C. de La Taille
D.A.T. IN2P3

IN2P3
Institut national de physique nucléaire
et de physique des particules

Direction Technique IN2P3 2012

IN2P3, an institute in CNRS

- **CNRS :**
  - Under the authority of the ministry for higher education and research
  - 11 500 researchers
  - 14 200 engineers, technicians, administration
  - 1 200 laboratories
  - 10 thematic institutes, including 2 national institutes : IN2P3 (created in 1971) and INSU

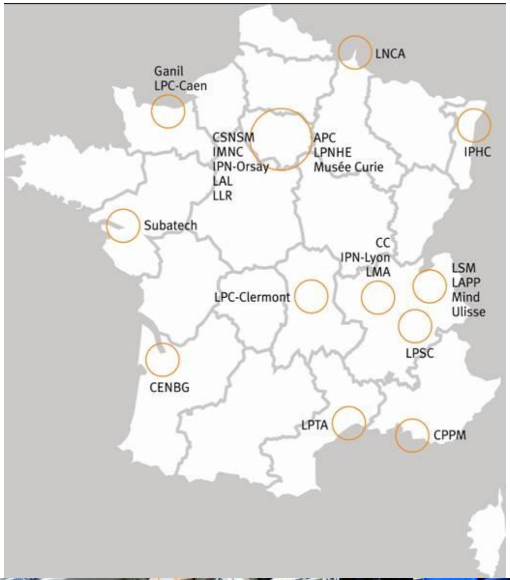
- **IN2P3 :**
  - 2 400 CNRS staff, researchers, engineers ands technicians; 600 university and other staff
  - Running budget from CNRS : 49 M€
  - 24 laboratories and platforms, most of them associated to an university
  - 40 large international projects

IN2P3 missions

- **Promote and federate research in nuclear physics, particle physics, astroparticle physics**
- **Coordinate the programs in the name of CNRS and Universities, in partnership with CEA**
- **Explore**
  - Particle physics
  - Nuclear and Hadronic physics
  - Astroparticules and Neutrinos
  - Nuclear energy and waste management
  - Research and Development of Accelerators
  - Instrumentation (new)
  - Computing grids
- **Bring its competence**
  - to other scientific domains
  - to contribute solving societal problems
- **Participate to the formation of students (University, grandes écoles)**
- **Help the companies benefit from its expertise**

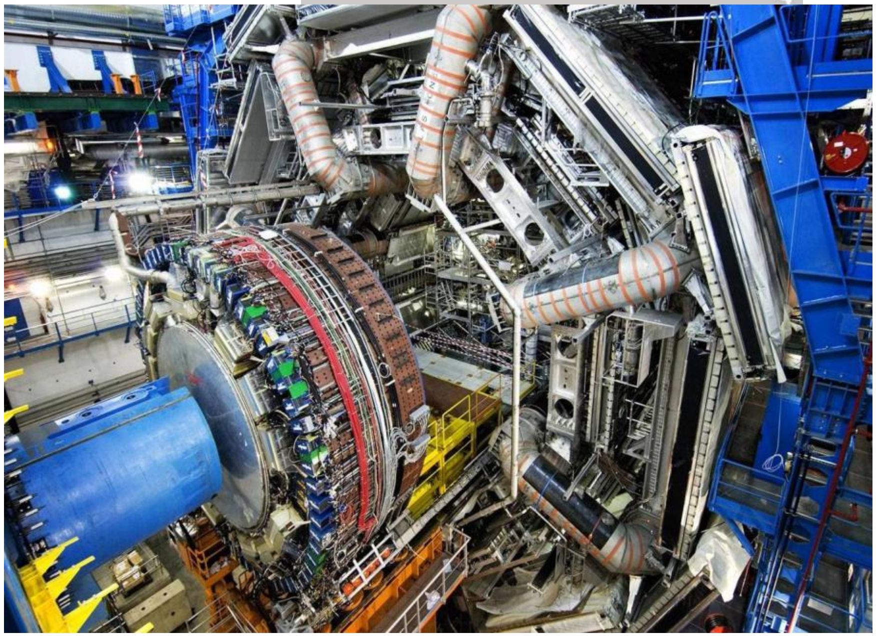
LHC - © Cern

Laboratories structured in a network



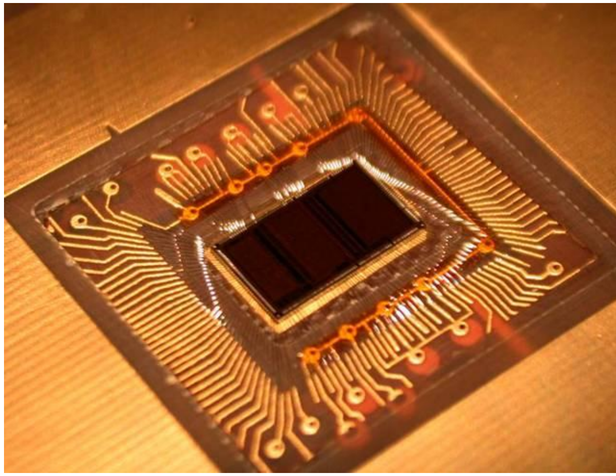
- **sharing and optimisation of the ressources and competences of the Institute**
  - large laboratories, infrastructures or technological platforms in limited number

- **Organization by projects**
  - Large International collaborations (LHC, GANIL, FAIR, HESS….
  - Custom detectors
  - Dedicated readout electronics/mechanics
    - High number of channels
    - Low power
    - Low material
    - High speed
    - High accuracy
    - Radiation tolerance
    - …
  - pushing the state of the Art

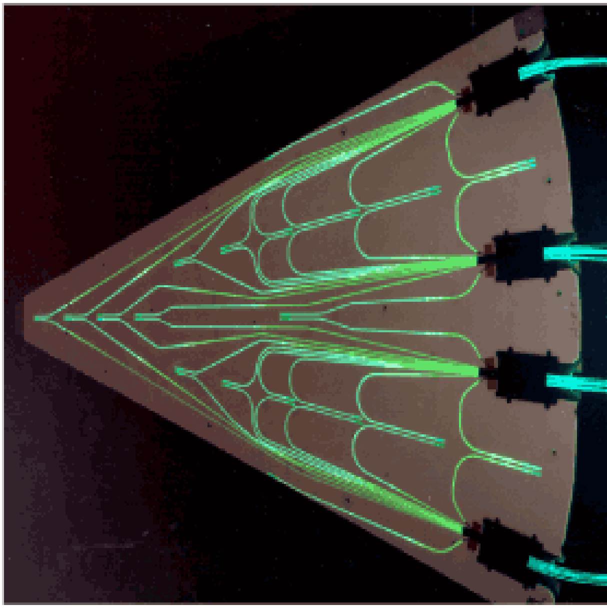


Instrumentation

- **R&D instrumentation**
  - Photodetectors (PM, SiPM, MCCP…)
  - Gaseous detectors (RPCs, Micromegas, TPCs…)
  - Semiconductor detectors (Ge, Si, MAPS…)
  - Bolometers (CMB, Edelweiss, 2Beta…)
  - Calorimeters (CALICE, sATLAS, ALICE…)
  - Radiodetection (MHz, GHz…)
  - Microelectronics (ASICs)
  - DAQ (NARVAL, FASTER, xTCA, …)
  - R&D mechanics (cooling, composites…)

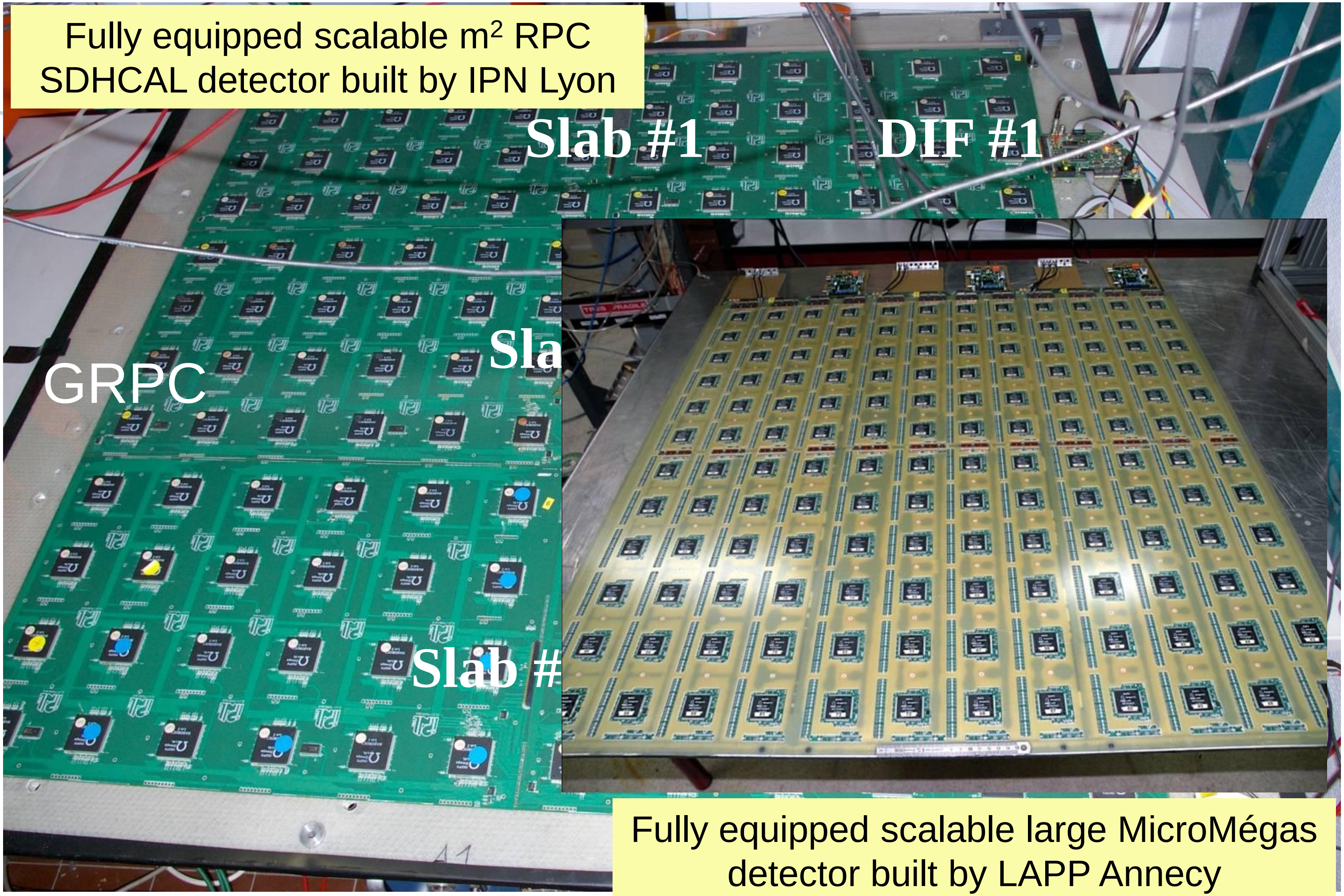


- **R&D organization**
  - Transversal thematic networks
  - Target next generation experiments
  - Centralized funding



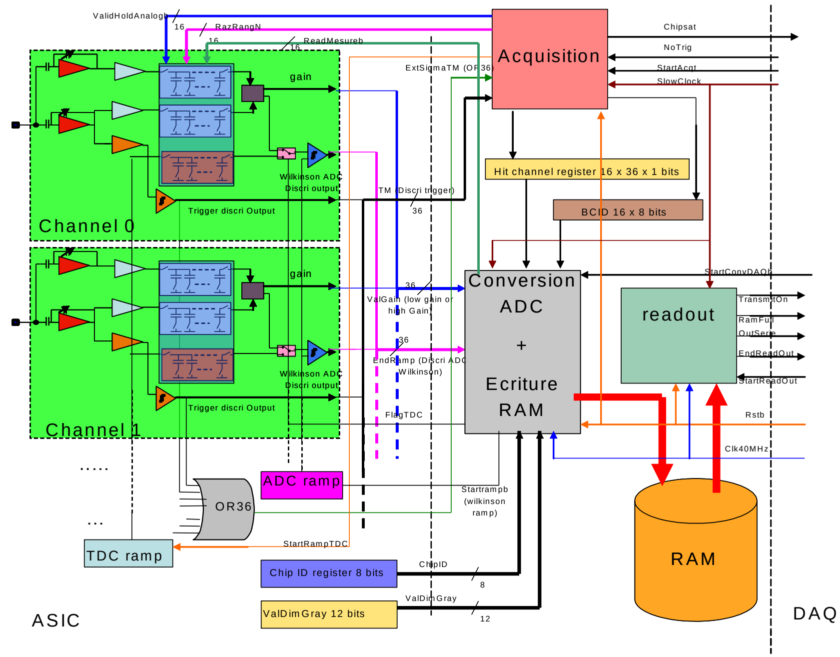
- **« Microelectronics poles »**

Square meter gaseous prototypes



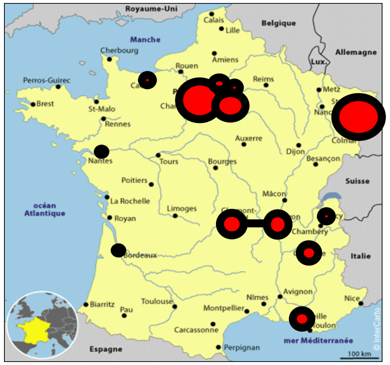
« Microelectronics poles »

- **Motivation :**
  - Continuous increase of chip complexity (SoC, 3D…)
  - Minimize interface problems



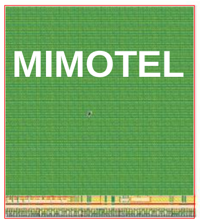
- **Importance of critical mass**
  - Daily contacts and discussions between designers
  - Sharing of well proven blocks
  - Cross fertilization of different projects

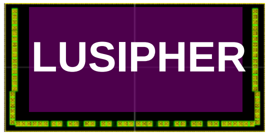
- **Creation of poles with critical mass (~10 persons)**
  - Orsay (OMEGA)
  - Clermont-Lyon (MICHRAU)
  - Strasbourg (IPHC)

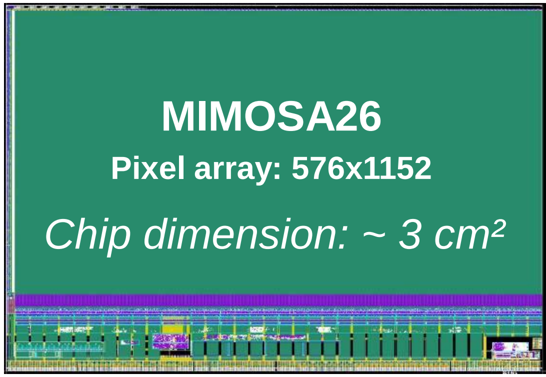


Examples of chips at IN2P3

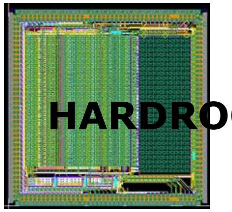
- **MAPS sensors at IPHC (Strasbourg)**

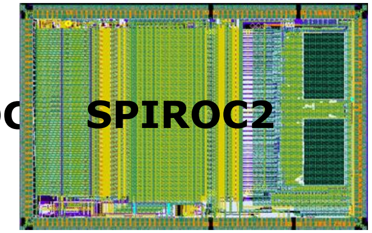


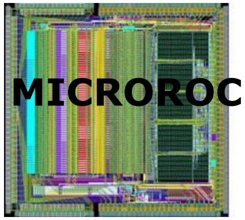


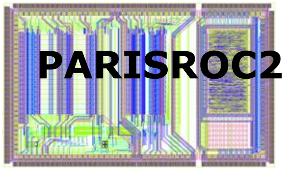


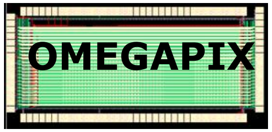
- **ROC chips at OMEGA (Orsay)**

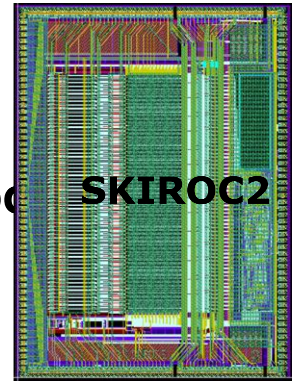




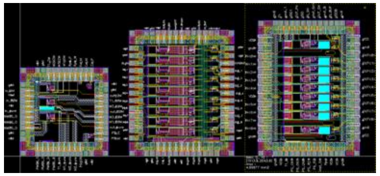
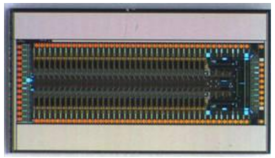
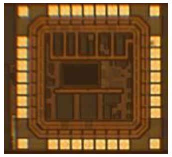
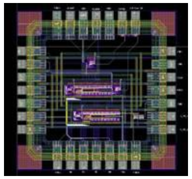








- **Chips at MICHRAU (Lyon-Clermont)**

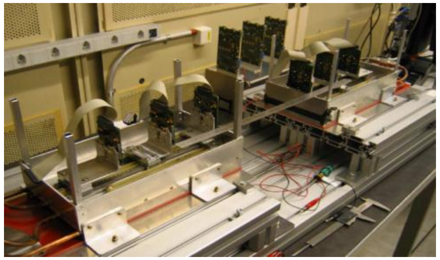
MAPS: A Long Term R&D

Main objective: ILC, with staggered performances

↳ *MAPS applied to other experiments with intermediate requirements*

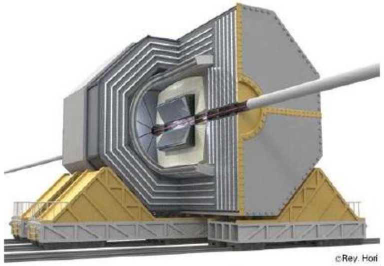
EUDET 2006/2010

Beam Telescope



ILC >2020

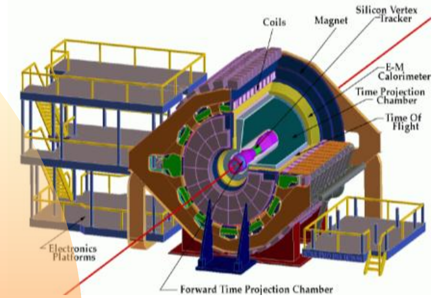
Internatinal Linear Collider



- EUDET (R&D for ILC, EU project)
- STAR (Heavy Ion physics)
- CBM (Heavy Ion physics)
- ILC (Particle physics)
- **HadronPhysics2 (generic R&D, EU project)**
- **AIDA (generic R&D, EU project)**
- **FIRST (Hadron therapy)**
- **ALICE/LHC (Heavy Ion physics)**
- **EIC (Hadronic physics)**
- **CLIC (Particle physics)**
- SuperB (Particle physics)
- **…**

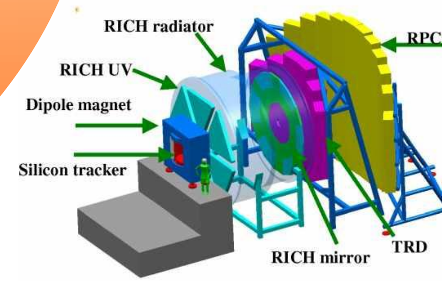
STAR 2012

Solenoidal Tracker at RHIC



CBM 2017

Compressed Baryonic Matter

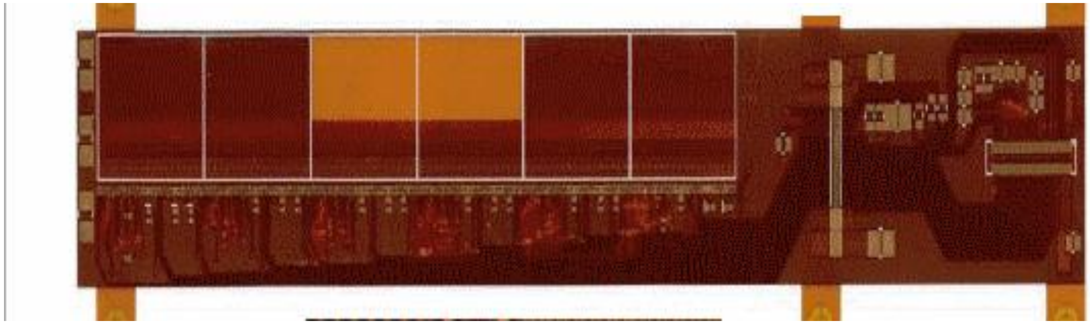


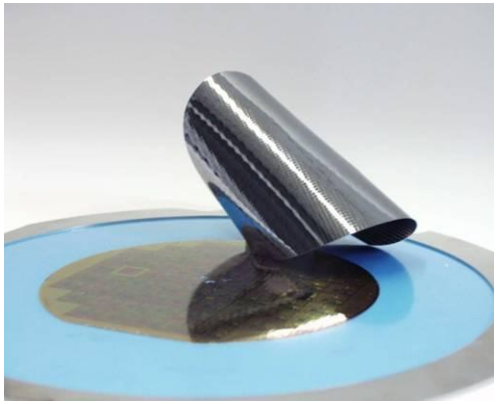
➔ Spinoff: Interdisciplinary Applications, biomedical, space …

Monolithic Active Pixel Sensors (MAPS) : imagers

Binary sparsified readout sensor for EUDET beam telescope:
> 2 cm^2 active area, 0.7 Mpixel tracker

- Medium speed readout (100 µm integration □10 kFrame/s)
- Spatial resolution < 4 µm for a pitch of 18.4 µm
- Efficiency for MIP > 99.5 %
- Fake hit rate < 10^{-6}
- Radiation hardness > 10^{13} n/cm^2 (high resistivity epi substrate)
- Easy to use, “off-shell” product: used already in several application

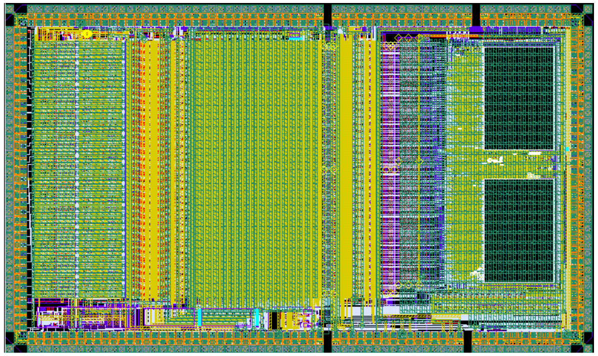


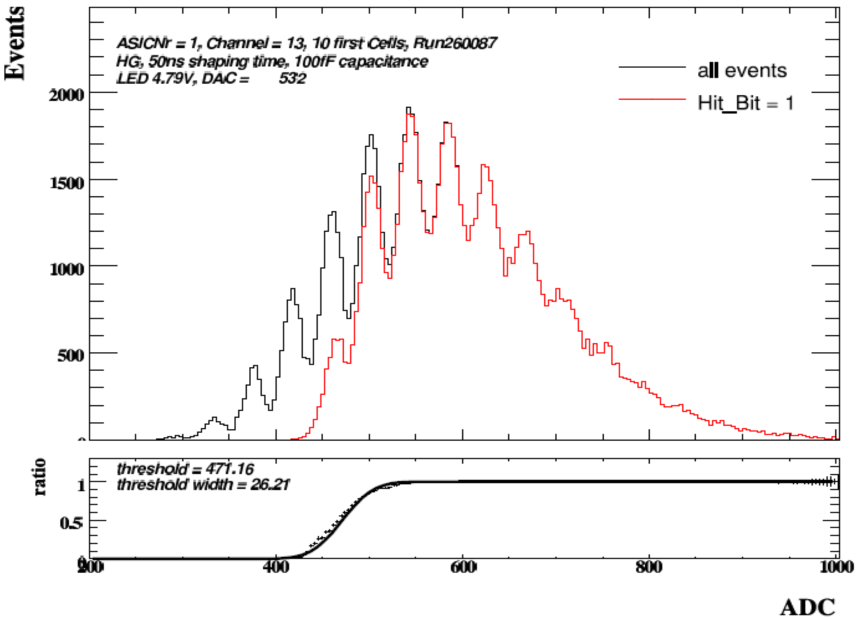


SPIROC for SiPM readout

- **SPIROC : Silicon Photomultiplier Integrated Readout Chip**
  - Developed to read out the analog hadronic calorimeter for CALICE (ILC)
  - DESY collaboration (EUDET project)
  - Chip embedded in detector : low power !
- **36 channels autotrigger 15bit readout**
  - Energy measurement : 15 bits in 2 gains
  - Autotrigger down to ½ p.e.
  - Time measurement to ~1ns
  - Power dissipation : 25µW/ch (power pulsed)

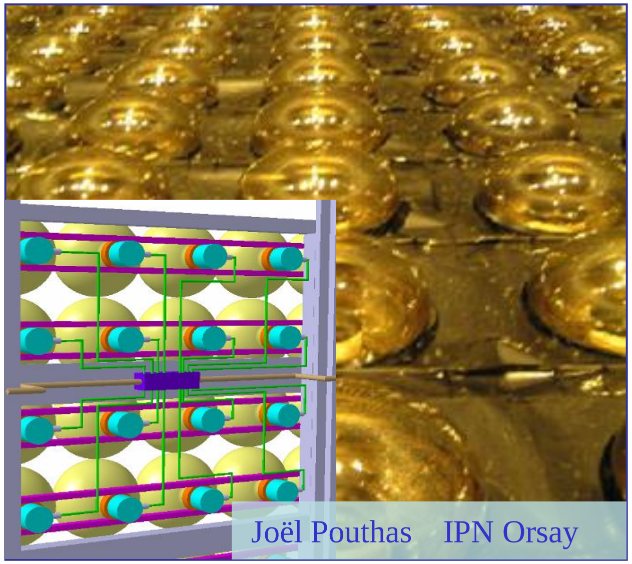
$(0.36m)^2$ Tiles + SiPM + SPIROC (144ch)

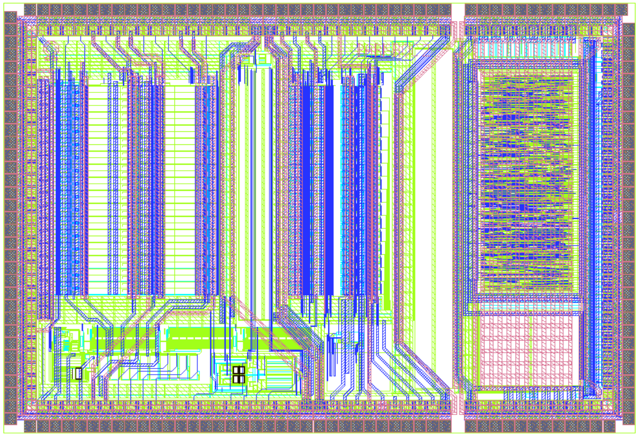


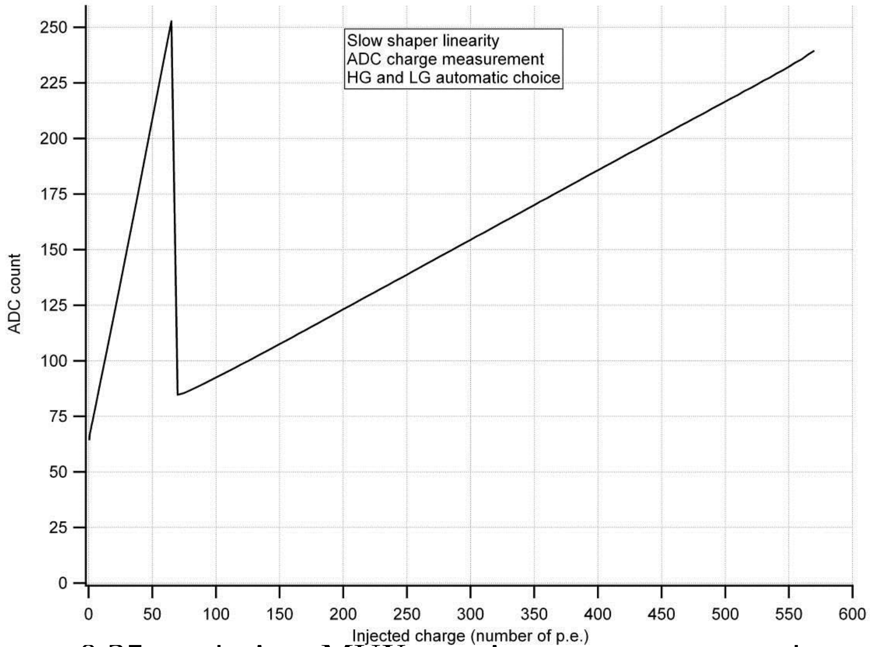


PARiSROC for PMm²

- **Photomultiplier ARray Integrated SiGe Read-Out Chip**
  - Replace large PMTs by arrays of smaller ones (PMm2 project)
  - Centralized ASIC 16 independent channels
  - Auto-trigger at 1/3 p.e.
  - Charge and time measurement (10-12 bits)
  - Water tight, common high voltage
  - Data driven : « One wire out »





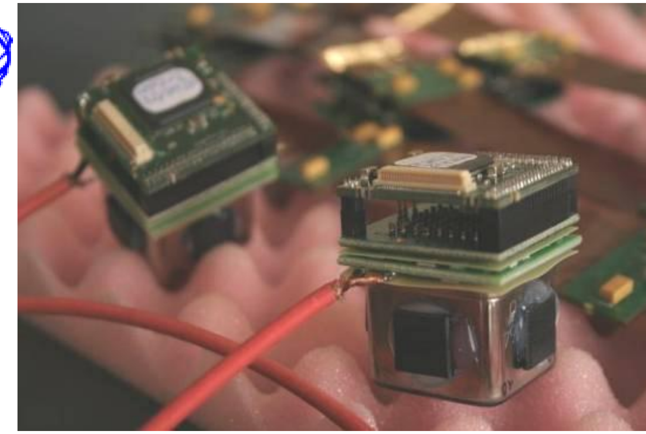


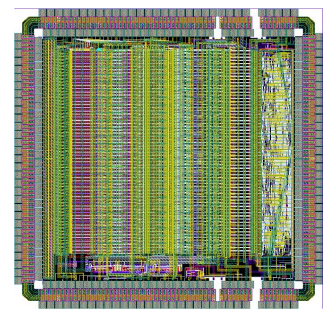
Conclusion

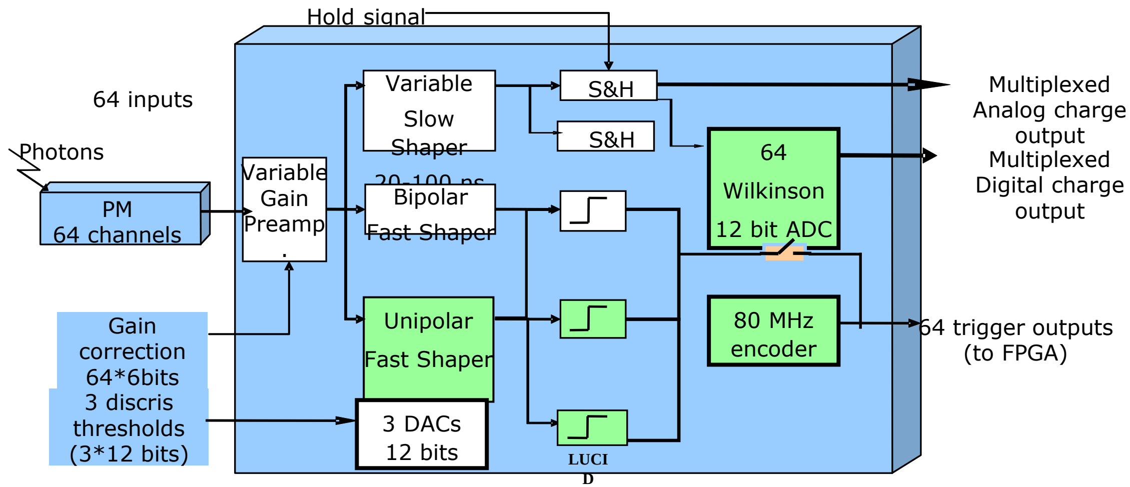
- **Fruitful collaboration record with German groups**
- **Interest to share experience in new detector developments**

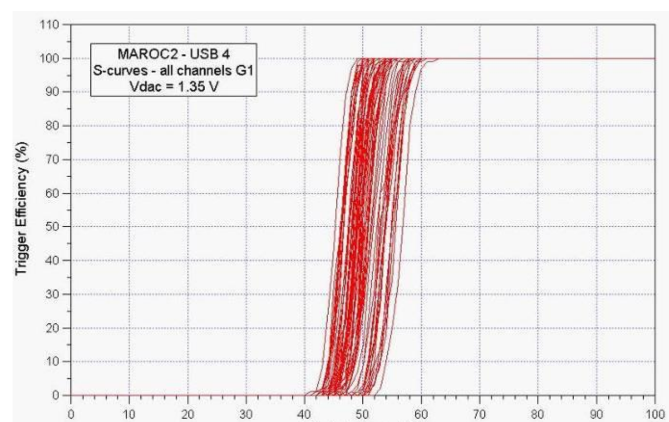
MAROC : MultiAnode Read-Out Chip

- **Complete front-end chip for 64 channels multi-anode photomultipliers**
  - 6bit-individual gain correction
  - Auto-trigger on 1/3 p.e. at 10 MHz
  - 12 bit charge output
  - SiGe 0.35 µm, 12 mm^2, Pd = 5 mW/ch
- **Bonded on a compact PCB (PMF) for ATLAS luminometer (ALFA)**
- **Also equips Double-Chooz, medical imaging…**





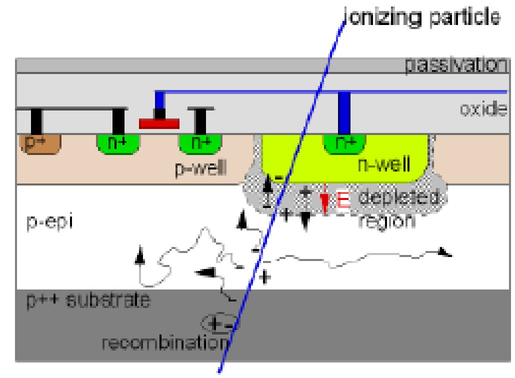




MAPS at Strasbourg

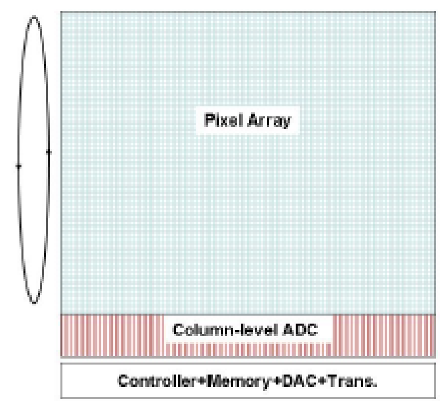
CMOS Pixel Sensors: State of the Art

- **Prominent features of CMOS pixel sensors:**
  - ⁕ high granularity ⇛ excellent (micronic) spatial resolution
  - ⁕ very thin (signal generated in 10-20 μm thin epitaxial layer)
  - ⁕ signal processing μ-circuits integrated on sensor substrate
    - ⇛ impact on downstream electronics (⇛ cost)



- **Organisation of MIMOSA sensors:**
  - ⁕ manufactured in 0.35 μm OPTO process
  - ⁕ signal sensing and analog processing in pixel array
  - ⁕ mixed and digital circuitry integrated in chip periphery
  - ⁕ read-out in rolling shutter mode

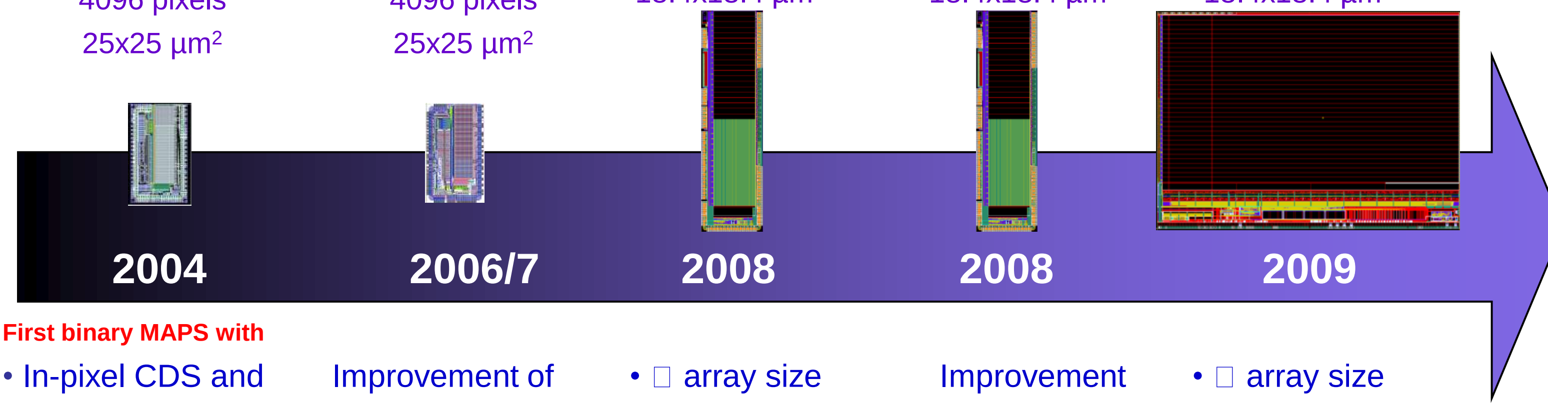
    (pixels grouped in columns read out in //)
    - ⇛ impact on power consumption



Binary MAPS developed by IRFU &IPHC coll. for ILC and EUDET High Resolution Beam Telescope

Chips, process, number of pixels, pitch:

MIMOSA-8	MIMOSA-16	MIMOSA-22	MIMOSA-22bis	MIMOSA-26
TSMC 0.25 µm dig.	AMS 0.35 µm opto	AMS 0.35 µm opto	AMS 0.35 µm opto	AMS 0.35 µm opto
(8-10µm epi)	(14µm epi, 20µm epi and without epi)	(14µm epi)	(14µm epi)	(14µm epi)
4096 pixels	4096 pixels	78 336 pixels	78 336 pixels	663 552 pixels
25x25 µm^2	25x25 µm^2	18.4x18.4 µm^2	18.4x18.4 µm^2	18.4x18.4 µm^2

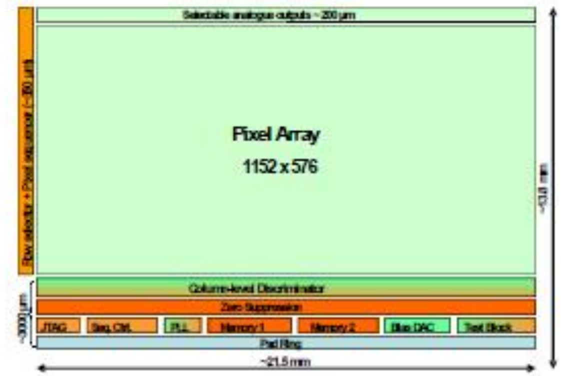


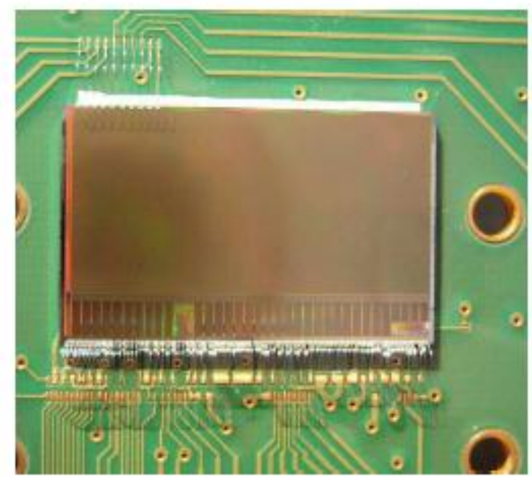
2004	2006/7	2008	2008	2009
First binary MAPS with • In-pixel CDS and amplification • Column-level discrimination	Improvement of MIMOSA-8 performances on an Opto process	• □ array size • □ pixel pitch • Improvement of MIMOSA-16 performances	Improvement of radiation hardness	• □ array size • □ functionalities (zero suppression)
□$_{dig}$=7 µm □$_{det}$ > 99.0 %	□$_{dig}$= 5 µm □$_{det}$ > 99.0 % for 14 µm epi	□$_{dig}$~3.5 µm □$_{det}$ > 99.8 %	□$_{dig}$~3.5 µm □$_{det}$ > 99.8 %	□$_{dig}$~3.5 µm □$_{det}$ > 99.8% *expected* [see Ch.Hu's talk]

MIMOSA26 : EUDET Beam telescope

CMOS Pixel Sensors: State of the Art

- **Main characteristics of MIMOSA sensor equipping EUDET BT:**
  - ⁎ 0.35 μm process with high-resistivity epitaxial layer (coll. with IRFU/Saclay)
  - ⁎ column // architecture with in-pixel amplification (CDS) and end-of-column discrimination, followed by $\emptyset$
  - ⁎ active area: 1152 columns of 576 pixels (21.2×10.6 mm^2)
  - ⁎ pitch: 18.4 $\mu m \rightarrowtail \sim$ 0.7 million pixels
    charge sharing $\Rrightarrow \sigma_{sp} \lesssim 4\ \mu m$
  - ⁎ $t_{r.o.} \lesssim 100\ \mu s$ ($\sim 10^4$ frames/s)
    $\Rrightarrow$ suited to $> 10^6$ part./cm^2/s
  - ⁎ $\sim$ 250 mW/cm^2 power consumption (fct of N_{col})



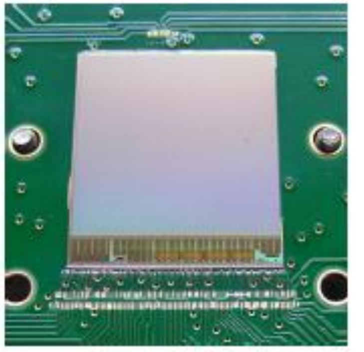


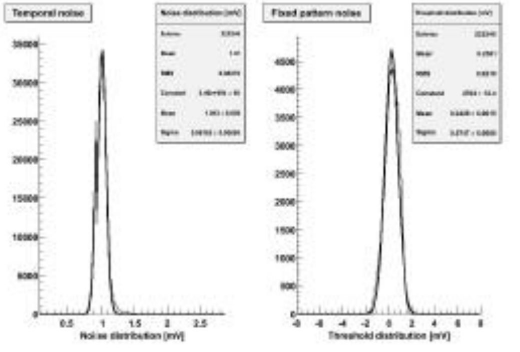
MIMOSA28 : STAR

© M. Winter (Strasbourg)

STAR-PXL Detector : MIMOSA-28

- **Use ULTIMATE sensor (alias MIMOSA-28) equipping STAR-PXL detector**
  - ▷ derived from MIMOSA-26 equipping EUDET BT
- **Main characteristics of ULTIMATE:**
  - ✳ 0.35 μm process with high-resistivity epitaxial layer
  - ✳ column // architecture with in-pixel cDS & amplification
  - ✳ end-of-column discrimination and binary charge encoding, followed by $\varnothing$
  - ✳ active area: 960 columns of 928 pixels (19.9×19.2 mm^2)
  - ✳ pitch: 20.7 μm $\rightarrowtail$ $\sim$ 0.9 million pixels
    - $\hookrightarrow$ charge sharing $\Rrightarrow$ $\sigma_{sp} \sim$ 3.5 μm expected
  - ✳ $t_{r.o.} \lesssim 200\ \mu s$ ($\sim 5 \times 10^3$ frames/s)
    - $\Rrightarrow$ suited to $> 10^6$ part./cm^2/s
  - ✳ 2 outputs at 160 MHz
  - ✳ $\lesssim$ 150 mW/cm^2 power consumption

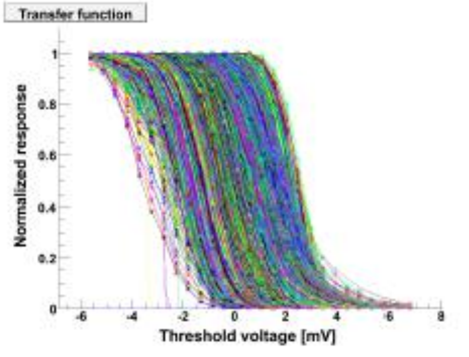




▷▷▷ Chip back from foundry $\Rrightarrow$ lab tests under way since early April :

- ✳ N $\lesssim$ 15 e$^-$ ENC at 30-35°C (as MIMOSA-22AHR)
- ✳ CCE (^{55}Fe) similar to MIMOSA-22AHR

—o **m.i.p. detection assessment at CERN-SPS in June-July '11**



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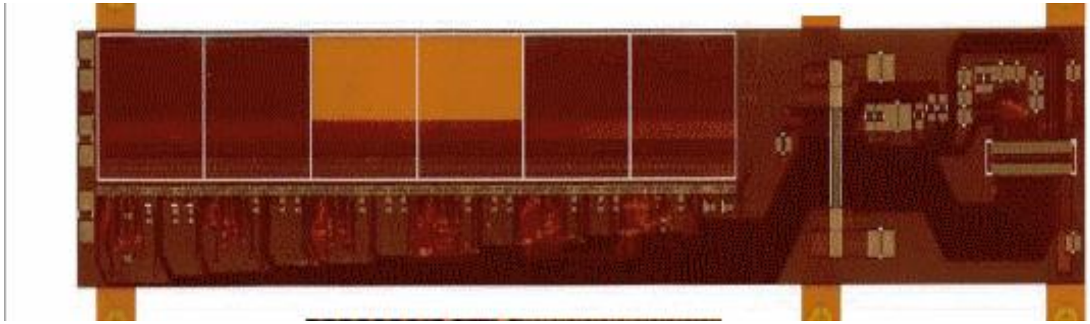
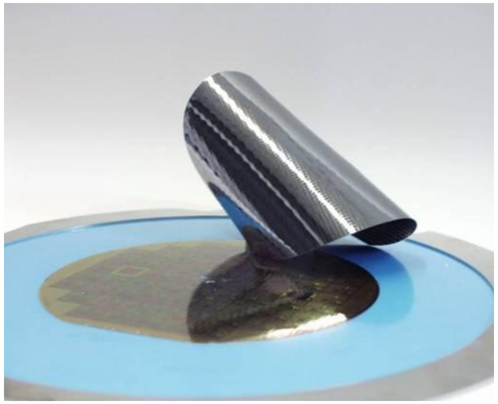
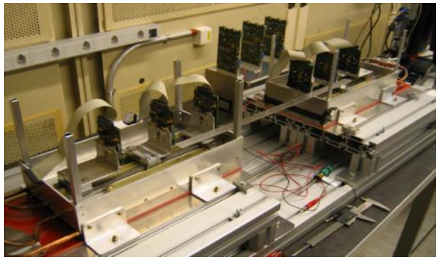




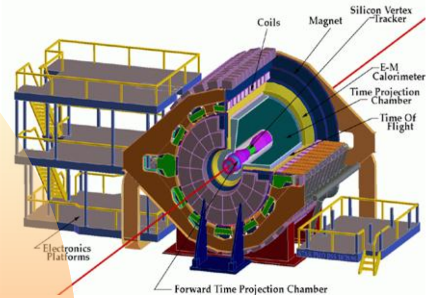
Monolithic Active Pixel Sensors (MAPS): A Long Term R&D

- **Main objective: ILC, with staggered performances**
  - **MAPS applied to other experiments with intermediate requirements**

EUDET 2007/2009
Beam Telescope

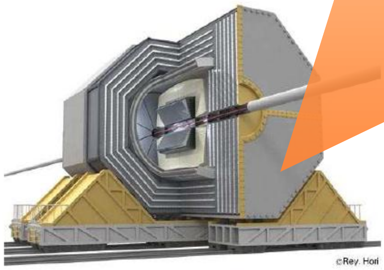


STAR 2010
Solenoidal Tracker at RHIC

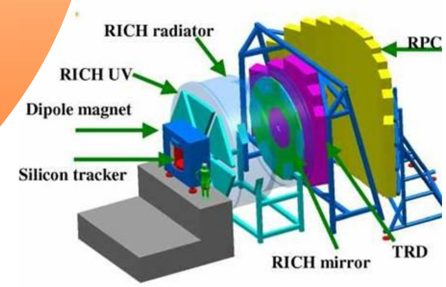


- *FP6 EUDET Project (DESY-Hamburg, Germany)*
  - **Surface** — **6 x 2 cm²**
  - **Read-out speed** — **A. 20 MHz □ D. at 100 MHz**
  - **Temp. & Power:** — **No constraints**
- *STAR Experiment (RHIC – Brookhaven, USA)*
  - **Surface** — **~1600 cm²**
  - **Read-out speed** — **A. 50 MHz □ D. up to 250 MHz**
  - **Temp. & Power** — **30°C, ~100mW/cm²**
- *CBM Experiment (GSI – Darmstadt, Germany)*
  - **Surface** — **~500 cm²**
  - **Read-out speed** — **D. 15 x 10^9 pixels/sensor/s**
  - **Rad Tol** — **1 MRad, > 10^{13} N_{eq} /cm²**
- *ILC Experiment*
  - **5-6 layers of detection** — **~3000 cm²**
  - **Read-out speed** — **D. 15 x 10^9 pixels/sensor/s**
  - **Temp. & Power** — **30°C, ~100 mW/cm²**
  - **Rad Tol** — **~300 kRad, ~10^{12} N_{eq} /cm²**

ILC >2012
International Linear Collider



CBM 2012
Compressed Baryonic Matter



□ *Spinoff: Interdisciplinary Applications, biomedical, …*

- ***Partnerships:* GIS IN2P3/Photonis & GIS IN2P3/SAGEM & Ohio University & Michigan University…**

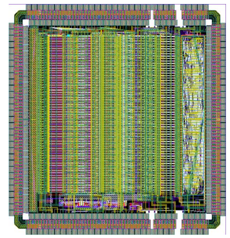
OMEGA/Orsay « ROC chips »

- **Move to Silicon Germanium 0.35 µm BiCMOS technology in 2004**
- **Readout for MaPMT and SiPM for ILC calorimeters and other applications**
- **Very high level of integration : System on Chip (SoC)**

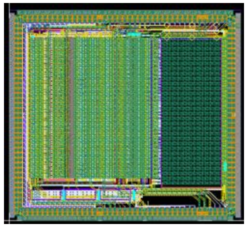
http://omega.in2p3.fr

Chip	detector	ch	DR (C)
MAROC	PMT	64	2f-50p
SPIROC	SiPM	36	10f-200p
SKIROC	Si	64	0.3f-10p
HARDROC	RPC	64	2f-10p
PARISROC	PM	16	5f-50p
SPACIROC	PMT	64	5f-15p
MICROROC	µMegas	64	0.2f-0.5p

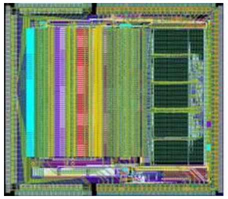
MAROC3



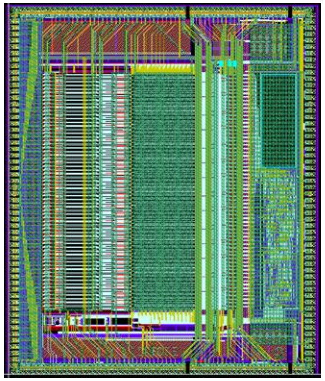
HARDROC2



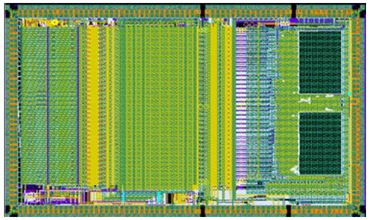
MICROROC1



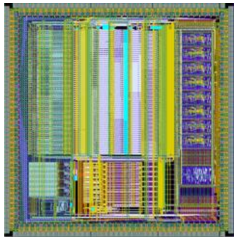
SKIROC2



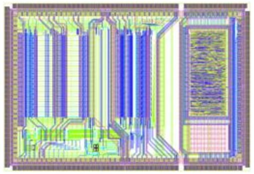
SPIROC2



SPACIROC

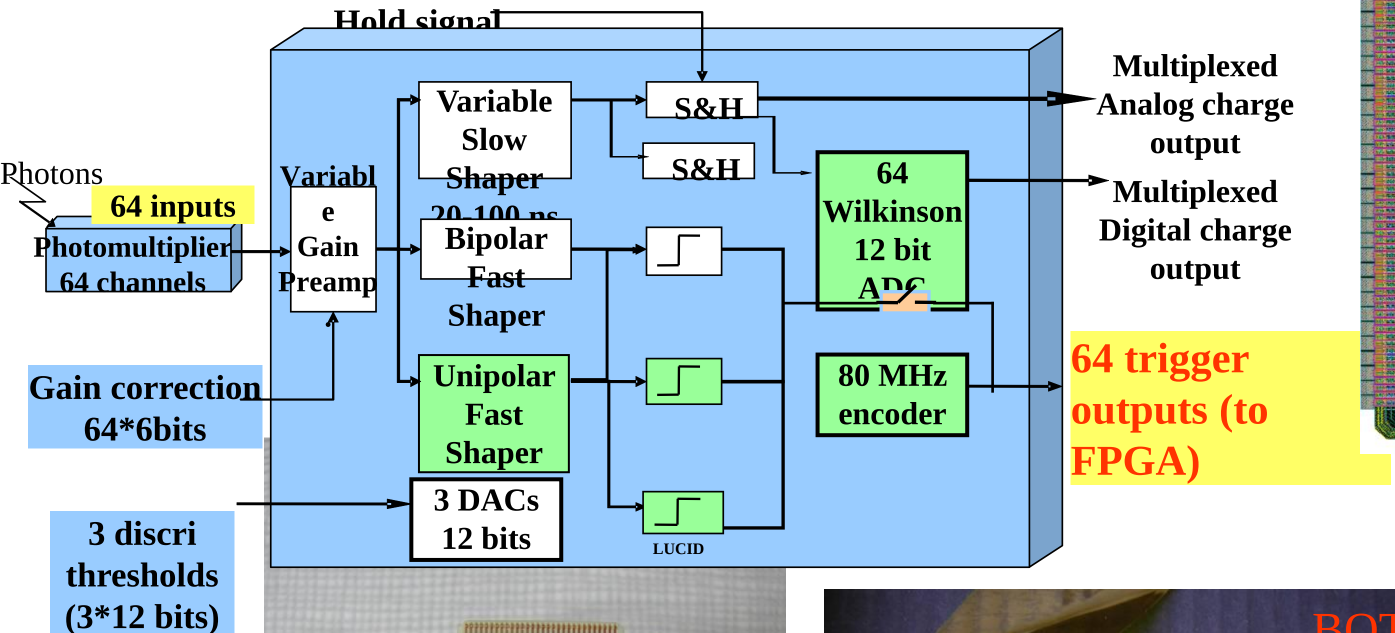


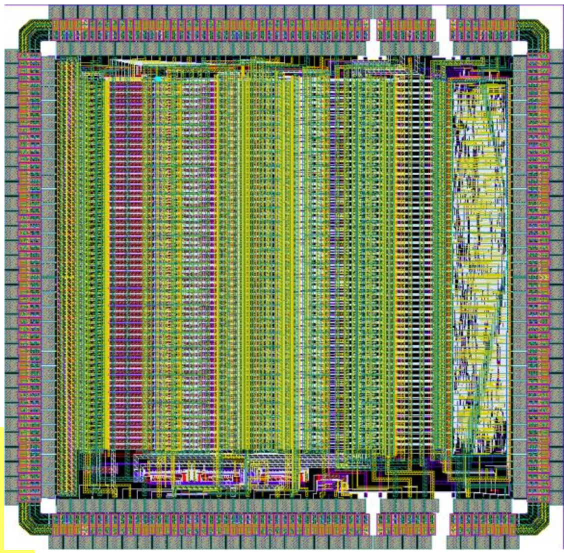
PARISROC2

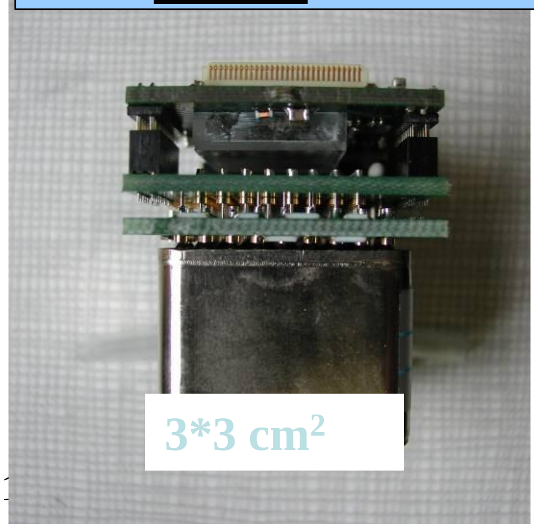


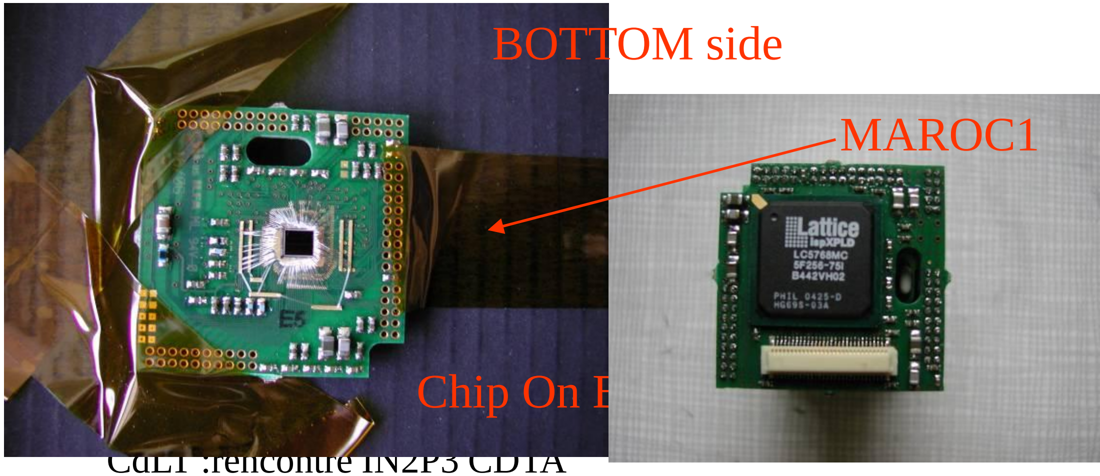
High integration : MAROC ‘Multi-Anode Readout Chip’

- **Complete front-end chip for 64 channels multi-anode photomultipliers**
  - Auto-trigger on 1/3 p.e. at 10 MHz, 12 bit charge output
  - SiGe 0.35 µm, 12 mm2, Pd = 350mW



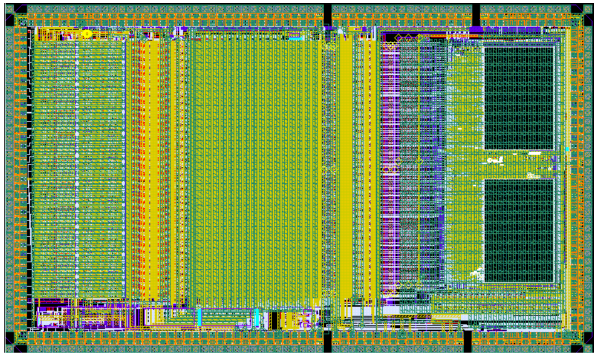






SPIROC main features

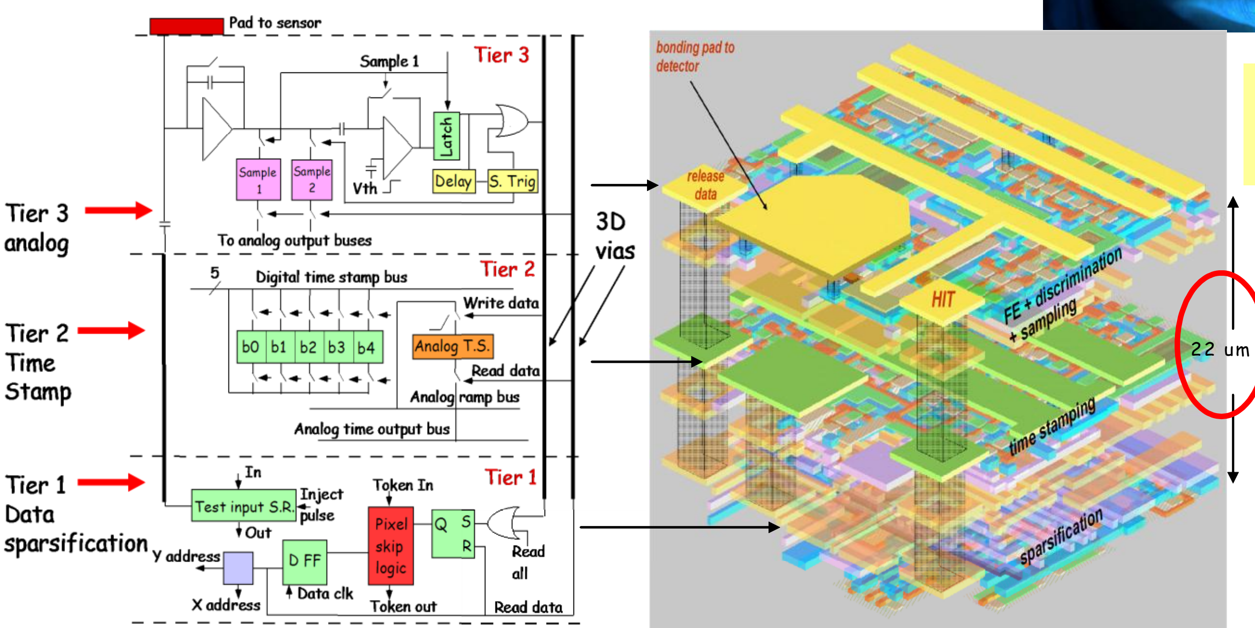
- **Internal input 8-bit DAC (0-5V) for individual SiPM gain adjustment**
- **Energy measurement : 14 bits**
  - 2 gains (1-10) + 12 bit ADC 1 pe ☐ 2000 pe
  - Variable shaping time from 50ns to 100ns
  - pe/noise ratio : 11
- **Auto-trigger on 1/3 pe (50fC)**
  - pe/noise ratio on trigger channel : 24
  - Fast shaper : ~10ns
  - Auto-Trigger on ½ pe
- **Time measurement :**
  - 12-bit Bunch Crossing ID
  - 12 bit TDC step~100 ps
- **Analog memory for time and charge measurement : depth = 16**
- **Low consumption : ~25 µW per channel (in power pulsing mode)**
- **Individually addressable calibration injection capacitance**
- **Embedded bandgap for voltage references**
- **Embedded 10 bit DAC for trigger threshold and gain selection**
- **Multiplexed analog output for physics prototype DAQ**
- **4k internal memory and Daisy chain readout**



3D technology

©A. Klumpp (IZM)

- **Increasing integration density**
  - Large industrial market (imagers, processors, memories…)
  - Uses ~1 µm Through Silicon Vias
  - Requires wafer thinning to ~10 µm
  - A new major revolution coming up !



V1P1 3D chip by FNAL

Auto-gain test (ADC measurements)

**The whole chain is tested, injecting a charge at the input of the channel:
the signal is amplified, auto-triggered, held in the SCA cell and converted by the ADC.**

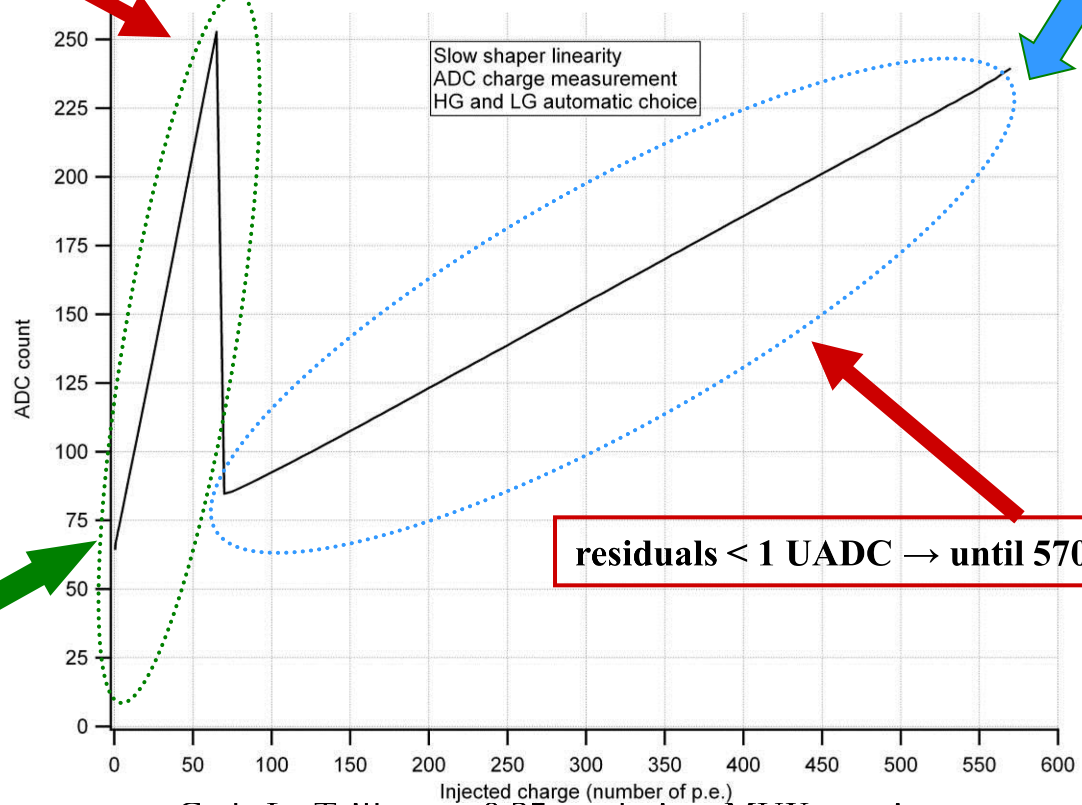
The charge measurements for different injected charges setting the gain threshold at 60 p.e.

residuals < 1 UADC → until 60 p.e.

Low gain Up to 570 p.e.

Automatic gain selection

Good performance of the whole chain.



residuals < 1 UADC → until 570 p.e.

High gain Up to 60 p.e.