Ecole IN2P3 de microélectronique - 2017

Microelectronic R&D at CPPM

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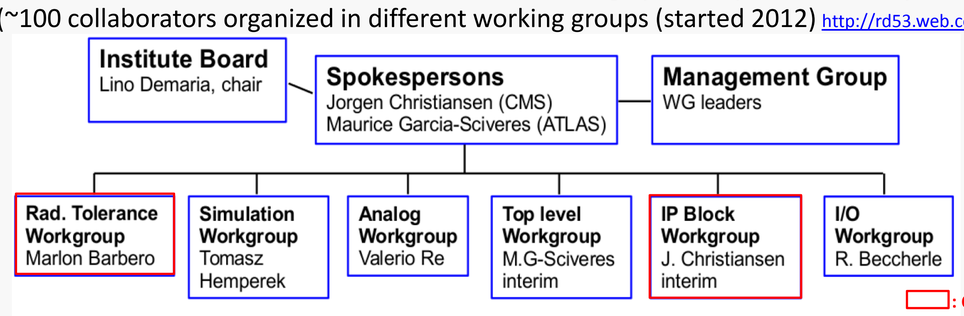
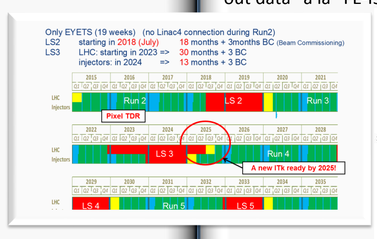
The Center for particle physics of Marseille (CPPM) is strongly involved in the development of front-end chips for physics particles experiences (ATLAS) and enhances its competences in interdisciplinary projects (Medical Imaging, Plasma Imaging).

HL-LHC ATLAS upgrade phase II

RD53 (Hybrid pixel)

•RD53: international collaboration for a common design pixel chips ATLAS/CMS phase II upgrades (~100 collaborators organized in different working groups (started 2012) http://rd53.web.cern.ch/RD53/)

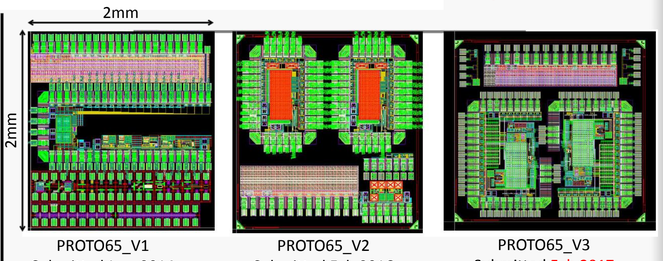




: CPPM/LAPP contributions

• Extremely challenging requirements for HL-LHC

Chip features	Phase2-FEx5 (TSMC 65nm)
Pixel size	50x50um²
Chip size	> 20 x 20 mm²
Transistors number	~1G
Hits rate	3 GHz/cm²
BPW	4-5 Gb/s
Trigger latency	up to 12.8µs (deep storage buffer)
Radiation	1GRad ->0.5GRad
Pixel density	40000 pix/cm²
Pixel quantity	<160000
Low power	~1/2 - 1 W/cm²

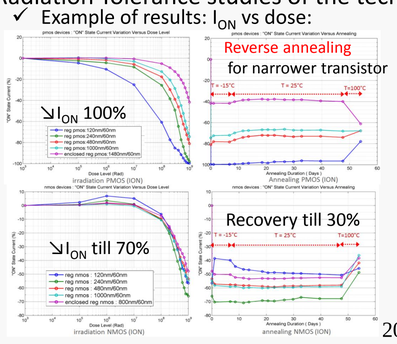


PROTO65_V1 Submitted June2014 | PROTO65_V2 Submitted Feb 2016 | PROTO65_V3 Submitted Feb 2017

- Transistors devices (Radiation Tolerance workgroup)
- SEU memories
- BandGap
- SAR ADC 12 bits (for monitoring)
- Temperature and radiation sensors

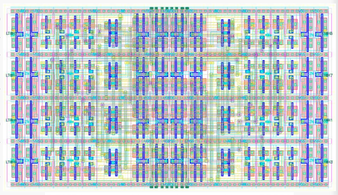
(IP Block Workgroup)

• Radiation Tolerance studies of the technology
✓ Example of results: I_{ON} vs dose:



• SEU test for DICE and TRL structure

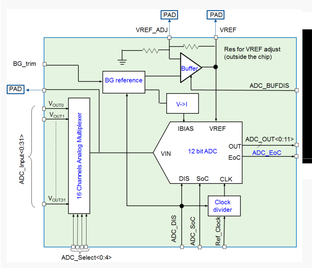
Cell	Area	Occupancy (8 bits/pixel)	Gain
Standard Latch	3x2µm²	2%	-
TRL	14x4µm²	18%	x 220
TRL + "LOAD" triplication	19x4µm²	24%	x 1160
TRL interleaved (2 bits)	38x4µm²	24%	x 3920
DICE	3.5x2µm²	2.2%	x 4.5
DICE + guard ring	6x2µm²	3.8%	x 5.6
DICE interleaved (2 bits)	7x2µm²	2.2%	x 9



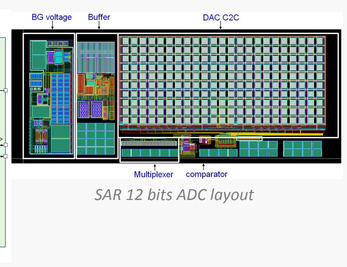
8 DICE interleaved Latches integrated in the RD53A

200Mrad and 500Mrad corner models have been provided to the RD53 collaboration

• IP activities: Monitoring Block for slow variation signals



SAR 12 bits ADC diagram

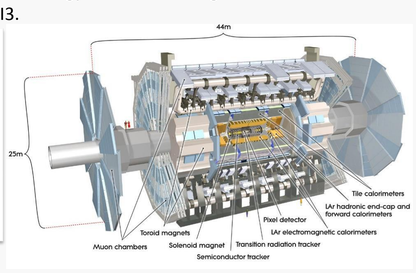


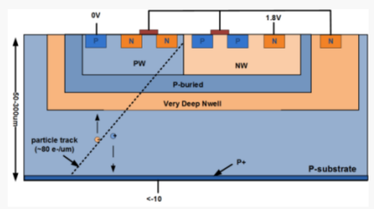
SAR 12 bits ADC layout

- ✓ Sampling rate: (<100) ksamples/s
- ✓ Architecture : SAR ADC
- ✓ Precision : 12 bits (LSB ~ 250 µV)
- ✓ DC accuracy :
  - INL: +/- 1 bit
  - DNL: +/- 0.5 bit
- ✓ Operating input voltage : 0 – 900mV
- ✓ Conversion time : 14 clock cycles
- ✓ TID: 500 Mrad
- ✓ Tempsens & Irradsens included in PROTO65_V3
- ✓ LabTest & Irrad Test foreseen this year…

DepMAPS (Depleted MAPS)

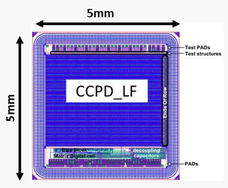
The HV-CMOS pixel sensors, called DepMAPS (Depleted MAPS) and using commercial processes seem to be well-suited, especially for the outer barrels of the ATLAS ITK upgrade. The actual demonstrators should fill all the requirement requested by the ATLAS PIXEL TDR. Several prototypes on LFoundry 150nm technology have been designed and tested. The last version, the MONOPIX chip is a full monolithic circuit, with a fast digital read-out data "à la" FE-I3.



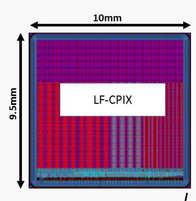


LFA150:
- L-Foundry 150 nm process (deep N-well/P-well)
- Up to 7 metal layers
- Resistivity of wafer: >2000 Ω·cm
- Small implant customization
- Backside processing

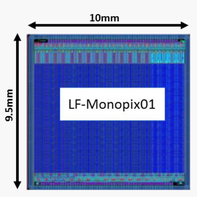
CCPD_LF
- Submitted in Sept 2014
- 33 x 125 µm² pixels
- Fast R/O coupled to FE-I4
- Standalone R/O for test

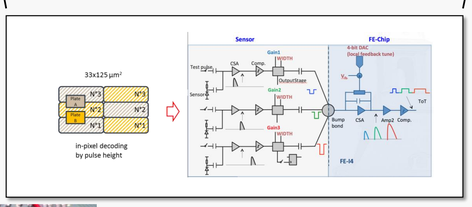


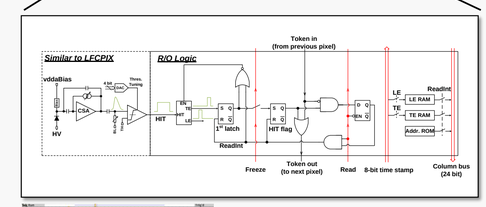
LF-CPIX (advanced CCPD_LF)
- Submitted in March 2016
- 50 x 250 µm² pixels
- ***CPIX demonstrator in LF***
- Fast R/O coupled to FE-I4
- Standalone R/O for test



LF-Monopix01 (monolithic)
- Submitted in August 2016
- 50 x 250 µm² pixels
- "Demonstrator size"
- ***Fast standalone R/O***
- Standalone R/O like for test



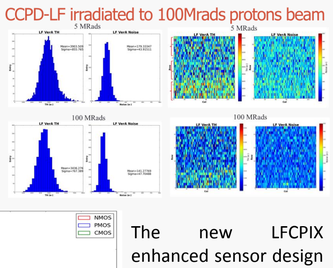




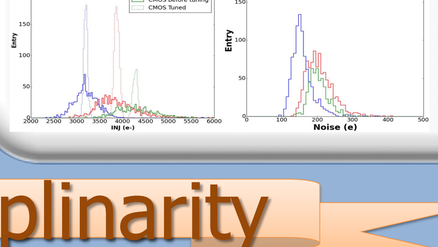
The CCPD-LF and the LFCPIX need to be connected to a Read-Out chip (FE-I4) by glue, or bump-bonding process. The AC direct coupling allows to read-out the pixels matrix.

CCPD-LF irradiated to 100Mrads protons beam

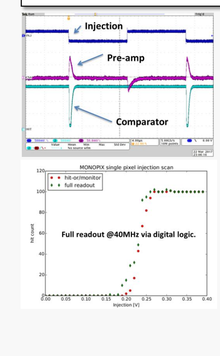
The CCPD-LF is rad-hard up to 100Mrads and fluence 10^{15} n_{eq}/cm^2 with a fully depleted sensor at 70V.



LFCPIX matrix dispersion



The new LFCPIX enhanced sensor design pushed the Break-Down voltage to 230V, with a tuned pixels matrix at 53e- rms.



The MONOPIX is an all-in-one chip with the same analog pixel part than LFCPIX and with the fast FEI-I3 digital readout.
The preliminary results show very good pixel responses, according the 40MHz full readout speed.

Interdisciplinarity

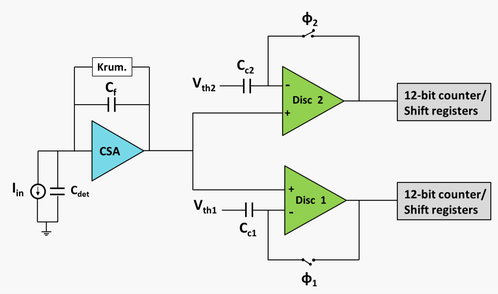
Demon

DEMON project is the result of collaboration between CPPM, PIIM, and CEA Cadarache, with the objective of developing advanced diagnostics aiming at measuring accurate fusion plasma properties. CPPM took in charge the design of a prototype hybrid X-ray photon counting detector with specifications to measure ions velocity and temperature in the WEST tokamak platform in Cadarache, with potential perspectives for ITER. The prototype matrix, named PLATO, is composed of 16 x 18 pixels with a 70 µm pixel pitch. New techniques have been used in analog sensitive blocks to minimize noise coupling through supply rails and substrate, and to suppress threshold dispersion across the matrix. The PLATO ASIC, designed in TSMC CMOS 0.13 µm technology, is currently under electrical tests. The presented performance summary is based on simulations.

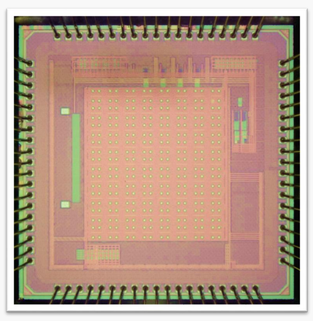
Performance Summary

Technology	TSMC CMOS 0.13 µm
Pixel pitch	70 µm
Detectable energy range	3 – 10 keV
Non linearity	< 3%
Charge to voltage gain	75 mV/ke-
Photon count rate	12 x10^7 ph/mm²/s
Power consumption	5.2 µW
Equivalent Noise Charge (ENC)	42 e-rms
Readout time	≤ 7 µs using 200 MHz clock and 6 parallel outputs
Leakage current compensation	50 pA to 10 nA/pixel

Pixel Architecture

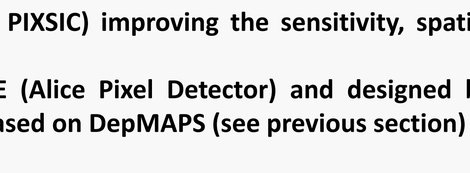


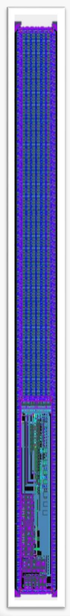
Microscope photo of PLATO Chip



MAPSSIC

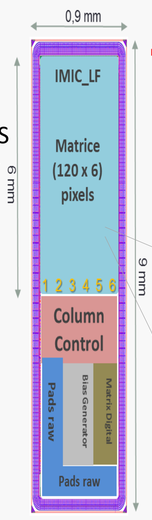
MAPSSIC is a bio-medical imaging project aiming at correlating in vivo processes of neuronal communication with behavior in real time. It is a collaboration with IMNC, IPHC, CERMEP, CRNL, and NeuroPSI.
The objective is to design β⁺ positrons probes directly implantable in rodent brain tissue on order to measure the radioactivity directly in the region of interest (few mm³). Such probes are part of an autonomous embedded system which must be operated in real time with wireless communication.
The MAPSSIC project is a second prototype (following PIXSIC) improving the sensitivity, spatial resolution and SNR of the radioactivity measurements.
Two probes has been designed, one based on ALPIDE (Alice Pixel Detector) and designed by colleagues at IPHC (cf. dedicated poster), and a second based on DepMAPS (see previous section) :

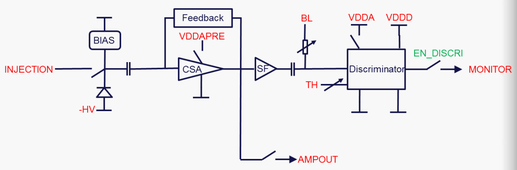




IMIC-LF chip

Size : 900 x 9 mm²
Sensitive area : 6 x 120 pixels
Technology : 0.15 µm Lfoundry CMOS process on high-resistivity 2kΩ.cm wafer
Pixel design : fully depleted 50µm
β⁺ sensitivity (4ke-)
and Gamma rejection (511kev)
Detection efficiency : 50 x 100 µm²
Based on DepMAPS (Depleted MAPS) :
- •Charge collection by drift
- •Asynchronous and synchronous operation
- •Standalone pixel and large fill factor
- •Analog and digital pixel readout





Pixel architecture