European Organization for Nuclear Research
Organisation Européenne pour la Recherche Nucléaire

From High Energy Physics to Industry: application of CERN microelectronics outside HEP

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CERN PH

OUTLINE

CERN microelectronics

- Focus and activities

CERN ASICs

- Sensors interface, front end
- Signal processing
- Power systems

Fields of applications

- Medical imaging
- Life science
- Industry

Technology transfer approaches

CERN focus of HEP ASIC R&D

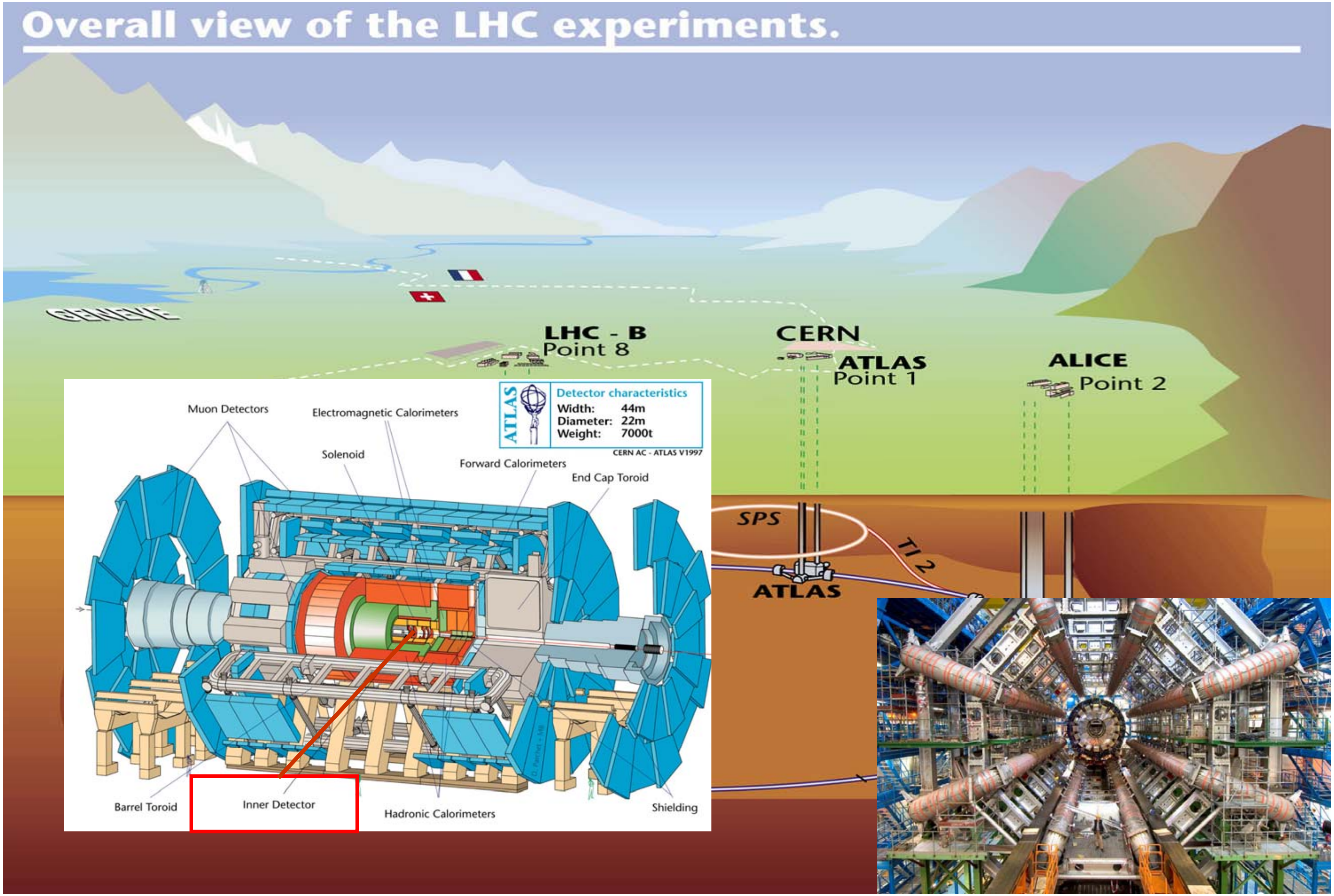
The last 15 years

- Develop ASICs for LHC experiments
  - Analog and mixed signal front end circuits interfacing sensors
  - Signal processing and optoelectronics circuits
- Develop radiation tolerance of ICs
  - Based on industrial microelectronics processes
    - Bipolar, BiCMOS, CMOS 0.25µm and 0.13µm
  - Partnership with semiconductor industry
    - In foundry service : IBM, ATMEL
    - Development of products with ST Microelectronics: voltage regulator, ASIC with ADC
- Design issues of sensor electronics,
  - Complex low power low noise mixed-signal circuits ASICs
    - High channel density: strip detector
    - Very high packing density: pixel detector
    - Ultra fast electronics: Time-of-Flight detector

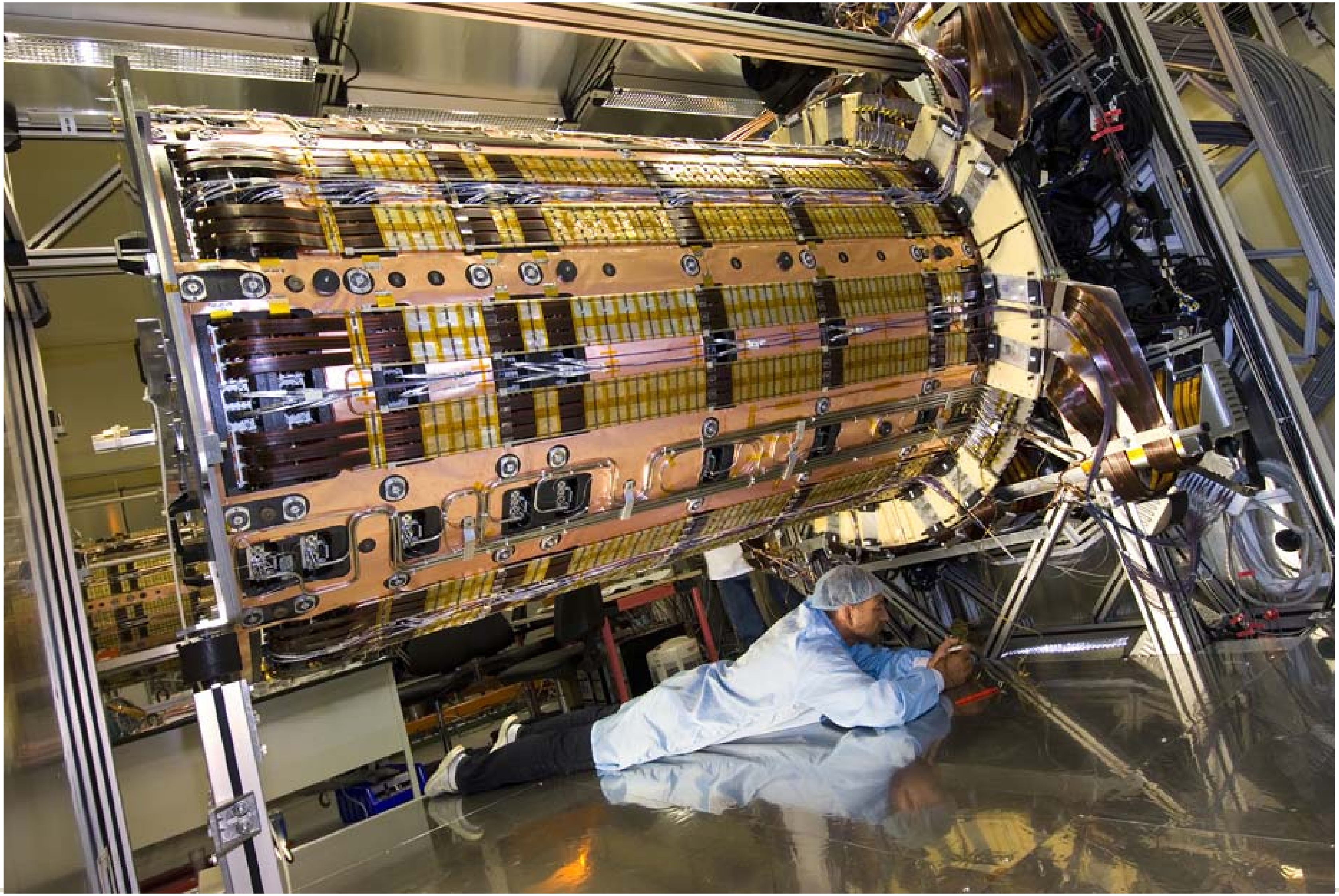
Technology transfer of HEP ASICs

4 technologies presented

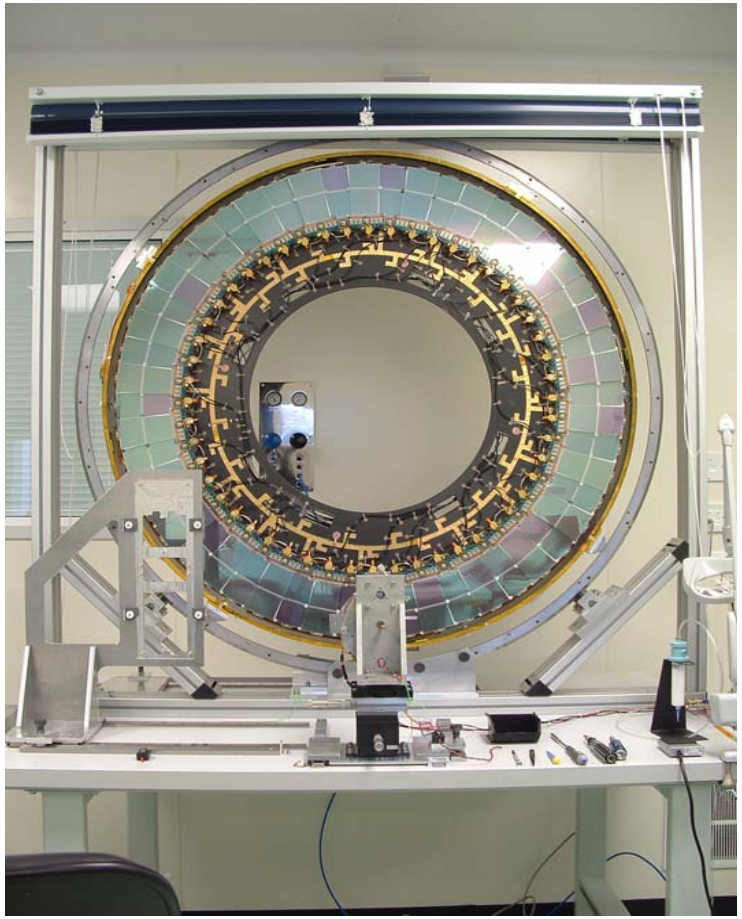
- Linear multi-channel arrays
  - ATLAS SCT silicon tracker
- Pixel arrays
  - ALICE and LHCb pixel detector
- Ultra fast ASIC channel
  - ALICE TOF detector
- Radiation hardening
  - Radiation hard ASIC

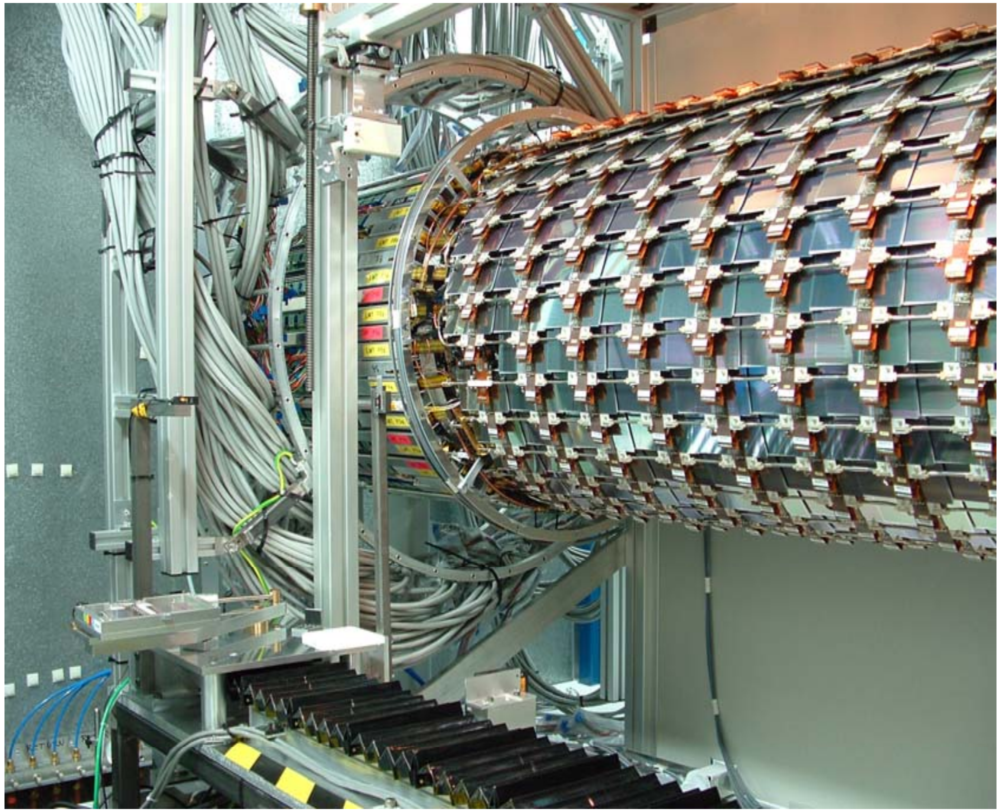

Overall view of the LHC experiments.
GENEVE
LHC - B
Point 8
CERN
ATLAS
Point 1
ALICE
Point 2
SPS
TI 2
ATLAS
Muon Detectors
Electromagnetic Calorimeters
Solenoid
Forward Calorimeters
End Cap Toroid
ATLAS
Detector characteristics
Width: 44m
Diameter: 22m
Weight: 7000t
CERN AC - ATLAS V1997
Barrel Toroid
Inner Detector
Hadronic Calorimeters
Shielding

ATLAS SCT barrel detector



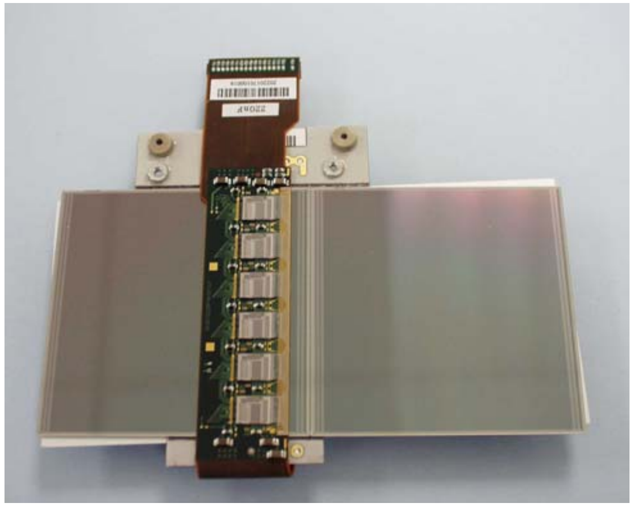
ATLAS SCT Tracker

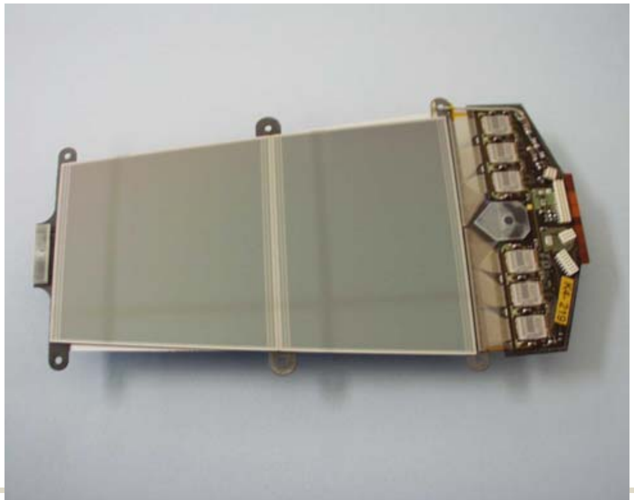


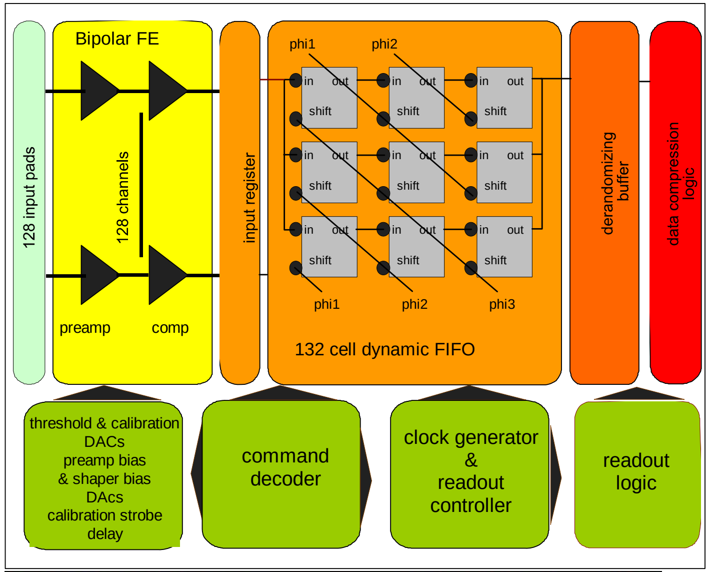


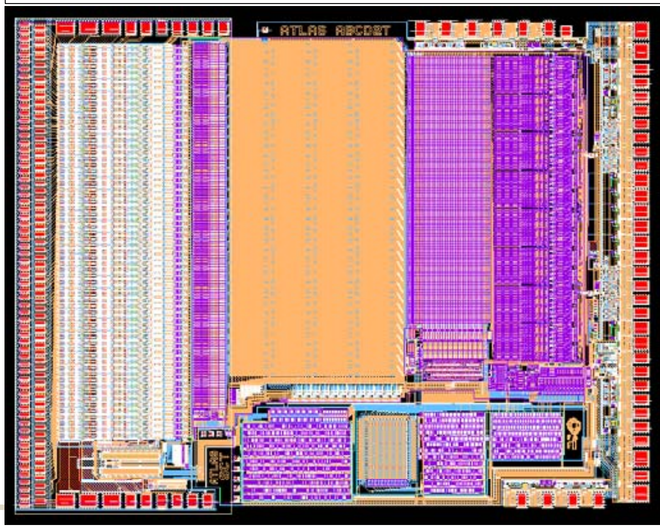
ATLAS SCT detector modules

Forward and Barrel modules, principle and die



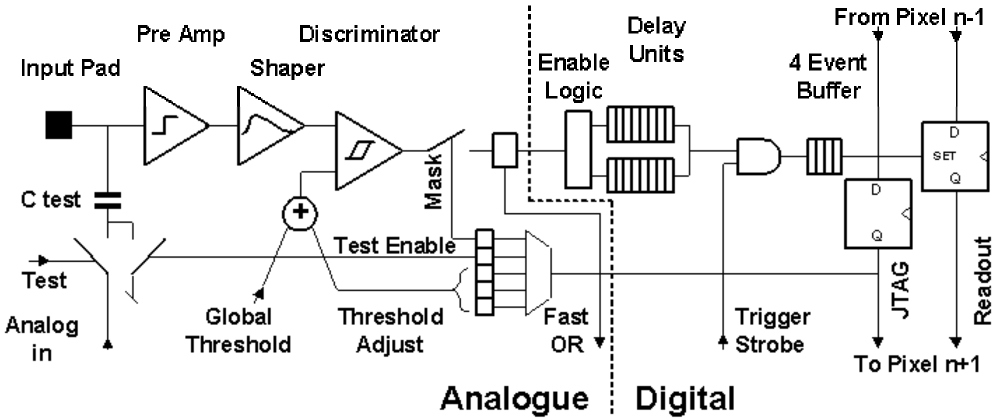


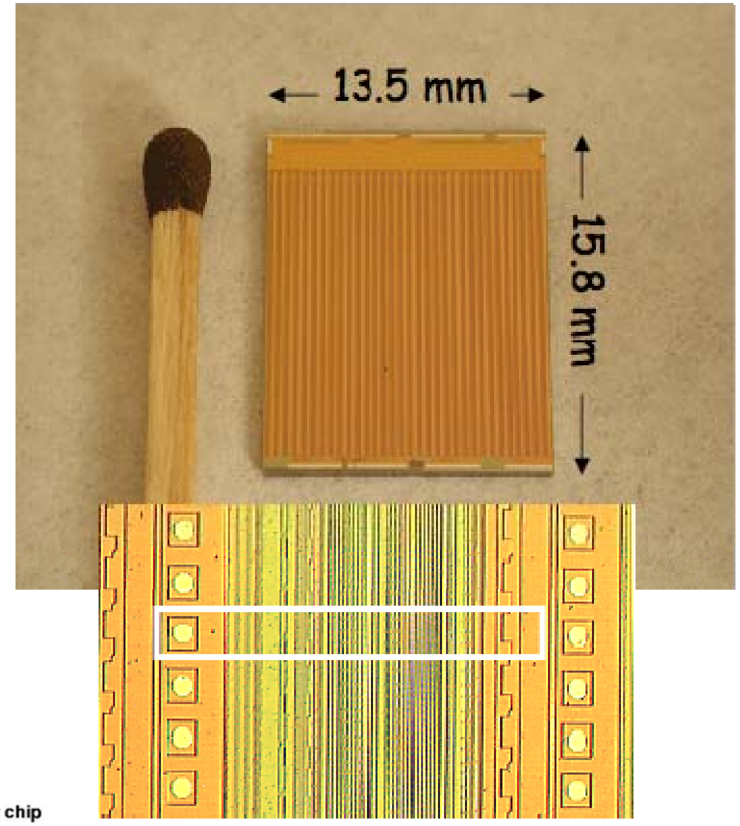




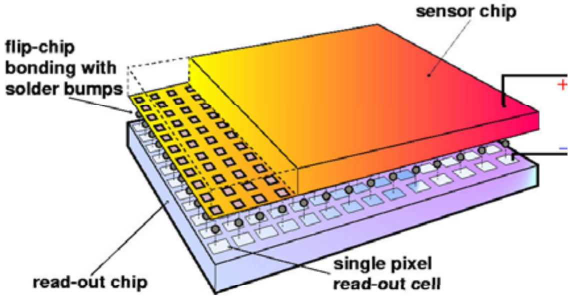
ALICE pixel detector

Principle & die

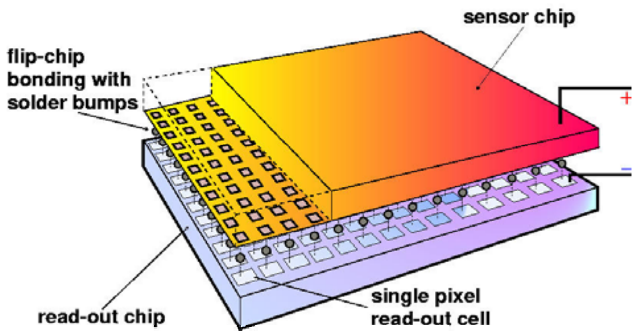


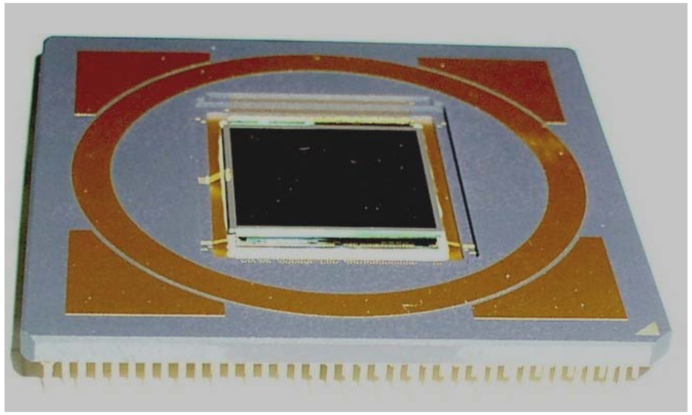


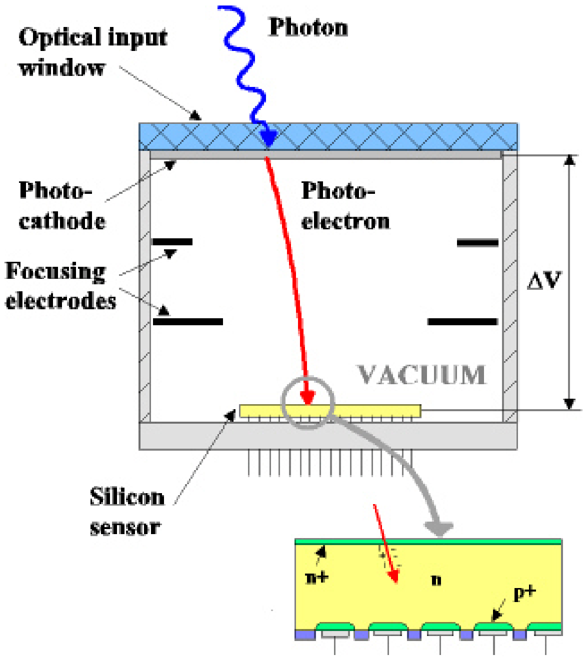
- CMOS6 0.25 µm (8” wafers)
- Radiation hard design (enclosed transistors)
- ≈ 13.10^6 transistors
- 8192 pixel cells 50 µm x 425 µm
- 256 rows, 32 columns
- Active area: 12.8mm x 13.6mm
- 10 MHz clock
- 1.8V power supply
- ~100 µW/channel

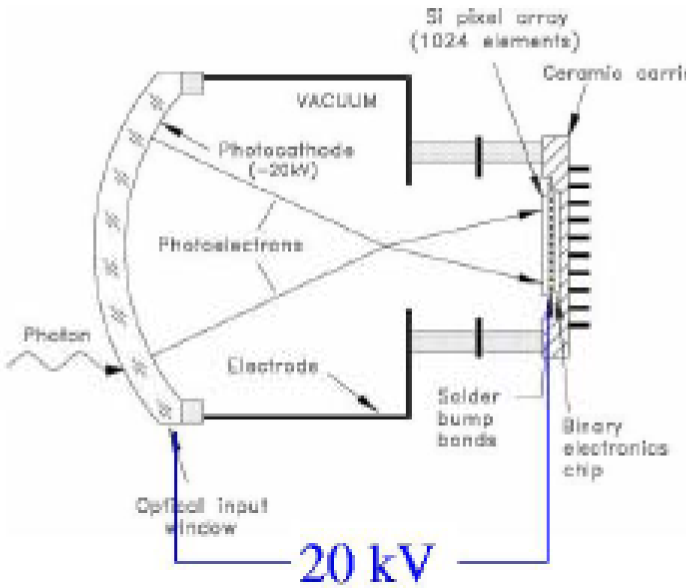


LHCb pixel HPD: a true single visible photon imager





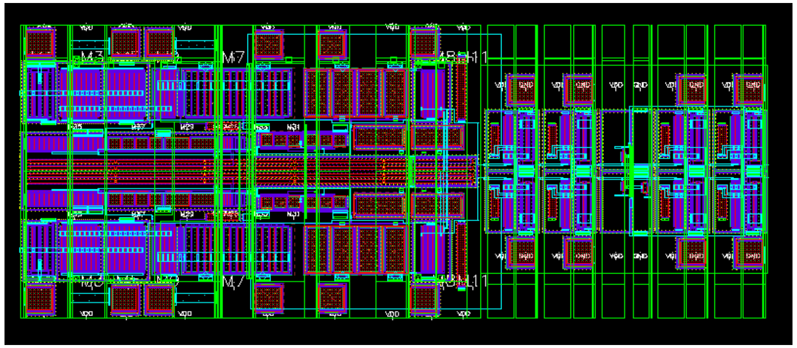


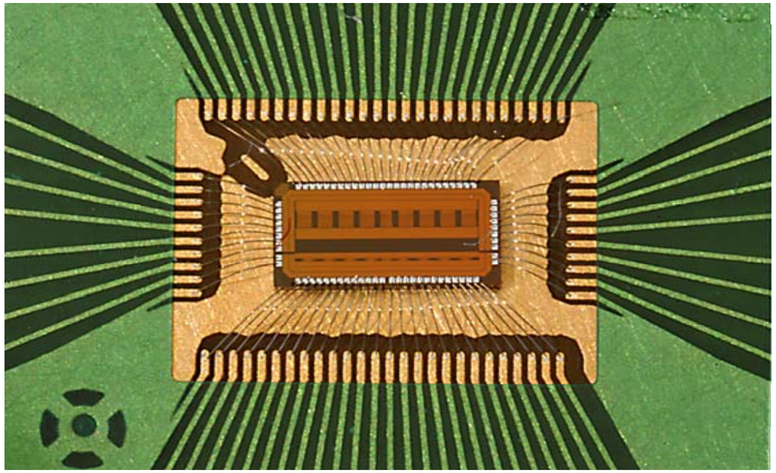


ALICE Time-of-Flight ASIC: NINO front end

NINO 8-channels

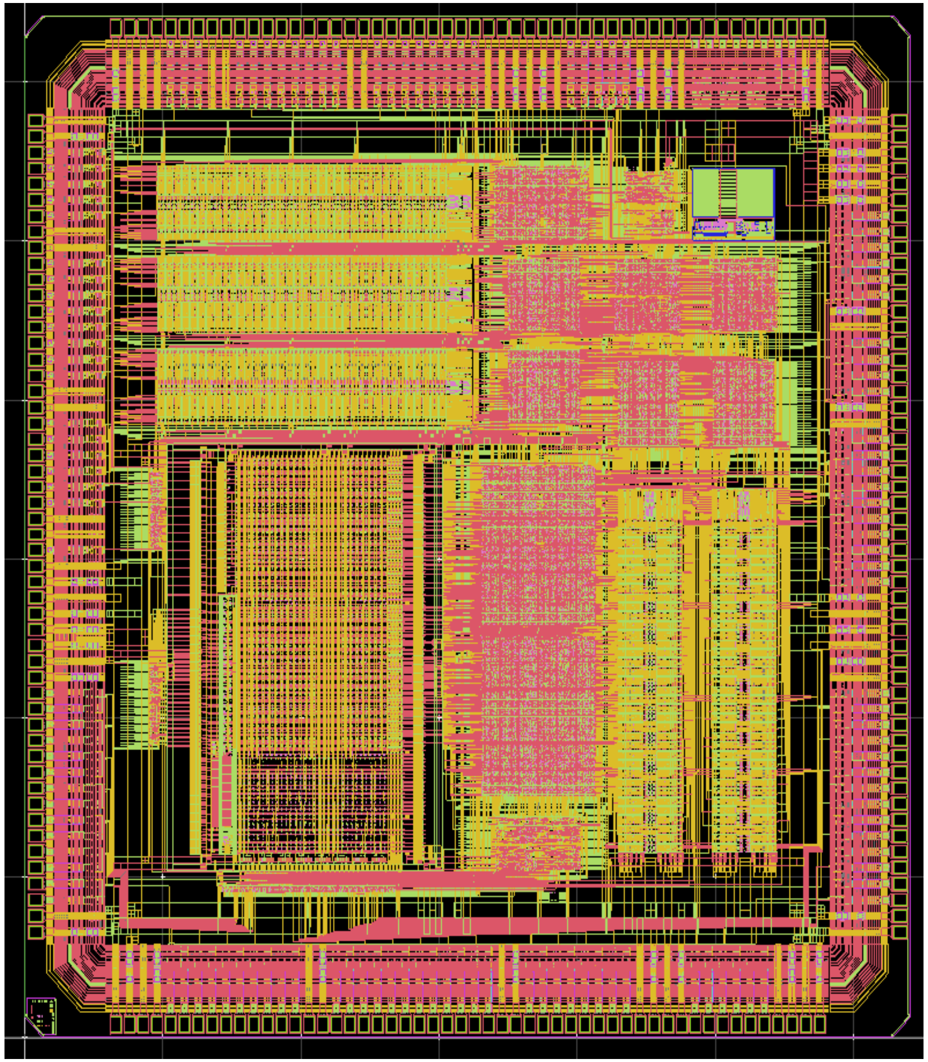
- an ultra-fast, low-power, front-end amplifier discriminator for the Time-Of-Flight experiment in ALICE
- 3 Ghz preamplifier bandwidth
- Measure timing with 20 ps resolution
- 25 000 chips for ALICE TOF Pion-Kaon identification





ALICE Time-of-Flight ASIC: TDC

- Time-to-Digital Converter
  - 0.25 mm CMOS
  - Semi-Custom
    - PLL @ 320 MHz
    - 4 Memory blocks
    - DLL and Hit registers
  - 32 channels, 25 and 100 ps resolution
  - 3.3 V I/O, 2.5V core
- 5.5x5.5 mm^2
- Used also in industry outside HEP



Front end design, other examples

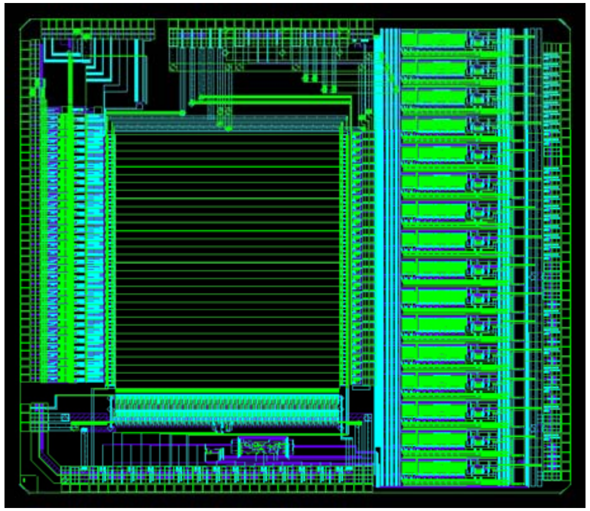
PASCAL 64 channels

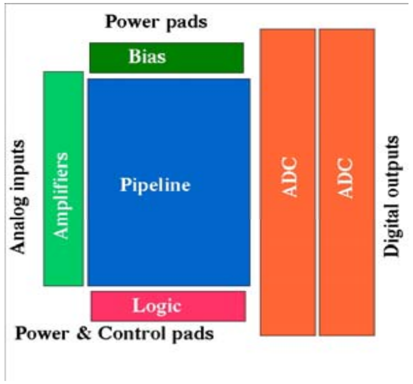
- low noise 300 e- rms
- 10 bit dynamic range
- 256 deep analog memory
- On chip 16/32 10 bit ADC

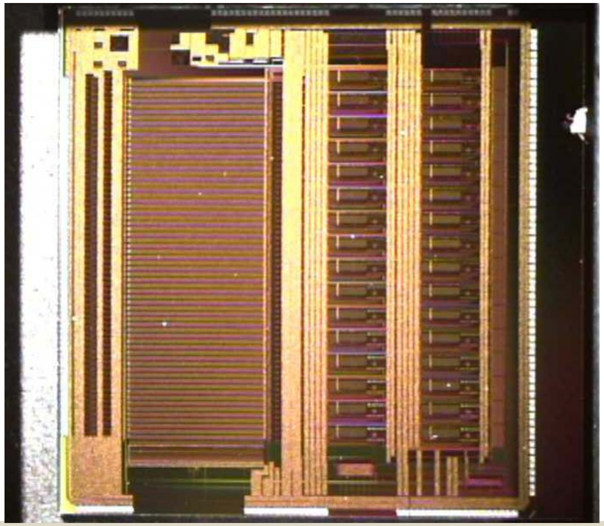
10 000 chips for ALICE SDD tracker

0.25 μm CMOS, 1P, 3M

“Special” design rules







Front end design other examples Calorimeter preshower

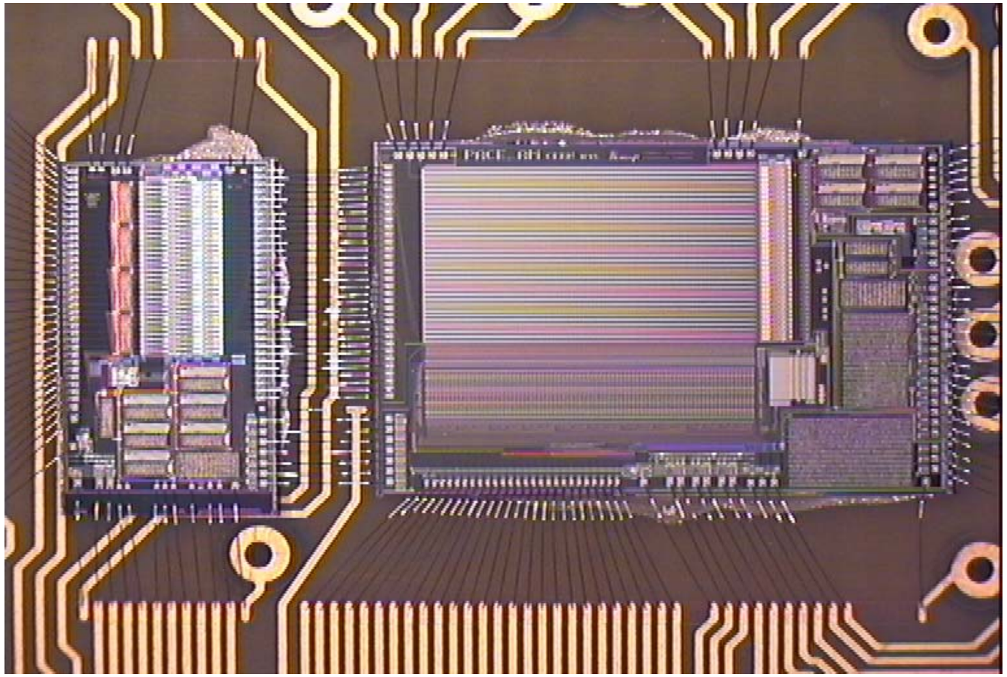
PACE 32 channels

- low noise
- 12 bit dynamic range
- 192 deep analog memory
- serial analog read-out

> 100,000 chips in CMS ECAL

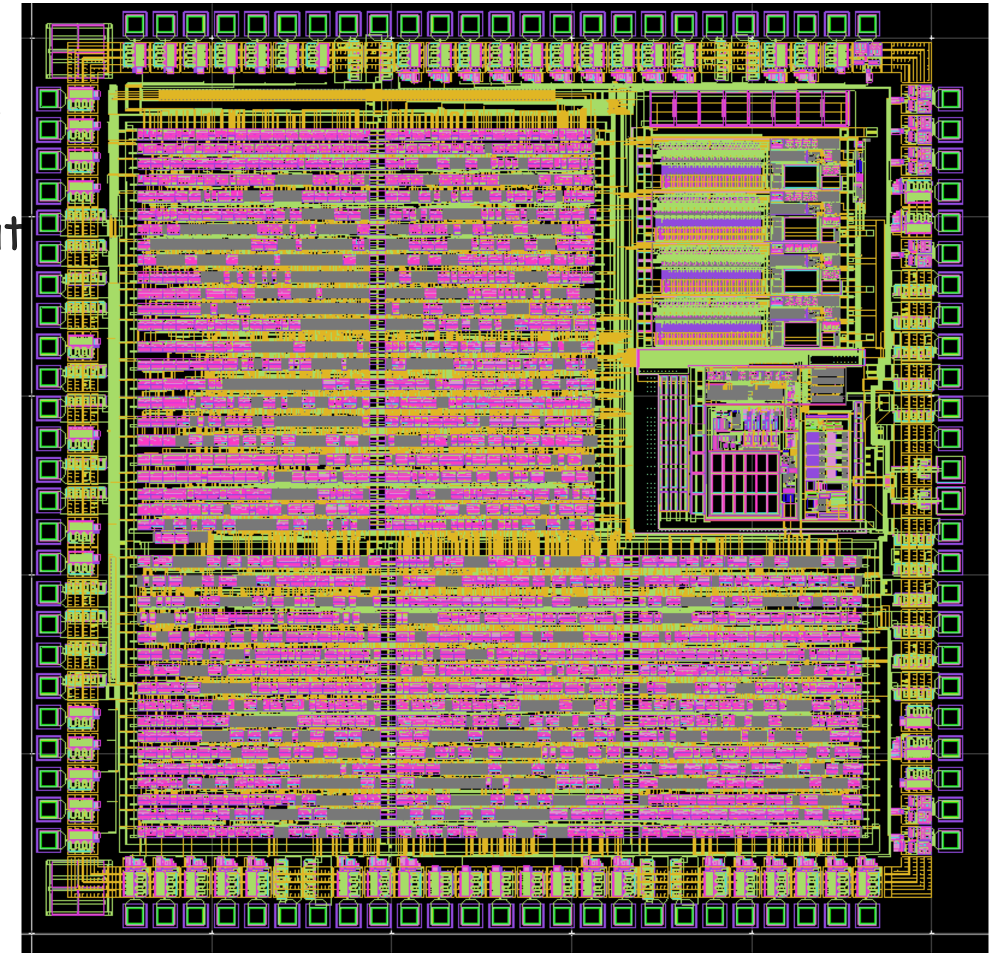
0.25 μm CMOS, 1P, 3M

"Special" design rules



ASIC for LHC timing distribution

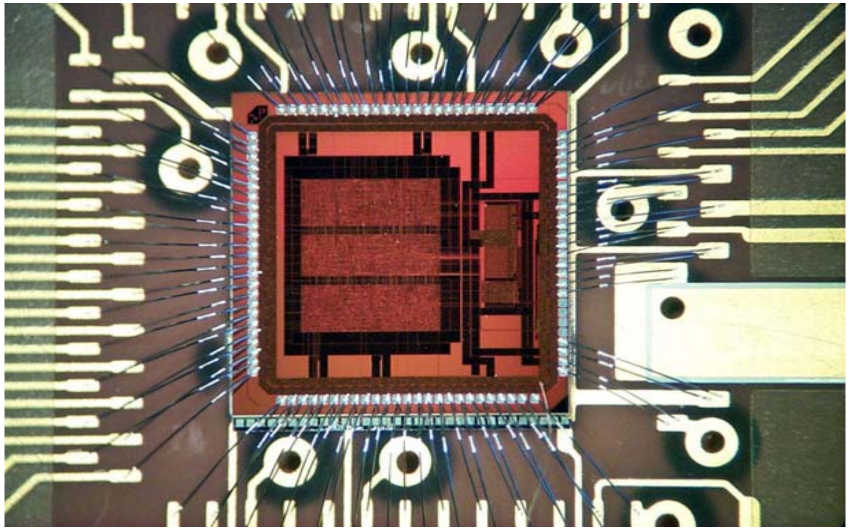
- TTCrx: 40 MHz opto-receiver for high precision clock distribution
  - 1 to 30,000 optical fan-out
  - 100 ps resolution
  - low jitter
- DMILL technology
  - rad-hard
  - 0.8 μm BiCMOS
  - ~ 5x5 mm2

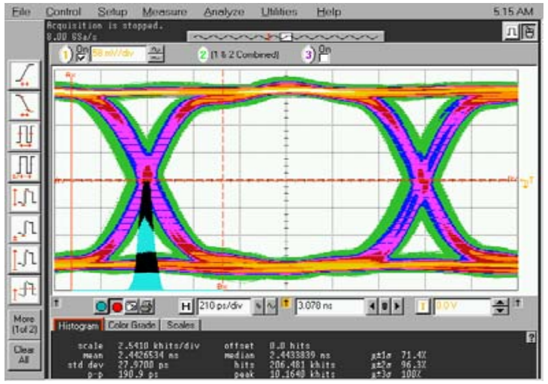


High Speed Serializer, radiation hardened

Gigabit Optical Link (GOL)

- 0.8 and 1.60 Gb/s optical link
- Unidirectional
- < 300 mW
- G-Link and Gigabit Ethernet protocol
- Redundant logic





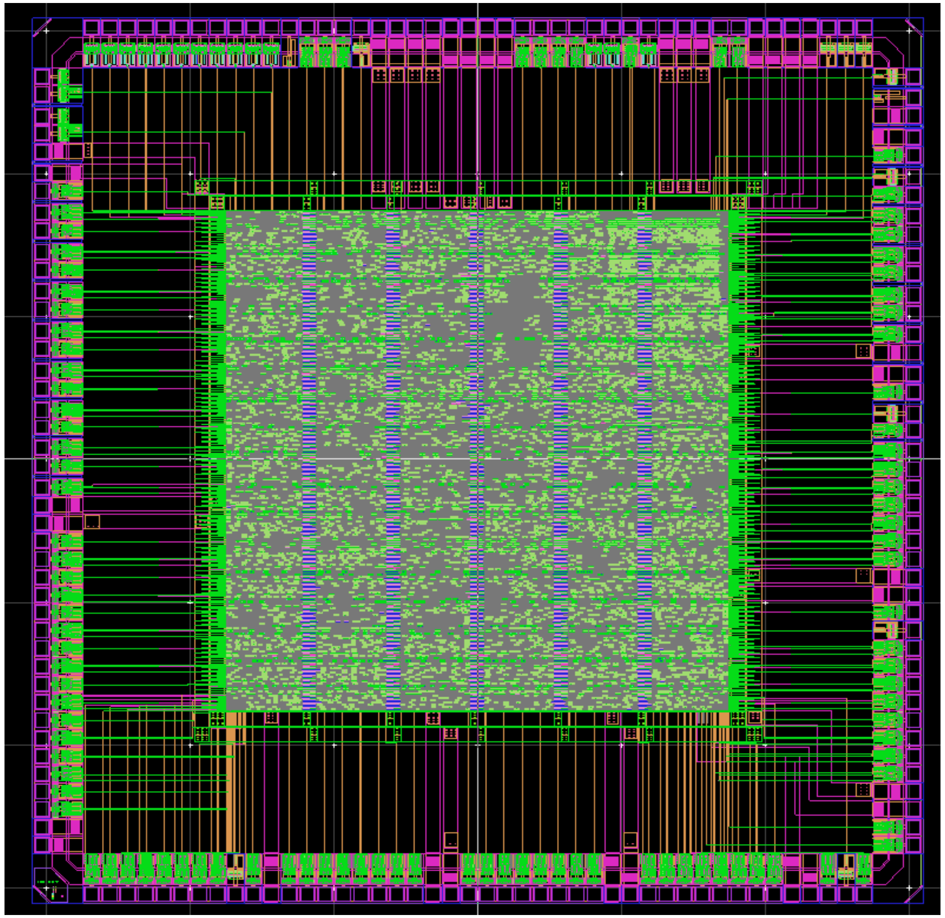
Slow Control Network Controller

CCU25: Radiation Tolerant Network Controller

- Token-Ring-like Protocol with redundancy
- 40 Mb/s (LHC frequency)
- Reconfigurable
- Support for multiple user-buses

Chip:

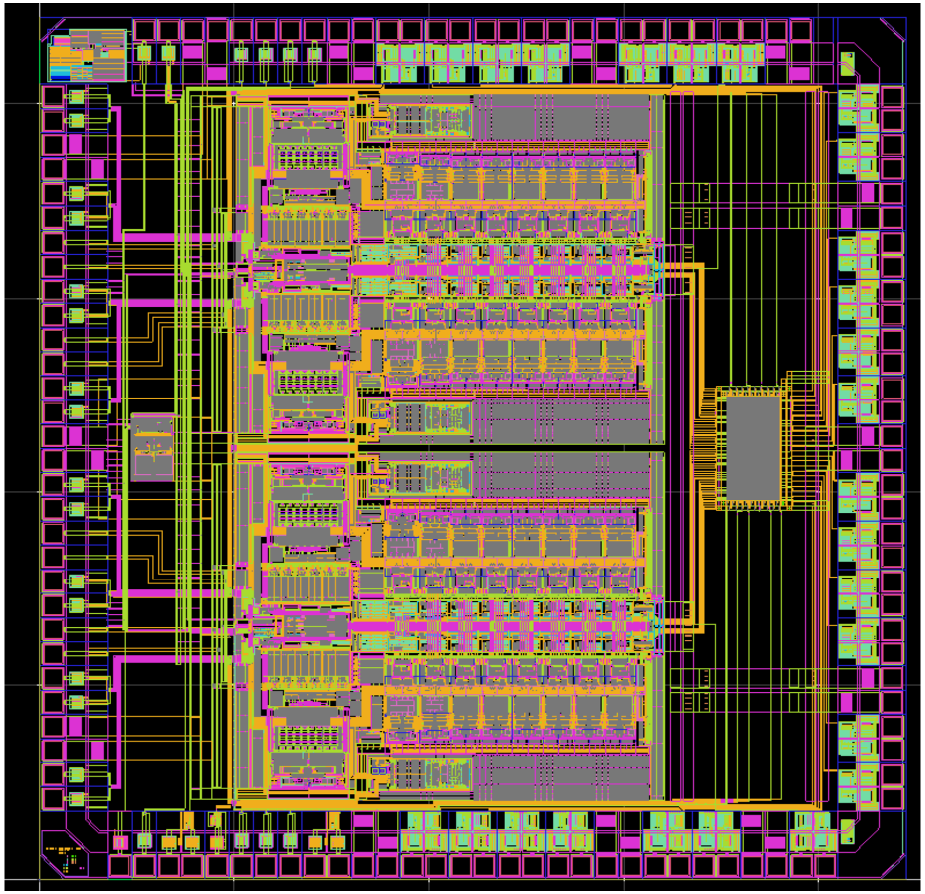
- 100% digital
- special library
- 120,000 gates
- SEU redundancy on critical blocks



12 Bit 40 Ms/s Converter, radiation hardened

4 channels, 12 bit 40 MS/s Analog to Digital Converter

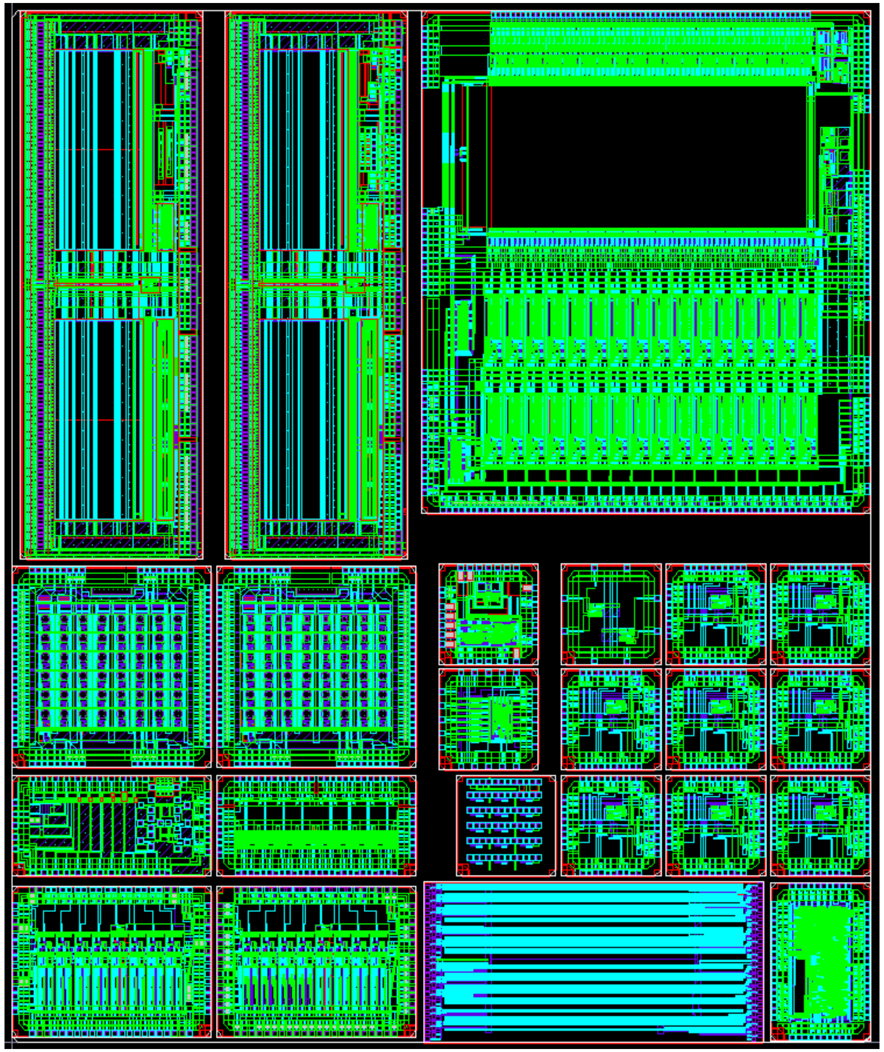
- < 500 mW
- several modes of operation
  - 4xADC @ 12 bit
  - 1xADC @ 14 bit
- Rad-tolerant
- 4x4 mm^2



CERN microelectronics MPW

Organization of MPW for High Energy Physics community and TT

- European and US Institutes, ~20 Design Groups
- 12 MPW
  20 production runs in 4 years



Radiation hardening

Radiation hardness characteristic has driven the technology choice for LHC

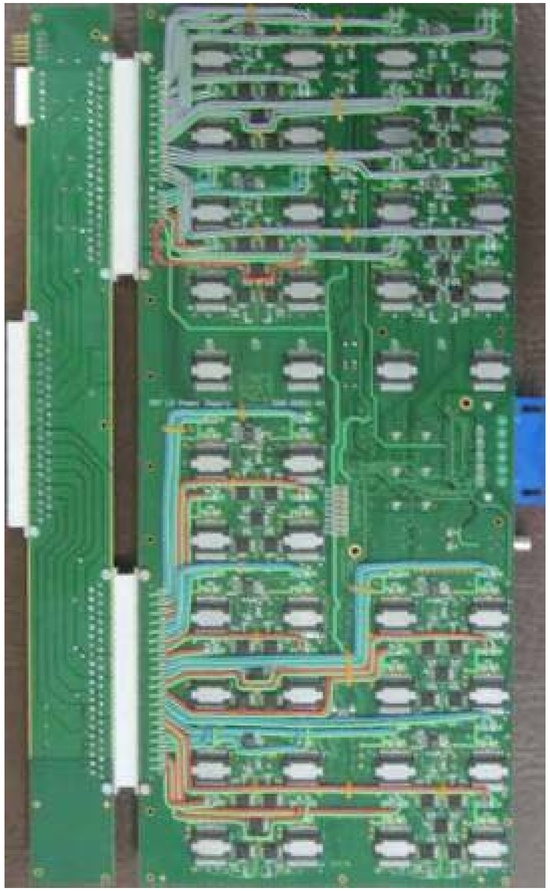
- 3 technologies selected in late 90's
  - DMILL from Atmel
    - BiCMOS 0.8 µm technology with rad-tolerance "by process"
  - 0.25 µm 'standard' CMOS
    - rad-tolerance "by design"
  - ST Microelectronics Bipolar process
    - For power device: radiation hardened regulator

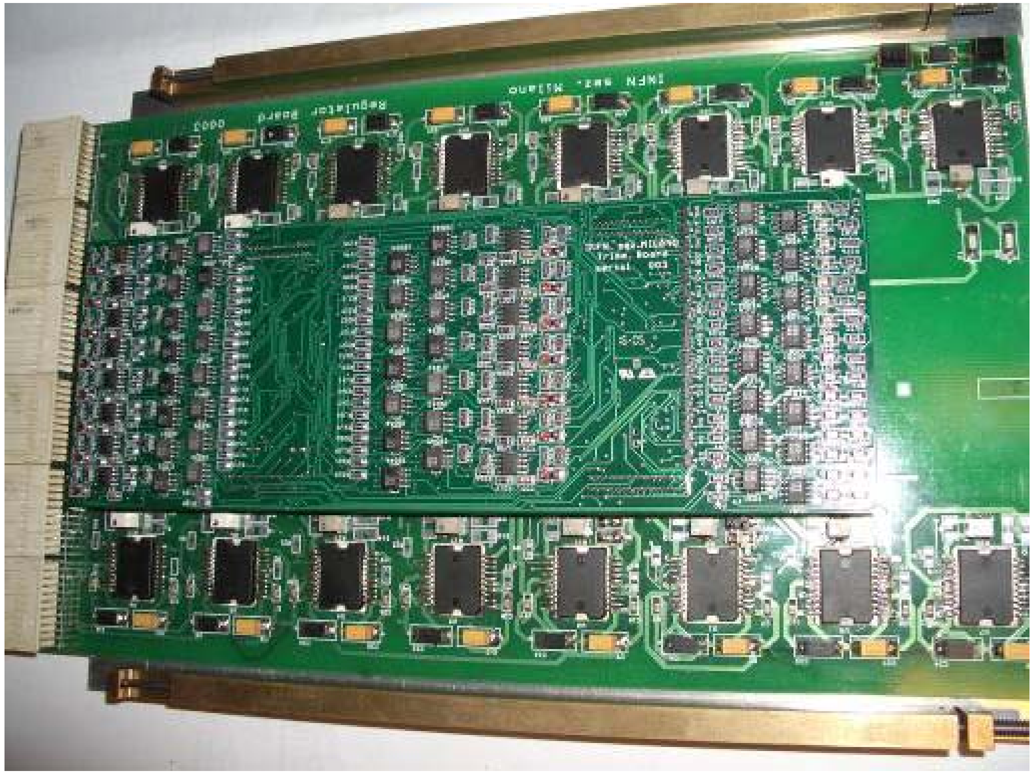
Special libraries (digital and analog) developed for LHC applications

Radiation hardened voltage regulator in ATLAS board

Developed in partnership with ST Microelectronics

- For LHC, spin off for aerospace industry





Signal processing telecom – HEP and single photon camera

Telecom

- Information is contained in the modulation of a carrier
- Source of data is analogue
  - Voice, video etc.. communication
- Signal processing
  - In frequency domain

HEP

- Information comes from quantum events
  - Single charge particle or photon hits a sensor
- Source of data is a quantum charge packet
  - Binary information
- Signal processing
  - Time domain: event time, number of hits

Applications of ASICs developed for HEP

Fields

- Life science
- Medical imaging
- X-ray and electron based instrumentation

Key performance

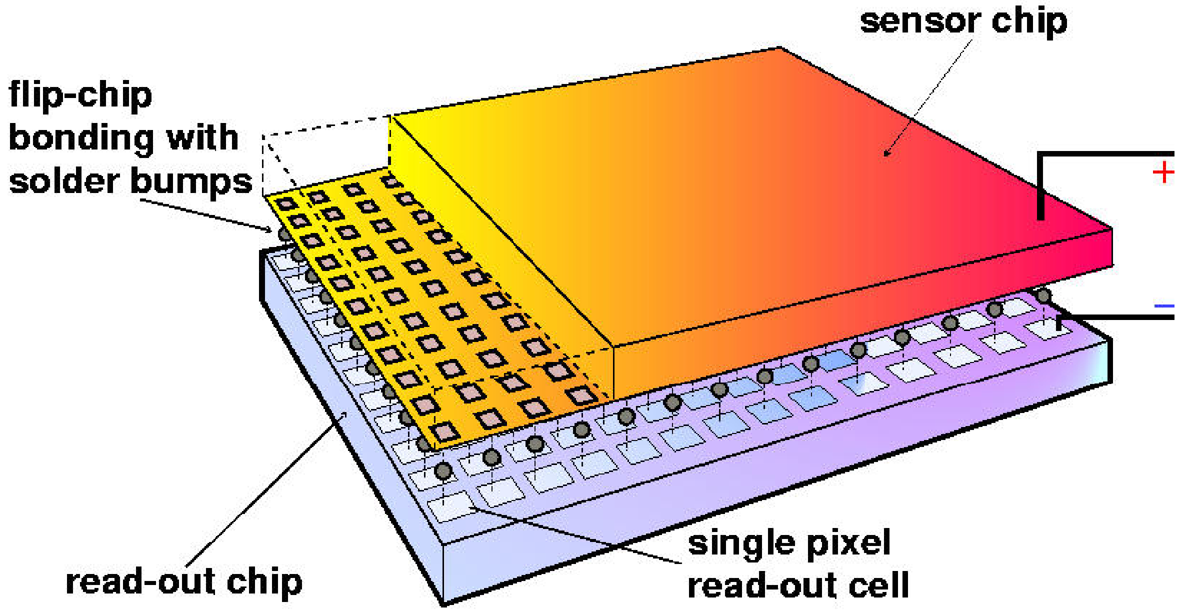
- Single quanta detection
  - Visible photon : camera for life science
  - X-ray photon : radiography
  - Gamma photon: nuclear medicine
- Architecture
  - Linear multichannel array
  - Pixel array
  - Signal processing
    - Counting
    - Time correlated measurement

Medipix

Photon counting readout chip used for medical, biological and physics applications.

The chip consists in an active matrix of 256x256 photon counting pixels.

- > 10 million transistors,
- 55 micron pixel cell



Life science applications

Standard imaging

- Imaging ensemble of molecules gives access only to averaged images
- one miss
  - Static heterogeneity of molecules distribution
  - Dynamic distribution of molecules
  - Existence of several different molecule species

Time-correlated single photon spectrometry

- Has revolutionized imaging in biology
- Labeling molecules (DNA, proteins) in living cells with fluorophores

Fluorescence Imaging technique

Fluorescence imaging

- Each visible photon quanta is detected and counted in a pixel or correlated with its time stamp

Single quanta detectors for visible photon

- Photomultiplier
- Microchannel plate
- Hybrid Photo detector
- SPAD

Non spectroscopy imaging

- Counting number of photons/pixel
  - Fast camera
  - wide-field microscopy

Time-correlated single photon in life science

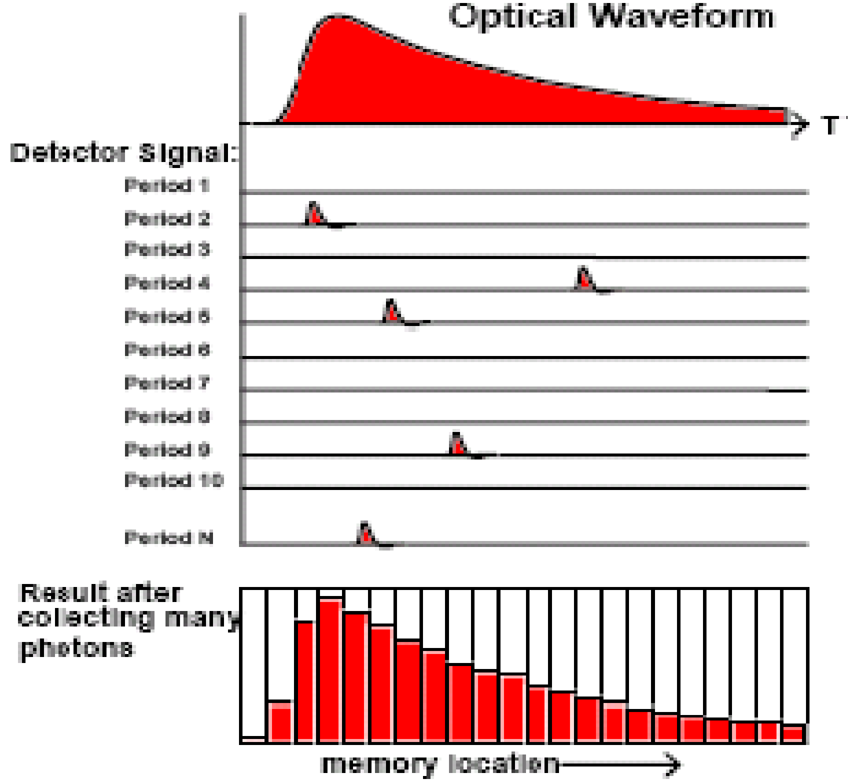
Some Applications

- Ultra-Fast Recording of Optical Waveforms, fast camera
- Fluorescence Lifetime Measurements
- Detection and Identification of Single Molecules
- DNA Sequencing
- Optical Tomography
- Fluorescence Lifetime Imaging
- FLIM and FRET fluorescence microscopy

Benefits

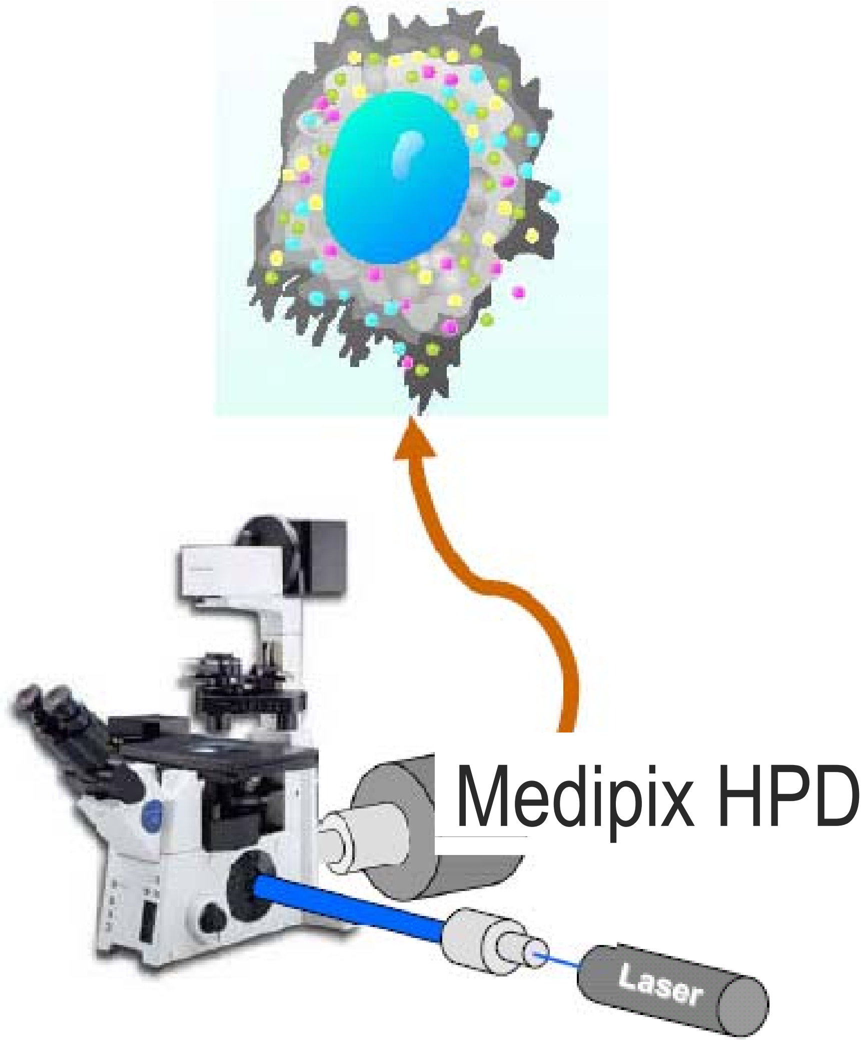
- Ultra-high Time Resolution - 25 ps fwhm in time correlated mod
- Ultra-High Sensitivity - down to the single photon level
- Short measurement Times
- High dynamic range - High Linearity in counting mode
- Signal-to-Noise Ratio - Limited by Photon Statistics only
- High Gain Stability, absolute calibration
- Suppression of Detector Leakage Currents

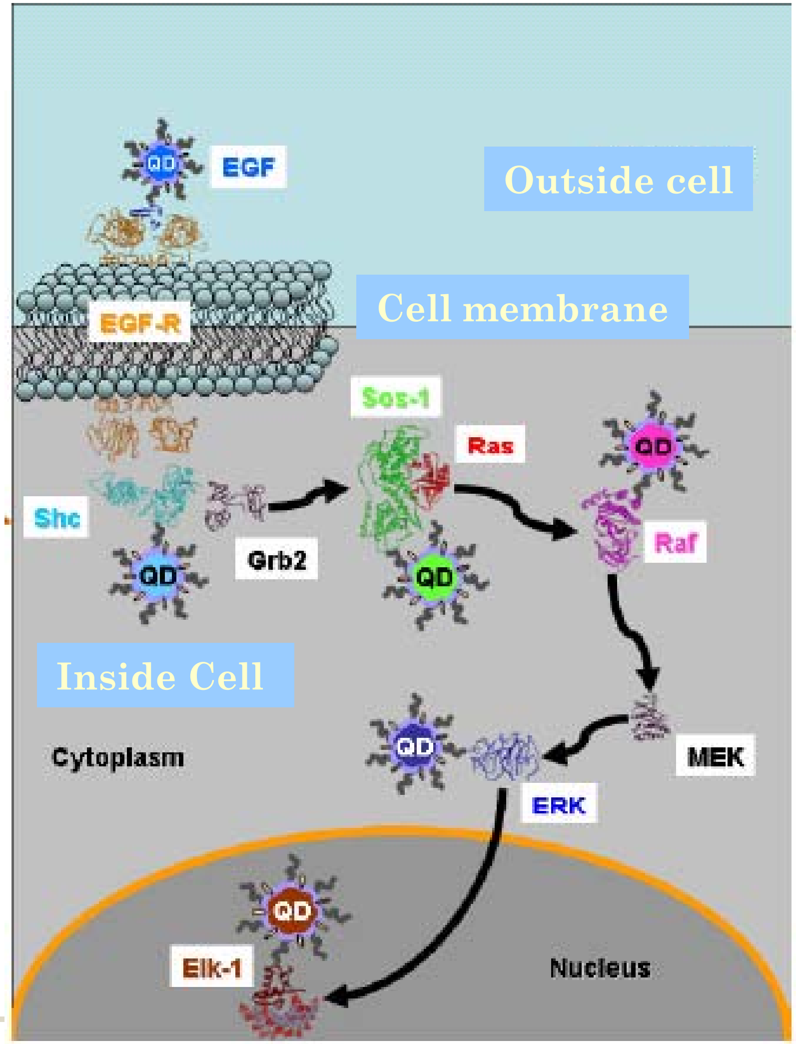
Principle of single photon time-correlated spectroscopy



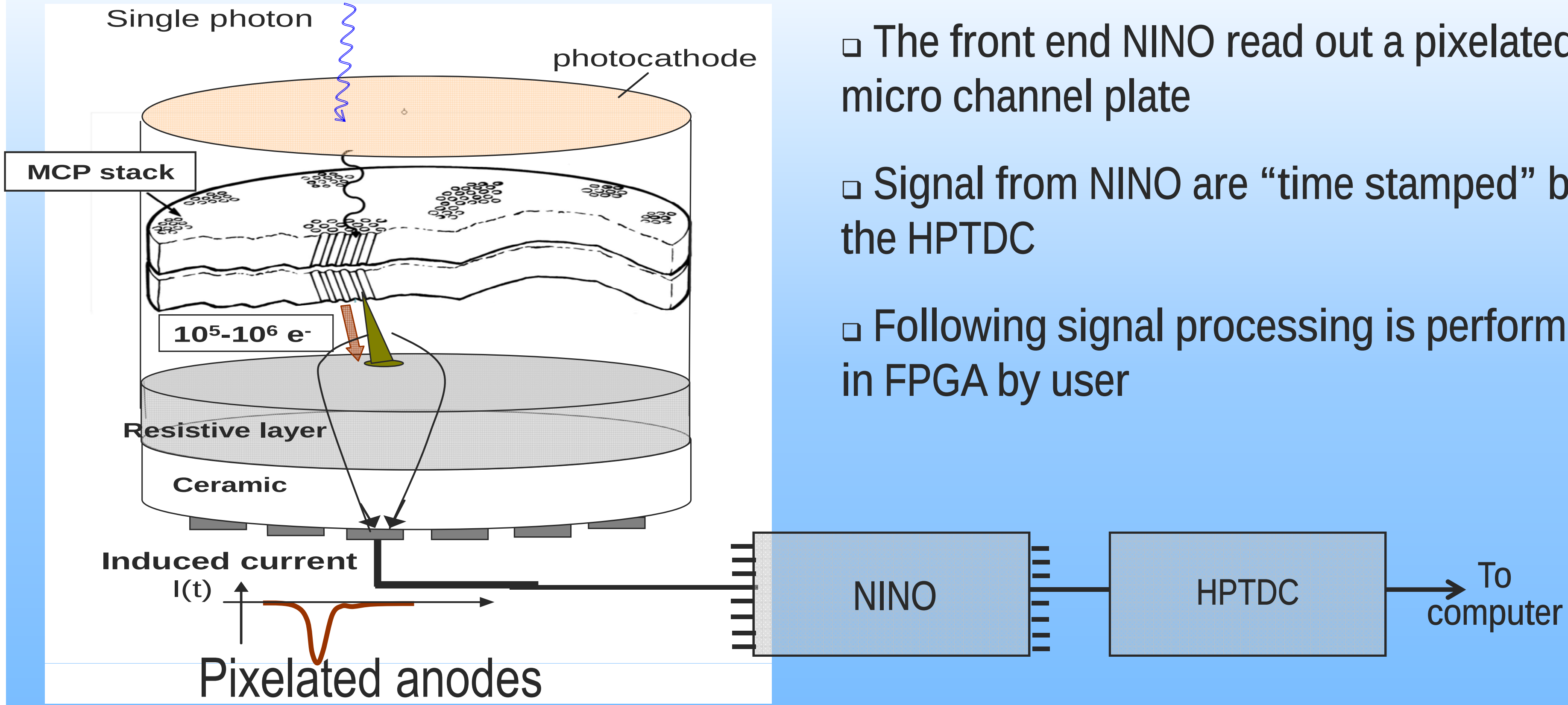
Single molecule imaging with fast camera

Imaging cellular processes at the sub-cellular or molecular levels





Single photon counting and imaging with microchannel plate



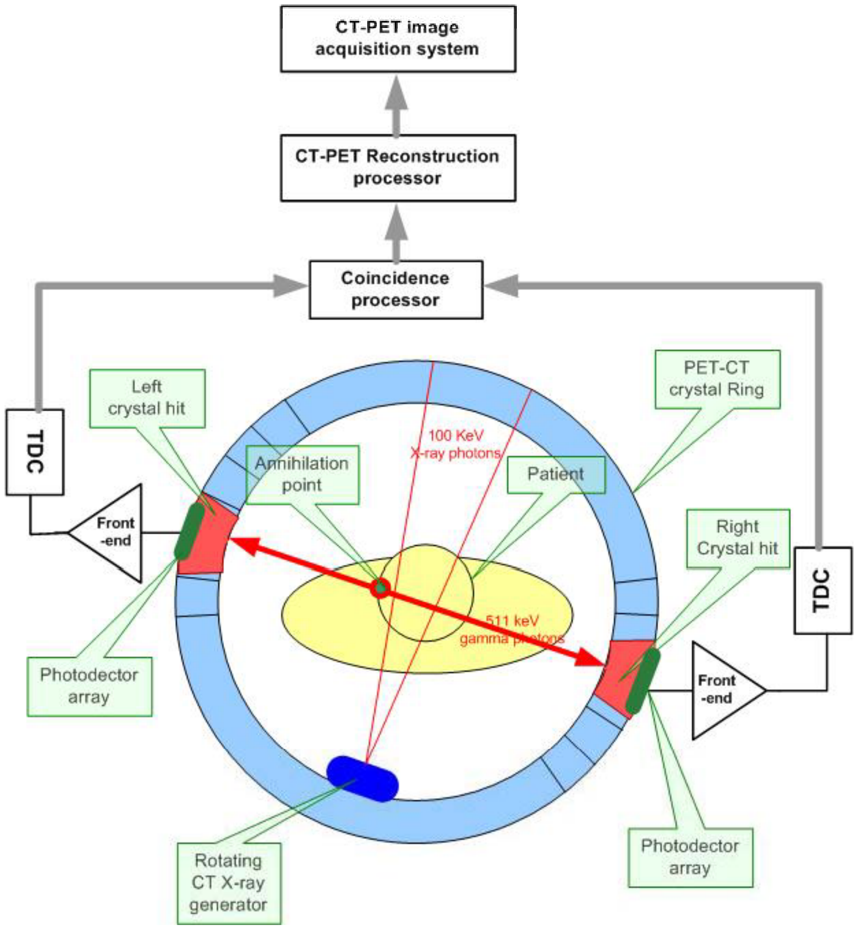
- The front end NINO read out a pixelated micro channel plate
- Signal from NINO are "time stamped" by the HPTDC
- Following signal processing is performed in FPGA by user

Medical imaging

Counting systems | *Time correlated systems in nuclear medicine*

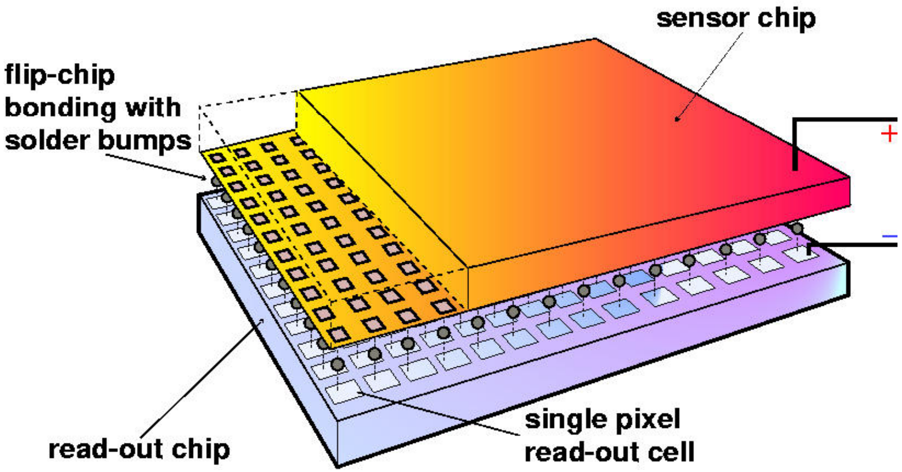
- X-ray radiography
- CT, SPECT tomography

PET



Medipix: X-ray Photon counting readout chip

- The chip consists in an active matrix of 256x256 photon counting pixels.
  - 10 million transistors, 55 micron pixel cell



How to do Technology Transfer in microelectronics

Direct use of existing ASIC

- Recommended for low volume
- Analysis of the ASIC integration in the instrument
- Needs adaptation on electronics boards only
- With or without a new wafer production

Use of existing ASIC design

- With slight design changes
- Cost: design time + wafer production + test

Use of existing functional blocks

- New ASIC design with existing know-how
- Expensive and long development time

Partnership with industry

- Develop in common a new product
- With ST Microelectronics on radiation hard voltage regulator

Partnership in a scientific collaboration

- Medipix
- EU projects

For a new instrument

- Do not underestimate system integration, even if components are available!
  - Establish a common language between technology users and technology providers
  - Technology compatibility, to sensor, to data acquisition

SUMMARY

CERN has several cases of successful technology transfer of ASIC technology

The main fields of technology transfer of ASICs based on single quanta detection

- Life science and imaging in medicine
- Material science instrumentation and aerospace

Two main domain of applications

- Single photon counting system
- Time resolved single photon spectroscopy

Development of sophisticated ASICs demand resources and time

- Use of existing ASIC is the best approach for low volume, limited resources and short time to market.
- Use of existing blocks to develop a new ASIC is the way to go, it needs much larger resources and time.