TIMEPIX4 – nuova sigla

G.Collazuol
INFN Padova
CdS 2024/7/5

Acronym: TIMEPIX4
Project duration: 3 years (2025, 2026, 2027)
Research area: Interdisciplinary / Detectors
Principal Investigator: Massimiliano Fiorini (INFN Sezione di Ferrara)
Participating Units: Ferrara, Laboratori Nazionali del Sud, Napoli, Padova, Pisa, Trieste

Ambito: : DRD4 - WG1 (Gaseous) / WP2 (Vacuum Based)

Aims: exploiting TIMEPIX4 chip => to develop detector systems beyond State-of-the-Art

Applications:

- Ultra-fast, high granularity MCP based photon detector => HEP
- X-ray, gamma ray and particle imaging w/ semiconductors => Medical Physics
- Photons detection and Tracking and w/ gas detectors => Padova proposal

Gruppo Padova-Trieste (gas/photon detectors)
Staff: G.Collazuol, S.Levorato, F.Tessarotto (INFN-TS)
Post-Doc: D.D'Ago, D.Henaff
Dottorandi: M.Feltre, M.Mattiazzi

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Hybrid vacuum photon detector - MCP / TIMEPIX4

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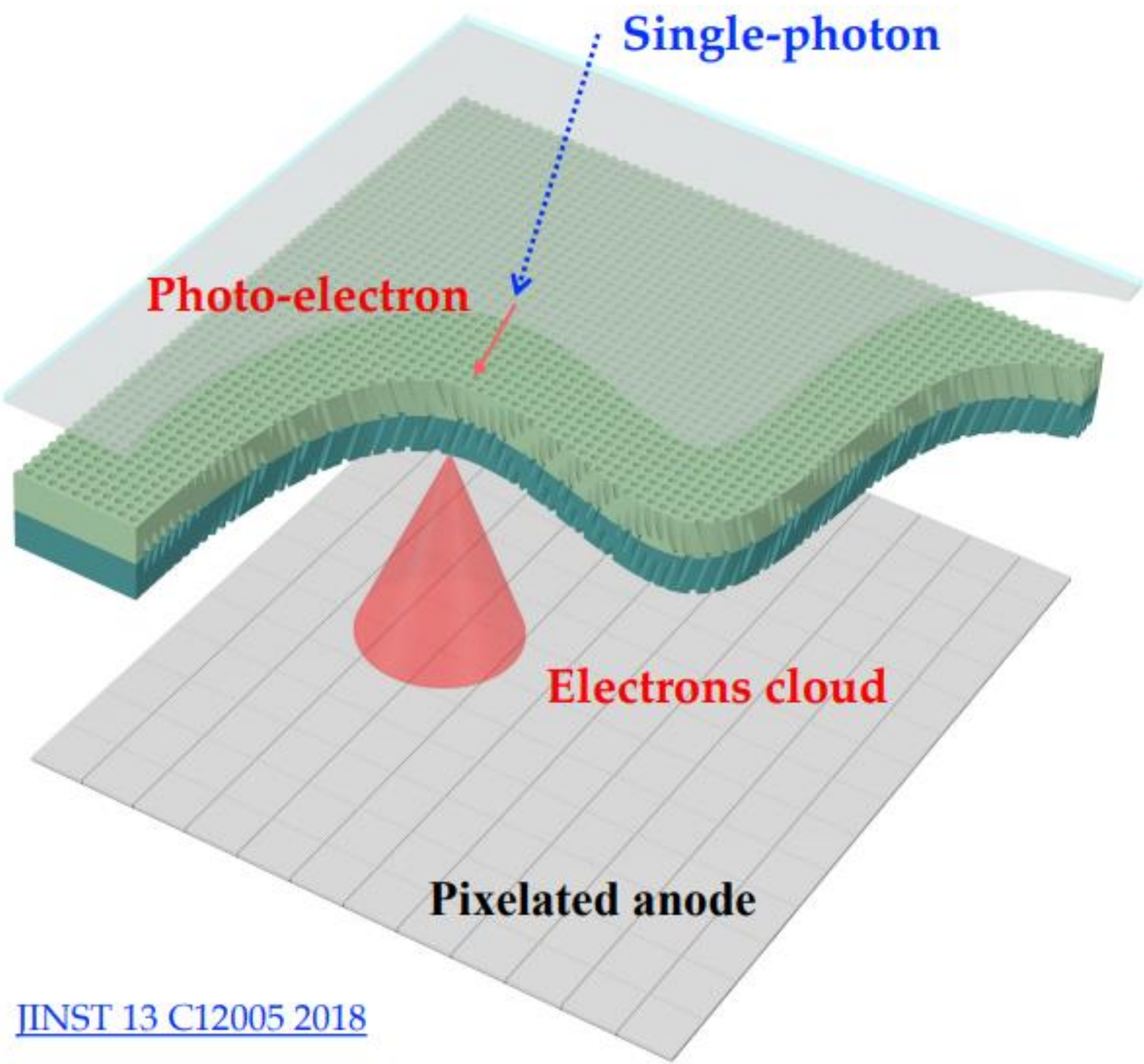


JINST 13 C12005 2018

- Entrance window + photocathode
- Microchannel plate stack
- Timepix4 ASIC as pixelated anode
  - ❑ Electron cloud (pixels cluster)
  - ❑ **55µm × 55µm** pitch
  - ❑ **0.23 M pixels** measuring arrival time and duration of input signals
  - ❑ **7 cm^2** active area
  - ❑ Up to **2.5 Ghits/s**
  - ❑ Local signal processing

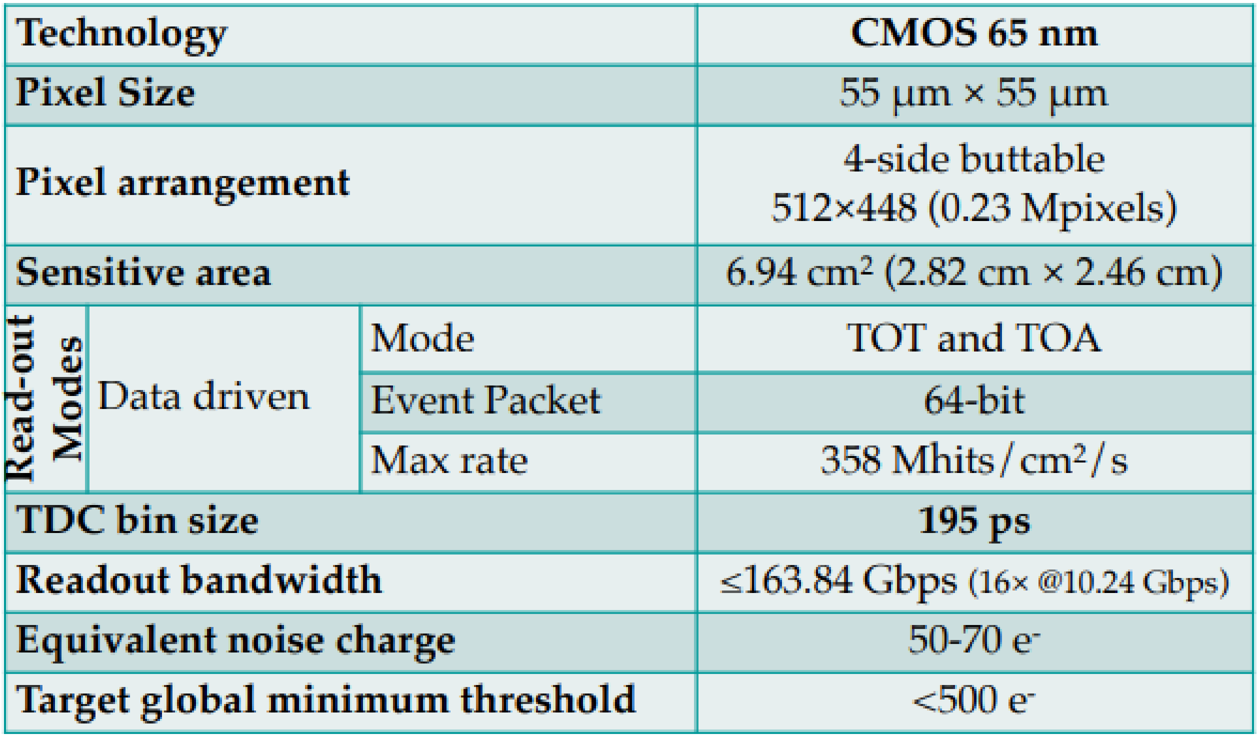
INFN access to TIMEPIX4 – MEDIPIX collaboration

TIMEPIX4

- Timepix4 ASIC in 65 nm CMOS (TSMC) **silicon pixel technology**
  - Developed and produced by the Medipix4 Collaboration for hybrid pixel detectors
- Charge sensitive amplifier, single threshold discriminator and TDC based on Voltage Controlled Oscillator
  - 4-side buttable (TSV)
  - Data-driven and frame-based read-out

medipix collaboration

JINST 17 C01044 2022



Technology			**CMOS 65 nm**
Pixel Size			55 µm × 55 µm
Pixel arrangement			4-side buttable 512×448 (0.23 Mpixels)
Sensitive area			6.94 cm^2 (2.82 cm × 2.46 cm)
Read-out Modes	Data driven	Mode	TOT and TOA
		Event Packet	64-bit
		Max rate	358 Mhits/cm^2/s
TDC bin size			**195 ps**
Readout bandwidth			≤163.84 Gbps (16× @10.24 Gbps)
Equivalent noise charge			50-70 e^-
Target global minimum threshold			<500 e^-

X. Llopart (CERN)

Padova Interests & contribution

TIMEPIX4

Aim

study of both Optical and Charge readouts with internal multiplication
based on resistive and capacitive micro-pattern gas detectors (MPGD)

Target sensitivity spectrum of the optical readout => VUV and DUV light
Target sensitivity for primary charge readout => single electron

Methods

- Coupling MicroMegas resistive embedded Anode (Resistive layer, eg DLC) with TIMEPIX4
- Couping nano-diamond / DLC photo-cathodes to ERAM

Applications

- detailed gas detector studies
- Micro-imaging detectors (tracks & x-rays)
- new robust x-ray & VUV & DUV gas-based detector

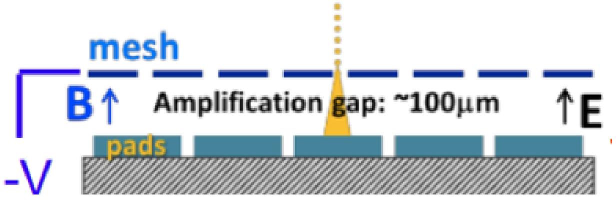
Charge readout – MicroMegas w/ resistive foil

Resistive layer enables Charge spreading
→ space resolution below 500µm with larger pads
→ less FEE channels (lower cost)
→ improved resolution at small drift distance
(where transverse diffusion cannot help)

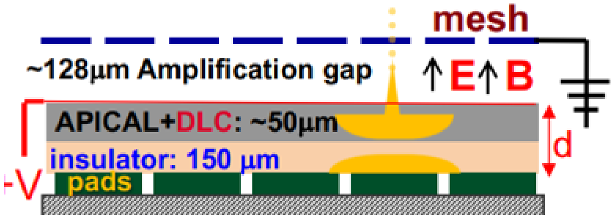
Resistive layer prevents charge build-up and hides sparks
→ enables operation at higher gain
→ no need for spark protection circuits for ASICs
→ compact FEE → max active volume

Resistive layer encapsulated and properly insulated from GND
→ Mesh at ground and Resistive layer at +HV
→ improved field homogeneity → reduced track distortions
→ better shielding from mesh and DLC → potentially better S/N

Standard bulk-MM



ERAM
= Encapsulated Resistive Anode MM



➔ ERAMs used for the new TPC of T2K
ERAMs are built at CERN MPGD Lab

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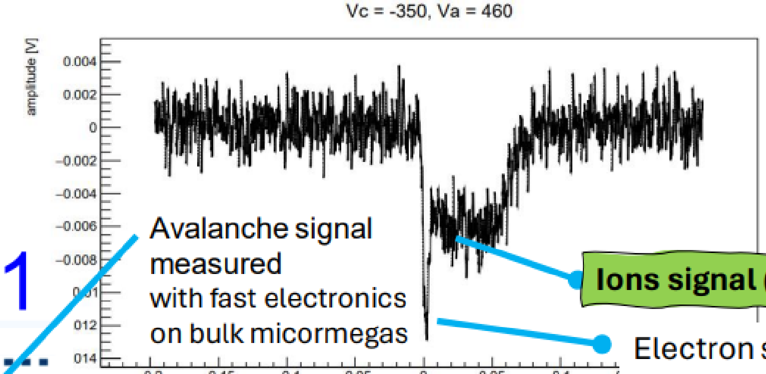
ERAM response – Signal formation model

Main ingredients

In the time scale ot our shaping time O(100ns)
Charge spread is properly described by

Solutions of 2D diffusion eqn.

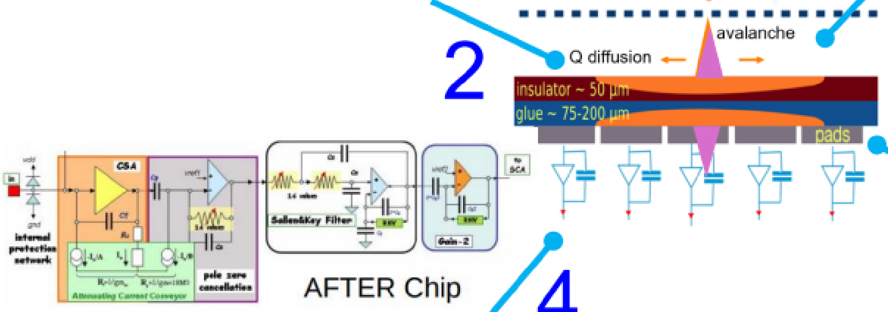
$$\Rightarrow \frac{\partial^2 \rho}{\partial^2 t}=\frac{1}{RC}\left(\frac{\partial^2 \rho}{\partial^2 x}+\frac{\partial^2 \rho}{\partial^2 y}\right) \quad \text{with } RC=\frac{C_S}{\sigma} \text{ in } s/m^2$$



Avalanche signal measured with fast electronics on bulk micormegas

Ions signal (slow)

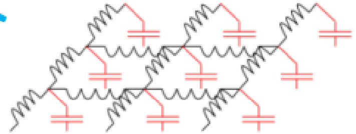
Electron signal (too fast for our shaping times)



AFTER Chip

3

Electrical model of the sensor



FEE Response Function

$$f(t;w_s,Q)=e^{-w_s t}+e^{\frac{-w_s t}{2Q}}\left[\sqrt{\frac{2Q-1}{2Q+1}}\sin\left(\frac{w_s t}{2}\sqrt{4-\frac{1}{Q^2}}\right)-\cos\left(\frac{w_s t}{2}\sqrt{4-\frac{1}{Q^2}}\right)\right]$$

w_s~1/Peaking time and Q quality factor

Note: of course **gas transport properties** (L, T diffusion) have to be accounted for

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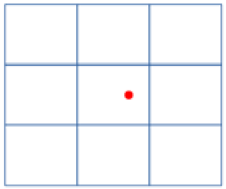
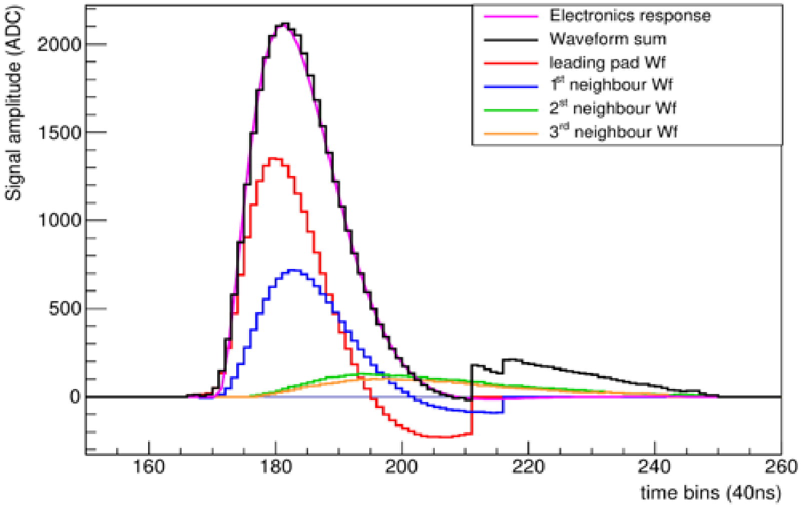
ERAM detector response – Signal formation

How does the signal look ? point deposition for example

Charge deposited punctually
on a pad (X ray)



ADC signal : max 4096 counts
Time window of 511 time bins
Time bin (typ.): 40 ns (25 MHz sampling)
Peaking time (typ.) : 412 ns



Leading pad: highest and earliest signal
⇒ current induced on pads from by avalanche, ie **ions** signal (as electrons' signal is too fast)

Adjacent pads: lower and later signals
⇒ current induced by potential field adjustments after **electrons** are collected by on DLC
(current induction by "charge spread on resistive layer")

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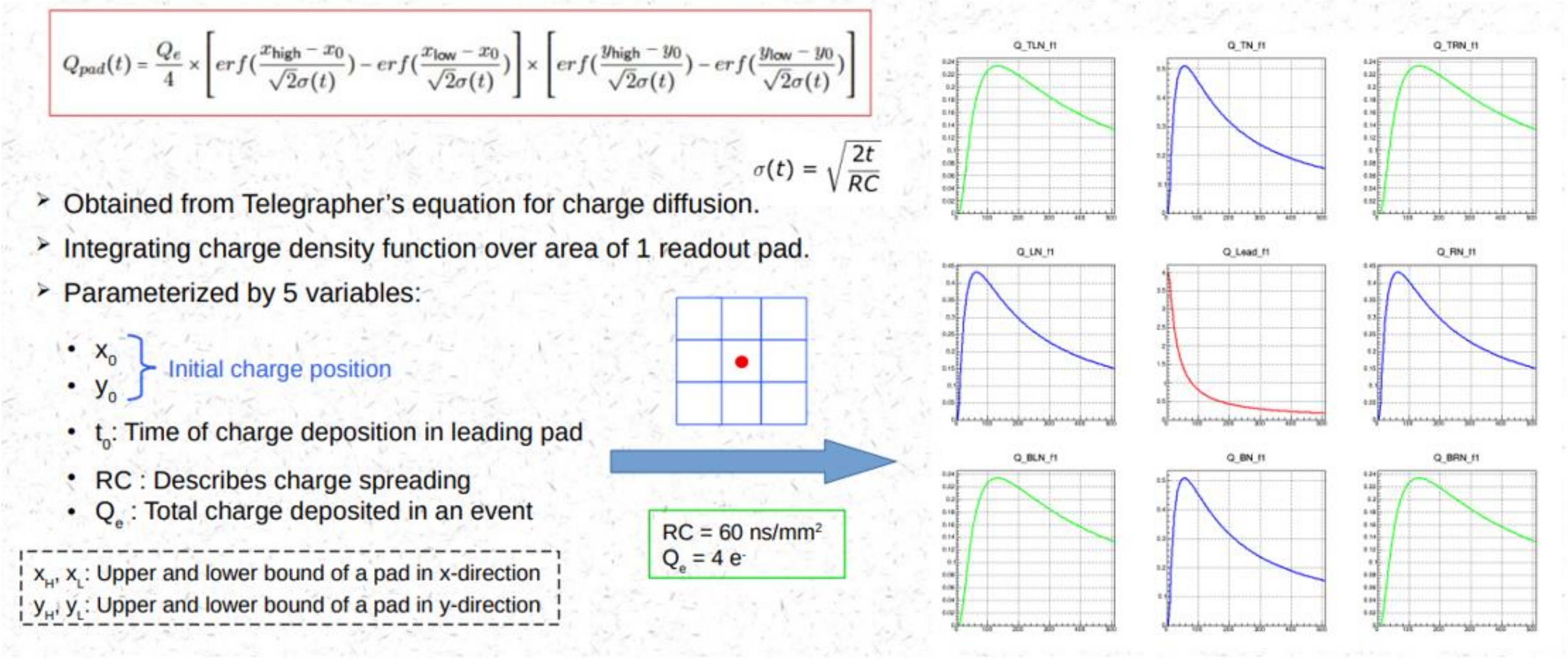
Reconstructing x-rays

Qpad(t) = Solution of 2D Teq. for diffusion of inititial Qe deposited charge (point-like, delta-pulse initial conditions)



$$Q_{pad}(t) = \frac{Q_e}{4} \times \left[erf\left(\frac{x_{\text{high}} - x_0}{\sqrt{2}\sigma(t)}\right) - erf\left(\frac{x_{\text{low}} - x_0}{\sqrt{2}\sigma(t)}\right) \right] \times \left[erf\left(\frac{y_{\text{high}} - y_0}{\sqrt{2}\sigma(t)}\right) - erf\left(\frac{y_{\text{low}} - y_0}{\sqrt{2}\sigma(t)}\right) \right]$$

$$\sigma(t) = \sqrt{\frac{2t}{RC}}$$

- Obtained from Telegrapher's equation for charge diffusion.
- Integrating charge density function over area of 1 readout pad.
- Parameterized by 5 variables:
  - x_0
  - y_0

    } Initial charge position
  - t_0: Time of charge deposition in leading pad
  - RC : Describes charge spreading
  - Q_e : Total charge deposited in an event

x_H, x_L: Upper and lower bound of a pad in x-direction
y_H, y_L: Upper and lower bound of a pad in y-direction

RC = 60 ns/mm^2
Q_e = 4 e$^-$

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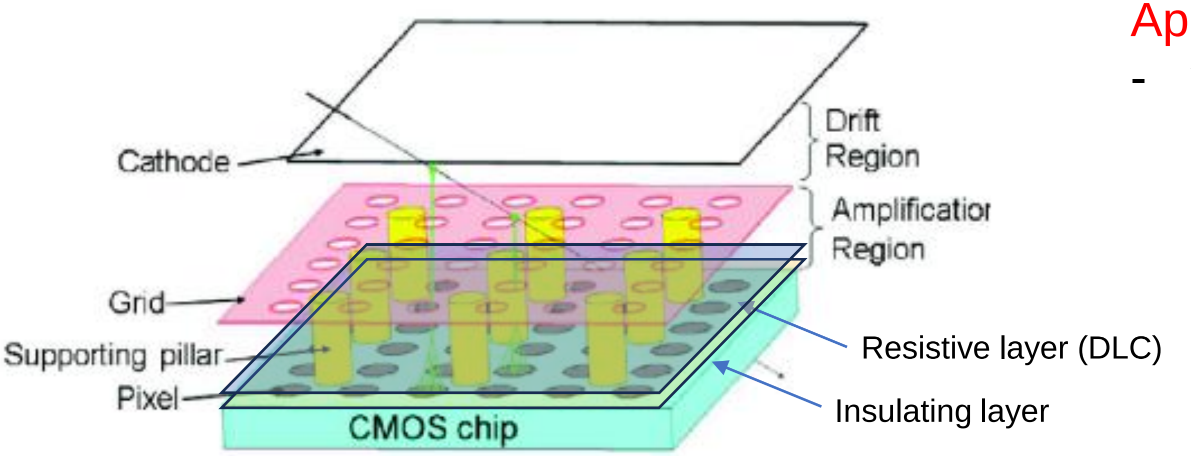
Coupling ERAMs + TIMEPIX4 chip = ERAPIX



Applications

- very fine grained tracker and X ray detector

Key points addressed (simulation and measurements) by TIMEPIX4

1. Choice of Diamond-Like-Carbon (DLC) resistivity
   and thickness of insulator layer (between pads and DLC)
   R x C => charge spread velocity

2. Geometry and dimension of grid/mesh with respect to pad
   Geometry in order to avoid Moire`- like effect

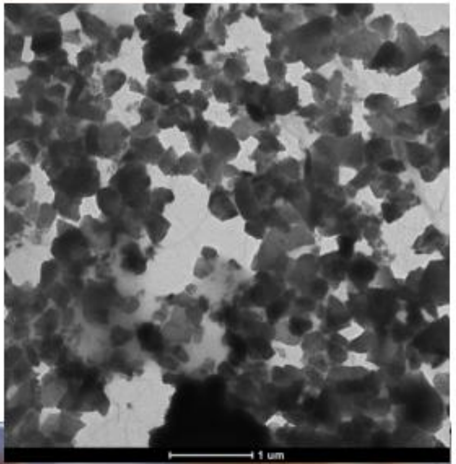
➔ Build prototype

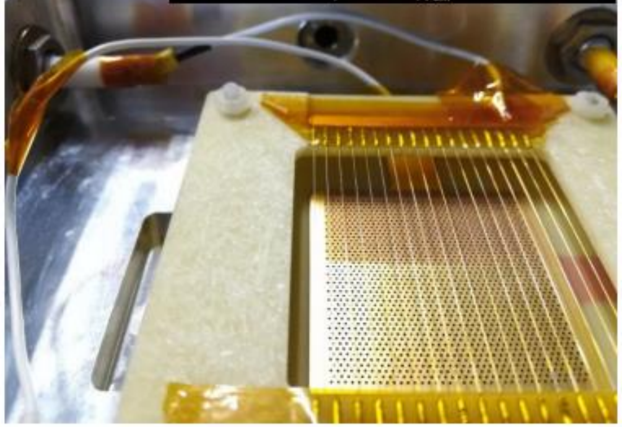
TIMEPIX4

Progress on coupling MPGD-based PDs with nanodiamond photocathodes

Fulvio Tessarotto

On behalf of the nanodiamond-THGEM group
(Trieste-Bari-CERN)





Motivation for the R&D
H-ND: production and spray coating
Photoemission measurements
THGEMs with nanodiamond coating
Measurements in different gas mixtures
Aging studies
Conclusions

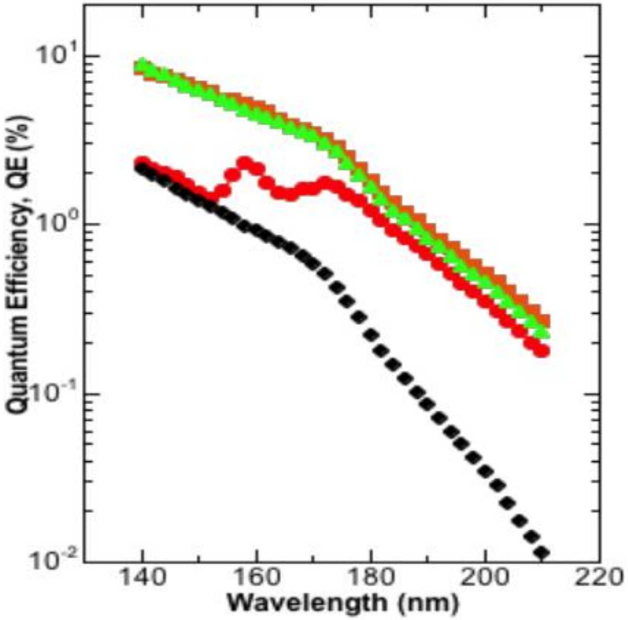
Nano-Diamond Q.E.

Phototube Hamamatsu

PCD_MgF2

Photocathode area ϕ 6 mm

Spectral response 110÷ 220 nm

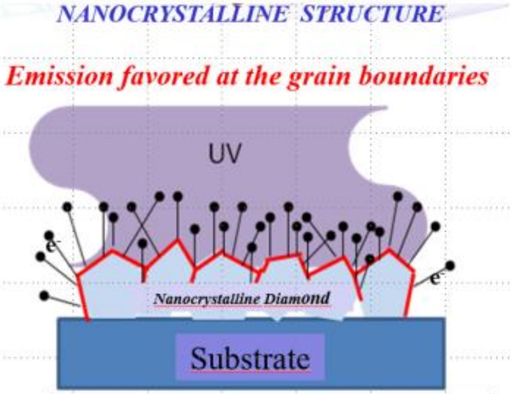


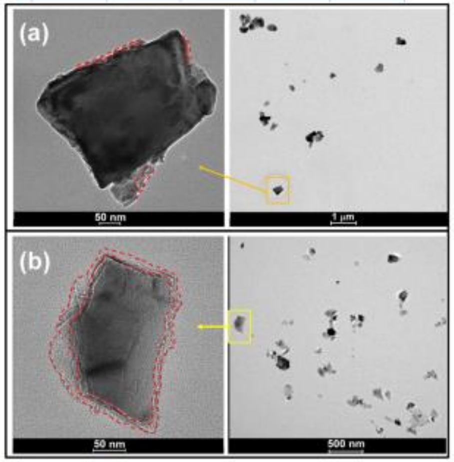
Hydrogenated powder

Hydrogenated powder

Phototube Hamamatsu

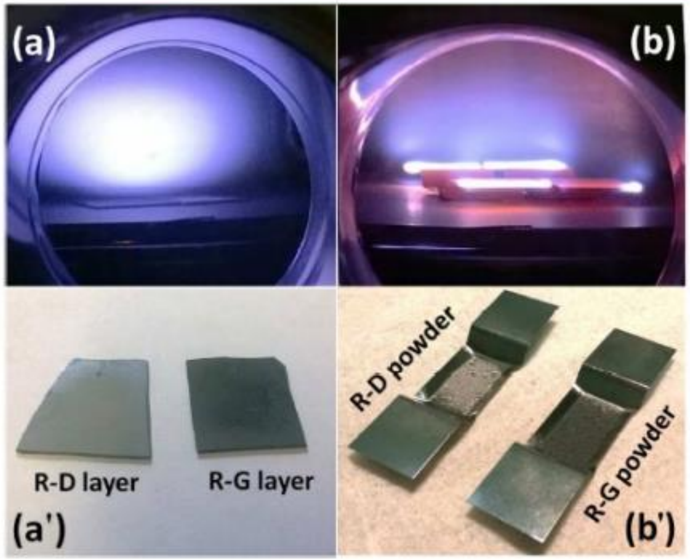
As received ND powder

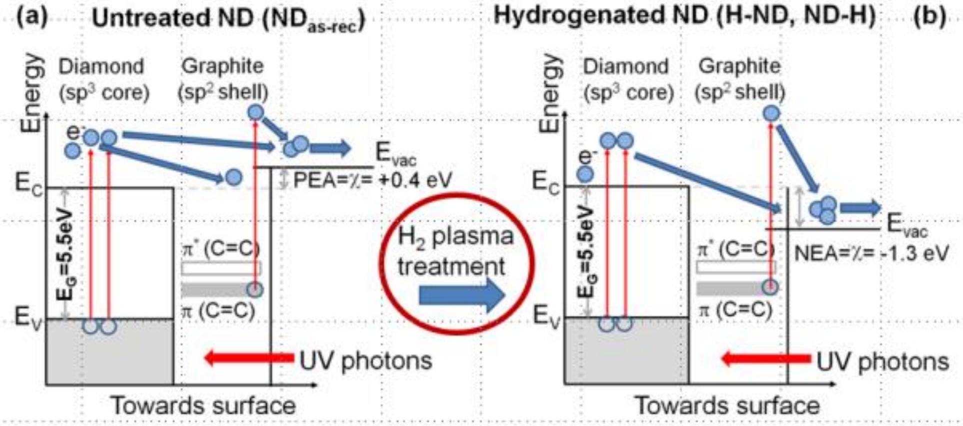




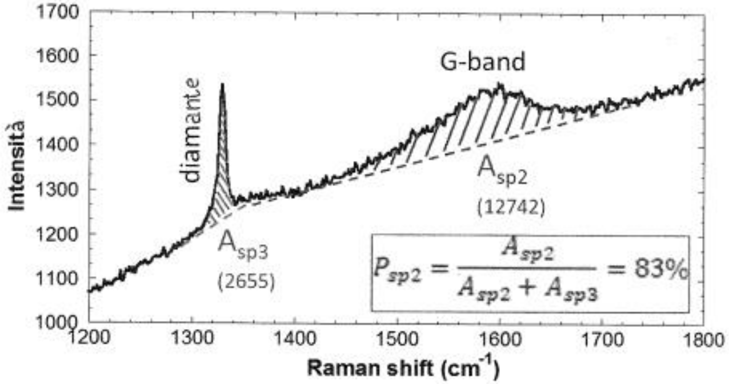
L. Velardi, et al
Diamond & Related Materials 76 (2017) 1–8

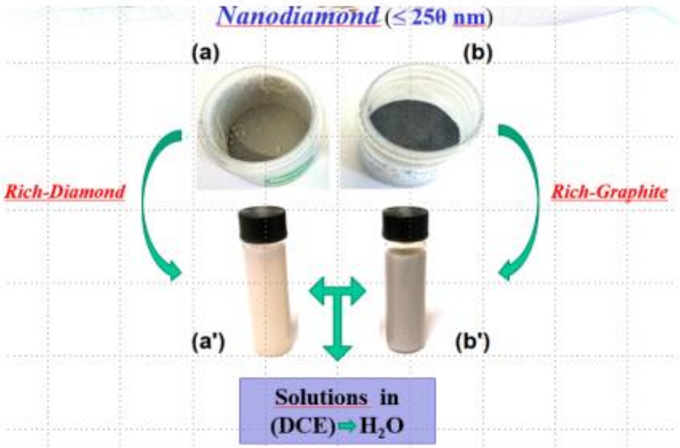
Hydrogenated Nano-Diamond



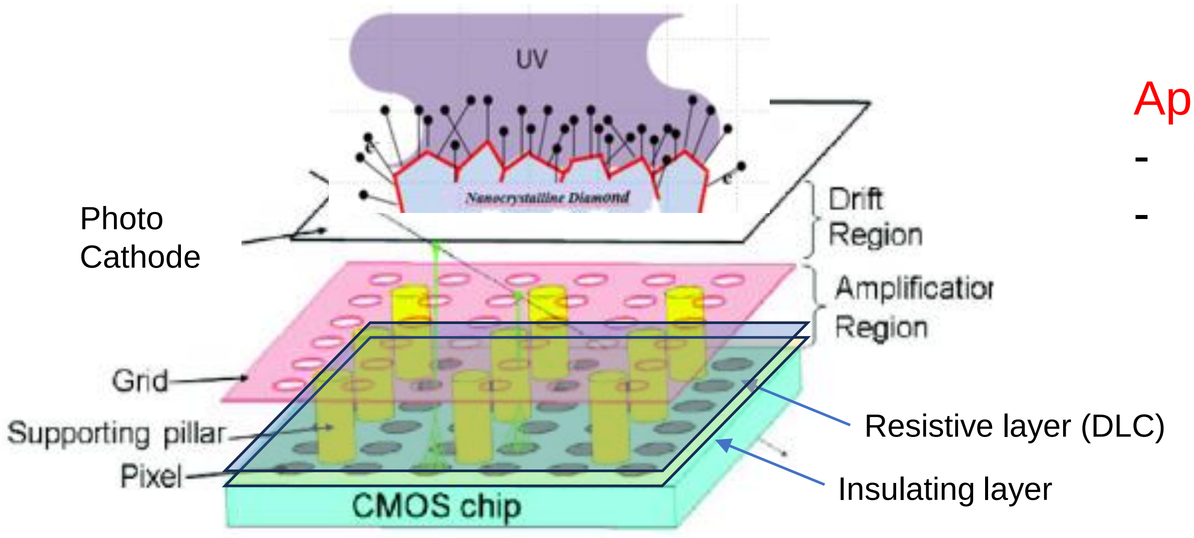


Schematic representation of the process of photoemission components **sp^3** e **sp^2** for **PEA** (a) and for **NEA** (b)





Coupling H-ND cathode + ERAMs + TIMEPIX4 chip



Applications

- very fine grained photo-det
- VUV-DUV imaging

Key points addressed (simulation and measurements) by TIMEPIX4

1. behavior of the hydrog. nano-diamond photo-cathode withT2K gas

2. study HV configuration and detector geometry for optimizing photo-electron collection and drift

➔ Build prototype

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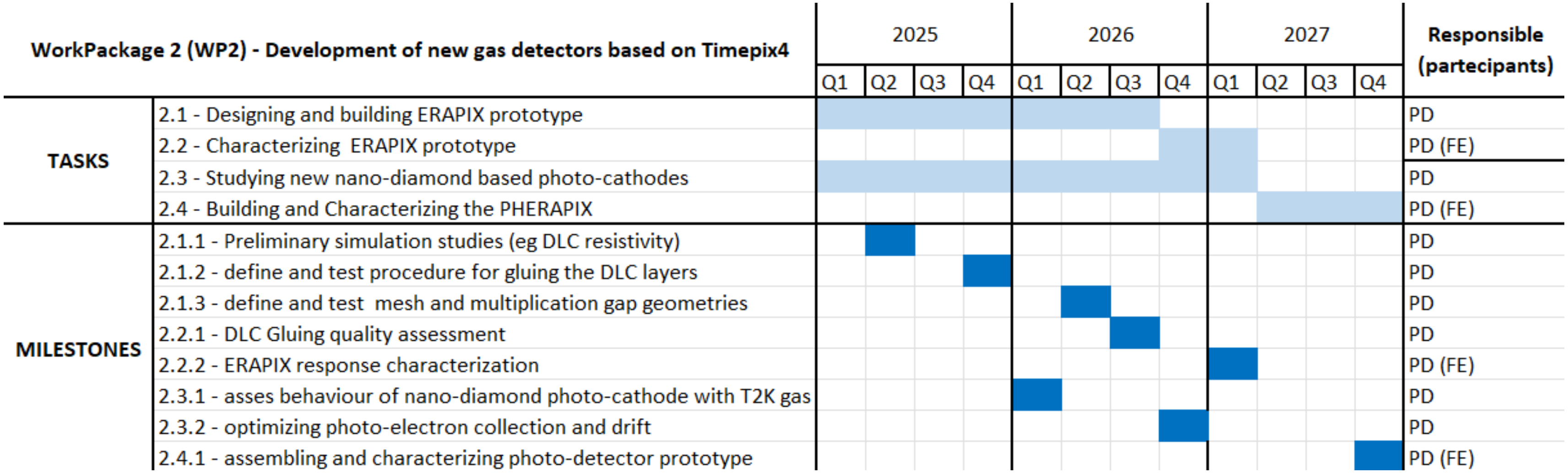
TIMEPIX4 – WP2 timeline and milestones



	WorkPackage 2 (WP2) - Development of new gas detectors based on Timepix4	2025				2026				2027				Responsible (partecipants)
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
TASKS	2.1 - Designing and building ERAPIX prototype	■	■	■	■	■	■	■						PD
	2.2 - Characterizing ERAPIX prototype								■	■				PD (FE)
	2.3 - Studying new nano-diamond based photo-cathodes	■	■	■	■	■	■	■	■	■				PD
	2.4 - Building and Characterizing the PHERAPIX										■	■	■	PD (FE)
MILESTONES	2.1.1 - Preliminary simulation studies (eg DLC resistivity)		■											PD
	2.1.2 - define and test procedure for gluing the DLC layers				■									PD
	2.1.3 - define and test mesh and multiplication gap geometries						■							PD
	2.2.1 - DLC Gluing quality assessment							■						PD
	2.2.2 - ERAPIX response characterization									■				PD (FE)
	2.3.1 - asses behaviour of nano-diamond photo-cathode with T2K gas					■								PD
	2.3.2 - optimizing photo-electron collection and drift								■					PD
	2.4.1 - assembling and characterizing photo-detector prototype												■	PD (FE)

Resources @ INFN Padova

FTE Padova 2024/7 => 100%

G.Collazuol	10 %
S.Levorato	5 %
F.Tessarotto	5 %
D.Henaff	20 %
D.D’Ago	30%
M.Feltre	30%

Preventivi 2025

- Consumo per circa 15kEuro
- Missioni (CERN) per 4kEuro

Richieste 2025 in Sezione PD

- Servizio Elettronica
  programmazione FPGA TimePix4 (collaborazione con INFN FE) ~ 3m.p. (overlap – con richiesta ADA-5D)

- Servizi Tecnici ed Elettronici
- Servizio Progettazione Meccanica
- Servizio Officina Meccanica

ASPIDES 2025 Dtz5 => Nuova sigla 2026

G.Collazuol
INFN Padova
CdS 2024/6/27

Acronym: ASPIDES - A CMOS SPAD and Digital SiPM Platform for High Energy Physics
Project duration: 3 years (2025, 2026, 2027)
Research area: rivelatori ed elettronica
Principal Investigator: Lodovico Ratti (Universita` e INFN Sezione di Pavia)
Participating Units: Pavia(PV), Bari (BA), Bologna (BO), Milano (MI), Napoli (NA), Padova (PD), Torino (TO), Trento (TIFPA)

Ambito: DRD4 - WG1 (dSiPM) / WP1 CMOS SPAD

Aims: development technology platform for the design, production and commissioning of digital silicon photomultipliers (dSiPMs) => detectors with single-photon sensitivity and embedded functionalities

Applications:

- scintillation and Cherenkov light detection in dual-readout calorimetry
- RICH detectors and large area neutrino detectors => involvement Padova

Gruppo Padova-Trieste (silicon/gas/photon detectors)
Staff: G.Collazuol, S.Levorato, F.Tessarotto (INFN-TS), R.Stroili, L.Silvestrin
Post-Doc: D.D'Ago, D.Henaff
Dottorandi: M.Feltre, M.Mattiazzi

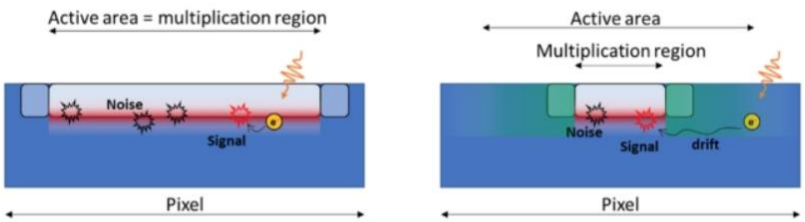
ASPIDES

ASPIDES will deliver 2D CMOS monolithic sensors

ASPIDES

Target technology

- 110 nm CMOS image sensor process



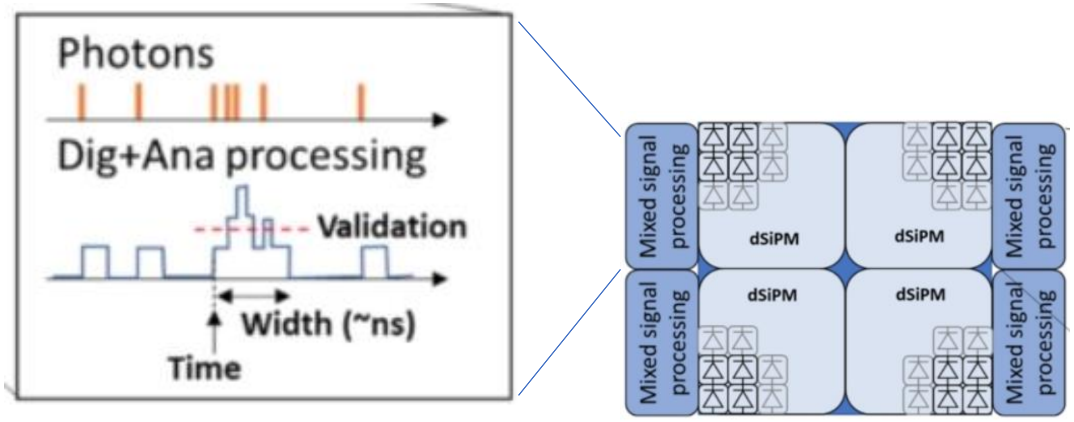
Ultra-low noise SPAD design through field shaping and charge focusing.

Main features

- Noise mitigation
  - Optimization for ultra-low noise spad cell
  - Single SPAD control (on/off)
  - threshold adjustment capabilities for noise rejection (output validation)

- Photons counting
  - fully digital output, obtained through a completely digital processing chain
  - or through analog, Q/V or I/V transformation and final A/D conversion
  - asynchronous counting with wide (1e3) dynamic range of simultaneous photons

- Timing features
  - time of arrival of the first photon
  - photon pulse duration (width) w/ 100ps resolution
  - … additional features available to measure accurately shape of photon pulse evolution)

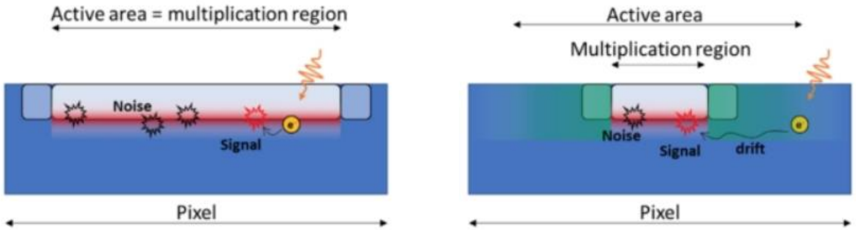


Possible floorplan and readout architecture

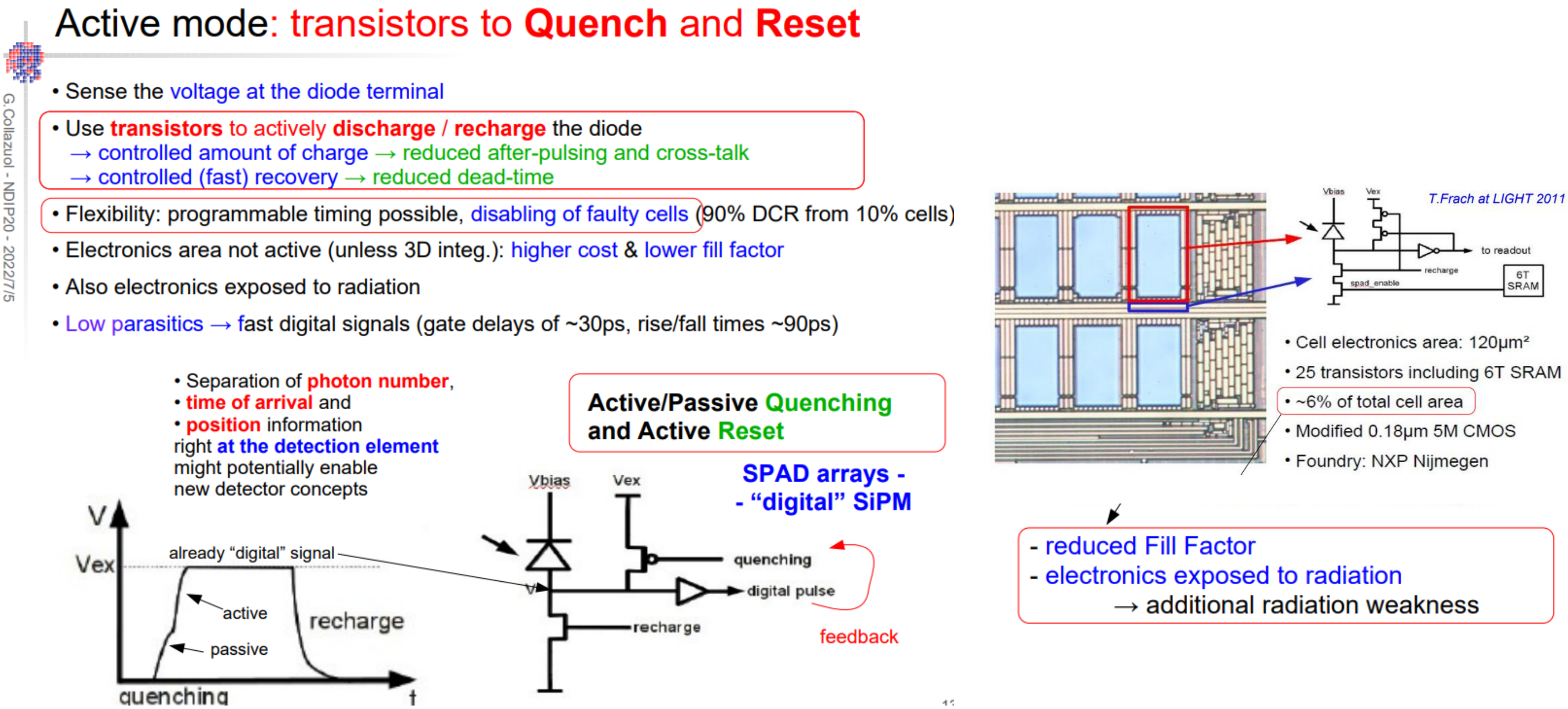
ASPIDES will deliver 2D CMOS monolithic sensors

ASPIDES

The technology offers SPADs with a DCR of around 100 kHz/mm2 , a PDP close to 50% at l=450 nm and excess voltage of 6 V and a sufficient integration density to pack all the needed functions in the available area without unacceptably degrading the sensor PDE



Ultra-low noise SPAD design through field shaping and charge focusing.



Active mode: transistors to **Quench** and **Reset**

- Sense the voltage at the diode terminal
- Use **transistors** to actively **discharge** / **recharge** the diode
  → controlled amount of charge → reduced after-pulsing and cross-talk
  → controlled (fast) recovery → reduced dead-time
- Flexibility: programmable timing possible, disabling of faulty cells (90% DCR from 10% cells)
- Electronics area not active (unless 3D integ.): higher cost & lower fill factor
- Also electronics exposed to radiation
- Low parasitics → fast digital signals (gate delays of ~30ps, rise/fall times ~90ps)

- Separation of **photon number**,
- **time of arrival** and
- **position** information

right **at the detection element** might potentially enable new detector concepts

Active/Passive Quenching and Active Reset

SPAD arrays -
- "digital" SiPM

- Cell electronics area: 120μm²
- 25 transistors including 6T SRAM
- ~6% of total cell area
- Modified 0.18μm 5M CMOS
- Foundry: NXP Nijmegen

- reduced Fill Factor
- electronics exposed to radiation
  → additional radiation weakness

ASPIDES will deliver 2D CMOS monolithic sensors

ASPIDES

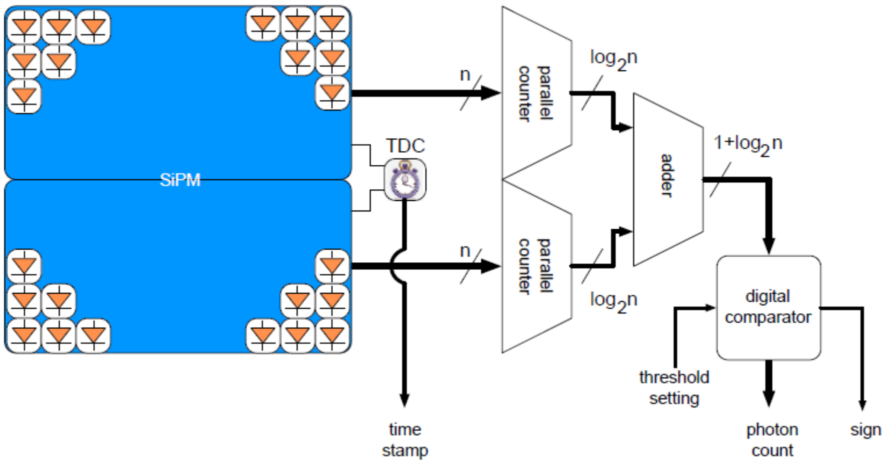


Figure 1. Block diagram of a dSiPM as proposed in the ASPIDES experiment.

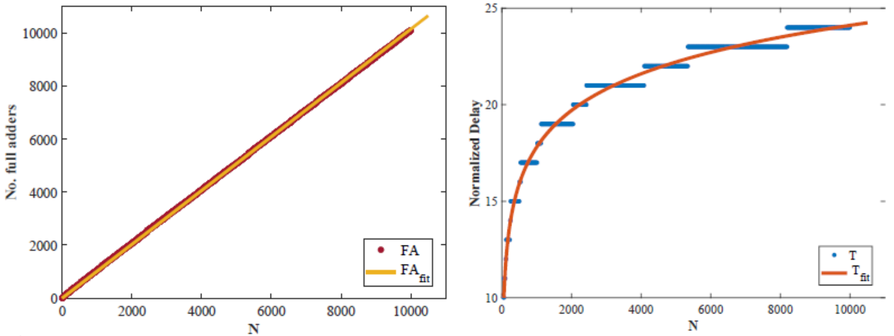


Figure 4. Number of full adders needed for a parallel comparator (left) and normalized delay between the input and the output of a parallel counter (right) bith as a function of the number N of inputs.

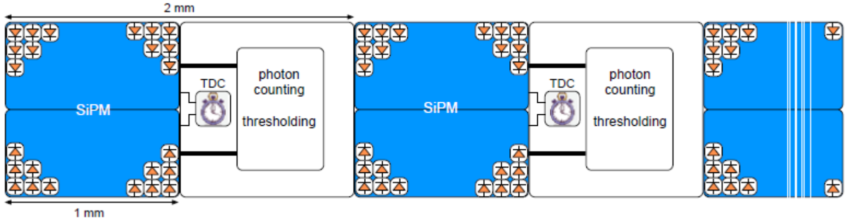
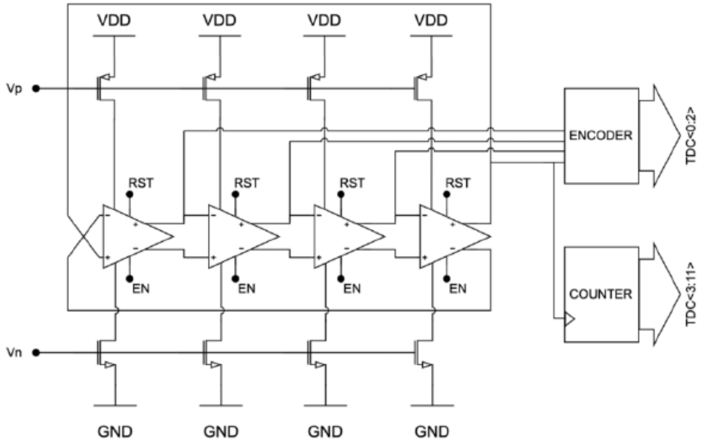


Figure 3. Modular structure for a dSiPM in dual-readout calorimetry.

Photon counting might be performed through a parallel counter based on adder trees, usually employed in digital multipliers to perform the sum of partial products (digital compressors as they reduce n bits into $[log2n]$ bits)

Possible alternative is mixed analog and digital approach based on I/V or Q/V conversion, followed by an ADC (current steering circuit integrated in each individual micro-cell to summing node when the micro-cell is hit and a trans-resistance amplifier or a charge preamplifier provides a measurement of the overall signal)



The time of arrival of the first photon will be measured by means of a time to digital converter (TDC) triggered by the first hit micro-cell through an OR-tree (or by a transition of one of the bits at the parallel counter output).

Block diagram of a 12-bit ring-oscillator-based TDC

ASPIDES will deliver 2D CMOS monolithic sensors

ASPIDES

Project Deliverables

- A prototype chip, including structures such as mini-SiPMs with O(1000) micro-cells with different pitch and single electronic blocks (e.g., TDC/QTC) for characterization purposes
- A final demonstrator, with full scale SiPMs and optimized fill factor for dual-readout calorimetry

Involvement in Padova

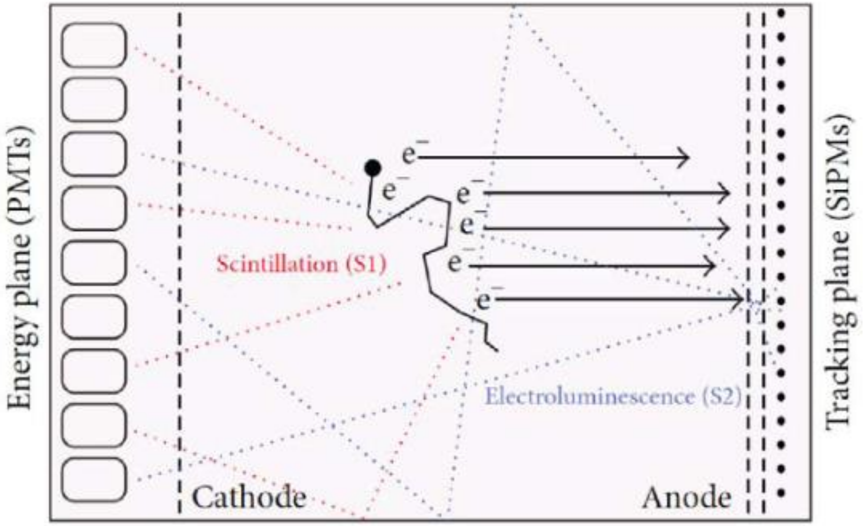
1) Characterization

- Investigation of radiation tolerance both to ionization and displacement damage
- Study device operation in cryogenic conditions or high pressure and different radiators
- PDE to light from 200nm to 1000nm

2) Applications

- Fucussed / Imaging
  Cherenkov applications

- Optical Readout
  for High Pressure TPC
  (H2 / CO2 / Ar + CF4)



(High Pressure TPC => Padova in DRD1)

ASPIDES timleine

ASPIDES

Work Package	Task	Q1-25			Q2-25			Q3-25			Q4-25			Q1-26			Q2-26			Q3-26			Q4-26			Q1-27			Q2-27			Q3-27			Q4-27		
		M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23	M24	M25	M26	M27	M28	M29	M30	M31	M32	M33	M34	M35	M36
WP1: ASIC design and verification	T1.1 - Specifications	🟧	🟧																																		
	T1.2 - Prototype design & production			🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧																				
	T1.3 - Demonstrator design & production													🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧								
	Milestones		Specifications drafted								Prototype submission												Demonstrator submission														
	Deliverables		Specification sheet														Prototype chip												Demonstrator chip								
WP2: Testing, data acquisition and integration	T2.1 - Setup for test chip	🟦	🟦	🟦	🟦																																
	T2.2 - Test chip characterization					🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦																								
	T2.3 - Setup for prototype chip													🟦	🟦	🟦	🟦																				
	T2.4 - Prototype chip characterization																	🟦	🟦	🟦	🟦																
	T2.5 - Setup for demonstrator characterization																					🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦								
	T2.6 - Lab characterization of demonstrator																													🟦	🟦	🟦	🟦	🟦	🟦	🟦	
	T2.7 - Module integration																																🟦	🟦	🟦	🟦	
	T2.8 - Test of the deonstrator on beam																																				🟦
	Milestones				Setup for test chip ready												Setup for prototype chip ready												Setup for demonstrator ready							Module is ready	
	Deliverables				Setup for test chip												Setup for prototype chip												Setup for demonstrator							Demonstrator module	
WP3: Radiation tolerance and cryogenic operation	T3.1 - Procedure for radiation and cryo testing	🟪	🟪	🟪	🟪																																
	T3.2 - Radiation and cryo characterization of test chip					🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪																								
	T3.3 - Cryo testing of prototype chip																	🟪	🟪	🟪	🟪	🟪	🟪														
	T3.4 - Cryo testing of demonstrator																													🟪	🟪	🟪	🟪	🟪	🟪	🟪	
	Milestones				Procedure for radiation tolerance and cryo tests drafted								Radiation and cryo characterization of test chip completed										Cryogenic tests of prototype chip completed													Demonstrator cryo test completed	
	Deliverables				Document describing characterization procedure								Report on t test results										Report on test results													Report on test results	
WP4: Sensor characterization, simulation and modeling	T4.1 - Rad effects and crio operation modeling					🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
	T4.2 - Test of single micro-cells from test chip					🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩																								
	T4.3 - Test of single micro-cells from prototype chip																	🟩	🟩	🟩	🟩	🟩	🟩														
	Milestones												Test of micro-cells from test chip comppleted										Test of micro-cells from prototype chip completed													Model for radiation damage and cryo operation available	
	Deliverables																																			Model for radiation damage and cryo operation	

Resources @ INFN Padova

FTE Padova 2024/7 => 40% ! Nel 2026 finito ADA_5D potremo superare 1 FTE

- G.Collazuol	10 %
- S.Levorato	5 %
- F.Tessarotto	5 %
- D.Henaff	10 %
- R.Strolili	10%
- L.Silvestrin	(10%)

Preventivi 2025

- Consumo per circa 10kEuro
- Missioni (Italia) per 4kEuro

Richieste 2025 in Sezione PD – non ci sono richieste per il 2025

- Servizio Elettronica
- Servizi Tecnici ed Elettronici
- Servizio Progettazione Meccanica
- Servizio Officina Meccanica

  parts for a small volume prototype high pressure TPC – 1 m.p.

Additional material