Simulation of photon-assisted streamers

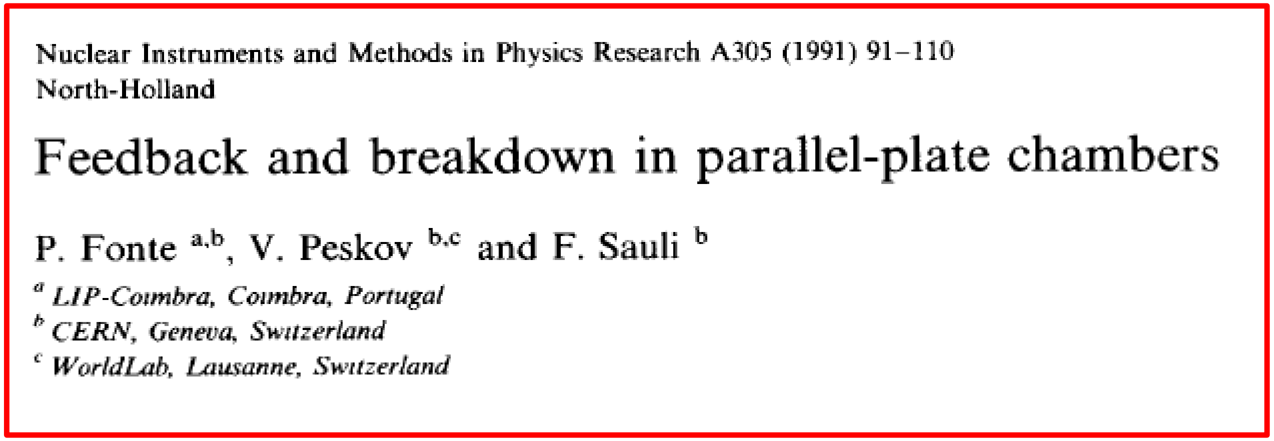
(a short description of the phenomenon in detectors… with no conclusions)

Diego Gonzalez Diaz (Uludag University)

11/03/2016, CERN

cautionary note: this is not my work!

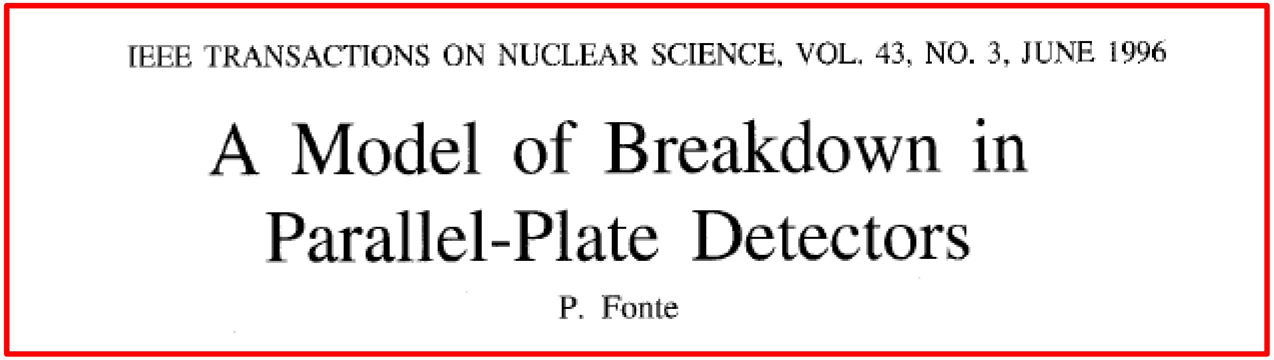
Materials used


Nuclear Instruments and Methods in Physics Research A305 (1991) 91–110
North-Holland

Feedback and breakdown in parallel-plate chambers

P. Fonte [a,b], V. Peskov [b,c] and F. Sauli [b]

[a] *LIP-Coimbra, Coimbra, Portugal*
[b] *CERN, Geneva, Switzerland*
[c] *WorldLab, Lausanne, Switzerland*


IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 43, NO. 3, JUNE 1996

A Model of Breakdown in Parallel-Plate Detectors

P. Fonte


Nuclear Instruments and Methods in Physics Research A 661 (2012) S168–S171

RPC simulation in avalanche and streamer modes using transport equations for electrons and ions

Ahmad Moshaii *, Larousse Khosravi Khorashad, Mehdi Eskandari, Somayeh Hosseini

Department of Physics, Tarbiat Modares University, P.O. Box 14115-175, Tehran, Iran

Calculation of streamer development in MPGDs in an axisymmetric hydrodynamic model

P. Fonte: https://indico.cern.ch/event/89325/session/0/contribution/16

Some ‘bread-and-butter’ phenomenology

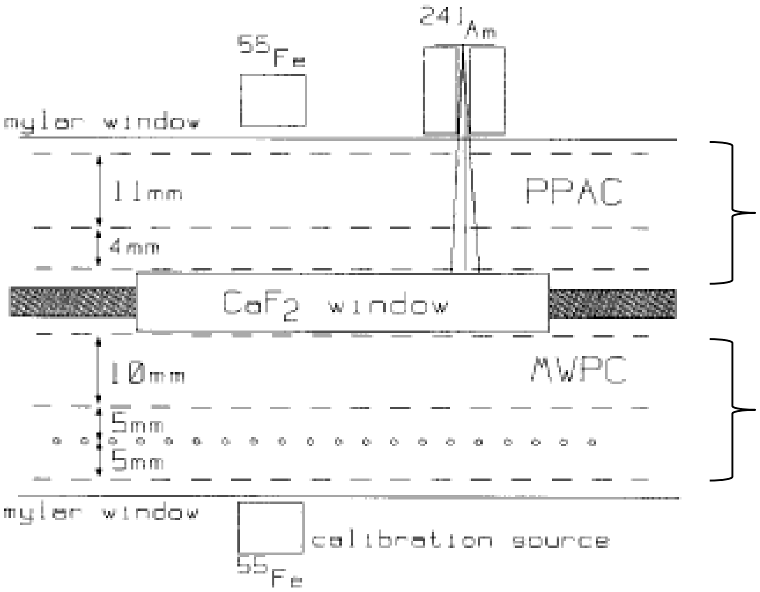
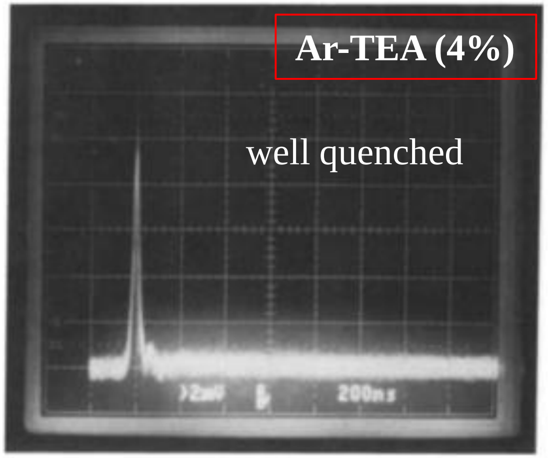


Fig. 1. Schematic view of the experimental setup.

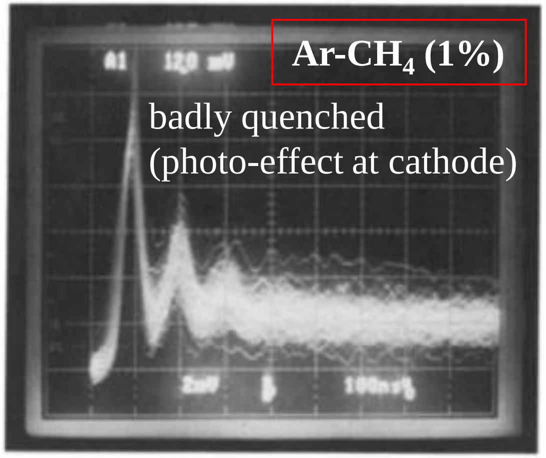
used to study breakdown

used to measure light emitted



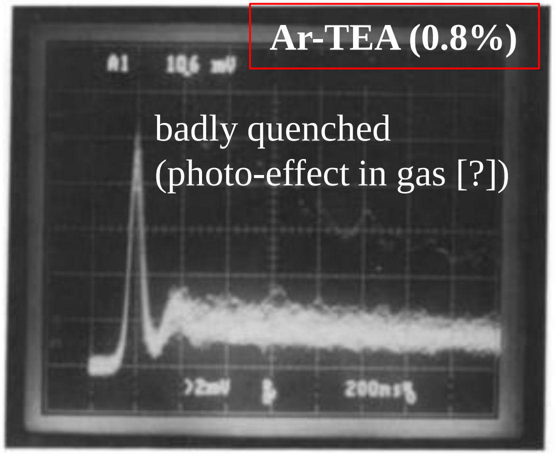
Ar-TEA (4%)

well quenched



Ar-CH_4 (1%)

badly quenched
(photo-effect at cathode)



Ar-TEA (0.8%)

badly quenched
(photo-effect in gas [?])

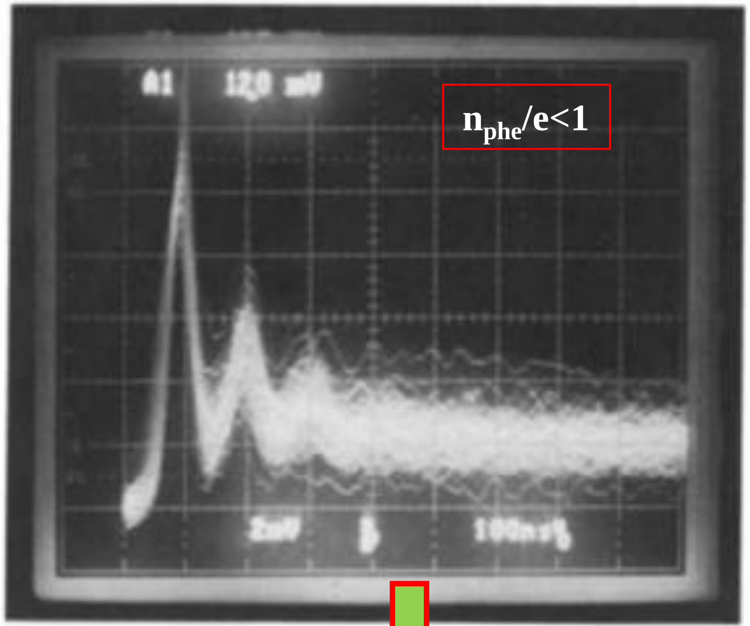
P. Fonte, V. Peskov, F. Sauli, NIM A, 305(1991)91

‘Slow’ breakdown, I

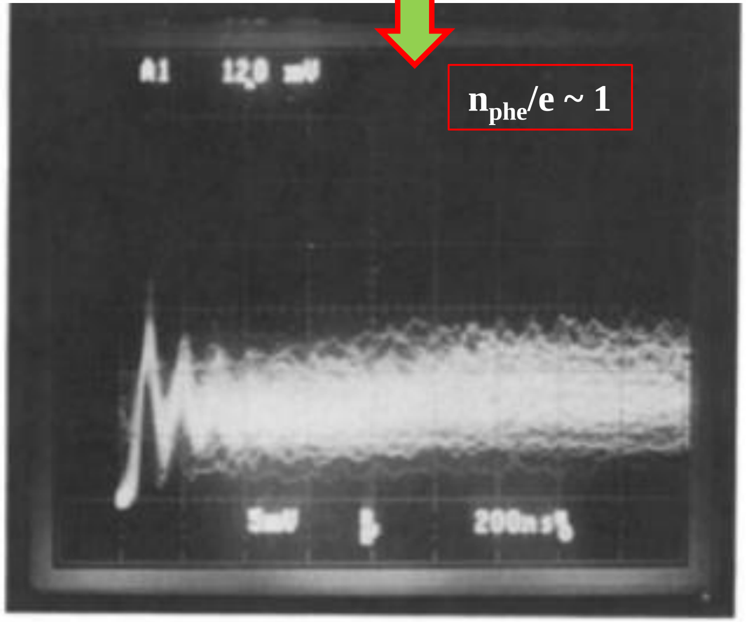
popularly known as:

- ‘Slow’ breakdown
- ‘Generation’ breakdown
- ‘Paschen/Townsend’ breakdown
- ‘Photon-feedback’

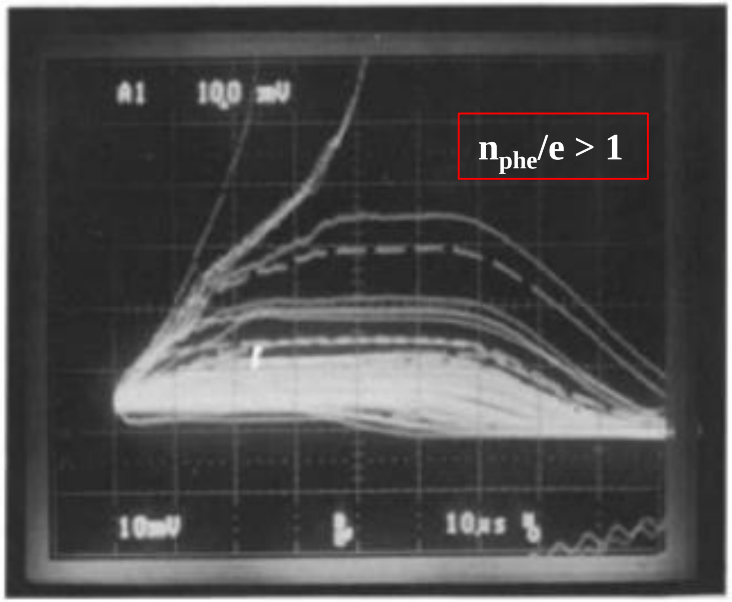
Ar-CH$_4$ (~1%)



$n_{phe}/e<1$



$n_{phe}/e \sim 1$



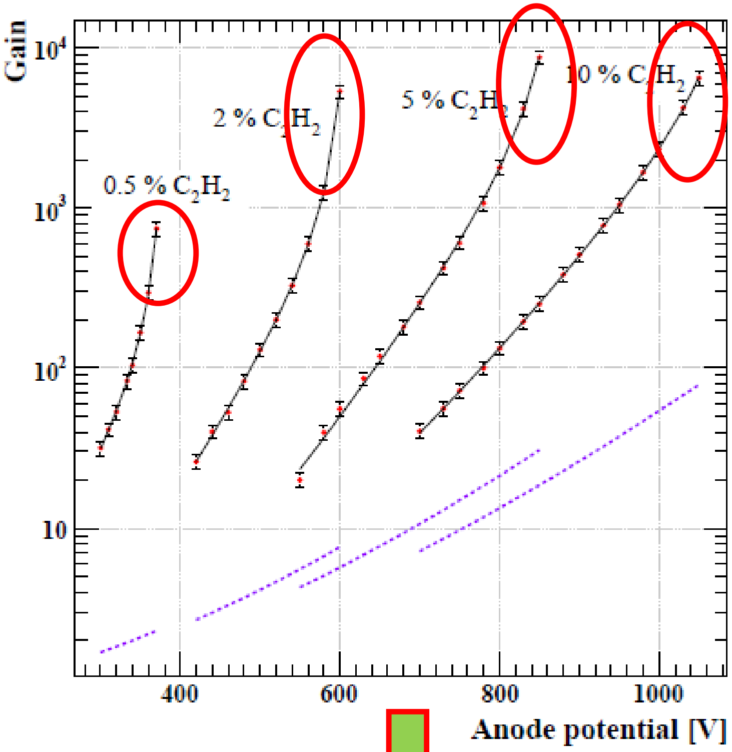
$n_{phe}/e > 1$

In the same paper… the parameter $n_{phe}/e=\beta$ is obtained from the gain deviations from an ~exponential law:

$$G(E) \cong \exp(A + BE)$$

$$G := G/(1-\beta G)$$

‘Slow’ breakdown, II

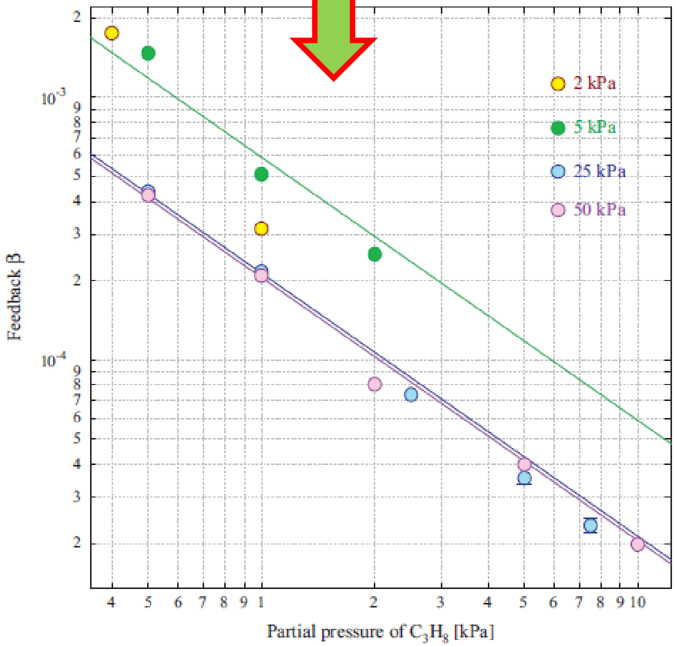


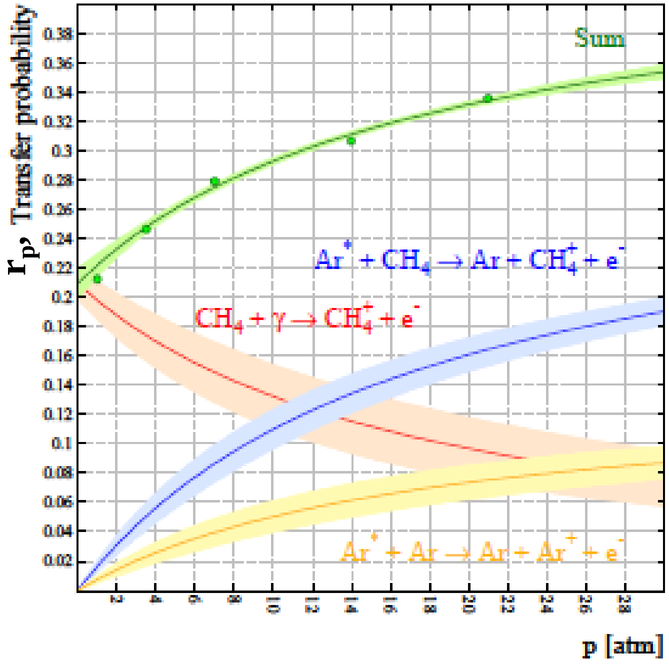
Modern way:

Number of fit parameters reduced from 3 to 2, and they [r_p, β] can be (usually) interpreted.

$$G = \exp \int_{\text{tube}}^{\text{anode}} dr\, \alpha(E(r)) \frac{\sum \nu_i^{\text{ion}}(E(r)) + \sum r_i \nu_i^{\text{exc}}(E(r))}{\sum \nu_i^{\text{ion}}(E(r))}$$

$$G := G/(1 - \beta G)$$



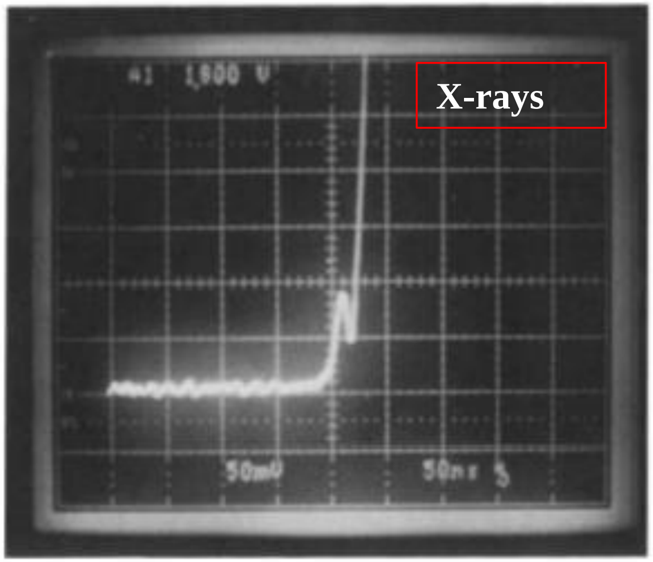


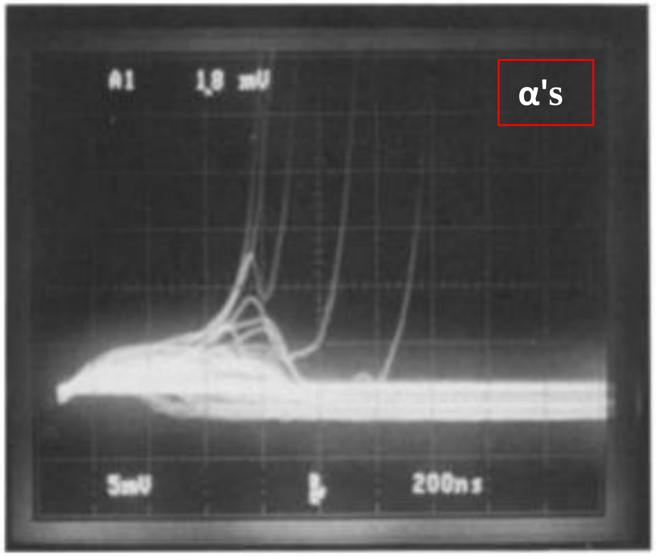
O. Sahin et al., JINST(2010)P05002
O. Sahin et al., NIM A 718(2013)432

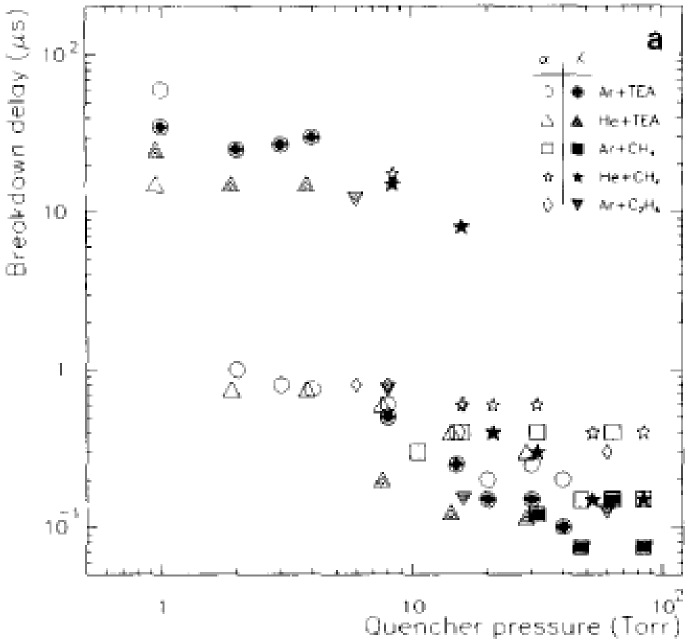
‘Fast’ breakdown

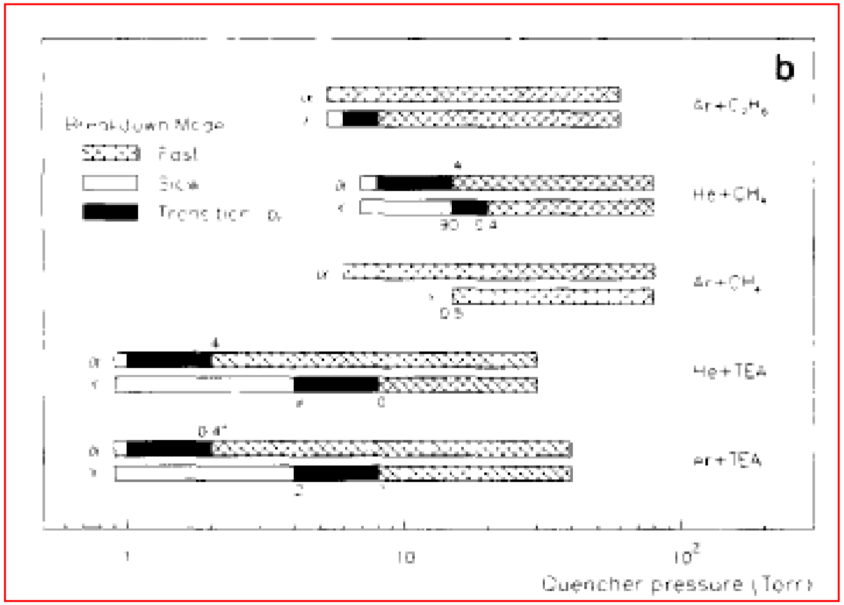
popularly known as:

- ‘Streamer’ mechanism





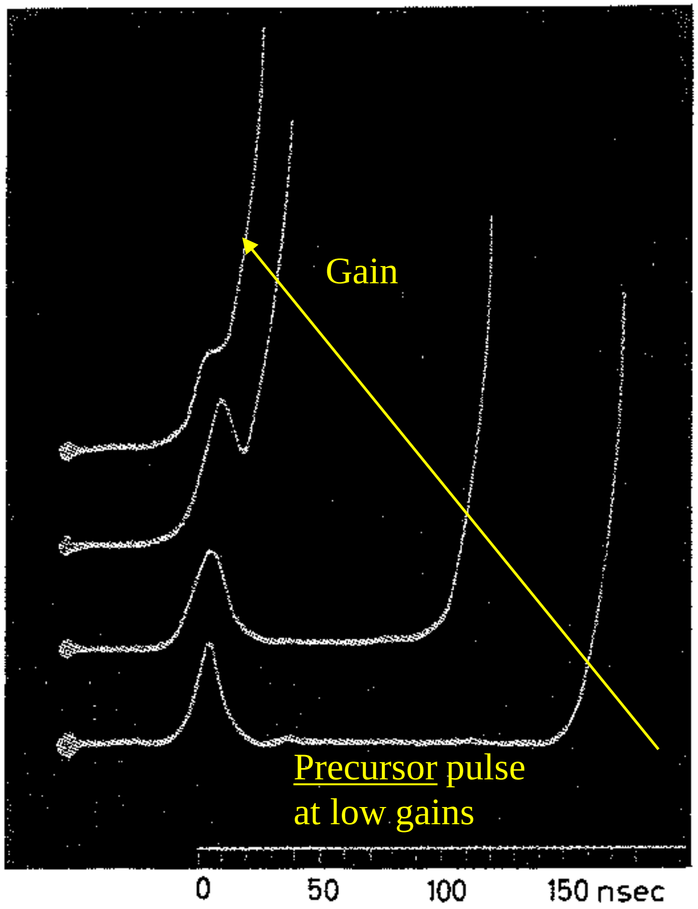




‘Fast’ breakdown - experimental evidence in detectors

Very fast process featuring a “precursor” pulse

[RAE64]



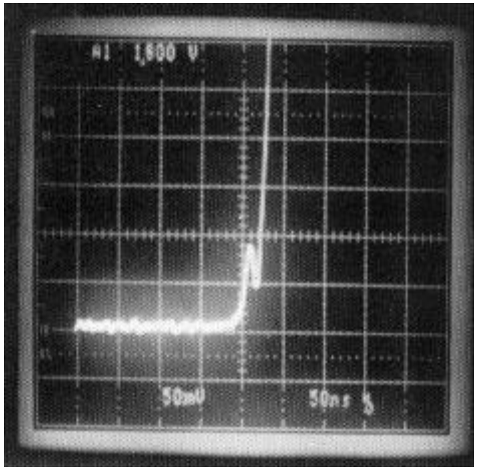
Gain

Precursor pulse
at low gains

Figure 5.14. Current oscillograms of static breakdown in methylal. Optical method. $E/p = 64{\cdot}4$, $pd = 230$ Torr cm, $d = 0{\cdot}8$ cm, $T_{-} = 90$ nsec $RC = 5$ nsec[36]

PPAC

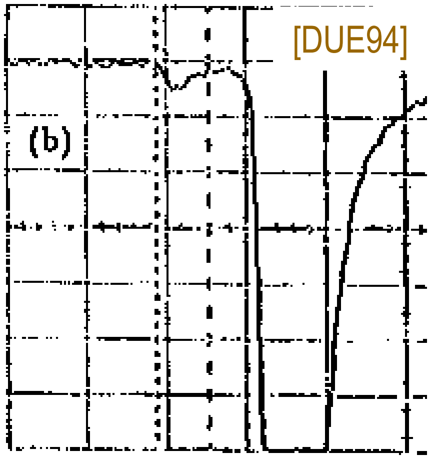
[FON91]



A signature of low-gain
cathode streamer-only
breakdown

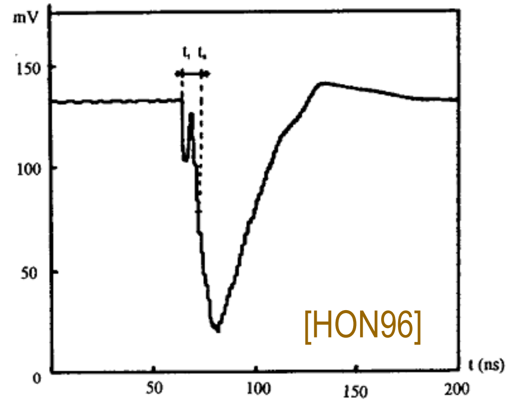
It certainly exists, but it may not be the only mechanism, or it may be the result of different physical processes.

RPC



[DUE94]

single-wire (SQS mode)



[HON96]

Fig. 1. The pulse shape of the SQS electrical signal $V = 2.45$ kV, Methylal/(Methylal + Ar) = 16.6%.

‘Fast’ breakdown (‘classical interpretation’)

$$\frac{\partial n_e(x,t)}{\partial t} + W_e\frac{\partial n_e}{\partial x} = S + \left(\alpha|W_e| - \frac{\partial W_e}{\partial x}\right)n_e; \qquad (1)$$

$$\frac{\partial n_i(x,t)}{\partial t} = S + \alpha|W_e|n_e; \qquad (2)$$

1D hydro equations for electrons and ions with photon-feedback term

$$\frac{\partial n_{ph}(x,t)}{\partial t} = \delta|W_e|n_e; \qquad (3)$$

$$S(x,t) = \frac{Q}{2\lambda}\int_{-\infty}^{\infty}\frac{\partial n_{ph}(x',t)}{\partial t}\Omega(x-x') \cdot e^{-|x-x'|/\lambda}\,dx'; \qquad (4)$$

$$\Omega(x-x') = \frac{1}{2}\left(1 - \frac{(x-x')}{\sqrt{R_0^2 + (x-x')^2}}\right)$$

photon-feedback term

$$\frac{E(x)}{2\pi} = \int_{-x}^{0}\rho(x+x')(-1-g(x'))\,dx' + \int_{0}^{d-x}\rho(x+x')(1-g(x'))\,dx';$$

$$g(x') = \frac{x'}{(x'^2+R_0^2)^{1/2}}; \qquad \rho(x) = e(n_i(x) - n_e(x))$$

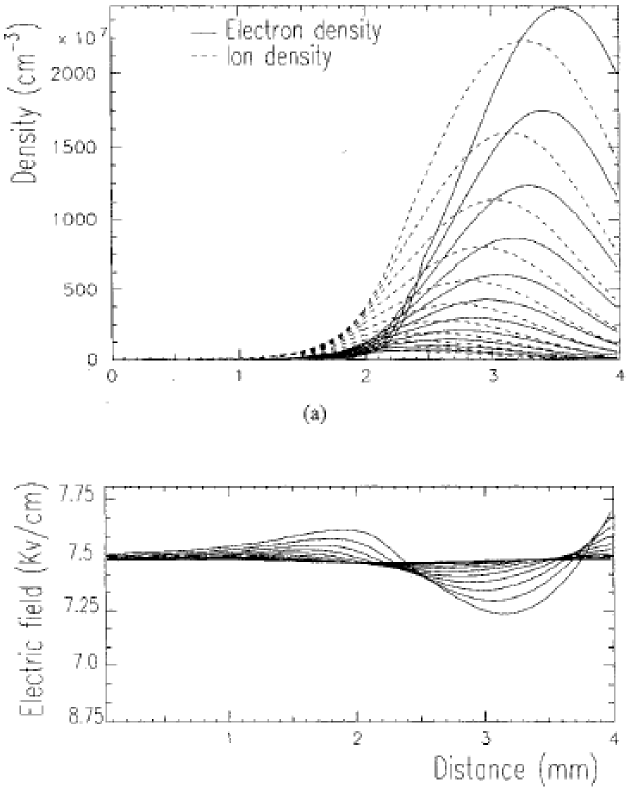
$$\frac{E(x,t)}{2\pi} = -\int_{-(d+x)}^{-x}\rho(x+x')(-1-g(x')) \cdot dx' + \int_{-x}^{0}\rho(x+x')(-1-g(x'))\,dx' + \int_{0}^{d-x}\rho(x+x')(1-g(x'))\,dx' - \int_{d-x}^{2d-x}\rho(x+x')(1-g(x'))\,dx' \qquad (5)$$

Space-Charge cylinder

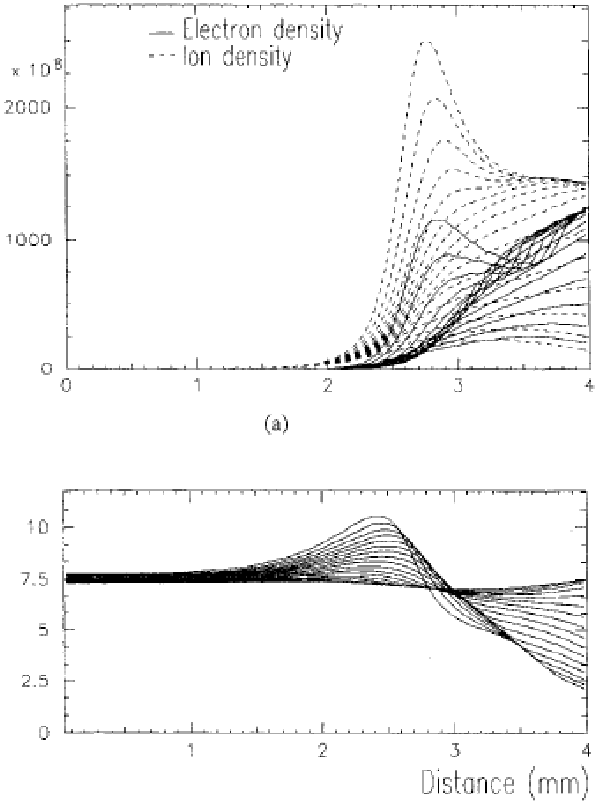
p	20 Torr	
A, B, k	Corresponding to the mixture Ar + TEA	
$W_{\max}$	5 cm/μs	
E_v	300 V/cm	
M	10^{-6}	?
λ	500 μm	
N_{e0}	100 electrons	
R_0	300 μm	?
σ_0	300 μm	
X_0	−900 μm	
G_0	4×10^6	
d	4 mm.	

parameters

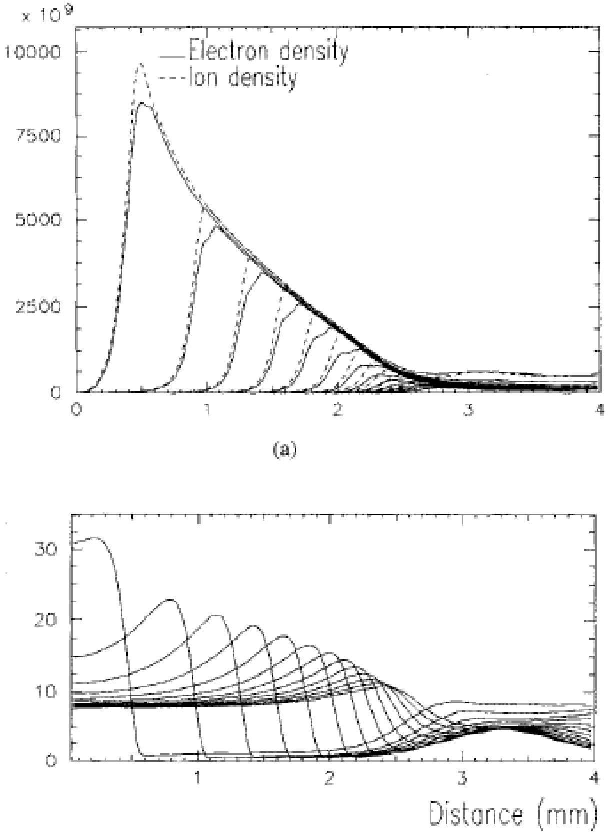
‘Fast’ breakdown (‘classical interpretation’)



‘proportional region’ [56ns-76ns]

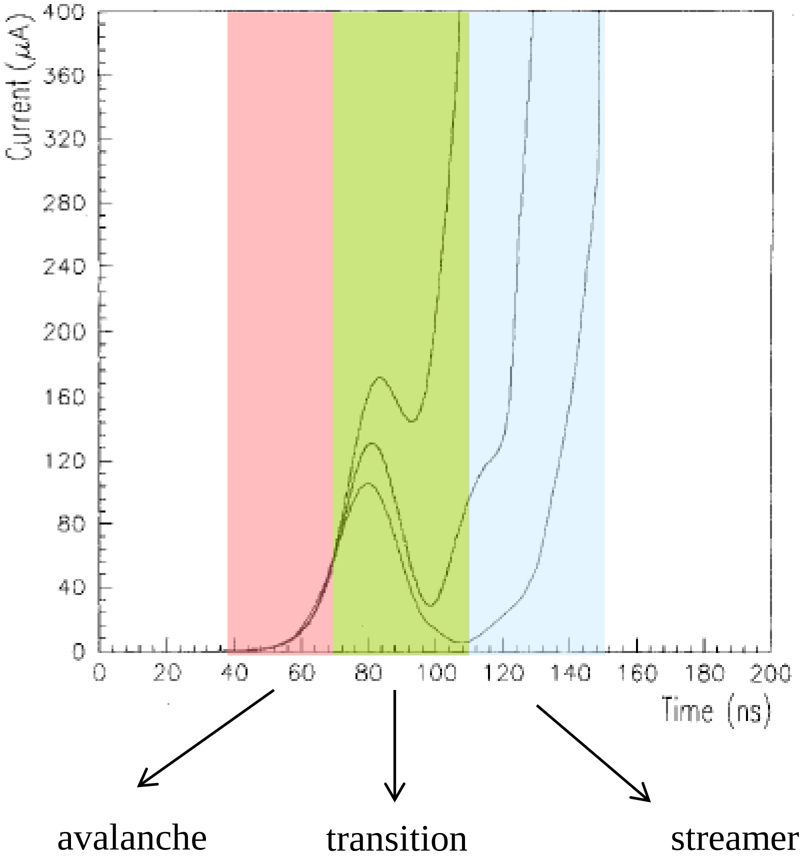


‘transition region’ [76ns-106ns]



‘propagation region’ [106ns-130ns]

‘Fast’ breakdown (‘classical interpretation’)



Main (technical) objections:

- Many free parameters, some difficult to experimentally access (spectrum of emission, photo-ionization x-section)

->getting better these days.

- Hydro solutions neglect avalanche or ionization fluctuations, but those will likely trigger breakdown earlier than the average solution to the equations.
- Approximate: transverse dynamics becomes a parameter.

->Probably solvable with present computing power.

Other objections:

- No quantitative comparison with data.
- Does not seem to reconcile well with the fact that improvements on maximum gain with quencher concentrations above some ~1% are very modest.
- Contrary to common wisdom, it does not need of Space-Charge to progress, except if invoking enhanced charge-recombination at low fields, making the process even more difficult to describe.
- It does not seem to be general enough to explain most known systematics on MPGD detectors.

GEM

hole: 60 µm

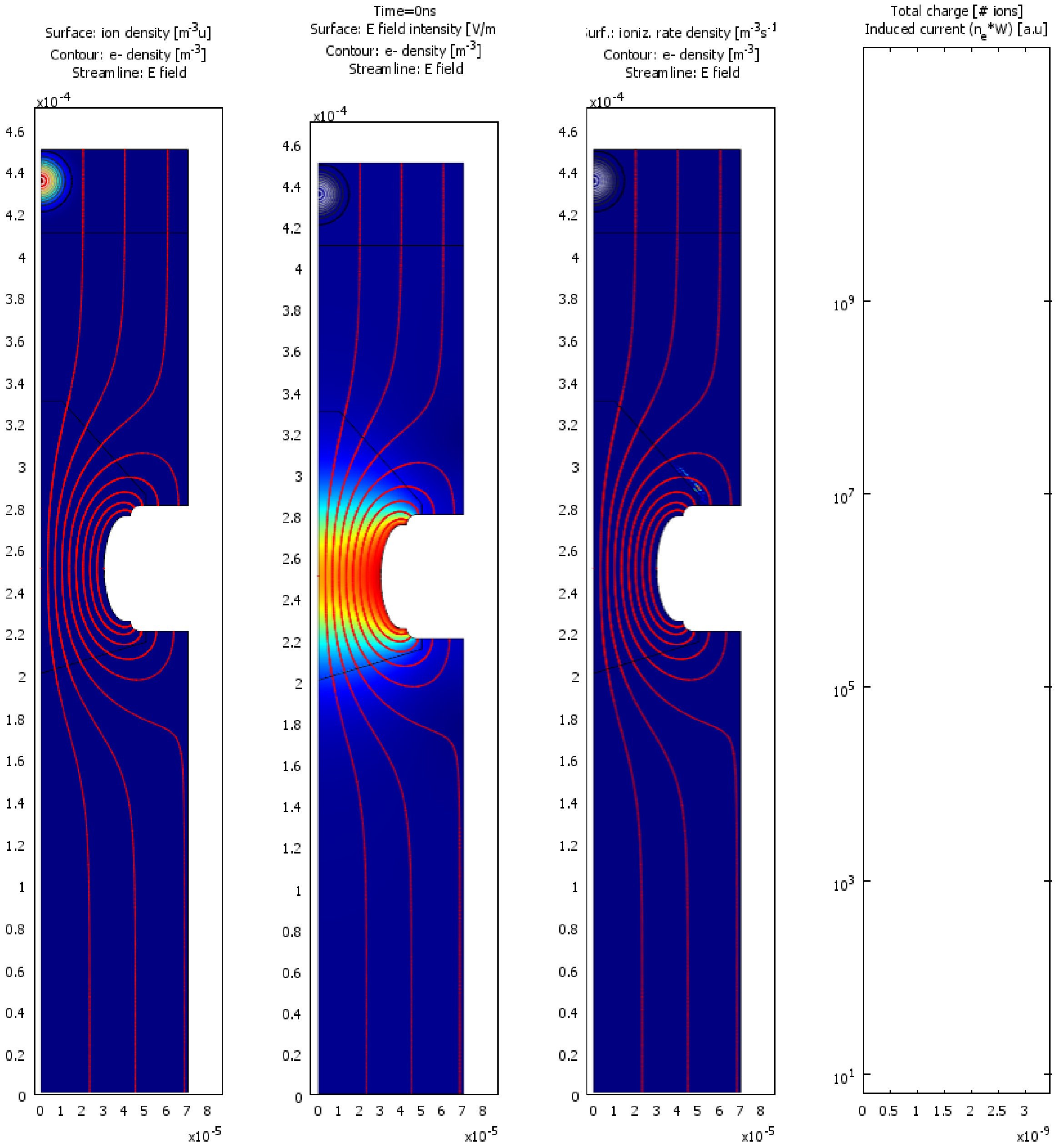
gap: 100 µm

N_0=100 e^-

V=1250V

Diffusion-assisted streamer (no photons)

Unfortunately, the presence of precursor is not an unambiguous fingerprint of the underlying physics mechanism!



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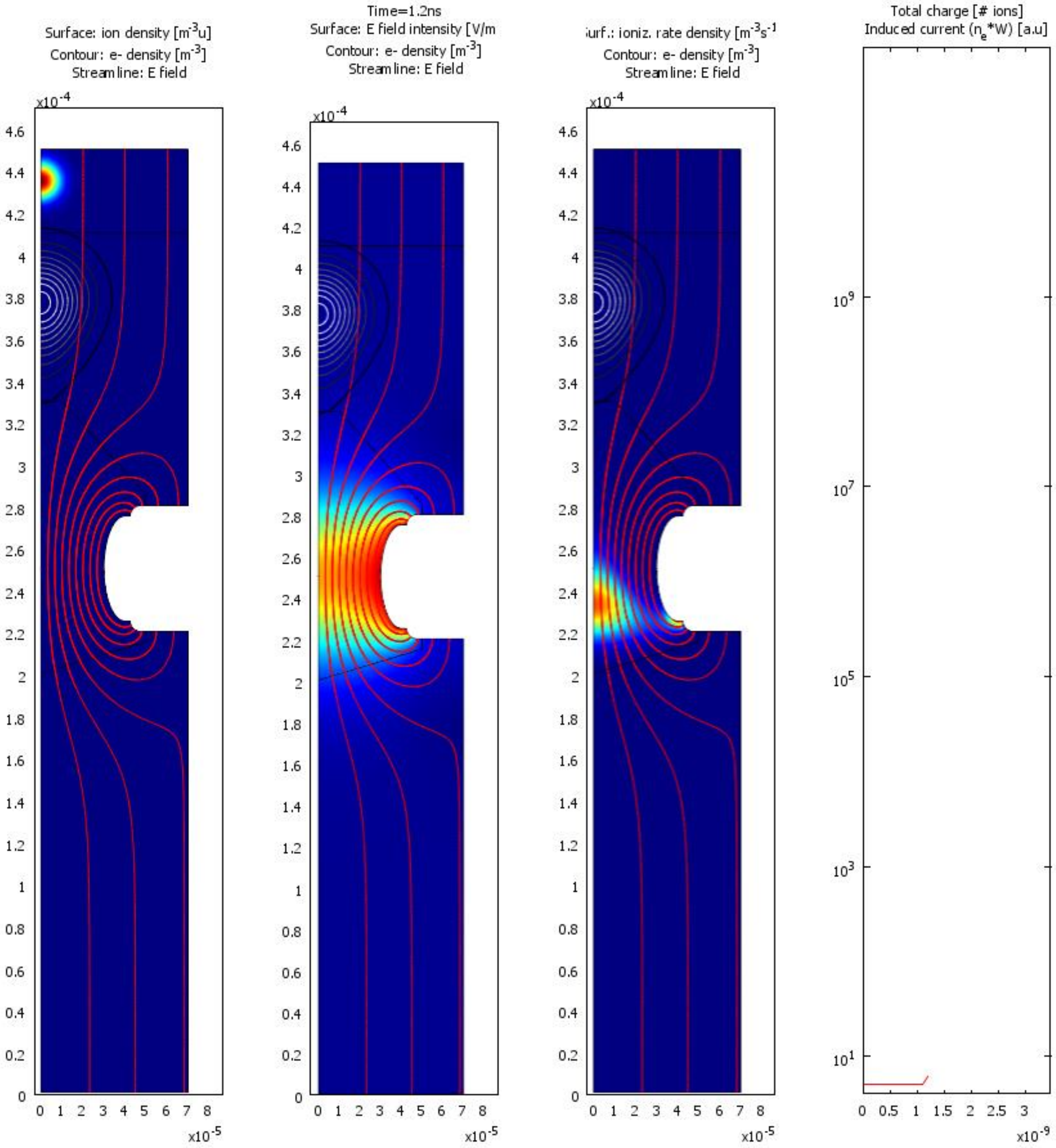
V=1250V



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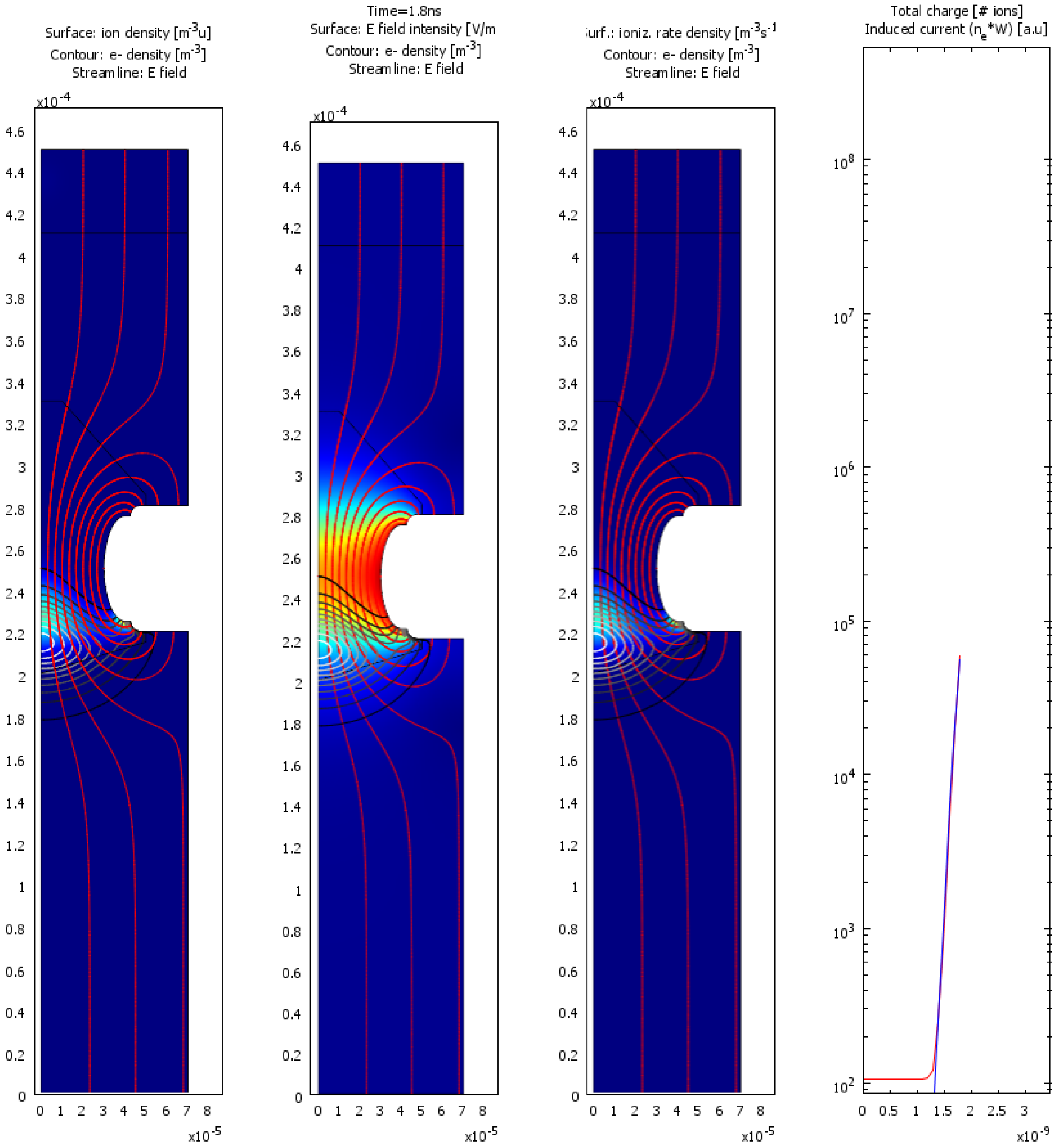

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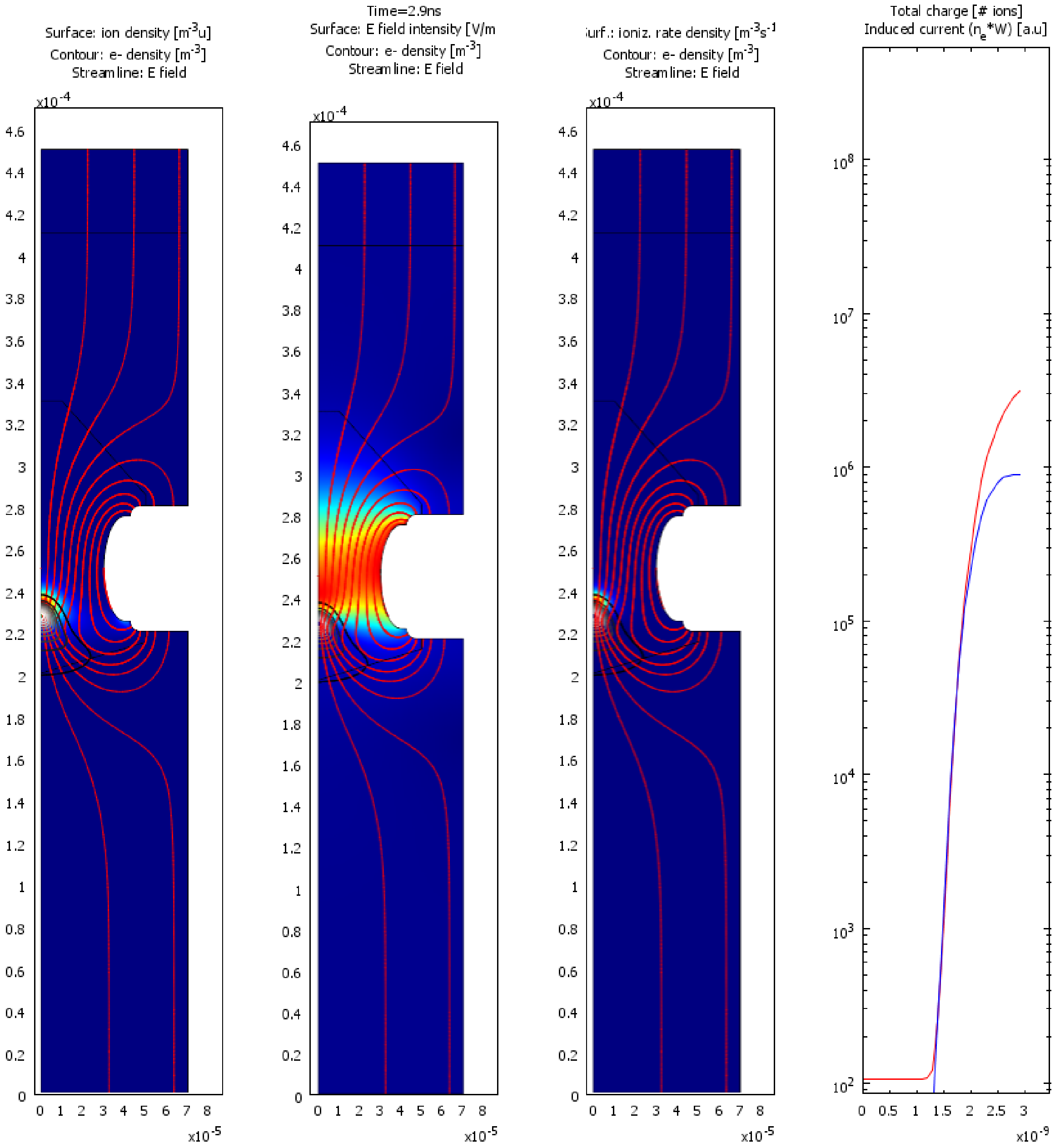

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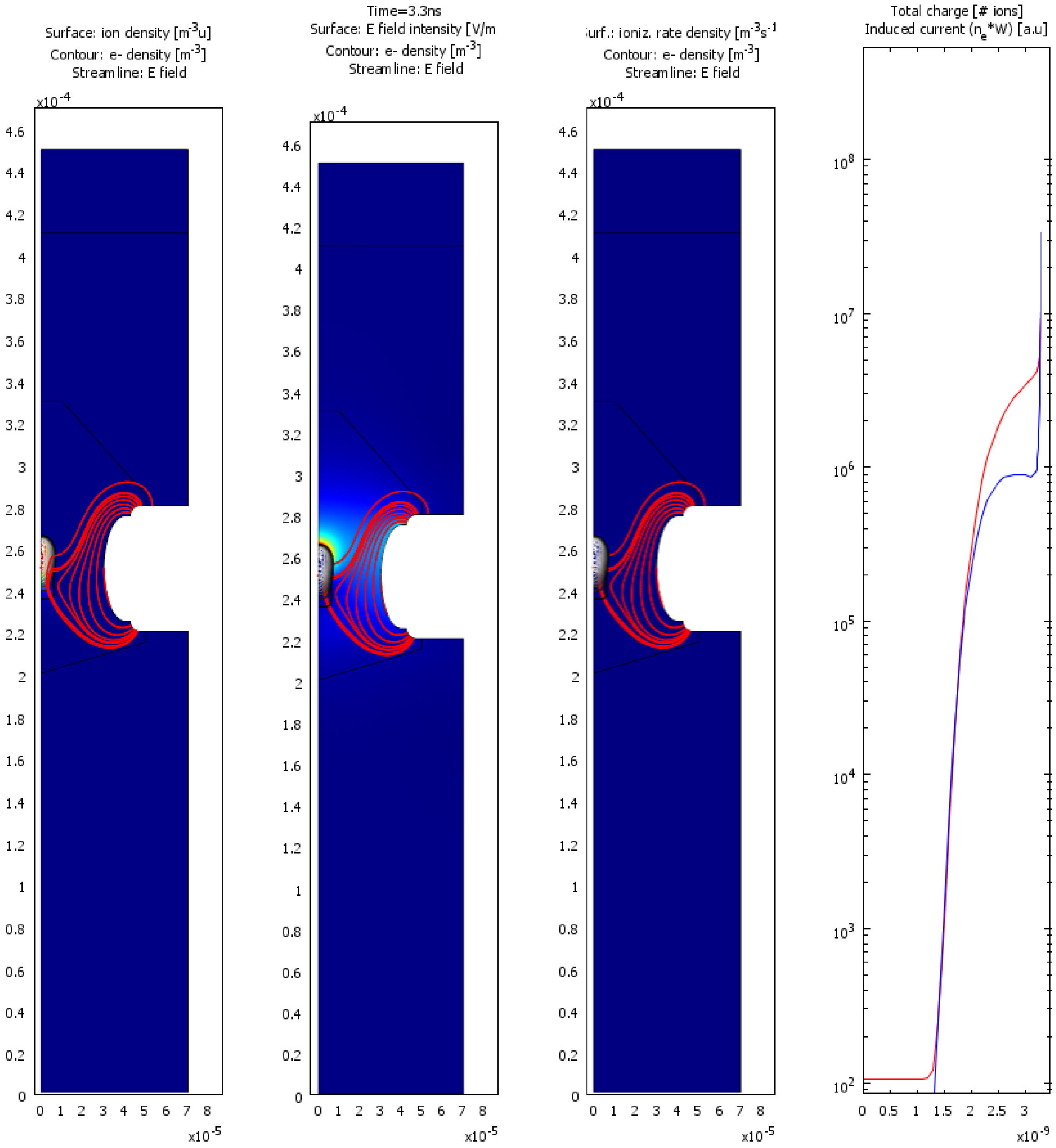

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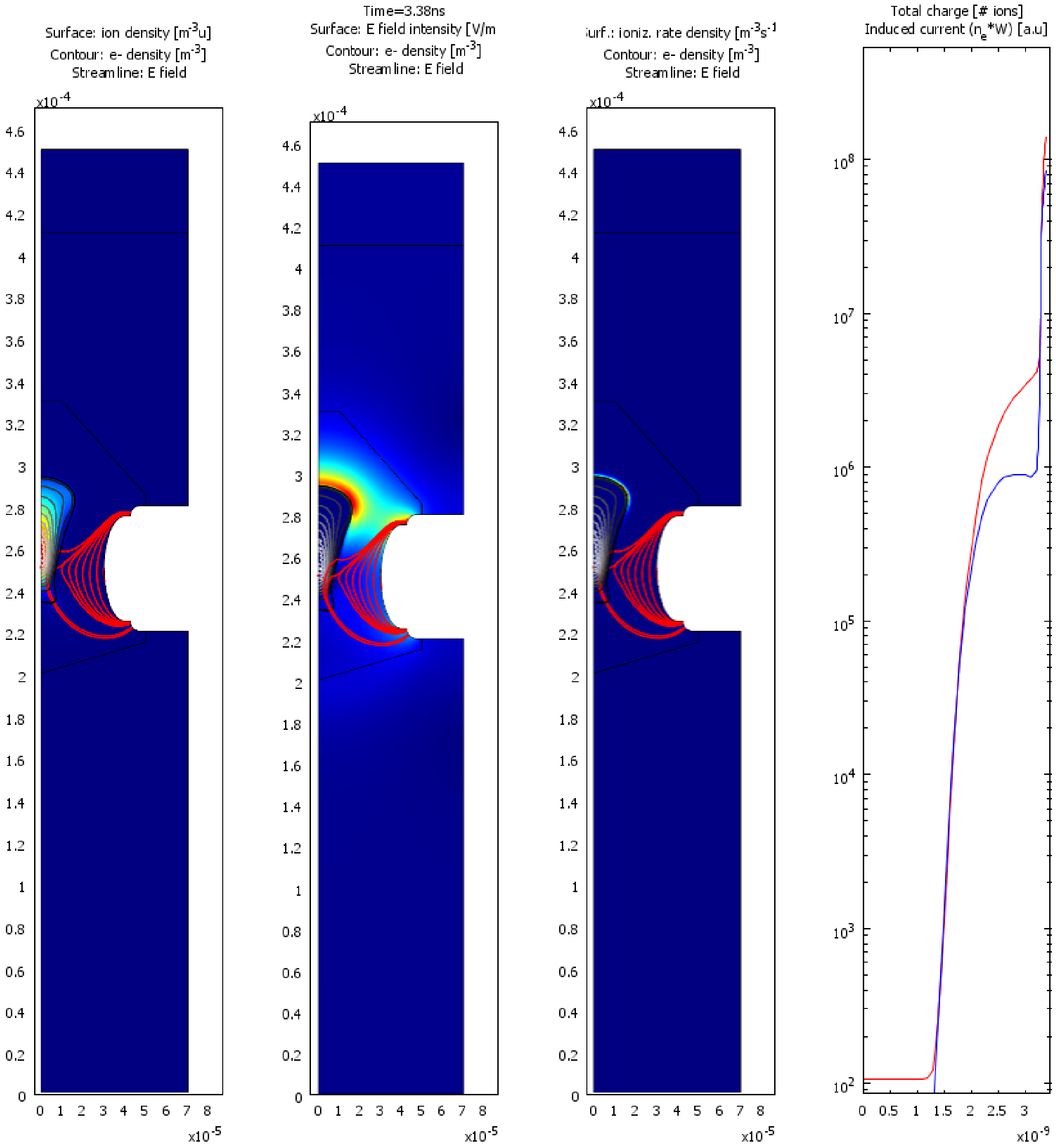

Diffusion-assisted streamer
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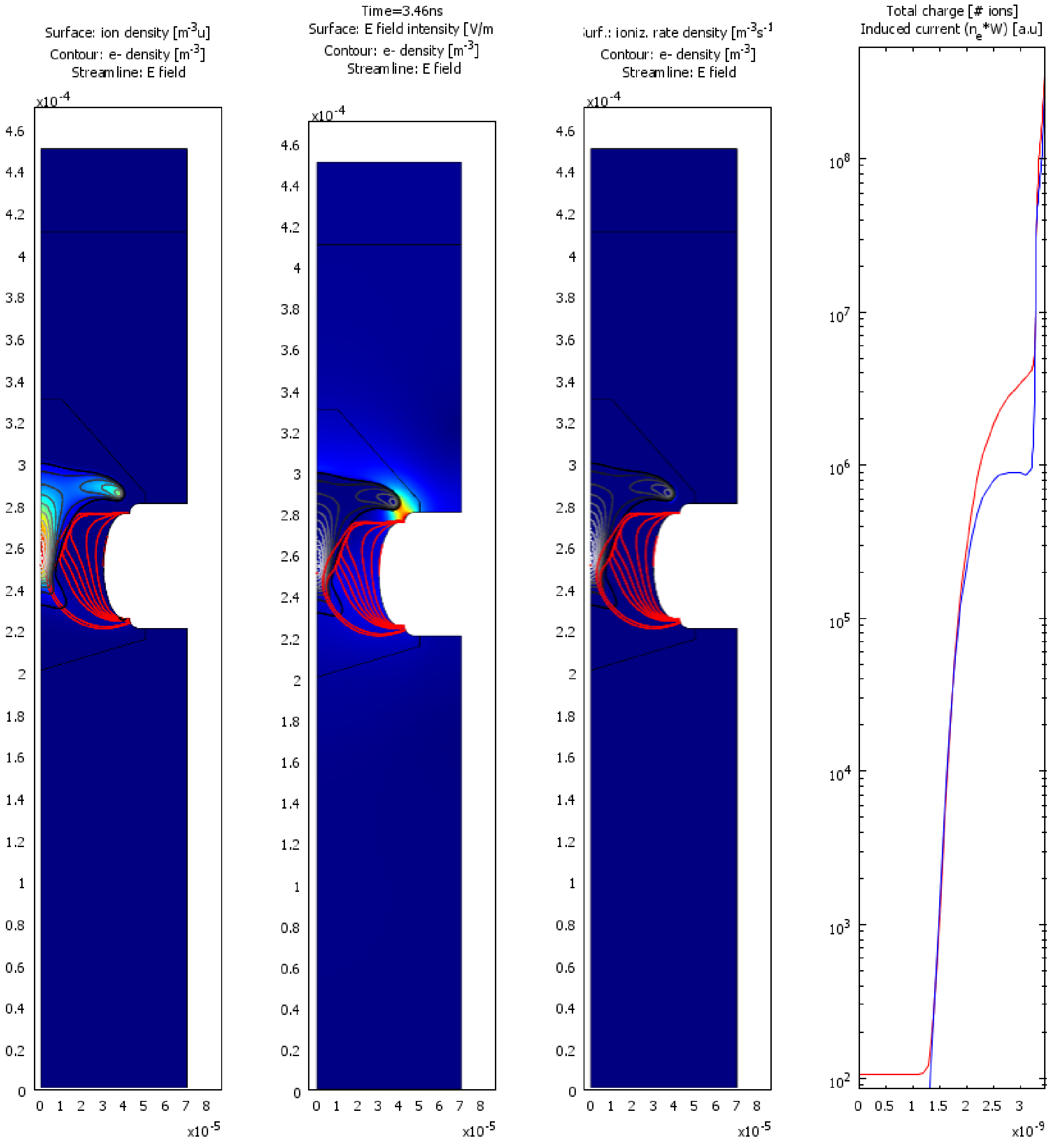
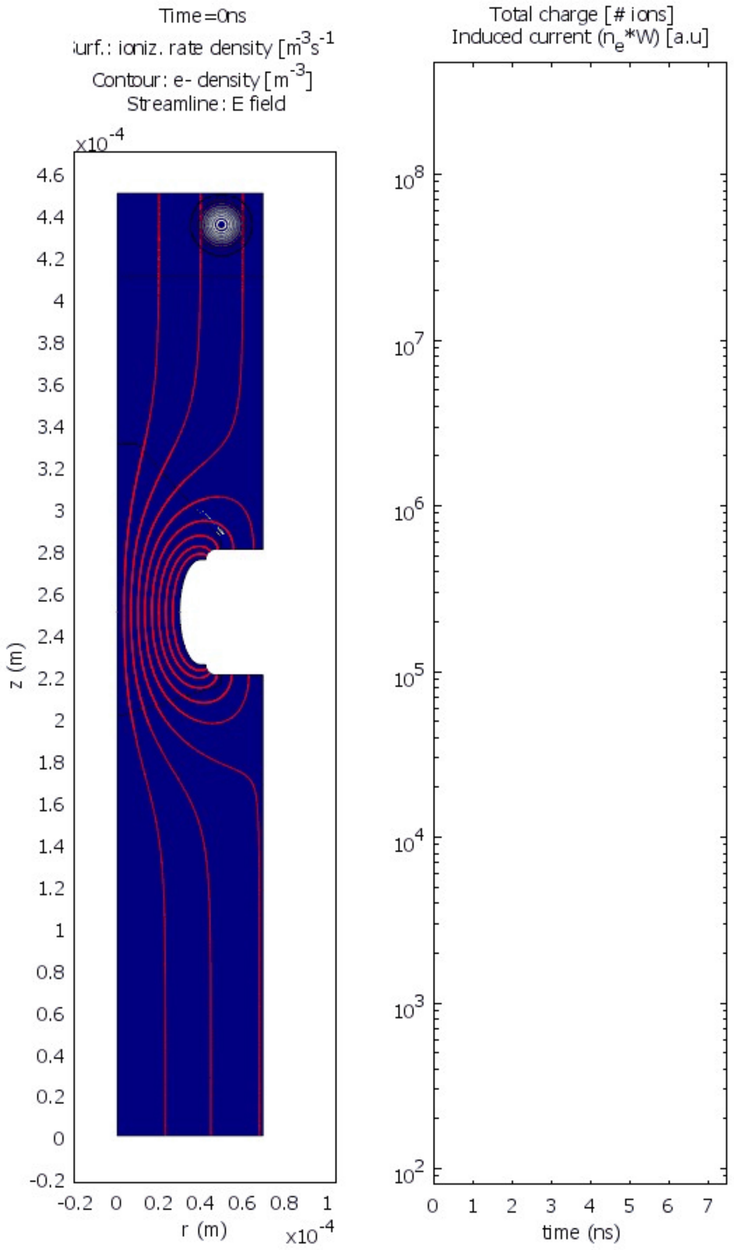


GEM lateral (ring) avalanche

hole: 60 µm
gap: 100 µm
N_0=100 e^-
V=1250V



Diffusion-assisted streamer (no photons)

Unfortunately, the presence of precursor is not an unambiguous fingerprint of the underlying physics mechanism!

GEM lateral (ring) avalanche

hole: 60 µm

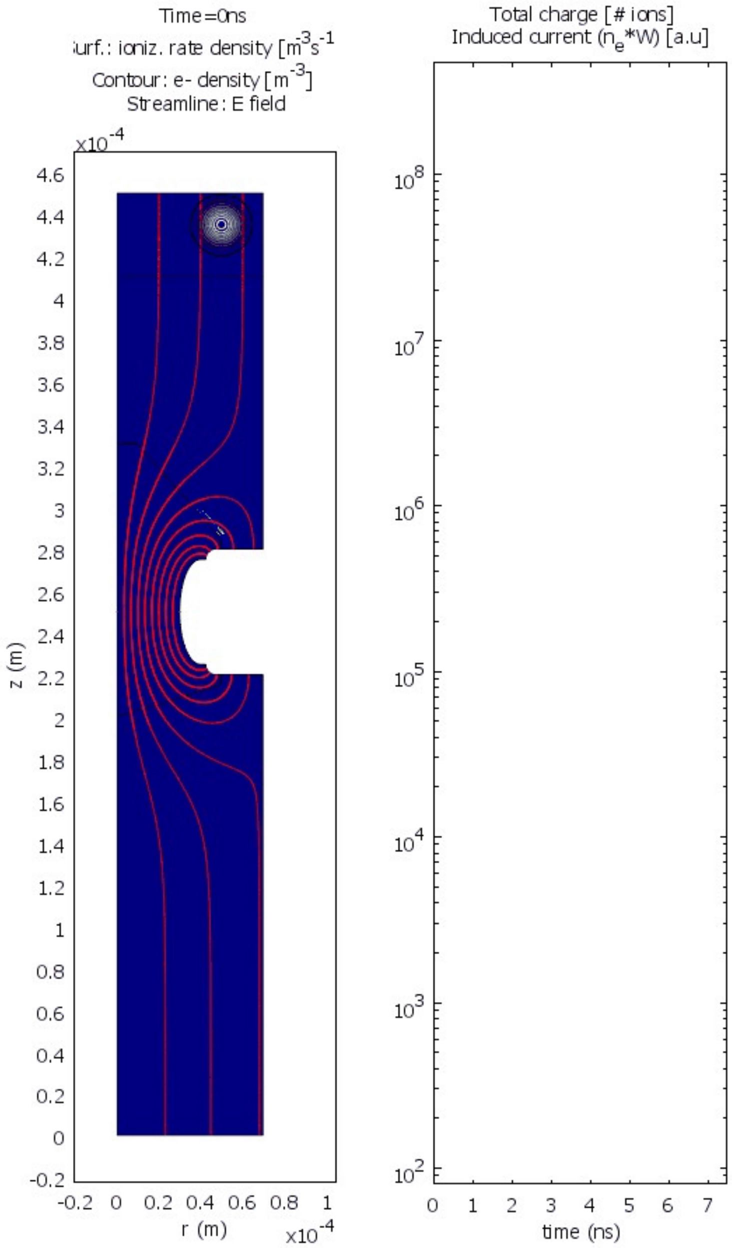
gap: 100 µm

N_0=100 e^-

V=1250V

Diffusion-assisted streamer
(no photons)

Unfortunately, the presence of precursor is not an unambiguous fingerprint of the underlying physics mechanism!

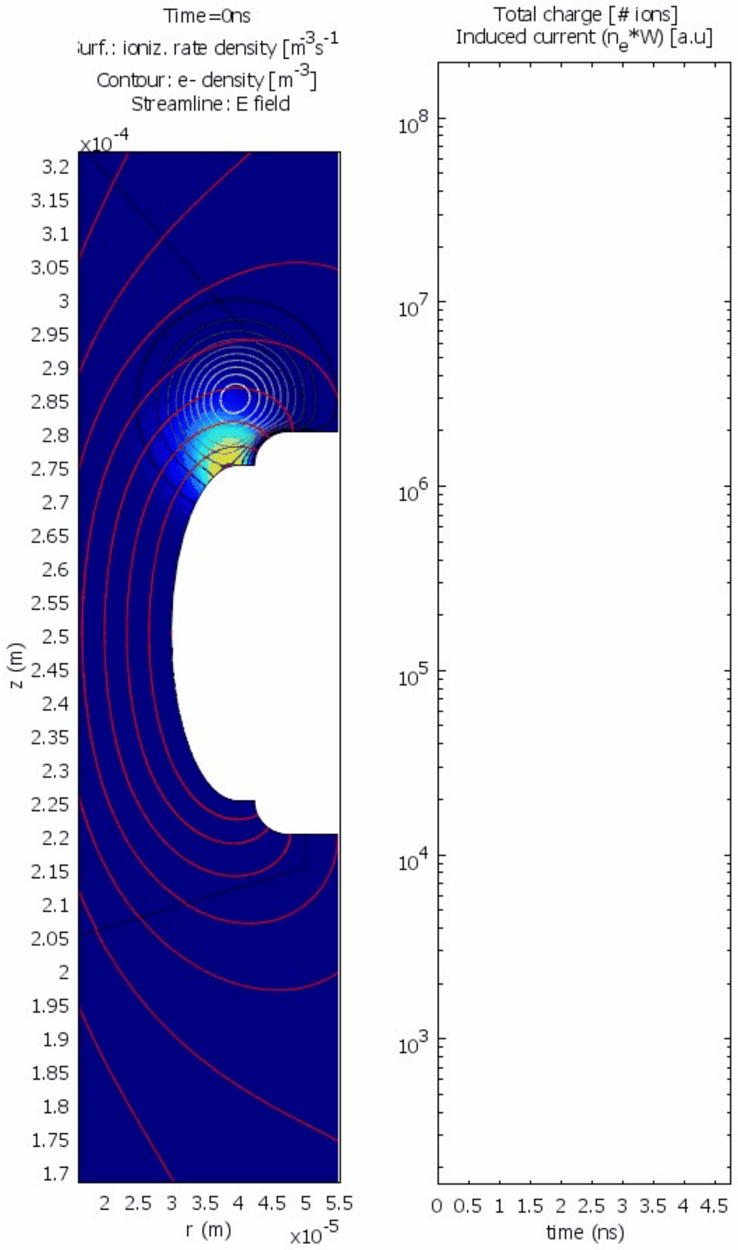


GEM
surface avalanche

hole: 60 µm
gap: 100 µm
$N_0=100\ e^-$
V=1150V

Diffusion-assisted streamer
(no photons)

Unfortunately, the presence of precursor is not an unambiguous fingerprint of the underlying physics mechanism!



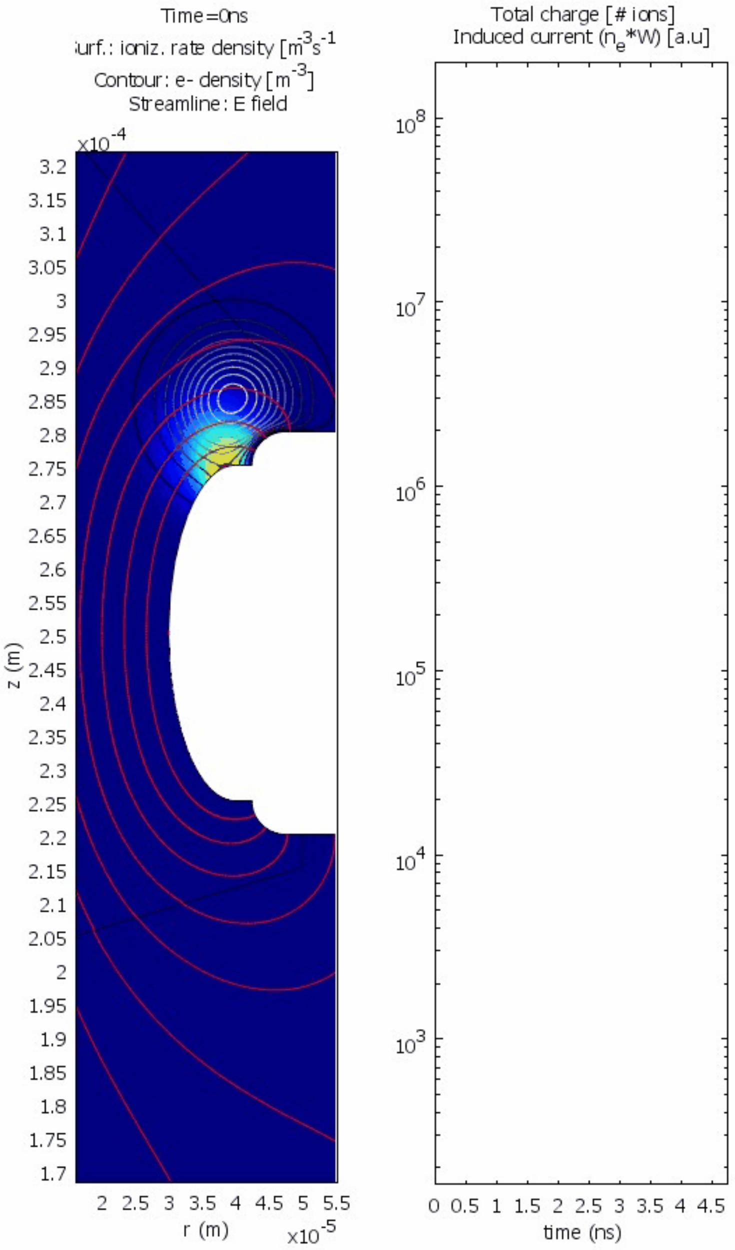
GEM
surface avalanche

hole: 60 µm

gap: 100 µm

N_0=100 e^-

V=1150V



This happens 100V below the streamer limit in the space, limiting the practical GEM gain.

Solved by multistepping.

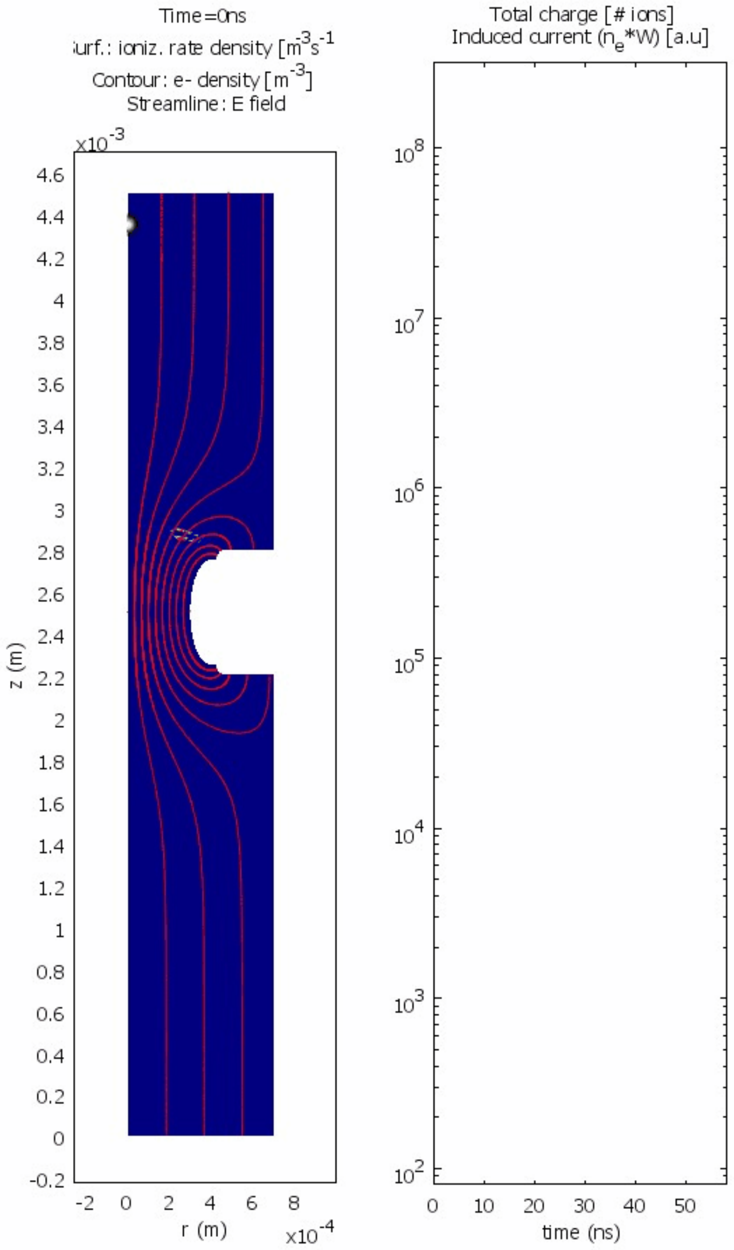
THGEM (GEMx10)

hole: 600 µm

gap: 1 mm

N_0=100 e^-

V=4600V



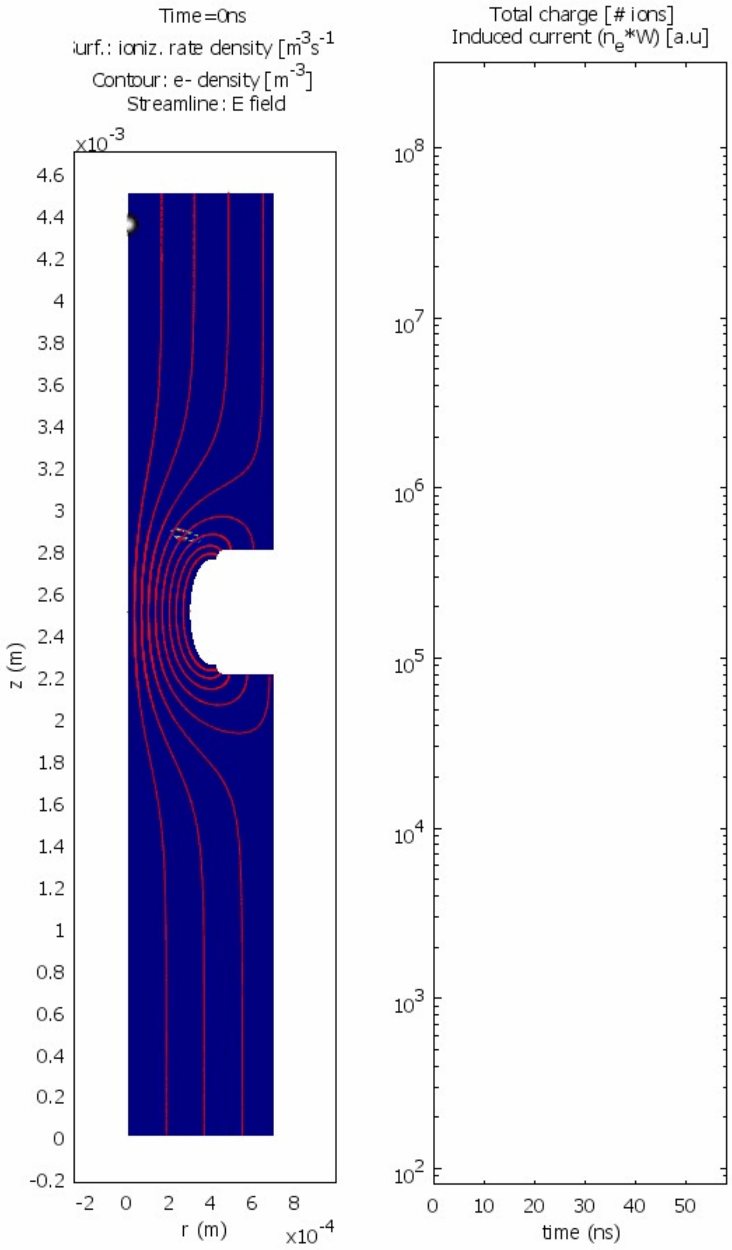
THGEM (GEMx10)

hole: 600 µm

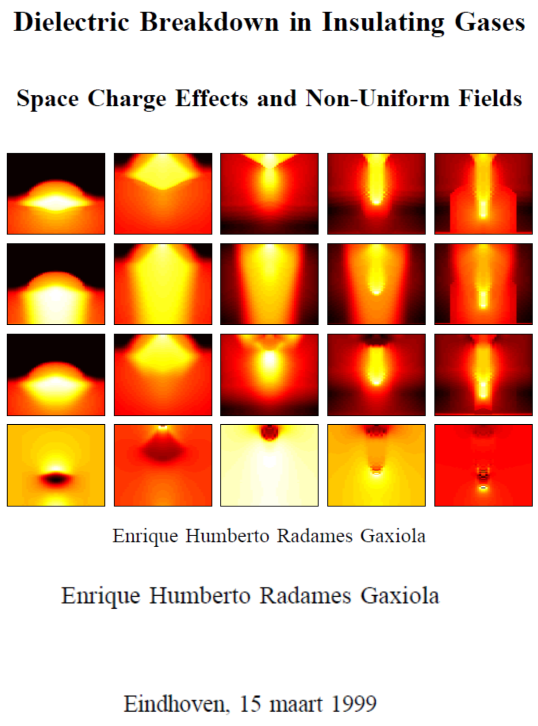
gap: 1 mm

N_0=100 e^-

V=4600V



Note: streamer and discharge simulations are ubiquitous these days (e.g.: plasma physics and insulation studies)



Dielectric Breakdown in Insulating Gases

Space Charge Effects and Non-Uniform Fields

Enrique Humberto Radames Gaxiola

Enrique Humberto Radames Gaxiola

Eindhoven, 15 maart 1999

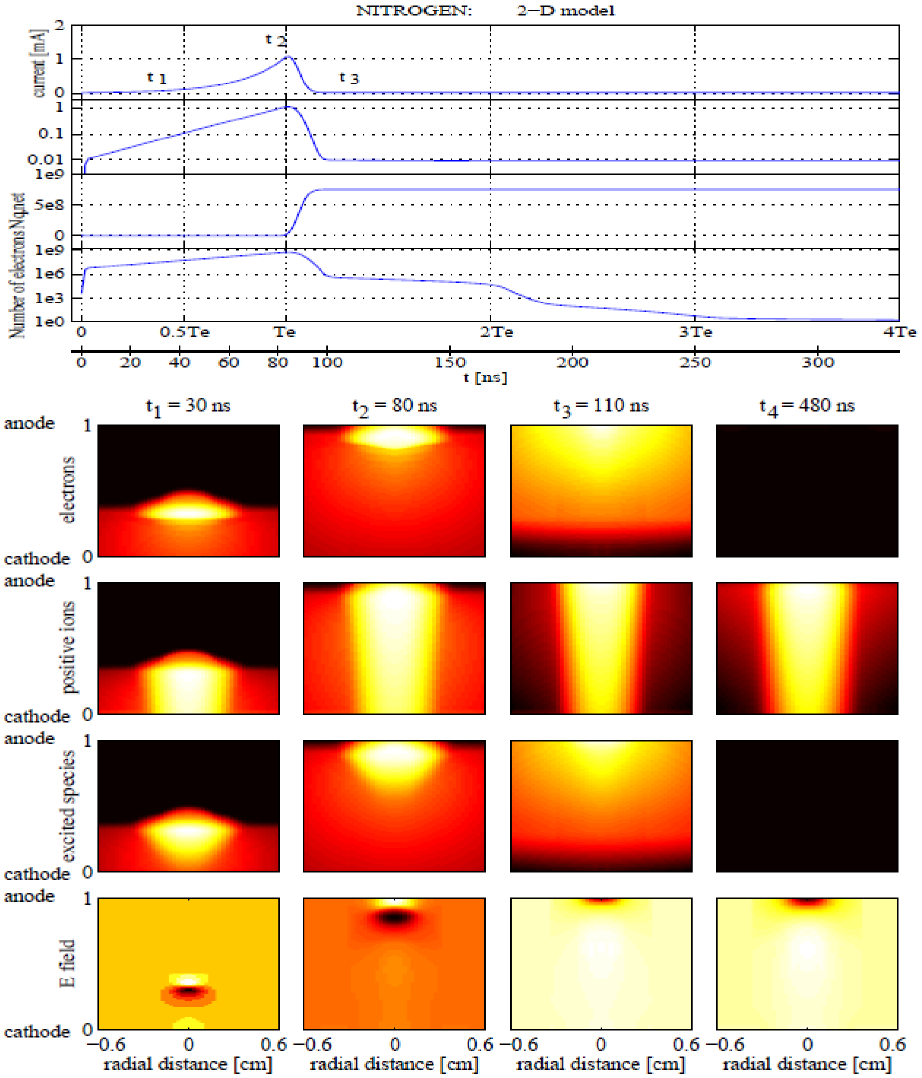


Fig.4.3 Simulated current waveform (*$N_0=5.5\cdot 10^6$*, *$T_e=83$ ns*, *$A=0.07$ cm^2*). Electron, positive ion and excited species density and resultant electrical field at various time instances.
Conditions: atmospheric nitrogen *E=30 kV/cm, gap=1 cm.*