NUMERICAL CALCULATION OF RPC TIME RESOLUTION

Presented By

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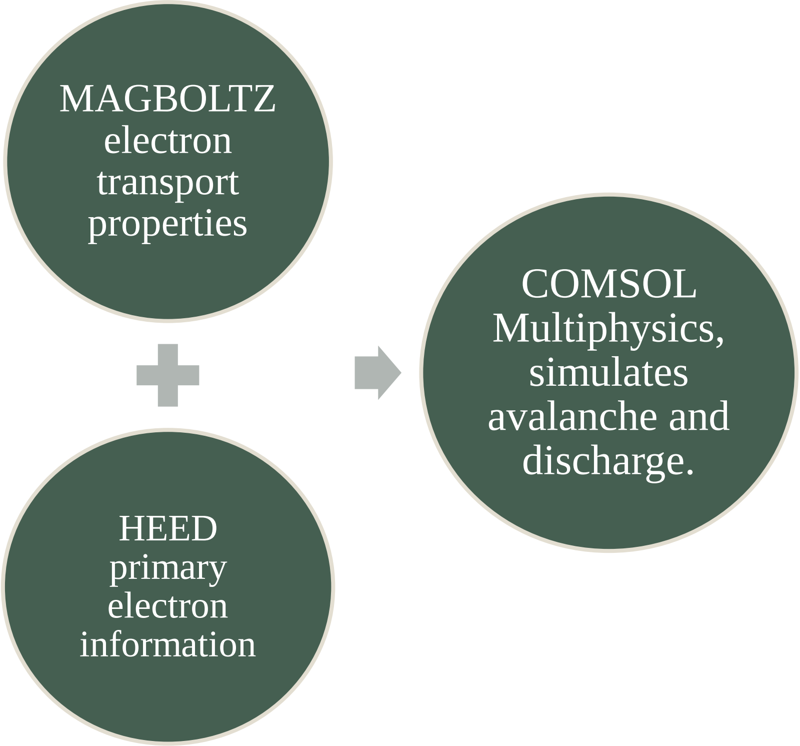
Motivation

- RPC or Resistive Plate Chamber is a particle detector, widely used in different experiments (CMS, ICAL, SHiP, ALICE etc.) for its good spatial resolution (~ mm) and time resolution (sub ns).
- The negative impact of the standard gas mixture used in avalanche mode RPC operation has motivated world-wide search for an alternative eco-friendly gas mixture (NIMA **958** (2020), 162073; JINST **11** (2016) C09018; JINST **16** P07012 (2021); JINST **15** C12006 (2020)).
- But other than being suitable for avalanche mode operation, good time resolution is also important, which is dependent upon the gas properties (JINST **14** P06024 (2019)).
- This is a ongoing work, which tries to develop a numerical model to predict the time resolution for different gas mixtures.

Simulation Framework

- The model is followed from the RD51–NOTE-2011-005, by Paulo Fonte and in RD-51 Open Lectures - 12/12/17–CERN by Filippo Resnati.
- The simulation framework utilizes hydrodynamic approach. The gas molecules, ions and electrons are considered as fluids.



MAGBOLTZ electron transport properties

HEED primary electron information

COMSOL Multiphysics, simulates avalanche and discharge.

Governing Equations

Hydrodynamic equations

$$\frac{\partial n_e}{\partial t} + \vec{\nabla} \cdot (-D\vec{\nabla} n_e + \vec{u}_e n_e) = S_e + S_{ph}$$

$$\frac{\partial n_i}{\partial t} + \vec{\nabla} \cdot (-D\vec{\nabla} n_i + \vec{u}_i n_i) = S_e + S_{ph}$$

$$S_e = (\alpha(\vec{E}) - \eta(\vec{E}))|\vec{u}_e| n_e(\vec{x}, t)$$

$$S_{ph} = Q_e \mu_{abs} \psi_0$$

Equations for photon propagation

$$\vec{\nabla}(-c\vec{\nabla}\psi_0) + a\psi_0 = f$$

$$c = \frac{1}{3\mu_{abs}}$$

$$f = \delta S_e$$

$$a = \mu_{abs}$$

Poisson's equation

$$\vec{E} = -\vec{\nabla} V$$

$$\vec{\nabla}.\vec{D} = \rho_v$$

$$\rho_v = \frac{q}{\epsilon_0}(n_i - n_e)$$

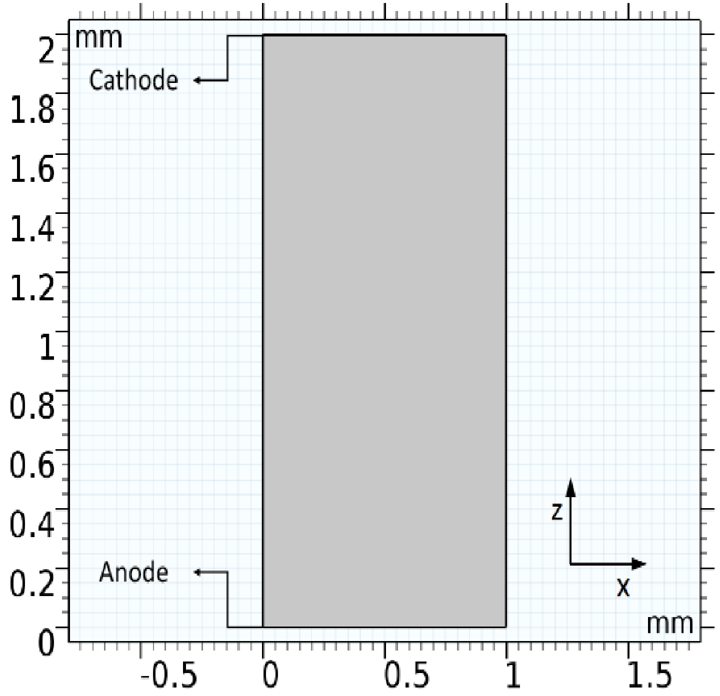
$$\vec{D} = \epsilon_0 \epsilon_r \vec{E}$$

Parameter	Description	Parameter	Description	Parameter	Description
n_e	Electron density	η	Attachment coefficient	μ_{abs}	Photon absorption coefficient
n_i	Ion density	D	Diffusion coefficient	f	Photon source term
$\vec{u}_e$	Electron drift velocity	S_e	Townsend amplification	δ	Photon emitted per ionization
$\vec{u}_i$	Ion drift velocity	S_{ph}	Photo-ionization amplification	c	Photon Diffusion
α	Townsend coefficient	ψ_0	Photon density	ρ_v	Space charge density

Ref: J. Datta et al, *JINST* **15** C12006 (2020), J. Capeillere et al, *J. Phys. D* **41** (2008) 234018.

Simulation Model

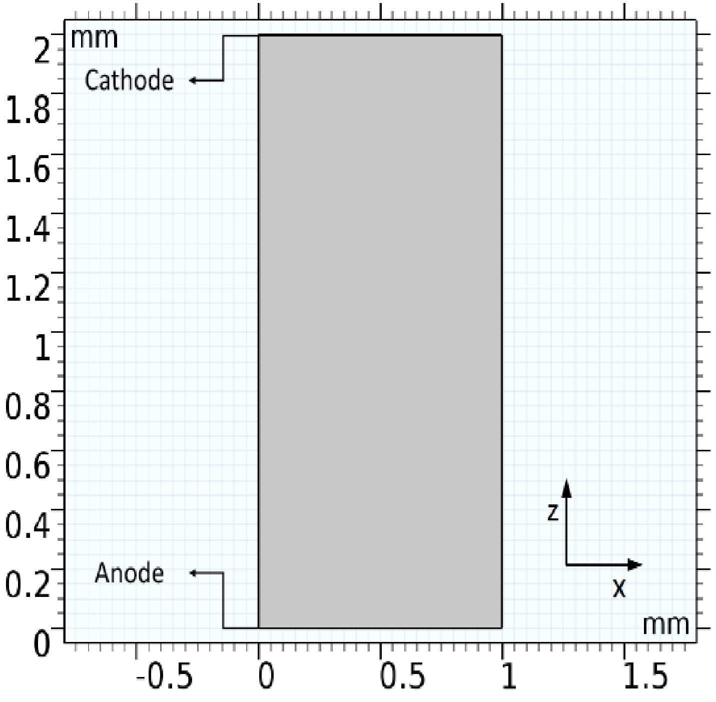
- We have considered a 2D model for the avalanche simulation in RPC.
- The gas mixture chosen for the work is R134a (95.2%) : i-C_4H_{10} (4.5 %) : SF_6 (0.3%).
- As the electrodes do not play any direct role in the avalanche propagation, so they were not incorporated in the simulation geometry.
- The induced current $i(t) = q_e n_0 e^{\alpha x(t)} \vec{v}.\overrightarrow{W}$, following Ramo's theorem.
- For this electrode of 2.8 mm thickness with relative permittivity of 8 considered.



Simulation geometry

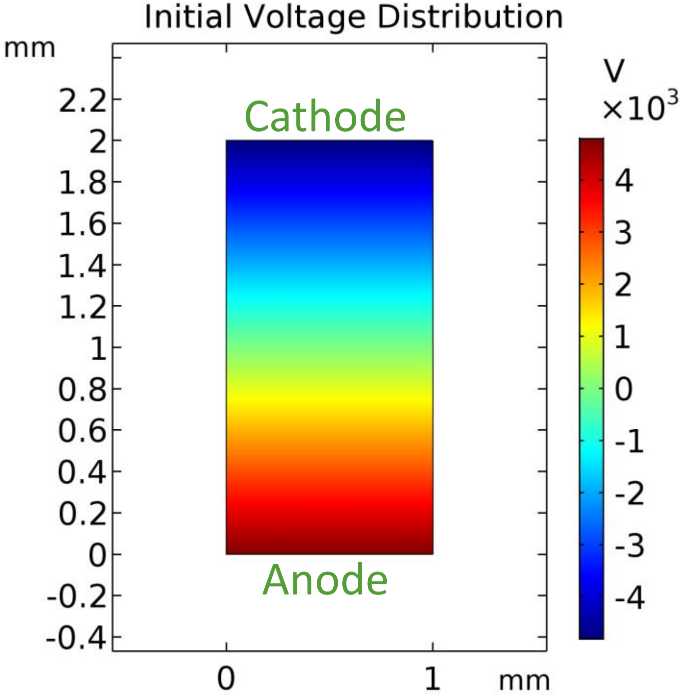
Boundary Conditions

- To take into account that electrons and ions get lost through the anode and cathode respectively, drift of the charged species through the respective electrodes are assumed.
- The two boundaries other than the cathode and anode are assumed to be open to incorporate the loss of the charged species in the whole RPC volume.
- Usually glass or Bakelite do not have scintillating properties so the photon flux from them has been assumed to be zero.
- As photons can be propagate out of the simulated volume, so the boundaries other than the electrodes are assumed to be open for them.

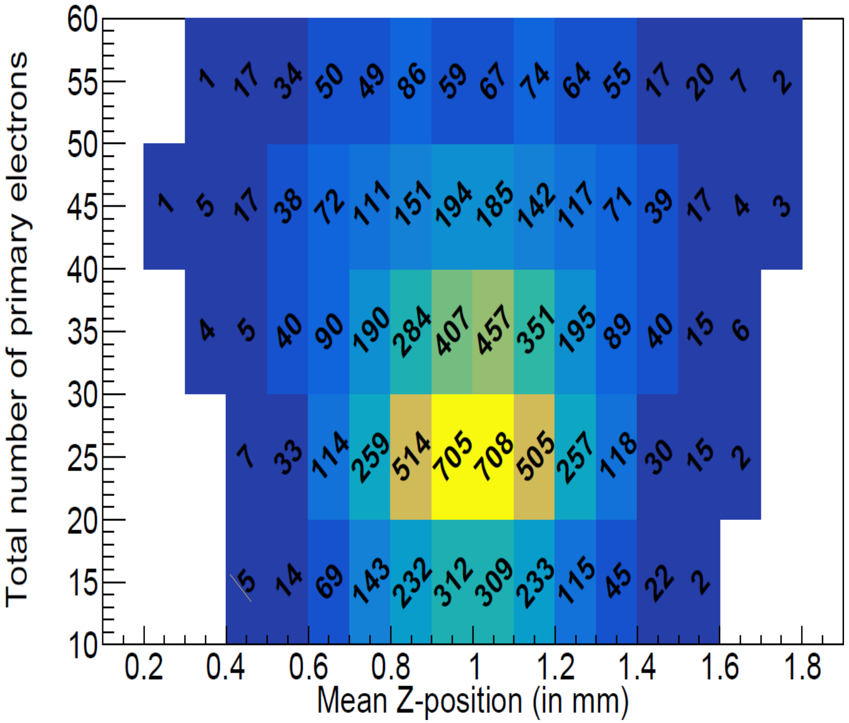


Simulation geometry

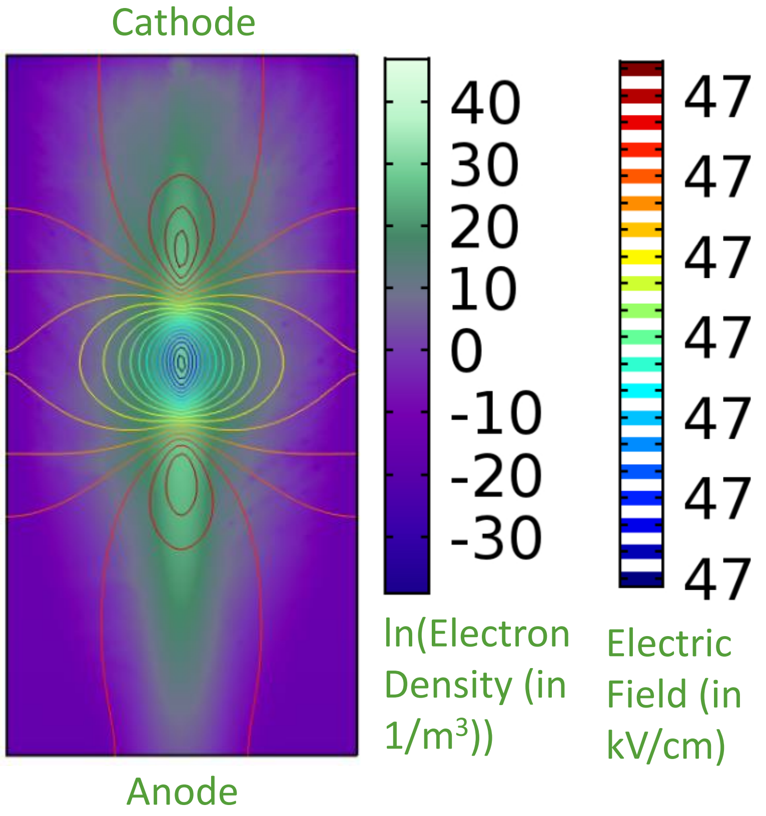
Avalanche Initiation



According to Ammosov et al. (*NIMA* 401 (1997) 217-228), and S. Das et al. (arXiv:2204.12986), the applied voltage is assumed to drop across the gas gap.

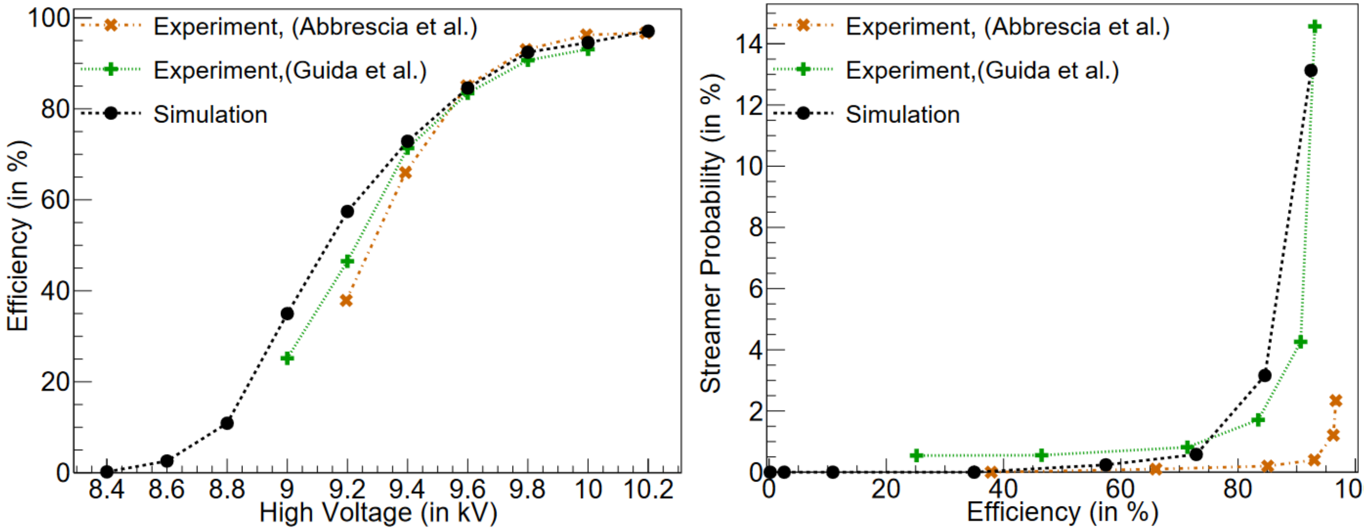


Distribution of events as function of number of primary electrons and mean Z-position for 10000 events, simulated using HEED.



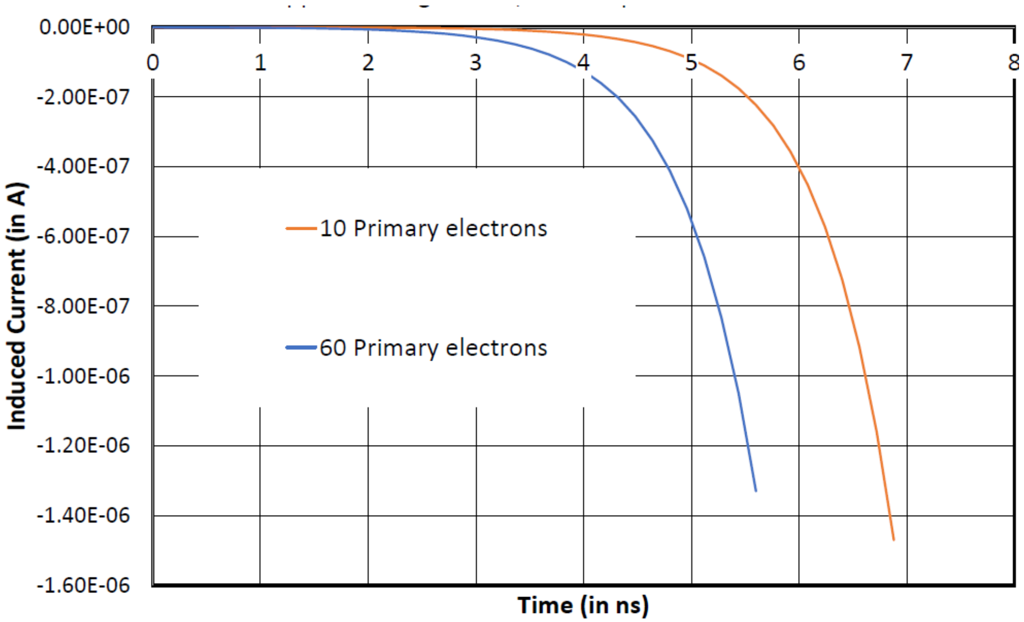
A gaussian distribution of primary electrons is used as the seed to initiate the avalanche.

Efficiency and Streamer Probability

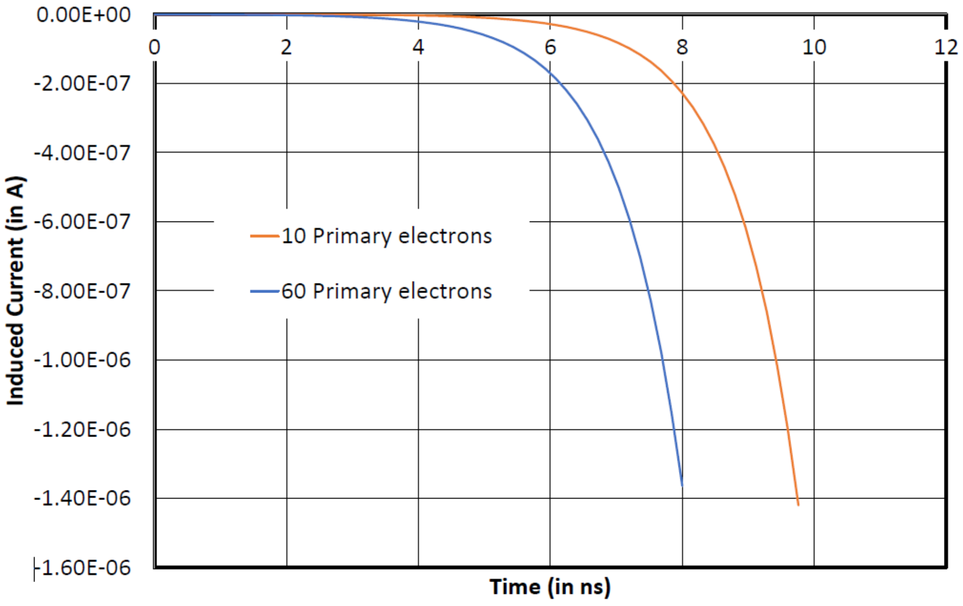


- For the same gas mixture efficiency and streamer probability have been calculated (JINST **16** P07012 (2021) and compared with other experimental results (NIMA **958** (2020), 162073; JINST **11** (2016) C09018).
- The close comparison between simulated and experimental data establishes the capability of the model to simulate avalanche in RPC.

Simulated Current



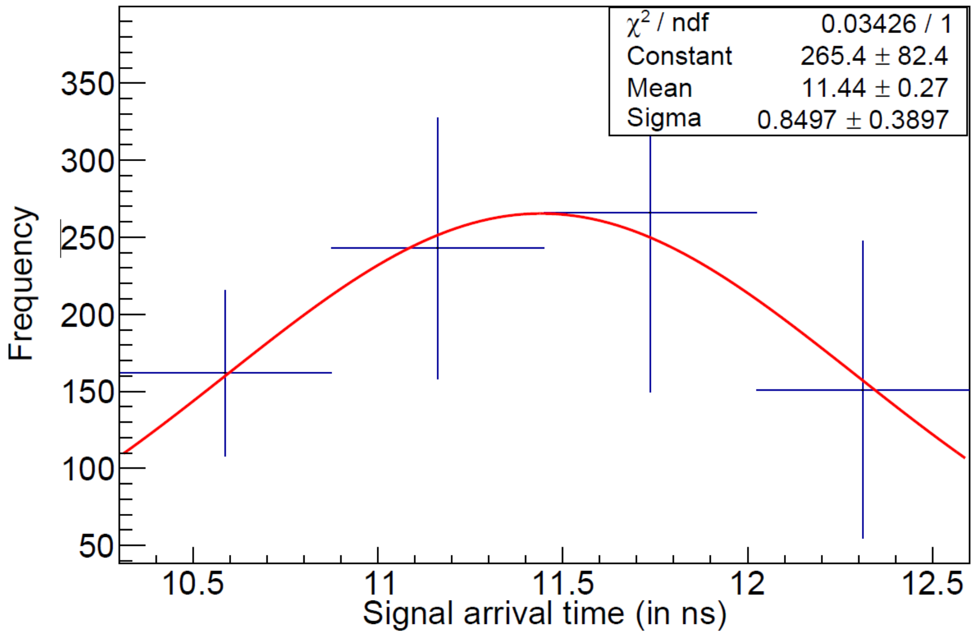
Applied HV 9.8 kV



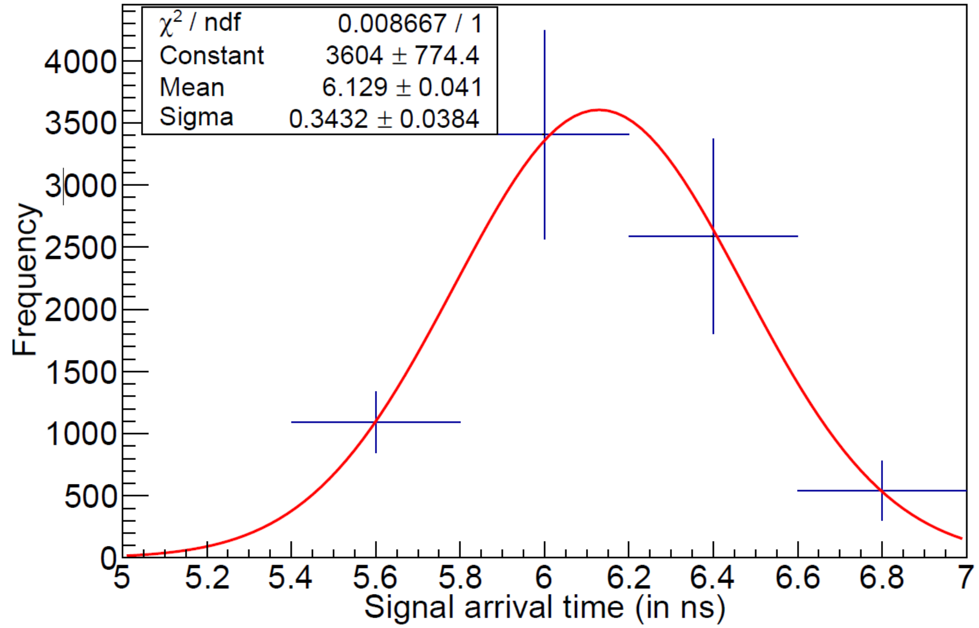
Applied HV 9.2 kV

- The induced current for different primary electrons and applied high voltages are shown here.
- No electronics noise is included in the simulation.
- The threshold is set to 1.25μA, which is equivalent to a 5 mV signal acquired across a 50Ω resistance after a pre-amplifier gain of 80.
- The simulation stops once the threshold is reached. This time is denoted as arrival time.

Result



Applied HV 8.8 kV



Applied HV 9.8 kV

- Number of events as function of arrival time is plotted and fitted with Gaussian distribution.
- Here the distribution of arrival times of pulses for two high voltages are shown as example. The left panel is for 8.8 kV and the right panel is for 9.8 kV.

Continued…

Applied electric field (in kV/cm)	Time resolution (this work)
44	0.85 ns
46	0.63 ns
47	0.55 ns
48	0.43 ns
49	0.34 ns

- The time resolution is the standard deviation of the distribution of arrival times for that voltage.
- The time resolution of a 2 mm gas gap RPC operated with the standard gas mixture is ~ 1ns at the working voltage (~ 49 kV/cm) (NIMA 500 (2003) 144-162; NIMA 456 (2000) 77-81).

Discussion

- In the simulation effect of gain fluctuation is absent also the effect of electronics is missing.
- Work on including these parameters are underway.
- In future we plan to compare the results with experimental data.

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THANK YOU