Latest advances in MRPC's for Fast Timing

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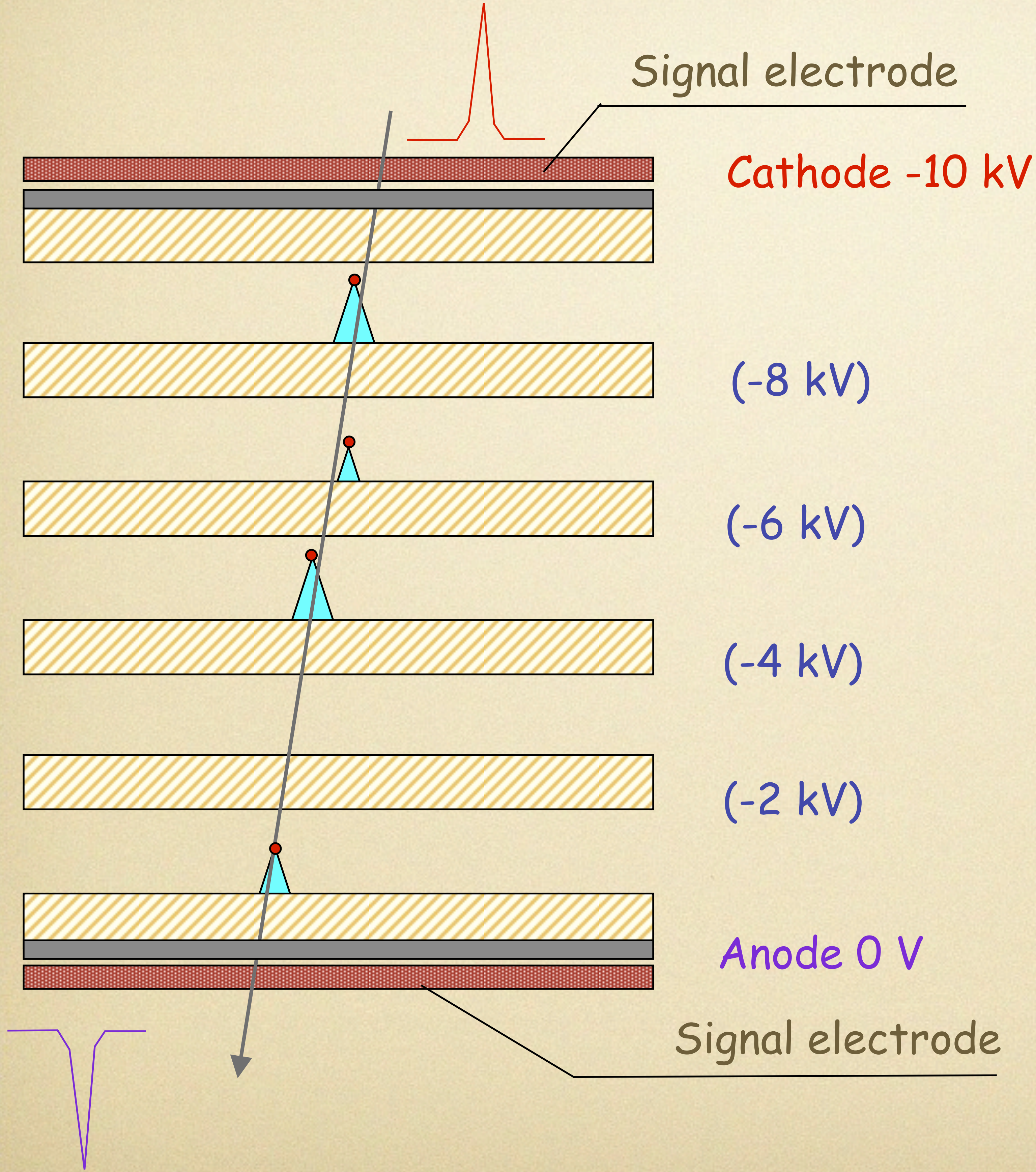
What is the Multigap Resistive Plate Chamber?

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

Key points

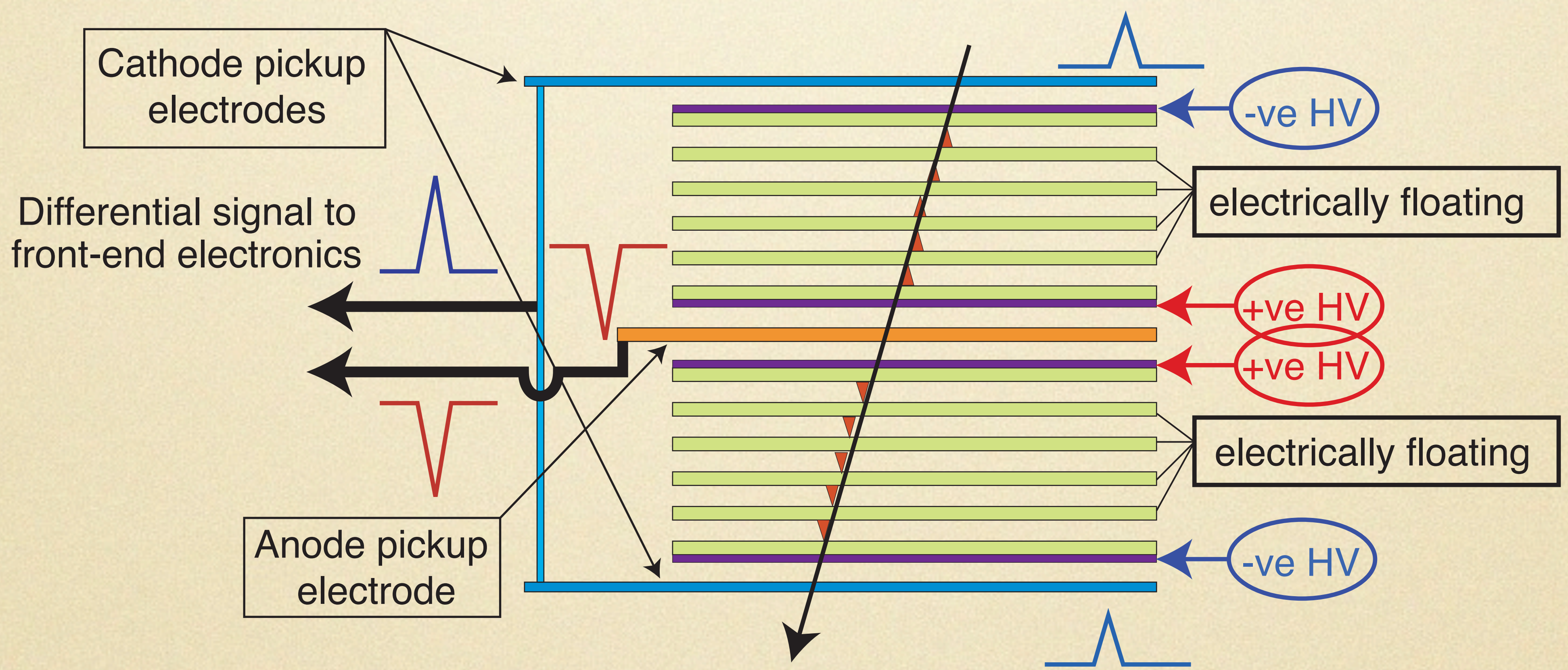
- voltage only applied to outer surfaces
- many very small gas gaps with very high electric field
- gas avalanche starts immediately
- induced signal is the sum of many avalanches all acting together
- small gaps: space charge is dominant: inhibits streamer production
    - space charge effects : leads to a relaxation of mechanical constraints and increase ratio of fast signal to total charge

ALICE MRPC for TOF

schematic view

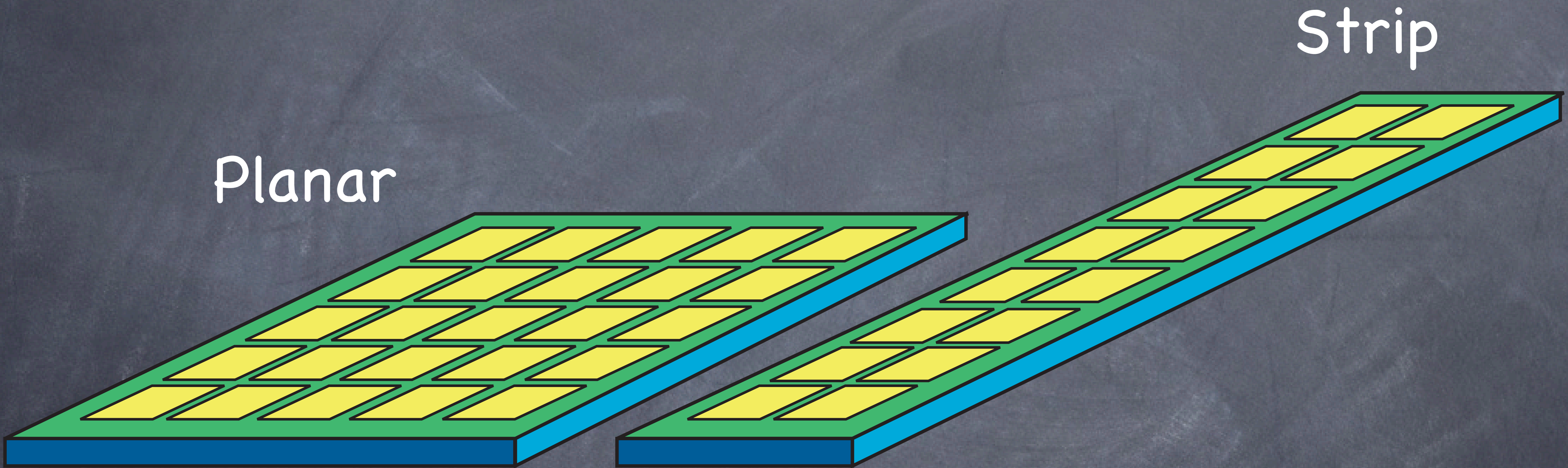
ALICE-TOF has 10 gas gaps (two stacks of 5 gas gaps) each gap is 250 micron wide

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



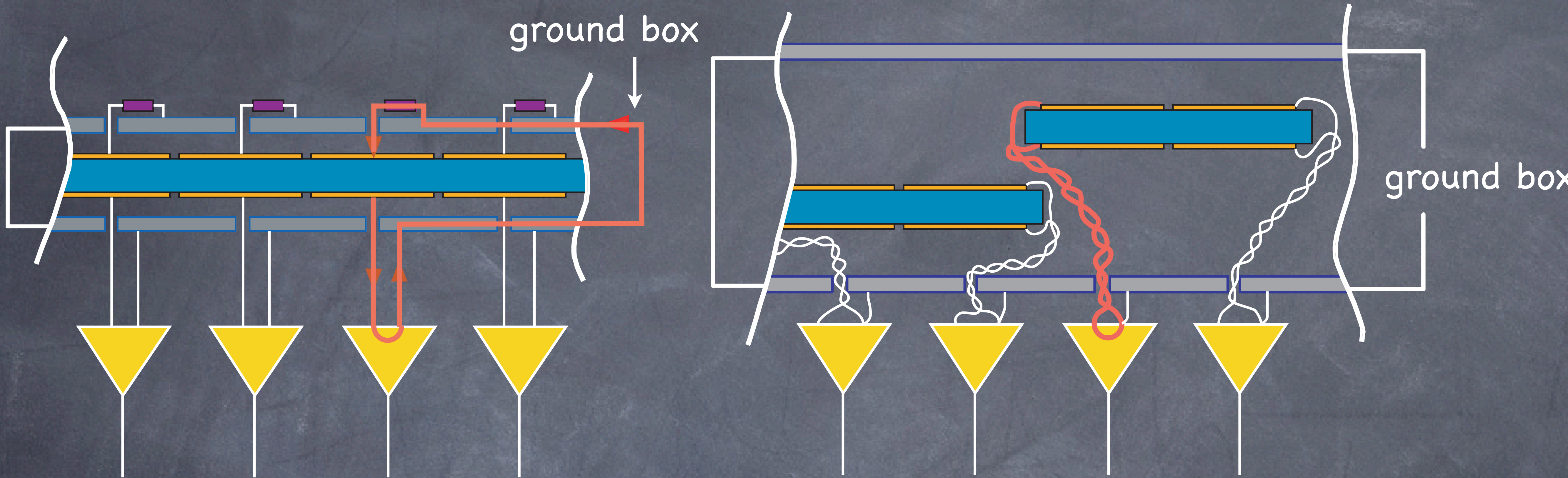
Note : HV only applied to outer surfaces of each stack of glass (internal glass sheets electrically floating) this makes it very easy to build.

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



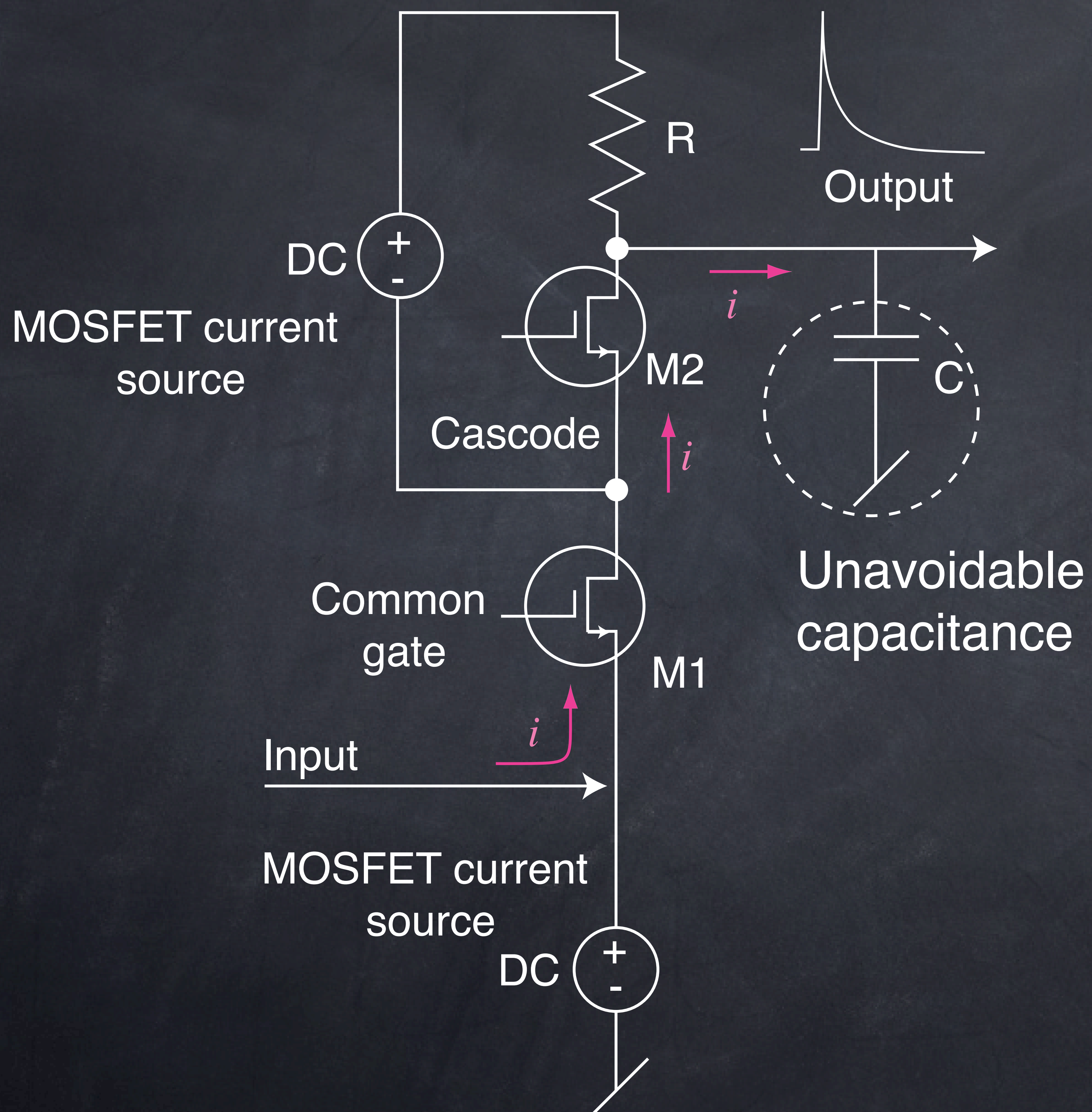
Strip has some advantages concerning the geometry but very large advantage for the readout electronics

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

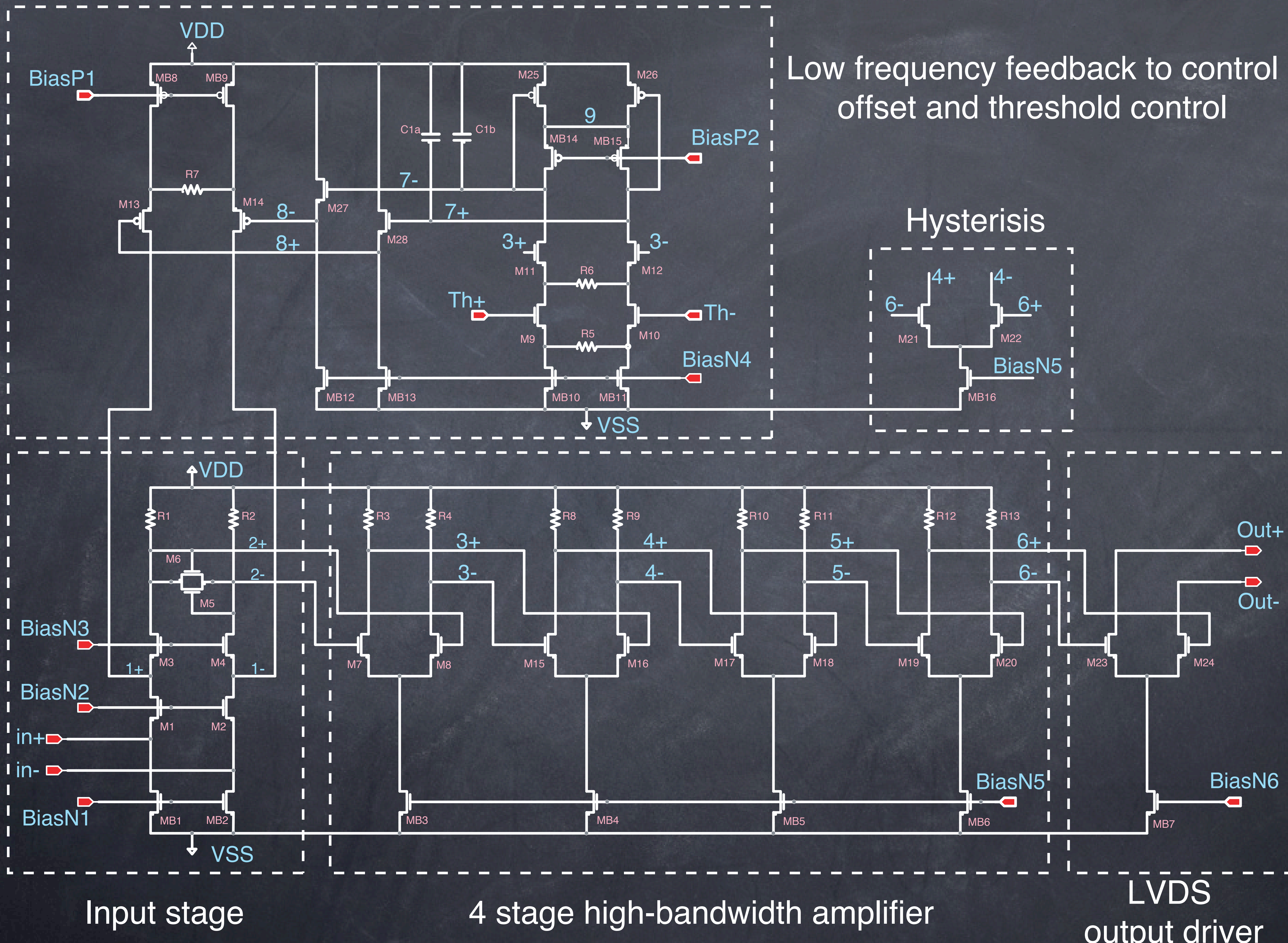


The signal is induced on the anode and cathode pickup pads - current flows from anode pad through amplifier and returns to cathode pad. The strip design allows the use of a transmission line (twisted pair cable) to connect this ‘signal generator’ to the amplifier - otherwise return path is via the outside 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



- The input current flows through the two transistors and charges the capacitor at the output (need to minimise C for maximum voltage)
- Trailing-edge of voltage pulse at output has RC time constant
- The impedance seen at the input is mainly the $1/g_m$ of the input transistor.
- The advantage of this configuration is the high bandwidth with excellent stability due to the absence of feedback element.


Low frequency feedback to control offset and threshold control
Hysterisis
Input stage
4 stage high-bandwidth amplifier
LVDS output driver
VDD
BiasP1
BiasP2
BiasN1
BiasN2
BiasN3
BiasN4
BiasN5
BiasN6
VSS
Th+
Th-
in+
in-
Out+
Out-
C1a
C1b
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
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R13
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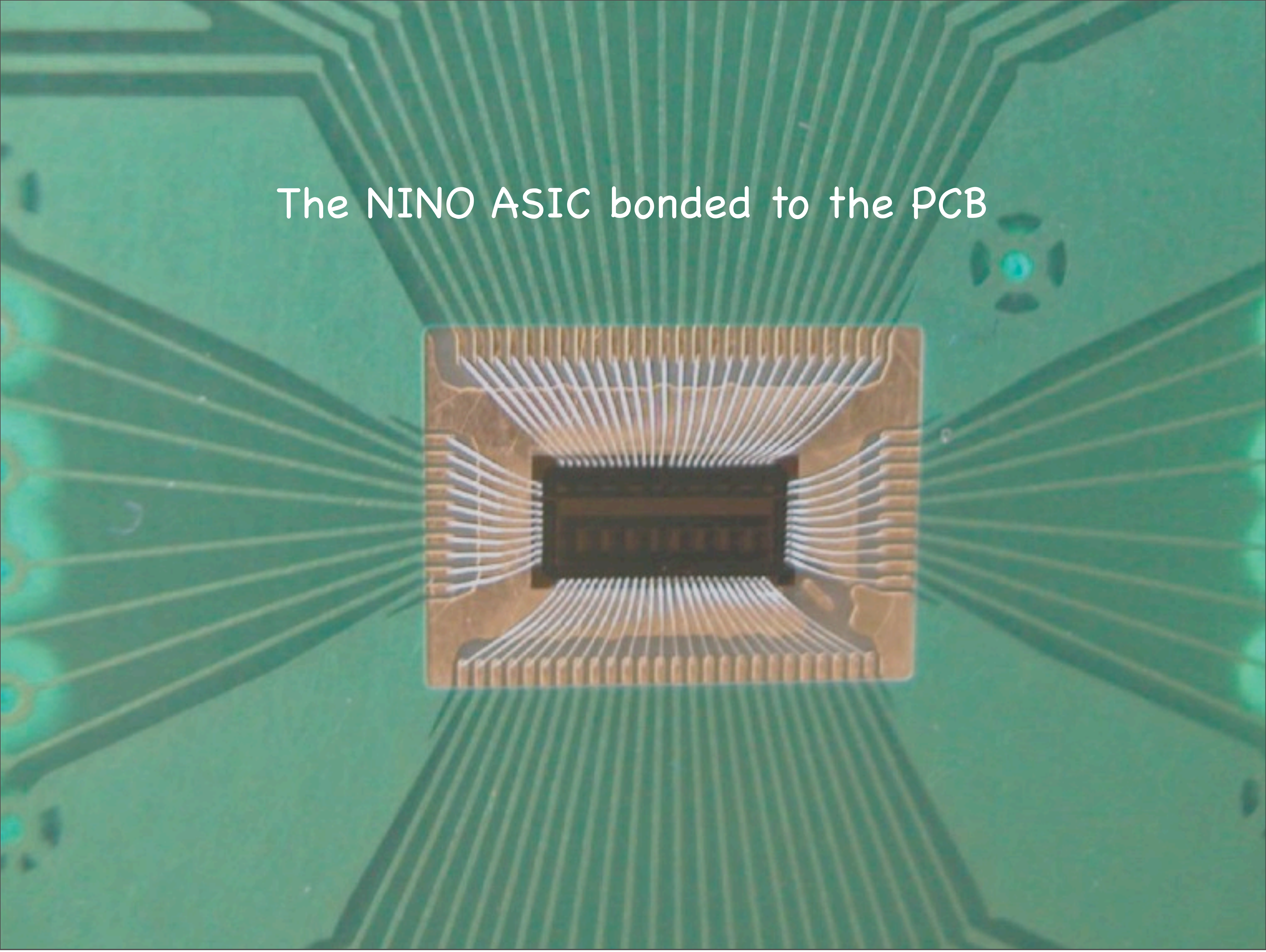
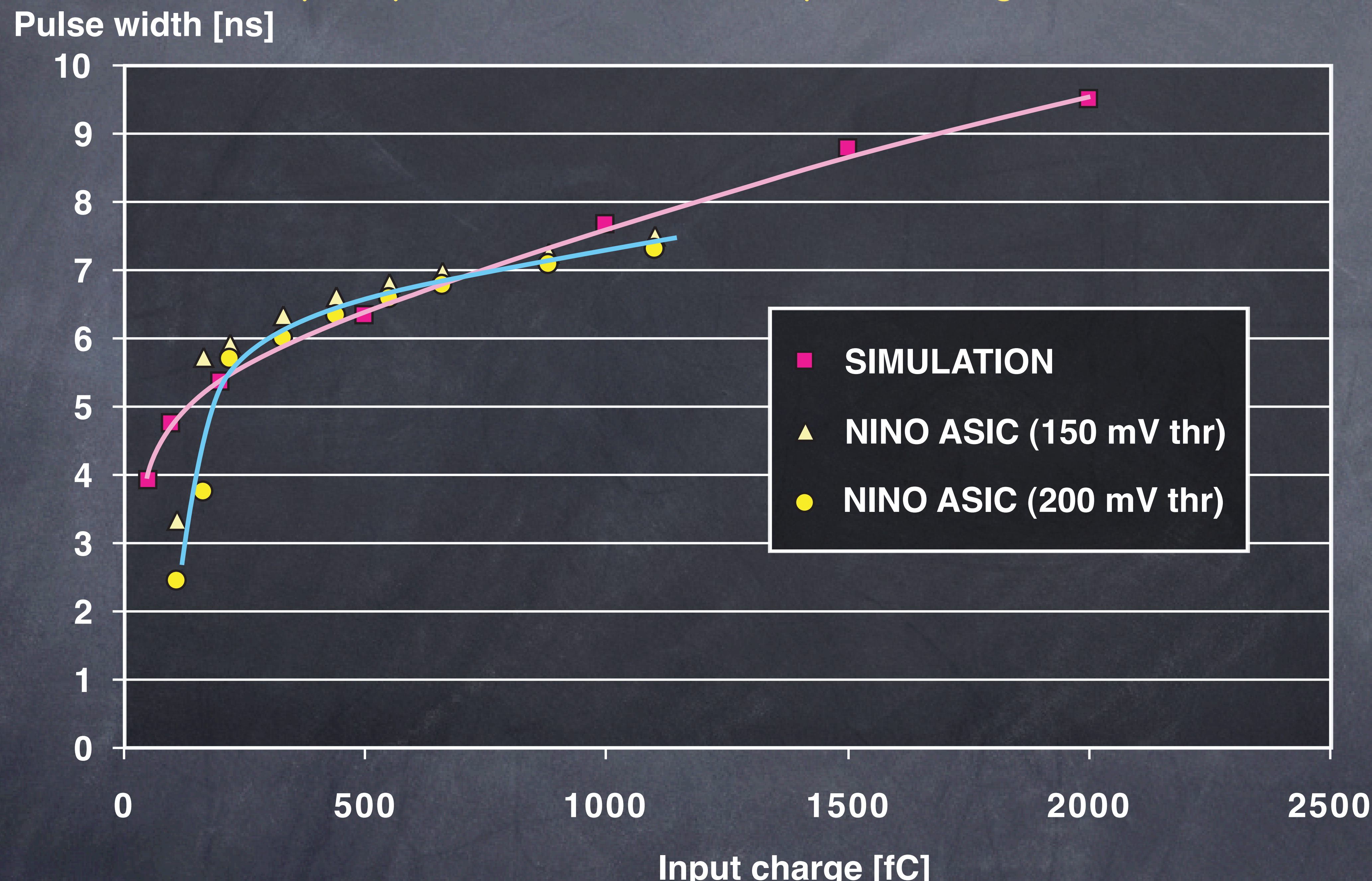
7+
7-
8+
8-
9

The NINO ASIC bonded to the PCB

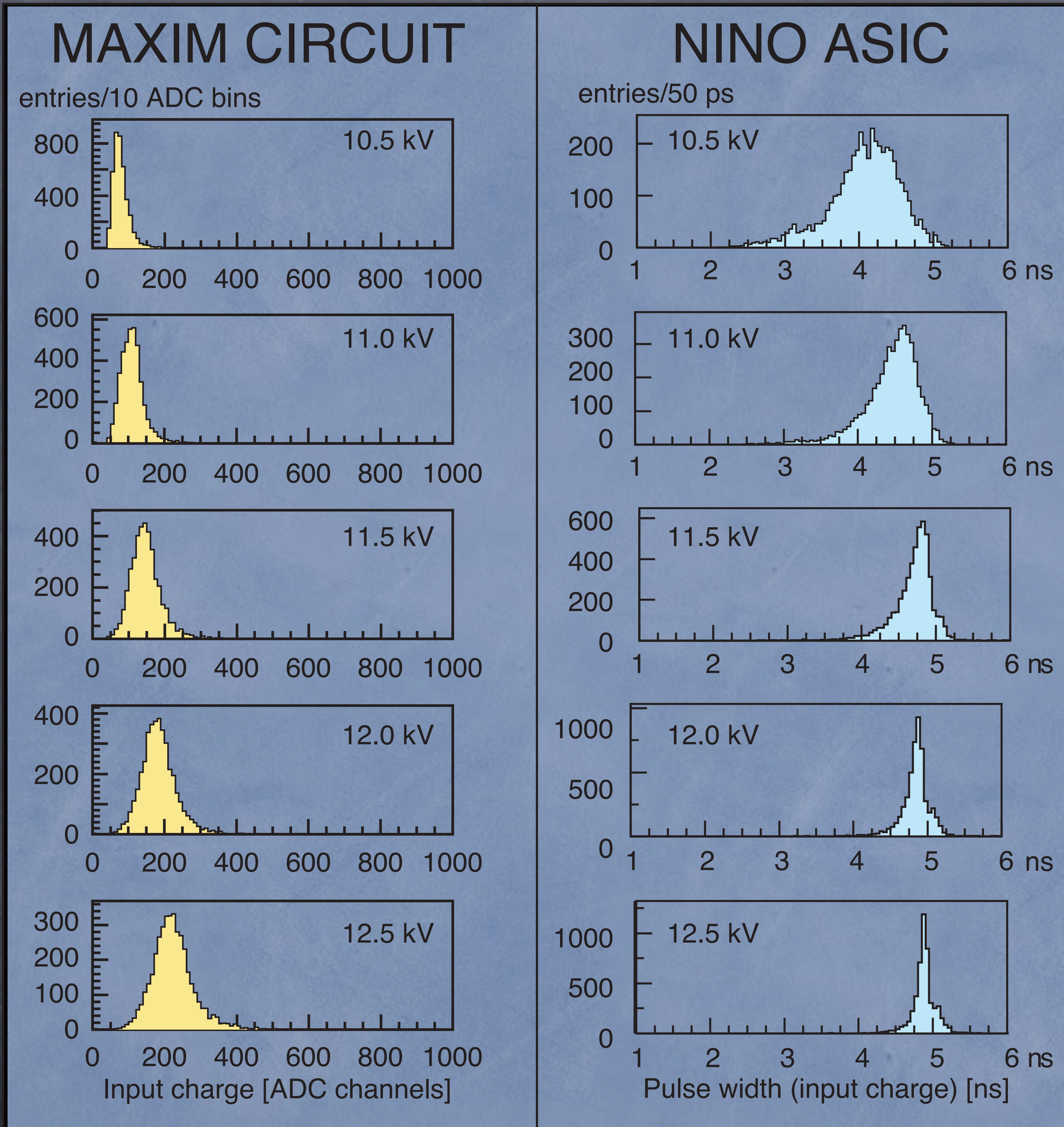


Simple threshold discriminator - need to correct time using pulse height (slewing correction)

Width of output pulse related to input charge - non linear

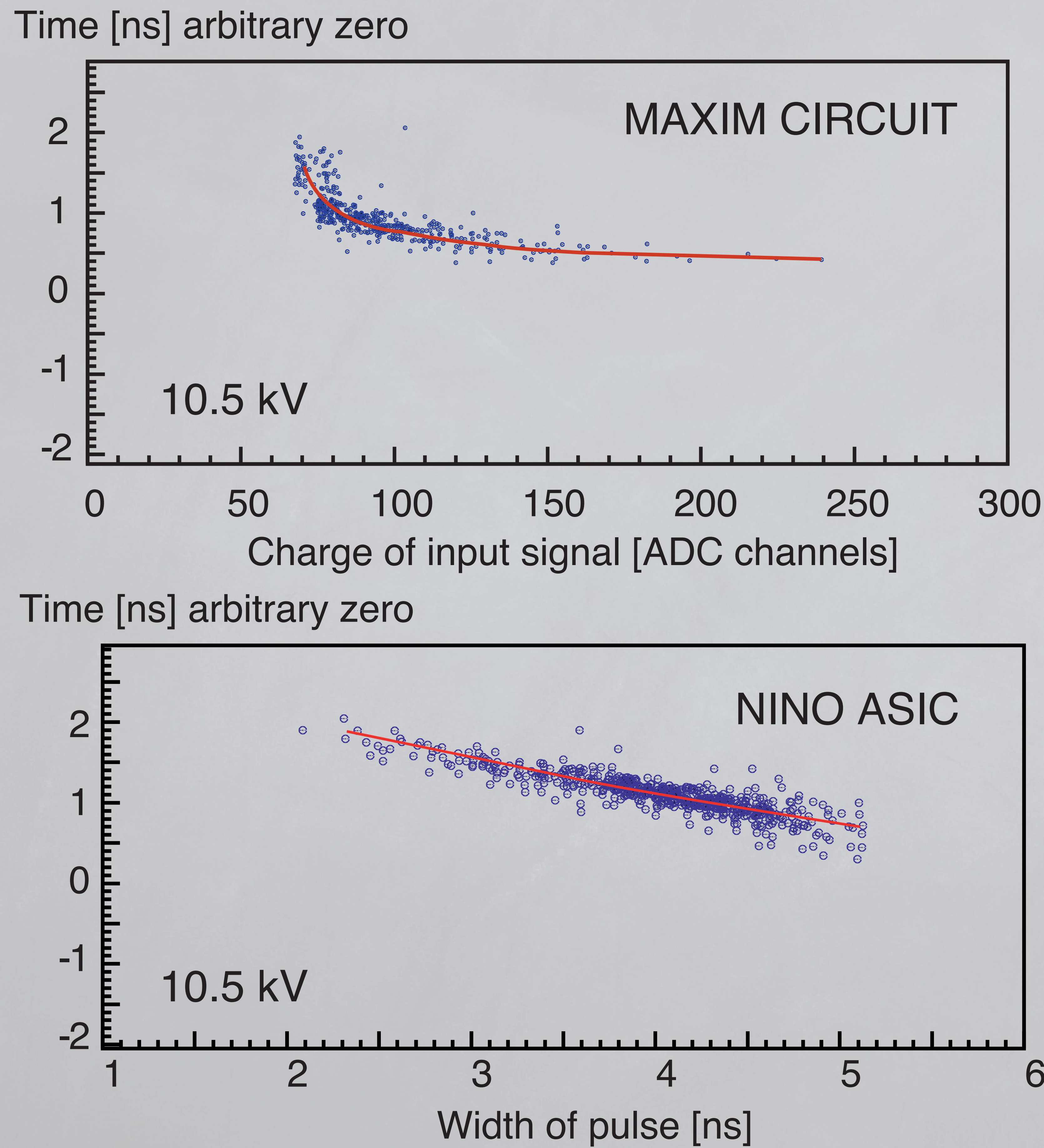


No ADC - instead use TDC (measuring leading and trailing edge)



ADC ToT

NINO ASIC expands the dynamic range for small input charge



Correction very steep at small pulse heights

HPTDC

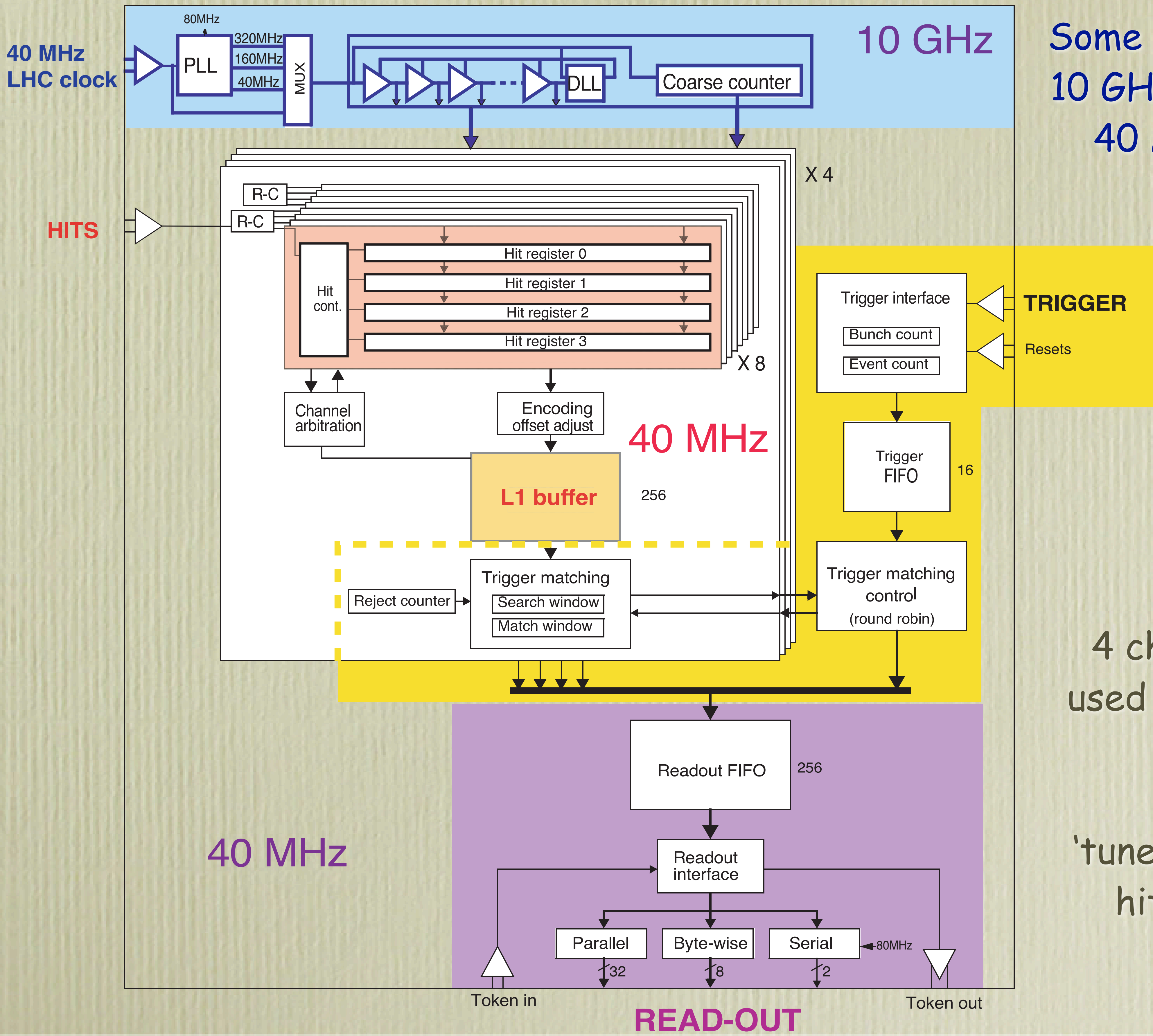
The basic idea : have high frequency clock running in sync with LHC clock of 40 MHz
On arrival of 'hit' record value of clock in a buffer

Runs continuously

'Trigger' : look in buffer and select hits within given time window

This is a system without deadtime

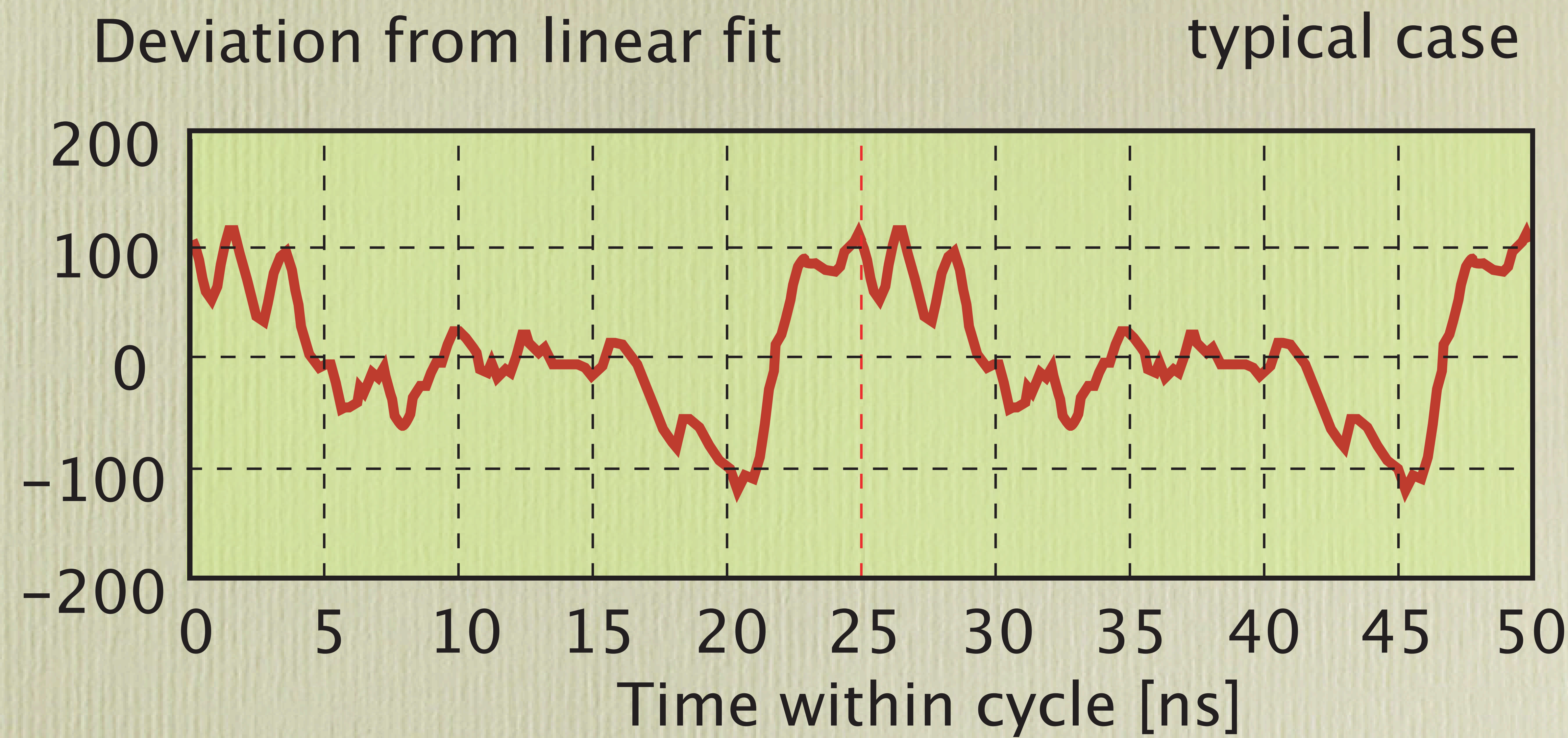
HPTDC



Some interference between 10 GHz clock for timing and 40 MHz clock for data control

4 channels (100 ps) are used to get down to 25 ps bin size

'tuned' RC circuit offsets hits signals by 25 ps

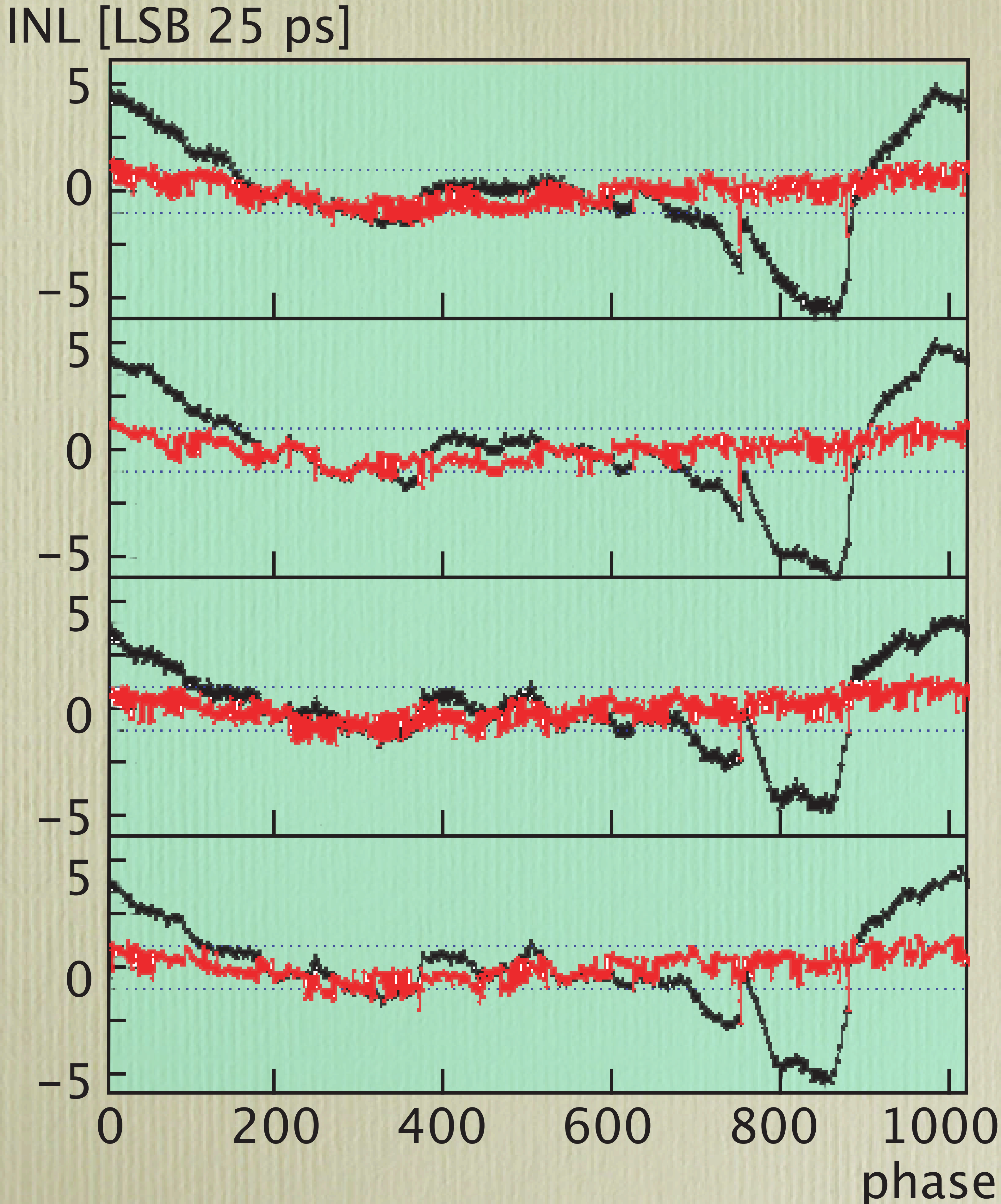


Such deviations would introduce 57 ps contribution to time resolution

However - (a) deviation is repeated every cycle

(b) very stable - measure at one time - and deviation does not change

Therefore this can be corrected



Lookup table used to correct each bin - remaining non-linear behaviour due to 25 ps binning

Automatic procedure using DSP to generate table - and to correct data on-line

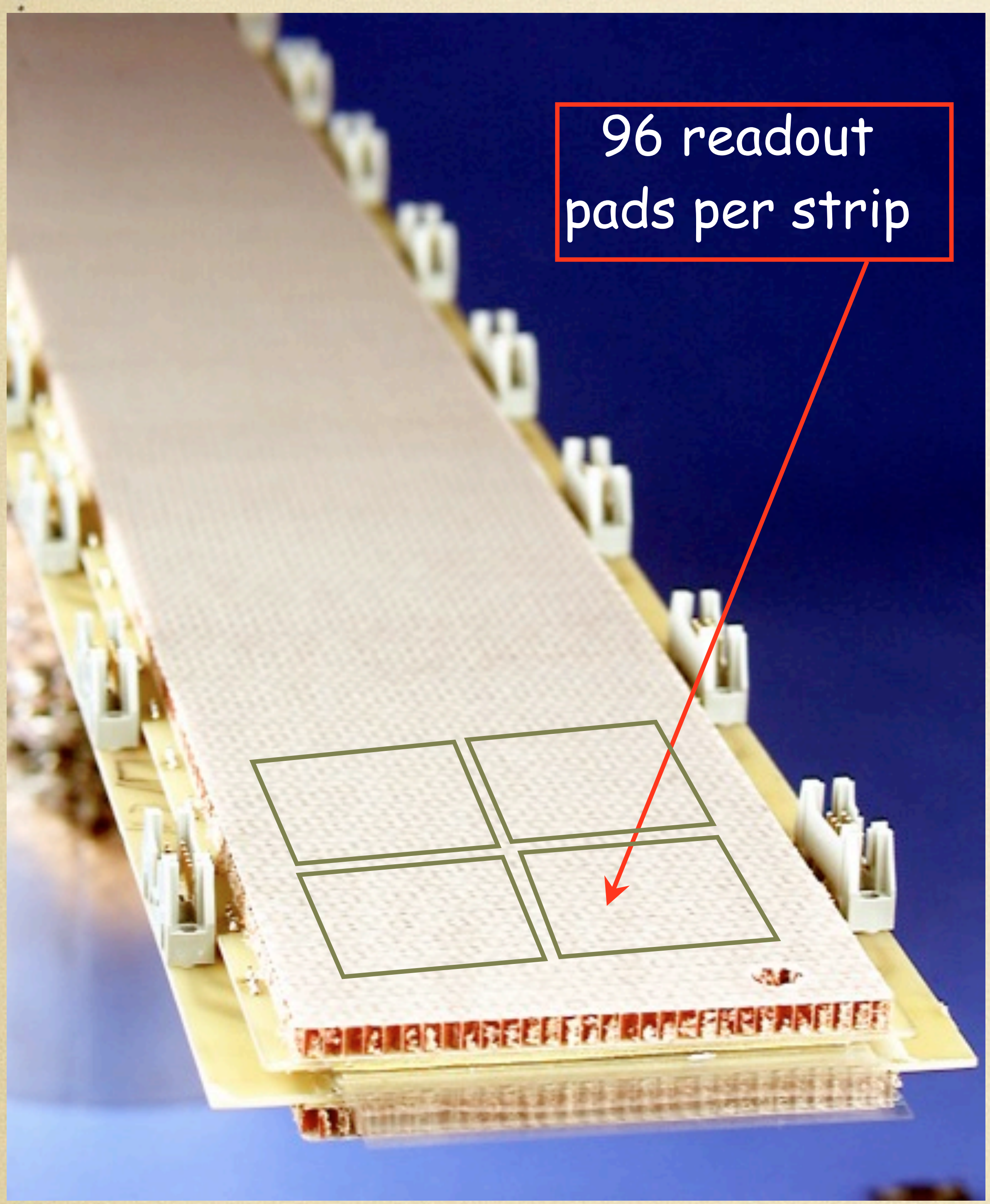
Plans for HPTDC

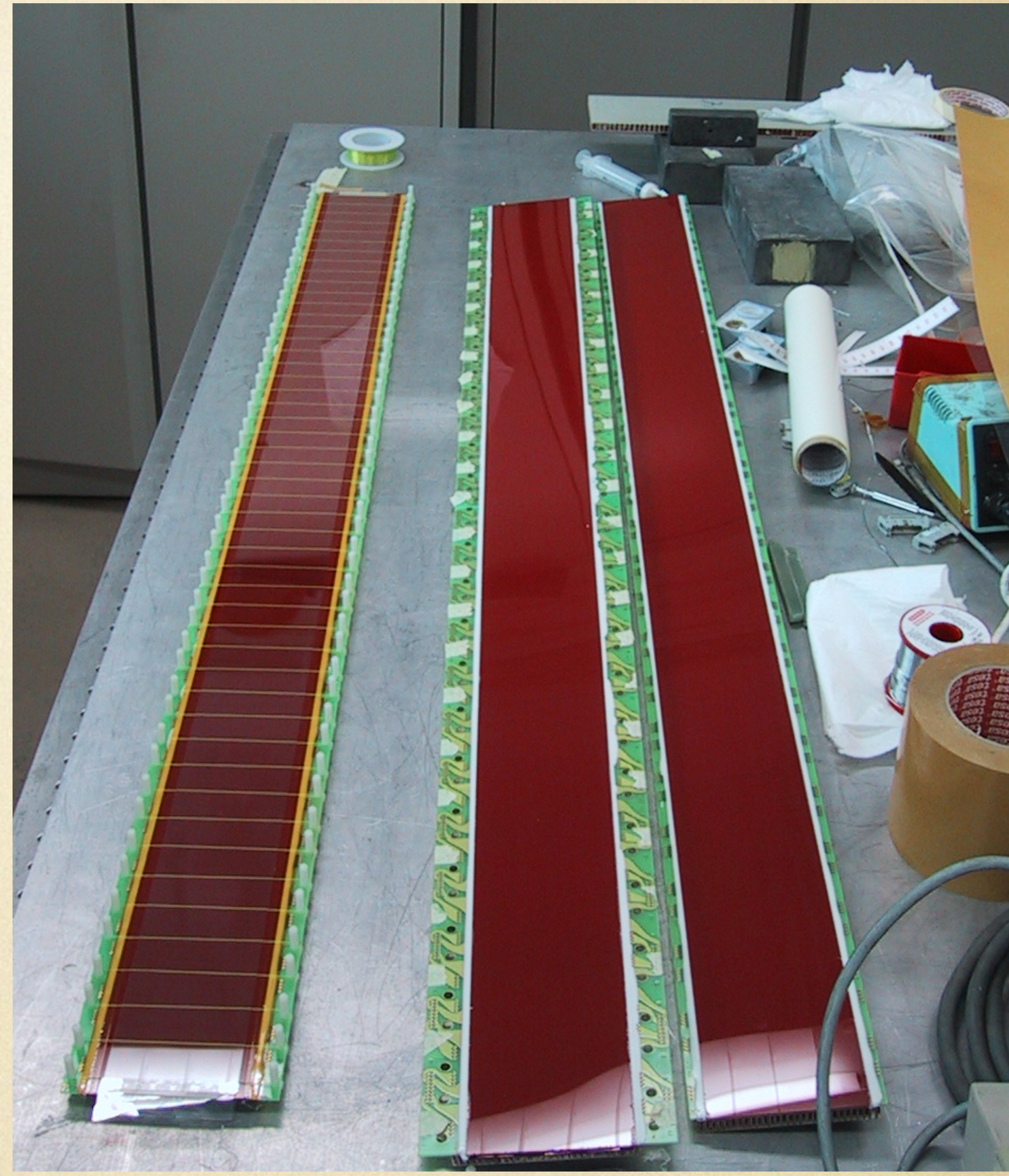
- Redesign in 0.13 micron cmos
- each channel will be capable of running with 25 ps bin width (rather than the 4 channel combination as at present)
- NINO front-end amplifier-discriminator also will be rebuilt in 0.13 micron cmos - and can be integrated into HPTDC package

So now back to the ALICE TOF

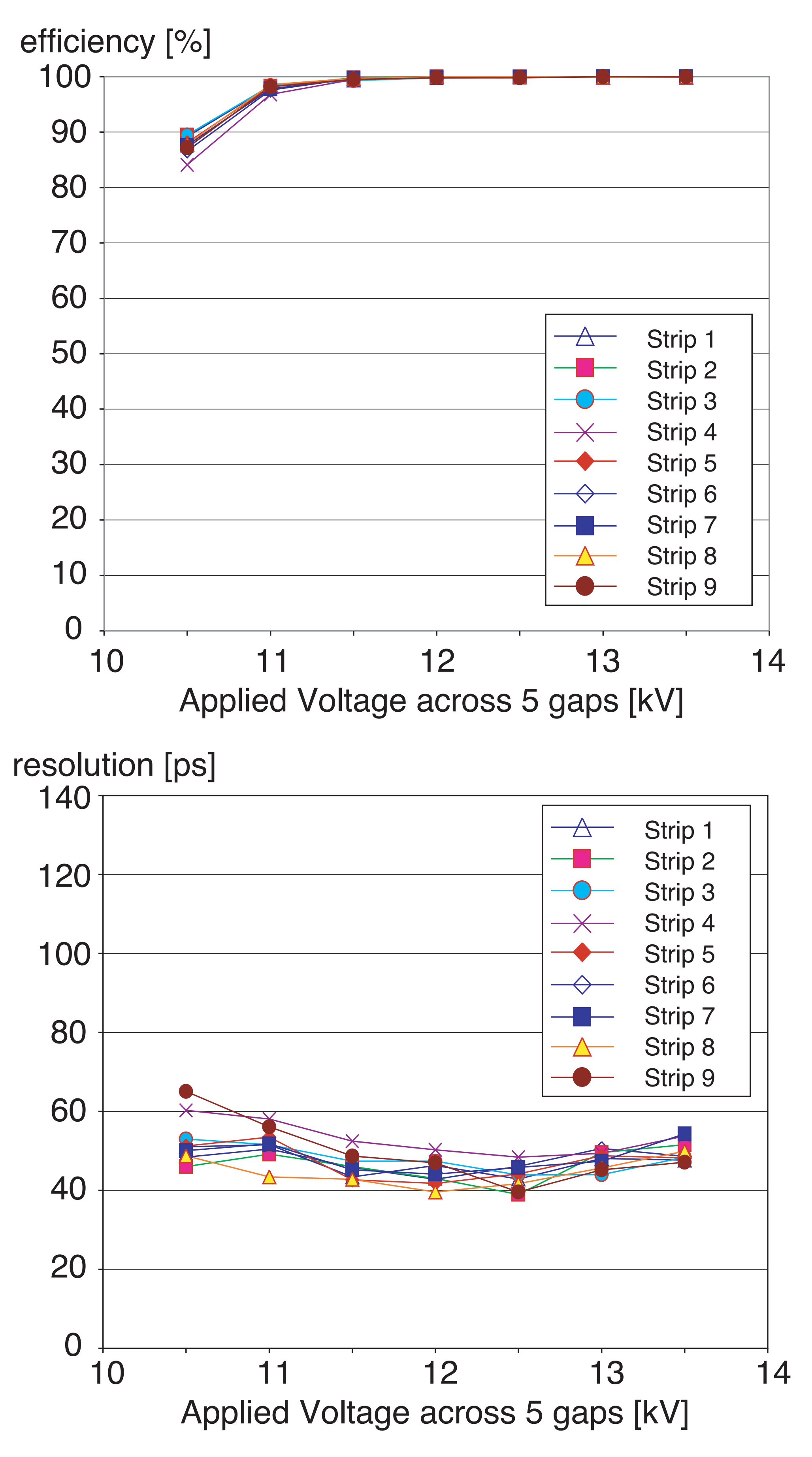
- 160 000 channels of electronics
- 150 m^2 array

ALICE TOF STRIP





96 pads - each 25 x 36 mm^2



Uniformity of ALICE Time-of-Flight

(a) long efficiency plateau

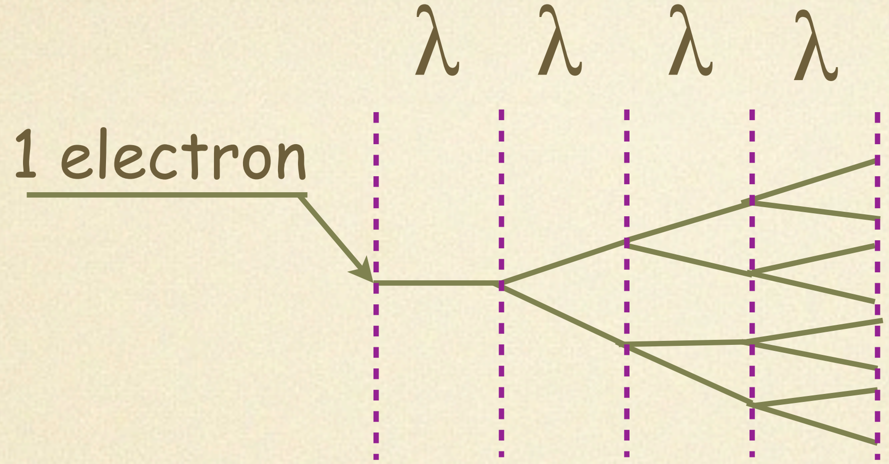
(b) time resolution 40-50 ps (after slewing corrections)

Time jitter - ALICE TOF

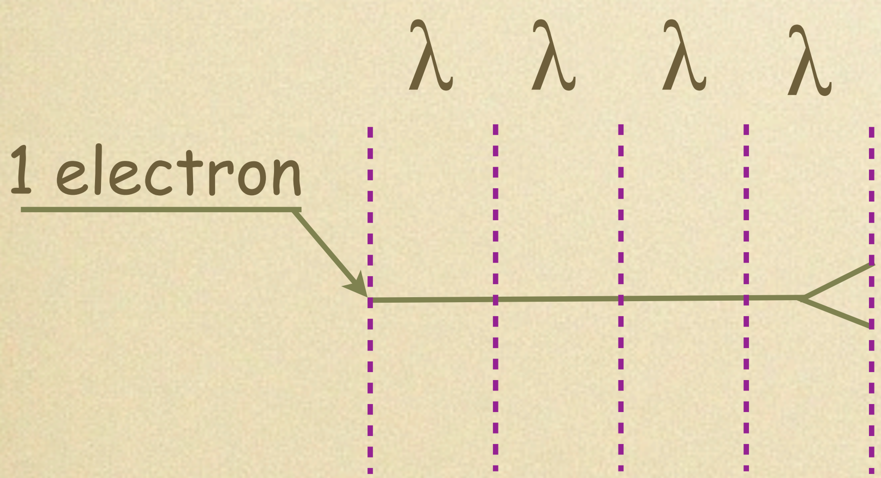
- tdc time resolution (time difference between two channels) 30 ps
- beam spot 1 cm in size (50 ps/√12) 14 ps
- NINO ASIC + cables + interface card 21 ps
- intrinsic MRPC time resolution 20 ps
- **total $\sqrt{(30^2 + 14^2 + 21^2 + 20^2)} = 44$ ps**

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

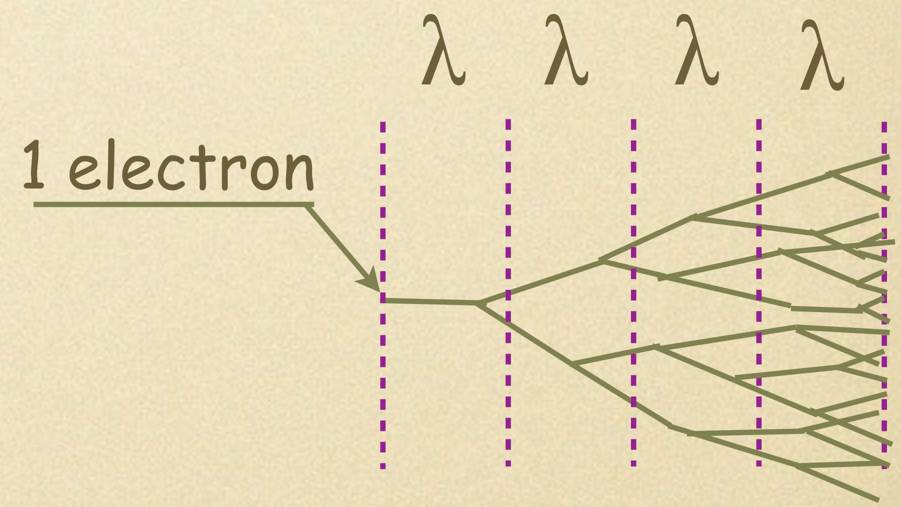
Source of time jitter in MRPC



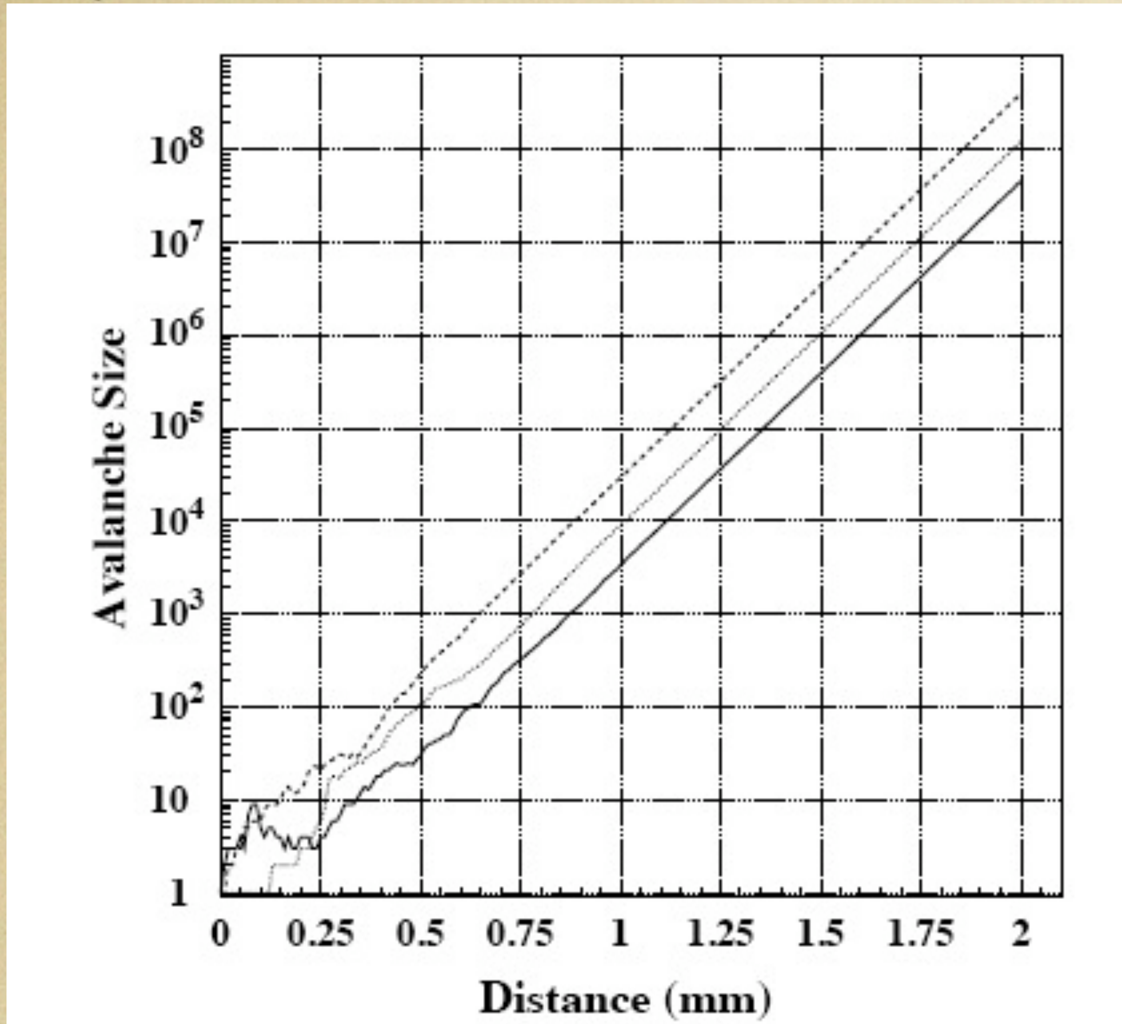
For a given electric field an electron will undergo an ionising collision every distance, λ, that it travels where λ is the average distance between ionising collisions ($1/\alpha$)



1 electron may go
3.5 λ before ionising collision

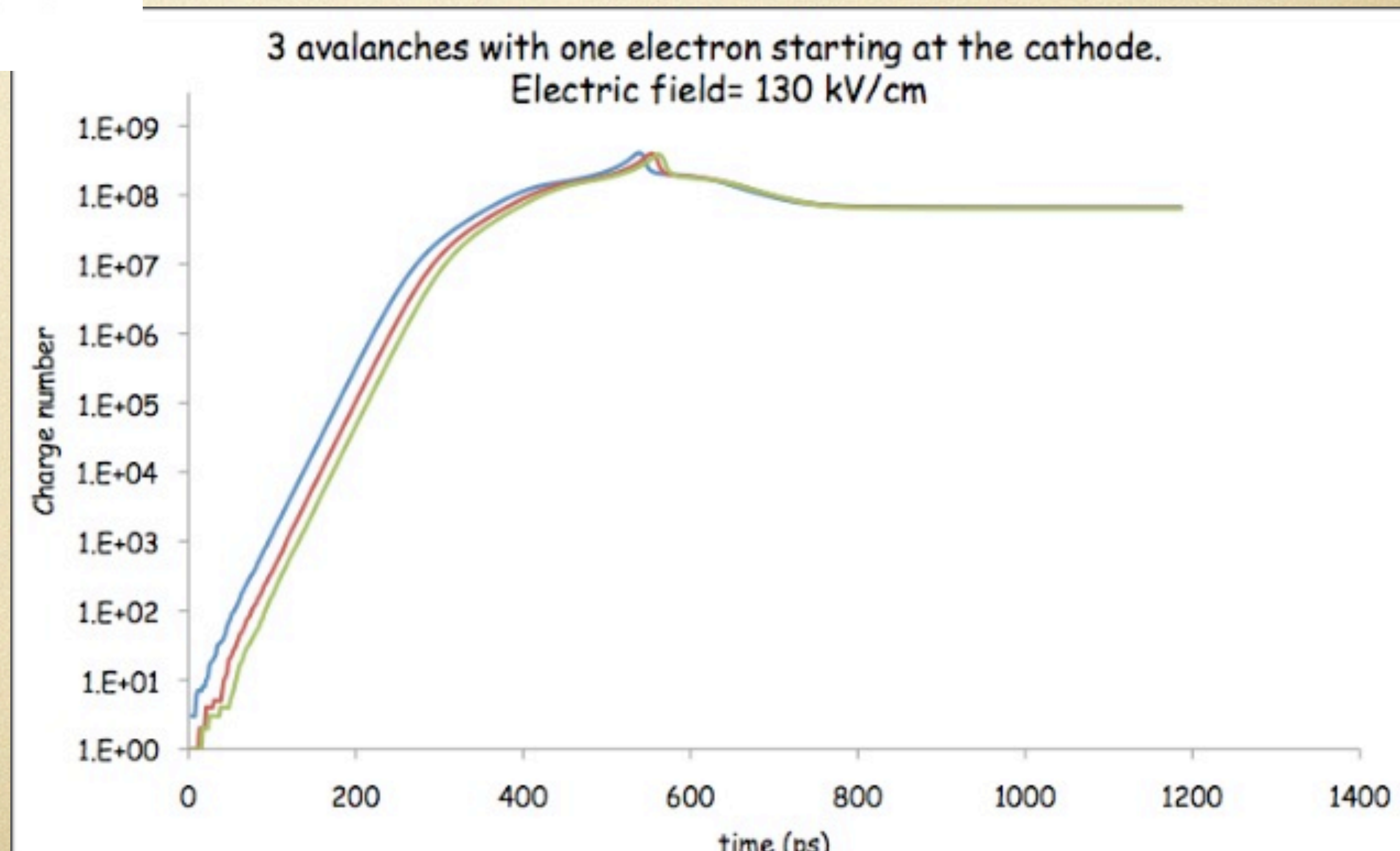


or have a series of ionising collisions at distances less than λ



Reigler et al. NIM A500(2003)144

2 mm gap
The fluctuations at the beginning of the avalanche decide the size of the avalanche. Once the avalanche has reached size then the avalanche grows smoothly exp($\alpha_{eff}.x$)



K. Doroud 250 micron gap
n.b. notice that avalanche growth limited by space charge above 10^7 electrons

So easy to see that time jitter depends on λ and the time to move 1 λ (i.e. 1/drift velocity)

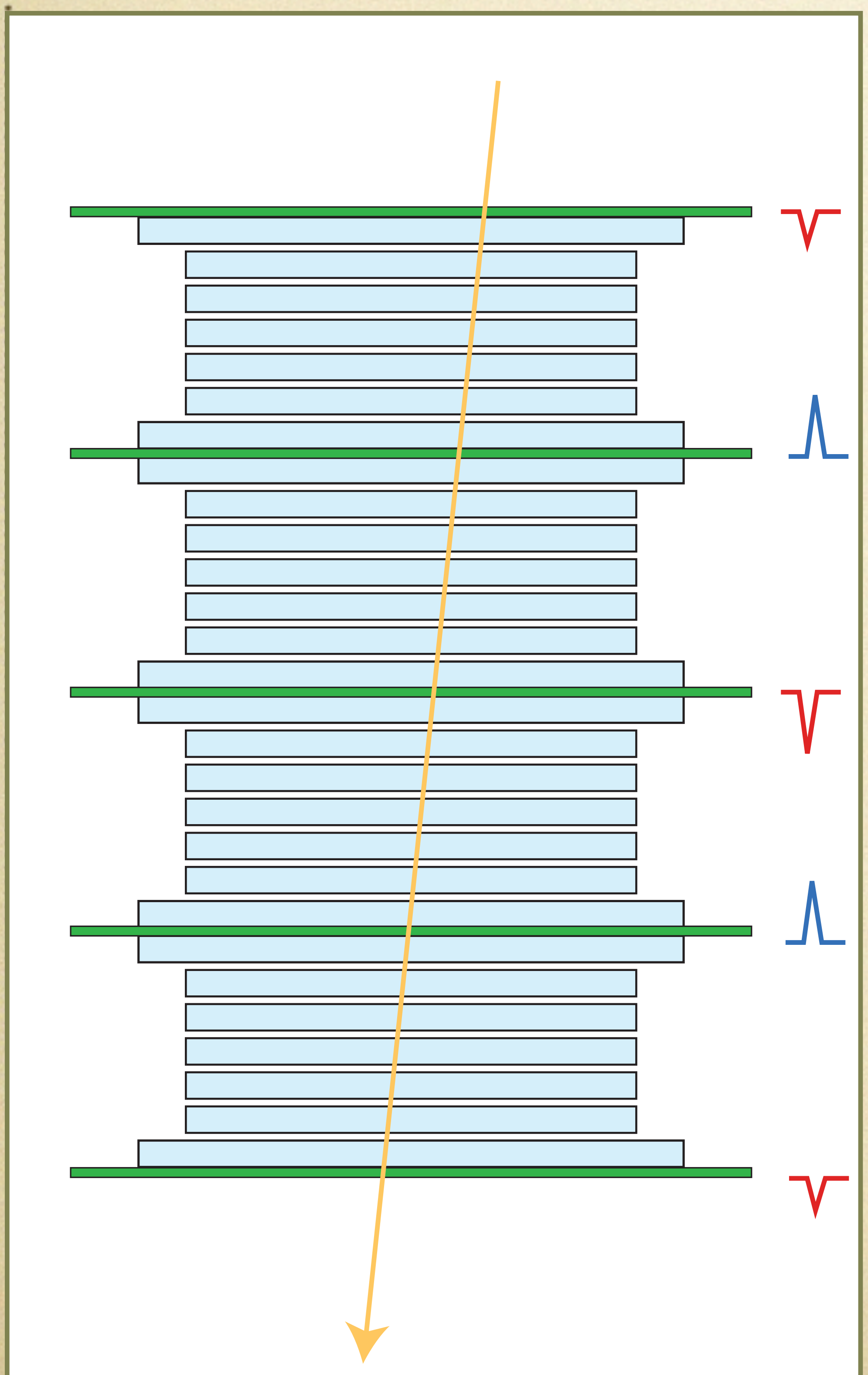
Jitter ~ λ /v

Riegler : $\sigma = 1.28\ \lambda_{eff}/v$

making gas gaps smaller forces the use of higher electric fields ... ie smaller values of λ and higher values of velocity, v, thus reducing the jitter

NOTE: typically there are many avalanches and the signal is the sum of all avalanches... so increasing the number of gas gaps can reduce jitter

24 gas gaps
160 micron width

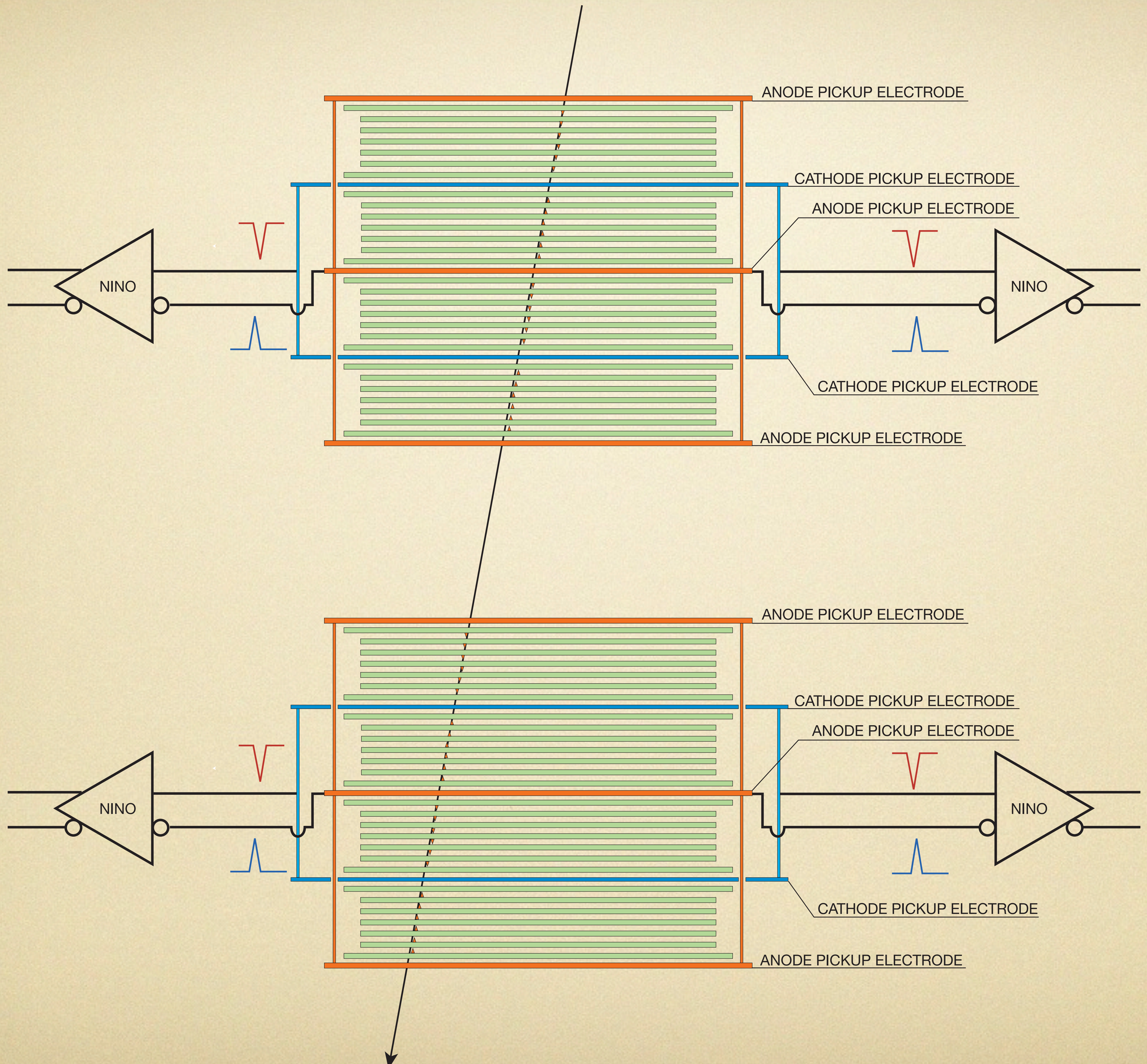


- will mount NINO ASICs as close to the pick up pads as possible
- Read out both ends of strip
- compared to 10 gap (250 micron) ALICE TOF expect
  - intrinsic jitter decrease from 20 ps to 9 ps (more primary ionising clusters -faster electron velocity in avalanche)
  - rise time to decrease by factor 2 (faster electron velocity in avalanche)
  - narrower charge spectrum further de-placed from zero (slewing corrections easier)

44 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 NINO on mrpc (also faster rise time) 5 ps
- intrinsic MRPC time resolution ~~20 ps~~
  24 gaps of 160 micron 9 ps

- total $\sqrt{(5^2 + 5^2 + 5^2 + 9^2)}$ = 12.5 ps expected from 24 gaps of 160 micron


ANODE PICKUP ELECTRODE
CATHODE PICKUP ELECTRODE
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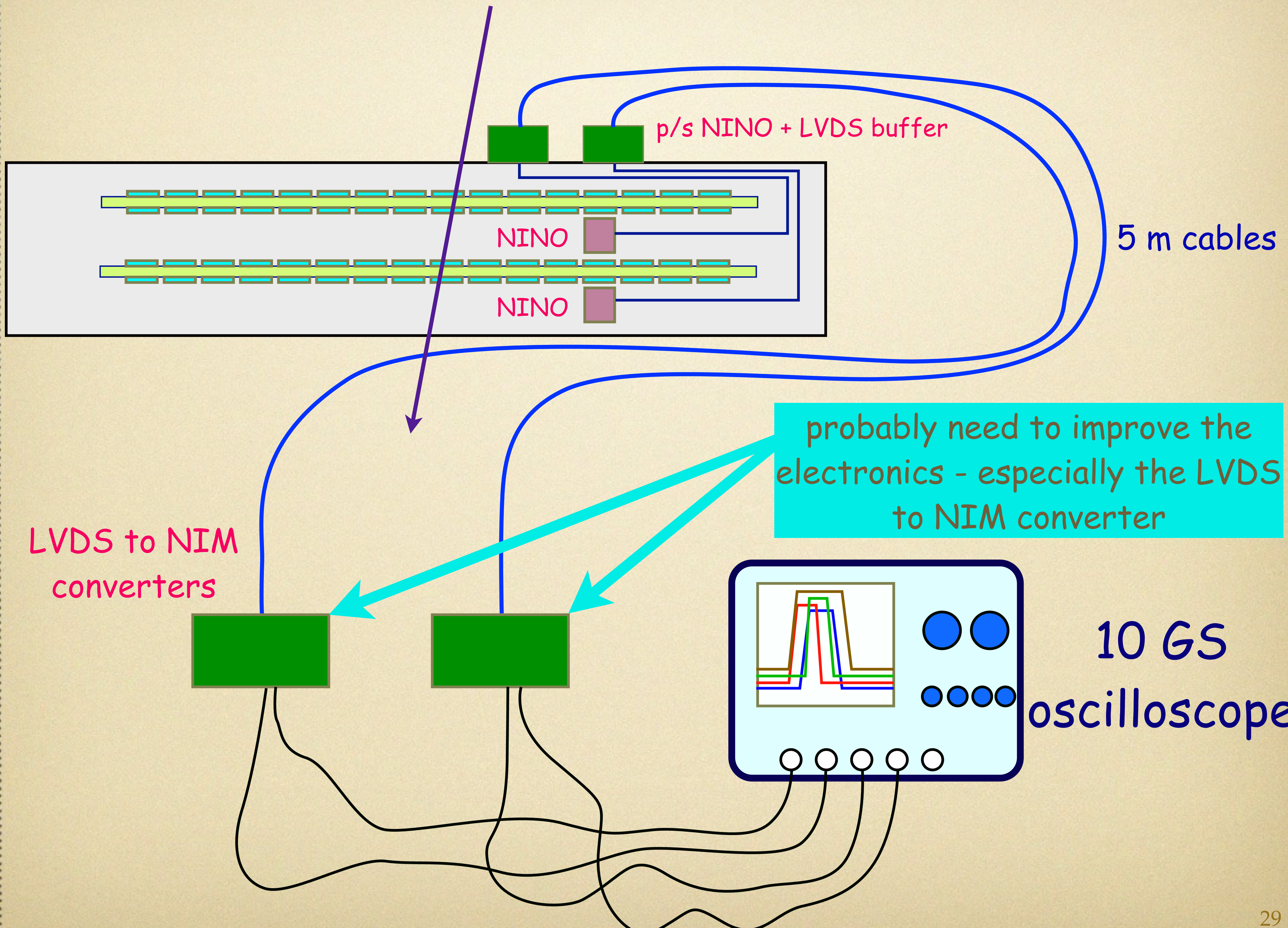
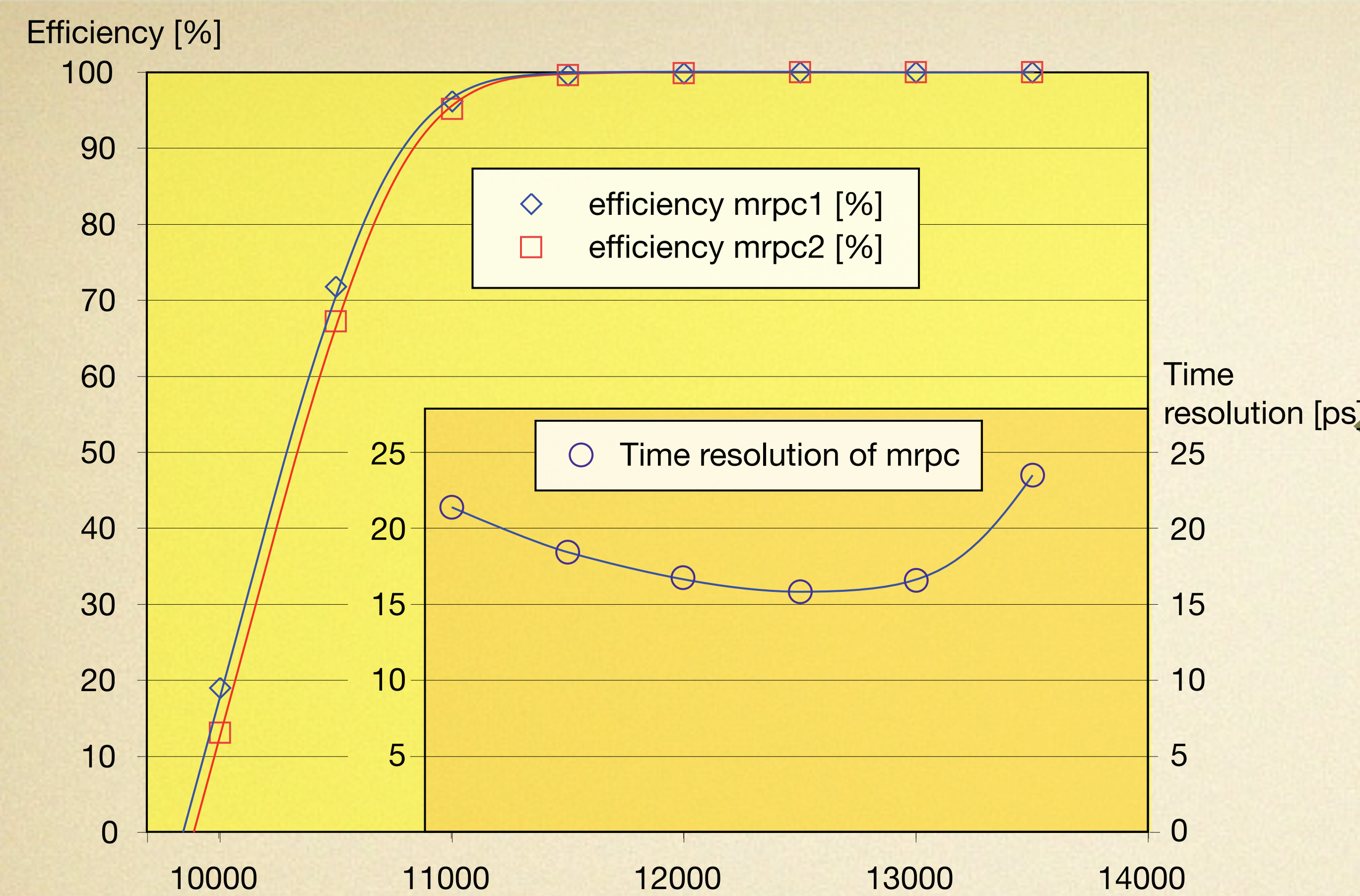
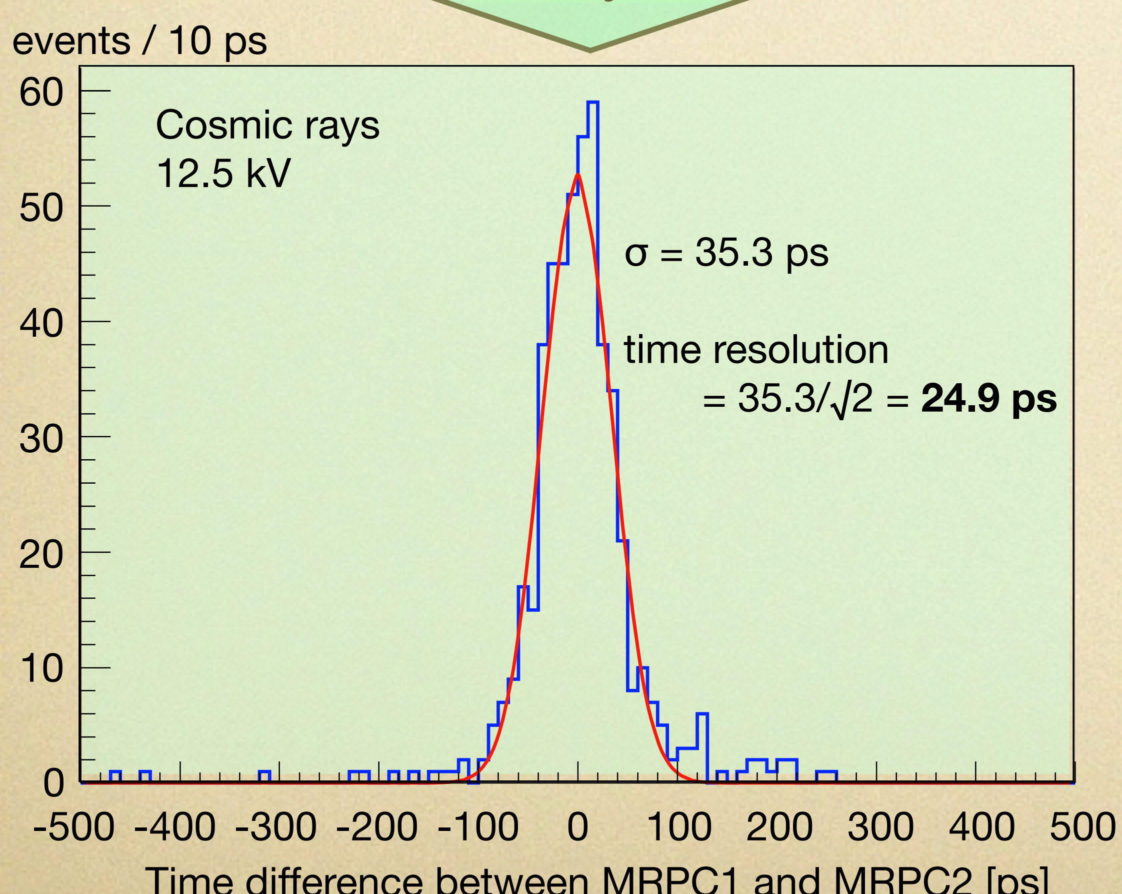
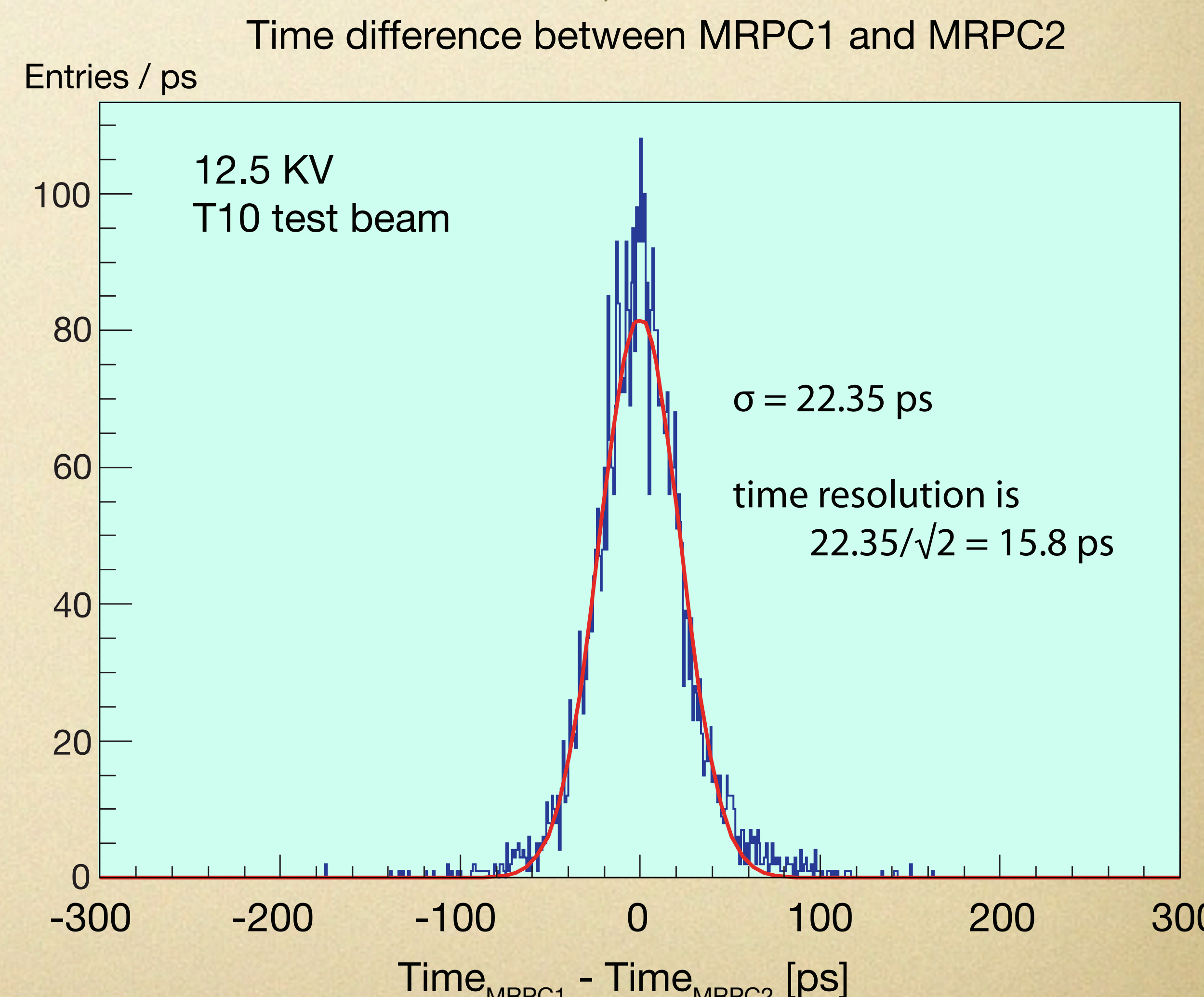

p/s NINO + LVDS buffer
NINO
NINO
5 m cables
probably need to improve the electronics - especially the LVDS to NIM converter
LVDS to NIM converters
10 GS oscilloscope



T10 test beam

Cosmic ray





Summary

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