Study of GEM saturation in CYGNO

Ideal behaviour

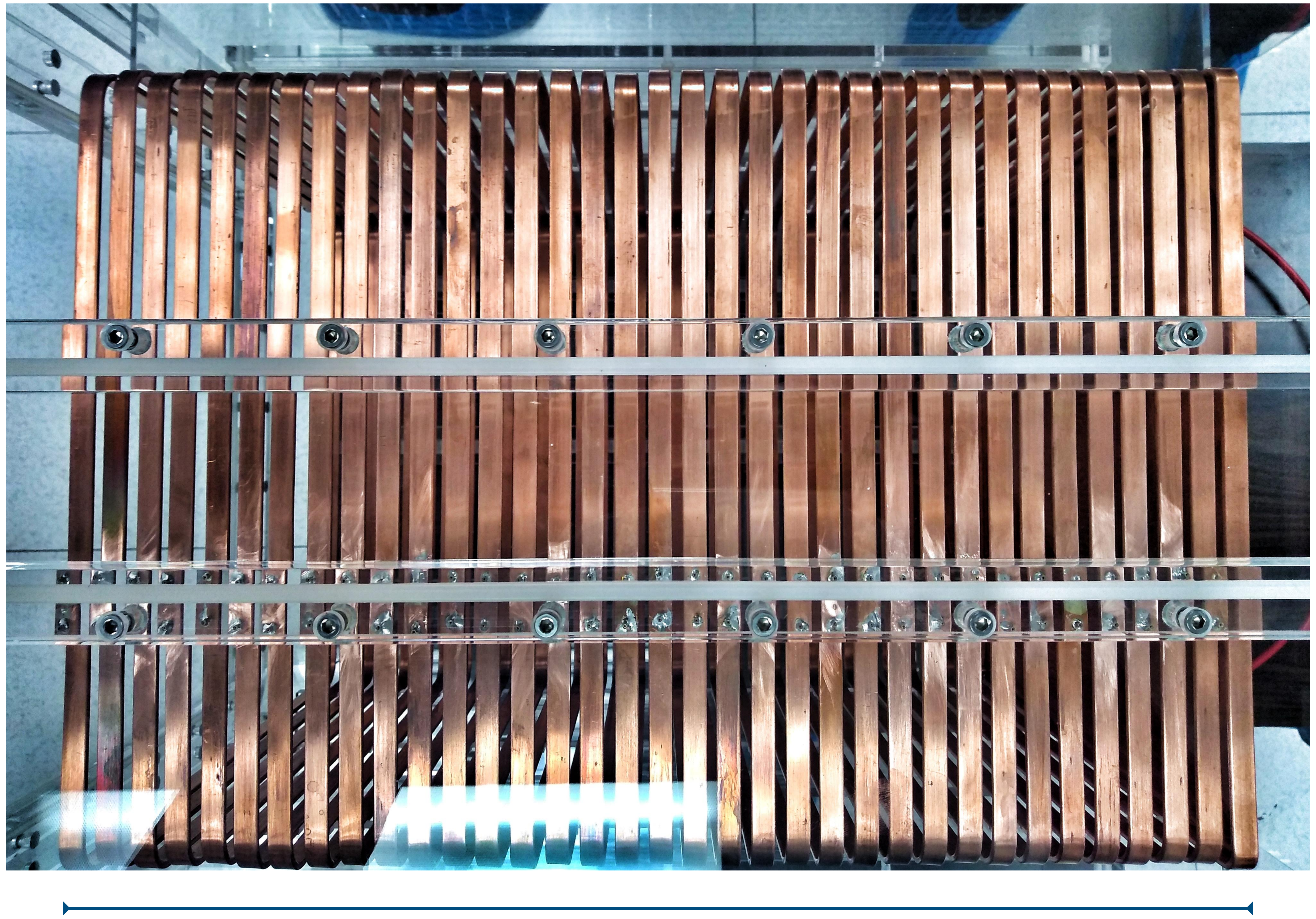
Imagine to illuminate a 50 cm long TPC with a ^{55}Fe radioactive source;

The 5.9 keV photons will produce 5.9 keV electrons in the gas that travels few hundreds of microns releasing all they energy;

A bunch of hundreds of atoms are ionised and electrons start drifting toward the anode where multiplication and signal is produced;

Because of the diffusion in the drift path, the size of the “spot” on the readout plane will be quite larger with respect to the initial one;

LIME

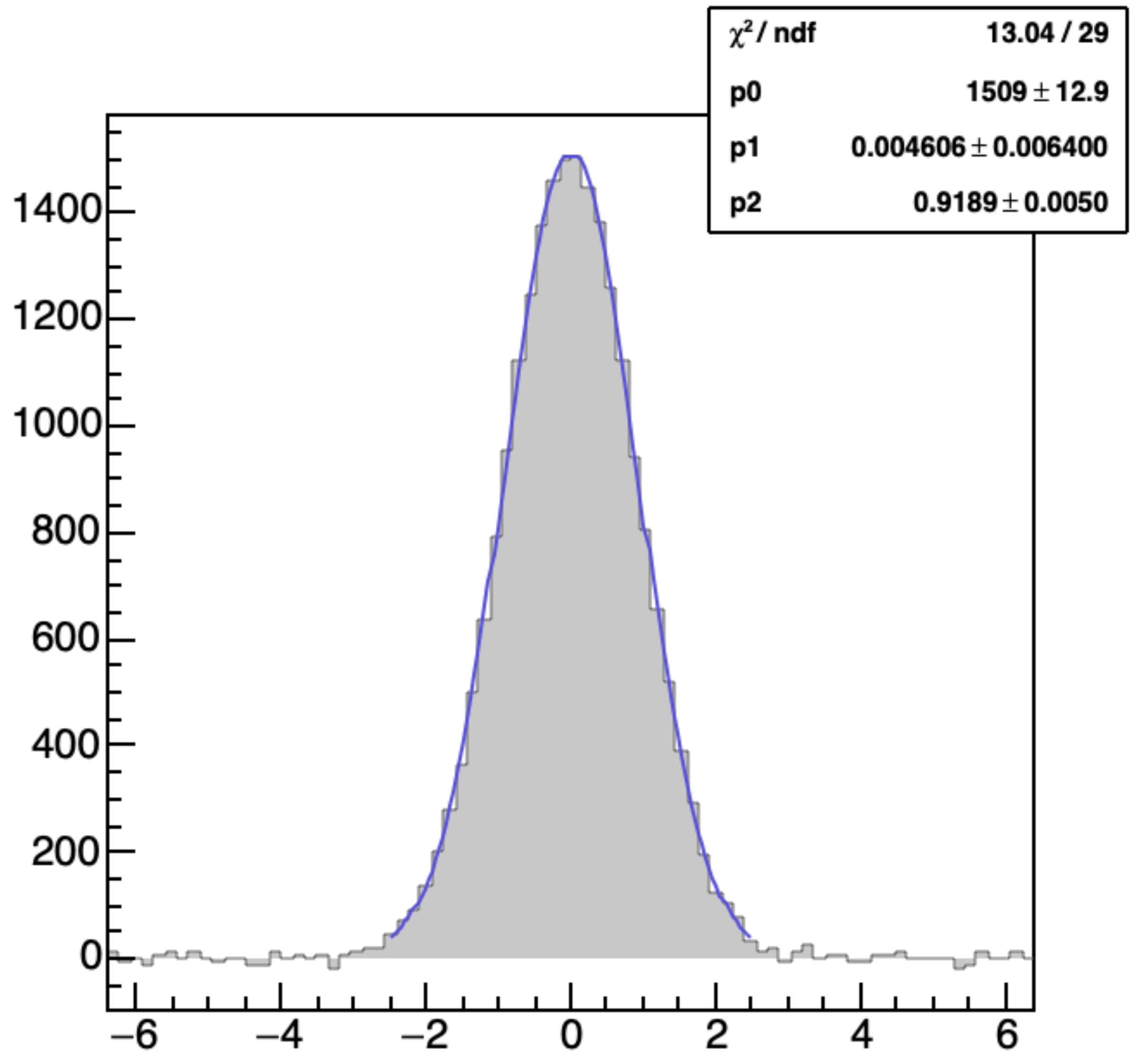


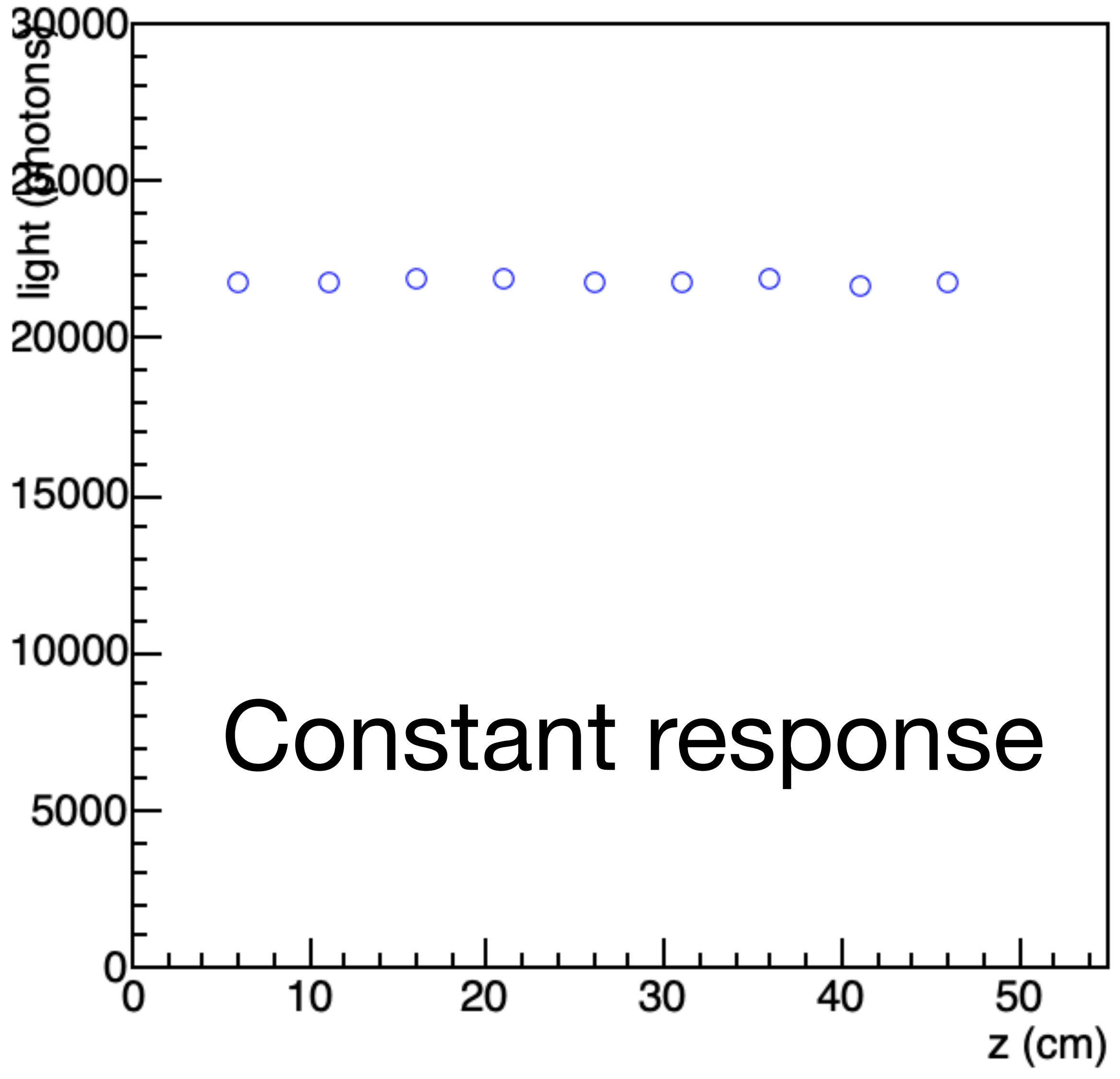
50 cm long Field Cage

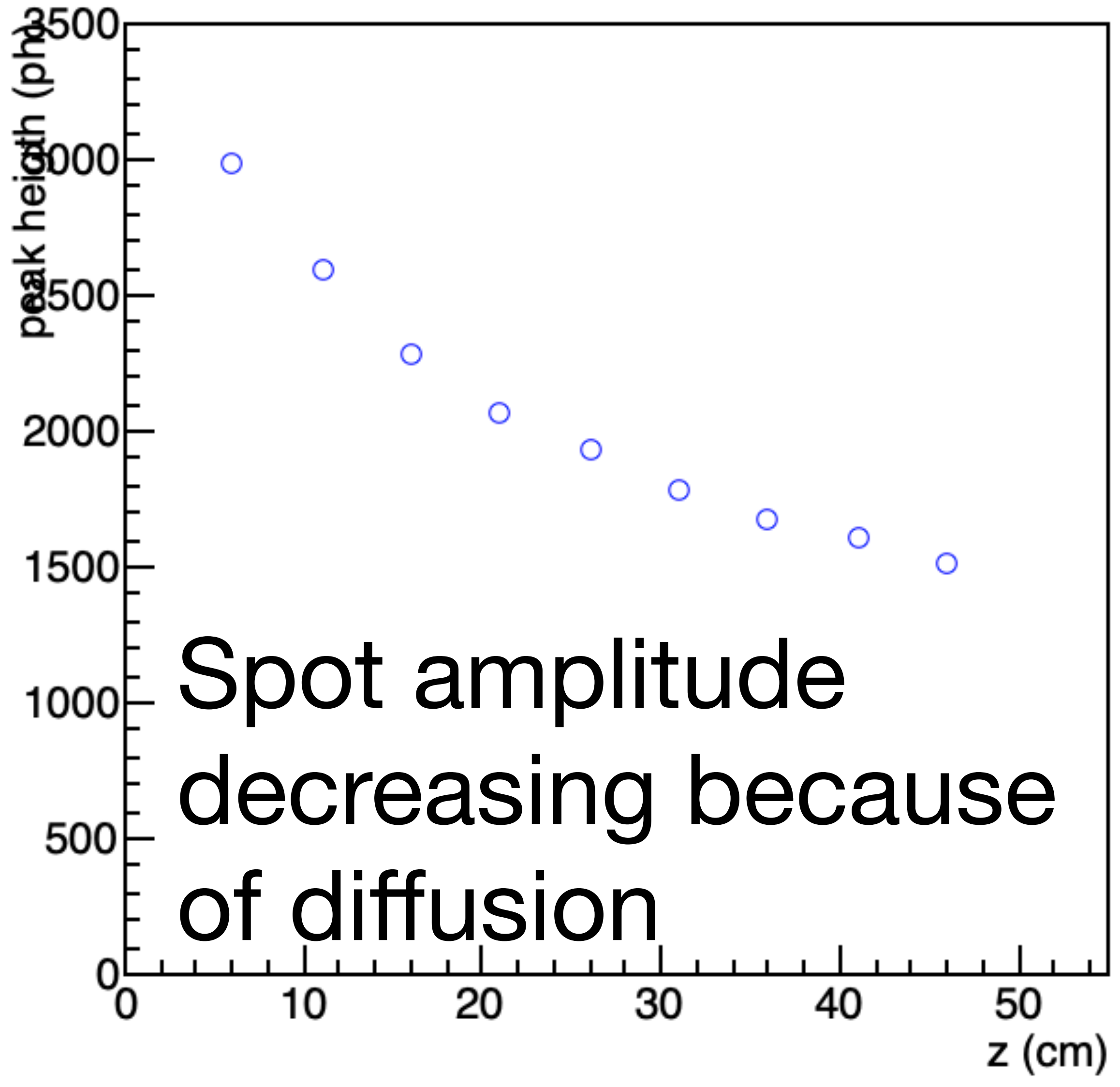
Ideal behaviour

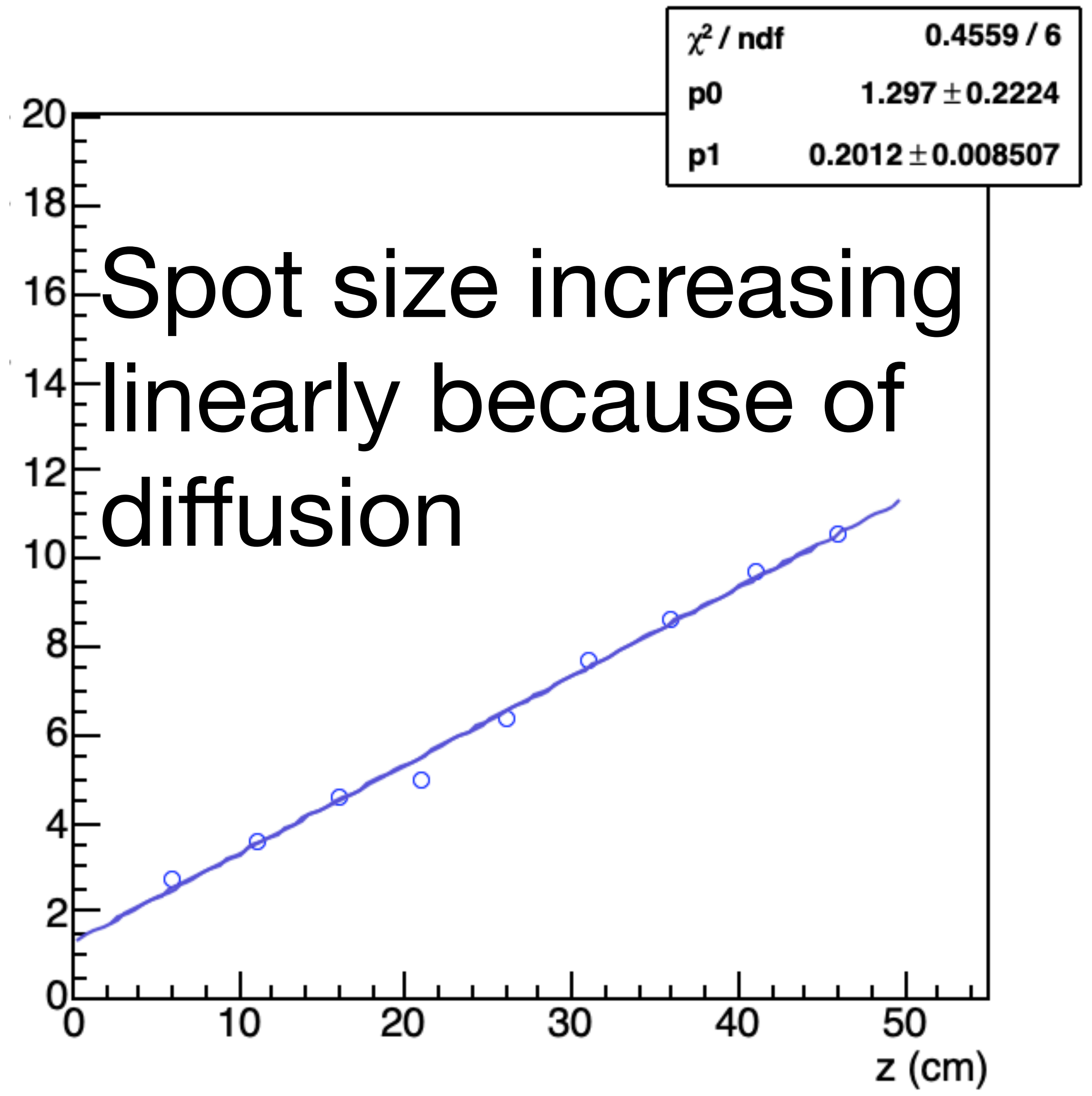
In an ideal optical TPC, if the source is placed at different distances (z) from the GEM:

- charges are efficiently drifted toward GEM;
- gain and light yield (ph/e) are constant -> linearity between light production and ionization;
- null sensor noise;



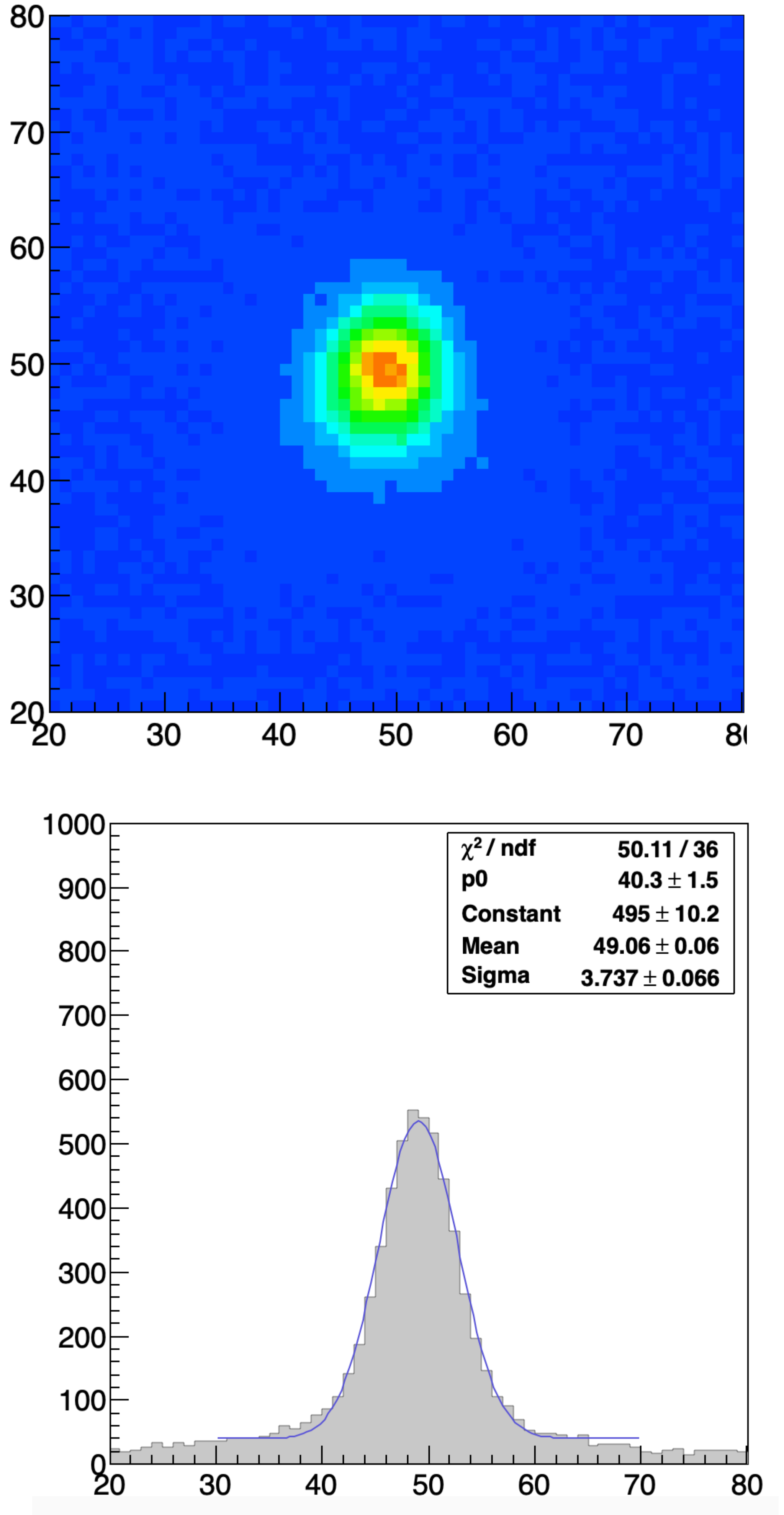




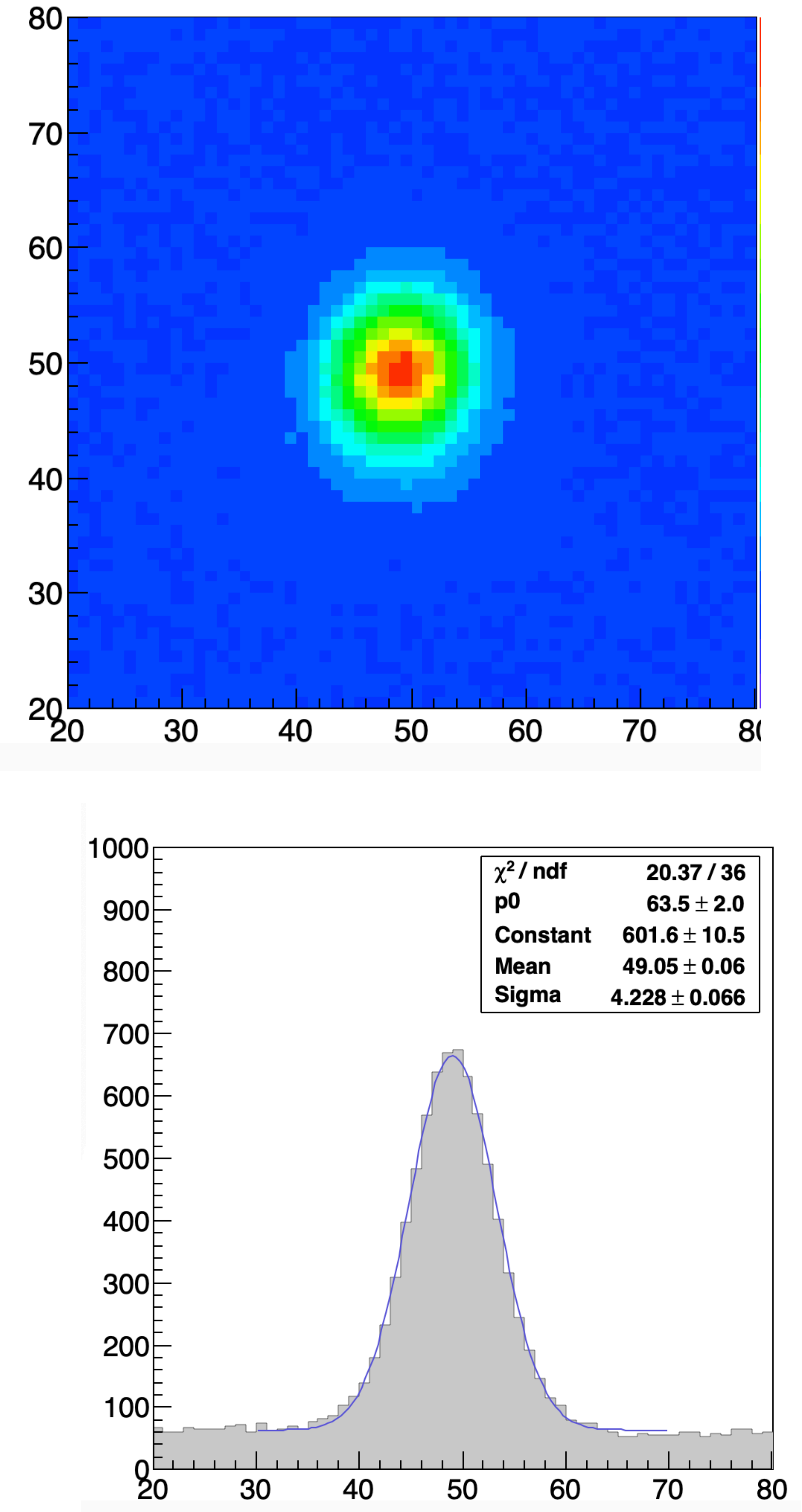


As a function of z (distance from GEM)

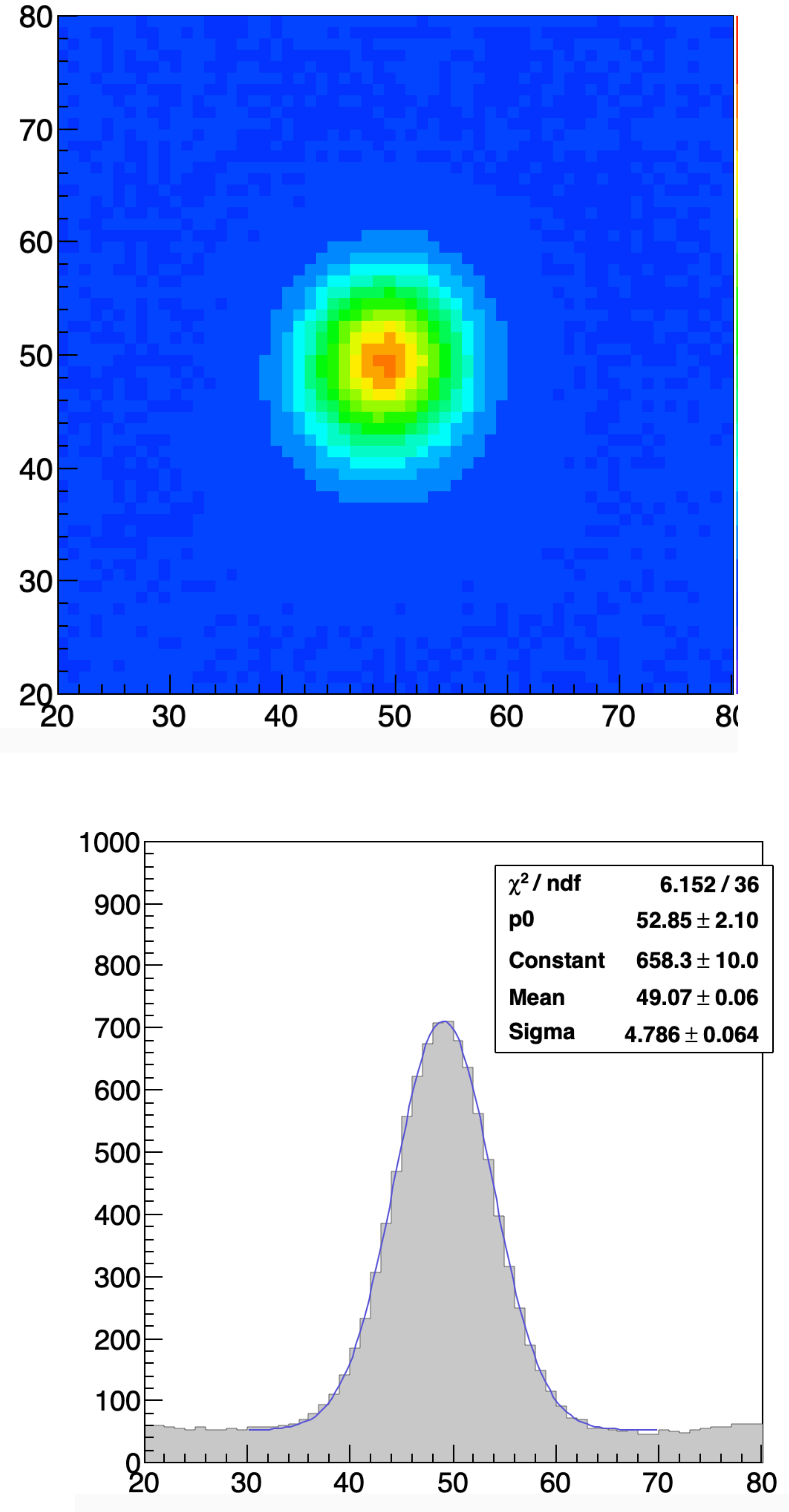
Experimental spot shapes



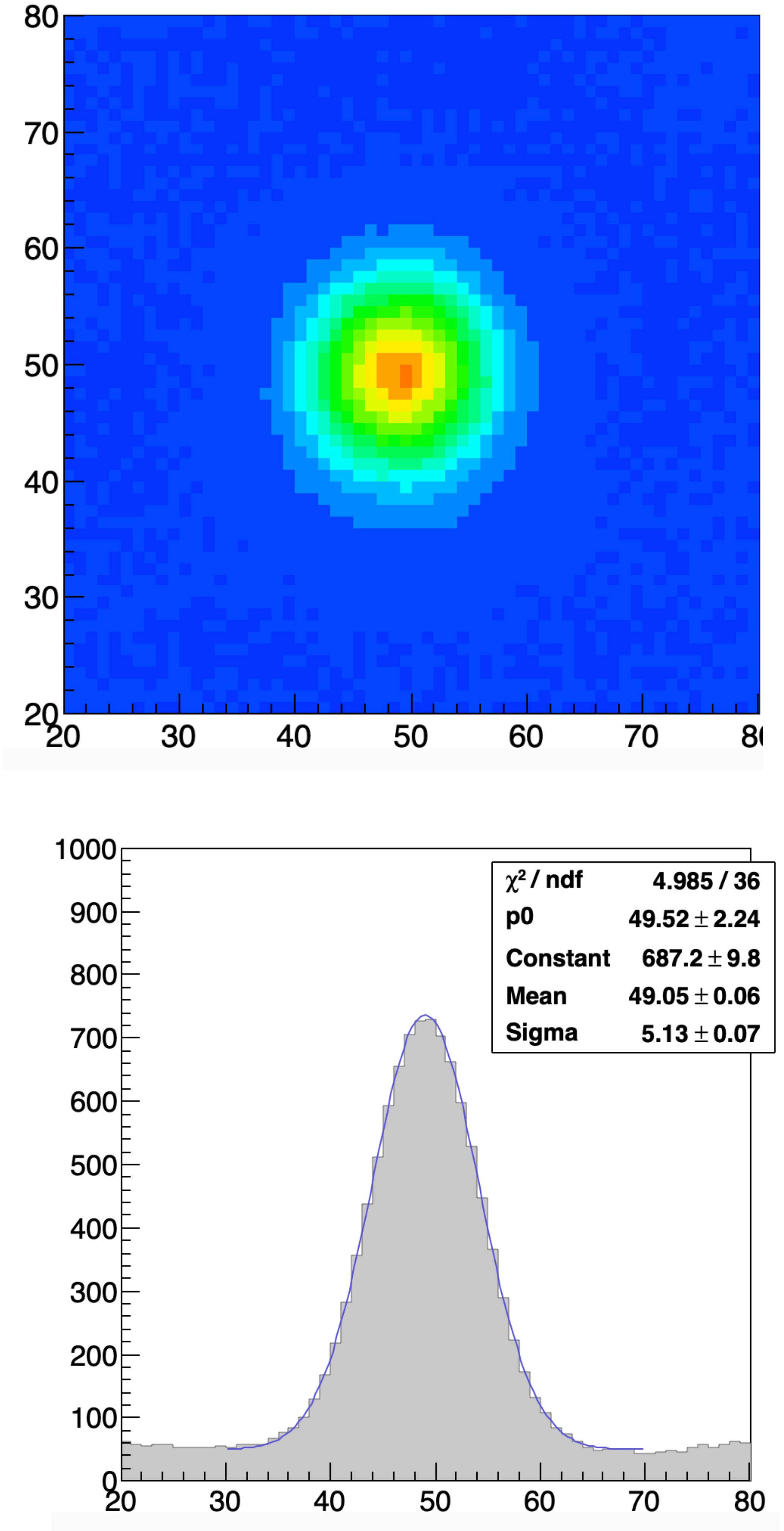
6 cm - light = 4635



11 cm - light = 6373

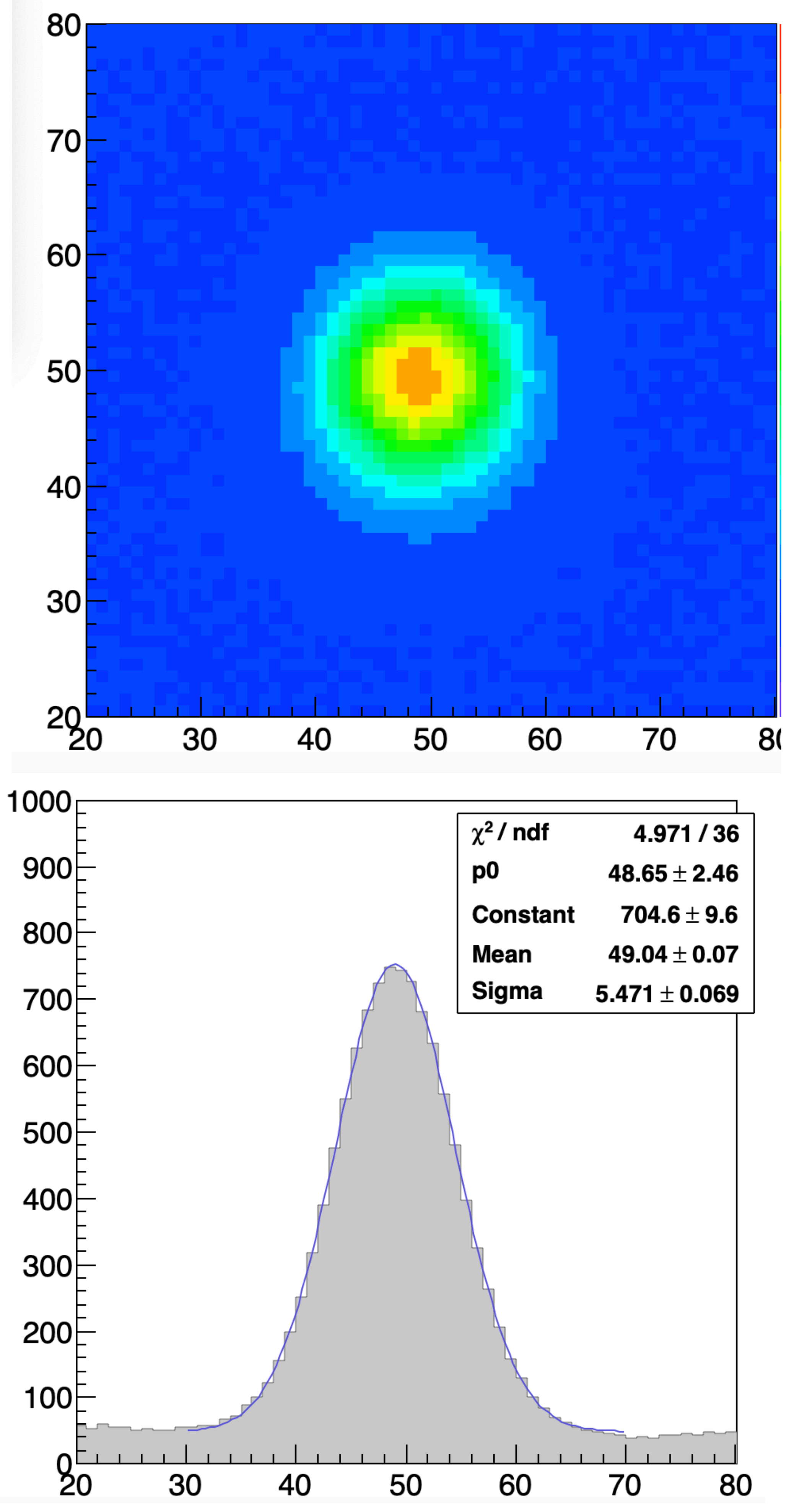


16 cm - light = 7895

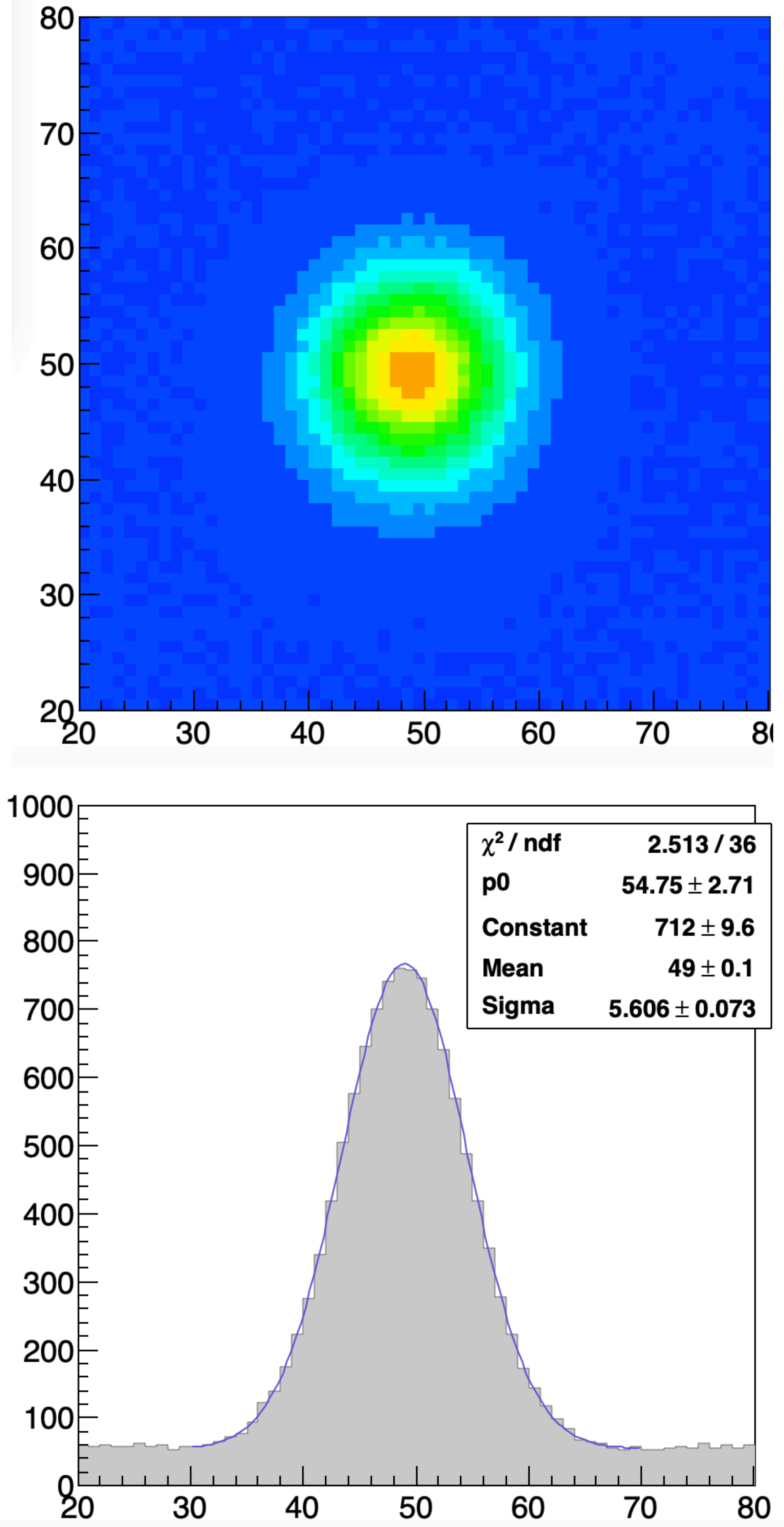


21 cm - light = 8834

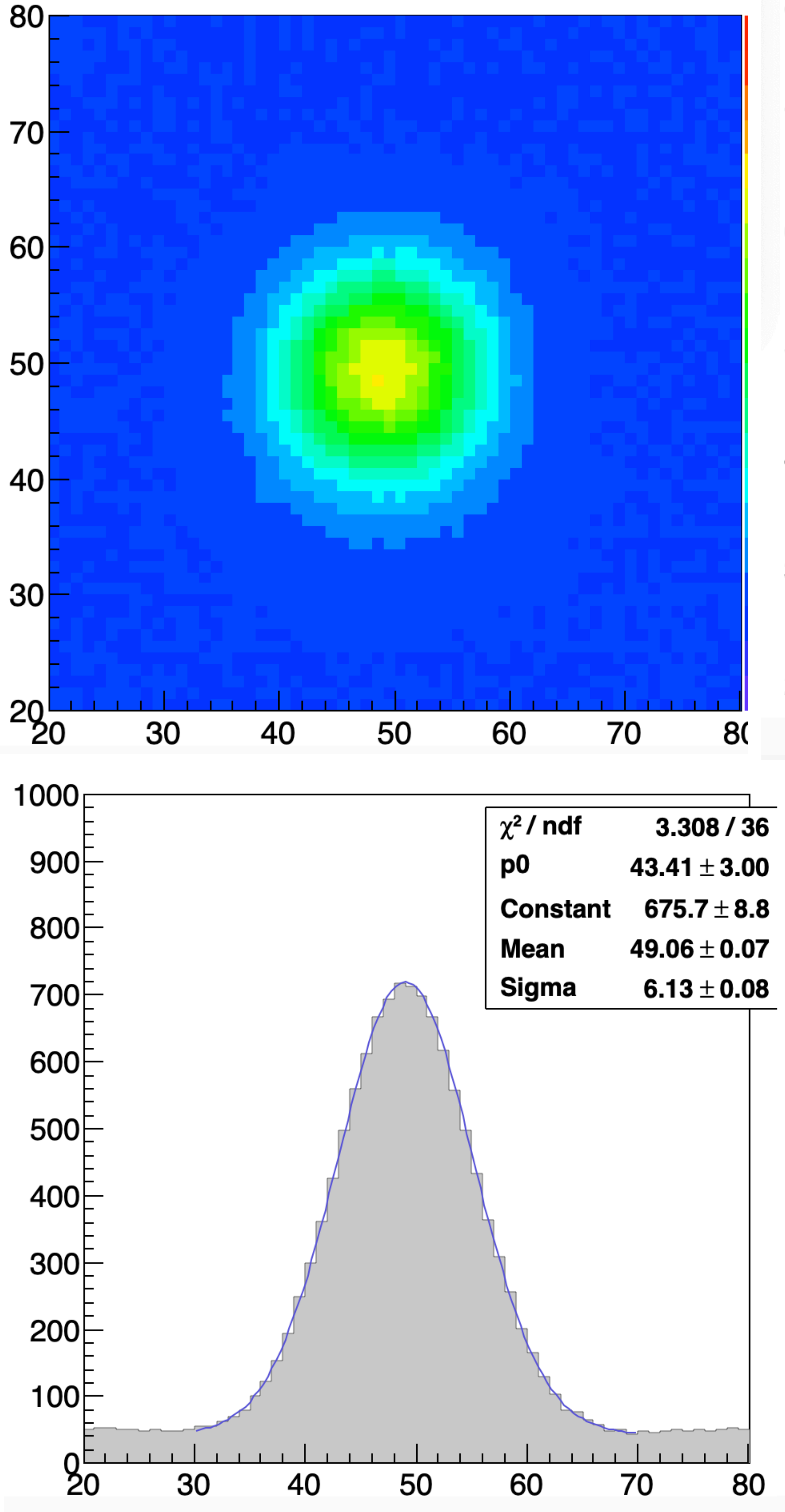
Experimental spot shapes



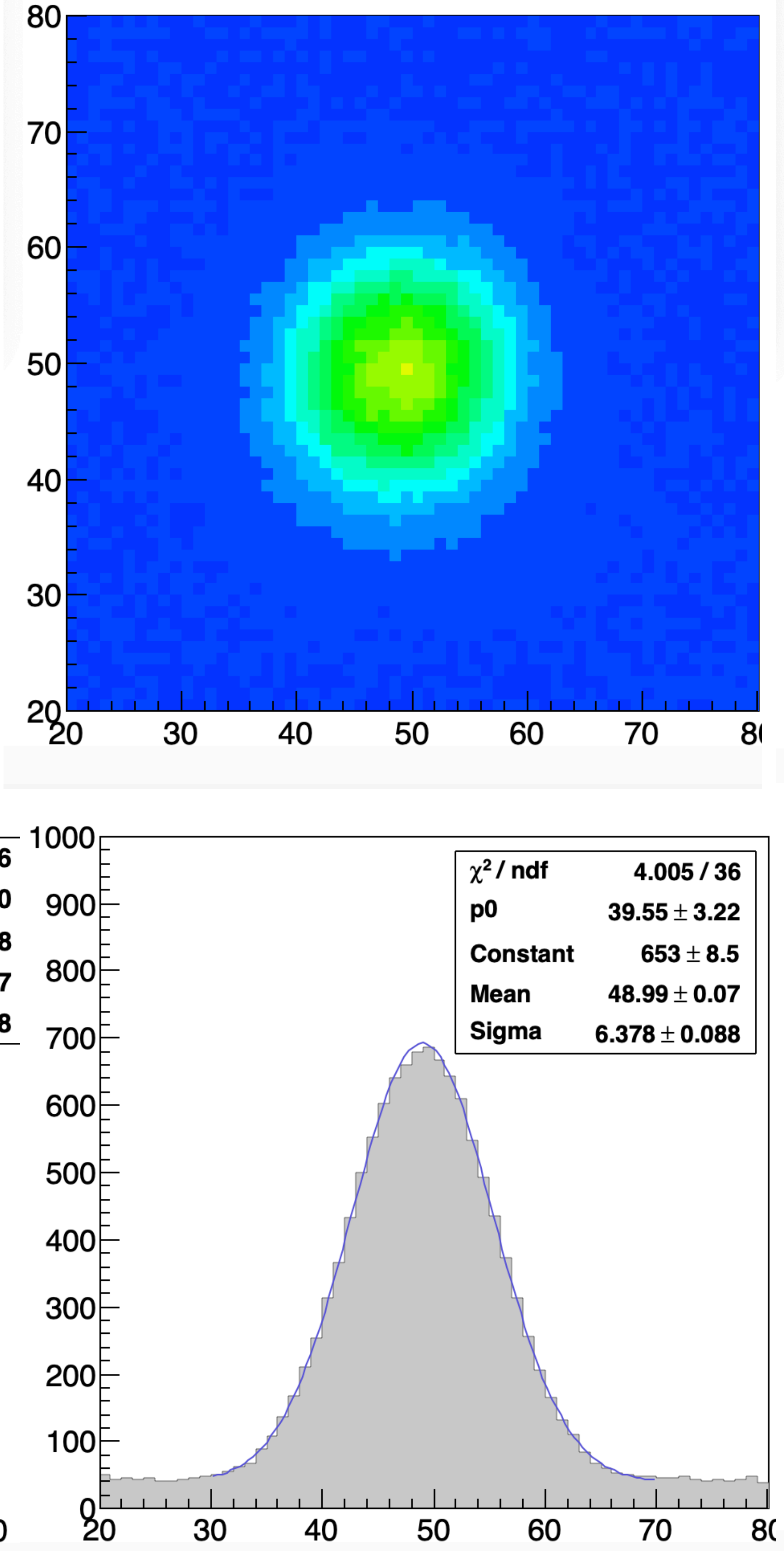
26 cm - 9659



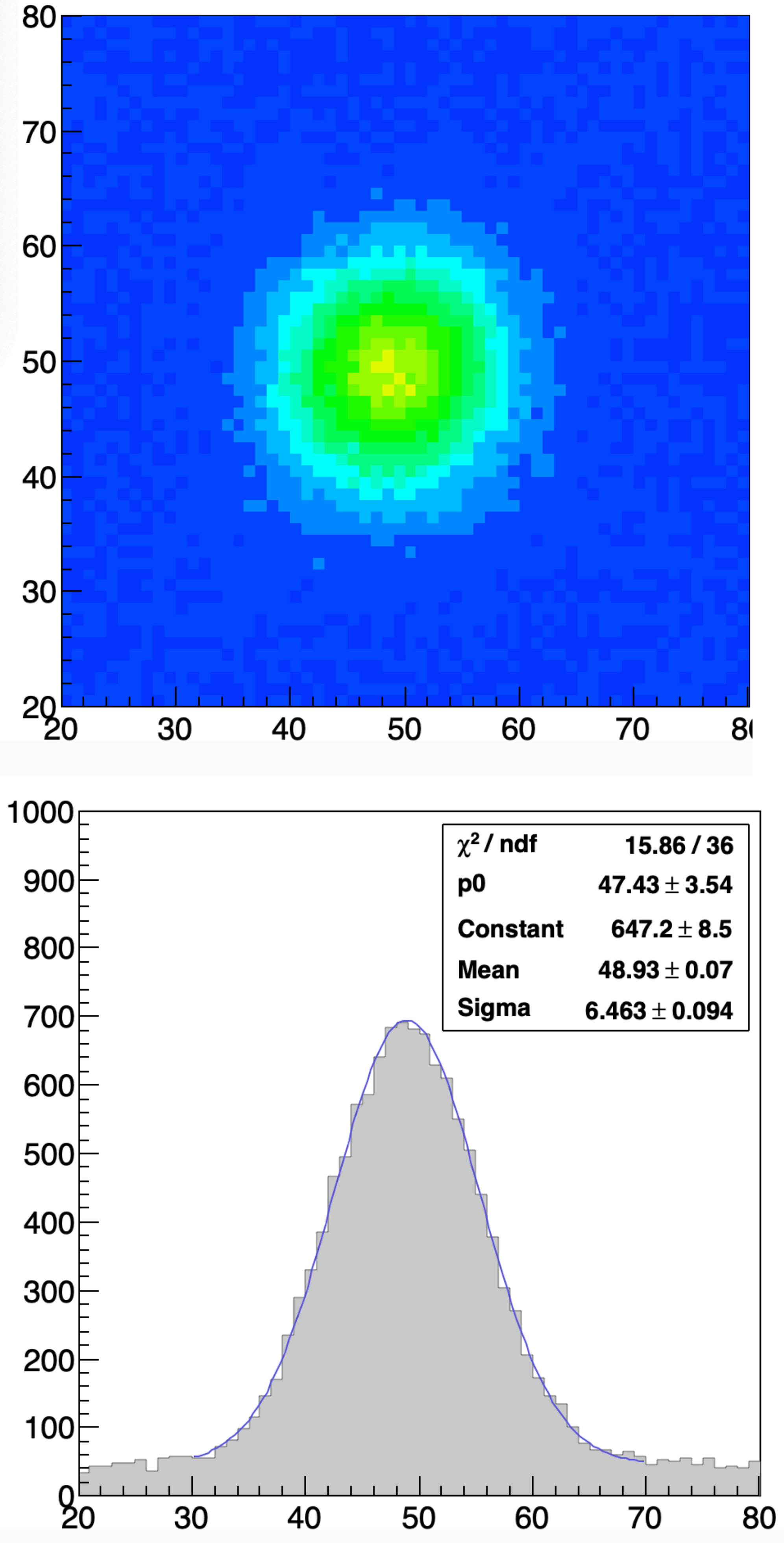
31 cm - 10001



36 cm - 10379



41 cm - 10436



46 cm - 10480

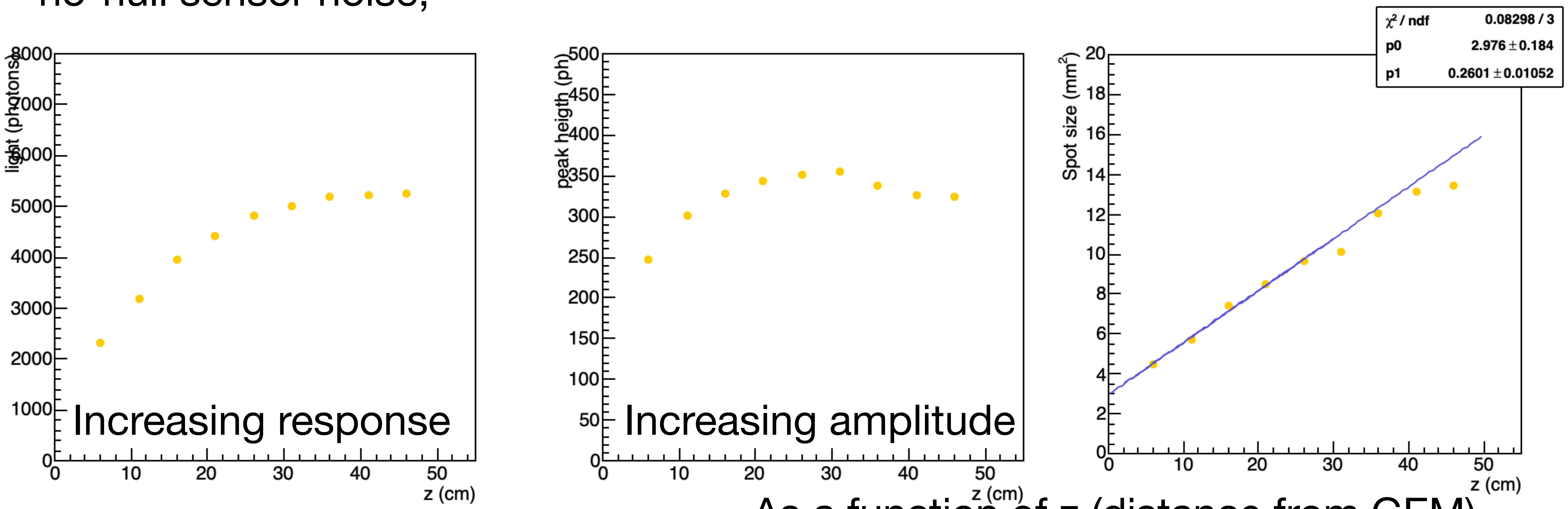
Real behaviour

In a real optical TPC:

- charges are inefficiently drifted toward GEM;

- gain and light yield (ph/e) are not constant -> no linearity between light production and ionization;

- no-null sensor noise;



Spot size increasing because of diffusion with some loss at large Z values

As a function of z (distance from GEM)

A simple model

We are operating the triple-GEM stack at a gain of 5.0e5 - 1.0e6;

If the charge in the channels is too high, in particular the positive ions can screen the electric field inside the channel producing a “dumping” in the avalanche;

In that case the gain “saturates” and the response of the detector is not linear;

Therefore, at each step of the avalanche development, the effective field present depends on the amount of pair produced so far: $E_{eff} = E_0(1 - \beta n)$;

Where β is the screening factor and E_0 is the nominal field in the channel;

We can imagine the field in the channel as produced by an equivalent charge Q_h accumulated on the copper planes $E_c = \dfrac{Q_c}{\delta C_c}$ where C_h: capacitance of the hole and δ: GEM thickness;

A simple model

When the amount of charge in the GEM channel is Q_c , the screening effect will be total

Therefore $\beta = \frac{1}{n_c}$ where $n_c = Q_c/e$

Taking into account the channel density, the typical capacitance per cm^2 of the GEM and an V_{GEM} of about 500 V the expected value for is of the order of 10^{-5};

We can now write a Townsend modified equation: $\frac{dn}{ds} = \alpha E_0(1 - \beta n)n$

And evaluate the gain G:

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

Where n_0 is the amount of charge entering the channel

A simple model

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

n_0 (the number of electrons entering the channels) plays a major role in the gain behaviour:

When n_0 is equal to n_c (i. e. to $1/\beta$) the gain is 1

If n_0 is negligible with respect to n_c (i. e. to $1/\beta$), the saturation of the gain is small

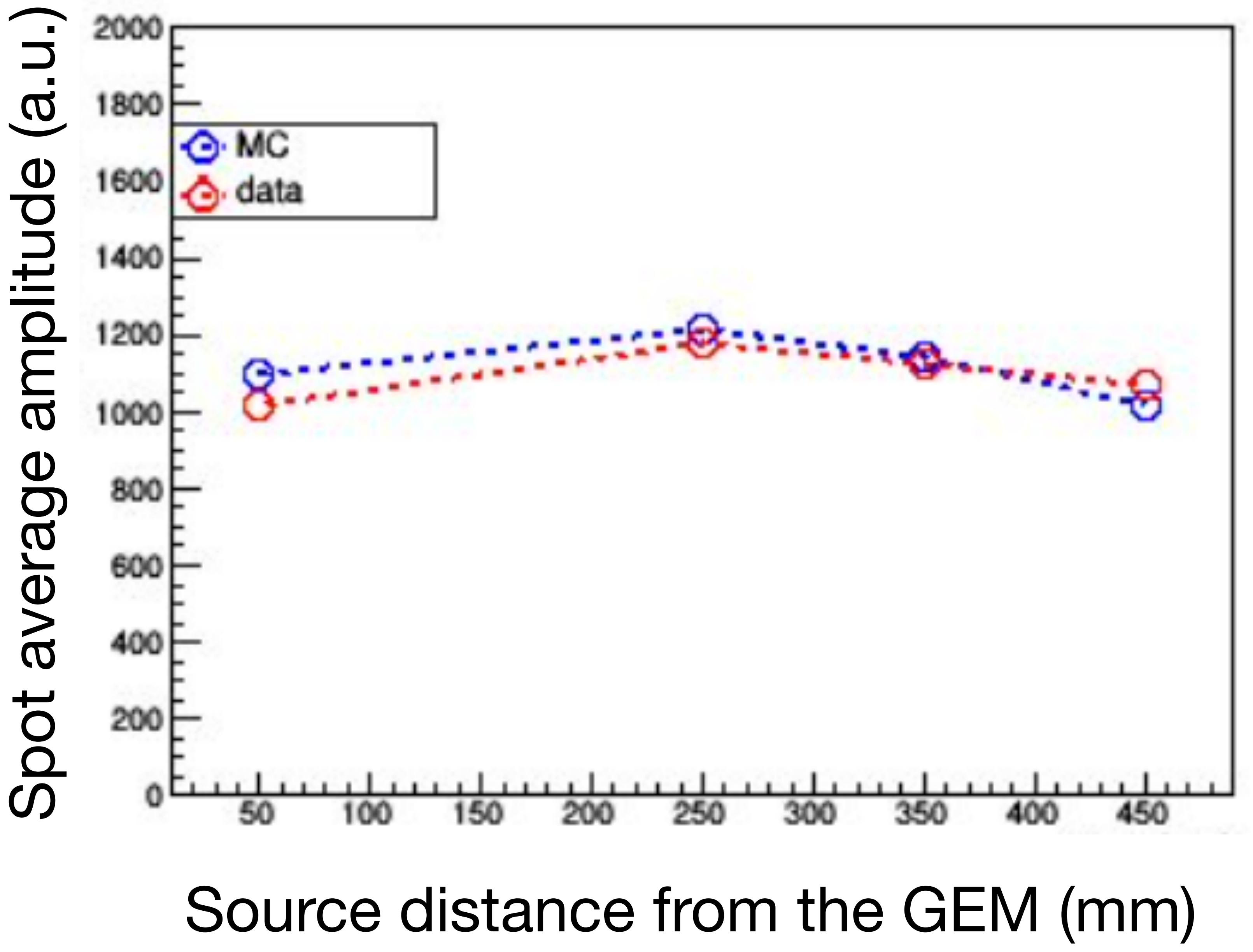
Therefore the *charge density* is the primary contribution to the non-linearity of the response;

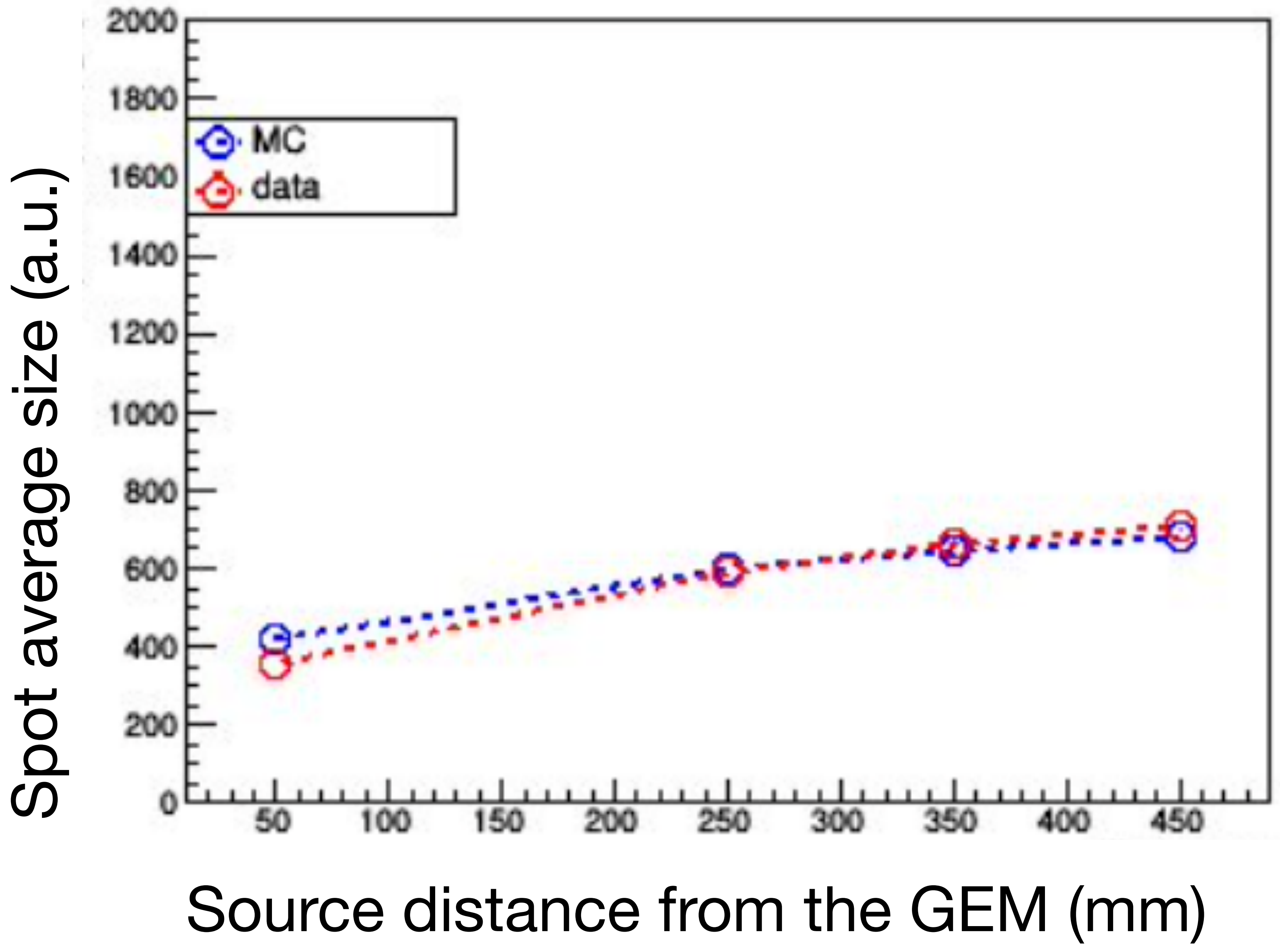
Moreover it is expected to affect mostly GEM3, the one where the charge is larger;

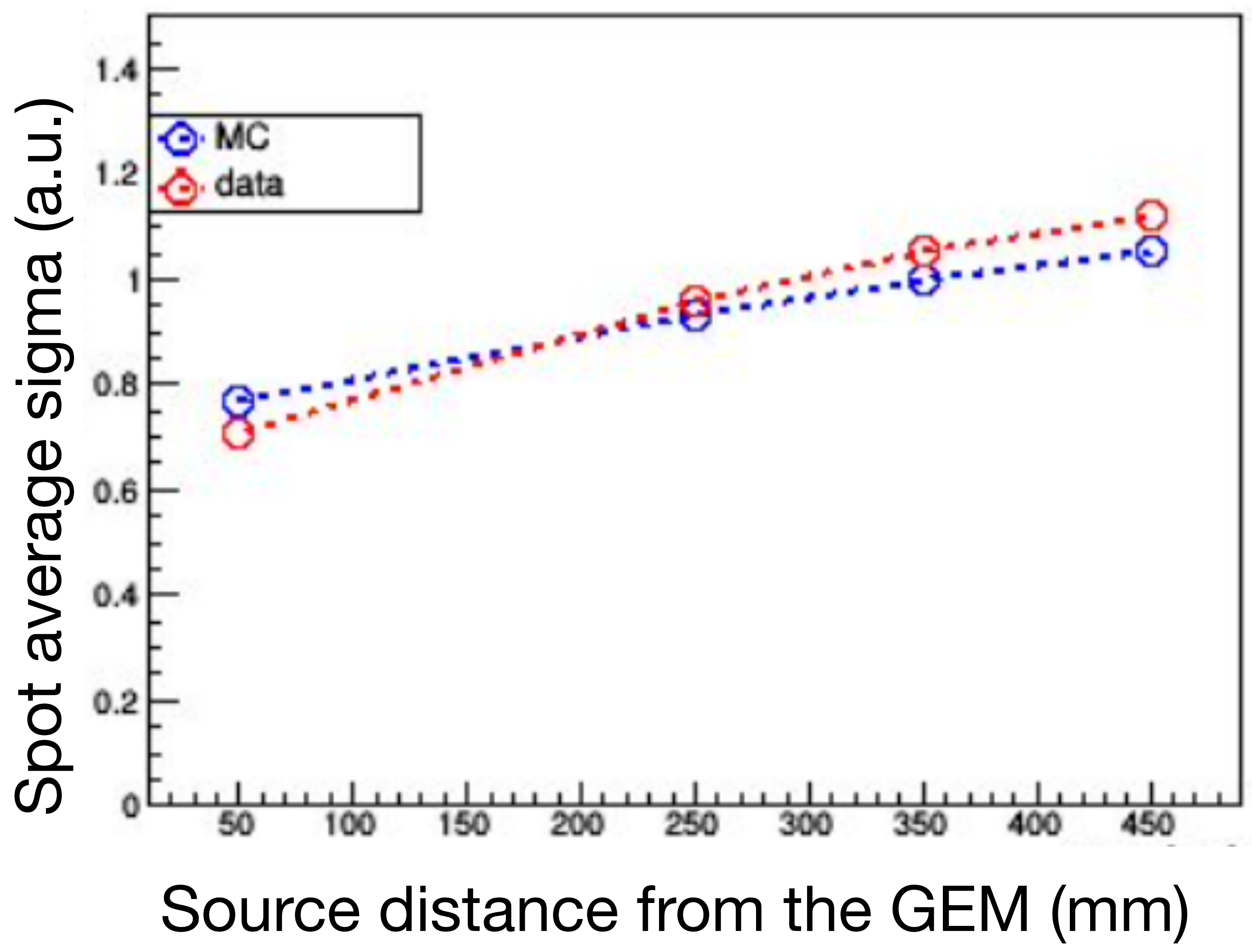
A simple model

By using the formula shown, we tried to simulate the response of the TPC to the ^{55}Fe photons in different positions;

After some tuning of the parameters, good results were found;







Open issue: still to verify if parameters are really “universal” or they depends on the effective gain