Some key aspects of the Multigap RPC

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Multigap RPC became known due to the ALICE Time of Flight....

- Reminder ...   very high multiplicity of particles - highly segmented

- Operates in magnetic field

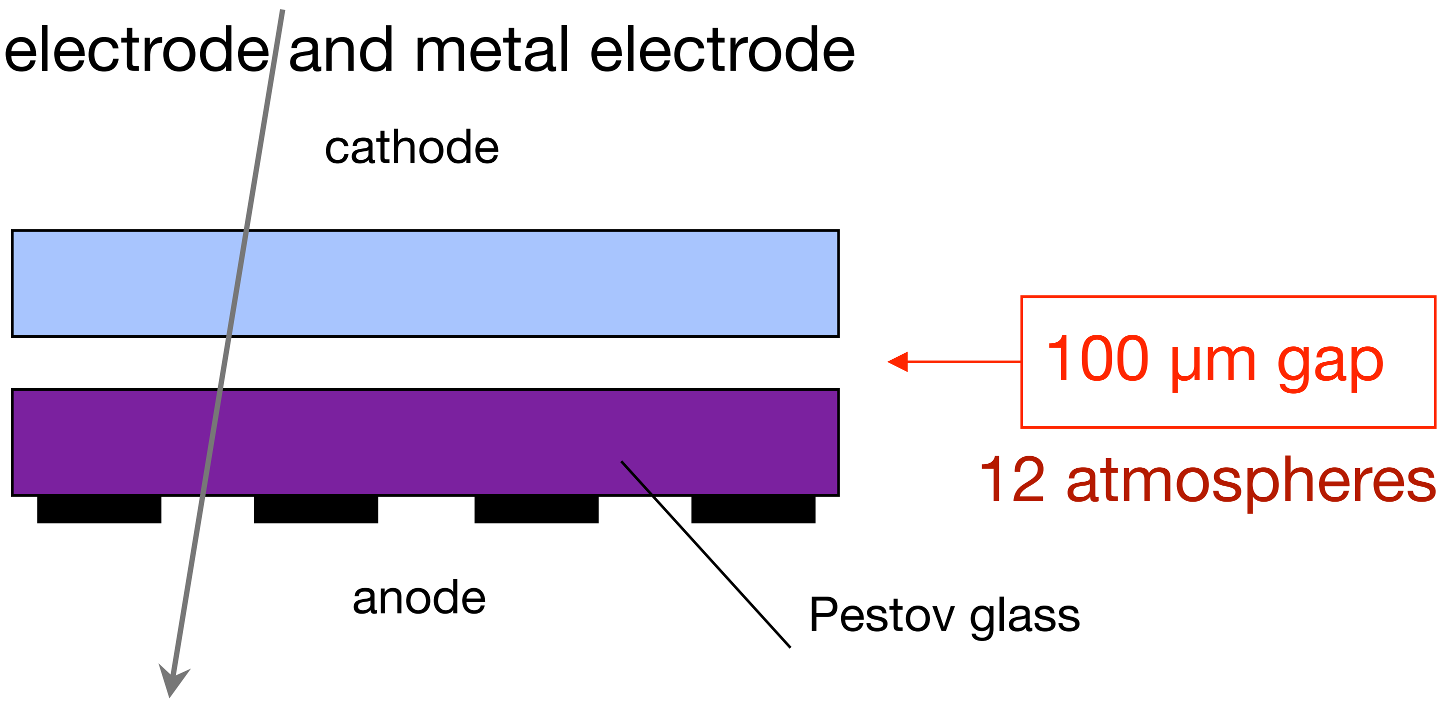
- Good timing - system time resolution better than 100 ps

- low material budget as often TOF in front of e.m. calorimeters

About 40 years ago: the PESTOF counter was invented

40 years ago Y. Pestov invented the Pestof chambers
- gas gap of 100 micron gives time resolution ≈ 50 ps.
This is also first example of resistive plate chamber

Glass electrode and metal electrode



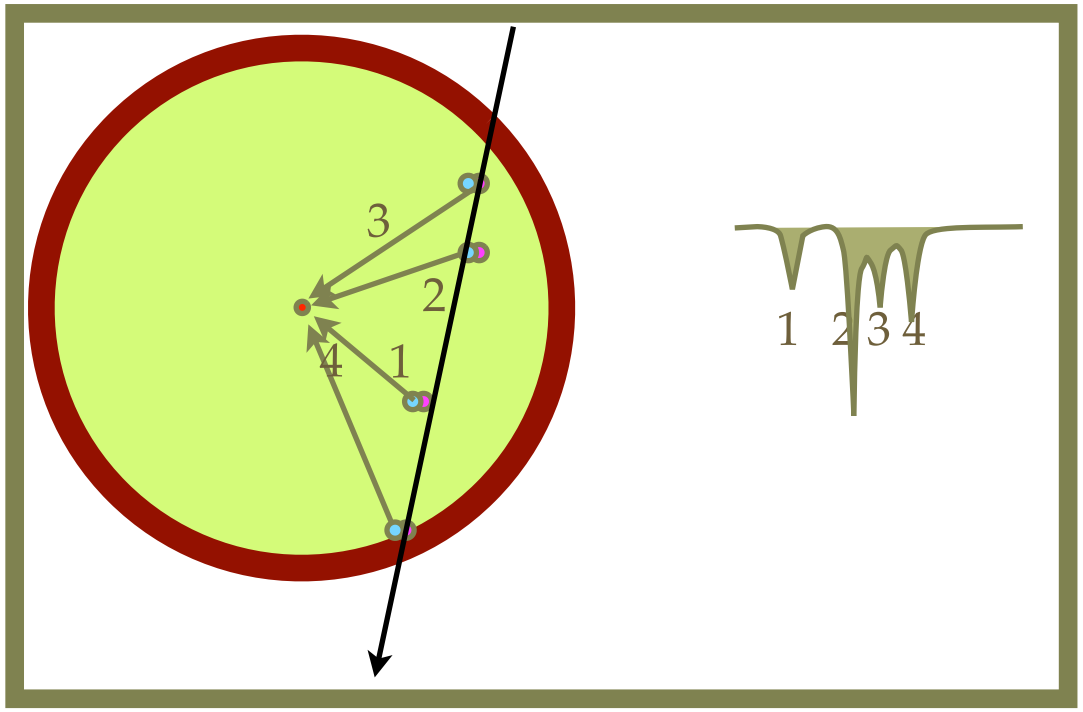
Excellent time resolution ~ 50 ps or better!

But long tail of late events
Mechanical constraints (due to high pressure)
Non-commercial glass
Needs very special gas mixture

Bottom line: small gas gaps very good for timing

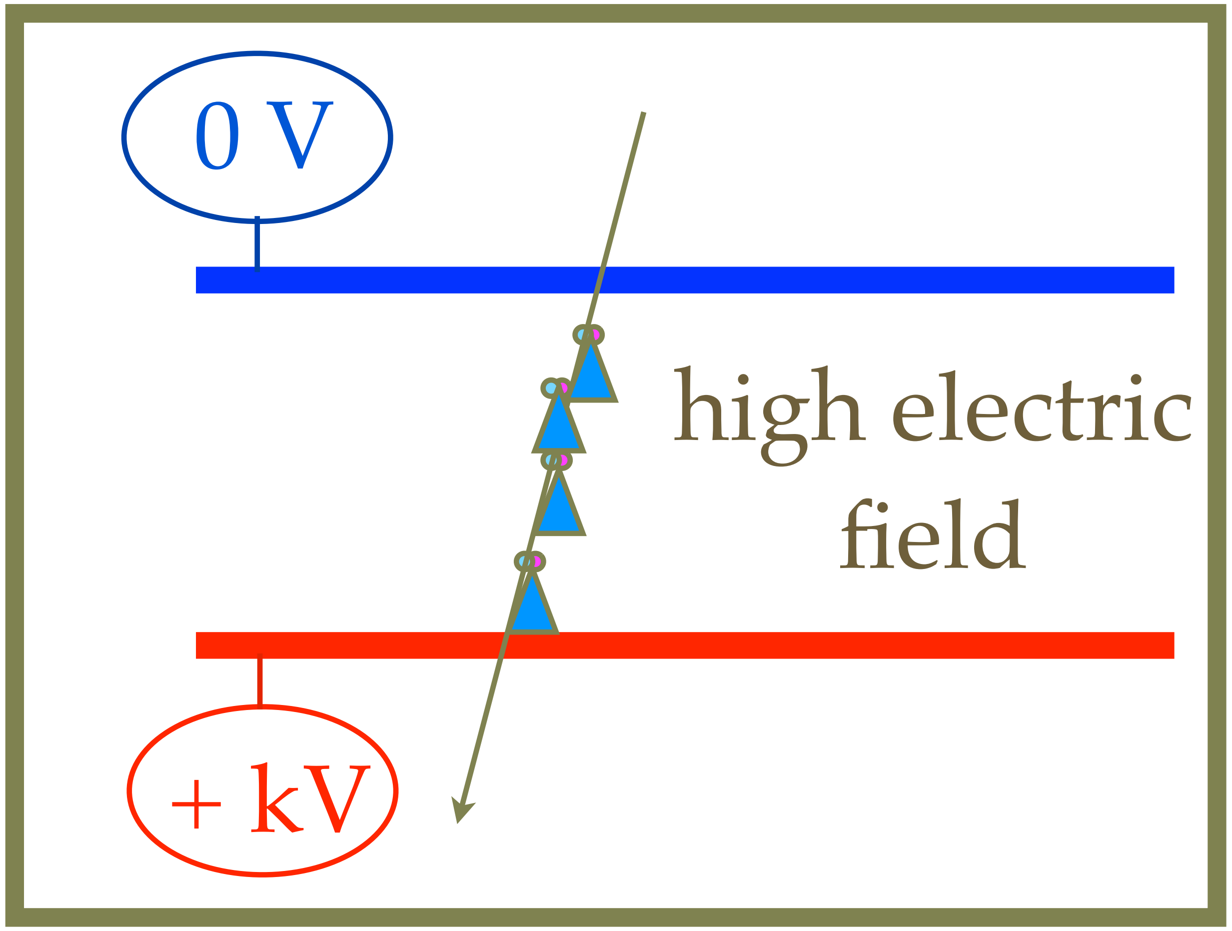
idea for multigap was born at an RPC conference

wire in a tube



signal dominated by arrival of closest cluster of electrons

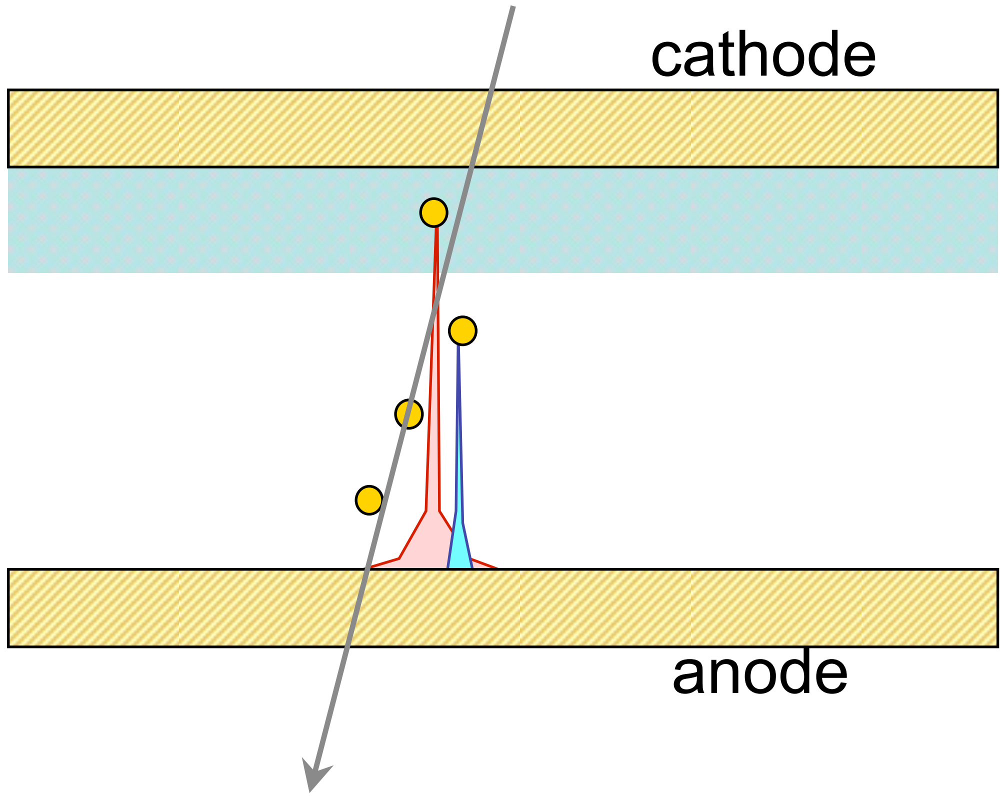
RPC



avalanches start immediately - induced signal is all avalanches acting in parallel

(santonico 1996 rpc conference)

great idea - but unfortunately not correct



Only avalanches that traverse full gas gap will produce detectable signals

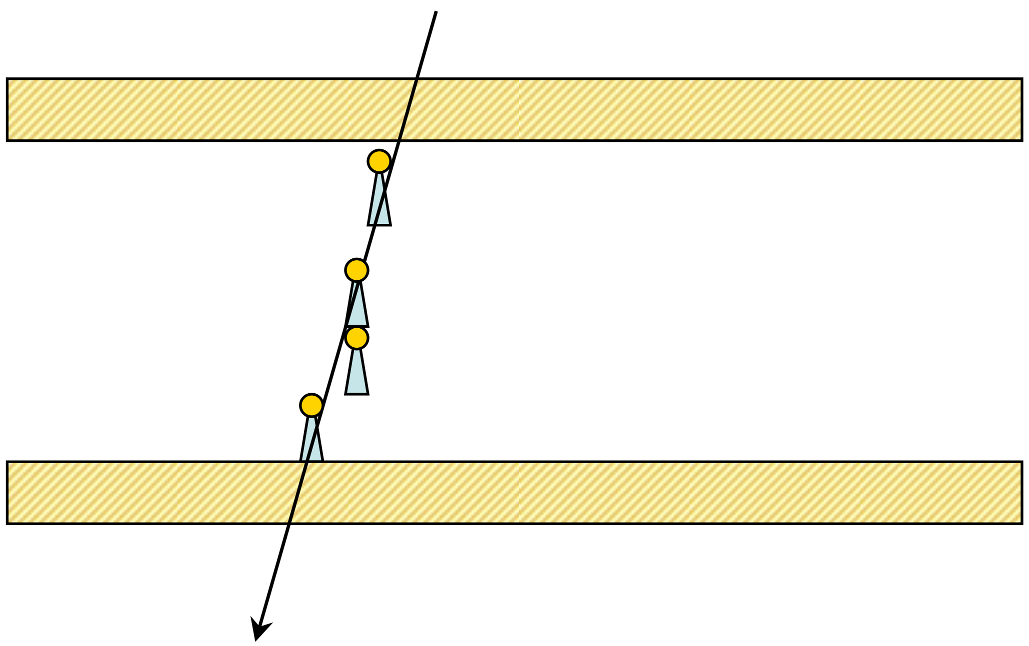
So only a few ionisation clusters (those created closest to cathode) take part in signal production - (2 mm gap RPC only ionising clusters within 0.5 mm of cathode can grow avalanches big enough to generate signal - if increase E field so that all clusters can grow big enough - we will have sparks - etc)

but what a nice idea - get many avalanches to act together simultaneously

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)



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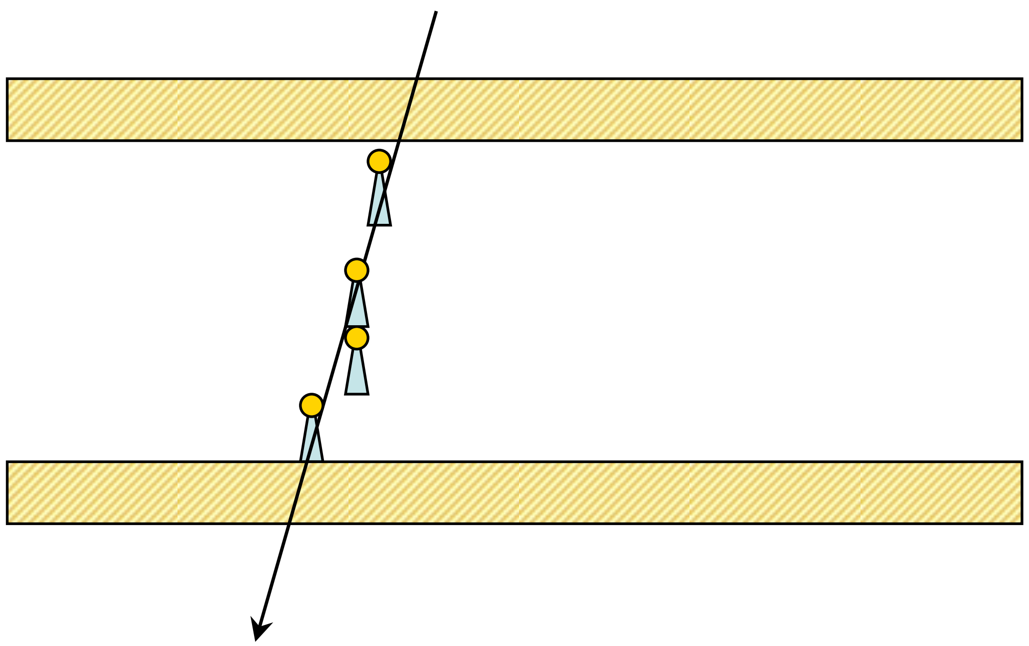
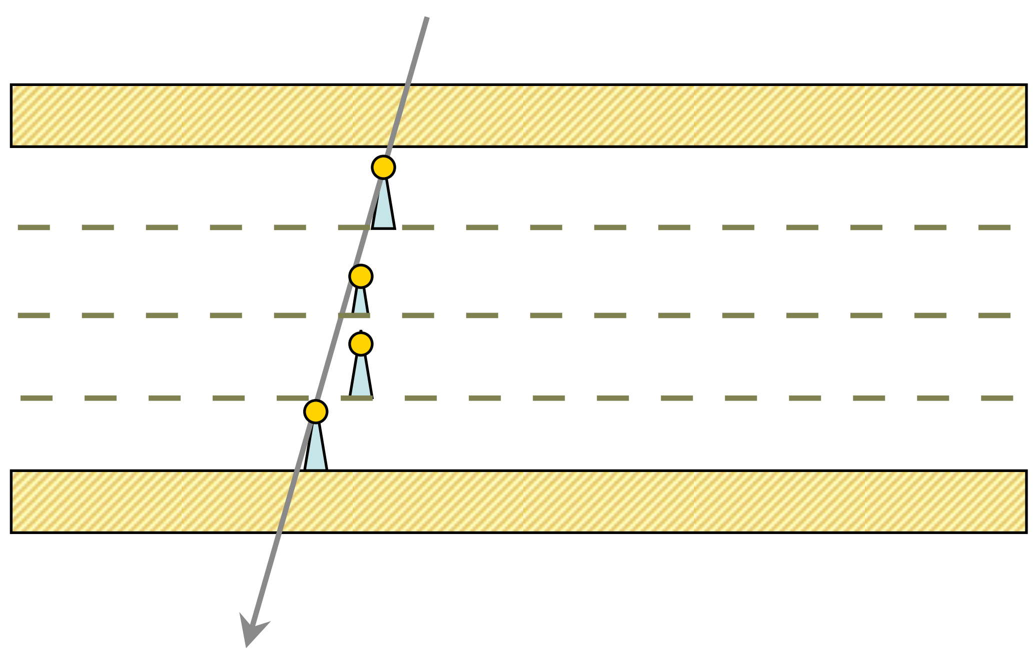
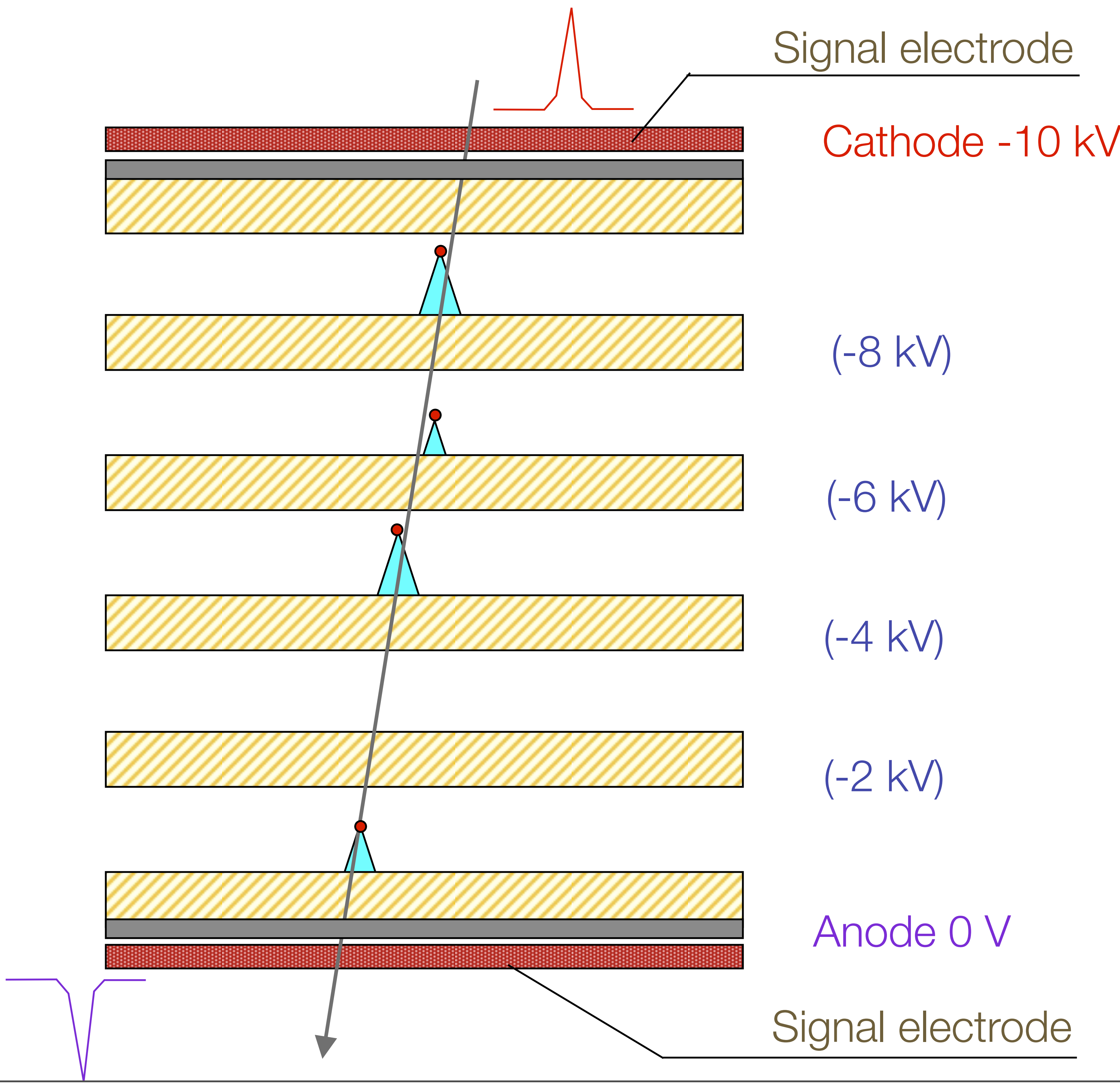




Answer: add boundaries that stop avalanche development. These boundaries must be transparent to the fast induced signal - induced signal on external pickup electrodes due to movement of charge in any of the avalanches

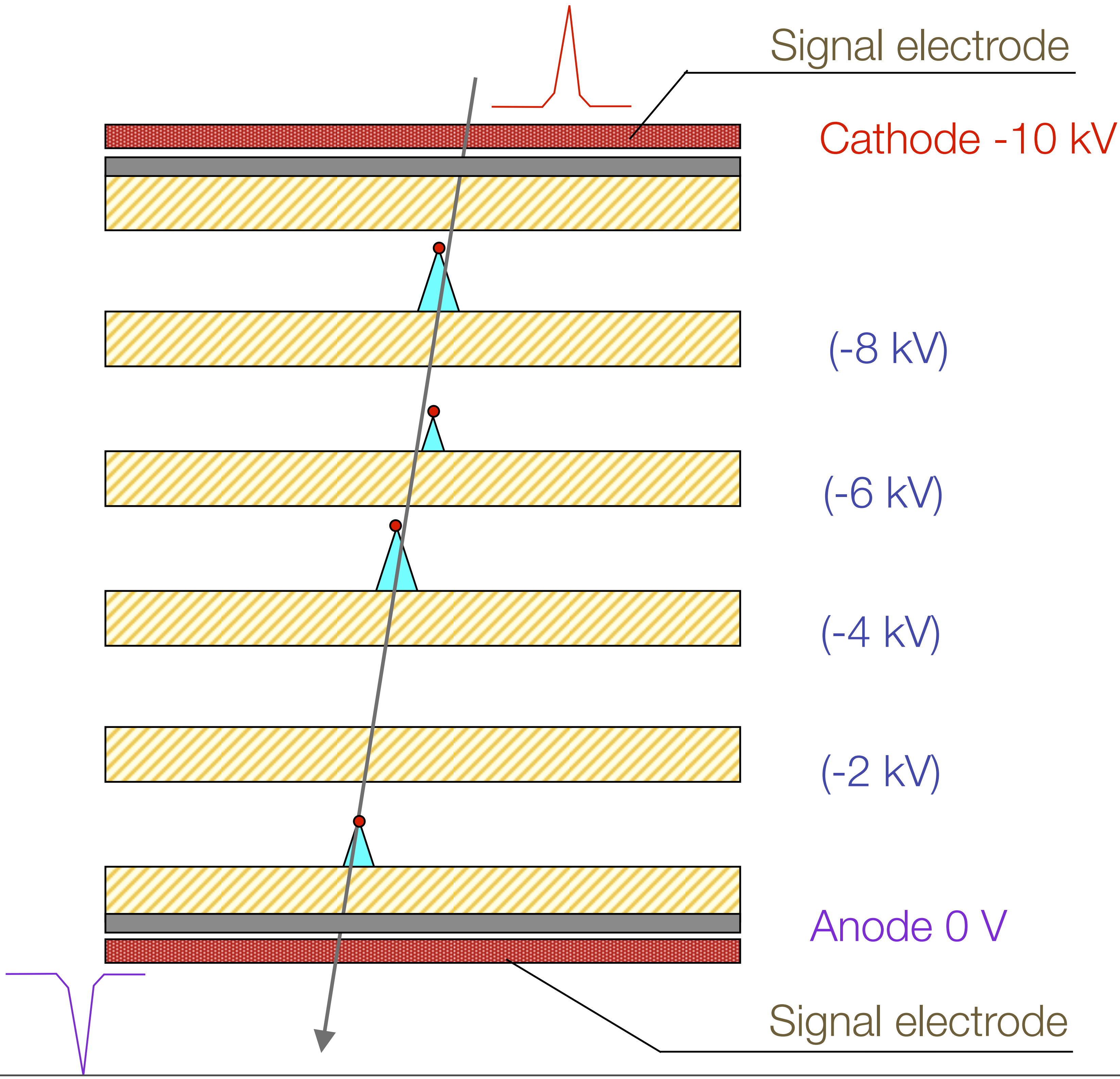
multigap resistive plate chamber



Stack of equally-spaced resistive plates with voltage applied to external surfaces

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

multigap resistive plate chamber



Stack of equally-spaced resistive plates with voltage applied to external surfaces

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

magic #1

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

an aside....

- some eminent physicists have said:
  "this device can not work ... intermediate plates will get charged up and it will stop operating"

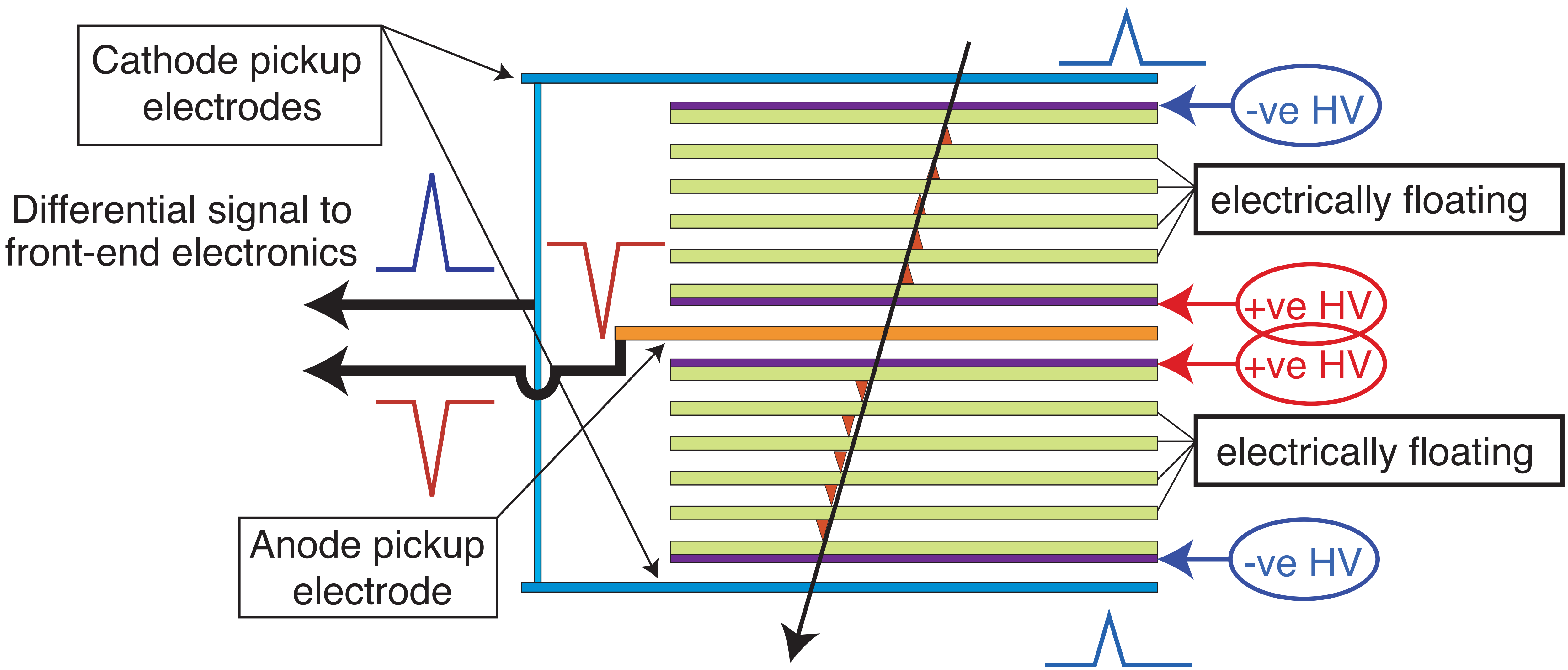
- after I explained why this was not so.....
  "you will never be allowed to build a device with floating internal plates... you will have to pretend that that you apply a voltage to all these plates"

- BUT IT DOES WORK ... and all the internal plates are electrically floating

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



OK - we have already seen the magic of the electrically floating intermediate plates...
are there any other magical aspects of the mrpc?

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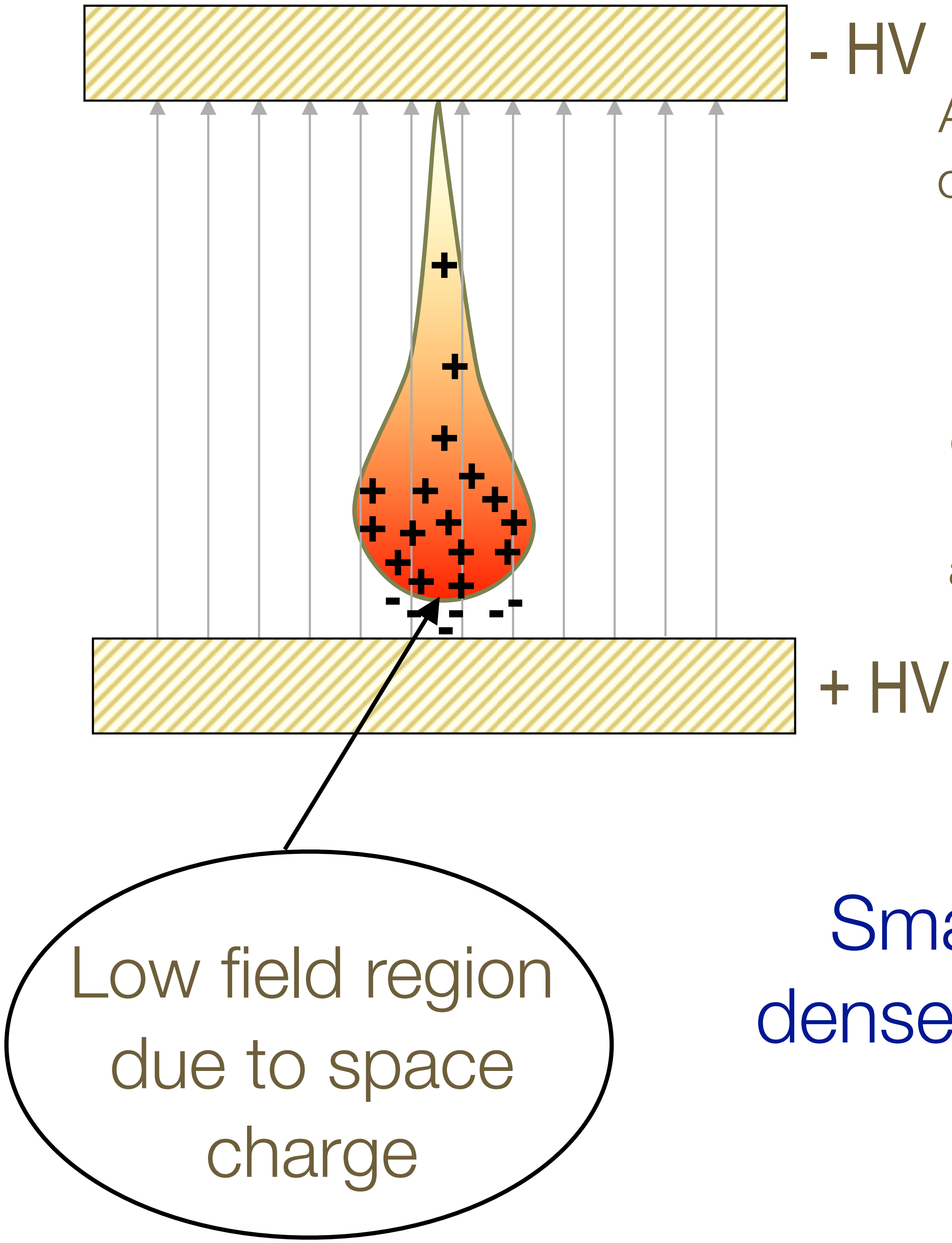
are there any other magical aspects of the mrpc?

space charge

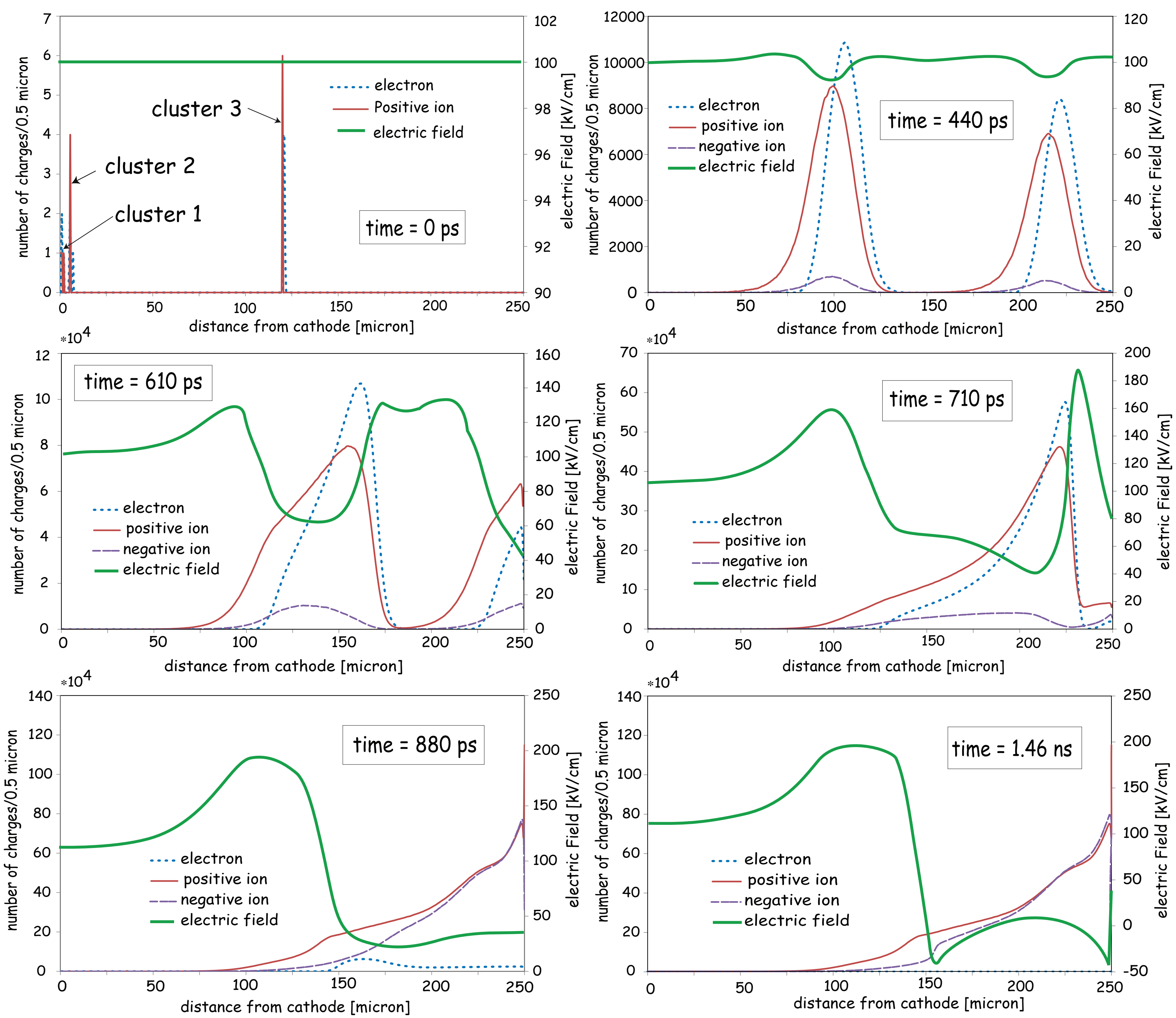
space charge



As the 'avalanche' grows - every ionising collision creates an electron and also a positive ion. Since the positive ion is heavy - it is stationary (in time scale of avalanche formation). The charge of these positive ions reduces the electric field experienced by the electrons in the 'head' of the avalanche. i.e. Gas gain is reduced - so avalanche grows to certain size and then growth slows down.

Small gas gaps - avalanche is more dense - space charge is more important

Simulation of avalanche growth in 250 micron gas gap



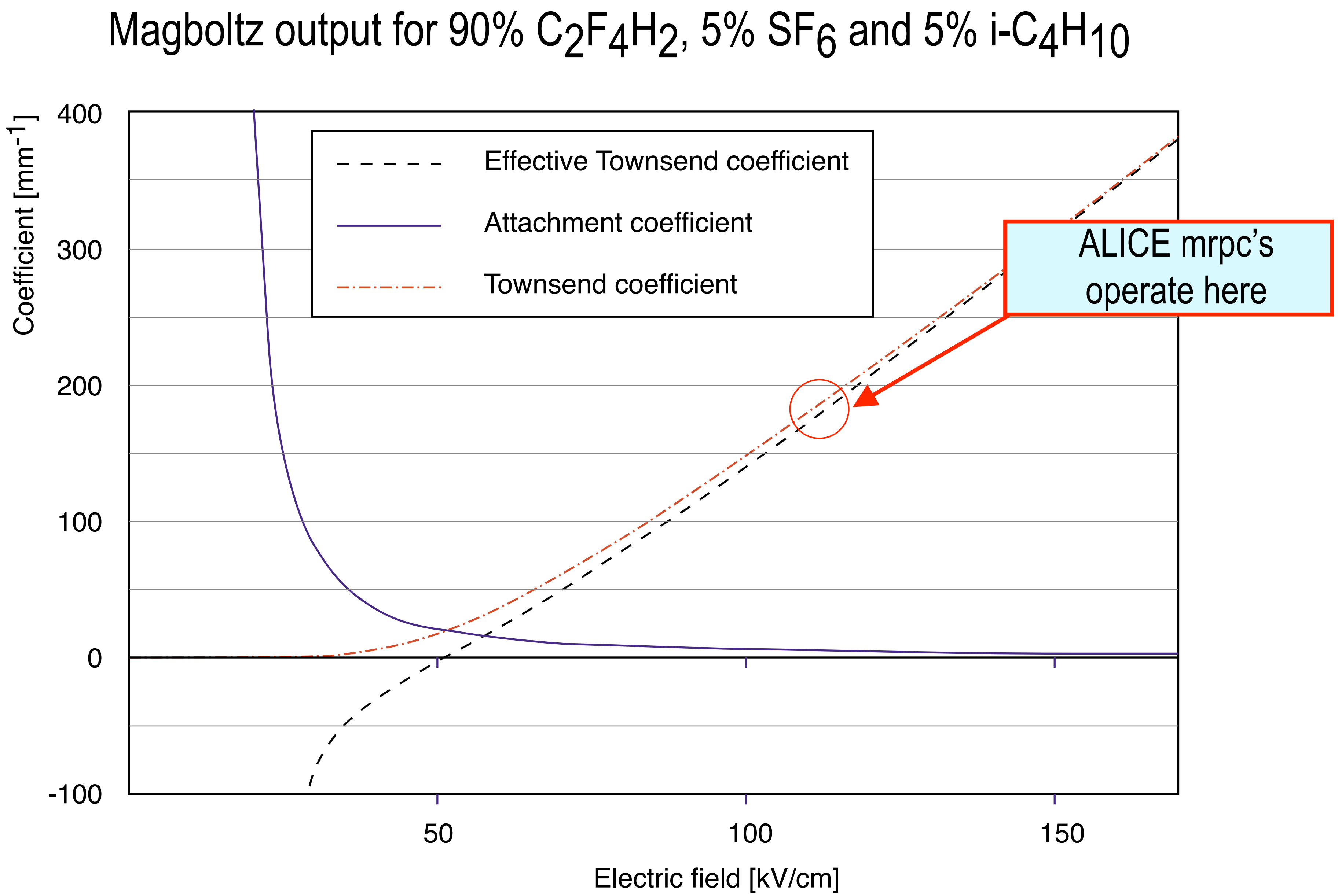
look at what happens to the electric field!

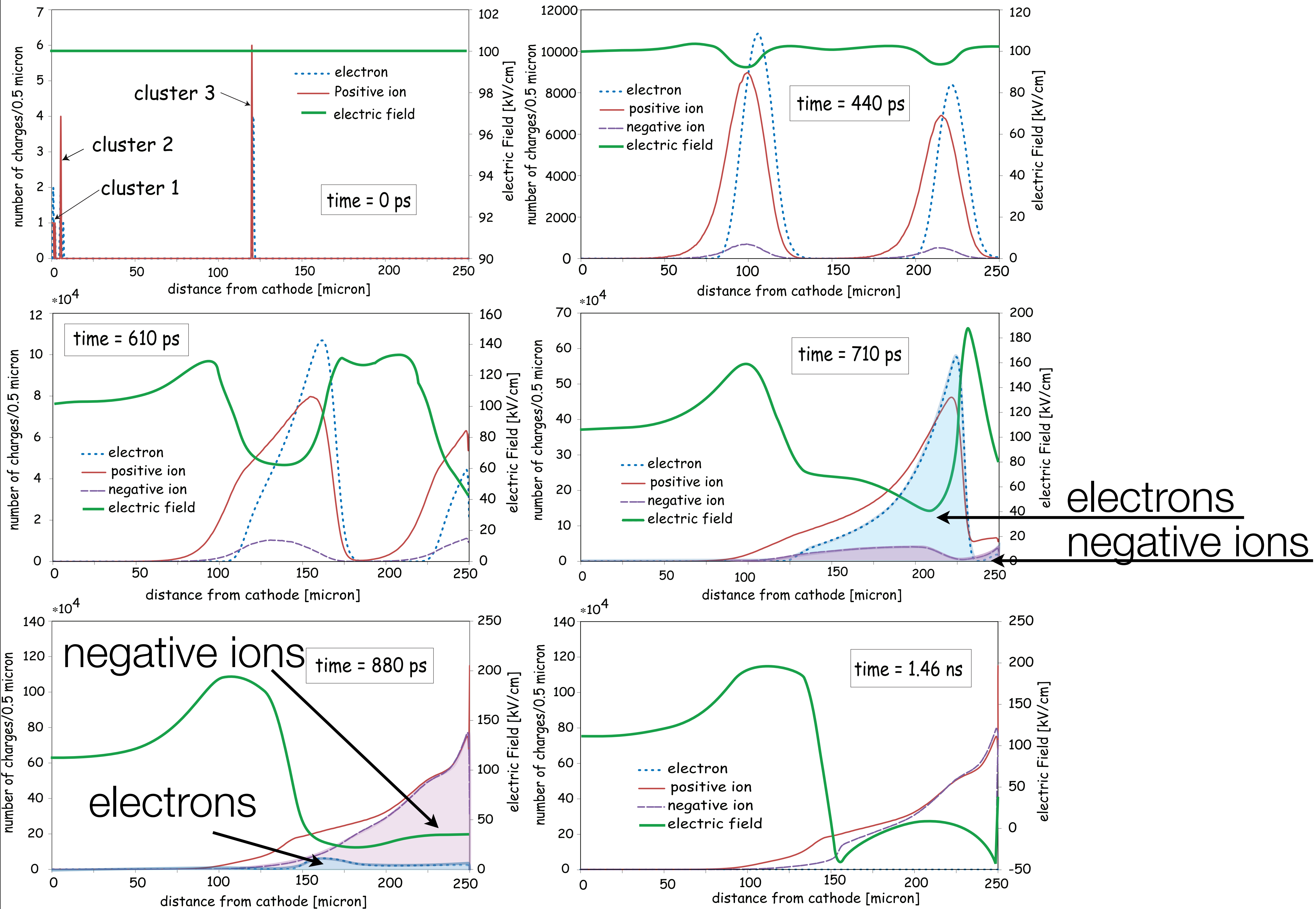
Space charge limits avalanche growth....

Important effect that allows looser mechanical tolerances: i.e. if there is a bump on a plate so that electric field is a bit higher then avalanche grows a bit faster and space charge kicks in slightly sooner...

but .....

at low fields - attachment coefficient becomes large





look at what happens between 710 and 880 ps

many electrons are attached to form negative ions.

so what?

answer: rate capability

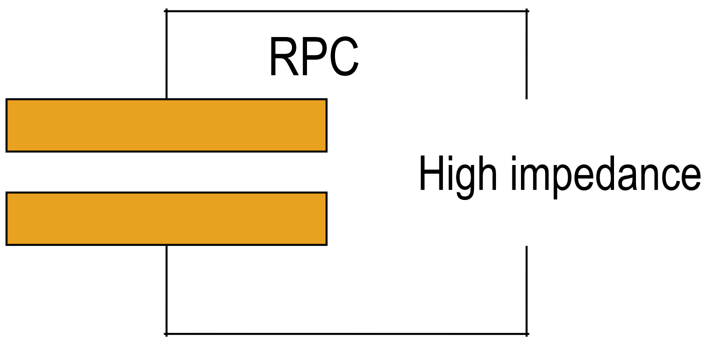
fast signal (useful signal) generated by movement of electrons

slow signal (not useful signal) generated by movement of ions

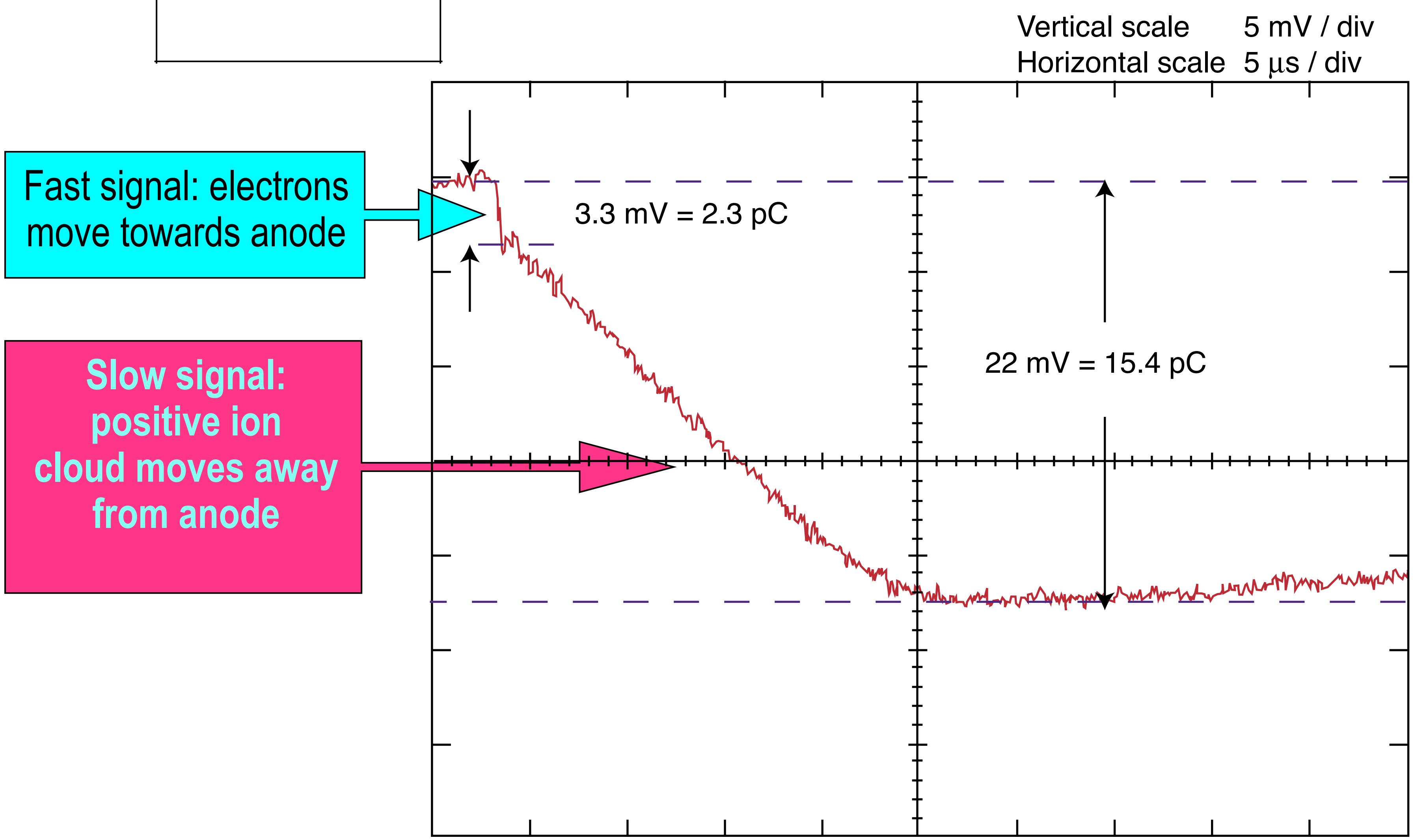
but total charge produced in the gas gap must traverse resistive plate and this current will create voltage drop across resistive and reduce field in gas gap ... and this leads to rate effects

however.......

RPC with 2 mm gas gap

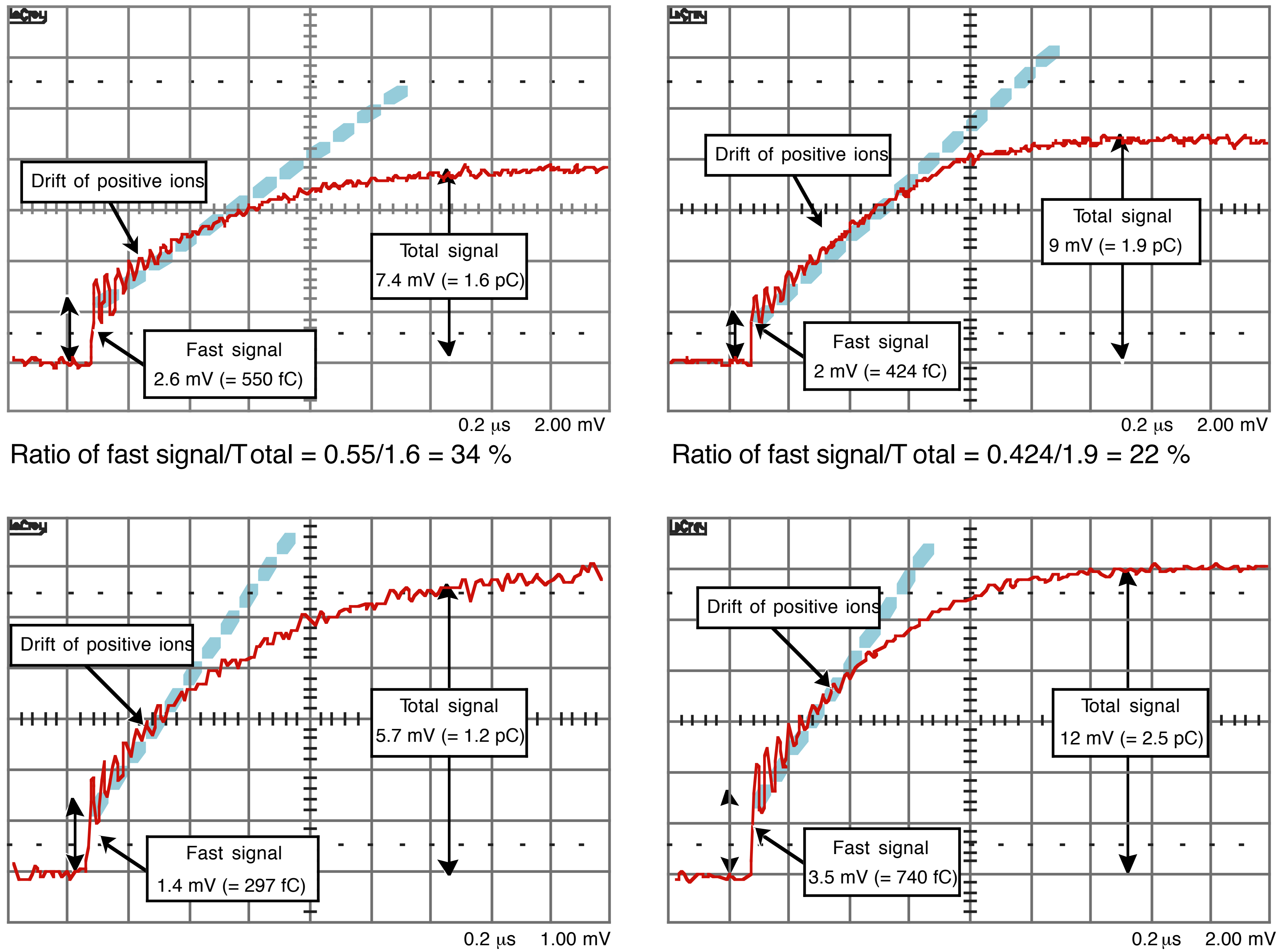


Can measure ratio of fast/total with oscilloscope



What happens fast/total charge in the case of the MRPC?

Avalanche signals: 10 gap double stack MRPC (250 micron gap) H.V . = 12.5 kV



Ratio of fast signal/Total = 0.55/1.6 = 34 %

Ratio of fast signal/T otal = 0.424/1.9 = 22 %

Ratio of fast signal/T otal = 0.297/1.2 = 25 %

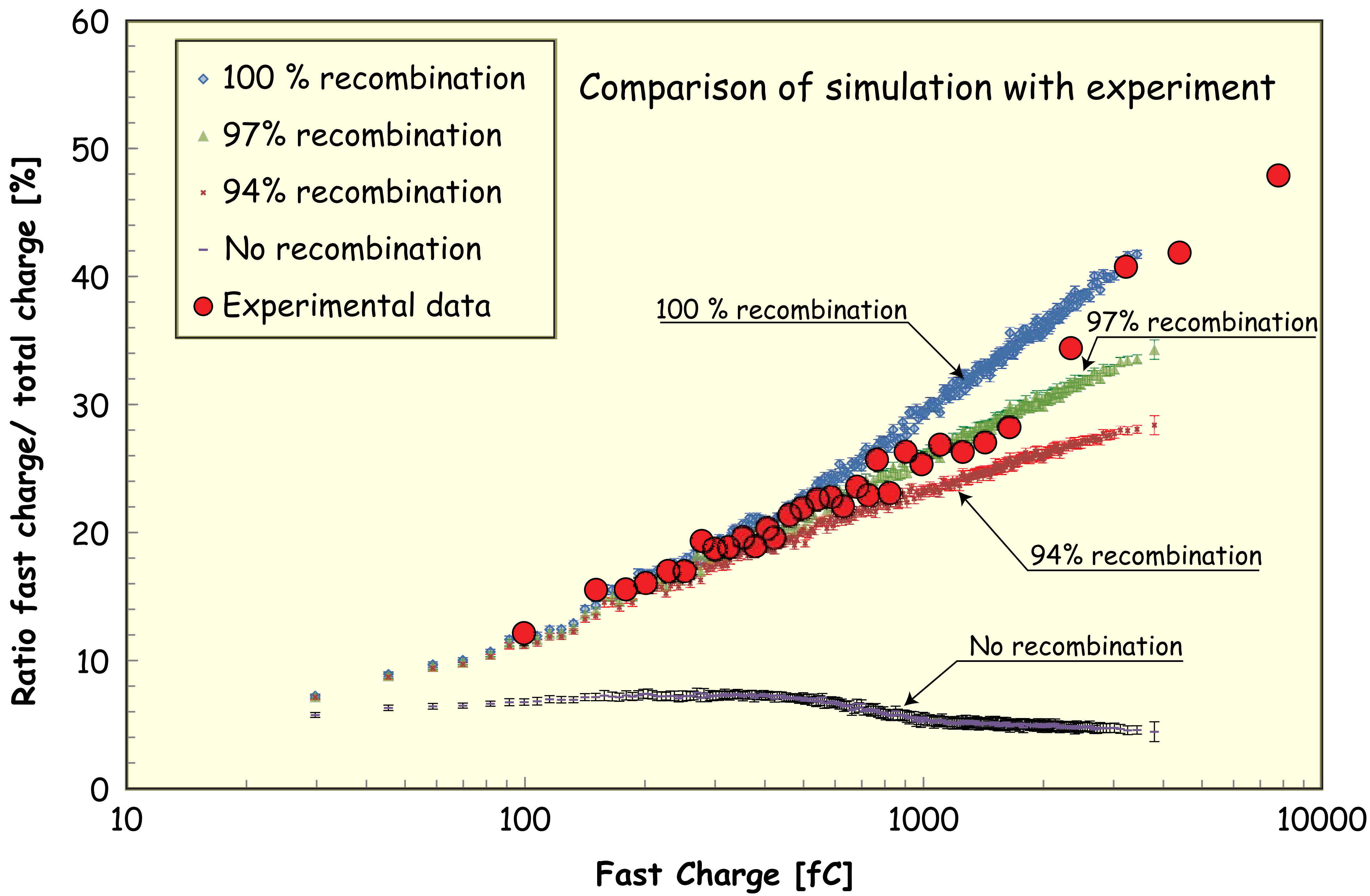
Ratio of fast signal/T otal = 0.74/2.5 = 30 %

MRPC

Non-linear ramp (positive ions not concentrated at a single position close to anode)

Fast/total large

however would have expected a much larger ionic signal (smaller fast charge/total charge)



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

multigap rpc

- worry about having intermediate plates at a floating voltage
    - No problem: feedback mechanism keeps gain equal in each gap

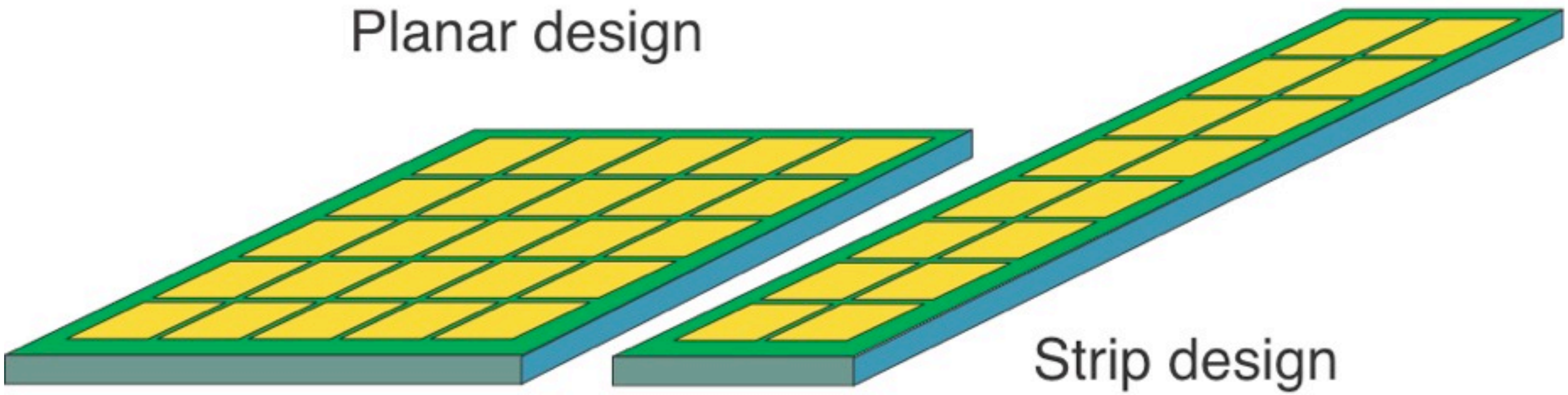
- worry about mechanical constraints of gas gap
    - no problem: strong space charge limits avalanche growth
        - loose mechanical constraints
        - growth of avalanche is limited below transition to streamer

- worry about large current from ion production
    - no problem: almost complete recombination between positive and negative ions

move away from the mrpc itself

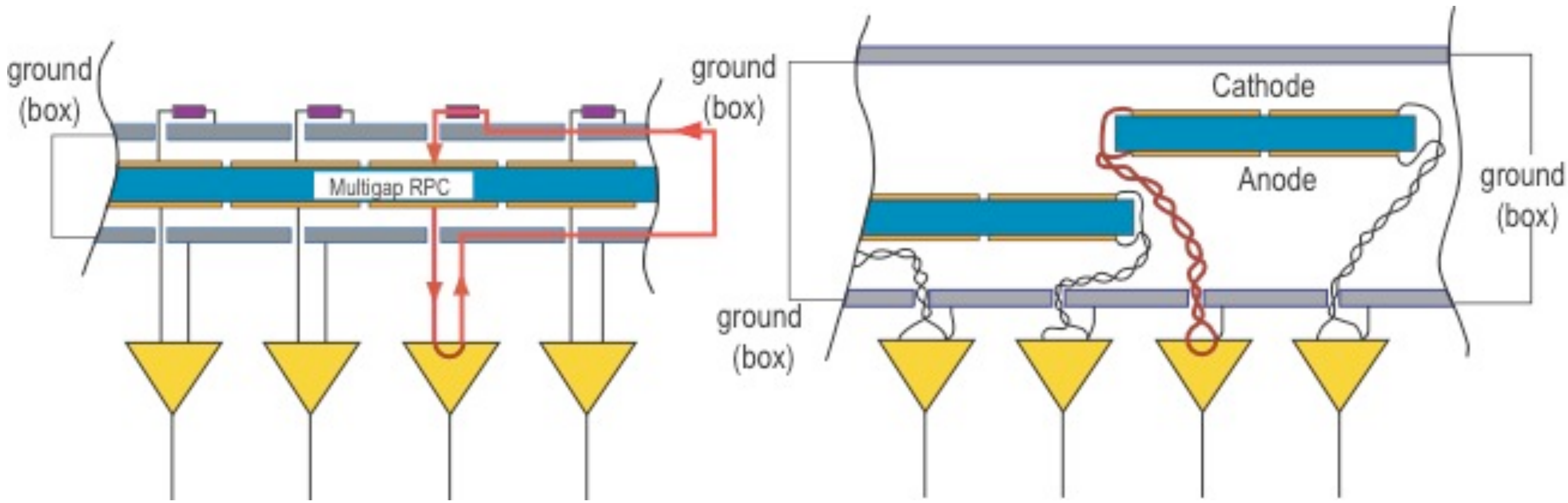
design of the tof .... electronics.....

our initial thought was to build large planar chambers



differential readout

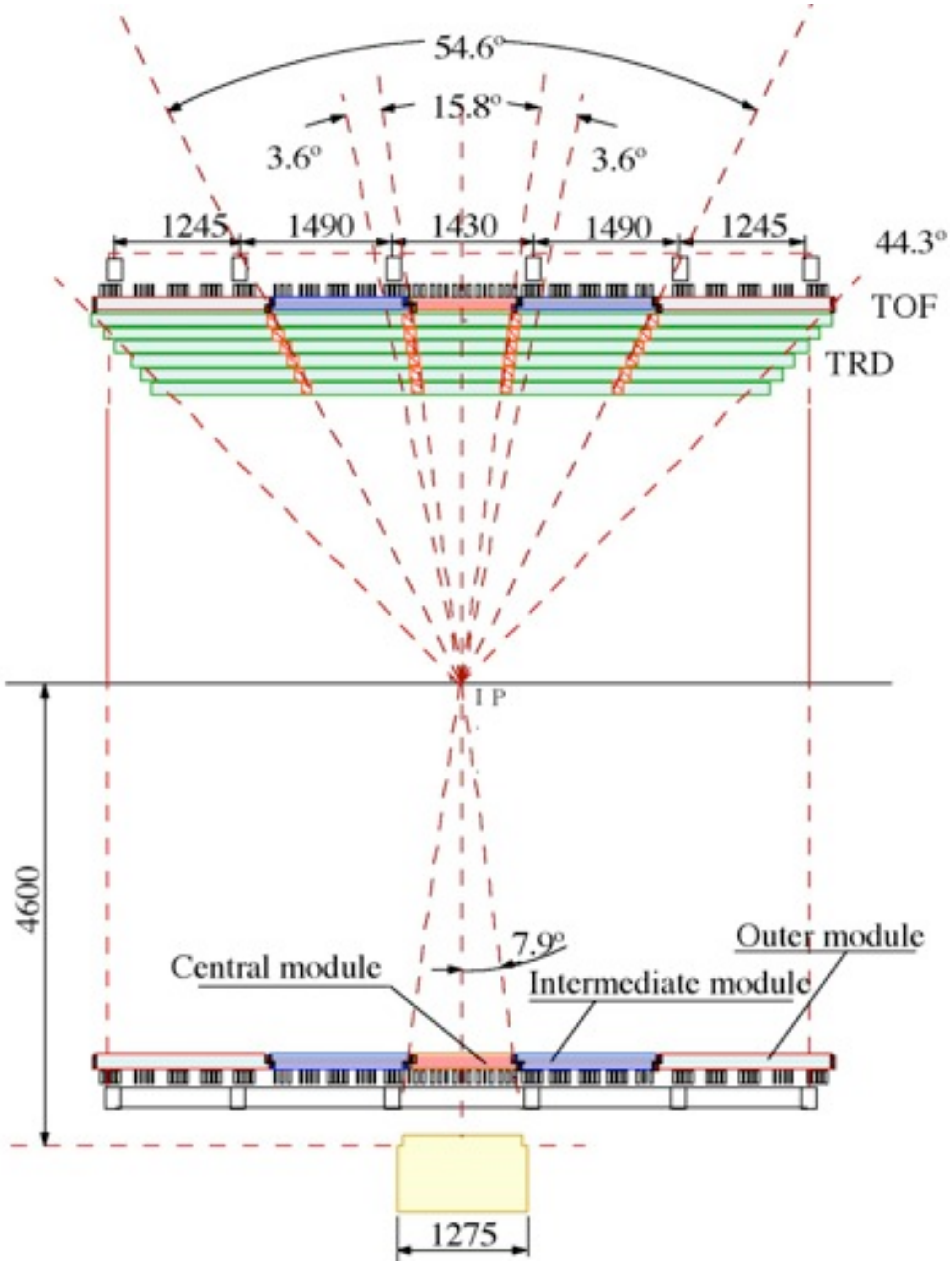
Big reduction in noise if care is taken with the signal return



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

rz view of alice

the tof is divided into 5 modules

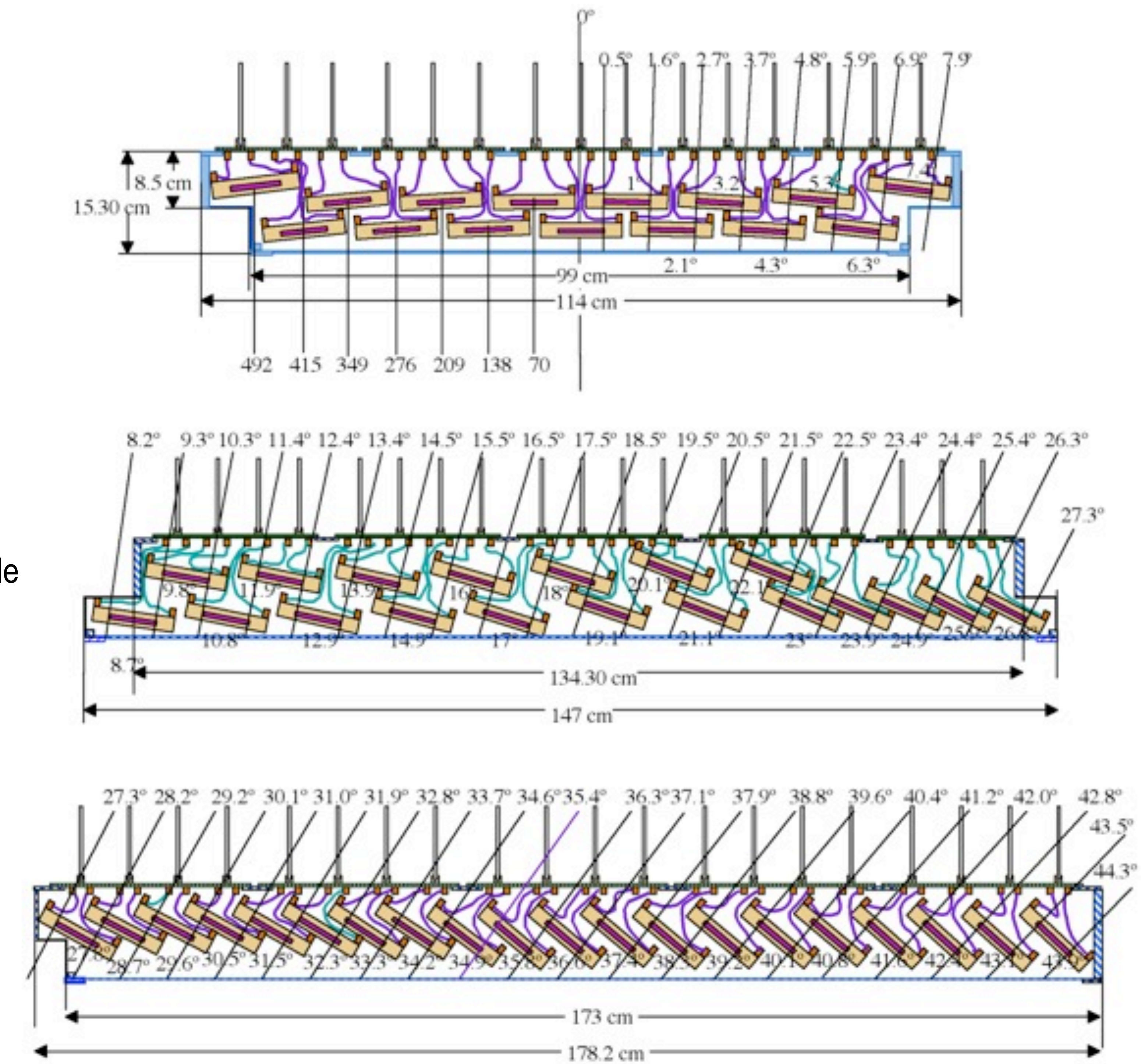


alice tof strips - all tilted to face interaction point

Central Module

Intermediate Module

Outer Module

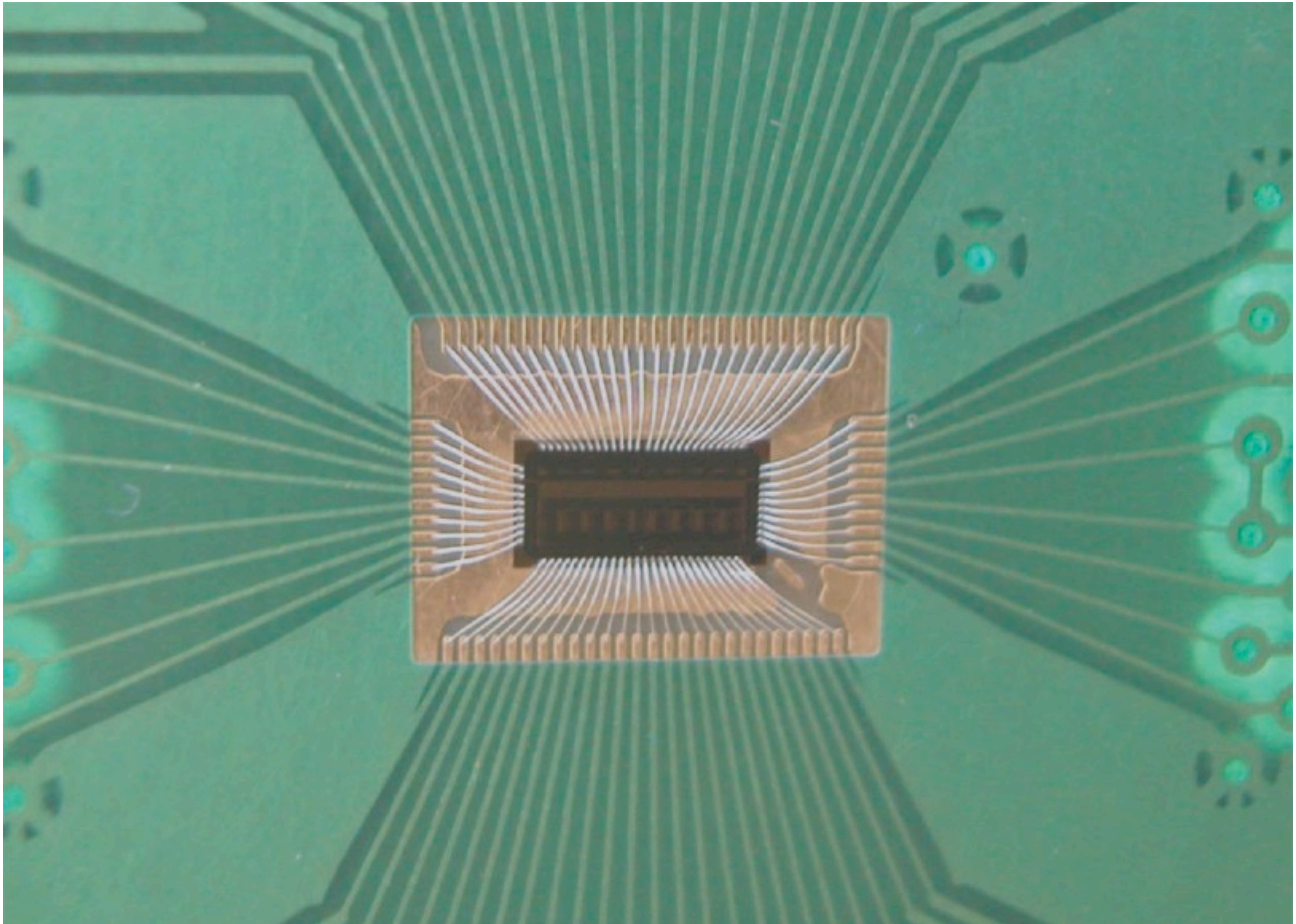


At end of 2001 decide to start development of suitable amplifier +discriminator+time-over-threshold ASIC in 0.25 μm CMOS technology

- Differential input
- Designed to be coupled to transmission line
- Fast (1 ns peaking time) to minimise jitter
- Differential design throughout to minimise cross-talk, etc
- Low power (less than 50 mW/channel was the target)
- Time-over-threshold measurement of input charge

The nino asic

The NINO ASIC bonded to the PCB

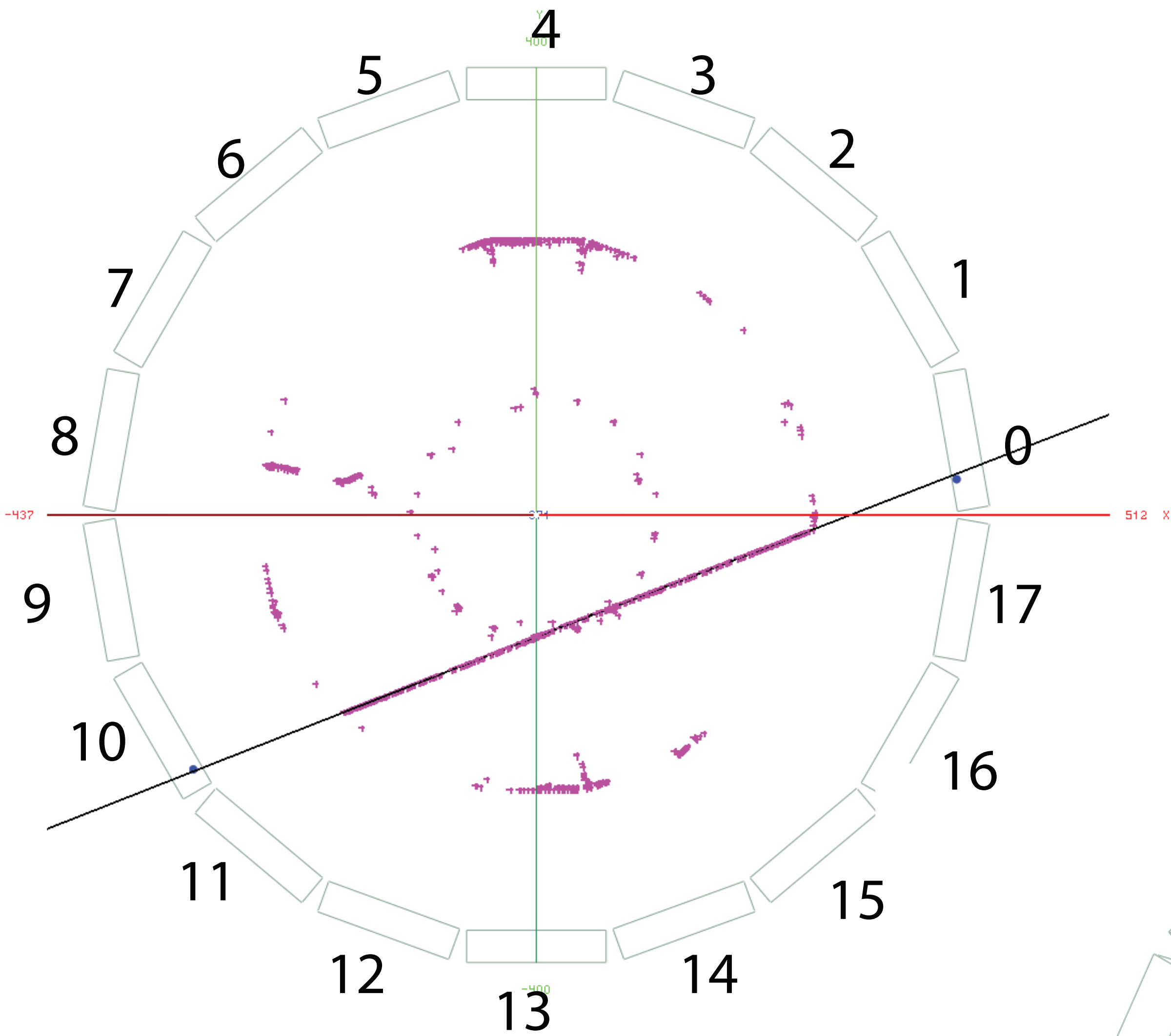


Now the NINO is being used for many detectors

MRPC
Standard phototubes (with differential readout)
SiPM

do not confuse the mrpc with the more standard rpc

- mrpc has long efficiency plateau that is streamer-free - ageing is not a problem (does not need a high gas flow)
- low dark current   10 nA /m^2
- low single rate 0.2 Hz/cm^2 - this allows mrpc to be used as a trigger

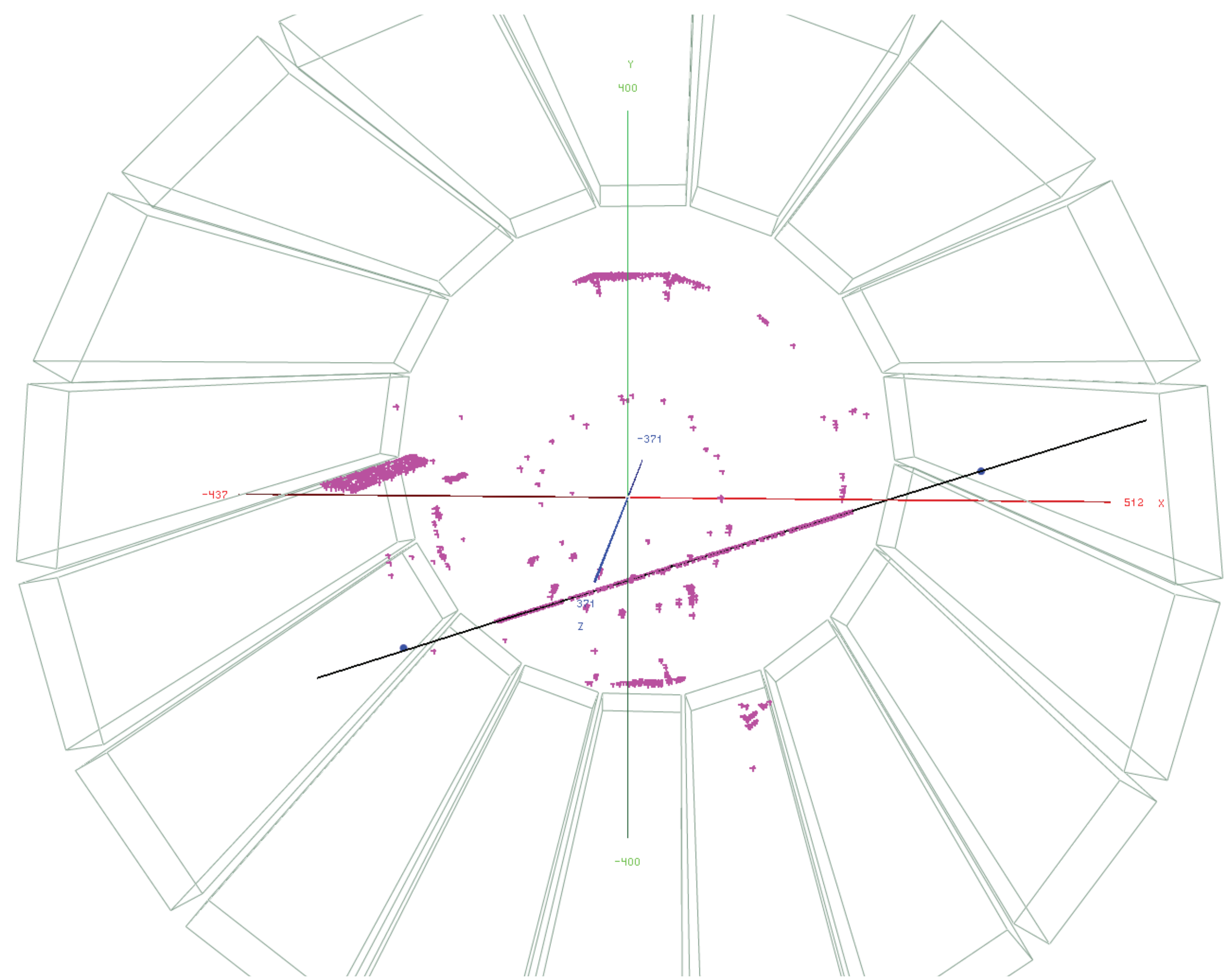


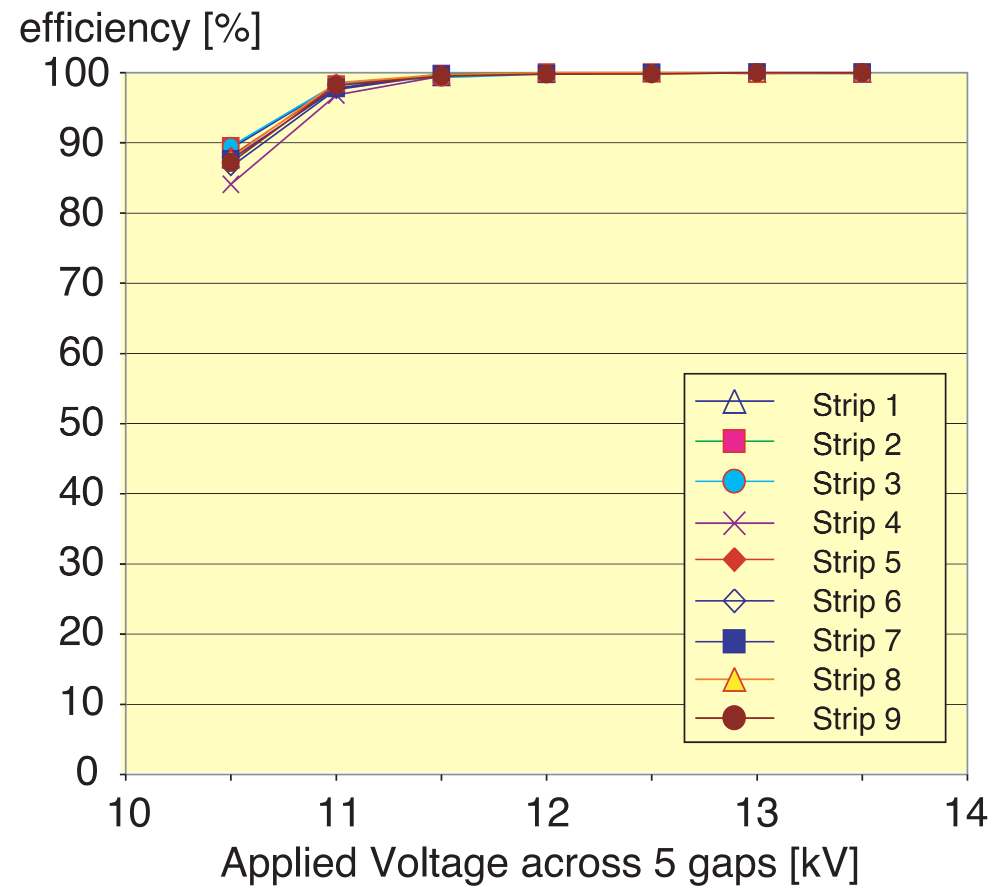
Run number: 37562

File name: 08000037562001.180.root

Event number: 60

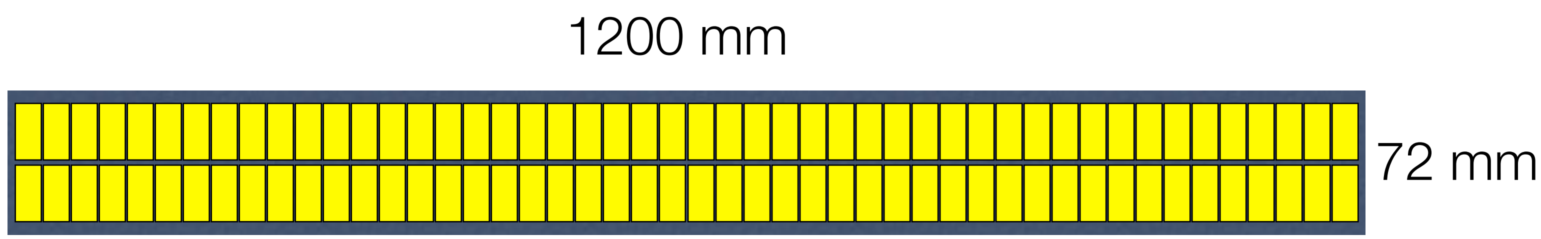
ALICE COSMIC EVENT TRIGGERED BY MRPC (just 2 hits in 150 m^2 TOF array)



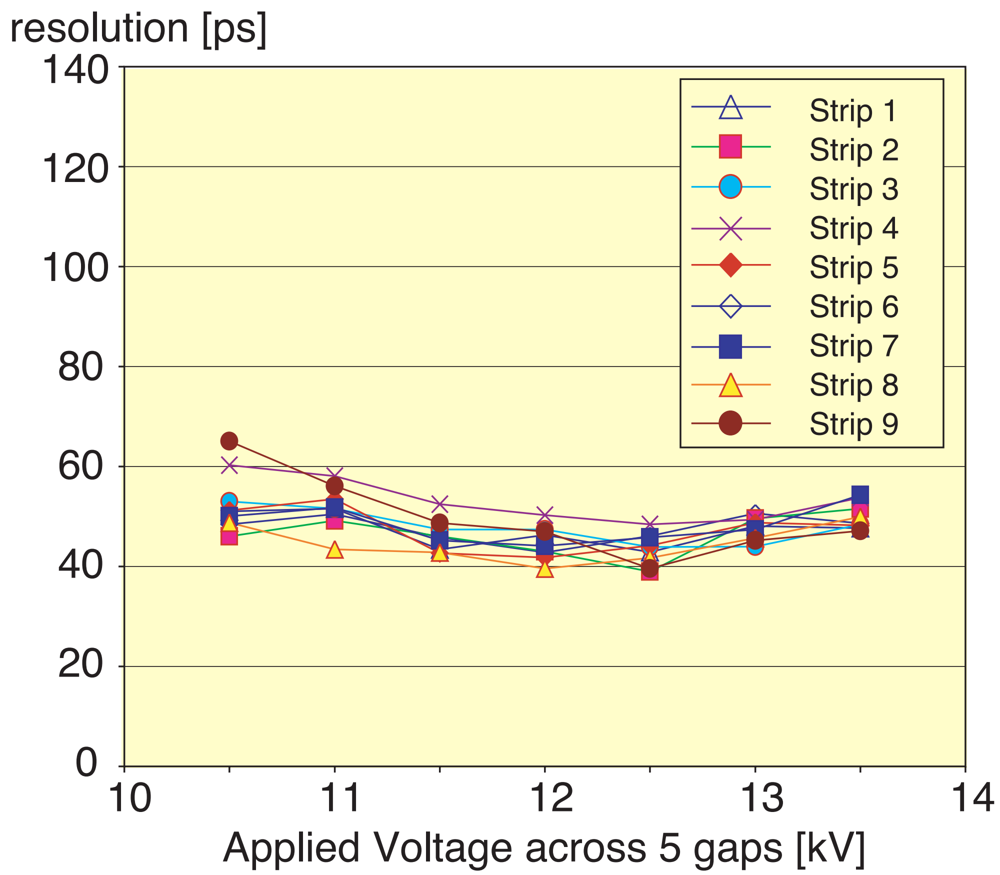


ALICE Time-of-Flight array

ALICE TOF strips



96 pads - each 25 x 36 mm^2



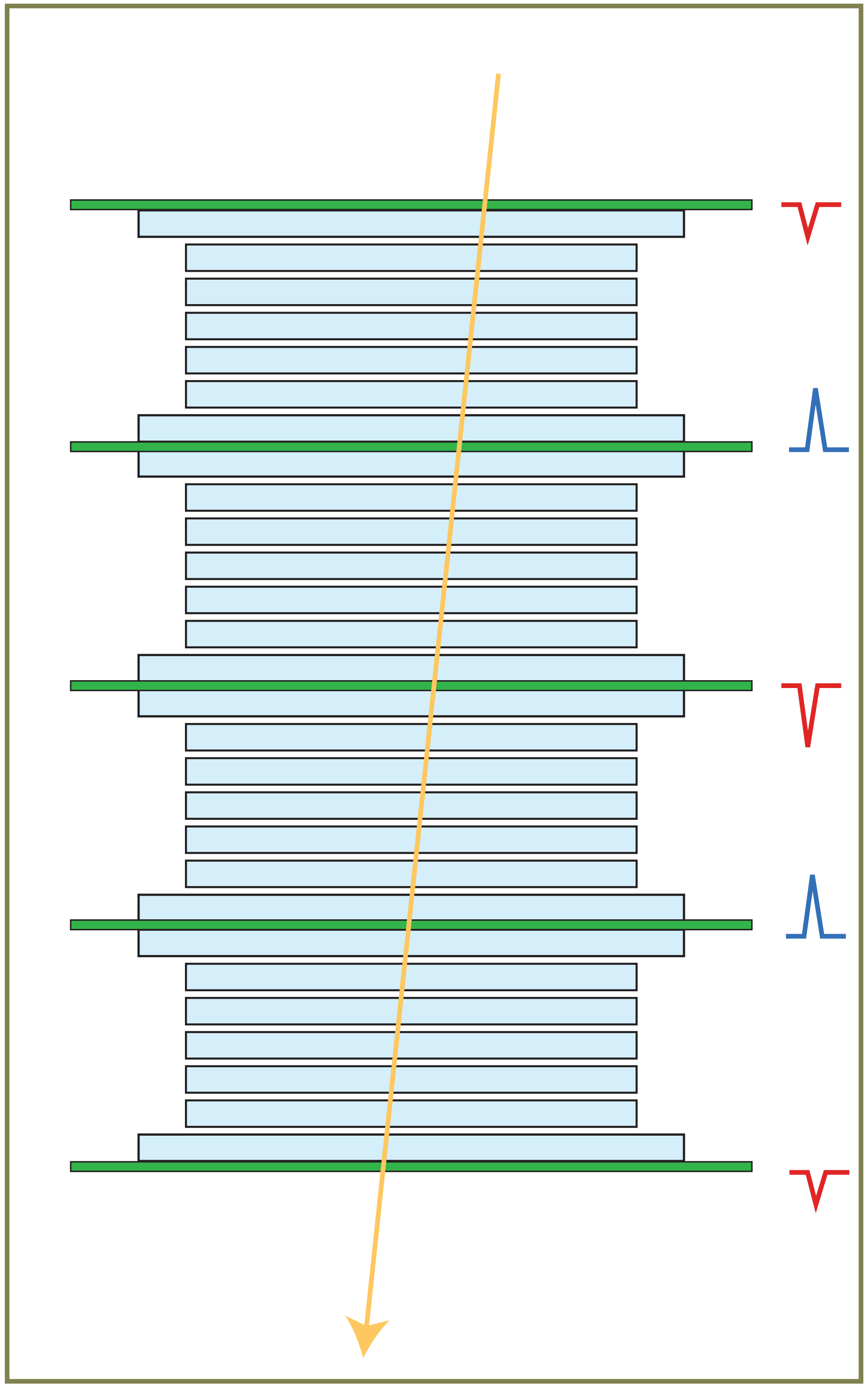
(a) long efficiency plateau (streamer free)
(b) time resolution 40-50 ps (after slewing corrections)

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 15 ps
- total $\sqrt{(30^2 + 14^2 + 21^2 + 15^2)} = 42$ ps

given this : can we hope to build a detector with, for example, 15 ps time resolution?

24 gas gaps
160 micron width



- will mount NINO ASICs as close to the pick up pads as possible

- compared to 10 gap ALICE TOF expect (back of an envelope calculation)

    - intrinsic jitter decrease from 15 ps to 8 ps (more primary ionising clusters -faster electron velocity in avalanche)

    - rise time to decrease by factor 2 (faster electron velocity in avalanche)

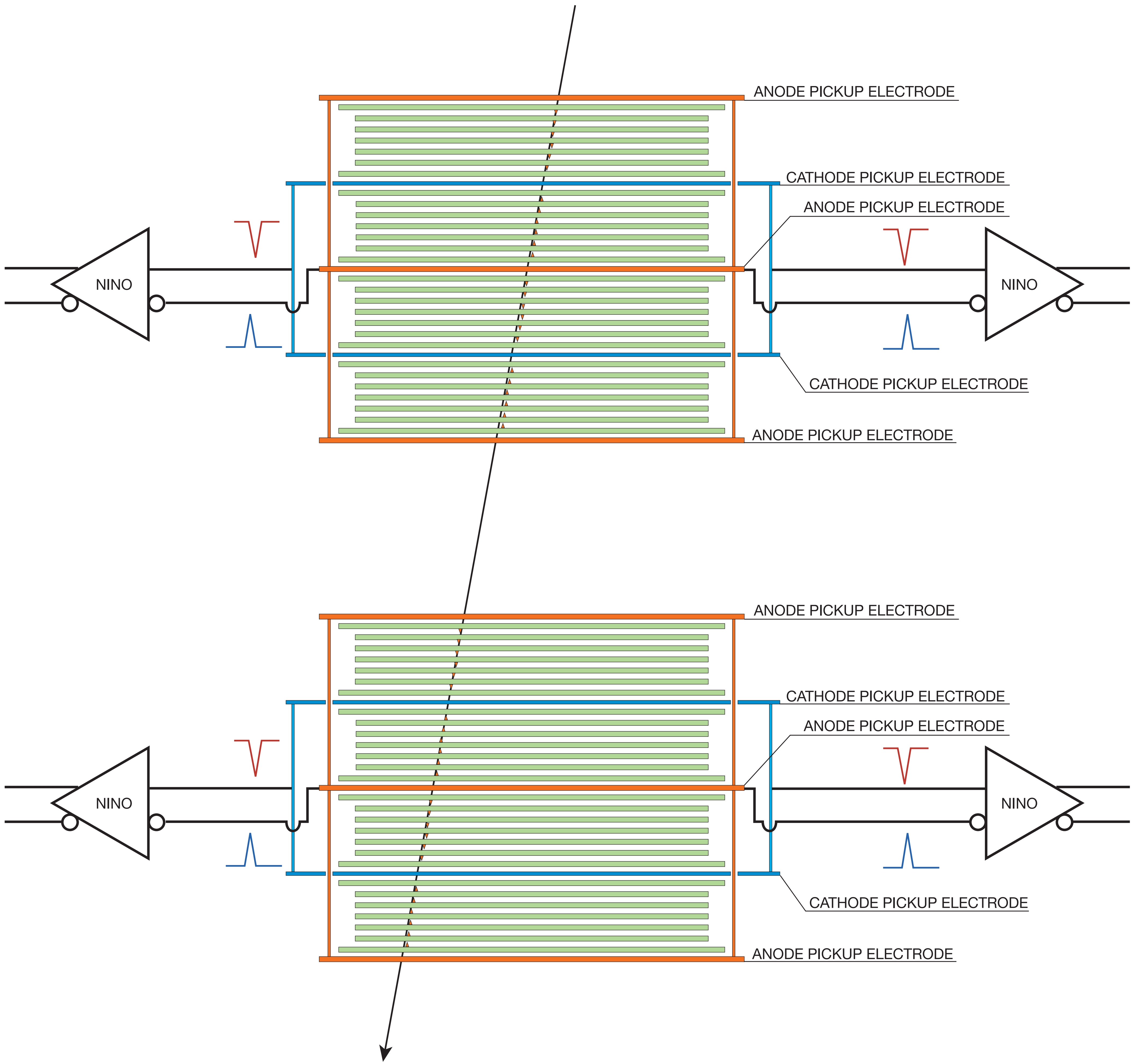
    - narrower charge spectrum more de-placed from zero

42 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 ~~15 ps~~
  24 gaps of 160 micron 8 ps

- total $\sqrt{(5^2 + 5^2 + 5^2 + 8^2)} = 12$ ps

maybe 15 ps time resolution is possible after all


ANODE PICKUP ELECTRODE
CATHODE PICKUP ELECTRODE
ANODE PICKUP ELECTRODE
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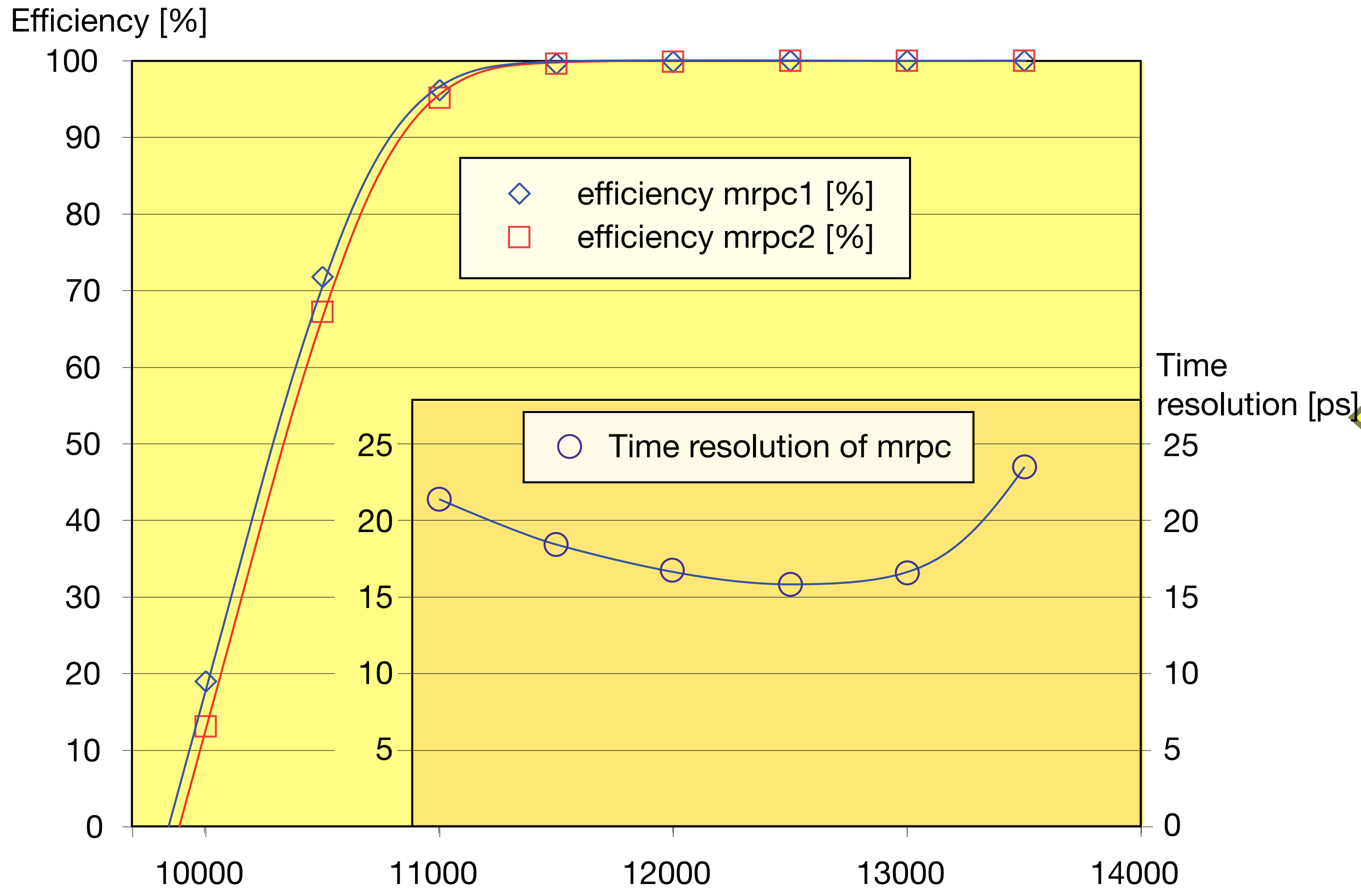
Efficiency [%]
efficiency mrpc1 [%]
efficiency mrpc2 [%]
Time resolution of mrpc
Time resolution [ps]
100
90
80
70
60
50
40
30
20
10
0
25
20
15
10
5
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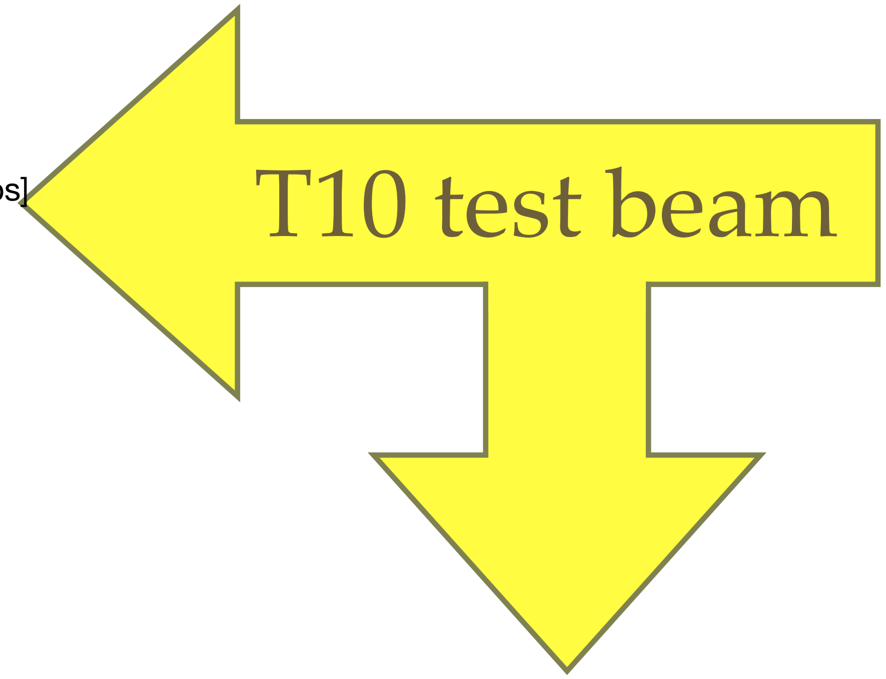
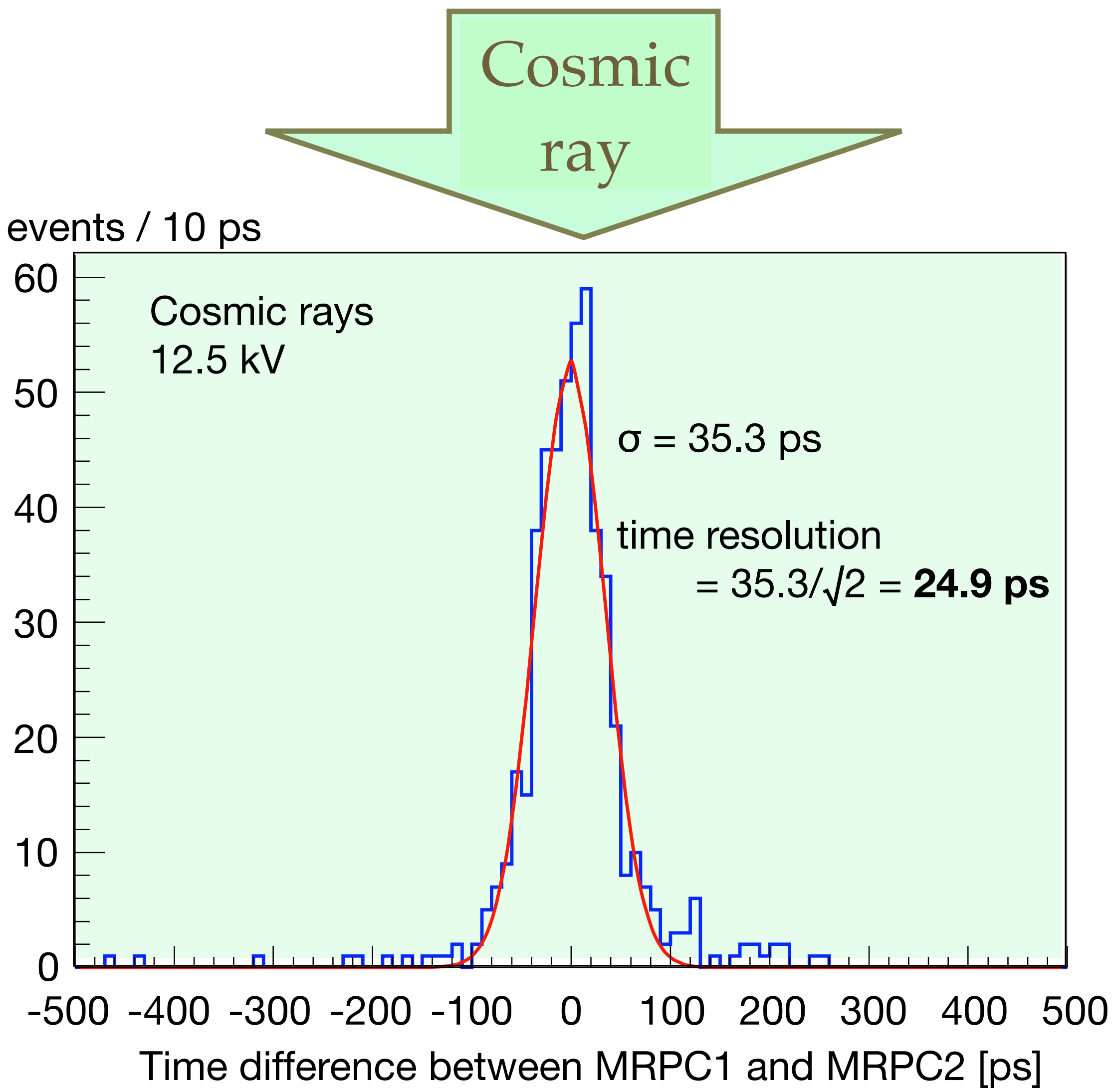
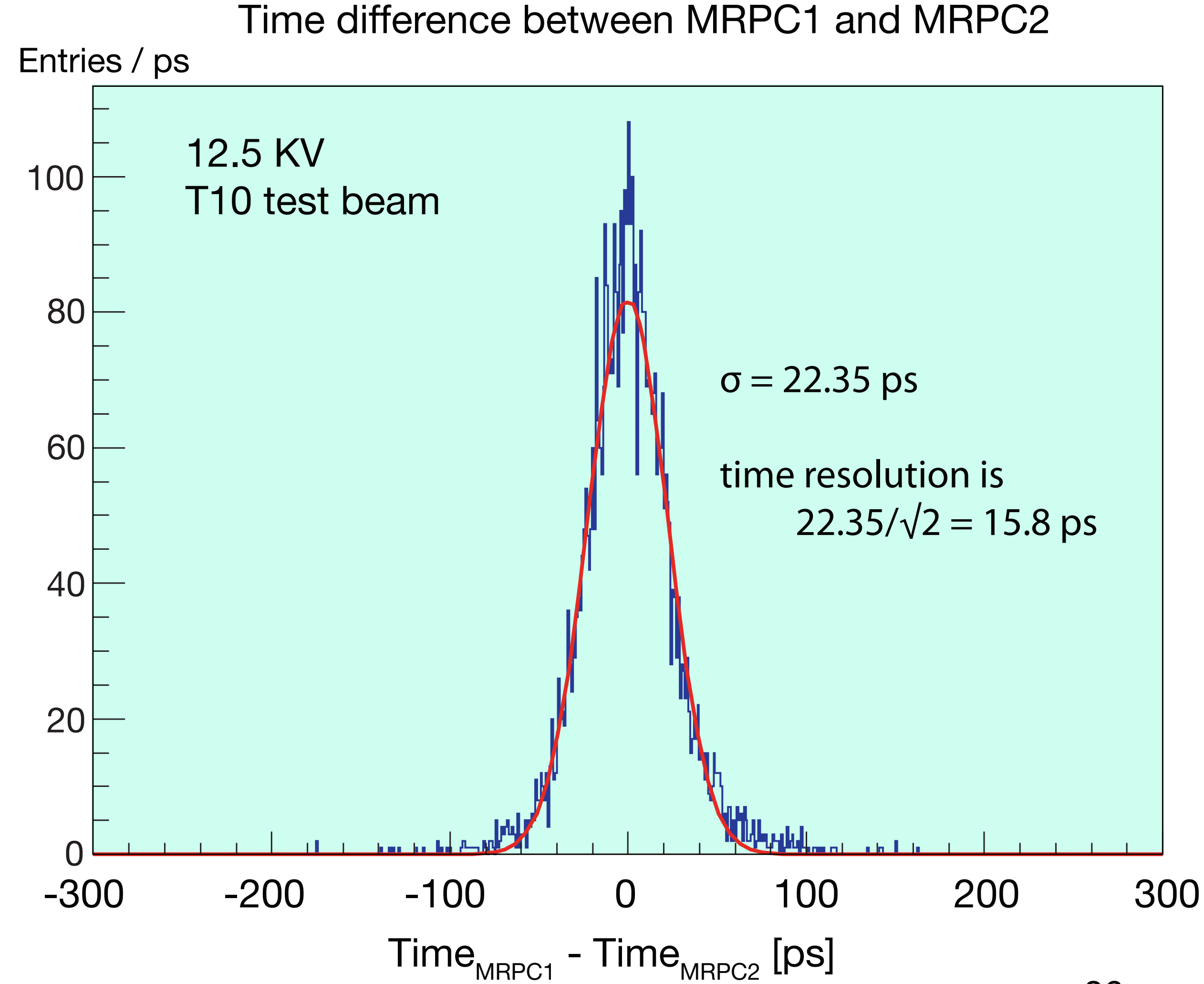
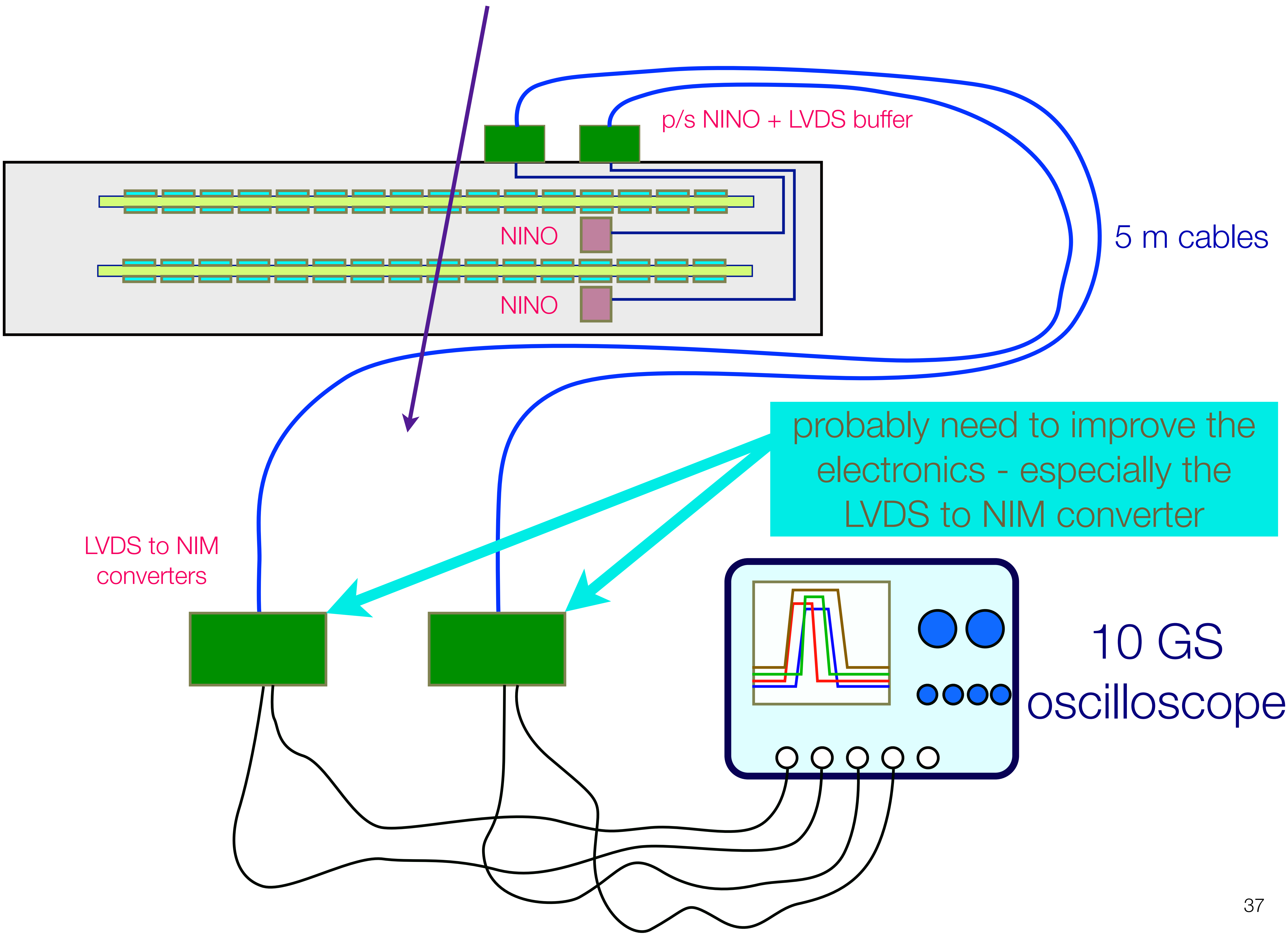
10000
11000
12000
13000
14000


T10 test beam

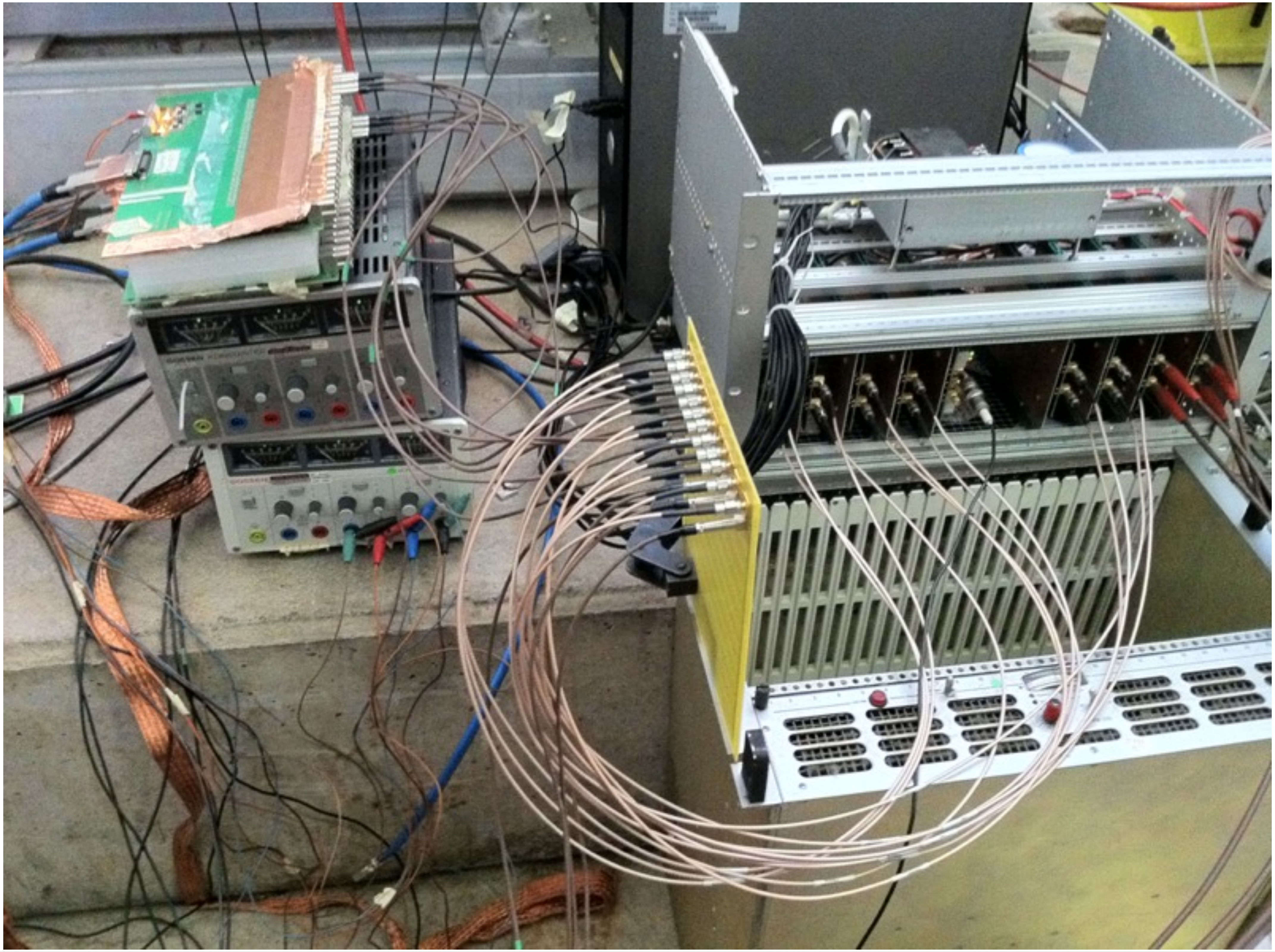

Cosmic ray
events / 10 ps
Cosmic rays
12.5 kV
σ = 35.3 ps
time resolution
= 35.3/√2 = 24.9 ps
60
50
40
30
20
10
0
-500 -400 -300 -200 -100 0 100 200 300 400 500
Time difference between MRPC1 and MRPC2 [ps]


Time difference between MRPC1 and MRPC2
Entries / ps
12.5 KV
T10 test beam
σ = 22.35 ps
time resolution is
22.35/√2 = 15.8 ps
100
80
60
40
20
0
-300 -200 -100 0 100 200 300
Time MRPC1 - Time MRPC2 [ps]



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

last beam test: test of tdc system (D Breton -Orsay) that has 5 ps time resolution



summary

- TOF needs: highly segmented detector that works in a magnetic field
  excellent time resolution
- MRPC is the only viable technology that meets this need
- there are some magic aspects of the mrpc (a) floating intermediate resistive plates (b) space charge limits avalanche growth to be below streamer transition (c) recombination cuts ionic charge residual in the gas gap and so boost rate capability
- differential readout really cuts noise and is essential to obtain good time resolution
- time resolutions close to 10 ps are possible - needs very good tdc