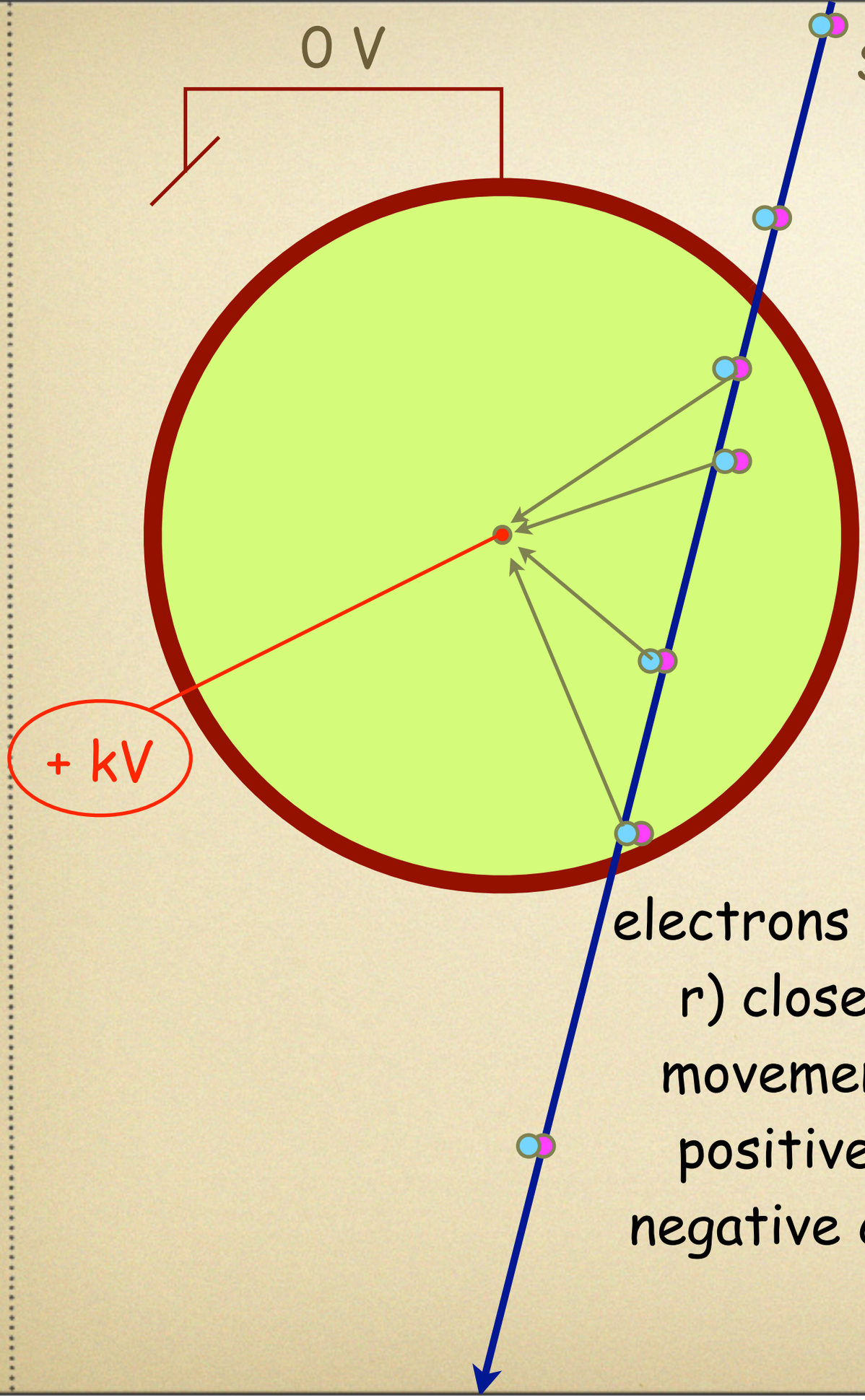
the multigap rpc: a detector for excellent time resolution

crispin williams

infn bologna

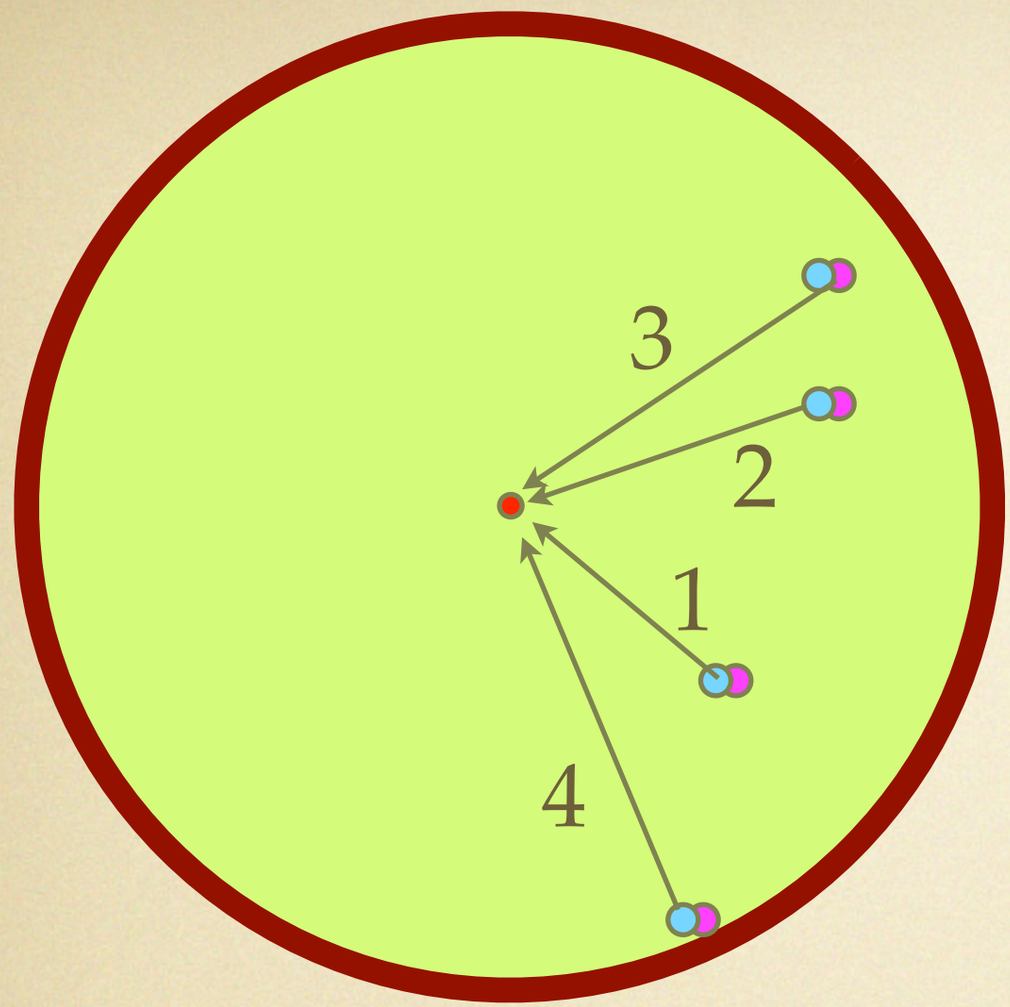


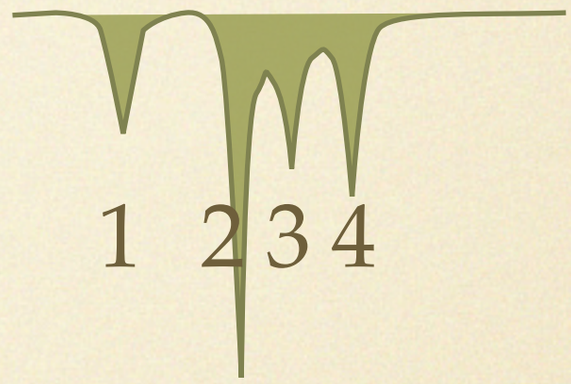
Simplest type of gaseous detector - thin wire inside tube filled with gas (voltage applied to wire - usually some kV

charged particle passes through gas volume

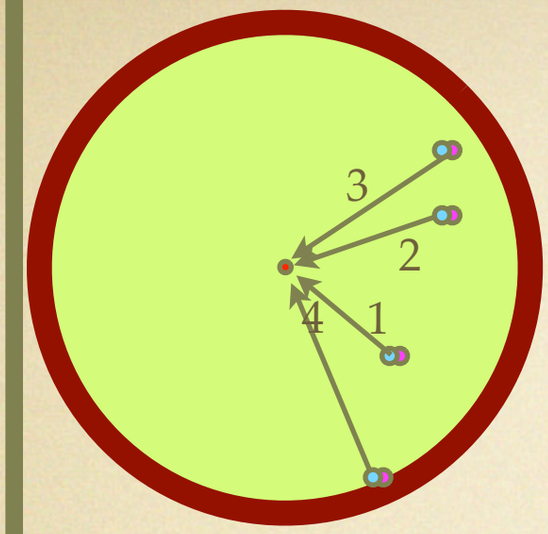
trail of electrons + positive ions

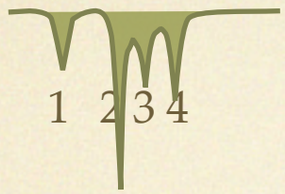
electrons drift to anode wire - high field (1/r) close to wire creates gas avalanche - movement of electrons towards wire and positive ions away from the wire induce negative charge on wire (positive charge on outer tube)





electrons drift at a finite speed and arrive at anode one after another : thus signals from wire a series of pulses. However normally set electronics to 'fire' with low threshold - ie first electron that arrives is important - the rest are wasted





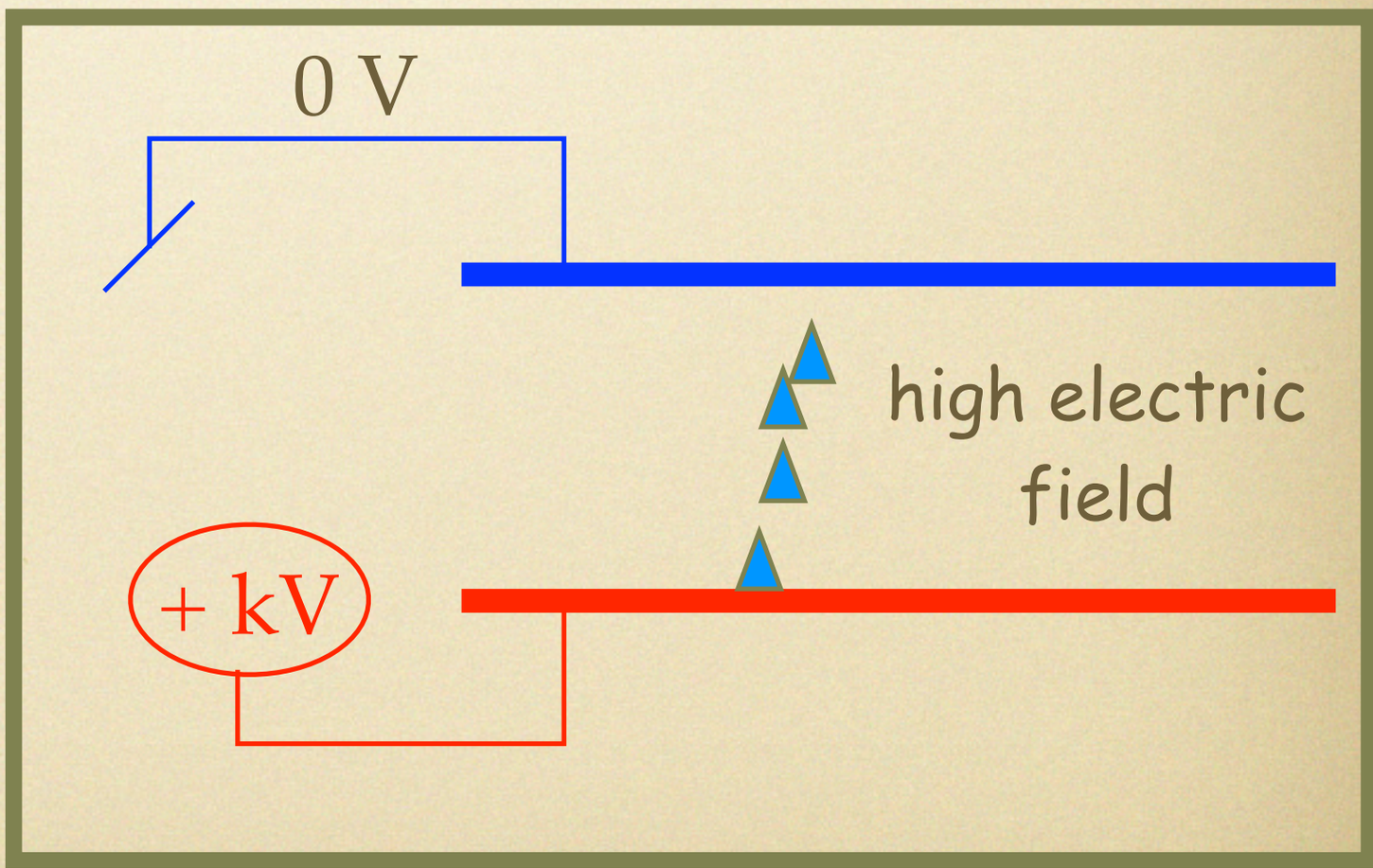
Tube with wire

series of gas avalanches

series of signal

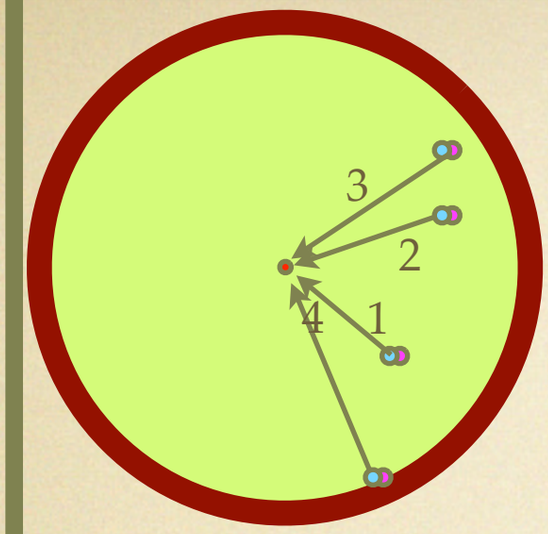
What about the parallel plate chamber?

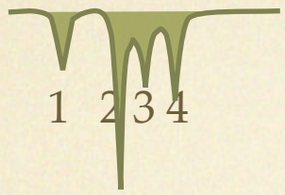
Electric field sufficiently strong so that gas avalanches start immediately - induced signal due to movement of charge in all avalanches - observed signal is all avalanches acting in parallel



Santonico - RPC conference 1996

THIS STATEMENT IS INCORRECT





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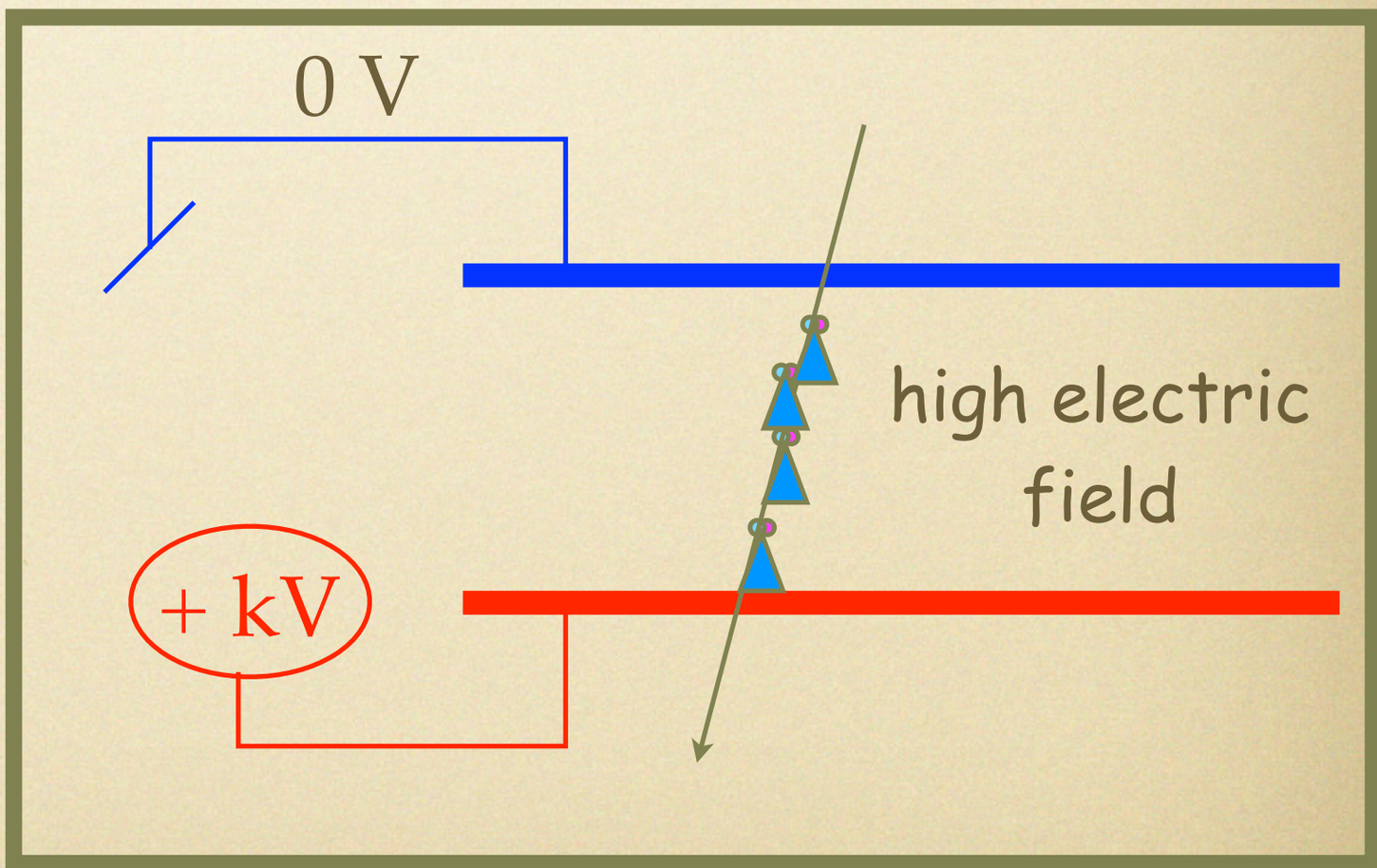

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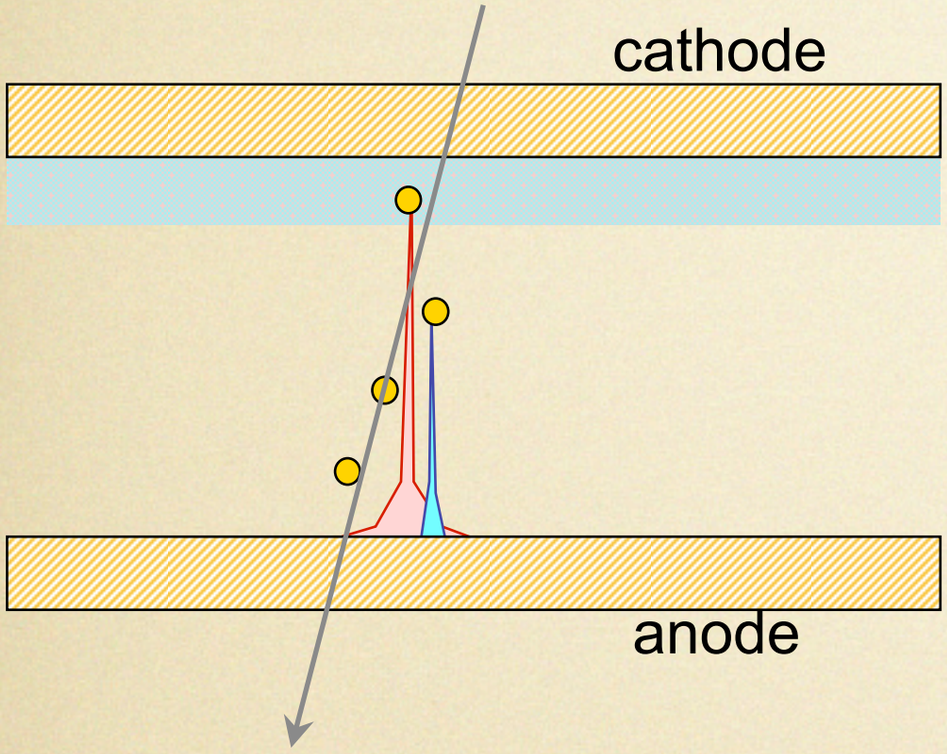
However - electron avalanche grows according to Townsend law: $N = N_0 e^{\alpha x}$



Only avalanches that traverse full gas gap will produce detectable signals - only clusters of ionisation produced close to cathode important for signal generation.

★ So only a few ionisation clusters (those created closest to cathode) take part in signal production

★ 2 mm gap RPC only ionising clusters within some hundred of microns of the cathode can grow avalanches big enough to generate signal

★ if increase E field so that all clusters could grow big enough - we will have sparks - etc)

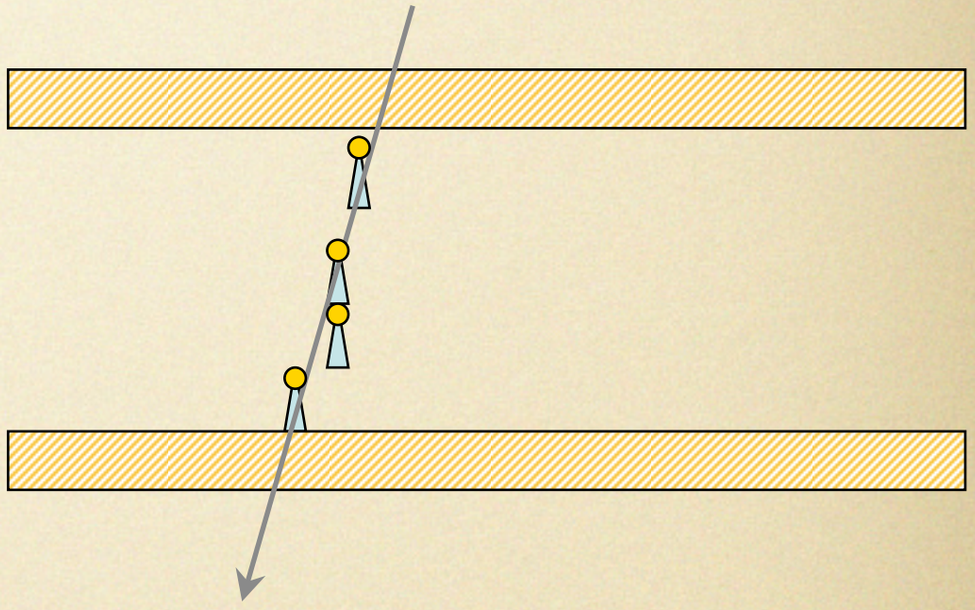
★ N.B. Time jitter due to how avalanche develops initially

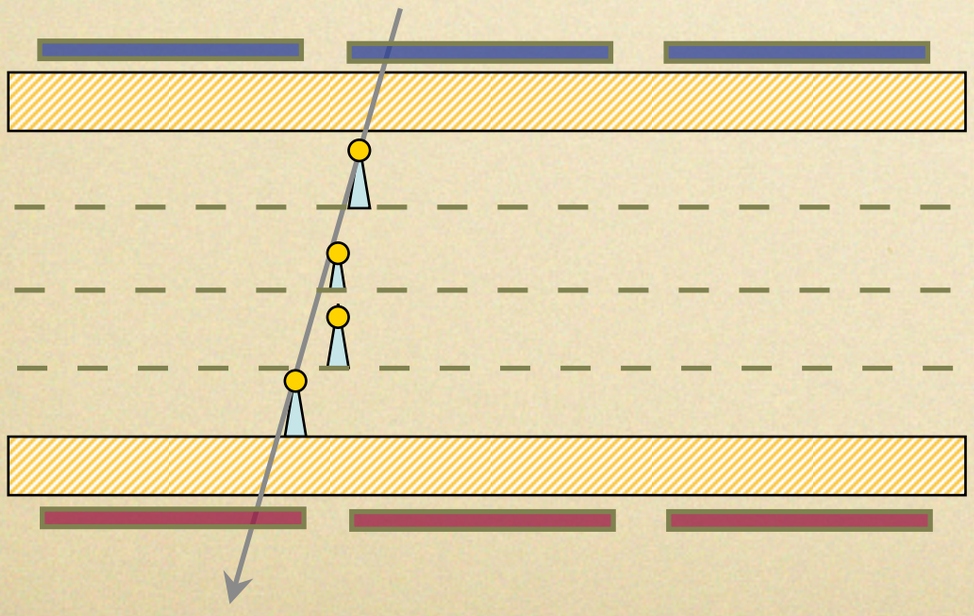
even though the description by Santonico in 1996 was incorrect ... it was a very appealing thought - i.e. get many avalanches to act together

Question: Can we increase gas gain such that avalanche produces detectable signal immediately?

(a) Need very high gas gain (immediate production of signal)

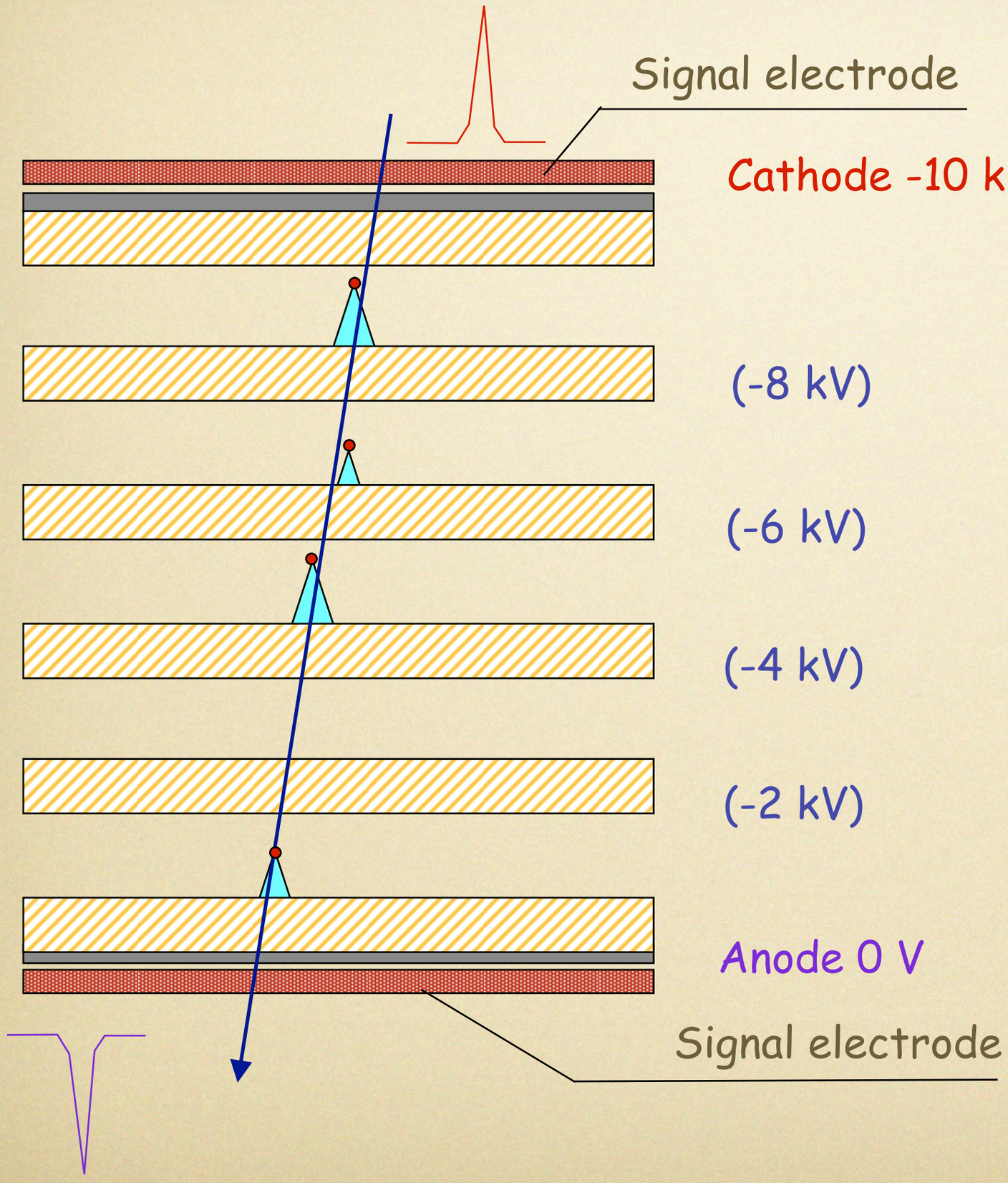
(b) Need way of stopping growth of avalanches (otherwise streamers/sparks will occur)





Answer: add boundaries that stop avalanche development. These boundaries must be invisible to the fast induced signal - induced signal on external pickup

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 - (any movement of charge in any gap induces signal on external pickup strips)

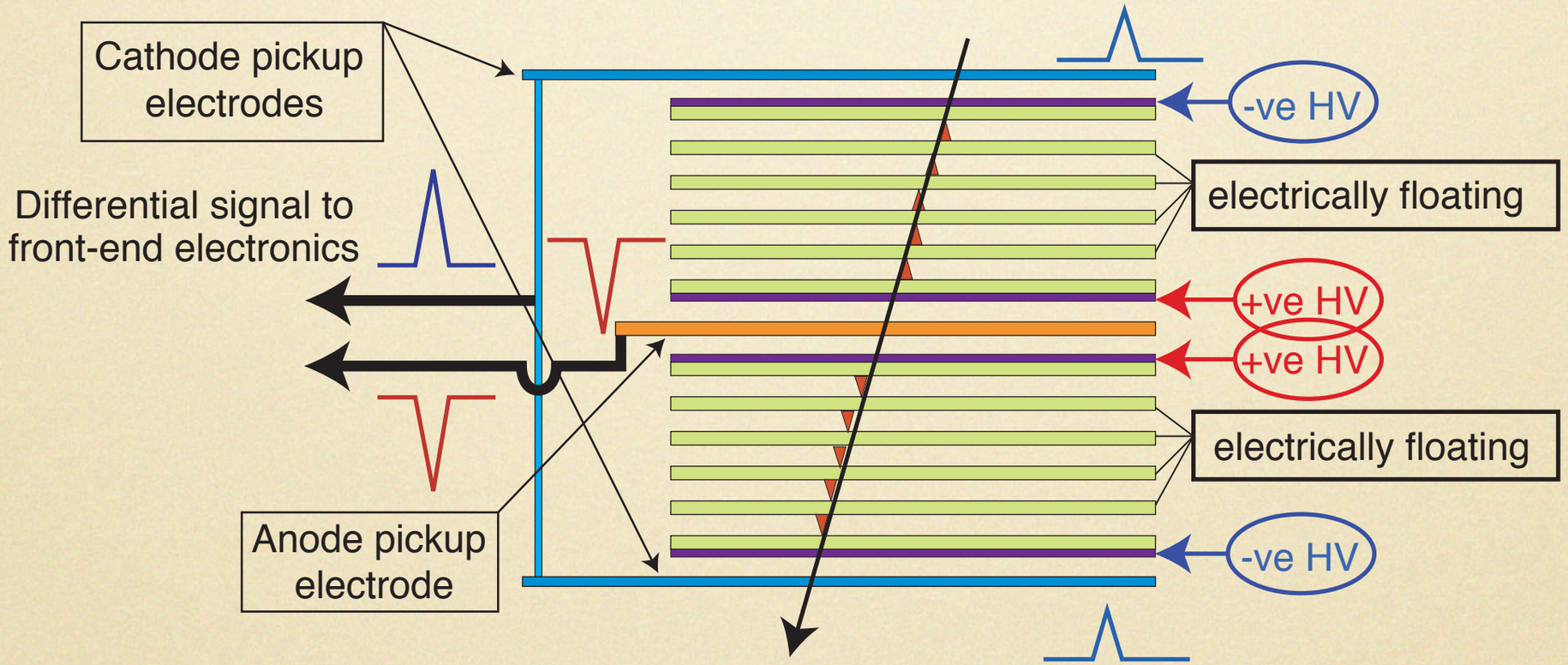
Internal plates take correct voltage - initially due to electrostatics but kept at correct voltage by flow of electrons and positive ions - feedback principle that dictates equal gain in all gas gaps

ALICE MRPC for TOF

schematic view

ALICE-TOF has 10 gas gaps (two stacks of 5 gas gaps) each gap is 250 micron wide

Built in the form of strips, each with an active area of 120 x 7.2 cm^2, readout by 96 pads



Note : HV only applied to outer surfaces of each stack of glass (internal glass sheets electrically floating) this makes it very easy to build.

Some magical aspects of the MRPC

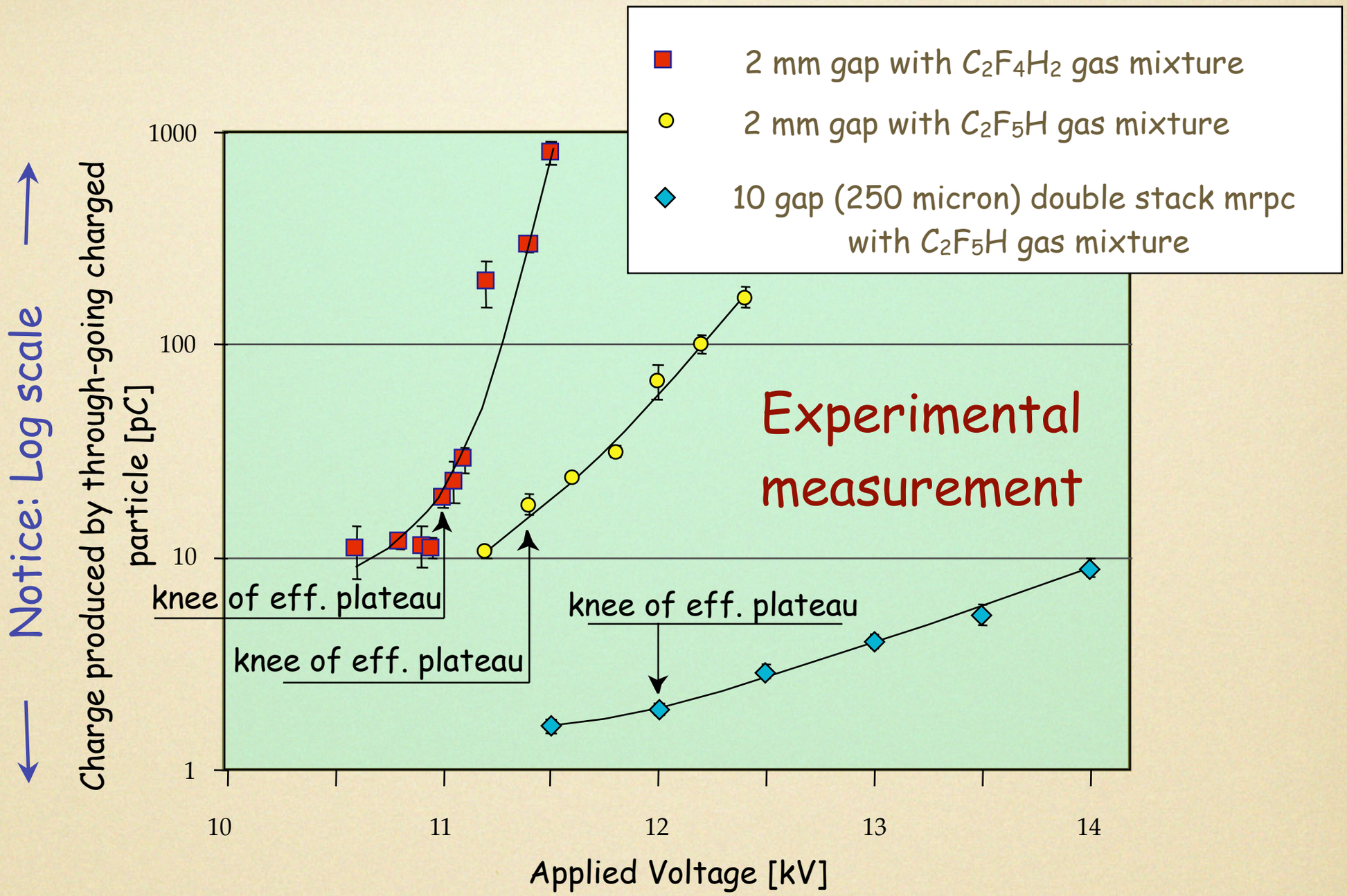
- Intermediate resistive plates 'float' at correct voltage
  - kept at correct voltage by flow of electrons and positive ions, feedback principle equalised the gas gain in each gap

- long streamer-free efficiency plateau
  - space charge* limits growth of avalanche before transition to streamer

- excellent fast signal/total charge ratio
  - space charge* limited avalanche growth
  - recombination : most of negative ions (electronegative gas) recombine with positive ions

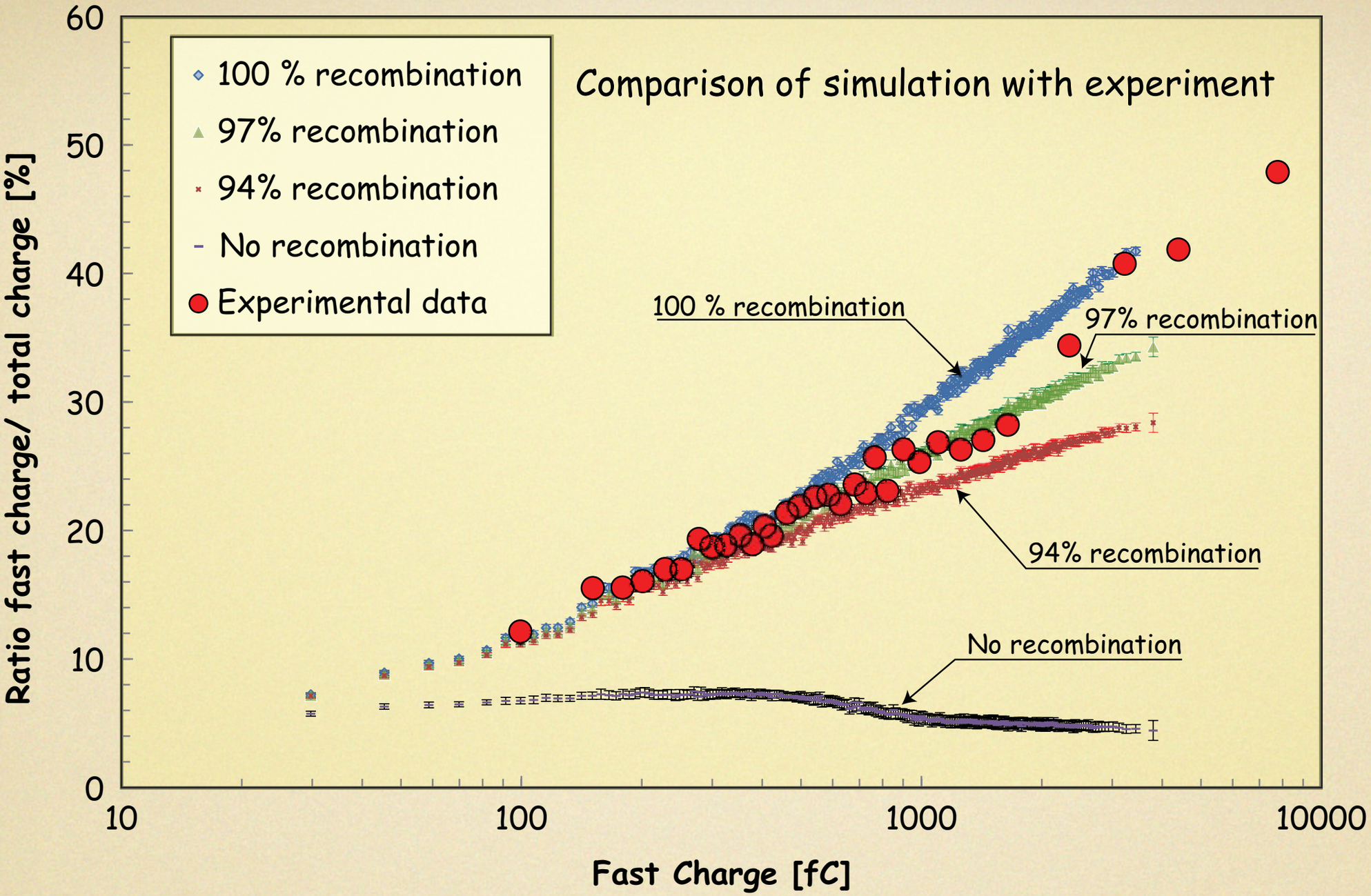
* small gas gaps makes space charge important
  small gas gaps is the route to good timing

Measure TOTAL charge of 2 mm RPC and ALICE-TOF MRPC



(a) observe how slow gain changes with voltage (factor 5 / 2 kV)

(b) MRPC (ALICE TOF) average total charge ~ 2 pC (good rate capability)



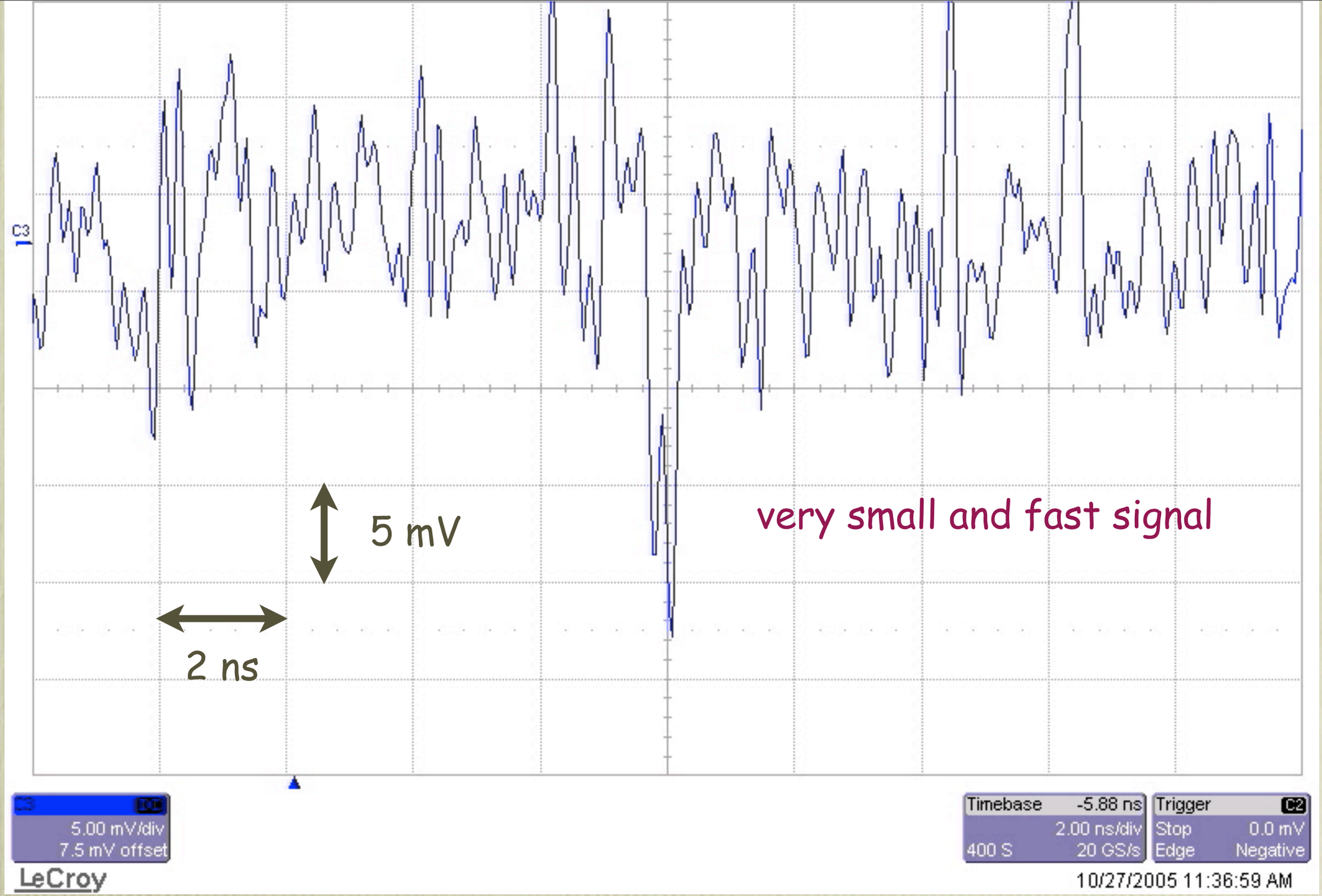
Want large fast signal and small total charge (rate capability)

Fast signal/total charge = 1/aD : around 5% for normal 2 mm gap RPC

Recombination very important effect - most negative ions recombine and do not drift to anode

OK - now you know that the MRPC is a fantastic chamber... what about timing??

... a little pause to consider electronics

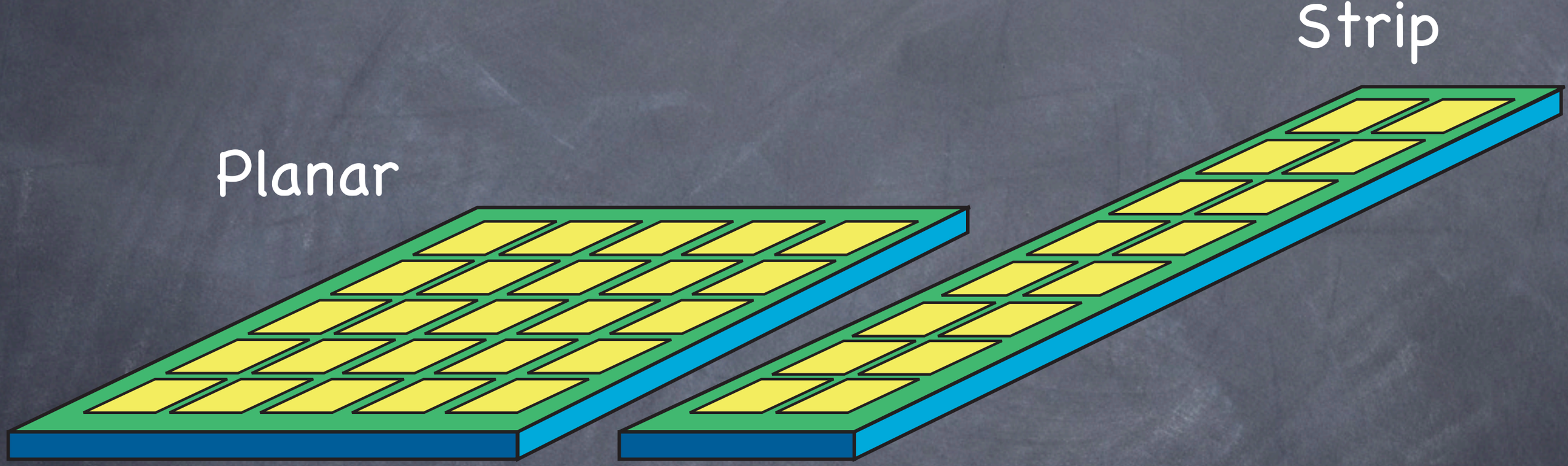


Injected signal of 200 fC measured with 3 GHz bandwidth differential probe

Of course measuring the voltage like this is the wrong approach

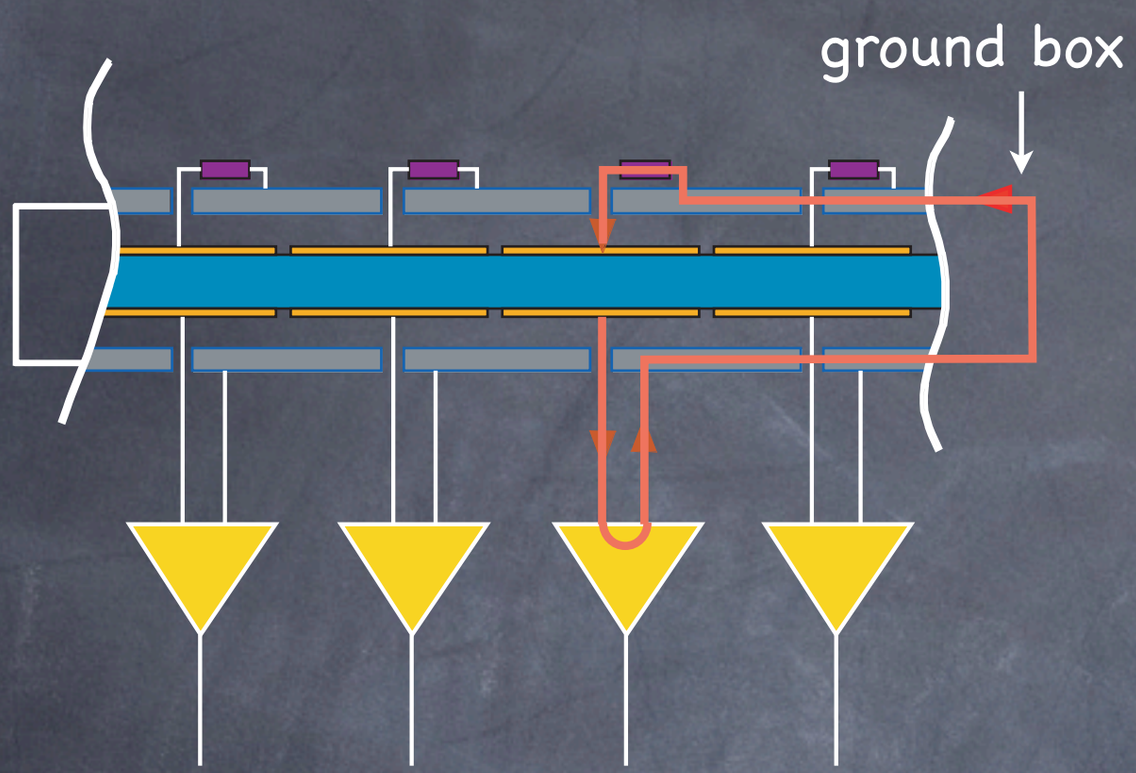
need fast current amplifier -
but bottom line is that for good timing we need to do everything we can to reduce noise

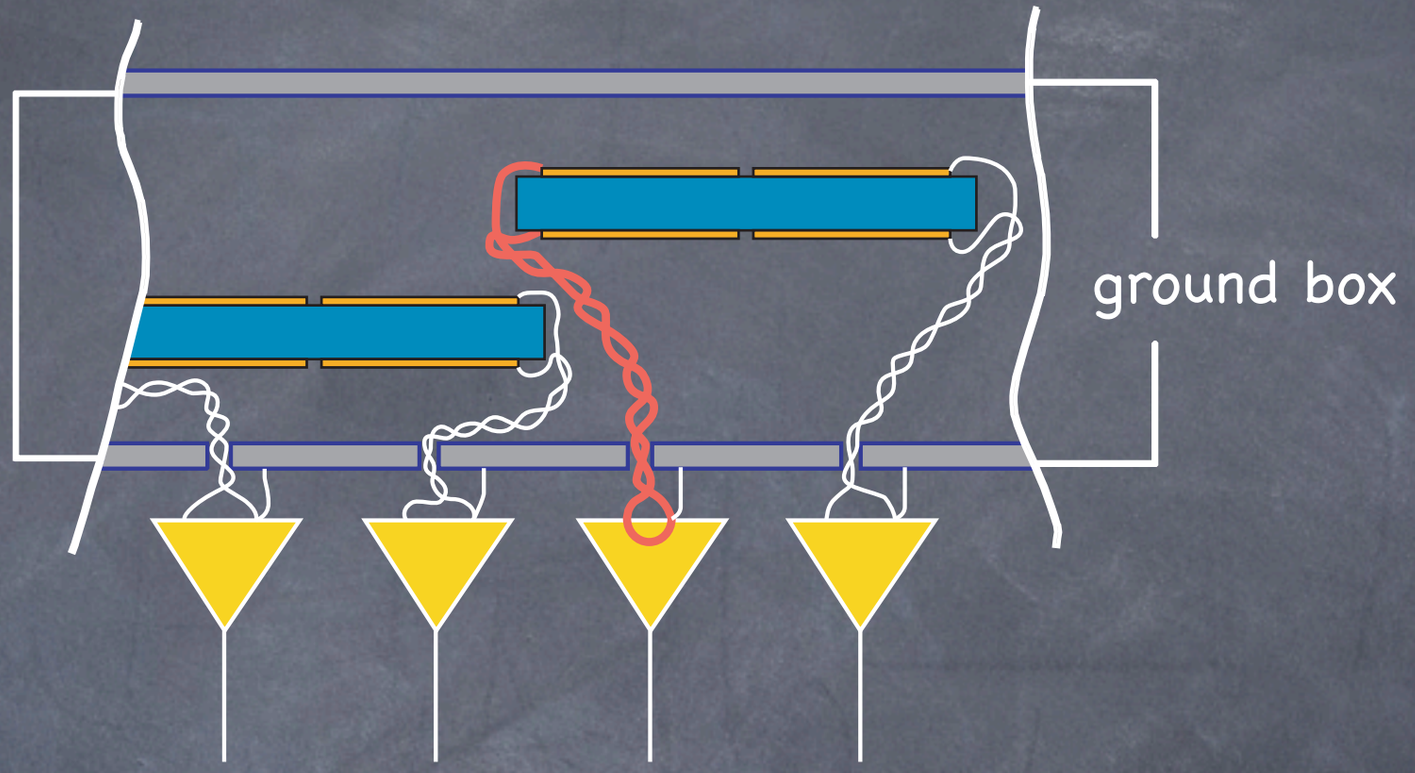
Minimise noise : good detector design as well as good electronics. Consider the case of the planar versus the strip MRPC detector



Strip has some advantages concerning the geometry but very large advantage for the readout electronics

Big reduction in noise if care is taken with the signal return



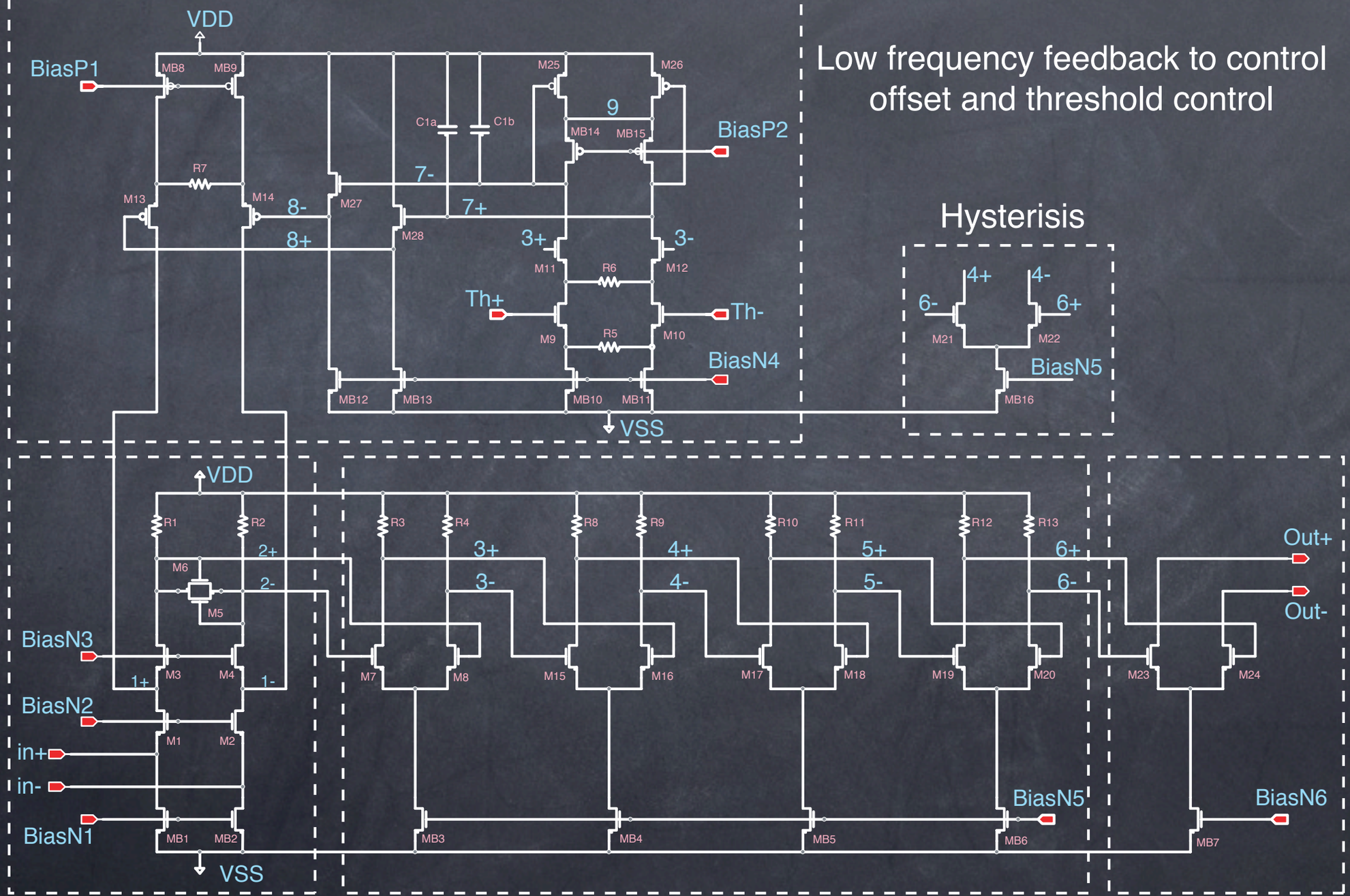


The signal is induced on the anode and cathode pickup pads - current flows from anode pad through amplifier and returns to cathode pad. The strip design allows the use of a transmission line (twisted pair cable) to connect this 'signal generator' to the amplifier - otherwise return path is via the outside grounding box (therefore sensitive to all the noise in the ground). In reality this is a key ingredient to substantially reducing the noise and improving the time resolution

If you want to get better than 50 ps time resolution - must use differential readout - must have access to anode and cathode readout pads

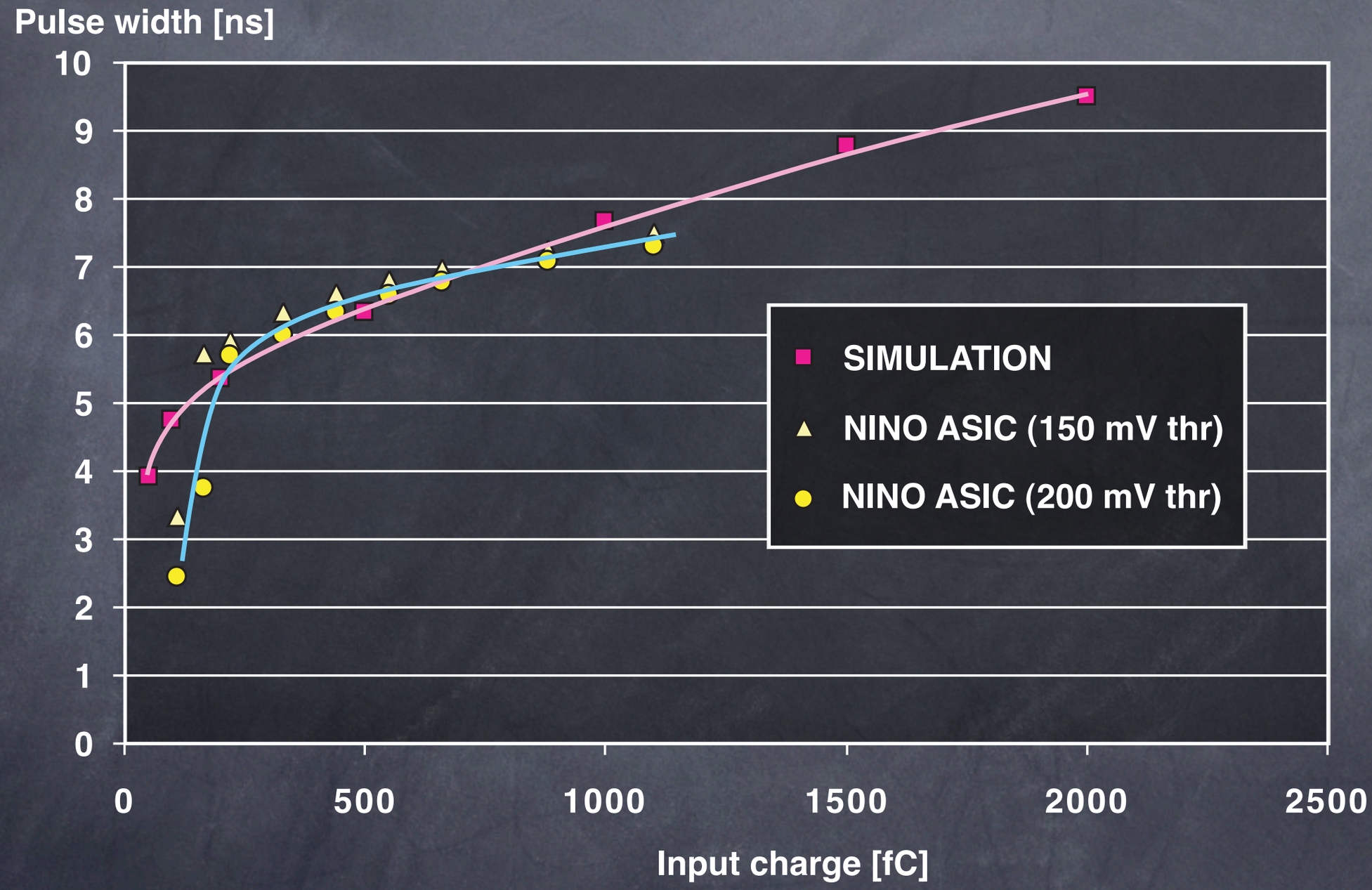
Designed dedicated front-end asic for ALICE TOF

differential input, 40-70 Ohm input impedance, 1 ns peaking time, encode input charge into output width

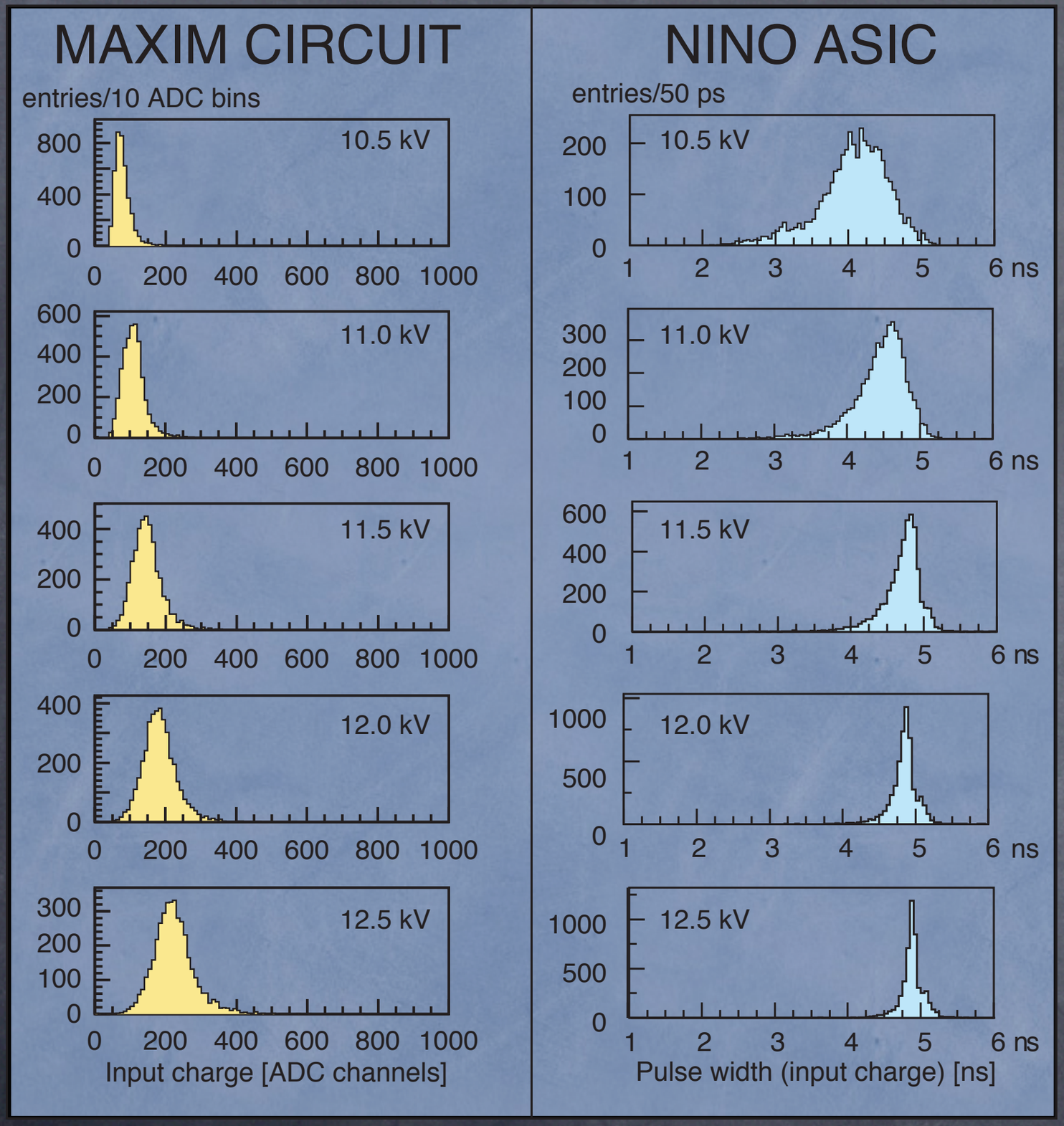


Simple threshold discriminator - need to correct time using pulse height (slewing correction)

Width of output pulse related to input charge - non linear



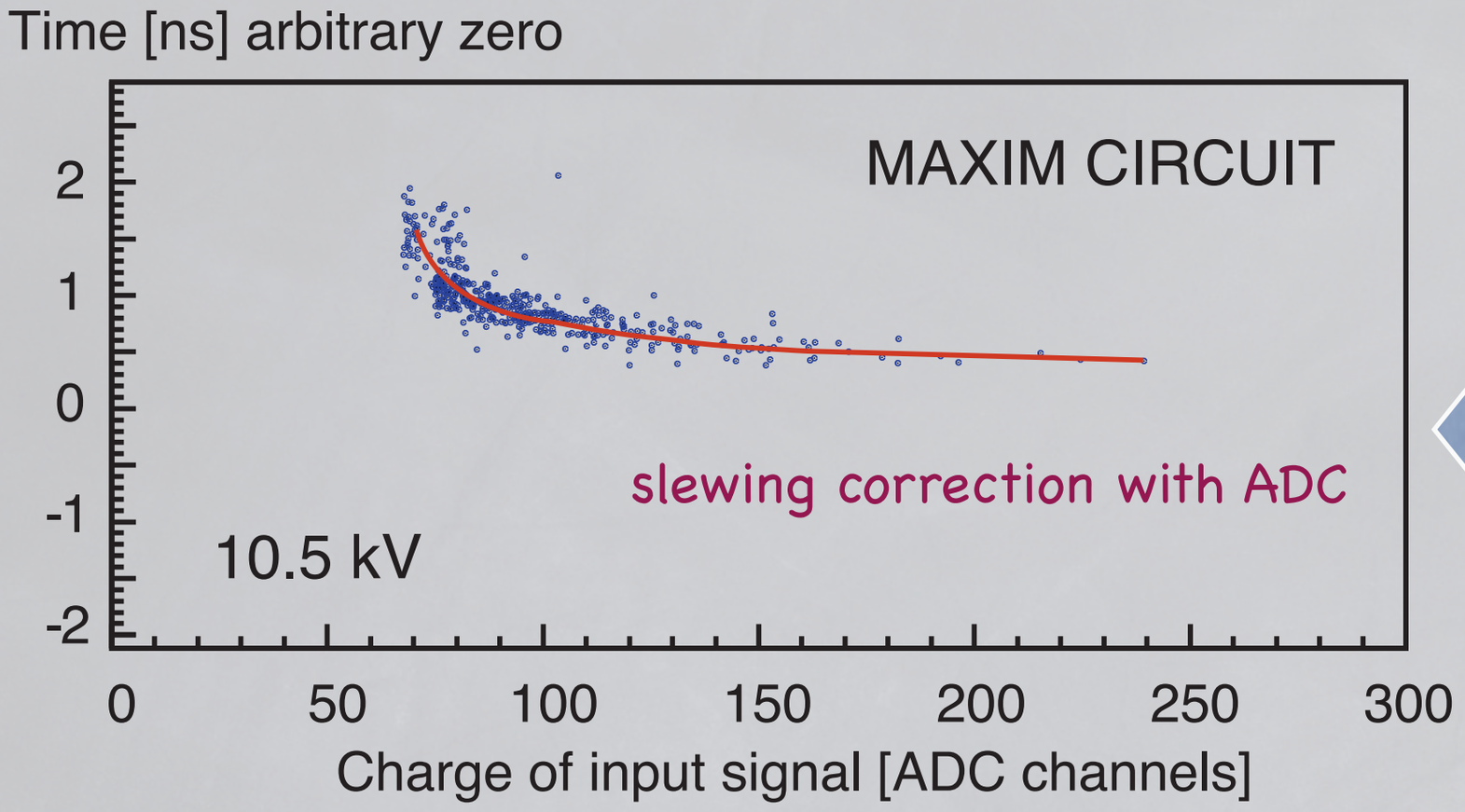
No ADC - instead use TDC (measuring leading and trailing edge)



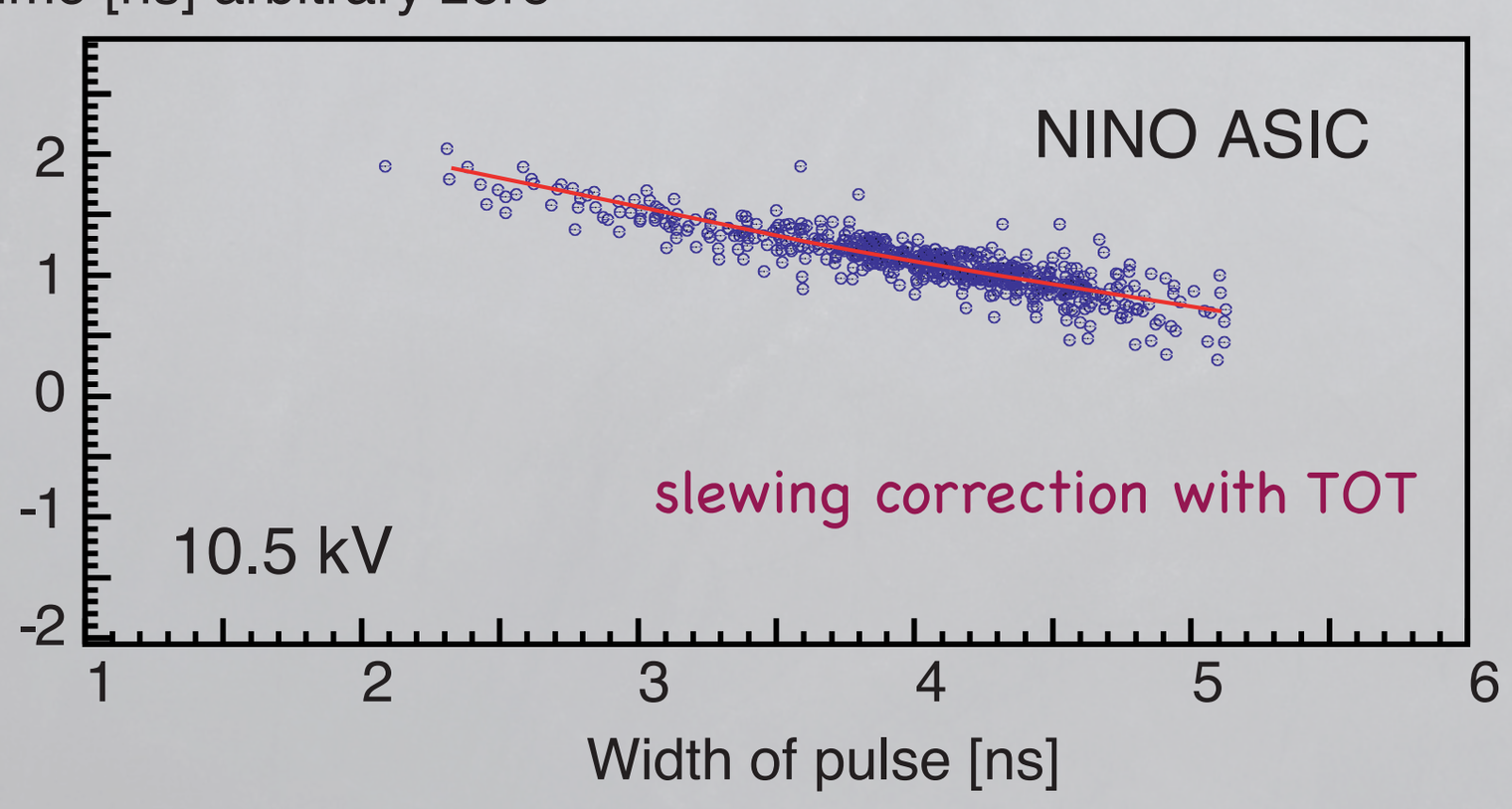
NINO ASIC expands the dynamic range for small input charge

ADC

ToT

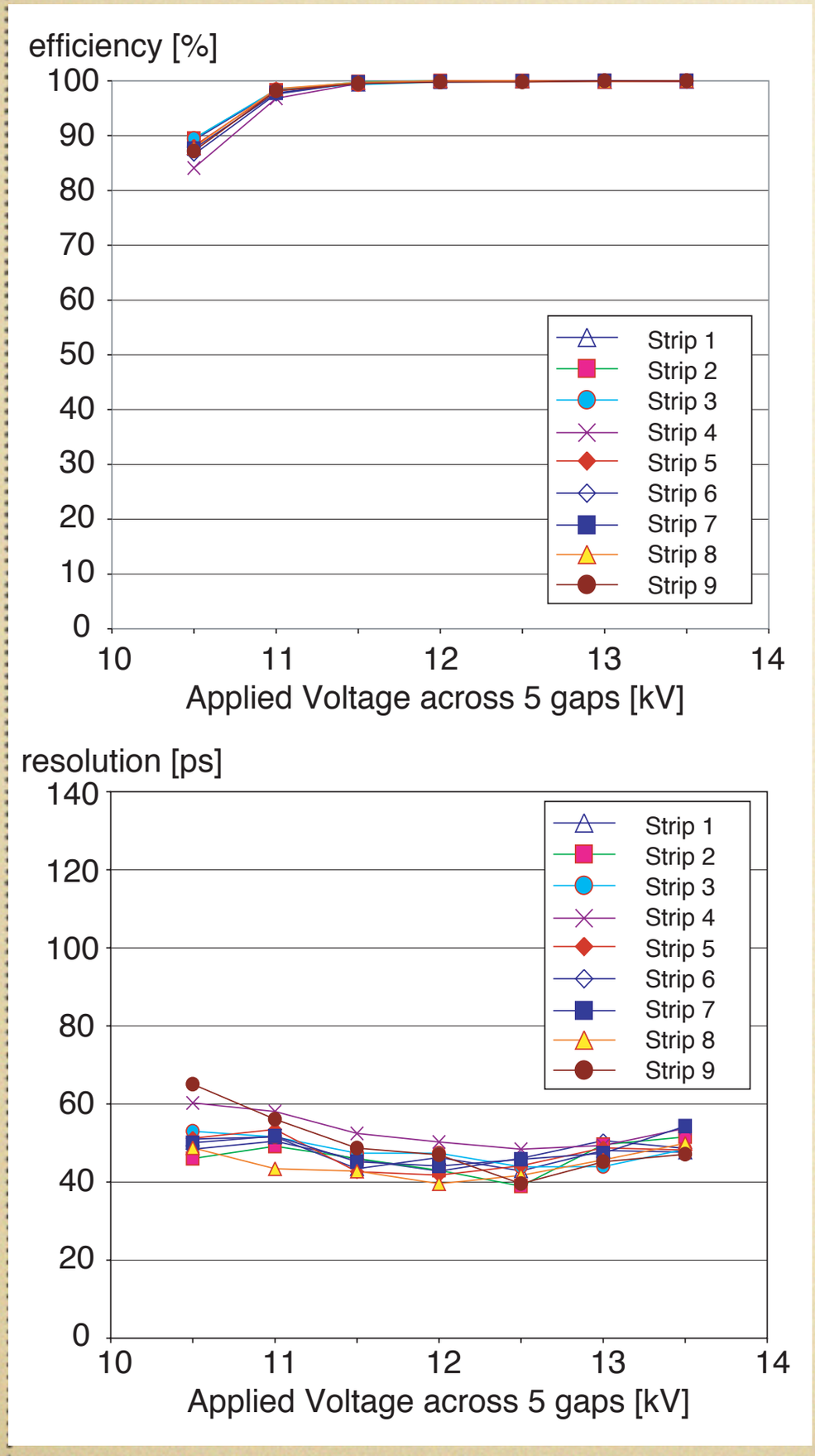


Correction very steep at small pulse heights



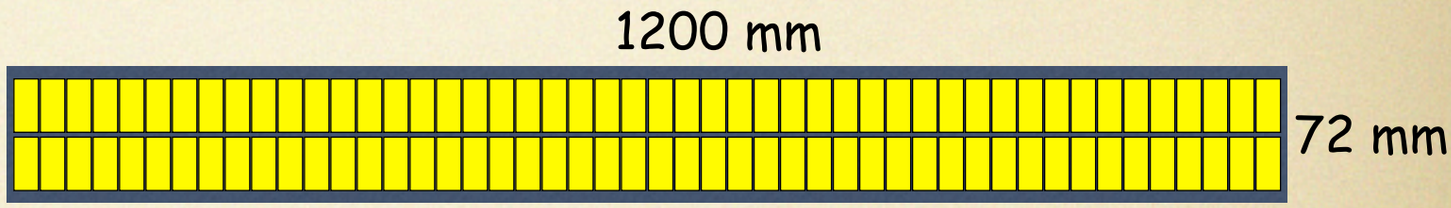
So now a few words on the ALICE TOF

- 160 000 channels of electronics
- 150 m^2 array



ALICE Time-of-Flight array

ALICE TOF strips



96 pads - each 25 x 36 mm^2

(a) long efficiency plateau
(b) time resolution 40-50 ps (after slewing corrections)

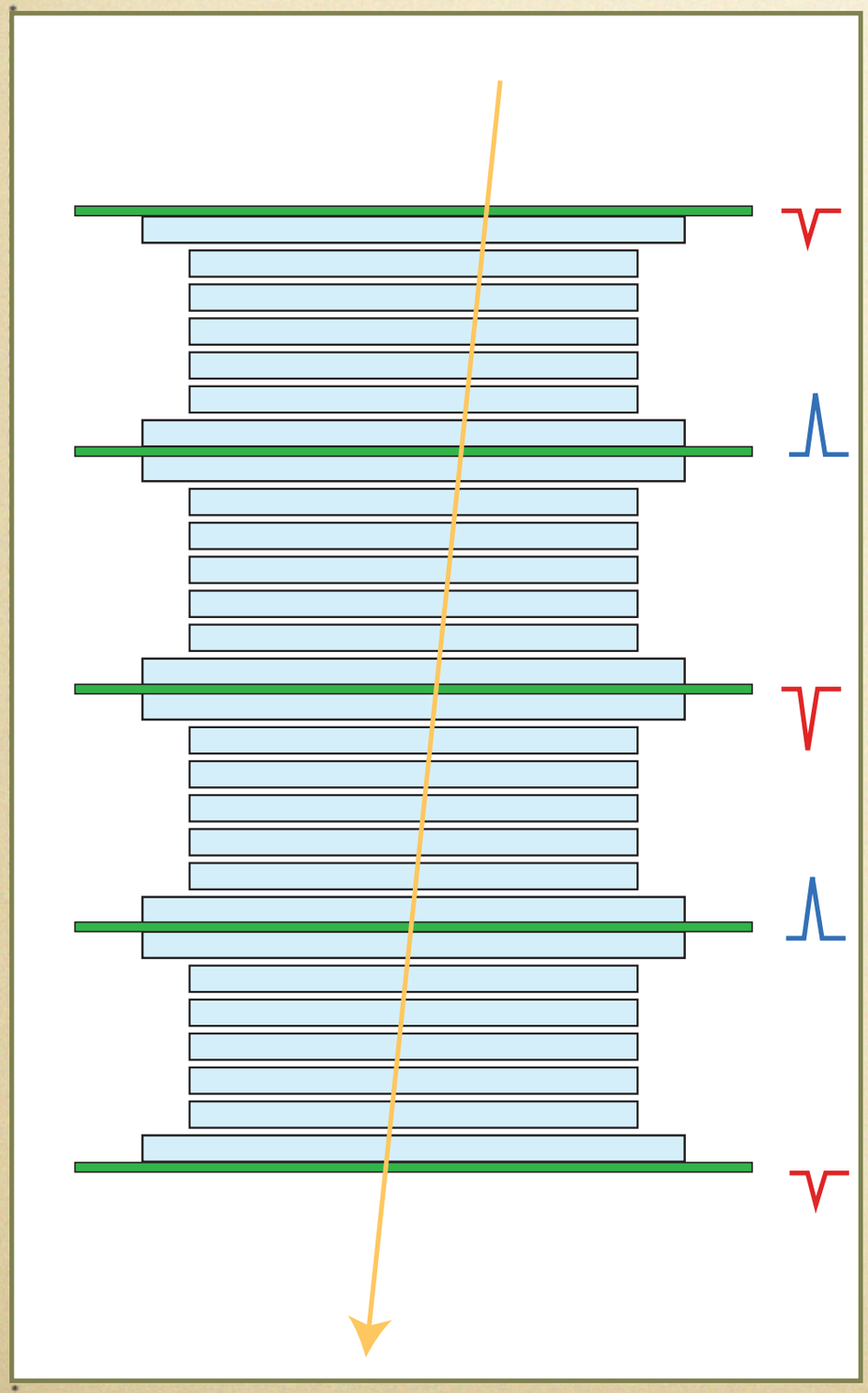
Time jitter

- tdc time resolution (time difference between two channels) 30 ps
- beam spot 1 cm in size (50 ps/√12) 14 ps
- NINO ASIC + cables + interface card 21 ps
- MRPC time resolution 11 ps

- total $\sqrt{(30^2 + 14^2 + 21^2 + 11^2)} = 41$ ps

given this : can we hope to build a detector with, for example, 10 ps time resolution?

24 gas gaps
160 micron width



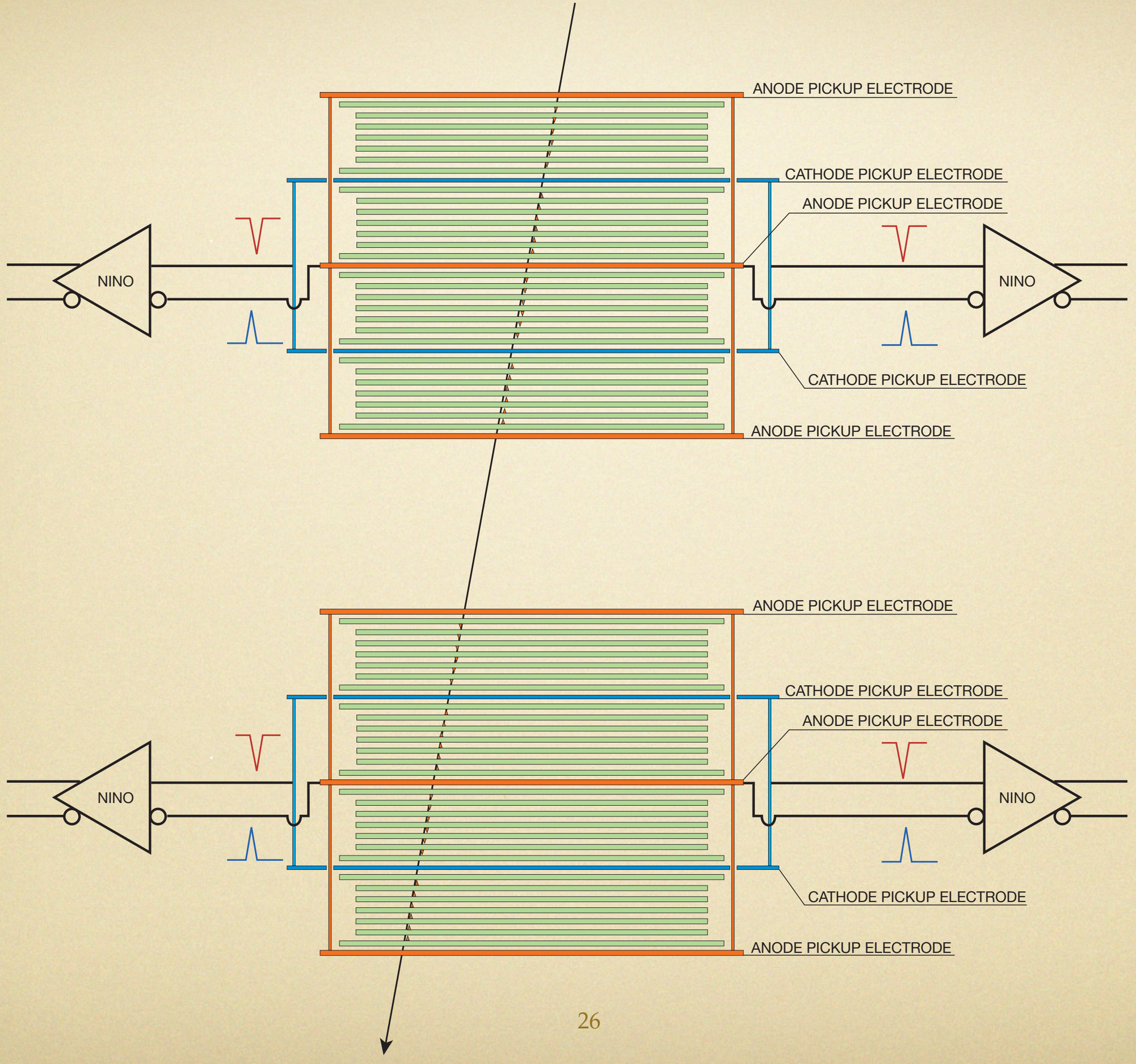
- compared to 10 gap ALICE TOF expect (back of an envelope calculation)
  - intrinsic jitter decrease from 11 ps to 5.4 ps (more primary ionising clusters -faster electron velocity in avalanche)
  - rise time to decrease by factor 2 (faster electron velocity in avalanche)
  - narrower charge spectrum more de-placed from zero

41 ps time resolution of 10 gap ALICE TOF detector

- tdc time resolution (time difference between two channels) ~~30 ps~~
  use oscilloscope (4 ch tdc) 5 ps
- beam spot 1 cm in size (50 ps/√12) ~~14 ps~~
  read out both sides of pad 5 ps
- NINO ASIC + cables + interface card ~~21 ps~~
  mount on mrpc (also faster rise time) 5 ps
- MRPC time resolution ~~11 ps~~
  24 gaps of 160 micron 5 ps

- total $\sqrt{(5^2 + 5^2 + 5^2 + 5^2)} = 10$ ps

maybe 10 ps time resolution is possible after all


ANODE PICKUP ELECTRODE
CATHODE PICKUP ELECTRODE
ANODE PICKUP ELECTRODE
NINO
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CATHODE PICKUP ELECTRODE
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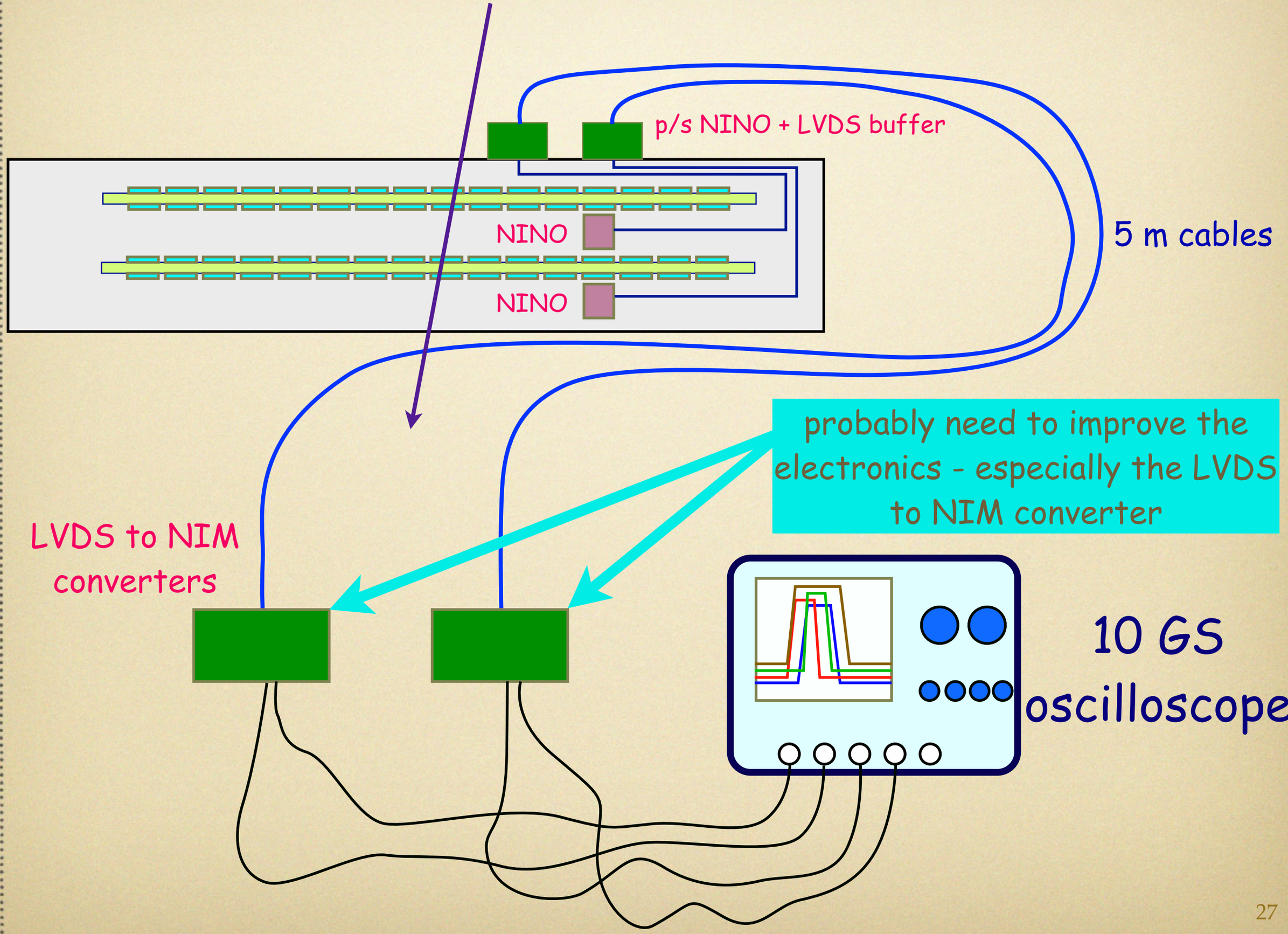
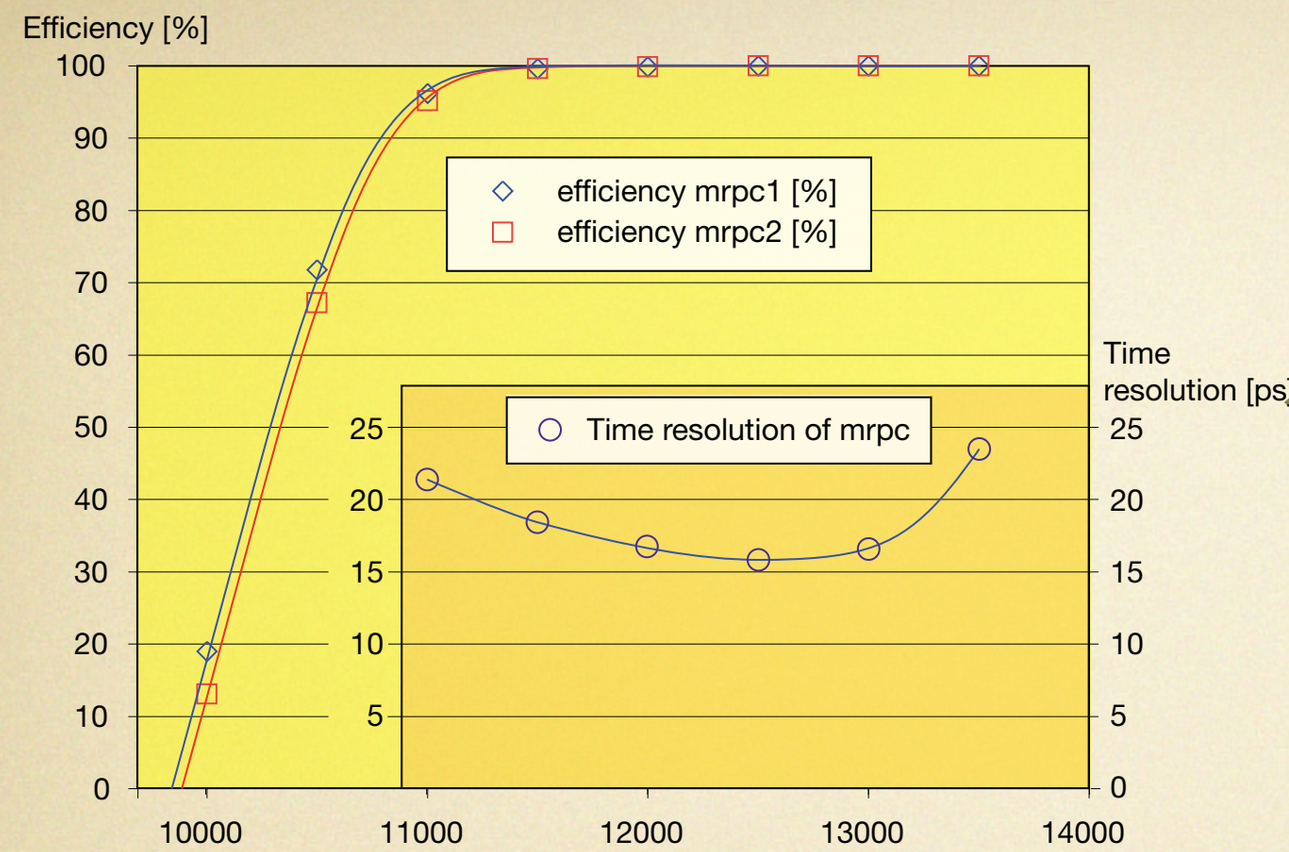
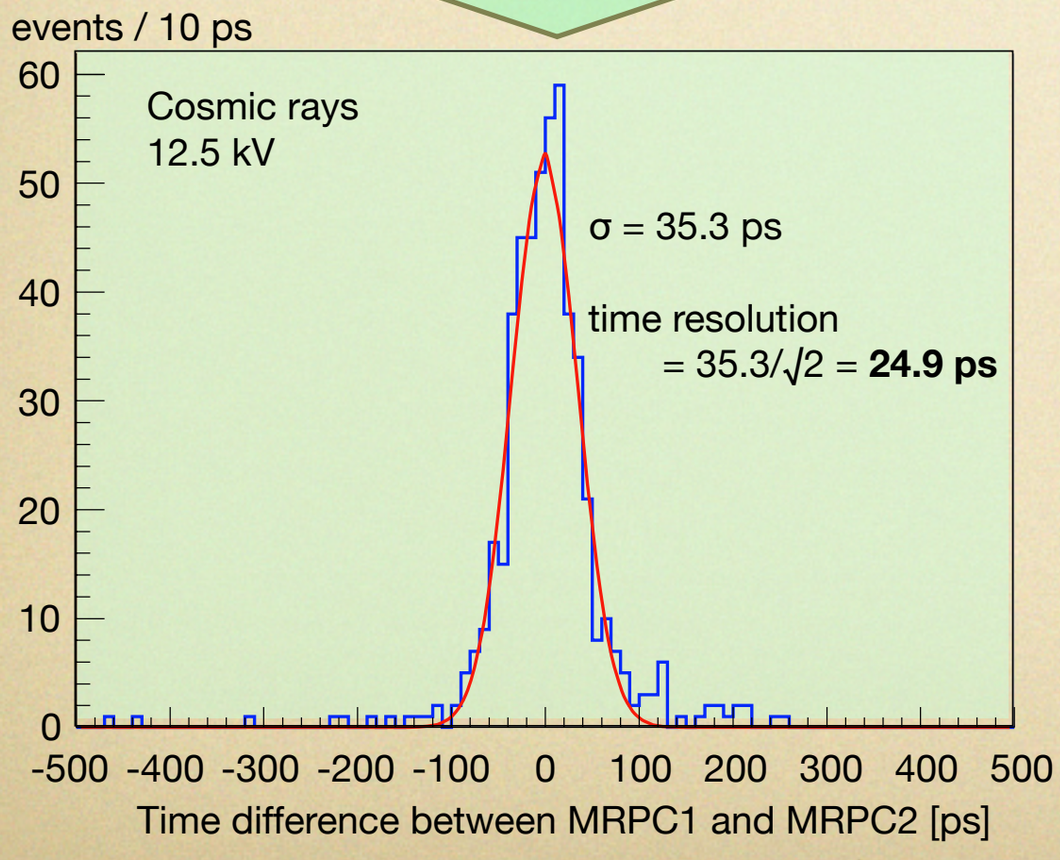

p/s NINO + LVDS buffer
NINO
NINO
5 m cables
probably need to improve the electronics - especially the LVDS to NIM converter
LVDS to NIM converters
10 GS oscilloscope

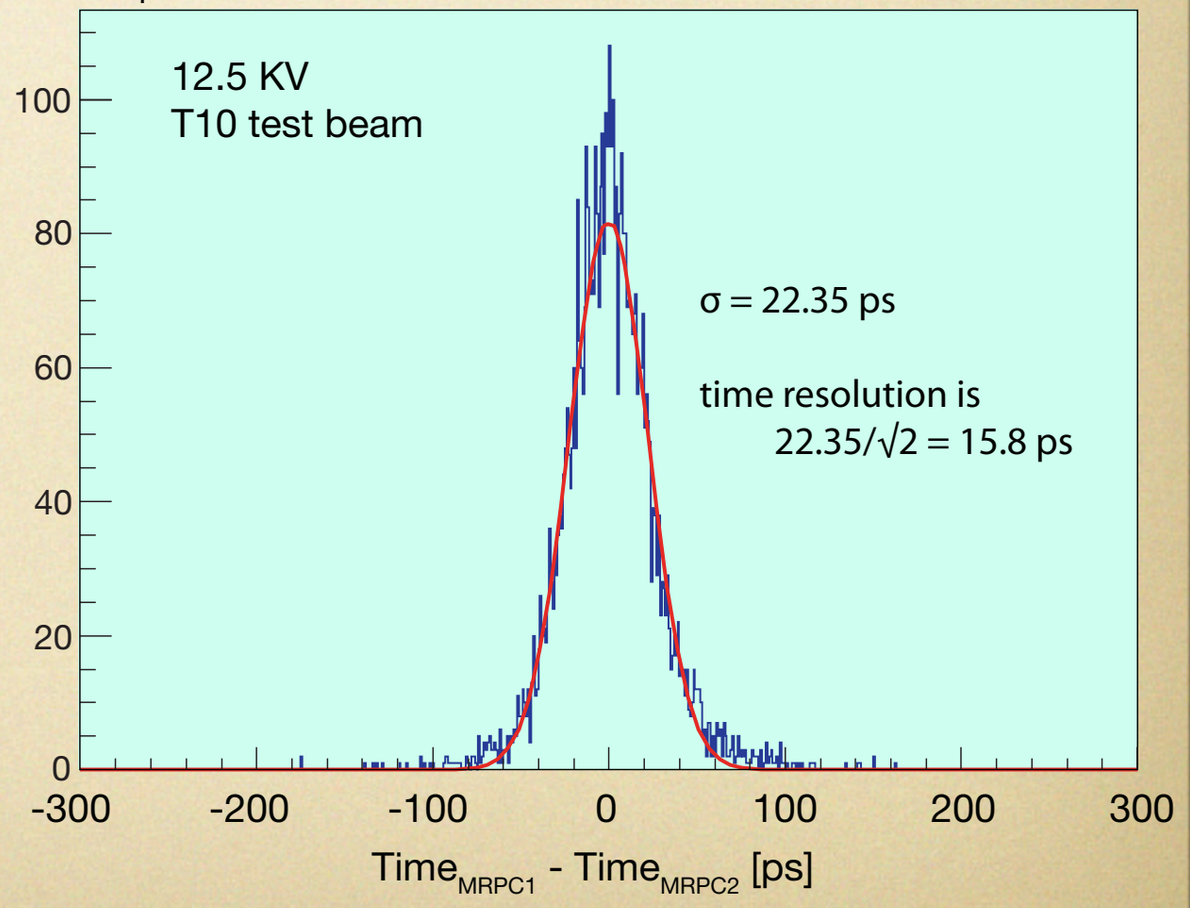


T10 test beam

Cosmic ray



Time difference between MRPC1 and MRPC2



Summary

- ALICE TOF conclusive proof of a new era of TOF devices
- excellent timing of mrpc now has encouraged mass implementation of Time-of-flight systems
- the physics behind the operation of this device makes it an interesting device to work on
- 10 ps devices possible - biggest problem will be the electronics : the TDC
- R&D in gaseous detectors possible with modest investment