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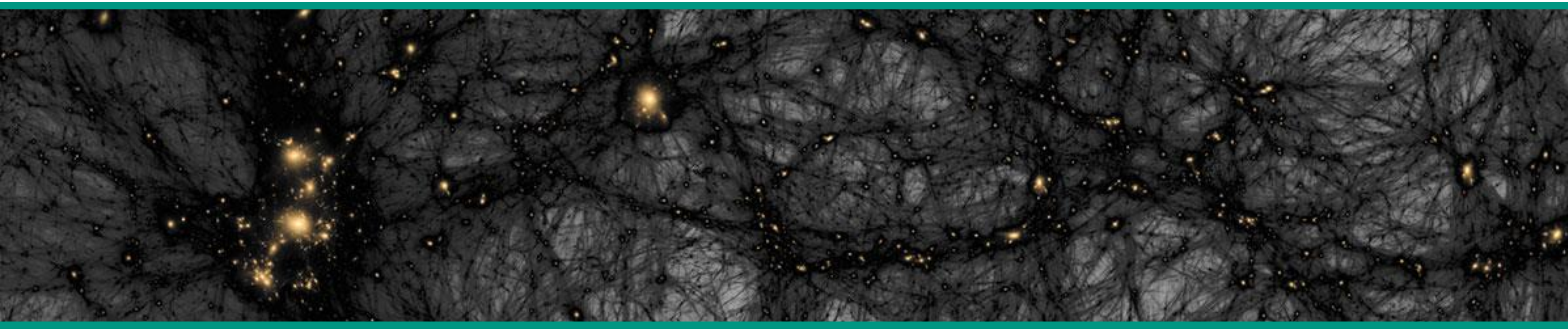
Astroparticle physics *I* – Dark Matter

Winter term 23/24 Lecture 18 Jan. 25, 2024



Recap of Lecture 17

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- **Evidences** & **upper limits:** $\boldsymbol{DAMA}$ & **1 – phase Liquid Noble gas experiments**

  - $\boldsymbol{DAMA-Libra}$: $\boldsymbol{250\ kg\ NaJ}$ scintillator crystals at $\boldsymbol{LNGS}$ (low background)
    ⇨ seasonal variation of rate over many years – is this a $\boldsymbol{WIMP}$ or **systematics**?

  - other $\boldsymbol{NaJ}$ experiments (and $\boldsymbol{LXe/LAr}$ detectors) exclude a $\boldsymbol{WIMP}$ interpretation

  - **scintillation** process of liquid noble gases based on formation of **excimers** & subsequent decay ⇨ leads to emission of $\boldsymbol{VUV}$ light ($\boldsymbol{LAr}$ requires $\boldsymbol{WLS}$)

  - **argon** detectors: intrinsic background from $\boldsymbol{\beta}$ – decay of $\boldsymbol{^{39}Ar}$ (⇨ $\boldsymbol{UAr}$)
    big advantage: pulse shape allows to suppress background (´$\boldsymbol{WIMP}$ **sprinter**´)

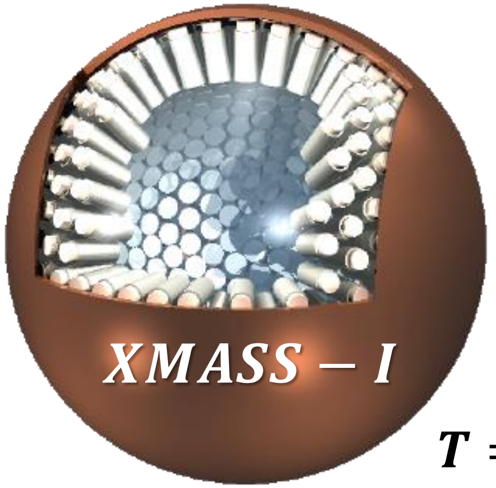
  - **xenon** detectors: cryodistillation of $\boldsymbol{^{85}Kr}$ ⇨ very pure target in fiducial volume

Liquid Xenon experiments: $XMASS$

- $XMASS$*: a single–phase LXe – detector at the $Kamioka$ mine (Japan)

  - $XMASS - I$ exposure: $M \cdot t = 832\ kg \cdot 16\ months$

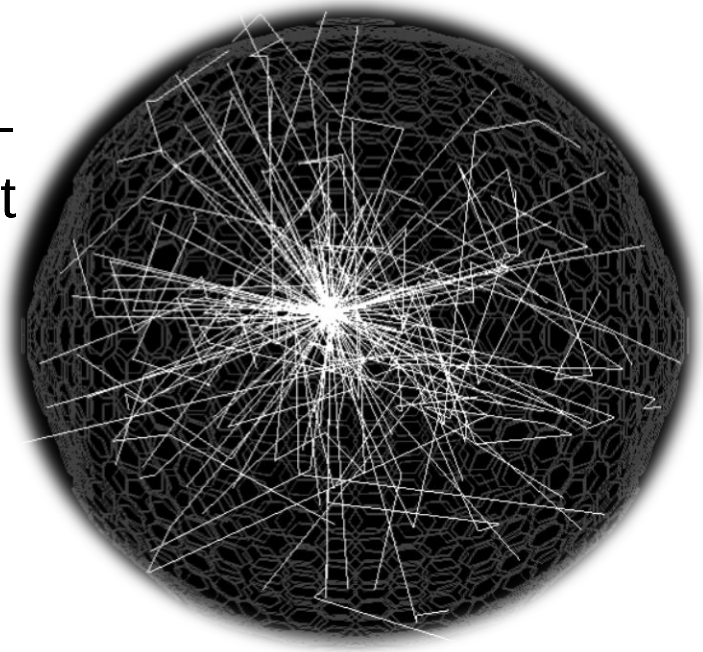
  - search for yearly modulation in data: **no signal**!

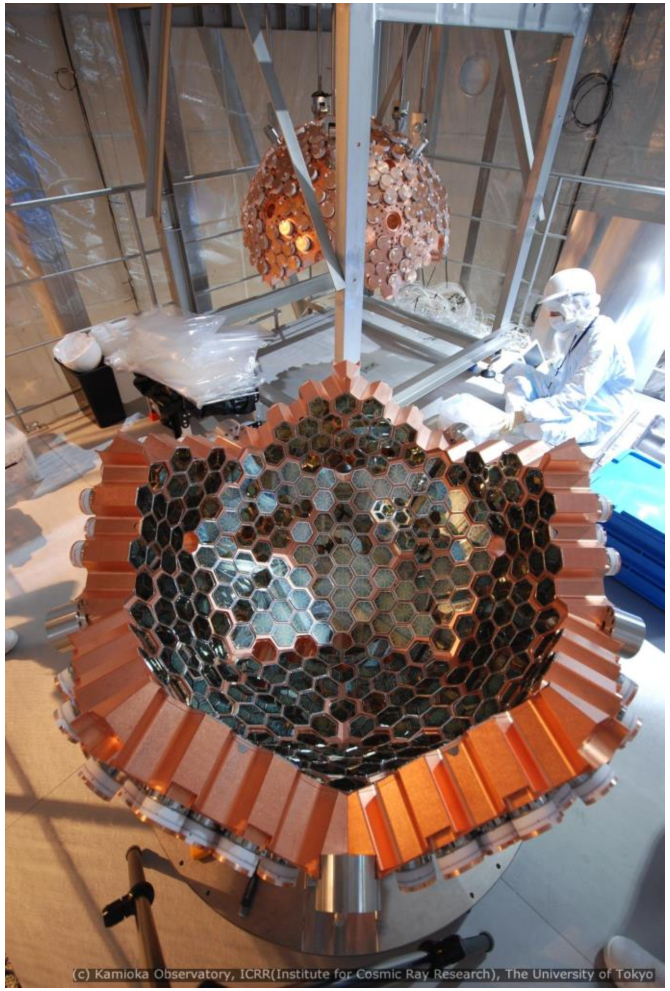


$T = 165\ K$

$M = 800\ kg\ (100\ kg\ fiducial)$

scintillation–
light





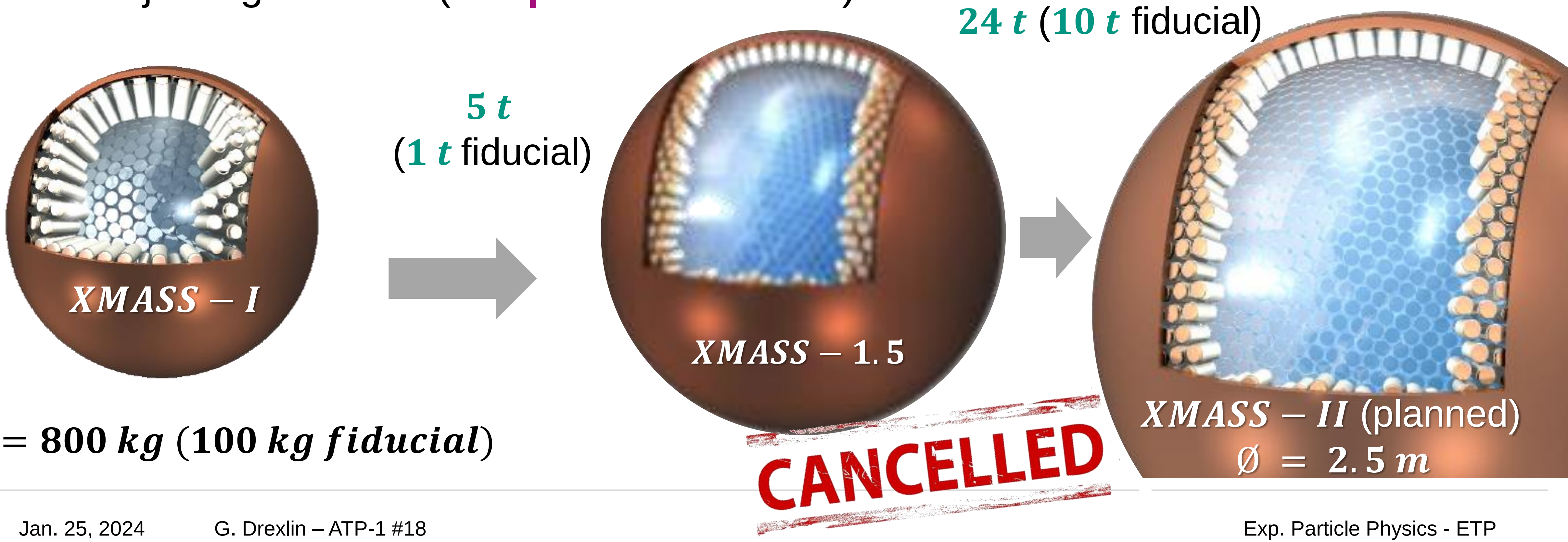
*Xenon detector for Weakly Interacting $MASS$ive Particles

Liquid Xenon experiments: $XMASS$

- **Projected increase in single−phase target mass by factor 30**

  - single−phase detector lacks $\boldsymbol{PID}$ based on **scintillation** & **ionization**

  - $\mathbf{2017}$: joining $\boldsymbol{XENON}$ (**2 – phase−detector**)

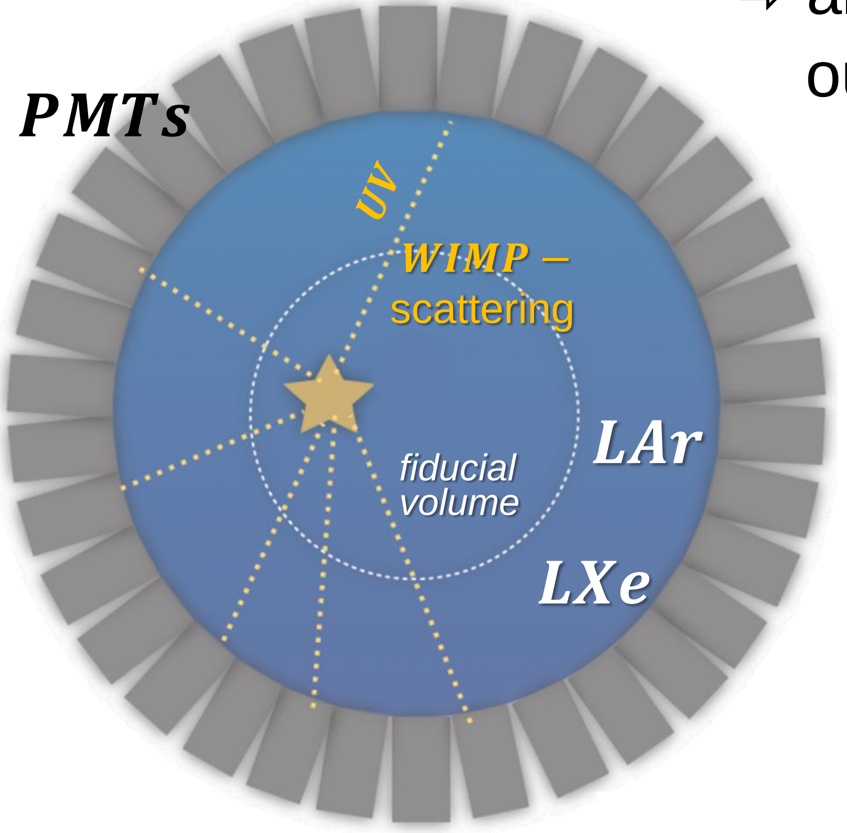


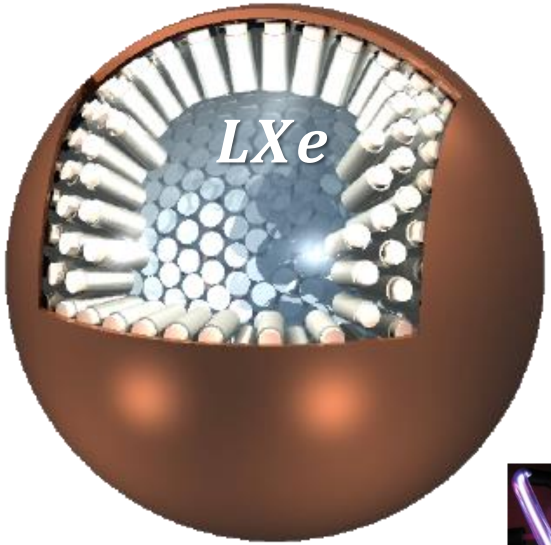
$\boldsymbol{M = 800\ kg\ (100\ kg\ fiducial)}$

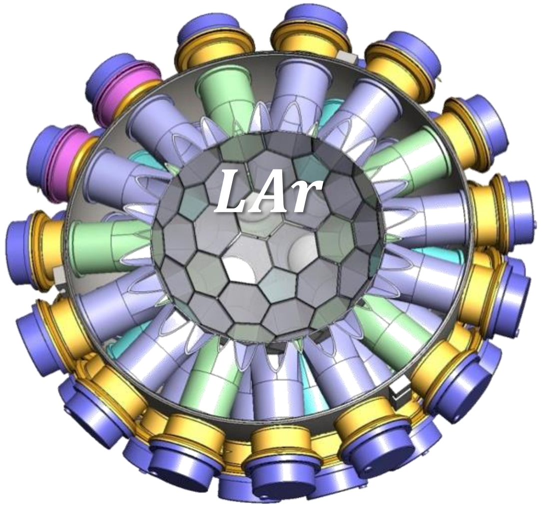
Liquid noble gas experiments: 1 – phase layout

- **Read–out of scintillation light only:** **no excellent *PID* (as is necessary)**

⇨ all single–phase–projects with ***LAr*** & ***LXe*** (read–out of **scintillation light only**) were **cancelled**!



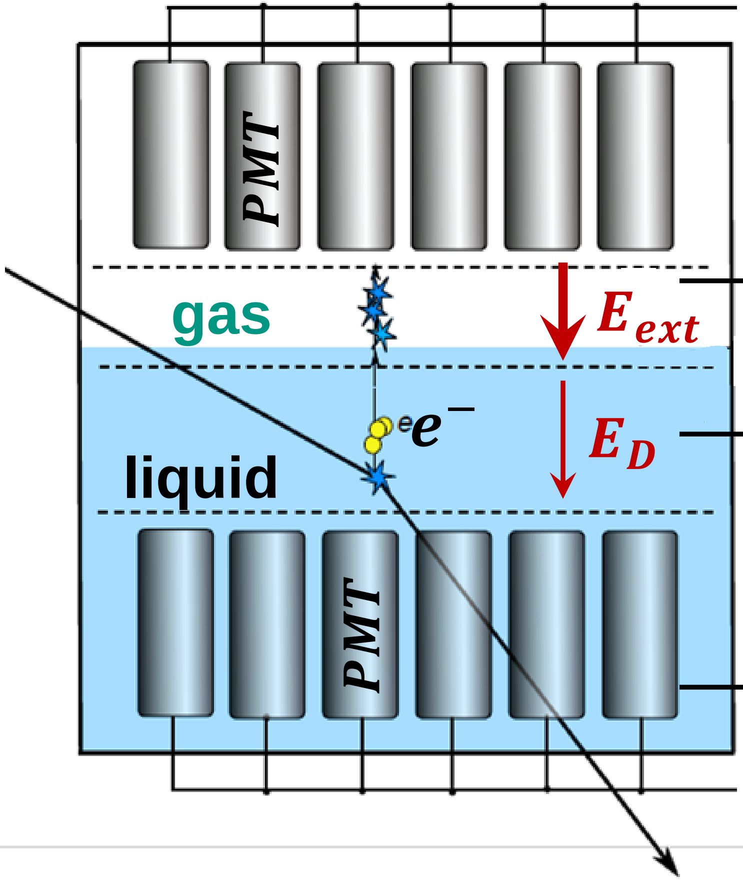




Liquid noble gas experiments: $2-$ phase layout

- **Read$-$out of scintillation light** & **ionisation: much better** $\boldsymbol{PID}$

cylindrical layout



$2-$phase$-$noble gas detectors: the ultimate in $\boldsymbol{DM}$

gaseous noble gas: read$-$out of **ionisation signal** via process of **electroluminescence ($\boldsymbol{EL}$)**

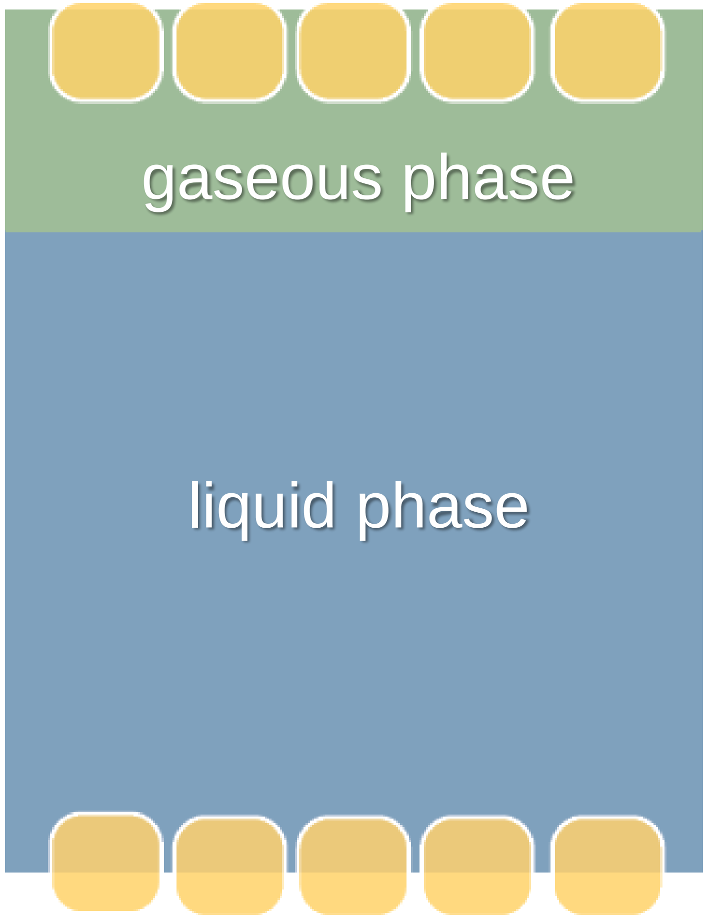
liquid noble gas: transport of the ionisation signal via electric field $-$ constant **drift of $\boldsymbol{e^-}$** to gas phase

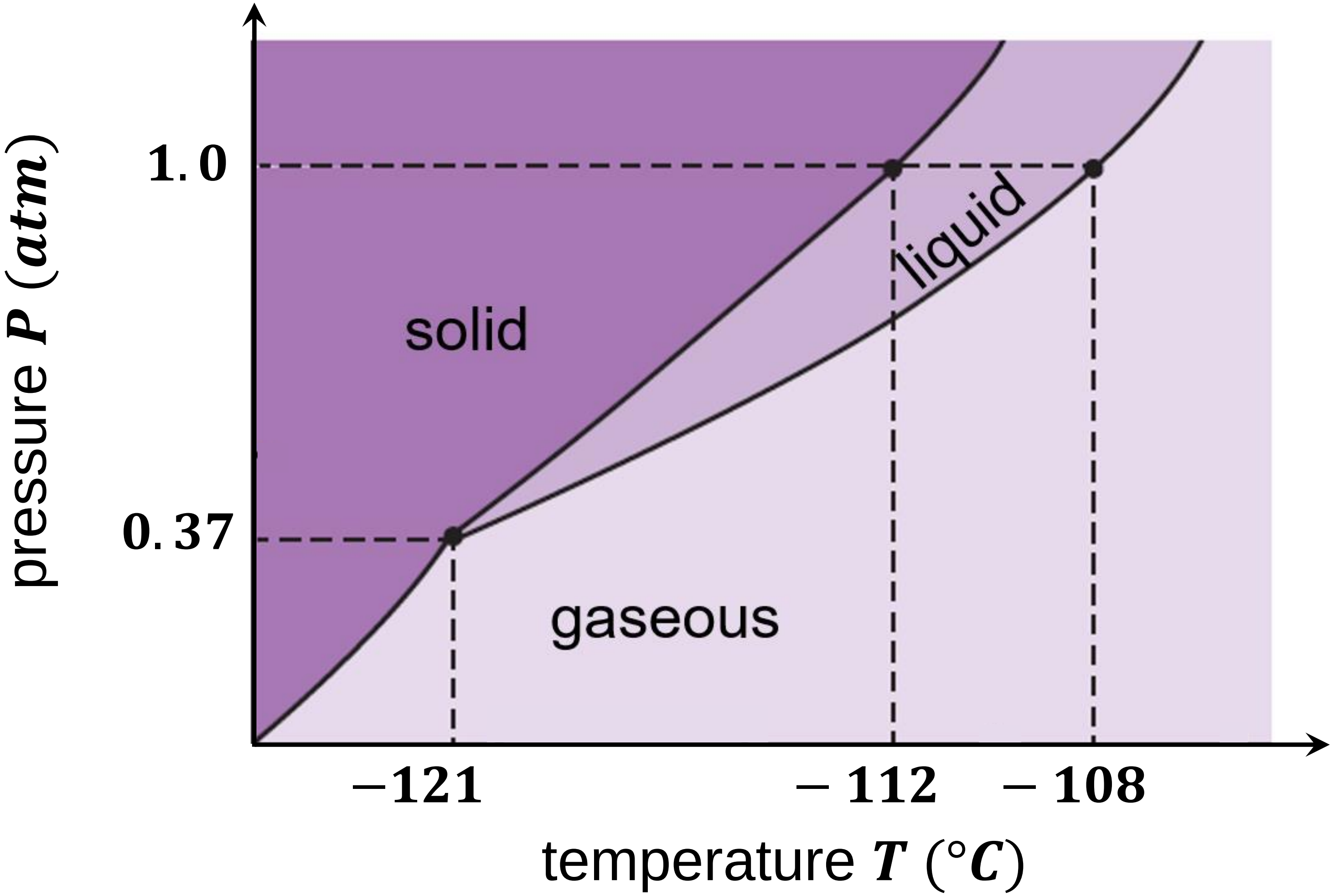
top$-$ & bottom $\boldsymbol{PMT}$ array: read$-$out of both the **scintillation**$-$ & **electroluminescence**$-$ signal

$\boldsymbol{Ar}$ ($\boldsymbol{Xe}$) as detector medium **with** (**without**) $\boldsymbol{WLS}$

Liquid noble gas experiments: 2 – phase layout

- **Operating temperature: thermodynamics of the liquid & gaseous phase**





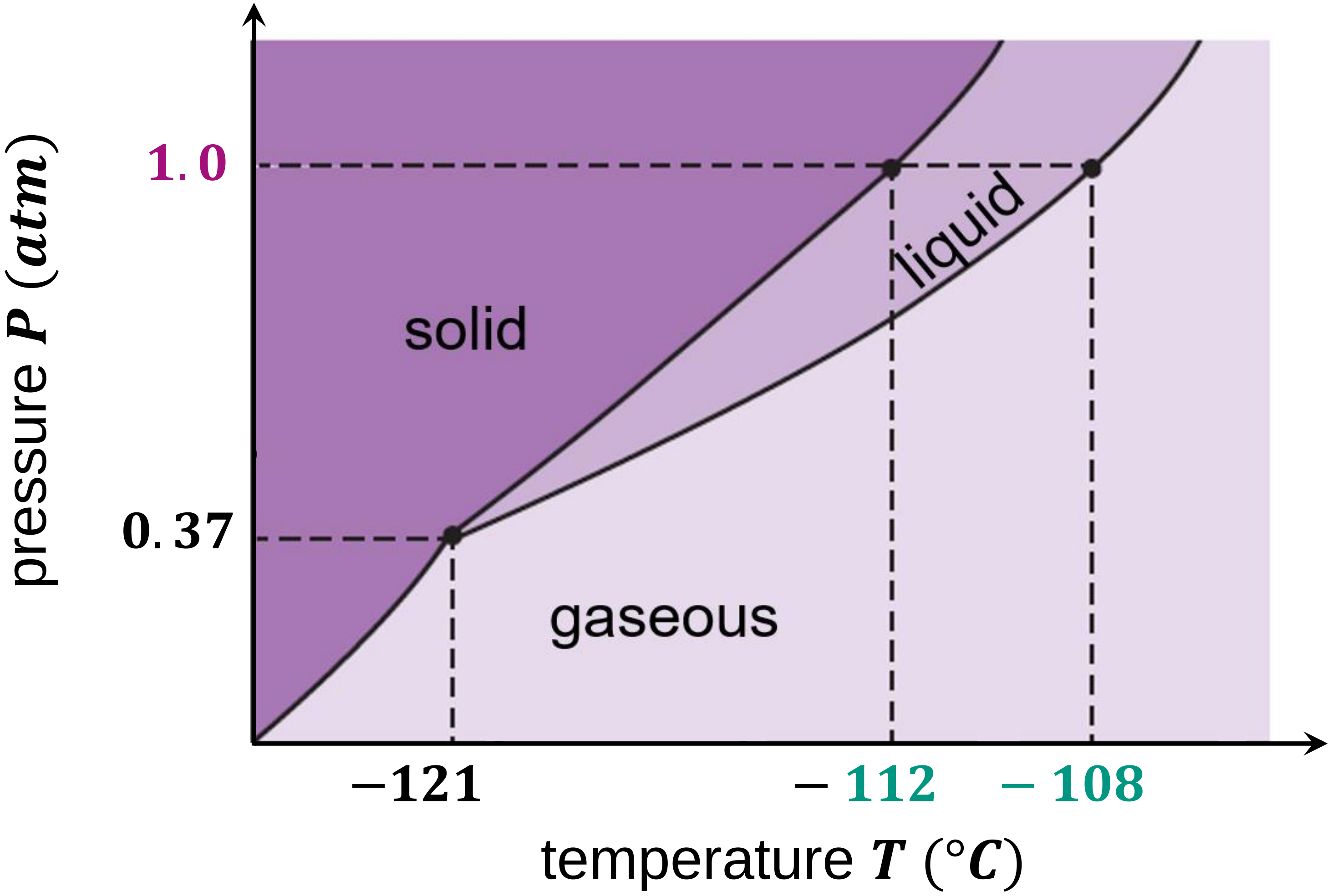
Liquid noble gas experiments: 2 – phase layout

■ **Operating temperature: thermodynamics of the liquid & gaseous phase**

- operation of Xe – vessel at a **pressure** $p \approx 1\ atm$

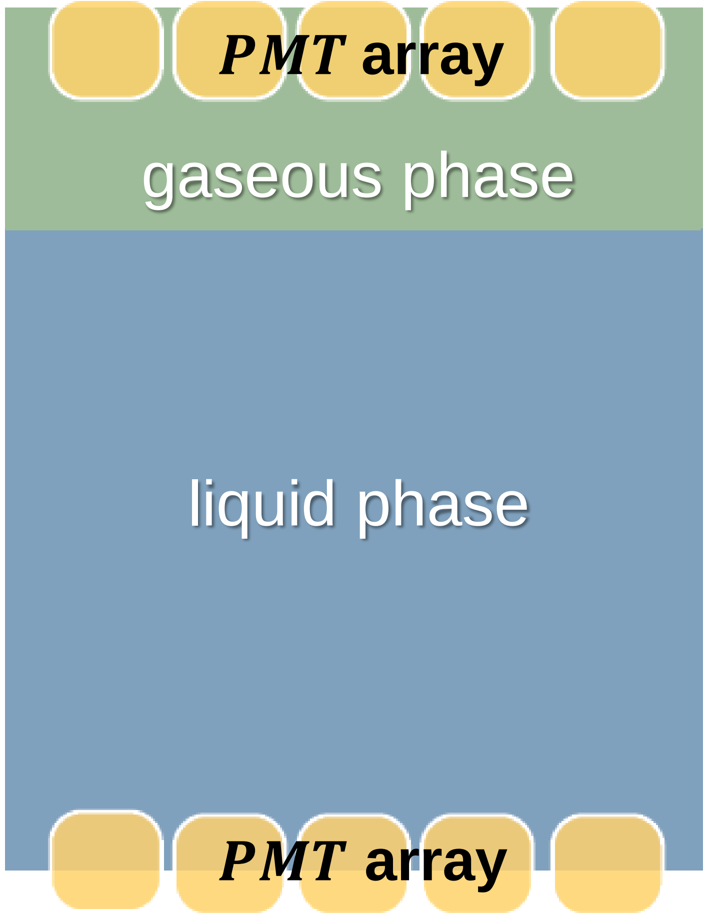
- **cryo–cooling** has to ensure $T = -108 \ldots -112\ °C$ to maintain the **liquid state**

- **fine–tuning** of temperature in the above range allows to adjust the **pressure level** of the **gaseous phase** above the liquid level



Liquid noble gas experiments: light detection

- Top and bottom PMT arrays to detect VUV scintillation & light from EL*

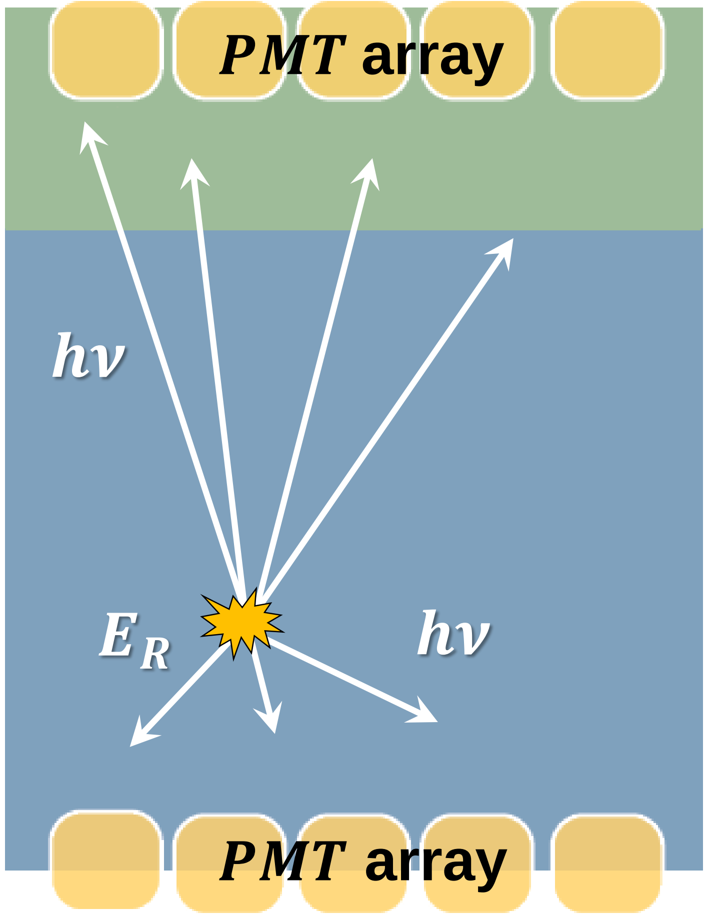


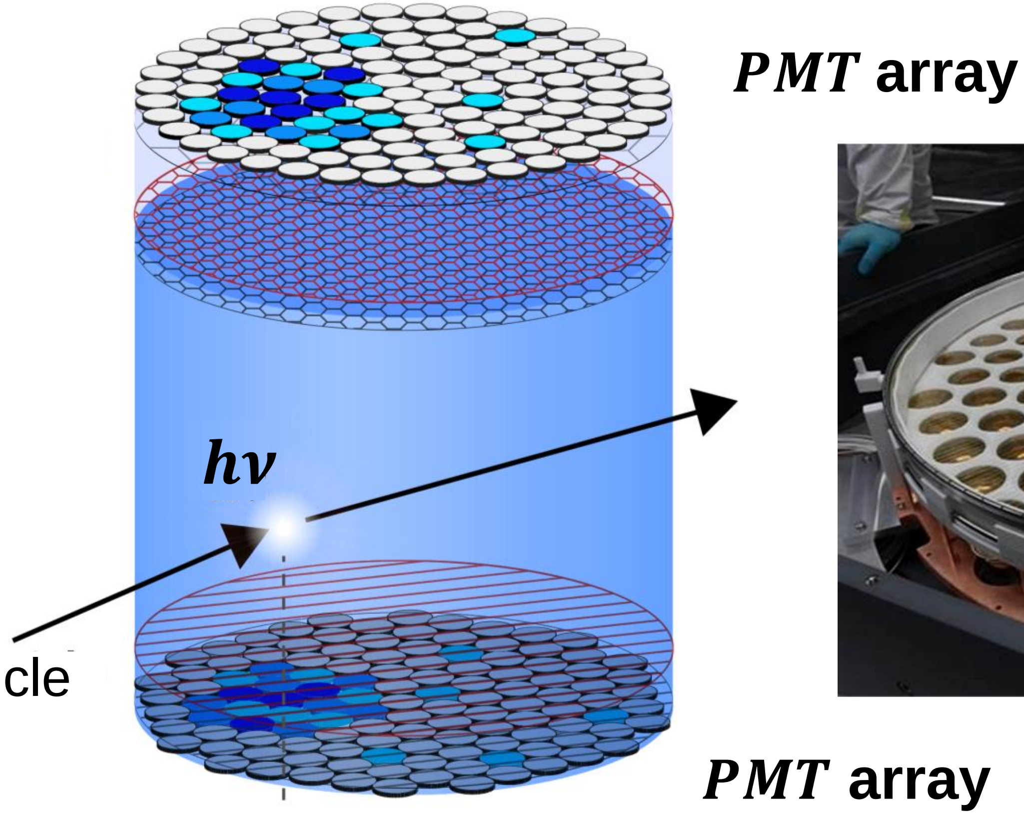
*Electro–Luminescence

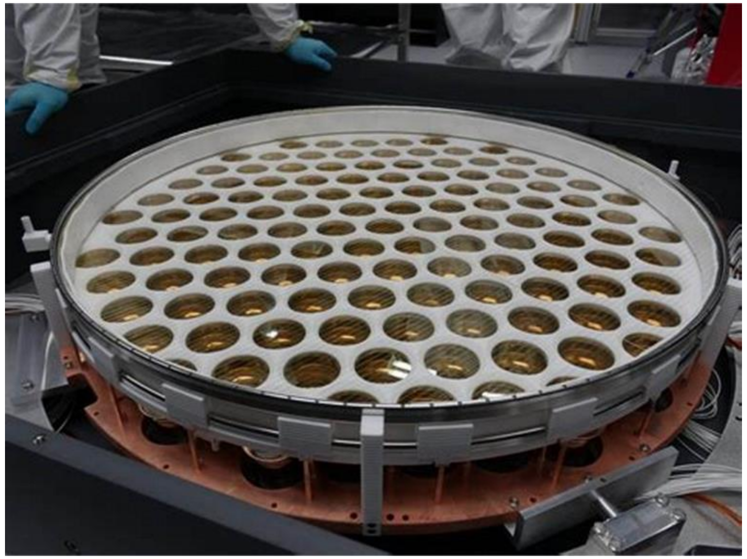
Liquid noble gas experiments: light detection

- **Top and bottom PMT arrays to detect VUV scintillation & light from EL**

- detection of **prompt scintillation** light in the VUV range

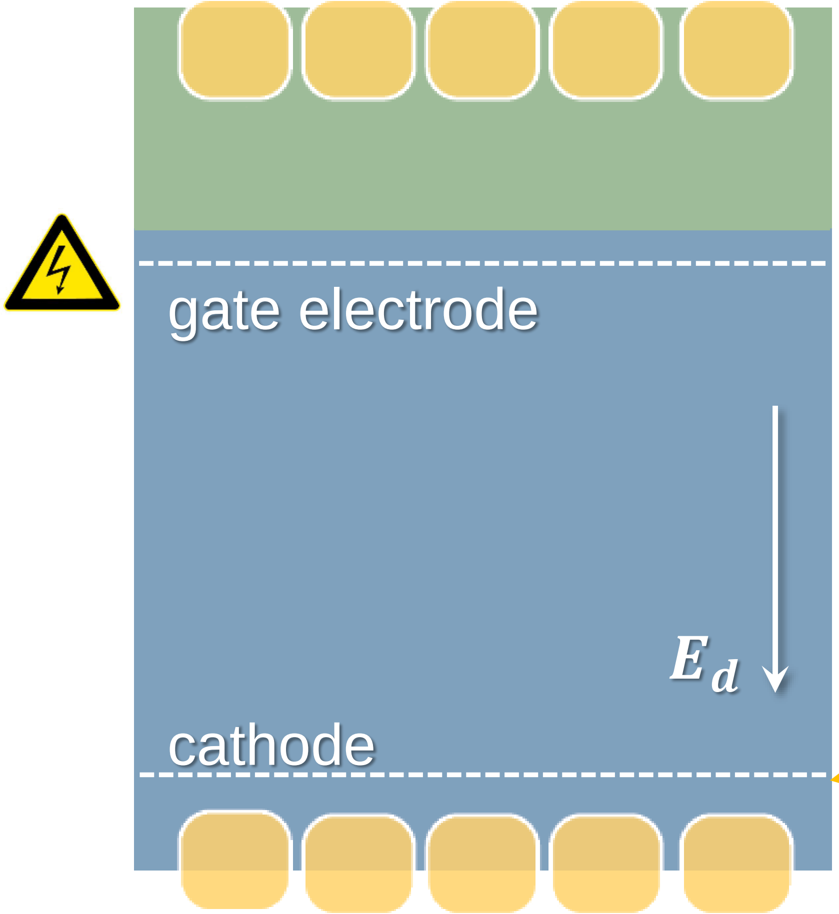




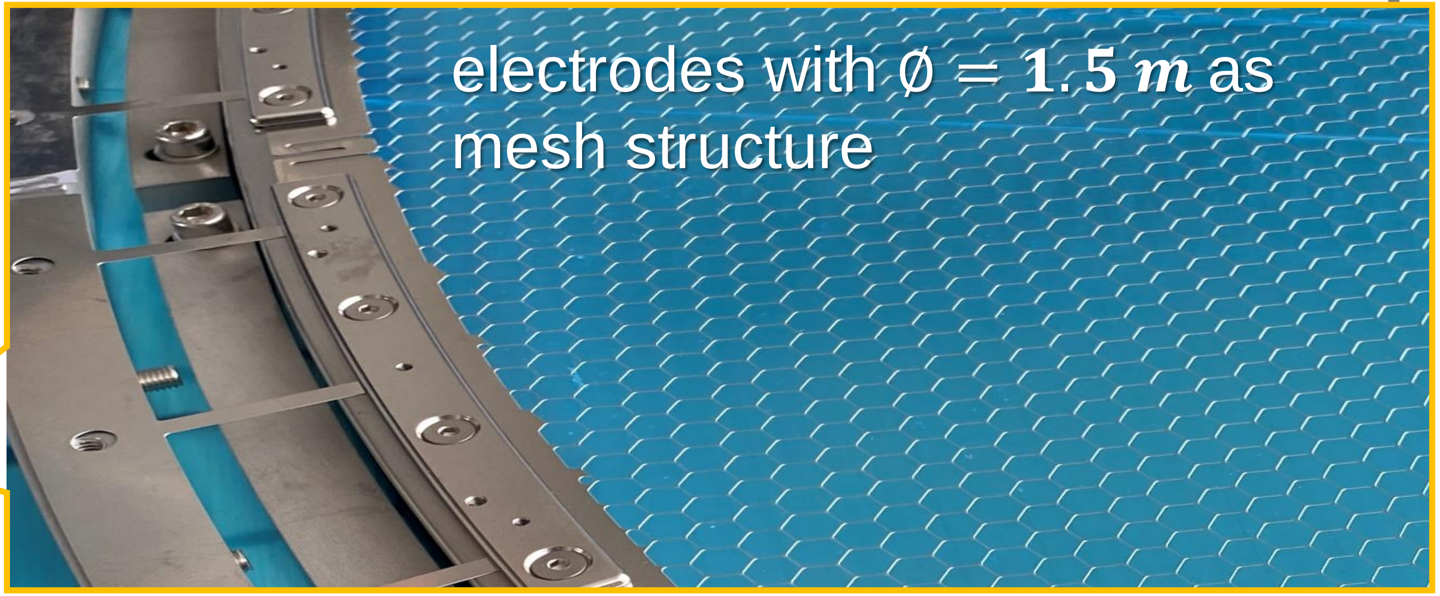


Liquid noble gas experiments: drifting of e^-

- Operated as Time Projection Chamber (TPC) to obtain $3D$ information



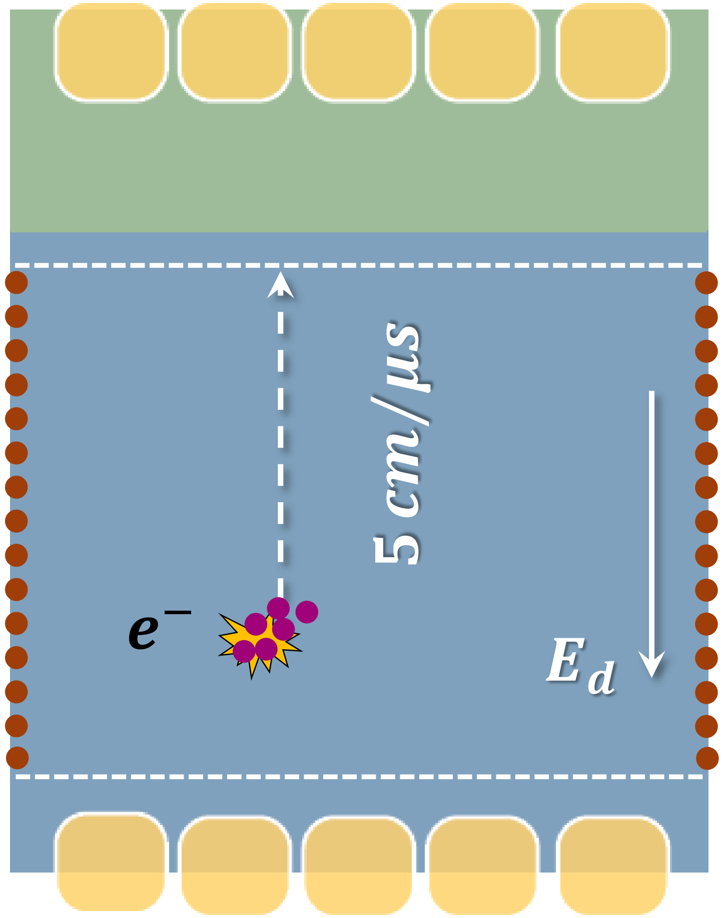
- **electrons** from an interaction are collected
- generation of a homogeneous drift field E_D by applying HV to gate electrode



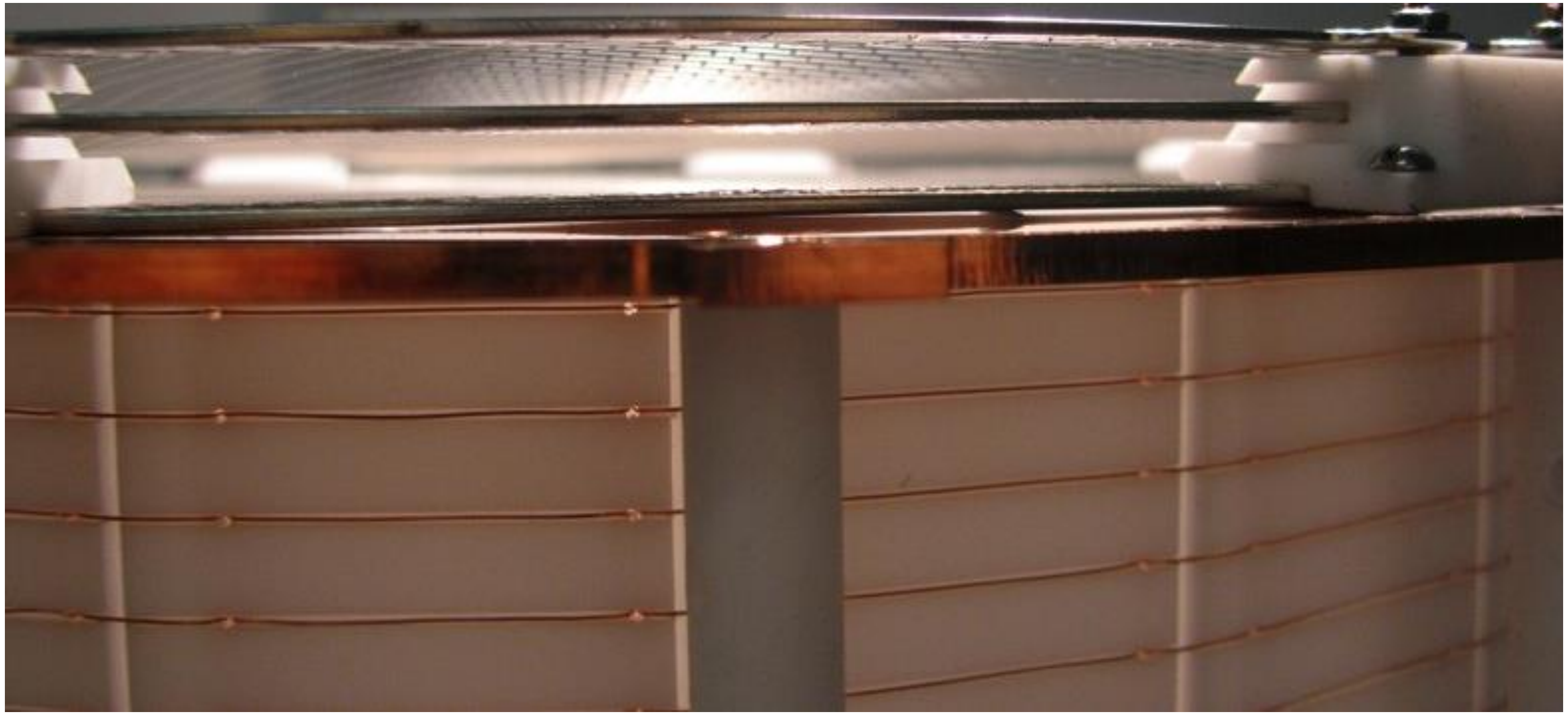
neg. HV

Liquid noble gas experiments: drifting of e^-

- **Operated as TPC for read−out of ionisation signal of an interaction in target**



- field cage by ´**guard rings**´ to ensure homogeneity of E_D



Redout of delayed light (EL) after drifting of e^-

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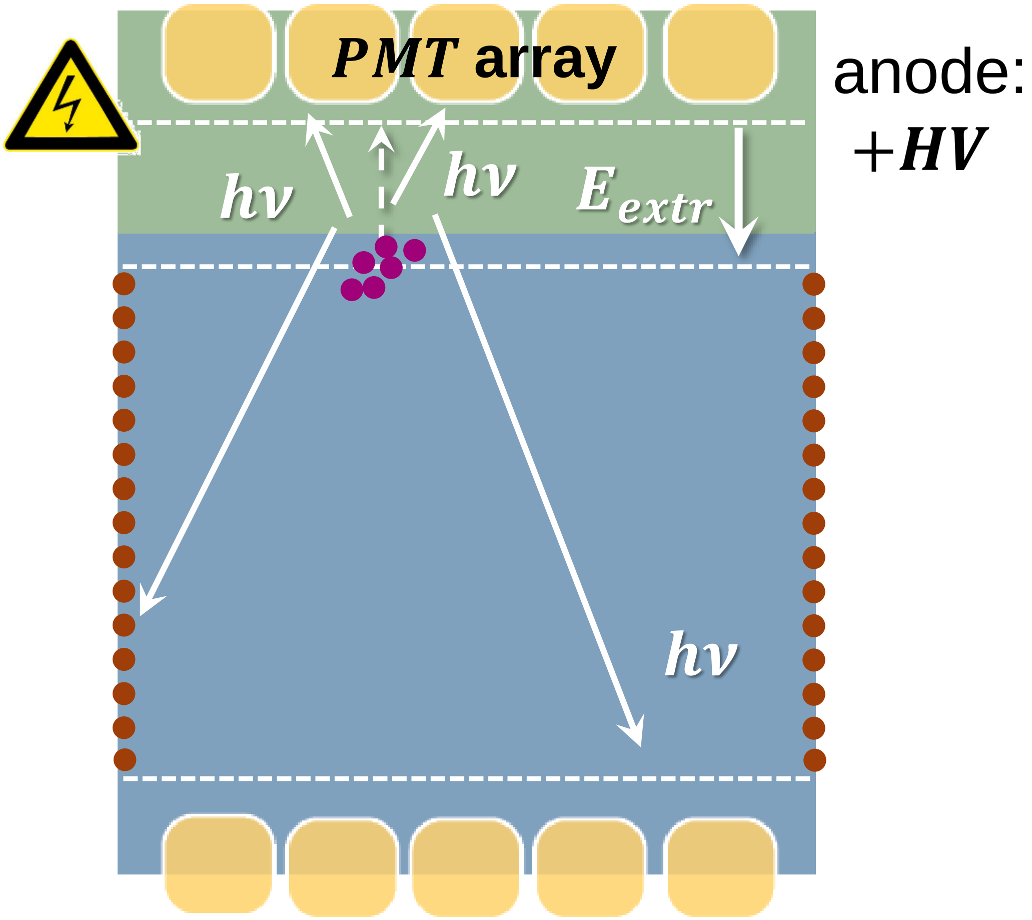
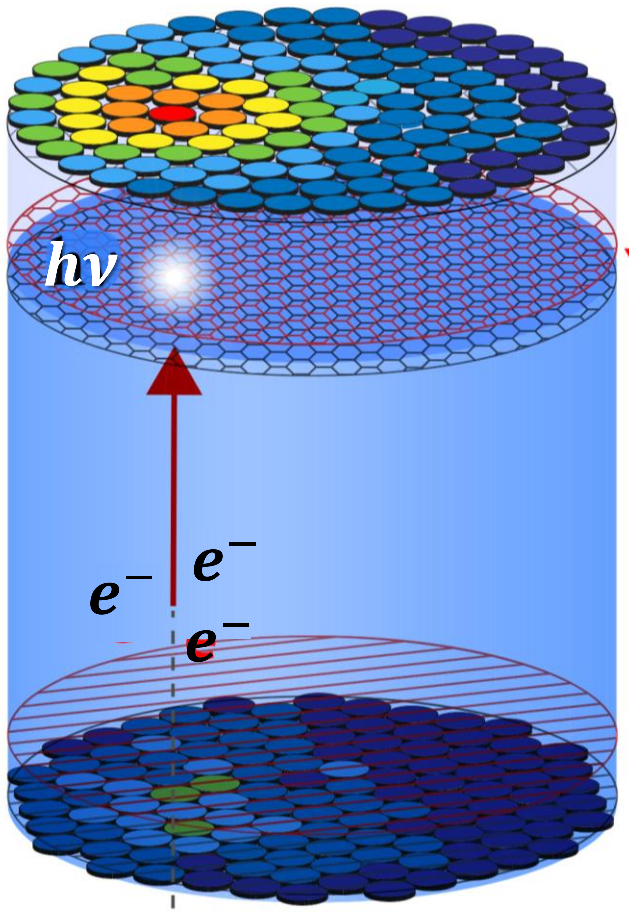
- **Applying a strong field to ´extract´ e^- into gaseous phase to induce EL**





- **electrons** are being accelerated by a **strong field** E_{extr} towards the anode in the gas phase

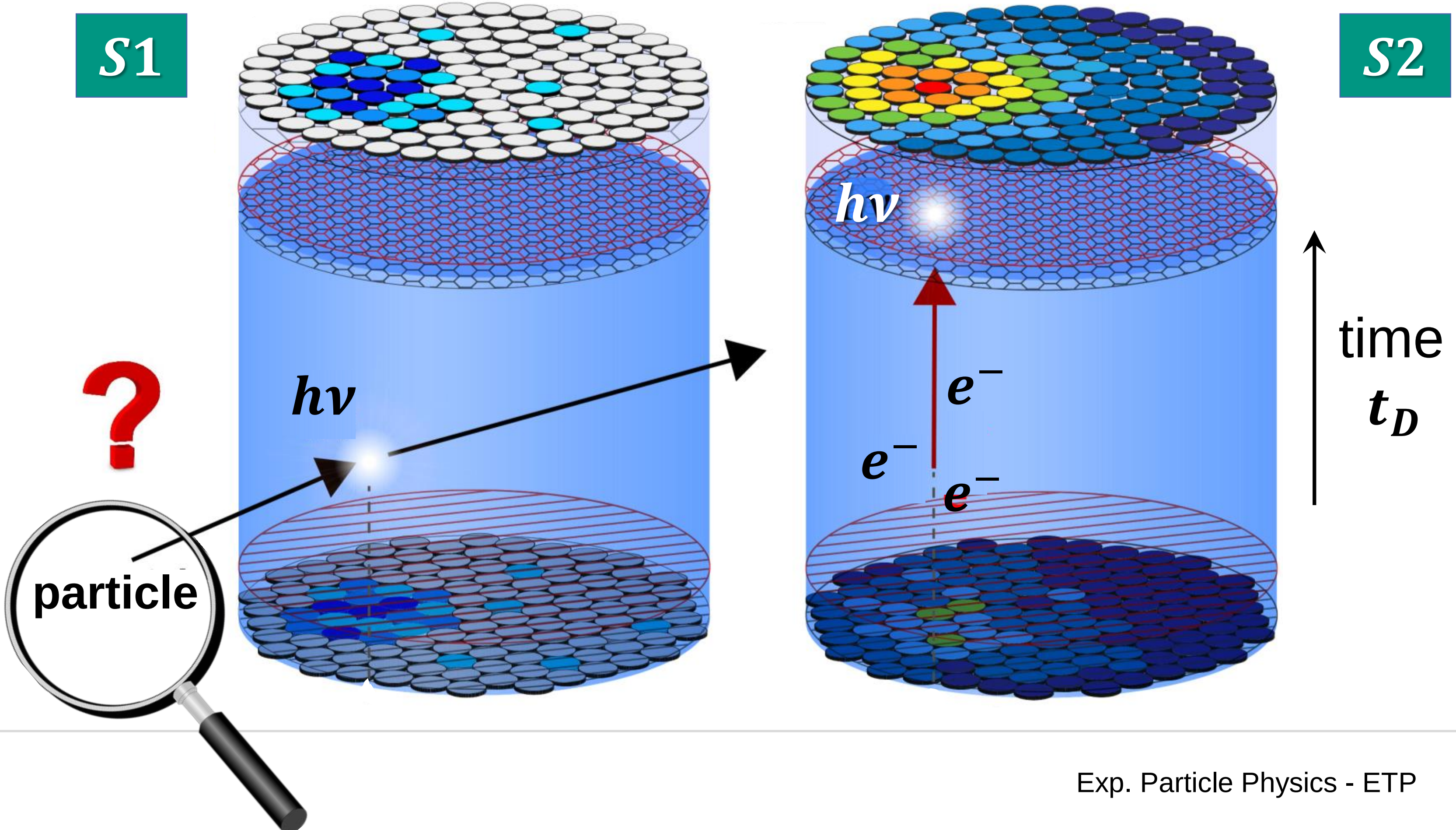
- **electrons** collide with gas atoms, this causes **electroluminescence**

- **electrons** detected by EL light via PMT arrays

Liquid noble gas experiments: signals $S1$ and $S2$

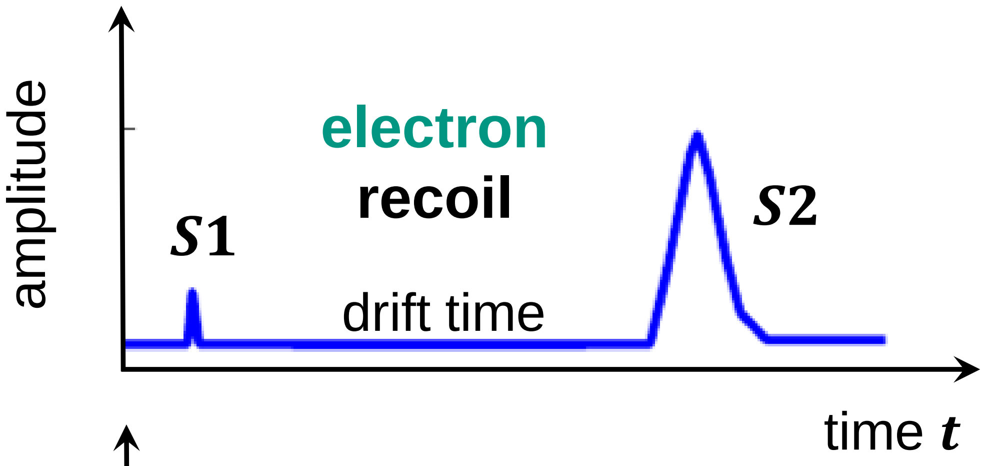
- TPC principle: PMT – hit pattern for (x, y) position, drift time t_D for z position

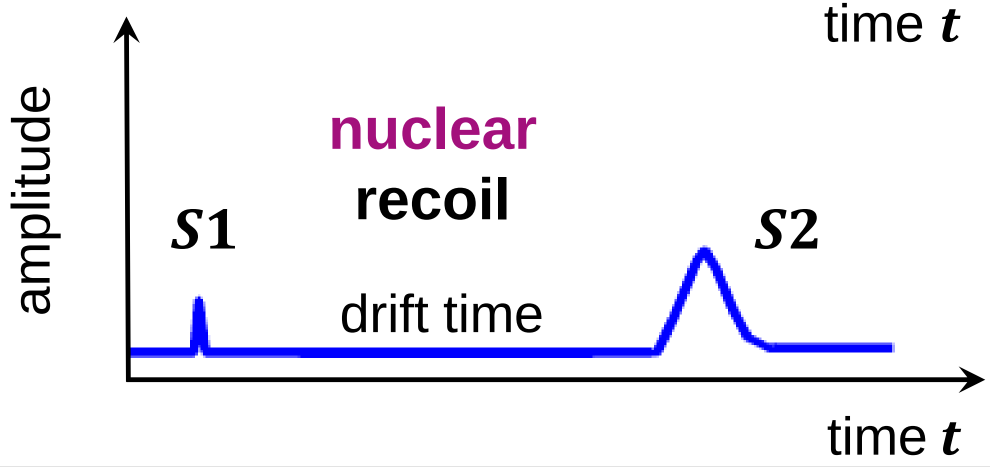
\- **background discrimination:** combining signals $S1$ (scintillation) & $S2$ (ionisation)



Liquid noble gas experiments: quenching of $S2$

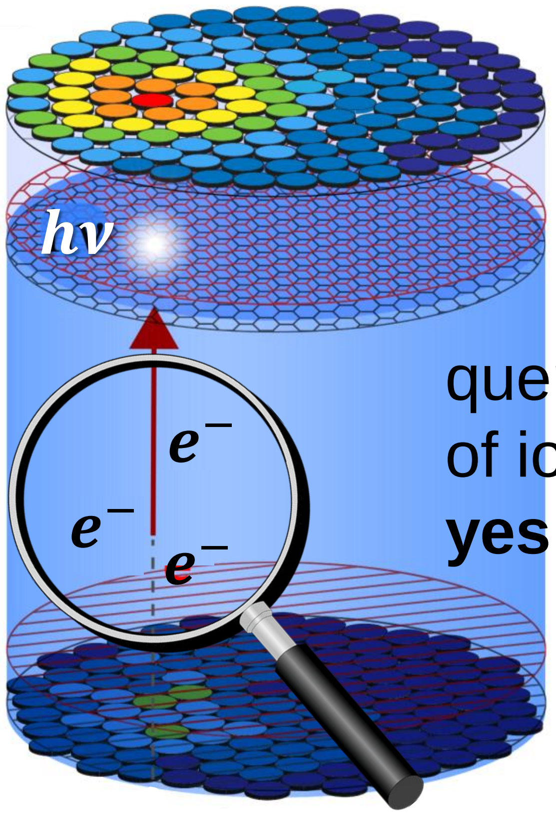
- **Particle Identification via ratio $S2$ / $S1$: ratio of delayed to prompt light**
  - ionization signal $S2$: **strong quenching in case of nuclear recoils**





$S2$ / $S1$ = large

$S2$ / $S1$ = small



$S2$

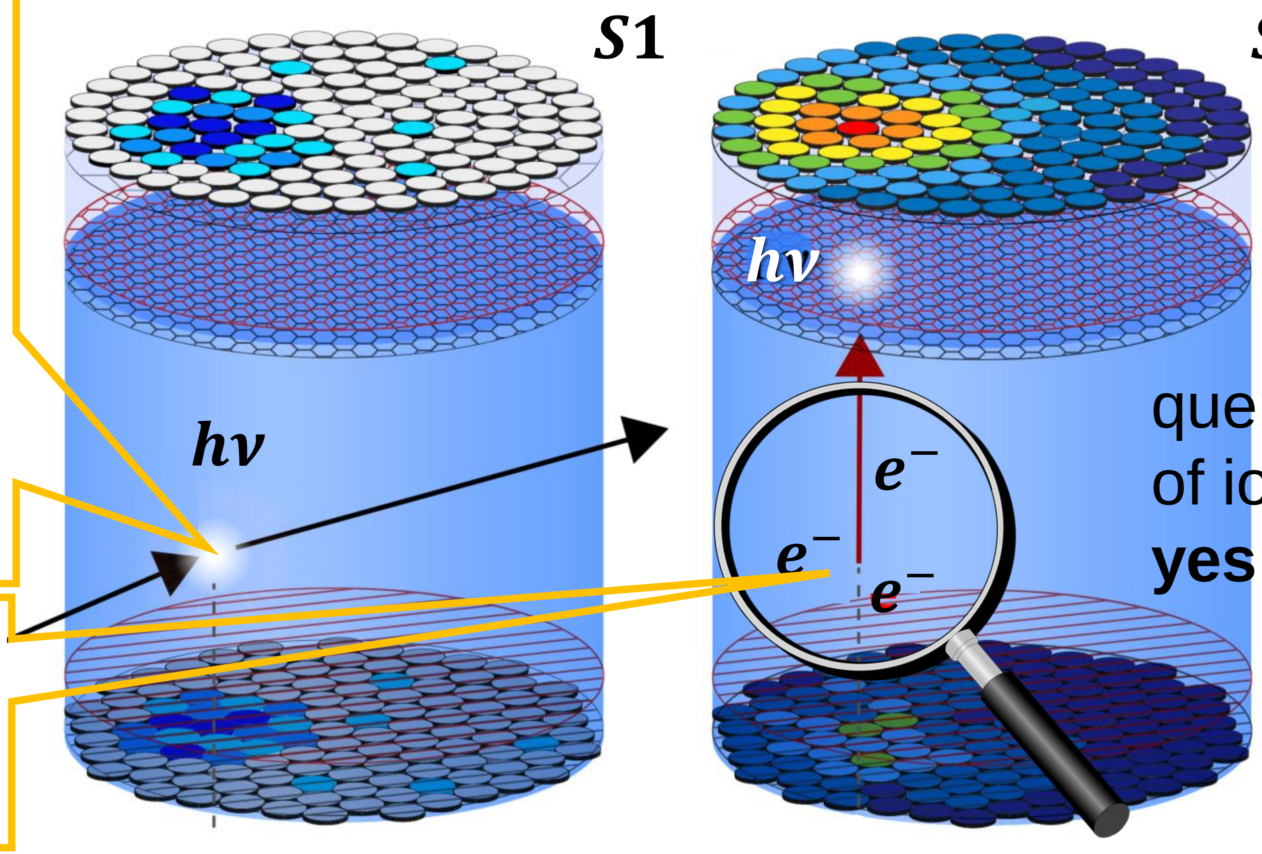
quenching
of ionisation
yes – no ?

Liquid noble gas experiments: $S1$ & $S2$ combined

- **Reconstructing the scattering event: energy scale E_R and particle type (PID)**
  - signals $S1$ & $S2$: we can determine both recoil energy E_R & the particle type (PID)

- basis for recoil energy E_R
  signal $S1$ is **independent** of particle type (no quenching)
  ⇨ $S1$ determines energy of primary interaction
  ⇨ we aim for an exceedingly low threshold of $S1$!

- basis for excellent PID
  signal $S2$ is ´amplified´ by **electroluminescence**



quenching of ionization
yes – **no** ?

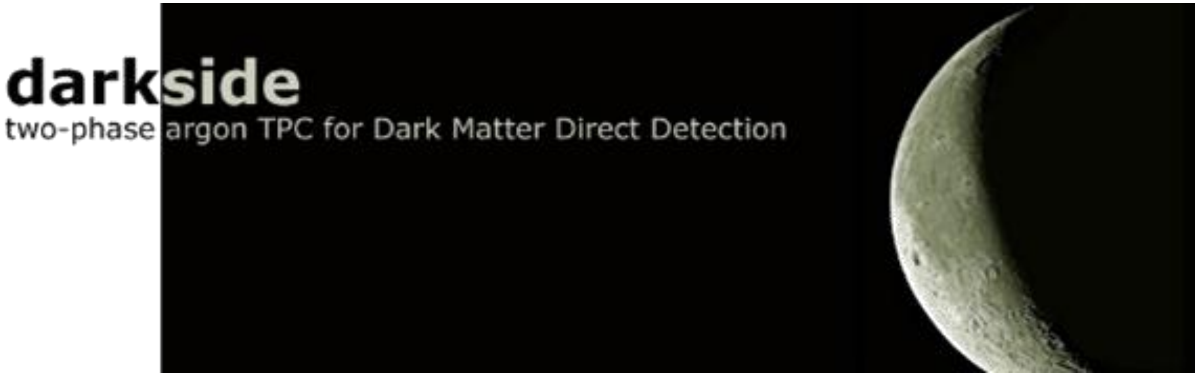
2 – phase experiments with argon: $DarkSide$ 50

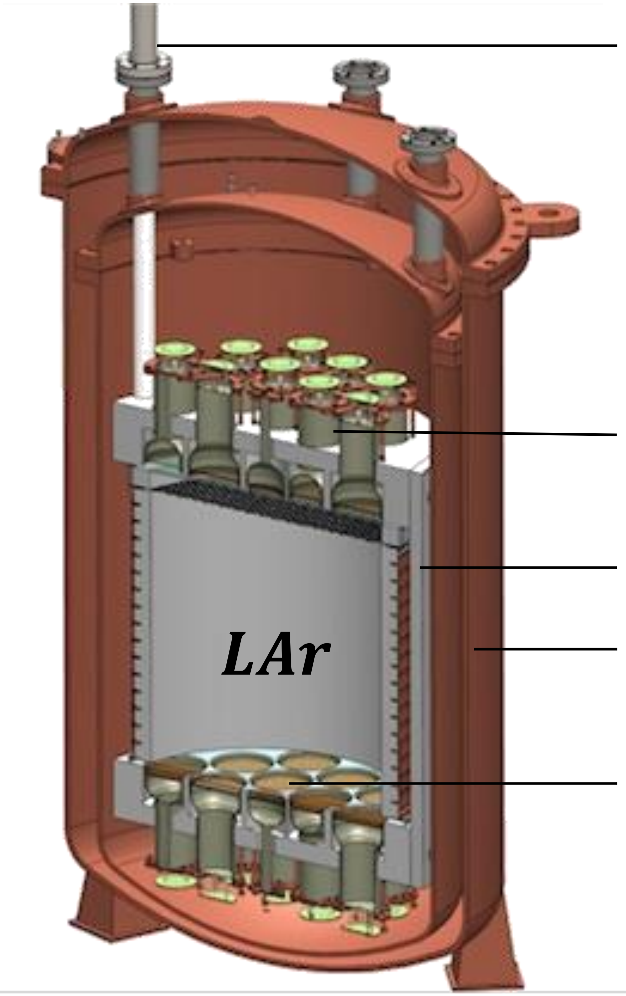
- $\boldsymbol{DarkSide}$ **50: the first $\boldsymbol{TPC}$ in a series of experiments of increasing size**

  - location: $\boldsymbol{hall\ C}$ at $\boldsymbol{LNGS}$

  - total active mass: $\boldsymbol{m = 50\ kg}$

  - depleted $\boldsymbol{^{39}Ar}$ – fraction, from an ´underground argon´ source in the $\boldsymbol{US}$





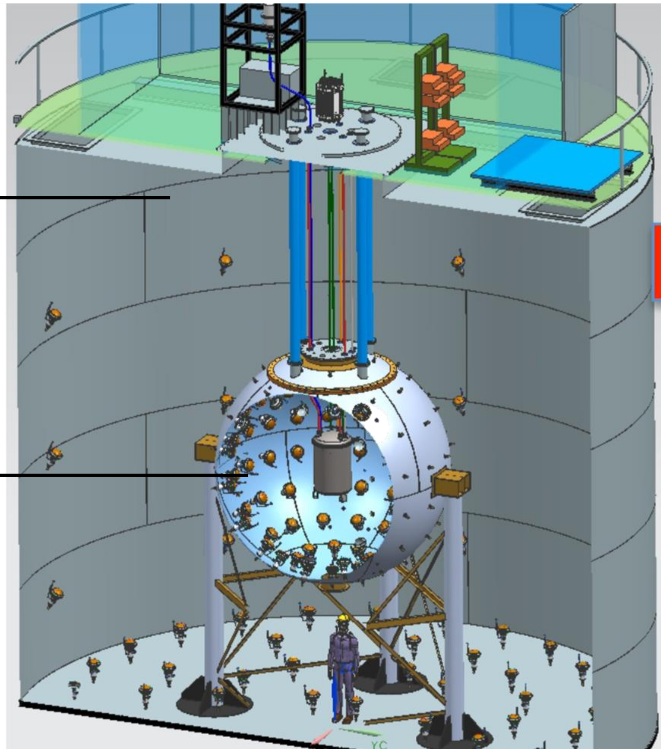
2 – phase experiments with argon: *DarkSide* 50

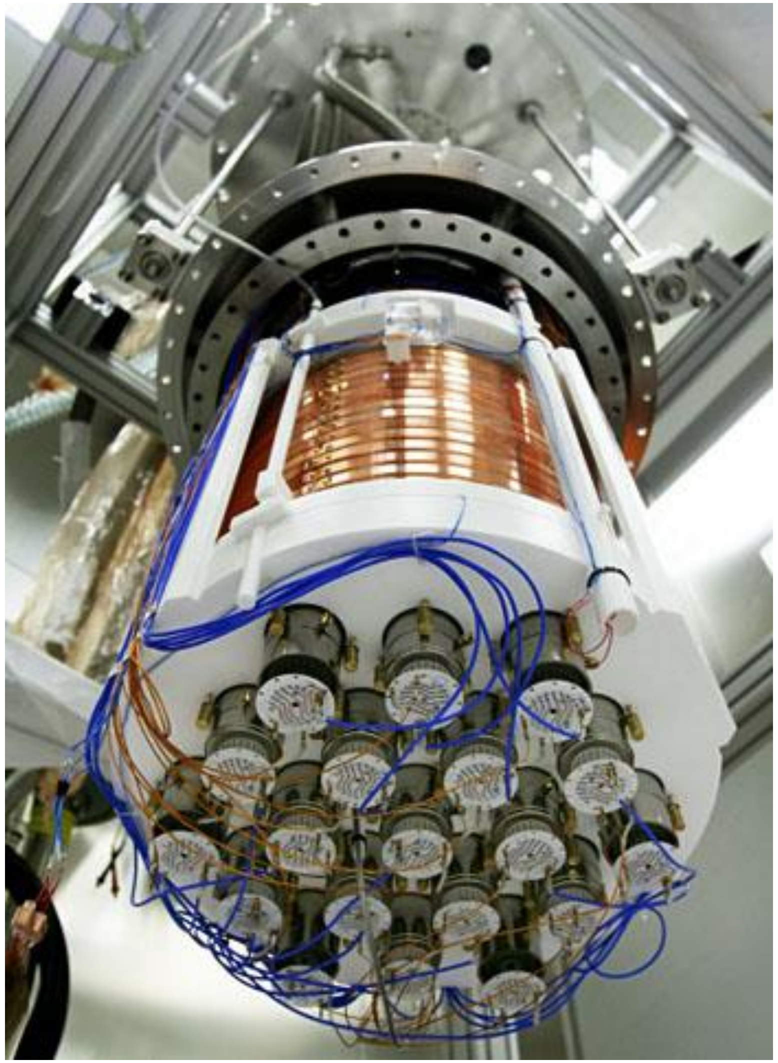
- **setup: *TPC* surrounded by an inner & outer veto detector against external background**

- outer veto: using the former ***C***ounting ***T***est ***F***acility ***CTF*** (***Borexino*** solar ν – experiment)

outer H_2O **Cherenkov-veto** for μ – identification

inner **liquid scintillator veto** aginst μ – induced neutrons





$DarkSide\,50$ – TPC setup in more detail

- **Prototype of today´s much larger DM – detectors…**

anode (grounded) in gas–phase: $E_{extr} = 2.8\ kV/cm$

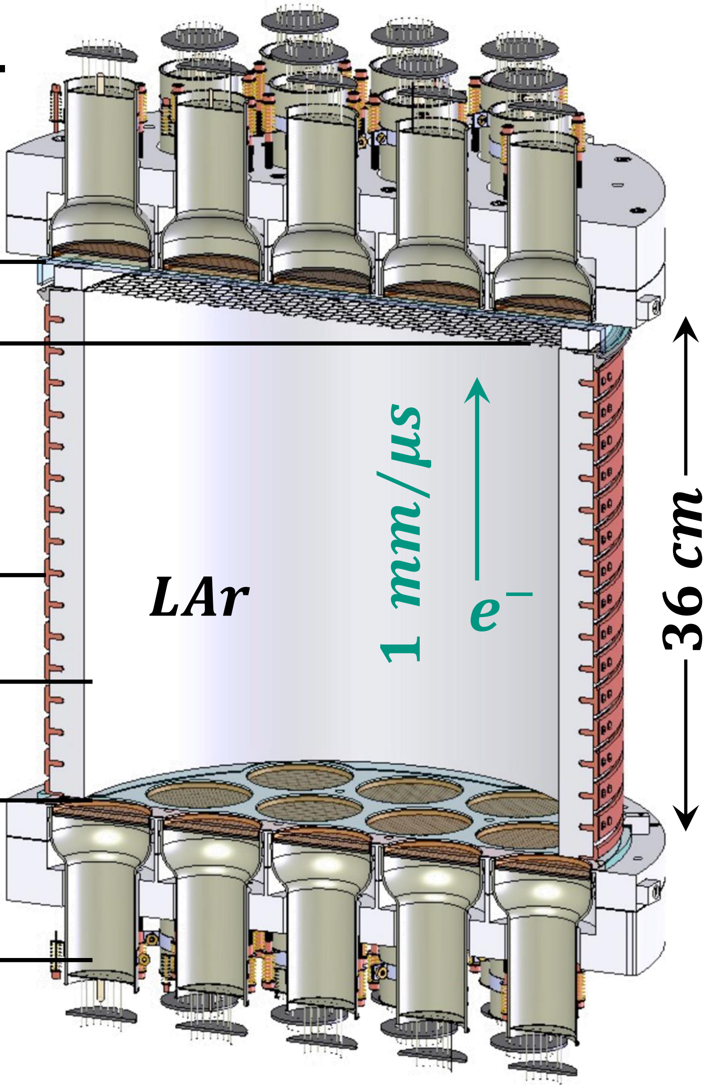
extraction grid for **drifted e^-**
for transition **liquid → gas**

$\vec{E}$ – field forming Cu – rings: $E_D = 200\ V/cm$

$PTFE$ (teflon) – reflector + WLS (TPB*)

cathode (up to $-60\ kV$)

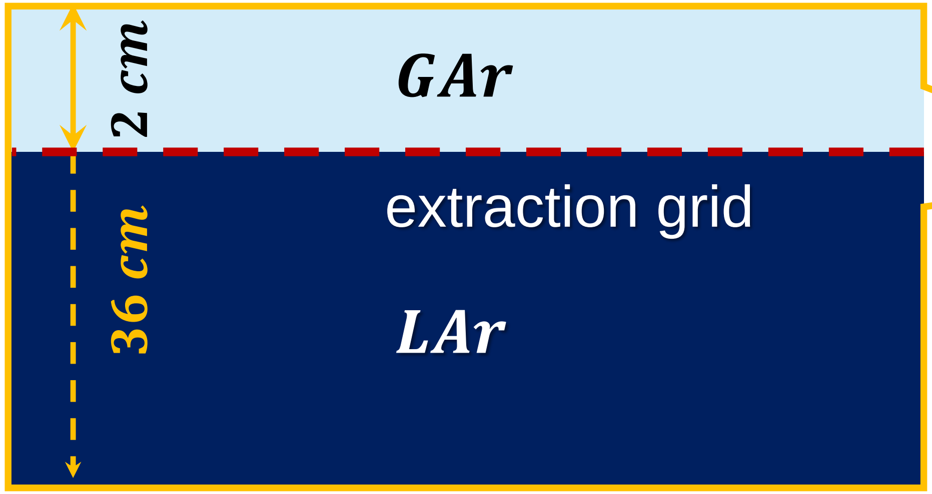
3 – $inch\ PMTs$ (Hamamatsu $R11065$)

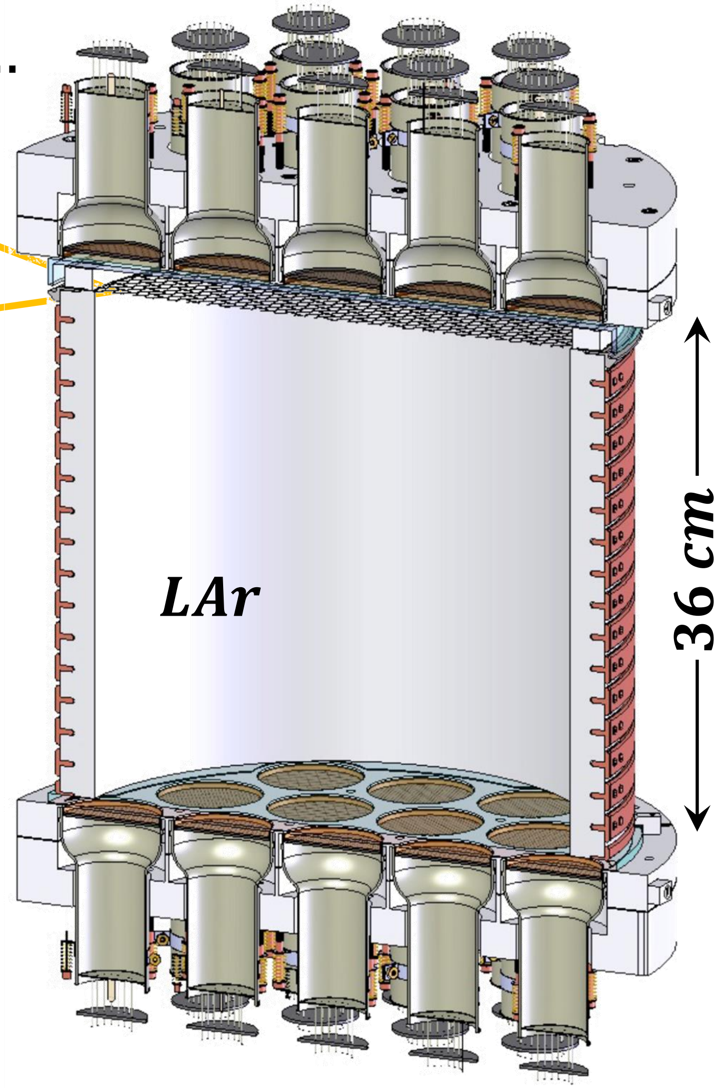


*Tetra–Phenyl–Butadiene

$DarkSide\ 50$ – TPC setup in more detail

- **Prototype of today´s much larger DM – detectors…**





- first measurements with atmospheric argon were unsuccessful, due to a very high ^{39}Ar background

$DarkSide$ 50 – background overview

- **Prototype as $proof - of - principle$ of UAr**

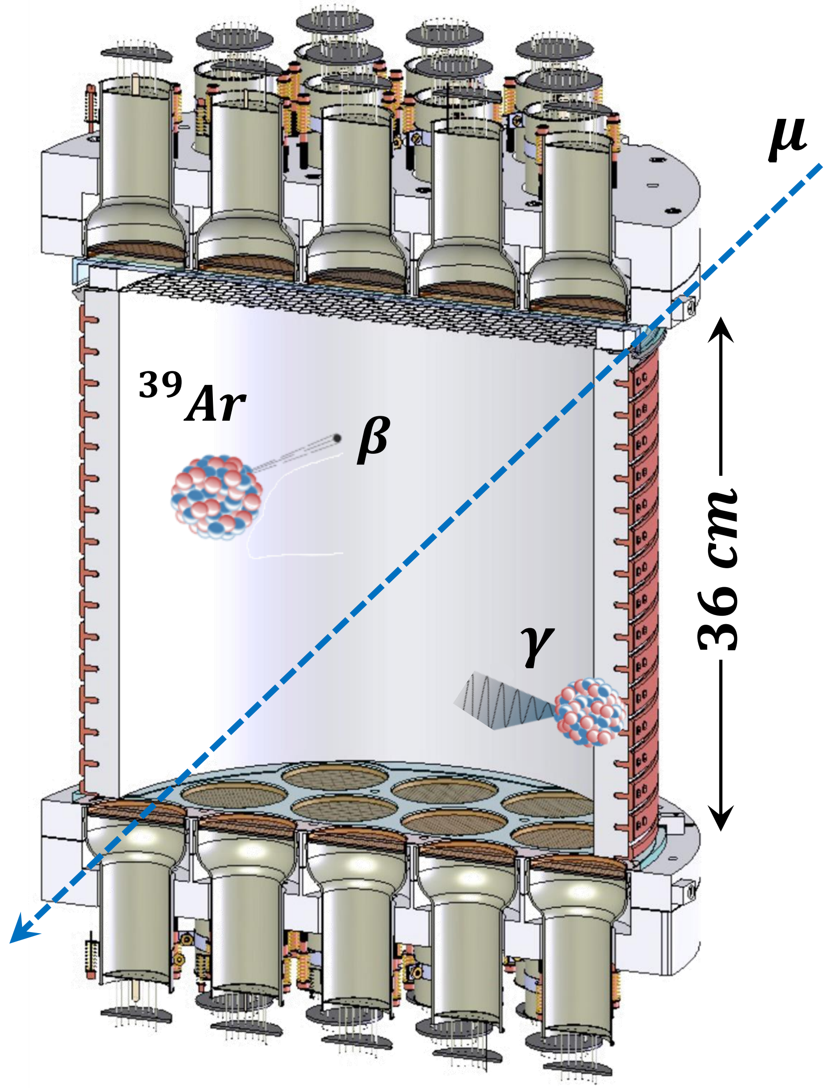
  - measurements with $\boldsymbol{U}$nder$-\boldsymbol{G}$round $\boldsymbol{Ar}$gon ($\boldsymbol{UAr}$)
    ⇨ reduction of $\boldsymbol{\beta}$ – decay rate by factor ~ $\mathbf{300}$

  - **background contributions:**

    - $\boldsymbol{\beta}$´$\boldsymbol{s}$ ($^{39}\boldsymbol{Ar}$) : ~ $\mathbf{90000}$ $\boldsymbol{events}$ / $\boldsymbol{kg}$ / $\boldsymbol{day}$
    - $\boldsymbol{gammas}$ ($\boldsymbol{e^-}$): ~ $\mathbf{100}$ $\boldsymbol{events}$ / $\boldsymbol{kg}$ / $\boldsymbol{day}$
    - $\boldsymbol{muons}$: ~ $\mathbf{30}$ $\boldsymbol{events}$ / $\boldsymbol{m^2}$/ $\boldsymbol{day}$
    - $\boldsymbol{alphas}$: ~ $\mathbf{10}$ $\boldsymbol{events}$ / $\boldsymbol{m^2}$/ $\boldsymbol{day}$

  - $\boldsymbol{WIMP}$ **signal*:**

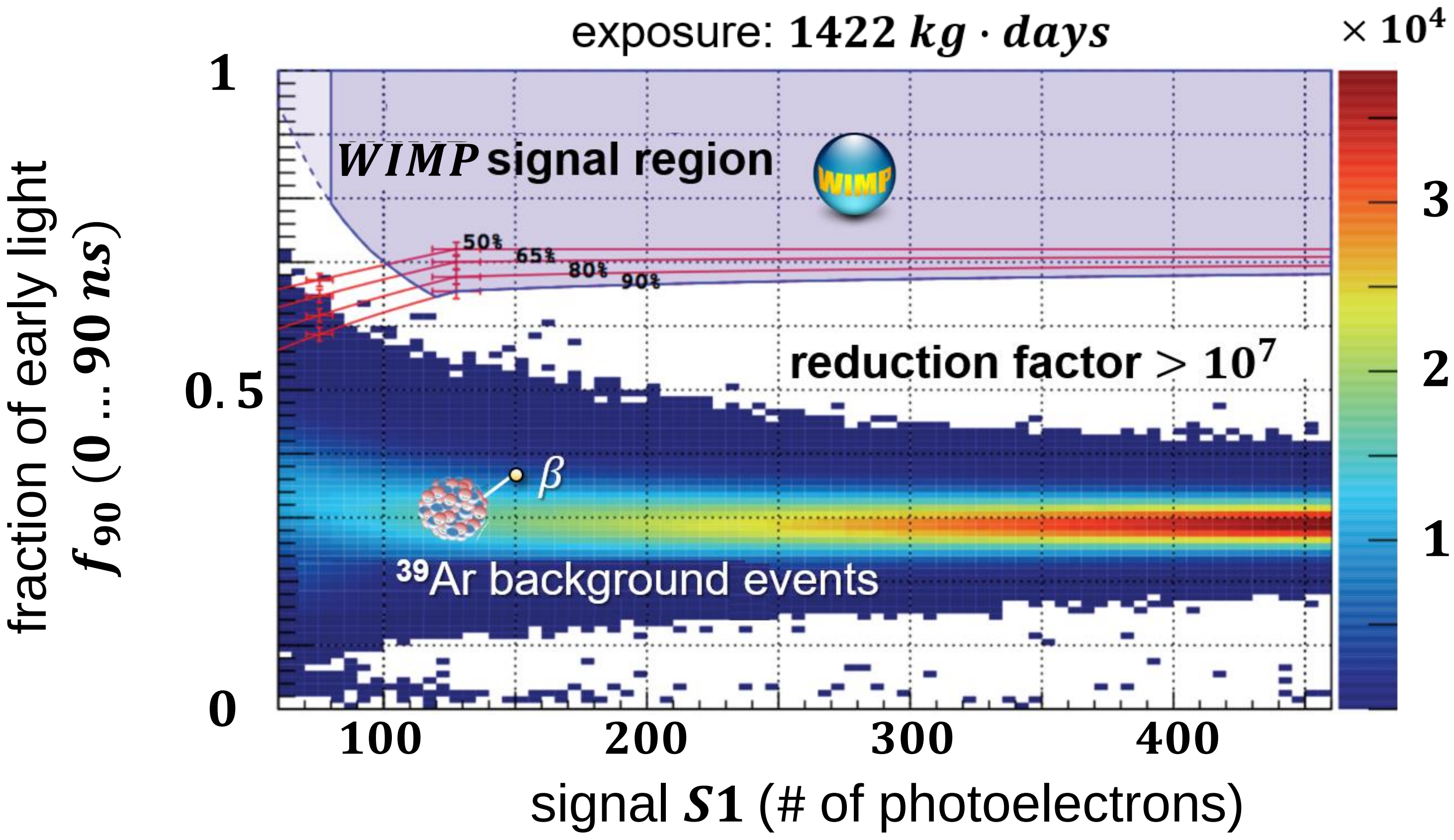
    - $\boldsymbol{Ar}$ – recoils: ~ $\mathbf{10^{-4}}$ $\boldsymbol{events}$ / $\boldsymbol{kg}$ / $\boldsymbol{day}$

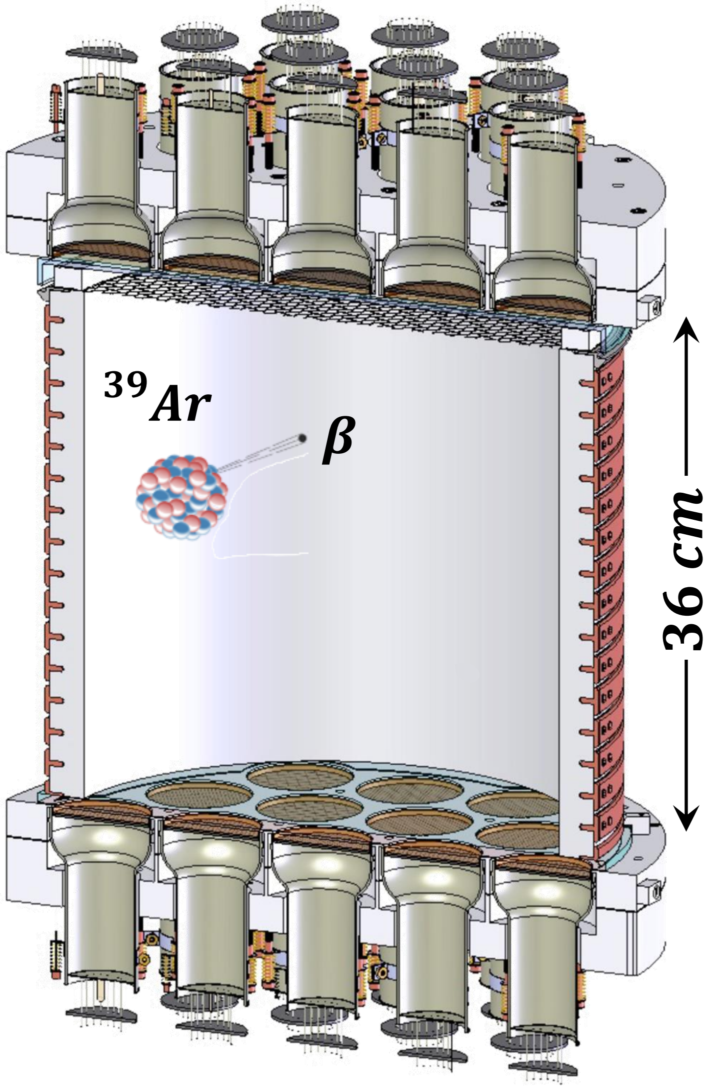


*for $\sigma_{SI} = 10^{-45}\ cm^2$ & $M_{WIMP} = 100\ GeV$

$DarkSide$ 50 – PID performance

- **background rejection verified by PSD**
  - excellent performance of the TPC in DM search





$DarkSide$ 50 – PID performance

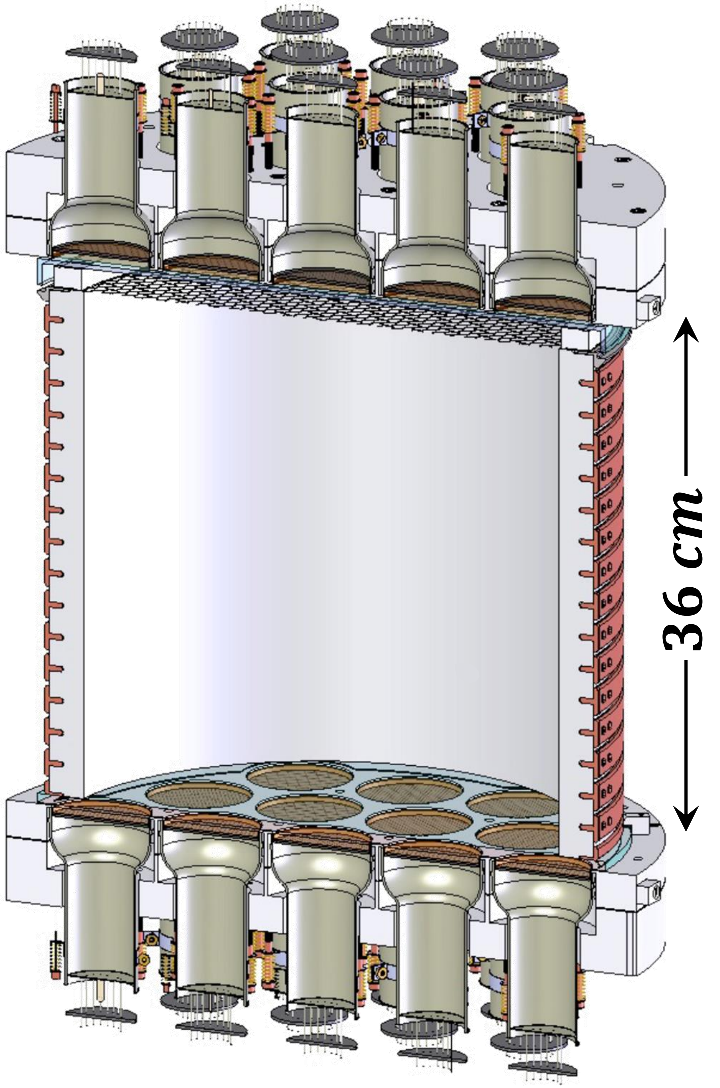
- **background rejection verified by PSD**

  - **long exposure** using untergound argon:
    $\mathbf{532}\ \boldsymbol{days}$ from $\mathbf{8/2015 - 10/2017}$
    $\boldsymbol{M \cdot t = 16600\ kg \cdot days}$

  - ´**blind**´ analysis within **pre–defined signal box**:
    $\mathbf{0}\ \boldsymbol{WIMP}$ **– events** after ´***unblinding***´

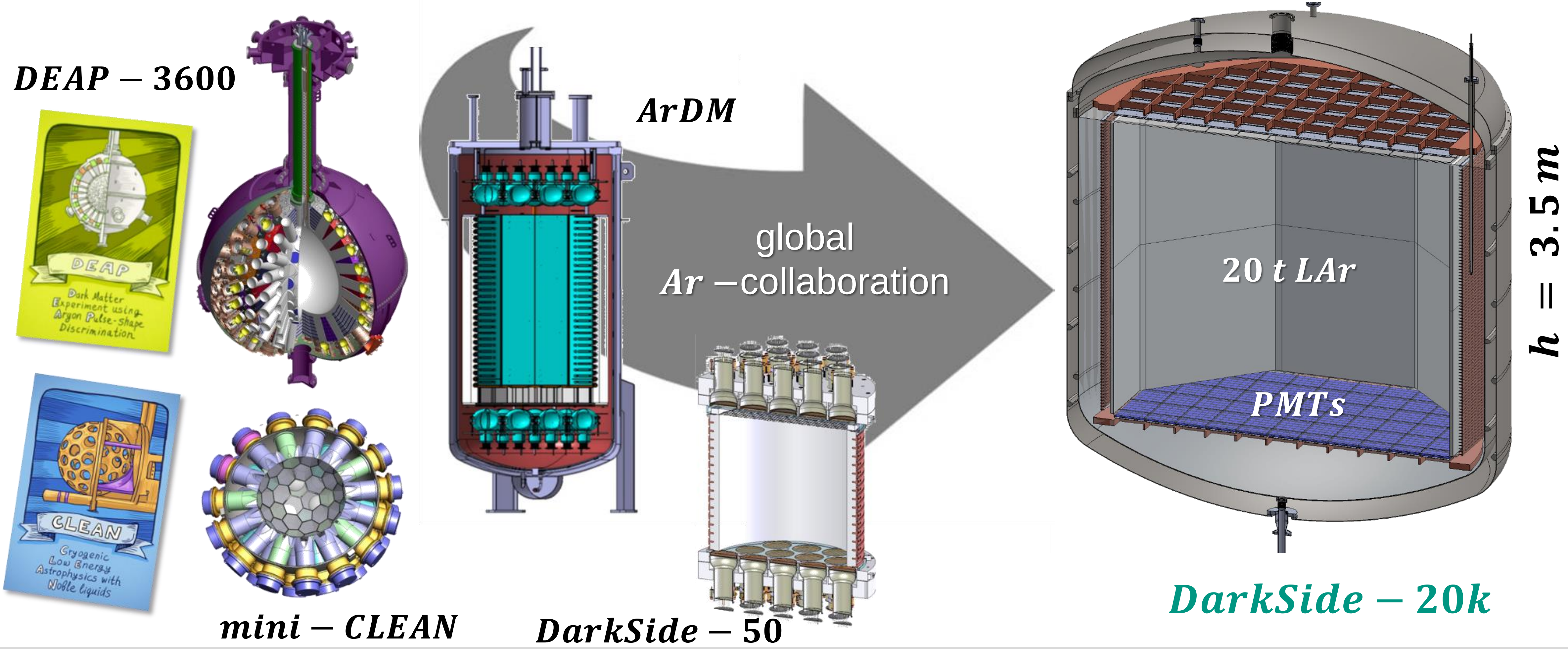
  - obtained $\boldsymbol{DarkSide}$ **50** exclusion limit:
    $\boldsymbol{\sigma_{SI} < 1.14 \times 10^{-44}\ cm^2}$
    (for $\mathbf{100}\ \boldsymbol{GeV - WIMP}$)

  - **breakthrough result for 2 – phase–$\boldsymbol{Ar}$ –detectors**



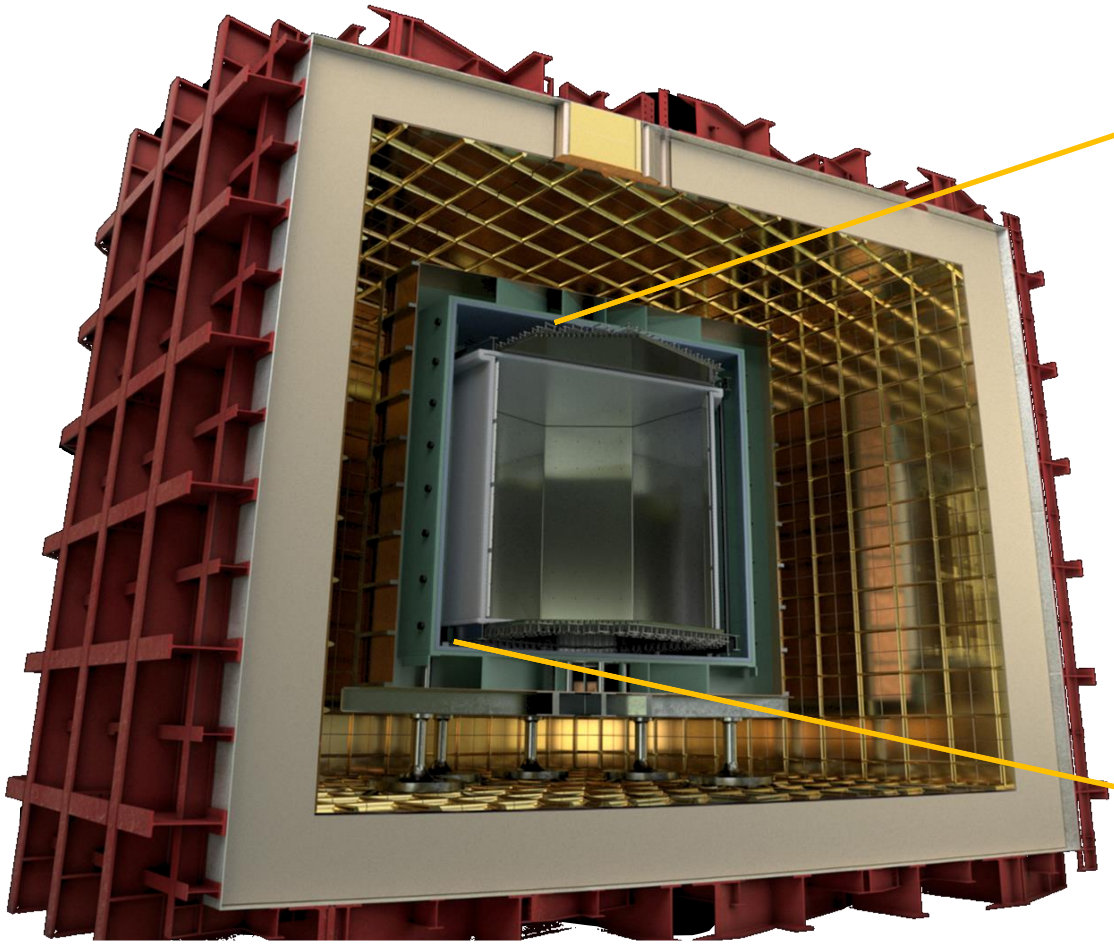
$Darkside\ 20k$: a global argon $DM-$ experiment

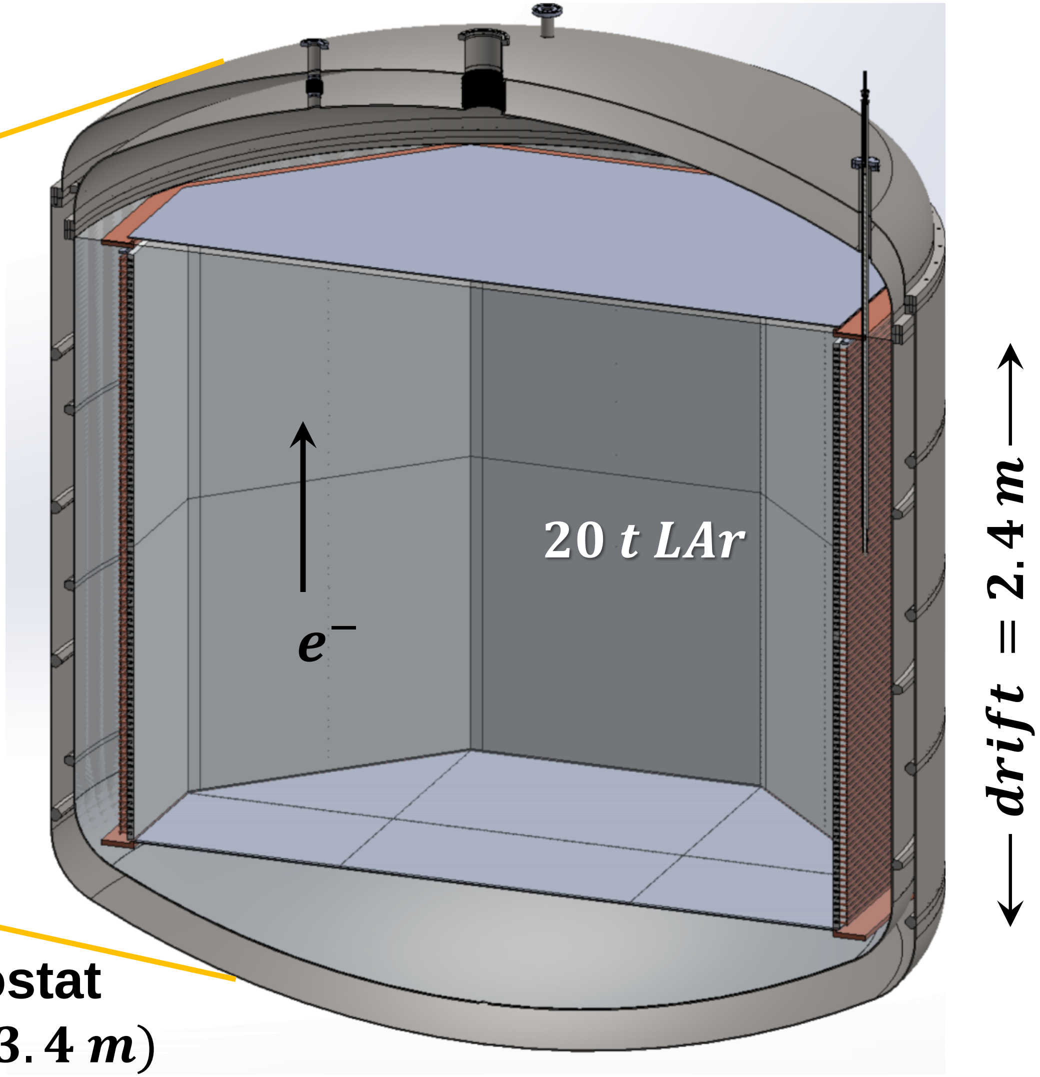
- Uniting all previous $argon-$ based project in a global argon collaboration



$Darkside\ 20k$: a global argon $DM -$ experiment

- Veto$-$detector & TPC for $DarkSide\ 20k$

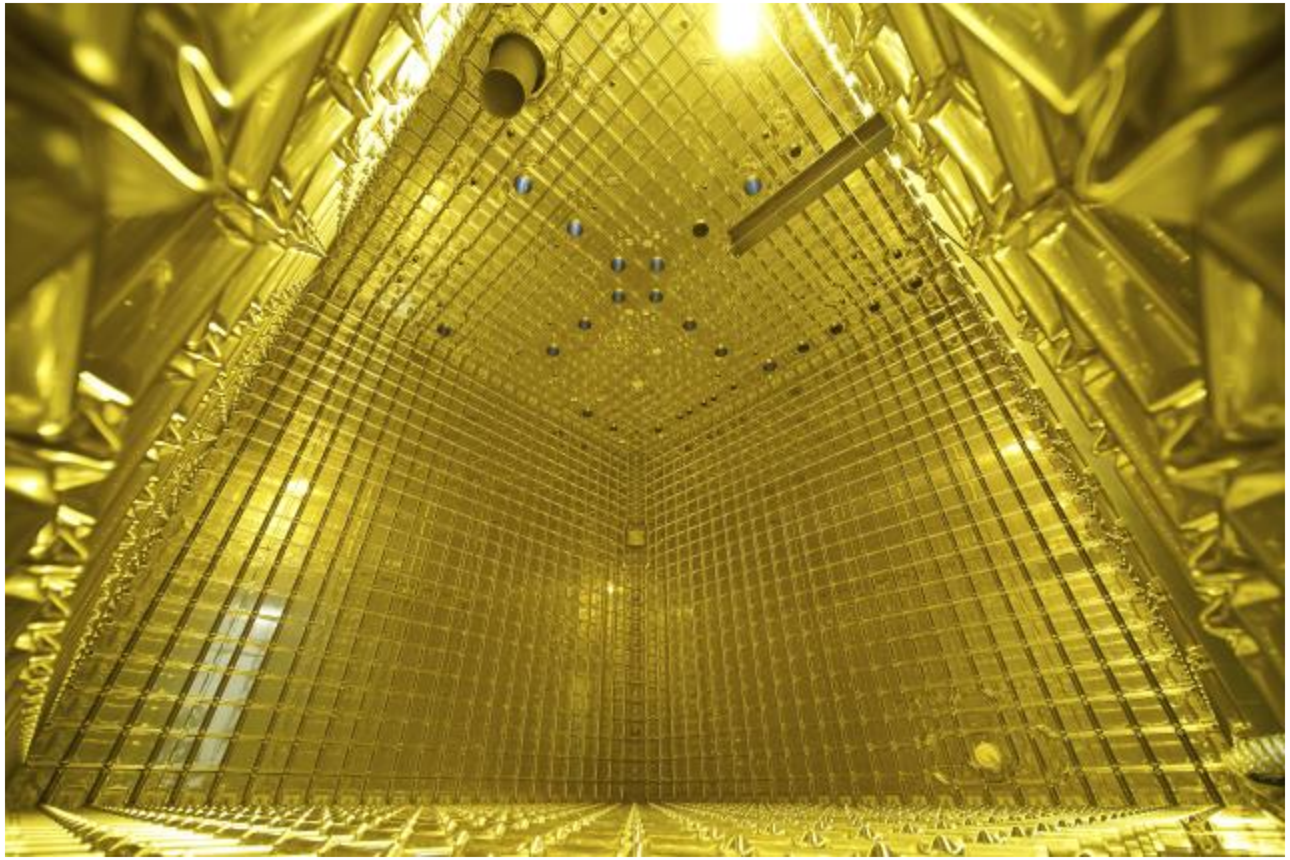


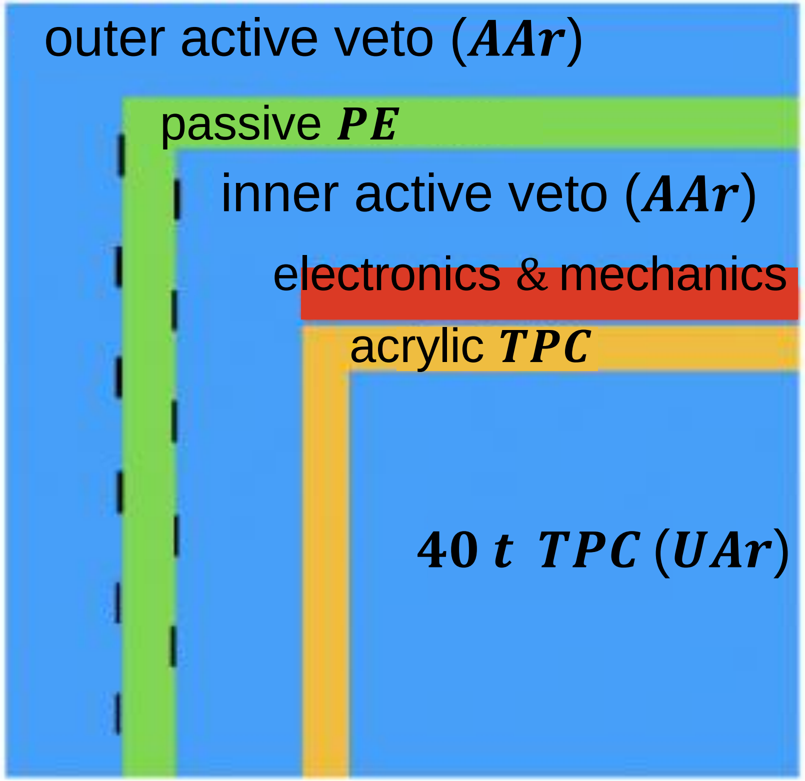


cryostat
($Ø\ =\ 3.4\ m$)

$Darkside\ 20k$: a global argon $DM-$experiment

- Veto$-$detector & TPC for $DarkSide\ 20k$





total argon mass: $50\ t$

Darkside 20k: set–up of 50 t argon TPC

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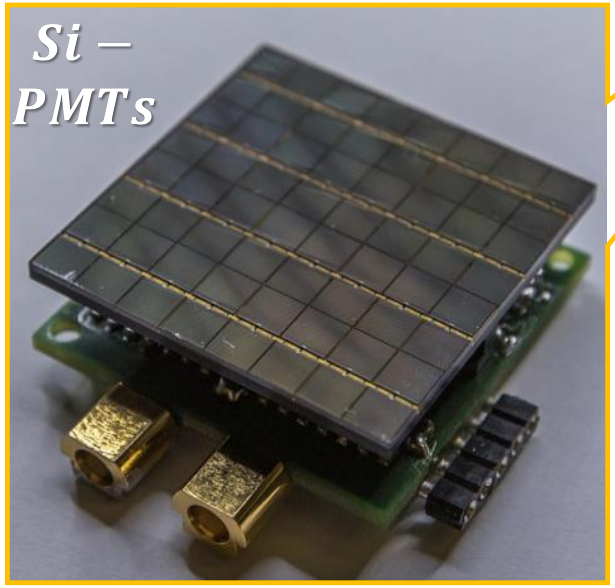
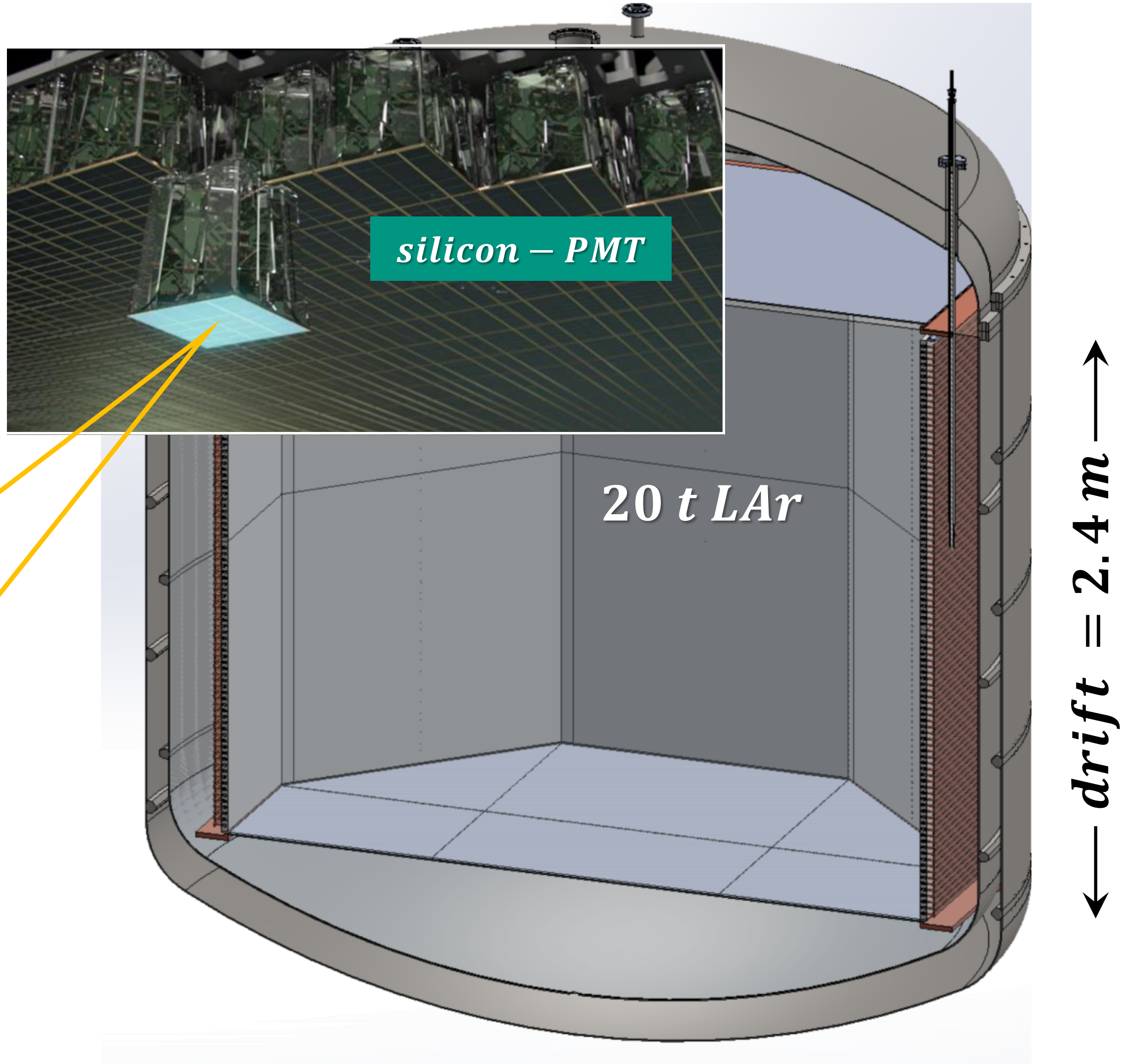
- **Design parameters of *DarkSide* 20k**
  - fiducial volume: **20 t**
  - octagonal ***PTFE**** (***teflon***) panels & ***Cu*** – elements for forming of $\vec{E}$ – field





8280 photosensors:
Si – PMT – panels
$A = 5 \times 5\ cm^2$

*Poly–Tetra–Fluoro–Ethylene

$\boldsymbol{Darkside\ 20k}$: ongoing & future timeline

- **Timeline** & **goals of** $\boldsymbol{DarkSide\ 20k}$

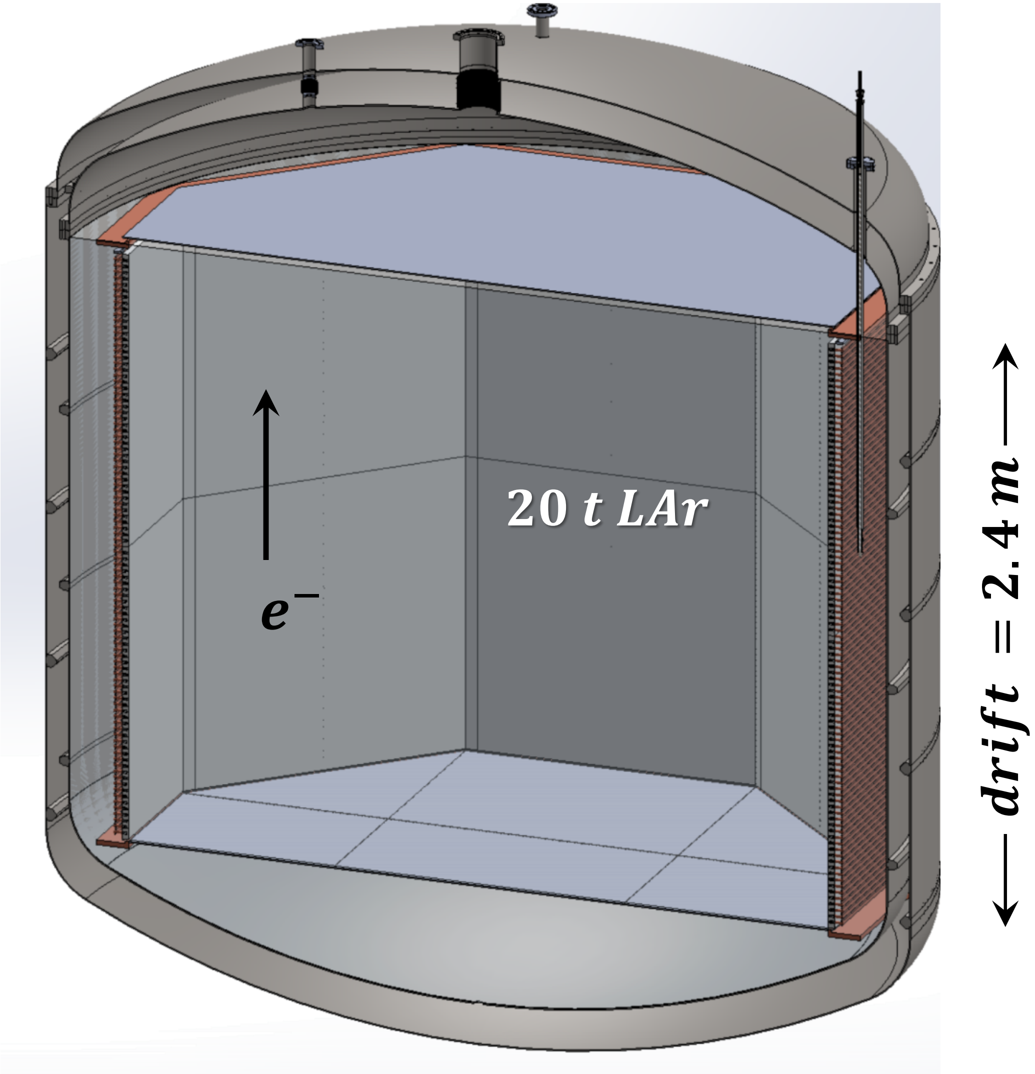
$\mathbf{2024}$: ongoing installation works at $\boldsymbol{LNGS}$

$\mathbf{2026}$: expected start of measurements

$> \mathbf{2026}$: planned long–term data taking, expecting a $\boldsymbol{WIMP}$ –result **free of background**

exposure: $\boldsymbol{M \cdot t = 200\ t \cdot yr}$

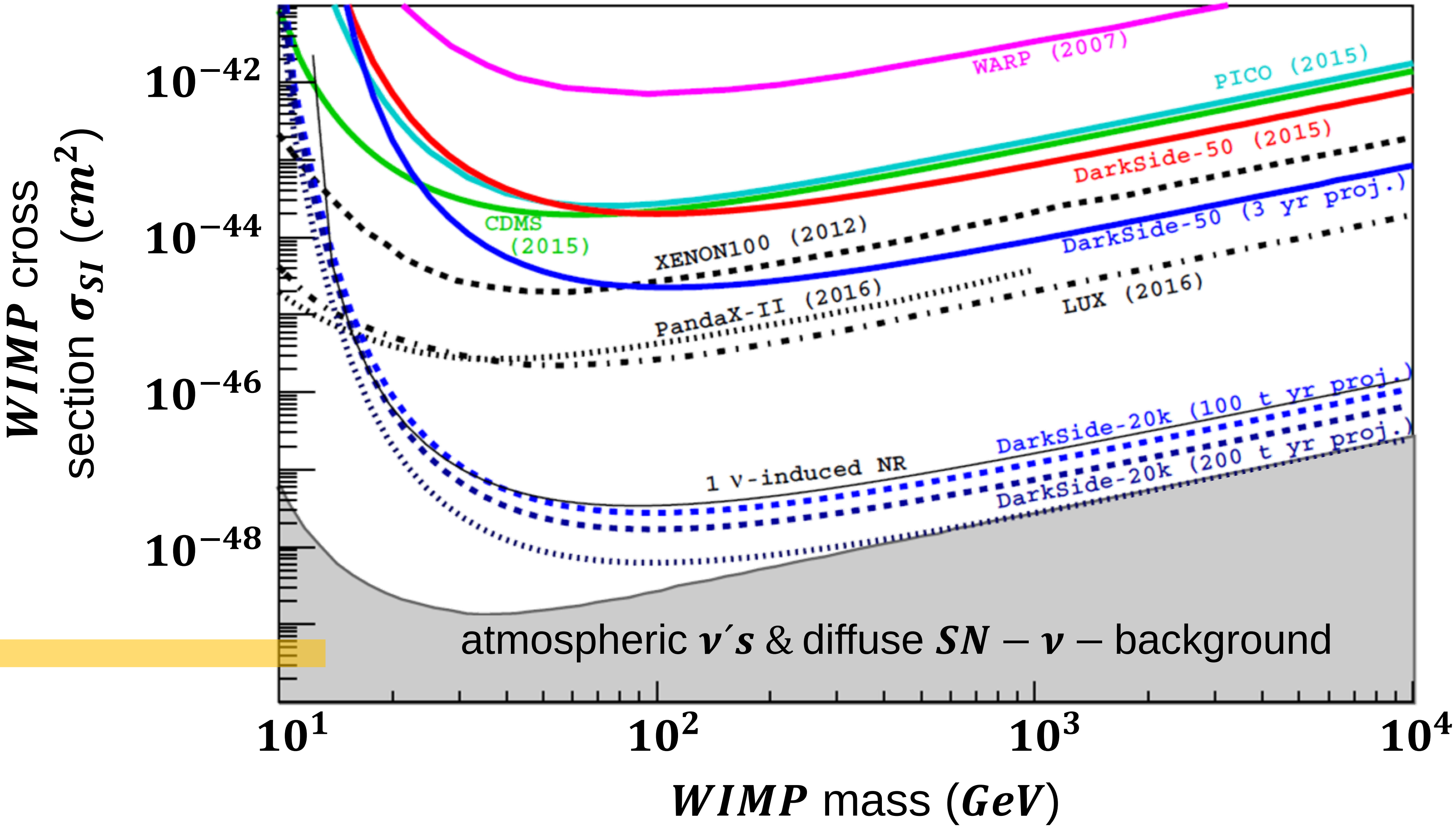
combination of $\boldsymbol{PSD}$ ($\boldsymbol{P}$ulse $\boldsymbol{S}$hape $\boldsymbol{D}$iscrimination) & $\boldsymbol{S1 - S2}$ ratio



$\mathit{Darkside}\ 20k$: expected sensitivity & comparison

- **All scales with exposure in case of no background**

- potential of **$2-$phase argon** experiments to push forward to **neutrino floor**



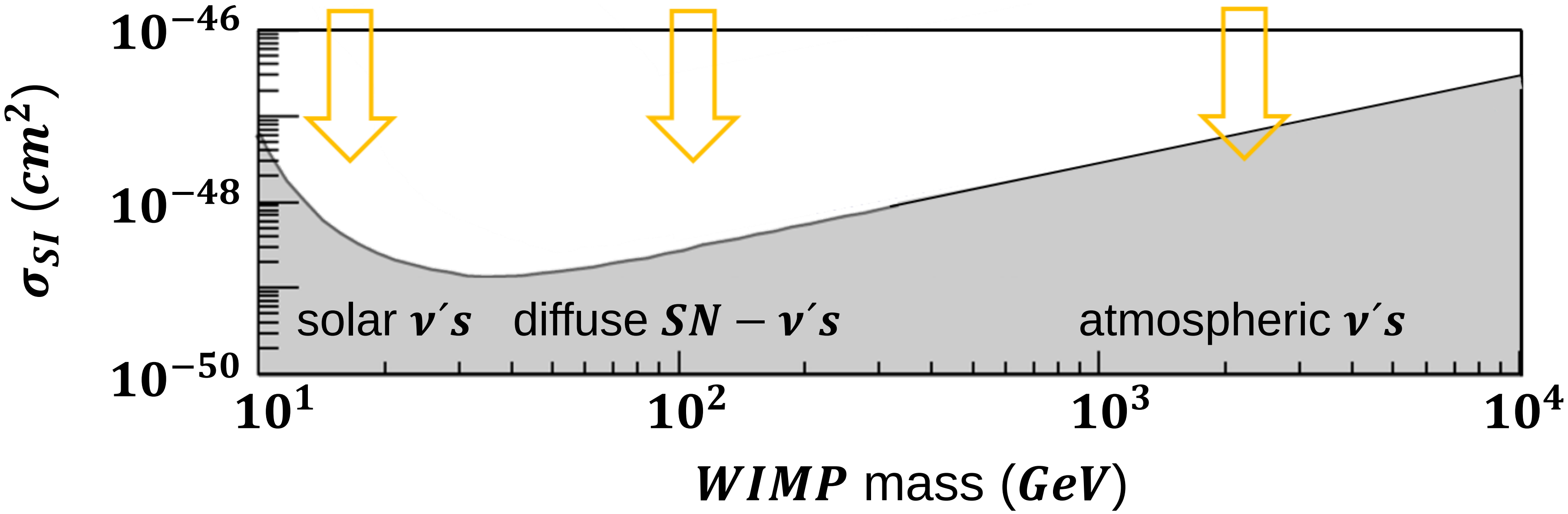
Neutrino floor – ultimate limit for DM – searches

- Coherent scattering of astrophysical neutrinos off target nuclei

- ν´s from the Sun, all previous SN´s & from the Earth´s atmosphere: **no shielding is possible**







Neutrino floor – kinematics of $\nu-$ scattering

Karlsruhe Institute of Technology

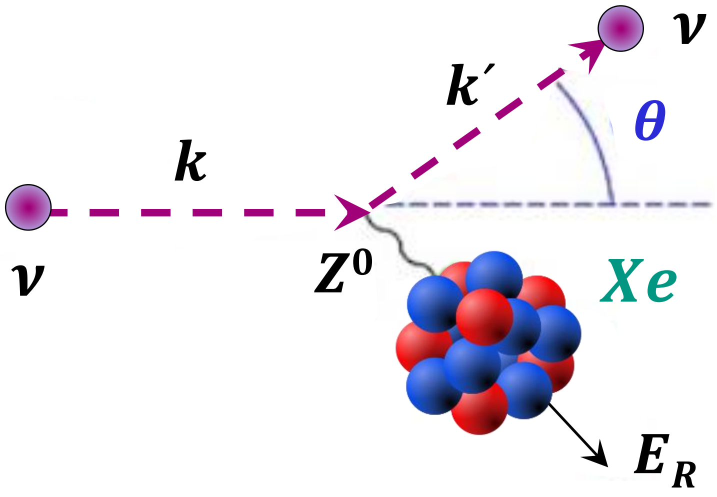
- **Coherent scattering of astrophysical neutrinos: from the $MeV \dots GeV-$ scale**

- primary interaction:
  $NC-$ **process via** Z^0

- **coherent** interaction:
  with **all** $\boldsymbol{neutrons}$ within
  the target nucleus ^{Z}A

$$\sigma_\nu(E_\nu) \sim N^2 \cdot E_\nu^2$$

N: number of $\boldsymbol{neutrons}$
in a nucleus



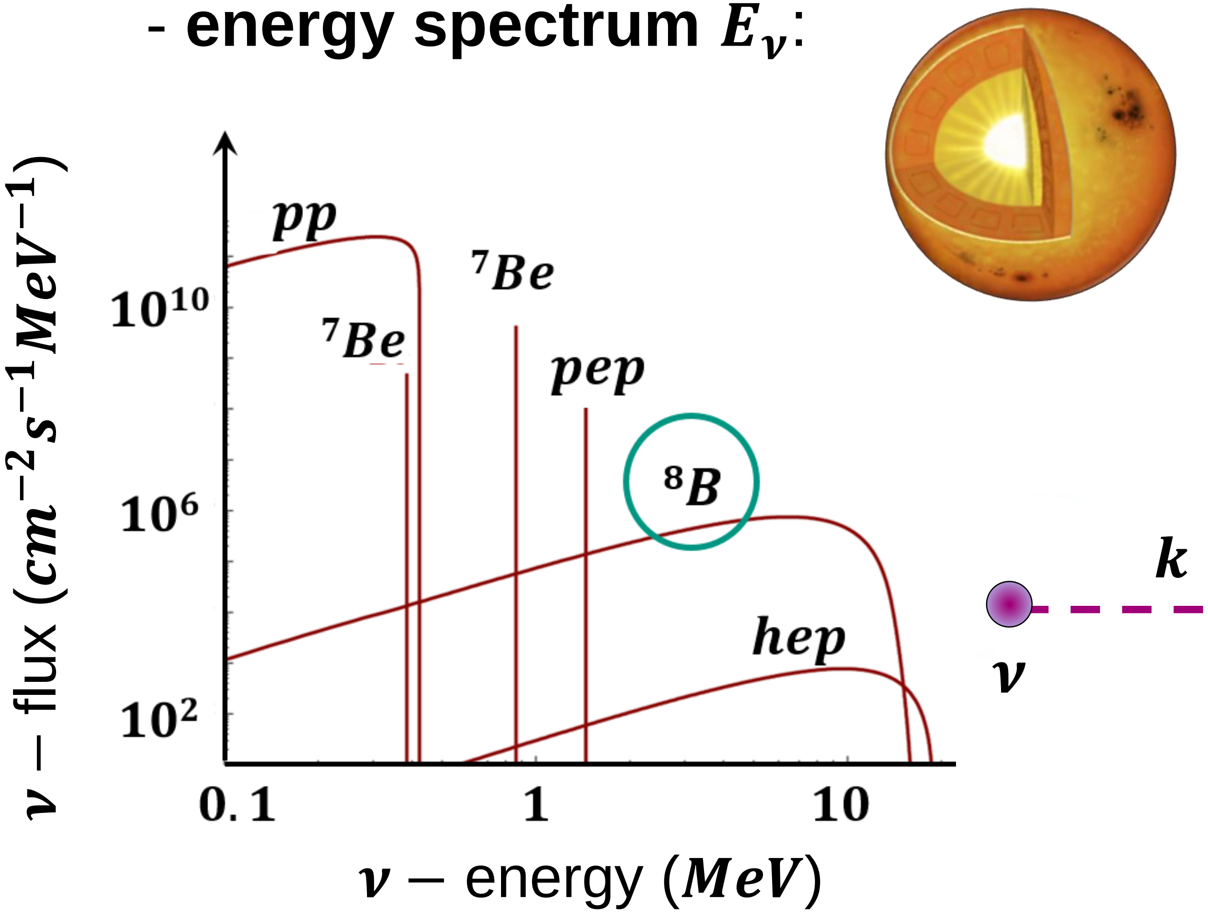
- kinematics:
  recoil of target nucleus

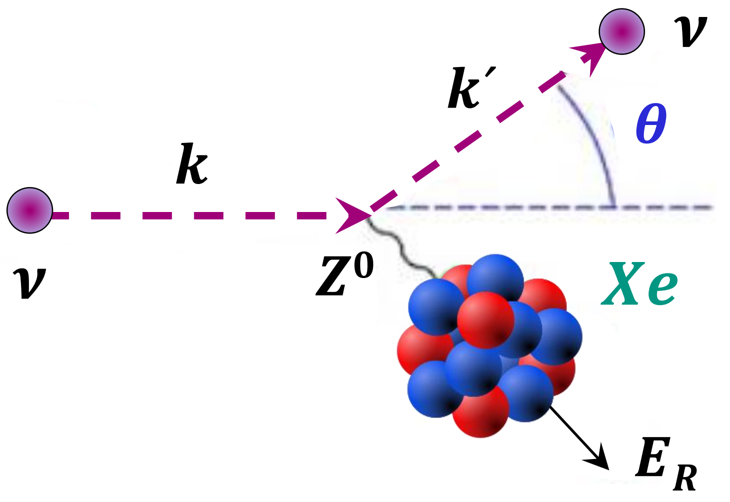
$$E_{R,max} \sim (E_\nu)^2/A$$

Neutrino floor – scattering of solar neutrinos

- **Coherent scattering of solar neutrinos: MeV – scale**

  - **energy spectrum E_ν:**





- background from: $^8B - \nu's$ scattering off a Xe – nucleus
- kinematics for a solar ν ($E = 3\ MeV$)
  $E_{R,max} \sim 150\ eV$
- cross section for a solar ν ($E = 10\ MeV$)
  $\sigma_{\nu-Xe} \sim 2 \cdot 10^{-39}\ cm^2$

2 – phase experiments with $xenon$: overview

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$XENON\ 10/100\ 1T/nT$

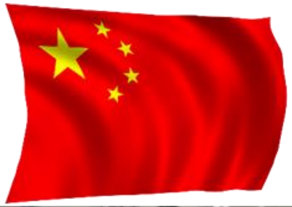
active mass:
$\mathbf{8.3}\ \boldsymbol{t}$

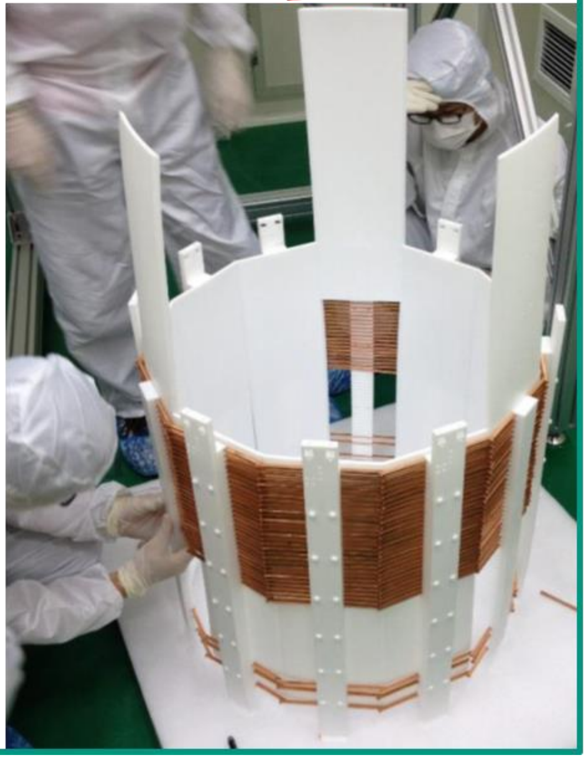
$ZEPLIN/LUX/LZ$

active mass:
$\mathbf{7}\ \boldsymbol{t}$

$PANDA-X$

active mass:
$\mathbf{4}\ \boldsymbol{t}$

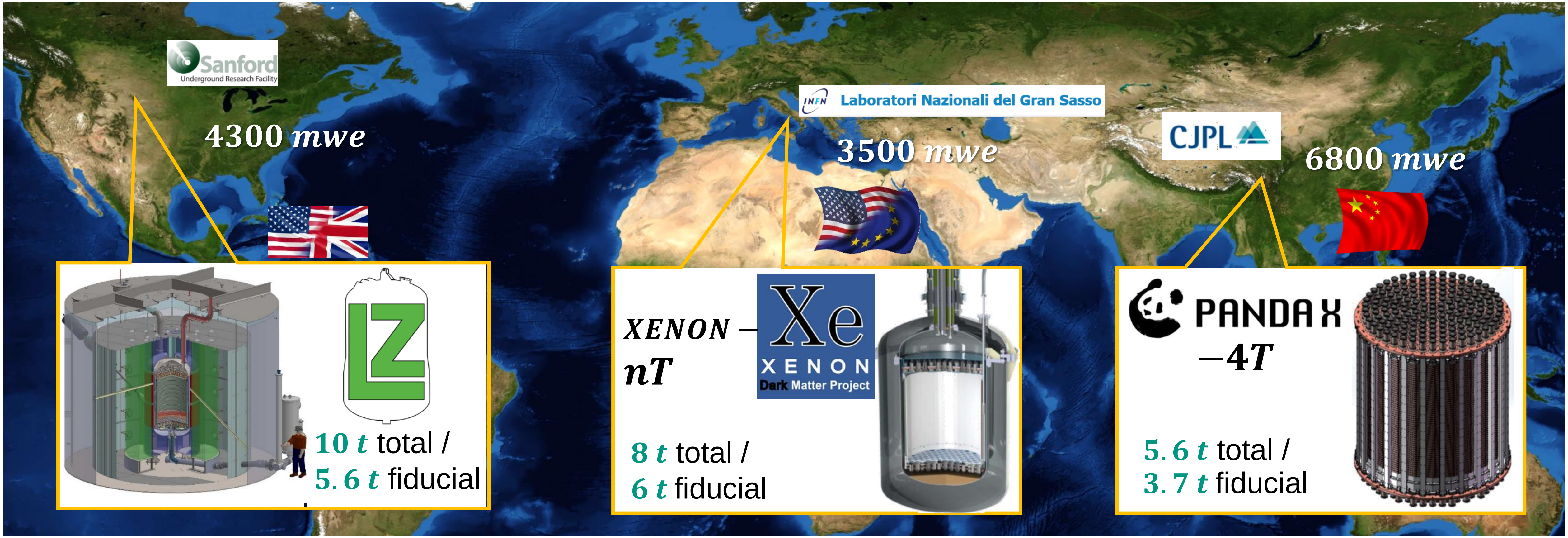




2 – phase experiments with $xenon$: overview

- **All three regions (US, EU, China) operate multi$-ton$ $Xe-$ targets**

- which continent will win the race to provide the best $WIMP$ sensitivity with $xenon$?

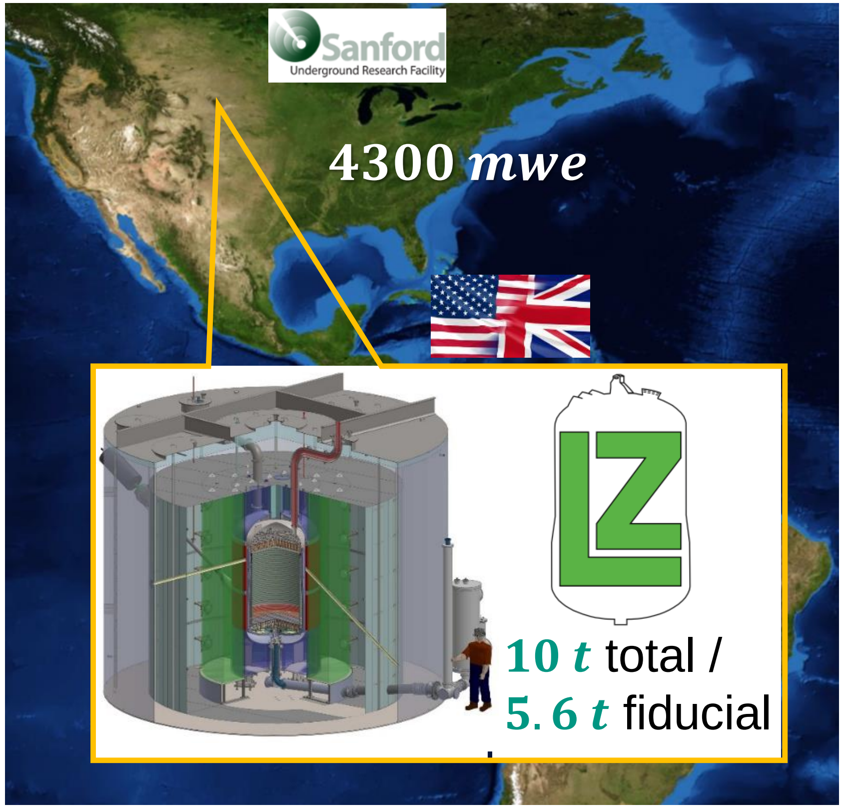


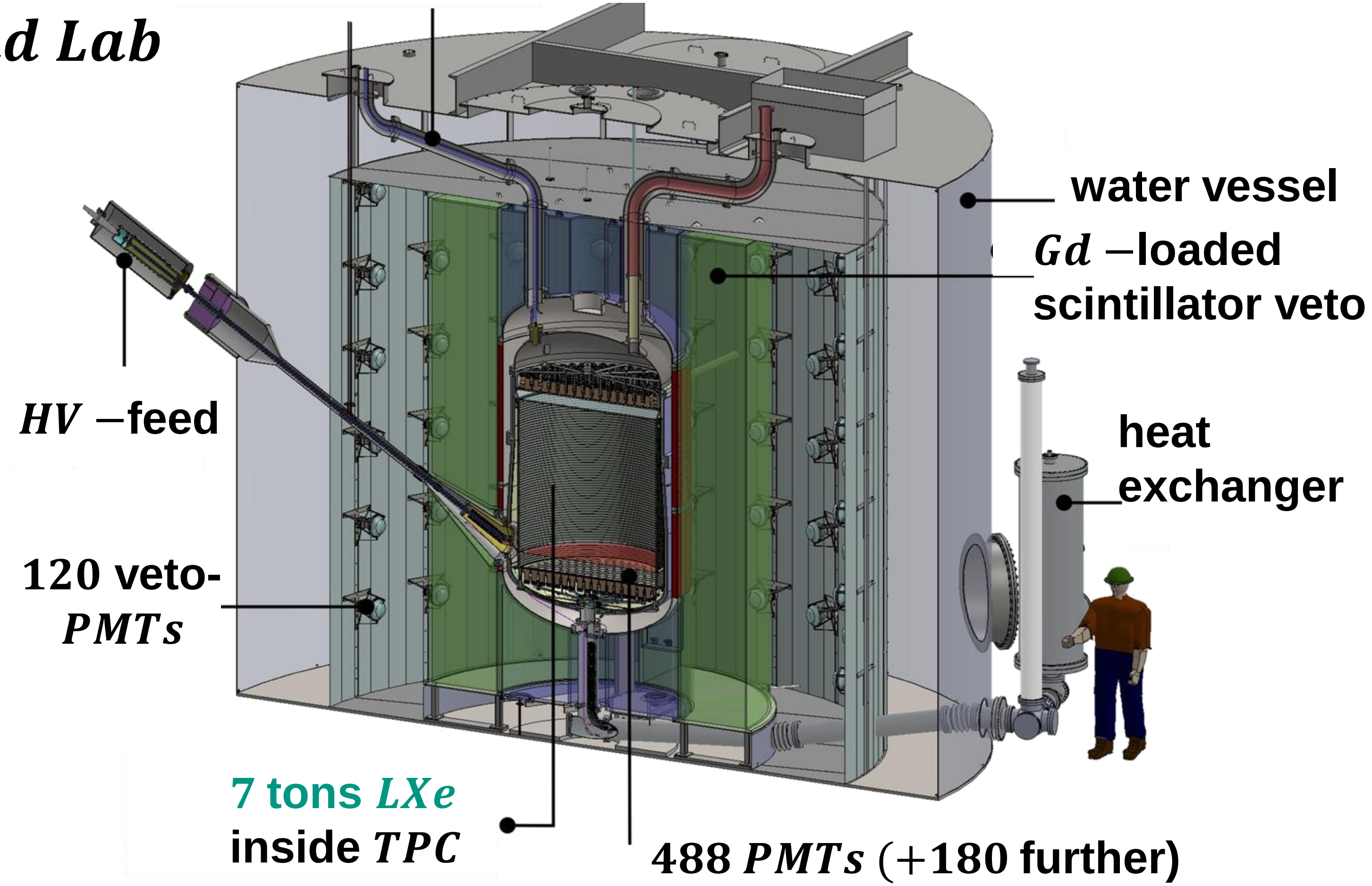
$Lux - Zeplin$ (LZ) experiment in the US

Karlsruhe Institute of Technology

- LZ is the successor from the merger of LUX (US) and $ZEPLIN$ (GB)

- operated at $Sanford\ Underground\ Lab$



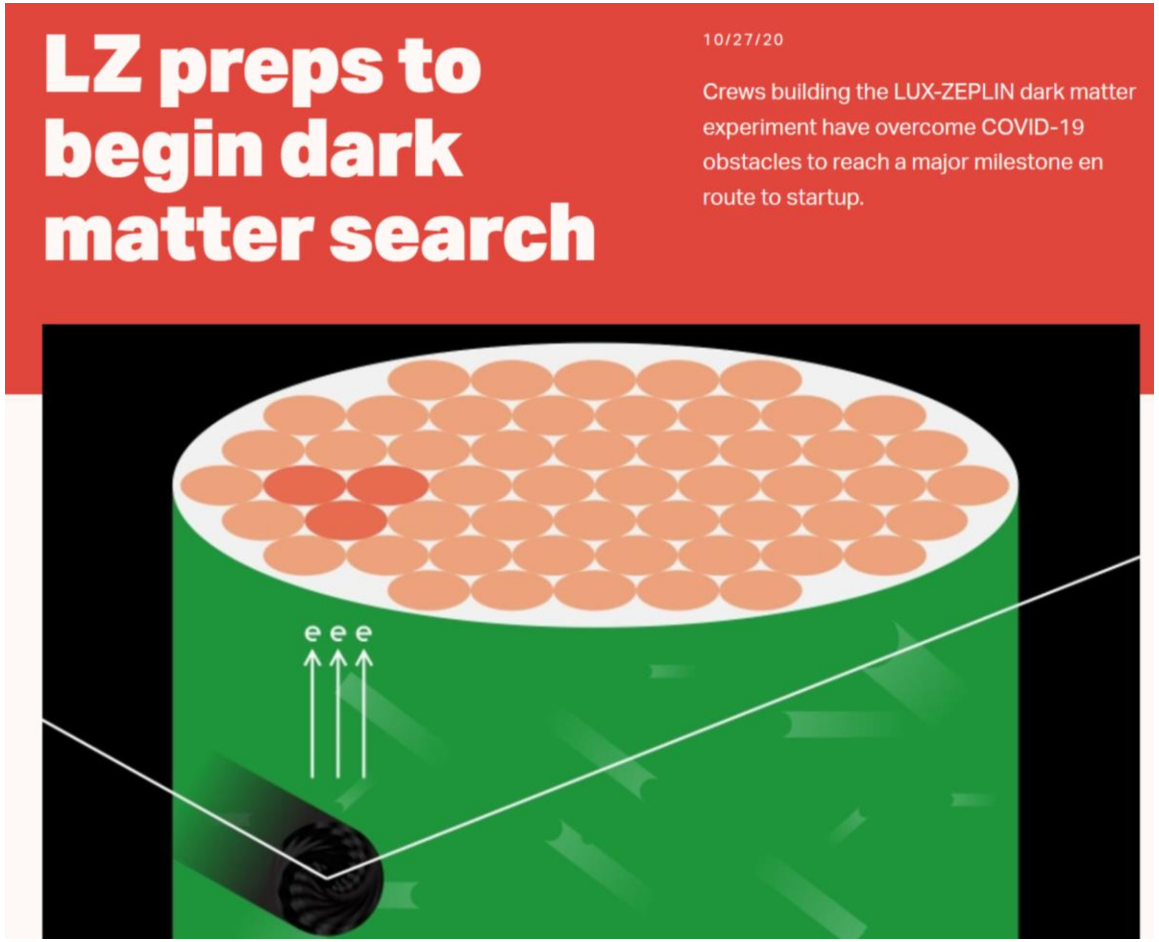


[The LZ Dark Matter Experiment | The status and science of the LZ dark matter experiment. (lbl.gov)]

$Lux - Zeplin$ (LZ) experiment in the US

- LZ is taking data since 2021, first (initial) data published in $July$ 2022

  - careful final investigations of the integrity of the $xenon - TPC$ by the LZ – collaborators, then: go!



$Lux - Zeplin\ (LZ)$ experiment: first results

- **Data collected from Dec $\mathbf{2021}$ … May $\mathbf{2022}$ (60 days)**

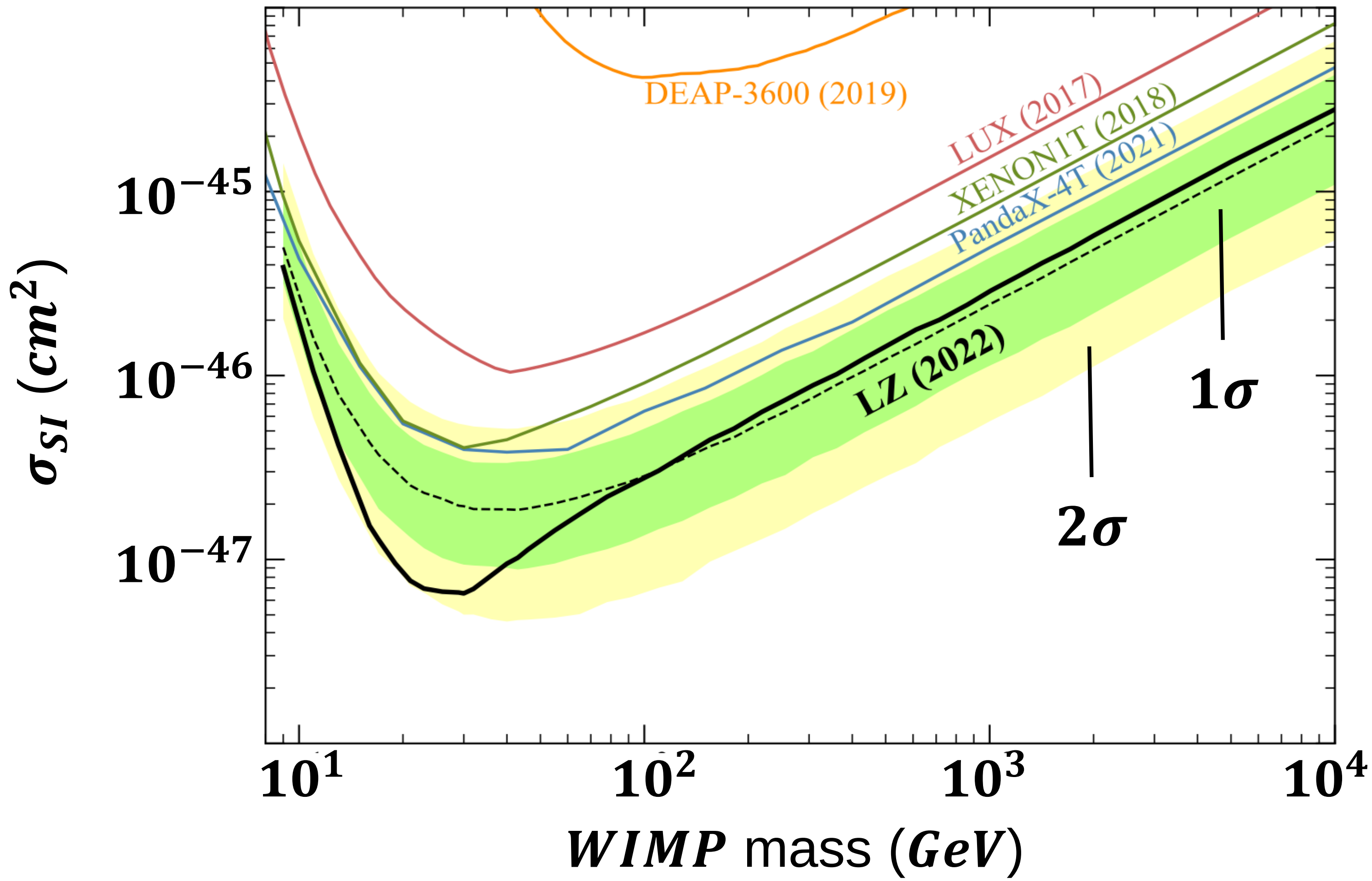
- data fully consistent with a **background–only** hypothesis (p – **value:** $\mathbf{0.96}$) – actual limit: **black line**

  ($\mathbf{1\sigma}$ & $\mathbf{2\sigma}$ bands from MC)

- world–leading sensitivity (at present) for $m_{WIMP} > 9\ GeV$

- $WIMP$ – sensitivity at $\mathbf{30}\ GeV$

  $$\sigma_{SI} < 6.5 \times 10^{-48}\ cm^2$$



$Panda\,X - 4T$ experiment in $Jinping\ Lab$, China

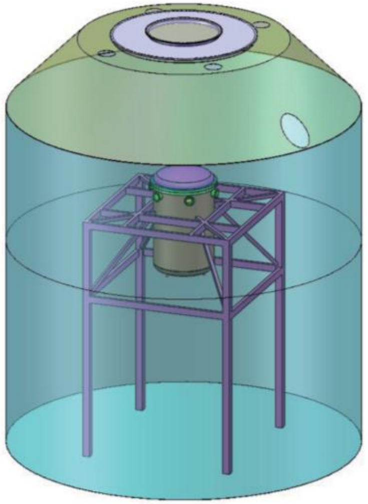
- $Panda\,X$ – Particle $and\ a$strophysical Xenon detector: multiple generations

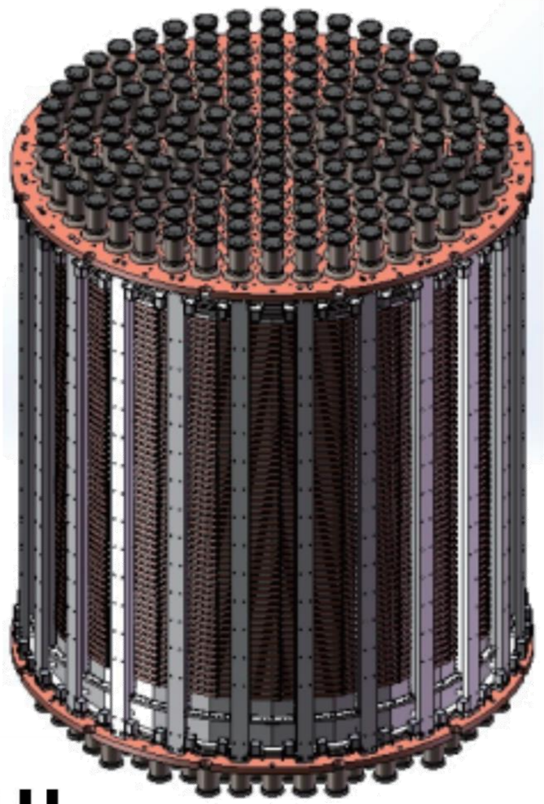
  - presently: $5.6\ t\ LXe$ (total mass), $3.7\ t\ LXe$ (sensitive target mass in TPC)

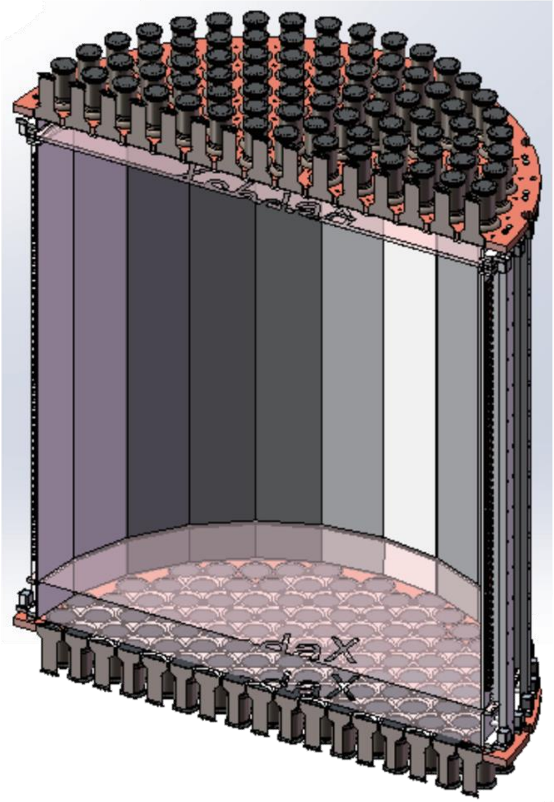
  - TPC surrounded by H_2O –veto–detector

  - TPC – dimensions: $\varnothing = 1.2\ m, h = 1.3\ m$

  - optical read–out via $3 - inch\ PMT$ –arrays Hamamatsu $R11410 - 23$







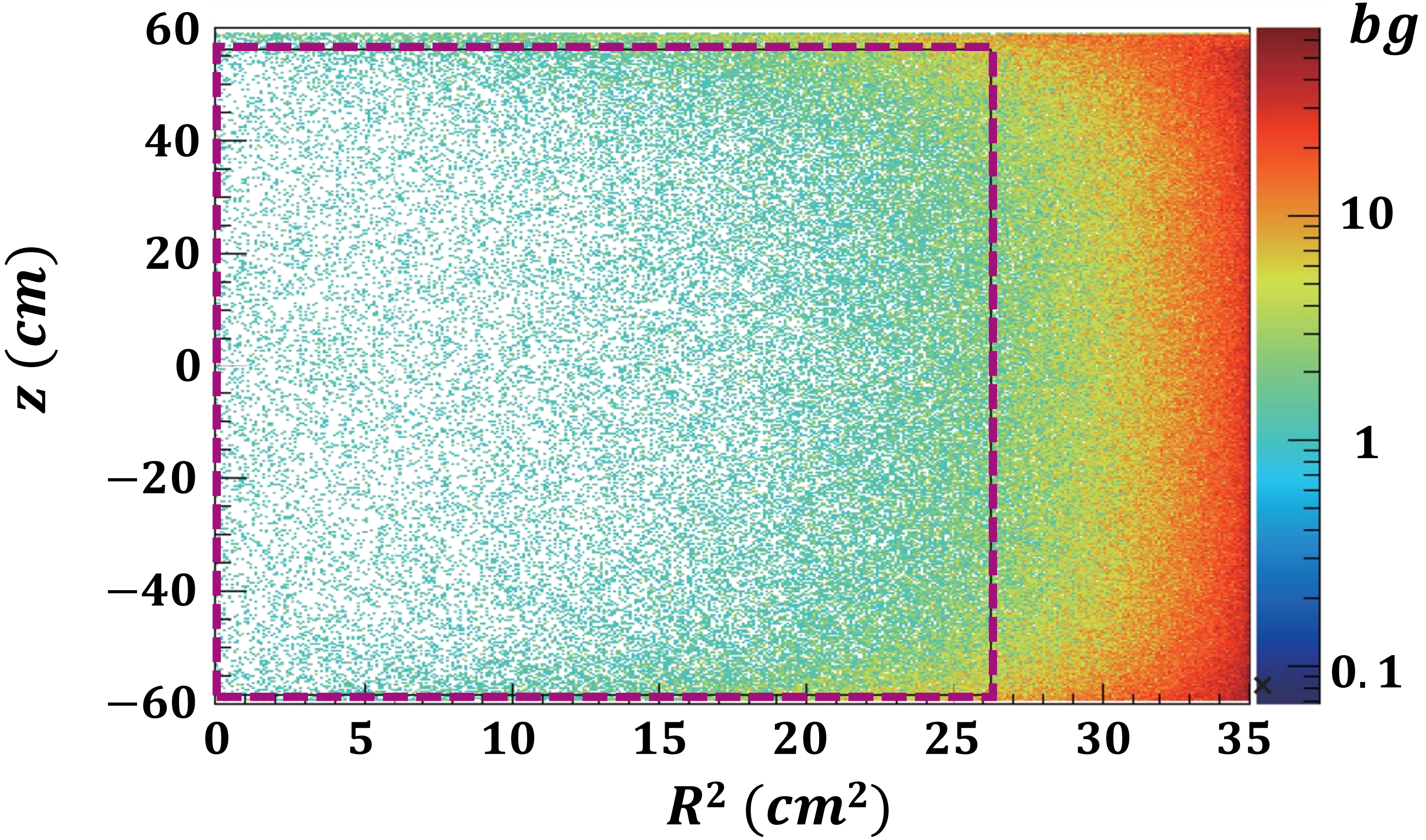
$PandaX-4T$: illustration of a fiducial volume

- **Distribution of background events in the LXe volume in a side view**

- background dominated by detector materials

- software cuts define ***fiducial volume***

inner region with lowest background level



$PandaX - 4T$: first results published 12/2021

- **Data analysis based on an exposure of $M \cdot t = 0.63\ t \cdot yr$**

  - **no $WIMP$ excess observed**

  - best $WIMP$ sensitivity achieved
    for $M = 40\ GeV$

  - $WIMP$ – limit ($90\ \%\ CL$) for $40\ GeV$

$$\sigma_{SI} < 3.8 \times 10^{-47}\ cm^2$$

  - limit is less stringent than LZ

$XENON - 1T$ experiment at $LNGS$

- **European experiment** $(+\ US$ **groups): long–term leader of the field**

- successor to earlier $\boldsymbol{XENON\ 10/100}$

- **construction period**: autumn $\mathbf{2013}$ up to autumn $\mathbf{2015}$ $(\mathbf{2}\ \boldsymbol{yr})$

- total (active) $\boldsymbol{LXe}$ mass: $\mathbf{3.3}\ \boldsymbol{t}$ $(\mathbf{2.0}\ \boldsymbol{t})$

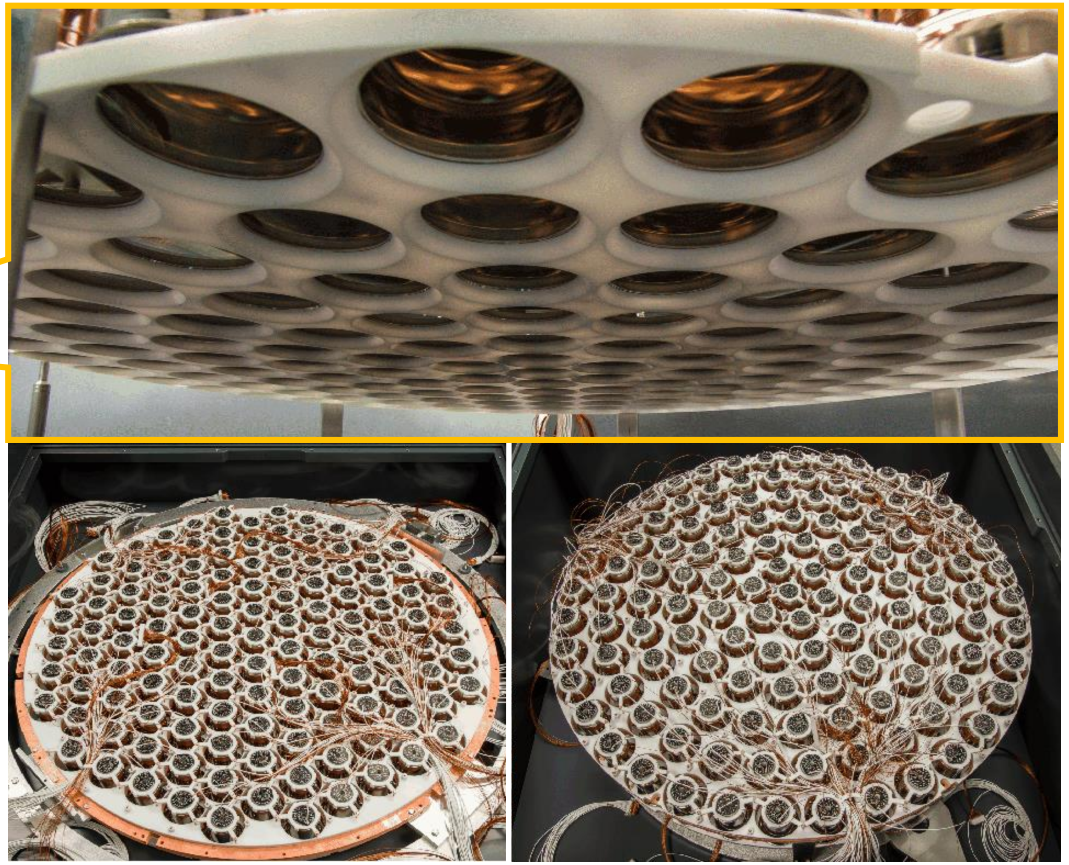
- measurement phase from autumn $\mathbf{2016}$ – end of $\mathbf{2018}$

$XENON - 1T$ experiment – TPC design

- **Special focus on an extremely low level of background of all TPC parts**

drift rings (field cage)

cryostat



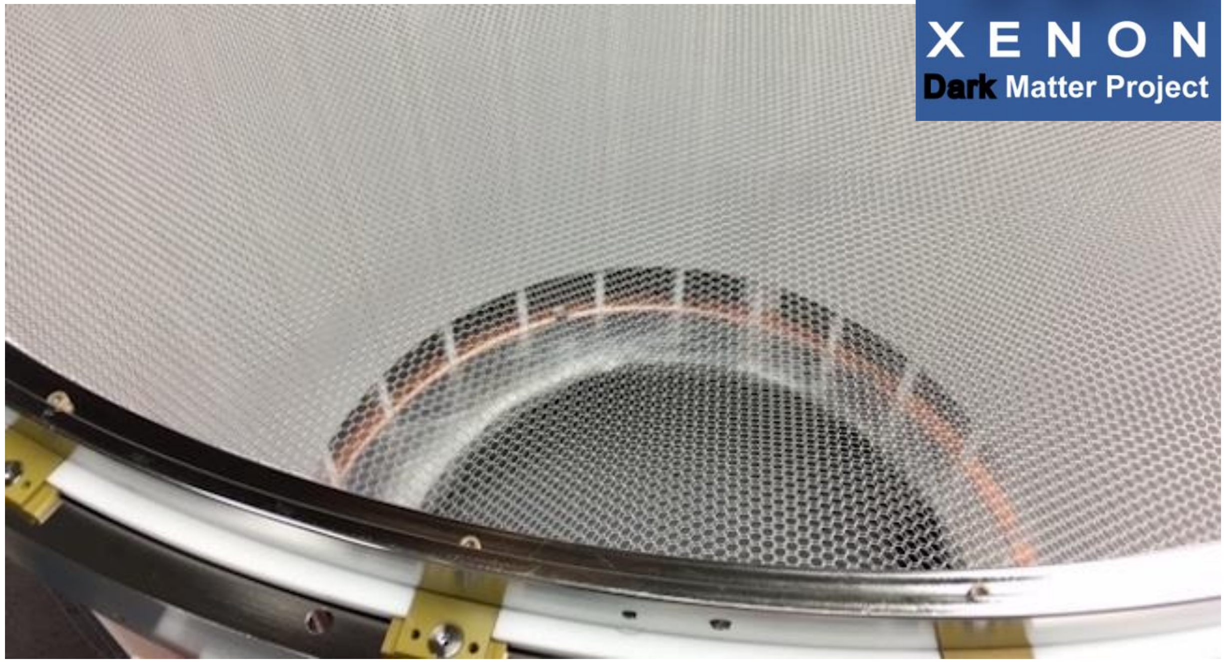
PMT – arrays

$XENON - 1T$ experiment – TPC construction

- **Special focus on an extremely low level of background of all TPC parts**

- assembly in clean room

- materials: selection/screening



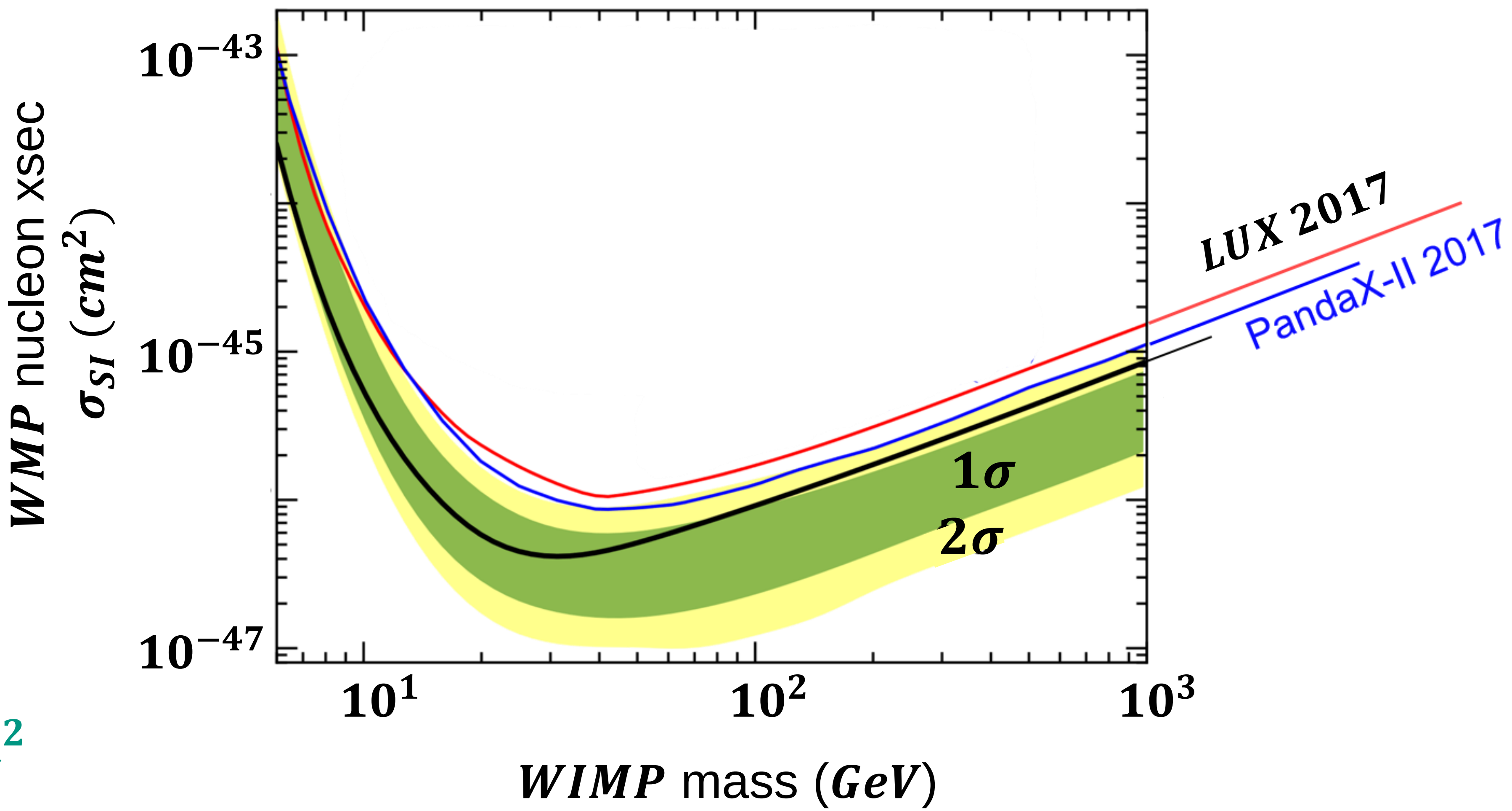
extraction electrode

$XENON - 1T$ experiment – final results

- **2018: publication of then world−leading DM − results from 270 days of data**

- fiducial mass of – $1T$
  $m = 1.3\ t$
- exposure
  $m \cdot t = 1.0\ t \cdot yr$
- **no** $WIMP$ signal in predefined box
- 90% CL upper limit for $30\ GeV\ WIMPs$:

$\sigma_{SI} < 4.1 \times 10^{-47}\ cm^2$

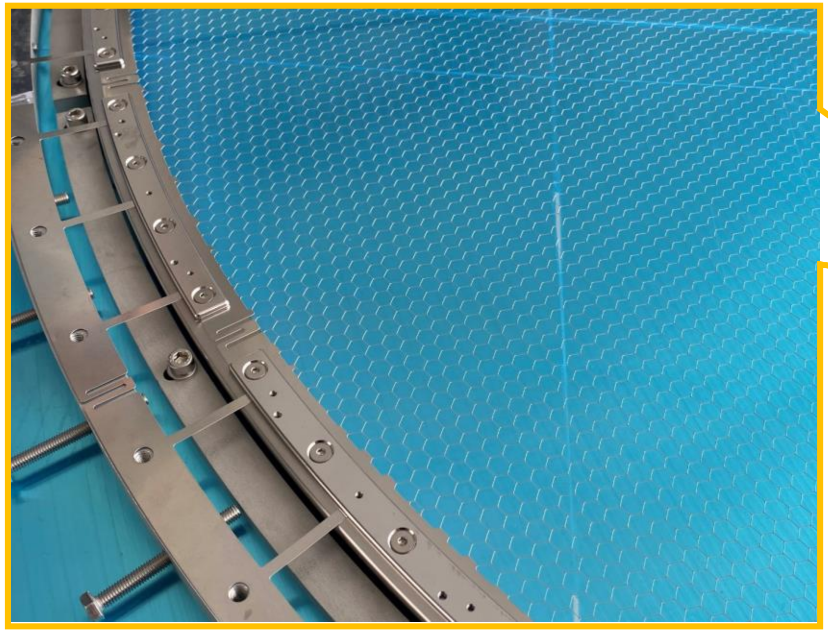


$XENONnT$ experiment – a much larger TPC joins

- **2022: the hunt for $WIMPs$ at $LNGS$ with 8.3 $tons$ of $xenon$ (re–)starts**

  - special focus on very **low–activity** materials

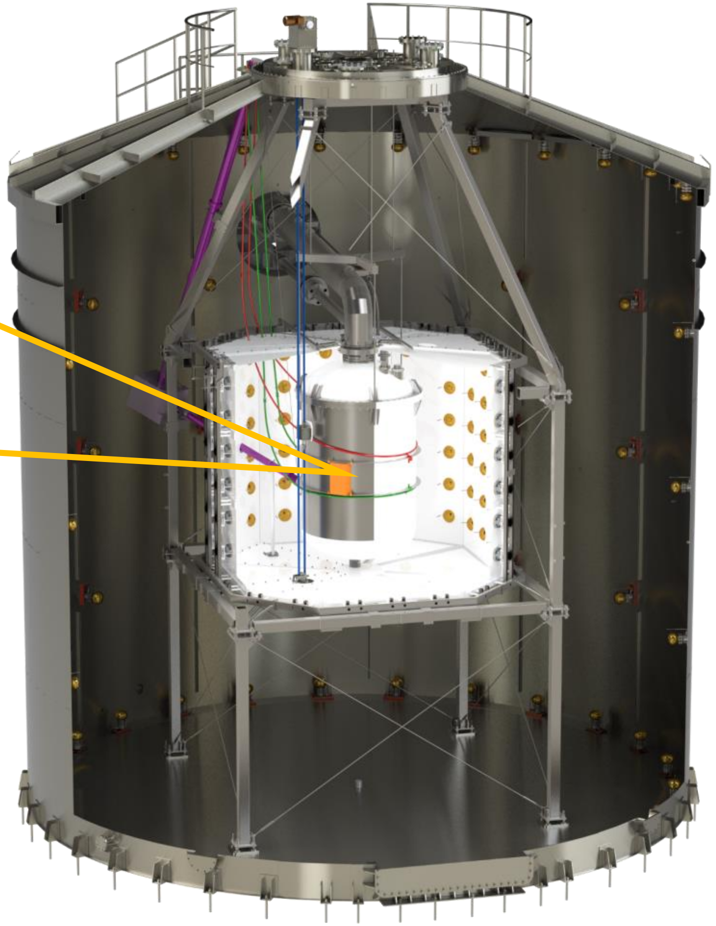
test of electrodes @ KIT



$XENONnT$ experiment – a much larger TPC joins

- 2022: the hunt for $WIMPs$ at $LNGS$ with 8.3 $tons$ of $xenon$ is finally on

the central TPC is ready…



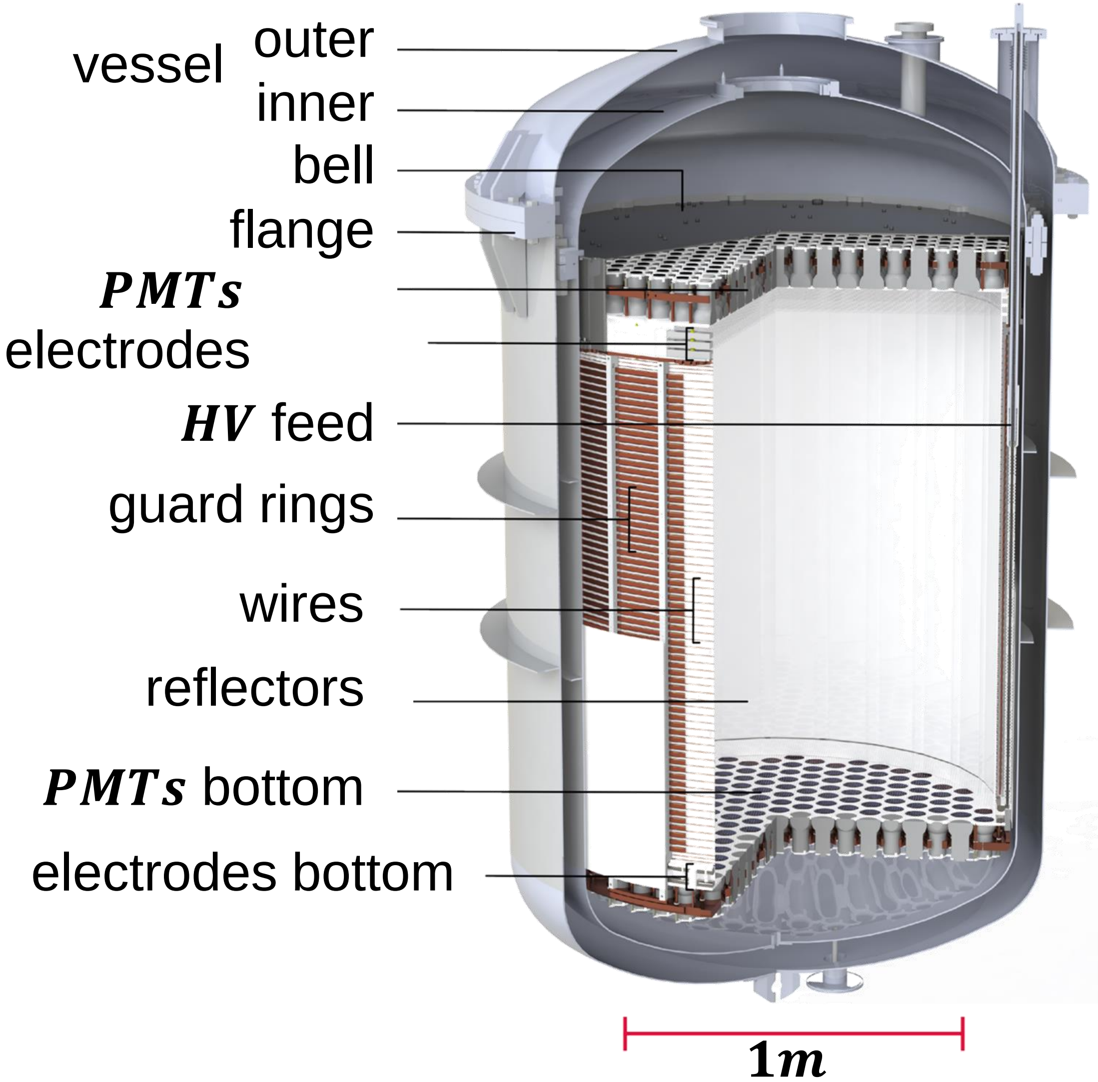
during assembly work…

$XENONnT$ experiment – a much larger TPC joins

- **$2022/23$: everything works perfectly**

  - drift field: $200\ V/cm$

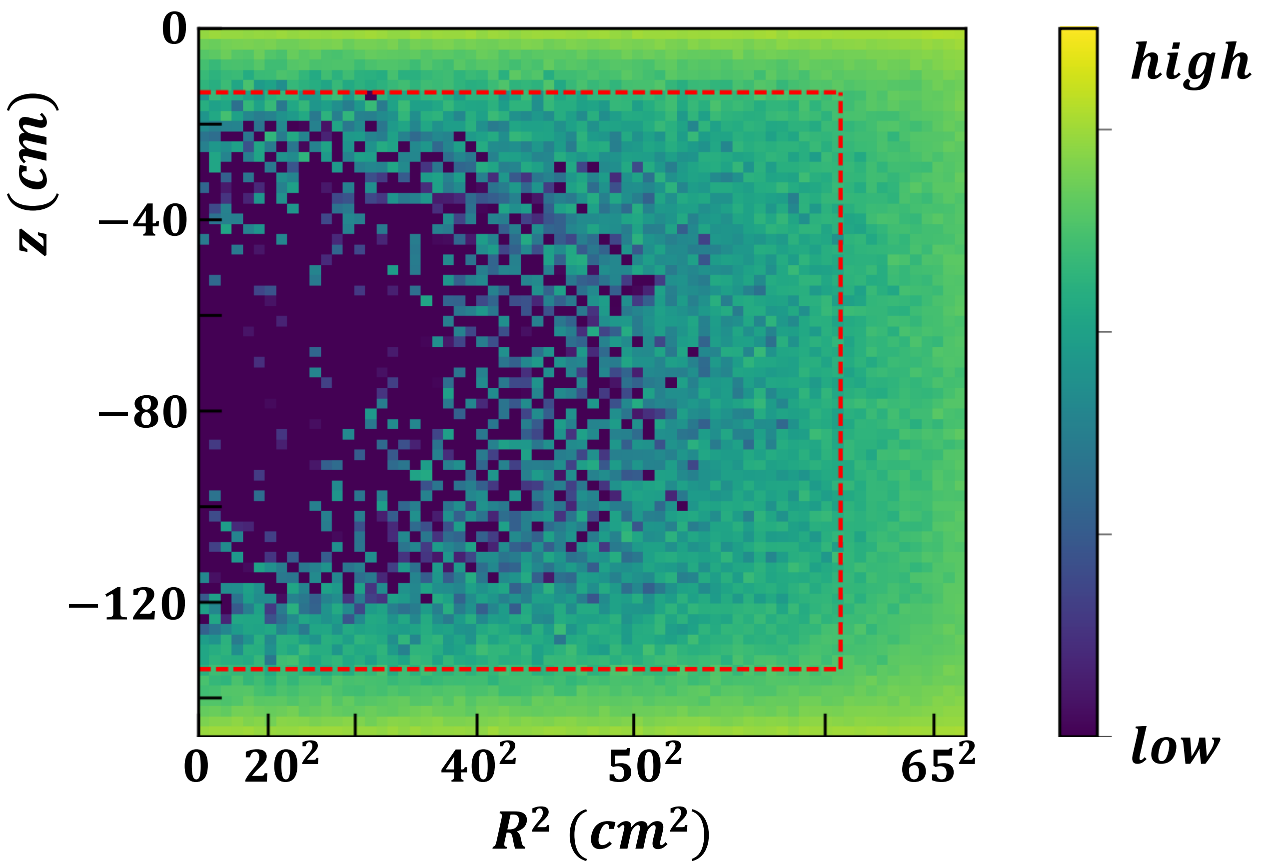
  - all materials were **screened** & **measured** very carefully

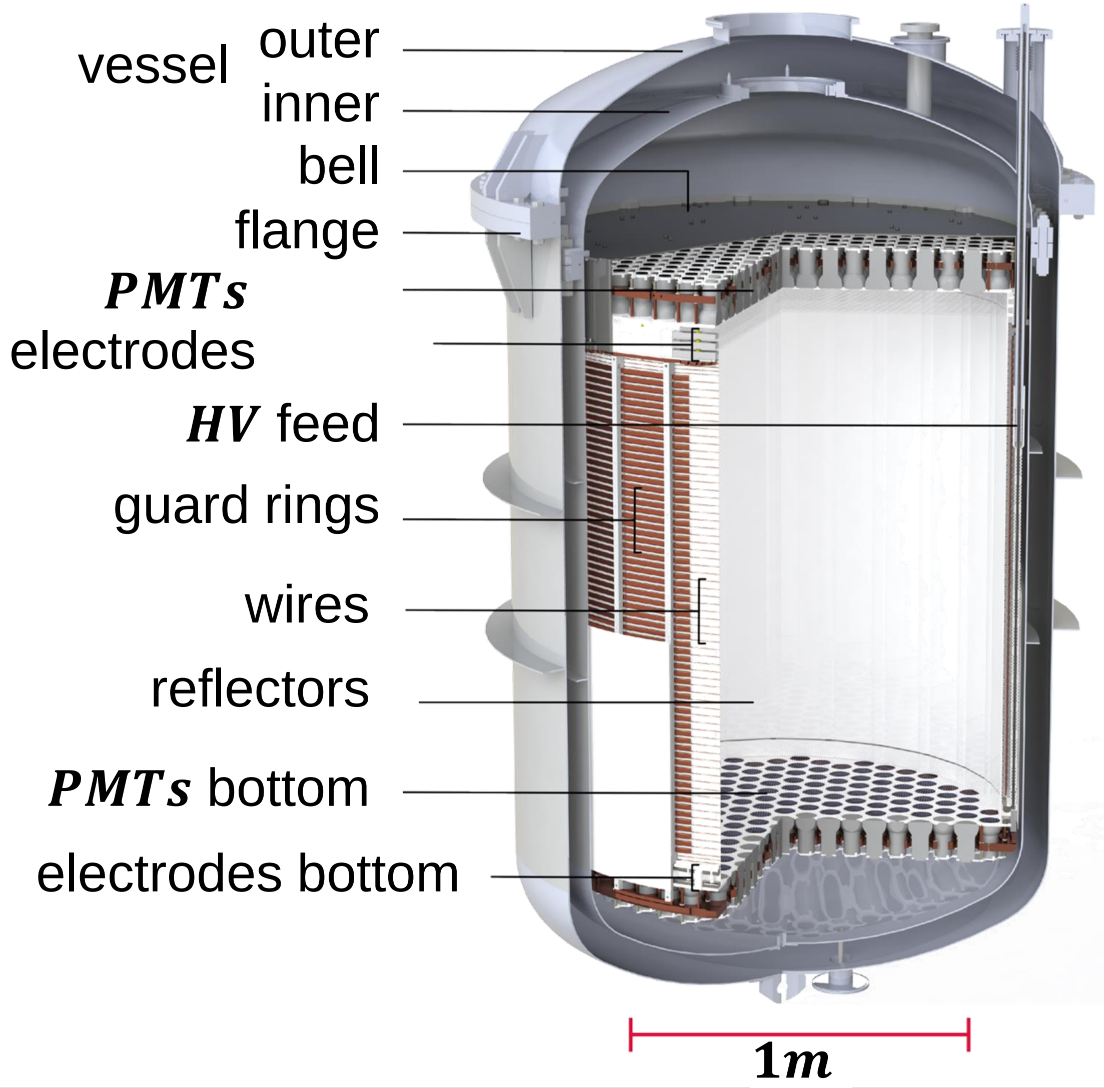


$XENONnT$ experiment – a much larger TPC joins

- **$2022/23$: everything works perfectly**

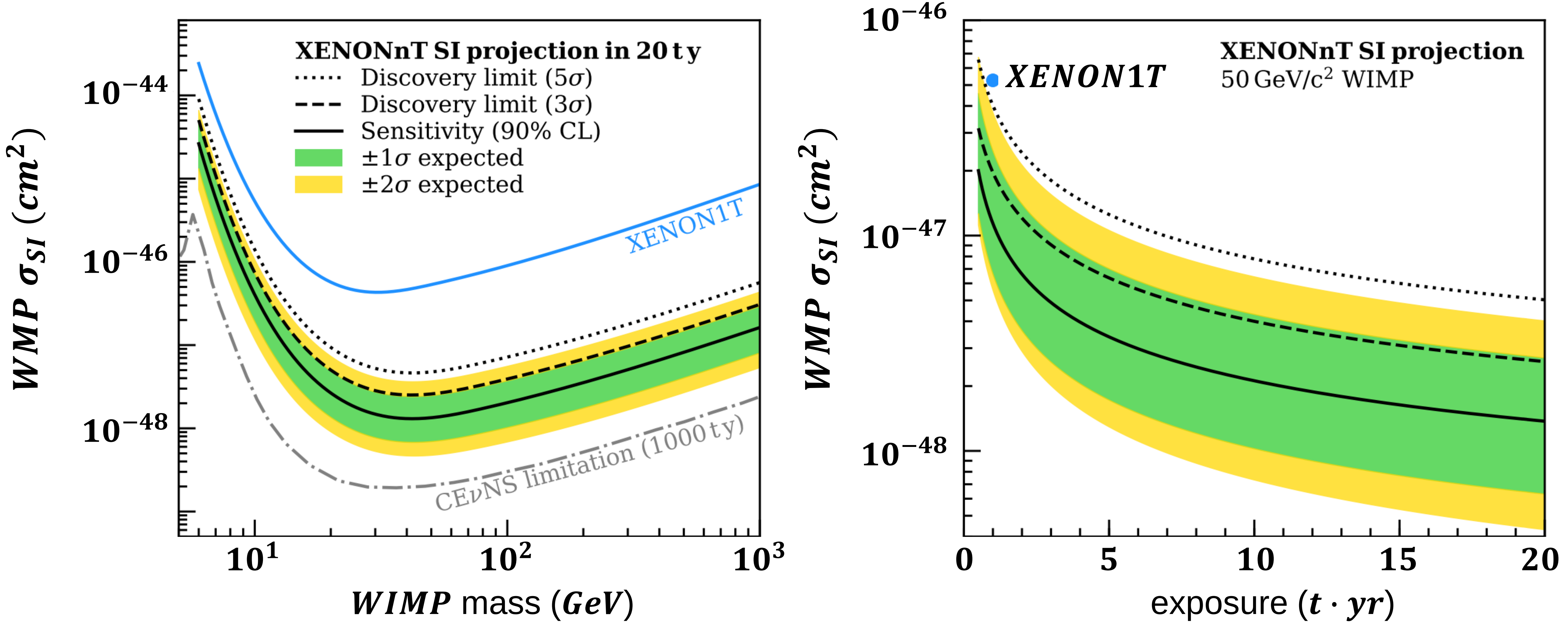
  - extremely low **background** from $n´s$





$XENONnT$ experiment – projected sensitivity

- **Expected signal sensitivity / exclusion limit as function of exposure $m \cdot t$**



$DARWIN$* experiment: the ´ultimate´ DM – search

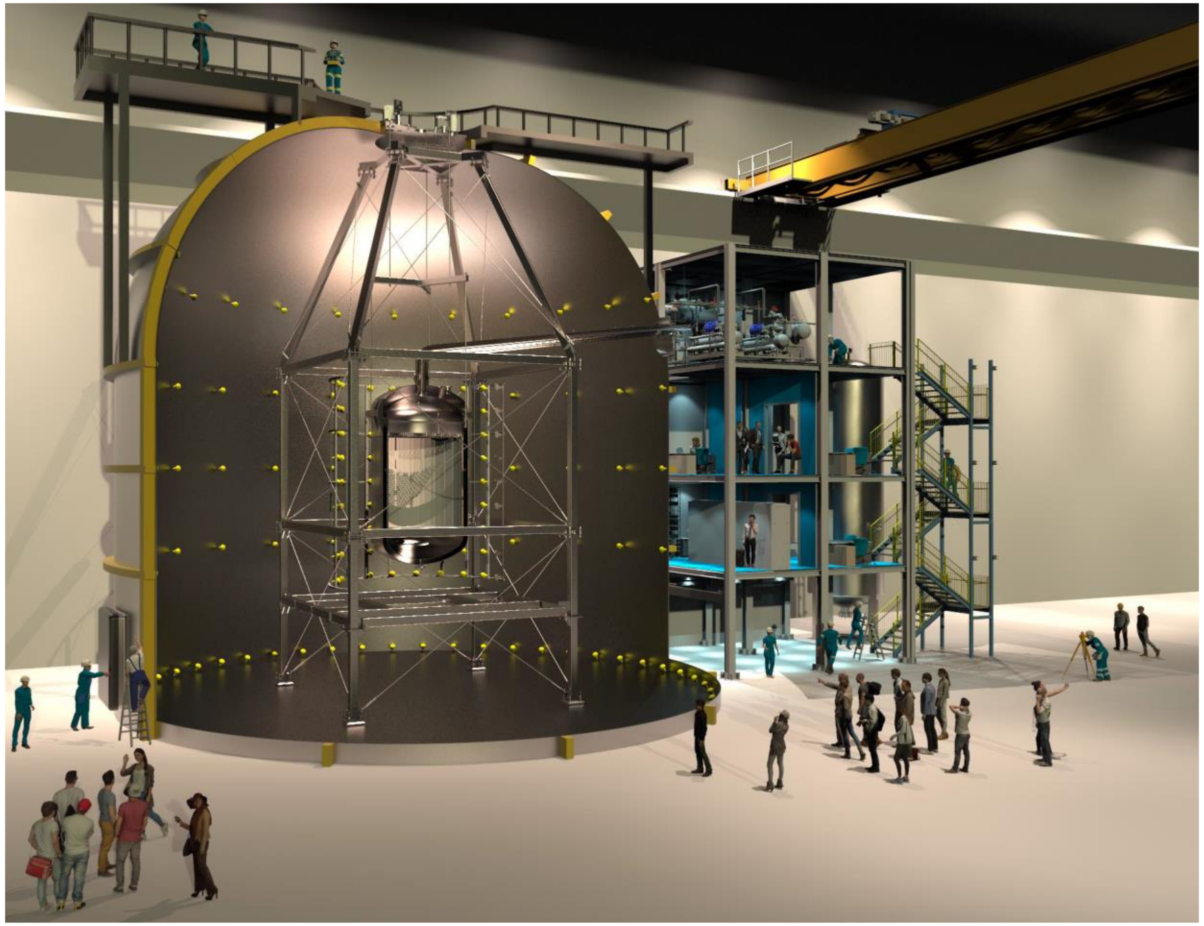
■ **Mission: going down into the neutrino floor with a TPC of 50 t target mass**

- low–energy threshold $E_{thres,NR} = 4\ keV$

- **focus: extremely low background level** from intrinsic & external sources

- remaining: equal contributions from **solar $\nu´s$ & ^{222}Rn**

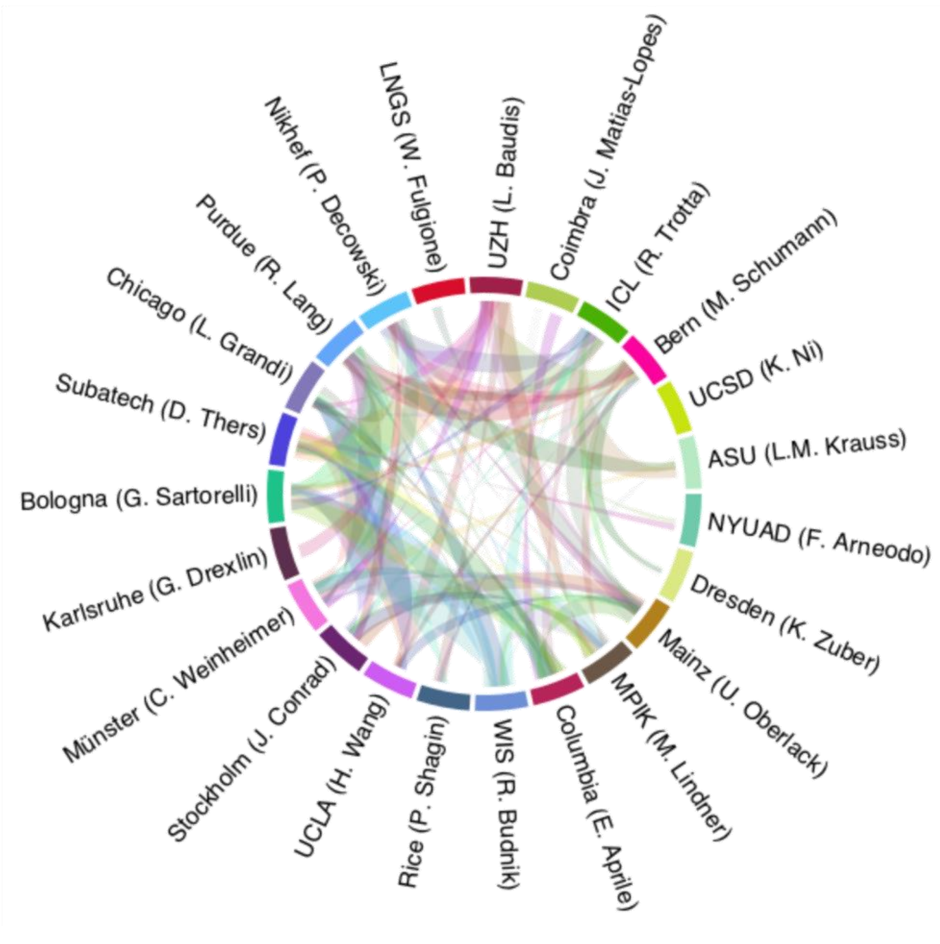
- many other physics channels:
  - search for $0\nu\beta\beta$
  - astrophysical $\nu´s$
  - ...



*DARk matter WImp search with liquid xeno$N$

$DARWIN$ – site at $LNGS$ & internat. collaboration

- A strong team at the ideal underground laboratory



CERN Courier March 2017

Dark-matter searches

Testing WIMPs to destruction

A surface building at Gran Sasso National Laboratory in Italy, below which lies a network of caverns shielded from cosmic radiation.

The DARWIN observatory to be built at Gran Sasso in the mid-2020s promises to be the ultimate dark-matter detector, probing the WIMP paradigm to its limit.

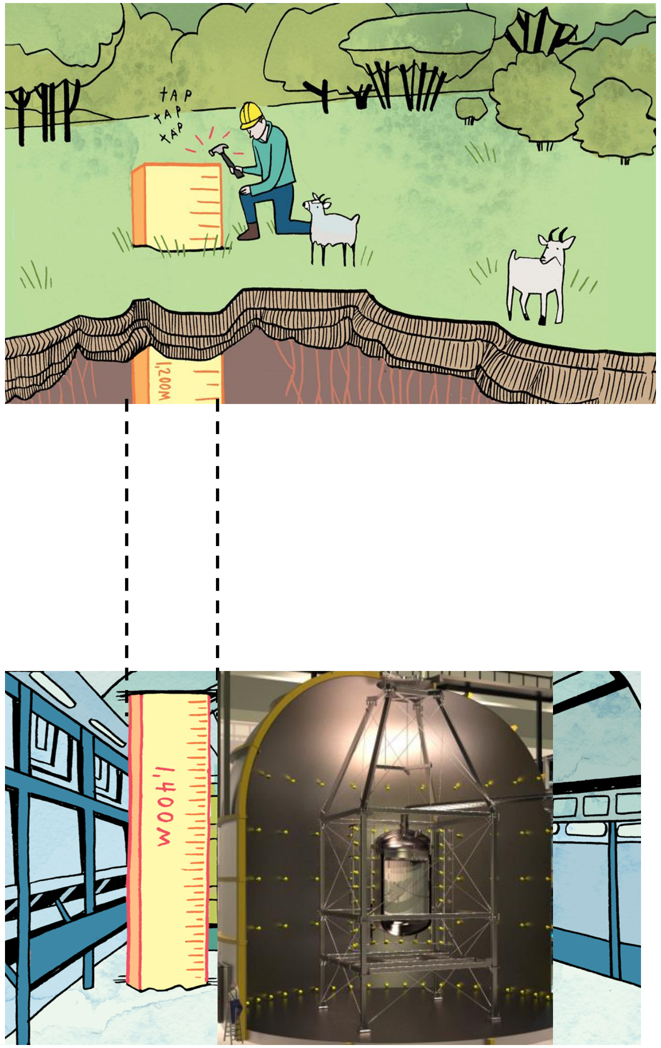
Dark matter is one of the greatest mysteries of our cosmos. More than 80 years after its postulation in modern form by the Swiss–American astronomer Fritz Zwicky, the existence of a new unseen form of matter in our universe is established beyond doubt. Dark matter is not just the gravitational glue that holds together galaxies, galaxy clusters and structures on the largest cosmological scales. Over the past few decades it has become clear that dark matter is also vital to explain the observed fluctuations in cosmic-microwave-background radiation and the growth of structures that began from these primordial density fluctuations in the early universe. Yet despite overwhelming evidence, its existence is inferred only indirectly via its gravitational pull on luminous matter. As of today, we lack the answer to the most fundamental questions: what is dark matter made of and what is its true nature?

DARWIN, the ultimate dark-matter detector using the noble element xenon in liquid form, will be in a unique position to address these fundamental questions. Currently in the design and R&D phase, DARWIN will be constructed at the Gran Sasso National Laboratory (LNGS) in Italy and is scheduled to carry out its first physics runs from 2024. The DARWIN consortium is growing, and currently consists of about 150 scientists from 26 institutions in 11 countries.

Worldwide search

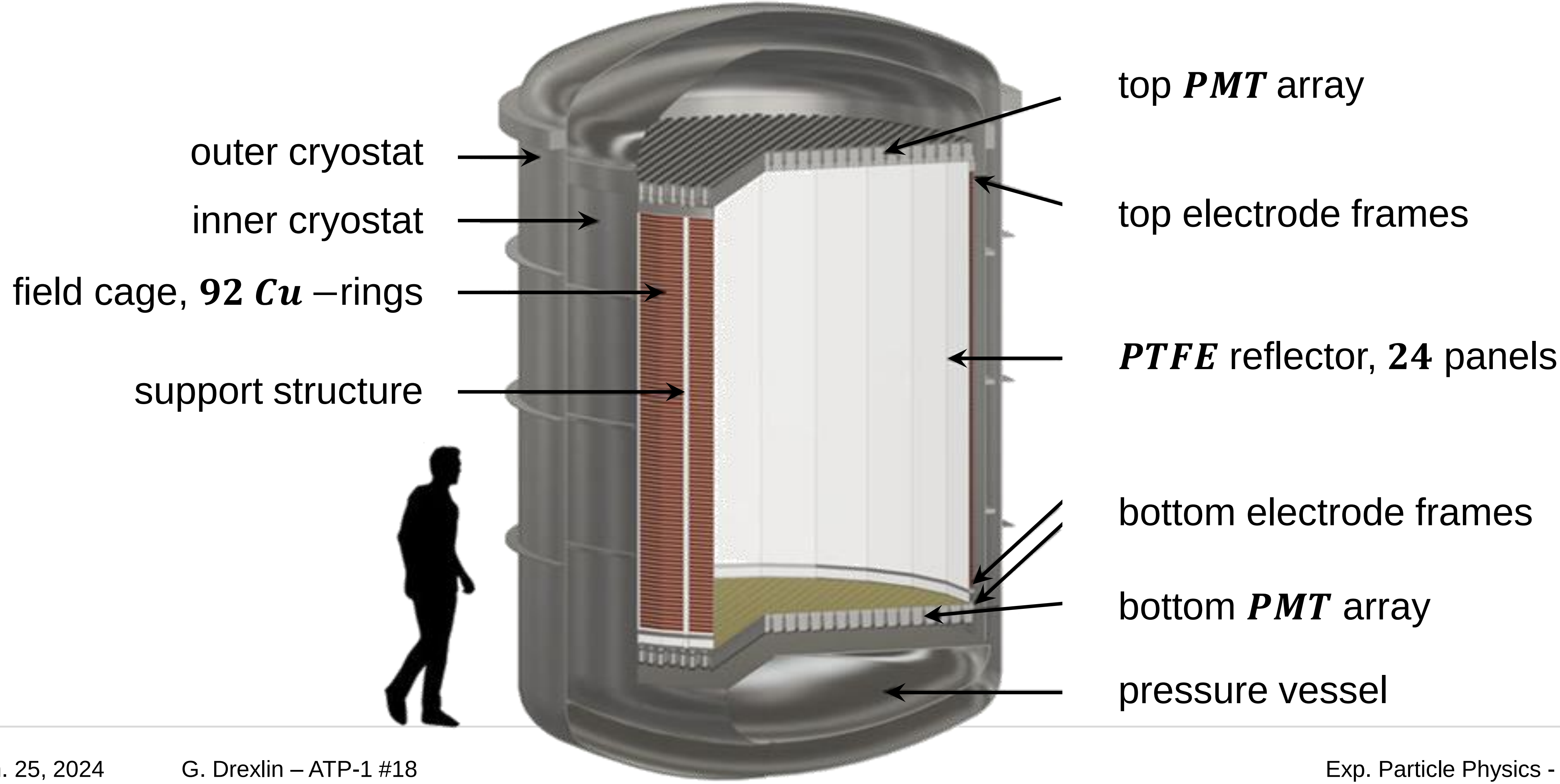
The particles described by the Standard Model of particle physics are unable to account for dark matter. Although neutrinos, the only elementary particles that do not interact with photons, would be ideal candidates, they are much too light and do not form the observed large-scale structures. Dark matter could, however, be made of new elementary particles that were born in the young and energetic universe. Such particles would carry no electric or colour charge, would be either stable or very long-lived and, similar to neutrinos, would interact only feebly (if at all) with known matter via new fundamental forces. Theories beyond the Standard Model predict a wealth of viable dark-matter candidates. The most ▷

1



$DARWIN$ – $design$ of the $xenon\ TPC$

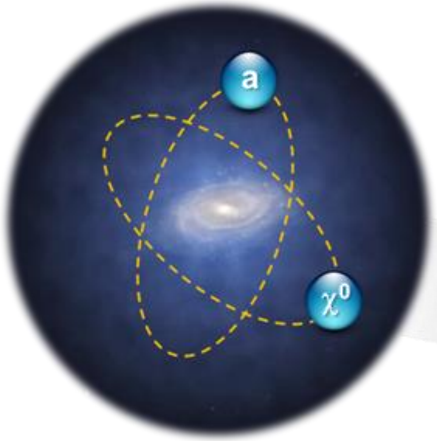
- **Total xenon inventory: $50\ t$ – inside the TPC: $40\ t$**



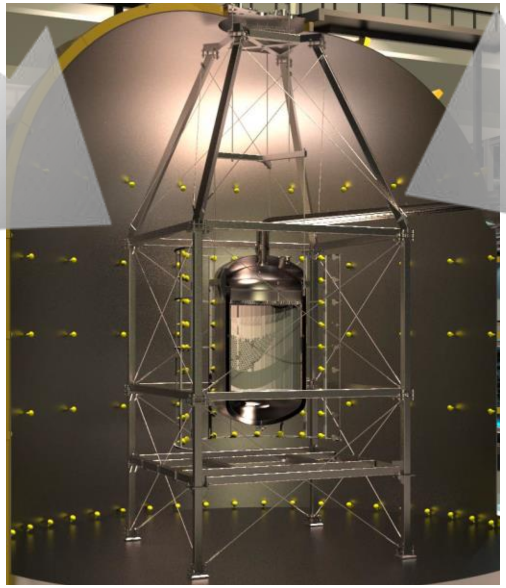
DARWIN experiment – a broad mission portfolio

- **Searching for *WIMPs* and other rare processes in astrophysics**

WIMPs* & *ALPs
(galactic halo)

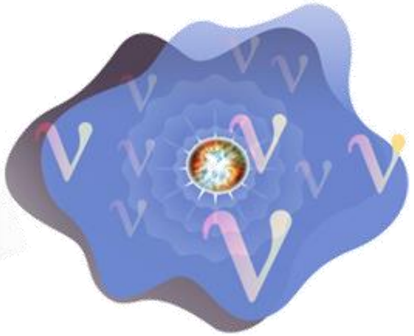


search for $\mathbf{0\nu\beta\beta}$



solar $\boldsymbol{pp-\nu's}$
$\boldsymbol{axions}$

supernova $\boldsymbol{\nu's}$



planned ***DARWIN*** exposure: $\mathbf{M \cdot t = 200\,t \cdot yr}$

$DARWIN$ – expected nuclear recoil spectra

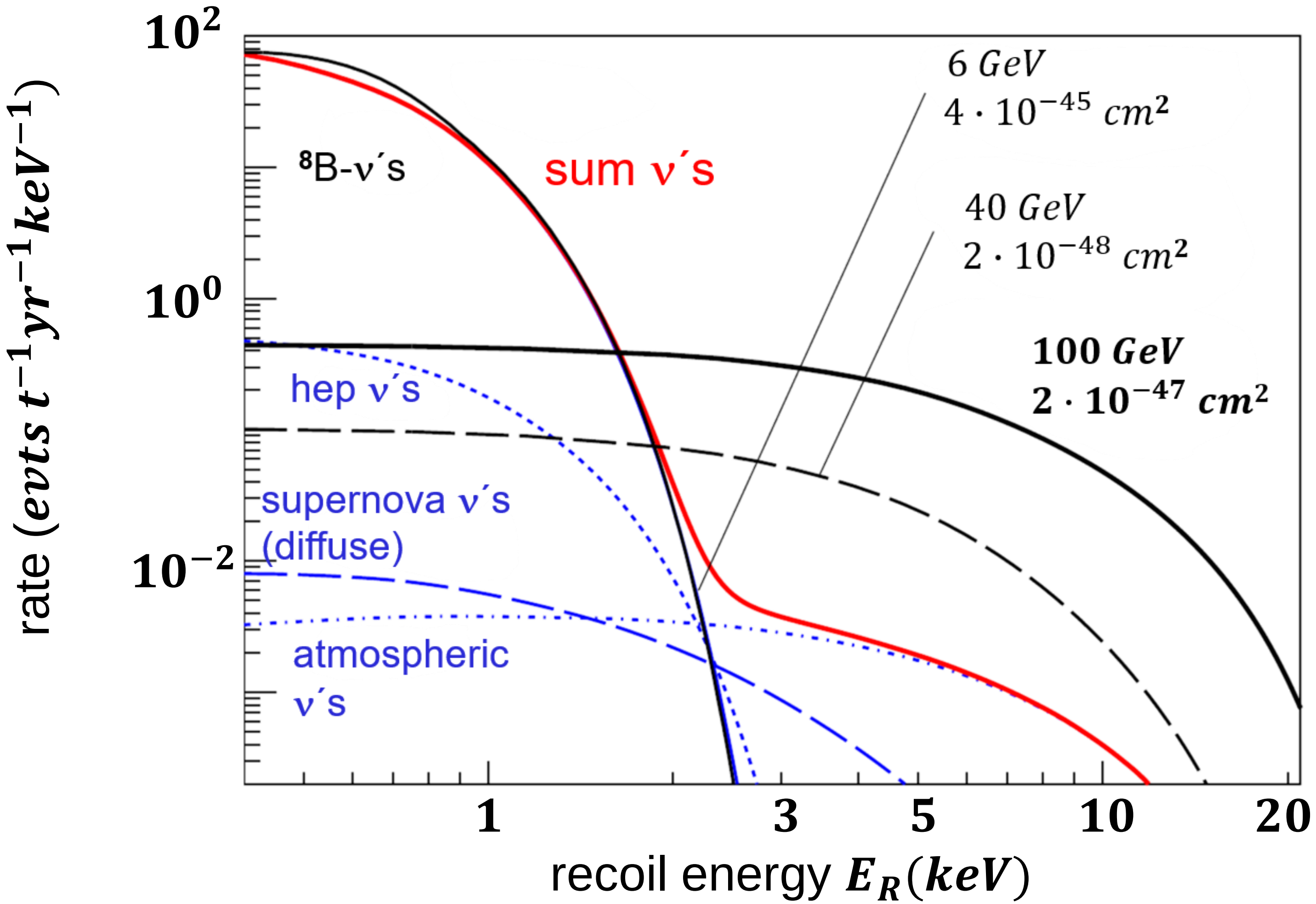
Karlsruhe Institute of Technology

- **Comparison of $WIMP$ spectra to astrophysical neutrinos**

- compare a $\mathbf{6}\ GeV\ WIMP$
  with **solar neutrinos** (^8B) :
  ⇨ identical recoil spectra

- compare a $\mathbf{100}\ GeV\ WIMP$
  with **atmospheric neutrinos**:
  ⇨ identical recoil spectra

- **neutrino floor as the ultimate barrier in direct DM searches**



$DARWIN$ – expected $WIMP$ sensitivity

Karlsruhe Institute of Technology

- Comparison of previous, present & future direct searches for $WIMPs$

- **larger masses**: sensitivity to very small $WIMP$ cross–sections σ_{SI}

- **lower thresholds**: sensitivity to very low $WIMP$ masses