Wavelength-shifting in Ar-CF_4 mixtures towards NDGAr

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P.Amedo[1], F. Brunbauer[2], D. González-Díaz[1],S. Leardini[1], A. Saá-Hernández[1] ,D. J. Fernández-Posada[1], E. Oliveri[2], L. Ropelewski[2]

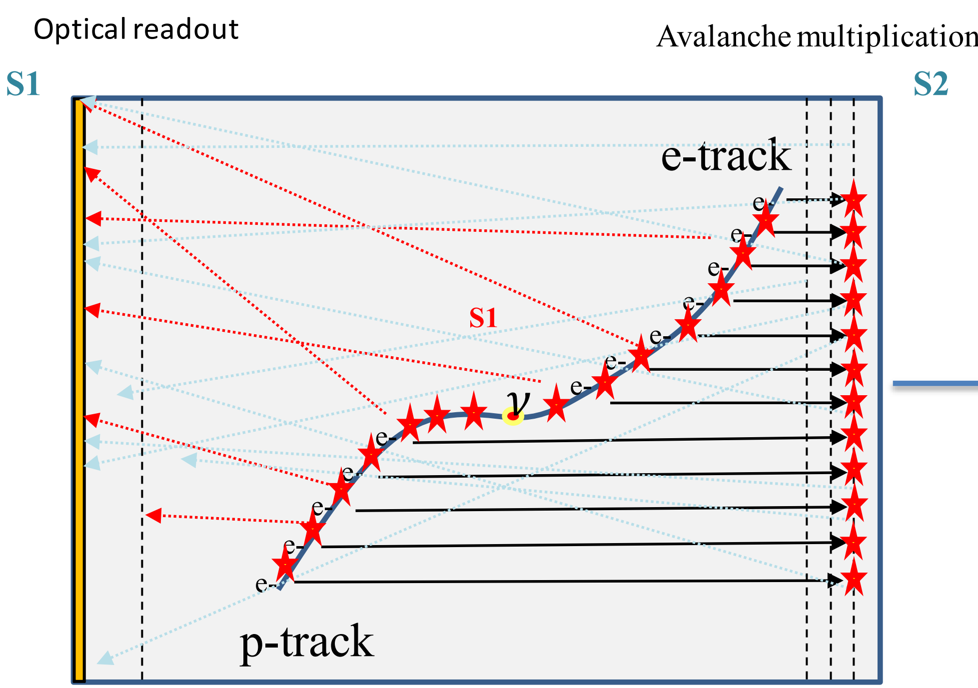
[1]Galician Institute for High Energy Physics (IGFAE), University of Santiago de Compostela

[2]CERN, Geneva, Switzerland

Introduction

- Our main goal is to try and enable an optical readout in ND-GAr, which would give us access to the T_0 information of the interactions

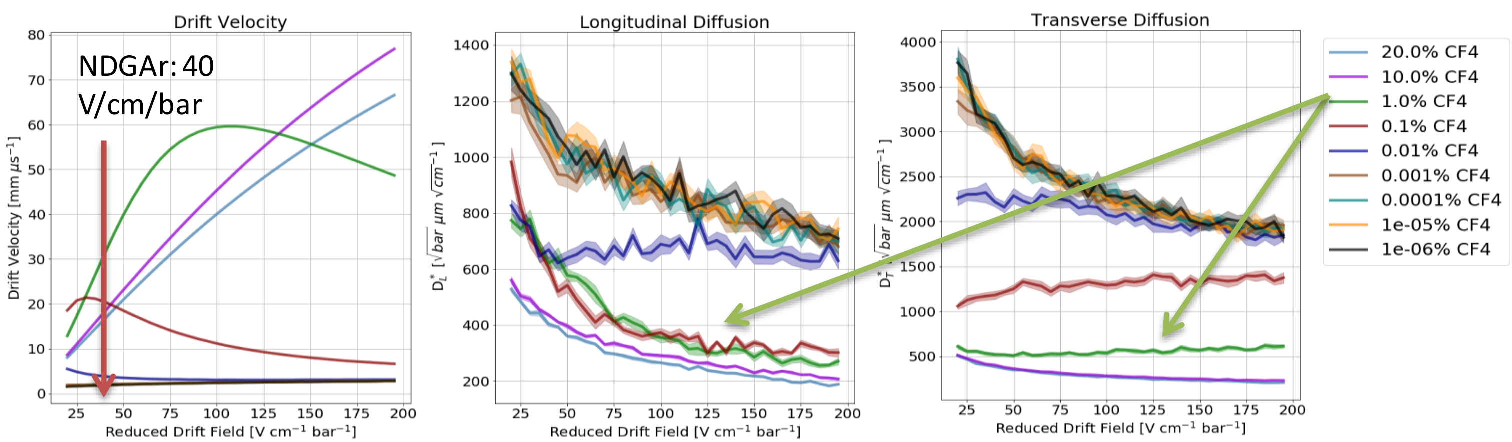
- This could improve track matching with ND-LAr, neutron/gamma identification via ToF, and open the possibility of doing very low-energy physics (like hyperons) and BSM.



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 increases drift velocity
  - It quenches VUV-photons and prevents destabilization of the avalanche-process due to photoelectric effect

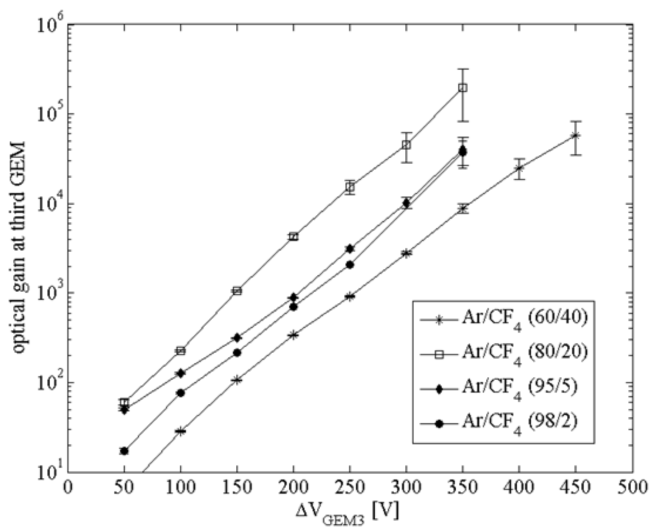
- However, finding a scintillating mixture that provides all those benefits while keeping the target Argon-pure is not obvious. Possible candidate: CF_4



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 baseline ND-GAr (from 3.1 at 2% CH_4 to 1.8 at 10% CH_4)
  - No attachment at working drift fields (40 V/(cm·bar))
  - At 1% of CF_4 the mass fraction is below the one of the P10 gas (Argon 90% CH_4 10%)
  - Highly inert and compatible with getters
  - It scintillates in the UV and visible bands so latter can be detected using commercial photosensors
  - Some previous works have shown charge gains up to 10^4-$3\cdot10^5$, with which optical gains of 10^4 are possible



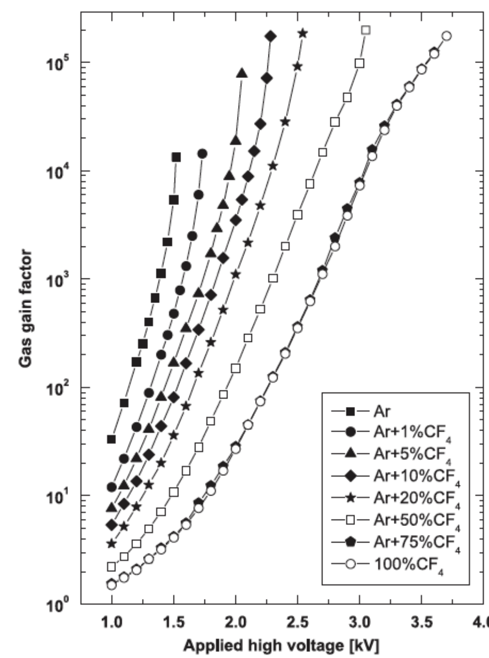
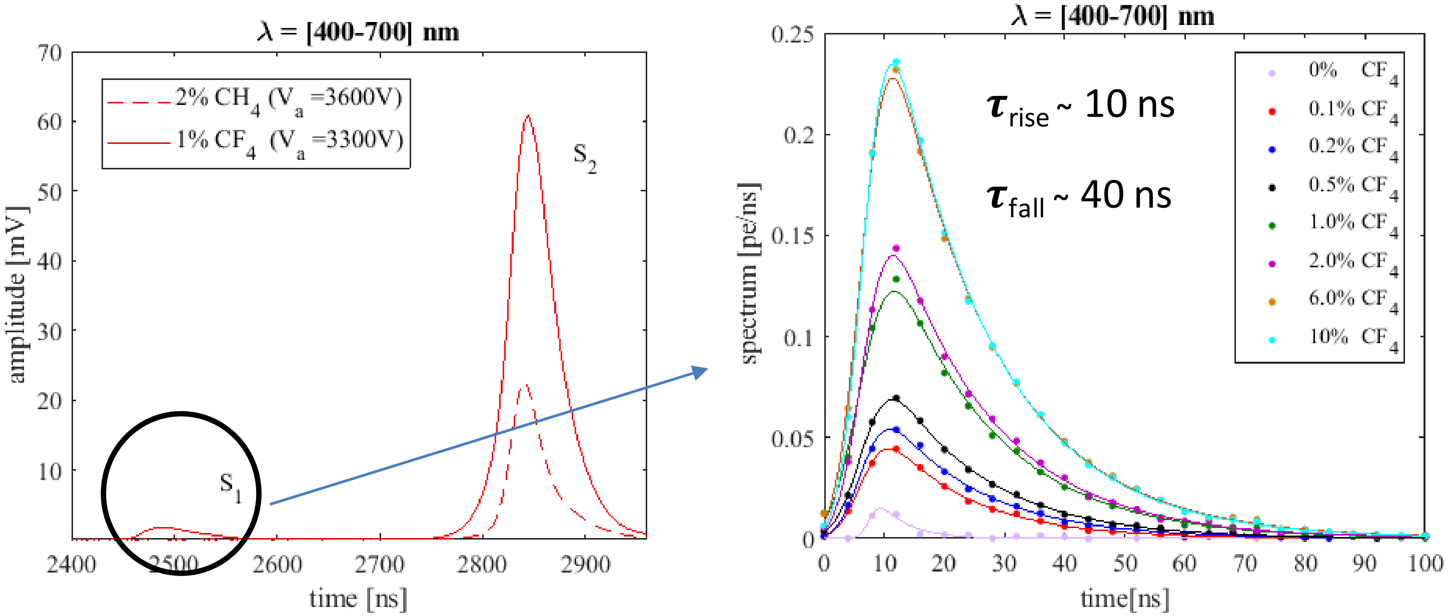


Fig. 1. Gas gain as the function of applied high voltage for Ar + CF_4 mixtures.

Previous results

- Yield measurements were done in our lab with an ^{241}Am source in the range of 400-700 nm and 250-400 nm
- We have found a gas mixture, Ar- CF_4 at 1%, which allows for the optical readout to be implemented while keeping the target nearly Argon-pure
- Geant4 simulations show that an energy threshold of 5 MeV and O(1ns) time tagging can be achieved through a SiPM plane at the cathode

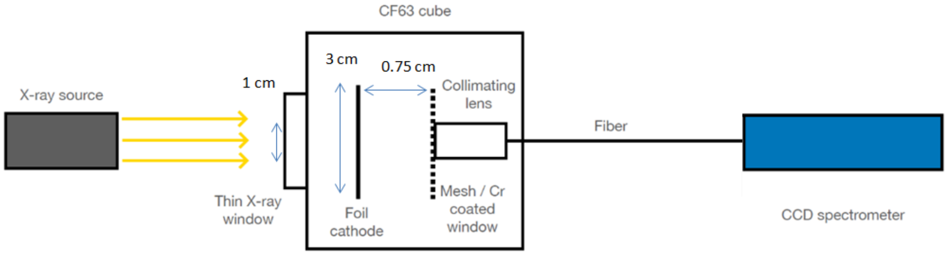


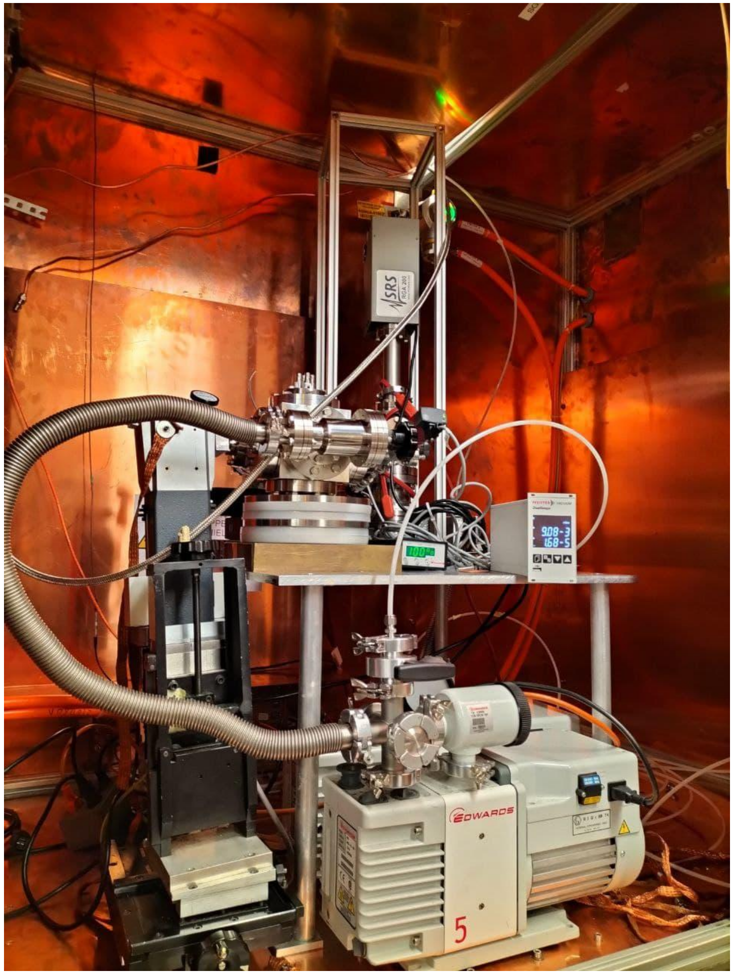
Objectives

- Nevertheless, there were no measurements of the spectral components of the primary scintillation in Ar- CF_4
- Our objective was to measure the S1 scintillation spectrum from Ar- CF_4 mixtures at low concentrations (0.1-10%) and different pressures using and x-ray tube

Experimental setup

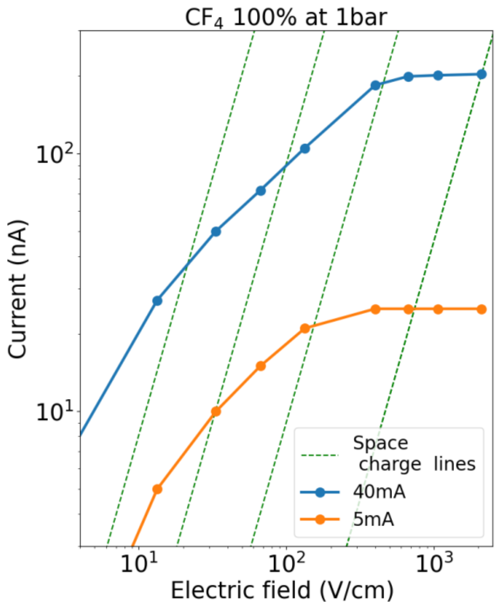
- A small chamber was built with a thin aluminum entrance window, an aluminum foil as cathode and an anode were we collected the current
- We collected the light with a CCD spectrometer after the gas was irradiated with an x-ray tube
- The system had an RGA for purity control and the main impurities found were water, nitrogen and oxygen

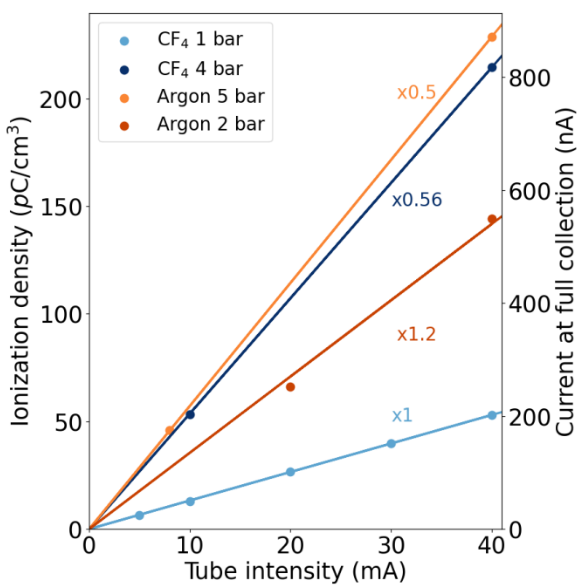




Experimental setup

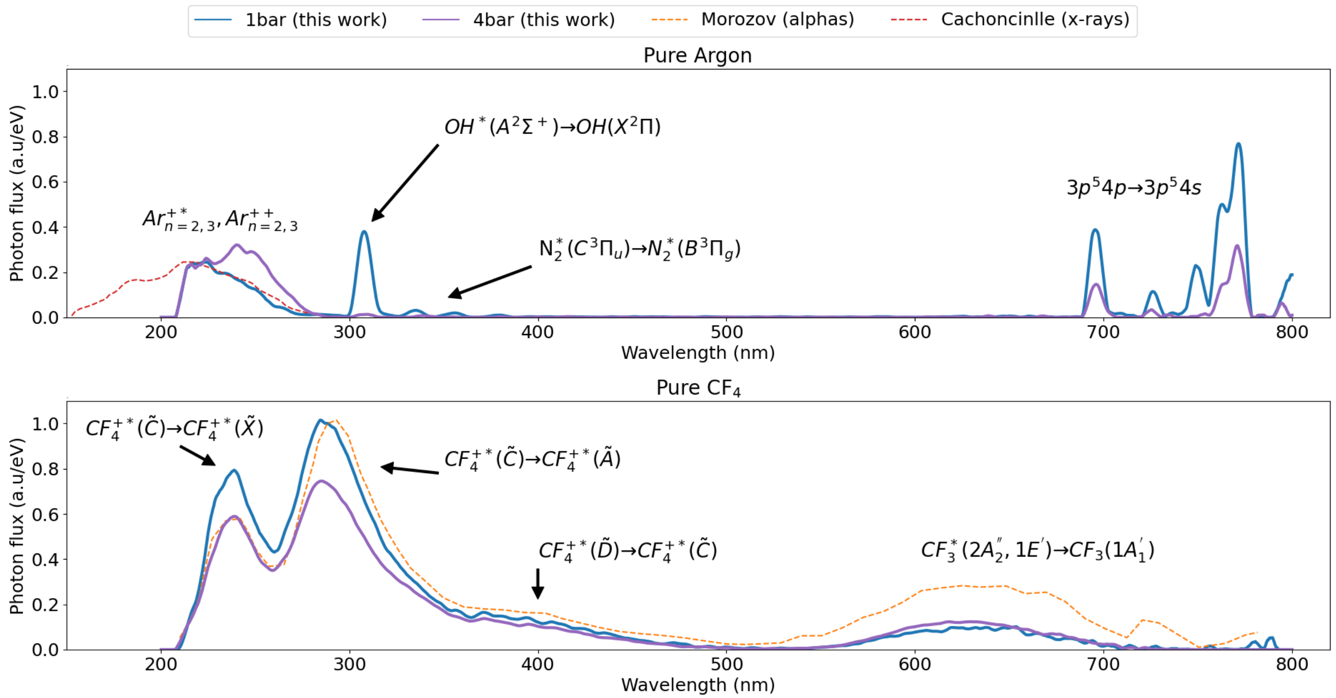
- Measurements were taken at no field and at a field high enough to ensure current saturation. Different tube intensities, pressures and mixtures were explored
- All results are proportional to the number of photons detected divided by the saturation current and the W_I value for each mixture
- We see 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 in CF_4^{+*}, CF_3^*, argon's third continuum and its atomic decays
- Peaks from impurities in the chamber come from OH and N_2



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

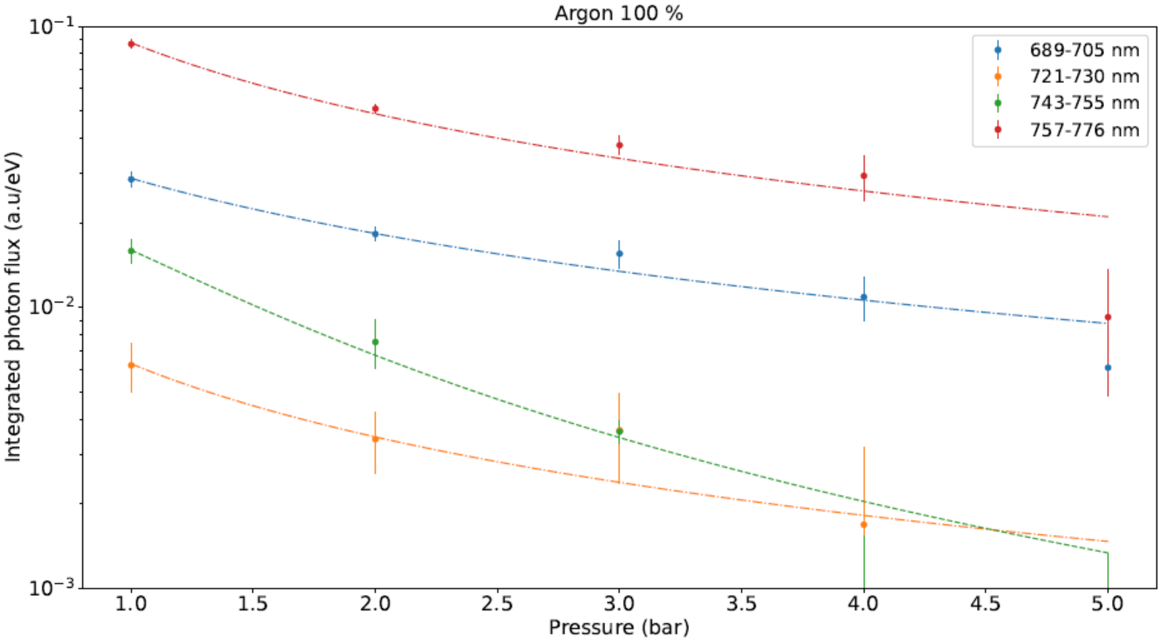
Effect of the electric field on the primary scintillation from CF4 A. Morozov et al

Peak analysis

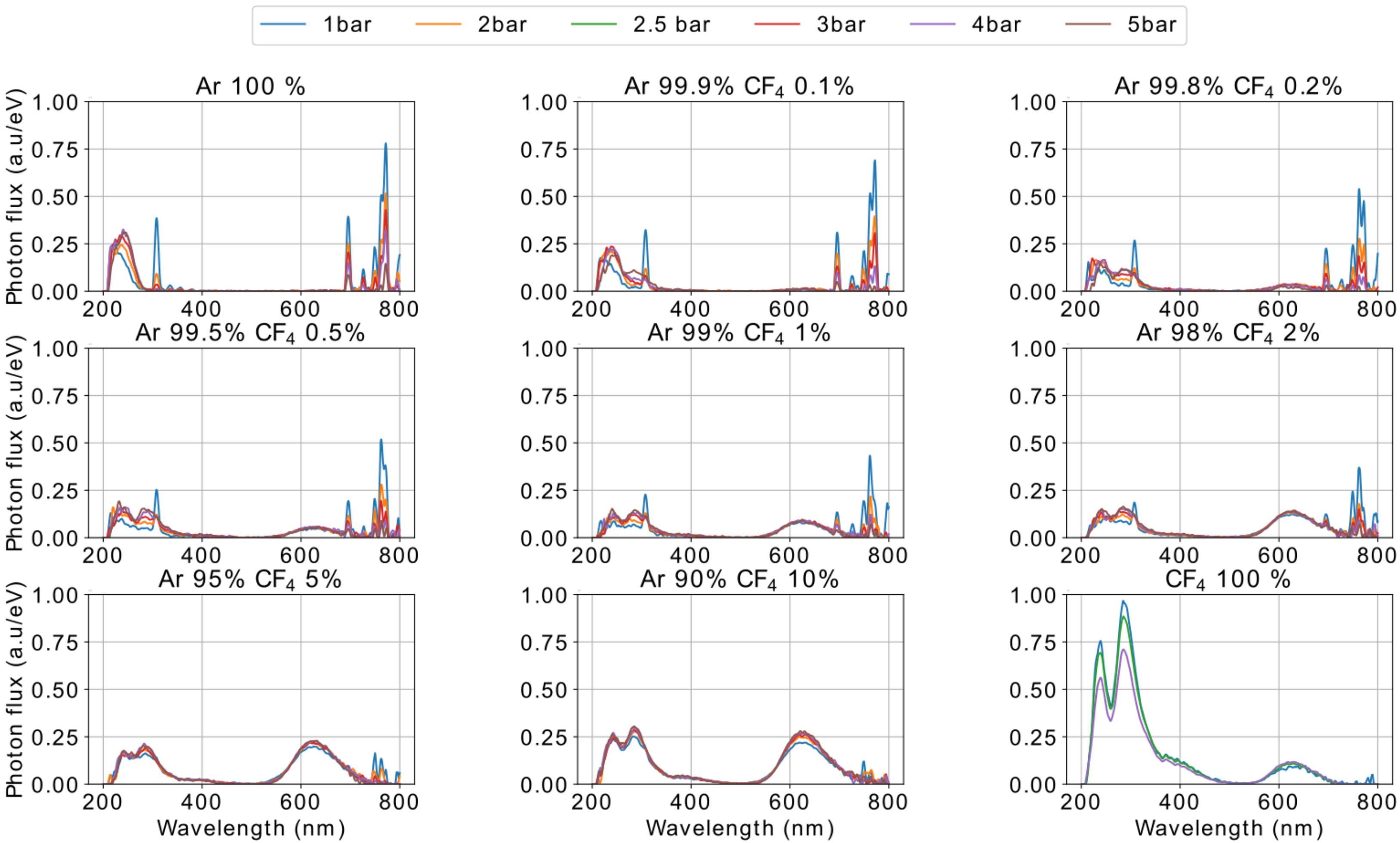
- In general, the impurity peaks tend to decrease with pressure and CF4 concentration

- 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

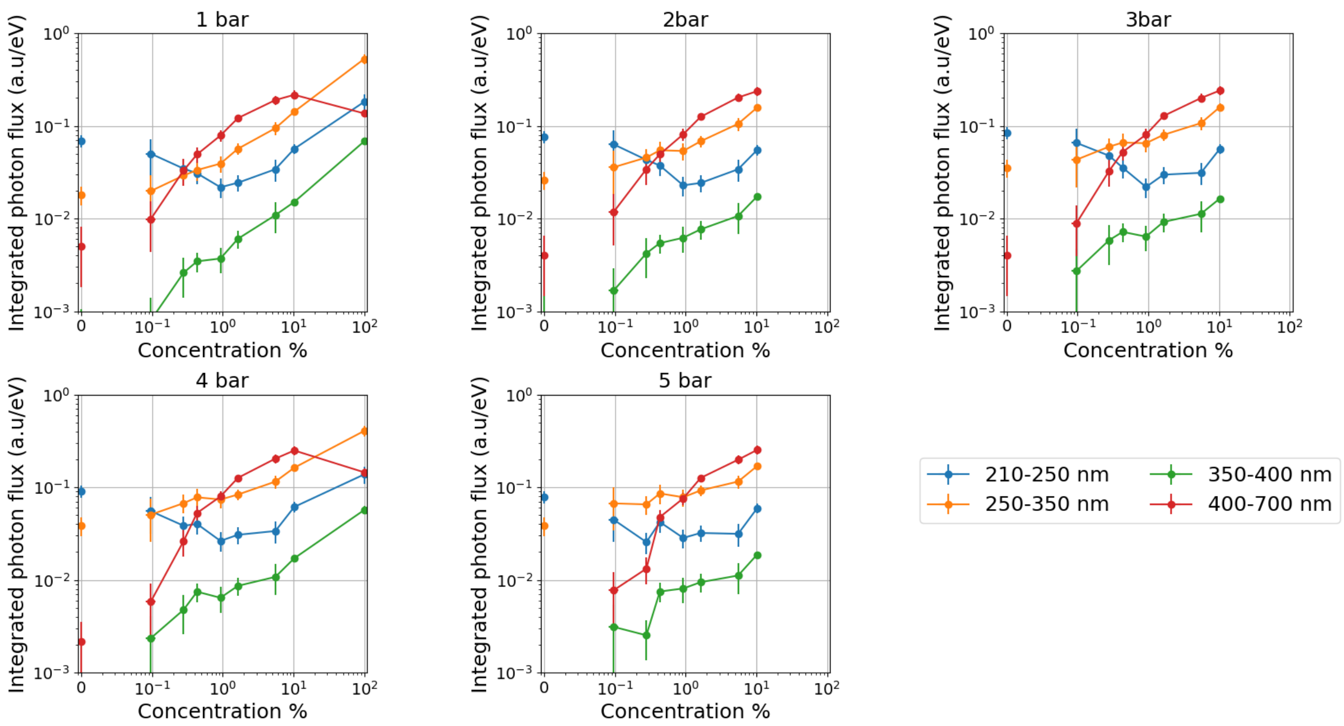


Spectra for Argon-CF4



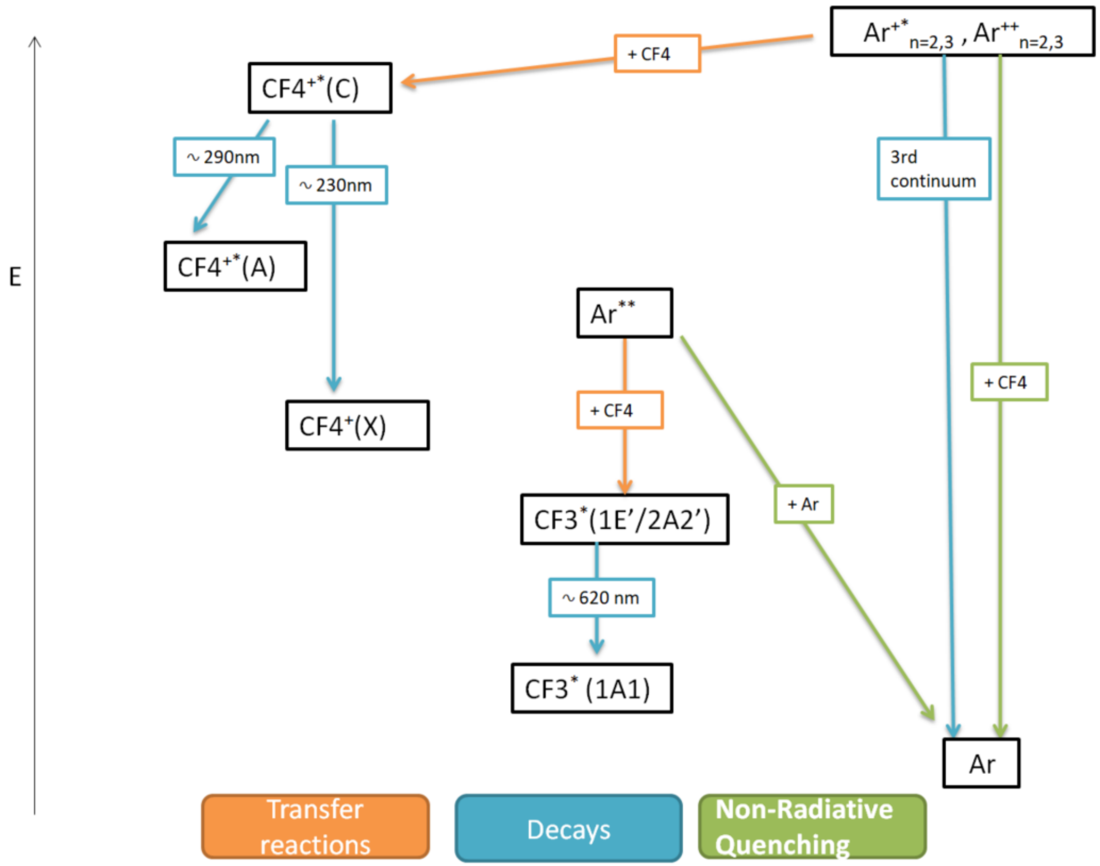
Band analysis

- 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

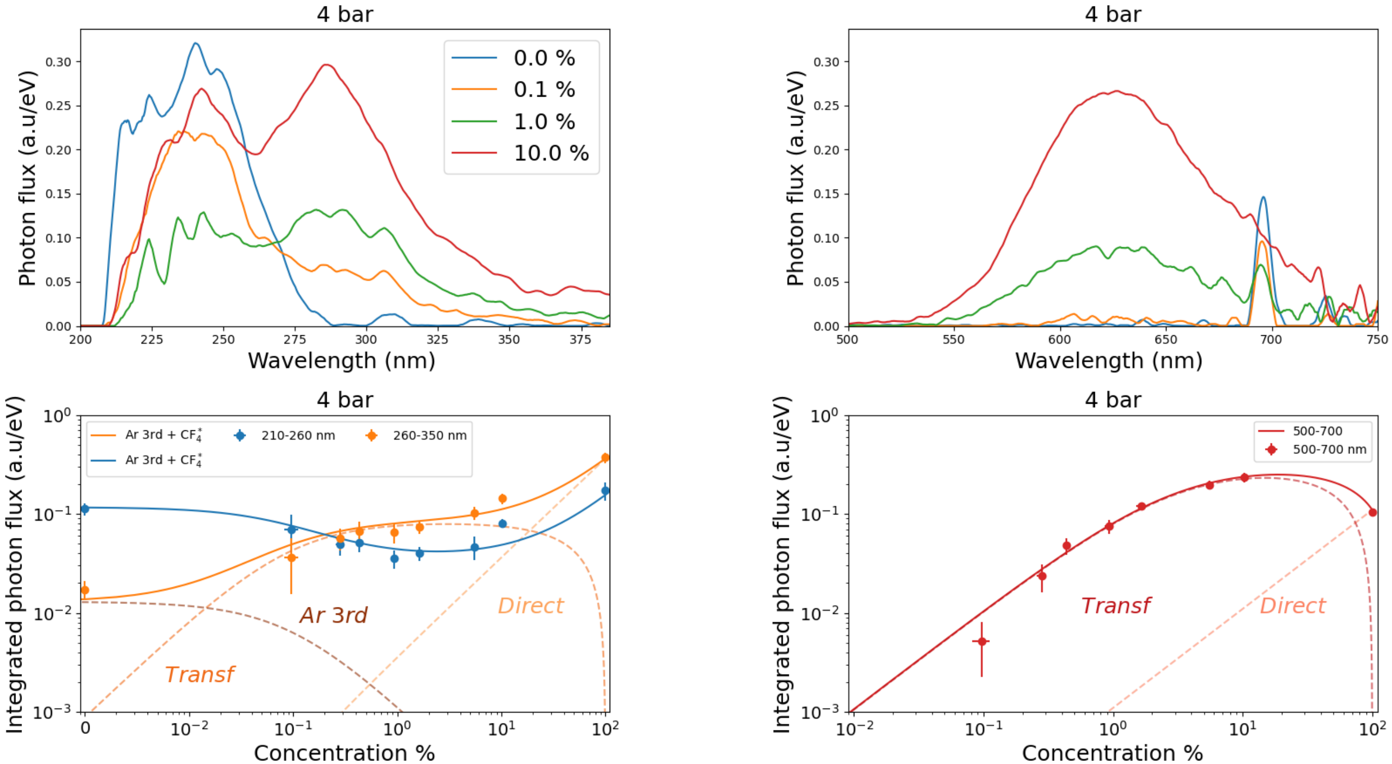
- A kinetic model was developed where we compute the scintillation probabilities of different states of interest, namely CF_4^{+*}(C), CF_3^{*}(1E´,2A2´) and an effective state representing the precursors of argon's third continuum



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



Summary and conclusions

- Recently, we measured the primary scintillation spectrum for different Ar- CF_4 mixtures and pressures, including pure Argon and pure CF_4, with an x-ray tube

- Based on our most up-to-date results, including simulations and experiments, a mixture of Ar- CF_4 at 1% is adequate for a future detector like NDGAr operated with optical readout

Mixture: Argon 99% CF4 1%				
UV yield (ph/MeV)	**VIS yield (ph/MeV)**	**Diffussion at 10 bar over 5 meters (mm)**	**Rise time (ns)**	**Fall time (ns)**
300	1400	3.54	~10	~40
Drift velocity (cm/μs) at nominal field (40 V/cm/bar)	**Breakdown voltage at 10 bar (kV)** [1]	**Optical gain at 1 bar**[2]	**Time resolution for 5 MeV hadrons (ns) (G4 sim)**[3]	**Time resolution for 5 MeV hadrons (ns) (G4 sim)**[3]
4	61 (1 cm) 670 (10 cm)	10^4-10^5	1-2.5	21-38

1-Dielectric Strength of Noble and Quenched Gases for High Pressure Time Projection Chambers, L. Norman et al, 2021

2- D. González-Díaz, A survey on GEM-based readouts and gas mixtures fo optical TPCs, Vienna Conference 2016, https://indico.cern.ch/event/391665/contributions/1827205/

3-Saá-Hernández et al, On the determination of the interaction time of GeV-neutrinos in large argon-gas TPCs, to be submitted to JHEP

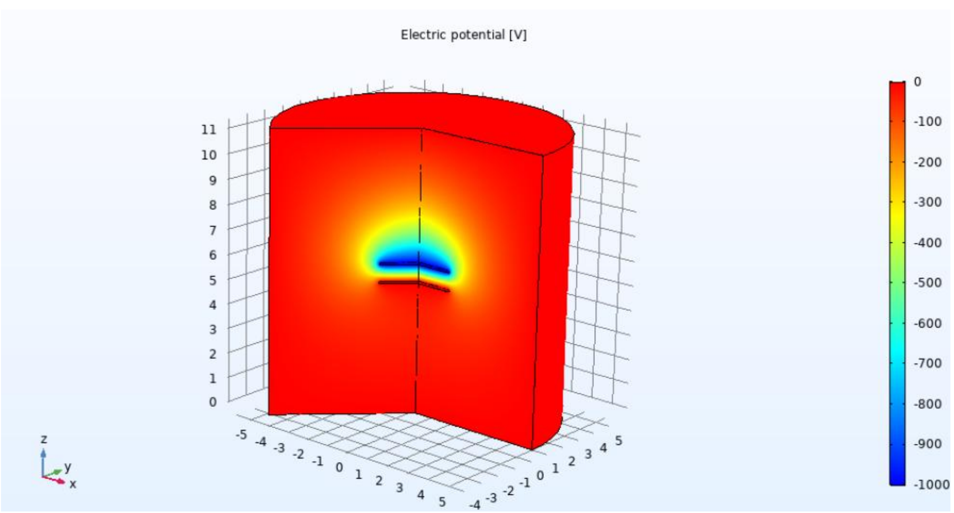
Fin

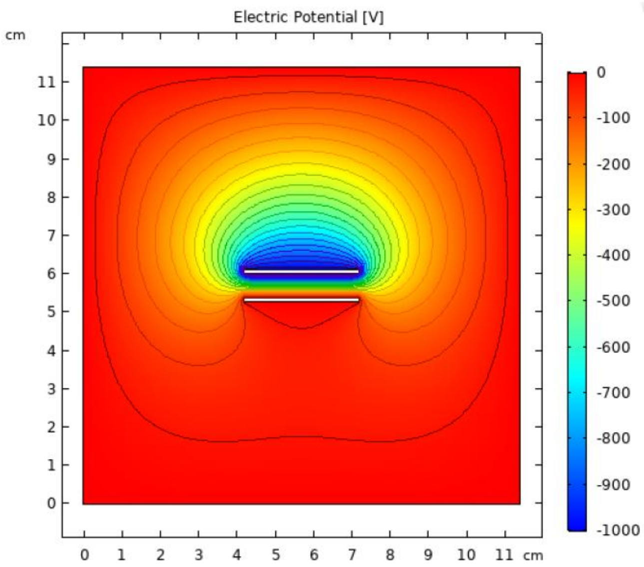
Thanks for your attention!

Appendix

Electric field uniformity

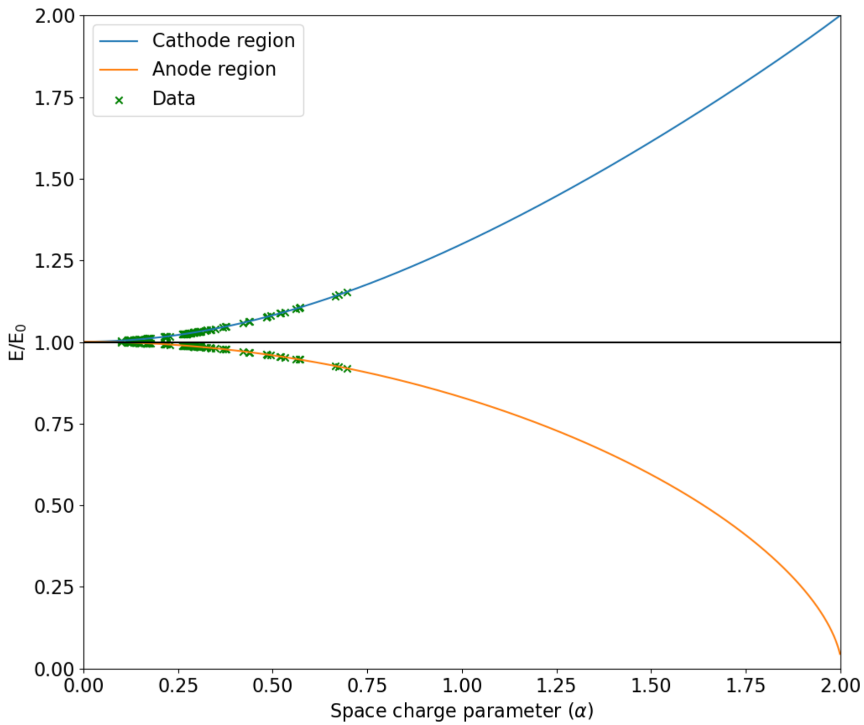
- A numerical simulation was run in COMSOL to check the field uniformity inside the chamber
- We were limited to a 1cm diameter window from the x-rays tube





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



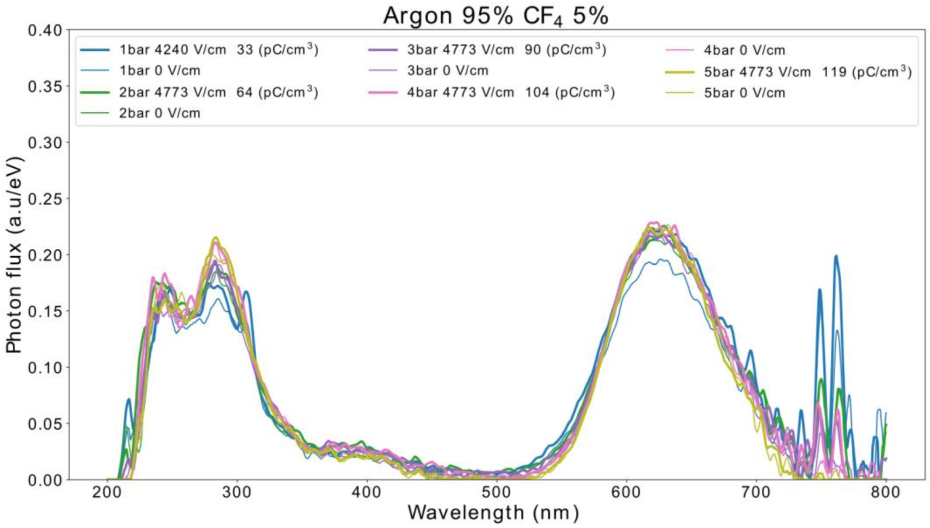
$$\alpha = \frac{D}{E_0}\sqrt{\frac{K}{\epsilon\mu}}$$

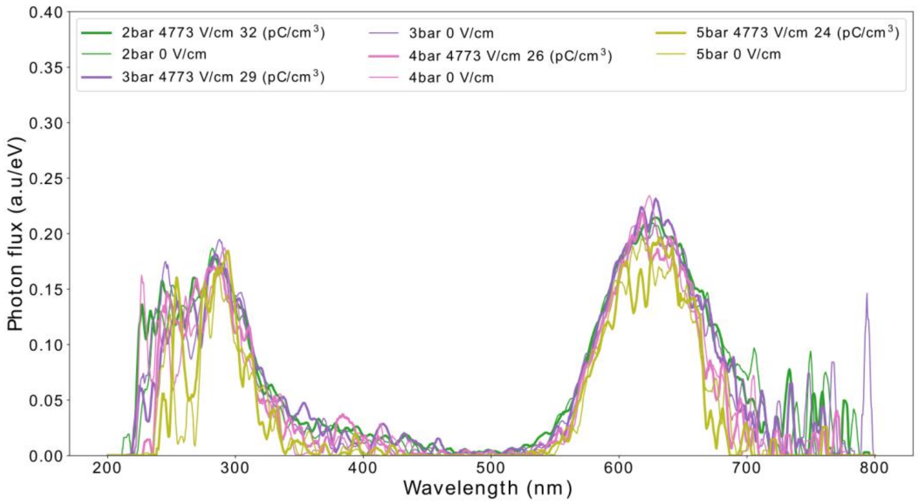
- D = Detector thickness
- E_0 = Applied field
- K = Number of ions
- Epsilon = Dielectric constant
- Mu = Ion mobility

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

		5MeV hadrons		20MeV hadrons		internal muons ($\simeq$ 20-50 MeV)		external muons ($\simeq$ 20-50 MeV)	
	E_{thres} [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