MCP based detectors – short introduction

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The Detector "identity chart"

Fundamental Questions :

Which kind of "particle" we have to detect? — Electrons/Photons/Ions

→ Main particle "properties" (energy, dimensions...)

Which is the required dimension of the detector? — 10 – 100 cm^2

Which "property" of the particle we have to know?

Position?	Yes		10 – 100 μm
Time?	Yes		10 – 100 ps
Number	Yes	Resolution?	Single count
Energy	No		
Polarity	No		

Which is the maximum count rate? — ~10^6 - 10^7 Counts/s

Which is the "events time distribution"? — Poissonian distribution

Charge Electron Multipliers (CEM)

Single photon/electron detection

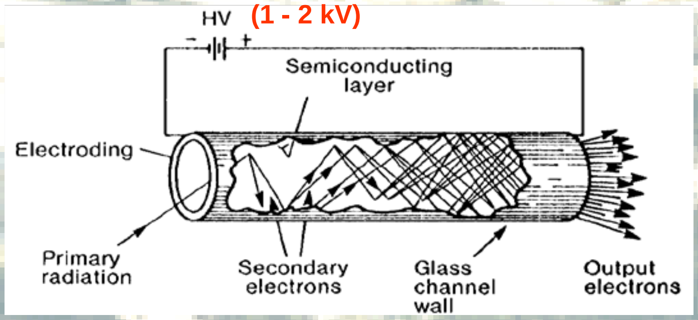
requires charge amplification

Channel Electron Multipliers (CEM)

devices that produce at their exit a cloud of some million electrons for each entering electron, thus producing a measurable charge

inner diameter of roughly 1 mm

D



L

length to diameter ratio (L/D) that ranges generally from 40 to 100

Charge Electron Multipliers (CEM)

CHANNEL ELECTRON MULTIPLIERS

MULTIANODES DETECTORS

BI-DIMENSIONAL DETECTORS

CENTROID FINDING POSITION DETECTORS

CROSS DELAY ANODES DETECTOR

Generally they present particular shapes to reduce "ion feedback"

ions are accelerated up the channel by the electric field and can strike the CEM walls near the input face (ion feedback) releasing electrons and causing a secondary electron avalanche totally indistinguishable from "real" events

The spirals and the curved surfaces avoid that these ions gain enough kinetic energy to produce the secondary emission when they strike the walls

Charge Electron Multipliers (CEM)

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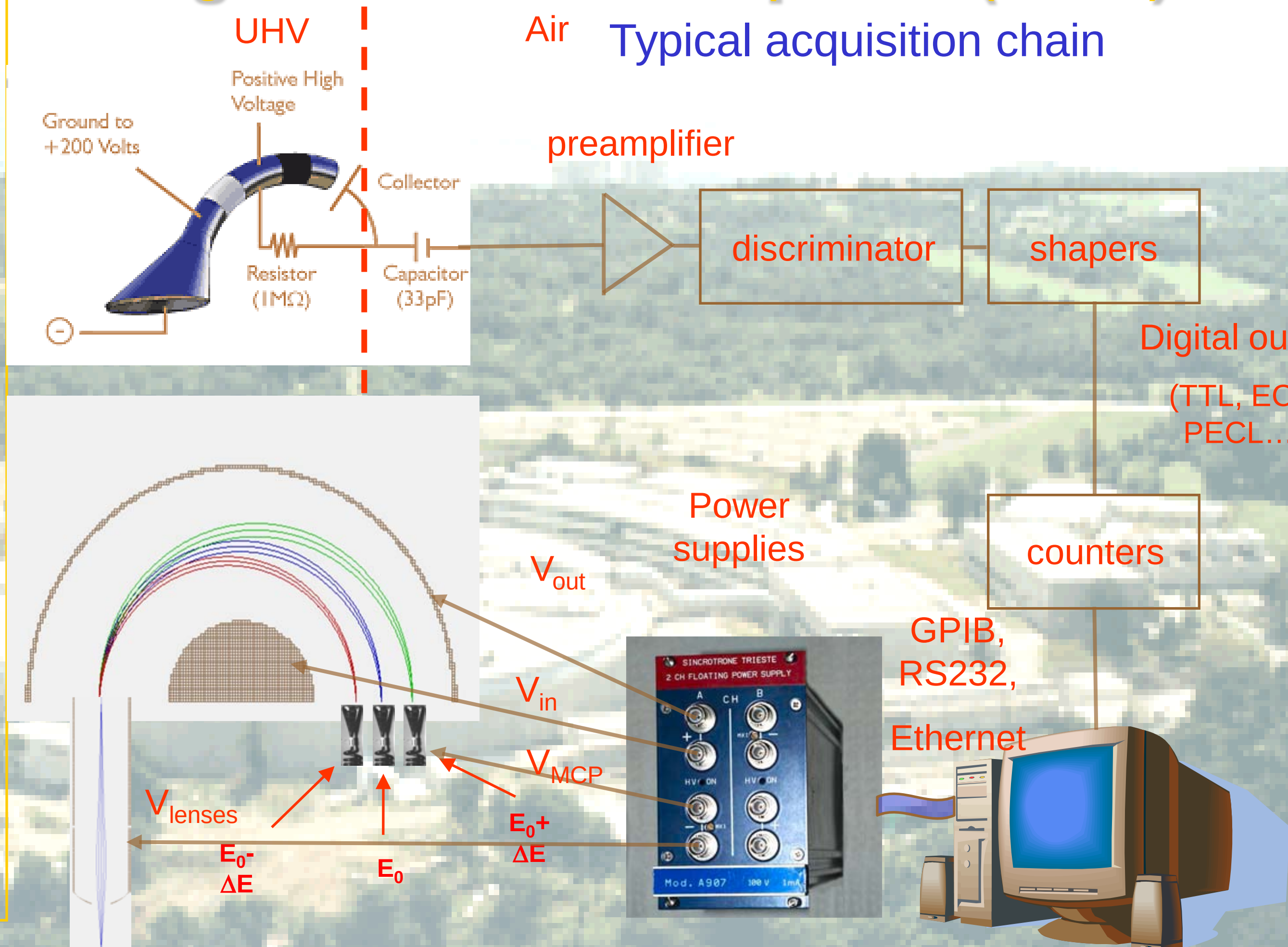

CEM dimensions limit the maximum number of channels

We need different kind of charge multipliers: Microchannel Plates (MCP)

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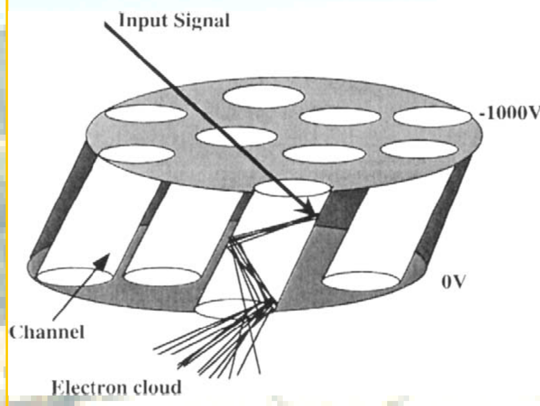
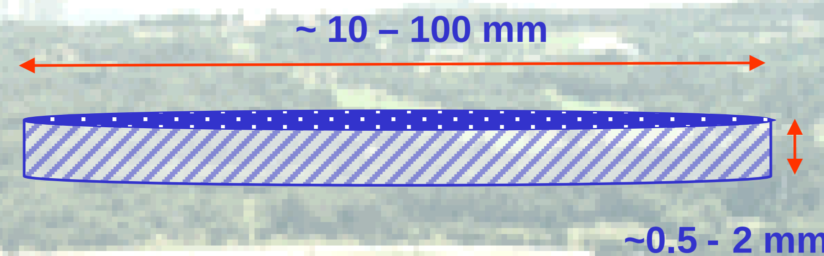
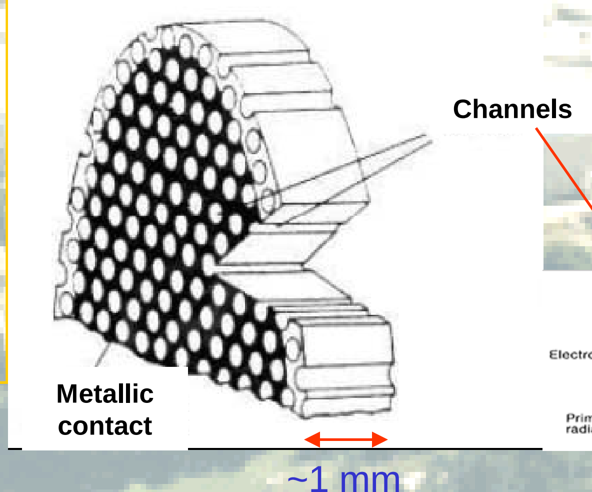
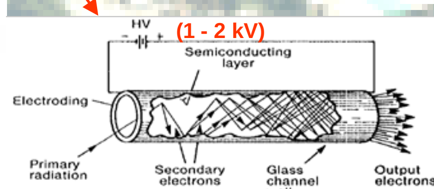
Essentially MCPs are thin (~ 1 mm), silicon-lead oxide glass wafers composed of a large number (> $10^5 cm^{-2}$) of small (~2 – 15 μ) CEM tubes called microchannels

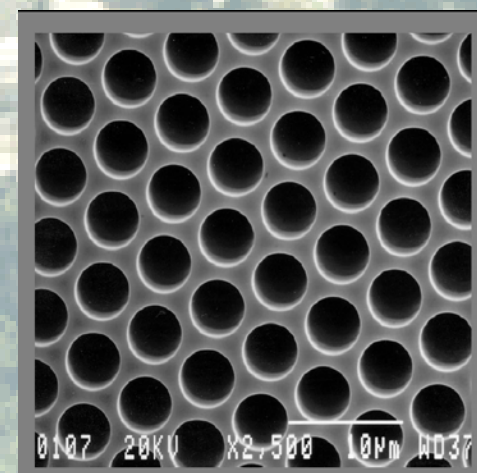




The MCPs are available in round or rectangular shapes with surface areas as high as 100 cm^2 and channel length to diameter ratios in the range from 40 to 150







Microchannel Plates and multianode detectors

CHANNEL ELECTRON MULTIPLIERS

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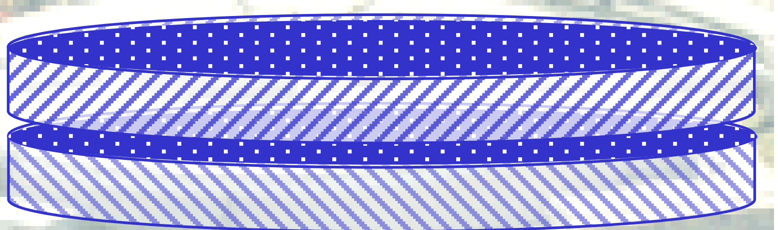
CROSS DELAY ANODES DETECTOR

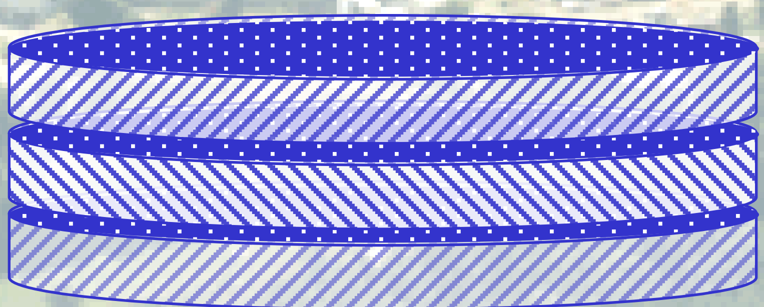
Typical gain of a single MCP disk: $10^3 - 10^4$

Still not enough!

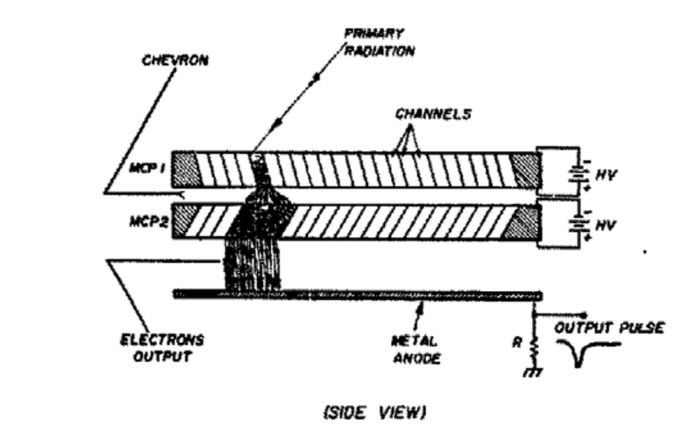
We require more amplification stages

2 MCP: Chevron assembly





3 MCP: Z-Stack assembly



The “zig-zag” of tilted channels reminds the curves of CEM and the goal is the same: to reduce ion feedback

Microchannel Plates and multianode detectors: the acquisition chain

CHANNEL ELECTRON MULTIPLIERS

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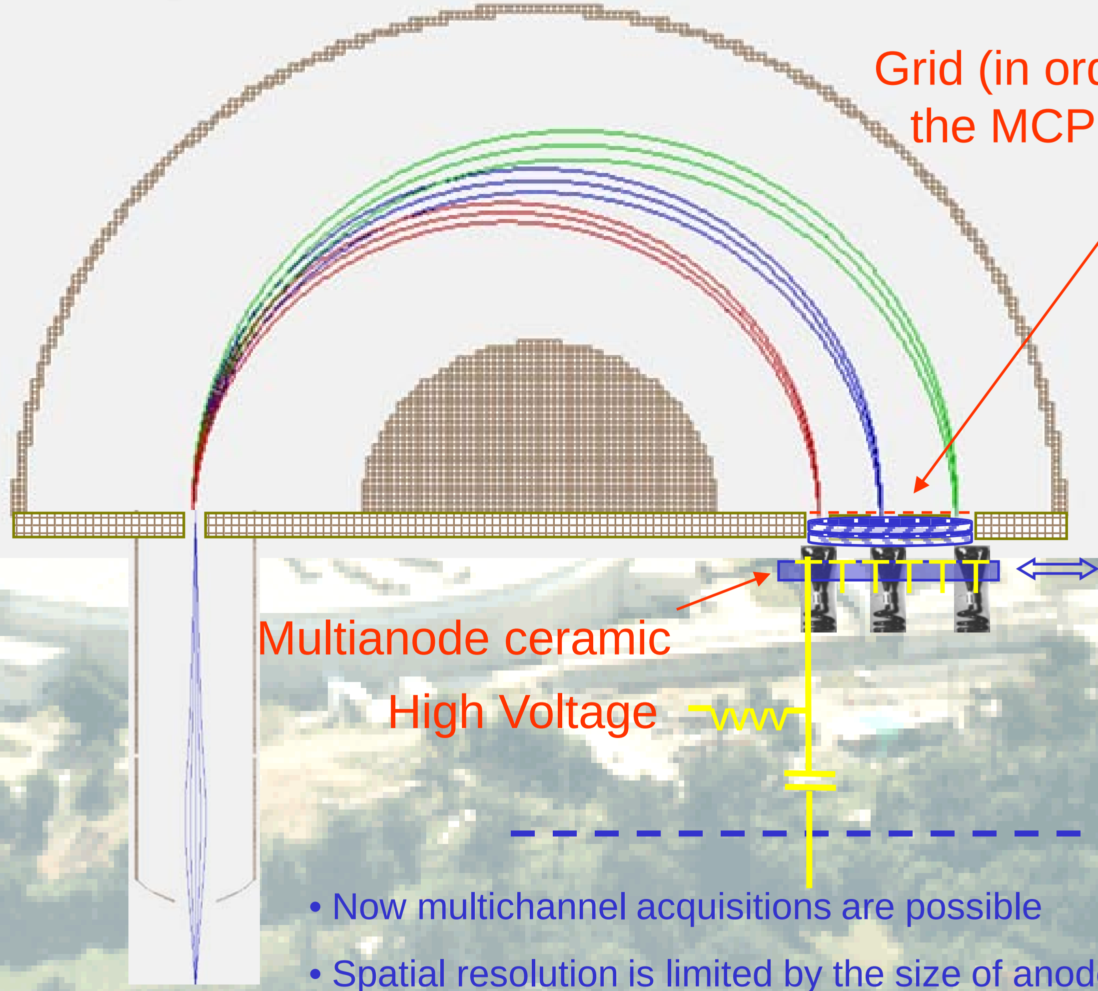
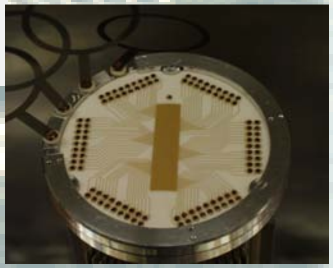


96 channels detector



- Now multichannel acquisitions are possible
- Spatial resolution is limited by the size of anodes (~ 100 micron)

Microchannel Plates and multianode detectors – weak points

CHANNEL ELECTRON MULTIPLIERS

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CROSS DELAY ANODES DETECTOR

Many preamplifiers, discriminators etc.

Very difficult to manage more than 100 anodes

Microchannel Plates and multianode detectors: the VLSI solution

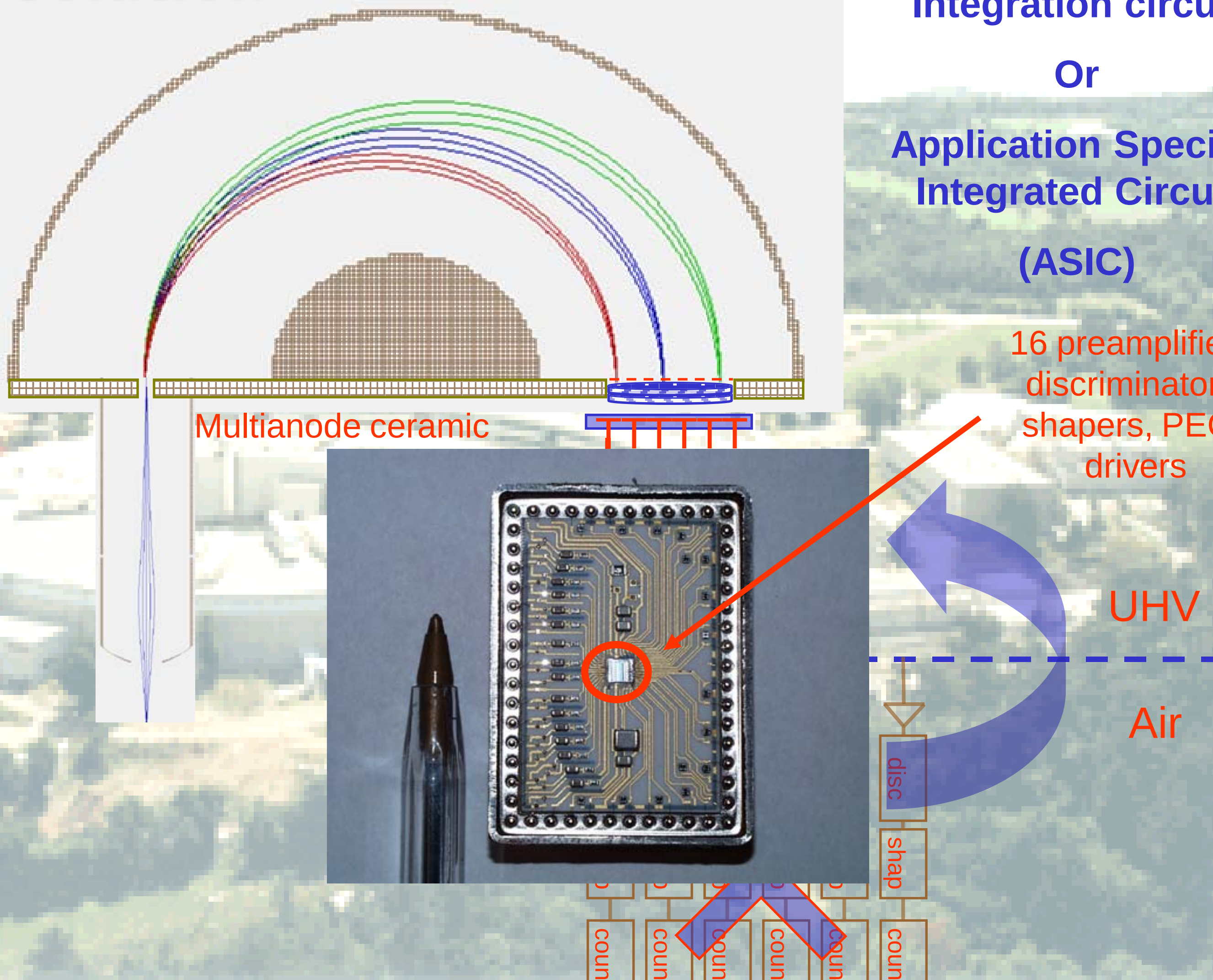
- CHANNEL ELECTRON MULTIPLIERS
- **MULTIANODES DETECTORS**
- BI-DIMENSIONAL DETECTORS
- CENTROID FINDING POSITION DETECTORS
- CROSS DELAY ANODES DETECTOR

Very Large Scale of Integration circuit

Or

Application Specific Integrated Circuit

(ASIC)



Microchannel Plates and multianode detectors: the VLSI solution

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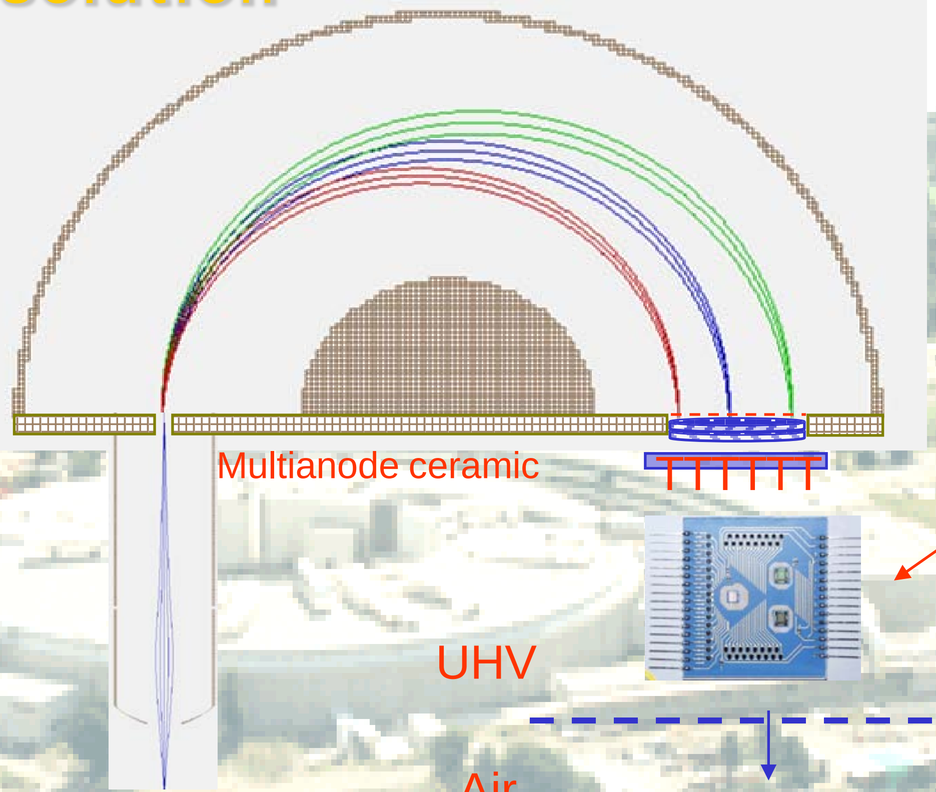
Very Large Scale of Integration circuit

Or

Application Specific Integrated Circuit

(ASIC)



16 preamplifiers, discriminators, shapers, PECL drivers

&

16 counters + fast serial conversion

Just one feedthrough to extract all counts

Very low noise

Up to > 800 channels (well resolved snapshot peaks)

Fully parallel system → very high count rate

Microchannel Plates and multianode detectors: the VLSI solution (blind sides)

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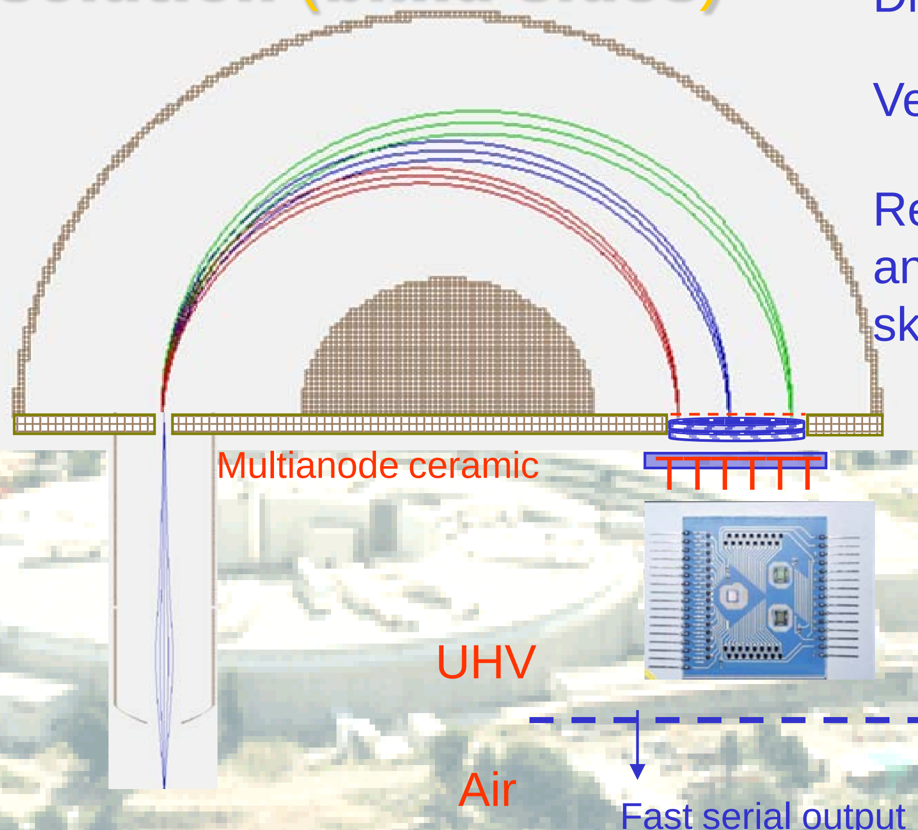
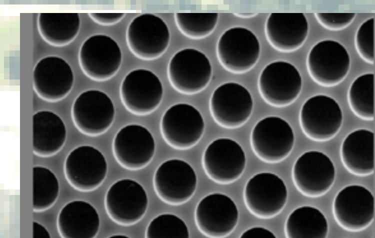
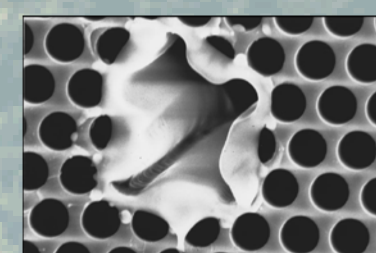


Dramatically fragile

Very expensive

Requires digital and analogue VLSI developing skill





And it is not a bi-dimensional detector!

CHANNEL ELECTRON MULTIPLIERS

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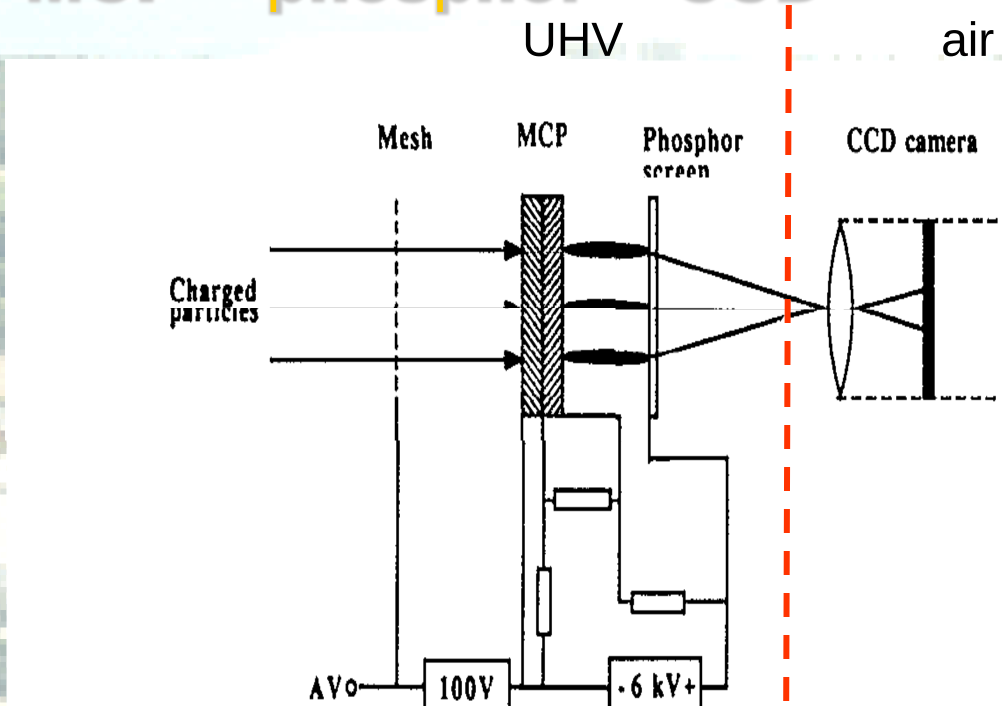
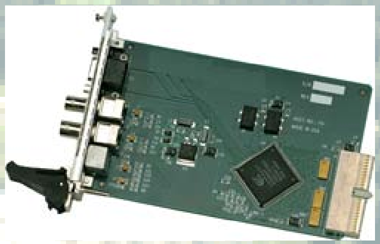
Bi dimensional detectors - first simple solution:

MCP + phosphor + CCD



Frame grabber board



Simple

Not very expensive but…

No feedthroughs

Not linear

It doesn't work in "counting mode"

Noisy (thermal noise, read noise…)

Useless if time resolution is required

Bi dimensional detectors – other possible solutions:

Brute force:

We can try the VLSI approach developing a matrix of pixels, each pixel followed by the mixed analogue - digital ASIC etc.

"Pixel detectors"

Too expensive! In terms of

Money

Time

Resources

Very brittle

Cunning trick:

We can derive individual event positions either with continuous readout anodes, or discrete element anodes with **interpolation** to provide a continuous position readout

Centroid finding detectors

CHANNEL ELECTRON MULTIPLIERS

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Bi dimensional detectors – centroid finding detectors

Electrons clouds from MCP present a symmetrical Gaussian charge distribution

If we are able to find the centroid of this charge in principle the spatial resolution is limited by the pore dimensions of the (top) MCP!

Charge Division Centroiding approach:

The MCP output charge is divided among several output terminals in a way that the relative amplitudes depend upon the event position

Delay Line Centroiding approach

Event position centroids are found by determination of the difference in arrival times of the event signal at the two (or four) ends of one (or two) high speed transmission line(s)

Bi dimensional detectors – centroid finding detectors

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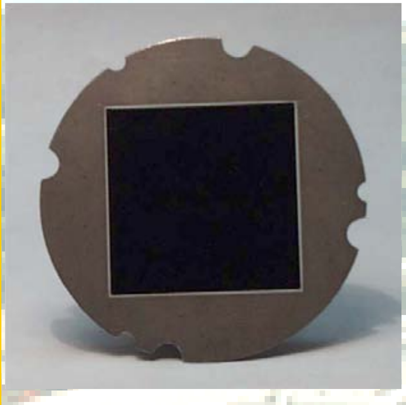
The most popular charge division centroid finding detector: the **resistive anode detector**

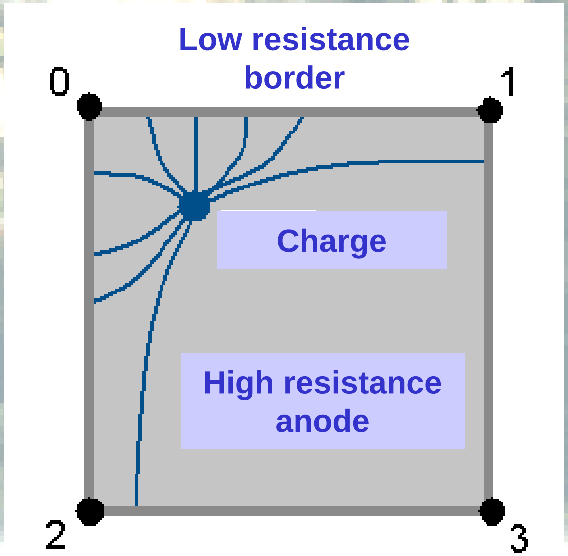


Just one single anode and 4 contacts!

Propagation of charge to the contacts from the event location gives pulse amplitudes that are proportional to the distance from the contact.

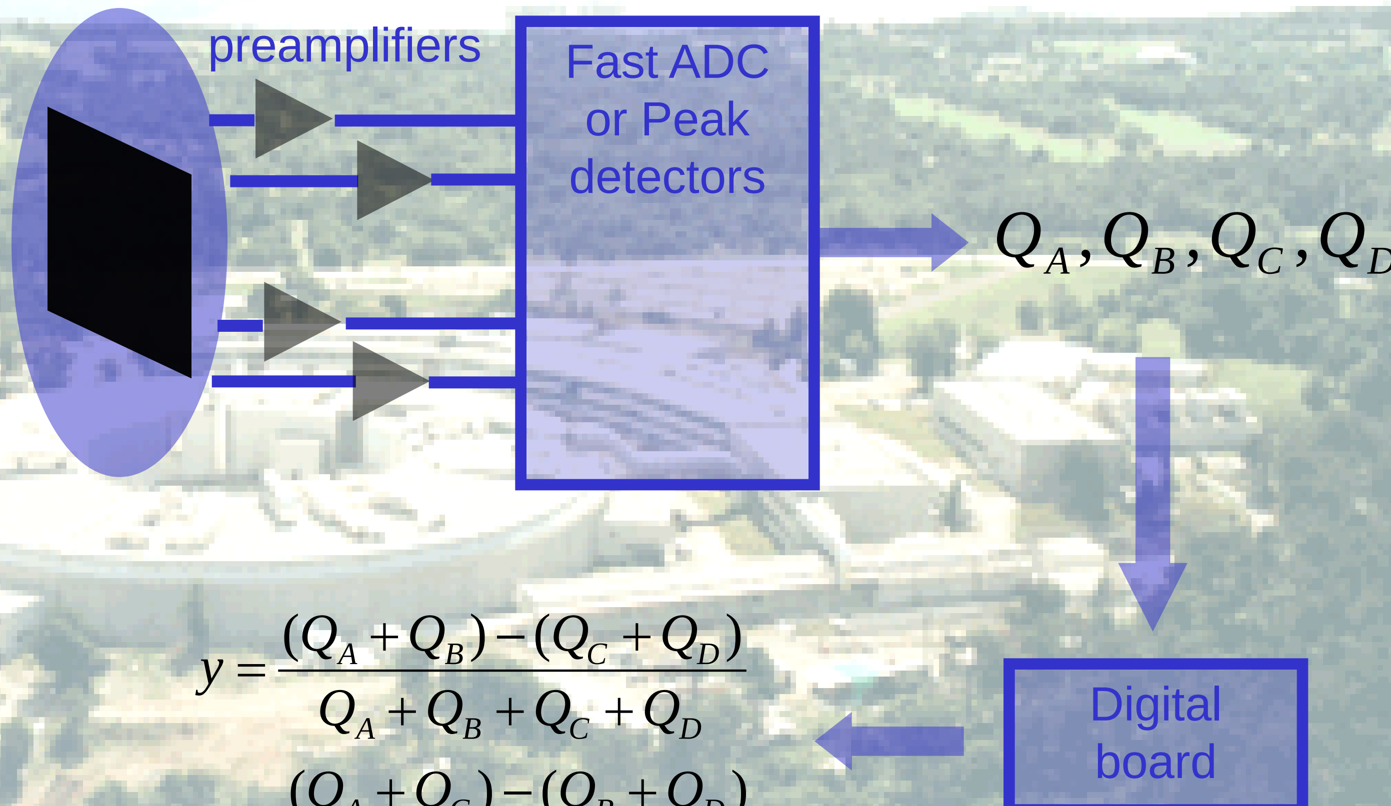
$$x = \frac{(Q_A + Q_B) - (Q_C + Q_D)}{Q_A + Q_B + Q_C + Q_D}$$

$$y = \frac{(Q_A + Q_D) - (Q_B + Q_C)}{Q_A + Q_B + Q_C + Q_D}$$



Bi dimensional detectors – centroid finding detectors

The most popular charge division centroid finding detector: the **resistive anode detector –** acquisition chain



$$y = \frac{(Q_A + Q_B) - (Q_C + Q_D)}{Q_A + Q_B + Q_C + Q_D}$$

$$x = \frac{(Q_A + Q_C) - (Q_B + Q_D)}{Q_A + Q_B + Q_C + Q_D}$$

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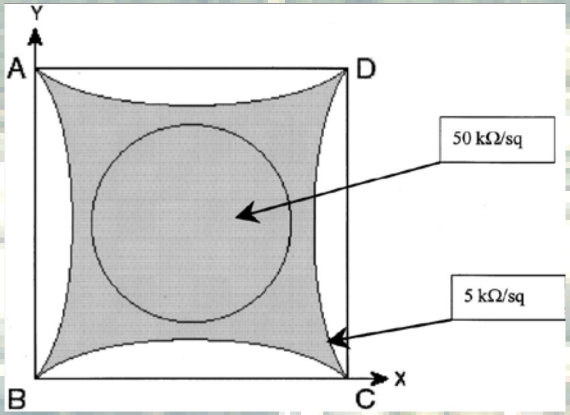
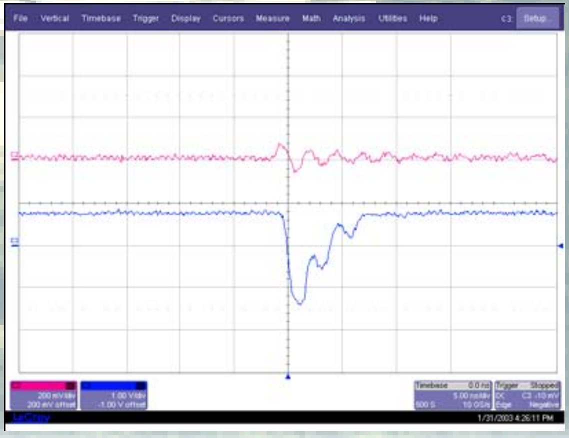
Bi dimensional detectors – centroid finding detectors

The most popular charge division centroid finding detector: the **resistive anode detector –** weak points

Particular shapes and specific ratio between anode and borders resistance are necessary in order to reduce distortions



Not great performances in terms of spatial resolution and count rate



Reflections at the borders are always present when the impedance is not matched

Bi dimensional detectors – centroid finding detectors

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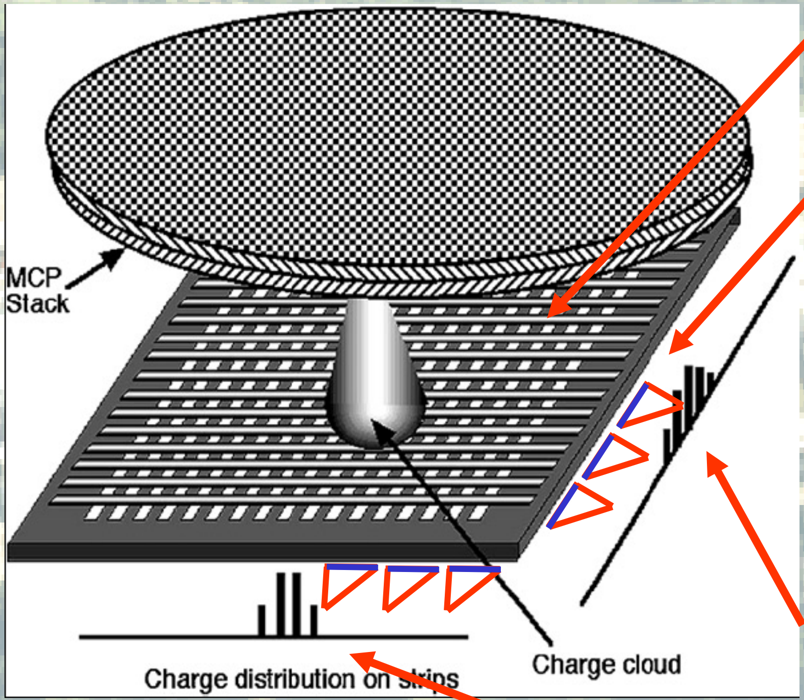
CROSS DELAY ANODES DETECTOR

A second charge division centroid finding detector: the **cross anodes detector**

Several crossed anodes are the detector



each anode is connected to a "preamplifier + ADC" block that acquires the pulses

measuring the charge repartition among the anodes it is possible to know the centroid with very high resolution (~ micron).

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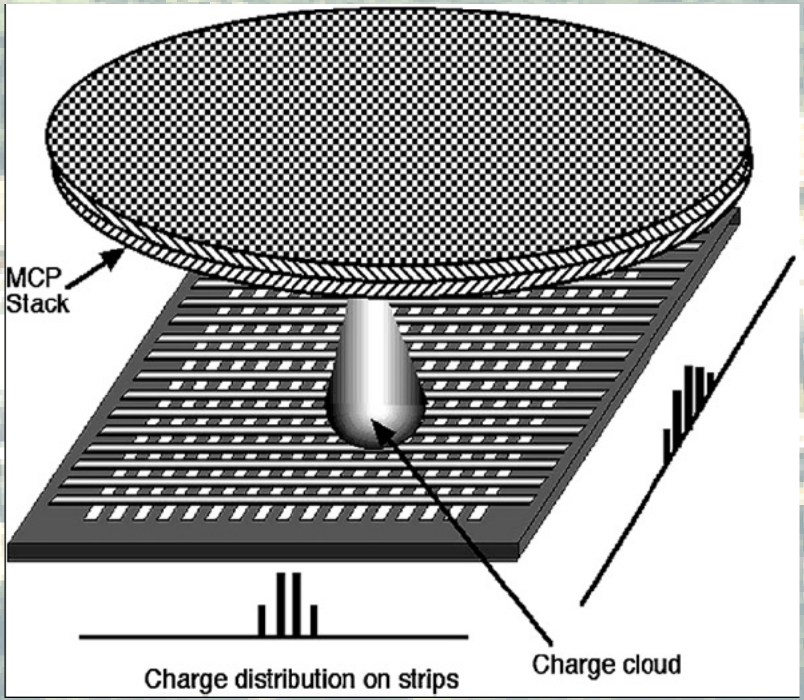
A second charge division centroid finding detector: the **cross anodes detector**



- Many preamplifiers ADC etc.

ASIC is required

- Count rate limited by the system complexity

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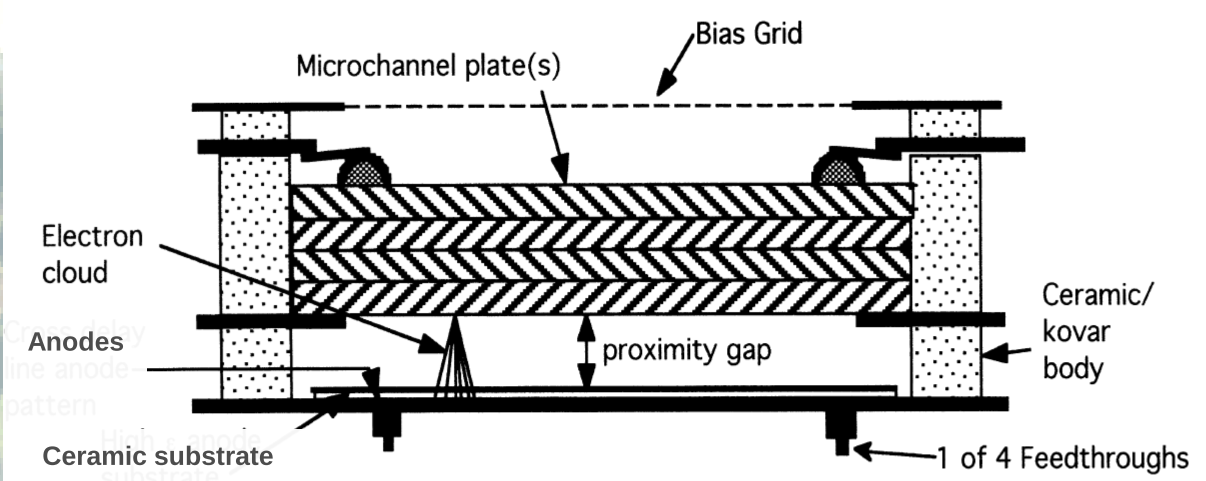
Bi dimensional detectors – centroid finding detectors

- Charge division centroid finding detector many other different shapes (Wedge & strip, Backgammon, Spiral anode…) but the principle is always the same: the position is extrapolated from the pulse electron charge distribution
- The "MCP + centroid finding detector" assembly is different from the "MCP + multianode detector": now we want that the electron cloud spread over more anodes in order to calculate the centroid



Bi dimensional detectors – centroid finding detectors

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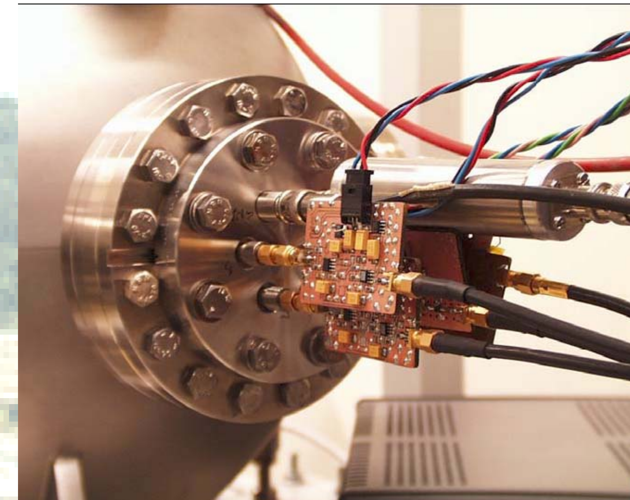
ATTENTION !



We pay the extreme simplification of the architecture in terms of count rate!

1 MCounts/s (for example) is the GLOBAL count rate;

This is an other way to say that the dead time of the detector is 1 microsecond.

But REAL counts are NOT uniformly distributed in time: a “MCount/s” detector starts to show non linearity already at 200 KCounts/s

Bi dimensional detectors – centroid finding detectors

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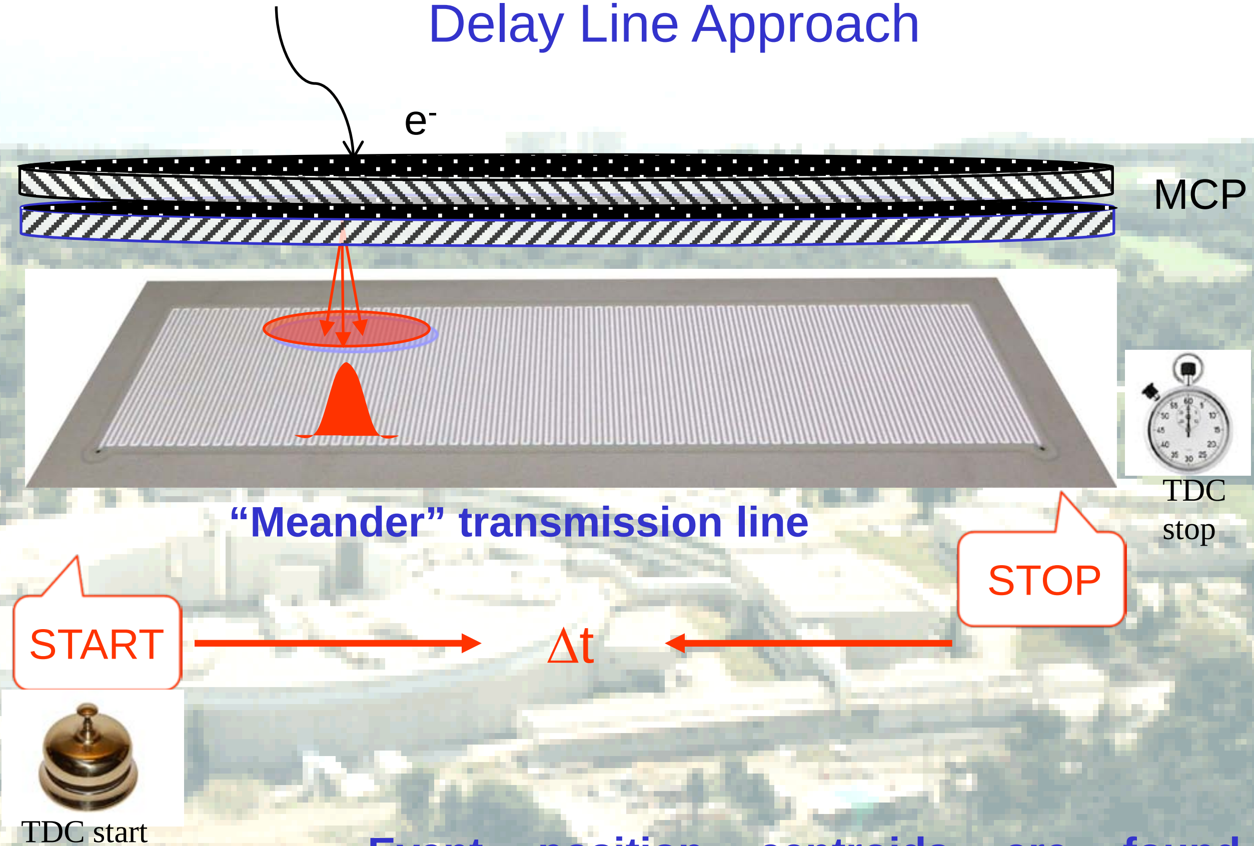
Delay Line Approach



Event position centroids are found by determination of the difference in arrival times of the event signal at the two (or four) ends of one (or two) high speed transmission line(s)

Bi dimensional detectors – centroid finding detectors

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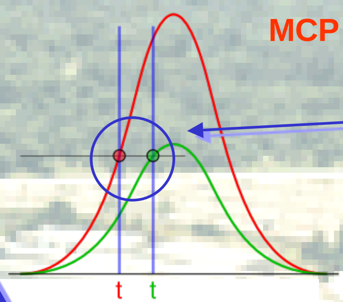
Delay Line Approach: the detector and the acquisition chain (now it is a bit more complicate…)

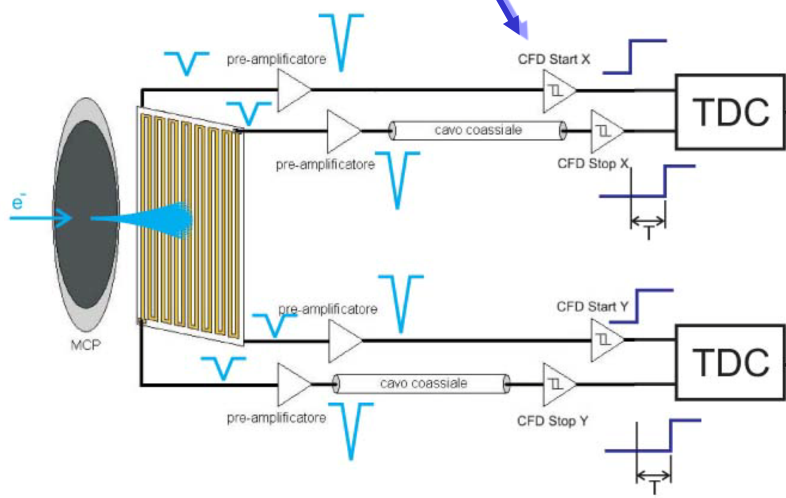
1. **Anodes impedance matching is fundamental**
2. **Constant fraction discriminator are necessary**

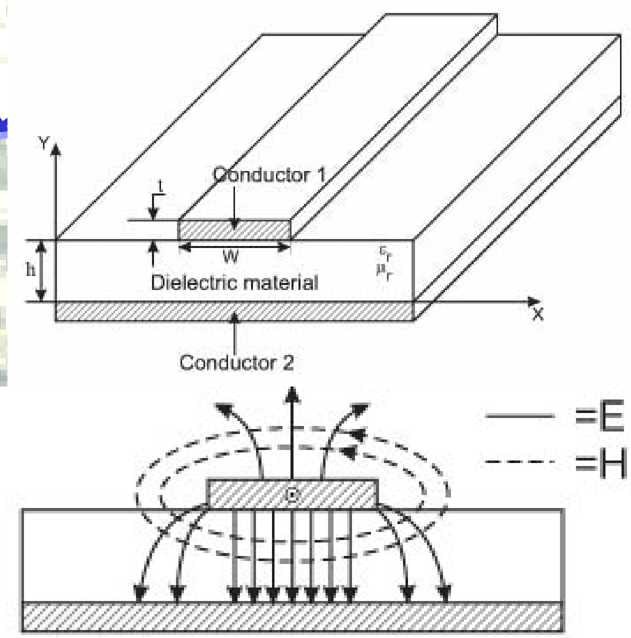
MCP output amplitudes (Pulse Height Distribution) are variable

100 – 200 ps indetermination, while tens of ps resolution is required



3. **Time to Digital**





Bi dimensional detectors – centroid finding detectors

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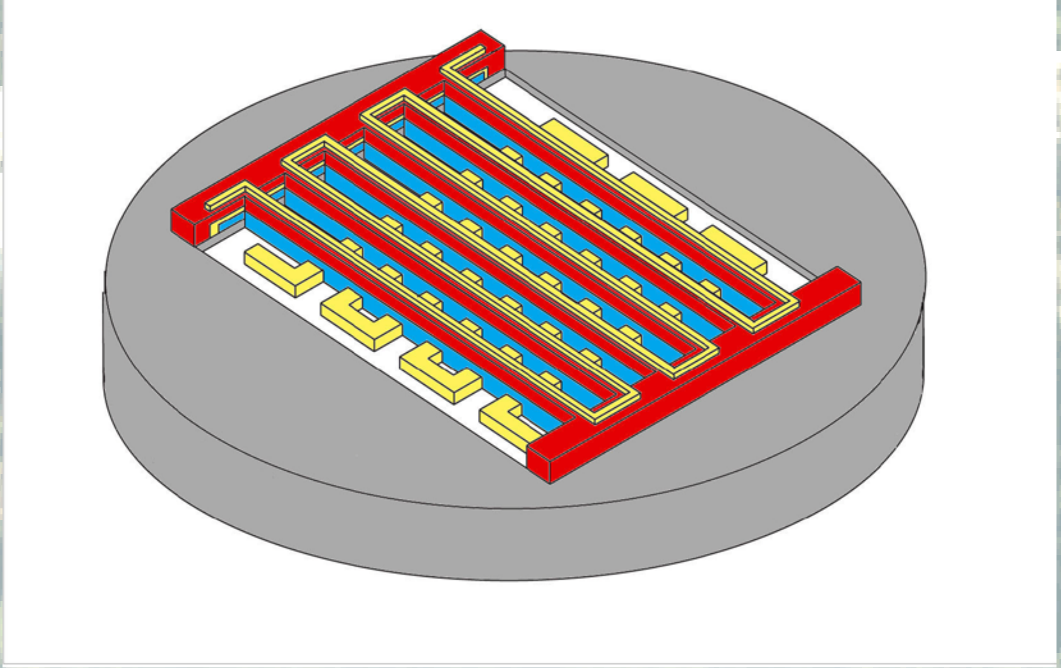
Delay Line Approach: the acquisition chain (now it is a bit more complicate…)

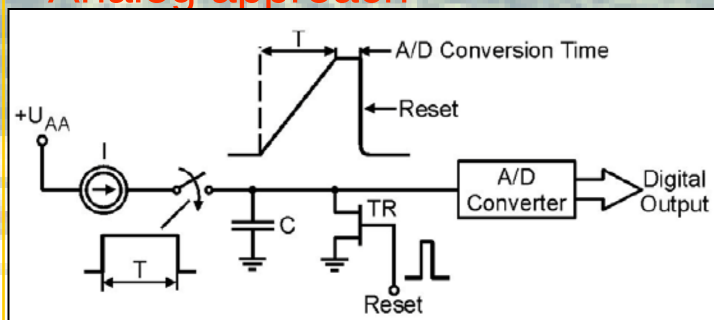
50 Ohm impedance matching is fundamental, but in case of cross delay line is very difficult to achieve



Bi dimensional detectors – centroid finding detectors

Delay Line Approach: The Time to Digit Converter (TDC)

Analog approach

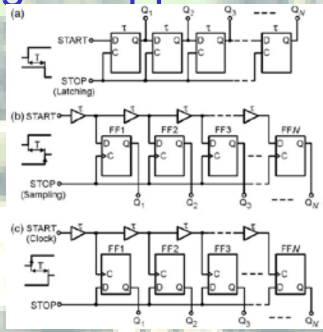


Great time resolution (few ps) but

Slow (~1MCount/S)

Time resolution depend on the total time window

Digital approach



Digital TDC works exploiting the known delay propagations times on dedicated digital VLSI

Worse time resolution (20 – 30 ps) but

Very fast (up to 100 MCount/s)

Time resolution worsens slowly with the total time window

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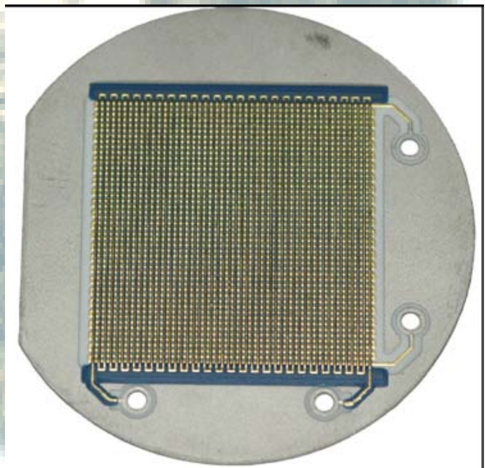
Bi dimensional detectors – centroid finding detectors

Delay Line Approach: Strength and weakness

- The “time resolution” is immediate: the time information is intrinsically present, because it is required for the spatial encoding
- Counting time is limited only by the delay line propagation time
- No image distortions

- Difficult to develop the anode (impedance matching etc.)
- Acquisition electronic is complicate



Time resolved acquisition – first example: TOF (Time Of Flight)

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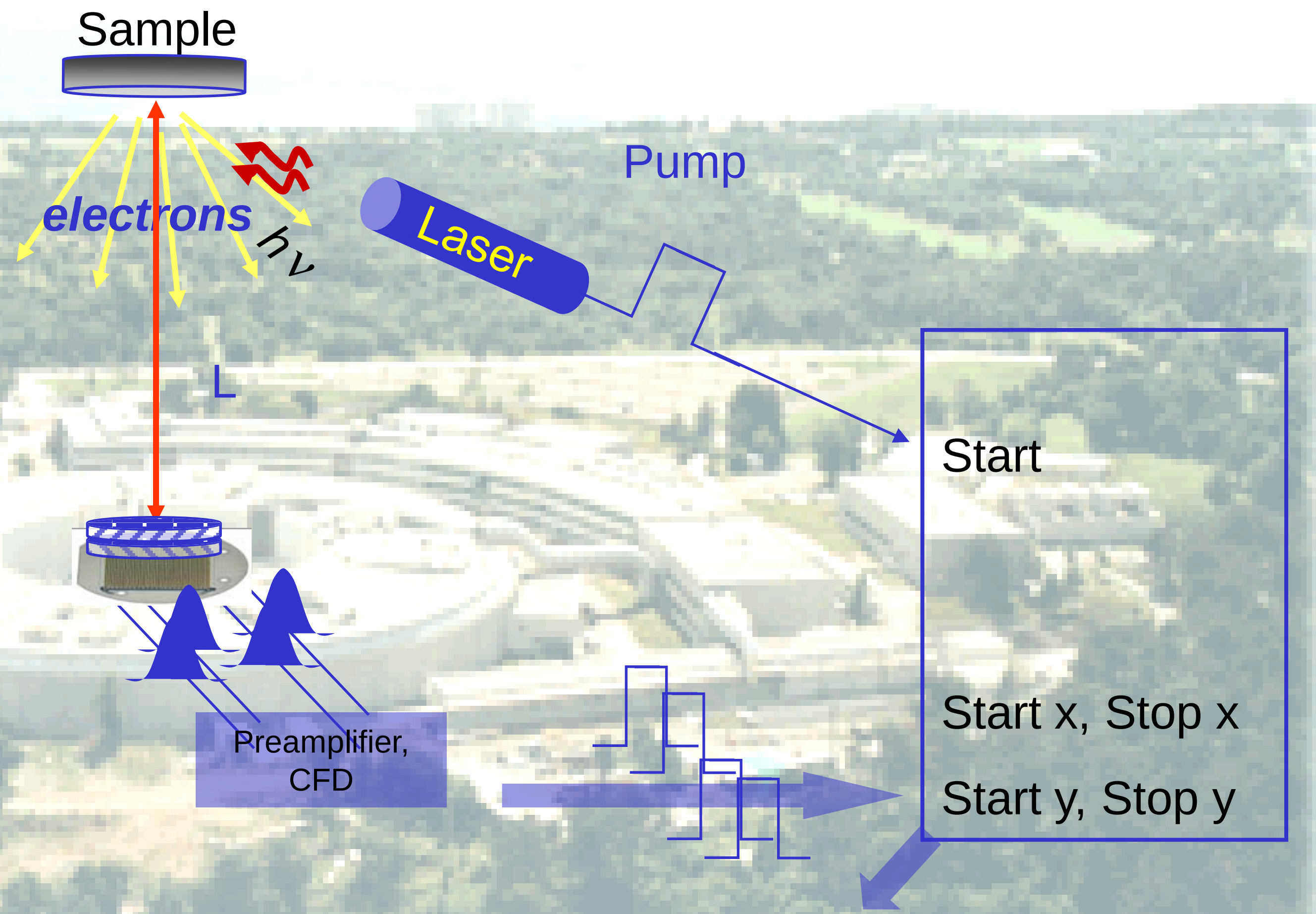

From the known propagation time of the delay line T and length distance L (sample – detector) we associate the energy to the position

Time resolved acquisition: second example

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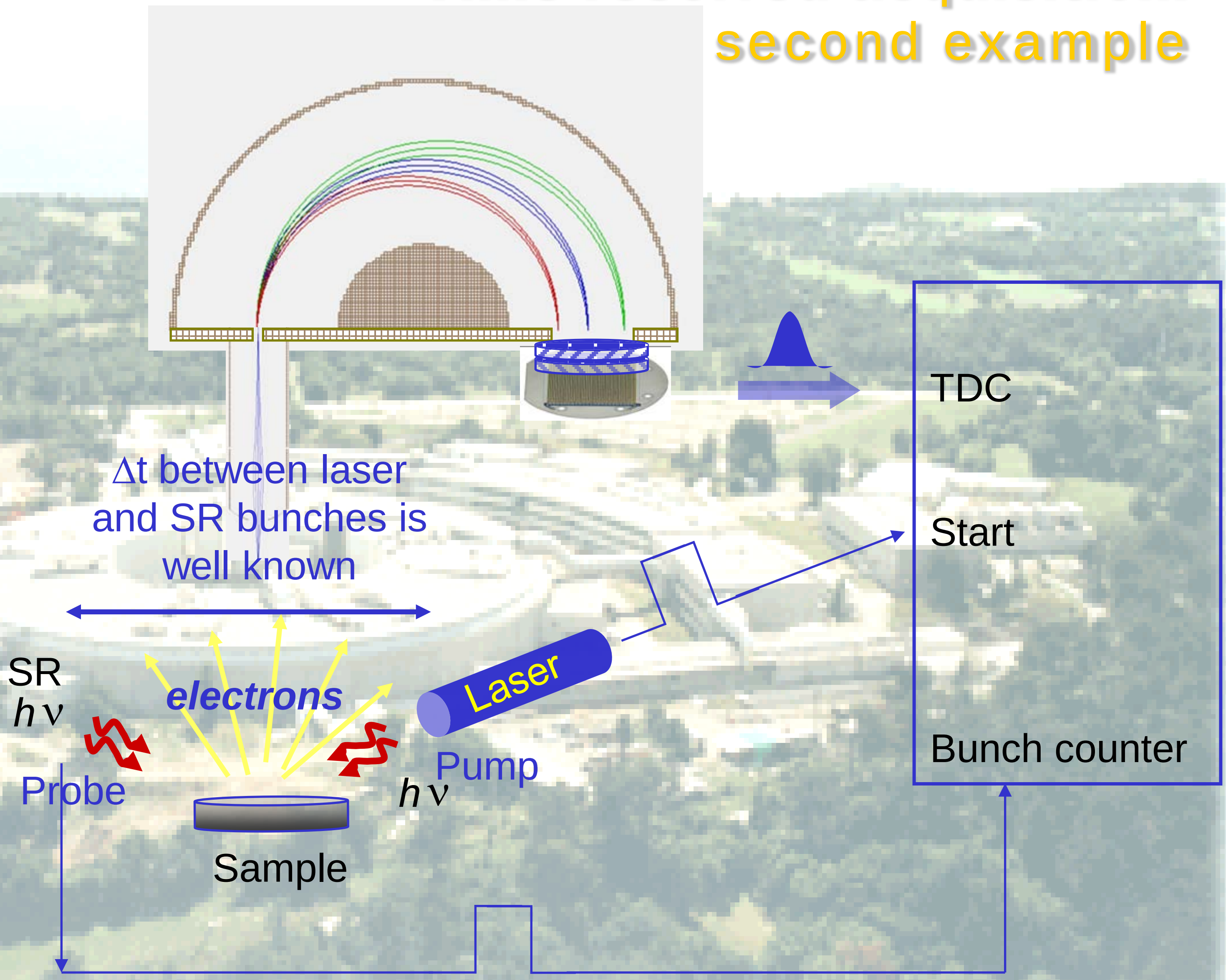

Final remarks

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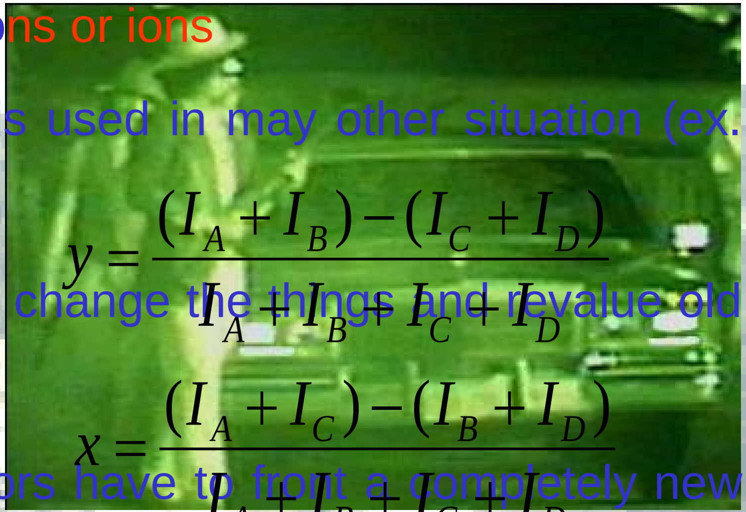
The described detectors are employed not only with electron analyzers, but also in many other different instruments and they can be used to detect also photons or ions

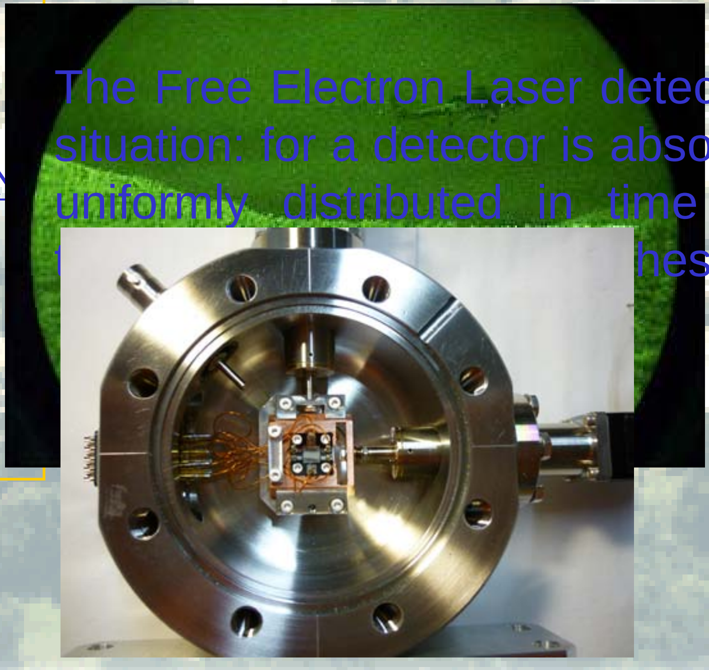


The centroid finding technique is used in may other situation (ex. Beam Position Monitors (BPM))

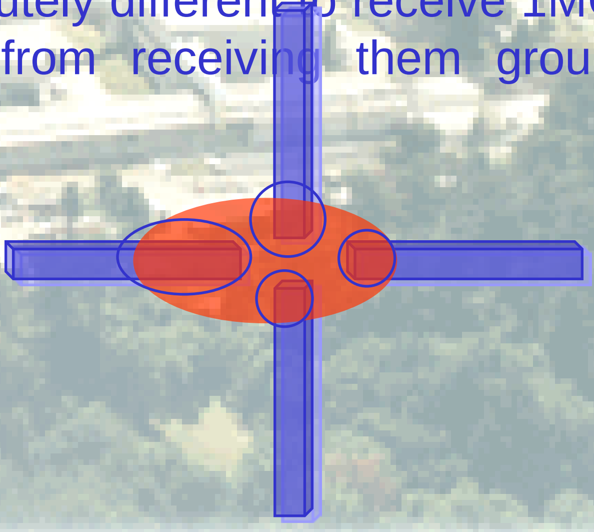
$$y = \frac{(I_A + I_B) - (I_C + I_D)}{I_A + I_B + I_C + I_D}$$

$$x = \frac{(I_A + I_C) - (I_B + I_D)}{I_A + I_B + I_C + I_D}$$

New electronic components can change the things and revalue old approaches



The Free Electron Laser detectors have to front a completely new situation: for a detector is absolutely different to receive 1MCount/s uniformly distributed in time from receiving them grouped all t hes



That's all...

CHANNEL ELECTRON MULTIPLIERS

MULTIANODES DETECTORS

BI-DIMENSIONAL DETECTORS

CENTROID FINDING POSITION DETECTORS

CROSS DELAY ANODES DETECTOR

Bi dimensional detectors:

Anodo resistivo

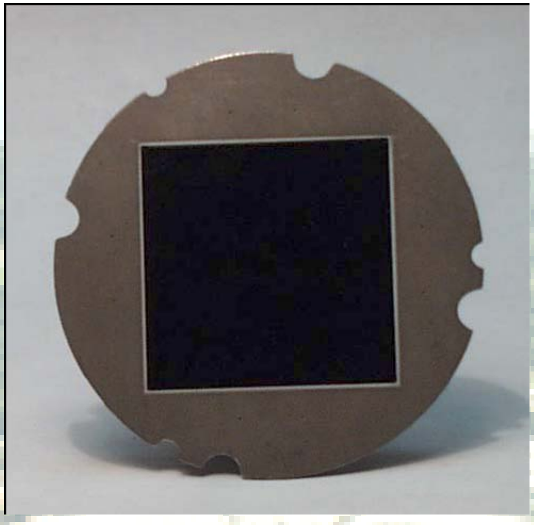
CHANNEL ELECTRON MULTIPLIERS

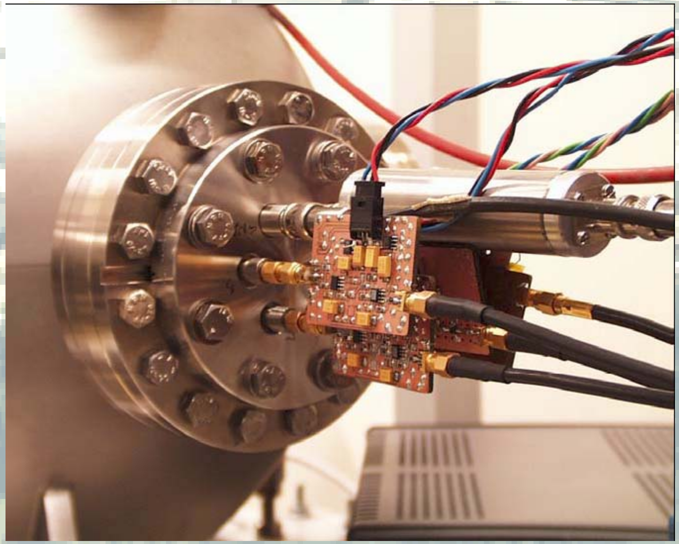
MULTIANODES DETECTORS

BI-DIMENSIONAL DETECTORS

CENTROID FINDING POSITION DETECTORS

CROSS DELAY ANODES DETECTOR





Bi dimensional detectors:

CHANNEL ELECTRON MULTIPLIERS

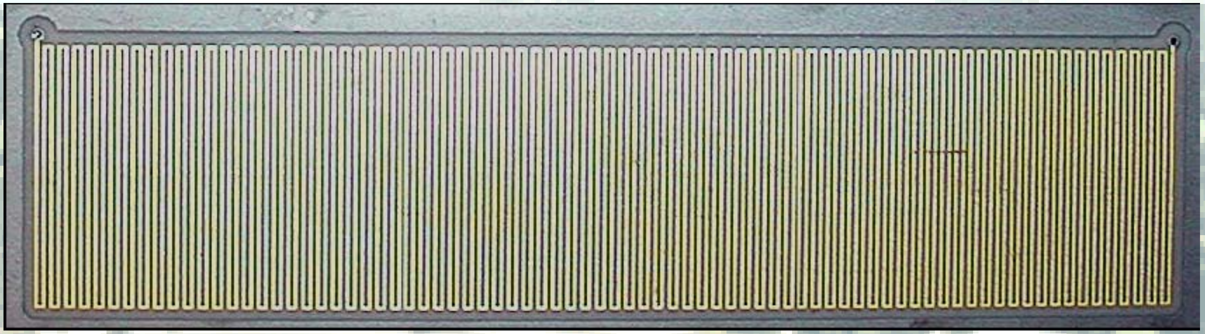
MULTIANODES DETECTORS

BI-DIMENSIONAL DETECTORS

CENTROID FINDING POSITION DETECTORS

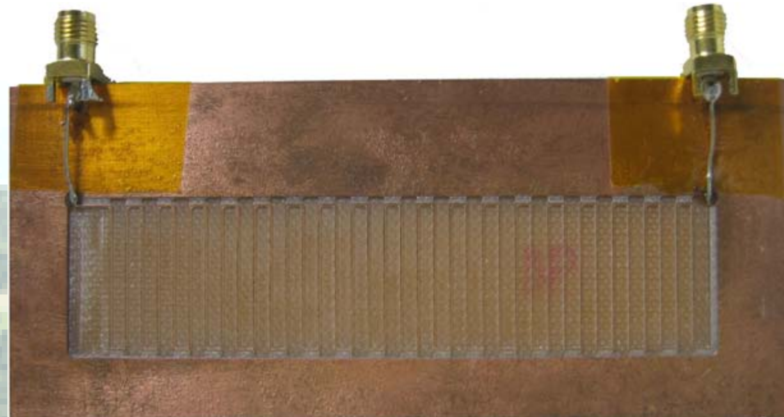
CROSS DELAY ANODES DETECTOR

Delay line



SVILUPPO DELAY LINE ANODE (II)

Ricerca della struttura migliore:

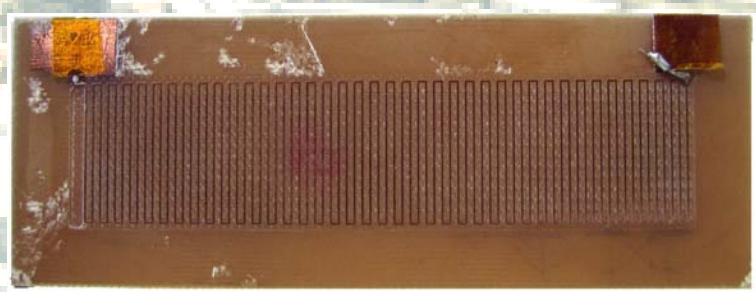


Interasse: 2.3 mm

Lunghezza meandro: 87 cm

Ritardo teorico: 5.1 ns

Ritardo misurato: 3.97 ns



Interasse: 1.15 mm

Lunghezza meandro: 169 cm

Ritardo teorico: 9.8 ns

Ritardo misurato: 6.05 ns

Interasse: 0.575 mm

Lunghezza meandro: 334 cm

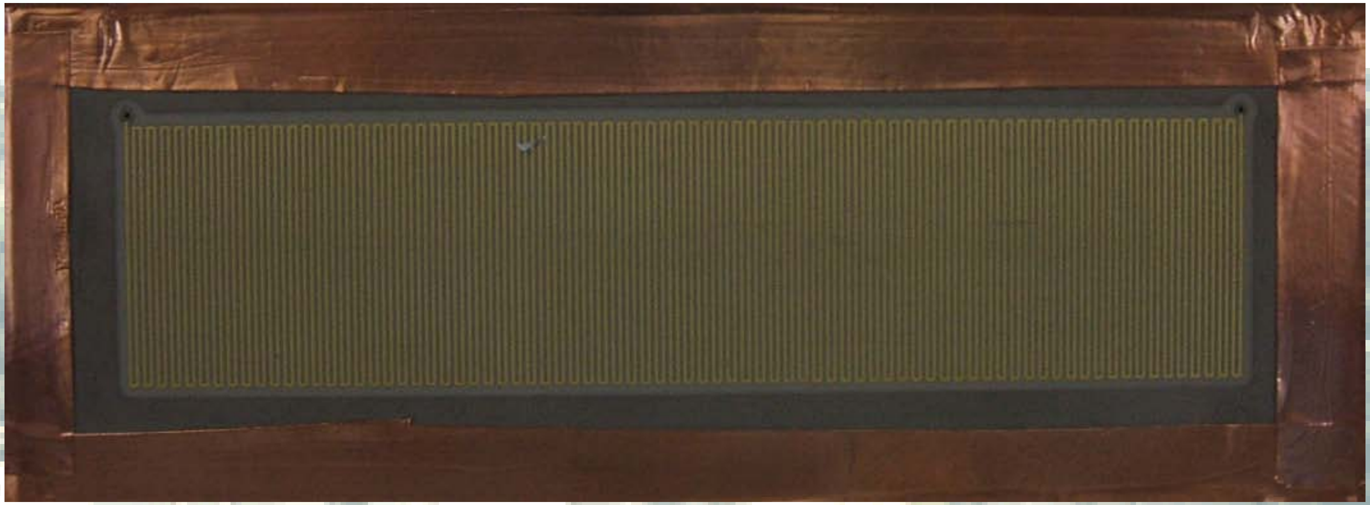
Ritardo teorico: 19.4 ns

Ritardo misurato: 7.21 ns

SVILUPPO DELAY LINE ANODE (II)

Ricerca materiali:

Substrato in titanato di bario (ε_r = 80)



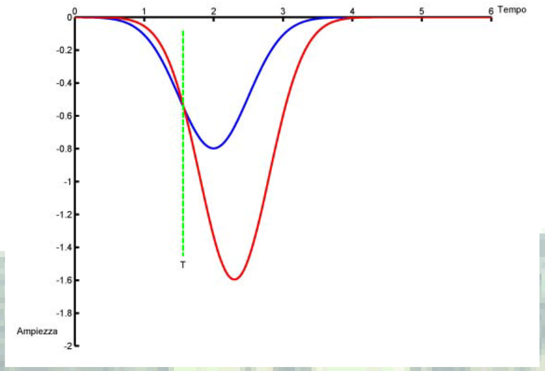
Impedenza caratteristica della serpentina 25 Ω

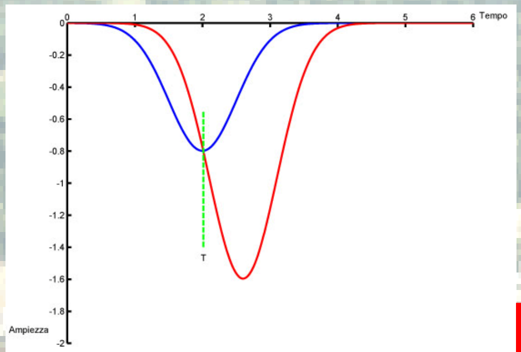
Adattata l'impedenza con trasformatori a larga banda

TIPI DI FUNZIONAMENTO DEL CFD

- INTRODUZIONE
- MISURE RISOLTE IN TEMPO
- SCHEMA DI MISURA
- (CROSS) DELAY LINES ANODE
- **CONSTANT FRACTION DISCRIMINATOR**
- TEST SISTEMA COMPLETO
- CONCLUSIONI & SVILUPPI FUTURI

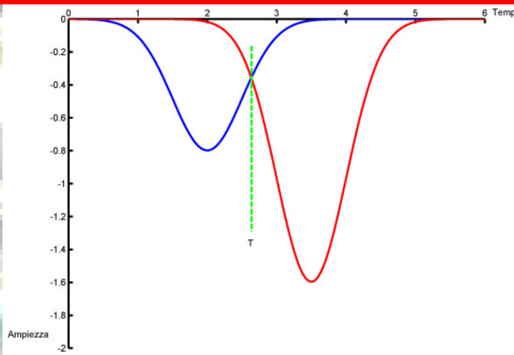
ARC (Amplitude Rise-time Compensated) ⇨





⇦ TCF Timing (True-Constant Fraction timing)

Fast Crossover ⇨



Jitter ⇨

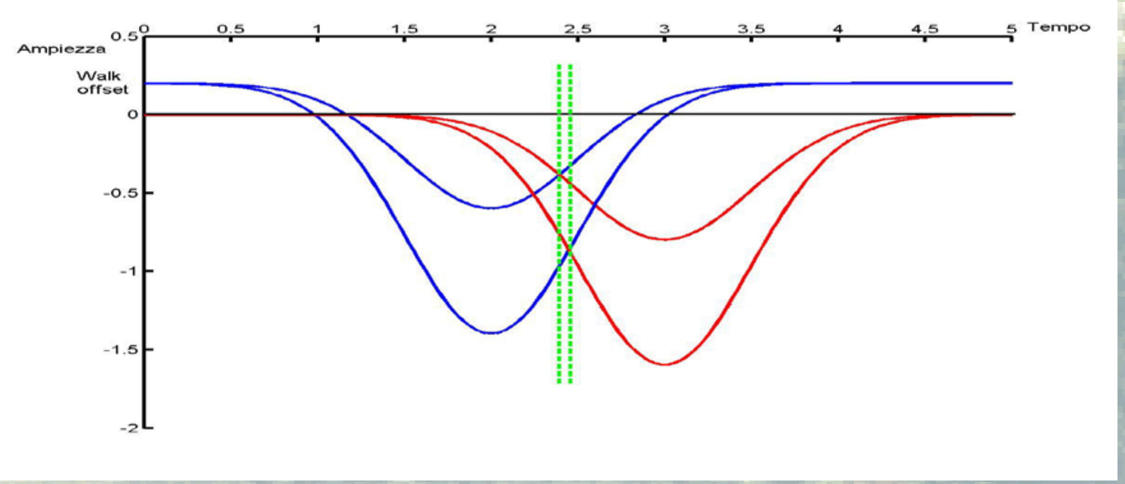
$$\sigma_T = \frac{\sigma_N}{\left(\frac{dV_1(t)}{dt} - \frac{dV_2(t)}{dt}\right)\Big|_{t=T_{cf}}}$$

EFFETTI INTRODOTTI DAL COMPARATORE

Comparatore introduce componente variabile di ritardo

$$\tau_{delay} = \sqrt{\frac{2V_0 \pi_0}{SR}} + \tau_D$$

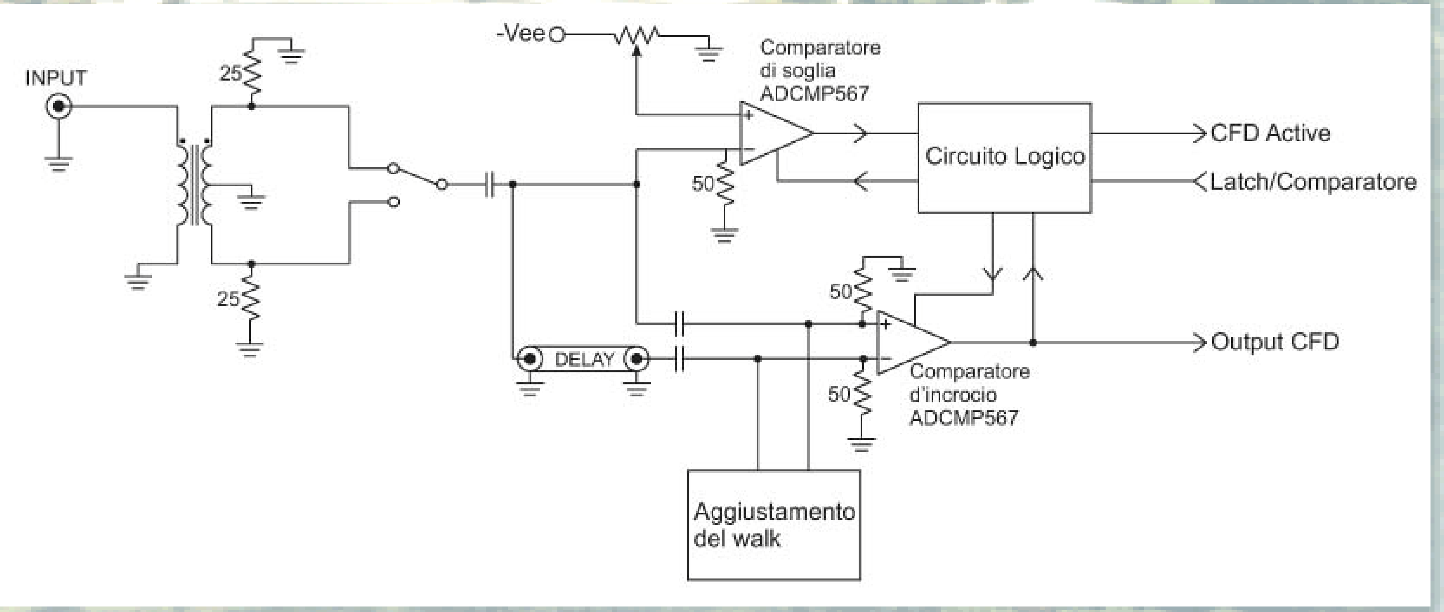
Per minimizzare la componente variabile del ritardo introdotto dal comparatore è conveniente massimizzare SR facendo lavorare il CFD in configurazione *fast crossover* ed utilizzare un cirucito di compensazione del walk



SCHEMA DEL CFD REALIZZATO

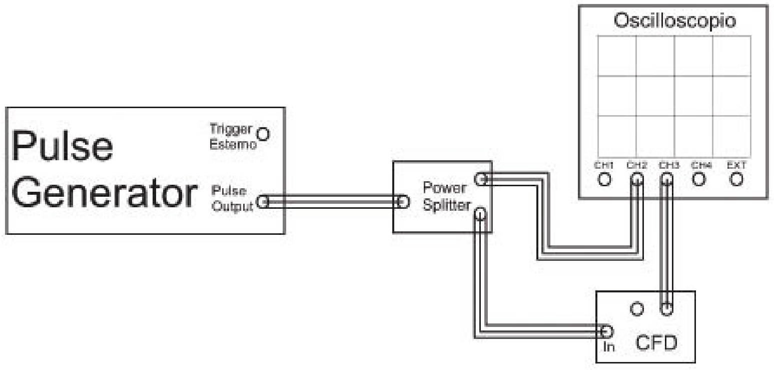
SPECIFICHE:

- ***Jitter* inferiore ai 20 ps;**
- ***Walk error* inferiore ai 40 ps;**
- **Ingresso in grado di gestire impulsi positivi e negativi;**
- **Uscite LVTTL o LVPECL;**
- **Ingresso e uscita adattati 50 Ω;**

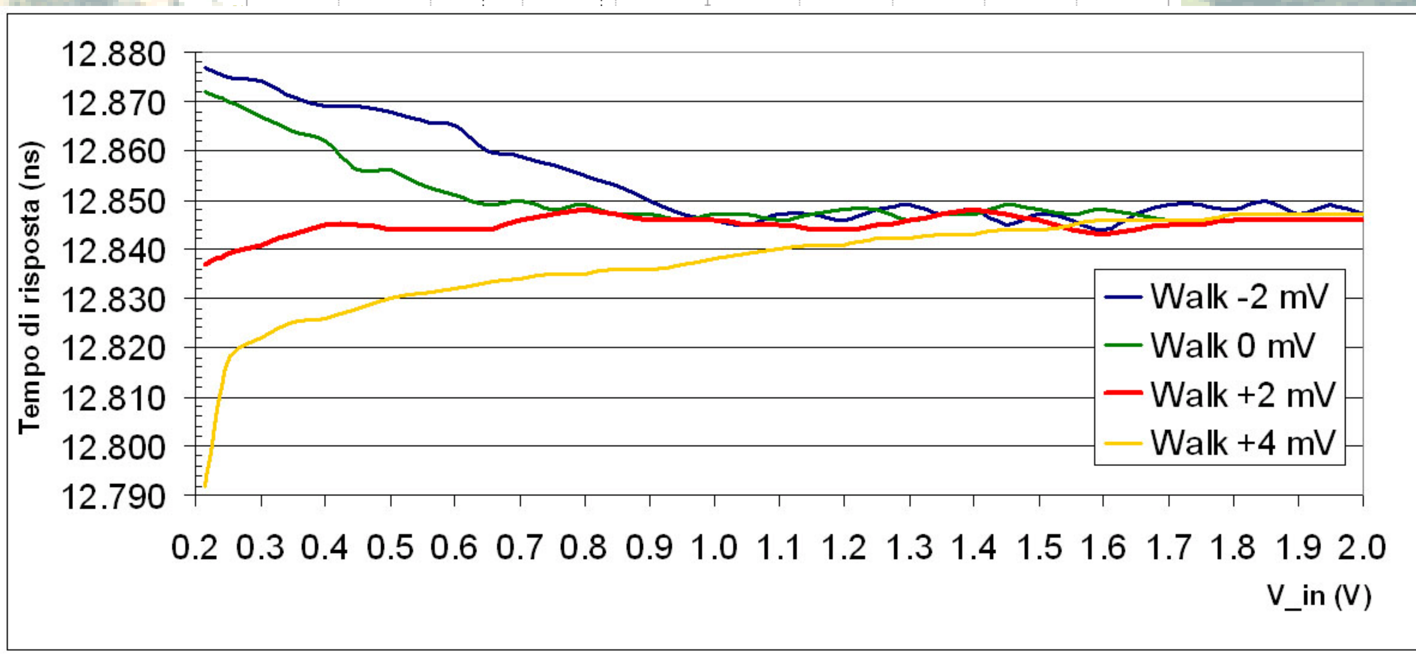


TEST DEL CFD

Schema utilizzato per il test del CFD

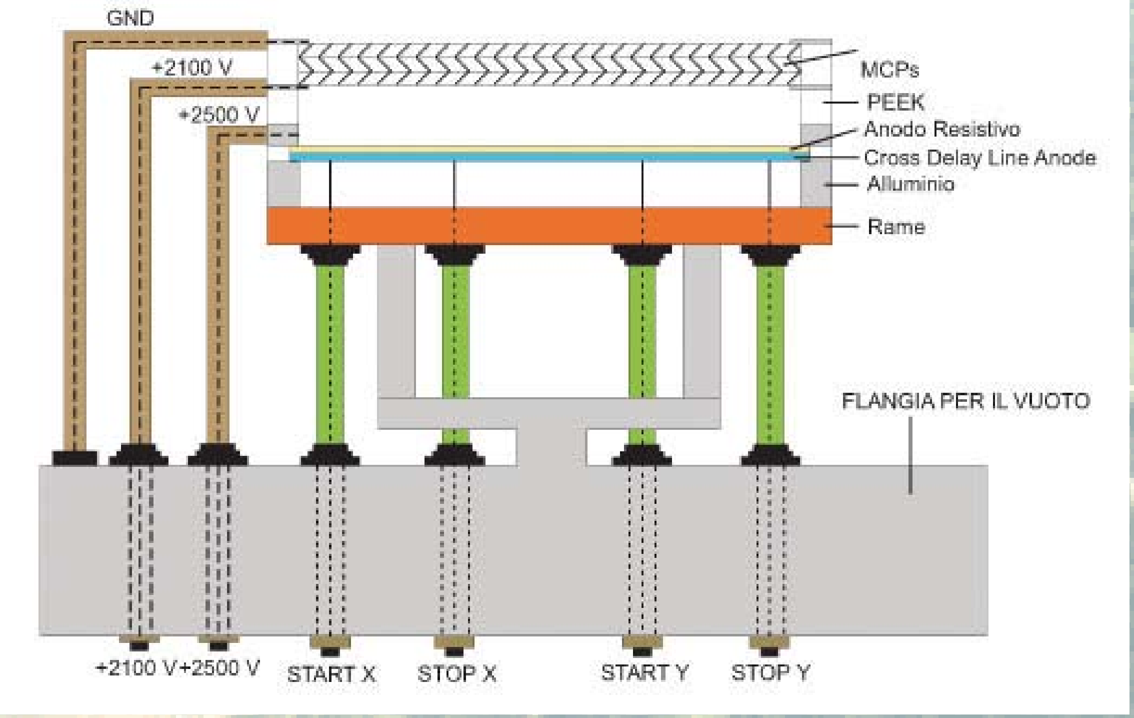


Risultati ottenuti:



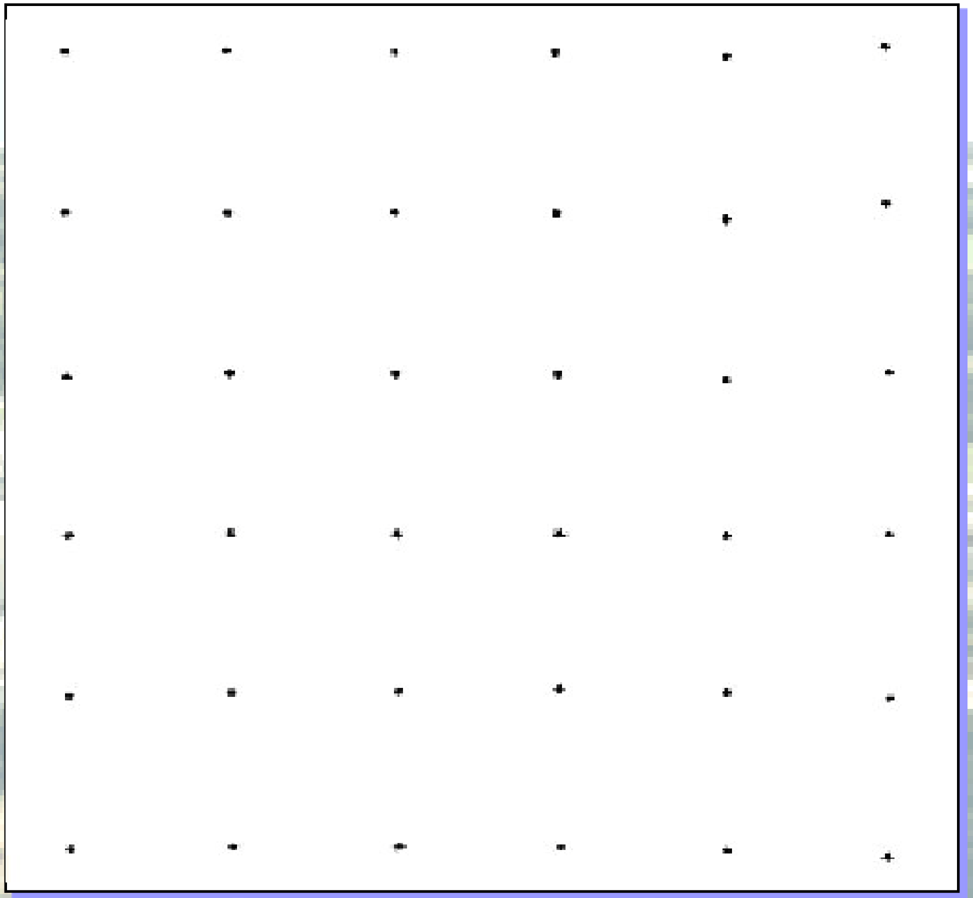
TEST DEL SISTEMA COMPLETO

Montaggio della parte in vuoto



TEST DEL SISTEMA COMPLETO

Misura risoluzione spaziale



Migliore di 100 μm