# Micro-electronics at CERN

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CERN, Switzerland
2008

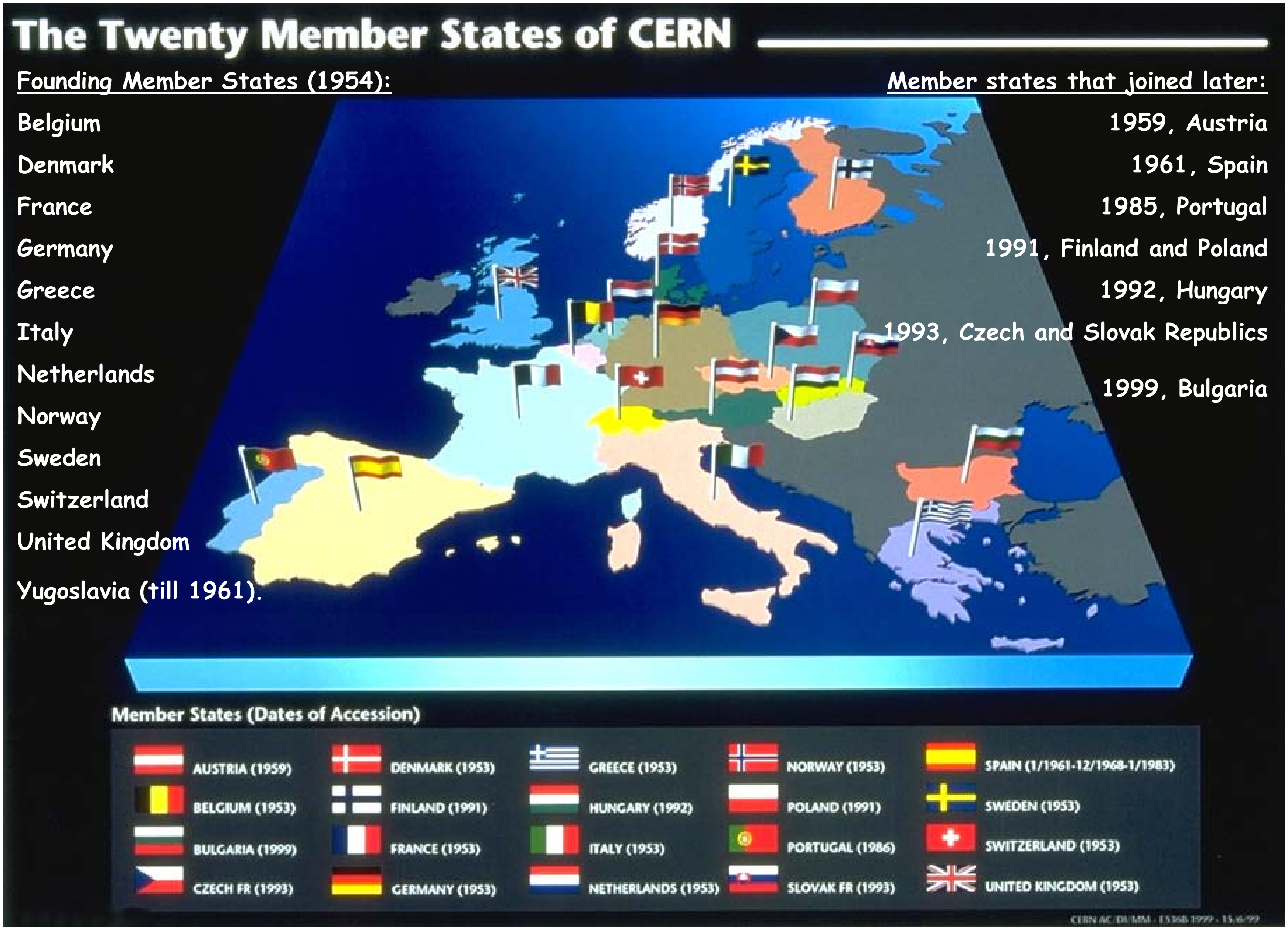
# Outline

- CERN
- LHC and its Detectors
- Electronics and the Physics experiments:
  - Electronics and radiation
  - Radiation tolerance by design
- The microelectronics Group
- LHC projects:
  - Timing & Time measurements:
  - Data links
  - Experiment control
  - Frontend electronics
- Medical applications

# CERN - European Organization for Nuclear Research

- Conseil Européen pour la Recherche Nucléaire
- The concept of an "European Science Laboratory" was first proposed by Louis de Broglie in 1949
- UNESCO "subscribes" the idea in 1950
- In 1952, 11 European governments agree to create a "provisional" CERN
- The European Organization for Nuclear Research formally comes in to being on 29 September 1954
- Today CERN counts with 20 member states

# CERN - Member States



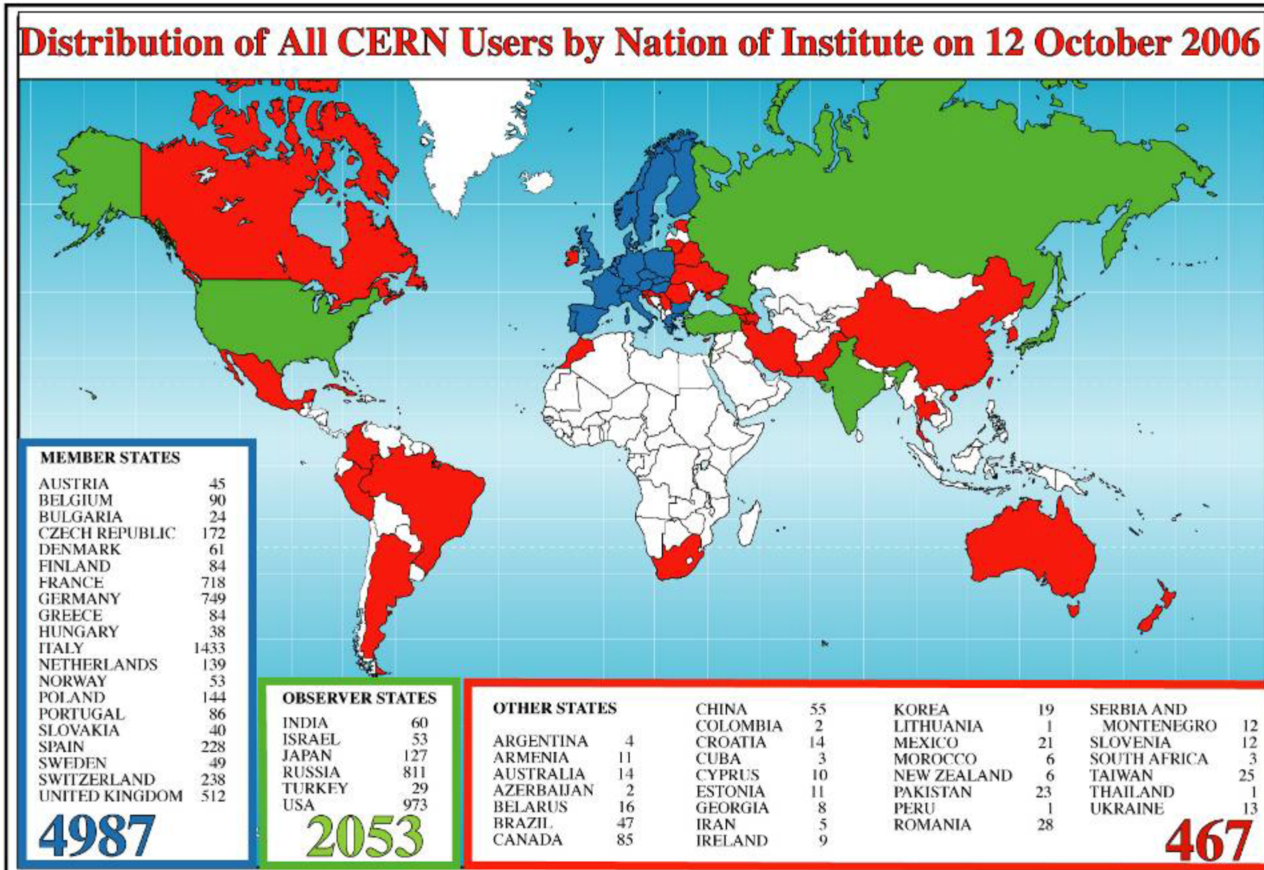
# CERN - Worldwide Collaboration

**CERN employs just under 3000 people:**

- Physicists
- Engineers
- Technicians
- Craftsmen
- Administrators
- Secretaries
- Workmen
- ...

**6500 visiting scientists representing:**

- 500 Universities
- 80 Nationalities

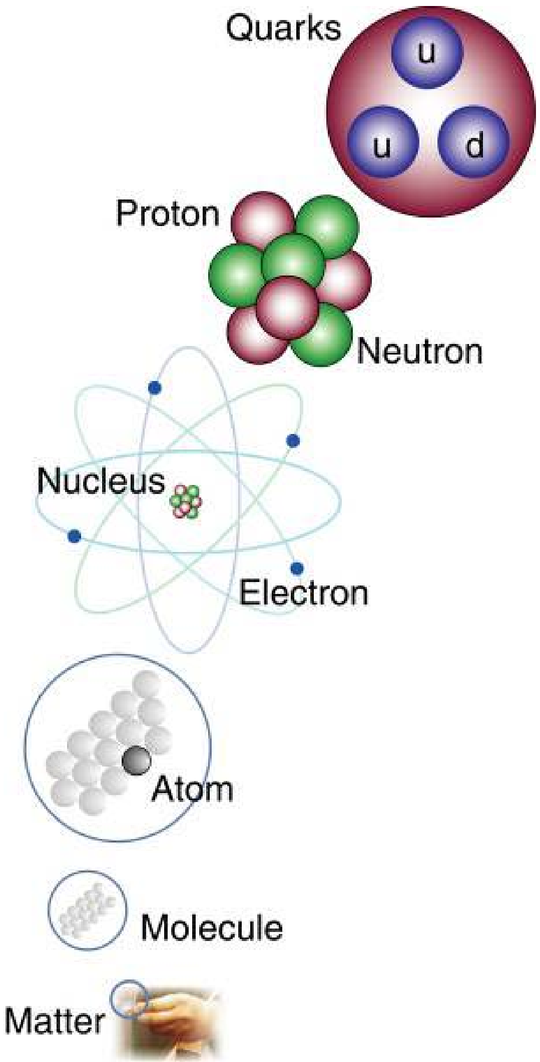


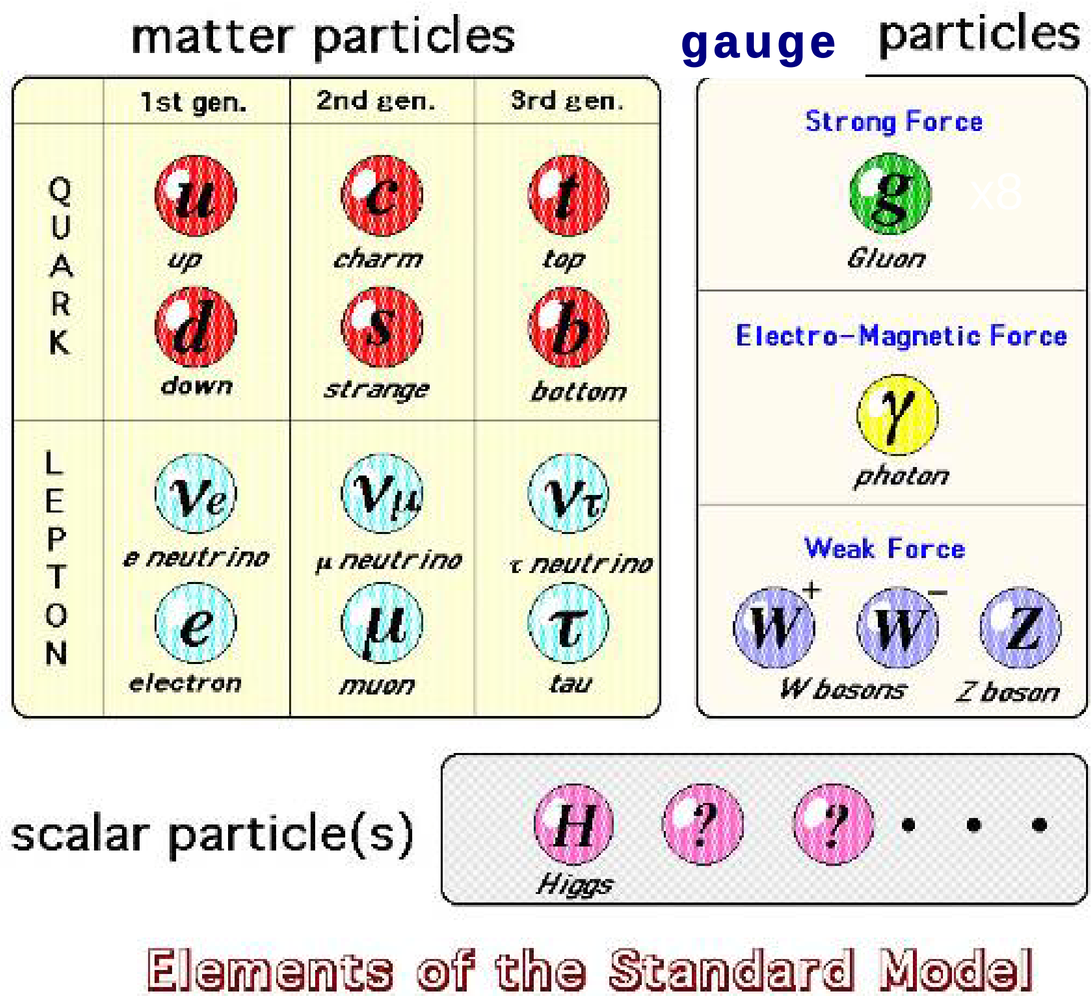
# CERN – Physics Research

- The goal of physicists that work at CERN is to understand:
  - How matter is made?
  - What forces hold it together?

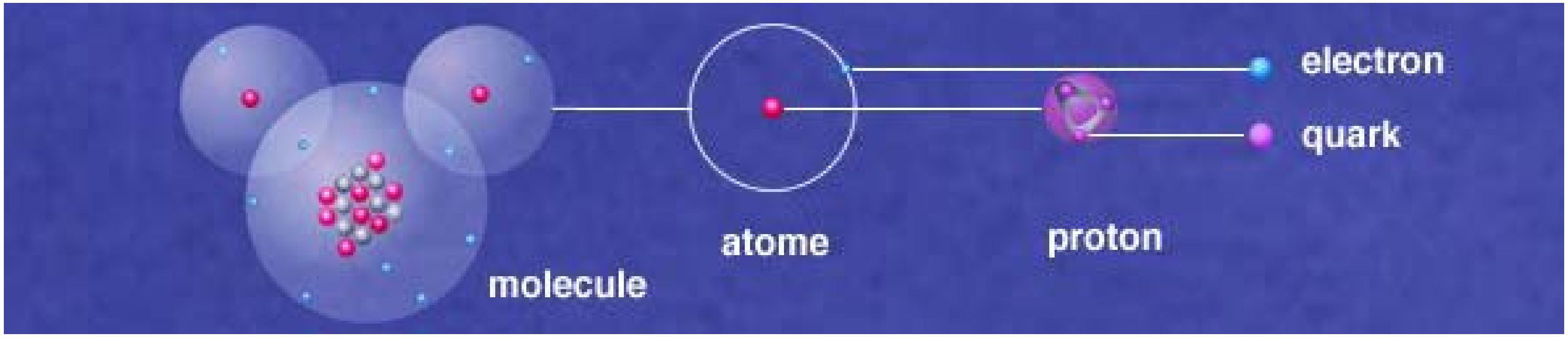
- CERN's mission is to provide the the infrastructures for the realization of High Energy Physics (HEP) experiments:
  - The particle accelerators
  - The particle detectors

# The study of elementary particles and fields and their interactions

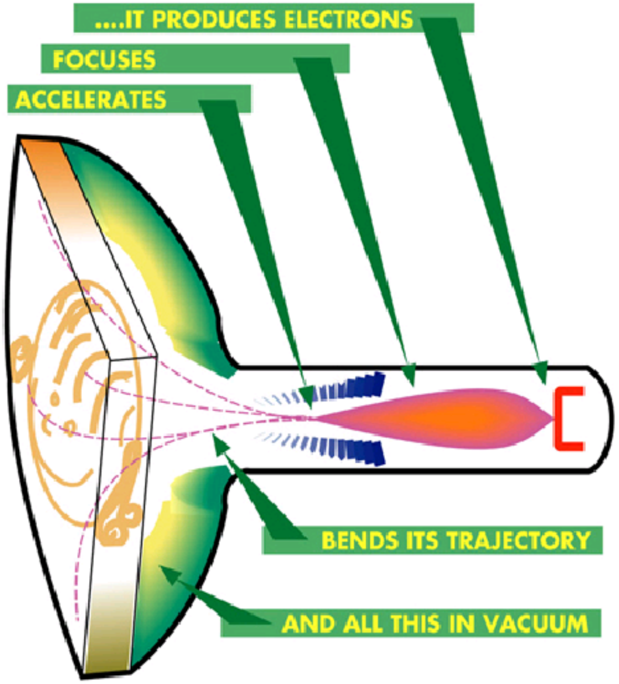


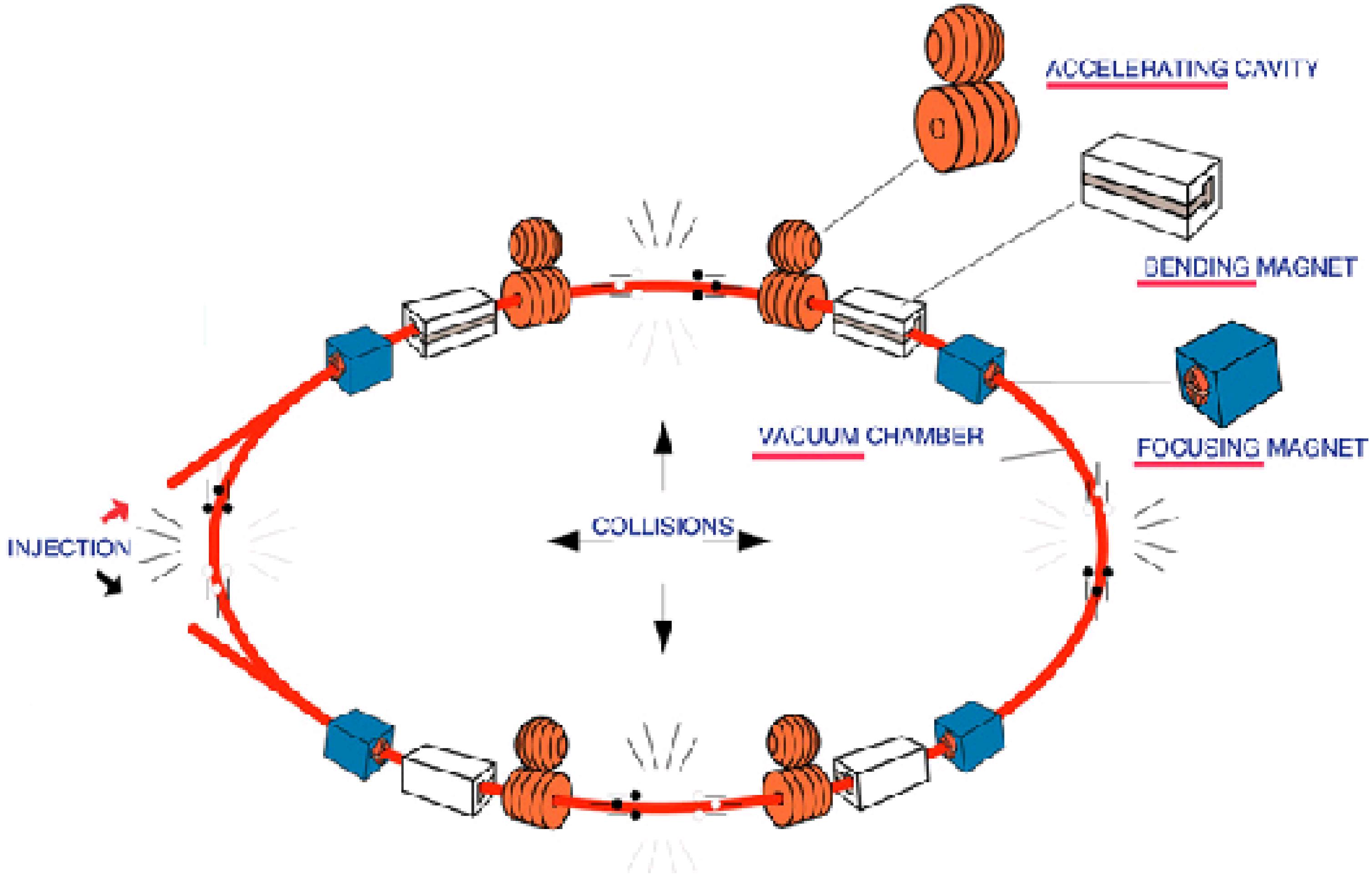
# CERN – Particle Accelerators




- Like atoms, protons and neutrons also possess an internal structure.
- Physicists collide particles at high energies to reveal their internal structure.
- High energies are achieved using particle accelerators.
- The most common type of particle accelerators is the Cathode Ray Tube (most likely you have one at home).

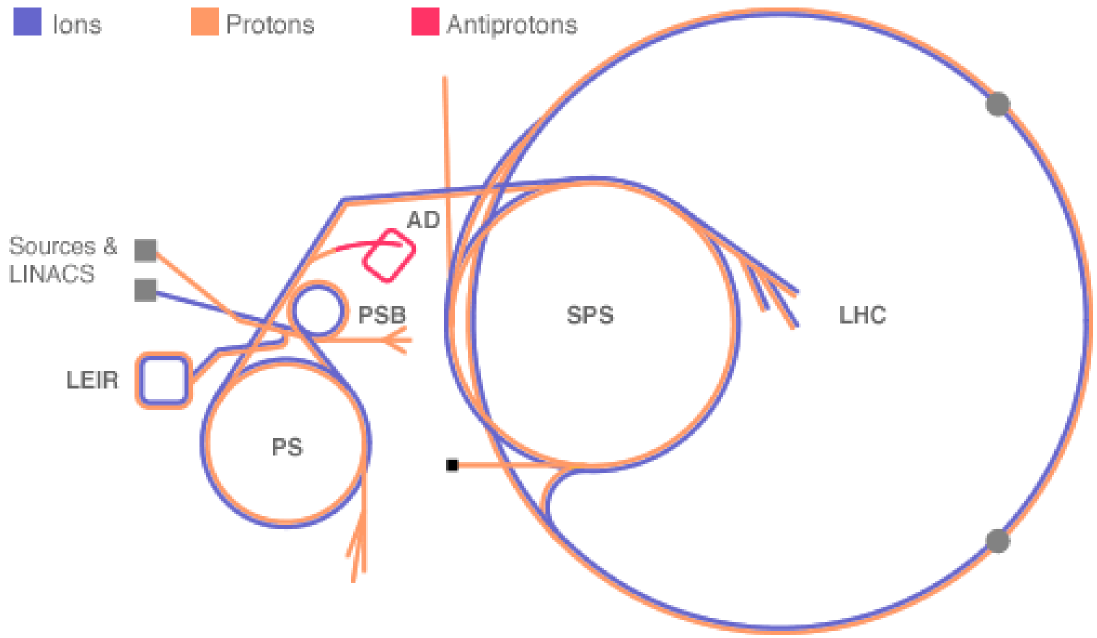


# CERN - Particle Accelerators



# CERN – Particle Accelerators

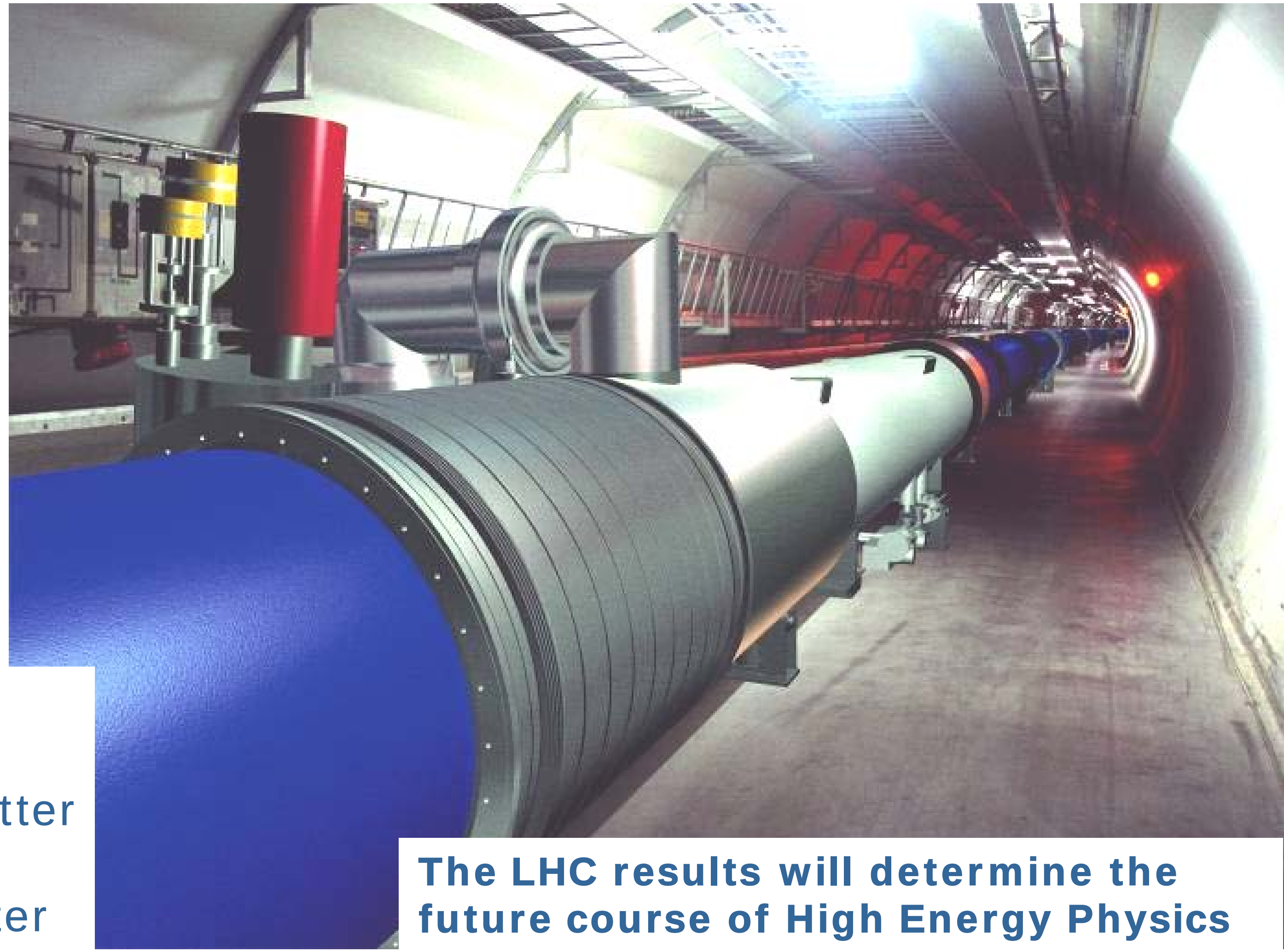
- A succession of machines bring the beam to high energies
- The highest level of energy will be achieved in the Large Hadron Collider
  - Collide proton beams with energies around 7-on-7 TeV
  - Collide beams of heavy ions such as lead with a total collision energy in excess of 1,250 TeV



# The LHC = Proton - Proton Collider

7 TeV + 7 TeV

Luminosity = $10^{34}$ cm$^{-2}$sec$^{-1}$

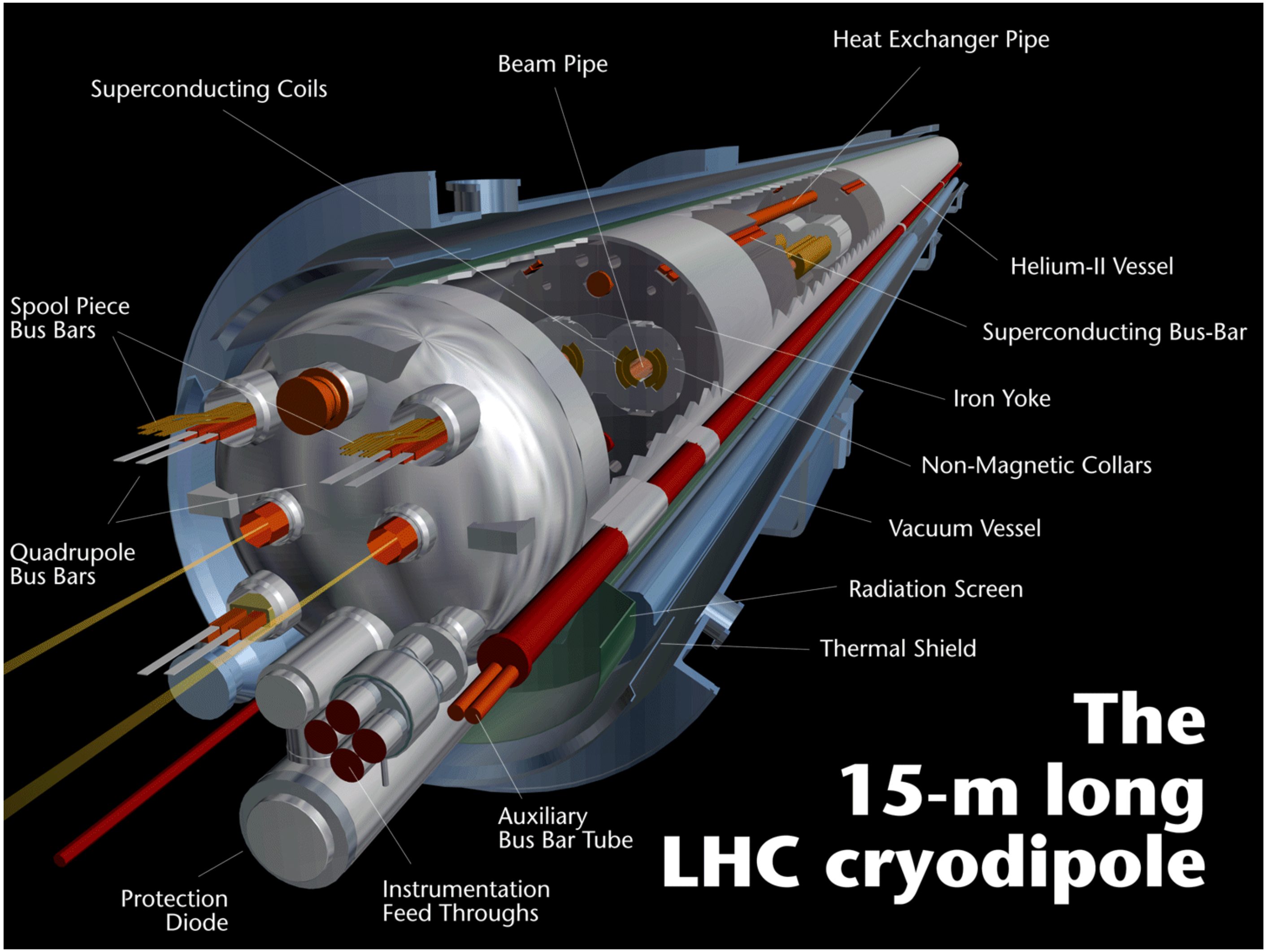


Primary targets:

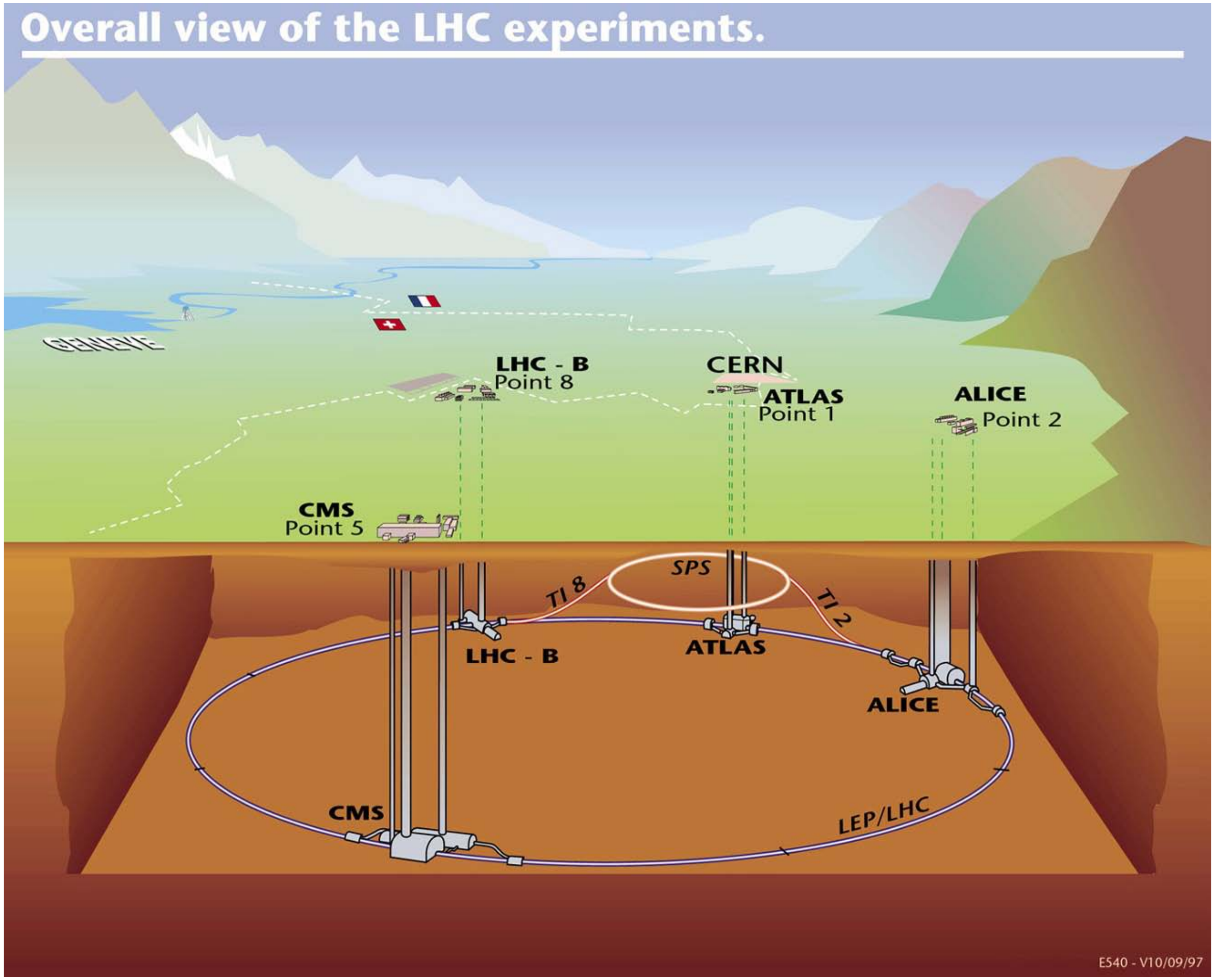
- Origin of mass
- Nature of Dark Matter
- Primordial Plasma
- Matter vs Antimatter

**The LHC results will determine the future course of High Energy Physics**

# Cryodipole

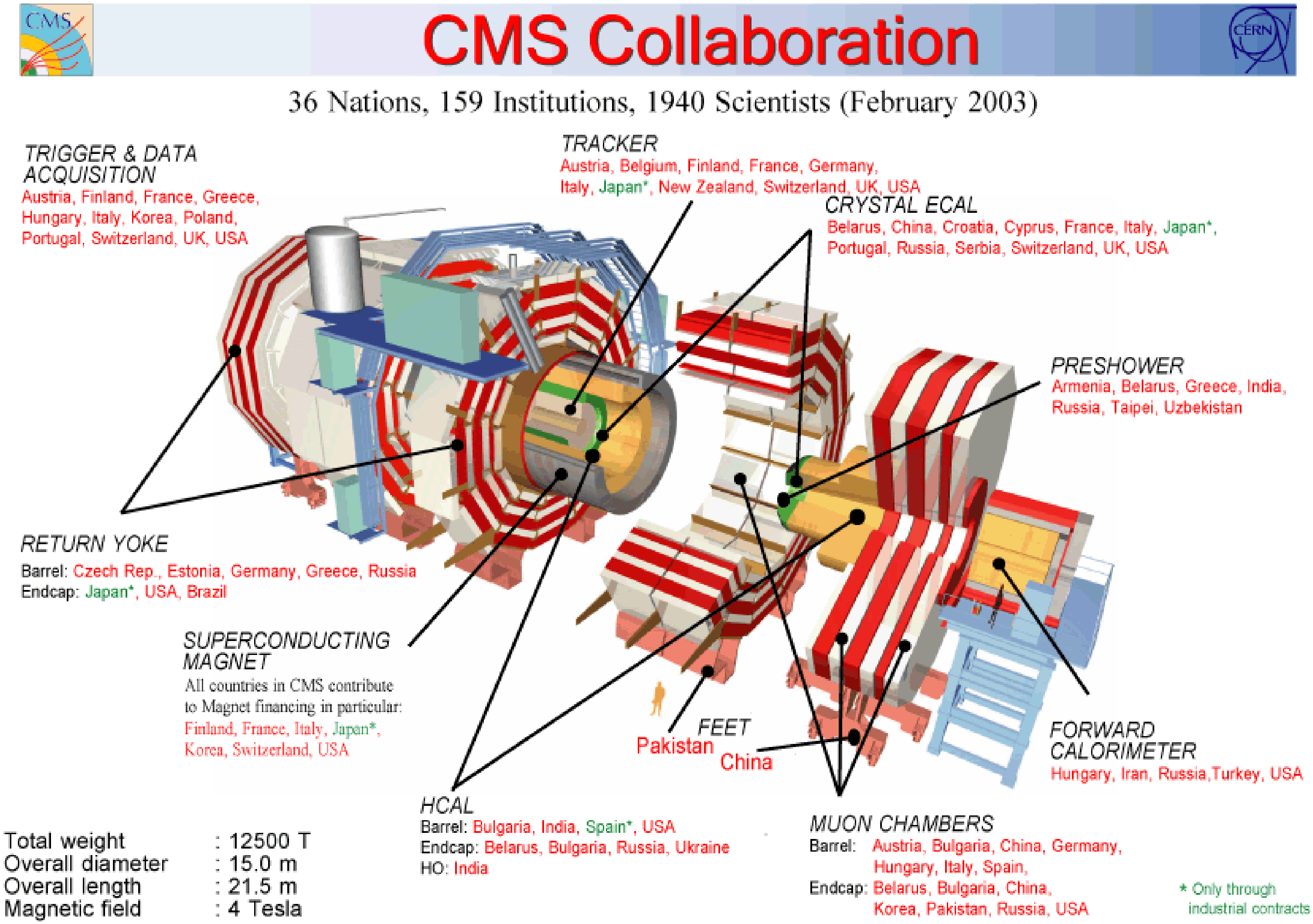

Heat Exchanger Pipe
Beam Pipe
Superconducting Coils
Helium-II Vessel
Spool Piece
Bus Bars
Superconducting Bus-Bar
Iron Yoke
Non-Magnetic Collars
Quadrupole
Bus Bars
Vacuum Vessel
Radiation Screen
Thermal Shield
The
15-m long
LHC cryodipole
Auxiliary
Bus Bar Tube
Protection
Diode
Instrumentation
Feed Throughs

# CERN – Particle Accelerators

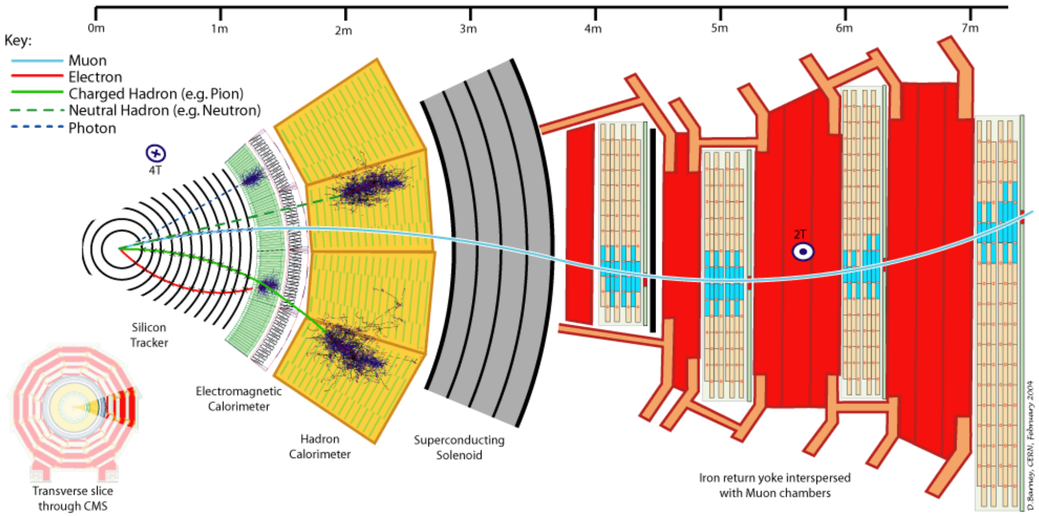


# CERN – Particle Accelerators

# LHC – Compact Muon Solenoide (CMS)



# LHC - CMS




## Solenoid:

- Length: 13 m
- Diameter: 5.9 m
- Superconducting coil (NbTi)
- Current: 20 kA
- Operating temperature: 4.4 K (- 269 C)
- Magnetic Field:
  - 4 Tesla
  - x 100 000 Earth field
  - Stored energy: 2.7 GJ

- Tracker: Silicon Pixel and Silicon Microstrip
  - Measurement of momentum of electrically charged particles
  - Reconstruction of vertices (interaction points + particle decays)
- Electromagnetic Calorimeter: Crystals of Lead Tungstate (PbWO4)
  - Measurement of the energy of: electrons/positrons and photons
- Endcap Preshower: Silicon Strip Sensors
  - Measurement of the transverse profile of electromagnetic showers
- Hadronic Calorimeter: Plastic Scintillators
  - Identification and measurement of quarks, gluons and neutrinos
  - Measurement of the energy and direction of jets
  - Measurement of missing transverse energy
- Muon chambers: Drift Tubes and Cathode Strip Chambers
  - Detection of muons

# LHC - CMS

- Silicon Pixels
  - 150 μm x 100 μm
  - 66 million pixels
- Silicon Microstrips:
  - Sensor size: 11 cm x 16 cm (microstrip pitch 140 μm)
  - Total area: 214 $m^2$
  - 11.4 million microstrips
- Electromagnetic Calorimeter
  - 22 to 23 cm long crystals
  - Avalanche Photodiodes (APDs) – barrel
  - Vacuum Phototriodes (VPTs) - endcaps
  - 76 000 detector elements (total)
- Endcap Preshower
  - Silicon strip sensors: 6.3 cm x 6.3 cm, 300 μm thick
  - 32 strips/sensor
  - 137 000 silicon strips

## LHC - CMS

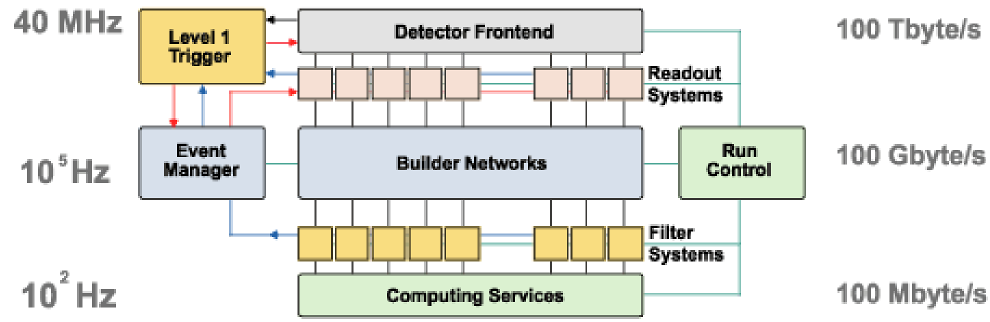
- Hadronic Calorimeter
  - 4 mm thick plastic scintillators
  - Hybrid Photo-Diodes (external to the detector)
  - 10 000 detector channels
- Muon chambers
  - Drift tubes (outside the solenoid)
  - Cathode Strip Chambers (forward region)
  - Resistive Plate Chambers
  - 576 000 detector channels

**Total number of detector channels ~78 million**

# CMS Trigger

- Beam crosses: 40MHz/s
- 25 proton-proton collisions per beam crossing
- 78 M detector channels
- Brut force data collection would be the equivalent of 10 000 Encyclopaedia Britannica per second!
- Trigger system:
  - Identify the interesting events (about 100/s only)
  - Start the acquisition of interesting events
  - Only selected detectors contribute to the trigger (1 Mbyte event size)
- Trigger processing is done in three levels:
  - L1 custom hardware (100 kHz)
  - L2 commercial processors (100 Hz)
  - L3 uses full event data. Slow and Sophisticated analysis

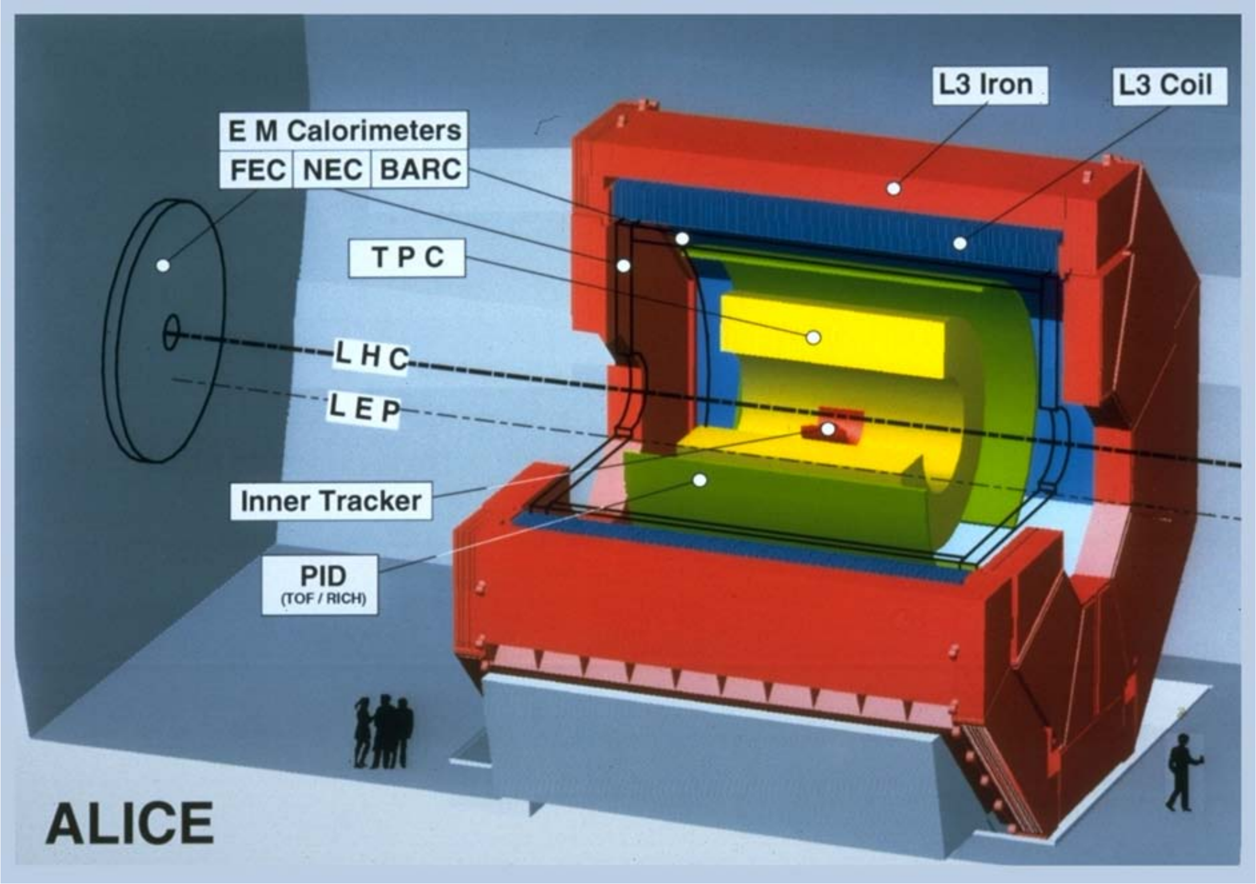
| Data Acquisition Main Parameters | |
|---|---|
| Collision rate | 40 MHz |
| Level-1 Maximum trigger rate | 100 kHz |
| Average event size | 1 Mbyte |
| No. of electronics boards | 10000 |
| No. of readout crates | 250 |
| No. of In-Out units (200-5000 byte/event) | 1000 |
| Event builder (1000 port switch) bandwidth | 1 Terabit/s |
| Event filter computing power | 5 $10^6$ MIPS |
| Data production | Tbyte/day |



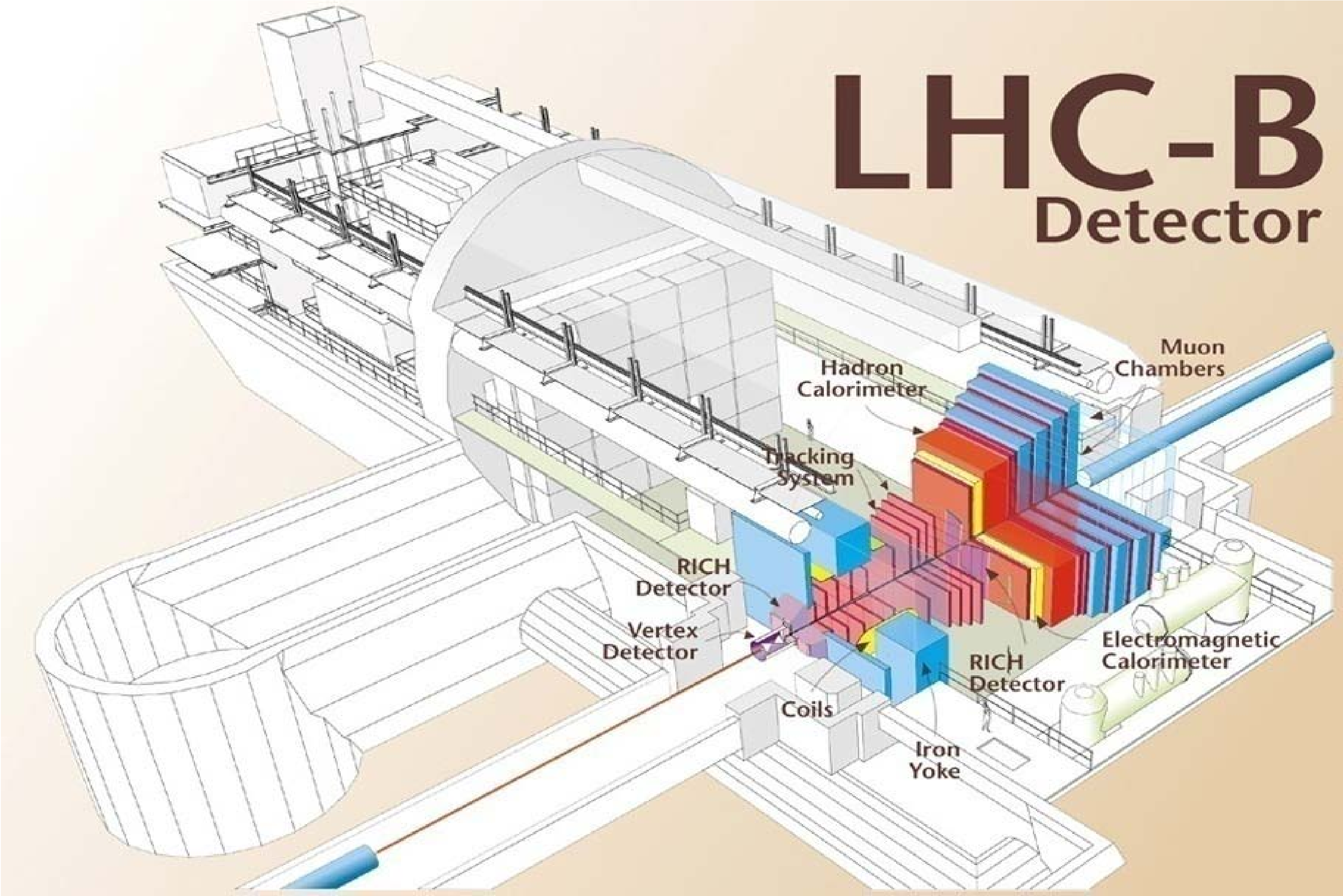

Trigger and Data Acquisition baseline structure

- Detector electronics contains memory to store the data to allow time for the trigger processor

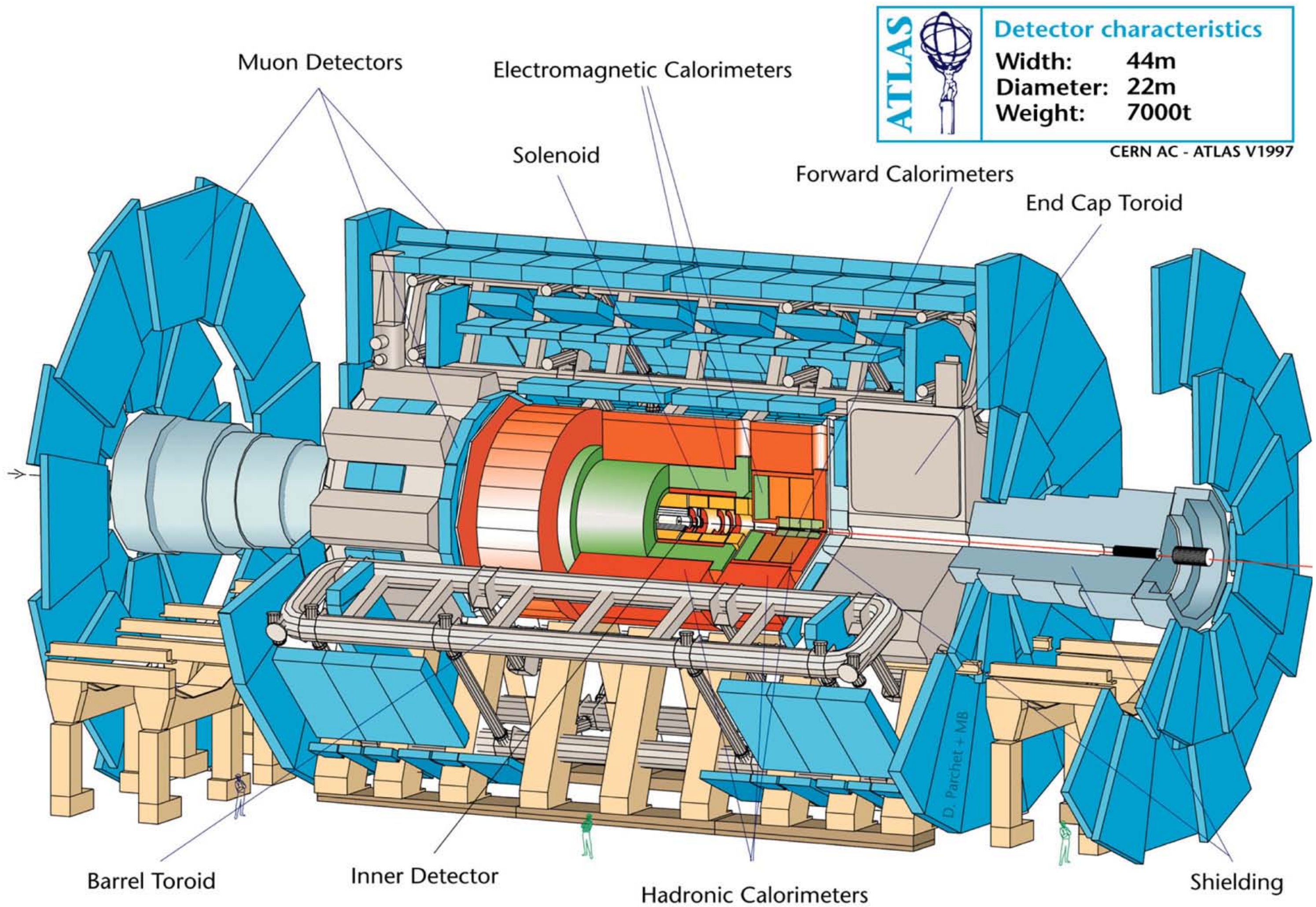
# LHC – Particle Detectors: ALICE

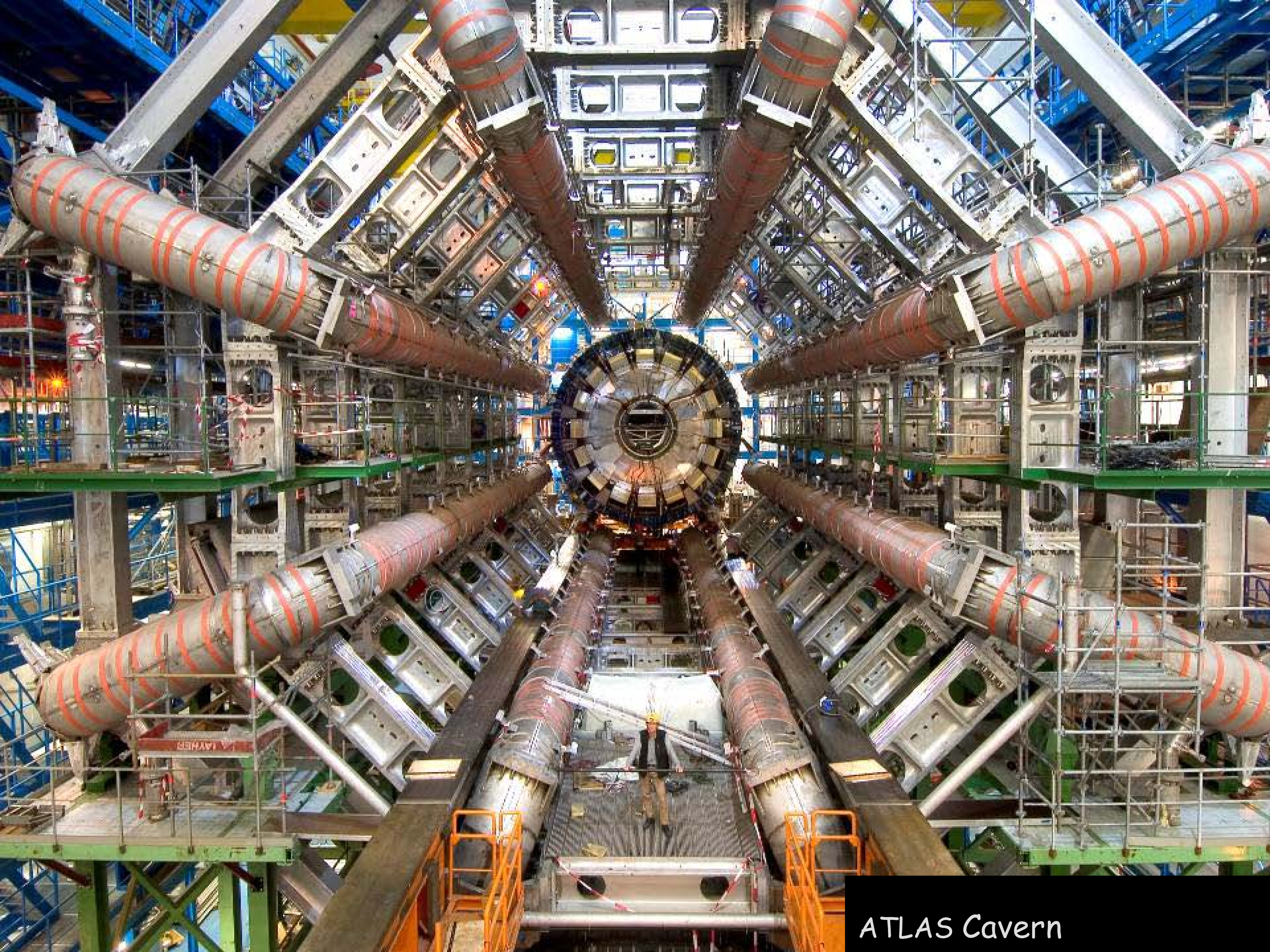


# LHC – Particle Detectors: LHCb



# LHC – Particle Detectors: ATLAS





ATLAS Cavern

# Radiation Levels in ATLAS:

## During the experiment lifetime (10 years)

| Detector zone | Total dose [rad] | Neutrons (1 MeV eq.) [n/cm$^2$] | Charged hadrons (> 21 MeV) [p/cm$^2$] |
|---|---|---|---|
| Pixels | 112 M | $1.47 \cdot 10^{15}$ | $2 \cdot 10^{15}$ |
| SCT Barrel | 7.9 M | $1.4 \cdot 10^{13}$ | $1.1 \cdot 10^{14}$ |
| ECAL (barrel) | 5.1 k | $1.7 \cdot 10^{12}$ | $3.6 \cdot 10^{11}$ |
| HCAL | 458 | $2.5 \cdot 10^{11}$ | $5.6 \cdot 10^{10}$ |
| Muon detector | 24.3 k | $3.8 \cdot 10^{12}$ | $8.7 \cdot 10^{11}$ |

Satellite applications typical requirement: < 100 Krad

# Summary of Radiation Effects

**Cumulative effects**

### Total Ionizing Dose (TID)

*Potentially all components*

### Displacement damage

*Bipolar technologies*
*Optocouplers*
*Optical sources*
*Optical detectors (photodiodes)*

**Single Event Effects (SEE)**

### Permanent SEEs

SEL
*CMOS technologies*
SEB
*Power MOSFETs, BJT and diodes*
SEGR
*Power MOSFETs*

### Static SEEs

SEU, SEFI
*Digital ICs*

### Transient SEEs

*Combinational logic*
*Operational amplifiers*

# Total Ionizing Dose (TID)

Ionization in $SiO_2$

In LHC: (charged hadrons, electrons, gammas, neutrons)

↓

Creation of electron-hole pairs

↓

Buildup of charge/defects

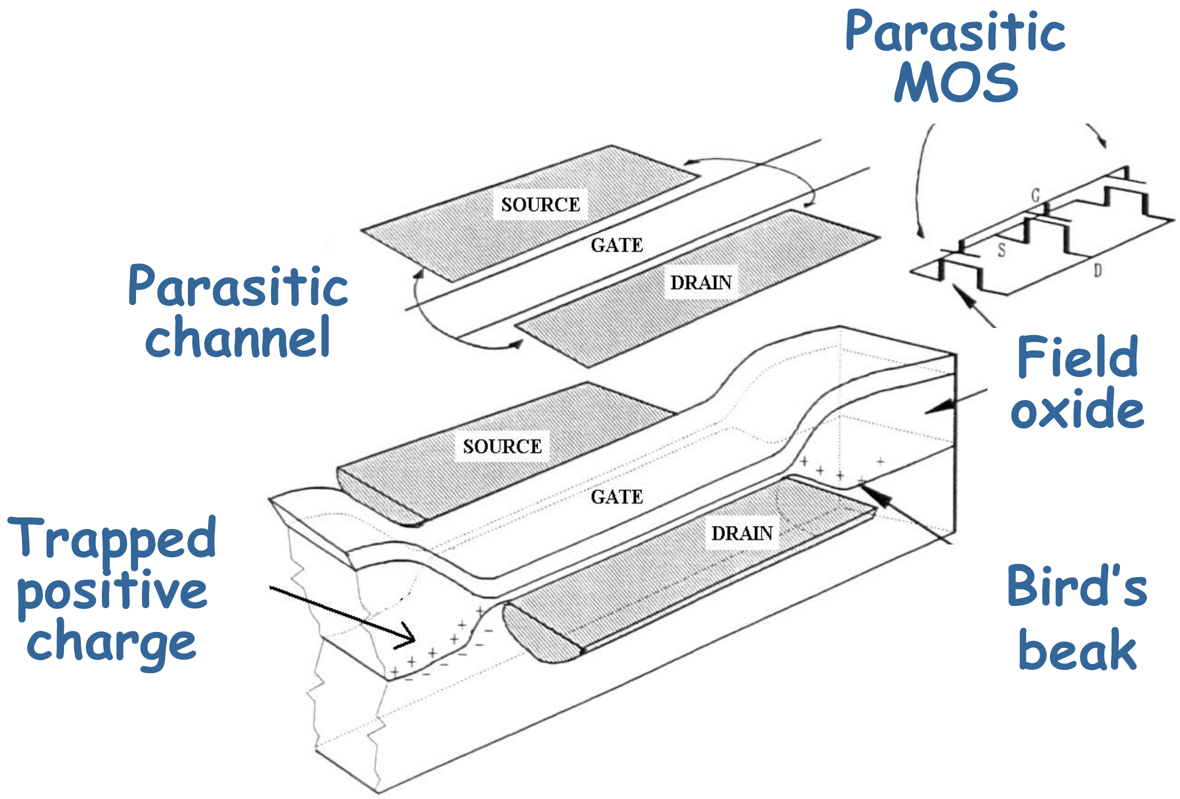
↓

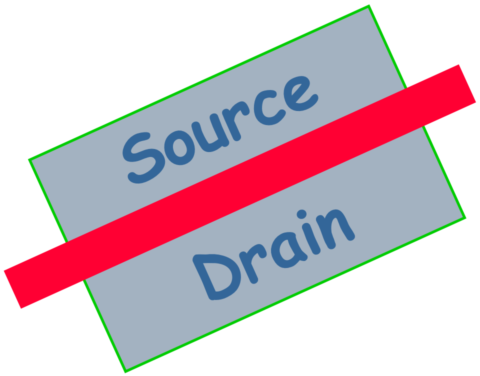
Device degradation

**Trapped holes:**
- Vt shift
- Noise
- Leakage
- Fast formation
- Annealing

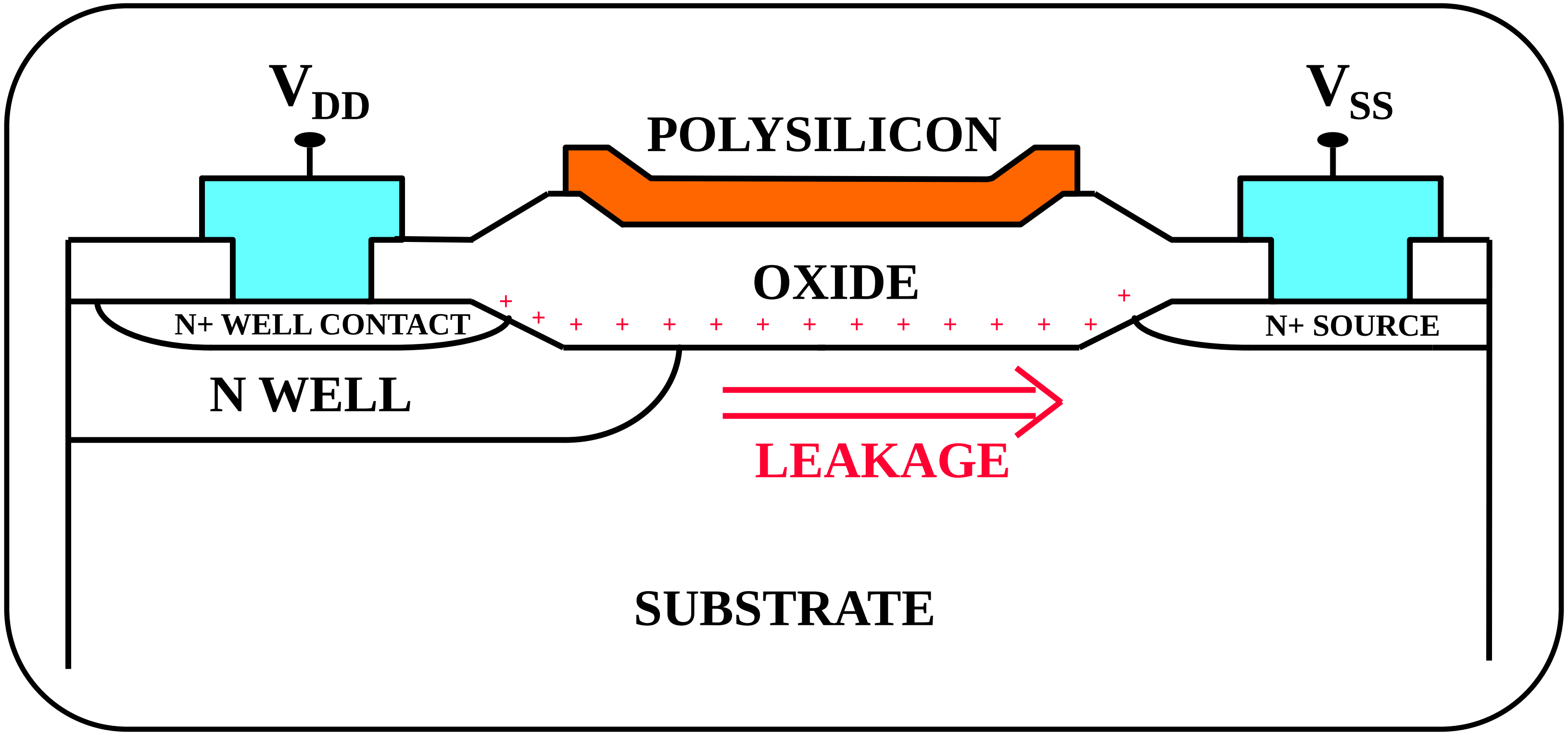
**Interface States:**
- Vt shift
- Mobility
- Transconductance
- Slow formation
- No annealing < 400 C

# Transistor Level Leakage



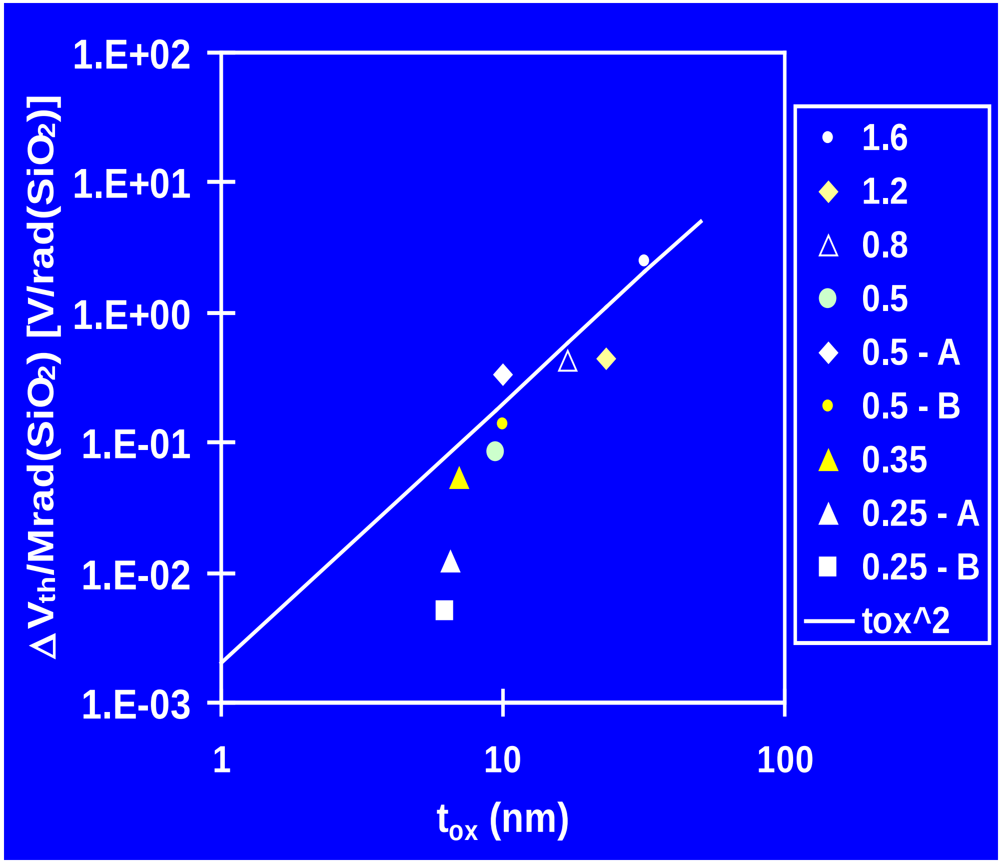
# IC Level Leakage



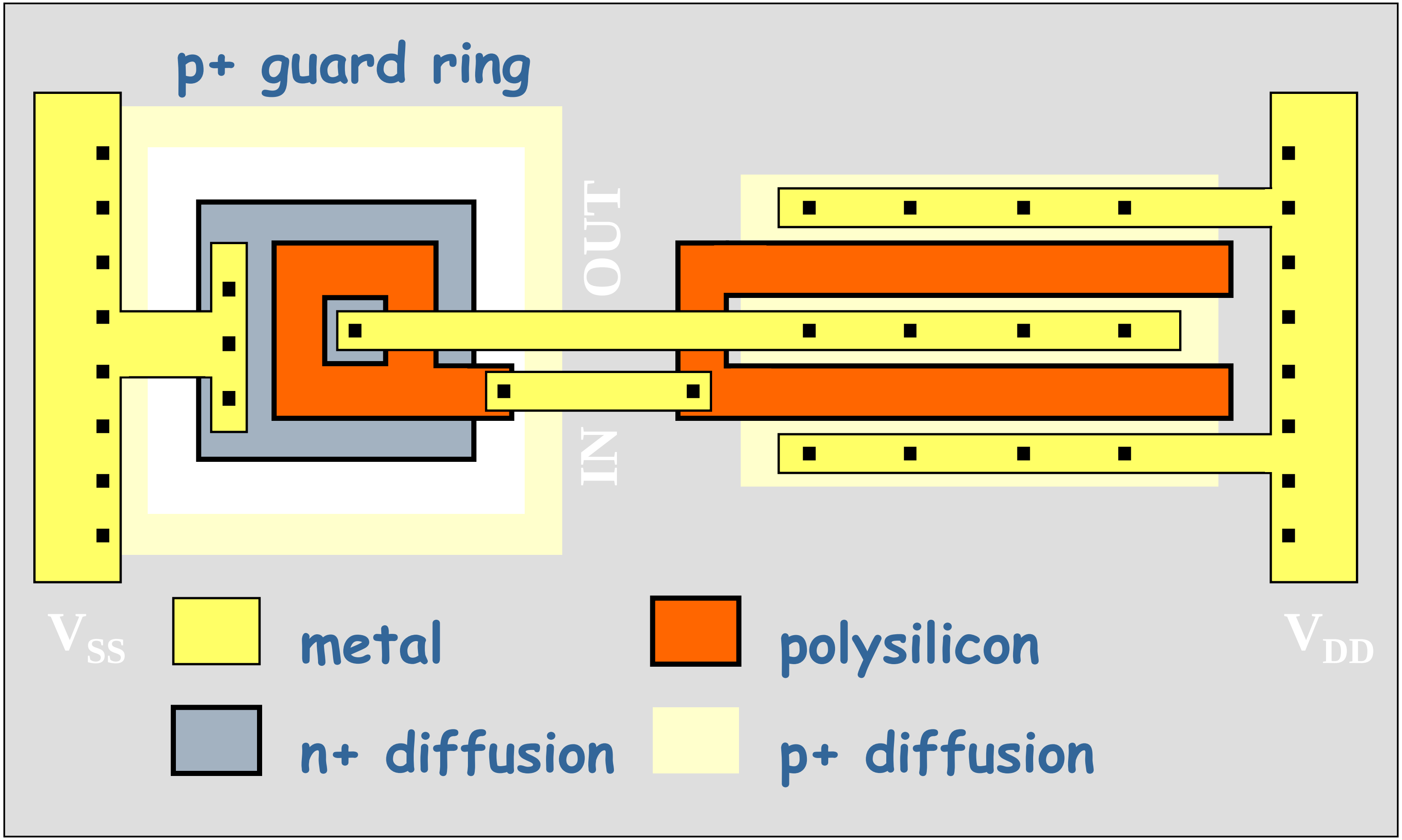
# Radiation Effects and $t_{ox}$ Scaling

## Damage decreases with gate oxide thickness

Measured on VLSI tech.

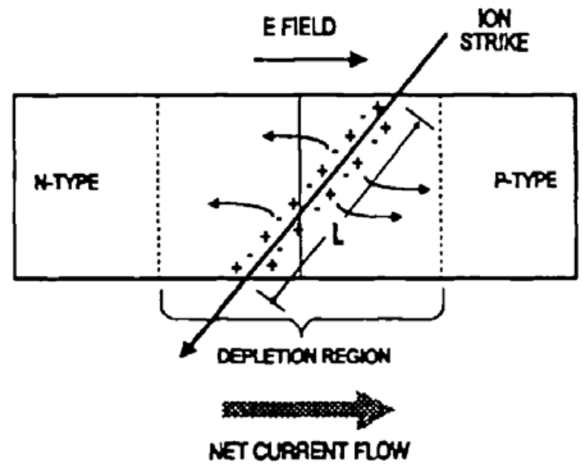


# Radiation Tolerant Layout Approach



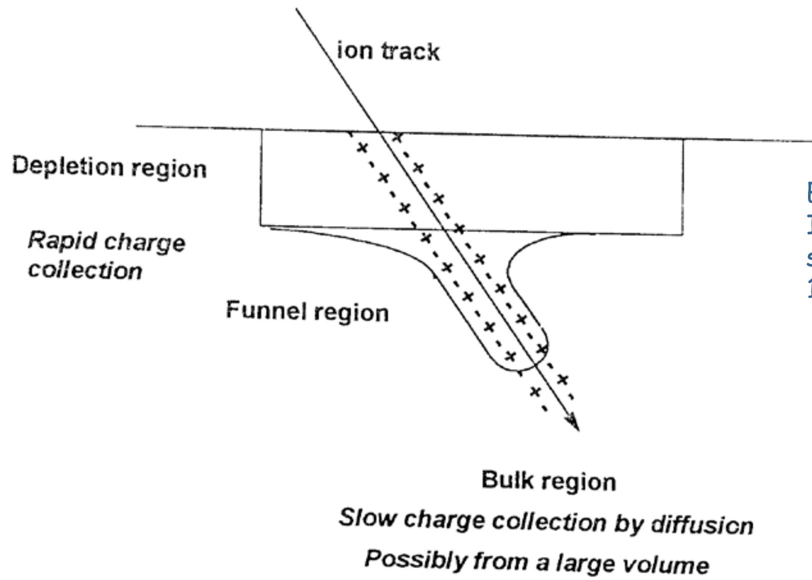
# Single Event Upset (SEU)

Along the ion track, e-h pairs are created. In presence of an electric field (depleted junction), the charge will flow and a current spike might be observed.



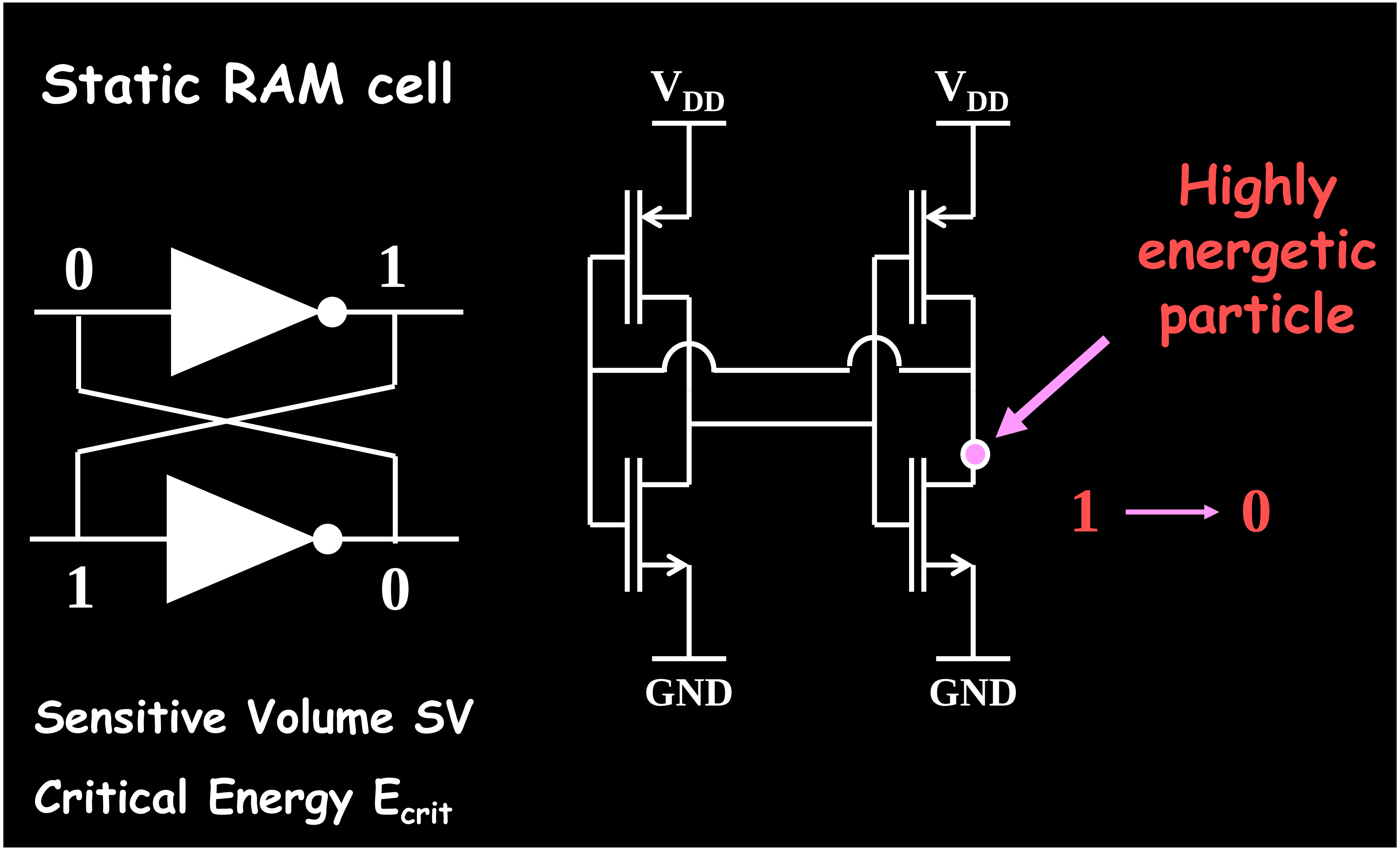

L.Massengill, IEEE NSREC short course, 1993

Charge collection has a prompt and a slow component, and might extend far from the depleted junction (funneling)




E.L.Petersen, IEEE NSREC short course, 1997

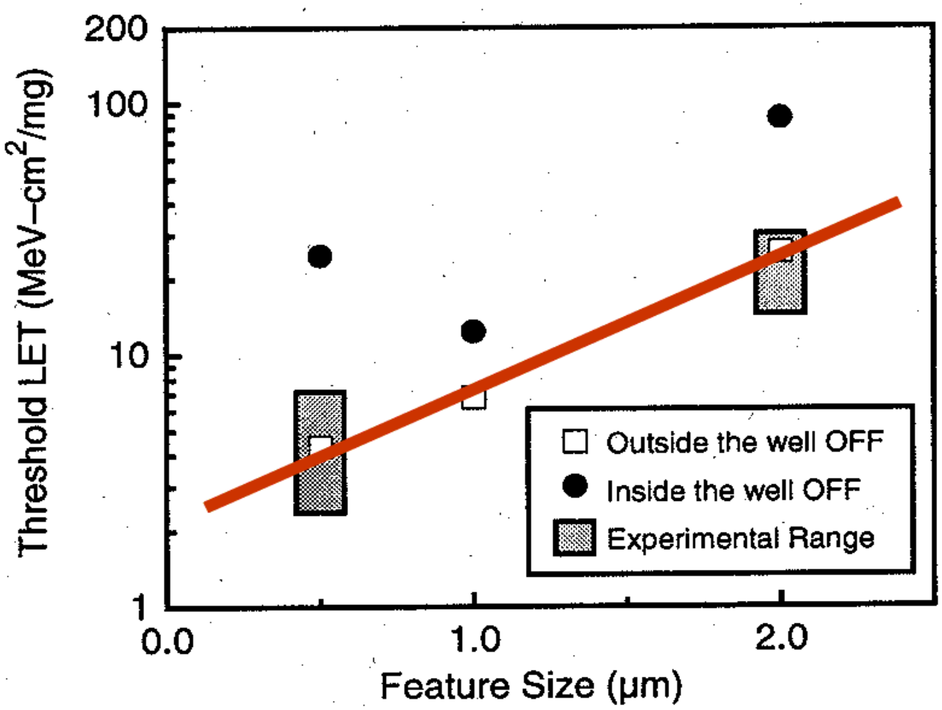
# Single Event Upset (SEU)



# SEU and Scaling

## The SEU problem worsens with scaling

- $V_{DD}$ reduced
- Node C reduced

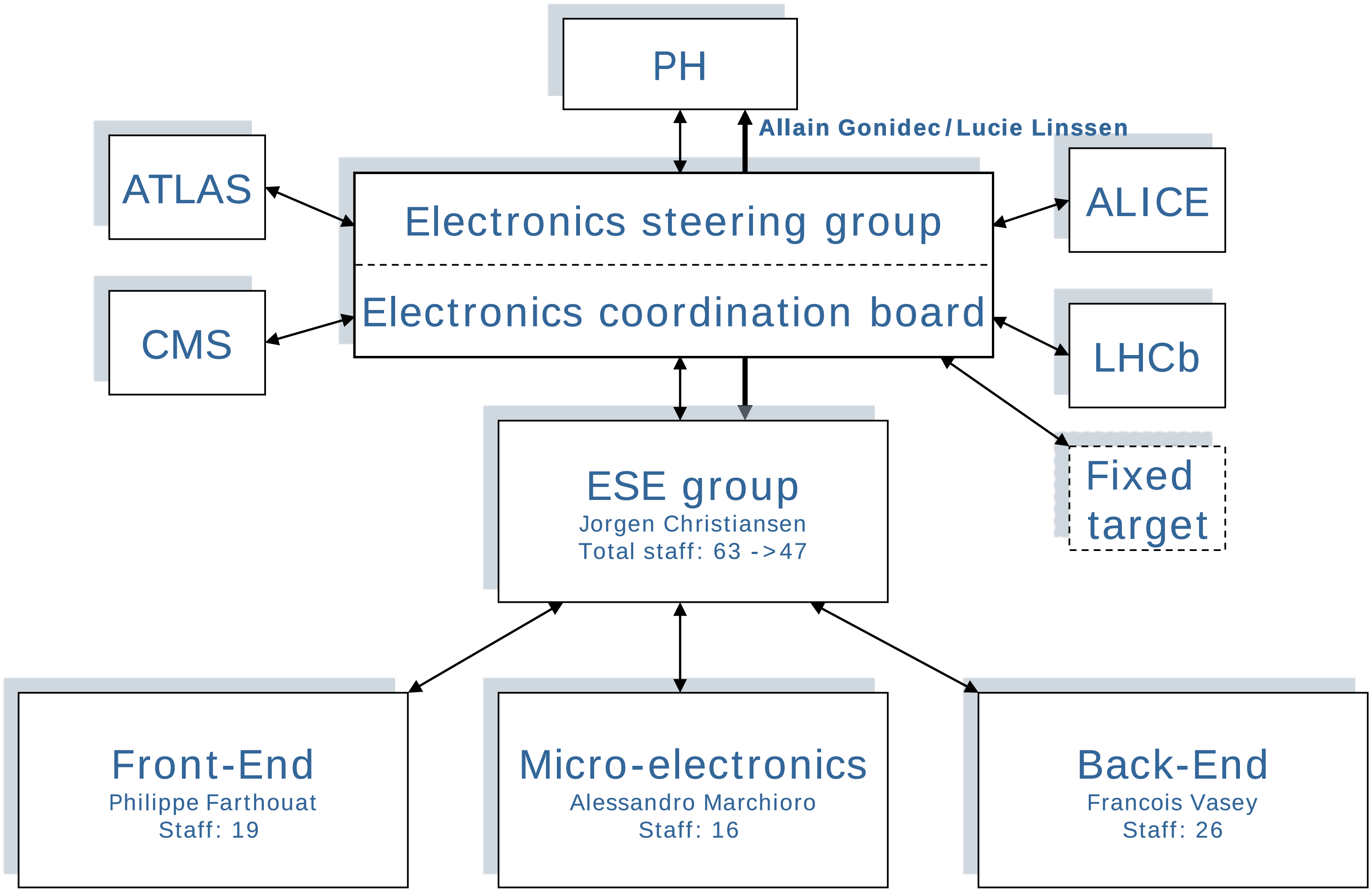



P.E. Dodd et al., IEEE TNS, Dec. 1996

# SEU Robustness

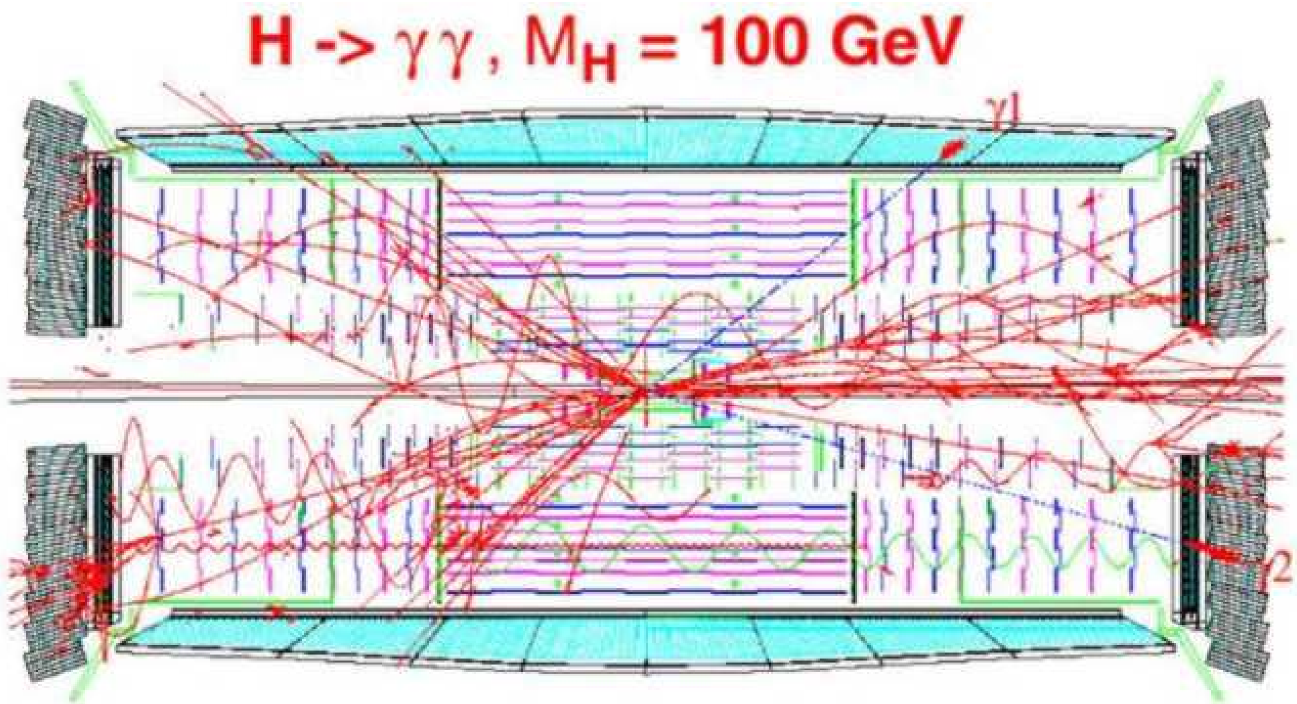
- Technology level (epitaxial substrates, SOI,…)
- Cell design (SEU-tolerant FF or memories)
- Voting (block or system level)
- EDAC techniques (system level)
- Duplication of the information (example: configuration data for FPGA)
- Special "error immune" architecture
- Always to be considered at system level

# Electronics Systems for Experiments (ESE - 2008)



# The Timing Trigger and Control (TTC) system

- The electronics inside/outside the detector has to work synchronously with the accelerator clock:
- Electronics synchronization is done at two levels:
  - Clock synchronization
  - Event tagging



# The TTC system

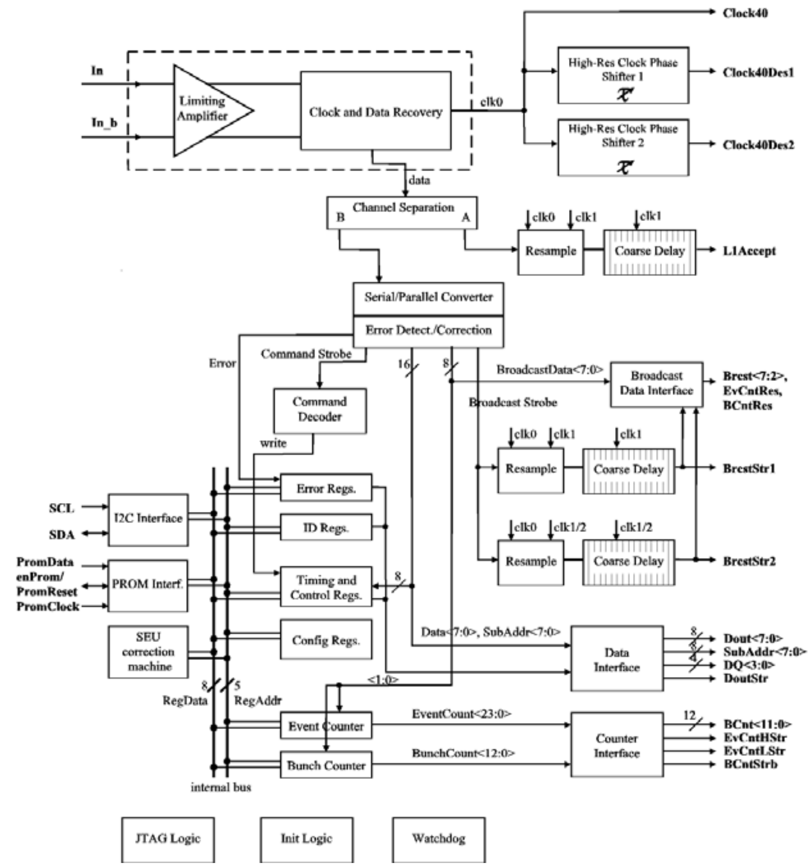
- Clock Synchronization
  - Multiple collisions will occur at a rate of 25 ns
  - The electronics will run at this frequency 40 MHz
  - Some detectors (or parts of then) require the clock phases to be within a few hundreds of ps
  - Clock jitter $<$ 50 ps for some systems
  - This function can be compared to a clock tree network in and ASIC:
    - This has to be made all over the detector volume
      - 7600 $m^3$ for CMS
      - 33400 $m^3$ for ATLAS
  - The system has to compensate for:
    - Intrinsic delays in the electronics
    - Signal distribution delays in cables/optical fibres
    - Travel times of the particles inside the detectors

# The TTC system

- Event tagging:
  - All the “collisions” must be marked with the collision number (Bunch Crossing Number)
  - Once an interesting physics phenomena is detected (called an event) data has to be marked with an Event Number.
- Data is transmitted out of the detectors:
  - Synchronously:
    - Triggers systems: finding events
    - Only a fraction of the detector’s data
    - BCN used to check data alignment
  - Asynchronously:
    - Event data can be transmitted asynchronously
    - BCN and EN are used for event reconstruction

# The TTC receiver ASIC (TTCrx)

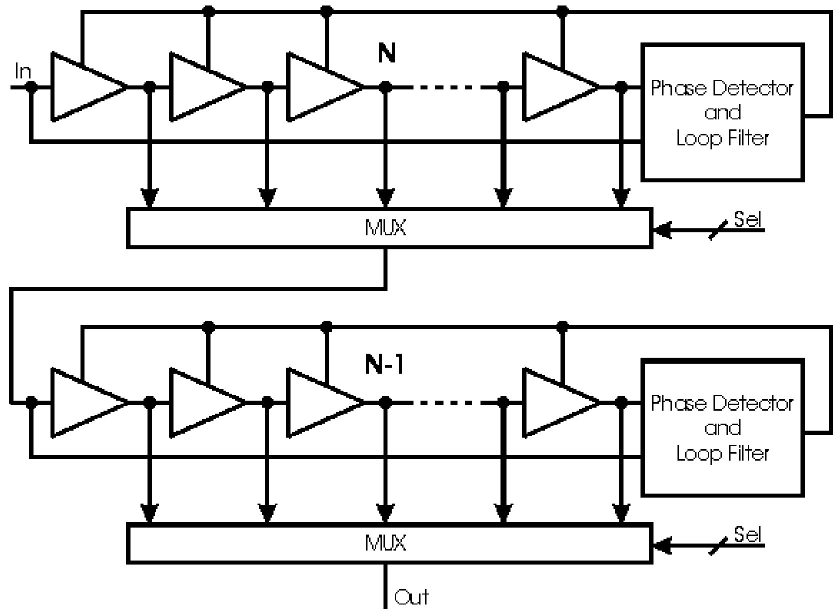
- Functionality:
  - Clock Deskewing
  - Tagging
  - Slow control commands
- It is the end element of an optical distribution network:
  - Single laser source
  - Two time division multiplexed channels 80 Mbit/s
  - Up to 1024 destinations
- Functions:
  - “Optical” post-amplifier
  - Deserializer
  - TD demultiplexer
  - Clock recovery PLL
  - 4 Clock de-skewing DLLs’
- Radiation Tolerance:
  - Hardened technology: 0.8μm DMILL
  - Registers Hamming encoded
  - Critical registers duplicated



# TTCrx: Clock Deskewing

- **Implementation:**
  - 1 μm CMOS (0.8 μm final)
  - Required resolution less than a buffer delay
- **A "Vernier" method was adopted to achieve the required resolution**
  - Two Delay-Locked Loops (DLL) are used in series
  - One divides the reference clock period in N equal intervals while the other one in N-1
  - The multiplexers "program" the clock phase
  - Since the clock is a periodic signal the "apparent" time resolution is:

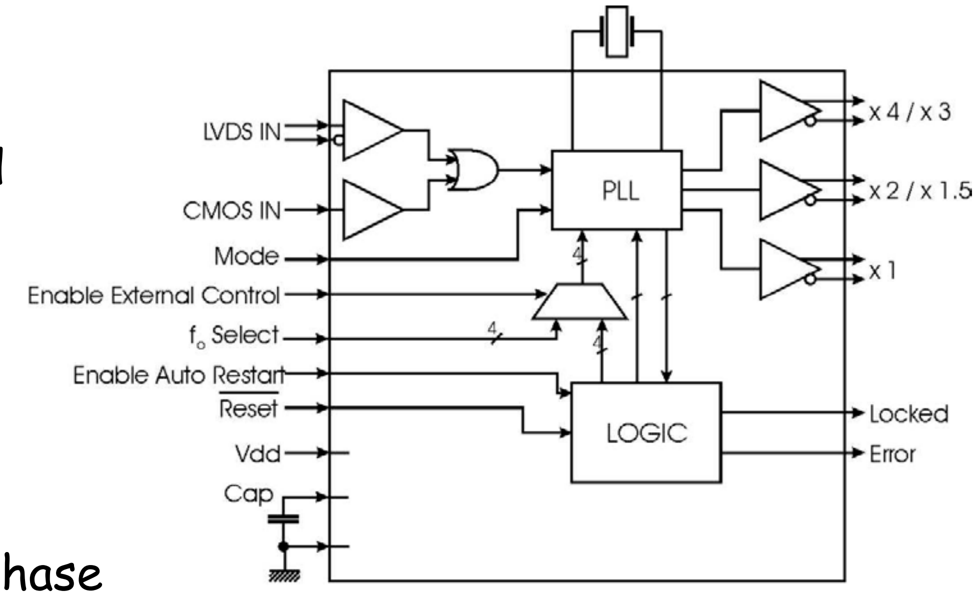
$$\Delta t = \frac{1}{N \cdot (N-1)} \times T$$




- **Circuit parameters:**
  - T = 25 ns
  - N = 16
- **Resolution:**
  - Δt = 104 ps
  - σ (diff) = 48 ps
  - pp (diff) = 324 ps
  - σ (int) = 74 ps
  - pp (int) = 326 ps

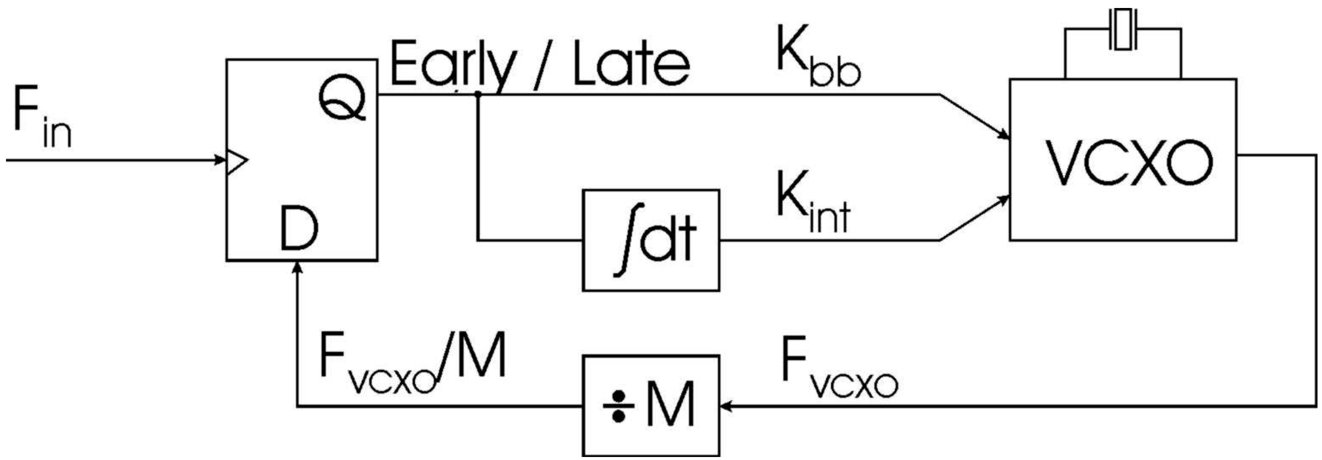
# QPLL:

- TTC system jitter excessive for:
  - Gbit/s Serializers and Deserializers
  - High resolution TDCs
  - High resolution ADCs
- QPLL: a PLL based on a VCXO:
  - VCXO – intrinsic low phase noise
  - Ideal for narrow band PLLs
  - Ideal for jitter filtering
- LHC nominal frequency:
  - 40.078666 MHz ±12 ppm



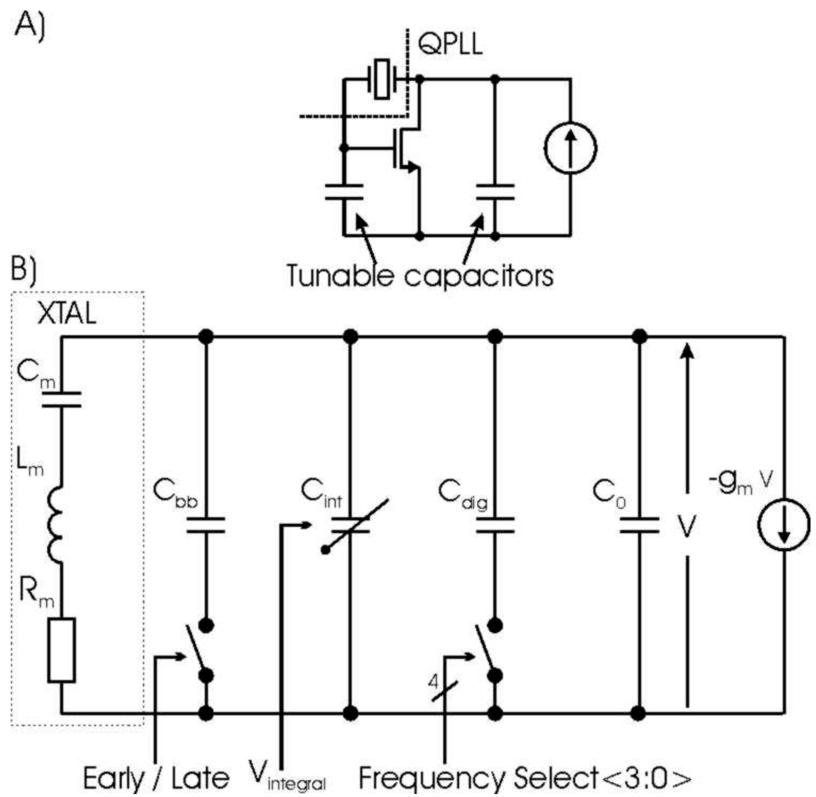
# QPLL: Operation Principles

- Phase detector:
  - Bang-bang type
  - Only early/late decision
- VCXO
  - Two control ports
  - Bang-bang control
  - Continuous control
- Control loop:
  - Two control branches
  - Bang-bang: phase and frequency control
  - Integral: average frequency control
  - Almost independent optimization of $K_{bb}$ and $K_{int}$



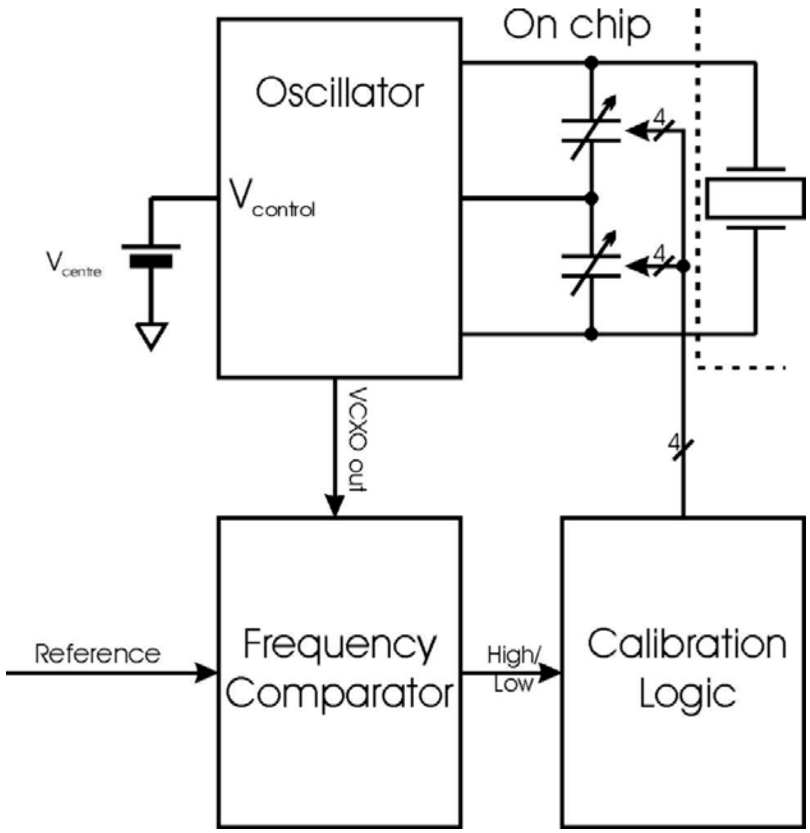
# QPLL: Operation Principles

- VCXO:
  - Pierce Oscillator
  - Two frequency control capacitors
- Three frequency control mechanisms:
  - Bang-bang control:
    - switched capacitor
  - Integral control:
    - voltage controlled n-well capacitor
  - Frequency centering:
    - four binary weighted switched capacitors. (Not under the PLL loop control)



# QPLL: Operation

- Lock acquisition, two phases:
  - Frequency centering
  - Standard frequency pull-in and phase lock cycle
- Frequency centering:
  - After start-up, reset or unlocked operation detected
  - Frequency-only detector used
- Frequency centering operations:
  - The bang-bang loop is disabled
  - The VCXO control voltage forced to its mid range value
  - A binary search is made to decide on the value of the frequency centering capacitor
  - Once the value found, control is passed to the PLL control loop



# QPLL

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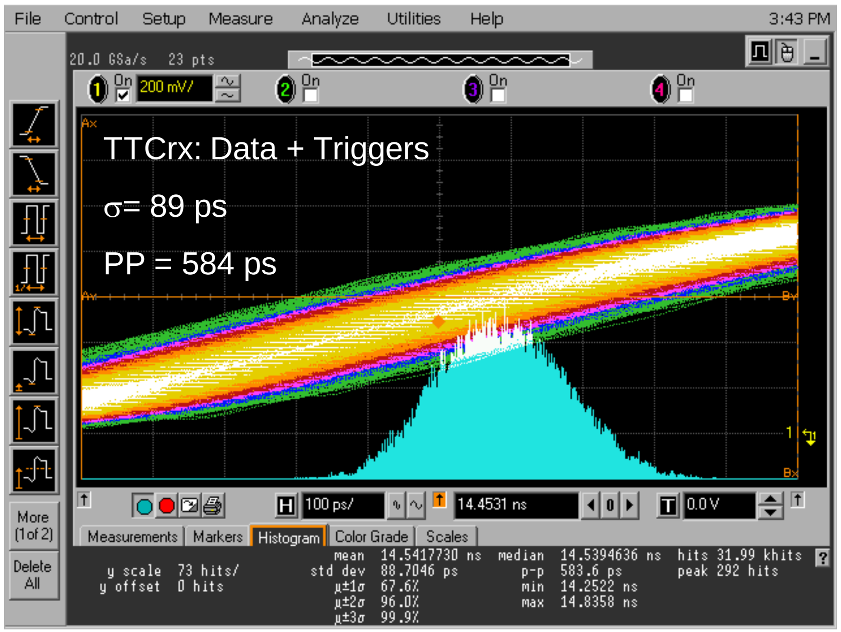


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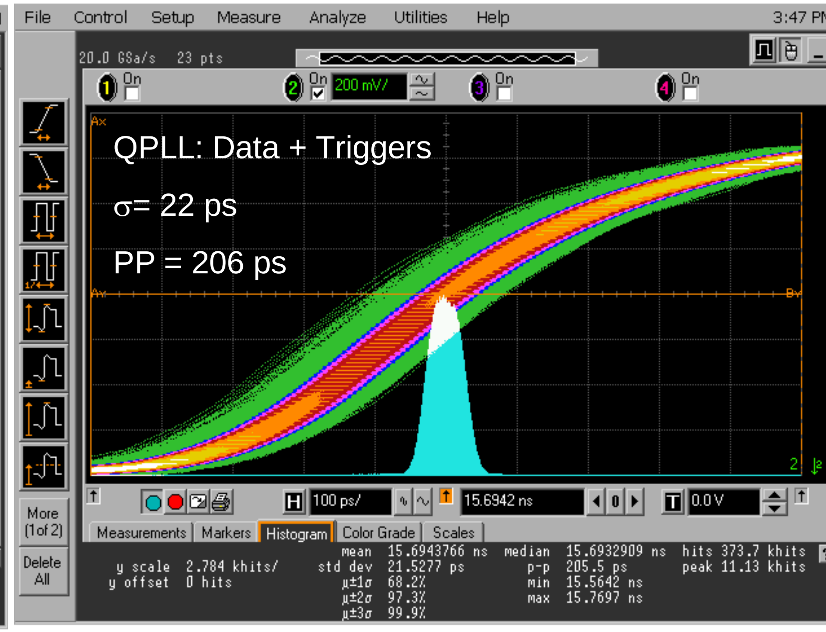
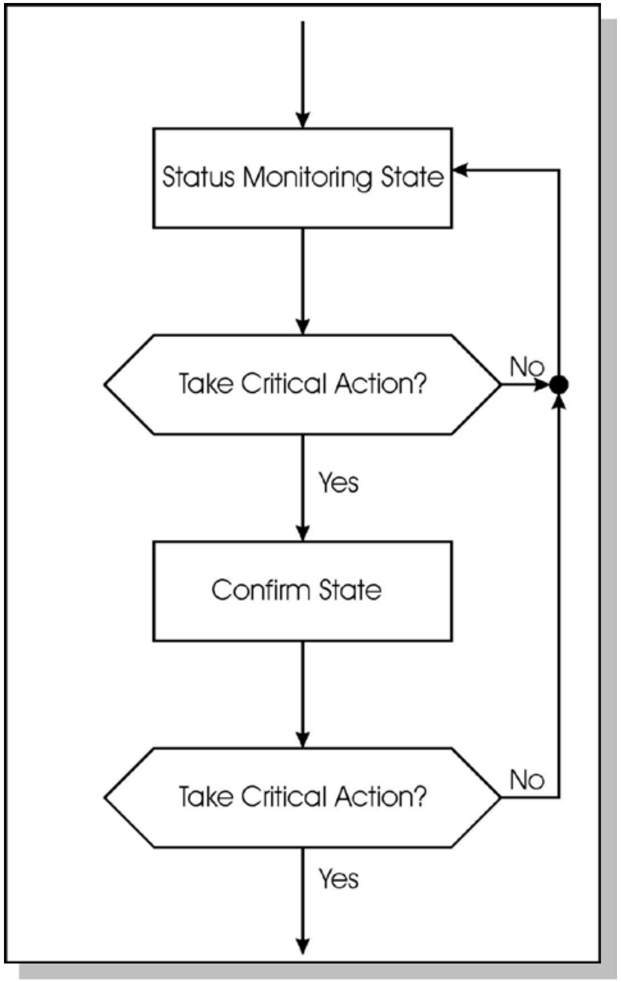



54855A Infinium Oscilloscope

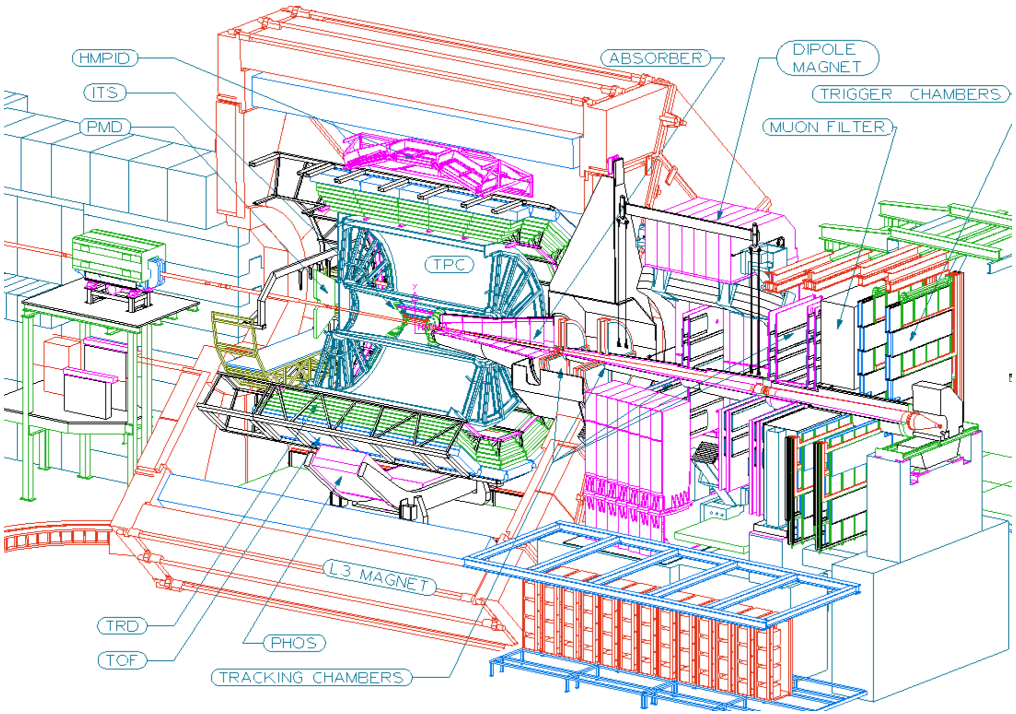
- Analog bandwidth: 6 GHz
- Real-time sampling
- Sample rate: 20 GSa/s

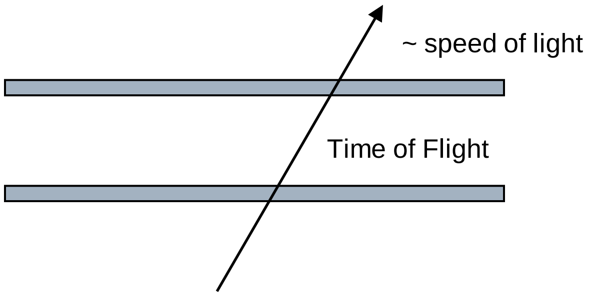
# QPLL: Radiation Tolerance

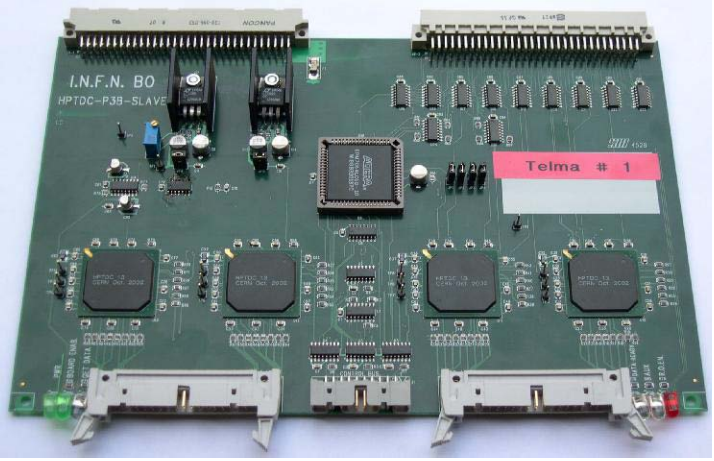
- Total dose:
  - 0.25 $\mu$m CMOS process
  - Enclosed NMOS
  - Guard rings
- Single Event Upsets:
  - Majority voting circuits
  - Confirm before acting
  - When in doubt, take the action with less impact for the system



# ALICE Time Of Flight (TOF)



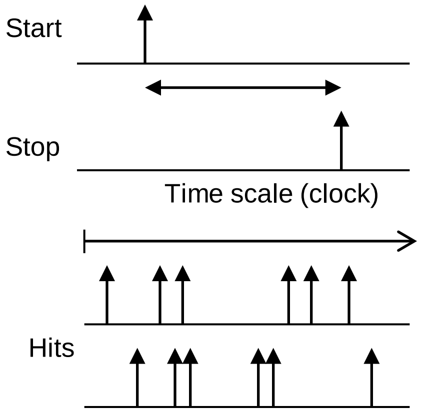




- ~25 ps resolution
- 160.000 channels
- Low hit rate: few tens of kHz
- Trigger rate: few kHz
- Trigger latency: 6.7 us
- Trigger window: 100ns

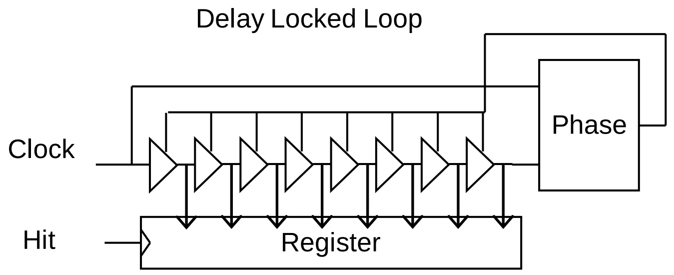
# What is a TDC and its use

- TDC's are used to measure time (intervals) with high precision
  - Start – stop measurement
    - Measurement of time interval between two events:
      - start signal – stop signal
    - Used to measure relatively short time intervals with high precision
  - Time tagging
    - Measure time of occurrence of events with a given time reference:
      - Time reference (Clock) - Events to be measured (Hit)
    - Used to measure relative occurrence of many events on a defined time scale
- Special needs for high energy physics
  - Many thousands of channels needed
  - Rate of measurements can be very high
  - Very high resolution
  - A mechanism to store measurements during a given interval and extract only those related to an interesting event, signaled by a trigger, must be integrated with TDC function

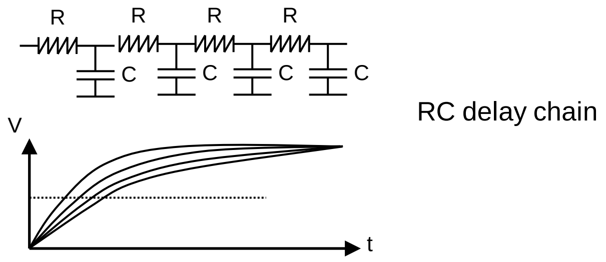


# HPTDC: Operation principles

- Delay locked loop
  - Self calibrating using external frequency reference (clock)
  - Allows combination with counter
  - Delicate feedback loop design (jitter)

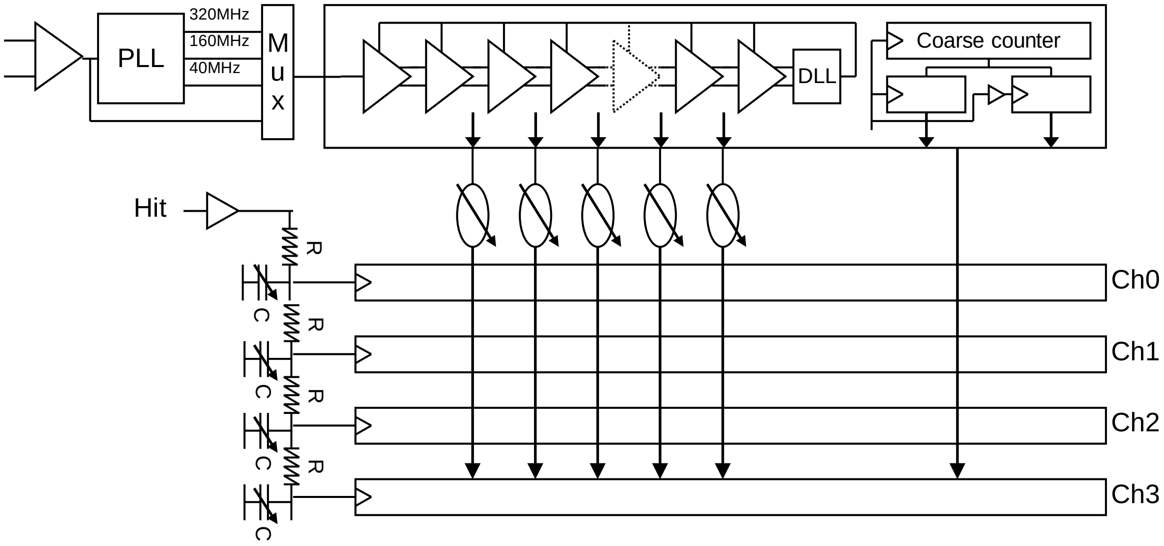


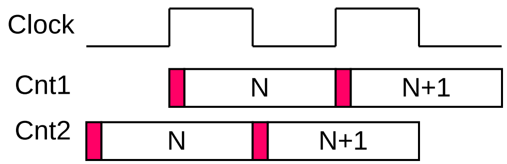

- R-C delay chain
  - Very good resolution
  - Signal slew rate deteriorates.
  - Delay chain with losses so only short delay chain possible
  - Large sensitivity to process parameters ( and temperature)



# HPTDC: Operation principles

- Combination of
  - Counter with PLL for clock multiplication (x1, x4, x8)
    - Double phase shifted counters to resolve possible metastability in coarse count measurement.
  - DLL with 32 taps for clock interpolation
    - Use of differential delay cell for power supply noise immunity
  - R-C delay line on hit signals for very high resolution
    - Channel reduction by factor 4 (8 channels per chip)

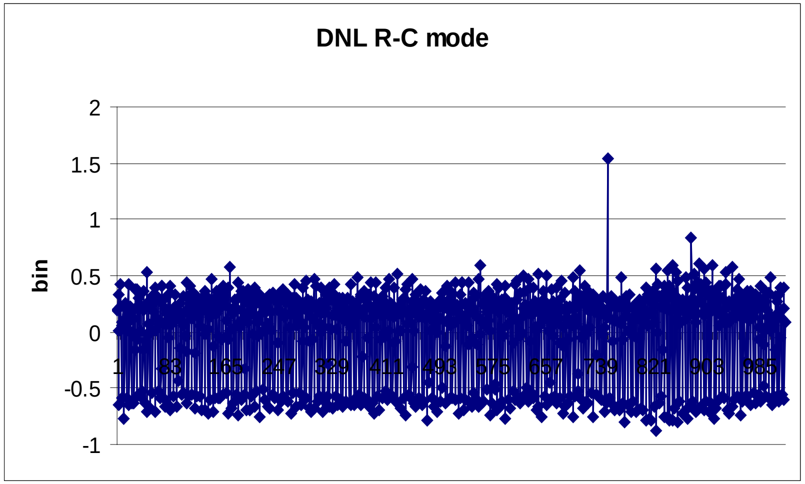


# HPTDC: Operation principles

- Very high resolution:
  - R-C delay line dependent on IC processing (Only small difference between chips seen)
  - R-C delay line independent of temperature in range of 20 deg
  - Infrequent calibration required
  - Calibration can be obtained with code density test with physics hits
  - Option of correcting integral errors from DLL
  - 8 channels per chip
  - Not possible to pair leading and trailing edges

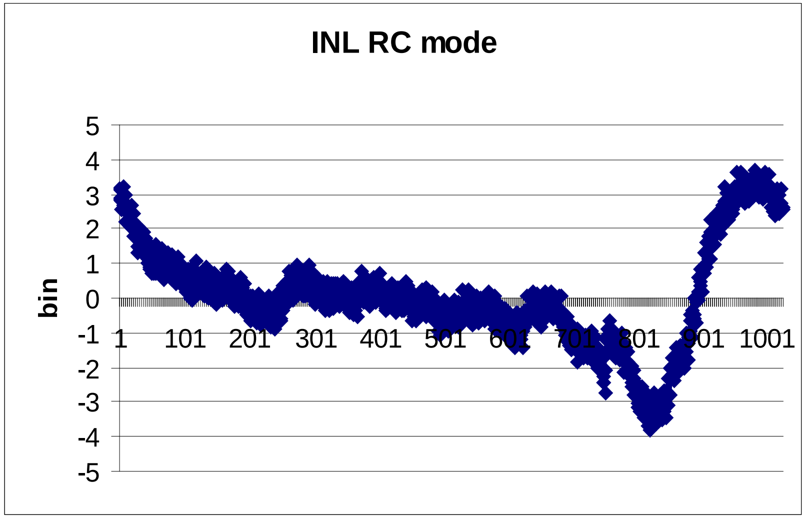
# HPTDC: Very high resolution (R-C mode)

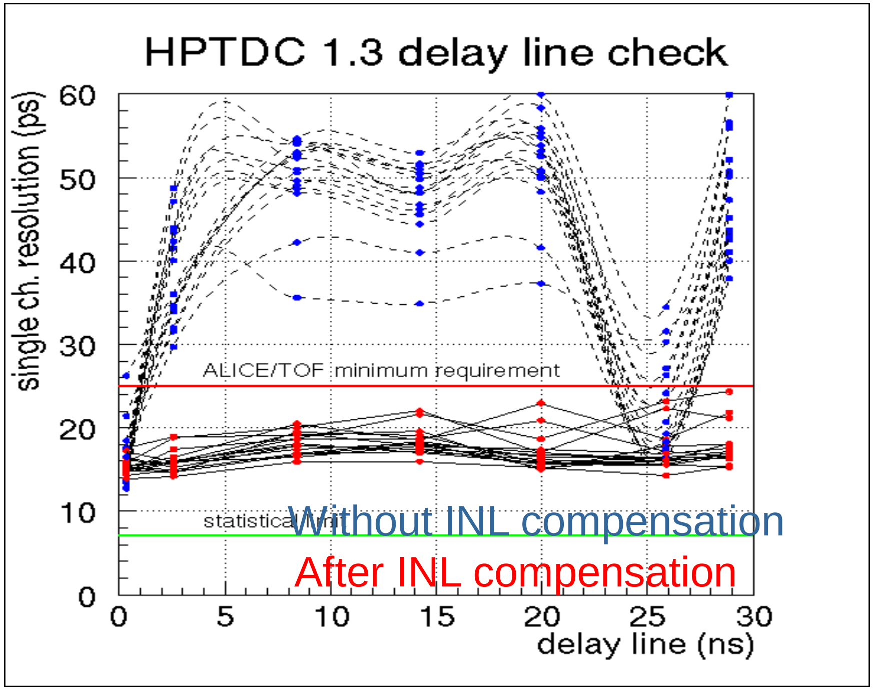



## Measurements from ALICE-TOF

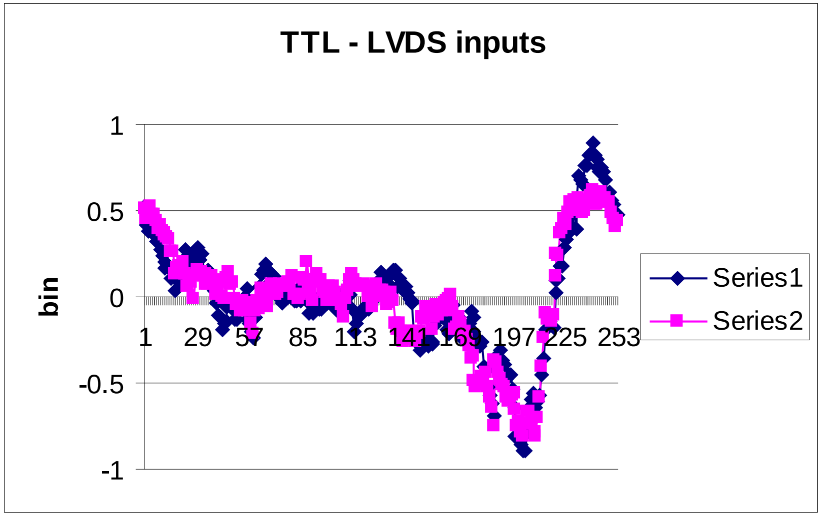
Effective RMS resolution:

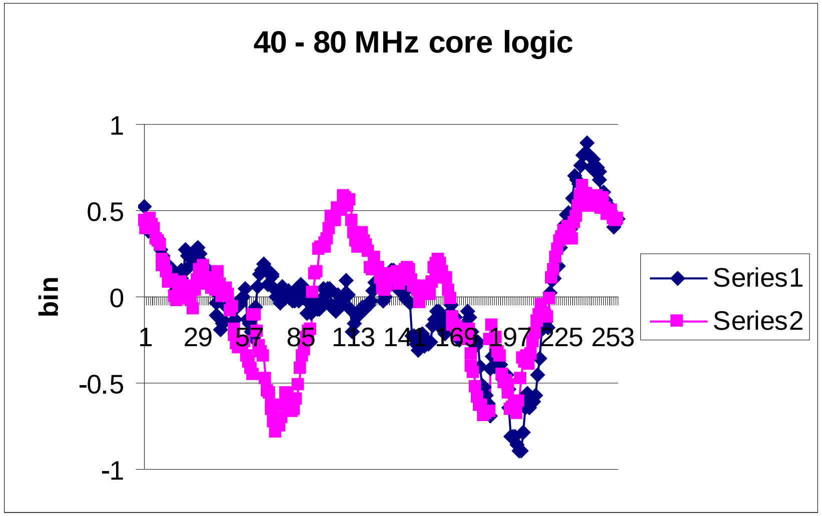
- 40ps
- 17ps with table correction



# HPTDC: Cause of INL Errors




It is clear that INL imperfections come from on-chip crosstalk from logic part of chip.

Several improvements have been made with limited improvement:
(special package with power/gnd plane, re-optimized signal routing, separation of power domains, etc.)

As logic clock is the same as the time reference for the time measurements this is a fixed pattern that can be compensated for if needed with a simple table look-up

# HPTDC: SEU Handling

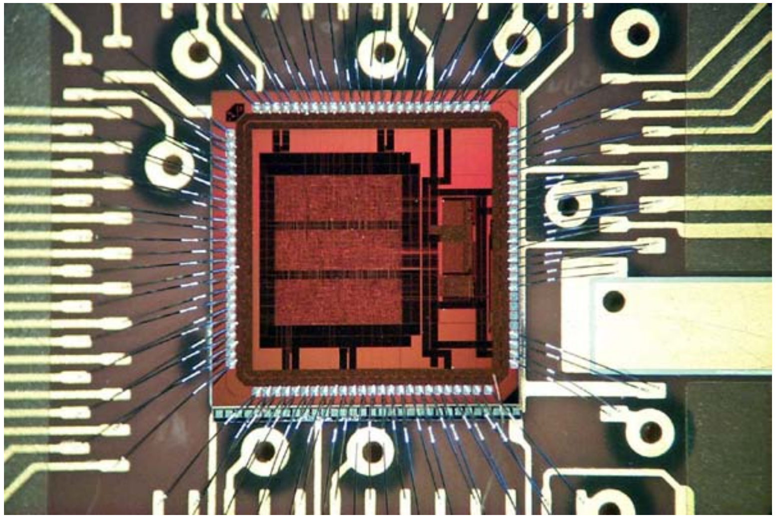
- SEU detection (not SEU immune)
- Programming data protected with parity check
- All internal memories have parity check
- State machines implemented with one hot encoding and continuous state check
- Measurements with parity error ignored in matching
- Error status with information about detected parity errors from different functional blocks
- Programmable global error state which can force the TDC into a passive state

# Data Transmission in HEP

- Data acquisition and trigger systems in the LHC require
  - 40,000 "analogue Links"
  - > 25,000 Gbit/s digital links
- These links are unidirectional:
  - Transmitters inside the detectors
  - Receivers in the counting rooms
- Transmitters are subject to high levels of radiation doses over the lifetime of the experiments:
  - No commercial product available
  - CERN to developed their own radiation tolerant high speed serializer and analogue links

# Gigabit Optical Link (GOL)

- Two encoding schemes:
  - G-link
  - Gigabit Ethernet (8B/10B)
- Transmission speed:
  - Fast: 1.6 Gbit/s , 32 bit data input @ 40 MHz
  - Slow: 0.8 Gbit/s , 16 bit data input @ 40 MHz
- Synchronous (constant latency)
- Drivers:
  - Laser driver
  - 50 Ω driver
- Interfaces for control and status:
  - I2C
  - JTAG



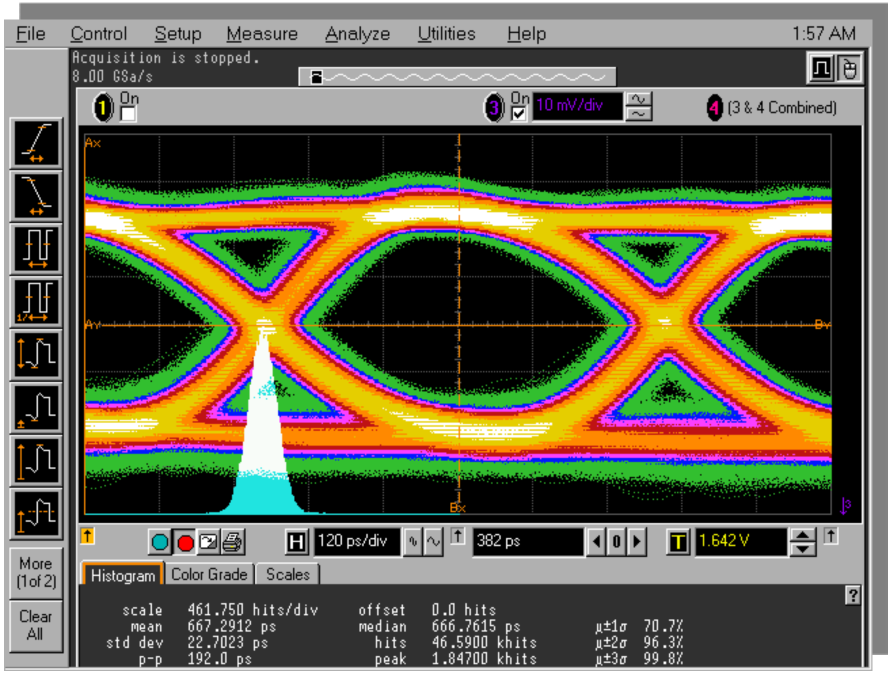
# GOL: Improving the SEU Tolerance

- Digital logic: different approaches adopted throughout the IC:
  - Configuration data:
    - hard-wired logic values
  - Configuration settings:
    - Hamming code protected memory
  - Data path:
    - Triple modular redundancy with majority voting
  - State Machines:
    - Triple modular redundancy with majority voting

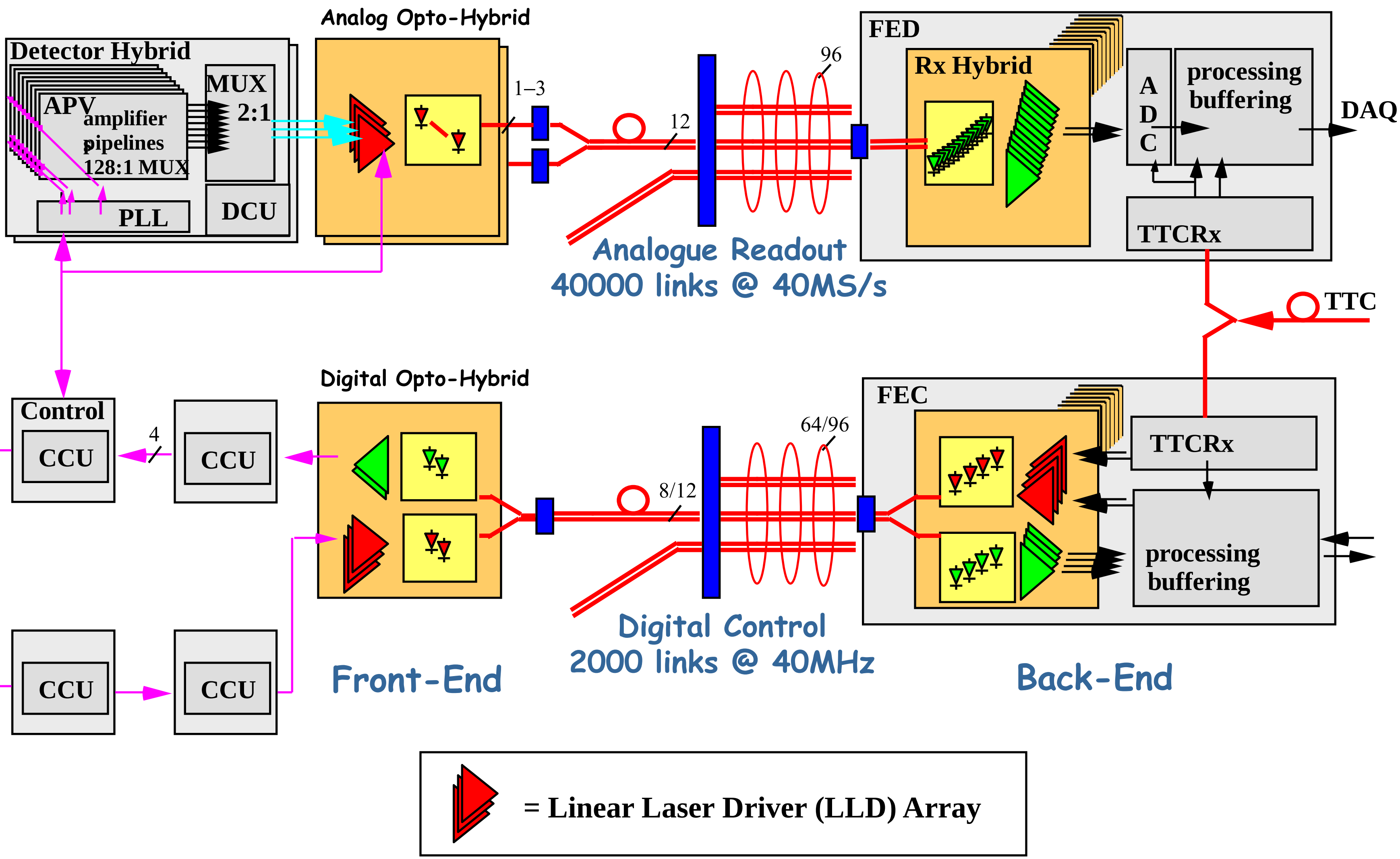
# GOL: Improving the SEU Tolerance

- Fast logic:
  - Increased size transistors
- Analog circuits:
  - Bias currents doubled were possible.
  - Loop-filter "impedance" reduced, maintaining loop-dynamics.
  - Node capacitance increased for "standstill" nodes.
- All this at the price of added power consumption:
  - 800 Mbit/s ⇒ 275 mW (includes 7.8 mA VCSEL bias current)
  - 1.6 Gbit/s ⇒ 390 mW (includes 7.8 mA VCSEL bias current)

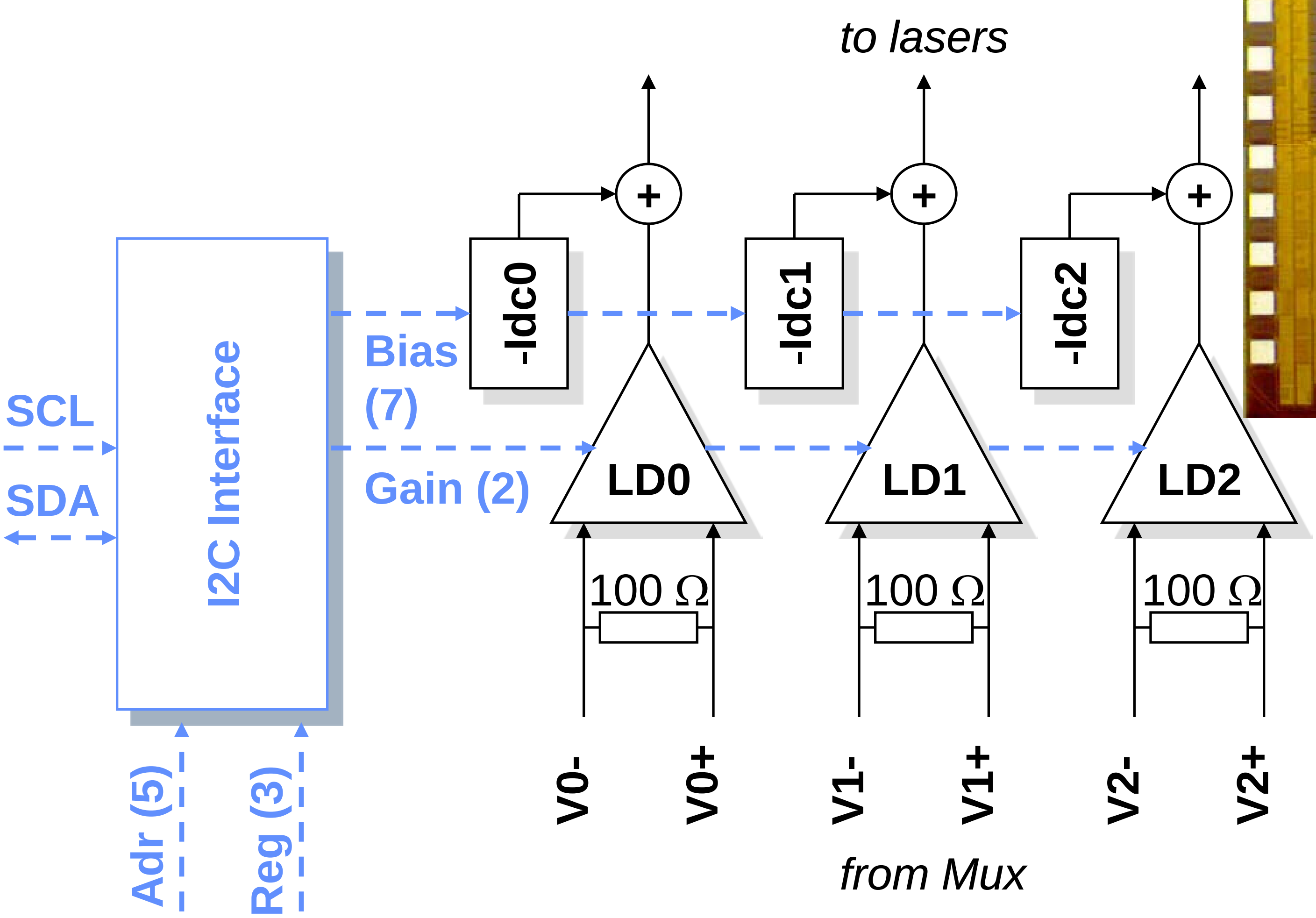
EELD: 1.6 Gbit/s

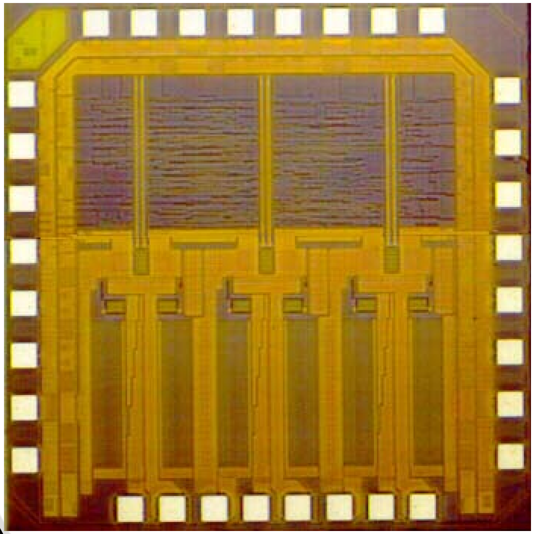


# CMS Tracker Readout and Control Electronics

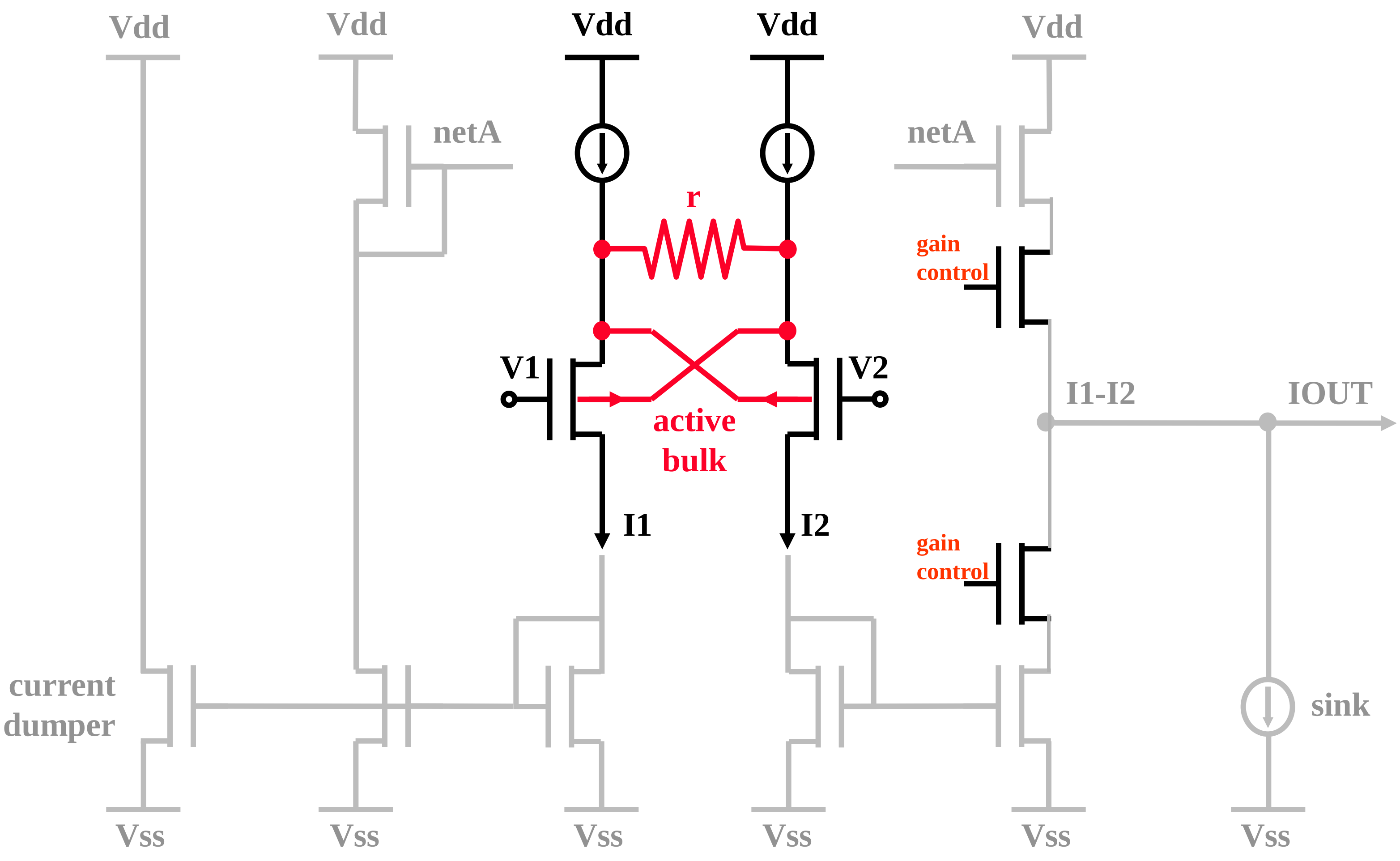


# Linear Laser Driver (LLD)



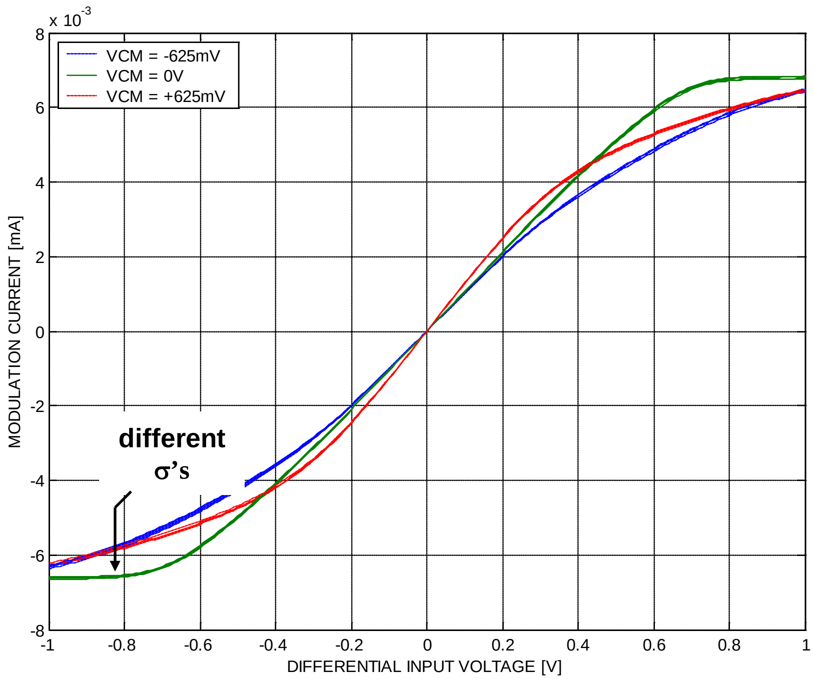



# LDD: Circuit

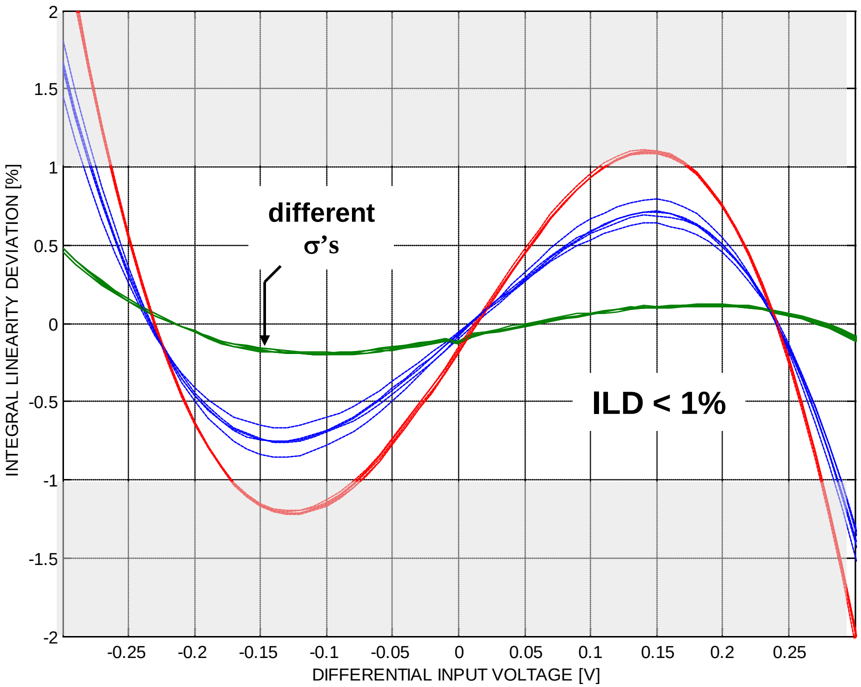

Vdd
Vdd
Vdd
Vdd
Vdd
netA
netA
r
gain
control
V1
V2
active
bulk
I1-I2
IOUT
I1
I2
gain
control
current
dumper
sink
Vss
Vss
Vss
Vss
Vss
Vss

# LLD: Gain and Linearity

## TRANSFER CHARACTERISTIC



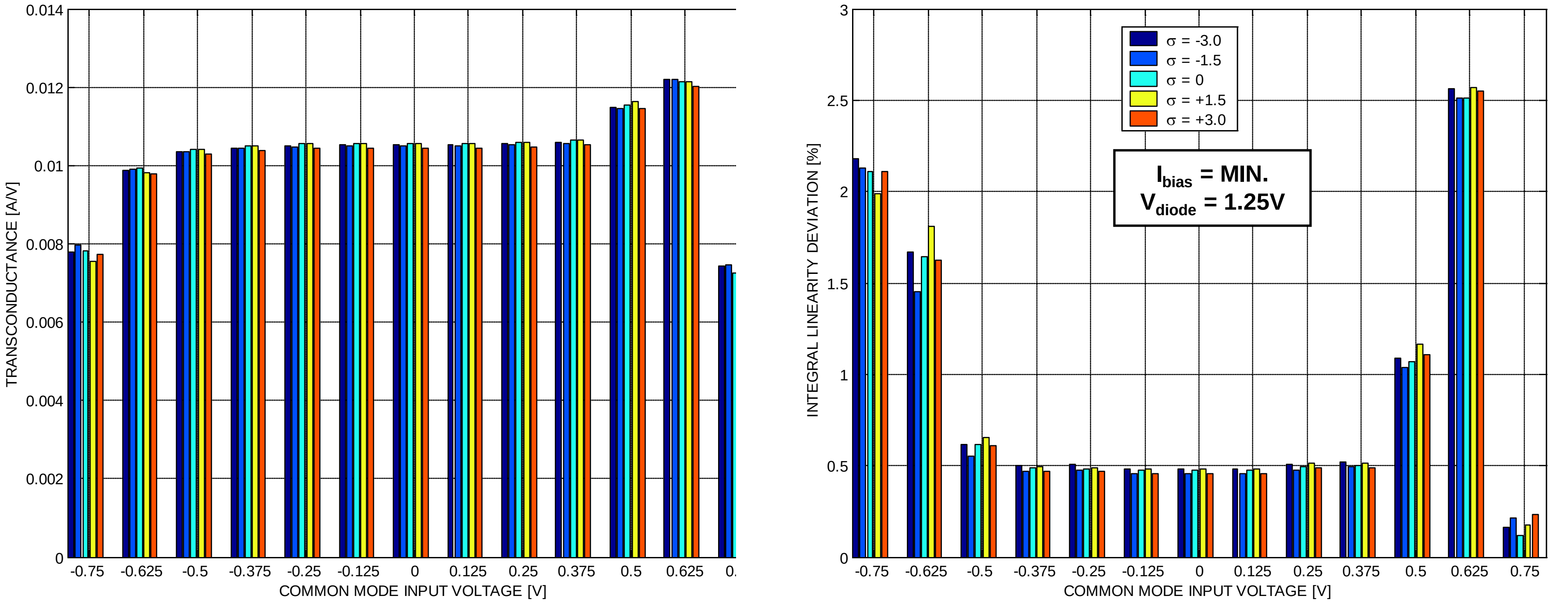

## LINEARITY




- Linear operating range: ±300mV
- Integral linearity deviation: <0.5% (Vcm=0)

# Common Mode

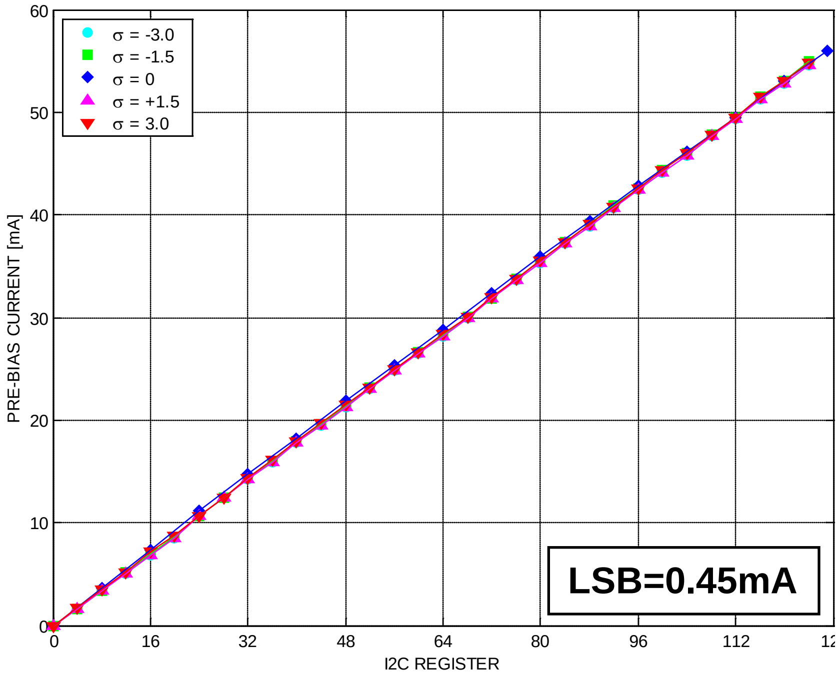
## GAIN AND LINEARITY VS. INPUT COMMON MODE



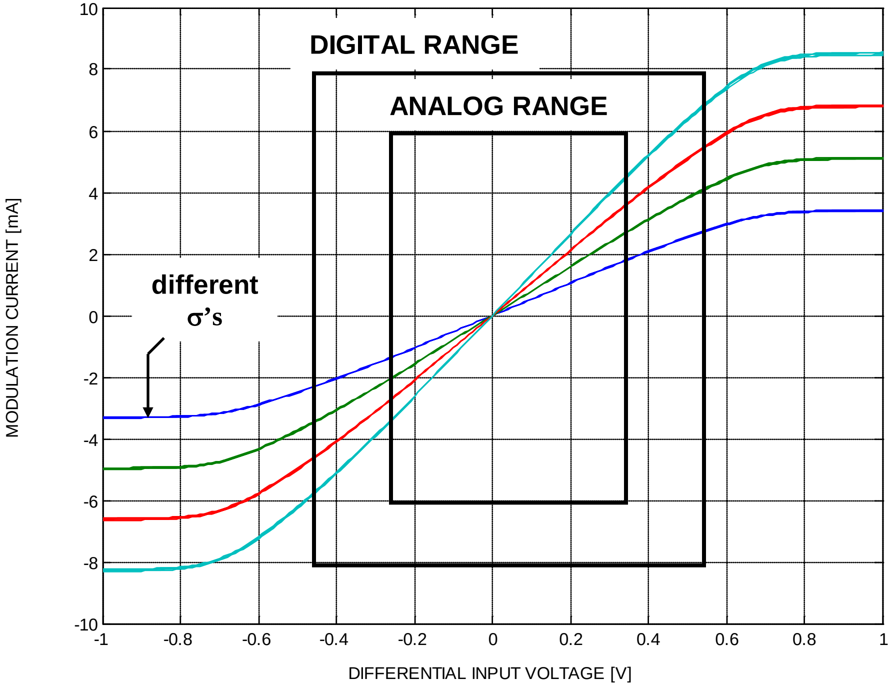

- Input common-mode range: ±350mV (for specified gain and linearity)

# LLD: characteristics

Laser Bias Current



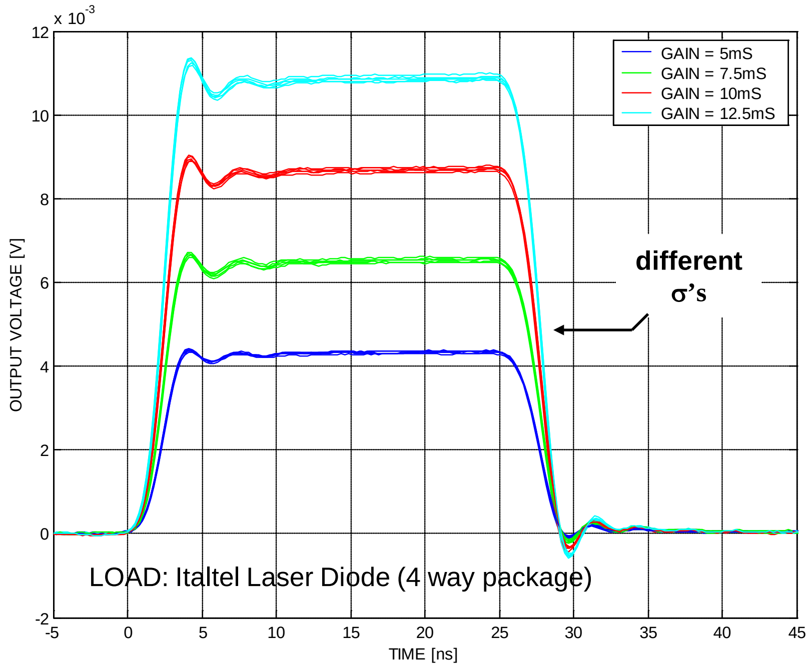

Transfer Characteristics

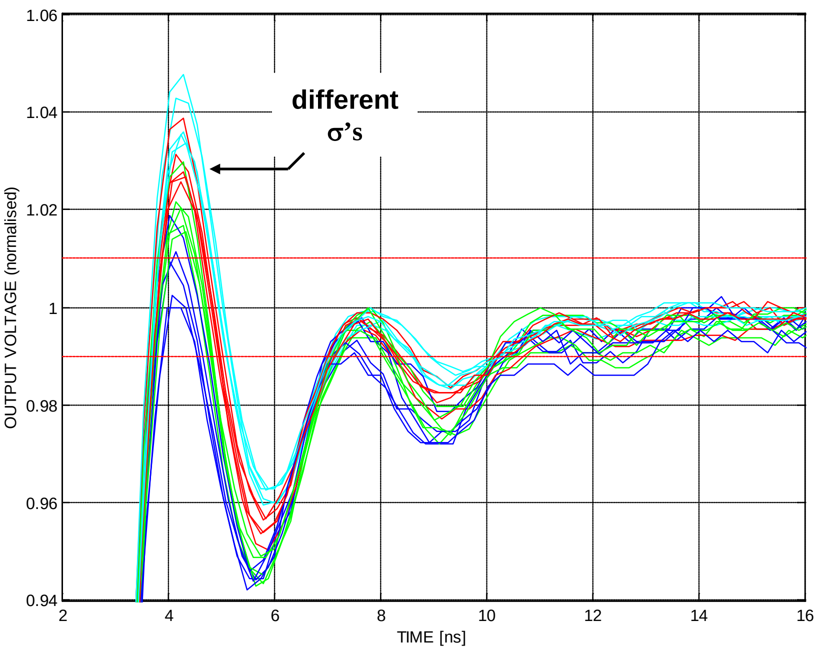



Programmable

- Laser bias: 55mA (7bits)
- Gains: 5mS, 7.5mS, 10mS, 12.5mS

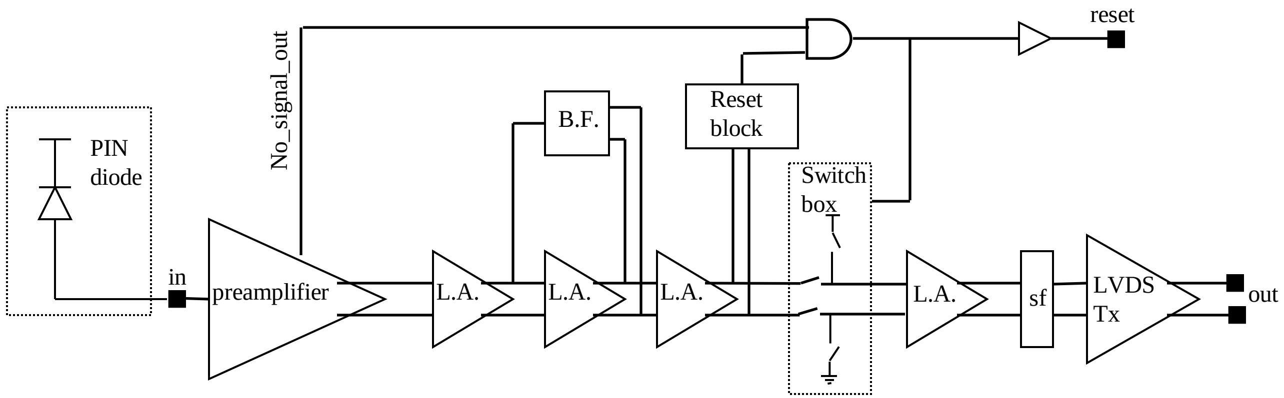
# LLD: Time response



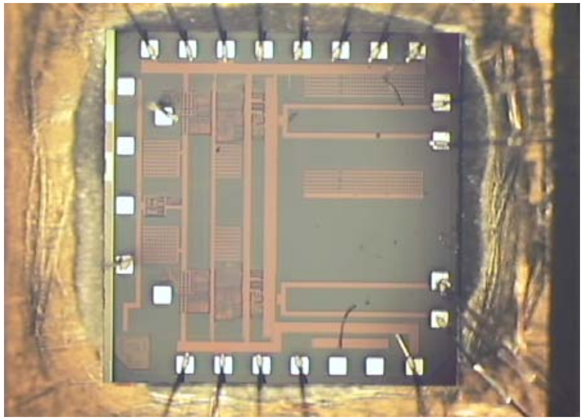

- Rise/Fall Times (10% to 90%): 2.5ns
- Settling Time (to 1% of final value): 10-12ns

# RX40 Optical receiver

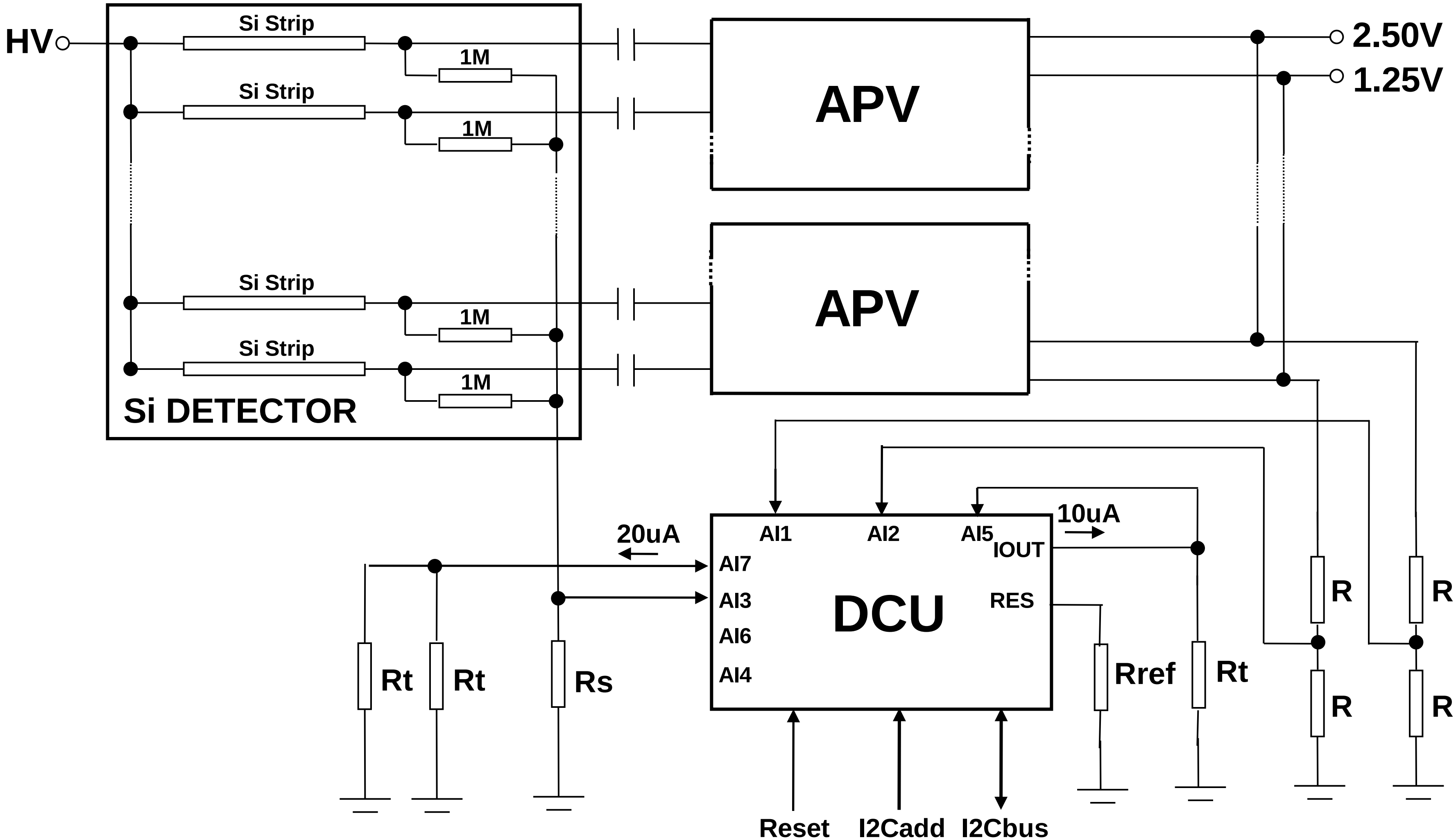



| | *Min* | *Typ* | *Max* | *Unit* | *Note* |
|---|---|---|---|---|---|
| **DC input current** | | | **500** | **µA** | **Baseline DC current** |
| **AC input current** | **10 (after rad)** | | **500** | **µA** | |
| **Bandwidth** | **80** | | | **MHz** | |
| **Low cut-off frequency** | | | **1-2** | **MHz** | |
| **Jitter** | | | **0.5** | **ns** | |
| **Output voltage level** | | **LVDS** | | | |
| **Supply voltage** | | **2.5** | | **V** | |
| **Sensitivity** | | **-20** | | **dBm** | |
| **Bit error rate** | | **$10^{-12}$** | | | |
| **Reset output** | | | | | **Low for >5µs for a transmission of 20 consecutive ‘0’** |
| **Coupling with p-i-n diode** | | **DC** | | | |
| **Diode bias voltage** | | **1.8** | | **V** | |

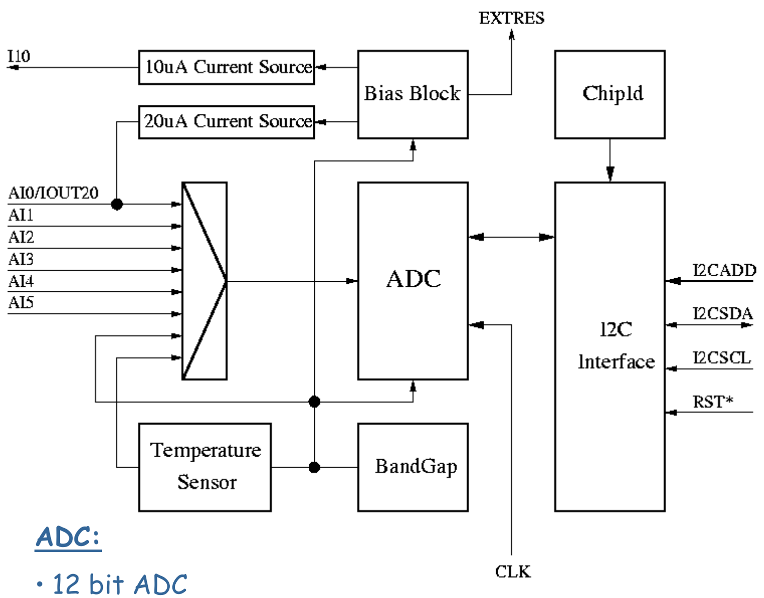
4 channels / chip

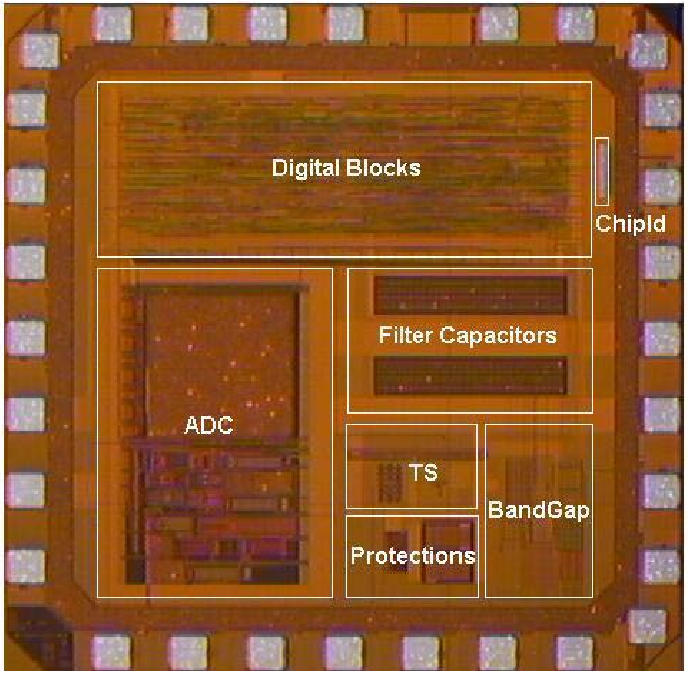


# Detector Monitoring System



# DCU Architecture



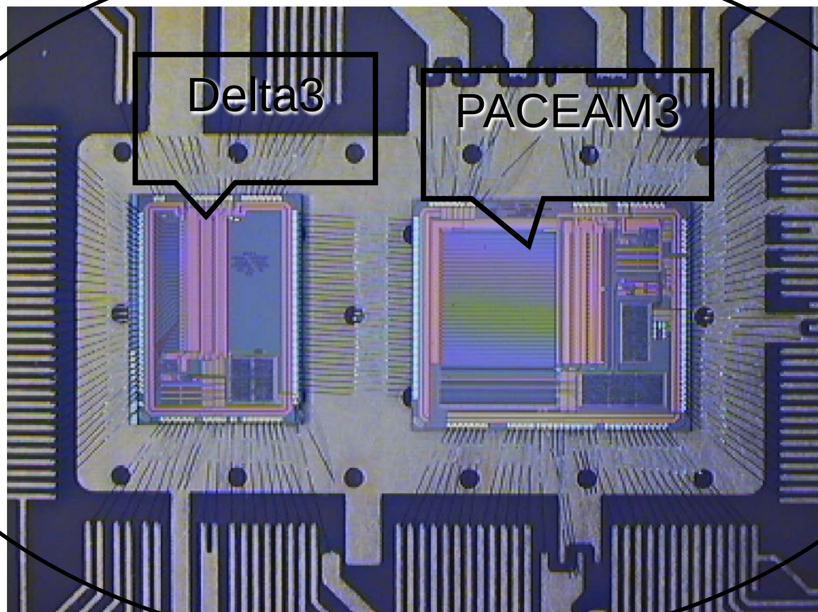

**ADC:**

- 12 bit ADC
- |INL| < 1 LSB (in the input range)
- |DNL| < 1 LSB (monotonic characteristic, no missing codes)
- Noise RMS < 0.5 LSB (transition noise)
- Conversion time: 0.25 ms (maximum value)
- Power Consumption: < 40 mW

**Integrated Temperature sensor:**

- Gain = 9.22 LSBs/C (resolution ~ 0.108 C)
- Out @ 25C 2469 (RMS = 32.3) ⇒ Calibration required
- INL < 2.5 LSBs (-30C → +30C)

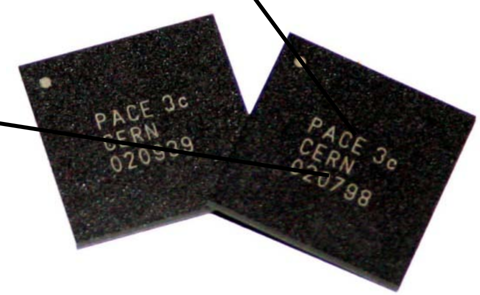
# PACE3




**Assembly of two ASICs**

**Delta3 and PACEAM3**

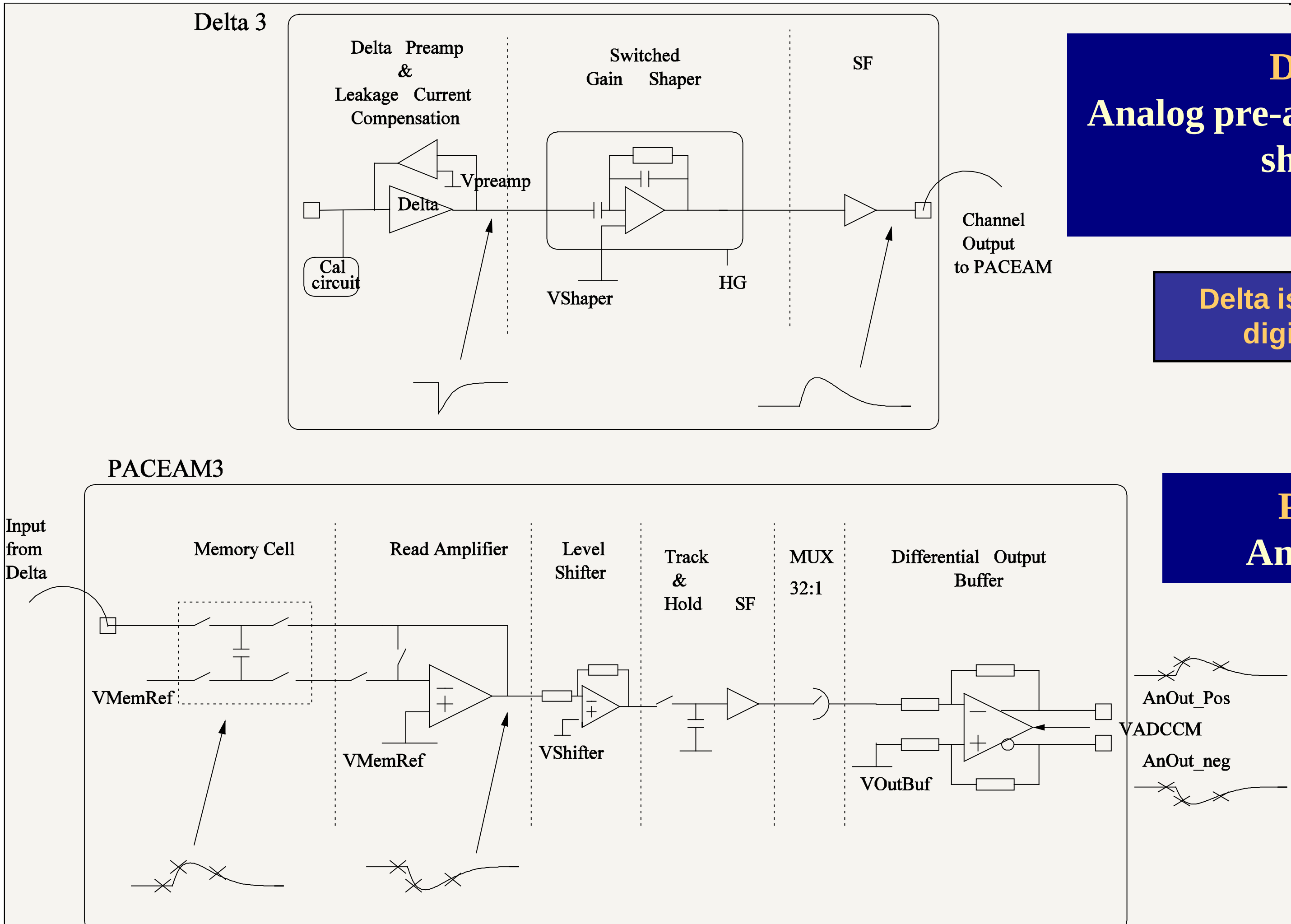
**Packaged within a 196 pin FPBGA**




**ASIC Technology**
**0.25μm CMOS**

**2.5V power supply**

# PACE3 analog chain



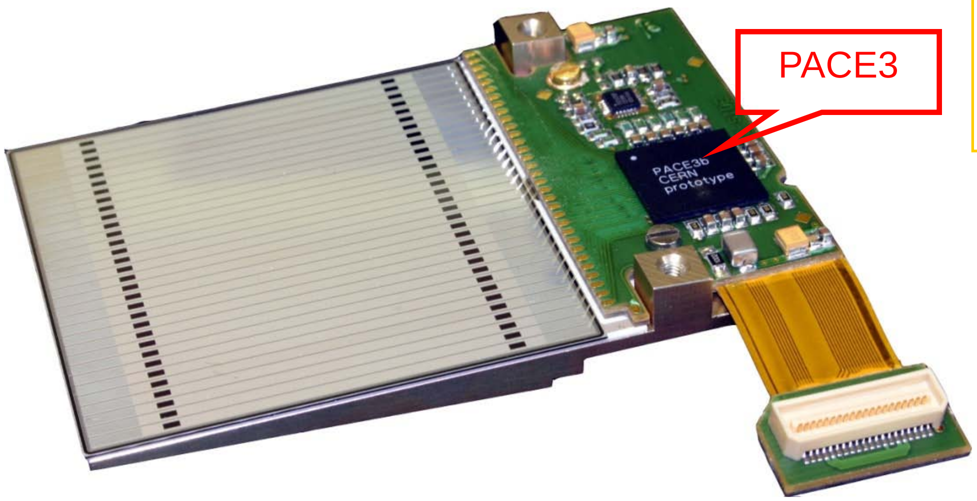

**Delta3:**
**Analog pre-amplification and shaping.**

**Delta is void of any digital clock.**

**PACEAM3:**
**Analog memory**

**3 samples stored per trigger.**

# PACE3 with Preshower Si Sensors




**The Preshower Micro-module**

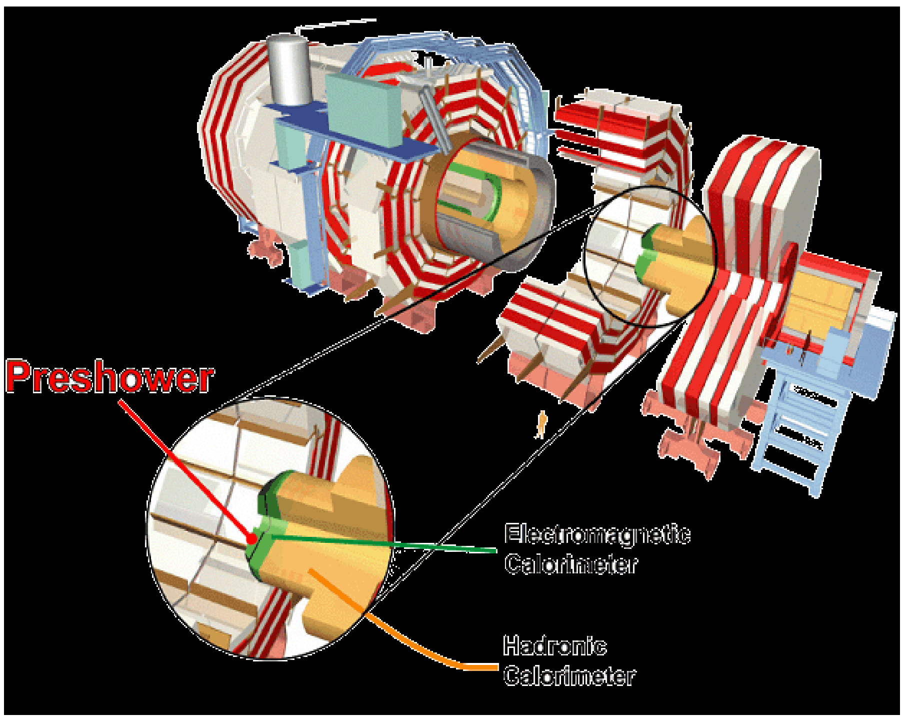
**Silicon sensor (~ 61mm x 61mm )**
**32 channels**
**(1.875 mm channel pitch)**

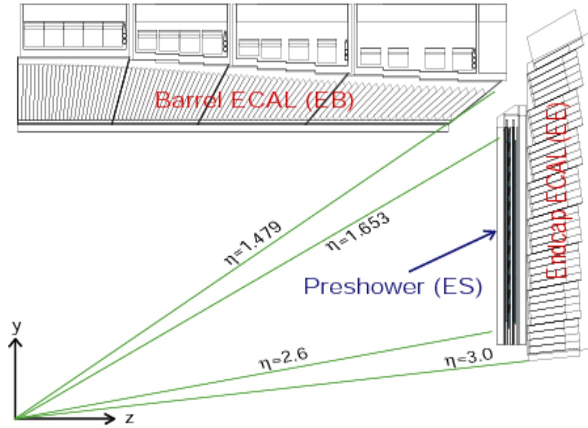
**Silicon thickness = 320µm**
**1 Minimum Ionising Particle deposits an average of 3.7 fC of charge (23257 e)**

# PACE3 Design Application

## The CMS Preshower Detector for LHC

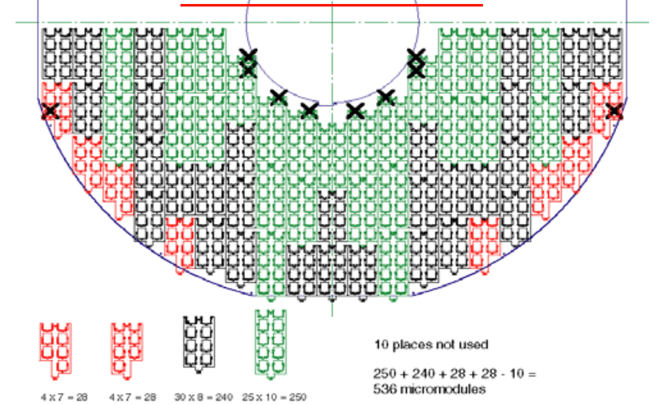
~ 4300 sensors
4.1 m$^2$ active silicon per disc




**2 layer sampling calorimeter to detect photons with a good spatial resolution for *Π0* rejection.**
**Incident photons on lead absorbers initiate electromagnetic showers of electrons, positrons and photons.**

Preshower Disc



# VFAT2 Functions

- **Trigger ……..**
  - Provide intelligent "FAST OR" information as an input for the first level trigger (LV1A).
  - Programmable segmentation for Roman Pot and GEM configurations.

- **Tracking …….**
  - Binary "hit" information for each of the 128 channels as triggered by the LV1A.

Reference for VFAT2:

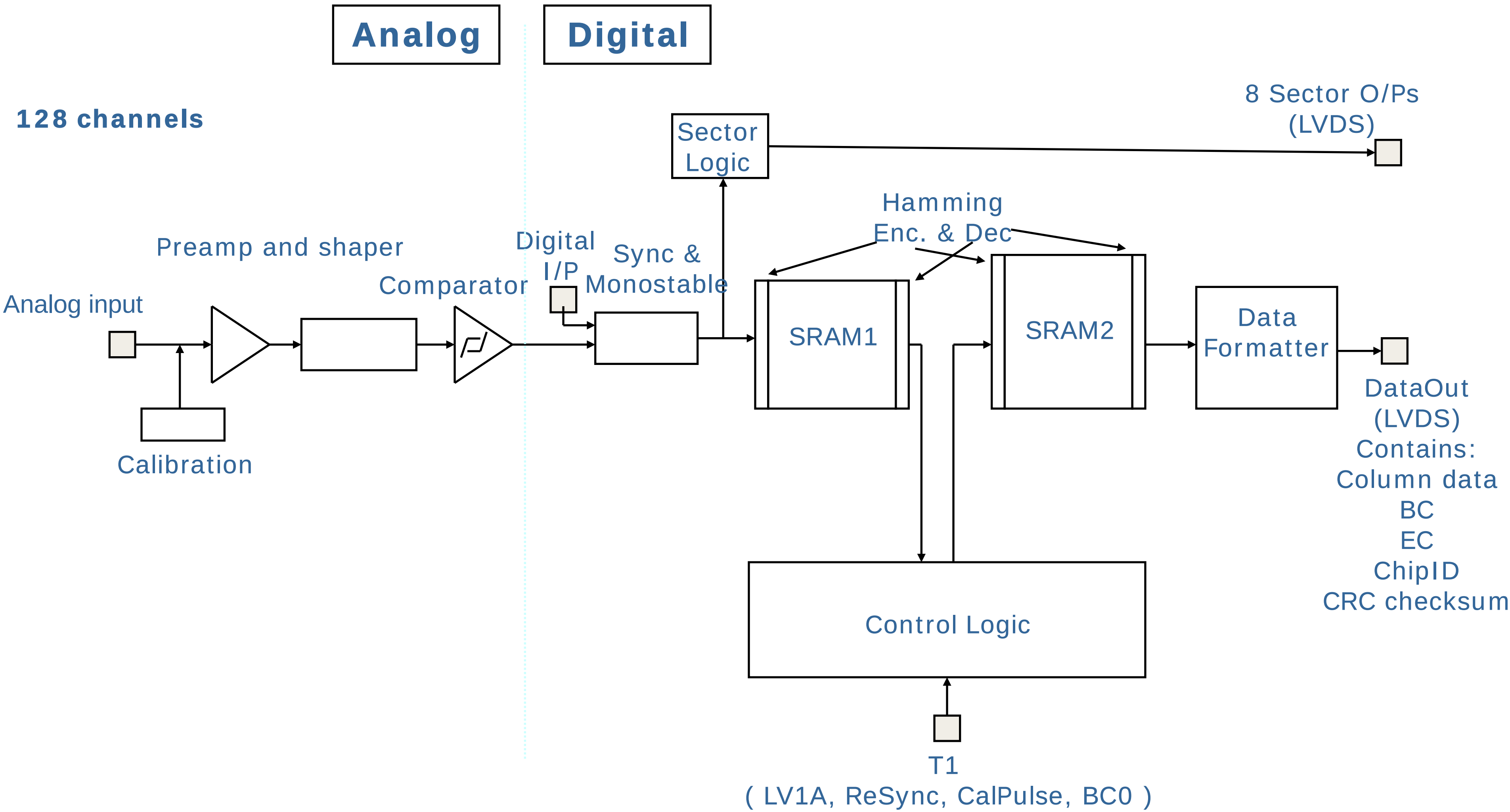
"VFAT2: A front-end system on chip providing fast trigger information, digitized data storage and formatting for the charge sensitive readout of multi-channel silicon and gas particle detectors."

Proceedings of TWEPP Prague, Czech Republic, 3-7 September 2007, ISBN 978-92-9083-304-8, p.292 .

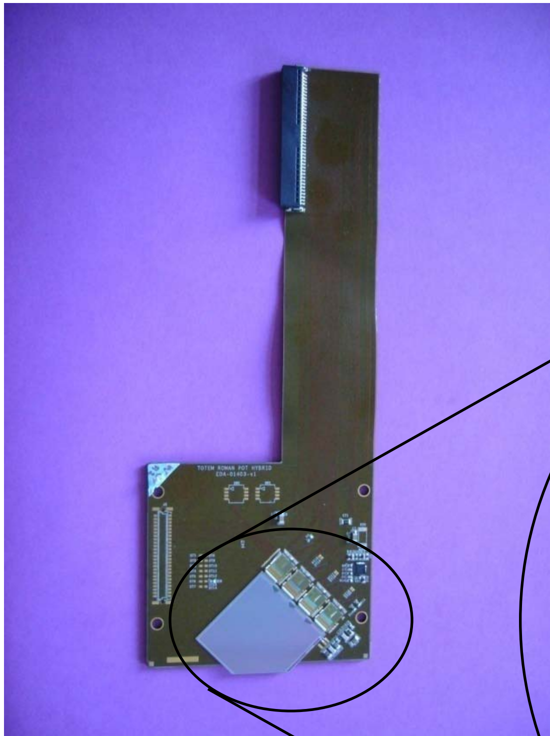
# Trigger and Tracking Functions

- **128 channel**
  - low noise front-end chip for binary readout of capacitive sensors.
- **40MHz signal sampling**
  - dead time free
- **Digital memory**
  - Programmable LV1A latency up to 256 clock periods.
  - Simultaneously storage of up to 128 triggered events.
- **Trigger building**
  - Programmable "fast-OR" trigger building outputs
- **Internal calibration**
  - via internal test pulses with programmable amplitude
- **Fully programmable**
  - through an I2C interface.
- **Data packet output**
  - includes headers, counters, flags and CRC check
- **Radiation tolerant design**
  - suitable for use in demanding radiation environments both with respect to ionizing radiation and Single Event Upset.

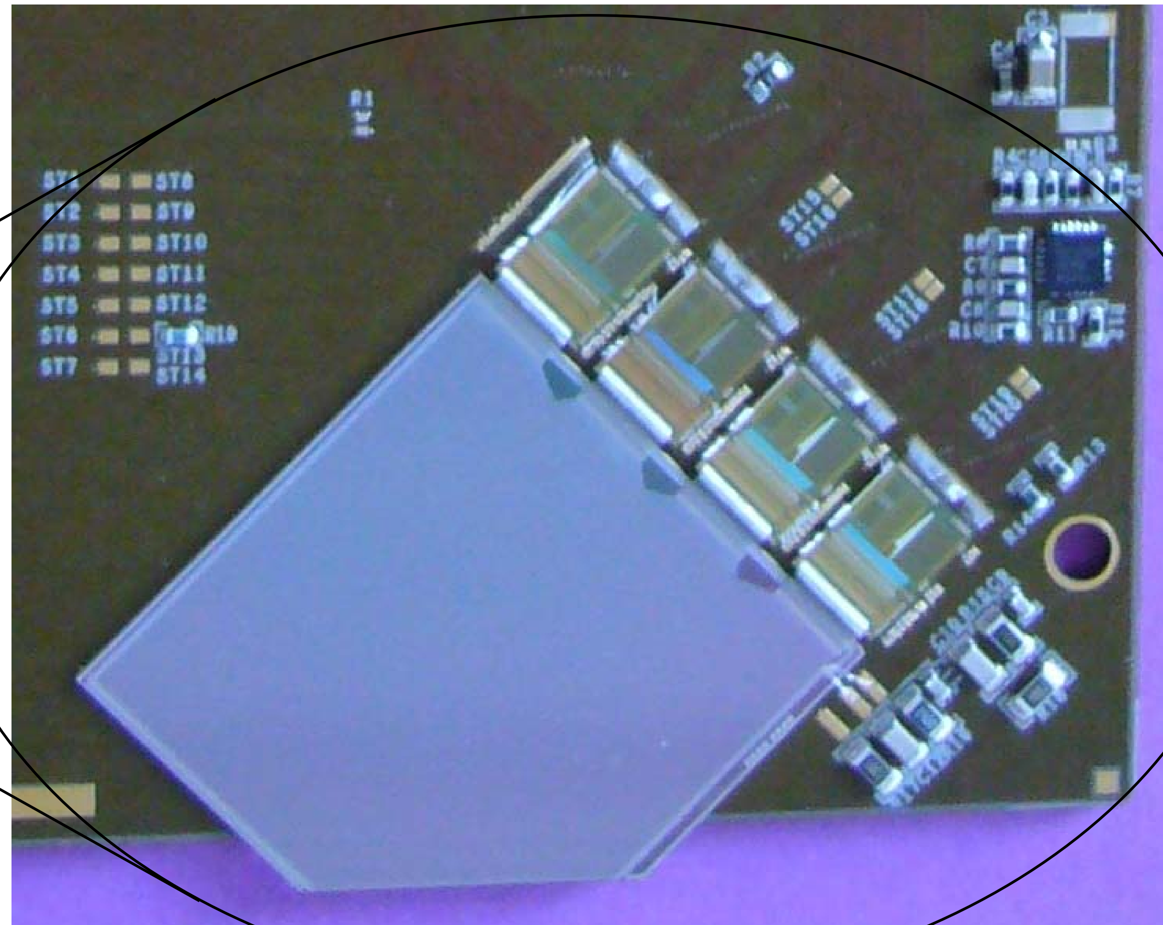
# VFAT2 Signal Flow



# Totem Si Sensor with 4 VFATs



Totem Roman Pot board with 4 VFATs



Silicon strips
512 channels
4 VFATs
Noise ~ 1000 e / channel

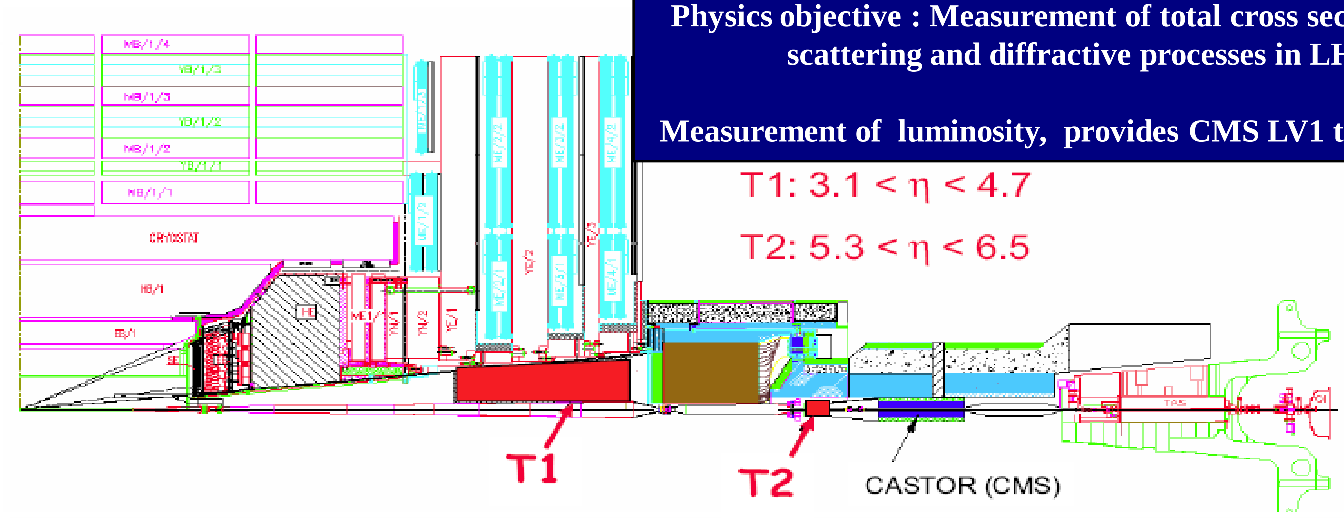
# VFAT2 Design Application

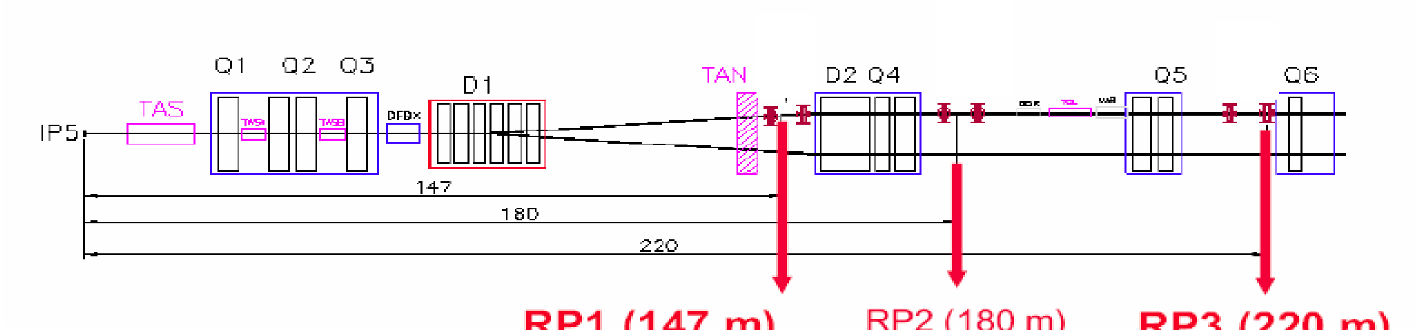
## TOTEM in LHC

**Physics objective : Measurement of total cross section, elastic scattering and diffractive processes in LHC.**

**Measurement of luminosity, provides CMS LV1 trigger input.**

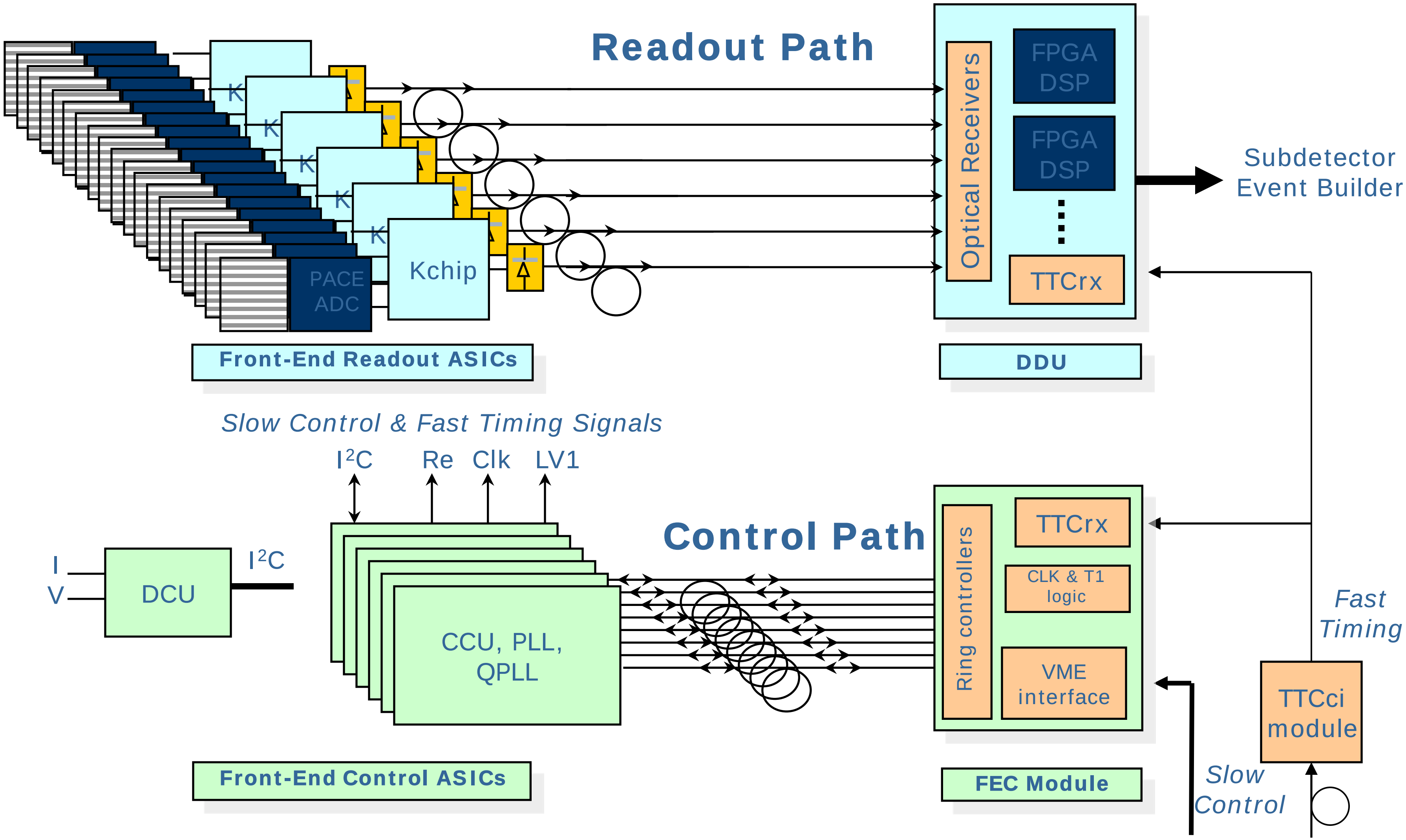
CMS



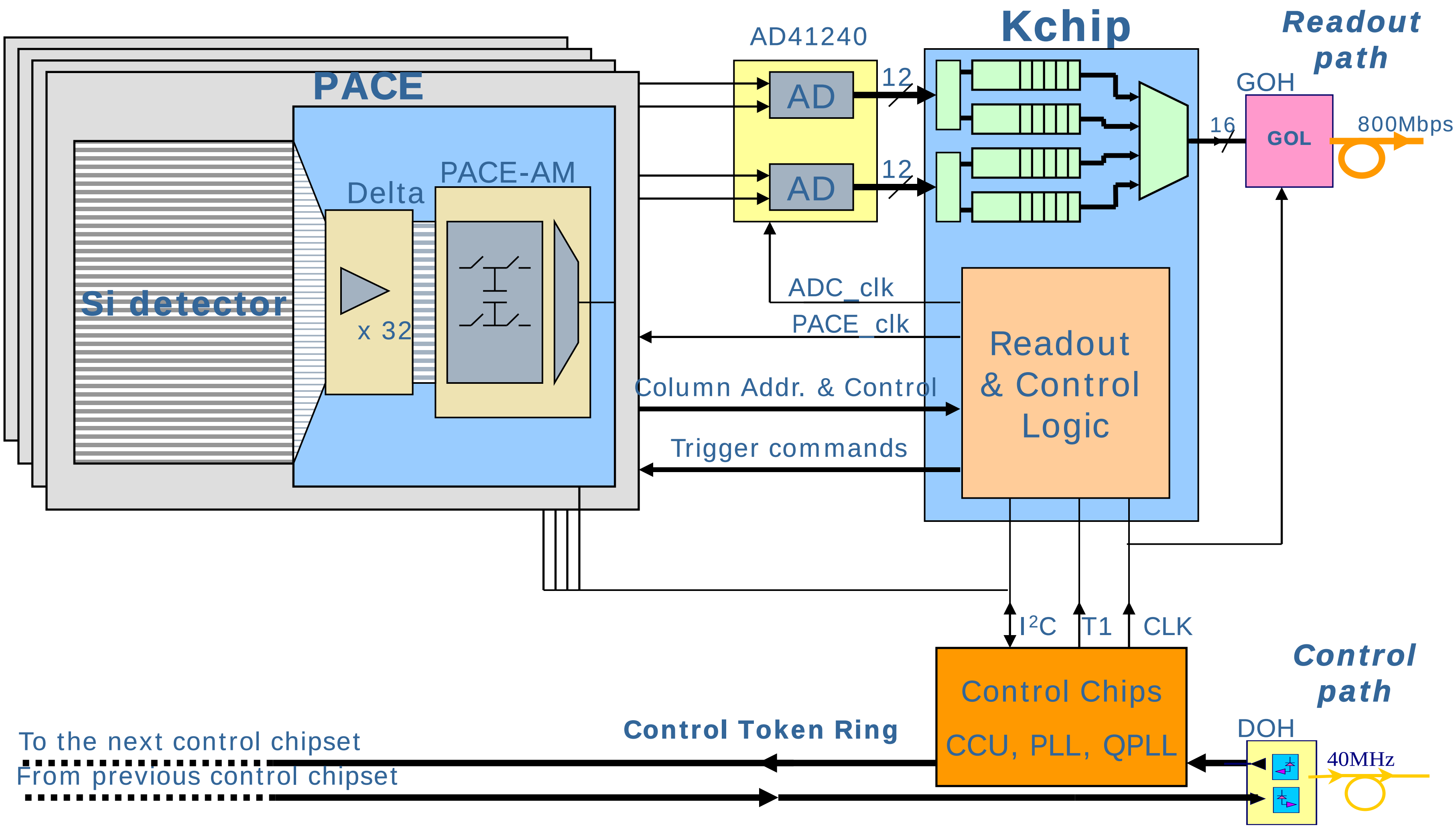




K.Eggert/CERN

# Preshower Front-End System



# Preshower Front-End Readout



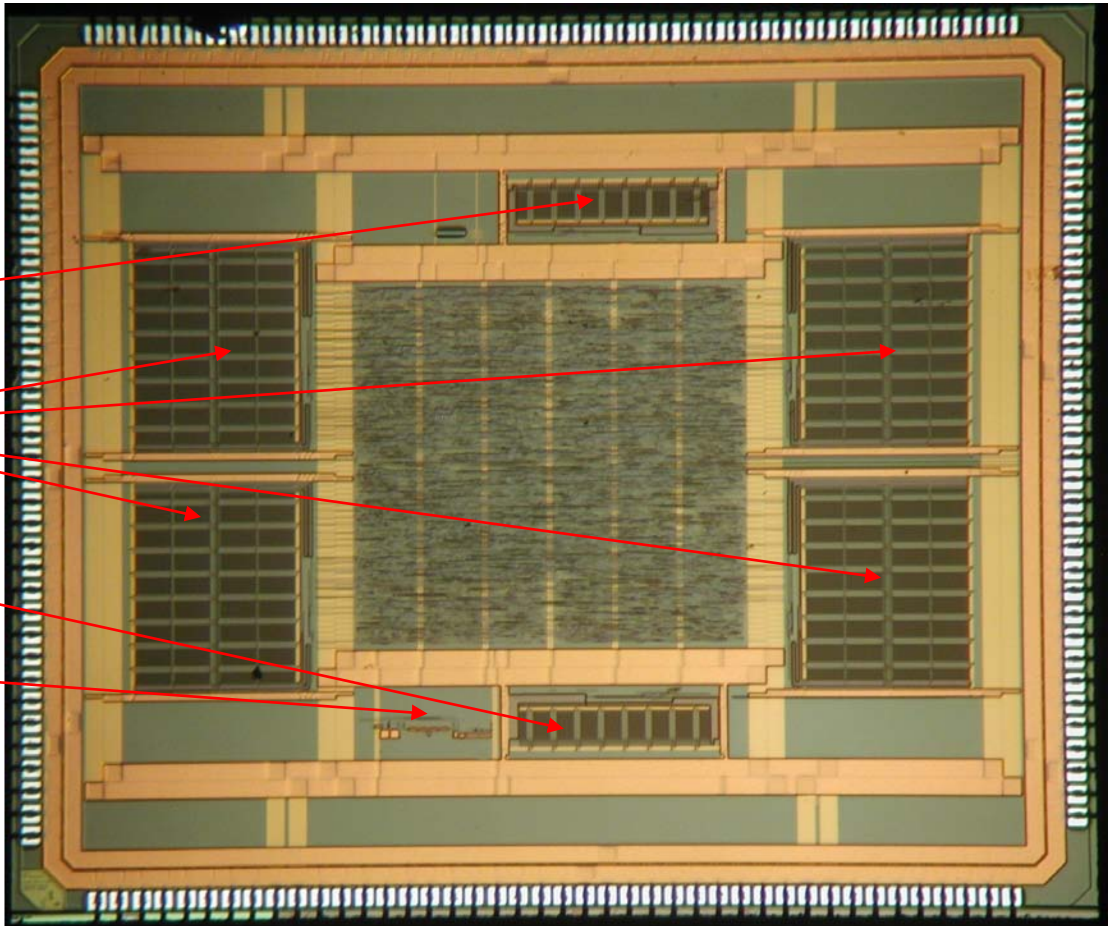
# Kchip Functionality

- Data Concentration
  - Can be configured to readout 1~4 PACE chips.
- Event Data Formatting
  - Align data into 16-bit words.
  - Assemble an Event Packet.
  - Assign a Bunch Count (BC) and Event Count (EC) Identifier.
  - Link Protocol for transmission through a Gigabit Optical Link.
- Readout Controller
  - Trigger Command Decoding
  - PACE Readout Synchronization Monitoring
  - Front-End Buffers Overflow Detection / Prevention
  - PACE & ADC clock and Trigger Command Distribution

# Kchip Layout

<u>$1^{st}$ Prototype</u>

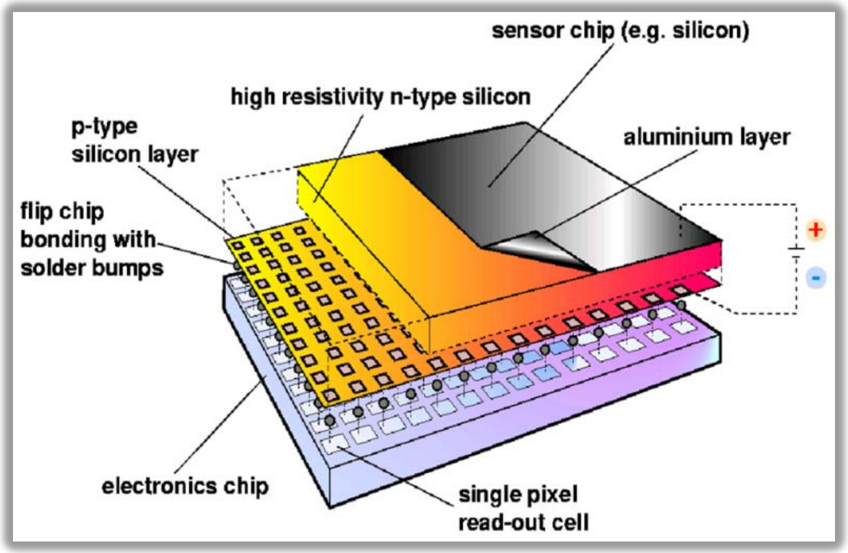
CERN MPW10
Submitted: Feb. 2003
Received: June 2003



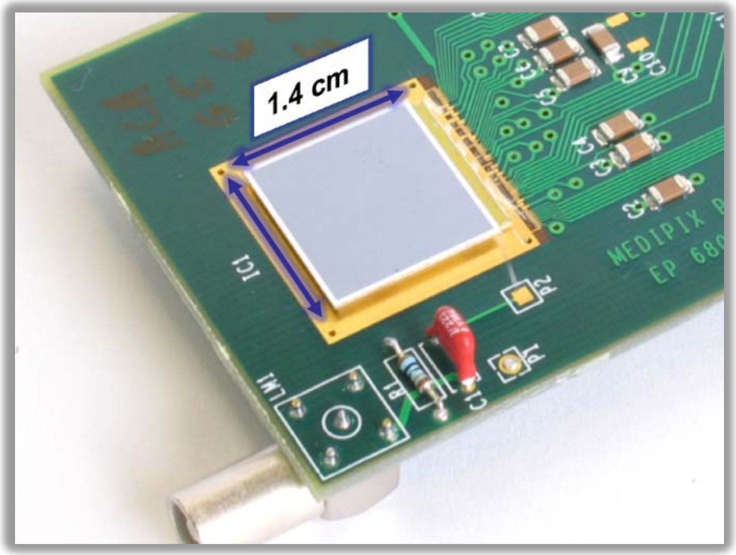
# The Medipix Project

- International collaboration formed by 18 members to exploit the acquired knowledge at CERN in the design of particle track detectors in HEP to provided a noise-free X-ray imaging system with small spatial resolution (55 µm).
- The Medipix chip uses direct detection single photon counting hybrid pixel detector approach:
  - Linear and unlimited dynamic range
  - Continuous data taking possible:
  - noise suppression, large SNR
  - Multi-thresholds → energy discrimination

Schematic of an hybrid pixel detector



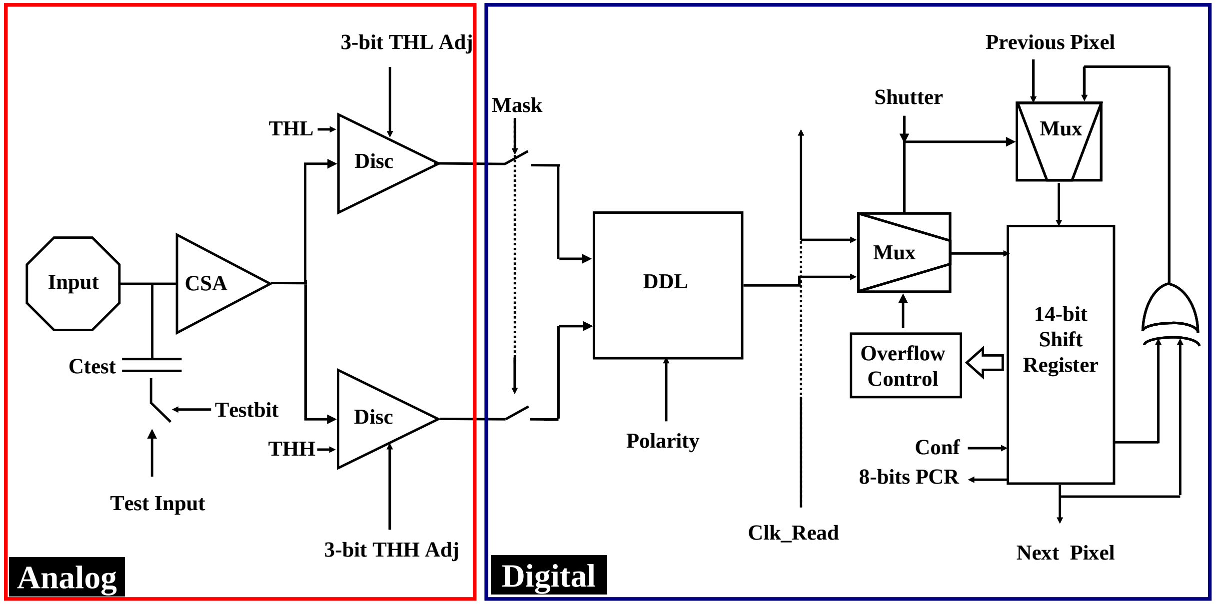

Medipix2 hybrid (1.4 x 1.4 cm$^2$)

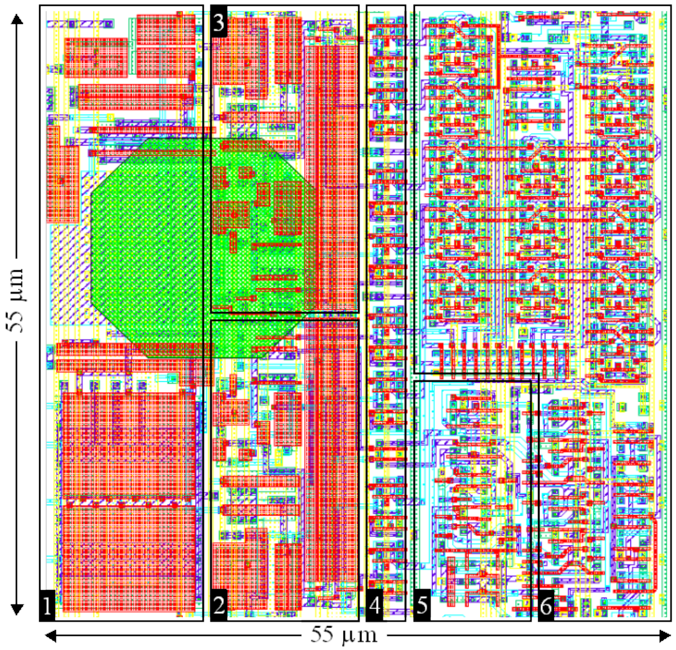


# Medipix2 pixel

- The Medipix2 chip contains 256 x 256 pixels
- Pixel properties:
  - DC leakage current compensation per pixel
  - Sensitive to positive and negative input charges
  - Energy window discrimination (2 thresholds)
  - 3-bit threshold adjustment per threshold
  - 14-bit counter (11810 counts) per channel
  - Static power consumption is 8μW per pixel

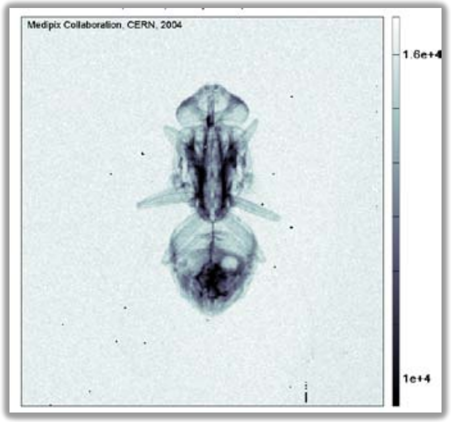
**Medipix2 schematic**



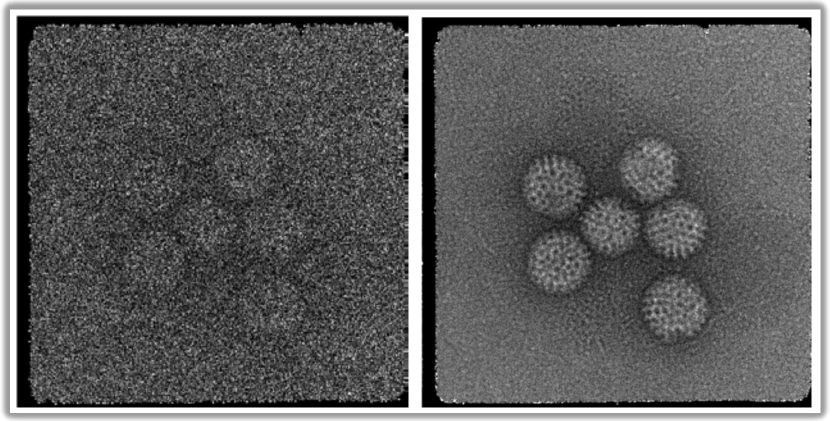



# Applications using Medipix2

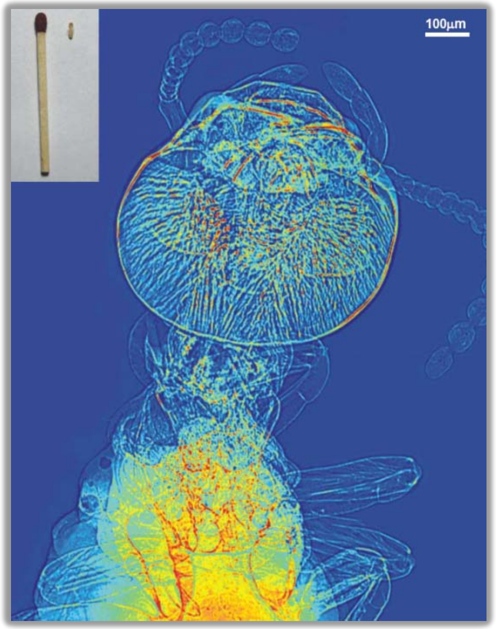
- Applications: Adaptative optics, X-ray diffraction, Micro-radiography, Neutron imaging, Computed tomography, Autoradiography, Gamma imaging, Electron microscopy, energy weighting, In vivo optical and radionuclide imaging, Micro-patterned gas detectors, Mammography…



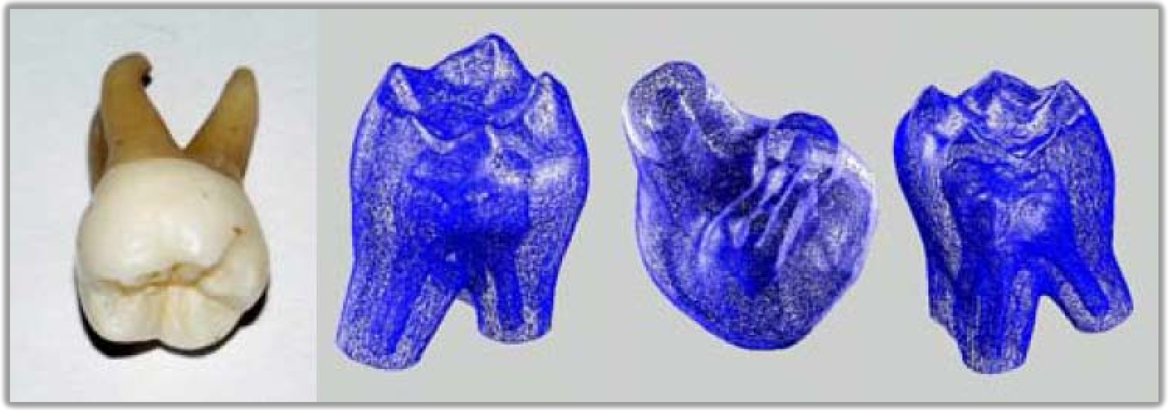

X-ray image of a house fly (CERN)



Electron microscopy: Rotavirus with 1.6 (left) and 160 (right) $e^-$/pixel, equivalent to: 0.04 $e^-$ /Å$^2$ at specimen (left) and 4 $e^-$ /Å$^2$ (right) (MRC, Cambridge)




Micro-radiography: Assembled radiograph of a termite. Real size of the image is approximately 1.4 mm x 1.7 mm (IEAP, Prague)



Neutron imaging: Photograph and tomographic 3D reconstructions of a tooth (IEAP, Prague)

**http://www.cern.ch/MEDIPIX**