Scintillation of Ar-CF_4 mixtures

LIDINE 2023

21/09/2023

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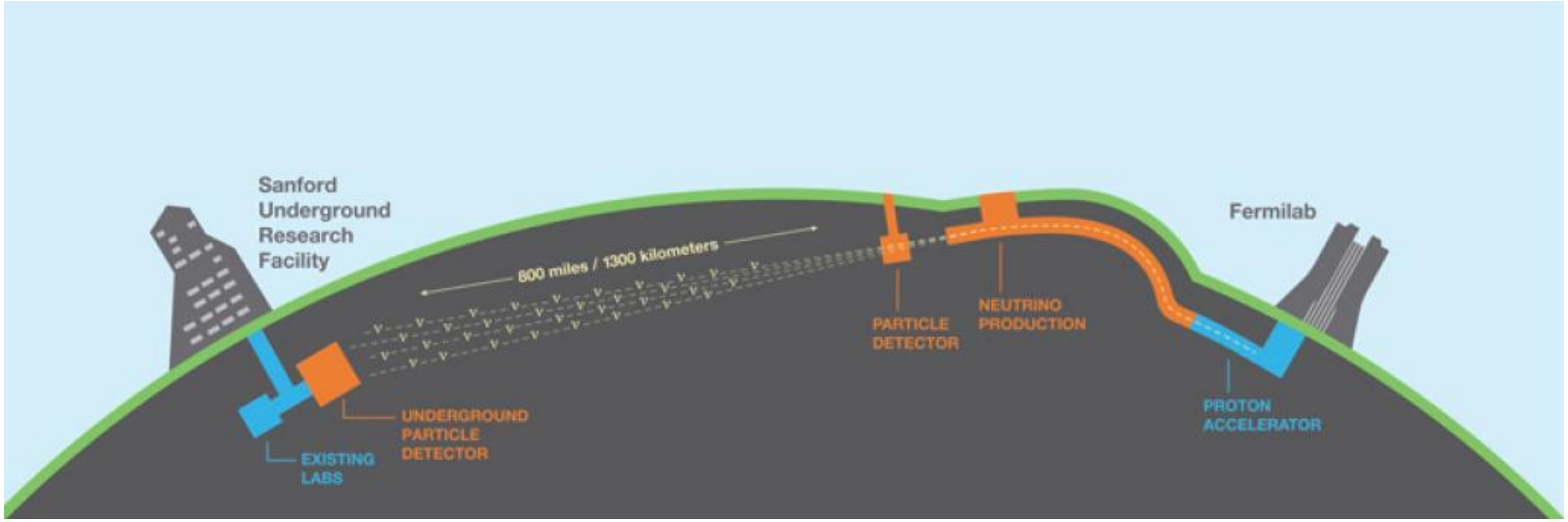
Introduction

- DUNE is an international collaboration aiming at measuring different properties of neutrinos, like oscillation parameters, mass hierarchy or the existence of a CP violation phase

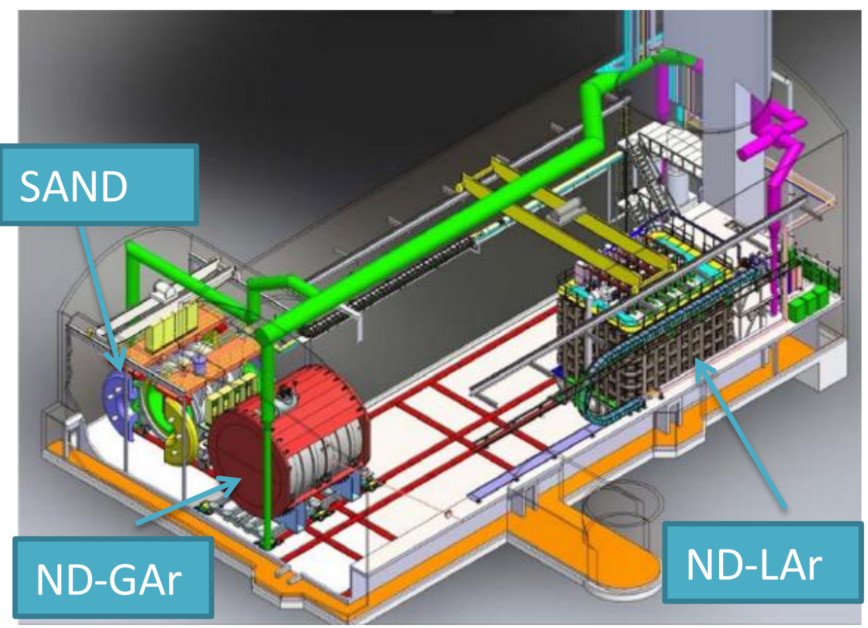
- For this, a far detector and a near detector are need to measure the neutrino fluxes and correct for systematics

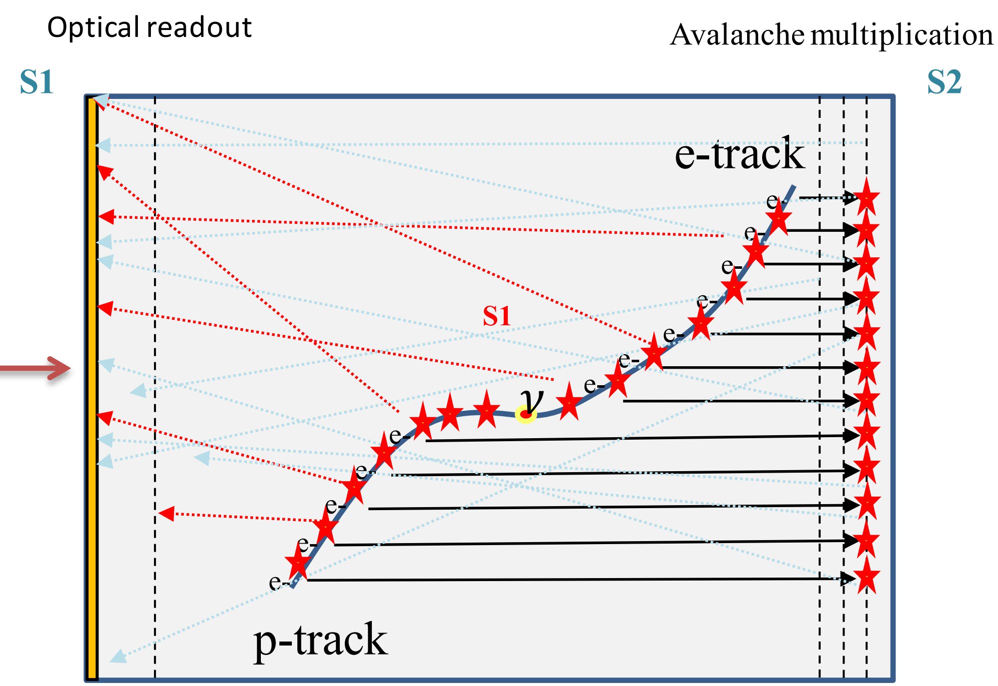


Introduction

- Our main objective was to develop a technological asset –a gas mixture- that could improve the reconstruction capabilities of low energy events and open the possibility of full optical readout of the ND-GAr

- This would give us access to the T_0 information of the interactions and facilitate reconstruction at O(2 mm) sampling

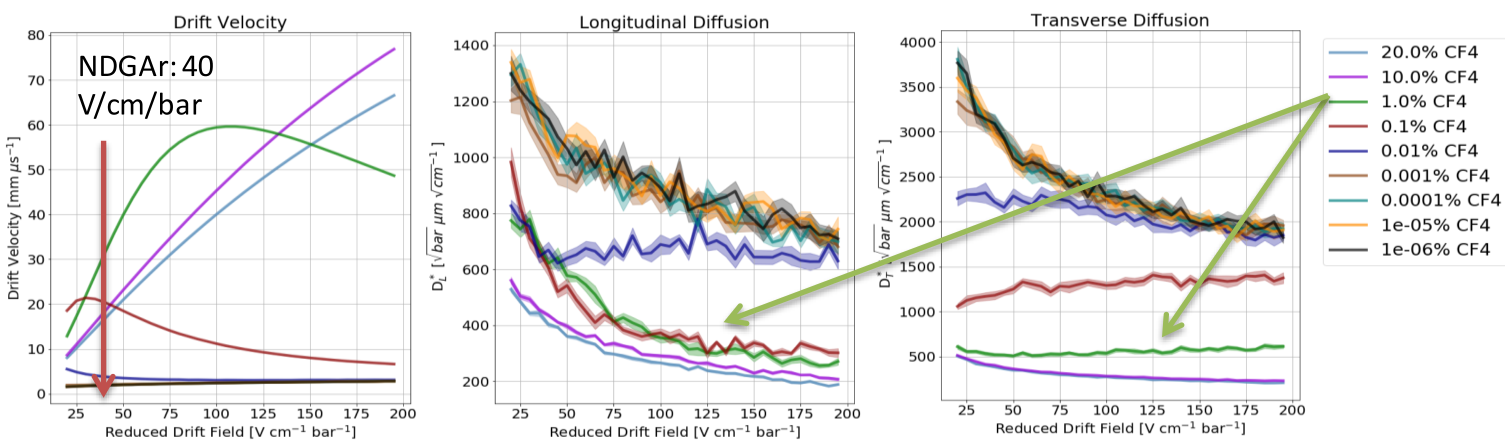




The role of gas mixtures in TPCs

- There are several reasons why we want a mixture and not just a pure noble gas
  - It reduces longitudinal and transversal diffusion
  - It allows to fine tune the drift velocity
  - It quenches VUV-photons and prevents destabilization of the avalanche-process due to photoelectric effect

- However, finding a scintillating mixture that provides all those benefits while keeping the target Argon-pure is not obvious. Possible candidate: CF_4

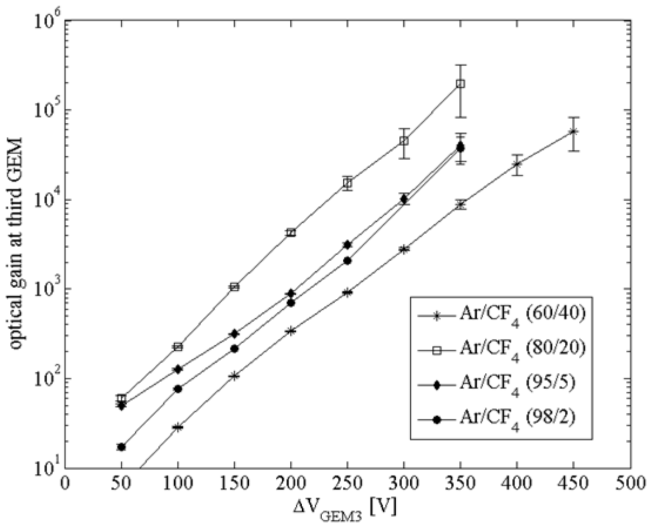


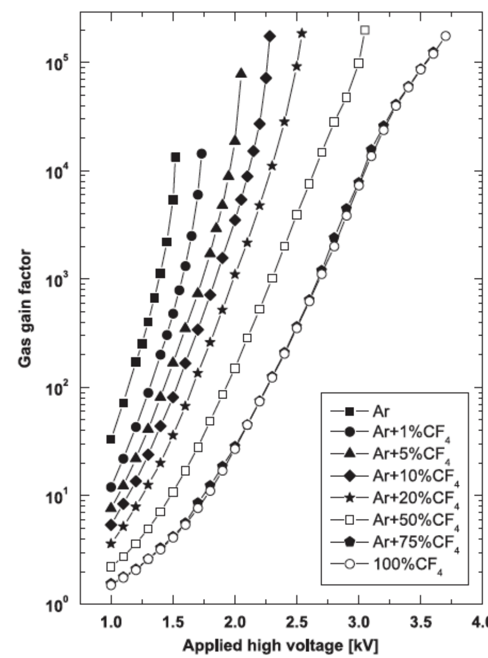
Taken from - https://github.com/UTA-REST

Why CF_4?

- Some good general properties
  - Transverse diffusion (at 1% mixing) of less than 1.6 mm/m$^{1/2}$, better than Alice (2.2), T2K (2.7) or P10 gas (1.8)
  - It scintillates in the UV and visible bands so latter can be detected using commercial photosensors
  - Previous works with a triple GEM setup have shown charge gains up to 10^6, with which optical gains of 10^5 are possible, enabling both optical and charge based readouts

Triple GEM





Single wire

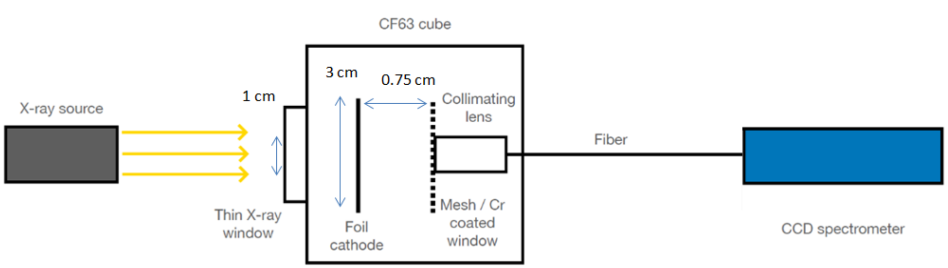
Fig. 1. Gas gain as the function of applied high voltage for $Ar + CF_4$ mixtures.

Experimental setup for spectroscopic measurements

- A small chamber was built with a thin aluminum entrance window, an aluminum foil as cathode and an anode were we collected the current

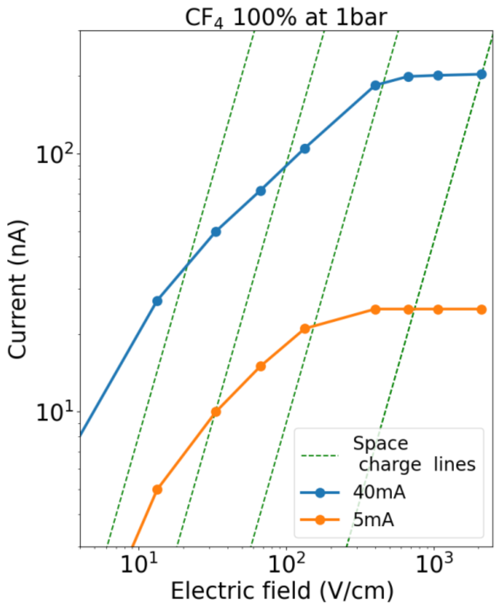
- We collected the light with a CCD spectrometer after the gas was irradiated with an x-ray tube

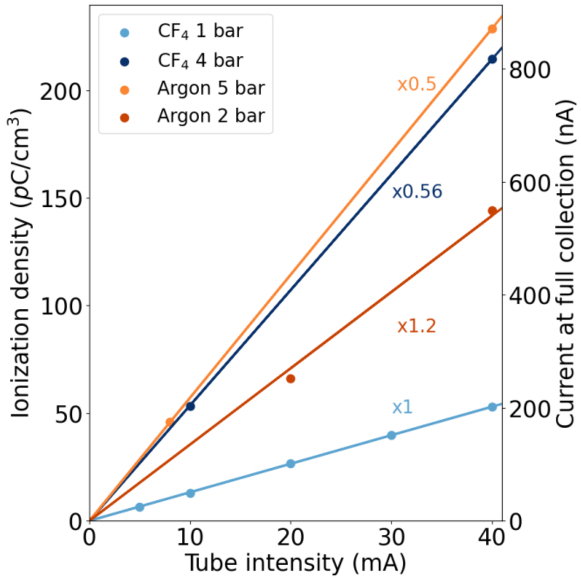
- The system had an RGA for purity control and the main impurities found were water, nitrogen and oxygen



Experimental setup for spectroscopic measurements

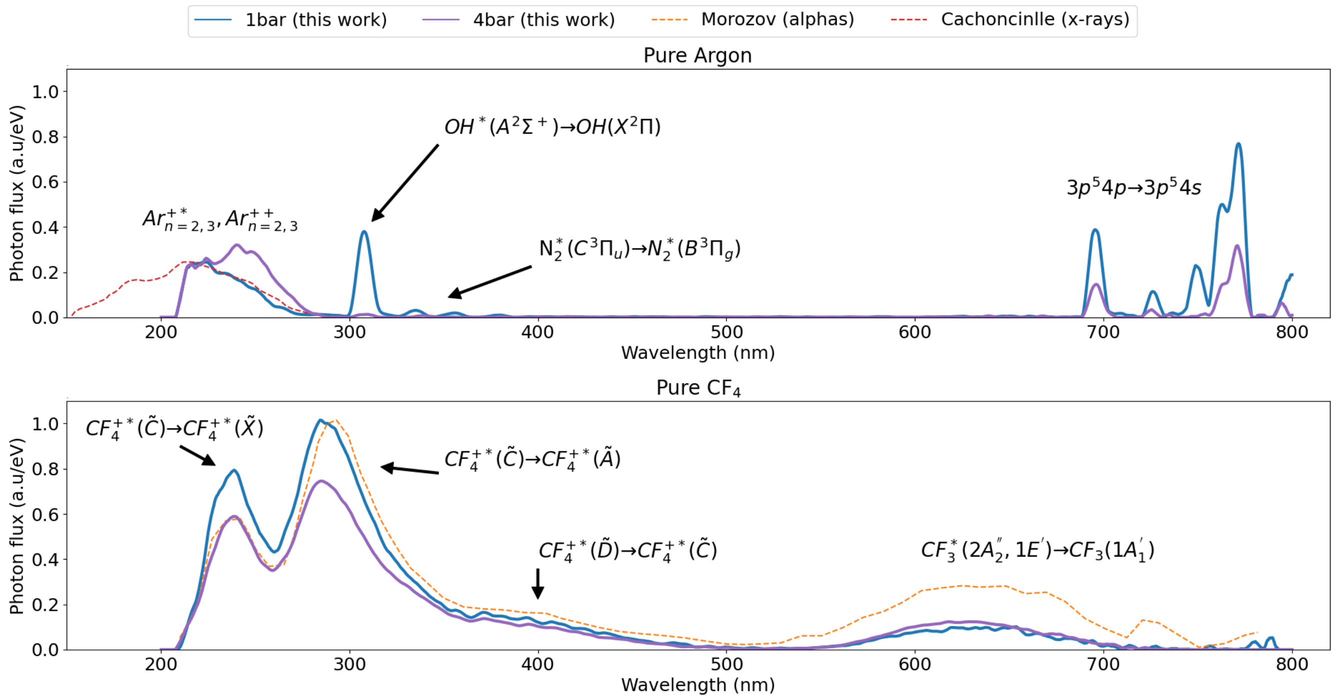
- Measurements were taken at no field and at a field high enough to ensure current saturation. Different tube intensities, pressures and mixtures were explored
- The results presented are proportional to the number of photons detected divided by the saturation current and the W_I value for each mixture
- We see no signs of space charge or recombination effects, as expected based on ionization density considerations





Results for pure gases

- The main bands come from transitions of CF_4^{+*}, CF_3^*, argon's third continuum and its atomic decays
- Peaks from impurities in the chamber come from OH and N_2 and are prominent at 1 bar

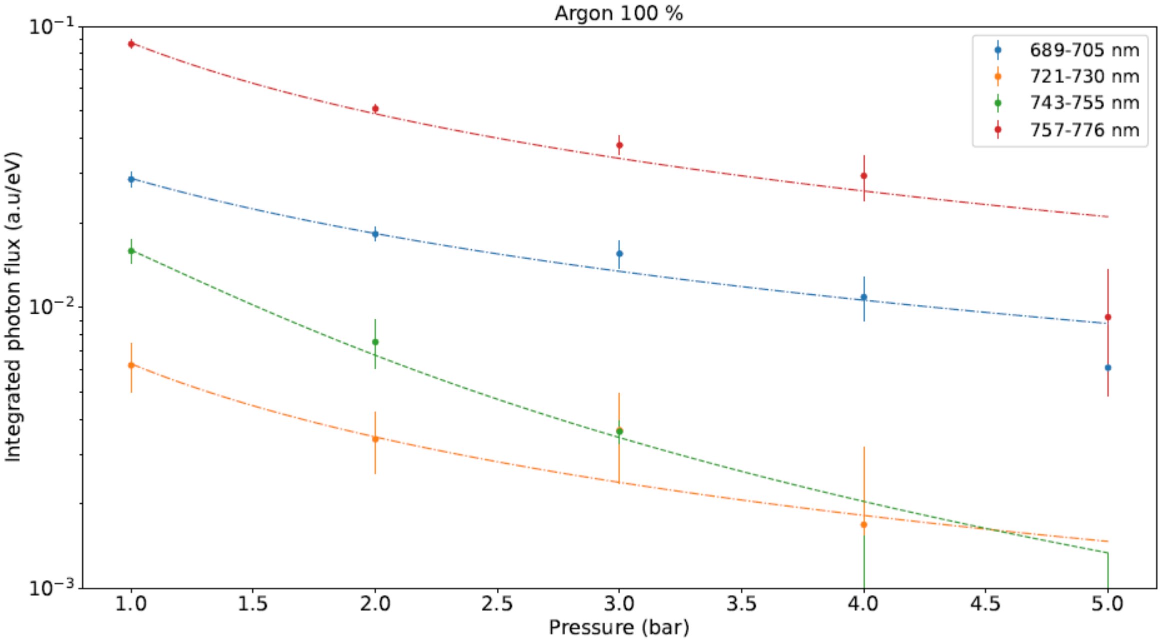


Time-resolved spectroscopy of high pressure rare gases excited by an energetic flash X-ray source, C. Cachoncille, 1995

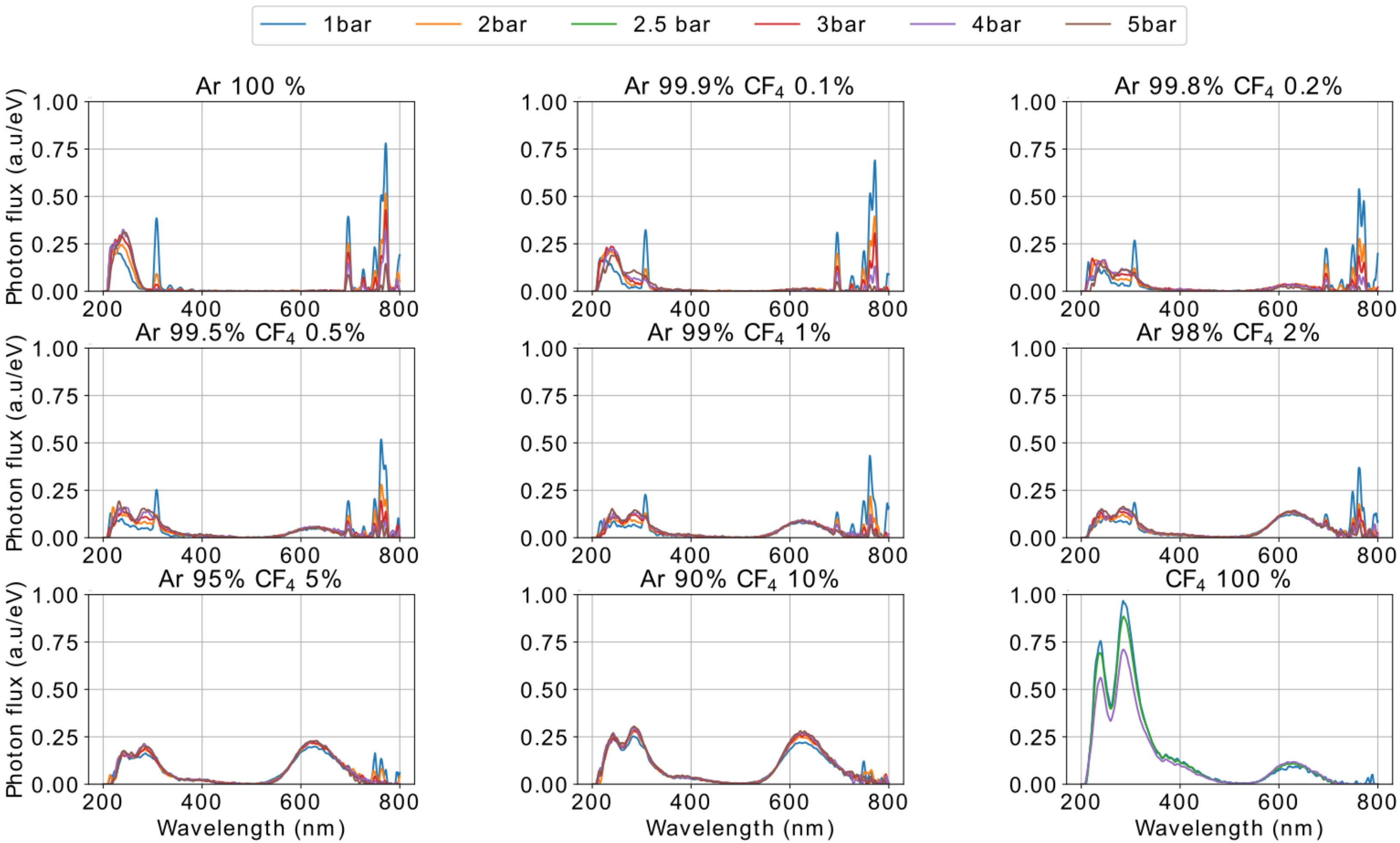
Effect of the electric field on the primary scintillation from CF4
A. Morozov et al

Infrared emission

- In general, the impurity peaks tend to decrease with pressure and CF_4 concentration
- The yield of the different argon infrared peaks decreases with pressure
- This behavior is consistent with self-quenching, be it either 2-body or 3-body

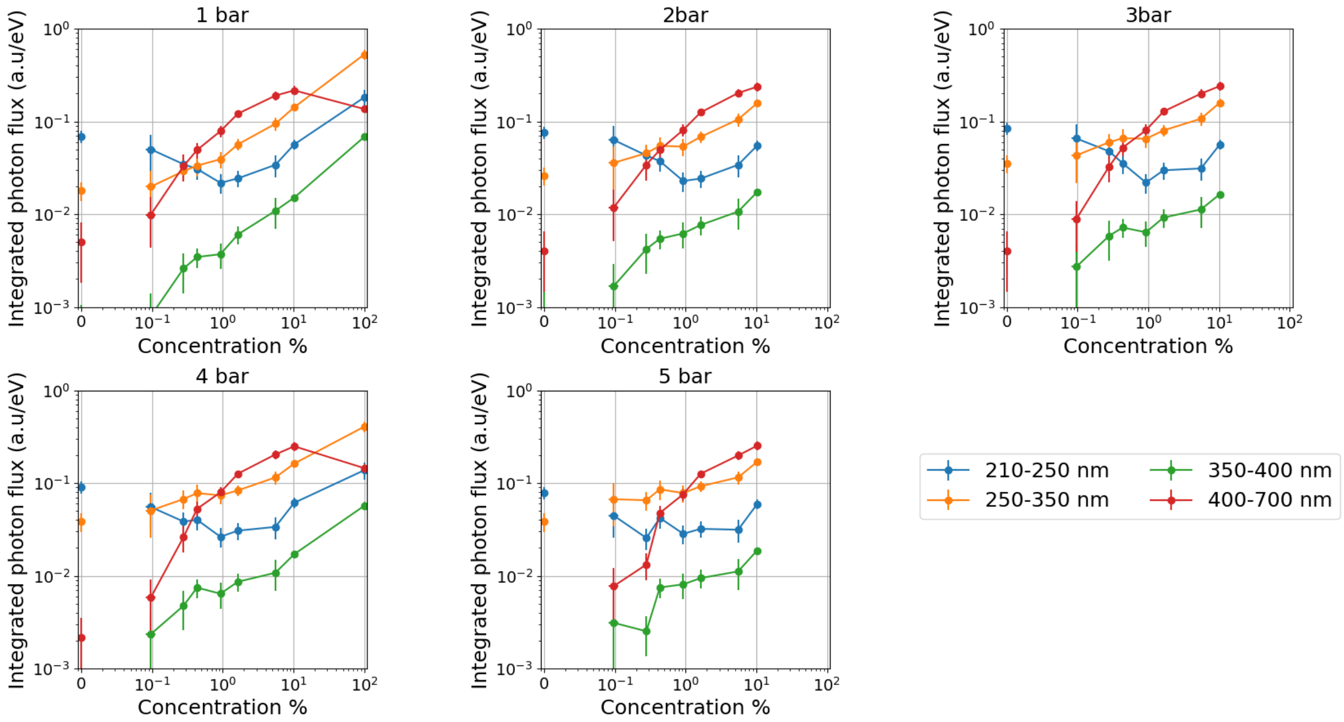


Spectra for Argon-CF_4



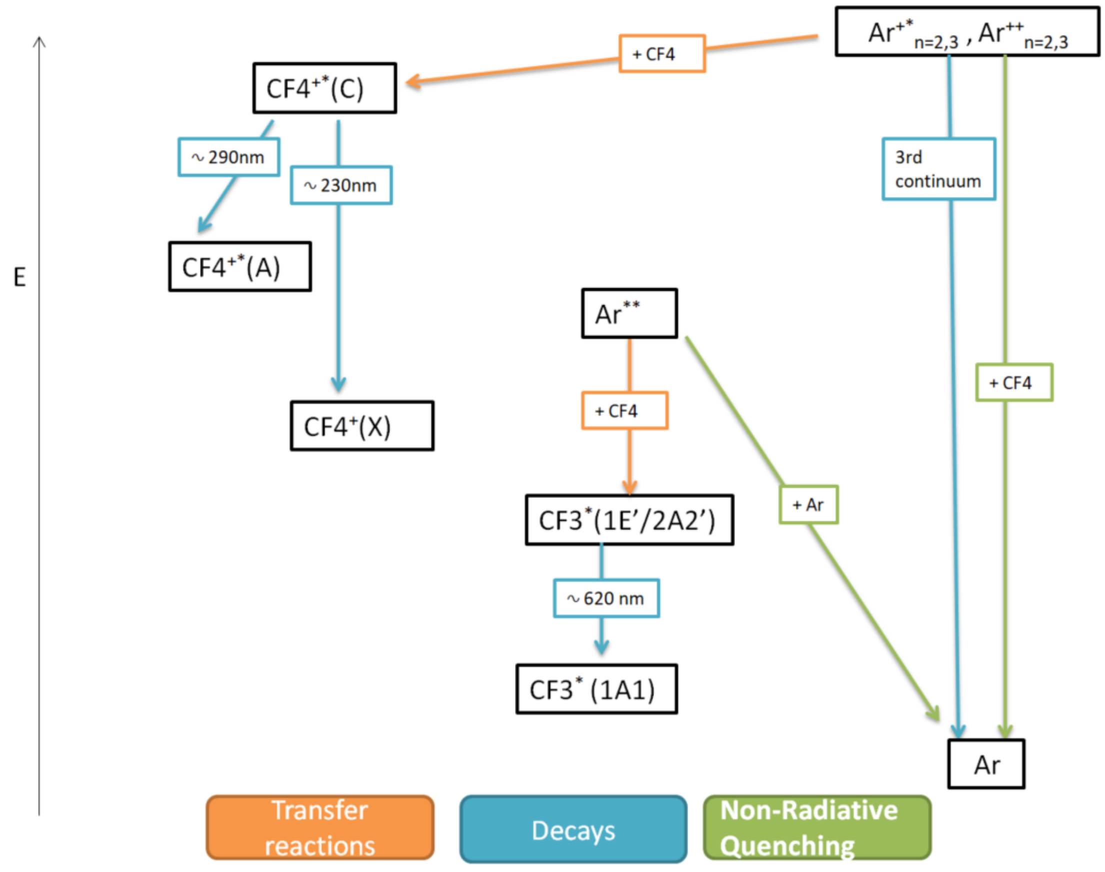
Band analysis

- The visible band seems to indicate the presence of an optimum
- The interplay of argon's third continuum and the UV scintillation of CF_4 causes the appearance of a minimum



Model and data comparison

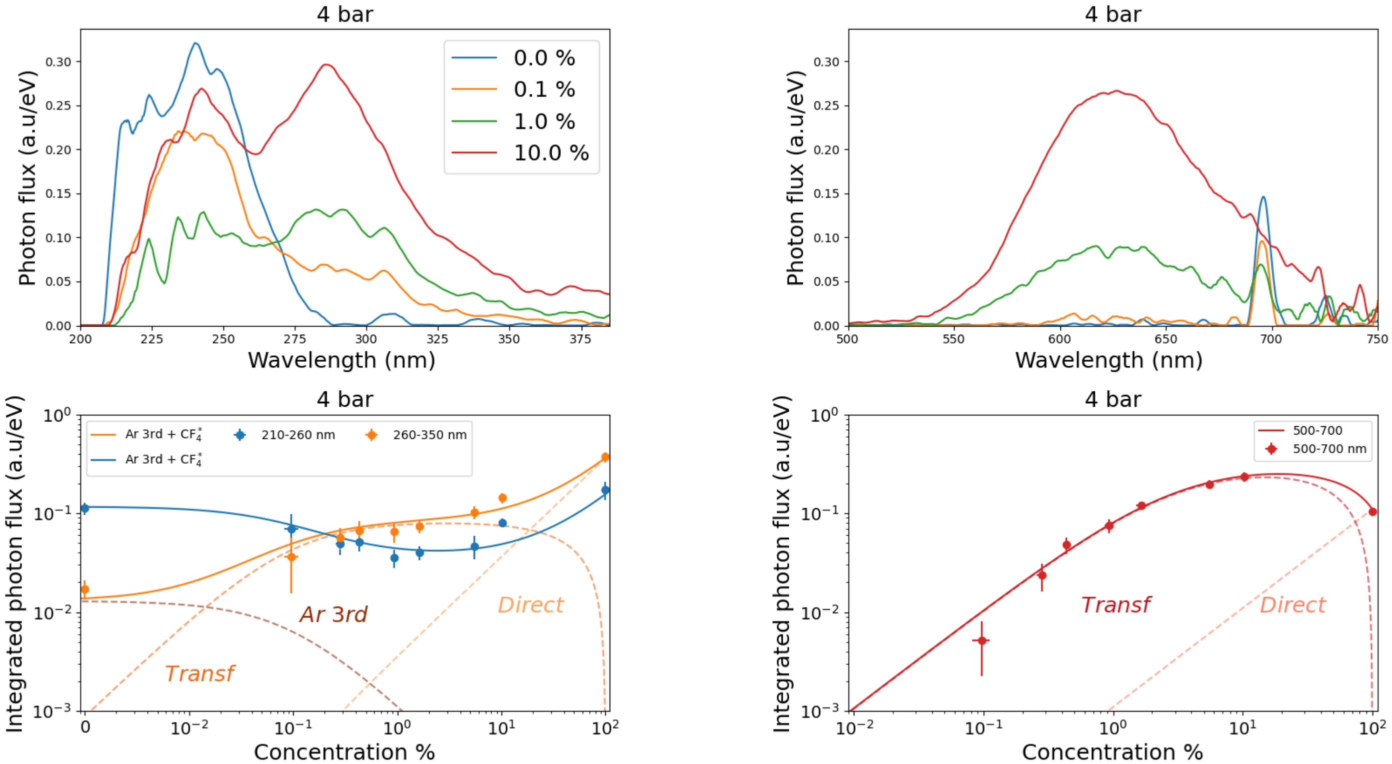
- A kinetic model was developed where we compute the scintillation probabilities of different states of interest, namely CF_4^{+*}(C), CF_3^{*}(1E´,2A2´) and an effective state representing the precursors of argon's third continuum



Model and data comparison

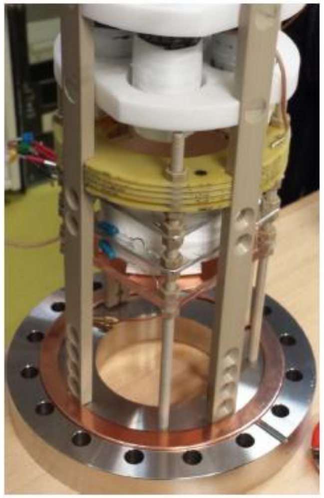
- A global fit to the data for each band was performed using a kinetic model with 4 free parameters -2 for the UV bands and 2 for the VIS bands-, resulting in a reduced chi-square of 1.5

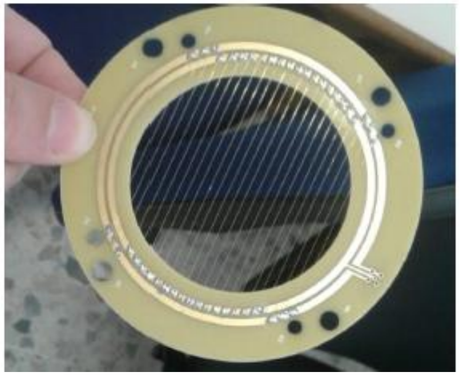
- Good agreement was found for both UV and VIS bands

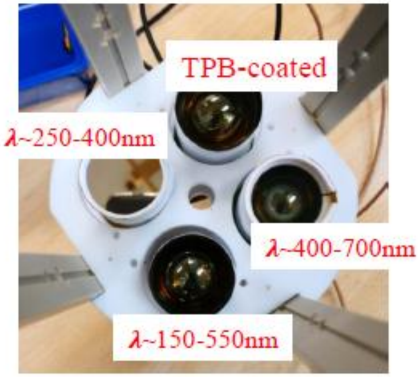


Experimental setup for yield measurements

- Yield measurements were done in our lab with an ^{241}Am source in the range of 400-700 nm and 250-400 nm at 10 bar
- Wire chambers design copied from ALICE and 4 PMTs with different filters, one of them coated with TPB



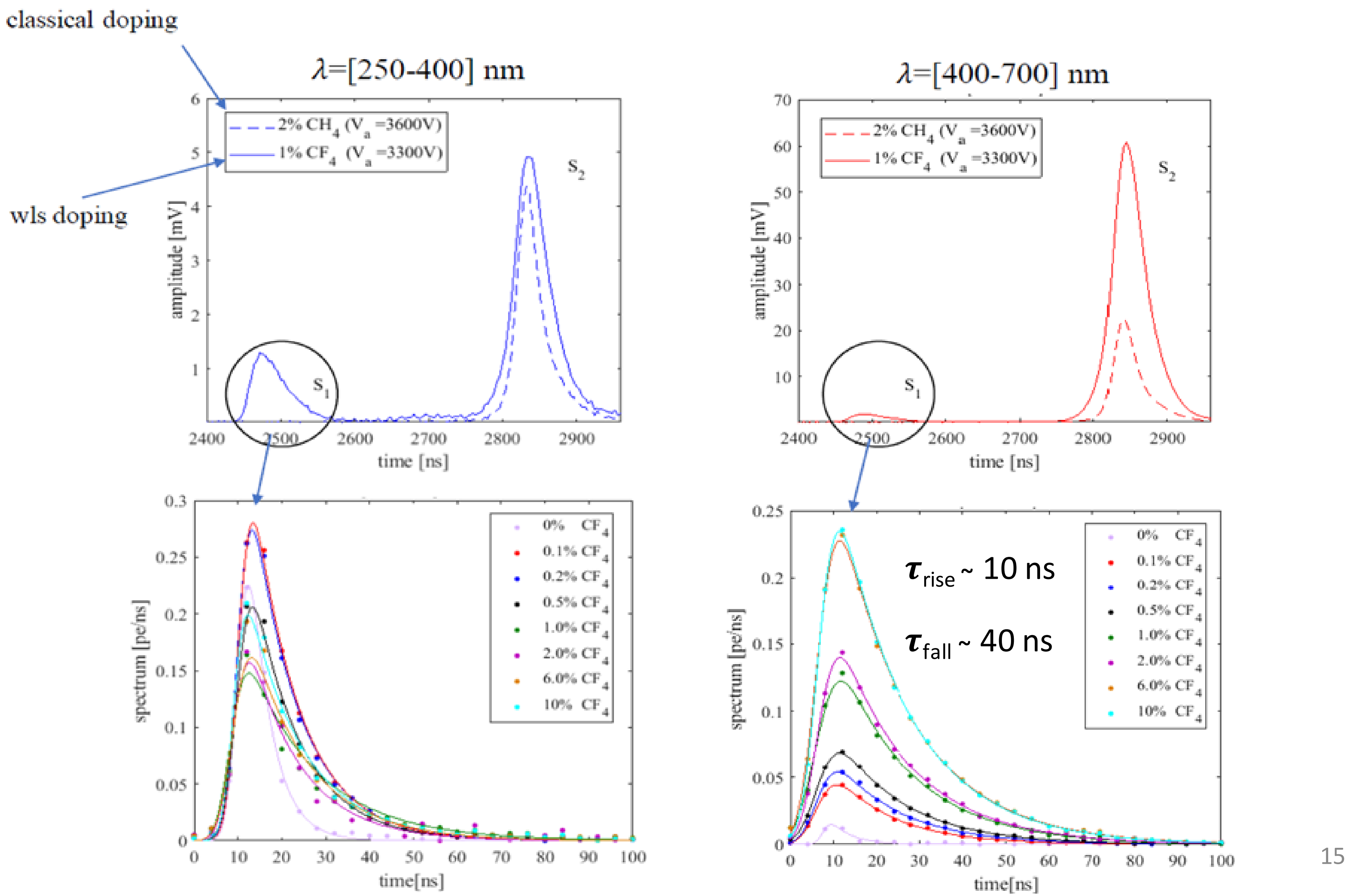




- We commissioned it in pure Xenon, with a purity compatible with less than 100 ppms of N_2, 1ppm O_2 and 1ppm H_2O
- Ws = 40 ± 10 eV and triplet constant of 98 ns

Time and band-resolved scintillation in time projection chambers based on gaseous xenon - S. Leardini et al

Time dependence of primary scintillation in Ar-CF_4 at 10 bar



Energy to produce a photon (W_{sc}) and time constant in $Ar\text{-}CF_4$ at 10 bar

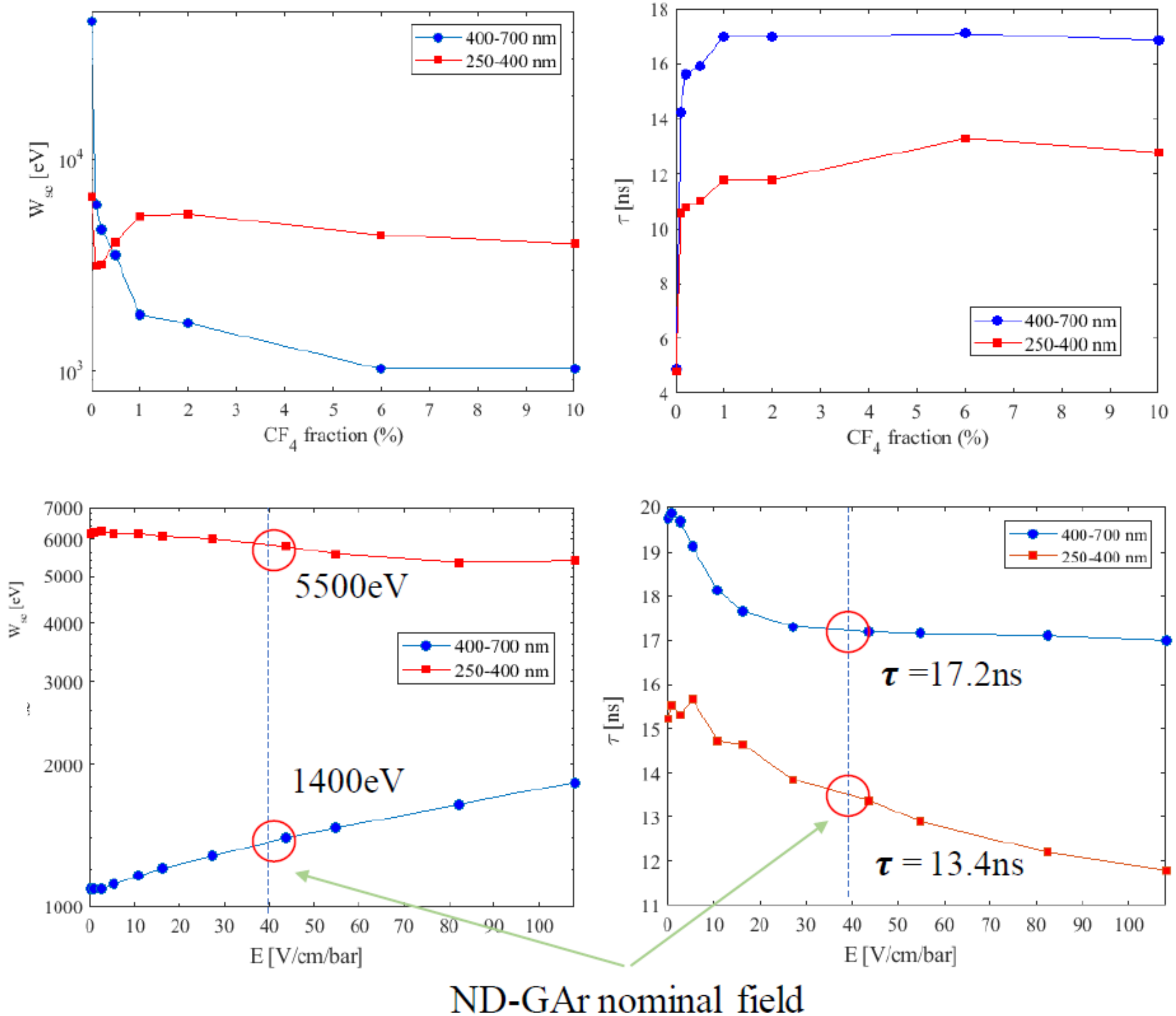
Results for different CF_4 concentrations at 100 V/cm/bar

Results for 1% with latest calibration:

1/Wsd [250-400 nm] = 200-300 ph/MeV

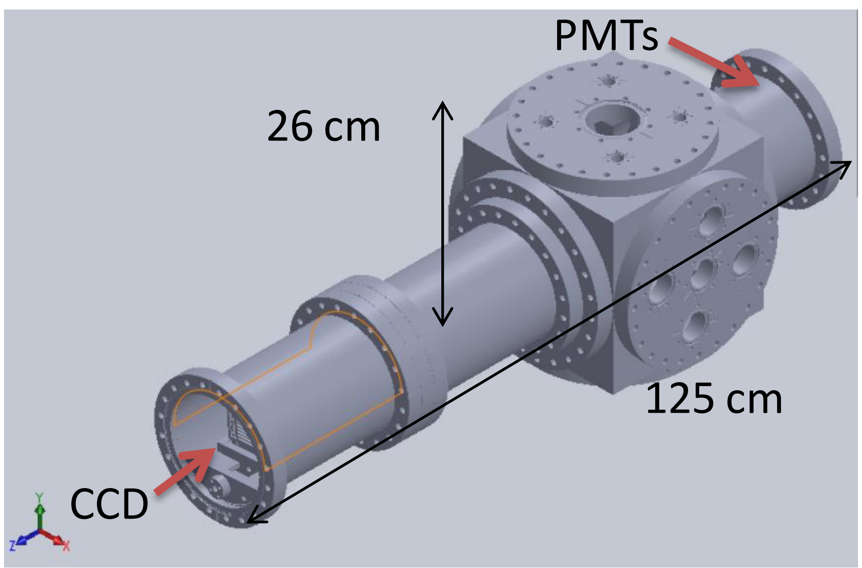
1/Wsd [400-700nm] = 1100-1800 ph/MeV

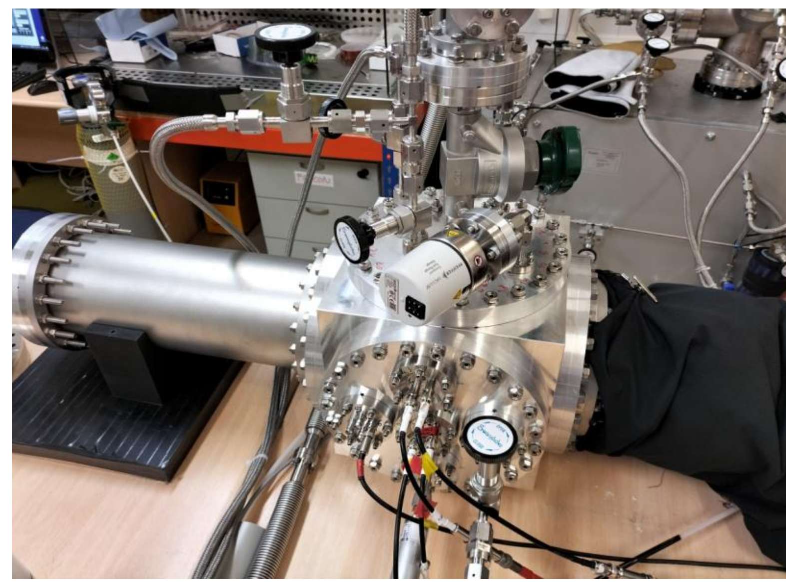
Results for 1% CF_4 for different reduced electrical fields



Technology demonstrator

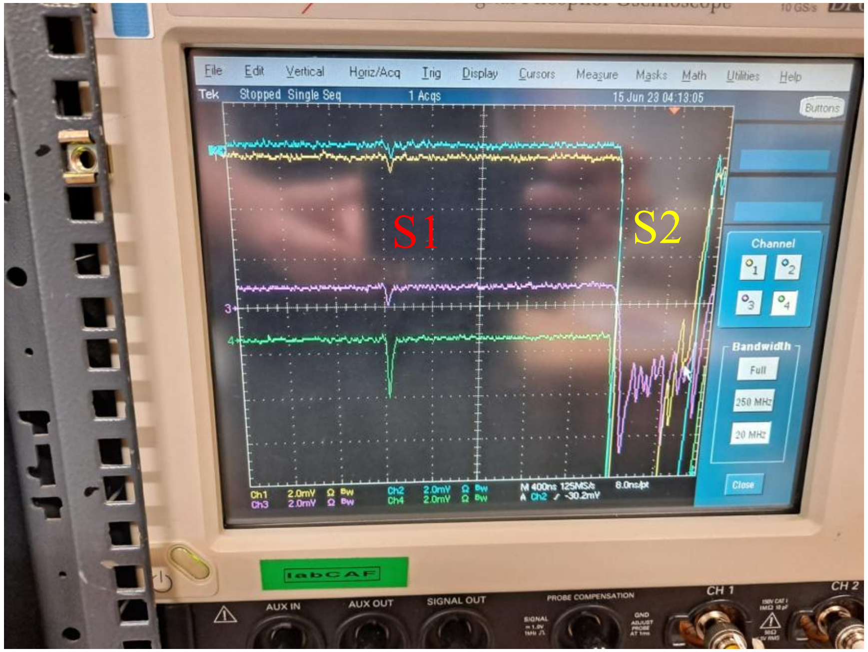
- An optical TPC has been assembled at the Galician Institute for High Energy Physics with an ^{241}Am source inside
- It has been instrumented with 4 PMTs to read the S1 and a CCD camera to do track readout. So far, only one acrylic THGEM is being used.

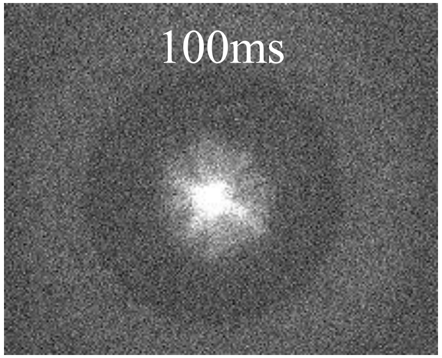


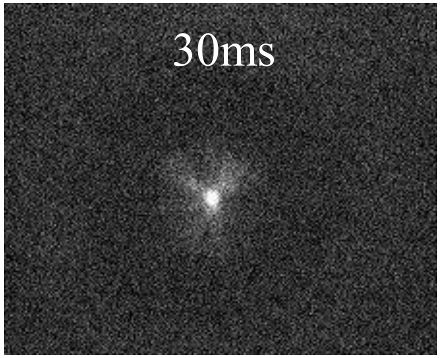


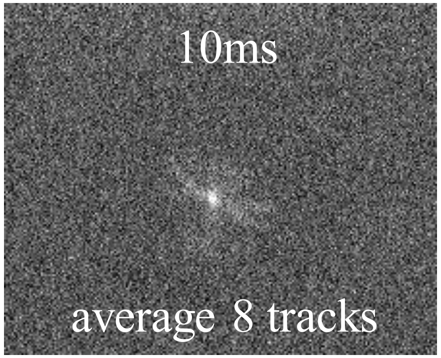
First light!

- Operated with 1% Ar-CF_4 at 1 bar
- Both S1 and S2 signals can be seen at the PMTs
- First tracks coming from the CCD camera









Summary, conclusions and future work

- There is convincing evidence of transfer reactions in Ar- CF_4 leading to a wavelength-shifting effect at CF_4 concentrations as low as 0.1%,
- At 1% there is strong scintillation both in the UV and VIS bands in the Ar- CF_4 mixture
- We have found a gas mixture, Ar- CF_4 at 1%, which allows a full optical readout to be implemented in ND-GAr while keeping the target nearly Argon-pure
- We have successfully built and instrumented an optical TPC using this gas mixture where we have seen alpha tracks with both S1 and S2 signals
- Our plans include an upgrade to a double THGEM and Timepix camera to do measurements at high pressure

Stay tuned!

Fin

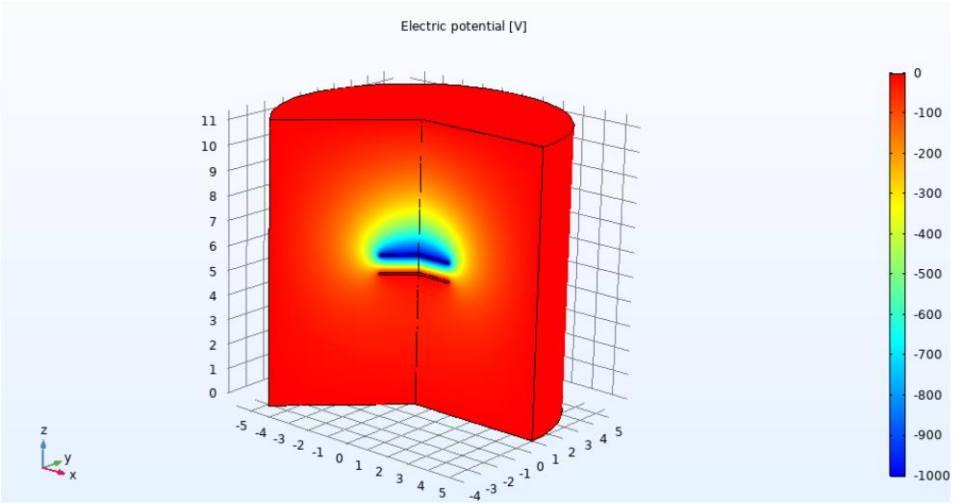
Thanks for your attention!

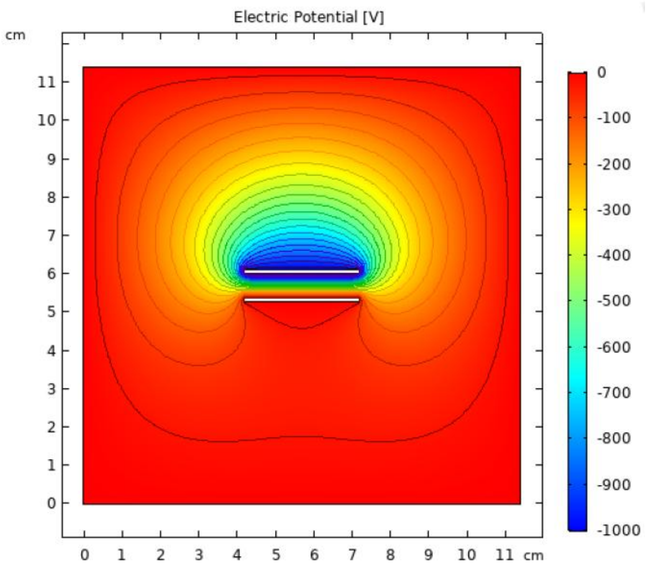
Appendix

Electric field uniformity

- A numerical simulation was run in COMSOL to check the field uniformity inside the chamber

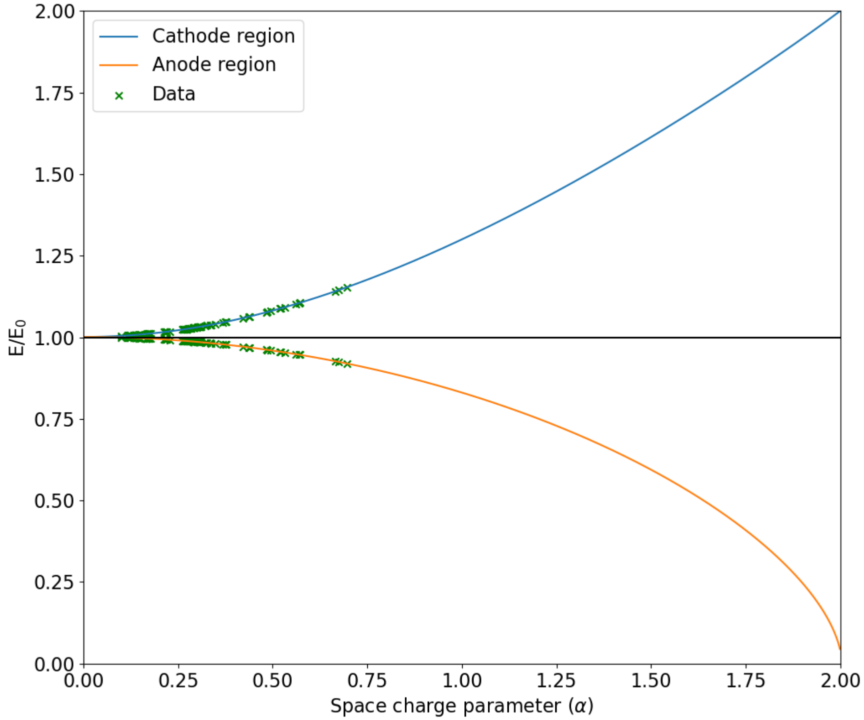
- We were limited to a 1cm diameter window from the x-rays tube





Space charge

- Particularly hard to demonstrate it is there and that it's affecting our measurements
- Following a reference paper we try to estimate this with an dimensionless parameter



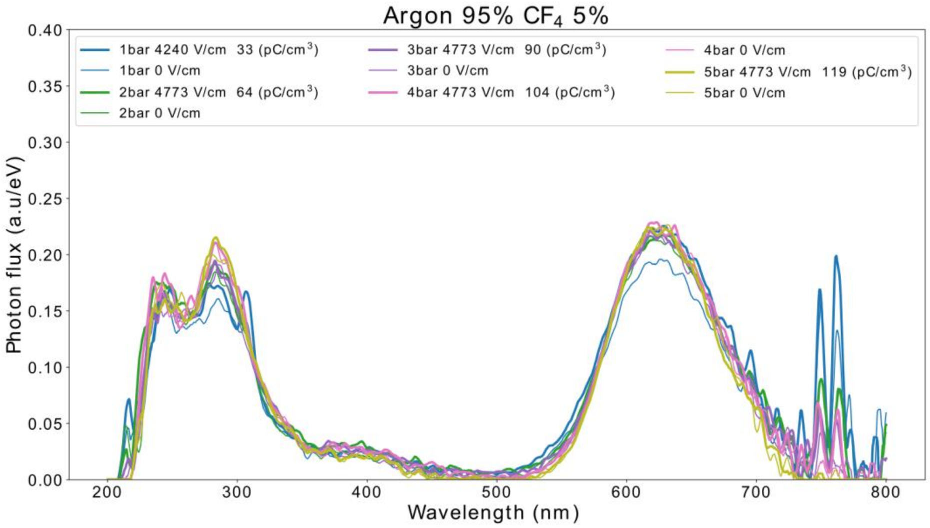
$$\alpha = \frac{D}{E_0}\sqrt{\frac{K}{\epsilon\mu}}$$

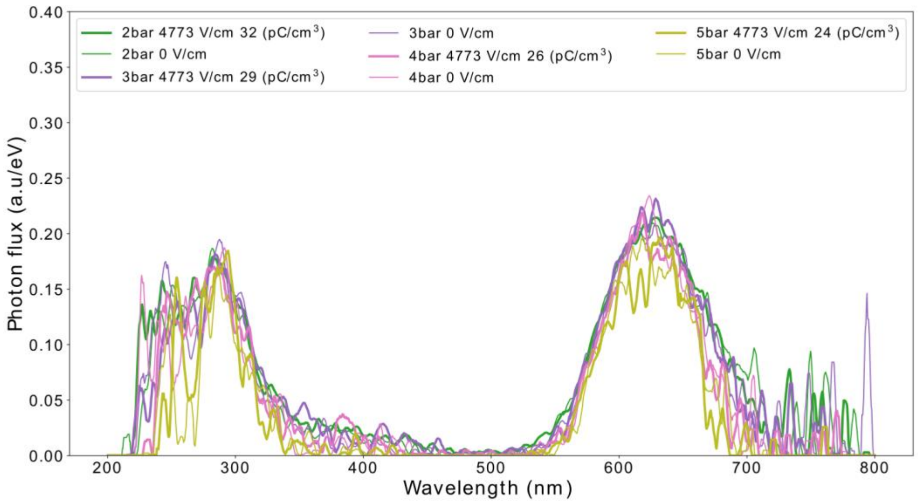
- D = Detector thickness
- E_0 = Applied field
- K = Number of ions
- Epsilon = Dielectric constant
- Mu = Ion mobility

Space Charge in Ionization Detectors, Sandro Palestini and Kirk T. McDonald, 2007 (updated 2016)

Recombination

- No sign of recombination in light emission
- Spectral shape is preserved between zero field and the collection field
- Ionization density (tube intensity) plays no role
- Based on previous experiments with alpha particles, this is expected given the ionization density





Simulation data

	E_{thres} [MeV]	5MeV hadrons		20MeV hadrons		internal muons ($\simeq$ 20-50 MeV)		external muons ($\simeq$ 20-50 MeV)	
		σ_t [ns]	σ_E/E	σ_t [ns]	σ_E/E	σ_t [ns]	σ_E/E	σ_t [ns]	σ_E/E
G_1	3.5 - 34	1 - 8.7	0.2 - 0.73	0.44 - 1.9	0.08 - 0.36	0.55 - 1.5	0.09 - 0.23	0.73 - 1.55	0.11 - 0.24
G_2	2.6 - 5.8	1 - 2.5	0.21 - 0.38	0.44 - 0.86	0.08 - 0.14	0.45 - 0.73	0.07 - 0.11	0.43 - 0.71	0.07 - 0.11
G_3	2 - 2.4	1 - 2.1	0.22 - 0.24	0.41 - 0.66	0.08 - 0.09	0.45 - 0.62	0.07 - 0.09	0.42 - 0.7	0.05 - 0.1