Development of a Front-end Pixel Chip for Readout of Micro-Pattern Gas Detectors.

Vladimir Gromov,
Ruud Kluit, Harry van der Graaf.
NIKHEF, Amsterdam,
The Netherlands.

TWEPP-08, Naxos, Greece.

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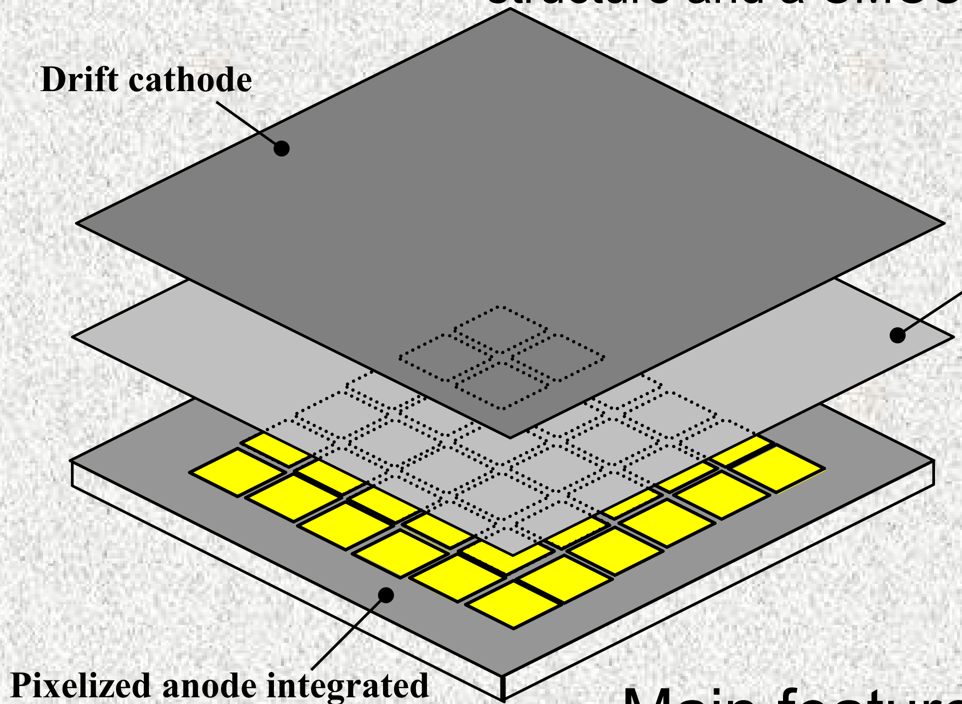
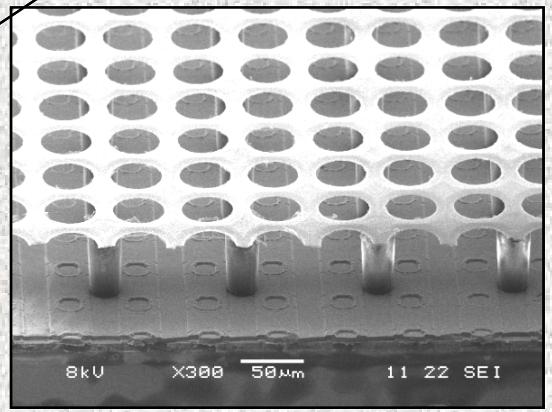
Outline

- Micro-pattern gas detectors: introduction and system requirements.
- Prototyping results: time measurement aspects.
- Defining the chip specifications.
- Summary.

Micro-Pattern Gas Detectors (MPGDs).

Combination of a gas layer as signal generator with a charge amplification structure and a CMOS readout pixel array.

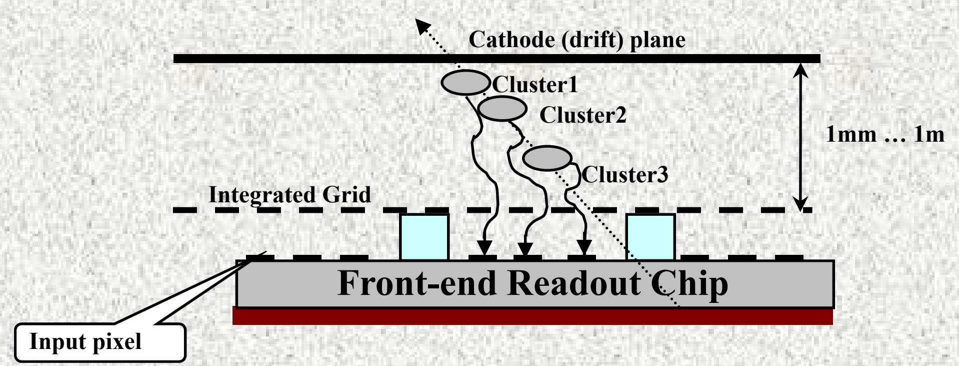




Main feature (RD51 proposal 2008-001).

- high spatial resolution
- high-rate capabilities
- radiation hardness
- low radiation length
- presence of discharges

Front-end Readout Chip for MPGDs.



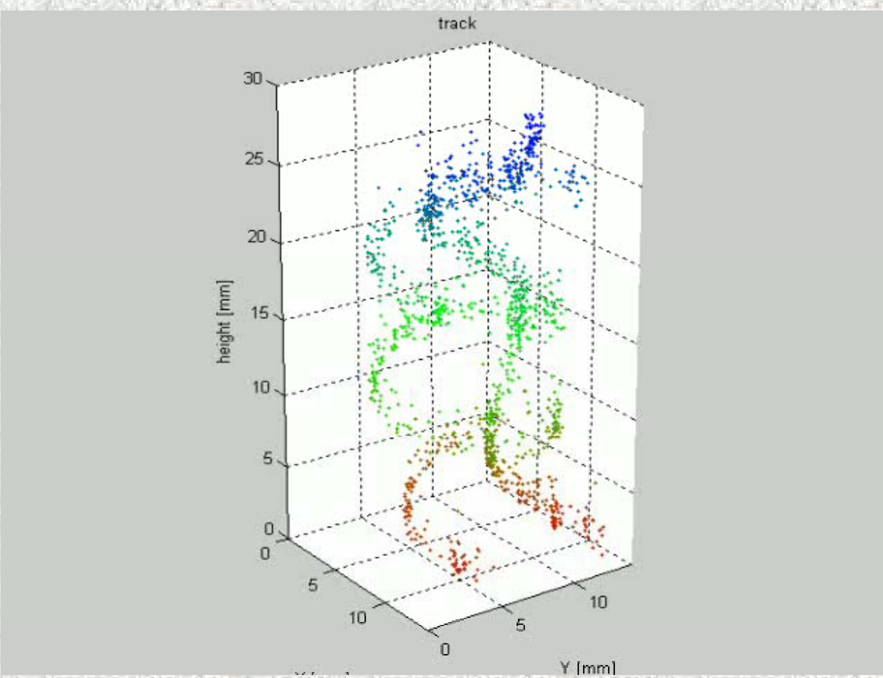
System Requirements.

- SLHC compatible
- high density pixel structure
- high efficiency of detecting of single primary electrons
- high resolution TDC-per-pixel
- a smart architecture of the pixels readout
- low power consumption

Timepix Chip (0.25um CMOS)

(M. Campbell , X. Llopart , CERN, 2006).

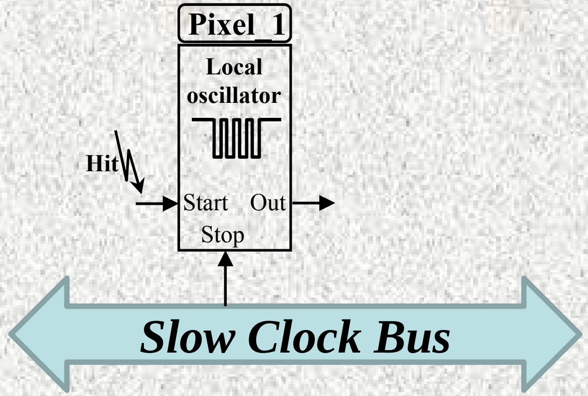
An evolution from the Medipix2 chip within EUDET program.

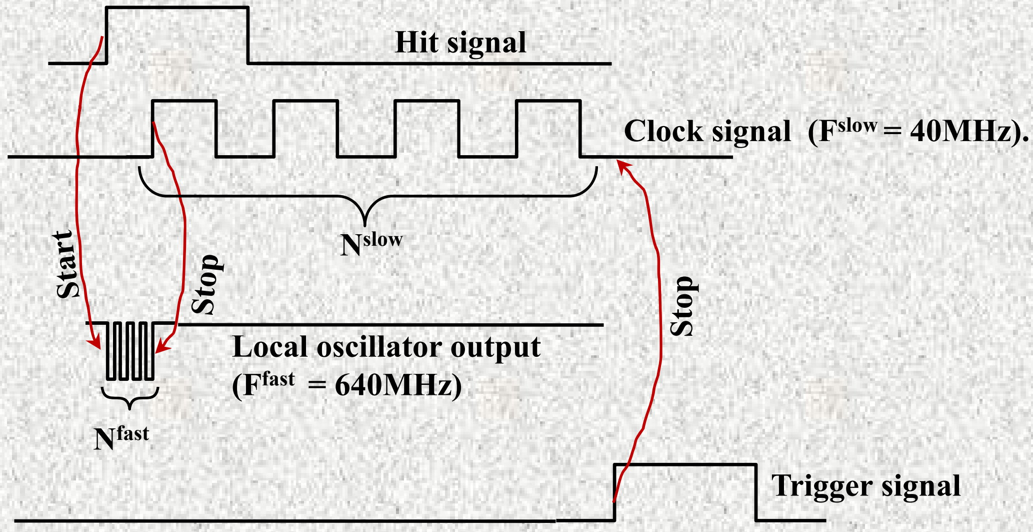


Spiral tracks of low-energy electrons in magnetic field taken by M.Fransen and H. van der Graaf (NIKHEF, Amsterdam)

- a full size readout chip with detection area 1.98cm^2
- pixel matrix 256 x 256 pixels of 55 x 55um^2
- allows for measurements of arrival time with 10ns accuracy
- 3D reconstruction of particle tracks
- an external clock (up to 100MHz) as a time reference

Low power Time-to-Digital Conversion based on local oscillator.





$$\text{Time} = N^{slow} / F^{slow} + N^{fast} / F^{fast}$$

-Time resolution is determined by the frequency (F^{fast}) and performance of the local oscillator circuit

-The local oscillator is active only within restricted time window
- Only "slow" Clock signal is being distributed across the chip

Low power consumption

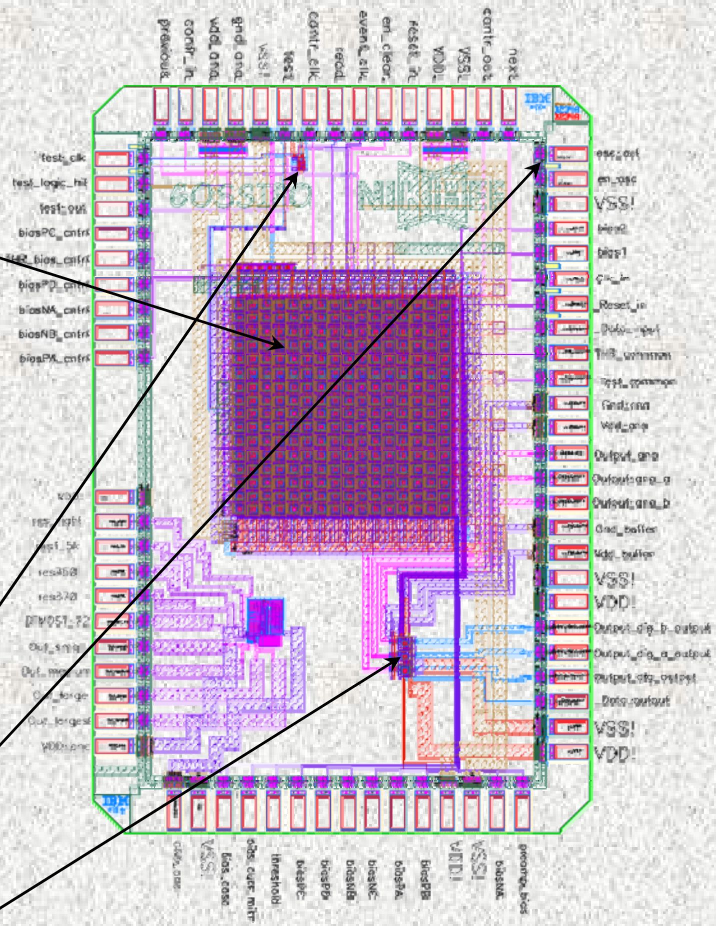
GOSSIPO-2 Chip (0.13um CMOS).

(V.Gromov, R. Kluit , NIKHEF, Amsterdam, 2006).

read-out pixel array:
- sensitive area: 0.88 mm^2
  (16 pixels x 16 pixels)
- pixel size: 55 um

analog front-end:
- fast, low-noise (ENC=70 e^-)
- low threshold =350 e^-,
- low-power (2 uW per channel)

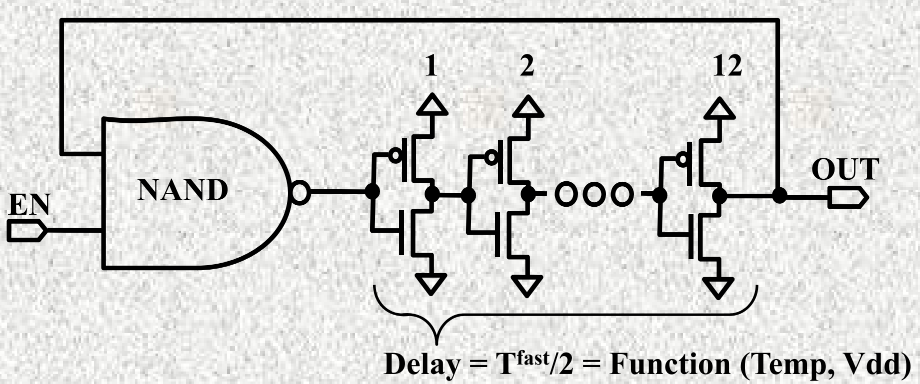
time measurement:
- 40MHz external clock as time reference
- high resolution
  TDC-per-pixel architecture (bin=1.8 ns)

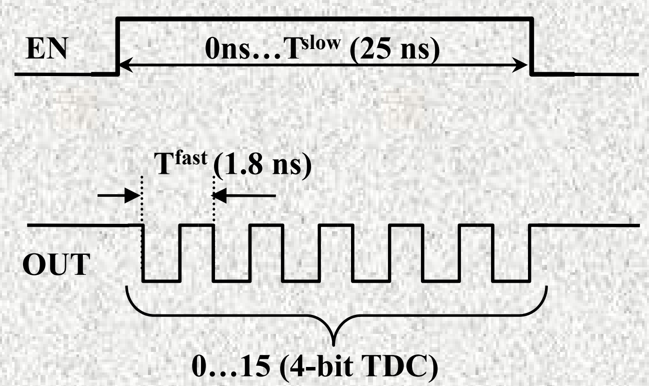


-separate TDC block
-separate local oscillator circuit
-analog monitor block

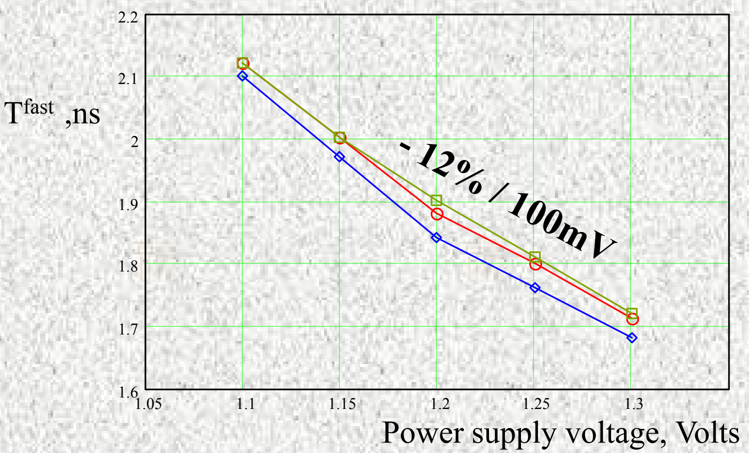
GOSSIPO-2: Performance of the local oscillator circuit.

Principle of the local oscillator.

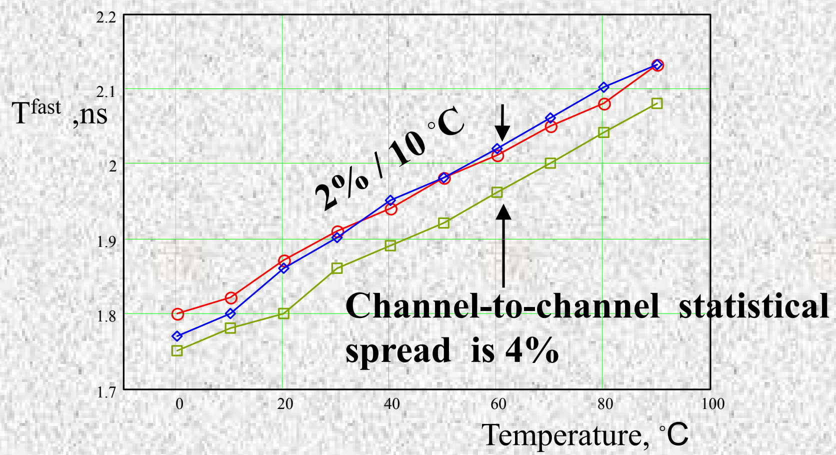




Effect of the power supply voltage



Effect of the temperature

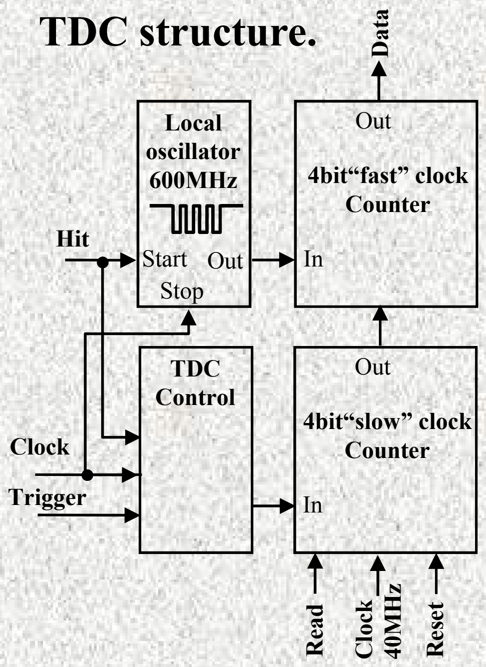


-If the power supply changes within 50 mV
-If the temperature changes within 30° C

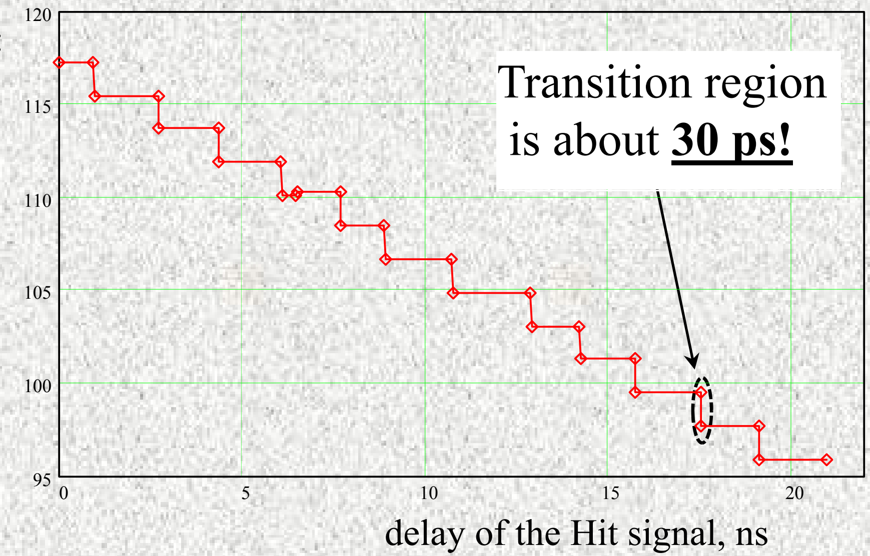
Accumulated error will be kept within 6% (1.8 ns or 1 bin of the 4bit TDC)

GOSSIPO-2: TDC block.

TDC structure.



Measured time :
$N^{slow} \bullet 25ns$ +
$N^{fast} \bullet 1.8ns$

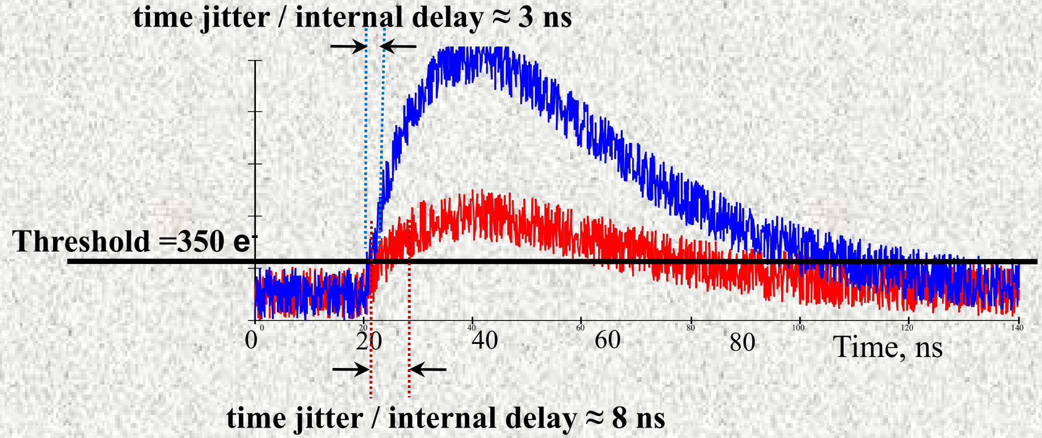


- time resolution is (T^{fast}) is 1.8 ns
- dynamic range is 4bit (F^{slow} = 40MHz) is 350 ns
- power ≈ 0.4 uW (hit rate 100 KHz)

GOSSIPO-2 chip: charge-sensitive preamplifier.

Features

- pulse response rise-time is 20 ns
- low noise (σ_n=70 e^- ENC) ⇨ threshold =350 e^-



Time jitter = Rise_time • 5σ_n / Signal

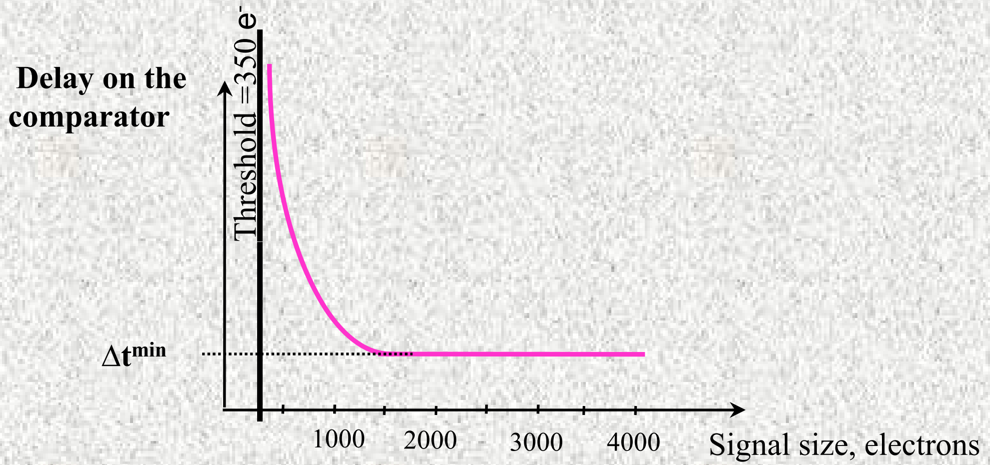
≈ 20ns ≈ 350 e^-

Time jitter < 1.8ns (bin of TDC) → Signal > 4000e^-

GOSSIPO-2 chip: voltage comparator.

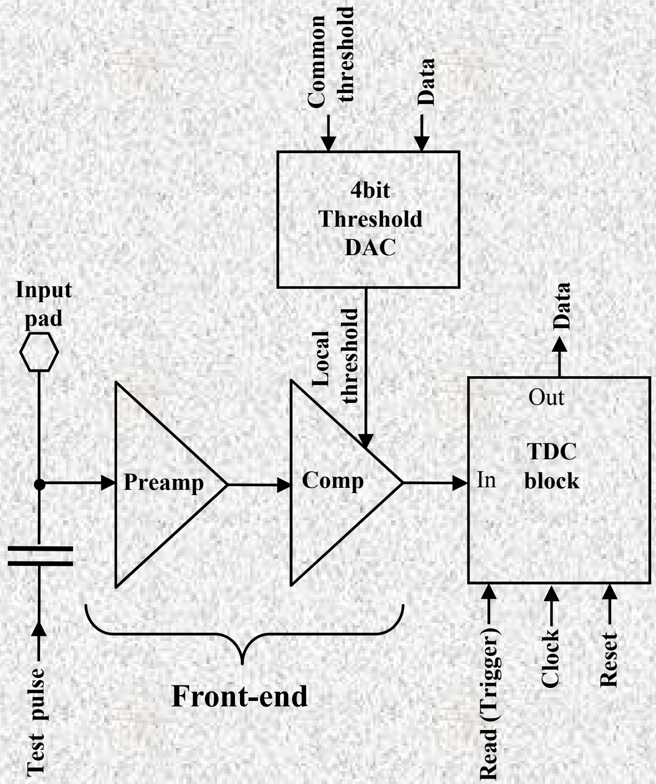
Features.

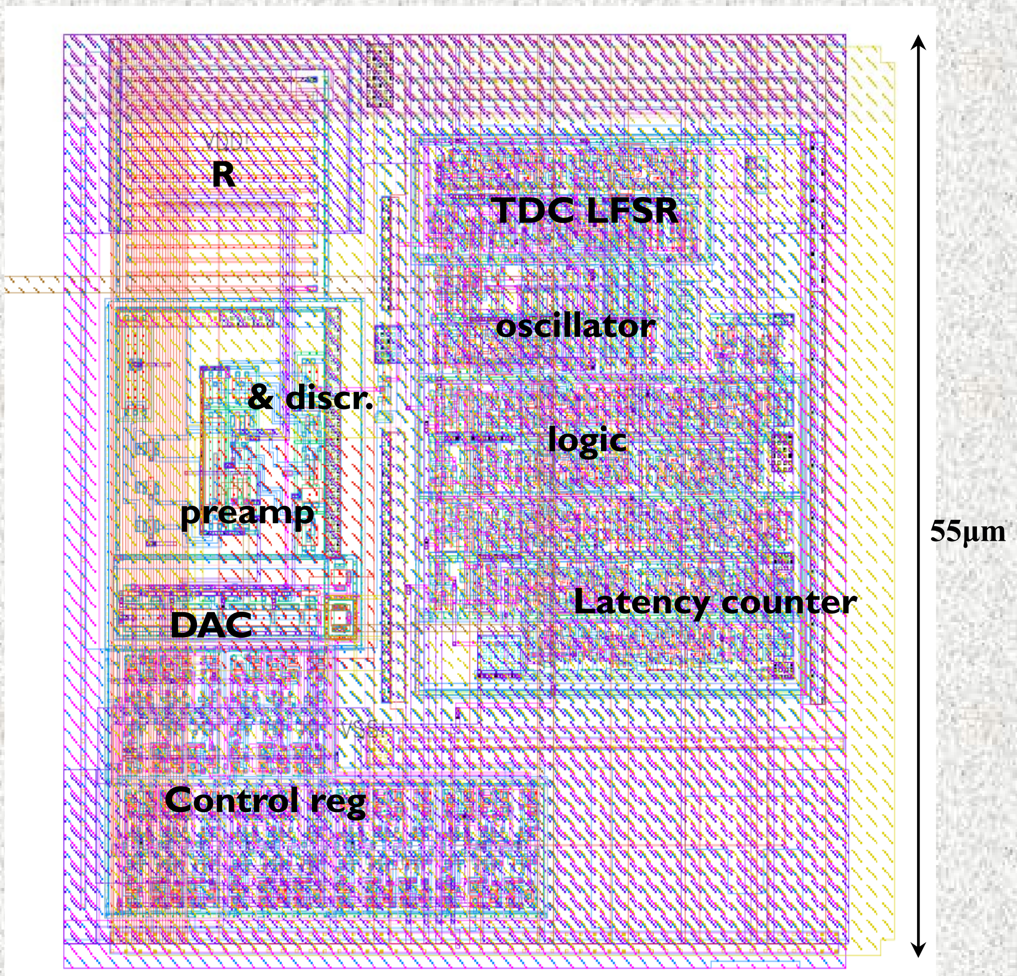
Δt^{min} *is temperature dependent*
is power supply voltage dependent
takes different values due to channel-to-channel mismatch



Δt^{min} < 1.8ns (bin of TDC)

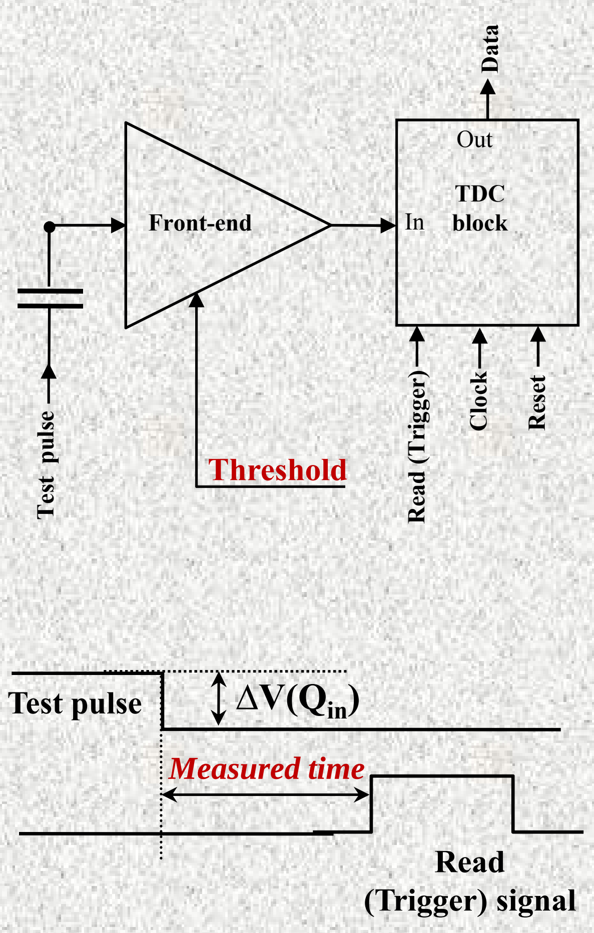
GOSSIPO-2 chip: pixel functionality.



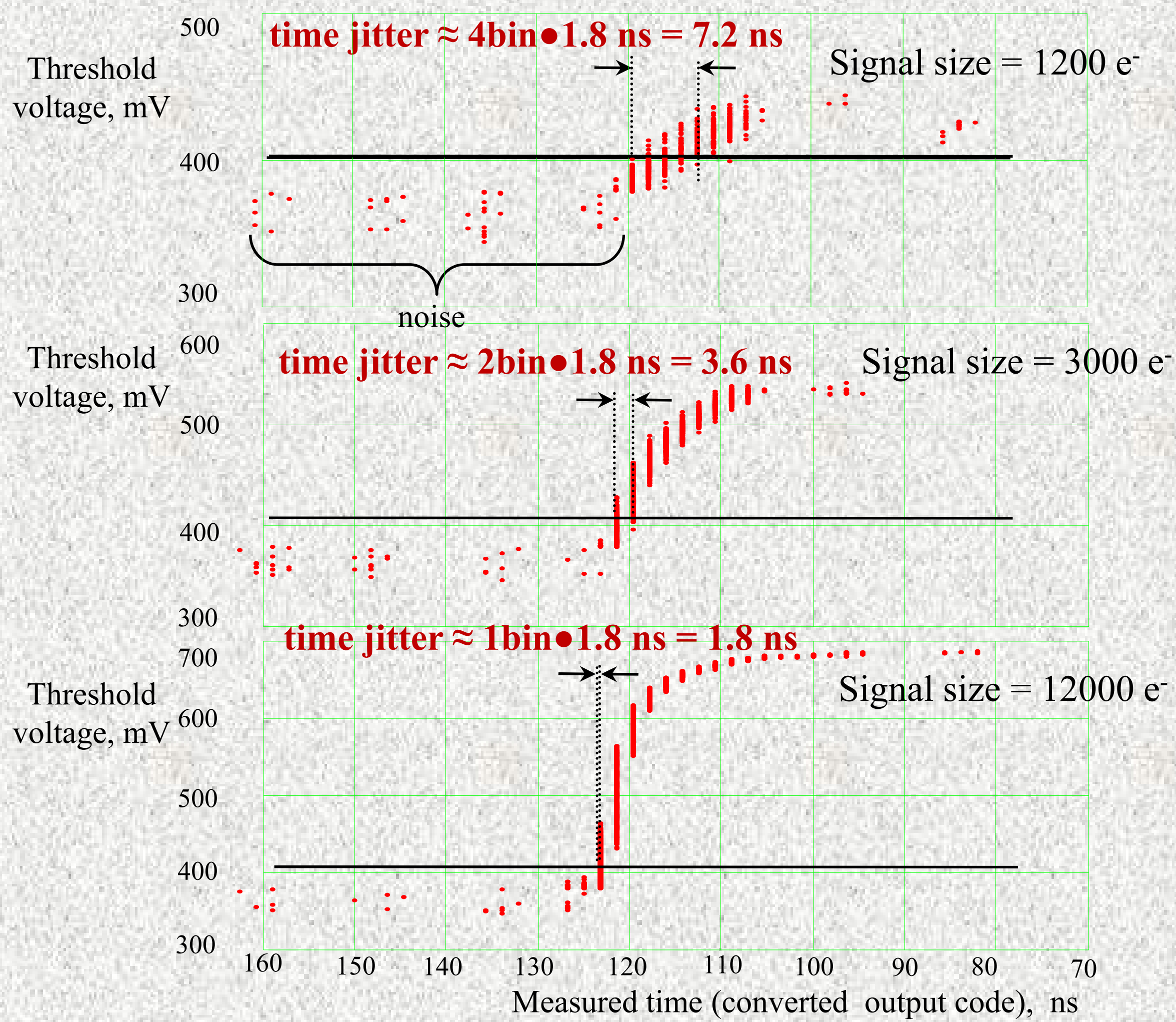


GOSSIPO-2: Time resolution as a function of threshold value.

Pixel cell structure.



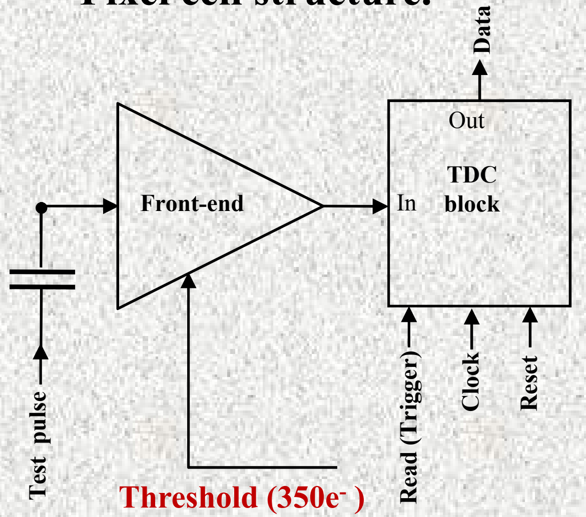
Threshold scan.

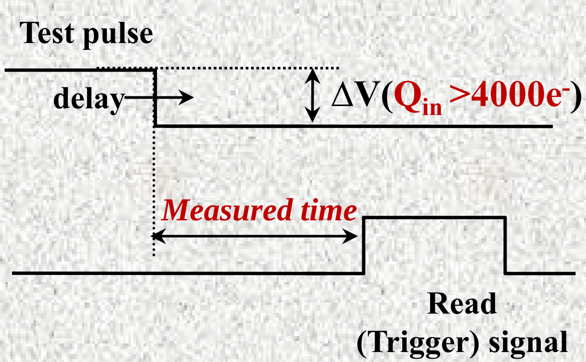


- Low threshold operation (350 e^-) in combination with large signal size (larger than 4000 e^-) will allow for high time resolution (jitter less than 1bin of the TDC = 1.8 ns)

GOSSIPO-2:Time scan.

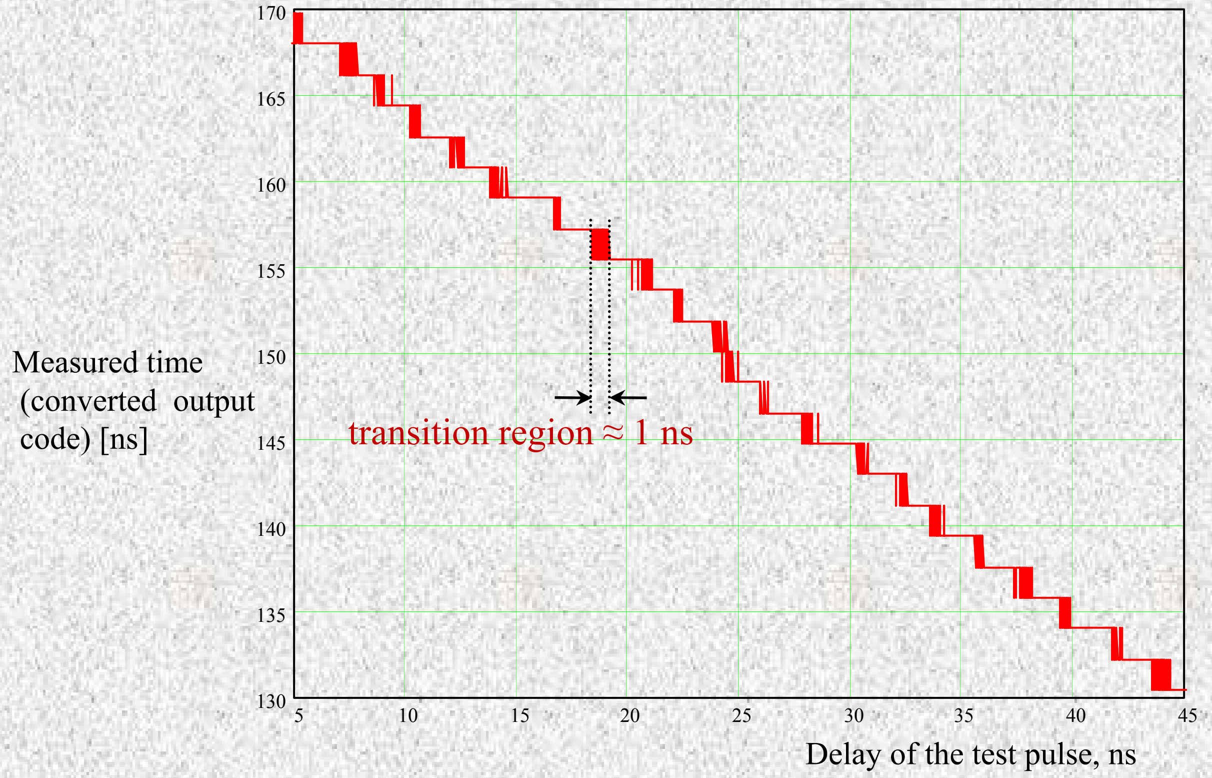
Pixel cell structure.





Measured time as a function of the delay of the test pulse.

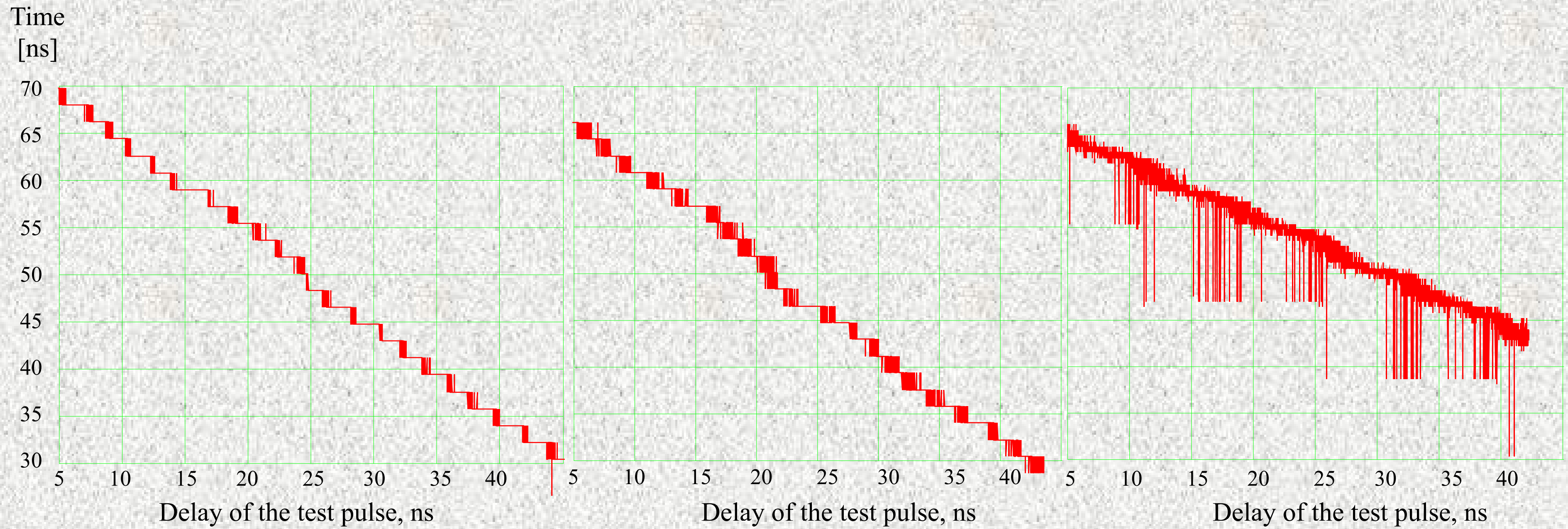
Large signal (> 4000 e^-) and low threshold operation (350 e^-)



- The complete read-out chain demonstrates good time resolution (transition region is 1ns) when the threshold is low (350e^-) and the input signal is large (>4000e^-)

GOSSIPO-2:Time scan.

Low threshold operation (350 e$^-$)



Signal > 4000 e$^-$ **Signal = 3000 e$^-$** **Signal = 1200 e$^-$**

Timepix-2 chip

Customers: future tracking detectors groups (TPCs, GOSSIP, large-area drift chambers), Medipix3 community, silicon vertex pixel detectors.

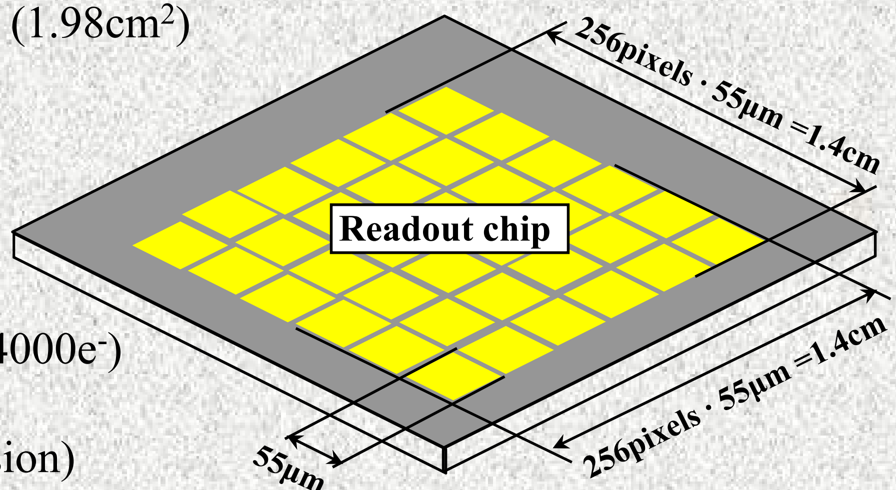
Designers: CERN, NIKHEF, Bonn, Saclay ......

Technology: IBM 0.13 um CMOS (engineering run cost ~ 250 000 €)

Power: ~ 0.5W/cm^2

Dimensions:
- total sensitive area: 14mm x 14mm (1.98cm^2)
- pixel pitch: 55um x55um
- array: 256 x 256

Functionality:
- single pixel operation only
- noise ~ 70e$^-$ RMS
- threshold < 400e$^-$ (spread ~ 40e$^-$)
- hit timestamp < 2ns (for signals > 4000e$^-$)
- TDC-per-pixel
- TDC dynamic range (under discussion)
- analog information ToT / Dual Threshold (under discussion)
- local (on-pixel) memory (multiple hits)



Readout:
- external 40MHz clock
- data taking and data readout are independent and run in parallel
- fast serial link (≥1Gb/s)

Modes :
- all pixel readout (time frame based) with zero suppression
- readout of the data associated with a specific BX (external clock number)
- event driven readout (fast OR)

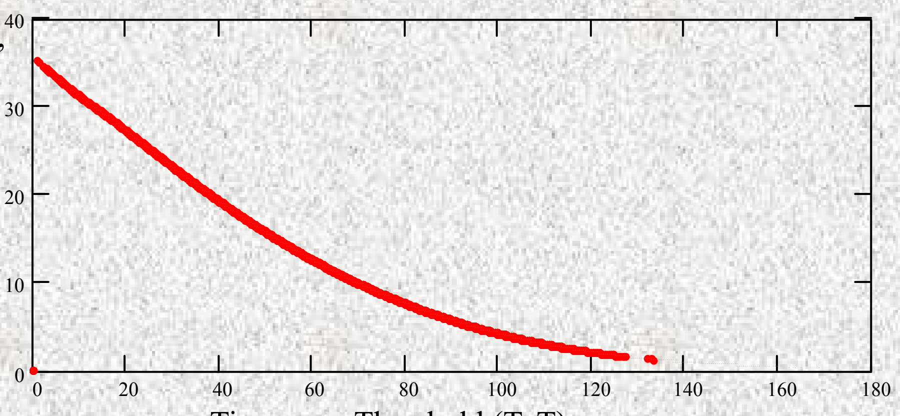
Summary.

- A new front-end chip is required for readout of micro-pattern gas detectors (MPGDs).
- It should be also suitable for detectors employing Si sensors.
- A number of prototypes have been fabricated in order to testify performances of some basic circuits.
- The TDC per pixel with local oscillator satisfies the design requirements: low power consumption (0.4uW/channel with 100kHz hit rate), high time resolution (1.8 ns bin) and simplicity.
- Low threshold (350 e^-) and fast peaking time (20 ns) enable for high quality drift time measurements (jitters 1.8 ns) at large input signals (>4000 e^-) and after accurate threshold equalization.
- We work on technical specifications and defining structure of the chip.

Correlation between ToT and TtT values.

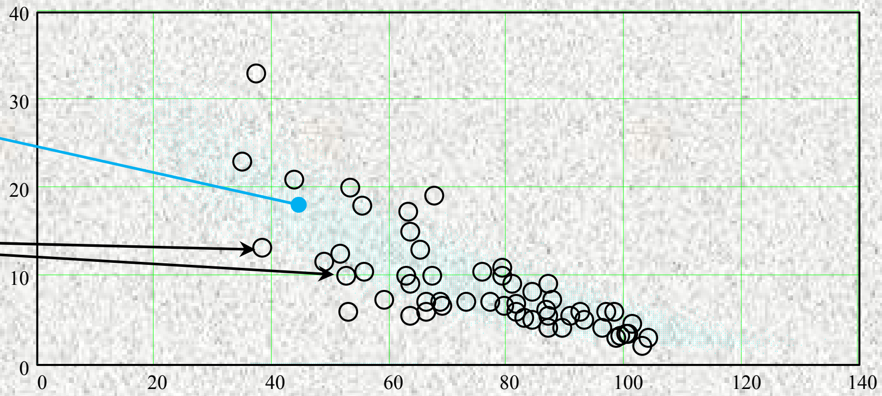
Threshold is 350 electrons, noise sigma is 70 electrons, time constants of the weighting function of readout electronics are $\tau 1$=15ns and $\tau 2$=20ns.

Optimistic approach



100% correlation !!!
Can be true ???

Pessimistic approach
and
Realistic approach



Correlation is very poor.

Pessimistic approach is a quite appropriate method to estimate correlation between ToT and TtT.

Shape of the input current.

$I_{in}(t)$ - input current :

Ion current occurs in the Micromegas-pad gap in the period

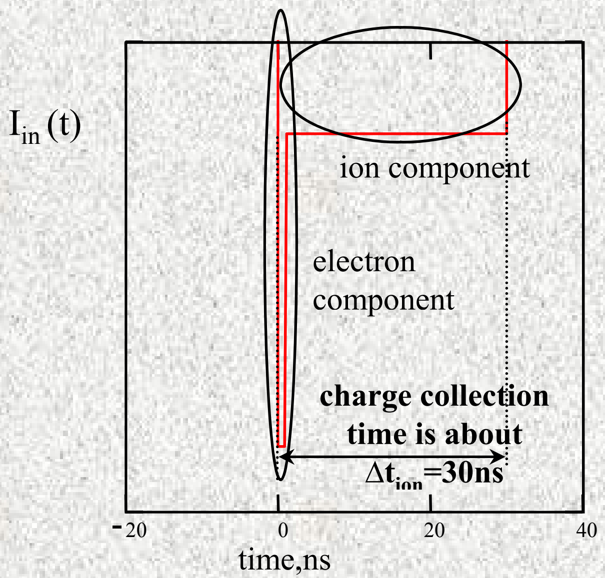
$$\Delta t_{ion} = (\Delta L)^2/\mu\, U \approx 30\text{ns},$$

where **ΔL** ≈ 50um is the Micromegas-pad distance

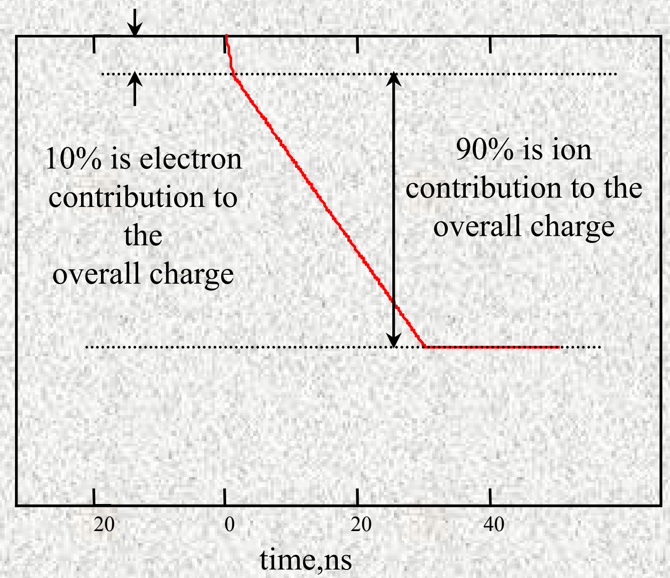
U ≈ 400V is Micromegas-pad voltage

μ= 1.72cm^{2}V^{-1} sec^{-1} is mobility of ions in Argon

Single-electron current in the detector

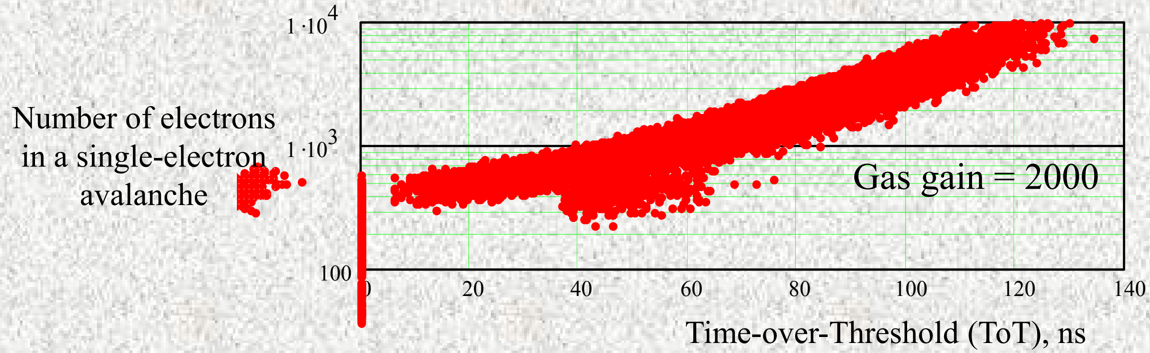


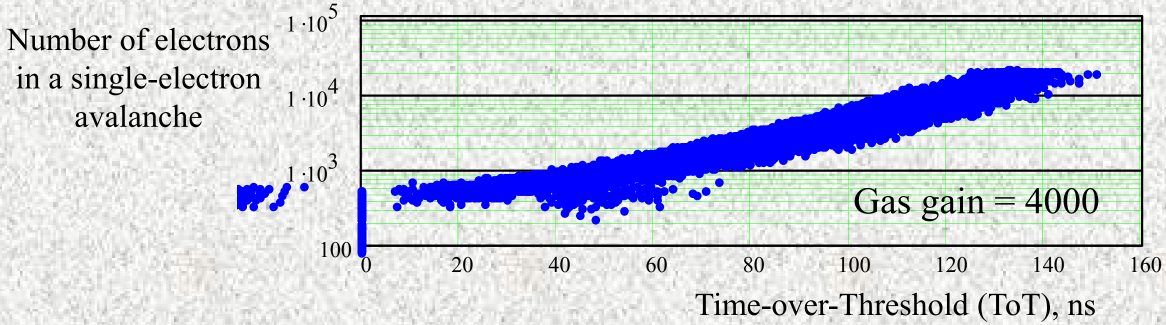
Integral of current induced by a single electron.

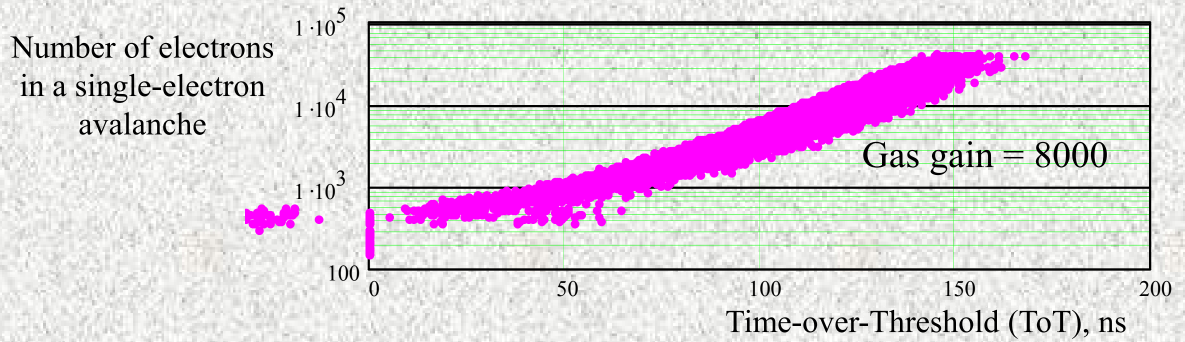


Correlation between the value of ToT and the number of electrons in a single-electron avalanche .

Threshold is 350 electrons, noise sigma is 70 electrons, time constants of the weighting function of readout electronics are τ1=15ns and τ2=20ns. **Pessimistic approach.**





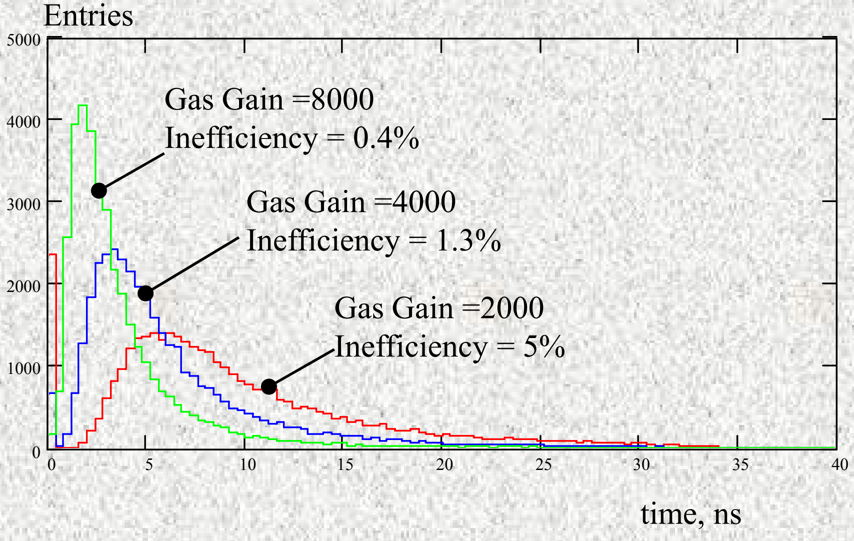


Single electron drift time resolution based on TtT statistics.

Threshold is 350 electrons, noise sigma is 70 electrons, time constants of the weighting function of readout electronics are τ1=15ns and τ2=20ns. **Pessimistic approach.**

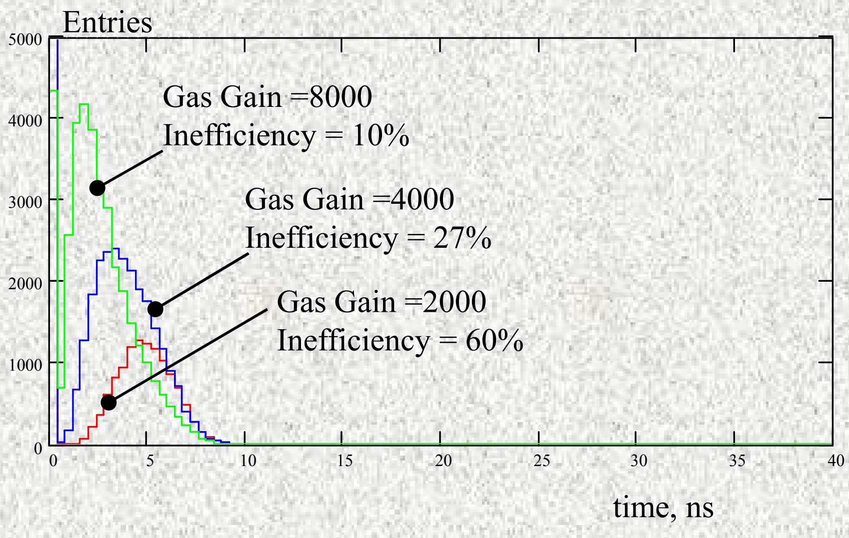
No signal selection:

Each signal larger than the threshold (350e) is taken into account.



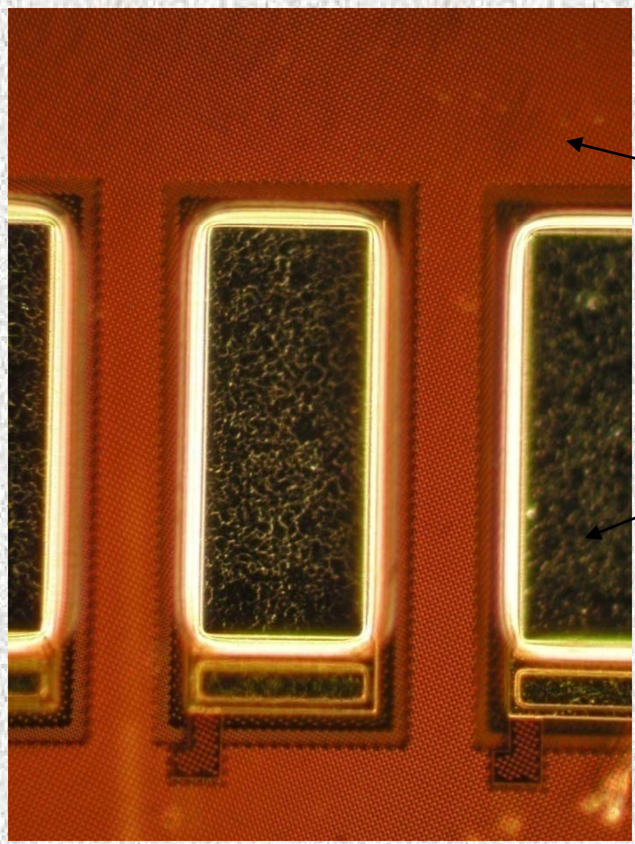
Signal selection is made on the basis of ToT information:

Only signals with ToT values larger than 100ns (2000e) are taken into account.

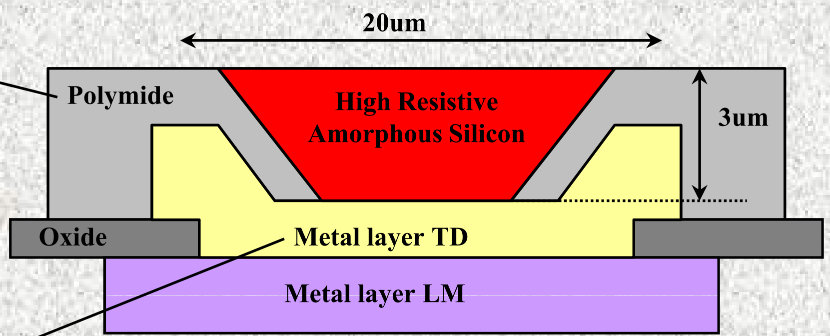


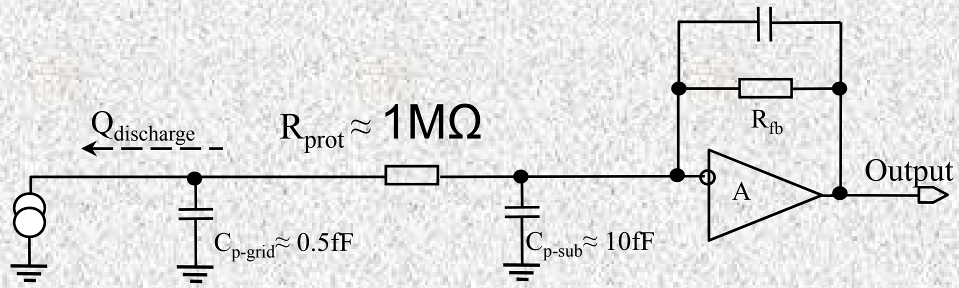
Additional slide.

Protection against discharges.



Layout of the input pad





- protective resistor causes neither signal distortion nor noise increase as long as $R_{prot} \bullet C_{p\text{-}grid}$ is less than 1ns.