



**I N 2 P 3**

**INSTITUT NATIONAL DE PHYSIQUE NUCLÉAIRE  
ET DE PHYSIQUE DES PARTICULES**

# Electronique en physique des particules

*Cargèse 2004*

**C. de LA TAILLE**

**LAL Orsay**

**Taille@lal.in2p3.fr**

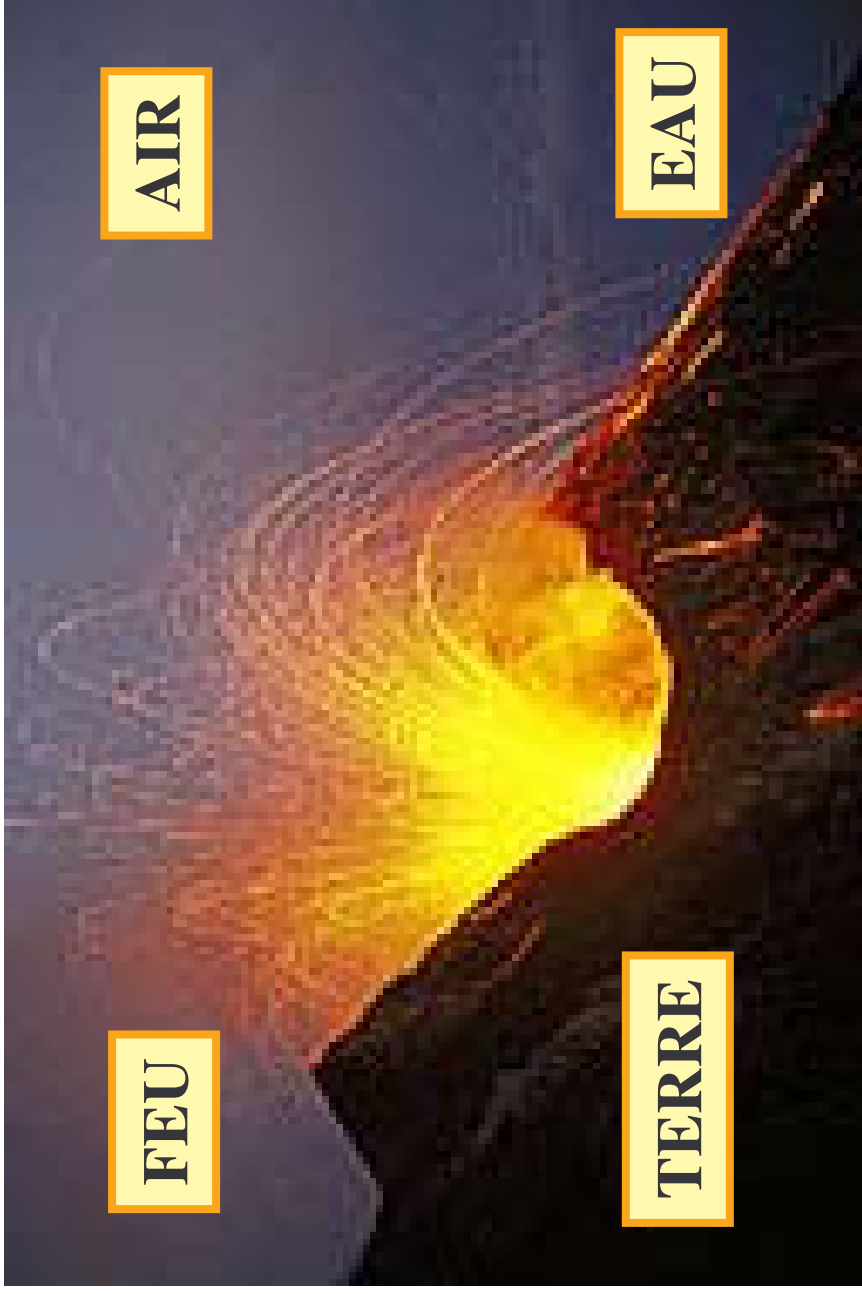
<http://www.lal.in2p3.fr/>

# Introduction aux enjeux de la physique des particules

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- Historique : de 4 éléments

[L. serin Roscoff 2003  
R. Landua CERN 2003 ]



- Et 2 forces : Amour et Haine



# Periodic Table of the Elements

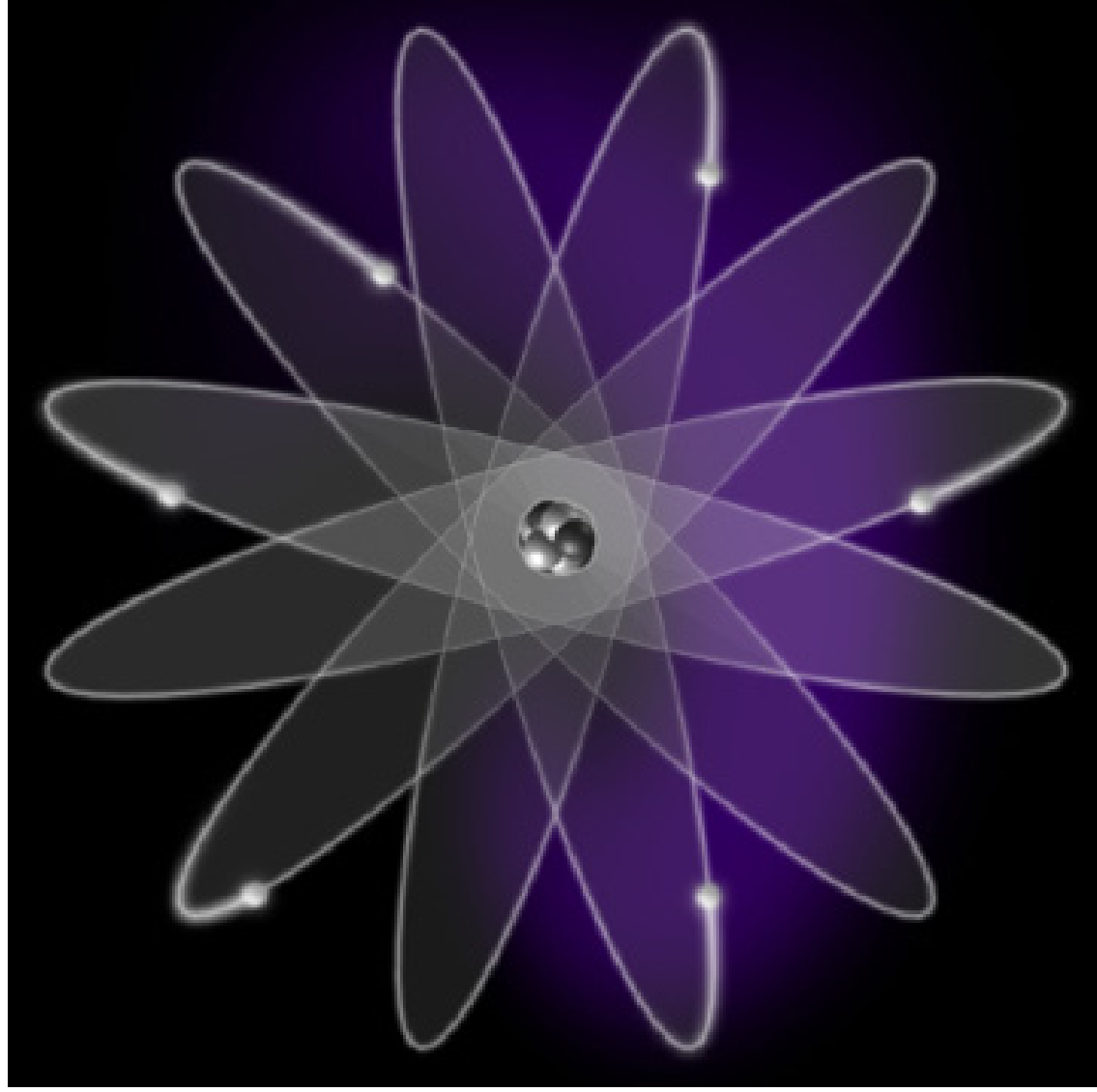
1	2	3	4	5	6	7	8	9	10
1A	2A	3A	4A	5A	6A	7A	8A	9A	0
1	2	3	4	5	6	7	8	9	0
H	He								
3	4	5	6	7	8	9	10	11	12
Li	Be	B	C	N	O	F	Ne		
11	12	13	14	15	16	17	18	19	20
Na	Mg	Al	Si	P	S	Cl	Ar		
19	20	21	22	23	24	25	26	27	28
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni
37	38	39	40	41	42	43	44	45	46
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd
55	56	57	72	73	74	75	76	77	78
Cs	Ba	*La	Hf	Ta	W	Re	Os	Ir	Pt
87	88	89	104	105	106	107	108	109	110
Fr	Ra	+Ac	Rf	Ha	106	107	108	109	110
					111	112	113	114	115
					116	117	118	119	120

Naming conventions of new elements

*Lanthanide Series	58	59	60	61	62	63	64	65	66	67	68	69	70	71
	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
+Actinide Series	90	91	92	93	94	95	96	97	98	99	100	101	102	103
	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

# Le modèle planétaire de l'atome

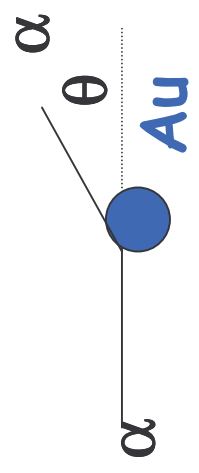
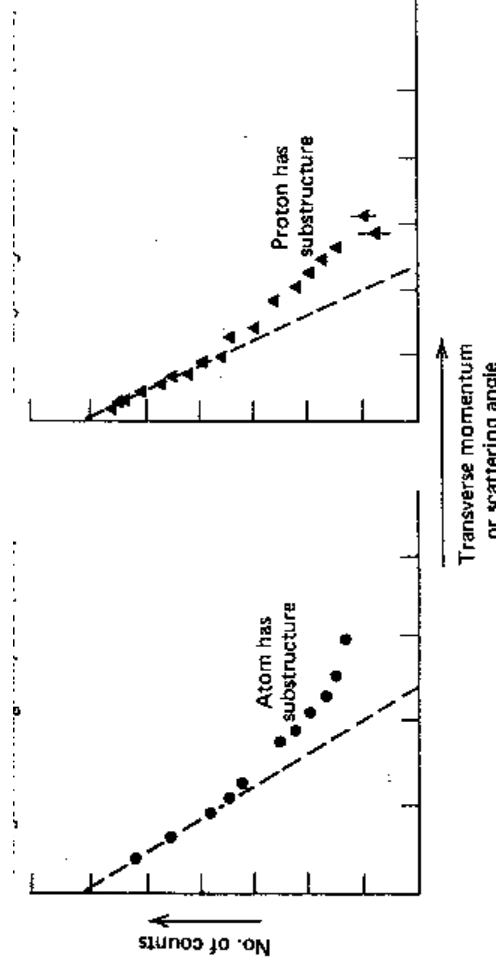
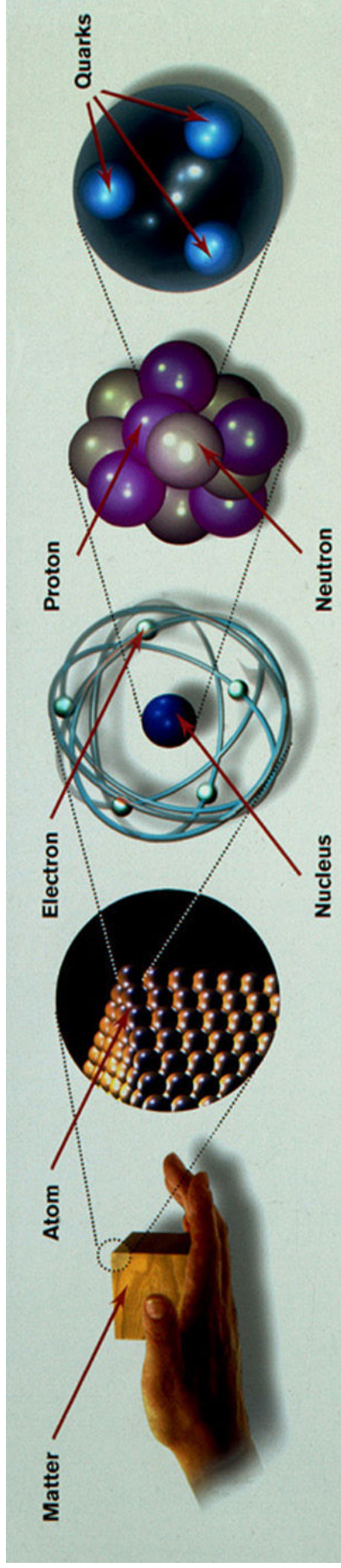
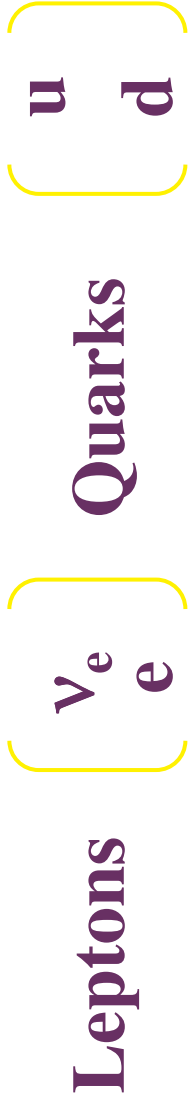
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$$R \sim 1/m_e$$

# Particules

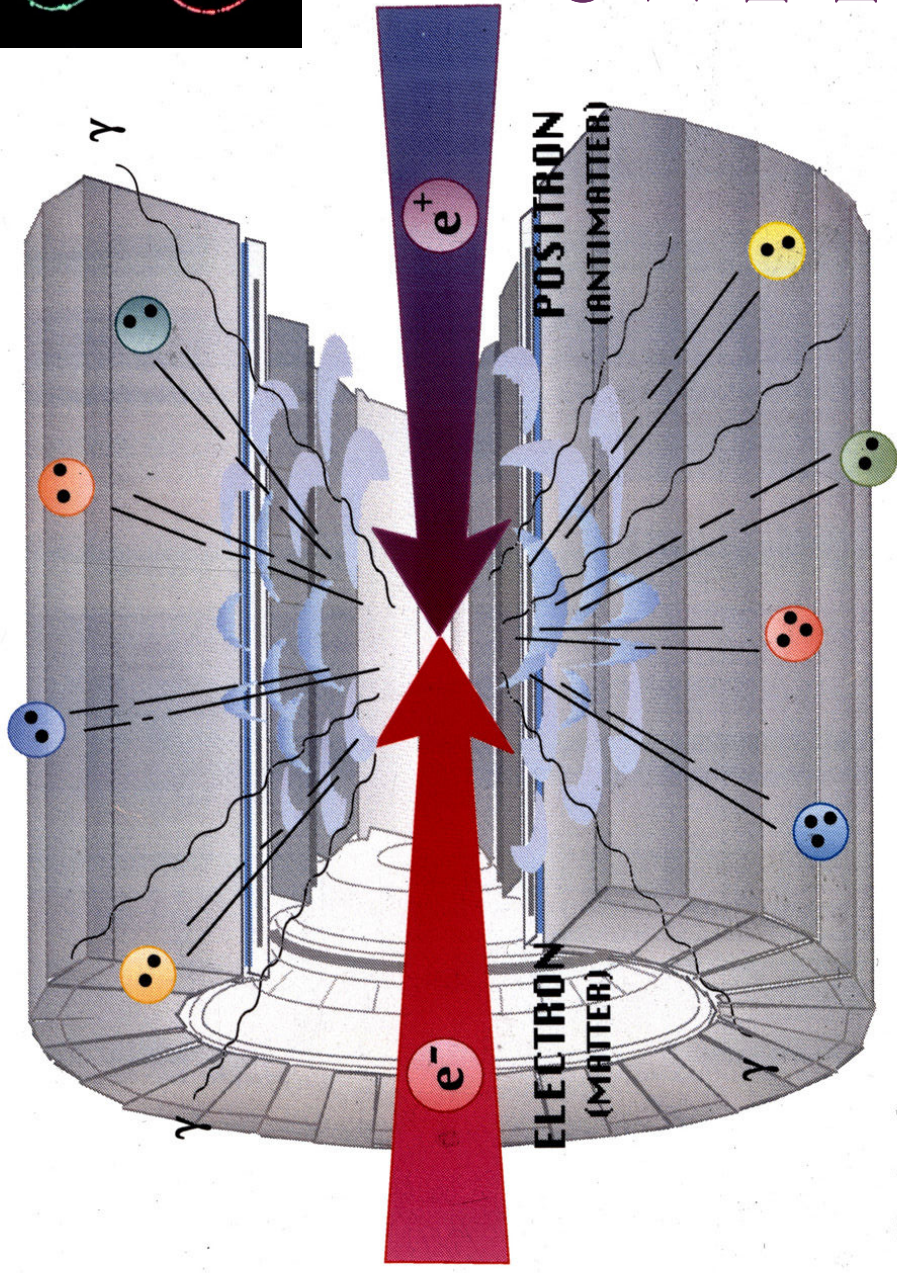
■ La matière est constituée de quarks et leptons



# Pourquoi accélérer les particules

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- $E = MC^2$  : "LA MASSE EST DE L'ÉNERGIE CONDENSÉE"
- CONCENTRER L'ÉNERGIE SUR UNE PARTICULE



## CREATION DE NOUVELLES PARTICULES

Eliane Omursal

# Forces = particules

**The forces in Nature**

## NUCLEI - ATOMS - STARS

TYPE	INTENSITY OF FORCES ( DECREASING ORDER)	BINDING PARTICLE ( FIELD QUANTUM)	OCCURS IN :
STRONG NUCLEAR FORCE	~ 1	GLUONS ( NO MASS)	ATOMIC NUCLEUS
ELECTRO -MAGNETIC FORCE	~ 10 <sup>-3</sup>	PHOTONS ( NO MASS)	ATOMIC SHELL ELECTROTECHNIQUE
WEAK NUCLEAR FORCE	~ 10 <sup>-5</sup>	BOSONS Z <sup>0</sup> , W <sup>+</sup> , W <sup>-</sup> ( HEAVY)	RADIOACTIVE BETA DESINTEGRATION
GRAVITATION	~ 10 <sup>-38</sup>	GRAVITONS ( ? )	HEAVENLY BODIES

**SAME**

THE EXCHANGE OF PARTICLES IS RESPONSIBLE FOR THE FORCE

Mystery

CERN AC\_Z04\_V25/8/1992

Pourquoi la gravitation est-elle si faible?

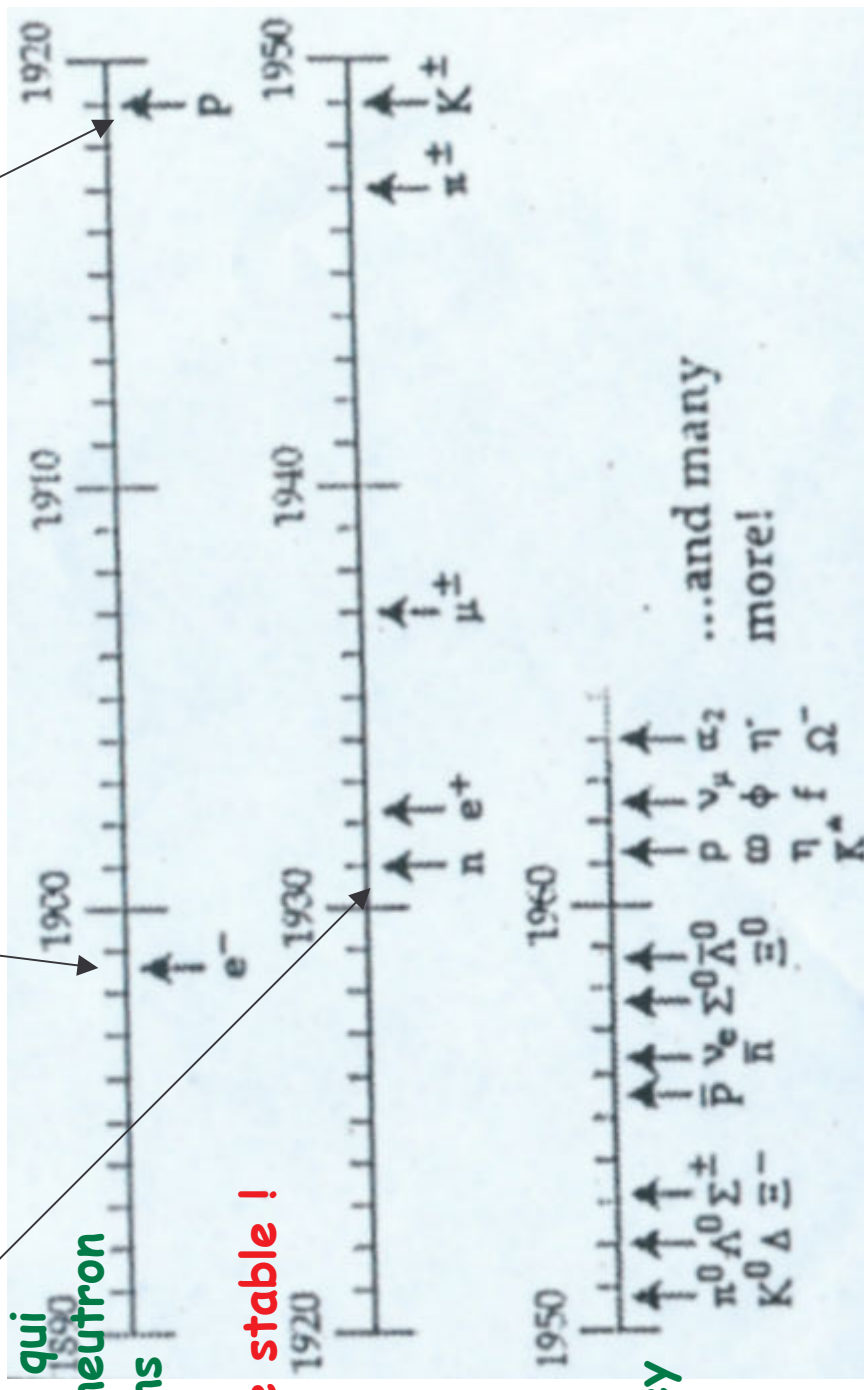
# Des cosmiques aux accélérateurs : inflation de particules

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Neutron par Chadwick,  
Interaction nucléaire  
décrite par Yukawa qui  
agit sur proton et neutron  
par échange de pions

JJ Thomson

E. Rutherford



**Le proton peut être stable !**

1952 début des  
Accélérateurs :  
Brookhaven, Berkeley



# Le modèle standard

## ■ Pourquoi 3 familles ?




Quarks	Leptons	Bosons
 up	 electron	 photon
 down	 muon	 gluon
 charm	 neutrino $e$	 $Z^0 W^\pm$
 strange	 tau	 Higgs
 top	 neutrino $\tau$	
 beauty		

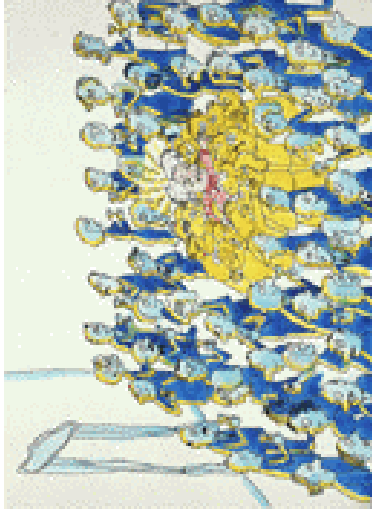
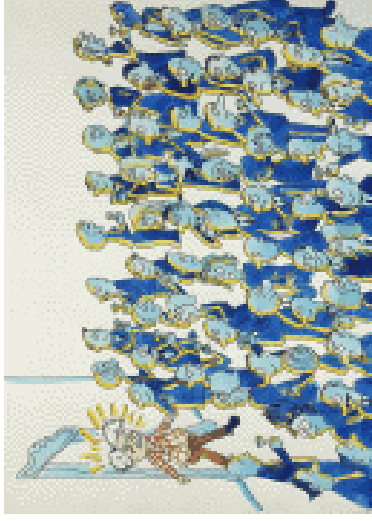
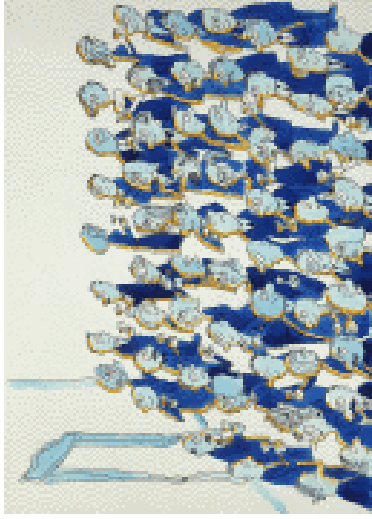
The Standard Model

A. Pich - CERN Summer Lectures 2003

# Les mystères de la physique des particules

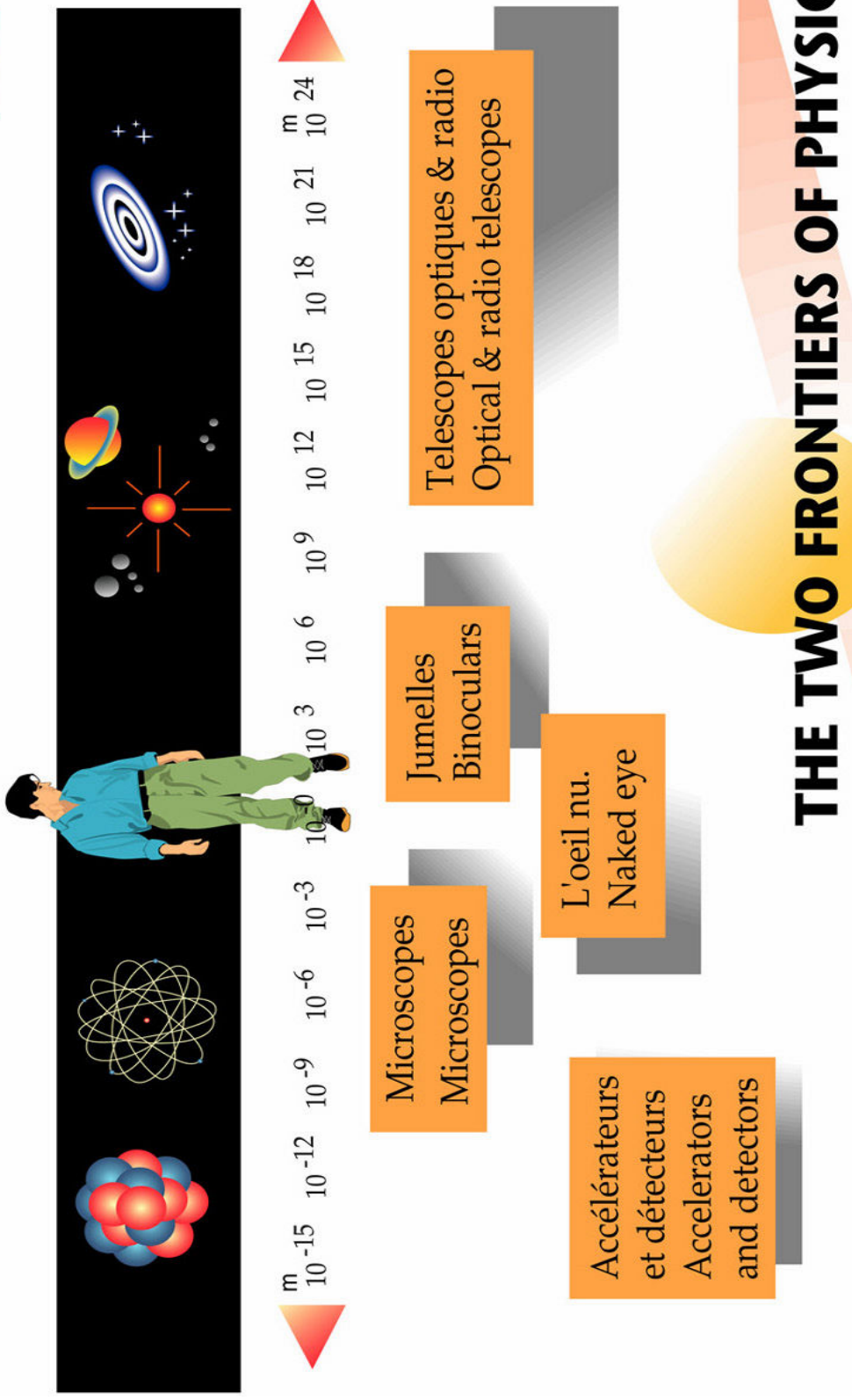
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- Origine commune des champs      Unification? 
- Dualité onde-corpuscule      Origine? 
- Fermions - Bosons      Supersymmetry? 
- Masse des particules      Boson de Higgs ?
- Les particules élémentaires sont-elles élémentaires ?
- Qu'est ce qu'une particule ?      String theory



# Can particle physics explain the universe?

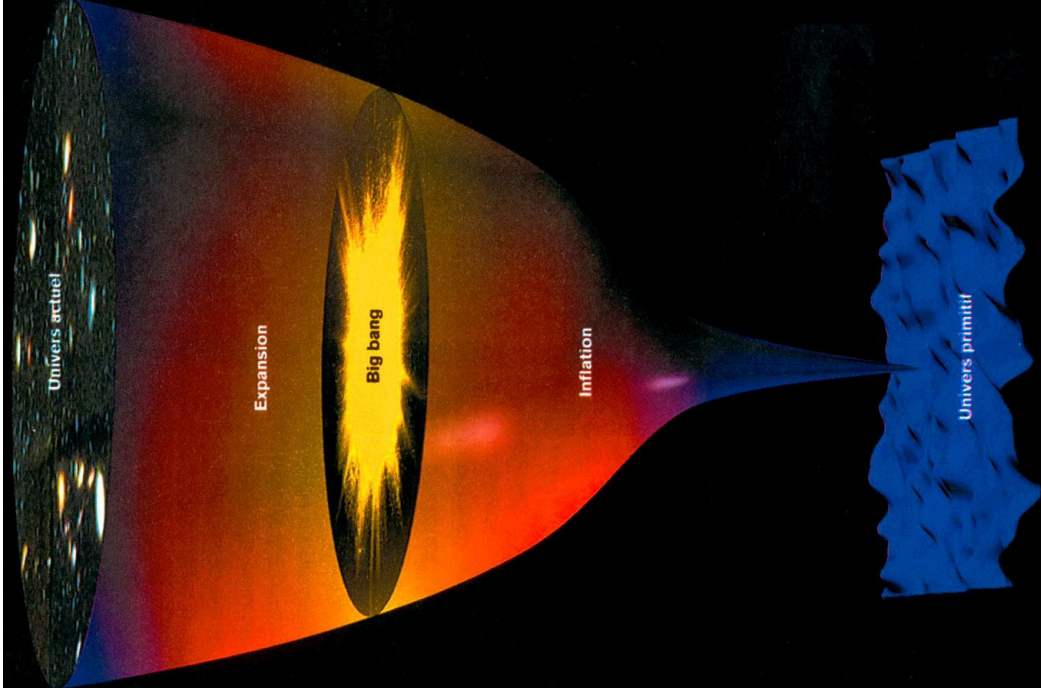
-  Particle physics looks at matter in its smallest dimensions.
-  Astrophysics looks at matter in its largest dimensions.



## THE TWO FRONTIERS OF PHYSICS

# BIG Bang - eras

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**380,000 YRS**  
**ATOMS**  
**10<sup>-10</sup> ... 1 SEC**  
**PARTICLES**  
**10<sup>-32</sup> SEC**  
**"BIG BANG"**

**"BIG**

**~10<sup>-34</sup> SEC:**  
**INFLATION**

**< 10<sup>-43</sup> SEC:**  
**ERA**

**PLANCK**

# Les succès du Big Bang

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Expansion cosmique (Redshift)

Age des objets cosmiques  
moins de ~ 12-13 milliards d'années  
Soleil ~ 4.7 milliards d'années

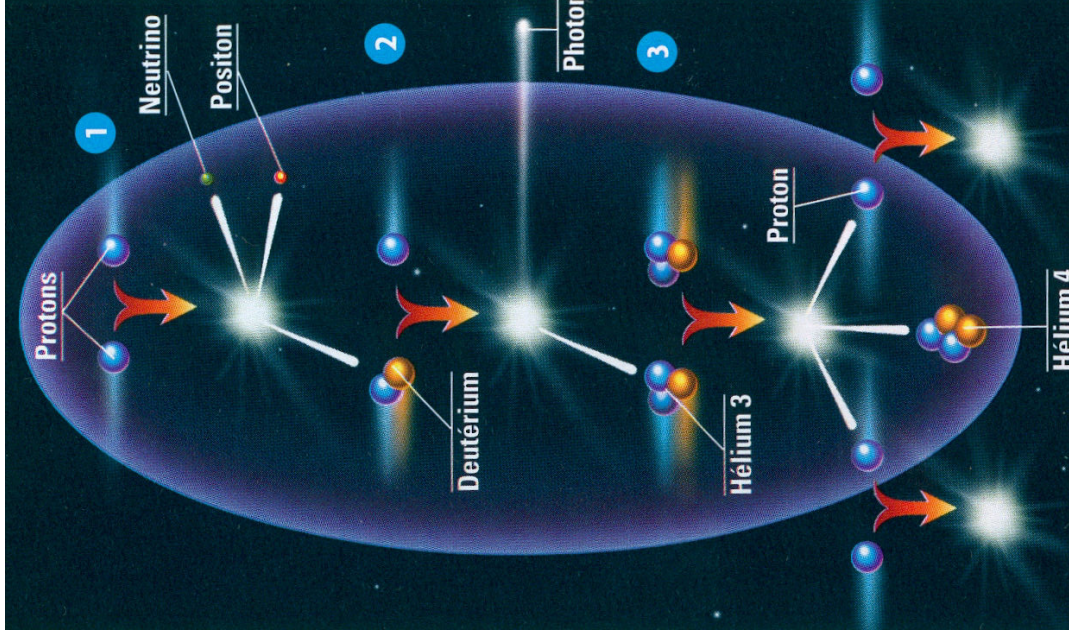
Ratio universel H:He ~ 3:1

Photo à  $t \sim 3$  min

Cosmic Microwave Background (CMB)

Rayonnement fossile à  $3^\circ\text{K}$

Photo de l'univers à  $t \sim 380,000$  yrs



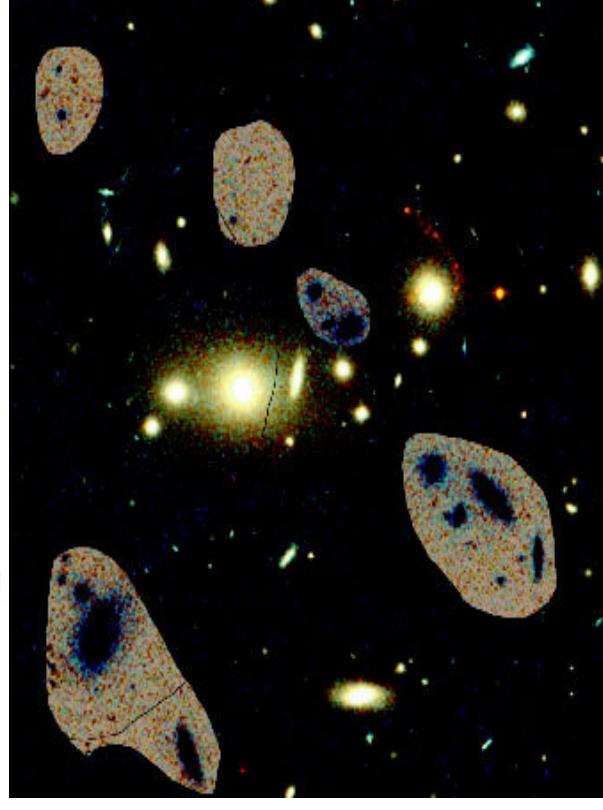
# Les mystères du Big Bang

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- D'où vient l'inflation?
  - Energie du vide ?
- Comment la symétrie initiale s'est-elle brisée ?
  - Hierarchie des interactions?
  - Masse des particules?



- Où est passée l'anti-matière ?

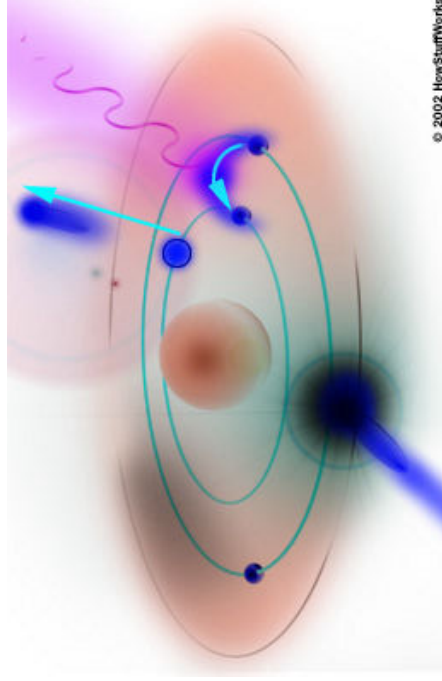


# L'étude de l'anti-hydrogène au CERN

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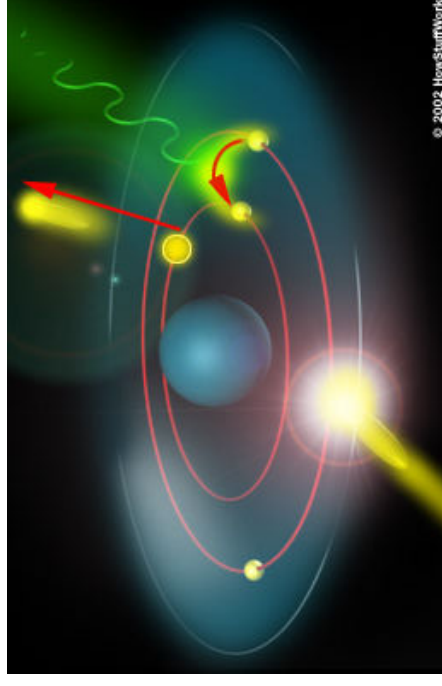
ANTIHYDROGEN

(ANTI-PROTON + POSITRON)



HYDROGEN

(PROTON + ELECTRON)

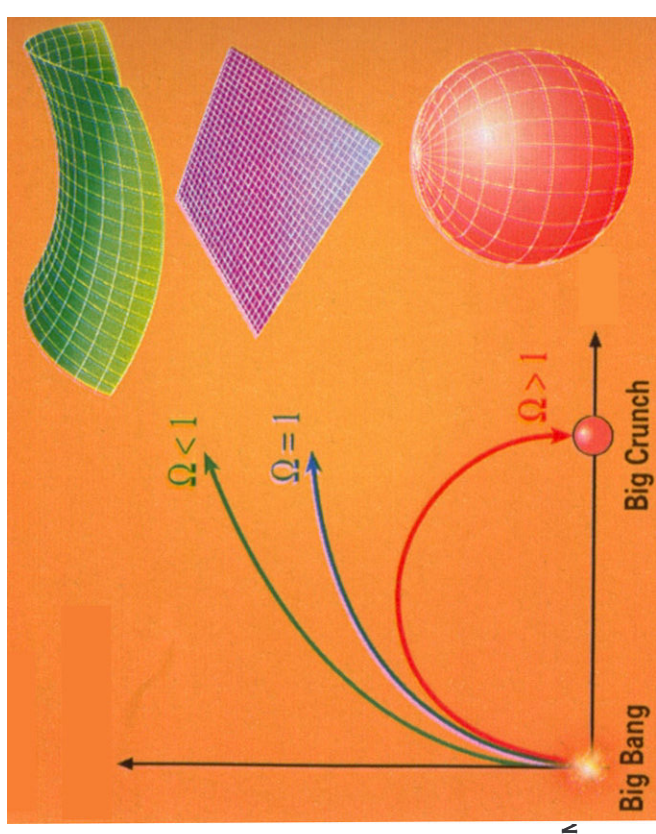
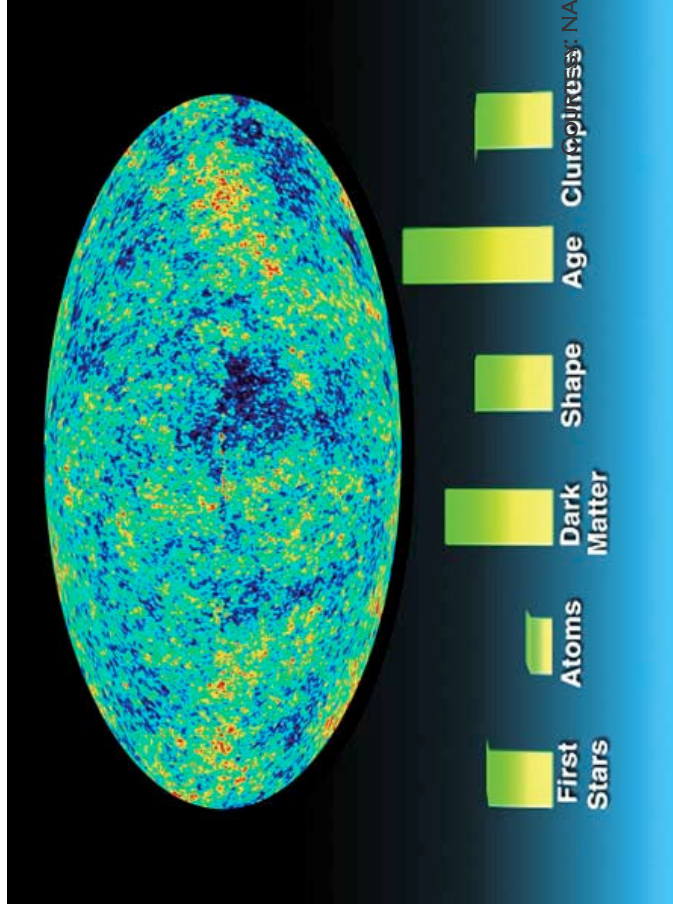


ARE THE ENERGY LEVELS IDENTICAL ?

TWO EXPERIMENTS AT CERN: ATHENA AND ATRAP

# L'observation du fond cosmologique

- Observation des anisotropies du fond cosmologique (MAP, Planck...)
- Détermination des constantes cosmologiques

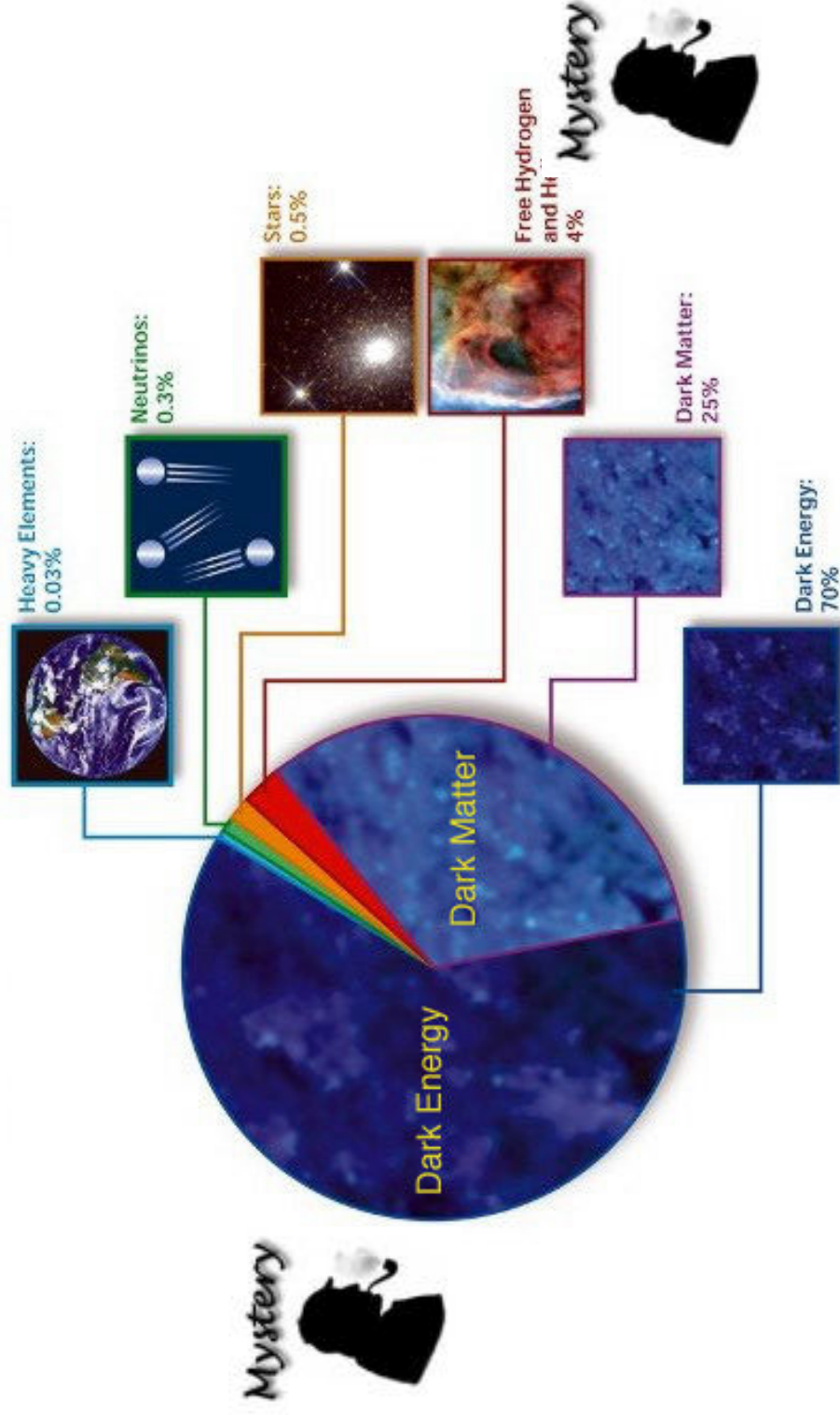




# Le mystère de la masse manquante

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- Les étoiles et les planètes ne représentent qu'un très faible partie de la masse de l'univers
- Le mystère de la matière noire et de l'énergie noire
- Particules super lourdes ? Les verra-t-on au LHC ?



# Contenu

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- **Signaux des détecteurs en physique des particules**
  - Expériences sur accélérateurs
  - Trajectographes
  - Calorimètres
  - Spectromètres à muons
  - Expériences hors accélérateurs
  - Astroparticules
  - Modélisation du détecteur

## ■ Préamplificateurs

- Préamplificateurs de charge
- Mesure des préamplis
- Préamplificateurs de courant

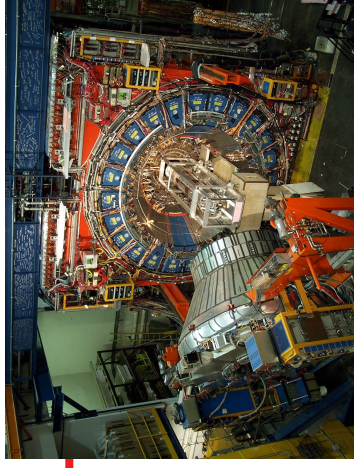
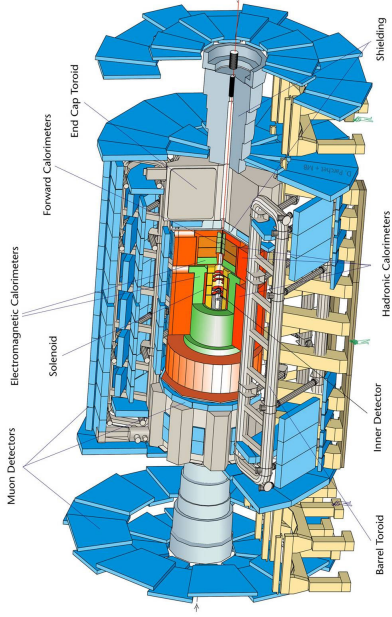
## ■ Filtrage

- Filtrage analogique
- Filtrage numérique

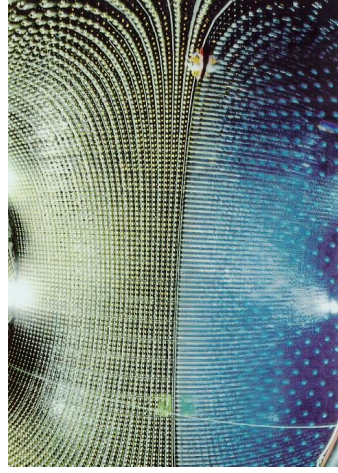
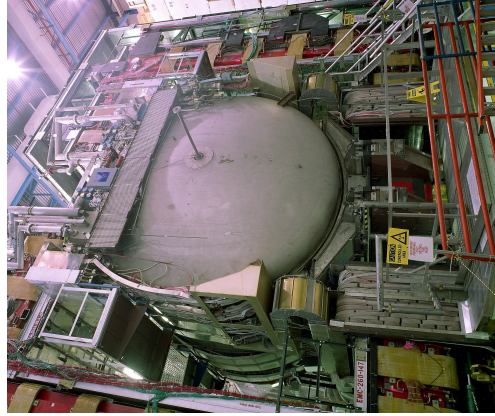
## ■ Remerciements

- Corine Athenol, Ursula Bassler, Jean-Claude Brient, Dominique Breton, Ronic Chiche, Eric Delagnes, Daniel Dzahini, Christine Hu, Jacques Lecoq, Julien Fleury, Richard Hermel, Pierre Jarron, Arnaus Lucotte, Bruno Mansoulié, Gisèle Martin, Joel Pouthas, Veljko Radeka, Ludovic Raux, Jean-Pierre Richer, Nathalie Seguin, Laurent Serin, Peter Sharp, Vanessa Tocut, Jean-Charles Vanel

© 2004

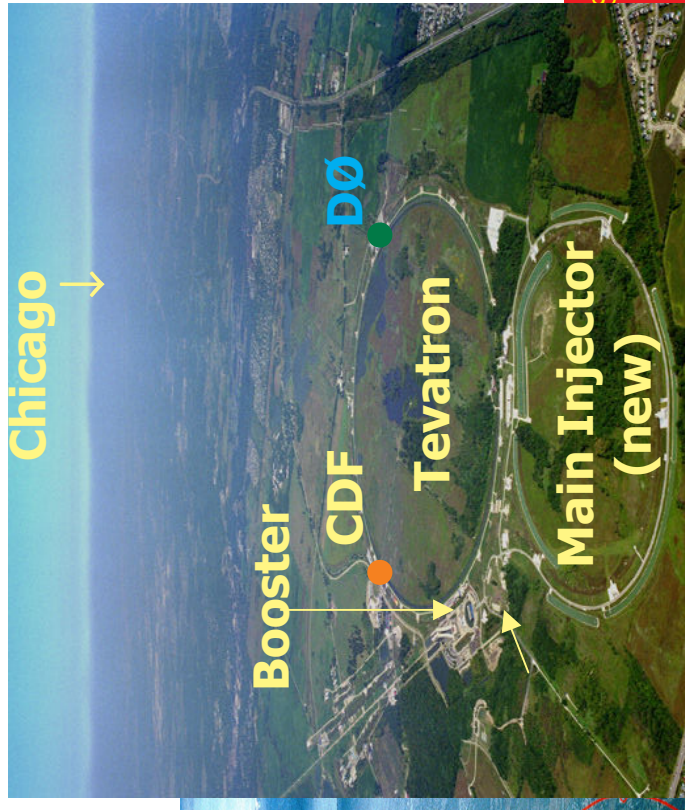


# 1. Signaux des détecteurs en physique des particules

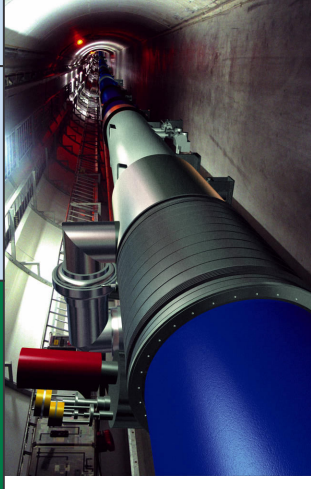
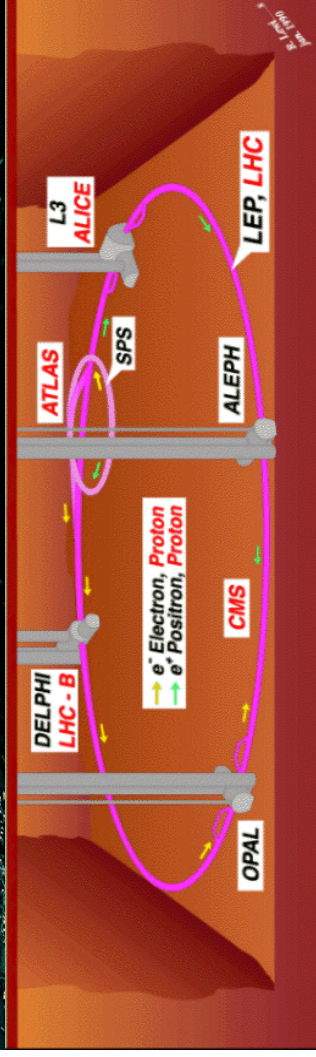


# Expériences sur accélérateurs

- CERN : 20 pays, 2000 employés
- DESY, SLAC, FNAL, BNL...

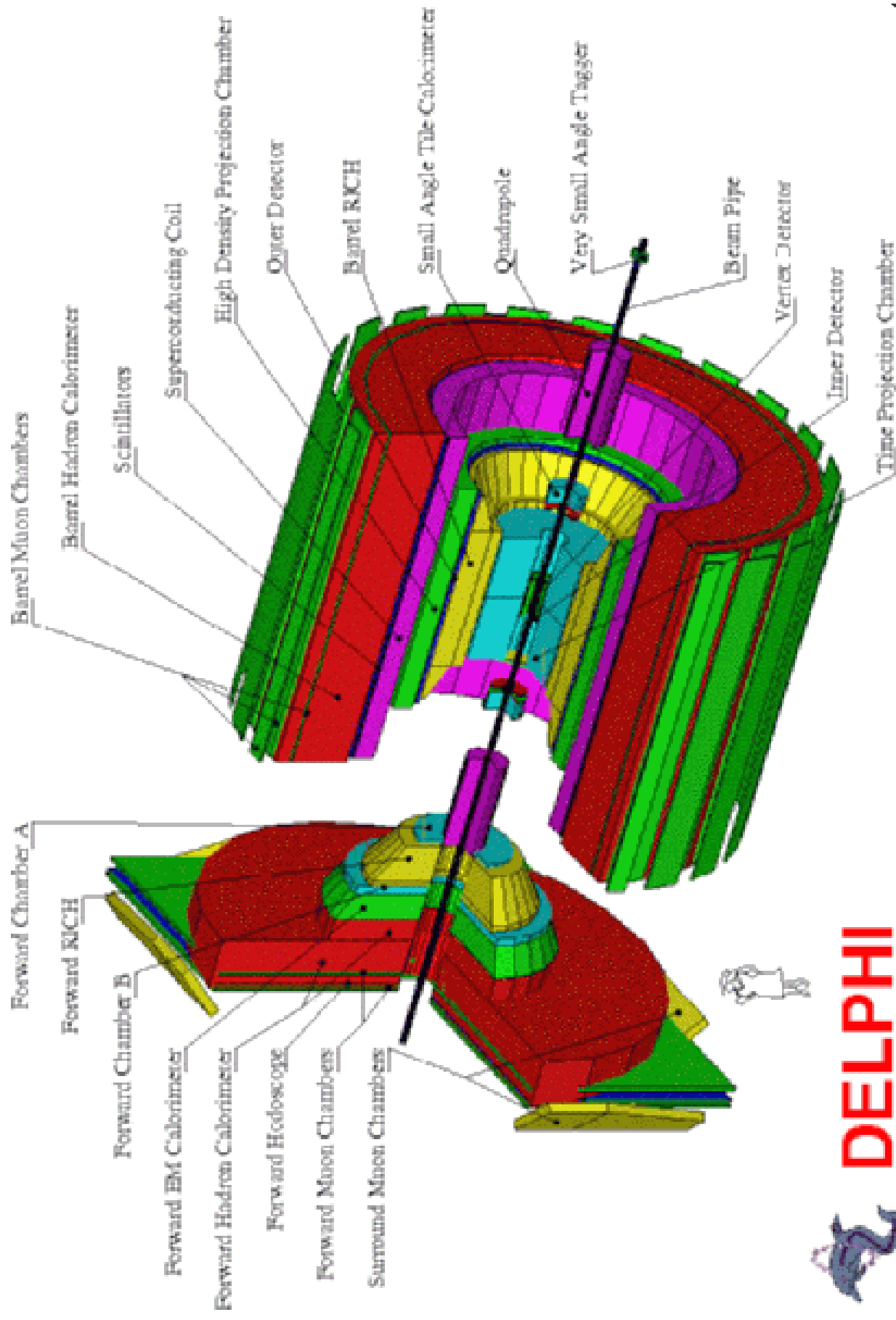


	Run 1b	Run 2a
#bunches	6x6	36x36
$\sqrt{s}$ (TeV)	1.8	1.96



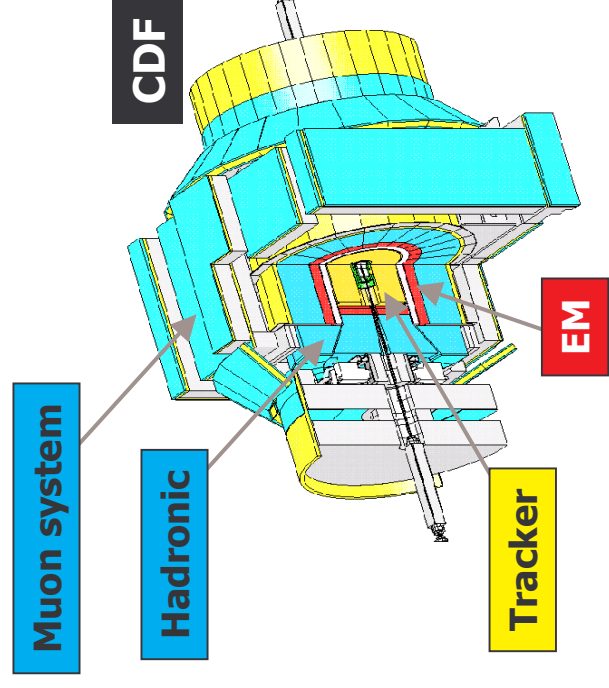
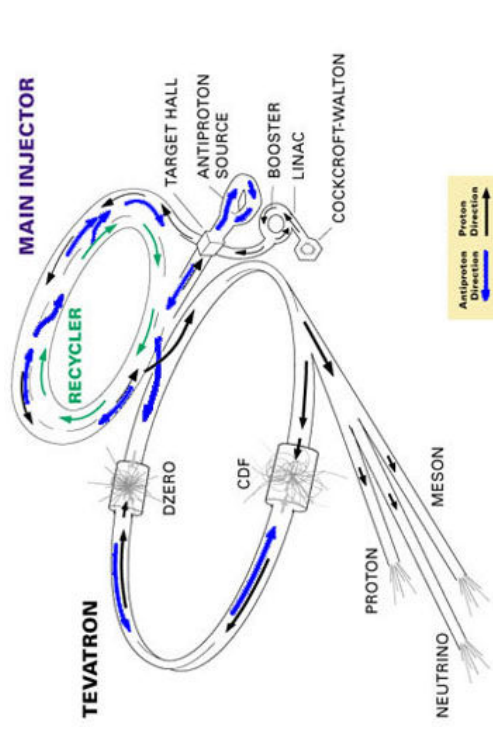
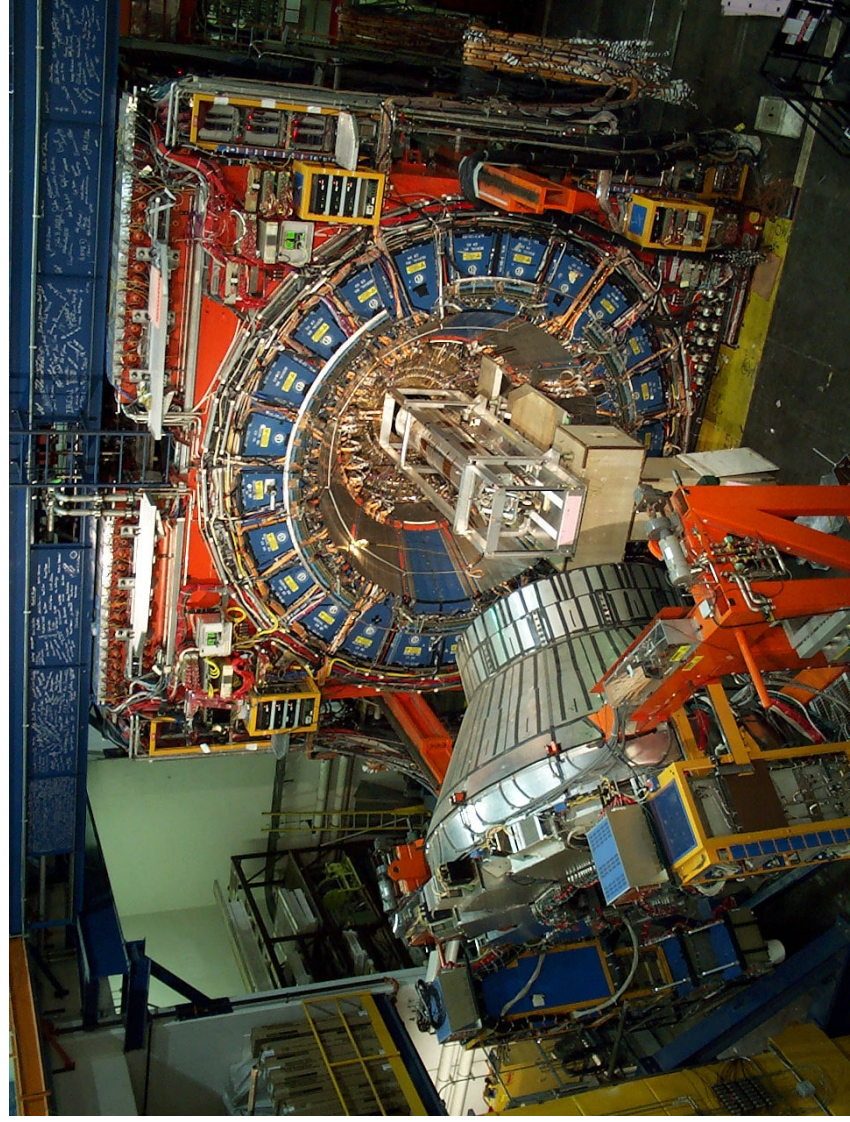
# Expériences sur accélérateurs : passé

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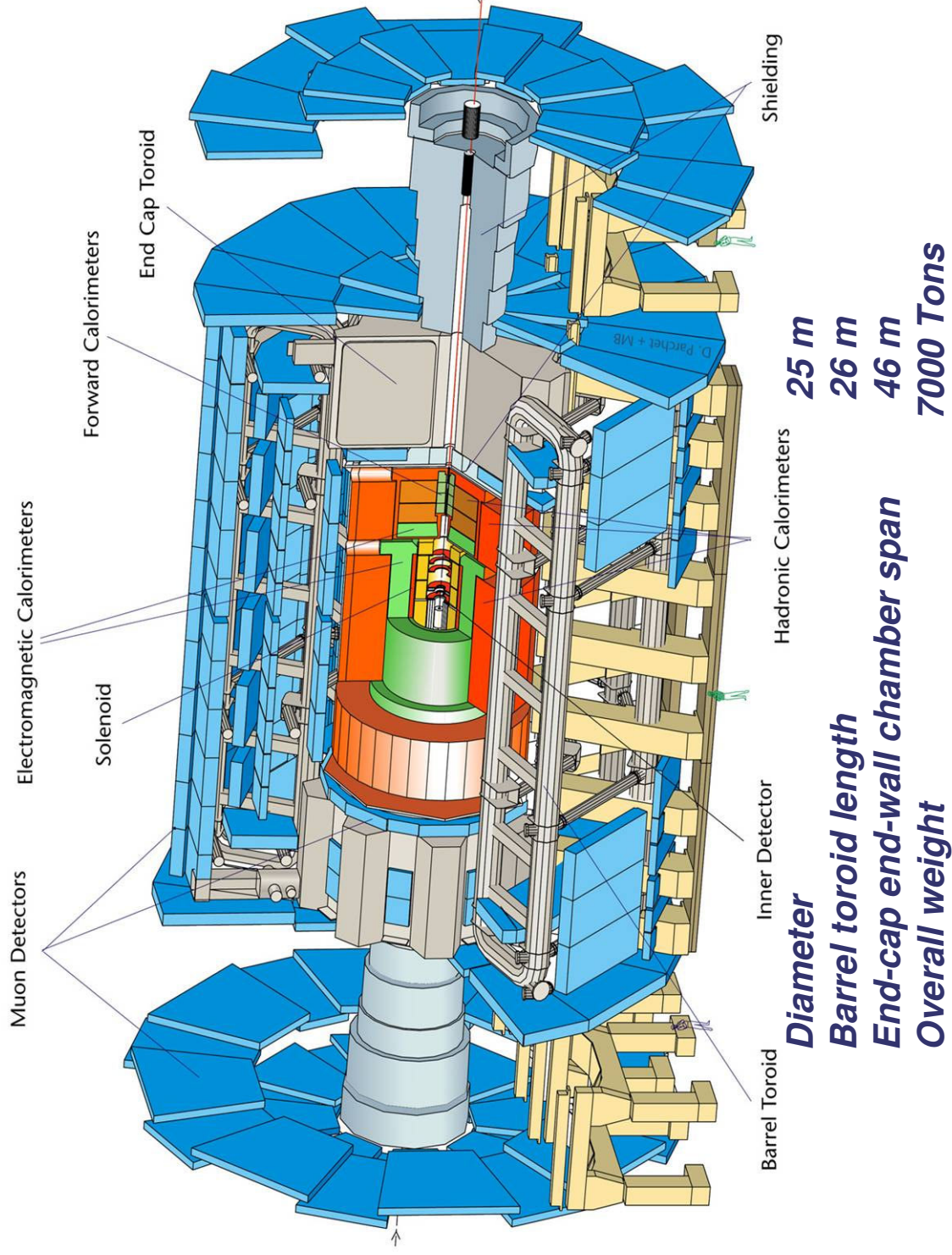
# Expériences sur accélérateurs : ~ présent

- Collisions  $p+/e-, e-/e-, pp$
- Exemple : CDF & DØ @ Fermilab



# Expériences sur accélérateurs : ~ présent

DTU/Imix-26/06/97



# Installation d'ATLAS

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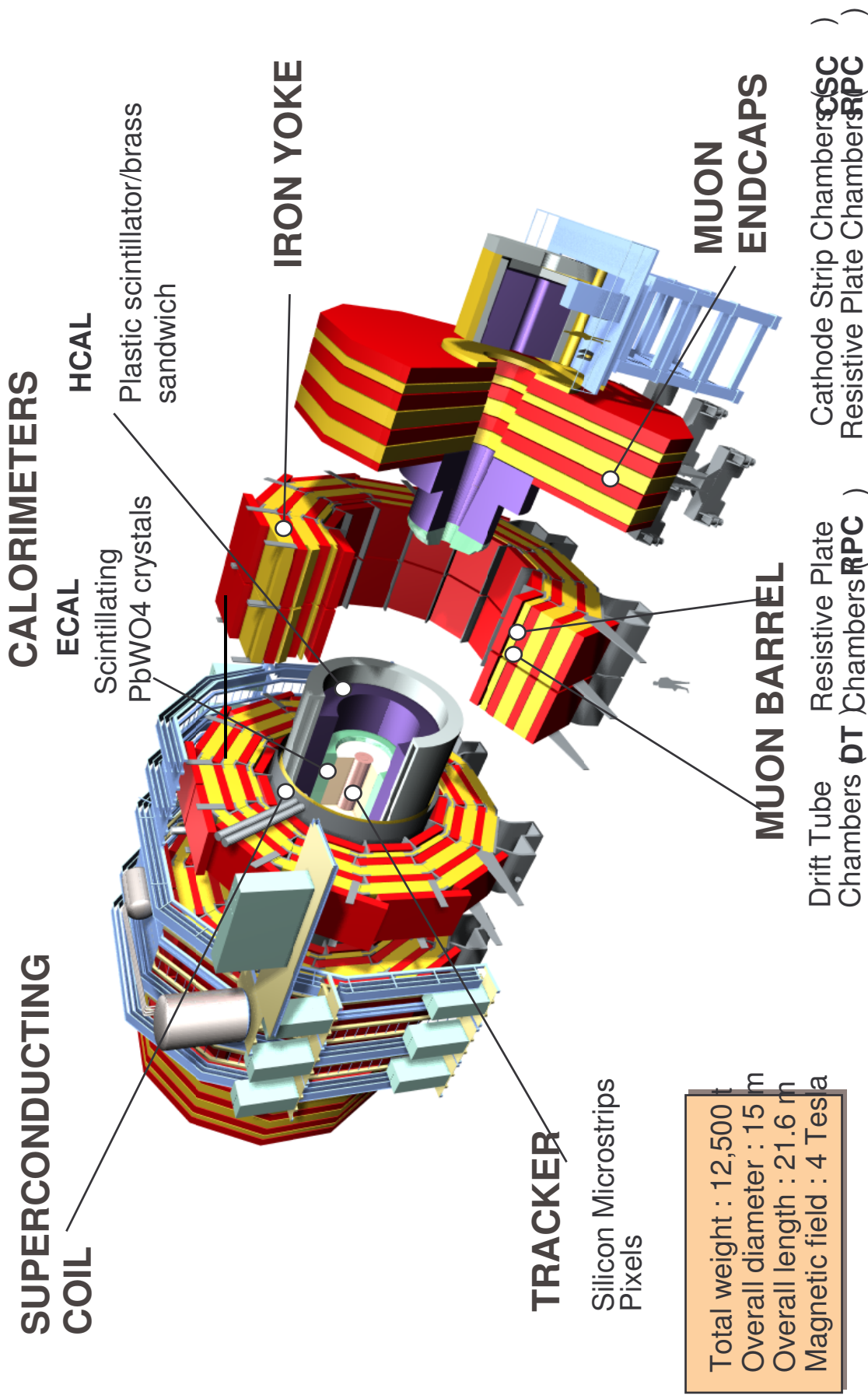


UX15 ulx16 Wed Jun 4 16:30:02 2003



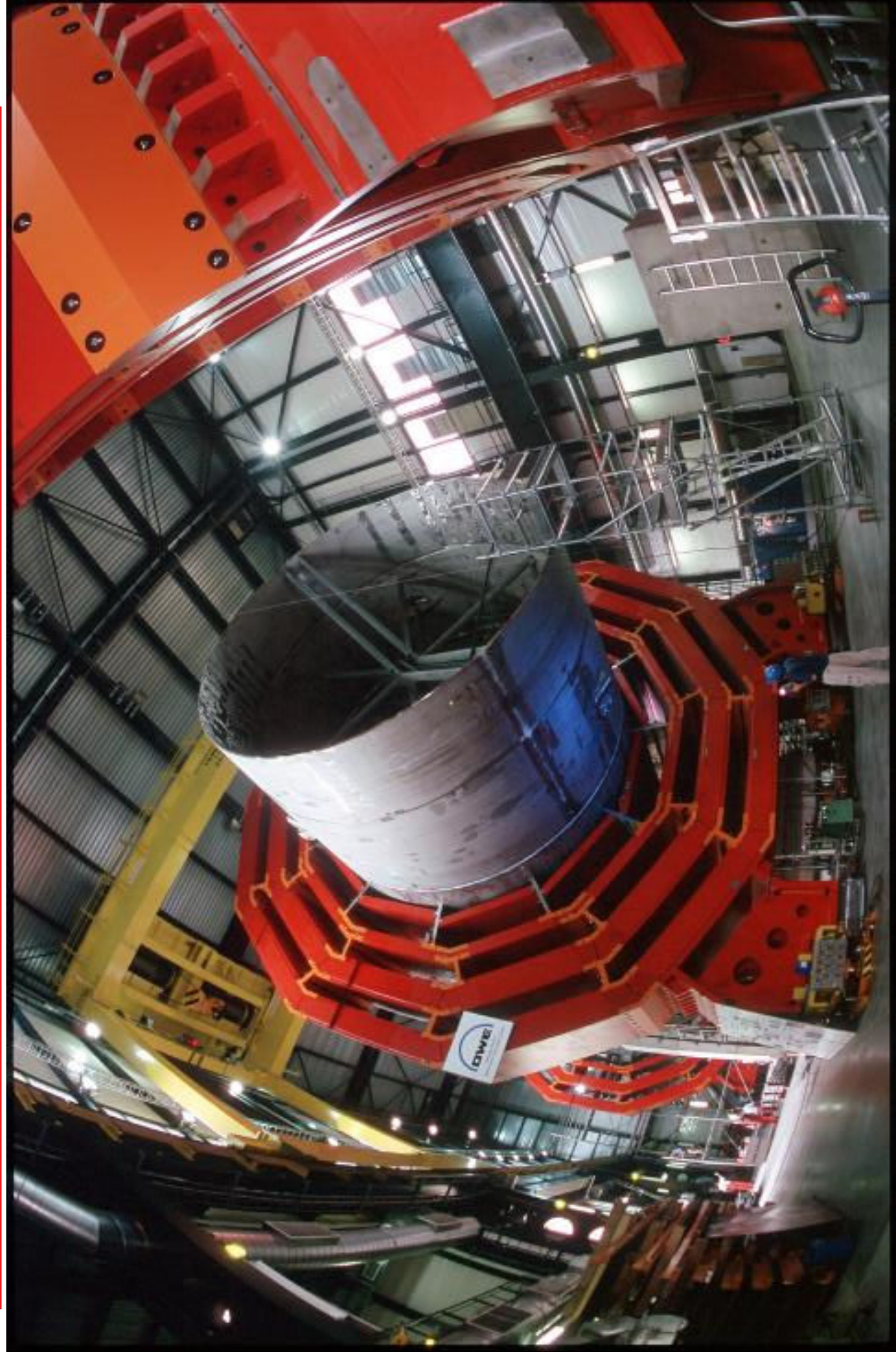
# The CMS Detector

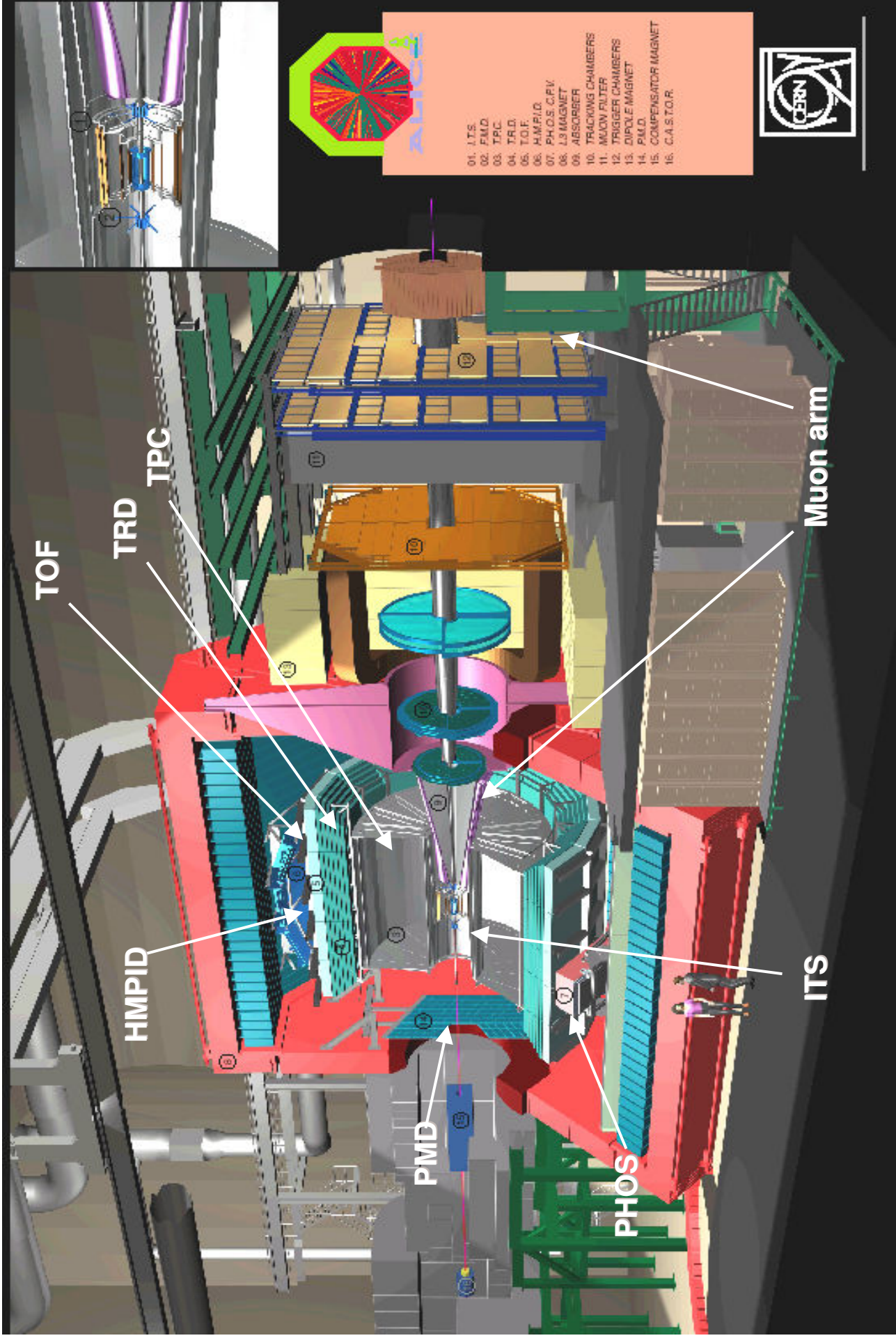
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Total weight : 12,500 t  
 Overall diameter : 15 m  
 Overall length : 21.6 m  
 Magnetic field : 4 Tesla

## Installation de CMS

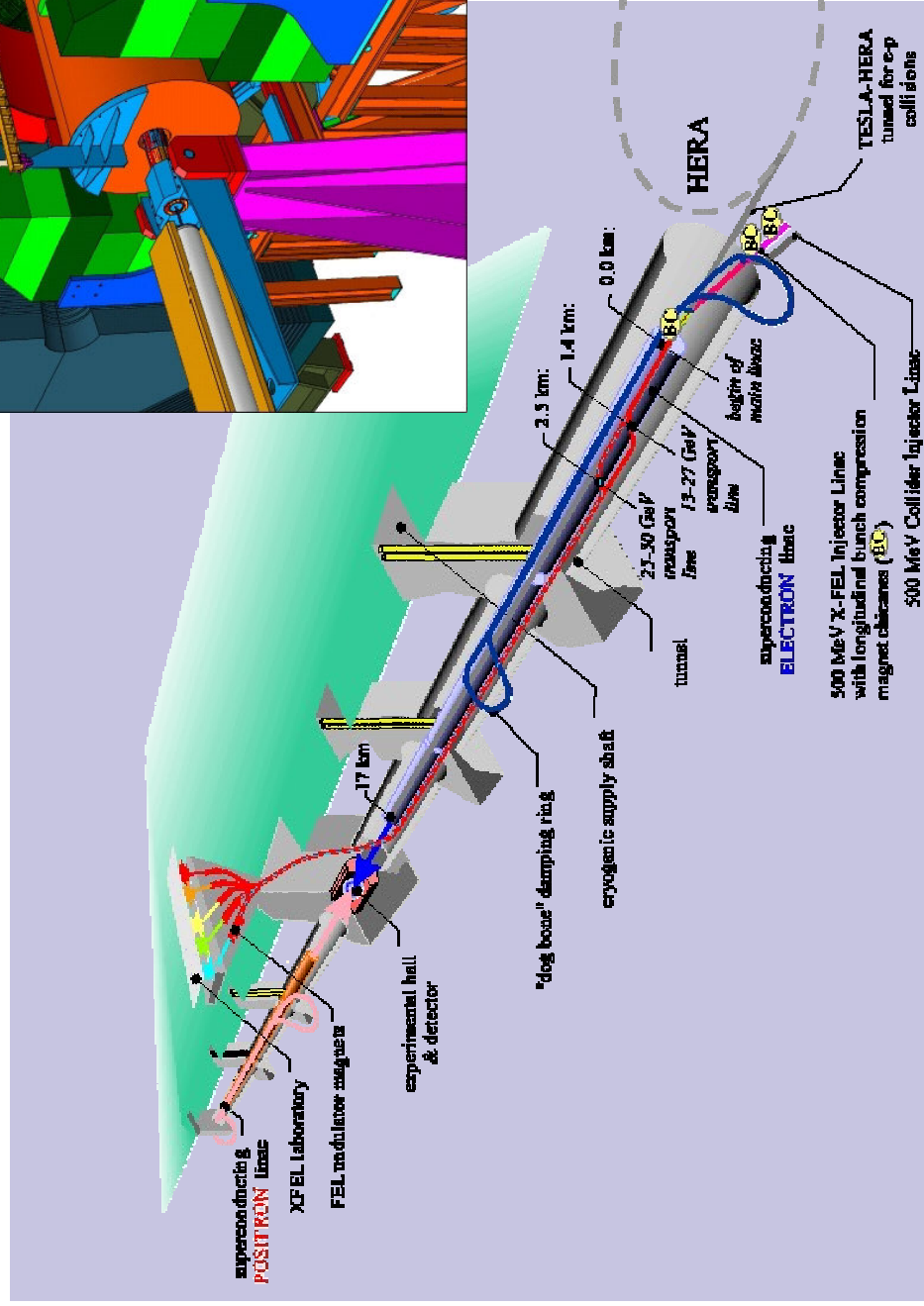
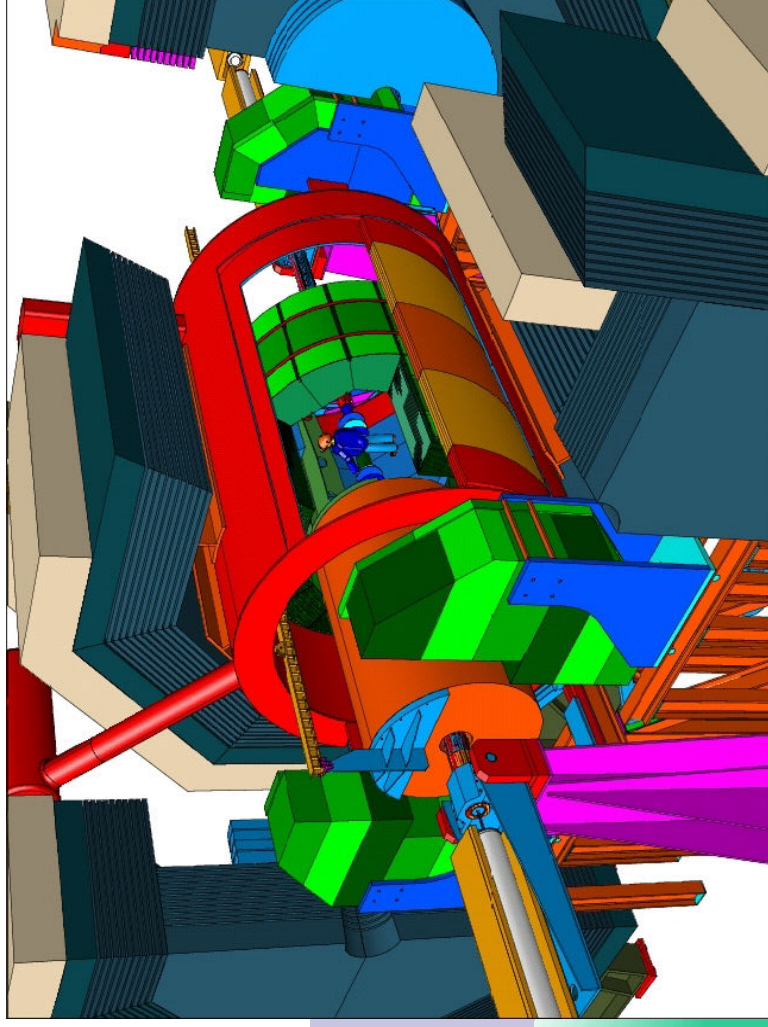




# ALICE Detector

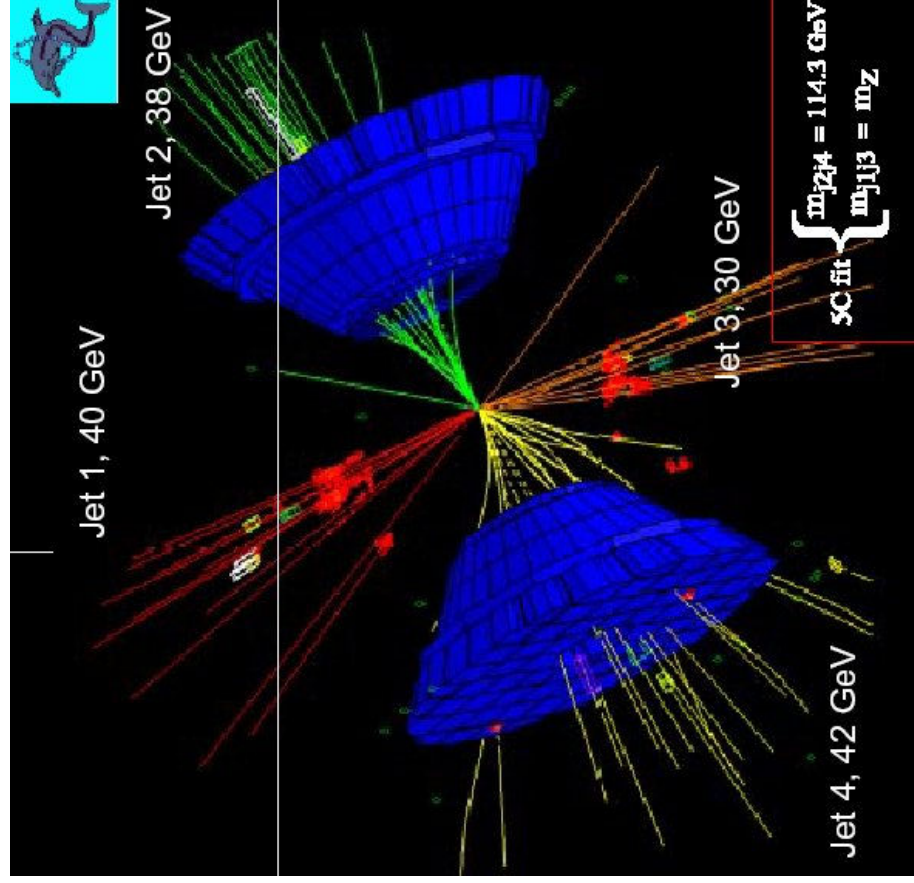
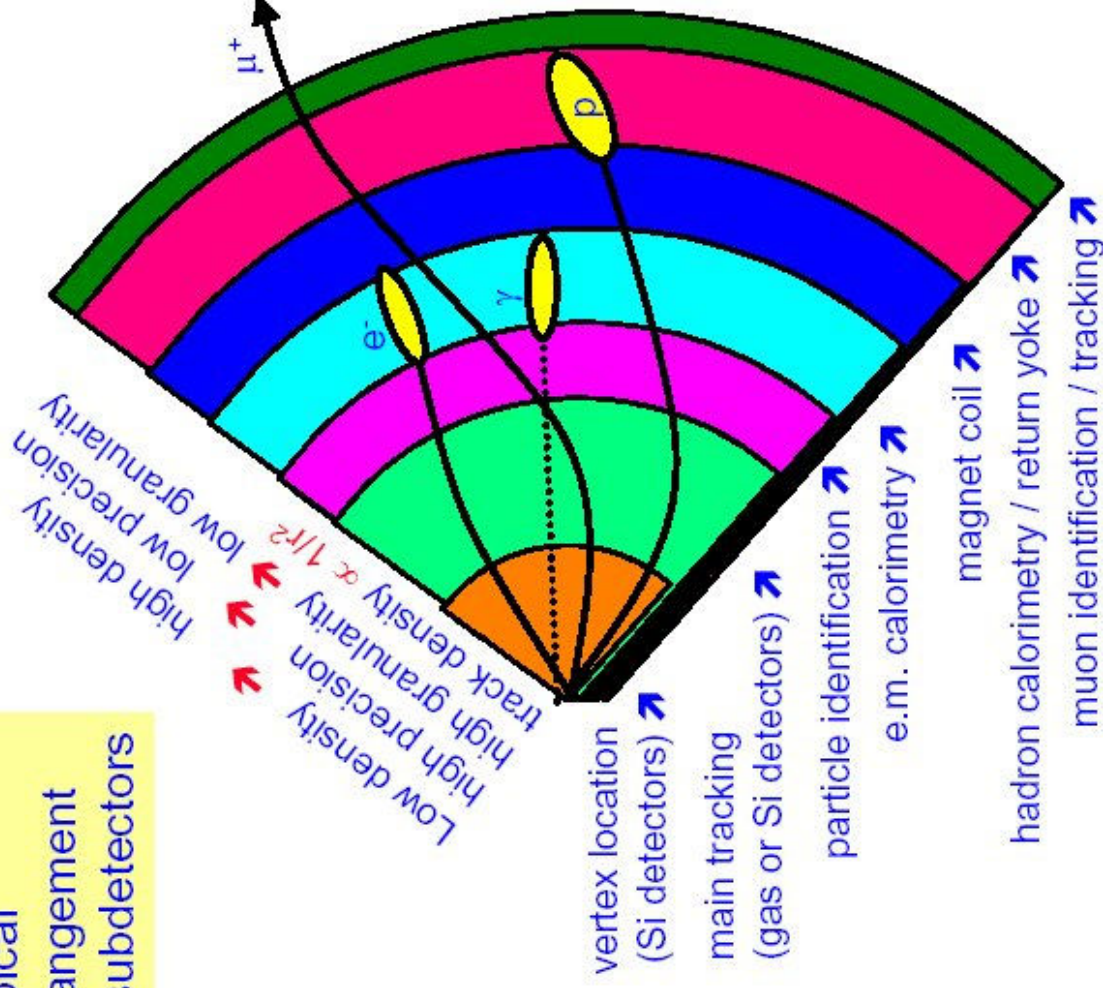
# Expériences sur accélérateurs : futur

- FLC : future Linear Collider
- Collisionneur e+ e- 500GeV
- 2015 ?



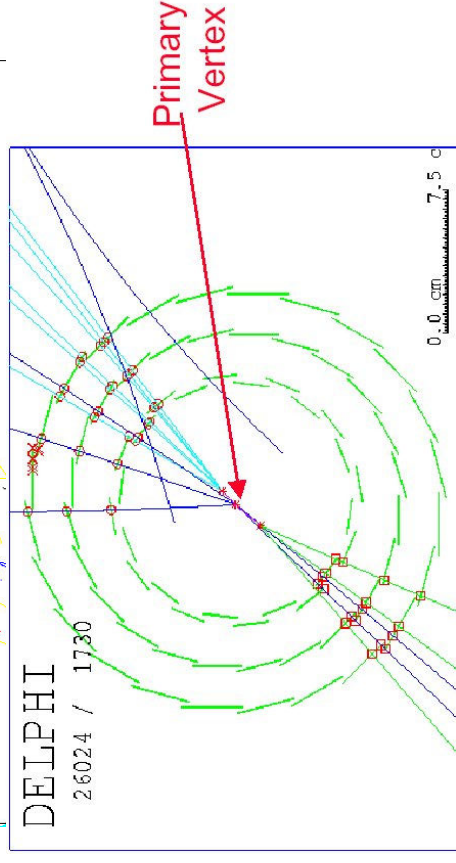
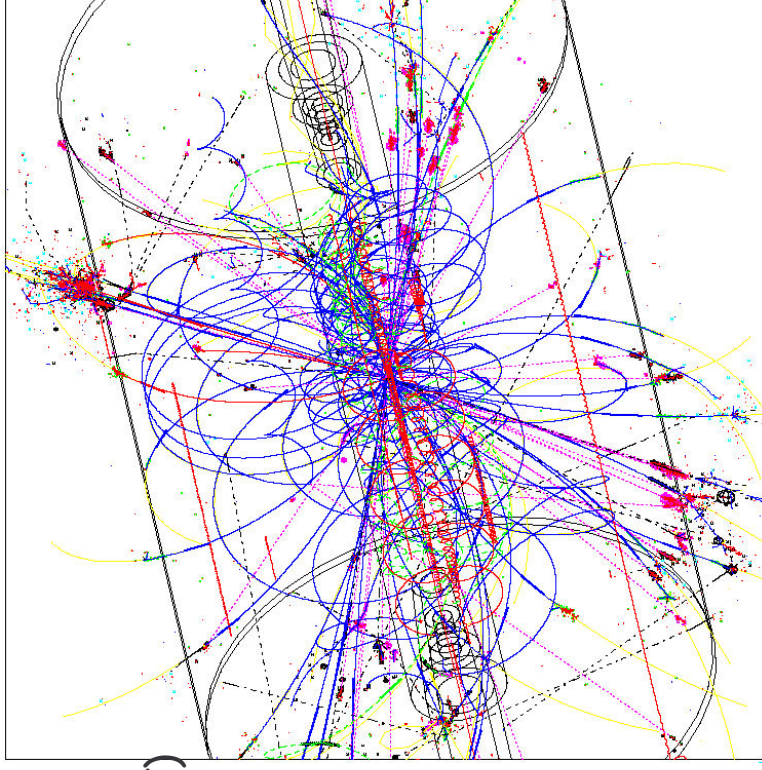
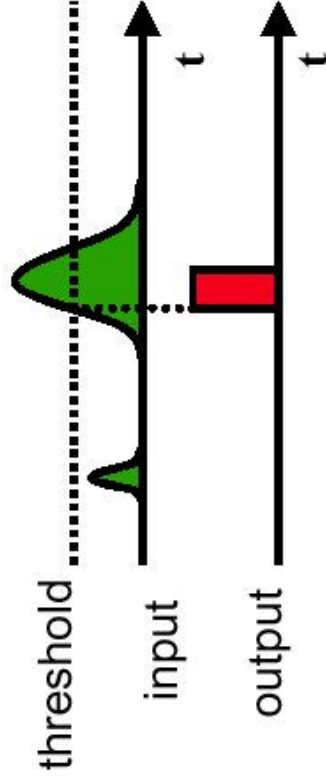
# Expériences sur accélérateurs : LHC

Typical arrangement of subdetectors



# Les trackers (trajectographes )

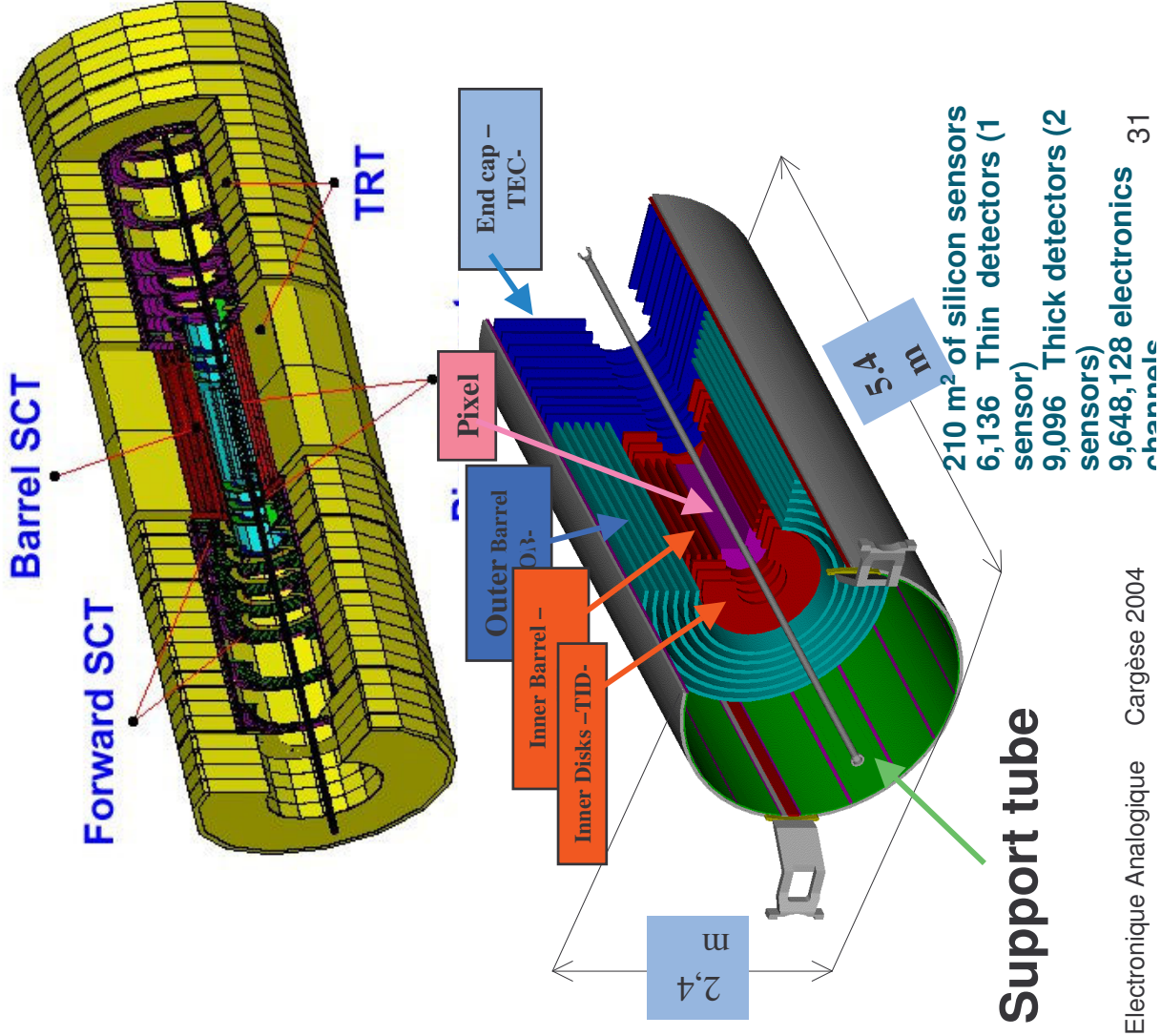
- **Mesure des traces des particules chargées**
  - Déviation dans un champ B puissant ( $\sim qqT$ )
  - **millions** de pixels ( $\sim 100 \mu m$ )
  - Signaux très faibles  $\rightarrow$  amplification
  - Lecture (quasi) binaire
  - Capacité détecteur très petite ( $\sim pF$ )
  - Très basse puissance, ( $qq \mu W/ch$ )
  - **Résistance aux radiations élevée**
  - $\Rightarrow$  **ideal pour ASICs**



# Trajectographes (trackers) : vocabulaire

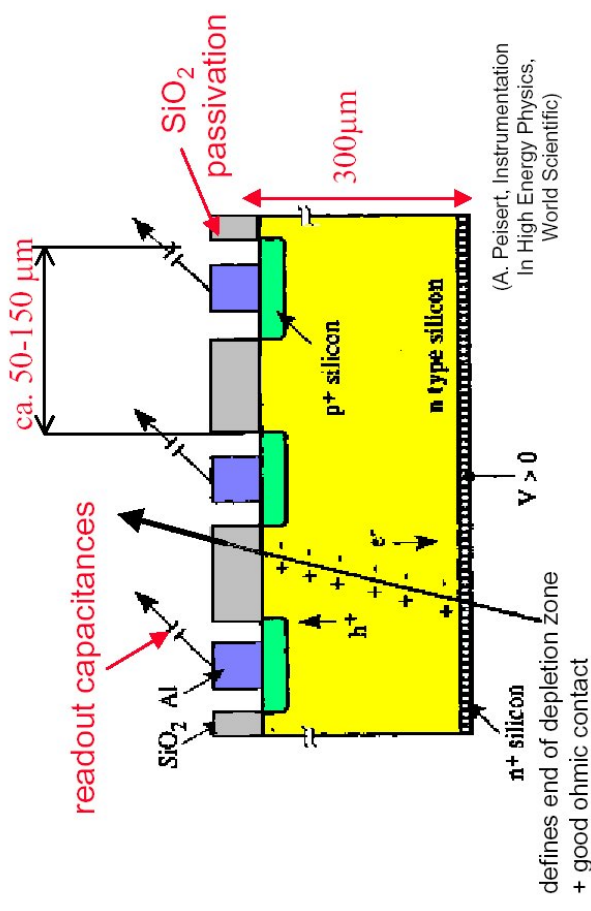
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- **Plusieurs sous-systèmes**
- **Pixels :**
  - Carrés typ  $100 \times 100 \mu\text{m}$
  - très plus proches du point d'interaction
- **Si Strips (SSD, SCT...)**
  - Bandes
- **Détecteurs gazeux**
  - TPC : time projection chamber
  - TRD : transition radiation detector
  - Peu de matière

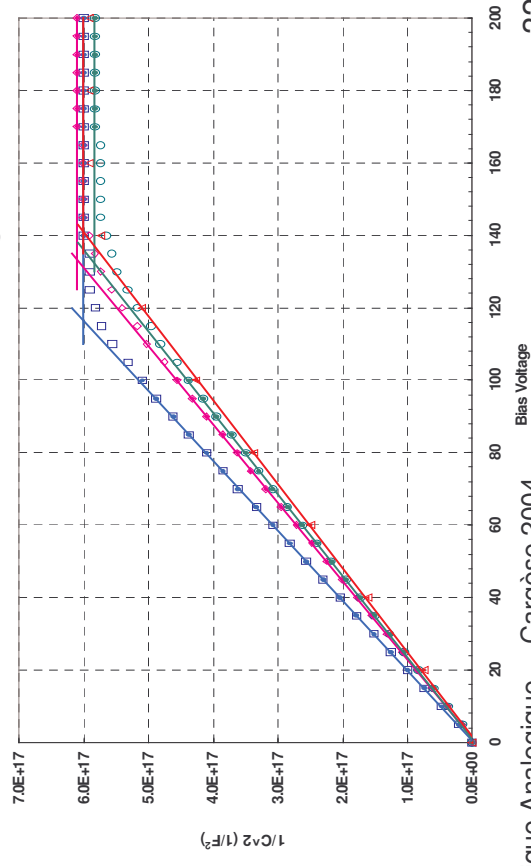


# Si sensors : semiconducteur

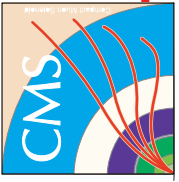
- **Silicium « détecteur grade »**
  - $10^{12} \text{ cm}^{-3}$  (n-)  $10^{15} \text{ cm}^{-3}$  (p+)
  - $R = 5 \text{ k}\Omega\text{cm}$
- **Signal :**
  - $\sim 100 \text{ e}^-/\text{h} / \mu\text{m} / \text{MIP}$
  - MIP = particule au minimum d'ionisation
  - Typ 30 000 e- (@300 $\mu\text{m}$ )
  - Signal rapide :  $\sim 10 \text{ ns}$
  - $\mu_e = 1450 \text{ cm}^2/\text{Vs}$  ;  $\mu_h = 450 \text{ cm}^2/\text{Vs}$
- **Capacité  $\sim \text{pF}$** 
  - Varie fortement avec la tension de bias
- **Leakage current**
  - Augmente sous irradiation
  - Opération à basse température
- **Full depletion voltage  $\sim 100\text{-}200\text{V}$**



**Before Irradiation Bulk Capacitance vs Bias Voltage**  
@ T = 20C & f = 10kHz, AC signal = 1V

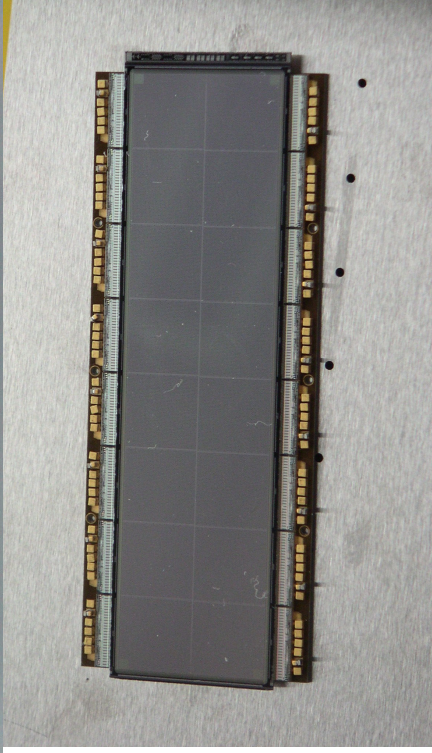
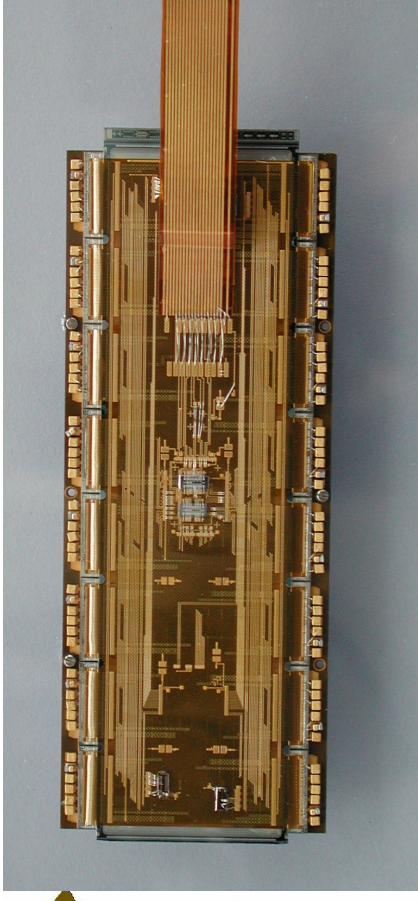
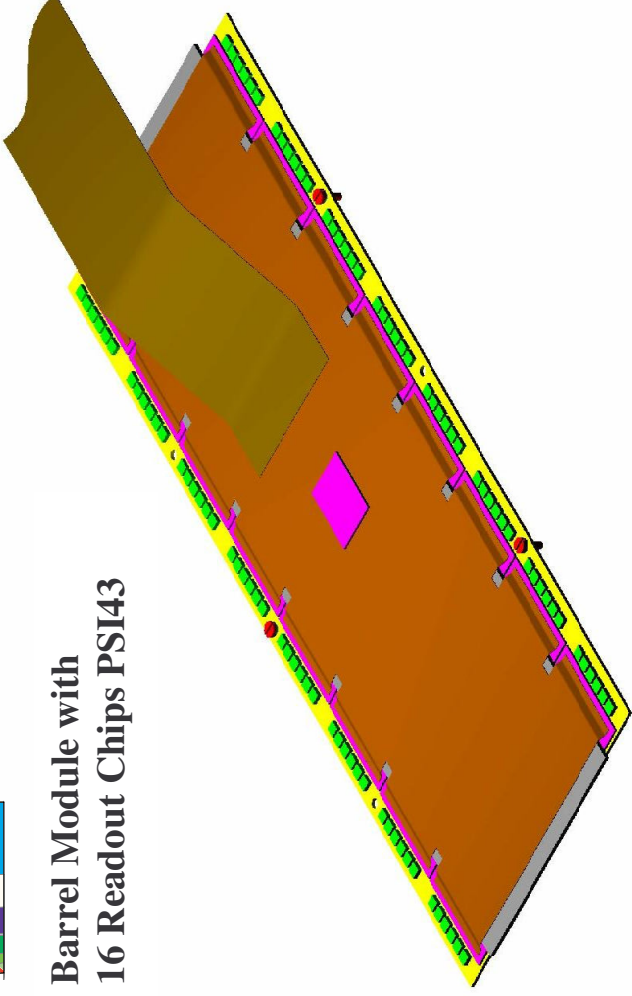




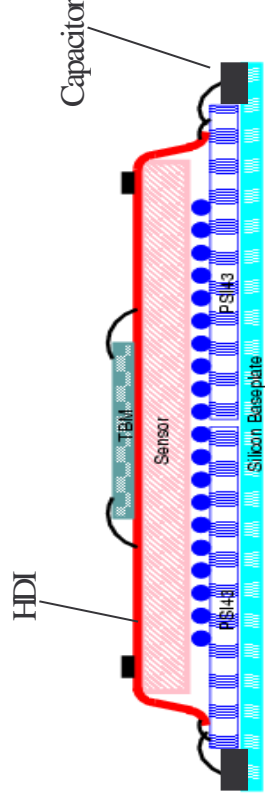


# CMS Pixels

**Barrel Module with  
16 Readout Chips PSI43**



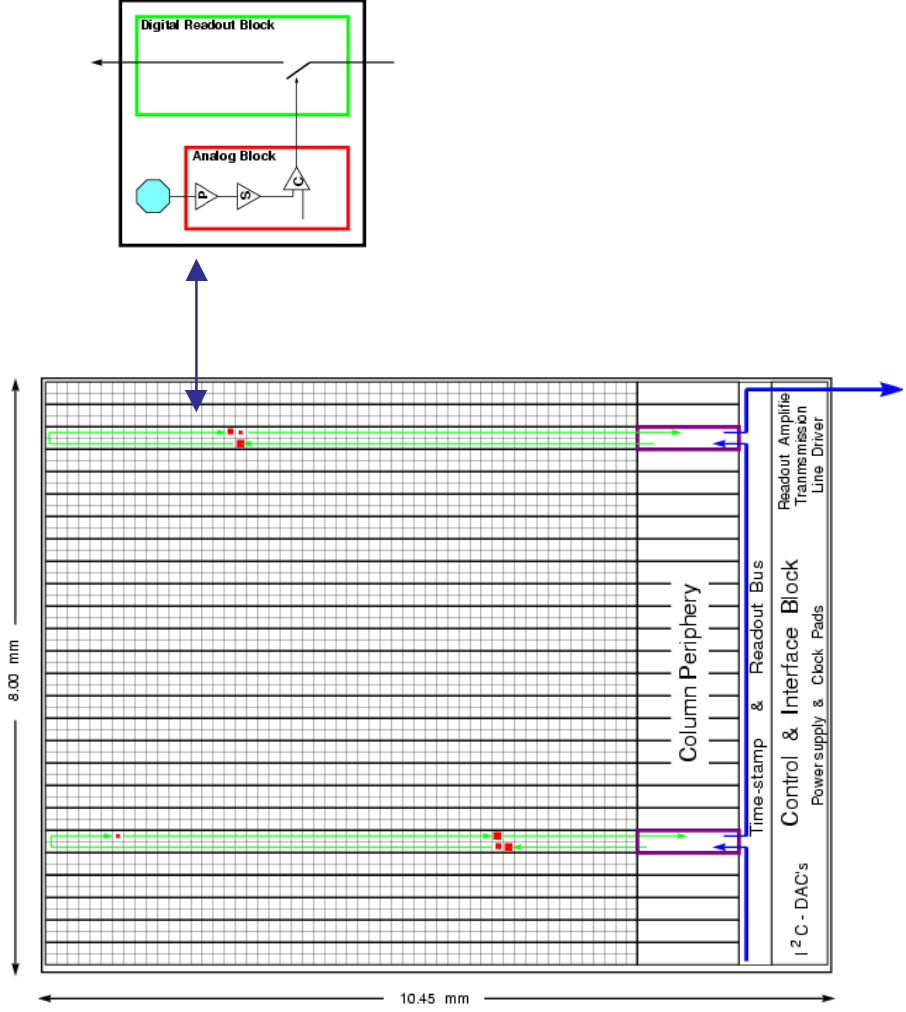
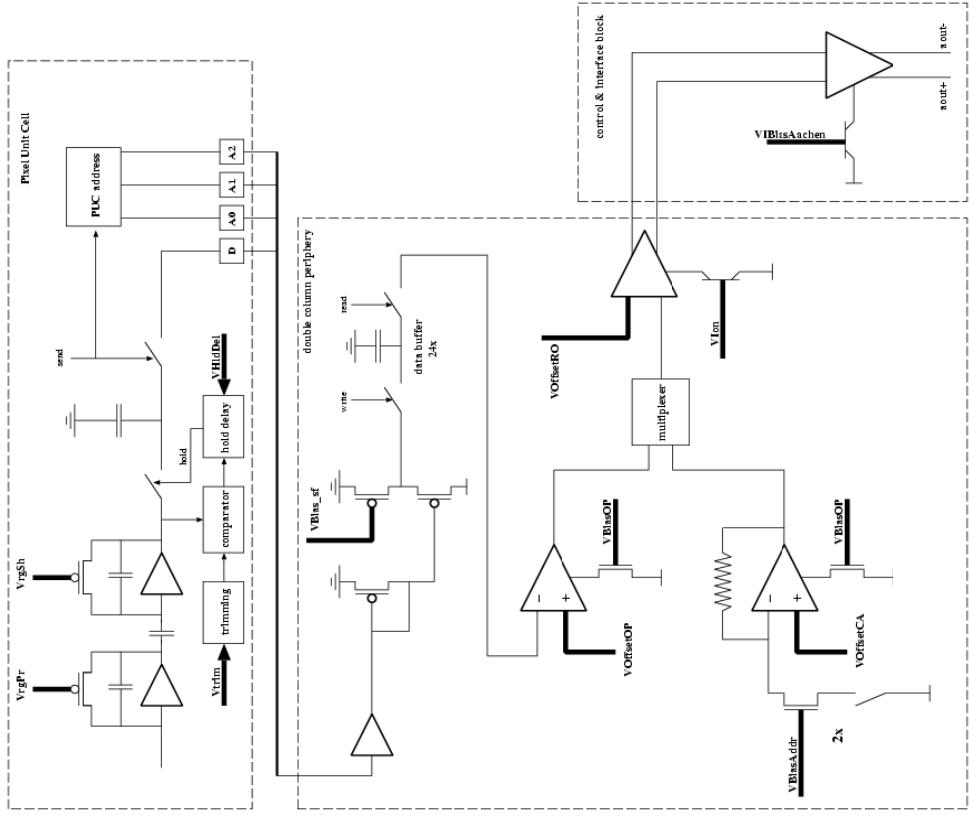
Layer	Radius [mm]	# Modules	Area [m <sup>2</sup> ]	Fluence [MHz/cm <sup>2</sup> ]
1	41-45	128	0.15	25
2	70-74	224	0.25	13
3	107-112	352	0.38	8



# CMS pixel readout chip

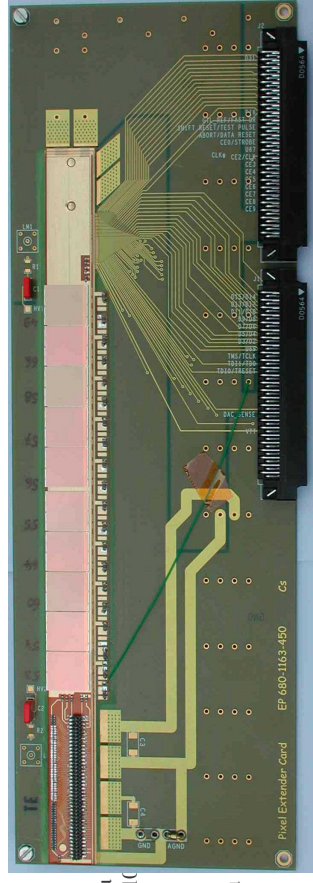
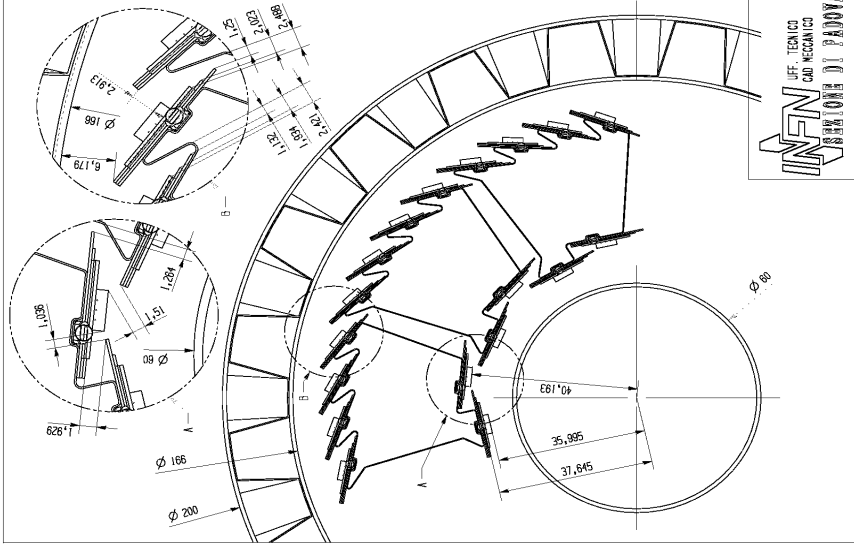
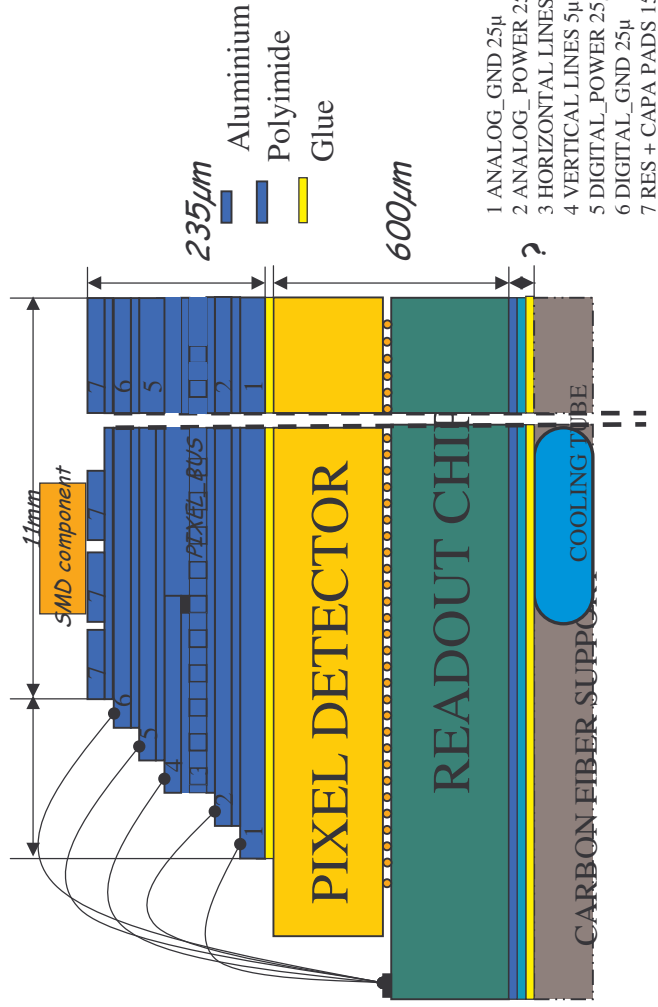
- 52 x 53 pixels, organised in 26 double column
- Pixel size: 150 x 150µm
- Column Drain Architecture

- 2 stage preamp with adjustable feedback
- adjustable comparator threshold, global and local trim
- sample/hold with programmable hold delay
- adjustable range and scale of pixel address and double column address



# ALICE Silicon Pixel Detector (SPD)

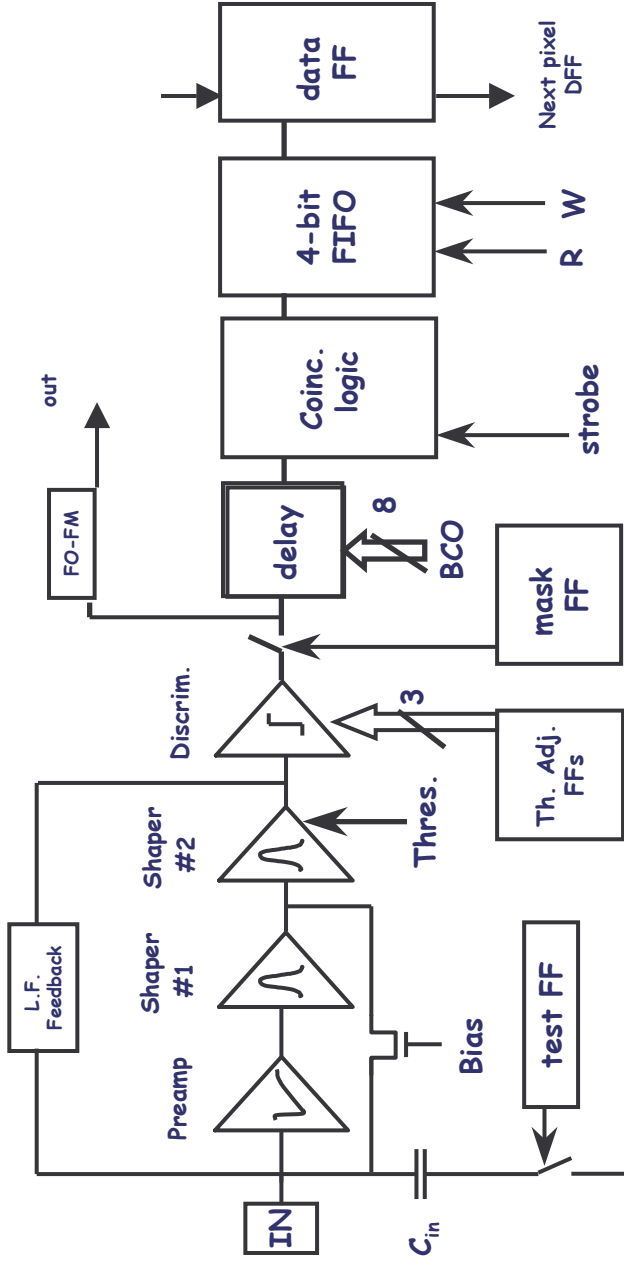
- Silicon Pixels (0.2 m<sup>2</sup>, 9.8 M channels)
- Pixel bus (Al/polyimide multilayer)
- Carbon fibre support
- Cooling system demonstrator



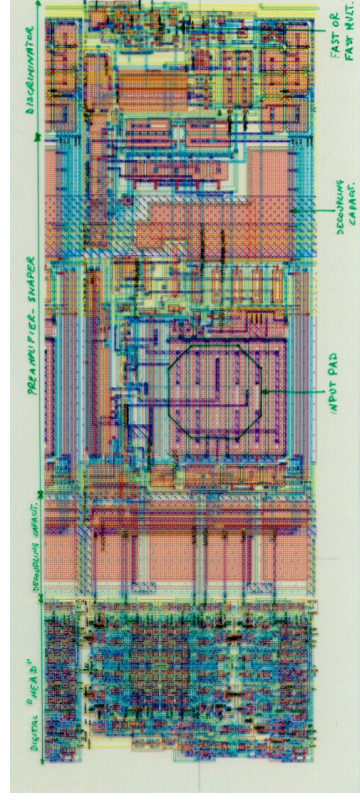
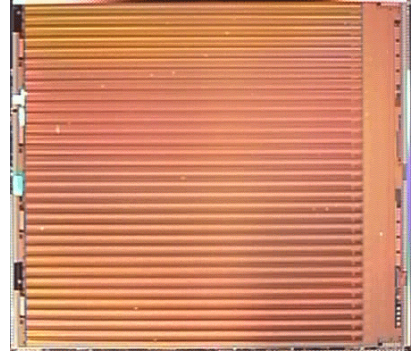
# Alice-LHCB pixel chip

[P. Jarron LEB8 Colmar 02]

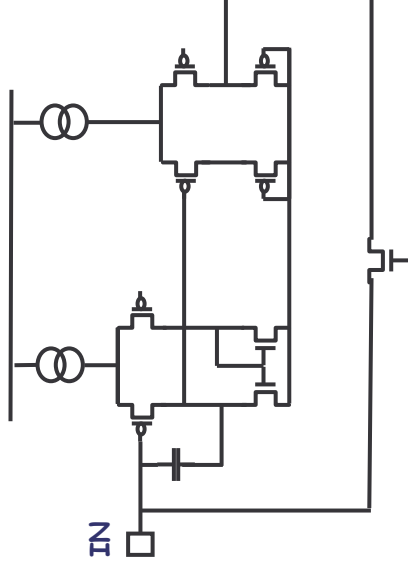
- ✓ 8192 pixel cells/die (32x256)
- ✓ 13 millions transistors/die
- ✓ 5 dies /detector
- ✓ Differential preamp
- ✓ Power/die: 0.8W (100  $\mu$ W/ch)
- ✓ Pixel size: 50 x 450  $\mu$ m
- ✓ All processing functions on pixel
- ✓ ENC = 100 e- rms @  $C_{det}=0.1$  pF
- ✓ Threshold mismatch: 150 e- rms
- ✓ Vdd=1.8V
- ✓ Chip size : 12.8\*13.6 mm
- ✓ 0.25  $\mu$ m CMOS process



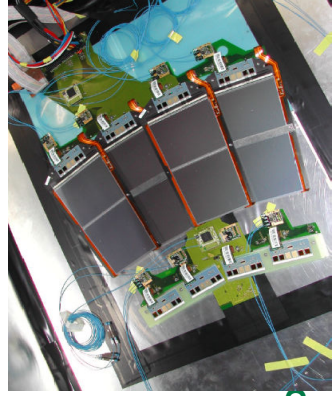
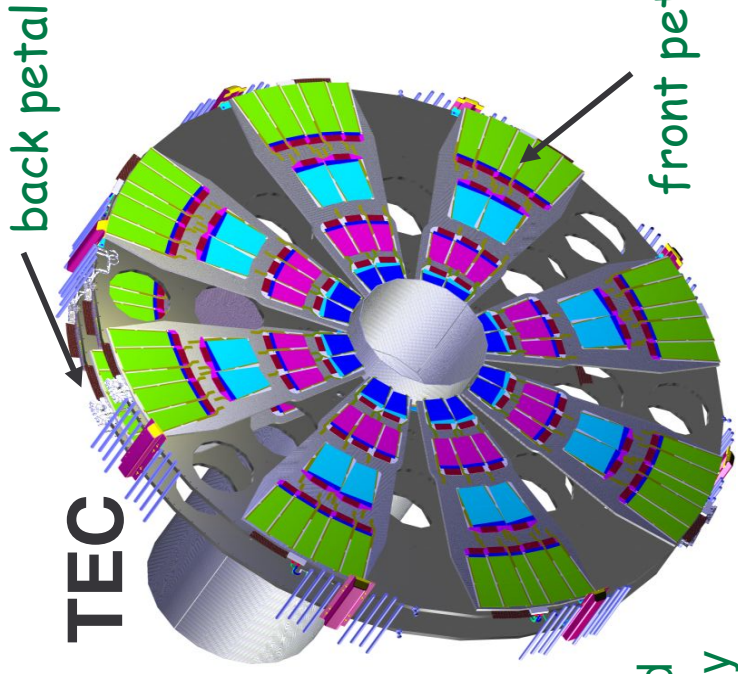
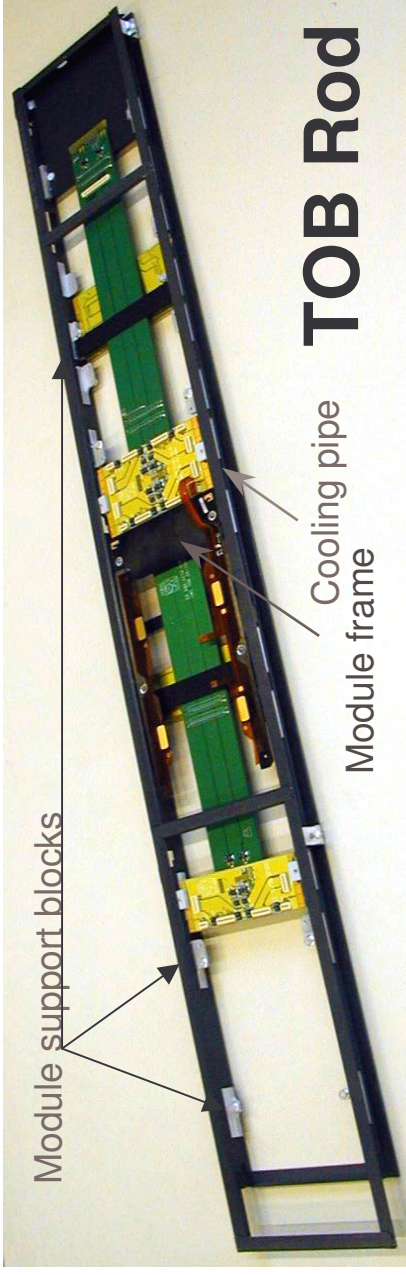
Analog test input



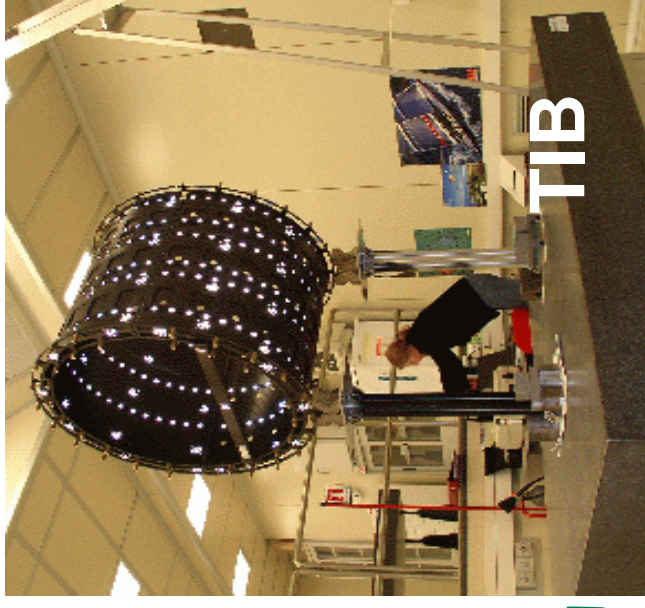
Preamplifier  $I=20\mu A$

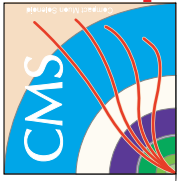


# CMS tracker : TIB/TOB/TEC Components



Produced and inserted individually

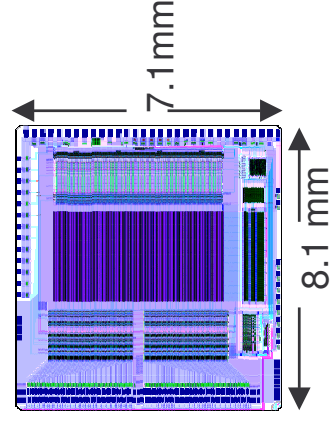
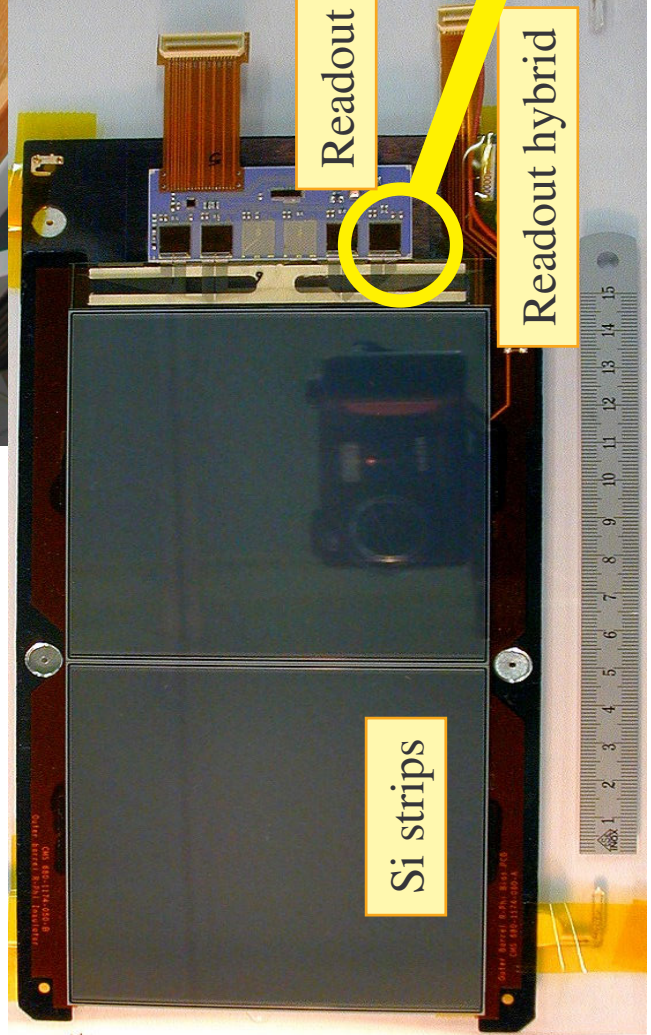
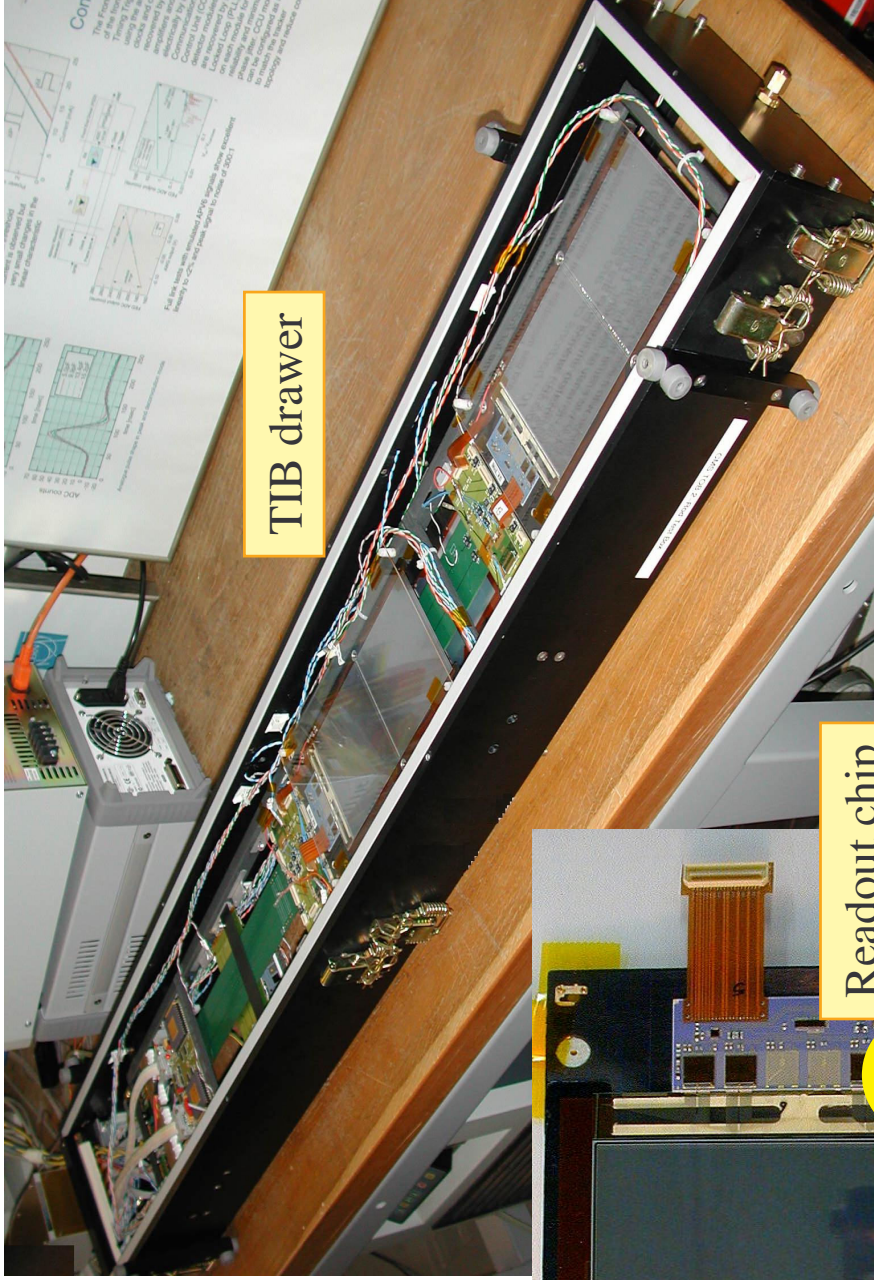


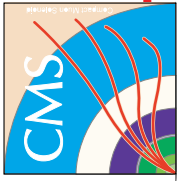


# Tracker electronics

[U. Goerlach LEB8 Colmar 02]

- CMS TIB
- Si strips





## Trackers circuits : exemple APV25 (CMS)

- **Intégration très poussée**
  - 128 preamps/shapers, 128\*160 analog pipelines
  - Mode peak & déconvolution, multiplexe'd output, internal calibration ...
- **Performance**
  - Dynamic range  $\pm 13$  MIP, low dissipation ( $2\mu\text{W}/\text{ch}$ ), Low noise :  $\sim 200\text{e}^-$

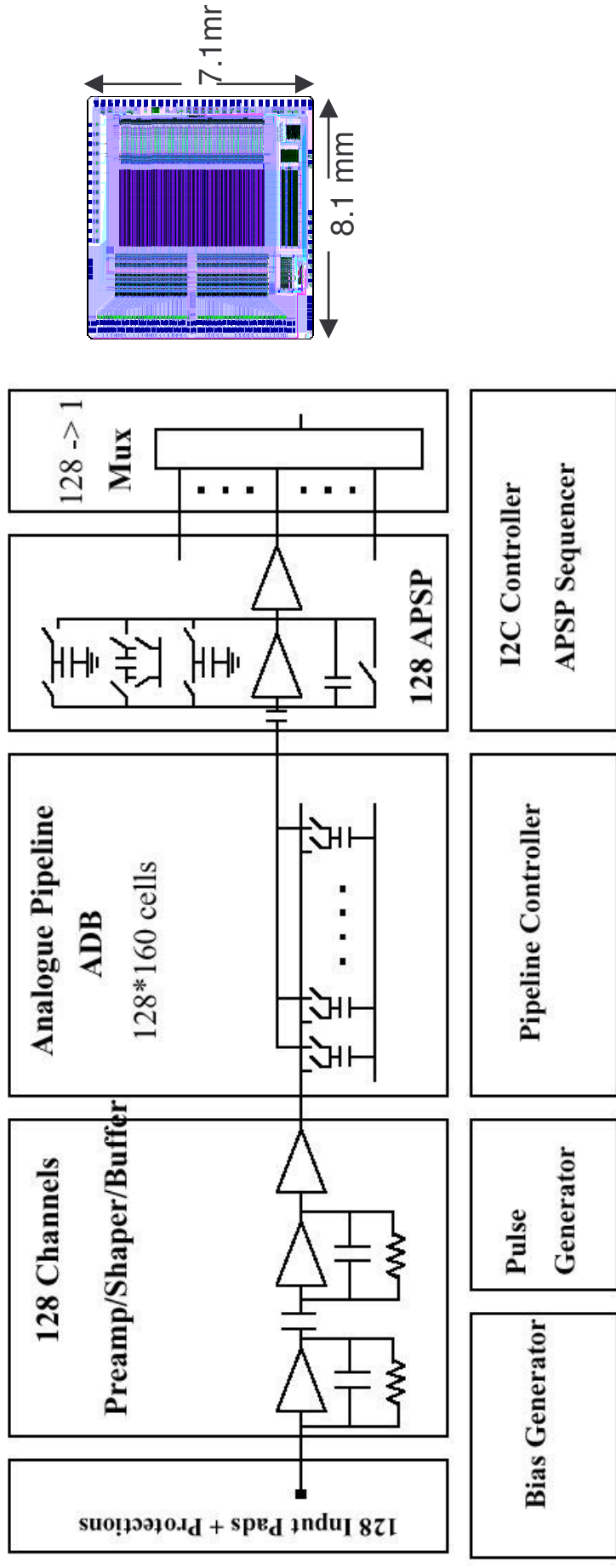
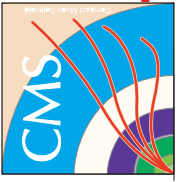
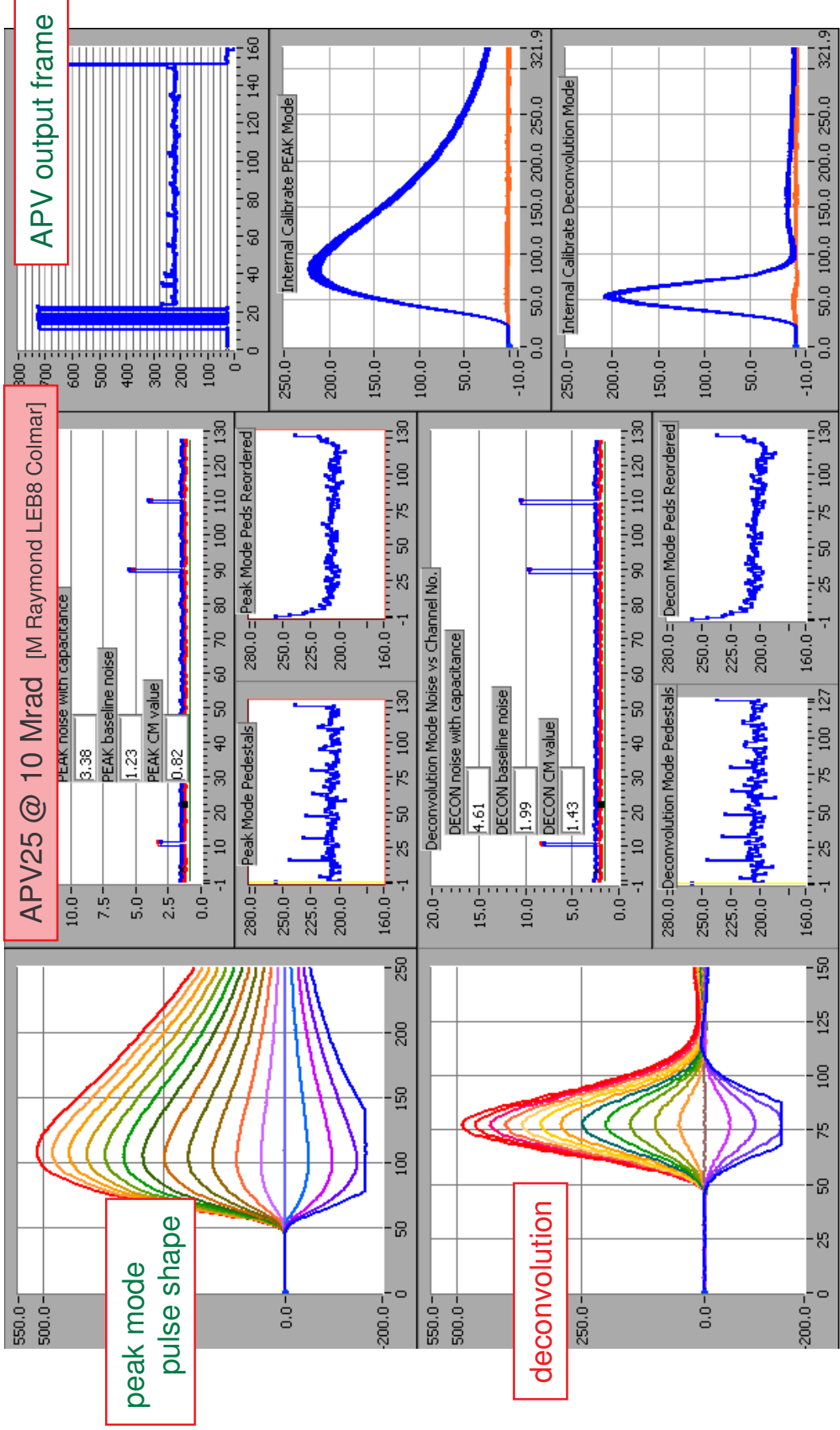


Fig. 1. APVD block diagram.



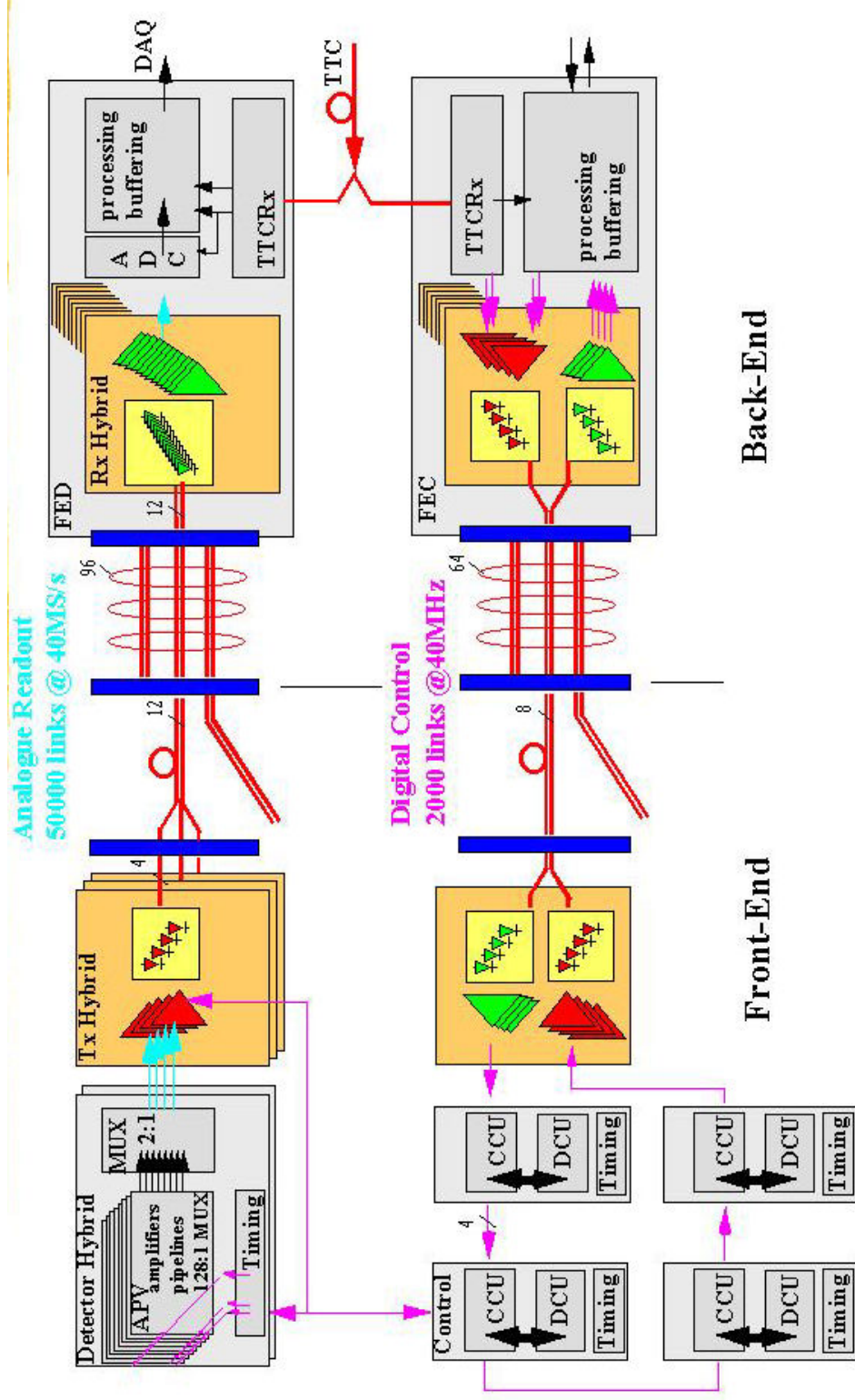
# APV25 performance

[M Raymond LEB8 Colmar 02]



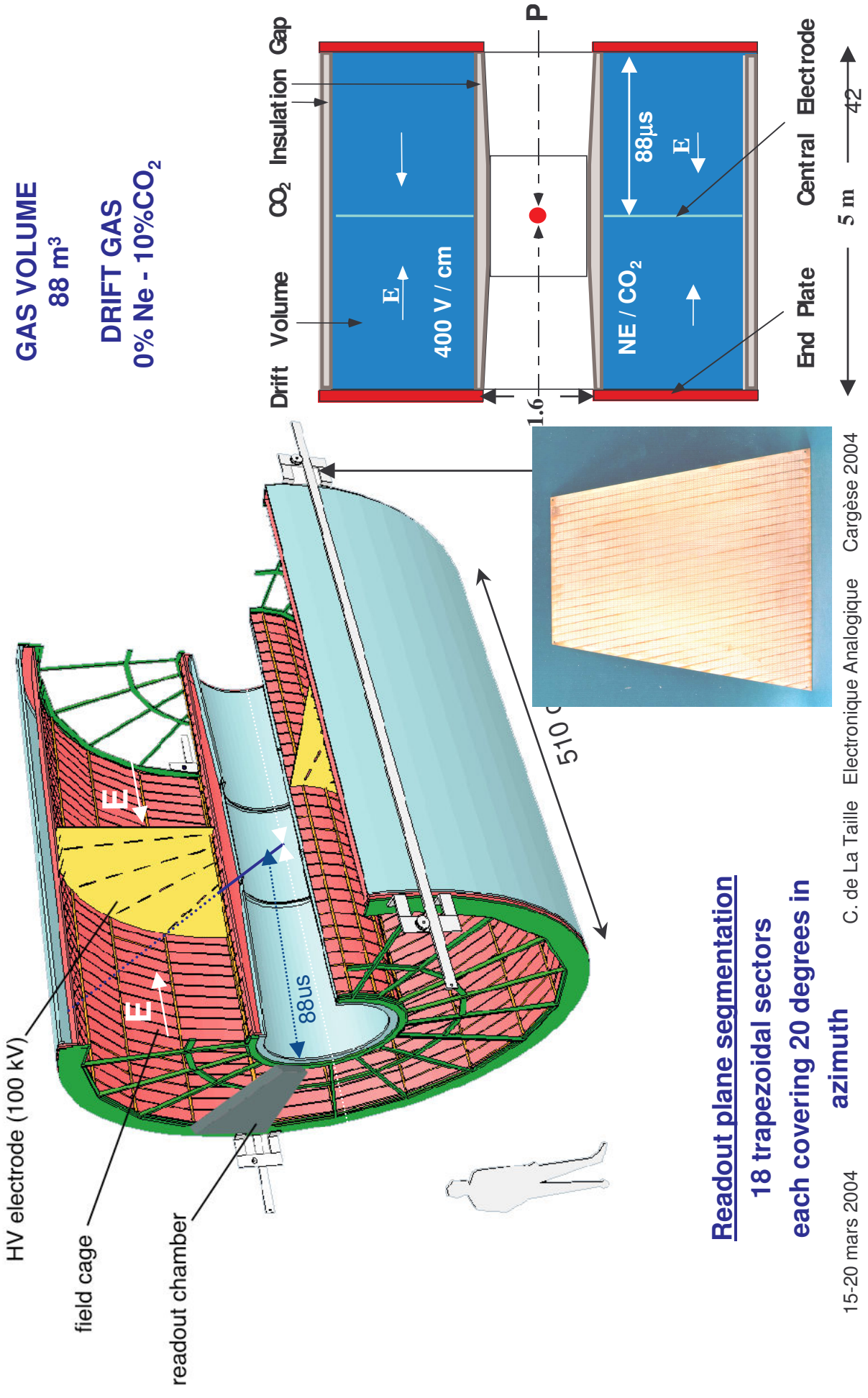


# Inner Tracker : CMS readout electronics



**9,096 Thick detectors (2 sensors) sor)**  
**9,648,128 electronics channels**

# Détecteurs gazeux : ALICE TPC layout



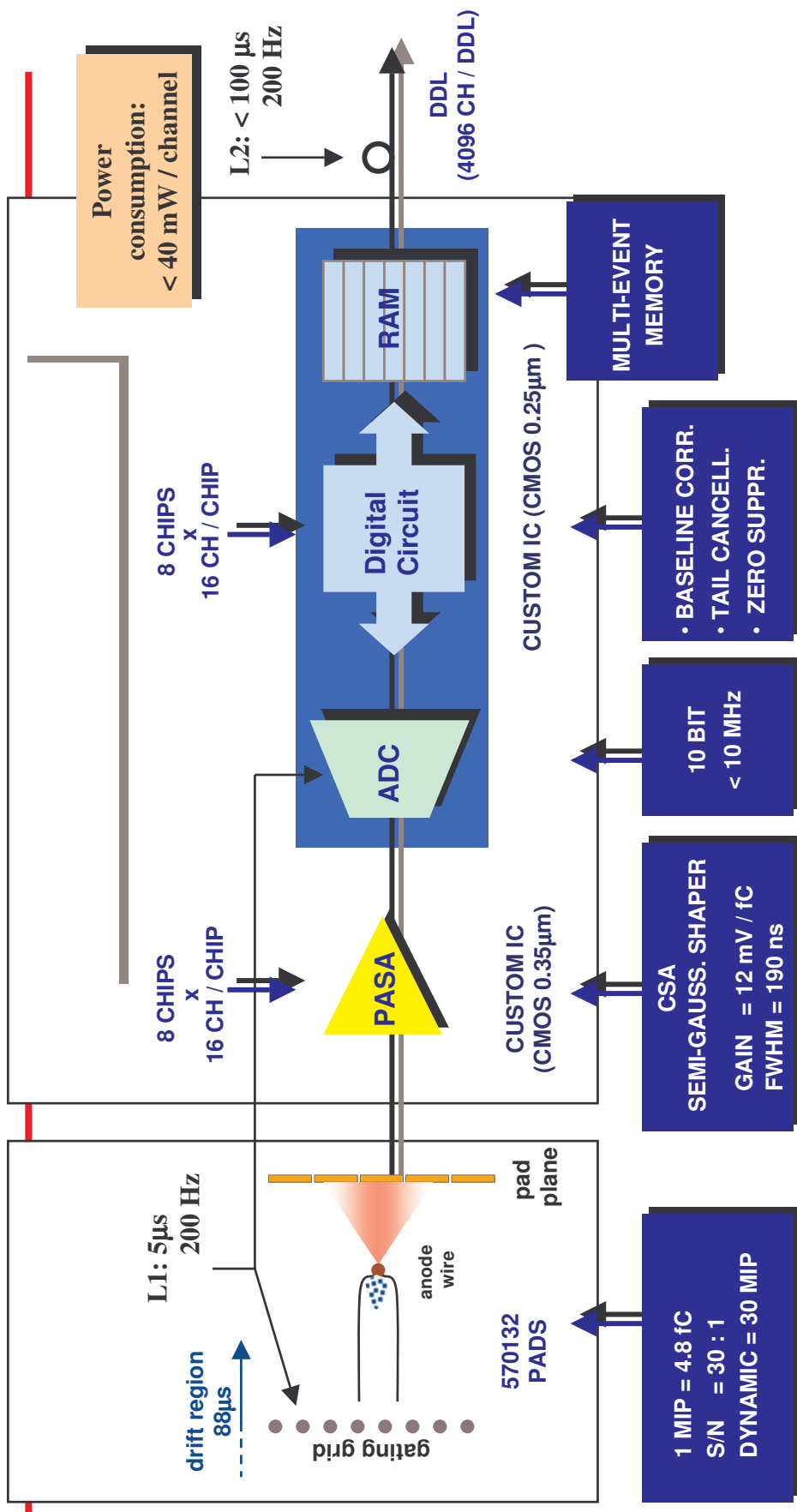
**Readout plane segmentation**  
**18 trapezoidal sectors**  
**each covering 20 degrees in**

**azimuth**

15-20 mars 2004

C. de La Taille Electronique Analogique Cargèse 2004

# TPC: Electronics

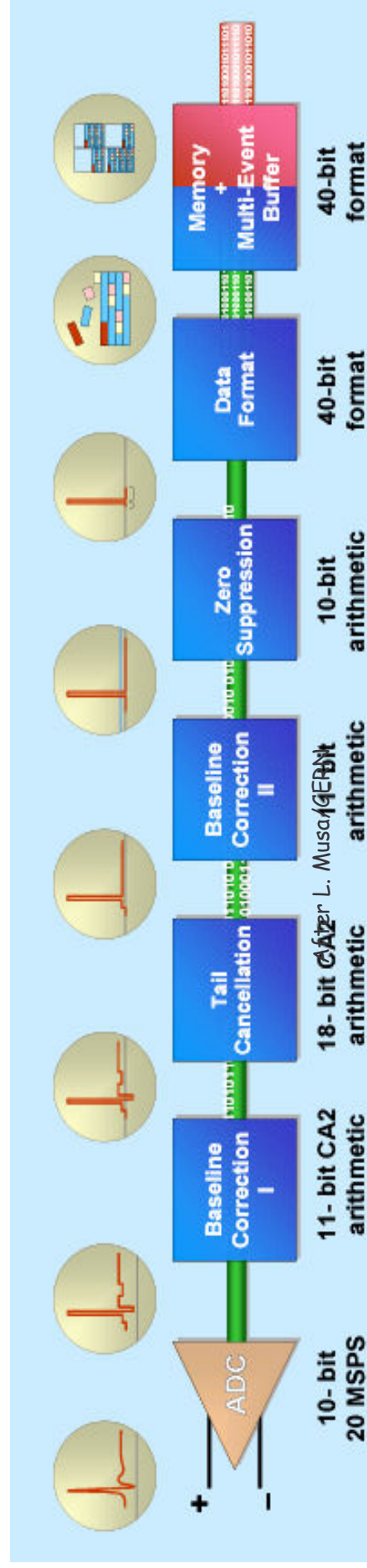
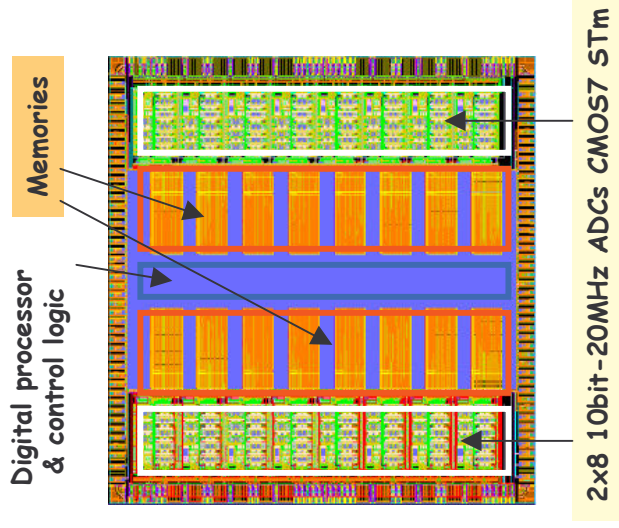
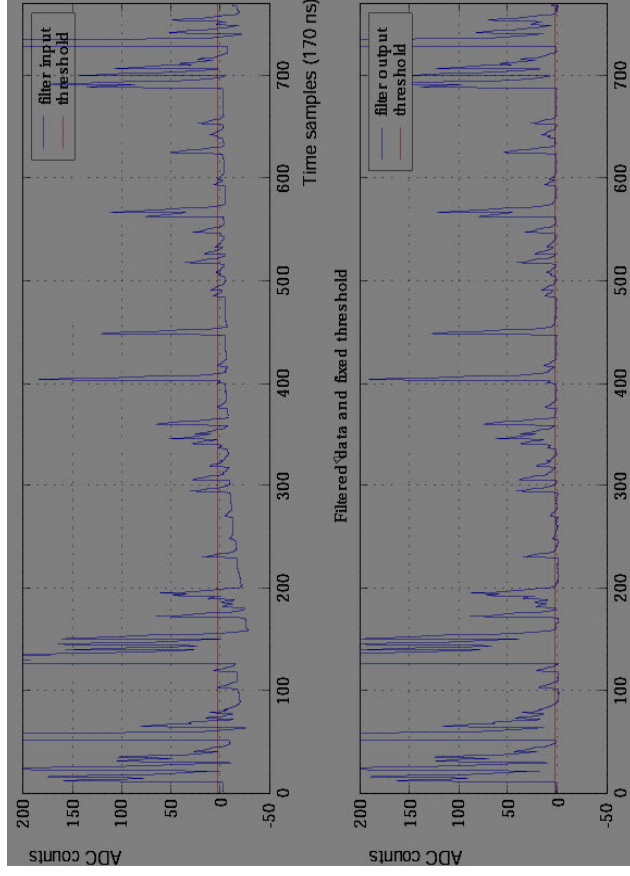


## ■ ALTR0: commercial ADC integrated with custom digital chip

- 0.25 micron technology (ST), 64 mm<sup>2</sup>, 29 mW/ch, SEU protection

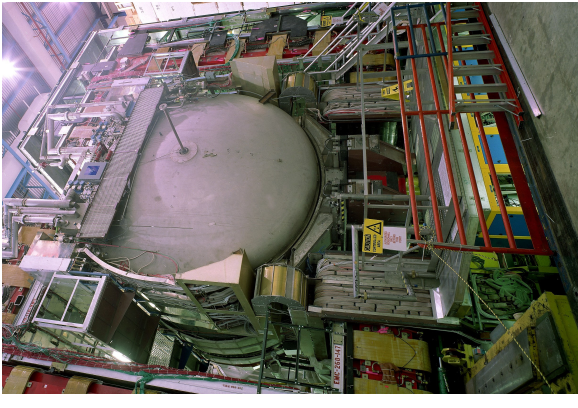
# ALTR0 chip ALICE TPC

[P. Jarron LEB8 Colmar 02]

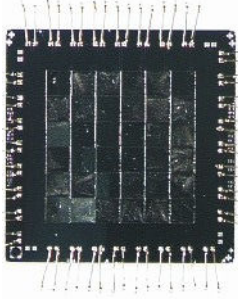
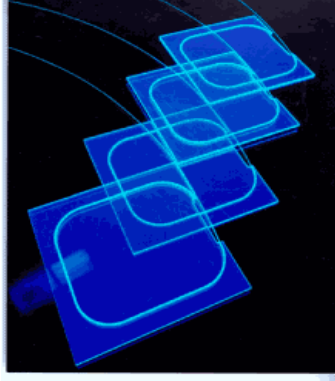
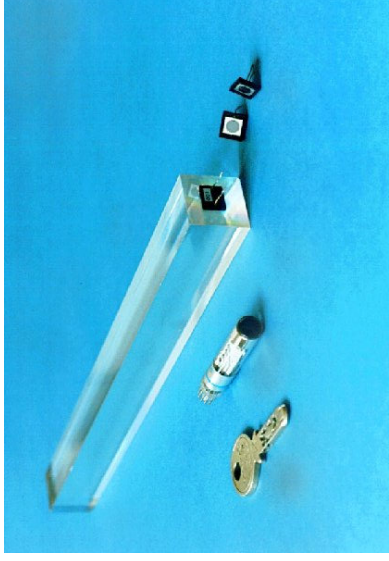


# Calorimétrie

- **Mesure** : énergie, position, temps, type de particule
- **Calorimètres** : bonne résolution, large, stable
- **≠ Spectromètres** : excellente résolution, acceptance limitée
- **Un vaste choix de détecteurs** :



D0 : Ø 4m  
1 to 1000 GeV



6x6 pixels, 4x4 mm<sup>2</sup>  
HgTe absorbers, 65 mK  
12 eV @ 6 keV

**Cd(Zn)Te**  
**AsGa**

**microcalo**

**Si**

**Crystals**

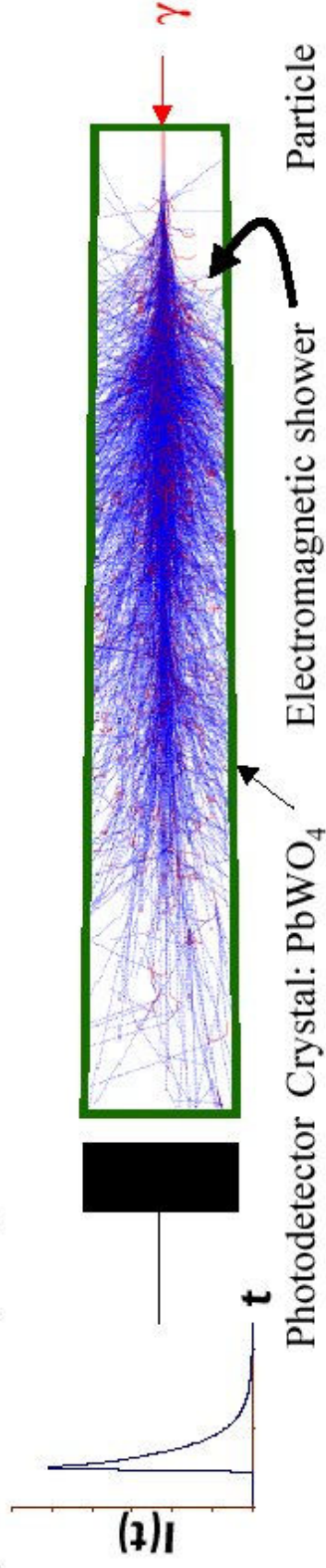
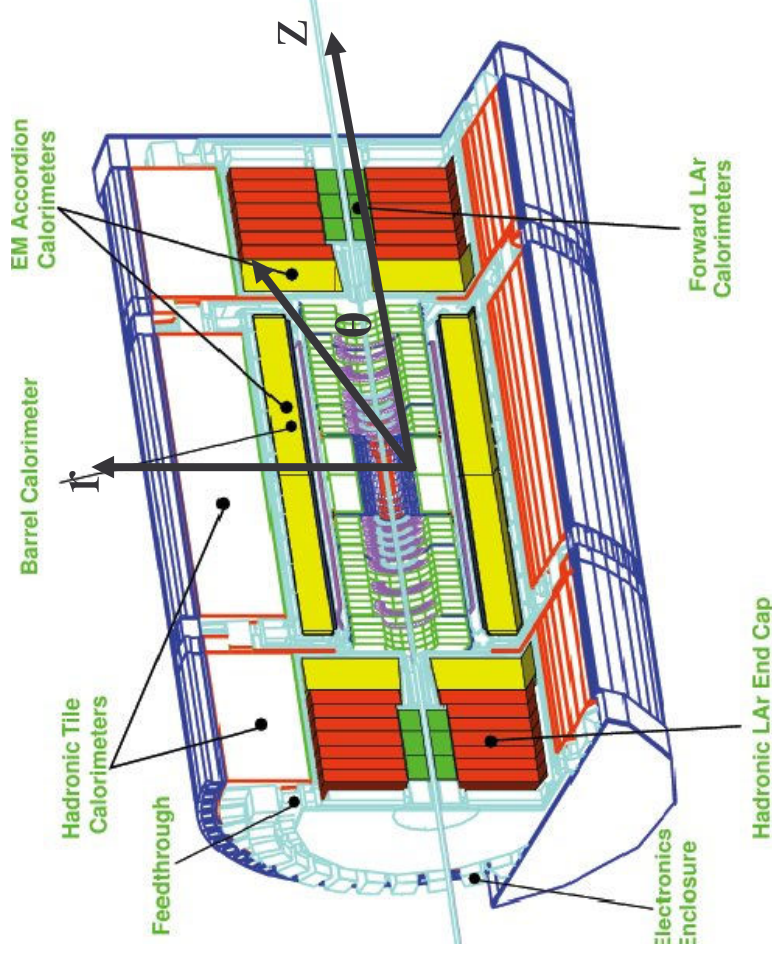
**Sampling**

**LKr**

**1**   **10<sup>3</sup>**   **10<sup>6</sup>**   **10<sup>9</sup>**   **10<sup>12</sup>**   **E (eV)**

# Basics on calorimetry : vocabulary

- Electromagnetic
- Hadronic
- Preshower
- Granularity :  $\theta, \varphi$
- Segmentation in depth :  $r$
- Rapidity :  $z, \eta = -\text{Ln}(\text{tg } \theta/2)$
- Barrel / End-cap / forward
- Energy resolution :  $\sigma(E)/E$  (%)



# Caractéristiques :

- **Résolution en énergie :**  
$$\sigma(E)/E = a/E \oplus b/\sqrt{E} \oplus c$$
  - **a** : bruit électronique
  - **b** : terme tochastique (physique)
  - **c** : terme constant
    - Non uniformities
    - Importance de la calibration

- **Gamme dynamique étendue : 10-18 bits**

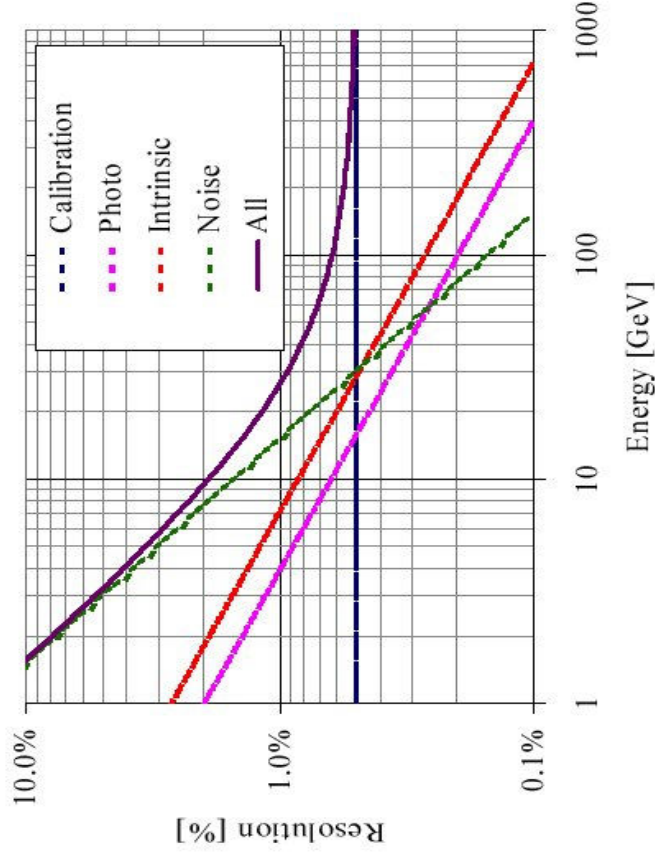
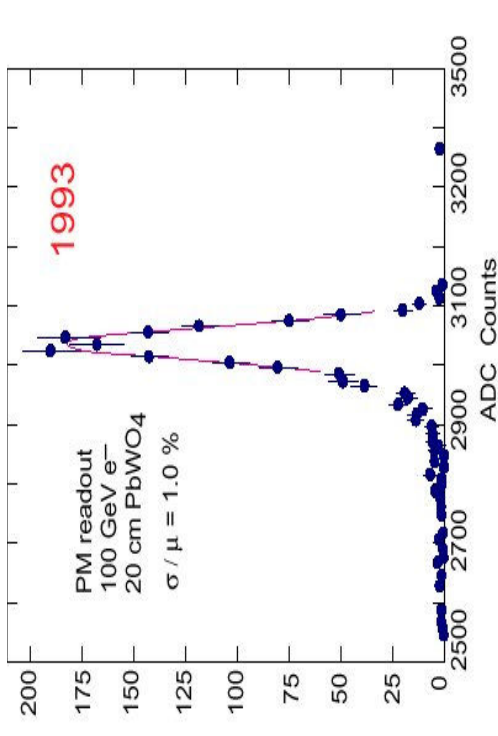
- 10 - 12 bits : preshowers,
- 16 - 18 bits : colliders

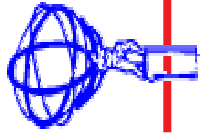
- **Mesures de précision ~1 %**

- 0.5 - 1 % in electromagnetic
- 1- 5% hadronic, preshowers
- Bonne linéarité : < 1%

- **Grand nombre de canaux**

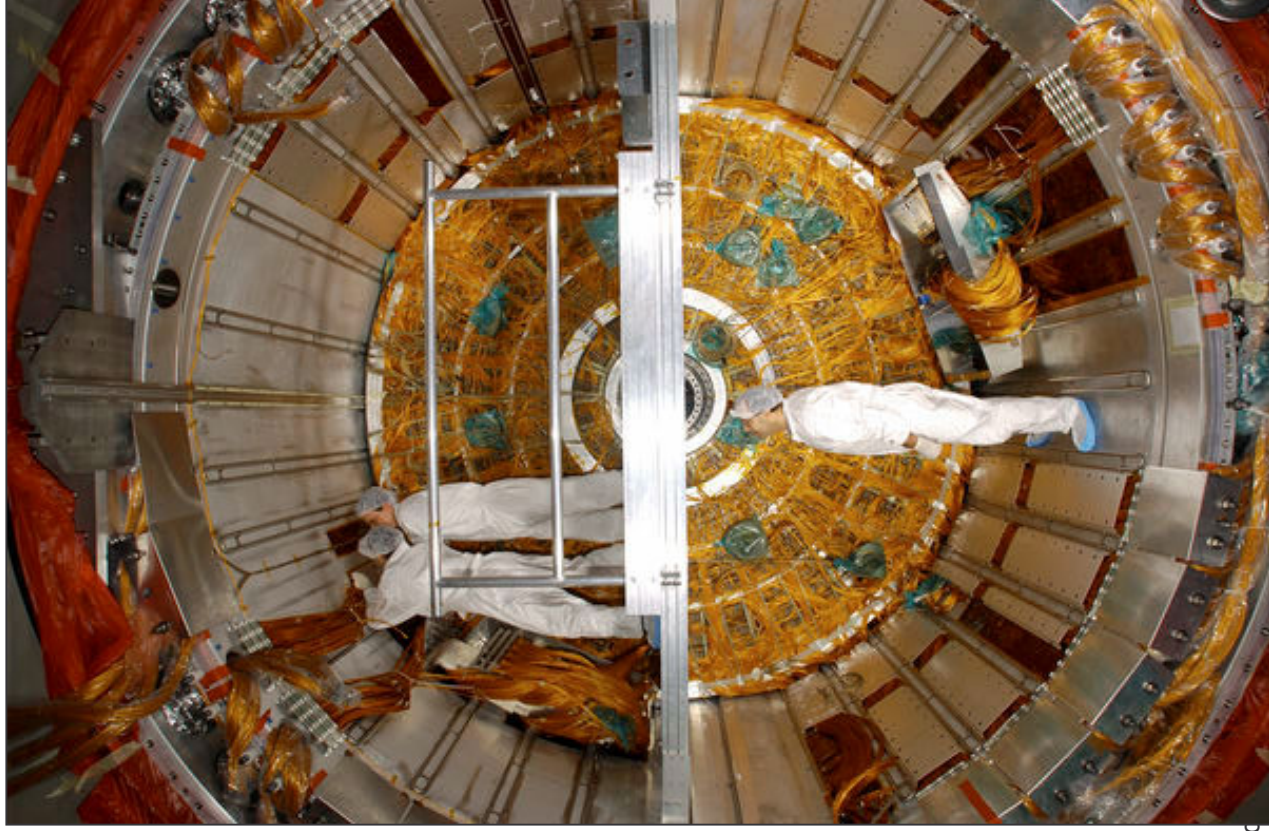
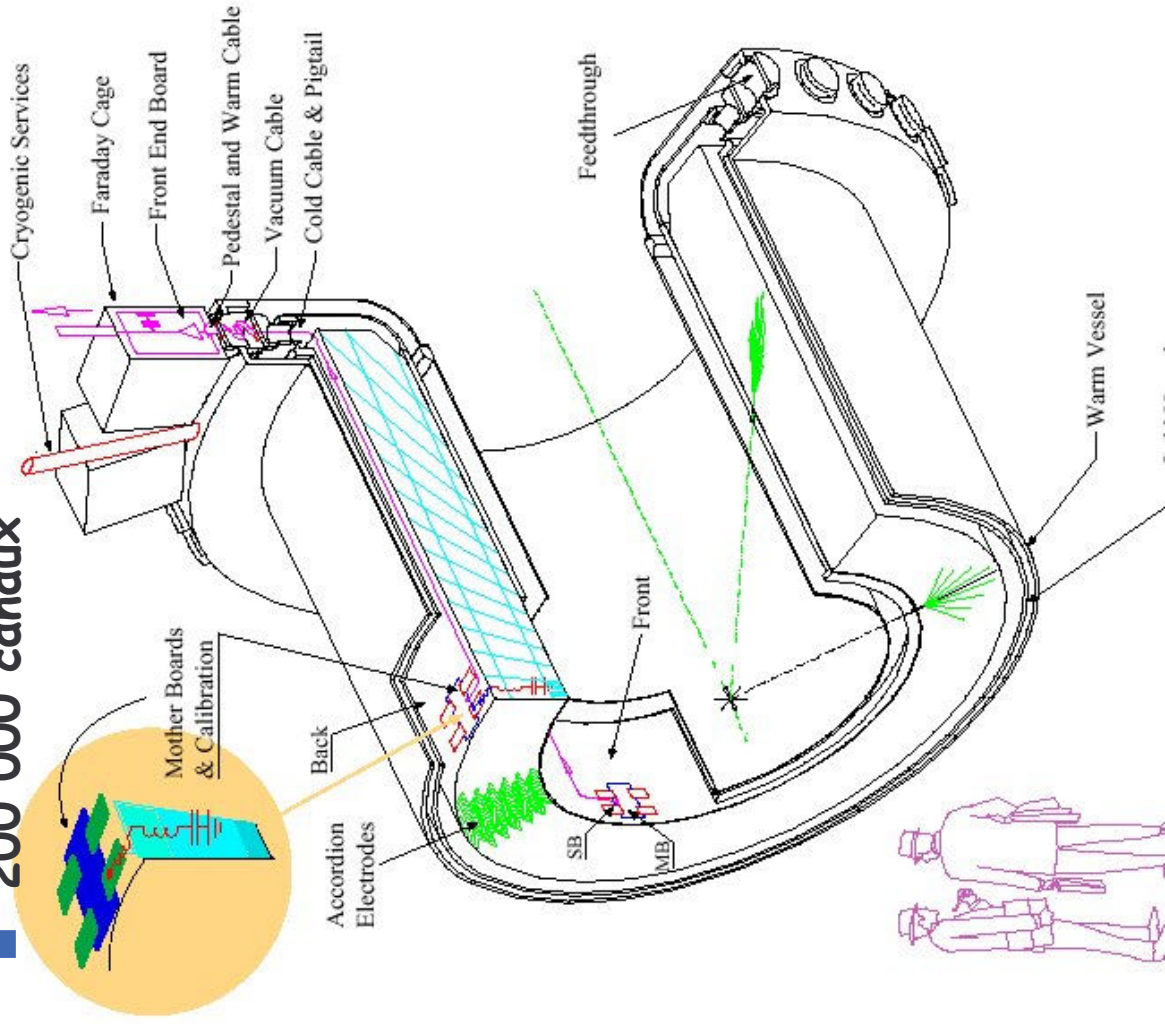
- Mesure de la position





# ATLAS : LAr e.m. calorimeter [111]

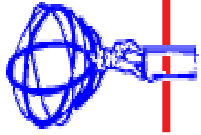
■ 200 000 canaux



15-20 mars 2004

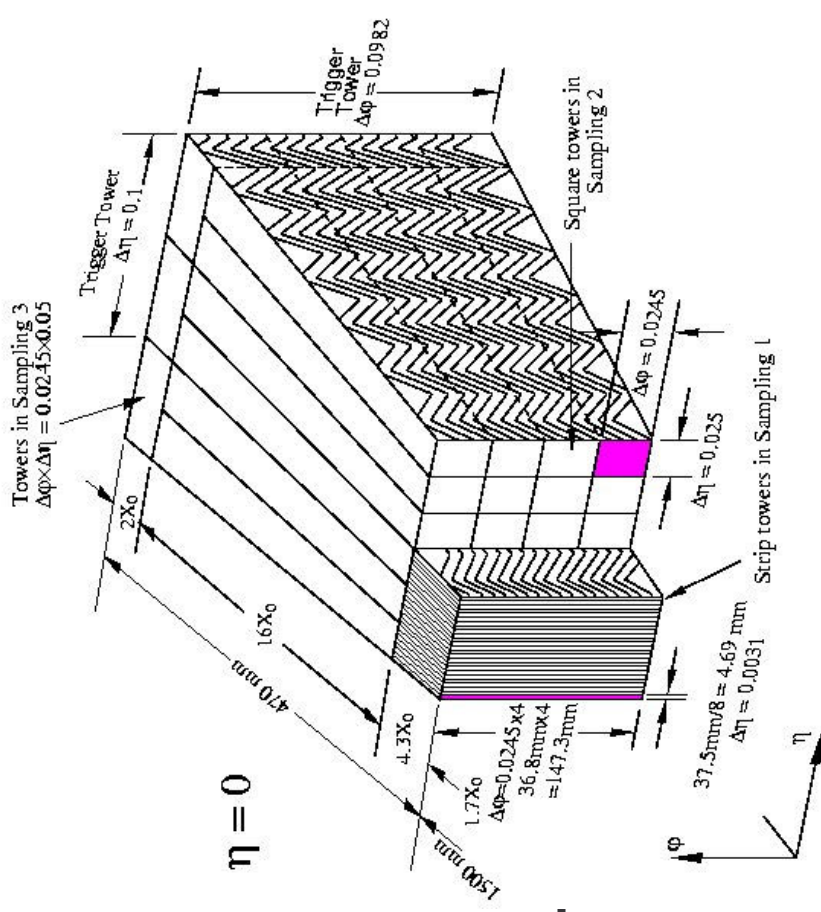
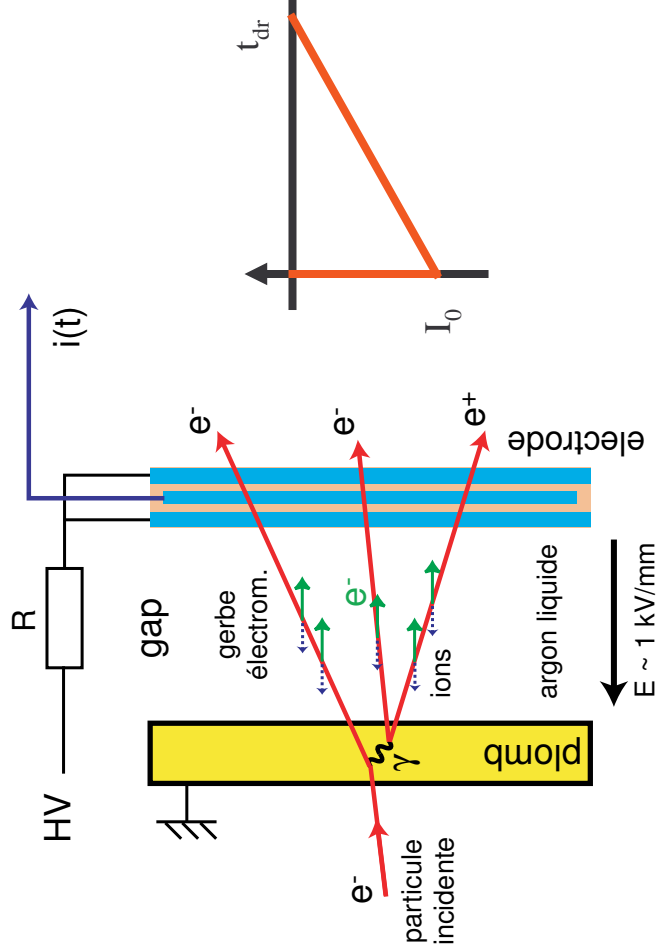
C. de La Taille Electronique Anal





# ATLAS : LAr e.m. calorimeter [11]

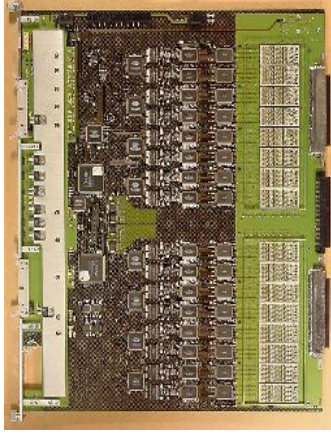
- **Gamme dynamique : 16 bits (50 MeV-3 TeV)**
  - Energy resolution :  $10\%/\sqrt{E} \oplus 0.7\%$
- **Segmentation : PS, Frt, Mid, Back**
  - Capacité : 200 pF - 2 nF
- **Signal d'ionisation triangulaire**
  - $I_0 = 2.5 \mu\text{A}/\text{GeV}$   $t_{\text{dr}} = 450 \text{ ns}$



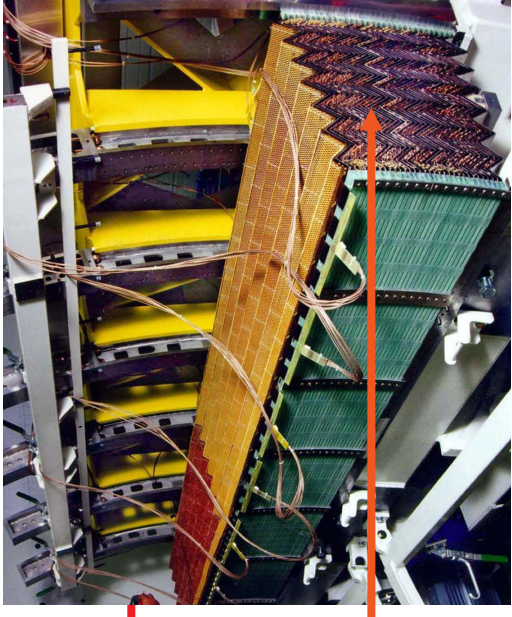
# ATLAS Lar calorimeter readout

Calibration :  
116 boards @ 128 ch

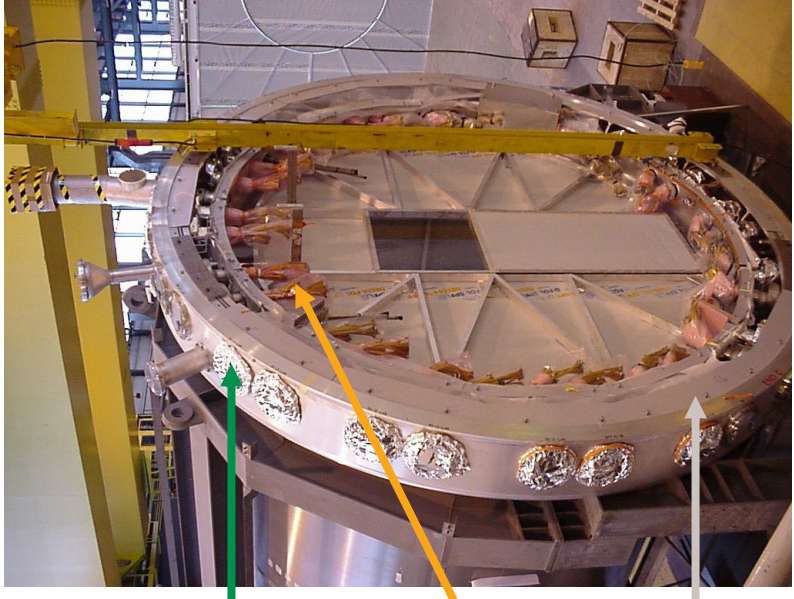
Front End Board (FEB) :  
1524 boards @ 128 ch



Electrodes

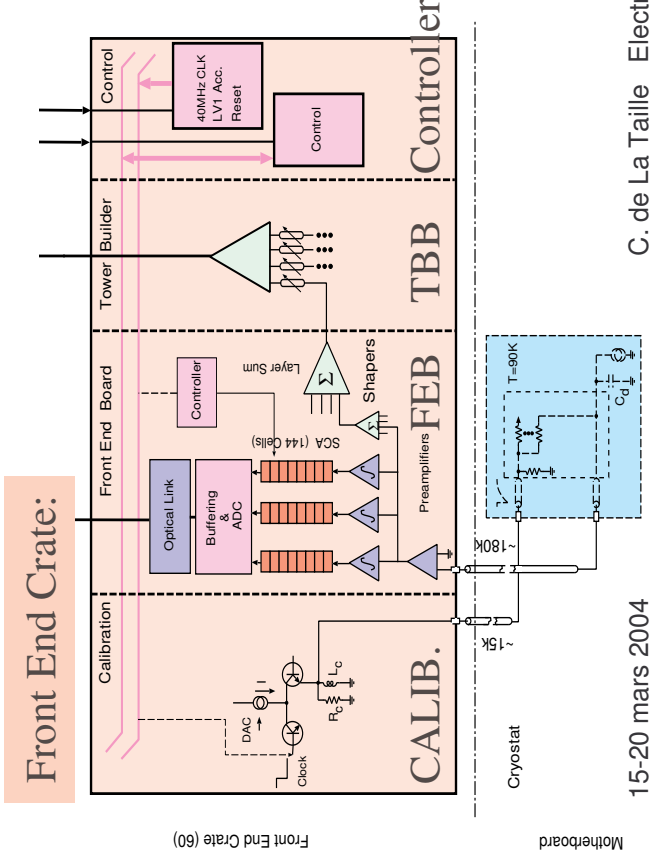


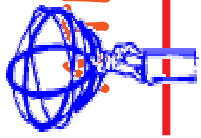
Cold to warm  
Feedthrough



Readout and  
Calib. signals

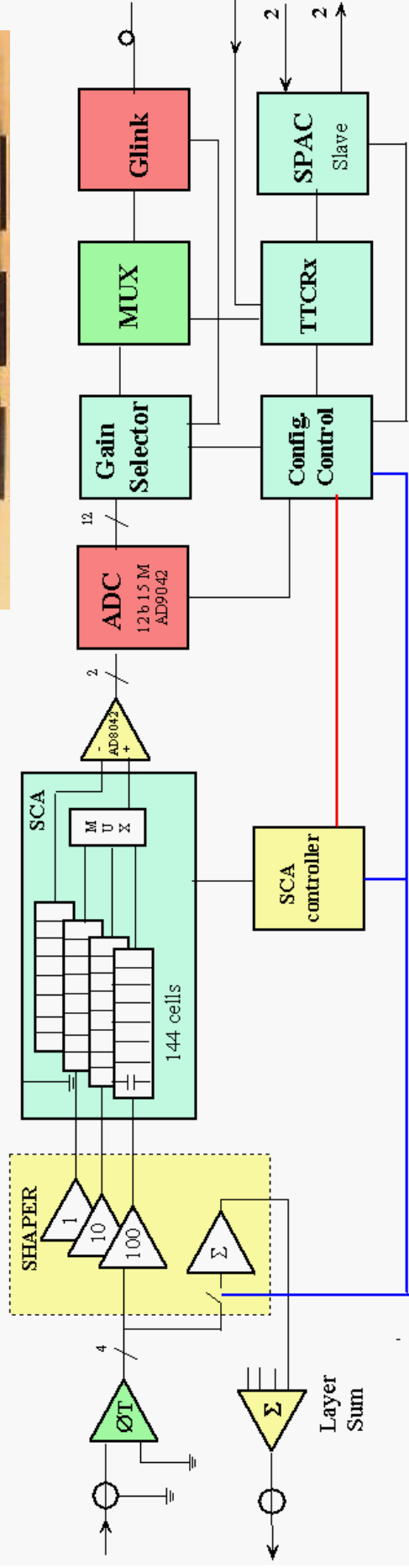
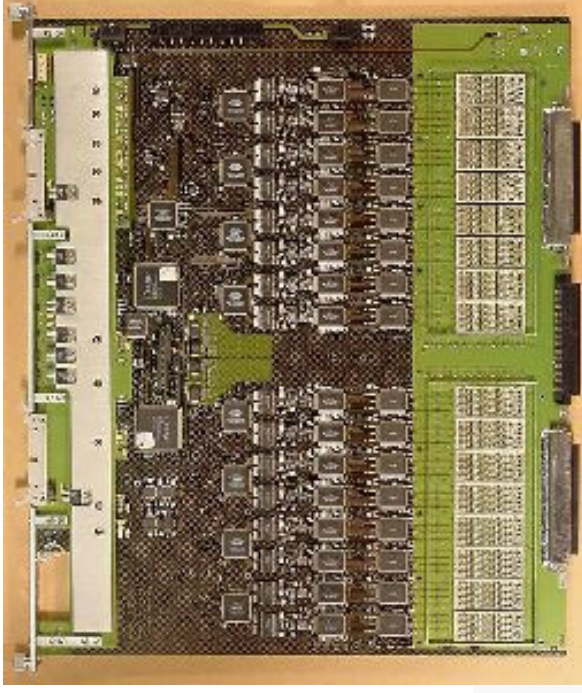
Cryostat

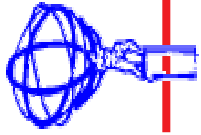




## LAS LAr : Front End boards

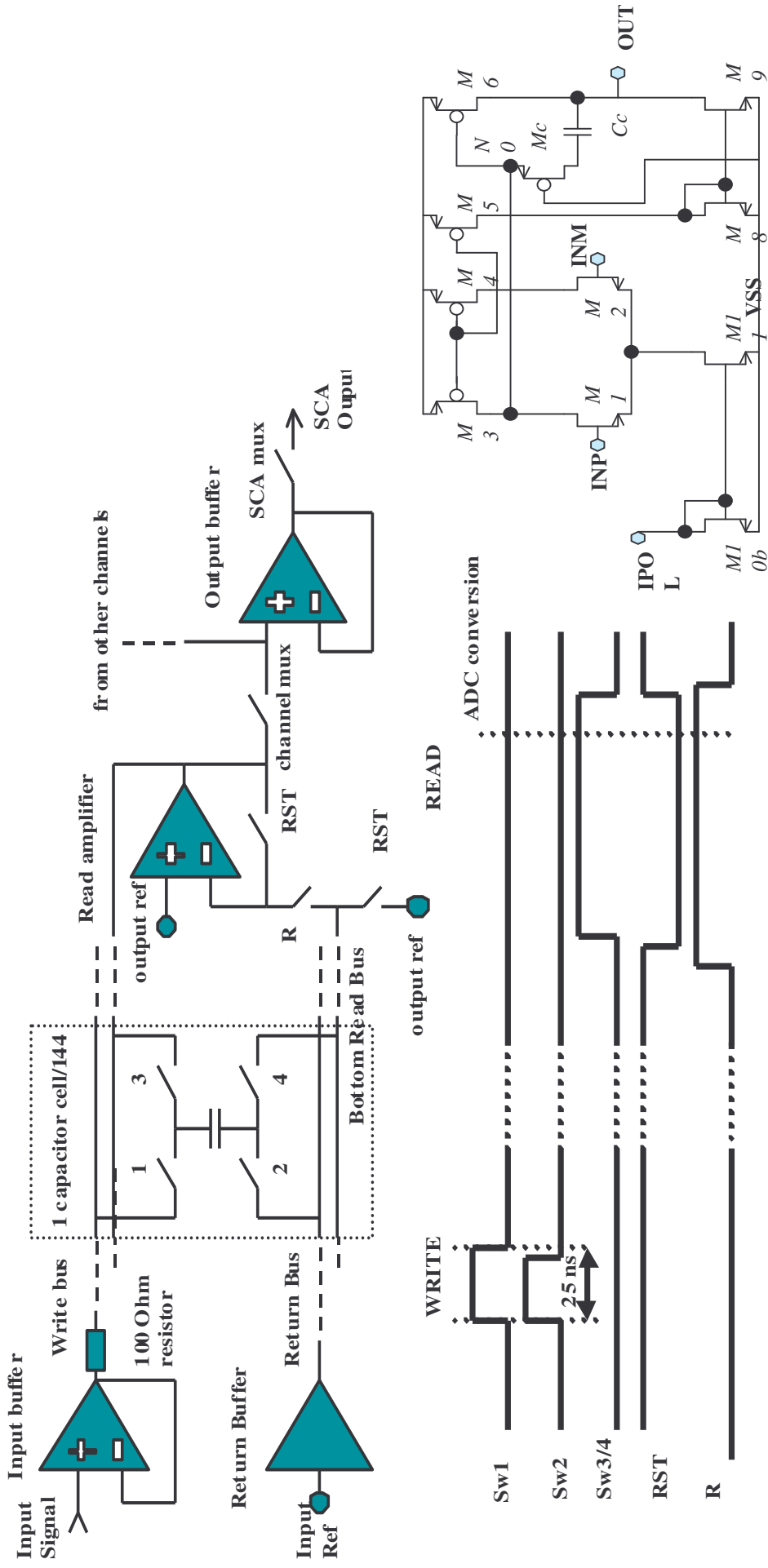
- Amplifier, filterer, stocker, digitiser
  - 128 preamplis de courant bas-bruit ( $\sim 1 \mu\text{V rms}$ )
  - 128 shapers tri-gain (1-10-100)  $t_p=50 \text{ ns}$
  - 128 quad pipelines analogiques 13bits 40MHz
  - 32 ADCs (12bits 5 MHz)
  - 1 optical output (Glink)

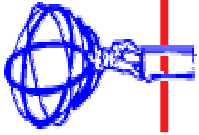




# ATLAS LAr : SCA [18]

## ■ Analog pipeline : voltage write, voltage read

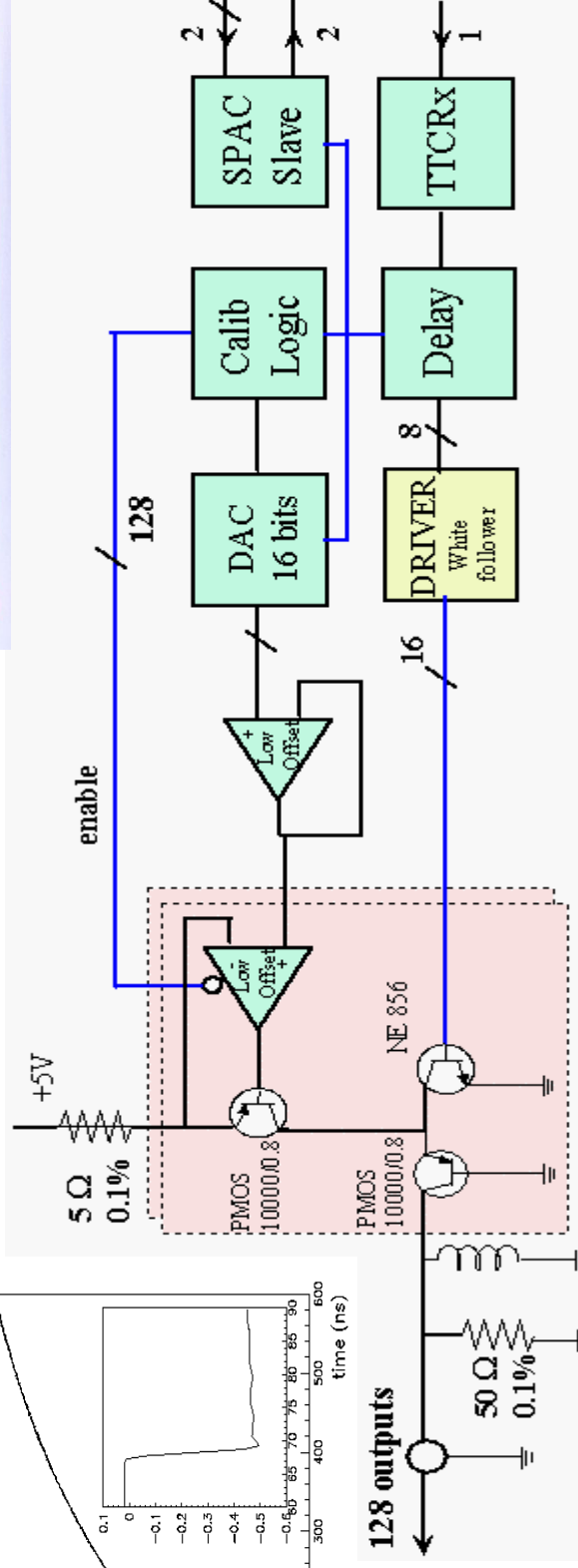
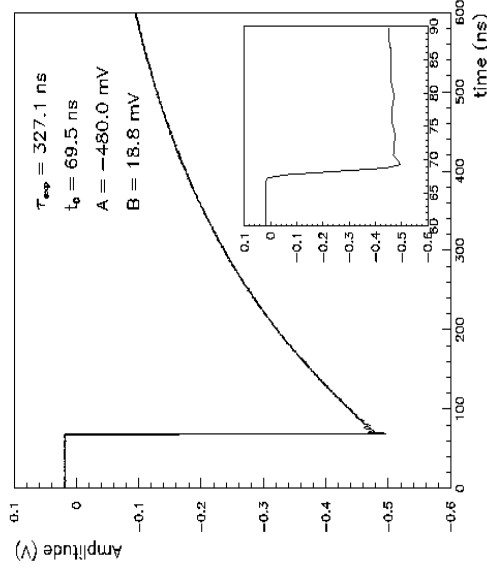
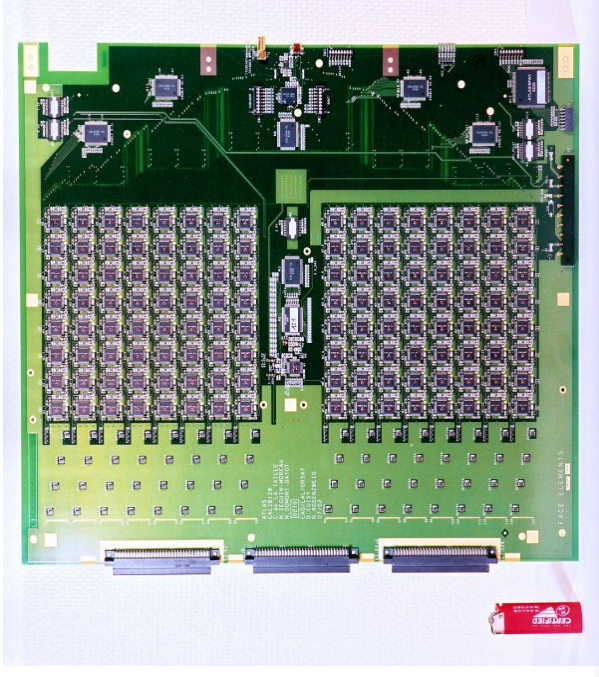




# ATLAS LAr : calibration

[N. Seguin LEB8 Colmar 02]

- Générer pulses avec une précisions de 0.2%
  - 16 bits dynamic range : 100  $\mu$ V - 5 V pulse
  - 1 ns risetime, 400 ns fall time
  - 0.1 % linearity
  - Injected inside LAr with 0.1% precision 1 k $\Omega$  resistors



# DC and Pulse Linearity

- Measured on 3 gains 1-10-100

- Pulse measurements

- In red
- After shaping ( $t_p=50ns$ )

- DC current measur.

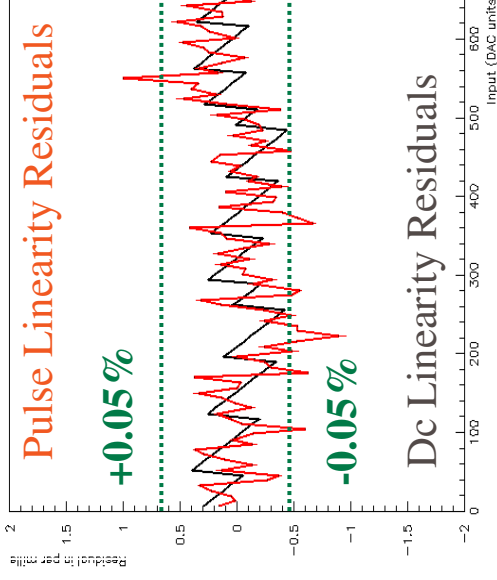
- In black
- With Keithley

- Example of problems

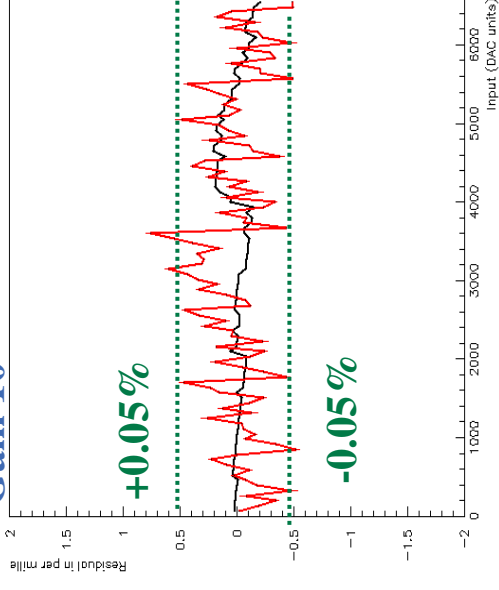
- DAC referenced to VP6 by mistake
- Bad  $5\Omega$  resistor brand

- Dynamic performance at the level to DC performance

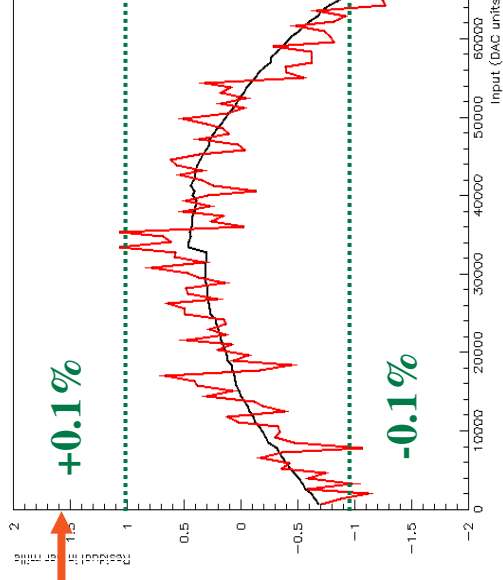
Gain 100



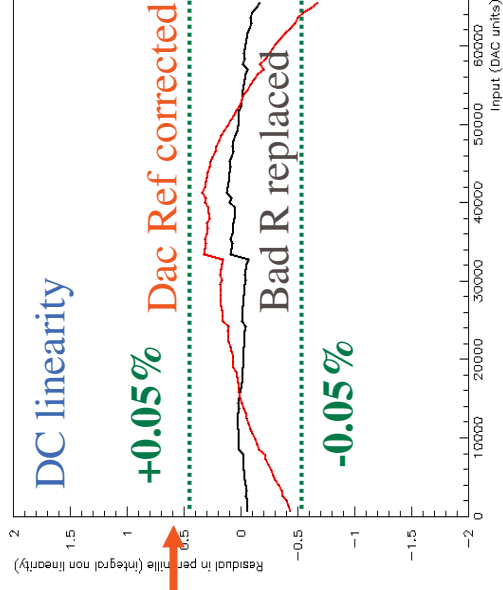
Gain 10

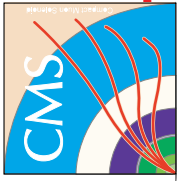


Gain 1



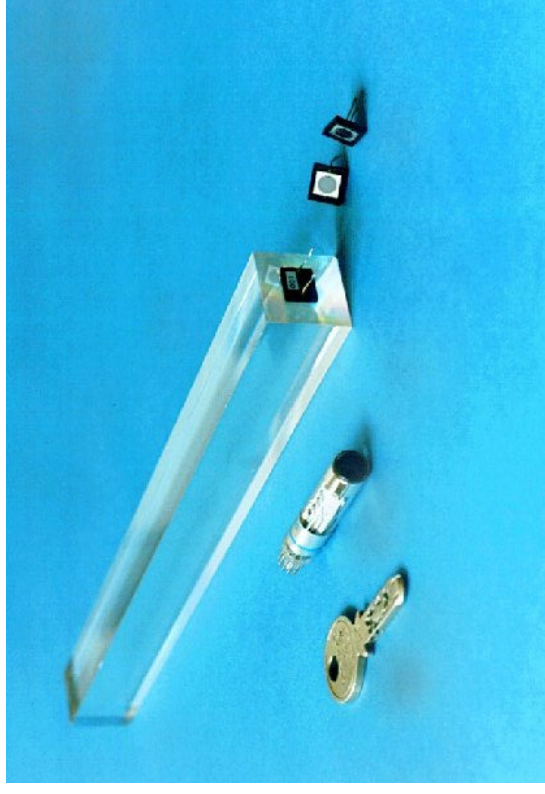
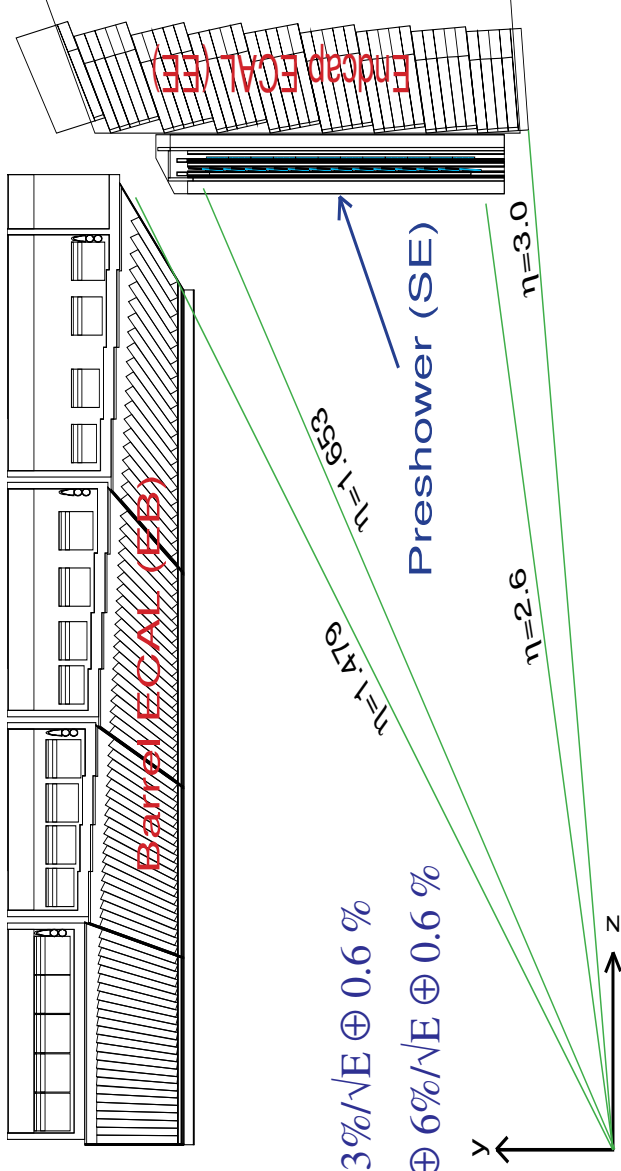
Gain 1





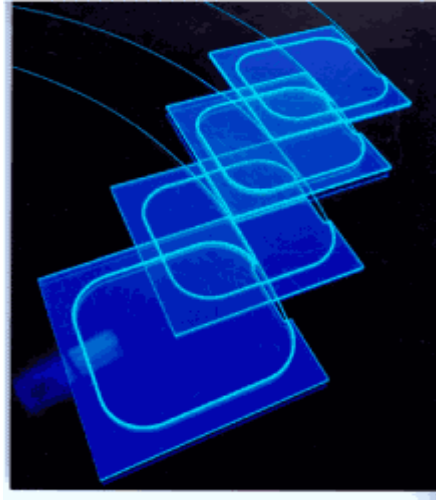
# CMS : em PbWO4 calorimeter [30]

- Lead-Tungstate crystals
  - light yield 9 p.e. /MeV
- Dynamic range : 16 bits
  - 50 MeV-3 TeV
- Energy resolution : ~ 0.5%
  - Barrel :  $\sigma(E)/E = 200 \text{ MeV} \oplus 3\% \sqrt{E} \oplus 0.6 \%$
  - End-cap :  $\sigma(E)/E = 200 \text{ MeV} \oplus 6\% \sqrt{E} \oplus 0.6 \%$
- Granularity : ~ 0.1 x 0.1
  - Barrel : 61 200 channels
  - End-cap : 16 000 channels

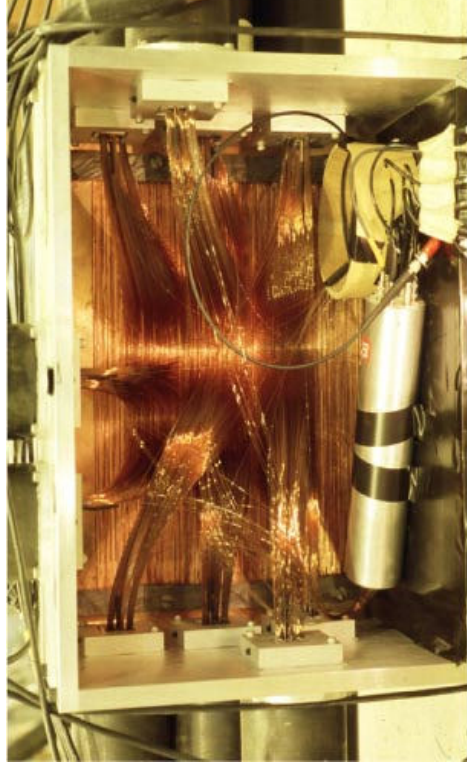
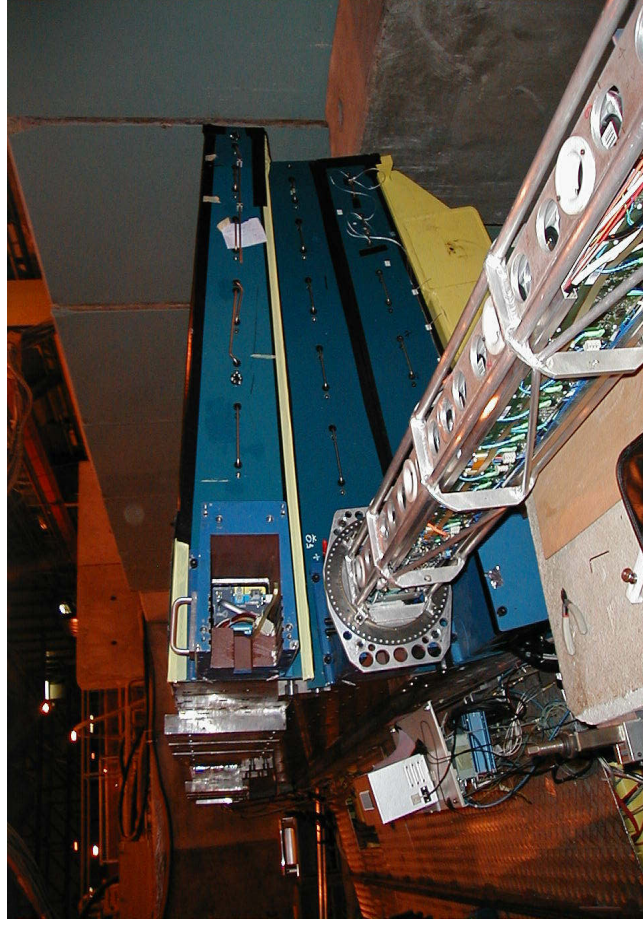
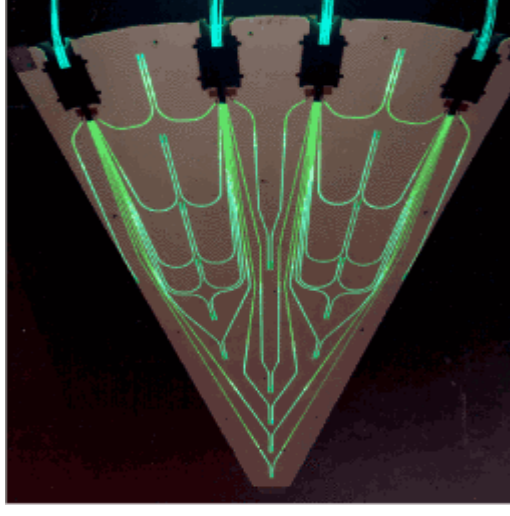


# Calorimètres Hadroniques

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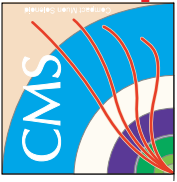
Barrel et EndCap :  
Tuiles de scintillateur  
et variateurs de  
longueur d'onde



Very forward : fibres quartz lues par

PM

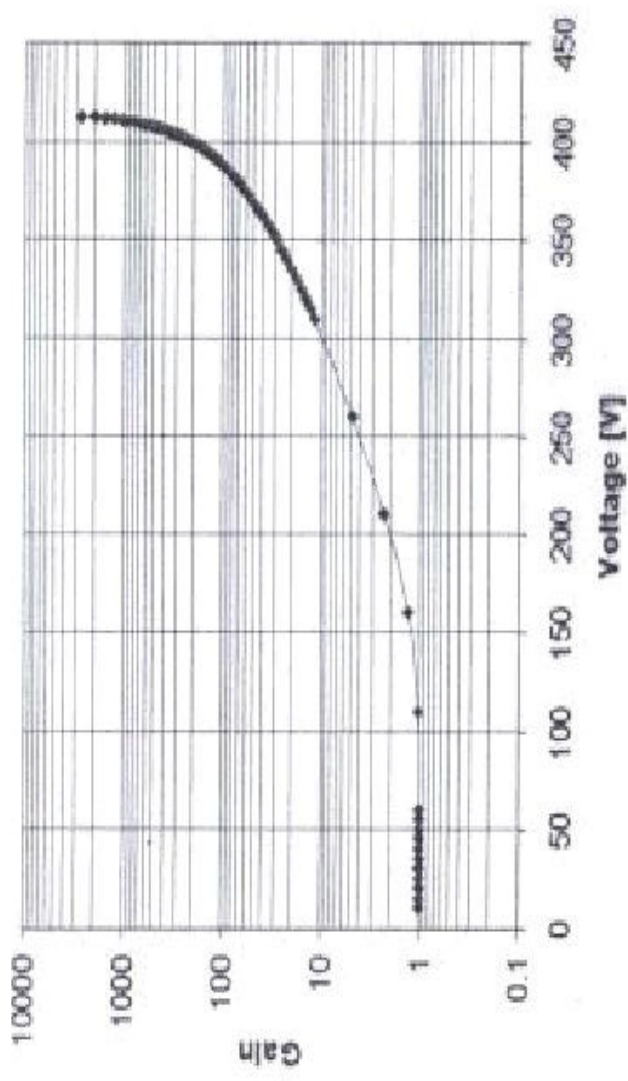
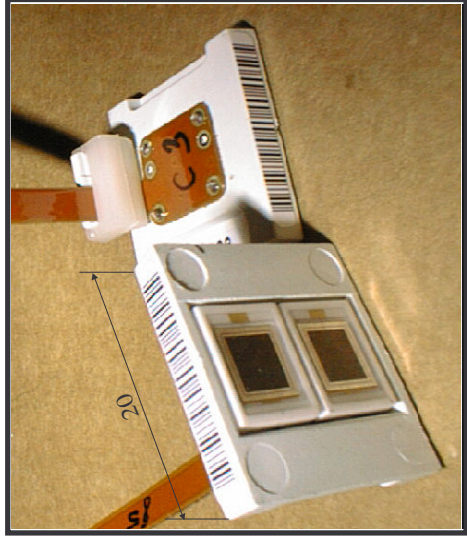
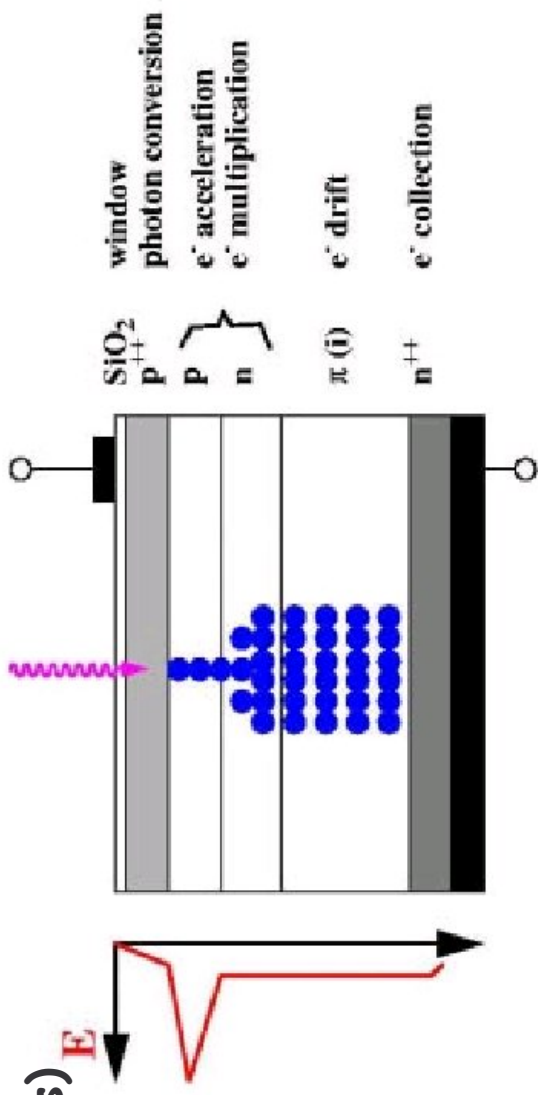




# CMS : em photodetector

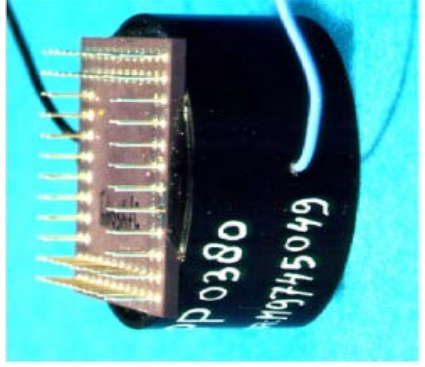
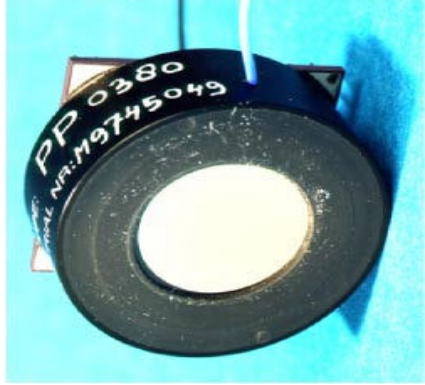
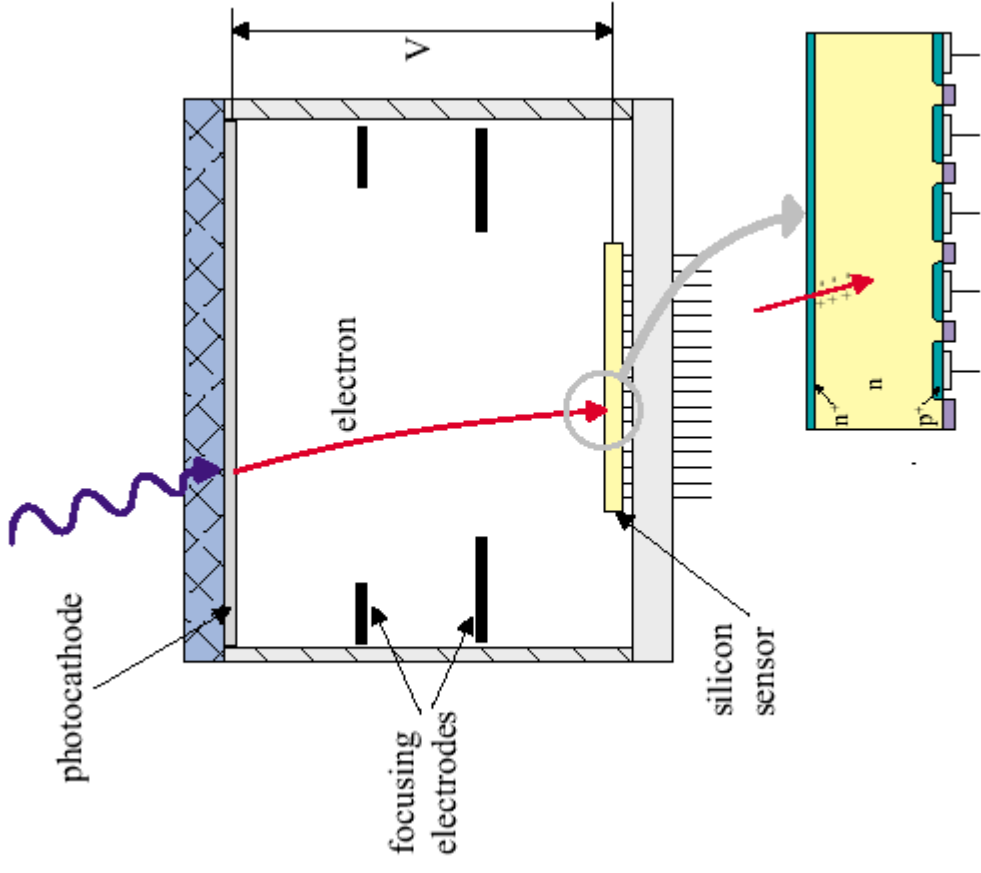
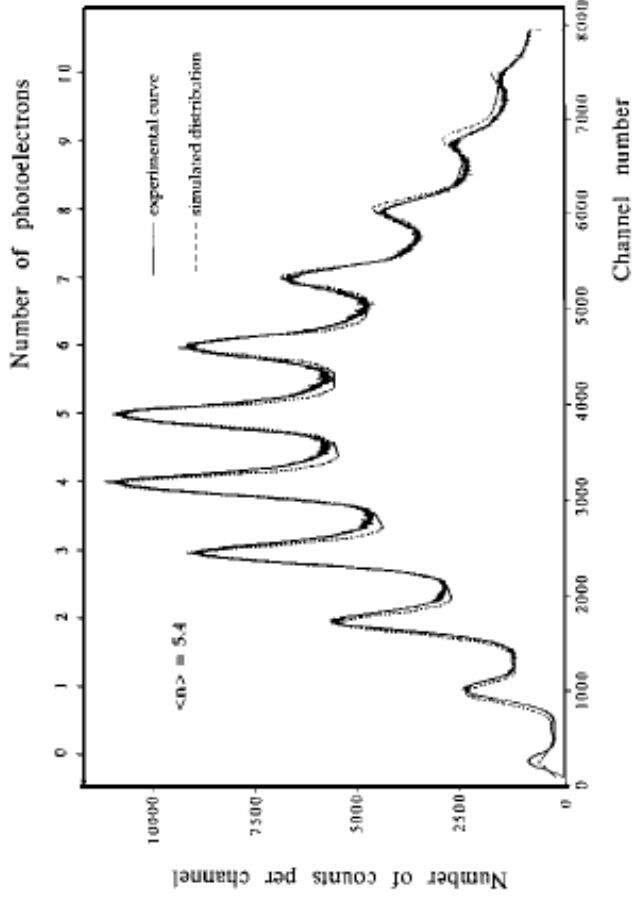
## Avalanche photodiodes (APDs)

- Area : 25 mm<sup>2</sup>, QE = 80%
- Gain = 50 TC = -2%/K
- Excess noise factor : 2.2
- C= 30 pF
- Polarisation ~200-300 V



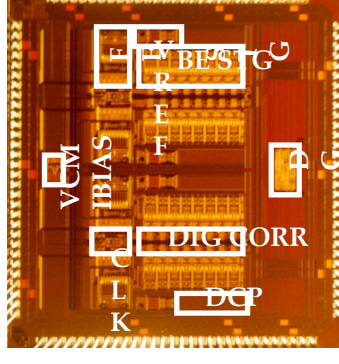
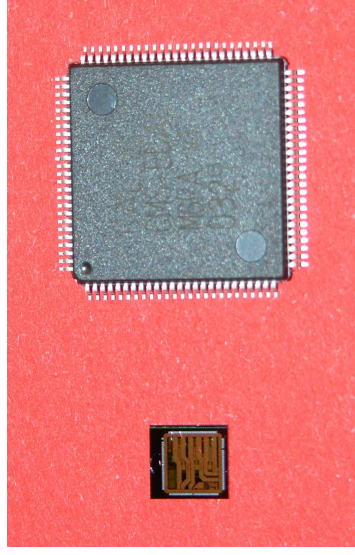
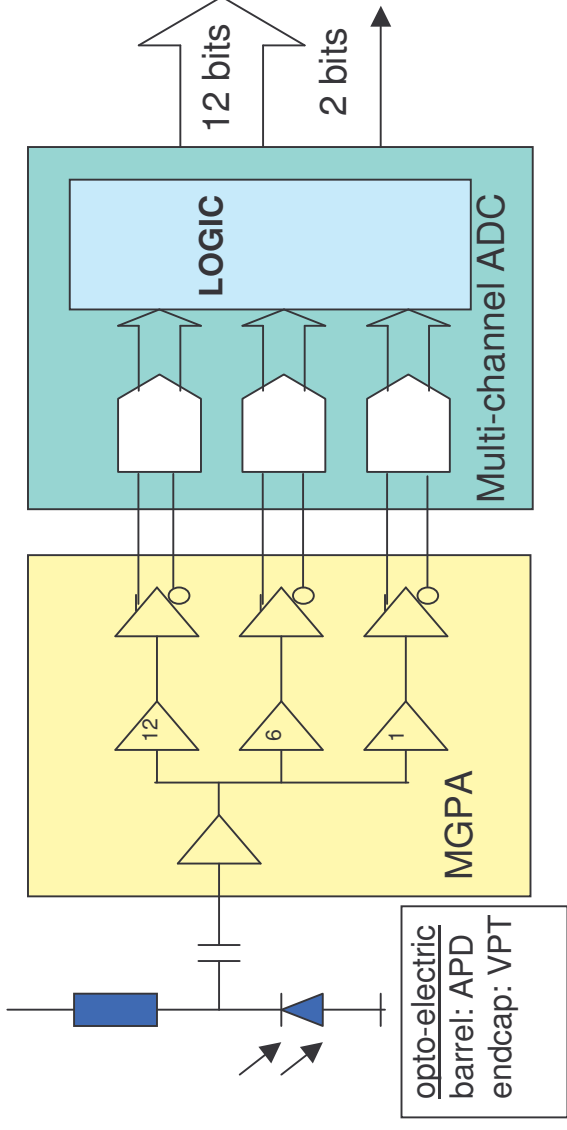
# HPD : Hybrid photodetector

## ■ Accélération des photoélectrons



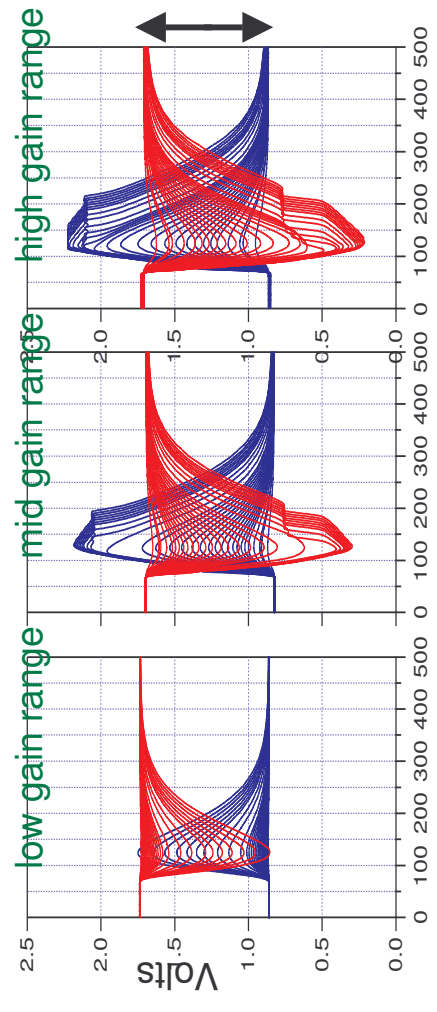
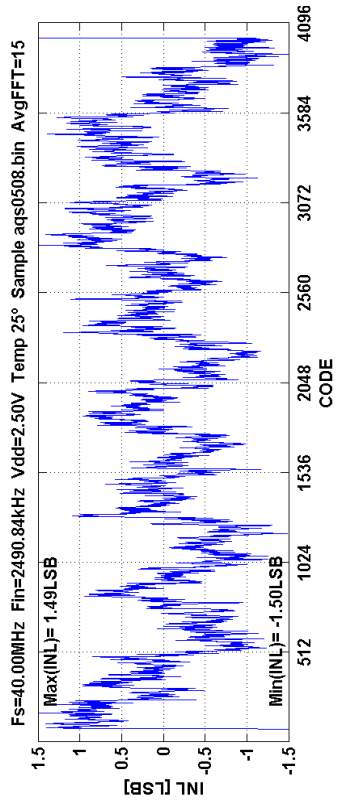
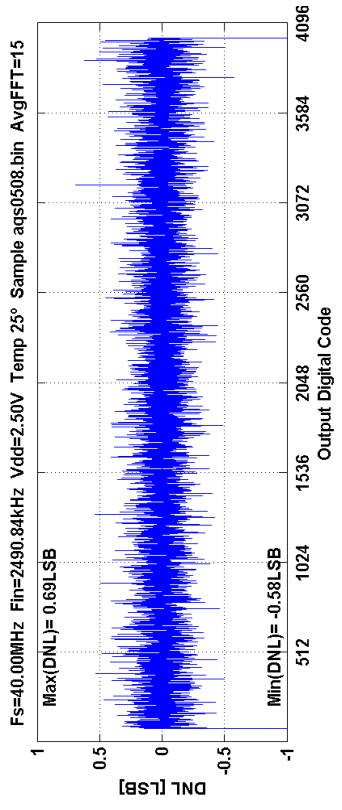
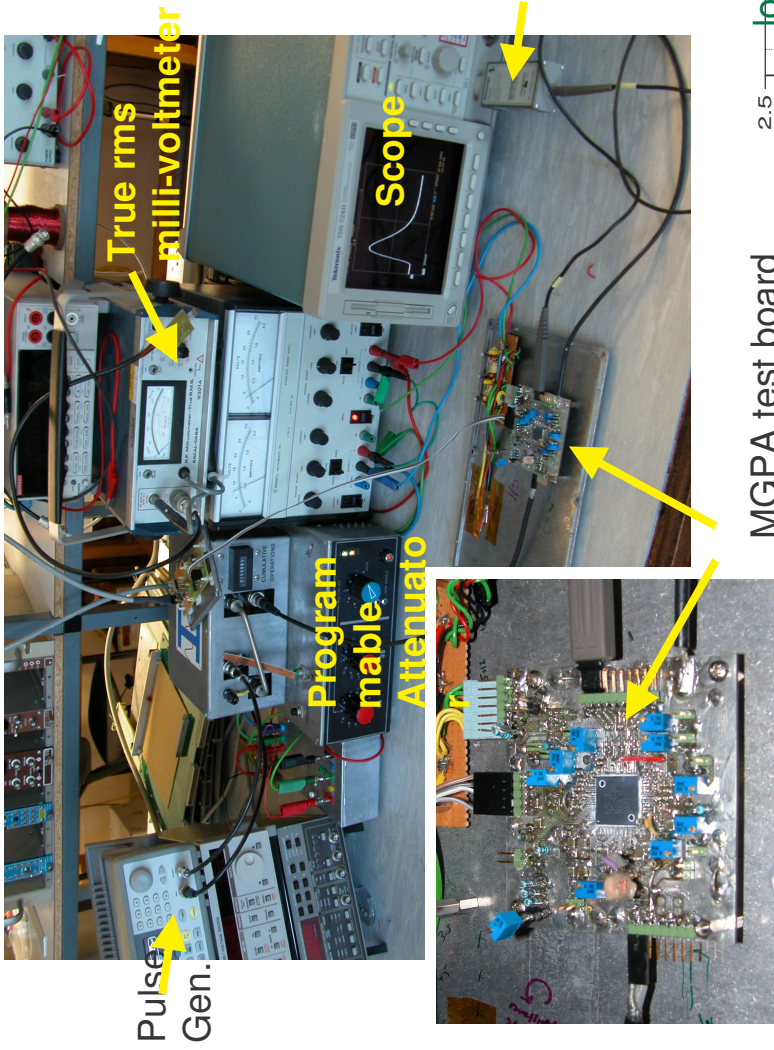
# CMS ECAL readout

- **Tri-gain preamp (MGPA)**
  - 1-6-12
  - 0.25 $\mu$ m CMOS
- **3 ADCs 12b 40MHz**
  - 12 bit Quad Pipeline ADC
  - 0.25 $\mu$ m CMOS 1P3M 2.5V
  - ENOB=11bit @ 40Ms/s Fin=2.5MHz
  - SNR=68dB
  - SNDR=67dB
  - SFDR=70dB
  - DNL/INL <math>\pm 0.7/\pm 1.5LSB
  - Area=3.96mm<sup>2</sup>/2ADC
  - Die size=11.8mm<sup>2</sup>
  - DCP area 0.29mm<sup>2</sup> (1.18nF)
  - 412mW power dissipation @ 2.5V (4ADCs + VCM & BIAS)
  - 144pin fpBGA Package
  - 150mW power dissipation per channel (gain amplif + dig. log.)





# Test Setup



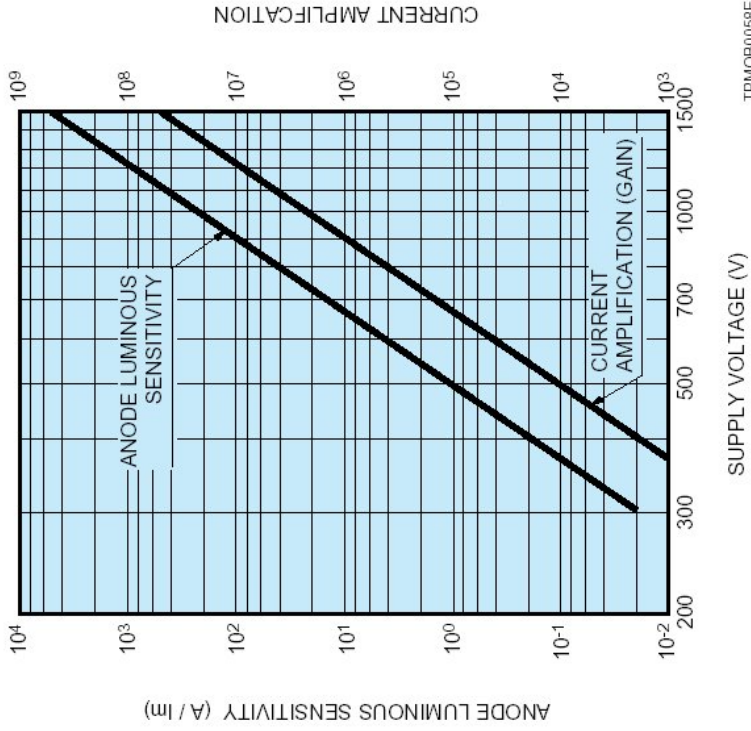
# Photomultiplicateurs

- Souvent utilisés pour calorimètres hadroniques

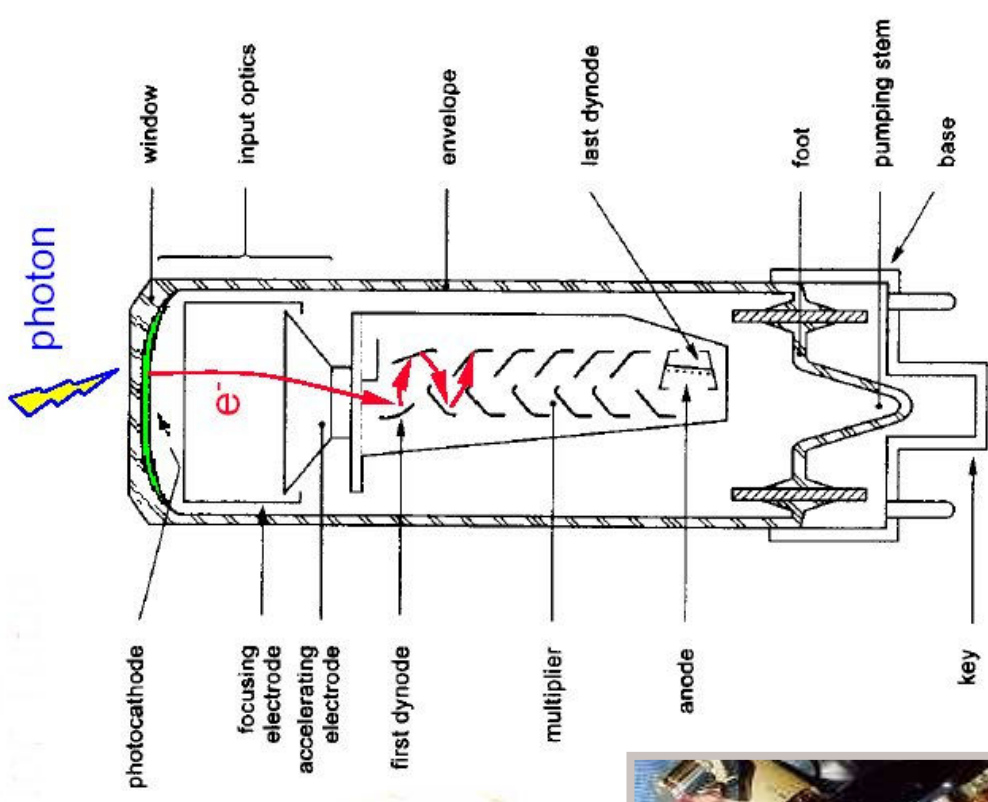
- Sensibles au champ magnétique
- Tubes segmentés : PM multianodes

- Gain très élevé

- $10^4 - 10^7$
- $Q_{out} = Gain * nb \text{ de photoélectrons}$

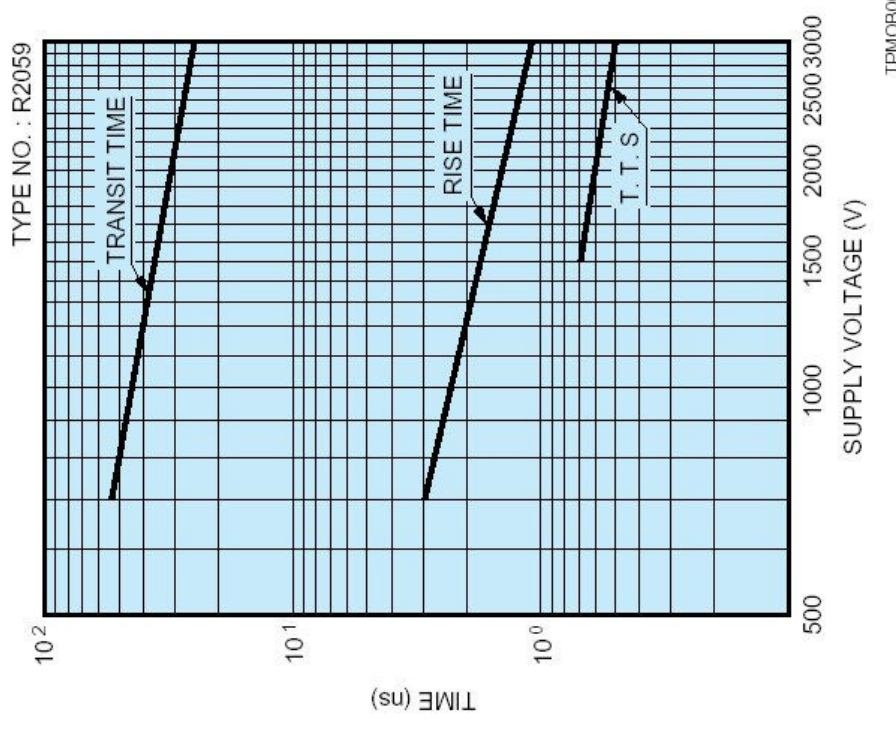
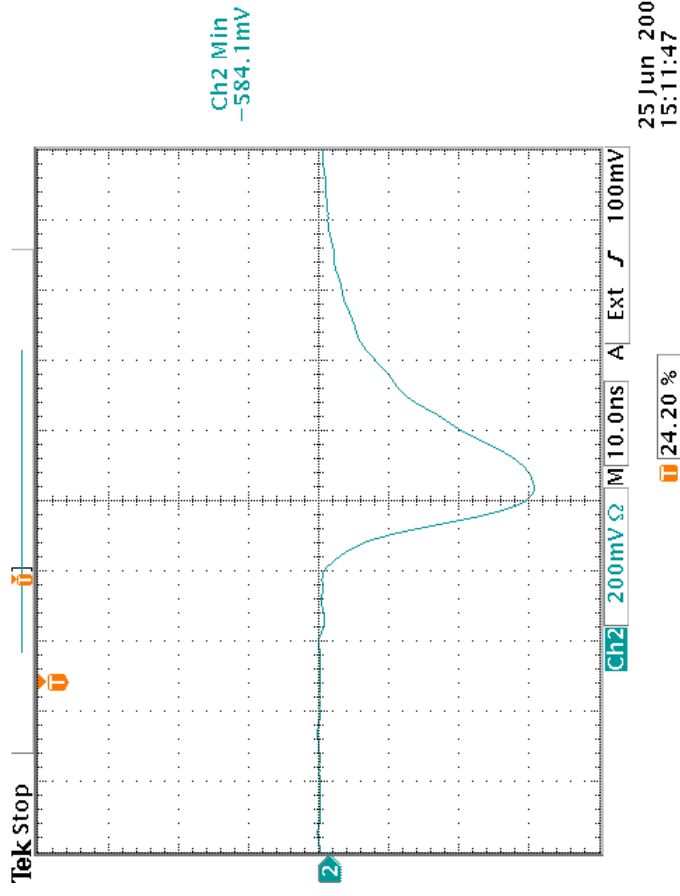


TPMOB0058EA



# Photomultiplicateurs

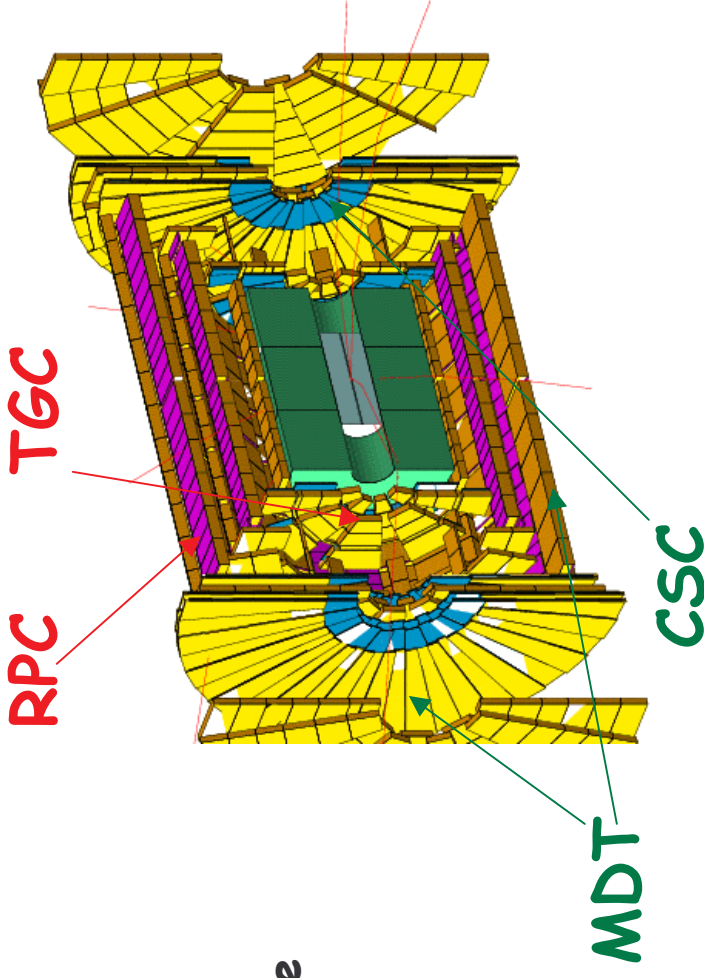
- **Signal**
  - Très rapide ~qq ns
- **Modélisation**
  - Capacité : 3-10 pF
  - Inductance série
  - Câble de connexion



# Chambres à muons : ATLAS

---

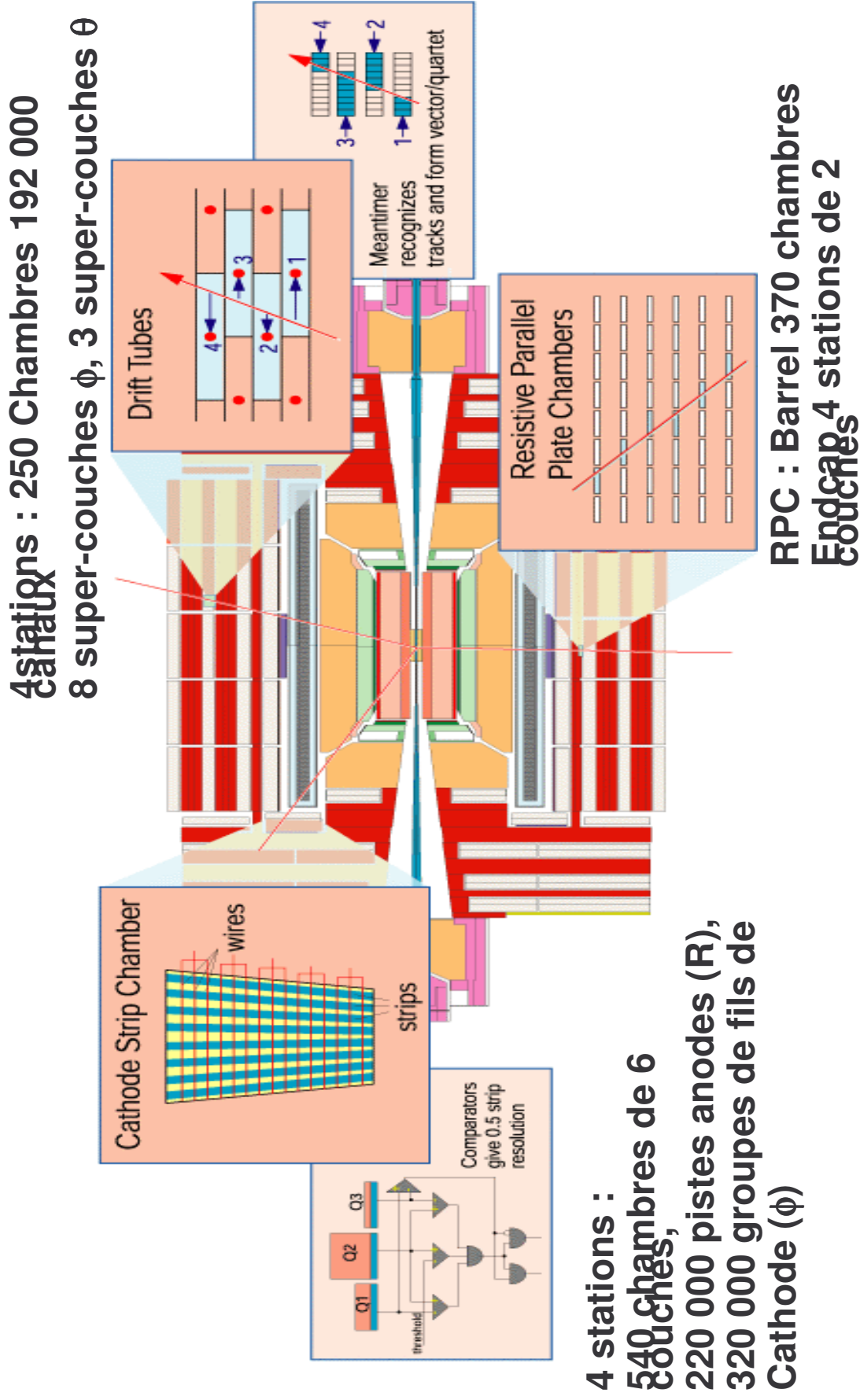
- **Détection des muons dans détecteurs gazeux**
  - RPCs : resistive Plate Chambers
  - CSC : Cathode Strip Chambers
  - MDT : Drift Tubes
- **Nombreux canaux de lecture**
- **Lecture analogique pour barycentre**



## Chambres de précision (MDT) :

- Tubes à dérives ( $\Phi=3\text{cm}$ )
- 370000 canaux, 1163 chambres
- 20  $\mu\text{m}$  rms sur la position des fils
- 80  $\mu\text{m}$  précision pour un hit
- En production, environ 1/3

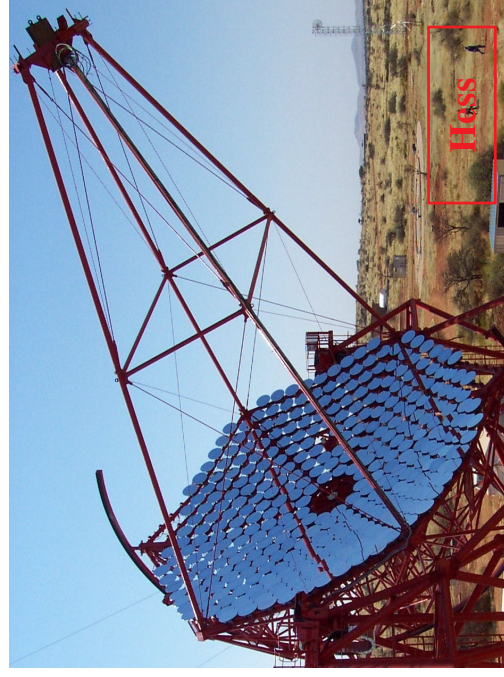
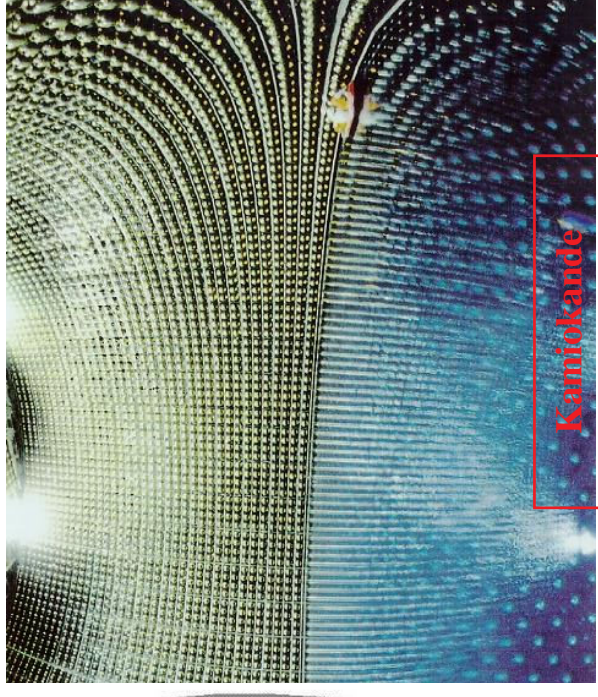
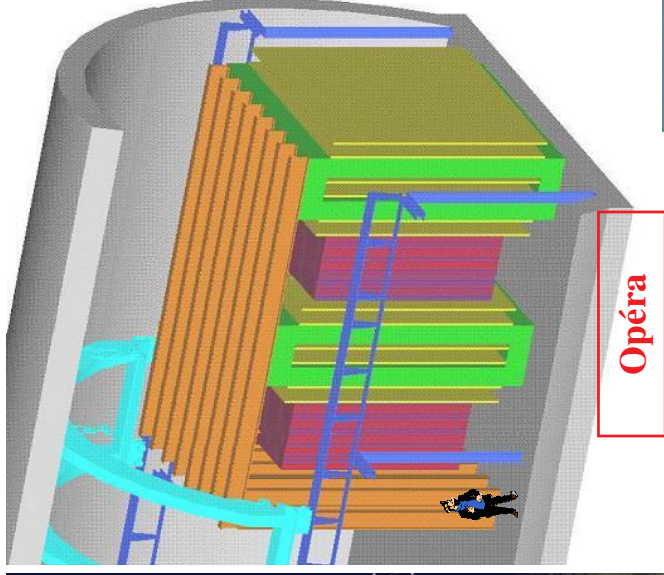
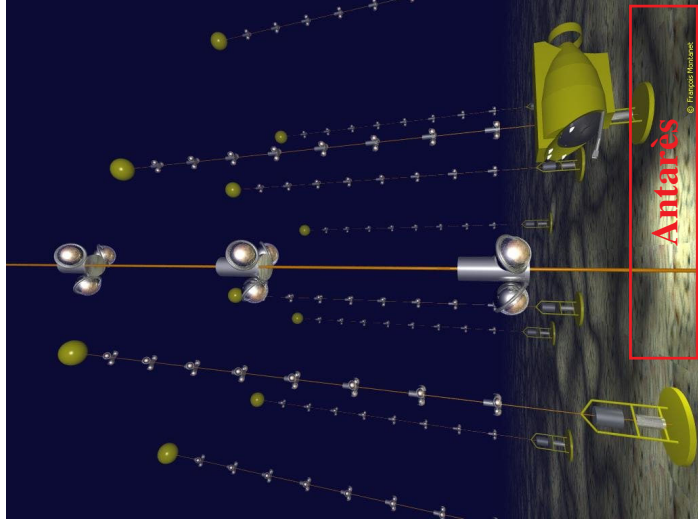
# Chambres à muons : CMS



4 stations :  
540 chambres de 6 couches,  
220 000 pistes anodes (R),  
320 000 groupes de fils de Cathode ( $\phi$ )



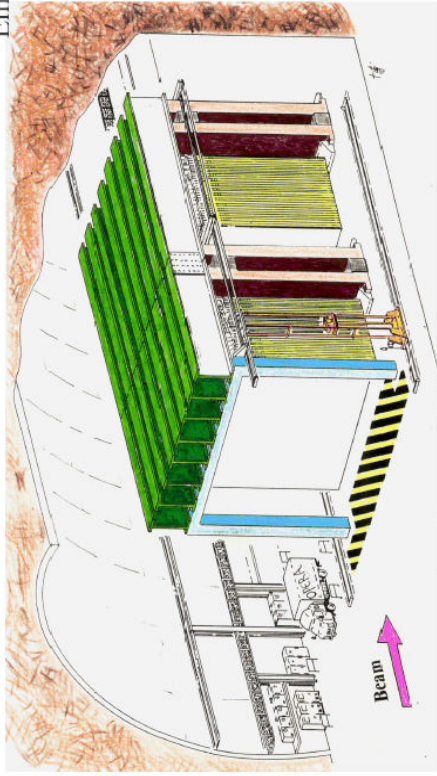
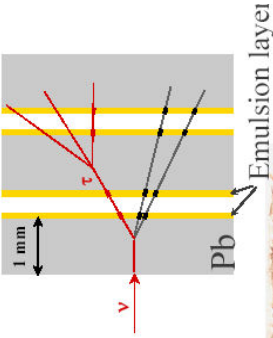
# Expériences hors accélérateurs : neutrinos, gammas



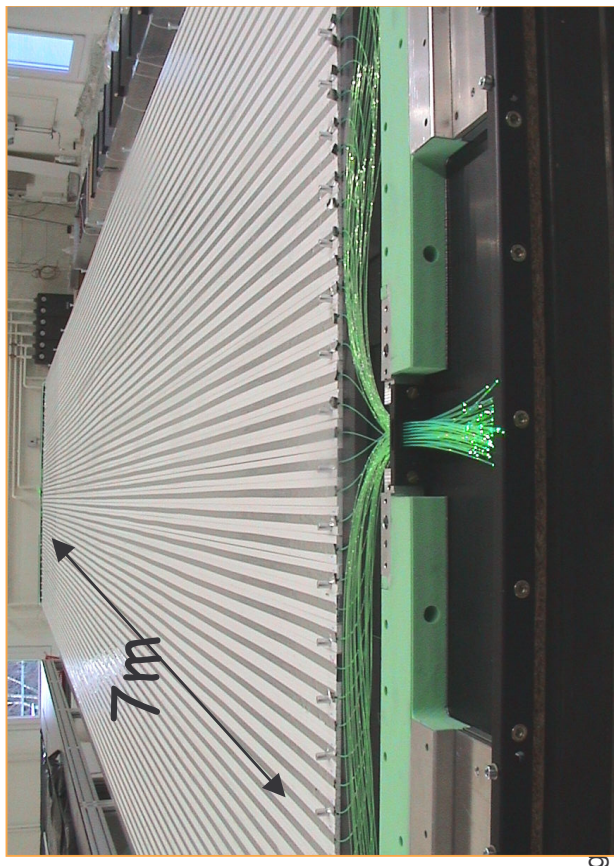
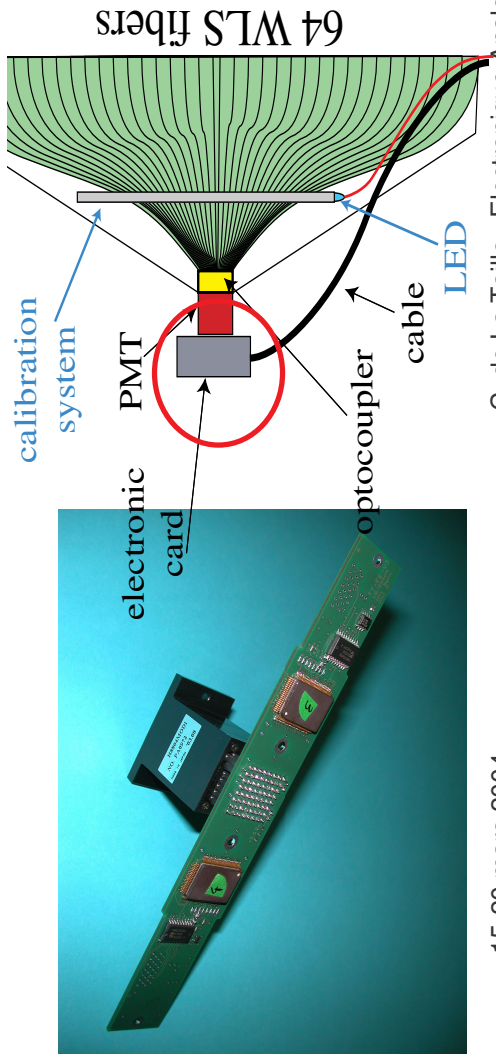
# Neutrinos OPERA : Target tracker

## Detector

ECC(Emulsion Cloud Chamber)  
to detect decay topology of  $\tau$   
proven by DONUT

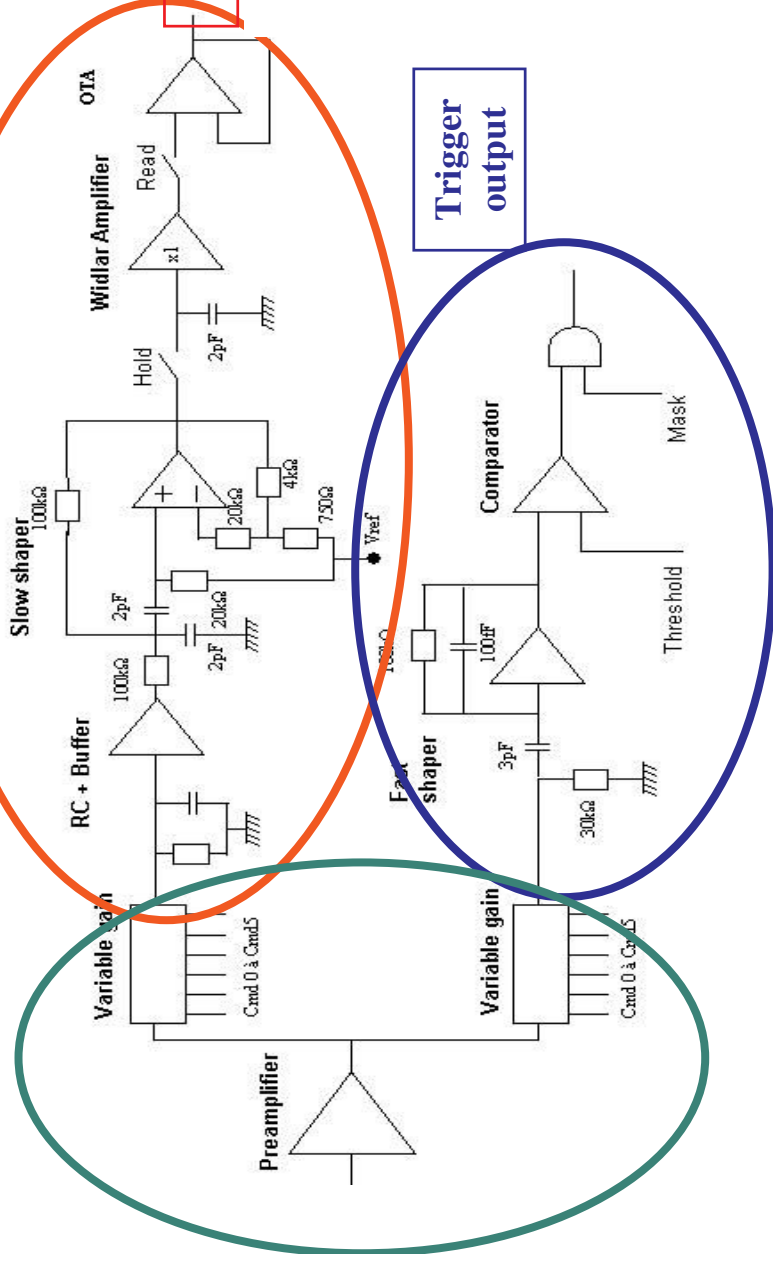
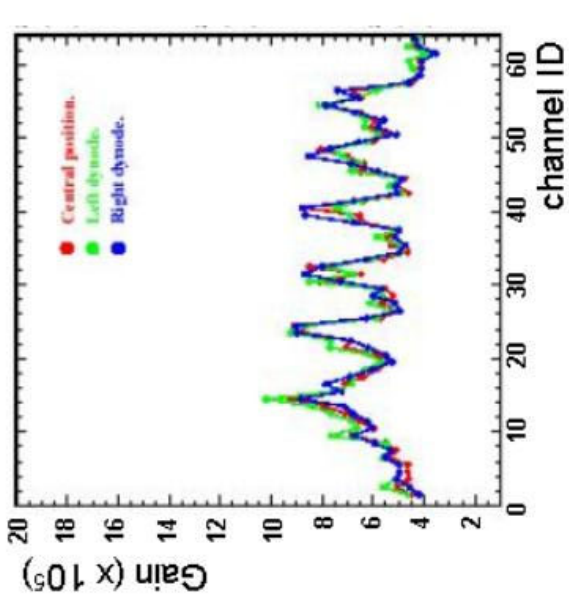


1. 7kton ECC detector



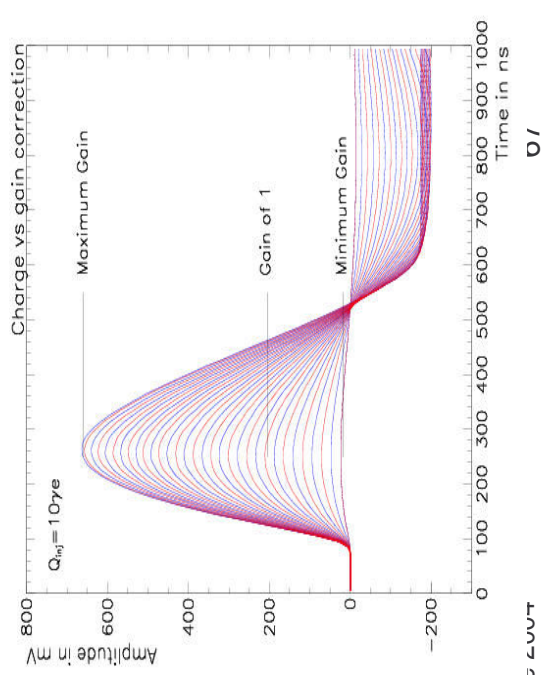
# OPERA : Target Tracker chip OPERA\_ROC

- Lecture de PM multi-anodes
  - Forte variation du gain (1-3) entre voies
  - -> Preampli de courant a gain variable (0-4, 5 bits)
  - Lecture de charge multiplexée (0.1-100p.e.)
  - Autotrigger on  $\frac{1}{4}$  p.e. in 15 ns
  - 32 channels chip, 180 mW



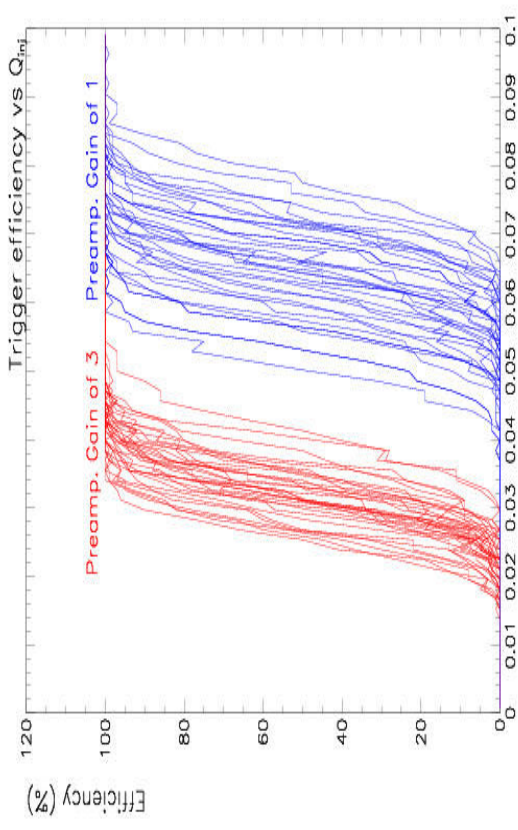
Charge output

Trigger output

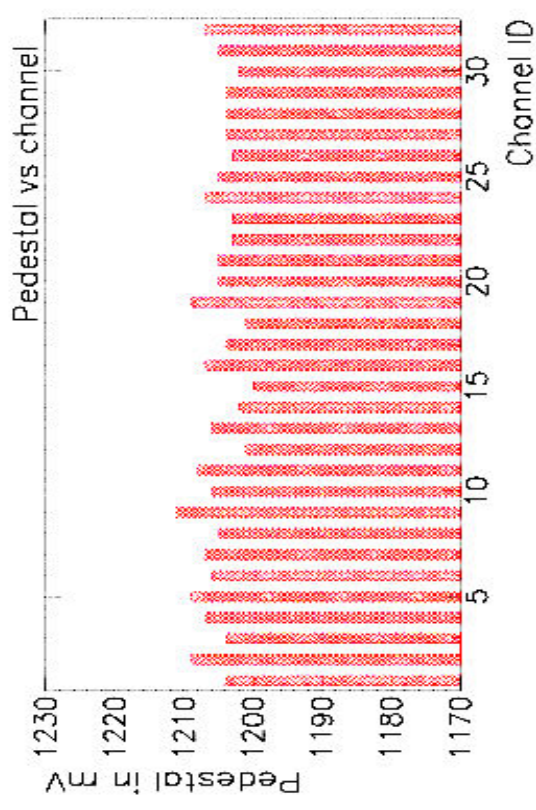
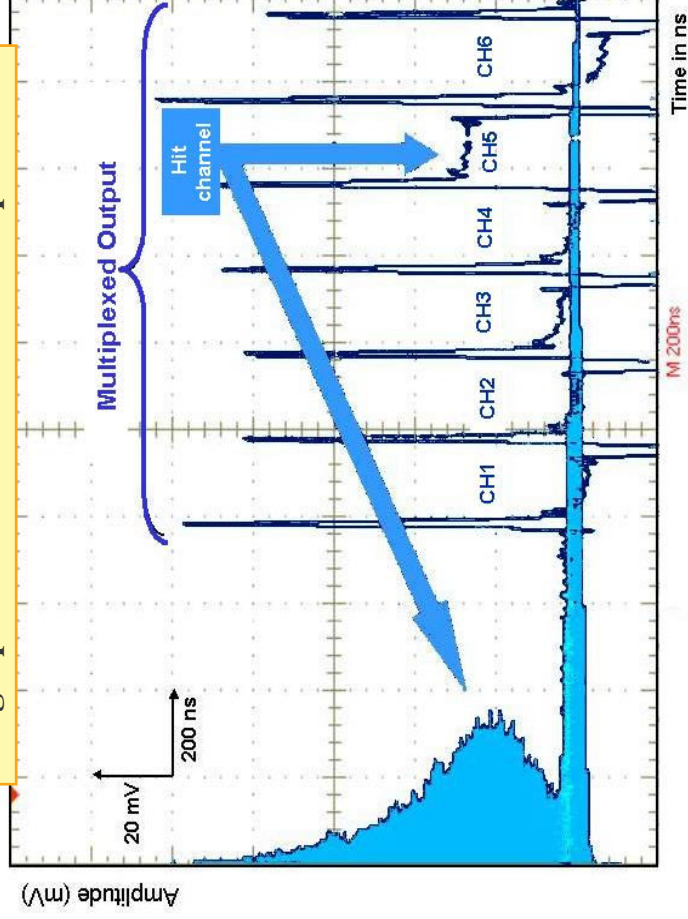


# Mesures avec le PMT

- **Efficacité de trigger**
  - « courbes en S »
- **Lecture multiplexée**
  - Dispersion de pedestal, bruit...
- **Specres**



Single photoelectron readout and spectrum

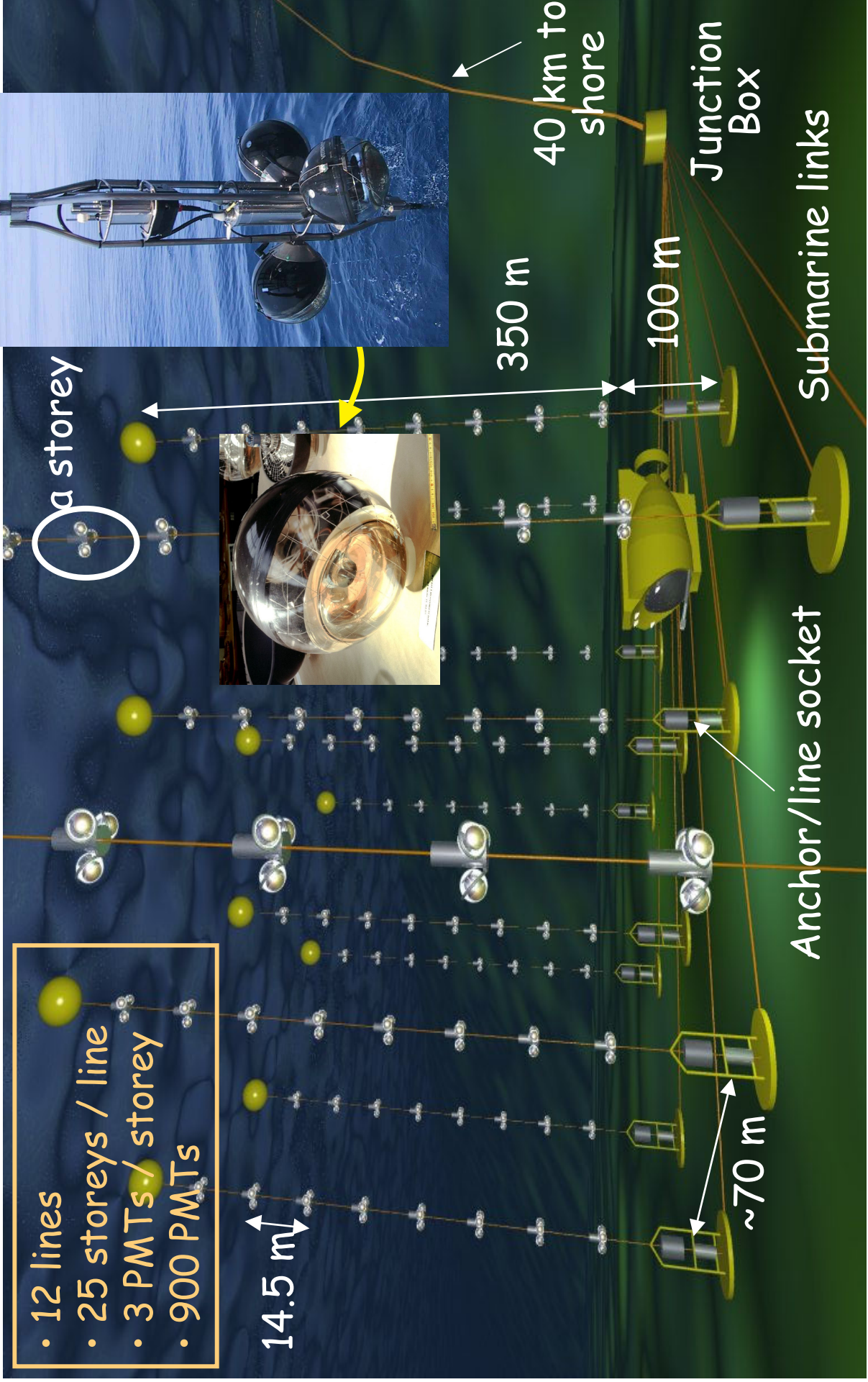


# Antarès

- 12 lines
- 25 storeys / line
- 3 PMTs / storey
- 900 PMTs

14.5 m

1 storey



350 m

100 m

40 km to shore

Junction Box

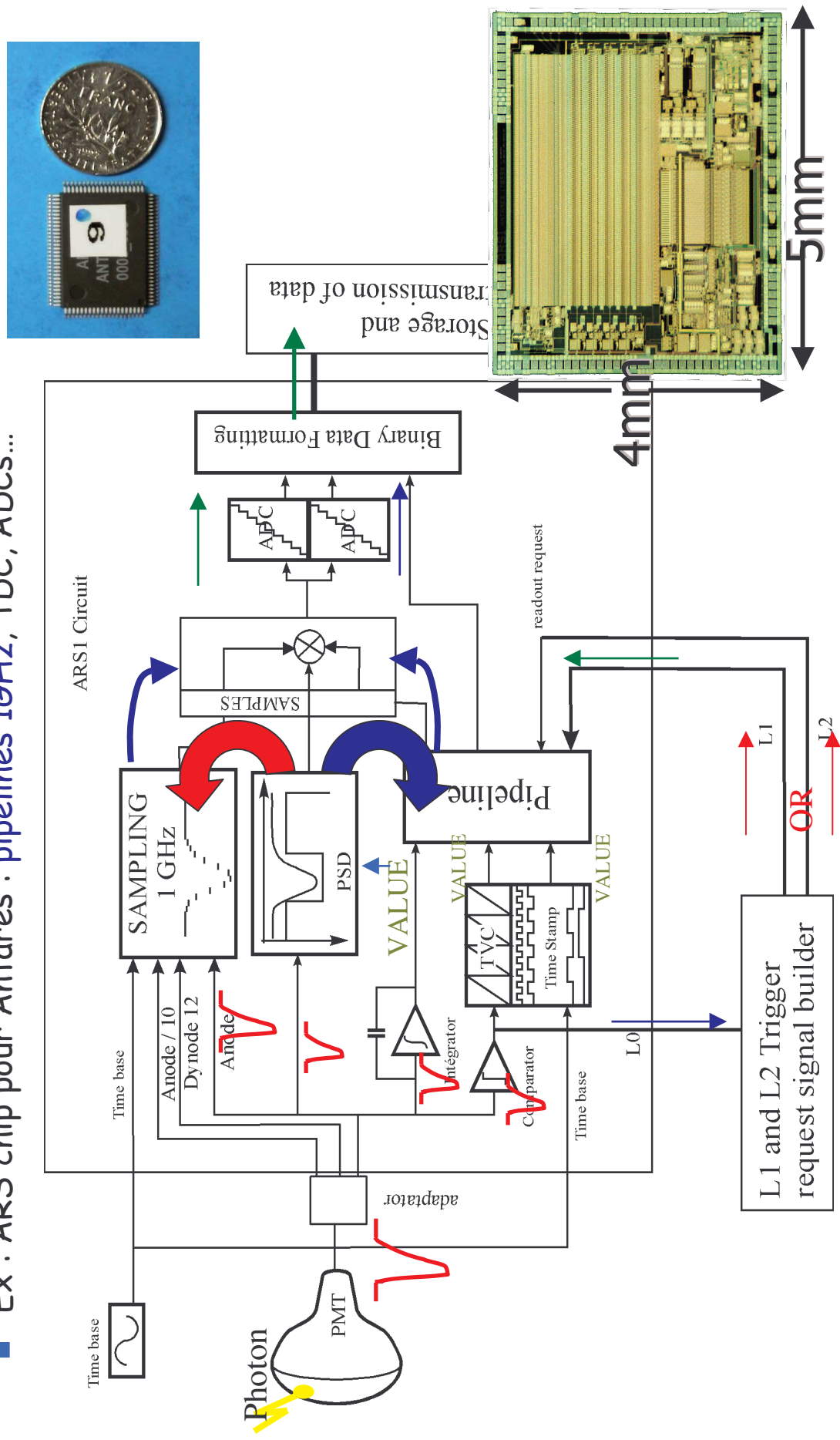
Submarine links

Anchor/line socket

~70 m

## ■ System on Chip (SoC) : multi-fonctionnalités intégrées

- Ex : ARS chip pour Antarès : pipelines 1GHz, TDC, ADCs...



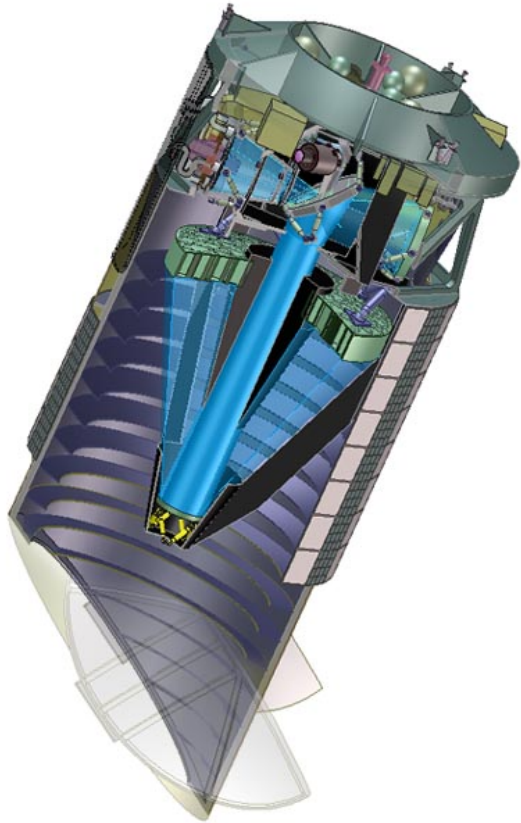
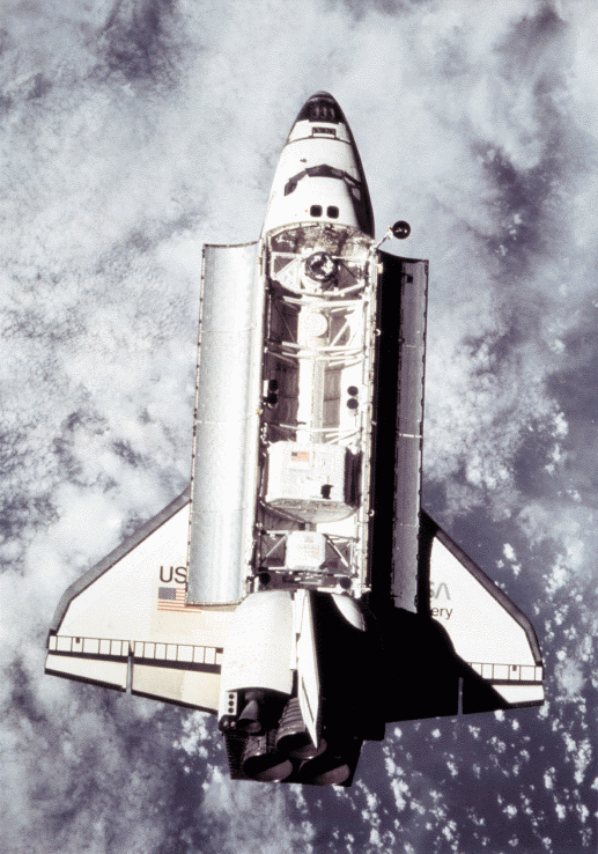
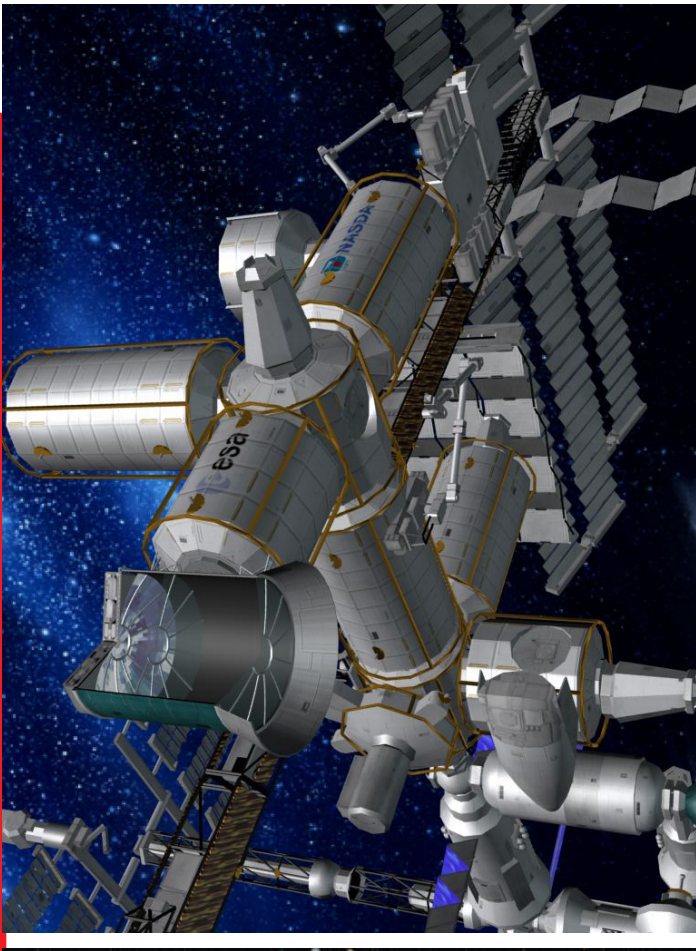
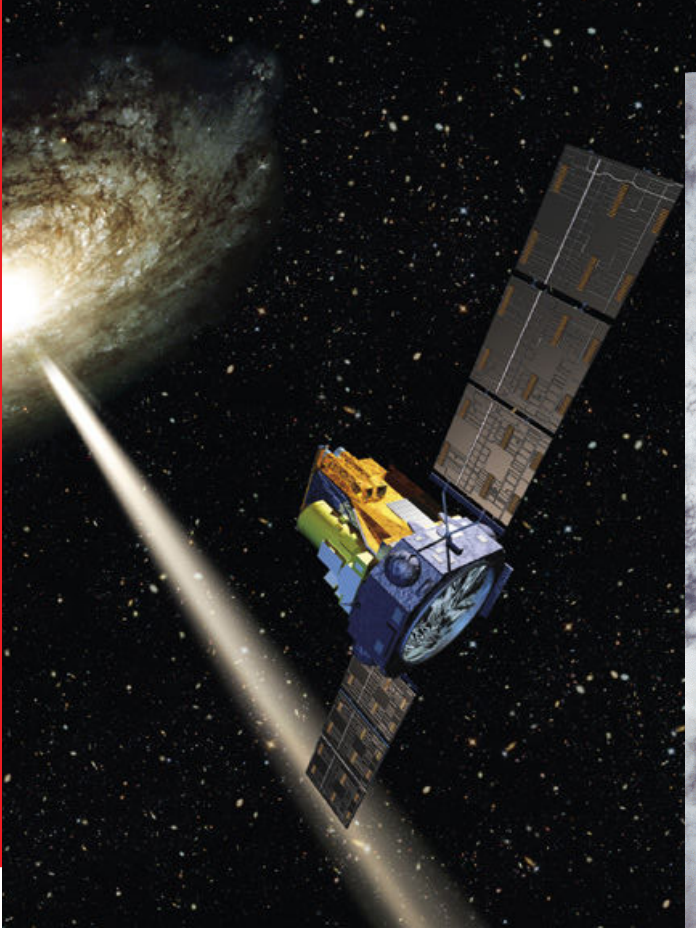
# Electromagnetic compatibility (EMC-EMI)

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- **Coexistence of low and high level signals**
  - Capacitive coupling, inductive coupling, common impedance coupling
  - Still Ohm's law (sometimes Maxwell) , but a full lecture...



# Astroparticules

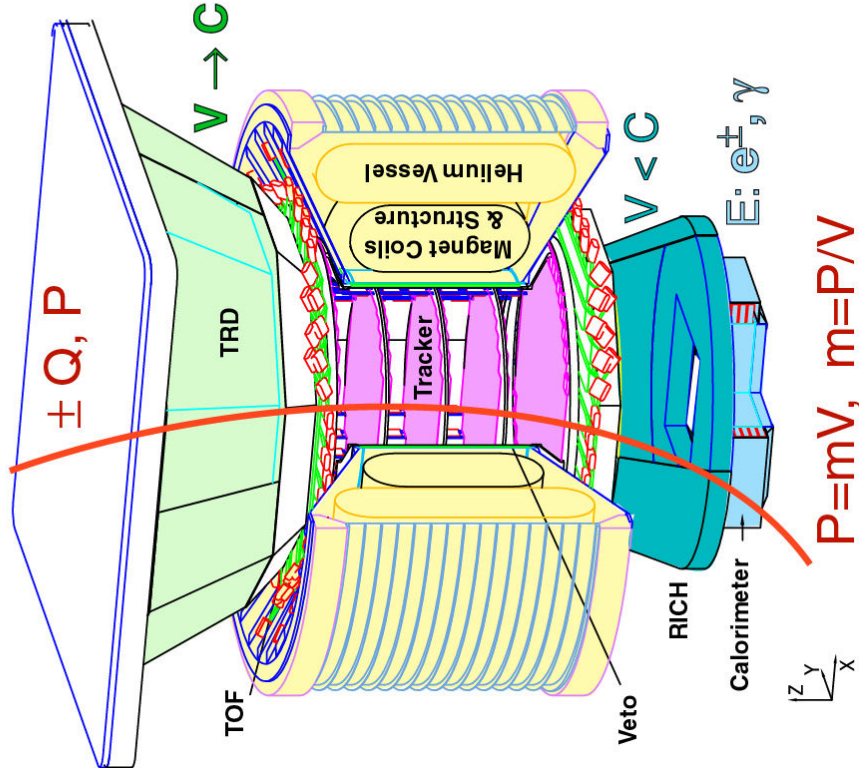




# Expériences de physique dans l'espace : AMS

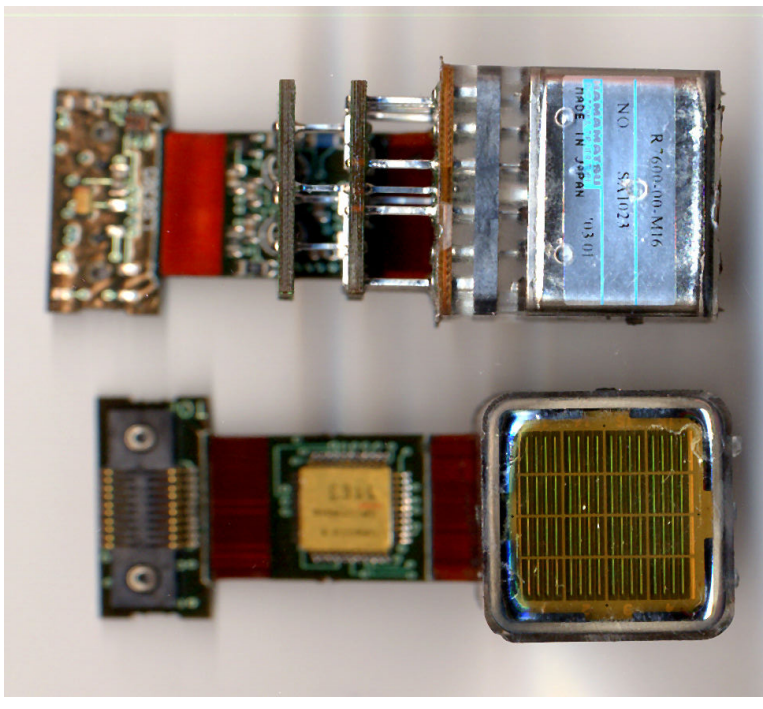
- Recherche d'anti-matière dans l'espace

## AMS-02

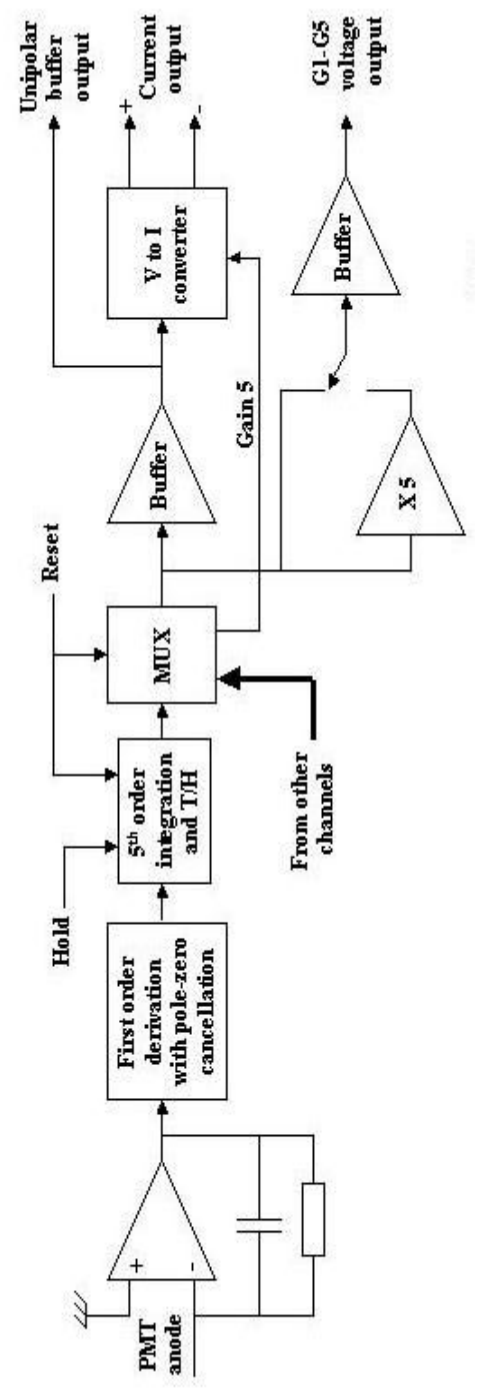


300 GeV	$e^-$	$e^+$	P	$\bar{\text{He}}$	$\gamma$	$\gamma$
TRD						
TOF						
Tracker						
RICH						
Calorimeter						

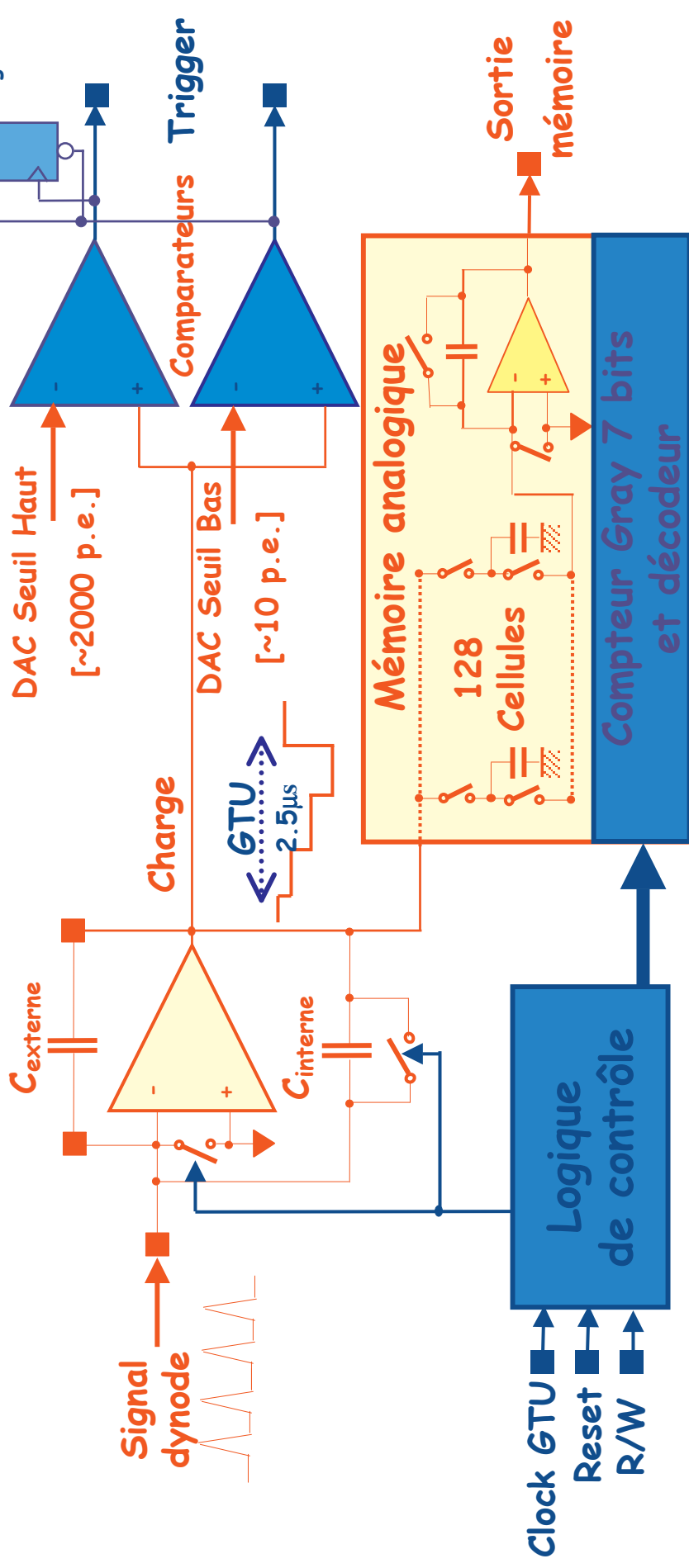
# Contraintes spatiales



- Basse puissance
- Fiabilité
- QA/QC
- Tenue aux vibrations
- Tenue aux radiations



- **Préamplificateur de charge à capacité commutée** → Cexterne: 80 à 120pF. → Cinterne : 20pF.
- **Double comparateurs de tension.**
- **Mémoire analogique : 128 cellules.**

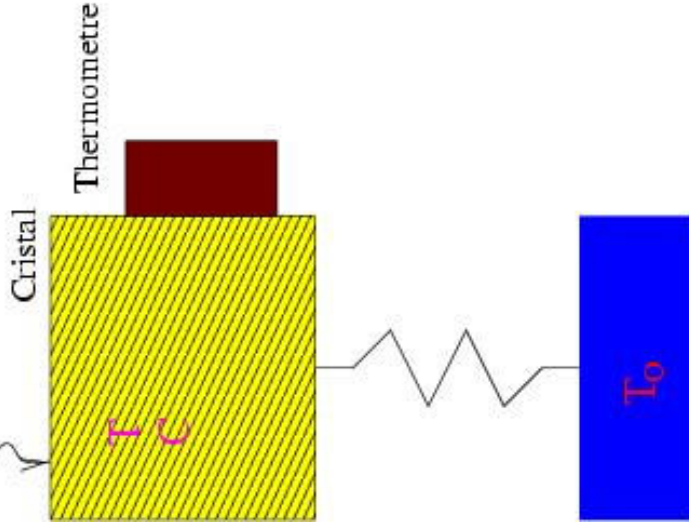


# Bolomètres

## ■ Bolomètres : interaction avec les phonons

- Mesure de variation de température
- En général par résistance

Un bolomètre est généralement un cristal couplé à un thermomètre capable de détecter de très faible température :



$$\Delta T = T - T_0 = \frac{E}{C} \Rightarrow \frac{dT}{dt} = \frac{P_{opt} - P_{elec} - G(T - T_0)}{C}$$

La **chaleur spécifique** diminue avec la température, le bolomètre sera d'autant plus sensible à basse température.

Le **thermomètre** est souvent une résistance :

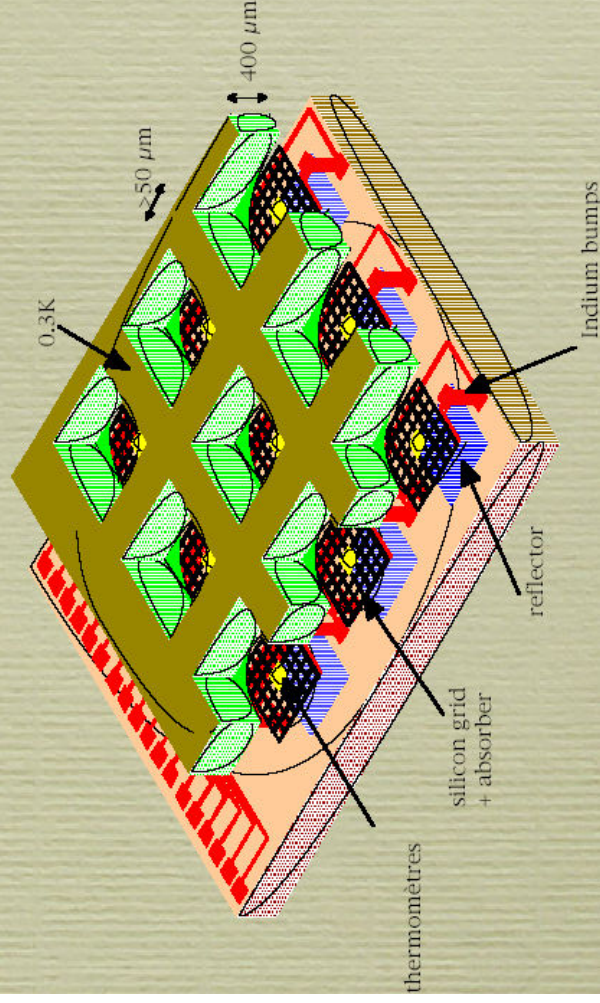
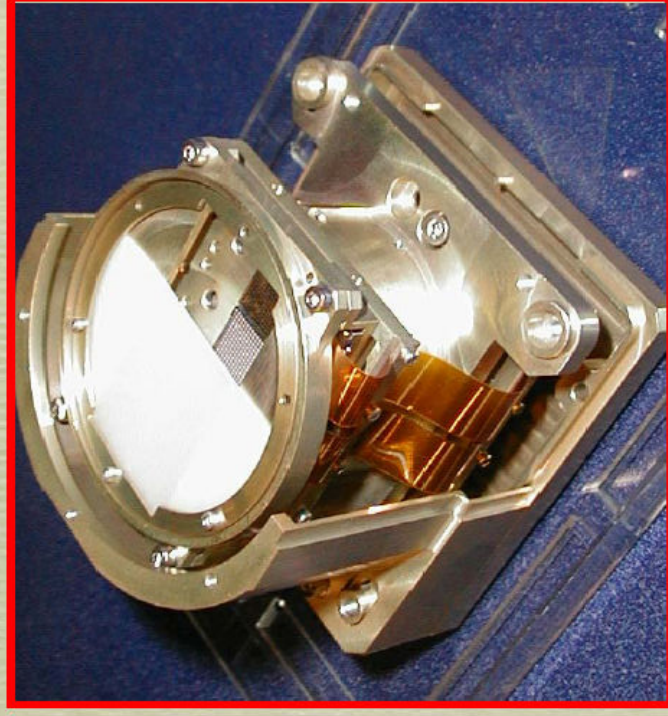
$$\frac{dV}{dT} = I_{bias} \frac{dR}{dT}$$

Dans le cas d'une thermistance au germanium

$$R(T) = R_0 \exp\left(\sqrt{\frac{\Delta}{T}}\right)$$

# Bolomètres

## Technologie du LETI



**Louis Dumoulin**  
**Michel Piat**

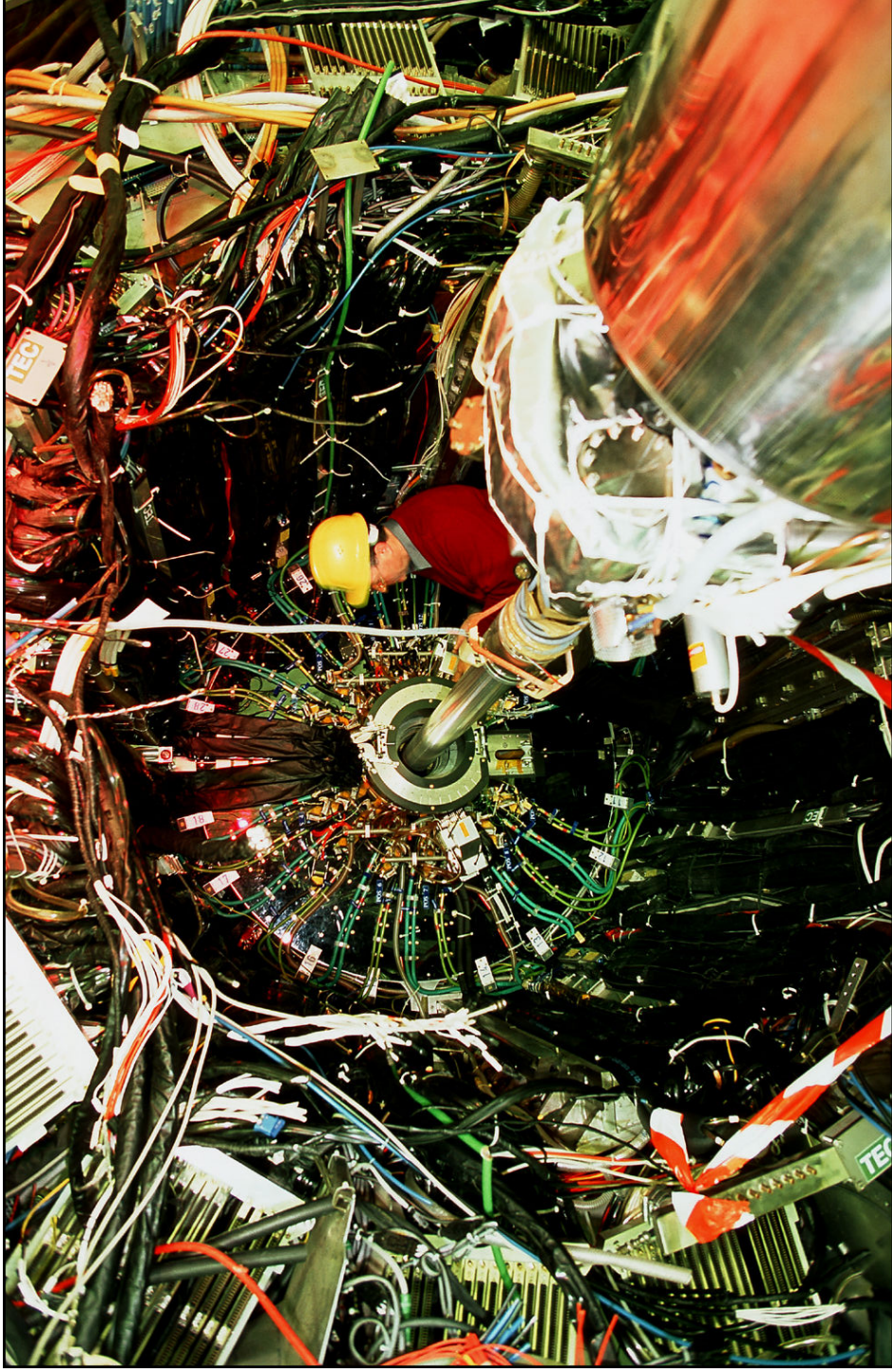
matrice de bolomètres @  $\approx 0.1 \text{ mm}$   
(PACS sur le satellite Herschel)

Réza Ansari

# Electronique dans les expériences

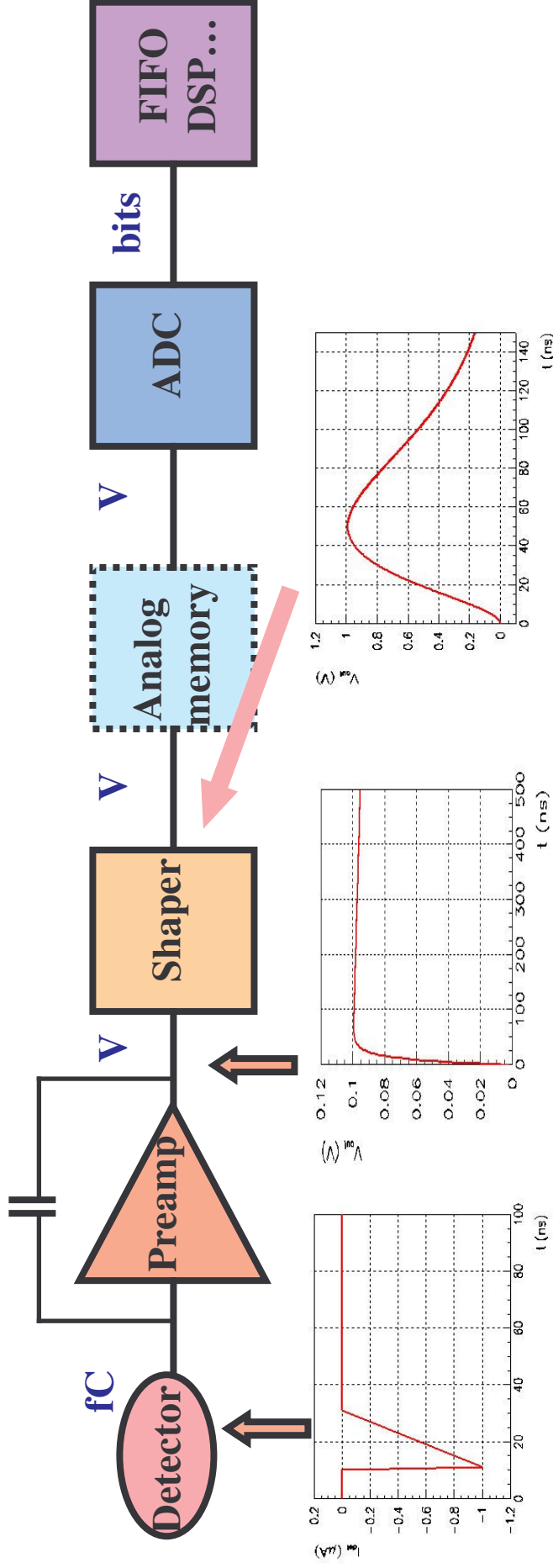
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- **Beaucoup d'électronique dans les expériences...**
  - Readout electronics : amplification, filtering... : Analog electronics (A,V,C) [see lecture of Cittolin]
  - Processing & Trigger electronics : Digital electronics (bits)
  - **La performance de l'électronique est souvent déterminante pour les détecteurs**



# Généralités sur l'électronique de lecture

- La plupart des front-ends suivent une architecture similaire



- Signaux très faibles (fC) -> nécessité **amplification**
- Mesures d'**amplitude** et/ou de **temps** (**ADCs, discris, TDCs**)
- Des **Milliers** à des **millions** de canaux

# Electronique associée : les contraintes

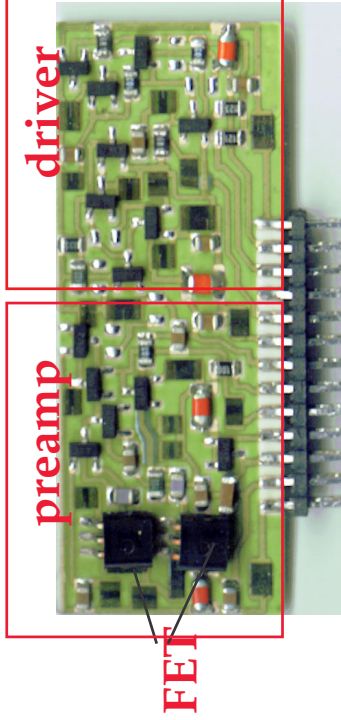
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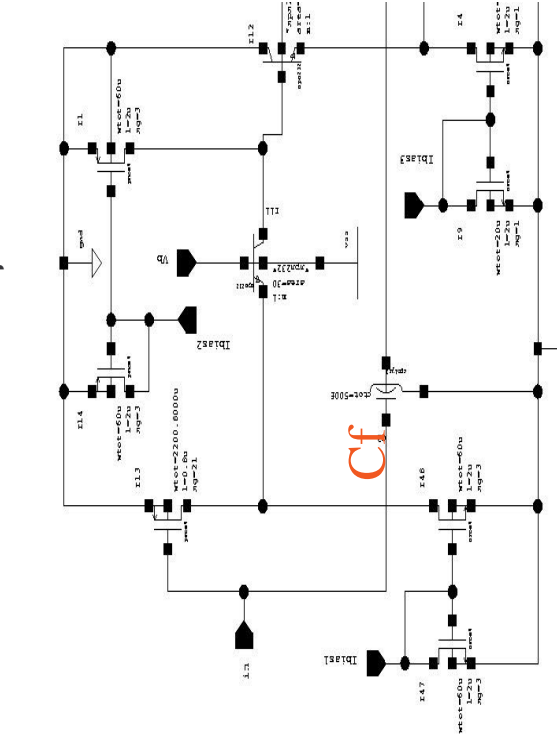
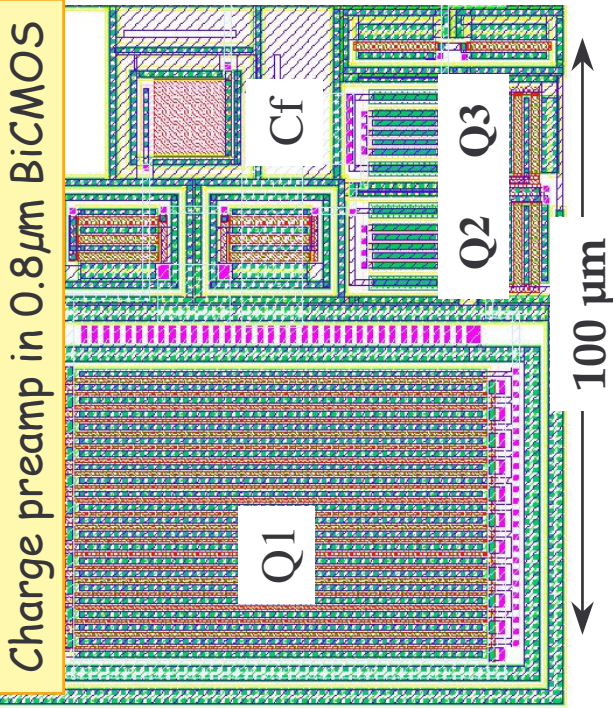
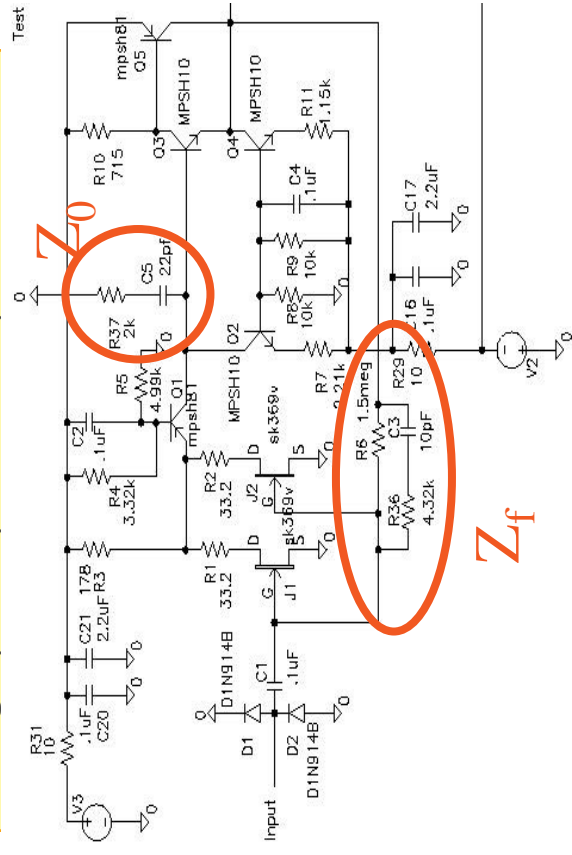
# (R)evolution of analog electronics (1)

## ■ The revolution of microelectronics



6 cm

## Charge preamp in SMC hybrid techno



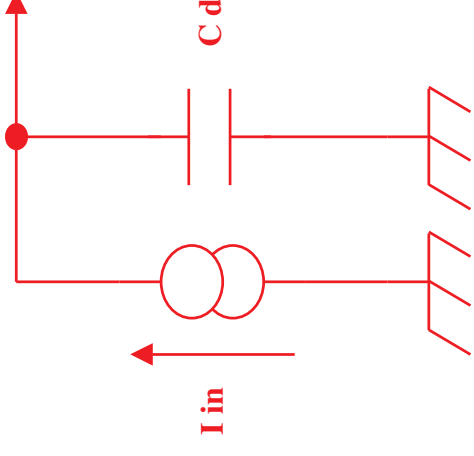
# Modélisation du détecteur

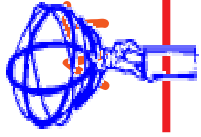
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- **Détecteur = capacité Cd**
  - Pixels : 0.1-10 pF
  - PMs : 3-30pF
  - Chambres d'ionisation 10-1000 pF
  - Capa ou ligne de transmission ?
- **Signal : source de courant**
  - Pixels :  $100e^-/\mu\text{m}$
  - PMs : 1 photoelectron  $\rightarrow 10^5\text{-}10^7 e^-$

## ■ Il manque

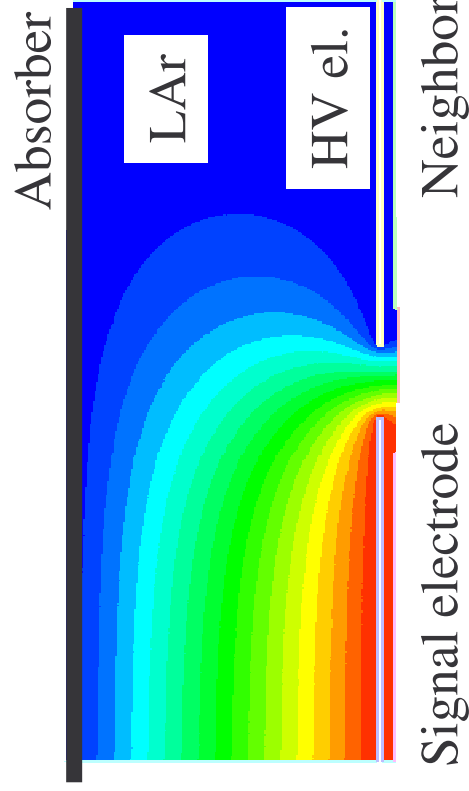
- Polarisation HT
- Connexions, grounding
- Voisins
- Calibration...

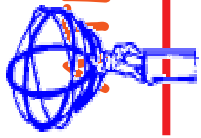




# LAS Lar : detector modelization

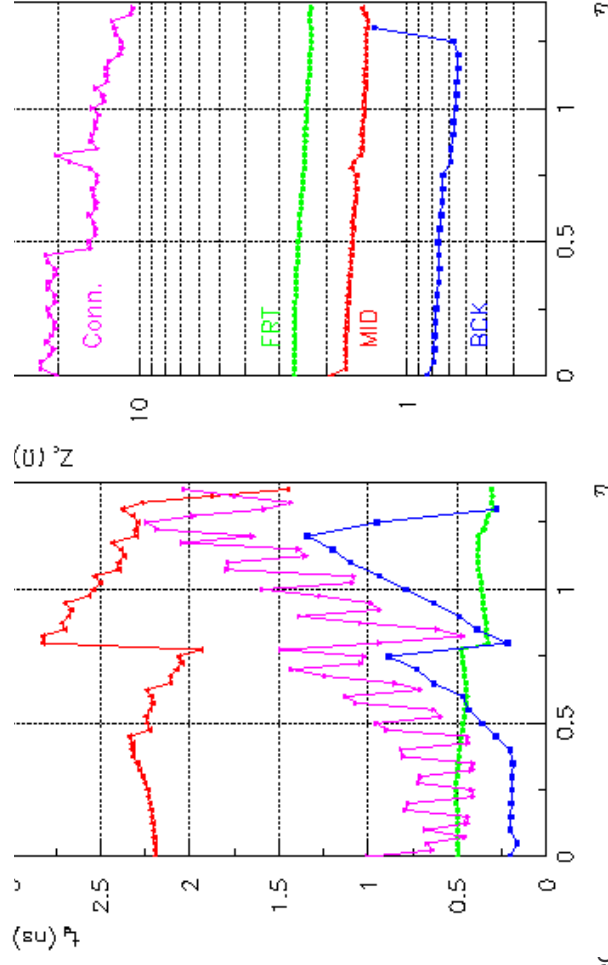
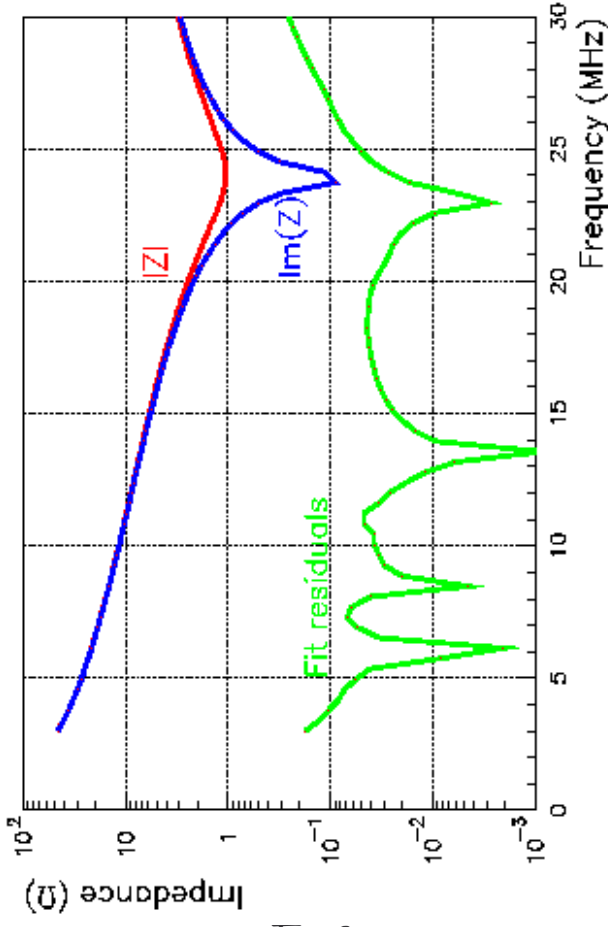
- **Modèle ligne**
  - "stripline" Absorber-LAr- HV-Kapton-Signal
  - LAr permittivity :  $\epsilon_r = 1.53$
  - 2.1 mm gap, 80  $\mu\text{m}$  kapton,
- **Resoudre Poisson**
  - Capacité vers la masse: Cd
  - Capacité vers voisins : Cx
- **Impedance :**
  - $Z_c = t_d/Ct$
  - $t_d = 4.12 \text{ ns/m}$
- **Lignes couplées**





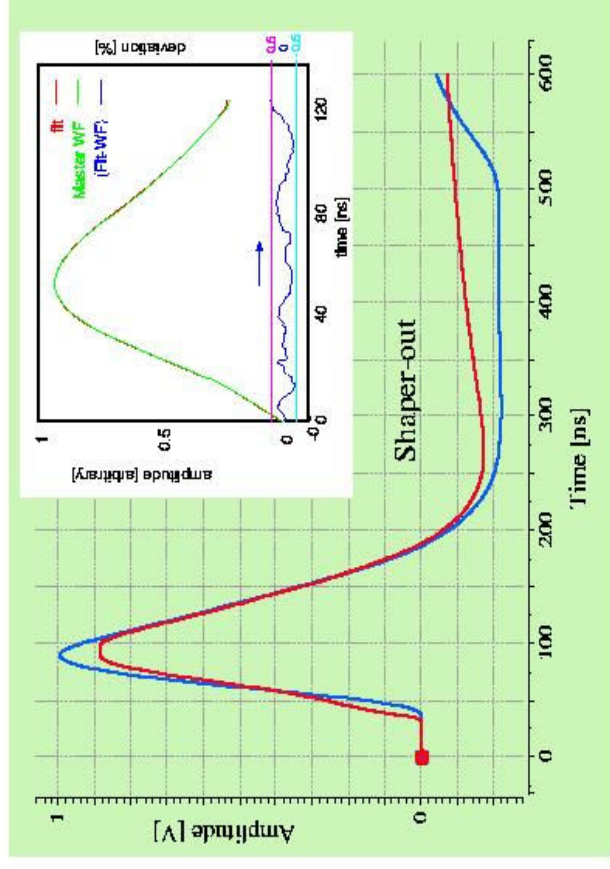
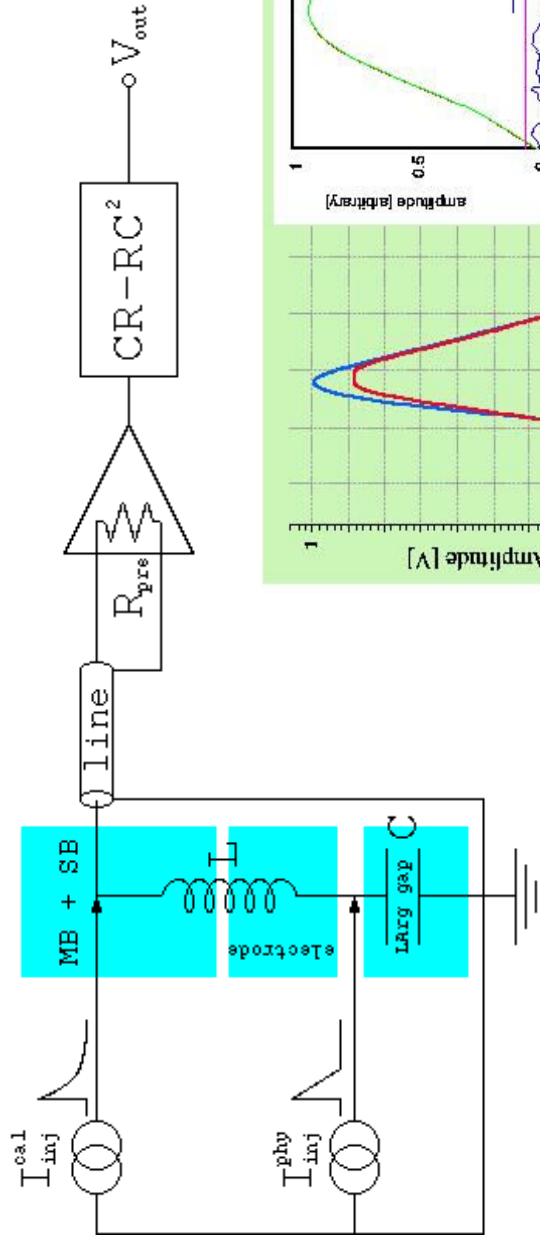
# ILAS Lar : detector modelization

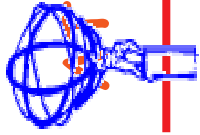
- **Lumped model**
  - Total capacitance ( $C_d + C_x$ )
  - Connection inductance for middle
- **Large effect**
  - 0.2%/nH on physics/calibration rat
  - Inductance measurement necessar



# Connexions

- Effet des inductances parasites
  - Résonance  $f = 1/2\pi \sqrt{LC}$
  - Coefficient de qualité :  $Q = 1/R \sqrt{L/C}$





# WILAS Lar : pulse reconstruction [21]

- Complete analytical modelization : quite complex...
  - Measure parameters for all element : more than thirty poles and zeros
  - Fit residuals within +/- 1%

## HEC Chain

