DUNE: intrinsic t0 via fluorescence in gas TPCs

D. González-Díaz (IGFAE)

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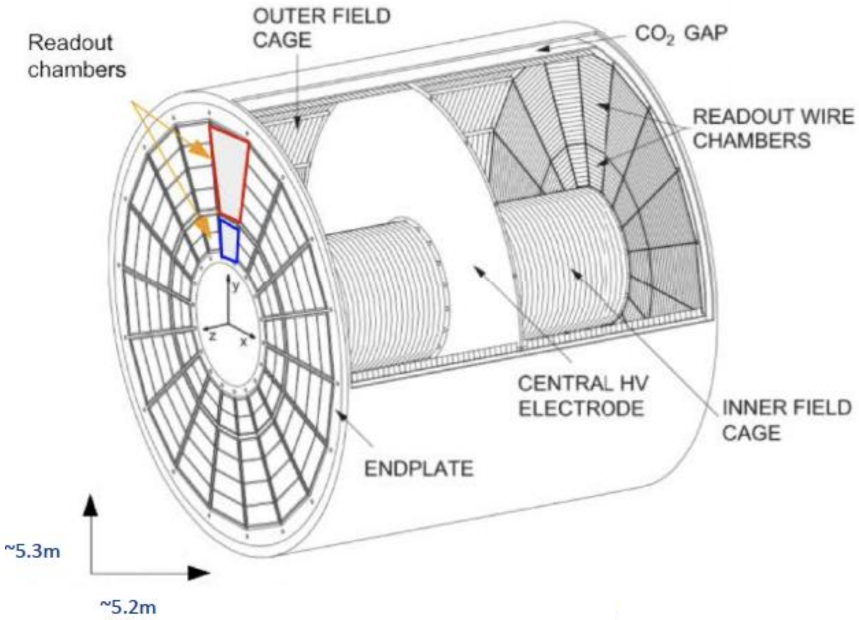
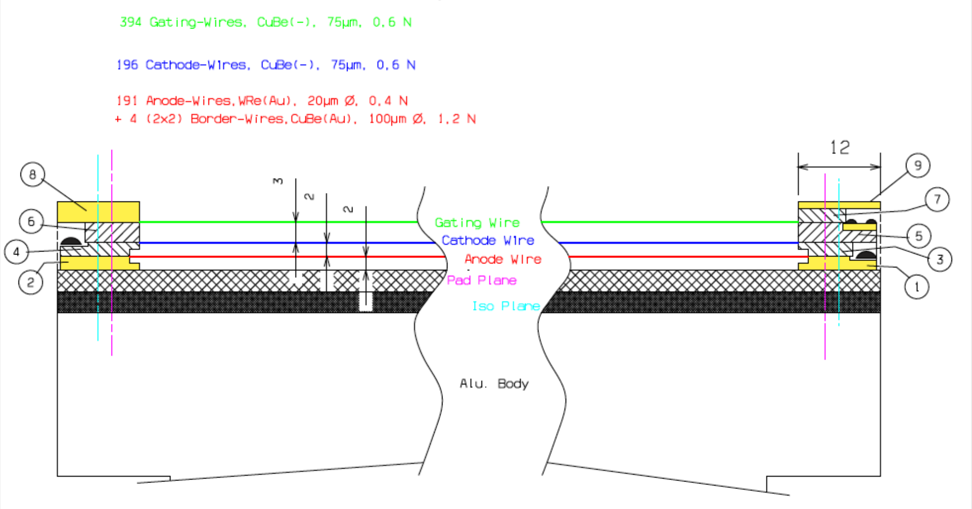
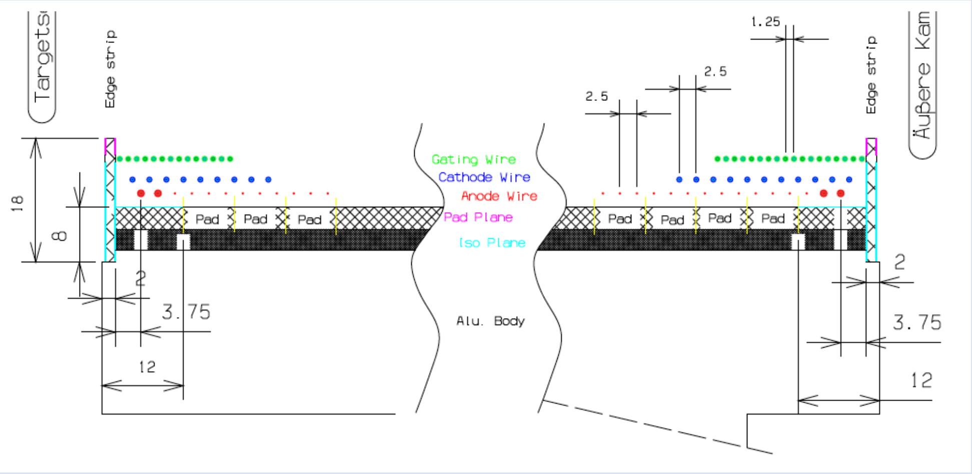
Instituto Galego de Física de Altas Enerxías



cross-section along wires (MWPC readout)



cross-section across wires (MWPC readout)



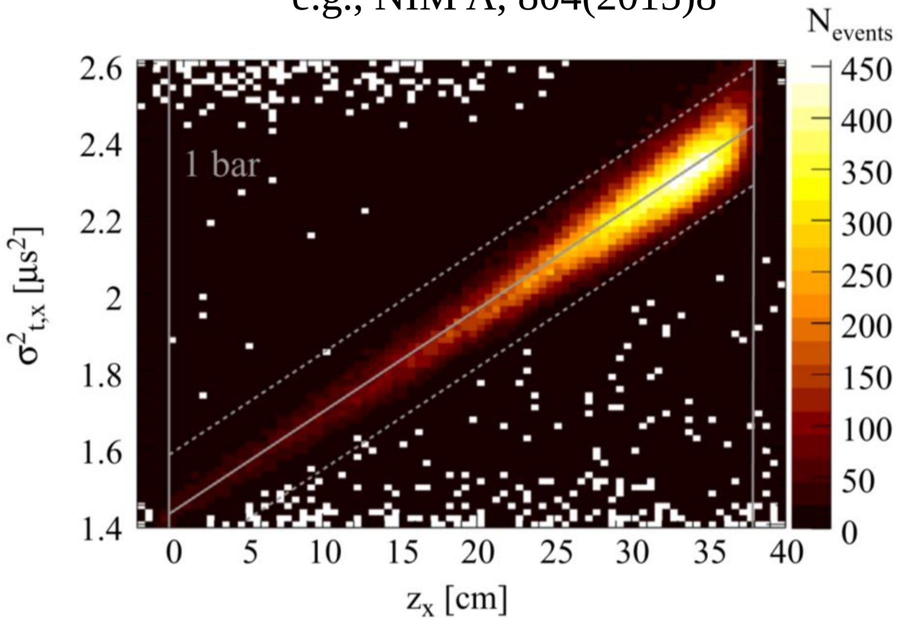
"Enabling a self-triggering capability, with a t_0 obtained through primary scintillation, has the potential to be transformational in various important aspects, like providing immunity with respect to uncorrelated backgrounds, fiducialization of the event, improved vertex assignment for neutral-current interactions, and even Particle ID for elastic scatterings with nuclei. This innovation is at the core of the present proposal."

…but how?

In a nutshell: can one respect the amplification hardware, make a subtle modification of the gas mixture, and change the functionality of the device?

three main (not totally sci-fi) ideas

e.g., NIM A, 804(2015)8



- Use track diffusion:

~1cm resolution for point-like tracks doable.
(what about extended tracks?)

- Use ions:

Ions can extract electrons when recombined at the cathode. They need to be locally amplified, plus, the process is suppressed at high pressure. No proof of concept so far.

- Use scintillation:

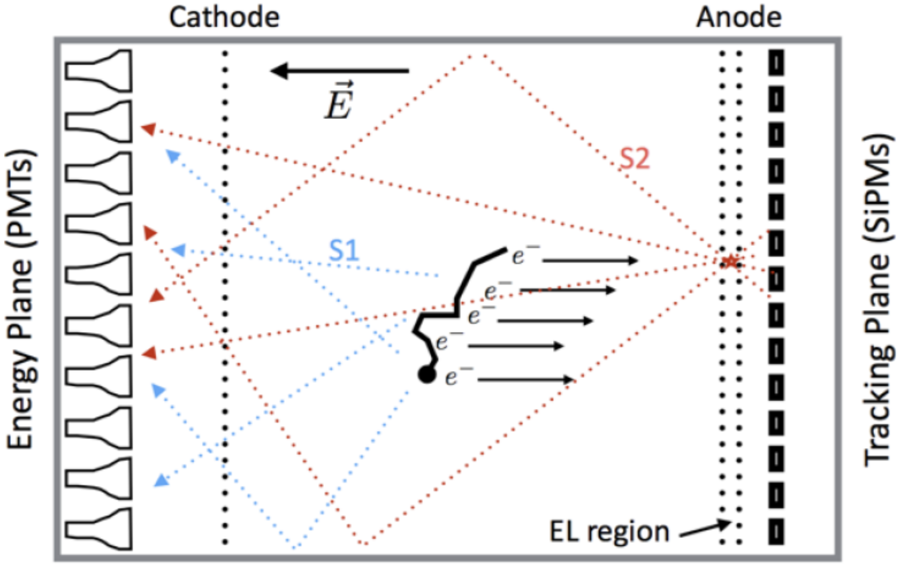
But wasn't the whole idea of MWPC operation to eliminate scintillation?

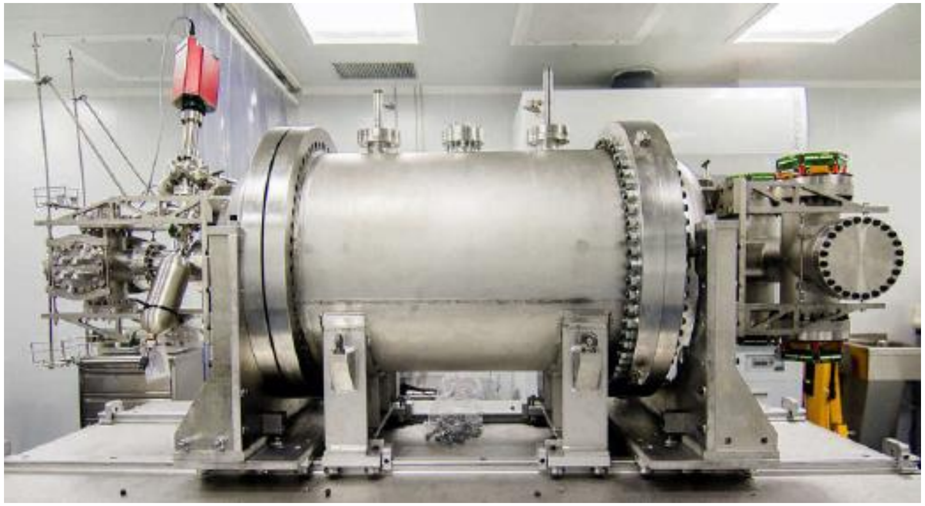
I. Primary scintillation

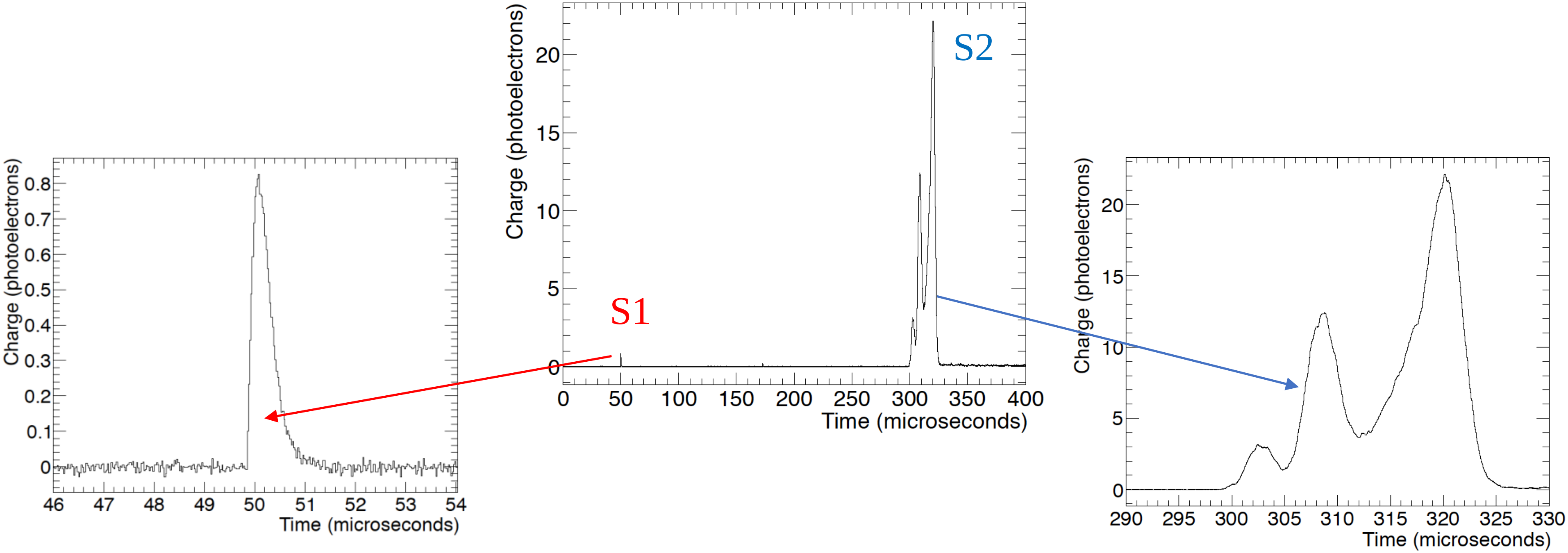
(actually obtaining the t0 in TPCs is relatively common these days)

NEXT experiment (1^{st} phase)

pure xenon (10bar)

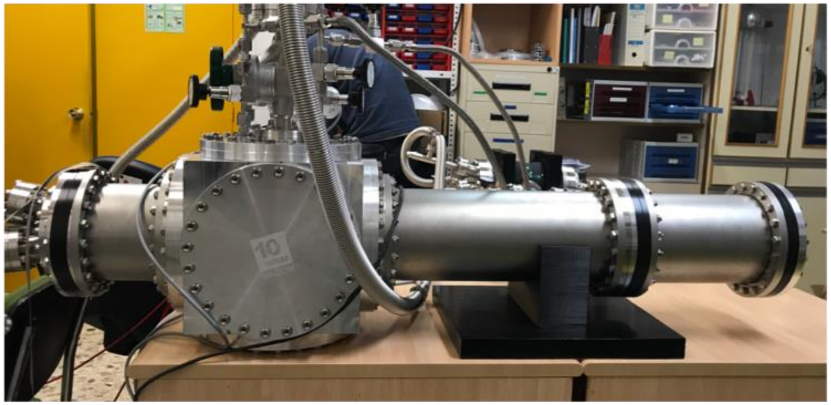




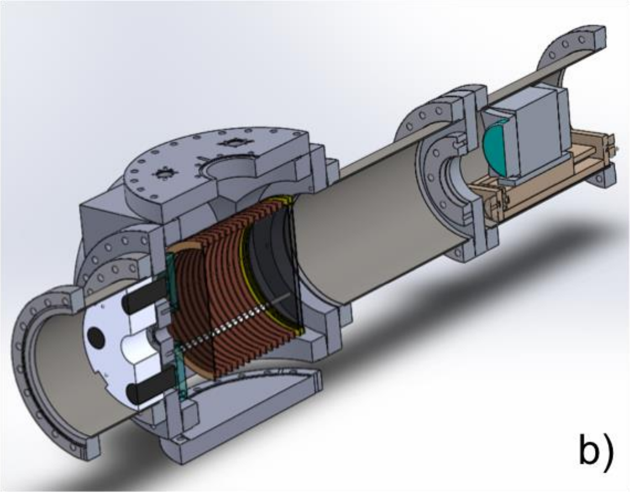


OTPC-prototype at IGFAE-Santiago

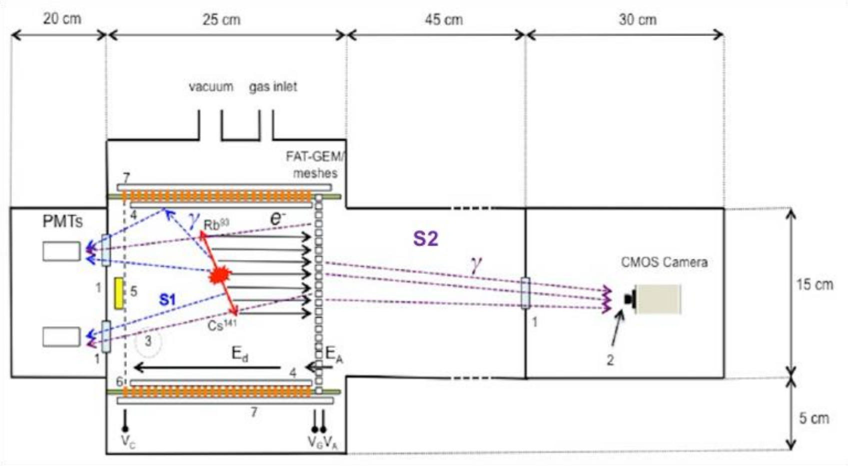
pure CF_4 (0.5bar)



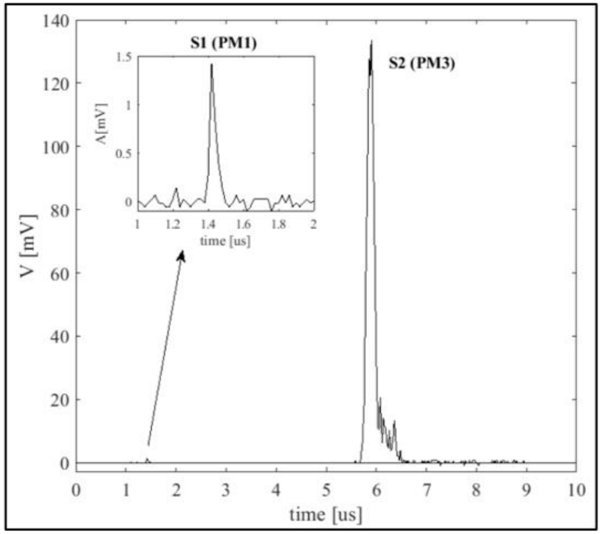
a)



b)



c)



d)

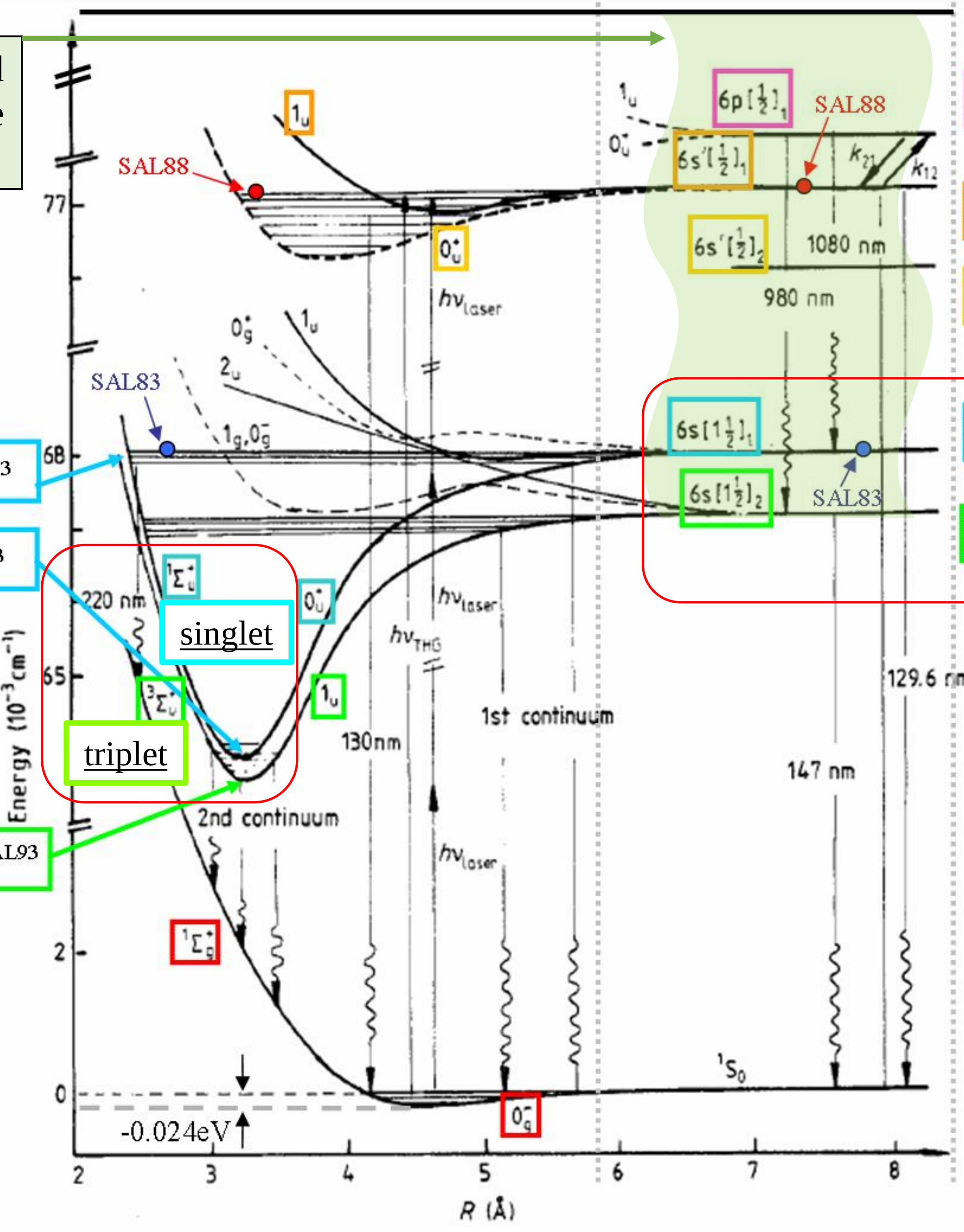
scintillation mechanism in noble gases

molecular state

atomic state

NIST

distribution of excited states generated by the primary particle.



$\tau(v_{high})=2ns^{SAL93}$

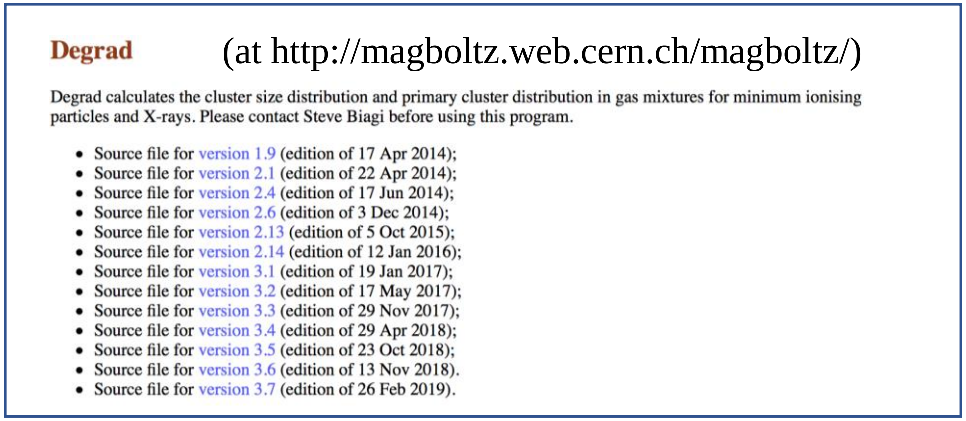
$\tau(v_{low})=6ns^{SAL93}$

$\tau(v_{low})=100ns^{SAL93}$

I=12.32eV

$2p_{10}$	E=9.58eV $\tau=40ns^{SAL93}$
$^1P_1$	E=9.57eV τ=3.56ns
$^3P_0$	E=9.45eV τ= ∞ [?]
$^3P_1$	E=8.44eV τ= 4.06ns
$^3P_2$	E=8.32eV $\tau=43s^{WAL95}$

example: xenon (analogous for other noble gases)



Degrad (at http://magboltz.web.cern.ch/magboltz/)

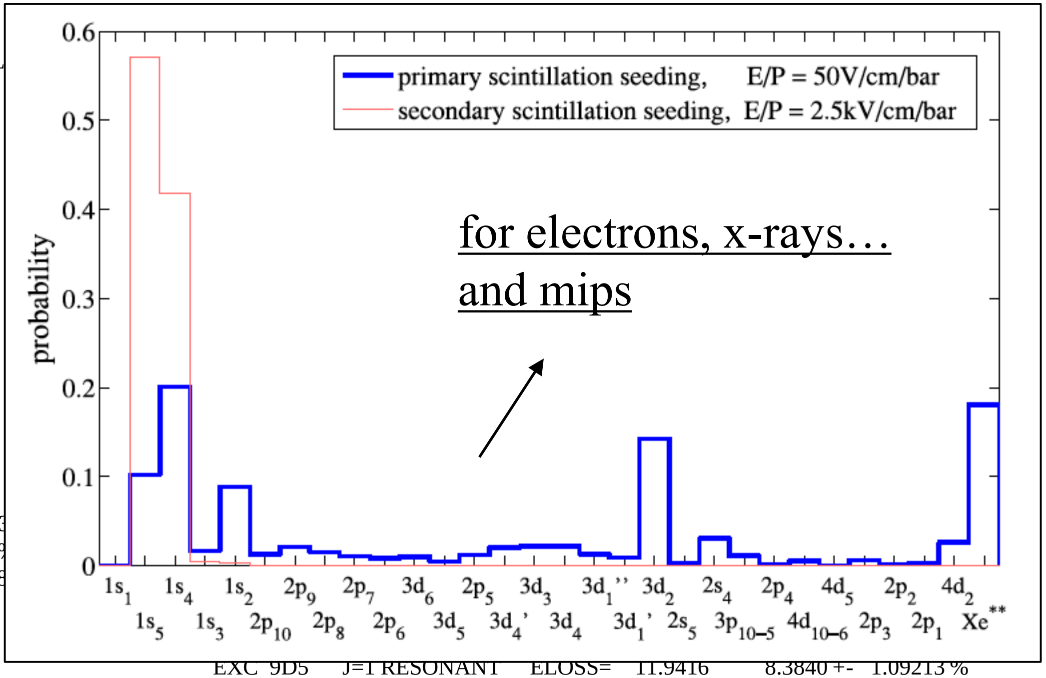
Degrad calculates the cluster size distribution and primary cluster distribution in gas mixtures for minimum ionising particles and X-rays. Please contact Steve Biagi before using this program.

- Source file for version 1.9 (edition of 17 Apr 2014);
- Source file for version 2.1 (edition of 22 Apr 2014);
- Source file for version 2.4 (edition of 17 Jun 2014);
- Source file for version 2.6 (edition of 3 Dec 2014);
- Source file for version 2.13 (edition of 5 Oct 2015);
- Source file for version 2.14 (edition of 12 Jan 2016);
- Source file for version 3.1 (edition of 19 Jan 2017);
- Source file for version 3.2 (edition of 17 May 2017);
- Source file for version 3.3 (edition of 29 Nov 2017);
- Source file for version 3.4 (edition of 29 Apr 2018);
- Source file for version 3.5 (edition of 23 Oct 2018);
- Source file for version 3.6 (edition of 13 Nov 2018).
- Source file for version 3.7 (edition of 26 Feb 2019).

```
NUMBER OF COLLISIONS PER DELTA =**********
  NUMBER OF INELASTIC COLL. PER DELTA = 151800.88
    NUMBER OF ELASTIC COLL. PER DELTA =**********
------------------------------------------------------------------------------

     COLLISIONS PER DELTA SORTED ACCORDING TO GAS AND TYPE OF COLL

   GASES USED              ELASTIC    SUPERELAS   INELASTIC  ATTACHMENT
IONISATION

  XENON 2013   ANISOTROPIC  **********        0.00     62432.75       0.00    89368.14

------------------------------------------------------------------------------

  NUMBER OF COLLISIONS PER EVENT FOR EACH GAS :



   XENON 2013   ANISOTROPIC
----------------------------

   ELASTIC ANISOTROPIC      XENON                   ************ +-   0.00036 %
   IONISATION CHARGE STATE=1       ELOSS=    12.12984     77904.6880 +-   0.0113
   IONISATION CHARGE STATE=2       ELOSS=    33.105       6647.7810 +-   0.03878
   IONISATION CHARGE STATE=3+4+5+6 ELOSS=    64.155       4294.8030 +-   0.048
   IONISATION  M5-SHELL          ELOSS=   676.4          243.2560 +-   0.20275 %
   IONISATION  M4-SHELL          ELOSS=   689.0          157.9240 +-   0.25164 %
   IONISATION  M3-SHELL          ELOSS=   940.6           60.7420 +-   0.40575 %
   IONISATION  M2-SHELL          ELOSS=  1002.1           26.3850 +-   0.61563 %
   IONISATION  M1-SHELL          ELOSS=  1148.7           17.6920 +-   0.75182 %
   IONISATION  L3-SHELL         ELOSS=  4786.            8.2450 +-   1.10130 %
   IONISATION  L2-SHELL         ELOSS=  5107.            3.6750 +-   1.64957 %
   IONISATION  L1-SHELL         ELOSS=  5453.            2.6440 +-   1.94477 %
   IONISATION   K-SHELL        ELOSS= 34561.            0.3040 +-   5.73539 %
   ATTACHMENT                                   0.0000 +-   0.00000 %
```

page 1

```
EXC  1S5      J=2 METASTABLE   ELOSS=     8.3153       6383.4070 +-   0.03958 %
EXC  1S4      J=1 RESONANT     ELOSS=     8.4365      12641.7050 +-   0.02813 %
EXC  1S3      J=0 METASTABLE   ELOSS=     9.4472       1063.8980 +-   0.09695 %
EXC  1S2      J=1 RESONANT     ELOSS=     9.5697       5498.2360 +-   0.04265 %
EXC  2P10     J=1              ELOSS=     9.5802        814.1010 +-   0.11083 %
EXC  2P9      J=2              ELOSS=     9.6856       1312.6240 +-   0.08728 %
EXC  2P8      J=3              ELOSS=     9.7207        932.6280 +-   0.10355 %
EXC  2P7      J=1              ELOSS=     9.7893        666.0850 +-   0.12253 %
EXC  2P6      J=2              ELOSS=     9.8211        504.1110 +-   0.14084 %
EXC  3D6      J=0              ELOSS=     9.8904        634.3830 +-   0.12555 %
EXC  3D5      J=1 RESONANT     ELOSS=     9.9171        269.1910 +-   0.19274 %
EXC  2P5      J=0              ELOSS=     9.9335        734.2000 +-   0.11671 %
EXC  3D4!     J=4              ELOSS=     9.9431       1273.6700 +-   0.08861 %
EXC  3D3      J=2              ELOSS=     9.9588       1355.9450 +-   0.08588 %
EXC  3D4      J=3              ELOSS=    10.0391       1374.8260 +-   0.08529 %
EXC  3D1!!    J=2              ELOSS=    10.1575        813.2470 +-   0.11089 %
EXC  3D1!     J=3              ELOSS=    10.2200        561.5580 +-   0.13345 %
EXC  3D2      J=1 RESONANT     ELOSS=    10.4010       8886.5320 +-   0.03355 %
EXC  2S5      J=2              ELOSS=    10.5621        137.4830 +-   0.26970 %
```

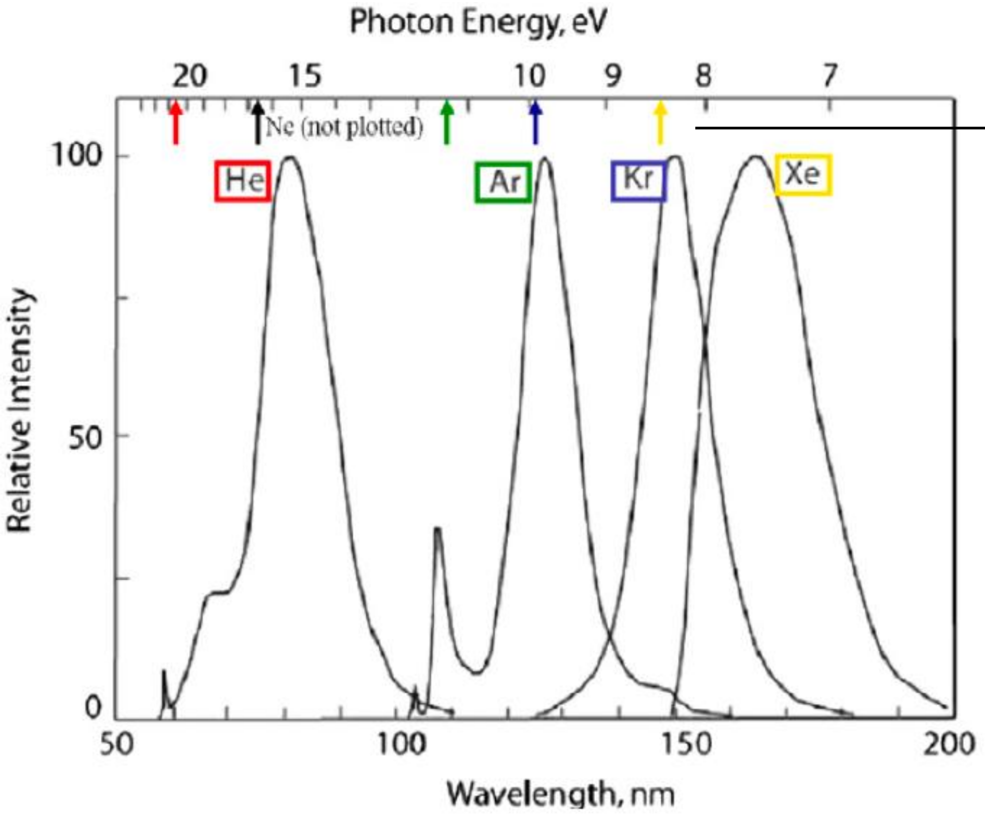


for electrons, x-rays…
and mips

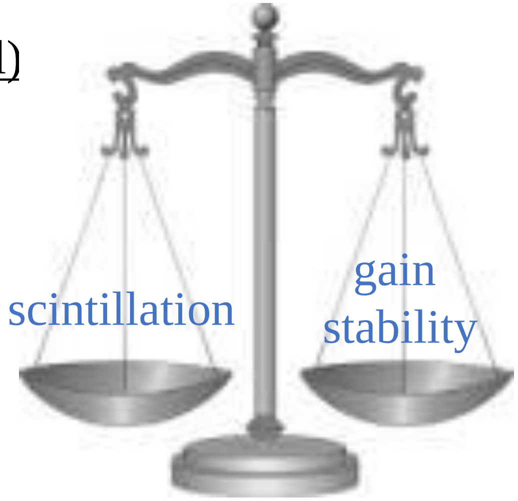
```
EXC  9D5      J=1 RESONANT     ELOSS=    11.9416          8.3840 +-   1.09213 %
EXC  9D2      J=1 RESONANT     ELOSS=    11.9550        417.3770 +-   0.15479 %
EXC  8S4      J=1 RESONANT     ELOSS=    11.9621         38.3010 +-   0.51097 %
EXC  10D5     J=1 RESONANT     ELOSS=    11.9789          8.3250 +-   1.09599 %
EXC  10D2     J=1 RESONANT     ELOSS=    11.9886        272.4310 +-   0.19159 %
EXC  9S4      J=1 RESONANT     ELOSS=    11.9939         23.4200 +-   0.65344 %
EXC  HIGH     J=1 RESONANT     ELOSS=    12.0          1377.5870 +-   0.08520 %
```

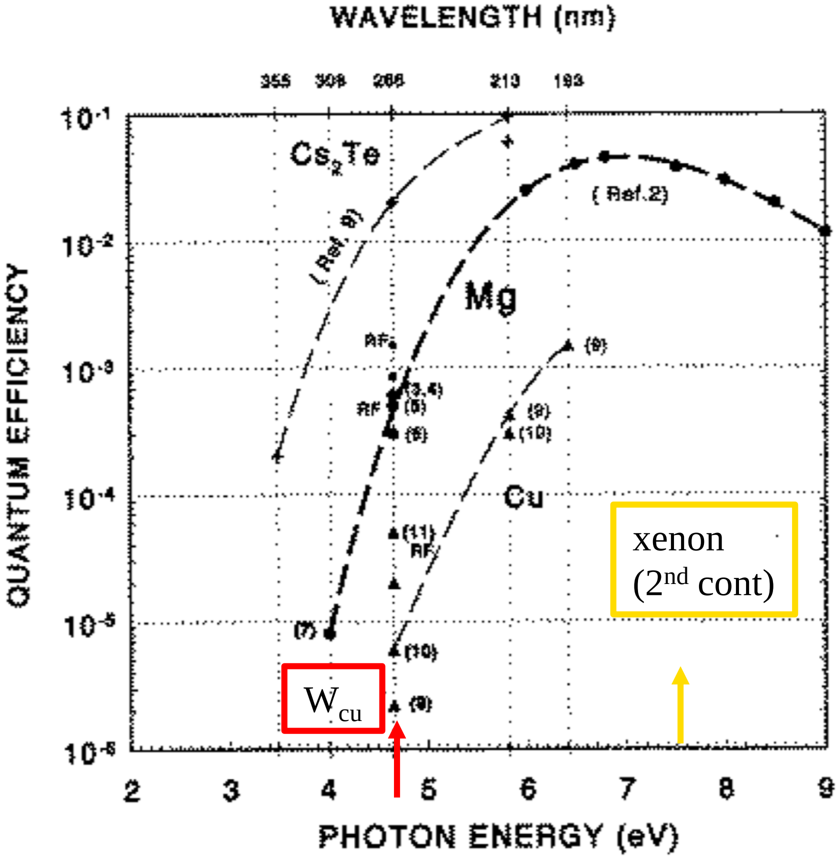
page 2

scintillation for noble gases (textbook level)



energy of
excited levels





‘2^{nd} continuum’
(dominant feature of pressurized
noble gases, i.e., above 100mbar)

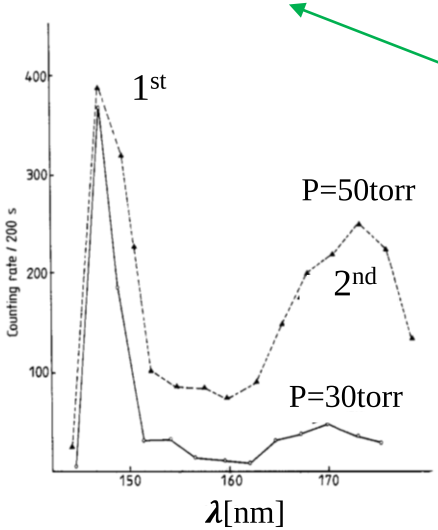
scintillation in pure xenon (wide-band)

1^{st} & 2^{nd} excimer continuum

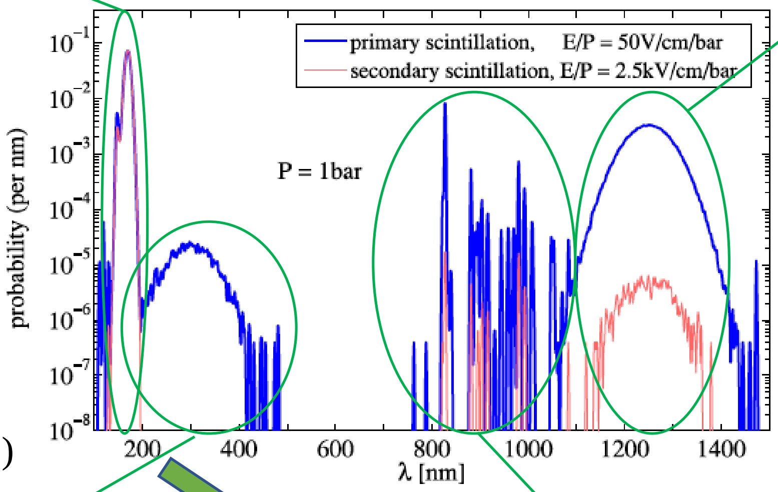
IR excimer continuum

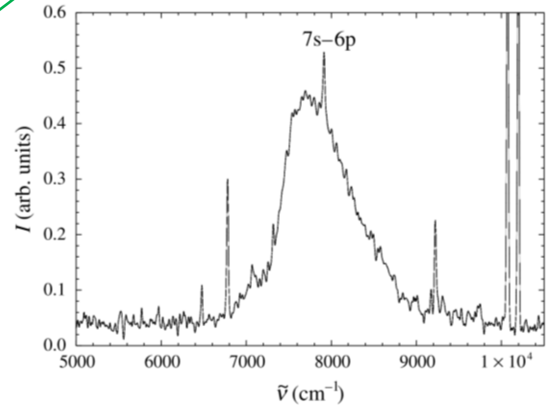
for electrons (simulation)

C. D. R. Azevedo et al., 10.1016/j.nima.2017.08.049



e.g., Y. Salamero et al (1983)

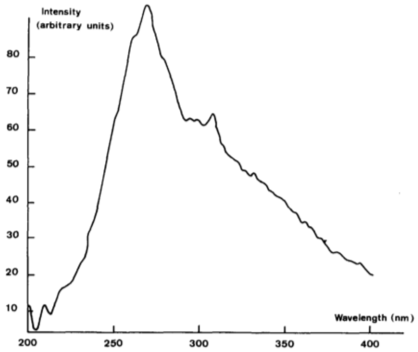




Borghesani, Carugno, Mogentale (2007)

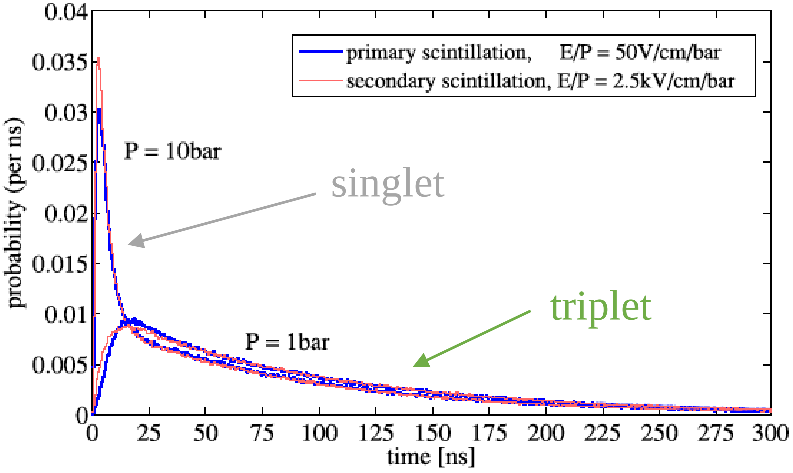
atomic lines

‘3^{rd}’ excimer continuum

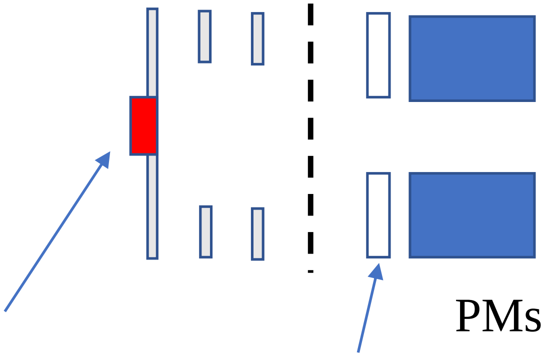


P. Millet et al (1978)

2^{nd} continuum (time spectrum)



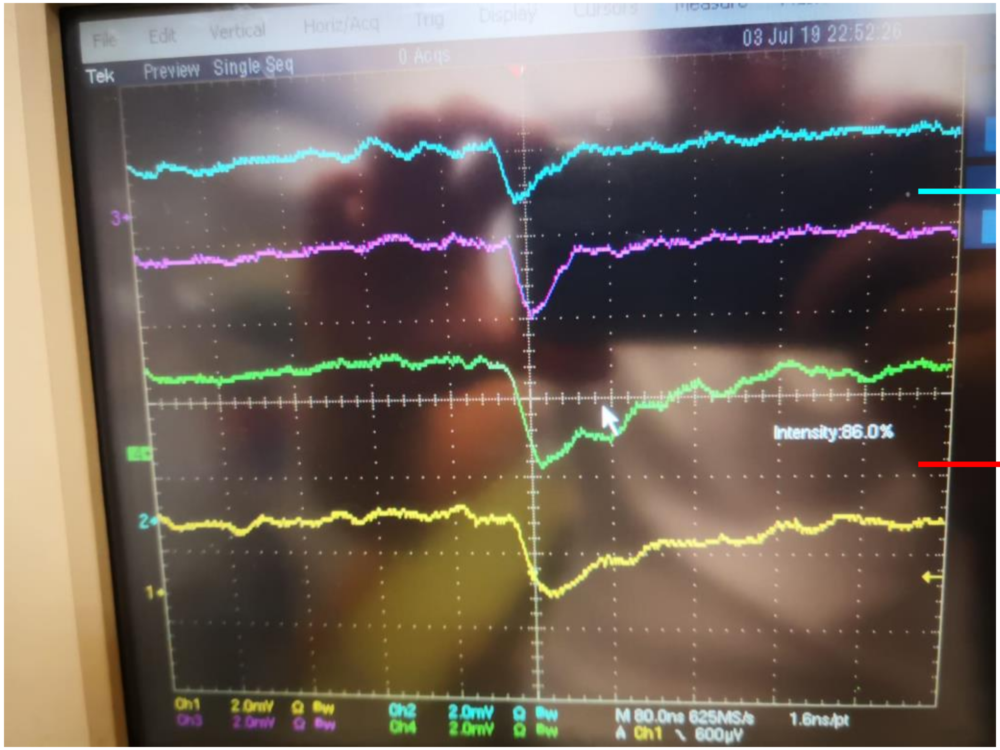
live example 1 week ago



source

PMs

filters

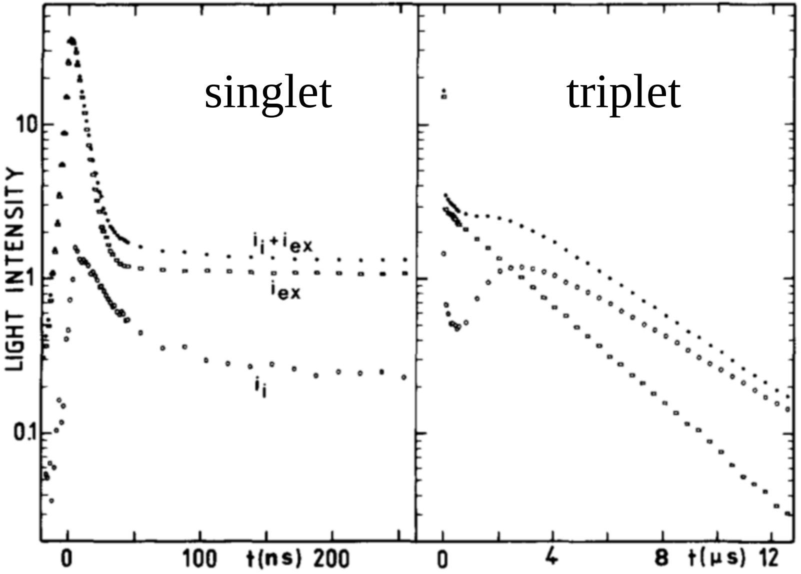


something else

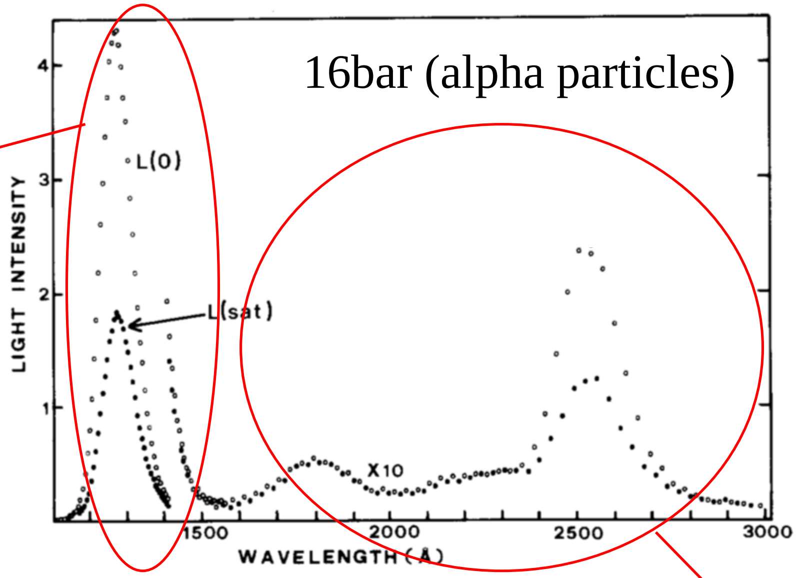
2nd continuum in xenon

scintillation in pure argon (wide-band)

1st & 2nd excimer continuum

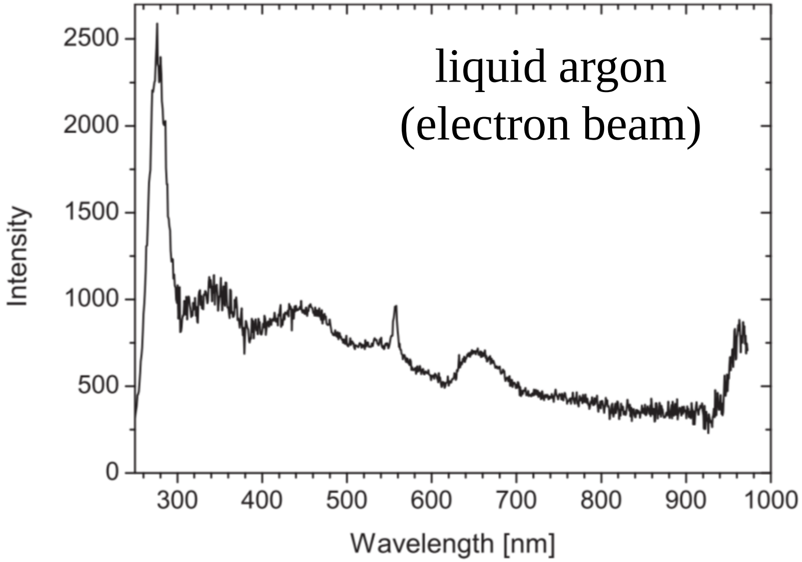

singlet

triplet


16bar (alpha particles)

Carvalho and Klein (1980)

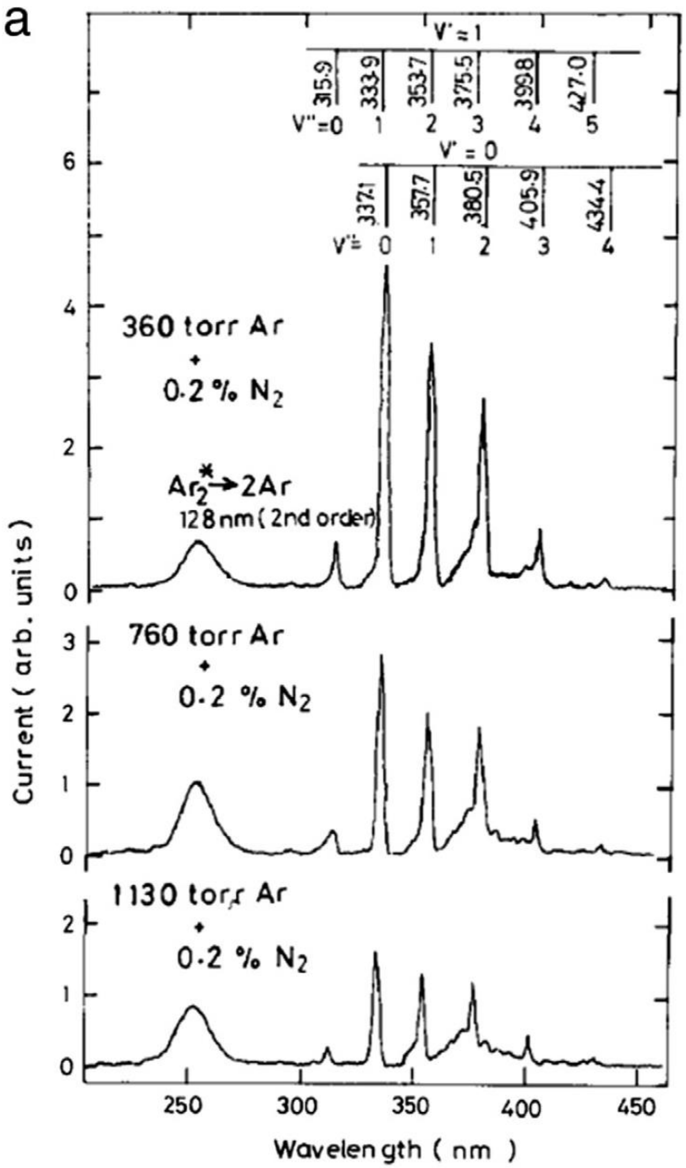
3rd excimer continuum


liquid argon (electron beam)

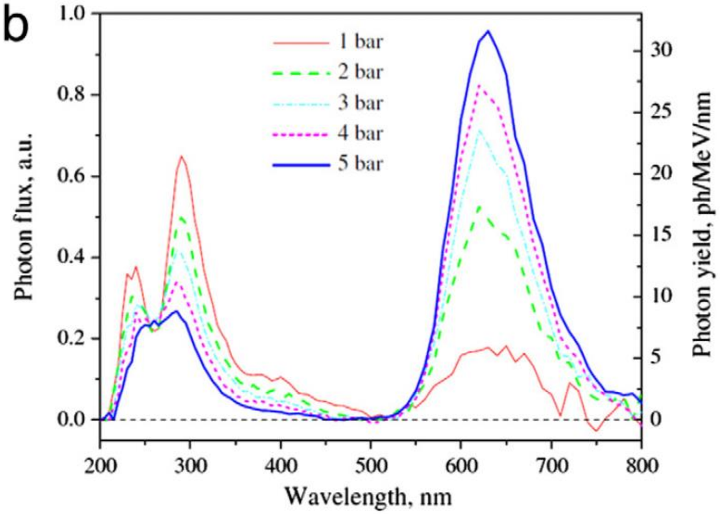
Heindl (2010)

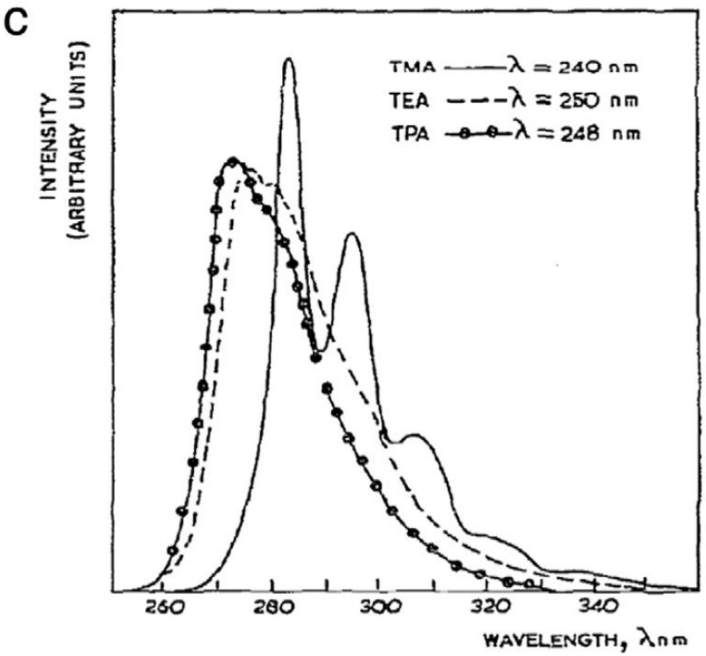
scintillation in other gases…

secondary scintillation in Ar/N_2



primary scintillation in CF_4 (alphas)





scintillation in tertiary amines (selective excitation)

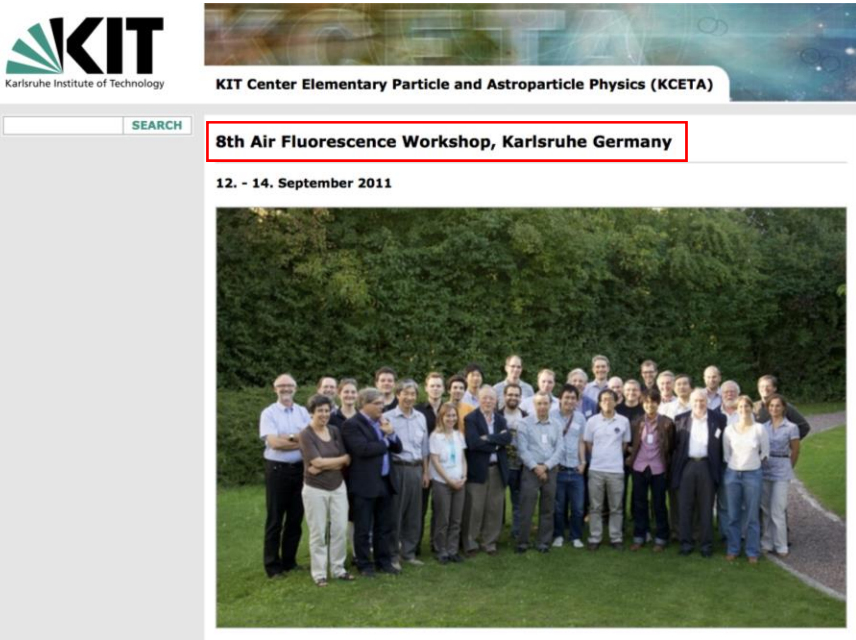
fluorescent yields in pressurized gases

• HP-xenon:	~32000ph/MeV (α's, E>30V/cm/bar).	Mostly VUV (172nm)
	~62500ph/MeV (α's, E=0).	Mostly VUV (172nm)
	~14500ph/MeV (electrons).	Mostly VUV (172nm)
• HP-argon:	~20000ph/MeV (α's, E>30V/cm/bar).	Mostly VUV (128nm)
	~40000ph/MeV (α's, E=0).	Mostly VUV (128nm)
• HP-CF_4:	~300ph/MeV (α's, E=0).	VUV (<210nm)
	~750ph/MeV (α's, E=0).	UV-visible (220-510nm)
	~4000ph/MeV (α's, E=0).	visible-IR (500-800nm)

some work on N_2, not very conclusive… nothing on gas mixtures!

fluorescent yields and the measurement problem

- Most measurements are done in conditions not relevant to particle detectors: (selective laser excitation, synchrotron radiation, electron/proton beams, discharge). What is worse, they were done in the 80’s and 90’s, and largely stopped since.
- Control on gas impurities essential. Requires vacuum-expertise.
- Obtaining light yield, spectral information and time constants not easy in a single experiment.
- Very large landscape of possible gas mixtures, pressures and fields.
- Scintillation for admixtures depends on transfer reactions between species, normally unknown. No additivity rules!.
- Very faint signals when using radioactive source. Need of special setups.
- Scintillation depends on the type of particle!

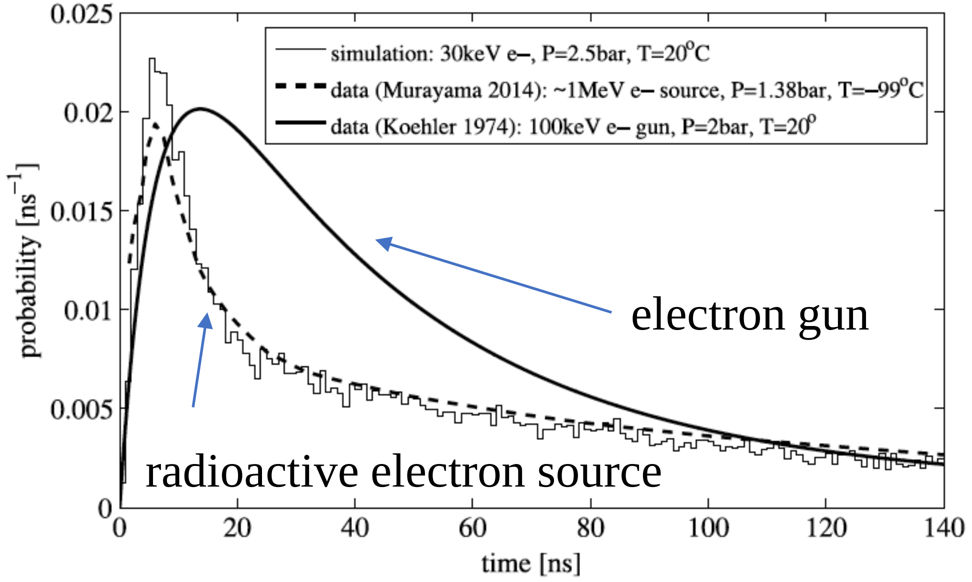


KIT Center Elementary Particle and Astroparticle Physics (KCETA)

8th Air Fluorescence Workshop, Karlsruhe Germany

12. - 14. September 2011

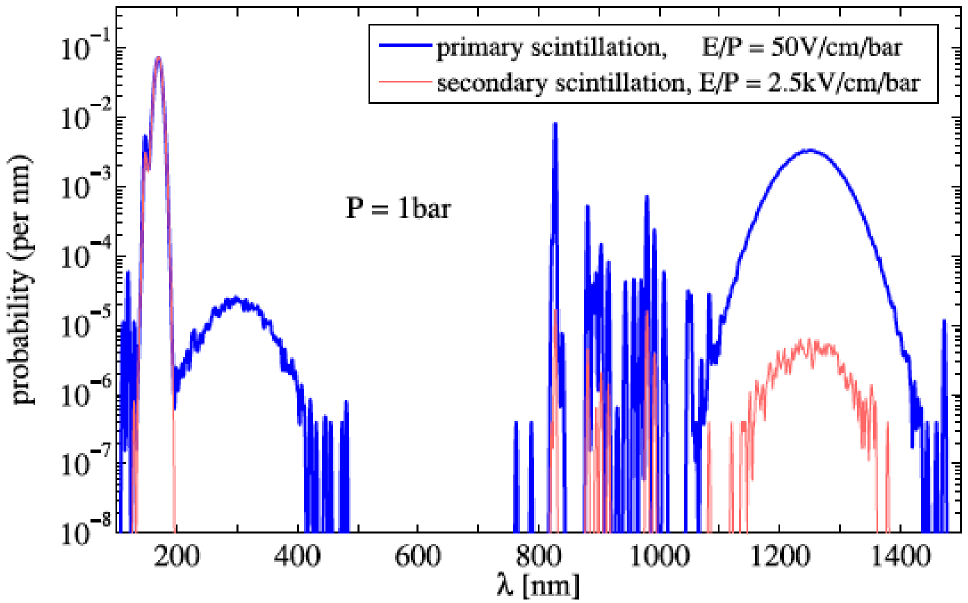
fluorescent yields and the measurement problem
(the excitation mechanism is ‘everything’ here)



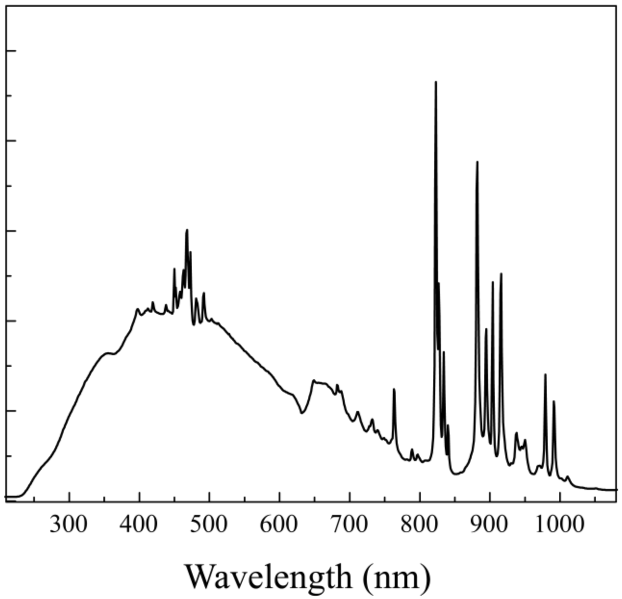
electron gun

radioactive electron source

radioactive electron source

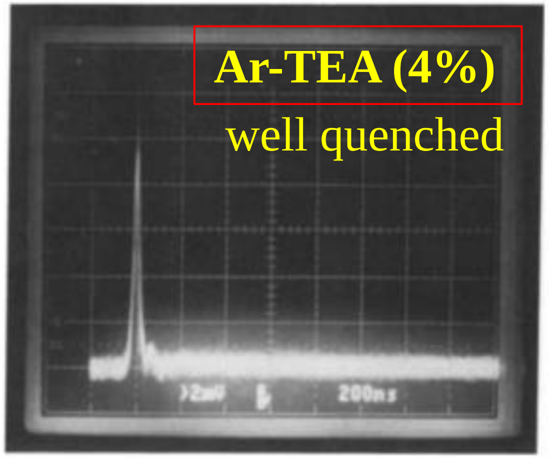


xenon lamp



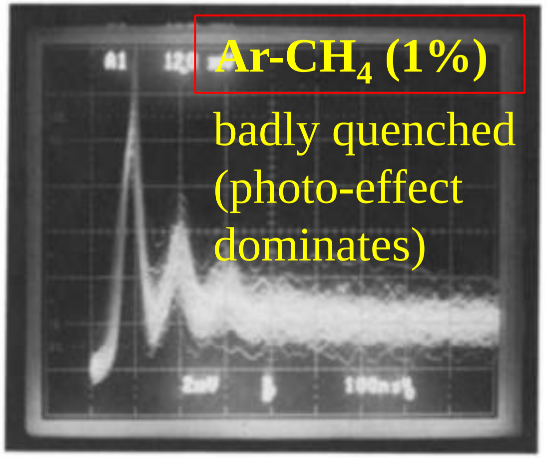
II. Avalanche multiplication

effect of quencher



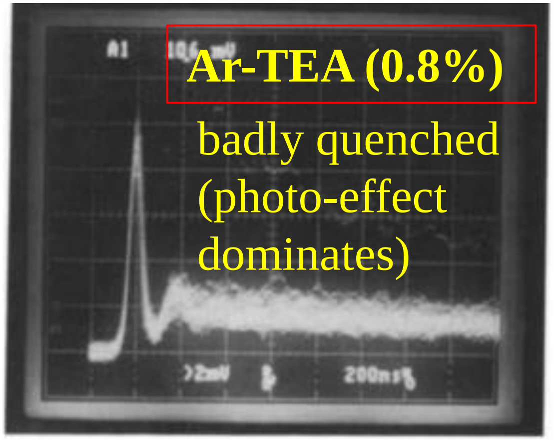
Ar-TEA (4%)

well quenched



Ar-CH$_4$ (1%)

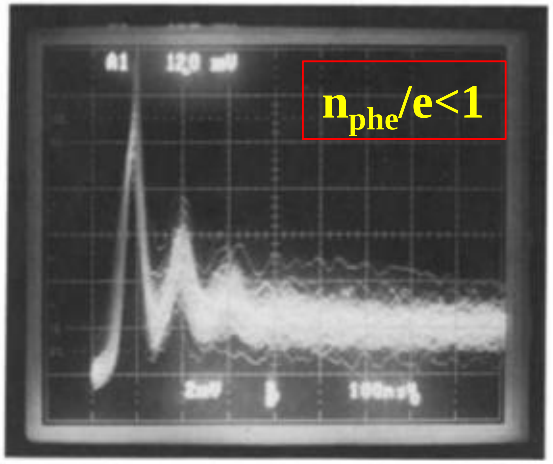
badly quenched (photo-effect dominates)



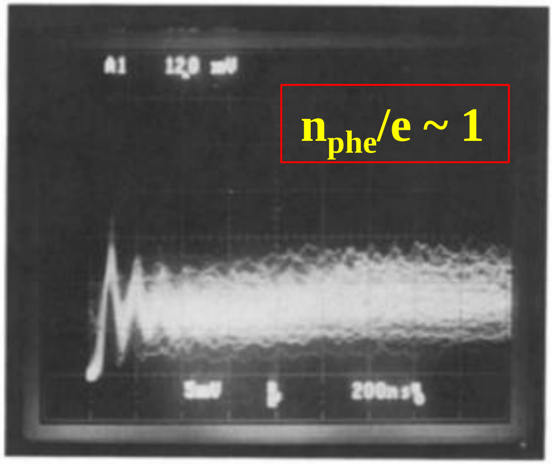
Ar-TEA (0.8%)

badly quenched (photo-effect dominates)

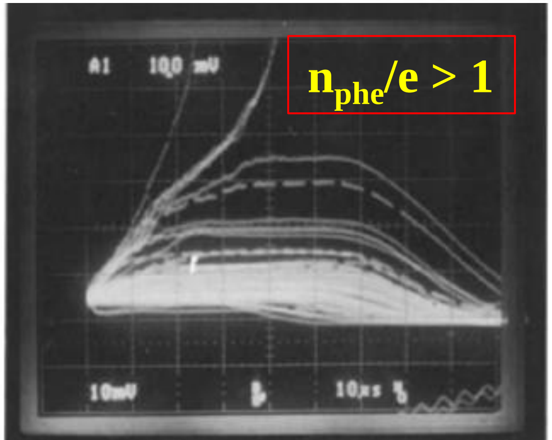
effect of field (Ar-CH$_4$ (1%))



$n_{phe}/e<1$

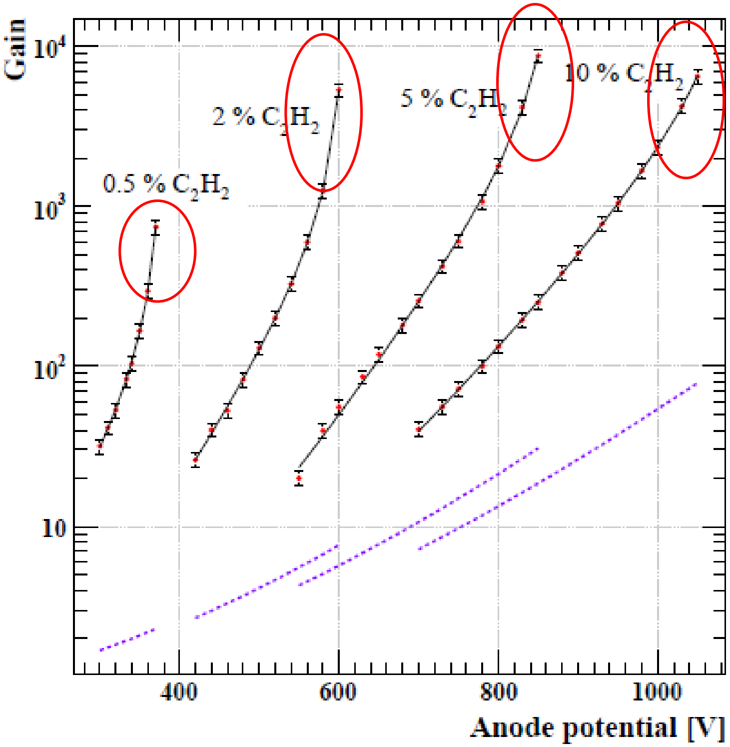


$n_{phe}/e \sim 1$



$n_{phe}/e > 1$

the problem with BADLY quenched gases

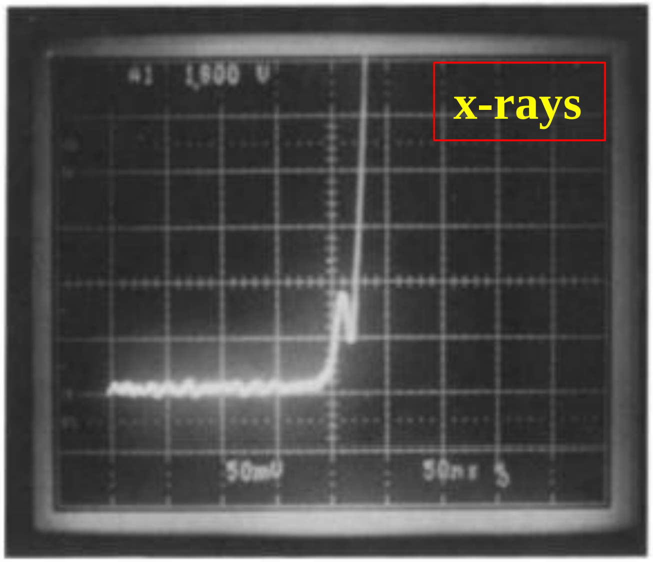


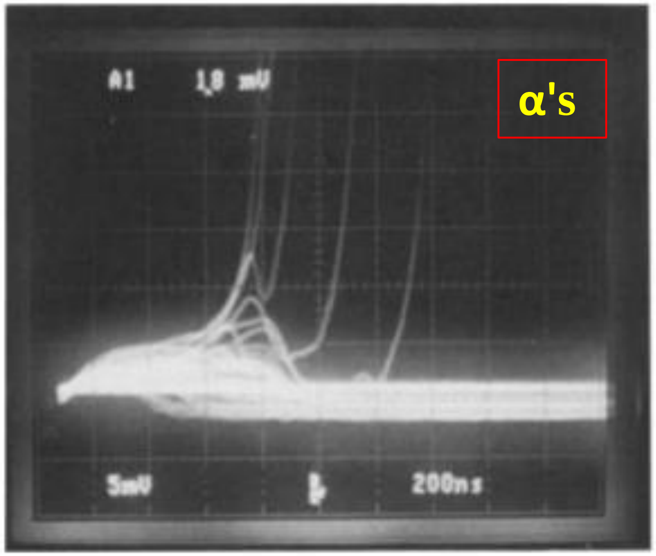
O. Sahin et al., JINST(2010)P05002
O. Sahin et al., NIM A 718(2013)432

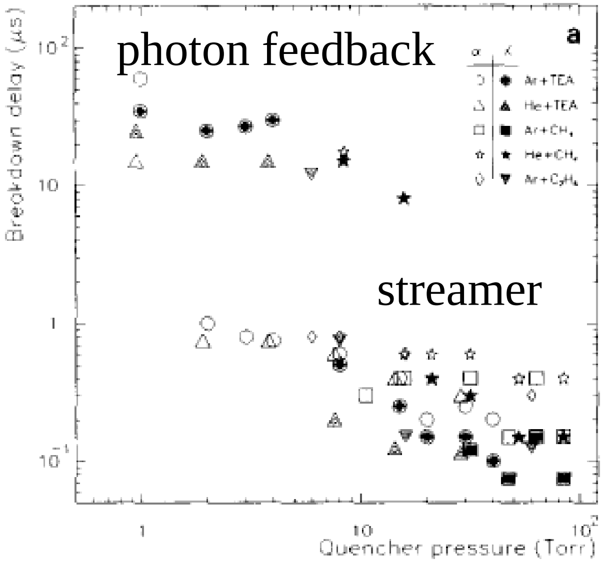
P. Fonte, V. Peskov, F. Sauli,
NIM A, 305(1991)91

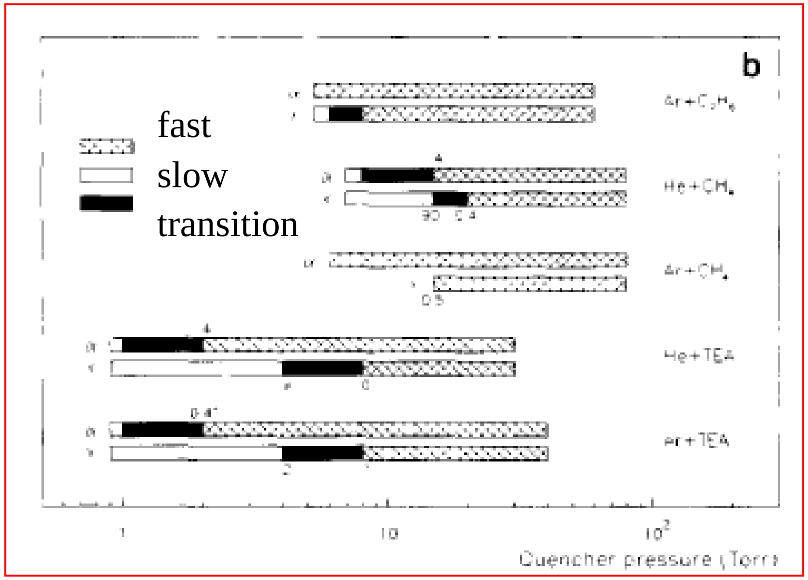
the problem with WELL quenched gases

streamer mechanism







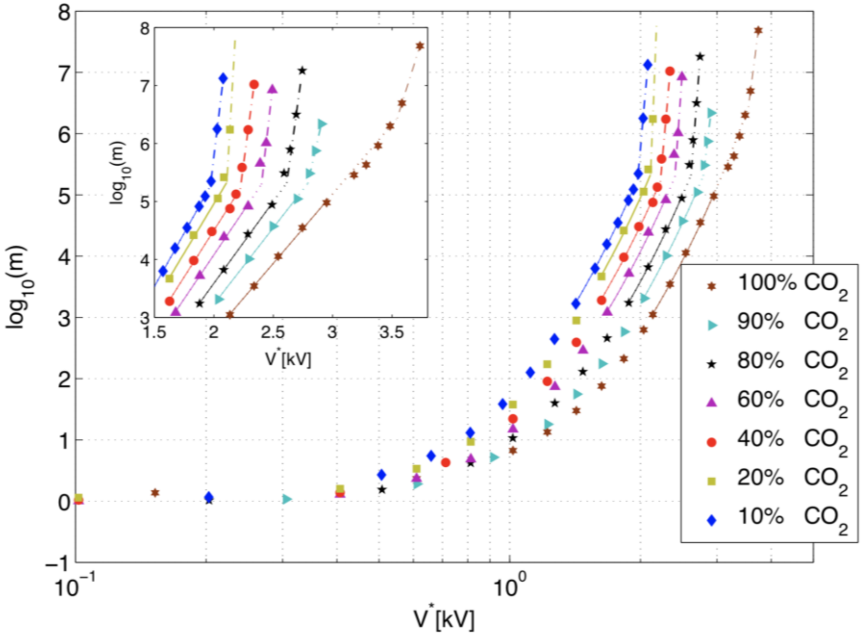


P. Fonte, V. Peskov, F. Sauli, NIM A, 305(1991)91

There is some common wisdom stating that *the more quencher the better*, but this is wrong. Above a certain point, the additional quencher is not really quenching… it is used just for tuning the drift-diffusion properties of the detector!

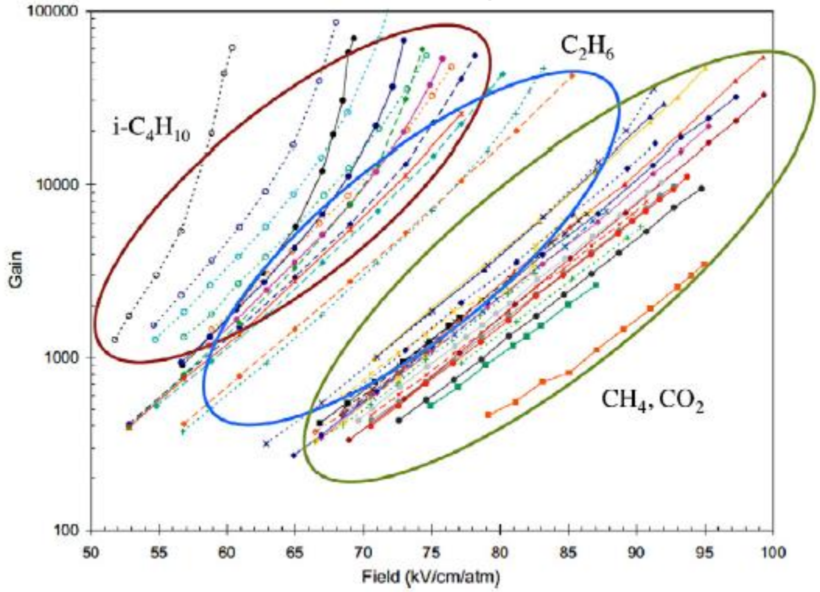
1. Above few %, the addition of more quencher does not make a difference concerning detector gain, in general.

wire chambers



Andronic, Garabatos, González-Díaz (2009)

micromegas



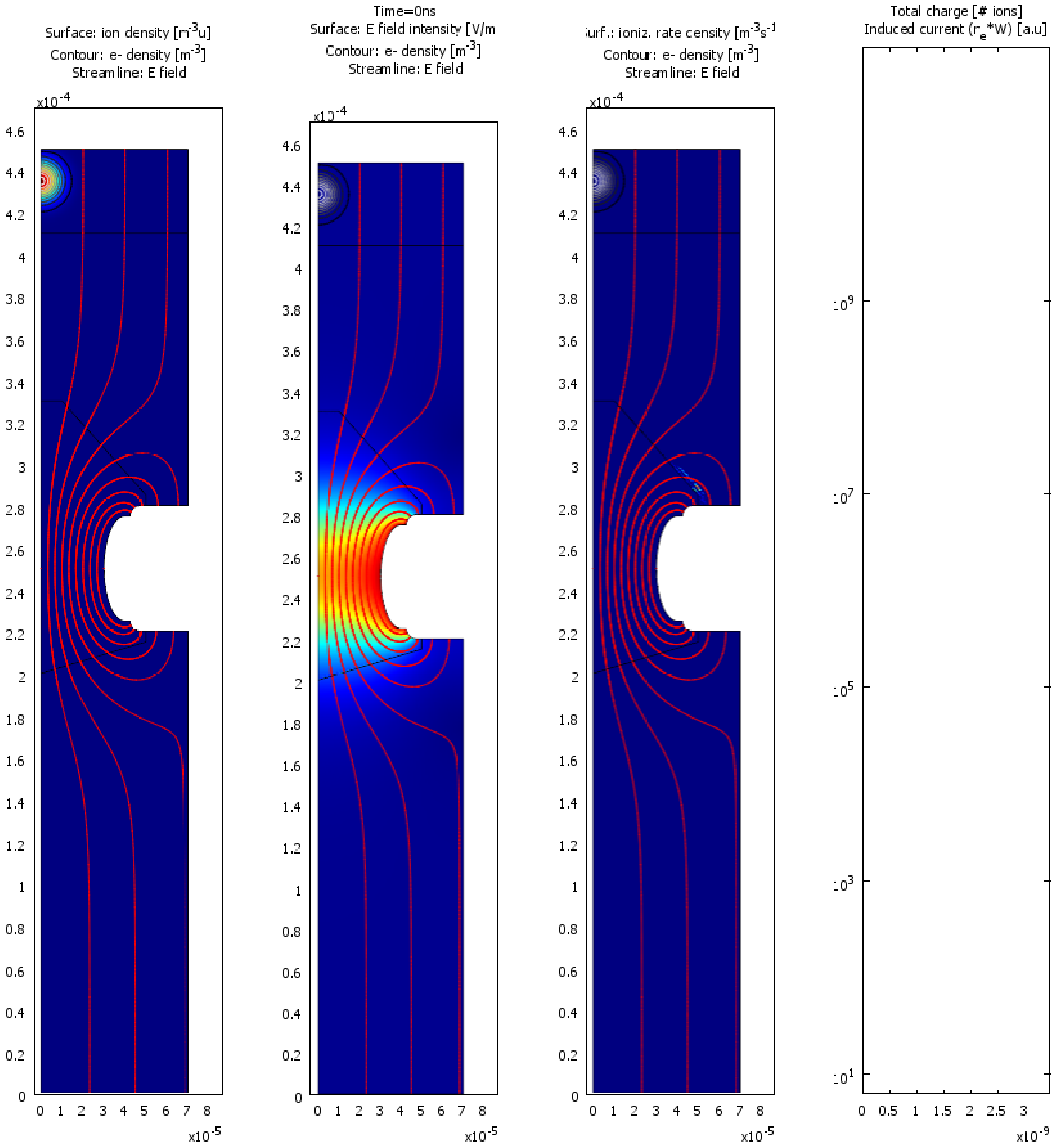
adapted from D. Attié (2009)

2. Noticeably, both ALICE and T2K use a *ternary* gas for drift-diffusion tuning, with one of the additives being fluorescent! (N_2, CF_4).
3. Importantly: there is no proof to date that the streamer mechanism is mediated by photons in conditions of interest to gaseous detectors!.

GEM

hole: 60 μm
gap: 100 μm
N_0=100 e^-
V=1250V

example of diffusion-assisted streamer (no photons)



P. Fonte

GEM

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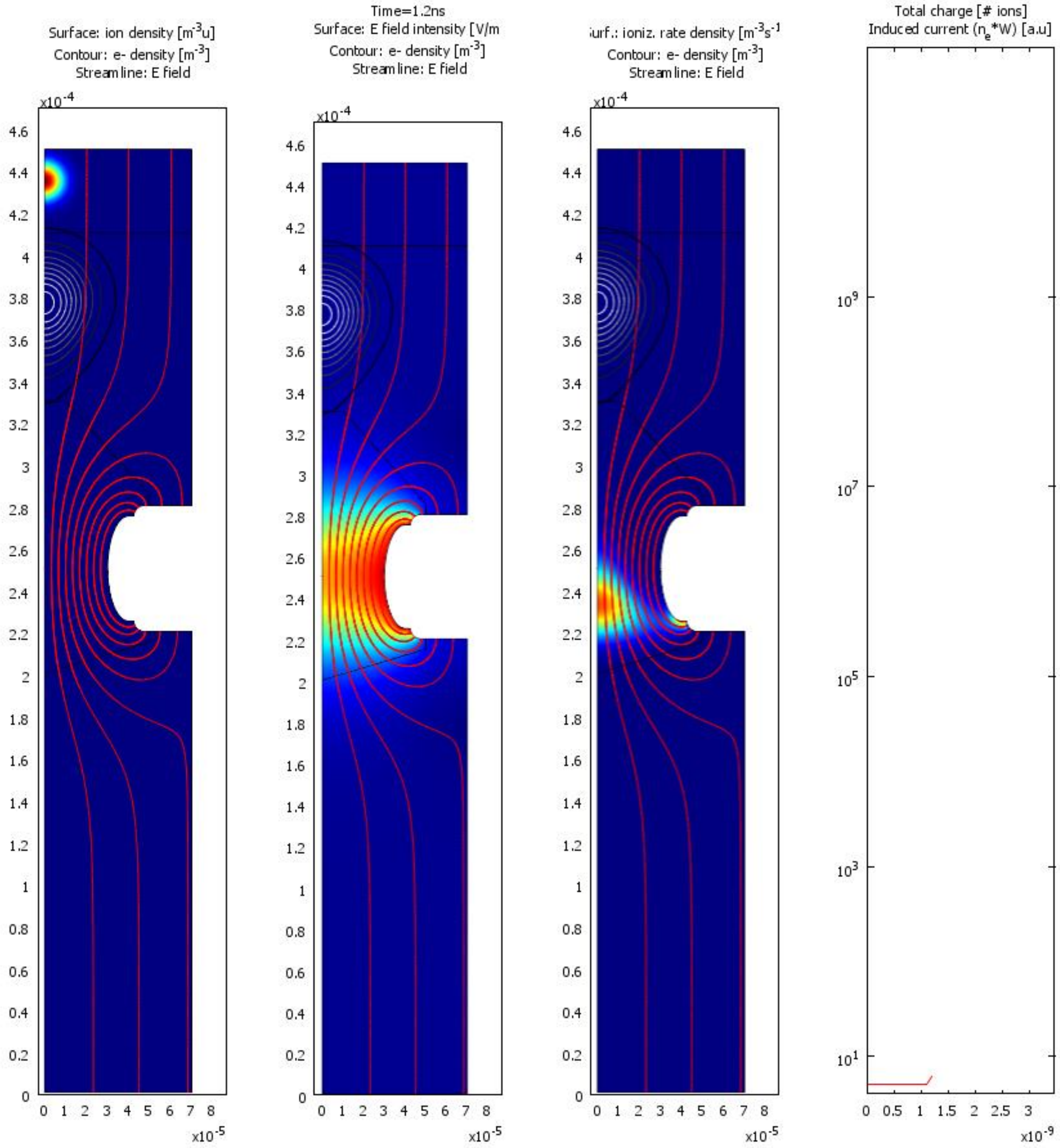
example of diffusion-assisted streamer (no photons)



GEM

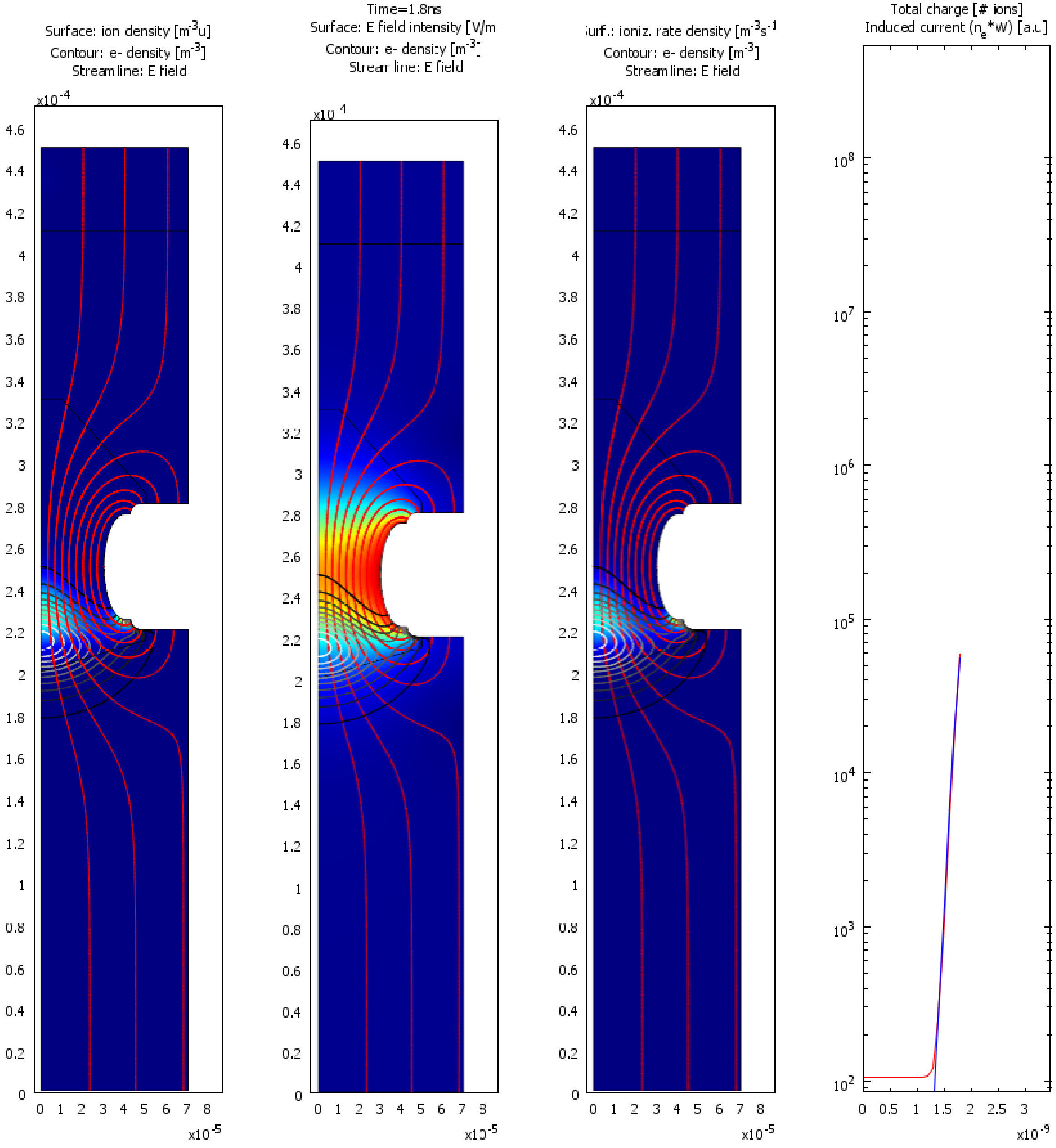
hole: 60 μm

gap: 100 μm

N_0=100 e^-

V=1250V

example of diffusion-assisted streamer (no photons)



GEM

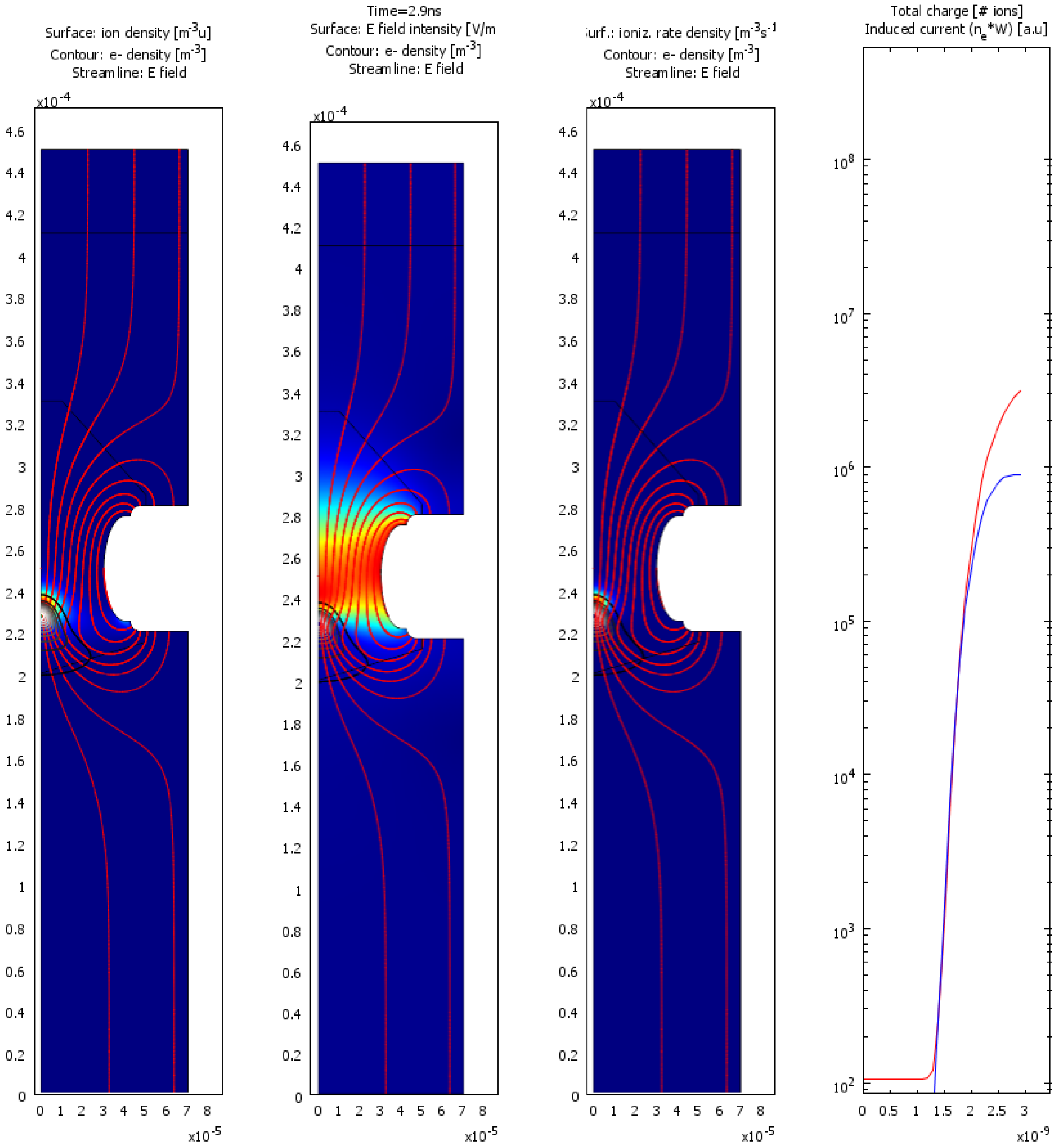
hole: 60 µm

gap: 100 µm

N_0=100 e^-

V=1250V

example of diffusion-assisted streamer (no photons)



GEM

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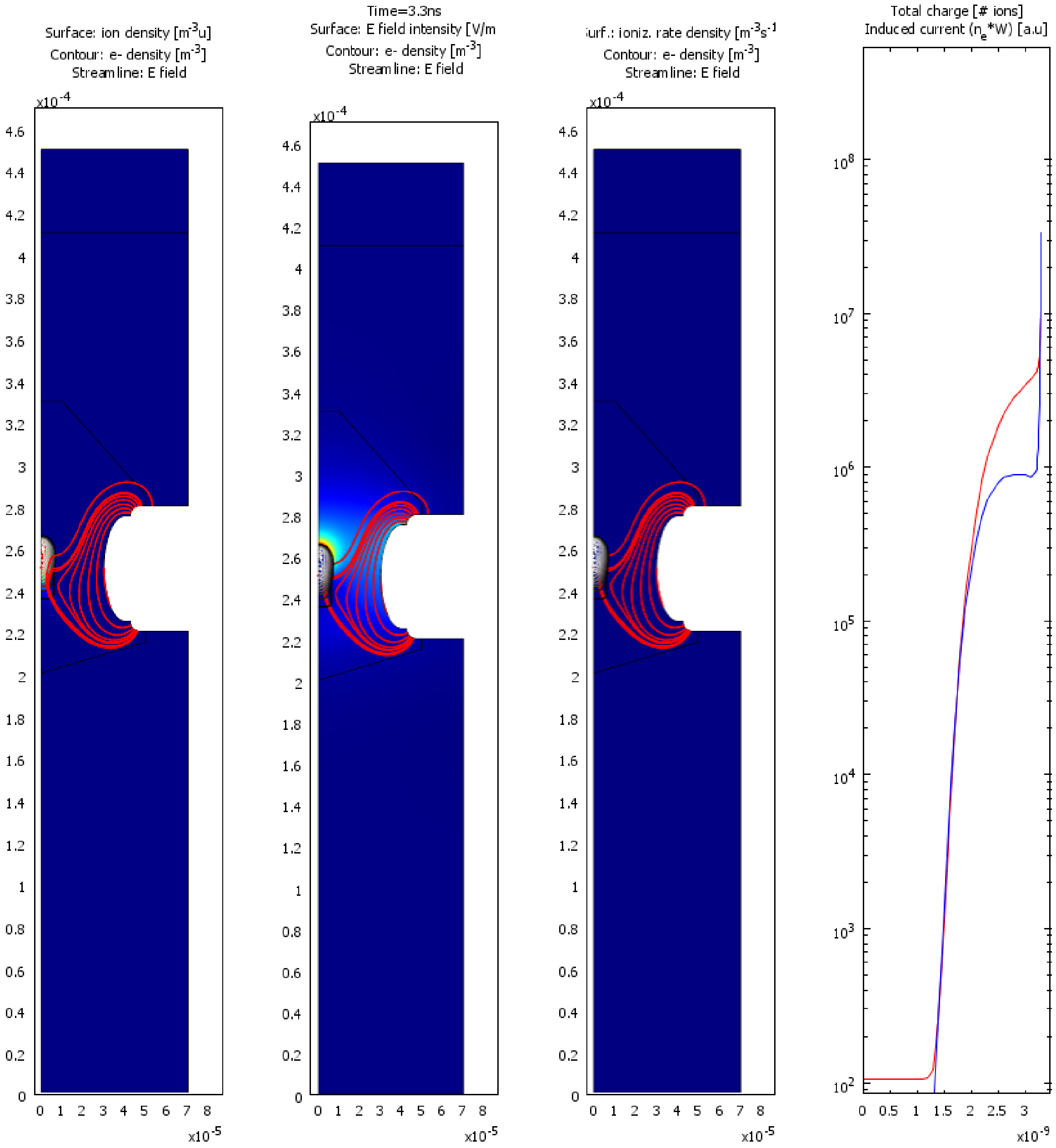
V=1250V

example of diffusion-assisted streamer (no photons)

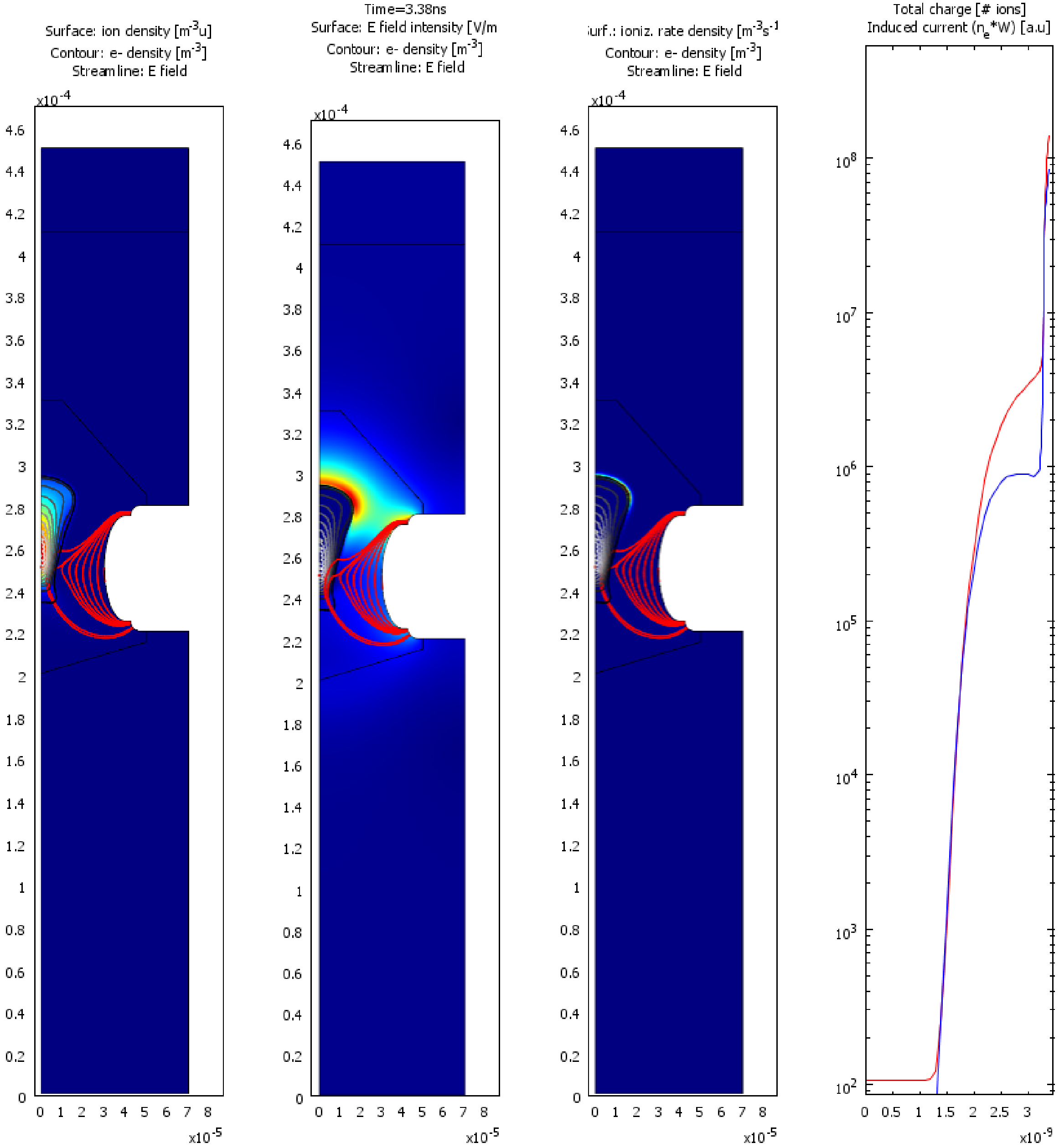


GEM

hole: 60 μm
gap: 100 μm
N_0=100 e^-
V=1250V

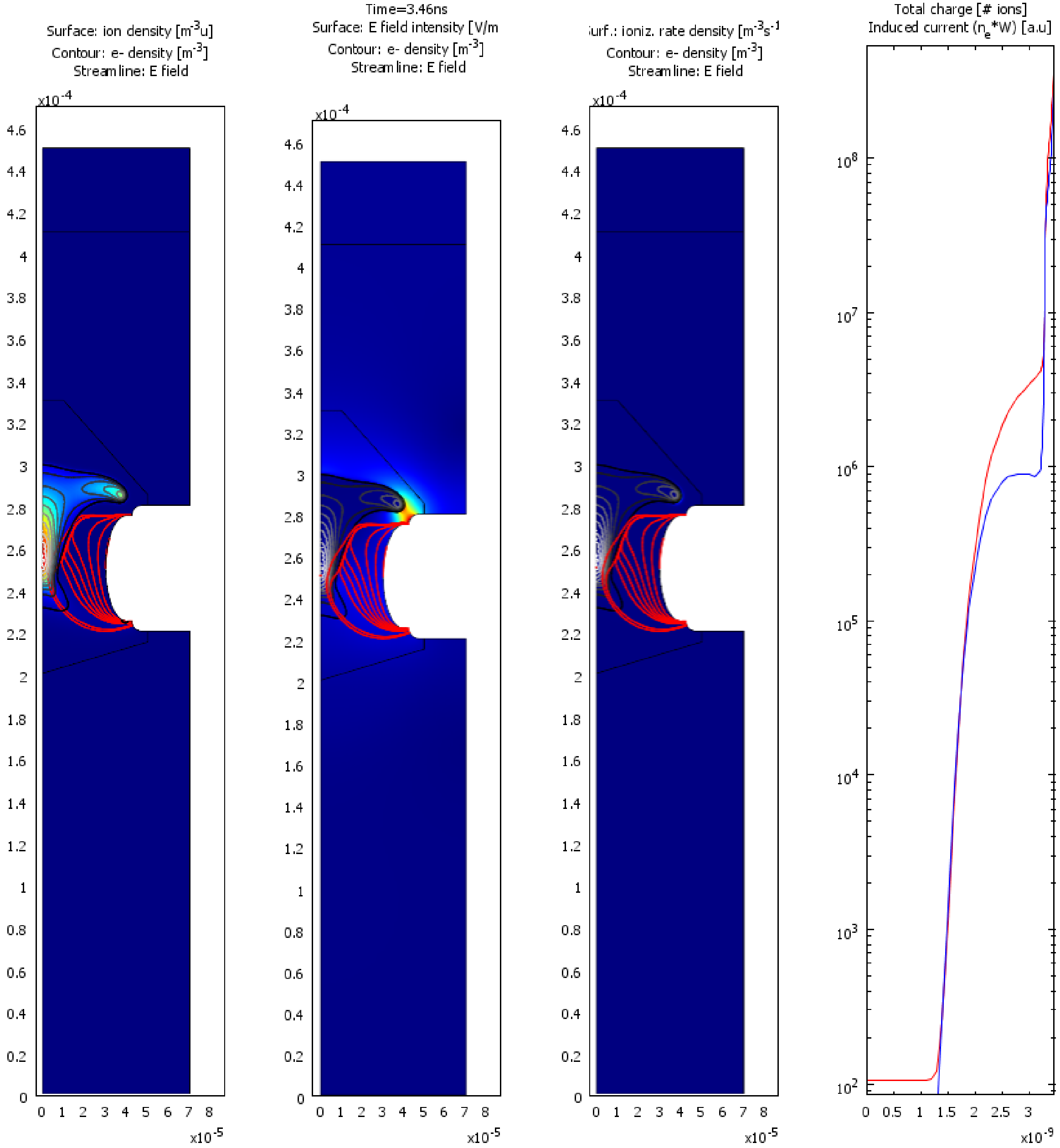
example of diffusion-assisted streamer (no photons)

(for more on this see P. Gasik's works and presentations of the DISCO collaboration)



GEM

hole: 60 μm
gap: 100 μm
N_0=100 e^-
V=1250V

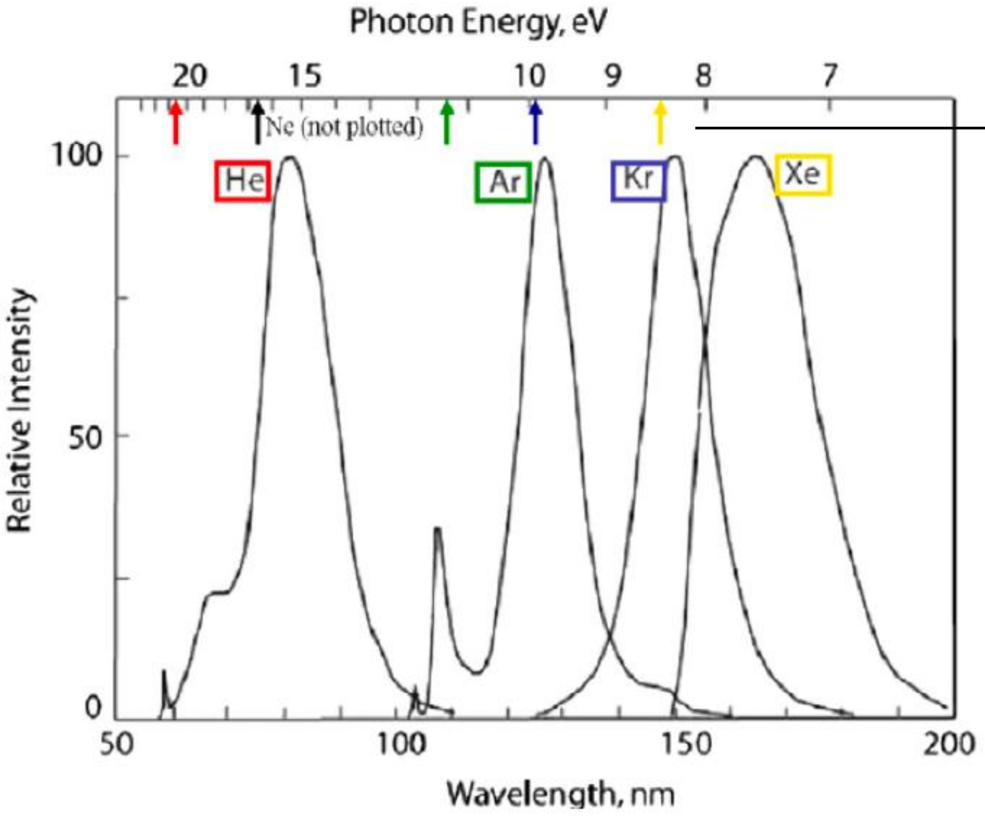


example of diffusion-assisted streamer (no photons)

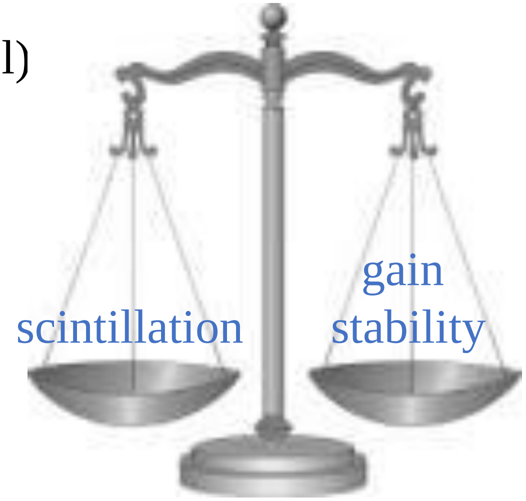
(for more on this see P. Gasik's works and presentations of the DISCO collaboration)

III. In search of a new magic gas

scintillation for noble gases (textbook level)

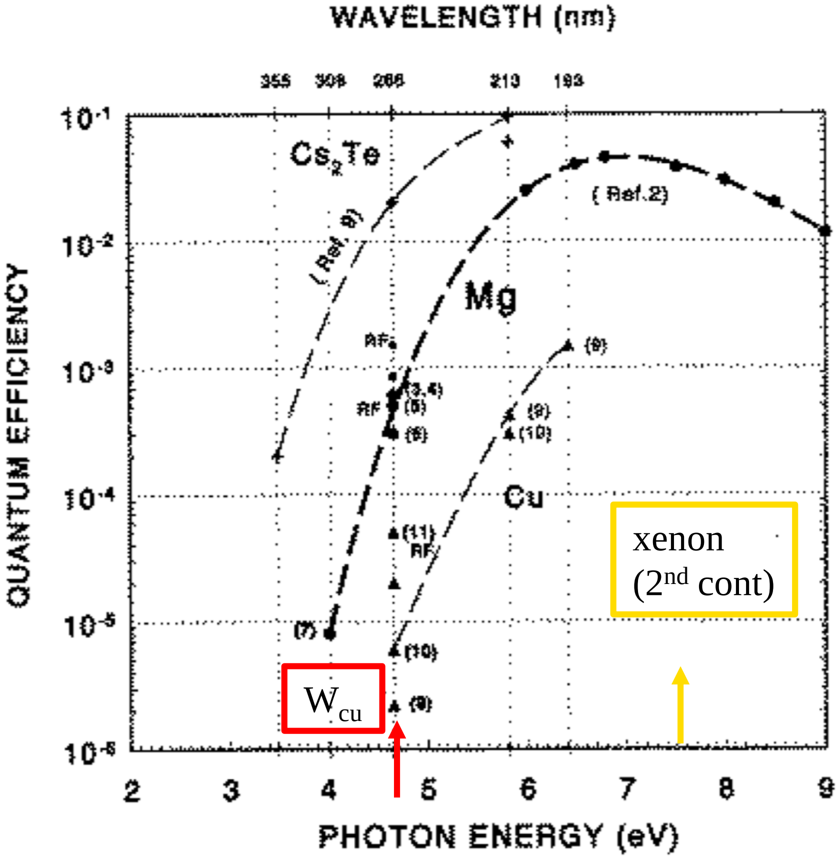


energy of
excited levels



scintillation

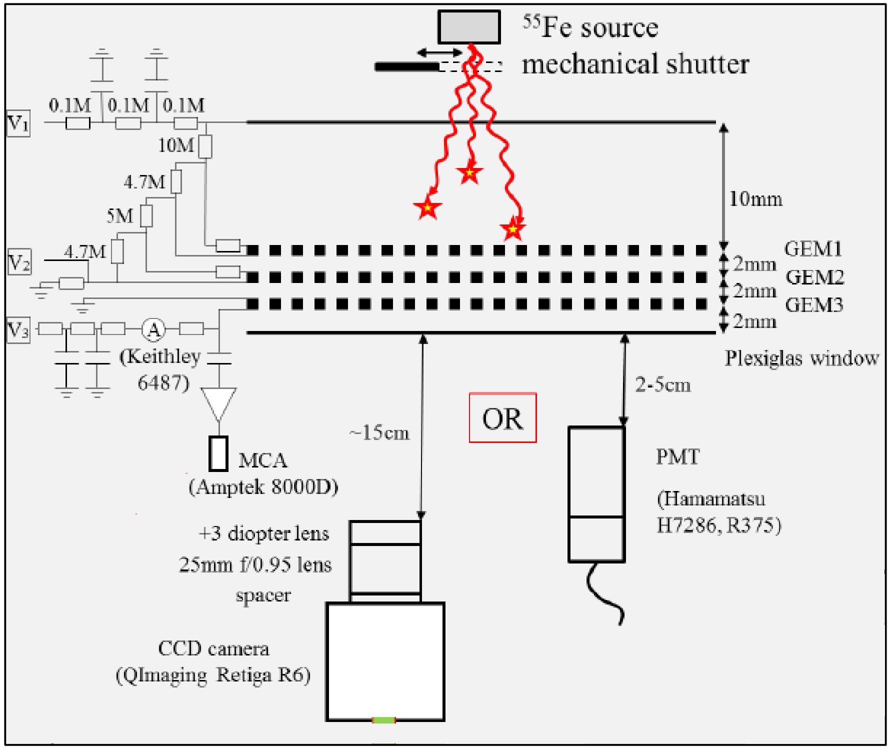
gain
stability

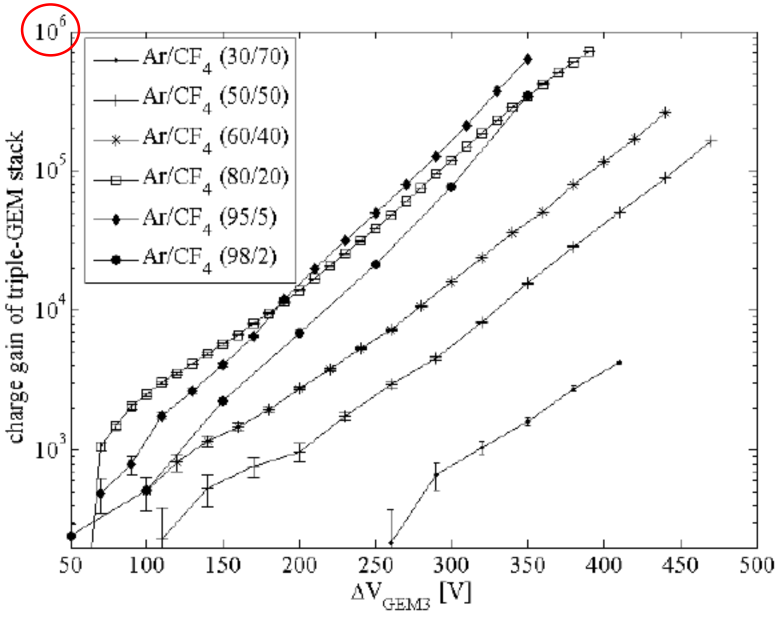


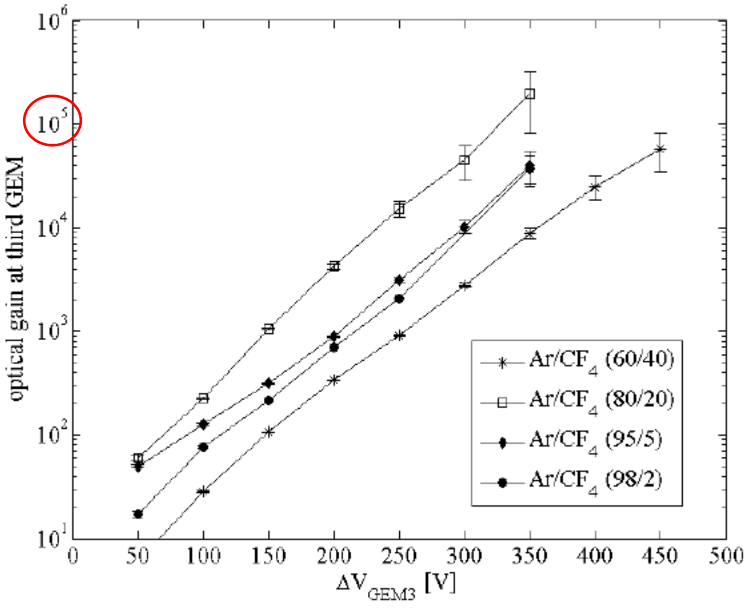
xenon
(2^{nd} cont)

W_{cu}

is this notion a bit old-fashioned?







e.g., measured at GDD-CERN (by DGD)

- diffusion-assisted streamer

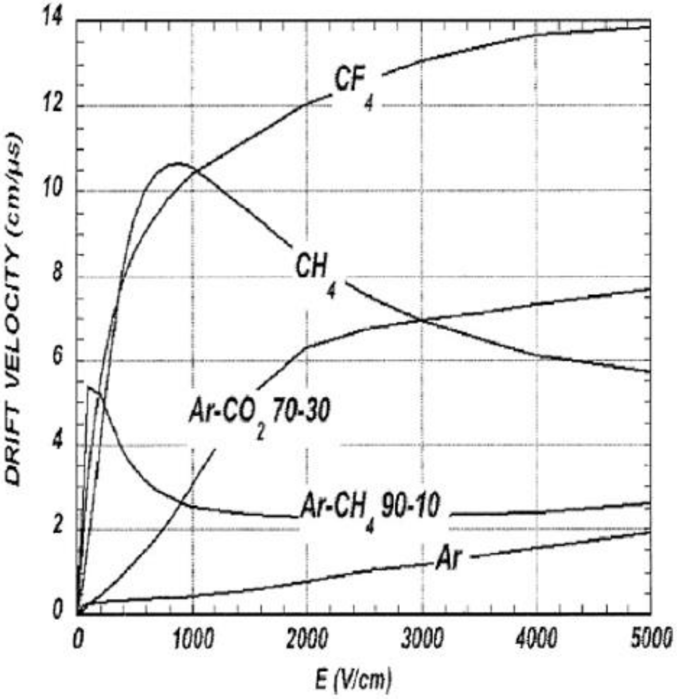
- electroluminescence chamber
- Ar/CF_4-based chamber

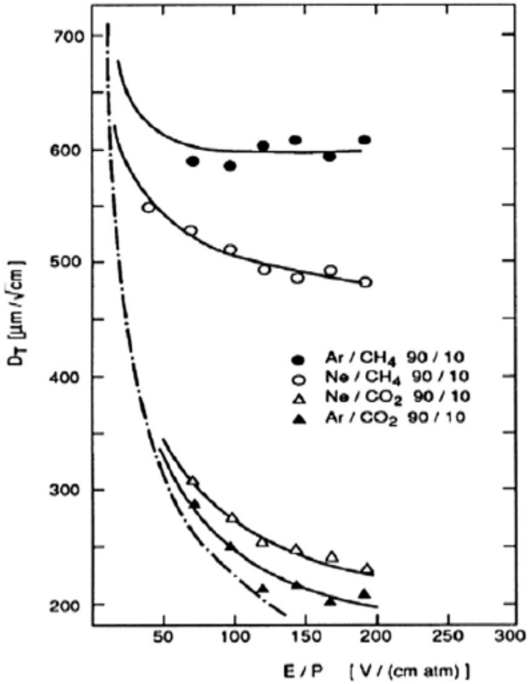
the role of the ~~quencher~~ additive

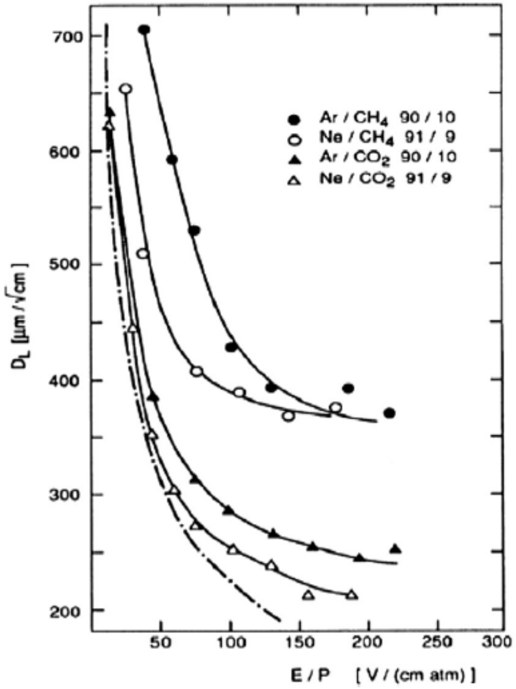
- Remove ~~photons~~

1. Tune drift-diffusion.
2. Quench excimer states.
3. Absorb emitted photons.
4. Wavelength-shift scintillation.

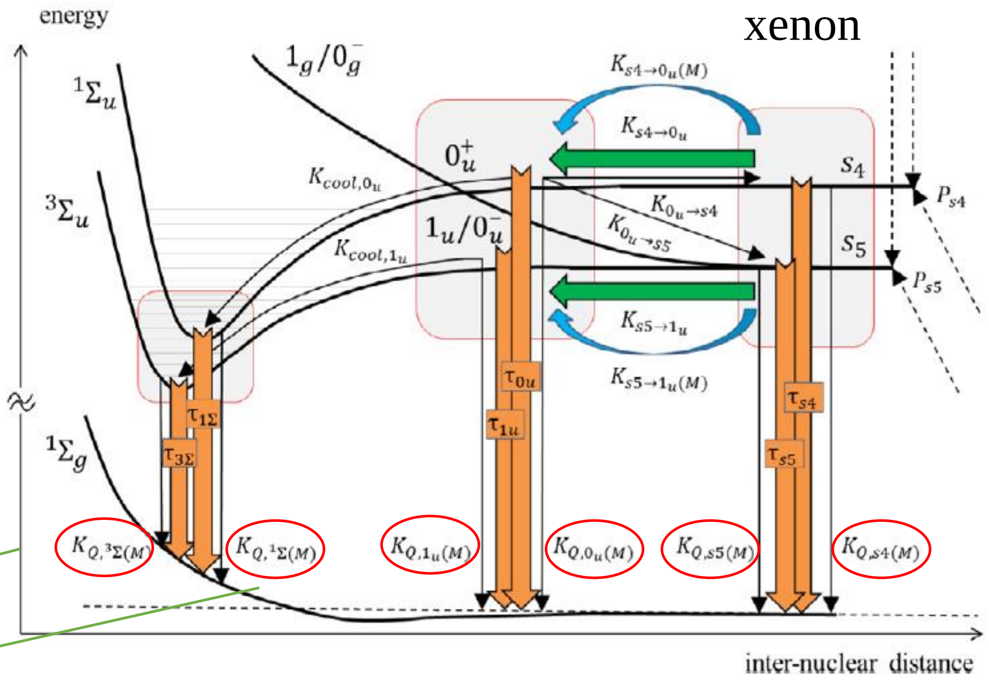
tune drift-diffusion







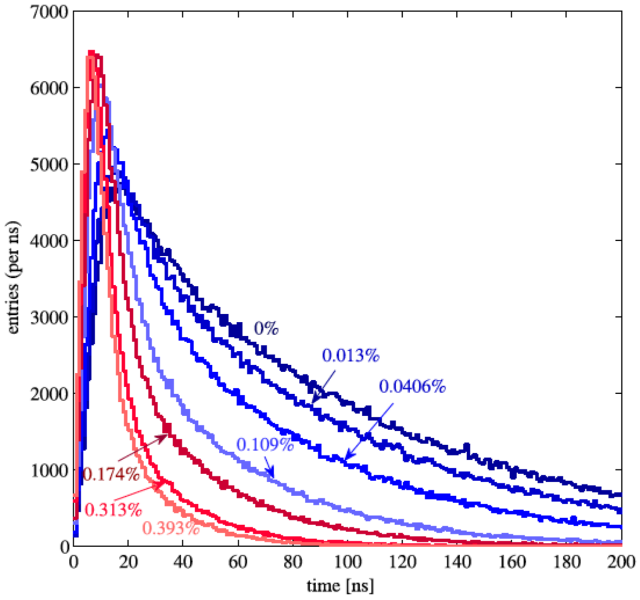
(non-radiative) quenching

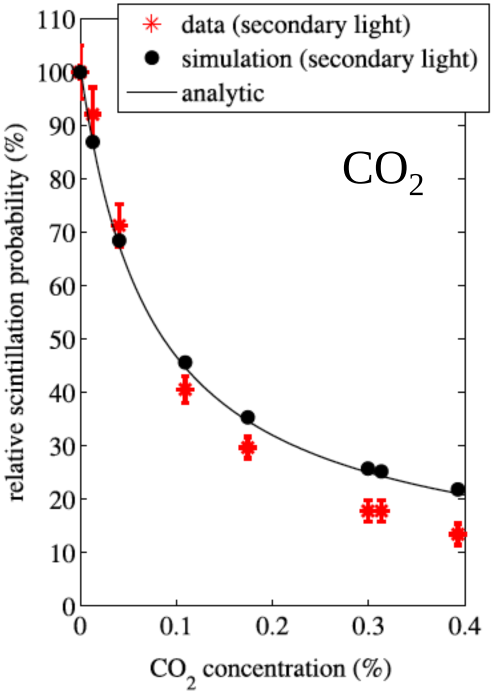


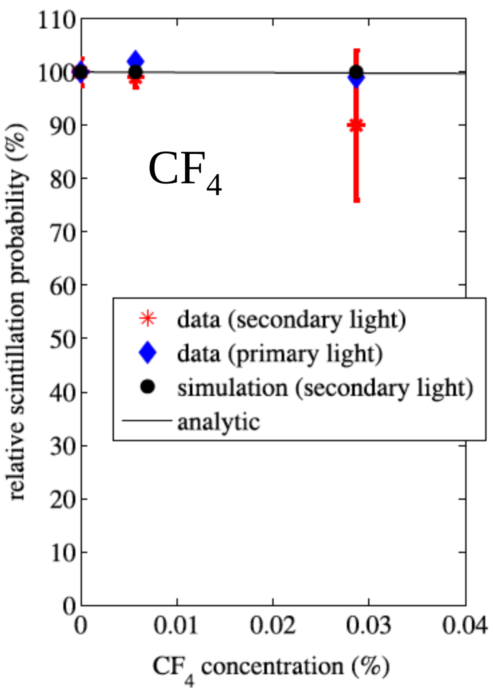
triplet lifetime (100ns)

singlet lifetime (4ns)

$$\mathcal{P}_{scin} \simeq \frac{F_1}{1 + f \cdot n \cdot \tau_{1_\Sigma} \cdot K_{Q,^1\Sigma}} + \frac{F_3}{1 + f \cdot n \cdot \tau_{3_\Sigma} \cdot K_{Q,^3\Sigma}}$$







C.D.R.Azevedo, DGD et al (2018)

transparency

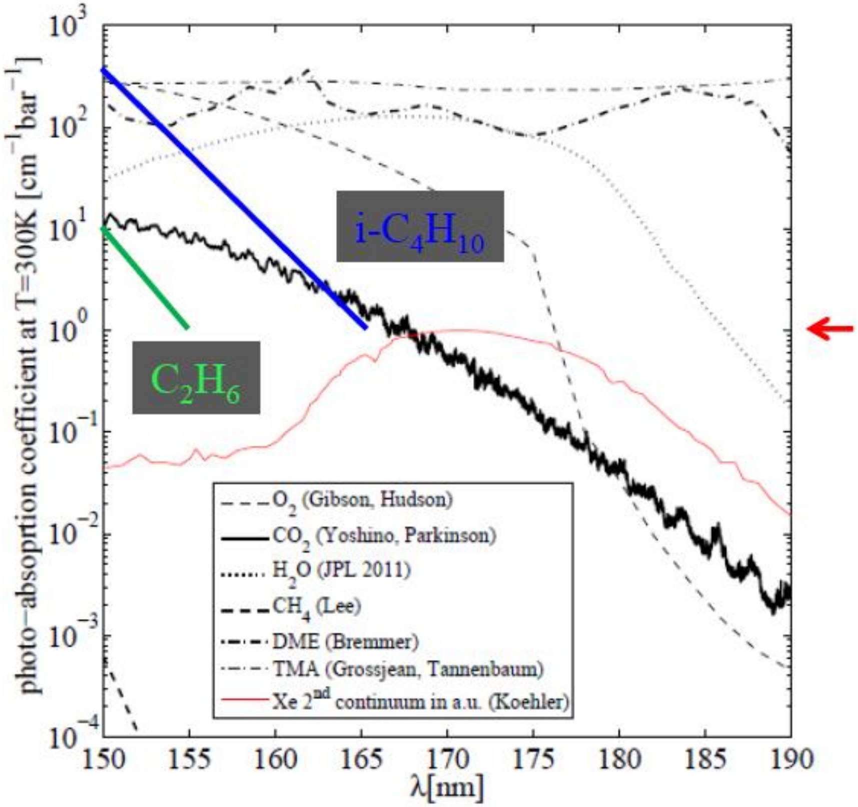


Fig. 1. Compilation of photo-absorption coefficients of some relevant TPC admixtures at around $T = 300$K in the region corresponding to the Xenon 2nd continuum, [9–18]. The reference spectrum from Koehler has been overlaid as a thin continuous line [2]. For H_2, N_2 and CF_4 there is no data in the region shown, and their cross-sections are plausibly orders of magnitude below that of CH_4.

$$\Pi = \frac{1}{P_o} N_o \sigma_a(\lambda)$$

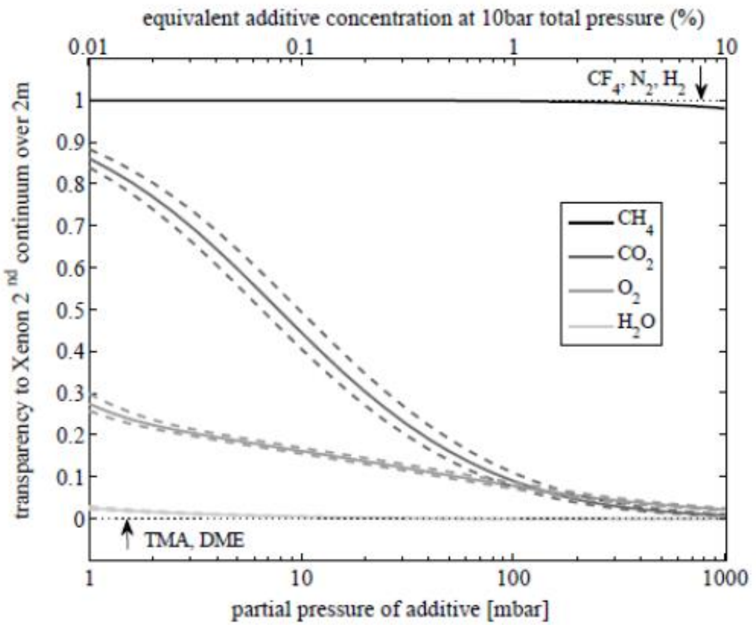


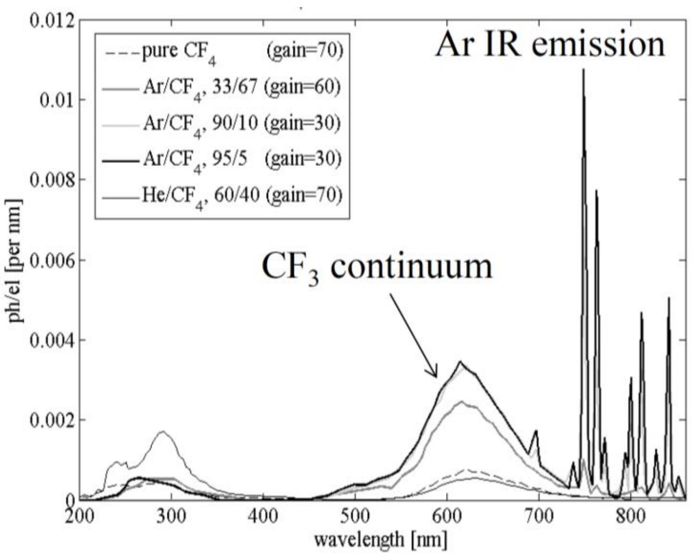
Fig. 2. Estimated transparency to scintillation from Xenon 2nd continuum as a function of partial pressure of the additive, over a 2 meter-long TPC. Dashed lines are obtained assuming 20% errors in the cross-sections.

$$\mathcal{T} \equiv \frac{\int_o^\infty \frac{dN}{d\lambda}\Big|_{2^{\rm nd}} e^{-N\sigma_a(\lambda)L}\, d\lambda}{\int_o^\infty \frac{dN}{d\lambda}\Big|_{2^{\rm nd}}\, d\lambda}$$

the difference between transparency and quenching is most clearly illustrated in xenon!

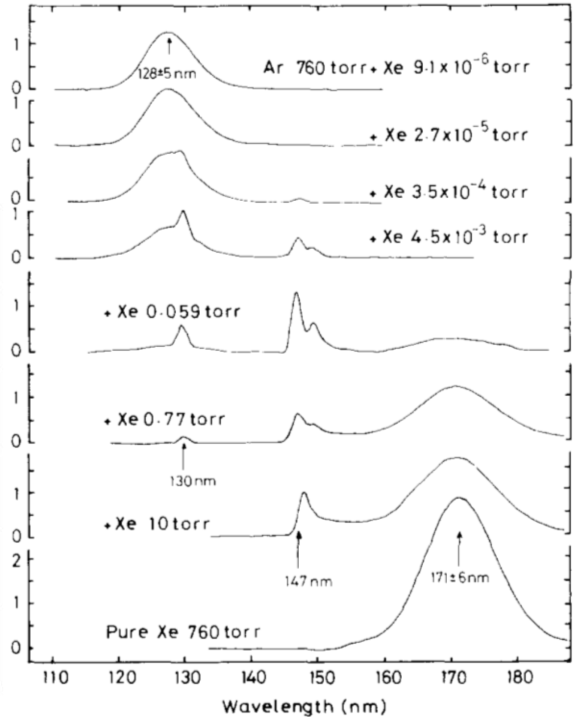
wavelength-shifting

128nm->600nm (Ar/CF$_4$)

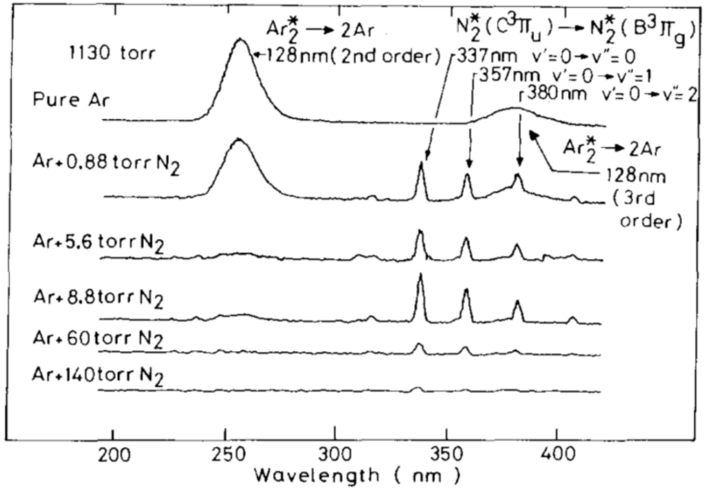


Fraga&Fraga (2002)
(secondary scint.)

128nm->172nm (Ar/Xe)

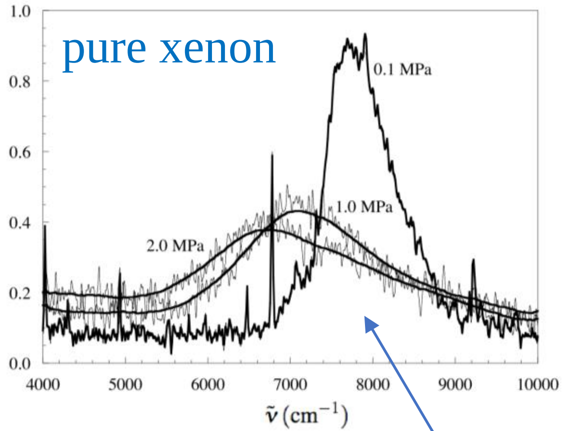


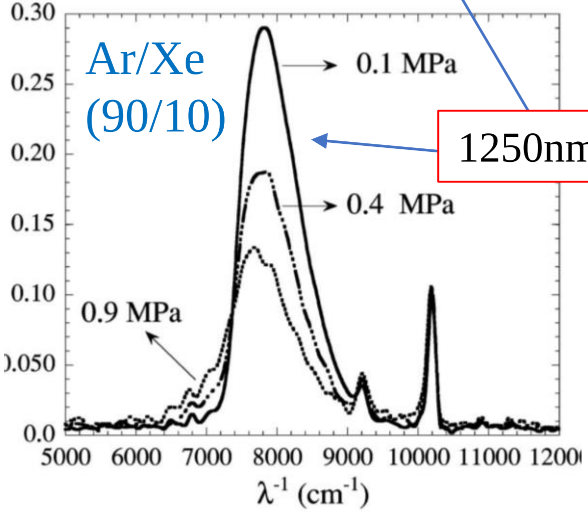
128nm->350nm (Ar/N$_2$)



T. Takahashi (1982) (secondary scint.)

128nm->1250nm





1250nm

absent in pure Ar!

A. F. Borghesani (2001)
(electron gun)

Therefore: can we find an additive that wavelength-shifts to a convenient (non-VUV) range and keeps a stable gain?

- If there is still too much VUV left for stable gain, is it possible to add a 3rd additive that absorbs only the VUV and not the wls component?.

- How much argon IR emission survives at high pressure nevertheless? (700-900nm).

- Is it possible in the medium term to seriously think of detecting the (copious) 1250nm emission in Ar/Xe mixtures?. GaInAs MPPCs + cooling will be needed!. A third gas component will be needed to quench/absorb the VUV emission.

- How do things depend on the type of particle, field and pressure?.

- What is the resilience of the usable scintillation to impurities?.

- Is there enough freedom of choice concerning the minimization of spurious neutrino-additive interactions and drift-diffusion tuning of the TPC?.

- What is the maximum gain achievable?.

- Assumption: enough space for a PM or MPPC plane. Impact on the energy sensitivity?

Gas TPCs with fast timing capability (T_0) for the DUNE Near Detector

IGFAE, Univ. Coimbra, Univ. Aveiro, Texas Arlington, Harvard Univ., Fermilab.

proposal submitted to IGNITE program