Study of saturation parameters

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When is saturation negligible for iron?

Looking at iron calibrations, if we find a configuration (z and HV) for which iron spots don’t saturate, we can estimate the **absorption length**, and the **unsaturated gain as a function of HV**.

Then, if we find a beta (saturation parameter) that allows us to simulate iron at different HV and z, we can say that we can **simulate saturation at different energies.**

So we look iron scans in both HV and z in stable conditions.

Data and analysis

Scans in HV and z. 50 runs in total.
(**15 dec 2023, RUN 4**)

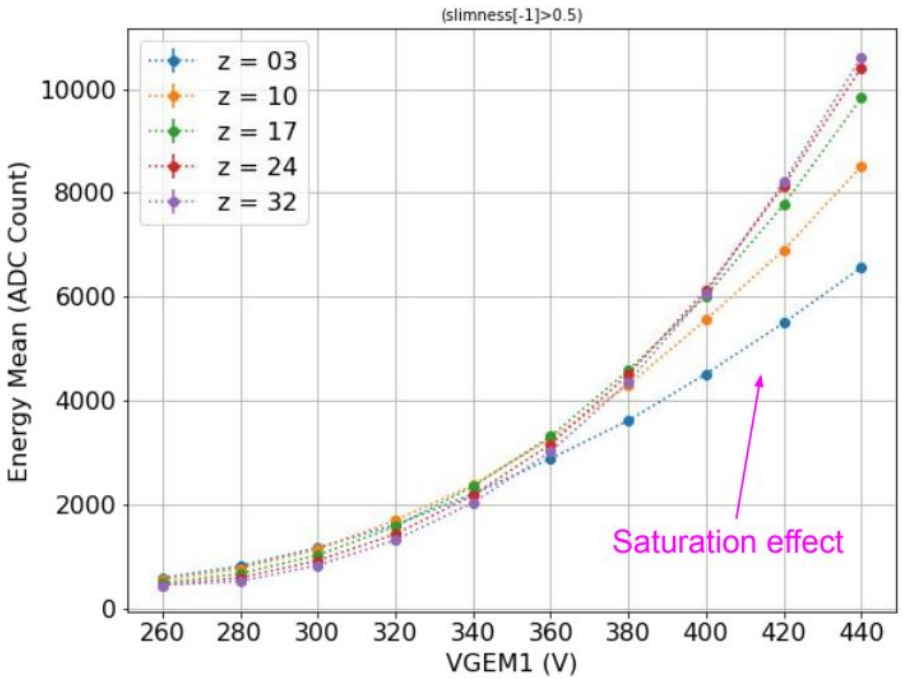
- 10 voltages: (260 V - 440 V) steps of 20 V
- Usual 5 steps: 5, 10, 15, 25, 35, 46.5 cm

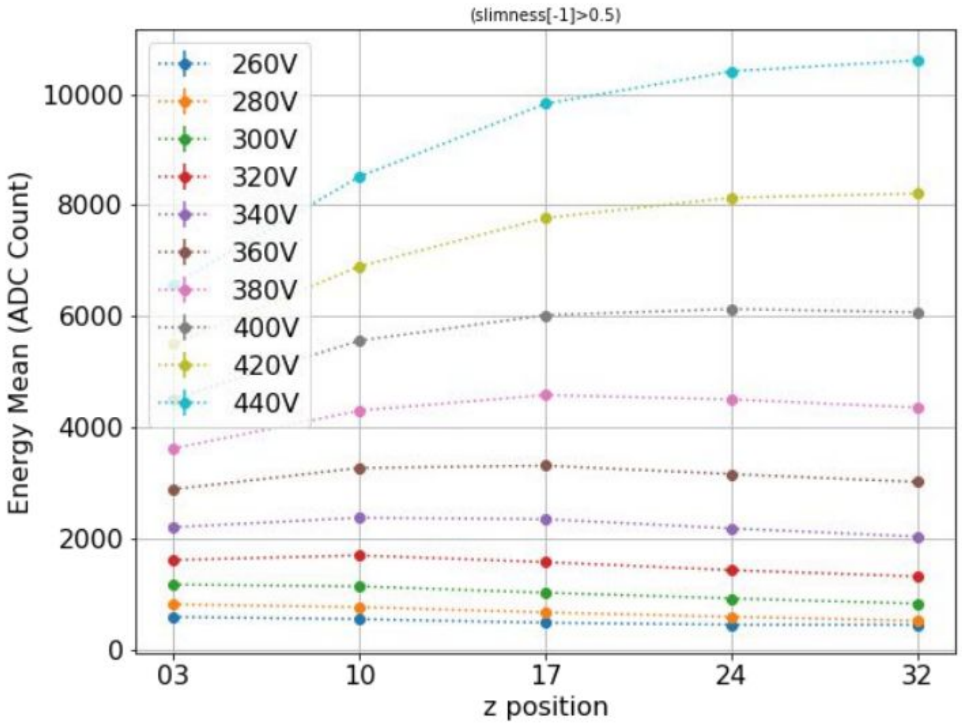
Cuts: sc_length < 500
sc_integral / sc_nhits < 100
sc_integral < 6e4
sc_width / sc_length < 1
sc_width / sc_length > 0.5
barycenter in circle with radius > 750 px

43050,step 5,260,32/33,101
43049,step 5,280,32/33,105
43048,step 5,300,32/33,102
43047,step 5,320,32/33,102
43046,step 5,340,32/33,103
43045,step 5,360,32/33,102
43044,step 5,380,32/33,102
43043,step 5,400,32/33,103
43042,step 5,420,32/33,103
43041,step 5,440,32/33,103
43040,step 5 PED,260,32/33,105
43039,step 4,260,24/25,104
43038,step 4,280,24/25,105
43037,step 4,300,24/25,102
43036,step 4,320,24/25,102
43035,step 4,340,24/25,101
43034,step 4,360,24/25,101
43033,step 4,380,24/25,104
43032,step 4,400,24/25,103
43031,step 4,420,24/25,103
43030,step 4,440,24/25,103
43029,step 4 PED,260,24/25,106
43028,step 3,260,17/18,104
43027,step 3,280,17/18,102
43026,step 3,300,17/18,103
43025,step 3,320,17/18,103
43024,step 3,340,17/18,101
43023,step 3,360,17/18,101
43022,step 3,380,17/18,103
43021,step 3,400,17/18,103
43020,step 3,420,17/18,103
43019,step 3,440,17/18,102
43018,step 3 PED,440,17/18,104

43017,step 2,260,10/11,105
43016,step 2,280,10/11,102
43015,step 2,300,10/11,103
43014,step 2,320,10/11,103
43013,step 2,340,10/11,102
43012,step 2,360,10/11,103
43011,step 2,380,10/11,104
43010,step 2,400,10/11,103
43009,step 2,420,10/11,102
43008,step 2,440,10/11,102
43007,step 2 PED,260,10/11,106
43006,step 1,260,03/04,102
43005,step 1,280,03/04,101
43004,step 1,300,03/04,103
43003,step 1,320,03/04,102
43002,step 1,340,03/04,102
43001,step 1,360,03/04,102
43000,step 1,380,03/04,102
42999,step 1,400,03/04,103
42998,step 1,420,03/04,101
42997,step 1,440,03/04,101
42996,step 1 PED,260,03/04,101
42995,parking position,260,00/00,101
42994,parking position,280,00/00,102
42993,parking position,300,00/00,101
42992,parking position,320,00/00,100
42991,parking position,340,00/00,105
42990,parking position,360,00/00,101
42989,parking position,380,00/00,103
42988,parking position,400,00/00,102
42987,parking position,420,00/00,105
42986,parking position,440,00/00,101
42985,parking position PED,400,00/0

We want to find a set of digitization parameters that reproduce these trends of sc_integral vs HV and vs z





From Rafael’s presentation

Absorption length estimation

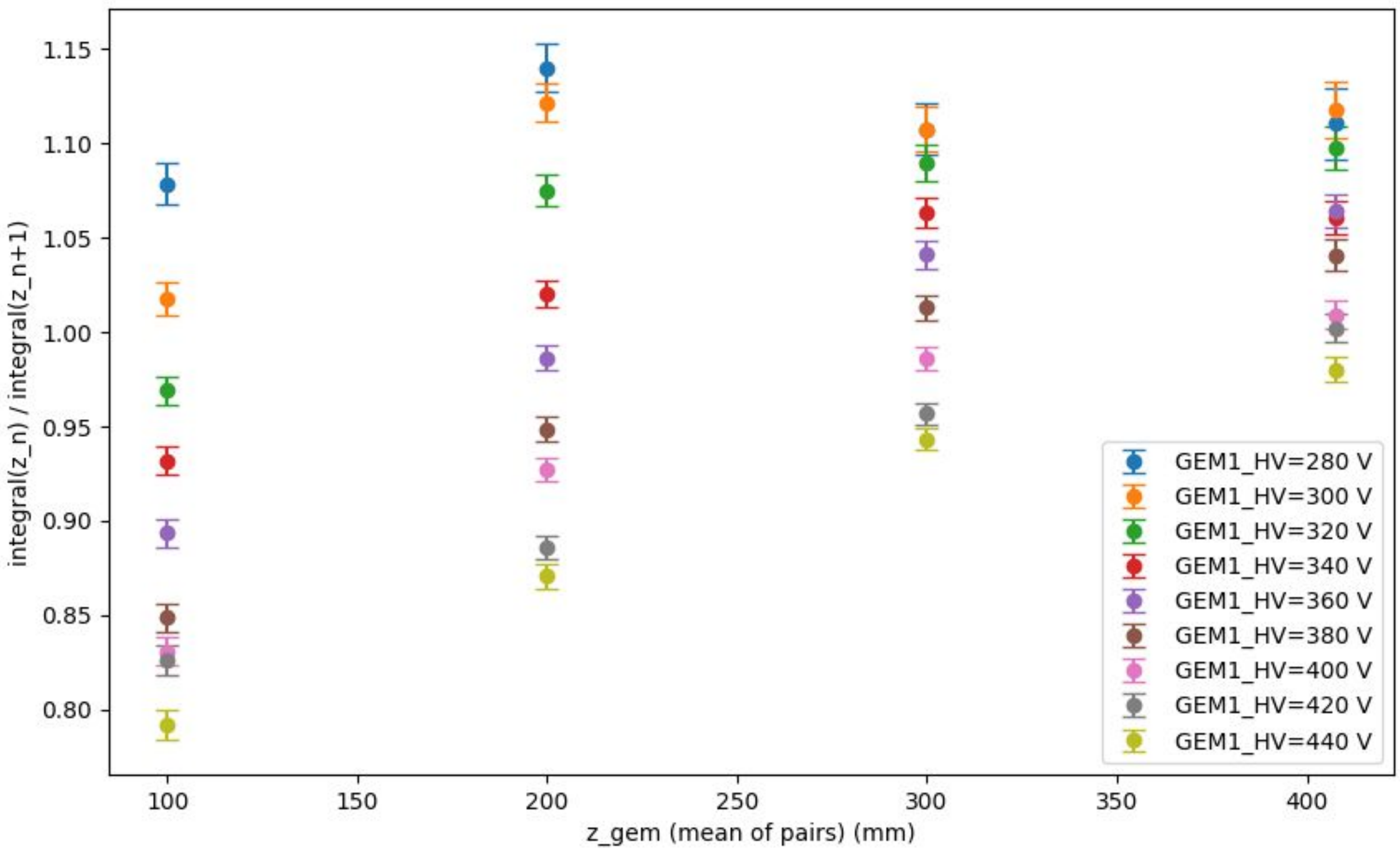
We start computing the ratio between sc_integrals at step5 (46.5 cm) and at step4 (35 cm) for each HV.

If the ratio is constant at low HV, we can say there is no saturation.

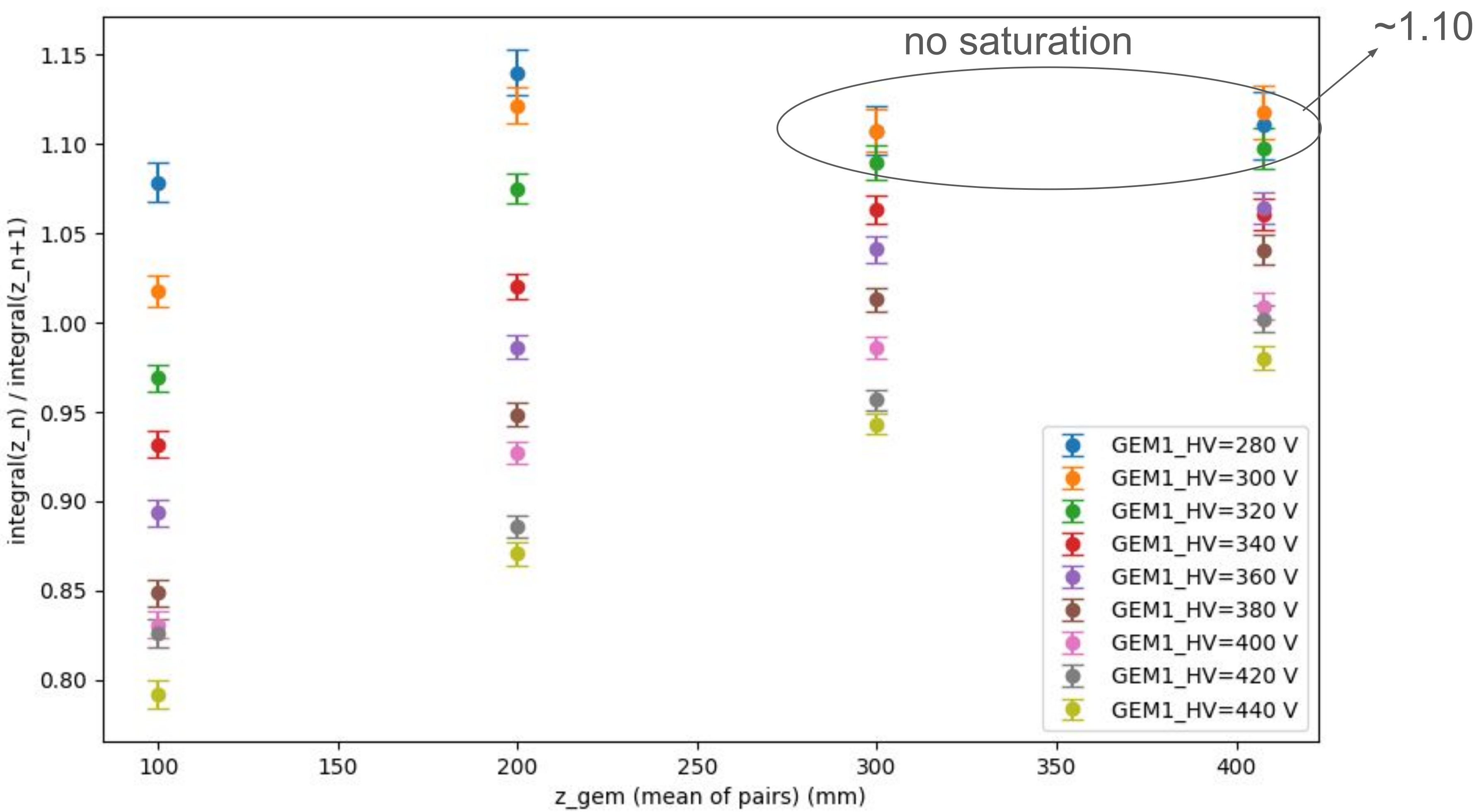
And since:

$$I(z) = I_0 \cdot e^{-\frac{z}{\lambda}}$$

Then the ratio is exp (delta_z / lambda)   so we can estimate lambda



integral(z_n) / integral(z_n+1)
z_gem (mean of pairs) (mm)
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
100
150
200
250
300
350
400
GEM1_HV=280 V
GEM1_HV=300 V
GEM1_HV=320 V
GEM1_HV=340 V
GEM1_HV=360 V
GEM1_HV=380 V
GEM1_HV=400 V
GEM1_HV=420 V
GEM1_HV=440 V


no saturation
~1.10
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
integral(z_n) / integral(z_n+1)
100
150
200
250
300
350
400
z_gem (mean of pairs) (mm)
GEM1_HV=280 V
GEM1_HV=300 V
GEM1_HV=320 V
GEM1_HV=340 V
GEM1_HV=360 V
GEM1_HV=380 V
GEM1_HV=400 V
GEM1_HV=420 V
GEM1_HV=440 V

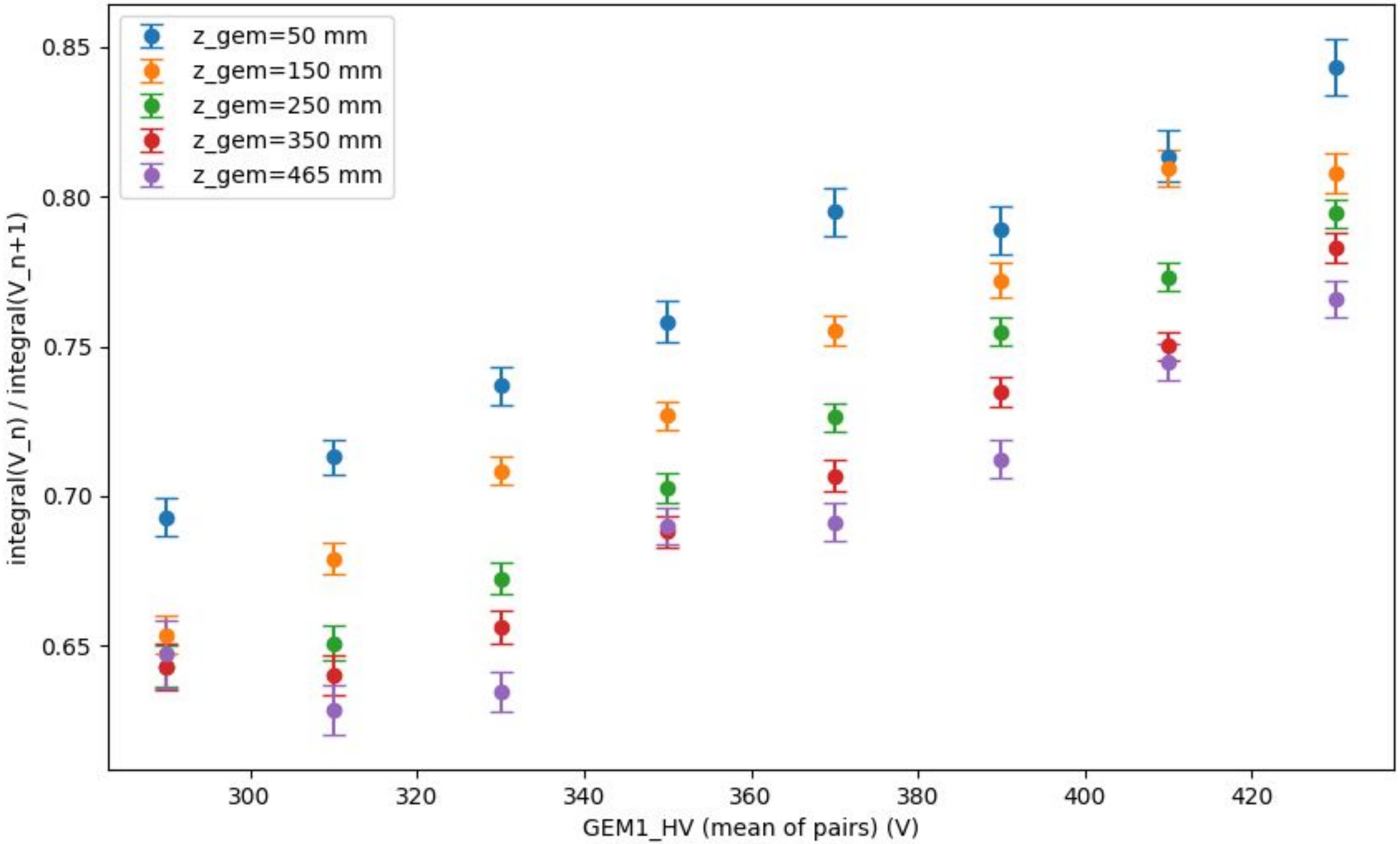
First estimation of lambda (by eye)

At a fixed depth z, under unsaturated conditions, the intensity follows the exponential decay law:

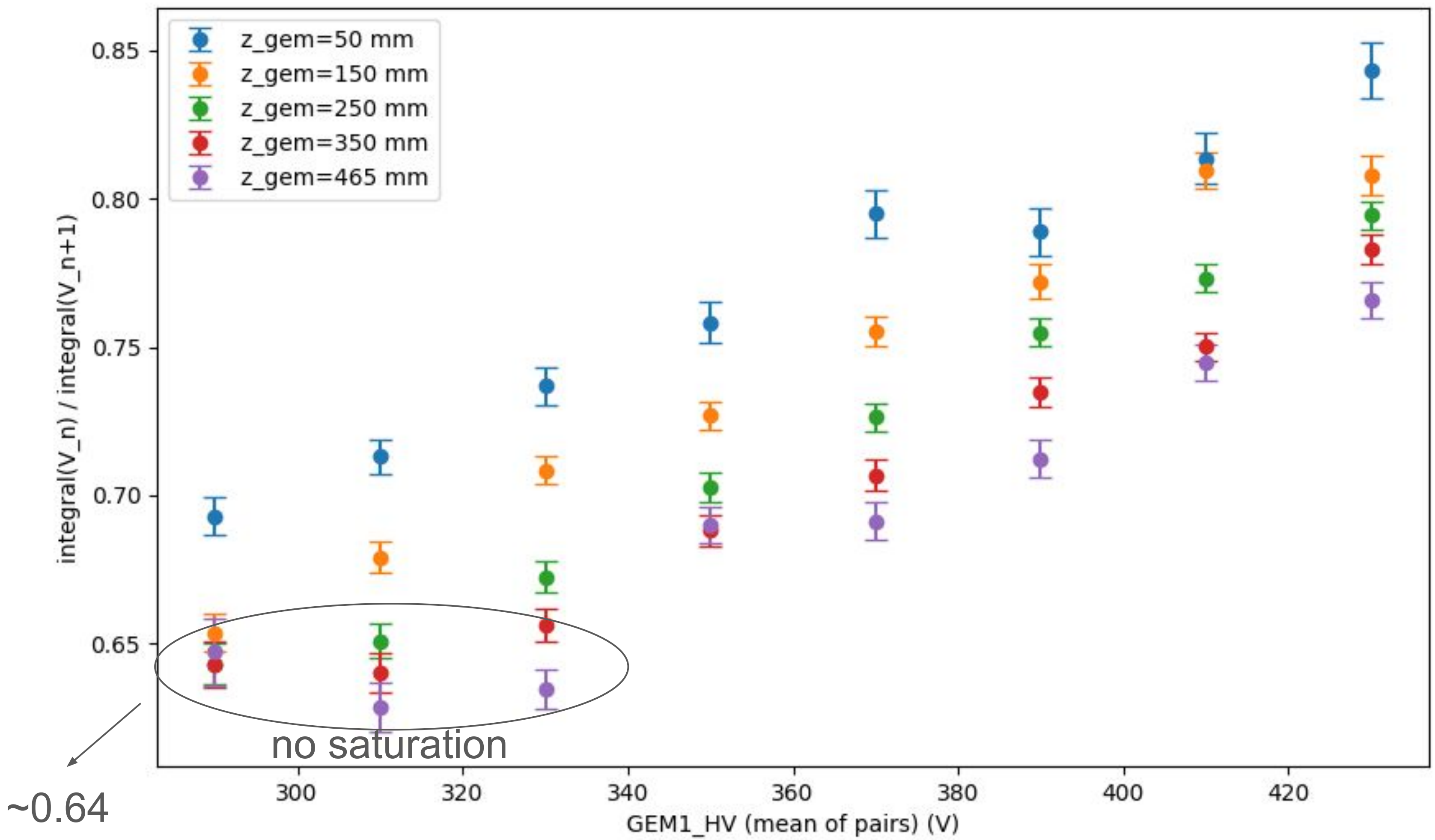
$$I = I_0 \cdot e^{-\frac{z}{\lambda}}$$

Given that the ratio of intensities at two different points is $\frac{I_1}{I_2} = 1.10$, we can solve for the attenuation length λ. For a 10 cm difference in depth:

$$\lambda = \left(\frac{\ln(1.10)}{10\,\text{cm}} \right)^{-1} = 105\,\text{cm}$$



z_gem=50 mm
z_gem=150 mm
z_gem=250 mm
z_gem=350 mm
z_gem=465 mm
0.85
0.80
0.75
0.70
0.65
integral(V_n) / integral(V_n+1)
300
320
340
360
380
400
420
GEM1_HV (mean of pairs) (V)


z_gem=50 mm
z_gem=150 mm
z_gem=250 mm
z_gem=350 mm
z_gem=465 mm
0.85
0.80
0.75
0.70
0.65
integral(V_n) / integral(V_n+1)
300
320
340
360
380
400
420
GEM1_HV (mean of pairs) (V)
no saturation
~0.64

First estimation of alpha (by eye)

At a fixed high voltage (HV), under unsaturated conditions, the intensity is given by the equation:

$$I = I_0 \cdot e^{\alpha \cdot \mathrm{HV}}$$

Given that the ratio of intensities is $\frac{I_1}{I_2} = 0.64$, we can determine the value of α. For a voltage difference of 20 V:

$$\alpha = -\frac{\ln(0.64)}{20\,\mathrm{V}} = 0.0223\,\mathrm{V}^{-1}$$

Thus, the parameter α, which governs the exponential dependence on HV, is found to be $0.0223\,\mathrm{V}^{-1}$.

Does alpha = 0.22 V^-1 make sense? yes!

```
## fit from Fernando Amaro's single GEM gain measurement
GEM1_gain = 0.0347 * np.exp((0.0209) * opt.GEM1_HV)
GEM2_gain = 0.0347 * np.exp((0.0209) * opt.GEM2_HV)
GEM3_gain = 0.0347 * np.exp((0.0209) * opt.GEM3_HV)
```

It’s around the value measured at LNF and we’ve been using it in digitization, even though we were not sure if environmental conditions (humidity) could affect it. Now we can say it seems unaffected, and we have to adjust only the gain at V = 0 in the digitization code.

Does alpha = 0.22 V^-1 make sense? yes!

```
## fit from Fernando Amaro's single GEM gain measurement
GEM1_gain = 0.0347 * np.exp((0.0209) * opt.GEM1_HV)
GEM2_gain = 0.0347 * np.exp((0.0209) * opt.GEM2_HV)
GEM3_gain = 0.0347 * np.exp((0.0209) * opt.GEM3_HV)
```

This constant (g_0) can instead be evaluated from a 2D exponential fit as a function of z and V:

$$I = I_0 \cdot e^{\alpha \cdot V} \cdot e^{-\frac{z}{\lambda}}$$

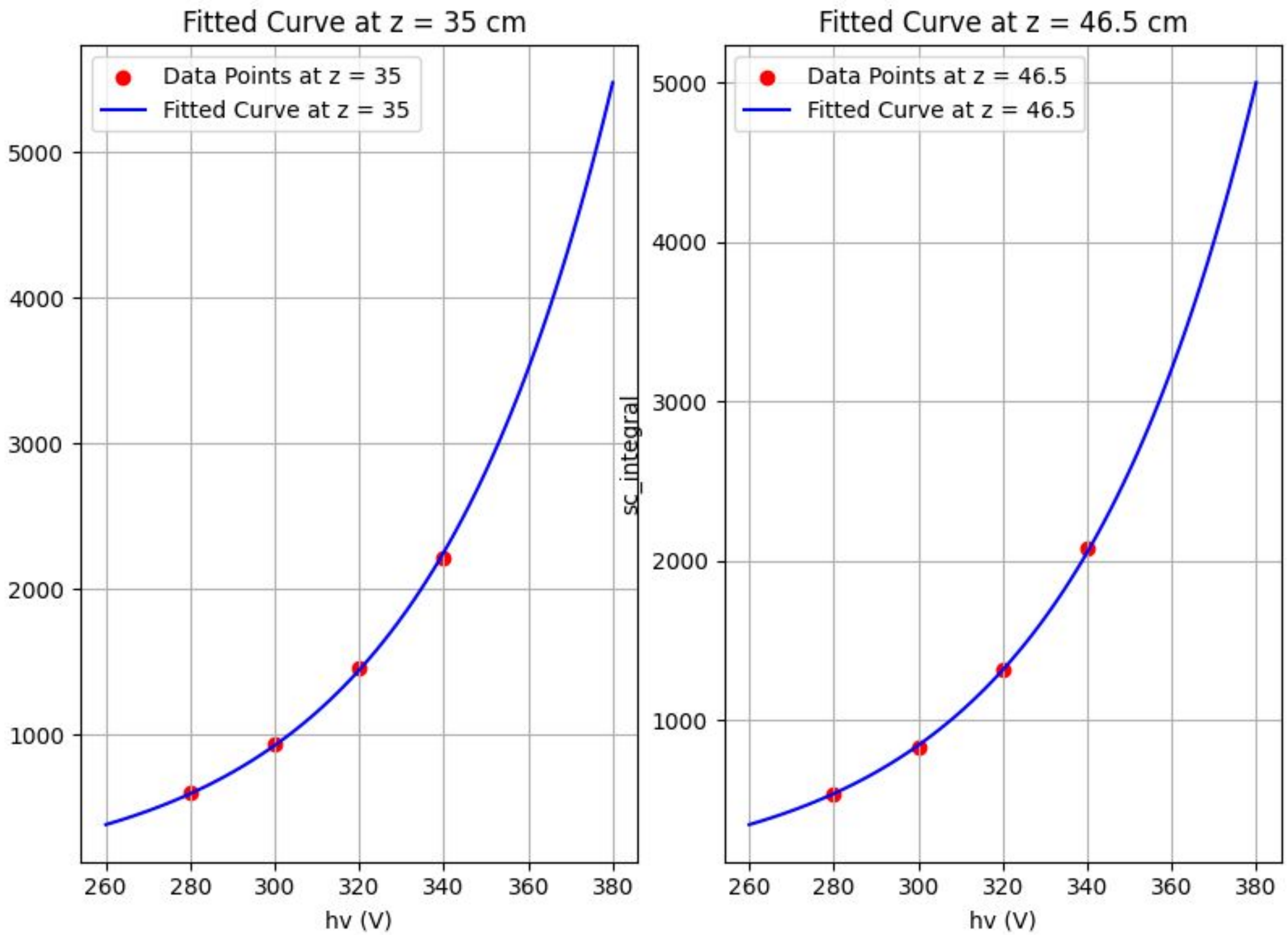
Where:

$$I_0 = \frac{E}{W} \cdot 0.07 \cdot 2 \cdot \Omega \cdot \mathrm{extr\_eff}^2 \cdot g_0^3 \cdot e^{2\alpha \cdot 440\,\mathrm{V}}$$

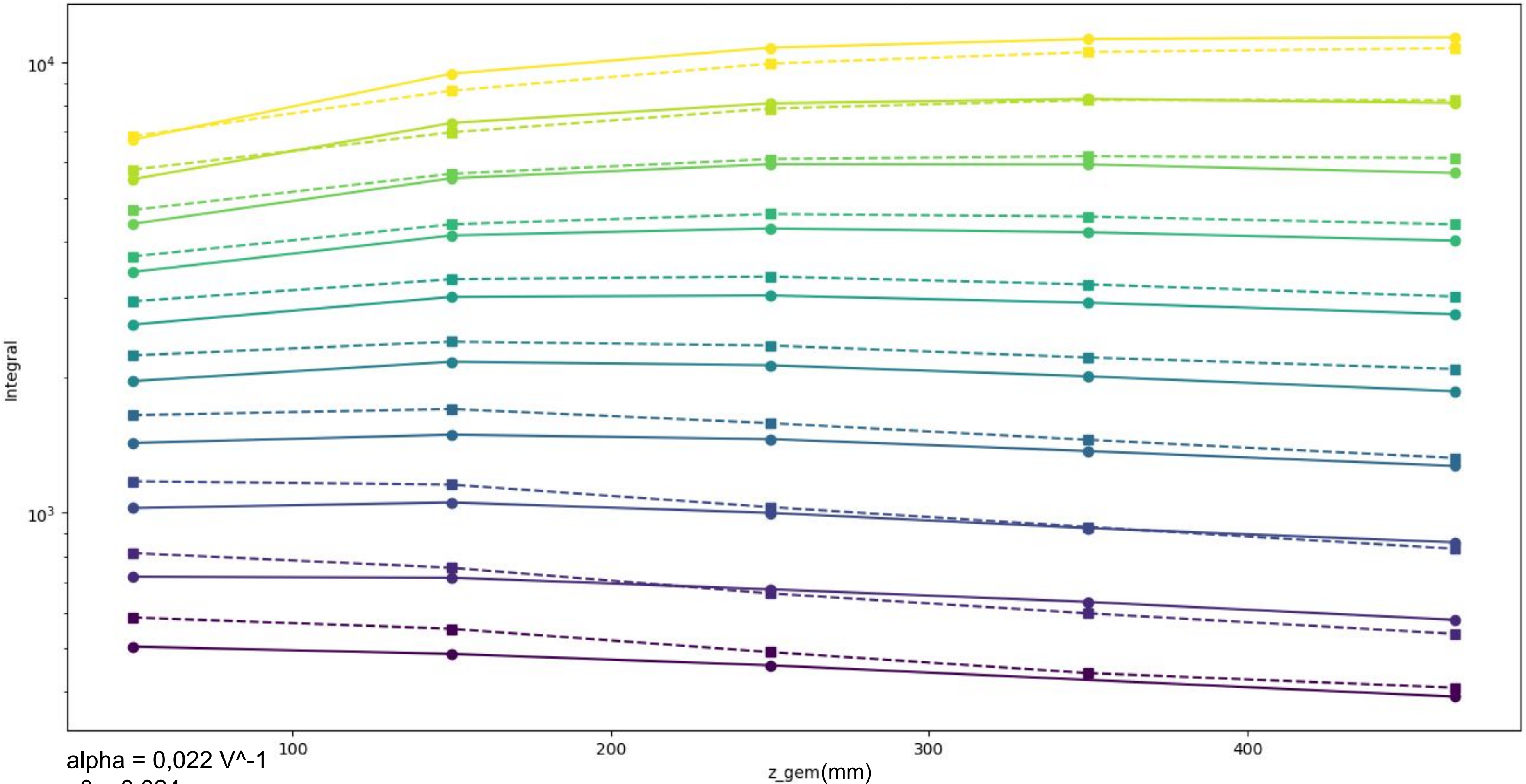
2D Fit

Considering the constant ratios between step 5 and step 4 at 280, 300, 320, 340 V we have 8 points to do a 2D fit with a function of HV and z :

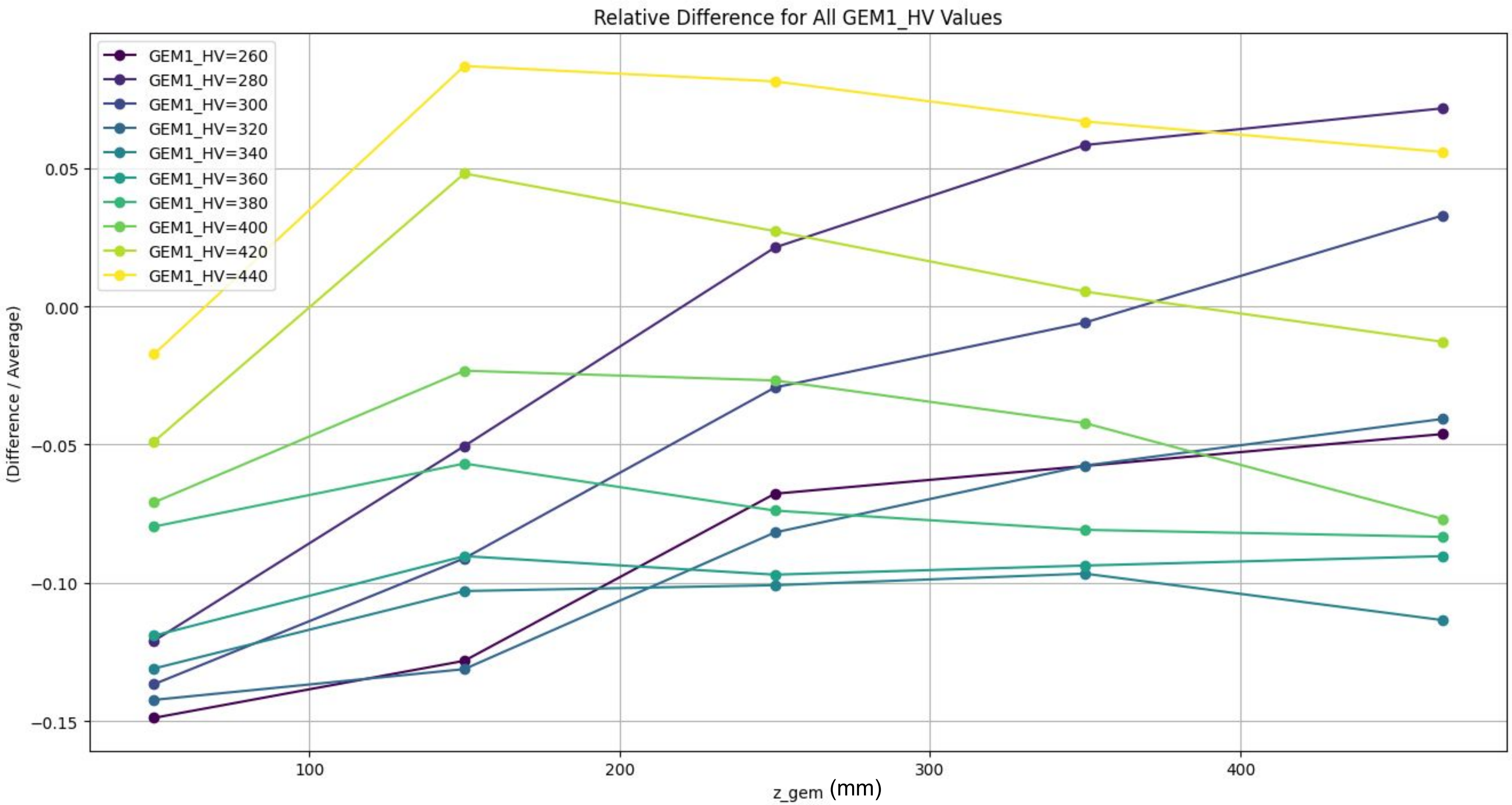
$$I = I_0 \cdot e^{\alpha \cdot V} \cdot e^{-\frac{z}{\lambda}}$$



Result of the 2D fit
alpha: 0.022 V^-1
lambda: 125 cm
I_0: 1.55
Chi2: 0.0001



alpha = 0,022 V^-1
g0 = 0.024
lambda = 125 cm
beta = 4e-06



Relative Difference for All GEM1_HV Values
GEM1_HV=260
GEM1_HV=280
GEM1_HV=300
GEM1_HV=320
GEM1_HV=340
GEM1_HV=360
GEM1_HV=380
GEM1_HV=400
GEM1_HV=420
GEM1_HV=440
0.05
0.00
−0.05
−0.10
−0.15
(Difference / Average)
100
200
300
400
z_gem (mm)

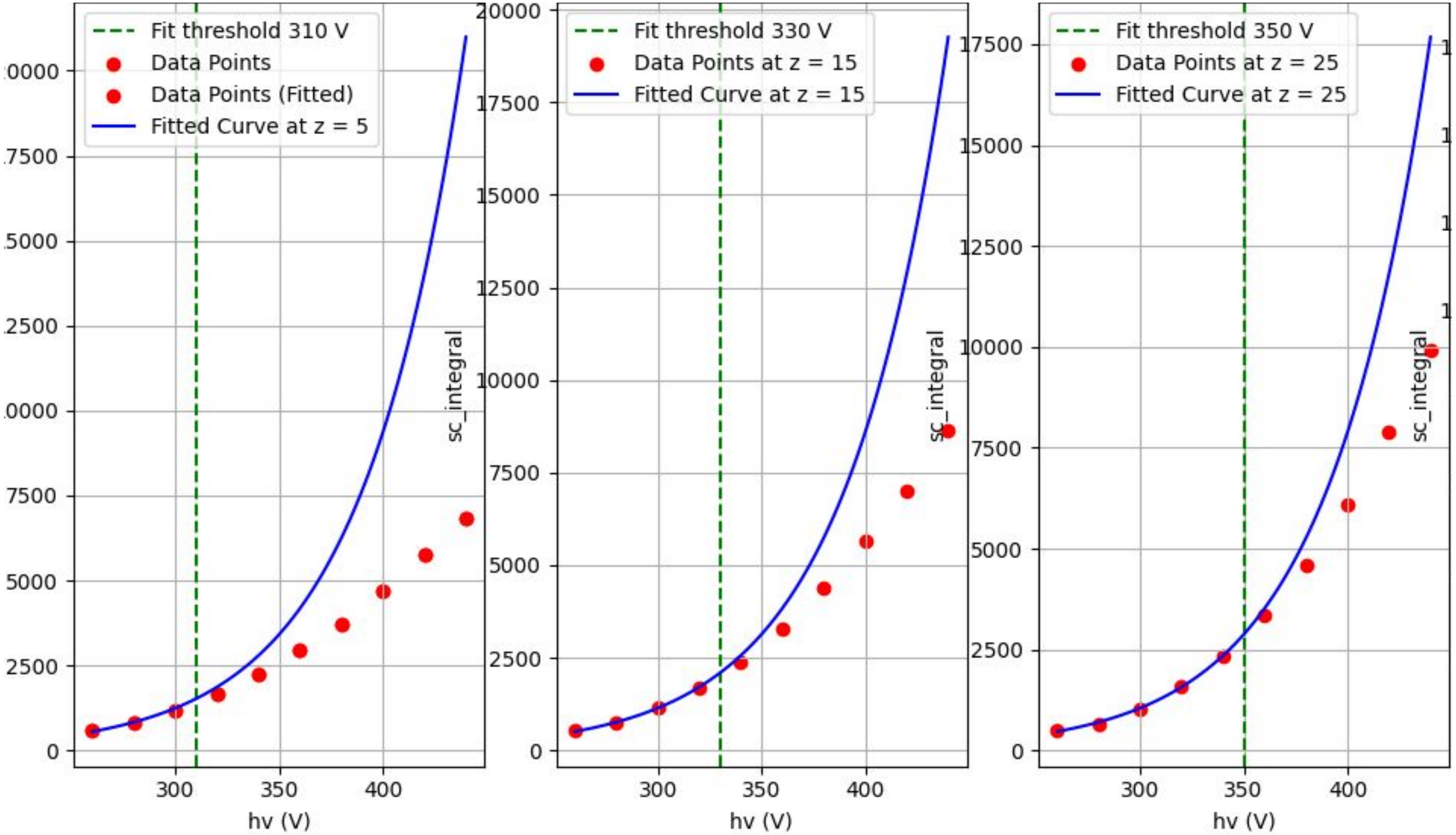
But does it change much if we use more points (at **low** HV and **high** z)?

We try with 25 data points:

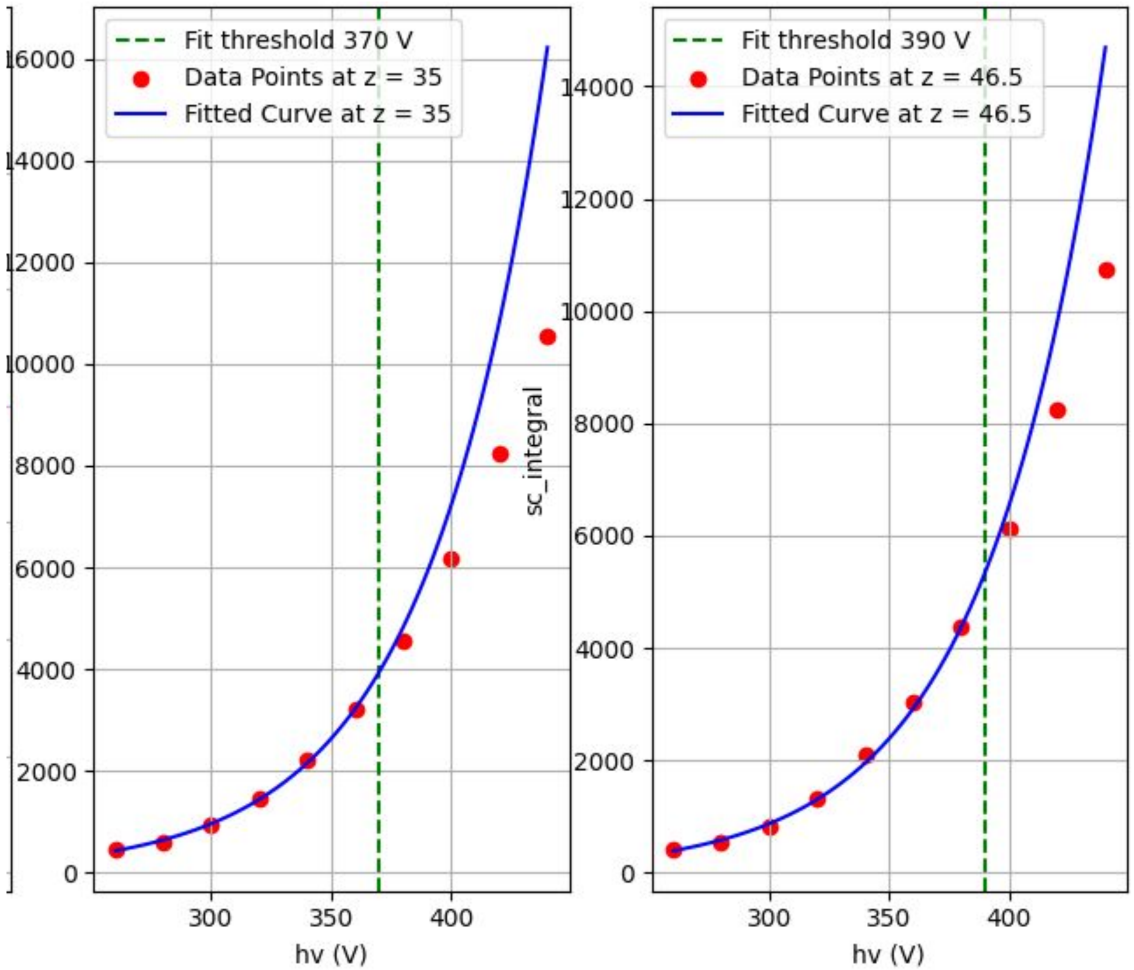
- 3 lowest voltage at 5 cm
- 4 lowest voltage at 15 cm
- 5 lowest voltage at 25 cm
- 6 lowest voltage at 35 cm
- 7 lowest voltage at 46.5 cm

2D fit results (step 1 to step 3)

(only points before threshold are fitted)



2D fit results (step 4 and step 5)



The fit is just one for all z

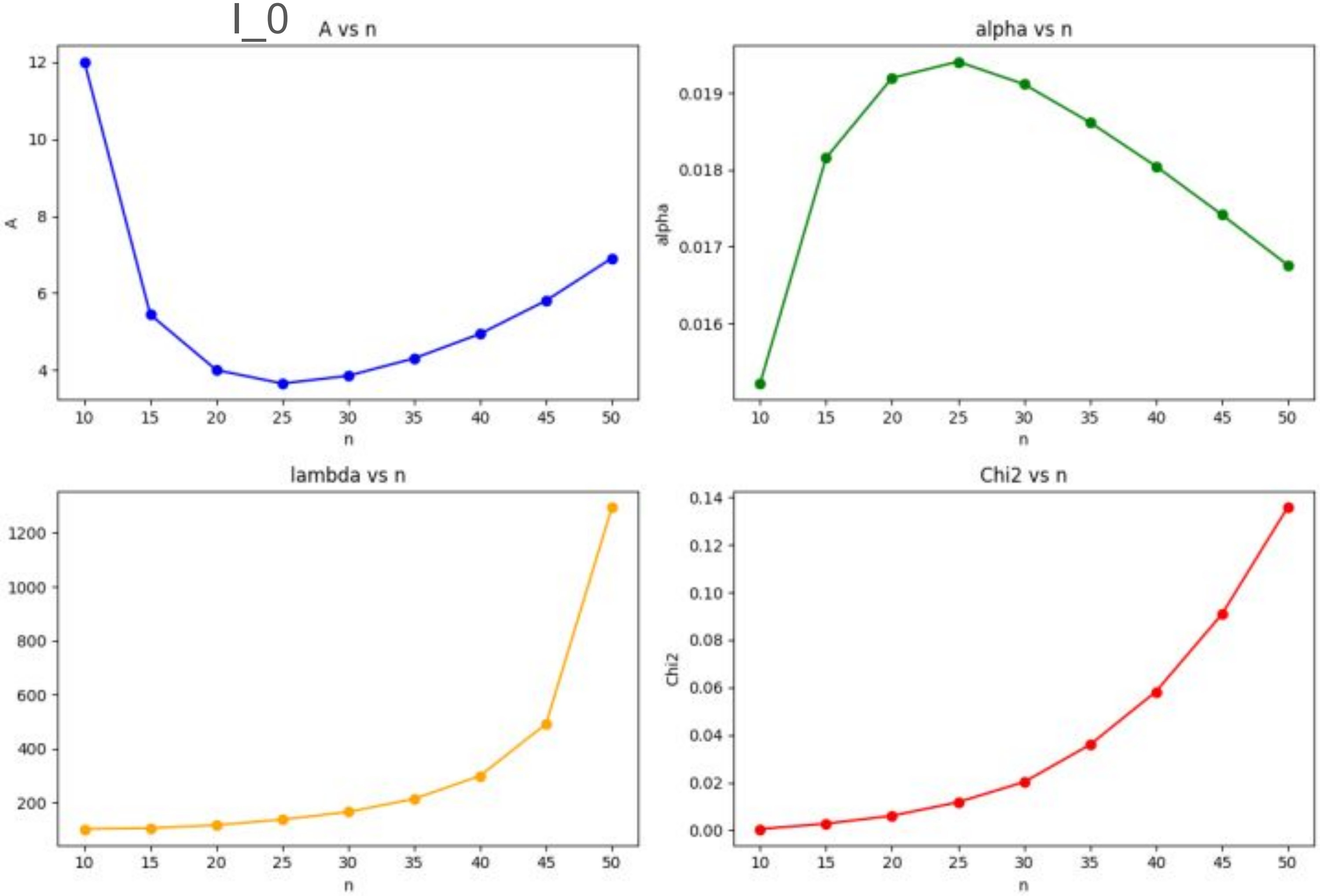
The points to the left of the threshold are not used for the fit.

Fit results:

lambda = 116 cm
alpha = 0.0201 V^-1
I_0 = 3.05

How much the choice of the points affects the results of the fit?

I_0

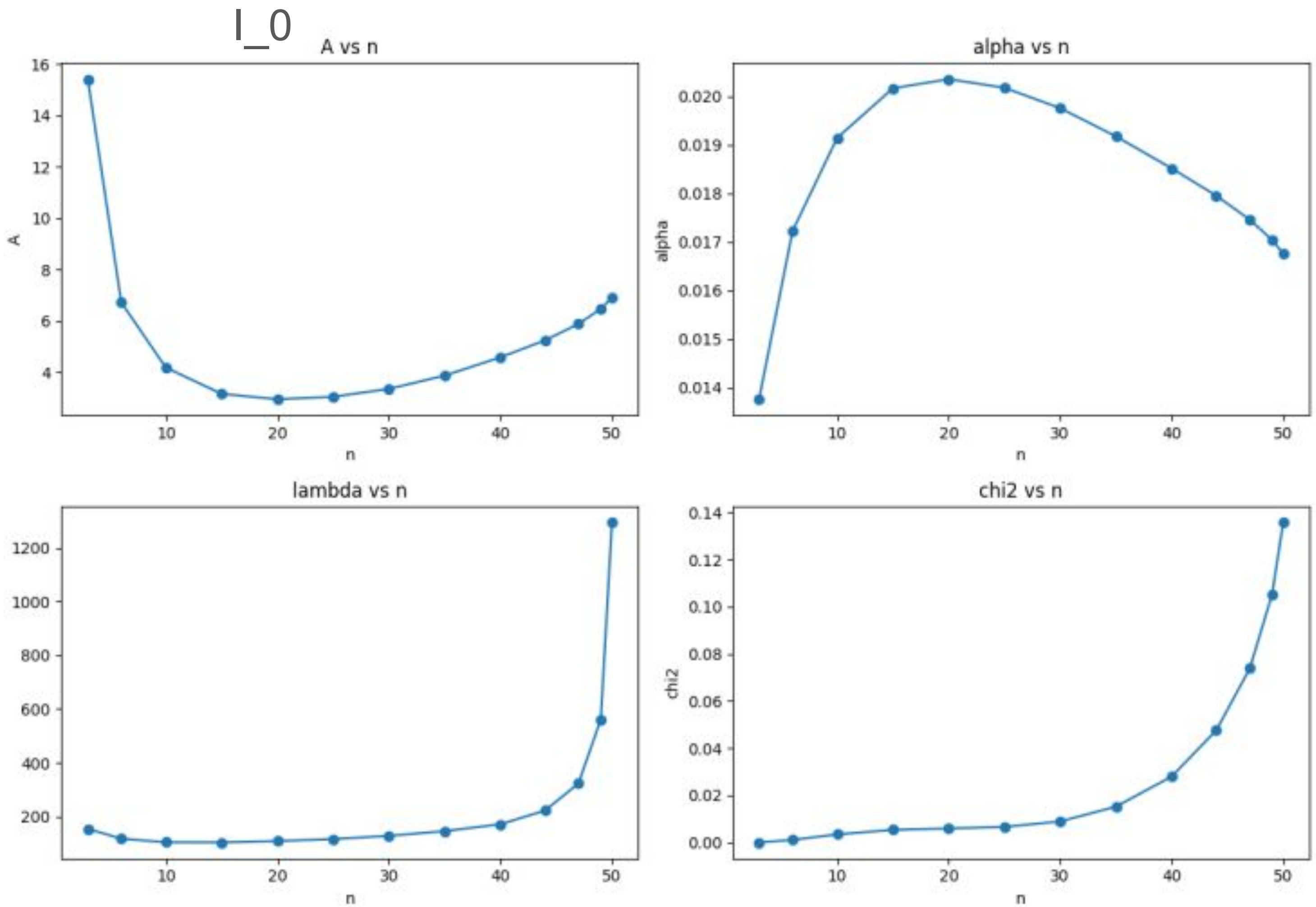


Selection criterion: starting with the 2 lowest HV at each z, then each time we increase the number of points we add one points to each z.

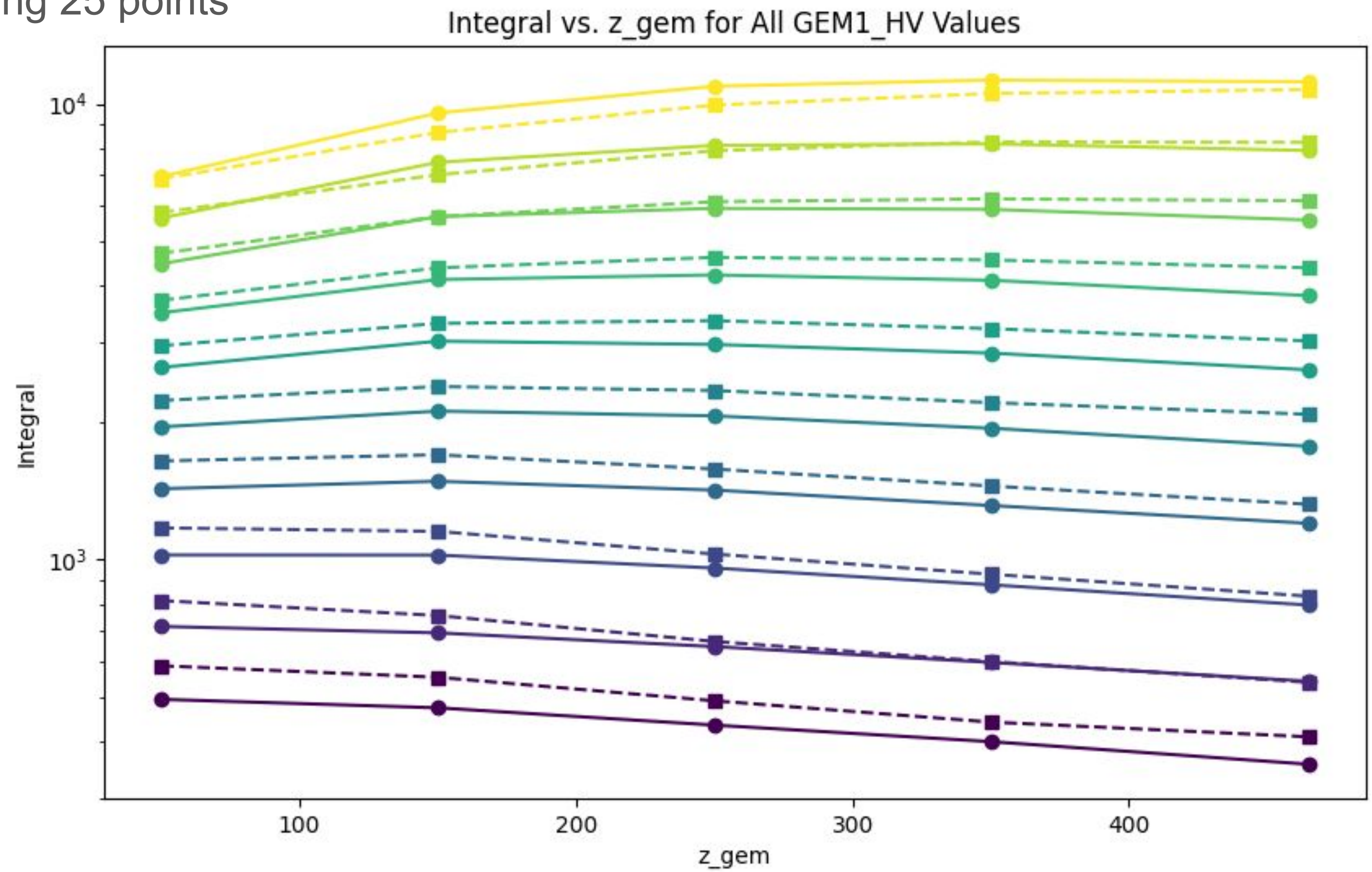
[s1, s2, s3, s4, s5]
[10, 10, 10, 10, 10],
[9, 9, 9, 9, 9],
[8, 8, 8, 8, 8]
[7, 7, 7, 7, 7]
[6, 6, 6, 6, 6]
…
…

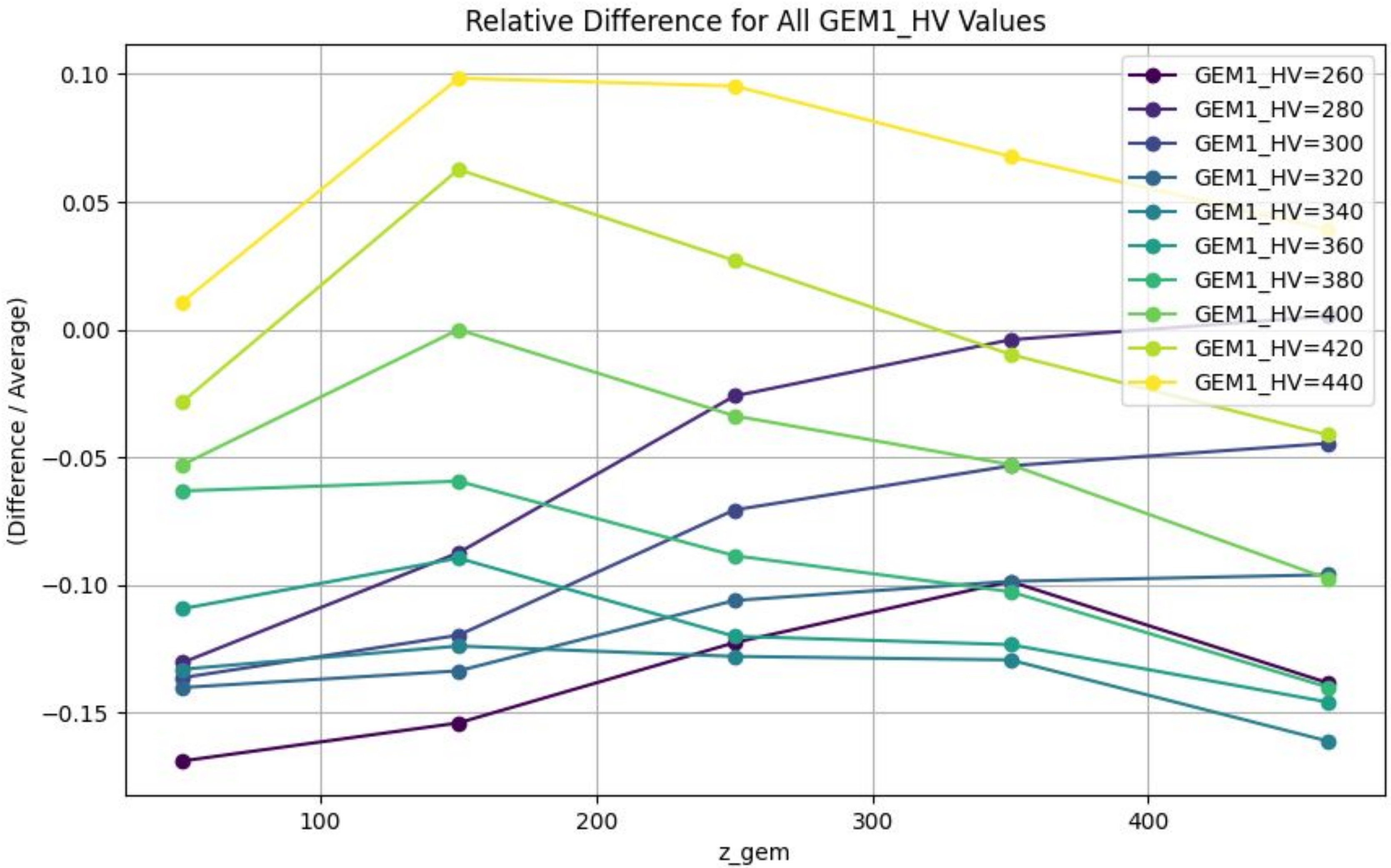
Alternative criterion: “oblique increasing”

[s1, s2, s3, s4, s5]
[10, 10, 10, 10, 10],
[9, 10, 10, 10, 10],
[8, 9, 10, 10, 10],
[7, 8, 9, 10, 10],
[6, 7, 8, 9, 10],
[5, 6, 7, 8, 9],
[4, 5, 6, 7, 8],
[3, 4, 5, 6, 7],
[2, 3, 4, 5, 6],
[1, 2, 3, 4, 5],
[0, 1, 2, 3, 4],
[0, 0, 1, 2, 3],
[0, 0, 0, 1, 2]



using 25 points




Relative Difference for All GEM1_HV Values
GEM1_HV=260
GEM1_HV=280
GEM1_HV=300
GEM1_HV=320
GEM1_HV=340
GEM1_HV=360
GEM1_HV=380
GEM1_HV=400
GEM1_HV=420
GEM1_HV=440
(Difference / Average)
0.10
0.05
0.00
−0.05
−0.10
−0.15
100
200
300
400
z_gem

Conclusions

We could better estimate **lambda**, **alpha** and **g0** to use in the digitization, with more data in the low saturation region:

- 280 - 340 V with 10 V steps
- 46.5- 30 cm with 5 cm steps

Then by comparison with data in the high saturation region, we can calibrate **beta.**

This procedure allows us to simulate saturation at different energies with 5-15% error. To further improve, we could fine-tune the parameters around the values.

Given the new fast digitization code (1 sec/img), it's now possible to do a fine tuning of the parameters found with the 2D fit, within 10 days (grid of 5x5x5x5 parameters, 5 data points and 250 images per point)