Front-end electronics for the PANDA MVD pixel detector

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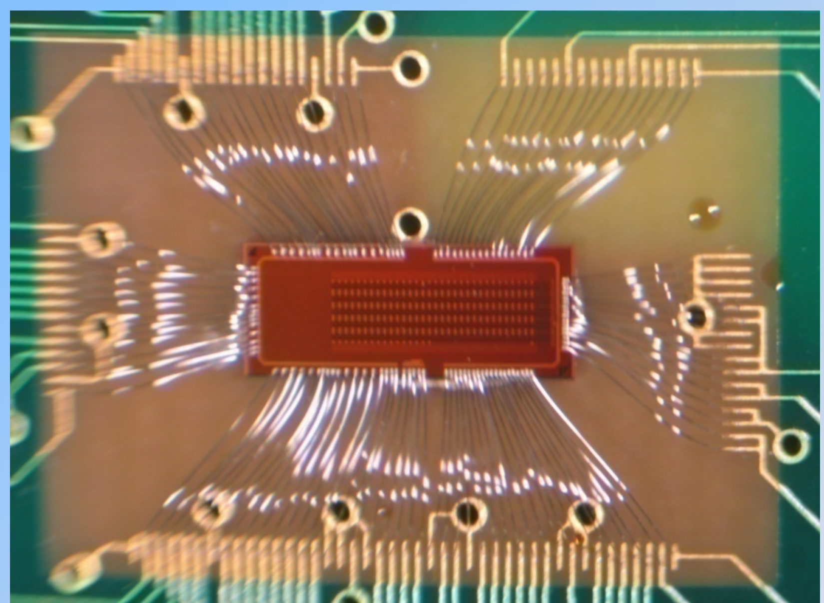

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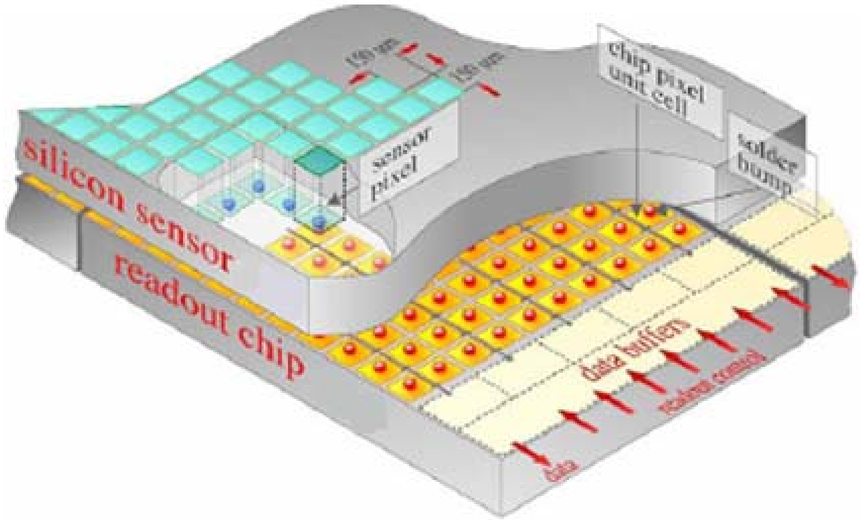
Student seminar session

Pixel detector

A grid made by sensor pixels gives a 2-dimensional information about the interaction point between the detector layer and the incident particle.
Each sensor pixel is a p-n junction with a negative bias and it is connected to a fast readout circuit cell.
The readout cells are arranged in a 2-dimensional array in order to match with the sensor pixels grid.



View of a hybrid pixel sensor detector

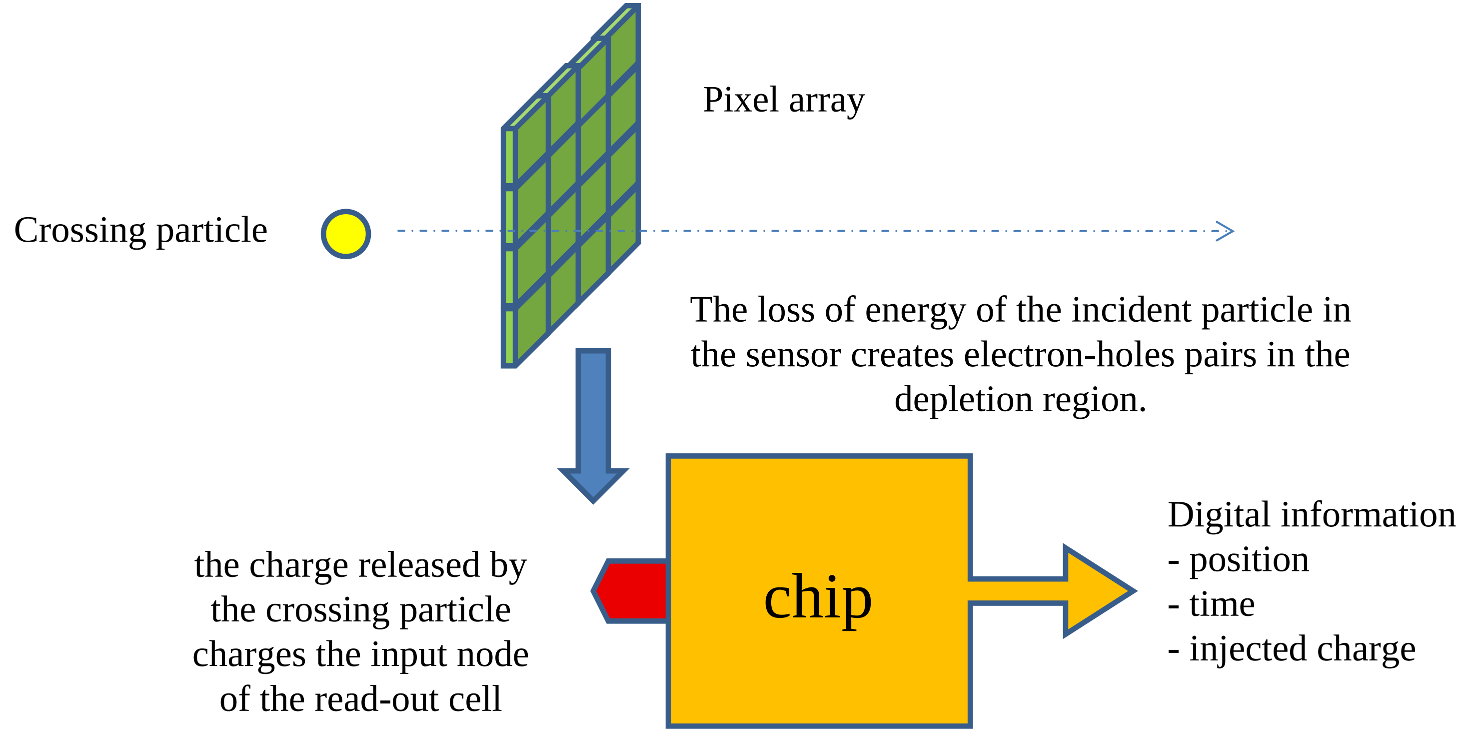
The pixel cell size is limited by the area required by each electronics read out cell.

Why an ASIC design?

The requirements for the PANDA Micro Vertex Detector in terms of track density and absence of a trigger signal lead to the need of a custom solution (ASIC) for the electronic readout of the silicon pixel detectors.

Information required for the track reconstruction

- The position and the time of each hit;
- Provide energy loss information to aid particle identification (dE/dx)



Read Out Electronics Requirement

<u>Spatial resolution</u>:

Should be better than **100 µm** along the beam axis (z-direction) . In addition the resolution in r/ϕ direction should not be sufficiently worse for a good momentum measurement.

<u>Temporal resolution</u>:

The interaction rate is 10^7/s. Therefore a timing resolution better than 100 ns is necessary to assign individual hits in the detector to a single interaction. A time resolution equal to the master clock period (**20 ns**) is adequate.

<u>Dynamic Range</u>:

Up to 2.5 MeV of energy loss, **700 ke$^-$** (112 fC)

<u>Noise</u>:

Lower than 0.032 fC (**200e$^-$**) in order to have a good signal to noise ratio even in case of minimum ionizing particle tracks crossing more than one pixel.

Time Over Threshold

With the ToT technique it is possible to measure the value of the injected charge at the input node measuring the time needed to discharge it with a constant current (Idis).
The ToT allows to achieve good linearity and excellent resolution even when the preamplifier is saturated, thus making room for an high dynamic range.

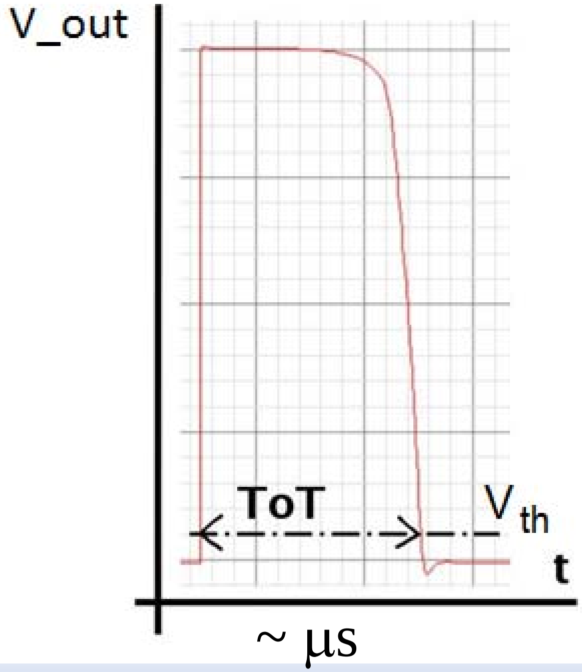
$$v_{out}(t) = A_v\, v_{in}(t) = \frac{A_v}{C_d}\int_0^t (I_{in}(t') - I_{dis}(t'))\, dt'$$

Since the charge injection time is 10^3 smaller than the discharging time:

$$v_{out}(t) = \frac{A_v}{C_d}(Q_{in} - I_{dis}\, t)$$

It is possible to calculate the injected charge Q_{in}

$$Q_{in} = I_{dis}\, ToT \Rightarrow ToT = \frac{Q_{in}}{I_{dis}}$$

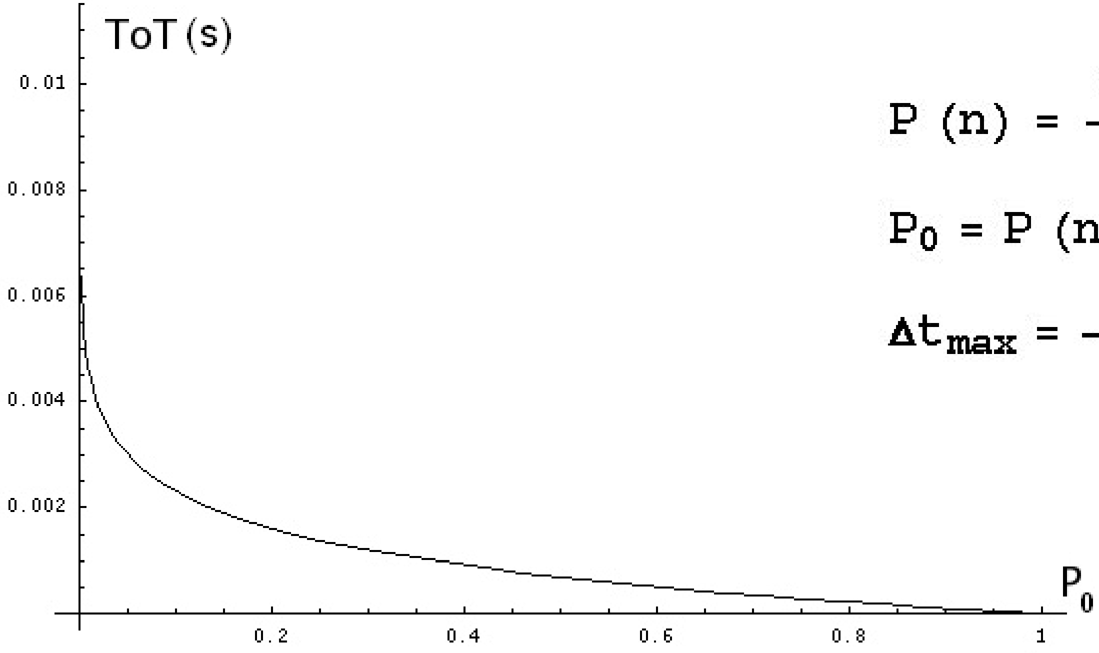


ToT vs detection efficiency

The statistical distribution of the events is a Poisson distribution

$$P(n) = \frac{(r\,\Delta t)^n\, e^{-r\,\Delta t}}{n!}$$

Example: maximum ToT value in order to avoid events during the discharging time with a probability of P(0) = 0.995 at 1kHz rate: 5 μs



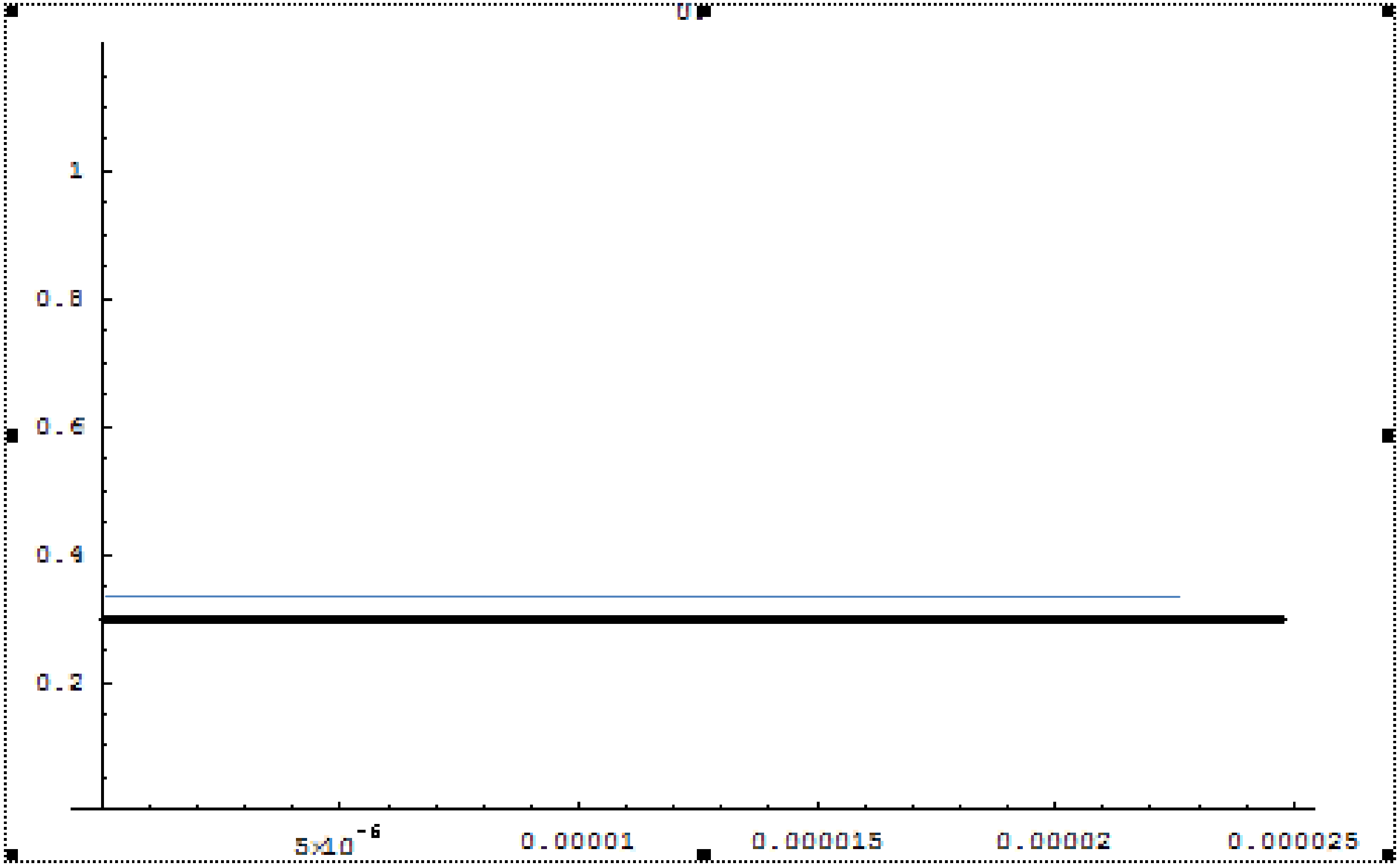
$$P(n) = \frac{(r\,\Delta t)^n\, e^{-r\,\Delta t}}{n!}$$

$$P_0 = P(n = 0) = e^{-r\,\Delta t}$$

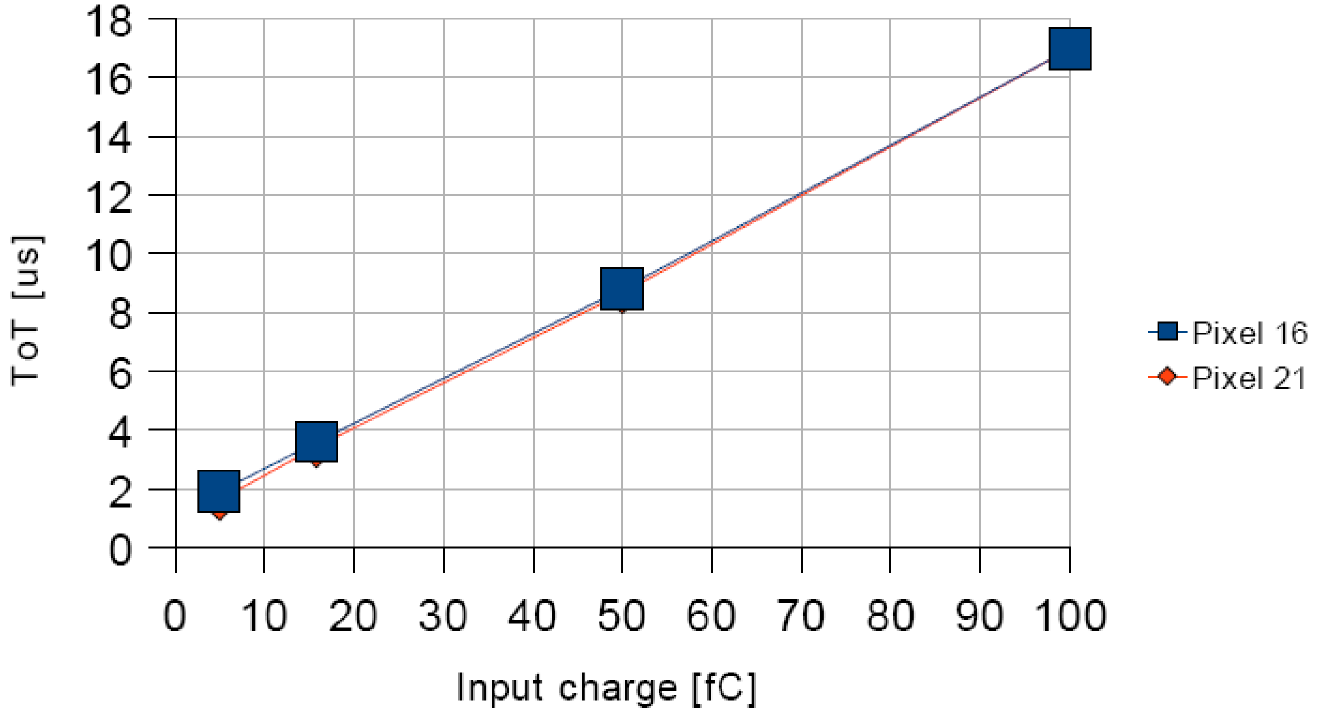
$$\Delta t_{max} = -\frac{\ln(P_0)}{r} = 5.012\ \mu s$$

Signal Shape

The ToT allows to achieve good linearity and excellent resolution even when the preamplifier is saturated, thus making room for an high dynamic range.



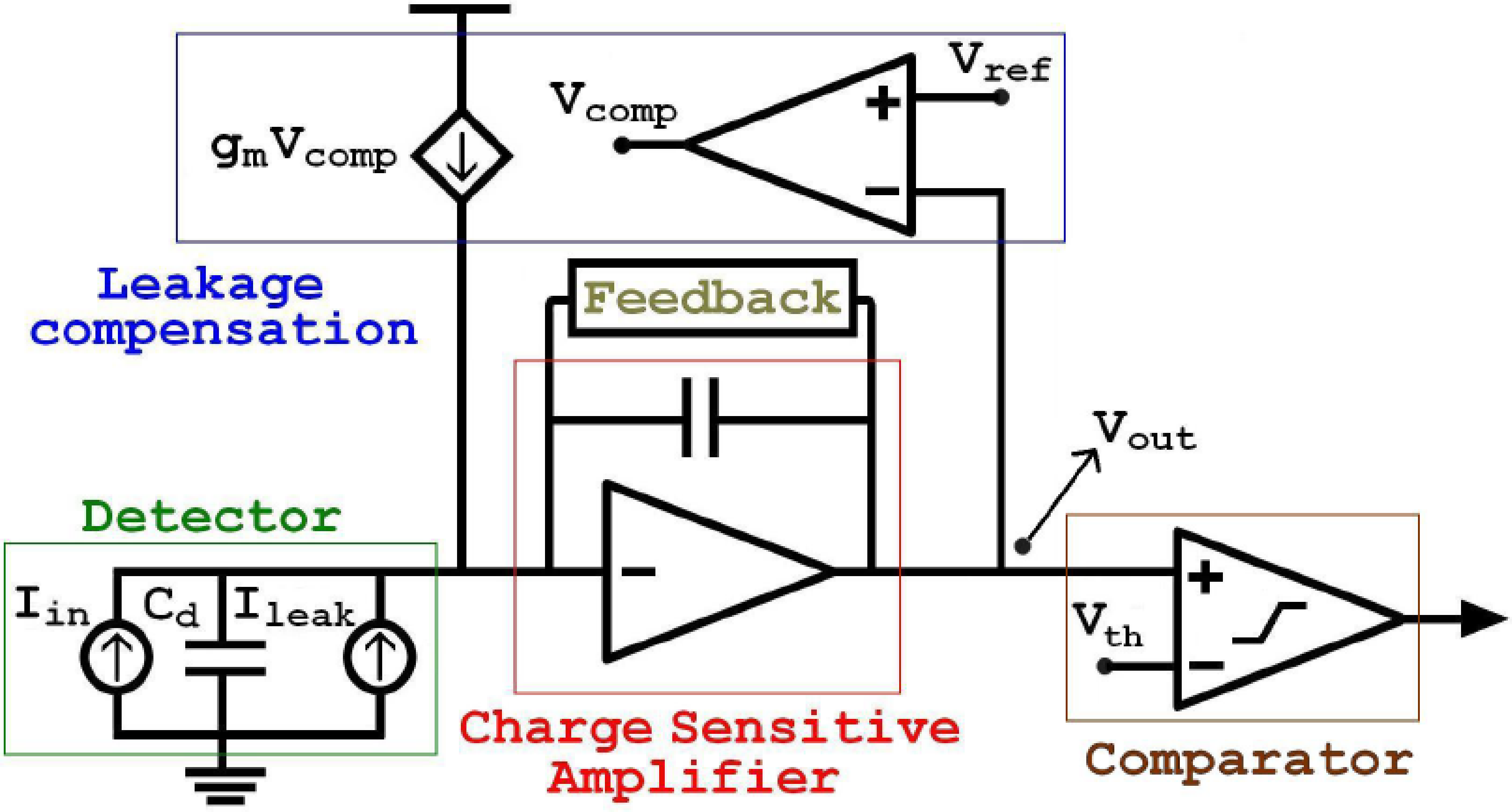
ToT Linearity Measurement



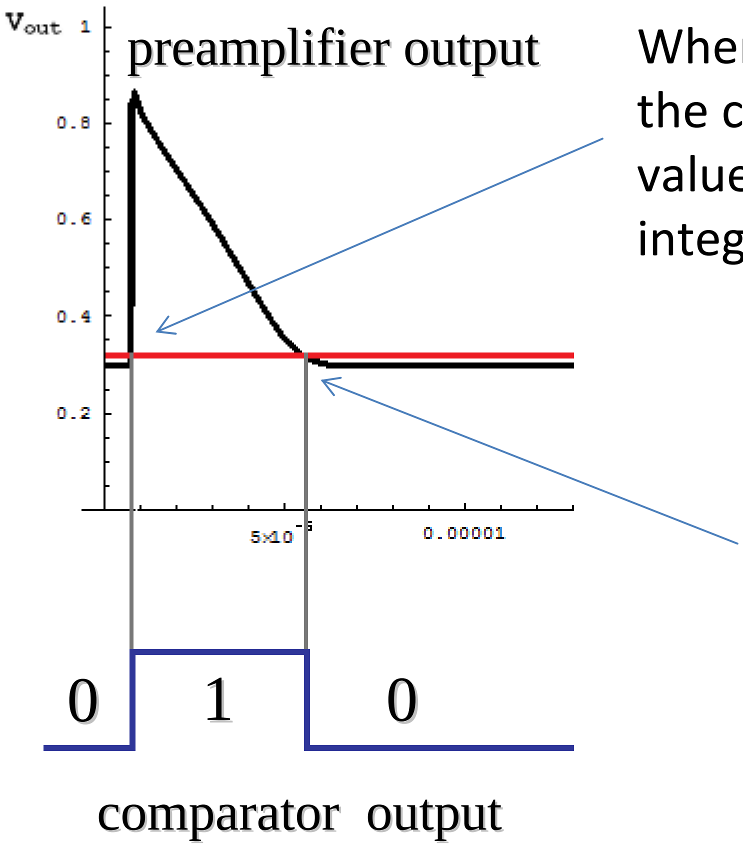
The measured average gain is 152 ns/fC with a σ of 6 ns/fC.

Analog Front-End

The analog front-end generates a pulse whose width is proportional to the injected charge by the pixel.



Comparator Output

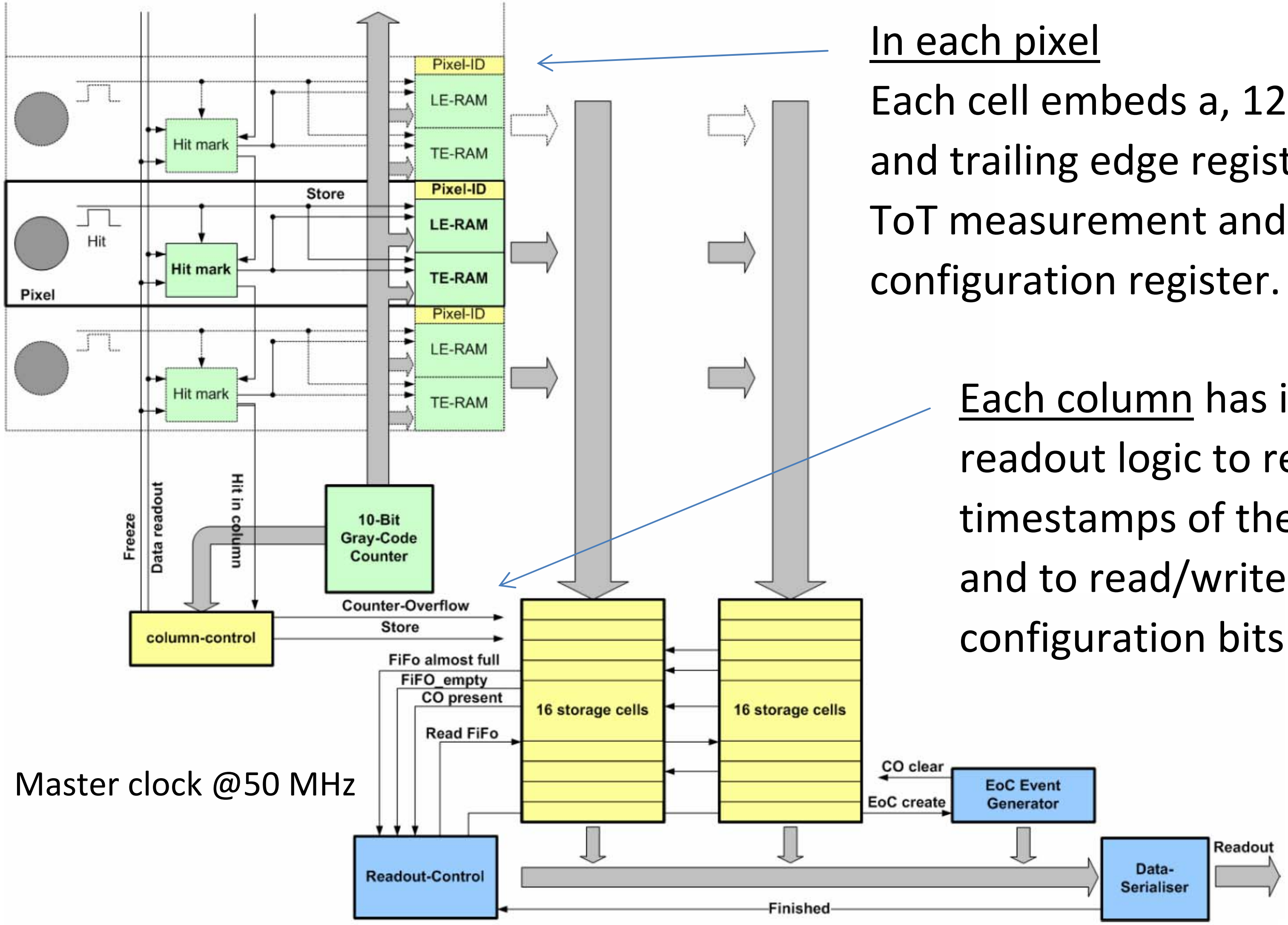


When the preamplifier output crosses the threshold, the comparator switches to 1 and the time stamp value is loaded into the leading edge register. The integrating capacitor is then slowly discharged.

When the amplifier output goes below the threshold, the comparator switches back to 0 and the time stamp value is loaded into the trailing edge register.

The time stamp value in the leading edge register gives the timing information, while the difference between leading and trailing edge time stamps gives the amplitude information

Digital Read-Out



In each pixel

Each cell embeds a, 12-bits leading and trailing edge register for time and ToT measurement and a 12 bit configuration register.

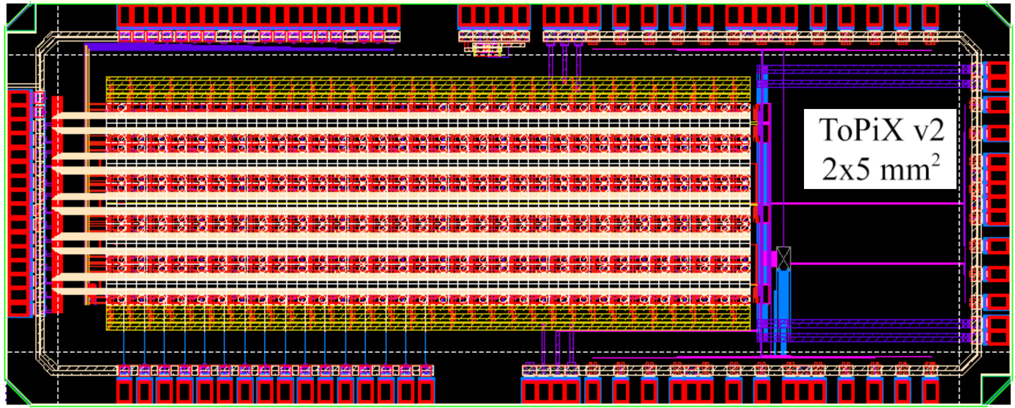
Each column has its separate readout logic to read the timestamps of the pixel cells and to read/write the configuration bits

Master clock @50 MHz

Topix 2.0

ToPix 2.0 is a reduced scale prototype chip for the hybrid pixel sensors in a CMOS 0.13 μm technology

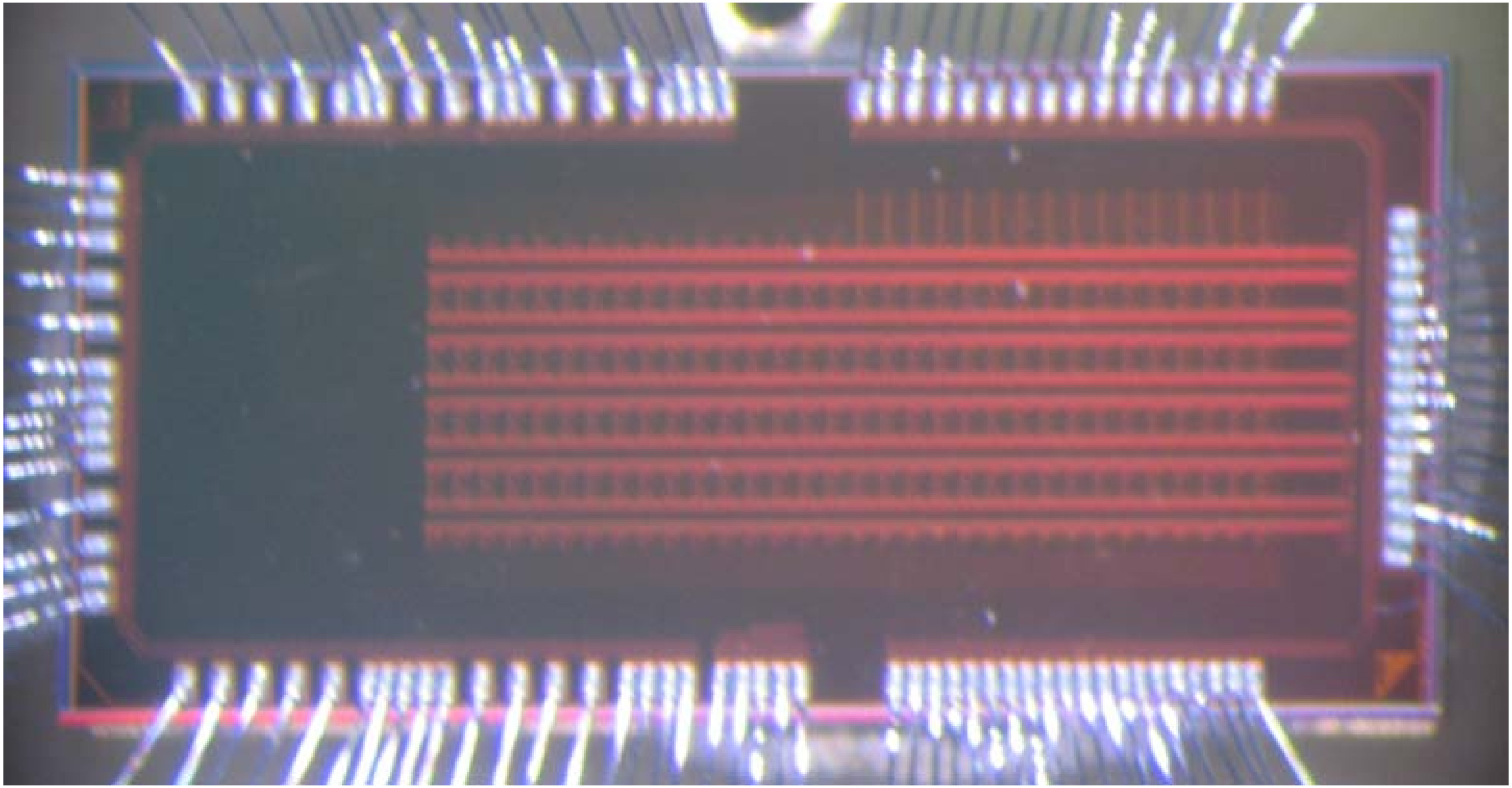
- The chip contains 384 reading pixel cell (two 128 cells and two 32 cells columns) Each **cell size is 100μm x 100μm**.



- Each cell consumes **15μW**.
- The input amplifier can be configured to accept signals of both polarities via control bits.

The final version of ToPiX will consist of a matrix of 100x100 cells with a pixel size 100 μmx100 μm, thus covering a 1 cm^2 active area.

The End



Topix 2.0.

BACKUP

Specification 1

In the final layout, the silicon pixel detector will cover an area of approximately 0.15 m^2 with 15 million pixels. The strip detector will cover an area of about 0.5 m^2 with 70.000 strips.

Parameter	**Requests**	**Different request ?**	**+ Safety factor**	**Final Specifications**
Pixel size	100 μm x 100 μm Chip: 1 cm^2, 10000 pixels	50 μm x 200 μm Chip: 1 cm^2, 10000 pixel		
dE/dx	ToT (Time over Threshold)			ToT
Charge dynamic range	100 fC (625000 e-, ~ 2.2 MeV) (90 fC for n, >100 fC for p)			
Clock	50 MHz	100 or 200 MHz		
Time resolution	5.77 ns rms @ 50 MHz (using one clock edge)	2.88 ns rm @ 50 MHz (using both clock edges)		
Time stamp	Clock defined	twice clock defined		
Data rate	800 Mbit/chip (50 bit/ev) 800 Mbit/chip (60 bit/ev) (12.3 Mhit/chip (1cm2)at max)	1.6 Gbit/chip	30% 8%	

Specification 2

Parameter	Requests	Different request ?	+ Safety factor	Specifications
Analog gain	~ 40 mV/fC			
ToT gain	180 ns/fC @ rms 5.77 ns	90 ns/fC @ rms 2.88 ns		
ToT spread				
Max ToT	18 µs @ rms 5.77 ns	9 µs @ rms 2.88 ns		
Signal polarity	Either (freedom of sensor choice)			Either
Noise quantization	~ 200 e- rms			
Noise analogue	~ 200 e- rms			
Leakage current (sensor)	50 nA/pixel			
Saturation σ for SEU				
Threshold LET for SEU				
Total Ionizing Dose (Panda lifetime)	10 Mrad			
Neutron fluence (Panda lifetime)	$5 \cdot 10^{14}$ n 1MeV eq./cm^2			
Power to dissipate	~ 750 mW/cm^2		33%	

Charge resolution

The charge resolution depends on the discharging current value and on the sampling frequency of the comparator output signal.
The equivalent input charge noise is ~ 200 e, our aim is to measure the charge with a lower resolution.

$$\delta Q = \frac{1}{f_c}\frac{\partial Q}{\partial t}\frac{1}{\sqrt{12}} = \frac{I_{dis}}{f_c}\frac{1}{\sqrt{12}} \Rightarrow I_{dis} = \delta Q f_c \sqrt{12}$$

With a discharging current I_{dis} = 5 nA, the charge resolution is:
dQ = 2.89 10^{-17} C
Equivalent to 180 e.

Read Out Electronics Requirement

The spatial resolution should be better than 100 *μm* along the beam axis (z-direction) to recognize *DD* events as decay products of *cc resonances. In addition* the resolution in r/ϕ direction should not be sufficiently worse for a good momentum measurement.
detection of secondary vertices from the decay of charmed mesons as well as those from kaons and hyperons.
The primary task of the MVD is the detection of charged particle hits with a resolution that yields an overall spatial accuracy better than the characteristic decay lengths of the involved particles, as D mesons.