Institut **N**ational de **P**hysique **N**ucléaire et de **P**hysique des **P**articules

Electronics Developments at IN2P3

- IN2P3 Profile
- Networks for Instrumentation & Microelectronics
- Microelectronics Developments for physics experiments
  - More than a Decade of R&D & Collaborations

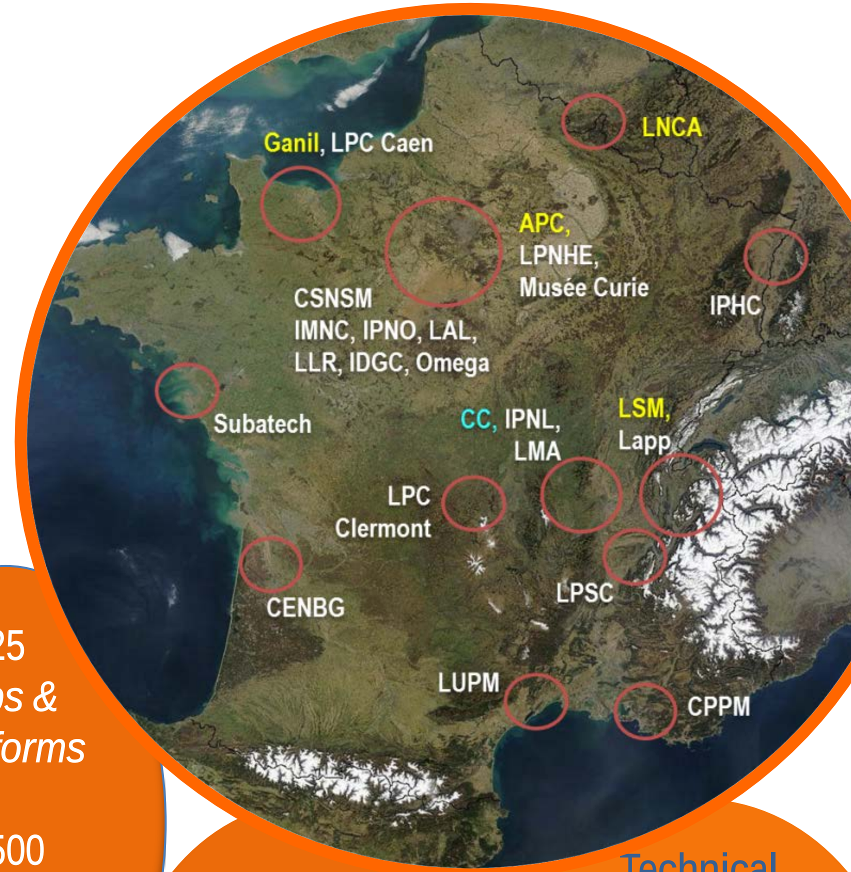
IN2P3, one of the 10 Institutes of CNRS

CNRS
10 institutes
1,100 research units
(95% in partnership)

34,000 *researchers, engineers, technicians*
€3.3 billion *budget*

25
labs & platforms

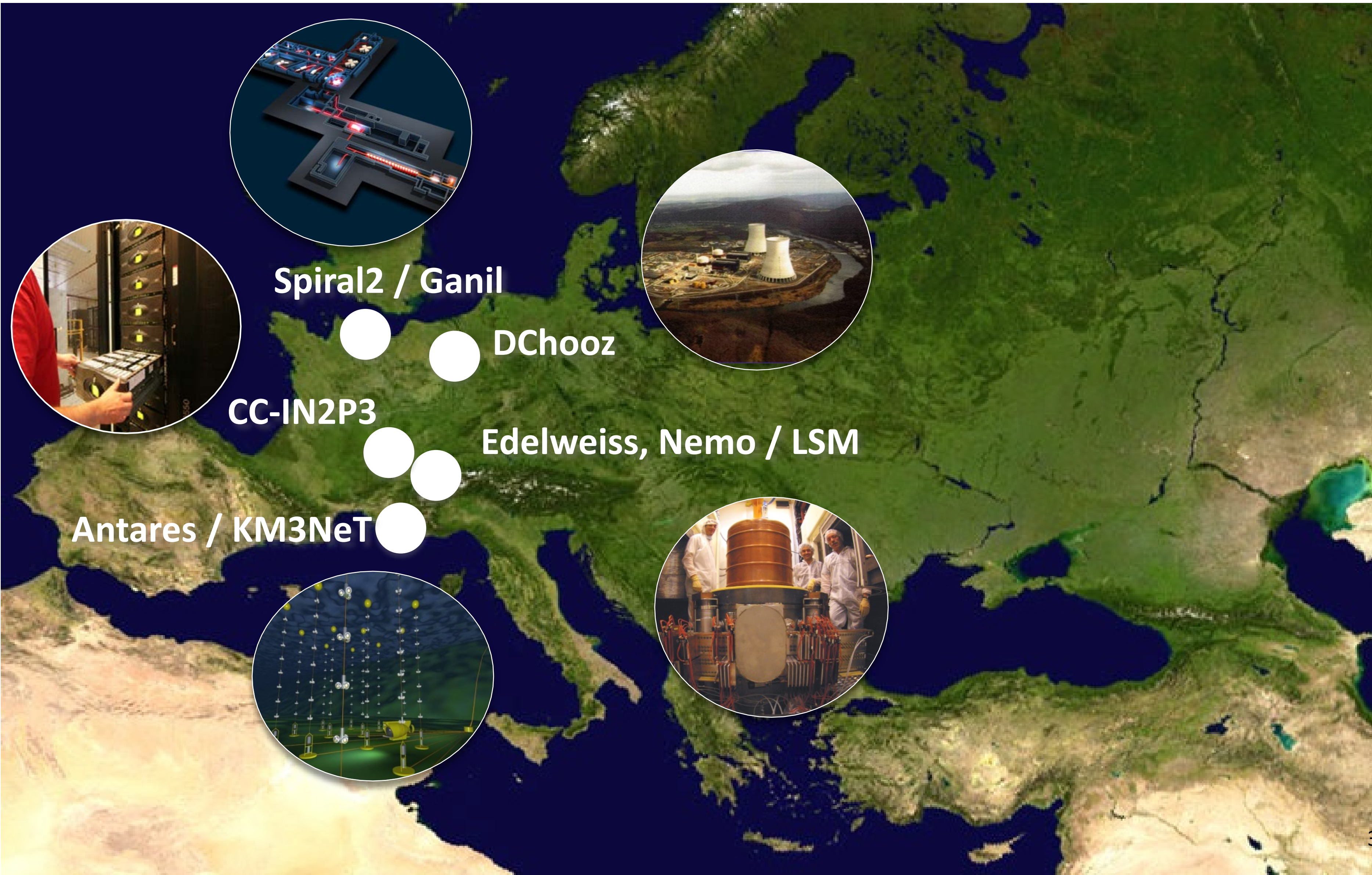
2500
researchers engineers technicians



Research in
Astroparticles
Particle Physics
Nuclear Physics

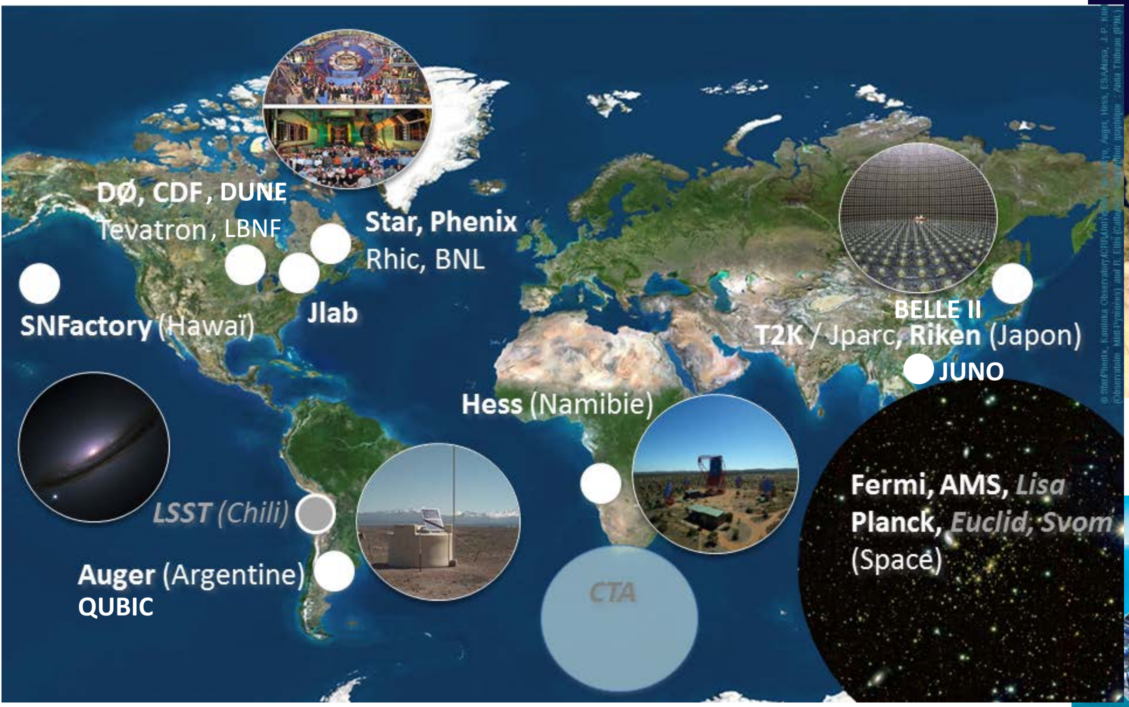
Technical Developments:
Instrumentation
Grid computing
Accelerator R&D
Nuclear Energy
Medical Applications

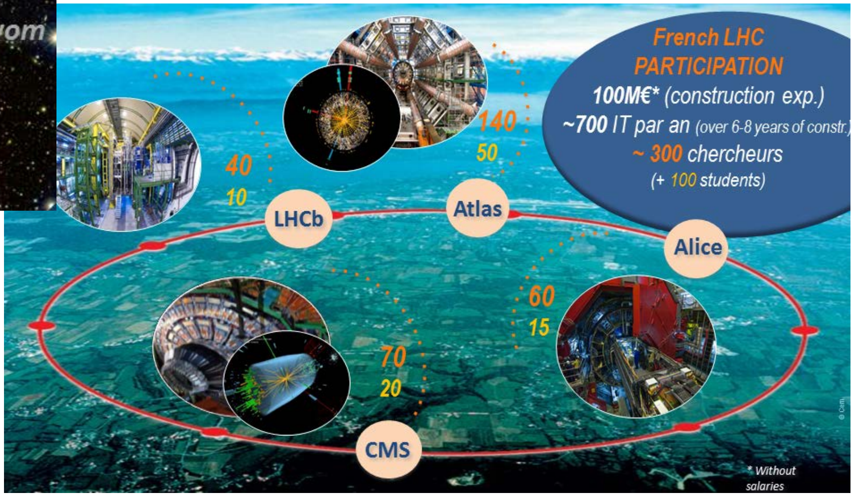
Research Infrastructures



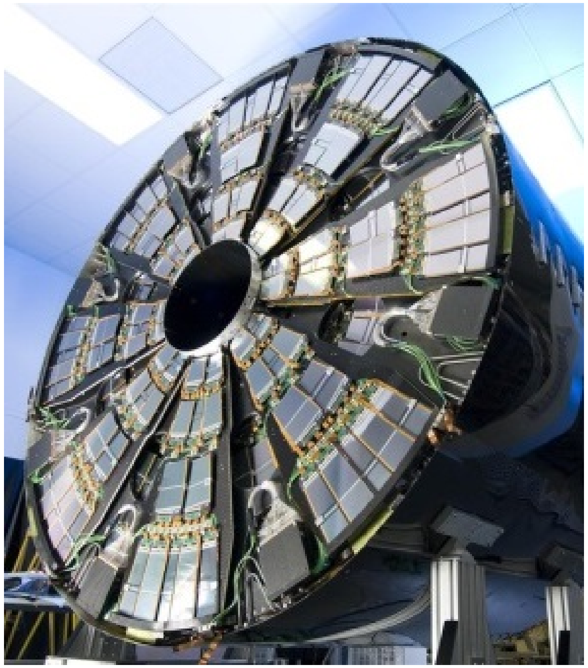
International Collaborations

- **40 Major International Projects**





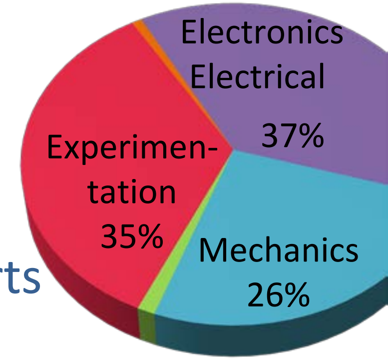
Commitment in R&D for Instrumentation



CMS Silicon Strips
Tracker End Cap Petals

Supporting Instrumentation R&D

730 Engineers & Technicians



Instrumentation Network

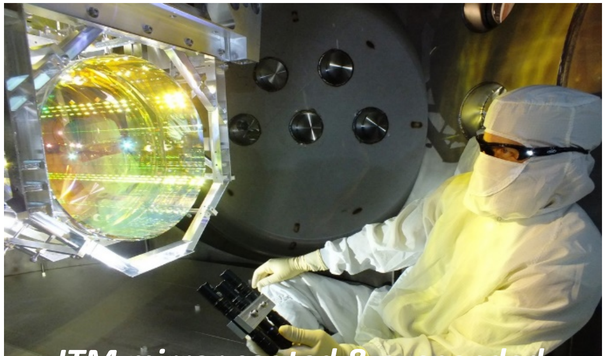
To improve exchanges between experts

To promote common actions

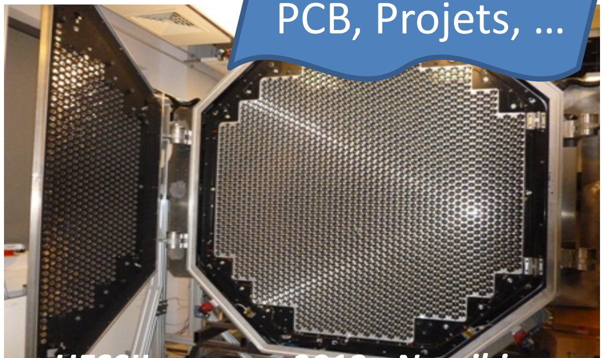
DETECTORS	CROSS-CUTTING
Radiodetection	Mechanics
Cryogenics	Microelectronics
Silicon detectors	Data Acquisition
Gaseous detectors	Command & control
Photo-detectors	

Bibliothèques, PCB, Projets, …

MultiWiresProportional Chamber
ALICE-Muon Arm - CERN



ITM mirror coated & suspended
in the Advanced LIGO interferometer



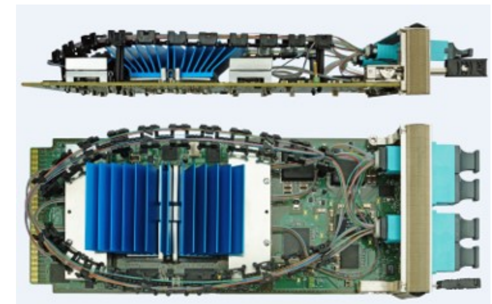
HESSII camera, 2012 - Namibia
- 2048 PMTs , Diameter 2.3m, 2000 kg

DAQ Network

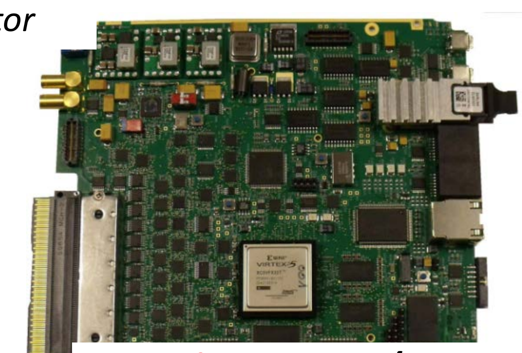
- **Existing since 2011**
  → 30 people
- **Promoting**
  - Common standards
  - Design reuse, shared FPGA IPs
  - Common developments centered on
    - LHC upgrades
    - GANIL experiments
- **Strong interest in xTCA standards**
  - Member of PICMG
    - *PCI Industrial Computer Manufacturers Group*
  - Working Group of xTCA for Physics
    - Clocks, Gates and Trigger distribution

***HEP* - LHCb Upgrade –LS2**
ATCA 40 Board -

***Radiodetection* - BAORADIO- PAON**
Digitizer Frequency Separator



***HEP* - ATLAS LAr upgrade – LS2**
AMC Board - LATOME -



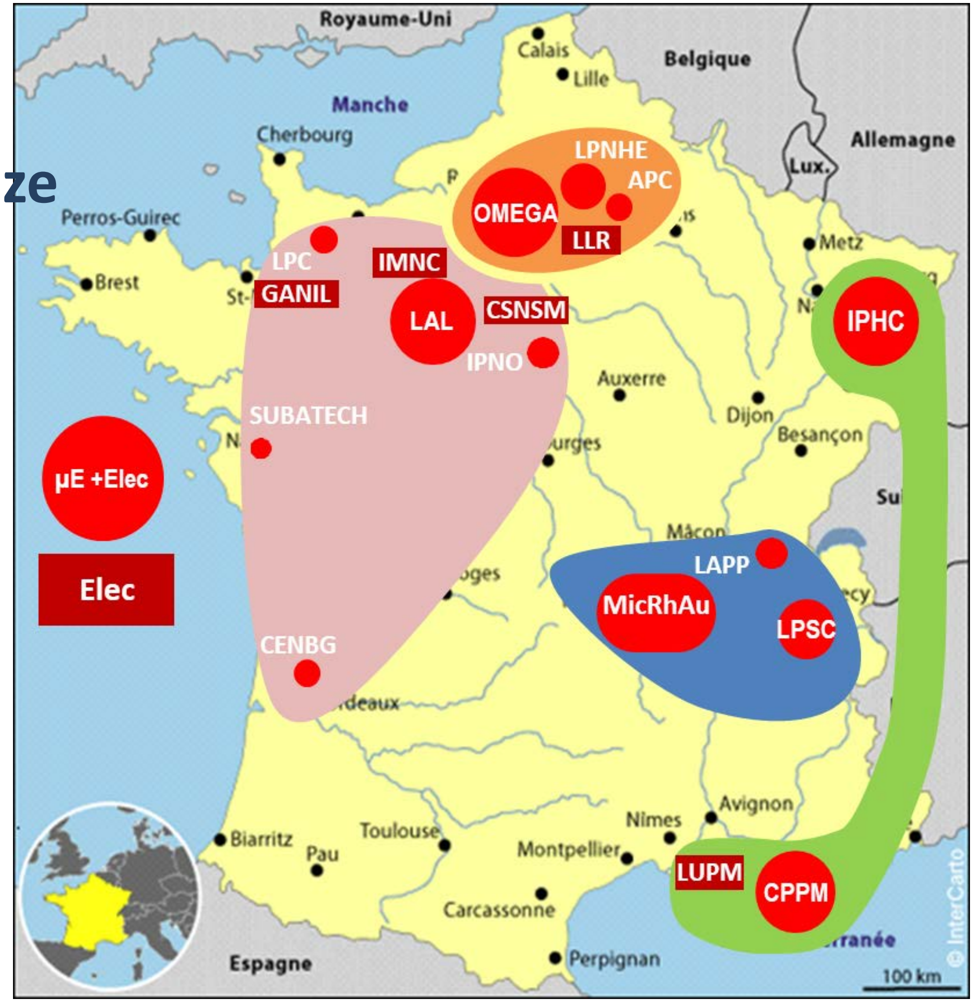
***Nuc Phy* - SPIRAL2/FAIR**
MUTANT

Microelectronics Network

- **~90 Engineers, design and test**
- **14 Teams gathered in**
- **4 Federations → reach critical size**
- **1 Advising Committee**

- **Internal workshops**
- **Upfront R&D projects**
  - 2019: OMME, PICMIC, QUARTET,
  - 2018: DiamAsic, Lojic130
  - 2016: BB-130
  - Knowhow / IP exchanges

- **Common CAD tools**
  - Remote collaborative tools
  - Unified management
  - Training program
    - On Cadence ASIC and PCB

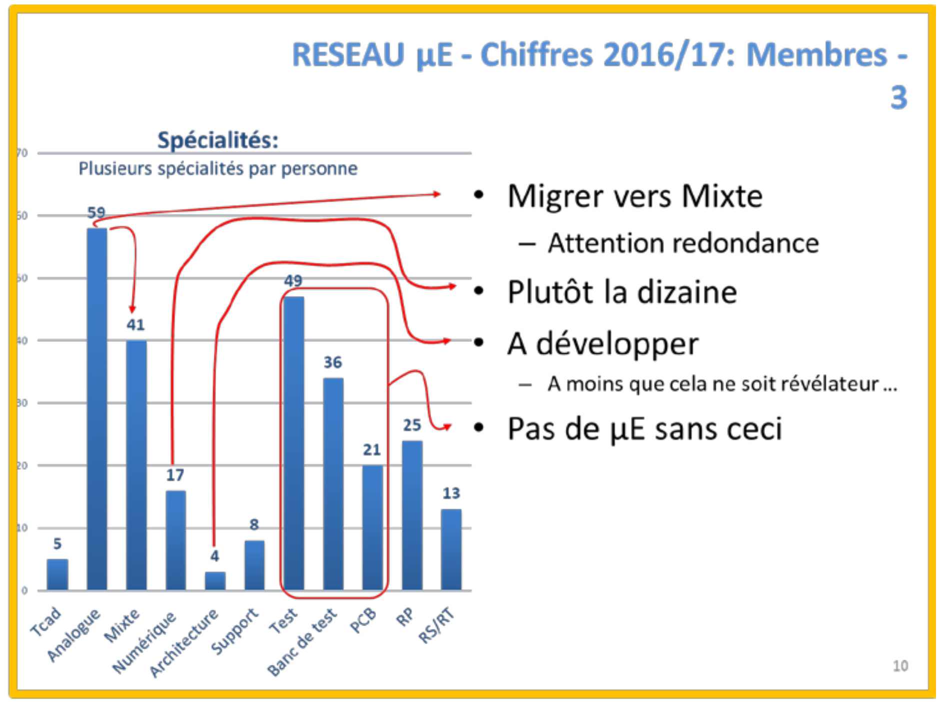


2. Réseau de la microélectronique

- Un réseau (2005) transverse au réseau Instrumentation (2012)
- Fédère les compétences de ~90 personnels, IN2P3, IRFU de la µE

Profil	IN2P3
	Déc/2016
Ingés Permanents	**73**
AI 3	
IE 8	
IR 62	
Ingés PostDoc / CDD	**4**
E-C / C	**4**
Visiteur	**1**
PhD	**9**
Masters	**10**
Autres	
Total – (Masters + Autres)	**91**

	Spécialités	# Personnels IN2P3
1	Tcad	5
2	Analogue	59
3	Mixte	41
4	Numérique	17 (5 PhD/CDD)
5	Architecture	4
6	Support	8
7	Test	49
8	Banc de test	36
9	PCB	21
10	Resp. Projets	25
11	Resp Serv./Tech	13
	Total/Max	*278/1001 (91 p)*



Présentation Ecole µE 2017: https://indico.in2p3.fr/event/14305/contributions/17777/

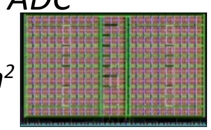
Skill & Knowhow

Building Blocks Program – BB130

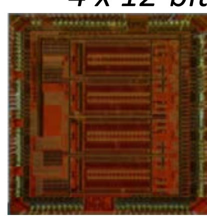
Libraries of low noise, low power & radiation tolerant Analog, Mixed, Digital blocks

- FE amplifiers, shapers
- DAC / ADC / TDC A-based, D-based
- Memories: Digital / Analog
- RO & Ctrl: Serializer, Tx , I2C, JTAG
- Band Gaps, Regulators, POR

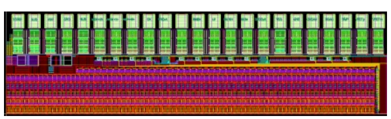
12-bits SAR ADC
100 kSPS
180 x 300 μm²
IBM 130 nm



4 x 12-bits SAR ADC

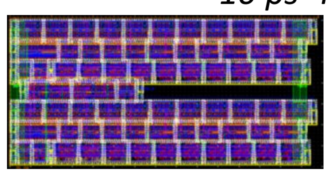


40 MSPS,
5mW/ch
10 mm²,
130 nm



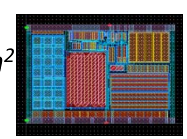
SEU Tolerant Memory
230 x 1820 μm² - *130 nm, FEI-4*

10 ps TDC R&D

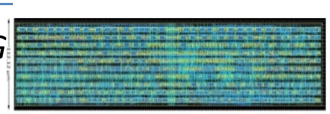


35 x 75 μm²
IBM 130 nm

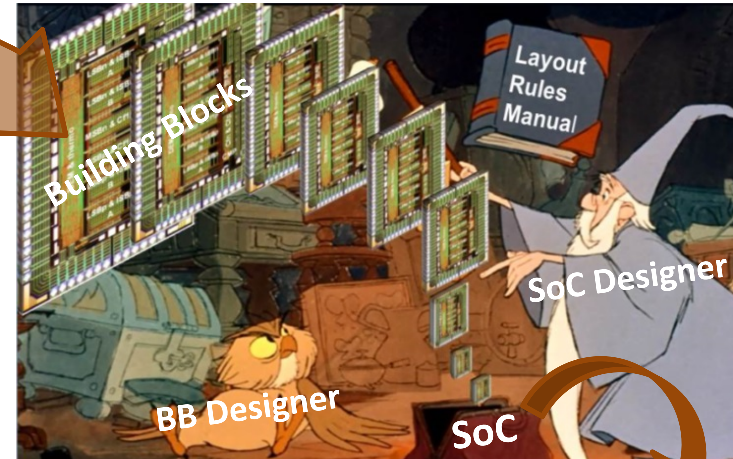
BAND CAP
196 x 133 μm²
TJ 180 nm



JTAG
Ctlr



725x112 μm², TJ 180 nm



System Level Design for SoC

Cmplx Architectures embedding

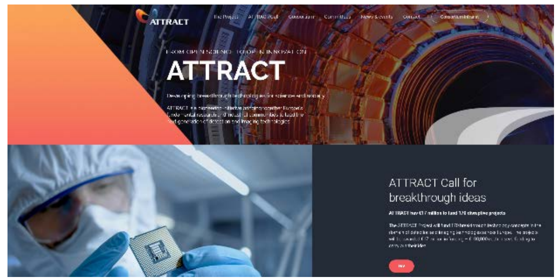
- Multi-Channel FE + Massive A 2 D
- Data Reduction Processing
- Memory Buffers/ Management
- Embedded Regulation Systems

Distribution

- Power Distribution Grid / Domain
- Clock Distribution
- Data Flow

Looking for synergies

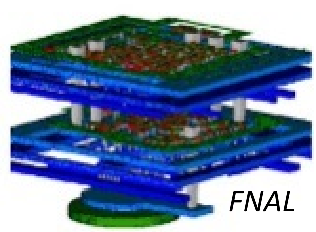
- **Participating to International R&D Programs**
  - CERN’s initiative for R&D on Experimental Technologies
  - ATTRACT 2018 (H2020)



  - AIDA (2011) + H2020
  - RD53 (2013)

RD-53 Collaboration

  - EUDET (2006-2010)
  - 3DIC - TSV (2009)



FNAL

Looking for synergies

- **R&D covers all IN2P3 physics and detectors domains**
  - Large discrepancy in the projects size ➔ From small analog ASIC to full SoC
    - Impact on profiles of the design teams
    - Impact on process #

  - New designs are always required but Design Reuse has to be considered first
    - Has an impact on manpower, schedule, budget

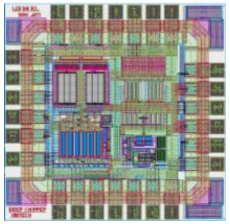
  - Pushing for coherent ASIC families development, which will provide flexible designs with staged performances

- **Networks and federations help to converge by gathering the experts**
  - Following of presentation is organized by detector categories
  - Focus on circuits Designed for specific projects,
    Reused for other applications

Radio-detection Network

- **Full Custom LNA optimized for associated antennas - Analog ASIC -**
- **LONAMOS for Butterfly & LWA**
  - Developed to detect Air Showers produced by Ultra-High-Energy cosmic rays
  - Optimized for 20-80 MHz
  - Efficient up to 200 MHz
- **Small but Successful**
  - 1rst generation, 0.8 µm CMOS
    - 2004, 400 chips
  - 2nd generation, 0.35 µm CMOS
    - 2011 700 chips
    - 2014 6000 chips

Experiment	Installed
CODALEMA@ Nançay-France	(60 Butterflies + 10 LWA) x 2
AERA @Auger-Argentina	200 Butterflies
TREND @ China	108 Butterflies
HELYCON @ Greece	12 Butterflies
NenuFAR @ Nançay-France	57 LWA x 2 + 6000
Ongoing discussion with the GRAND experiment Giant Radio Array for Neutrino Detection - China	



LONAMOS 1,4 x 1,4 mm^2
CMOS 0.35 µm , 2011

Butterfly Antenna, 2.2 x 1.5 m
Codalema @ Nancay - France

Long-Wavelength Antenna
NenuFAR @ Nancay - France

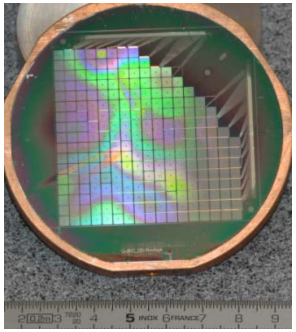
Fully differential architecture
Zin digitally adjustable
OIP3=33dBm
NF<1dB
Gp=27dB
BW>200MHz

17/04/19

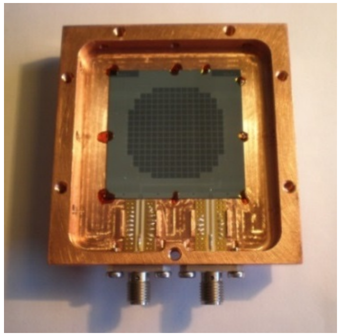
science & médecine

NenuFAR, un radiotélescope dernière génération

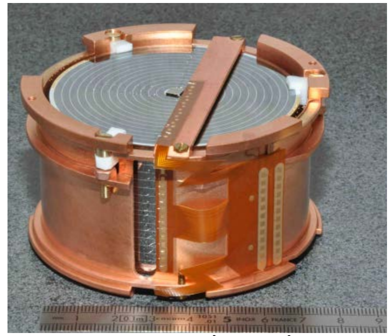
Cryogenics Network



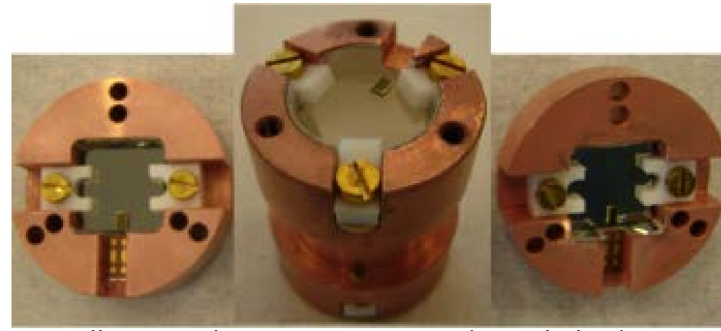
250 pixels **TES** matrix
(Transition Edge Sensors)
QUBIC @ Argentina



***K**inetic **I**nductance **D**etector*
NIKA @ Pico Veleta, Spain

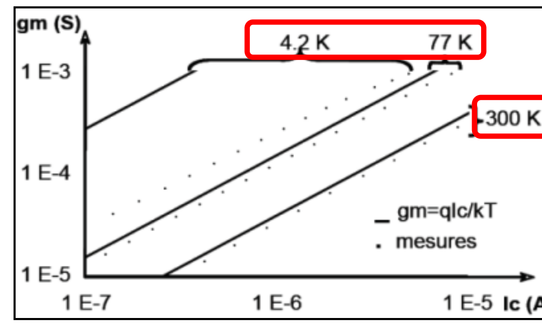


HP-Ge ionizing-heat detector
EDELWEISS @ LSM, France

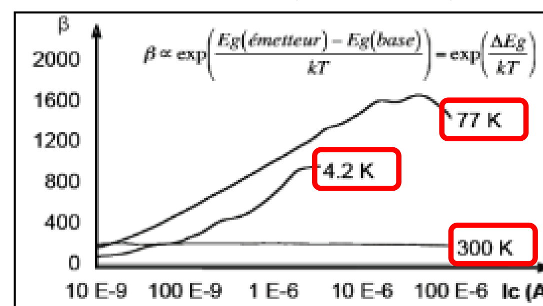


Scintillating Bolometer ZnMo4 and its 2 light detectors
LUMINEU @ LSM, France

- **RO Electronics @ ~4 - 40 K (QUBIC)**
  - Industrial process do not provide valid transistor models
    ➔ Characterization
    - Bipolar: gm ↗, β ↗ …
    - MOS: Substrate becomes Insulated ➔ Kink Effect
      → $T_{parasitic}$, $I_{leakage}$, V_{th} distorsions



Gm of SiGe bipolar 0.35µm

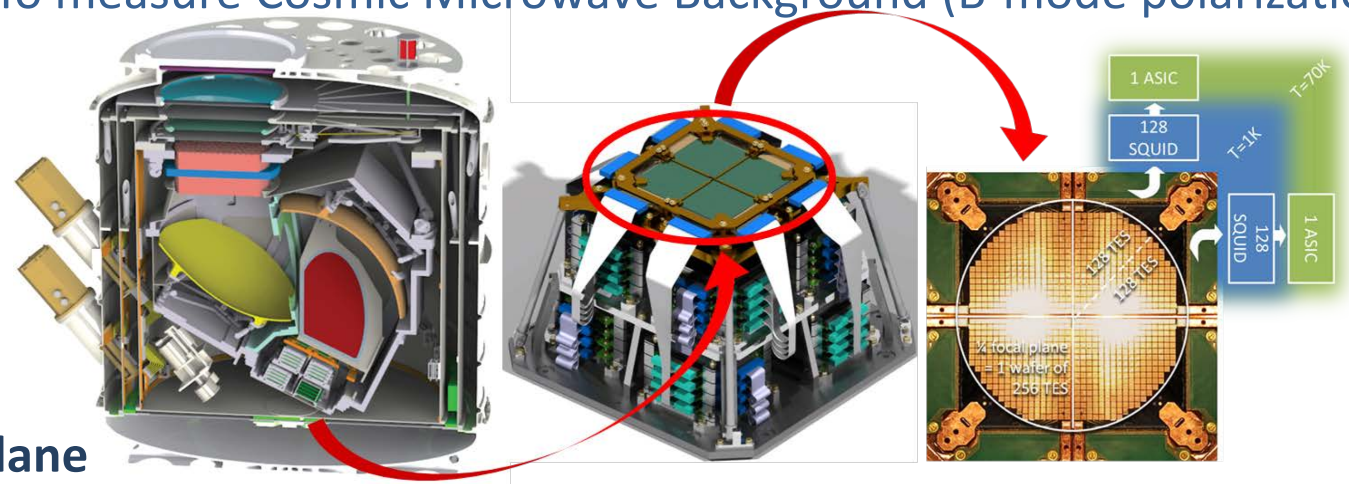


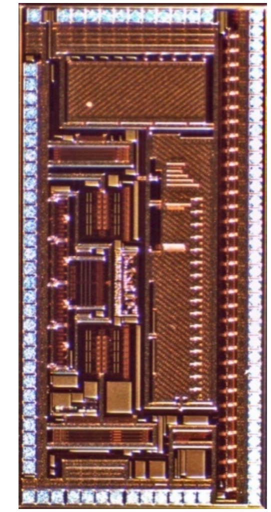
β of SiGe bipolar 0.35µm

- **Thermal & Electric effects of Interconnects**

Cryogenic electronics for QUBIC

- **QUBIC Cryostat, 2019 in Argentina**
  – To measure Cosmic Microwave Background (B-mode polarization)





SQMUX128 evo AMS BICMOS SiGE 350 nm

Focal plane

- 4 x 256 NbSi **T**ransition **E**dge **S**ensor @ 0.3 K
- 1 TDM Readout system for ⅛ focal plane
  - 128 SQUID @1 K + 1 ASIC @40 K

Mixed ASIC, SQMUX128_evo

- Analog
  - FE LNA with mplx inputs (1:4)
  - SQUIDs bias with mplx current supply (1:32)
- Digital → Full custom library, cryogenics effects

6 modules in 2025: 96 ASIC

CRYO: Don't forget WA105 / DUNE

Chip variant for PMO collaboration

(Purple Mountain Observatory - China)

- Submitted Q4 2017

Spin-off for **ATHENA** space mission

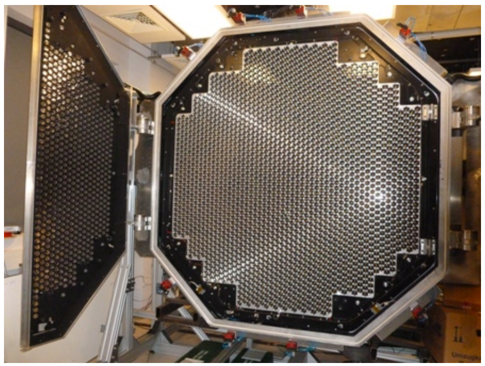
- Hot and Energetic Universe science

X-IFU instrument

- Micro-calorimeter measuring X-ray range
- Equipped with 4 k pixels of TES

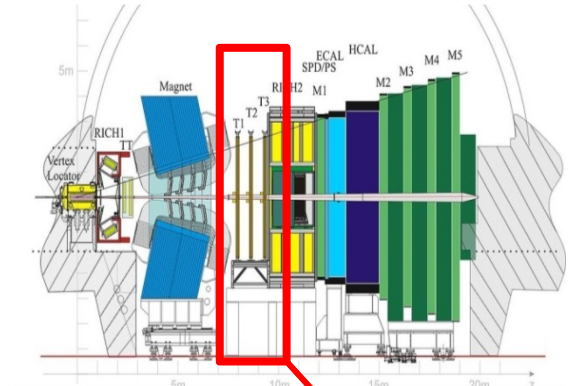
Photo-detectors Network

- **PMT, MA-PMT, MCP-PMT, Si-PM, Scintillators, …**
  - Overlap with Semiconductors Network (CCD, SiPM, APD)



HESSII camera, 2012 - Namibia

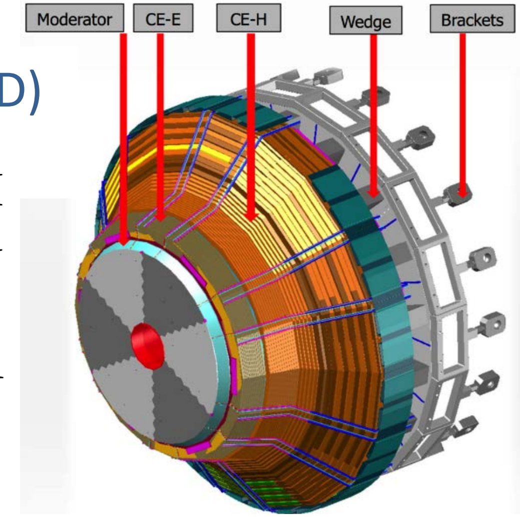
- 2048 PMTs, Dia. 2.3m, Weight 2 Tons



LHCb Tracker upgrade Phase 1 - CERN

FEE for SciFi + SiPM, LS2 (2019-20)

HGCAL



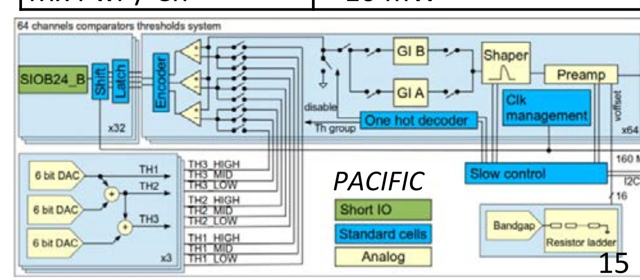
CMS Endcap Calorimeters for HL-LHC

HGCAL: Si Sensors & SiPM, LS3 (2024-26)

- **FEE increases in complexity**
- **Team @ critical size (10-20) / collaborations**
- **2 categories of FEE**
  - Shapers and Peak Detectors circuits
  - Waveform Sampling circuits
- **Successive improved generations**
- **Derived for different application fields**

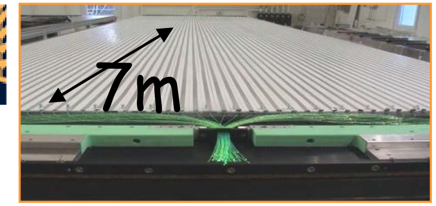
PACIFIC: Barcelona, Valencia, Heidelberg Universities, ETH Zurich & IN2P3 Collaboration

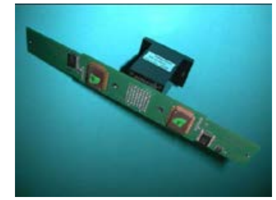
Detector	300 000 channels
PACIFIC chip (2015)	64 ch, TSMC 130 nm
Input Dynamic Range	0.5 to 32 pe
ADC resolution	Nonlinear, 2-bit, 40 MHz
SNR	≥ 10
Mx Pwr / Ch	< 10 mW

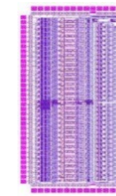


Shapers & Peak Detectors circuits

- **ROC chips : OPERA-ROC, early 2000**
  - For OPERA Target Tracker at Gran Sasso, 3000 chips



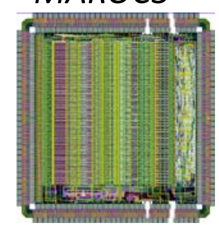




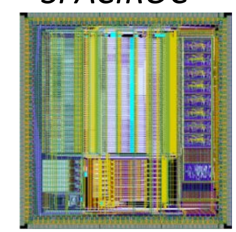
Chip	DType	Ch	Plrty	Dyn Range	Spec
MAROC	PM	64	< 0	5 fC- 5 pC	64 trigger outputs, internal 8/10/12-bit ADC for charge measurement
SPACIROC	PM	64	< 0	2 pC - 220 pC	Fast photon counting (50 Mhz)
PARISROC	PM	16	< 0	50 fC - 100 pC	Internal TDC (<1 ns), 16 trigger outputs
SPIROC	SiPM	36	> 0	10 fC -300 pC	36 HV SiPM tuning (8 bits), internal 12-bit ADC for charge & time measurement
EASIROC	SiPM	32	> 0	10 fC -300 pC	32 HV SiPM tuning (8 bits), 32 trigger outputs
CITIROC	SiPM	32	> 0	10 fC -300 pC	32 HV SiPM tuning (8 bits), 32 trigger outputs
PETIROC	SiPM	32	< 0	100 fC -300 pC	32 HV SiPM tuning (8 bits), 32 trigger outputs, internal 10-bit ADC for charge & time (25 ps)

- **Flexible Front-End → Variants suited to**
  - Detector type, # of channels, Input Dynamic Range
- **Adaptive Back-End**
  - 8/10/12-bits ADC for charge measurement
  - W /Wo time measurement, 1 ns / 25 ps TDC
  - Counting
- From .35 µm SiGe BiCMOS To 130 nm CMOS

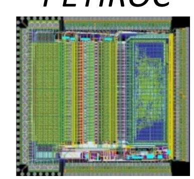
MAROC3



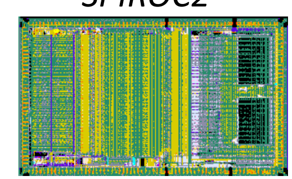
SPACIROC



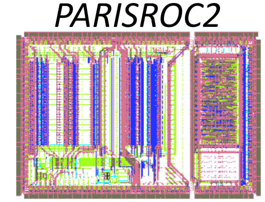
PETIROC



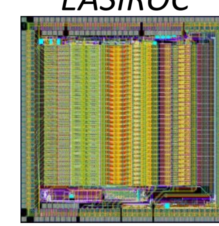
SPIROC2



PARISROC2

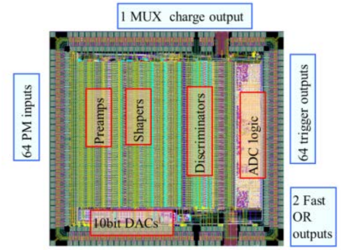


EASIROC



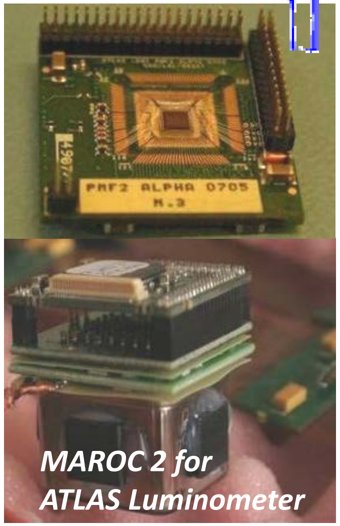
Evolution of PMT Read-Out Chips

- **From MAROC for ATLAS**
  - Produced for ATLAS Luminometer
    - 1000 chips, 2006s
  - Improved Maroc3
    - 1000 chips (2010) for > 50 users
      - Double-Chooz, Neutrinos experiment
      - Medical Imaging, …



MAROC 3, 16 mm², 0.35 SiGe

64 channels (Z_{in} 50-100 Ω)
6-bit individual gain correction
Auto-trigger on 1/3 p.e. at 10 MHz
12-bit Wilkinson ADC Multiplexed on the Charge Output
Power = 3 mW/ch



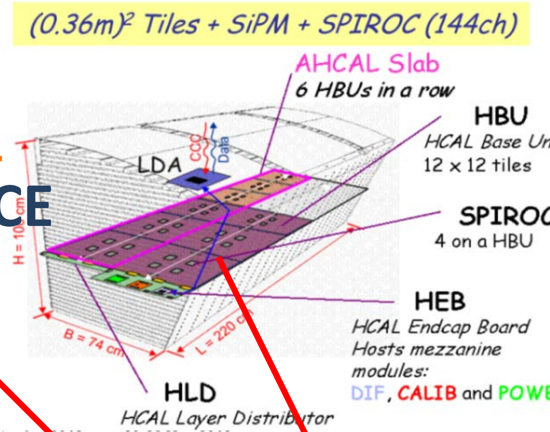
MAROC 2 for ATLAS Luminometer

- **To CATIROC for JUNO** (Jiangmen Underground Neutrino Observatory)
  - Determination of neutrino mass hierarchy: 20 ktons liquid scintillator detector
  - 2000 chips to produce (Q4 2018)
    for reading 25,000 small 3” PMTs inserted between ~18,000 20” PMTs (75% of inner area)

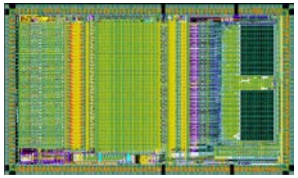
128 small PMTs RO Board – 8 CATIROC chips

16 independent channels: Analog FE + Trigger outputs + charge and time digitization
Dual gain front-end, Charge dynamic range 0 to 400 p.e.(at PMT gain 10^6)
Time stamping, resolution ~ 170 ps rms / 25 ns
Charge resolution 10 bits, 160 MHz
Autotrigger mode, 100% efficiency @ 1/3 p.e
Hit rate 100 kHz/ch (all channels hit)
Serial Read Out 80 MHz (50 bits / channel)

Evolution of SiPM Readout chips

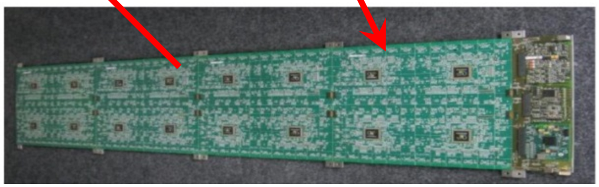


- **SPIROC for Analog hadronic calorimeter of CALICE**
  - F-E customized for 36 channels
  - B-E implements Time Measurement
  - Power pulsing for Power budget
    - Embedded inside the detector



SPIROC, 0.35 SiGe BiCMOS

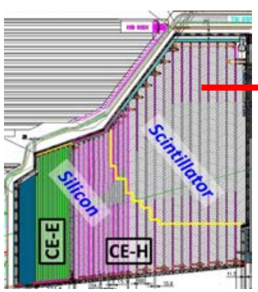
36 ch., auto-trigger & 15bit readout	
Energy measurement : 15 bits, 2 gains	
Auto-trigger down to ½ p.e.	
Time measurement up to ~1ns	
Power: 25µW/ch (pulsed power)	

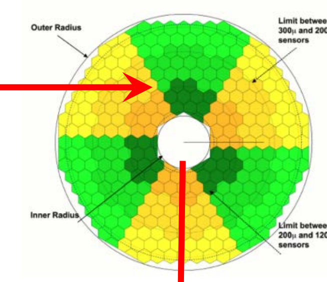


HCAL Base Units

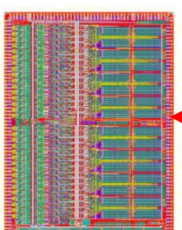
- **HGCROC for 5D HG Calorimeter of CMS**
  - Large collaboration of designers
  - F-E @ 32 → 72 channels
  - Energy, ToT & ToA
  - Cmplx trigger strategy
  - Tight schedule
    - July 17: HGCROCv1, 5x7 mm²
      - All analog and mixed blocks; large part of digital blocks
    - Dec 18 : HGCROCDV1, 15x6 mm²
      - Final size, packaging and I/Os
  - 100 000 FE chips to produce

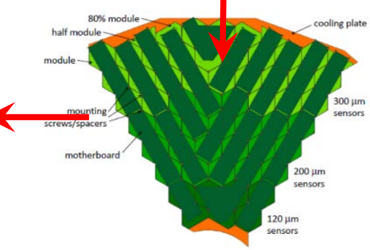
32 ch., Dual Polarity, Trigger Strategy	
Time Over Threshold, 50ps/200-400ns	
Time Of Arrival: 10/11 bits over 25ns	
ADC 11 bits, 40 MHz	
Serial link 1.28 GHz	





HGCROCv1, 130nm CMOS

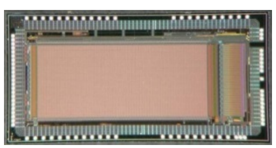


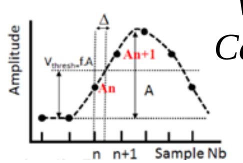


Switched Analog Memories

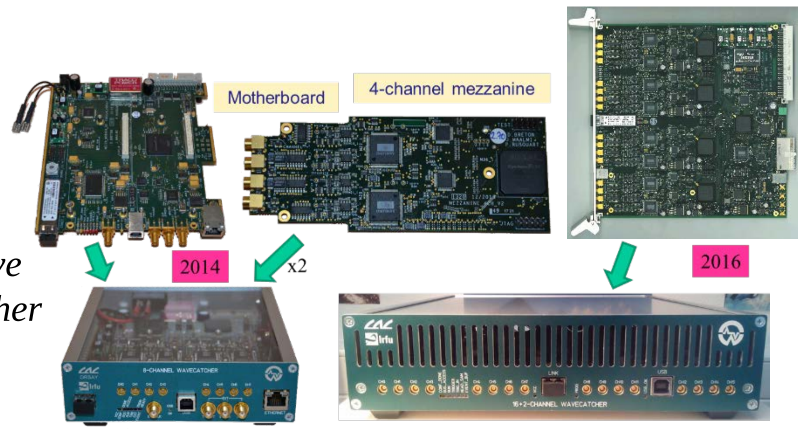
- **Fast Waveform Sampling → Amplitude & Time for signal reconstruction**
- **Common IRFU & IN2P3 developments**
  - Based on initial IRFU's R&D on HAMAC chip for ATLAS LAr Calorimeter, 80 000 chips, 2002
- **Constant improvements: sampling speed, memory size, embedded A2D**

SAMLONG
2 Inputs @2 GS/s, 1024 cells
AMS CMOS 0.35µm, 300 kT, 18 mm²
2010-14

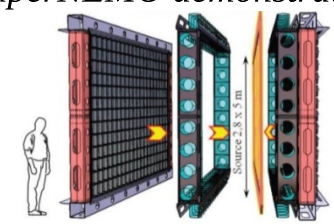


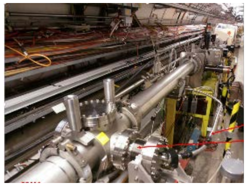


Wave Catcher



SuperNEMO demonstrator

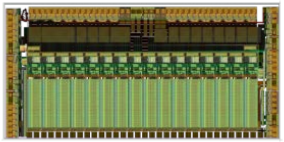




Proton Flux Monitors

Quality Control

SAMPIC
16 Inputs @10 GSPS for ~1 ps resolution
AMS CMOS 0.18µm, 7 mm²
V1 2013, V2 2014



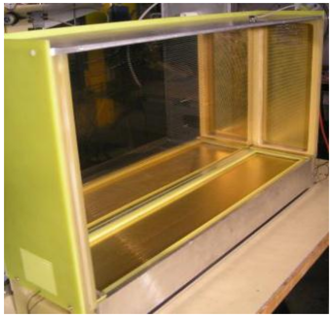
32-channel module

Tested with PMTs, MCPPMTs, APDs, SiPMs, Fast Silicon Detectors, Diamonds
Test beams of **TOTEM and ATLAS HGTD at CERN**
Test beams of **SHIP** collaboration
PANDA EndCap DIRC caracterization
Different R&Ds ongoing with the **TOF-PET** community (CERN, …)

- **Powerfull & versatile, used in numerous applications, @labs & on sites**

Gaseous Detectors Network

Drift **C**hambers



Drift chamber - SHARAQ spectrometer -Japan

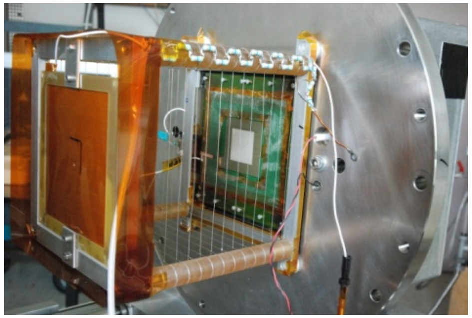
Multi **W**ire **P**roportional **C**hambers

MWPC 1m²
ALICE-Muon Arm - CERN

Micro **P**attern **G**aseous **D**etectors
- Micromegas or GEM -

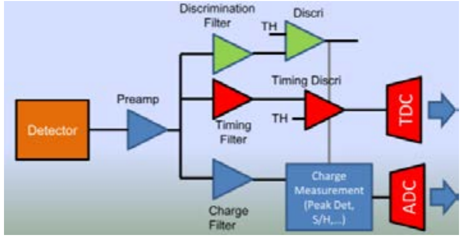
Micromegas
SDHCAL- ILC

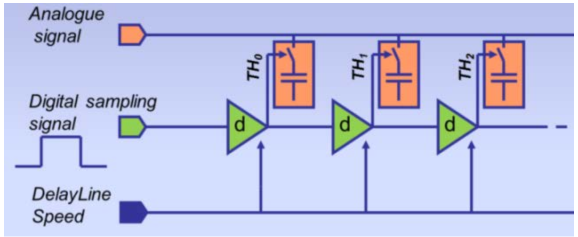
Ionizing **C**hambers
TPC (IO + MPGD or MWPC)



Micro TPC + Micromegas for MIMAC @ LSM Modane

- **FEE for Gaseous detectors is similar to FEE for photo-detectors**
  - Shapers and Peak Detectors & Waveform Samplers





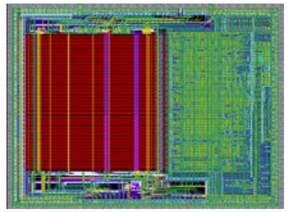
  - With additional constraints such as material and power budgets

Extended FEE for Gaseous Detectors

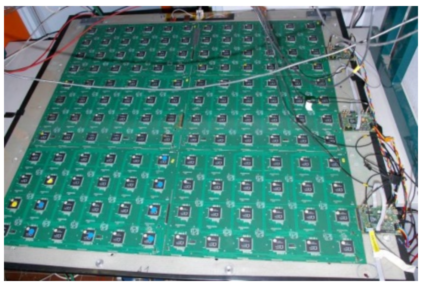
HARDROC: GRPC DHCAL - CALICE

- 64 ch, 3 discri/ch
  - 3 encoded charge values
- Event memory
- Power pulsing

HARDROC2



26 mm², SiGe 0.35 µm

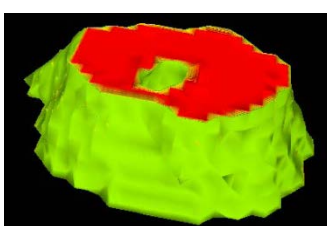


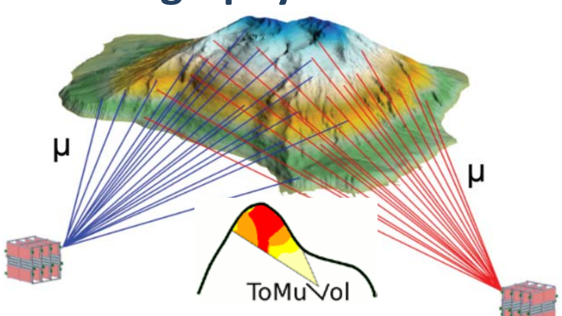
Scalable GRPC detector layer
Embedding FEE

Demonstrator, 1 m³
40 layers, 400 000 Channels

GRPC FEE Spinoff

TOMUVOL: Volcano Tomography with Muons

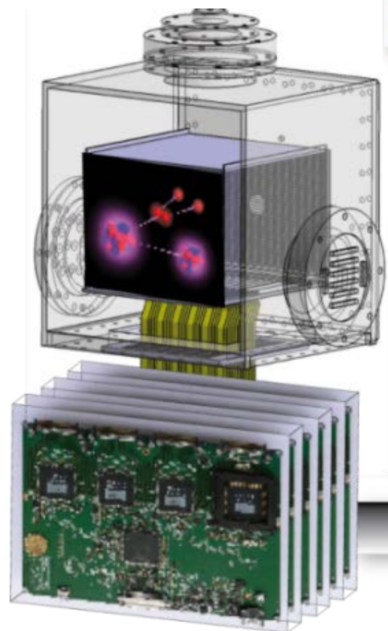




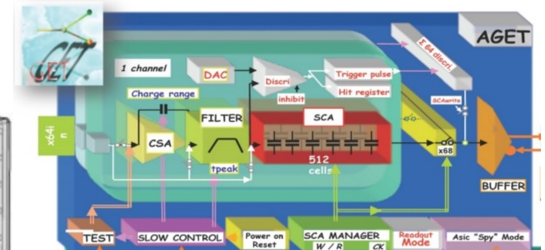
AGET for ACTAR TPC R&D

- To Study exotic nuclear structures @SPIRAL2
- AGET for the 2048 channels of the TPC
  - Variant of AFTER for µmegas @ T2K (6000 chips)

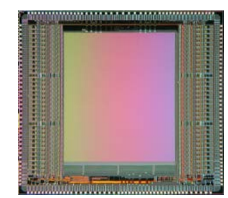
Active Target TPC



256 channels AsAd board
- 4 x AGET
- 12-bits, 25 MHz digitizer
- AGET steering,
test, calibration



AGET 0.35 µm CMOS, 65 mm²,
2010



64-ch, Pos / Neg polarity
4 Ranges : 120 fC; 240 fC; 1 pC; 10 pC
16 Peaking Time Values (**50ns to 1µs**)
Fsampling: **1-100MHz**; Fread: **25MHz**
Auto trig: discri/ch + DACthreshold
Ch RO: All, Hit, Specific channels
SCA cells readout: **128/256/512**

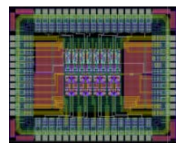
Designs for specific configurations

Trigger upgrade of Dimuon Spectrometer of ALICE

– FEERIC dedicated to new RPC in avalanche mode
– To replace ADulT chips for actual RPC in streamer mode
– To provide calibrated pulses to trigger logic
– >3000 chips produced for install during LS2

SHiP @ CERN: ~ 2000 chips foreseen

FEERIC 4mm²
0.35µm CMOS



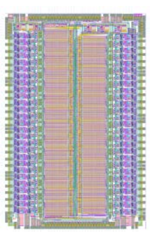
Number of ch.	8
Input polarity	±
Dynamic range	Q=20 fC-3 pC
Input noise (rms)	$< 4fC$
Power cons.	$< 100mW/ch$
Power supply	3 V
One-shot	yes(100ns)
Time resolution (rms)	< 1 ns
Time walk	< 2 ns
Output format	LVDS, 23 ± 2 ns

Also RPC @ CMS
Cf CRONOTIC

TDC for SNEMO @ LSM

- 54 ch. TDC, 3.6 ns resolution
- Configurable Inputs - gain & discri. threshold - for anodic and cathodic signals
- 150 samples

Test board



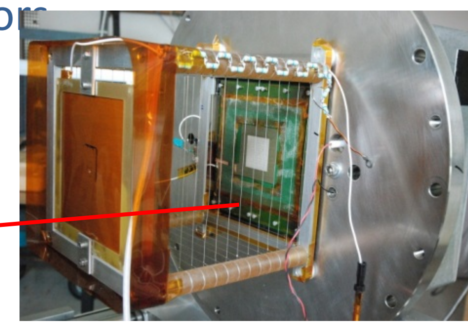
0.35 CMOS
40 mm2
2011

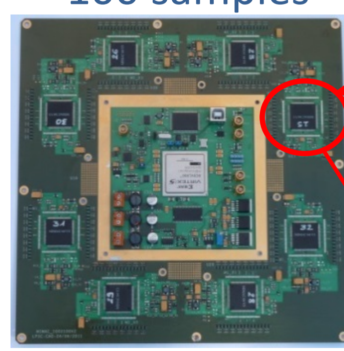
Drift Chamber

Manchester-UK courtesy

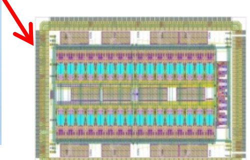
Micromegas TPC, MIMAC @ LSM

- 64 ch., Coincidences detect. + TOT measures
- 50 MHz discriminators
- 400 MHz serializer
- ~100 samples





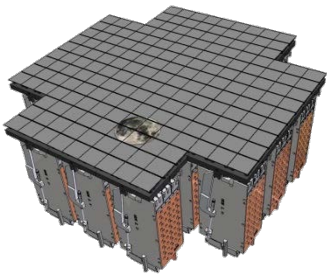
256 channels board



.35 µm
SiGe BiCMOS
23 mm²
2010

Semiconductors Network

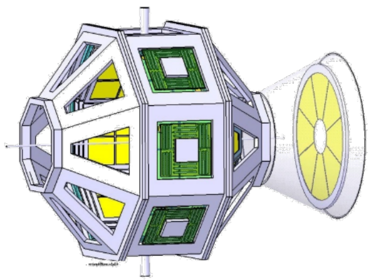
CCD



CCD for LSST - Chile
Studies &
Production testing

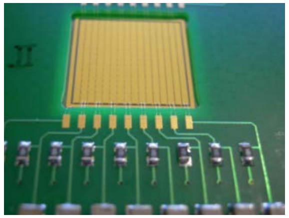
Strips Detectors

Silicon



DSSD for GRIT
@ GANIL-SPIRAL2
FE electronics

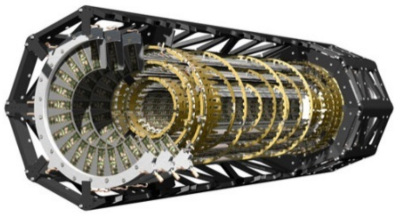
Diamond



Beam profiler
SPIRAL-France
DSSD & FE electronics

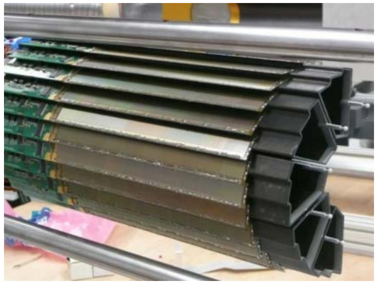
Pixel Detectors

Hybrid **P**ixel **S**ensors



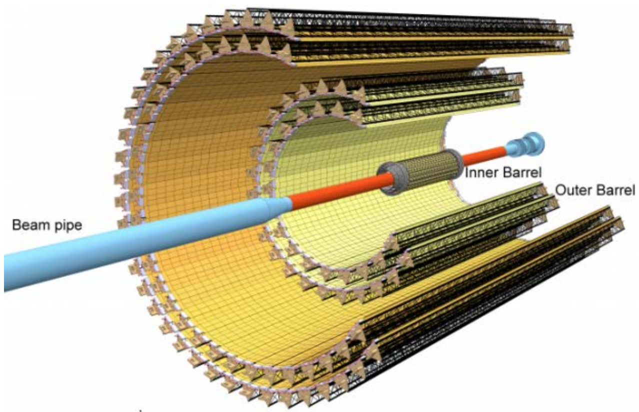
ATLAS Pixel Tracker
Test & Construction,
HPS design – Phase1

CMOS **P**ixel **S**ensors



STAR PXL Tracker
CPS design

Pixel sensors everywhere



ALICE – Internal Tracker System -
Studies & Production

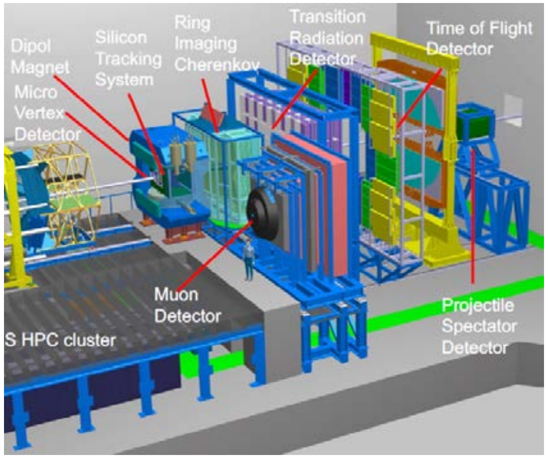
RD 53A

ATLAS EXPERIMENT

CMS

ATLAS CMOS PIXELS

Hybrid & HV CMOS Pixels
Ongoing R&D

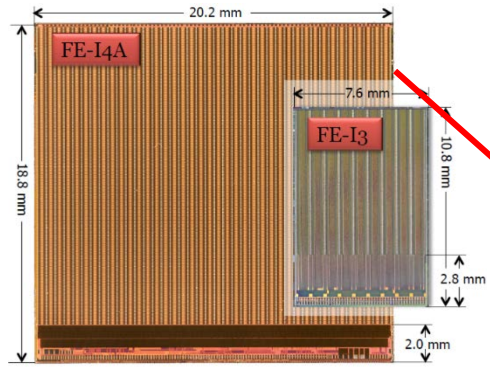


CBM – MVD @ GSI/ FAIR
Ongoing R&D

Hybrid Pixel Sensors

- **FE-I4 chip for Insertable B-Layer of ATLAS upgrade (2014)**
  - IB-Layer: 16 ladders, 384 FE-I4 with associated pixels

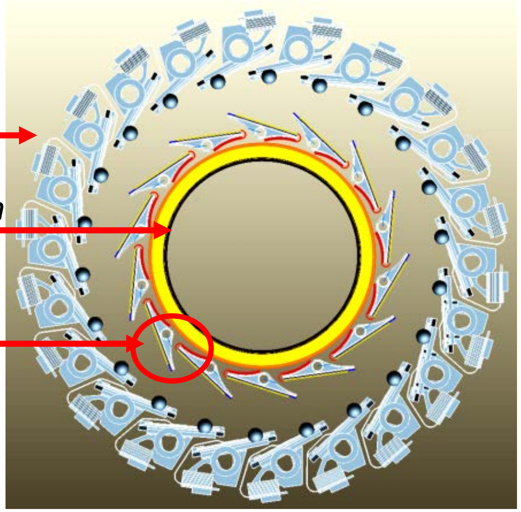
Pixel size	50 x 250	μm^2
Matrix array	80 x 336	pixel
Chip size	20.2 x 19.0	mm^2
Active fraction	89	%
A - D currents	10 - 10	µA/pix
Analog voltage	1.4	V
Digital voltage	1.2	V
Process	130 nm	
Radiation Tol	> 200	Mrad



Existing B-layer

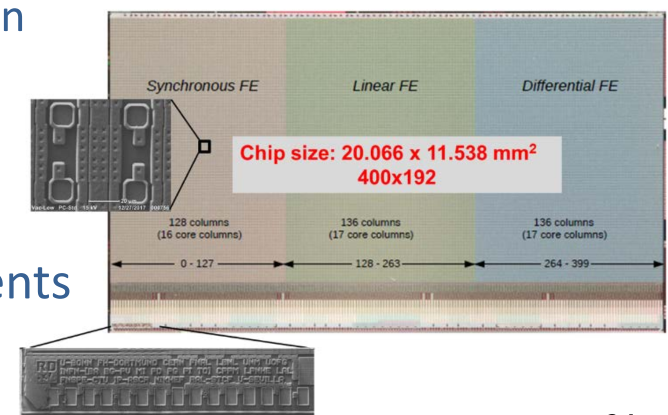
Narrow beam pipe 3,3 cm

Ladder: FE-I4 + Detector



IBL on new beam pipe

- **RD53 ATLAS/CMS - Phase 2**
  - Involved in many WP of in RD53A pixel RO chip
    - Calibration, Monitoring and building blocks Integration
    - Digital Readout and Control Interface
    - Digital Libraries
    - Radiation effects and models
  - An example for future sophisticated SoC developments
    - Strong interactions among international design teams (20 people) via Co-design Tools



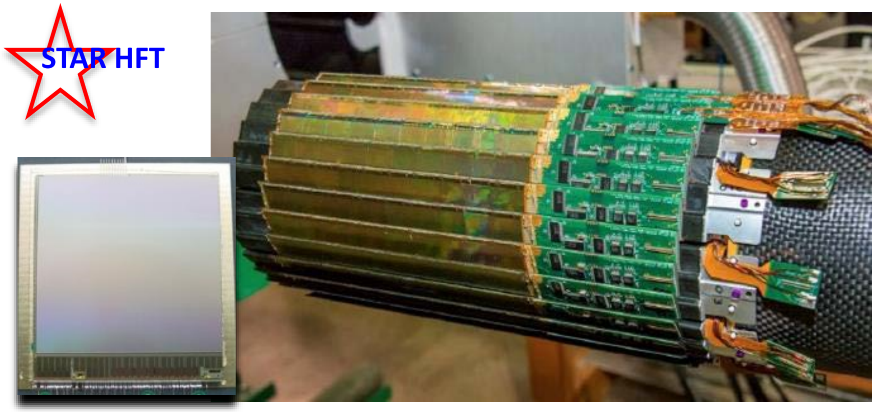
RD53 chip – CMOS 65 nm

Cmos Pixel Sensors for Heavy Ion Physics -1

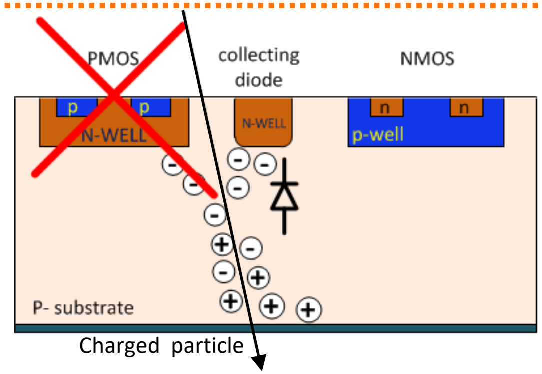
Design evolutions versus Foundry processes

- **Mimosa28, ~4 cm², 1 Mpixels**
  - 2014: HFT of STAR, 360 Mpx, 0.16 m²

STAR HFT

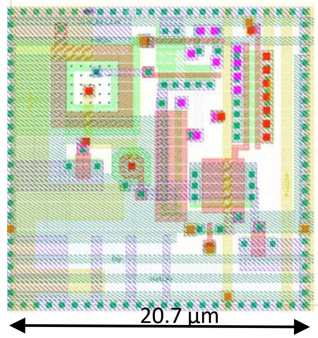


- **1st CPS System in HEP**



350nm Twin well process

PMOS not allowed inside pixels



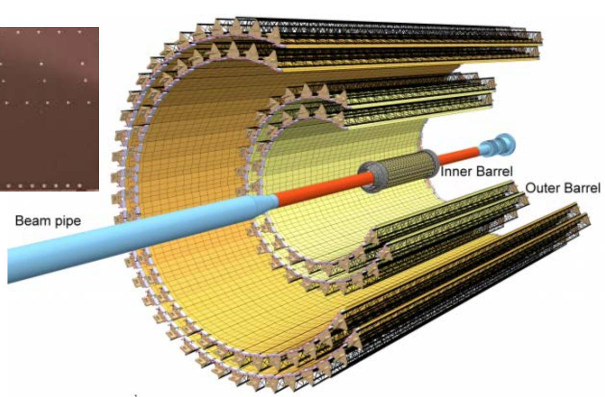
Pixel Layout

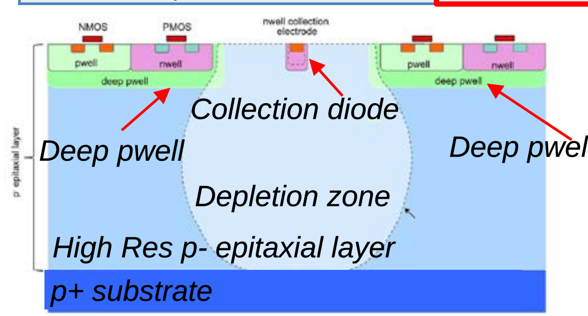
Pixel Layout

	STAR – PXL	ALICE - ITS
Spatial Resolution [µm]	3.5	5
Time resolution [µs]	< 200	< 20
Particle rate [kHz/mm²]	4	10
Total Ionizing Dose [Mrad]	0.2	0.7
NIEL [n_{eq}/cm²]	> 10^{12}	> 10^{13}
Digitization (1 bit)	Bottom Column	In Pixel
Data compression	Outside Matrix	In Matrix

- **ALPIDE, ~4.5 cm², 0.5 Mpixels**
  - LS2 - 2019: ITS of ALICE, 12.5 Gpx, 10 m²

ALICE

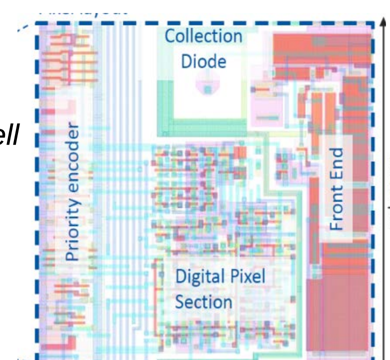




***180nm Quadruple well process**:*

allows N & P MOS

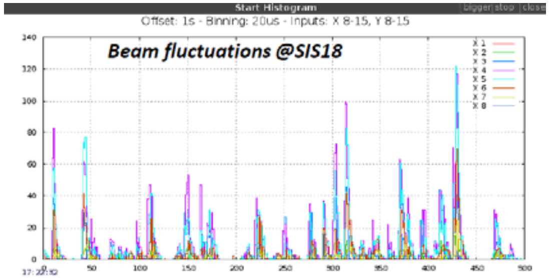
→ Better performances, speed & power



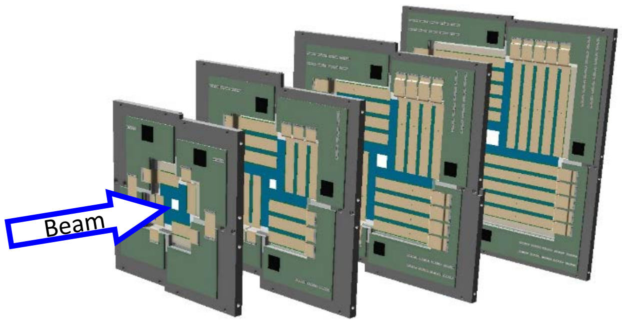
Pixel Layout

CPS for Heavy Ion Physics -2

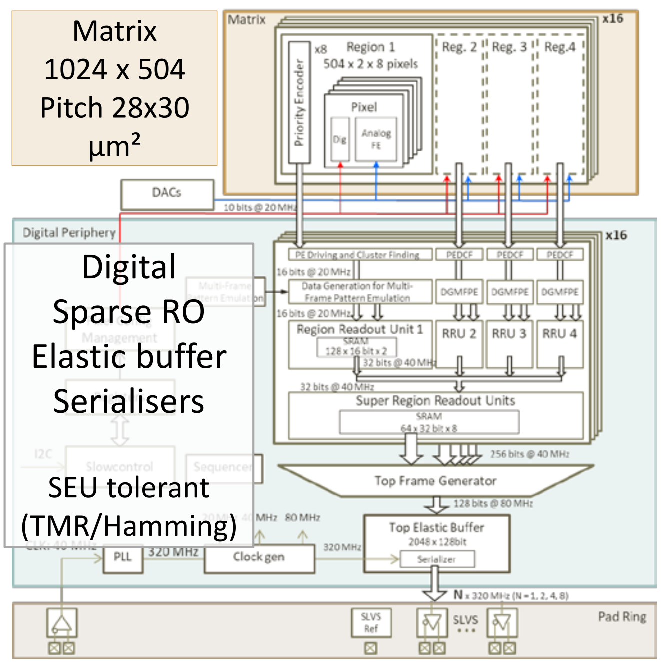
- **MIMOSIS ~4,5 cm², 0.5 Mpixels, Matrix RO similar to ALPIDE**
  - For Micro Vertex Detector of CBM @ GSI/Fair
  - Beam fluctuations in terms of hit density in time and space
  - Sensor Improvements on Time resolution & Data reduction



ALPIDE / MIMOSIS	ALPIDE ALICE – ITS	MIMSOSIS (MVD Design Goal)
Particle rate [kHz/mm²]	> 10	700 (peak)
Time resolution [µs]	< 20	5
Data reduction	Cont. / Trigger	Elastic buffer
GBTx compatible	No	Yes



Micro Vertex Detector, 4 plans, 300 sensors



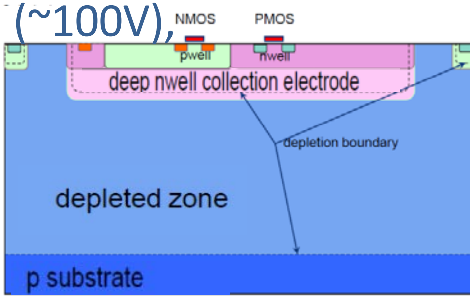
- Q2 2017: demonstrator of matrix 1/16 scale
- Q1 2019: Full size chip V1 – Production in 2020/21
- Evolution of the µE Design & Methodologies in HEP
  - Increase of digital functionalities
  - Digital On Top for Integration & Verification
    - Digital models for all blocks, analog included
    - Standardized methods and tools
      → **U**niversal **V**erification **M**ethod, SystemVerilog

ATLAS CMOS PIXEL COLLABORATION

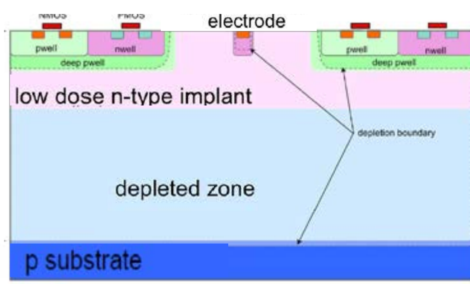
Diode geometries and Process evolutions

Cf. ACES 2018 WS
T. Kugathasan Talk

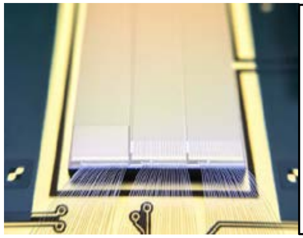
- **Improved Radiation Tolerance**
  - 5th layer pixel of ITK requires O (50 Mrad, 10^{15} n_{eq}/cm^2) tolerance
  - Limiting non-ionizing radiation effects (displacement damage): creating fast collection by drift in order to decrease signal charge trapping probability → large depletion → 2 solutions
- **Large collection electrode (Deep n-well) - HV CMOS**
  - Transistors isolated from substrate → High reverse substrate voltage (~100V),
  - High resistivity p-substrate (>2 kΩ cm) → Charge collected by drift
  - Limited in pixel circuit area, large capacitance (C > 100 fF)



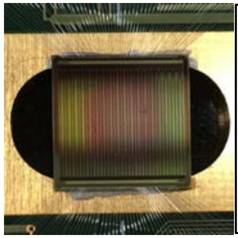
- **Small collection electrode**
  - Low capacitance → lower power, less prone to coupling
  - Possibility to achieve full depletion of the sensing volume
    - Modified process developed in collaboration with the Foundry
    - Planar n-type layer significantly improves depletion under deep PWELL



Large collection electrode demonstrators



ATLASPIX
AMS 180 nm
Substrate:
ρ = 80 Ω cm
HV= -60 V

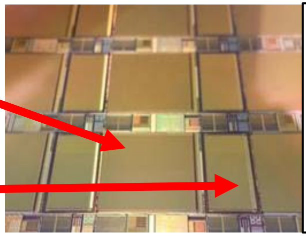


LF-Monopix
150 nm
Substrate:
ρ > 2 kΩcm
HV= -100 V

Small collection electrode demonstrators

MALTA
4 cm²

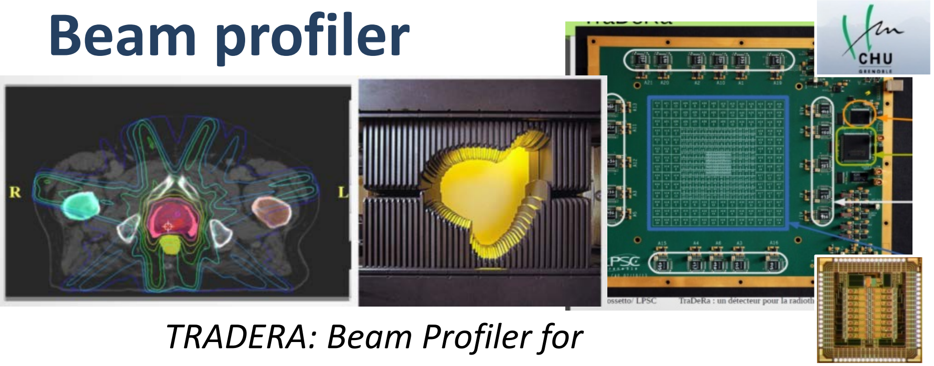
TJ-Monopix
2 cm²



TJ 180 nm
Modified process
Substrate:
ρ > 1 kΩcm
HV= - 20 V

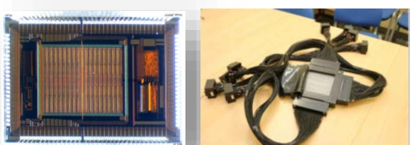
R&D for Societal Applications

Beam profiler

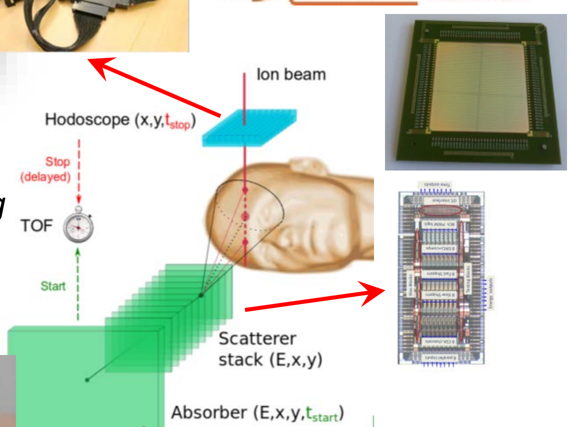


TRADERA: Beam Profiler for Intensity modulated radiation therapy

Deposited dose monitoring

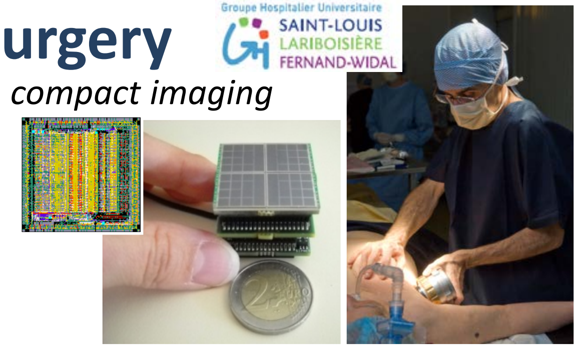


Compton camera for ion range monitoring during hadron therapy



Radioguided surgery

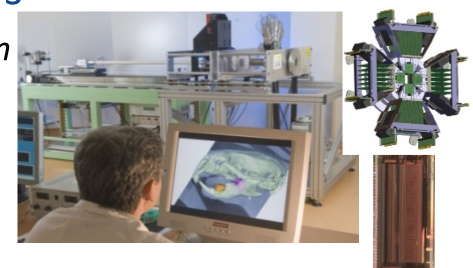
MAGICS: Peroperative compact imaging gamma camera. Sentinel lymph-node mapping protocol.



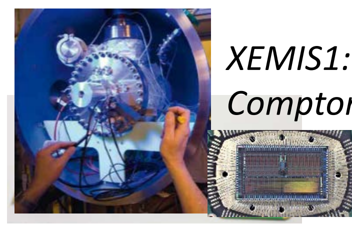
Imaging

- CT & SPECT scanners

IMABIO: Multimodal platform for small animal imaging µCT, µSPECT, µPET



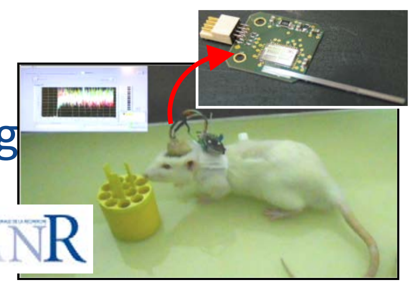
- PET scanners



XEMIS1: Liquid Xenon Compton camera

- In vivo neuroimaging

PICSIC: Brain implantable β+ radiosensitive probe



Dosimetry

FASTPIXN: Neutron dosimetry for nuclear power plants survey

Summary

- **Numerous projects of physics, on large scope**
  → Instrumentation Networks are helping for creating synergies

- **ASIC developments**
  - Intense and diversified activity
  - Many circuits used by international collaborations
  - Evolutionary SoC / Sensors → help to diffuse these technologies
    - Digital functionalities are becoming critical
  - Design teams with critical size are required → collaborative tools

- **Microelectronics**
  - Actual Microelectronics R&D is clearly structured by the big experiments
    - LHC upgrades, future colliders
  - Helps to diffuse know-how and to adapt ASICs for the others domains of our physics
  - Is an important vector in our exchanges with international R&D initiatives

Thank you for your attention