Primary and secondary scintillation of Ar/N2 and Ar/CF4 mixtures under X-ray irradiation

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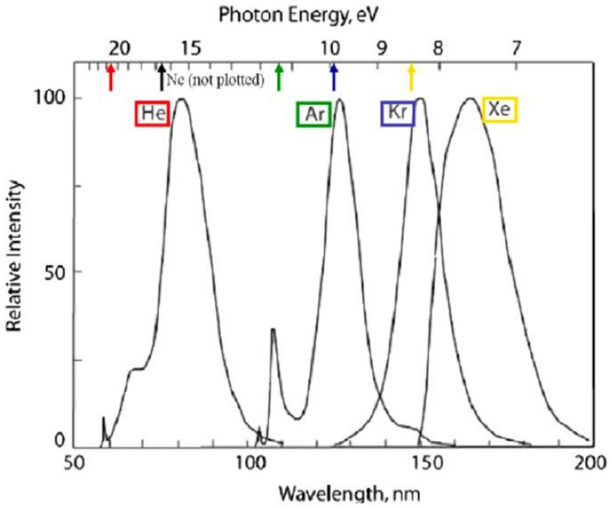
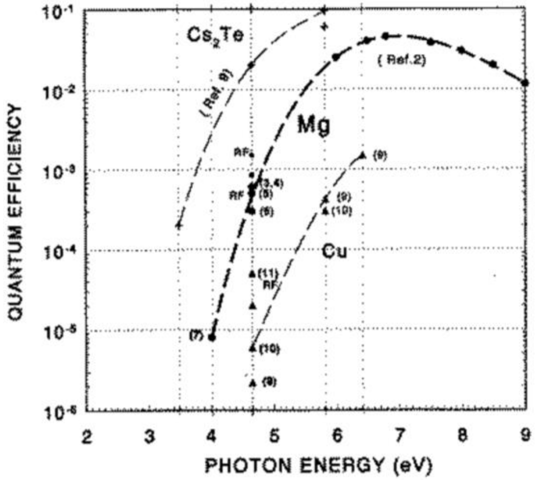
Optical readout

- Alternative to traditional charge readout
- Advantages:
  - Cheaper
  - Easier to get highly pixelated readouts
  - Simpler readout
- Principal problem: VUV emission and photon feedback



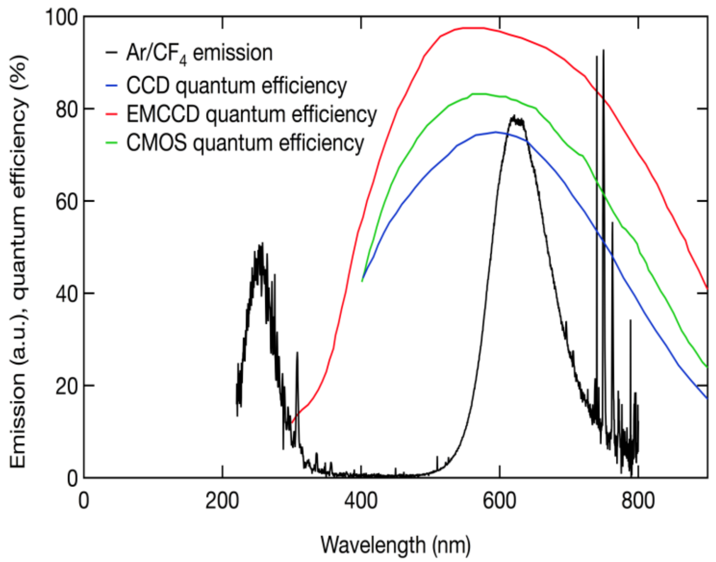


CF4 and motivation for this work

- CF_4:
  - Good VUV quencher
  - Scintillation spectra in the visible region (good Q.E.)
  - Good electron cooler
- Problems:
  - High GWP
  - Becoming more expensive

Need to find alternative gases (eco-gases)

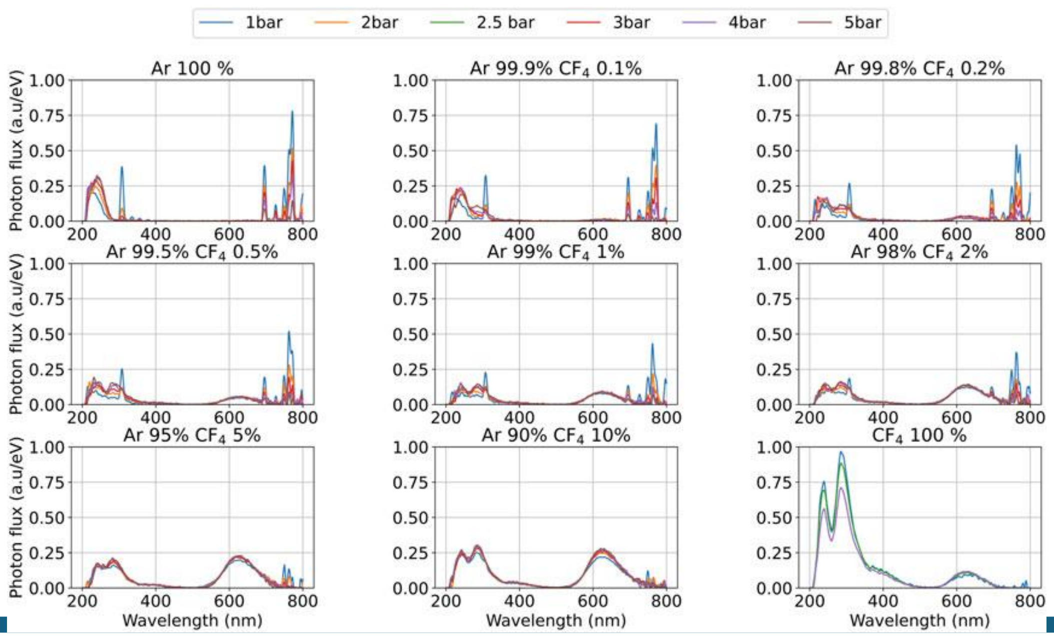
Nitrogen

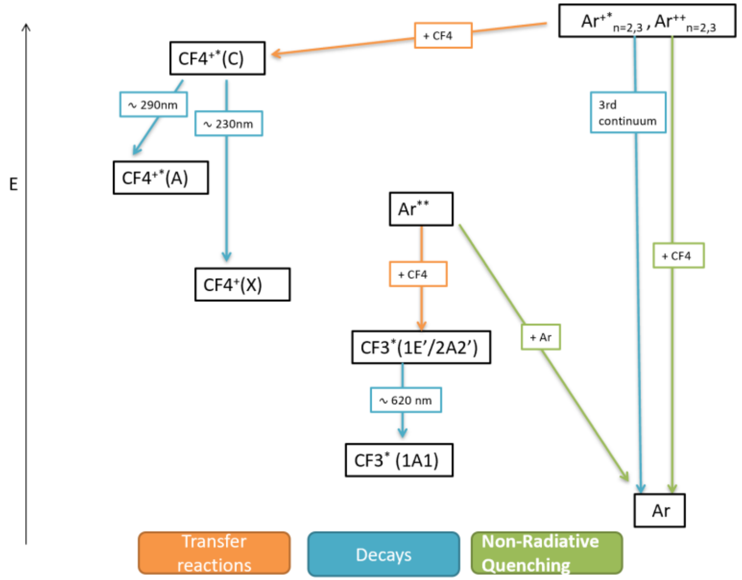


GHG	Lifetime (years)	GWP
CH_4	12	18
N_2O	114	298
HFC-125	29	4,713
HFC-134a	14	1,966
HFC-152a	1.4	191
HFC-143a	52	7,829
CF_4	50,000	7,597
C_2F_6	10,000	17,035
SF_6	3,200	31,298

Primary scintillation: previous work

- Measurements on Ar/CF_4 for different concentrations and pressures → Good agreement with spectra
- Scintillation model for Ar/CF_4
- Good understanding of CF_4 wavelength-shifting mechanism





$$CF_4^{+,*}(\tilde{C}) \overset{\tau_{CF_4(C->X)}}{\longrightarrow} CF_4^{+}(\tilde{X}) + h\nu(230\text{ nm})$$

$$CF_4^{+,*}(\tilde{C}) \overset{\tau_{CF_4(C->A)}}{\longrightarrow} CF_4^{+,*}(\tilde{A}) + h\nu(290\text{ nm})$$

$$CF_3^{*}(2A_2'', 1E') \overset{\tau_{CF_3}}{\longrightarrow} CF_3(1A_1') + h\nu(630\text{ nm})$$

$$Ar^{**} + CF_4 \overset{k_{Ar^{**}->CF_3^*}}{\longrightarrow} Ar + CF_3^{*}(2A_2'', 1E')$$

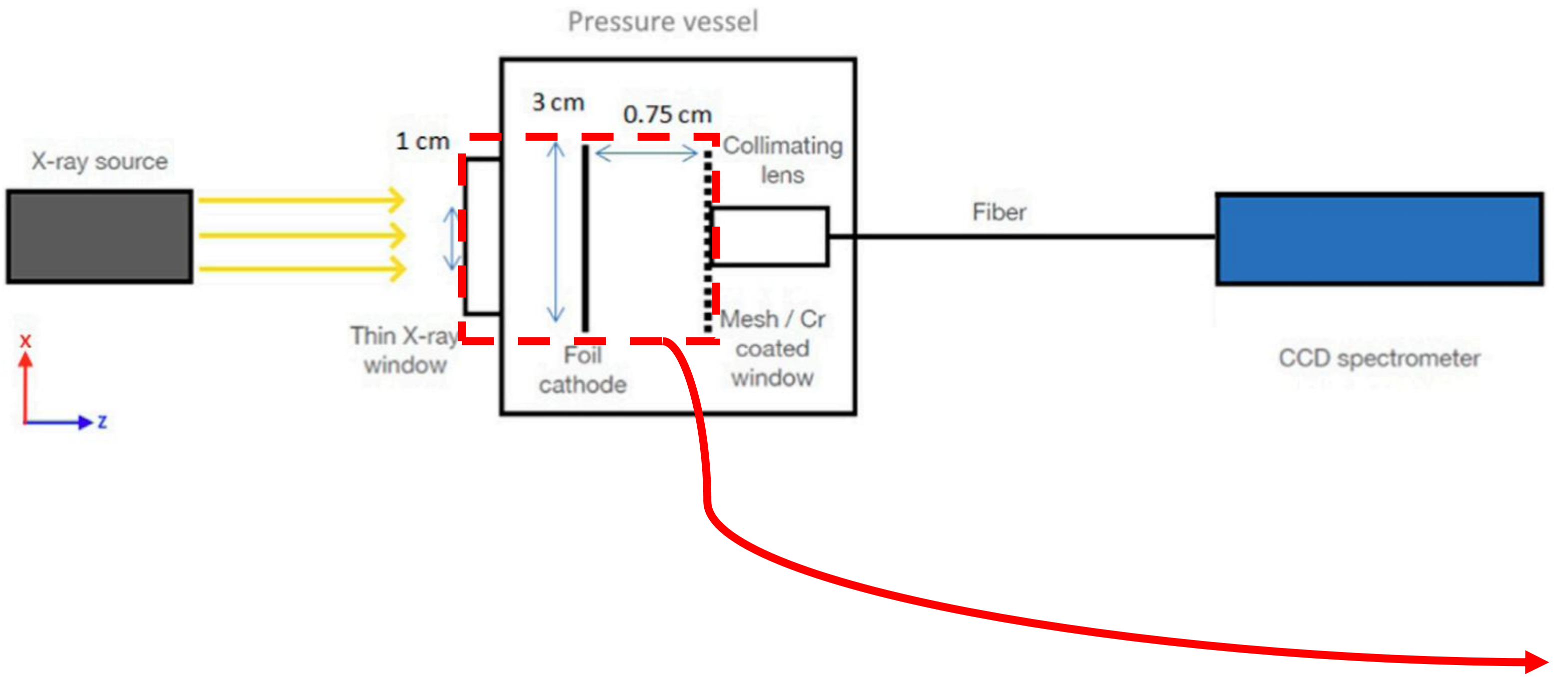
$$Ar^{**} + Ar \overset{k_{Ar^{**}->Ar^*}}{\longrightarrow} Ar^{*} + Ar$$

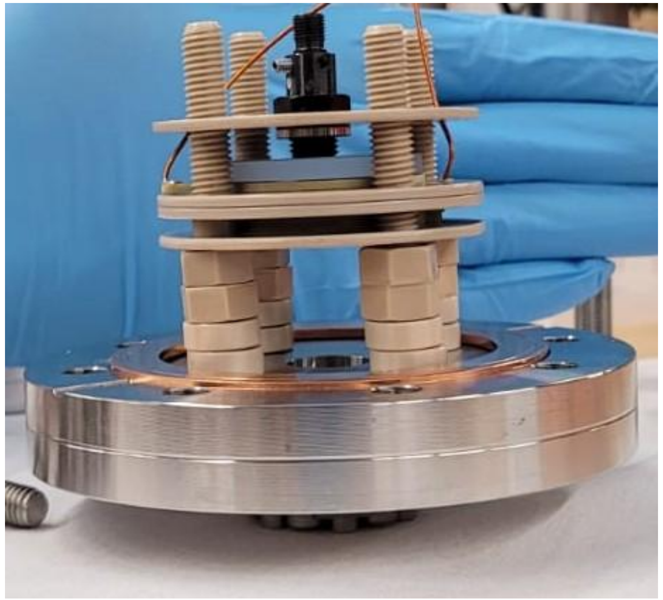
$$Ar_{n=2,3}^{+,*}(Ar_{n=2,3}^{++}) + CF_4 \overset{\kappa_{Ar3rd->CF_4^{+,*}}}{\longrightarrow} Ar + CF_4^{+*}(\tilde{C})$$

$$Ar_{n=2,3}^{+,*}(Ar_{n=2,3}^{++}) + CF_4 \overset{k_{Ar3rd->Ar}}{\longrightarrow} \text{non} - \text{radiative}$$

Amedo, P., et al. "Observation of strong wavelength-shifting in the argon-tetrafluoromethane system." *Frontiers in Detector Science and Technology* 1 (2023): 1282854.

Scintillation setup



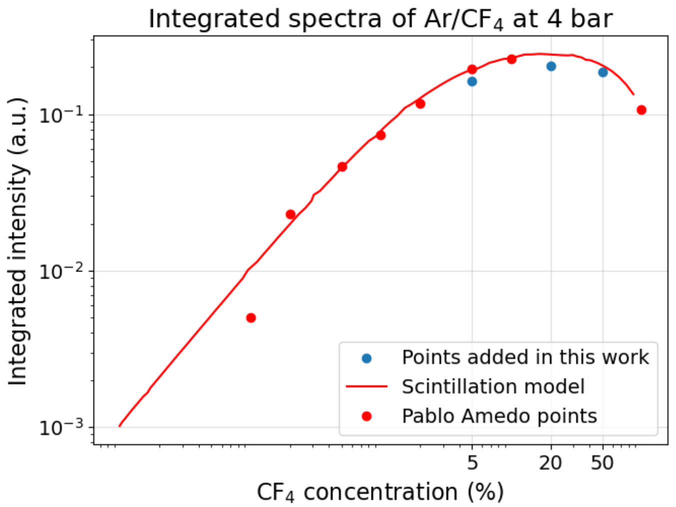


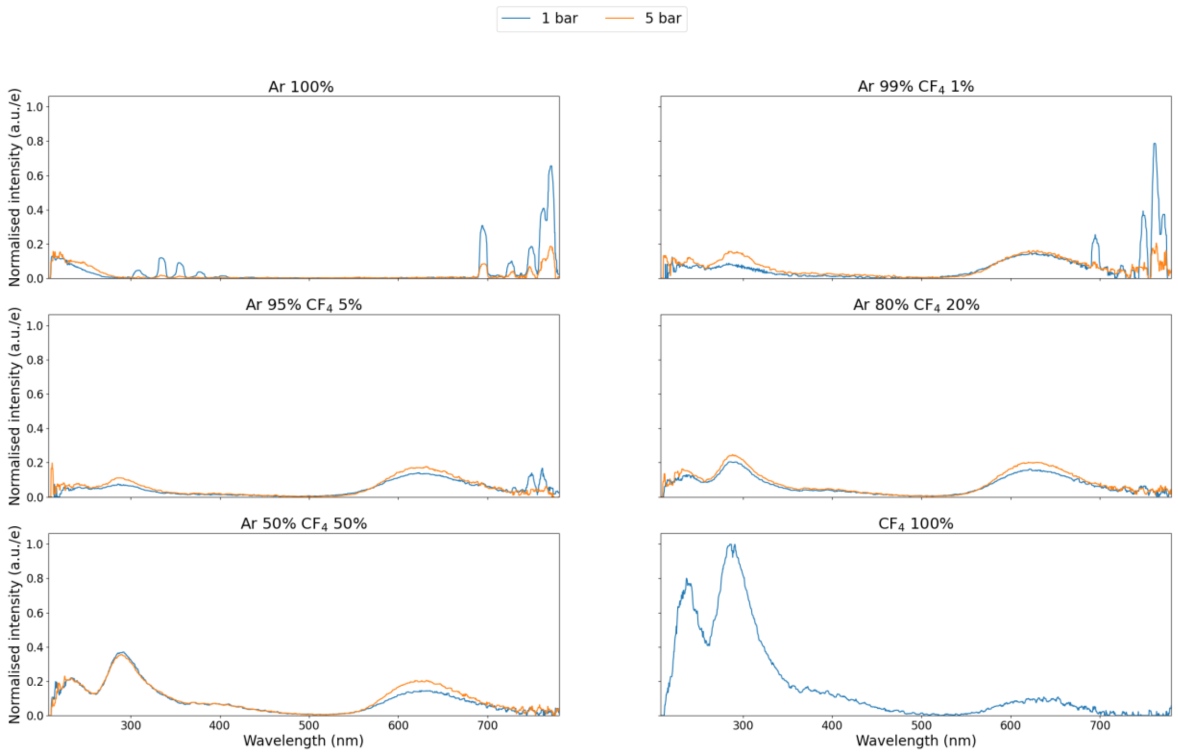
- PEEK structures → High purity system
- Aluminum cathode
- Cr anode over crystal window

Chamber bake-out

Recommissioning of the system (Ar/CF_4)

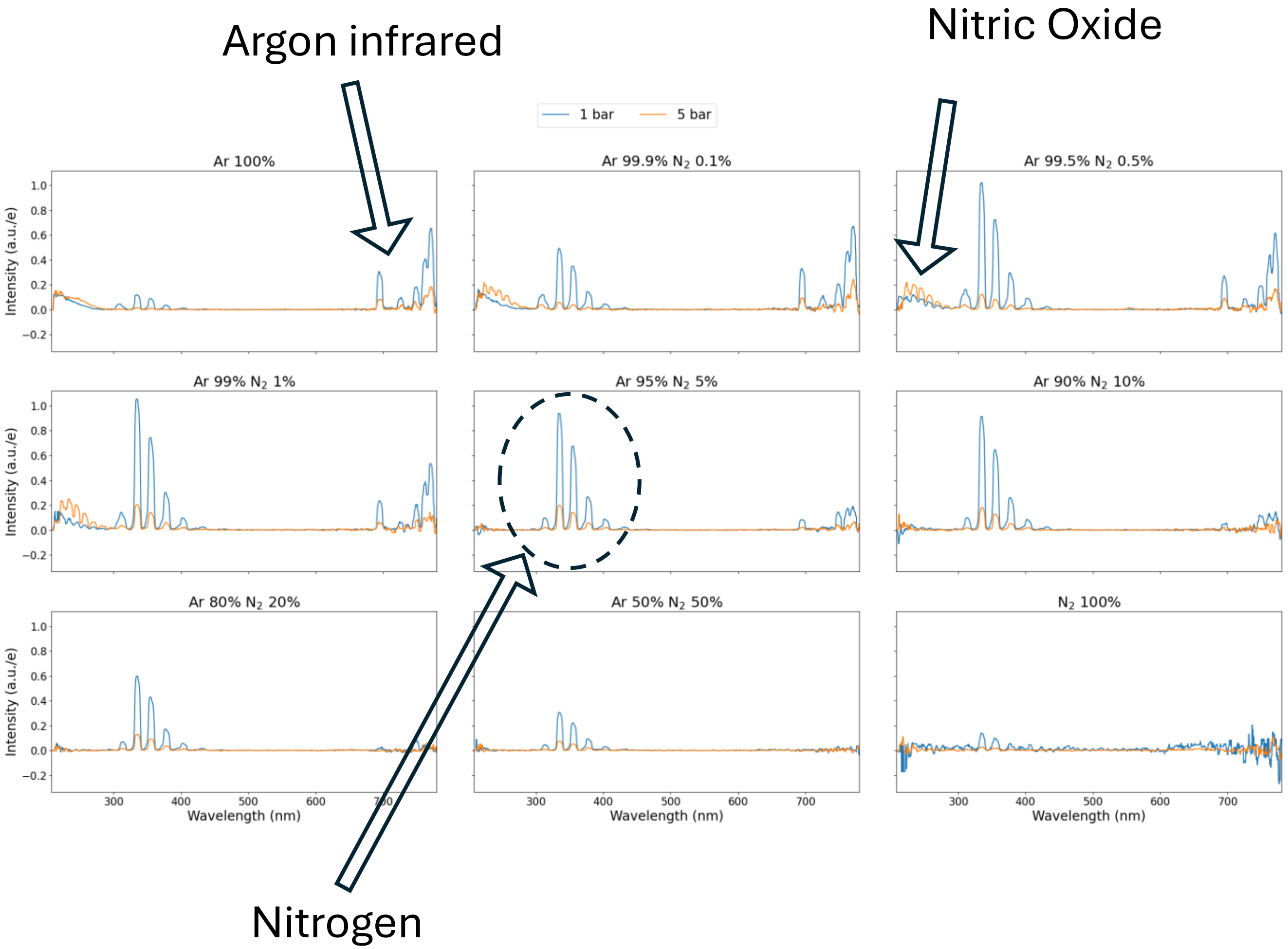
- Absence of an absolute calibration
  - Rescaling of new measurements to old measurements standard
  - Normalization of all spectra to 290 nm of pure CF_4 at 1 bar
- Extension of the measurements to concentrations of 20% and 50% of CF_4
- Checkup: model prediction for new points (yield)





Ar/N_2 primary scintillation

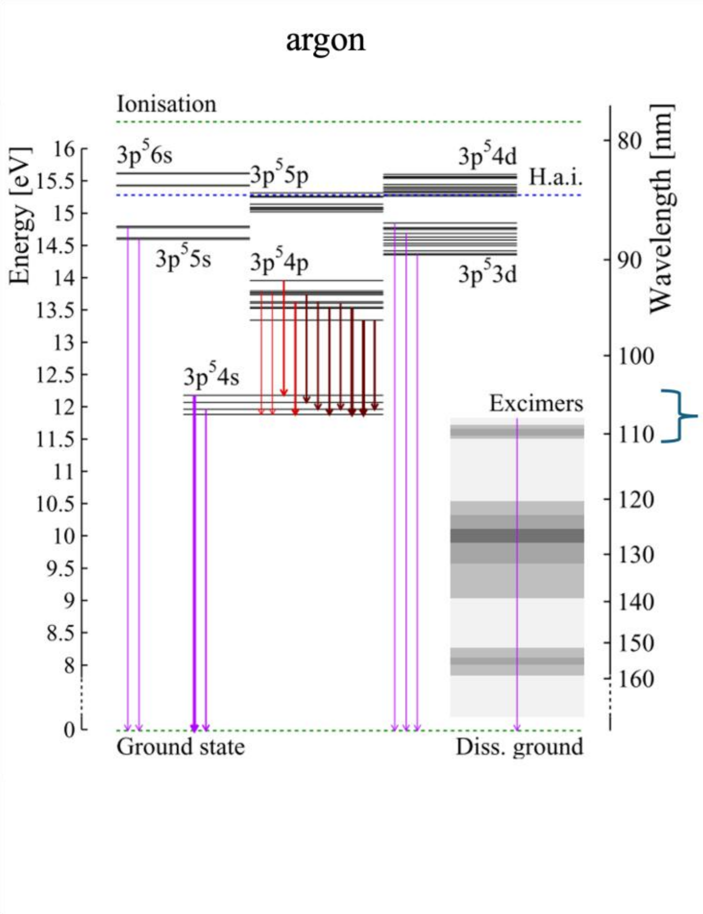
- Normalized to 1bar pure CF_4 290nm peak
- Intensity divided by collected primary electron
- Scintillation plateau between 0.5% and 10% of N_2
- Quenching of Argon infrared peaks with increasing concentrations
- Reduction with increasing pressure (self-quenching?)

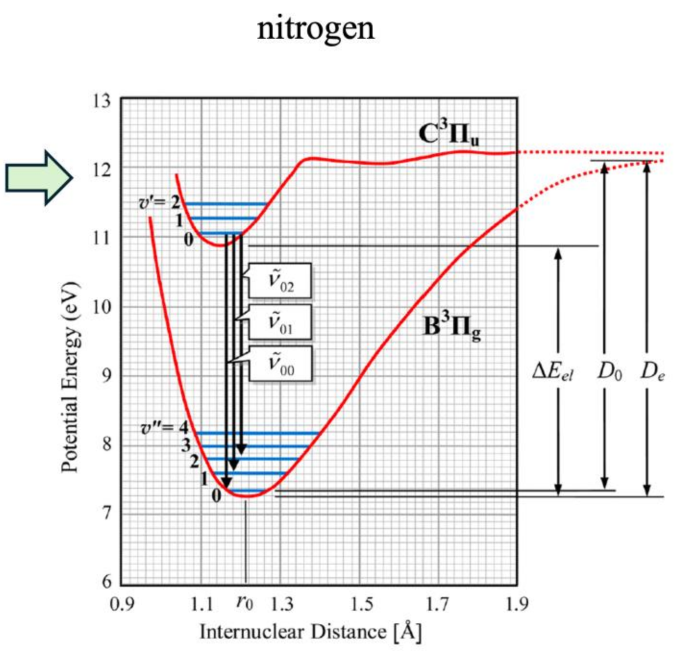


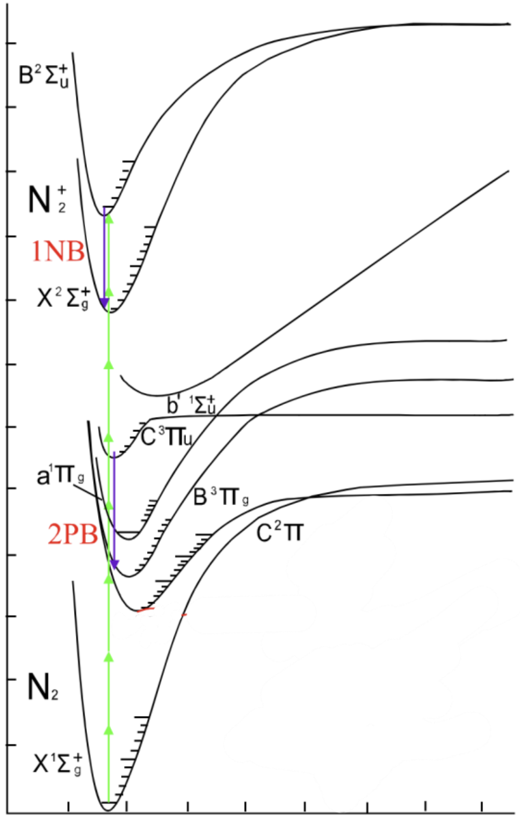
N_2 wavelength-shifting

- Close energy levels between argon and nitrogen → Energy transfer

Nitrogen emissions responsible of scintillation

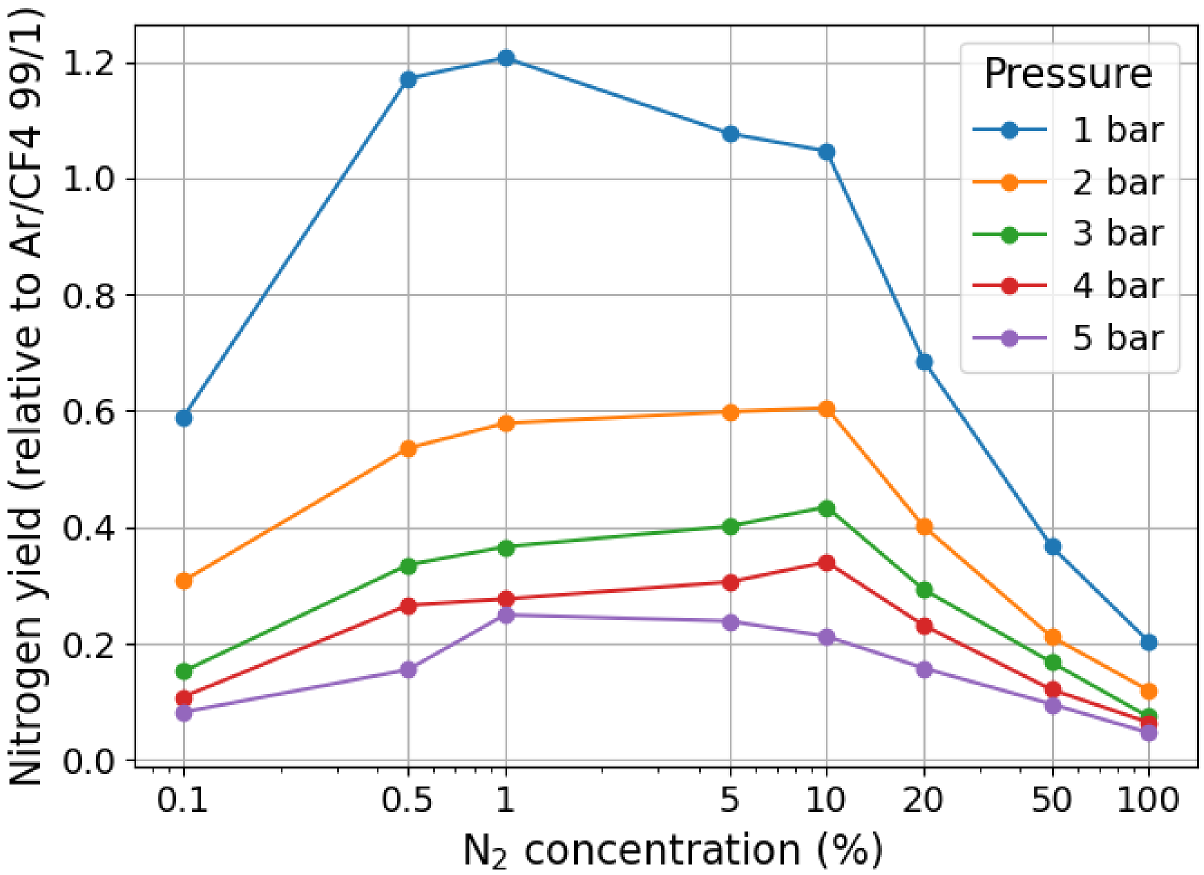






Comparison between Ar/N_2 and Ar/CF_4 yields

- Comparison with Ar/CF_4 99/1 at 5 bar visible emission (of interest for DUNE's NDGAr. See Pablo Amedo's talk 6th October)
- Same yield for 1 bar. Degradation with pressure.
- Large yields for the plateau

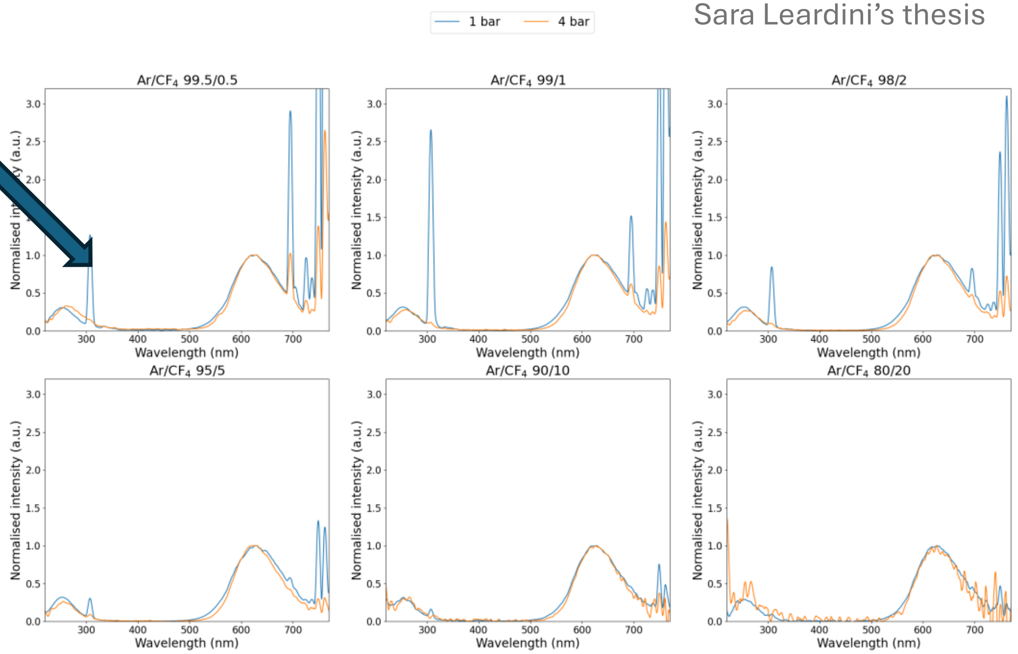


Secondary scintillation: previous work

- Important for optical tracking
- Secondary scintillation measurements for different pressures, electric fields and concentrations of CF_4
- Observation of change in scintillation spectra relative to primary (UV region)

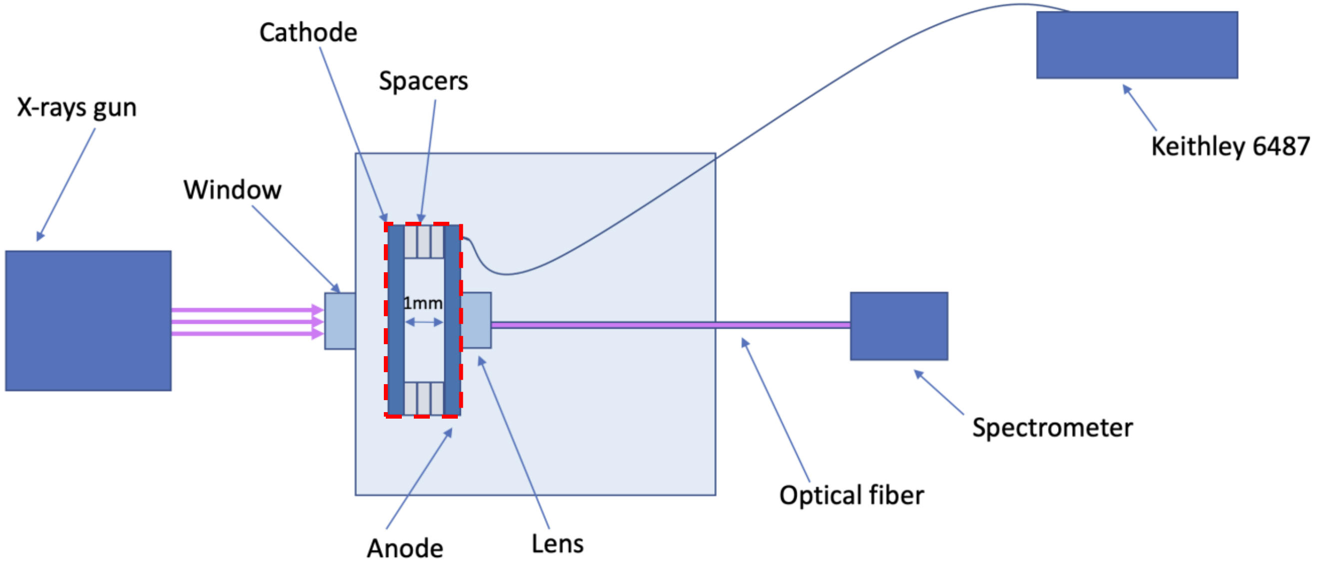
Water contamination
(OH peak)

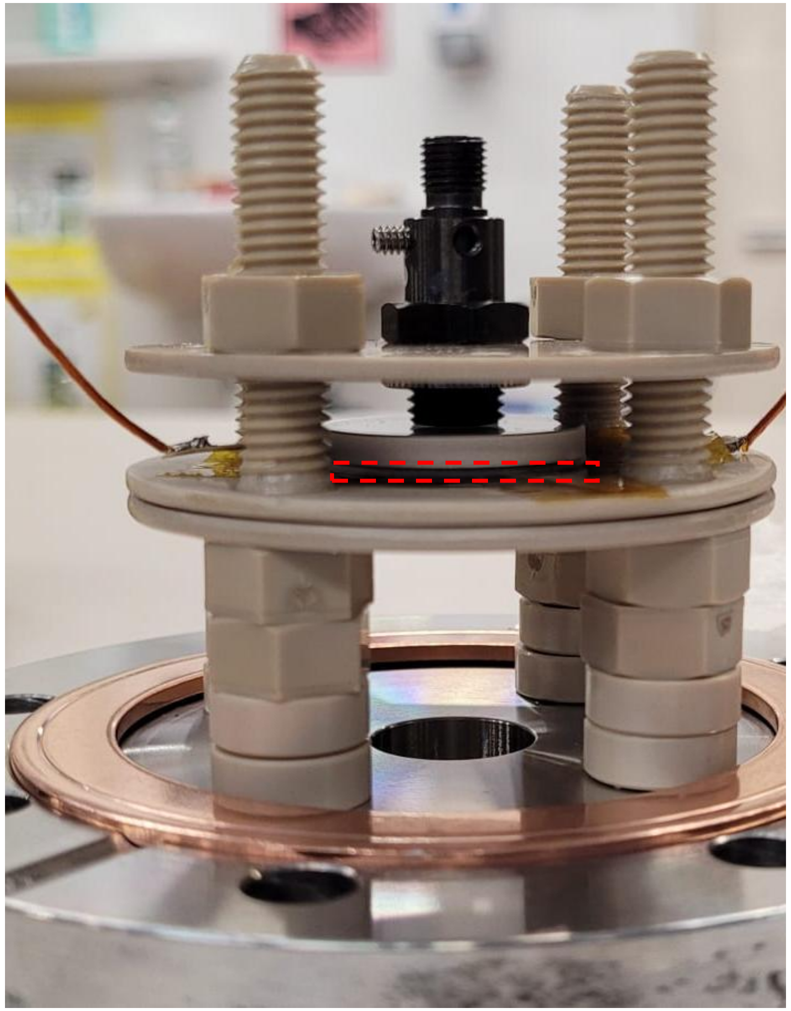
- Shape of the scintillation spectrum independent of pressure



Sara Leardini's thesis

Scintillation setup (amplification)





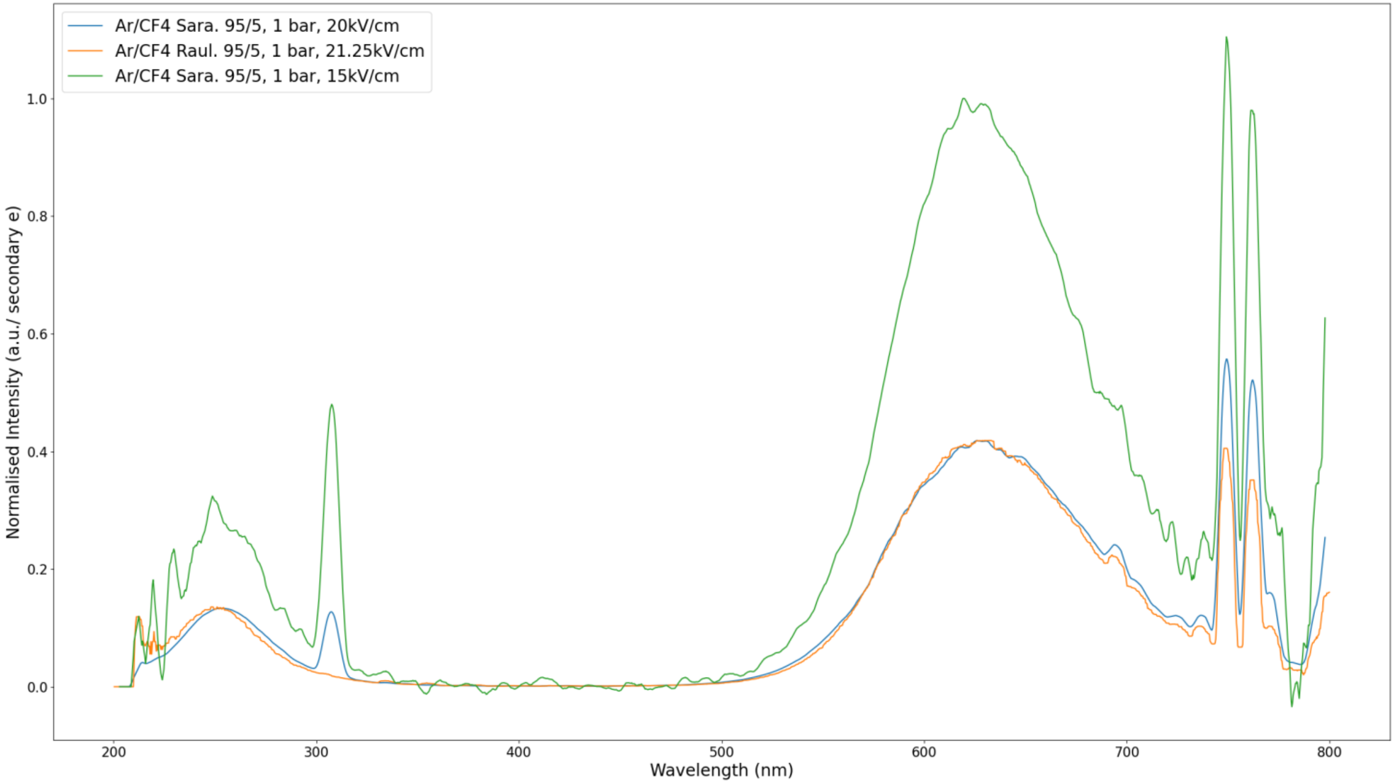
- Smaller gap → Allows for amplification
- Parallel plate setup
- Gap size: 1mm

Recommissioning of the S2 setup

- Rescaling of spectra to match calibrations between similar conditions (Ar/CF_4 95/5 at 1 bar in similar electric fields)
- Good agreement between spectra

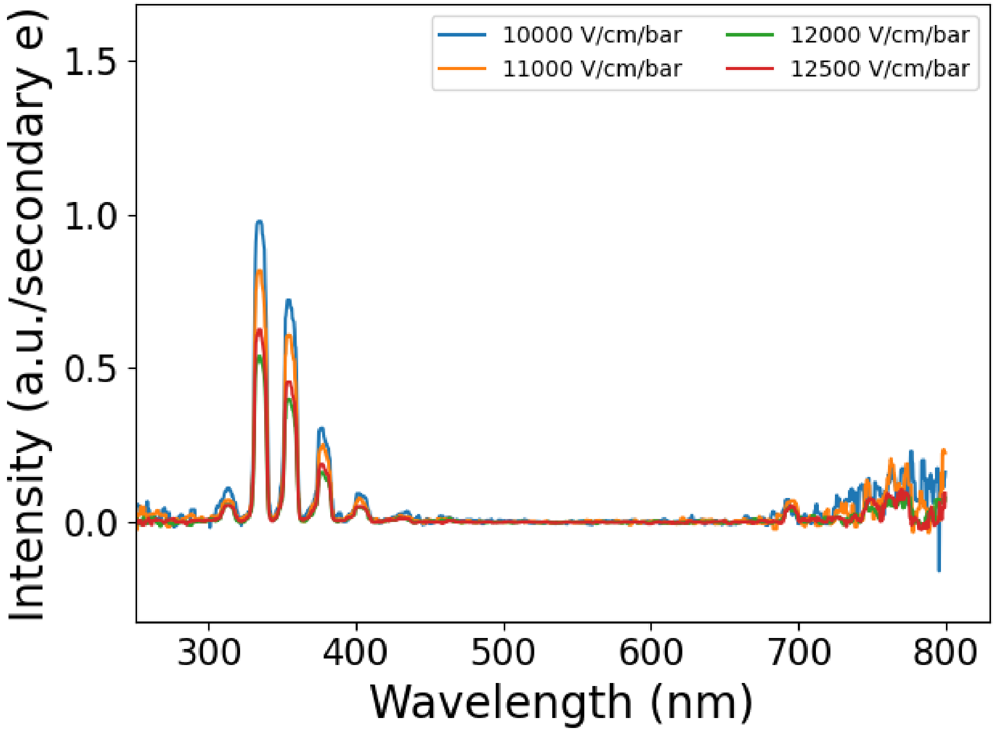
Comparability between calibration and old and new setup conditions

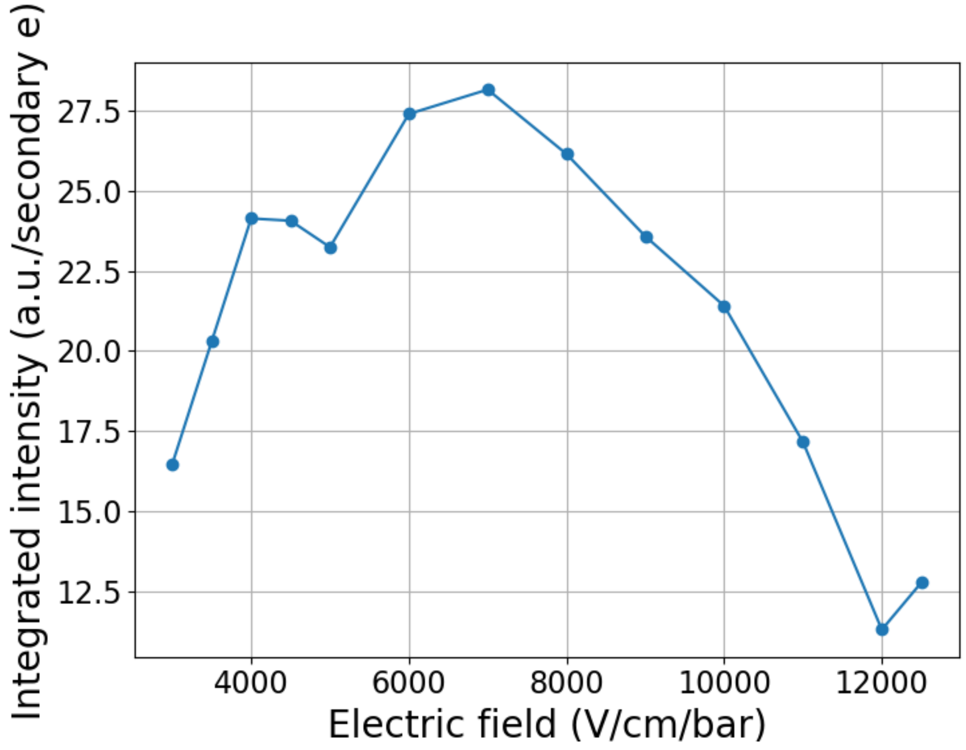
We can compare new nitrogen measurements with old CF_4



Electric field scan on Ar/N_2 99/1

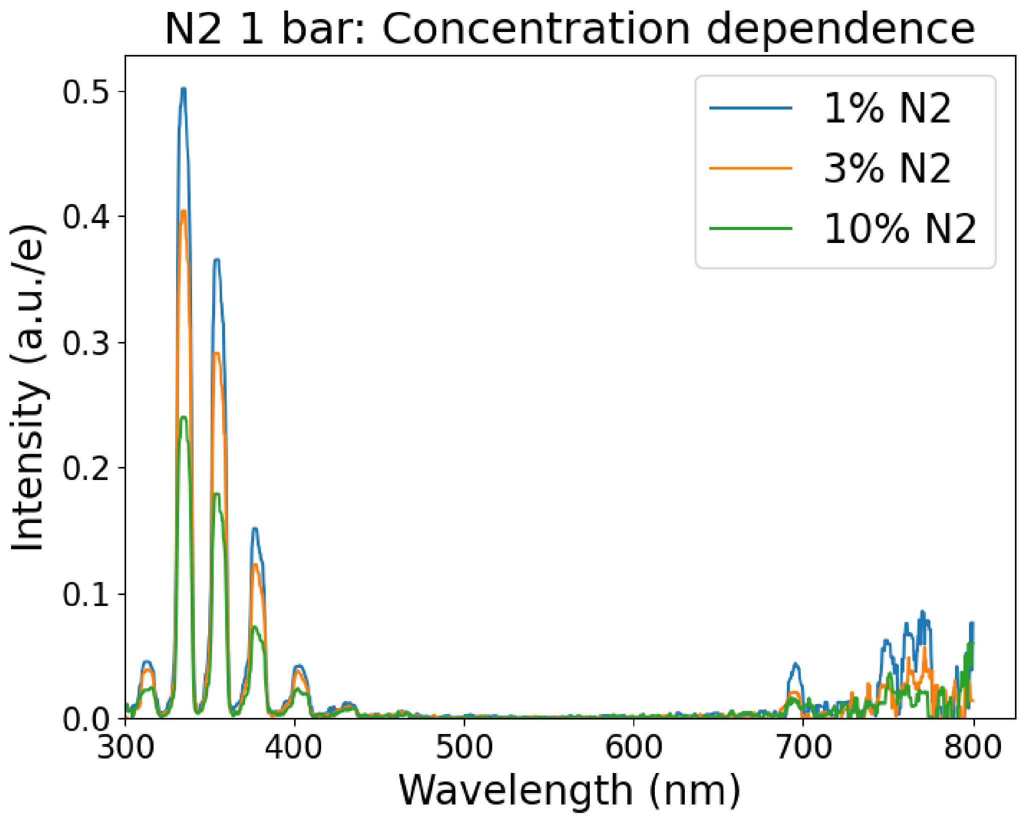
- Measurements at 1 bar
- Scintillation strength (photons per secondary electron) pretty much flat for all electric fields (Similar to Ar/CF_4)

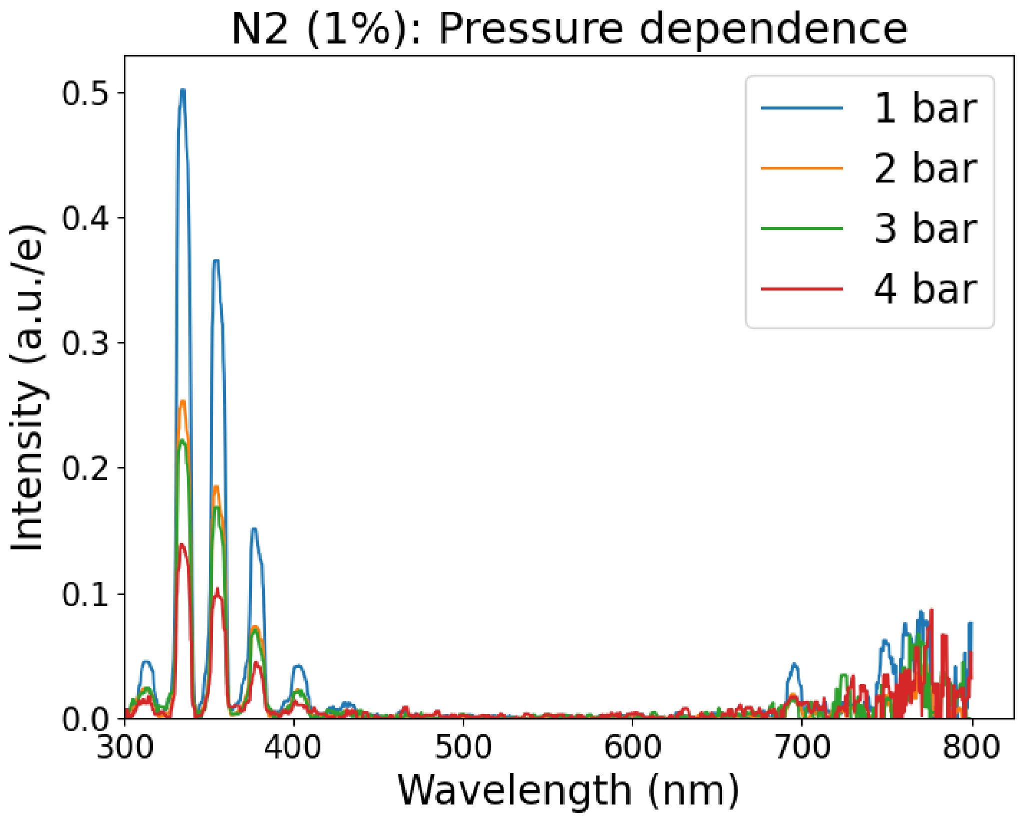




Pressure and concentration scan for Ar/N_2 99/1

- 1/P dependence (compatible with self-quenching)

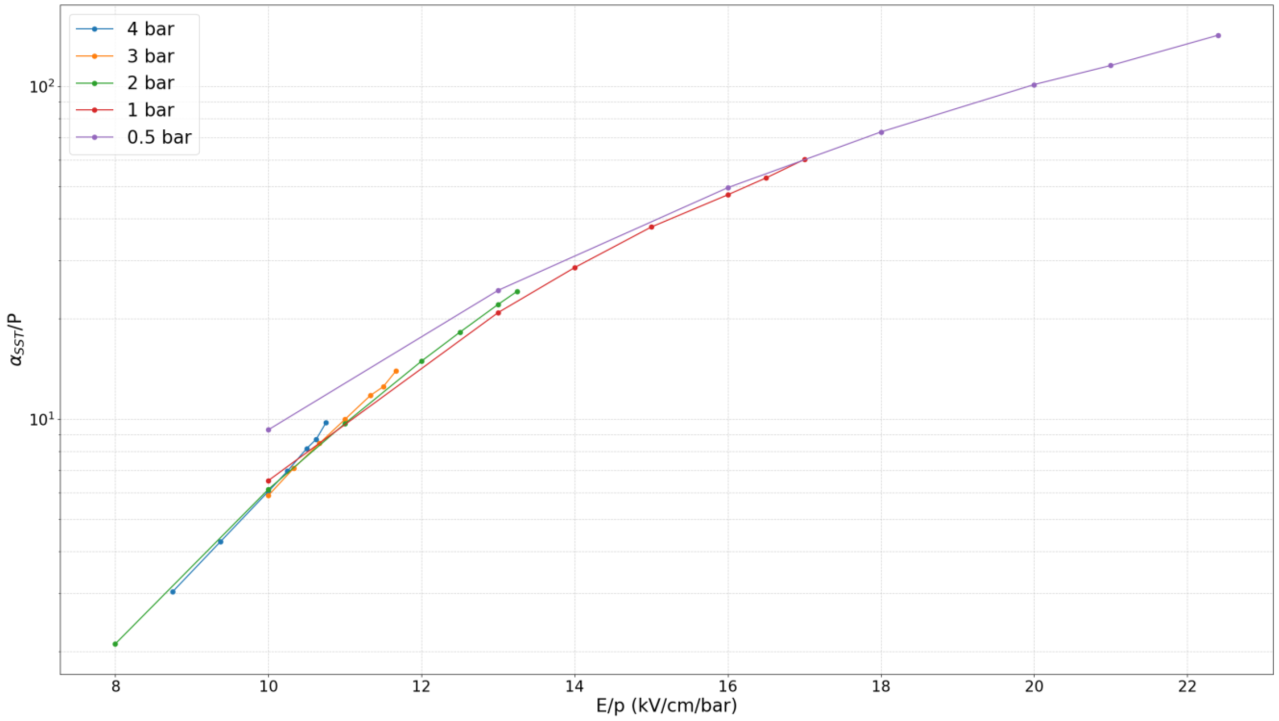




Charge gain vs pressure

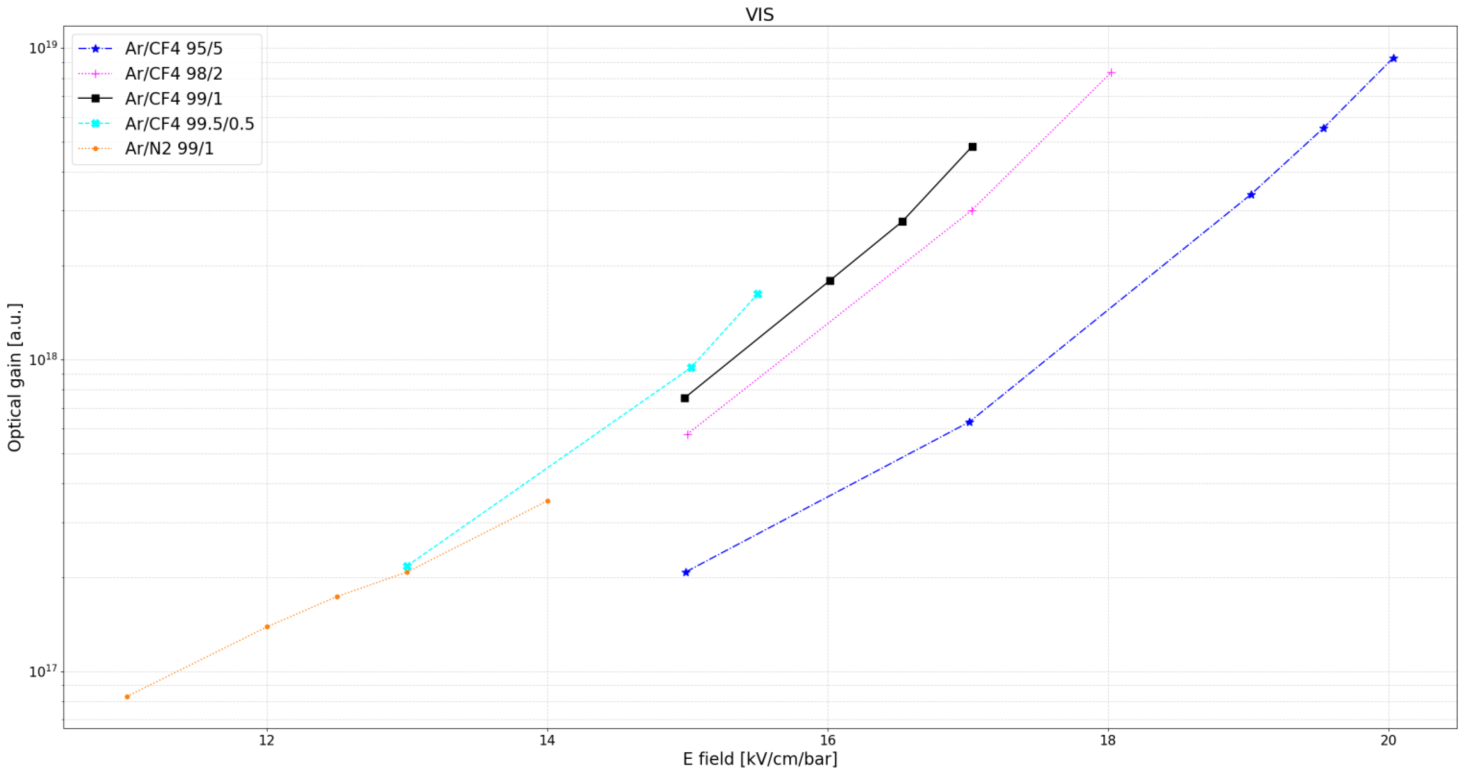
- Towsend coefficient:
  - $I_{anode} = I_0 \, \frac{1}{d} \int_0^d e^{\alpha \quad x} \, dx$
- We recover the expected scaling law for α (α/P over E/P)

$$\frac{\alpha}{P} \equiv f\left(\frac{E}{P}\right)$$



Optical gain comparison

- Optical Gain=$\frac{\int n_{ph}(\lambda)d\lambda)}{I-I_0}\,e^{\alpha d}$
- Lower maximum gain than Ar/CF_4
- ~10 times less scintillation



Preliminary!!!

Summary

- Primary scintillation measurements under X-rays for Ar/N_2:
  - Ar/N_2 scintillation comparable to Ar/CF_4 (99/1) at 1 bar. Decreasing at high pressure (compatible with self-quenching)
  - Optimal region for wavelength-shifting (0.5-10%)
  - Scintillation increase with respect to pure nitrogen around a factor of 5

- Secondary scintillation measurements for Ar/N_2:
  - Scintillation strength (photons per secondary electron) highly independent of field $\Rightarrow$ similar to Ar/CF_4
  - Optical gain about 10 times smaller than Ar/CF_4 at 1% concentration

  - Maximum voltage limited by discharges in the spacers
  - We plan to eliminate spacers and study more systematically the dependence with N_2 concentration as well as the maximum optical gain with GEMs at high pressure

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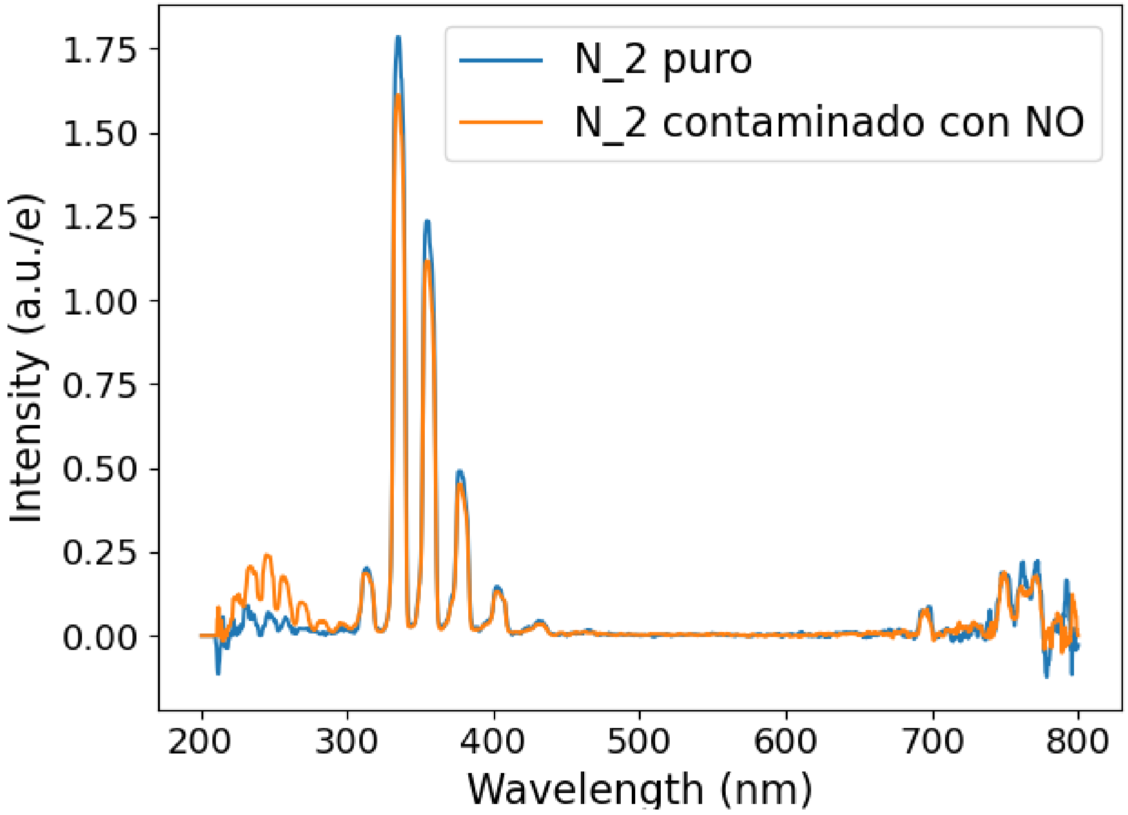
Backup

Independence from oxygen contamination



Setup instability

Ar/N_2 99/1 at 1bar