Study of space charge effects in LGAD sensors

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Analysis of space charge effects

1) Investigate space charge effects in LGAD sensors:

- **Is a gain saturation observed with large amounts of charge?**

→ study of the behavior of gain in LGAD with variable amount of released charge provided by a laser

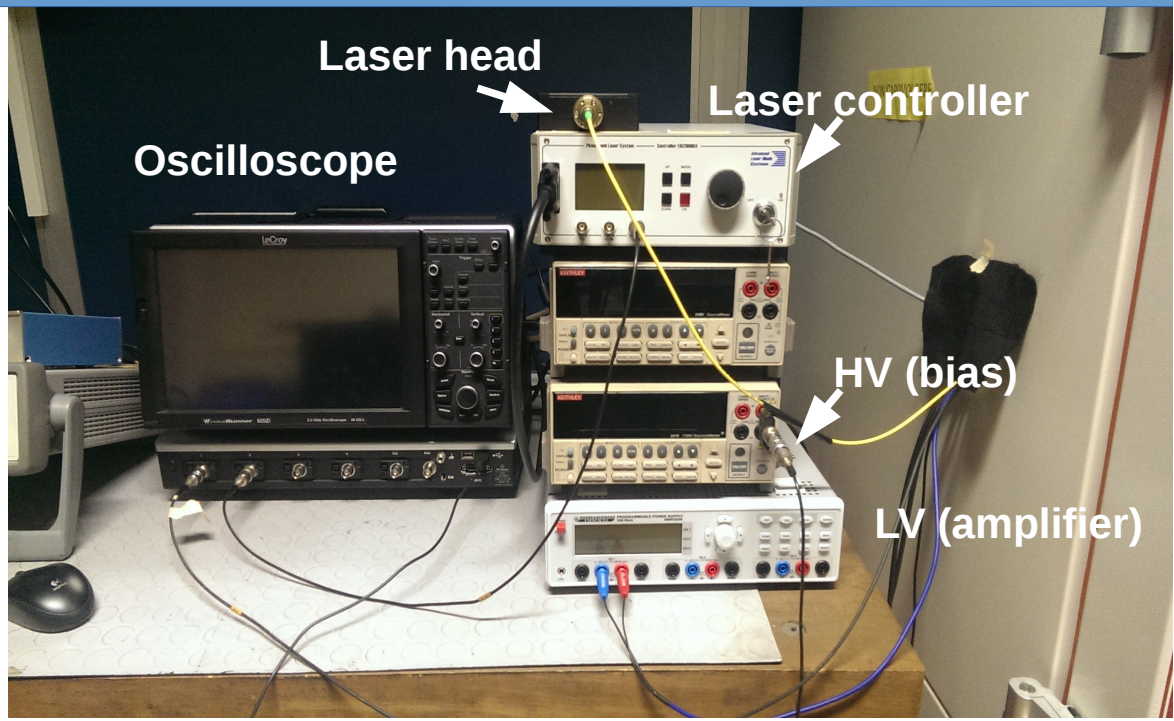
2) Analyze gain linearity

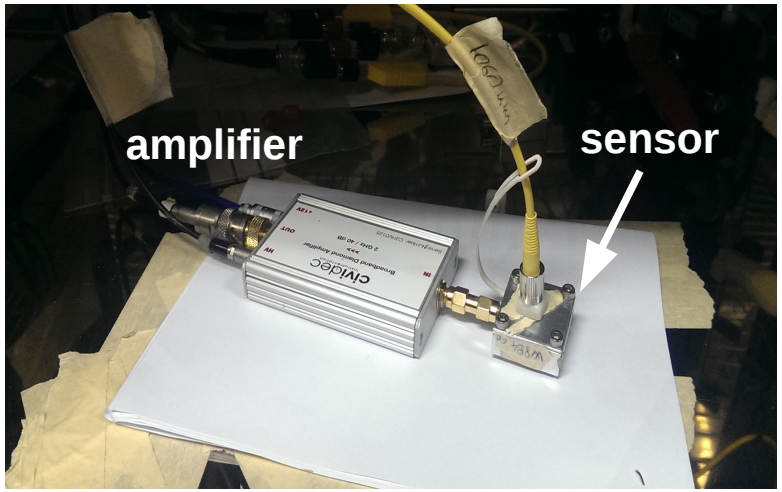
- **Do we observe non gaussian effects in multiplication?**

Experimental setup

Experimental setup:

- Picosecond laser
- Laser heads 1060, 405 nm
- Voltage source Keithley 2410
- Power supply Rohde & Schwarz HMP2030



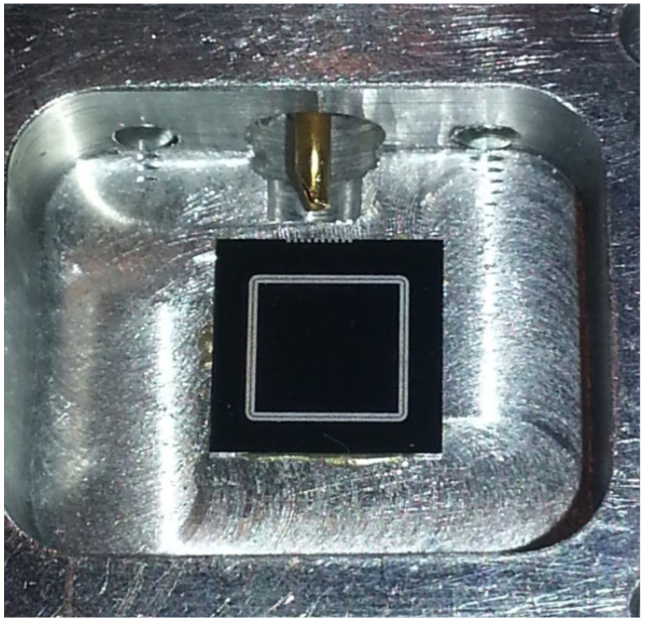


- Broadband amplifier Cividec, 40 dB, 2 GHz BW
- Oscilloscope LeCroy Waverunner 2.5 Ghz BW
- Sensor gain=1, CNM W9B6
- Sensor gain=10, CNM LGAD W8B4

Sensors under test

Reference sensor, no gain
CNM W9B6, run 6474
Area 5.2 mm x 5.2 mm
Thickness 300 um
Vbreak > 500 V
Vdep ~40 V
No metalization

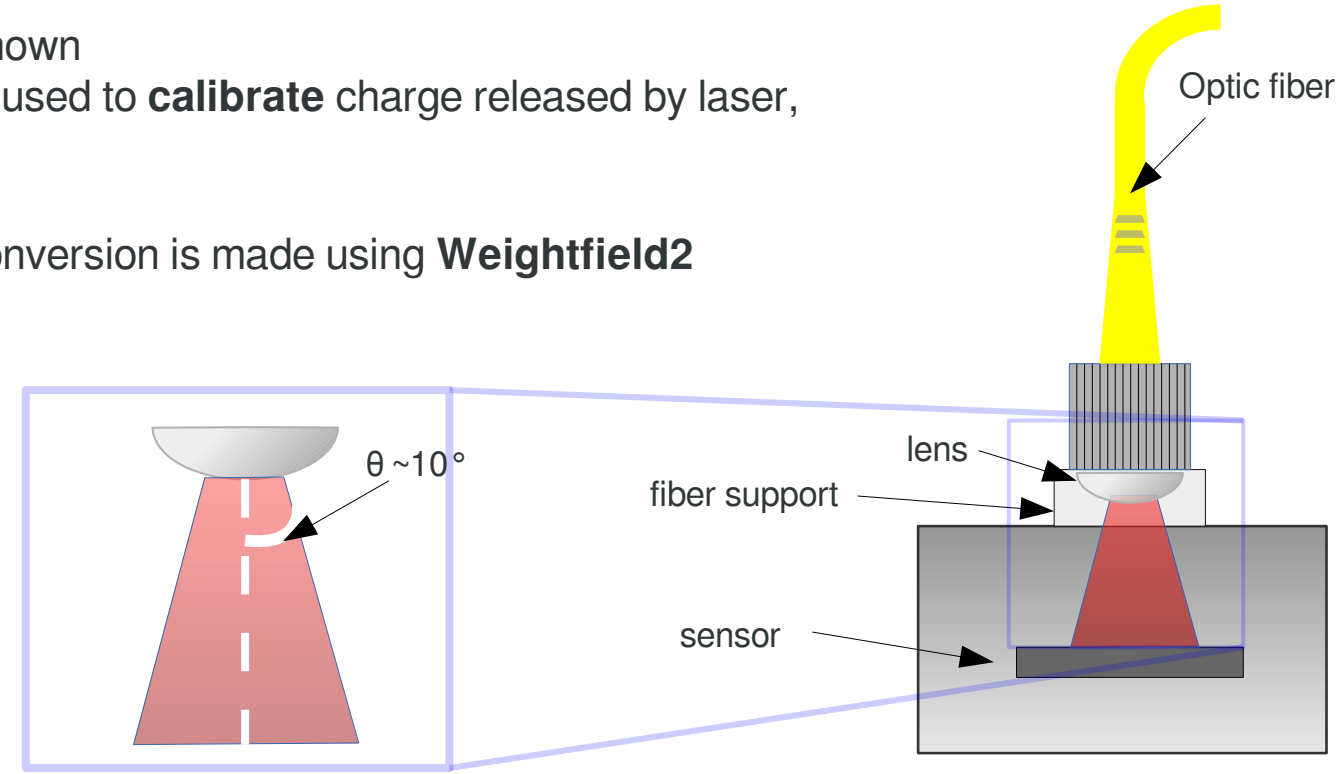
Analyzed sensor, gain=10
CNM W8B4, run 6474
Area 5.2 mm x 5.2 mm
Thickness 300 um
Vbreak > 1000 V
Vdep ~80 V
No metalization



Procedure

- MIP and alpha particle are emulated by **laser beam** hitting the detector (trigger freq 5 kHz)
  λ= 1064 nm to emulate MIP
  λ= 405 nm to emulate α
- Signal area is measured on the oscilloscope (100 signals average), for a given value of Vbias, **varying the amount of charge released** by laser
  → Laser attenuation has been gradually reduced, from 85% to 0% (5% each step)
- Laser attenuation is **not linear**
- Actual charge density not known
  → **Sensor without gain** is used to **calibrate** charge released by laser, measuring area at 100 V
- Area (pVs) to charge (fC) conversion is made using **Weightfield2**

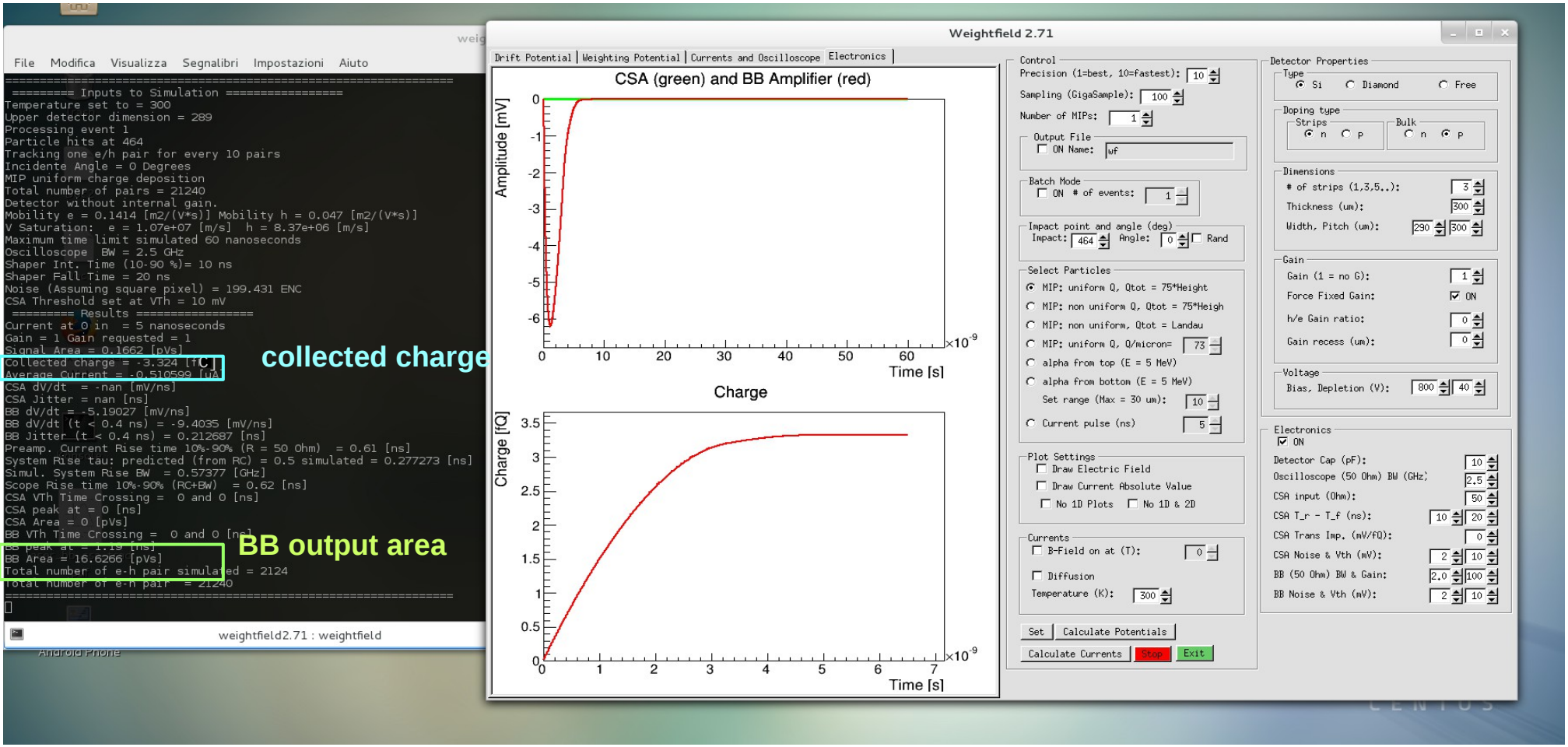
Light cone from optic fiber:
Ø~ 5 um at lens



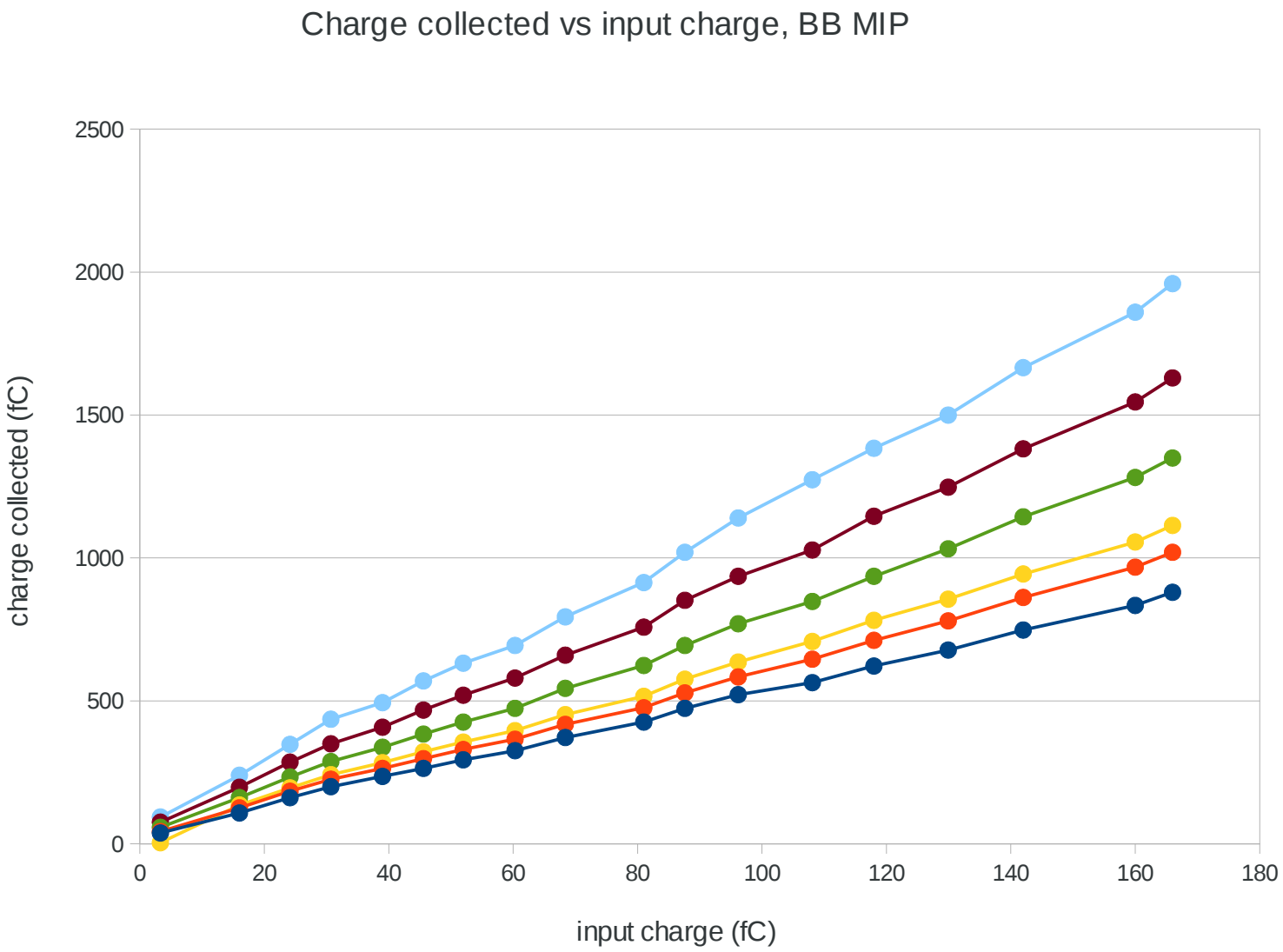
Area → charge conversion

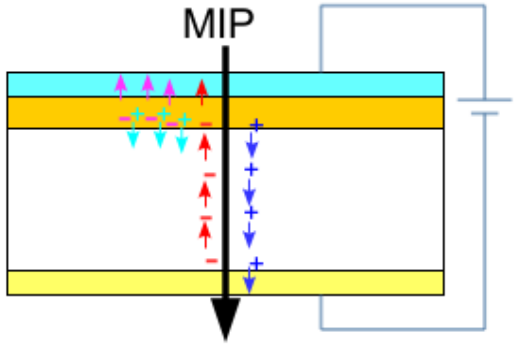
Weightfield 2 to evaluate the amount of charge released:

- Simulation of a sensor with same geometry of W9B6 + broadband amplifier (BW 2 GHz, gain=100)

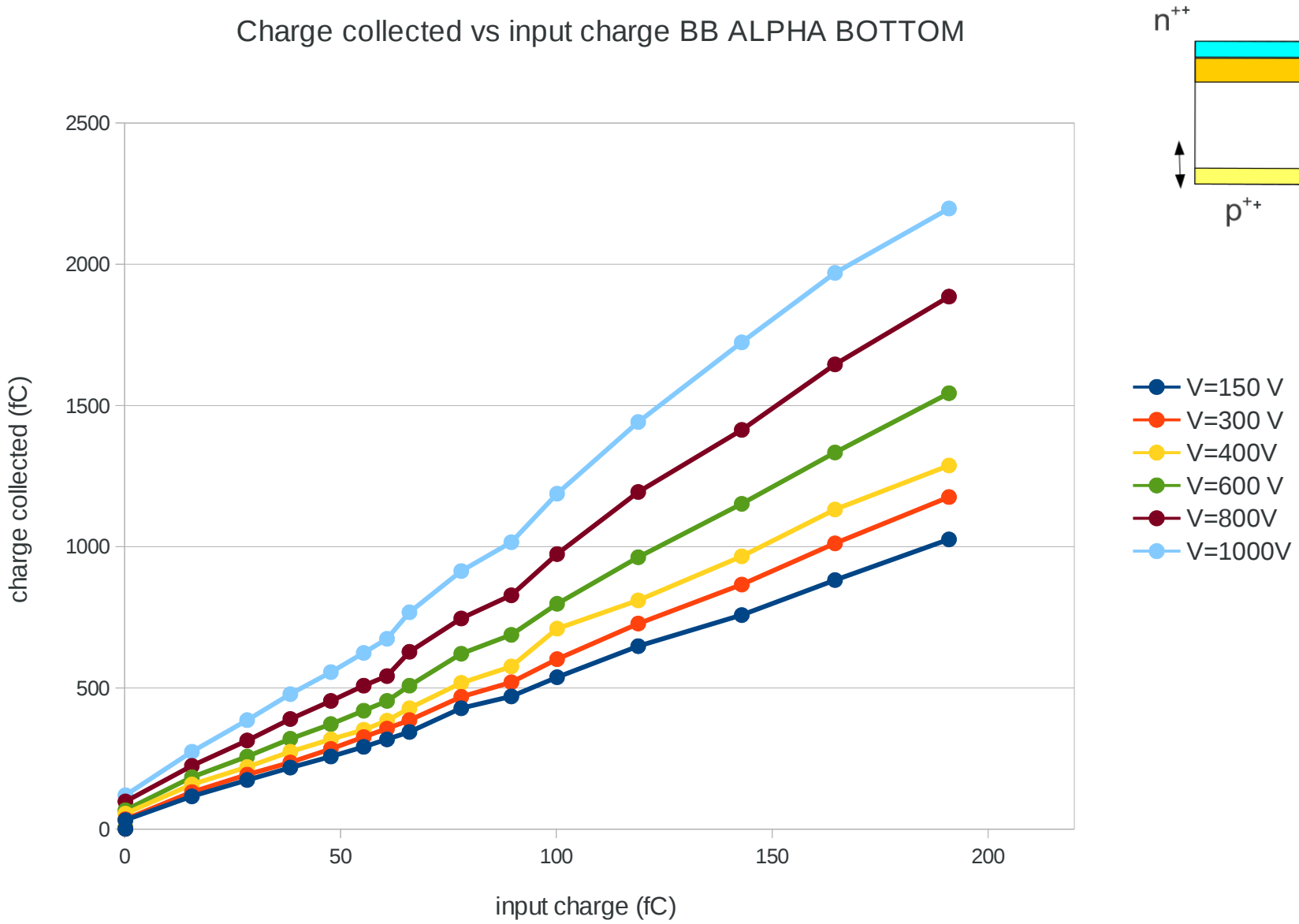


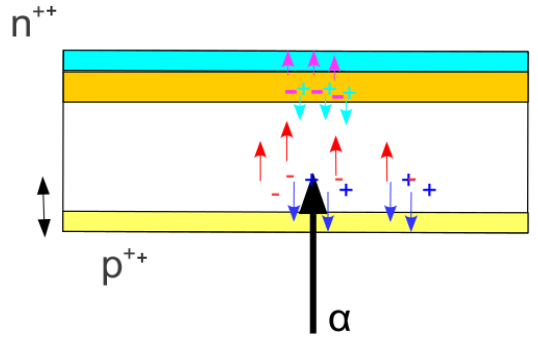
Results – 1060 nm laser (MIP)



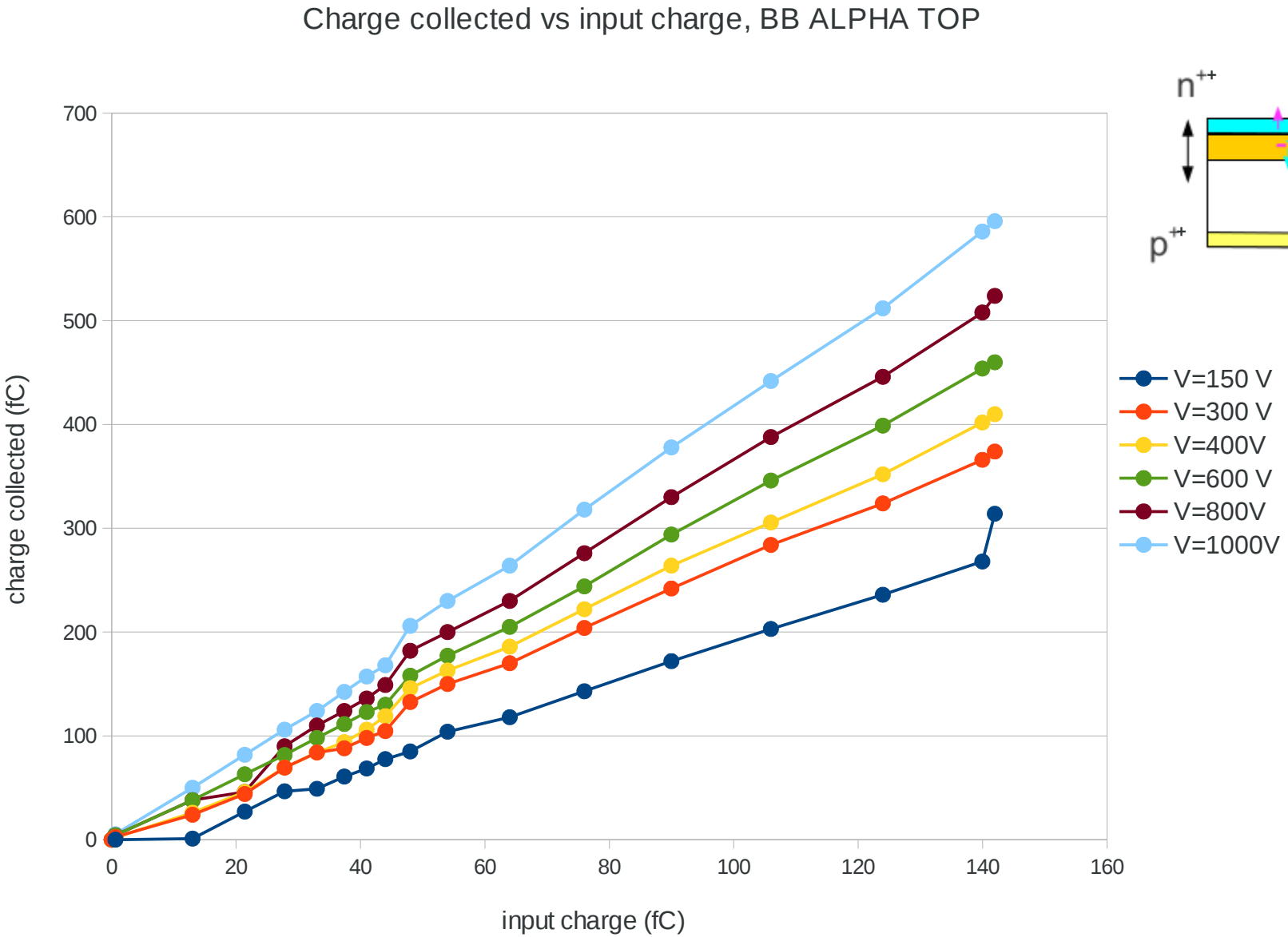


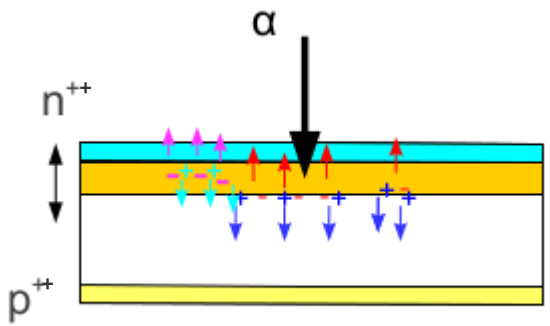
Results – 405 nm laser (alpha from bottom)





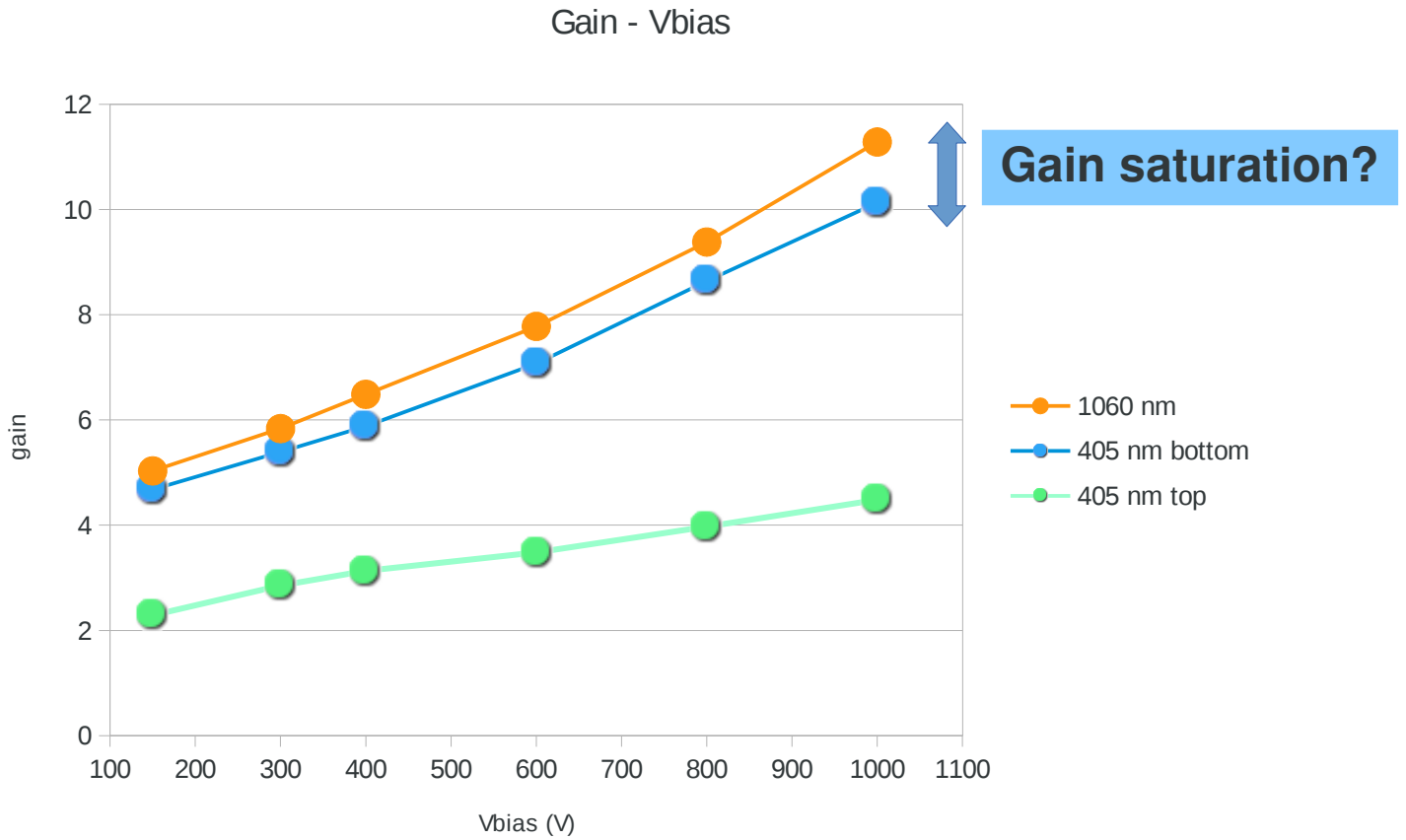
Results – 405 nm laser (alpha from top)





Behavior of gain with bias voltage

Expected LGAD gain=10



- 405 nm photons stop in few um under the surface and do generate pairs deeper than gain layer

  → charge deposition just above the p+ implant

  → only partial charge multiplication

Study of gain linearity

Is the gain mechanism gaussian?

Search for “non gaussian” tails in the amplitude distribution

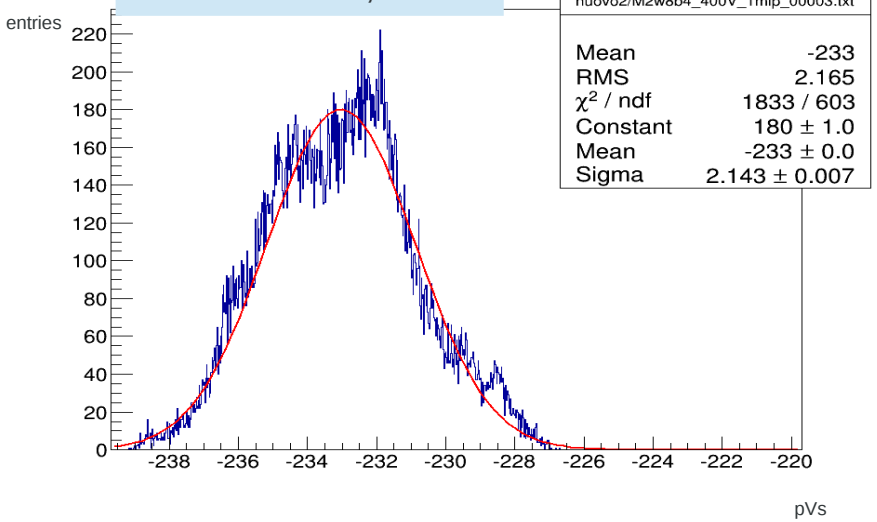
→ analysis of signal amplitude distribution with respect to:

- Gain amount: variable Vbias → gain increases
- Released charge: variable laser intensity

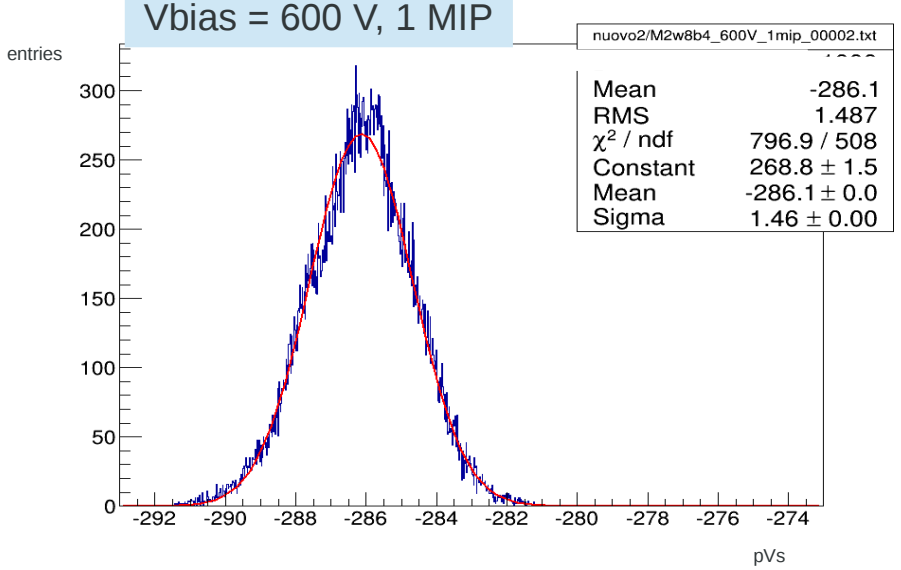
Behavior of signal area for gain variations - fixed charge

Higher gain is still gaussian

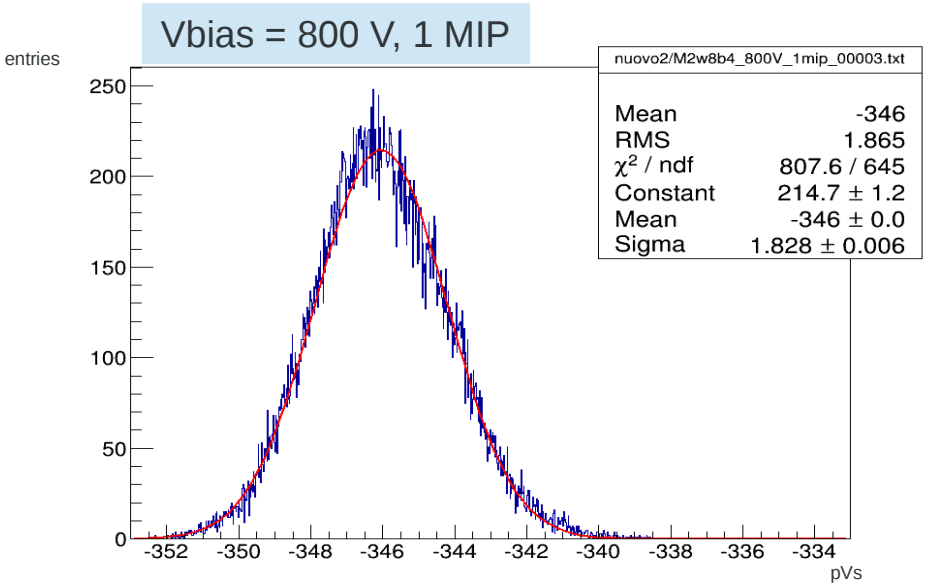
Vbias = 400 V, 1 MIP



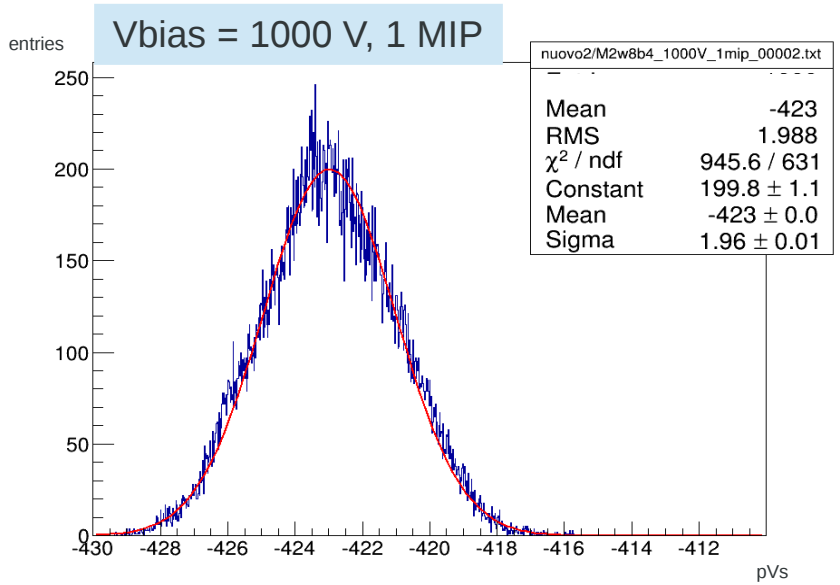
Vbias = 600 V, 1 MIP



Vbias = 800 V, 1 MIP



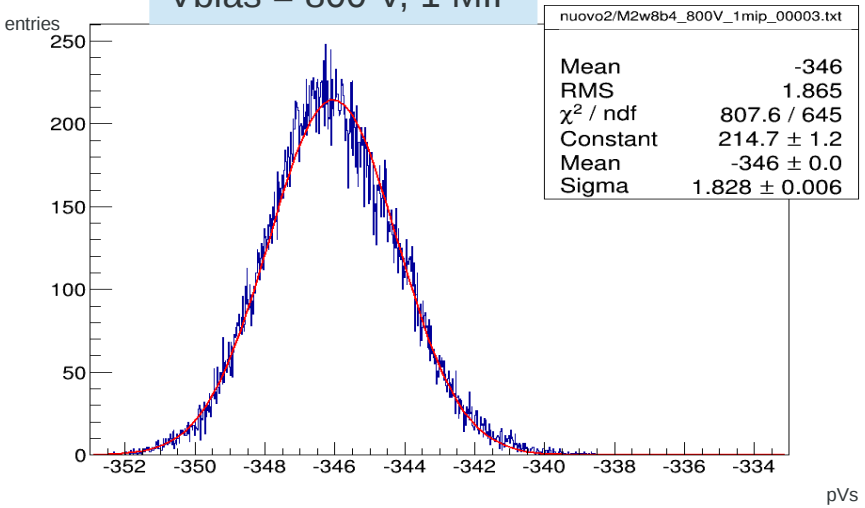
Vbias = 1000 V, 1 MIP



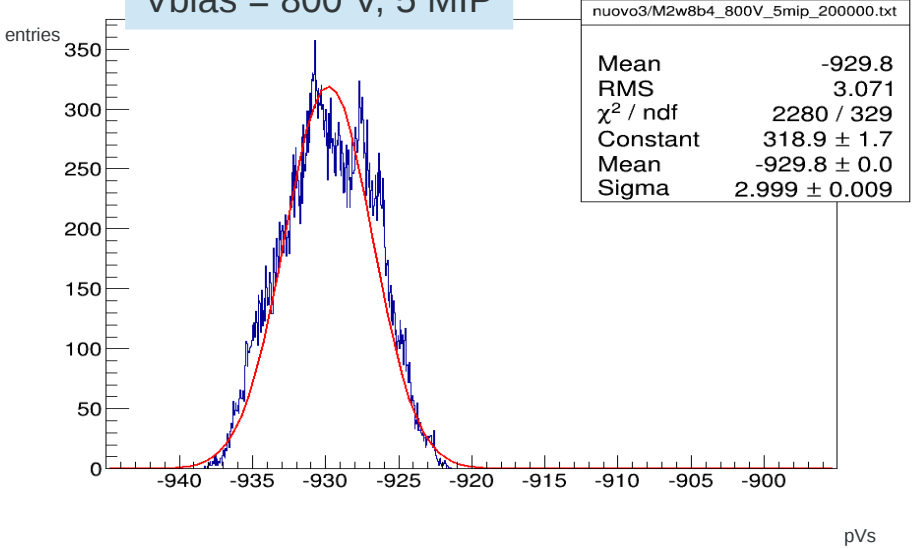
Behavior of signal area for charge variations - fixed gain

Gain mechanism remains gaussian even at 20 MIP

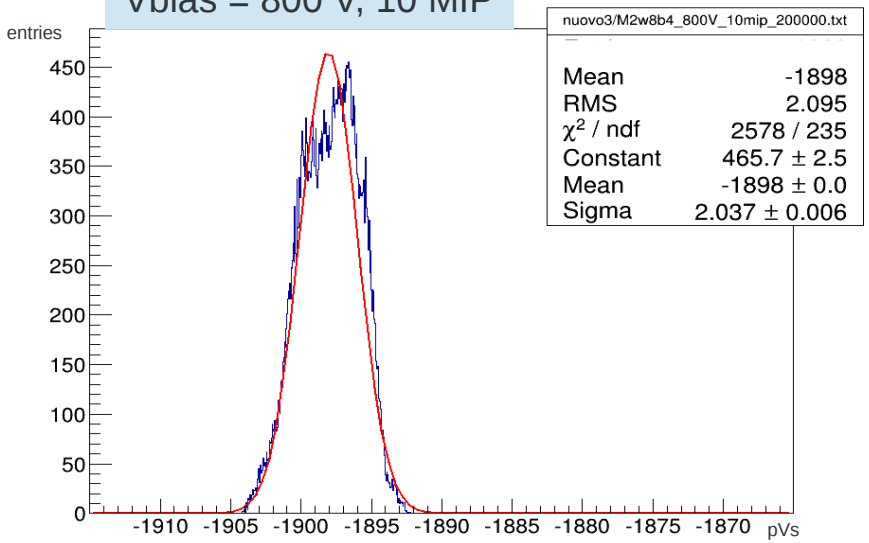
Vbias = 800 V, 1 MIP



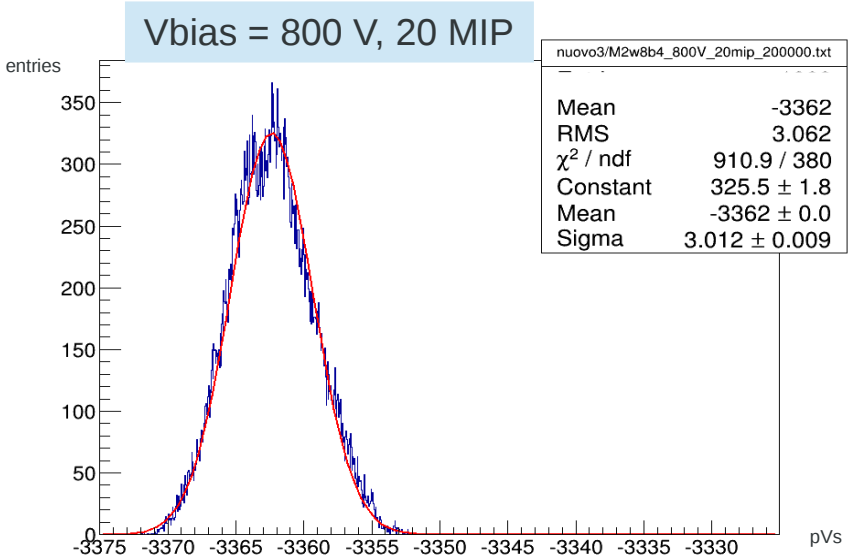
Vbias = 800 V, 5 MIP



Vbias = 800 V, 10 MIP



Vbias = 800 V, 20 MIP



Sigma/mean ratio vs Vbias and input charge

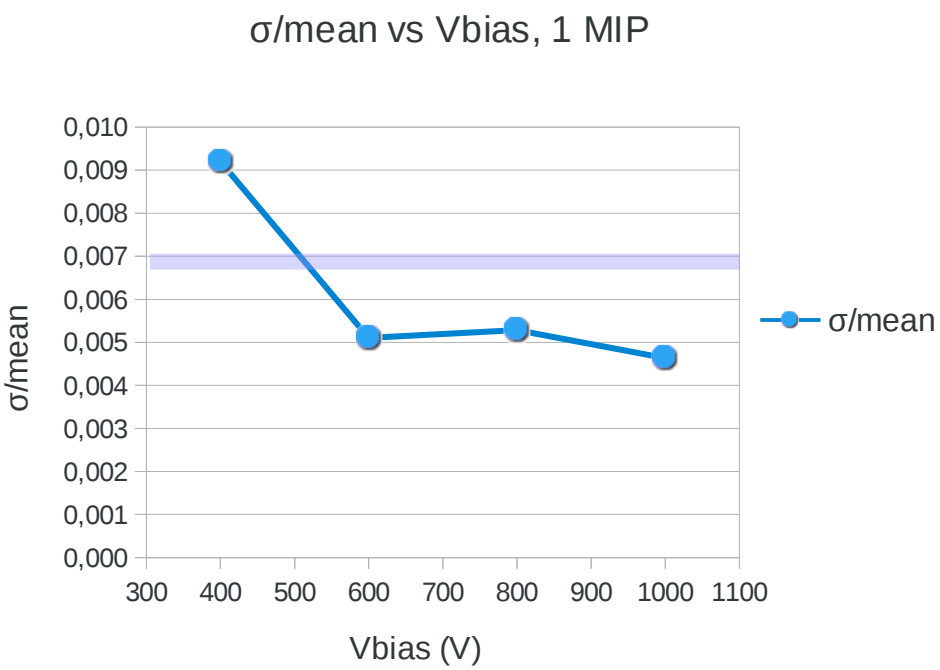
Behavior of sigma/mean ratio

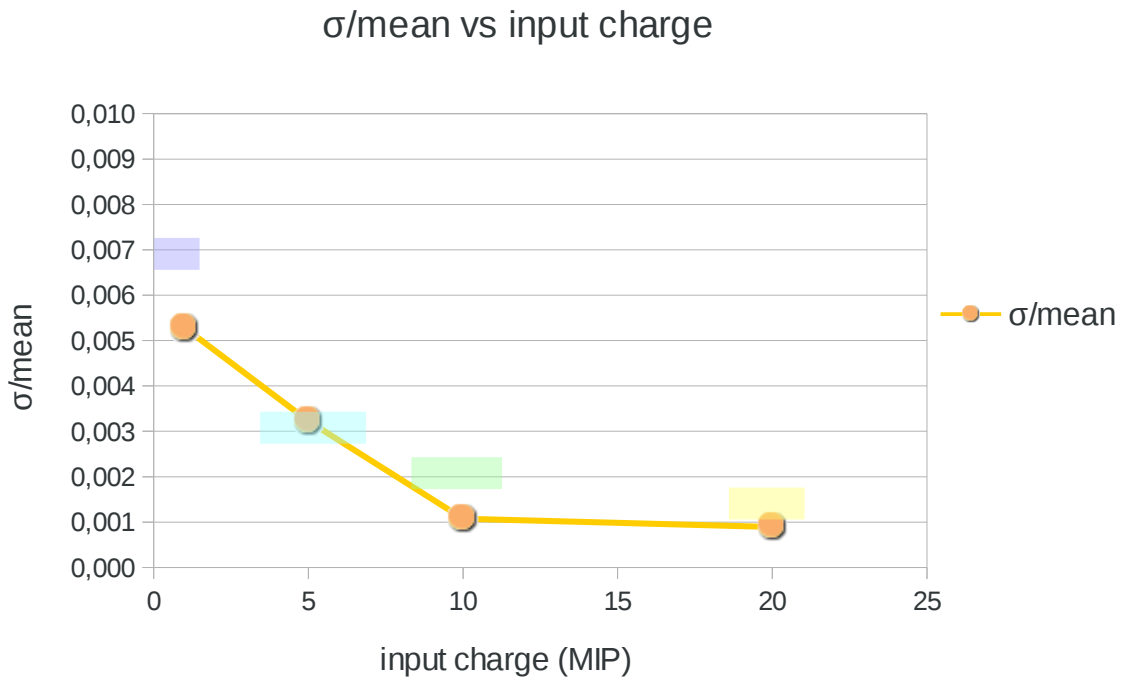
$$\sigma^2 = \sigma_{EL}^{\ 2} + \sigma_{\gamma}^{\ 2} + \sigma_{MULT}^{\ 2} + \sigma_{LASER}^{\ 2} + \ldots$$

where:

- σ_{EL} = electronics noise $\rightarrow$ constant
- σ_{γ} = photons statistics $\rightarrow \sqrt{(\#\ photons)}$
- σ_{MULT} = multiplication noise $\rightarrow$ increases with multiplication
- σ_{LASER} = laser noise $\rightarrow$ constant

Sigma/mean ratio vs Vbias and input charge





σ_y = photons statistics → √(# photons)

1 MIP = 21000 photons → σ/mean ~ 0.7 %
5 MIP = 105000 photons → σ/mean ~ 0.3 %
10 MIP = 210000 photons → σ/mean ~ 0.2 %
20 MIP = 420000 photons → σ/mean ~ 0.15 %

- **photons statistics is the major effect in the amplitude distribution spread**
- **multiplication noise does not significantly affect amplitude distribution**

Conclusions

1) Analysis of space charge effects:

we measured a difference in gain value for MIP and alpha bottom
this effect may be due to gain saturation with large charge densities.
Needs further studies

2) Study of gain linearity:

- gain does not show non gaussian tails, for both higher gain and released charge values
- the spread of the amplitude distribution is mainly due to photons statistics