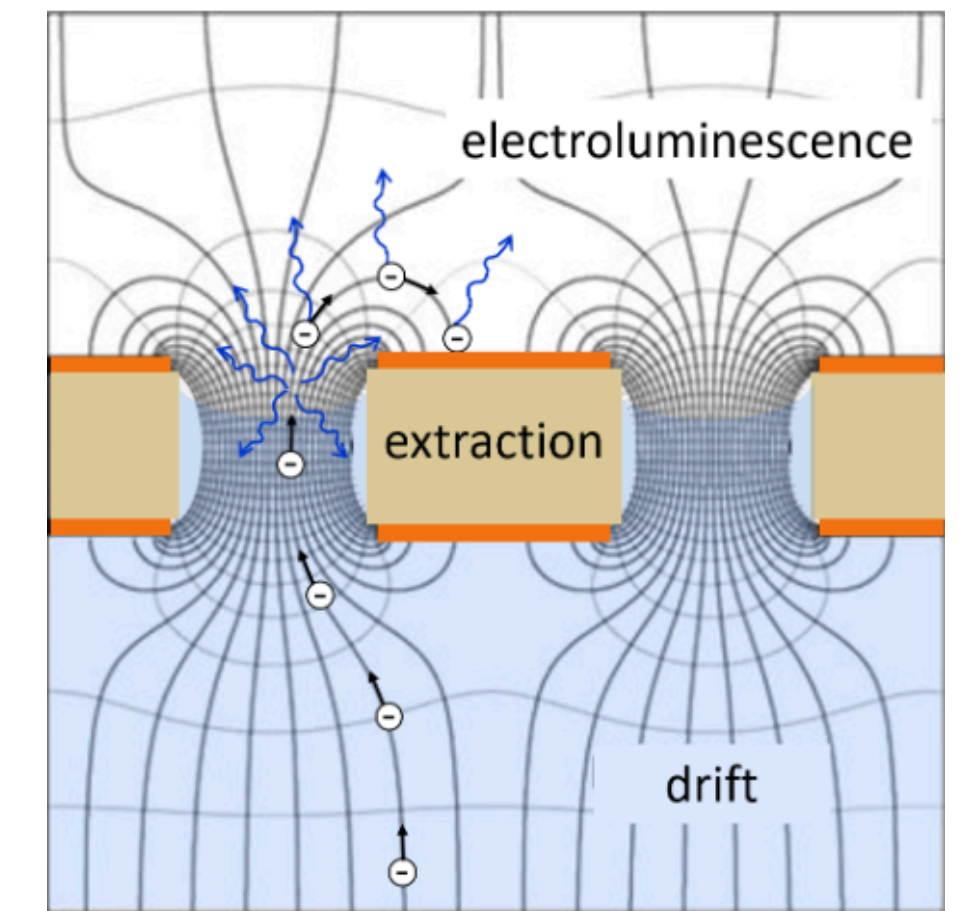# Charge collection

Pixelated TPCs

- Move away from wire planes to eliminate reconstruction ambiguities
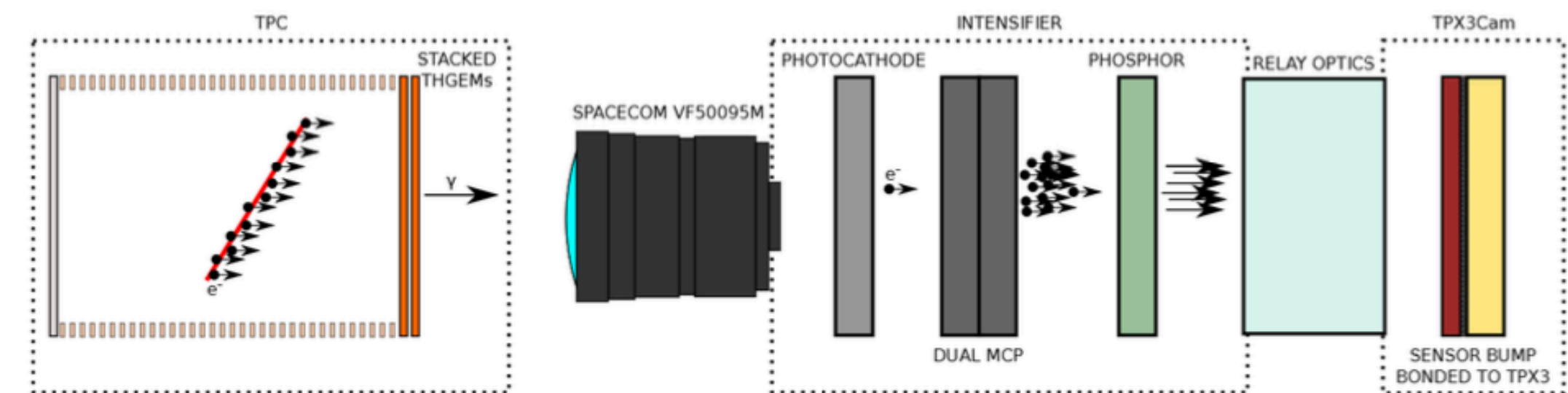
    ‣ **True 3D reconstruction**

- **Charge amplification**
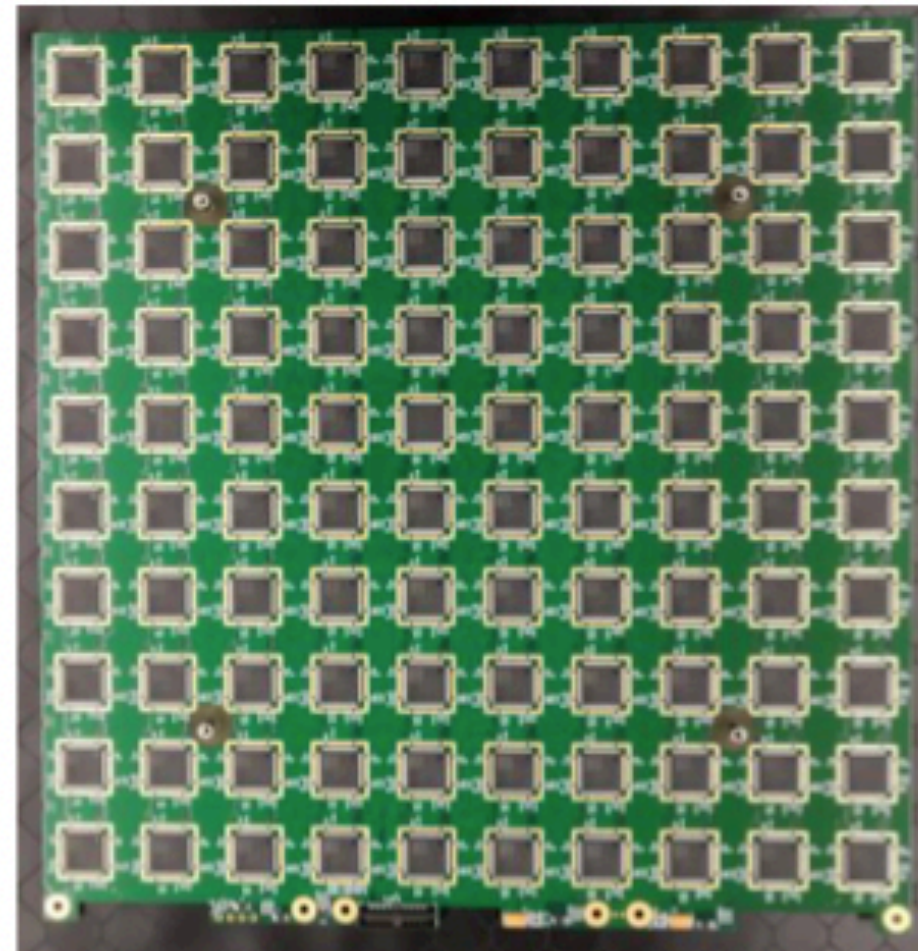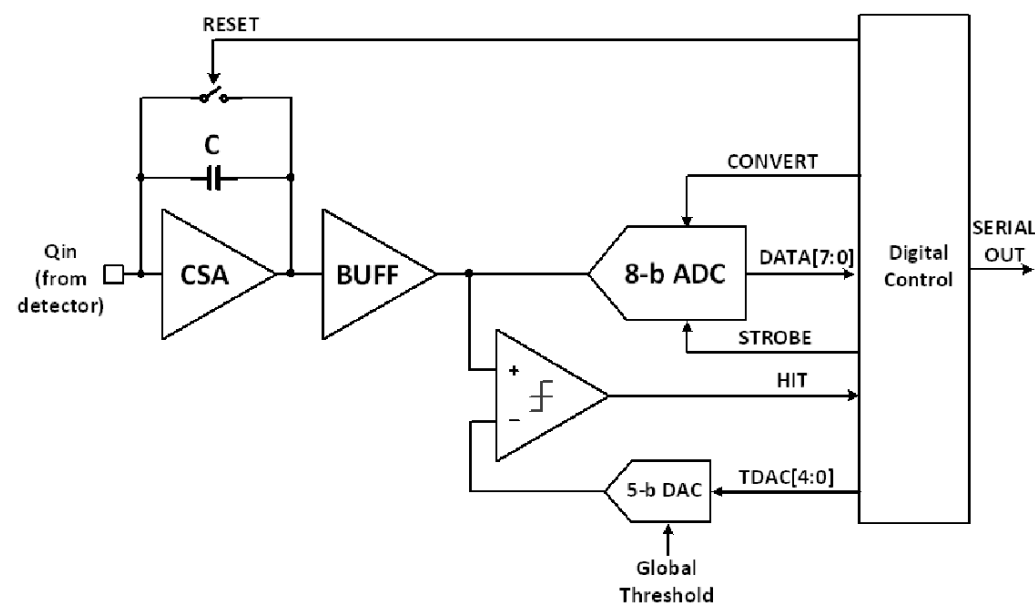
- **Charge-to-light** conversion
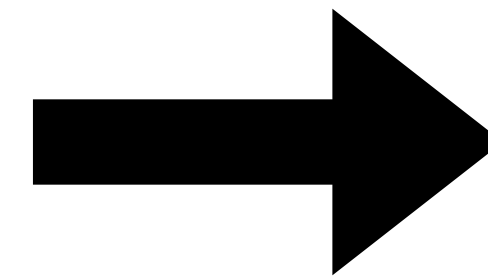
Floating THGEMs

Granular S2 light readout of ionisation charge

And more!

Pixels

LArPix

- Low power

- Self triggered digitisation and readout

- Technology **developed in ArgonCube**
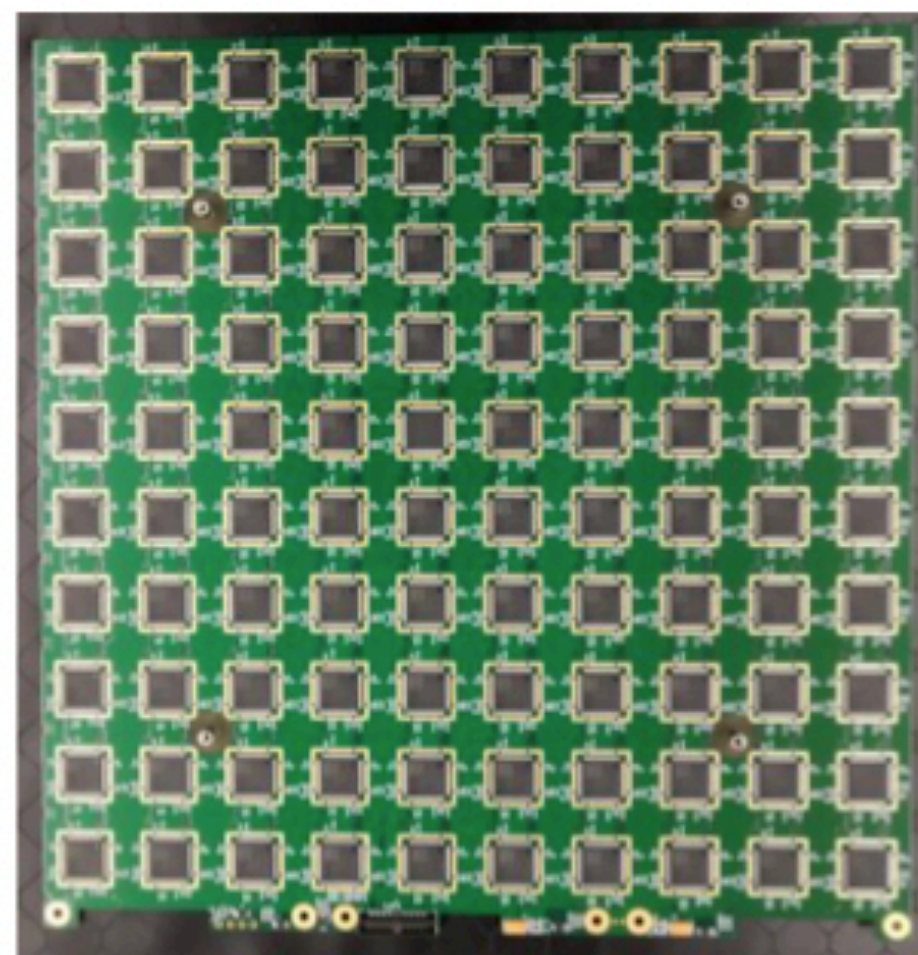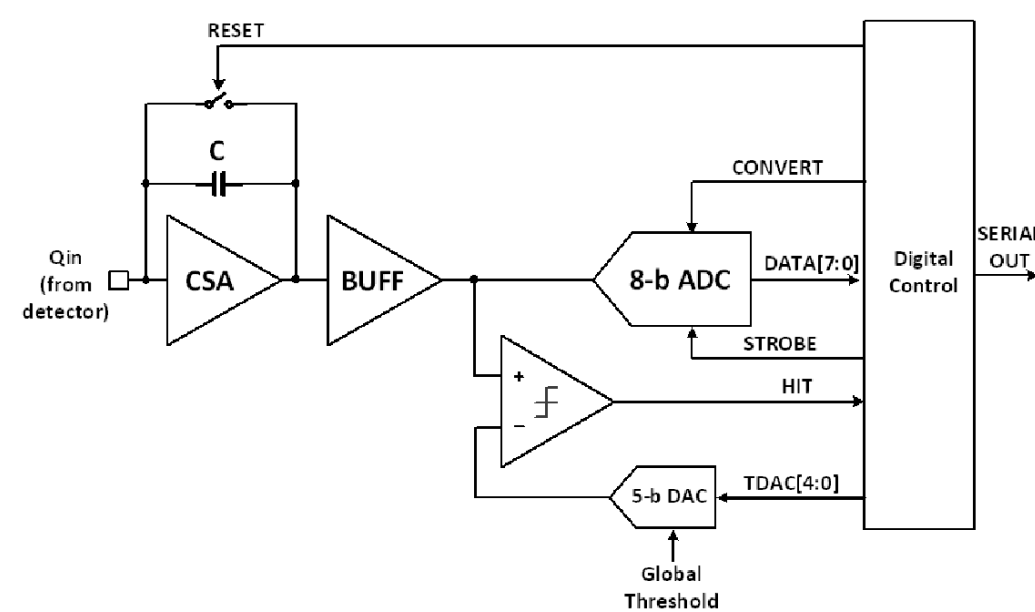
- 2x2 DUNE ND demonstrator at Fermilab

Q-Pix

- Developed to **solve the data rate issue** of pixellated readouts

- **Electronic principle of least action**

- Saves time stamps instead of full waveforms

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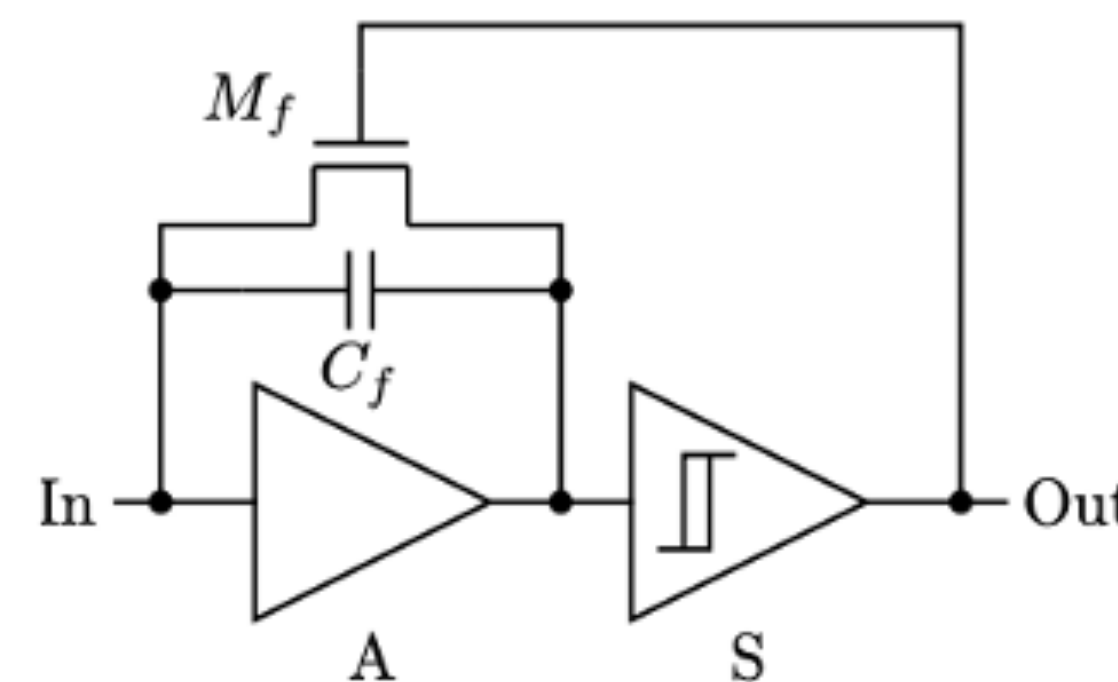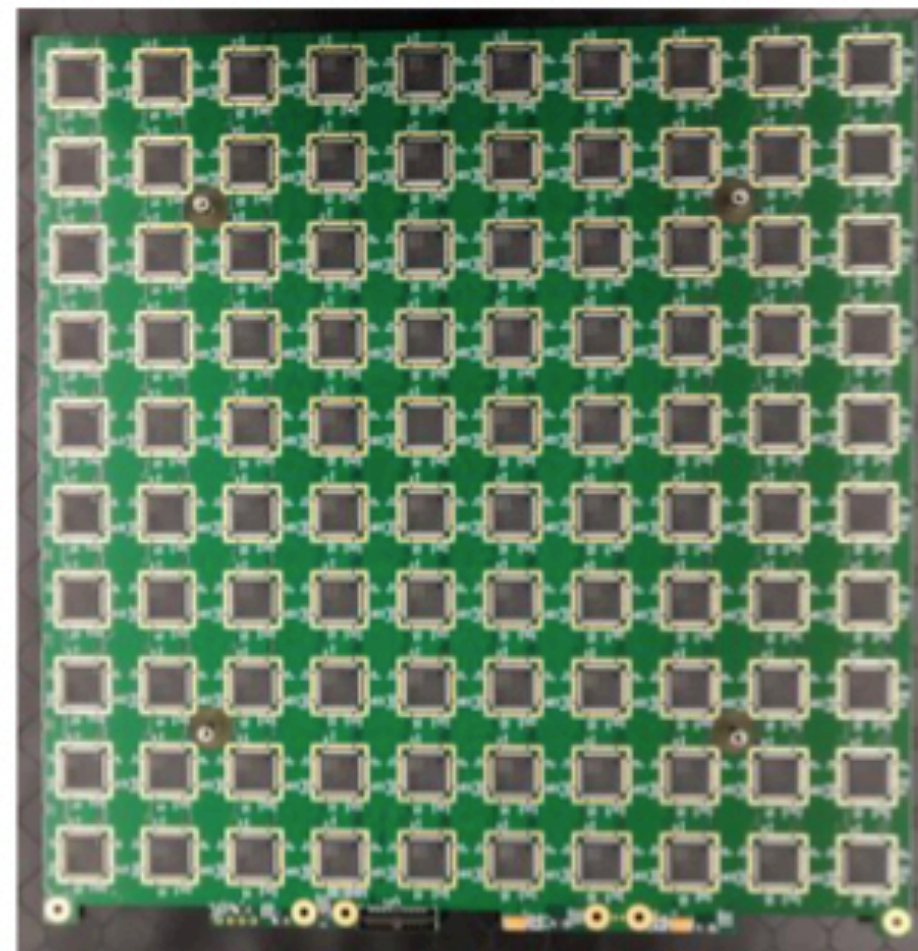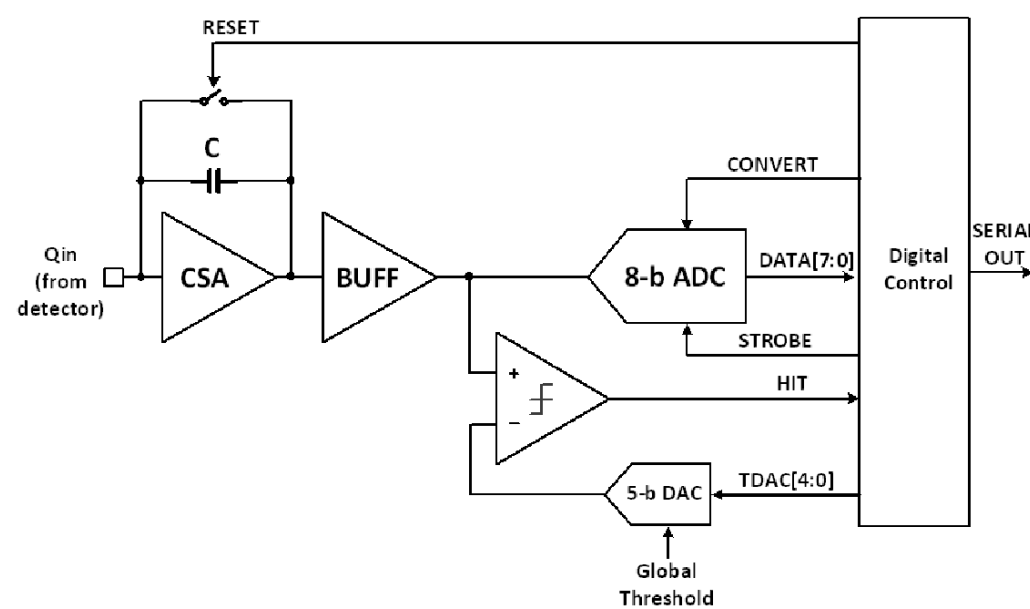- Saves time stamps instead of full waveforms

- Each channel integrates Charge Integrate Reset circuit

- Resets when charge $> \Delta Q / C_f$

- Measure reset times with embedded clock

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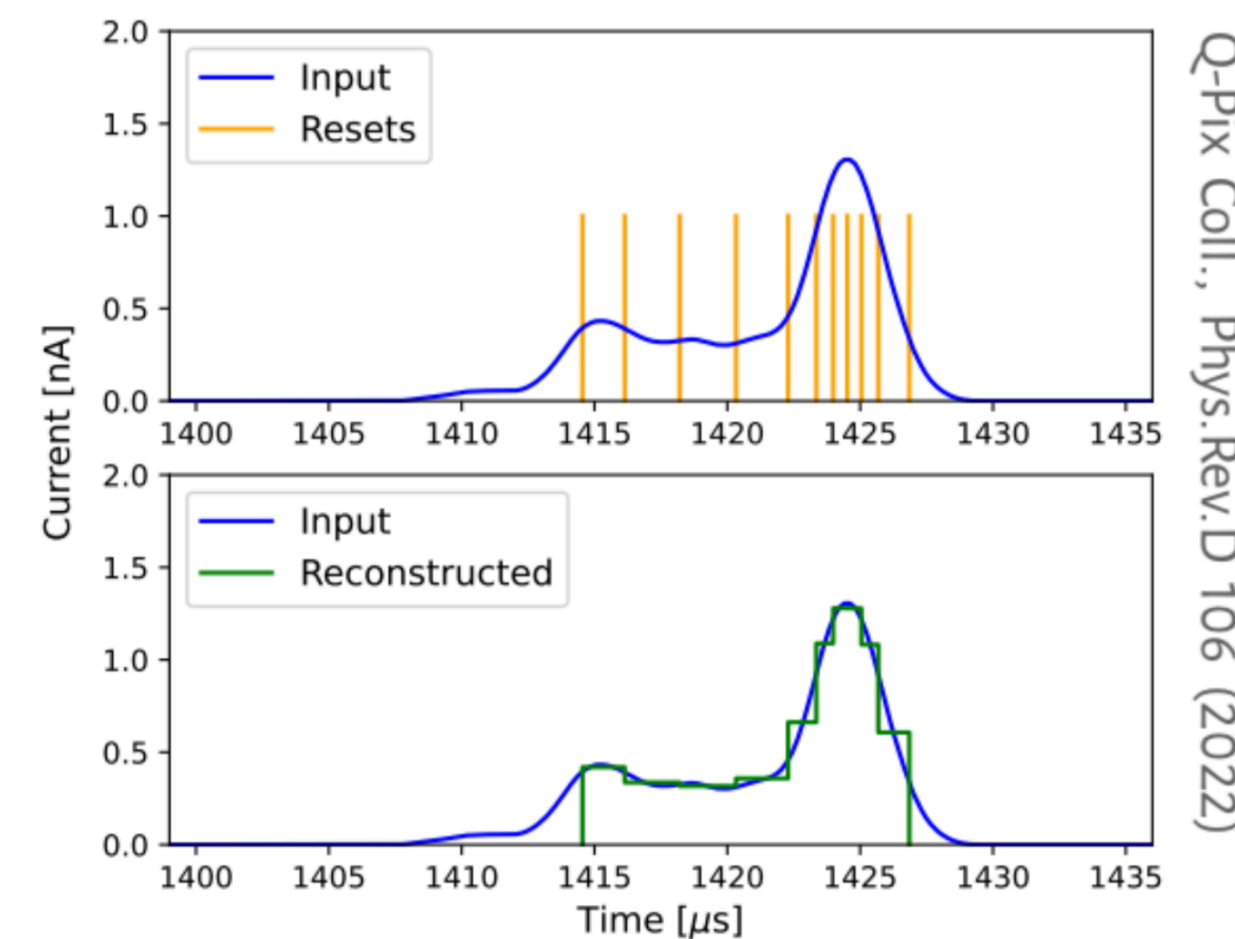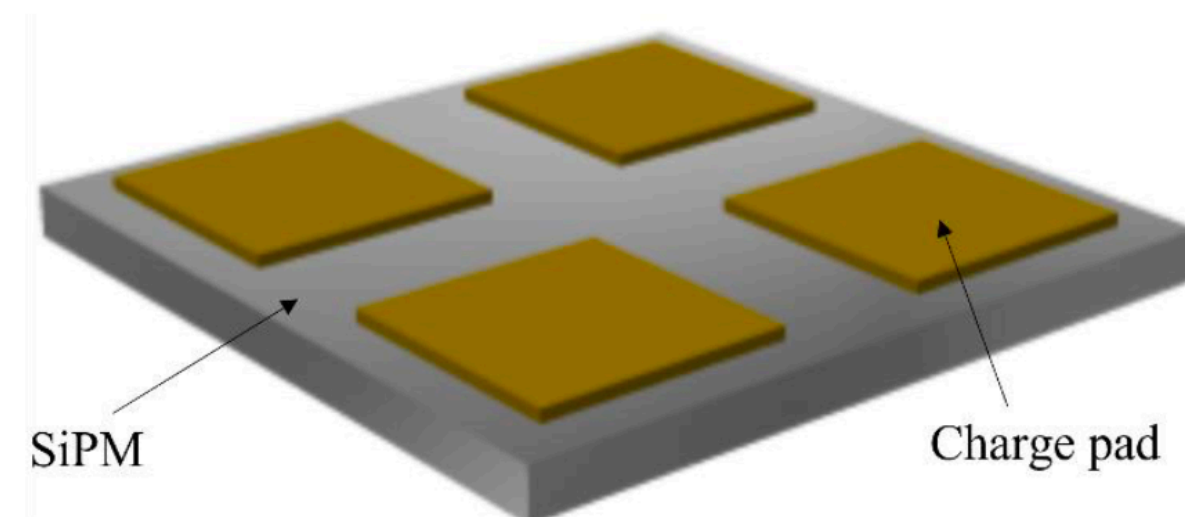
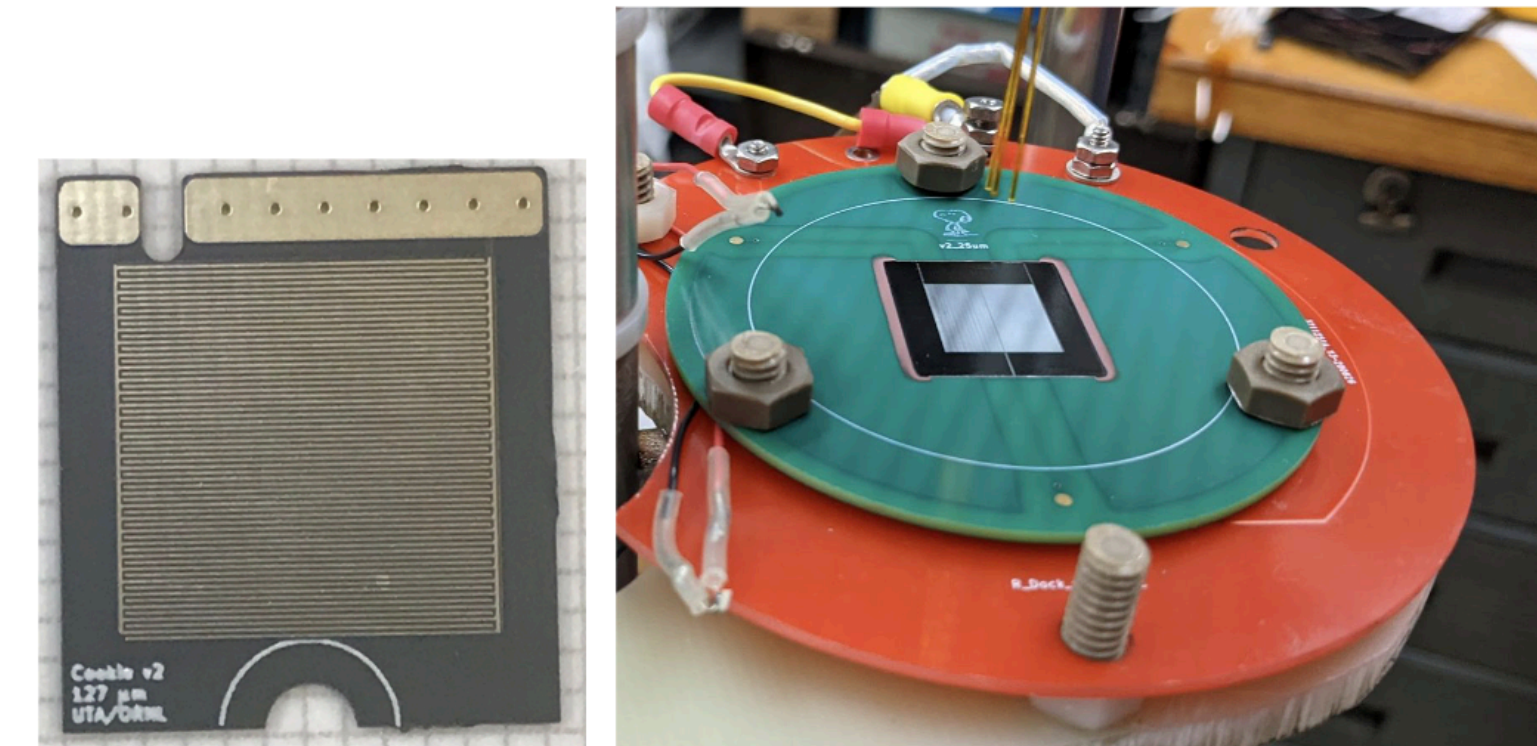- Measure reset times with embedded clock

Combined charge & light readouts

Correlated light & charge emission is a strength of TPCs

‣ Combined readouts boost detection capabilities, especially at low energy

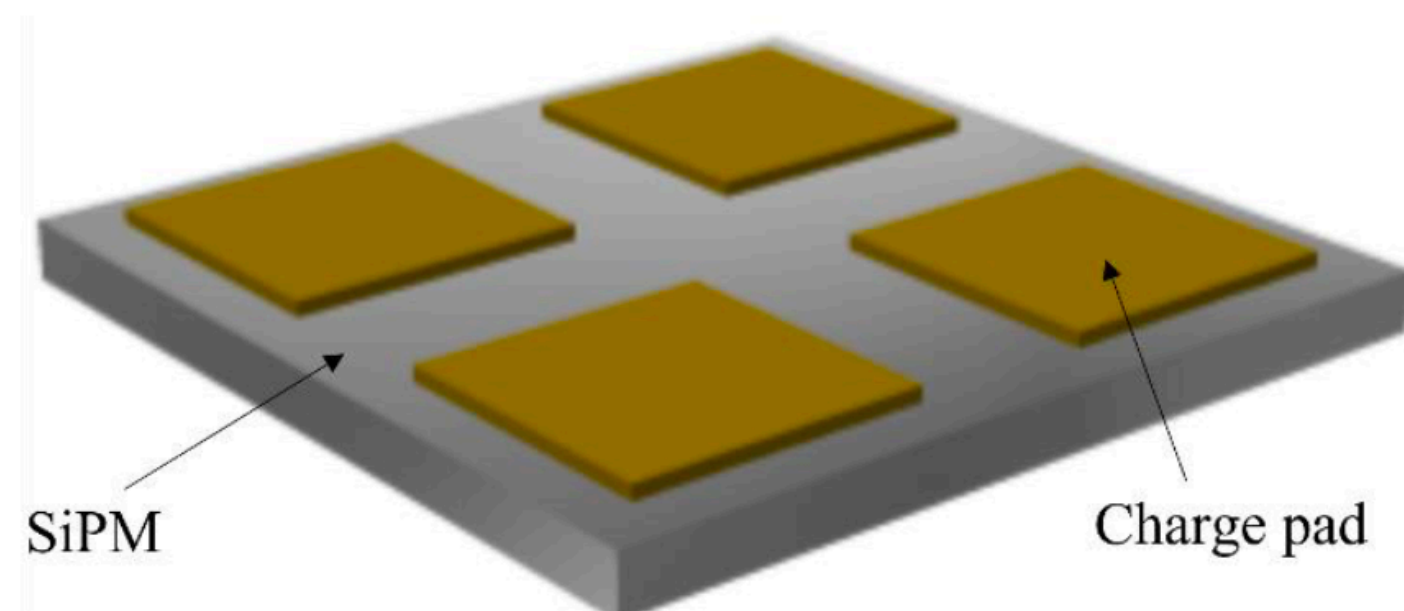**Light & charge readout tile: SoLAr**
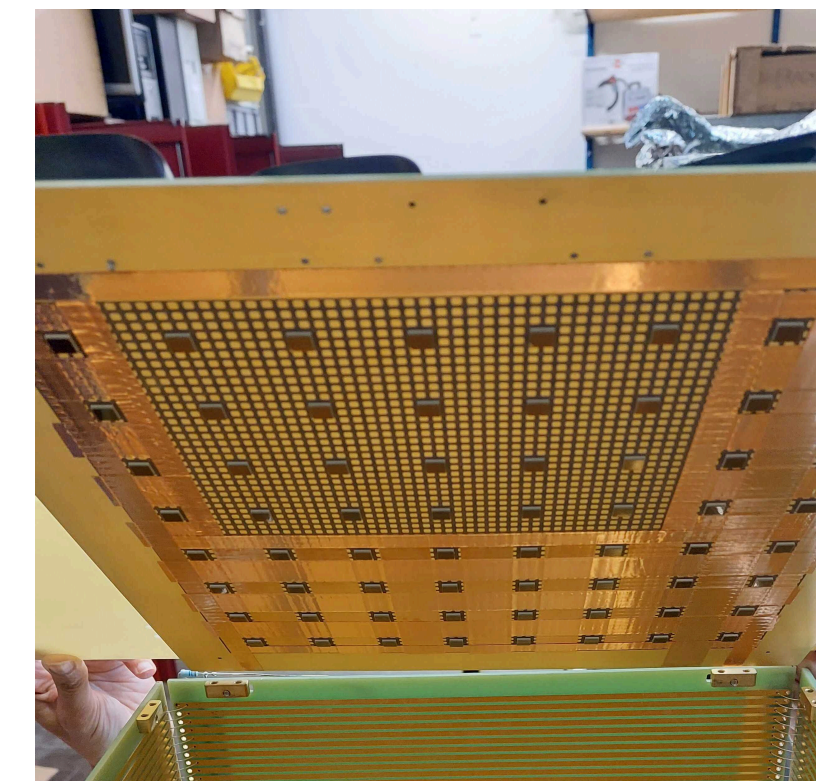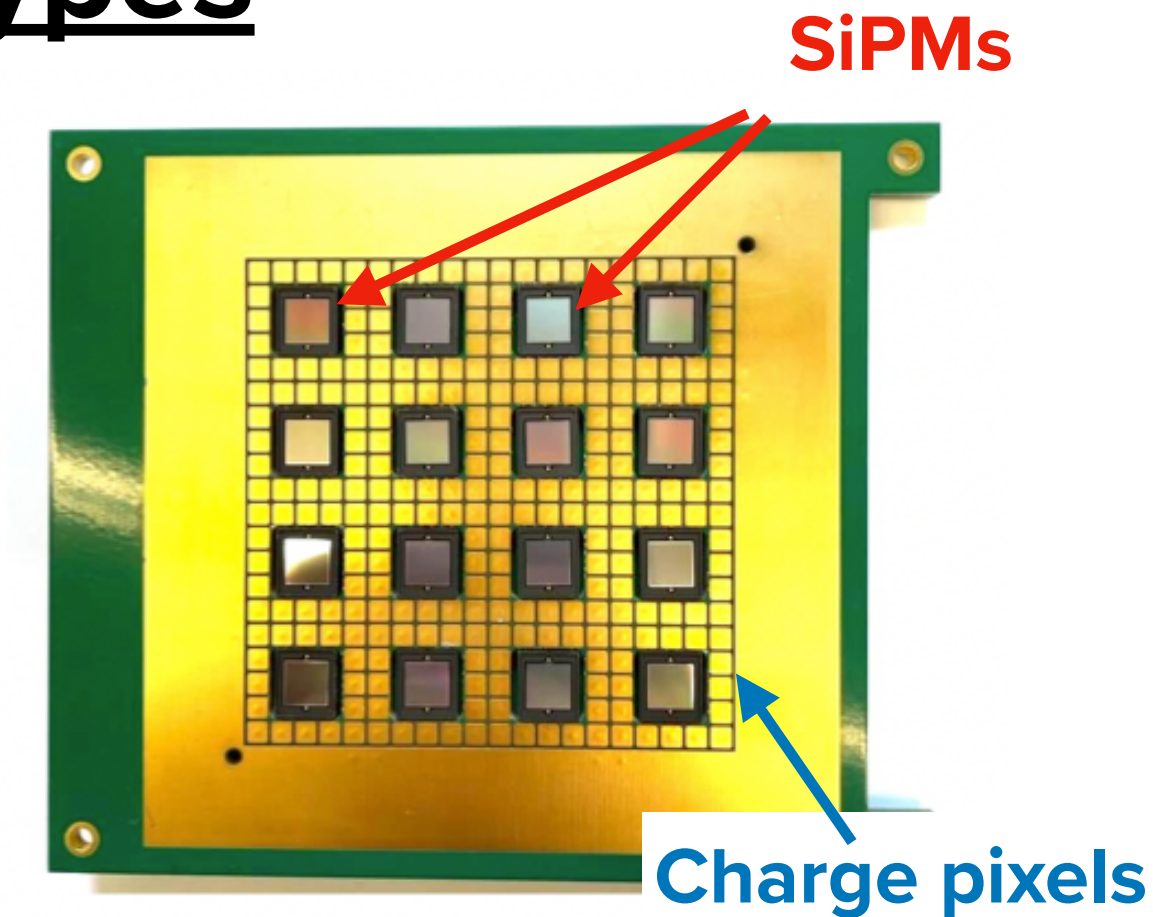

Multiple modality pixels

SoLAr

Concept

- Novel LArTPC readout technology for low energy neutrino physics

- All-silicon pad with CMOS layer divided into many p-n junctions and operates as a VUV SiPM

- Prototyping using **VUV SiPMs** and **LArPix chips**

Prototypes

- Run in LAr at LHEP Bern in **October 2022**

- 7 x 7 cm² readout tile

- 16 VUV SiPMs

- 4 LArPix chips
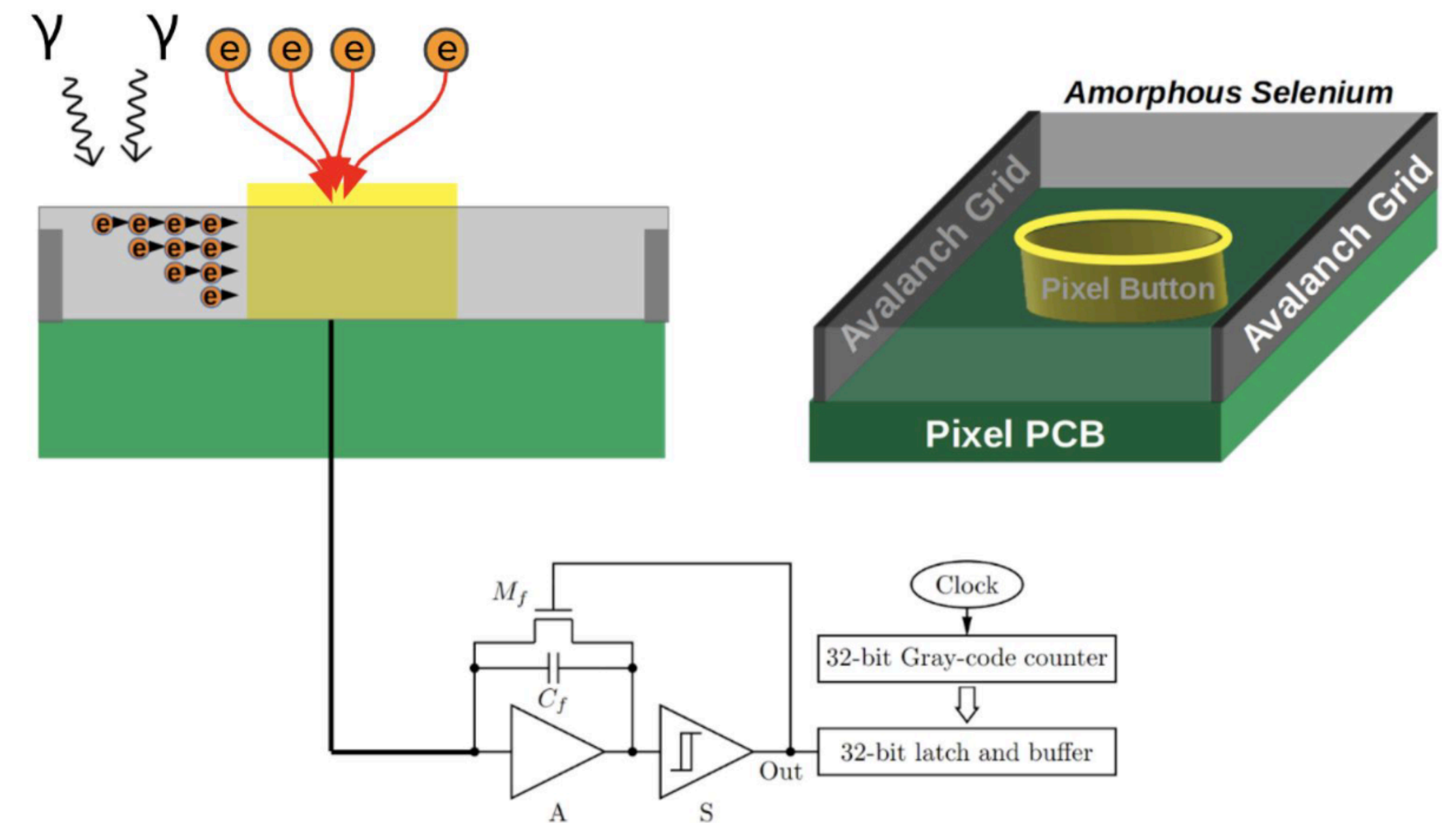

SiPMs

Charge pixels

- Run in **July 2023**

- 30 x 30 cm² readout tile

- 64 LArPix chips

- 64 Hamamatsu VUV SiPMs

Multiple modality pixels

- **Principle:** convert light into charge by coating pixels with photo-conducting material

- Amorphous selenium (A-Se) as coating material
  - ‣ QE > 99%
  - ‣ 1 γ ↔ resulting on avg in ~1.3 e-h pairs
    - ➡ Possible sensitivity to single photons
  - ‣ First tests demonstrated performance at cryogenic temperatures

When VUV γ strikes the A-Se, the γ is absorbed and a e-h pair is created with an extremely high probability if the A-Se layer is thick enough.
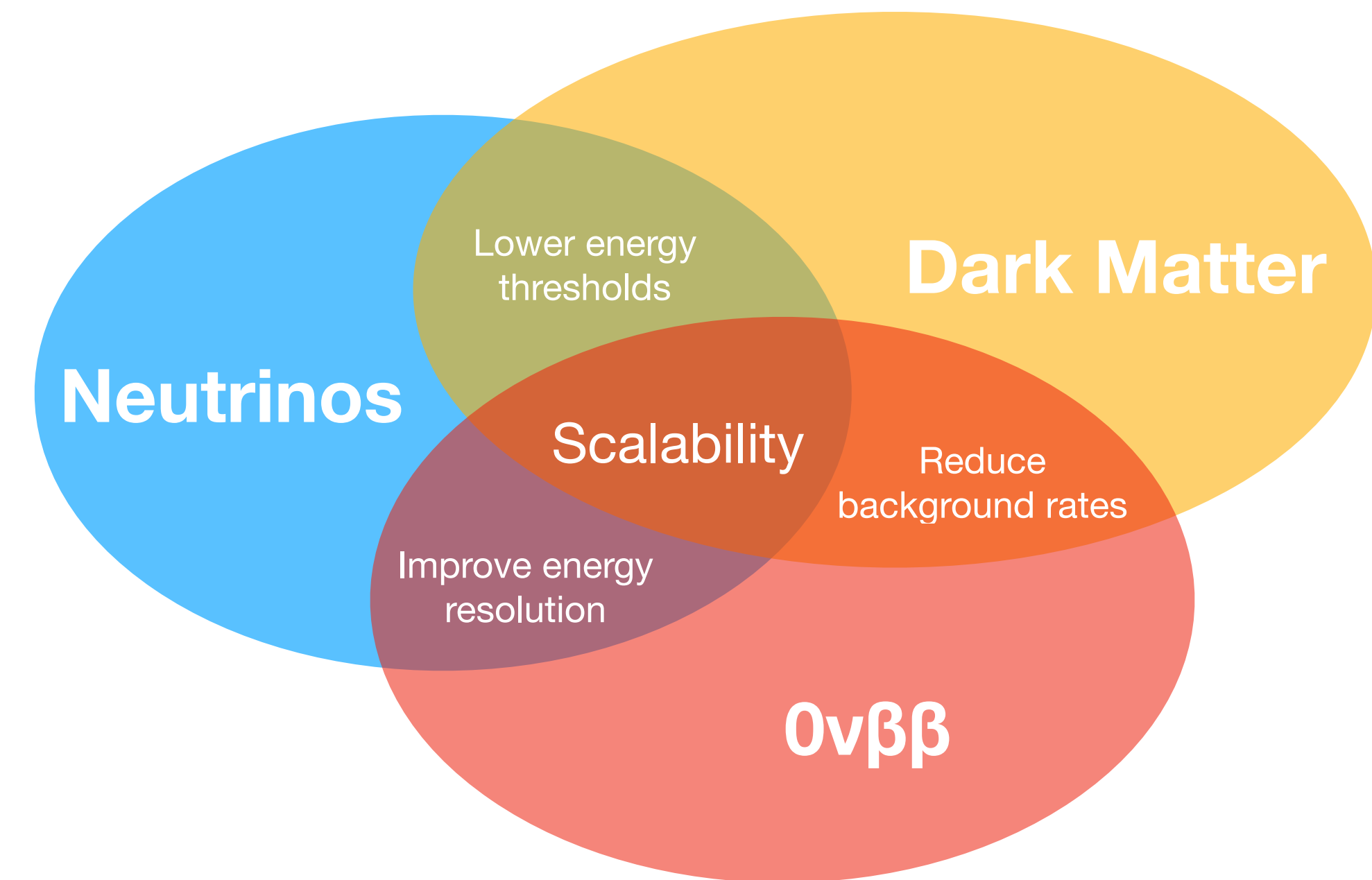

Amorphous Selenium

Avalanch Grid

Pixel Button

Avalanch Grid

Pixel PCB

Q-Pix Readout

Summary

- **Many R&D areas** for liquid detectors

  - Partial overview

  - Synergies between subgroups & science topics

  - Network of R&D facilities and shared resources

  - **More details** can be found in <u>ECFA Liquid Detectors Meeting</u>

- Can be **combined** to design extremely performant detectors

- **New detector technologies** under study for future generation

Summary
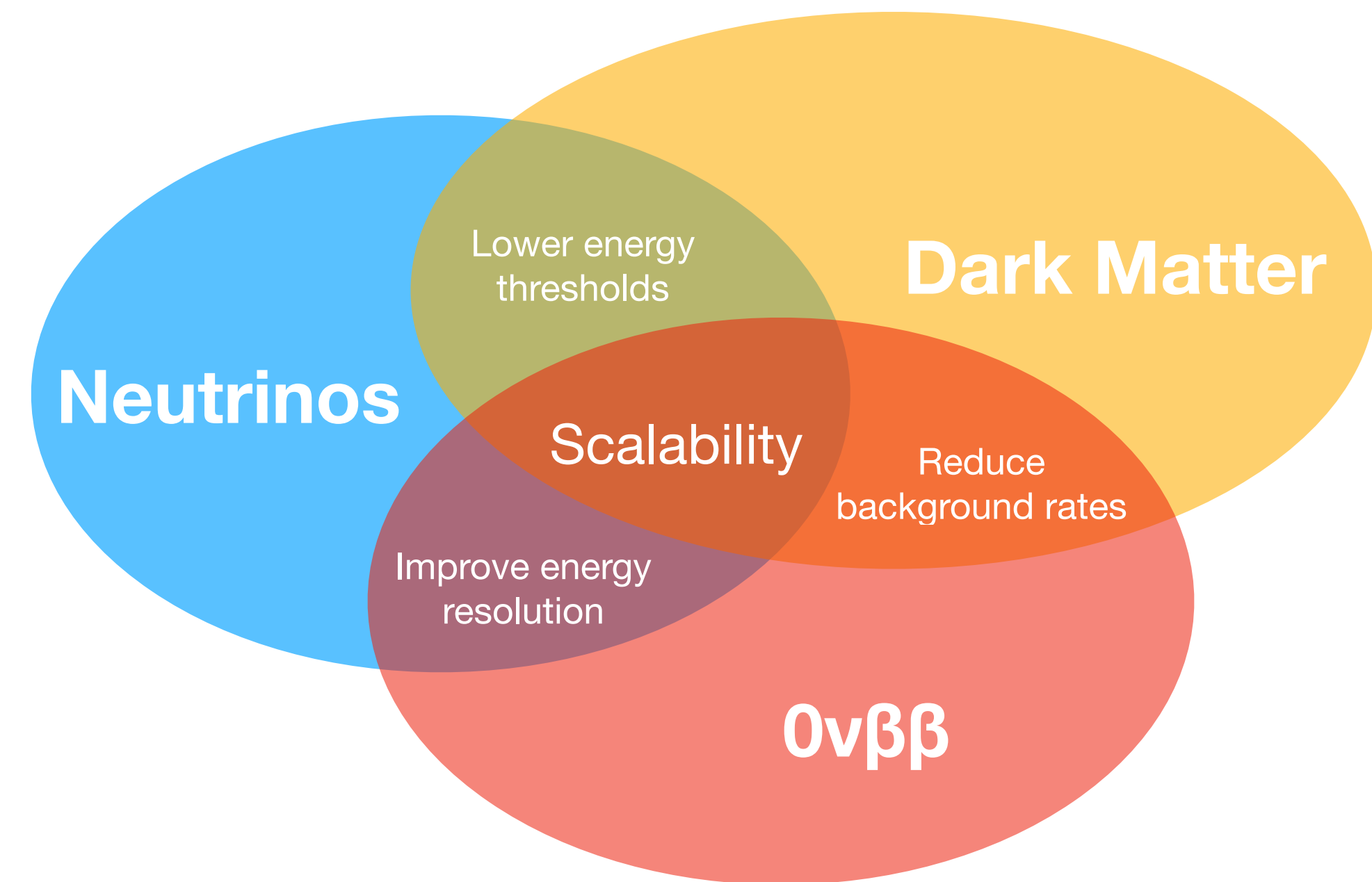
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Discuss!