RPCs and applications to the Particle Physics

5th Particle Physics Workshop

Islamabad 20-25 Nov 2006

By R. Santonico

Basic detector physics

- Gaseous detectors brief history
- Primary Ionization
- Uniform field vs 1/r electric field
- Signal pick up
- Simple exponential model of the avalanche discharge in the RPCs
- The avalanche to streamer transition
- Operating voltage vs gas gap
- Pressure and temperature corrections: operating voltage vs gaseous target thickness

Gaseous detectors brief history

- A gaseous detector is characterized by a target of a proper gas mixture subject to an electric field
- The field is strong enough to accelerate the small number of free ionization electrons left by the incoming particle and to produce of an avalanche of size detectable by the front end electronics
- The first type of gaseous detectors which found application to the particle physics is the wire detector/chamber based on the field produced by a positive charged wire
- The family of the wire chambers, derived from the G&M counter developed in the decade of 1920, have found very relevant applications to particle physics since a long time

Gaseous detectors brief history (2)

- In 1949 Keuffel proposed a new type of gaseous detector, based on the uniform field generated by a plane capacitor, which was very attractive for his potential time resolution
- This detector was so critical and unstable that could never find applications
- It triggered however (indirectly) the development of a new family of planar pulsed detectors: the optical spark chamber, with narrow and wide gap, and the pulsed streamer chamber, which were (together with the bubble chambers) the main instrument of the particle physics up to the years 70

Gaseous detectors brief history (3)

- The main limit of these detectors was to be not continuously sensitive but to need a trigger detector to be activated
- For timing applications Yu Pestov proposed a DC coupled planar detector under high pressure, with one glass electrode, which showed a 30 ps time resolution
- The Resistive Plate Chambers, RPC, developed in 1979, were proposed as planar detectors suitable for large area applications with 1 ns time resolution

RPC characteristics summary

- Resistive electrodes with ρ ranging from 10^{10} to 10^{12} Ω cm depending on the rate requirements
- Plastic laminate resistive electrodes of thicknees 2 mm
- Gas gap 2.0 mm kept uniform with an array of 1 cm^2 spacers for 100 cm^2 detector area
- External graphite painted electrodes to uniformly distribute the field in the gap area
- Gas: $C_2H_2F_4/iC_4H_{10}/$ = 94.7/5.0/0.3 (in avalanche mode) No SF_6 and some Argon in streamer mode
- Single gap efficiency 97- 98%
- Time resolution ~1 ns

RPC characteristics summary (2)

- At the beginning the RPC worked in streamer mode
- more recently the development of a new high gain front end electronics allowed the operation in avalanche mode
- The streamer is a thin plasma column interconnecting the two electrodes
- It is originated by the avalanche (precursor) through multiple photo-ionization processes

RPC characteristics summary (3)

- The RPC working principle can be summarized as follows
  - In steady conditions the applied voltage is fully transferred to the gas
  - The growth of the electrical discharge is quenched by the combined action of the electrode resistivity: the relaxation time ρε is of the order of 1 ms (or longer) to be compared with the characteristic time of the discharge of about 10 ns → no energy can be transferred by the power supply
  - and the UV photon absorbtion in the gas forbids the propagation of the discharge through photo-ionization processes

Gas ionization

- The energy loss of a charged particle in matter by ionization and atomic excitation is described by the Bethe-Bloch formula

$$-\frac{dE}{dx} = Kz^2 \frac{Z}{A} \frac{1}{\beta^2} \left(\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 T_{\max}}{I^2} - \beta^2 - \frac{\delta}{2} \right)$$

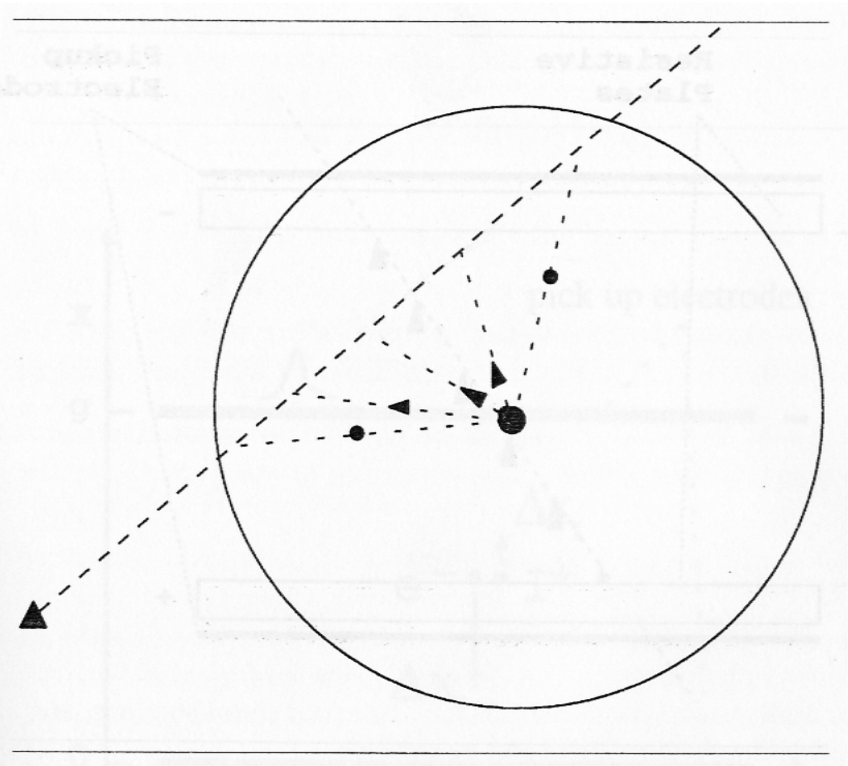
were I is the mean excitation energy and T_{max} is the maximum kinetic energy that can be transferred to a free electron in a single collision

Gas ionization (2)

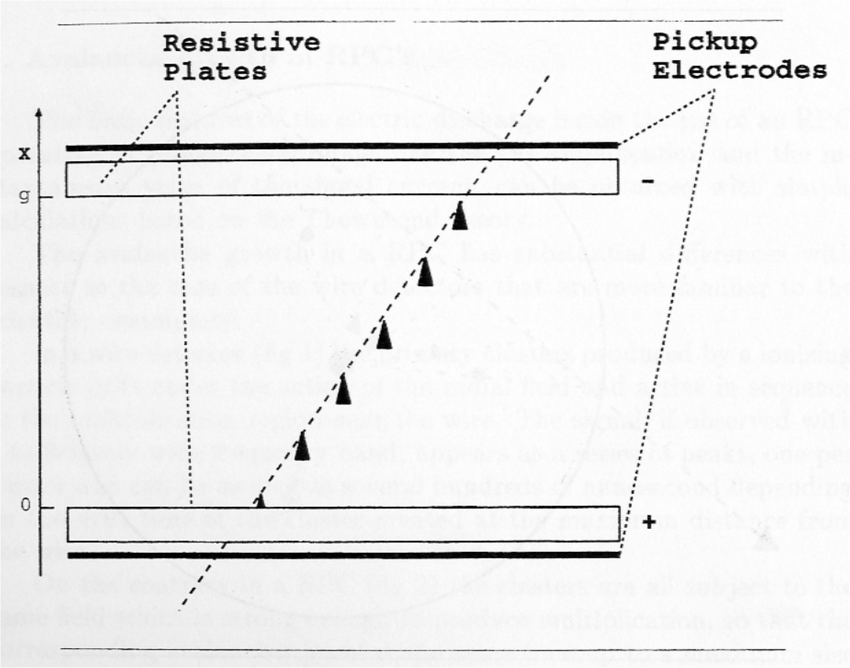
- Delta rays: secondary electrons with kinetic energy T>>I (mean excitation energy) with kinetic energy distribution dN/dxdT=..1/T2
- Delta rays of kinetic energy T>Ionization Energy can again ionize the gas
- As a consequence in each ionization point a cluster of one or several free electrons is left by the incoming particle
- Each gas is therefore characterized, as target for ionizing particles detectors, by two main parameters defined for a minimum ionizing particle:
  - - the yield of free electrons
  - - the yield of ionization collisions=1/λ
- It should be stressed that the probability of no ionization in a layer of gas of thickness Δx depends on the number of ionization collisions

Induced signal in a wire detector (drift tube)

- Strong field gradient E = k/r
- Primary clusters drift toward the anode wire and do not produce visible signal except very close to the wire
- At a distance of about one wire diameter the field is intense enough to produce multiplication
- The signal is in principle a sequence of pulses each one produced by a different cluster

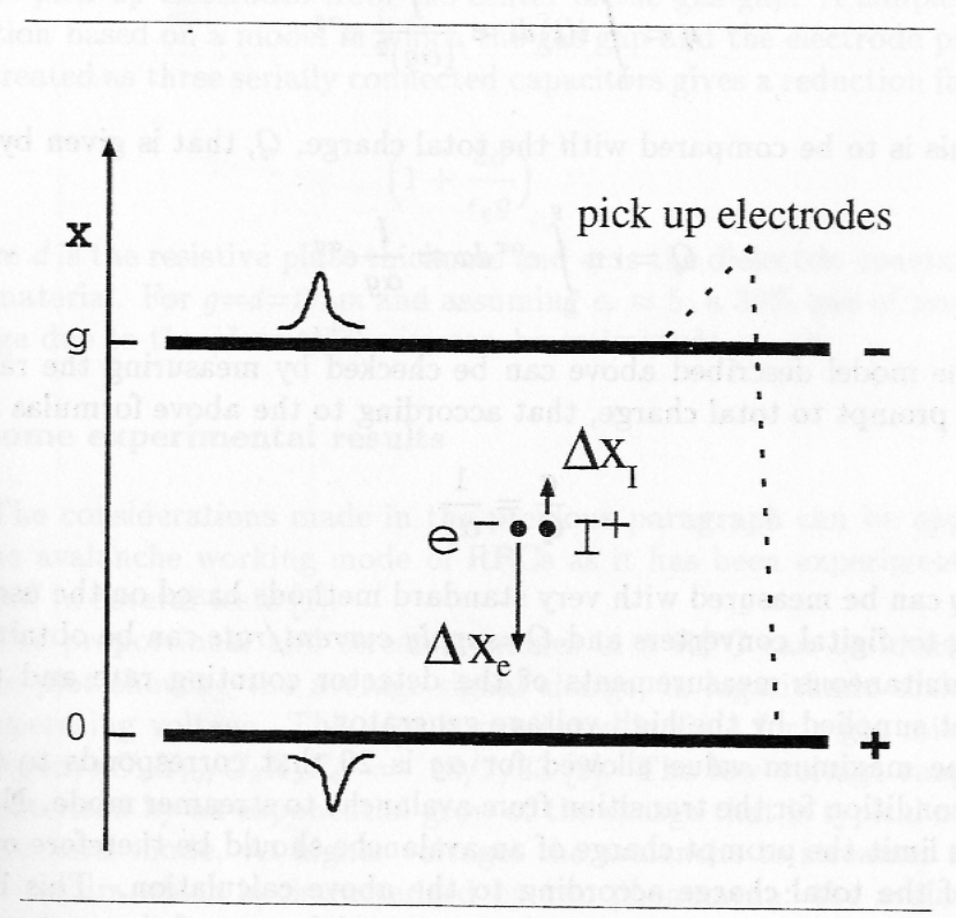


Induced signal in a planar detector



- All primary clusters drift toward the anode plate with velocity v and simultaneously originate avalanches
- Very fast induced signal with good time resolution
- A cluster is eliminated as soon it reaches the anode plate

Induced signal in a planar detector (2)



- A free electron and a positive ion produced in a ionization process drift in opposite directions

Induced signal in a planar detector (3)

- The charge induced on the pick electrodes, according to elementary relationships is

  $q = (-e\Delta x_e + e\Delta x_I)/g$

- The induced current of a single pair

  $i = dq/dt = e\,(v + V)/g \sim ev/g$

  depends only on the electron motion as the ion drist velocity $V = 10^{-3}\, v << v$

- → The prompt charge in the RPCs is dominated by the electro drift

The avalanche exponential growth

- A ionizing particle crossing the gas gap g produces ng free electrons, n being the average number per unit length
- Number of drifting electrons at the time t after gas ionization

$$\mathcal{N}(t)=n(g-vt)e^{\alpha t}$$

- Current induced on the pick up electrodes

$$i=e\mathcal{N}(t)v/g=ev\mathcal{N}(1-vt/g)e^{\alpha t}$$

- The integral $q=\int idt$ between 0 and $t_{max}=g/v$ is the “prompt charge”

$$q=Ie^{\alpha g}/(\alpha g)^2 \qquad \text{and} \qquad I=eng$$

is the electron charge delivered by the incoming particle

The avalanche exponential growth (2)

- The total charge delivered in the gas is given by

  $$Q=en\int e^{\alpha x}dx = Ie^{\alpha g}/\alpha g$$

  (with the integral extended between 0 and g)
- The ratio of the prompt to total charge

  $$q/Q= 1/\alpha g$$

  is $<<1$ αg being moderately smaller than 20 (the limit of the avalanche to streamer transition)
- This is due to the fact that most free electrons are produced very near to the anode plate

- This simple model of avalanche exponential growth is unrealistic for two reasons
- It is based just on average values and do not contain the fluctuations of primary ionization
- Even more important in the RPC case it do not contain the avalanche saturation due to the space charge effects

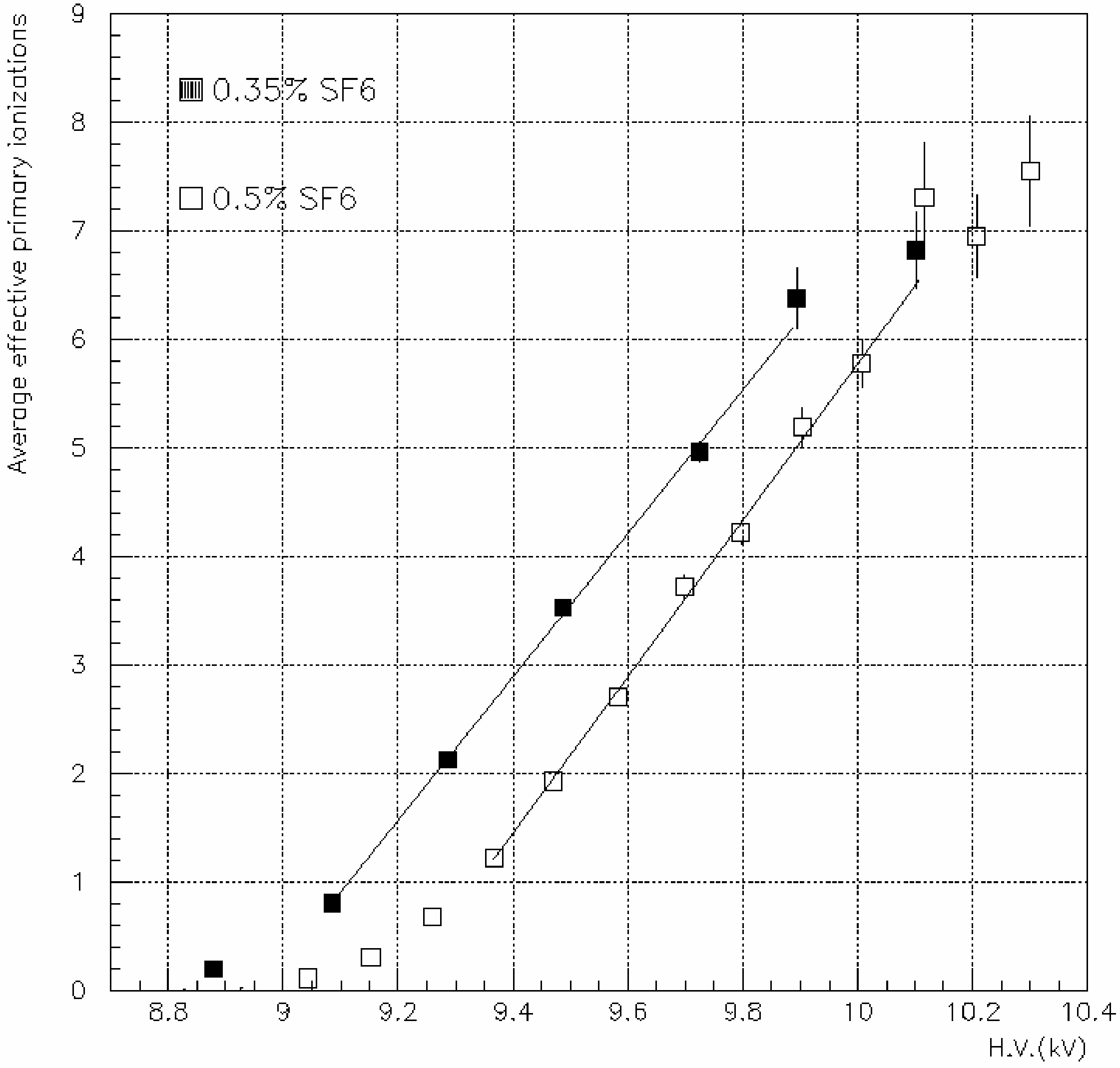
Intrinsic RPC efficiency

- The RPC achievable efficiency is limited, as for any real detector, by blind areas due to structural elements like spacers and edge frame
- If the effect of the blind areas is discounted the residual inefficiency is intrinsic to the detector
- If $<\mathcal{N}>$ is the average number of effective primary clusters contributing to the efficiency

$$1-\varepsilon = e^{-<\mathcal{N}>} \quad <\mathcal{N}>=ln(1-\varepsilon)^{-1}$$

- The value of $<\mathcal{N}>$ is not easy to evaluate also because primary clusters produced near the anode plate are completely ineffective

Average number of primary clusters contributing to the efficiency



The avalanche to streamer transition in RPCs

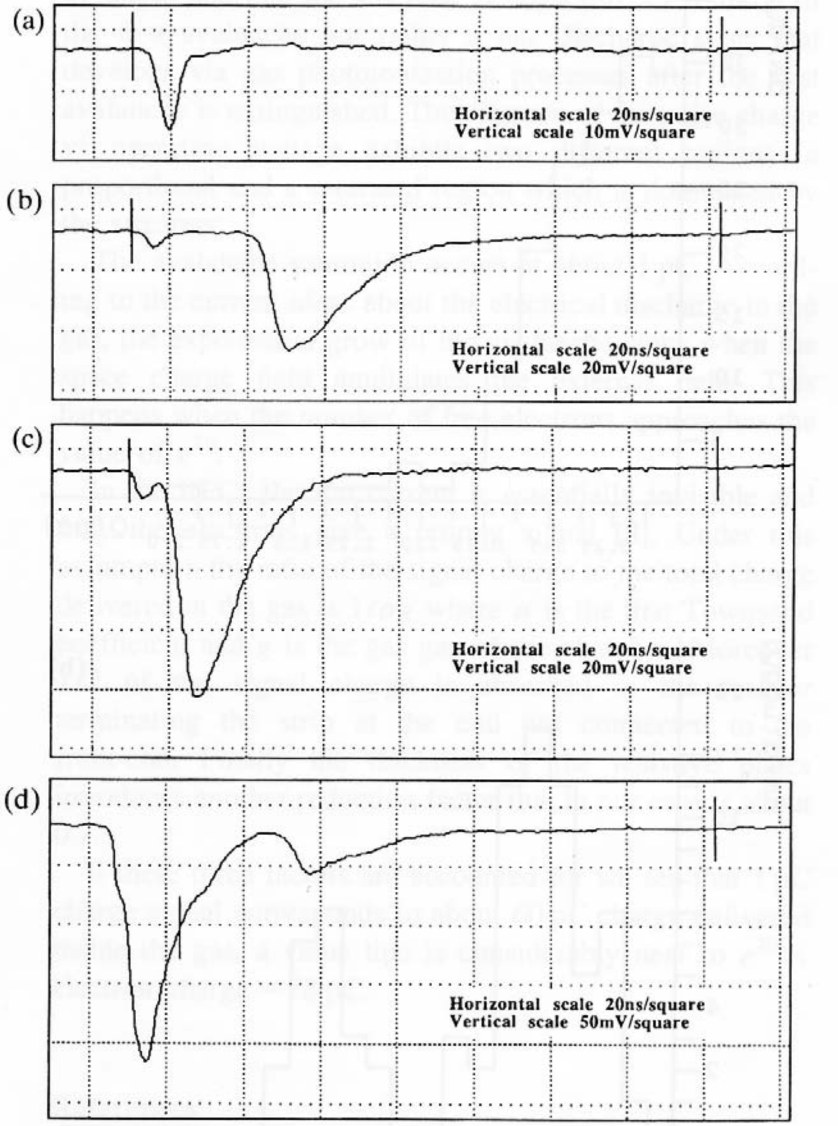


Fig. 2. Signal waveforms at different opearting voltages. The avalanche signal (a, 9.4 kV) has a typical duration of 4–5 ns FWHM. A streamer signal follows the avalanche with a delay of 38 ns (b, 9.6 kV). At higher voltages (c, 10.2 kV) the avalanche to streamer delay becomes gradually shorter and finally (d, 11.4 kV) the avalanche and streamer signals merge into a single pulse. Multistreamer signals are also observed.

Streamer suppression with SF_6

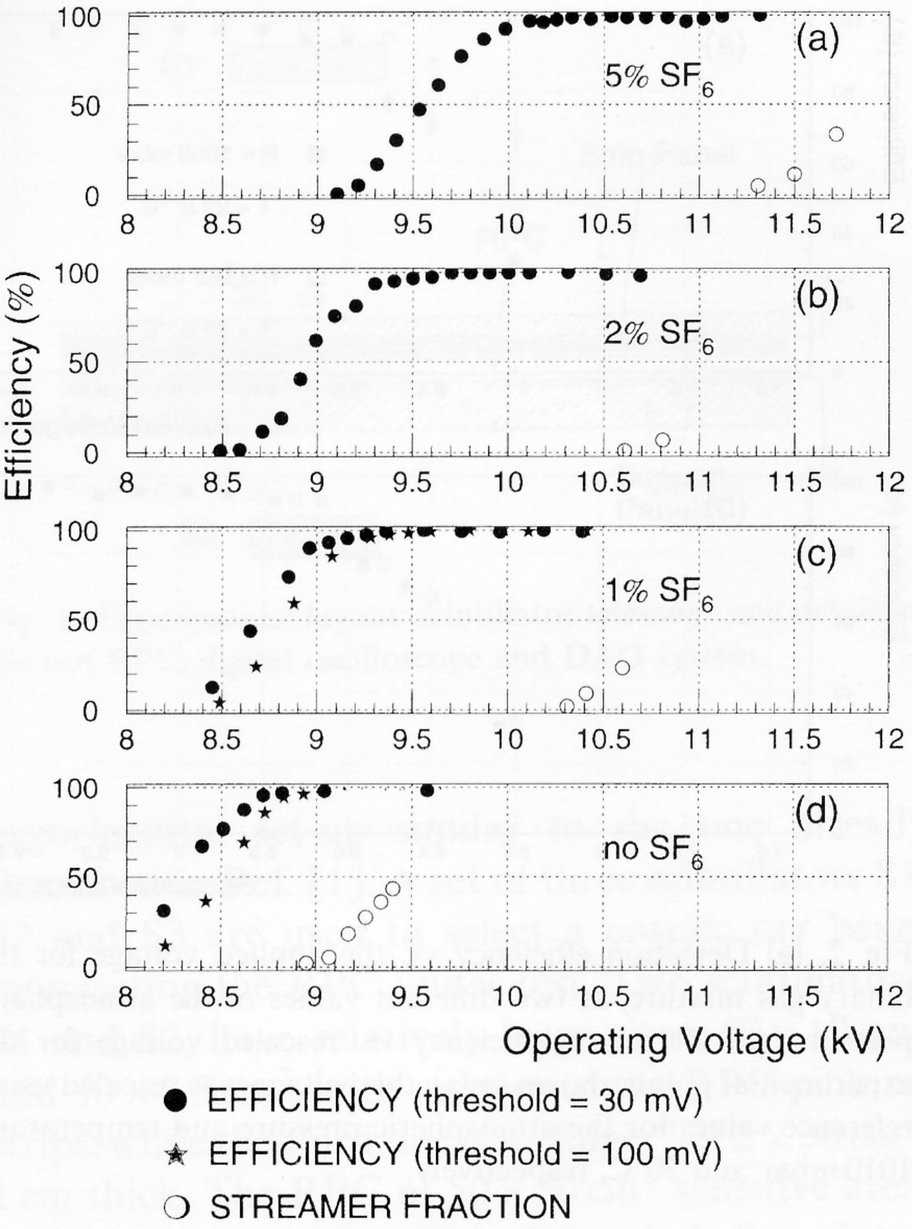


Fig. 4. Detection efficiency and streamer probability vs. operating voltage for (a) 5%, (b) 2%, (c) 1% SF_6 concentrations and (d) no SF_6.