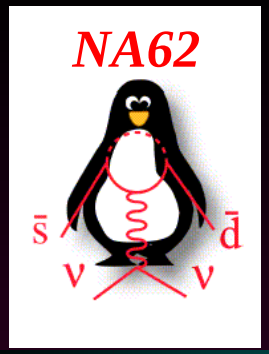


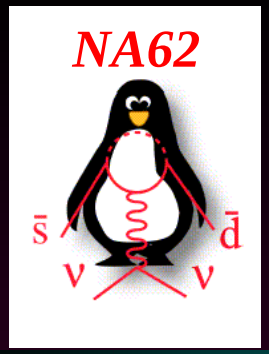
NA62 GTK

Sezione di Torino

A Silicon Pixel Readout ASIC with 100 ps time resolution for the NA62 Experiment

G. Dellacasa[a], S. Garbolino[a,b], F. Marchetto[a], S. Martoiu[a], G. Mazza[a], A. Rivetti[a], R. Wheadon[a]

[a] *INFN sez. di Torino, Italy*
[b] *DFS Università di Torino, Italy*



Outline

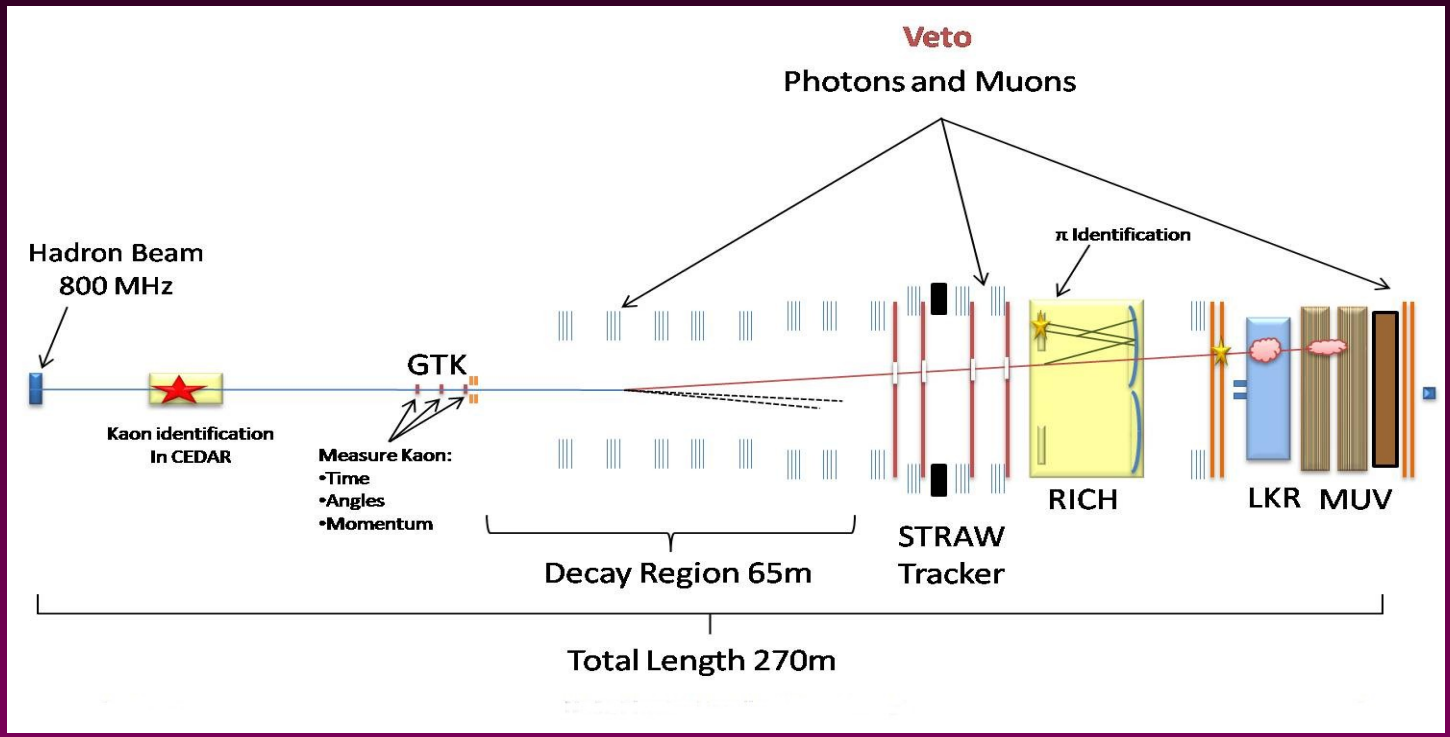
Sezione di Torino

- The NA62 GigaTracker detector
- Readout requirements and architectural options
- On-pixel TDC option (pTDC)
- Test results
- Conclusions

The NA62 experiment

Sezione di Torino

Goal : study of the rare decay $K^+ \to \pi^+ \upsilon \bar{\upsilon}$



20% K^+ decays in the vacuum region, only 10^{-11} is of interest.

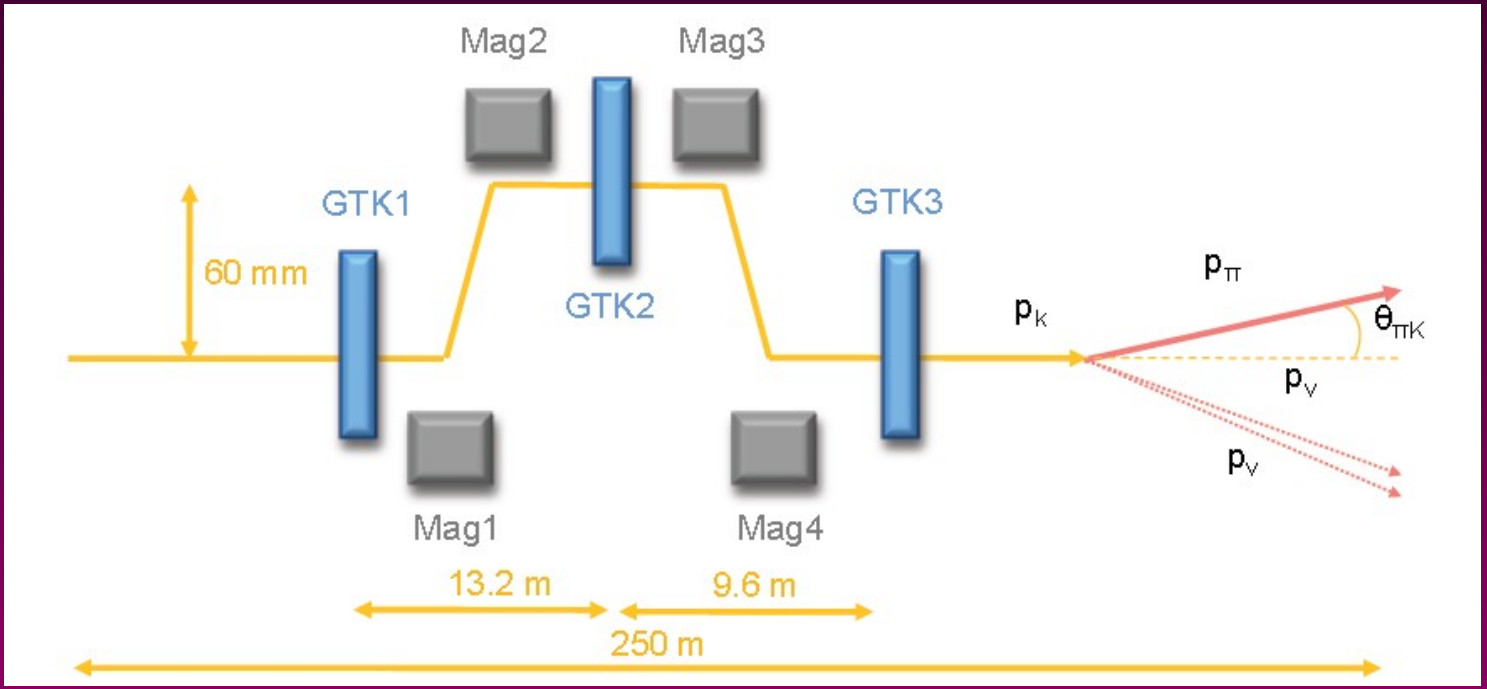
Only ~80 events expected in 2-3 years of data taking .

To match tracks between the GTK and the straw Tracker @ $0.8 \cdot 10^9$ particles/s, a 150 ps r.m.s. time resolution is required.

NA62 Gigatracker

Sezione di Torino

The GTK consists of 3 stations of hybrid pixel sensors operating in vacuum.
Station size : 60 mm × 27 mm
Pixel size : 300 μm × 300 μm
Max beam intensity (central region) : $1.5 \cdot 10^6$ particles/(mm^2·s)



Spatial resolution :
± 150 μm

Time resolution :
200 ps per station
150 ps total

Material budget :
0.5% X_0

F/E specifications

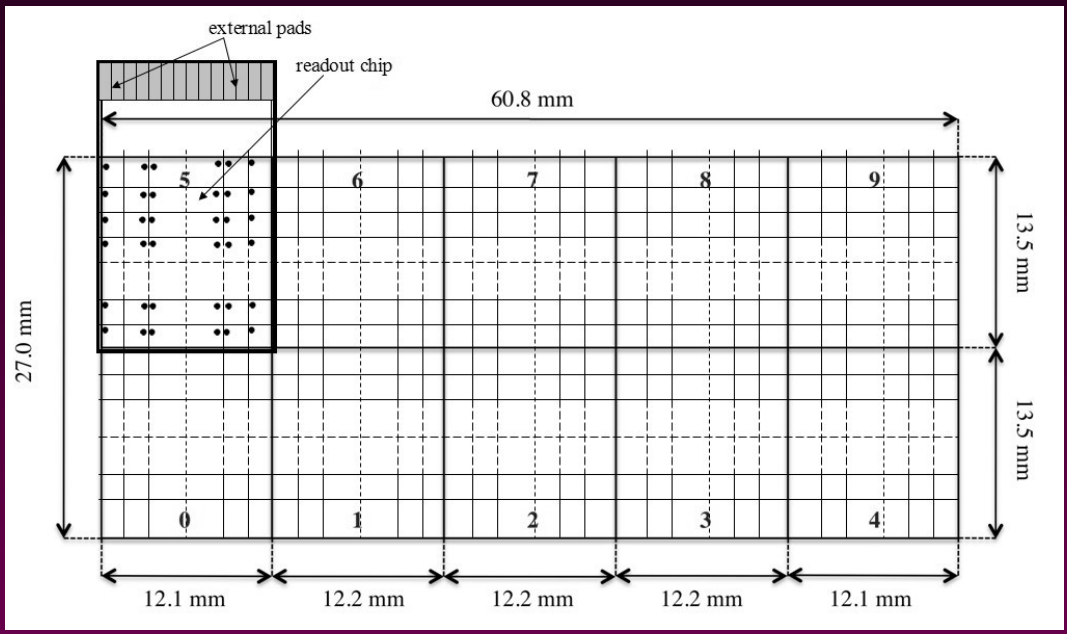
Sezione di Torino

Station readout : 2× 5 F/E chips
F/E active area : 12.1 mm × 13.5 mm
Pixel size : 300 μm × 300 μm
Pixel matrix : 45 rows × 40 columns

Input signal : 0.6÷10 fC

Max rate/chip : $130 \cdot 10^6$ particles/s
Max rate/pixel : $140 \cdot 10^3$ particles/s
Data rate (avg) : 4.2 Gb/s
Data rate (max) : 6 Gb/s

Total dose : 10^5 Gy/year
Power budget : < 2 W/cm^2
Operating temperature : < 5 °C
Trigger latency : < 1 ms



Main challenges for electronic R/O :

- time-walk compensation
- required n. of TDCs
- data transmission

Readout options

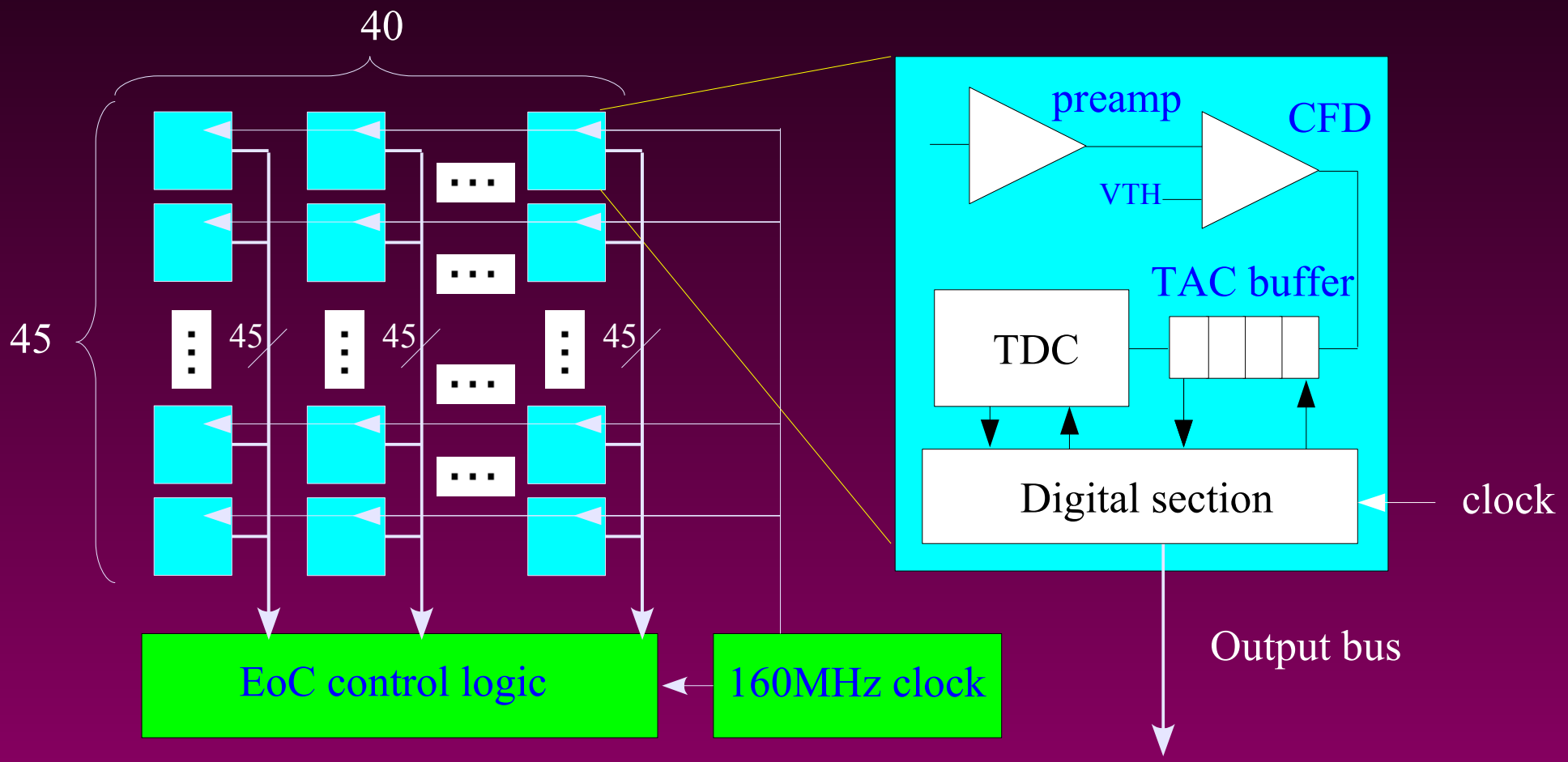
Sezione di Torino

Two approaches have been investigated :

- pTDC :
  - time walk compensation via CFD
  - TAC-based on pixel TDC
    - → *this presentation*
- EocTDC :
  - time walk compensation via ToT correction
  - DLL-based TDC at the end of the column
    - → *M. Noy presentation (later in this session)*

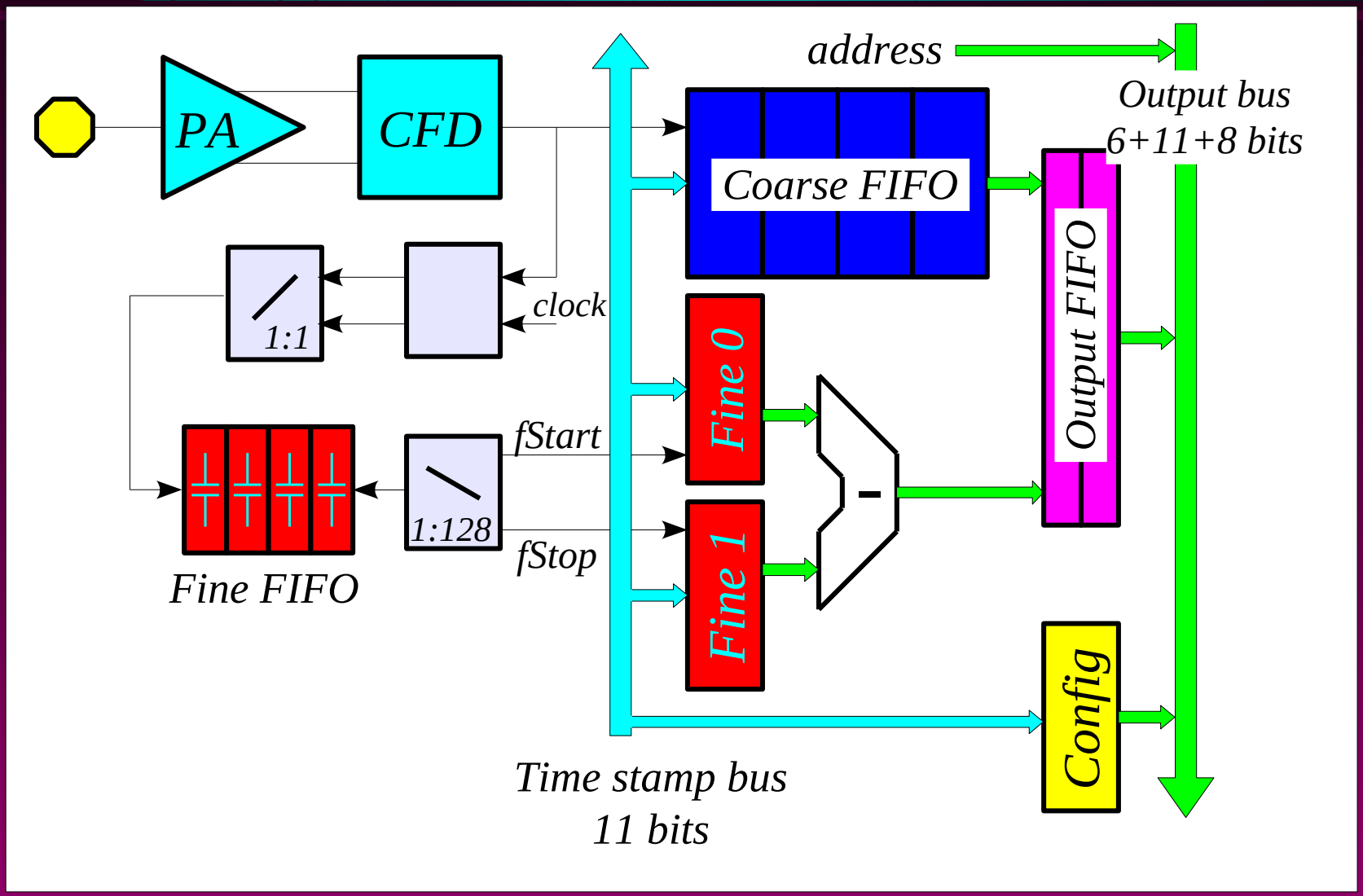
pTDC architecture

Sezione di Torino



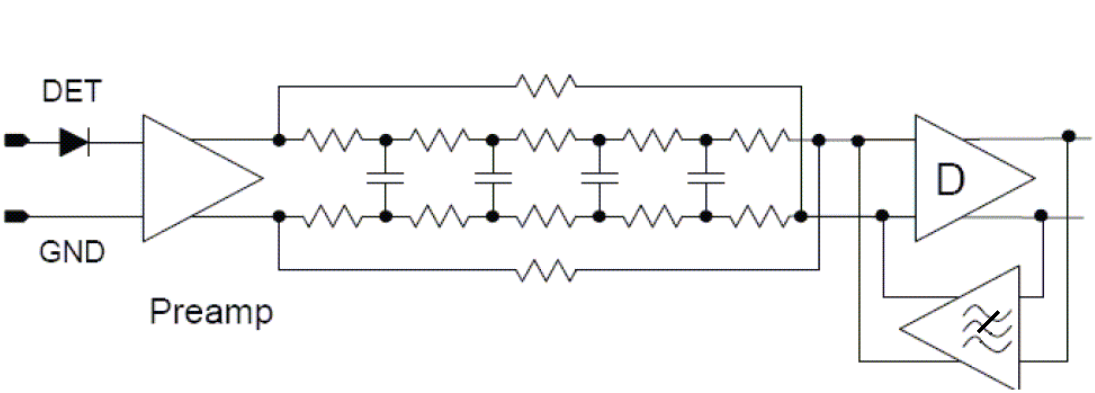
Pixel schematic

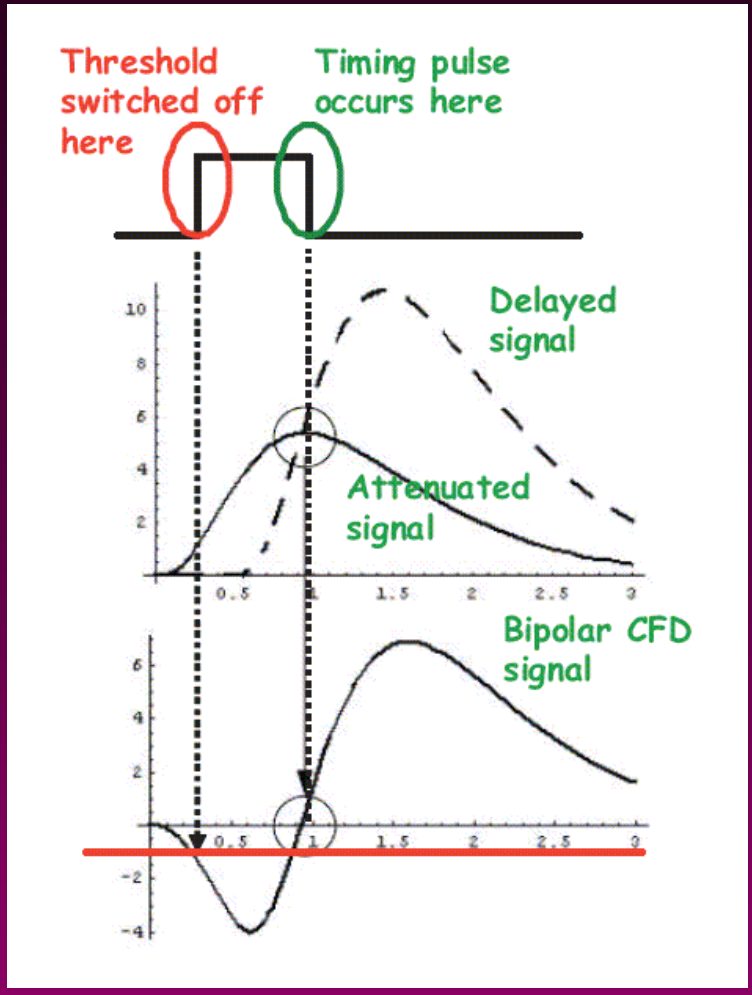
Sezione di Torino



CFD

Sezione di Torino



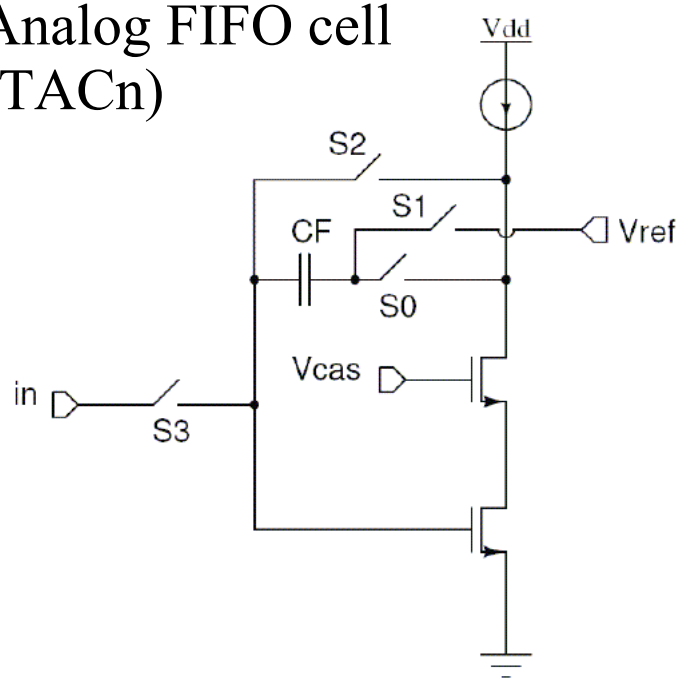


→ Fully differential implementation
→ RC passive net to implement delay
→ Attenuation factor : 0.3 or 0.5

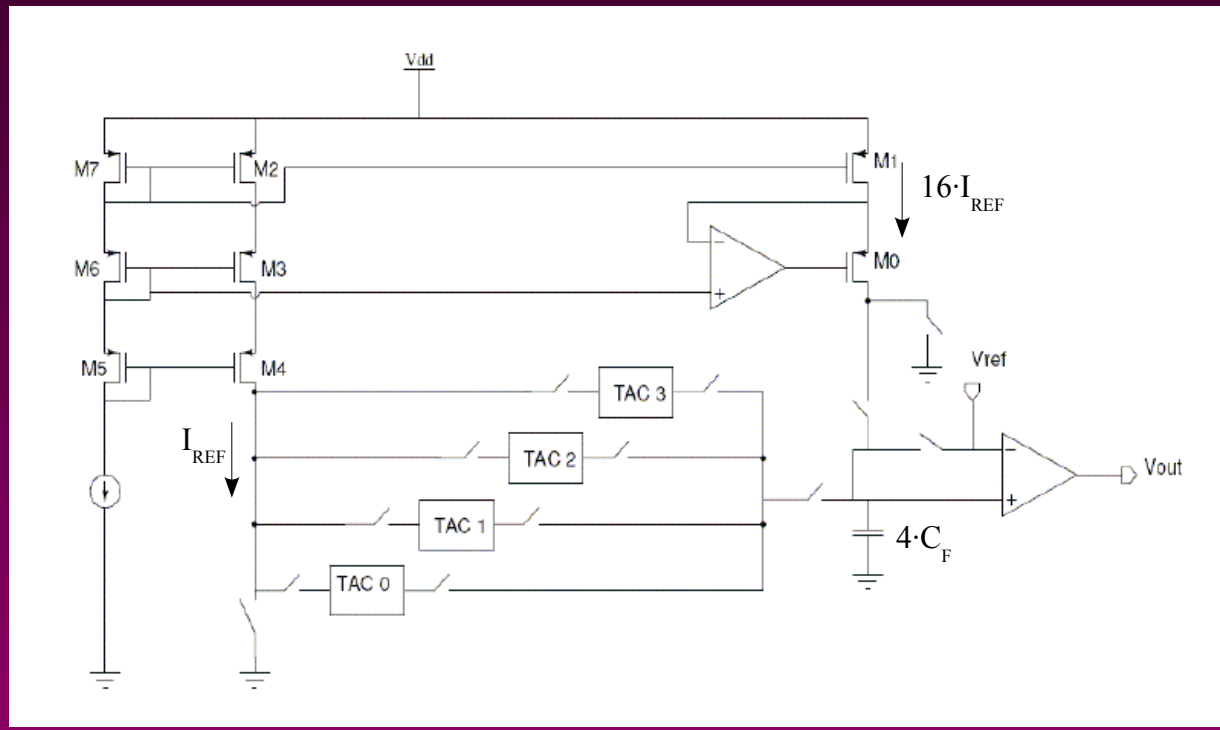
TAC-based TDC

Sezione di Torino

Analog FIFO cell (TACn)



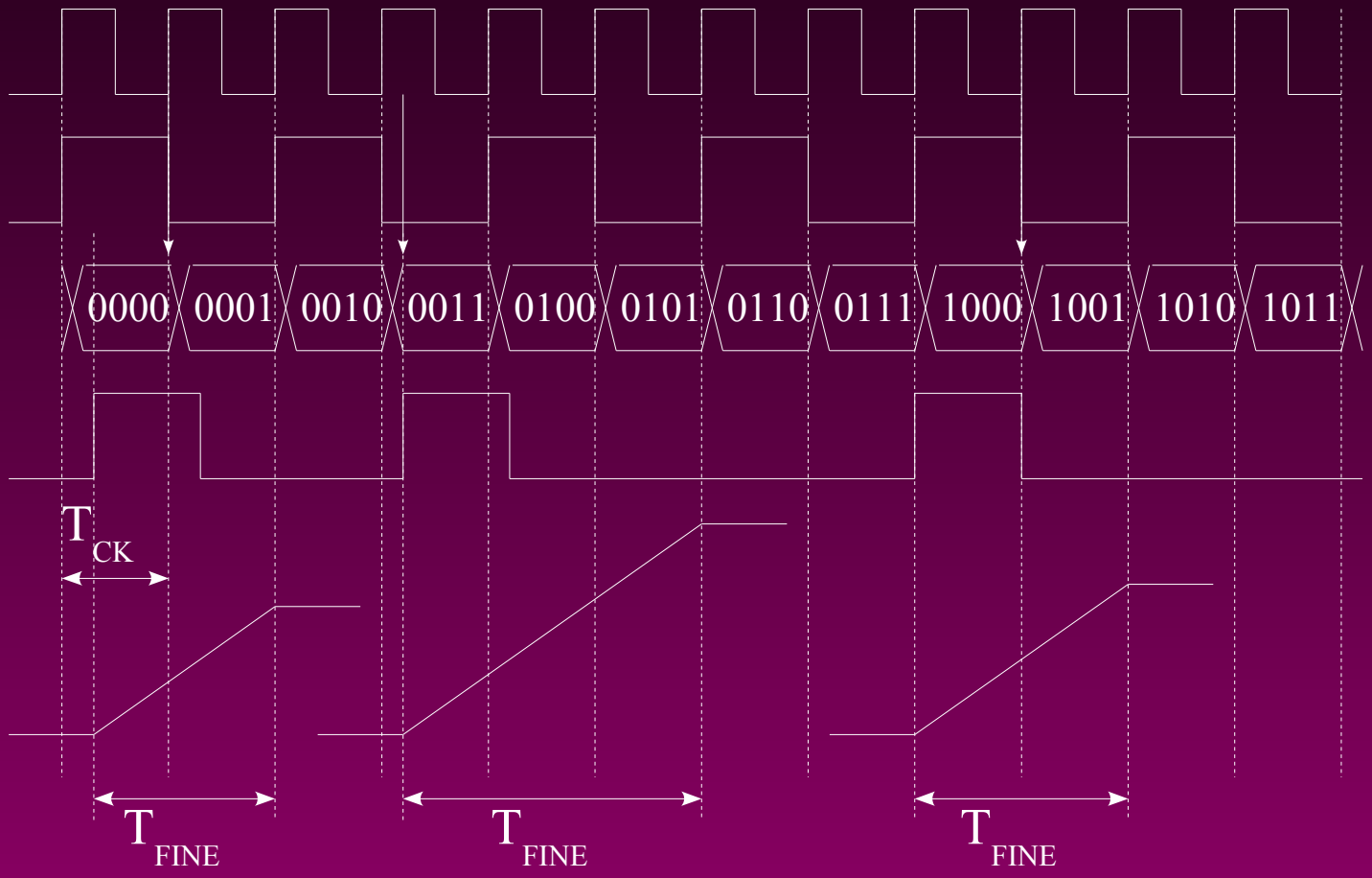
	$T_{RAMP\text{-}UP}$	T_{RAMP_DOWN}	Count
MIN	6.25 ns	400 ns	64
MAX	18.75 ns	1.2 µs	192



S0, S3 *OFF*, S1, S2 *ON* : reset
S0, S3 *ON*, S1, S2 *OFF* : operation

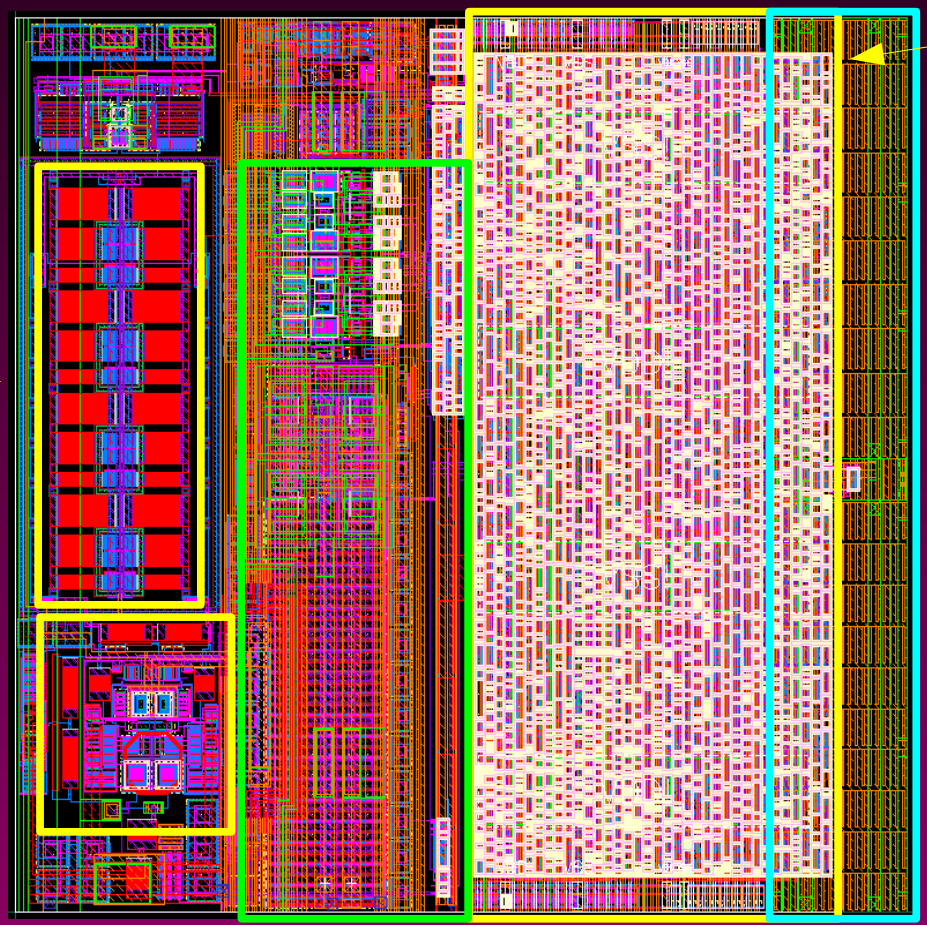
Time measurement

Sezione di Torino



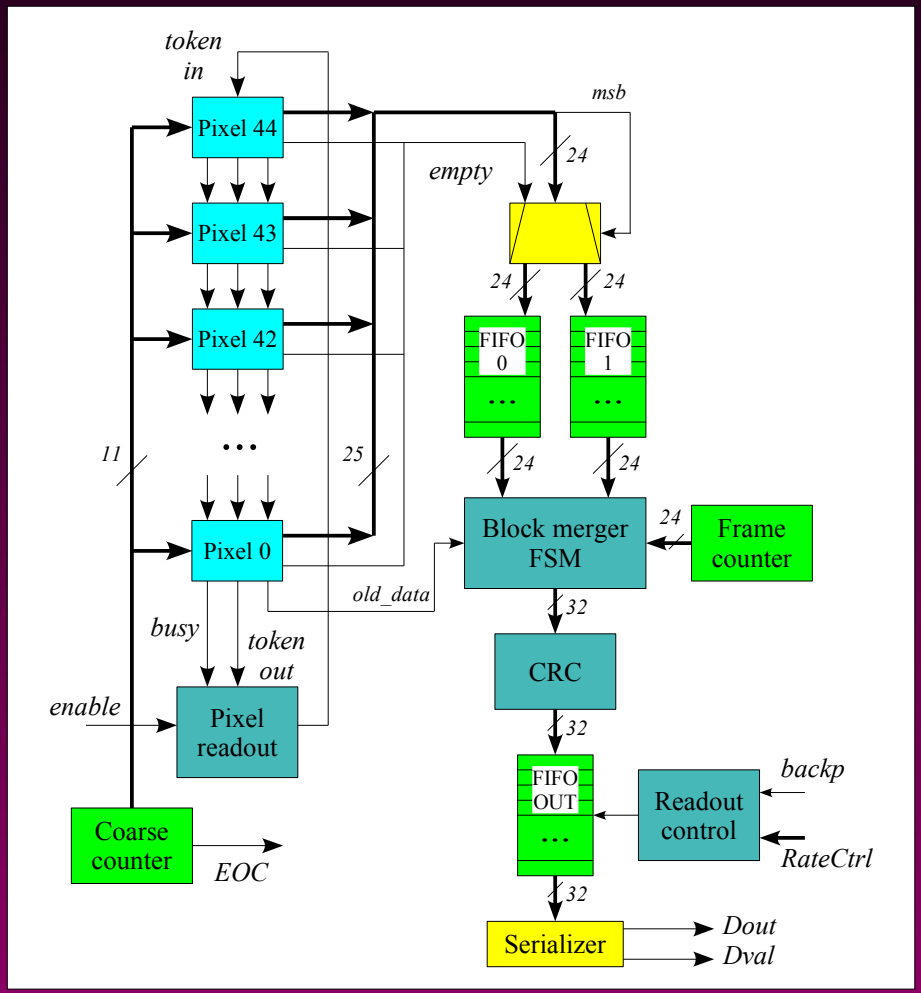
Cell layout

Sezione di Torino

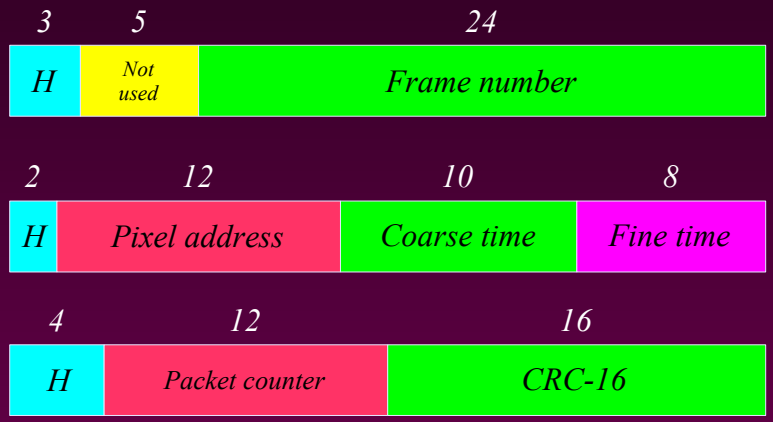


End of column logic

Sezione di Torino



Output packet format :



	Range	Resolution
Fine time	6.25÷18.75 ns	98 ps
Coarse time	6.4 μs	6.25 ns
Frame	107.3742 s	6.4 μs

GtkTo prototype

Sezione di Torino

- Two 45-cells column + one 15 cells column
- Full pixel cell with bump bonding pad
- Full end of column buffers and readout
- SEU protection via Hamming encoding
- Technology CMOS 0.13 µm
- Die size 4 mm × 5 mm
- *High speed serializer not yet implemented*

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Prototype layout

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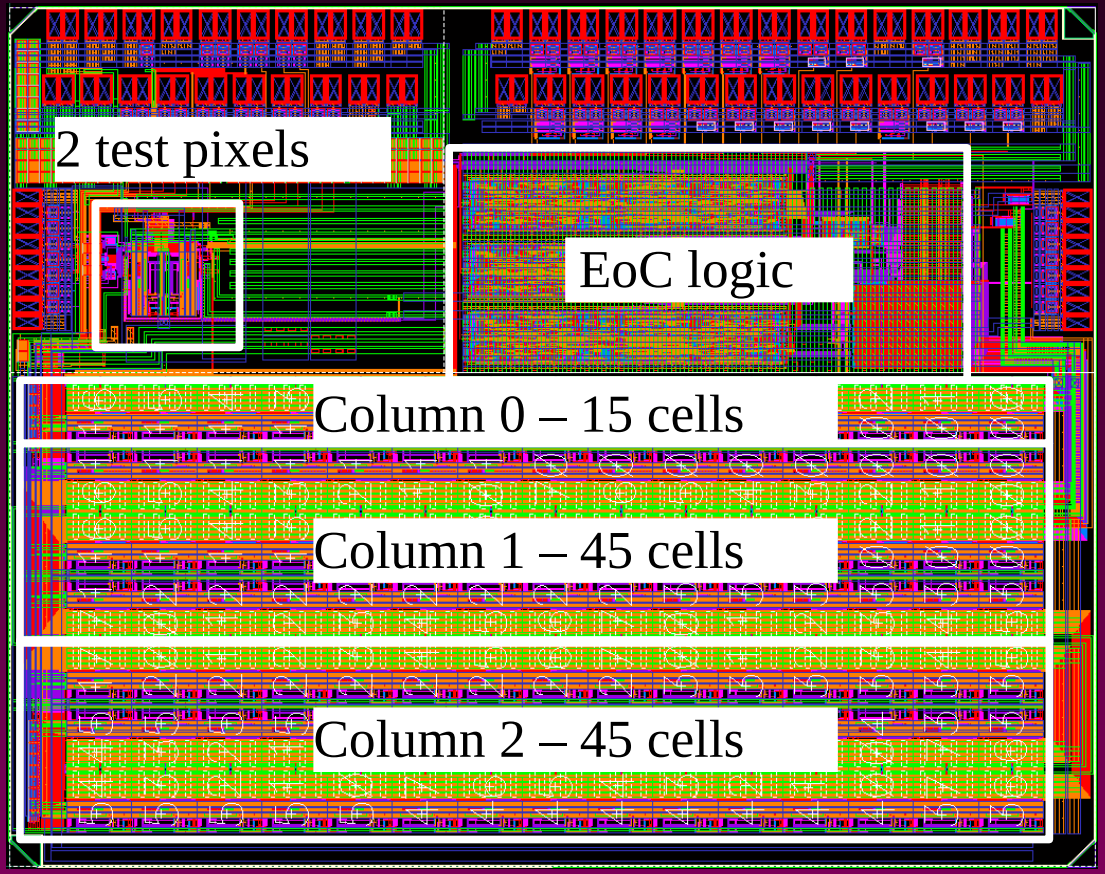

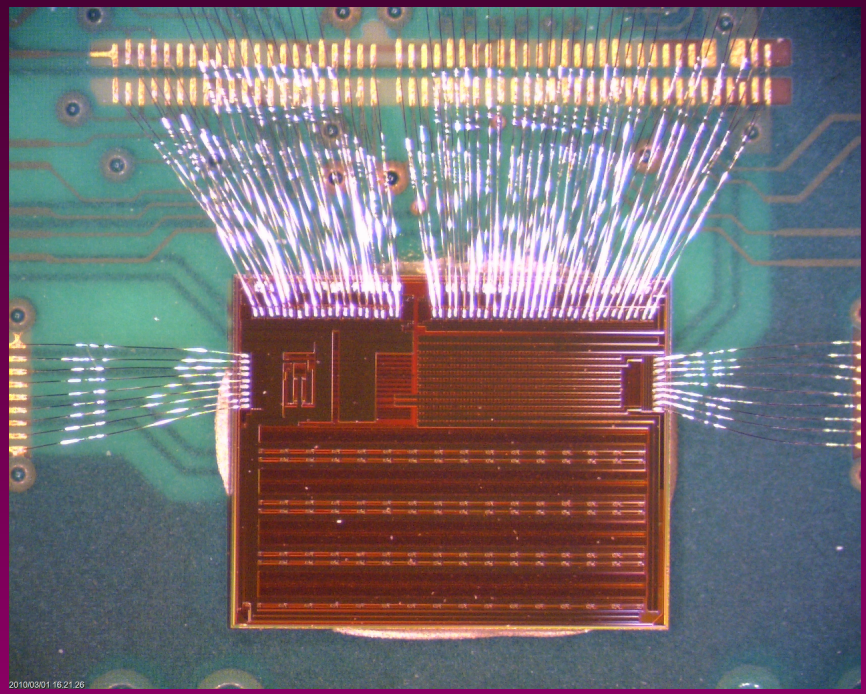

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Test boards

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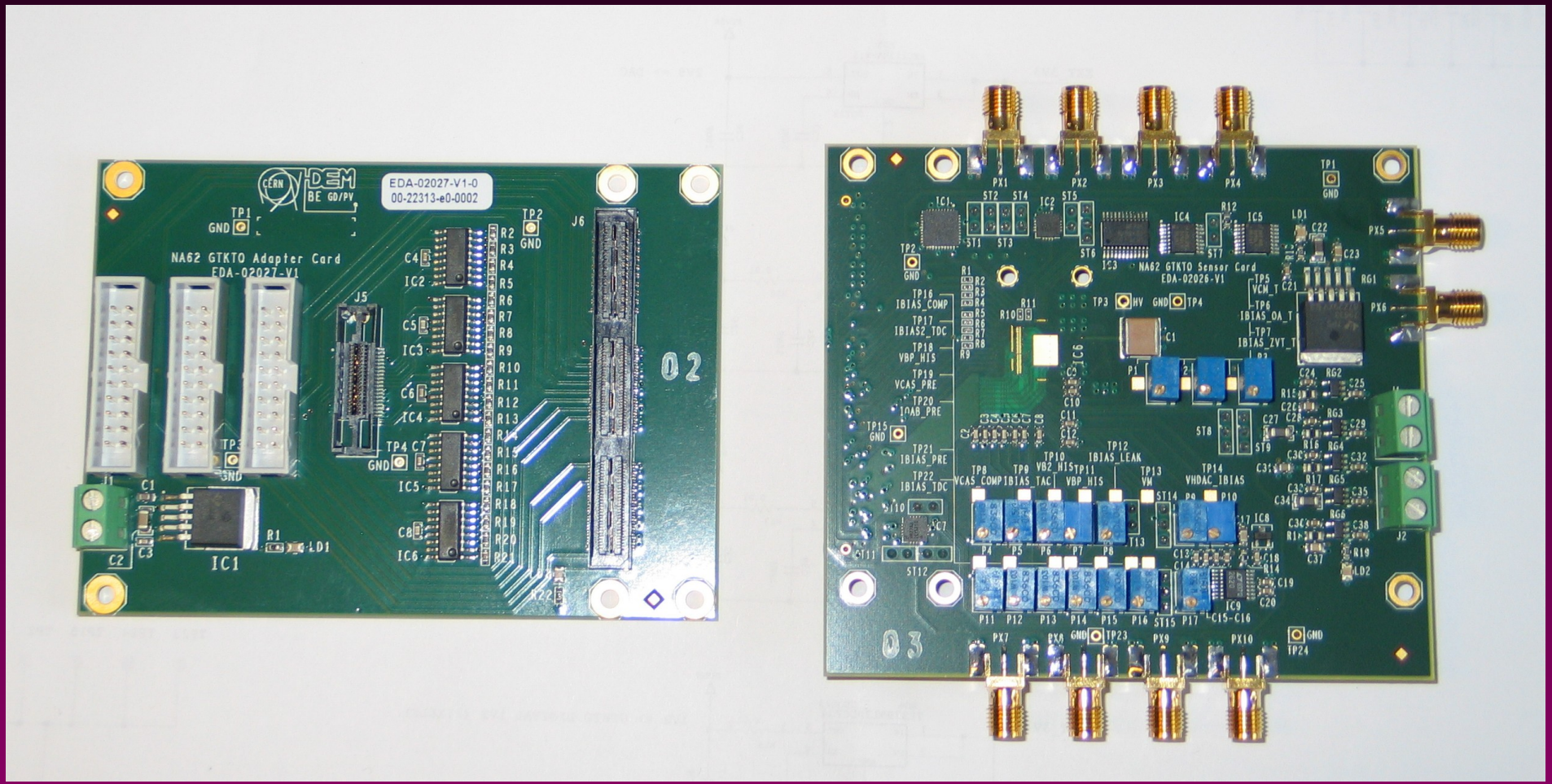
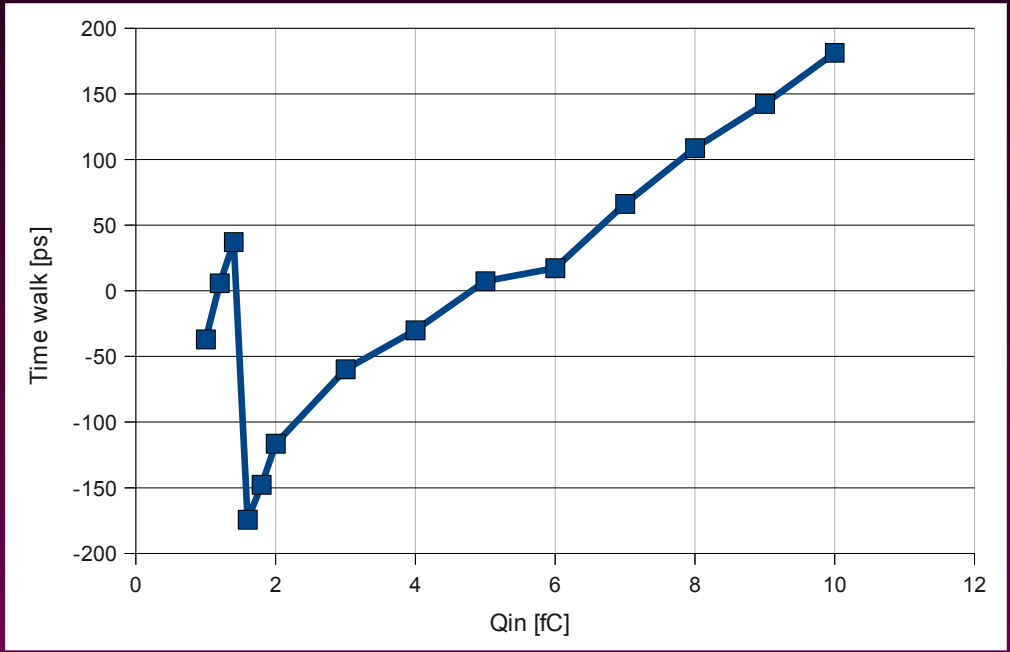
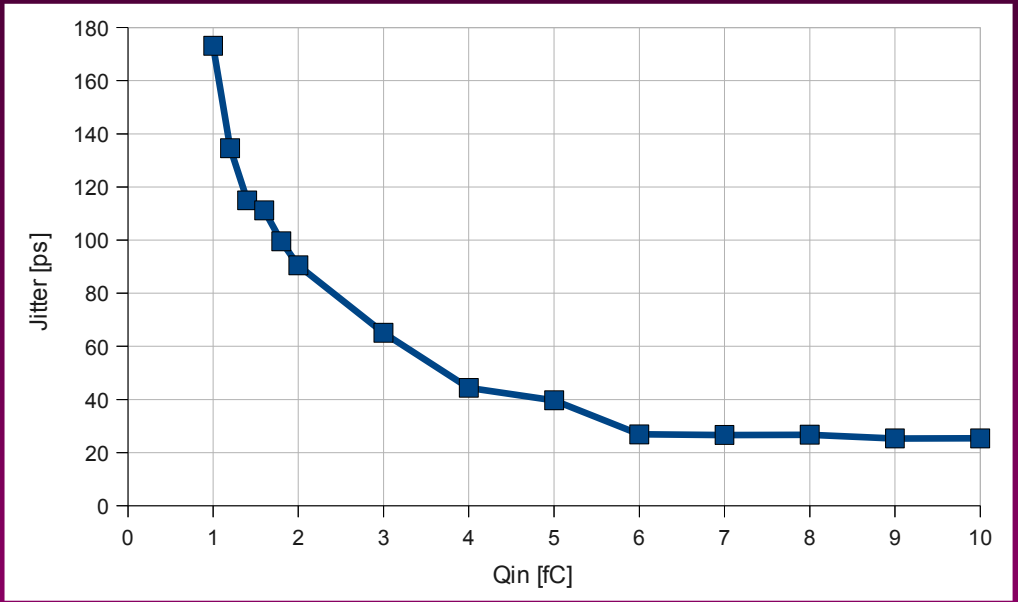
Sezione di Torino



CFD results

Sezione di Torino

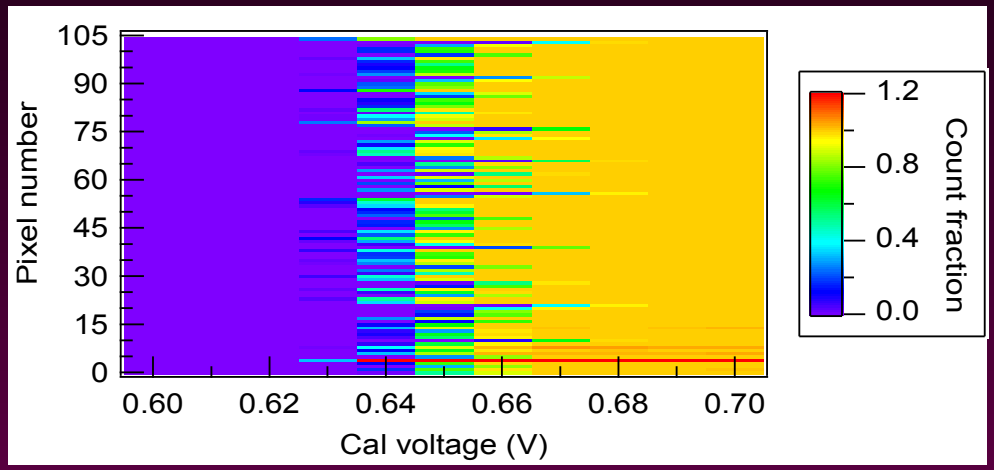


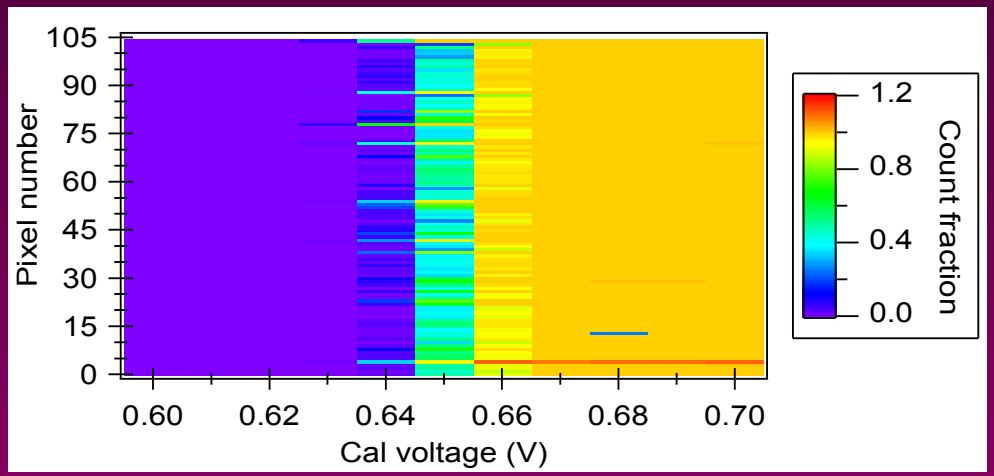


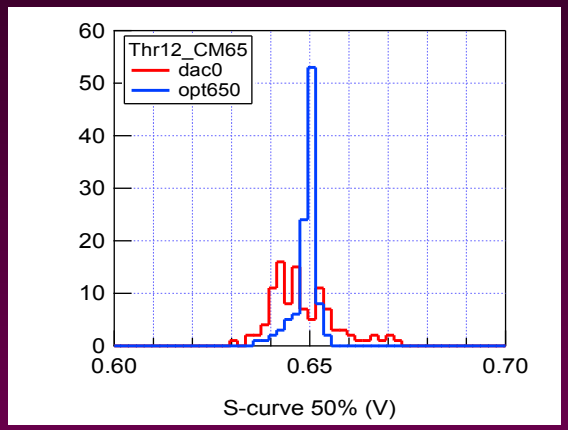
Time walk contribution (rms) : 103 ps
Jitter contribution : < 180 ps

Efficiency

Sezione di Torino







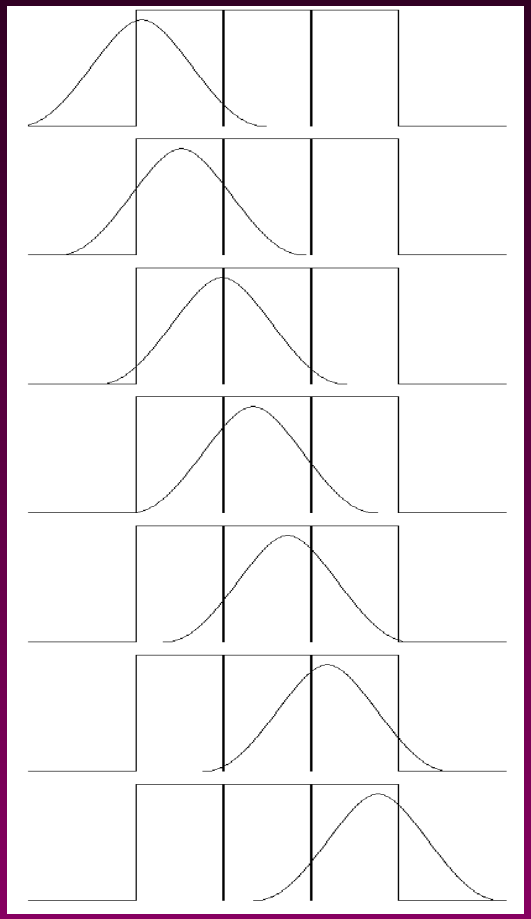
Pixel efficiency before and after calibration (via on pixel DAC)

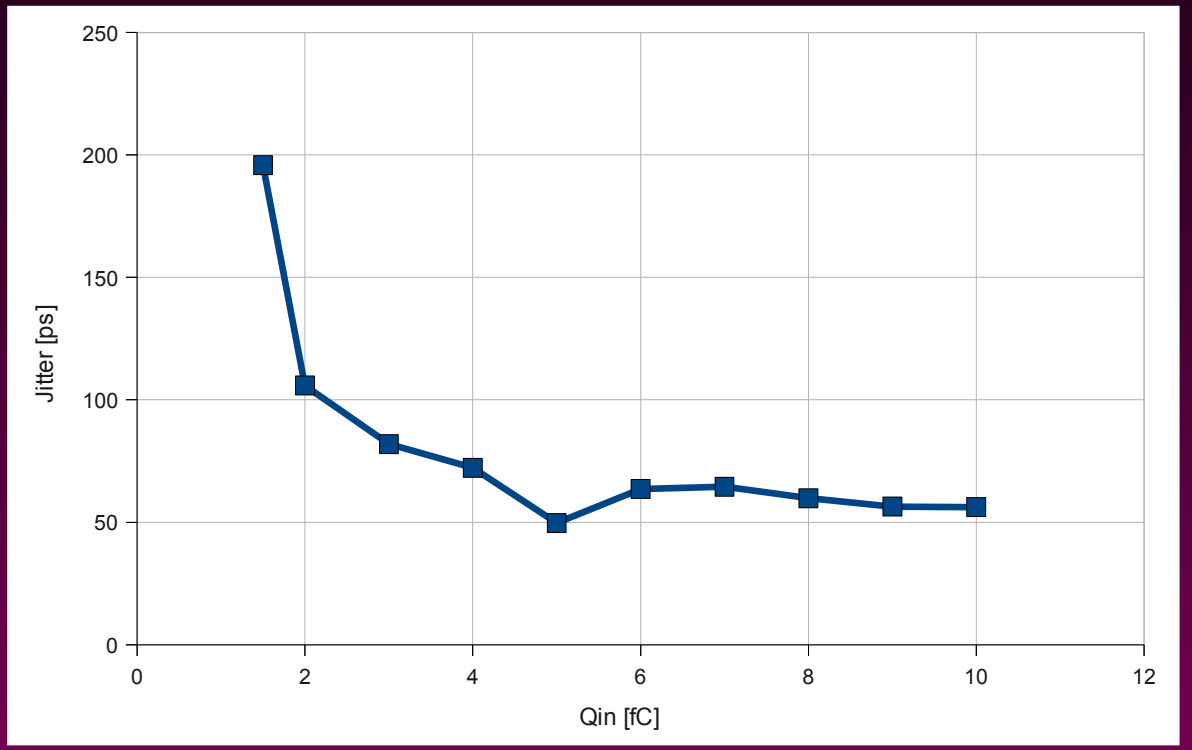
1 fC ≈ 45 mV

Jitter

Sezione di Torino

time bin: i-1 i i+1





Test pulse moved in steps of 20 ps
CFD output signal counted
Jitter : rms value of the obtained distribution

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TDC performances

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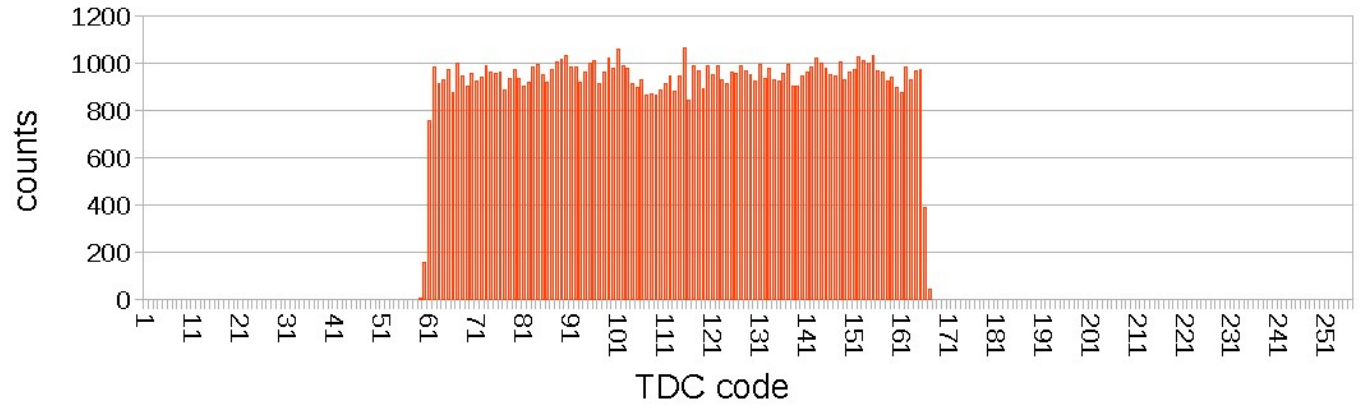
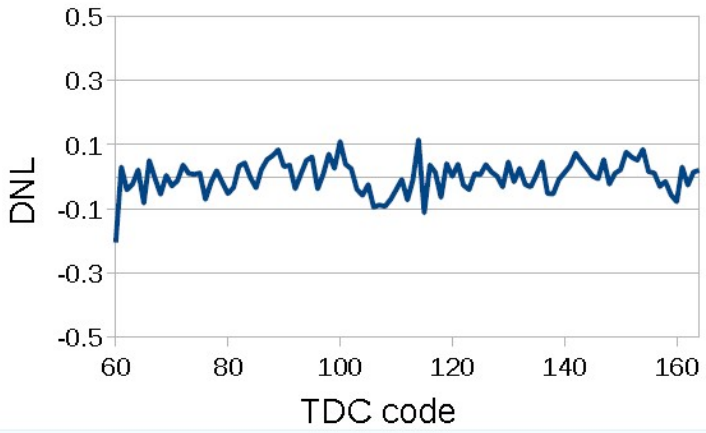
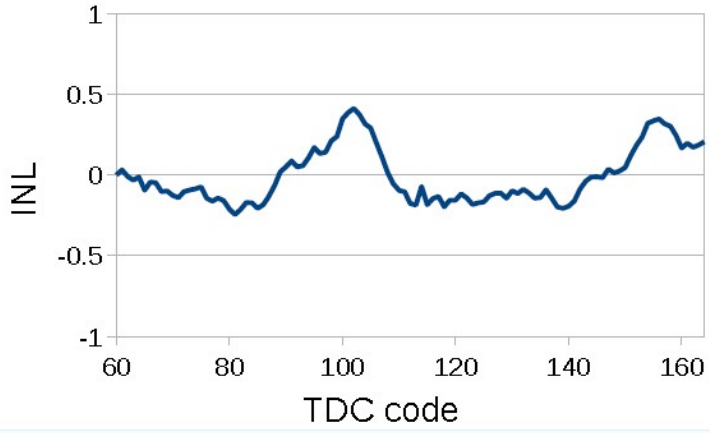






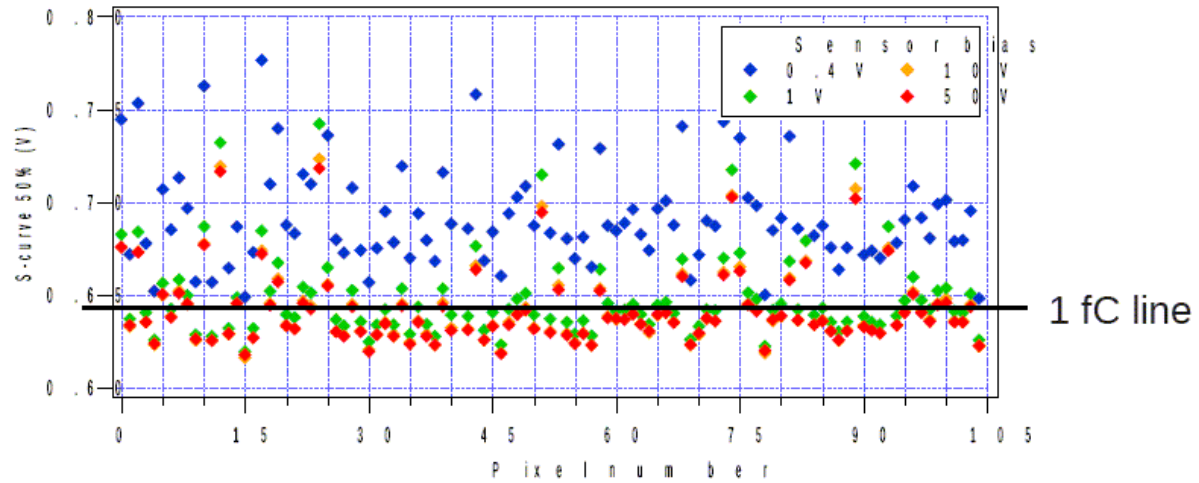
10^5 random test pulses

TDC range (theor.) :
64-191
TDC range (meas.) :
59-162

→ Gain error due to a systematic offset *to be corrected in the next version*

Preliminary tests with detector

Sezione di Torino



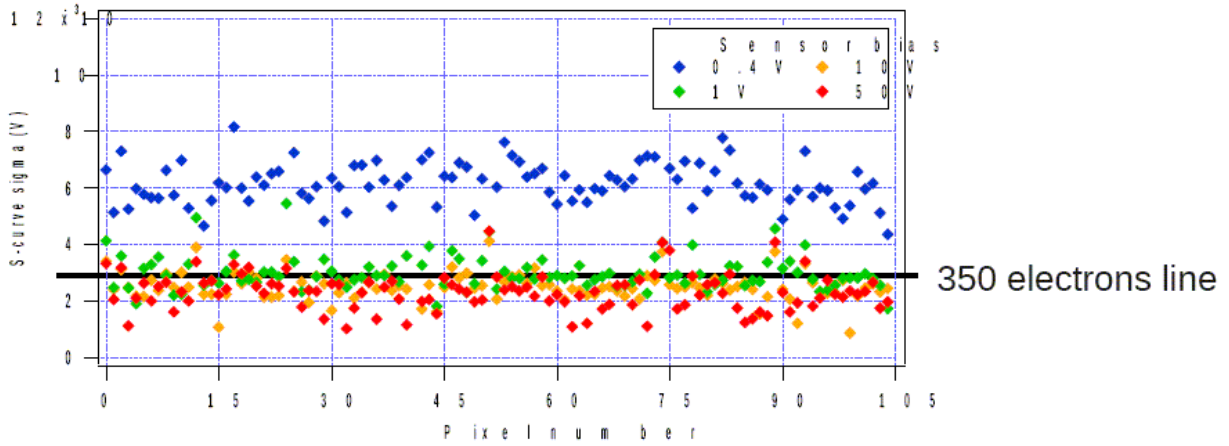
- no failure in bump bonding
- no sign of oscillations

still work in progress :

- no threshold equalization here
- no bias equalization

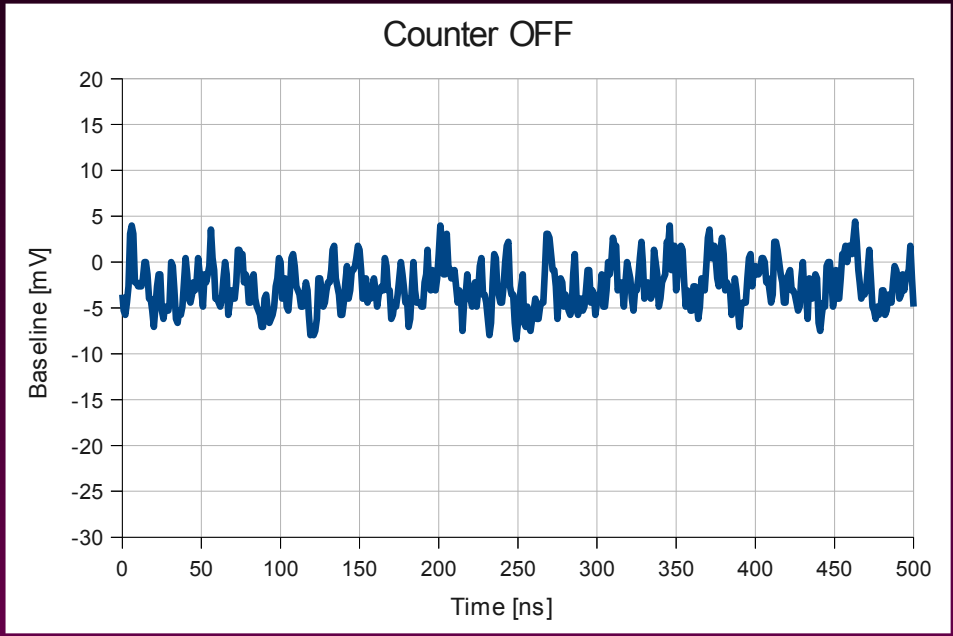
- noise decreases sharply with sensor bias
- no improvement above 50 V

A beam test is ongoing right now...

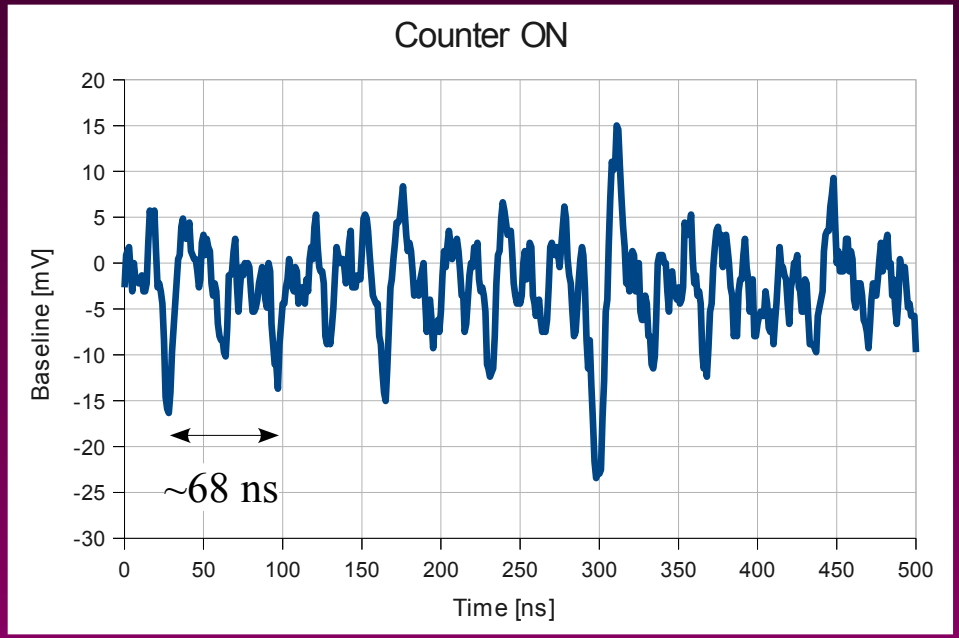


Baseline variations

Sezione di Torino

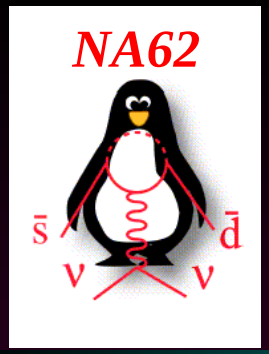


Counter OFF : baseline variation ~12 mV (pk-pk)
Counter ON : baseline variation ~ 40 mV (pk-pk)



Digital noise substrate coupling is an issue.
To alleviate the problem :

→ separate bulk from drain in digital nMOS
→ triple well nMOS for bus drivers



Conclusions

Sezione di Torino

- A SPD readout architecture with 100 ps rms time resolution based on one TDC per pixel has been proposed
- A reduced scale prototype in a CMOS 0.13 μm technology has been designed and tested
- Overall results shows that the proposed architecture can achieve the required resolution
- A substrate noise problem has been identified and will be corrected in the next version
- Tests with detector ongoing.

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Backup slides

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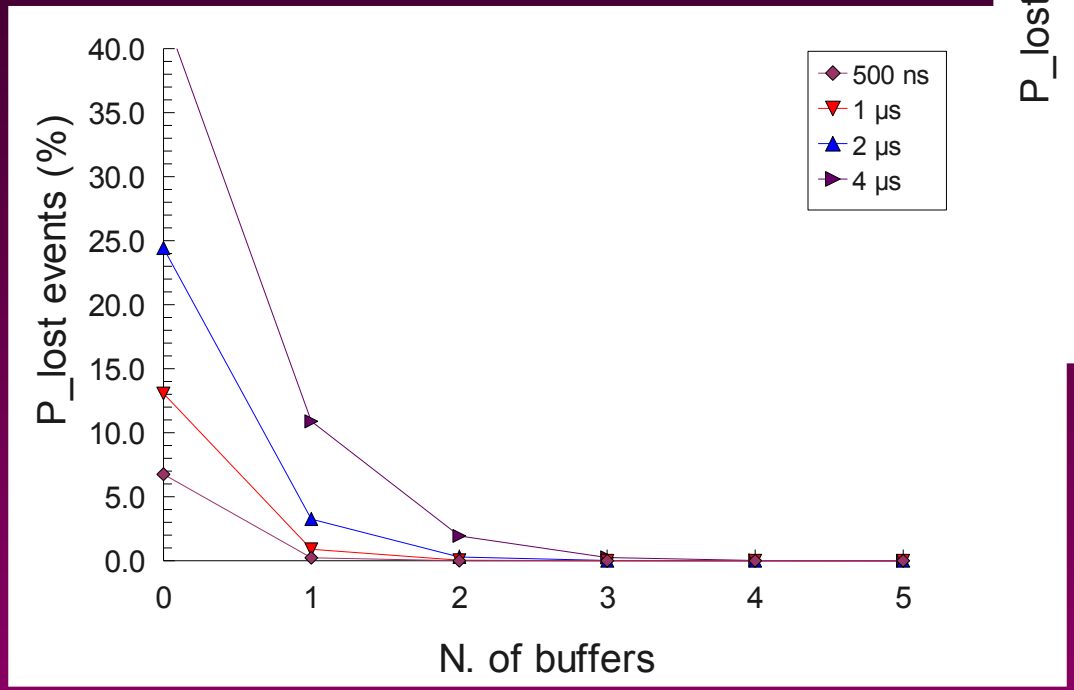
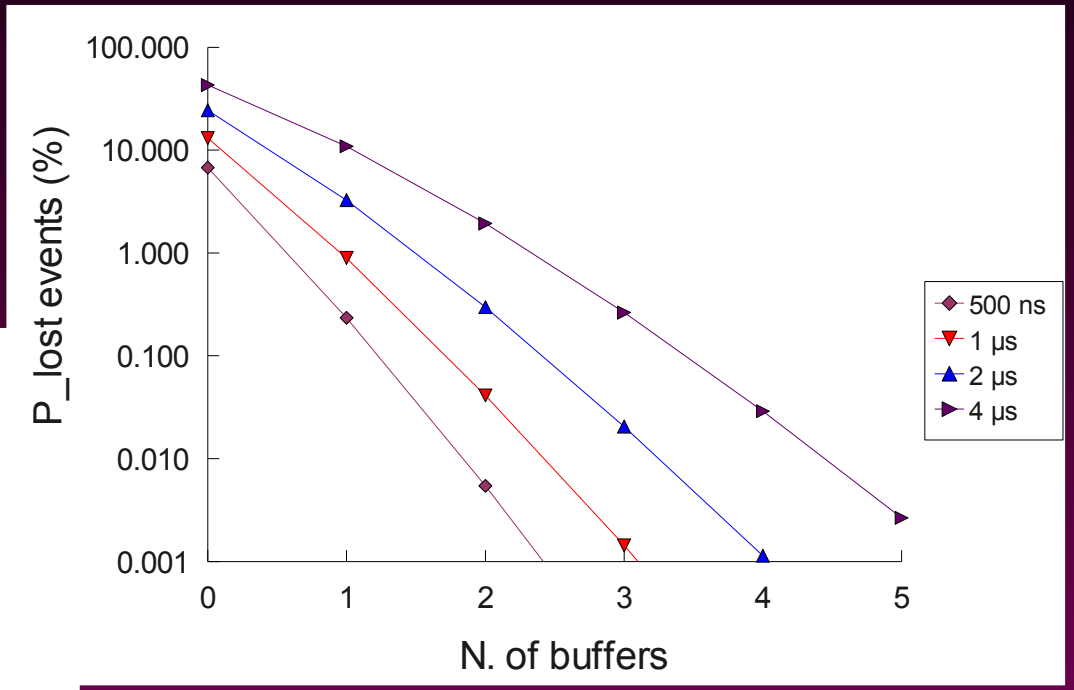
Sezione di Torino

Backup slides

Multi-event buffering

Sezione di Torino





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Simulations

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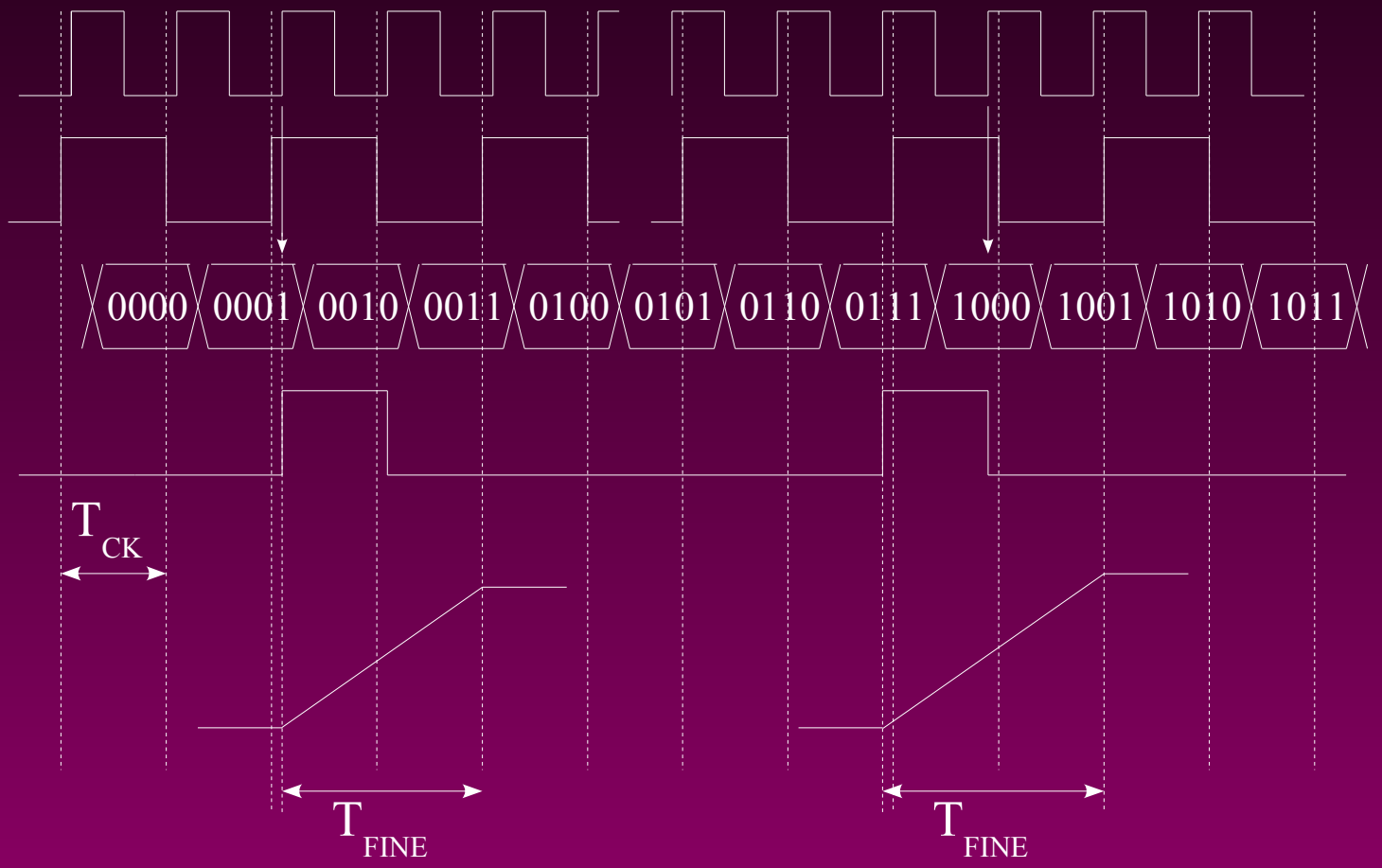
VHDL simulation of the architecture with $1 \cdot 10^4$ events

Hit rate [$\times 10^3$]	*Dead time lost events*	*Coarse FIFO lost events*	*Output FIFO lost events*
140	*18*	*0*	*0*
160	*18*	*0*	*0*
180	*19*	*0*	*0*
200	*25*	*1*	*0*
220	*22*	*0*	*0*
240	*26*	*1*	*0*
260	*28*	*3*	*0*
280	*31*	*4*	*0*

Time correction



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Correction table

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Coarse LSB	Fine MSB	Fine Counter	Time
0	0	$FC < 128$	$T = T_{COARSE} + 2 \times T_{CK} - T_{FINE}$
1	1	$FC \geq 128$	$T = T_{COARSE} + 3 \times T_{CK} - T_{FINE}$
0	1	$96 \leq FC < 160$	$T = T_{COARSE} + 2 \times T_{CK} - T_{FINE}$
1	0	$96 \leq FC < 160$	$T = T_{COARSE} + 3 \times T_{CK} - T_{FINE}$
1	0	$FC < 96$	$T = T_{COARSE} + T_{CK} - T_{FINE}$
0	1	$FC \geq 160$	$T = T_{COARSE} + 4 \times T_{CK} - T_{FINE}$

TDC uniformity

Sezione di Torino