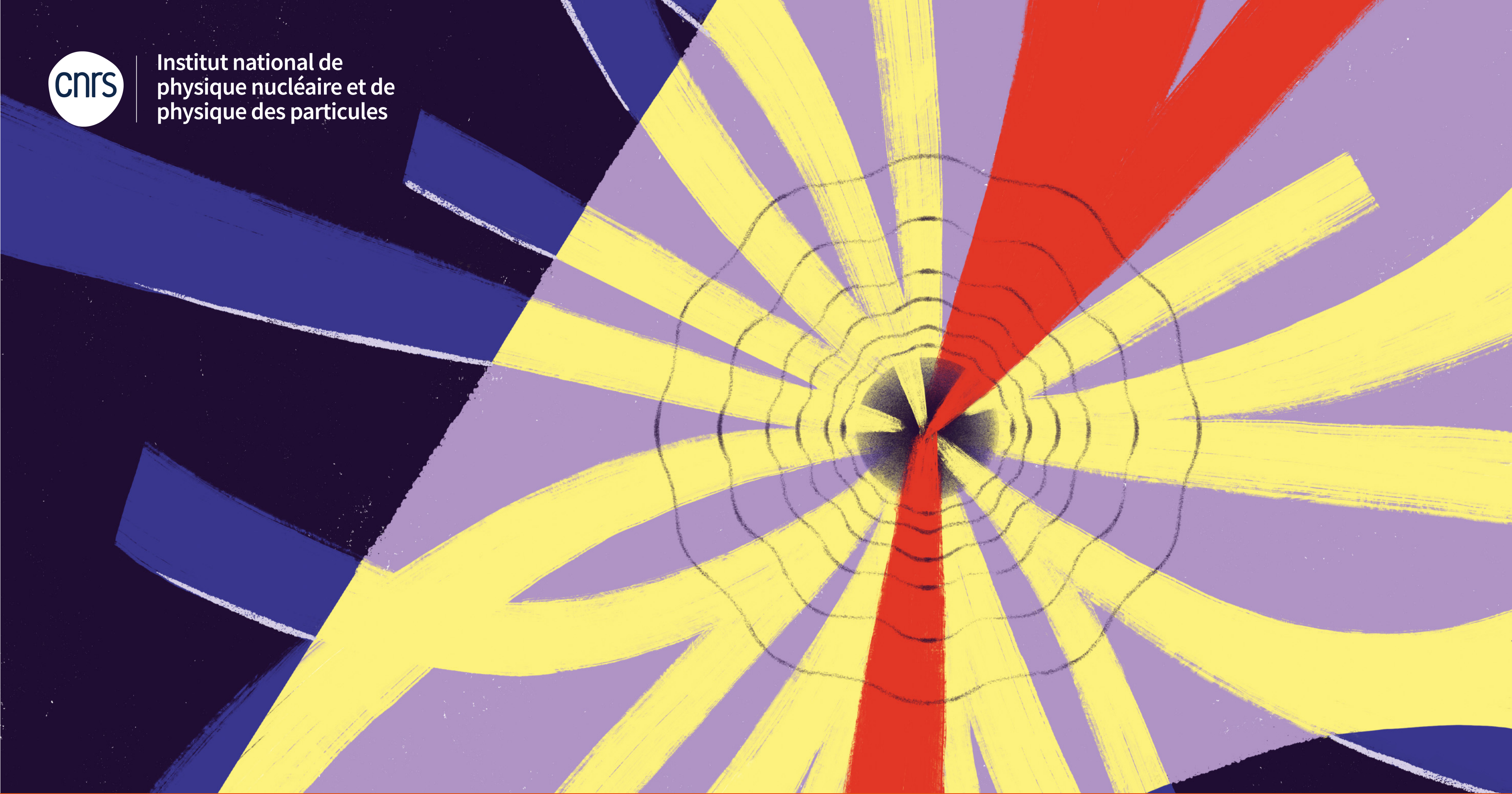




Institut national de  
physique nucléaire et de  
physique des particules

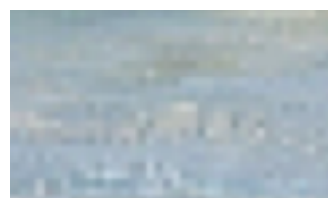
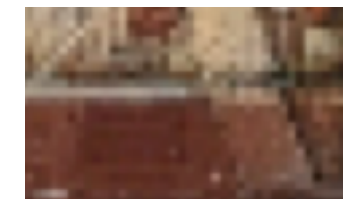
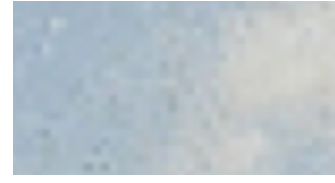
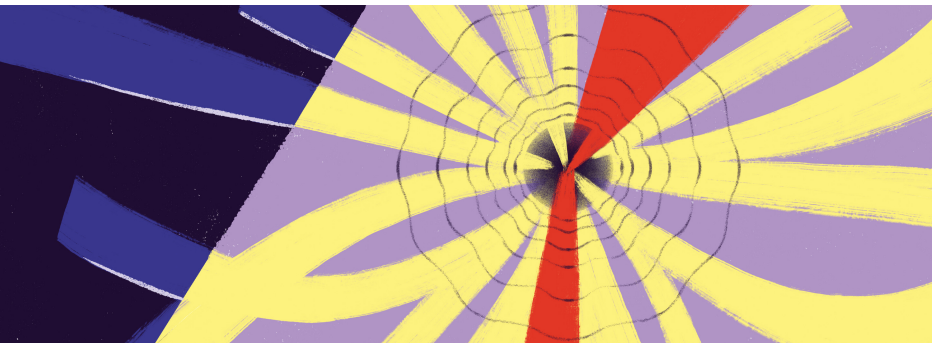


**COLLOQUE** **BOSON  
DE HIGGS**  
10 ans après, l'aventure continue

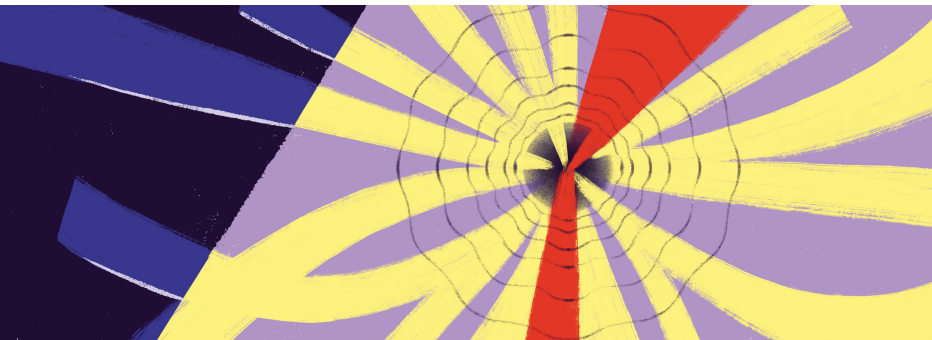
En route vers une découverte ?  
Isabelle Wingarter-Seez  
CNRS-IN2P3-CPPM

*6 juillet 2022*

# EN ROUTE vers une DÉCOUVERTE ?

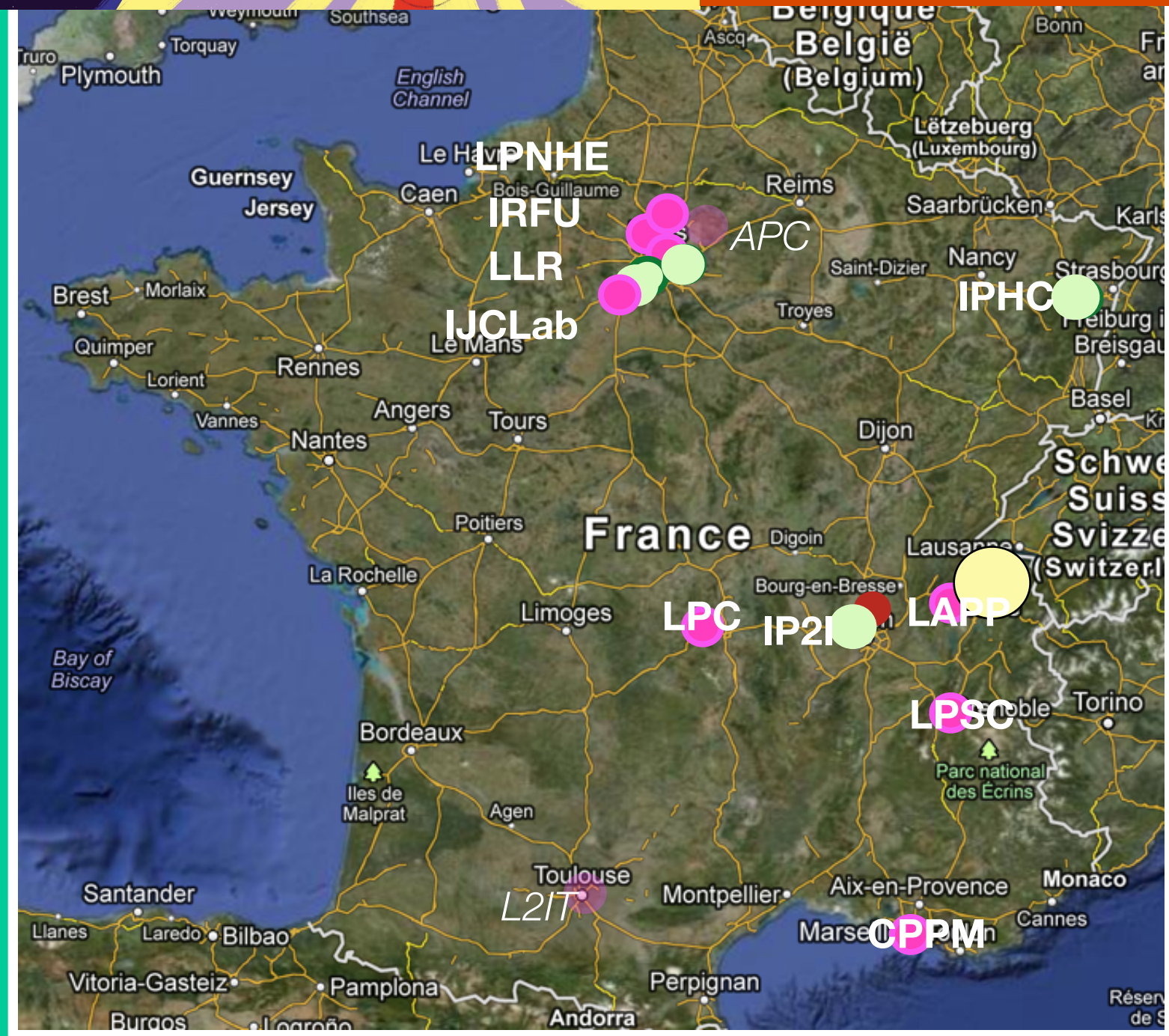


**Isabelle Wingerter-Seez**  
**CNRS - Centre de Physique des Particules de Marseille**  
**Boson de Higgs: dix ans après l'aventure continue - APC-Paris**

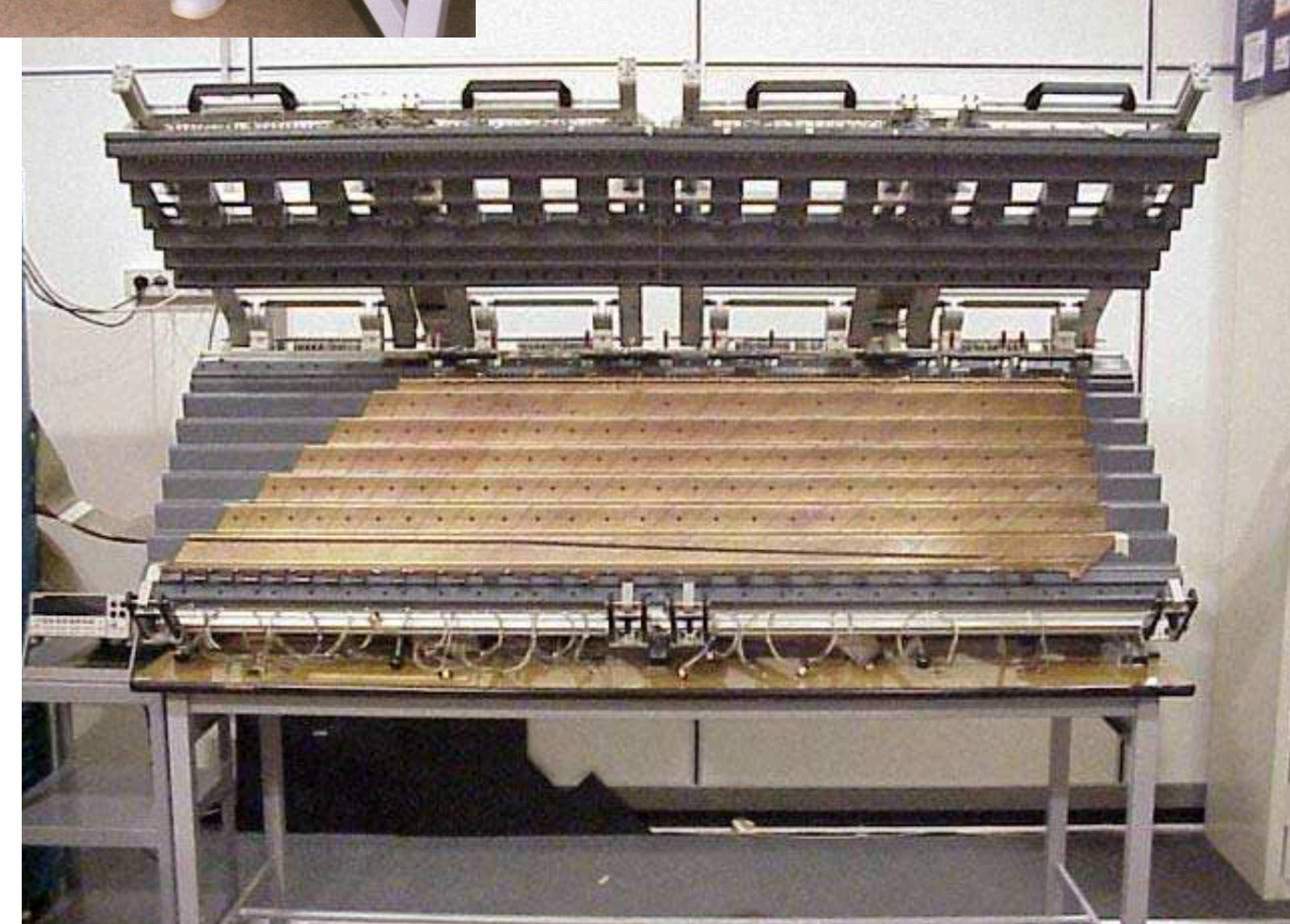
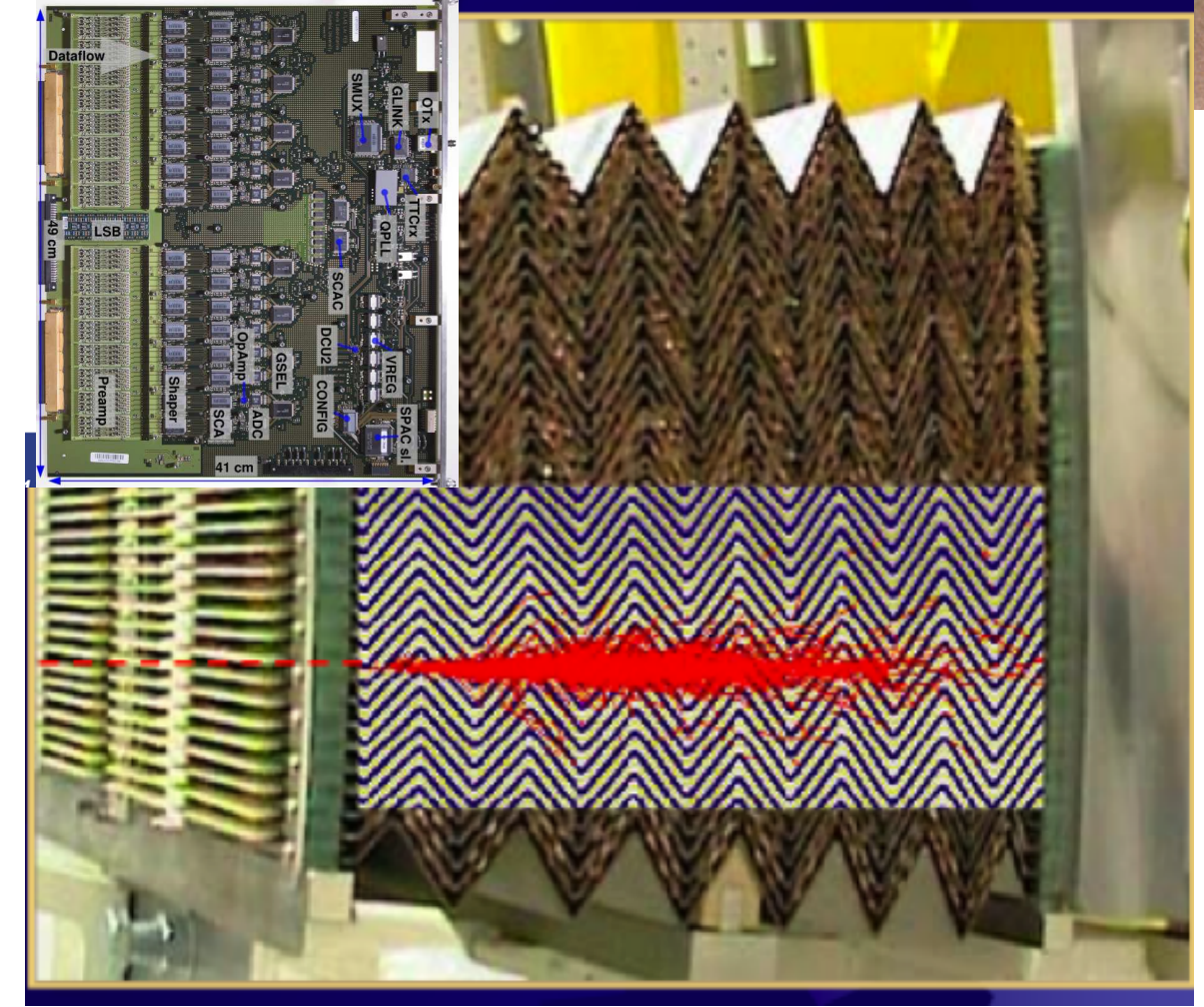
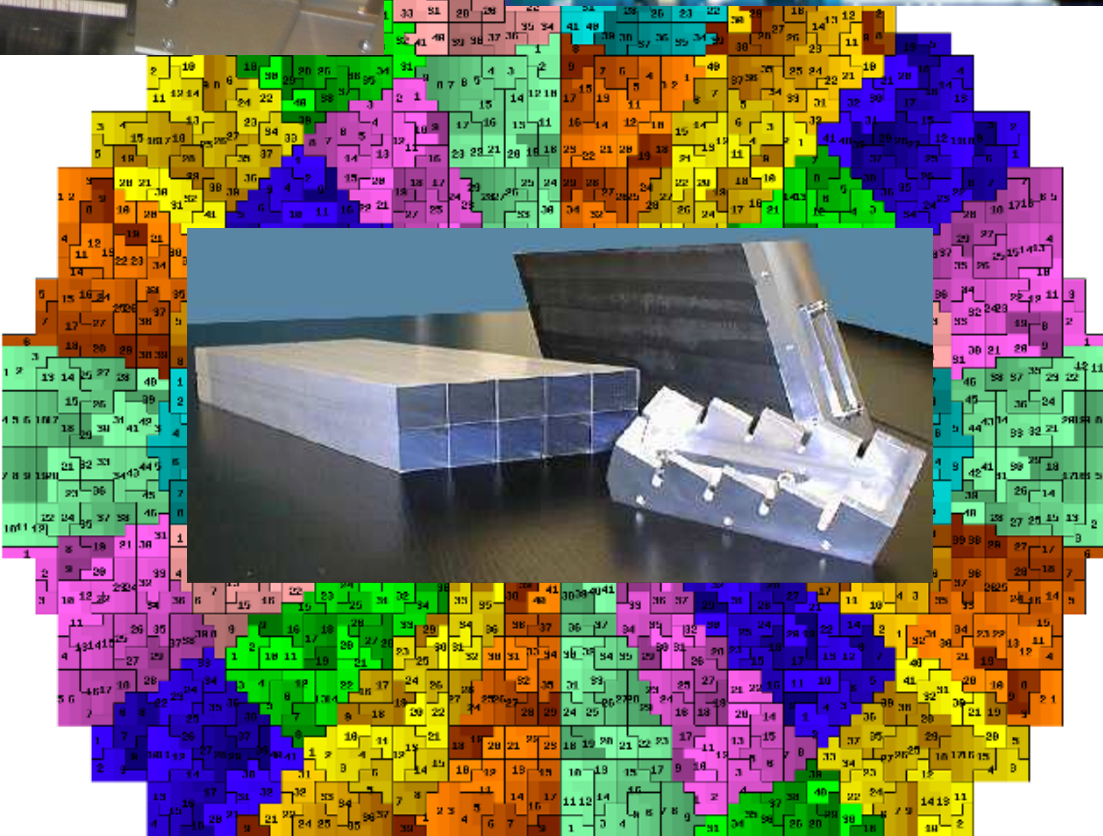
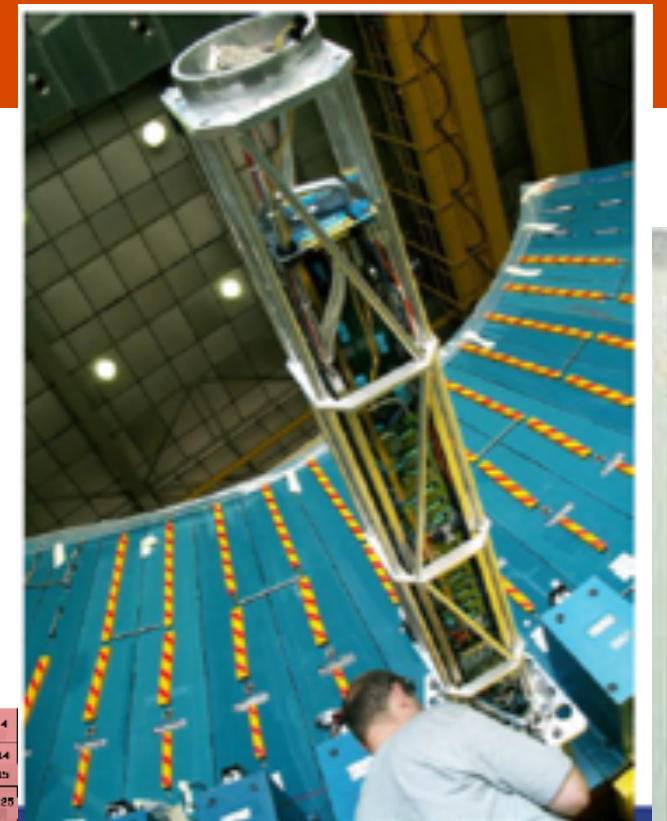


# NEUF LABORATOIRES de L'IN2P3

+ CC-IN2P3 + IRFU

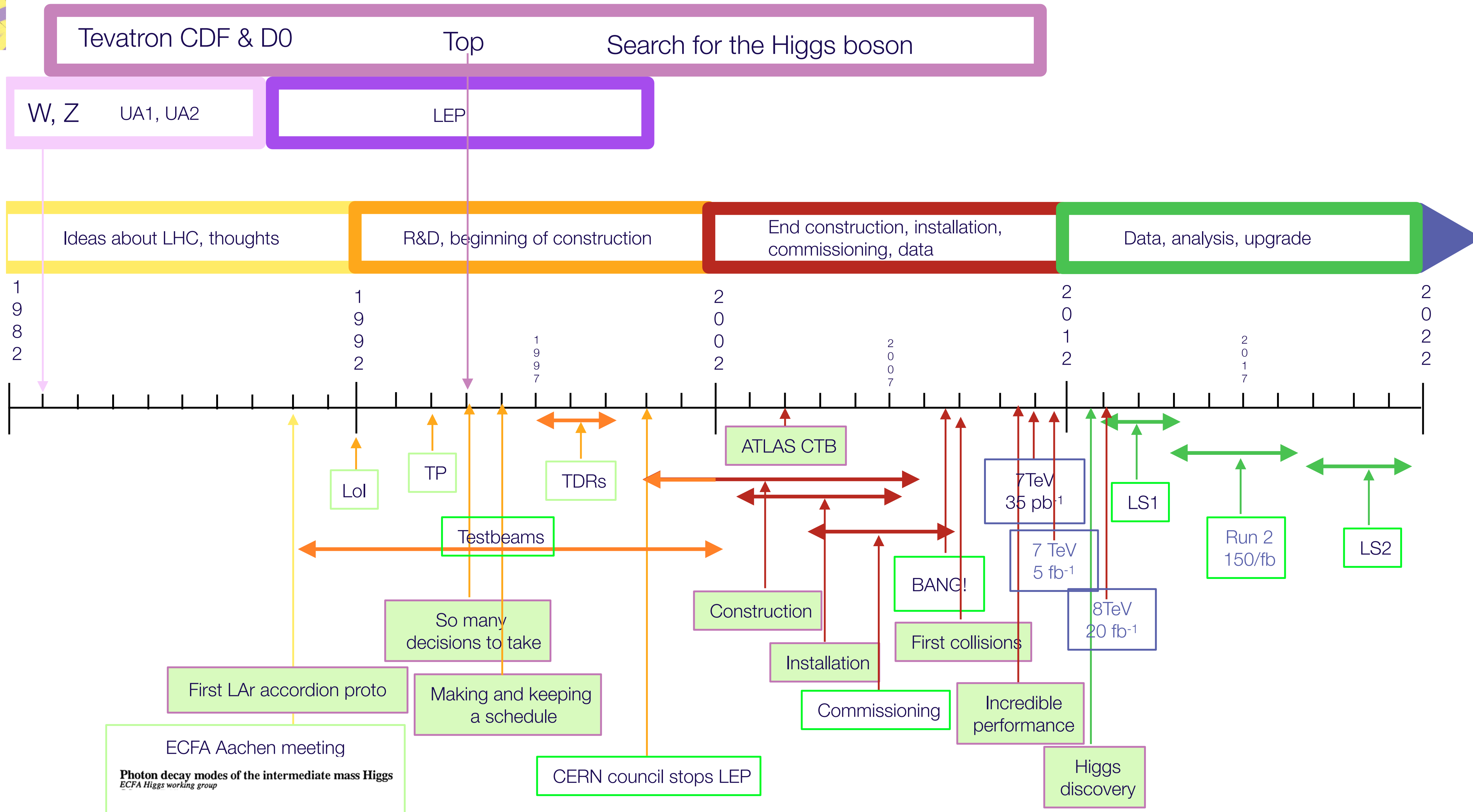


- ATLAS
- CMS
- CC-IN2P3
- CERN



06.07.2022

1964 - Higgs mechanism proposed by P. W. Higgs, F. Englert and R.Brout, G.S. Guralnik, C.R. Hagen and T.W.B. Kibble.

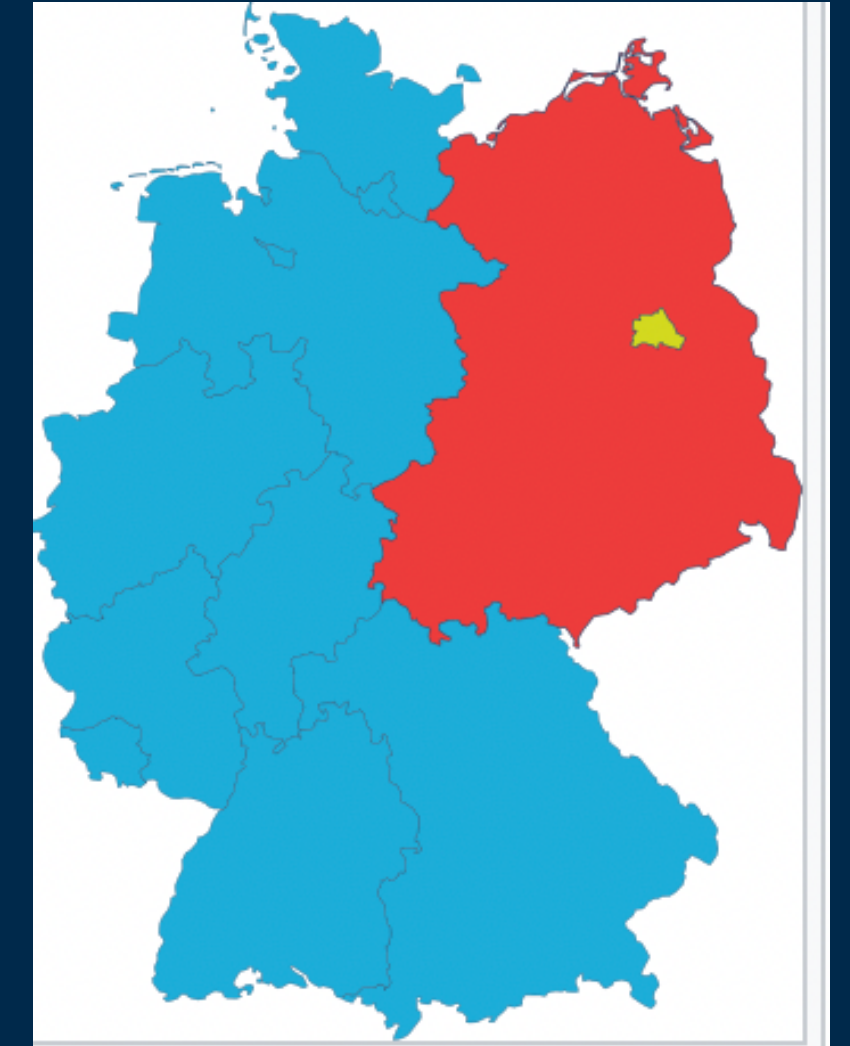


# BACK IN 1990

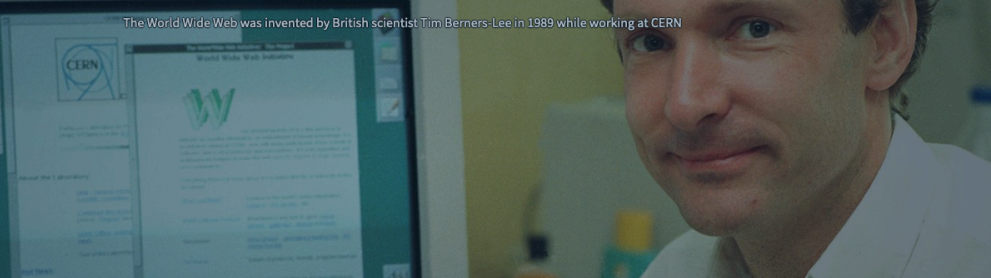


27 Km tunnel completed  
8 February 1988

1988



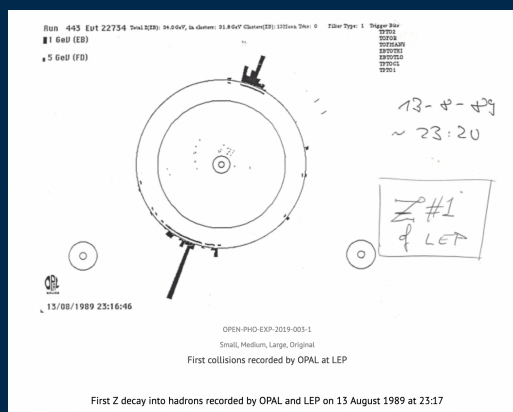
1989 The birth of the Web



1,200 x 900

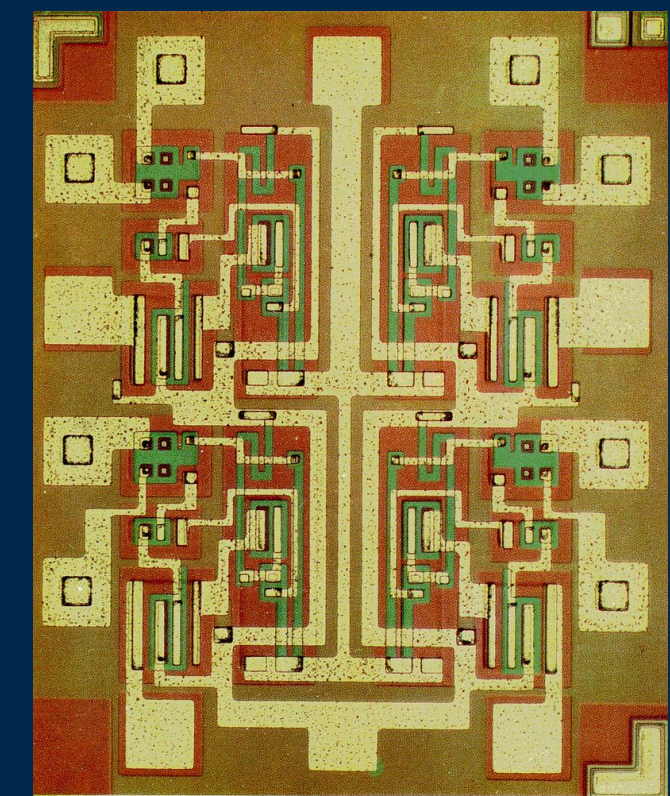
1:00

15.06.1990 le ministre de l'environnement Brice Lalonde lance un « plan vert » pour l'environnement.



1989

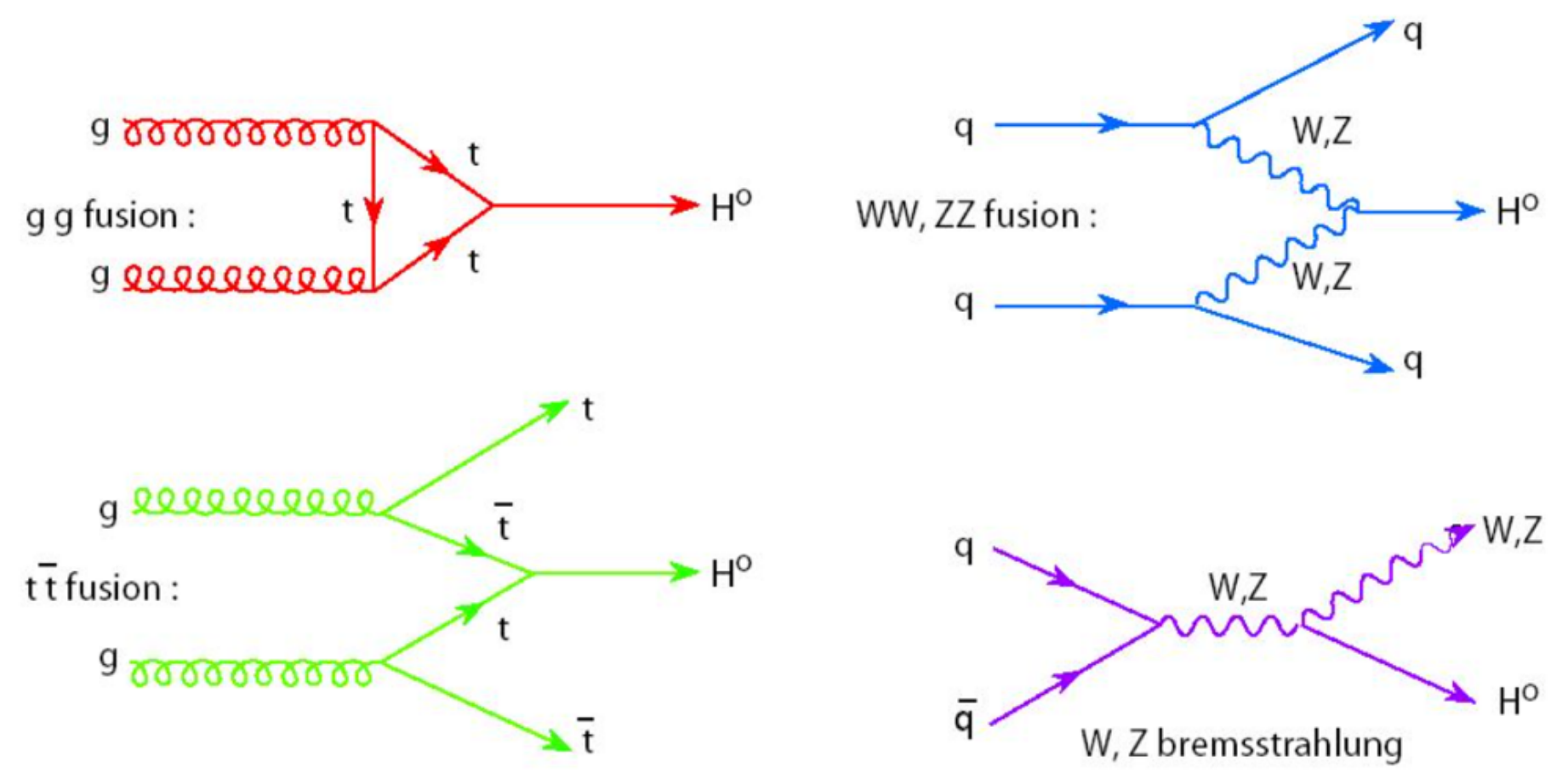
This event marks the start of operation of the largest scientific instrument in the world



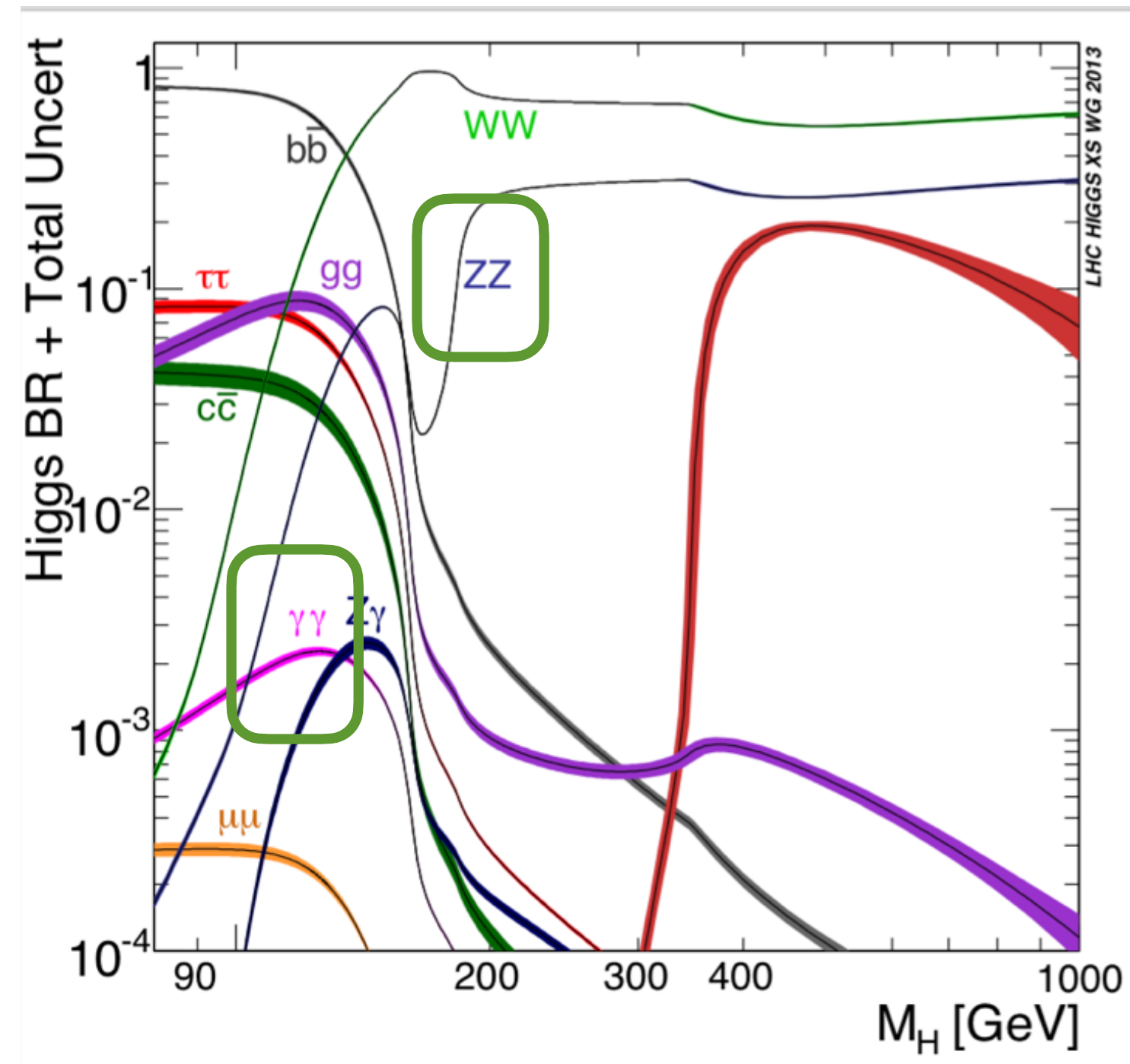
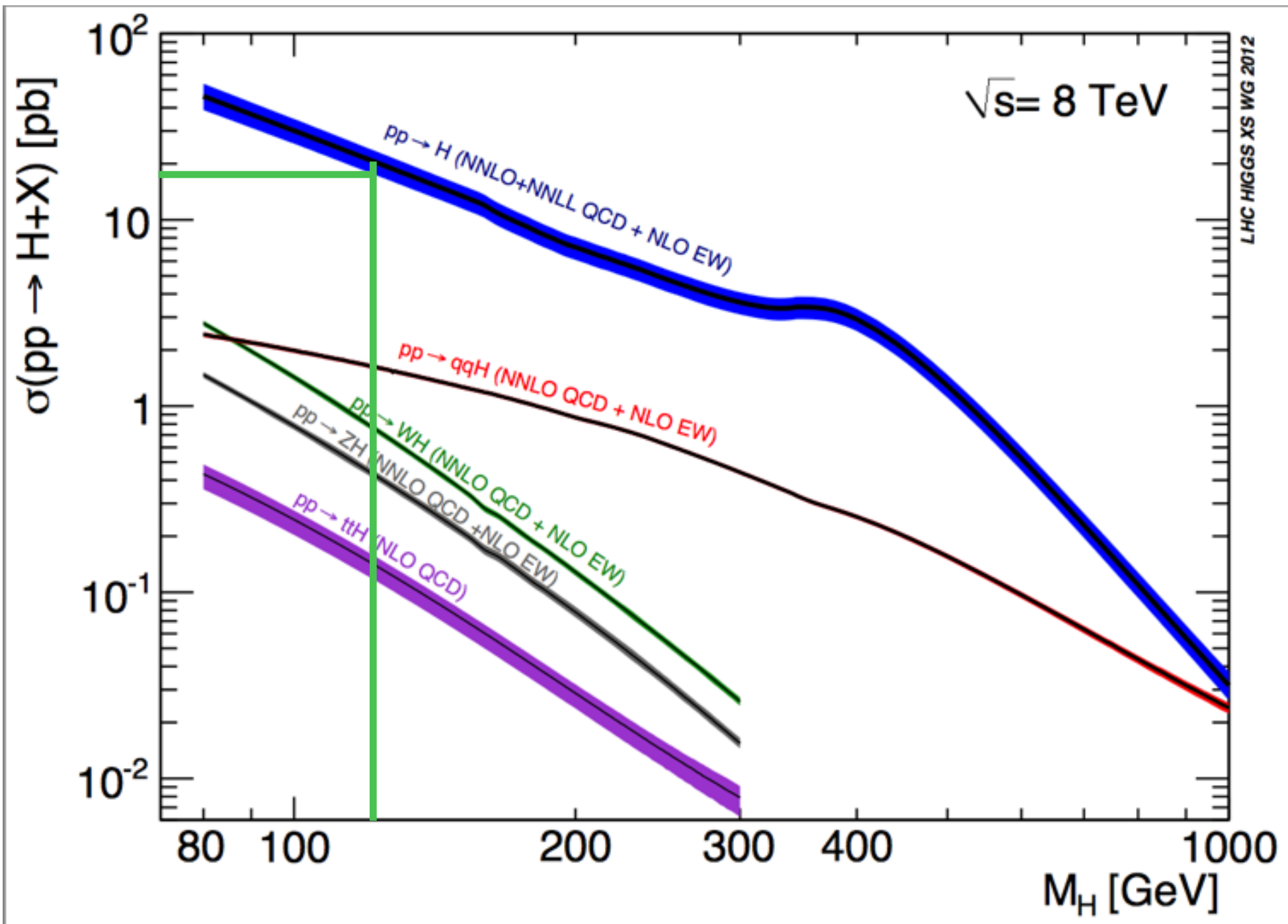
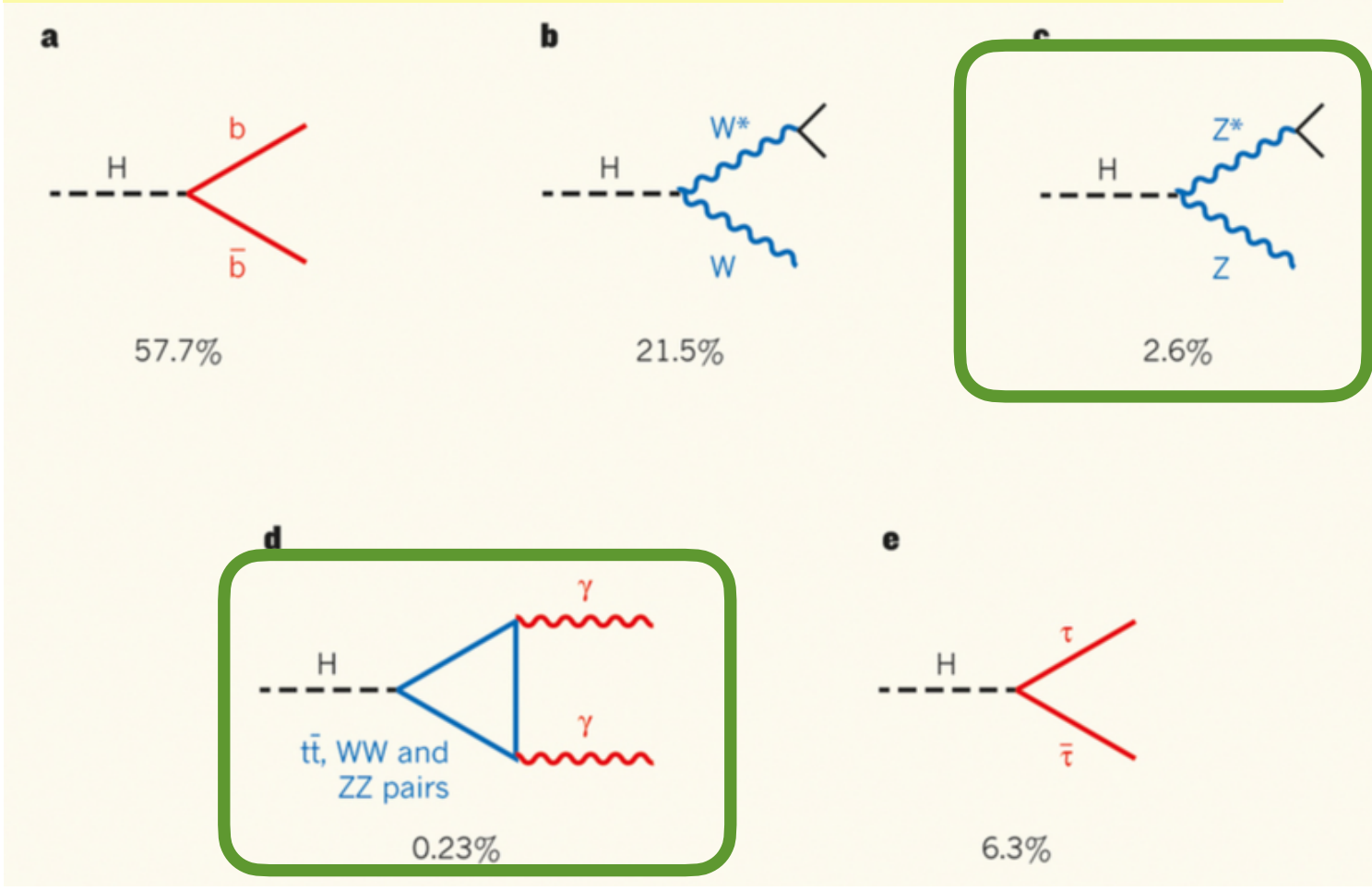
1990: 600 nm  
2020: 5 nm

# STANDARD MODEL PREDICTIONS

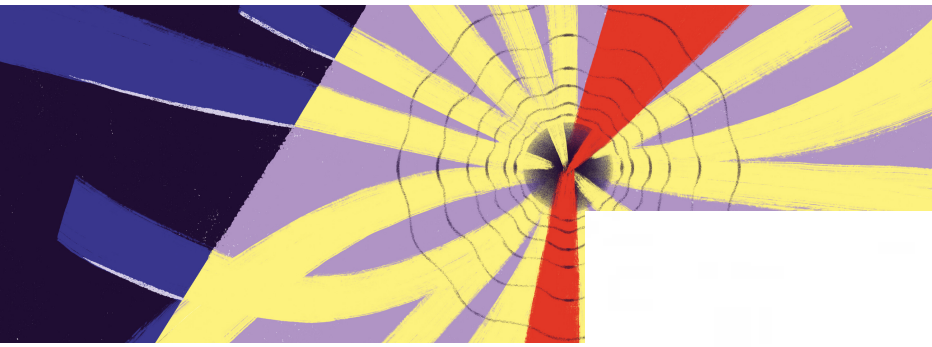
## production @ proton-proton collider



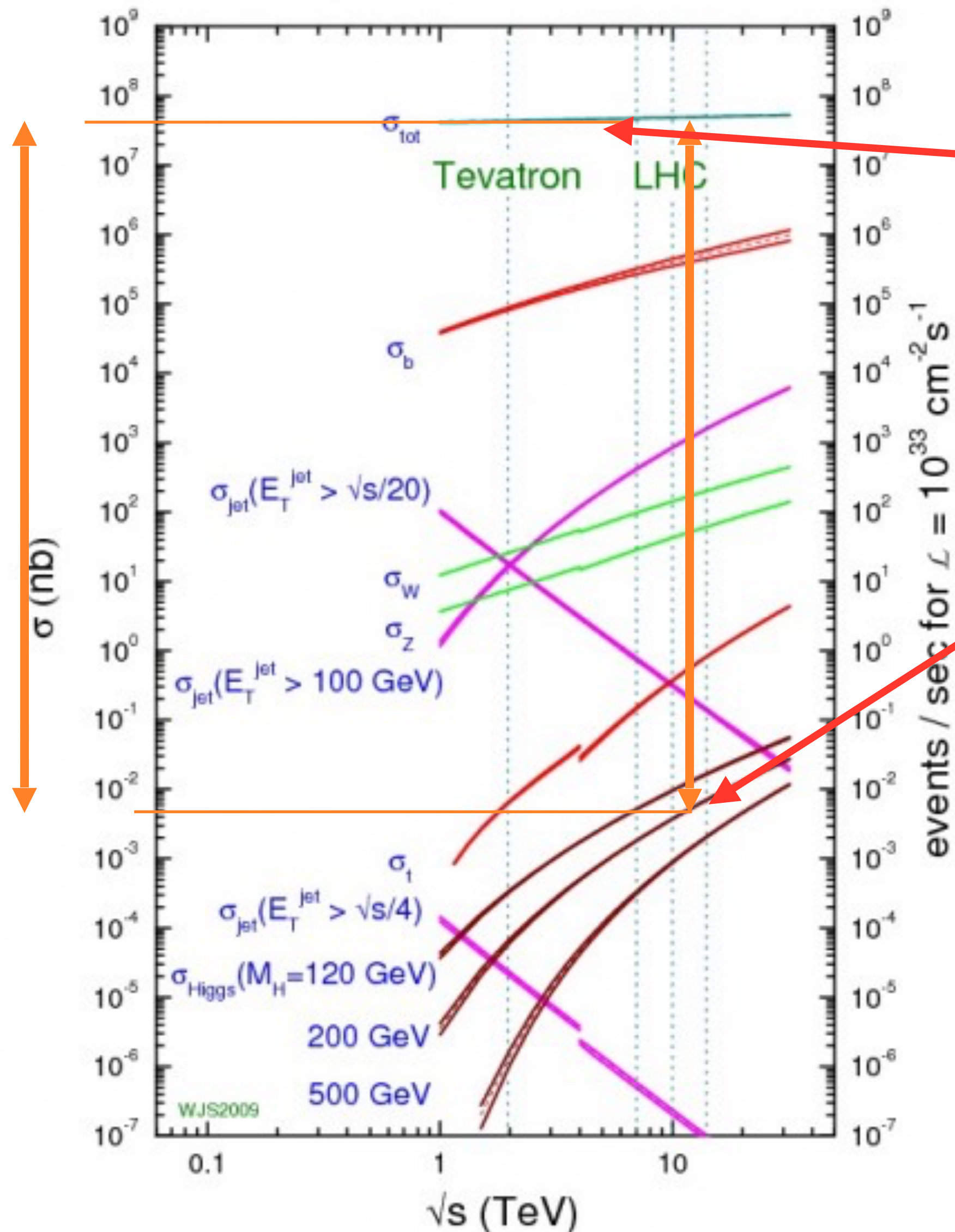
## Decay modes @ $m_H=125$ GeV



# LES DÉFIS



proton - (anti)proton cross sections



$10^{-9}$

Higgs boson production is a very small fraction of the standard p-p collisions:  $10^{-9}$

Higgs production is rare: cross-section is  $\sim 10$ -100 pico-barn.

High energy to explore unknown territory

High frequency & high beam intensity:

Maximize number of proton-proton collisions

Try to reveal rare phenomena.

# DU PAIN sur la PLANCHE

No access



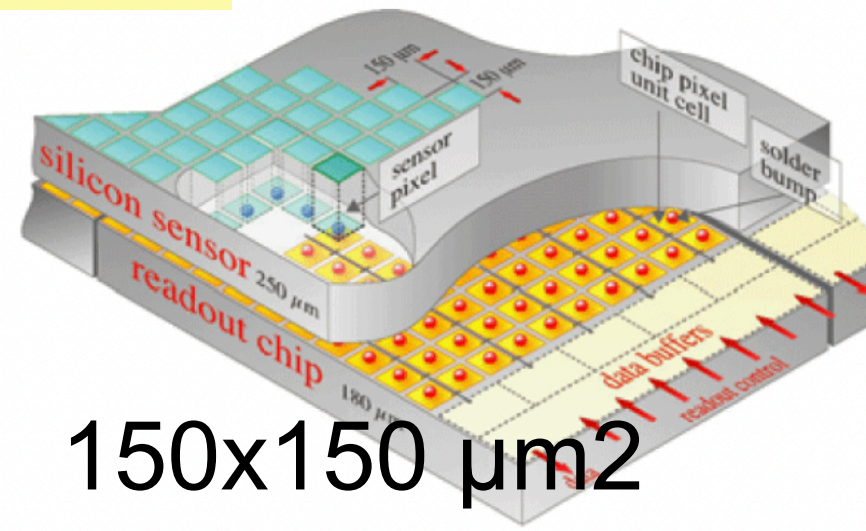
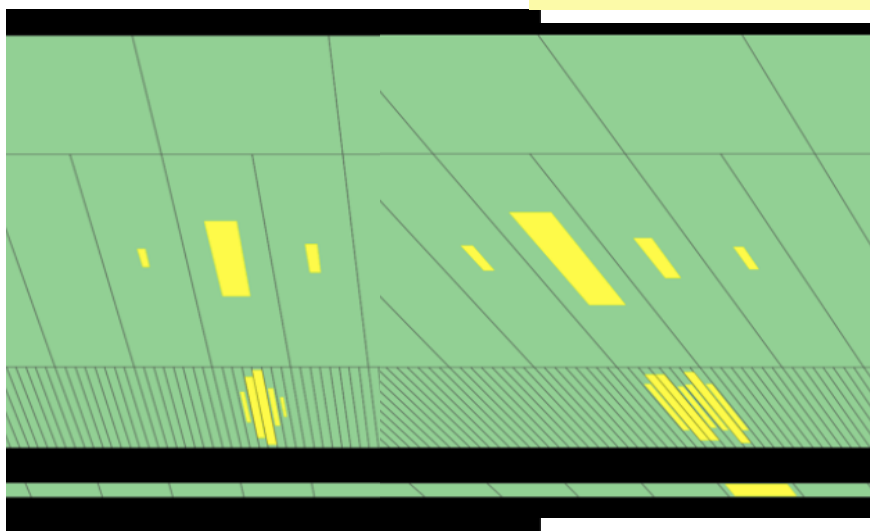
A large collaboration



42 countries  
182 institutions  
3000 scientific participants,  
including 1000 students

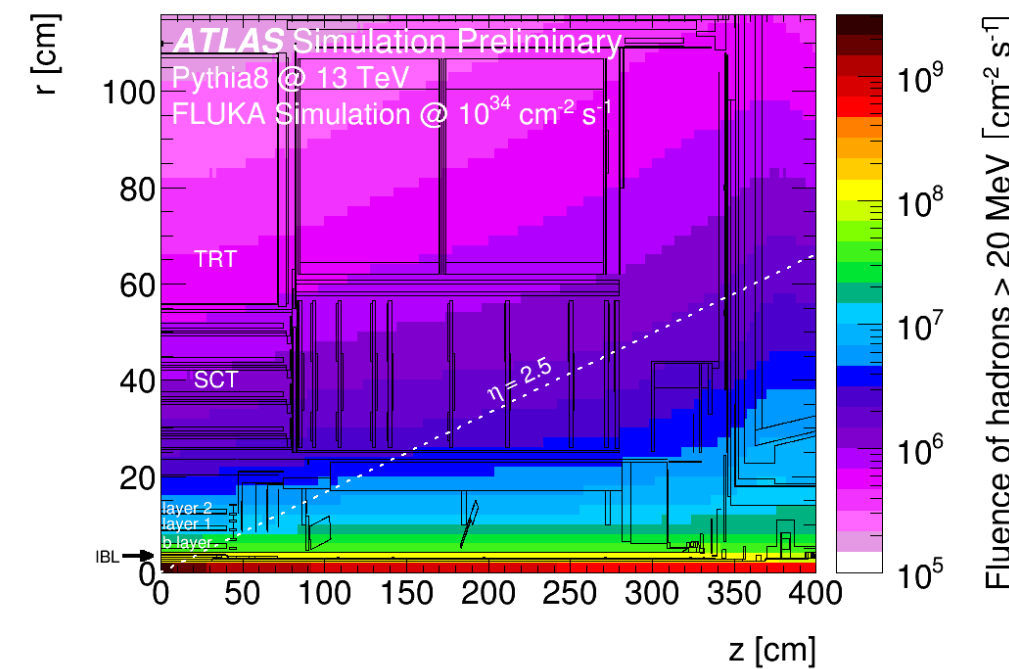
ATLAS  
Collaboration

Segmentation



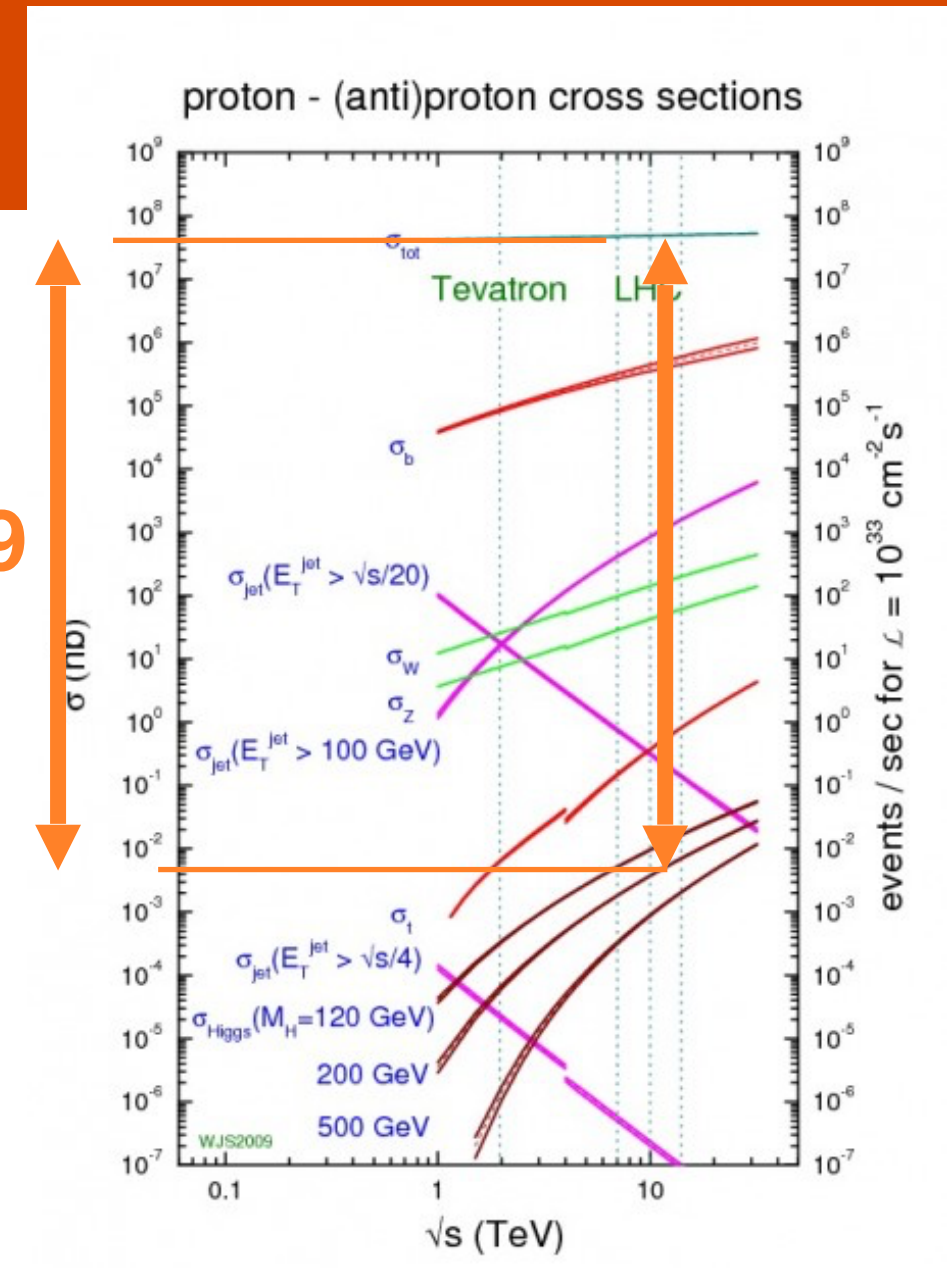
150x150  $\mu\text{m}^2$

	LHC design	LHC 2012	LEP
$\sqrt{s}$ [TeV]	14	7	0.09 - 0.2
$\Delta t$ [ns]	25	50	2000
Nbre bunchs	2808	1380	4-8
p/bunch [ $10^{11}$ ]	1.15	1.7	2.5
Peak luminosity [ $10^{34} \text{ cm}^{-2}\text{s}^{-1}$ ]	1	0.77	0.01 Max
Max nbre events/crossing	20	35	1
Stored beam energy [MJ]	362		



Radiations

Trigger

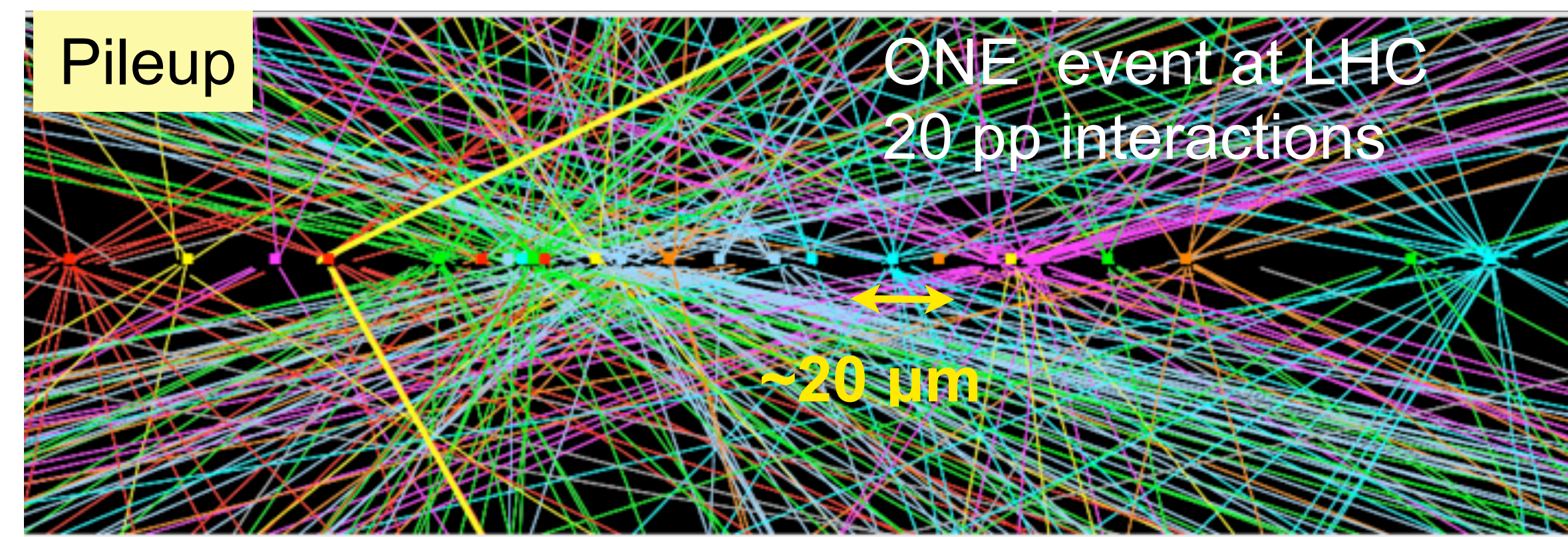


$10^{-9}$

LHC  
Crossings 40 MHz  
L1 trigger 100 kHz  
On disk 1 kHz

LEP  
50 kHz  
1 Hz  
-

Pileup

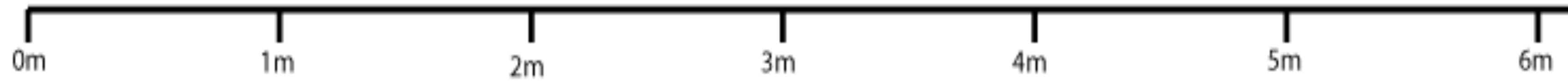
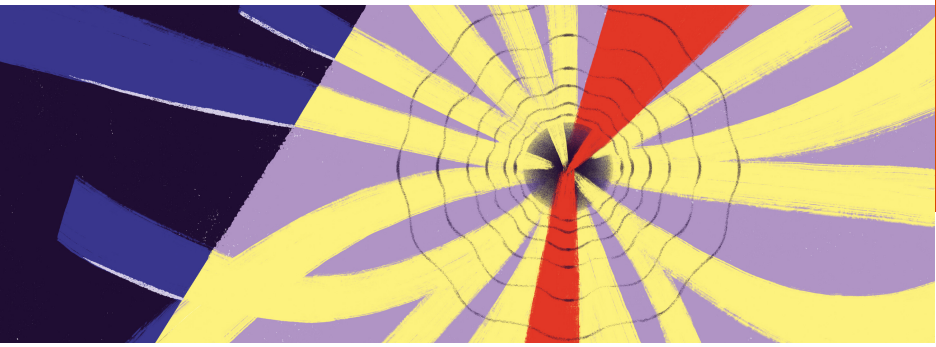


ONE event at LHC  
20 pp interactions

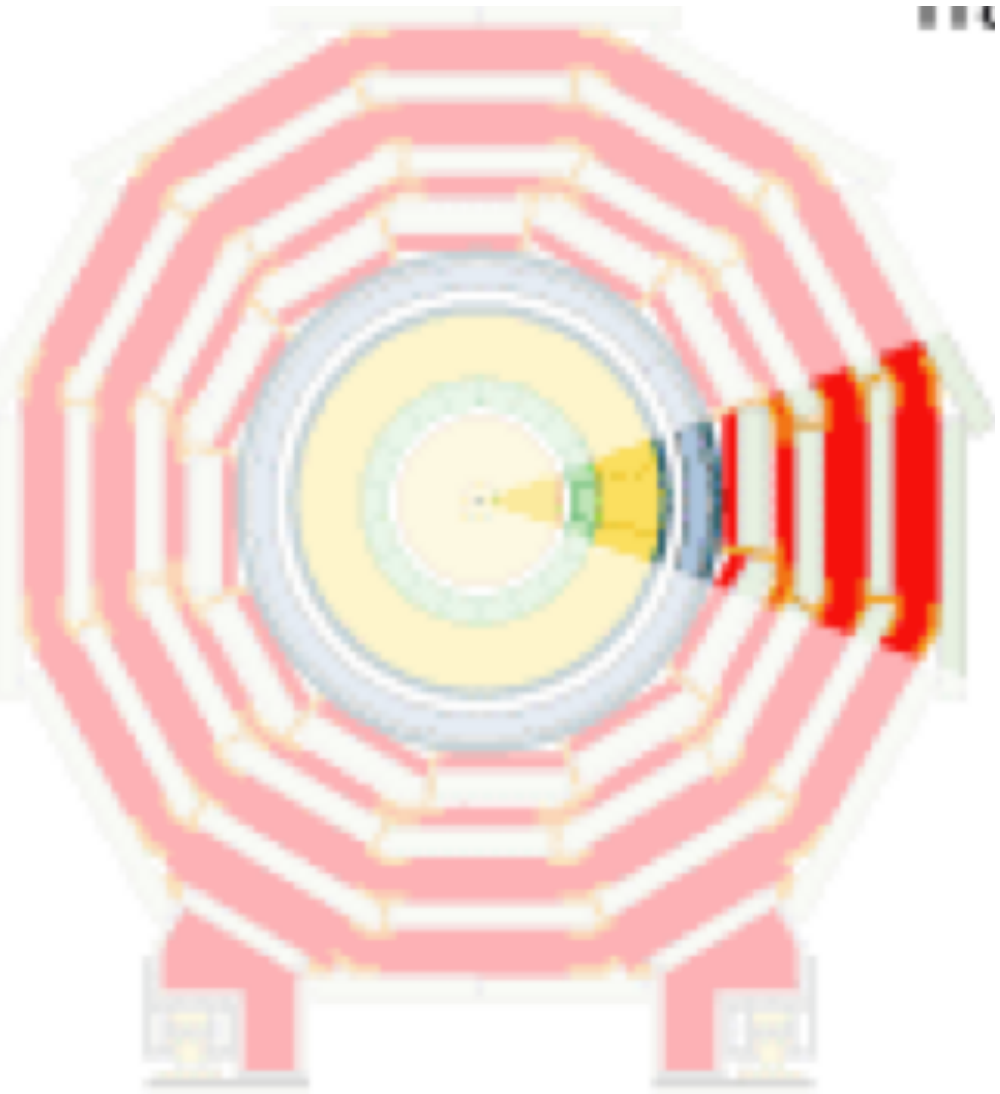
$\sim 20 \mu\text{m}$



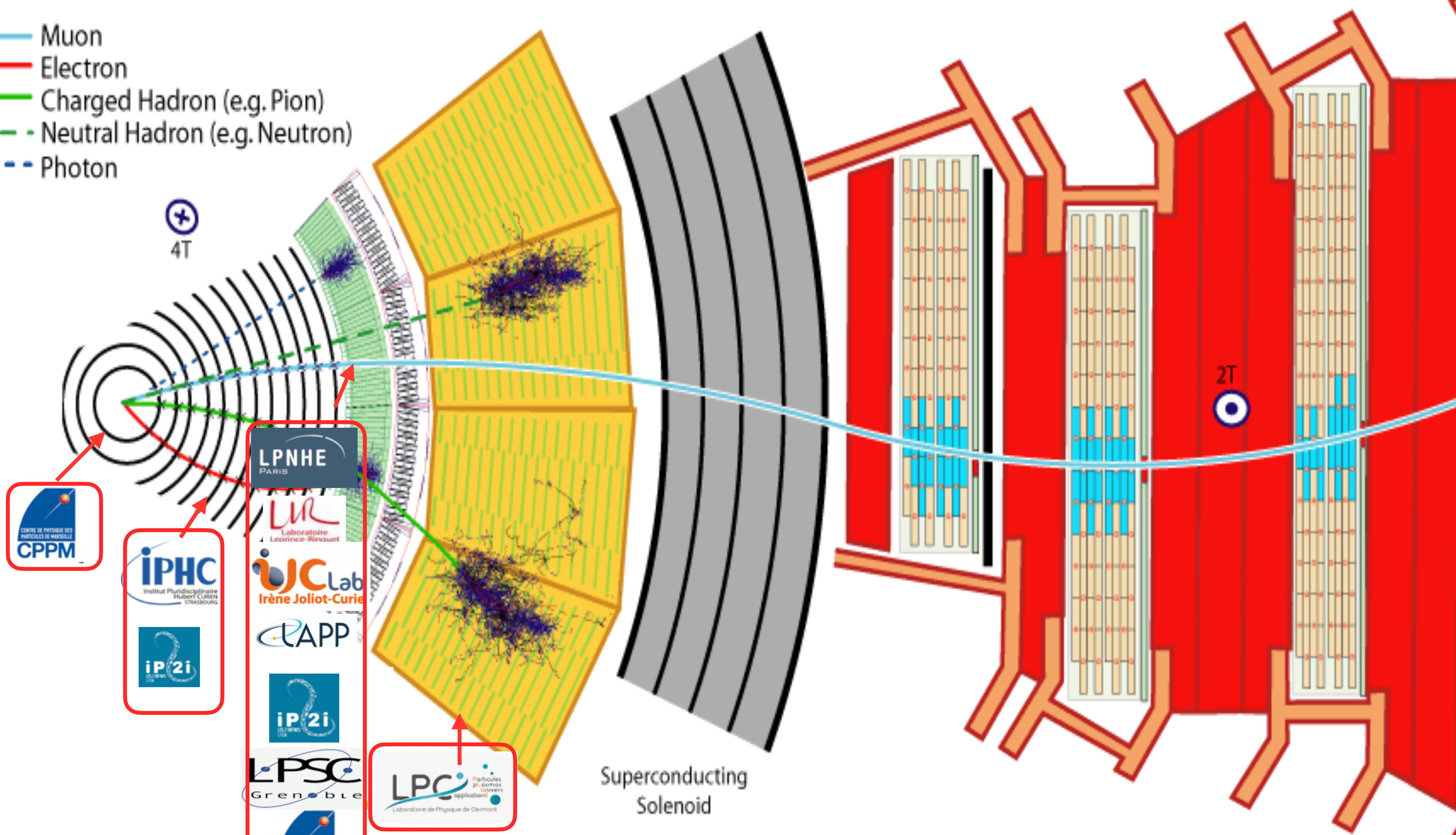
# ONE TYPICAL DETECTOR



- Key:
- Muon
  - Electron
  - Charged Hadron (e.g. Pion)
  - Neutral Hadron (e.g. Neutron)
  - Photon



Transverse slice through CMS



Superconducting Solenoid

Iron return yoke interspersed with Muon chambers

LPNHE PARIS

LIR Laboratoire Leonie-Rinauet

UJCLab Irène Joliot-Curie

LAPP

iP2i

LPSC Grenoble

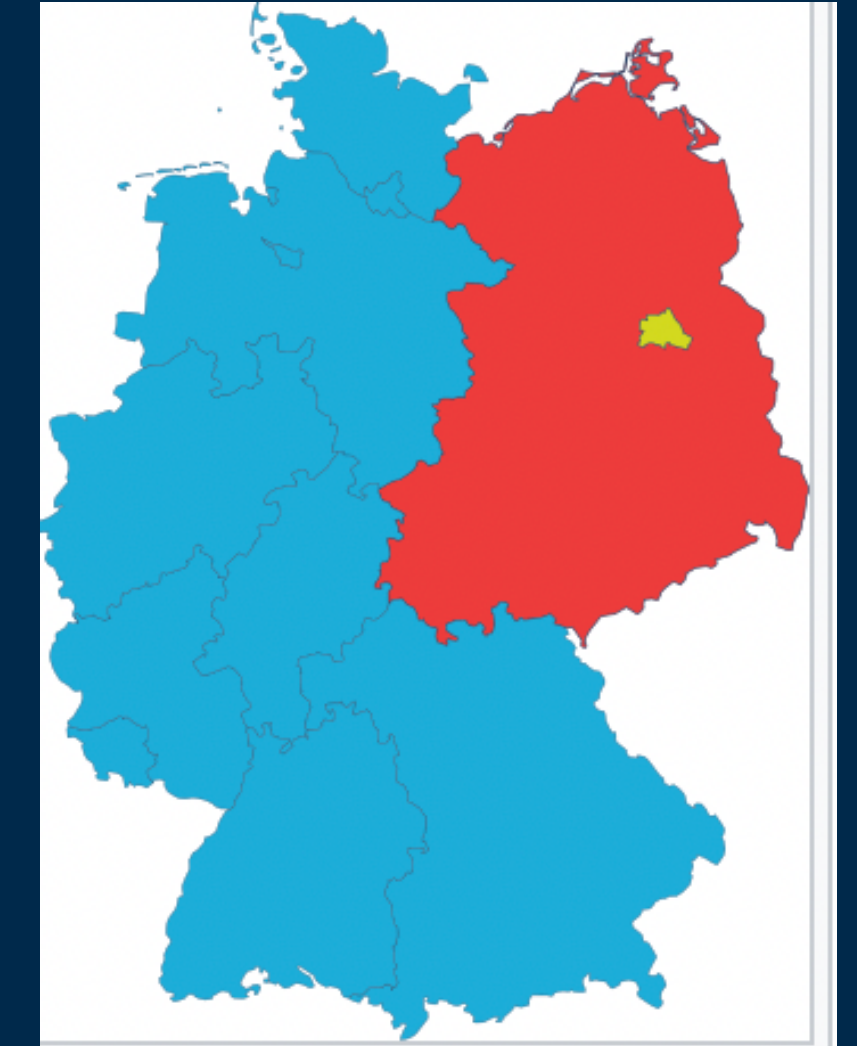
LPC Laboratoire de Physique de Clermont

# BACK IN 1990

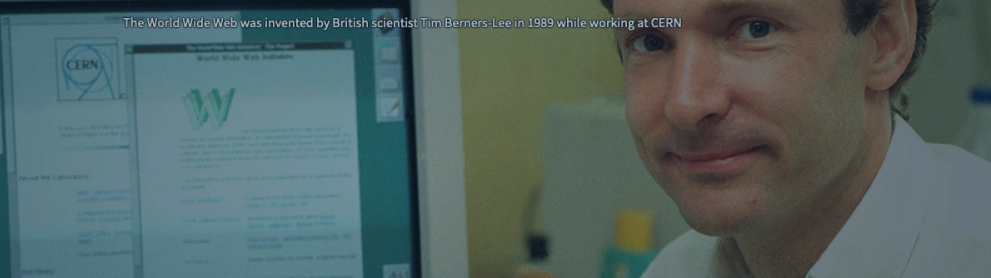


27 Km tunnel completed  
8 February 1988

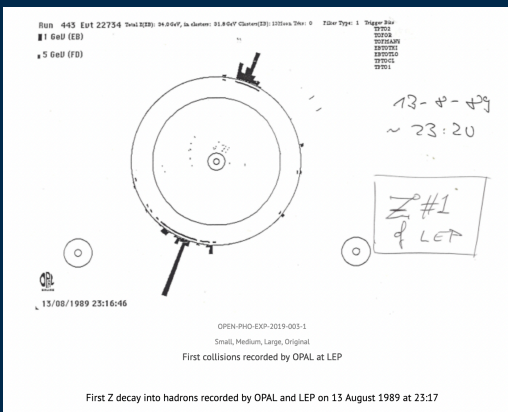
1988



1989 The birth of the Web

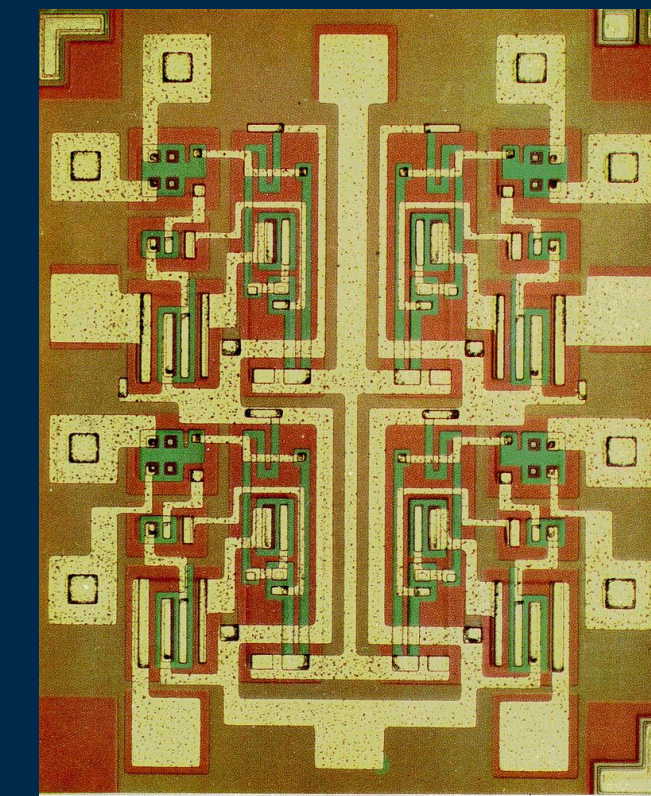


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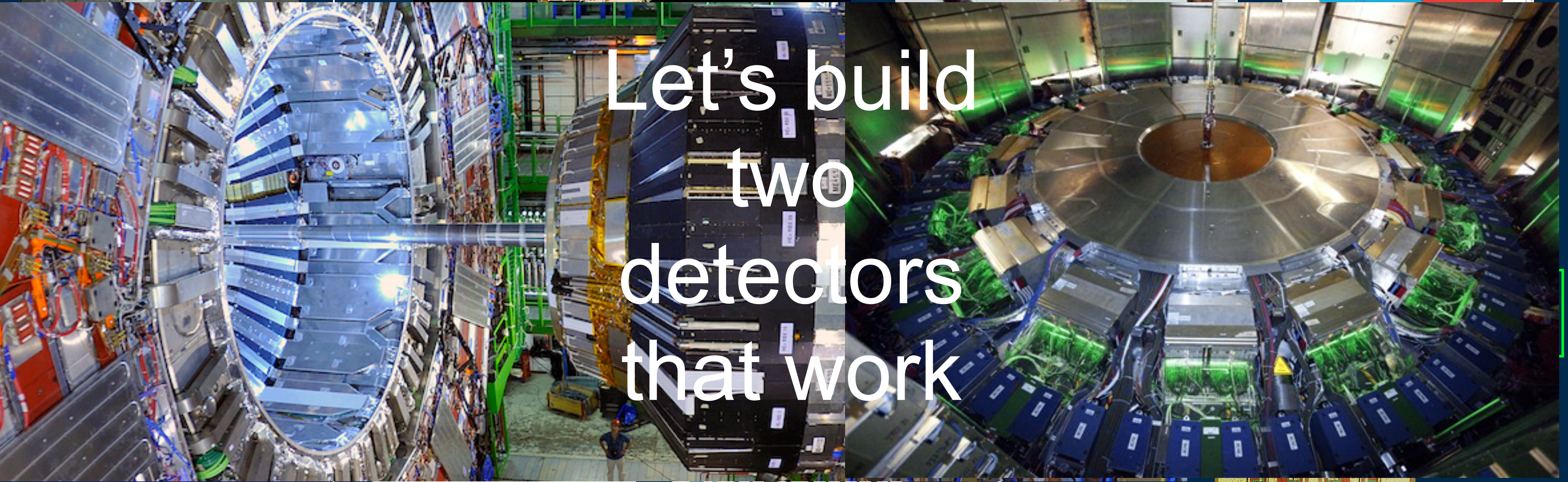
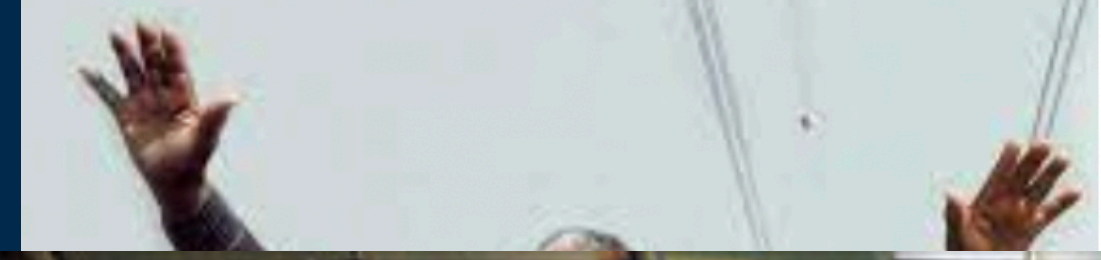
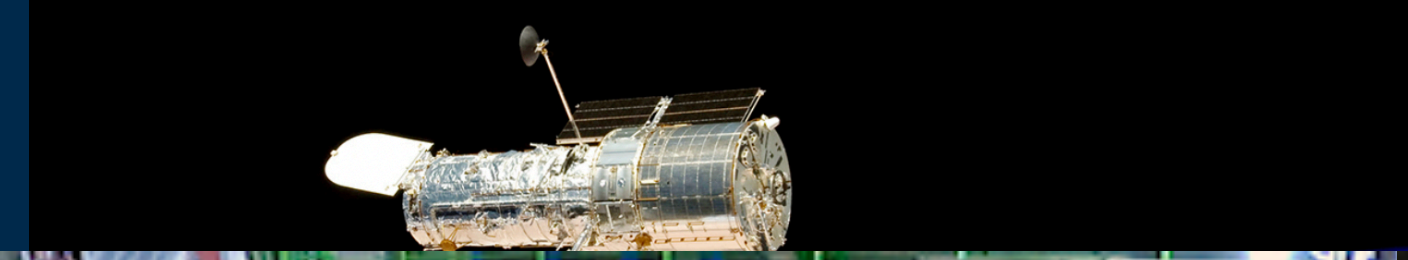
1989

This event marks the start of operation of the largest scientific instrument in the world



1990: 600 nm  
2020: 5 nm

# BACK IN 1990



Let's build  
two  
detectors  
that work

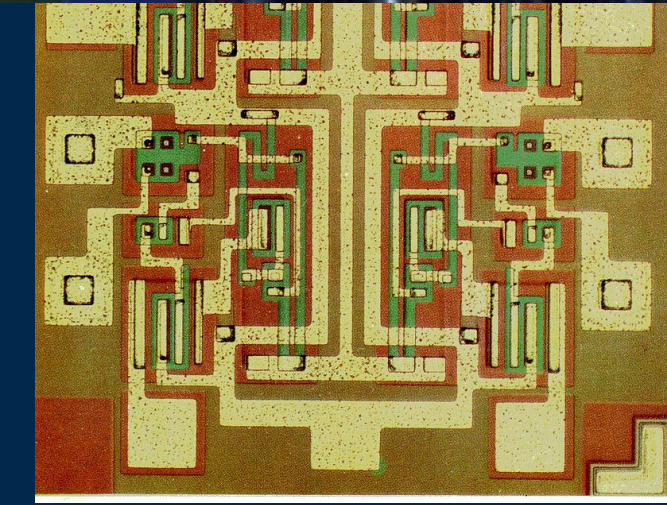


1989

This event marks the start of operation of the largest scientific instrument in the world

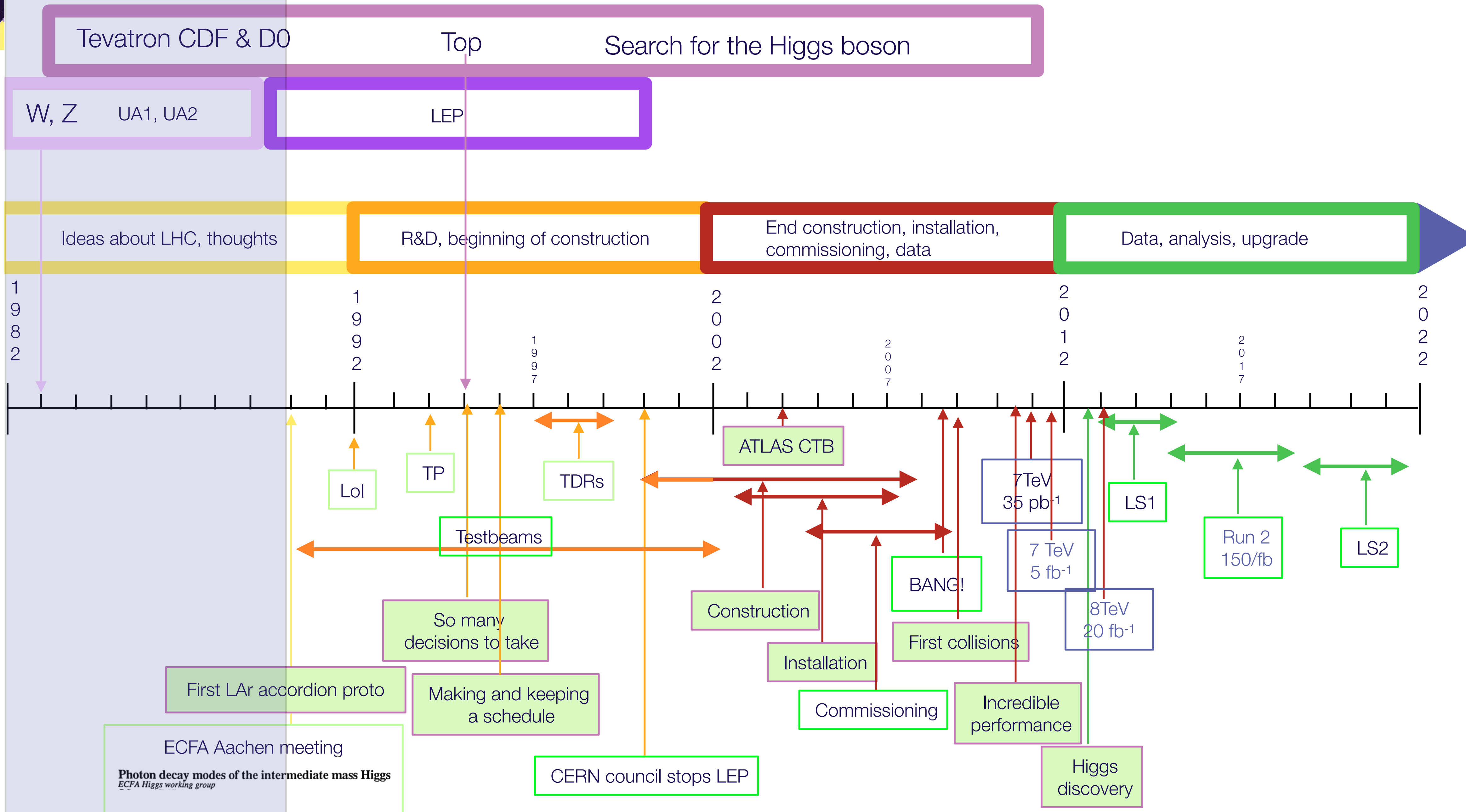


1/12/1990



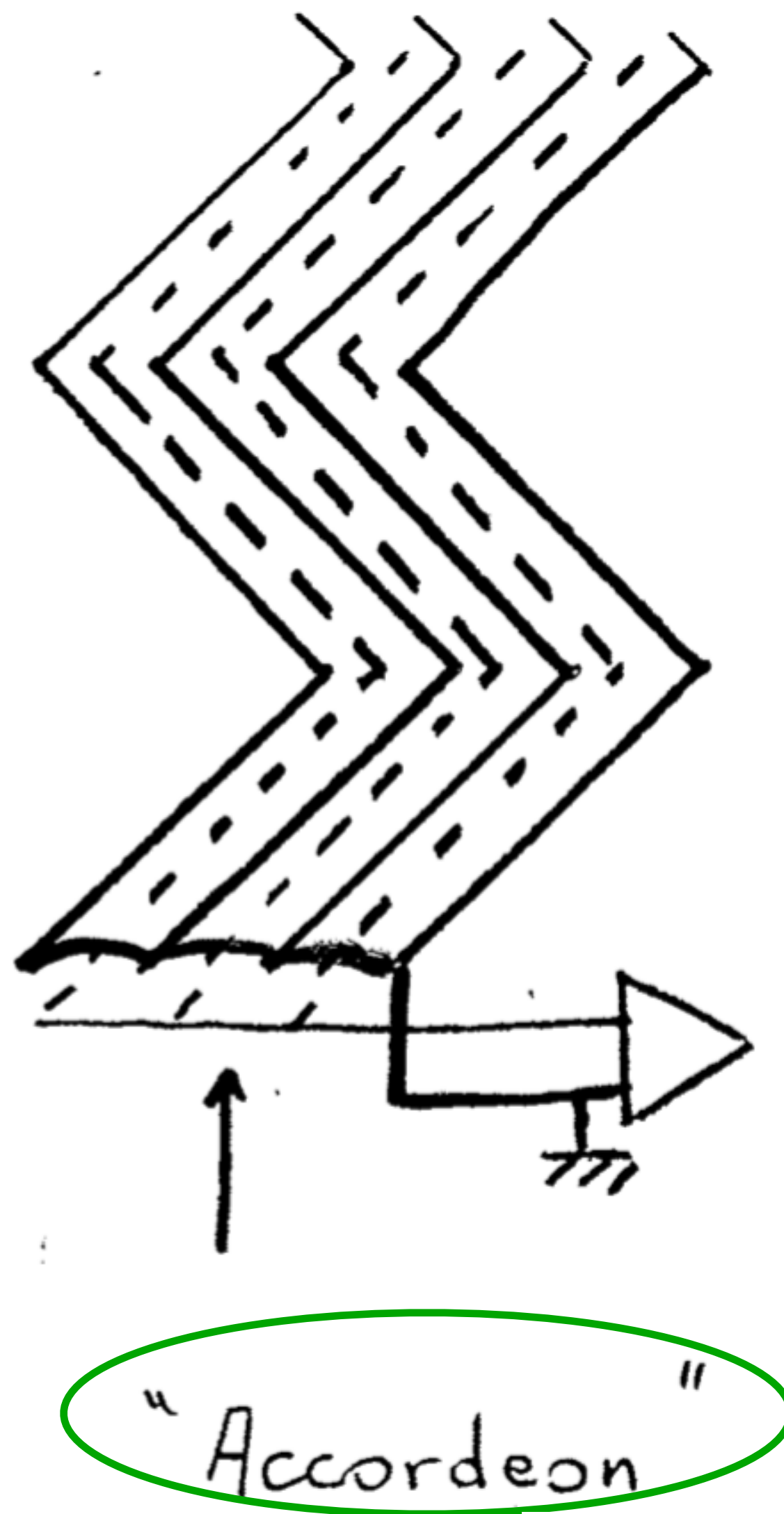
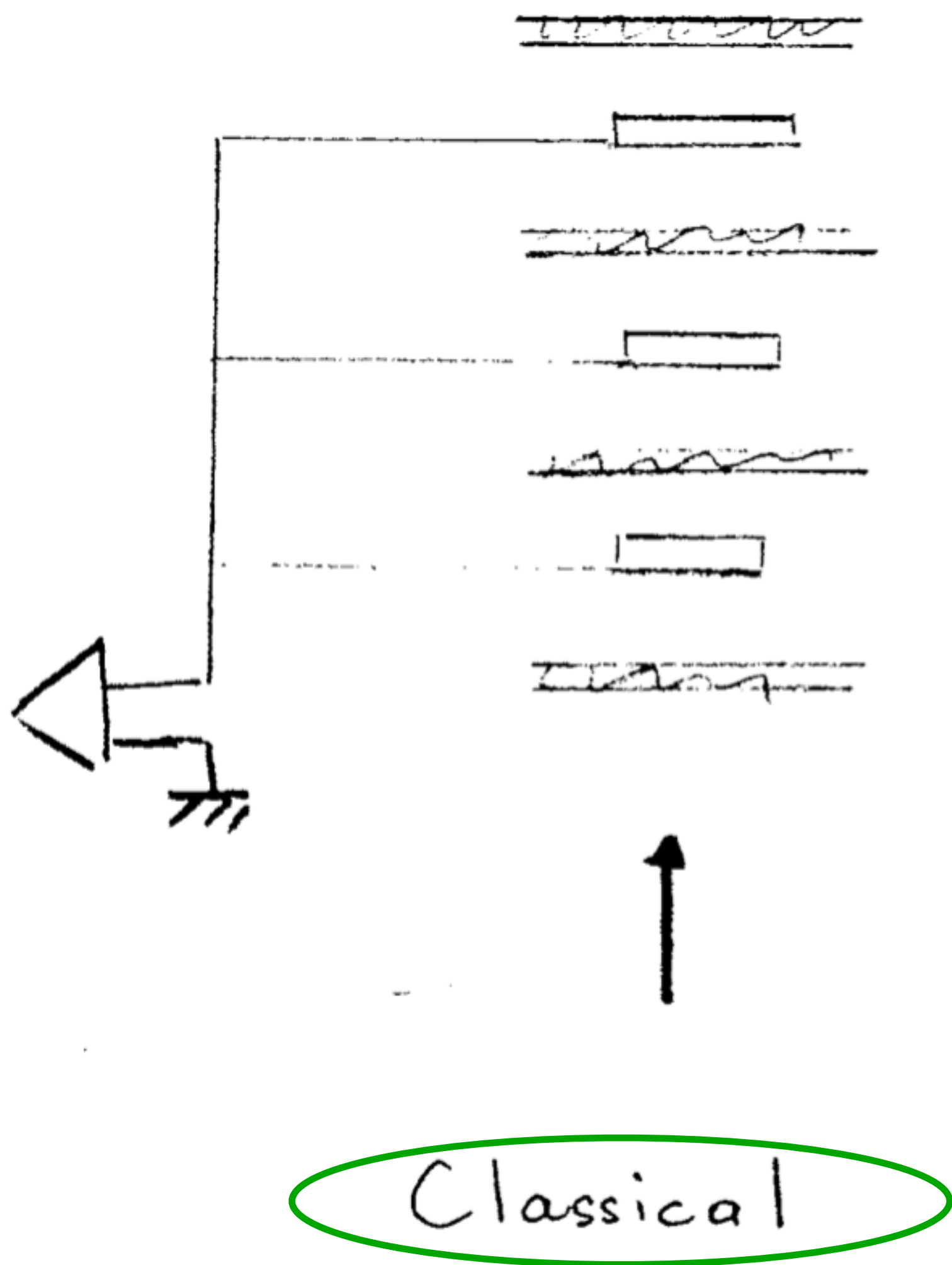
1990: 600 nm  
2020: 5 nm

1964 - Higgs mechanism proposed by P. W. Higgs, F. Englert and R.Brout, G.S. Guralnik, C.R. Hagen and T.W.B. Kibble.



# A fast calorimeter

Reminder  $\Delta t = 25 \text{ ns}$



Janvier 1990

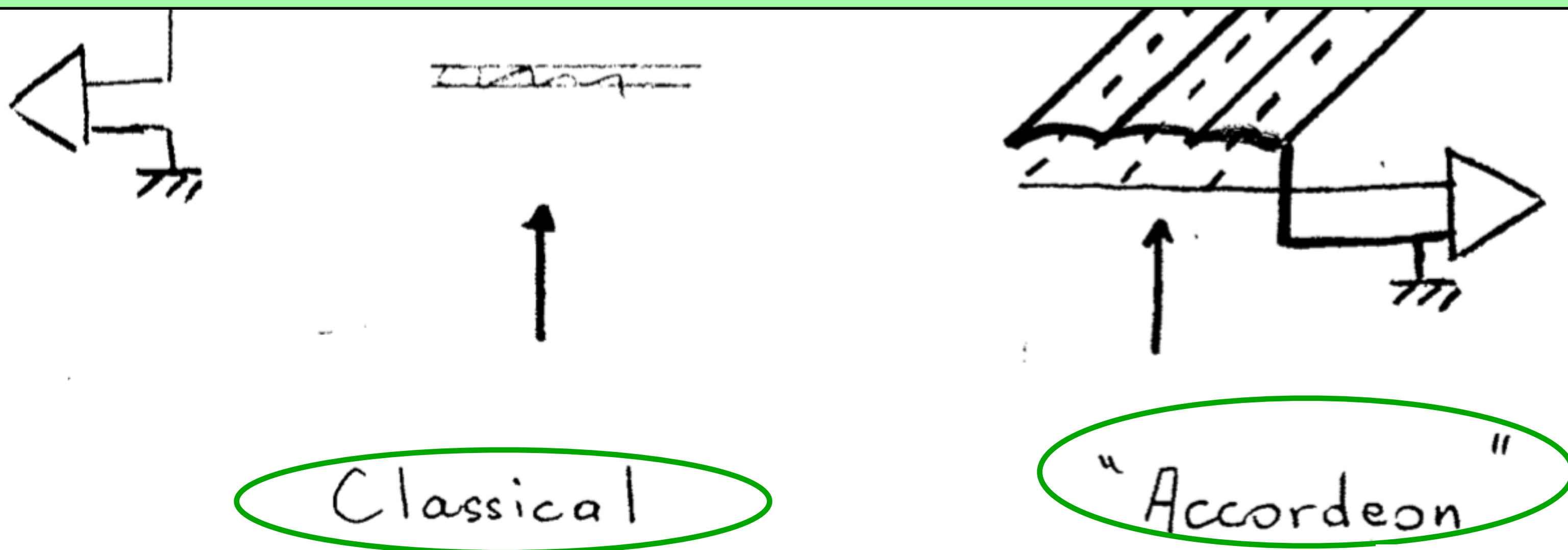
Daniel Fournier

# A fast calorimeter

Reminder  $\Delta t = 25 \text{ ns}$

The benefit of such a scheme is that each tower can be connected to a preamp located on the tower itself, in the front or back of the calorimeter.

Thus this proposal solves (in principle) the problem of dead space around modules to allow for connections. Such a problem is harder and harder when the granularity increases. It also implies the use of long connecting lines, which are a serious adverse effect against speed (Radeka & Rescia NIM A265)



Janvier 1990

Daniel Fournier

# A fast calorimeter

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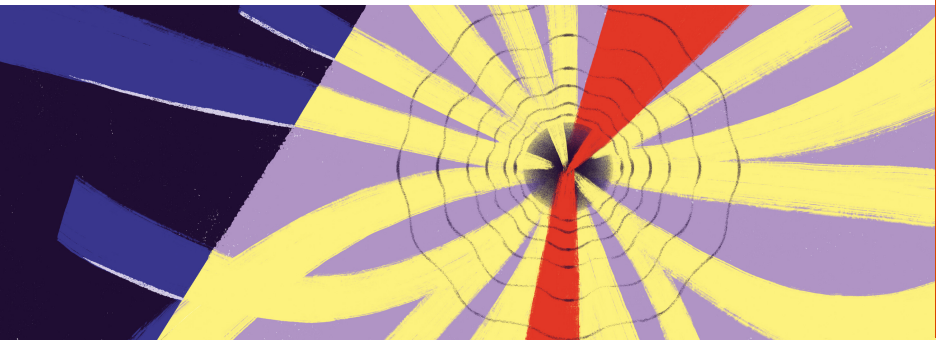
Although it is clear that difficulties will show up when trying to make a real design, one could envisage to use such

Classical

"Accordeon"

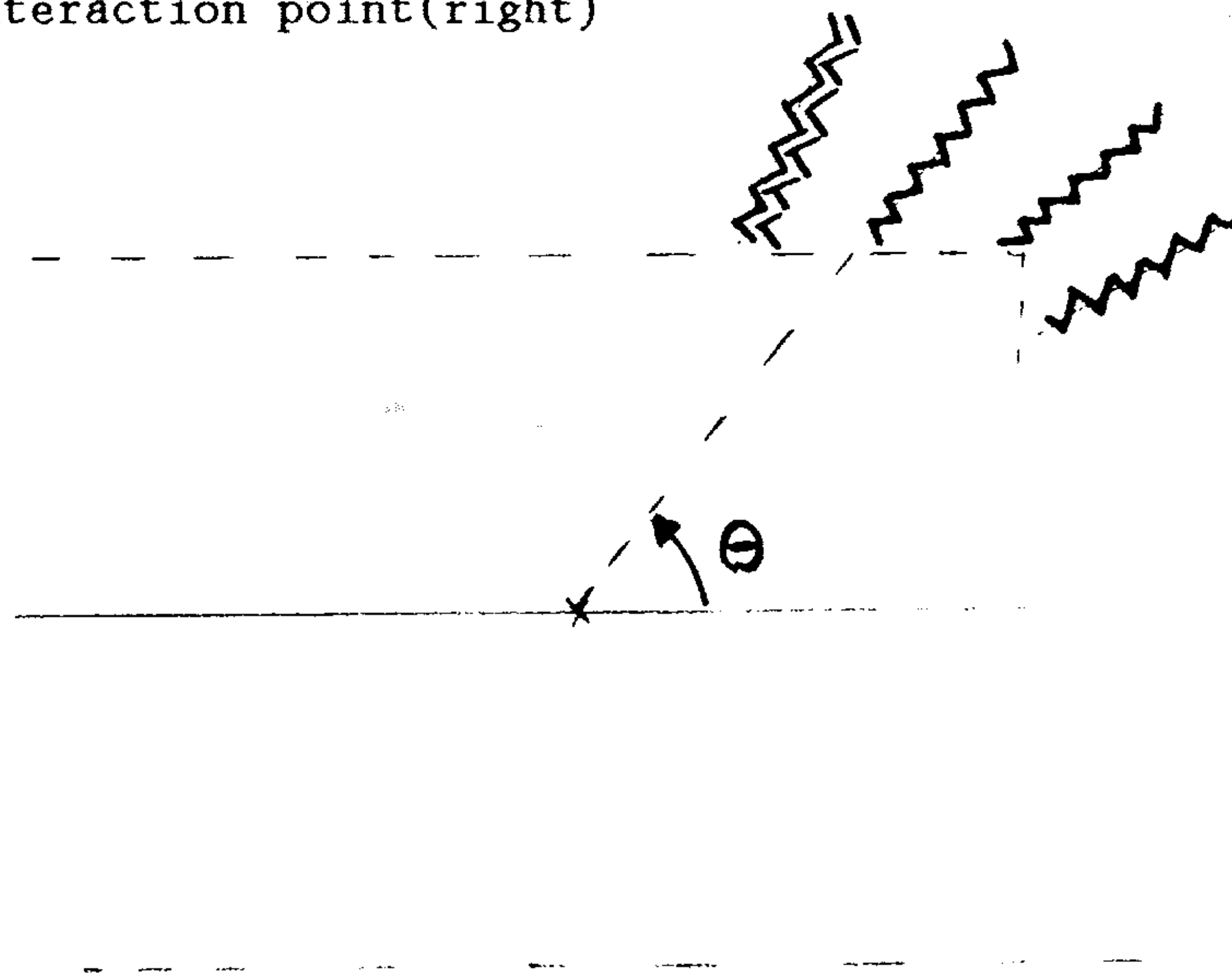
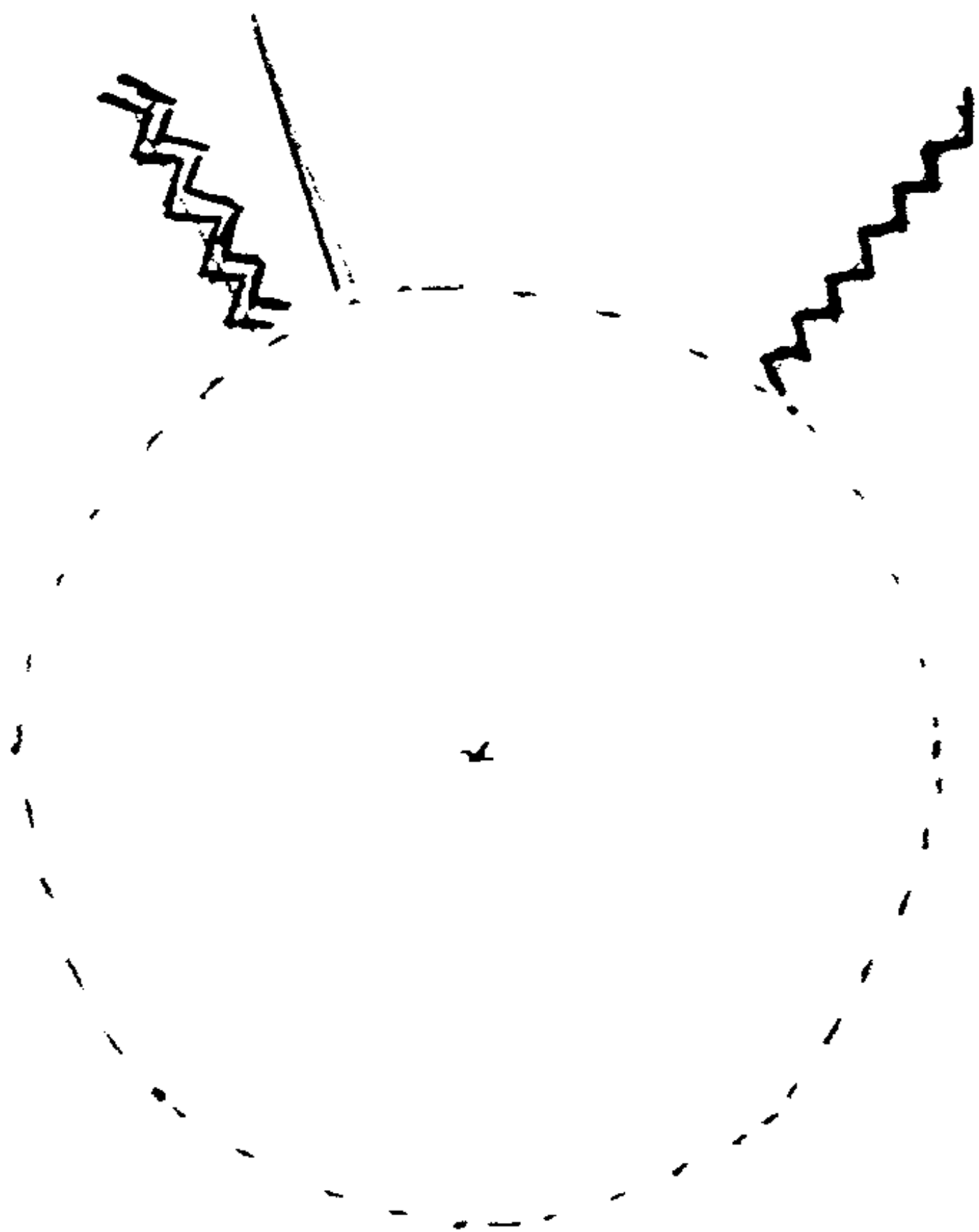
Janvier 1990

Daniel Fournier



# An hermetic calorimeter

a scheme either with  
- "wiggled" plates parallel to the beam axis (left)  
or with  
- "wiggled" cones pointing to the interaction point (right)

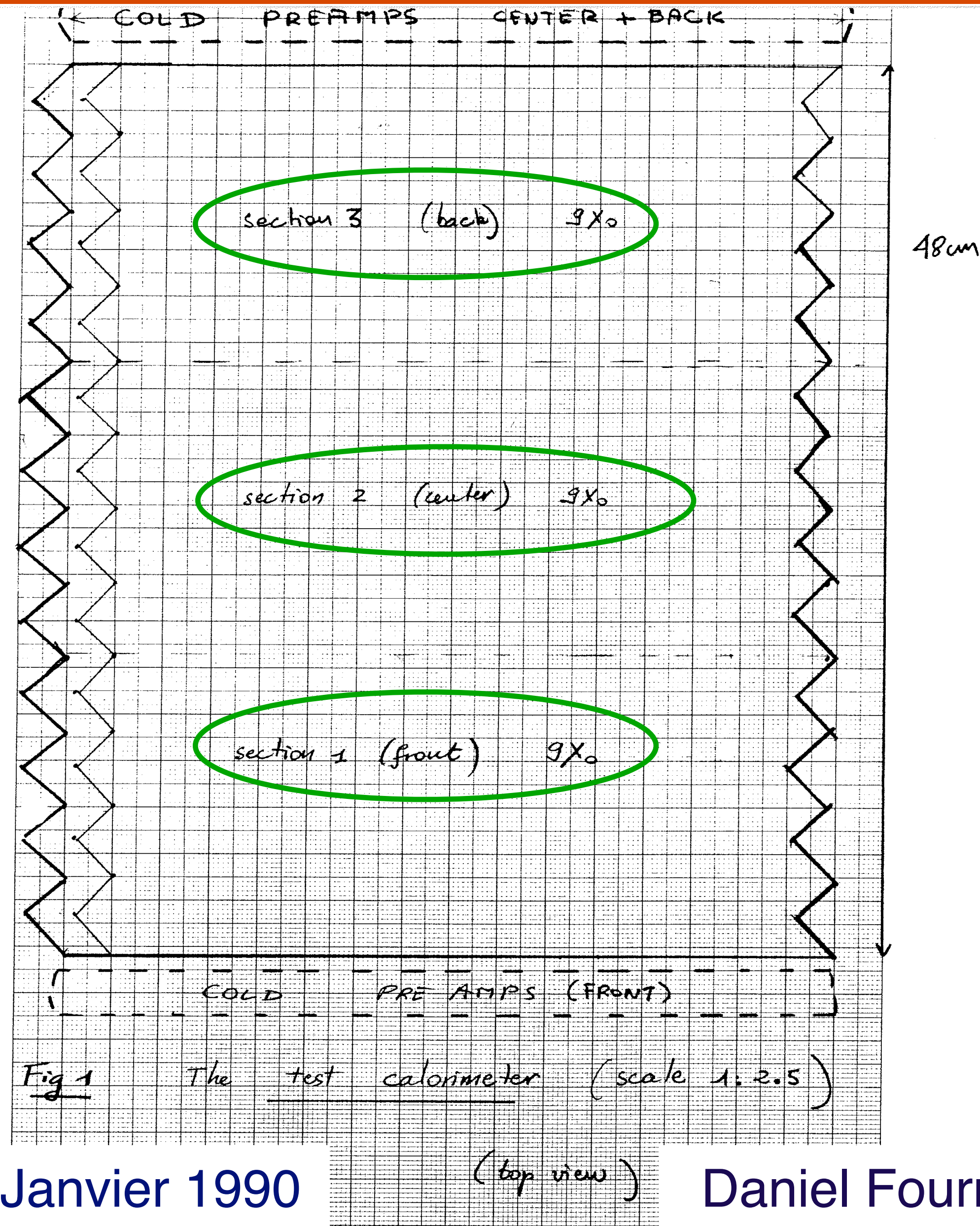


Janvier 1990

Daniel Fournier

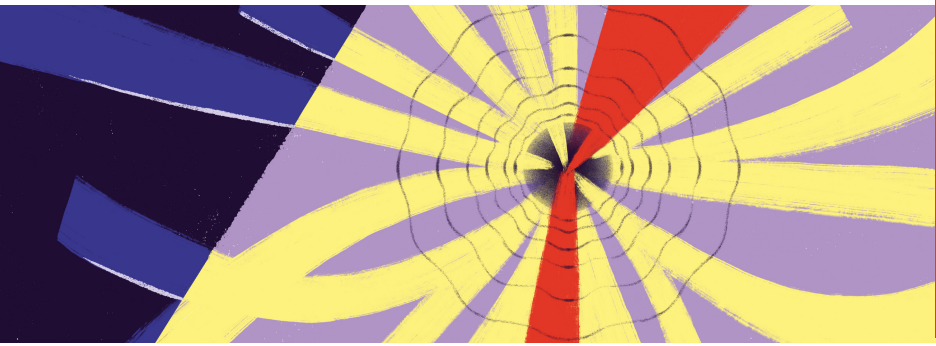


# A segmented calorimeter



Janvier 1990

Daniel Fournier

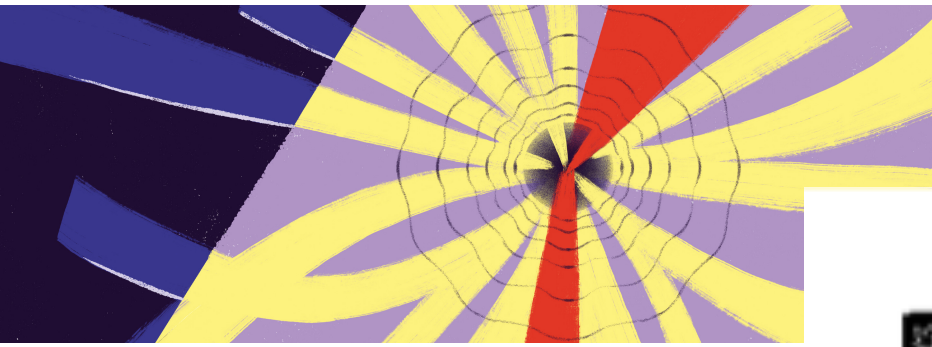


# A seg

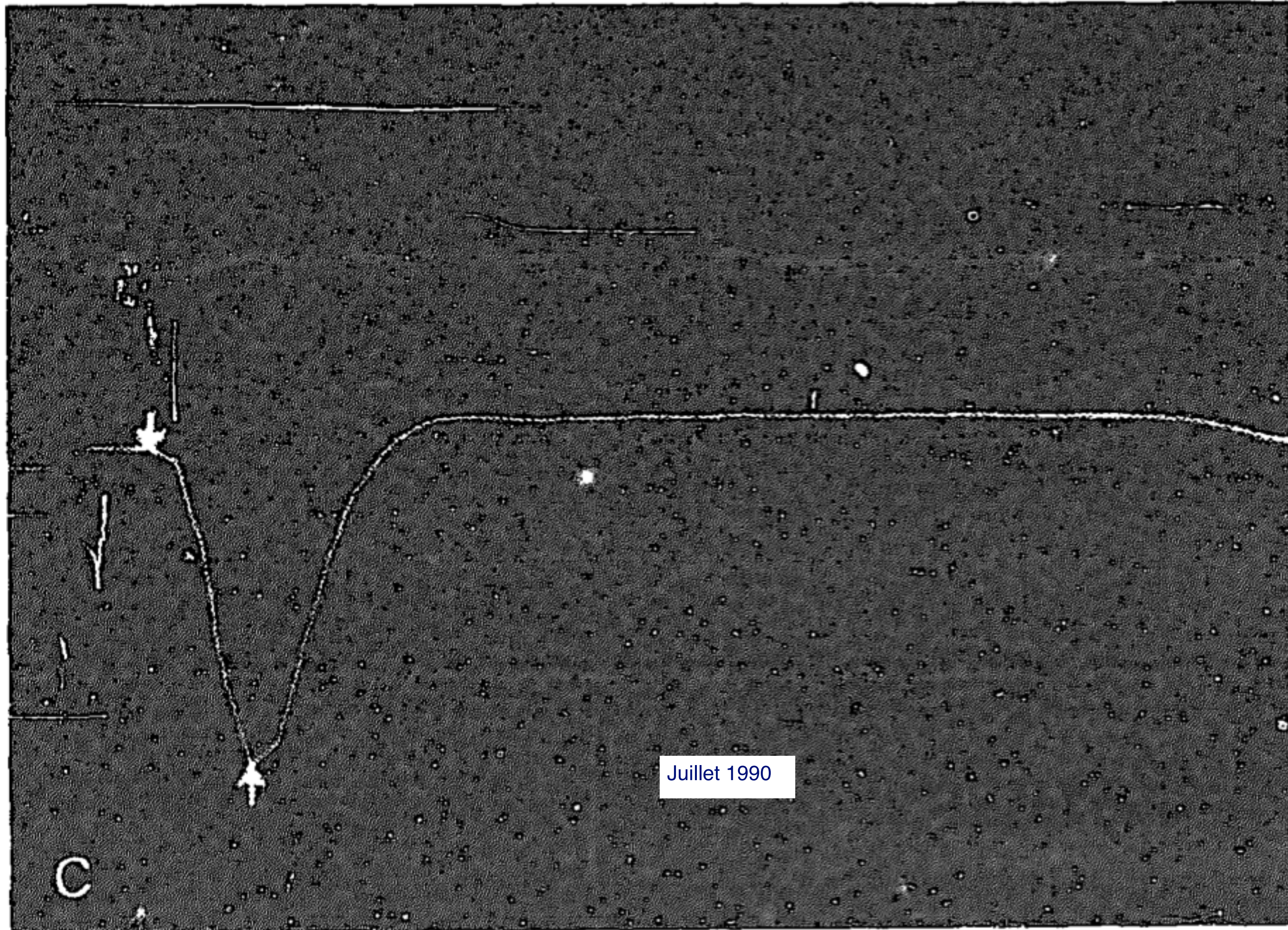


Jan

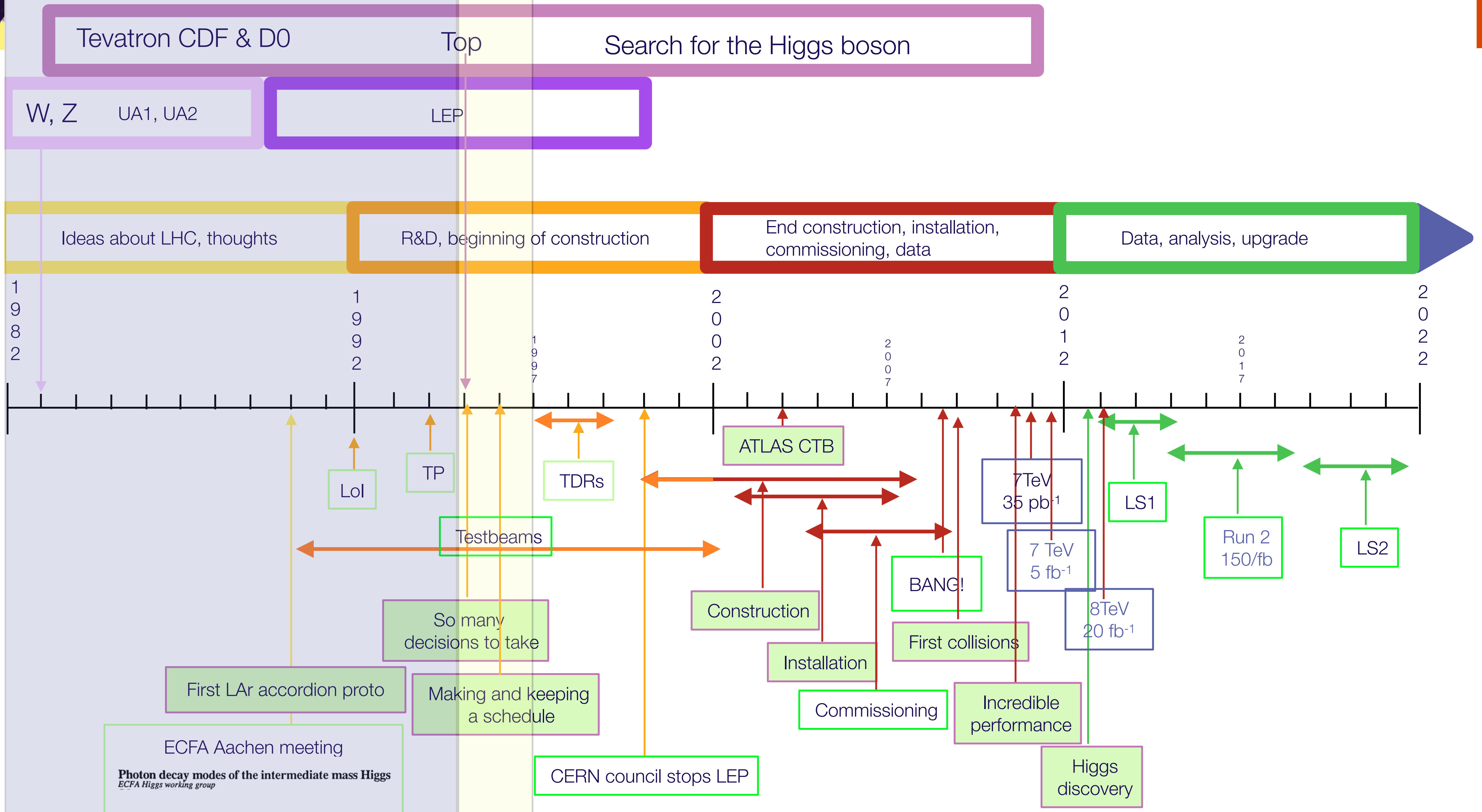
July 1990



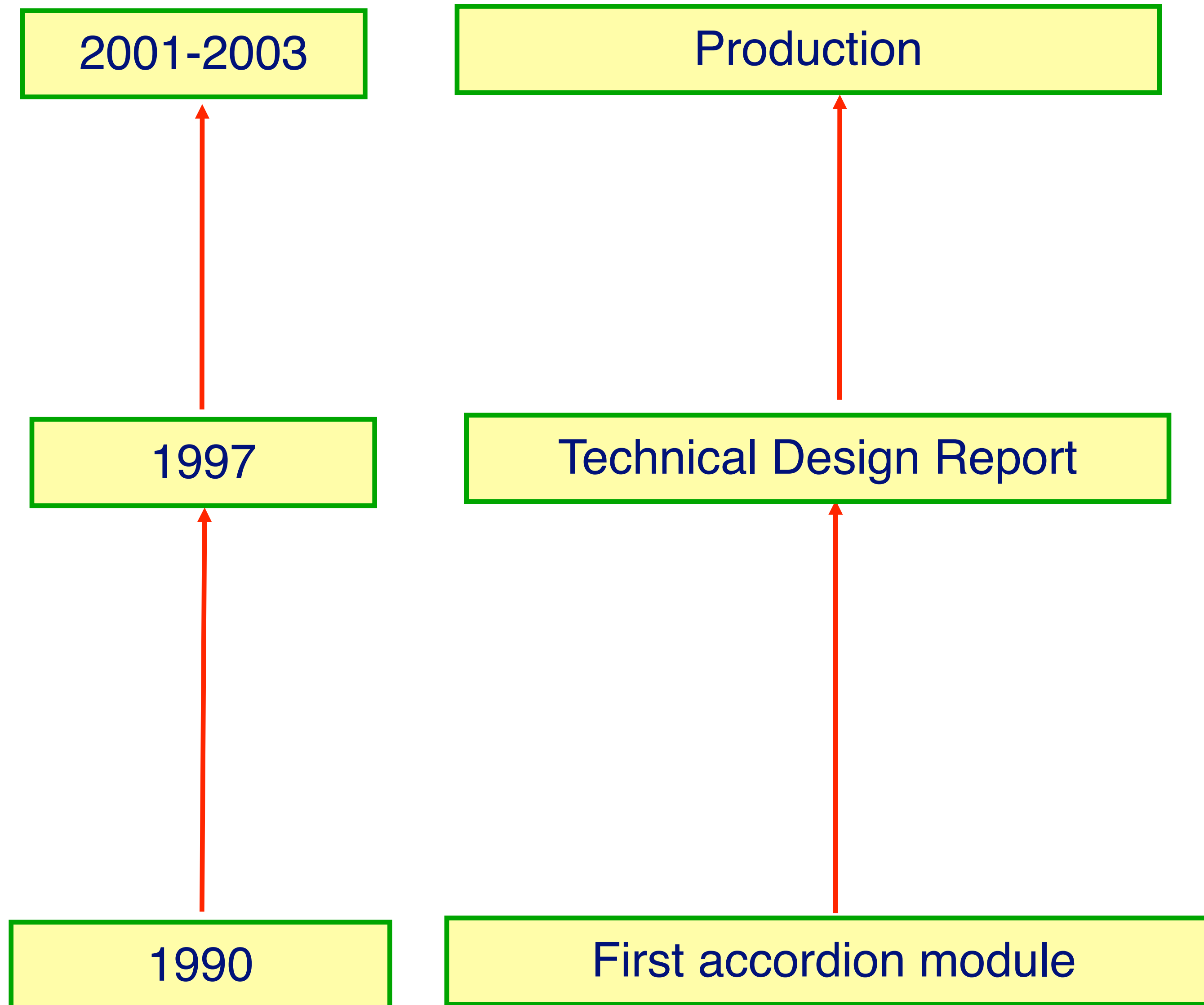
A sea



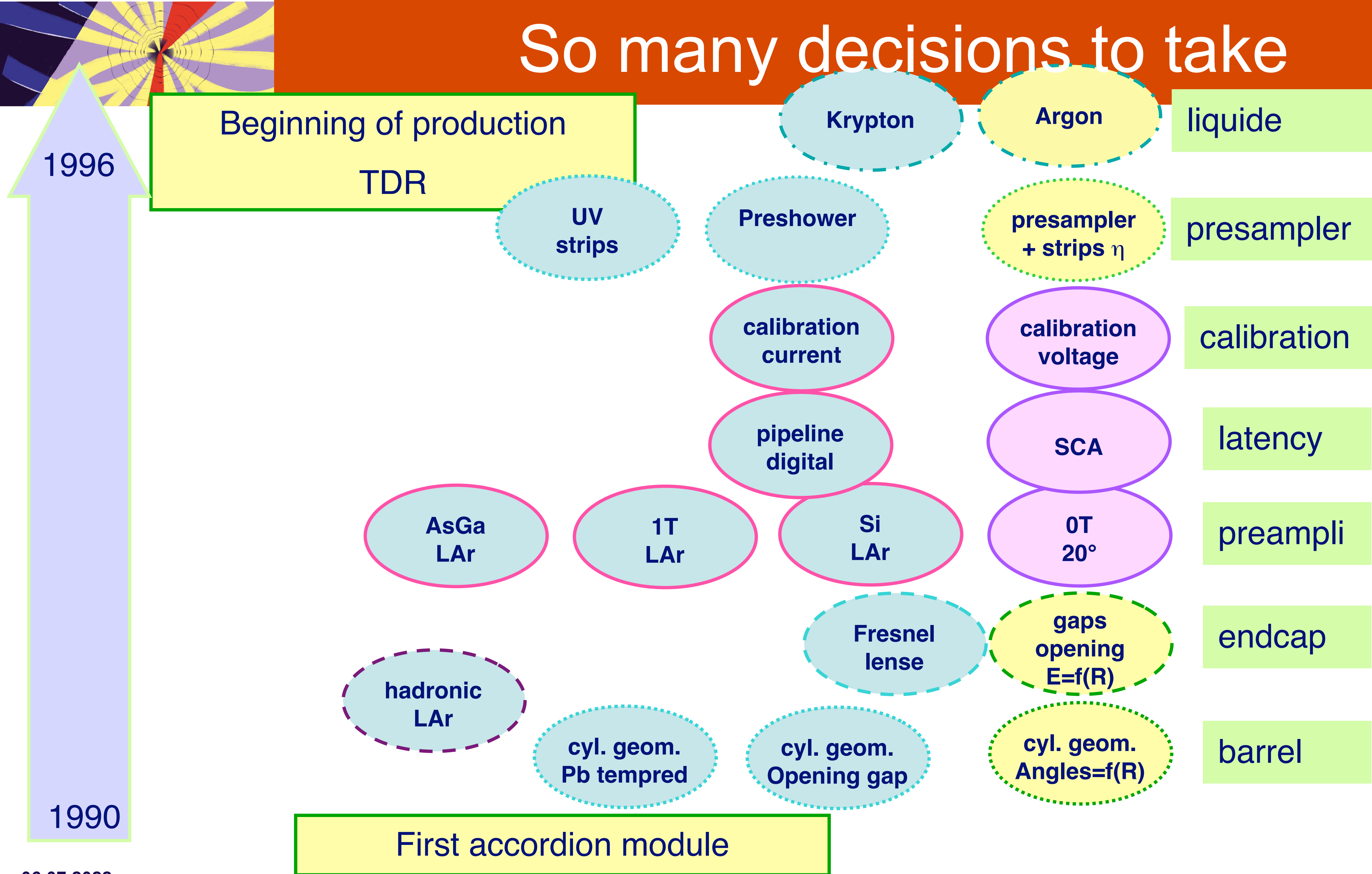
1964 - Higgs mechanism proposed by P. W. Higgs, F. Englert and R.Brout, G.S. Guralnik, C.R. Hagen and T.W.B. Kibble.

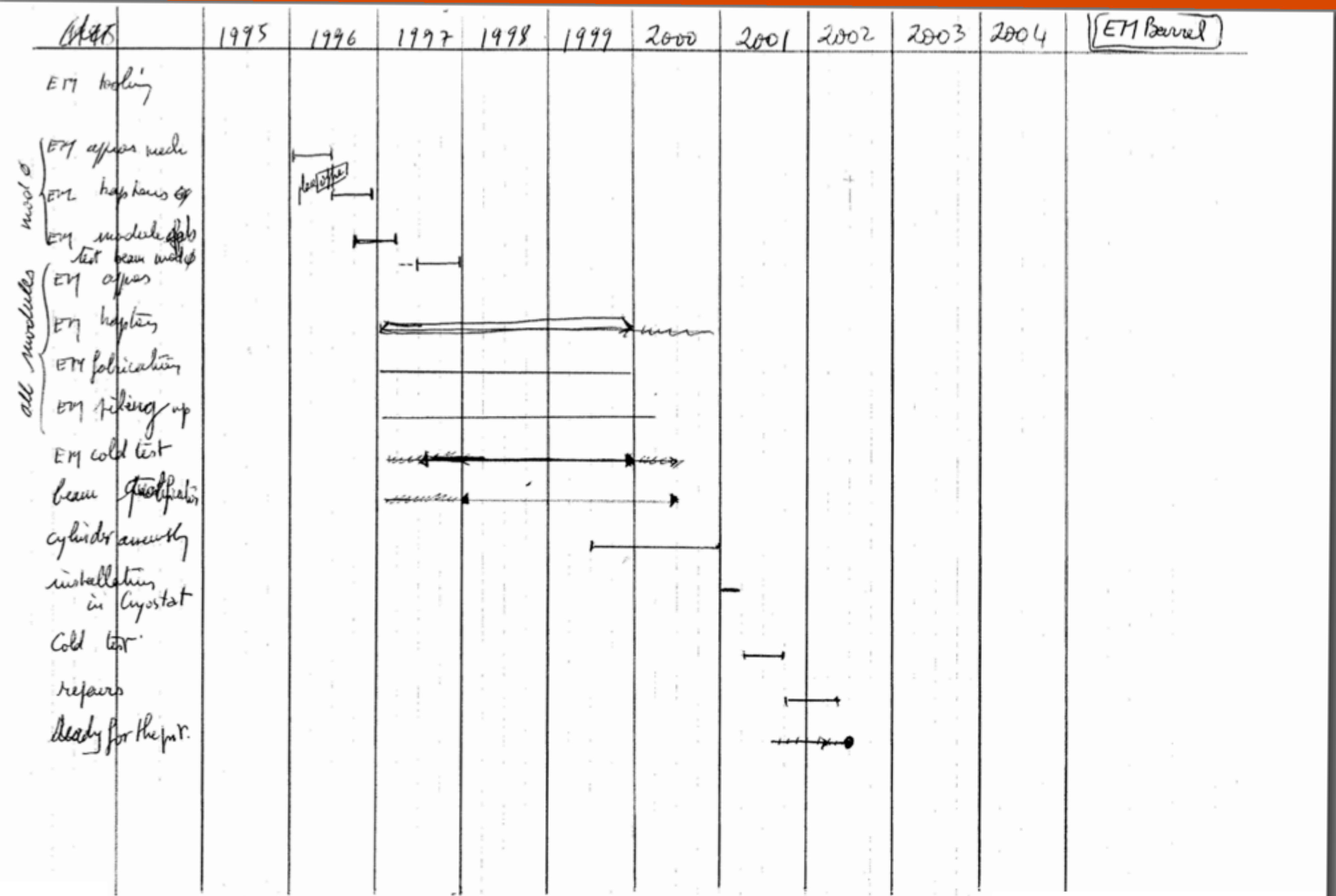
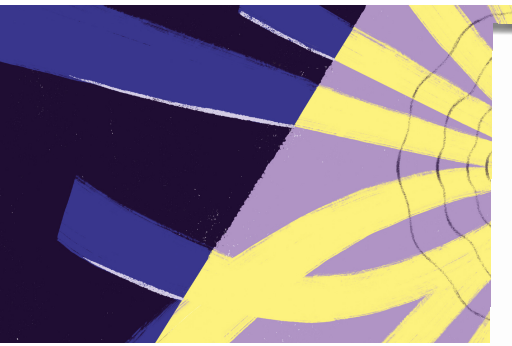


# So many questions to answer



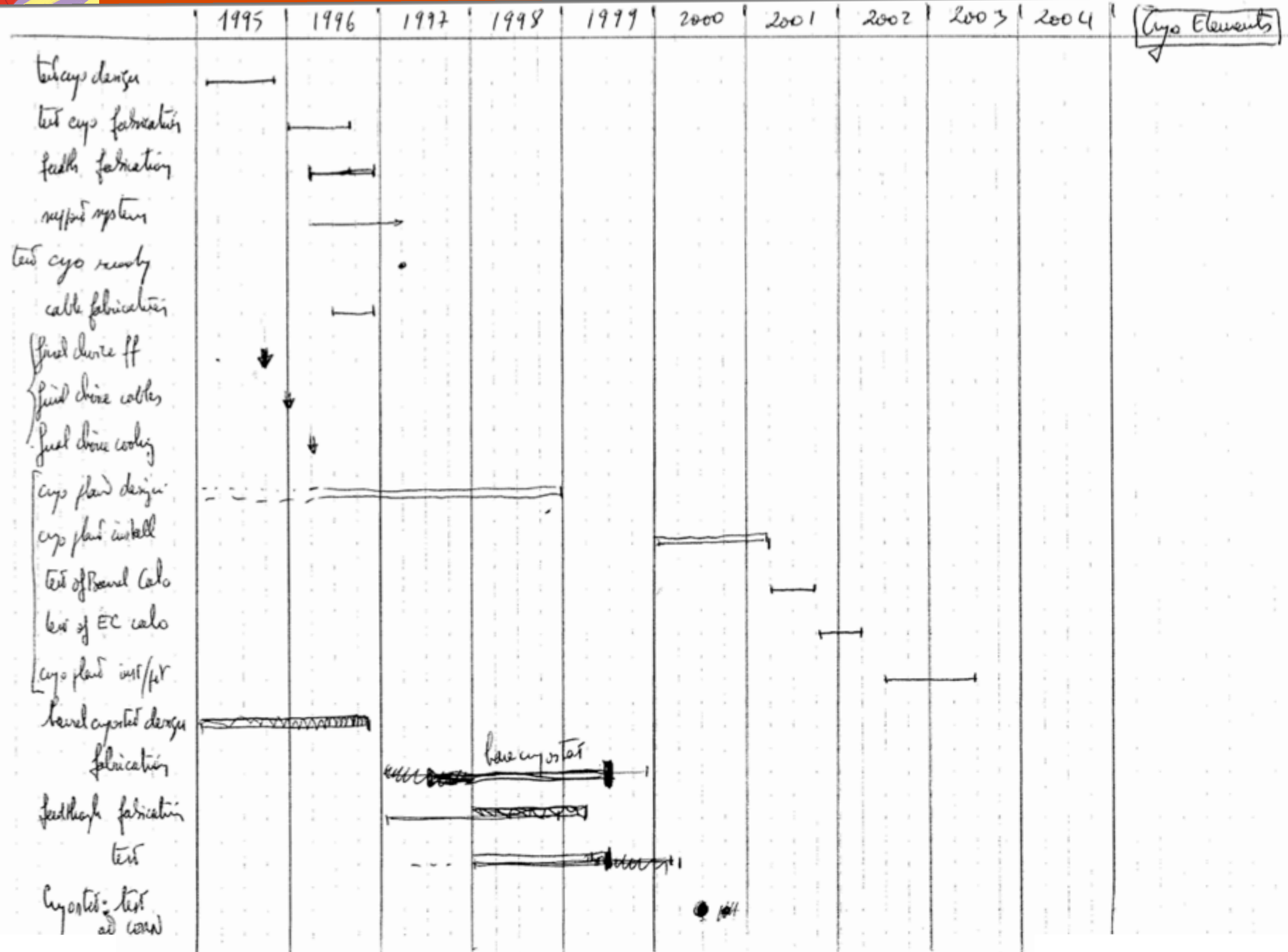
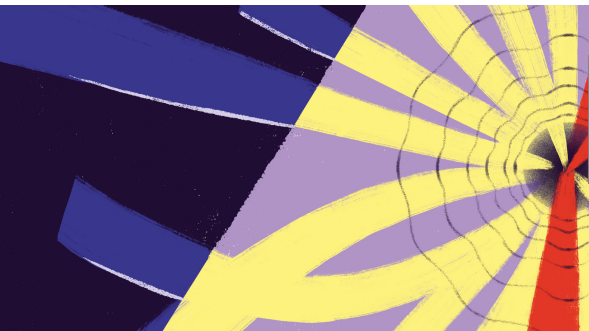
# So many decisions to take





1995

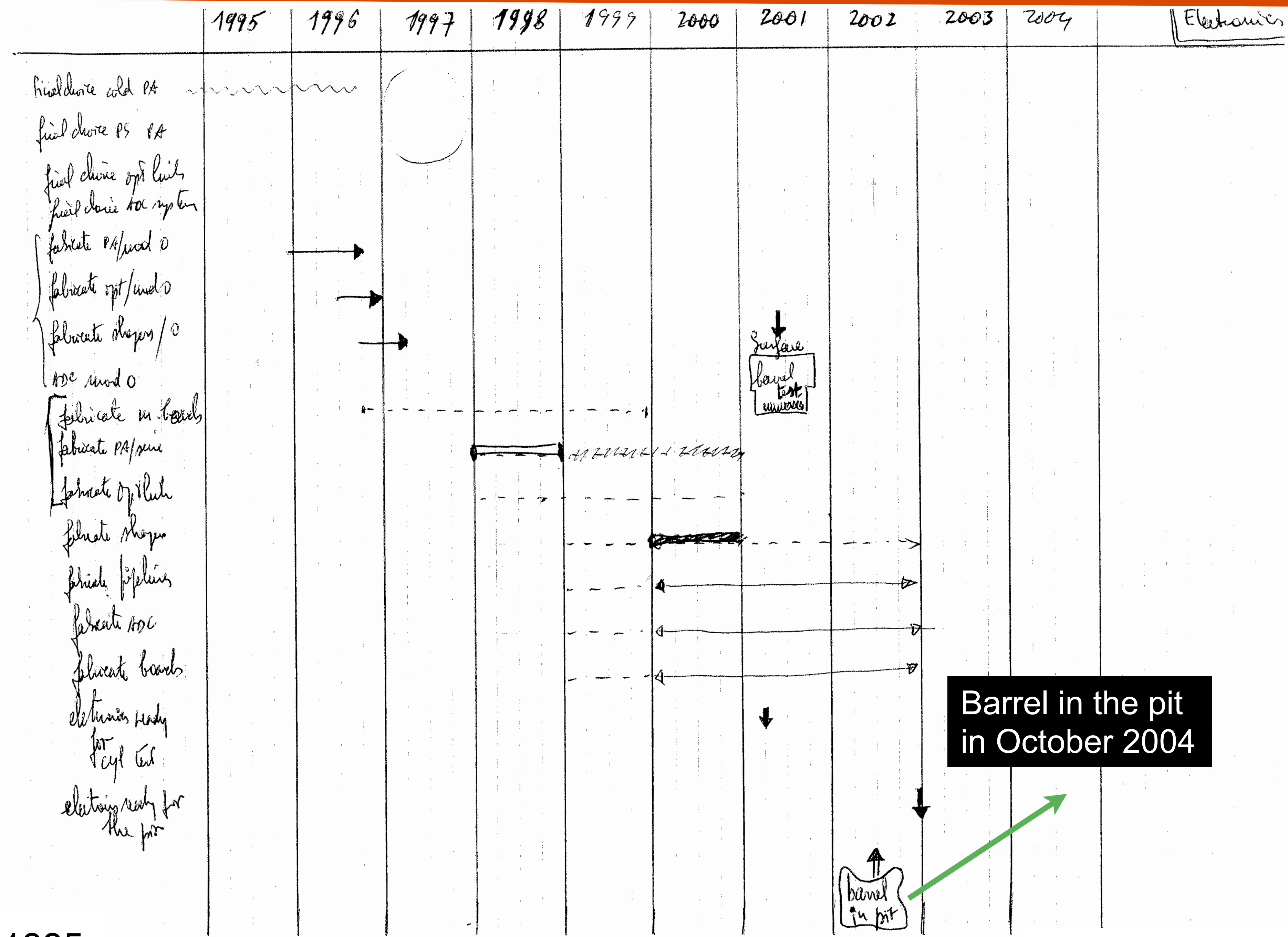
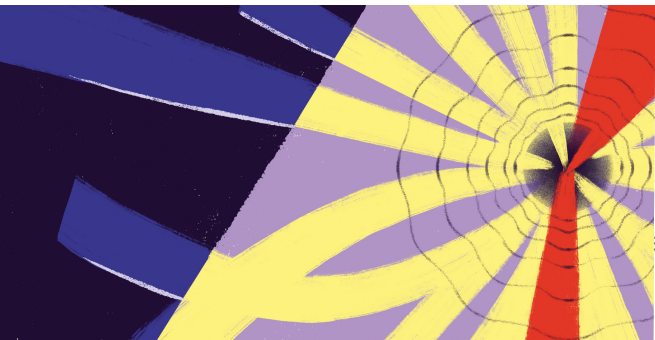
Daniel Fournier



1995

Daniel Fournier





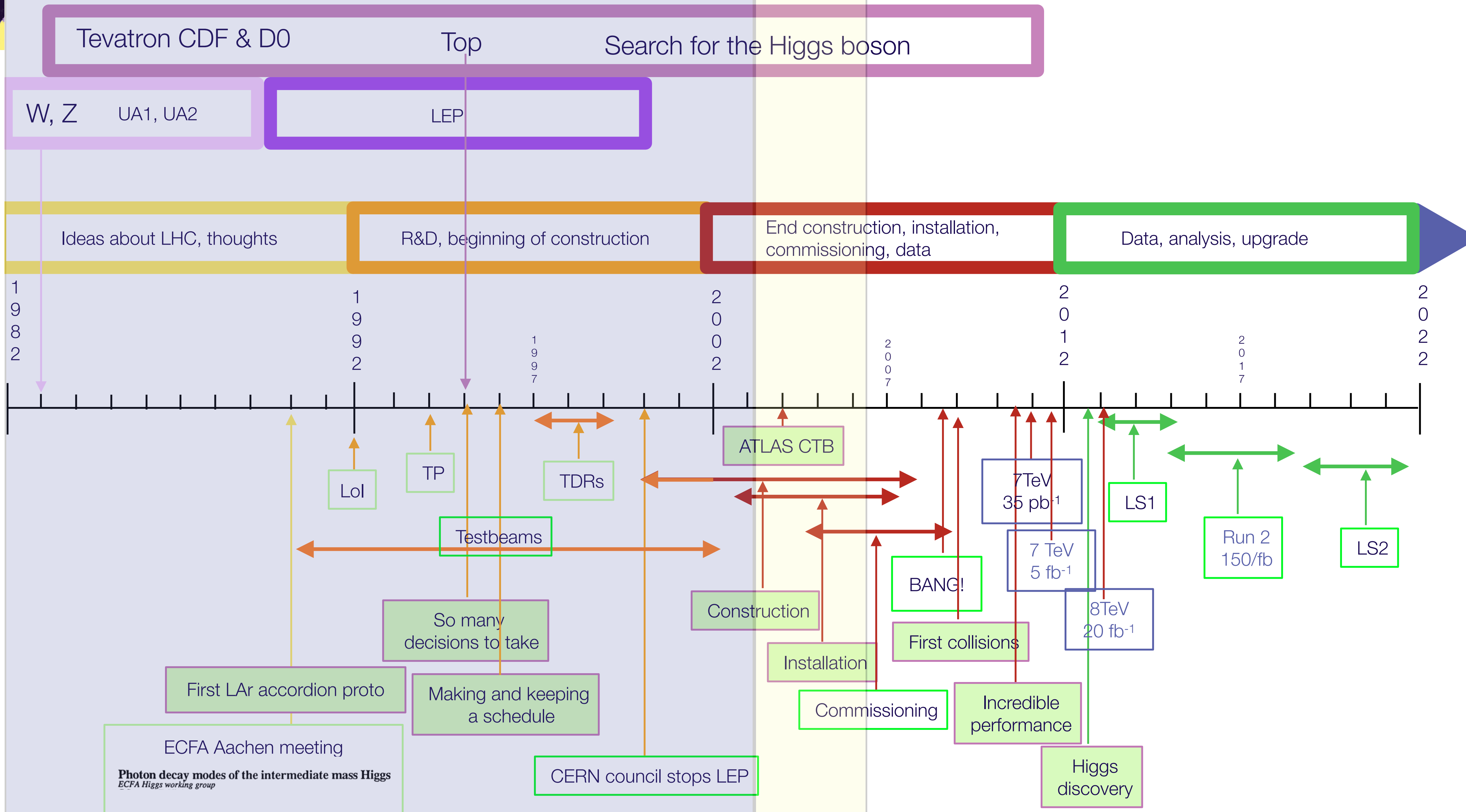
Barrel in the pit in October 2004

barrel in pit

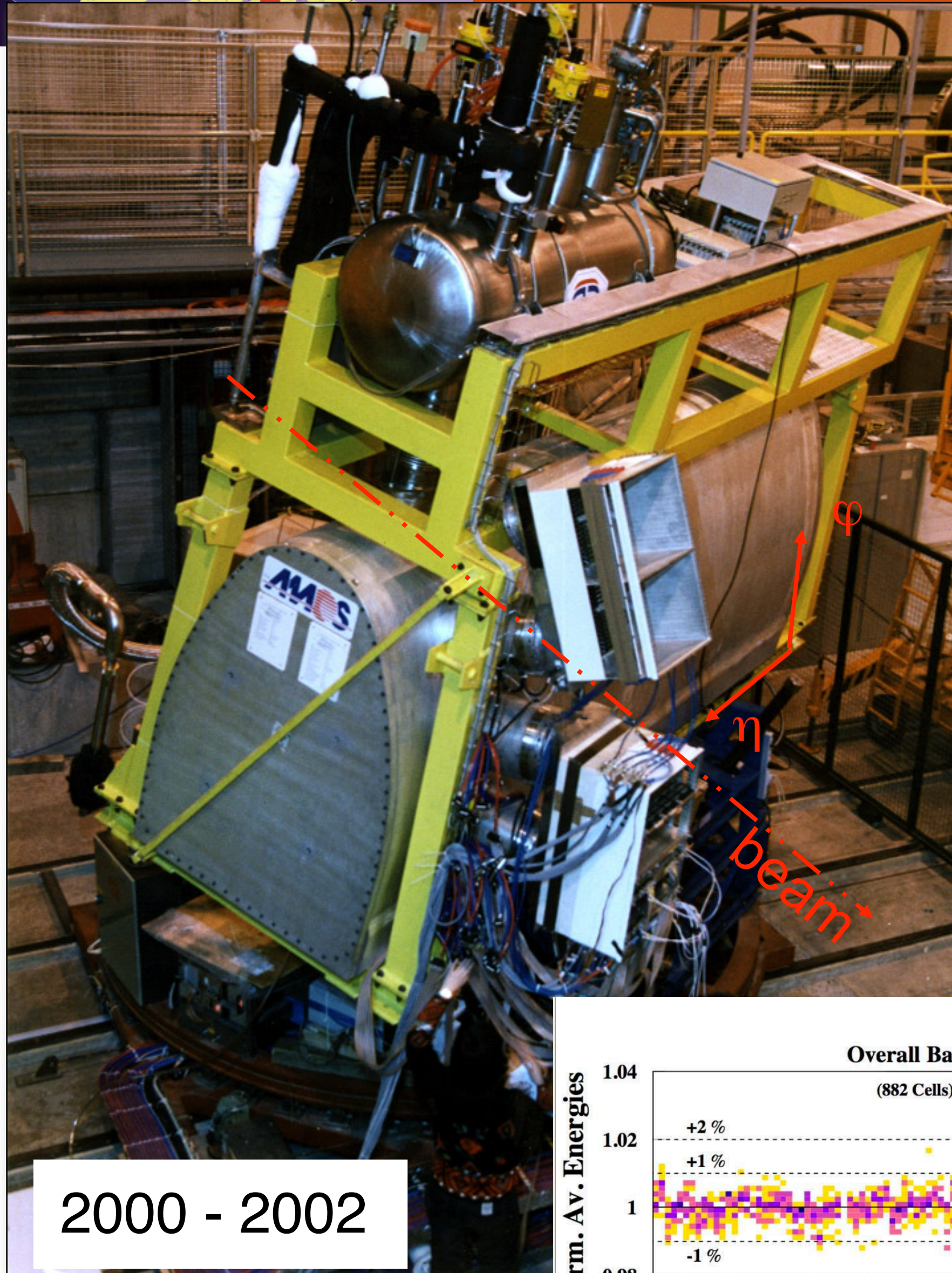
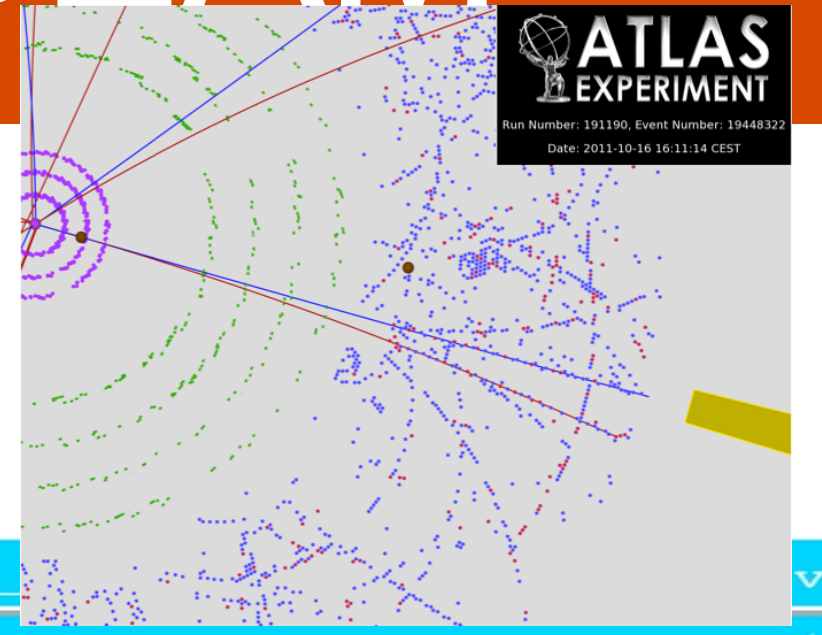
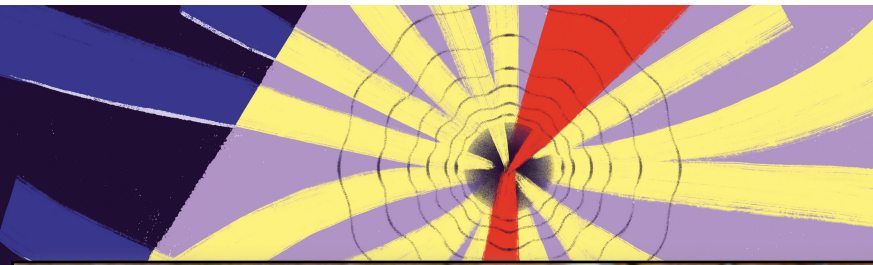
1995

Daniel Fournier

1964 - Higgs mechanism proposed by P. W. Higgs, F. Englert and R.Brout, G.S. Guralnik, C.R. Hagen and T.W.B. Kibble.

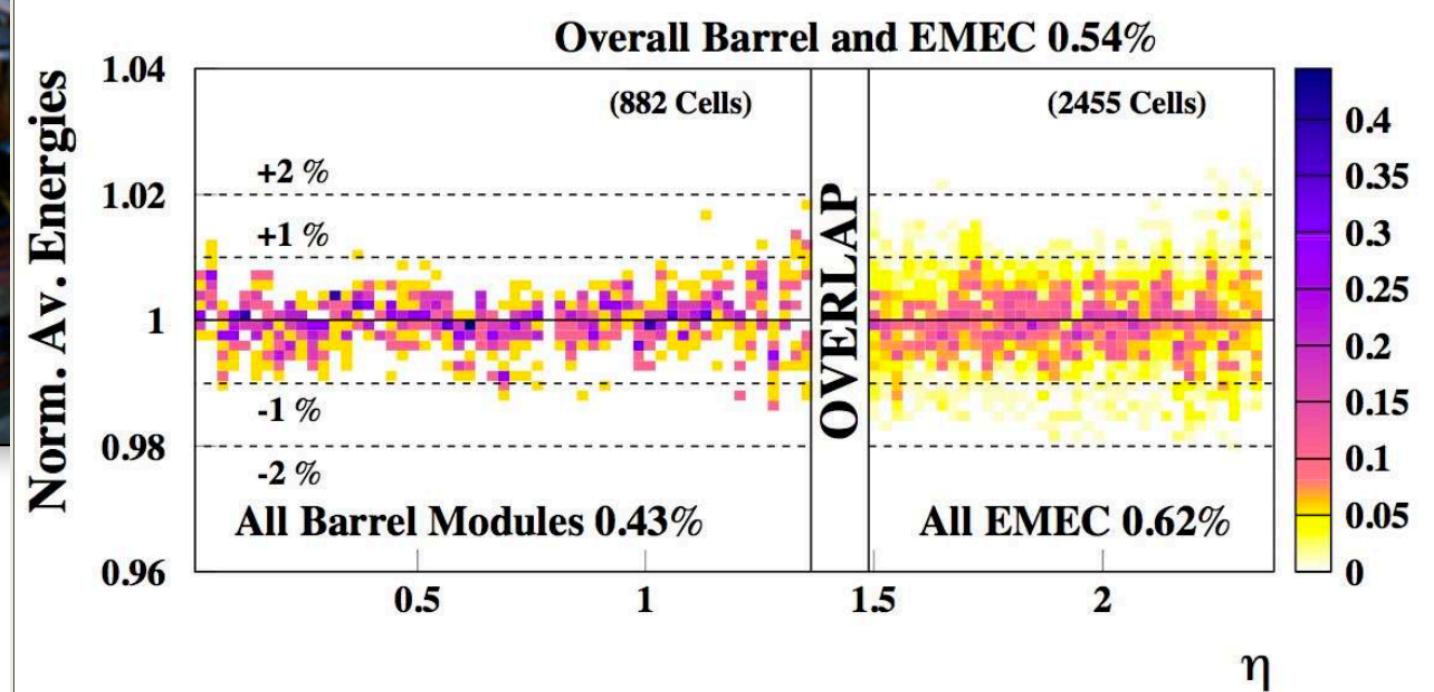
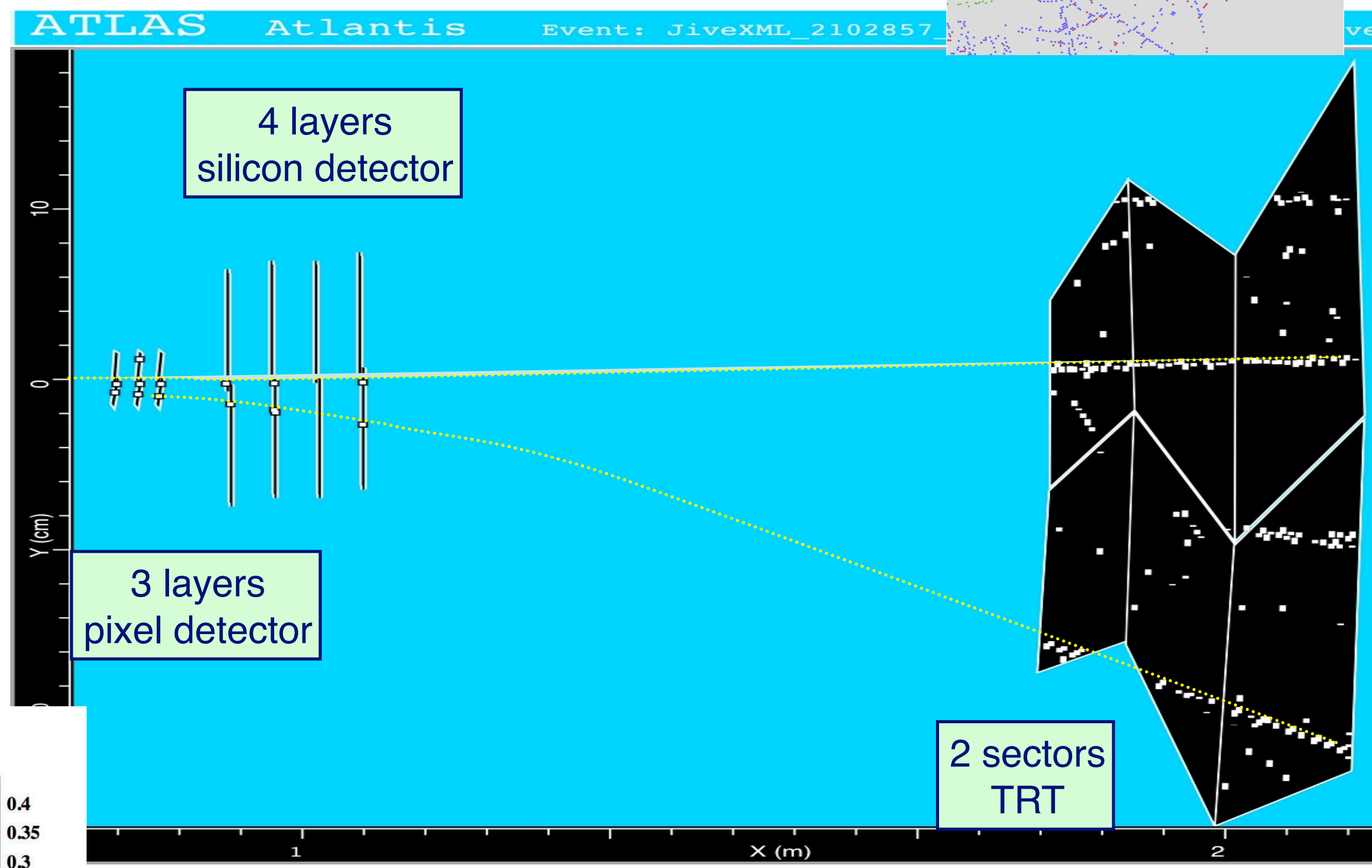


# TESTBEAM, TESTBEAM, TESTBEAM

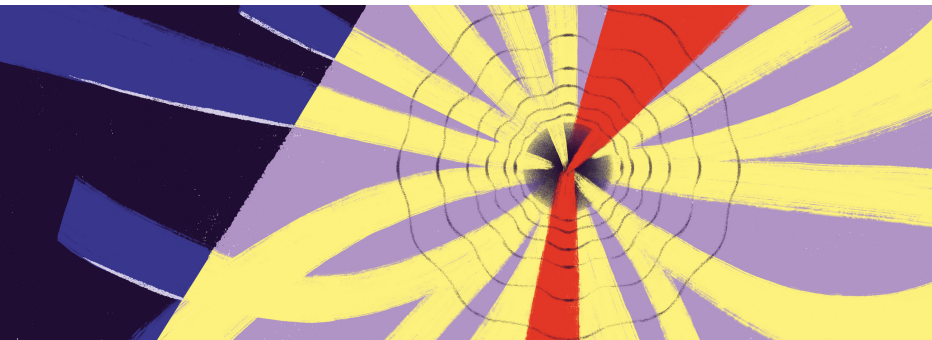


2000 - 2002

The ATLAS combined testbeam in 2004



Where the ATLAS reconstruction was born.  
Lines of code dating from the CTB are still running today.

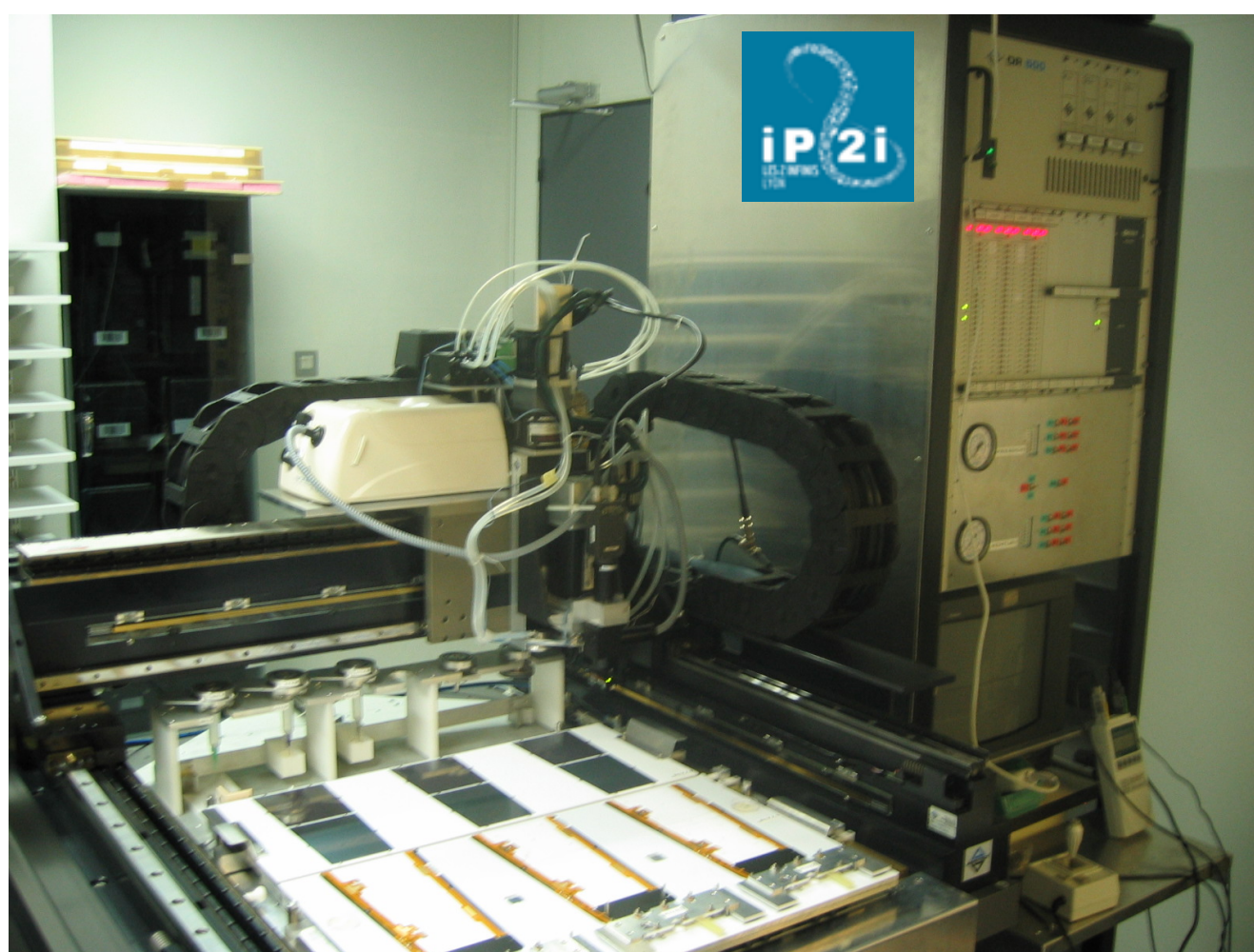


# CMS ENDCAP TRACKER @ IPHC & IP2I

Remember: the two labs were engaged with MSGCs and *gently* joined the Si technology when CMS decided to go "full Silicium"

After a long R&D phase with the RD58 CERN program....  
construction starts in the years 2000

Bancs d'assemblage



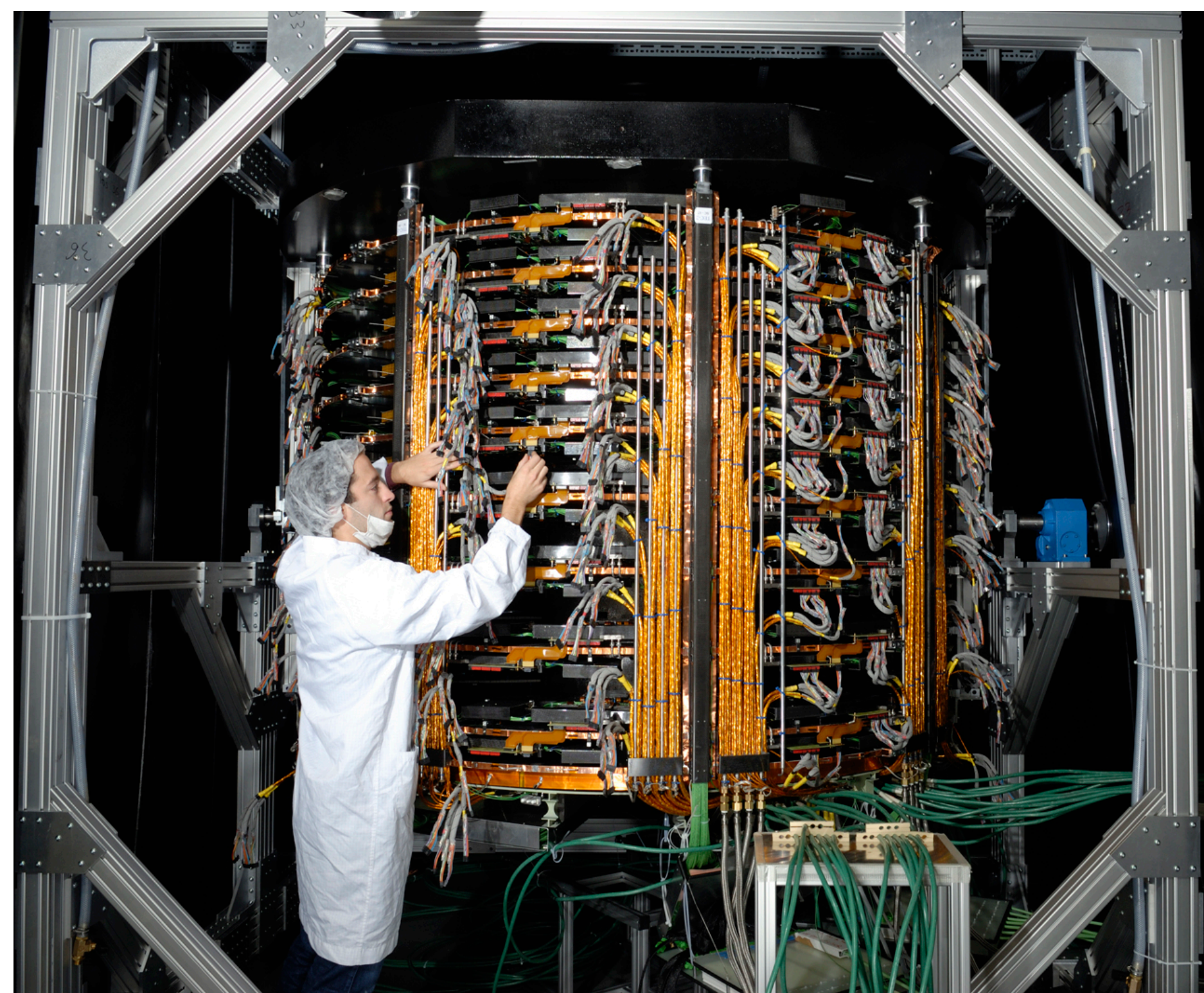
Assemblage et  
déverminage des « pétales »



Au final intégration par IP2I au CERN du bouchon que l'on attendait plus\*...

Un développement DAQ piloté et supporté au CERN par IP2I et IPHC pour tout le trajectomètre  
Prêt pour la mise en œuvre et les premières prises de données

*\* Avec Louvain redéployé au CERN pour la préparation des derniers pétales*

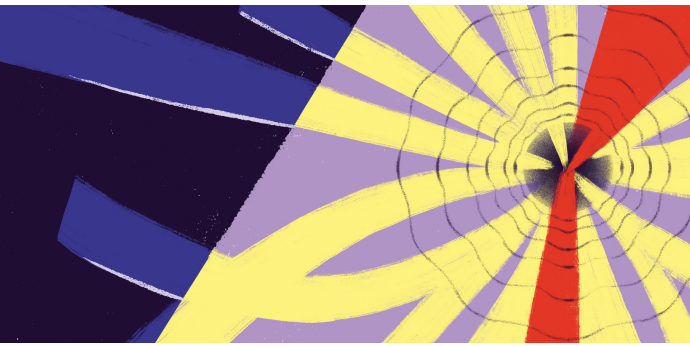


Management du consortium\* de construction des deux bouchons

Développement de la base de données de construction et de logistique

Gestion du flux des composants vers les centres de production des pétales

\* Aachen I et III, Bruxelles, Hambourg, Karlsruhe, Louvain, Lyon, Strasbourg, Vienne



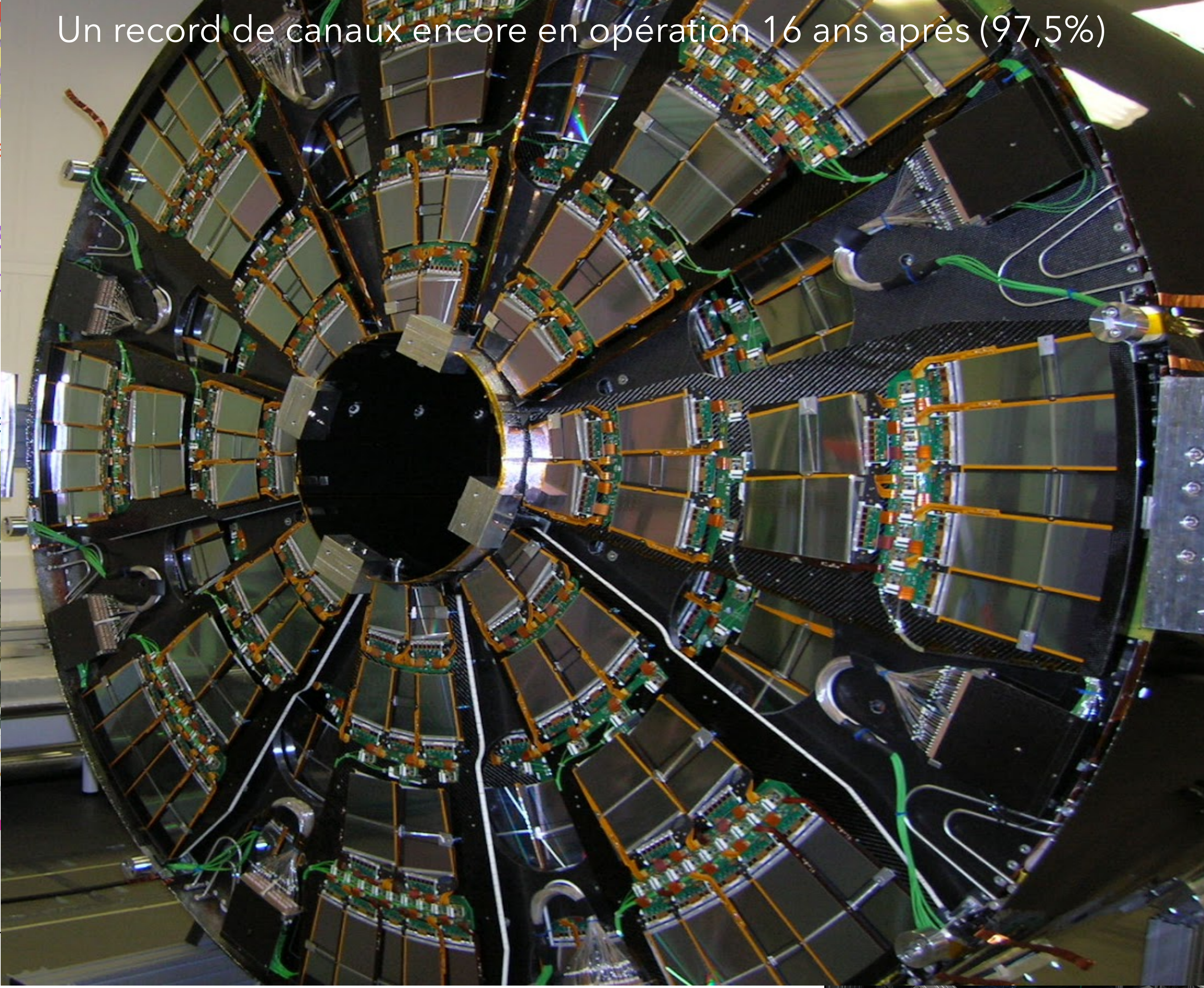
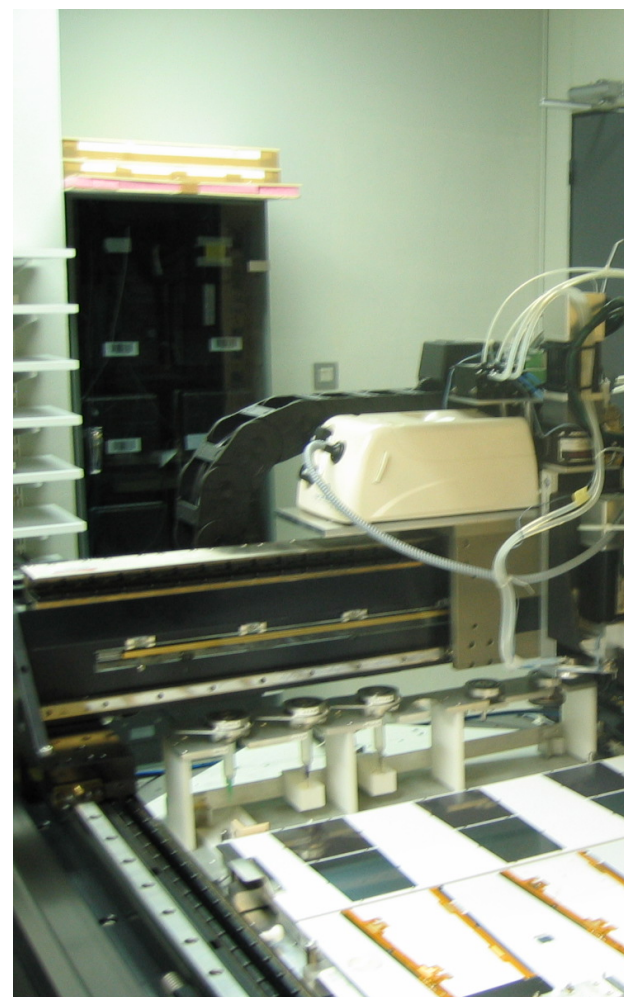
Un record de canaux encore en opération 16 ans après (97,5%)

C & IP21

Remember: the

After a long

Bancs d'a

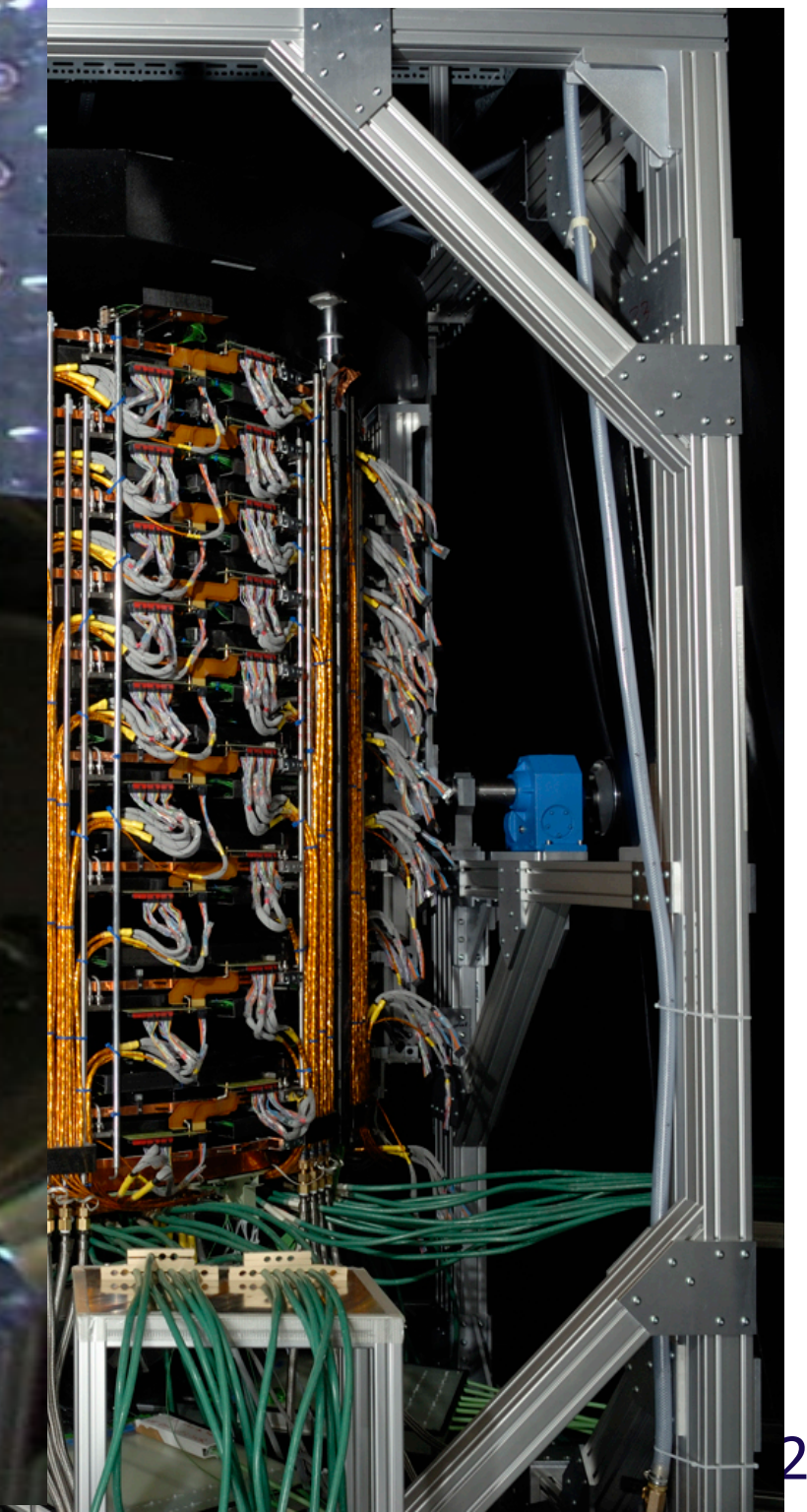


ed to go "full Silicon"

u CERN du bouchon

loté et supporté au  
out le trajectomètre  
et les premières prises

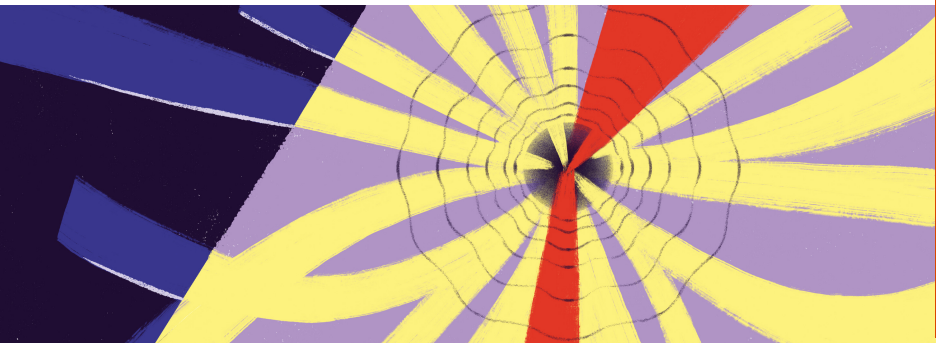
des derniers pétales



Managemen  
Développement  
Gestion du flux d  
\* Aachen I et III, Bru

06.07.2022

# TESTS, TESTS, TESTS,..... FRIENDS

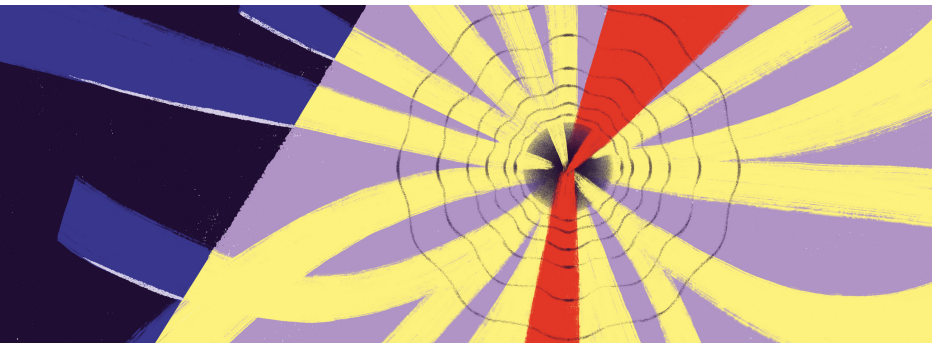


Brookhaven Mars 2003



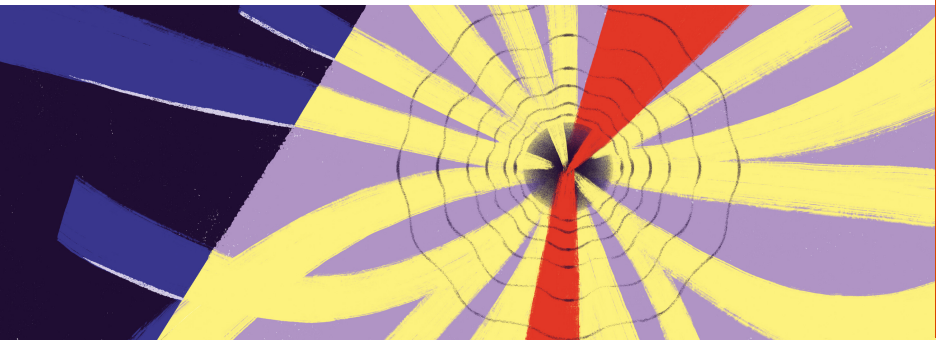
La carte calibration fonctionne





Brookhaven Mars 2003





# CMS-ECAL @ LLR & IP2I

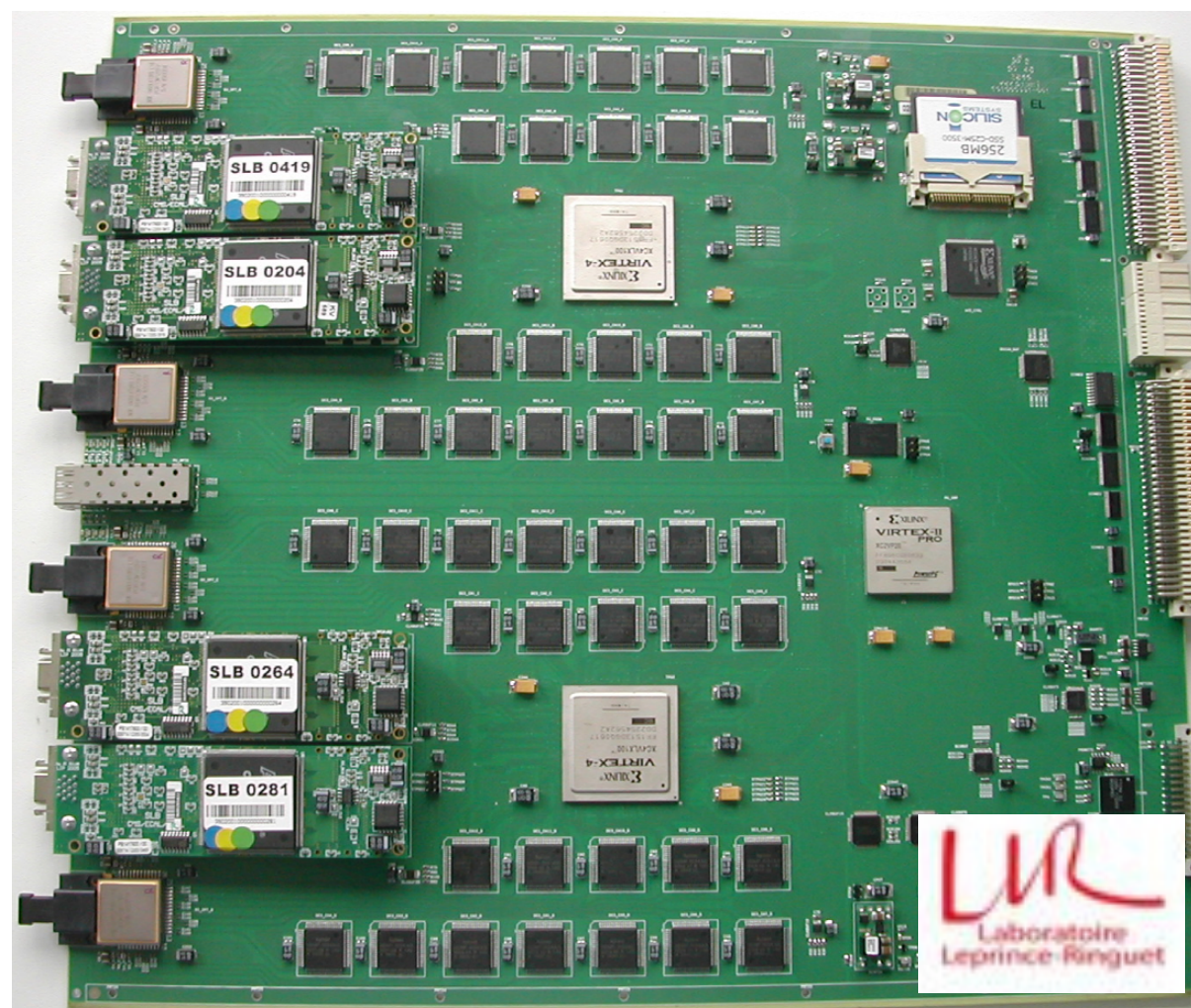
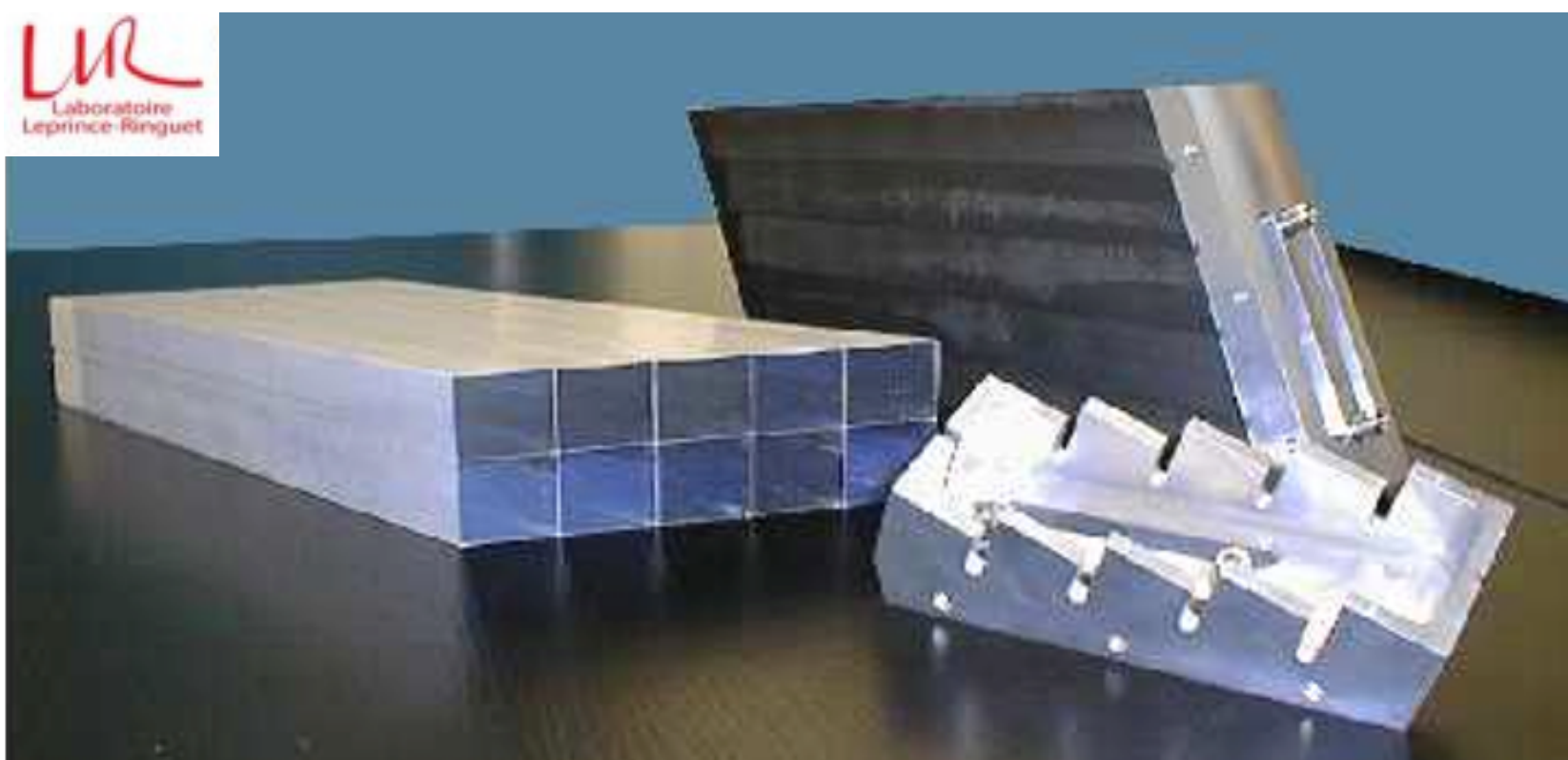
After R&Ds with SPACAL, ECAL scintillating fibers, Shashlik Tower, LLR joint ECAL PbWO<sub>4</sub> in 1994, when CMS decided to build its calorimeter with crystals.

Design of the barrel calorimeter mechanical structure with honeycomb

Challenge: ultra thin but solid, 100 t, several shapes, radiation rad

R&D@LLR: mechanical strength, optical reflectivity.

Production in industry: ~10000 *alvéoles* then tests in lab and shipping to CERN



Trigger concentrator card

Design, production, firmware, reception & installation (\*); ~110 boards for barrel & EC.

Very versatile boards: implementation in firmware of spikes rejection algo (*un tour de force*)

Board were operational on day 1 and still are.

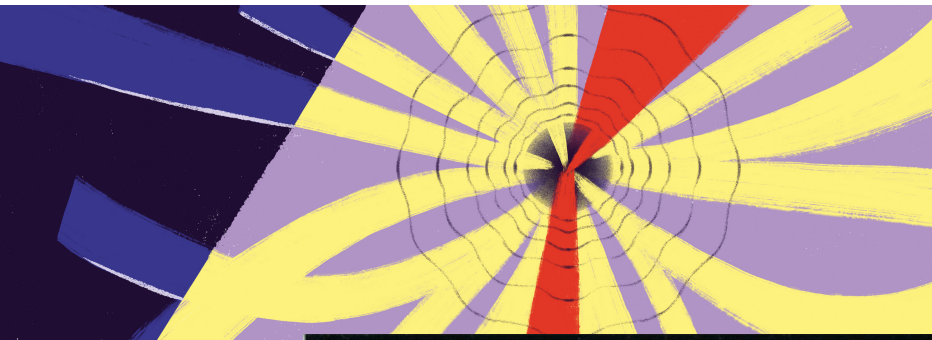
\* with IRFU, LIP Lisboa

APD validation

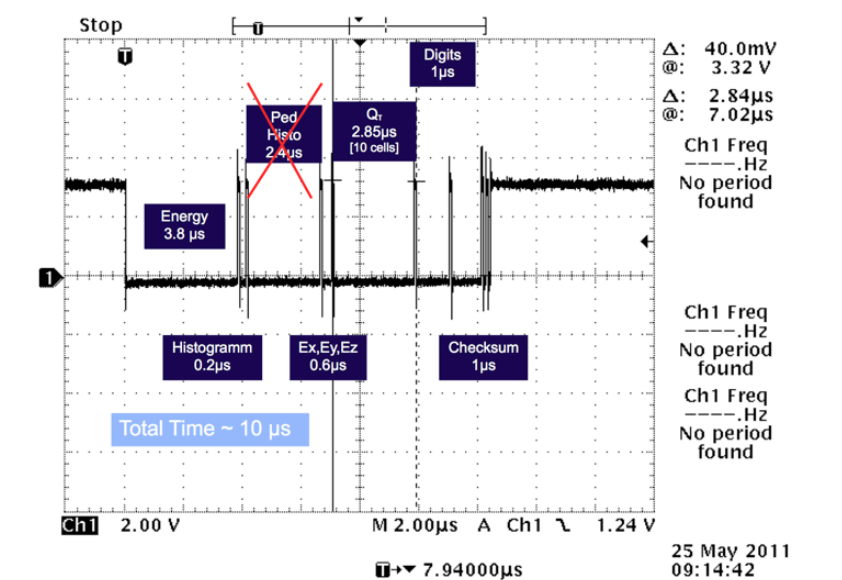
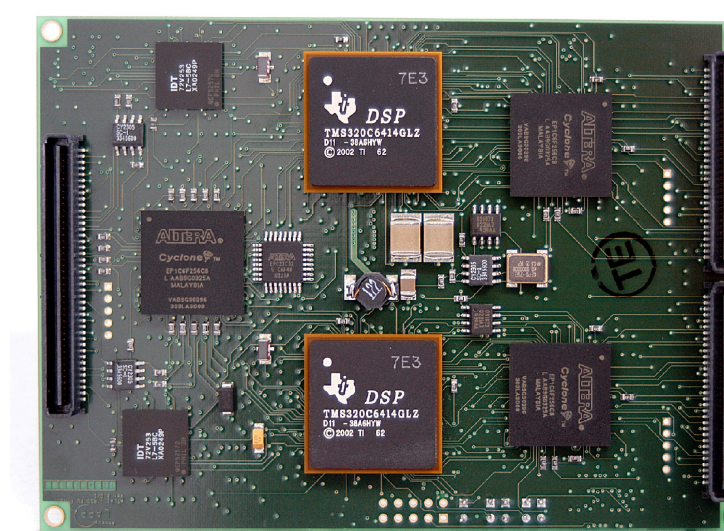
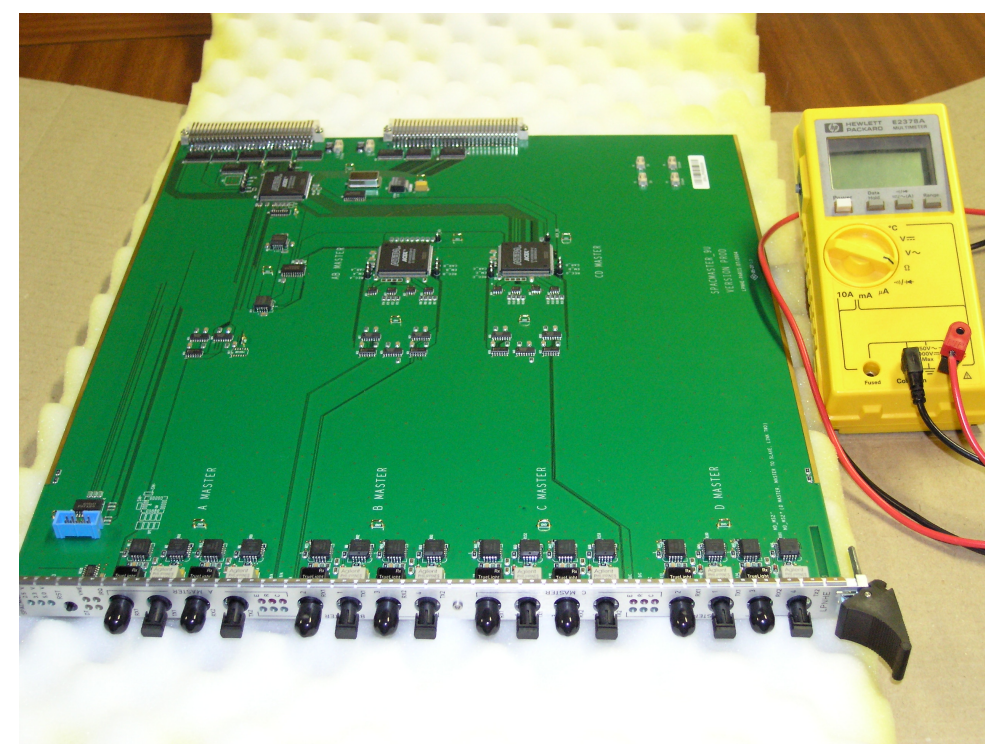
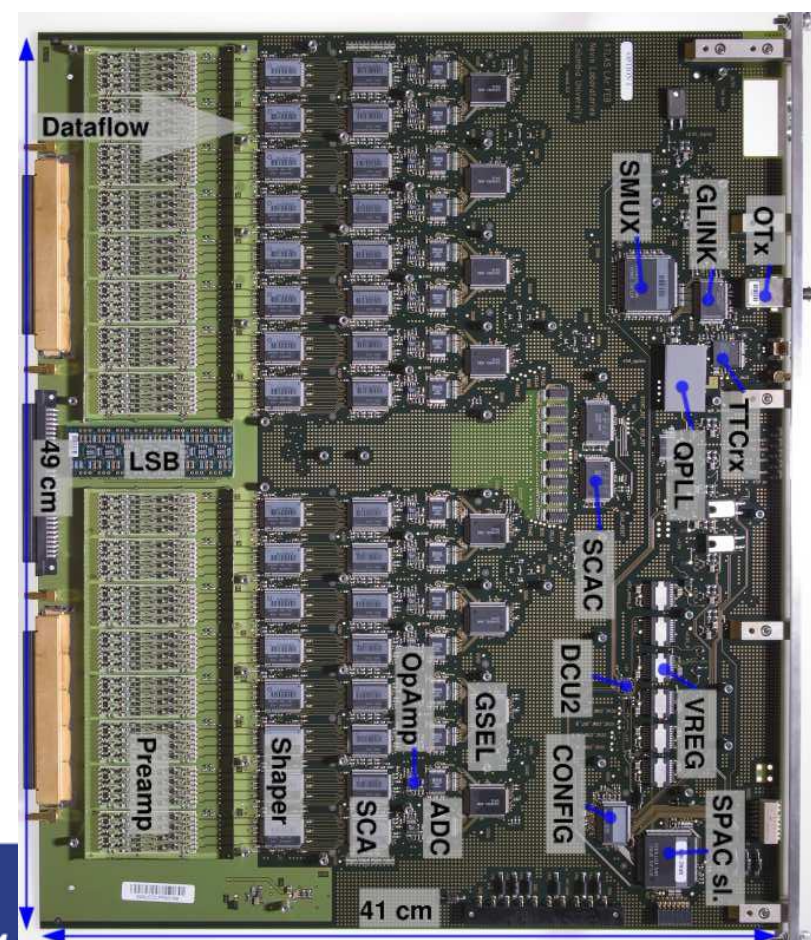
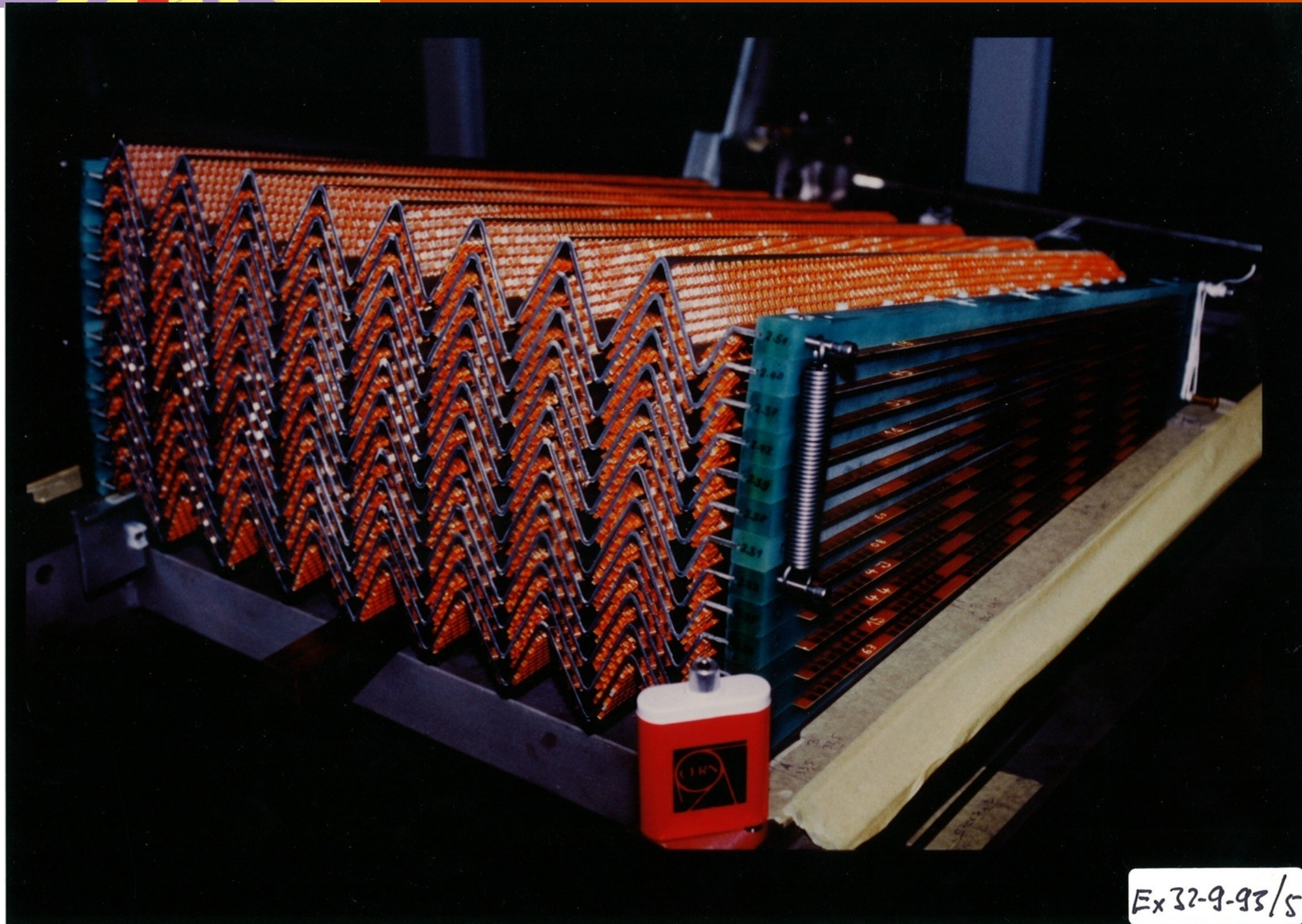
Fabrication & validation of APD for CMS ECAL @ IP2I & CERN







# ACCORDION @ LPNHE, LAL, LAPP, LPSC, CPPPM



# ATLAS-PIXELS@CPPPM

Idea of ATLAS pixel detector proposed by Pierre Delpierre from CPPM, as an alternative to the well established Si strip detector.

Lessons learnt from the construction of the ATLAS pixel detector, by Sasha Rozanov:

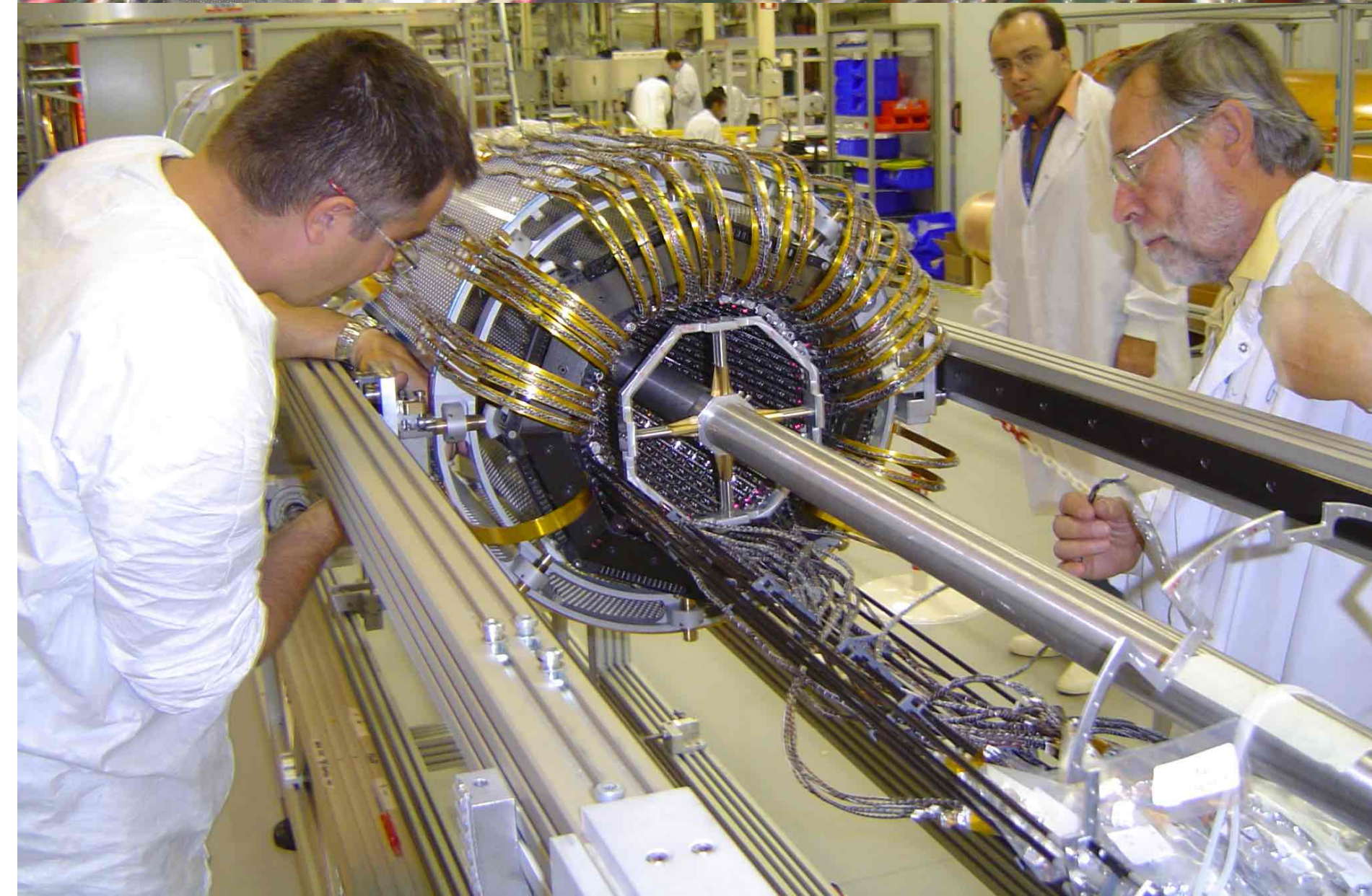
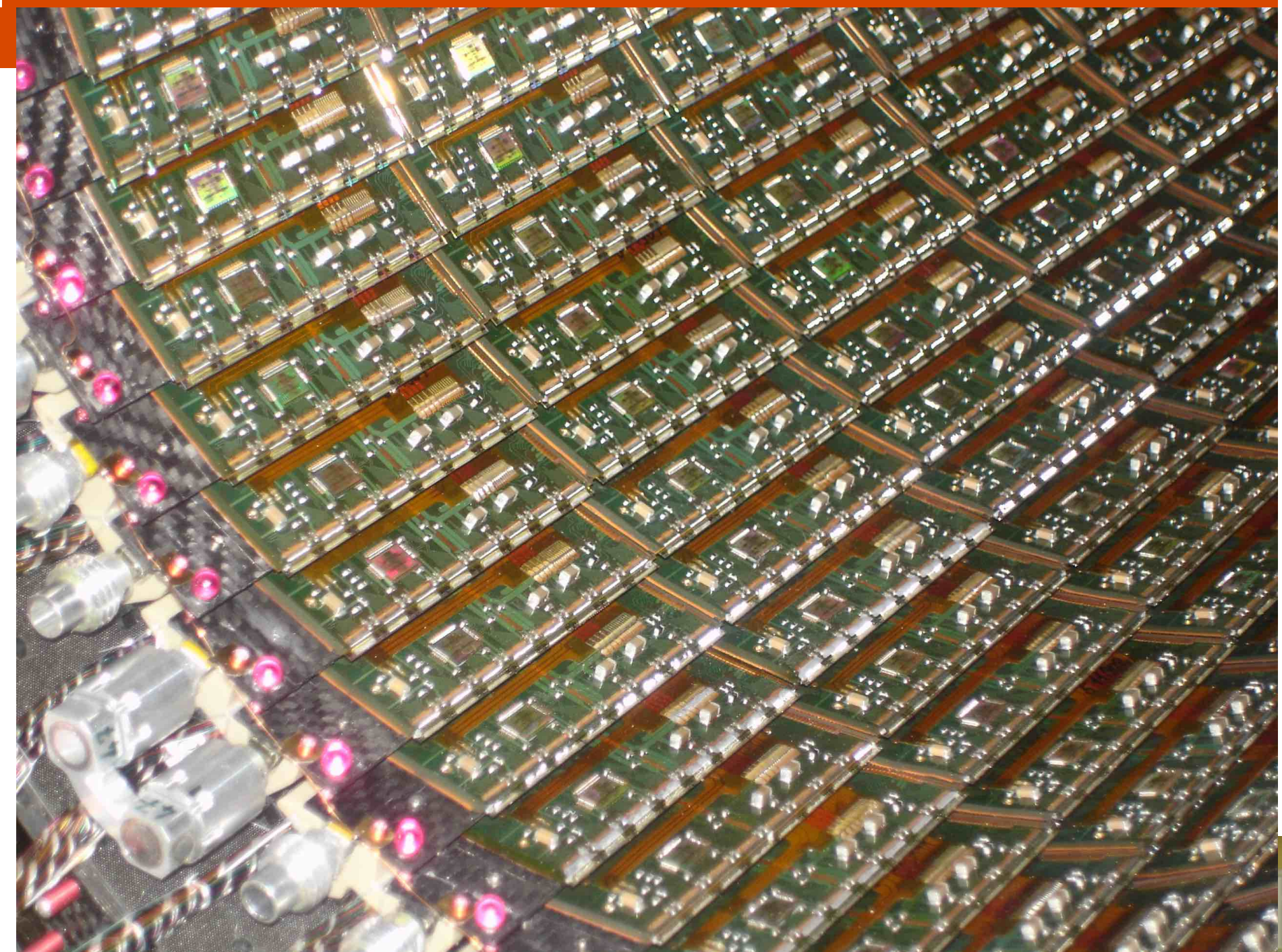
Do not be afraid to be **innovative** and be against the party line

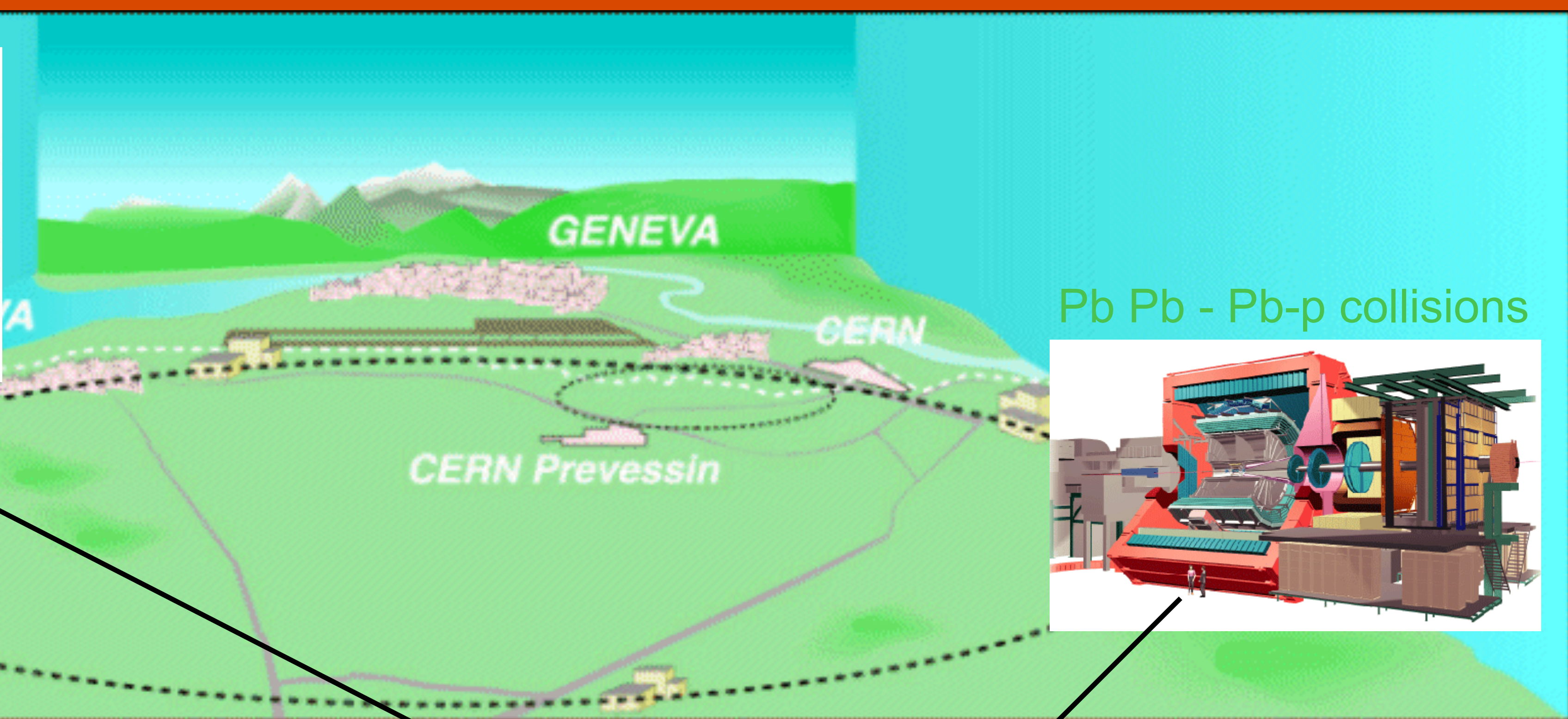
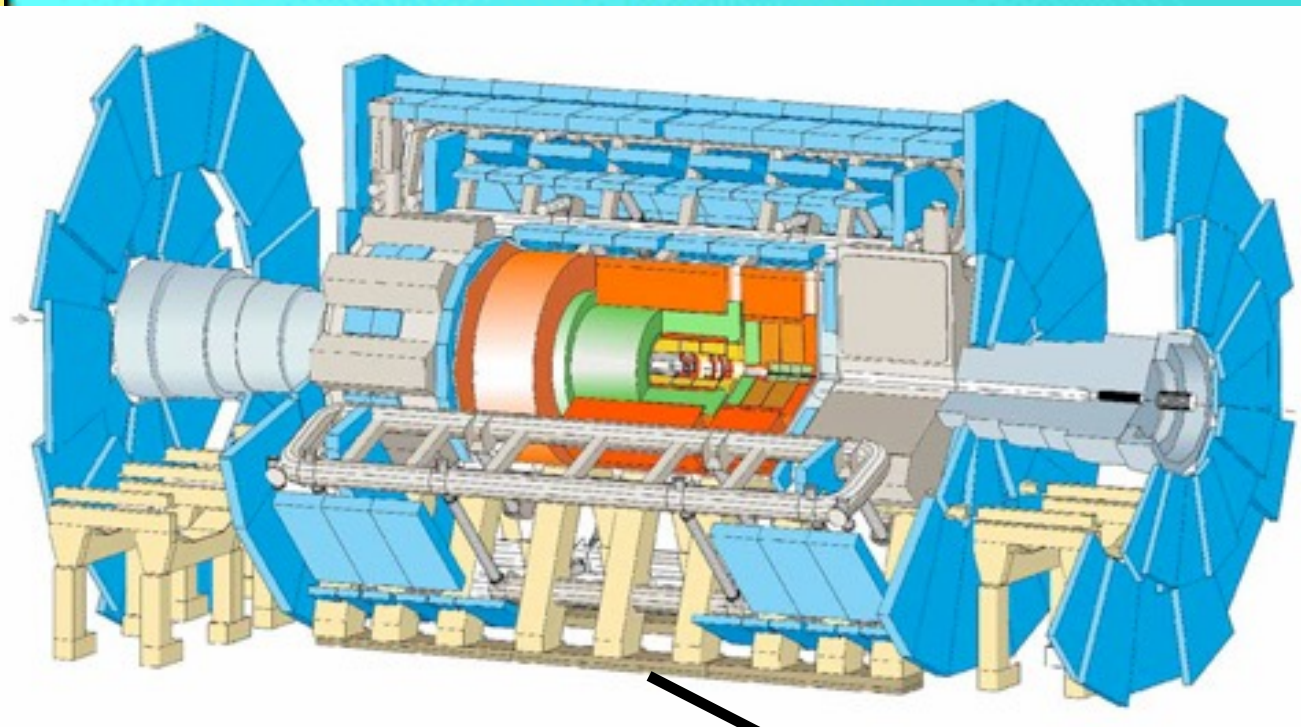
Importance of the long term investment into **high tech electronics engineers**, clean room and equipment facilities

Very unstable delivery of components from industry (mainly bottleneck bump-bonding problems at IZM) required **very strong peak production capabilities to save the overall schedule** and flexible cooperation in multiple production sites

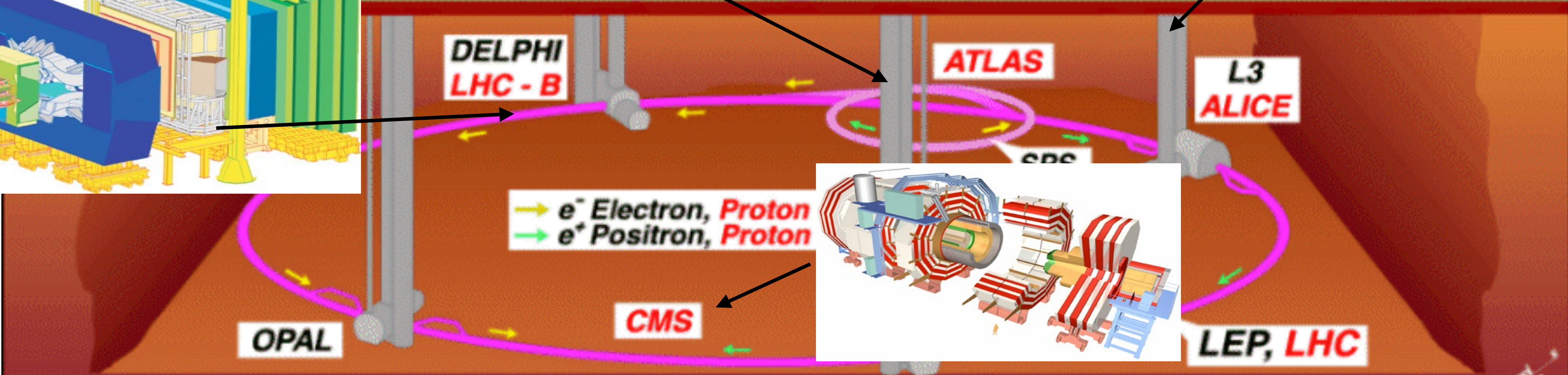
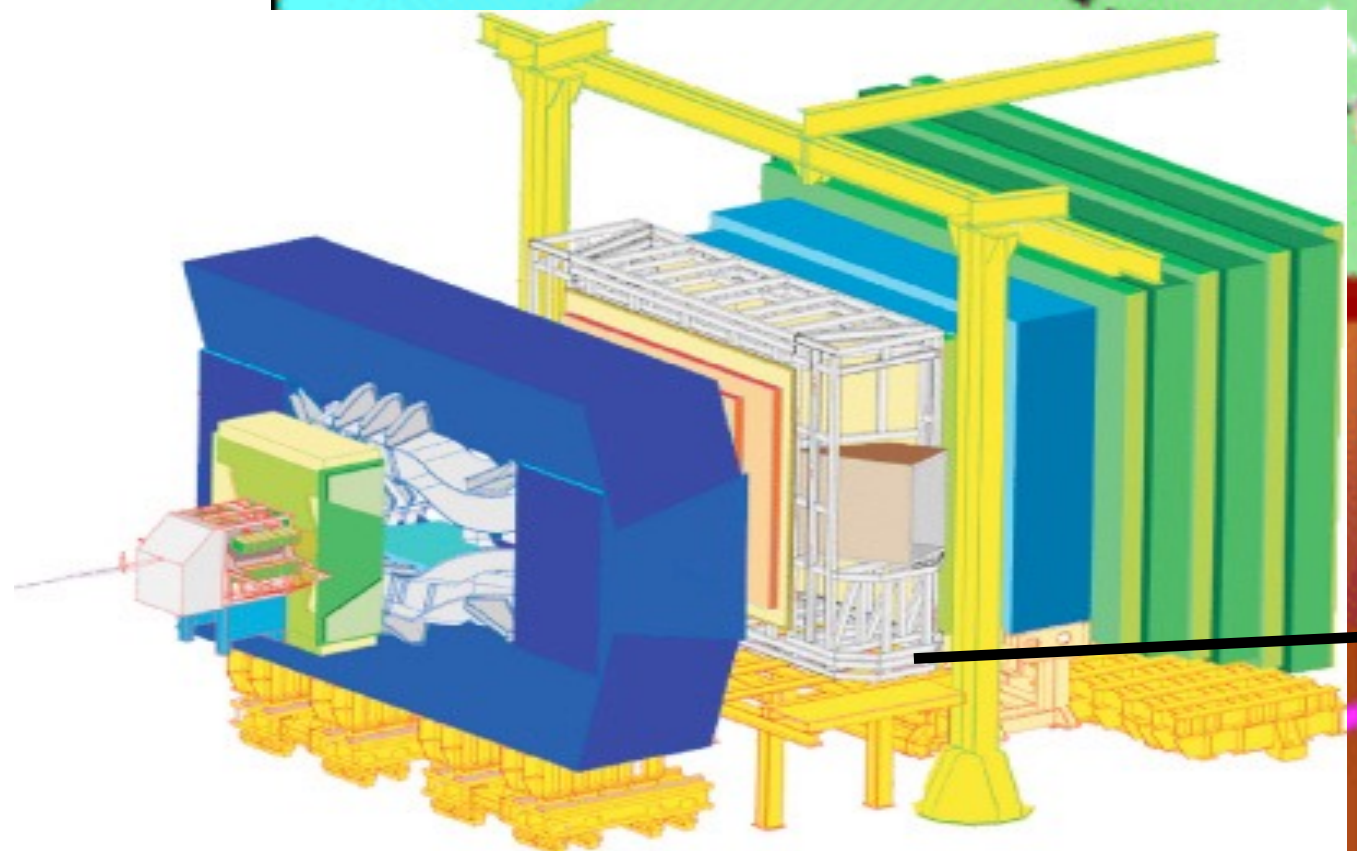
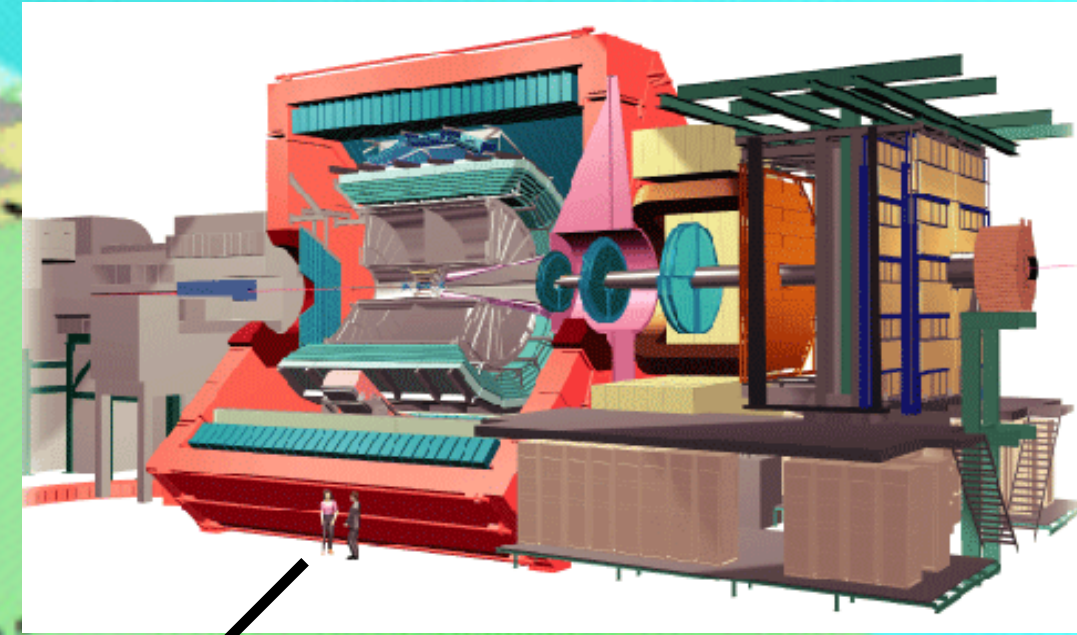
**Strict humidity control needed** not only at home lab, but also in all collaborating institutes (visits, common, tests, discussions, documentations). Do not forget humidity (85/85) tests on the electronics.

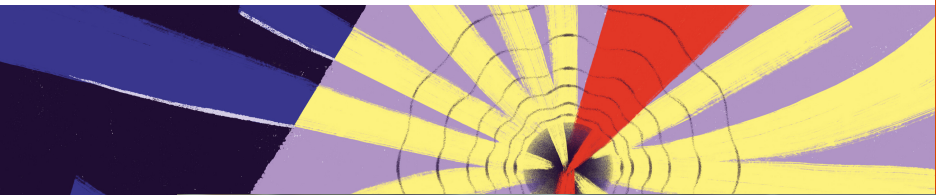
**Do not economize on thermal cycling tests** before massive production.





Pb Pb - Pb-p collisions





LHC Point 1 - UX 15 Cavern - Concrete walls 6th lift - 20-02-2003 - CERN ST-CE





ESIPAP, Archamps, 26-1-2015  
Jenni (Freiburg and CERN)



The Clermont-Ferrand group participated to the design, construction, installation and commissioning of the ATLAS Tile calorimeter.

The group takes great care of the detector maintenance.

The group created the “drawers for electronics”, built the HV system, installed the detector in the pit, made first system tests at CERN and laser calibration.



PAP, Archamps, 26-1-2015  
ni (Freiburg and CERN)

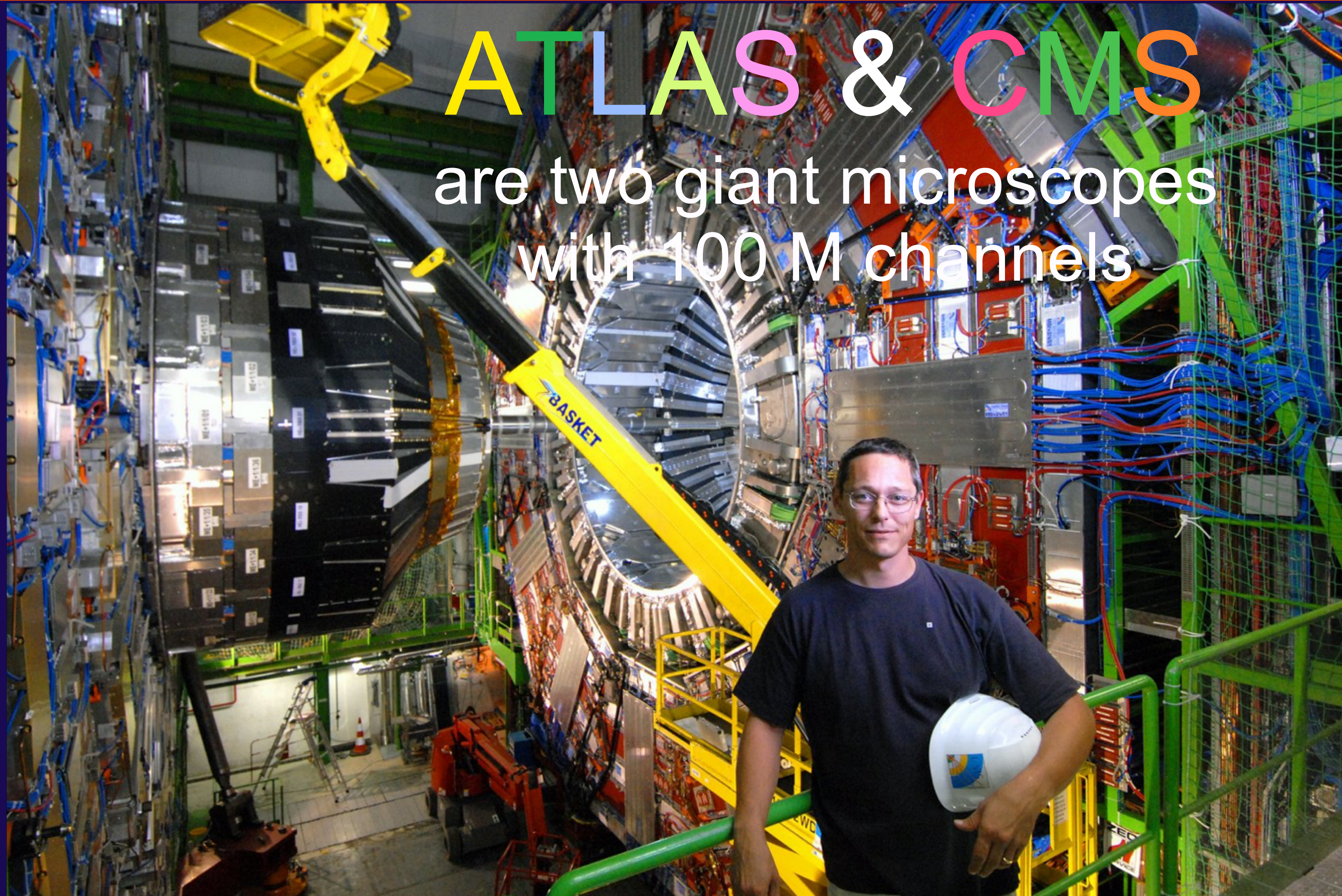
# PRECISION DETECTORS

## ATLAS & CMS

are two giant microscopes  
with 100 M channels

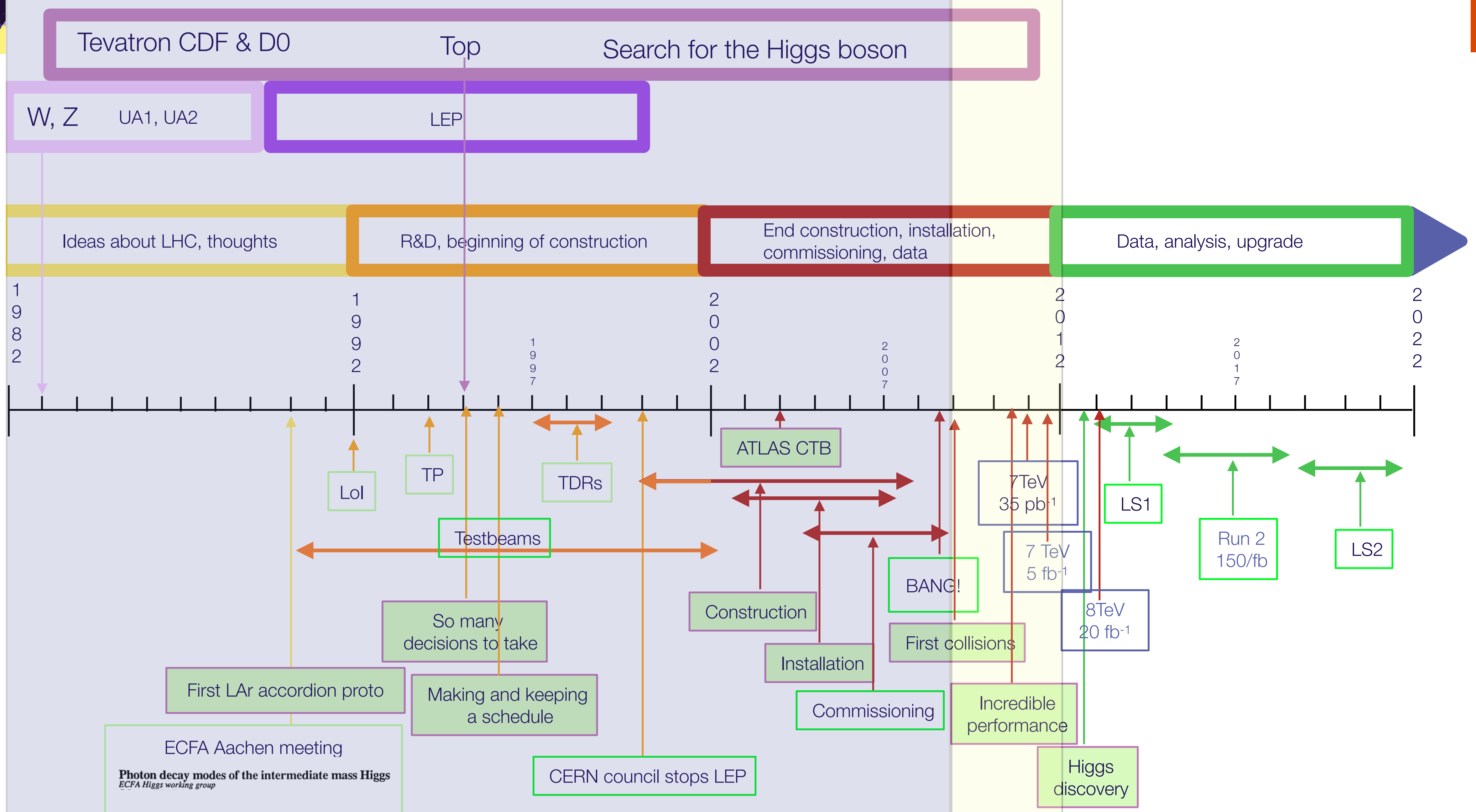
Particle trajectory  
with a accuracy of  
0.0002 m (20 $\mu$ m)

and energy at  
1%





1964 - Higgs mechanism proposed by P. W. Higgs, F. Englert and R.Brout, G.S. Guralnik, C.R. Hagen and T.W.B. Kibble.



ECFA Aachen meeting  
Photon decay modes of the intermediate mass Higgs  
ECFA Higgs working group

# BEAMS COLLIDE on 23rd NOVEMBER 2009



2009

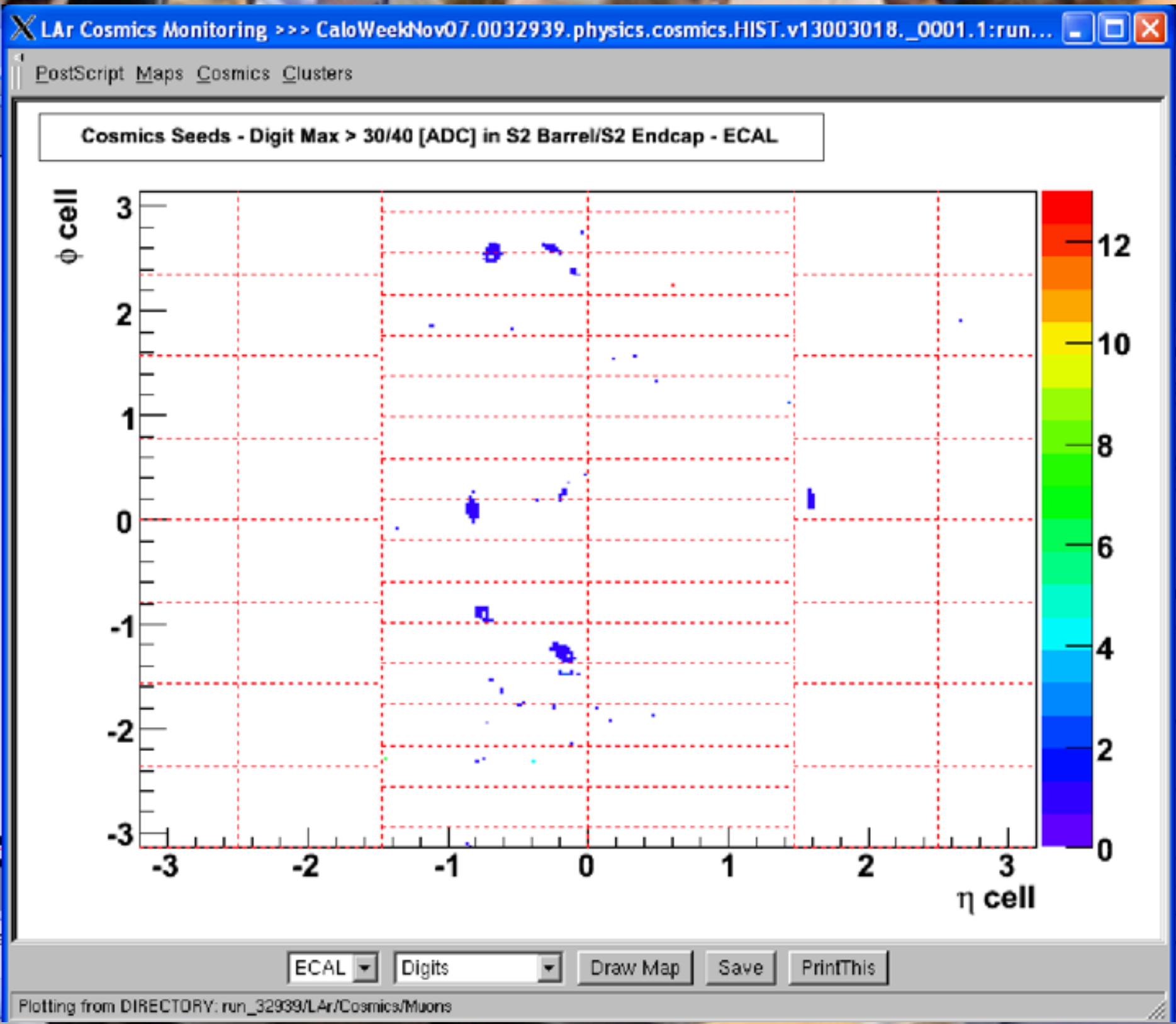
# BEAMS COLLIDE on 23rd NOVEMBER 2009

Jessica Lévéque is not happy: she immediately saw that something was wrong with the calorimeter!

2009

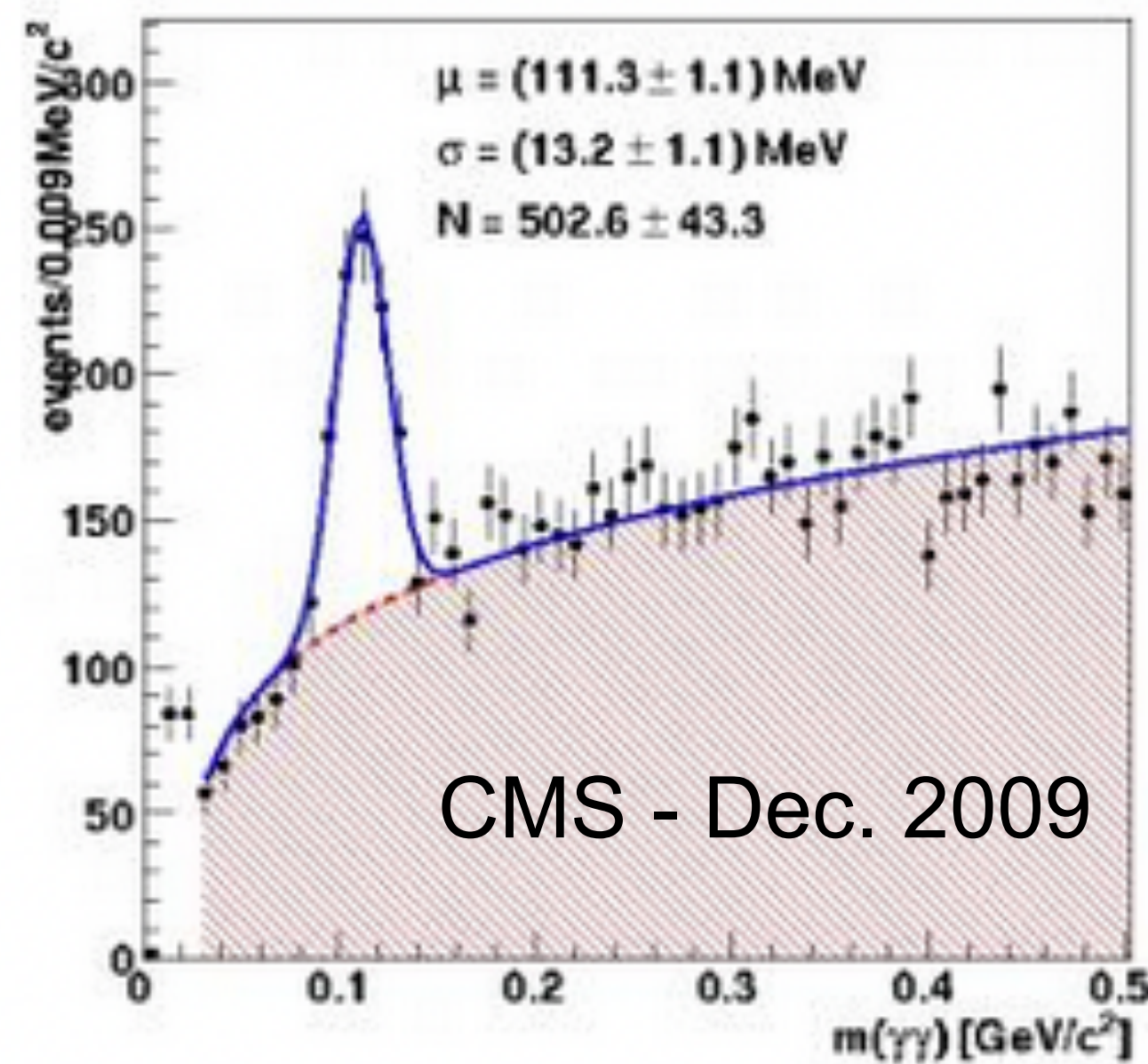
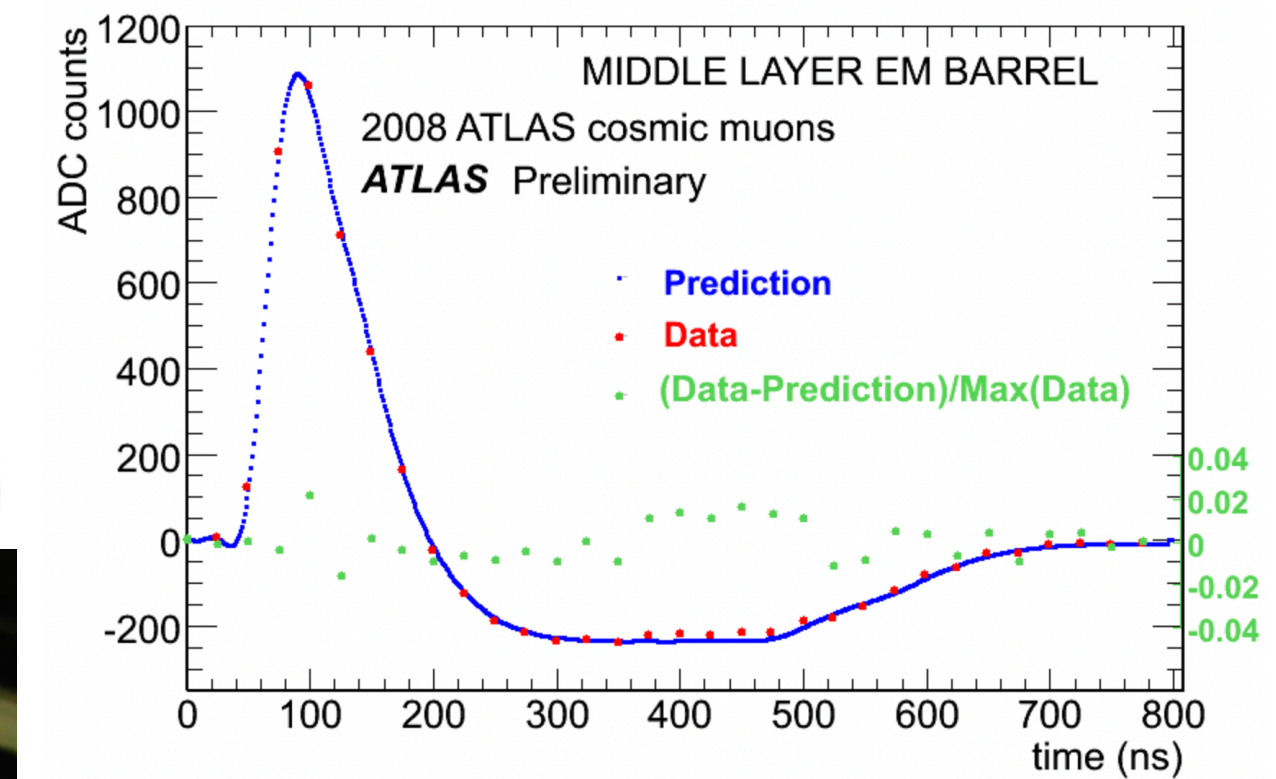
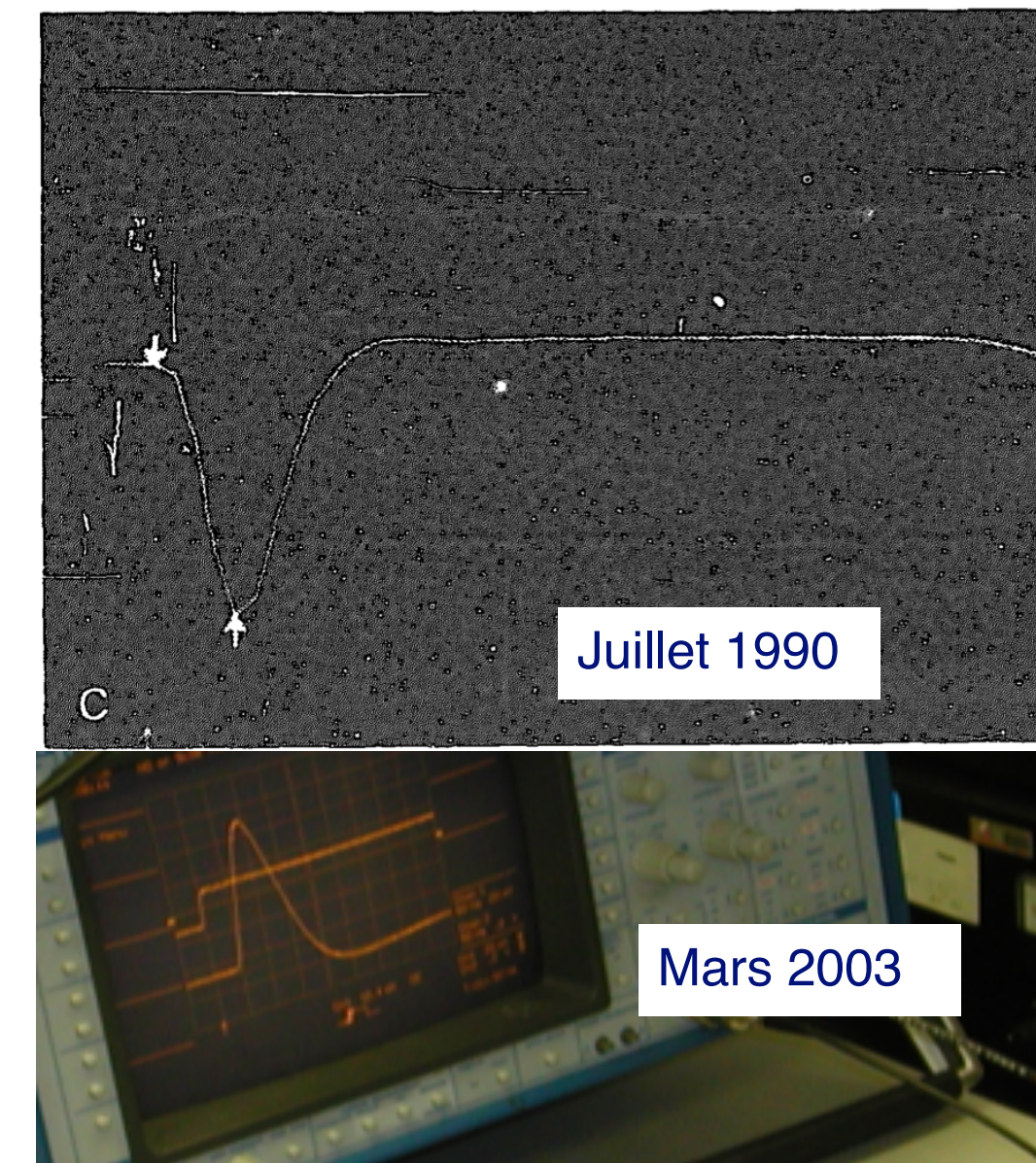
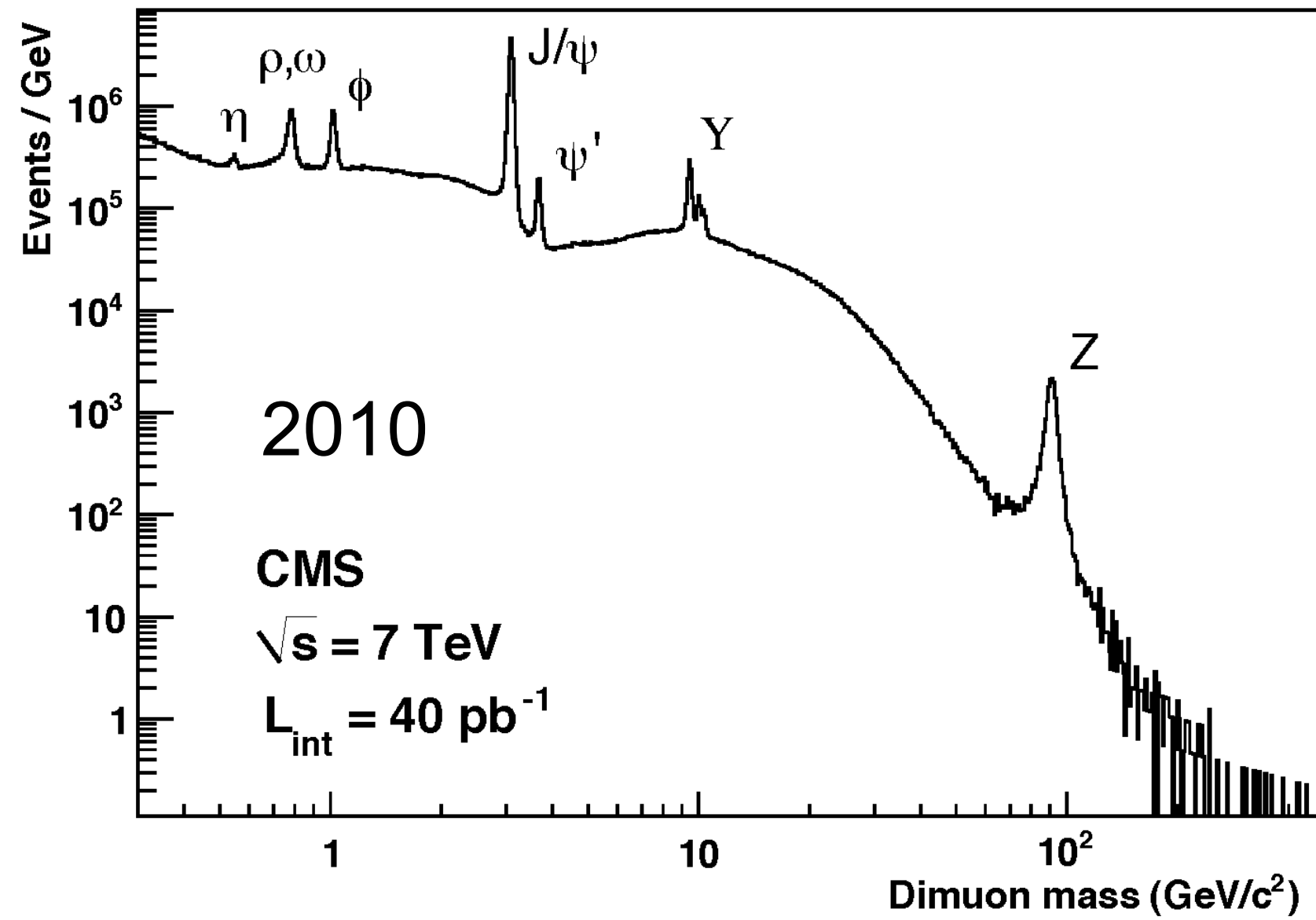
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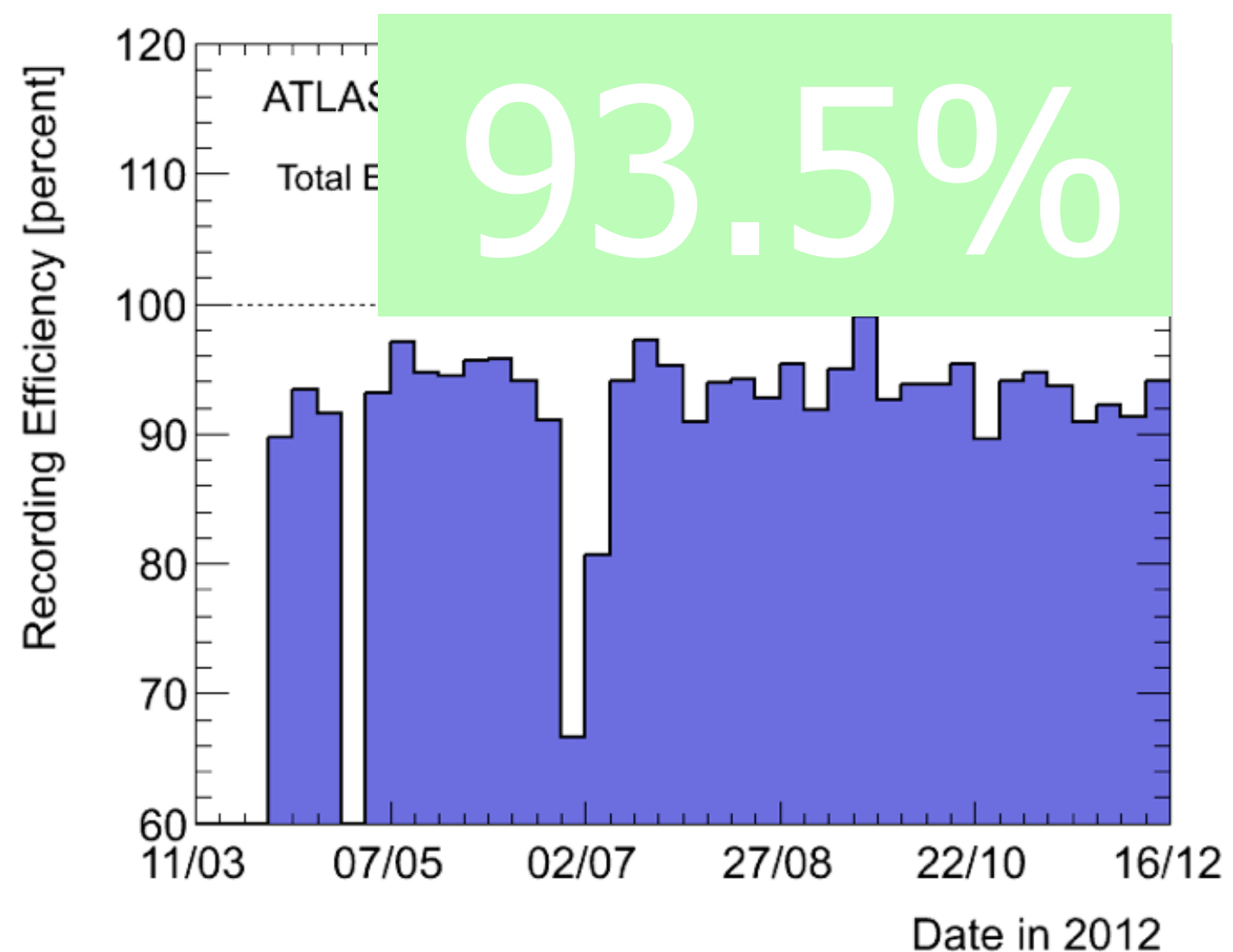
2009

# A GLIMPSE at PERFORMANCE



Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	95.0%
SCT Silicon Strips	6.3 M	99.3%
TRT Transition Radiation Tracker	350 k	97.5%
LAr EM Calorimeter	170 k	99.9%
Tile calorimeter	9800	98.3%
Hadronic endcap LAr calorimeter	5600	99.6%
Forward LAr calorimeter	3500	99.8%
LVL1 Calo trigger	7160	100%
LVL1 Muon RPC trigger	370 k	100%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	96.0%
RPC Barrel Muon Chambers	370 k	97.1%
TGC Endcap Muon Chambers	320 k	98.2%

# DATA TAKING and QUALITY



X

95.8%  
All good for physics

ATLAS p-p run: April-December 2012										
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.9	99.4	99.8	99.1	99.6	99.6	99.8	100.	99.6	99.8	99.5

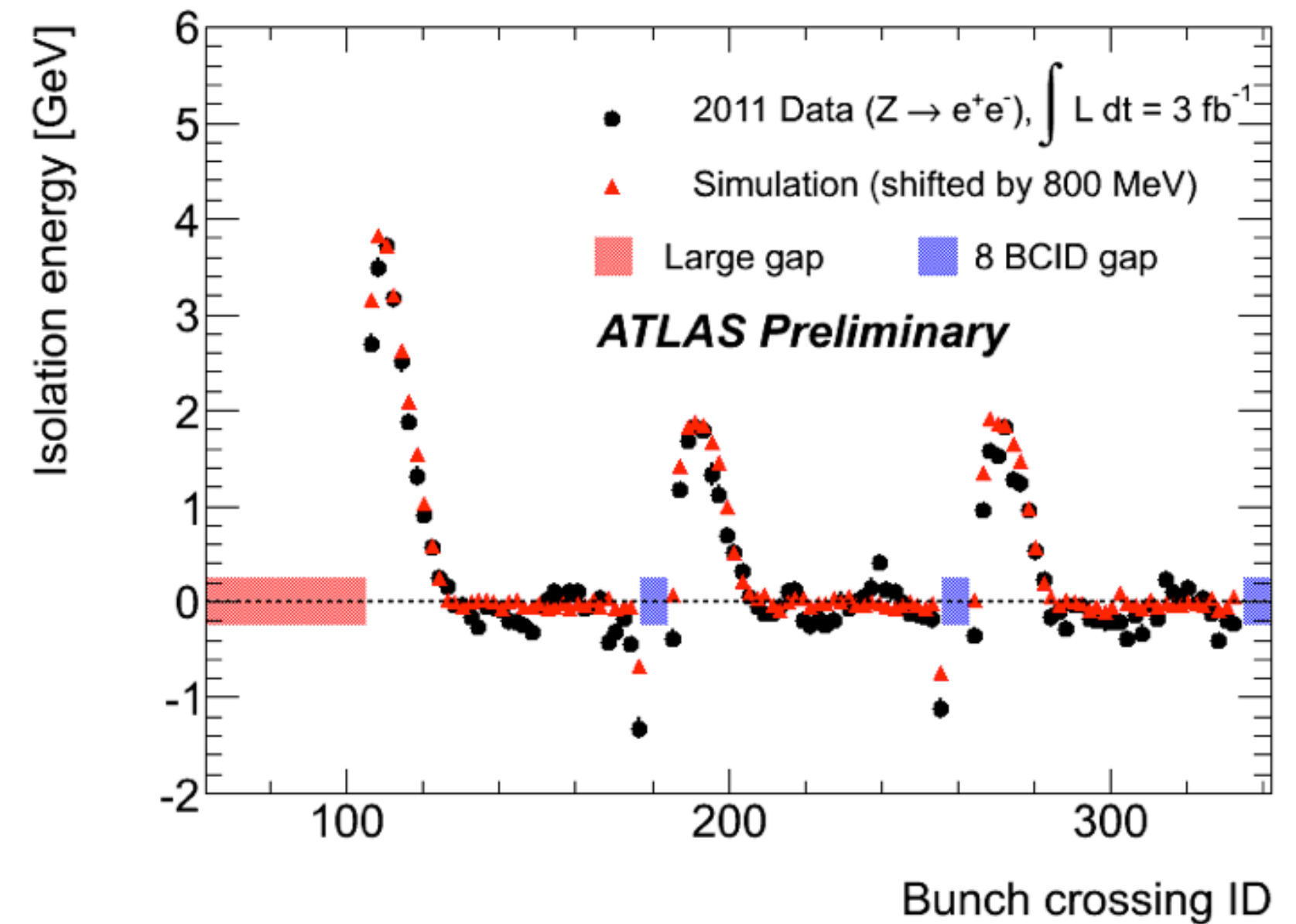
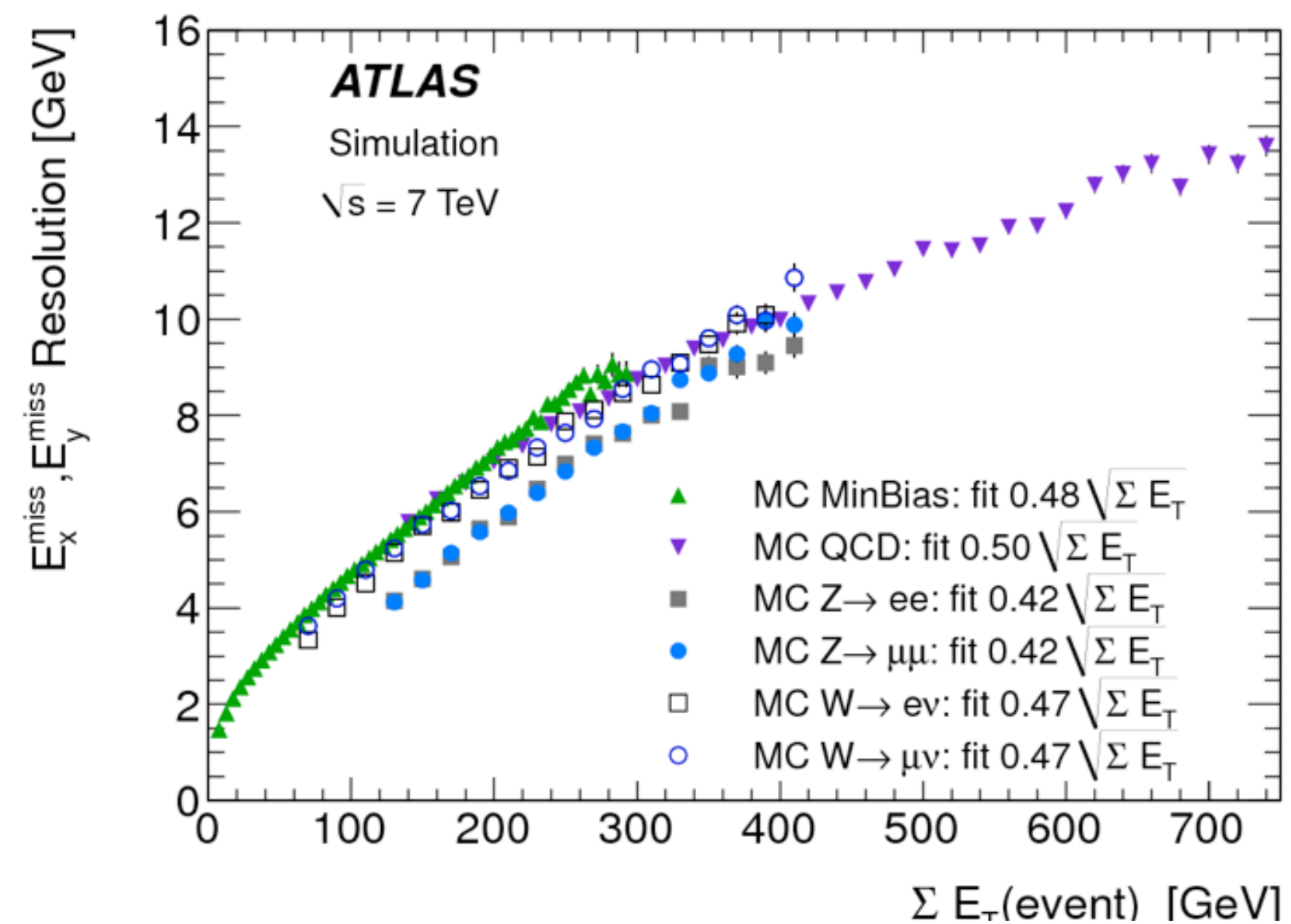
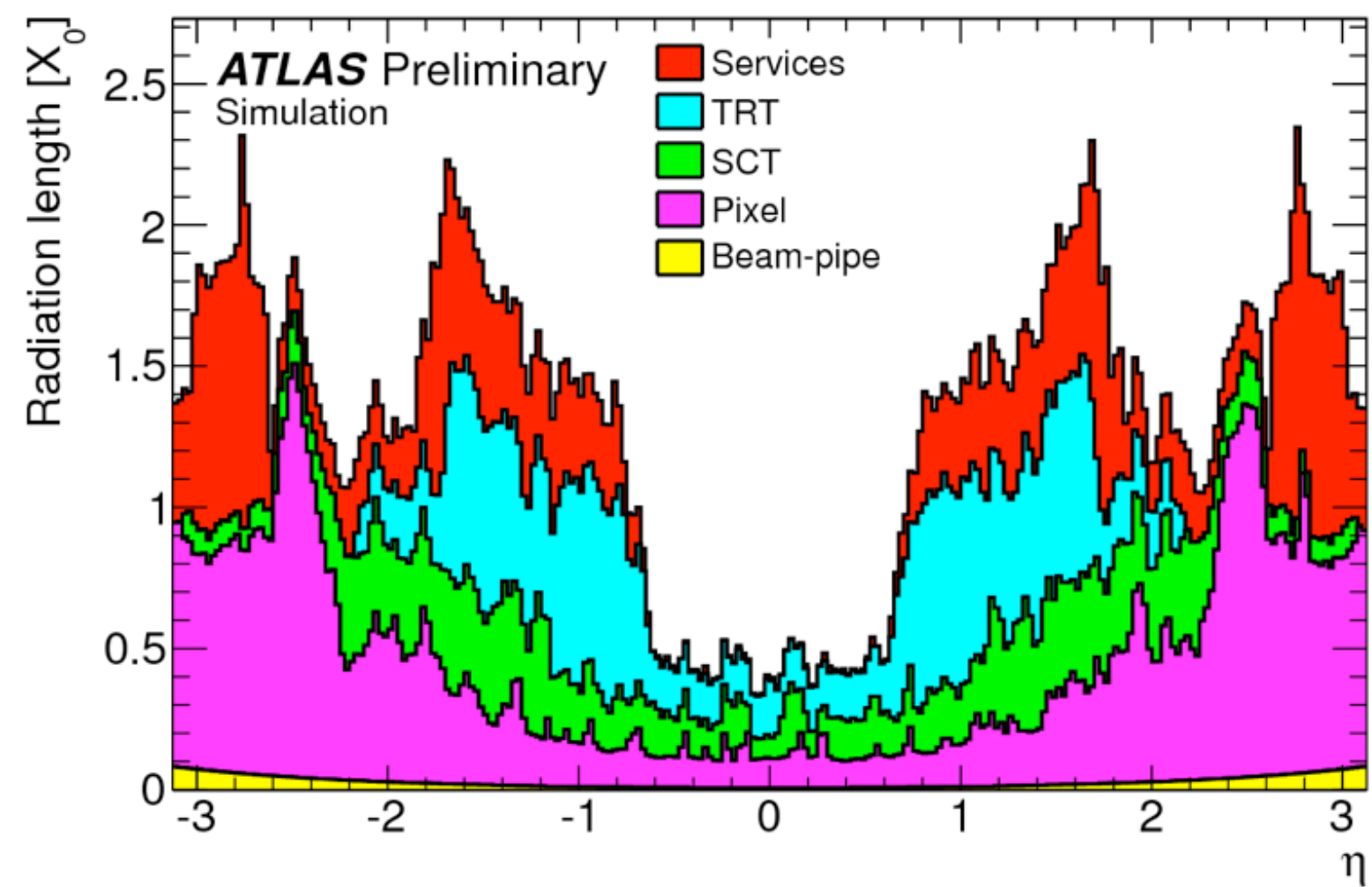
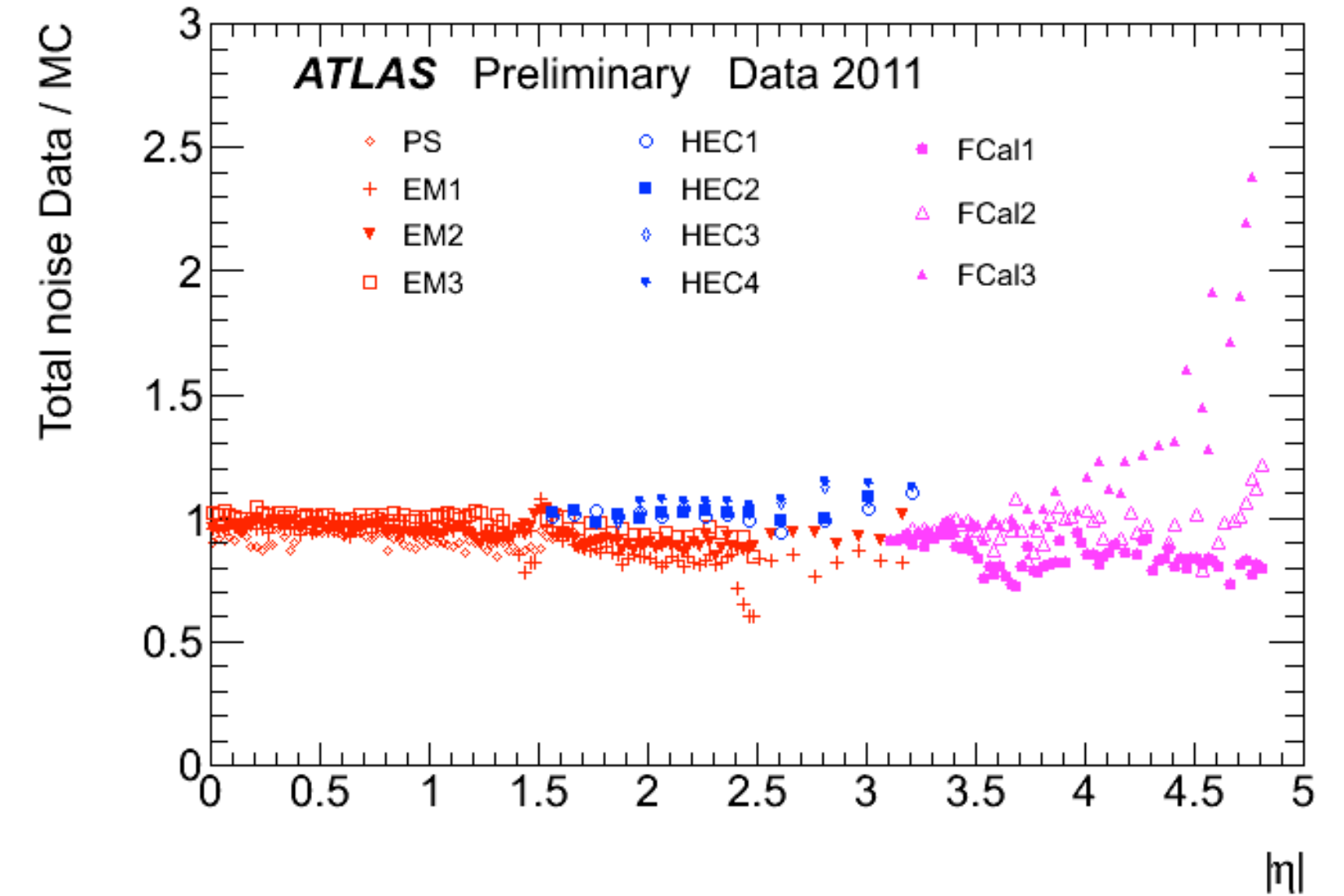
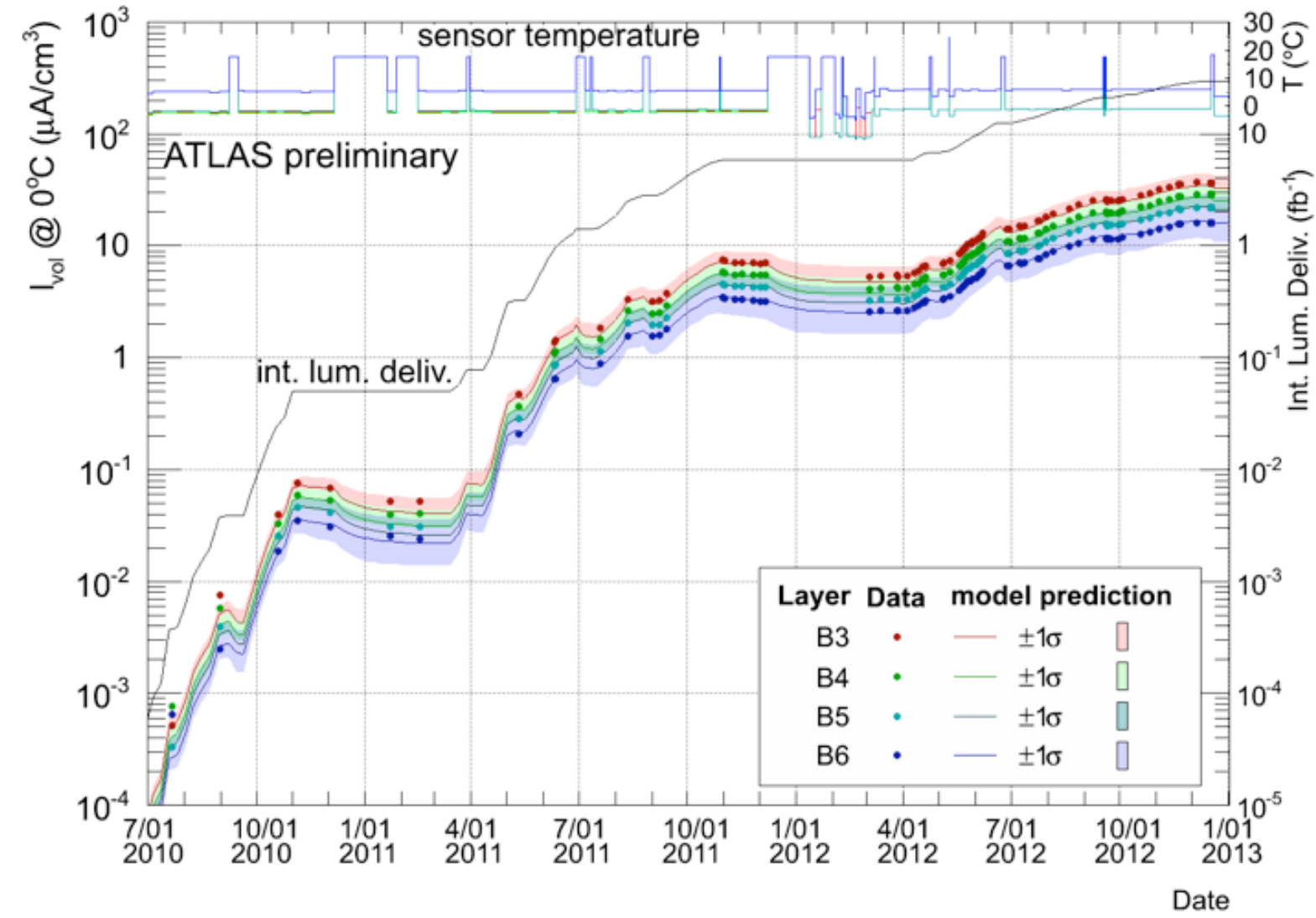
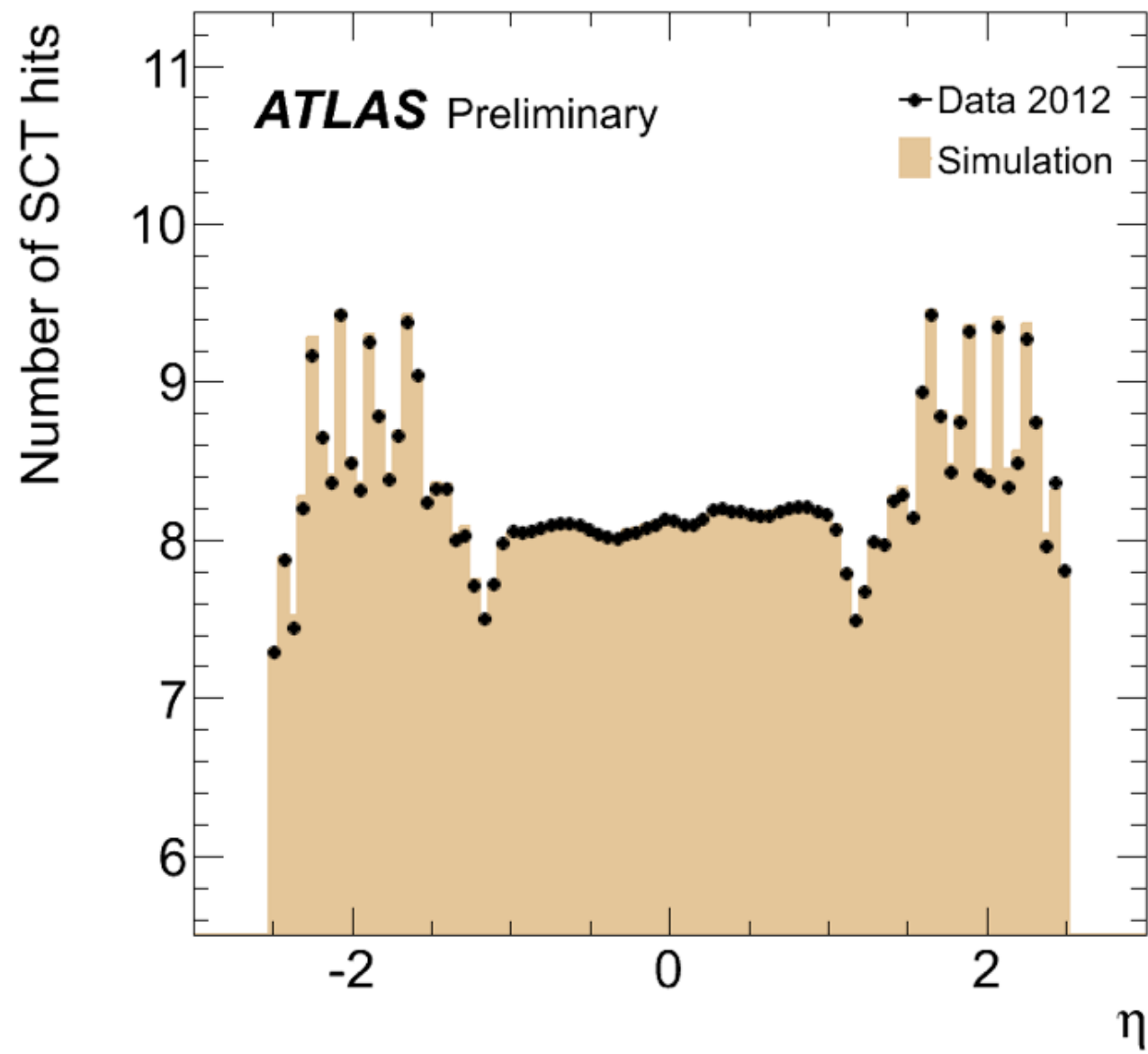
In 2012, 89.5% of DELIVERED data were good for physics.

To my knowledge, never an experiment has reached such a level of efficiency. Even experiments at e<sup>+</sup>e<sup>-</sup> colliders, pp at lower intensity, ..... with much less challenges.

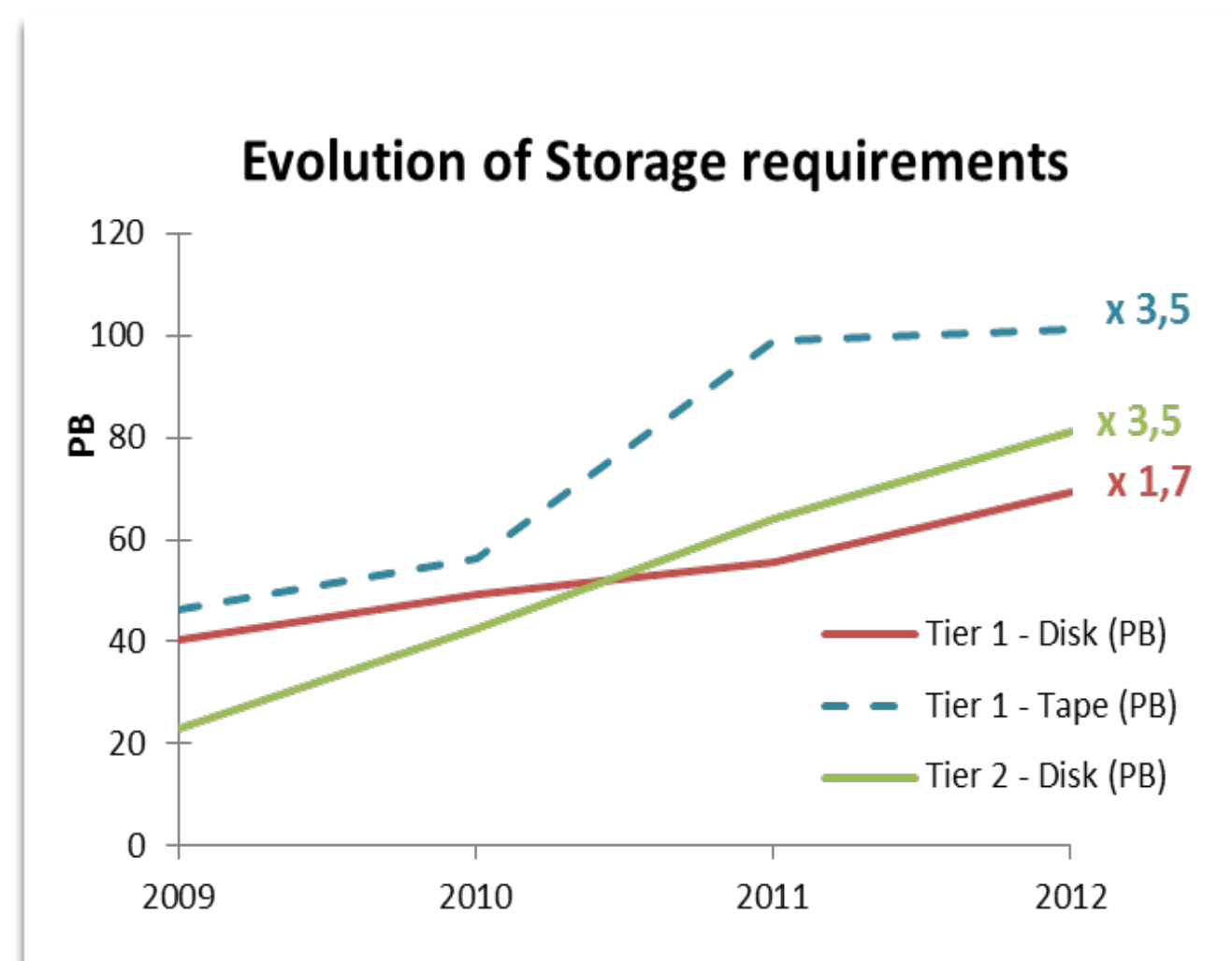
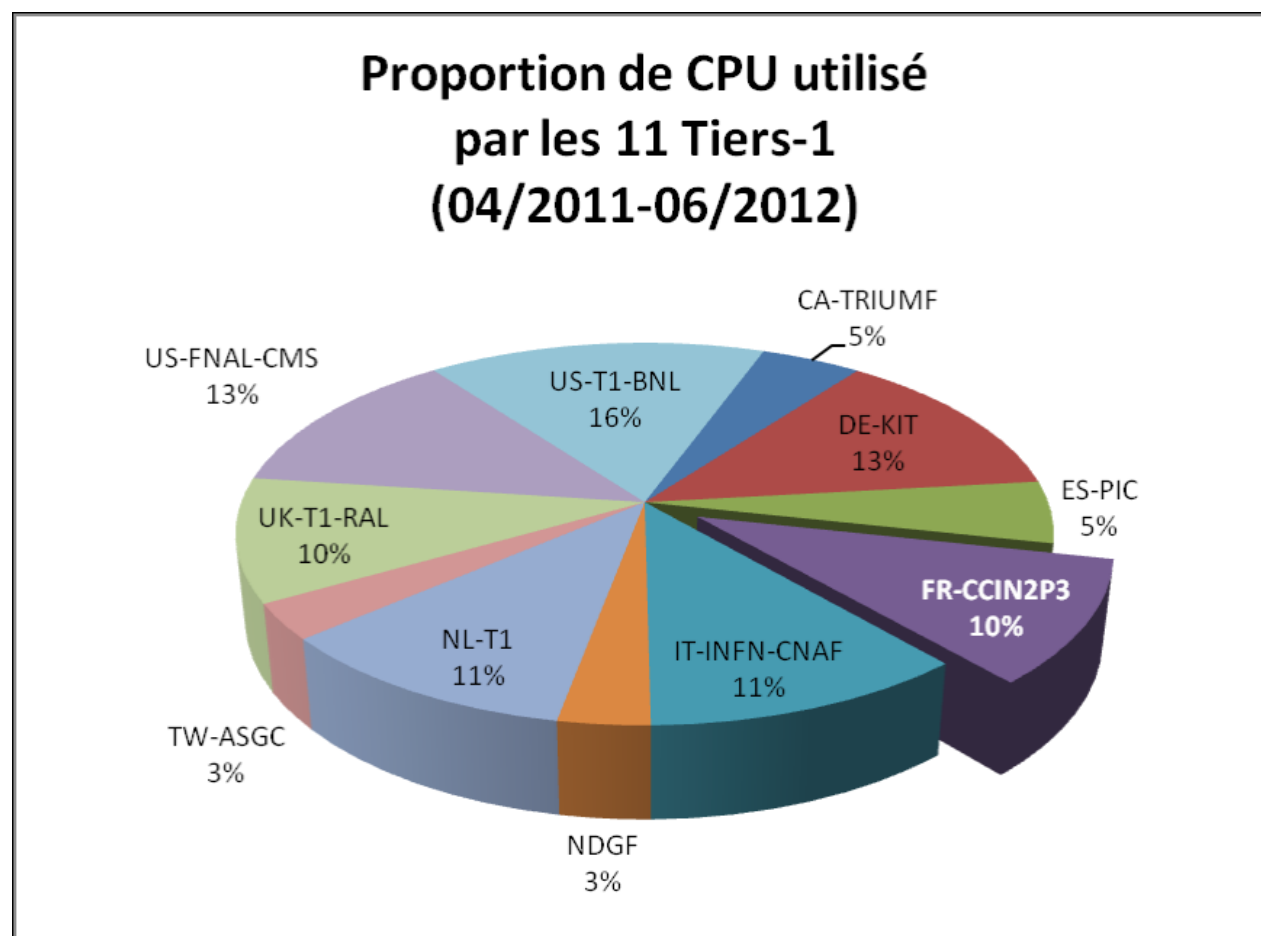
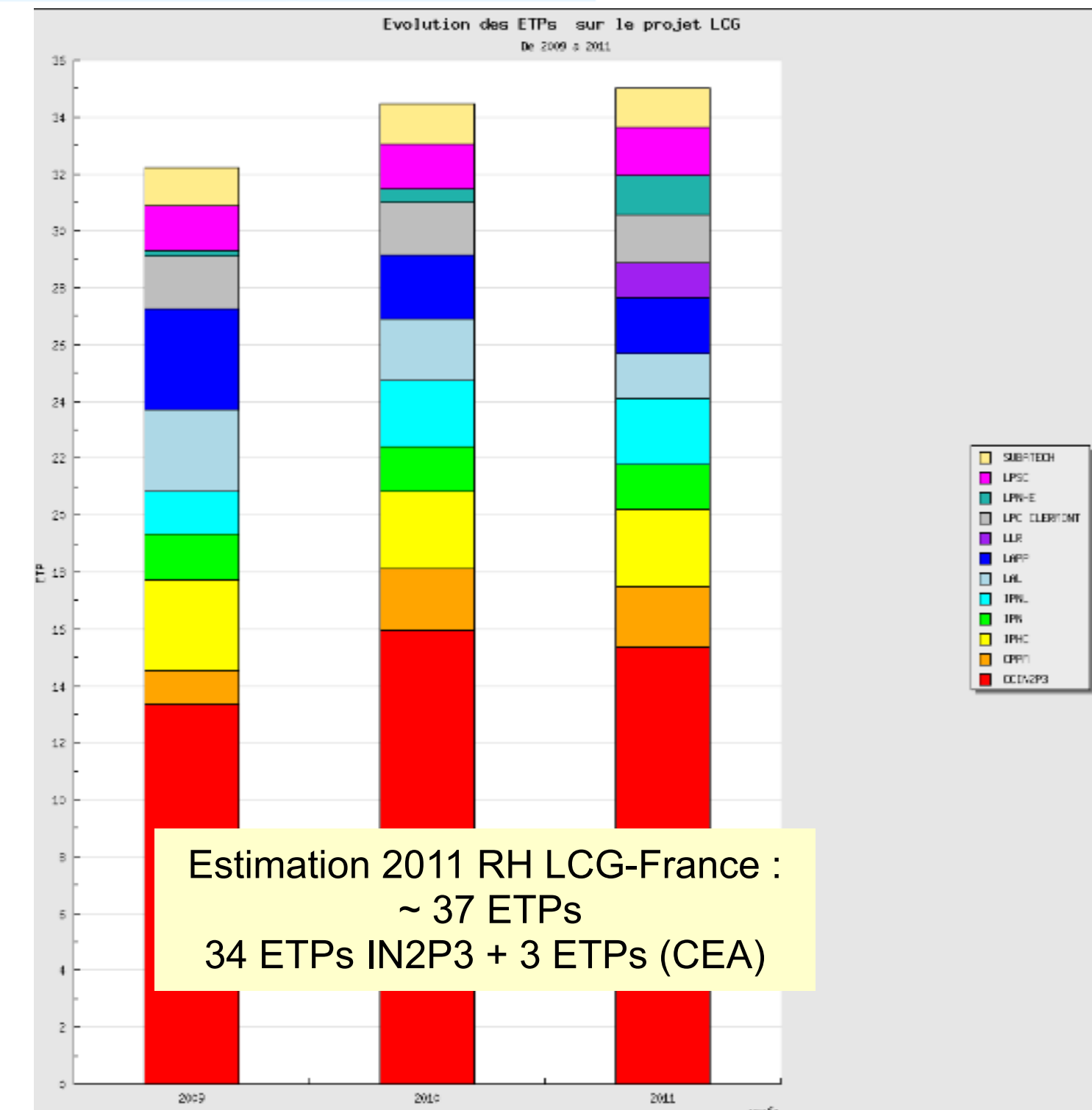
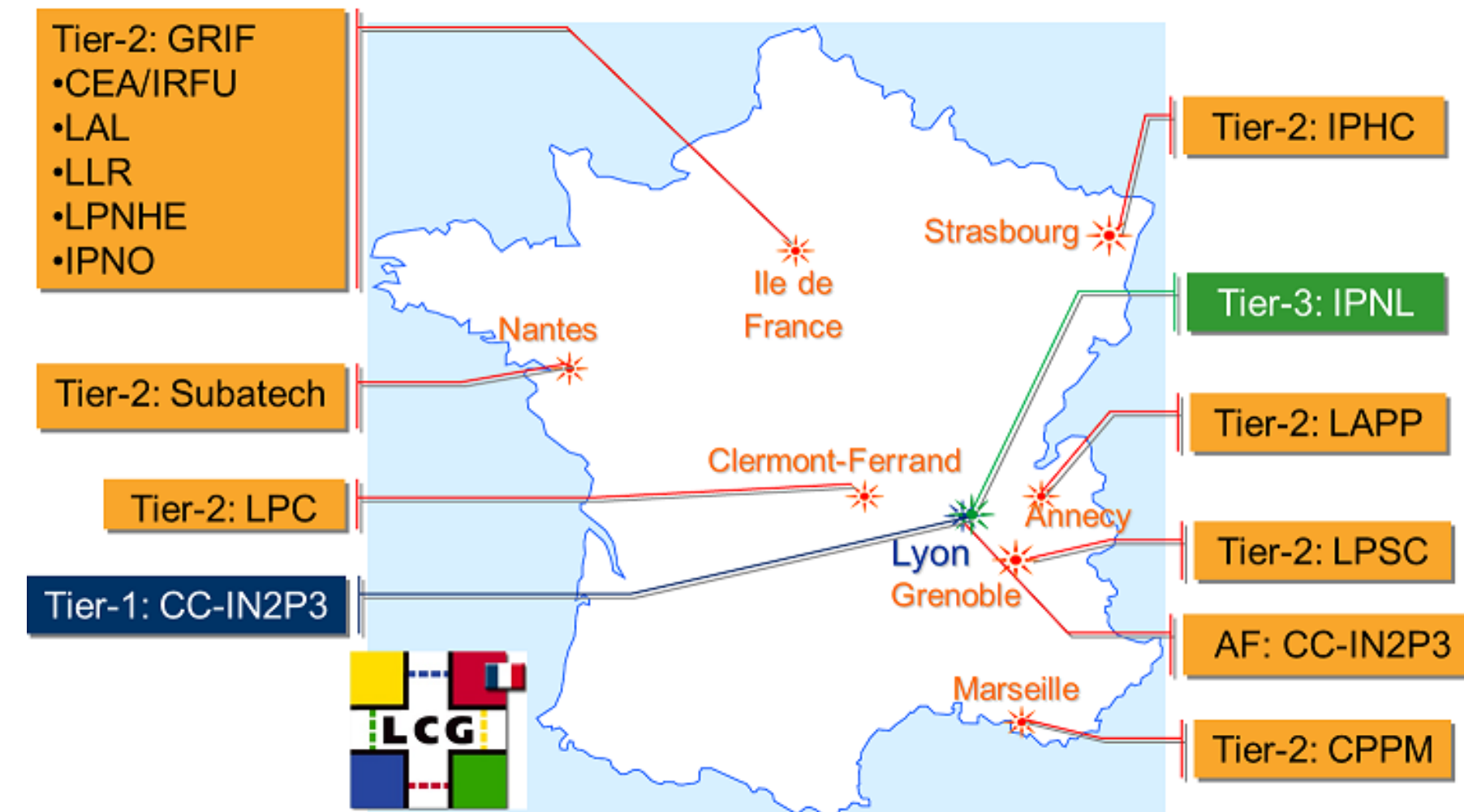
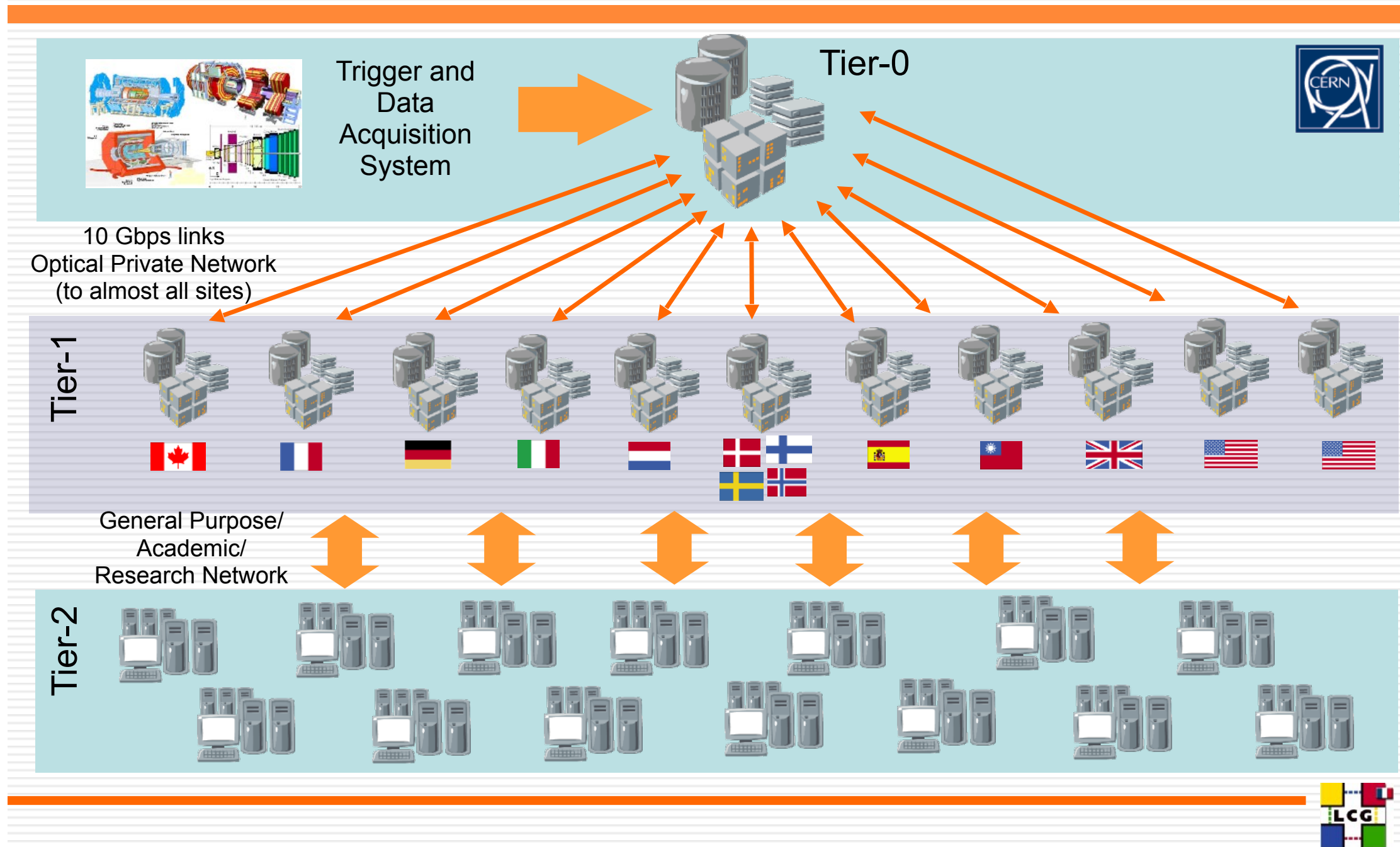
At LHC, even with more pile-up than designed, we are happy!

My interpretation: the coherence between motivation, rigour, the challenging physics aim (the aim is not to discover; it is to find out what is there), the very spirited people.

# SIMULATION: A TOOL towards PHYSICS

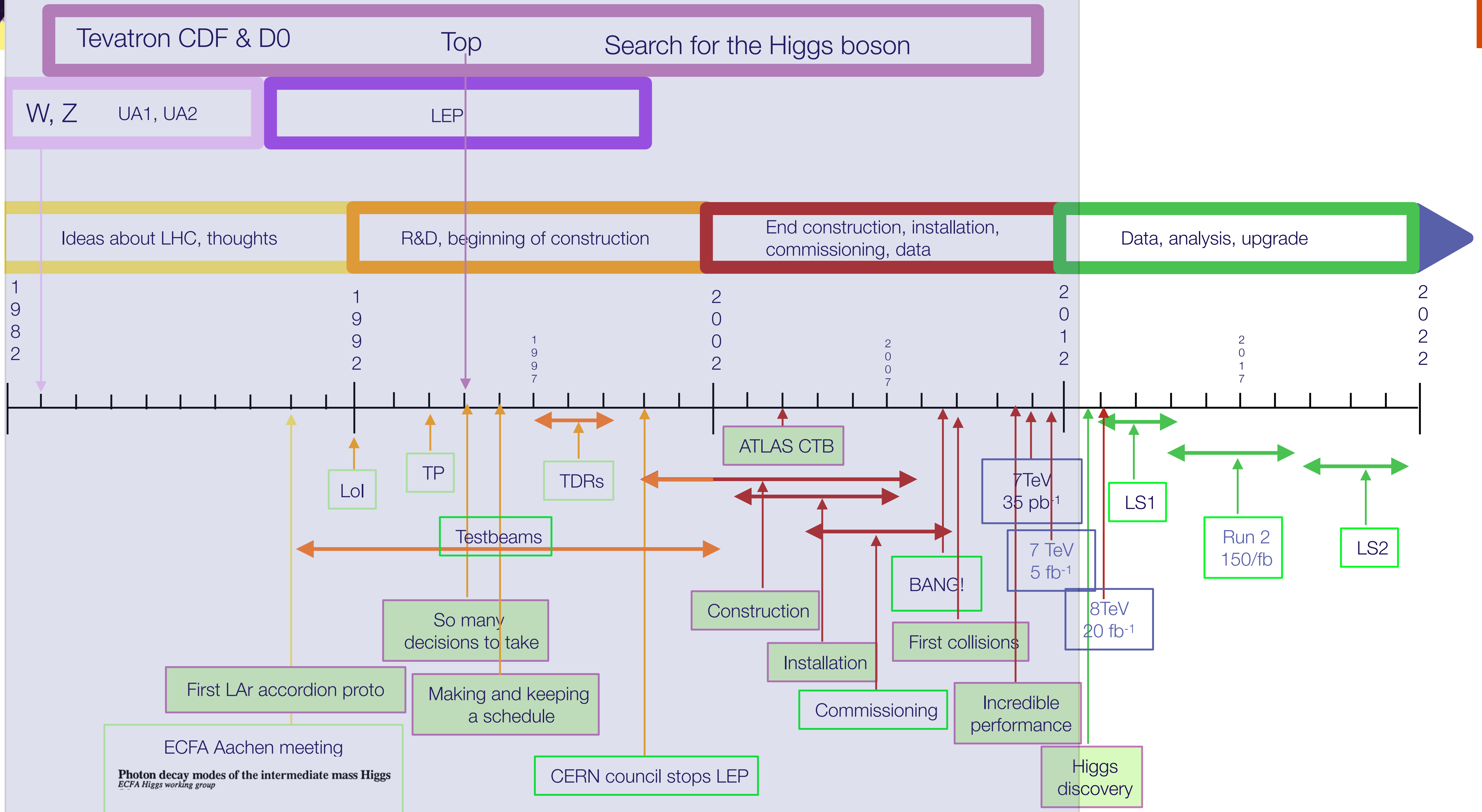


# LHC COMPUTING GRID in FRANCE





1964 - Higgs mechanism proposed by P. W. Higgs, F. Englert and R.Brout, G.S. Guralnik, C.R. Hagen and T.W.B. Kibble.



ECFA Aachen meeting  
Photon decay modes of the intermediate mass Higgs  
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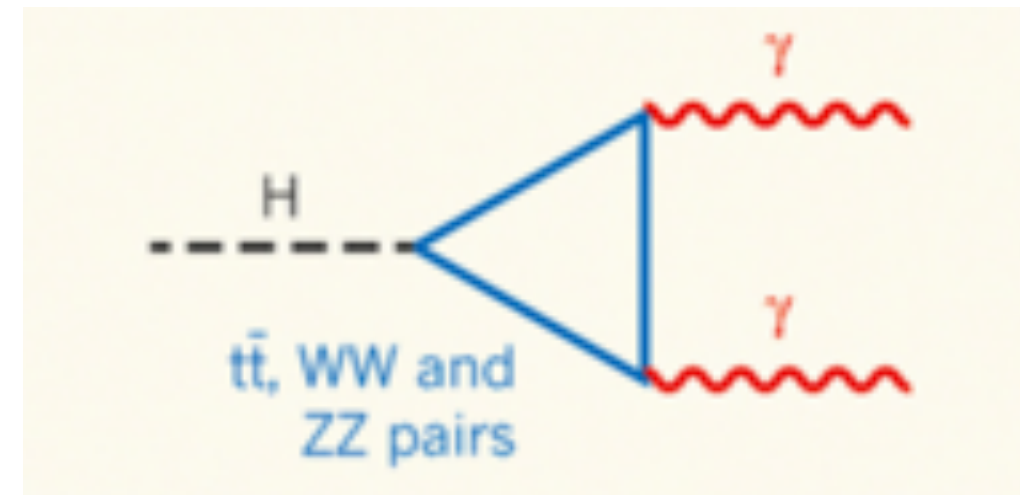
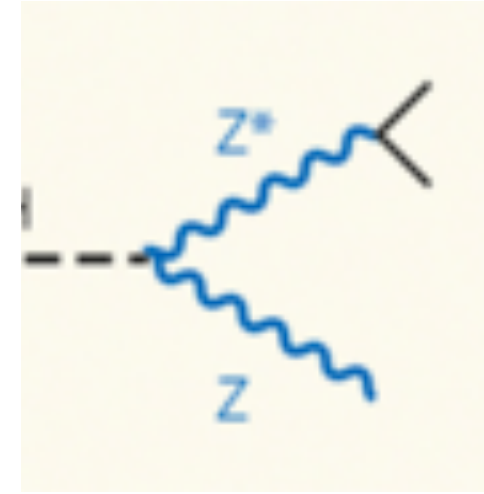
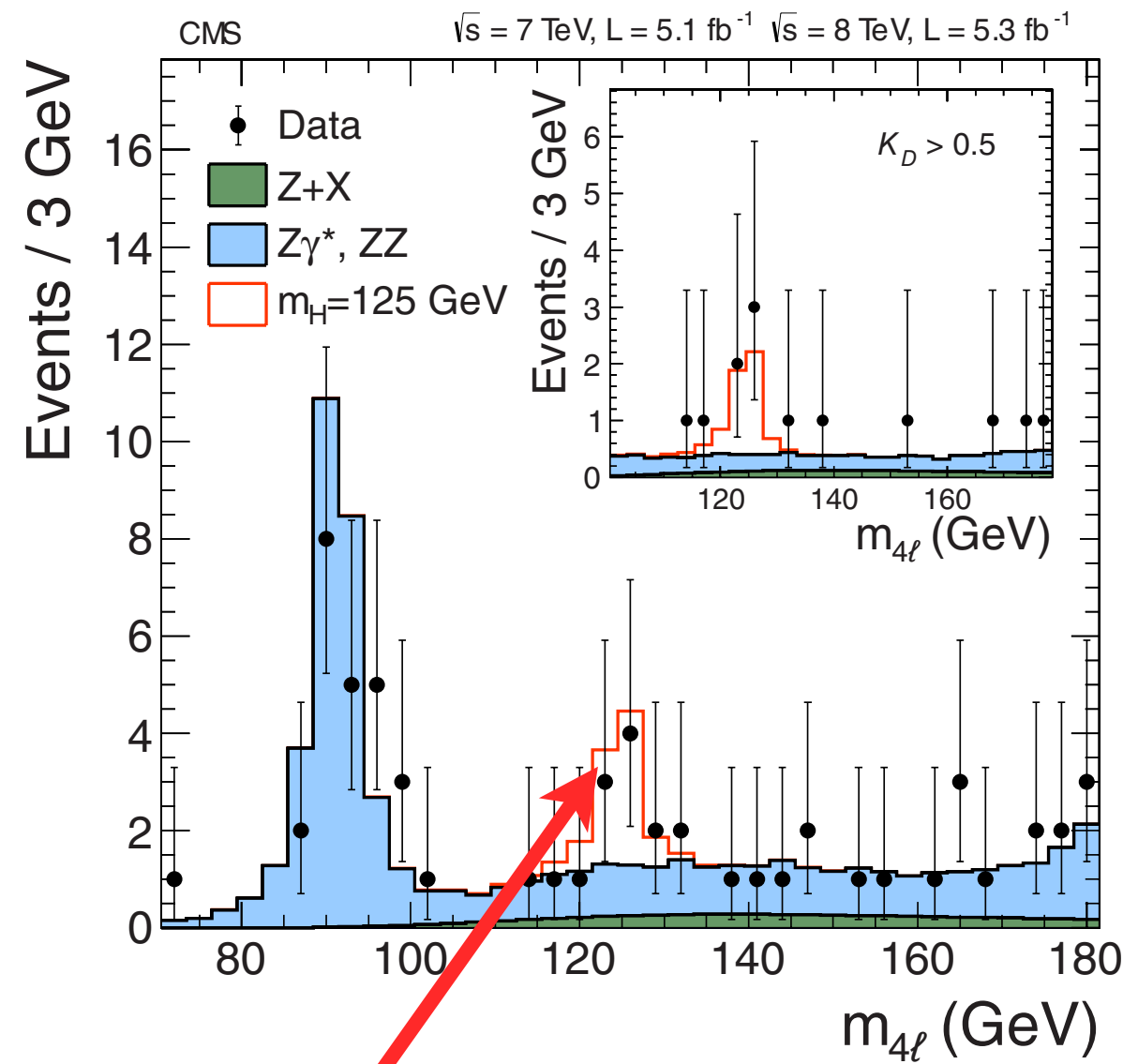
# LE SUSPENSE EST à SON COMBLE

Juin 2012 - Le dévoilement des données dans CMS



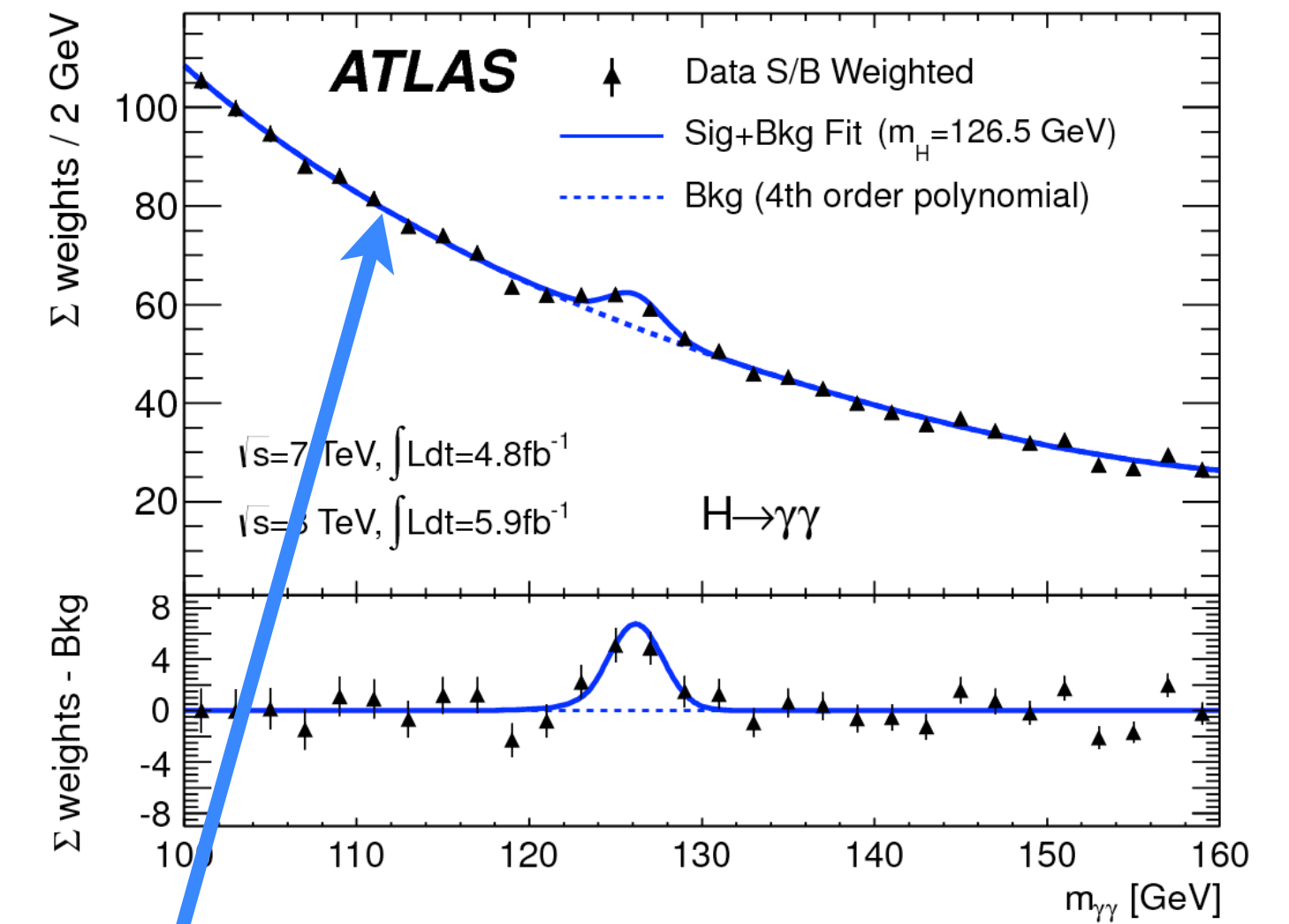
# 4th July 2012 - HIGGS DISCOVERY with ATLAS & CMS

## H → 4 leptons



● ▲ : THE data

## H → 2 photons



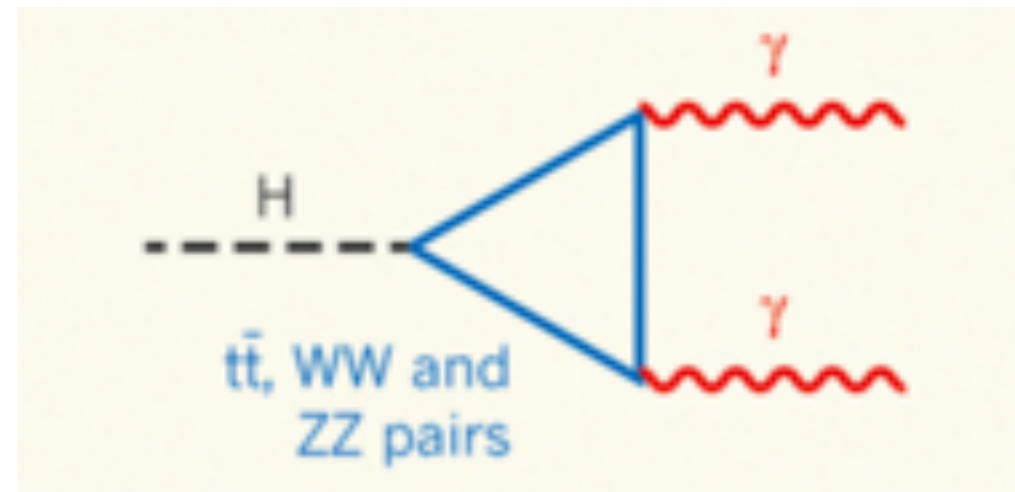
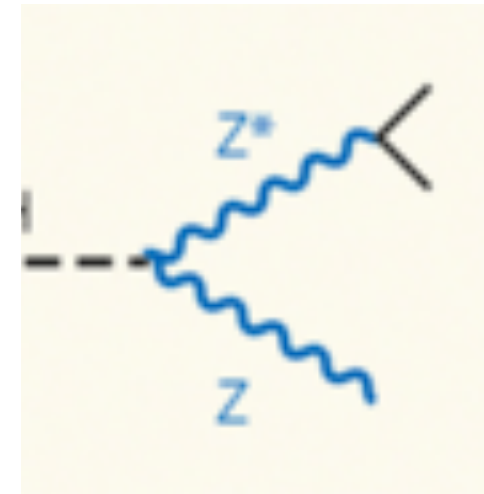
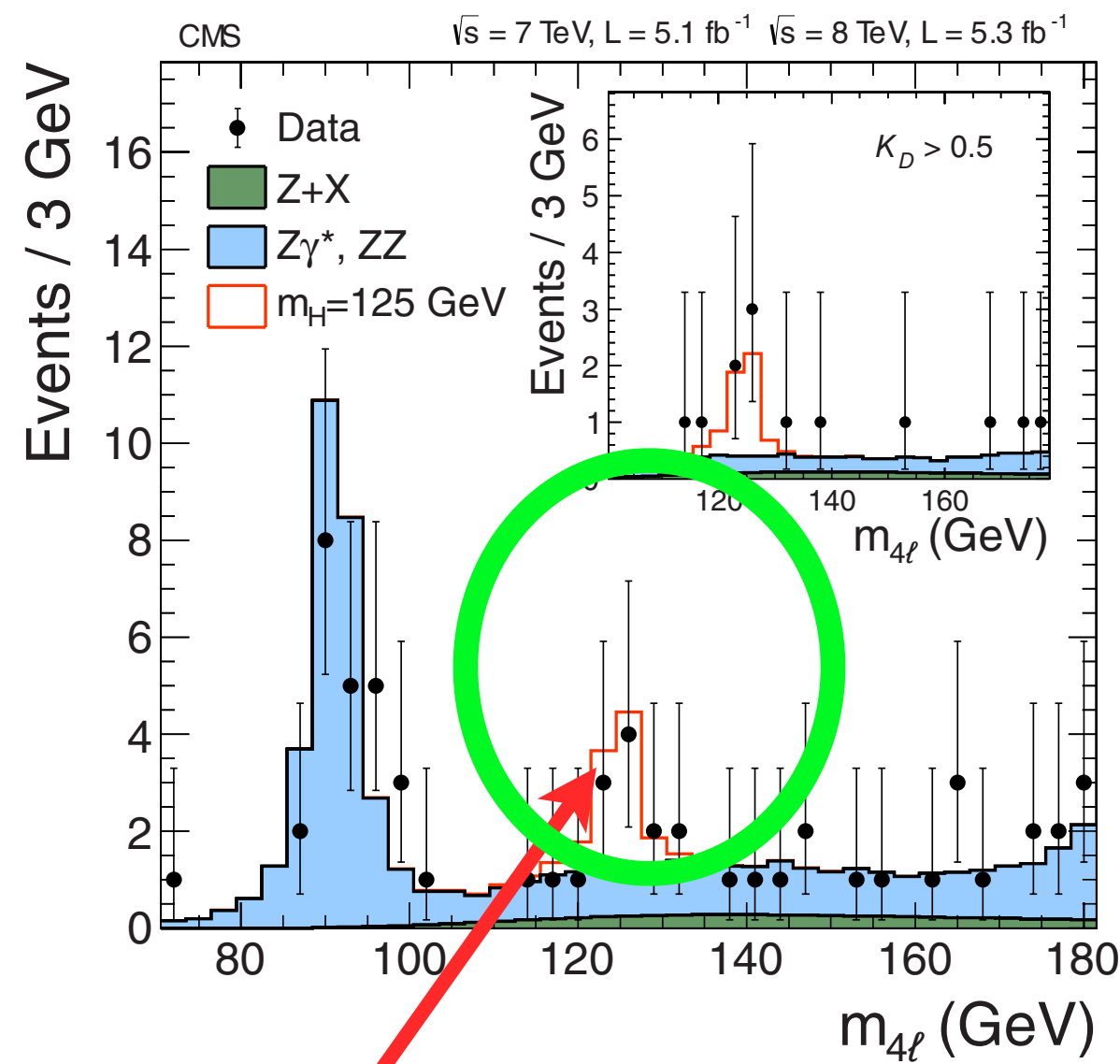
Higgs boson (prediction)

background

background + Higgs boson

# 4th July 2012 - HIGGS DISCOVERY with ATLAS & CMS

## H → 4 leptons



● ▲ : THE data

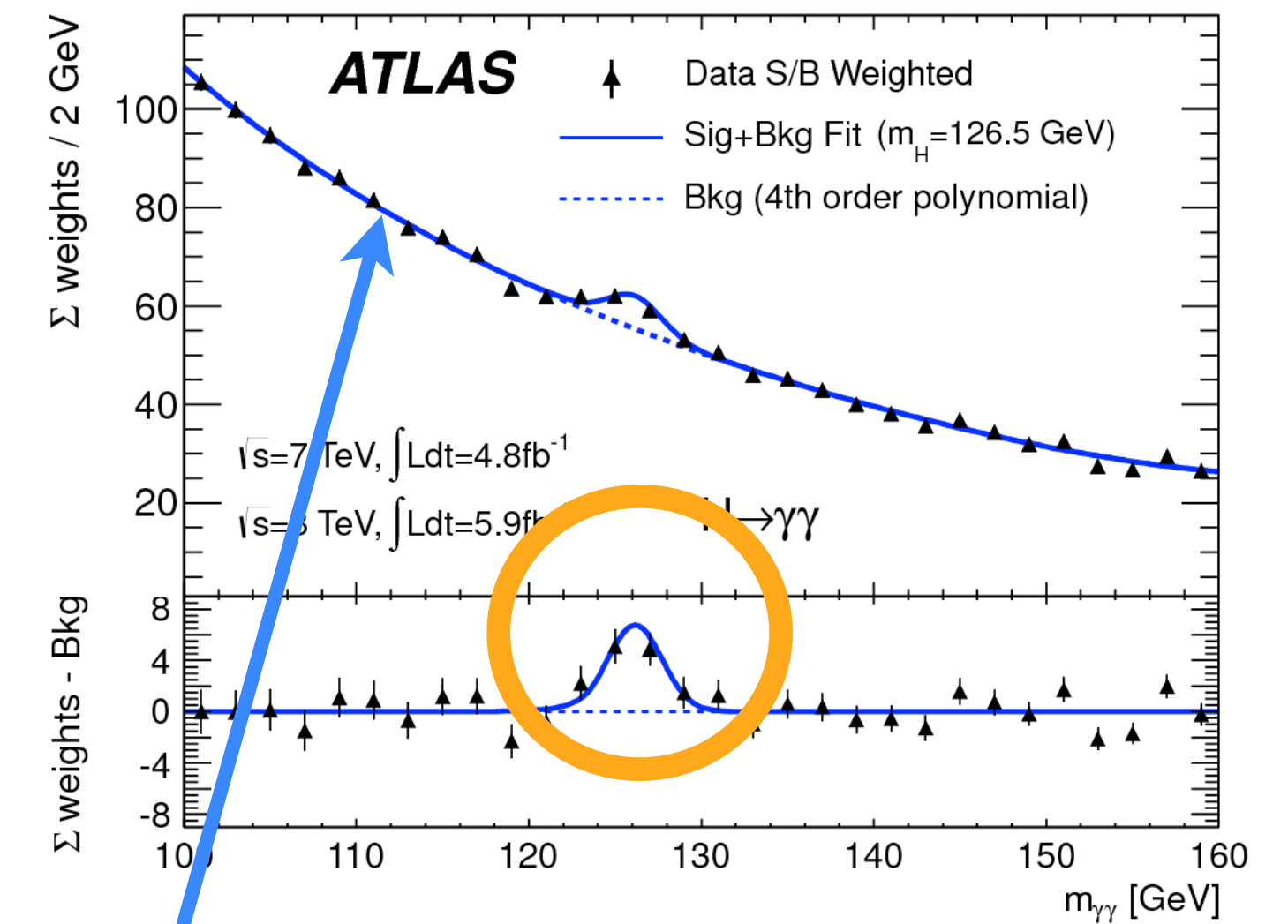
Higgs boson (prediction)

background

Data *need* the Higgs boson.

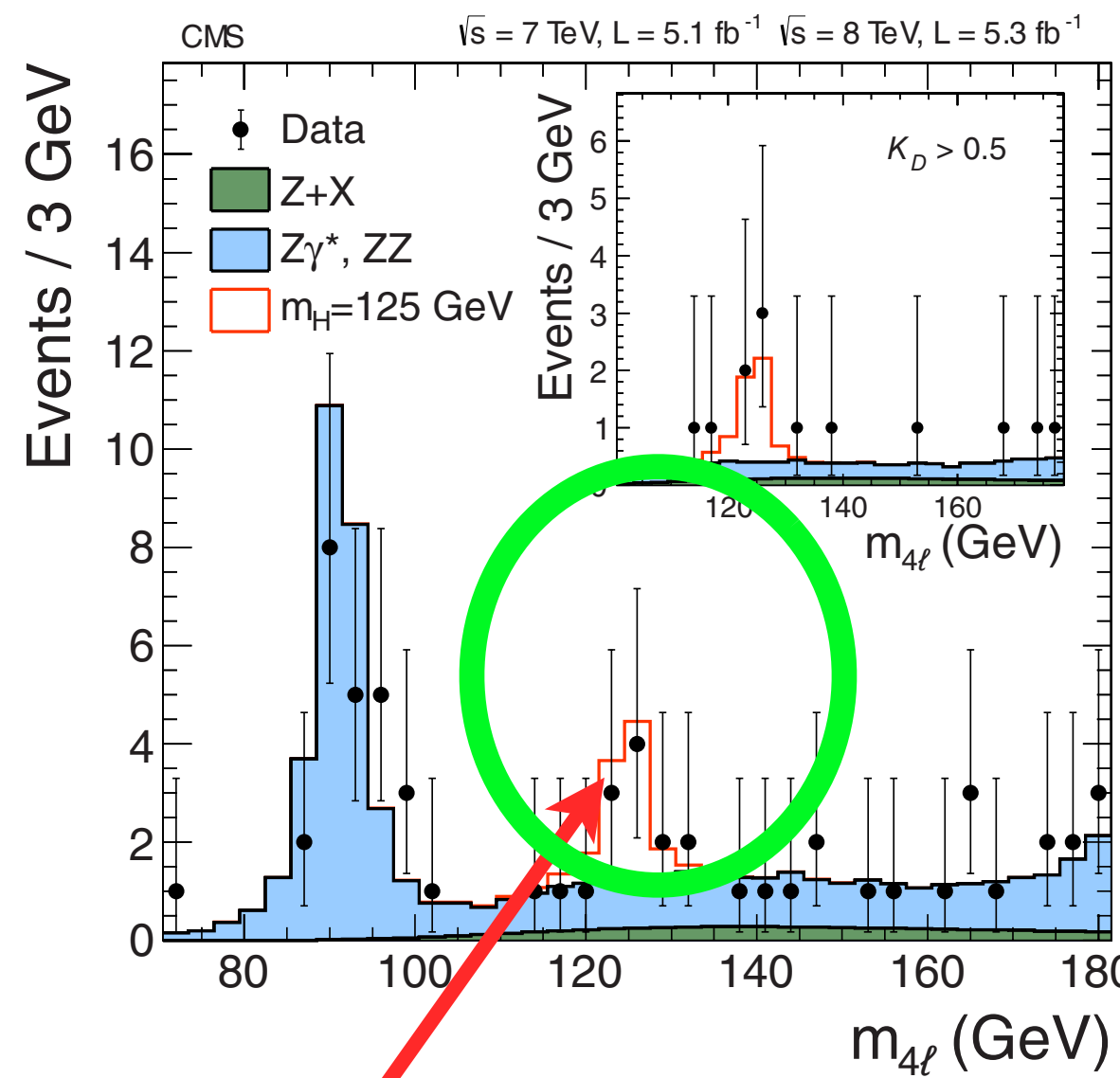
Excess also observed in WW channel

## H → 2 photons



background + Higgs boson

H → 4 leptons

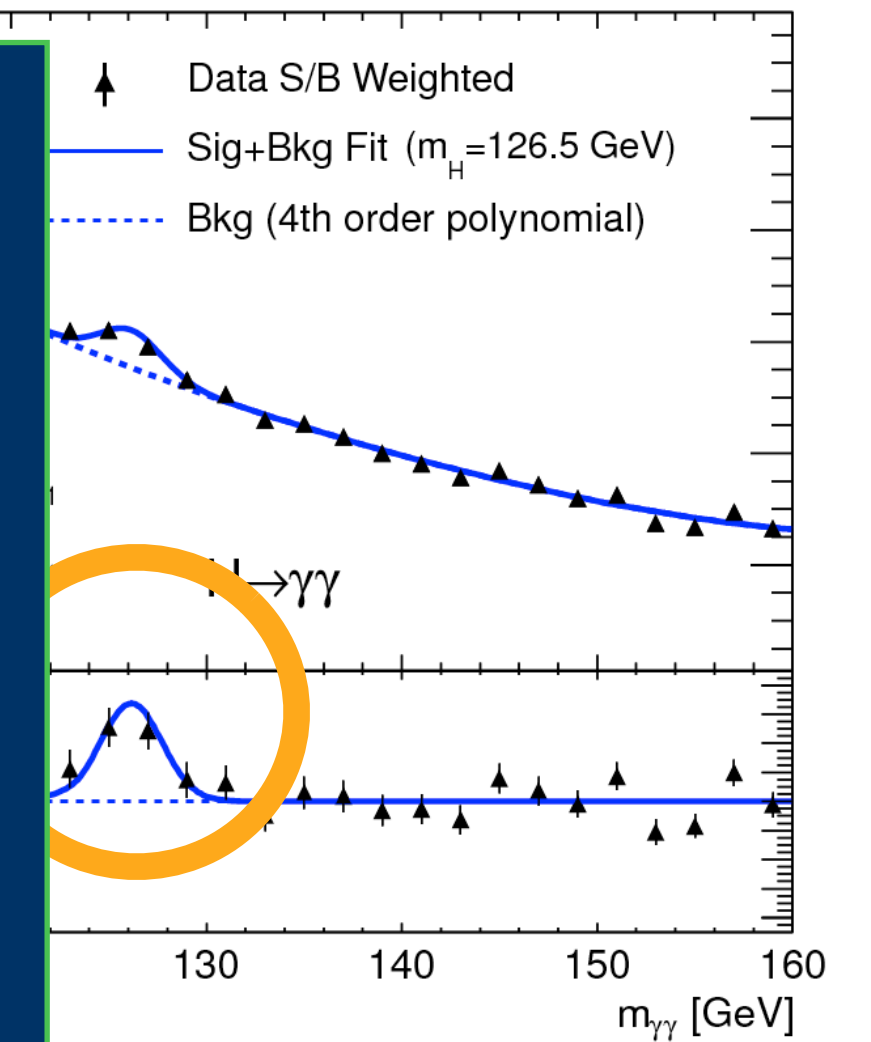


Higgs boson (prediction)

background

ATLAS & CMS  
collaborations have  
observed the  
Higgs boson

H → 2 photons

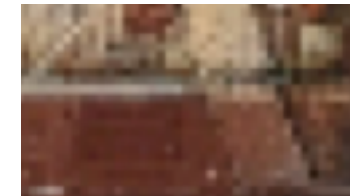
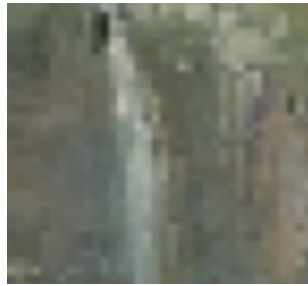
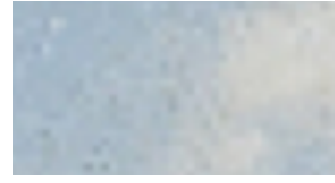
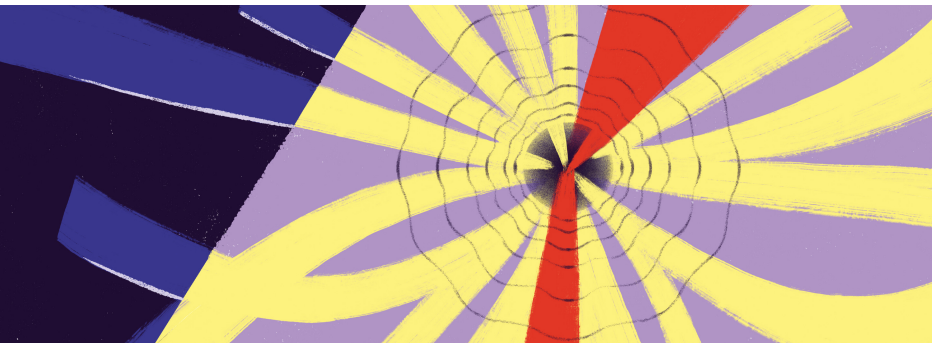


background + Higgs boson

Data *need* the Higgs boson.

Excess also observed in WW channel

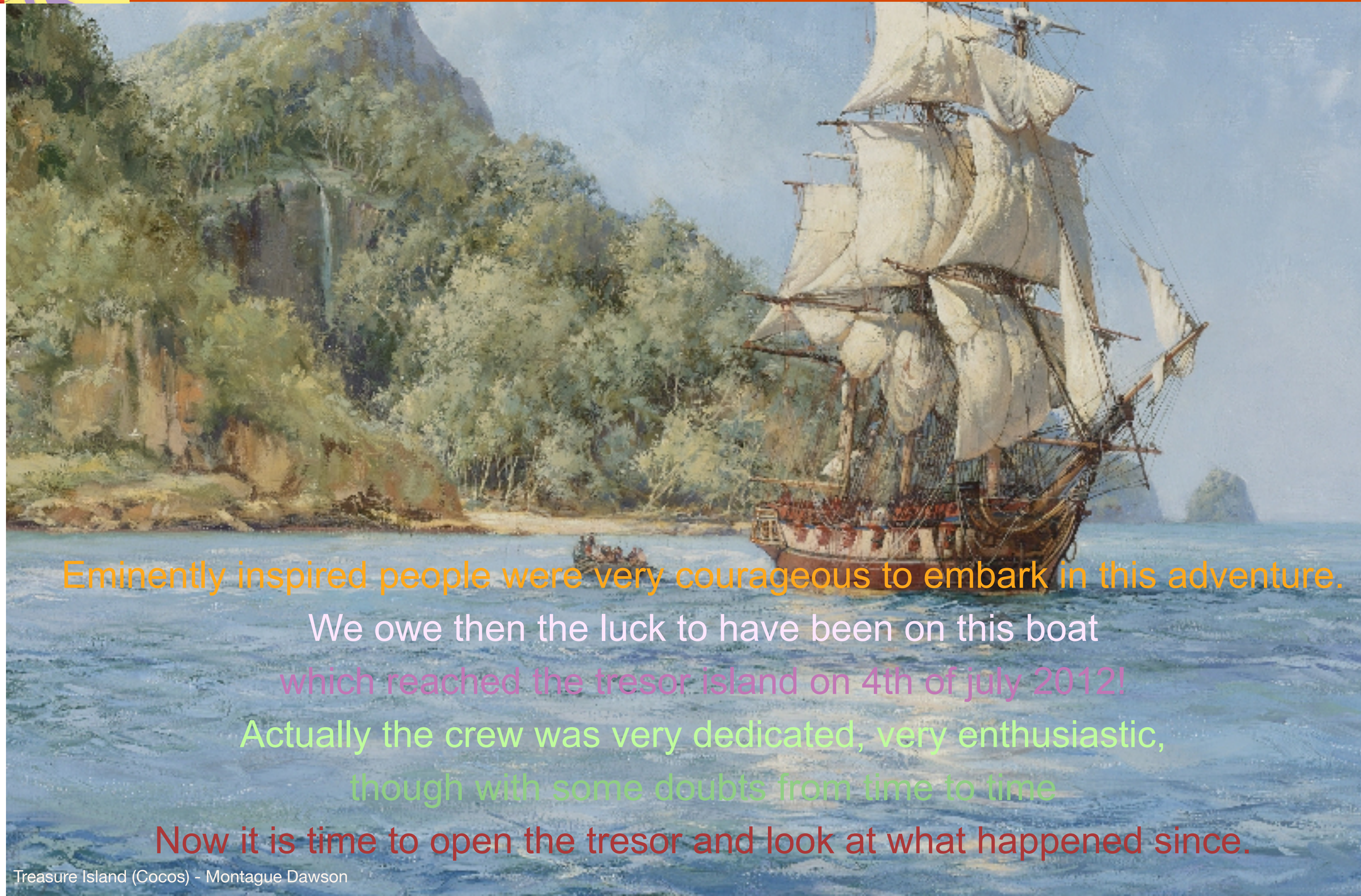
# EN ROUTE vers une DÉCOUVERTE ?



# THIS IS ACTUALLY THE BEGINNING



# THIS IS ACTUALLY THE BEGINNING



Eminently inspired people were very courageous to embark in this adventure.

We owe then the luck to have been on this boat

which reached the tresor island on 4th of July 2012!

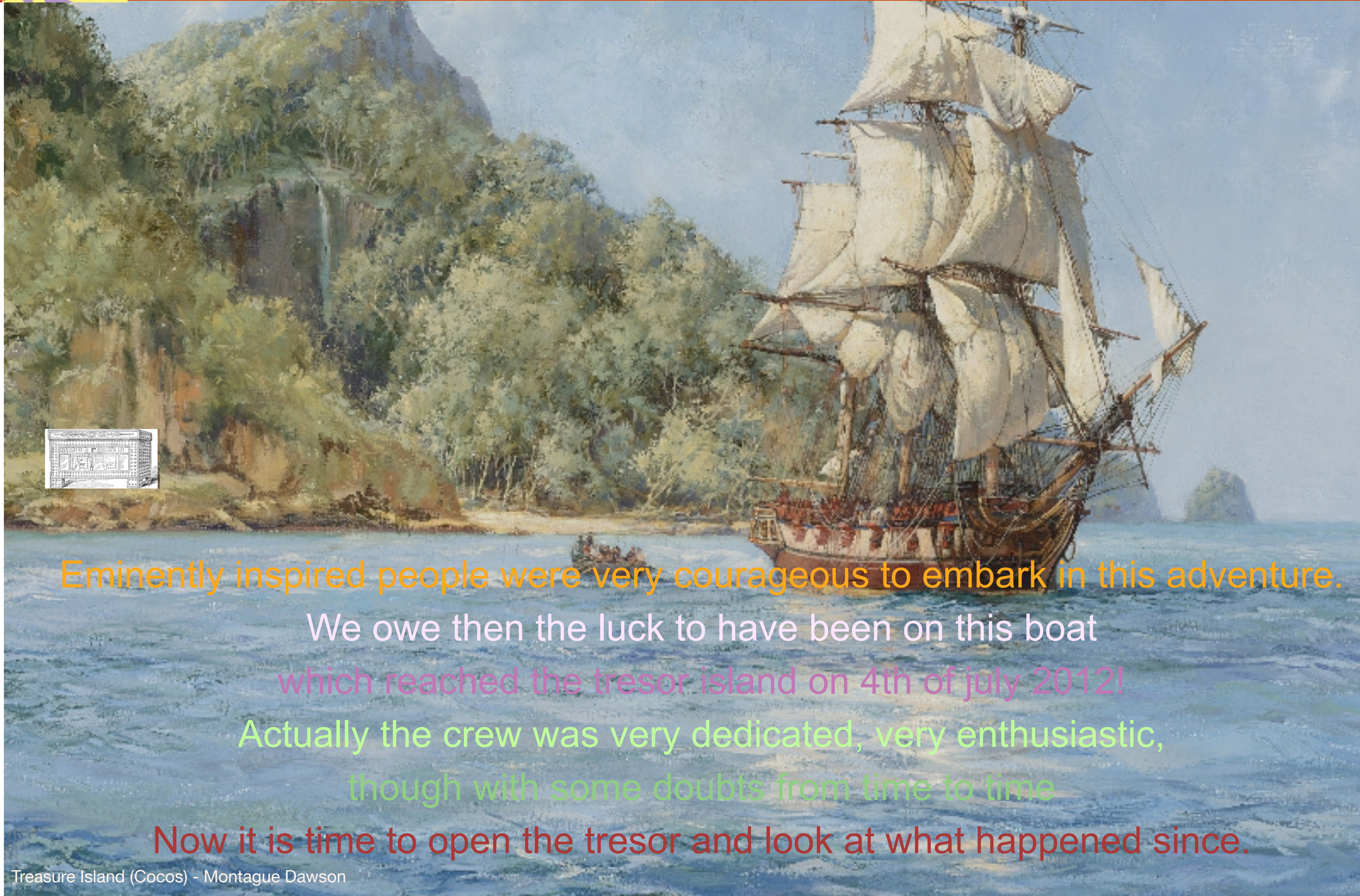
Actually the crew was very dedicated, very enthusiastic,

though with some doubts from time to time

Now it is time to open the tresor and look at what happened since.



# THIS IS ACTUALLY THE BEGINNING



Eminently inspired people were very courageous to embark in this adventure.

We owe then the luck to have been on this boat

which reached the tesor island on 4th of july 2012!

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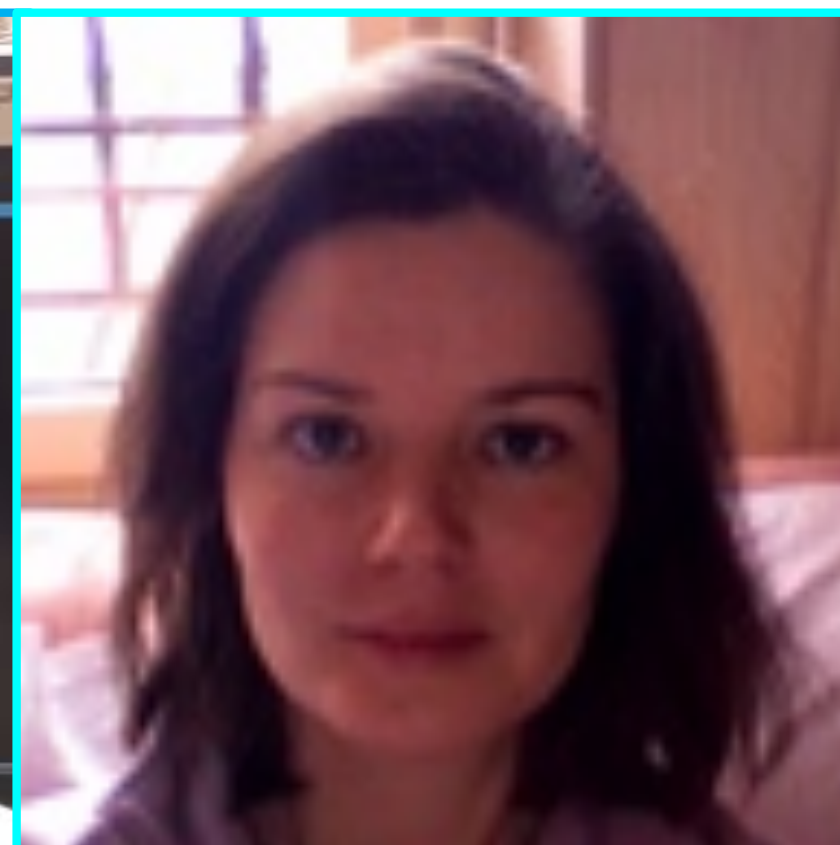
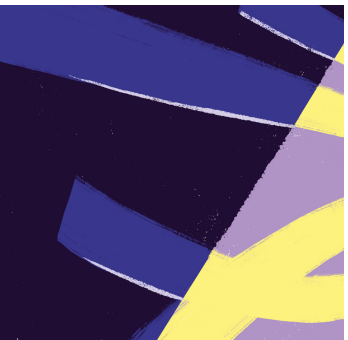










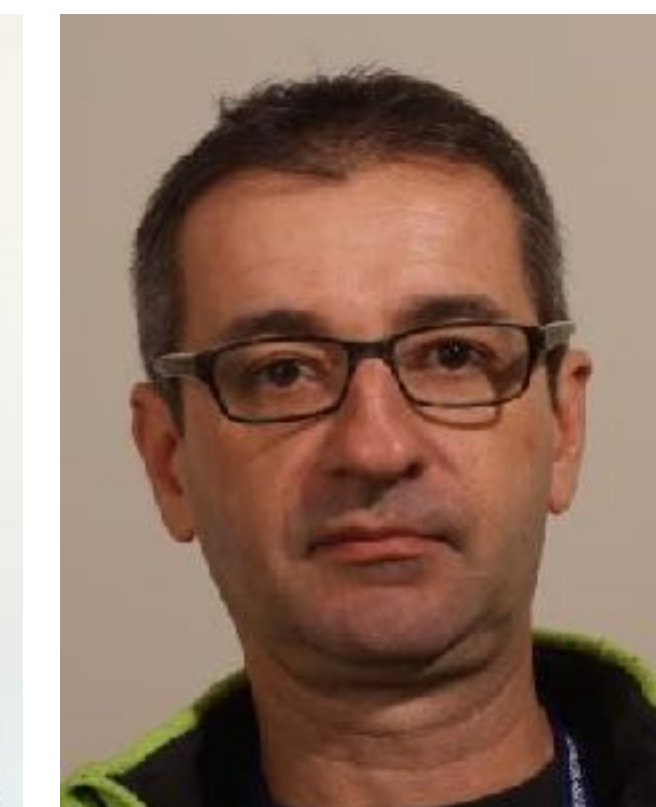


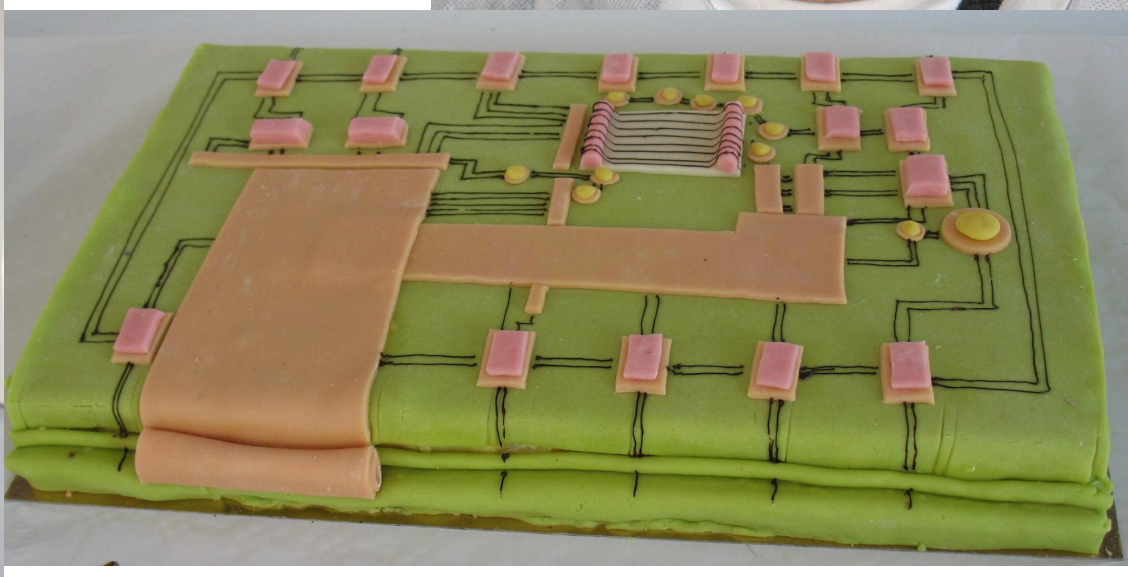
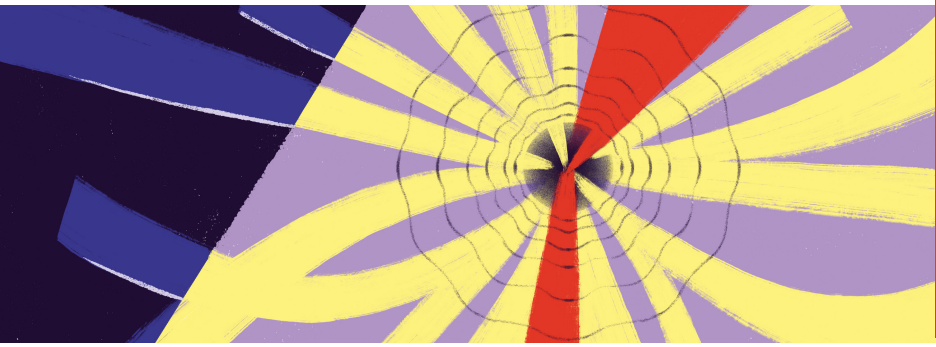


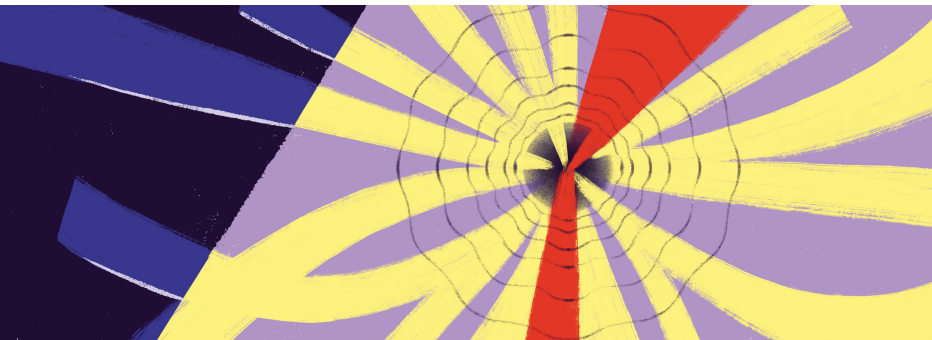
06.07.2022











# LE MOT DE LA FIN

# MERCI

Suzanne Gascon-Shotkin

Djamel Boumediène

Jean-François Muraz

Farès Djama

Didier Laporte

Jennifer Grapin

Louis Fayard

Philippe Busson

Laurent Duflot

Anne-Catherine Le Bihan

Eric Vigeolas

Lydia Roos

Olivier Linossier

Stéphane Jézéquel

Tanya H'rynova

Florian Beaudette

Andrea Jérémie

Elisabeth Petit

Julie Prast

Didier Contardo

Fairouz Malek

Marlon Barbero

Daniel Bloch

Anne-Catherine Le Bihan  
Reina Camacho Toro  
Nicolas Morange  
Elisabeth Petit  
Roberto Salerno