GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

Spectroscopy of the Ar scintillation light for rare event searches

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CPAN Network on Instrumentation and Detectors

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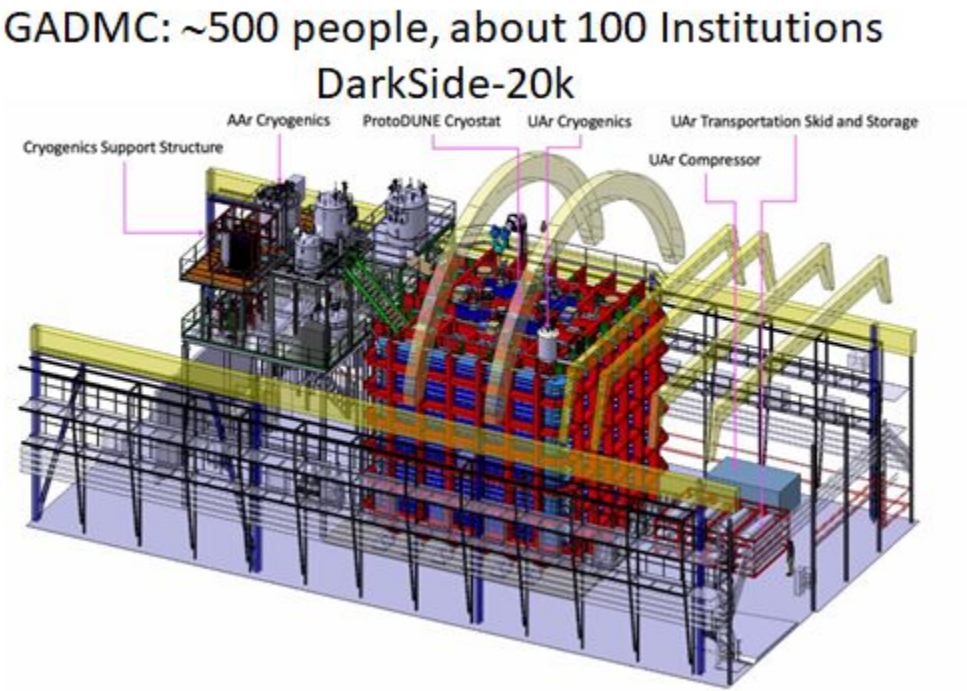
CIEMAT-DM

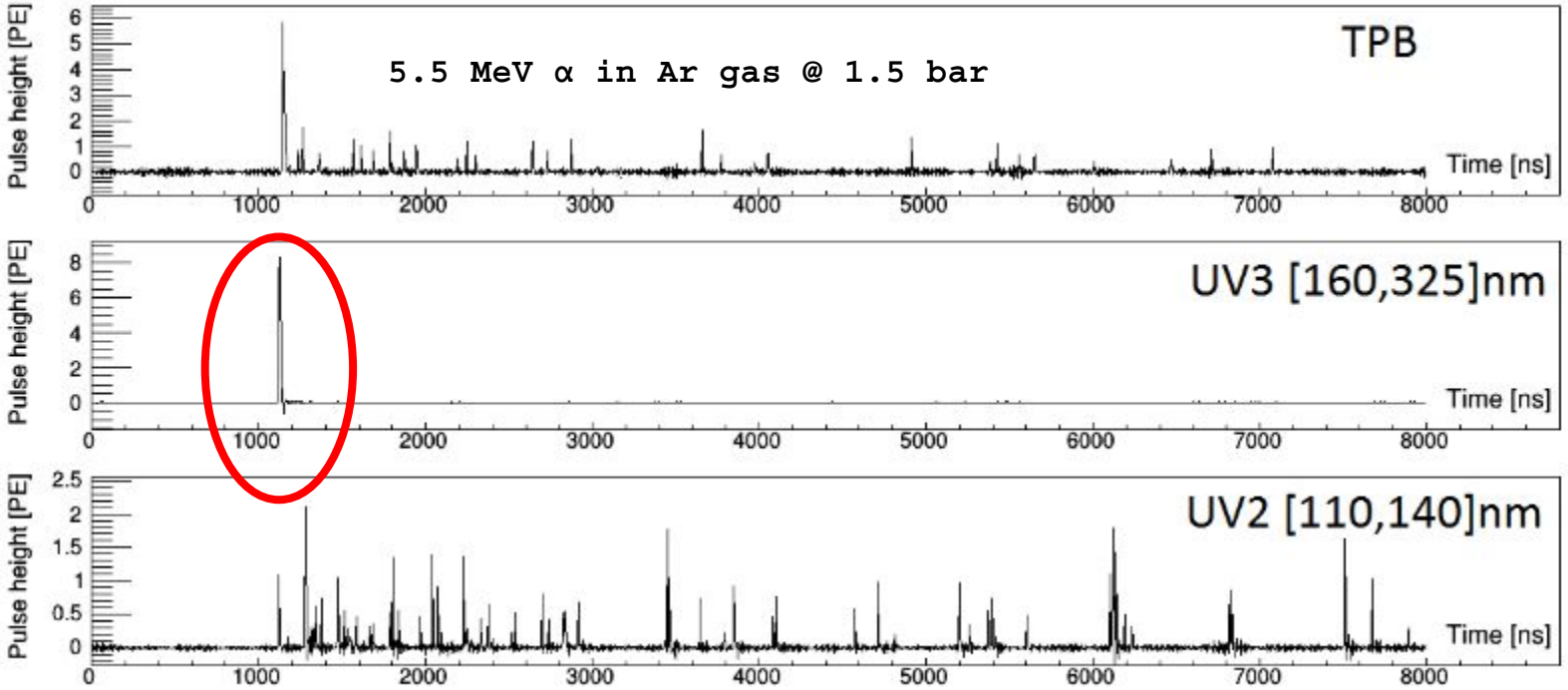
Context of this work:

- The direct search of WIMPs: needle in a haystack kind of problem. PID is central.
- The CIEMAT-DM team has a long time experience in noble elements detector, and **LAr technology** in particular.
- constant detector R&D to overcome the evolving experimental limits. R&D goes in parallel with physics (no sharp separation between experiment activity and R&D).
- Global Argon Dark Matter Collaboration: building DarkSide-20k (+DArT + Urania + ARIA) and starting the conceptual design of ARGO



Summary

R. Santorelli et al. Eur. Phys. Journal C 21, 622 (2021)



3rd continuum, produced in presence of high ionization yields, is spectroscopically distinct and its relative intensity is sizable event-by-event.

ArDis

Compact central cubic volume:

- validated to hold 21 bar,
- with 4 MgF_2 viewports mounted on CF40 flanges,
- Maximize light collection,
- Minimize reflections and cross-talk.

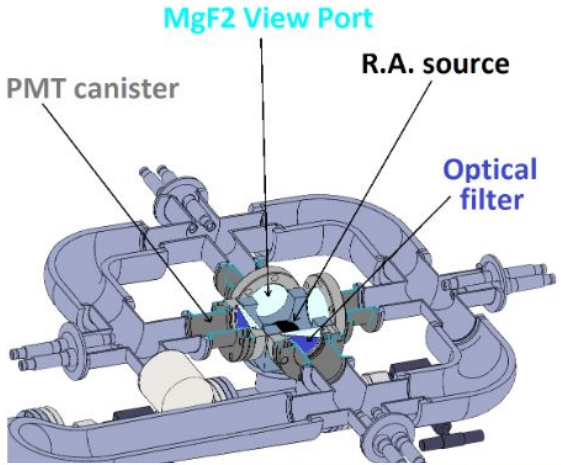
Decoupled volume for PMTs, working in vacuum.

Radioactive source at the bottom:

- ^{241}Am [5.5 MeV α @ 500 Bq]

Combination of different PMTs, filters and wavelength shifters to control the spectral range.

Collaboration with D. González Díaz'

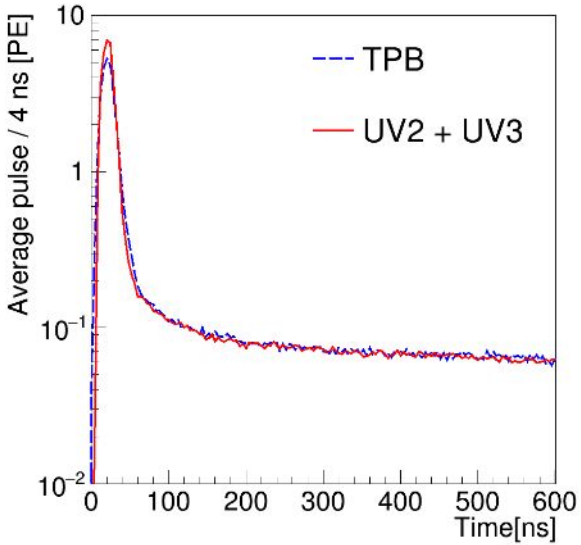


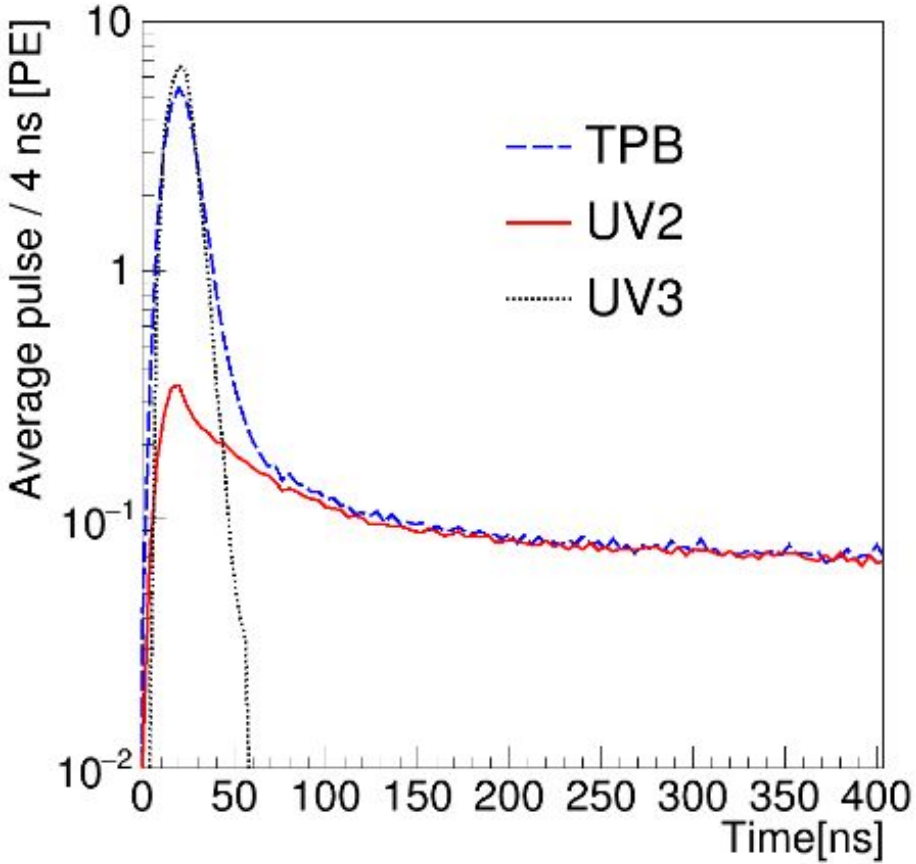
Average pulse shapes @ 1.5 bar

Prompt light not so prominent in the UV2 region,

A lot of light in the UV3 region,

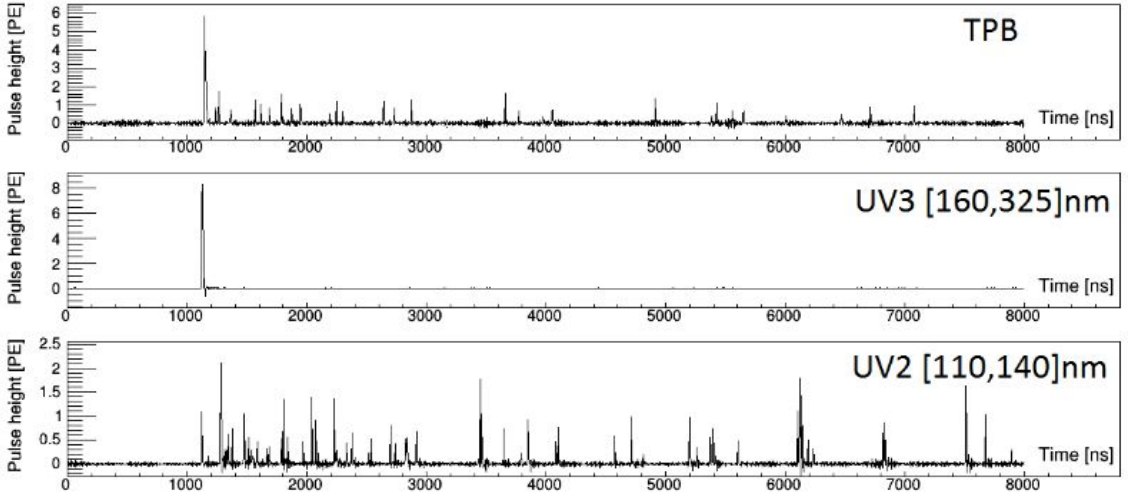
All the light in the **UV3 is prompt.**



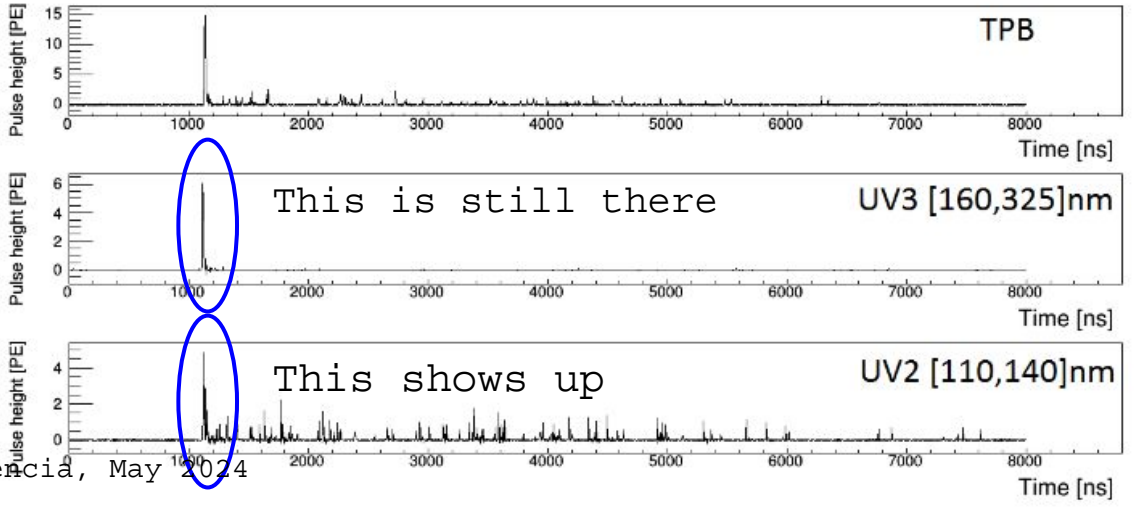


5.5 MeV alphas in gas

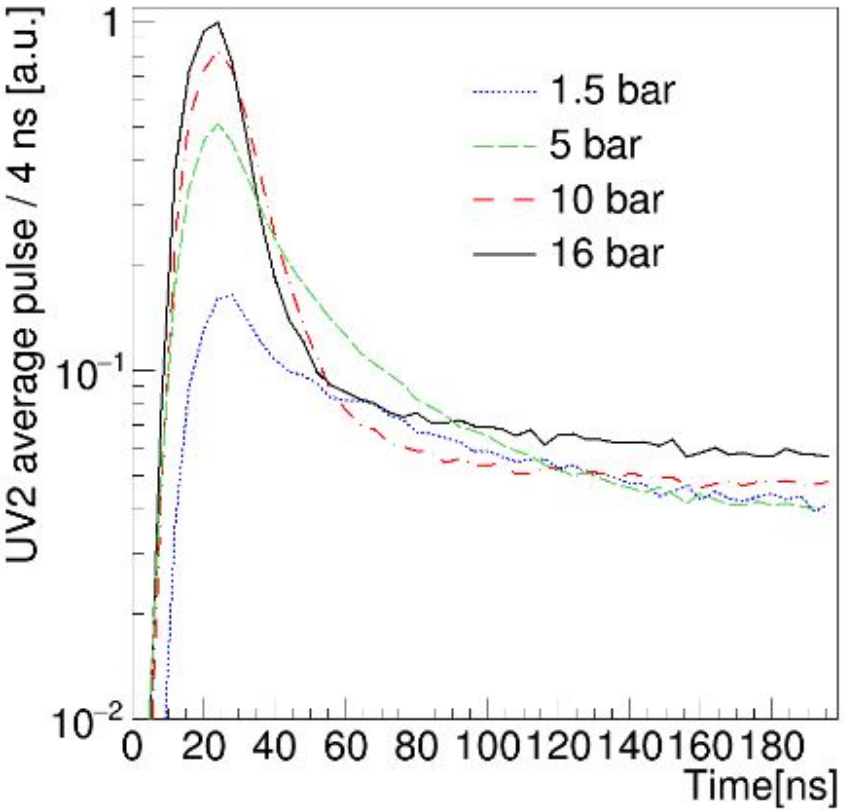
1.5 bar

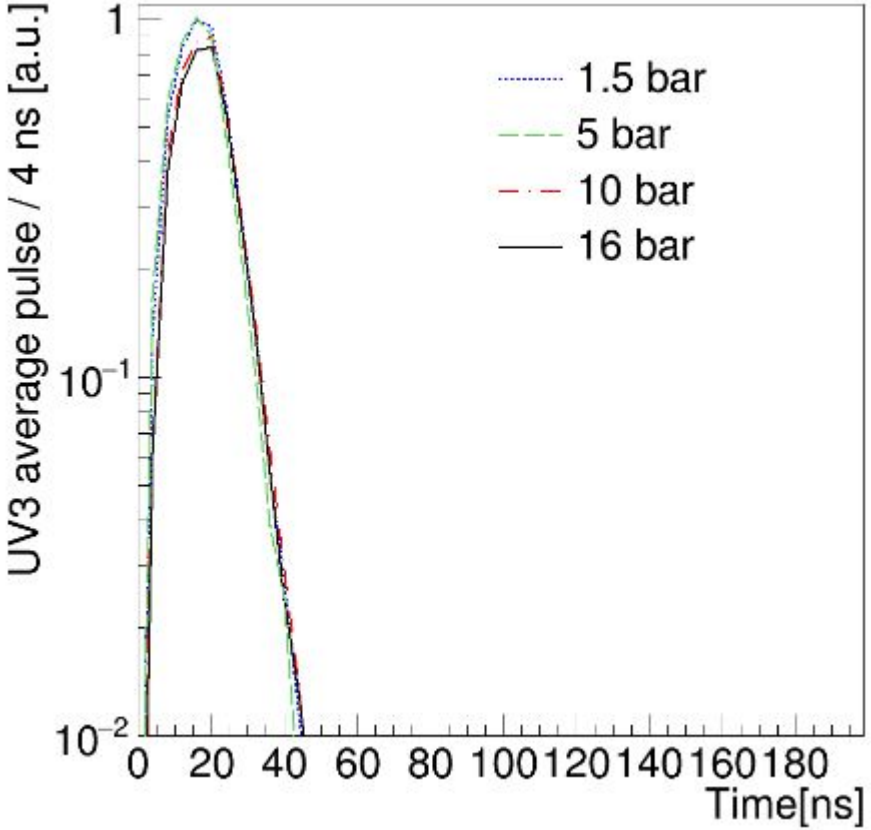


16 bar



Average pulse for different pressures





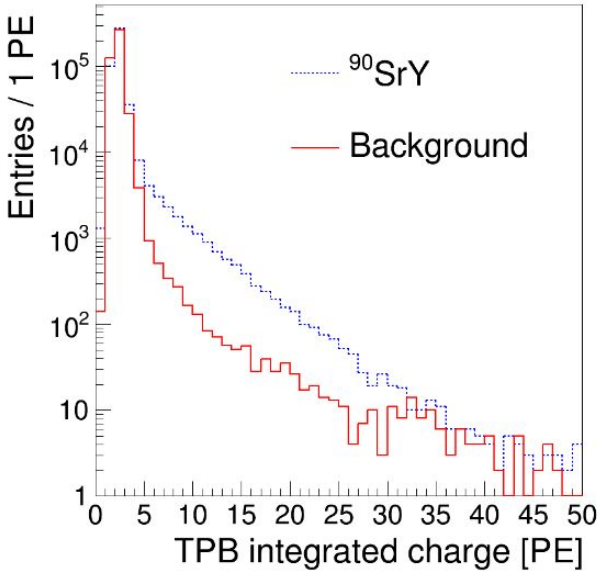
What about betas?

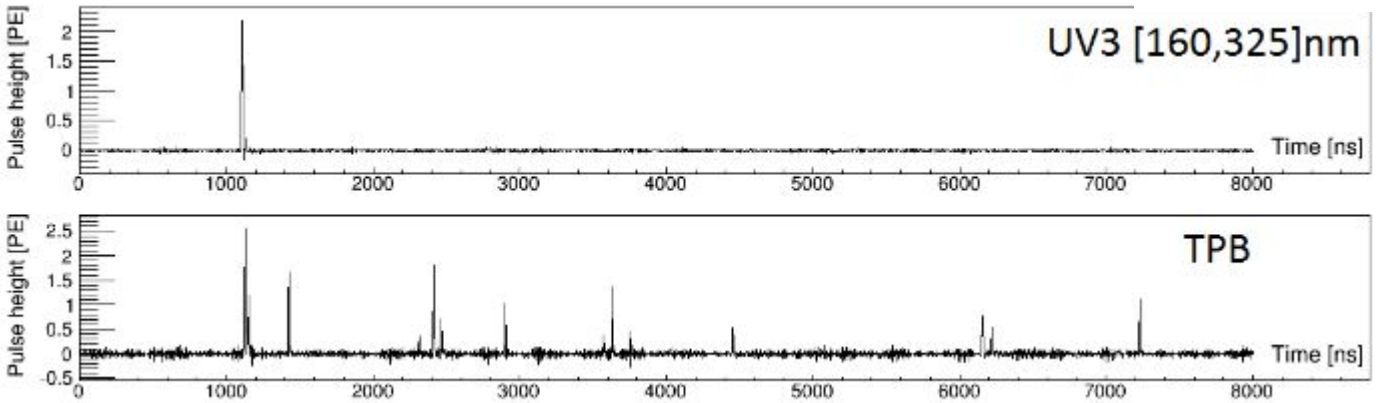
Clear light yield increase,

UV3 light is there,

Instrumental effects do not allow more conclusive statements (yet):

-E uncertainty, long path, asymmetry...

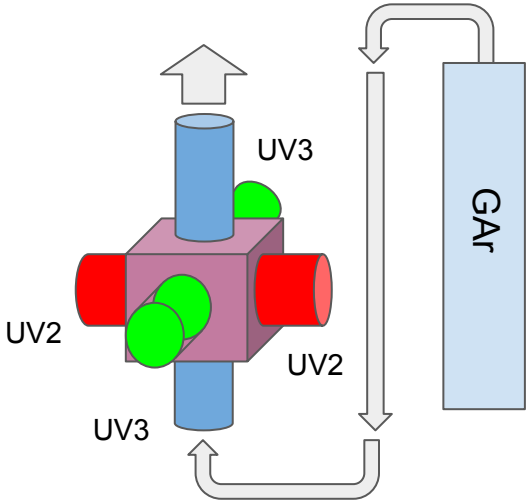


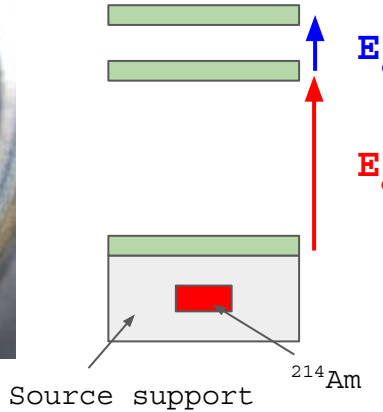


ArDis - Electroluminescence

Setup devoted to study the spectral properties of the electroluminescence induced in dual-phase detectors.

UV2 ⇒ [115, 140] nm (2nd cont.)
UV3 ⇒ [160, 650] nm (3rd cont.)





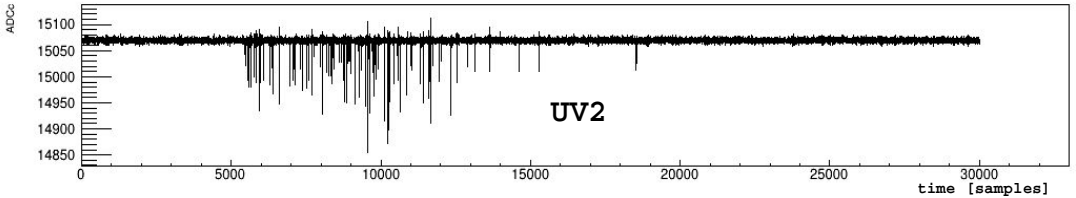
E_{extr} = 1.7 kV/cm

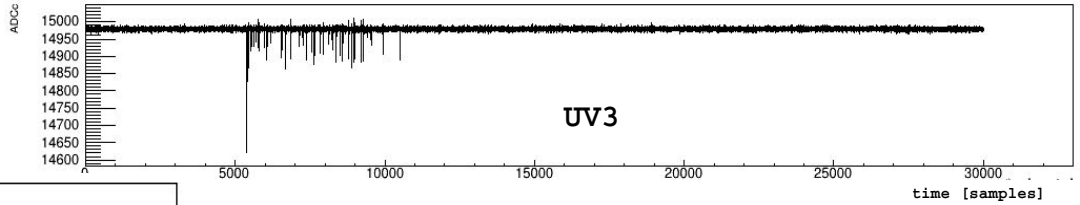
E_{drift} = 265 V/cm

P_{GAr} = 1.08 b

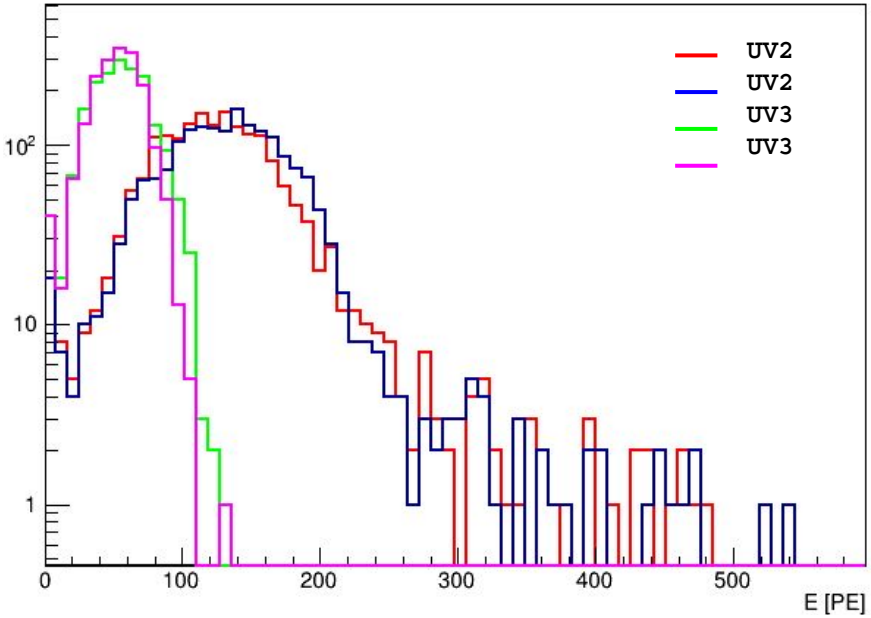
ArDis - Electroluminescence

Waveforms of an electroluminescence event





Energy spectrum



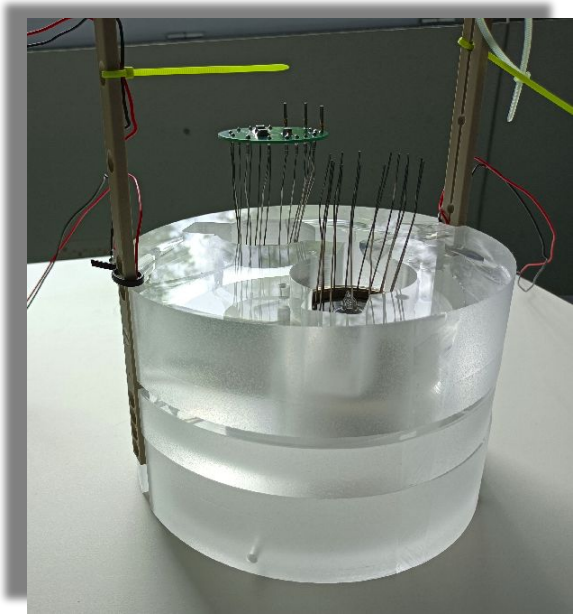
$\bar{E}_{UV2}$ = 133.7 PEs

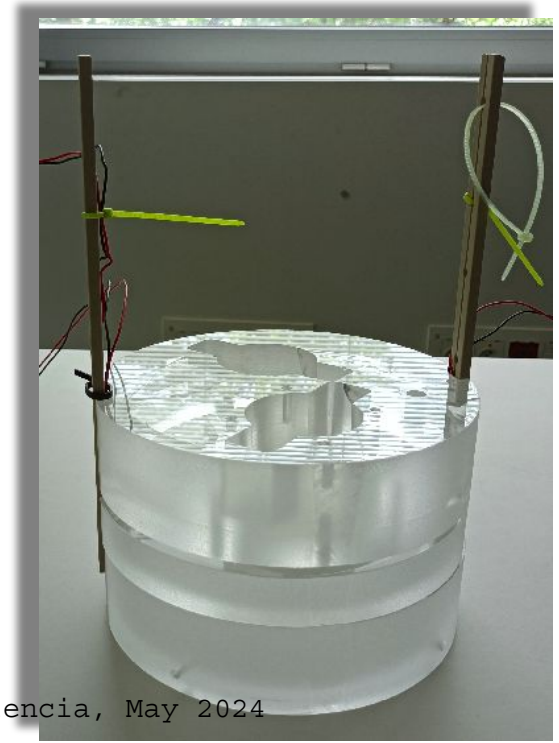
$\bar{E}_{UV3}$ = 53.2 PEs

Part of electroluminescence light emitted as 3rd continuum,
P dependence and systematics under evaluation.

PILSNER: Particle Identifier based on Light Spectroscopy in Noble Elements for Rare event searches

GOAL: Characterize the spectral response in liquid Ar: hardware already operative at Laboratorio Subterráneo de Canfranc.

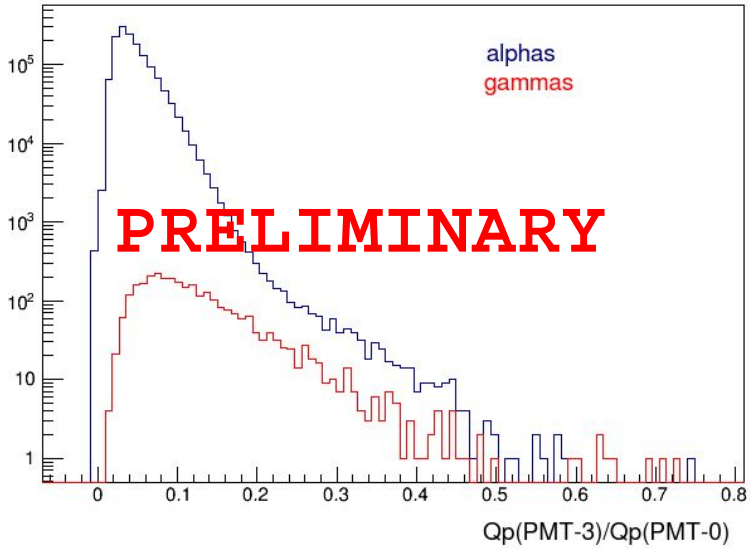




PILSNER

GOAL: Characterize the spectral response in liquid Ar: hardware already operative at Laboratorio Subterráneo de Canfranc.

- **UV3 light already observed in LAr with an alpha source and a PMT R6041-506 (operative @ 85 K).**
- **This measurement is very sensitive to impurities (in particular O and Xe. Getter + cryogenic filling pipe to be installed soon.**
- **Spurious sparks/corona effect appearing after short periods of operation. Setup improvements ongoing.**
- **Project funded with Europa Excelencia call.**



PILSNER

Collaboration with Grupo de Óptica de Láminas Delgadas (**GOLD**-CSIC)

Development and characterization of **broadband and narrowband** solutions for the Xe and Ar relevant wavelengths.

Ad-hoc development of narrowband dichroic filters using **multi-layer** evaporation. **Specifically tuned** for the LAr scintillation and spectral discrimination.

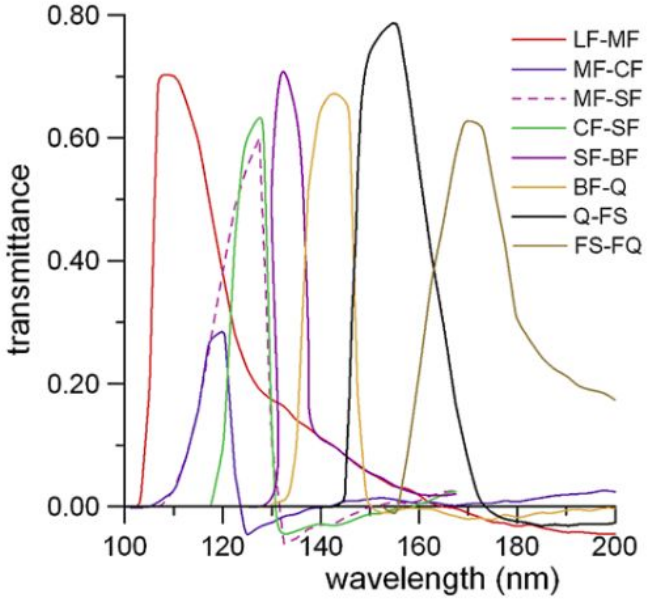


Fig. 3 Synthetic filters based on the difference in transmittance of blanks of various materials. *LF*: LiF, *MF*: MgF_2, *CF*: CaF_2, *SF*: SrF_2, *BF*: BaF_2, *Q*: quartz, *FS*: fused silica, *FQ*: fused quartz. Note: the original data was collected from different suppliers for blanks with various thicknesses

PILSNER

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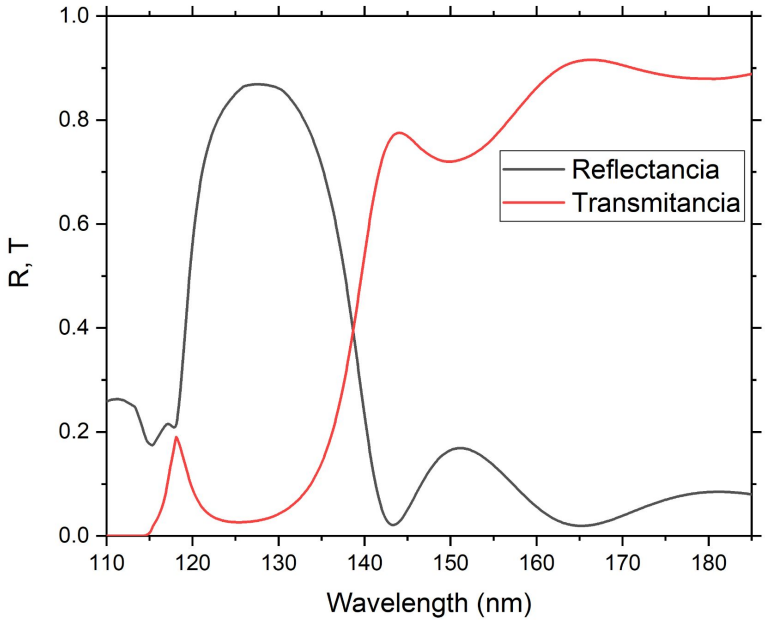
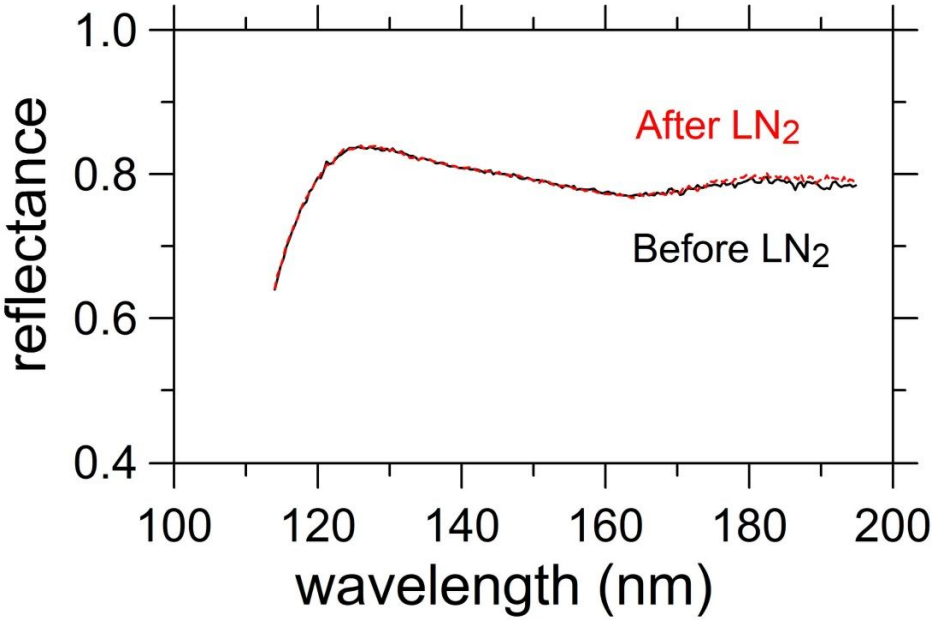


PILSNER

Challenges:

- **Cryogenic** robustness
- Uncertainty in **refraction index** of LAr at short wavelengths has a sizable impact.

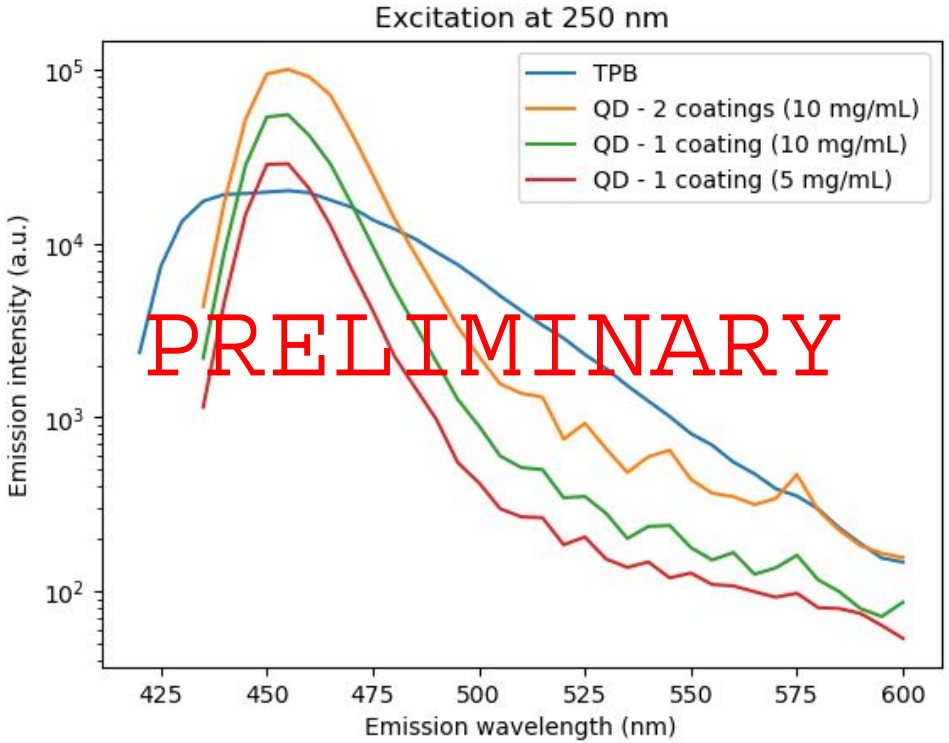


- Important **angle** dependence: not possible to have sharp changes of behaviour at a particular wavelength and angle independence at the same time.

Other collaborations

Roberto Soleti and Francesc Monrabal (Donostia International Physics Center)

Study of wavelength shifting efficiency of **quantum dots** in Ar gas and liquid and comparison with TPB.



Conclusions

Wavelength shifters maximize the light collection efficiency, but hide the spectral richness of Ar scintillation.

We have built and operated wavelength sensitive detectors at pressures up to 21 bar and in LAr.

Currently studying the spectral-temporal features in liquid and in the electroluminescence phase.

There are hints pointing **towards feasible particle discrimination** techniques based on light spectroscopy only: **path worth exploring.**

We have several collaborations to study instrumental developments that improve the current state-of-the-art and prospect this PID path. **Feel free to reach out!**

Thanks for your attention!

BACKUP

ArDis

Combination of different PMTs and filters to control the spectral range:

- R7378A x2 (UV3): [160, 325] nm
- R6095 + TPB (TPB): integral range
- R6835 (UV2): [110, 140] nm

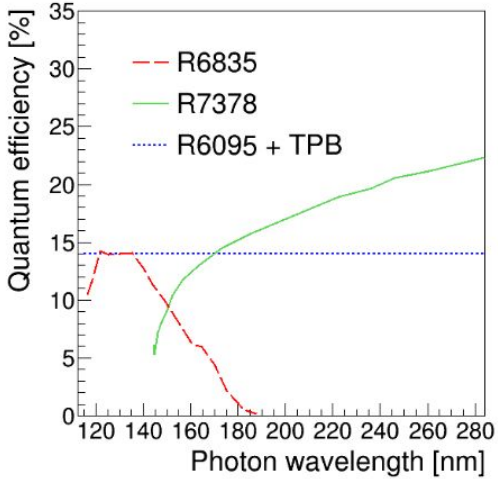
[naming after the index of the continuum]

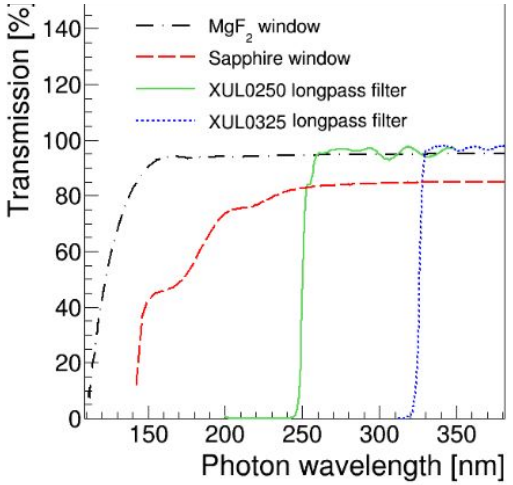
R7378A + XUL0325 → no light

R6835 + Sapphire → no light

We are certain the light they are getting are at shorter wavelength than those filters.

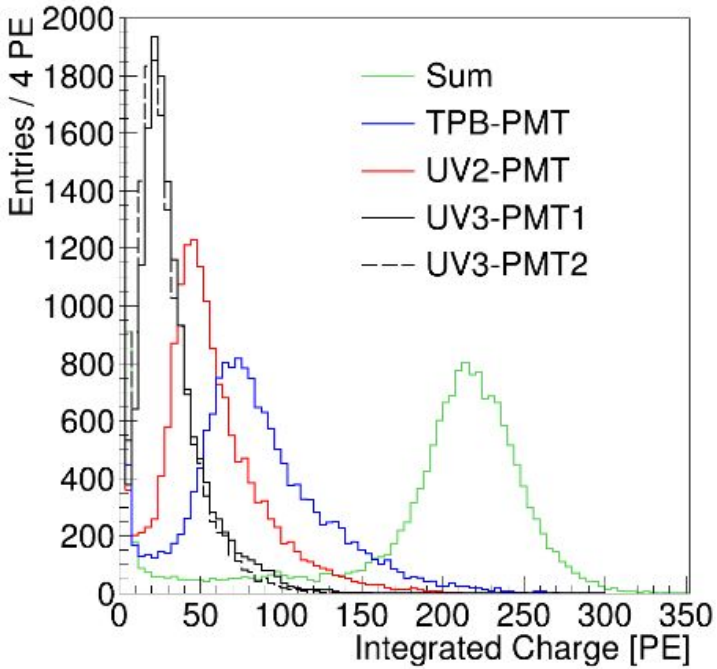
Once verified, we operate without filters.



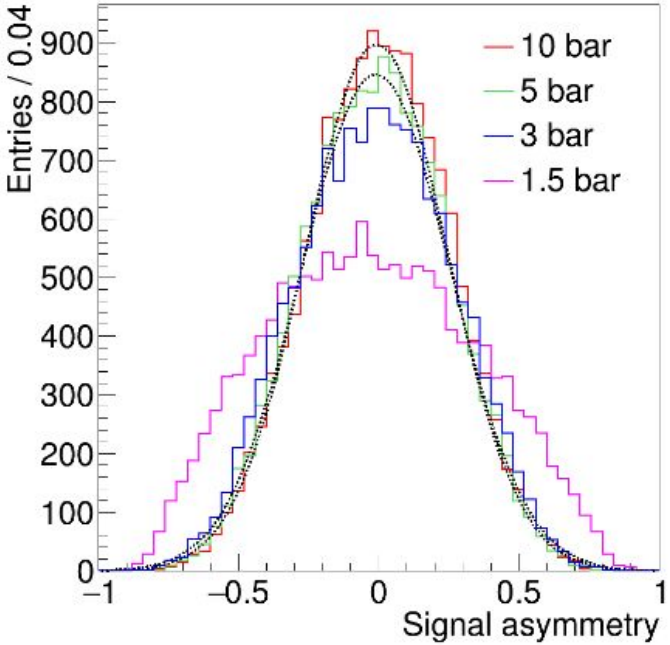


Order 0 cross checks

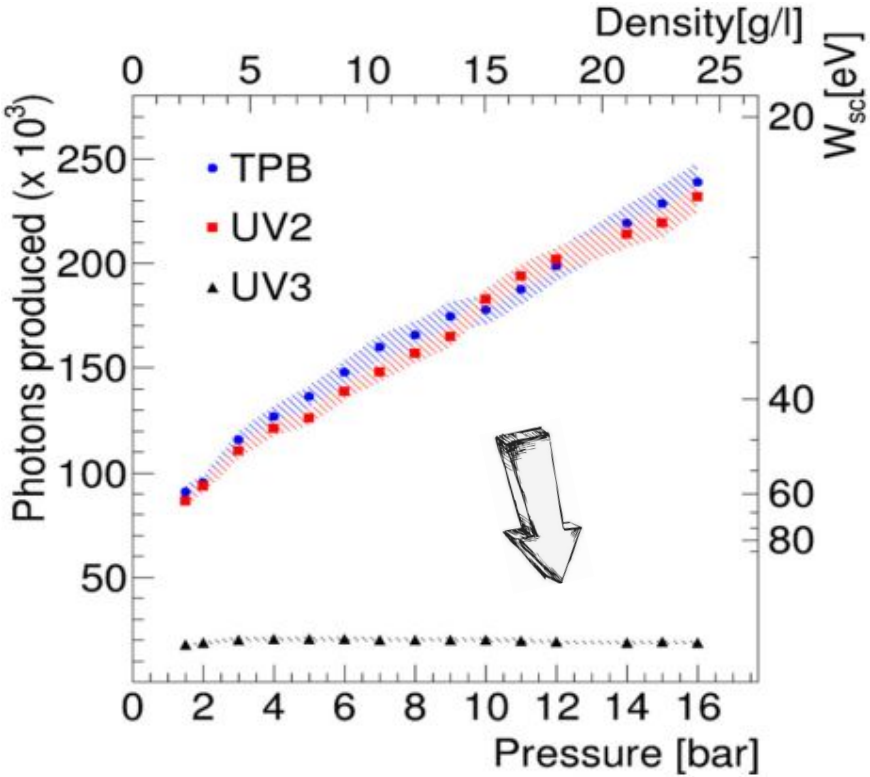
Amount of light in all PMTs is large enough

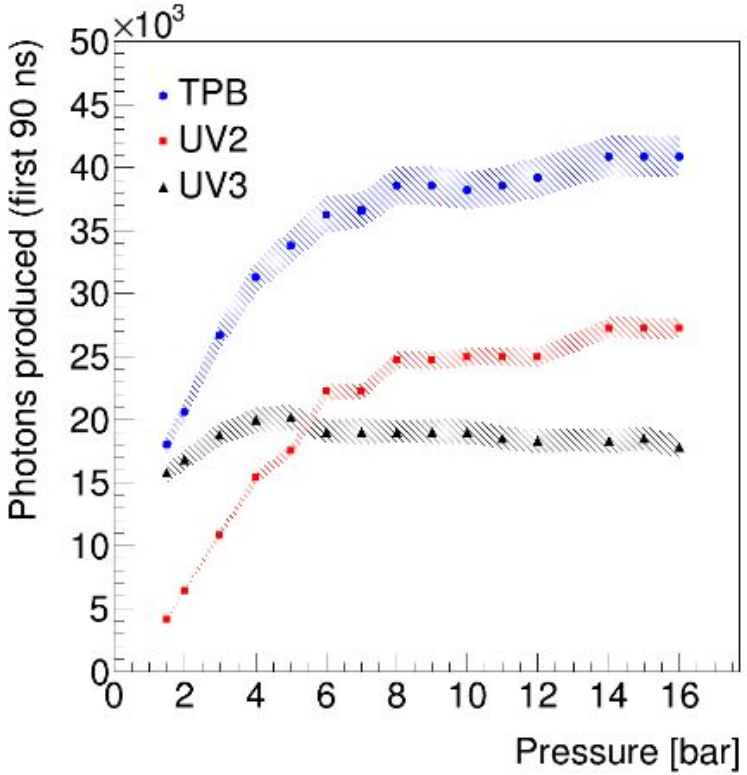


Asymmetry goes down at higher pressure (shorter path)

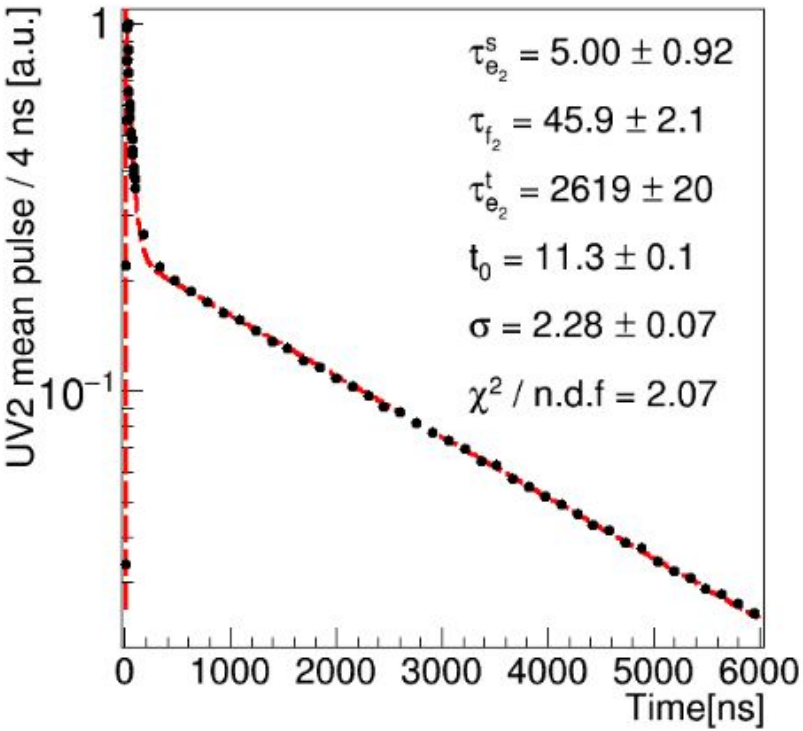


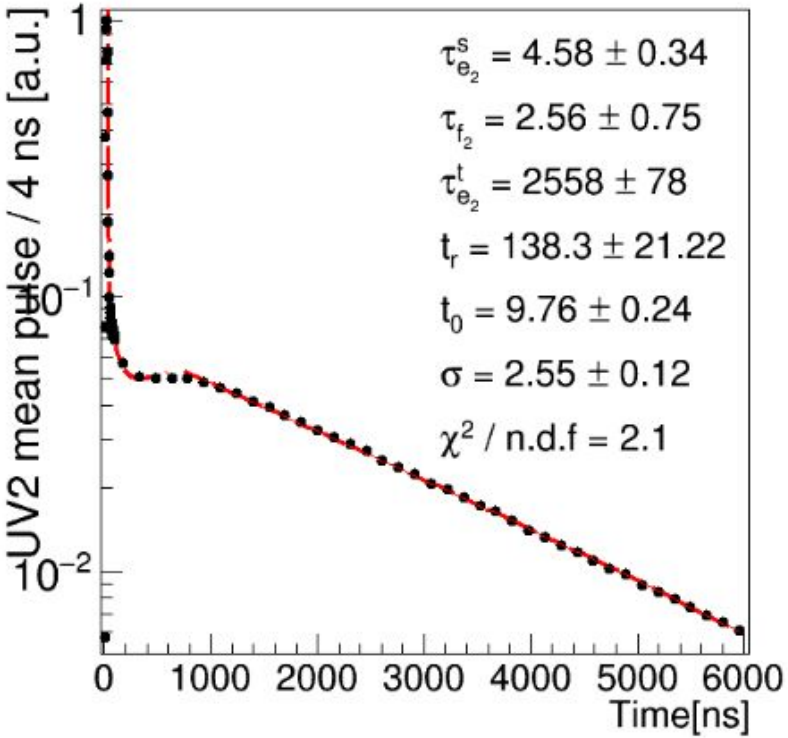
Light yield as a function of P





1.5 and 16 bar


UV2 mean pulse / 4 ns [a.u.]
1
10^{-1}
$\tau^{s}_{e_2}$ = 5.00 ± 0.92
τ_{f_2} = 45.9 ± 2.1
$\tau^{t}_{e_2}$ = 2619 ± 20
t_0 = 11.3 ± 0.1
σ = 2.28 ± 0.07
χ^2 / n.d.f = 2.07
0 1000 2000 3000 4000 5000 6000
Time[ns]

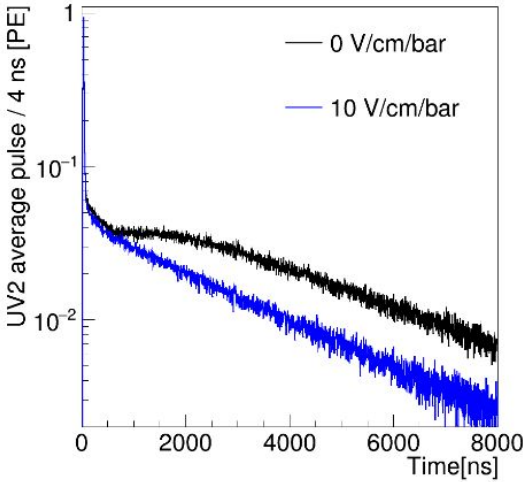

UV2 mean pulse / 4 ns [a.u.]
1
10^{-1}
10^{-2}
$\tau^{s}_{e_2}$ = 4.58 ± 0.34
τ_{f_2} = 2.56 ± 0.75
$\tau^{t}_{e_2}$ = 2558 ± 78
t_r = 138.3 ± 21.22
t_0 = 9.76 ± 0.24
σ = 2.55 ± 0.12
χ^2 / n.d.f = 2.1
0 1000 2000 3000 4000 5000 6000
Time[ns]

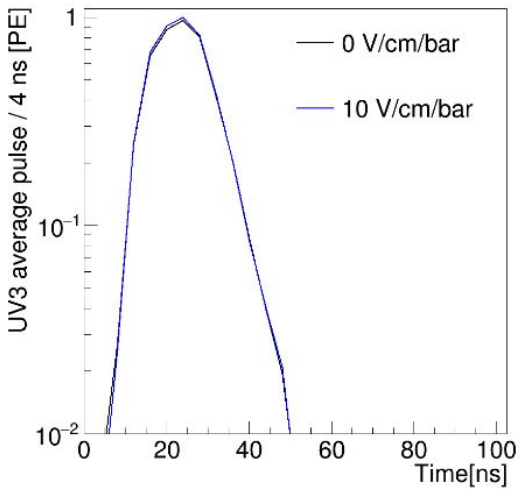
Field dependence

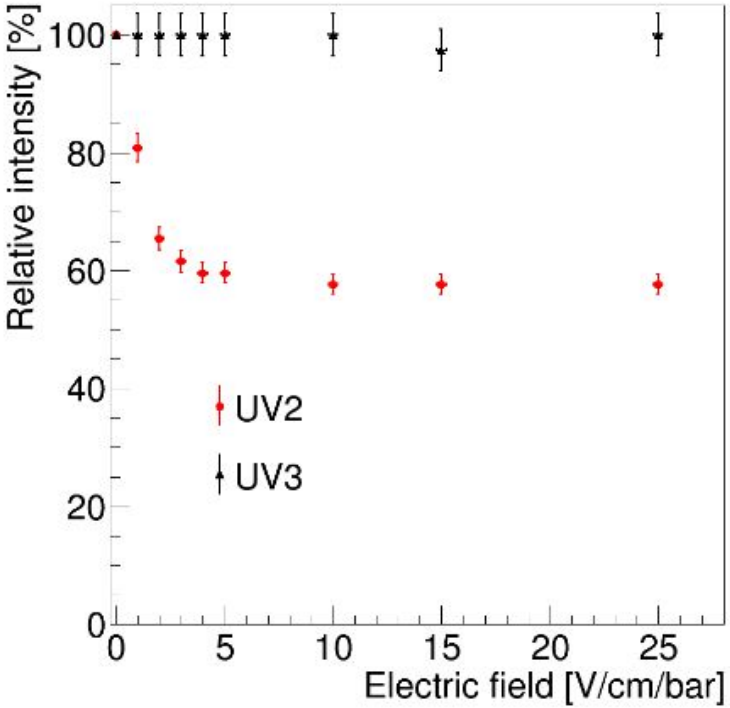
UV2 decreases with field

UV3 says "what field?"

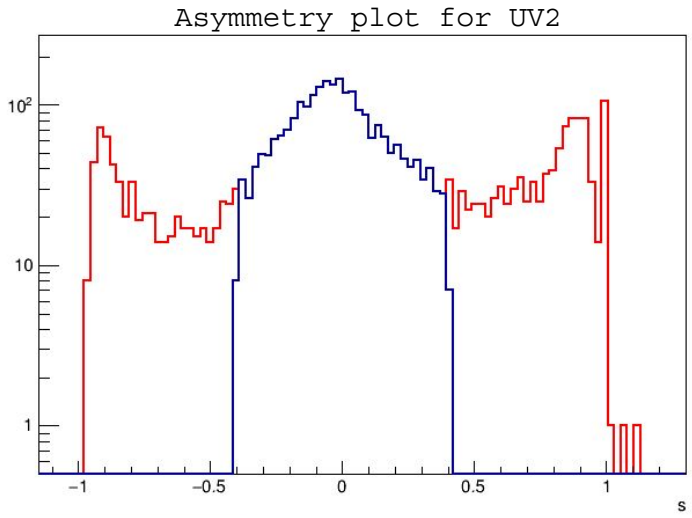
Recombination happens in UV2





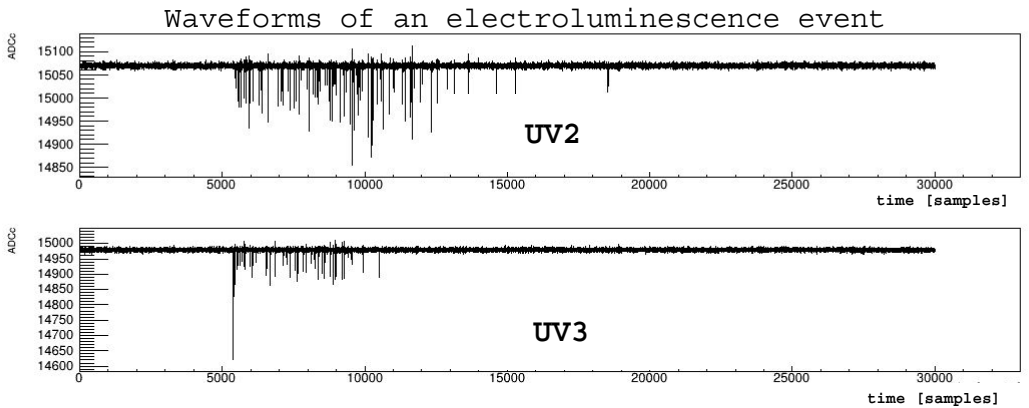


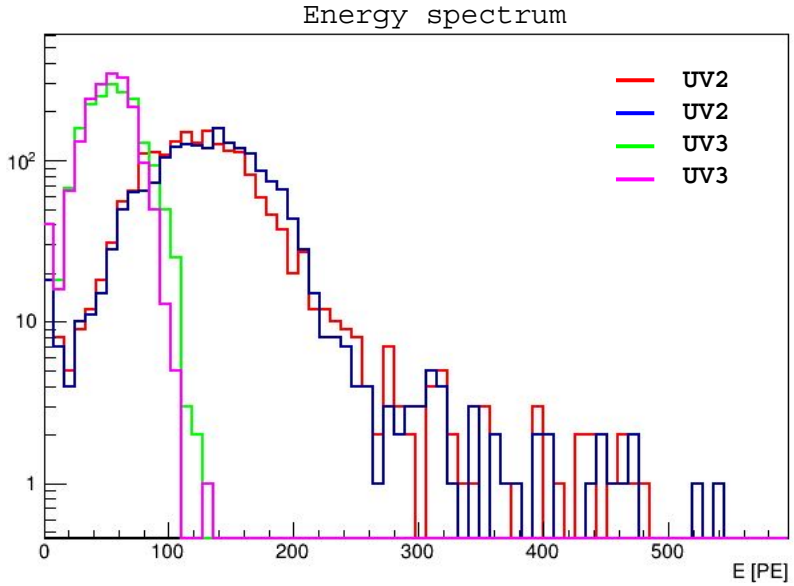
ArDis - Electroluminescence



With an **asymmetry cut** only events in the middle of the chamber are selected

$$s = (Q_1 - Q_2)/(Q_1 + Q_2)$$



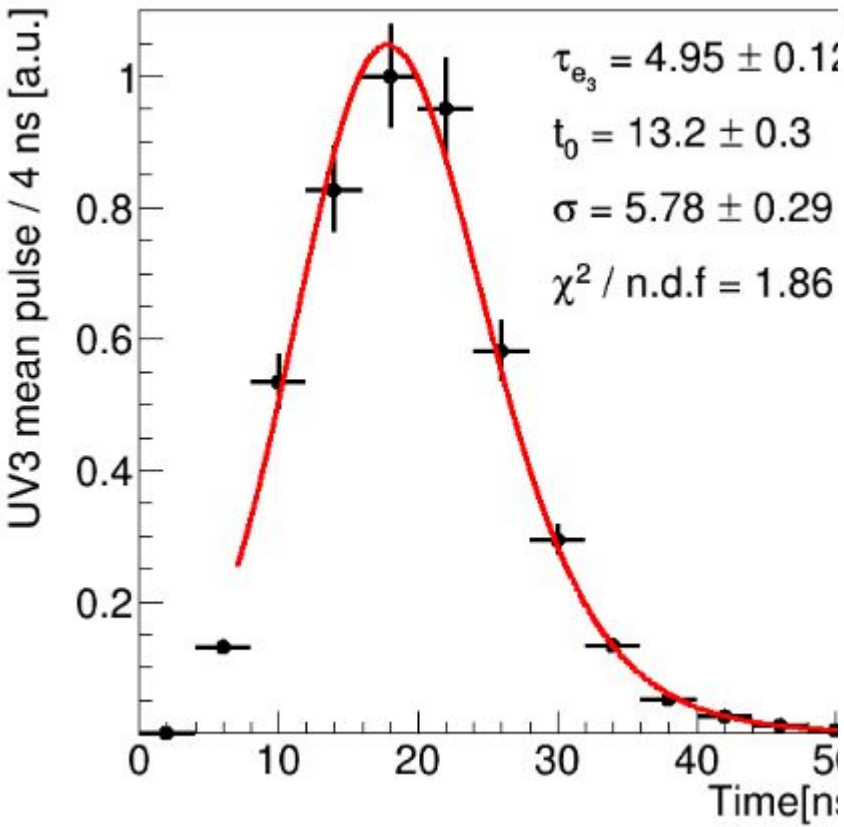


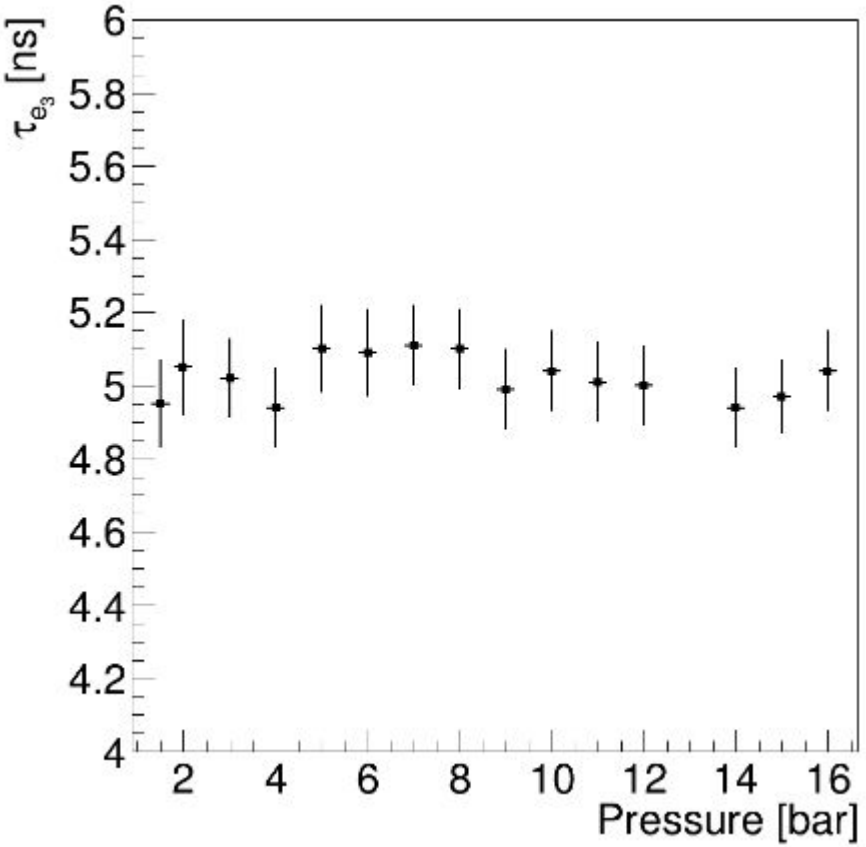
$\bar{E}_{UV2}$ = 133.7 PEs

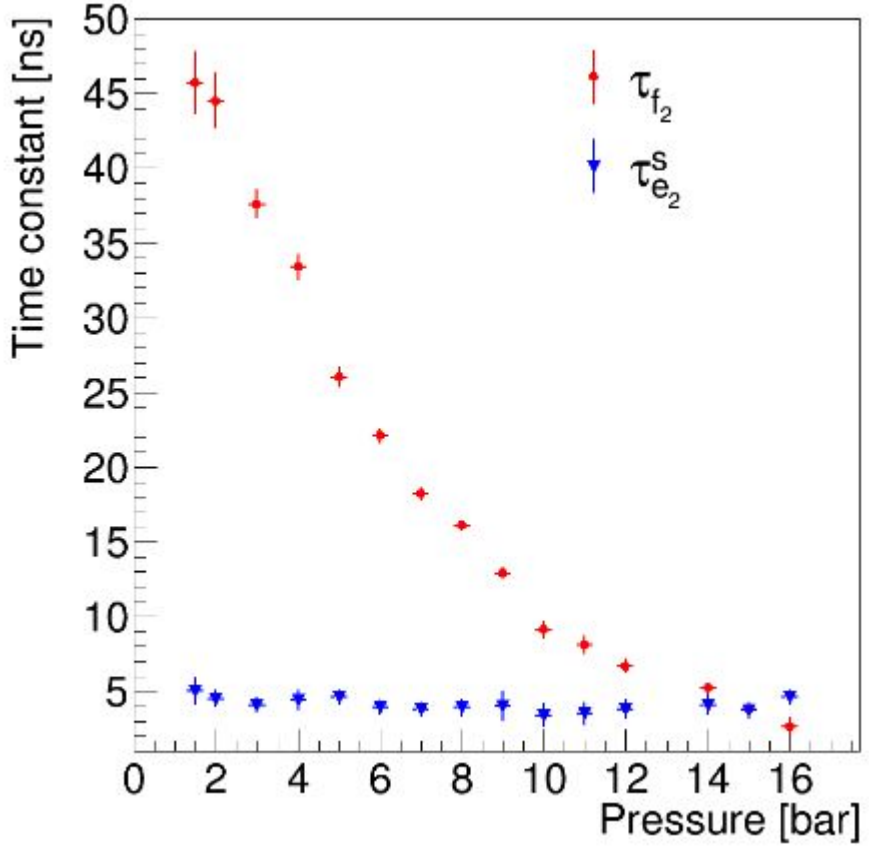
$\bar{E}_{UV3}$ = 53.2 PEs

Part of electrolum. light emitted as 3rd continuum

$$I_{UV2}(t) = \left[\frac{L_1}{\tau_{f_2} - \tau_{e_2}^s} (e^{-t/\tau_{f_2}} - e^{-t/\tau_{e_2}^s}) + \frac{L_2}{\tau_{f_2} - \tau_{e_2}^t} (e^{-t/\tau_{f_2}} - e^{-t/\tau_{e_2}^t}) \right] \otimes G(t - t_0, \sigma)$$


UV3 mean pulse / 4 ns [a.u.]
τ_{e_3} = 4.95 ± 0.12
t_0 = 13.2 ± 0.3
σ = 5.78 ± 0.29
χ^2 / n.d.f = 1.86
Time[n


τ_{e_3} [ns]
Pressure [bar]


Time constant [ns]
50
45
40
35
30
25
20
15
10
5
0
2
4
6
8
10
12
14
16
Pressure [bar]
τ_{f_2}
$\tau^{s}_{e_2}$