NEWS-G

New Experiments With Spheres-Gas

Detector Response Modelling Of NEWS-G Dark Matter Search Experiment

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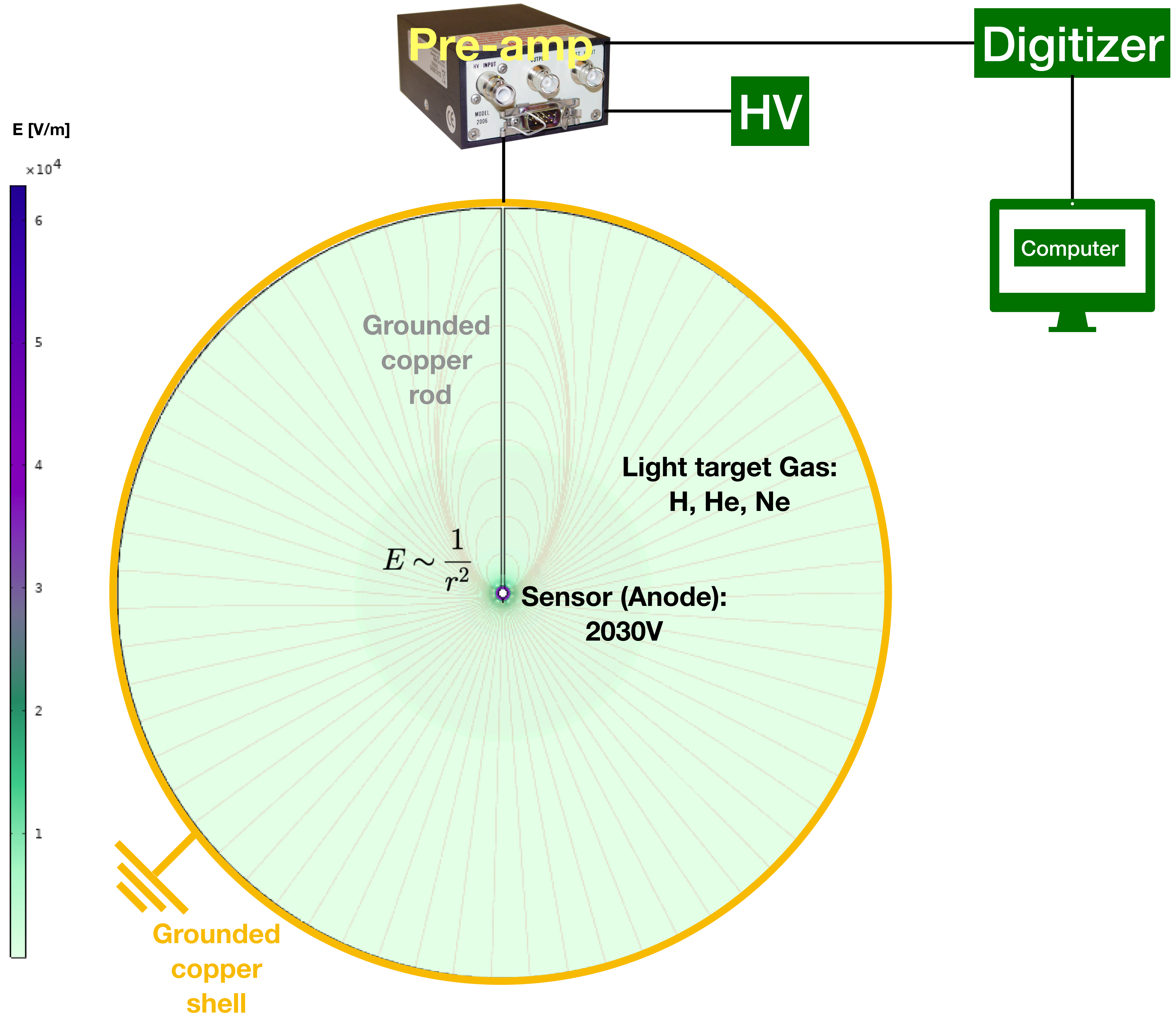
2021 CAP Virtual congress
June 10th 2021

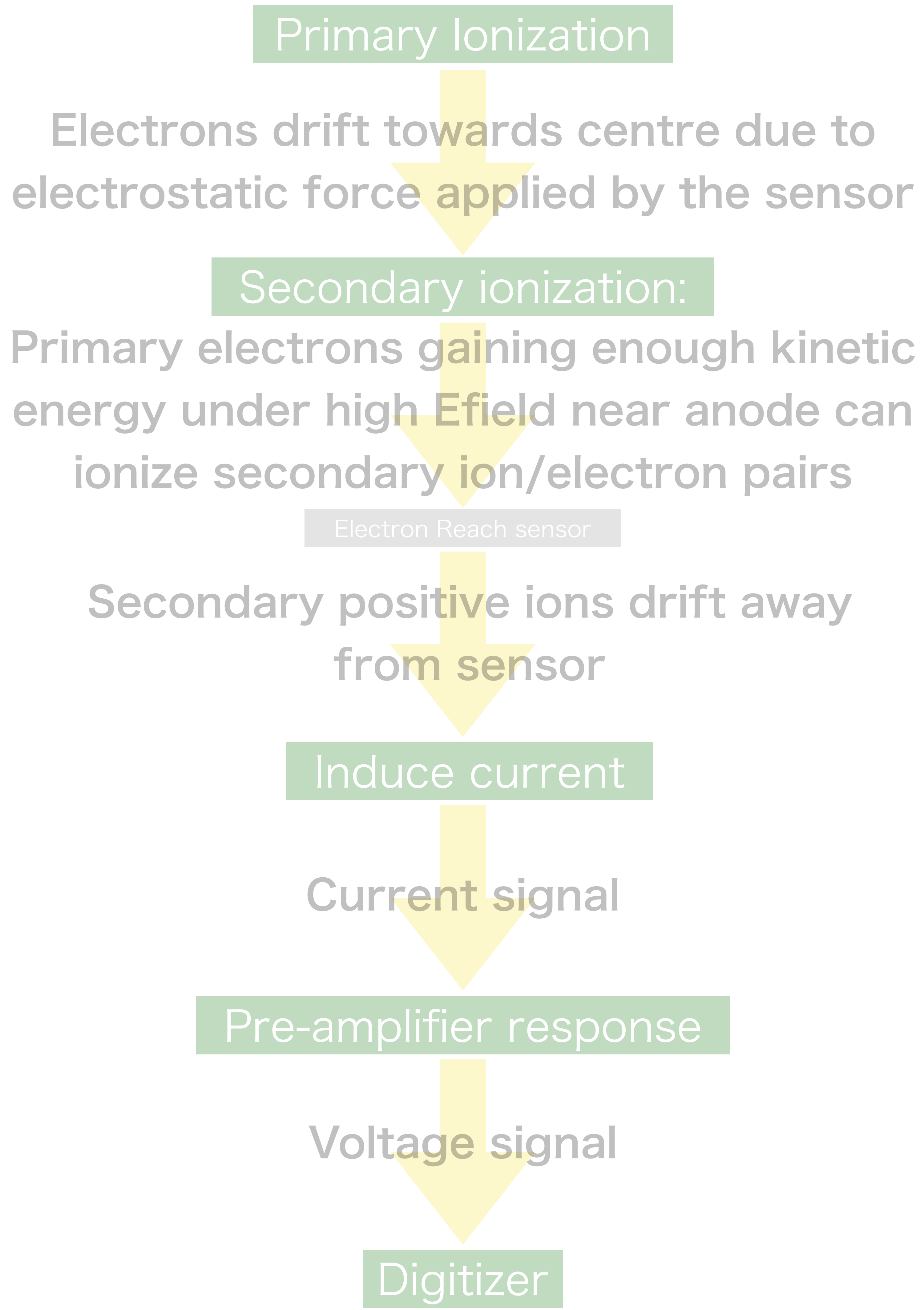
UNIVERSITY OF ALBERTA

Canadian Association of Physicists
Association canadienne des physiciens et physiciennes

Arthur B. McDonald
Canadian Astroparticle Physics Research Institute

- NEWS-G: a collaboration developing spherical proportional counters (SPC) for different particle physics studies, including search for low-mass dark matter





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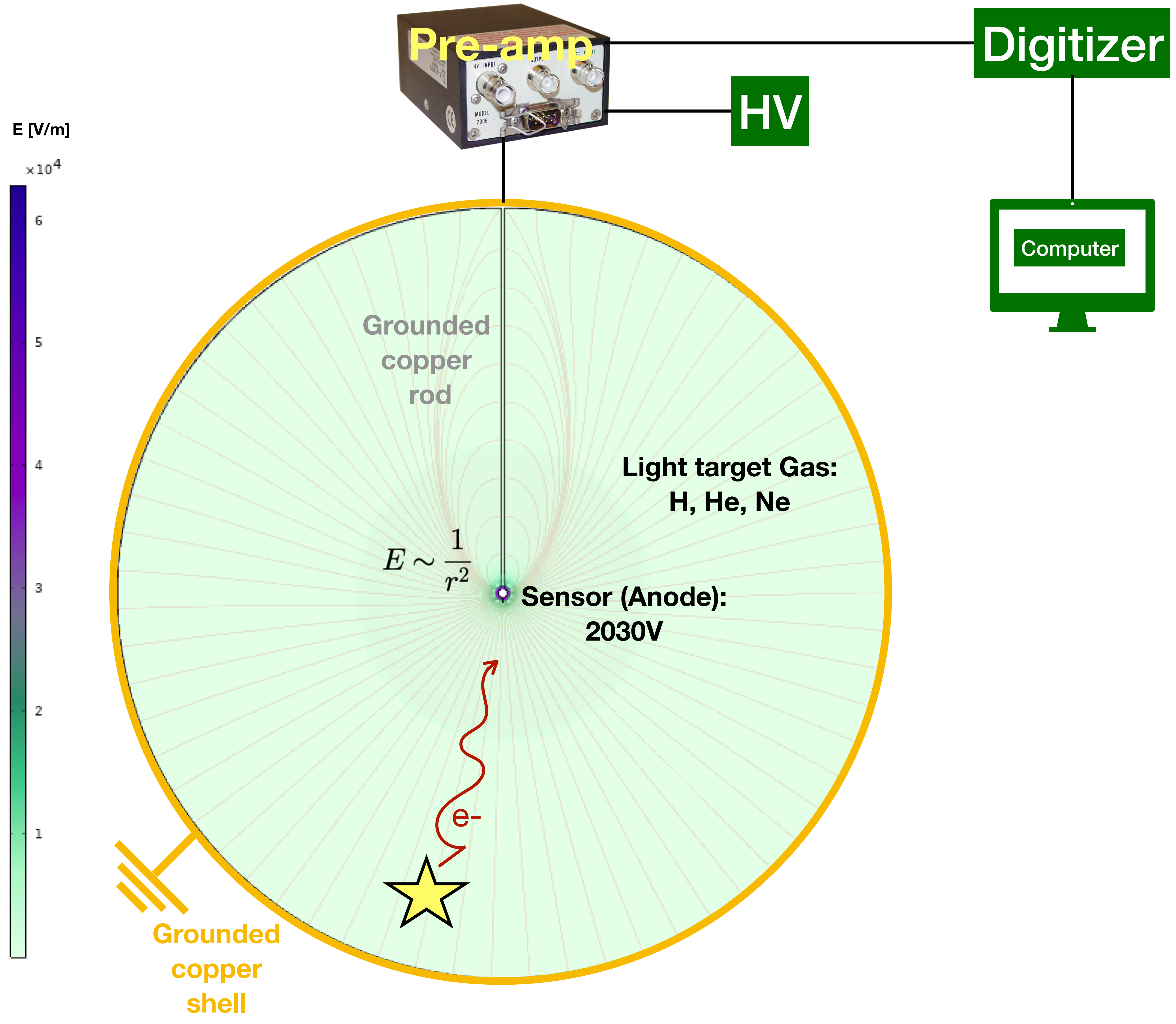

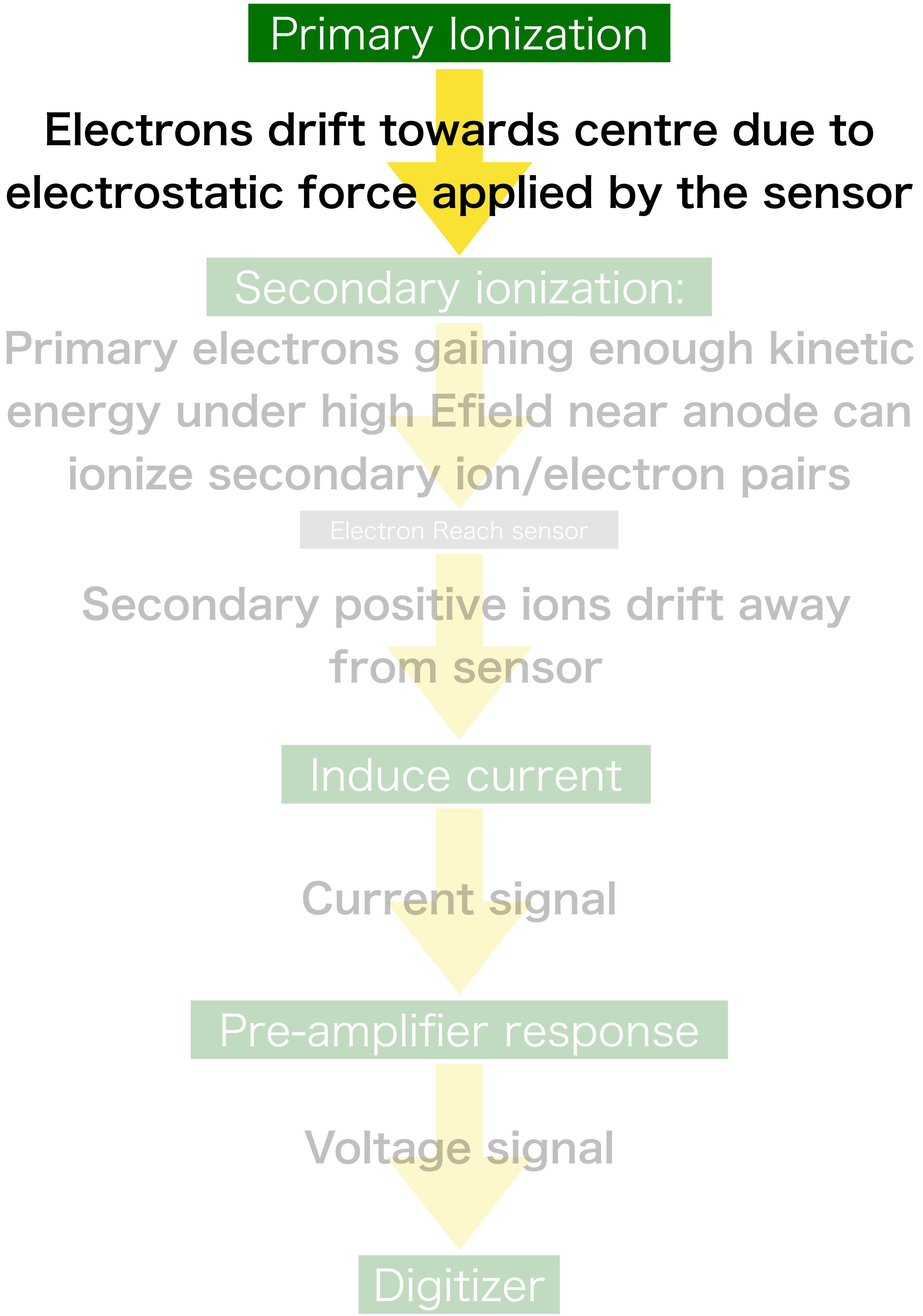

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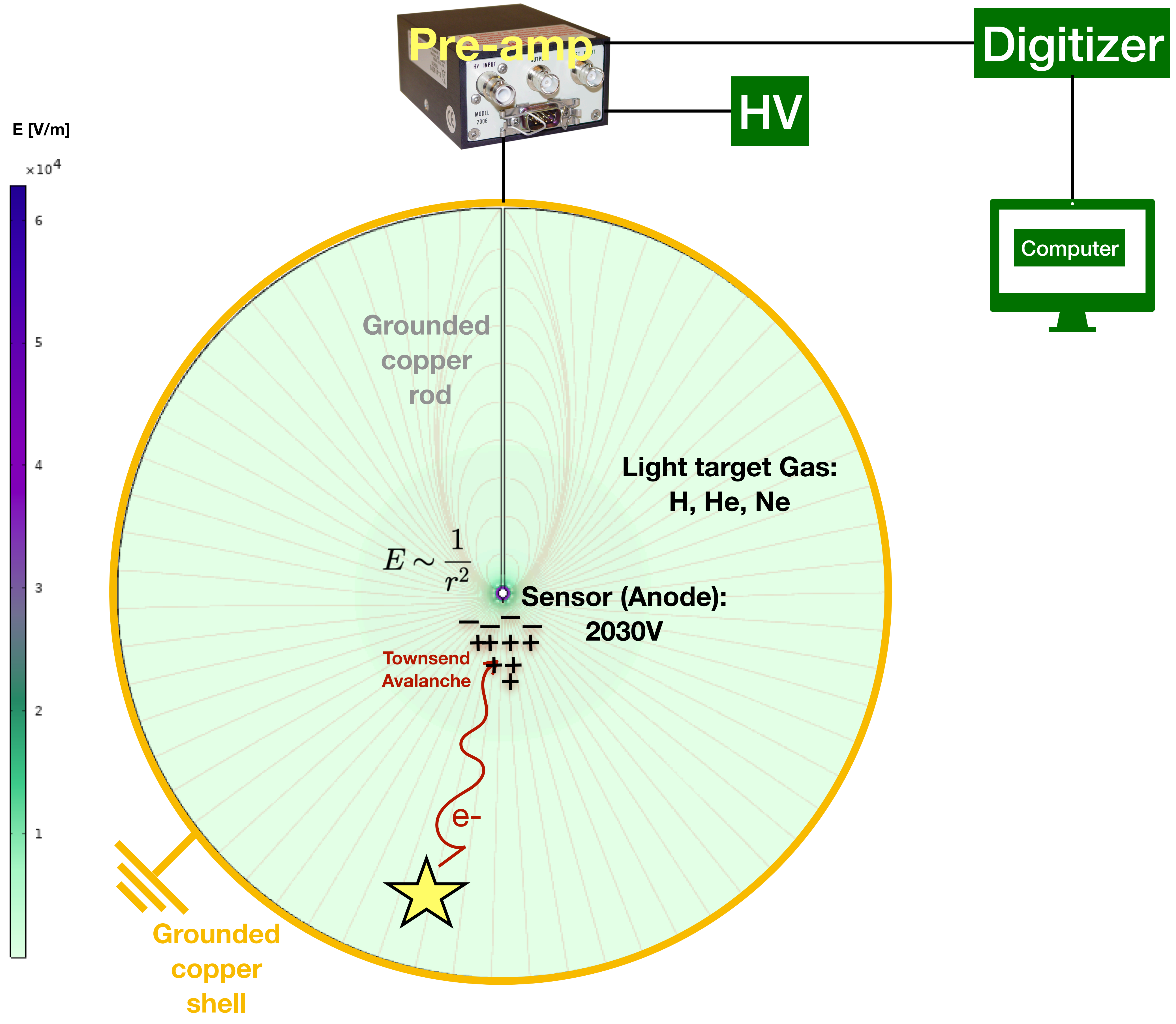

Primary Ionization

Electrons drift towards centre due to electrostatic force applied by the sensor

Secondary ionization:

Primary electrons gaining enough kinetic energy under high Efield near anode can ionize secondary ion/electron pairs

Electron Reach sensor

Secondary positive ions drift away from sensor

Induce current

Current signal

Pre-amplifier response

Voltage signal

Digitizer

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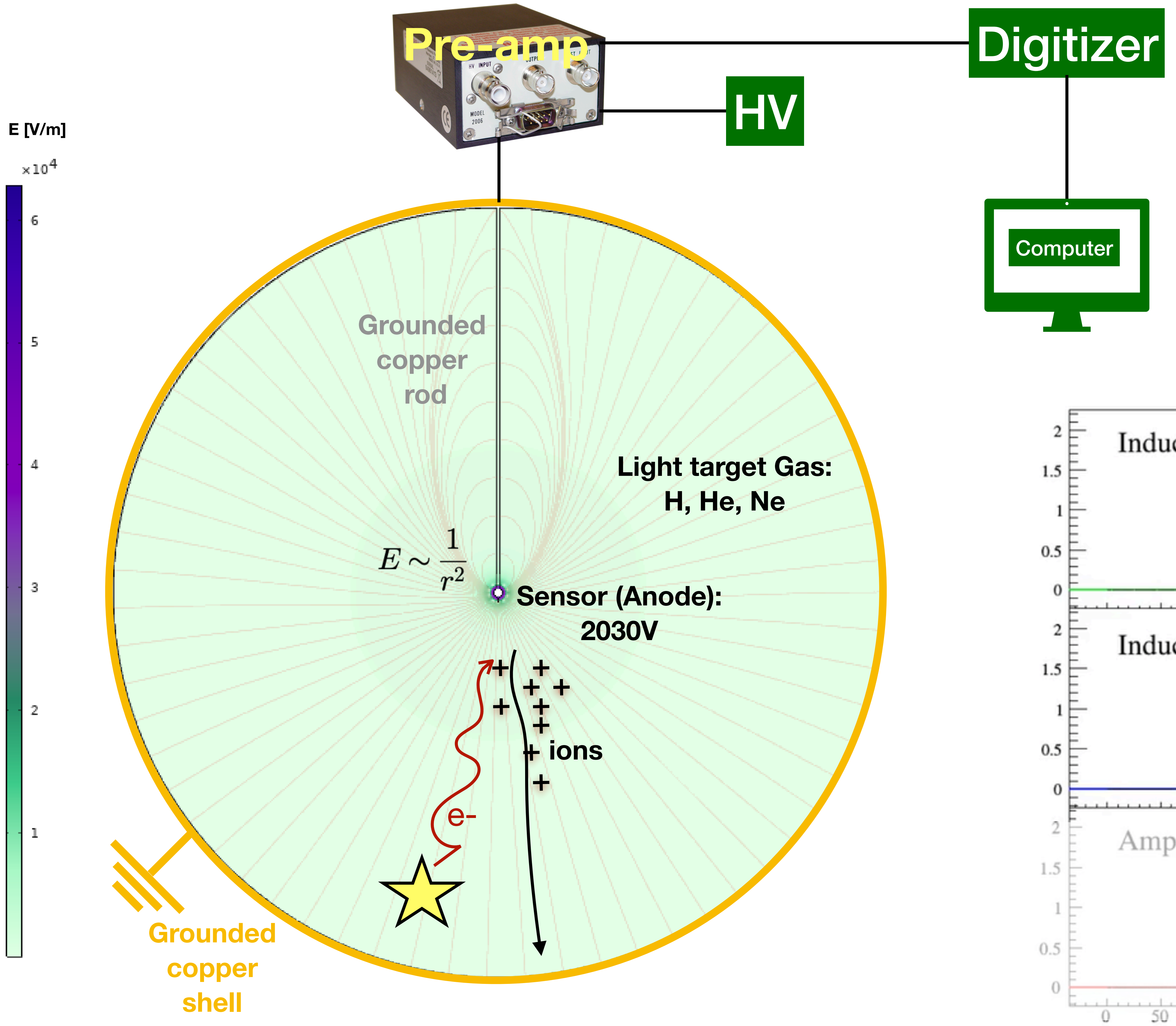

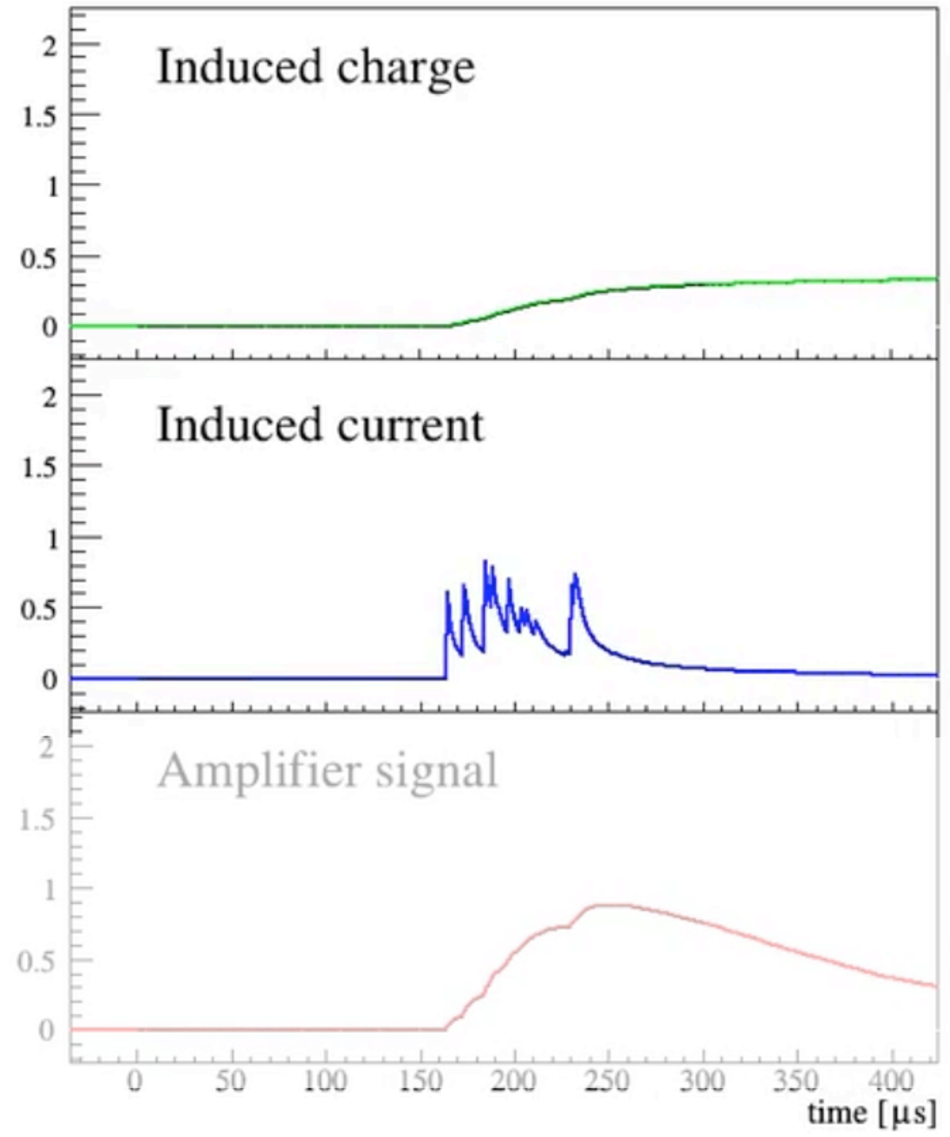

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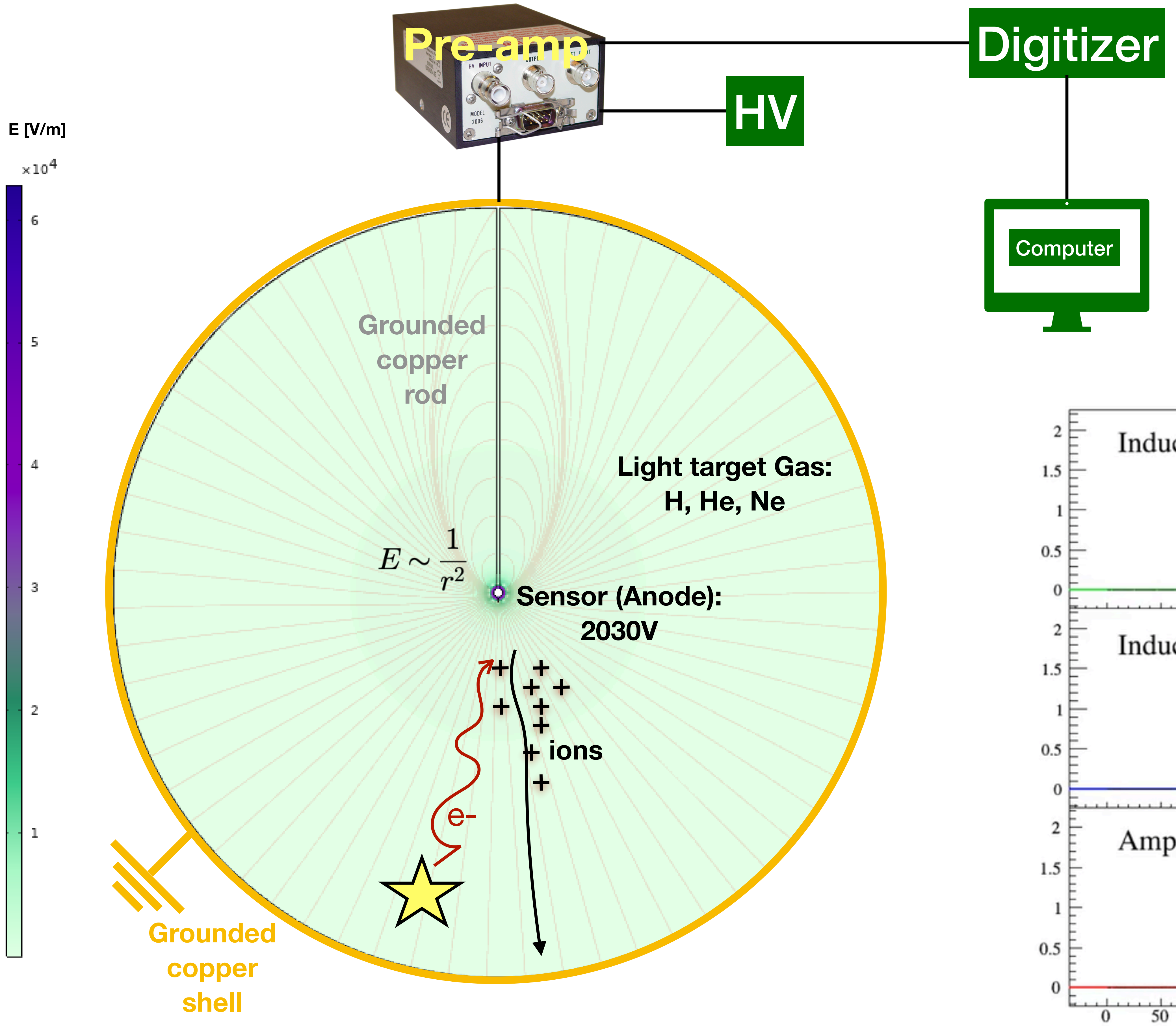

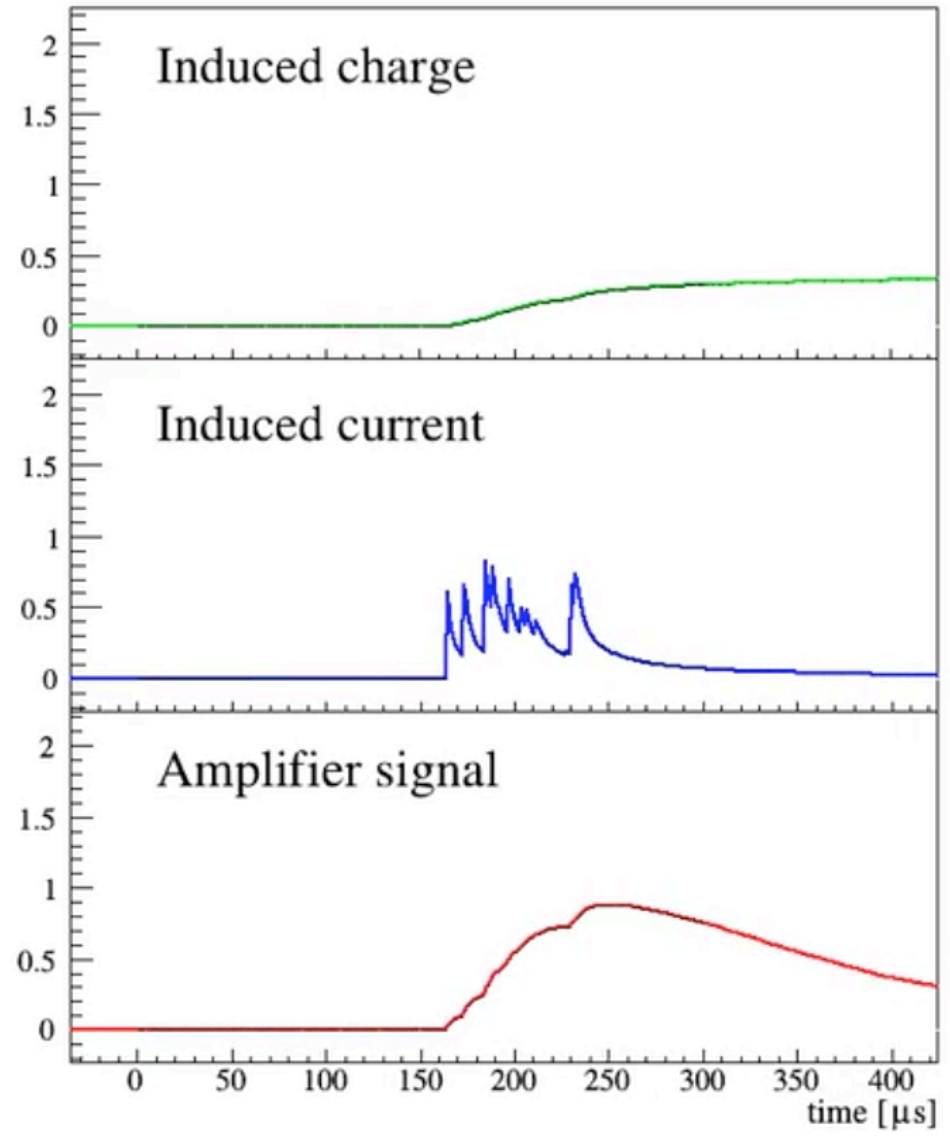

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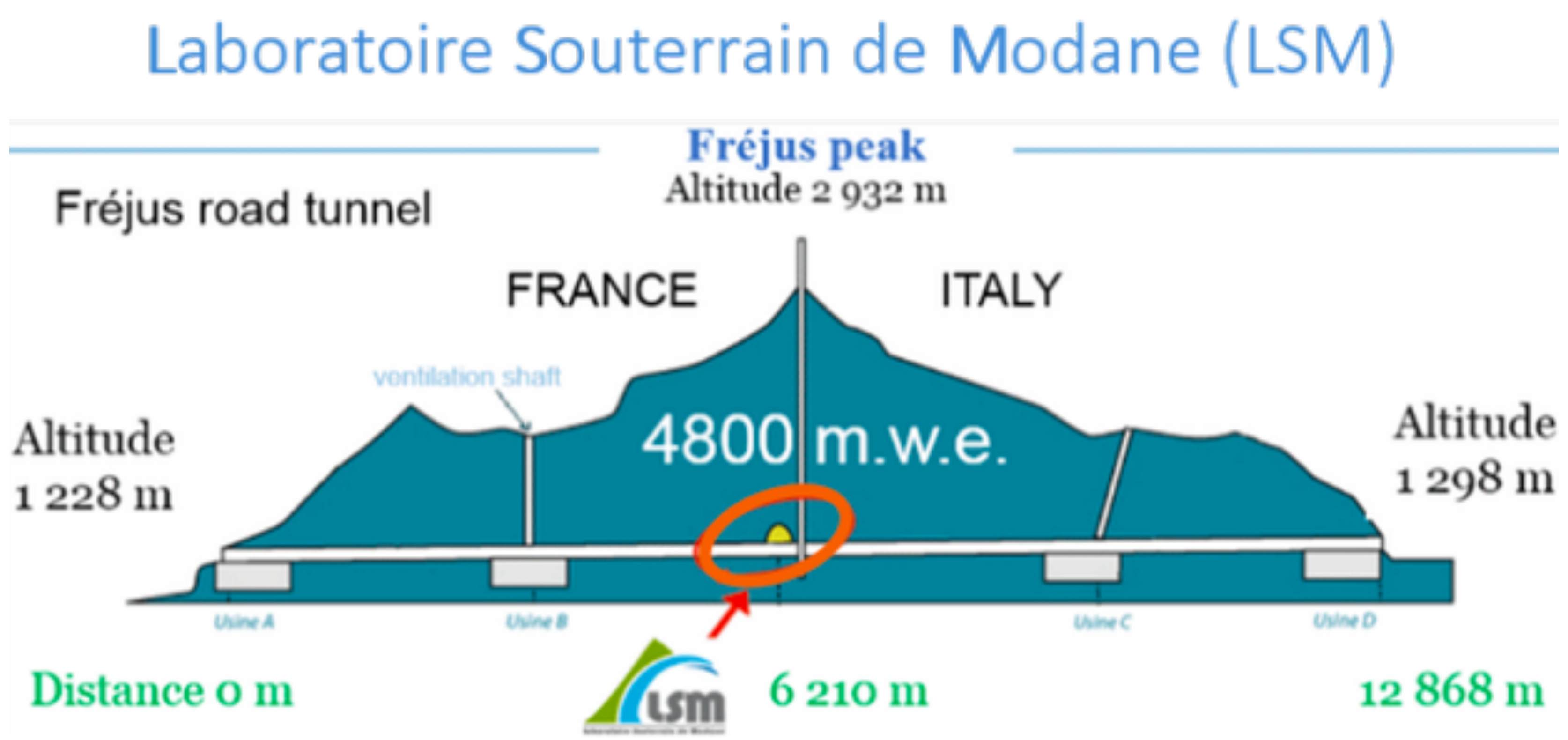
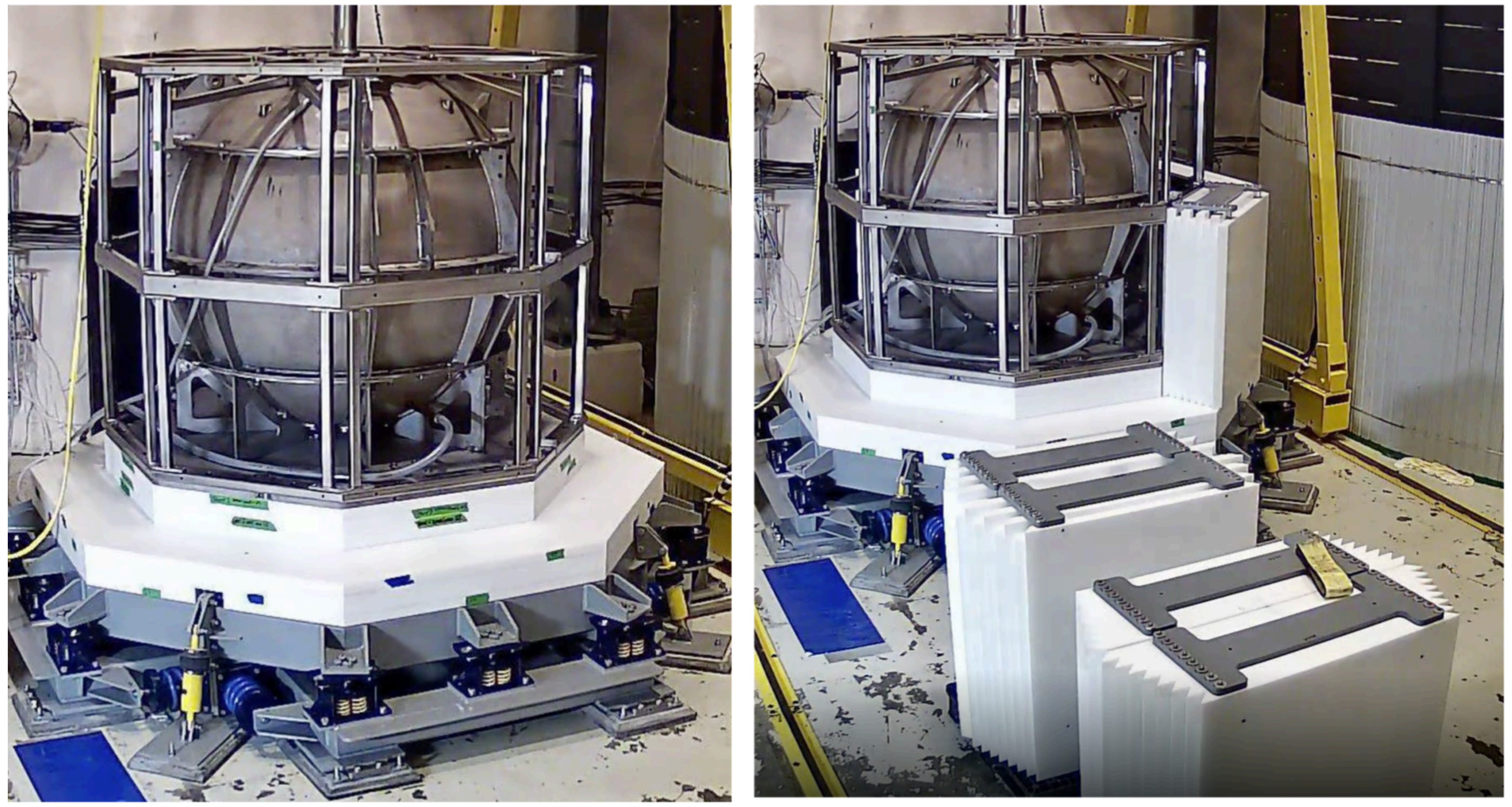
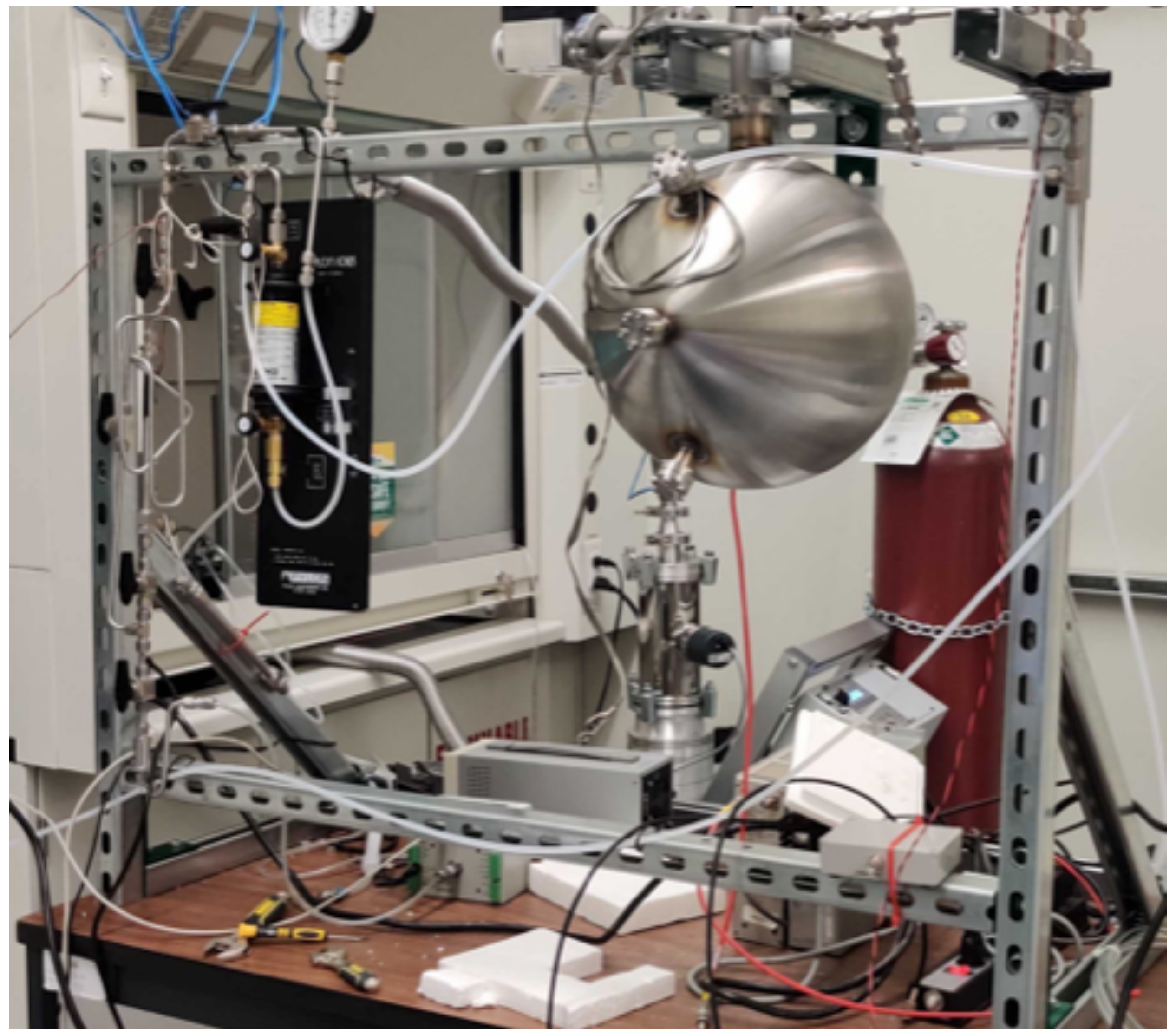
Physics and non-physics data were taken with a 1.35m diameter SPC under 135 mbar using pure CH_4 at LSM in 2019



This SPC has been moved and installed in SNOLAB



U of A is also equipped with 30 cm diameter SPC to perform dedicated studies



- Ar-37 along with pure CH_4 was filled in SPC
- Ar-37 emit X-rays at 270 eV and 2.8 keV induced by electron capture in L and K shell
- X-rays are uniformly distributed throughout the detector

Calibration Physics run

Radioactive source: Ar37

UV laser

Electrons drift towards centre due to electrostatic force applied by the sensor

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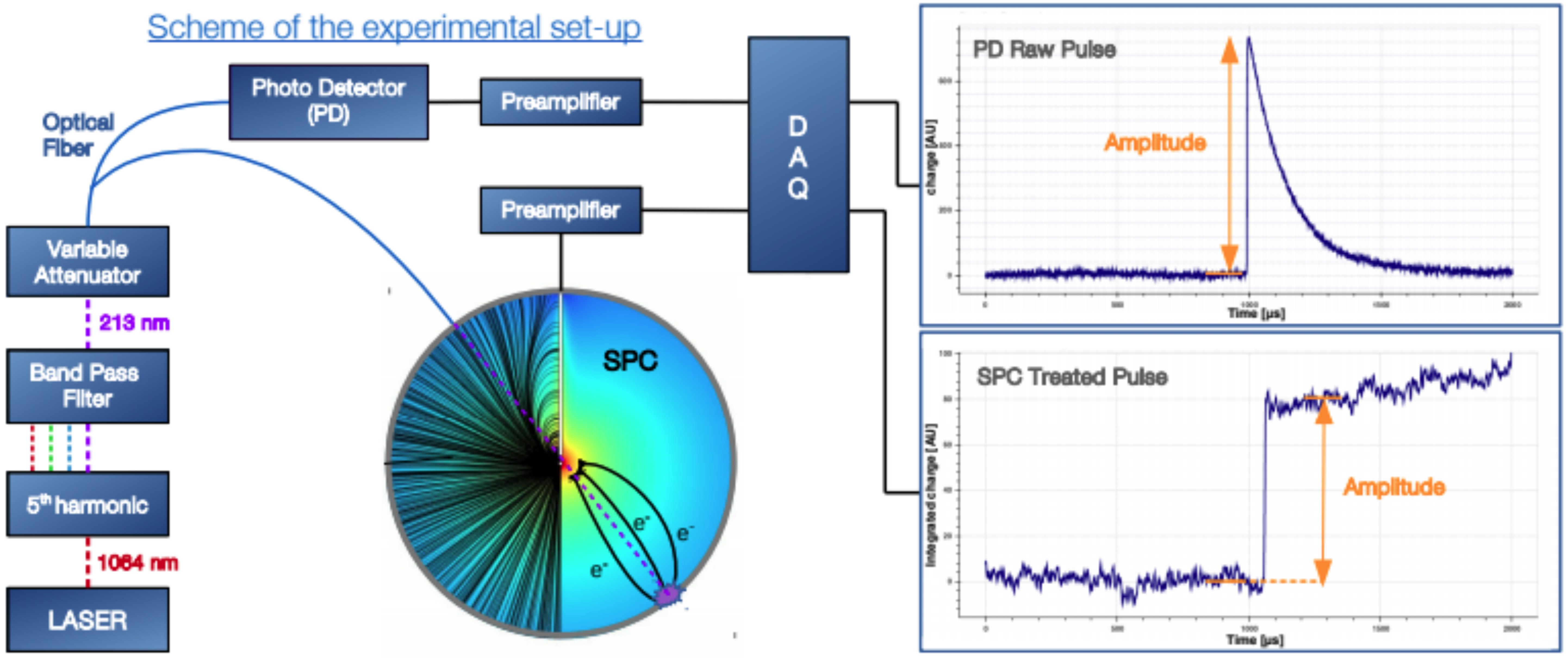


Q. Arnaud et al., Precision laser-based measurements of the single electron response of SPCs for the NEWS-G light dark matter search experiment, arXiv:1902.08960

- Compare with data and verify our understanding on the physics happened in our detector, identify different interactions
- Determine cut efficiency/WIMP signal acceptance, further extracting the WIMPs limits on cross section
- Fiducialization (Refer to Carter Garrah's presentation)

Step1: Electric field simulation: Finite element software COMSOL

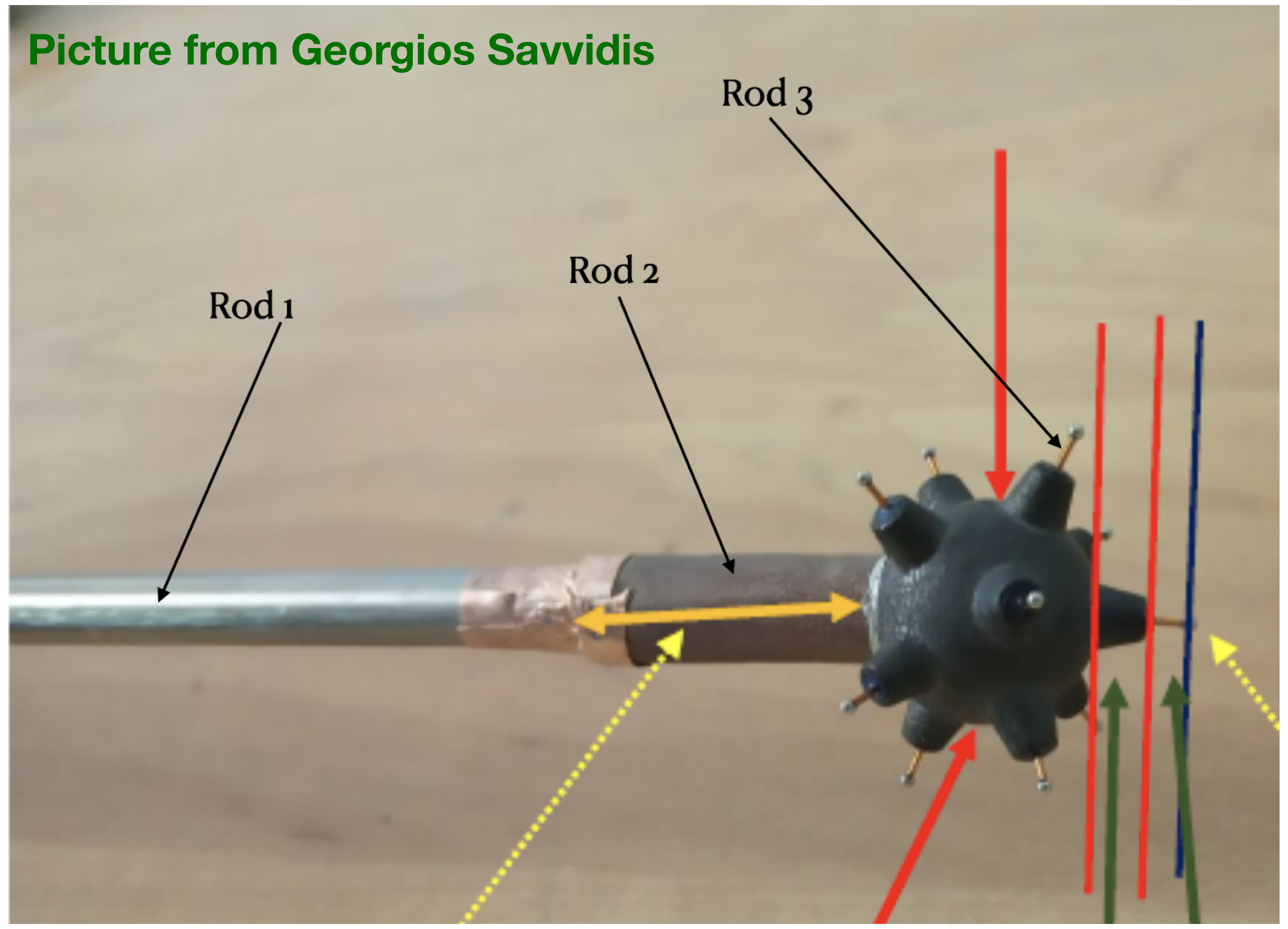
Step2: Primary ionization

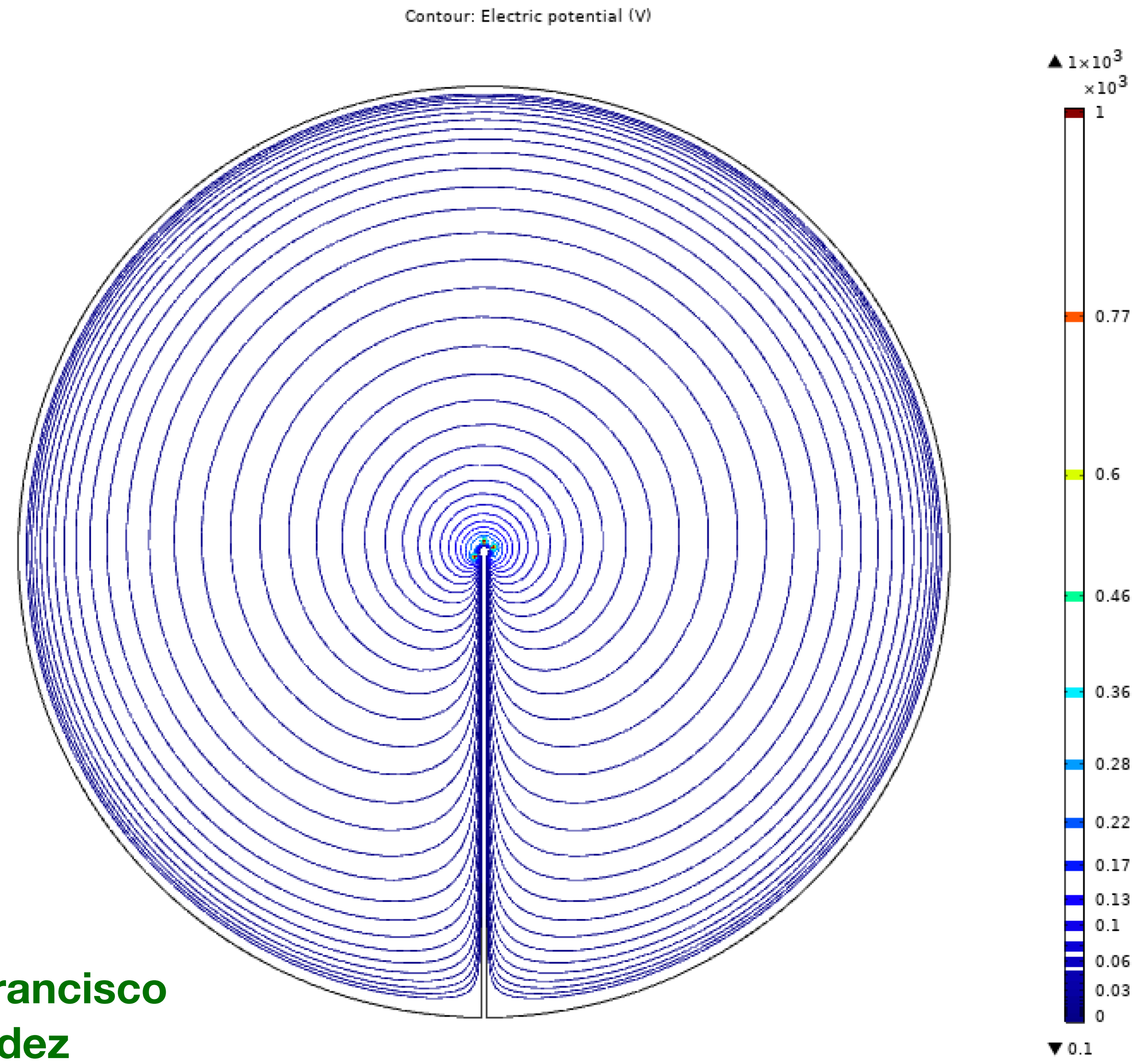
Step3: electron transportation

Electron drift time determined

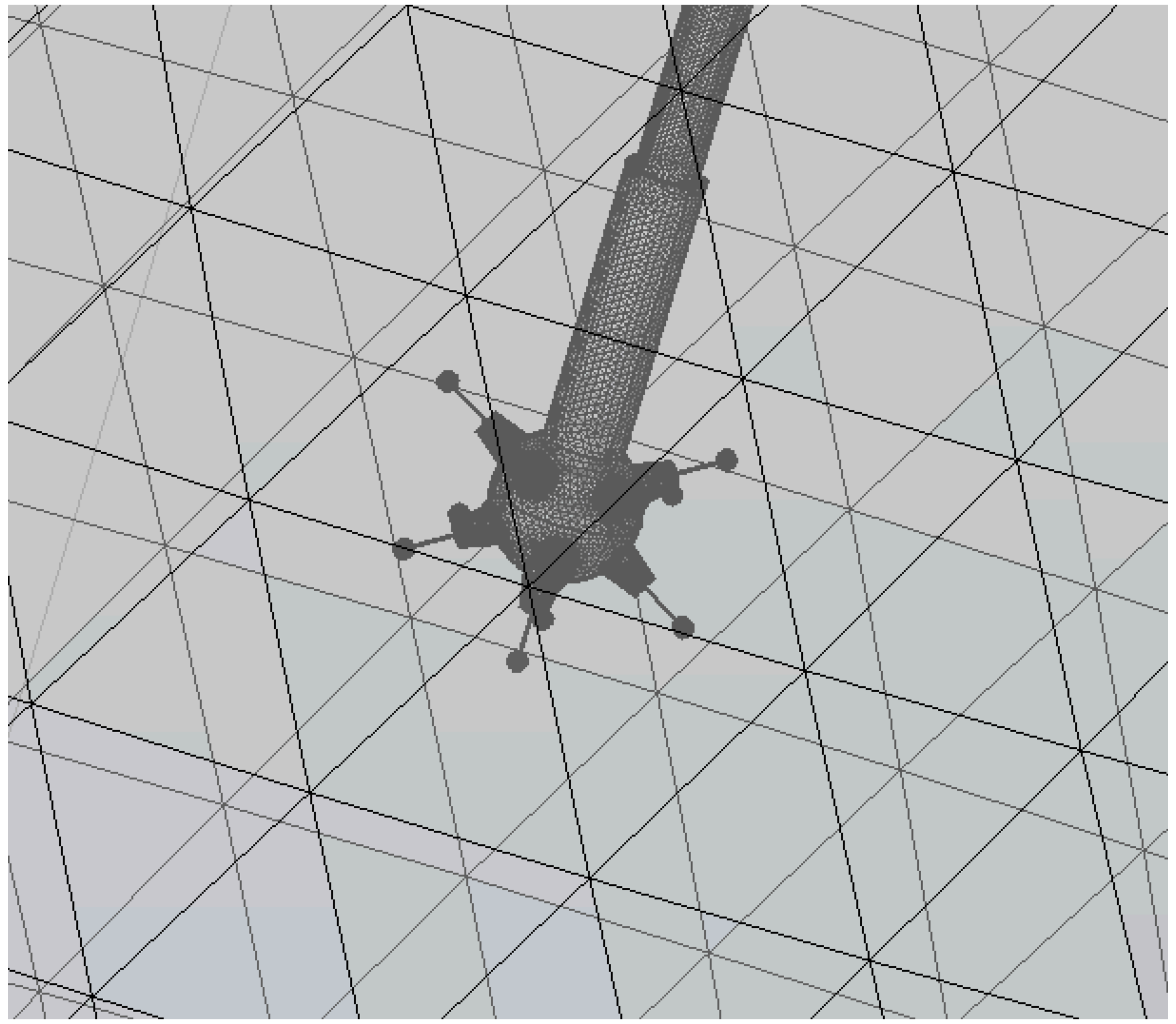
Step4: signal formation

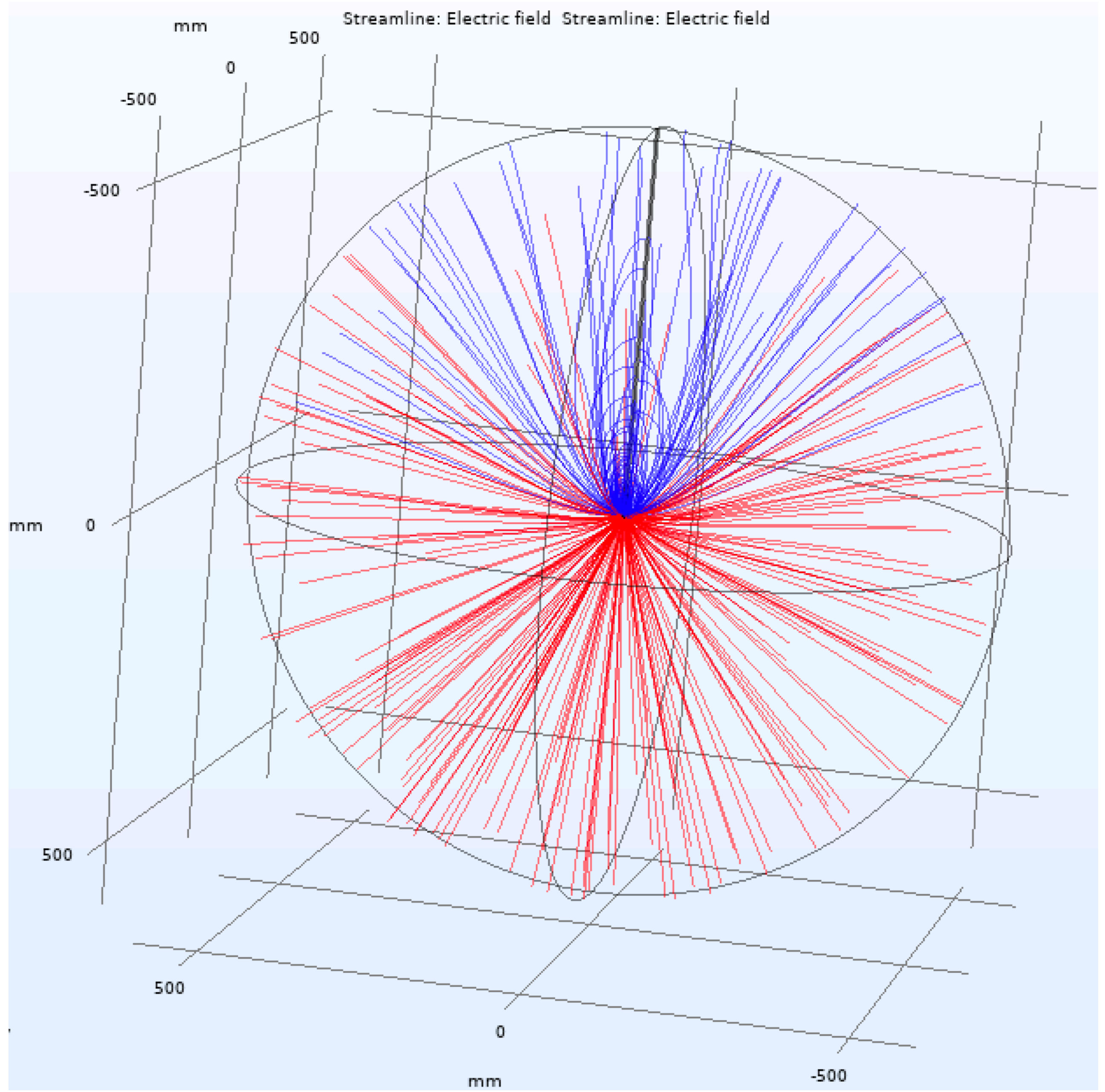
Rise time determined





A simulation work done by Francisco Vazquez de Sola Fernandez





Step1: Electric field simulation:
Finite element software COMSOL

Step2: Primary ionization
(Ar-37 Events)

Step3: electron transportation

Electron drift time determined

Step4: signal formation

Rise time determined

- **The Conway Maxwell - Poisson (COM-Poisson) distribution:**

$$P(x|\lambda,\nu) = \frac{\lambda^x}{(x!)^\nu Z(\lambda,\nu)}$$

$$Z(\lambda,\nu) = \sum_{j=0}^{\infty} \frac{\lambda^j}{(j!)^\nu} \quad \lambda \in \{\mathbb{R} > 0\}, \quad \nu \in \{\mathbb{R} \geq 0\}$$

- **The assumption that the number of primary electrons produced follows poisson distribution doesn't significantly affect simulation result:**

A. Expectation value is a function of deposited energy:

$$\mu = \frac{E}{W(E)}$$

B. W is the mean energy needed to create electron/ion pair in gaseous detectors.

C. W values being measured in pure CH_4 under 135 mbar is 31.2 eV for 2.8 keV X-rays

D. At 2.8 keV, the mean number of primary electrons being ionized is ~ **90**

- **Initial kinetic energy is not high enough to further ionize gas molecules before entering high E field region**

Step1: Electric field simulation: Finite element software COMSOL

Step2: Primary ionization

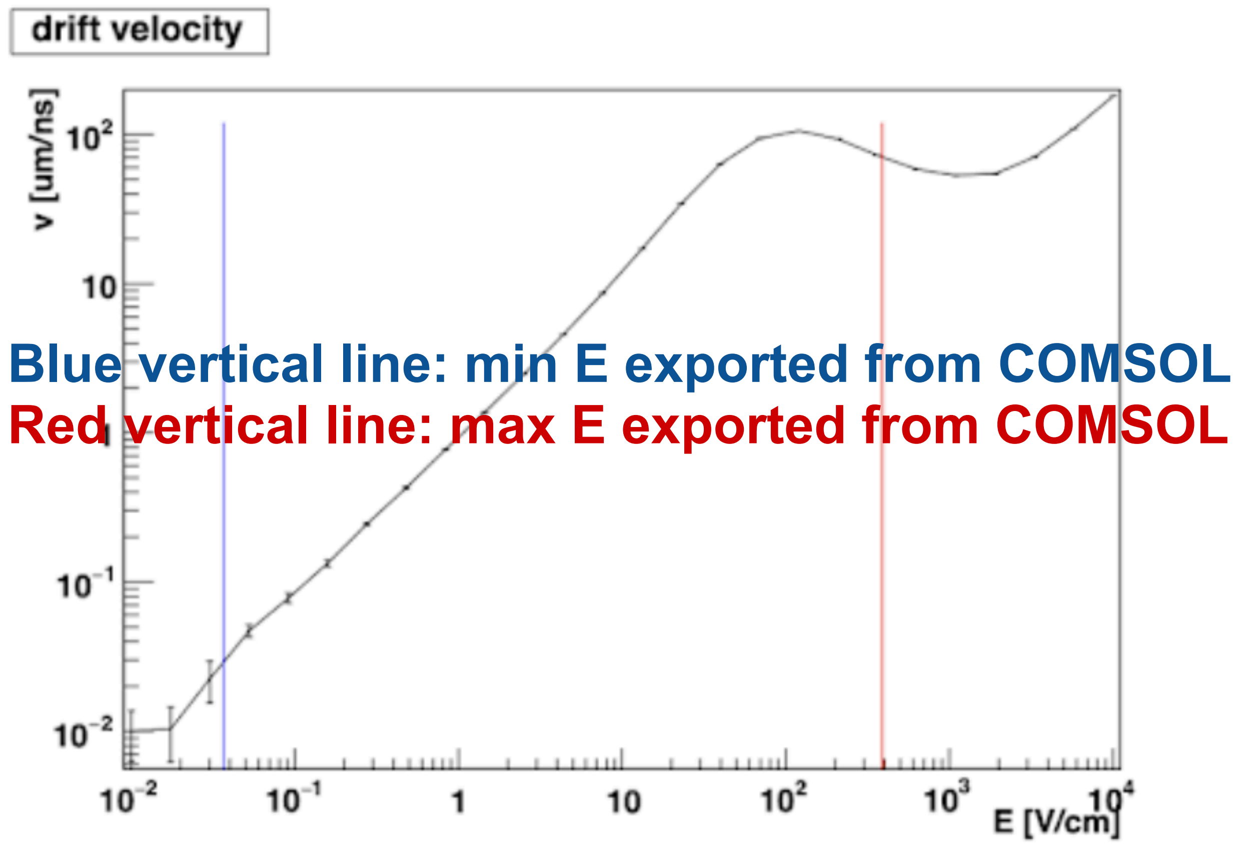
Step3: electron transportation

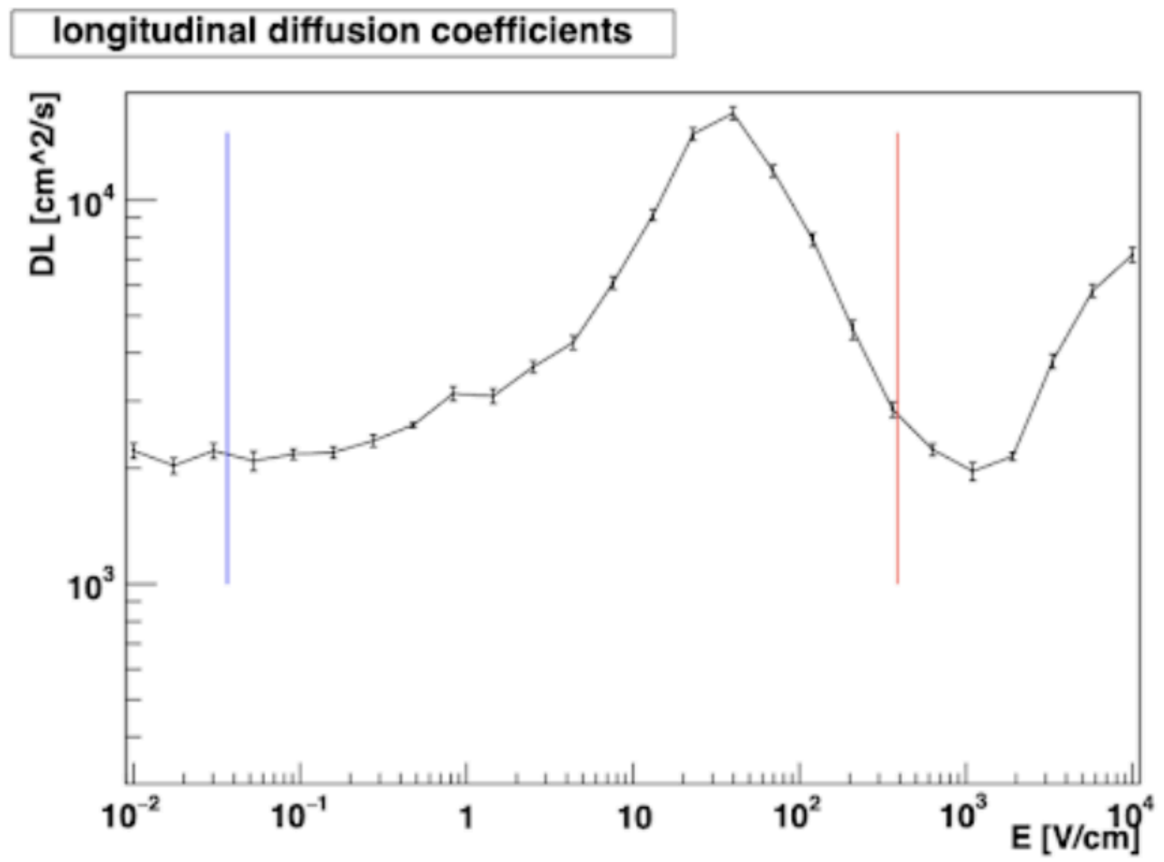
Electron drift time determined

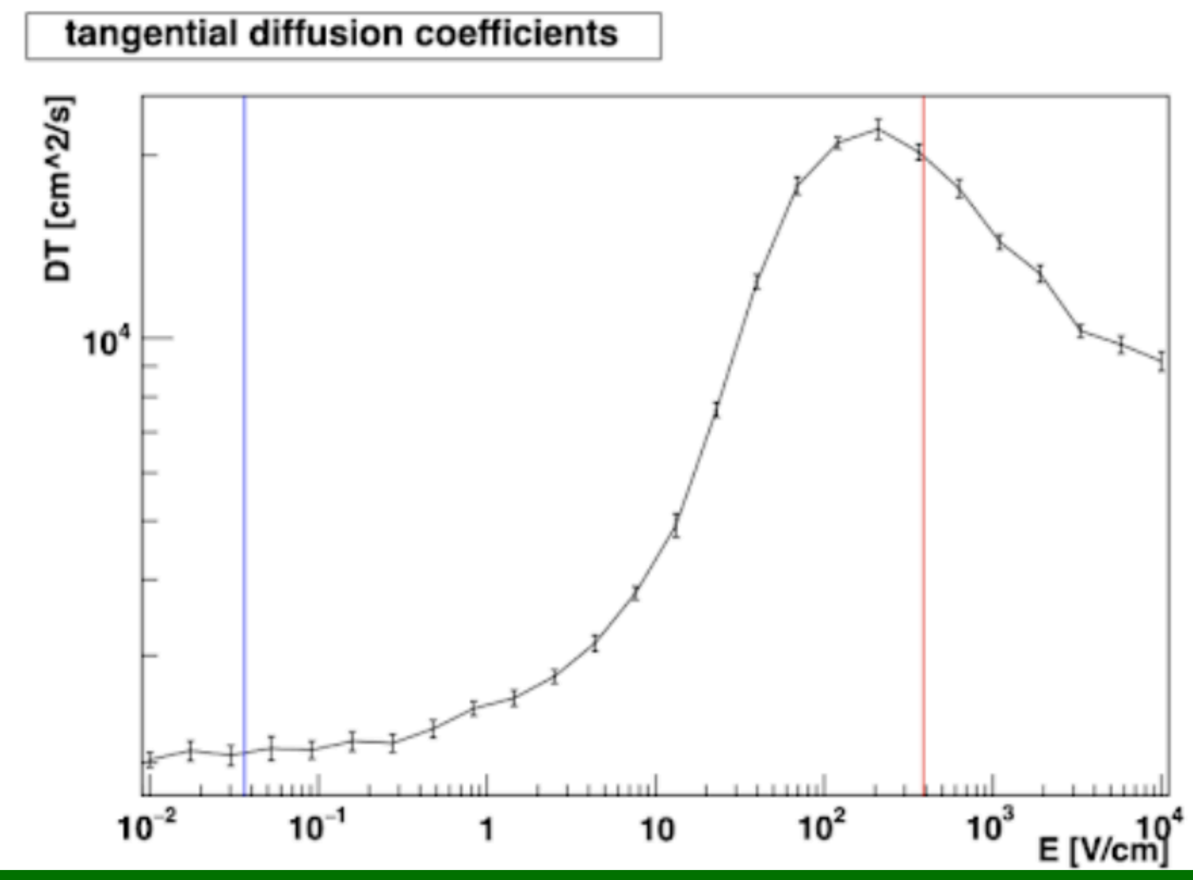
Step4: signal formation

Rise time determined

- **Drift velocity of electrons: constant in material under uniform electric field**
- **Fick's 2nd law:**
  - Charges diffuse in the gas due to scattering on the atoms of the gas
  - Describes how concentration change with respect to time
  - Expression in 1D: $\frac{\partial \varphi}{\partial t} = D \frac{\partial^2 \varphi}{\partial x^2}$
  - Fundamental solution: $\varphi(x,t) = \frac{1}{\sqrt{4\pi D t}} \exp\left(-\frac{x^2}{4Dt}\right)$
  - Standard deviation: $\sqrt{2Dt}$
- **CERN simulation package: Magboltz:**
  - Output: drift parameters: drift velocities, longitudinal/ transverse diffusion coefficients
- **Monte Carlo method used to determine the electron drift time and locate the position of the events**







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Electron drift time determined

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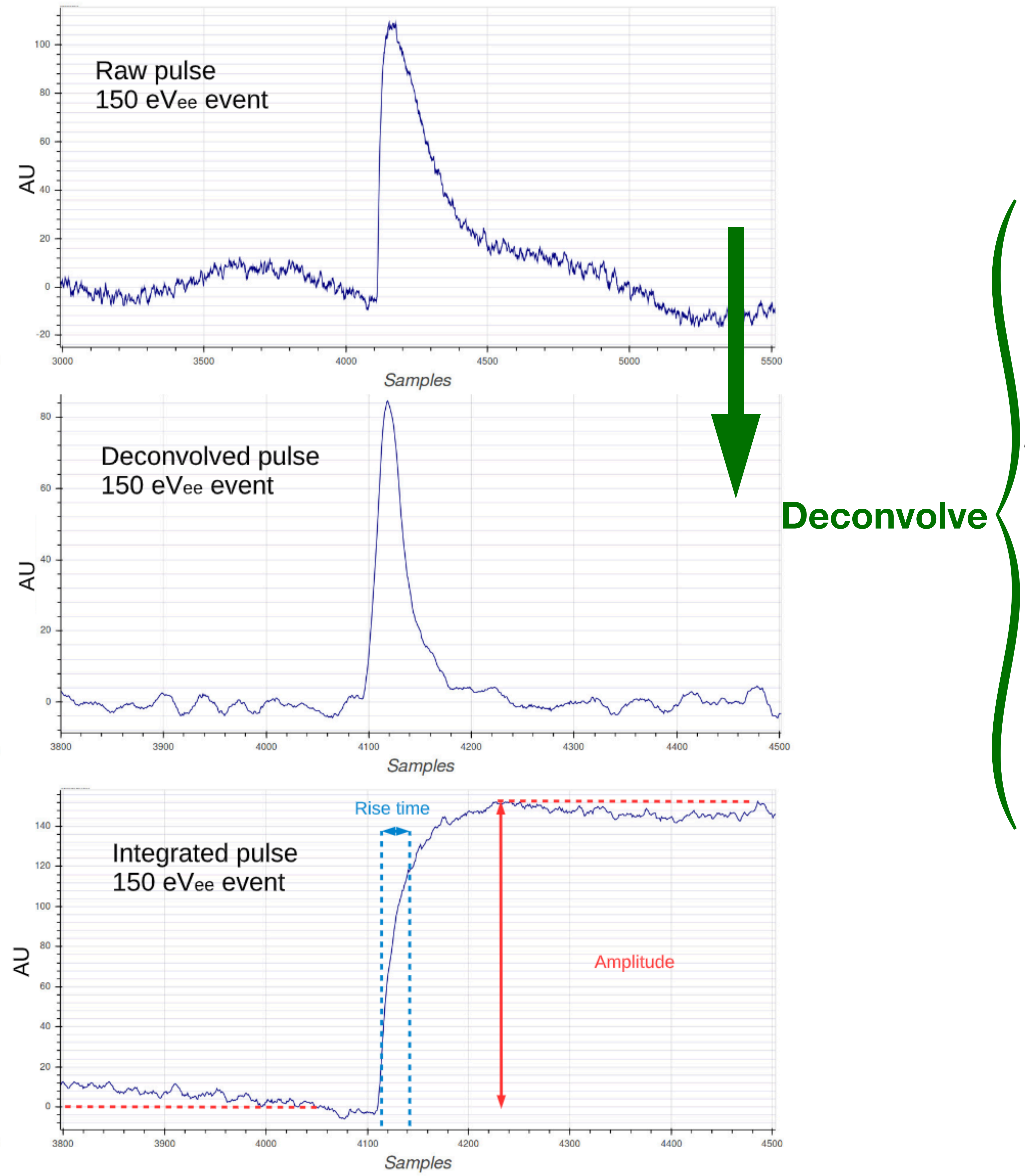

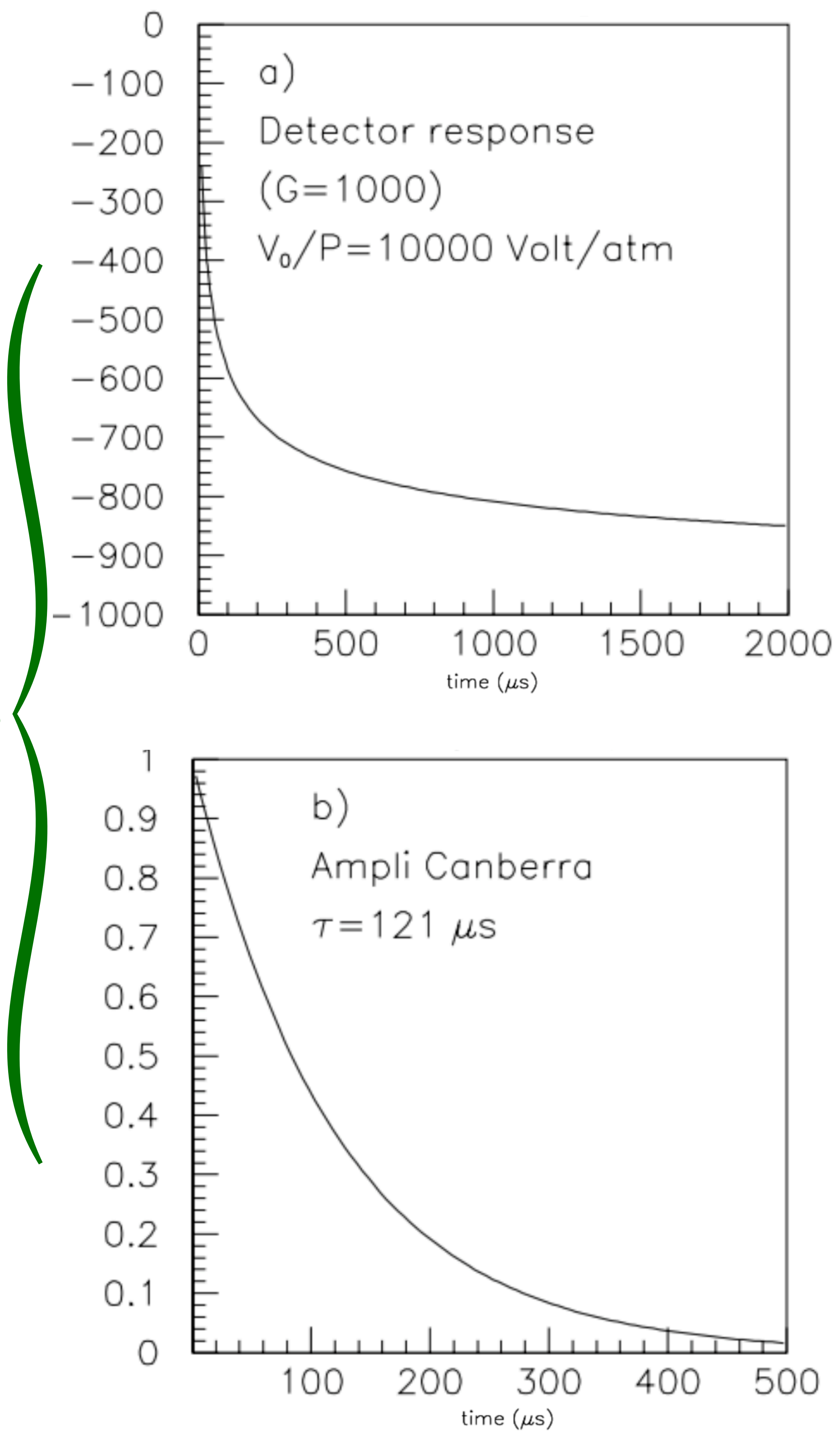

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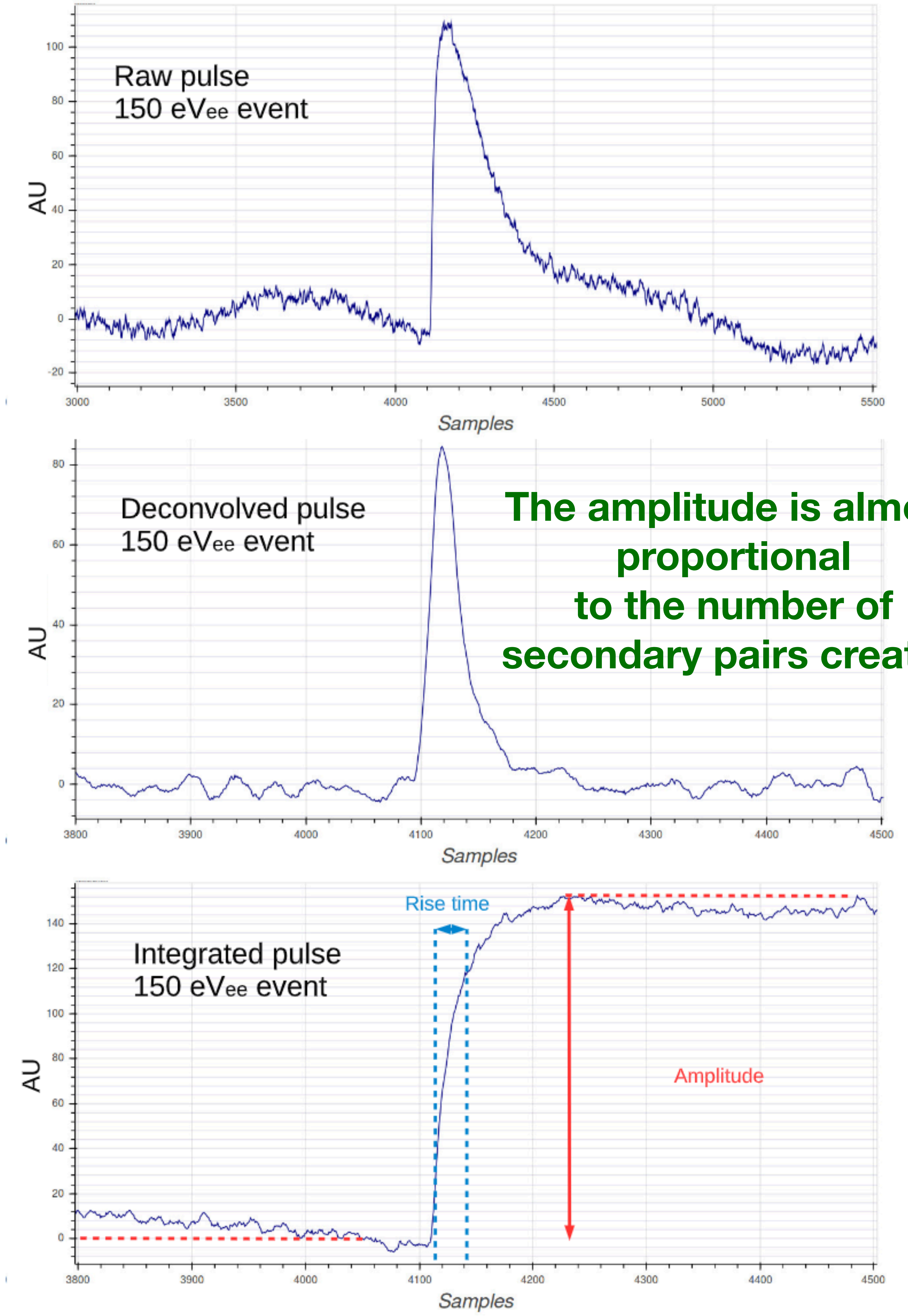


The amplitude is almost proportional to the number of secondary pairs created

- **Secondary ionization:**
  - PEs reaching high E field region will gain enough kinetic energy from collisions with gas molecules to ionize the gas and create secondary electron/ion pairs
  - Number of secondary ionizations can be parametrized by Polya distribution:

$$P(\frac{n}{\langle n\rangle}) = \frac{(1+\theta)^{(1+\theta)}}{\Gamma(1+\theta)}\left(\frac{n}{\langle n\rangle}\right)^{\theta}\exp\left[-(1+\theta)\frac{n}{\langle n\rangle}\right]$$

- **Rise time: time difference between 75% and 10% of the amplitude**

Step1: Electric field simulation: Finite element software COMSOL

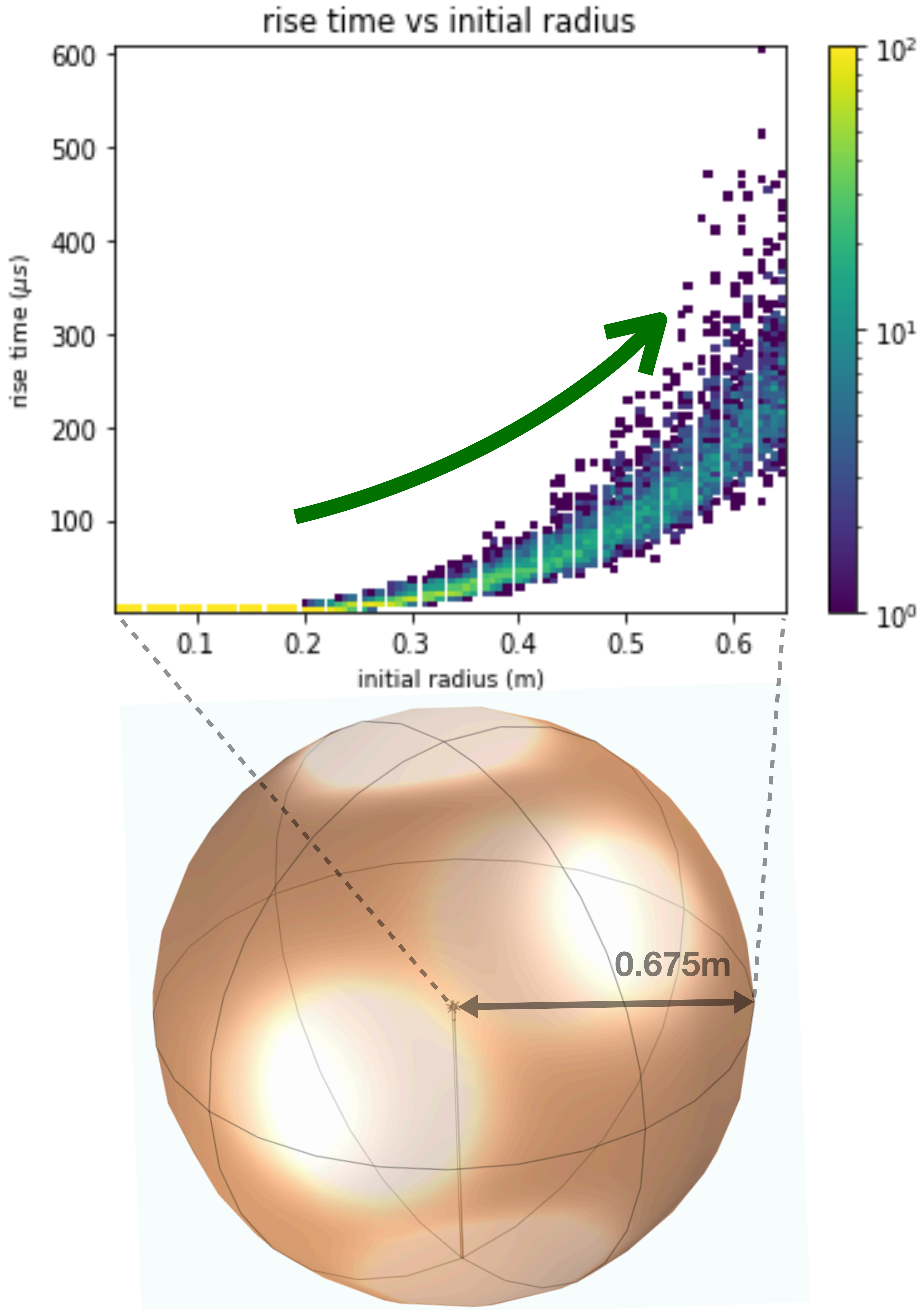
Step2: Primary ionization

Step3: electron transportation

Electron drift time determined

Step4: signal formation

Rise time determined



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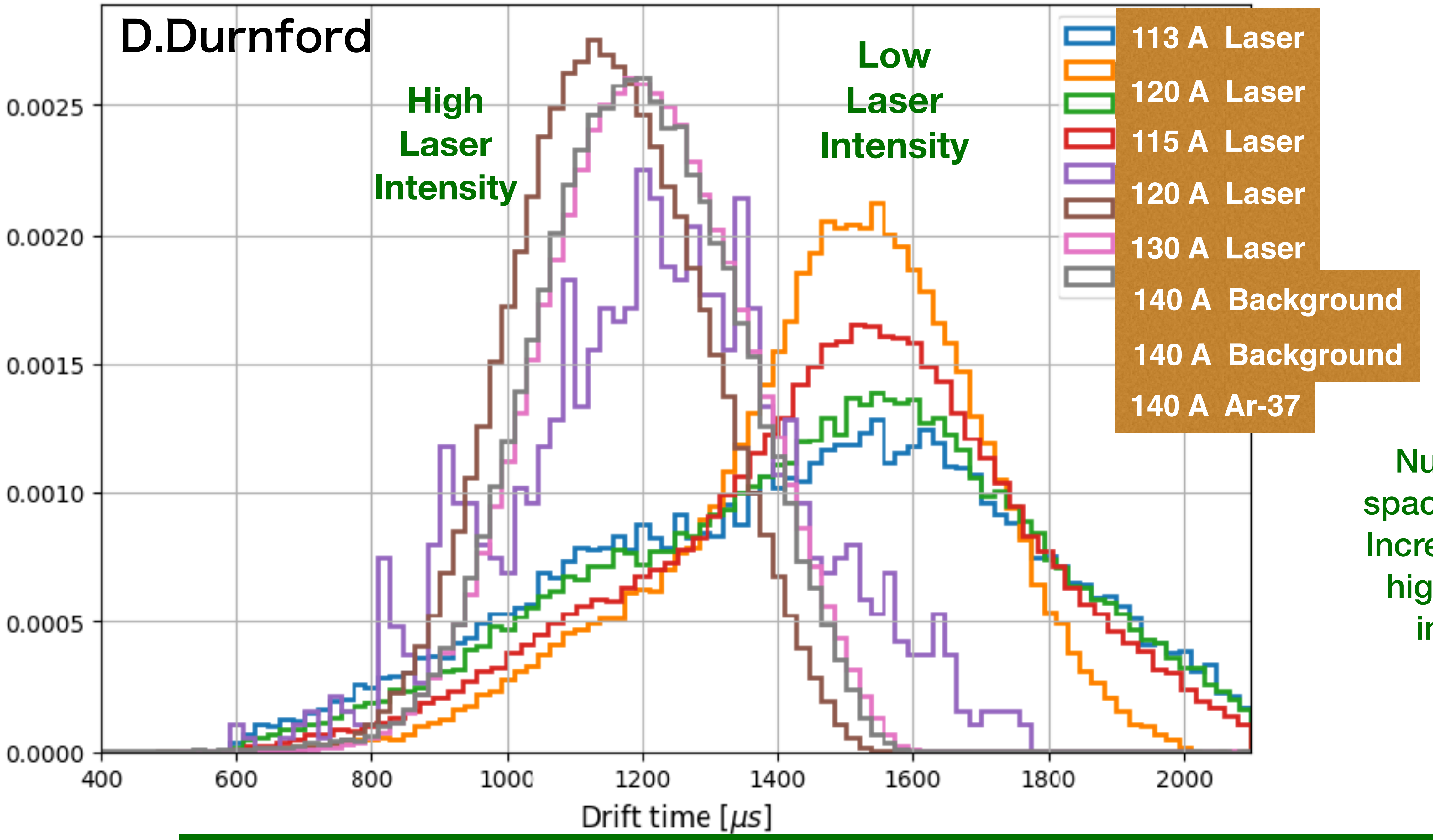
- **Rise time: time difference between 75% and 10% of the amplitude**
  - represents how much diffusion the charges undergo; Higher starting position results in more dispersion of charges
  - Discriminate bulk events and surface events

Laser events drift time simulation: Events all originates from very south point of SPC

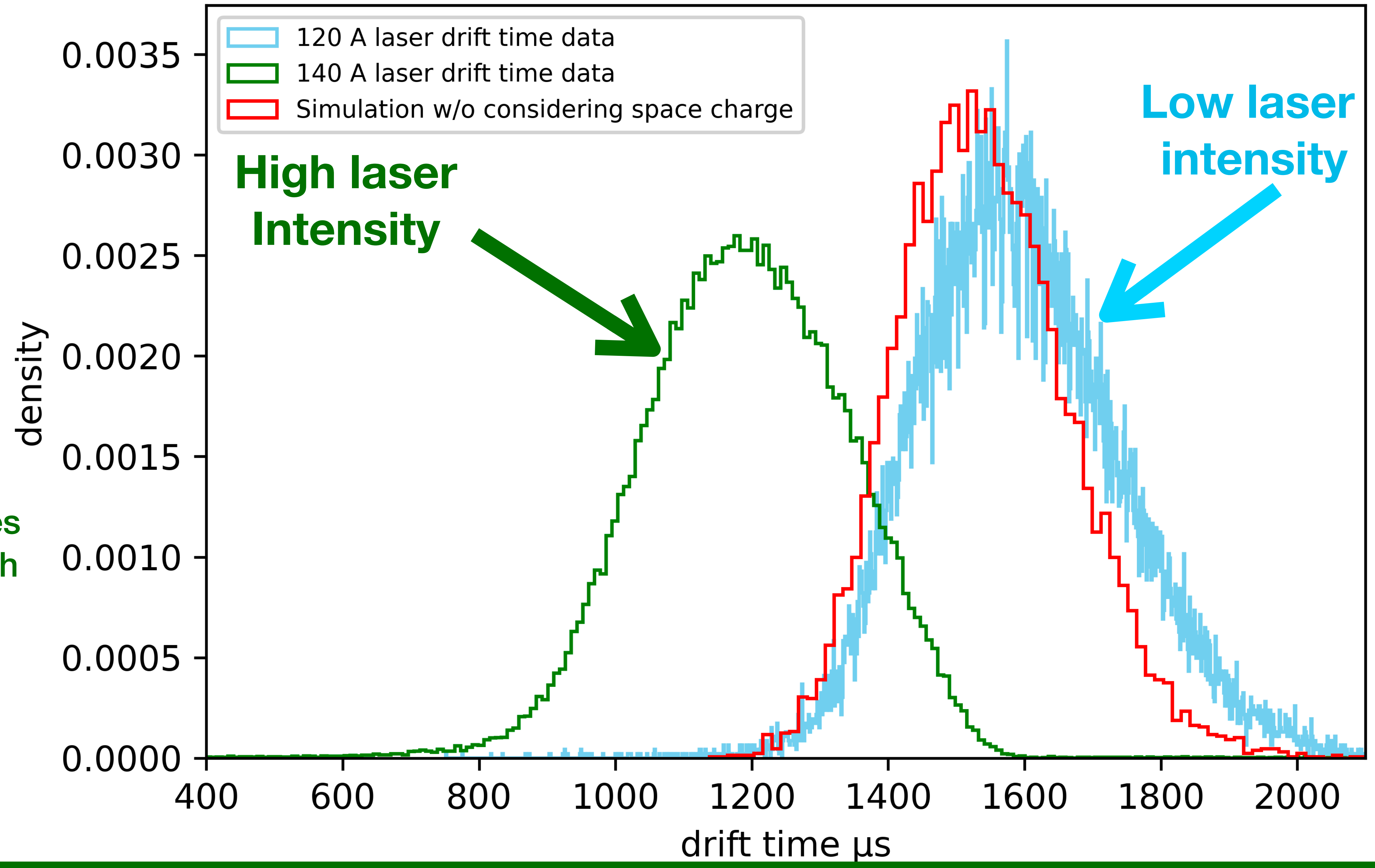
- **Left:** Laser LSM data show a different mean drift time between high and low laser intensity
- **Right:** Simulation shows agreement with real data at low laser intensity
- The decrease of drift time for higher laser intensity run can possibly be explained by space charge effect

* Some data sets have lower tails due to alpha correlated events which cannot be effeciently removed in low-intensity laser data

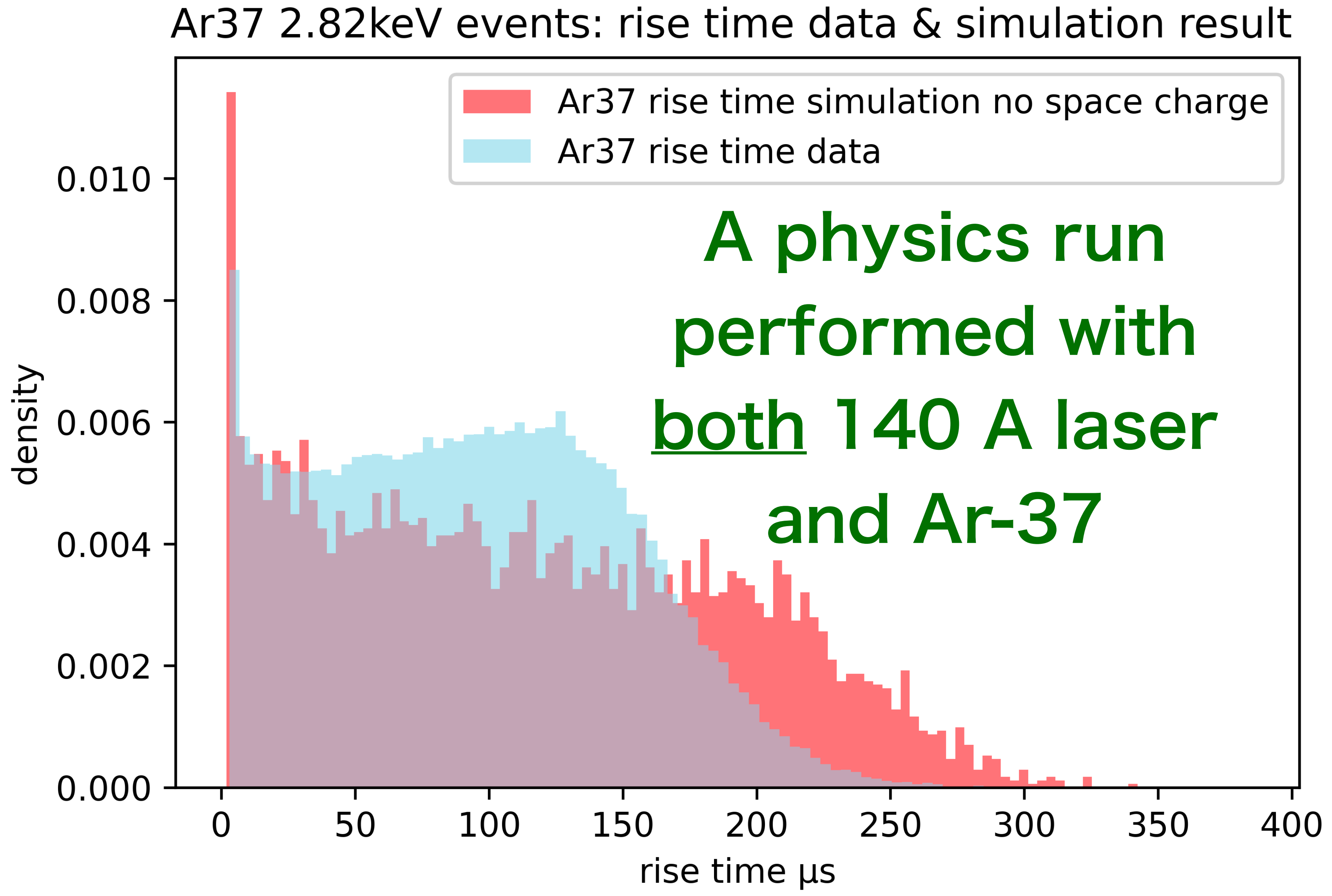


Number of space charges Increases with higher laser intensity

120A and 140 A laser drift time data compare with laser events drift time simulation without considering space charge

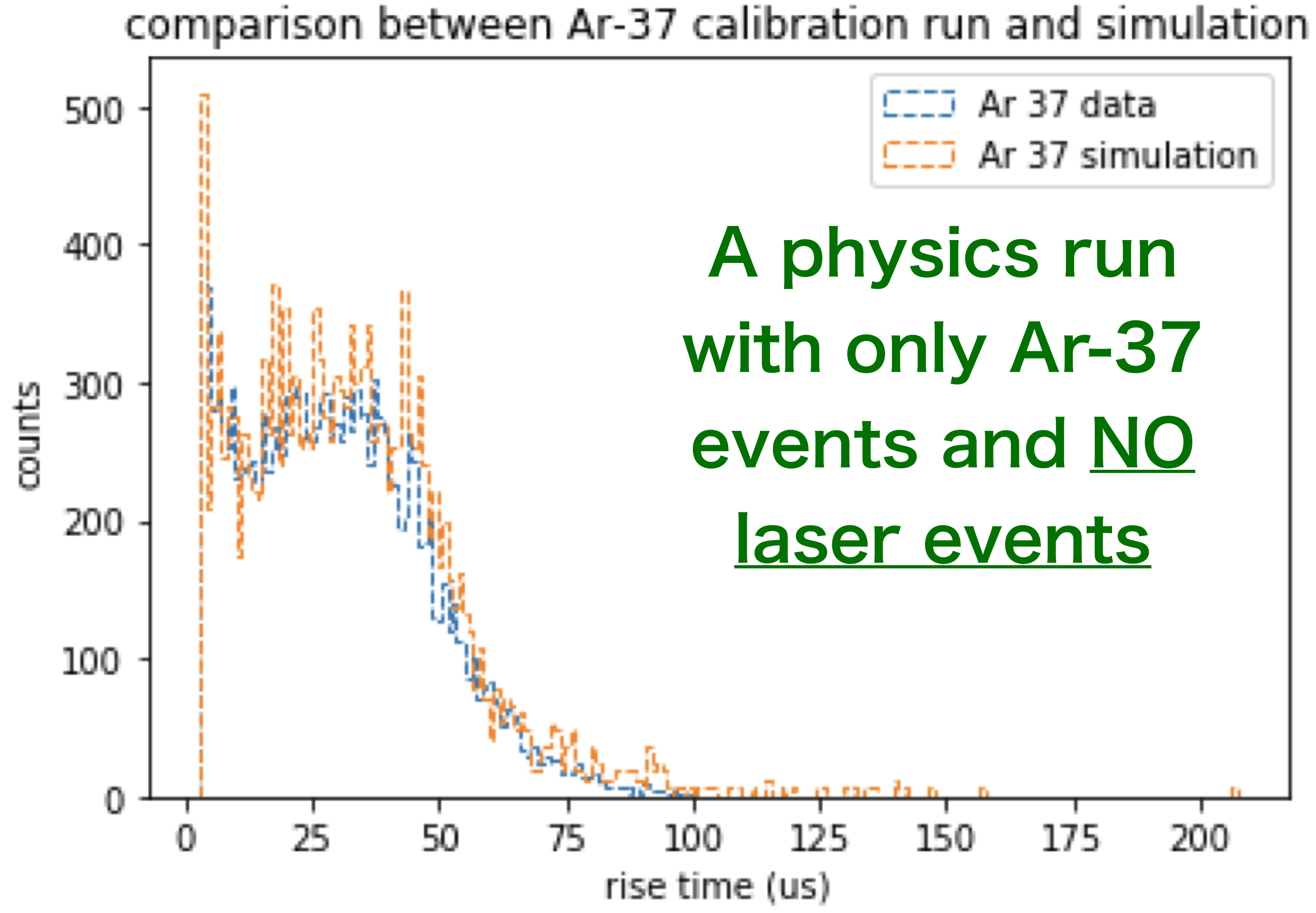


Ar37 events rise time simulation: events uniformly distributed in sphere



A physics run performed with both 140 A laser and Ar-37

Same method



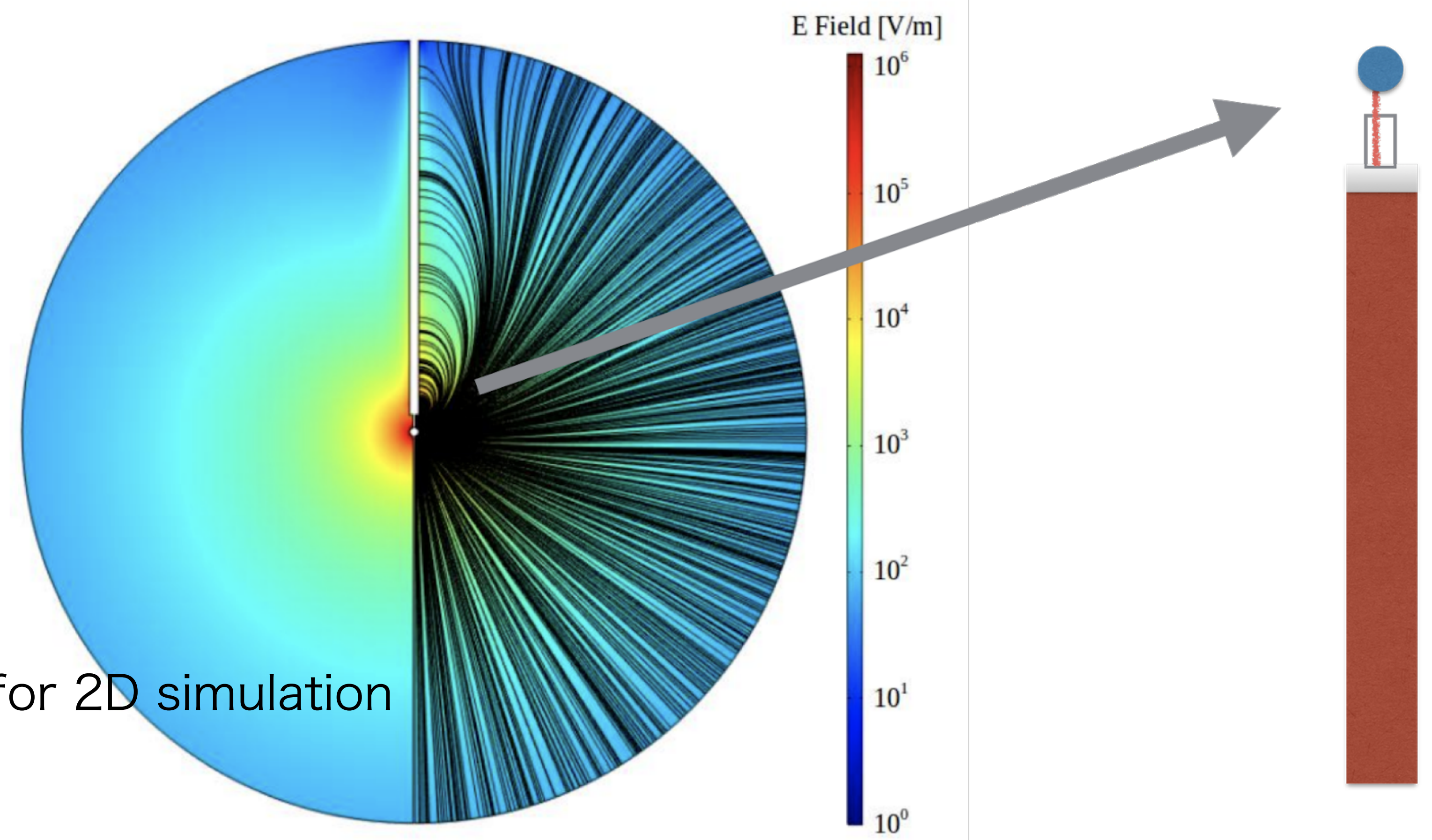
A physics run with only Ar-37 events and NO laser events

Simulation for SNOGLOBE

- Tuning the model used to simulate primary ionization or pulse shape doesn't improve the result;
- The amount of oxygen introduced to the detector is unknown, which can trap electrons and reduce the number of electrons that reach the sensor.
- The significant disagreement is most likely due to the secondary ions created during avalanche (especially from **laser events**), called space charge effect

Simulation for SEDINE:

1. An SPC of **60cm** diameter
2. 99.3% Ne + 0.7% CH_4 under 3.1 bar
3. Ar-37 events simulation at 2.8 keV
4. W value measured: 28 eV
5. **Simpler sensor** geometry allowing for 2D simulation
6. Magboltz and COMSOL were used

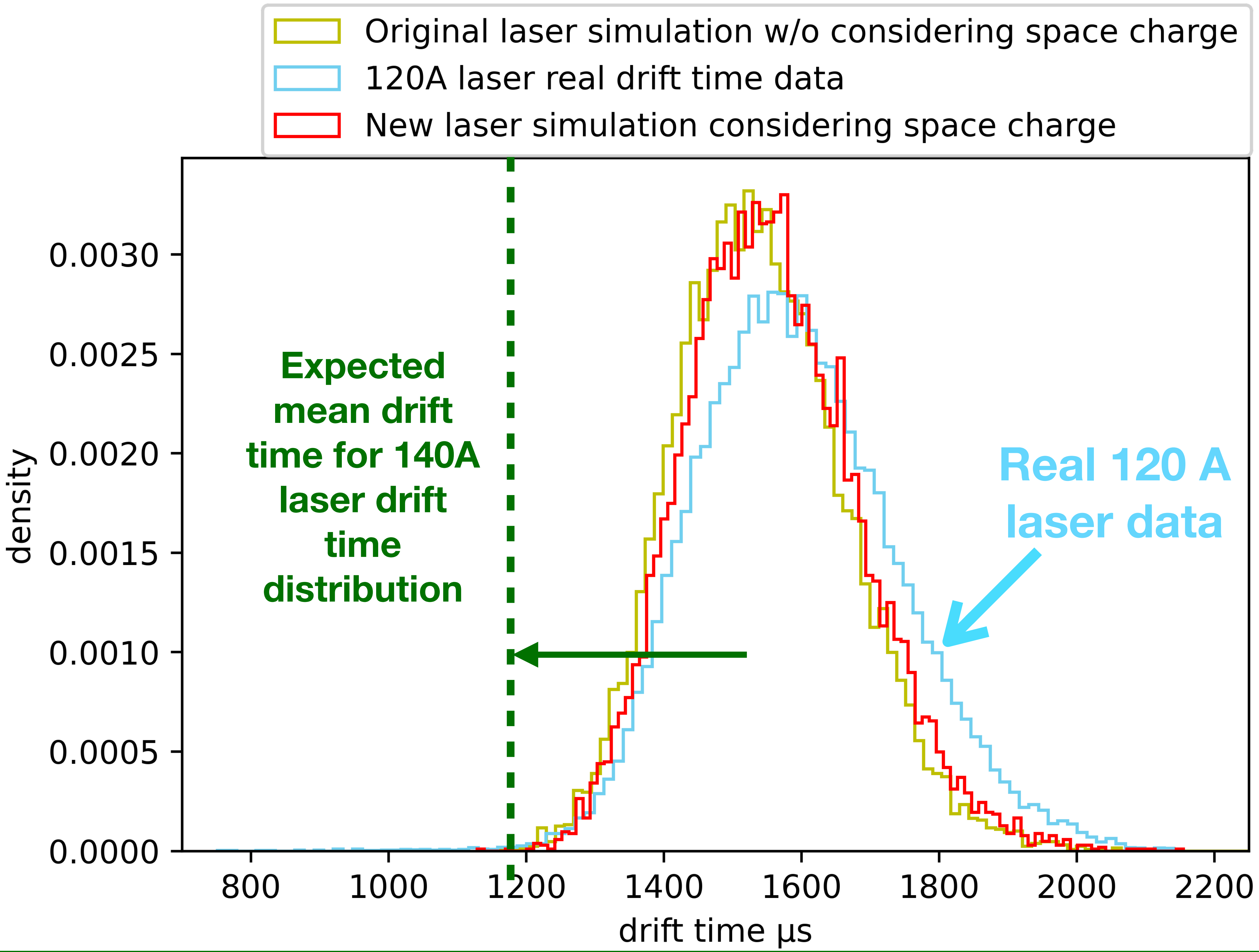


- **Ion drift simulation:**
  - The amount of secondary ions from 140 A laser events **seen** by the detector is known
  - Assuming the diffusion of ions can be neglected
  - Assuming reduced ion mobility K_0 of all kinds of ion species is 2.2 $cm^2/V/s$
  - Drift velocity depends on the Efield:

$$K_0 = K\frac{n}{n_0} = K\frac{T_0}{T}\frac{p}{p_0}$$

$$v_d = KE$$

- **Ion drift time: 5 ~ 7s**
  - The number of ions exist in the detector can be deduced knowing the laser event rate.
- **Conclusion:** The number of secondary ions live in the detector (before reaching the cathode) is not large enough to increase the overall Efield that can reconcile the primary electrons drift time distribution with the data [Upper right plot]



- **Investigation on the created ion species is probably needed (mass spectrometer)**
  - **The possibility of extremely slow moving ions existence**
- **Other possibilities:**
  - **Ions attached onto the DLC material of sensor**
- **We plan to use U of A sphere to perform more dedicated laser calibration with different intensity to further investigate the space charge**

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Extra slides

Advantage of SPC

3.2. SPHERICAL PROPORTIONAL COUNTER 42

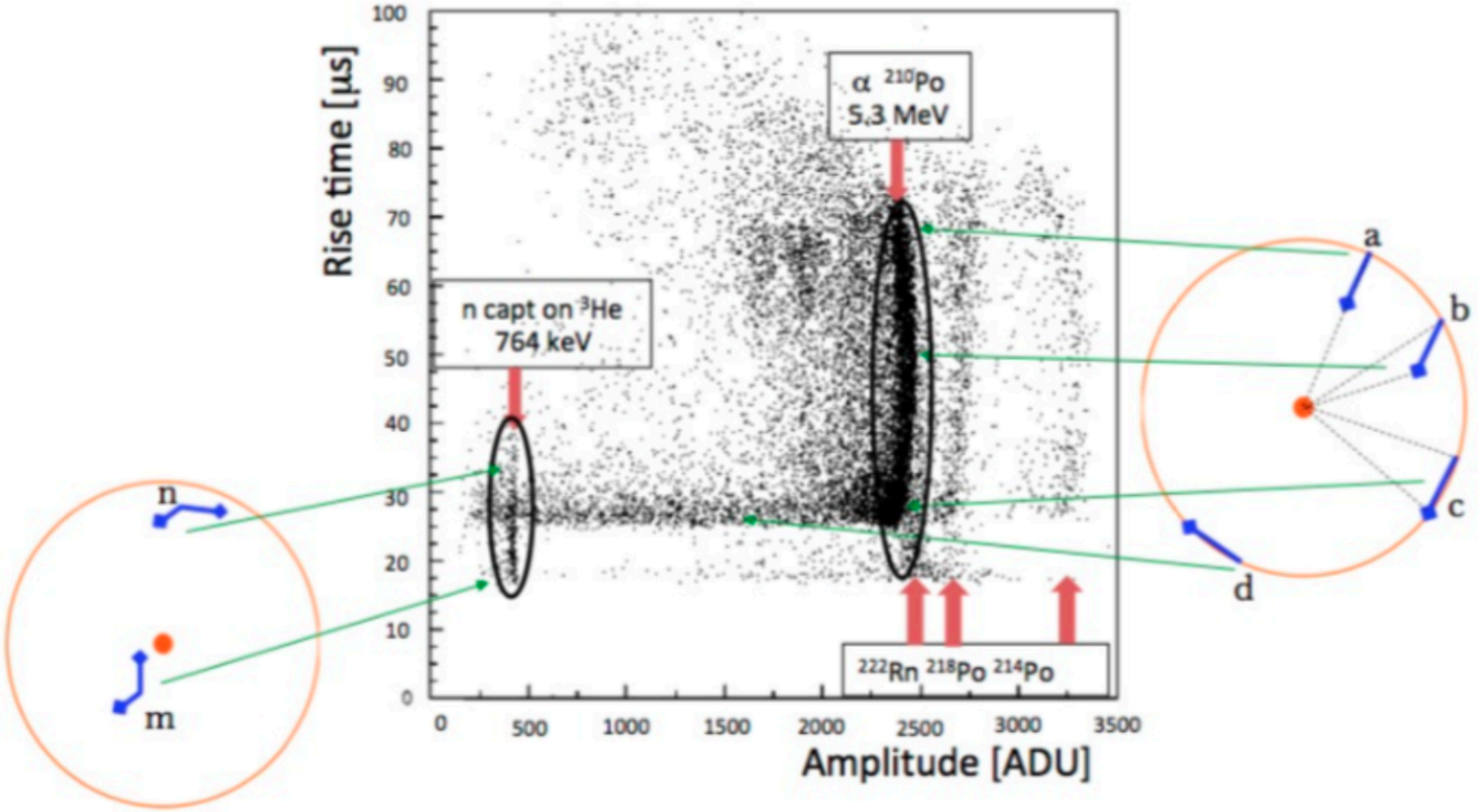
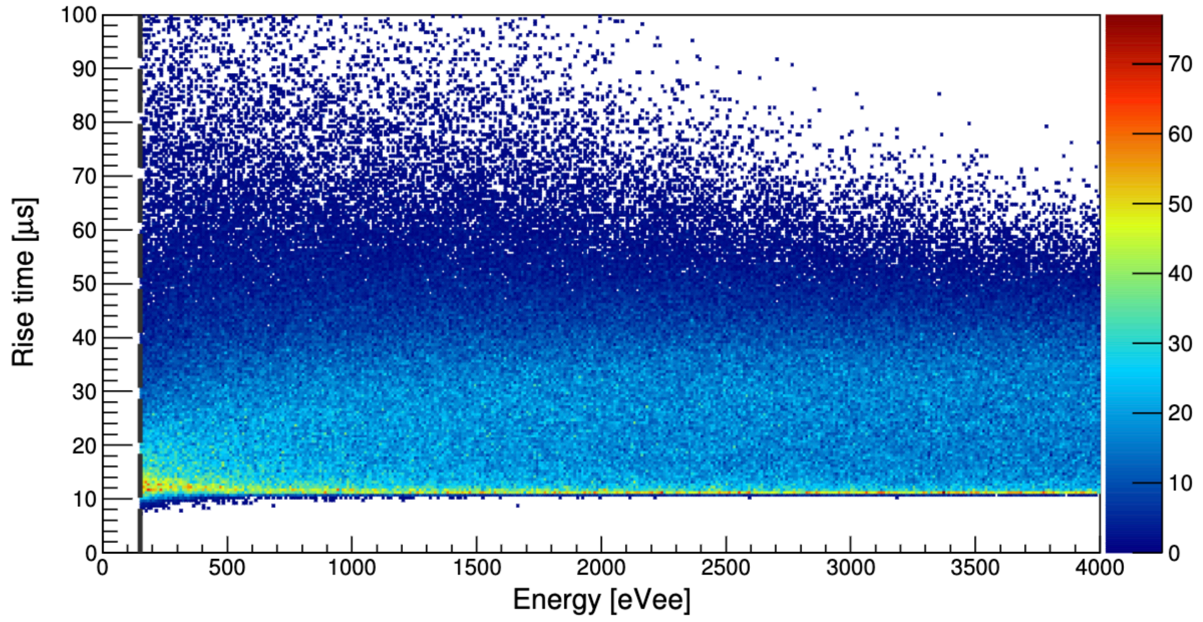
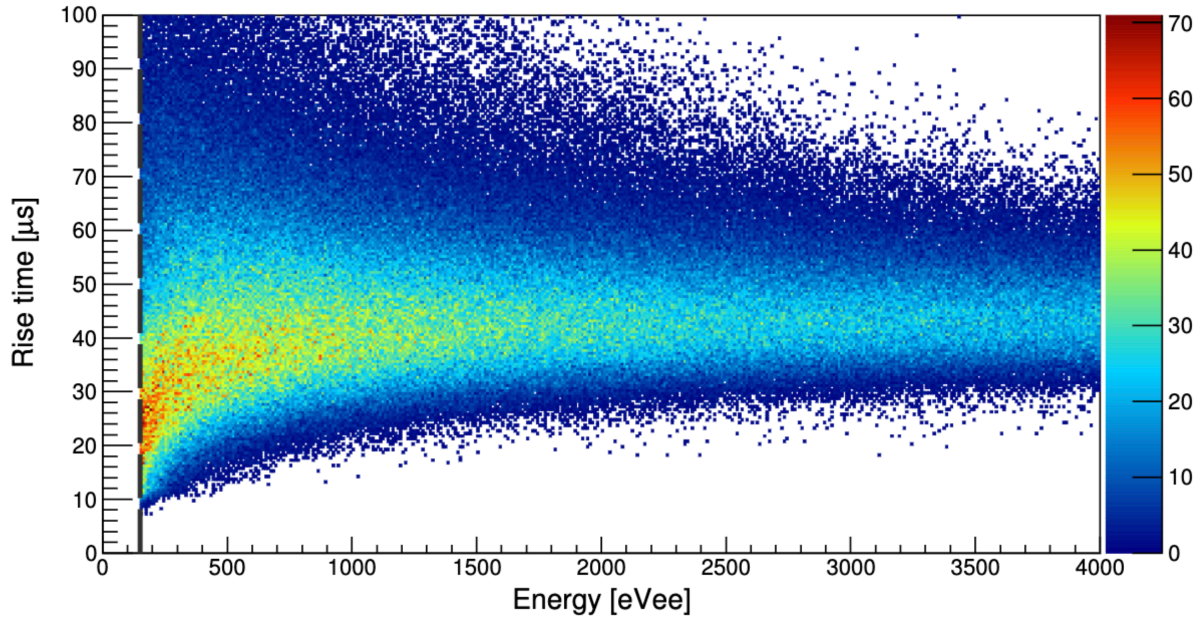


Figure 3.6: Risetime vs Amplitude of the signal for a 200 mbar Ar + CH_4 (2%) + ^{3}He (0.4%) gas mixture. The horizontal line at 27 μs corresponds to surface events. [30]



Bulk events



Surface events

- Q. Arnaud et al. First results from the NEWS-G direct dark matter search experiment at the LSM. Astropart. Phys., 97:54–62, 2018.

Cross Section: $$\sigma = Const.\frac{M_\chi}{\varepsilon(E_{th}, M_\chi)}\left(\frac{R}{M_{\det}}\right)$$

Expected rate

Detection efficiency

Threshold Energy

Detector mass