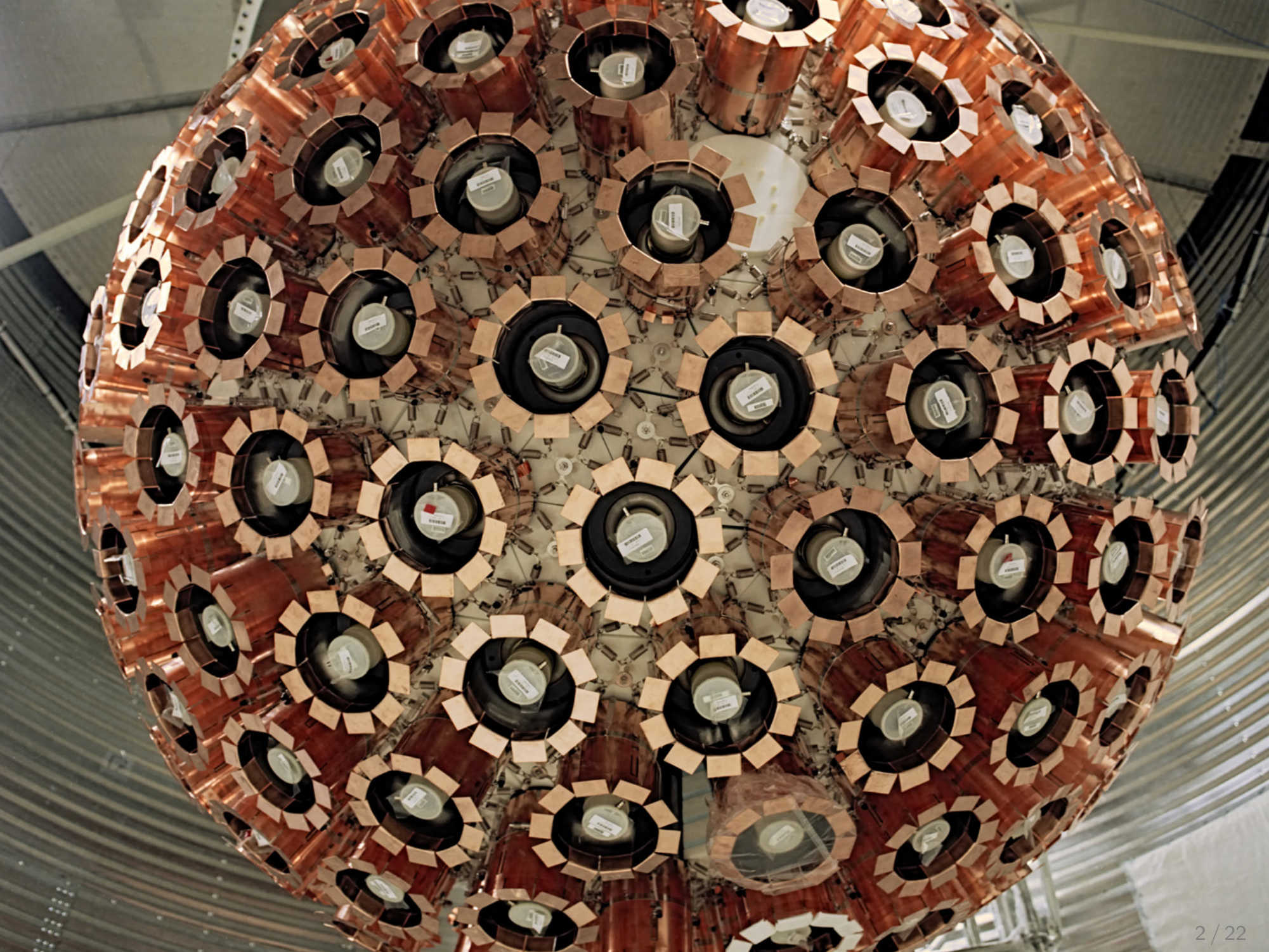
CLEANING DATA FOR DARK MATTER DETECTION

CAP CONFERENCE, 2017
KINGSTON, ON.

ROB STAINFORTH
CARLETON UNIVERSITY



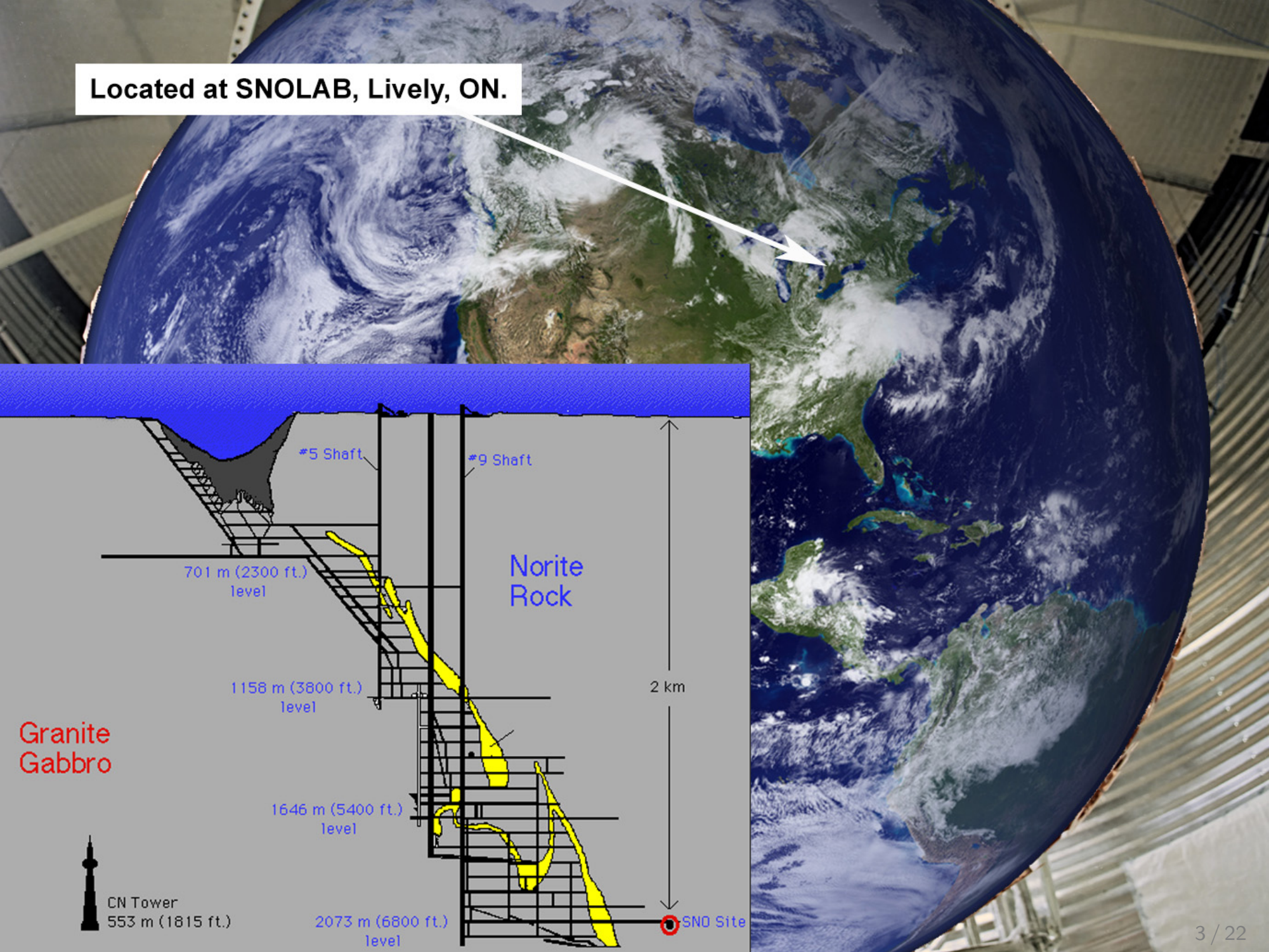

Located at SNOLAB, Lively, ON.
#5 Shaft
#9 Shaft
701 m (2300 ft.) level
Norite Rock
1158 m (3800 ft.) level
2 km
Granite Gabbro
1646 m (5400 ft.) level
CN Tower
553 m (1815 ft.)
2073 m (6800 ft.) level
SNO Site

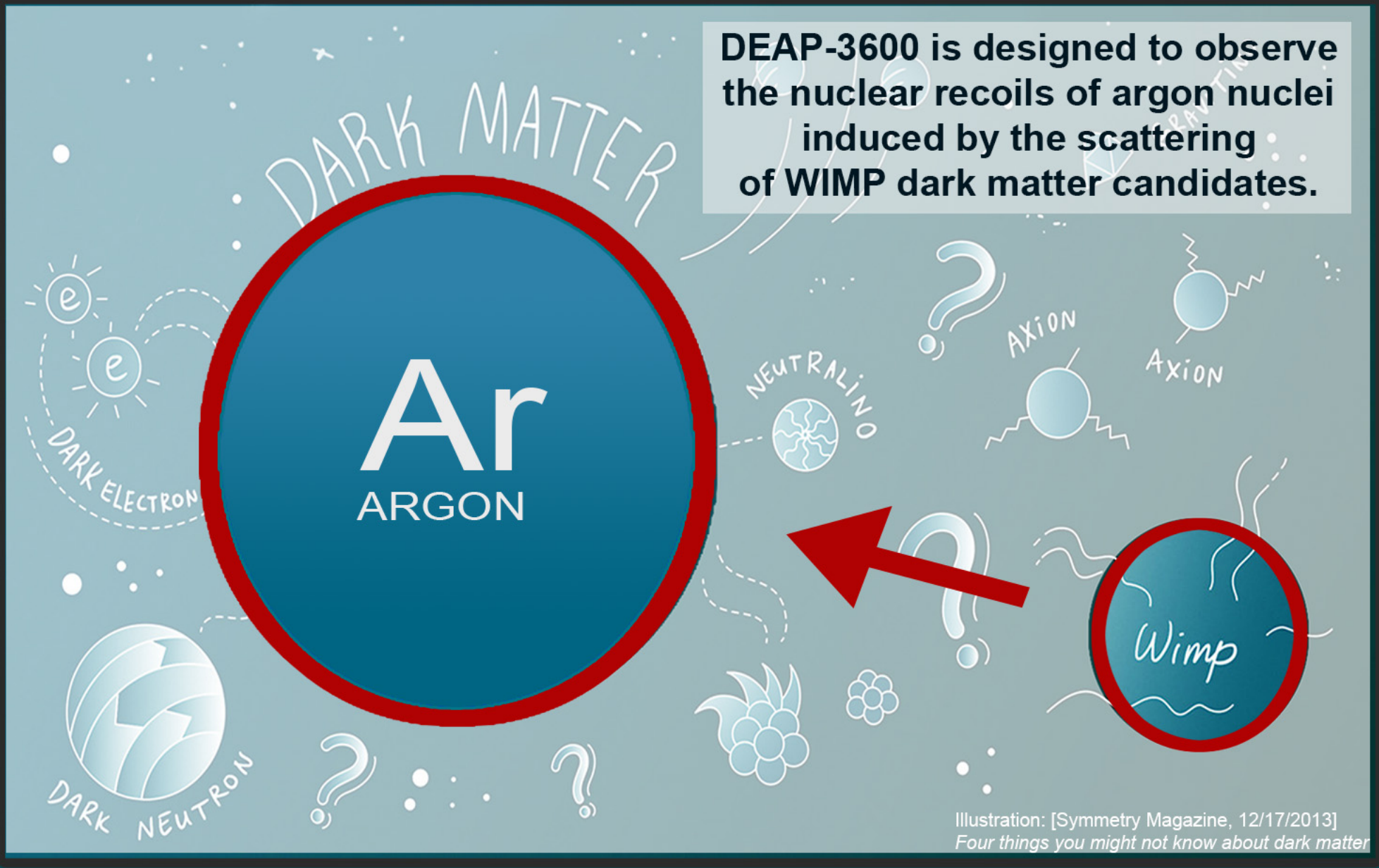
Illustration: [Symmetry Magazine, 12/17/2013]
Four things you might not know about dark matter

Primordial black holes [arXiv:0711.5006 [hep-ph]], axions and other similar particles:

- **[Phys. Rev.D16, 1791 (1977)]**
- **[http://pdg.lbl.gov/2016/reviews/rpp2016-rev-axions.pdf]**

Sterile neutrinos: [arXiv:1702.08430 [hep-ph]]
WIMPS: [Phys. Rprt. Vol. 267, I5–6, 1996, pp. 195-373]

DEAP-3600 is designed to observe the nuclear recoils of argon nuclei induced by the scattering of WIMP dark matter candidates.



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Detector Schematic

Inner acrylic vessel filled with ~3.3 tonnes of liquid argon

χ = Dark Matter (WIMP)

χ + ^{40}Ar

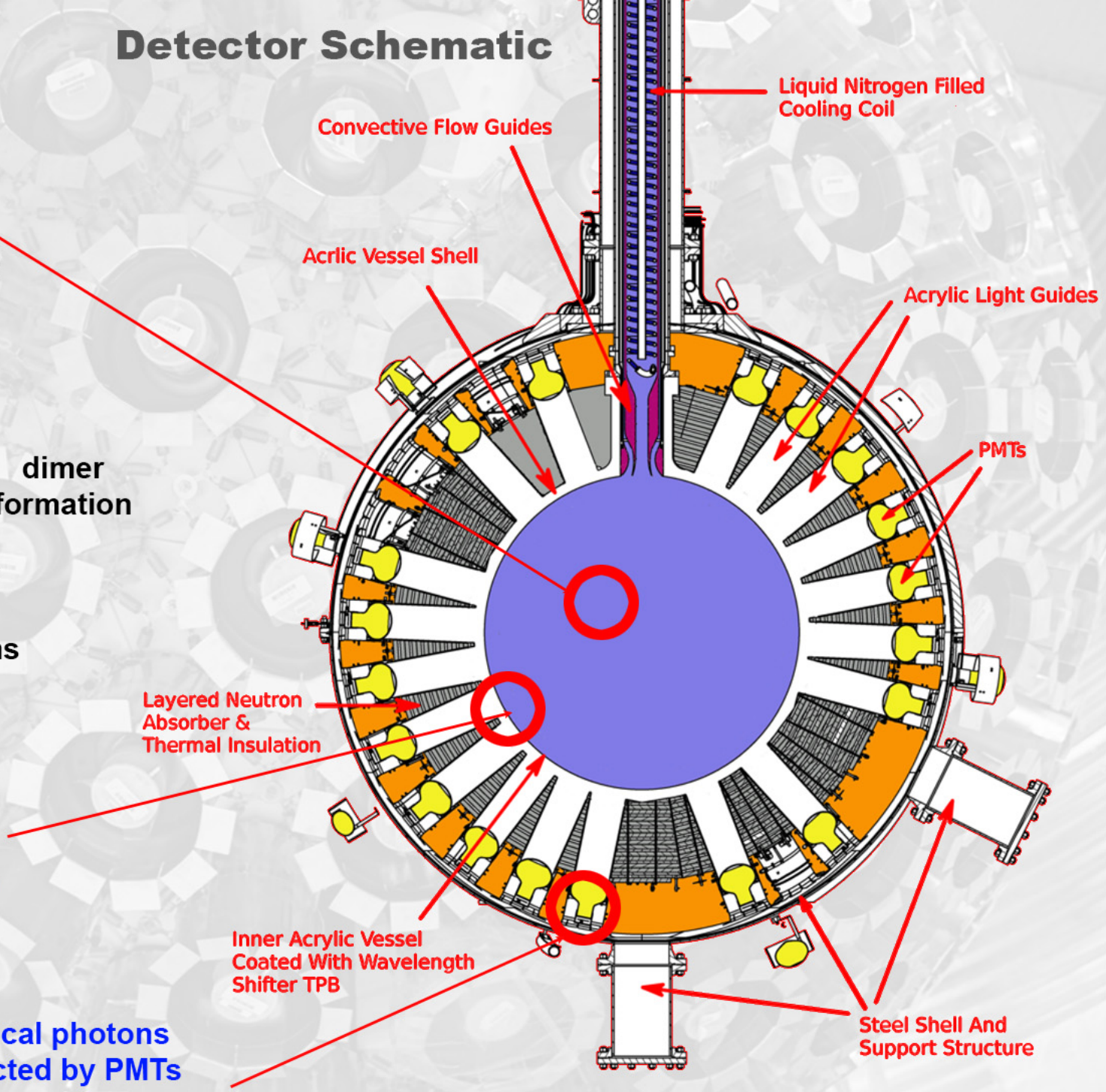
dimer formation

Ar^{2*}

γ = Ultra-violet photons (Argon scintillation)

UV -> Optical wavelength via 'wavelength shifting' in TPB.

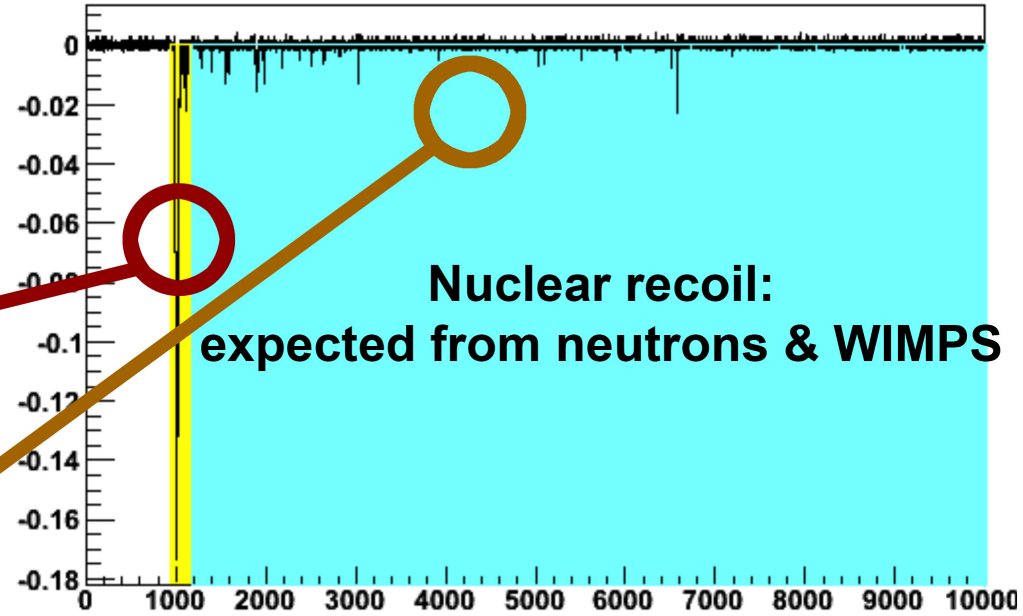
Optical photons detected by PMTs

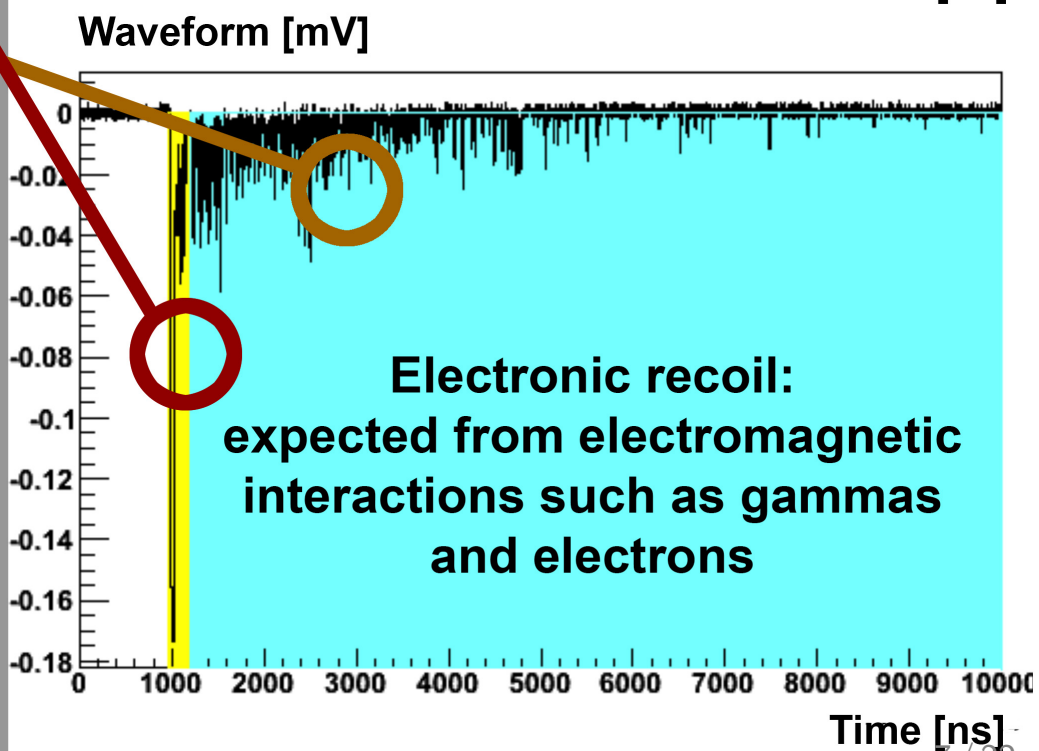


The time profile of Argon scintillation light differs based on the type of ionising radiation that caused it.

Prompt signal

Late emitted light

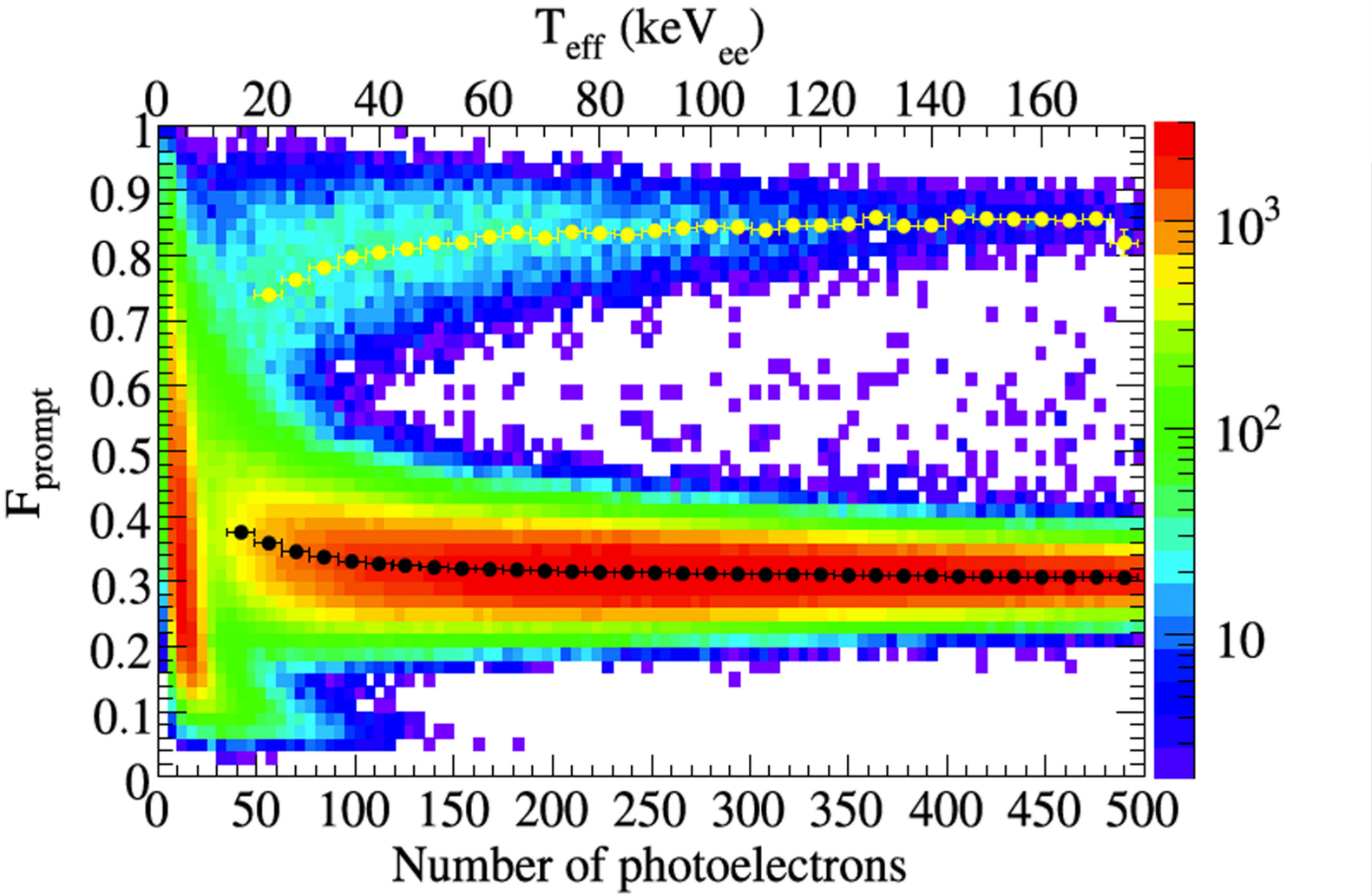




Pulse Shape Discrimination Variable

$$\frac{\text{Prompt signal}}{\text{Prompt signal} + \text{Late emitted light}}$$

Fprompt

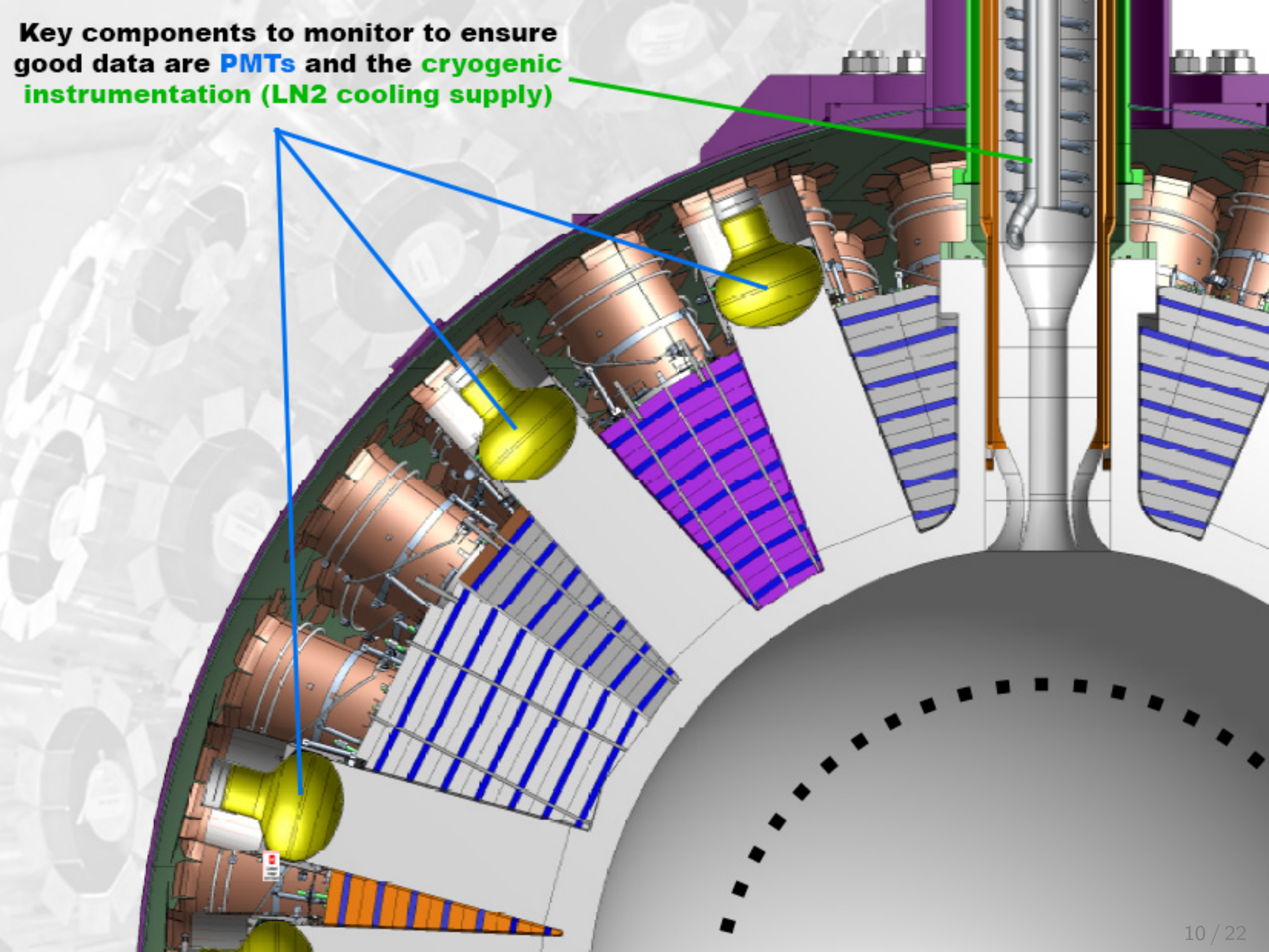


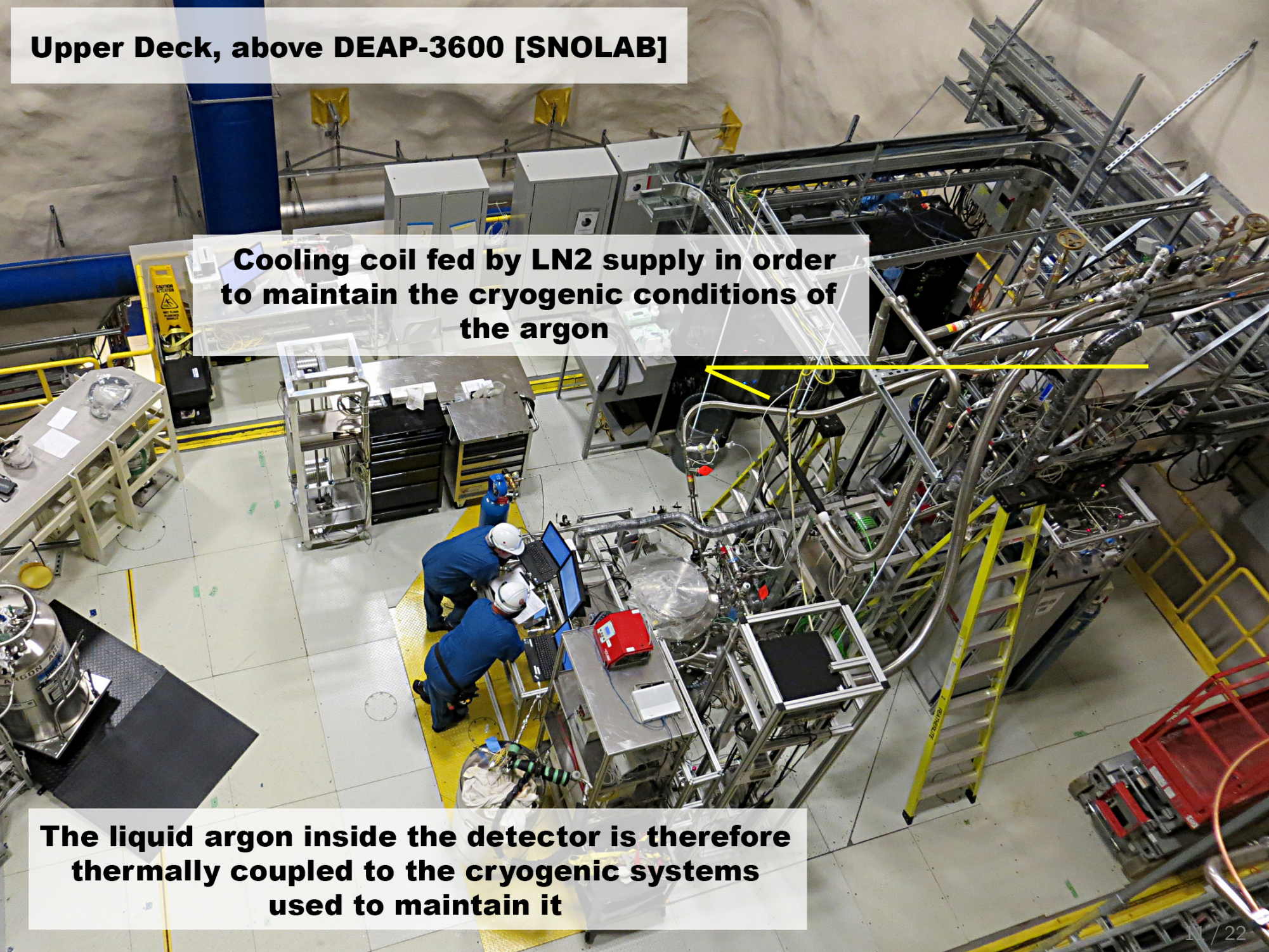
Demonstrated in **DEAP-1**:
Fprompt versus energy distribution for neutrons and gamma-rays from an Am-Be calibration source.

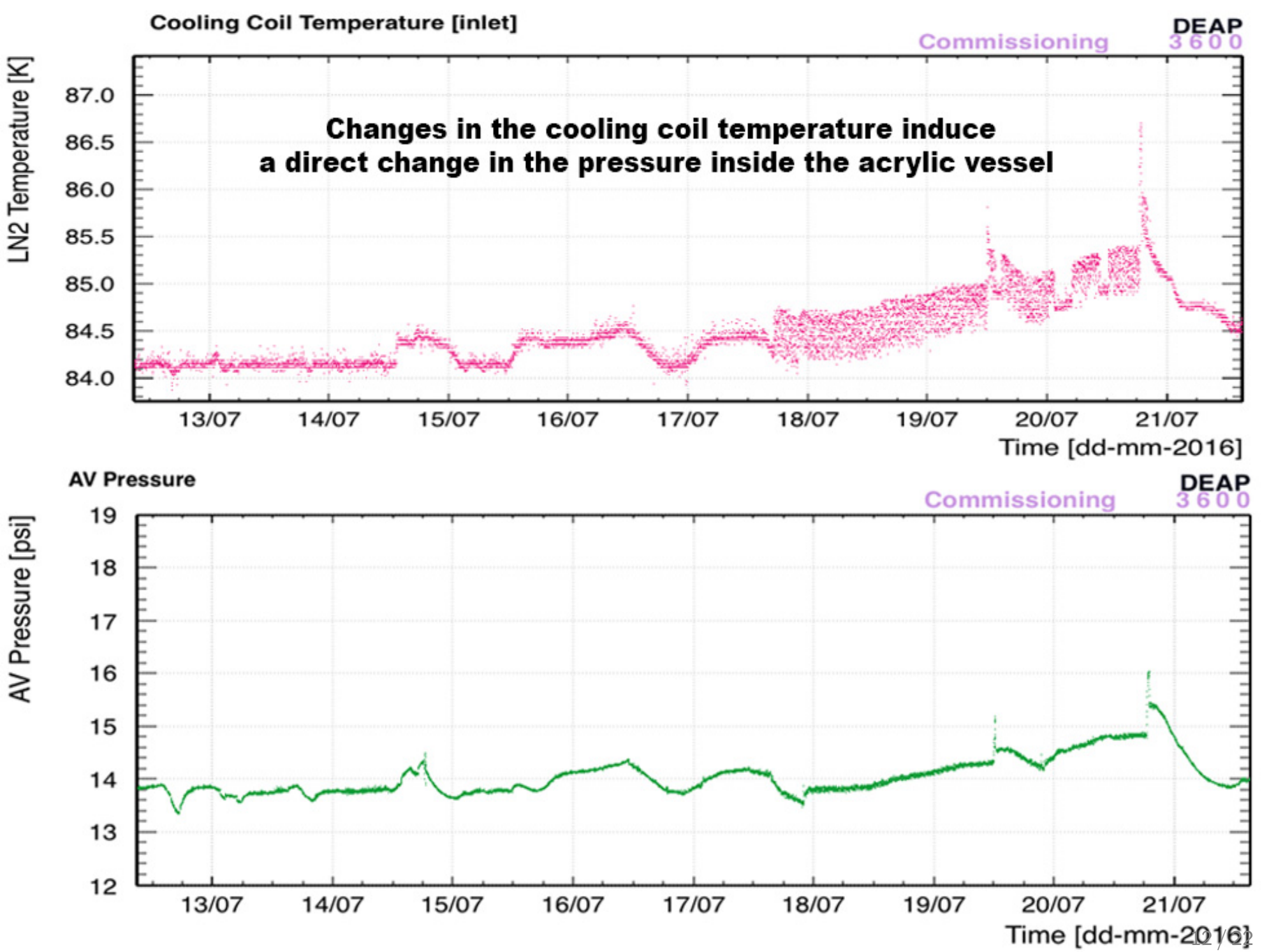
[Astroparticle Physics 85 (2016) 1-23]

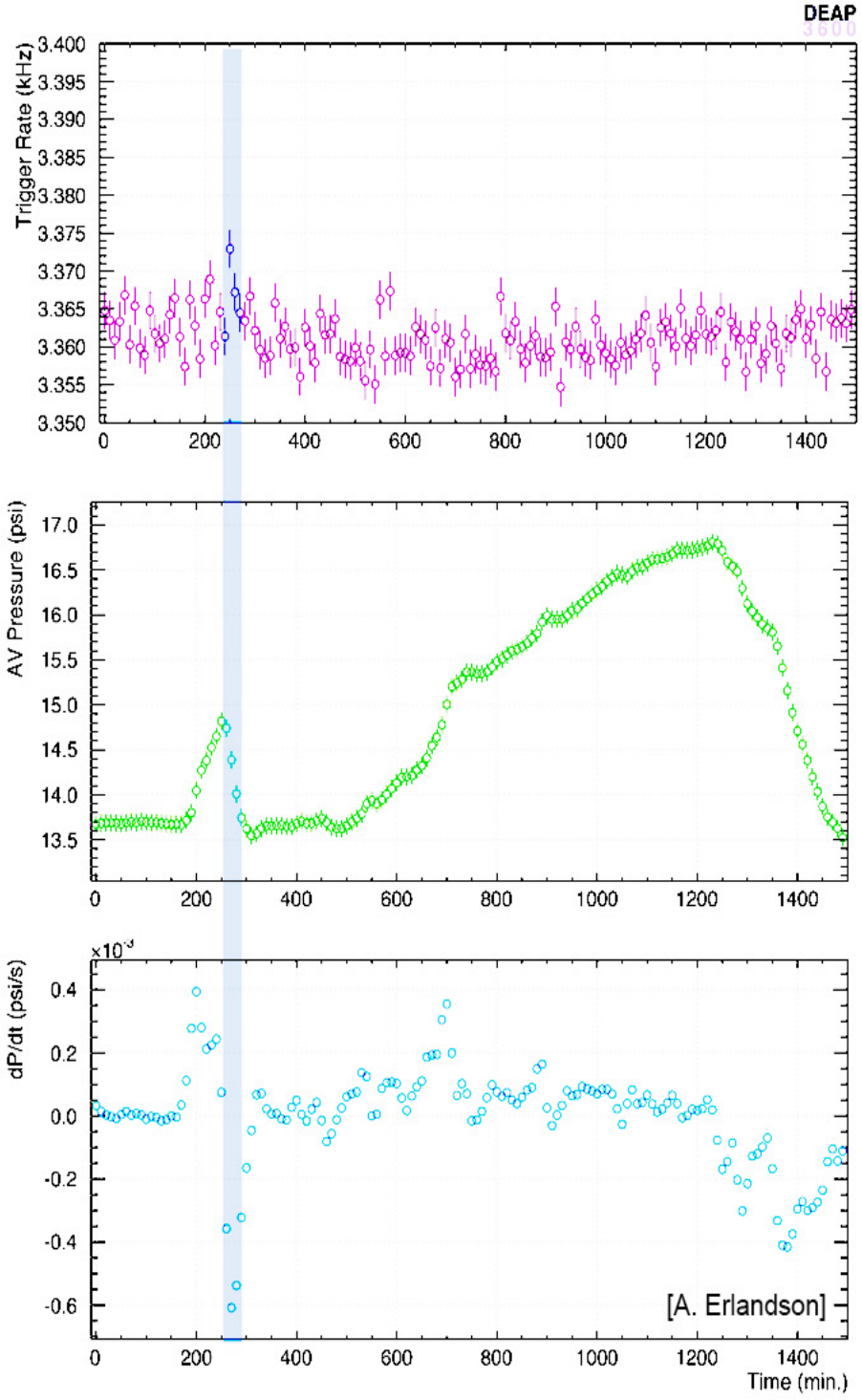
types of particles!


Cleaning data for a dark matter result is the natural extension to the design & construction phase of the experiment, leading into a physics analysis
Design: Stringent selection of detector materials subjected to radio-assays
Construction: Resurfacing of acrylic vessel to minimise surface radon contamination following exposure to emanated radon from mine walls
[Details in upcoming detector paper, 2017]
Data Quality: Selection of physics data based on low-level and auxillary detector information
[discussed here]
Analysis: Insitu measurement & mitigation of background events in data
[See talk by B. Lehnert]
DIRTY SIDE
CLEAN SIDE


Key components to monitor to ensure good data are PMTs and the cryogenic instrumentation (LN2 cooling supply)


Upper Deck, above DEAP-3600 [SNOLAB]
Cooling coil fed by LN2 supply in order to maintain the cryogenic conditions of the argon
The liquid argon inside the detector is therefore thermally coupled to the cryogenic systems used to maintain it


Cooling Coil Temperature [inlet]
DEAP
Commissioning
3600
LN2 Temperature [K]
87.0
86.5
86.0
85.5
85.0
84.5
84.0
Changes in the cooling coil temperature induce
a direct change in the pressure inside the acrylic vessel
13/07
14/07
15/07
16/07
17/07
18/07
19/07
20/07
21/07
Time [dd-mm-2016]
AV Pressure
DEAP
Commissioning
3600
AV Pressure [psi]
19
18
17
16
15
14
13
12
13/07
14/07
15/07
16/07
17/07
18/07
19/07
20/07
21/07
Time [dd-mm-2016]



Dominant contribution to the global trigger rate is from the beta-decay of Ar39 nuclei:

1.01 +/ 0.1 Bq / kg
[WARP collaboration]
[Nucl.Instrum.Meth. A574 (2007)]

upper-left: raw trigger rate ~ 3.3 kHz [during commissioning]
middle-left: AV pressure
bottom-left: AV pressure time-derivative

Fast changes in the AV pressure increase the global trigger rate

Nature of additional events under investigation (see poster by A. Erlandson)

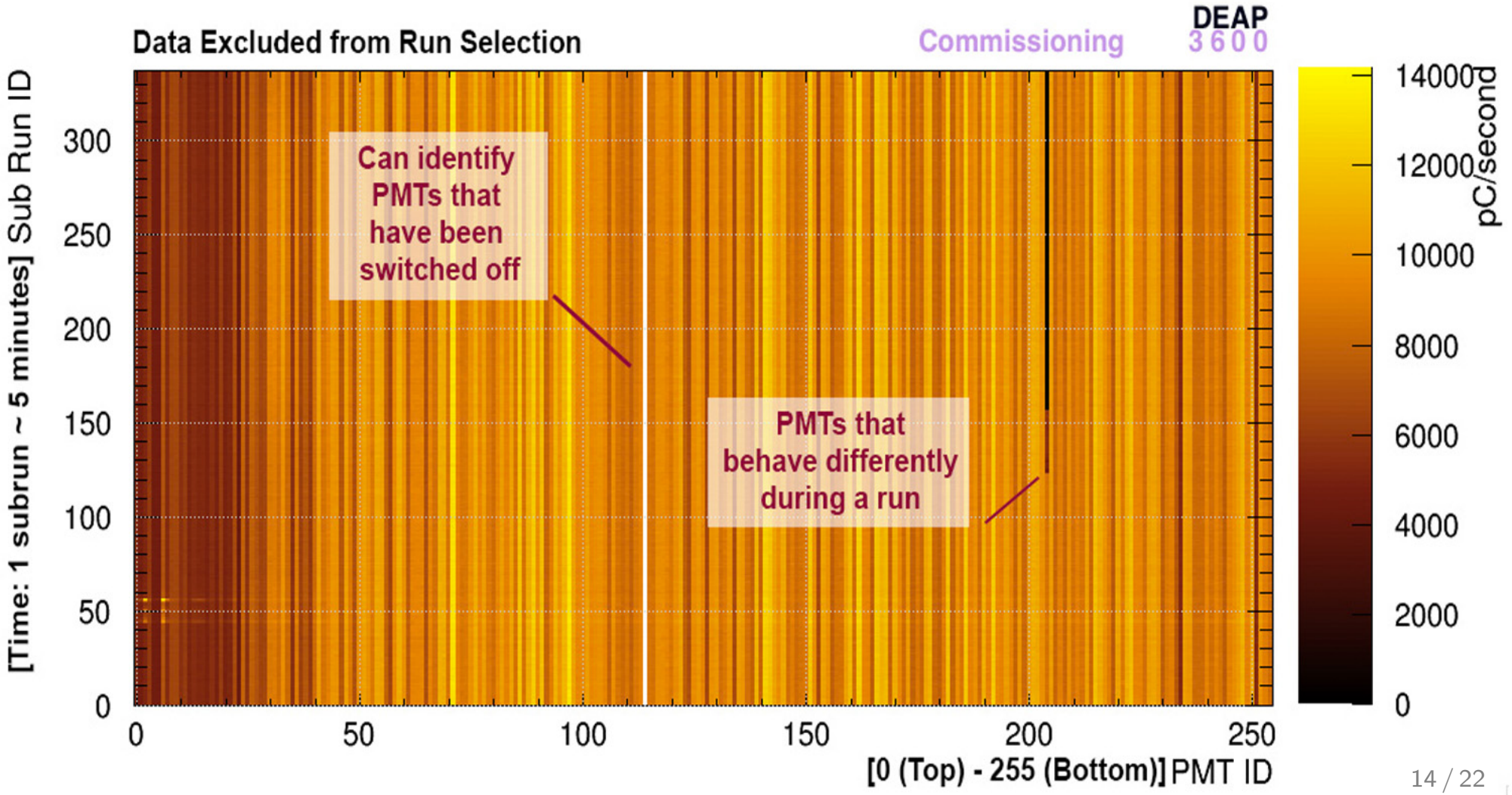
Using this AV pressure information, data can be excluded from run selection

DEAP-3600 contains 255 Hamamatsu R5912 photomultiplier tubes

[PMT paper submitted to JINST]

Regular optical calibration of the PMTs is performed
using an insitu fibre based light injection calibration system at 435 nm

Can also monitor the charge readout of the PMTs during data taking
to identify anomalous behaviour



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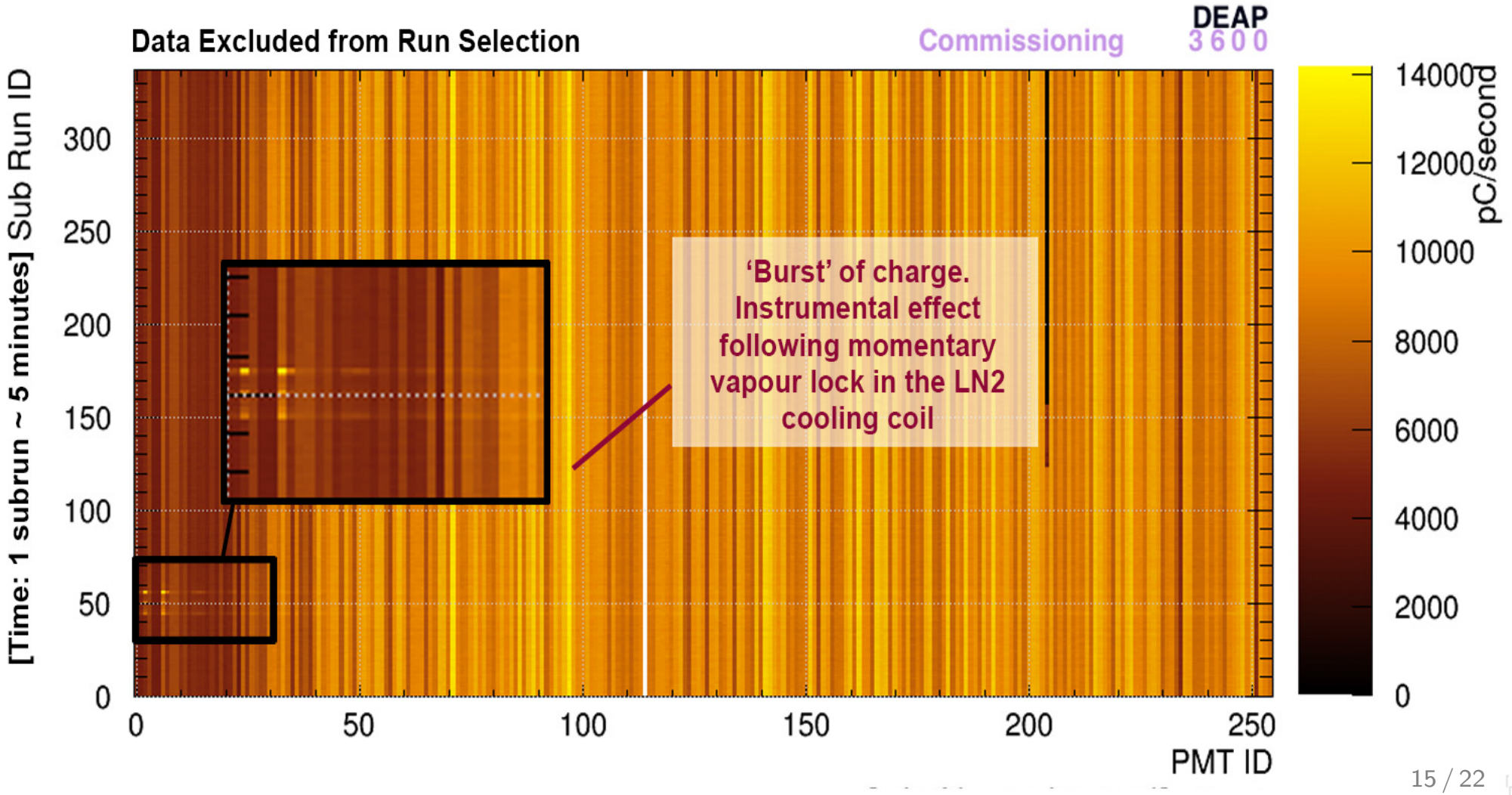

Once data is prepared for analysis, can begin to determine the exposure for a dark matter result. Consider the following formulation...

- Exposure, $T_{\text{exp.}}$ [kg days] defined as follows:

$$T_{\text{exp.}} = \tau \times \epsilon^{\text{fid.Vol.}}\left(\vec{r}\right) \times \mu_{\text{LAr}}\left(\text{DAQ}\right) \times \text{Acc.}\left(\vec{\psi}\right) \times \epsilon^{\text{fprompt}},$$

  - where;
  - τ: Livetime [days]. **data cleaning**
  - $\epsilon^{\text{fid.Vol.}}\left(\vec{r}_{\text{fit}}\right)$: Fiducial volume efficiency. The fraction of recoil-like events in the detector that are inside a parametric volume of radius $\vec{r}_{\text{fit}}$. **position rec.**
  - $\mu_{\text{LAr}}\left(\text{DAQ}\right)$: Livetime weighted average mass [kg] of liquid argon. Mass is inferred from the measured rate of Ar39 events. The rate is used to infer the mass from the activity. Implicit to this is the trigger efficiency. **energy rec., background, low-level**
  - $\text{Acc}\left(\vec{\psi}\right)$: Acceptance. Given events which reconstruct inside our fiducial volume, this is the fraction that survive a series of cuts, $\psi_1, \ldots \psi_n$. **all**
  - $\epsilon^{\text{fprompt}}$: FPrompt efficiency for nuclear recoils. **pulse-shape discrimination**

Once data is prepared for analysis, can begin to determine the exposure for a dark matter result. Consider the following formulation...

- Exposure, T_{exp} [kg days] defined as follows:

Determination of all terms in the exposure brings together all expertise of the collaboration
[expect first results soon]

Conclude here with a brief discussion of what the acceptance depends upon under this formulation

- where:
- τ: Livetime [days] data cleaning
- $\epsilon^{\text{fid.Vol.}}(\vec{r}_{\text{fit}})$: Fiducial volume efficiency. The fraction of recoil-like events in the detector that are inside a parametric volume of radius $\vec{r}_{\text{fit}}$. position rec.
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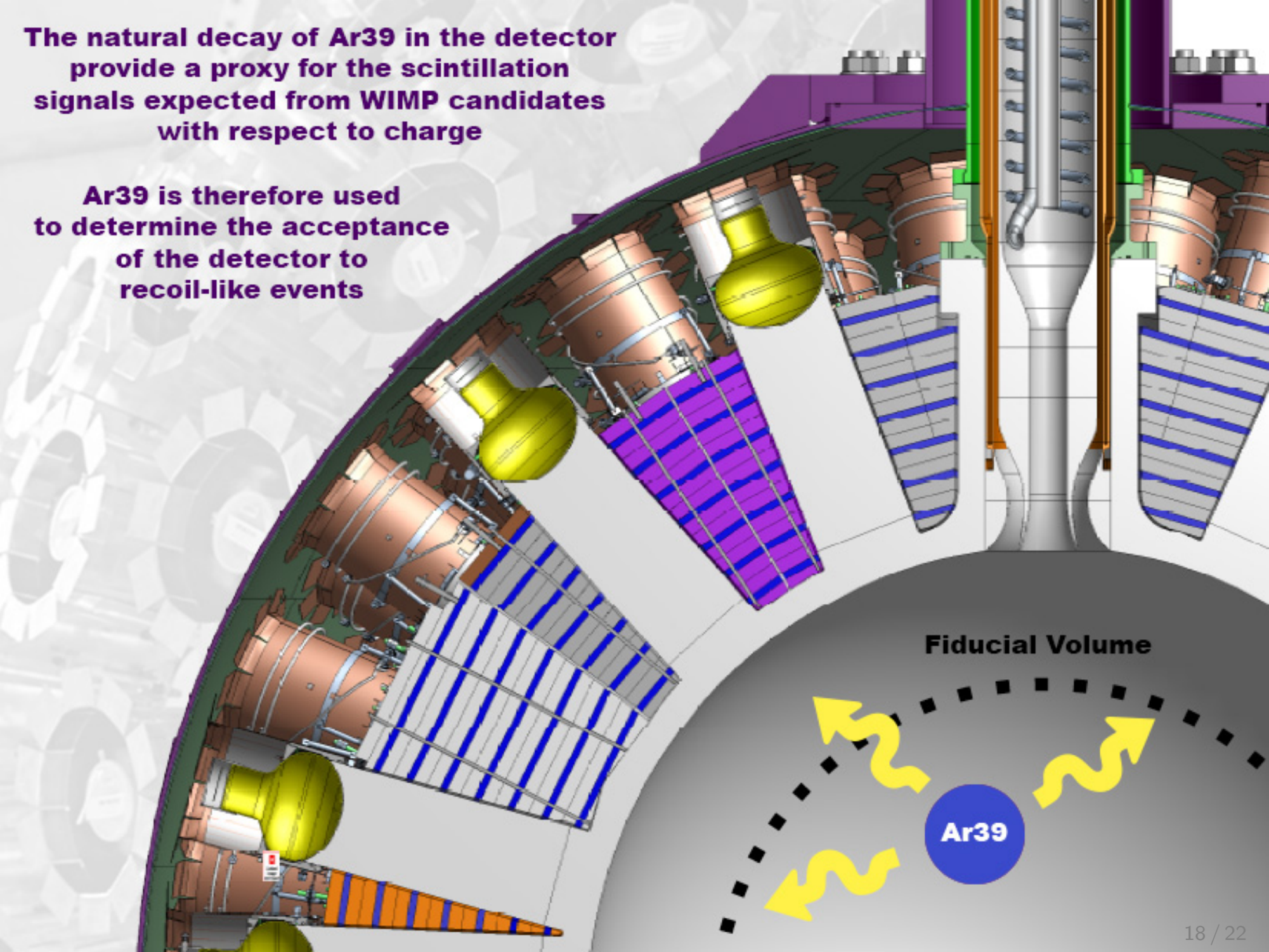
- $\epsilon^{\text{fprompt}}$: FPrompt efficiency for nuclear recoils. pulse-shape discrimination

The natural decay of Ar39 in the detector provide a proxy for the scintillation signals expected from WIMP candidates with respect to charge

Ar39 is therefore used to determine the acceptance of the detector to recoil-like events



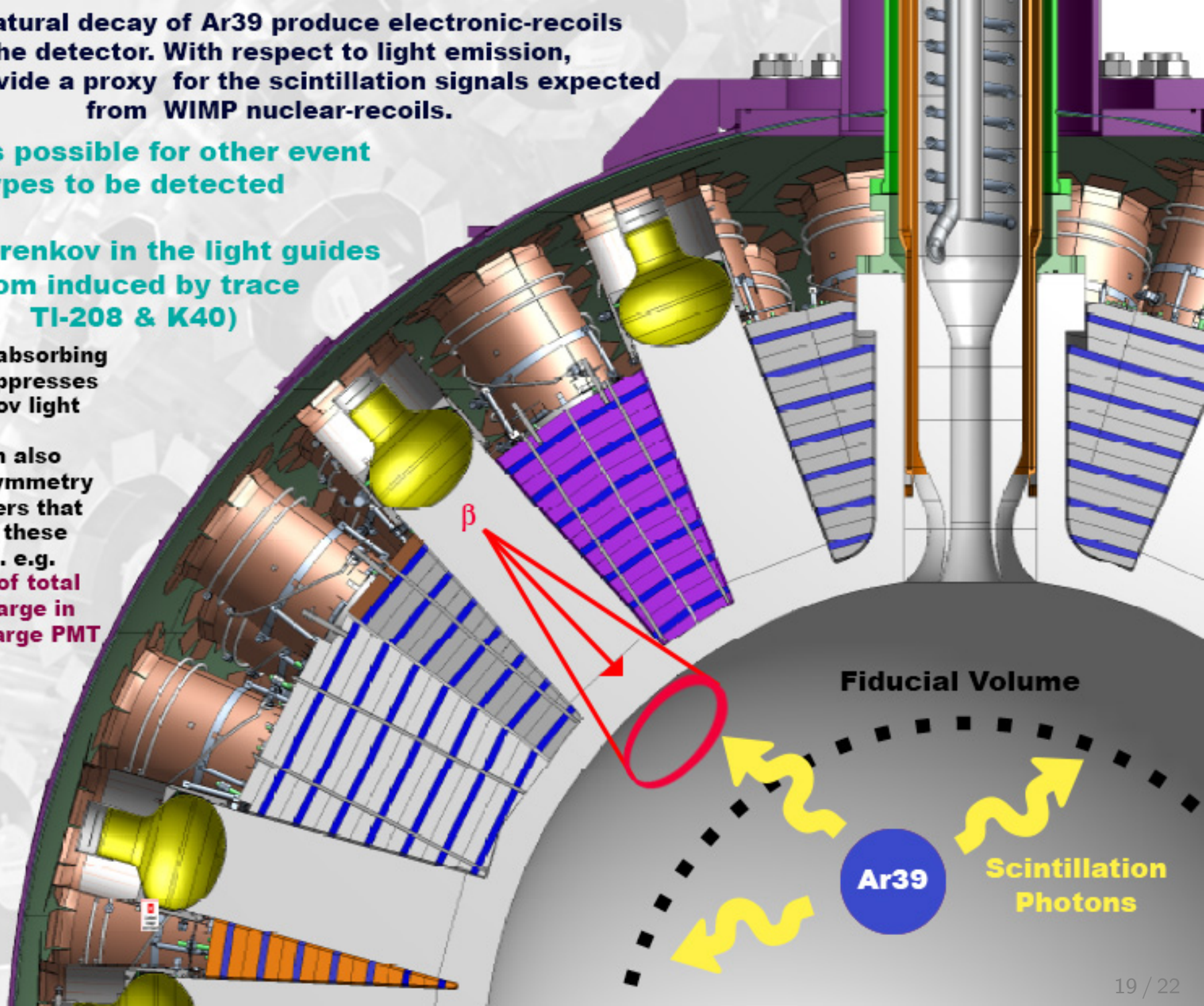
The natural decay of Ar39 produce electronic-recoils in the detector. With respect to light emission, these provide a proxy for the scintillation signals expected from WIMP nuclear-recoils.

But it is possible for other event types to be detected

e.g. Cherenkov in the light guides (from induced by trace Tl-208 & K40)

Use of UV absorbing acrylic suppresses Cherenkov light

But can also define asymmetry parameters that remove these events. e.g. fraction of total event charge in highest charge PMT



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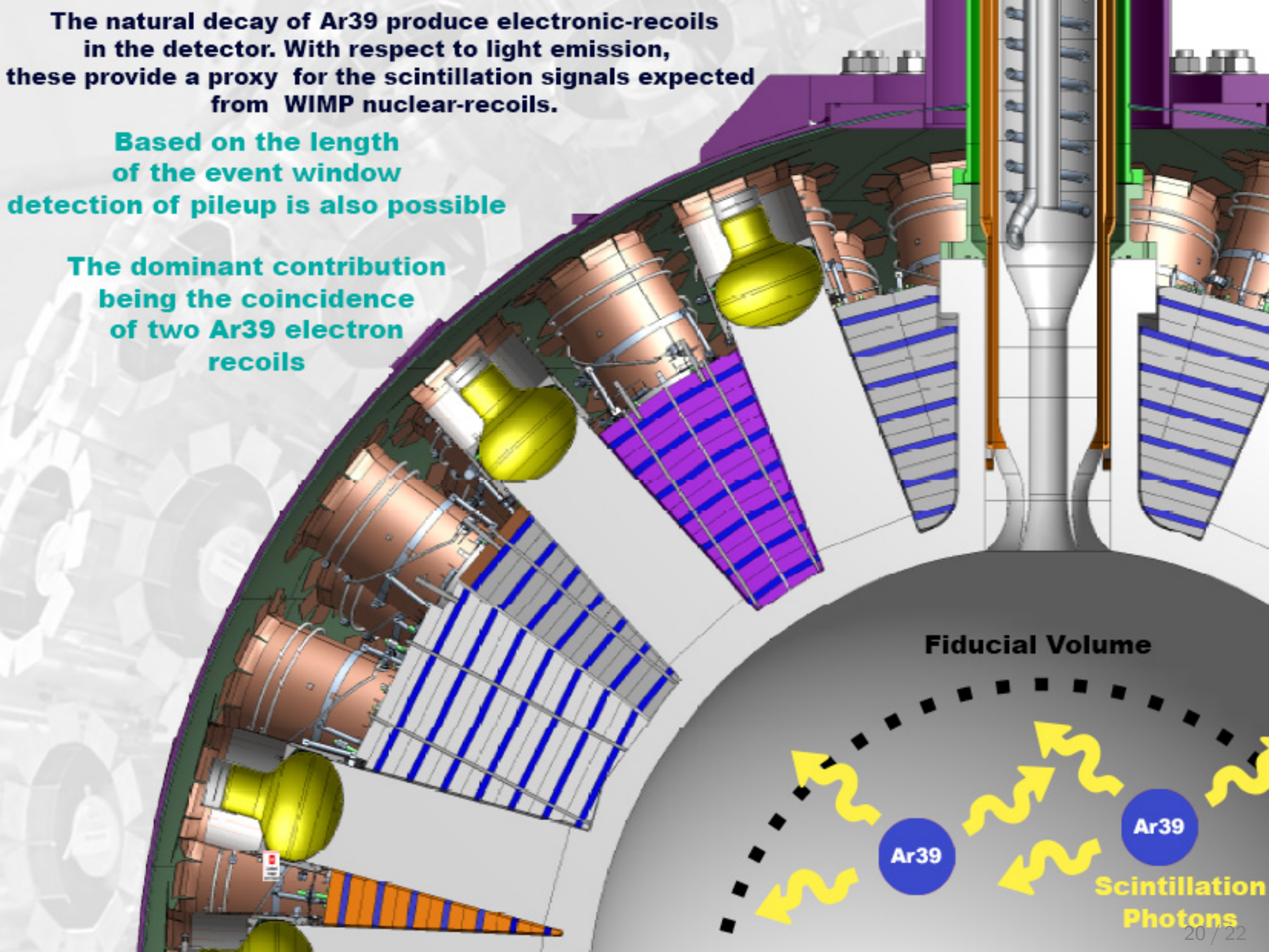
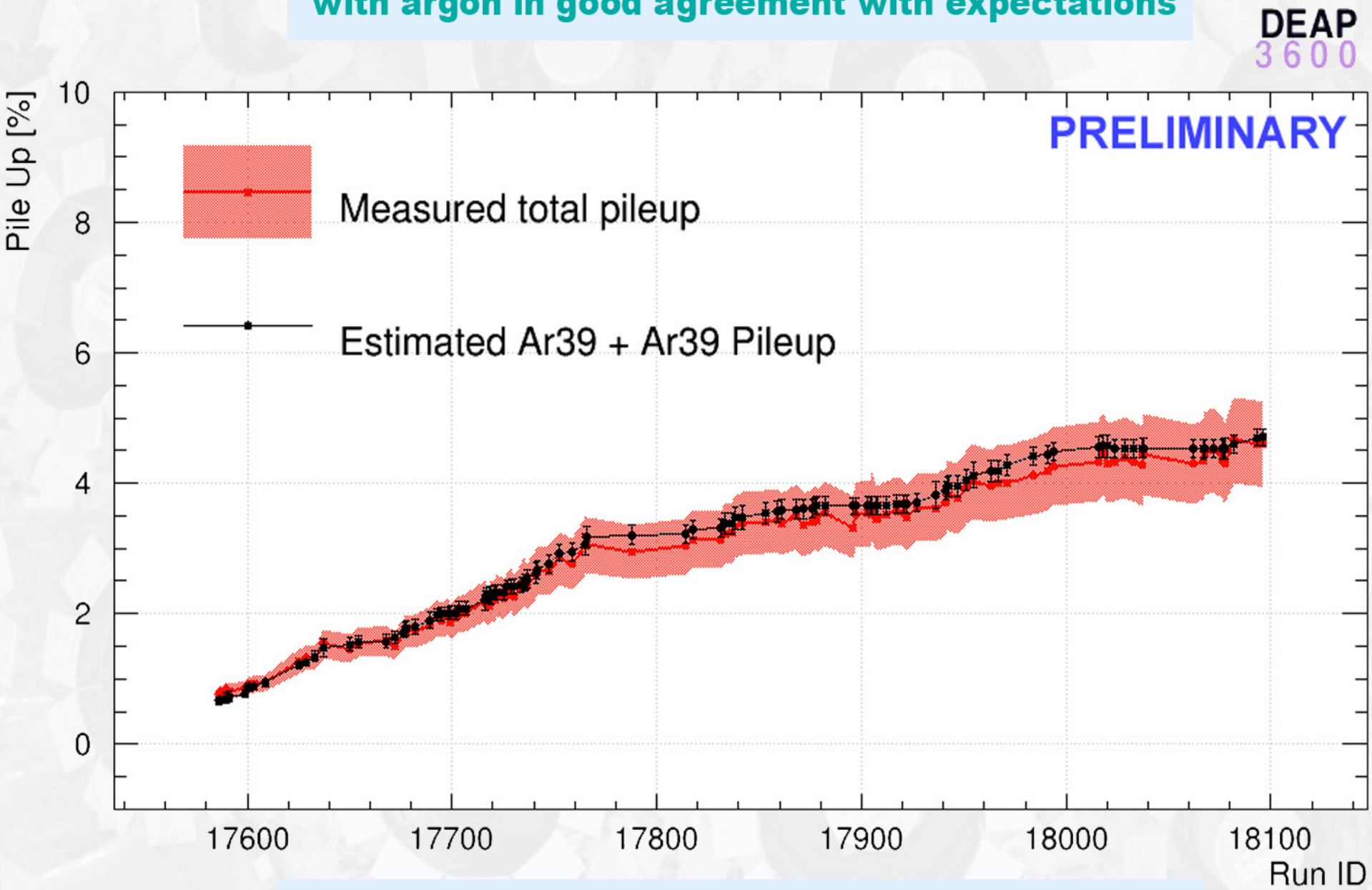
Based on the length of the event window detection of pileup is also possible

The dominant contribution being the coincidence of two Ar39 electron recoils



Identification of pileup whilst filling DEAP-3600 with argon in good agreement with expectations



Run ID := Time, filling of the acrylic vessel with Ar

Summary

- DEAP-3600 sensitive to nuclear recoils of WIMP dark matter candidates off of Ar40 nuclei

- Argon target provides strong pulse shape discrimination against electron recoils e.g. Ar39

- Cooling instrumentation integral to maintaining the neccessary cryogenic conditions required for dark matter result

- Auxillary information from such instrumentation and PMTs provide an unbiased source of quality control for run selection, mitigating anomalies

- Good understanding of non recoil-like events and coincidence events

- Expect first results and more details soon in upcoming publication

Thank you for listening

contact: rpfs@physics.carleton.ca