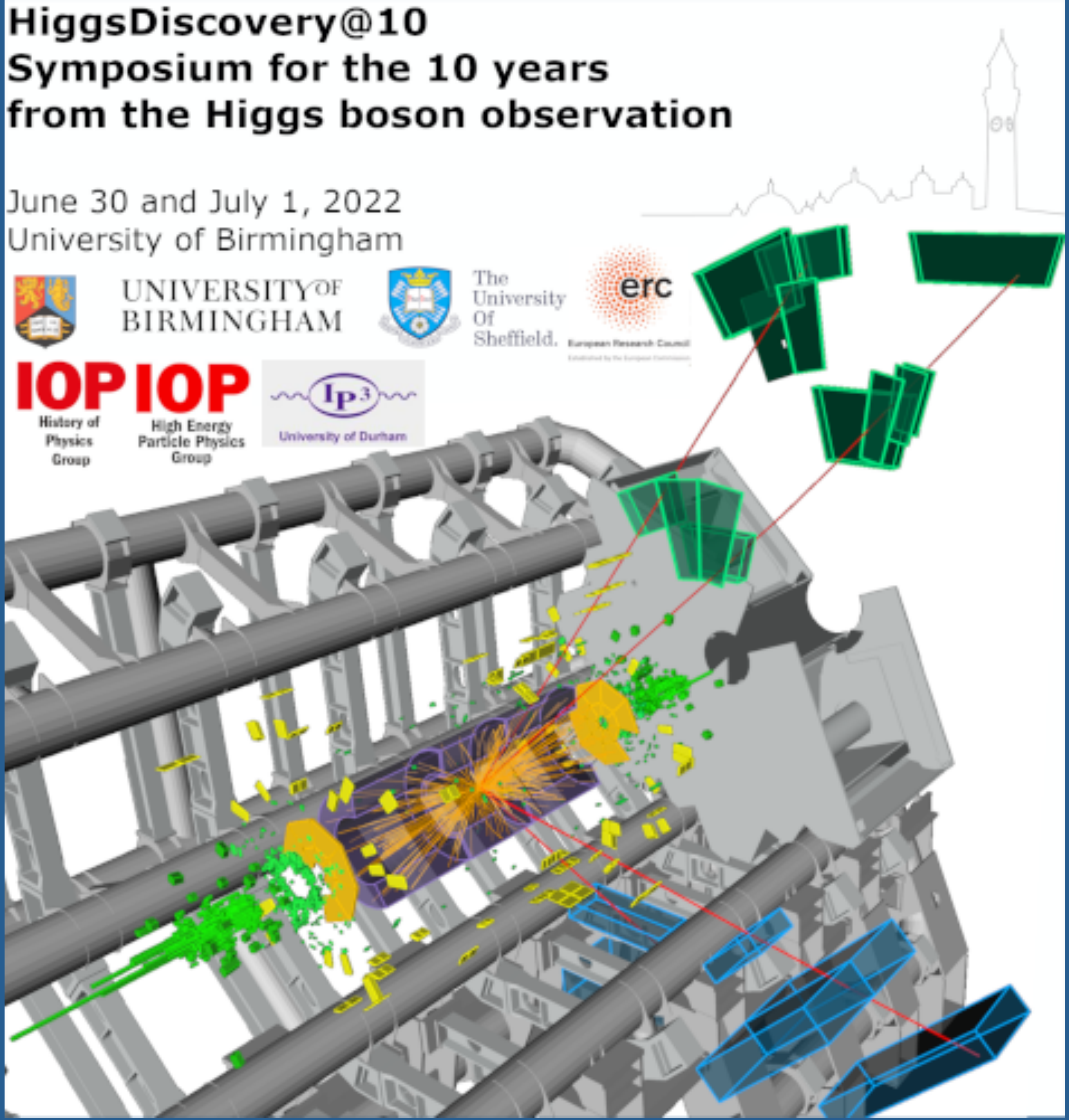
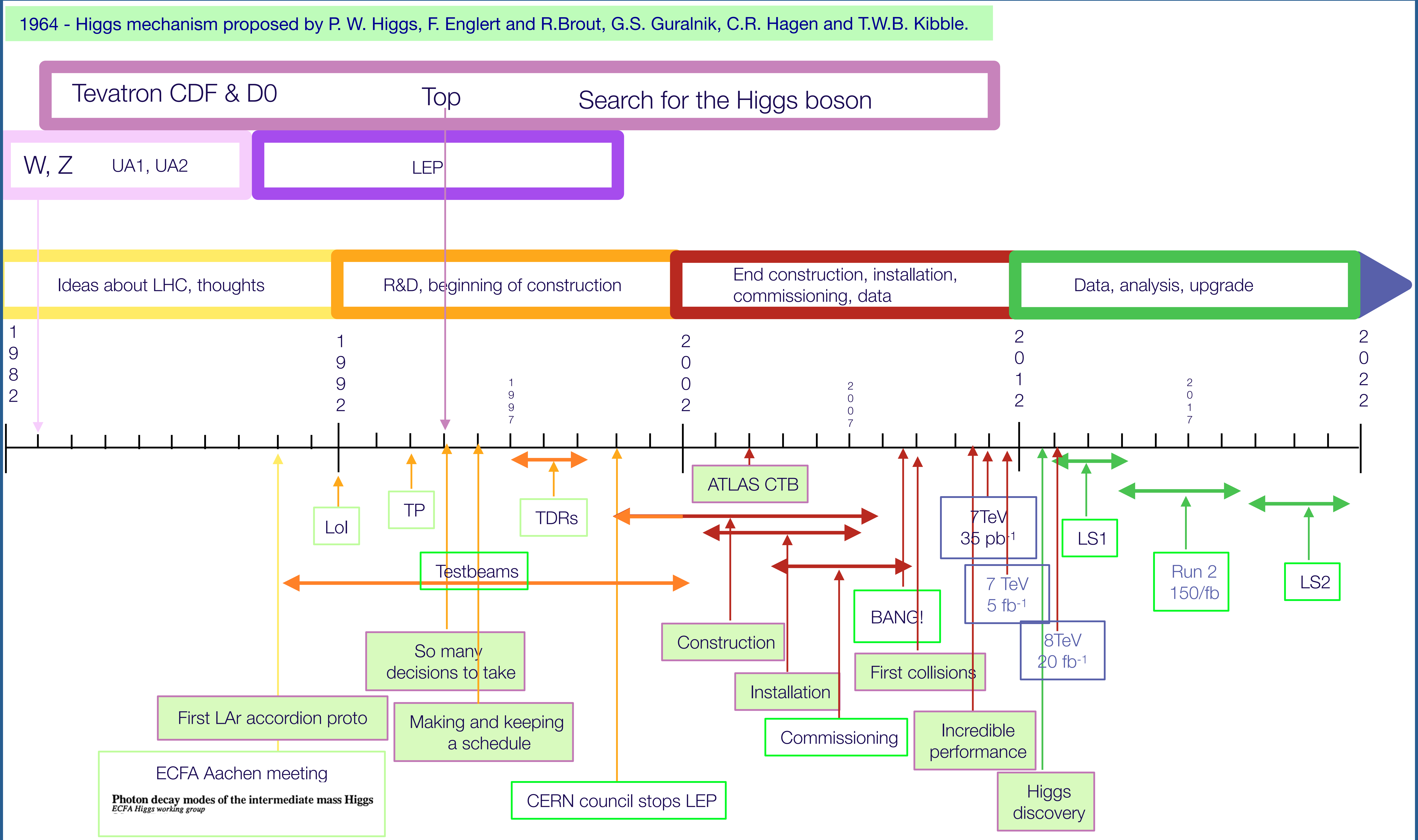
PREPARING for a DISCOVERY



Isabelle Wingerter-Seez
CNRS - Centre de Physique des Particules de Marseille
HiggsDiscovery@10 - Birmingham



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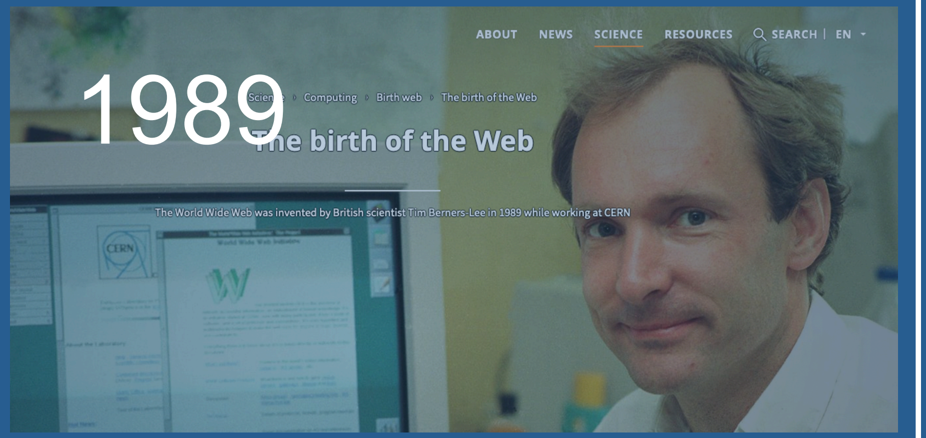

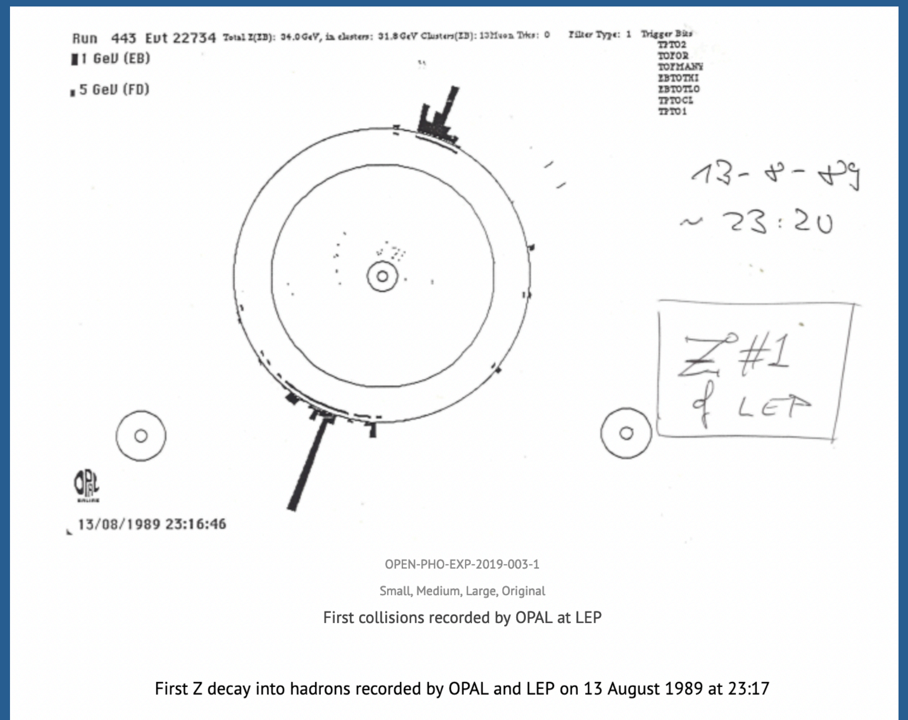

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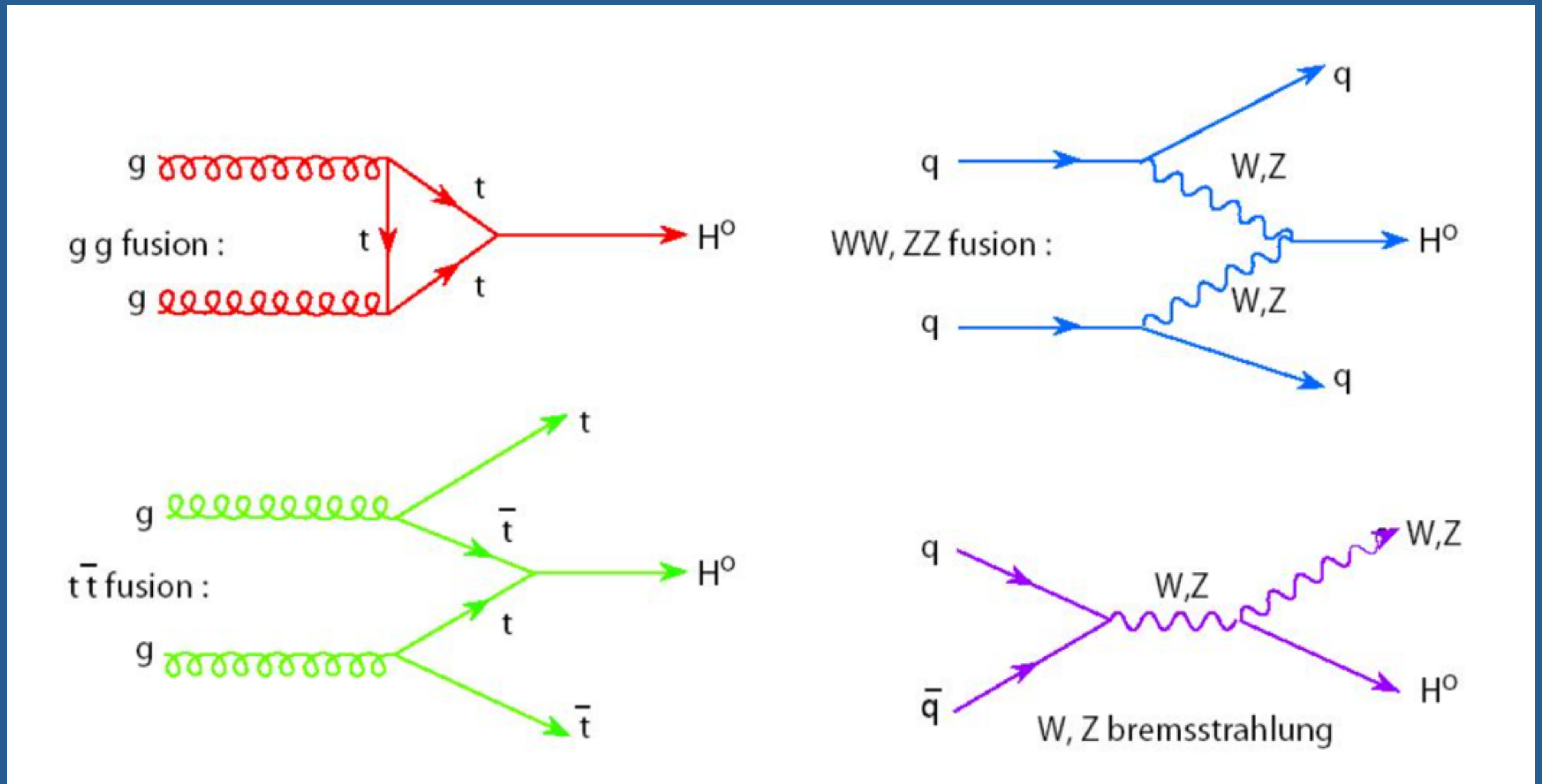
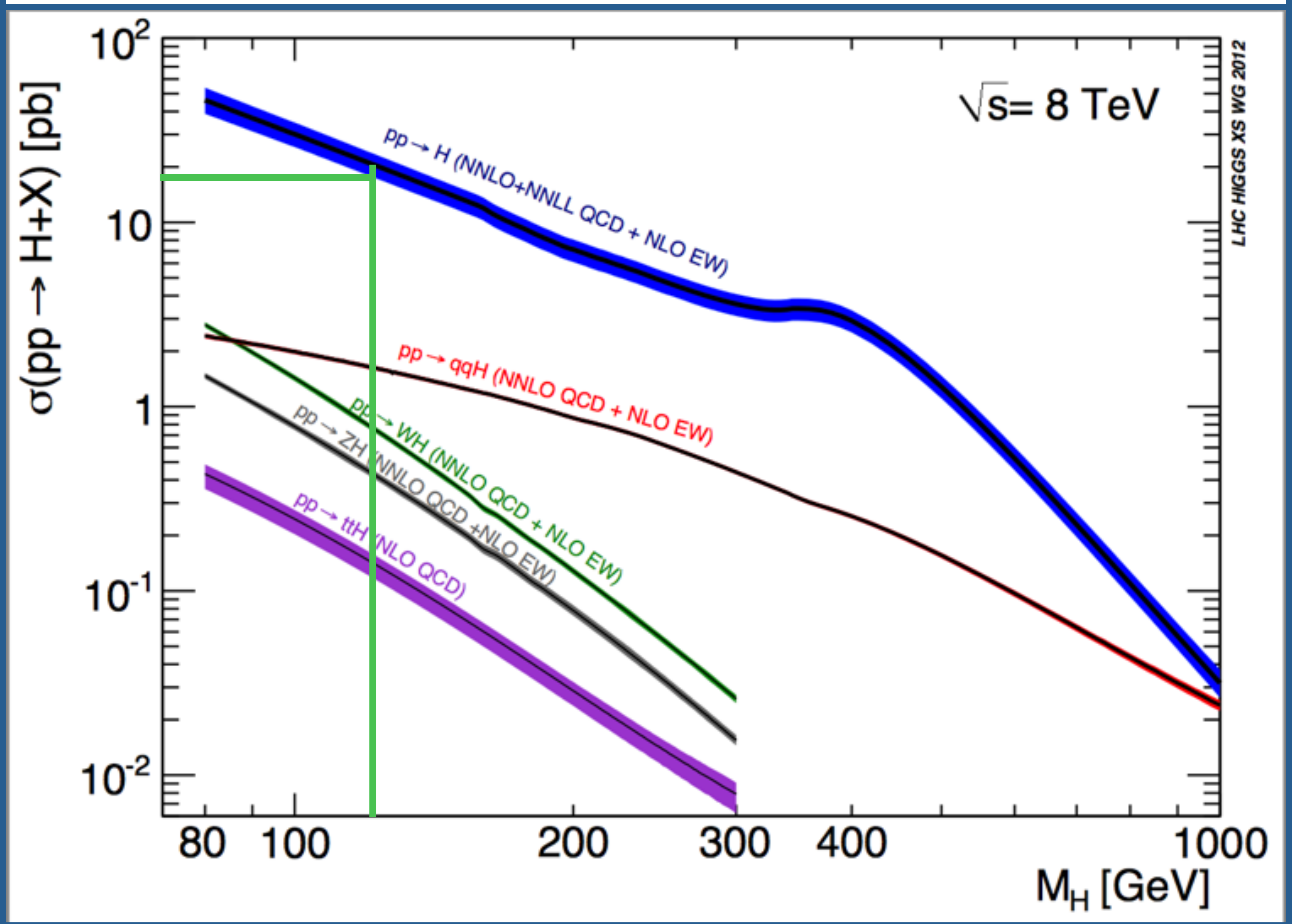
HOW CAN the HIGGS BOSON be PRODUCED ?

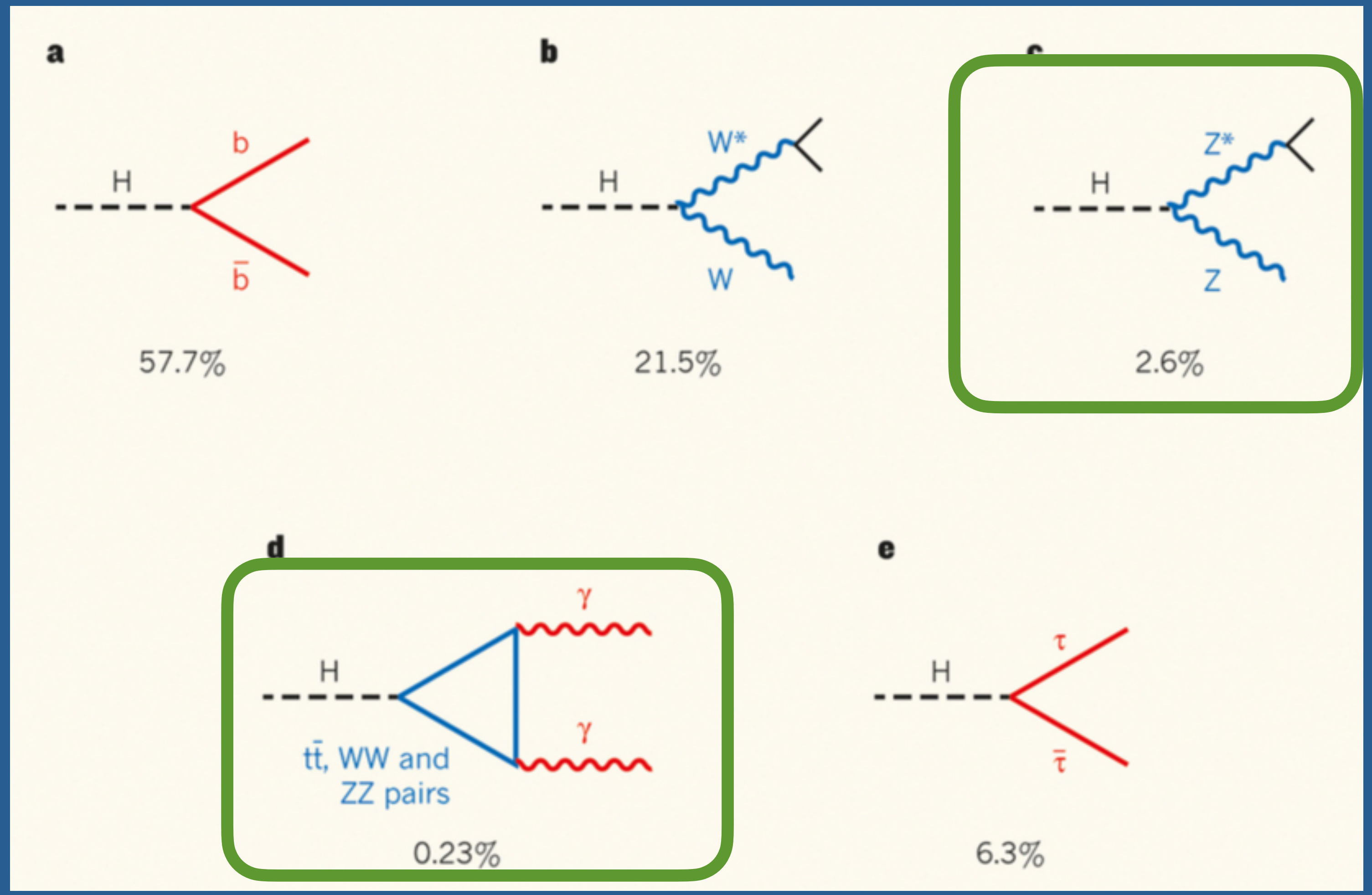
STANDARD MODEL PREDICTIONS

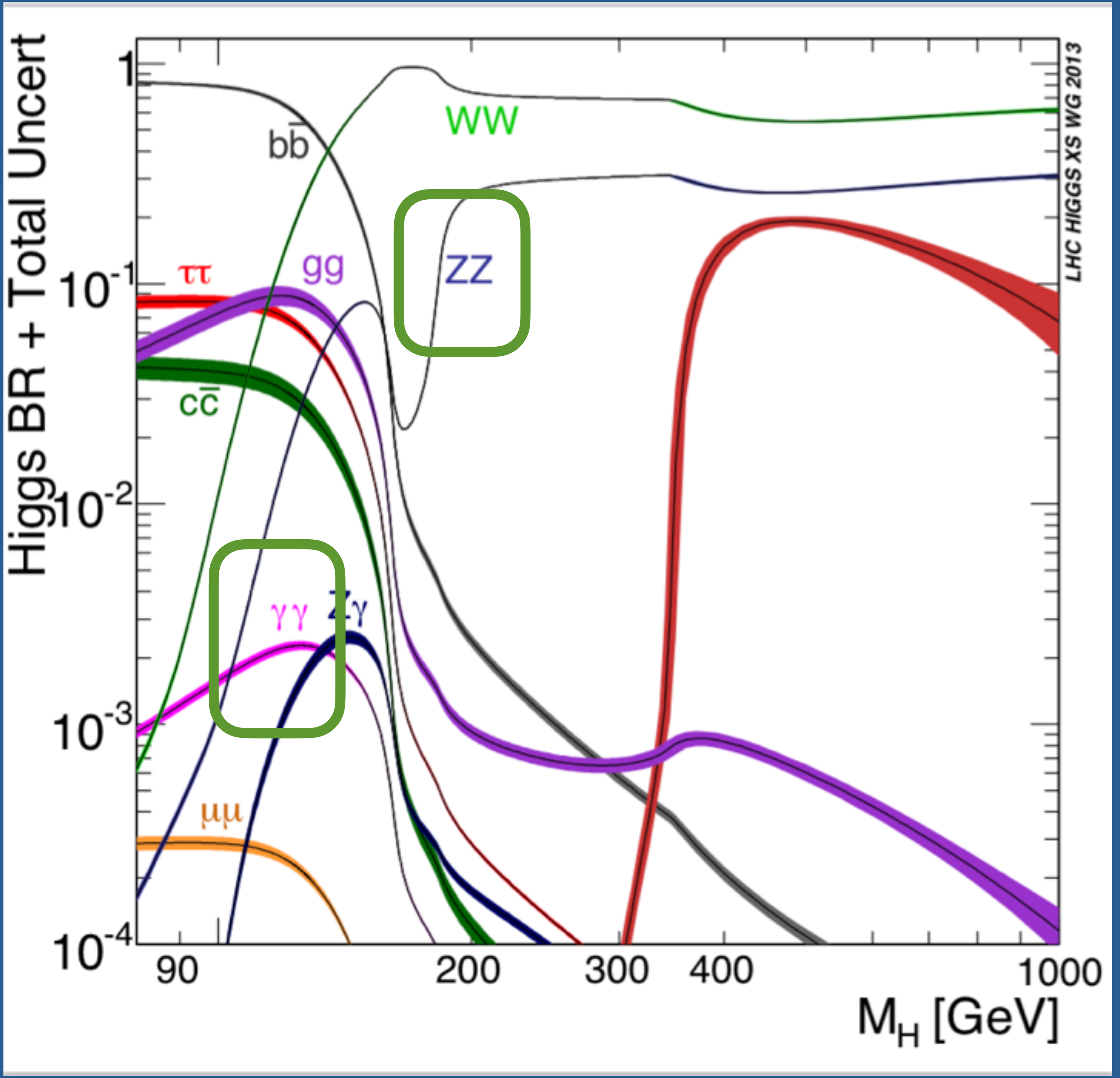
Production





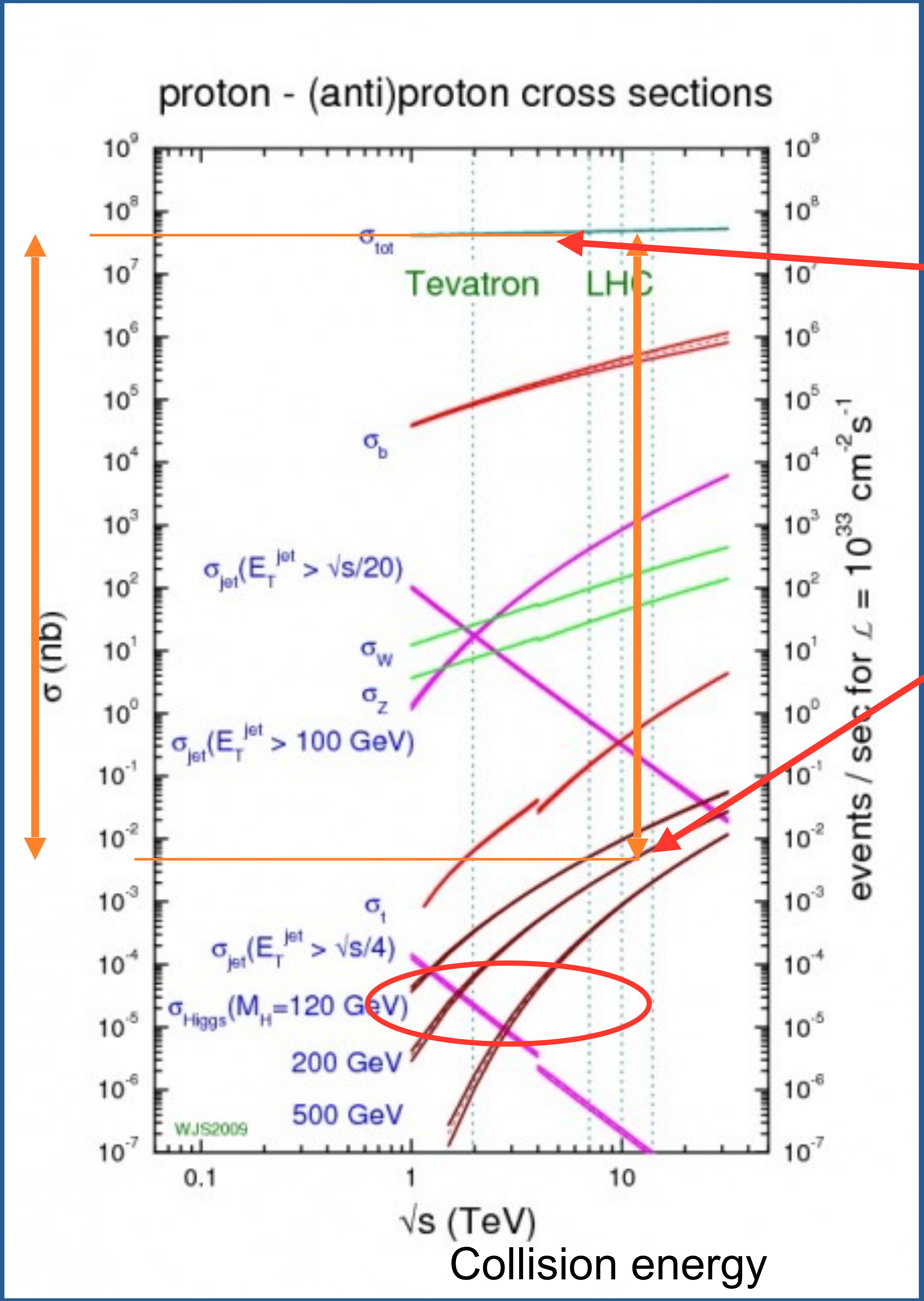
Decays





HIGGS PRODUCTION in proton-proton collisions

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 ~10-100 pico-barn.

High energy to explore unknown territory

High frequency & high beam intensity:

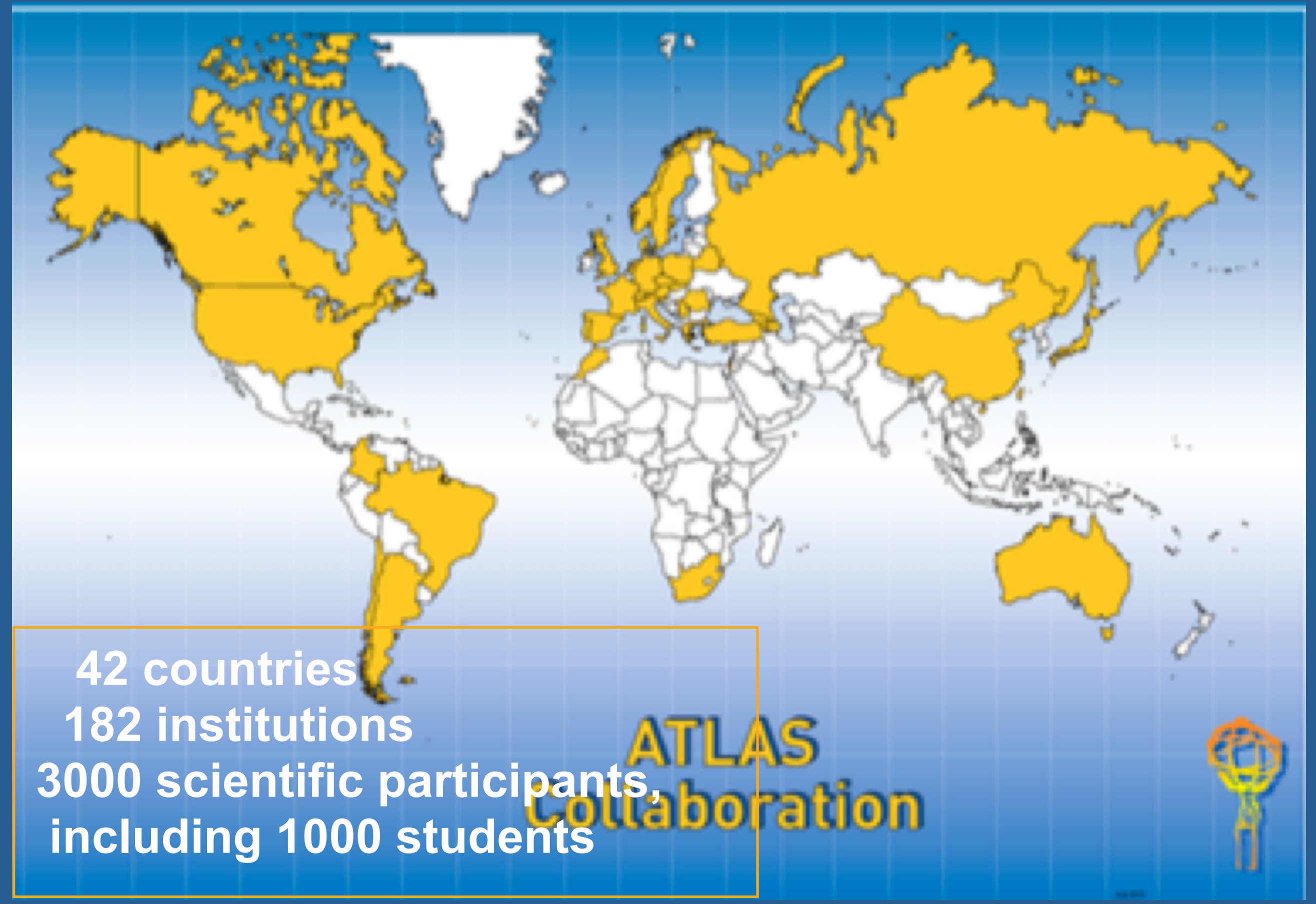
Maximize number of proton-proton collisions

Try to reveal rare phenomena.

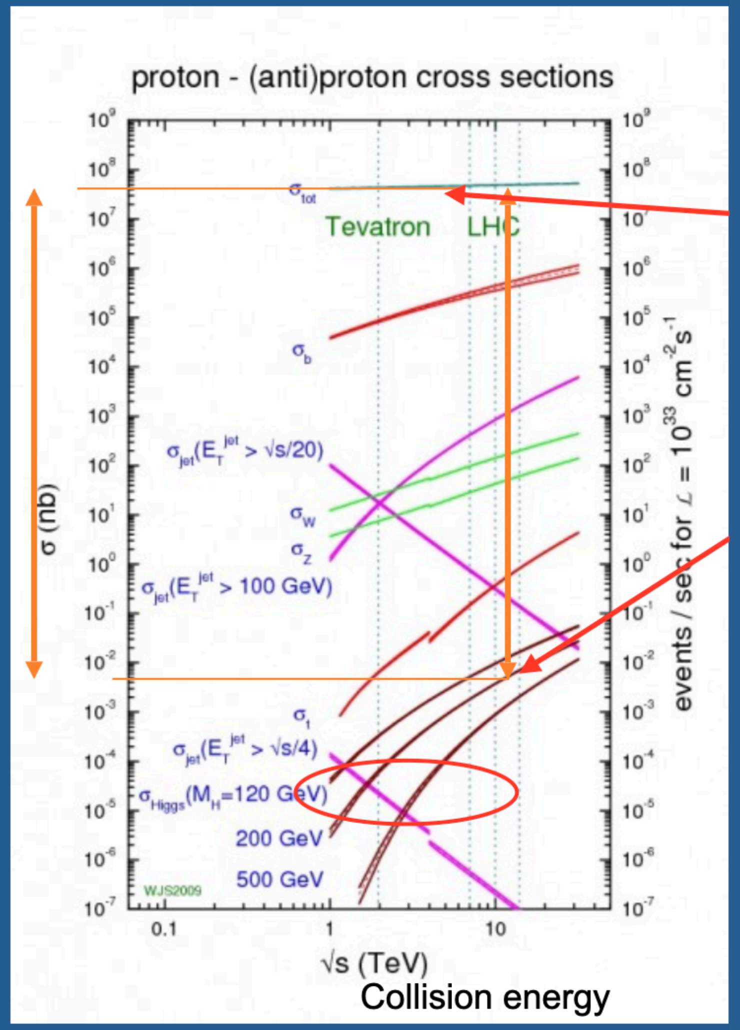
This good idea came with many many obstacles to master

No access

A large collaboration

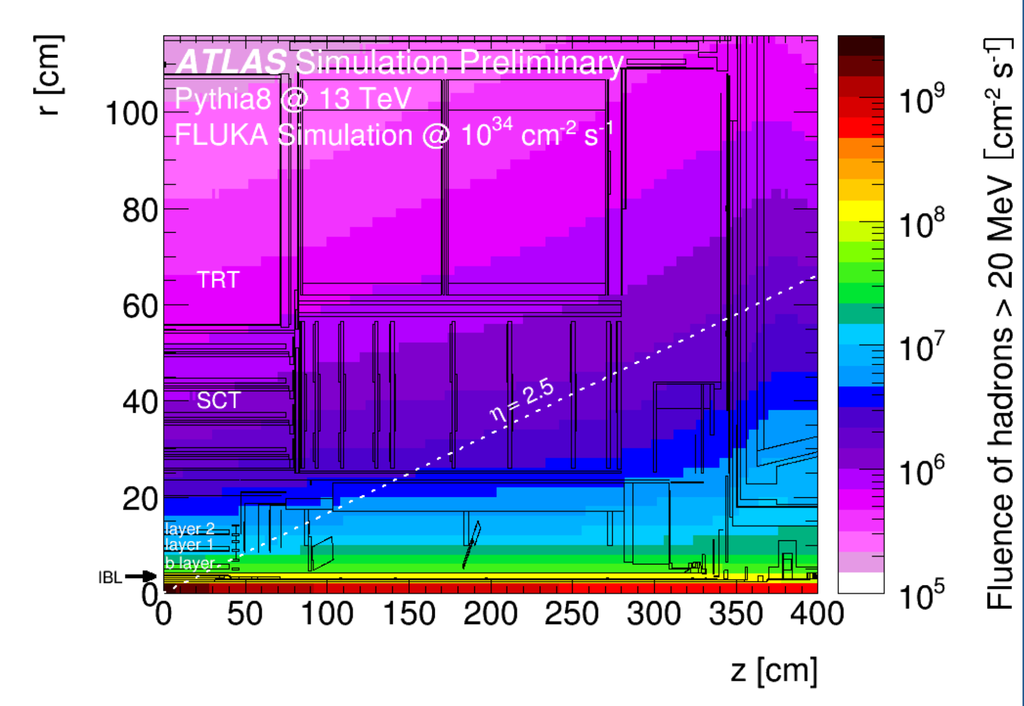


	LHC design	LHC 2012	LEP
√s [TeV]	14 TeV	7 TeV	0.09 - 0.2
Δt [ns]	25	50	2000
Nbre bunchs	2808	1380	4-8
p/bunch [10^{11}]	1.15	1.7	2.5
Peak luminosity [10^{34} $cm^{-2}s^{-1}$]	1	0.77	0.01 Max
Max nbre events/corssing	20	35	1
Stored beam energy [MJ]	362		



10^{-9}

Trigger

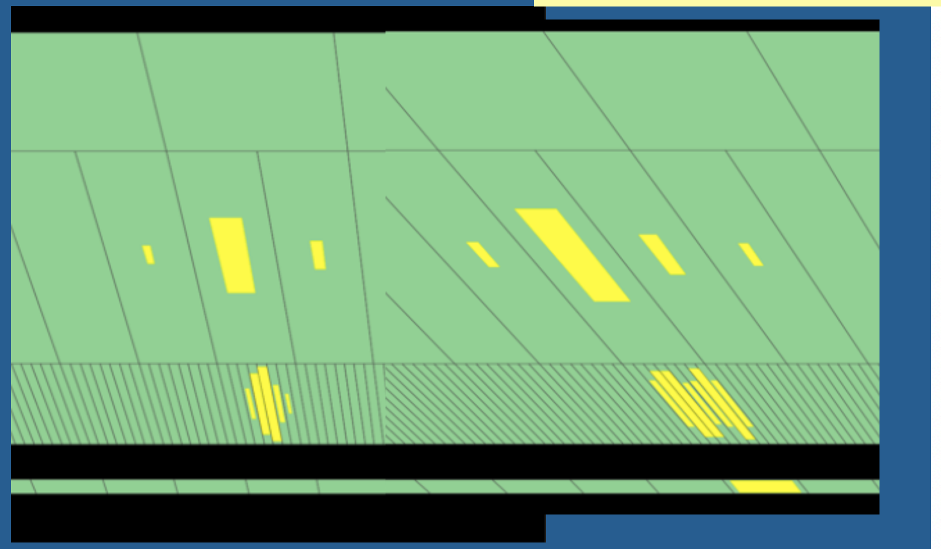


Radiations

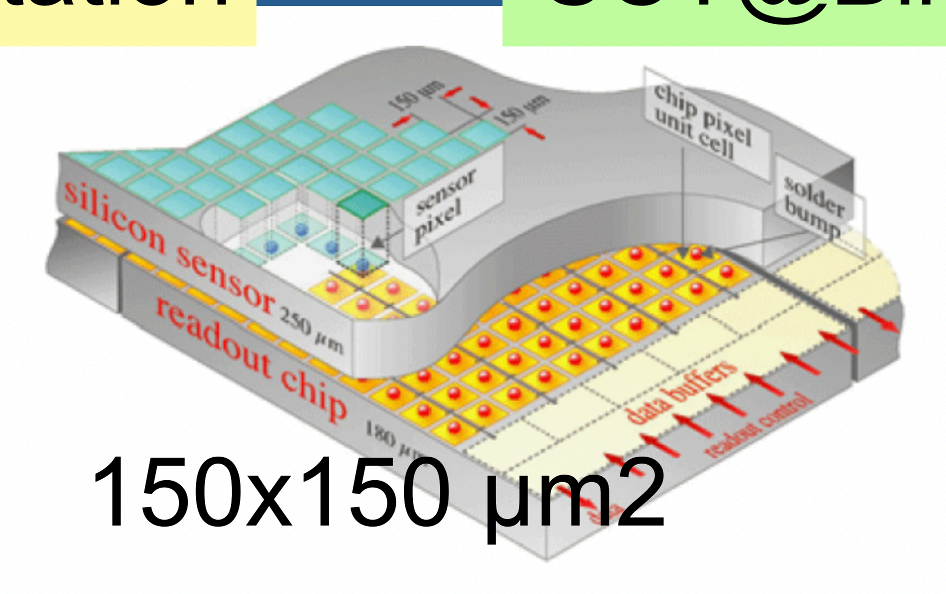
L1 Calo@Birmgham

	LHC	LEP
Crossings	40 MHz	50 kHz
L1 trigger	100 kHz	1 Hz
On disk	1 kHz	-

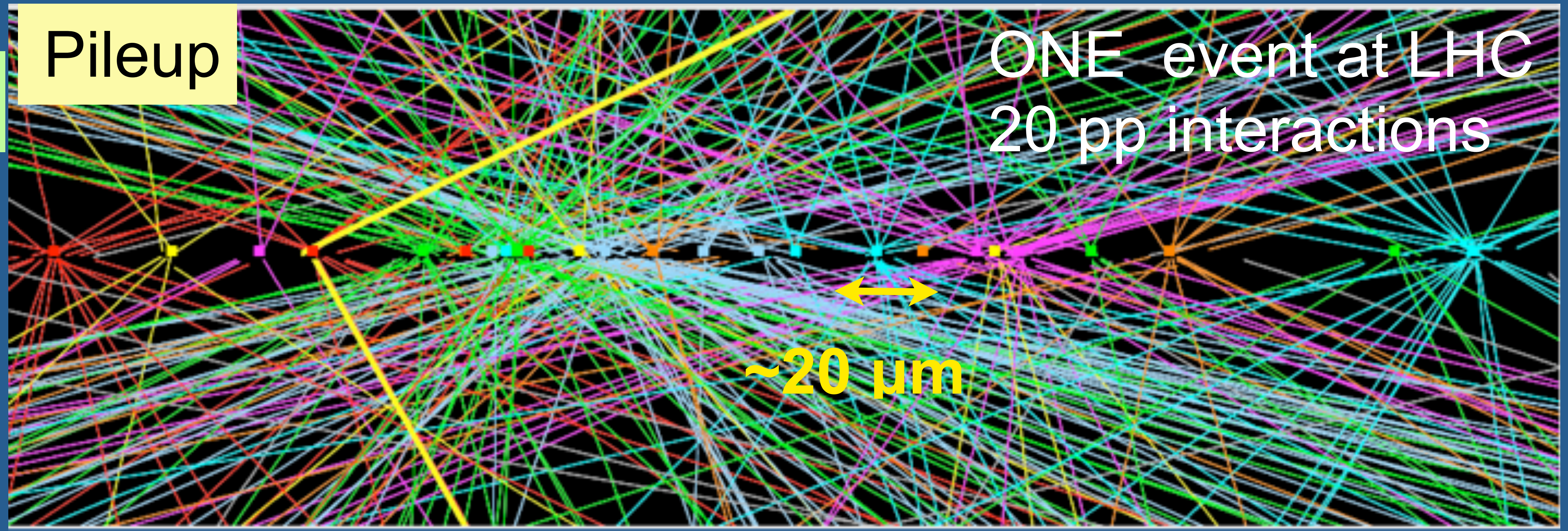
Segmentation



SCT@Birmingham



Pileup



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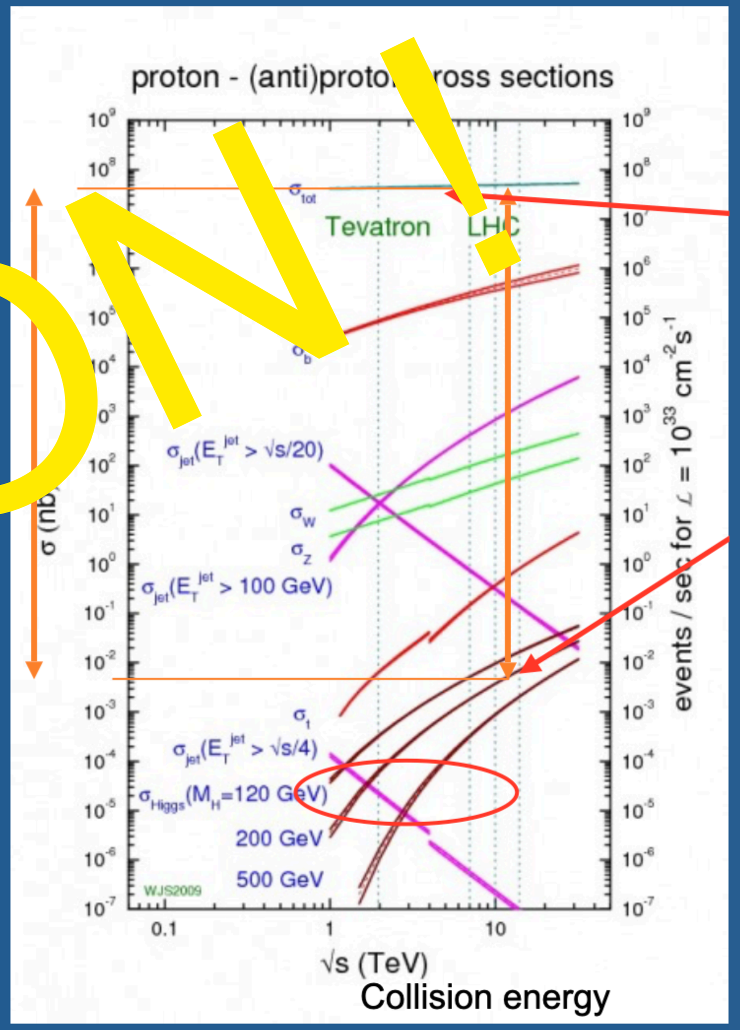
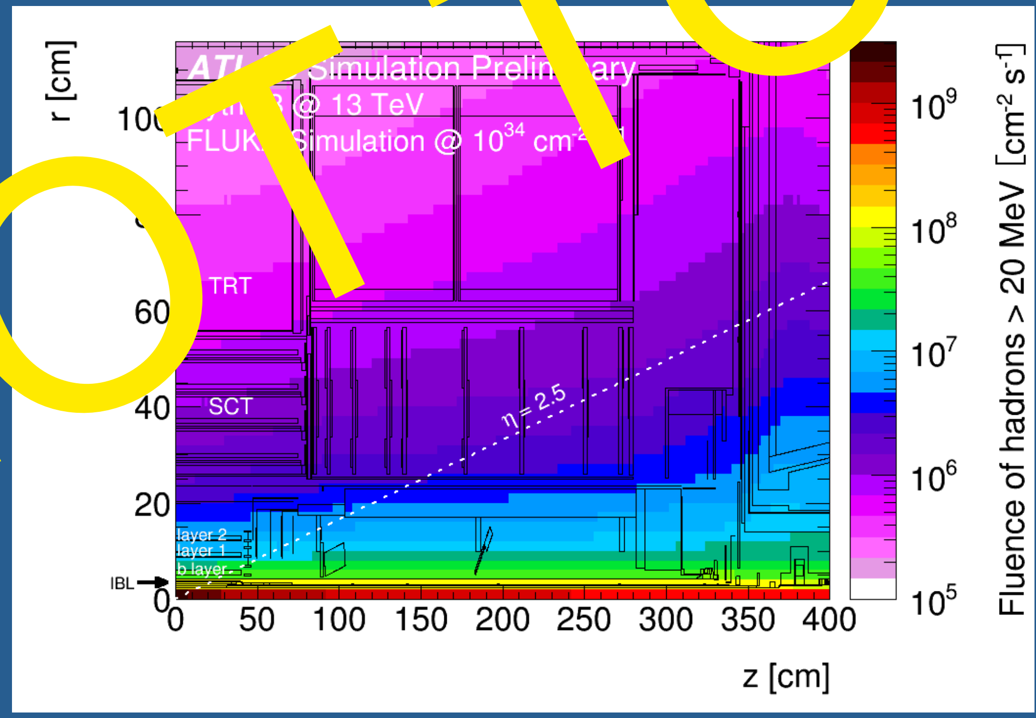
QUITE A LOT TO CHEW ON !



Trigger

Radiations



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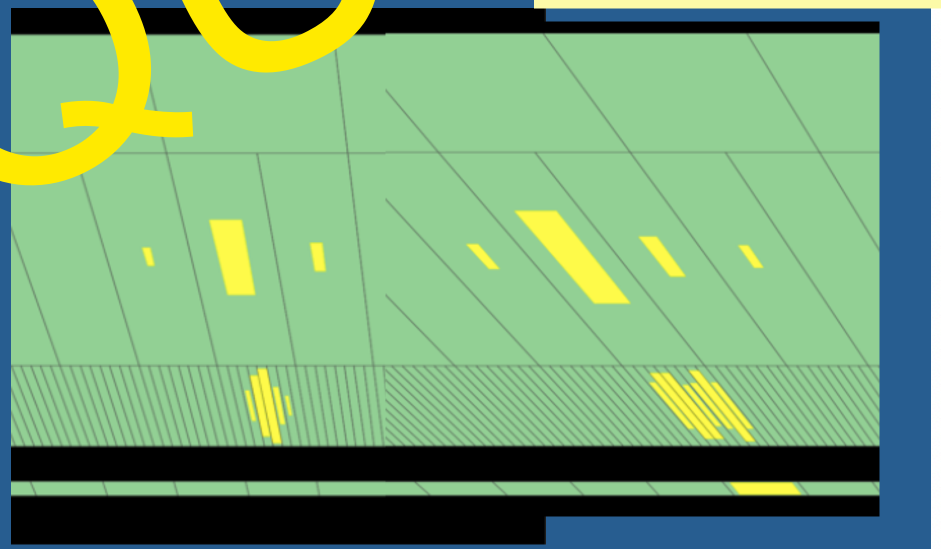

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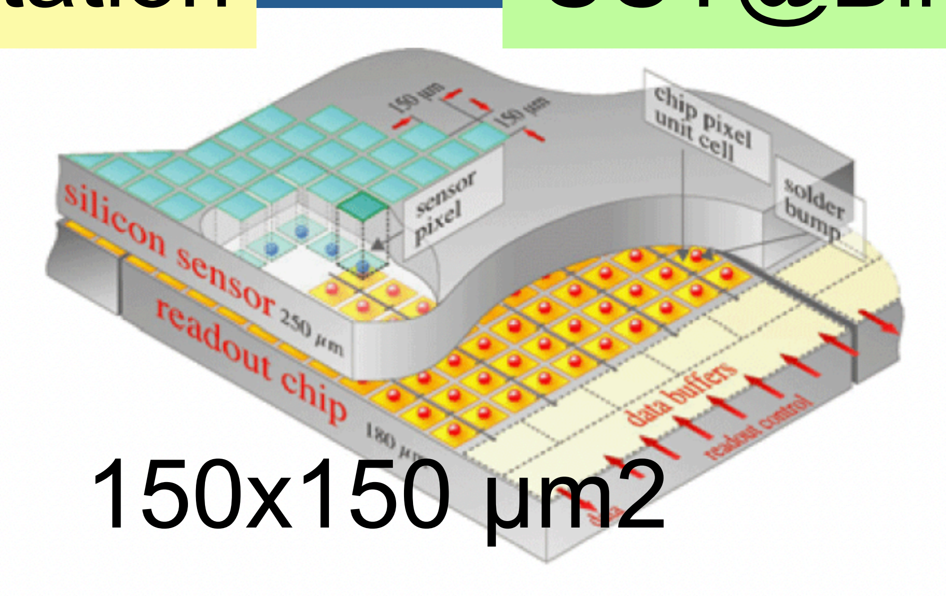

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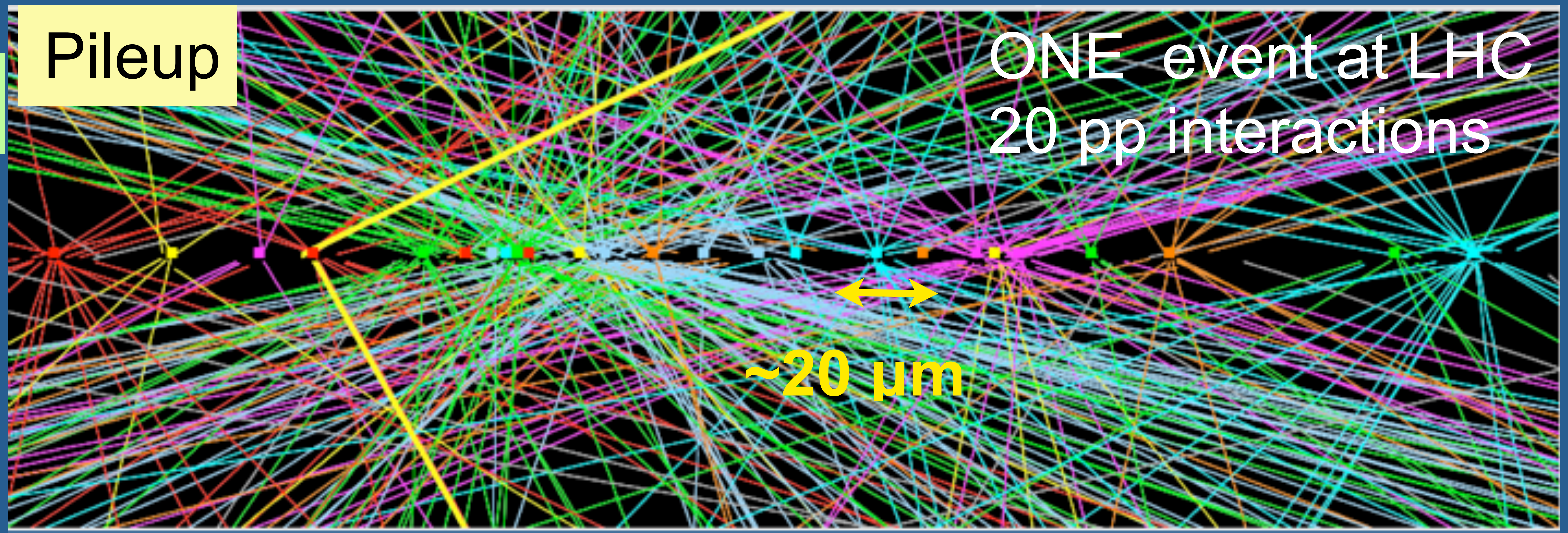

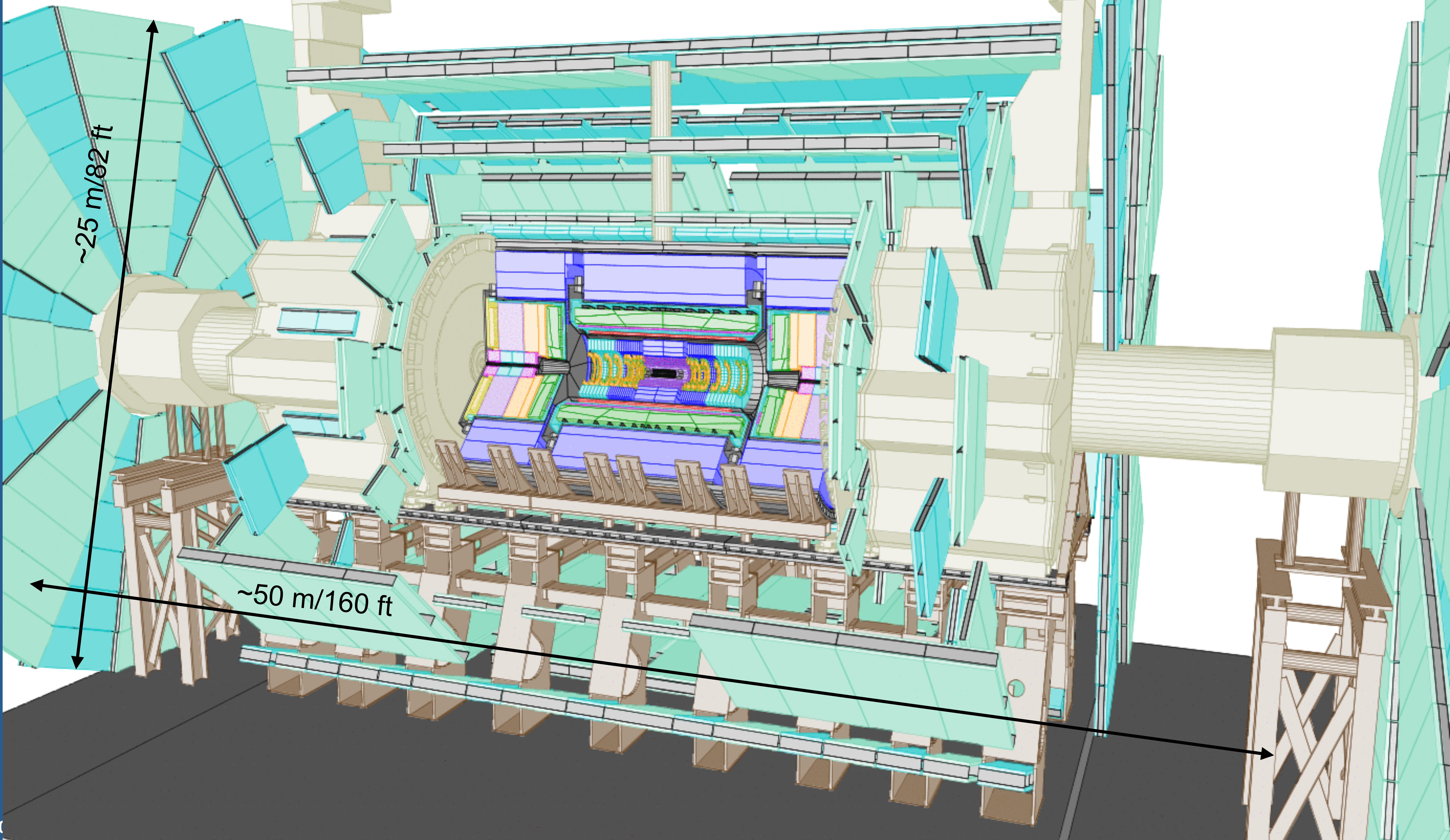
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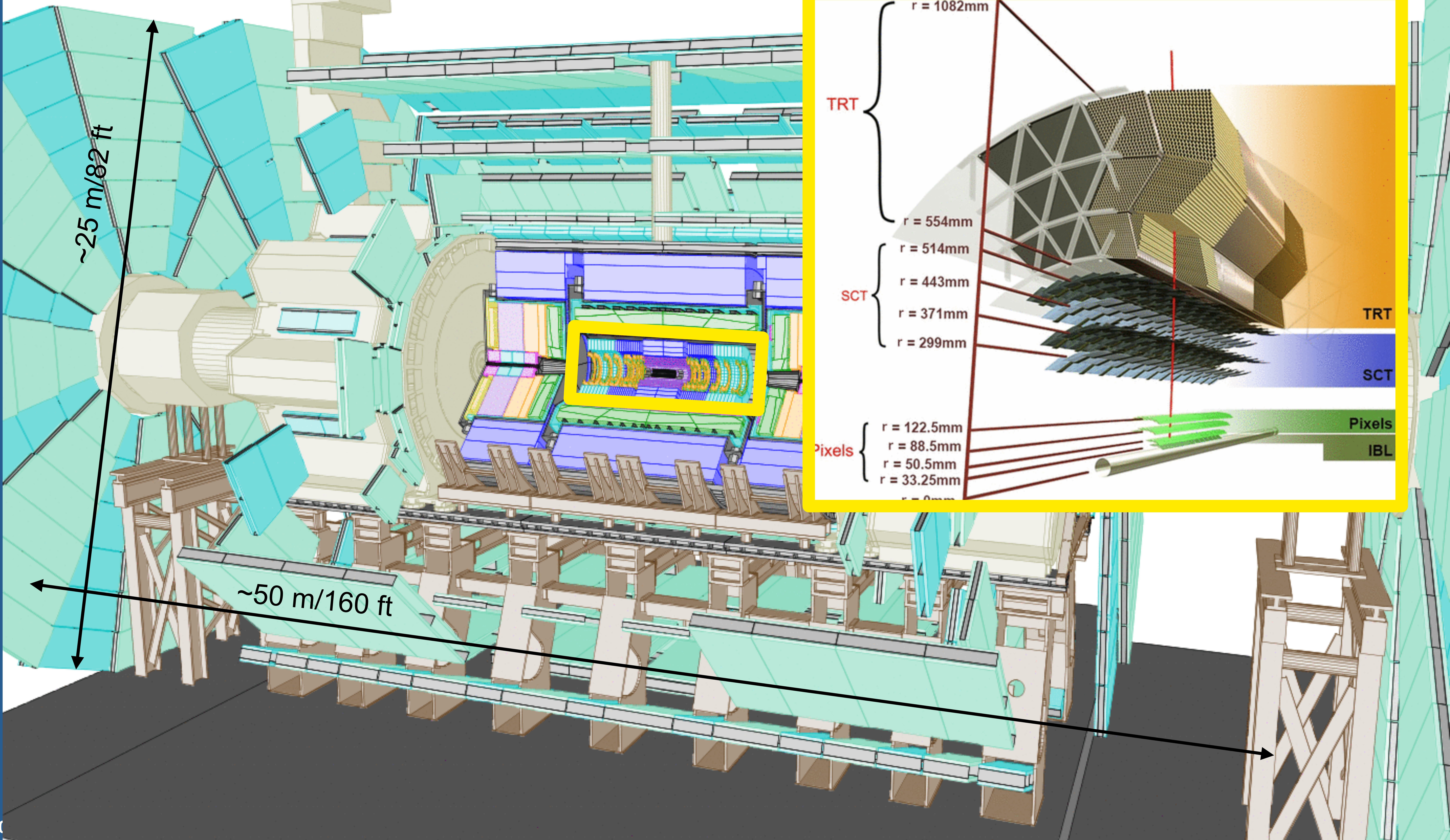
~50 m/160 ft


~25 m/82 ft
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TRT
r = 554mm
r = 514mm
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SCT
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r = 299mm
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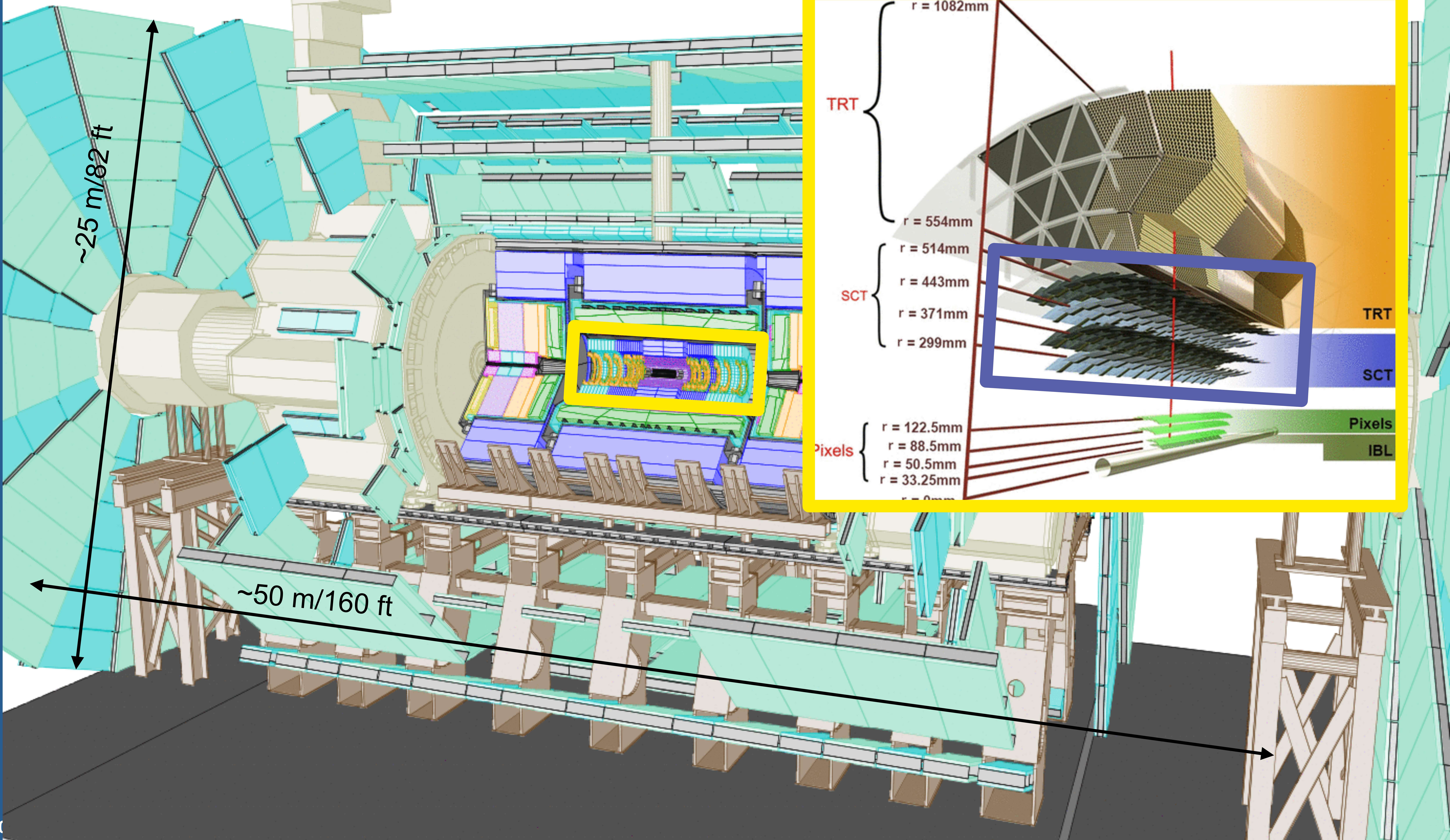
Pixels
r = 50.5mm
r = 33.25mm
Pixels
IBL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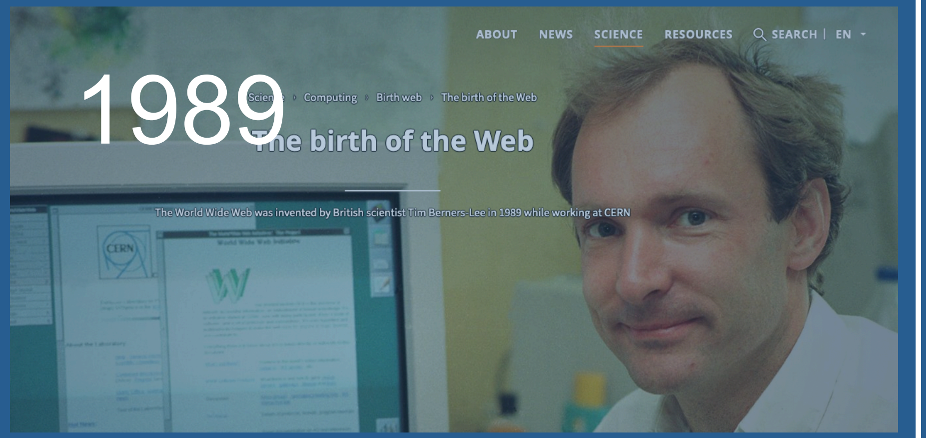
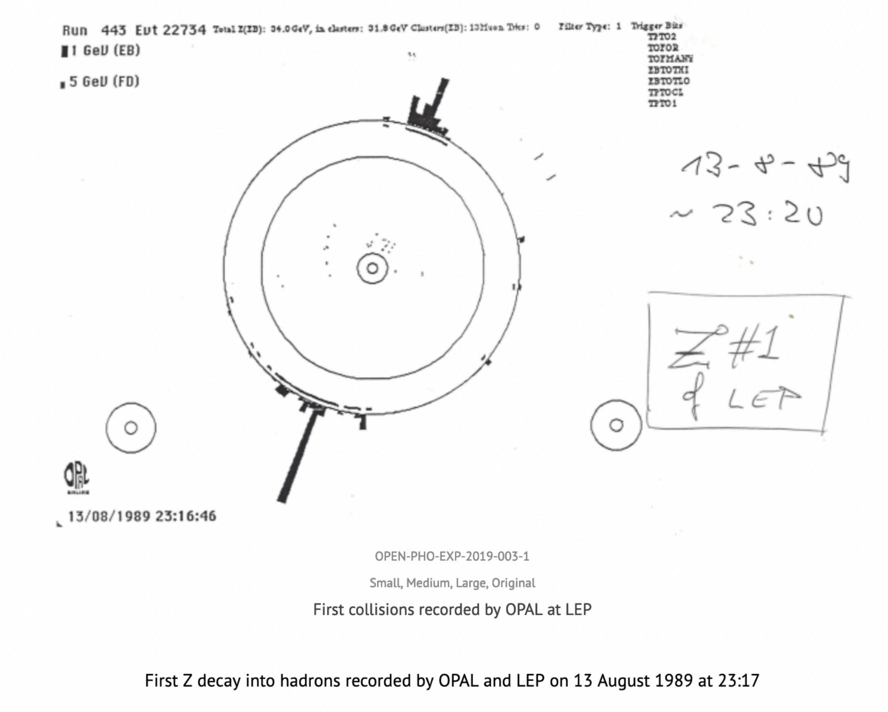
Back in 1990





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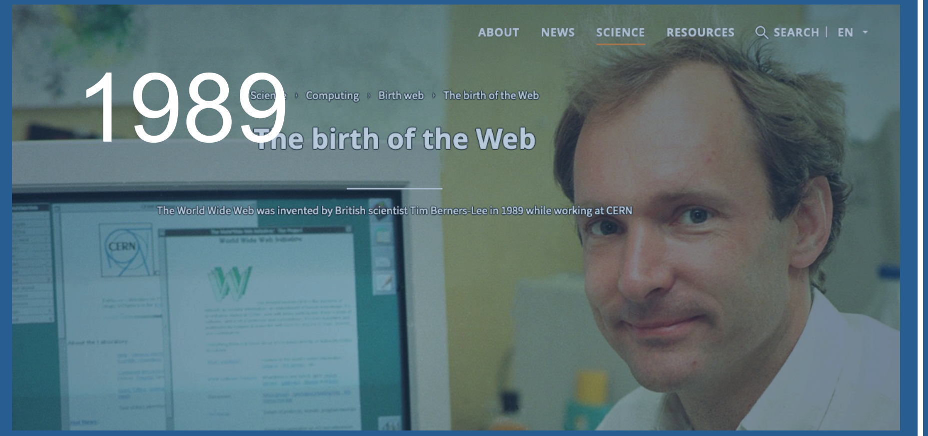
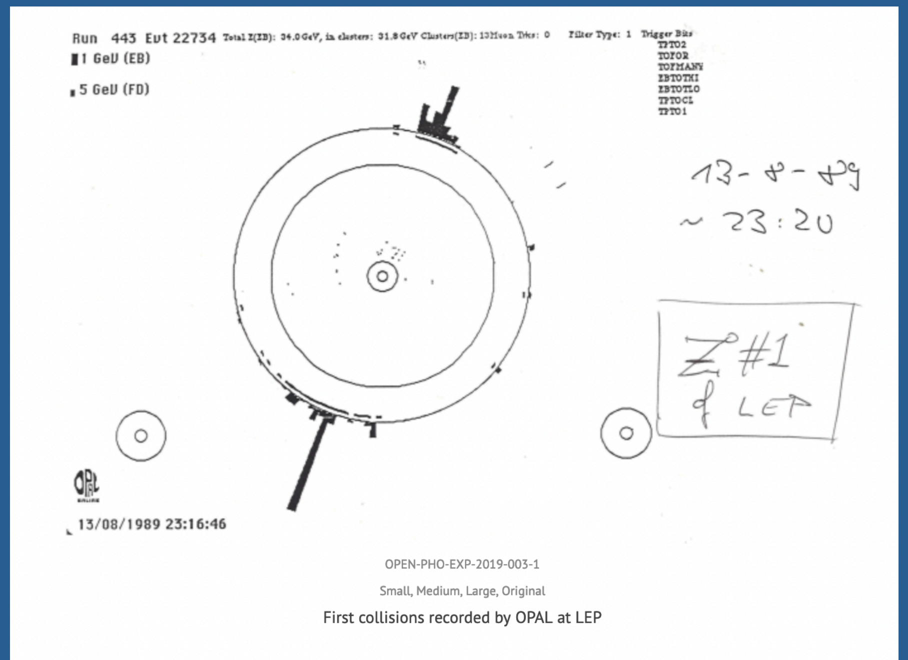
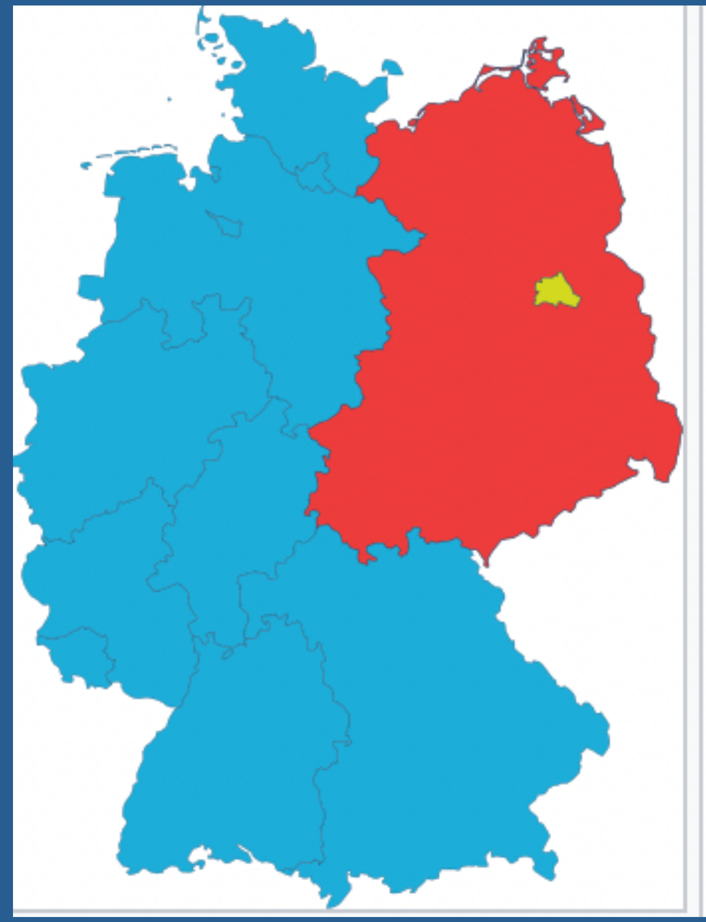
Ba 0

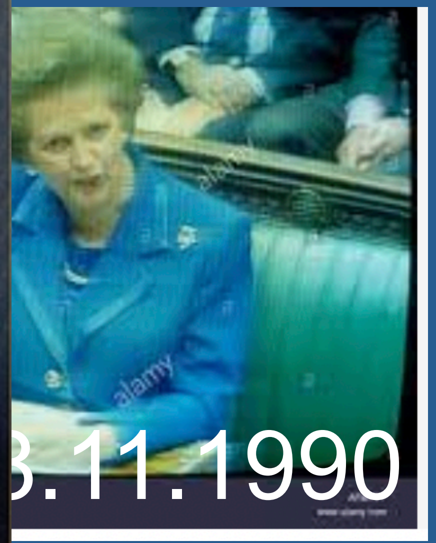




First Z decay into hadrons recorded by OPAL and LEP on 13 August 1989 at 23:17

July 1990





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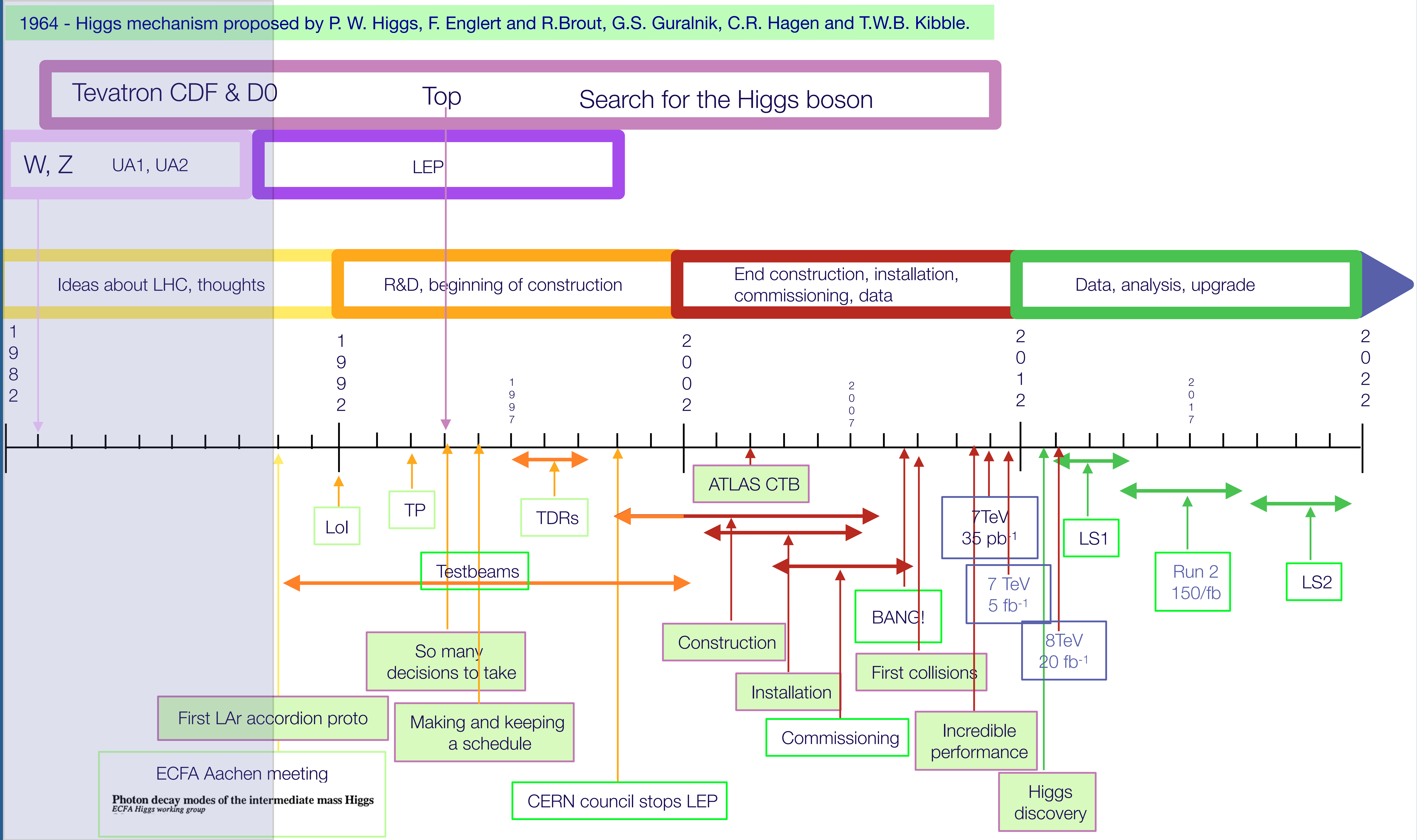
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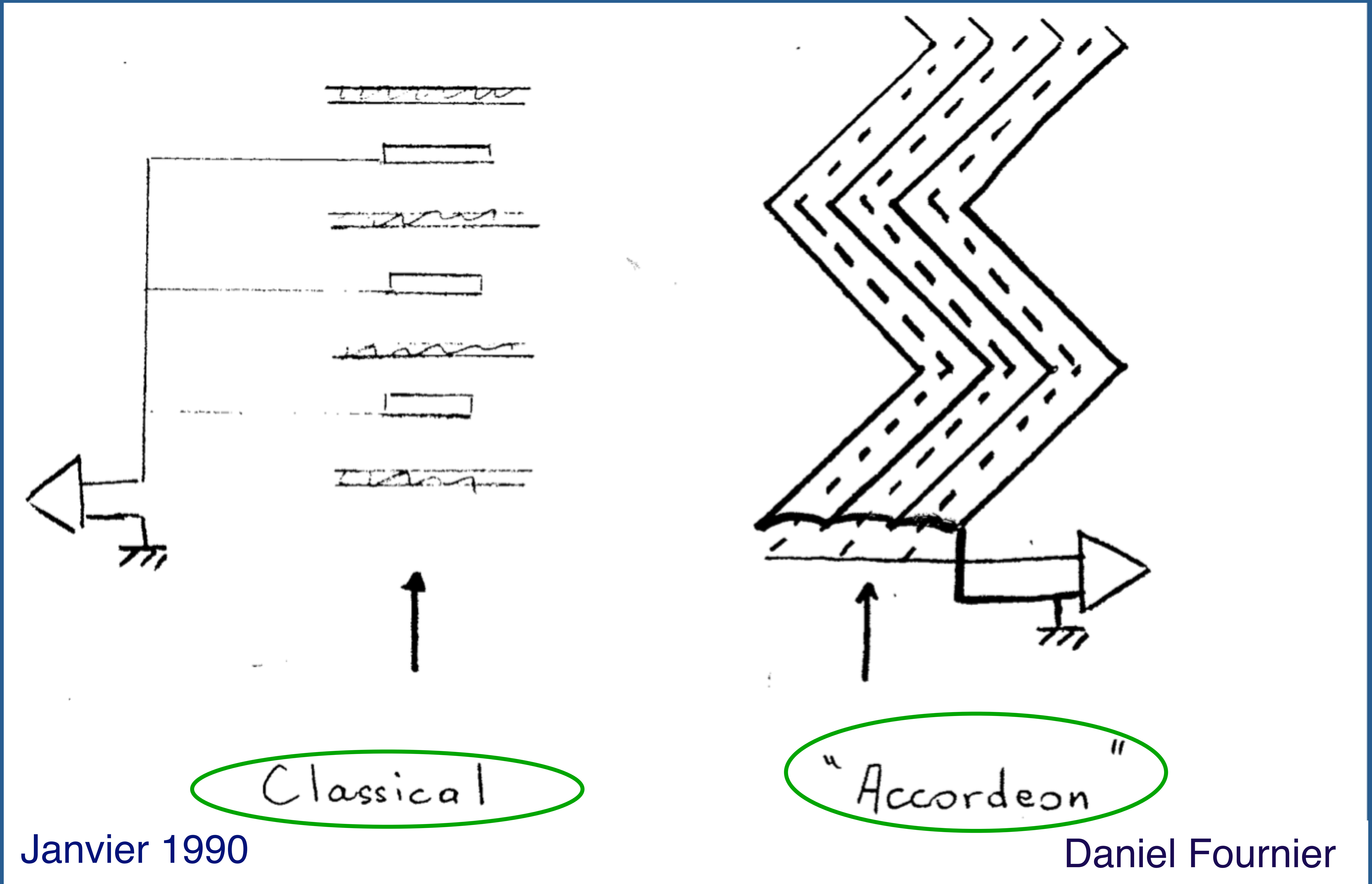
A fast calorimeter

Reminder Δt=25 ns



A fast calorimeter

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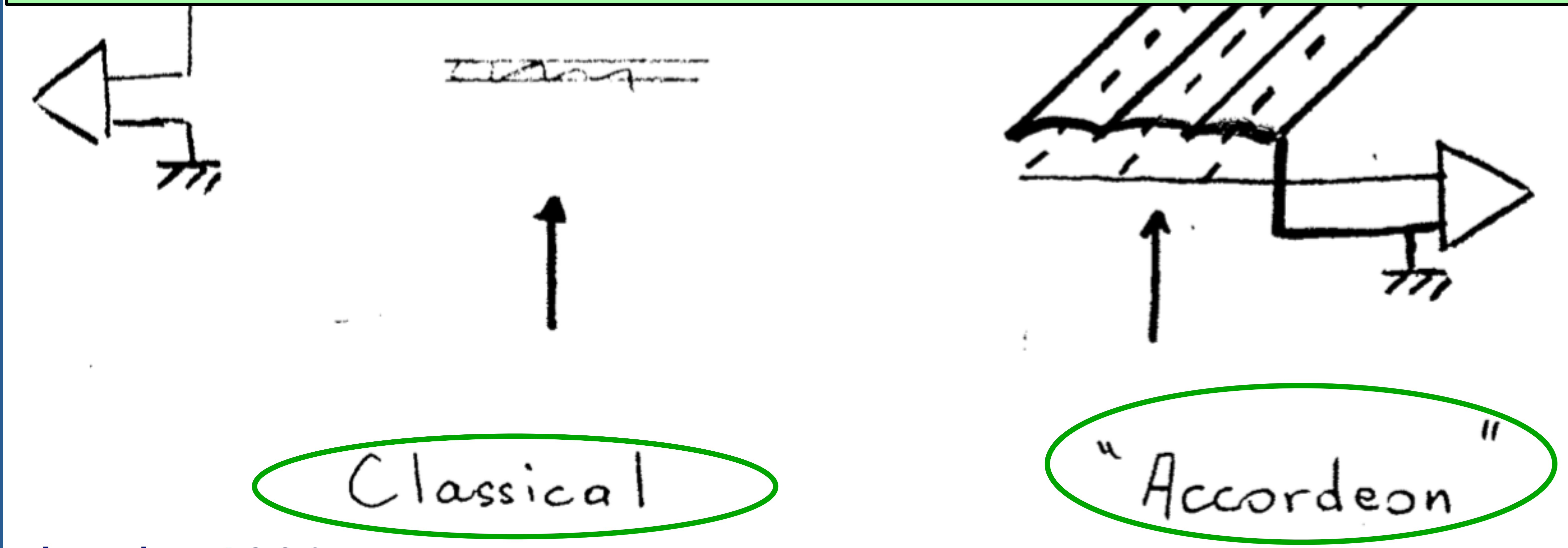
The benefit of such a scheme is that each tower can be connected to a preamp located on the tower itself ,in the front or back of the calorimeter.

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

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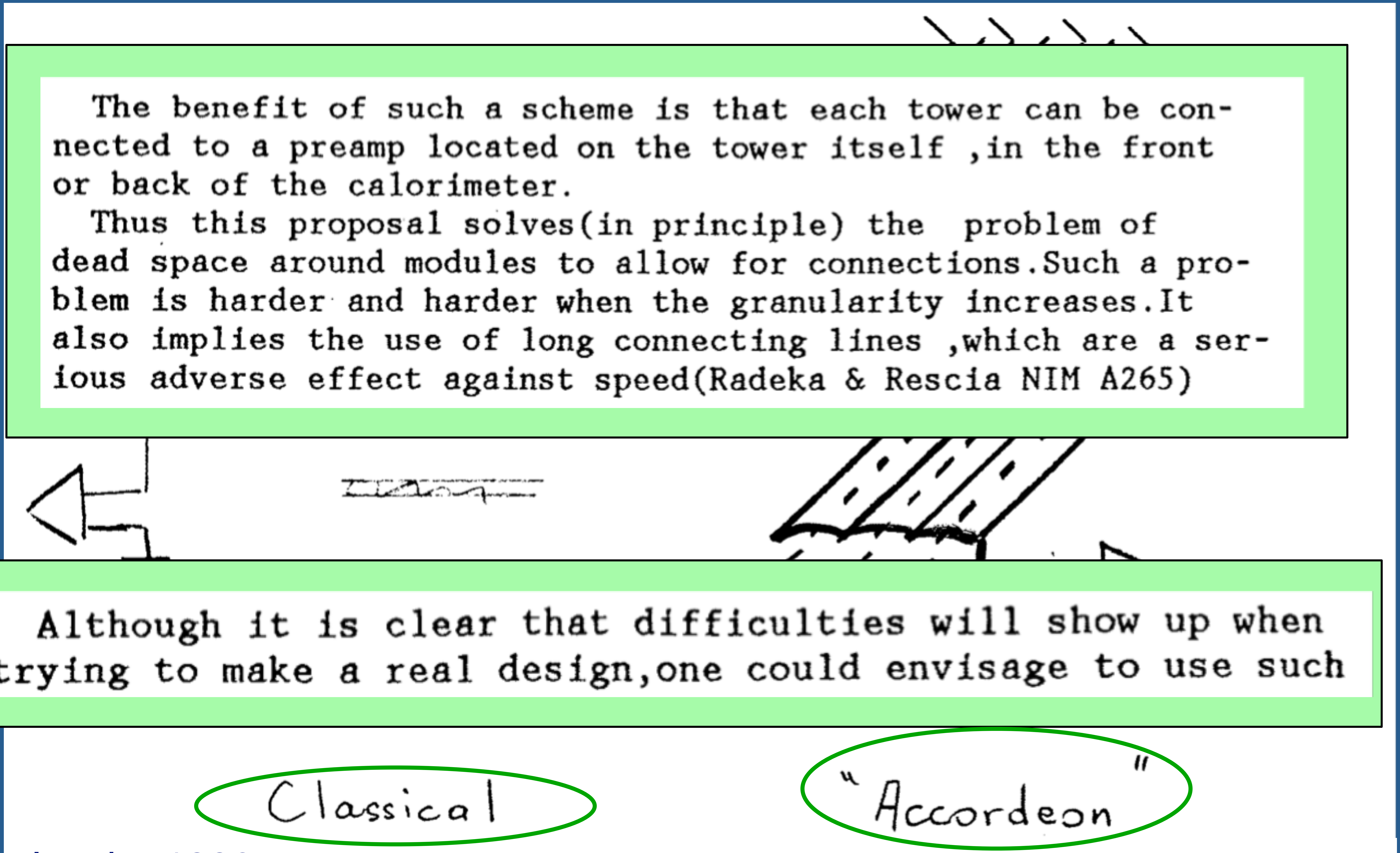

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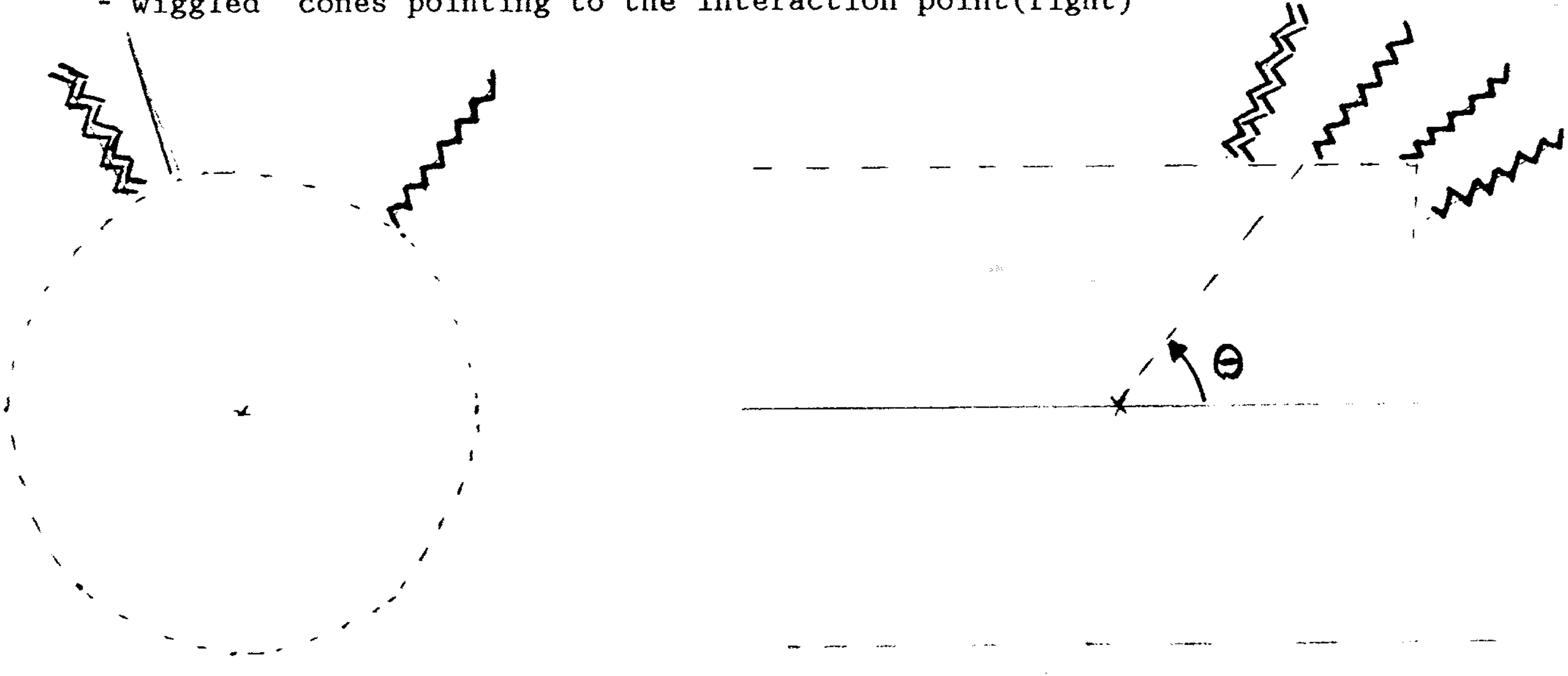
Although it is clear that difficulties will show up when trying to make a real design,one could envisage to use such

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)



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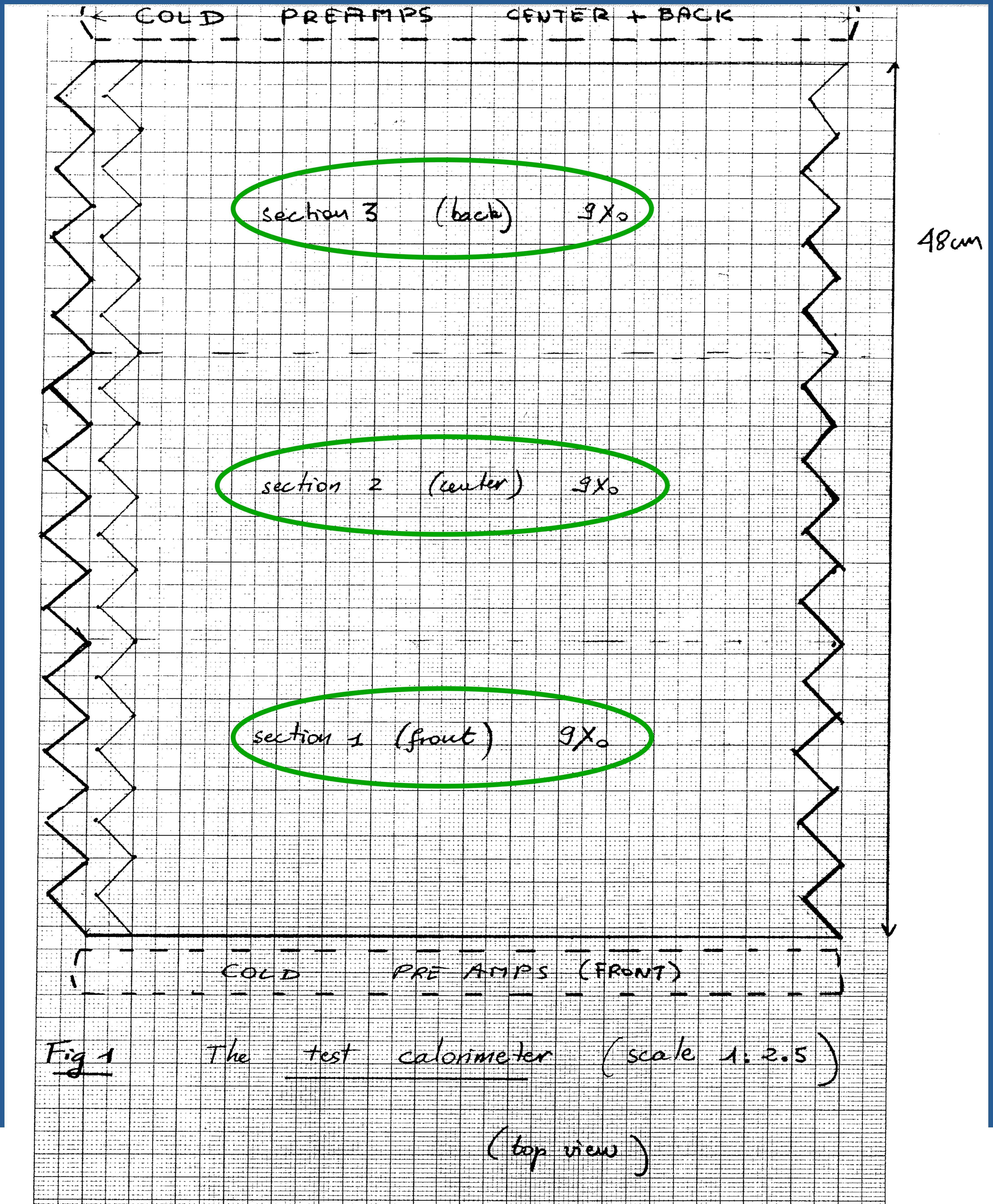
A segmented calorimeter



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Performance of a liquid argon electromagnetic calorimeter with an “accordion” geometry

RD3 Collaboration

Nuclear Instruments and Methods in Physics Research A309 (1991) 438–449
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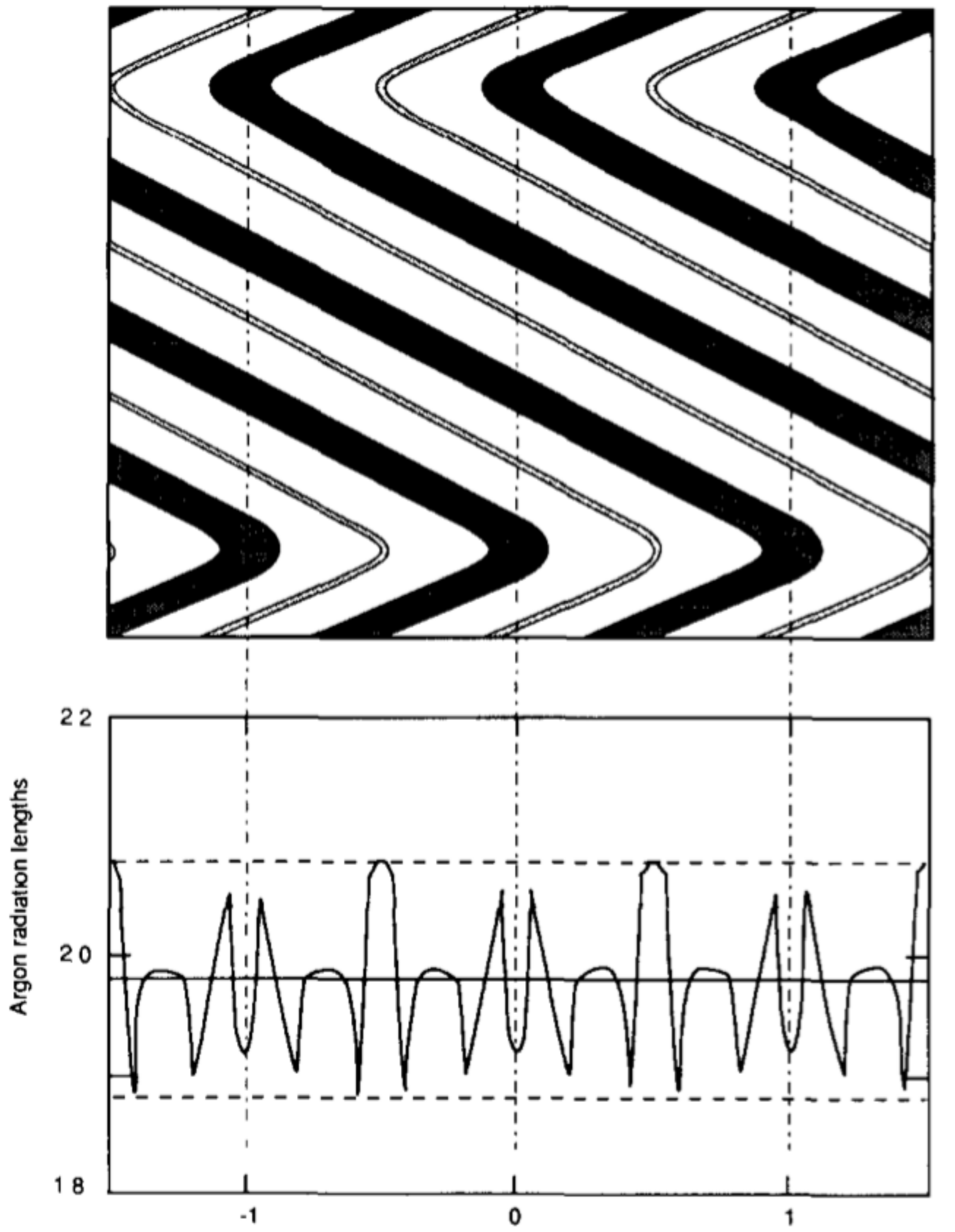

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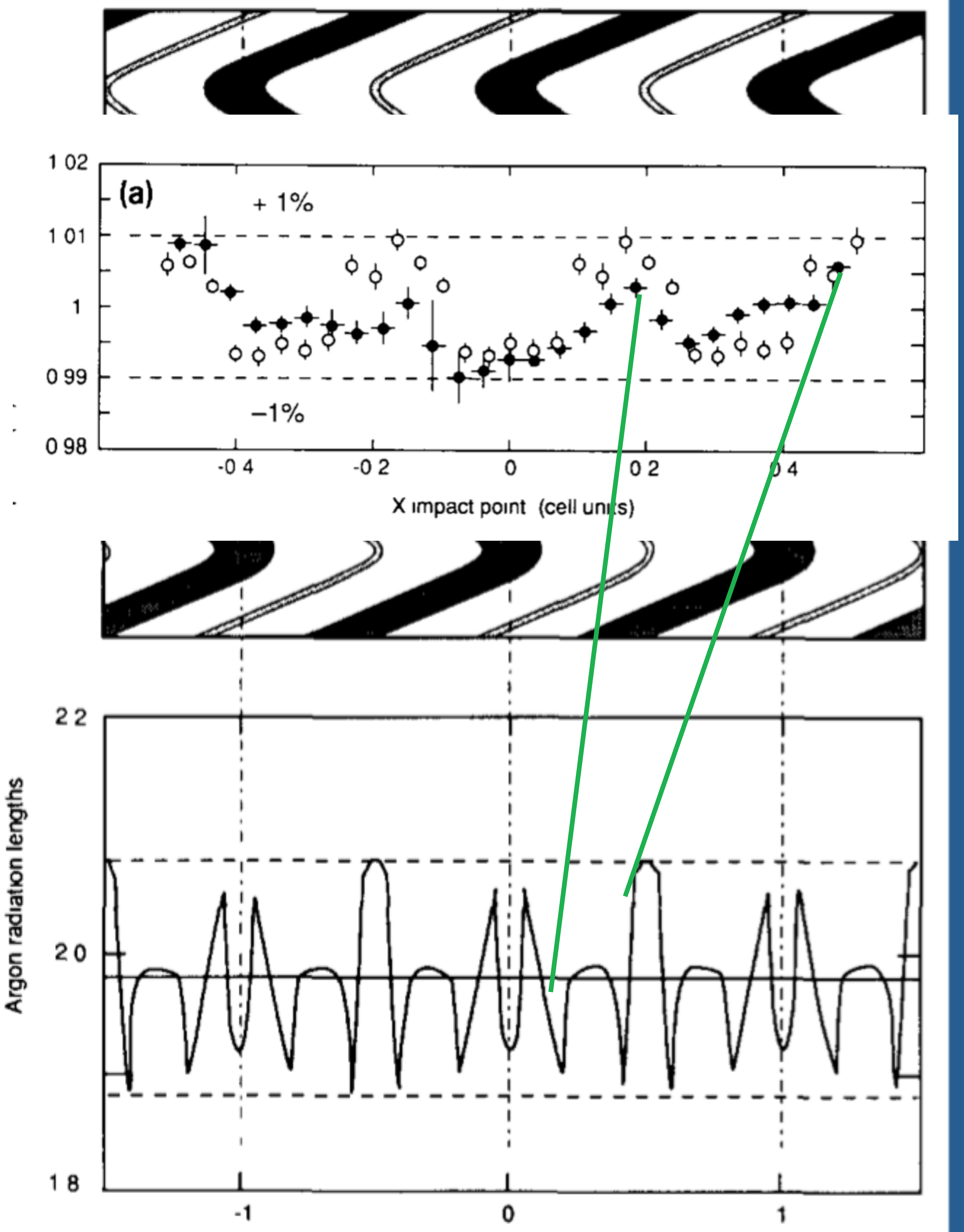

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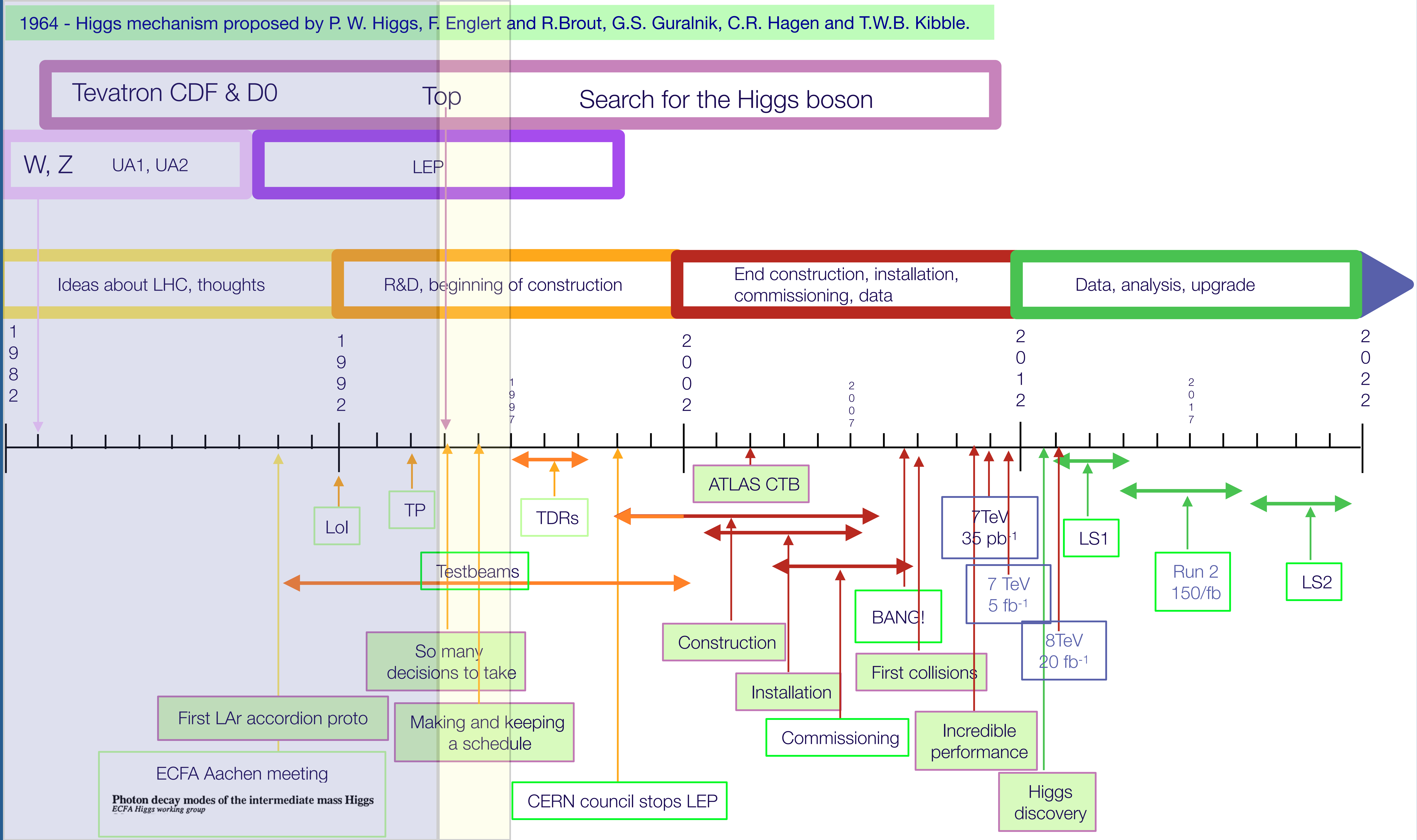
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So many questions to answer

2001-2003	Production
↑	↑
1997	Technical Design Report
↑	↑
1990	First accordion module

?

Beginning of production

TDR

1996

Krypton

Argon

liquide

UV strips

Preshower

presampler + strips η

presampler

calibration current

calibration voltage

calibration

pipeline digital

SCA

latency

AsGa LAr

1T LAr

Si LAr

0T 20°

preampli

Fresnel lense

gaps opening E=f(R)

endcap

hadronic LAr

cyl. geom. Pb tempred

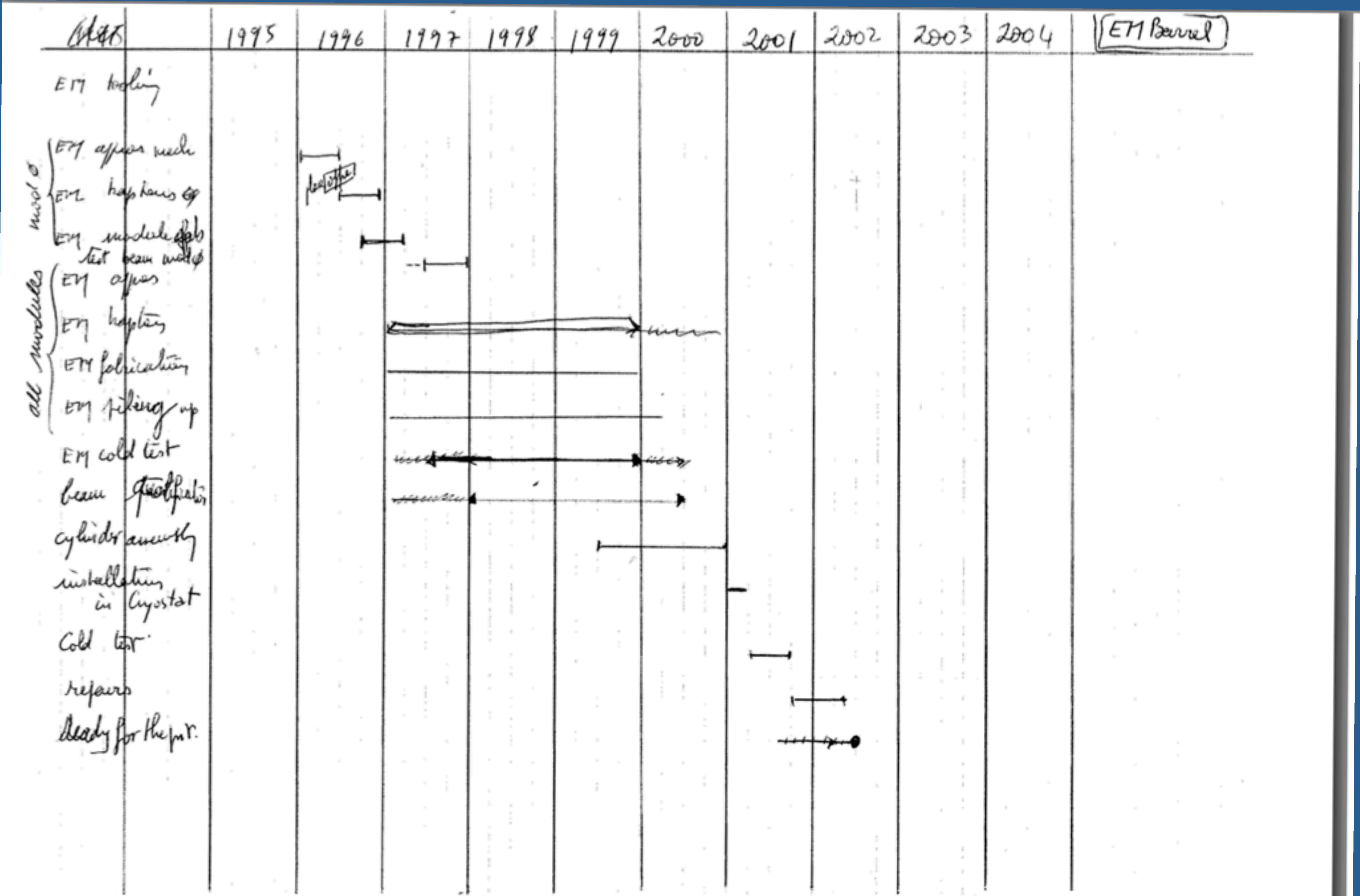
cyl. geom. Opening gap

cyl. geom. Angles=f(R)

barrel

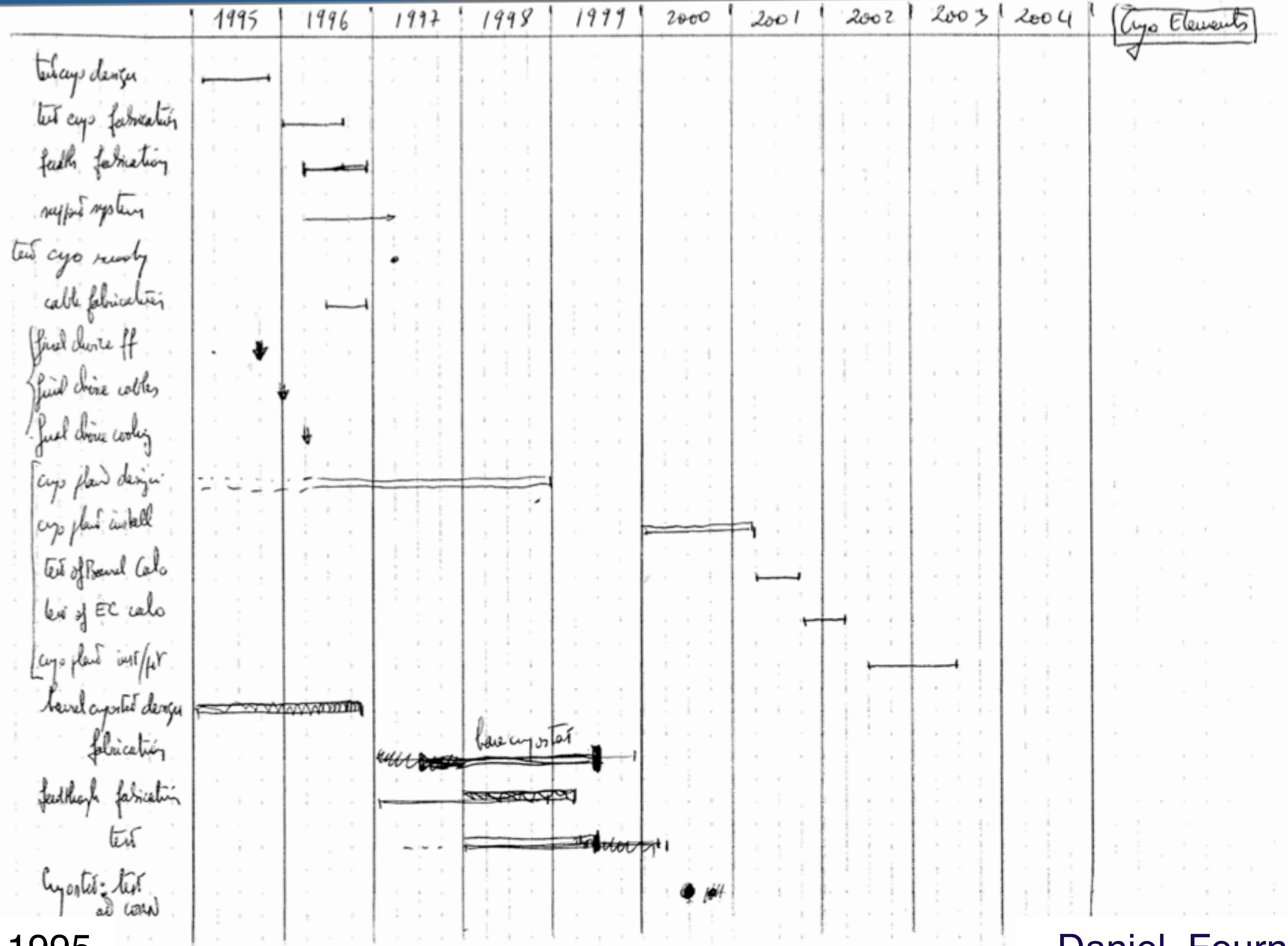
1990

First accordion module



1995

Daniel Fournier



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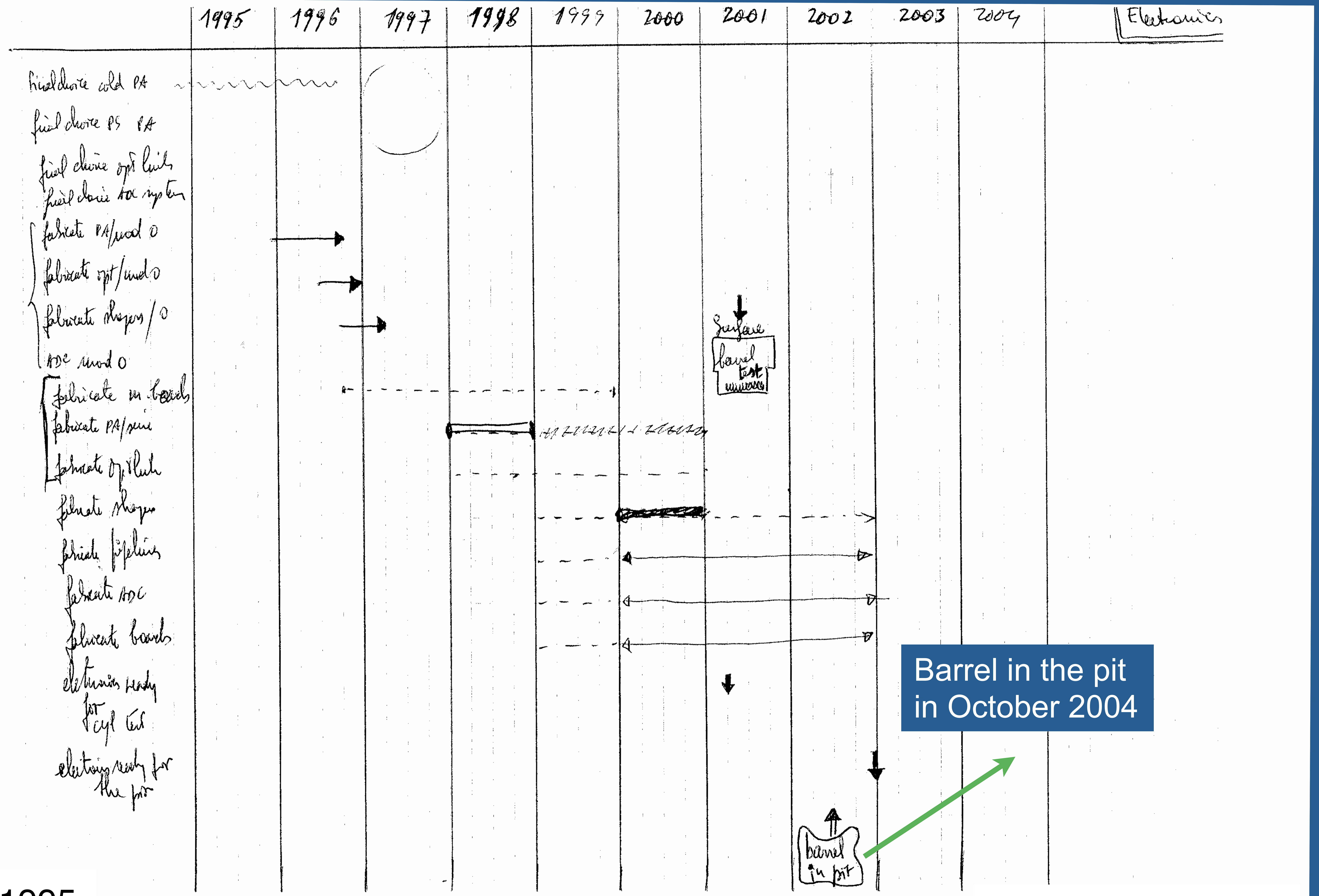
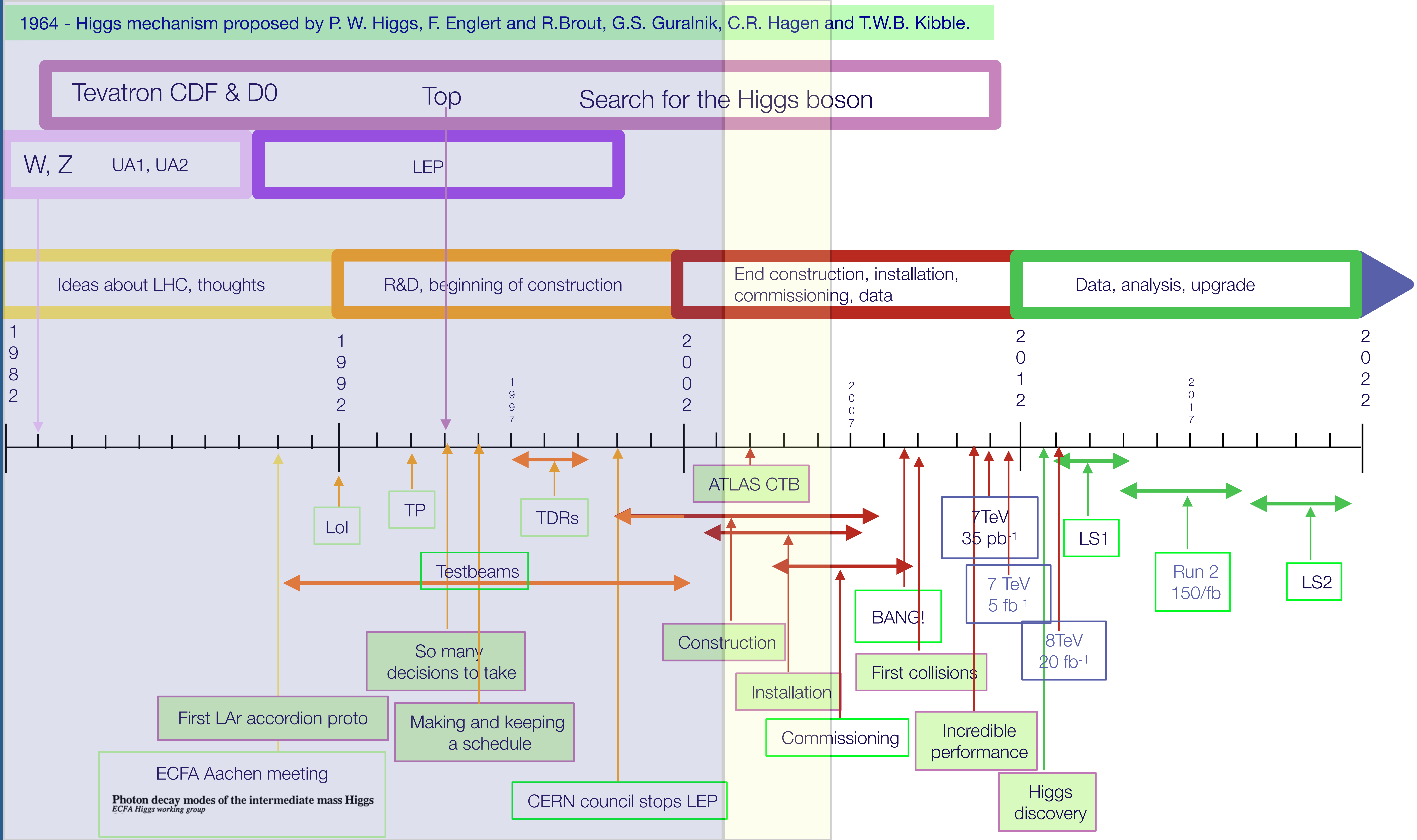


Barrel in the pit
in October 2004

1995

Daniel Fournier



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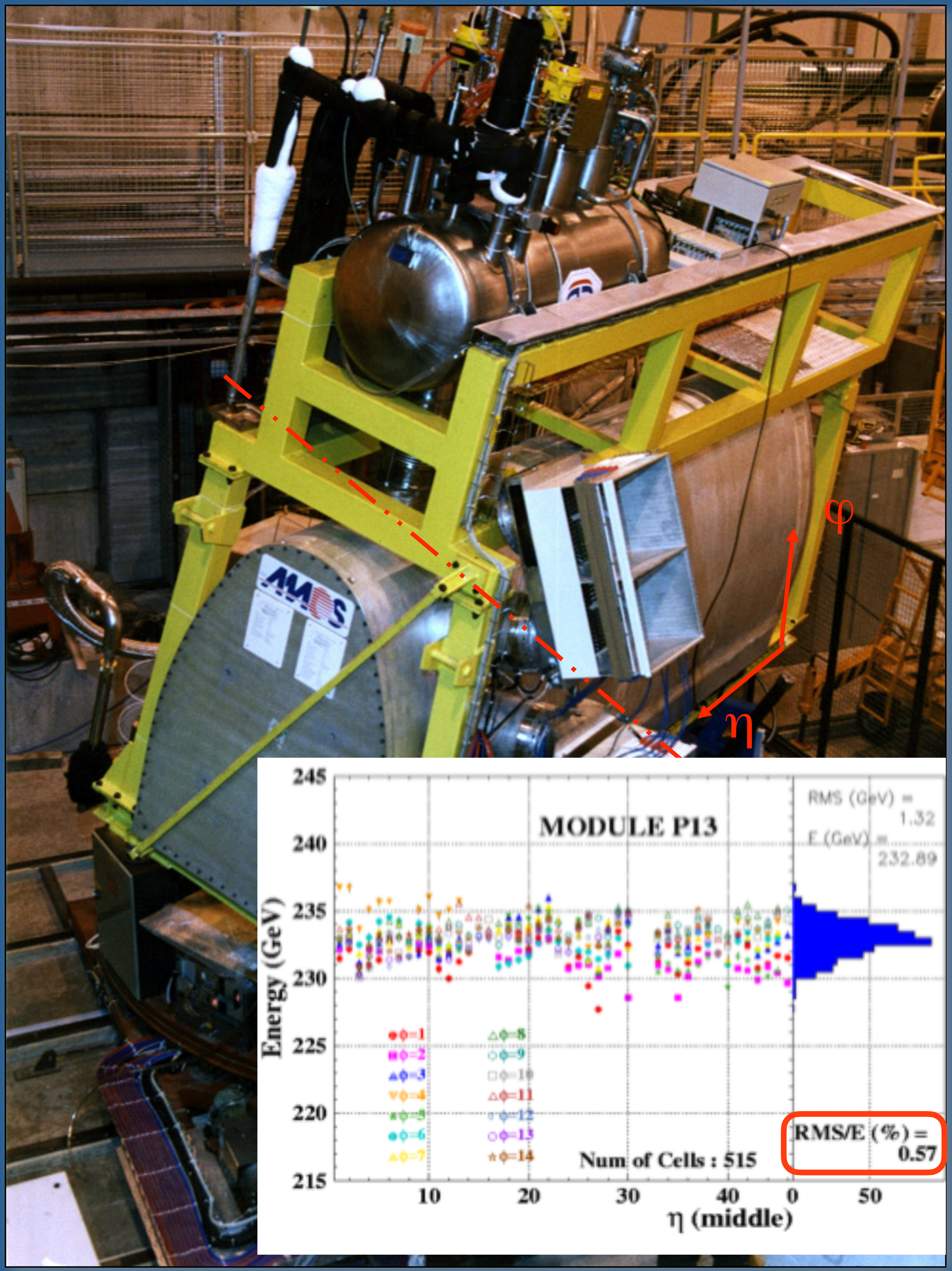
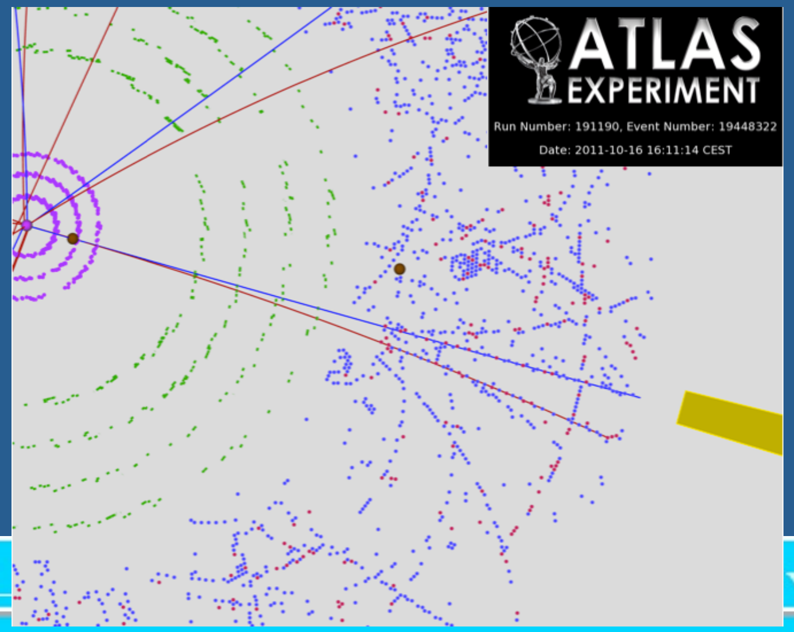
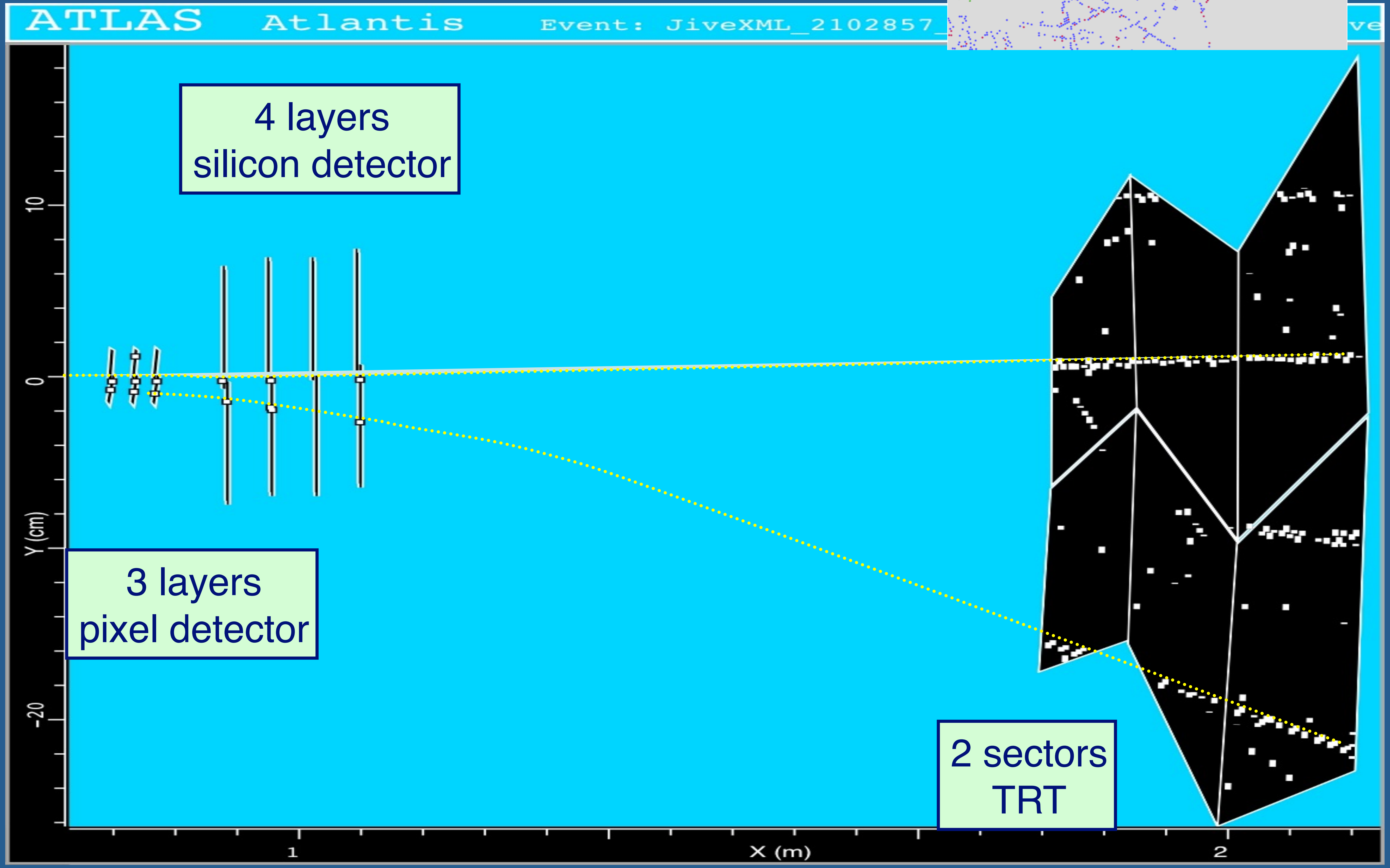


2000 - 2002

The ATLAS combined testbeam in 2004

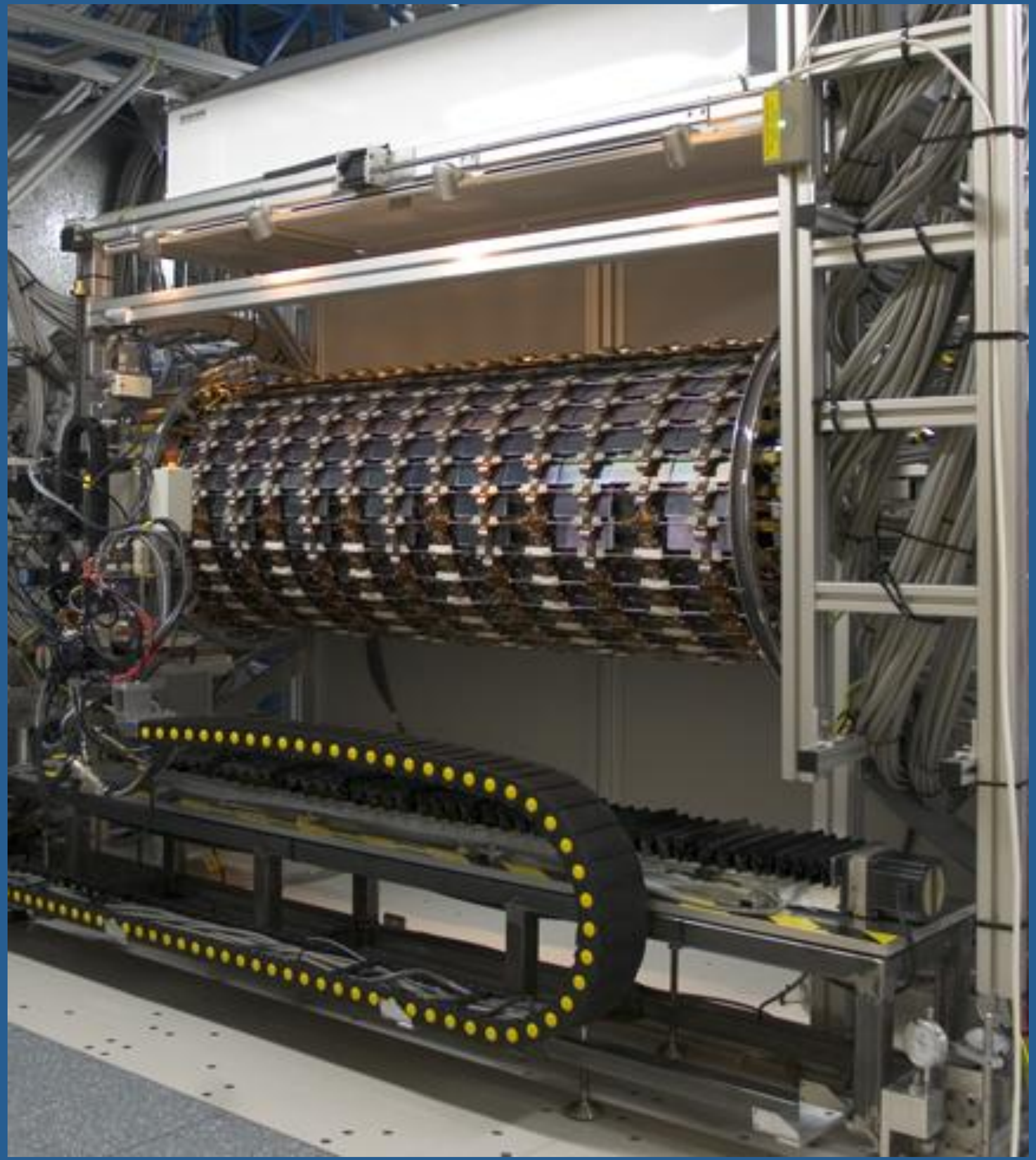


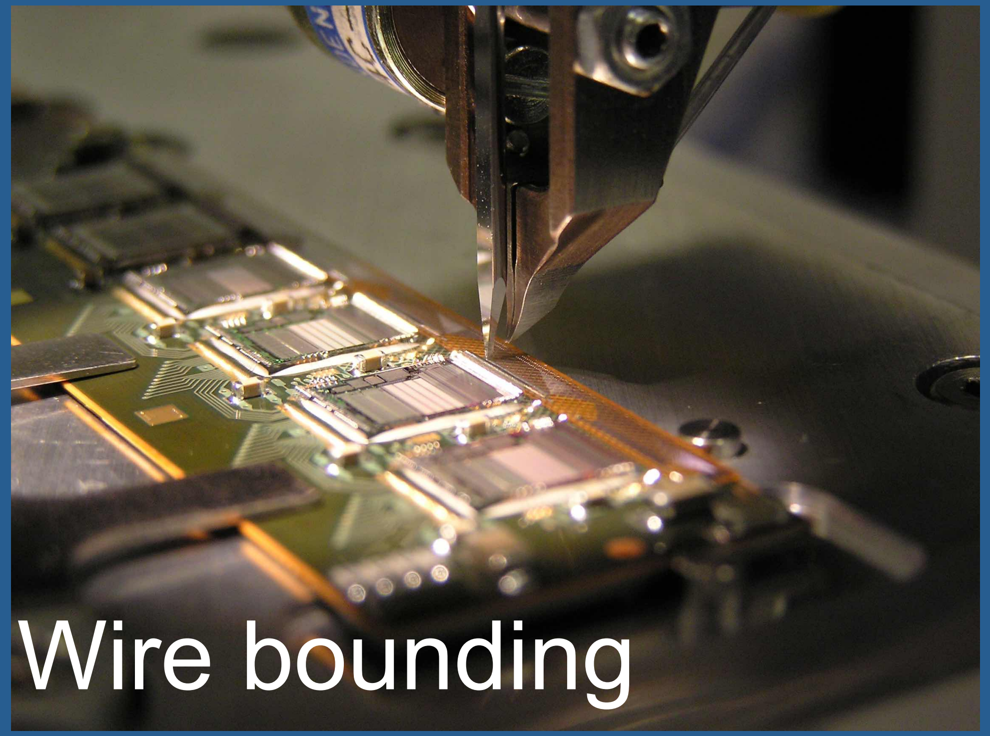


Where the ATLAS reconstruction was born.
Lines of code dating from the CTB are still running today.

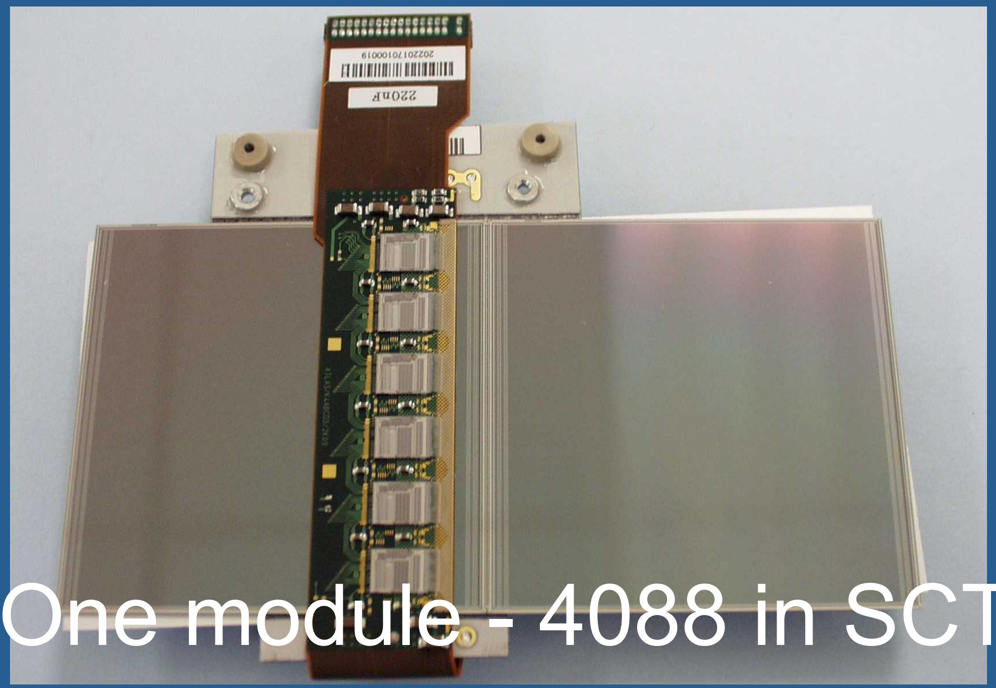
Construction at Birmingham

Silicon Tracker - SCT

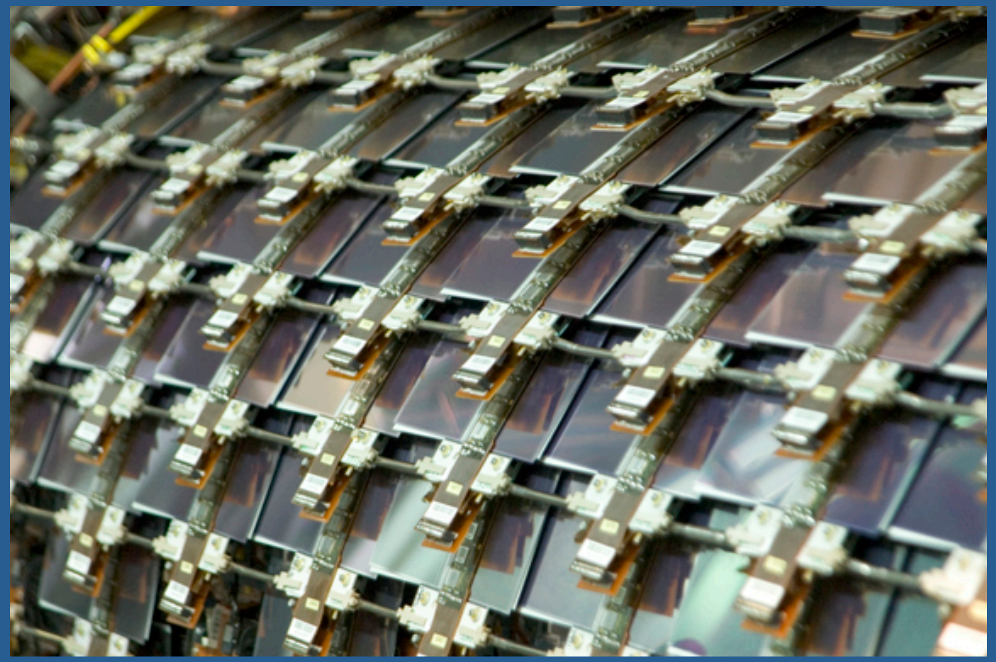




Wire bounding



One module - 4088 in SCT



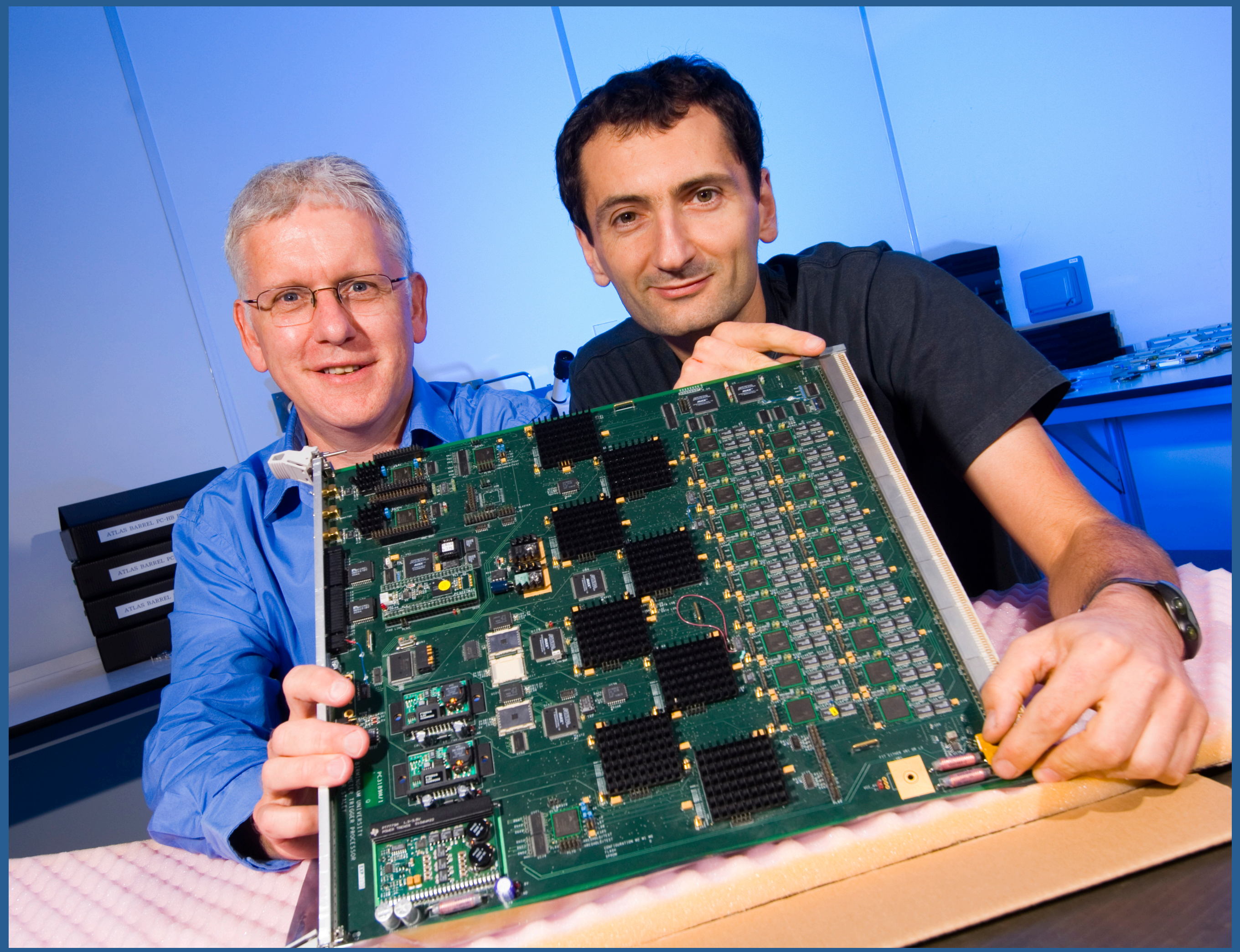
Silicon strip sensors, 80μm pitch → 23μm spatial precision

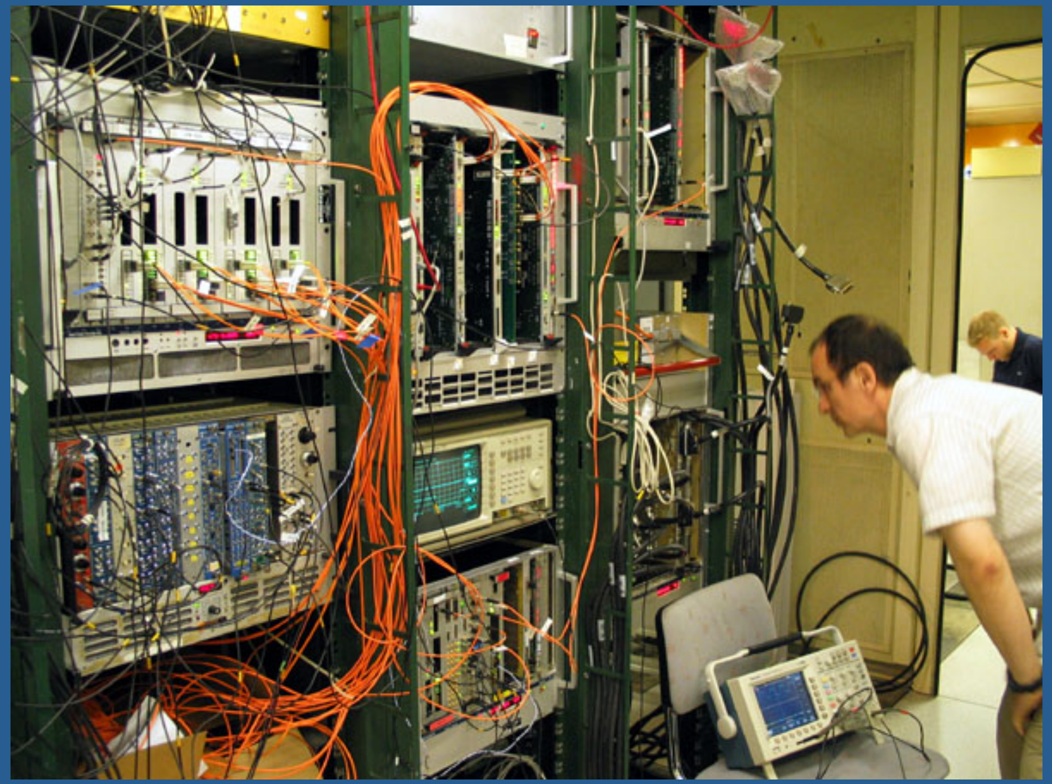
High precision tracking

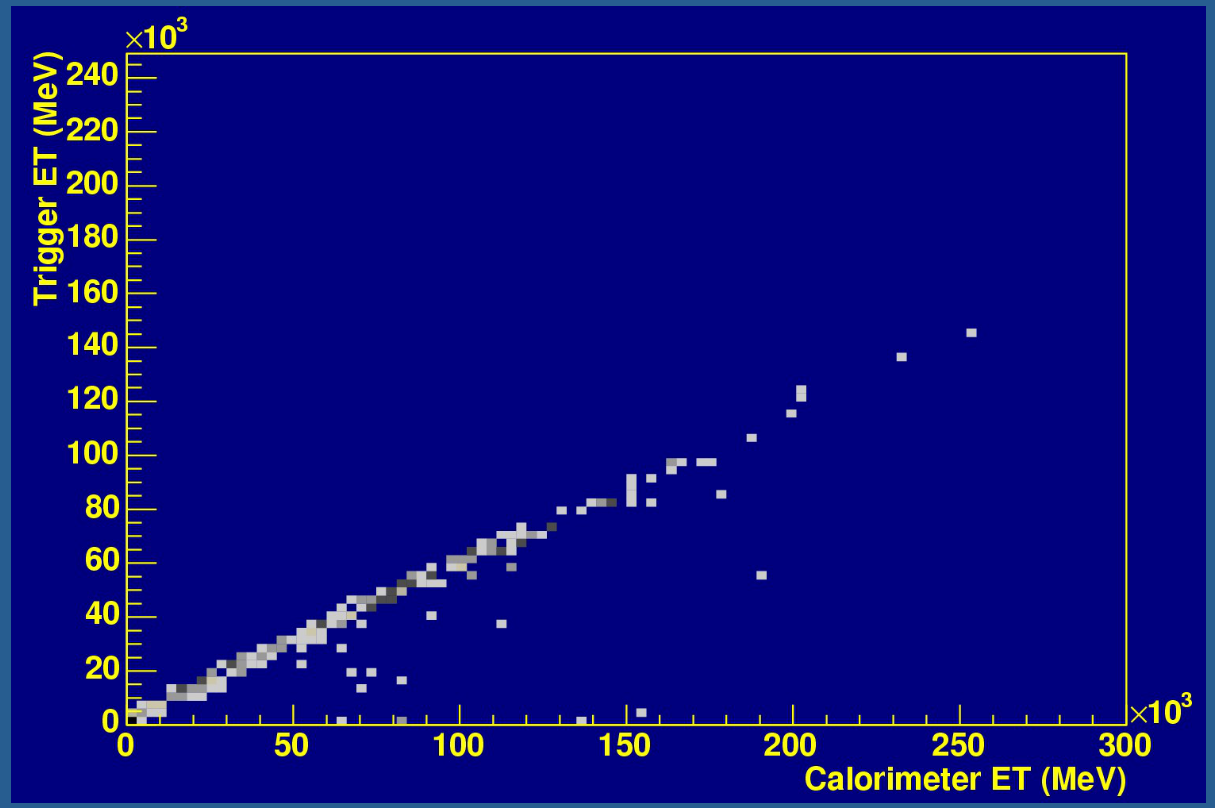
- Measure momenta very well – esp. high momentum particles
- Reconstruct decay vertices (b, c, τ)

L1Calo

Richard Staley & Gilles Mahout with a Cluster Processor Module at Birmingham (Richard designed the module)

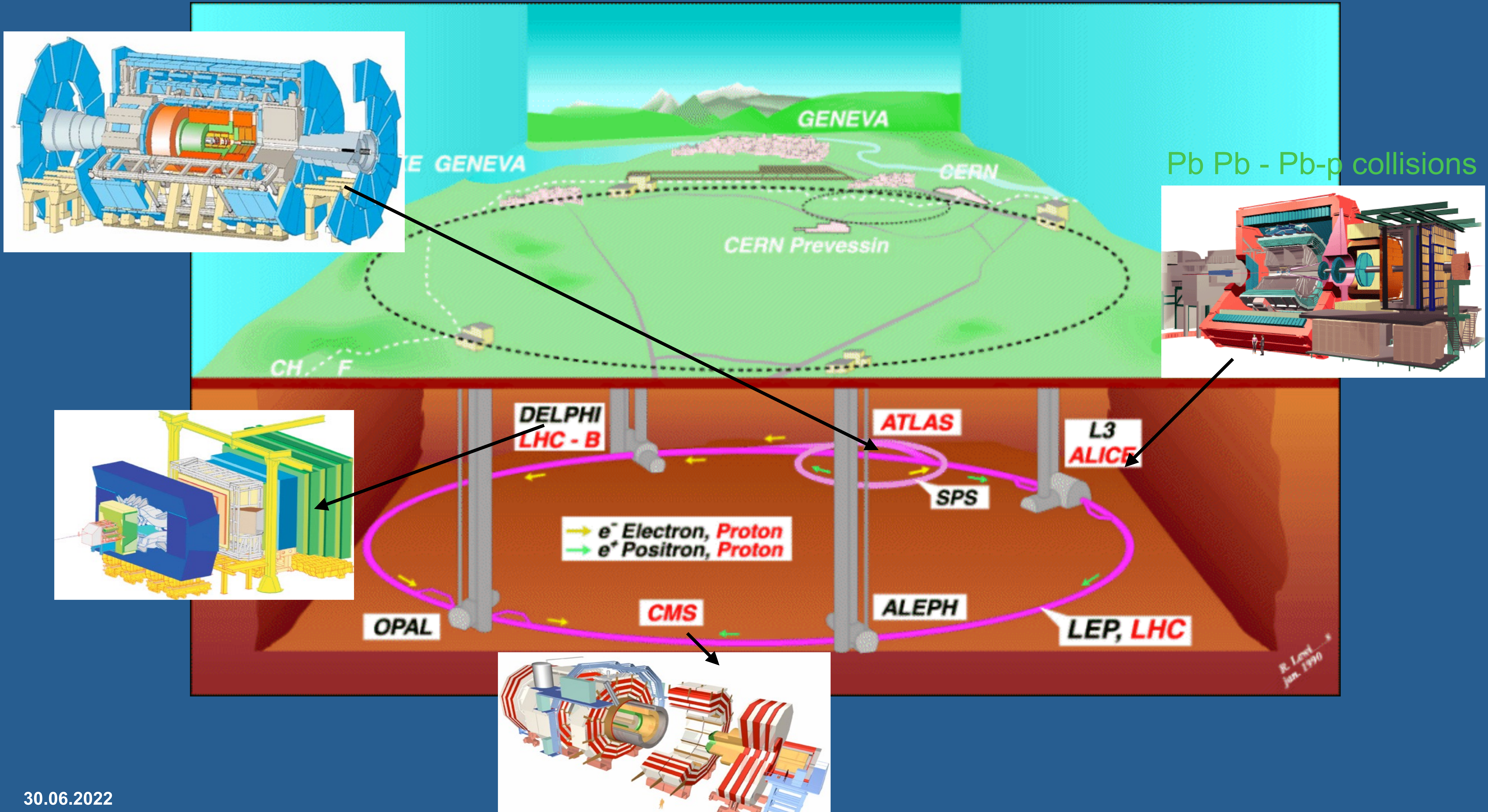






L1Calo @ CTB in 2004
Trigger saw the beam.

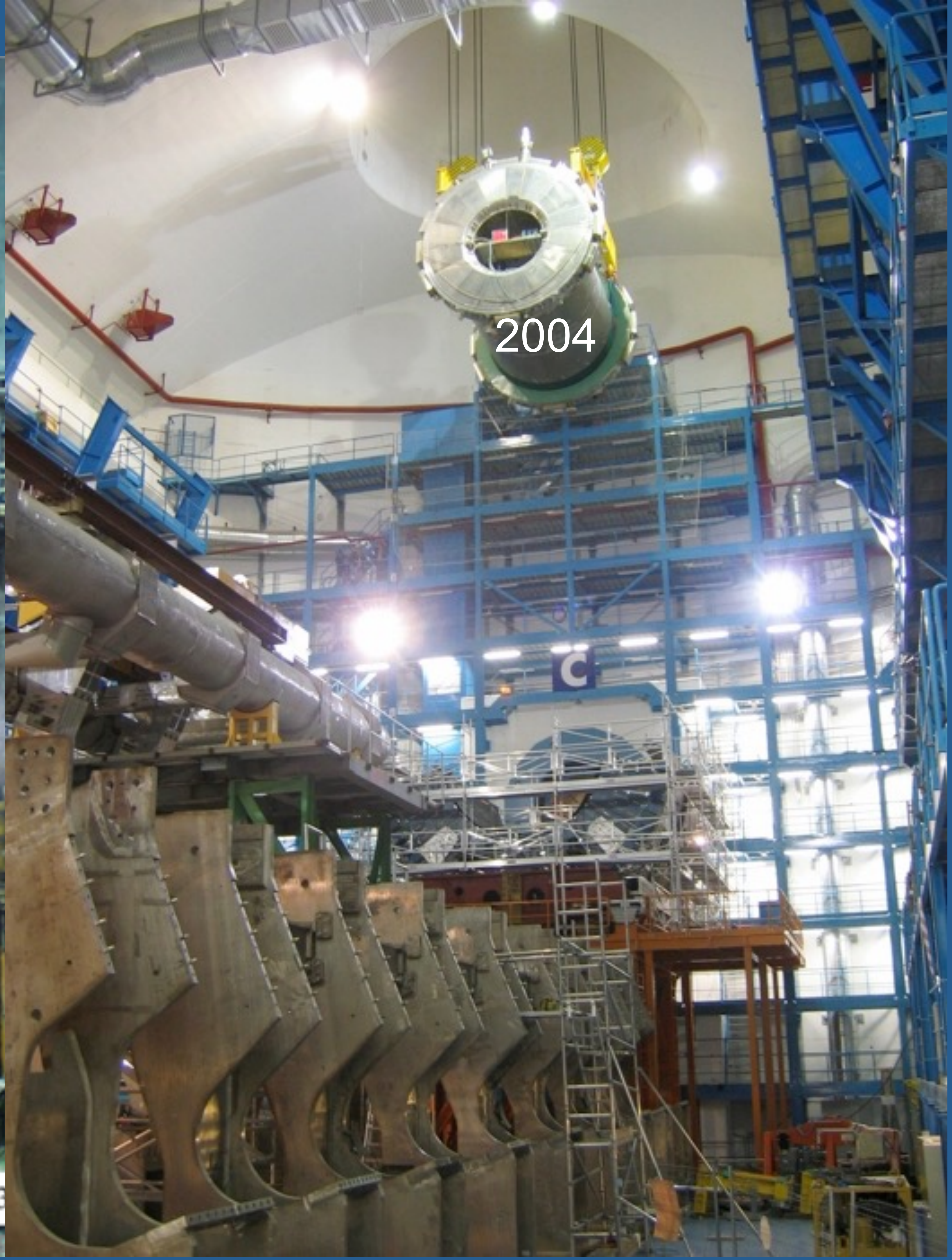
ARTIST view of the LHC and the experiments




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


2004


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


2004


LHC Point 1 - UX 15 Cavern
2007
ESIPAP, Archamps, 26-1-2015 P
Jenni (Freiburg and CERN)

Installation in the ATLAS counting room

Xen supervising Pete Watkins and Eric Eisenhander pulling underfloor cables

Steve with a lot of cables

Dave as part of the underfloor crew

ATLAS

is a giant microscope
with 100 M channels

ATLAS

is a giant microscope with 100 M channels

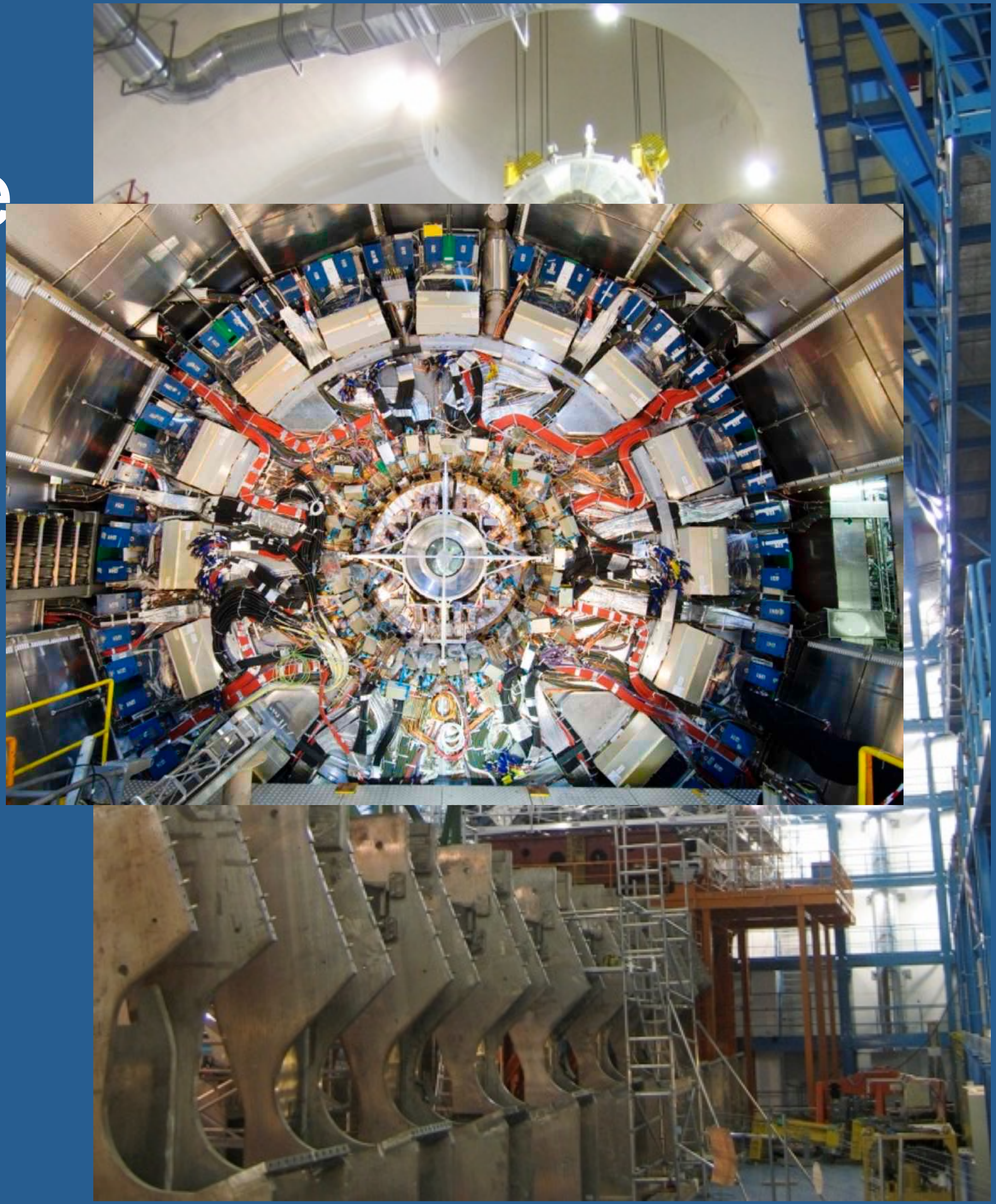
100 metres underground
50m long
25m high
7000 tonnes (one Eiffel tower)

ATLAS

is a giant microscope with 100 M channels

100 metres underground
50m long
25m high
7000 tonnes (one Eiffel tower)

Measure particle trajectory
with a precision of
0.0002 m (20µm)



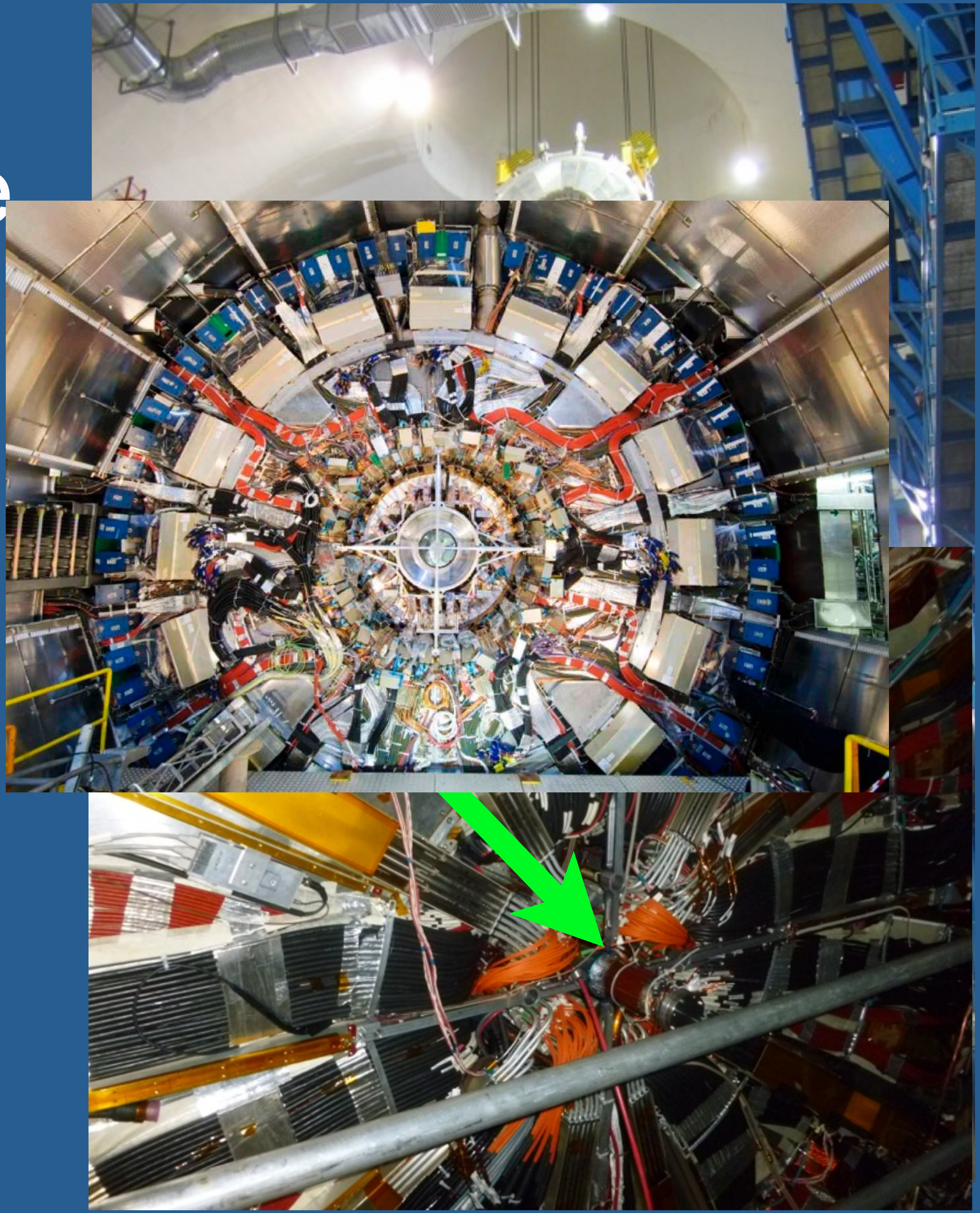
ATLAS

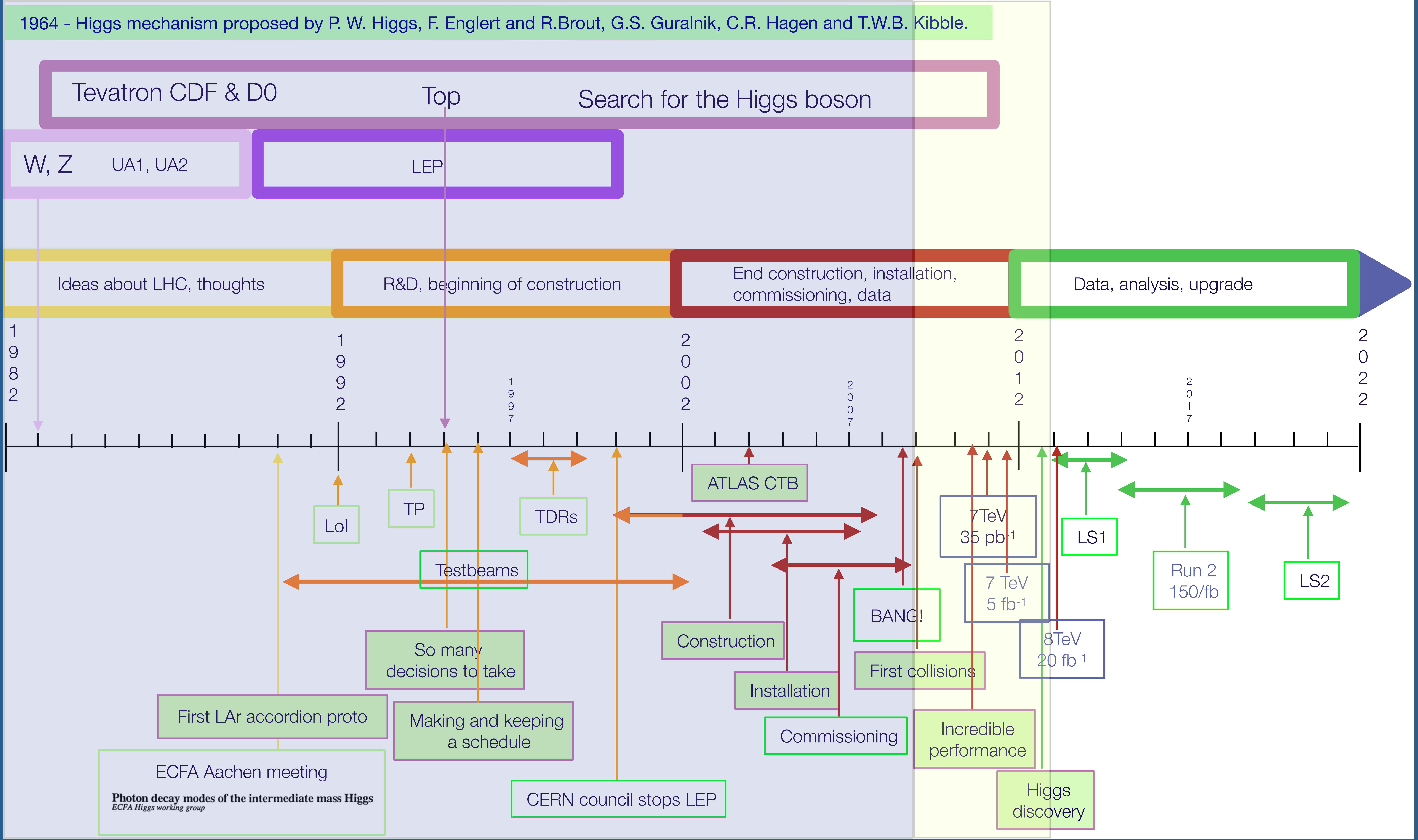
is a giant microscope with 100 M channels

100 metres underground
50m long
25m high
7000 tonnes (one Eiffel tower)

Measure particle trajectory
with a precision of
0.0002 m (20μm)

and the 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.
Tevatron CDF & D0
Top
Search for the Higgs boson
W, Z
UA1, UA2
LEP
Ideas about LHC, thoughts
R&D, beginning of construction
End construction, installation, commissioning, data
Data, analysis, upgrade
1982
1992
1997
2002
2007
2012
2017
2022
LoI
TP
TDRs
ATLAS CTB
Testbeams
So many decisions to take
Making and keeping a schedule
First LAr accordion proto
ECFA Aachen meeting
Photon decay modes of the intermediate mass Higgs
ECFA Higgs working group
CERN council stops LEP
Construction
Installation
Commissioning
BANG!
First collisions
Incredible performance
7TeV 35 pb-1
7 TeV 5 fb-1
8TeV 20 fb-1
Higgs discovery
LS1
Run 2 150/fb
LS2

Expecting in the ATLAS Control Room the first LHC beam to collide on November 23rd, 2009....

Beams collide on 23rd November 2009

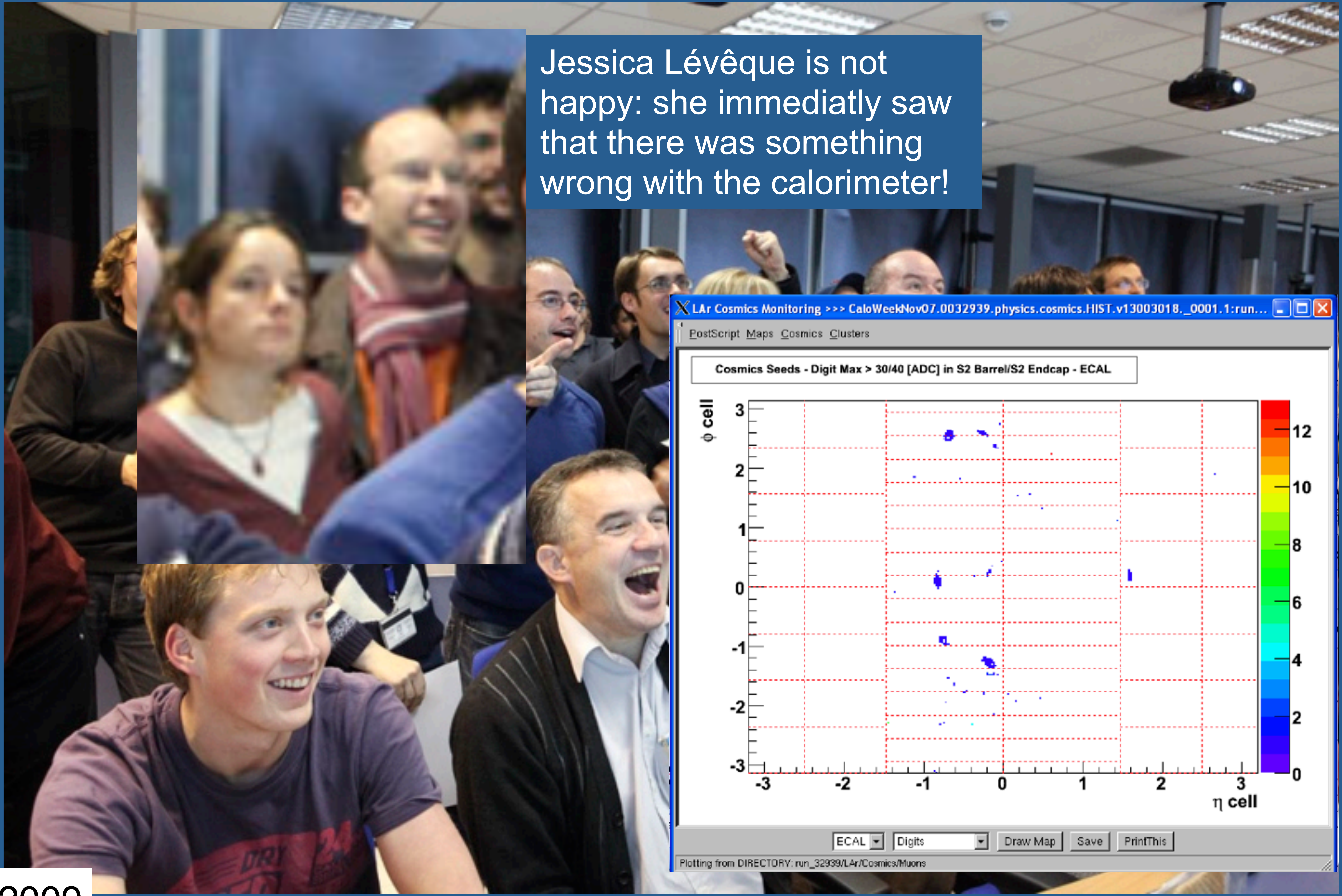
2009

Beams collide on 23rd November 2009

Jessica Lévêque is not happy: she immediatly saw that there was something wrong with the calorimeter!

2009

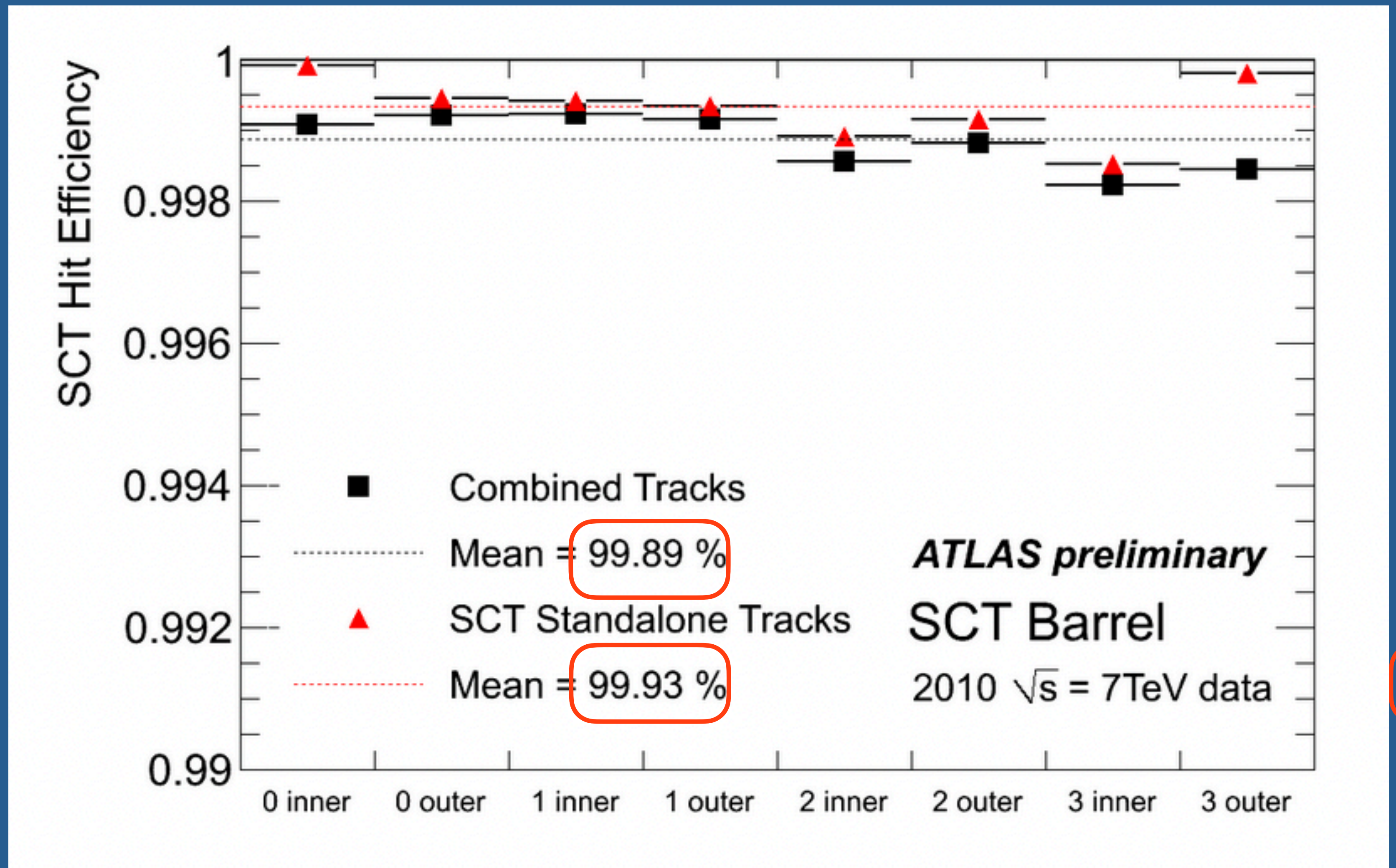
Beams collide on 23rd November 2009

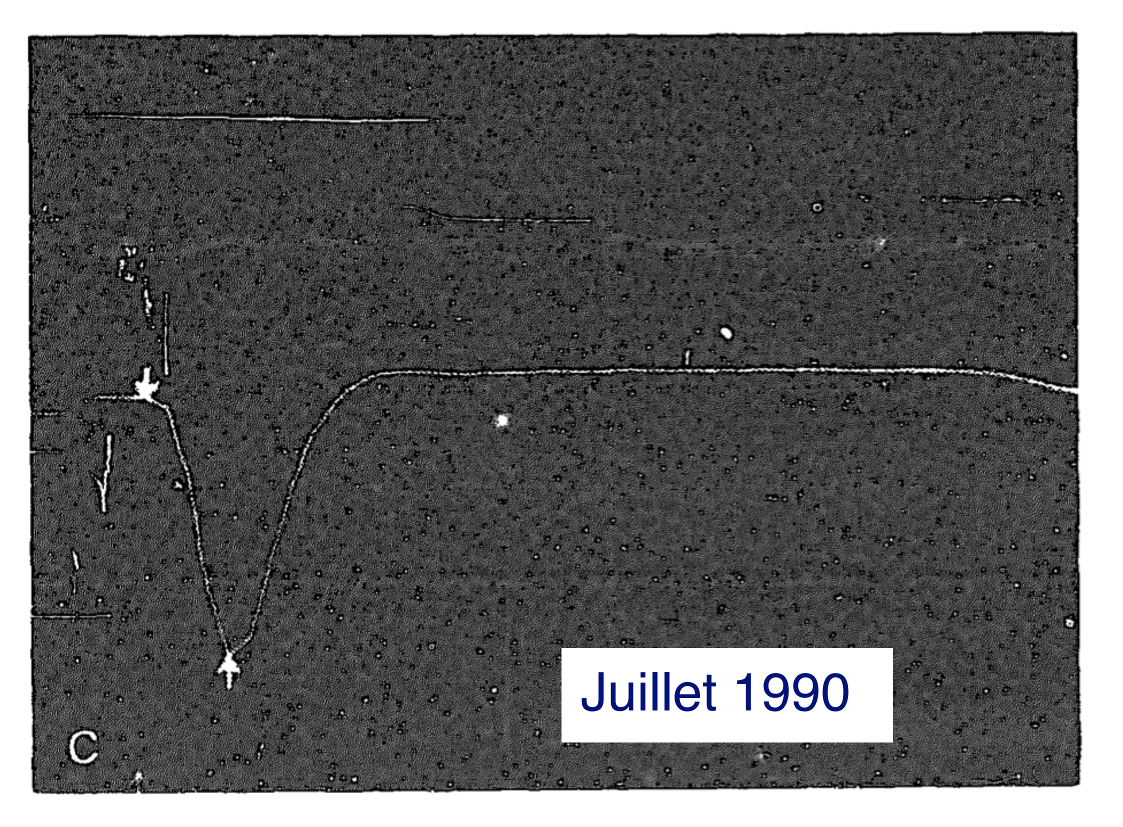


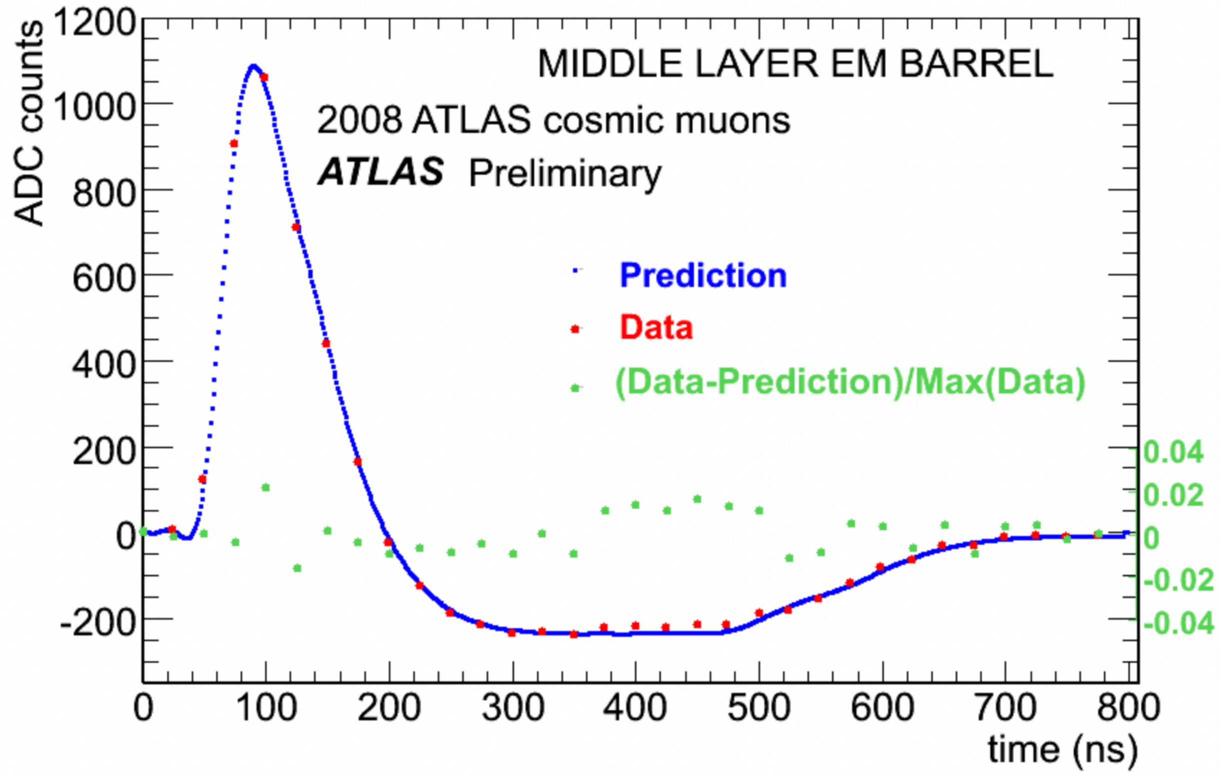
Jessica Lévêque is not happy: she immediatly saw that there was something wrong with the calorimeter!

2009

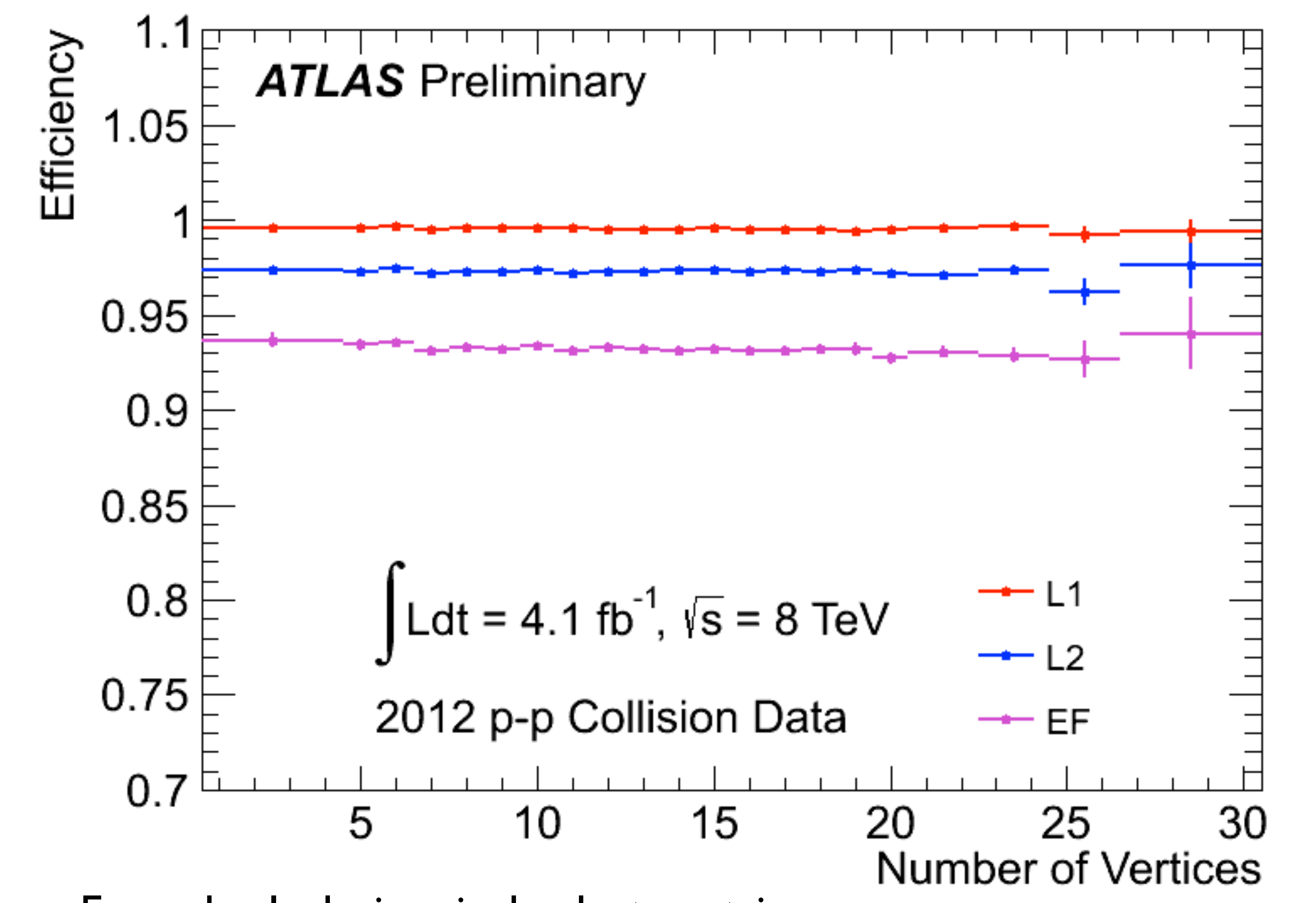
A glimpse at performance



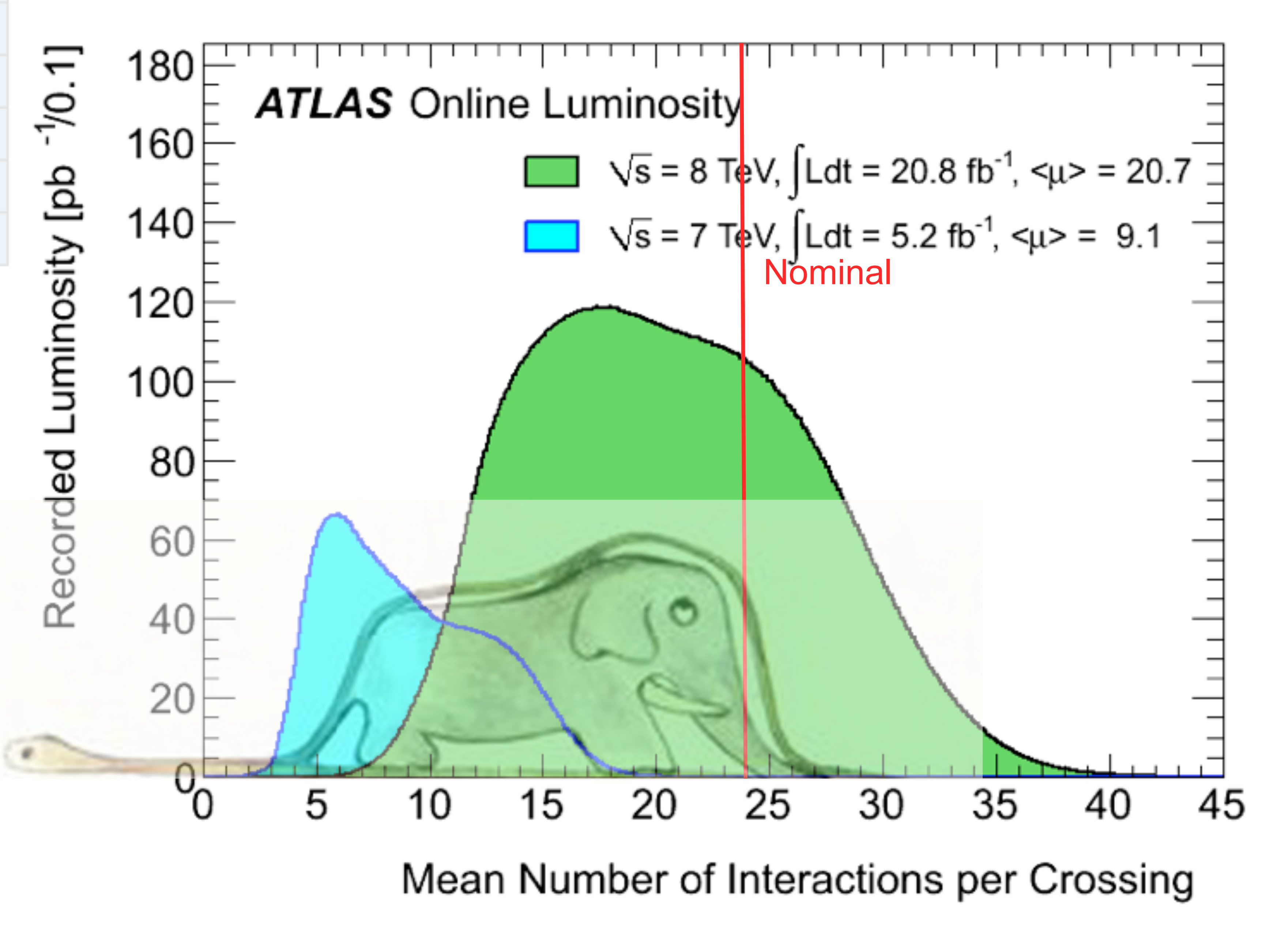




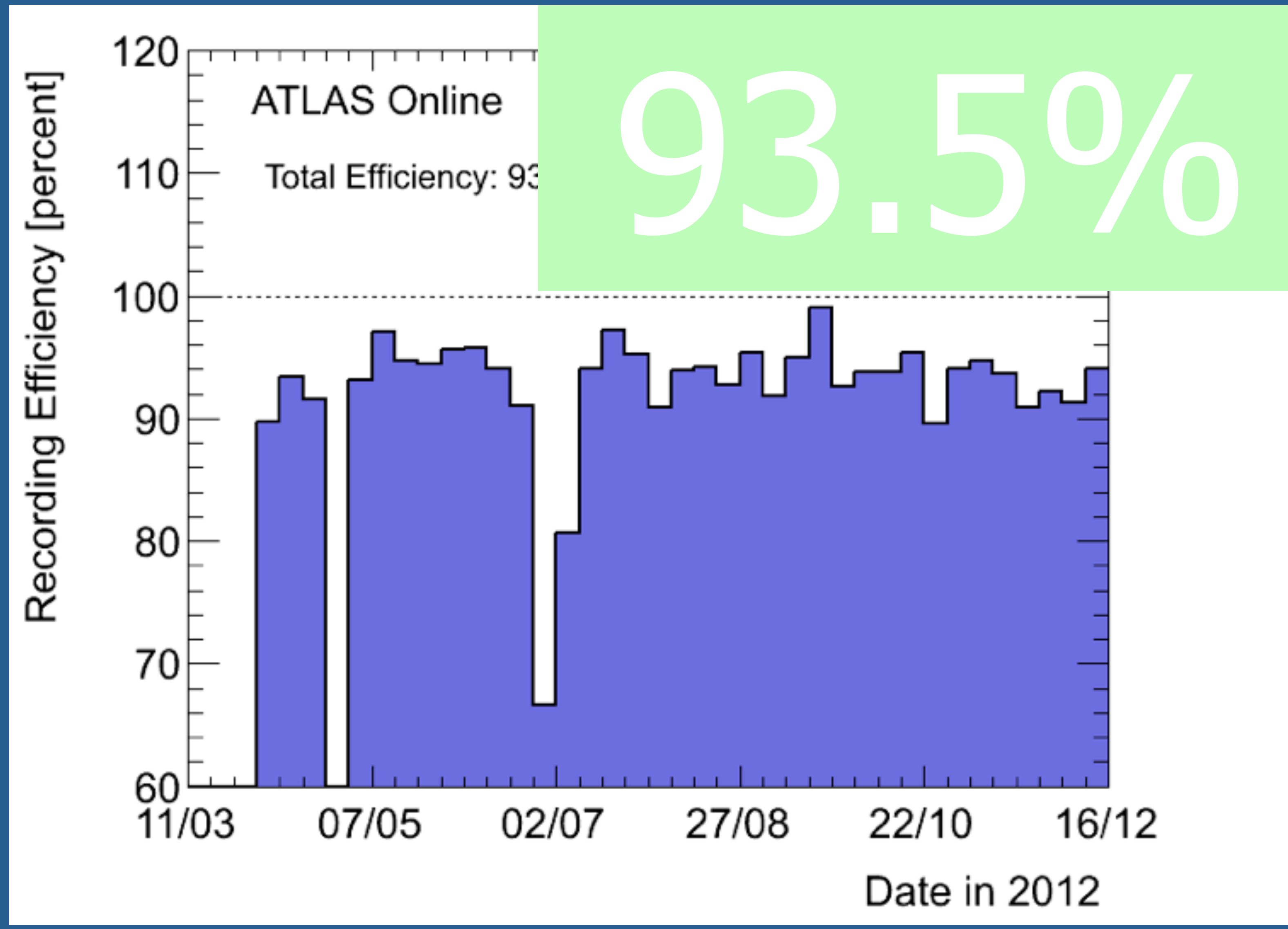
Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	95.0%
SCT Silicon Strips	6.3 M	99.3%
TRT Transition Radiation Tracker	350 k	97.5%
LAr EM Calorimeter	170 k	99.9%
Tile calorimeter	9800	98.3%
Hadronic endcap LAr calorimeter	5600	99.6%
Forward LAr calorimeter	3500	99.8%
LVL1 Calo 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%



Example : Inclusive single electron trigger
High efficiency for electrons with E_T > 25 GEV and |n| <2.47



ATLAS data taking and data quality



X

DQ	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

95.8%
All good for physics

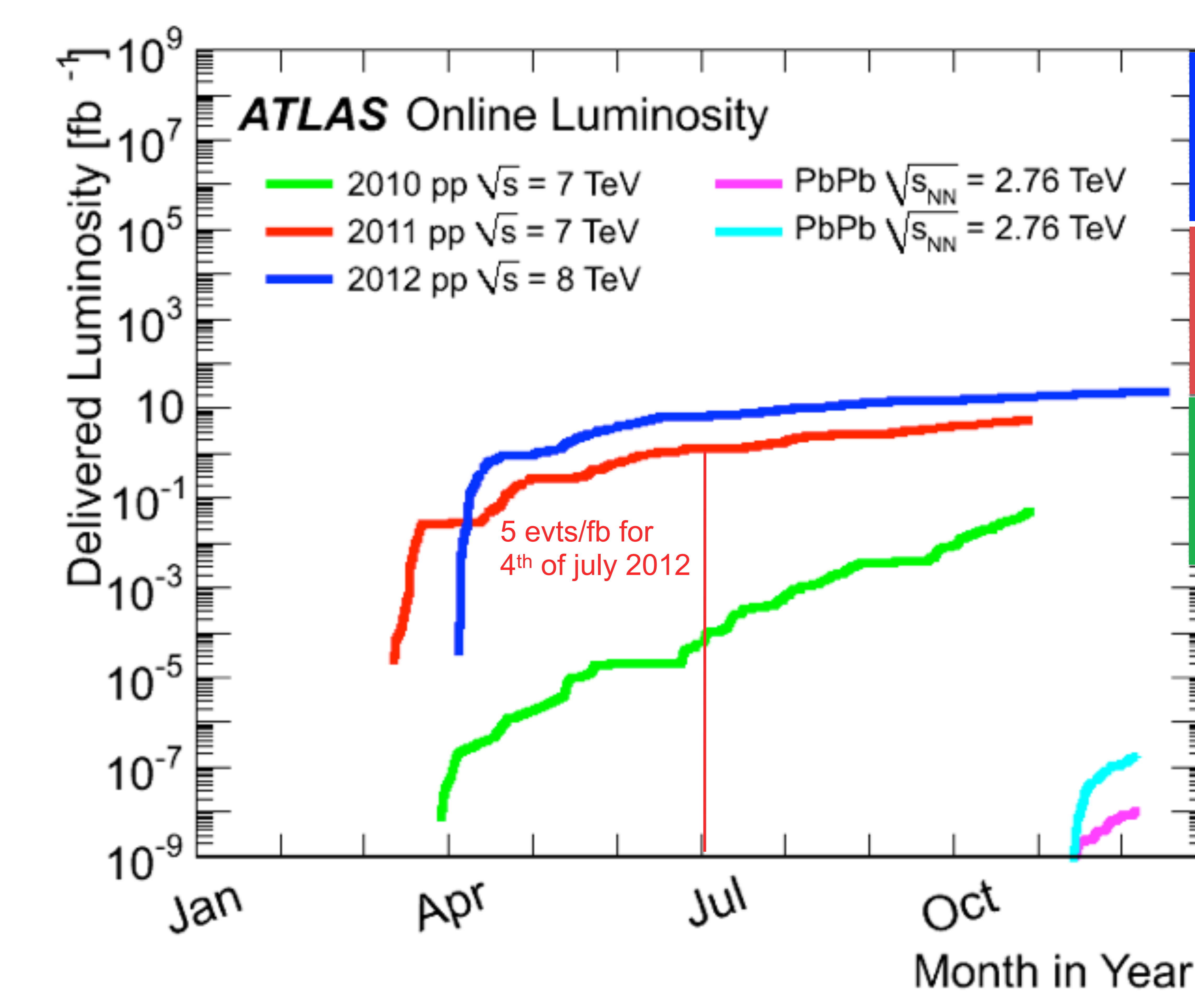
In 2012, 89.5% of DELIVERED data were good for physics.

To my knowledge, never an experiment has reached such a level of efficiency.
Even experiements at e^+e- 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.

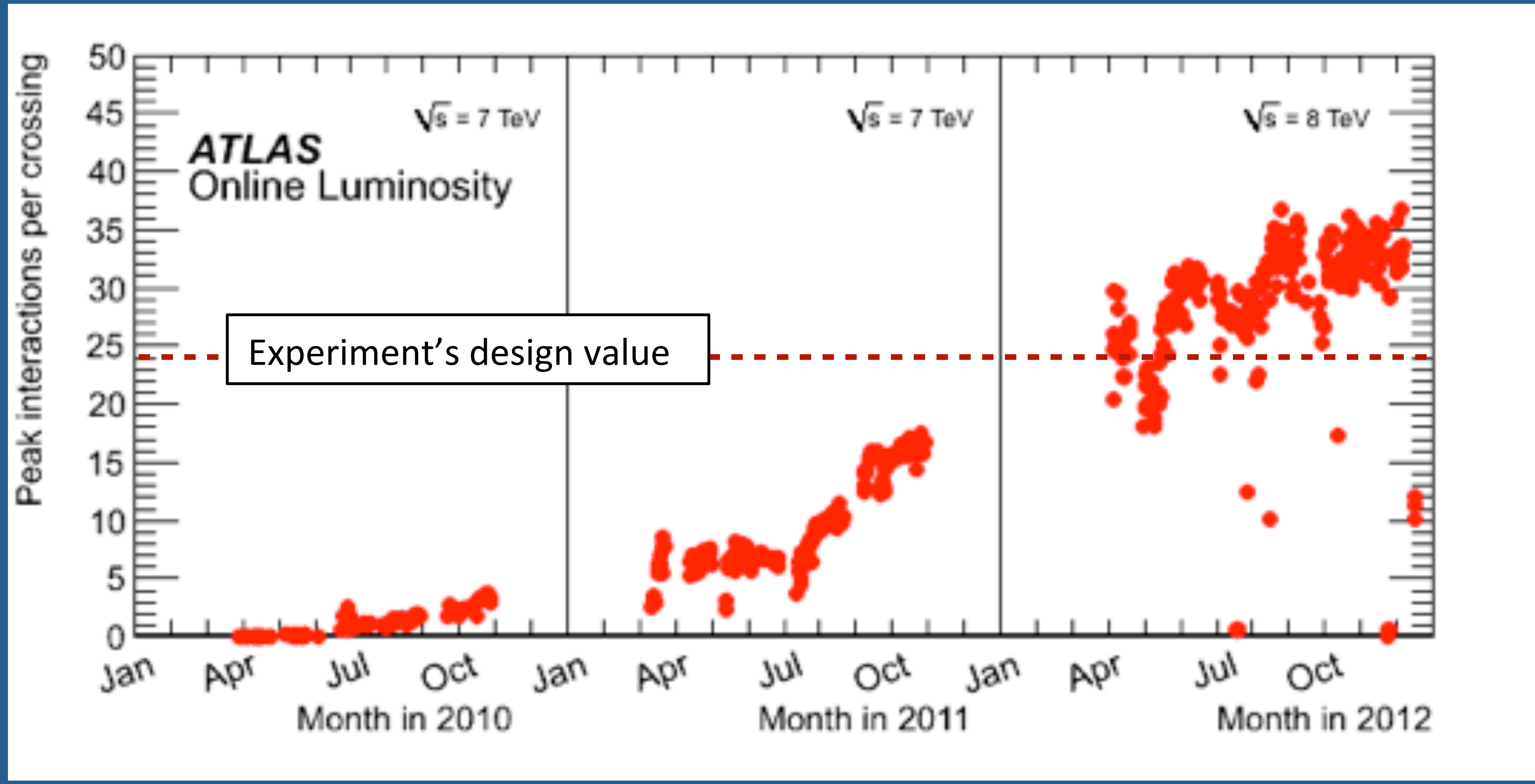
2010-2012 data taking



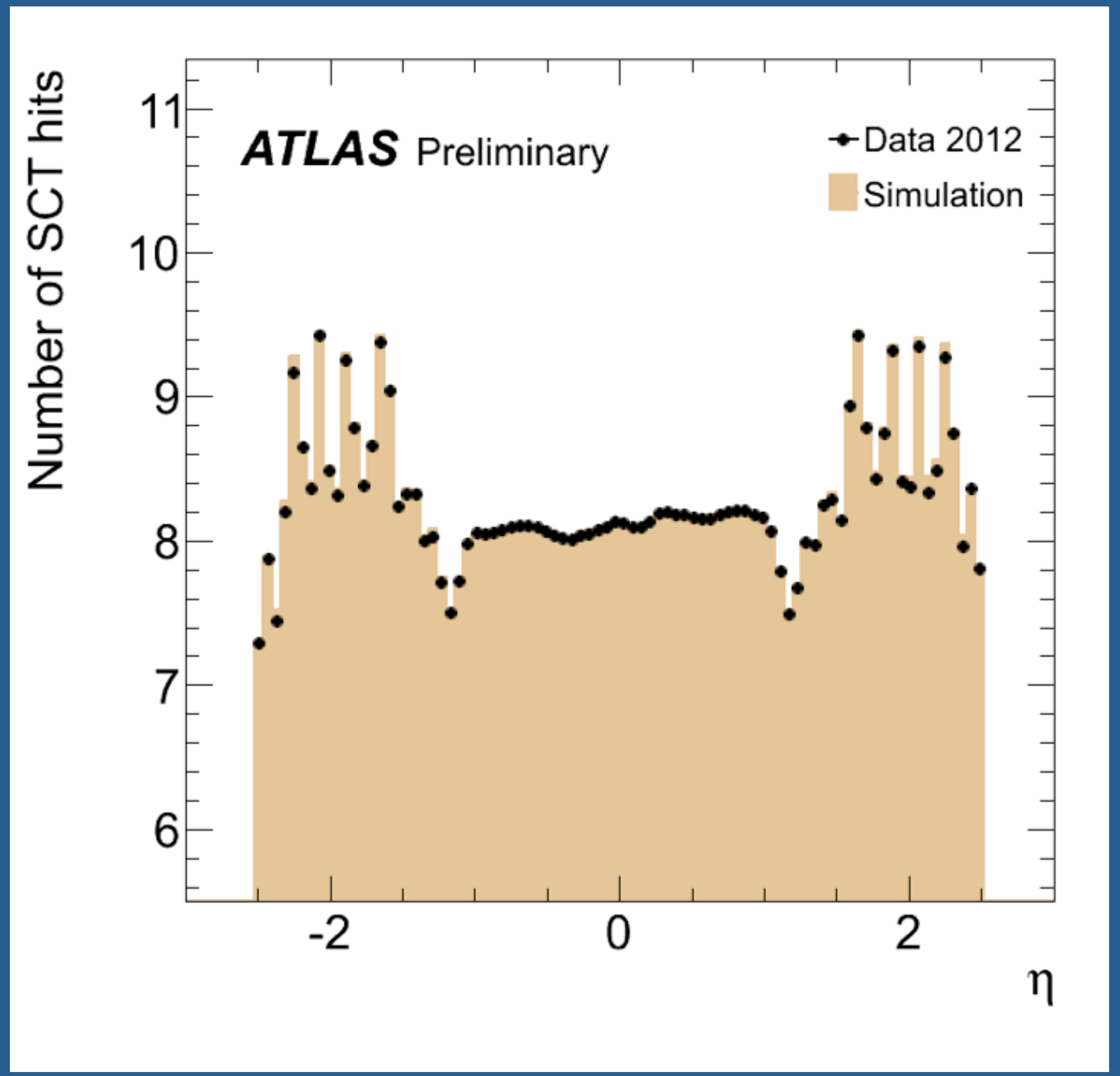
2012 - 8TeV
23 evts/fb

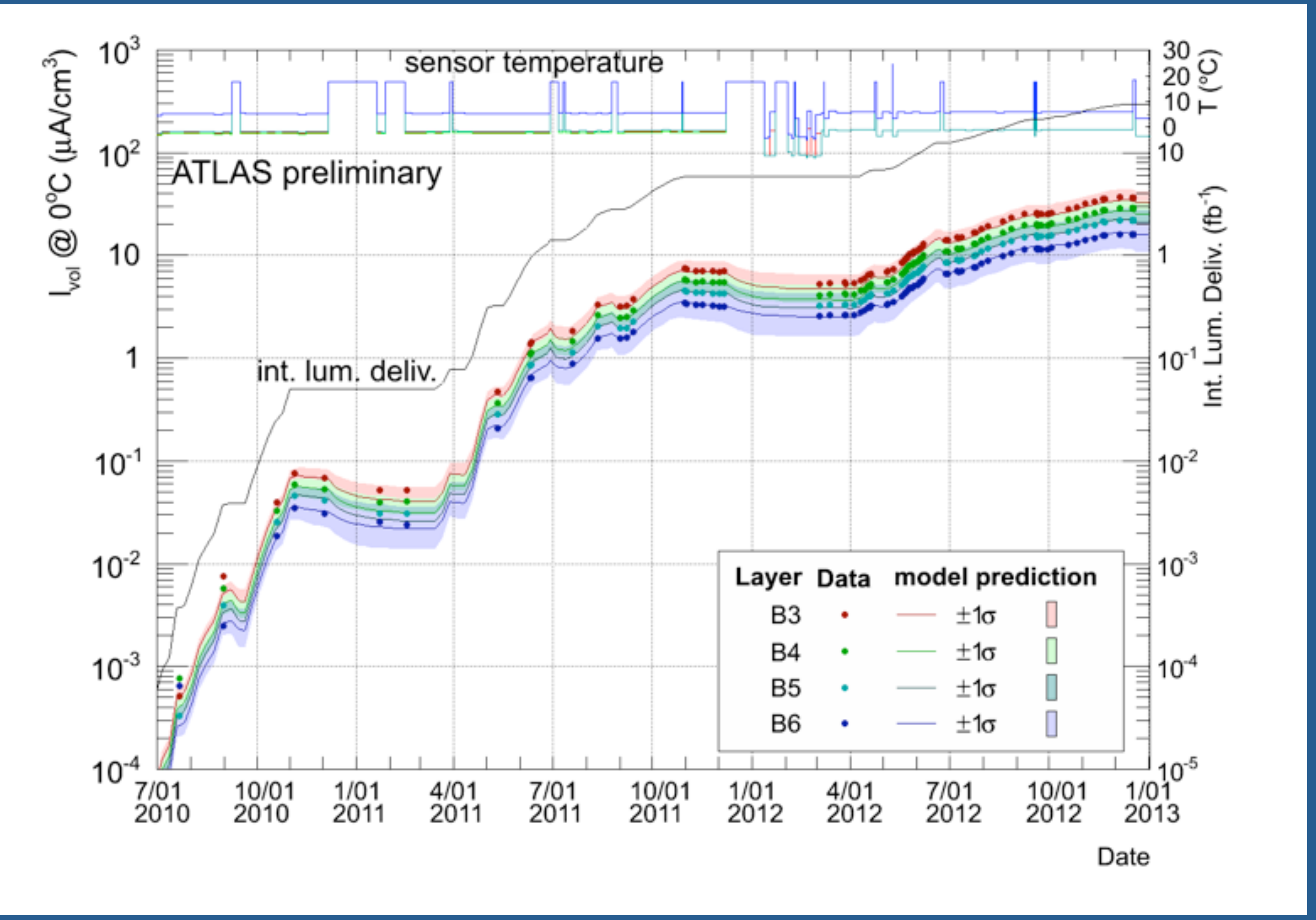
2011 - 7TeV
5 evts/fb

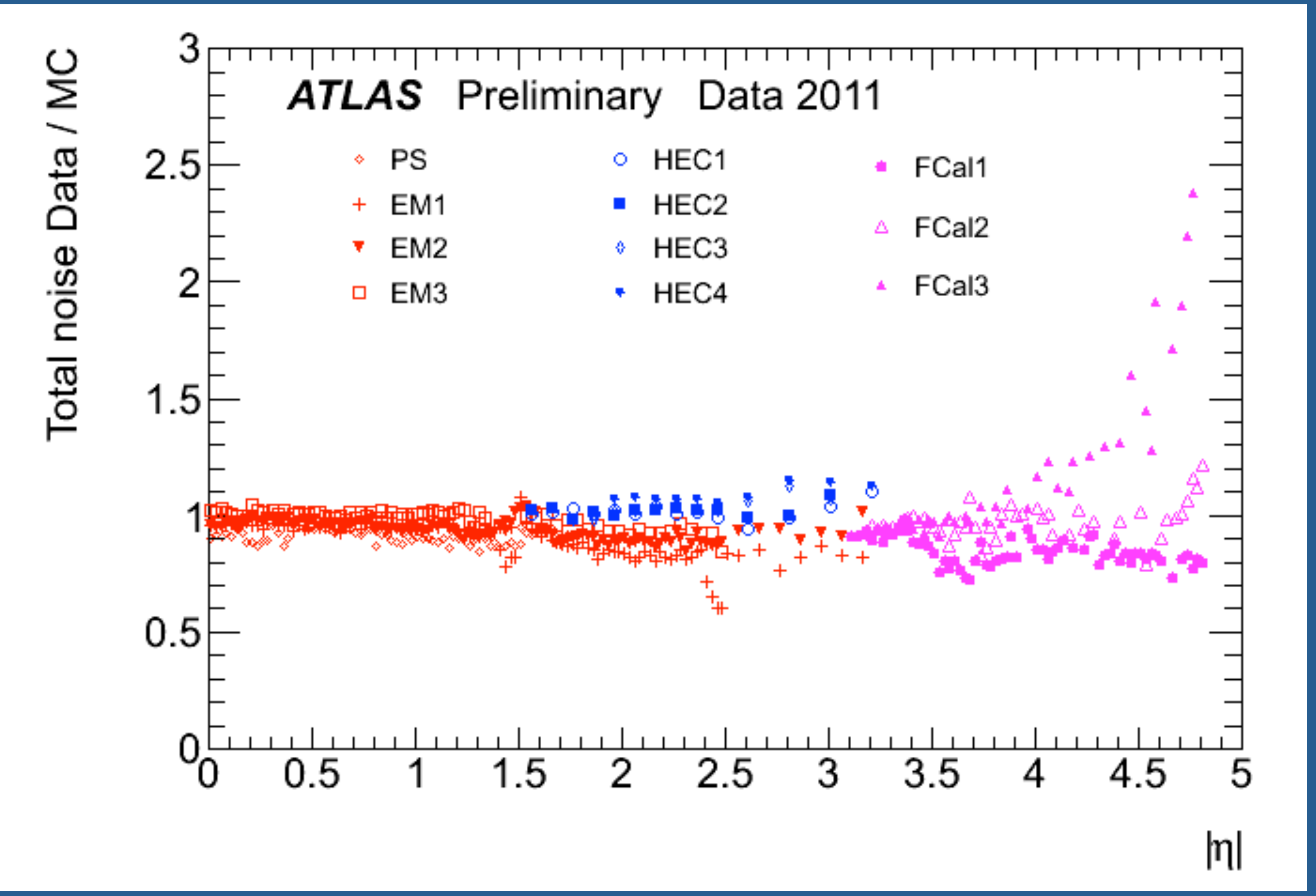
2010 - 7TeV
0.05 evts/fb

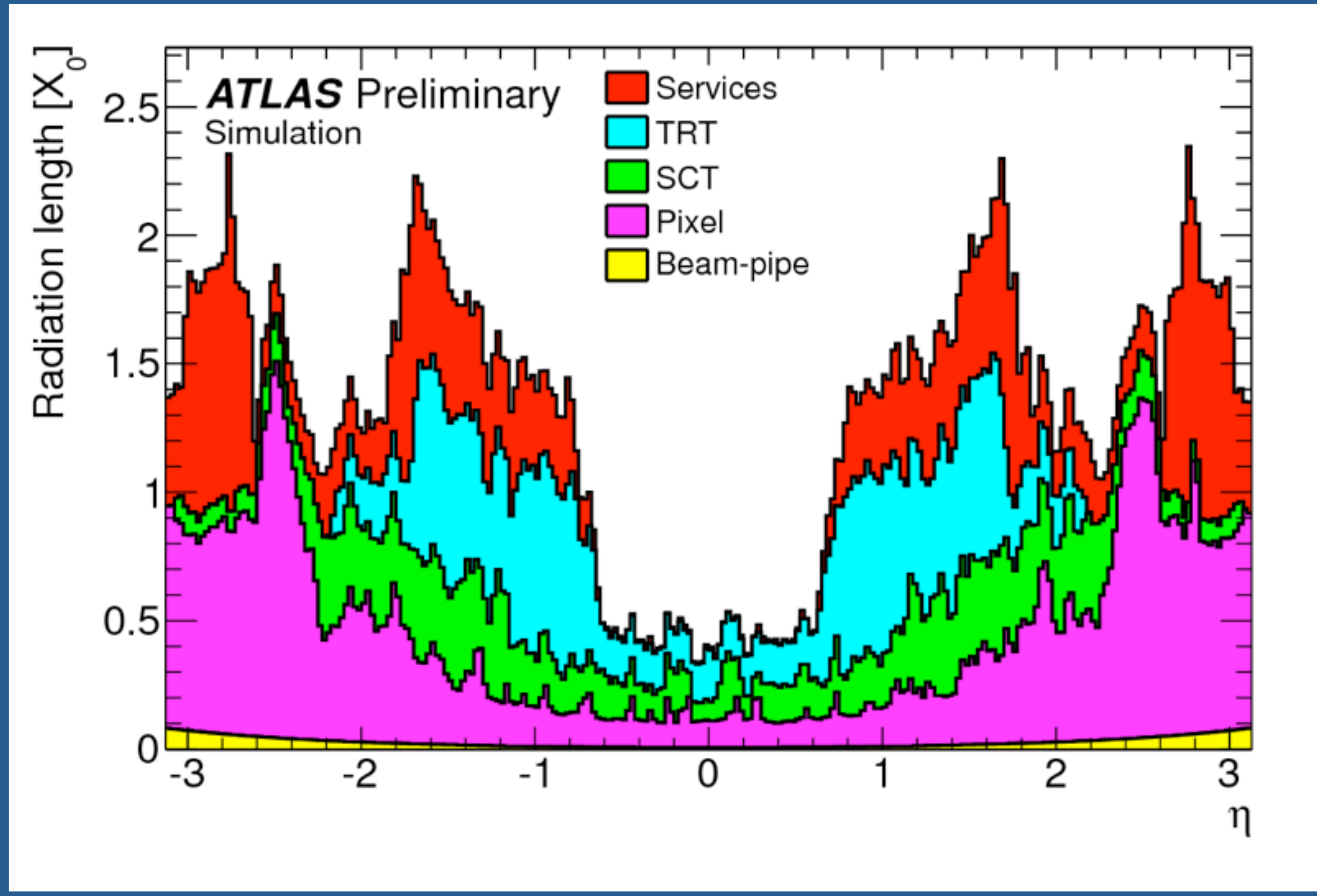


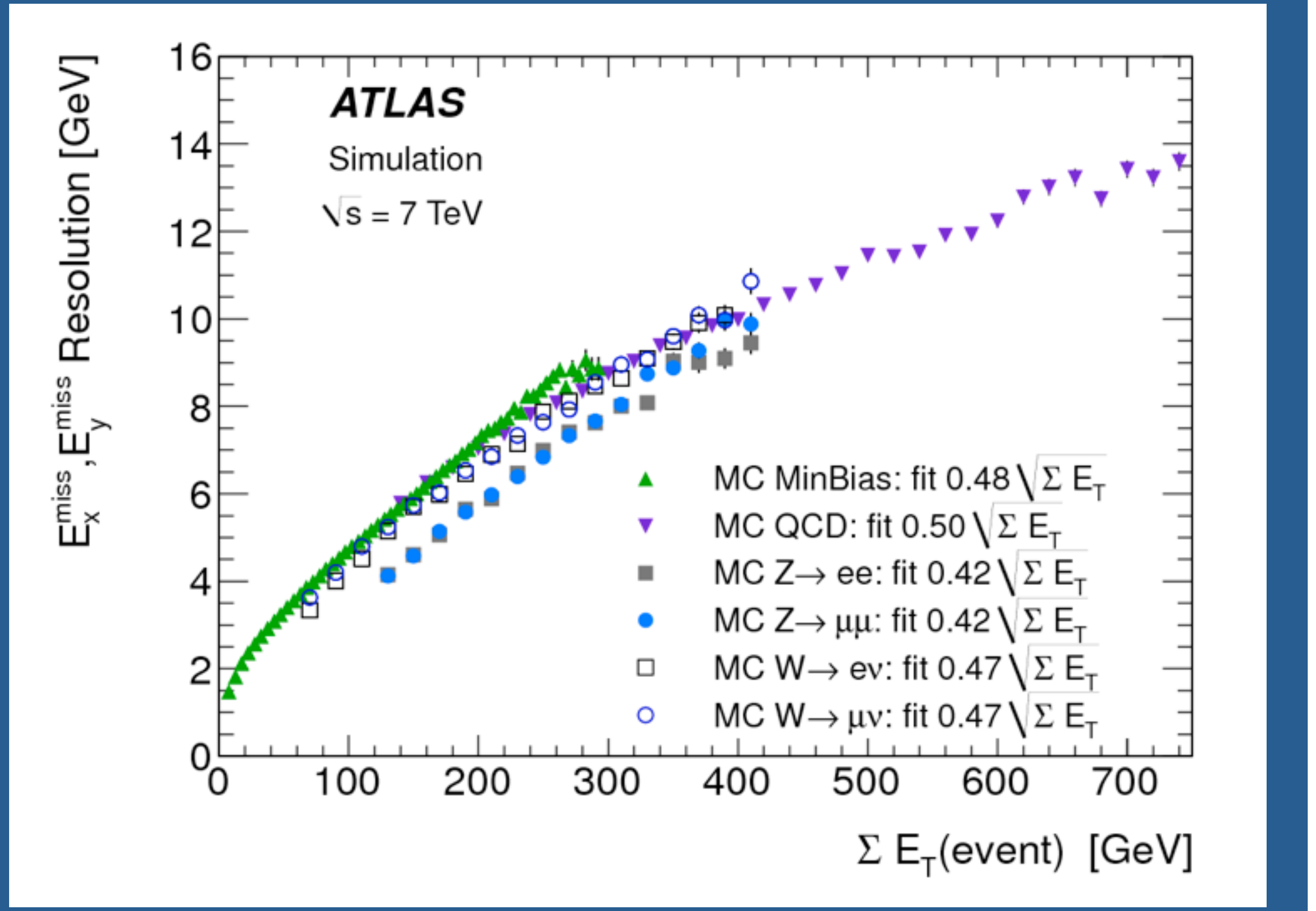
ATLAS detector simulation: a tool towards physics

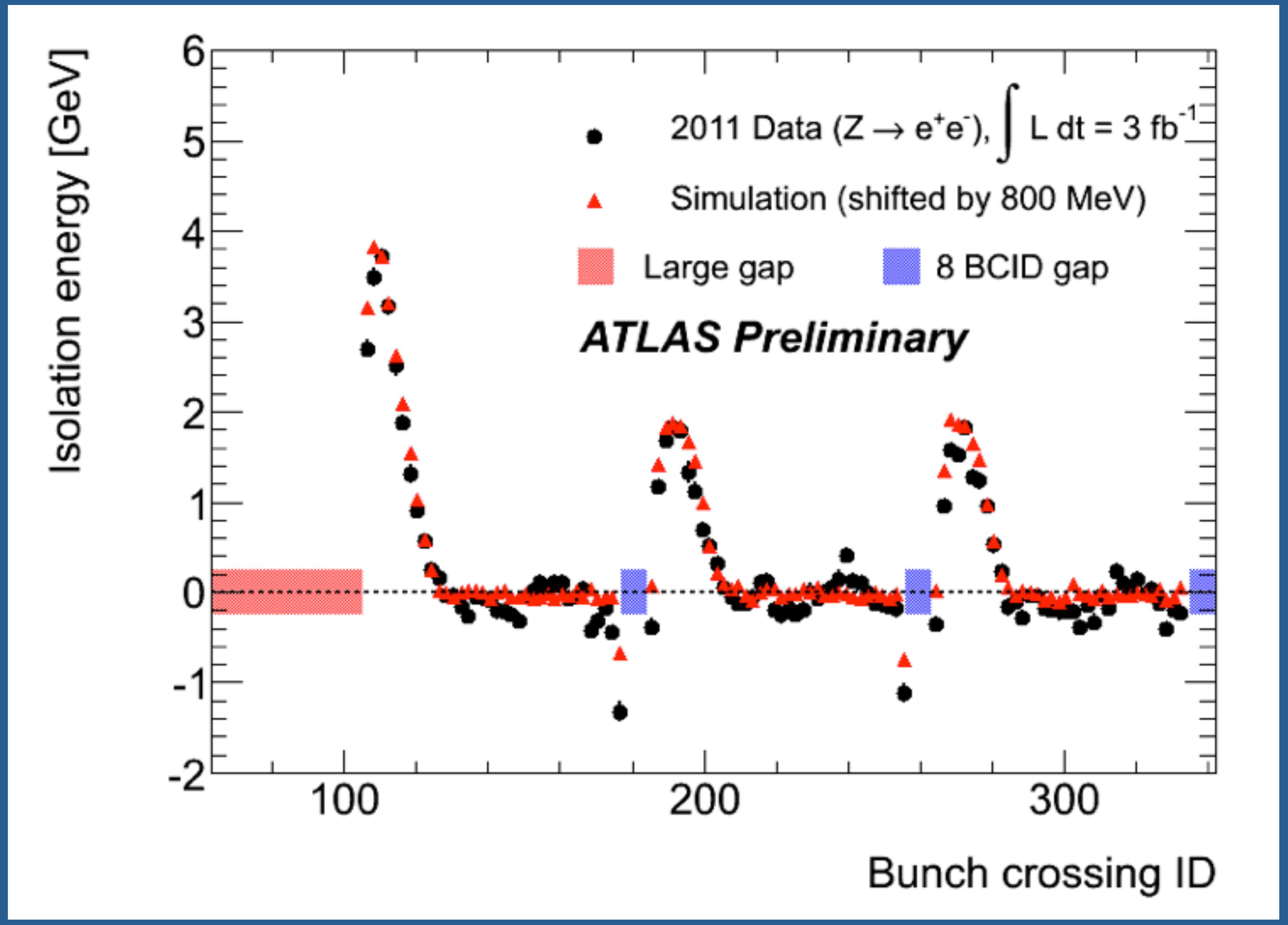








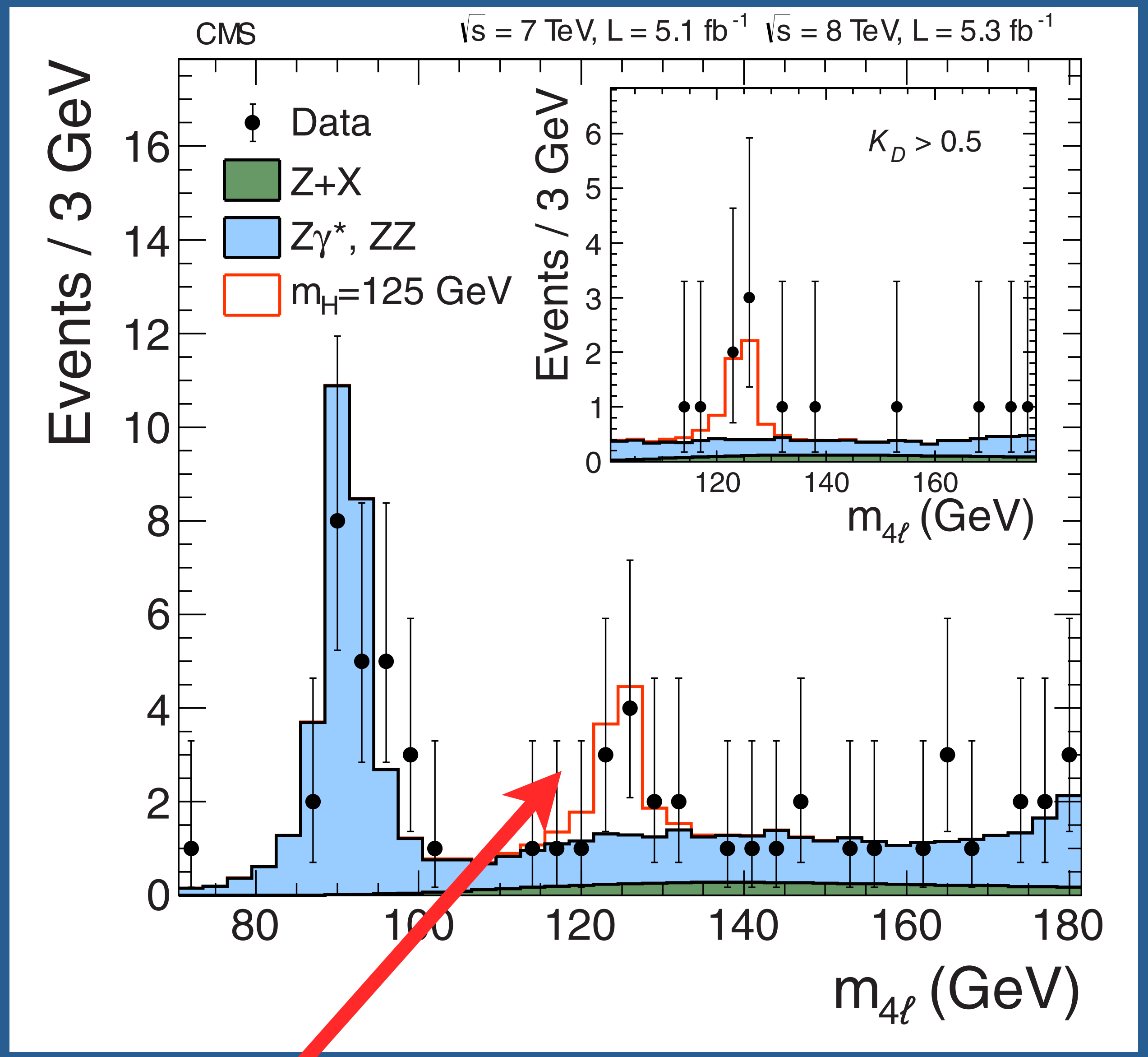


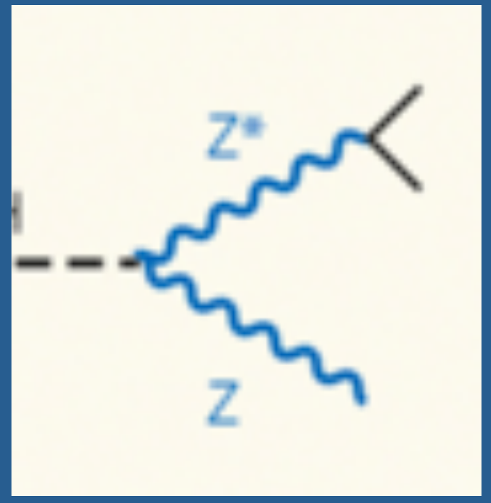


4^{th} July 2012

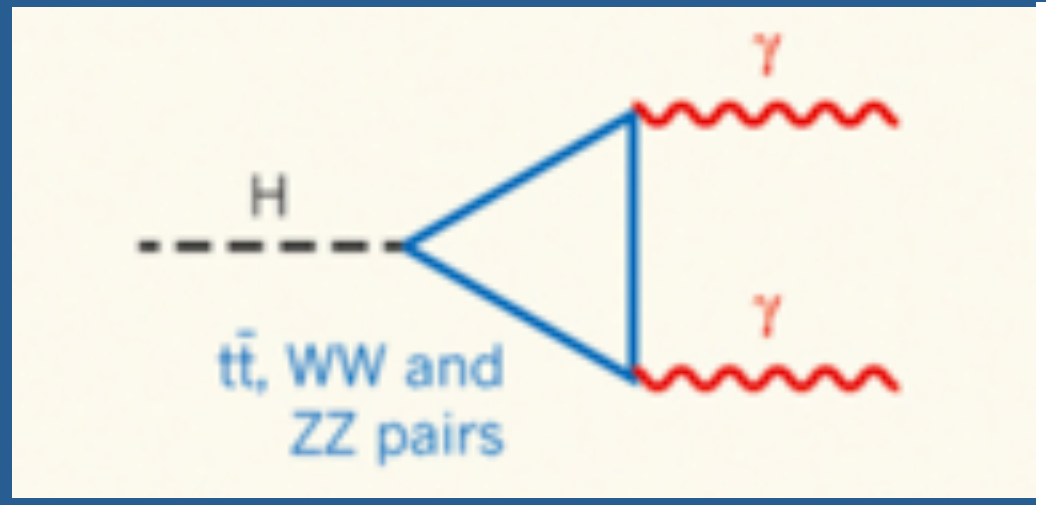
4th July 2012 - HIGGS DISCOVERY with ATLAS & CMS

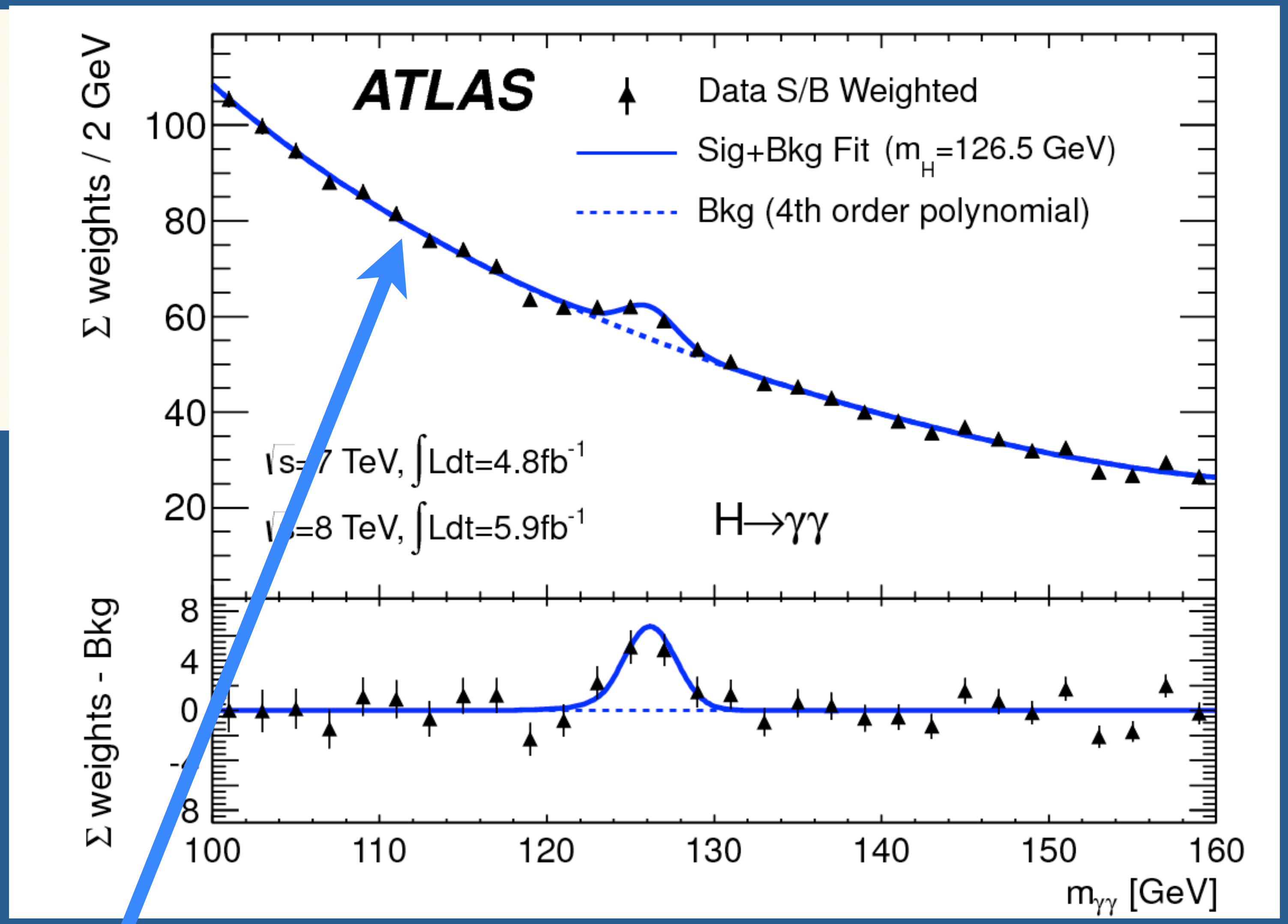
H→4 leptons





H→2 photons





● ▲ : THE data

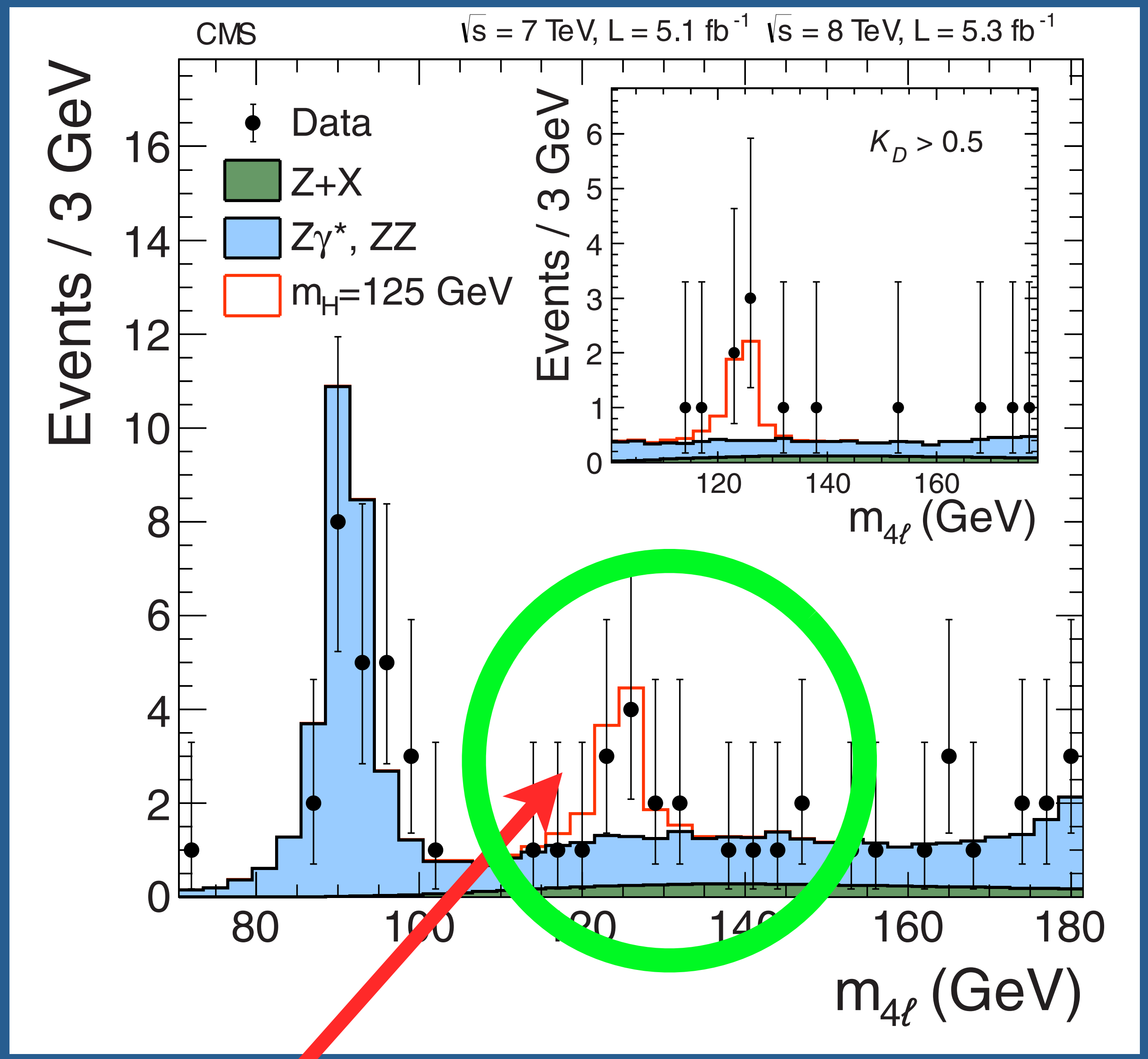
Higgs boson (prediction)

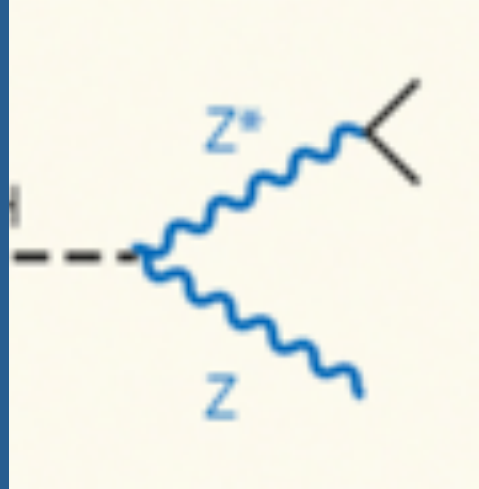
background + Higgs boson

background

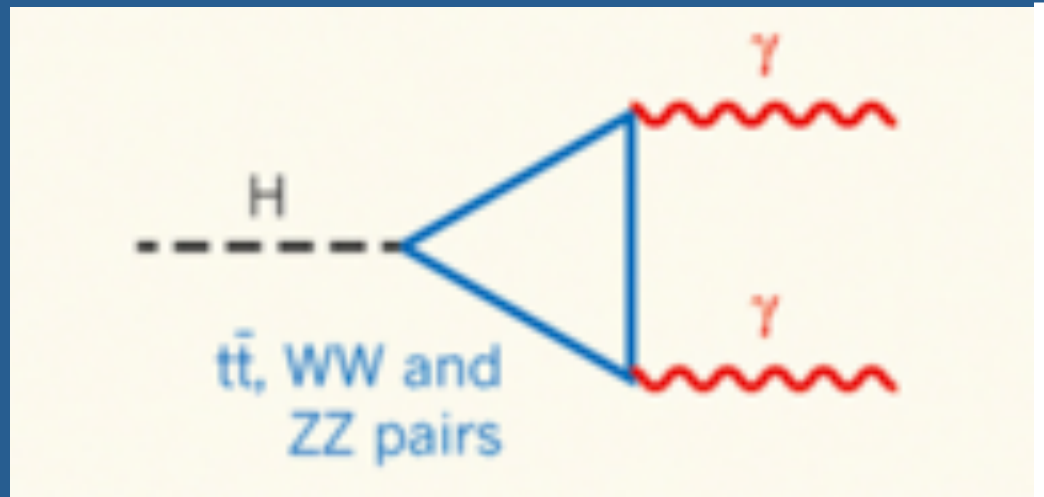
4th July 2012 - HIGGS DISCOVERY with ATLAS & CMS

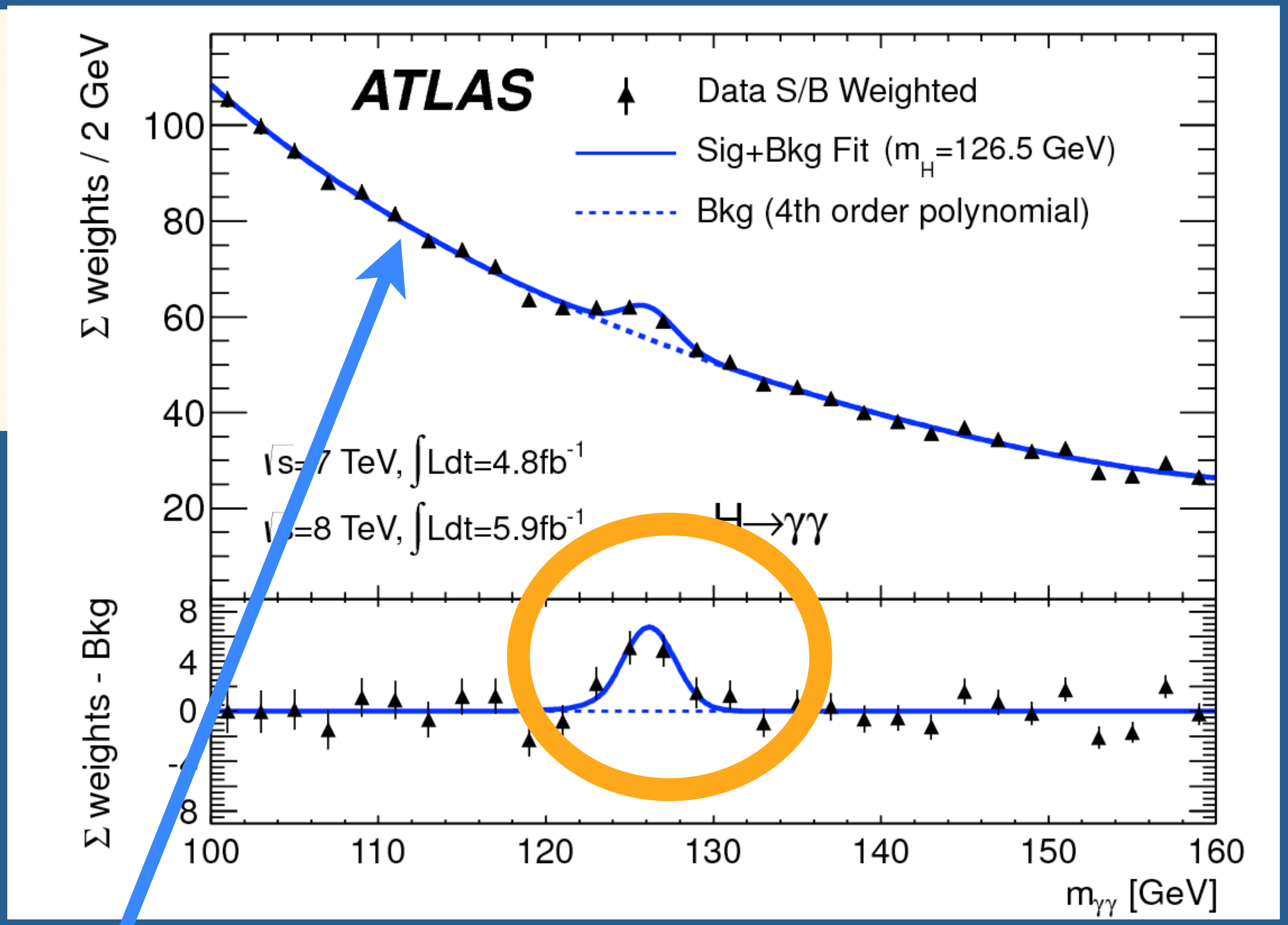
H→4 leptons





H→2 photons





● ▲ : THE data

Higgs boson (prediction)

background

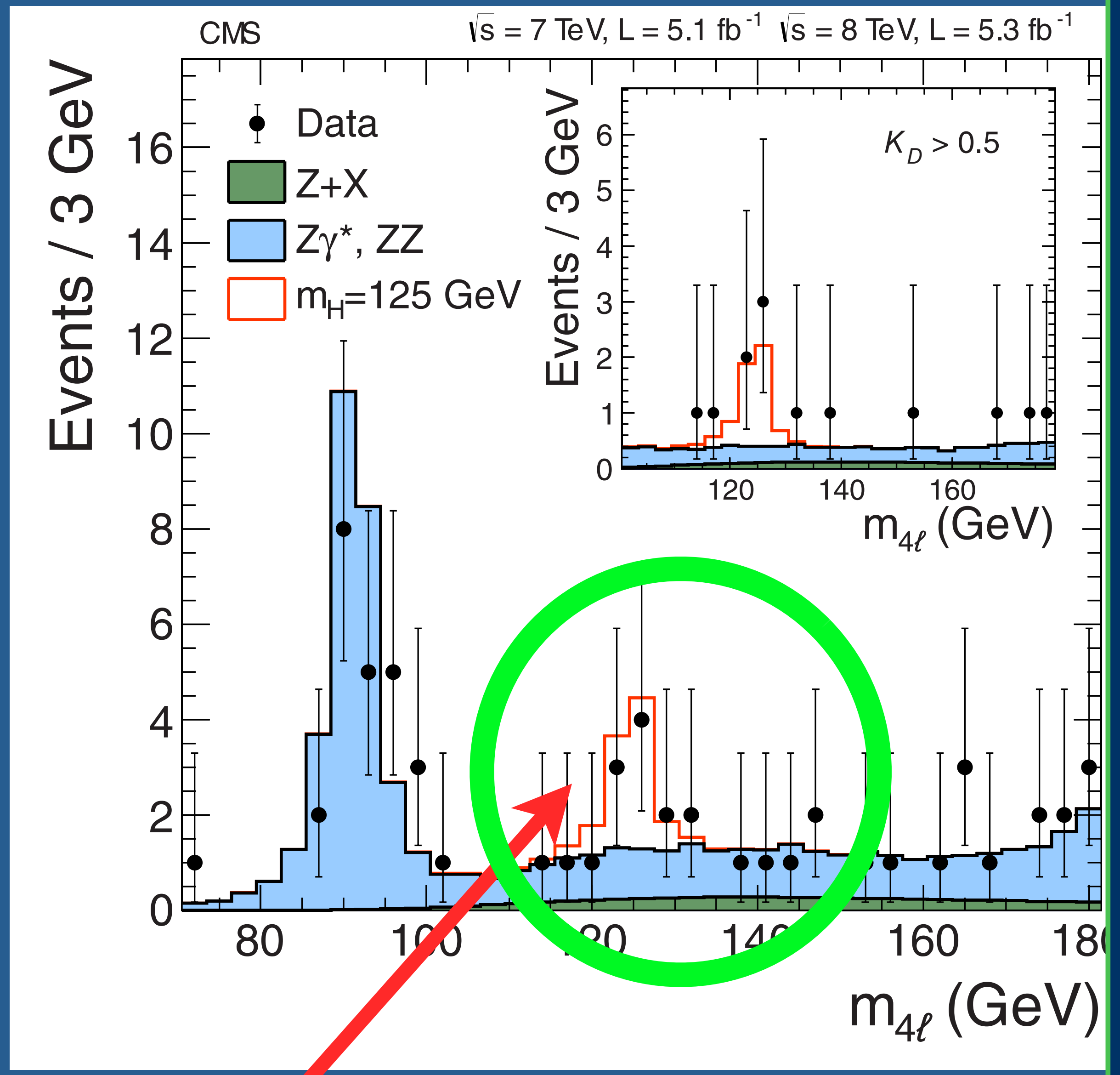
background + Higgs boson

Data *need* the Higgs boson.

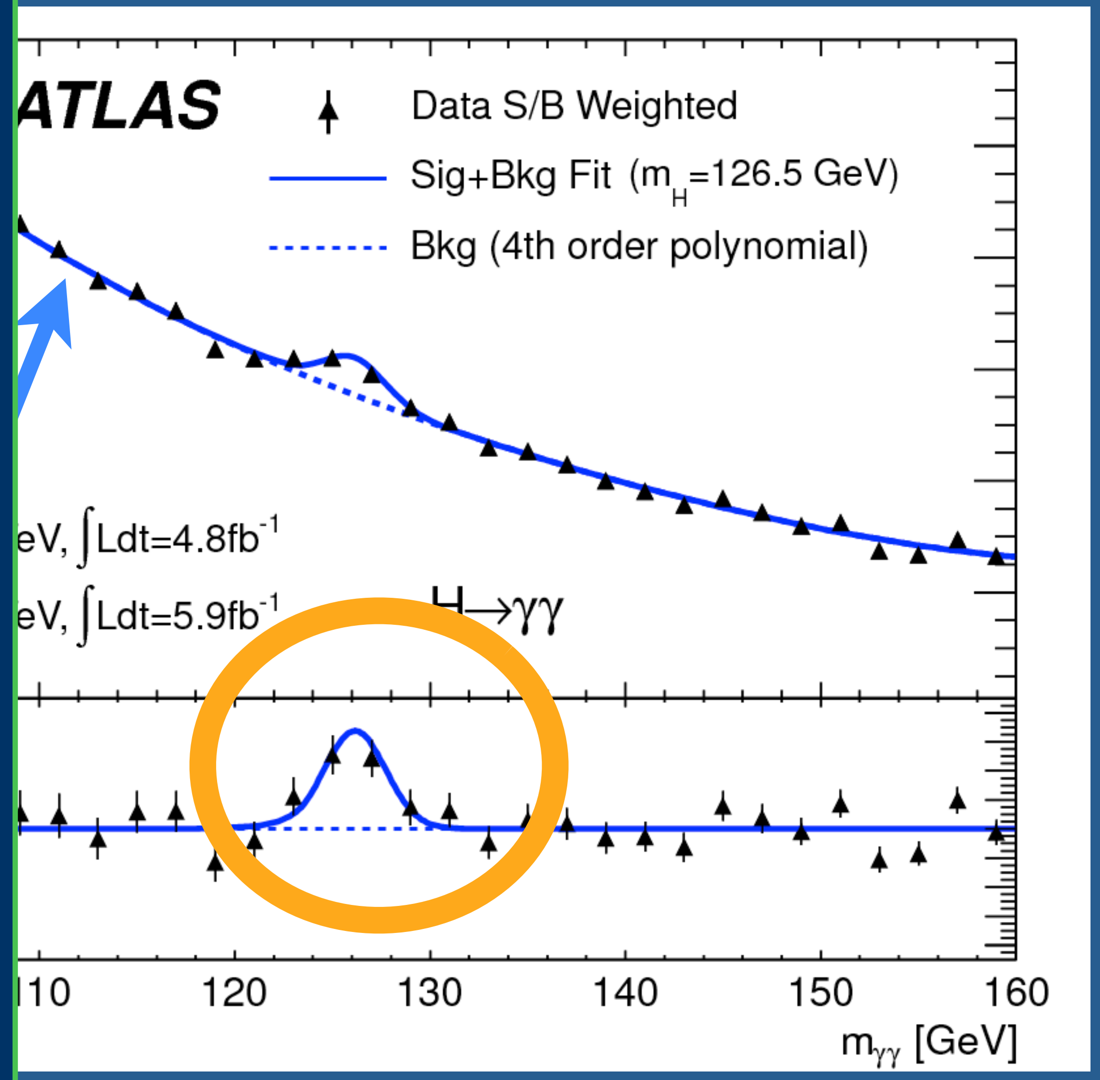
Excess also observed in WW channel

4th July 2012 - HIGGS DISCOVERY with ATLAS & CMS

H→4 leptons



H→2 photons



ATLAS & CMS collaborations have observed the Higgs boson

Higgs boson (prediction)

background

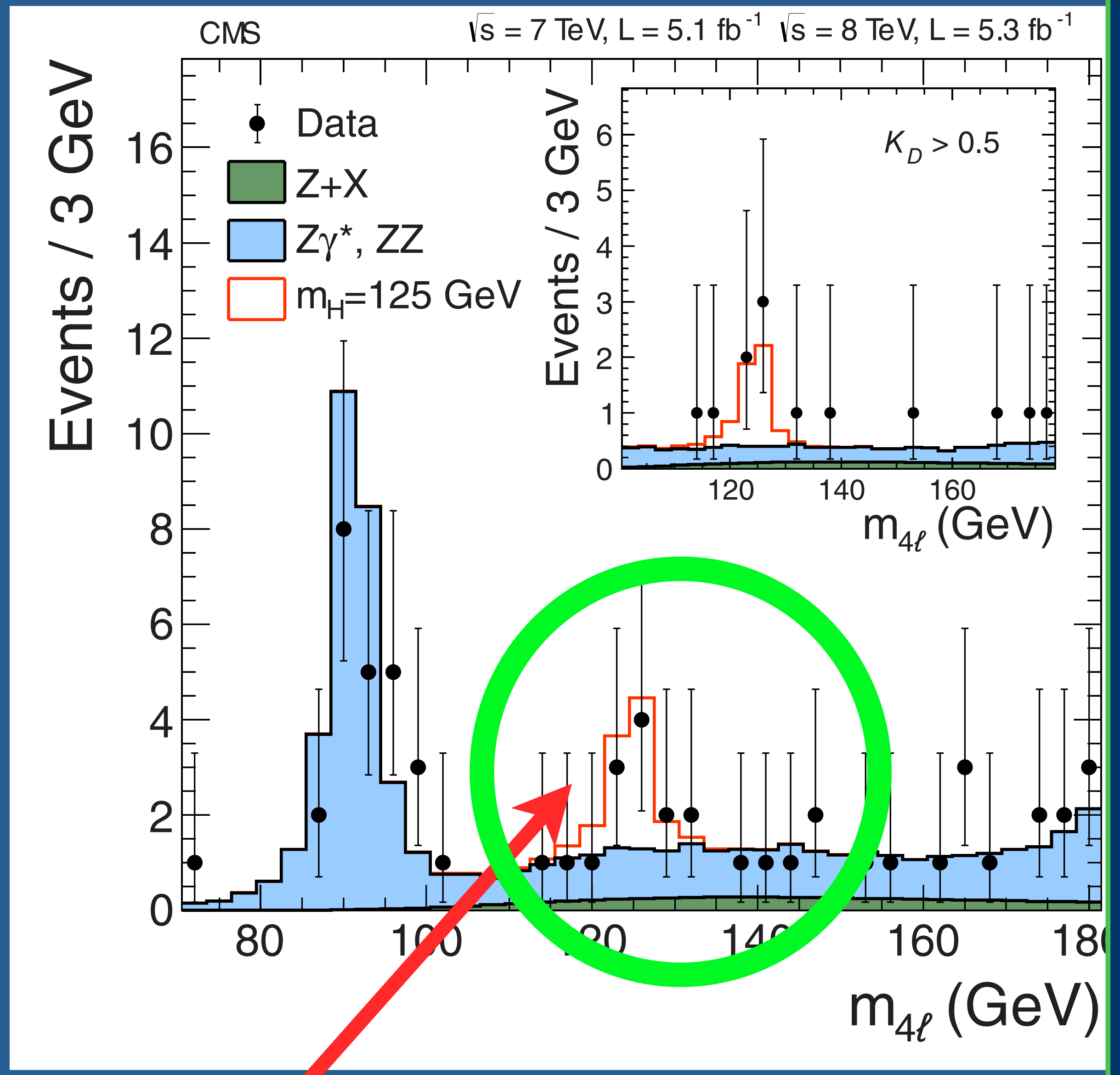
background + Higgs boson

Data *need* the Higgs boson.

Excess also observed in WW channel

4th July 2012 - HIGGS DISCOVERY with ATLAS & CMS

H→4 leptons

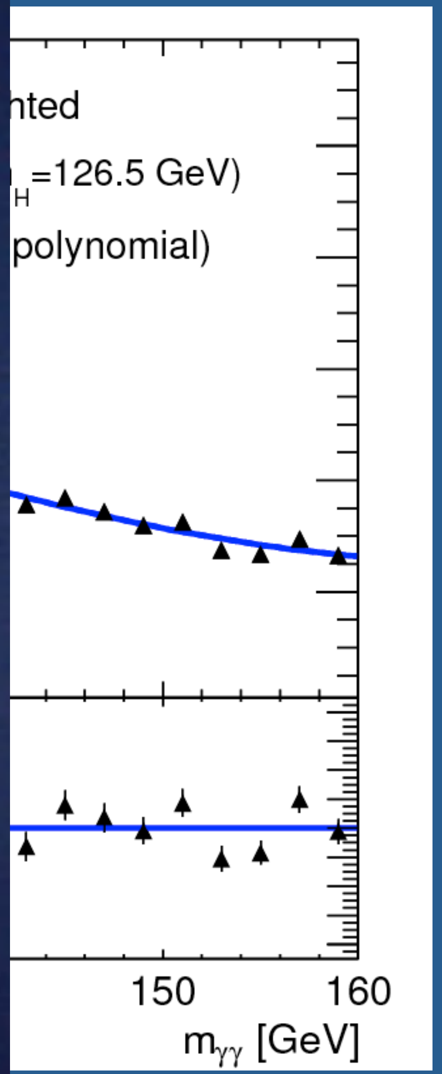


ATLAS & CMS

co

ha

Hi



Higgs boson (prediction)

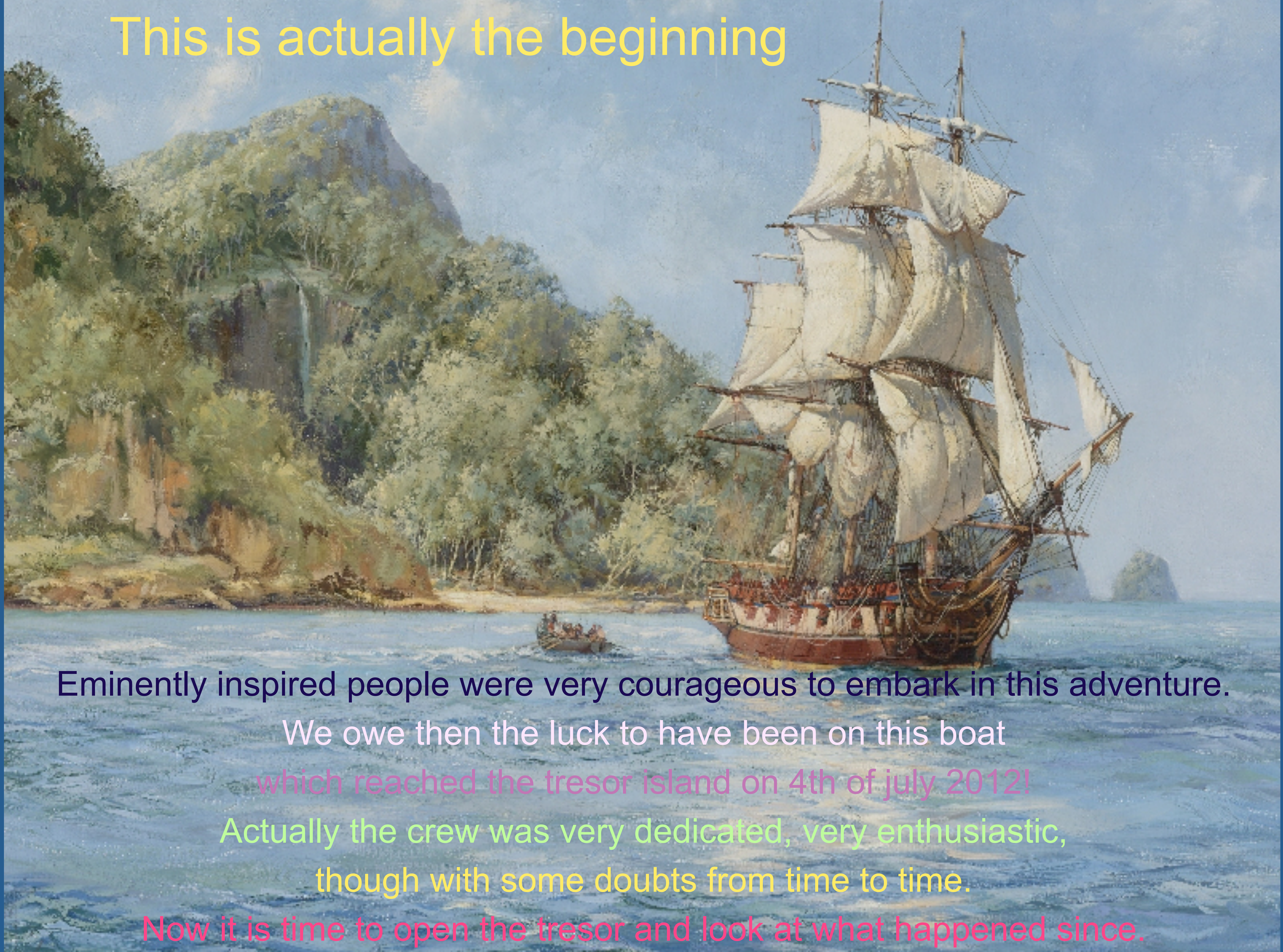
background

s boson

Data *need* the Higgs boson.

Excess also observed in WW channel

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

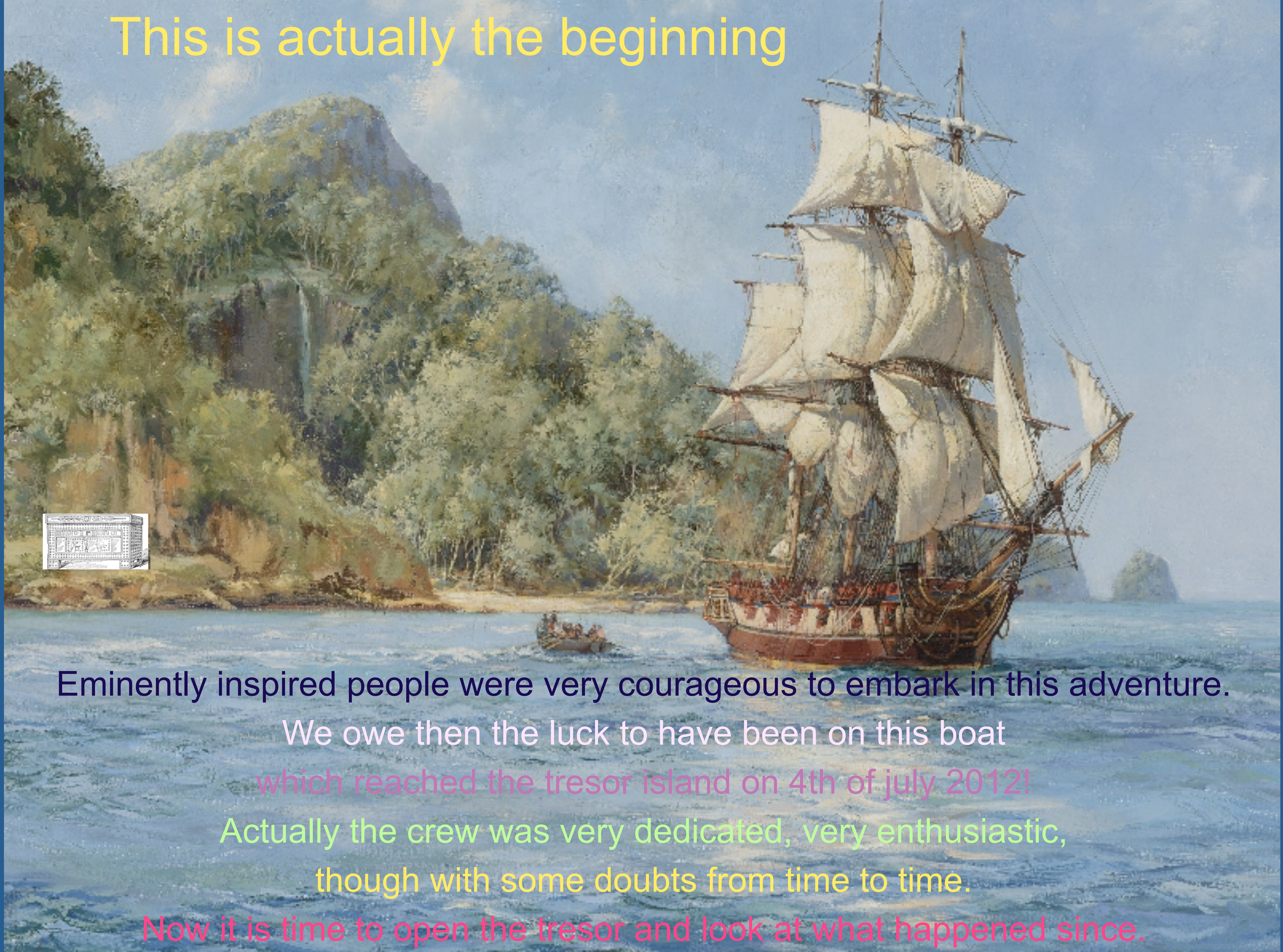
which reached the tresor island on 4th of july 2012!

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



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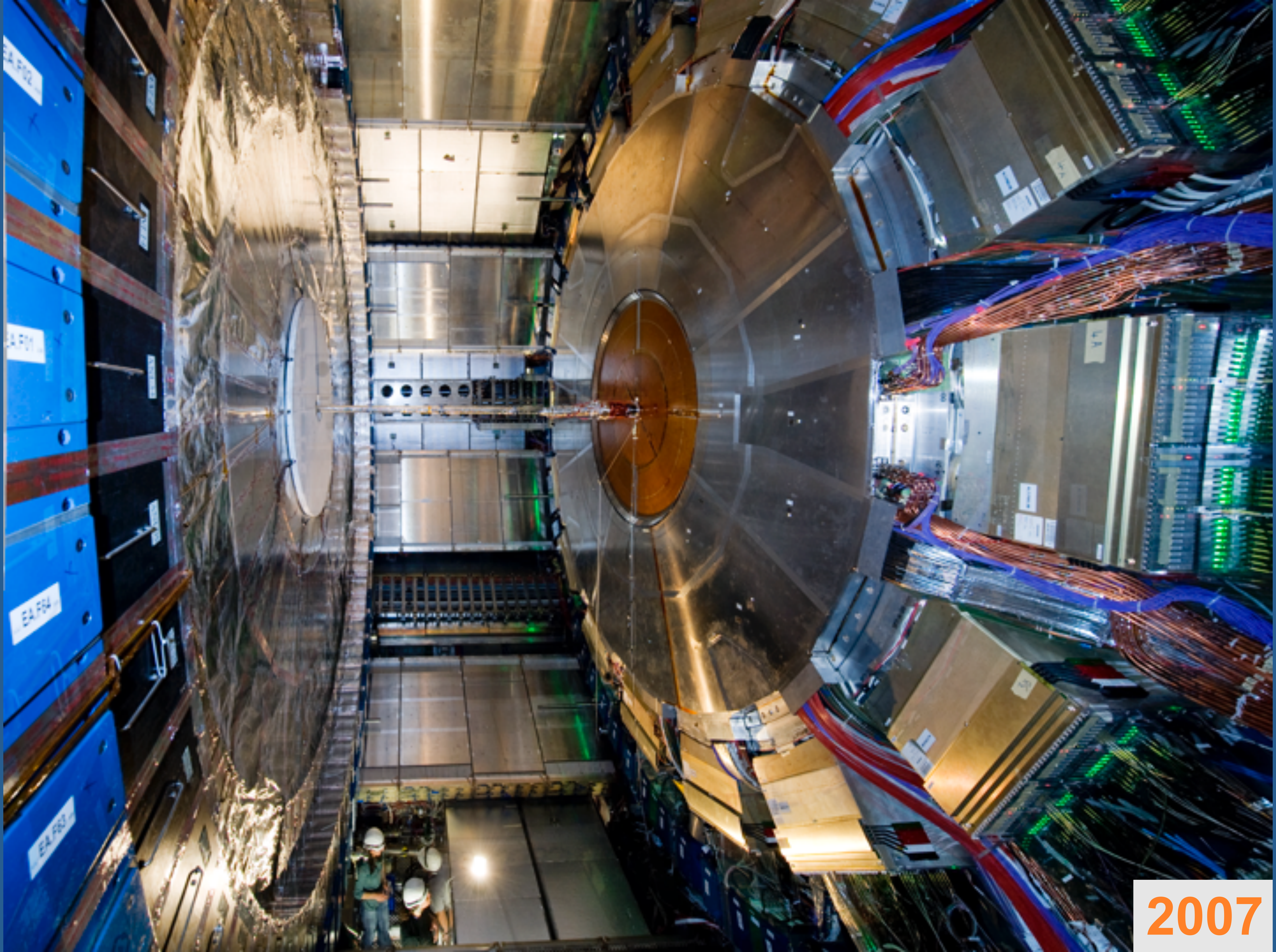
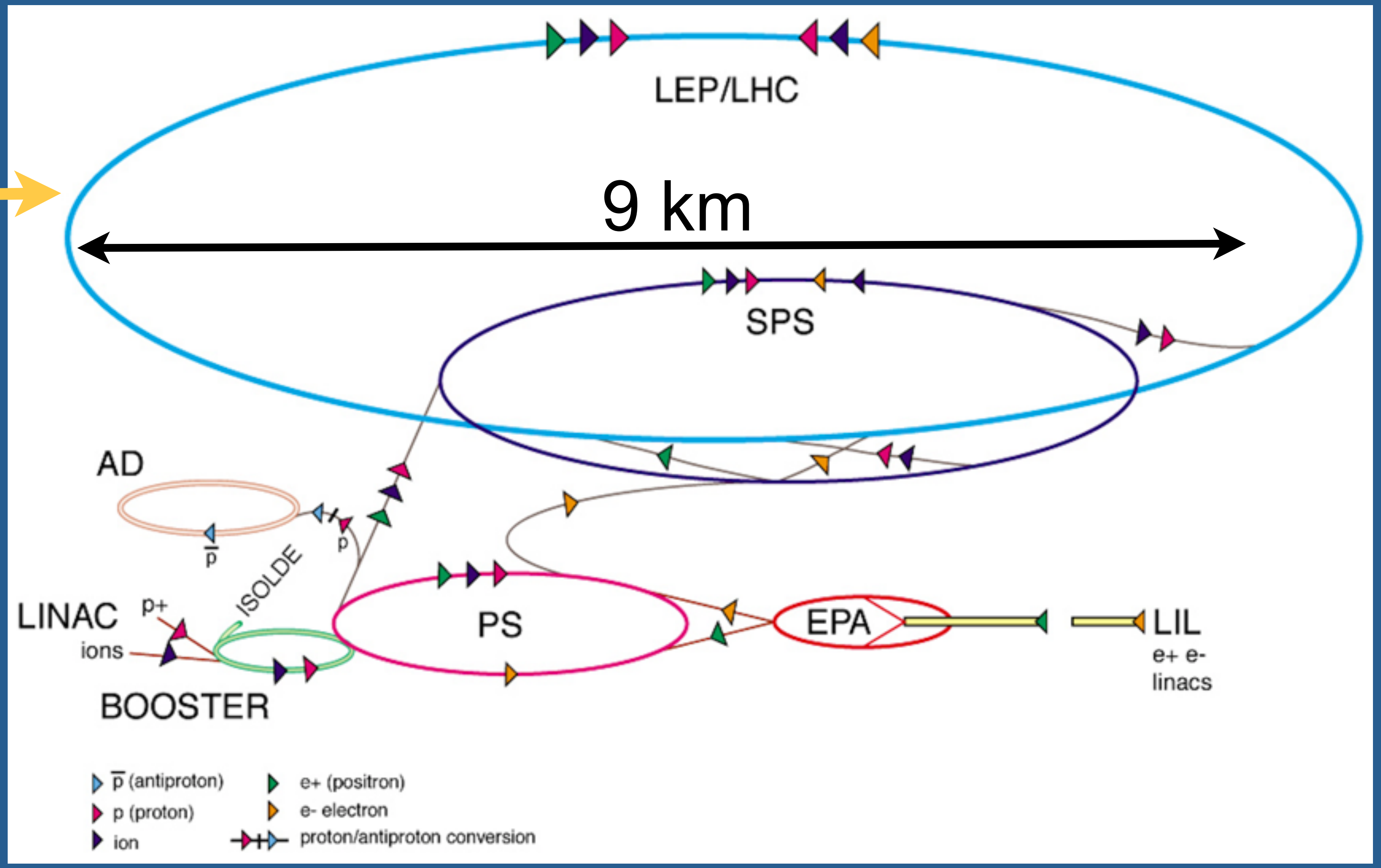
EXTRA


2007

The LARGE HADRON COLLIDER at CERN

LEP tunnel exists at CERN:
  27 km circonference

It was built in the 80's to produce electron-positon collisions:
  to study the Z boson
  to test the standard model
  discover the Higgs boson



December 1994: the LHC will be installed inside the LEP tunnel
  proton-proton collider at very high energy

LEP operation stops in 2000
  The Higgs boson has not been observed:
    The Higgs boson mass is higer than 114.6 GeV

The HIGGS mechanism and the HIGGS boson

Peter Higgs, François Englert, Robert Brout and a few more theoreticians, proposed in **1964** a mechanism to explain how the W and Z bosons can acquire a mass: *the Higgs mechanism,* and at the same time preserves the requirements from the theory.

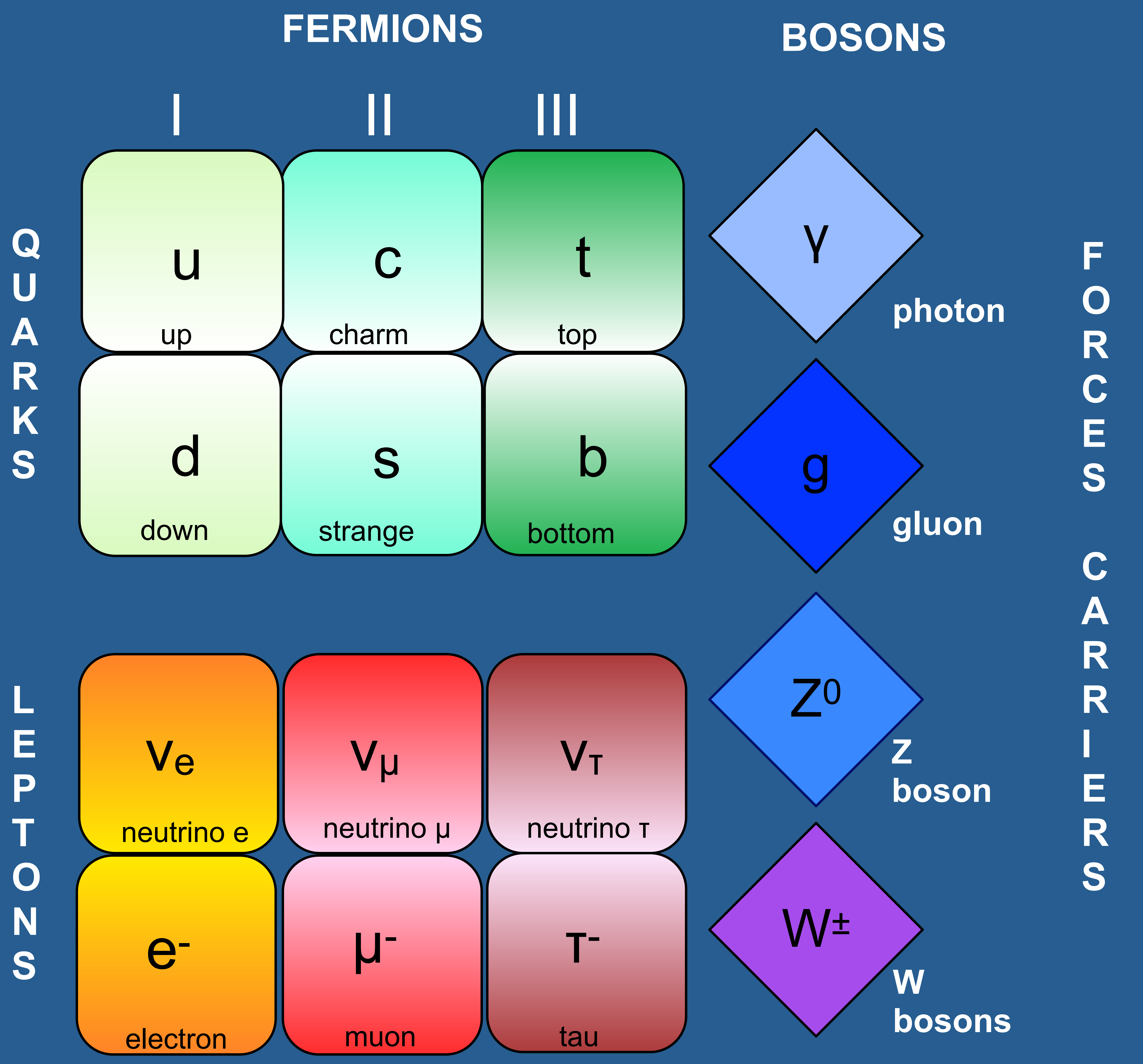
The Higgs field fills the space and interacts with particles, following rules.

The existence of this field leads to the existence of a massive spin-0 particle which mass is not predicted.

The search for the Higgs boson started.

Several experiments have looked for the Higgs boson:

- the four LEP experiments in 1989-2000 (m_H>114.6 GeV);
- the CDF and DZero at the Tevatron at Fermilab (USA) (1985-2011)



The Large Hadron Collider (LHC)

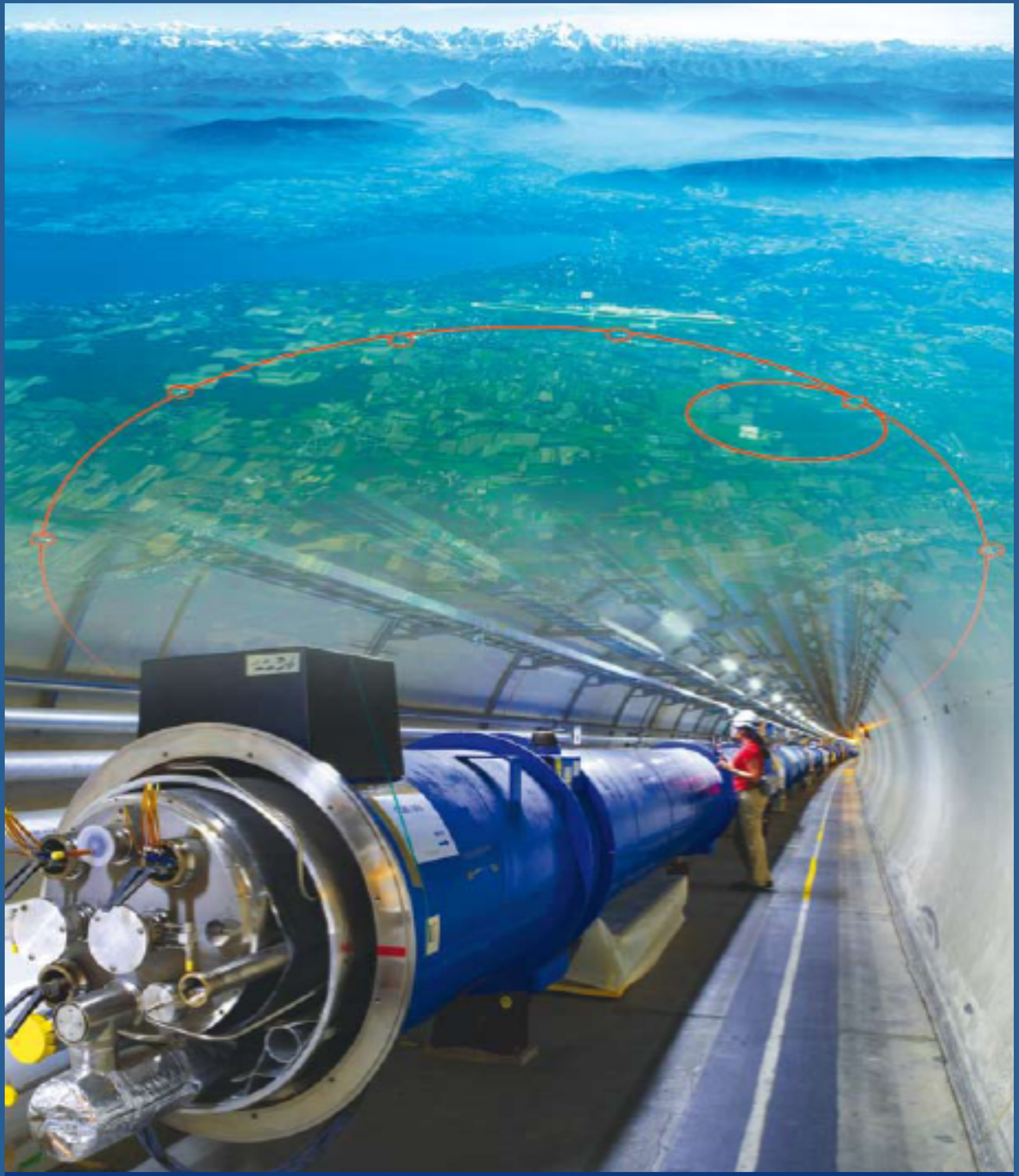
1983	First studies for the LHC project
1988	First magnet model (feasibility)
1994	Approval of the LHC by the CERN Council
1996-1999	Series production industrialisation
1998	Declaration of Public Utility & Start of civil engineering
1998-2000	Placement of the main production contracts
2004	Start of the LHC installation
2005-2007	Magnets Installation in the tunnel
2006-2008	Hardware commissioning
2008-2009	Beam commissioning

~ 25 years

2010-2040… **Physics exploitation**

2010 – 2012	Run 1 ;7 and 8 TeV
2015 – 2018	*Run 2 ; 13 TeV*
2021 – 2024	Run 3 (14 TeV)
2025 – 2026	HL-LHC installation
2027 – 2040…	HL-LHC operation

~ 30 years



A 27 km circumference collider…