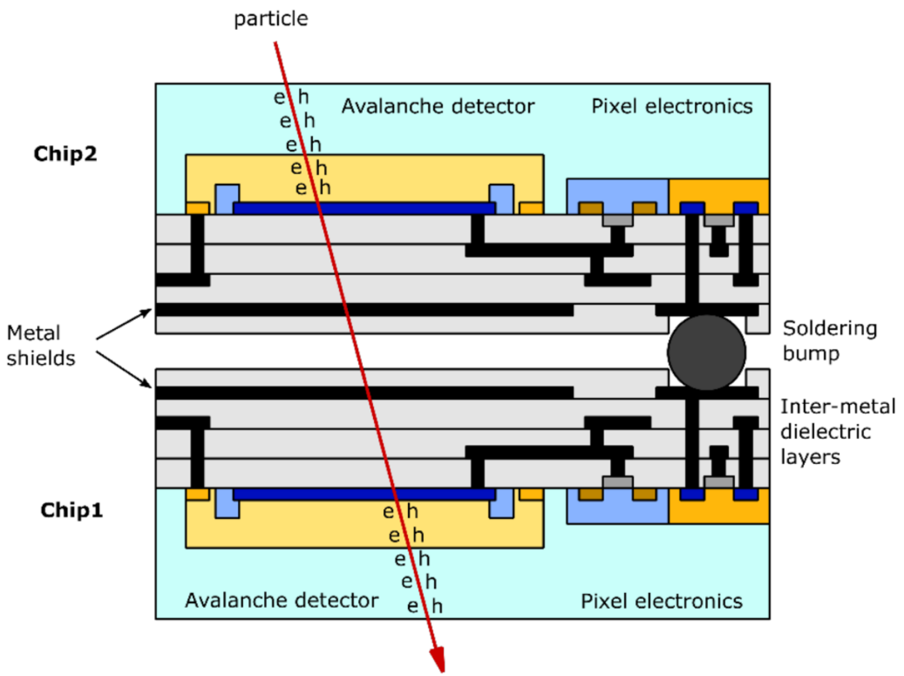
ASPiDeS

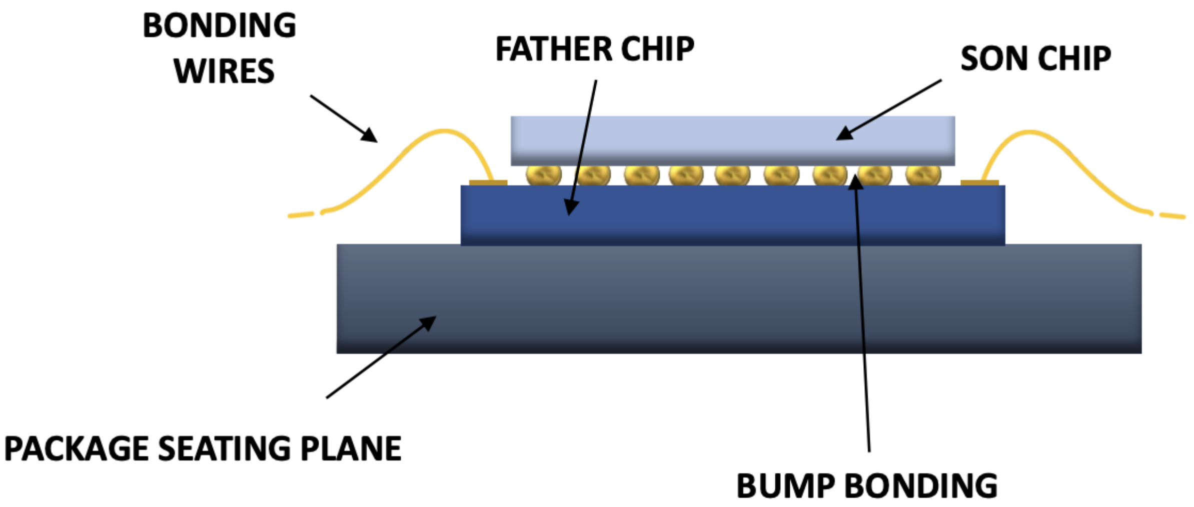
A CMOS SPAD and Digital SiPM platform for High Energy Physics

- **Goal**: develop SiPMs in CMOS technology (digital SiPMs) for fast (100 ps):
  - high dynamic range applications in dual-readout calorimetry
  - Small signals for **RICH/Cryogenics** operation for **Neutrino** physics and **DM** searches
- Participating units: Bari, Bologna, Milano, Pavia, Trento, Napoli, Padova, Torino

LF 110 nm technology

- uCell originally developed by FBK (L. Pancheri-INFN TS)
- Evolution of Apix2 (LF150nm) and ASAP project (LF 110nm)





Dual-readout Calorimetry

Millimeter scale, 2D monolithic silicon photomultipliers providing

- **fully digital output** obtained through a completely digital processing chain (or, as a possible alternative, through current or charge integration and A/D conversion)
- **time of arrival** of the first bunch of photons and bunch duration with better than **100 ps** resolution
- **threshold adjustment** capabilities for noise rejection
- possibility of **individual micro-cell enabling**
- asynchronous counting over a more than three decade wide dynamic range of simultaneously firing micro-cells (order of a few thousands, **15/20 micron pitch**)

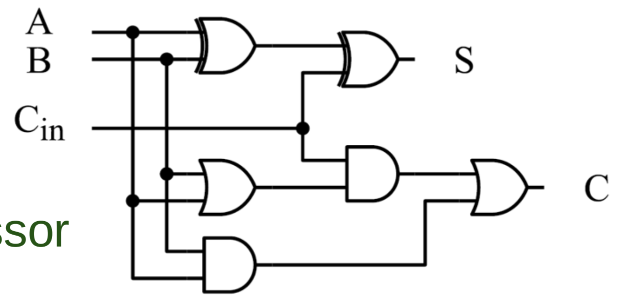
Integration of the sensing element and the processing electronics in the common substrate of a CMOS process is instrumental in accomplishing all of the above features

“A **Parallel Counter** is a combinational network which provides q outputs, processing the signals coming from its **$p \leq 2^q - 1$** inputs. The binary number represented by the q outputs is the number of bits at 1 fed as inputs”

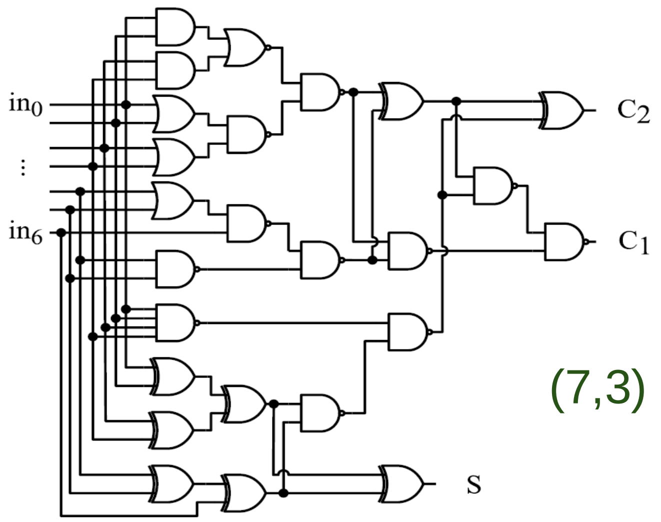
L. Dadda, “On Parallel Digital Multipliers”, Alta Frequenza, 1976

2^{11}	2^{10}	2^9	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0	*Binary Weight*
						y_5	y_4	y_3	y_2	y_1	y_0	Multiplicand
						x_5	x_4	x_3	x_2	x_1	x_0	Multiplier
						x_0y_5	x_0y_4	x_0y_3	x_0y_2	x_0y_1	x_0y_0	
					x_1y_5	x_1y_4	x_1y_3	x_1y_2	x_1y_1	x_1y_0		
				x_2y_5	x_2y_4	x_2y_3	x_2y_2	x_2y_1	x_2y_0			Partial Products
			x_3y_5	x_3y_4	x_3y_3	x_3y_2	x_3y_1	x_3y_0				
		x_4y_5	x_4y_4	x_4y_3	x_4y_2	x_4y_1	x_4y_0					
	x_5y_5	x_5y_4	x_5y_3	x_5y_2	x_5y_1	x_5y_0						
p_{11}	p_{10}	p_9	p_8	p_7	p_6	p_5	p_4	p_3	p_2	p_1	p_0	Product

(n,m) compressors are devices capable of collapsing n input lines into m output lines interpreted as the binary representation of the number of ones at the input ($m \geq \lceil \log 2\ n \rceil$)

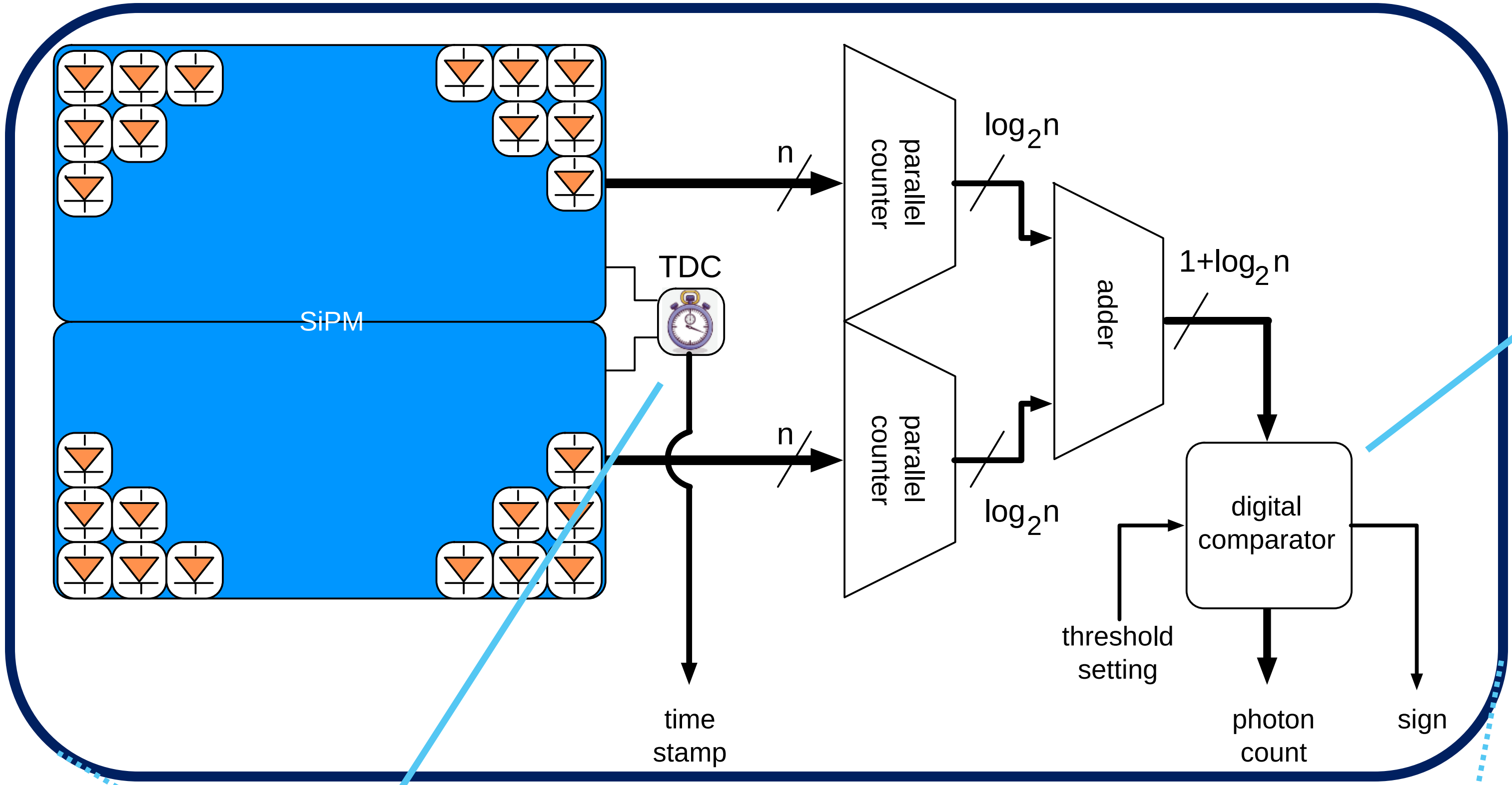


(3,2) compressor



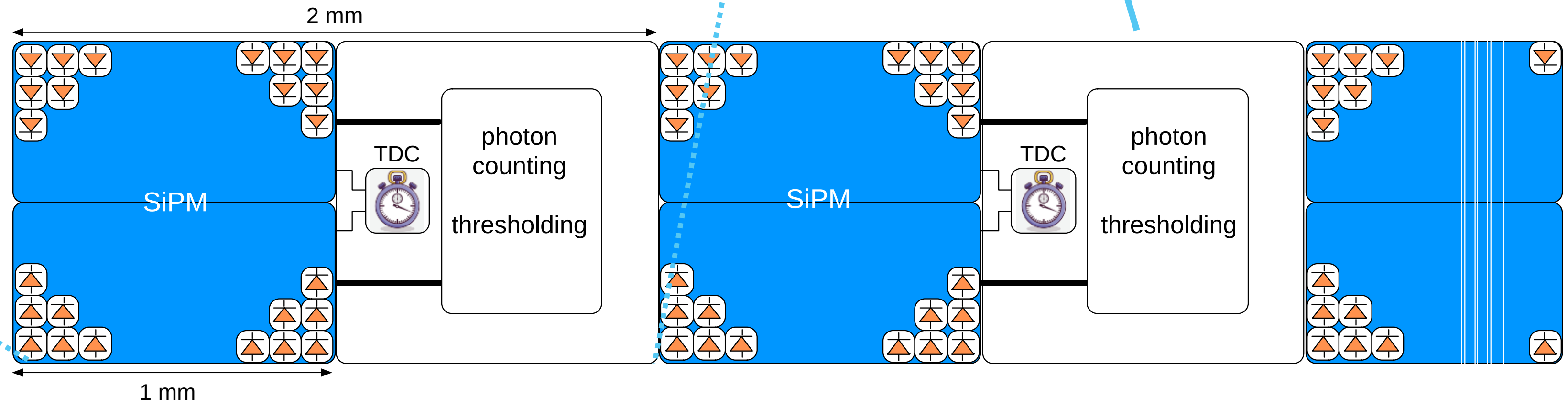
Mehta et al. 1991

(7,3) compressor



thresholding - virtually any threshold might be set

electronics laid out in the inter-SiPM region, accommodating the capillary tubes



time stamping – close to the signal source, re-triggering TDC for signal duration

Small signal (RICH, DM, Neutrino)

Different specifications as compared to DR calorimetry

- **large SiPM area**, few to 10 mm side, but milder granularity requirements – better trade-off possible between functional density and PDE
- very small signal, setting some demanding specs on **dark count rate** – operation at low temperature for noise performance improvement

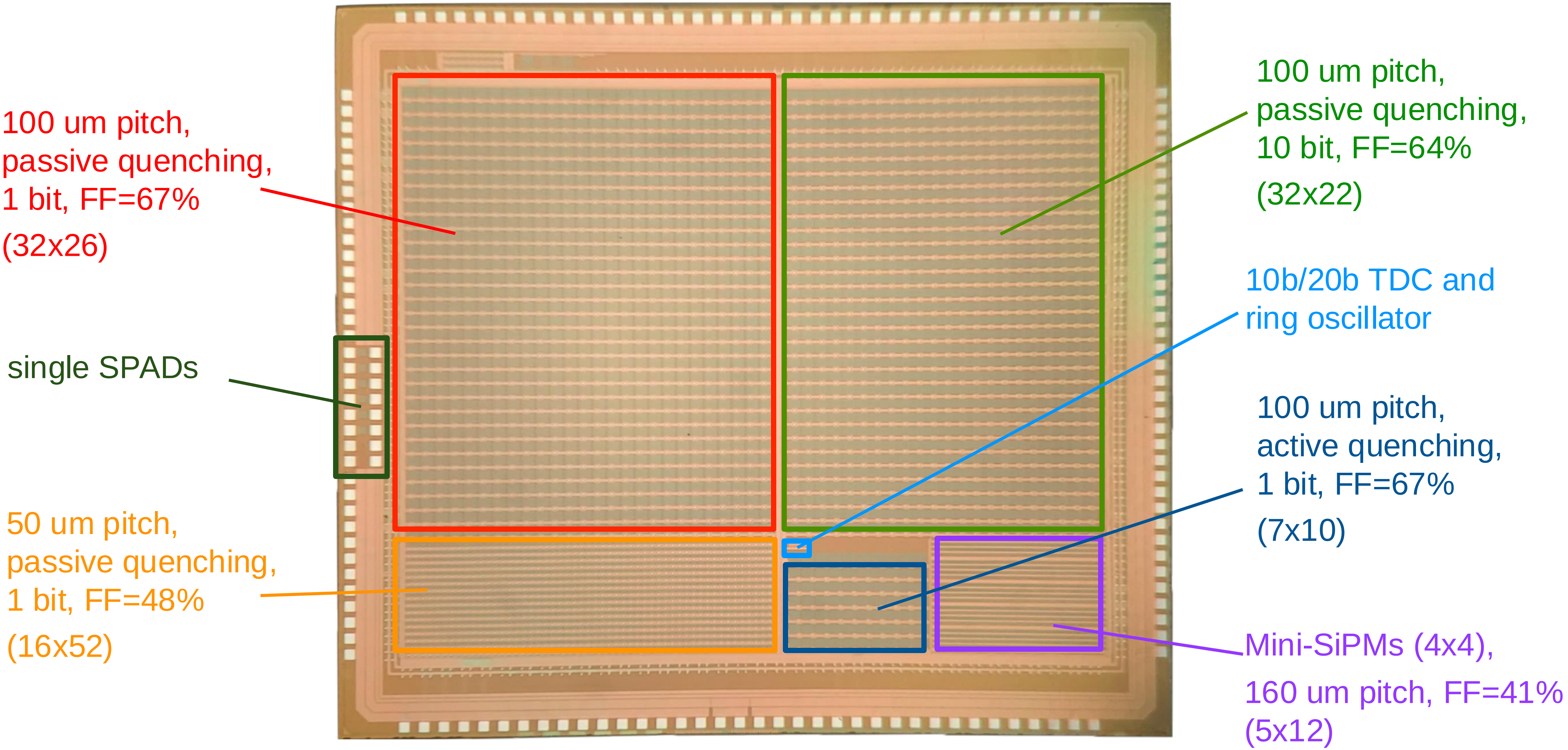
One of the ASPiDeS goals is the investigation of dSiPM operation in **cryogenic conditions**

- **modeling** of sensor behavior at LN temperature
- **modeling** of transistors and processing circuit behavior at cryogenic temperature

Improvement with decreasing temperature may be limited by BTB or TA tunneling

- **TCAD simulations** to optimize the sensor by reducing weakly temperature dependent contributions to DCR

ASAPLF110 chip – a technology characterization platform



Activity

2025:

- Characterization of the **ASAP110LF**
- Investigation of radiation damage and SPAD operation in cryogenic conditions

2026:

- Production od prototypes of CMOS SiPMs consisting of about 1000 SPADs with 15-20 um pitch with on sensor electronics
- specific structures included to study the chip functionalities

2027:

- Development of a demonstrator with 8 SiPMs, each with a 1 mm2 area and a 2 mm pitch (64x64 cells, 15 um pitch) – dual readout calorimetry
- smaller versions of dSiPMs for application to **RICH, DM** and **neutrino** experiments (larger SPADs)
- Characterization in radioactive and cryogenic environment

Bologna is involved in the design (mainly in the digital part) and characterization. Possibilities to develop tailored devices