Factors that influence the timing properties and rate capability of Multigap Resistive Plate Chambers

Crispin Williams

OUTLINE

A brief outline of the development of the MRPC

Intrinsic jitter

Time slewing

Noise: Single-ended/Differential readout

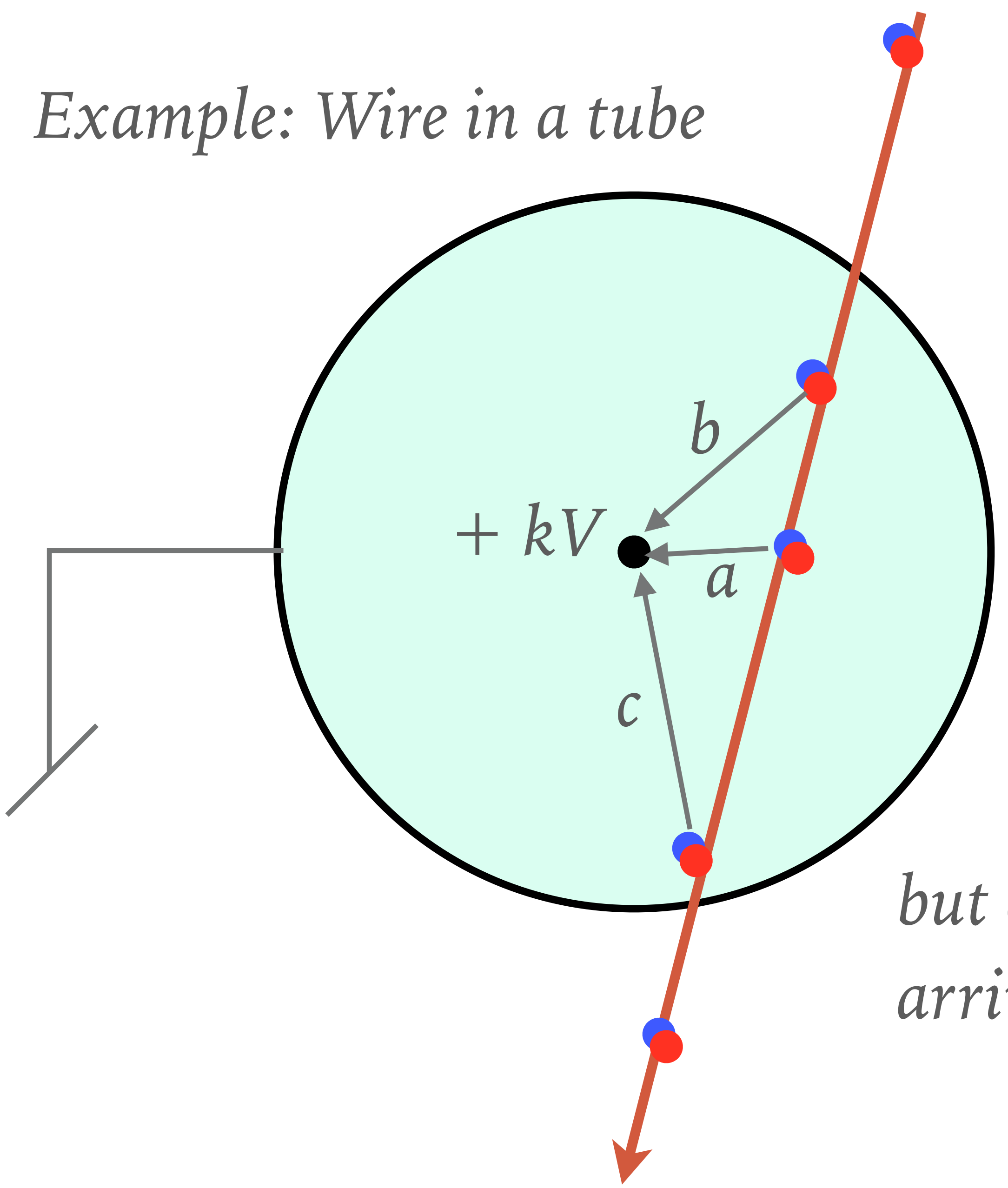
Time resolution degraded at high rates

Summary

The Multigap RPC was born at the '95 RPC conference

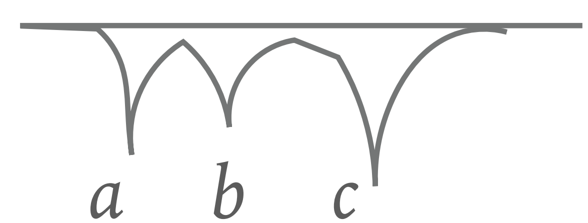
Rinaldo Santonico explained a critical difference between the 'wire chamber' and the 'parallel plate detector'.

Example: Wire in a tube



electrons drift and arrive at the wire one after another - depending on drift distance

Signal on wire comprises of a series of signals



but only the first avalanche (produced by first arriving electron) is used for timing measurements

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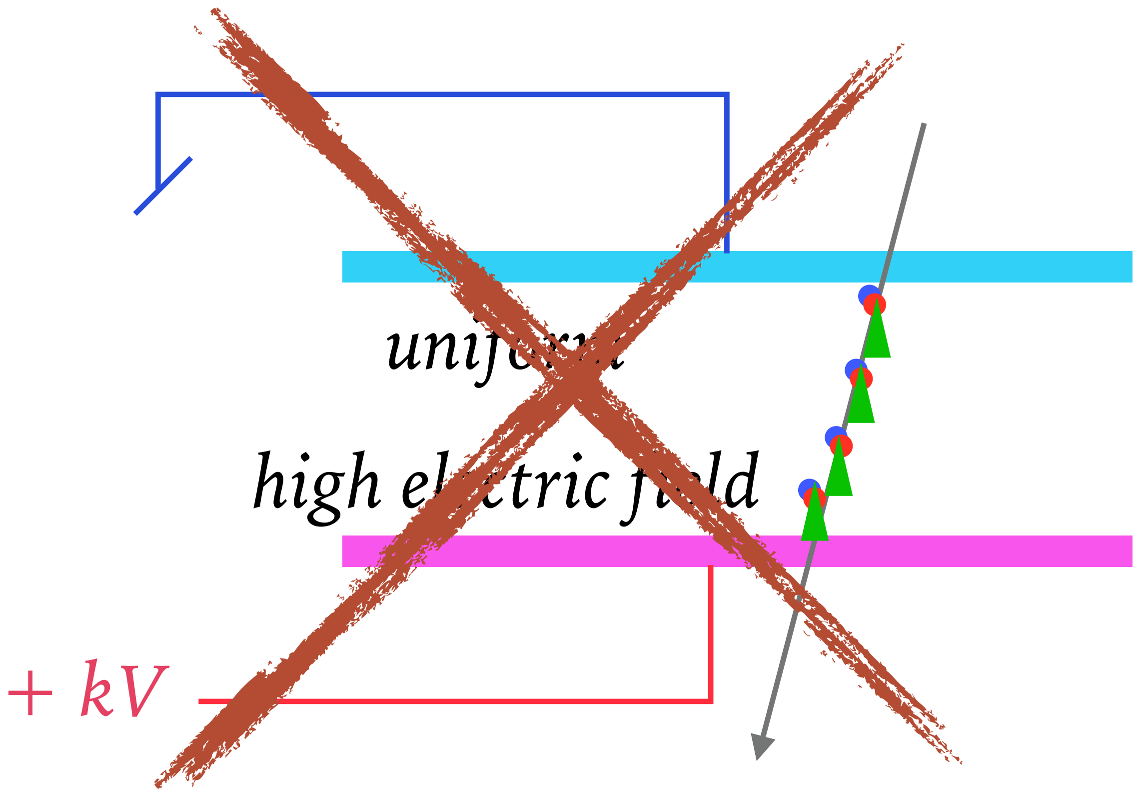
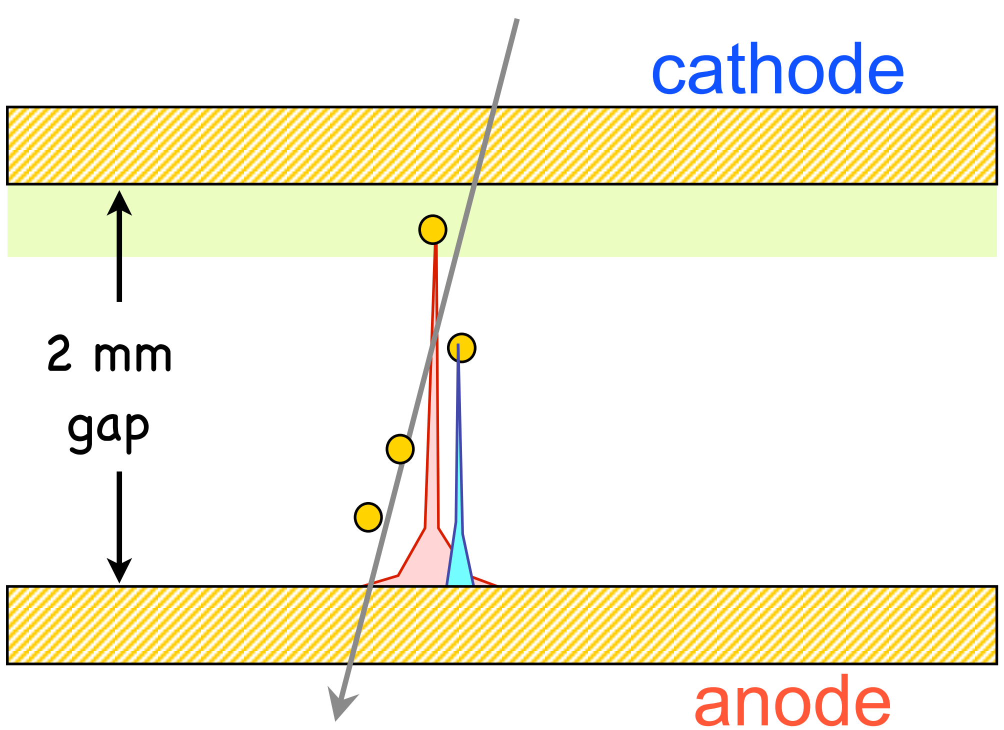
Parallel Plate Chamber



All electron avalanche processes start immediately: the induced signal (due to movement of charge) is the sum of all avalanches: thus all ionisation produced in chamber plays a role.



However: not so clear in practice: avalanche grows across full gap width (this means that only avalanches that originate close to cathode will ever grow sufficiently large to generate a signal).

Putting in some numbers:

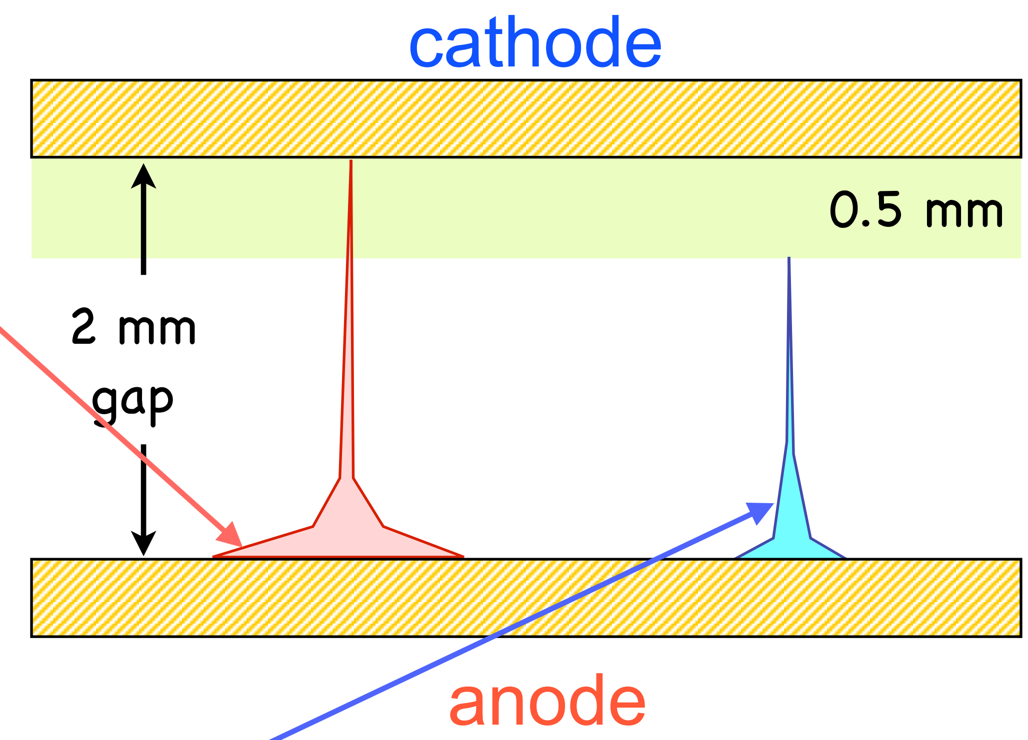
Set the gain for a single electron to be 10^8 across a 2 mm gap (just below the transition to streamers)

fast signal/Total charge= 1/aD

fast signal is 800 fC

Now if initial electron is 0.5 mm from cathode: gain reduced to 10^6:

fast signal is 8 fC



Only avalanches that start with some hundreds of micron of cathode will grow large enough to create detectable signal.

fast signal created movement of the electrons within some 100's of microns of anode

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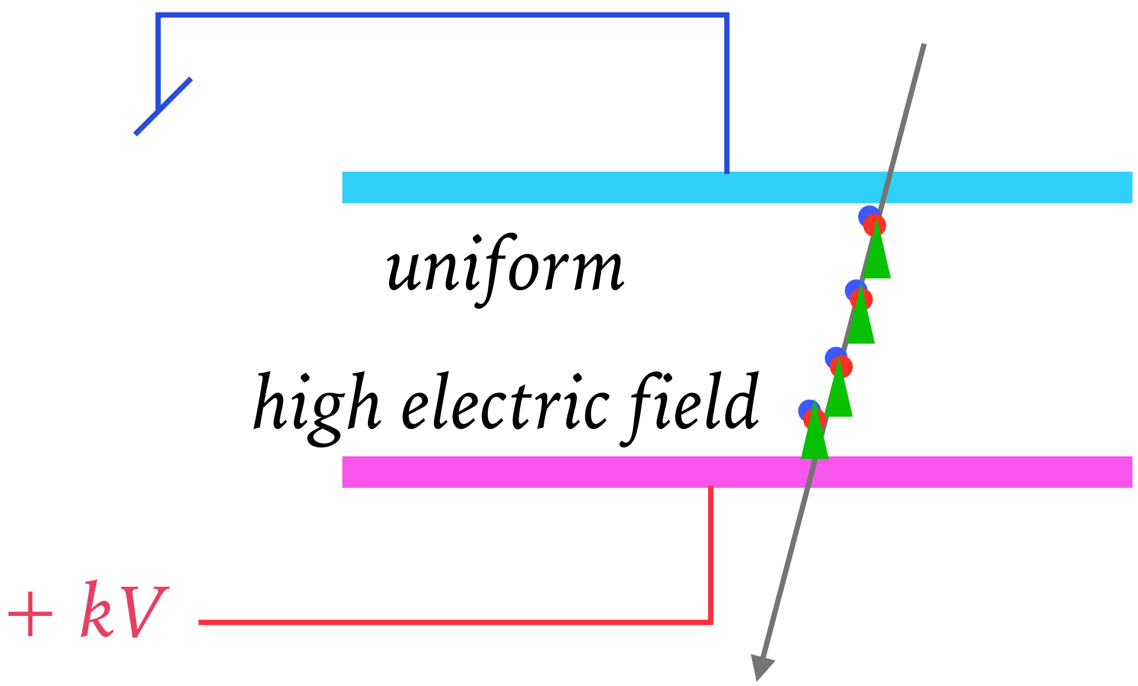
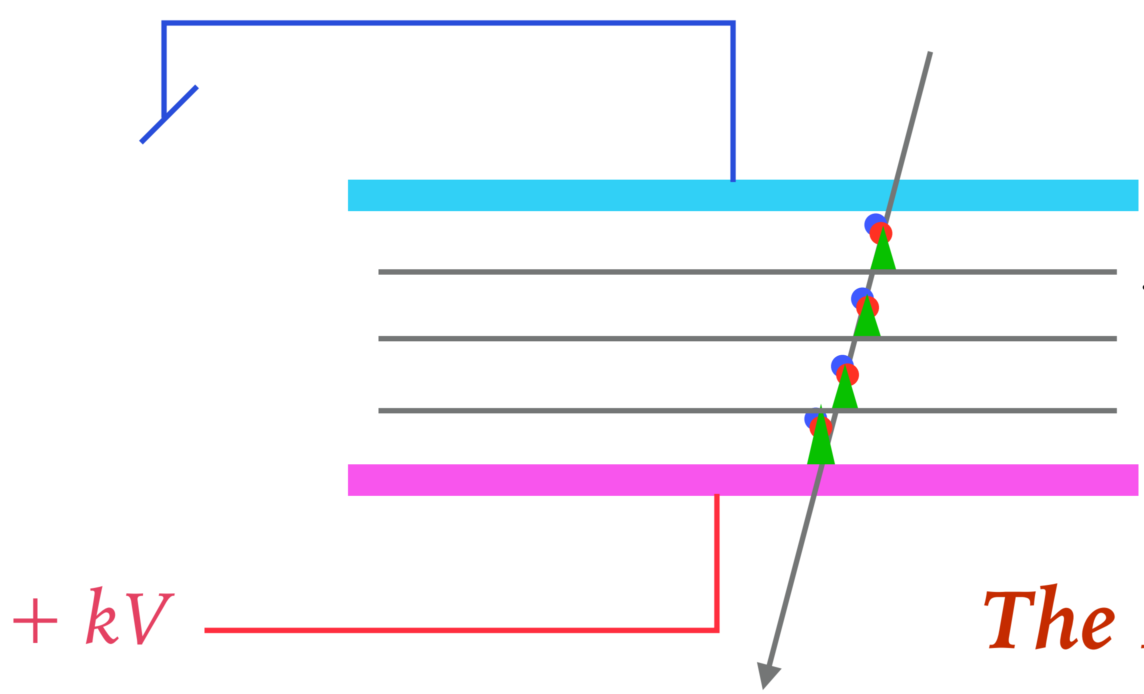
Going back to Santonico's picture



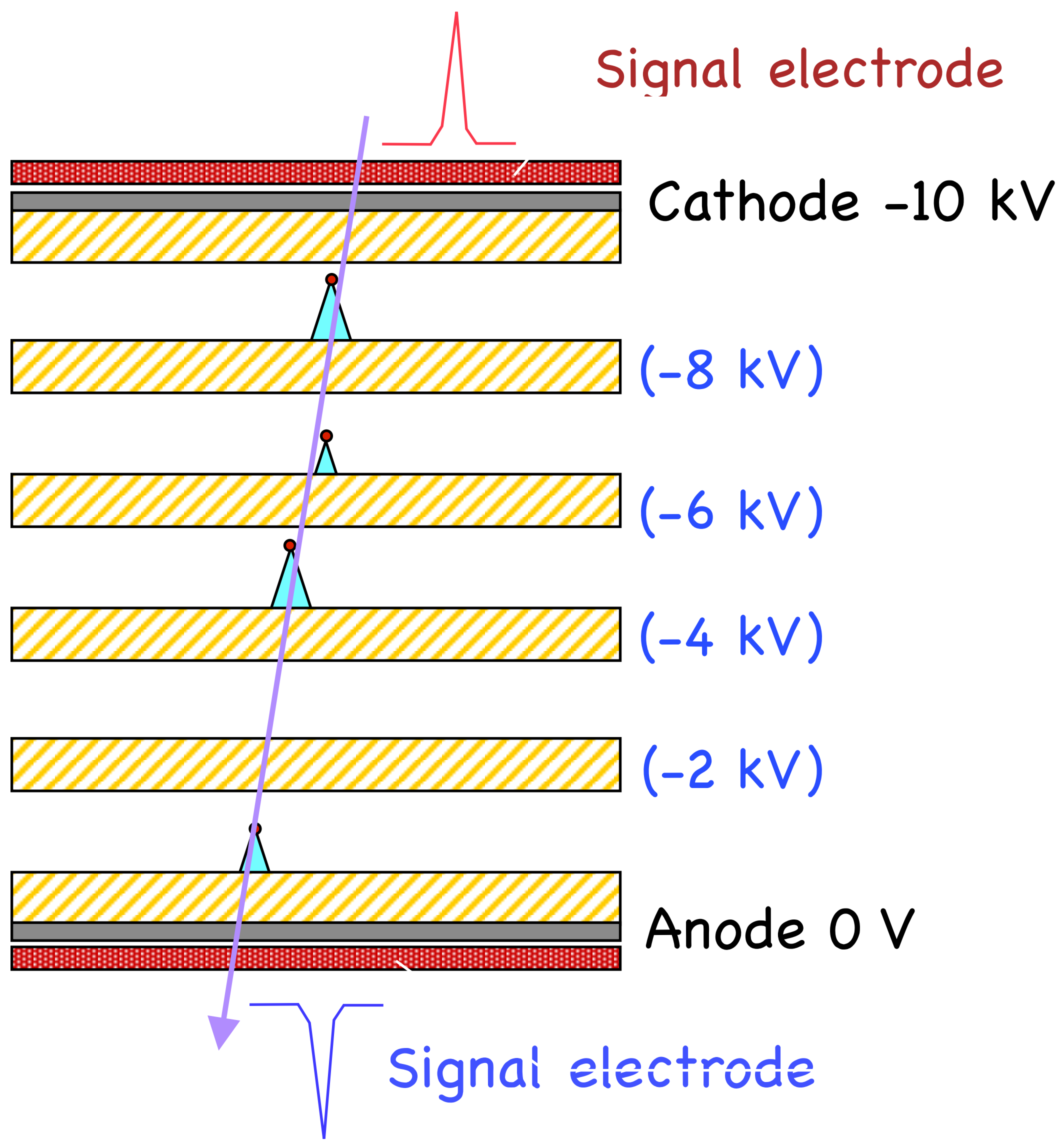
To get these avalanches each producing a detectable signal at the start of the avalanche would require setting the gas gain extraordinary high - sparks,etc



Solution: add barriers within the gas gap to stop development of the avalanche

The Multigap Resistive Plate Chamber

MULTIGAP RESISTIVE PLATE CHAMBER



Stack of equally-spaced resistive plates with voltage applied to external surfaces (all internal plates electrically floating)

Pickup electrodes on external surfaces (resistive plates transparent to fast signal)

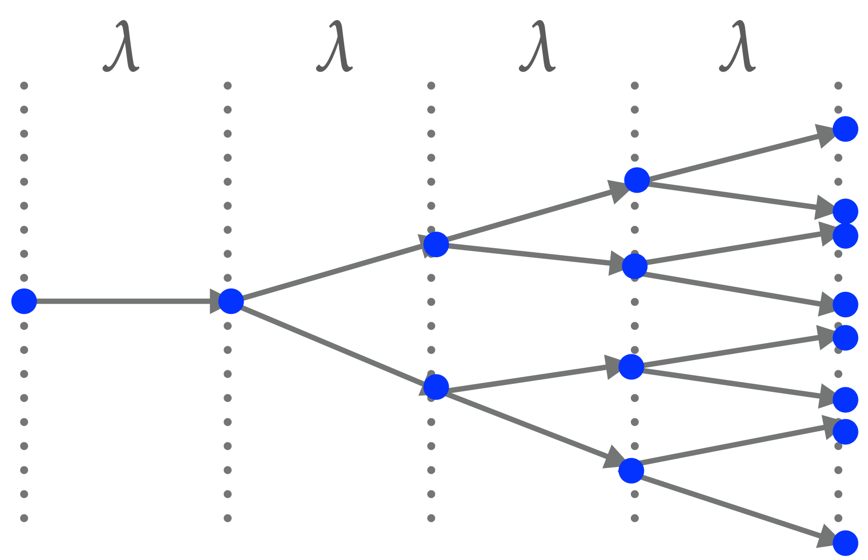
Internal plates take correct voltage - initially due to electrostatics but kept at correct voltage by flow of electrons and positive ions - feedback principle that dictates equal gain in all gas gaps

Note bene

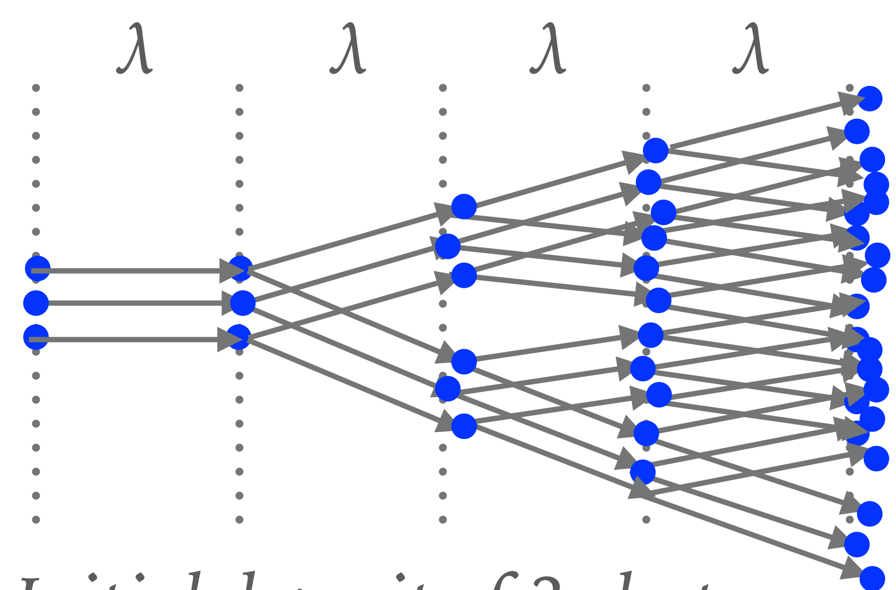
The MRPC was inspired by the desire to get the signals of ***many*** *avalanches really acting in parallel as Rinaldo Santonico outlined in Pavia 1996.*

Intrinsic Time Jitter

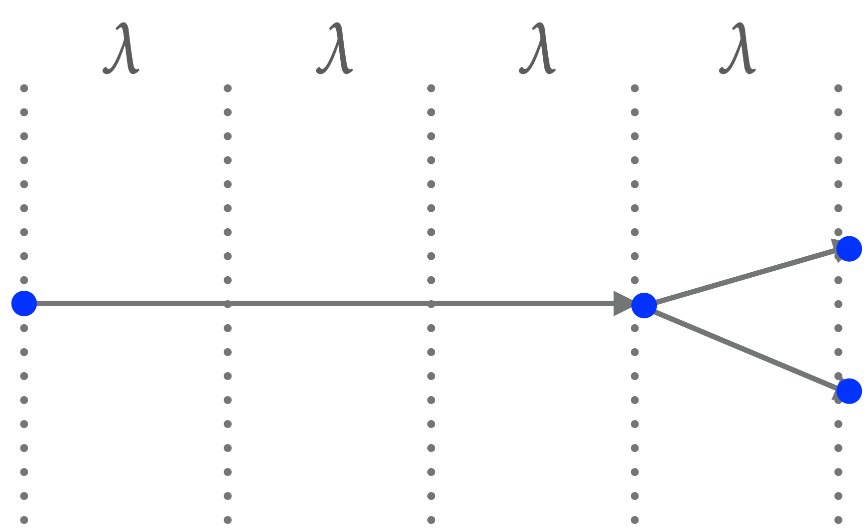
λ distance between ionising collisions   α *(Townsend coefficient)* = *1/λ*



Avalanche with average behaviour



Initial deposit of 3 electrons



Avalanche by chance delayed by 3λ

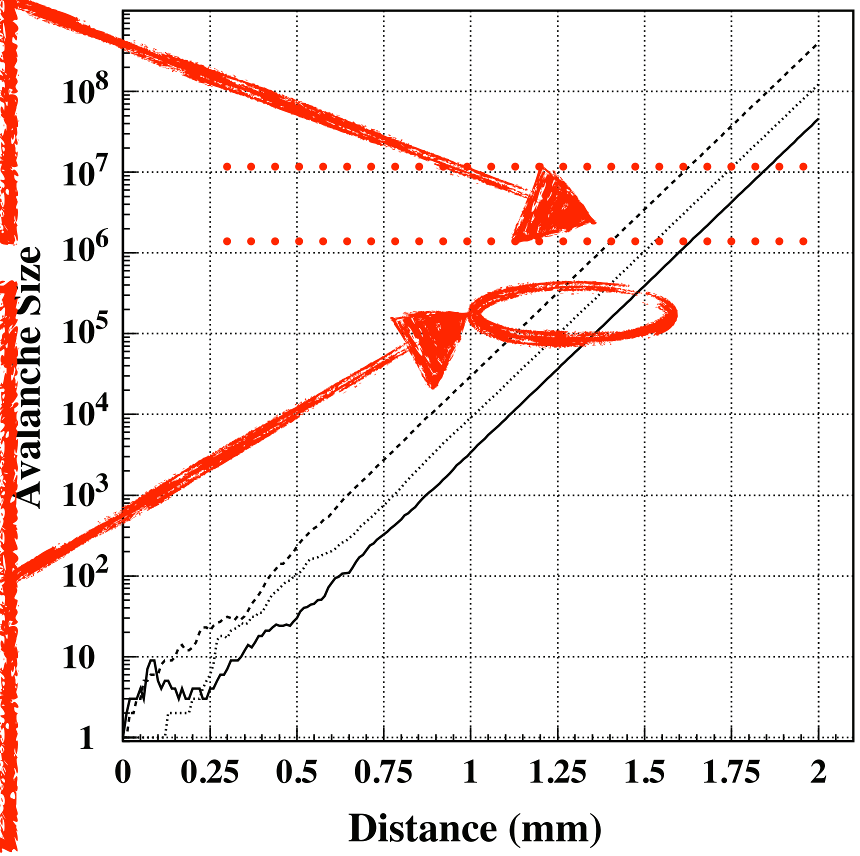
Time jitter ~ λ/(drift velocity of electron)

$$\sigma_t = 1.28/(\alpha - \eta)v$$

W. Riegler, C. Lippmann and R. Veenhof NIMA 500(2003)144

Time Development of avalanches

lowering the threshold ***will not*** *reduce the time jitter*

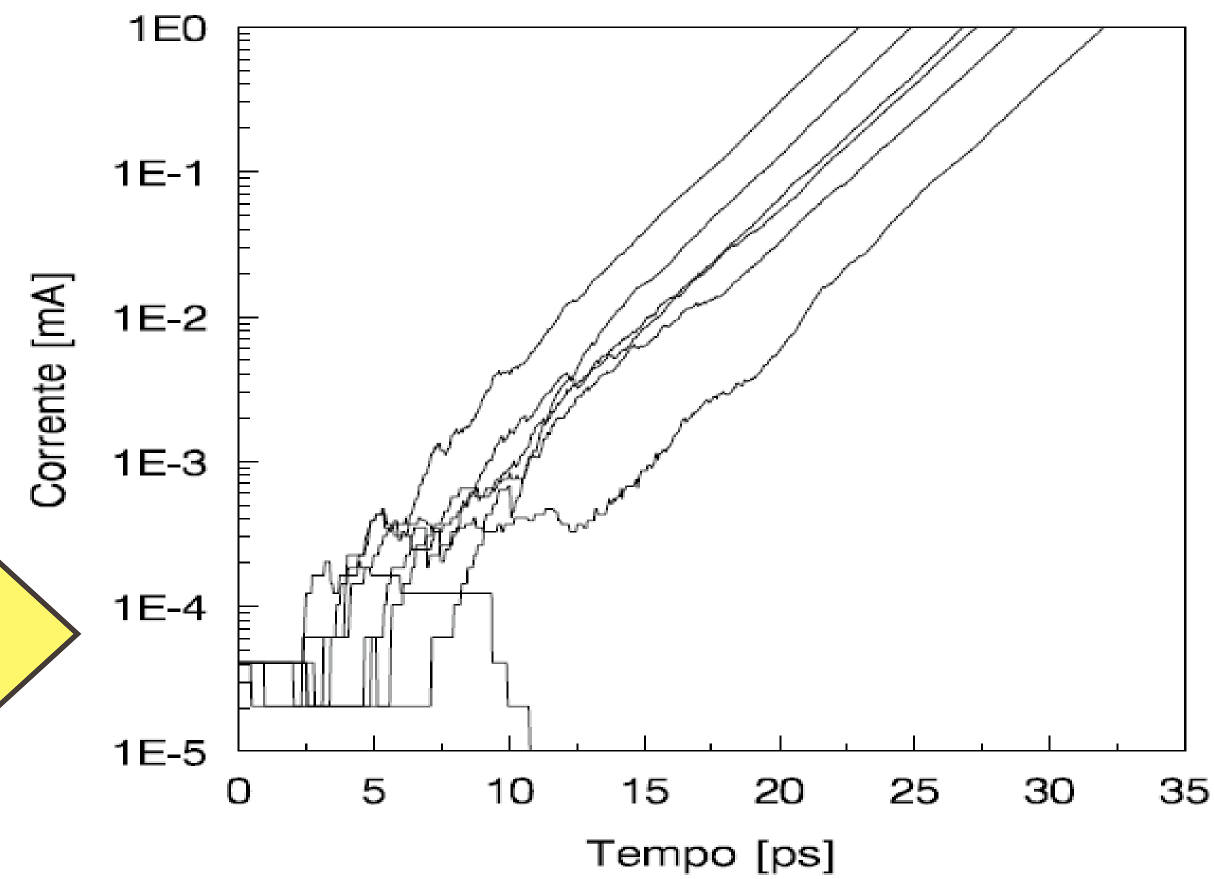


Averaging the growth of several avalanches ***will*** *reduce time jitter*

Detector physics and simulation of resistive plate chambers
Werner Riegler*, Christian Lippmann, Rob Veenhof NIMA 500 (2003) 144–162

Development of avalanche in 2 mm gap RPC

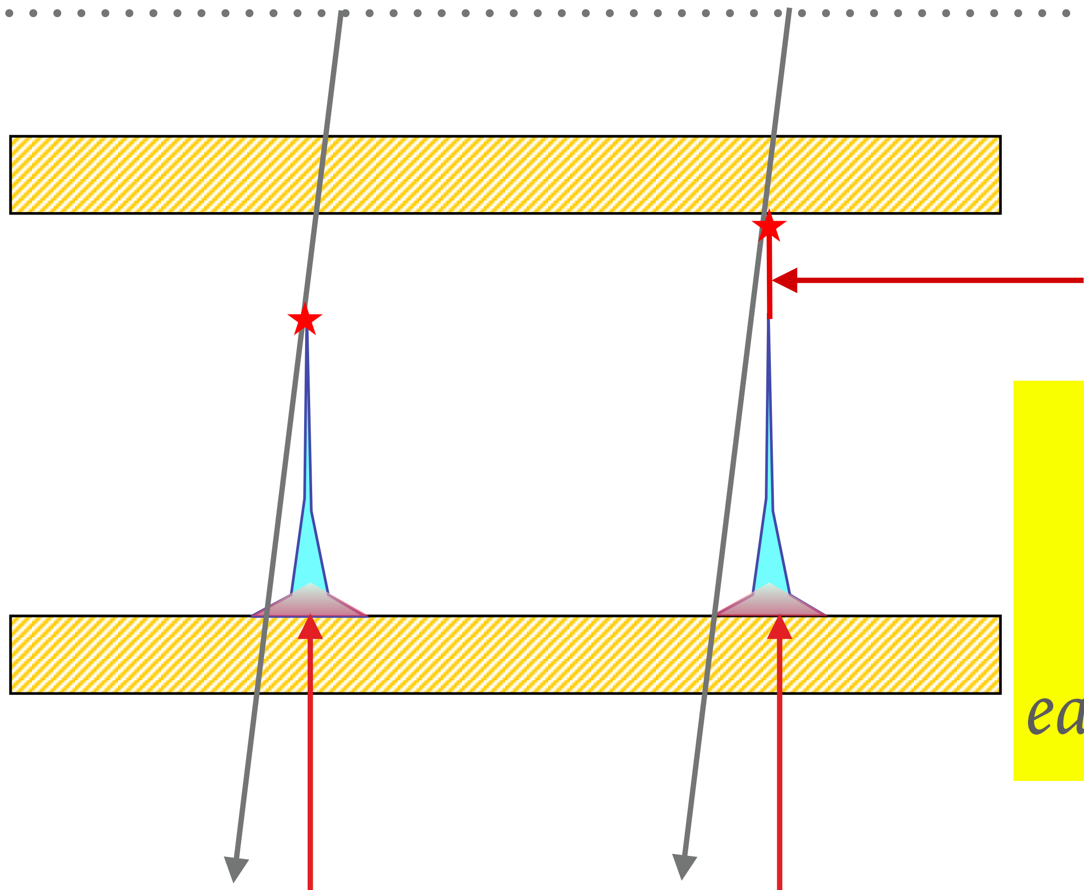
A. Spinelli Ph.D thesis (1996)



Development of avalanche in Silicon PM

In both cases the timing jitter is created during early development of avalanche

Time jitter



electron drifts for e.g. 2λ before avalanche begins to grow

2 mm RPC

$\lambda = 110$ micron $v = 150$ micron/ns

easy to find the ~ 1 ns time resolution of RPC

Observable signals produced only when the avalanche is close to the anode

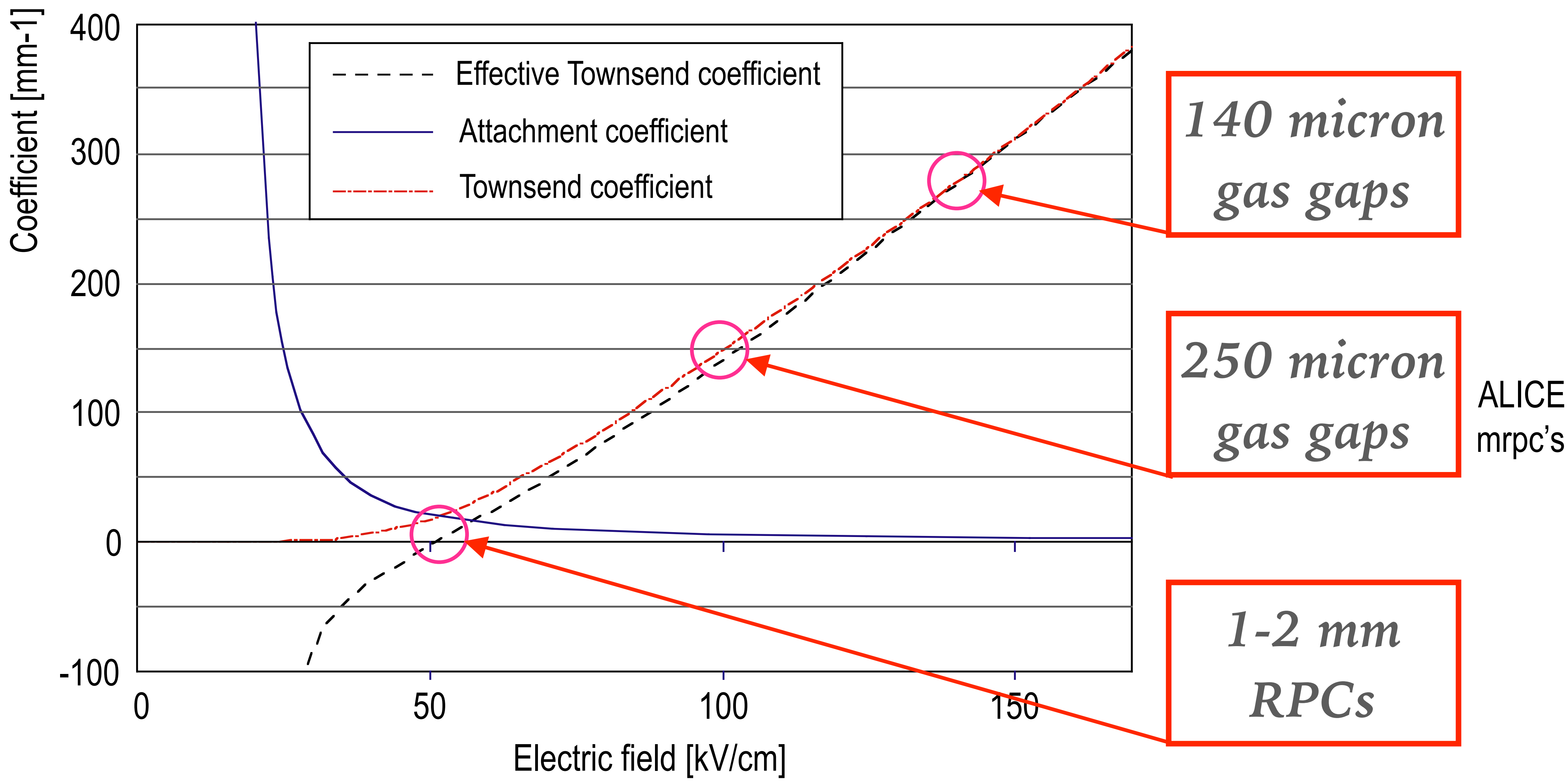
Reduce jitter by: (a)reducing λ,

(b) increasing electron drift velocity

(c) having simultaneous signals from many avalanches

The role of space charge

Magboltz output for 90% $C_2F_4H_2$ 5% SF_6 5% $i\text{-}C_4H_{10}$

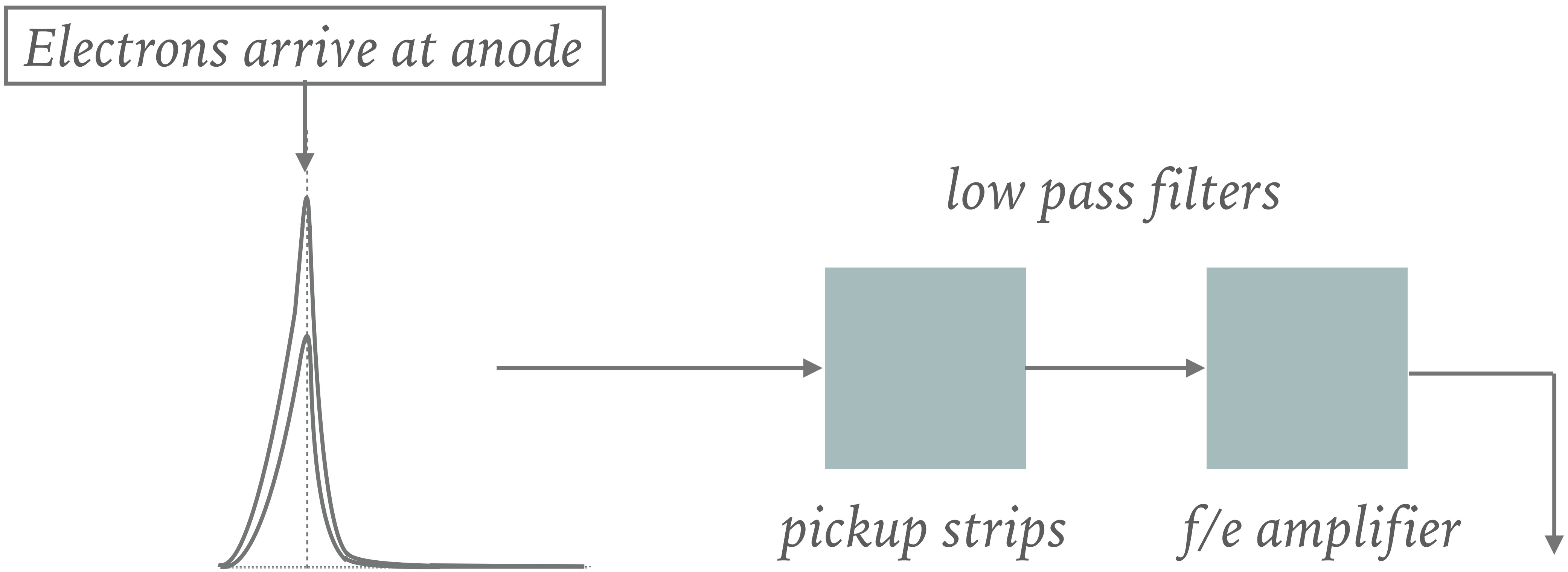


N, the number of electrons in avalanche given by: $N_o e^{\alpha x}$ where α is the Townsend coefficient

α 150 mm^{-1}, gap is 250 μm: **2.10^{16} electrons in avalanche when arrives at anode**

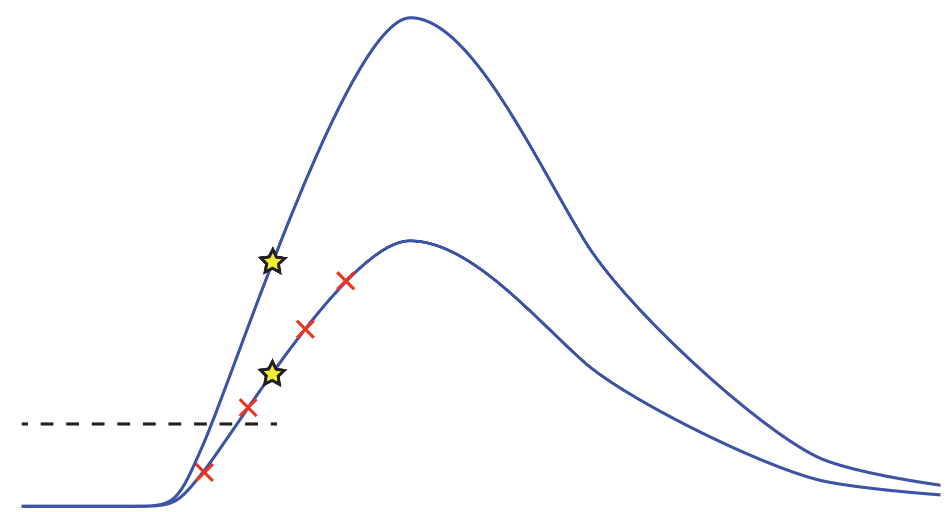
This gas gain too high: so what is going on here??

Time slewing



Fixed threshold will introduce time difference according to pulse height

correct with measurement of pulse height (TOT), or constant fraction - or sample rising edge of pulse



Signal within Front-end electronics

- Signal within front-end electronics usually has slower rise time than original MRPC signal - therefore will need a significant slewing correction (bigger effect for slower electronics):

Fixed threshold: corrected by signal amplitude /Time over Threshold

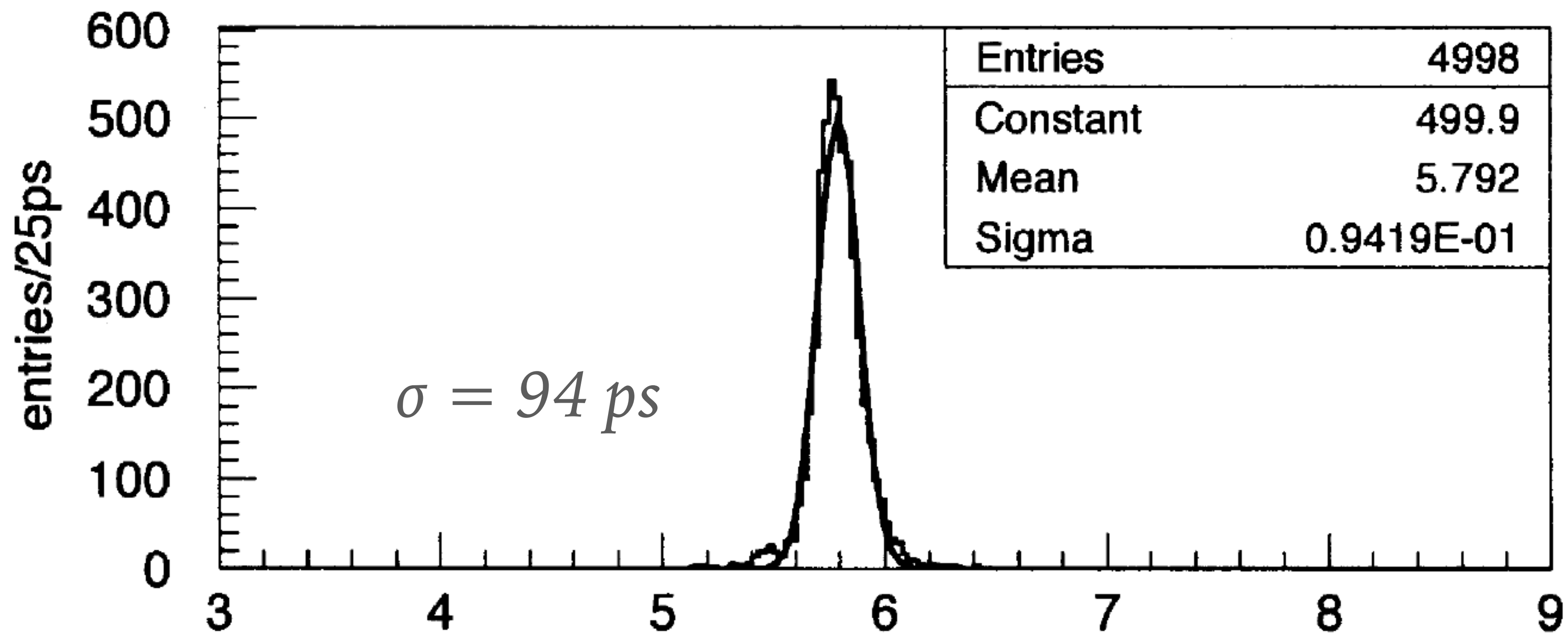
Constant-Fraction discriminator

Sample voltage during rising edge

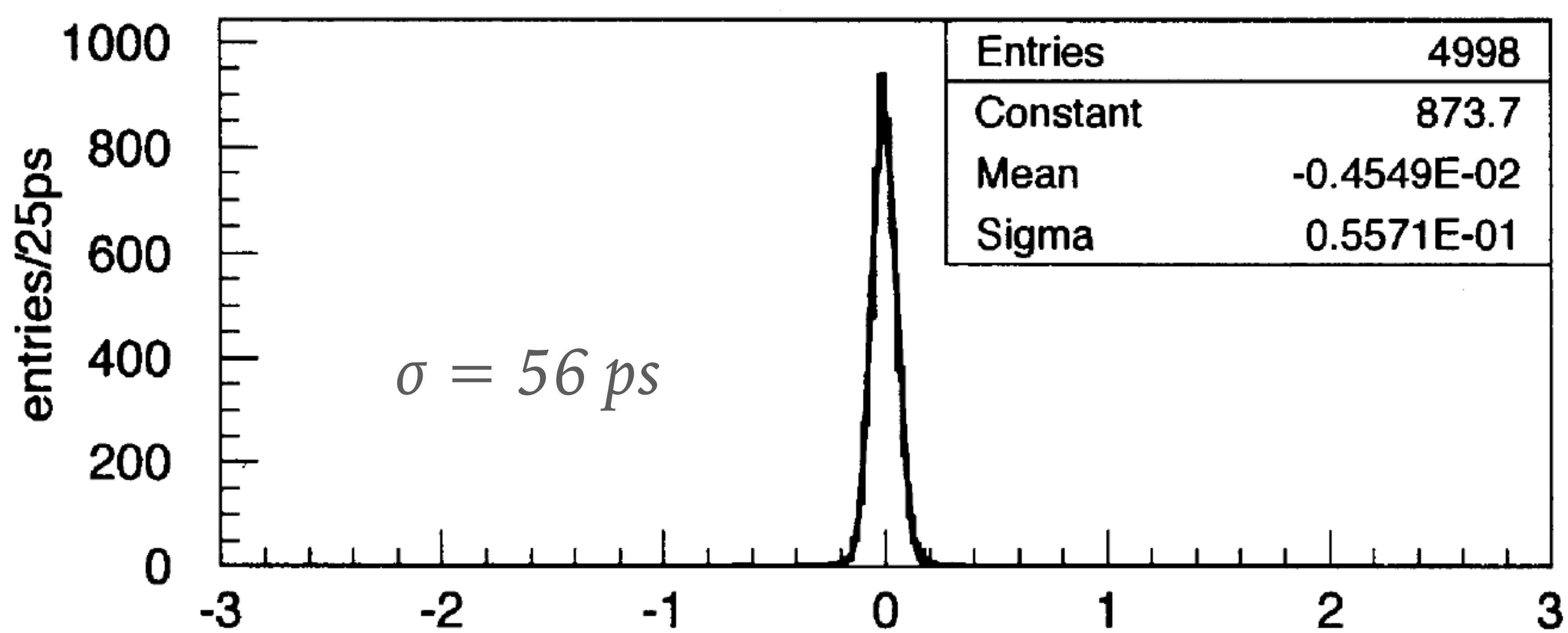
- All correction techniques give similar values

Typical slewing correction (ALICE TOF R&D) (10 gaps of 250 micron)

Time jitter contribution from slewing is 75 ps.



(a)

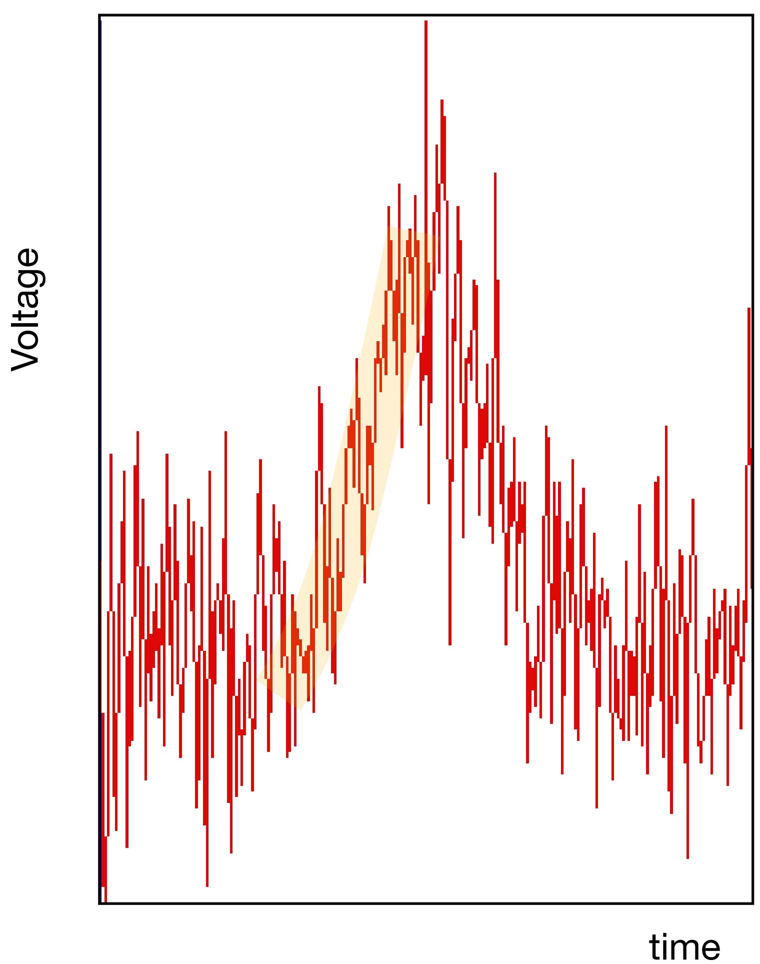


(b)

from Angelo Rivetti

$$\sigma_t = \frac{\sigma_V}{\frac{dV}{dt}} \qquad \frac{dV}{dt} \approx \frac{V}{t_r} \rightarrow \sigma_t = \frac{t_r}{SNR}$$

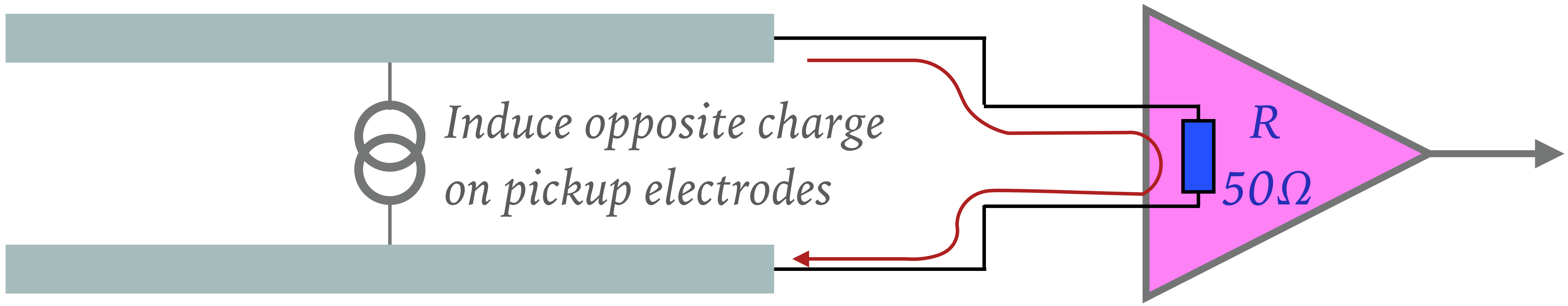
time jitter ~ risetime/signal-to-noise-ratio



To improve time resolution
- must enhance SNR

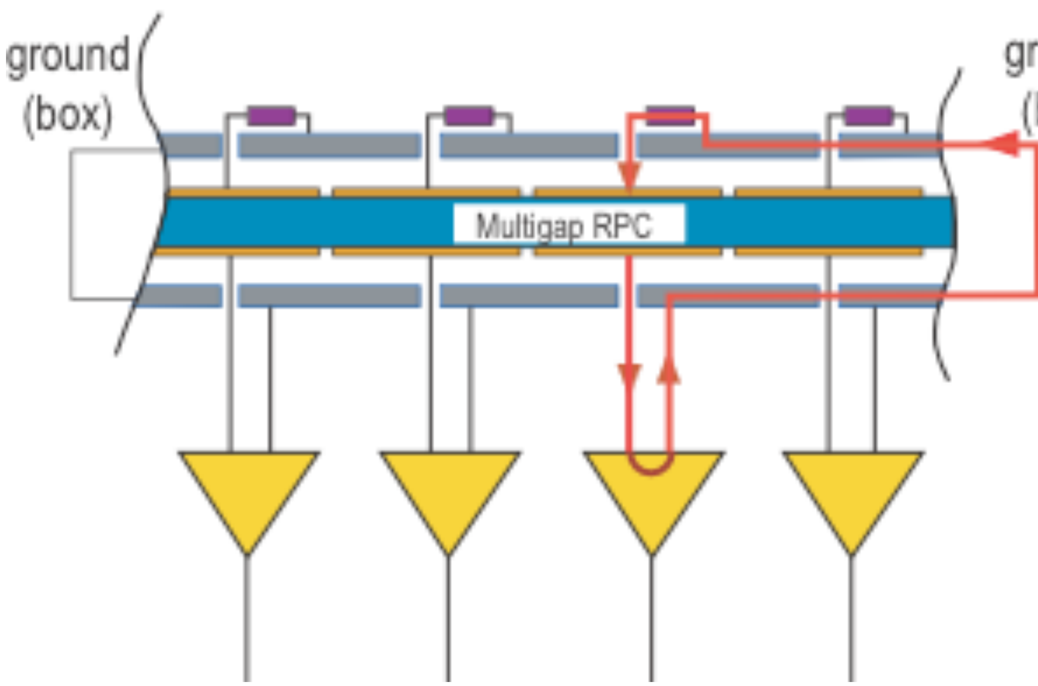
i.e. reduce noise

Signal from detector

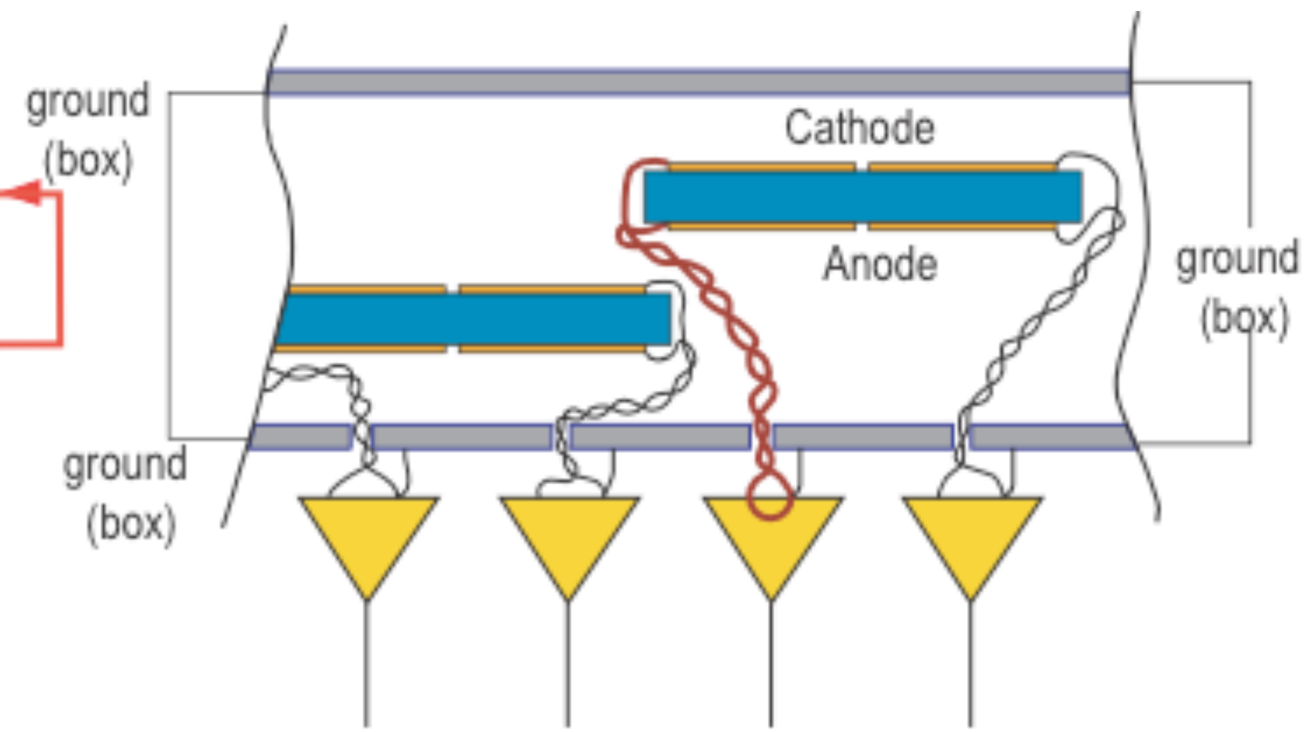


Current flows from one pickup electrode -
through the front-end electronics and back to the
other pickup electrode

Alice R&D

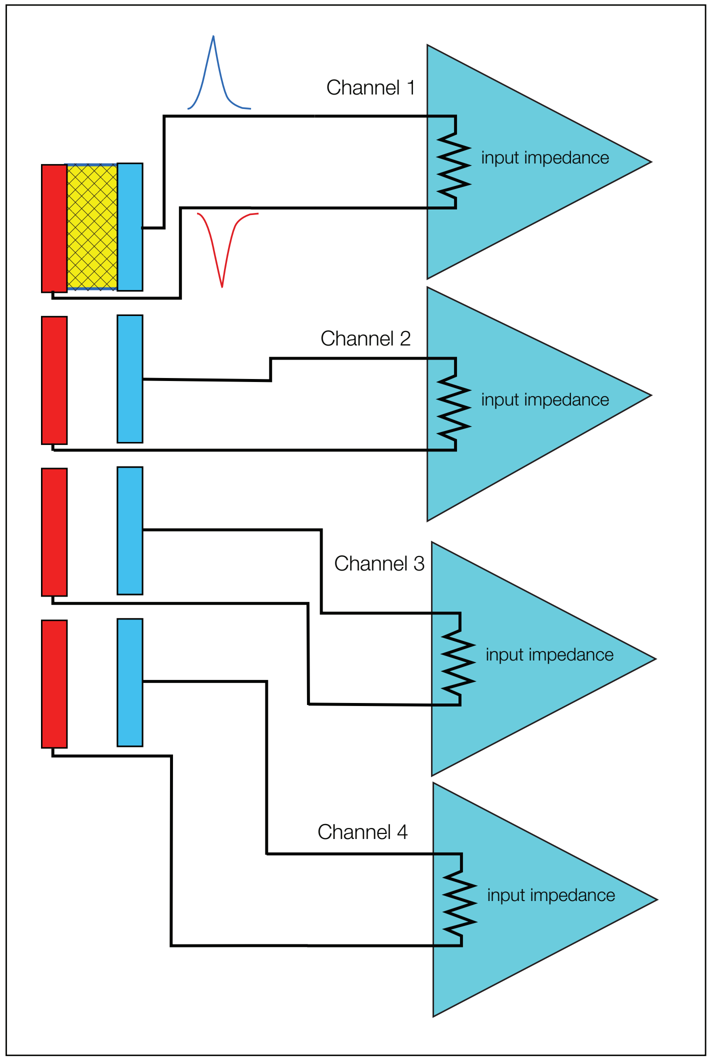


Planar chamber uses outside box for signal return

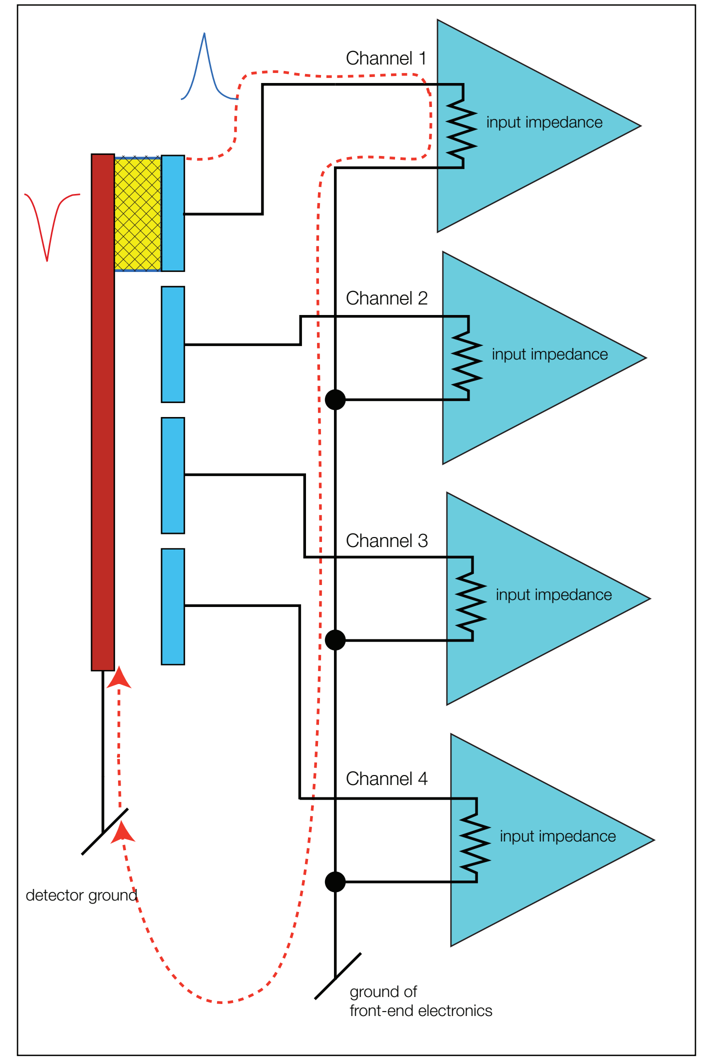


Strips allow access to both anode and cathode

Differential

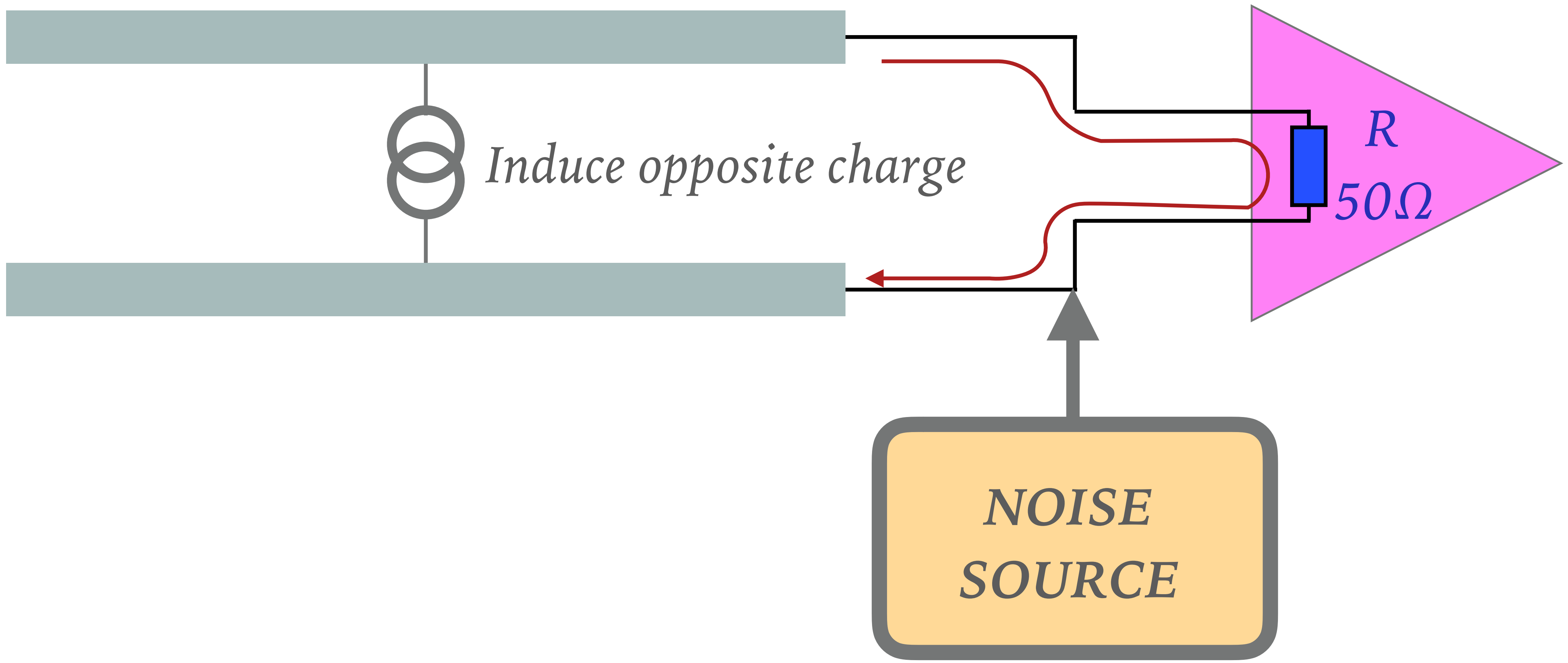


Single-ended



With the single-ended readout: fast current pulses are fed into the common ground; that is the reference level. This is an important source of 'noise' and cross-talk. This is especially true when precise timing (< 100 ps) is the goal.

Single-ended readout of 'multicell' device



Example: single-ended readout of SiPM array

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

Volume 717, 21 July 2013, Pages 5-10

Differential-readout: The technique to optimise timing in a monolithic MPPC array

K. Doroud et al. / Nuclear Instruments and Methods in Physics Research A 717 (2013) 5 –10

K. Doroud [a], E. Auffray [a], P. Jarron [a, b], T. Meyer [a], P. Lecoq [a]

Measure single-photon time resolution and then switch on additional cells

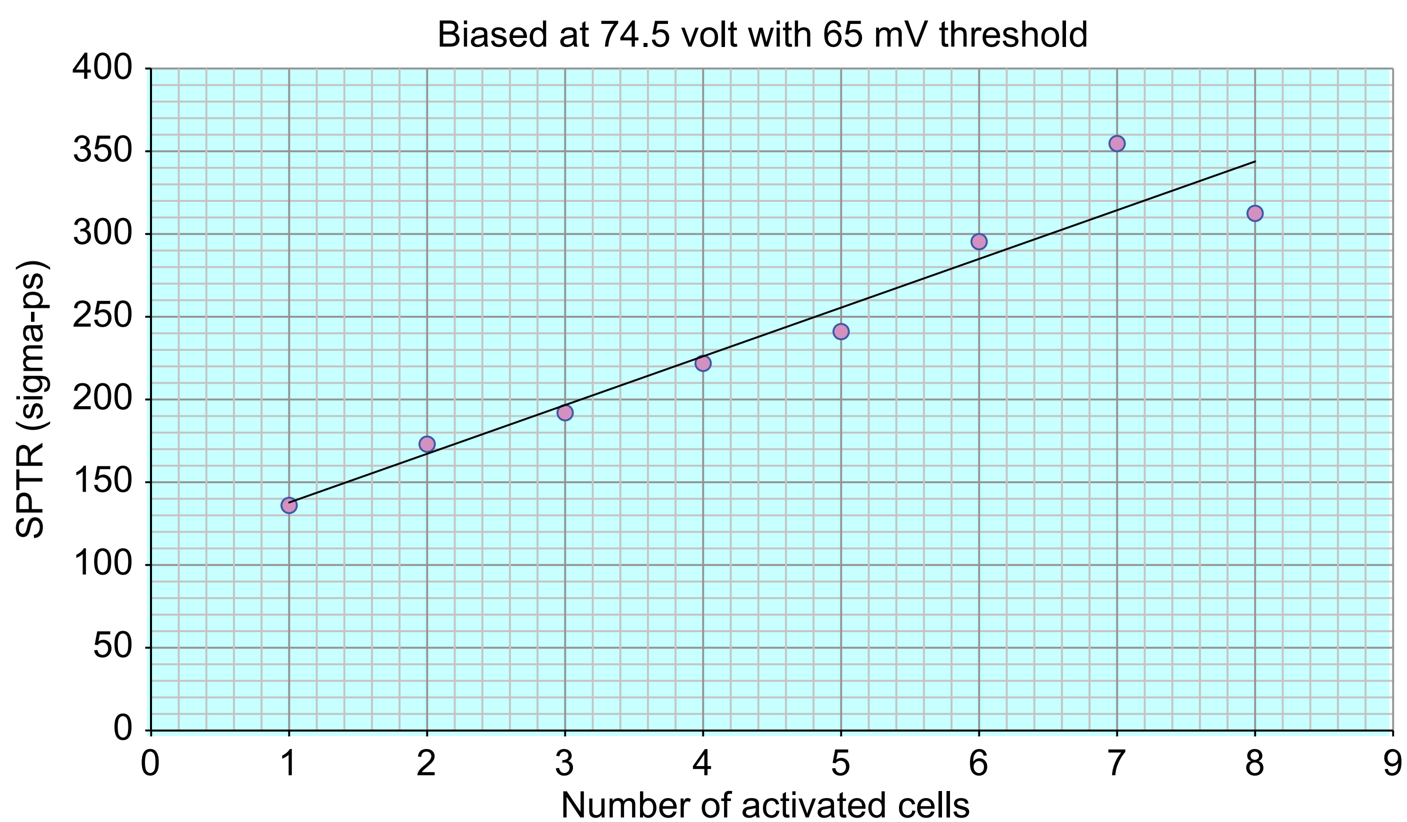
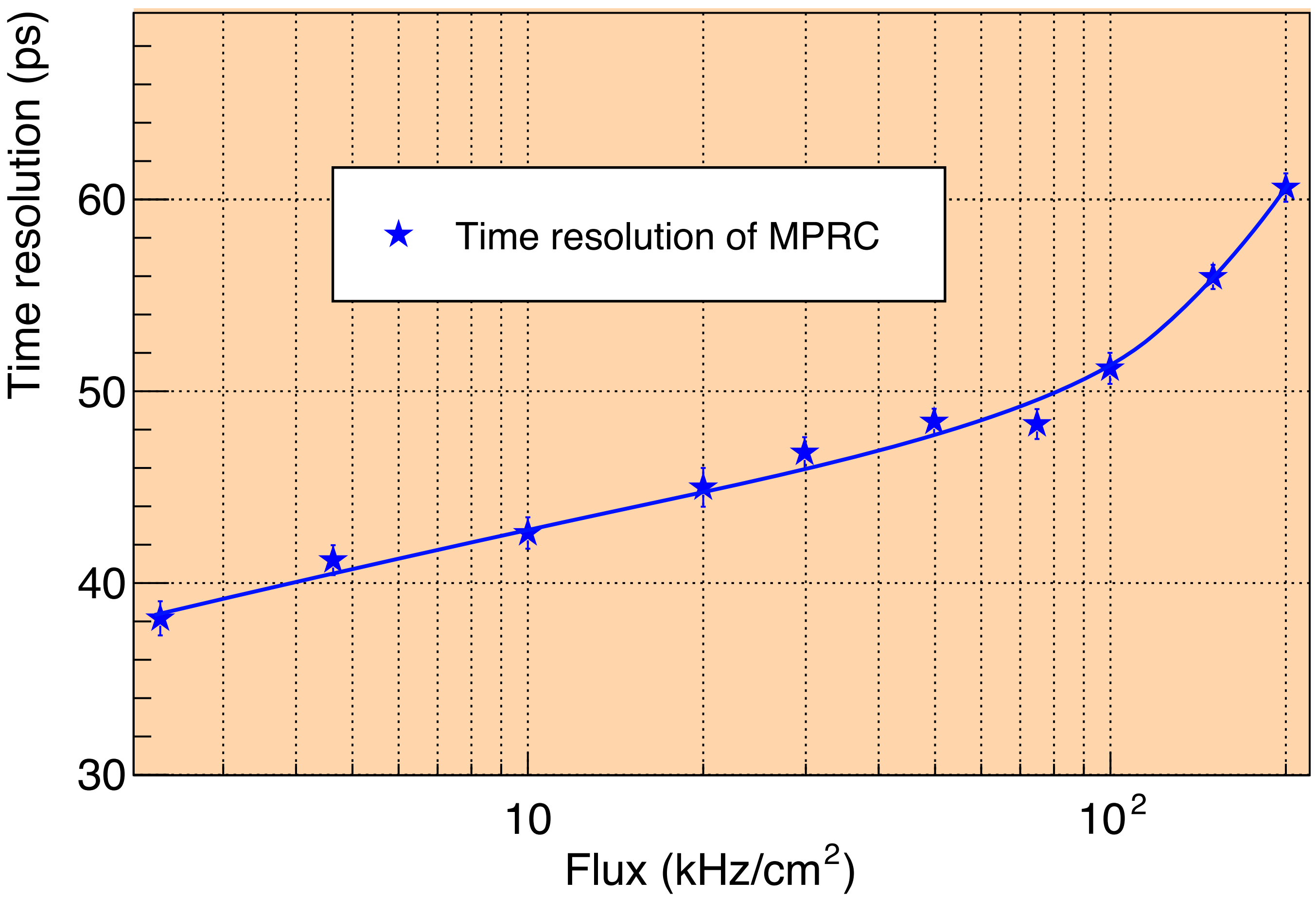


Fig. 9. SPTR of the C2 cell of the Hamamatsu array at a constant applied voltage of 74.5 V and 65 mV threshold shown versus the number of activated cells.

Time resolution degradation with rate

Please see talk of Lothar Naumann: First high rate test of a MRPC detector with novel low resistivity float-glass electrodes 11 Feb 2020, 15:00

Test of 10 gap MRPC at very high flux of particles



Time resolution degrades from 38 to 51 ps with background flux of 100 kHz/cm^2

Why ??

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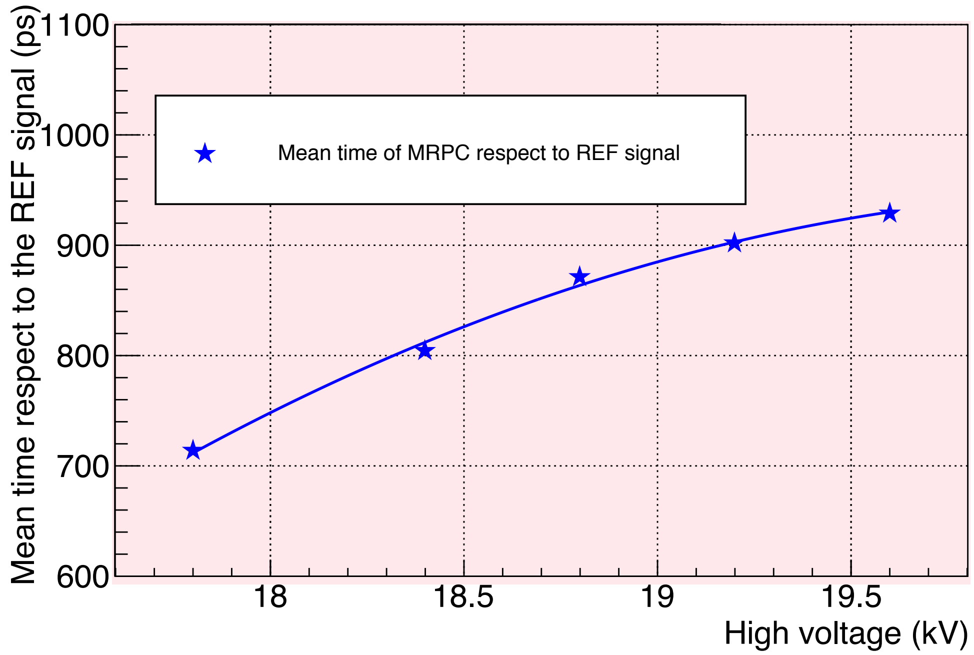
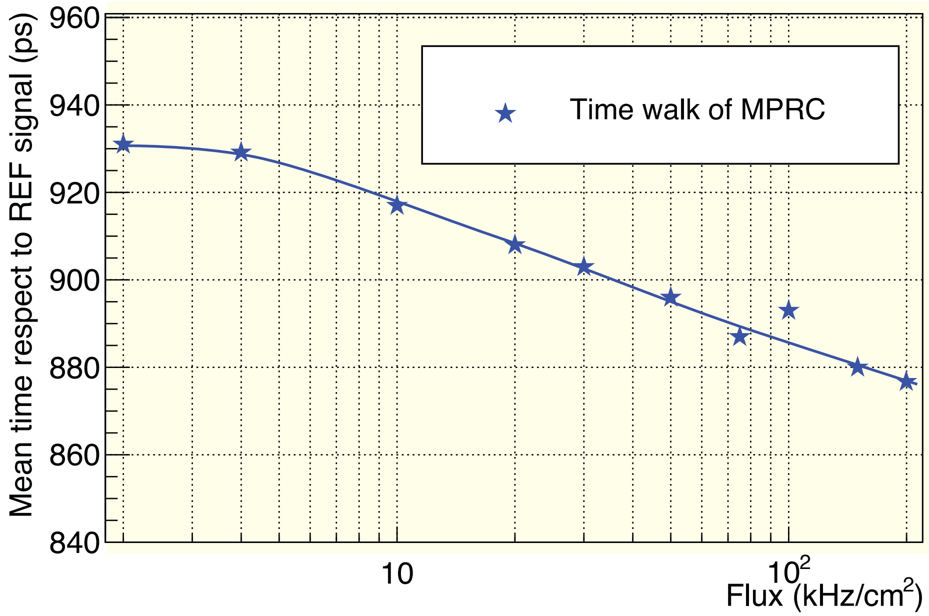
Time-walk with voltage and Time-walk with background flux



Signals get bigger and earlier with increasing voltage

Measure time-walk versus flux - informs us of the voltage drop



Instantaneous variations in flux will introduce voltage fluctuations - and cause time-walk fluctuations

Summary

- Intrinsic jitter produced at the beginning of avalanche process:
  - reduced by working at high Townsend coefficient
  - reduced by an increase in drift velocity (high Electric field)
  - reduced by taking 'average' of many avalanches
- Other contributions to time jitter
  - Time slewing - finite rise time of electronics - however relatively easy to correct
  - Noise: Single-ended / Differential read-out front-end electronics important for time resolutions below 150 ps
  - Rate effects: Voltage drop on resistive plates - more R&D needed

Thank you for your attention

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