EL Yield & R_E of Xe - M_x mixtures for the NEXT TPC

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Introduction

Why is so important for NEXT to reduce e^- diffusion on Xe?

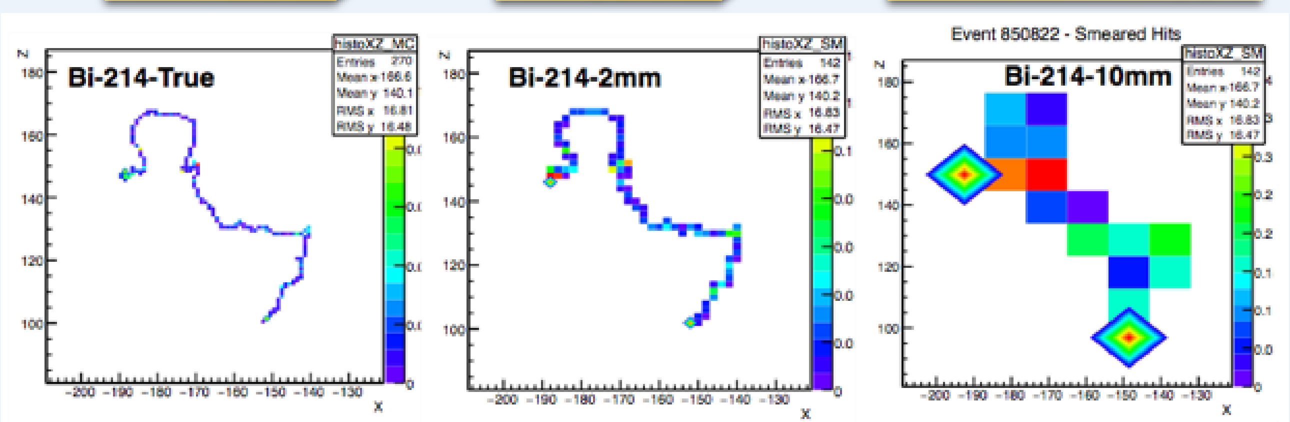
Longitudinal resolution:

- EL gap (5mm) → 1.5 mm
- $\boldsymbol{D_L\ (Xe) \sim 4.5\ \mathrm{mm/m}}$

Transverse resolution:

- SiPMs pitch + barycenter algorithm → 1 mm
- $\boldsymbol{D_T\ (Xe) \sim 10\ \mathrm{mm/m}}$

background event → **2mm - still background** → **e^- after 1m drift in Xe – 10mm → false $\beta\beta$**



C.D.R. Azevedo et al., “An homeopathic cure to pure Xenon large diffusion”

The best molecule and concentration range

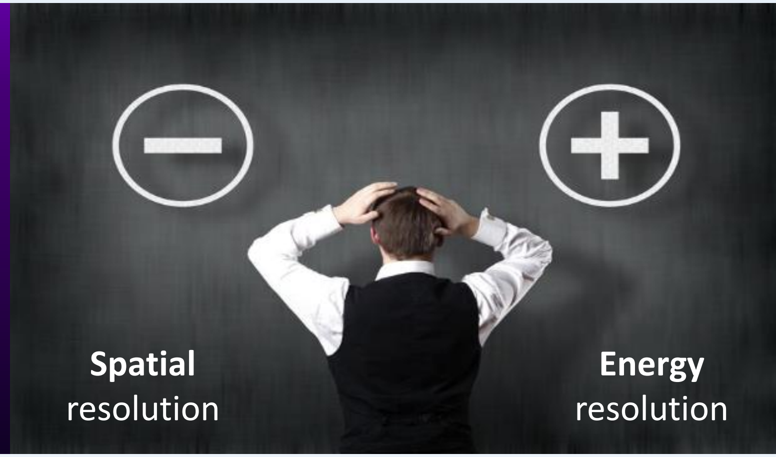
Xe + molecular

⇩

Electron cooling

⇩

Reduced e^- diffusion

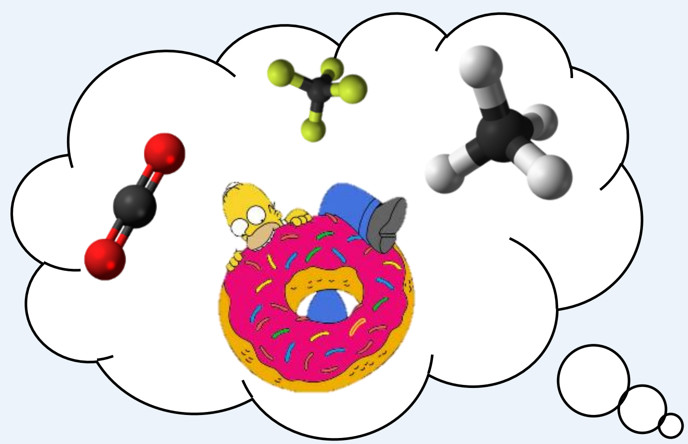


It may also degrade:

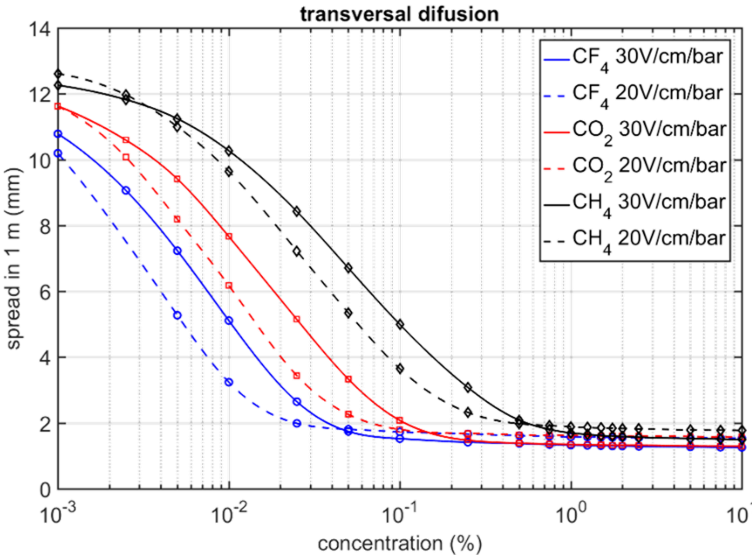
- **S1 and S2 yield**
- **Energy resolution**

GOAL

Finding the additive and concentration which give us the **best compromise** between **spatial** and **energy** resolutions

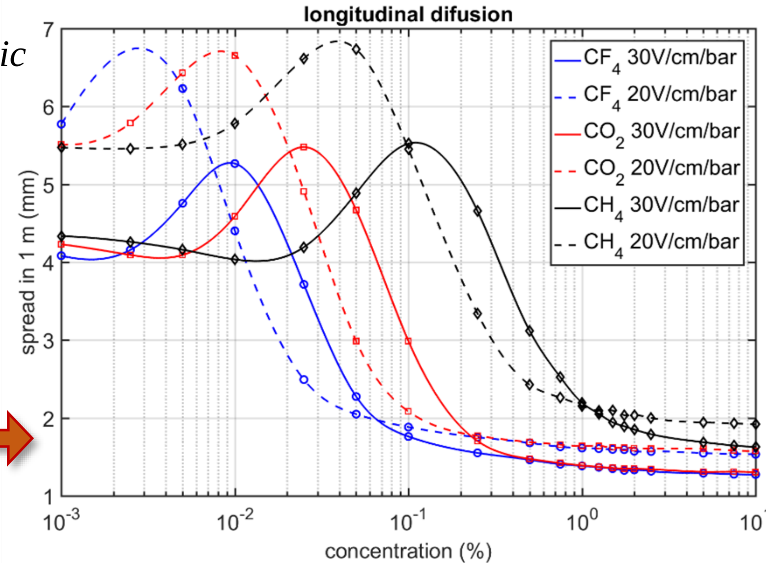


1) Xe – M_x reduces e^- diffusion: e^- cooled by vibrational excitation modes of M_x



Ref: *An homeopathic cure to pure Xenon large diffusion* [2]

Thermal limit of diffusion at room temperature



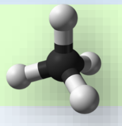
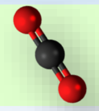
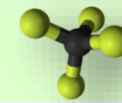
2) Xe – M_x degrades S1, S2 and R_E:

- ***e^-* cooling** → lower Y for fixed E (S2)
- **quenching** by M_x (S1, S2)
- **attachment/recombination**: in drift or EL regions (S2)
- **lower transparency** to VUV (S1, S2)

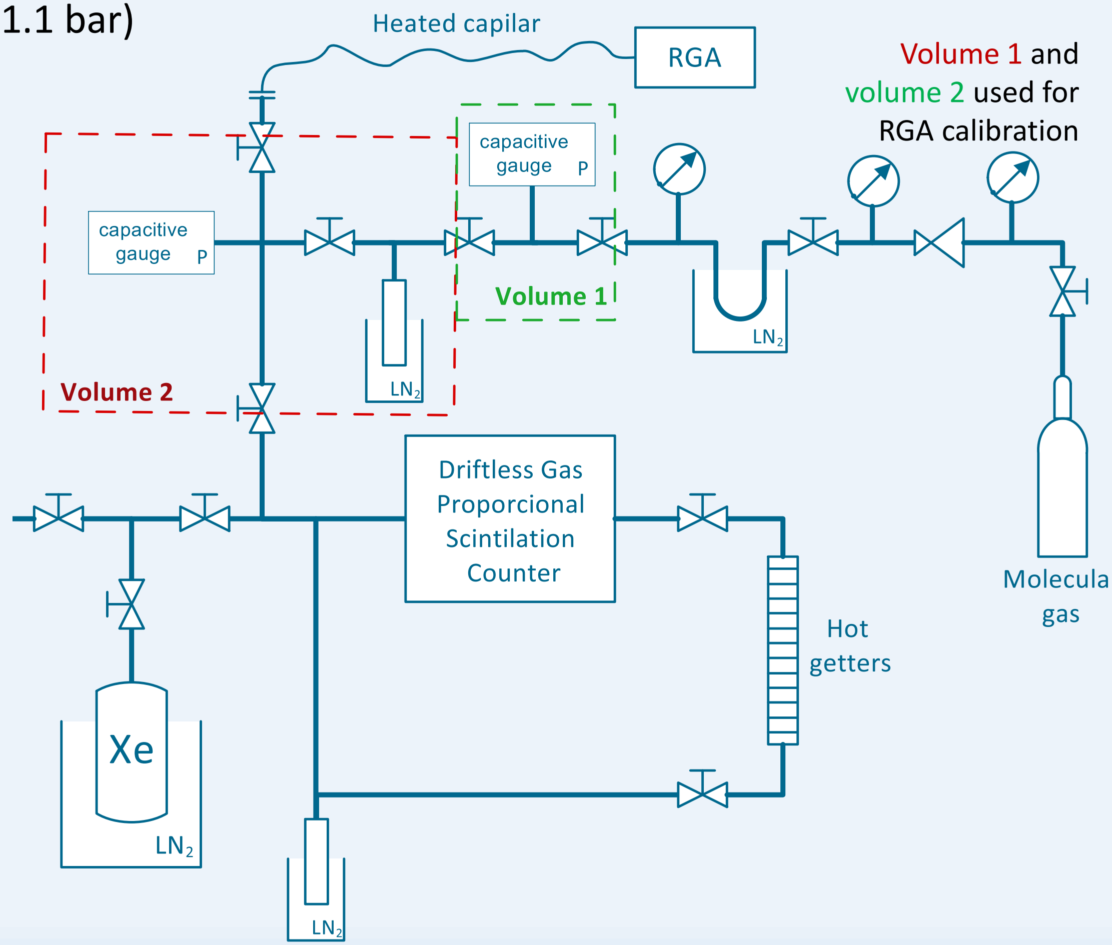
3) Xe – M_x technical issues:

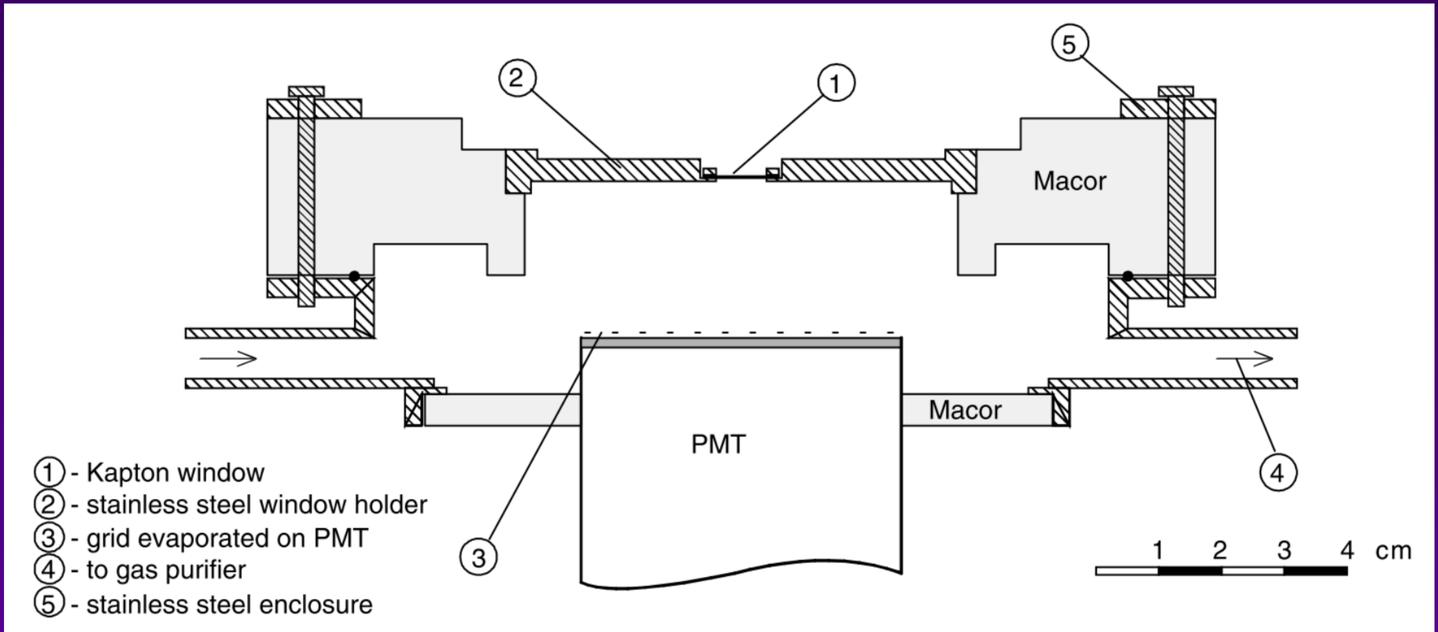
- **stable & compatible** (with detector and purification system)
- ***of easy handling and cleaning***

Experimental setup

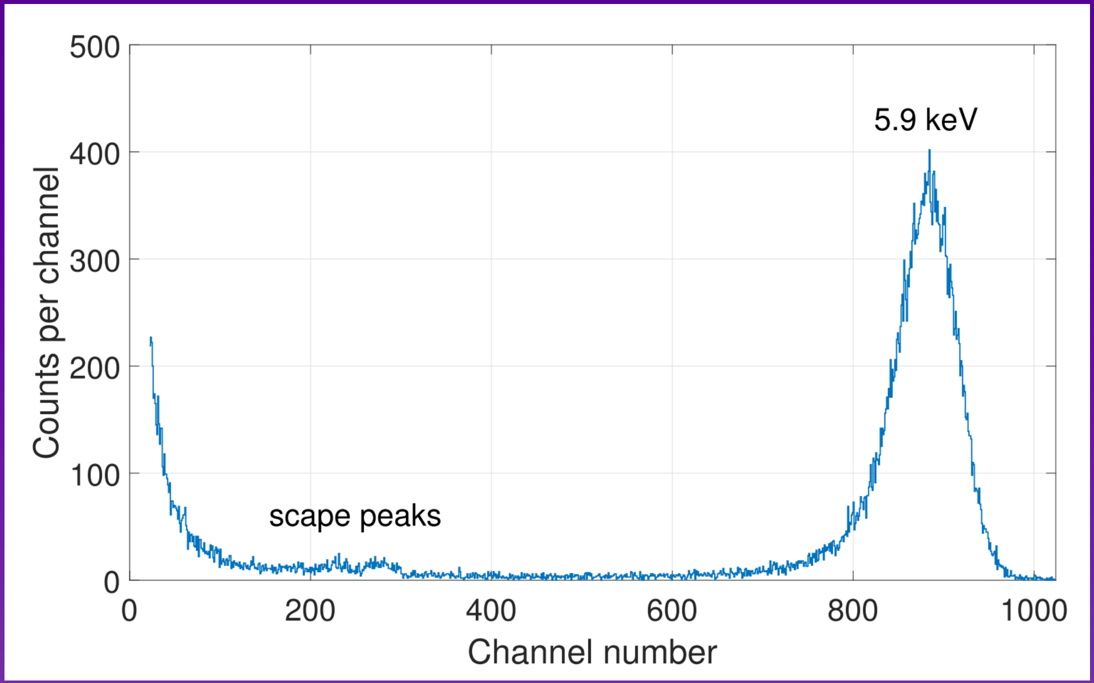
$Xe - CH_4$  **$Xe - CO_2$**  **$Xe - CF_4$** 

- **Driftless Gas Scintillation Proportional Counter (GSPC) with $\mathrm{EL_{gap}} = 25\mathrm{mm}$**
  - Eletroluminescence and R_E (@ ~1.1 bar)
- **Residual Gas Analyzer (RGA)**
  - real-time mixture concentration
- **Gas purified by SAES hot getters**
  - Pure Xe at 250° C
  - $Xe - CH_4$ and CF_4 at 120° C
  - $Xe - CO_2$ at 80° C





2
1
5
Macor
Macor
PMT
4
3
1 2 3 4 cm
① - Kapton window
② - stainless steel window holder
③ - grid evaporated on PMT
④ - to gas purifier
⑤ - stainless steel enclosure



5.9 keV
scape peaks
Counts per channel
Channel number
0
100
200
300
400
500
0
200
400
600
800
1000

Energy resolution $\left(R_E = {}^{FWHM}/_{centroid}\right)$

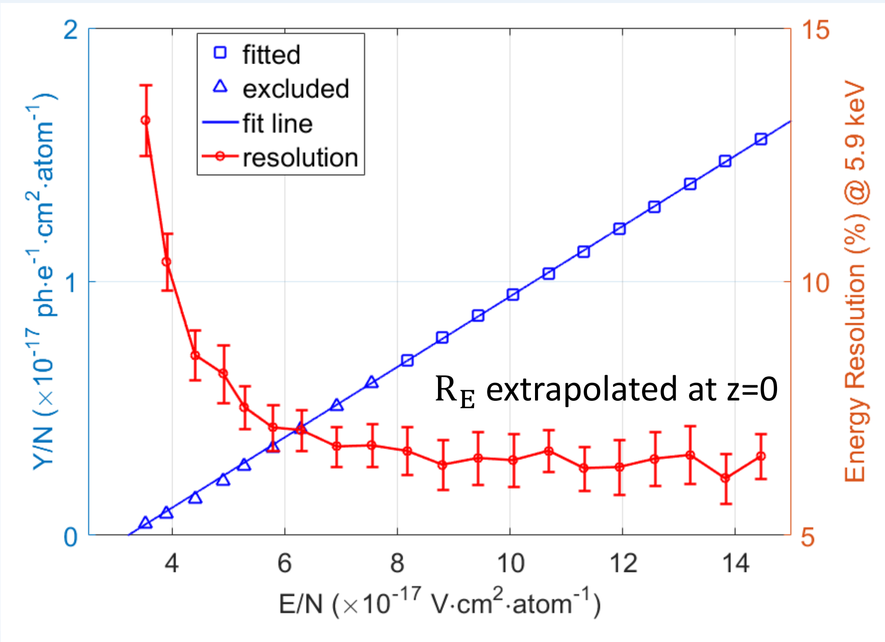
$$\boldsymbol{R_E = 2.35\sqrt{\frac{F}{\overline{N}_e} + \frac{Q}{\overline{N}_e} + \frac{1}{\mathrm{k}\cdot\overline{N}_e\cdot\overline{N}_{EL}}\left(1+\frac{\sigma_G^2}{G^2}\right)}}, \qquad \overline{N}_e = \frac{E}{w_i}$$

σ in primary charge production
$\boldsymbol{N_e}$ → primary e^-

σ in EL photon production

σ in PMT signal
k → light collection efficiency
$\boldsymbol{\sigma_G}$ → fluctuations in PMT gain
$\boldsymbol{N_{EL}}$ → EL emitted photons

EL Yield (Y) & $\boldsymbol{R_E}$ in a driftless GSPC (pure Xe)



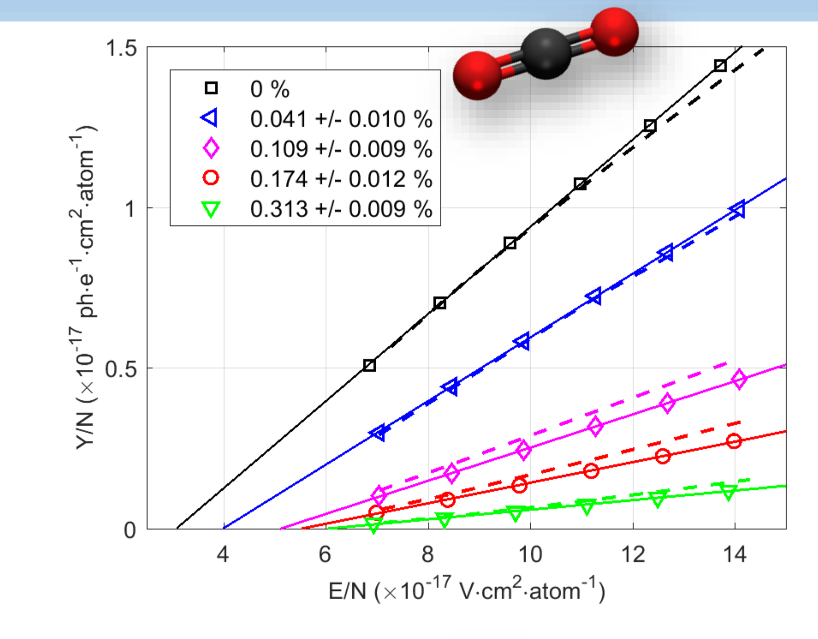
1) For E/N such as $F, PMT \gg Q$
   $\rightarrow \mathbf{R_E}^{\mathbf{2}} \propto (\mathbf{N_{EL}})^{-1}$
2) Contributions from **F** and **PMT** can be determined using data from pure Xe
3) In mixtures, the contribution from **Q** can be isolated
4) Then, R_E in NEXT100 can be estimated

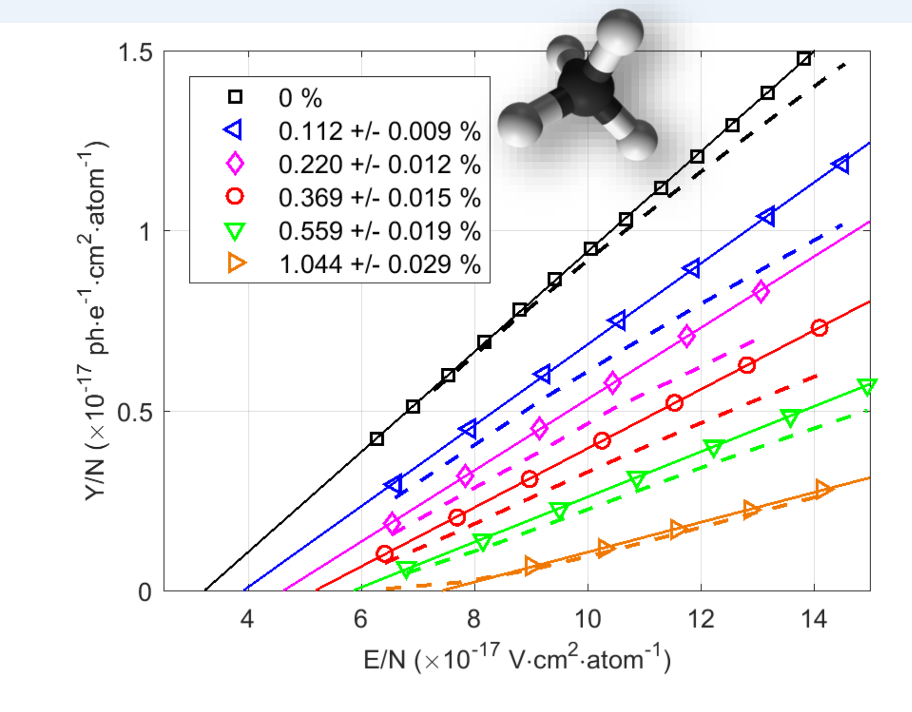
Experimental results with a driftless GSPC

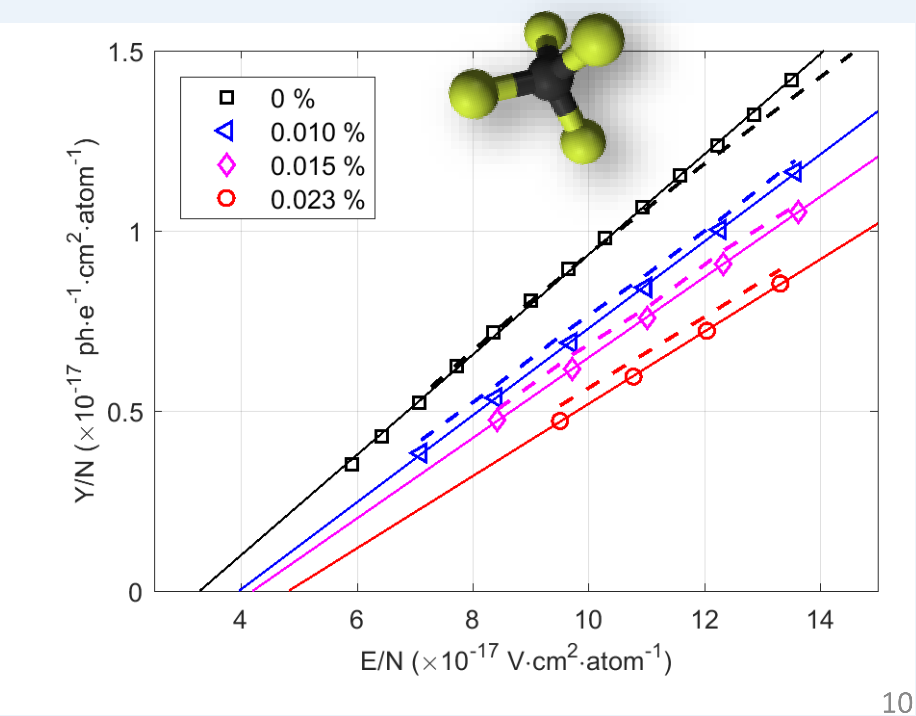
EL Yield | Energy Resolution | Q (fluctuations in EL production fluctuations) | P_{sci} (Scintillation probability)

Results: Yield

1. **EL threshold increases** (the average energy of electrons is lower → stronger fields are needed to excite Xe)
2. **Y vs E slope decreases,** resulting from:
   - Mostly quenching in CH4
   - Mostly attachment in CF4
   - Quenching and attachment in CO2
3. **Dashed lines:** simulation data (still preliminary)



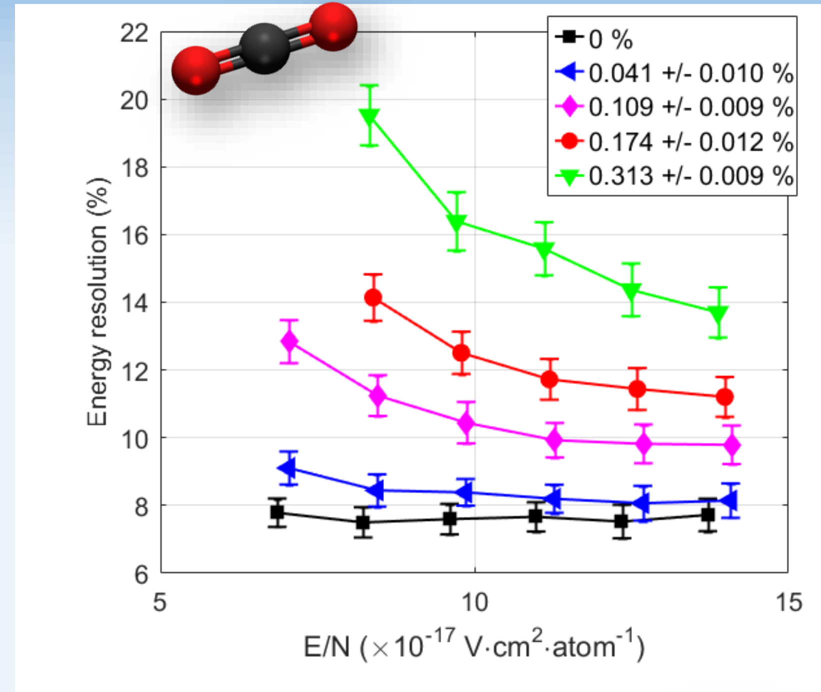


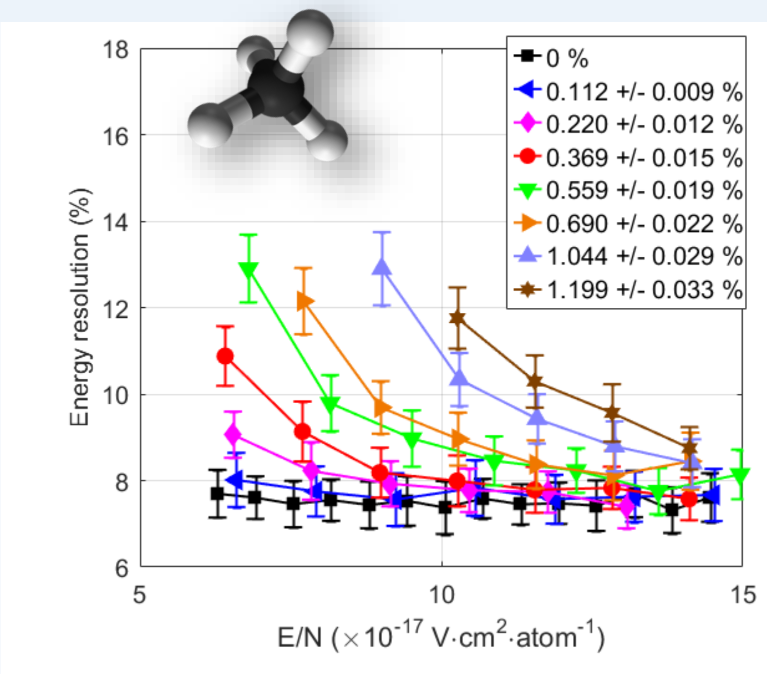


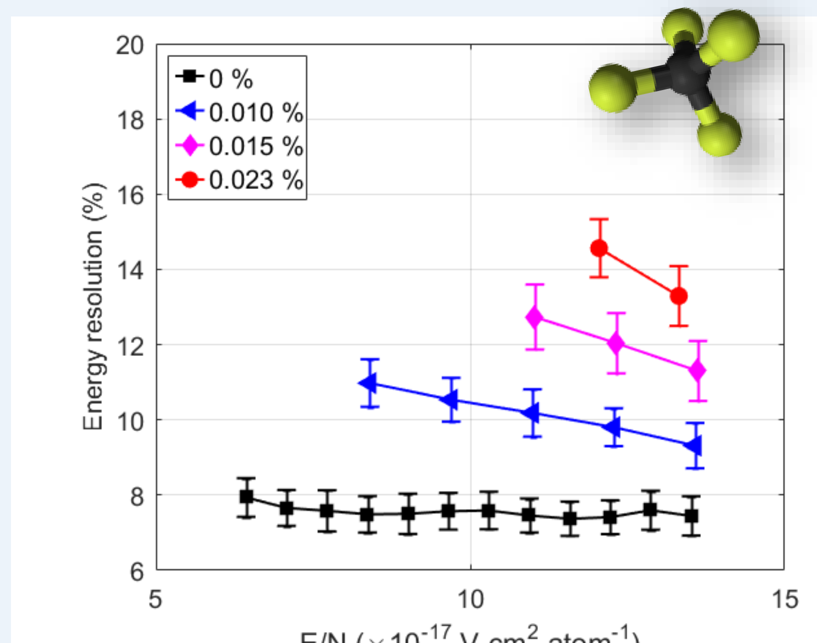
Results: R_E

1. **R_E is estimated for zero x-ray penetration** using a fitting function, which takes into account the exponential X-rays absorption in Xe gas

2. **R_E decreases with E:**
   - Stronger in CH4, since more photons are emitted, fluctuations in PMT are reduced
   - Weaker in CF4, since R_E degradation is manly due to attachment





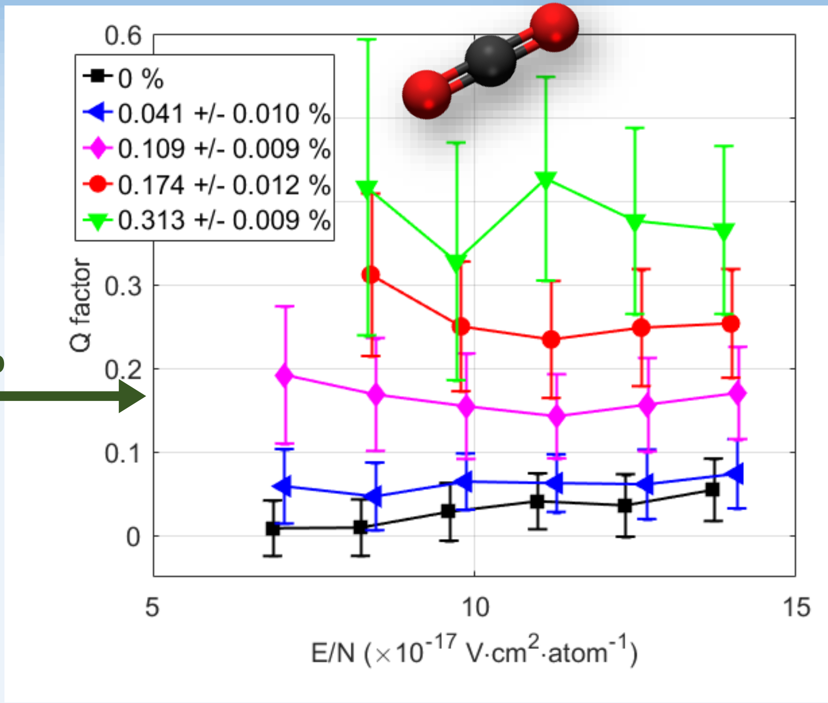


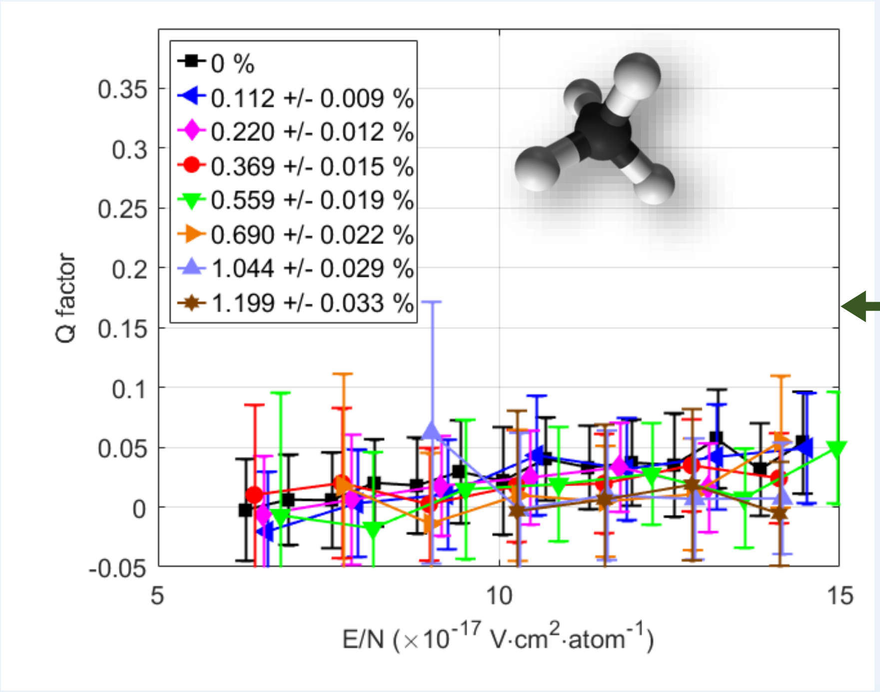
Results: Q

Q (relative fluctuations in the number of produced **EL photons**) was estimated:

- **CH4**: Q negligible (≪ F)
- **CO2**: Q ~ ½ Fano (for conc. within ROI)
- **CF4**: Q ≫ Fano (high attachment)

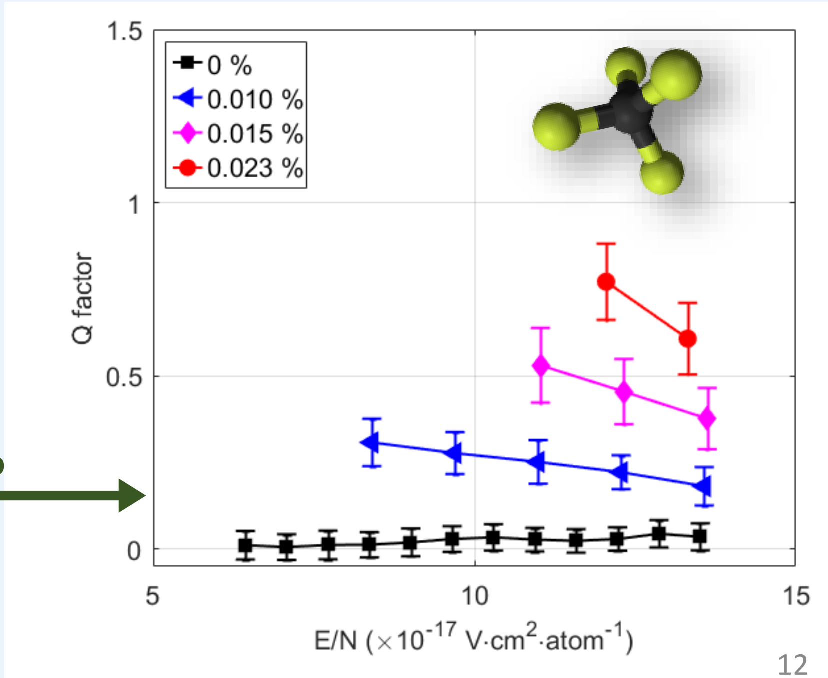
Fano





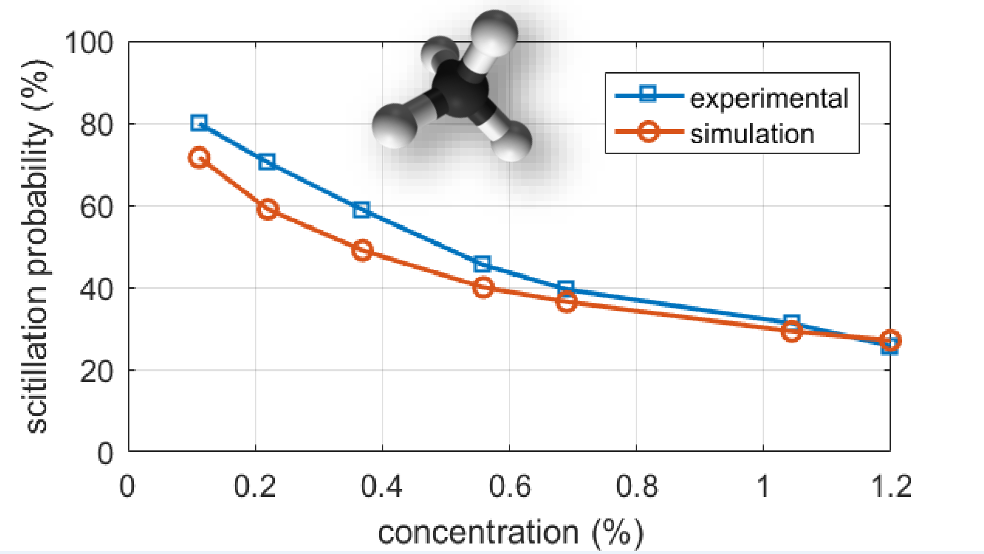
Fano

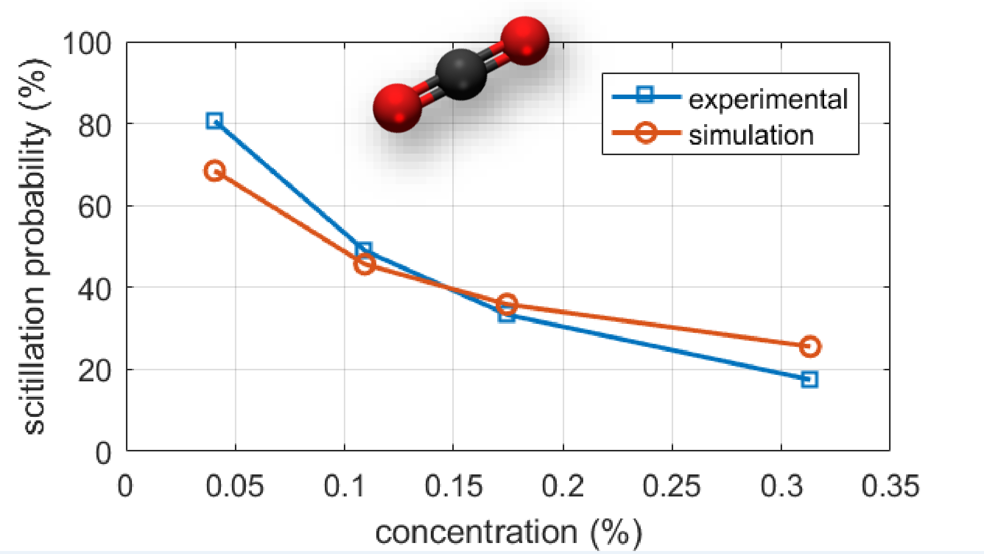
Fano



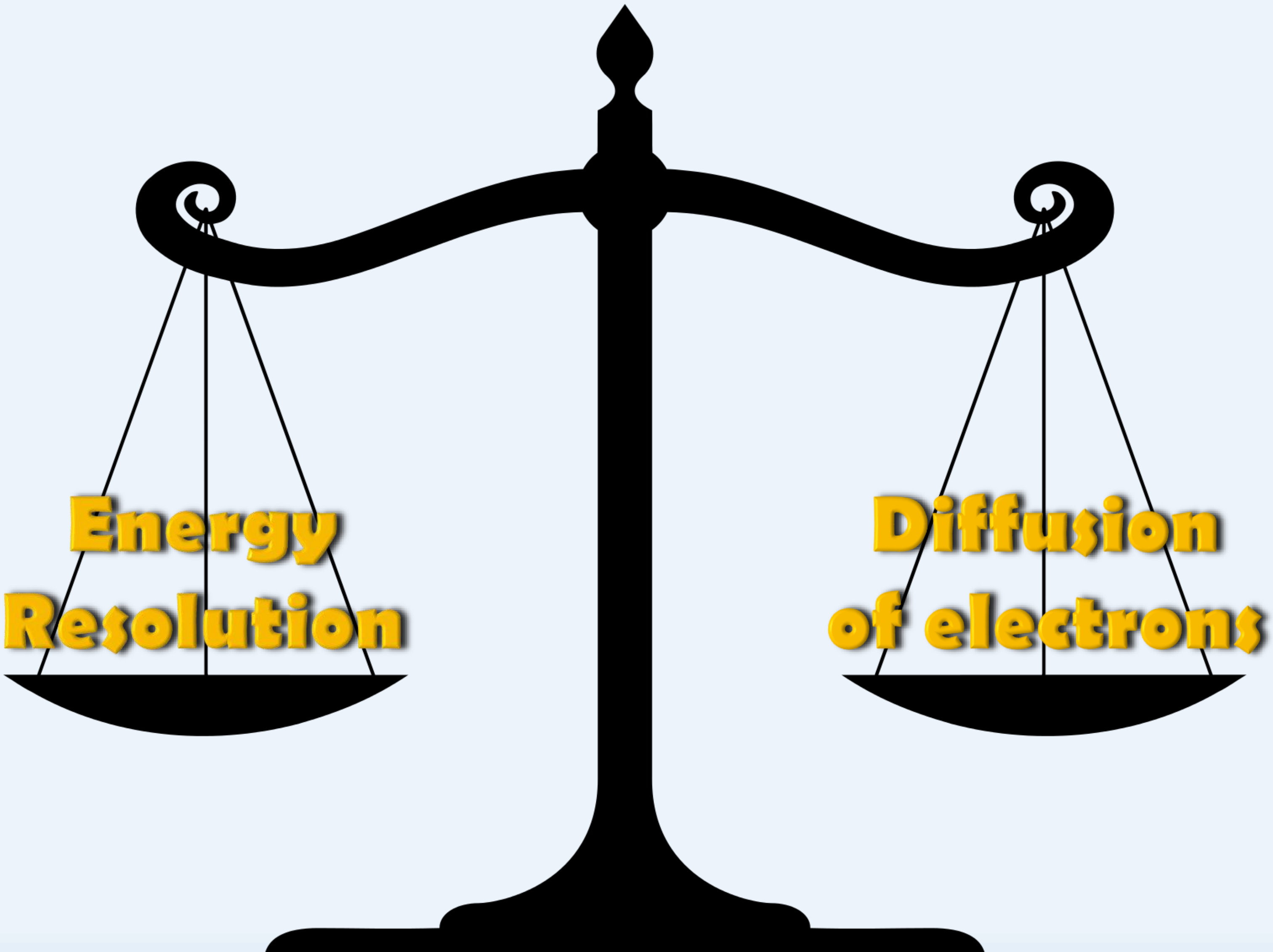
Results: scintillation probability (P_{sci})

1) **For CH4:**
   - Assuming no attachment and 100% for pure Xe
   - P_{sci} estimated from the ratio between pure Xe and mixtures Y/N vs E/N fitted slopes
2) **For CO2:**
   - Attachment is estimated from Q
   - Effect from attachment on Y/N is subtracted
   - Then, P_{sci} estimated as in CH4
3) **For CF4**
   - P_{sci} is assumed to be near 100% as no quenching is expected

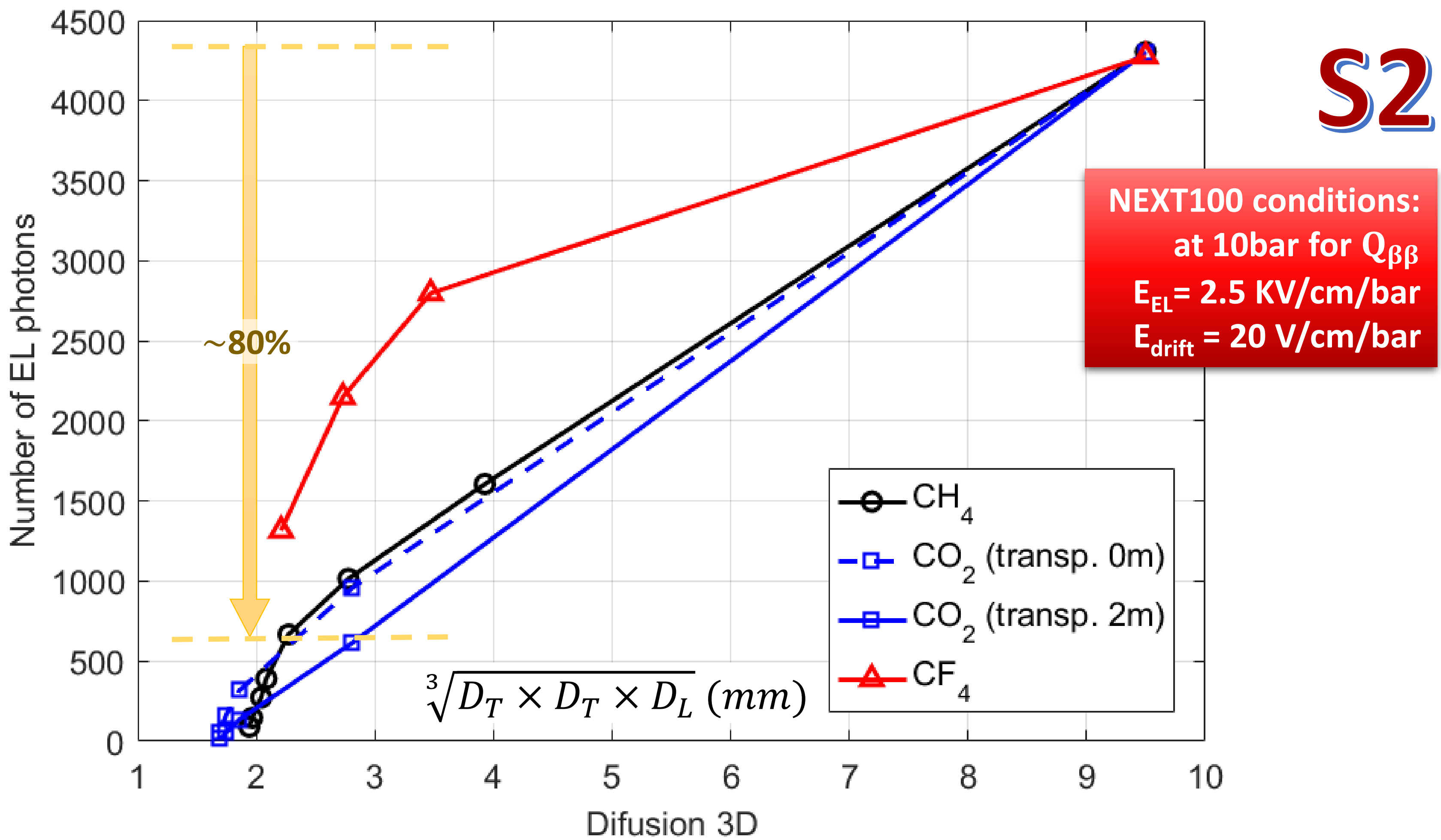




Comparing additives & the compromise



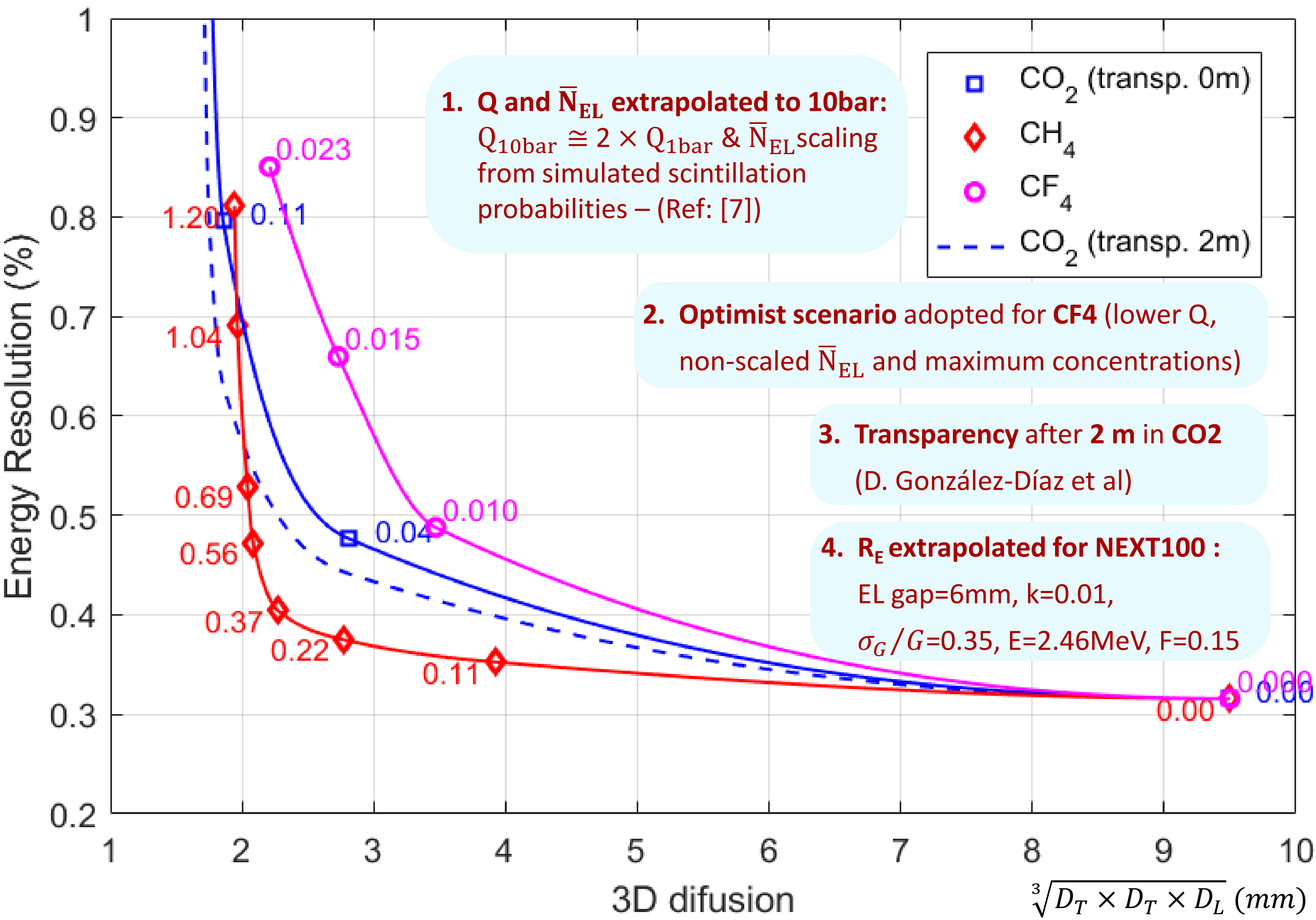
The best molecule and compromise



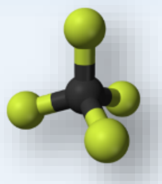
S1 According to simulated scintillation probabilities (Ref: [7]) + experimental data, S1 may decrease **~80% CO2, ~85% CH4 and almost 0% in CF4.**

Compromise between spatial and energy resolutions

at 10bar E_{EL}= 2.5 KV/cm/bar E_{drift} = 20 V/cm/bar



Final verdict:

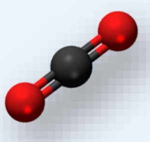


CF4

Low quenching, high transparency → S1 (also S2) slightly affected

High attachment → R_E extremely degraded (dominated by Q)

Stable, but minute concentrations (~100ppm) are hard to handle and measure

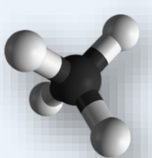


CO2

S1 and S2 affected by **quenching** and **transparency** (also attachment)

Good $\mathbf{R_E}$ (attachment still low) within concentrations ROI

Very reactive with hot getters, CO production (specific cold getters?)



CH4

S1 and S2 affected by the **high quenching**

Excellente $\mathbf{R_E}$ (Q~0), increasing E/N improves significantly $\mathbf{R_E}$ (reaching almost the same R_E as in pure Xe)

Stable & high concentrations (~4000ppm) are easier to handle and measure

CH4 → best performance and easier to work with

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Thank you for your time

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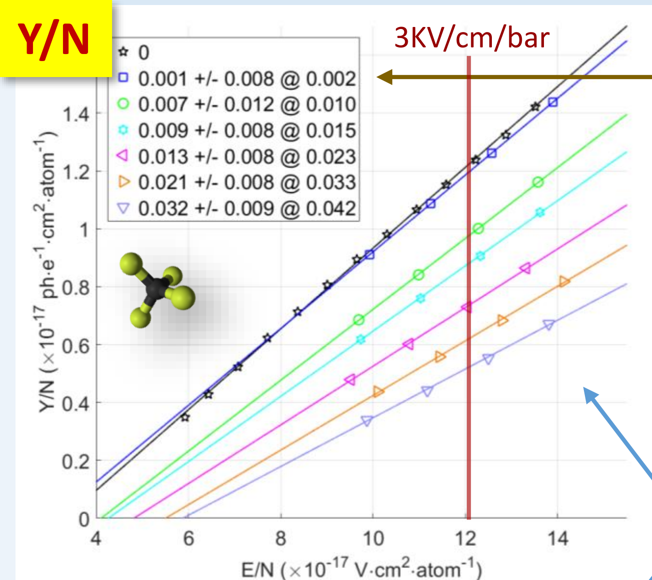
Backup

The CF_4 case

Y/N



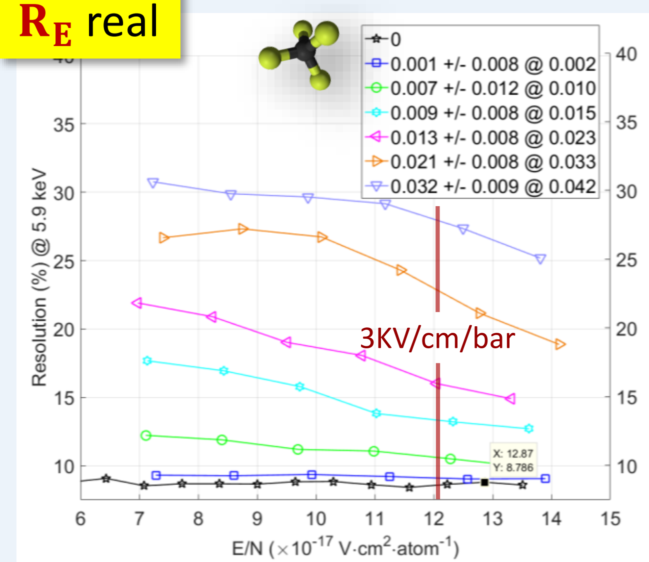
Huge **uncertainty** in low RGA's measurements:

Initial/max values from P-V calculation are also shown

! There is not a systematic error – RGA's calibration was successfully tested after taking data !

- **EL Y** well preserved if compared with $\mathbf{R_E}$
- Lower $\mathbf{R_E}$ dependence on E/N

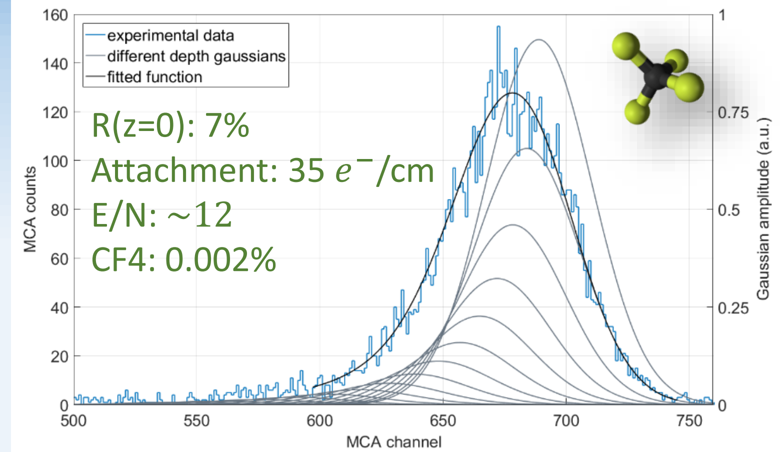
$\mathbf{R_E}$ real

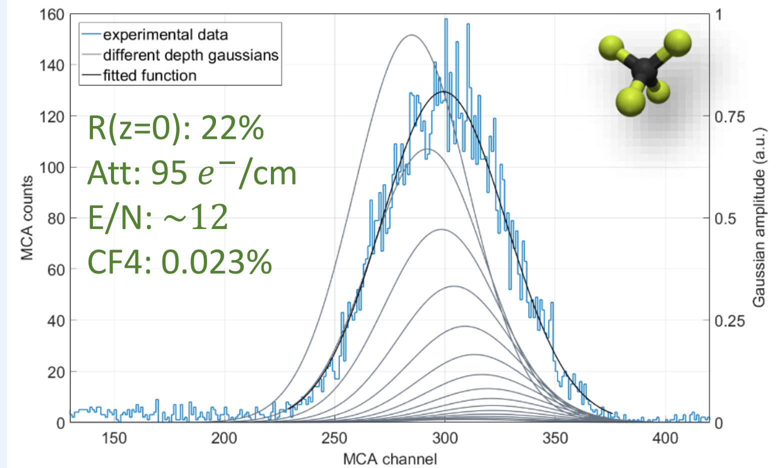


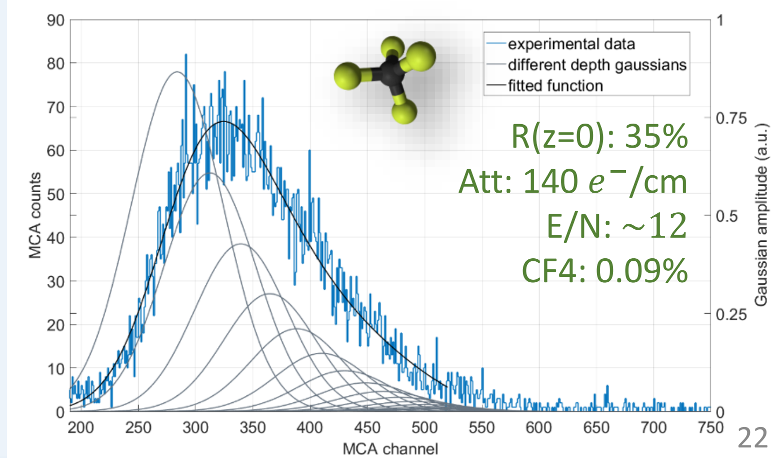
With 1 more free fitting parameter (attachment), $\mathbf{R_E}$ **(z=0)** extrapolation could be not reliable:

← Here, the real driftless GSPC $\mathbf{R_E}$

↓ Next, previous z=0 extrapolation used but ignoring right-tailed spectrums







What about NEXT - $Q_{\beta\beta}$ at 10 bar, EL_{gap} = 5mm

$$R_E = 2.35\sqrt{\frac{F}{\bar{N}_e} + \frac{Q}{\bar{N}_e} + \frac{1}{\bar{N}_{ep}} + \frac{\sigma_G^2}{\bar{N}_{ep} G^2}}$$

$$\bar{N}_e = \frac{E_x}{w_{ion}} = \frac{2.457\mathrm{MeV}}{22\ \mathrm{eV}},$$

$$\mathbf{F} \sim 0.15 \mp 0.02$$

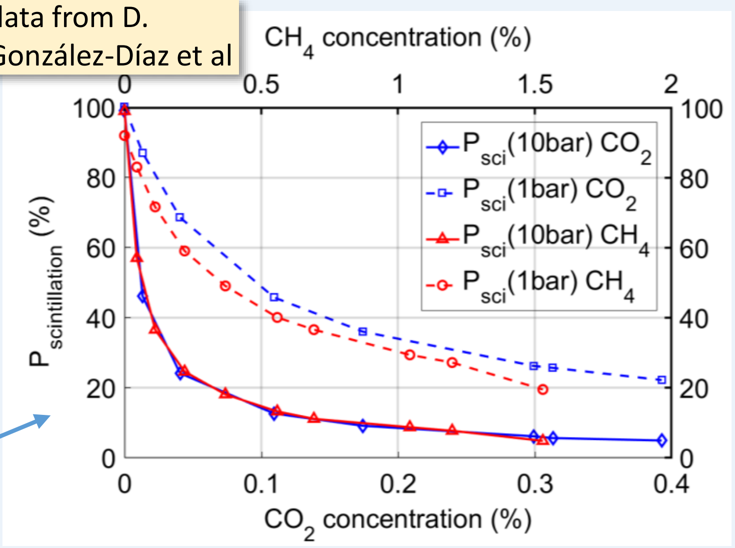
$$\bar{N}_{ep} = k \cdot \bar{N}_e \cdot \bar{N}_{EL}$$

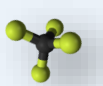
Expected features in NEXT-100:

- EL photon collection efficiency **(k) = 0.01**
- Relative fluctuations in PMT's gain **(σ_G/G) = 0.6**

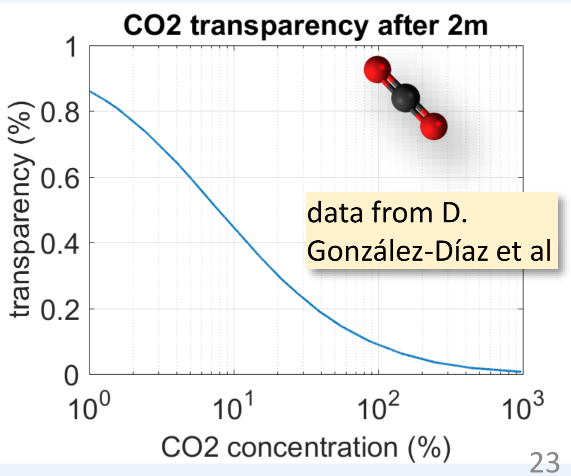
1. **Q(10bar) ≅ 2 × Q(1bar)** since $\frac{10bar}{1bar} \times \frac{5mm\ gap}{25mm\ gap}$,
   if dominated by attachment → **in CH4 Q(1bar) = Q(10bar)**

2. $\bar{\mathrm{N}}_{\mathrm{EL}}$**(10 bar)** ≅ $\bar{\mathrm{N}}_{\mathrm{EL}}$**(1 bar)** × $\mathbf{P_{scint}(10bar)/P_{scint}(1bar)}$
   from simulations (Diego-Azevedo), when reduction in Y is due to e^- cooling (threshold) and quenching, ie. in **CH4** and **CO2**



3. **For CF4** the more optimist scenario is adopted: **Q for max(E/N), max/initial concentrations** adopted, 
   and $\bar{N}_{EL}$**(10 bar)** ≅ $\bar{N}_{EL}$**(1 bar)** – 20% lower at 10bar in ROI (2 × att)

4. **Transparency** to EL photons after 2 m in **CO2**
   100% in CH4 and CF4

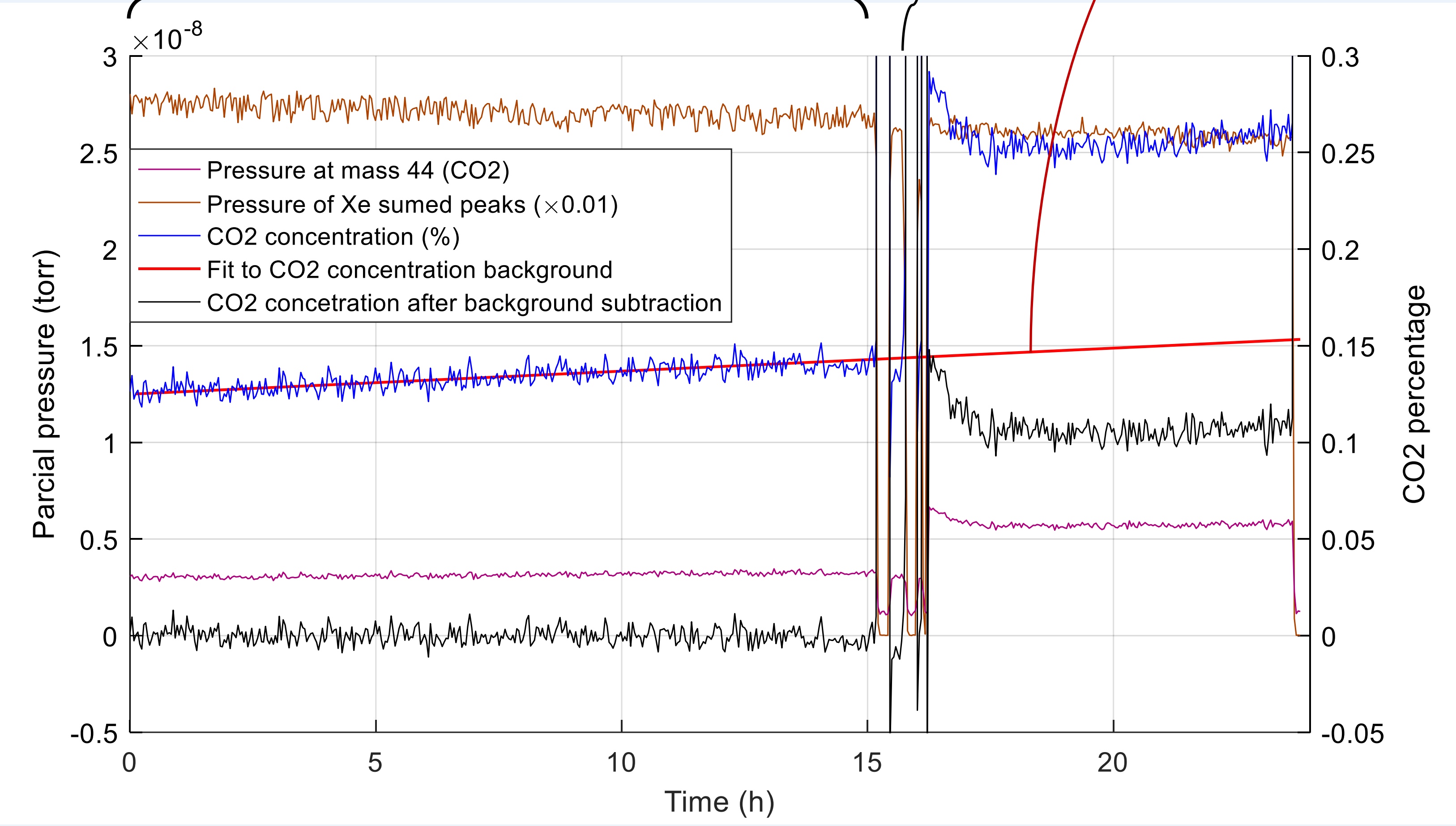


RGA's Calibration

Background measurement – CO2 reading after V2 is filled with pure Xe

CO2 added here, then CO2 + Xe are liquefied

For CO2 background estimation after mixing



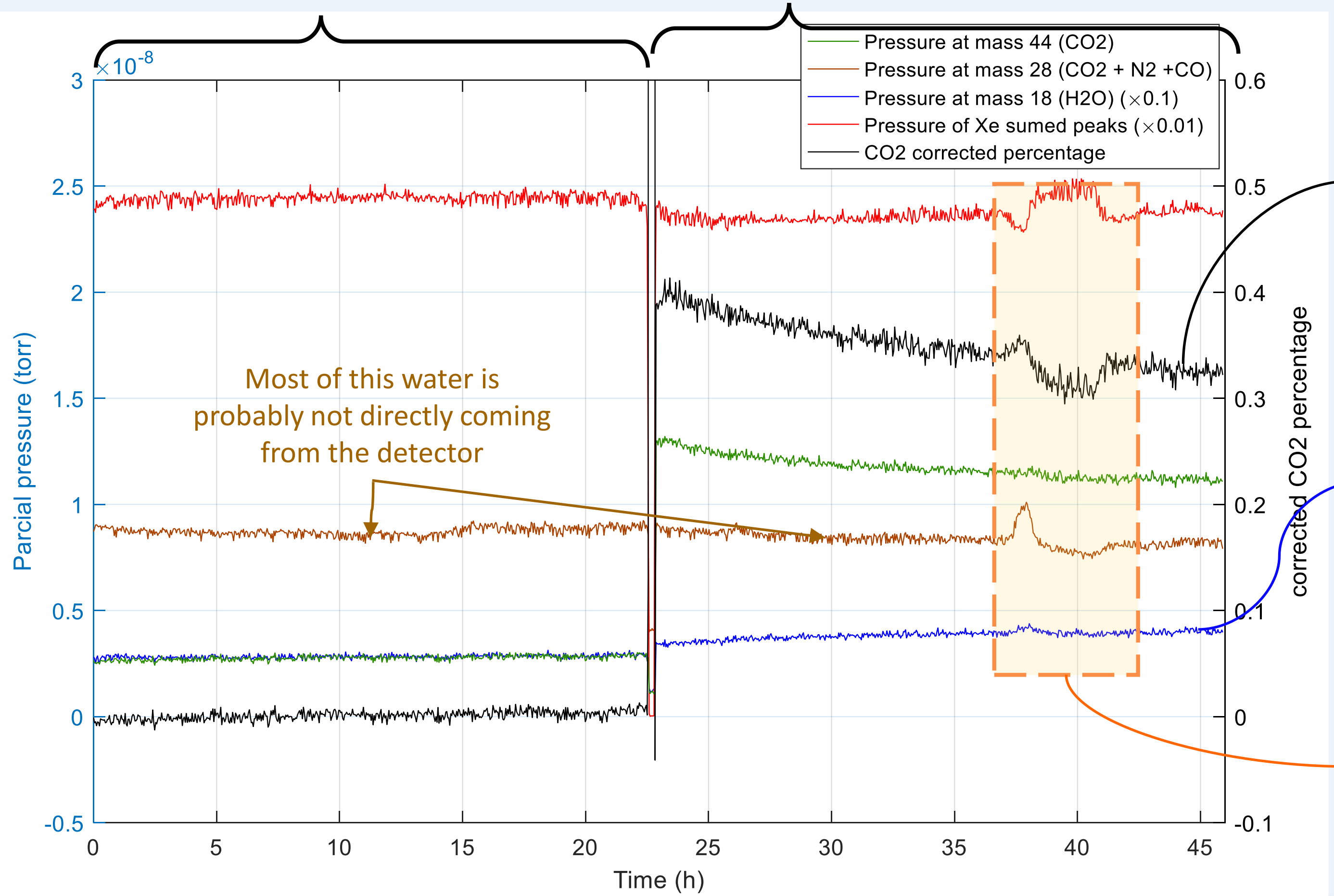
↑ RGA's example spectrum of a calibration point (0.088 %)

Results – RGA's example spectrum → $CO2/(Xe + CO2) = 0.44\%$

1) Pure Xe with getters at 250° C is recorded for background quantification at the beginning of each mixture → $CO2/(Xe + CO2) \approx 0.1$ % changing at each mixture

2) Getters are set to 80° C one hour before CO2 is introduced → for a more efficient mixing, Xe + CO2 are liquefied after adding the CO2.

- 0.44 % introduced (estimated from volume-pressure calculation) – 0,33 % @ after 21h (estimated from RGA data)



CO2 percentage in relation to Xe + CO2 → corrected using RGA's calibration line

- EL measure was done in the last hour (44h – 45h)

Partial pressure at mass 28 rises in time after adding CO2 → 28 is the main peak of N2 and CO, and a secondary peak of CO2 (~5 % → obtained in calibration)

A typical non-explained perturbation → usually, these perturbations are stronger in H2O and Xe, and often periodic (T=24h)

Results – CO production

➢ **Pressure at mass 28 rises after adding CO2** → **Mass 28 is a combination of:**

- Nitrogen (major fragmentation peak)
- CO (major fragmentation peak)
- CO2 (secondary fragmentation peak)

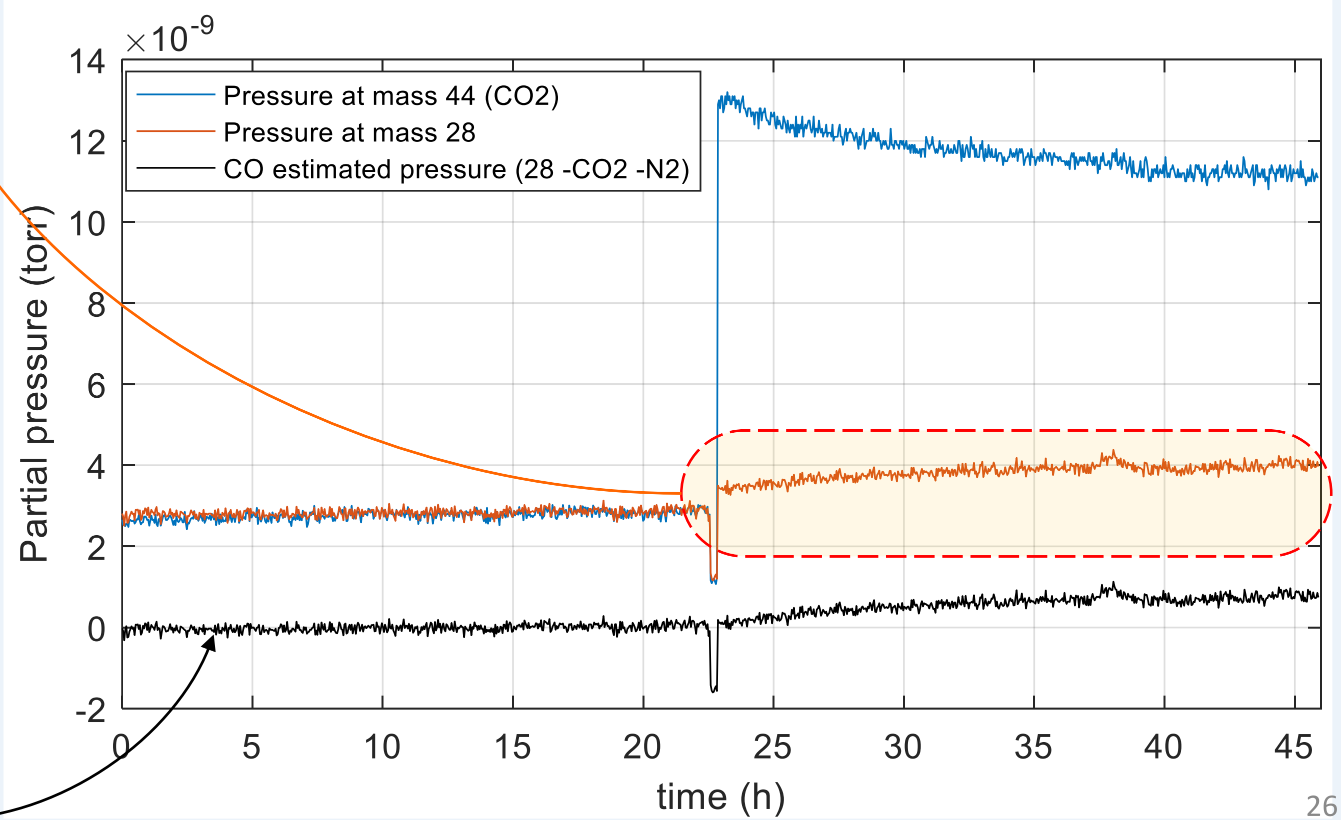
If the growth at 28 was just coming from CO2, it would not be continually rising
Is this due to CO production?

Assuming:

- N2 keeps constant after adding CO2
- Experimental cracking pattern of CO2 obtained during calibration
- CO is zero before CO2

We can:

Estimate CO pressure at mass 28 by subtracting CO2 and N2 contributions



Results – Getters' temperature & CO

- **Two different mixtures became stable at 0.18 %** → in the last one we **raised up** the temperature of getters in order to absorb CO2 → however **CO have raised even more as the getters' temperature was increased.**

Temperatures were raised up just for some time, then they are cooled down to 80° C again