Electronics Developments at IN2P3

- IN2P3 Profile
- Networks for Instrumentation & Microelectronics
- Microelectronics Developments for physics experiments
  - More than a Decade of R&D & Collaborations
CNRS
10 institutes
1,100 research units
(95% in partnership)

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

IN2P3, one of the 10 Institutes of CNRS

25 labs & platforms
2500 researchers engineers technicians

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

Research in
Astroparticles
Particle Physics
Nuclear Physics

IN2P3
National Institute of Nuclear and Particle Physics

IN2P3, one of the 10 Institutes of CNRS
Research Infrastructures

Spiral2 / Ganil
CC-IN2P3
DChooz
Edelweiss, Nemo / LSM
Antares / KM3NeT
International Collaborations

• 40 Major International Projects
Commitment in R&D for Instrumentation

Supporting Instrumentation R&D
730 Engineers & Technicians

Instrumentation Network
To improve exchanges between experts
To promote common actions

<table>
<thead>
<tr>
<th>DETECTORS</th>
<th>CROSS-CUTTING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiodetection</td>
<td>Mechanics</td>
</tr>
<tr>
<td>Cryogenics</td>
<td>Microelectronics</td>
</tr>
<tr>
<td>Silicon detectors</td>
<td>Data Acquisition</td>
</tr>
<tr>
<td>Gaseous detectors</td>
<td>Command &amp; control</td>
</tr>
<tr>
<td>Photo-detectors</td>
<td></td>
</tr>
</tbody>
</table>

DETECTORS CROSS-CUTTING

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

Commitment in R&D for Instrumentation

CMS Silicon Strips
Tracker End Cap Petals

MultiWires Proportional 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
• Existing since 2011
  \( \rightarrow \) 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
    • \textit{PCI Industrial Computer Manufacturers Group}
  – Working Group of xTCA for Physics
    • Clocks, Gates and Trigger distribution

\textbf{HEP - LHCb Upgrade – LS2}
ATCA 40 Board –

\textbf{HEP - ATLAS LAr upgrade – LS2}
AMC Board – LATOME –

\textbf{Radiodetection - BAORADIO- PAON}
Digitizer Frequency Separator

\textbf{Nuc Phy - SPIRAL2/FAIR}
MUTANT
Microelectronics Network

- > 70 Engineers, design and test
- 14 Teams gathered in
- 4 Federations \(\rightarrow\) reach critical size
- 1 Advising Committee

- Internal workshops
- Upfront R&D projects
  - Knowhow / IP exchanges

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

**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

---

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

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

**4 x 12-bits SAR ADC**
- 40 MSPS
- 5mW/ch
- 10 mm², 130 nm

**BAND CAP**
- 196 x 133 μm²
- TJ 180 nm

**10 ps TDC R&D**
- 35 x 75 μm²
- IBM 130 nm

**JTAG Ctrl**
- 725x112 μm², TJ 180 nm
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)
  - EUDET (2006-2010)
  - 3DIC - TSV (2009)
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**
  - 1\textsuperscript{st} generation, 0.8 \(\mu\)m CMOS
    - 2004, 400 chips
  - 2\textsuperscript{nd} generation, 0.35 \(\mu\)m CMOS
    - 2011 700 chips
    - 2014 6000 chips

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Installed</th>
</tr>
</thead>
<tbody>
<tr>
<td>CODALEMA @ Nançay-France</td>
<td>(60 Butterflies + 10 LWA) x 2</td>
</tr>
<tr>
<td>AERA @ Auger-Argentina</td>
<td>200 Butterflies</td>
</tr>
<tr>
<td>TREND @ China</td>
<td>108 Butterflies</td>
</tr>
<tr>
<td>HELYCON @ Greece</td>
<td>12 Butterflies</td>
</tr>
<tr>
<td>NenuFAR @ Nançay-France</td>
<td>57 LWA x 2 + 6000</td>
</tr>
</tbody>
</table>

Ongoing discussion with the GRAND experiment

Giant Radio Array for Neutrino Detection - China

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fully differential architecture</td>
<td></td>
</tr>
<tr>
<td>Zin digitally adjustable</td>
<td></td>
</tr>
<tr>
<td>OIP3=33dBm</td>
<td></td>
</tr>
<tr>
<td>NF&lt;1dB</td>
<td></td>
</tr>
<tr>
<td>Gp=27dB</td>
<td></td>
</tr>
<tr>
<td>BW&gt;200MHz</td>
<td></td>
</tr>
</tbody>
</table>

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

Long-Wavelength Antenna
NenuFAR @ Nancay - France

LONAMOS 1.4 x 1.4 mm\(^2\)
CMOS 0.35 \(\mu\)m, 2011
Cryogenics Network

- RO Electronics @ ~4 - 40 K (QUBIC)
  - Industrial process do not provide valid transistor models
  - Characterization
    - Bipolar: \( gm \uparrow, \beta \uparrow \ldots \)
    - MOS: Substrate becomes Insulated \( \rightarrow \) Kink Effect
      \( \rightarrow T_{\text{parasitic}}, I_{\text{leakage}}, V_{\text{th}} \) distortions

- Thermal & Electric effects of Interconnects
Cryogenic electronics for QUBIC

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

- **Focal plane**
  - 4 x 256 NbSi Transition Edge Sensor @ 0.3 K
  - 1 TDM Readout system for \( \frac{1}{8} \) focal plane
  - 128 SQUID @ 1 K + 1 ASIC @ 40 K

- **Mixed ASIC, SQMUX128_evo**
  - Analog
    - FE LNA with mxplx inputs (1:4)
    - SQUIDs bias with mxplx current supply (1:32)
  - Digital → Full custom library, cryogenics effects
    - Steering, Slow Control

- **6 modules in 2025: 96 ASIC**

---

**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)

- 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
Shapers & Peak Detectors circuits

**ROC chips: OPERA-ROC, early 2000**

– For OPERA Target Tracker at Gran Sasso, 3000 chips

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

**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**
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, ...

• 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)

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)

**HGCROC for 5D HG Calorimeter of CMS**
- Large collaboration of designers
- F-E @ 32 → 72 channels
- Energy, ToT & ToA
- Complex 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
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

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

SuperNEMO demonstrator
Proton Flux Monitors
Quality Control

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 characterization
Different R&Ds ongoing with the TOF-PET community (CERN, ...)

• Powerfull & versatile, used in numerous applications, @labs & on sites
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
HARDROC: GRPC DHCAL - CALICE
- 64 ch, 3 discri/ch
- 40 layers, 400 000 Channels
- 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

AGET 0.35 µm CMOS, 65 mm², 2010

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

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 ADuIT 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

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

Micromegas TPC, MIMAC @ LSM
- 64 ch., Coincidences detect. + TOT measures
- 50 MHz discriminators
- 400 MHz serializer
- ∼100 samples

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of ch.</td>
<td>8</td>
</tr>
<tr>
<td>Input polarity</td>
<td>±</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>Q=20 fC-3 pC</td>
</tr>
<tr>
<td>Input noise (rms)</td>
<td>&lt; 4 fC</td>
</tr>
<tr>
<td>Power cons.</td>
<td>&lt; 100 mW/ch</td>
</tr>
<tr>
<td>Power supply</td>
<td>3 V</td>
</tr>
<tr>
<td>One-shot</td>
<td>yes (100 ns)</td>
</tr>
<tr>
<td>Time resolution (rms)</td>
<td>&lt; 1 ns</td>
</tr>
<tr>
<td>Time walk</td>
<td>&lt; 2 ns</td>
</tr>
<tr>
<td>Output format</td>
<td>LVDS, 23 ± 2 ns</td>
</tr>
</tbody>
</table>

FEERIC 4mm² 0.35µm CMOS

Drift Chamber

0.35 CMOS 40 mm² 2011

90-cells tracker prototype
Manchester-UK courtesy

256 channels board

.35 µm SiGe BiCMOS 23 mm² 2010
Semiconductors Network

**CCD for LSST - Chile**  
Studies & Production testing

**Strips Detectors**  
Silicon

**DSSD for GRIT @ GANIL-SPIRAL2**  
FE electronics

**Beam profiler SPIRAL-France**  
DSSD & FE electronics

**Pixel Detectors**  
Hybrid Pixel Sensors

**ATLAS Pixel Tracker**  
Test & Construction, HPS design – Phase1

**CMOS Pixel Sensors**  
STAR PXL Tracker CPS design

**Pixel sensors everywhere**

**ALICE – Internal Tracker System for LSST**  
Studies & Production

**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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel size</td>
<td>50 x 250 µm²</td>
</tr>
<tr>
<td>Matrix array</td>
<td>80 x 336 pixel</td>
</tr>
<tr>
<td>Chip size</td>
<td>20.2 x 19.0 mm²</td>
</tr>
<tr>
<td>Active fraction</td>
<td>89 %</td>
</tr>
<tr>
<td>A - D currents</td>
<td>10 - 10 µA/pix</td>
</tr>
<tr>
<td>Analog voltage</td>
<td>1.4 V</td>
</tr>
<tr>
<td>Digital voltage</td>
<td>1.2 V</td>
</tr>
<tr>
<td>Process</td>
<td>130 nm</td>
</tr>
<tr>
<td>Radiation Tol</td>
<td>&gt; 200 Mrad</td>
</tr>
</tbody>
</table>

• 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 Mpxixels**
  - 2014: HFT of STAR, 360 Mpx, 0.16 m²

- **1st CPS System in HEP**

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

<table>
<thead>
<tr>
<th>STAR – PXL</th>
<th>ALICE - ITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial Resolution [µm]</td>
<td>3.5</td>
</tr>
<tr>
<td>Time resolution [µs]</td>
<td>&lt; 200</td>
</tr>
<tr>
<td>Particle rate [kHz/mm²]</td>
<td>4</td>
</tr>
<tr>
<td>Total Ionizing Dose [Mrad]</td>
<td>0.2</td>
</tr>
<tr>
<td>NIEL [n_{eq}/cm²]</td>
<td>&gt; 10^{12}</td>
</tr>
</tbody>
</table>

- **Digitization (1 bit)**
  - Bottom Column
  - In Pixel

- **Data compression**
  - Outside Matrix
  - In Matrix

**350nm Twin well process**
PMOS not allowed inside pixels

**180nm Quadruple well process**
allows N & P MOS
→ Better performances, speed & power
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

<table>
<thead>
<tr>
<th>ALPIDE / MIMOSIS</th>
<th>ALPIDE ALICE – ITS</th>
<th>MIMOSOSIS (MVD Design Goal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle rate [kHz/mm²]</td>
<td>&gt; 10</td>
<td>700 (peak)</td>
</tr>
<tr>
<td>Time resolution [µs]</td>
<td>&lt; 20</td>
<td>5</td>
</tr>
<tr>
<td>Data reduction</td>
<td>Cont. / Trigger</td>
<td>Elastic buffer</td>
</tr>
<tr>
<td>GBTx compatible</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

- 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
      → Universal Verification Method, SystemVerilog
• Improved Radiation Tolerance
  – 5th layer pixel of ITK requires $O \left( 50 \text{Mrad}, 10^{15} \text{n}_{\text{eq}}/\text{cm}^2 \right)$ tolerance
  – Limiting non-ionizing radiation effects (displacement damage): creating fast collection by
    drift in order to decrease signal charge trapping probability $\rightarrow$ large depletion $\rightarrow$ 2 solutions

• Large collection electrode (Deep n-well) - HV CMOS
  – Transistors isolated from substrate $\rightarrow$ High reverse substrate voltage ($\sim 100\text{V}$)
  – High resistivity p-substrate ($>2 \text{k}\Omega \text{cm}$) $\rightarrow$ Charge collected by drift
  – Limited in pixel circuit area, large capacitance ($C > 100 \text{fF}$)

• Small collection electrode
  – Low capacitance $\rightarrow$ 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:
$\rho = 80 \text{\Omega cm}$
HV= -60 V

LF-Monopix
150 nm
Substrate:
$\rho > 2 \text{k}\Omega \text{cm}$
HV= -100 V

Small collection electrode demonstrators

MALTA
4 cm²
TJ 180 nm
Modified process
Substrate:
$\rho > 1 \text{k}\Omega \text{cm}$
HV= -20 V

TJ-Monopix
2 cm²
R&D for Societal Applications

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

Imaging
- CT & SPECT scanners
- PET scanners
- In vivo neuroimaging
  PICSIC: Brain implantable $\beta^+$ 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
  – Plays a important role in our exchanges with international R&D initiatives
Thank you for your attention