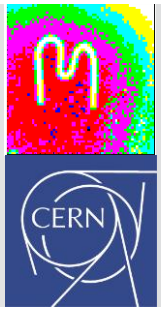


MEDIPIX AND TIMEPIX READOUT CHIPS

M. Campbell[1], J. Alozy, R. Ballabriga, P. Christodoulou,

A. Dorda, E.H.M. Heijne, I. Kremastiotis, X. Llopart, M. Piller, V. Sriskaran, and L.Tlustos

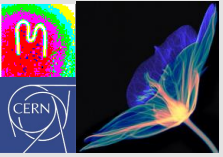
CERN, EP Department

1211 Geneva 23

Switzerland

[1] Honorary Professor at Glasgow University

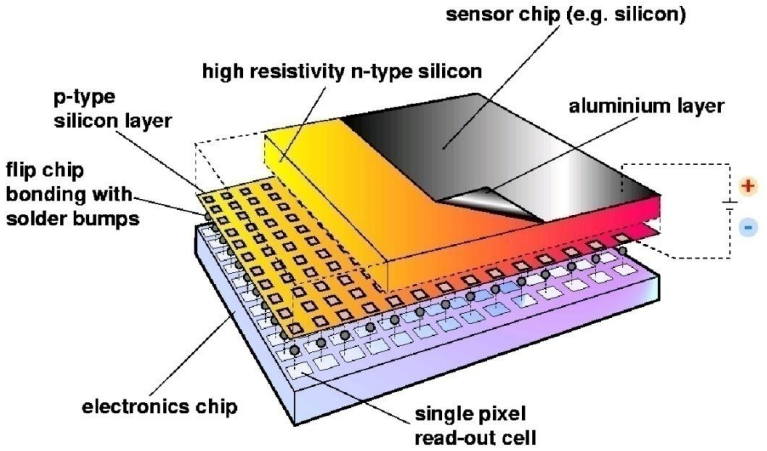
Medipix2 (1999 ->)	Medipix3 (2005 ->)	Medipix4 (2016 ->)
Albert-Ludwig Universität Freiburg, Germany	Albert-Ludwig Universität Freiburg, Germany	CEA, Paris, France
CEA, Paris, France	AMOLF, Amsterdam, The Netherlands	CERN, Geneva, Switzerland
CERN, Geneva, Switzerland	Brazilian Light Source, Campinas, Brazil	DESY-Hamburg, Germany
Czech Academy of Sciences, Prague, Czechia	CEA, Paris, France	Diamond Light Source, England, UK
ESRF, Grenoble, France	CERN, Geneva, Switzerland	IEAP, Czech Technical University, Prague, Czeciah
IEAP, Czech Technical University, Prague, Czech Republic	DESY-Hamburg, Germany	IFAE, Barcelona, Spain
IFAE, Barcelona, Spain	Diamond Light Source, England, UK	JINR, Dubna, Russian Federation
Mid Sweden University, Sundsvall, Sweden	ESRF, Grenoble, France	NIKHEF, Amsterdam, The Netherlands
MRC-LMB Cambridge, England, UK	IEAP, Czech Technical University, Prague, Czech Republic	University of California, Berkeley, USA
NIKHEF, Amsterdam, The Netherlands	KIT/ANKA, Forschungszentrum Karlsruhe, Germany	University of Canterbury, Christchurch, New Zealand
University of California, Berkeley, USA	Mid Sweden University, Sundsvall, Sweden	University of Geneva, Switzerland
Universität Erlangen-Nurnberg, Erlangen, German	NIKHEF, Amsterdam, The Netherlands	University of Glasgow, Scotland, UK
University of Glasgow, Scotland, UK	Univesridad de los Andes, Bogota, Columbia	University of Houston, USA
University of Houston, USA	University of Bonn, Germany	University of Maastricht, The Netherlands
University and INFN Section of Cagliari, Italy	University of California, Berkeley, USA	University of Oxford, England, UK
University and INFN Section of Pisa, Italy	University of Canterbury, Christchurch, New Zealand	INFN, Italy
University and INFN Section of Napoli, Italy	Universität Erlangen-Nurnberg, Erlangen, German	
	University of Glasgow, Scotland, UK	
	University of Houston, USA	
	University of Leiden, The Netherlands	
	Technical University of Munich, Germany	
	VTT Information Technology, Espoo, Finland	

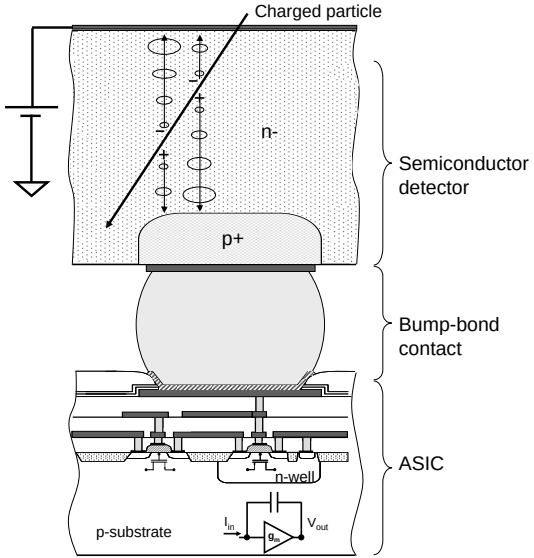


Outline

- Introduction
- Some examples of applications (within HEP and outside of HEP)
- Timepix3
- Through Silicon Vias
- Timepix4
- Conclusions and future

Hybrid Silicon Pixel Detectors



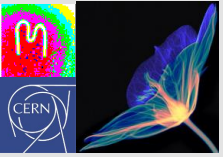


- Noise-hit free images possible (high ratio of threshold/noise)
- Standard CMOS can be used (follow industry)
- Sensor material can be changed (Si, GaAs, CdTe..)
- Semiconductor sensor can be replaced by a gas gain grid or MCP

The Medipix and Timepix ASICs - Timeline

Collaboration	2003	2006	2013	2014	2017	2018	2020	2021	2023?
Medipix2	Medipix2	Timepix				Timepix2			
Medipix3			Medipix3	Timepix3					
Medipix4							Timepix4	Medipix4	

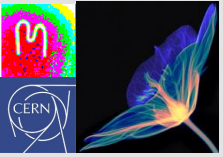
- Medipix chips aim at energy sensitive photon counting and typically use frame-based readout
- Timepix chips are more oriented towards single particle detection



The Medipix and Timepix ASICs - Timeline

Collaboration	2003	2006	2012	2013	2017	2018	2020	2021	2025?
Medipix2	Medipix2	Timepix				Timepix2			
Medipix3			Medipix3	Timepix3				Medipix4	
Medipix4							Timepix4		
LHCb					VELOpix				VELOpix2

- Medipix chips aim at energy sensitive photon counting and typically use frame-based readout
- Timepix chips are more oriented towards single particle detection
- This talk will focus on the recent Timepix chips and in particular Timepix4

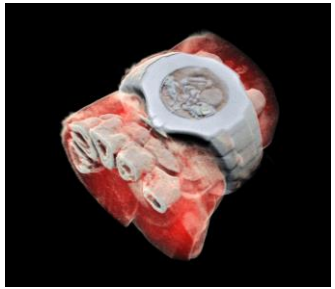


Timepix Chip family

	Timepix	Timepix2	Timepix3	Timepix4
Tech. node (nm)	250	130	130	65
Year	2005	2018	2013	2019
Pixel size (μm)	55	55	55	55
# pixels (x x y)	256 x 256	256 x 256	256 x 256	448 x 512
Time bin (resolution)	10ns	10ns	1.5ns	200ps
Readout architecture	Frame based (sequential R/W)	Frame based (sequential or continuous R/W)	Event driven or Frame based (sequential R/W)	Event driven or Frame-base (sequential or continuous R/W)
Number of sides for tiling	3	3	3	4

Applications beyond HEP

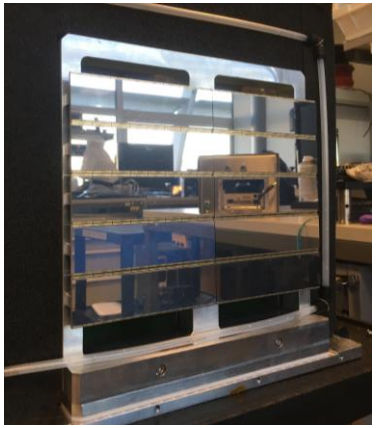
Spectroscopic X-ray imaging



Mars Bio-imaging

InsightArt

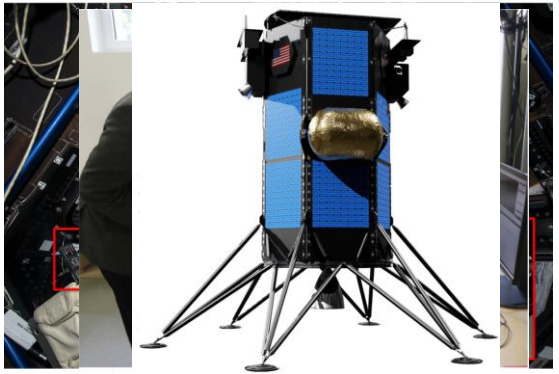
Time resolved X-ray imaging



Diamond Light Source

Background radiation measurents

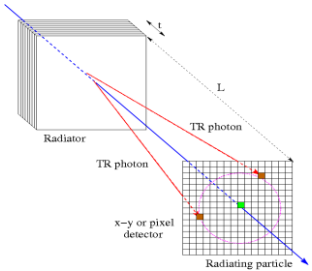
Admira Project

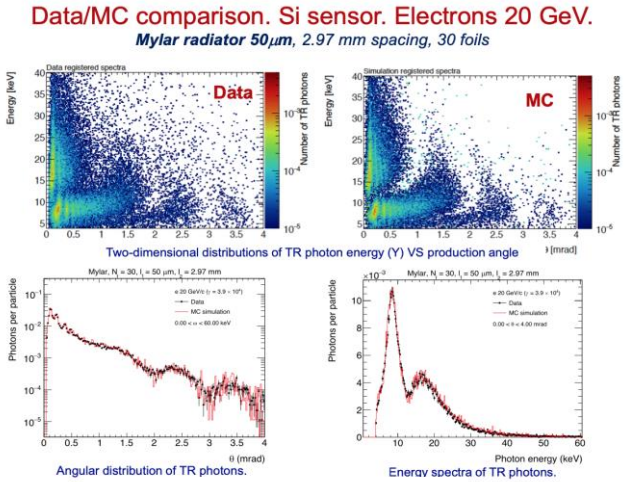


Advacam, Houston, IEAP, NASA

Examples of applications inside HEP

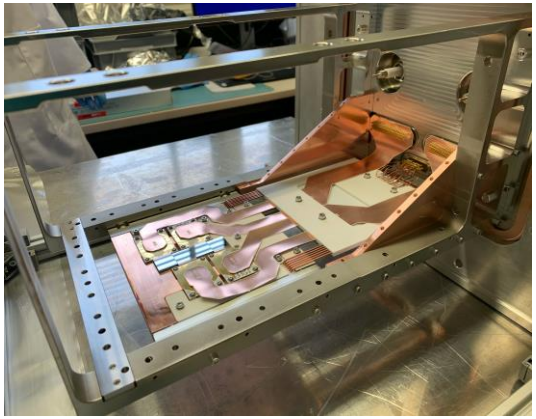
Transition radiation measurements



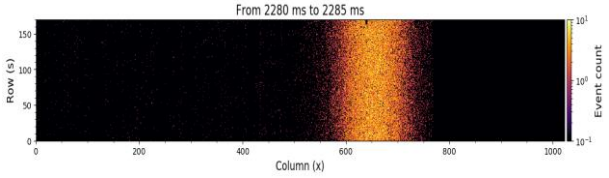


A. Romaniouk et al.

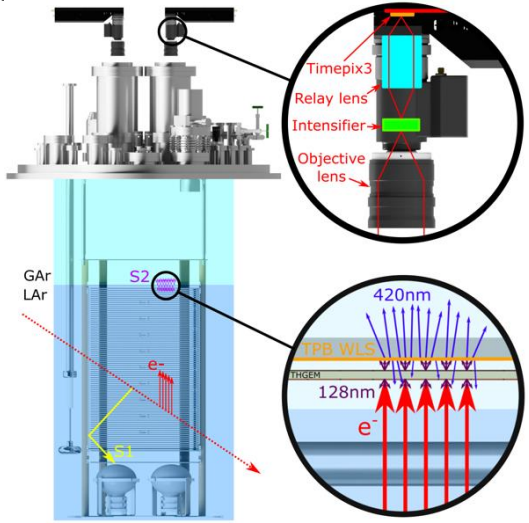
Beam gas monitoring CERN PS

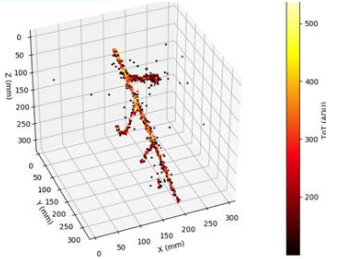


J. Storey, et al.

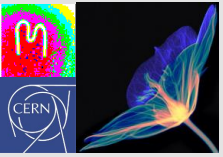


Optical readout neutrino detector





K. Mavrokoridis et al

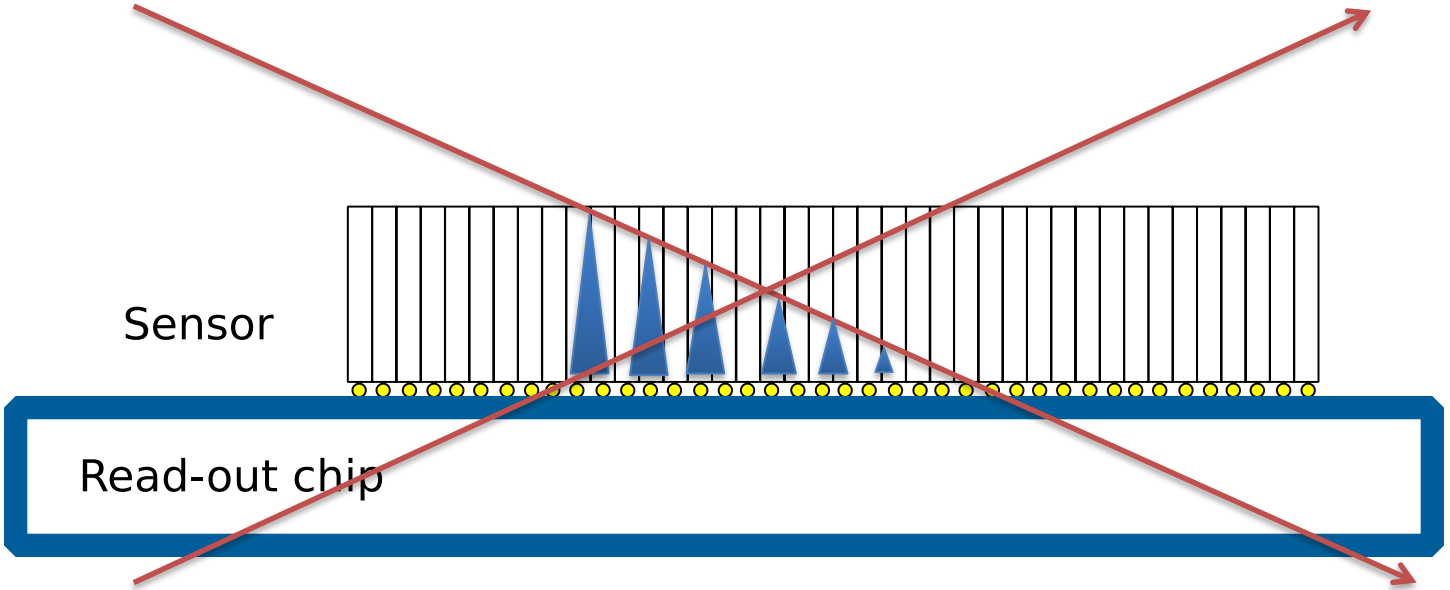


Timepix3 Specs

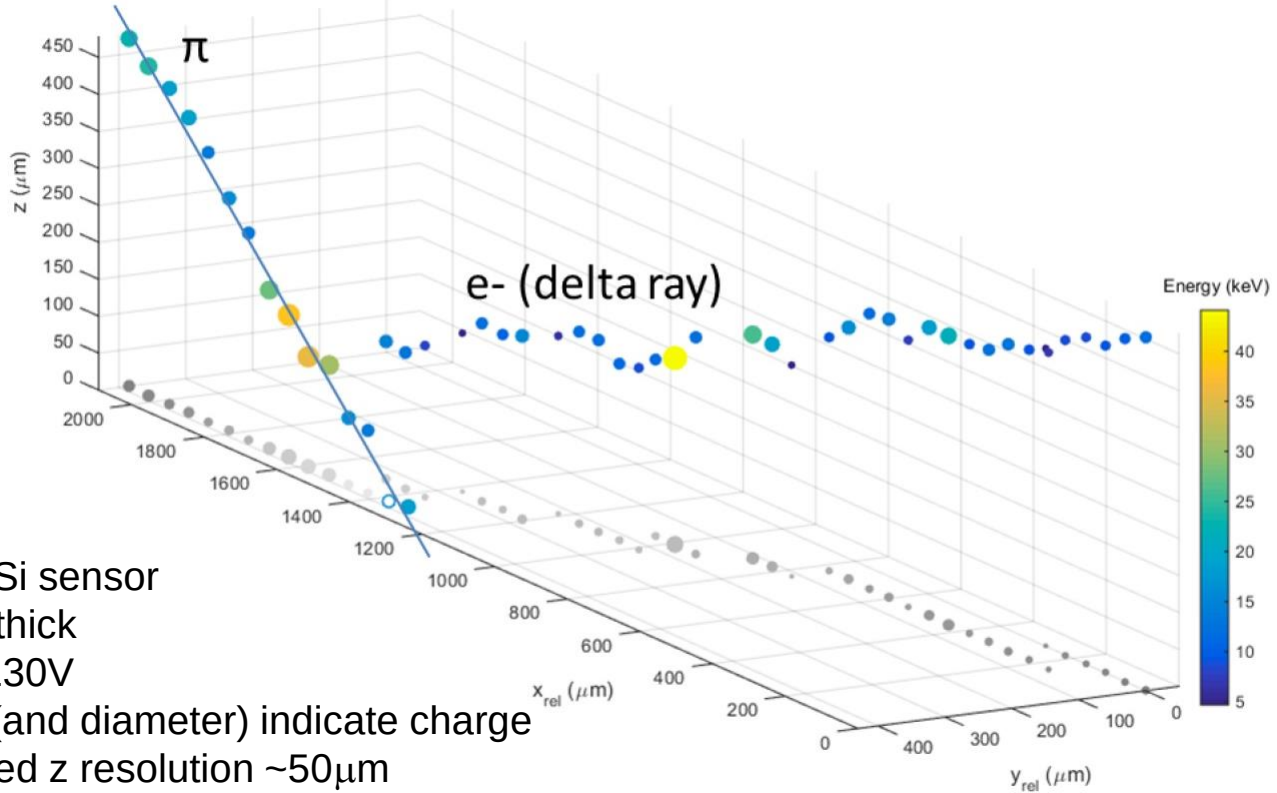
CMOS node	130nm
Pixel Array	256 x 256
Pixel pitch	55μm
Charge collection	e^-, h^+
Pixel functionality	TOT (Energy) and TOA (Arrival time)
Preamp Gain	~47mV/ke^-
ENC	~60e^-
FE Linearity	Up to 12ke^-
TOT linearity (resolution)	Up to 200ke^- (<5%)
TOA resolution*	Up to 1.6ns
Time-walk	<20ns
Minimum detectable charge	~500e^- → 2 KeV (Si Sensor)
Power power (1.5V)	700 mW/cm^2
Maximum hit rate	80Mhits/sec (in data driven)
Readout	Data driven (44-bits/hit @ 5Gbps)

* Thanks to V. Gromov, et al. Nikhef, C. Brezina et al., Bonn

Tracking in a single Si layer



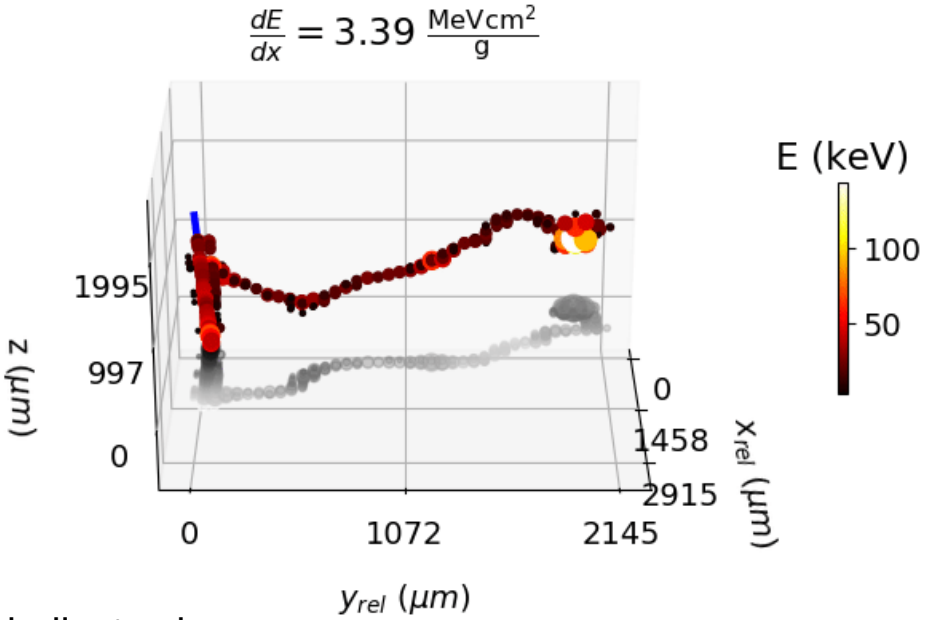
Test with 120GeV/c Pion Track



60 deg
p+ in n Si sensor
500μm thick
V_{bias} = 130V
Colour (and diameter) indicate charge
Measured z resolution ~50μm

Slide courtesy of B. Bergmann, S. Pospisil, IEAP, CTU, Prague

3D rendering of traversing particle with delta electron



45 deg
CdTe sensor
2mm thick
V_{bias} = 130V
Colour (and diameter) indicate charge

Slide courtesy of B. Bergmann, S. Pospisil, IEAP, CTU, Prague

Through Silicon Via processing of Medipix3/Timepix3

Through Silicon Vias offer the possibility of creating 4-side buttable tiles

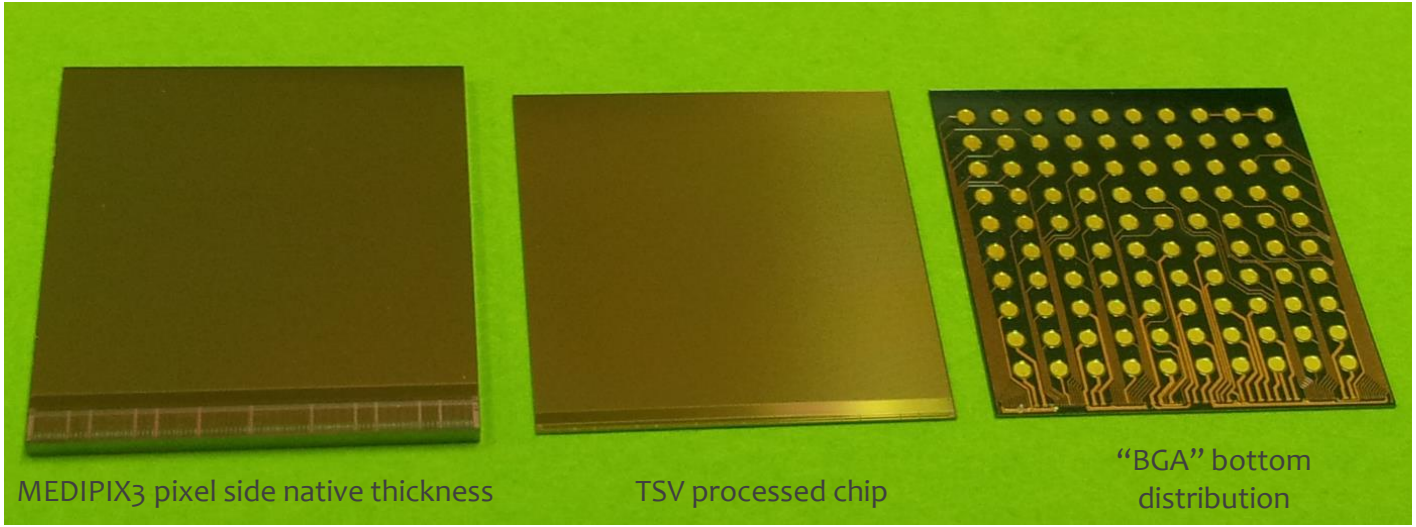
3 projects for been undertaken with LETI
- Funding mainly from Medipix3 Collaboration, AIDA and LCD group

1) 2011 - Feasibility of TSV processing on Medipix3 (low yield wafers)

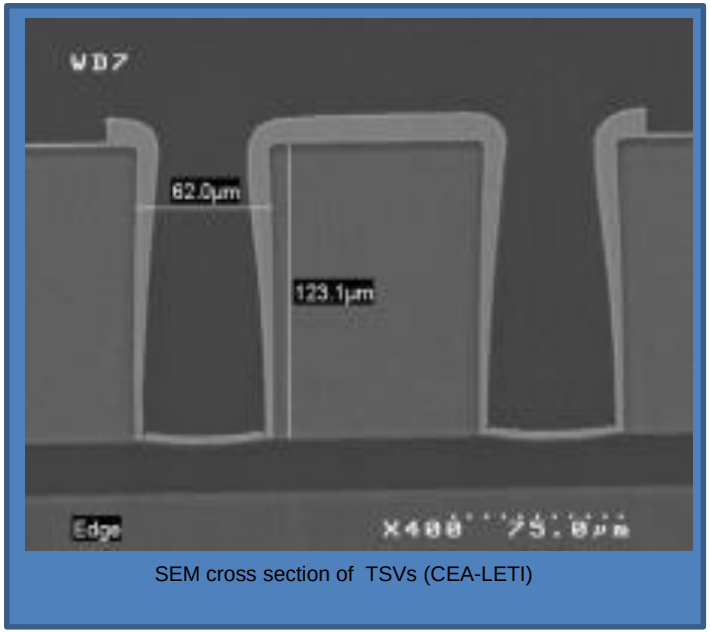
2) 2013 - Proof of yield using Medipix3RX wafers (6 wafers)

3) 2014 - TSV processing of ultra-thin Medipix3/Timepix3 wafers (50μm)

TSV processing on the Medipix3



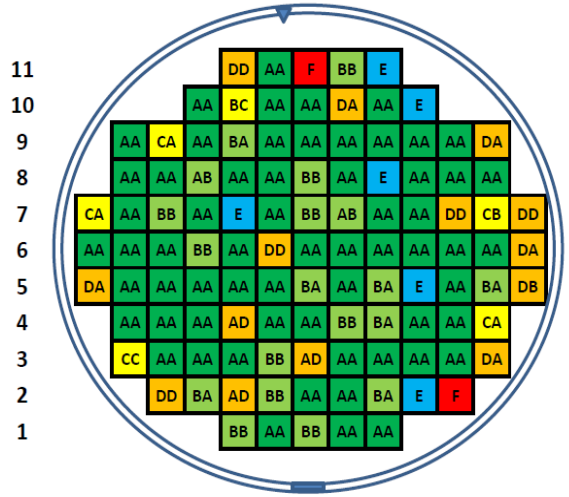
TSV Process – CEA LETI



SEM cross section of TSVs (CEA-LETI)

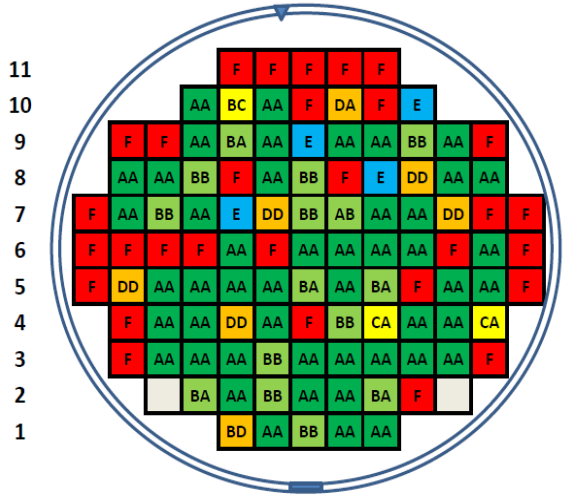
Yield verification of TSV processed wafers

W128_AZPGBPH_before_TSV

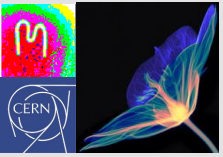


	AA	62	57%
	BB, BA or AB	19	17%
	CC, CA, AC, BC or CB	6	6%
	D	14	13%
	E	6	6%
	F	2	2%
	Total	**109**	100%

W128_AZPGBPH_after TSV



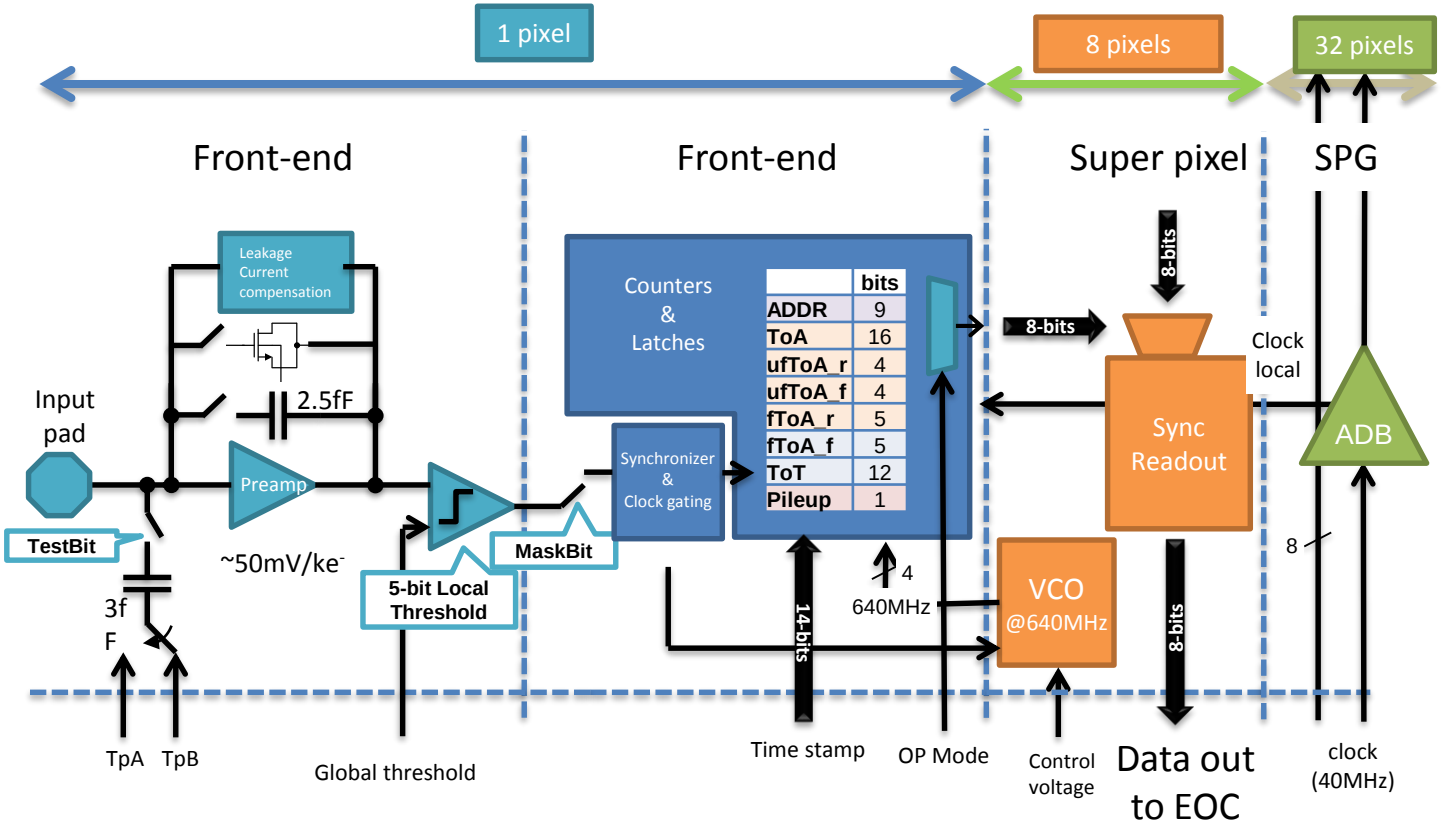
	AA	48	45%
	BB, BA or AB	15	14%
	CC, CA, AC, BC or CB	3	3%
	D	7	7%
	E	4	4%
	F	30	28%
	Total	**107**	100%



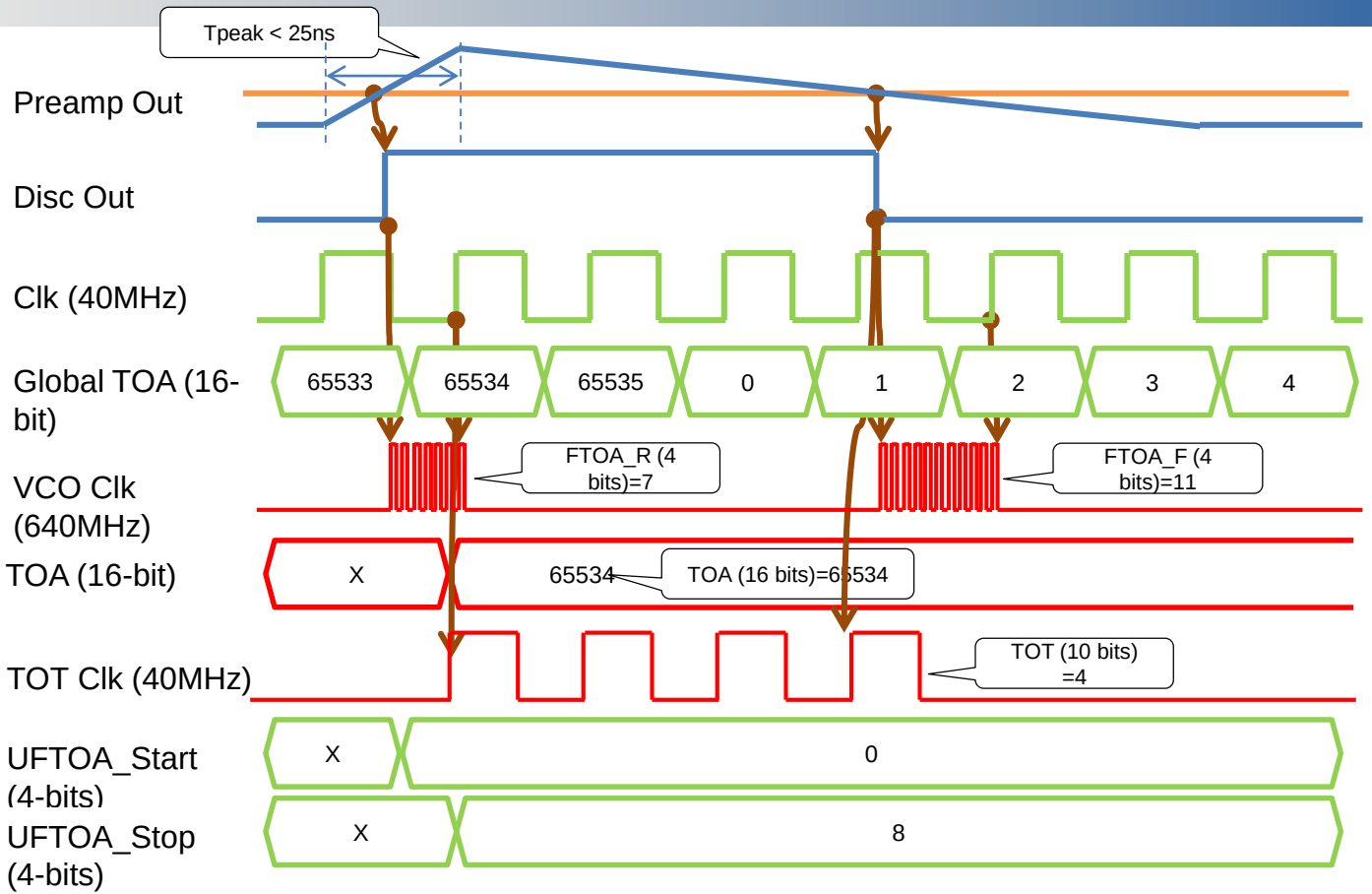
Timepix3 → Timepix4

			Timepix3 (2013)	Timepix4 (2018/19)
Technology			130nm – 8 metal	65nm – 10 metal
Pixel Size			55 x 55 µm	55 x 55 µm
Pixel arrangement			3-side buttable 256 x 256	4-side buttable 512 x 448
Sensitive area			1.98 cm^2	6.94 cm^2
Readout Modes	Data driven (Tracking)	Mode	TOT and TOA	
		Event Packet	48-bit	64-bit
		Max rate	<80 Mhits/s	<358 MHz/cm^2/s
		Max pix rate	1.3kHz/pixel	10.6kHz/pixel
	Frame based (Imaging)	Mode	PC (10-bit) and iTOT (14-bit)	CRW: PC (8 or 16-bit)
		Frame	Zero-suppressed (with pixel addr)	Full Frame (without pixel addr) CRW (8-bit / 16-bit) Up to 44 KHz frame @8b
		Max count rate	82 Ghits/cm^2/s	~800 Ghits/cm^2/s
TOT energy resolution			< 2KeV	< 1Kev
Time resolution (bin size)			1.56ns	~200ps
Readout bandwidth			≤5.12Gb (8 x SLVS@640 Mbps)	≤163 Gbps (16 x 10.24 Gbps)
Target global minimum threshold			<500 e^-	<500 e^-

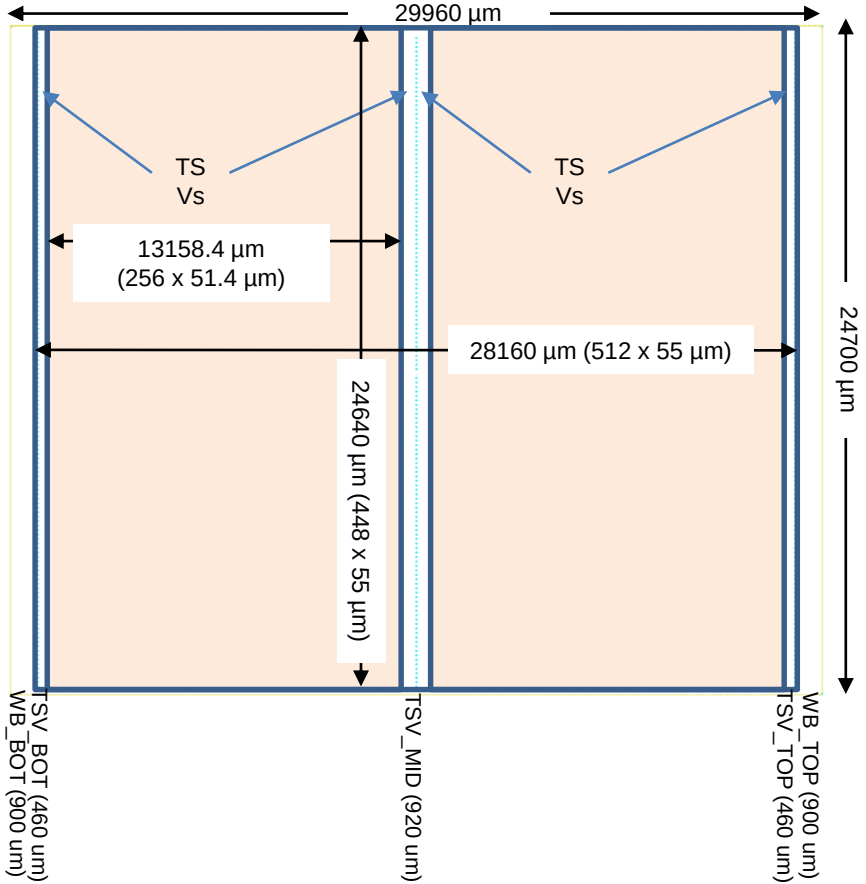
Timepix4 Pixel Schematic



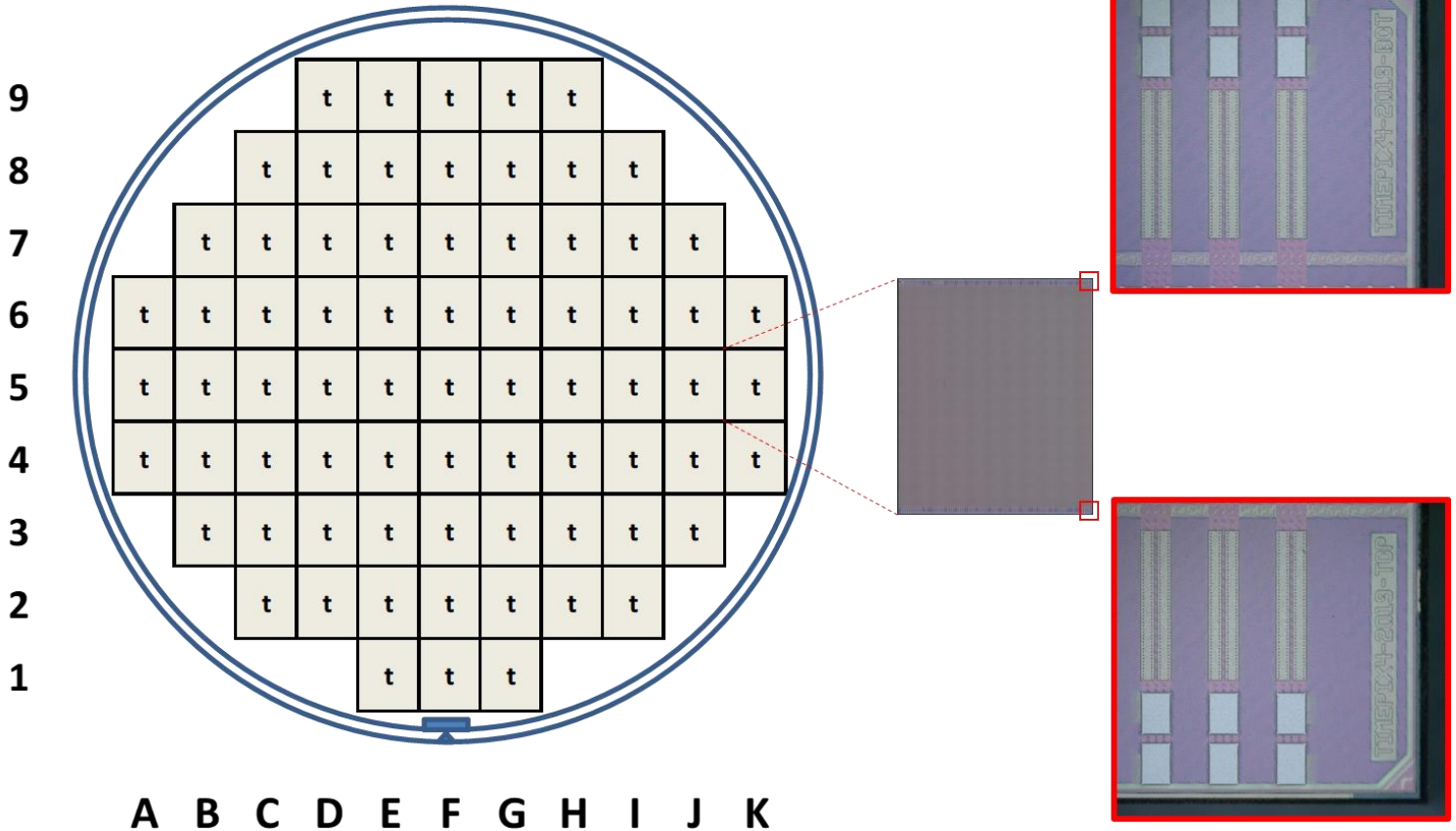
Pixel Operation in TOA & TOT [DD]



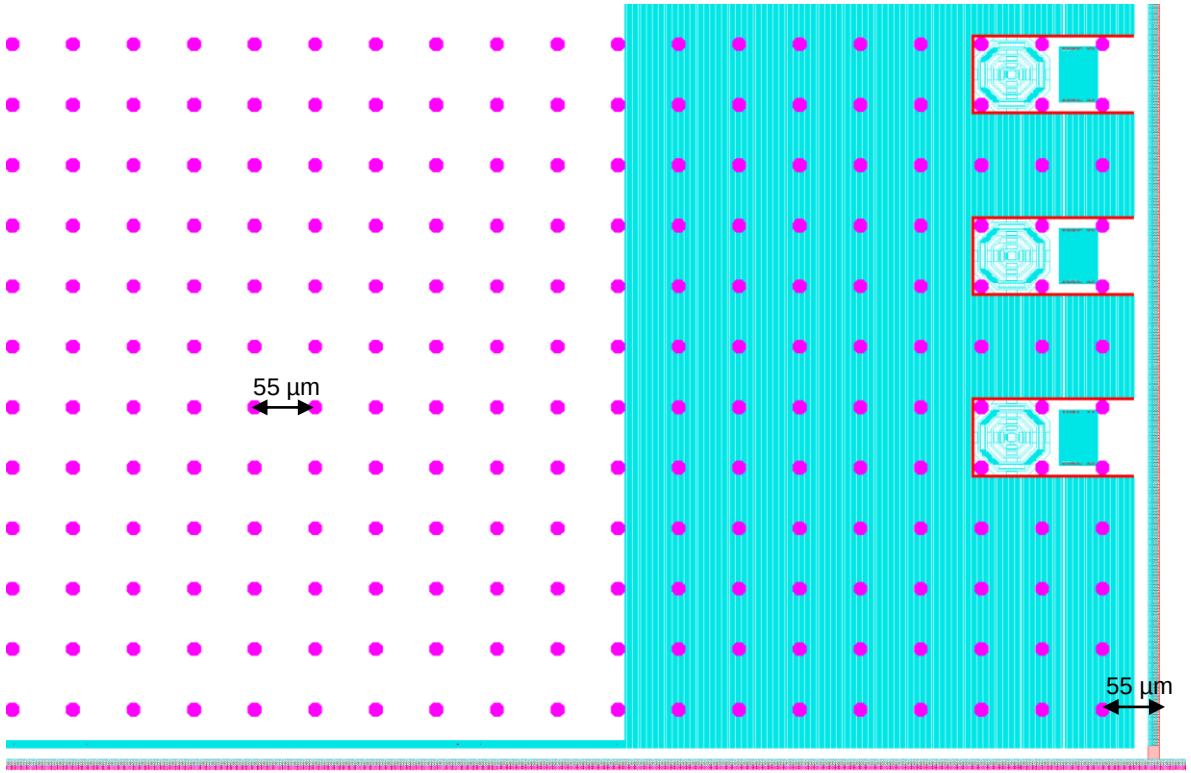
Timepix4 Floorplan



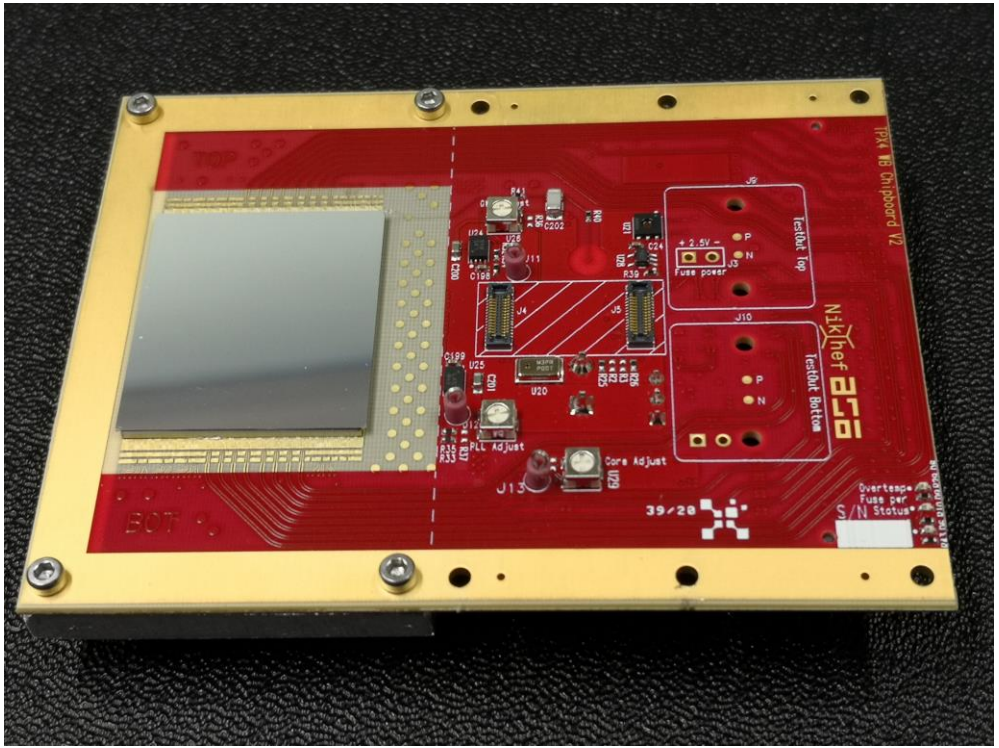
Timepix4 wafer map



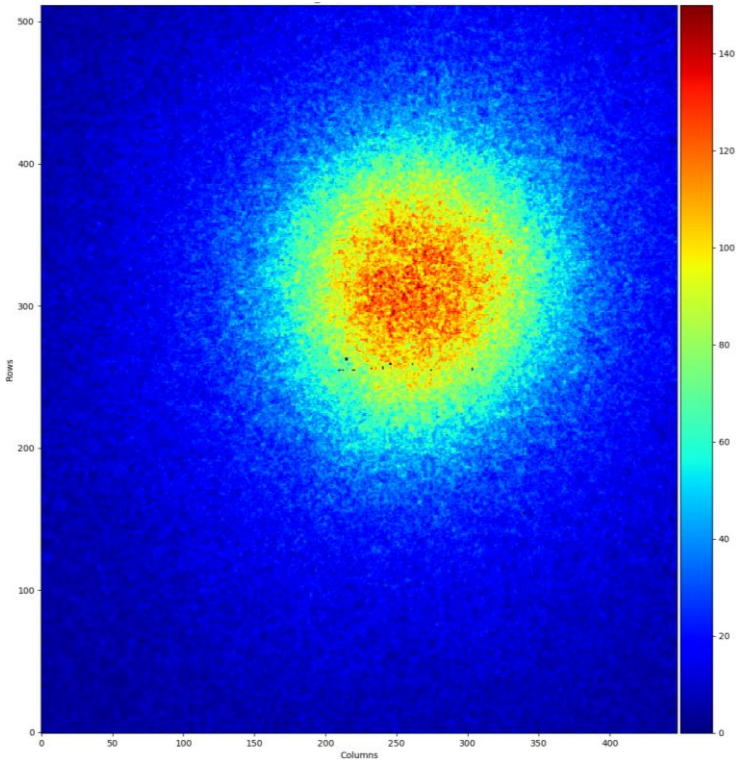
TSV (on M1) and BUMPs (on M10)



Timepix4 – works! ☺



10s exp. ^{90}Sr



Threshold ~ 800e$^-$

6.1 M packets @ 5 Gbps

Summary of the evolution of Timepix chips

- With each new generation more funtionality has been added to readout chips
- In particular, we moved from frame-based readout (Timepix and Timepix2) to event driven readout (Timepix3 and Timepix4)
  - Requires excellent signal to threshold ratio
  - Escapes the need for high frame rates to obtain precise hit time tagging
- This – possibly unique feature – has opening many new applications in particle detection
- With Timepix4 (combined with TSVs and edgeless sensors) we can cover large areas seamlessly
- Such a feature may be especially useful for the gas detector community

Some references and links

“An introduction to the Medipix family ASICs,” R. Ballabriga, M. Campbell, X. Llopart, *Radiation Measurements* 136 (2020) 106271

“VeloPix: the pixel ASIC for the LHCb upgrade,” T. Poikela et al. *Journal of Instrumentation*, Volume 10, January 2015

MARS Bio-imaging

InsightArt

Advacam cameras

Diamond Light Source detector group

Admira project

“Development of a rest gas ionisation profile monitor for the CERN Proton Synchrotron based on a Timepix3 pixel detector,” S. Levasseur et al., *Journal of Instrumentation*, Volume 12, February 2017

“Optical Readout of the ARIADNE LArTPC Using a Timepix3-Based Camera,” Adam Lowe et al *Instruments* 2020, *4*(4), 35;

“Registration of the transition radiation with GaAs detector: Data/MC comparison,” J Alozy et al, 2020 J. Phys.: Conf. Ser. 1690 012041

3D reconstruction of particle tracks in a 2 mm thick CdTe hybrid pixel detector,” Bergmann, B., Burian, P., Manek, P. *et al. Eur. Phys. J. C* 79, 165 (2019).

Thank you for your attention!

Medipix3RX images: S. Procz et al.