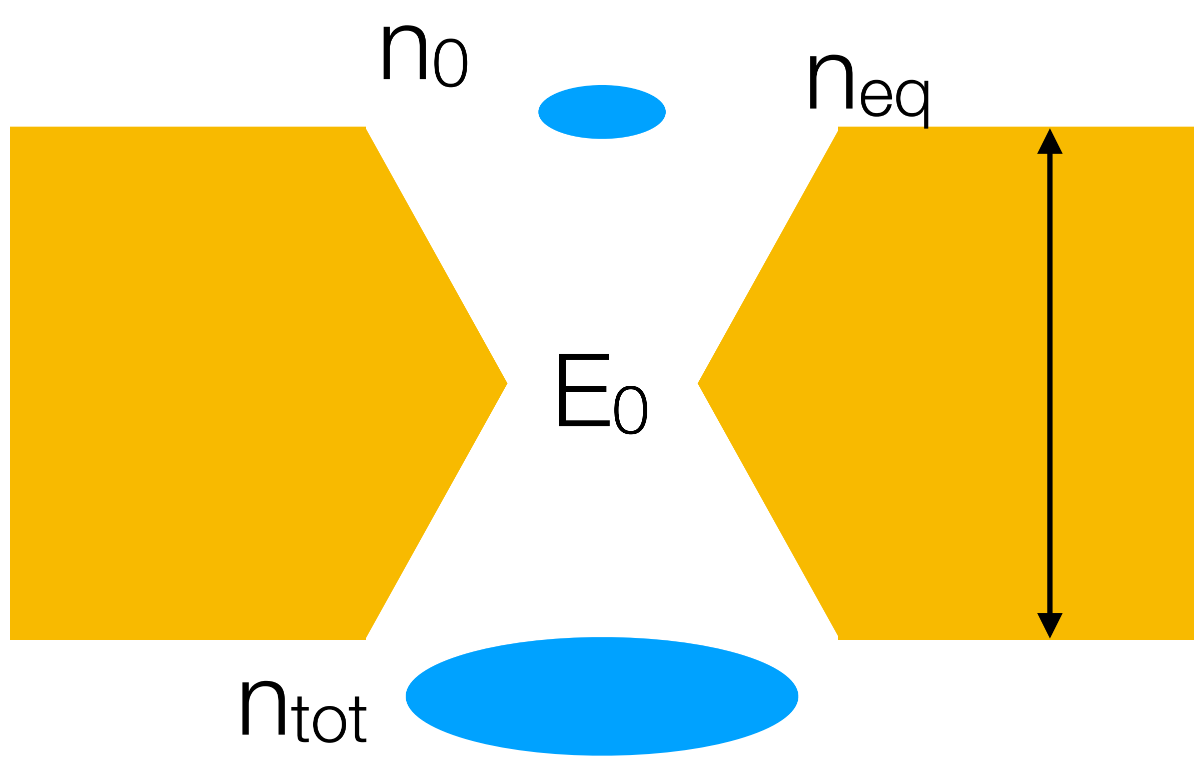
Saturation of the GEM gain

A simple model

Let's suppose that during the development of the avalanche within the gem multiplication channels a significant amount of electrons and positive ions are produced.

Under the effect of the electric field present in the channel, these slowly migrate toward the lower potential plane of the GEM, tending to partially shield the field itself.

If n_0 is the number of electrons entering a GEM channel and $E_0 = V_{GEM}/d$ the electric field in it:



d is the GEM thickness

V_{GEM} is the voltage drop between GEM sides

Multiplication is described by a modified Townsend equation

$$\frac{dn}{ds} = \alpha E_0(1 - \beta n)n$$

where β is can be interpreted as the inverse of the number of charges $\beta = 1/n_{eq}$ present on the GEM border of the channel and needed to produce E_0 in it ($\beta \propto 1/V_{GEM}$);

A simple model

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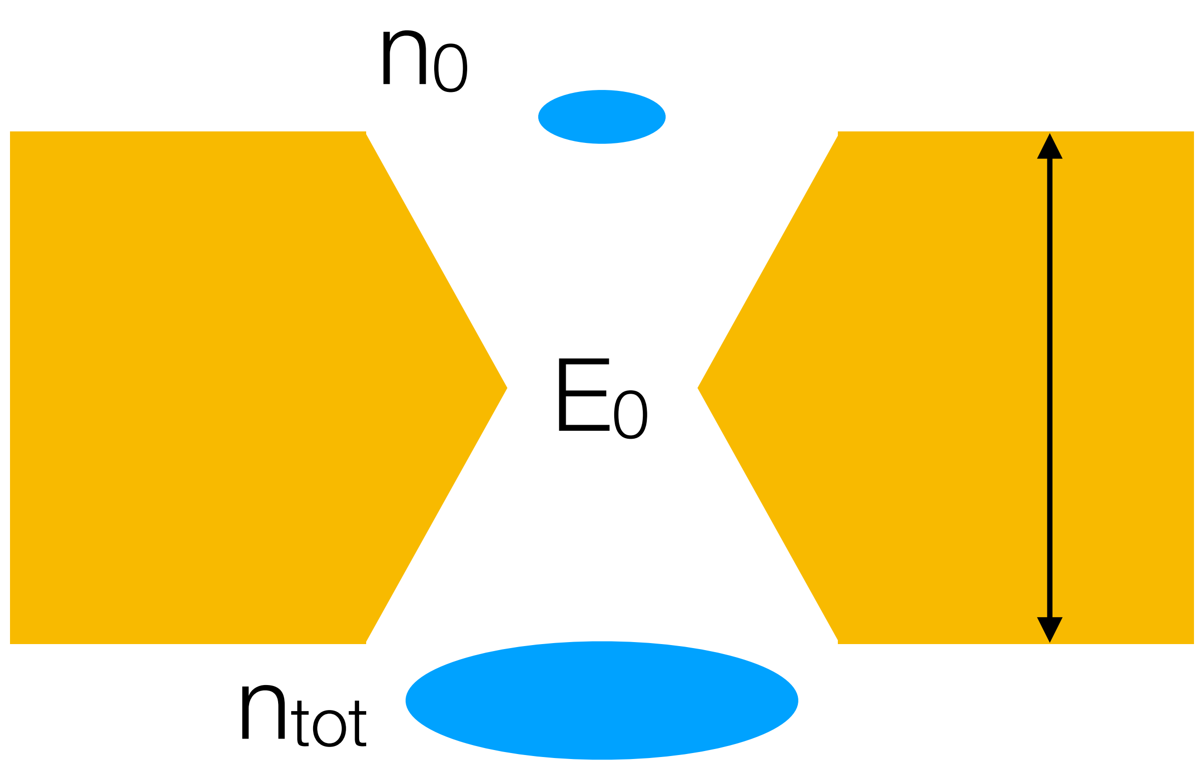

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$$\int_{n_0}^{n_{tot}} \frac{dn}{(1-\beta n)n} = \int_0^d \alpha E_0 ds$$

$$G = \frac{e^{\alpha V}}{1 + \beta n_0(e^{\alpha V} - 1)}$$

where $G = n_{tot}/n_0$ is the average gain of the single channel.

It should be noticed that it depends on the amount of primary electrons entering the channel. In particular it decreases with n_0 and:

- if $\beta n_0 \simeq 0$ (i.e. negligible screen effect), $G = e^{\alpha}V$
- if $\beta n_0 \simeq 1$ (i.e. total screen effect), $G = 1$

A simple model

To fix ideas let us now assume that after a drift over a path z drift and the multiplication process in the first 2 GEMs (GEM#1 and GEM#2) the electron cloud has a distribution in space describable as a Gaussian in 3 dimensions all with RMS equal to σ:

the total volume will then be approximately proportional to σ^3 and the amount of charge collected by each channel will decrease as $1/\sigma^3$

In the last GEM, the amount of charge collected by each channel n_0:

- Increases with the primary ionisation in the gas n_e;
- decreases as $1/\sigma^3$;
- increases as the product of the gains of G_1 and G_2

$$n_0 \propto n_e G_1 G_2 / \sigma^3 \qquad \beta n_0 = p_1 G_1 G_2 / \sigma^3$$

A simple model

Let's suppose that only in GEM#3 we have non linear gain because of the larger amount of charges.

$$G_{tot} = \frac{G_1 G_2 e^{\alpha V}}{1 + \beta n_0 (e^{\alpha V} - 1)} = \frac{G_1 G_2 G_3}{1 + p_1 G_1 G_2 / \sigma^3 \ (G_3 - 1)}$$

If $G_1 = G_2 = G_3 = e^{\alpha V} = p_0$

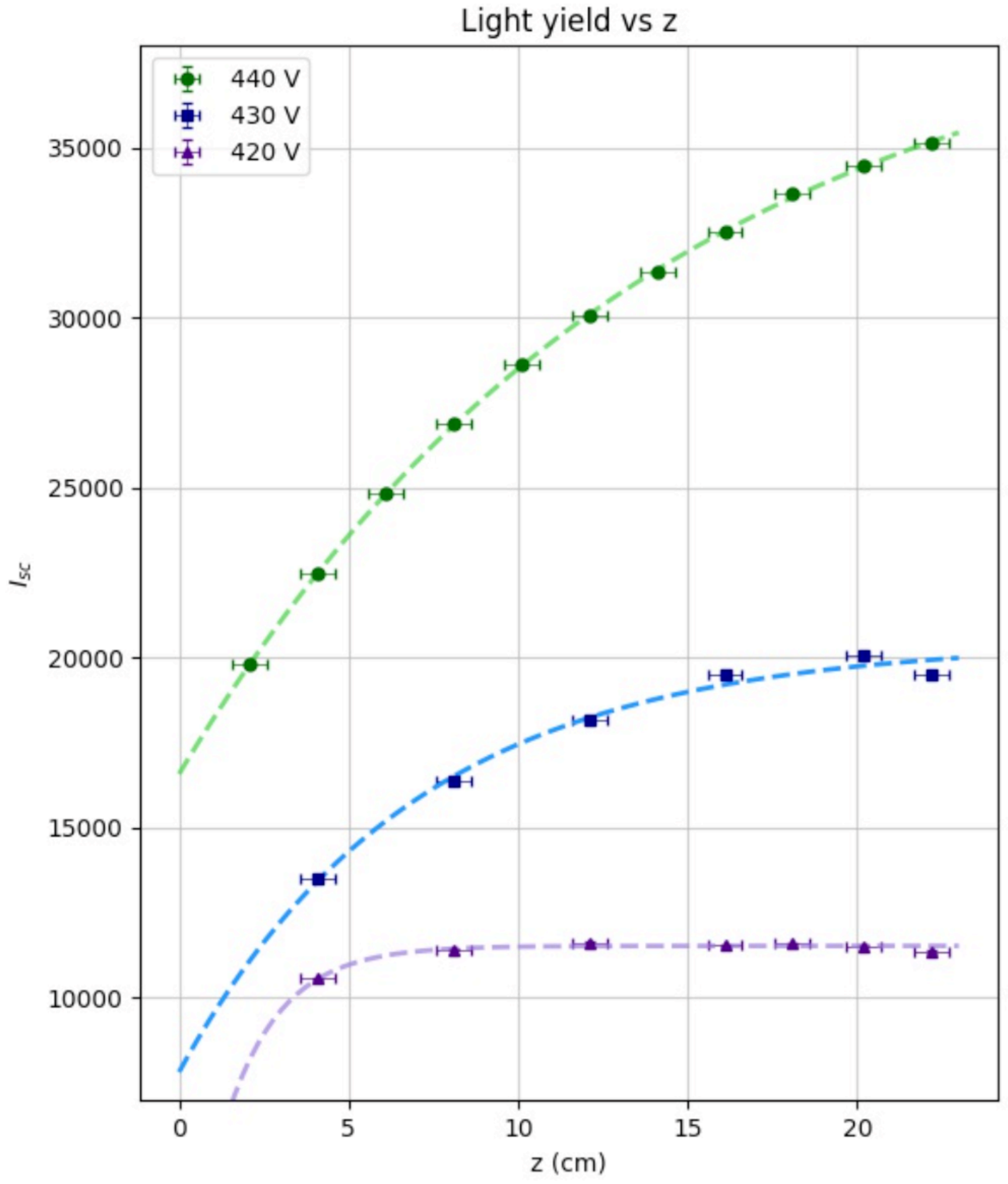
$$G_{tot} = \frac{p_0^3}{1 + p_1 p_0^2 / \sigma_3 (p_0 - 1)} = \frac{p_0^3 \sigma^3}{\sigma^3 + p_1 p_0^2 (p_0 - 1)}$$

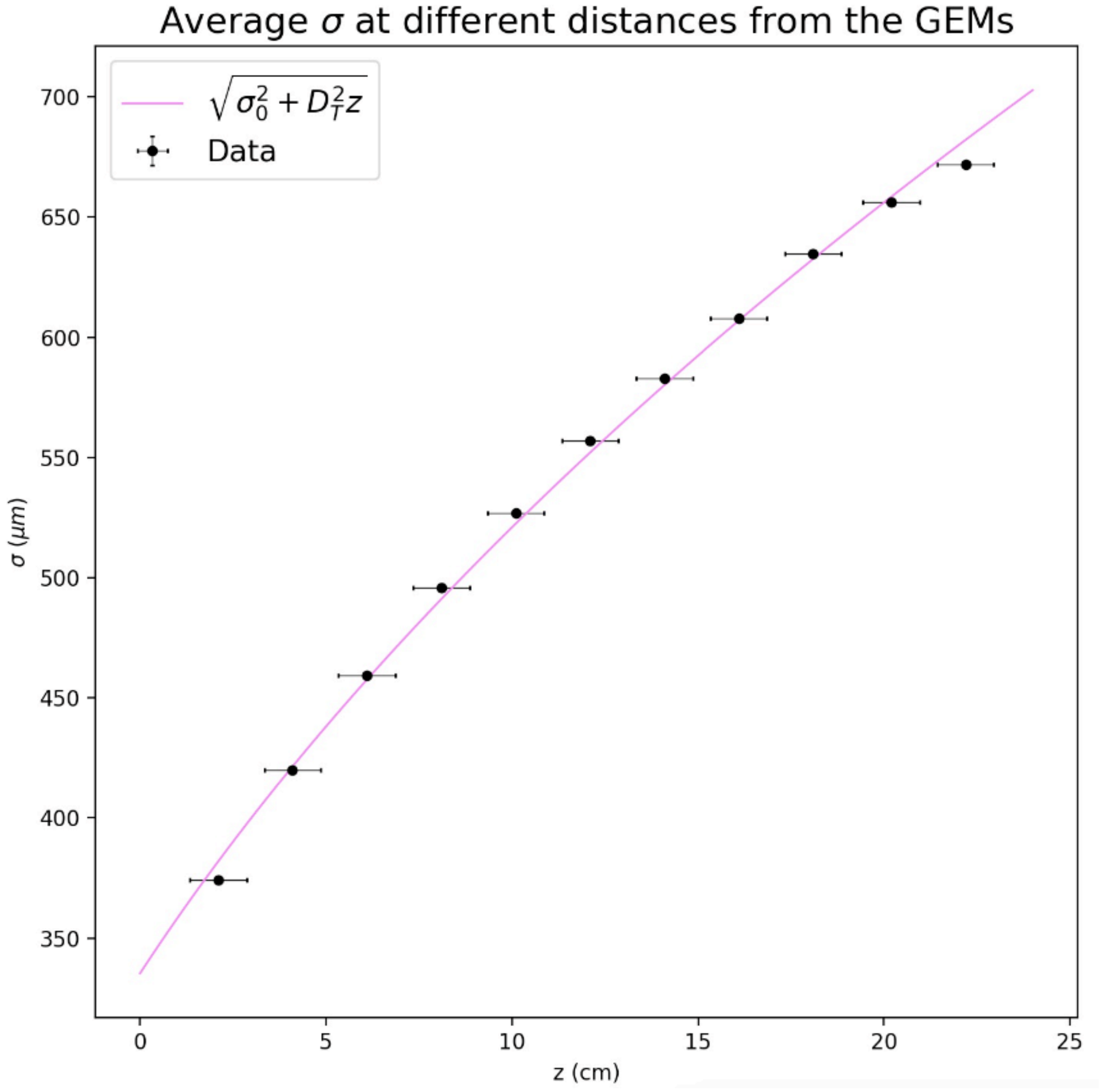
- We can try to fit this last function on the data expecting:
  - p_0 to be the not-saturated gain of the three GEMS;
  - p_1 to almost constant and just slightly dependent on the V_{GEM}

A simple model

- From the GIN data we can evaluate the electron gain in 3 different V_{GEM} setup (440, 430 and 420) and the behavior of σ

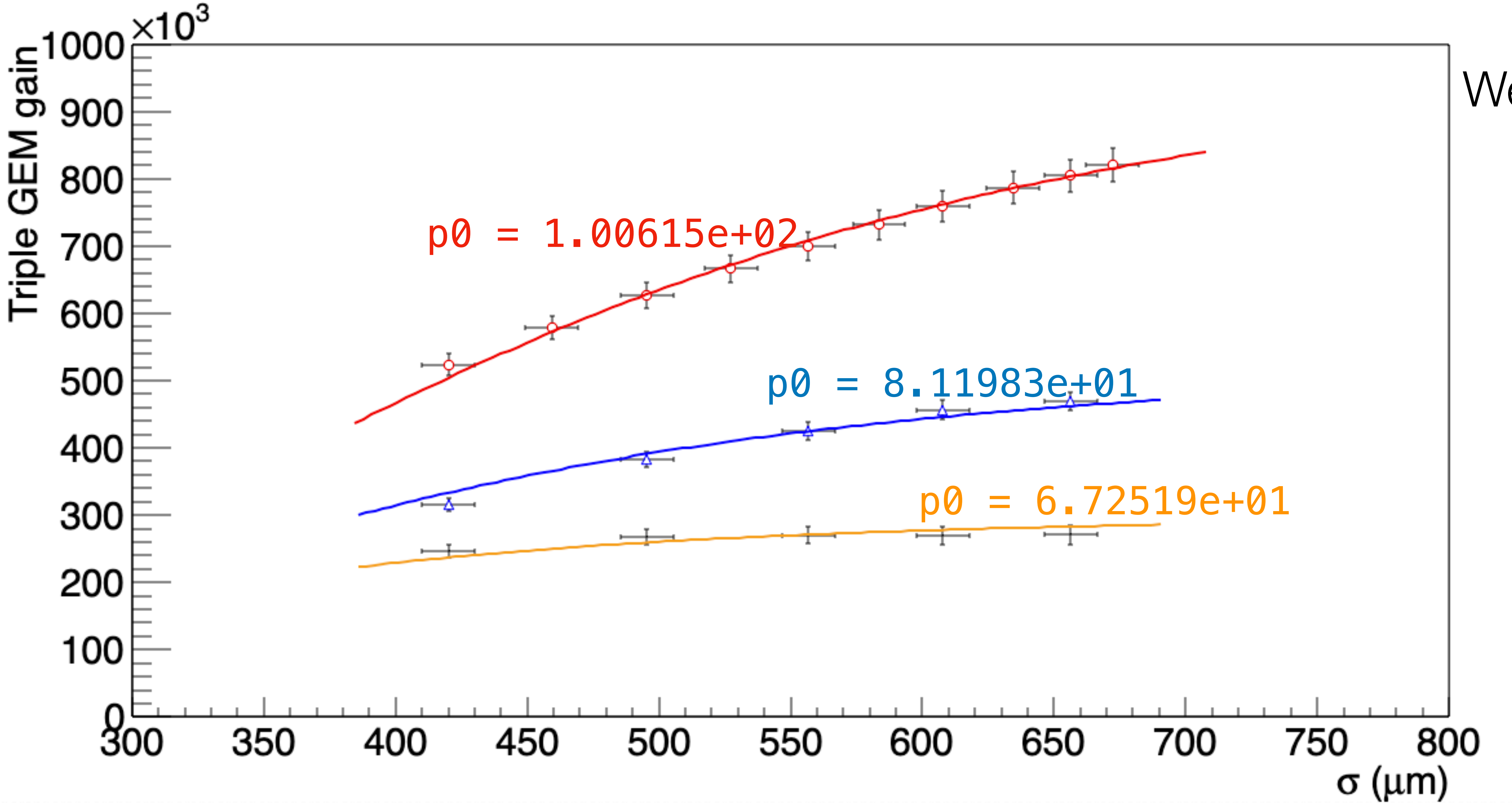
- We can start from the light yield for ^{55}Fe spots





- The electron gain is evaluated by taking into account 0.07 γ/e, 150 n_e and $\Omega = 9.2 \text{x} 10^{-4}$

A simple model



We can fit the behavior

$$G_{tot} = \frac{p_0^3 \sigma^3}{\sigma^3 + p_1 p_0^2 (p_0 - 1)}$$

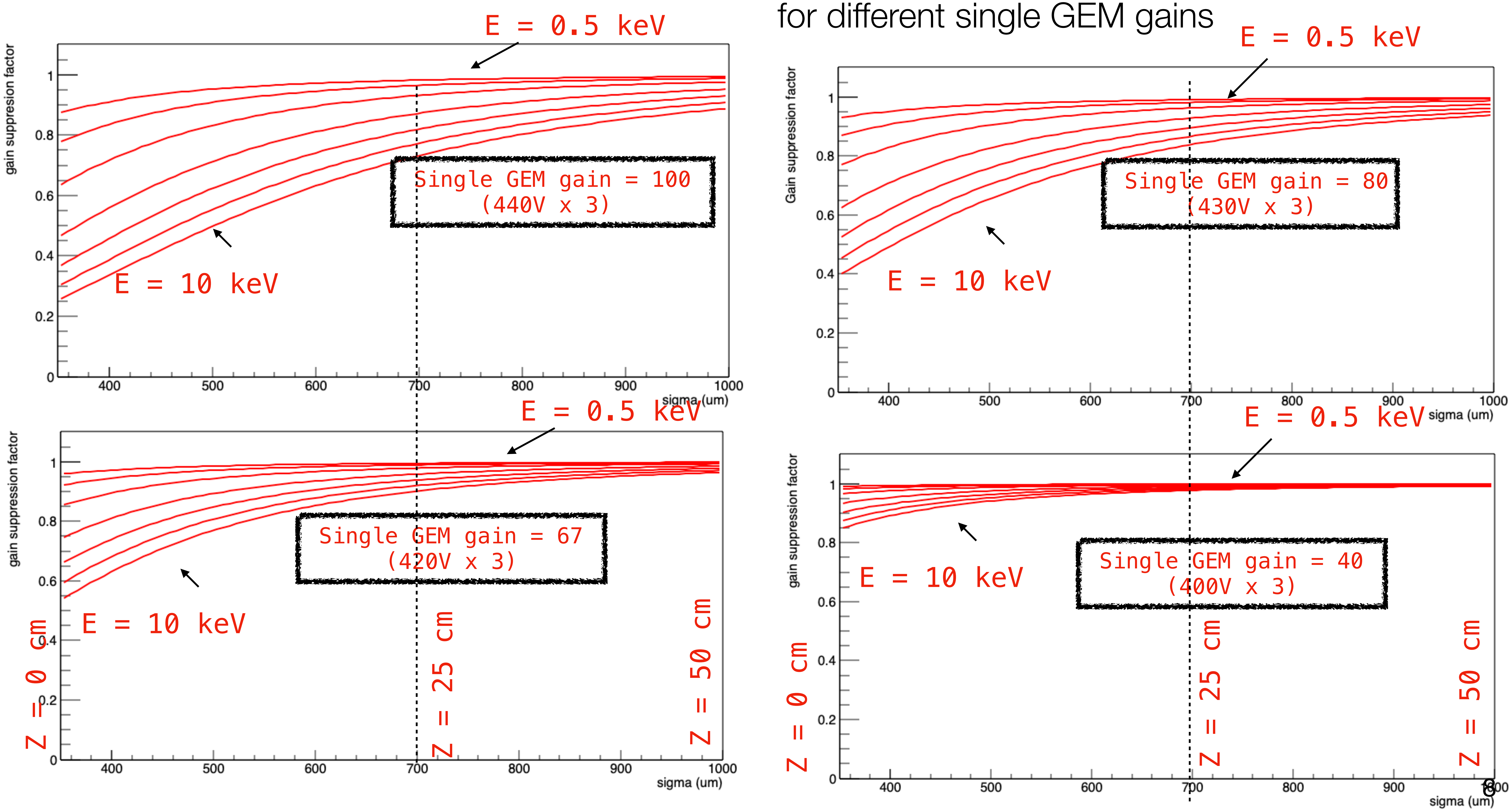
Where p_0 is the single GEM non-saturated gain;

From their ratios we can evaluate two values of alphas: 0.021 and 0.019, close to the one used in the digitization 0.022;

p_1 is about 80 in all the three fits

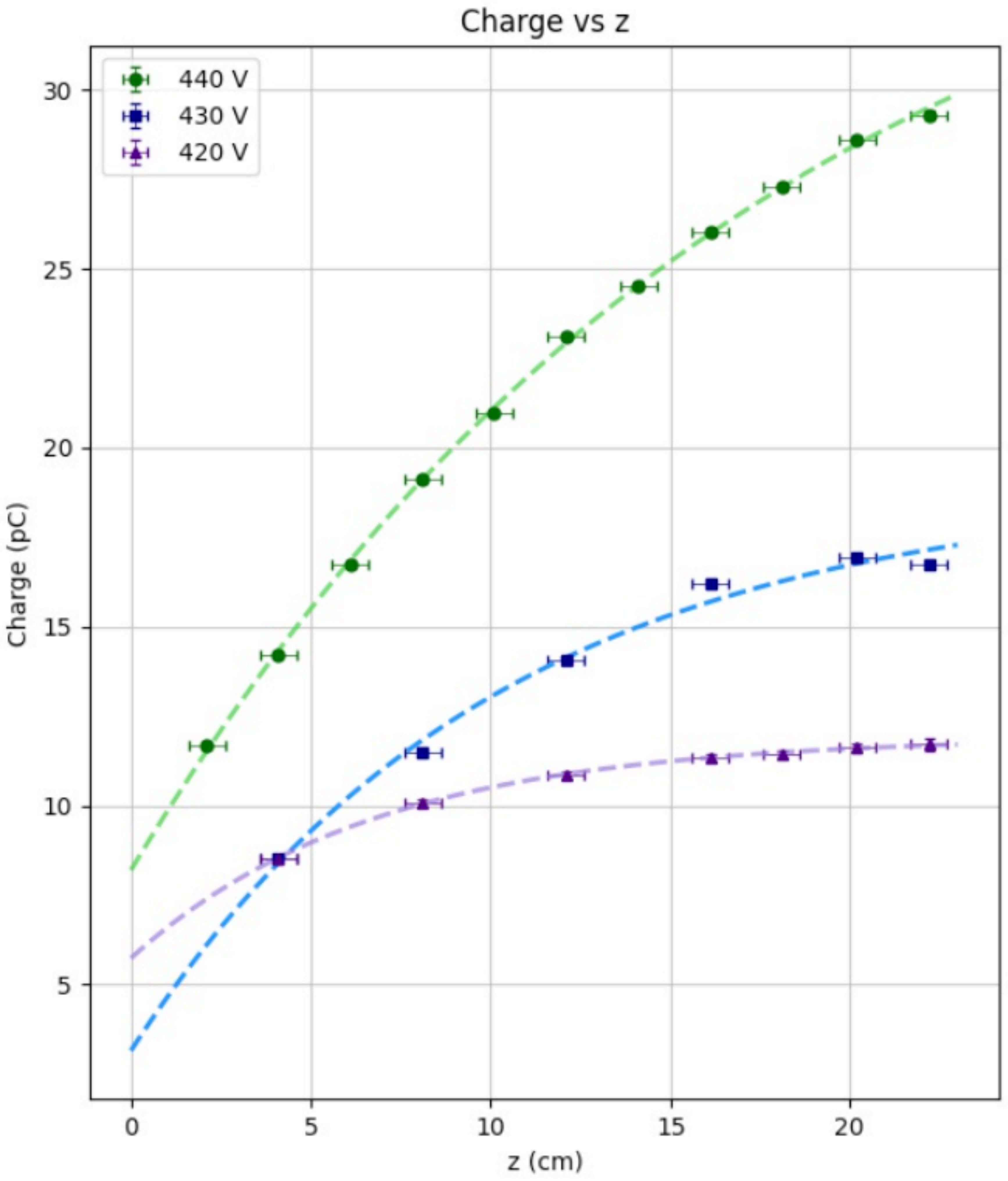
A simple model

By using the fitted function and the fit results, one can evaluate the saturation as a function of energy released: 10, 8, 6, 4, 2, 1, 0,5 keV for different single GEM gains

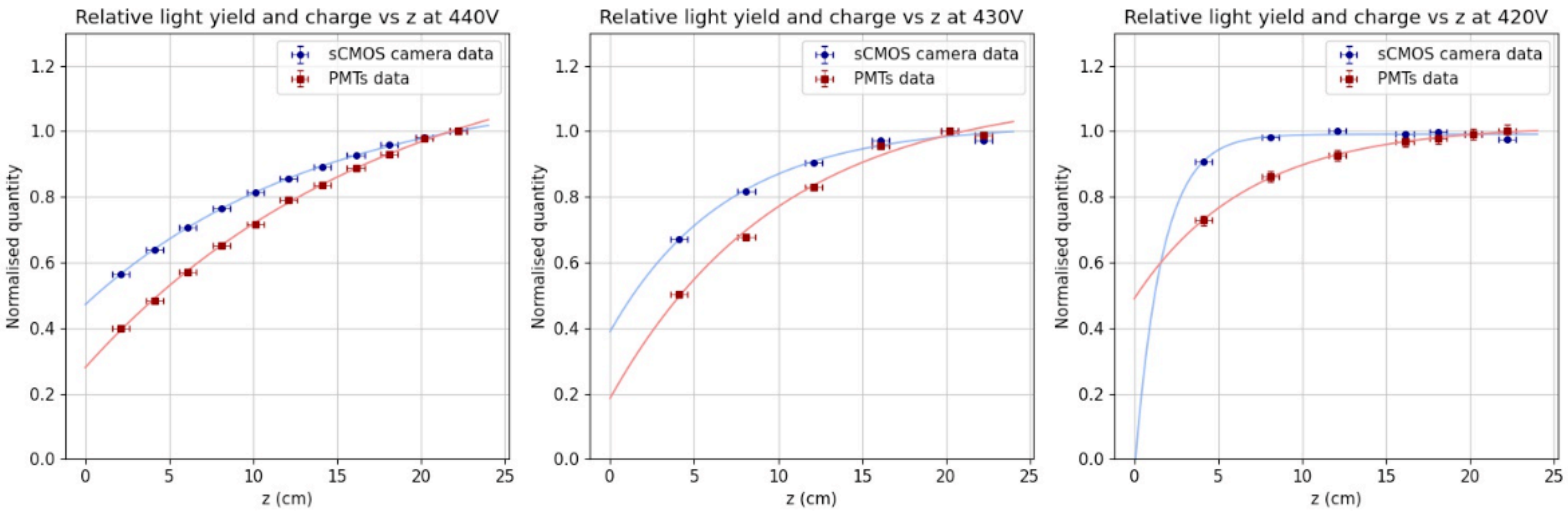


PMT saturation

We evaluated the behaviour of the PMT integrated charge as a function of z



A clear saturation effect is visible



In general is seems that light in PMT decreases faster than in the CMOS

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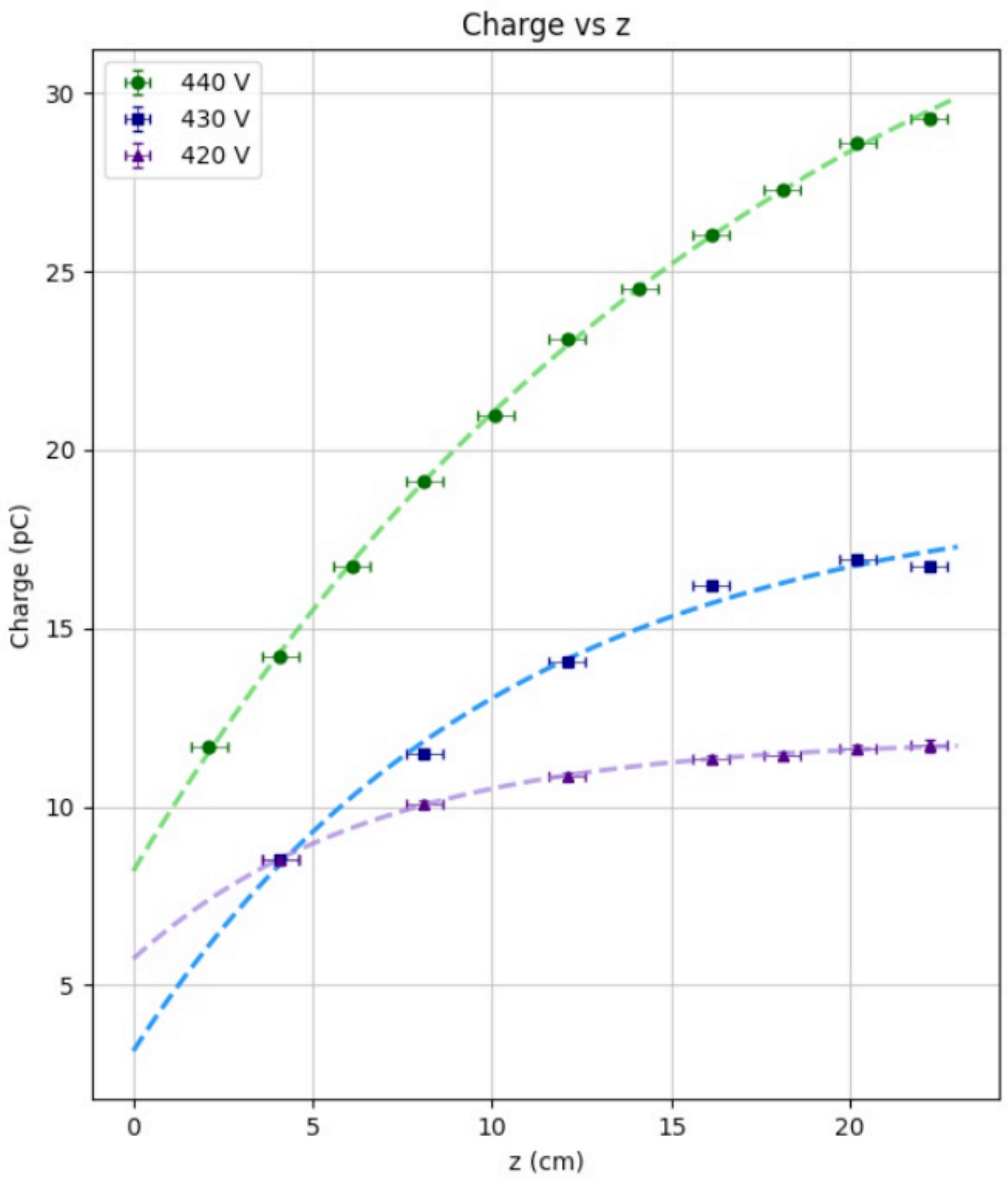

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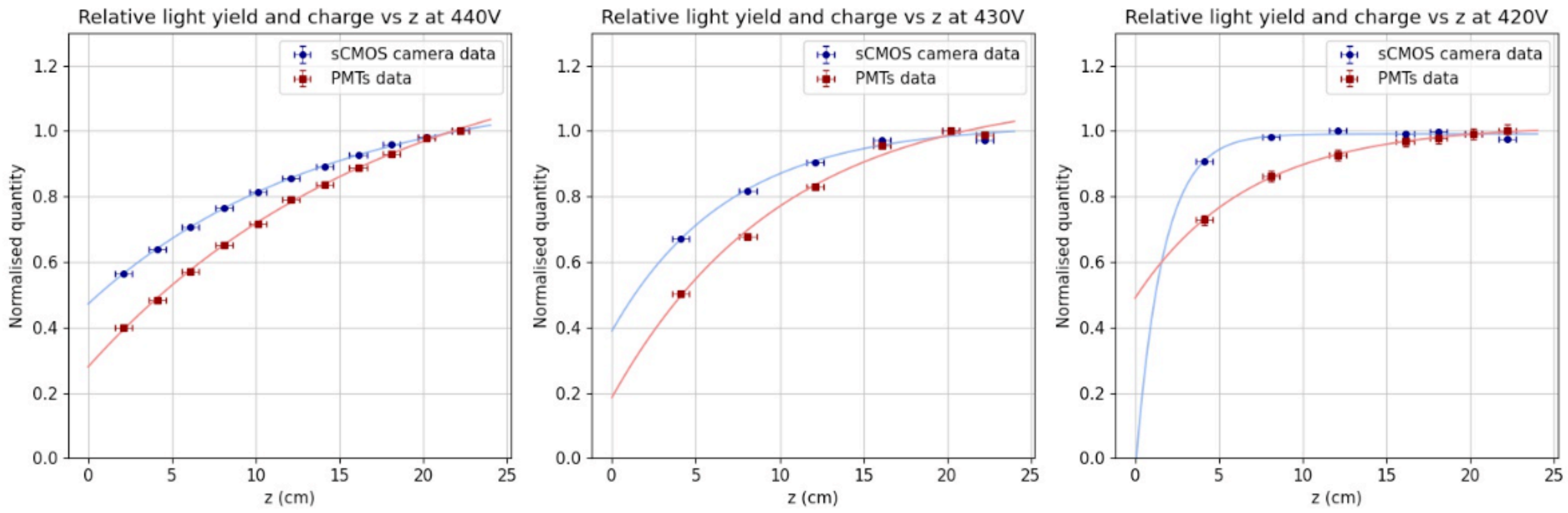

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Can it be a convolution with PMT saturation?