Physics Program

of the experiments at

Large Hadron Collider

Lecture 1

Introduction

Outline of this course

- Introduction to LHC, its experiments, physics programme and experimental challenges
- First physics and performance results with 900 GeV and 2.36 TeV
- First measurements with 7 TeV collisions:
  - SM physics: W, Z, top, QCD jets
- More to come:
  - Extra dimensions and exotics
  - The SM and MSSM Higgs
  - Sypersymmetry
- First heavy ion results

Outline of this lecture

- What is CERN and brief history toward the LHC?
- What is LHC?
- Why the LHC?
- The general purpose experiments: ATLAS and CMS
- Brief overview of the physics programme
- Experimental challenges

LHC at CERN laboratory

- CERN: the world’s largest particle physics laboratory
  - International organisation created in 1953/1954, initial membership: 12 countries
  - Poland is a member starting from year 1991
  - About 10000 active physicists, computing scientists, engineers

Situated between
Jura mountains
and Geneva
(France/Swiss)

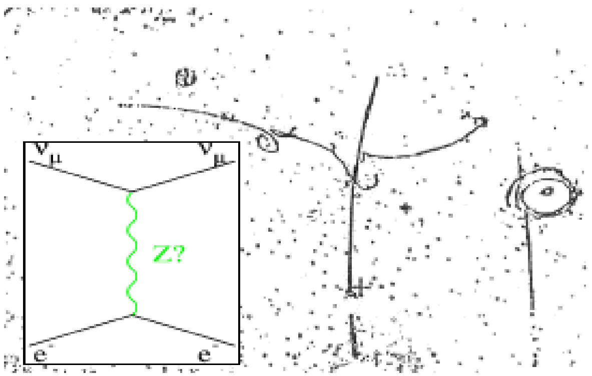
http://public.web.cern.ch

A brief historical overview: toward LHC

1964: First formulation of Higgs mechanism (P.W.Higgs)

1967: Electroweak unification, with W, Z and H (Glashow, Weinberg, Salam)

1973: Discovery of neutral currents in ν_μ e scattering (Gargamelle, CERN)

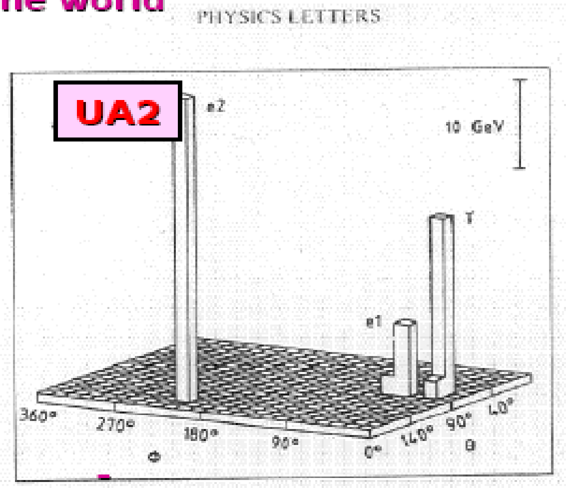


1974: Complete formulation of the standard model with $SU(2)_W \times U(1)_Y$ (Iliopoulos)

1981: The CERN SpS becomes a proton-antiproton collider LEP and SLC are approved before W/Z boson discovery

1983: LEP and SLC construction starts W and Z discovery (UA1, UA2)

One of the first Z-bosons detected in the world



$q\bar{q} \to Z \to e^+ e^- \gamma$

A brief historical overview: toward LHC

1984: Glimmerings of LHC and SSC

1987: First comparative studies of physics potential of hadron colliders (LHC/SSC) and e^+e^- linear colliders (CLIC)

1989: First collisions in LEP and SLC
Precision tests of the SM and search for the Higgs boson begin in earnest
R&D for LHC detectors begins

1993: Demise of the SSC

1994: LHC machine is approved (start in 2005)

1995: Discovery of the top quark at Fermilab by CDF (and D0)
Precision tests of the SM and search for the Higgs boson continue at LEP2

Approval of ATLAS and CMS

2000: End of LEP running

2001: LHC schedule delayed by two more years

2008: LHC started but after few days of operating with single beam very serious accident

2009: Restarted back just before Xmass with 900 GeV collision

2010: Since March collecting data at 7 TeV pp collision.
Time shared between machine commissioning and physics runs. About 10pb-1 collected by each experiment as of today.

The LHC

- pp machine (mainly):

$\sqrt{s}$ = 14 TeV   7 times higher than present highest energy machine (Tevatron/Fermilab: √s = 2 TeV)

→search for new massive particles up to m ~ 5 TeV

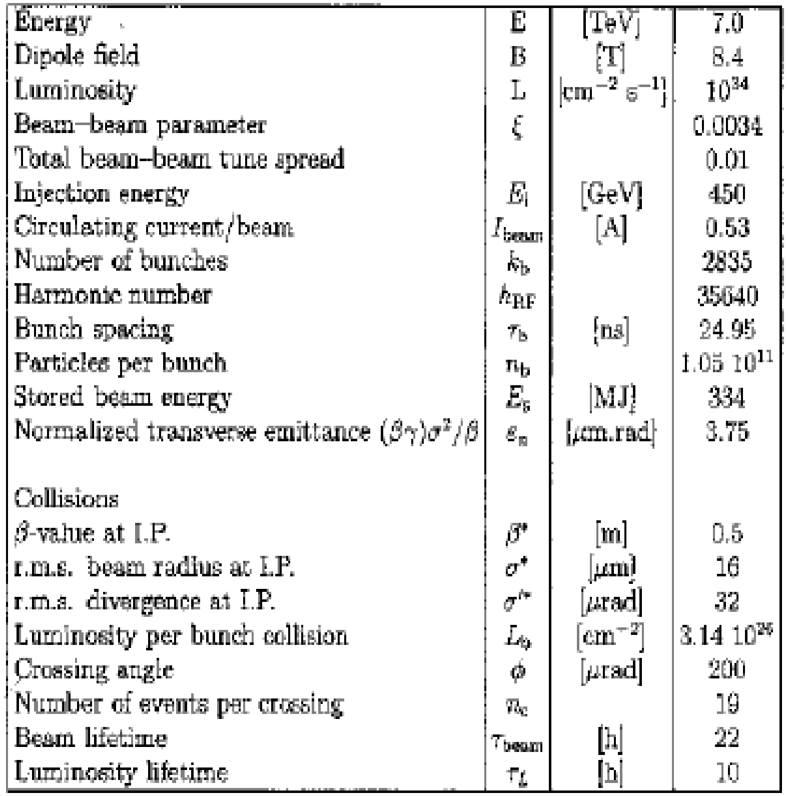
Note : √s limited by needed bending power.
LHC : 1232 superconducting dipoles with B = 8.4 T
working at 1.9 Kelvin (biggest cryogenic system in the world)

$$L \propto \frac{N_1 \ N_2}{\delta x \ \delta y} = 10^{34} \ \mathrm{cm}^{-2} \ \mathrm{s}^{-1}$$

~ 10^3 larger than LEP2, Tevatron

→search for rare processes with small σ (N = Lσ)

A few machine parameters: (nominal)



Energy	E	[TeV]	7.0
Dipole field	B	[T]	8.4
Luminosity	L	$[\mathrm{cm}^{-2}\,\mathrm{s}^{-1}]$	10^{34}
Beam–beam parameter	ξ		0.0034
Total beam–beam tune spread			0.01
Injection energy	E_i	[GeV]	450
Circulating current/beam	I_{beam}	[A]	0.53
Number of bunches	k_b		2835
Harmonic number	h_{RF}		35640
Bunch spacing	τ_b	[ns]	24.95
Particles per bunch	n_b		$1.05\ 10^{11}$
Stored beam energy	E_s	[MJ]	334
Normalized transverse emittance $(\beta\gamma)\sigma^2/\beta$	ε_n	[μm.rad]	3.75
Collisions			
β-value at I.P.	β^*	[m]	0.5
r.m.s. beam radius at I.P.	σ^*	[μm]	16
r.m.s. divergence at I.P.	σ'^*	[μrad]	32
Luminosity per bunch collision	L_b	$[\mathrm{cm}^{-2}]$	$3.14\ 10^{26}$
Crossing angle	ϕ	[μrad]	200
Number of events per crossing	n_c		19
Beam lifetime	τ_{beam}	[h]	22
Luminosity lifetime	τ_L	[h]	10

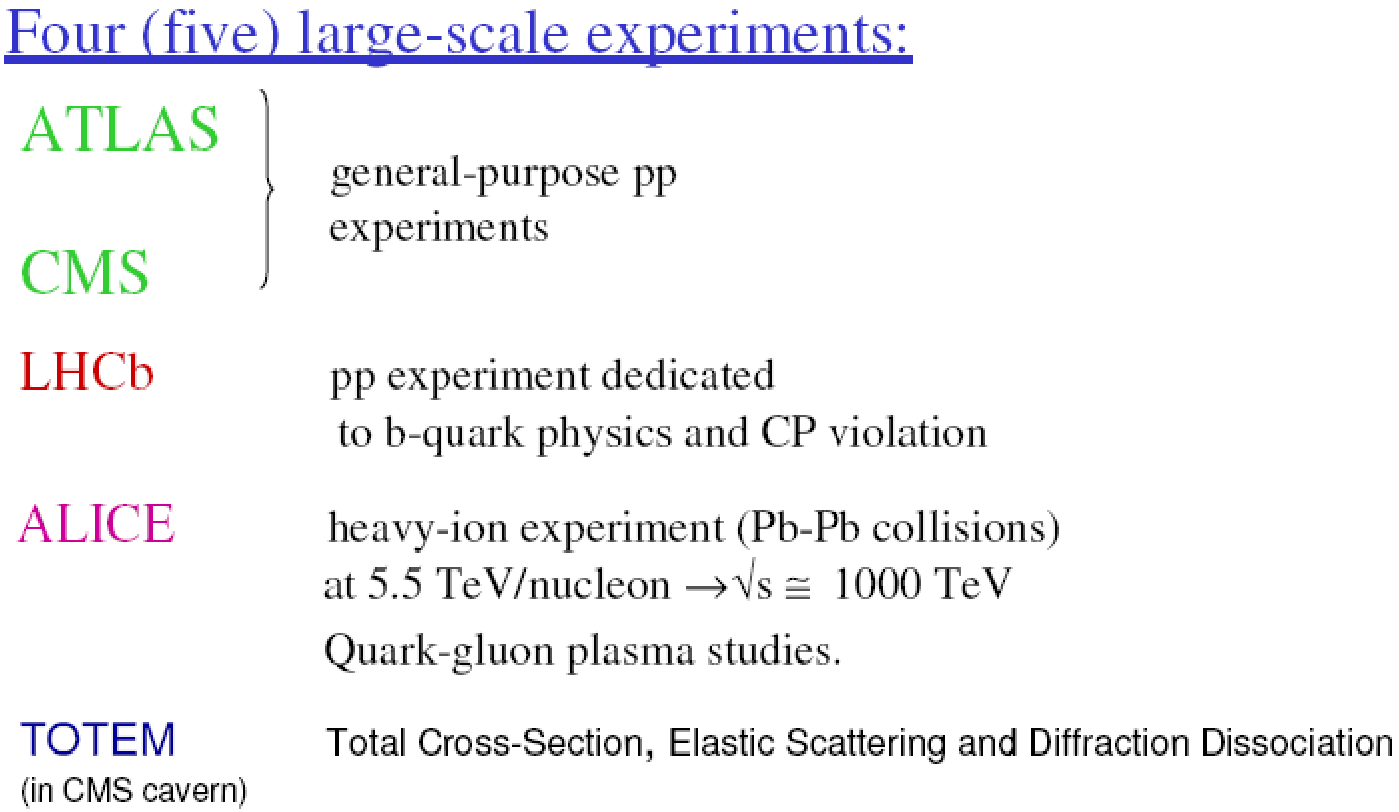
← Limiting factor for √s :
bending power needed to fit ring
in 27 km circumference LEP tunnel:

p (TeV) = 0.3 B(T) R(km)

= 7 TeV = 4.3 km

LHC :
B=8.4 T : ~ 1300 superconducting dipoles working at 1.9 K
(biggest cryogenic system in the world)

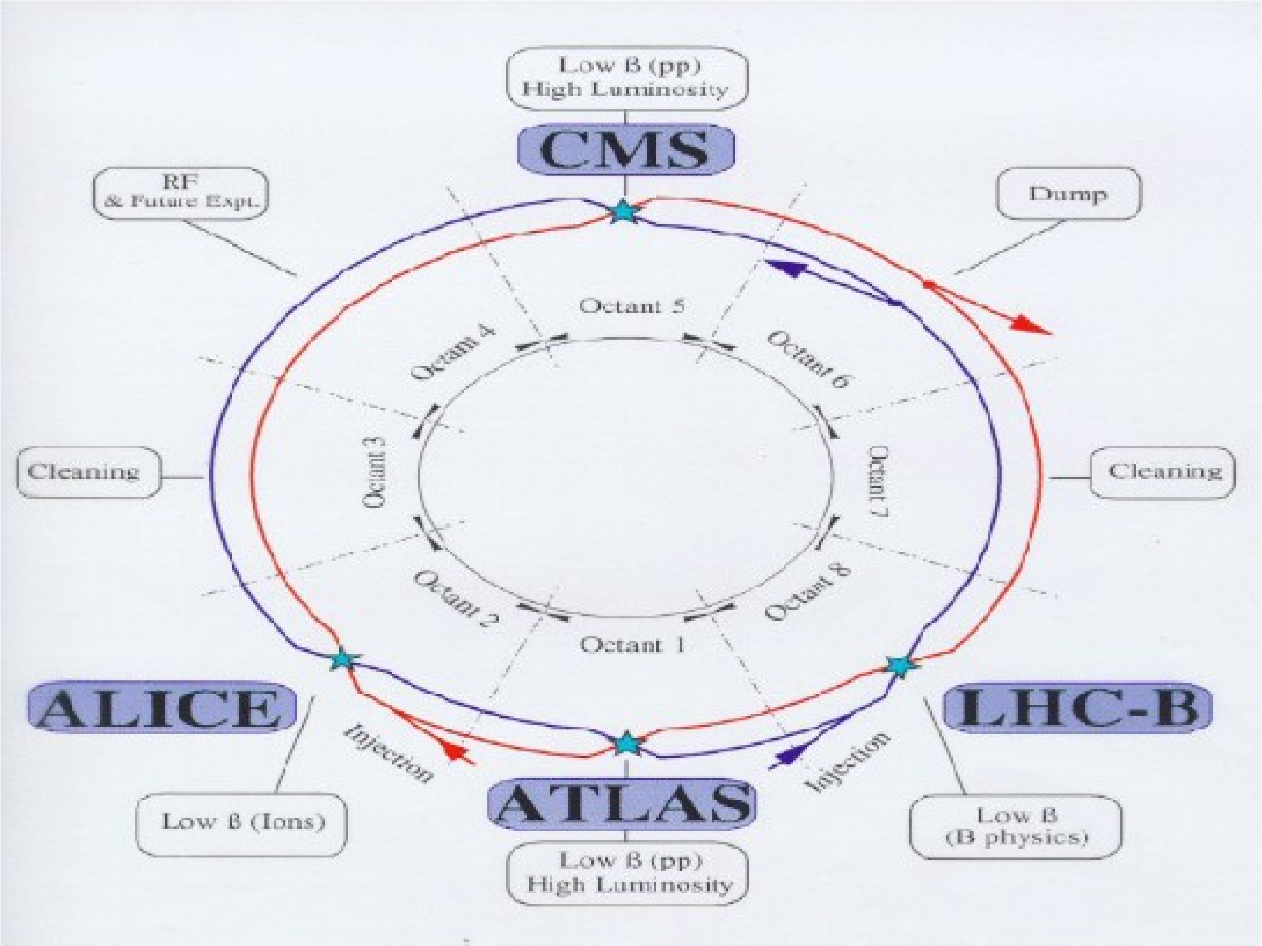
Experiments



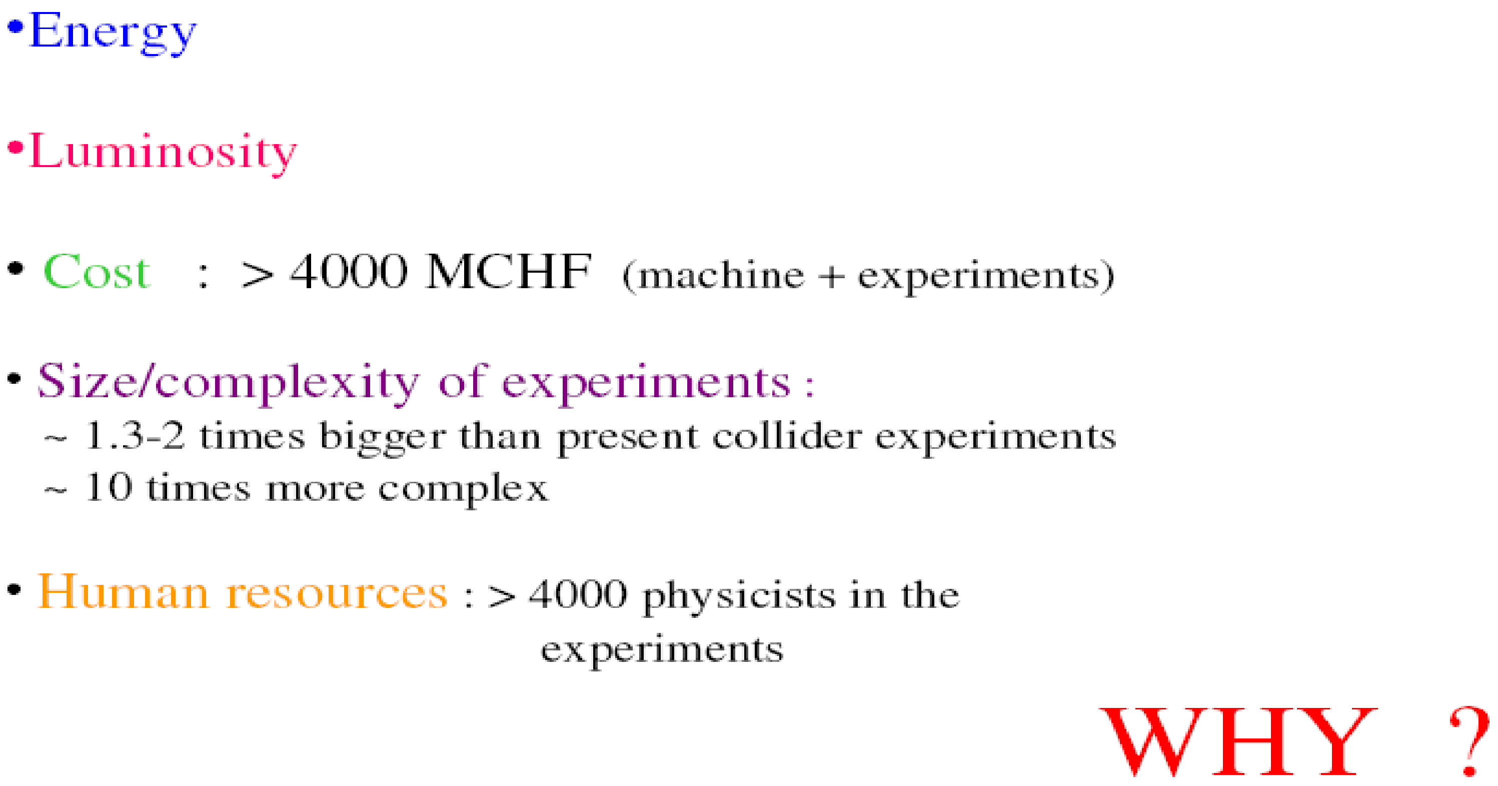
Four (five) large-scale experiments:

ATLAS CMS	general-purpose pp experiments
LHCb	pp experiment dedicated to b-quark physics and CP violation
ALICE	heavy-ion experiment (Pb-Pb collisions) at 5.5 TeV/nucleon → $\sqrt{s} \cong 1000$ TeV Quark-gluon plasma studies.
TOTEM (in CMS cavern)	Total Cross-Section, Elastic Scattering and Diffraction Dissociation

Experiments



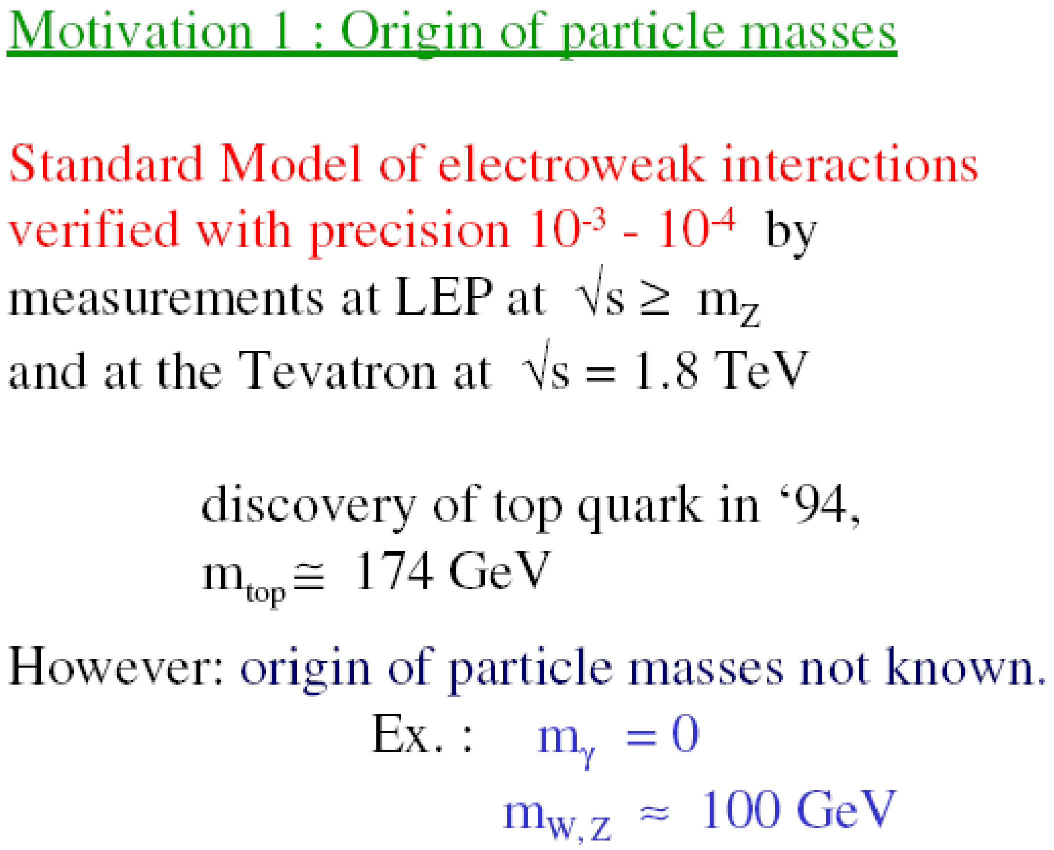
LHC is an unprecedented machine



- Energy
- Luminosity
- Cost : > 4000 MCHF (machine + experiments)
- Size/complexity of experiments :
  ~ 1.3-2 times bigger than present collider experiments
  ~ 10 times more complex
- Human resources : > 4000 physicists in the experiments

WHY ?

Motivation for LHC



Motivation 1 : Origin of particle masses

Standard Model of electroweak interactions verified with precision 10^{-3} - 10^{-4} by measurements at LEP at $\sqrt{s} \geq m_Z$ and at the Tevatron at $\sqrt{s} = 1.8$ TeV

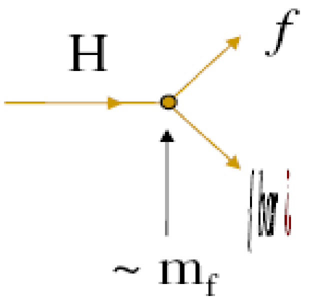
discovery of top quark in ‘94,
$m_{top} \cong 174$ GeV

However: origin of particle masses not known.

Ex. : $m_\gamma = 0$
$m_{W,Z} \approx 100$ GeV

Motivation for LHC

SM : Higgs mechanism gives mass to particles
(Electroweak Symmetry Breaking)



$m_H < 1$ TeV from theory

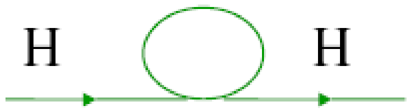
However:

-- Higgs not found yet: only missing (and essential) piece of SM
-- present limit : $m_H > 114.4$ GeV (from LEP)
-- Tevatron may go beyond (depending on luminosity)
$\Rightarrow$ need a machine to discover/exclude
Higgs from $\approx$ 115 GeV to 1 TeV

Motivation for LHC

Motivation 2 : Is SM the "ultimate theory" ?

- Higgs mechanism is the weakest part of the SM:
  -- "ad hoc" mechanism
  -- due to radiative corrections



Λ : energy scale up to which SM is valid (can be very large).

$\Delta\ m_H^2 \sim\ \Lambda^2$

$\Rightarrow$ radiative corrections can be very large ("unnatural") and Higgs mass can diverge unless "fine-tuned" cancellations $\rightarrow$" bad behaviour " of the theory

Motivation for LHC

Motivation 2 : Is SM the "ultimate theory" ?

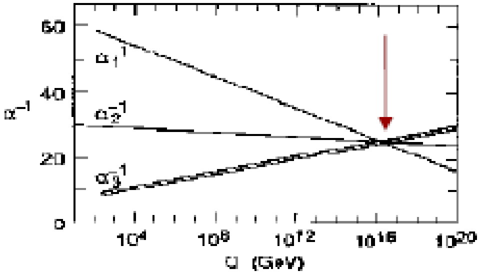
•Hints that forces could unify at high energy

$\alpha_{EM} \equiv \alpha_1 \approx 1/128 \approx 0.008$

$\alpha_{WEAK} \equiv \alpha_2 \approx 0.03$

$\alpha_S \equiv \alpha_3 \approx 0.12$

$\left.\right\}$ $\sqrt{s} = 100$ GeV

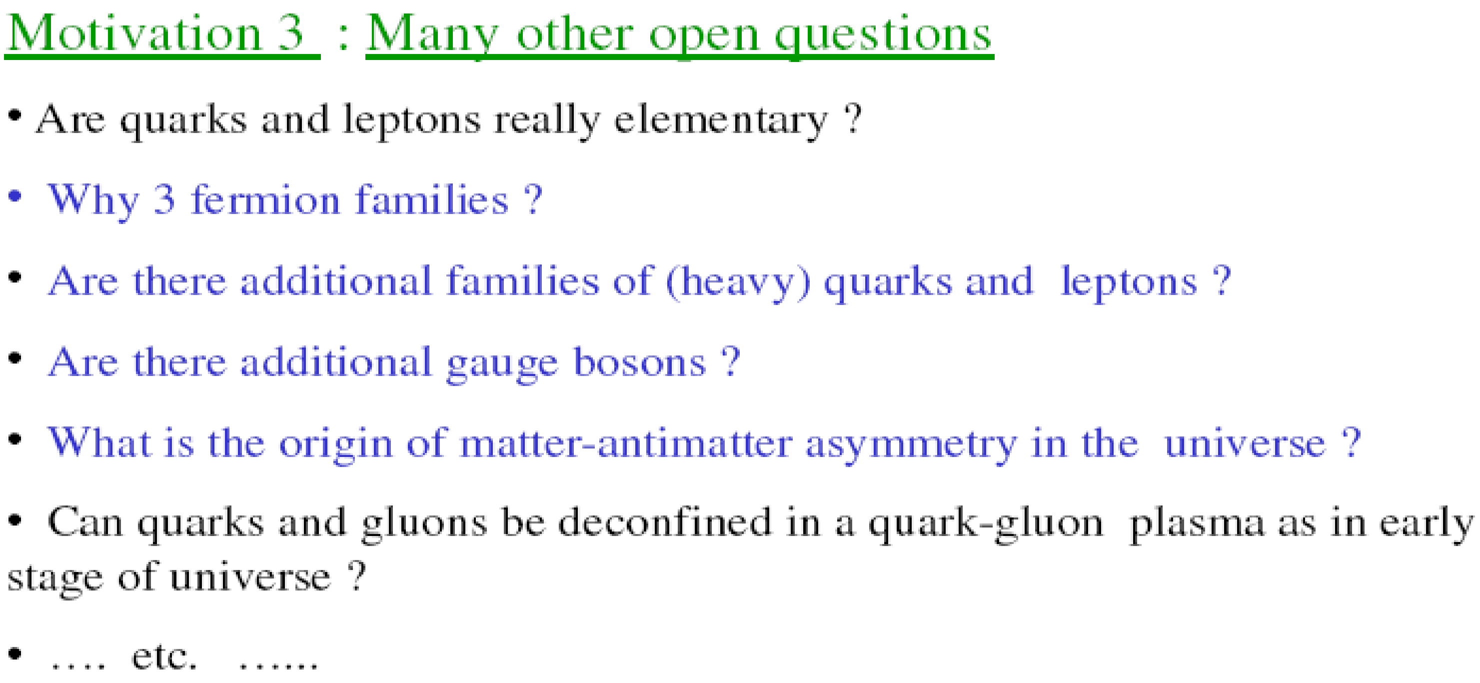


- E-dependence of coupling constants proven experimentally
- Grand Unified Theories: EM/Weak/Strong forces unify at E ~ 10^{16} → beyond physics become simple (one force with strength α_G)

Motivation for LHC

- SM is probably low-energy approximation of a more general theory
- Need a high-energy machine to look for manifestations of this theory
- e.g. Supersymmetry : $m_{SUSY} \sim$ TeV
  Many other theories predict New Physics at the TeV scale

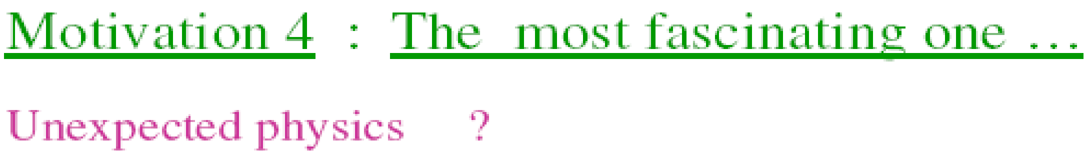
Motivation for LHC



Motivation 3 : Many other open questions

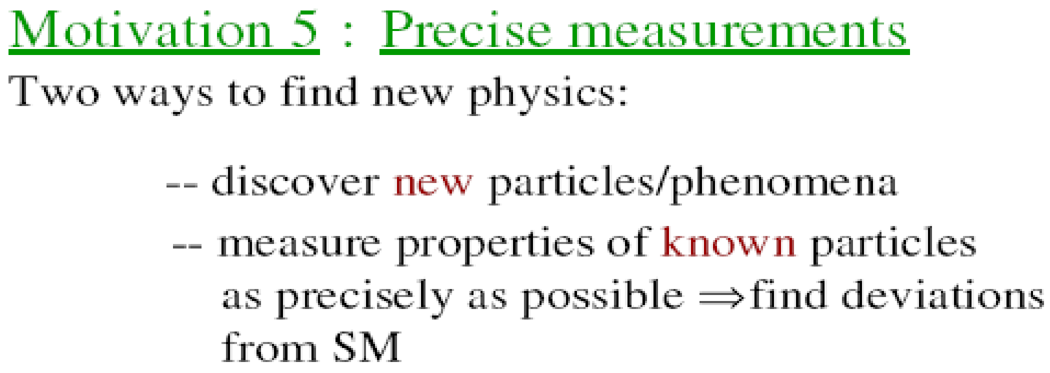
- Are quarks and leptons really elementary ?
- Why 3 fermion families ?
- Are there additional families of (heavy) quarks and leptons ?
- Are there additional gauge bosons ?
- What is the origin of matter-antimatter asymmetry in the universe ?
- Can quarks and gluons be deconfined in a quark-gluon plasma as in early stage of universe ?
- …. etc. ……

Motivation for LHC



Motivation 4 : The most fascinating one …

Unexpected physics ?



Motivation 5 : Precise measurements

Two ways to find new physics:

-- discover new particles/phenomena

-- measure properties of known particles
as precisely as possible ⇒find deviations
from SM

Motivation for LHC

LHC: known particles (W, Z, b, top, …)
produced with enormous rates thanks to
high energy (→ high σ) and L (→ high rate)

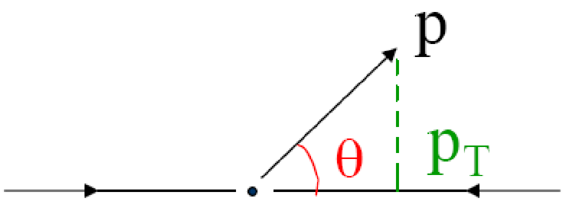
Ex. : 1 year at low luminosity

$5\ 10^8$ $W \rightarrow l\nu$
$5\ 10^7$ $Z \rightarrow ll$
10^7 tt pairs
10^{12} bb pairs

→ many precision measurements possible
thanks to large statistics
(stat. error ~ $1/\sqrt{N}$)

<u>Note</u> : measurements of Z parameters performed at LEP and SLD, however precision can be improved for :
-- W physics
-- Triple Gauge Couplings $WW\gamma$, WWZ
-- b-quark physics
-- top-quark physics

Phenomenology of pp collision



Transverse momentum

(in the plane perpendicular to the beam) :

$$p_T = p \sin\theta$$

$\theta = 90^o \rightarrow \eta = 0$
$\theta = 10^o \rightarrow \eta \cong 2.4$
$\theta = 170^o \rightarrow \eta \cong -2.4$

Rapidity: $\eta = -\log\left(\mathrm{tg}\ \frac{\theta}{2}\right)$

Total inelastic cross-section:

$\sigma_{tot}\,(pp) = 70$ mb $\sqrt{s} = 14$ TeV

$$\text{Rate} = \frac{\text{n. events}}{\text{second}} = \underset{\uparrow\ 10^{34}\ \text{cm}^{-2}\ \text{s}^{-1}}{L} \times \sigma_{tot}\,(pp) = 10^9\ \text{interactions/s}$$

Phenomenology of pp collision

Class 1:

Most interactions due to collisions at large distance between incoming protons where protons interact as “ a whole ” → small momentum transfer ($\Delta p \approx 1/\Delta x$) → particles in final state have large longitudinal momentum but small transverse momentum (scattering at large angle is small)

$< p_T > \approx$ 500 MeV of charged particles in final state

charged particles uniformly distributed in ϕ

$$\frac{dN}{d\eta} \approx 7$$

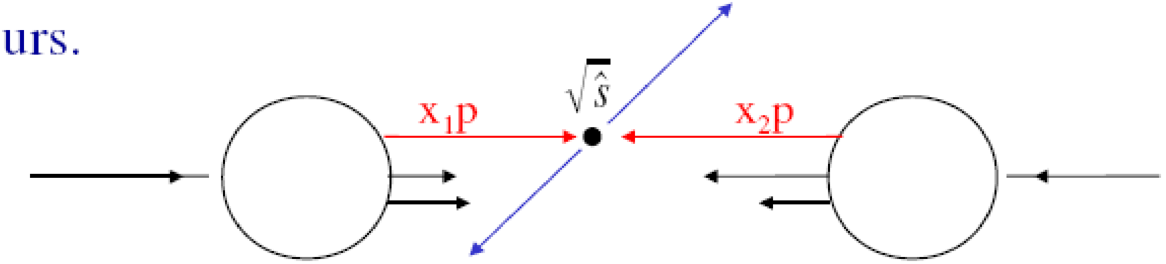
Most energy escapes down the beam pipe.

These are called minimum-bias events (“ soft “ events).
They are the large majority but are not very interesting.

Phenomenology of pp collision

Class 2:

Monochromatic proton beam can be seen as beam of quarks and gluons with a wide band of energy. Occasionally hard scattering (“ head on”) between constituents of incoming protons occurs.



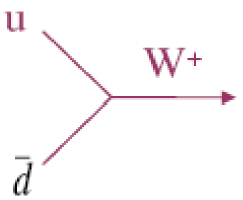
p ≡ momentum of incoming protons = 7 TeV

Interactions at small distance → large momentum transfer → massive particles and/or particles at large angle are produced.

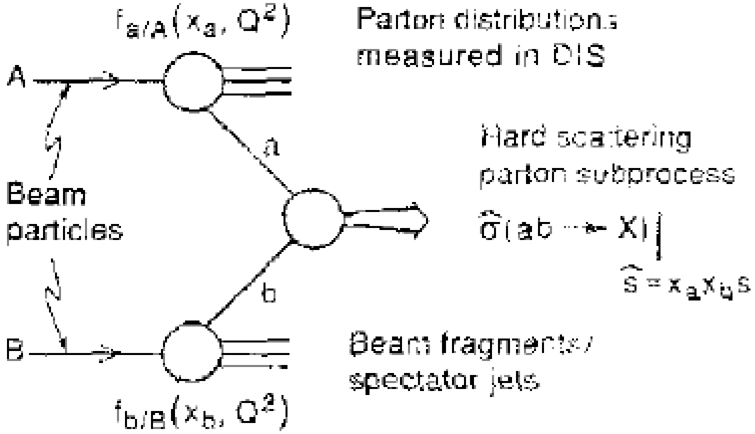
These are interesting physics events but they are rare.

Ex. $u + \bar{d} \rightarrow W^+$

$\sigma\ (pp \rightarrow W) \approx 150\ \text{nb} \approx 10^{-6}\, \sigma_{tot}(pp)$



Unlike at $e^+ e^-$ colliders



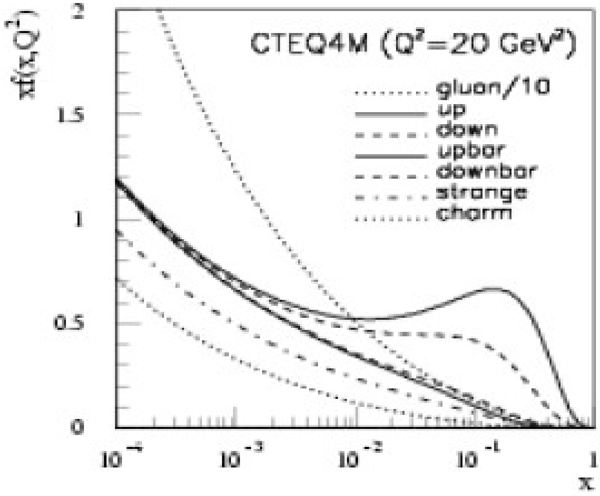
- effective centre-of-mass energy $\sqrt{\hat s}$ smaller than √s of colliding beams: → to produce m ≈ 100 GeV x ~ 0.01
  to produce m ≈ 5 TeV x ~ 0.35

$$\left.\begin{array}{l}\vec p_a = x_a \vec p_A \\ \vec p_b = x_b \vec p_B\end{array}\right\} \quad p_A = p_B = 7\ \mathrm{TeV} \qquad \sqrt{\hat s} = \sqrt{x_a x_b s} \underset{\substack{\uparrow \\ \text{if } x_a \approx x_b}}{\approx} x\sqrt{s}$$

Unlike at $e^+ e^-$ colliders

- cross-section :

$$\sigma = \sum_{a,b} \int dx_a \, dx_b \, f_a(x_a, Q^2) \, f_b(x_b, Q^2) \, \hat{\sigma}_{ab}(x_a, x_b)$$



$\hat{\sigma}_{ab}$ ≡ hard scattering cross-section

$f_i\,(x, Q^2) \equiv$ parton distribution function

$p \equiv uud$

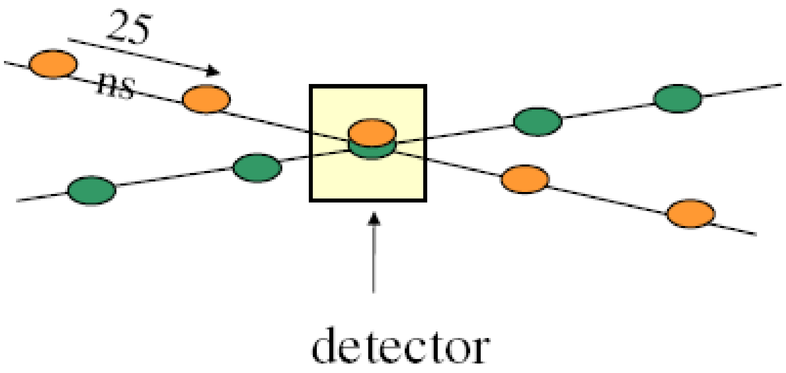
Two main difficulties

Typical of LHC:

$R = L\sigma \;=\; 10^9$ interactions / second

Protons are grouped in bunches (of $\approx\; 10^{11}$ protons)

colliding at interaction points every 25 ns



⇒ At each interaction on average

$\approx$ 25 minimum-bias events are produced.

These overlap with interesting (high p_T)

physics events, giving rise to so-called

pile-up

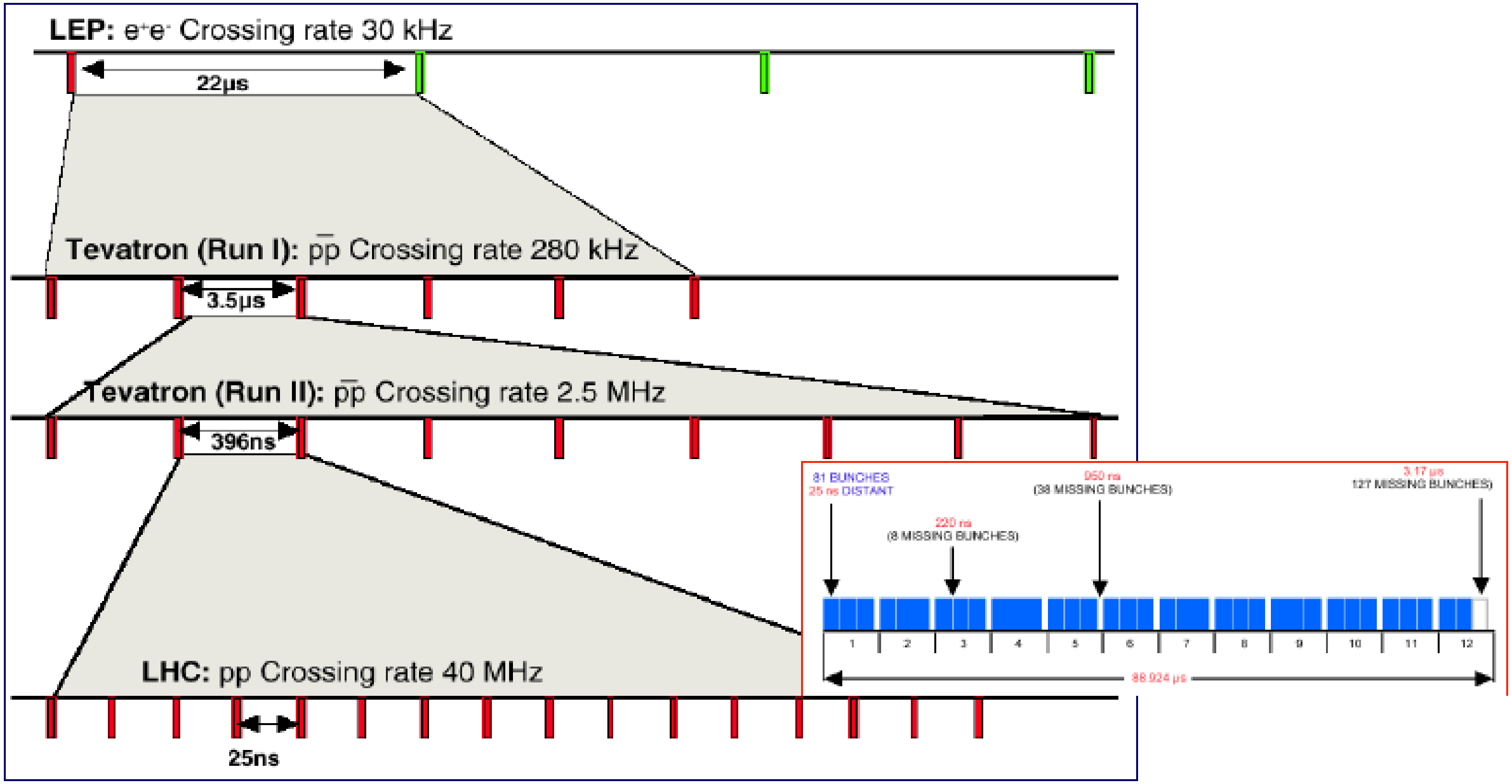
~1000 charged particles produced over $|\eta\,| < 2.5$

at each crossing. However $< p_T > \approx$ 500 MeV

(particles from minimum-bias).

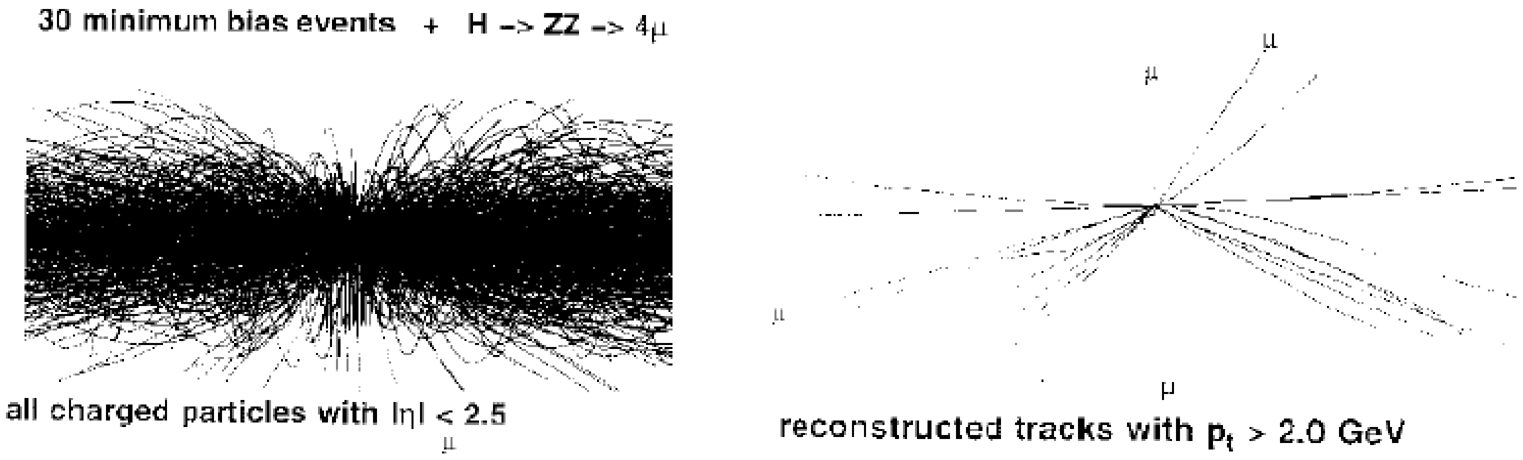
→ applying p_T cut allows extraction of interesting particles

Bunch crossing rates



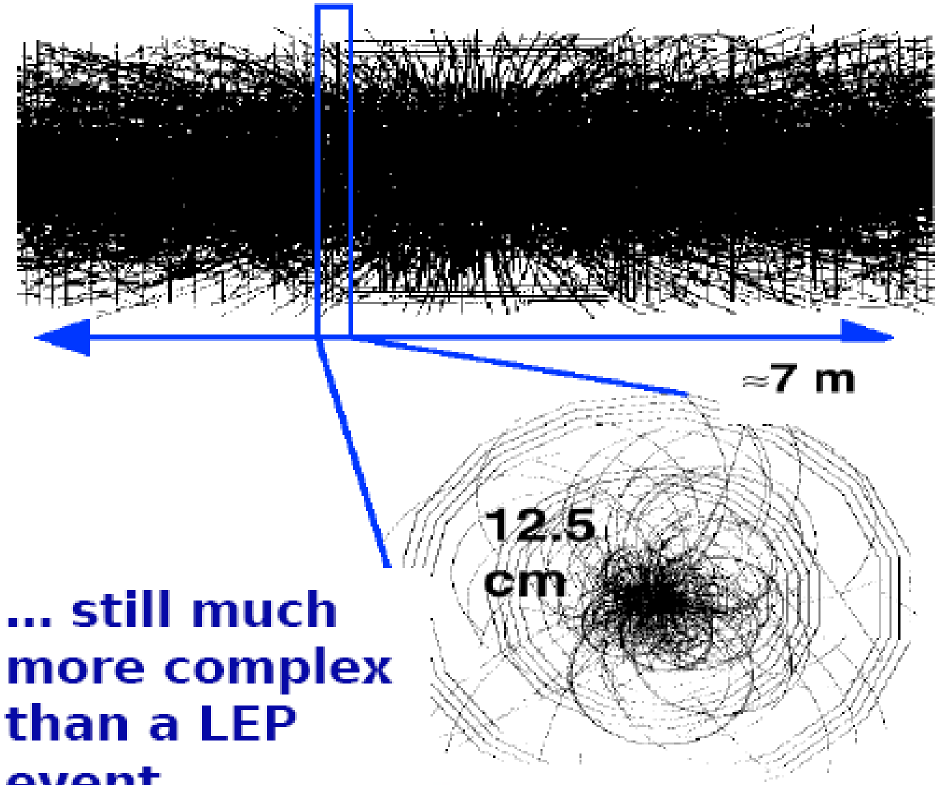
Two main difficulties

$H \rightarrow ZZ \rightarrow 4\mu$



Particle multiplicity

- η = rapidity = $\log(\mathrm{tg}\theta\ /2)$
  (longitudinal dimension)
- u_{ch} = no. charged particles / unit-η = **7**
- n_{ch} = no. charged particles / interaction
- N_{ch} = no. chrgd particles / bunch xing
- N_{tot} = no. particles / bunch xing

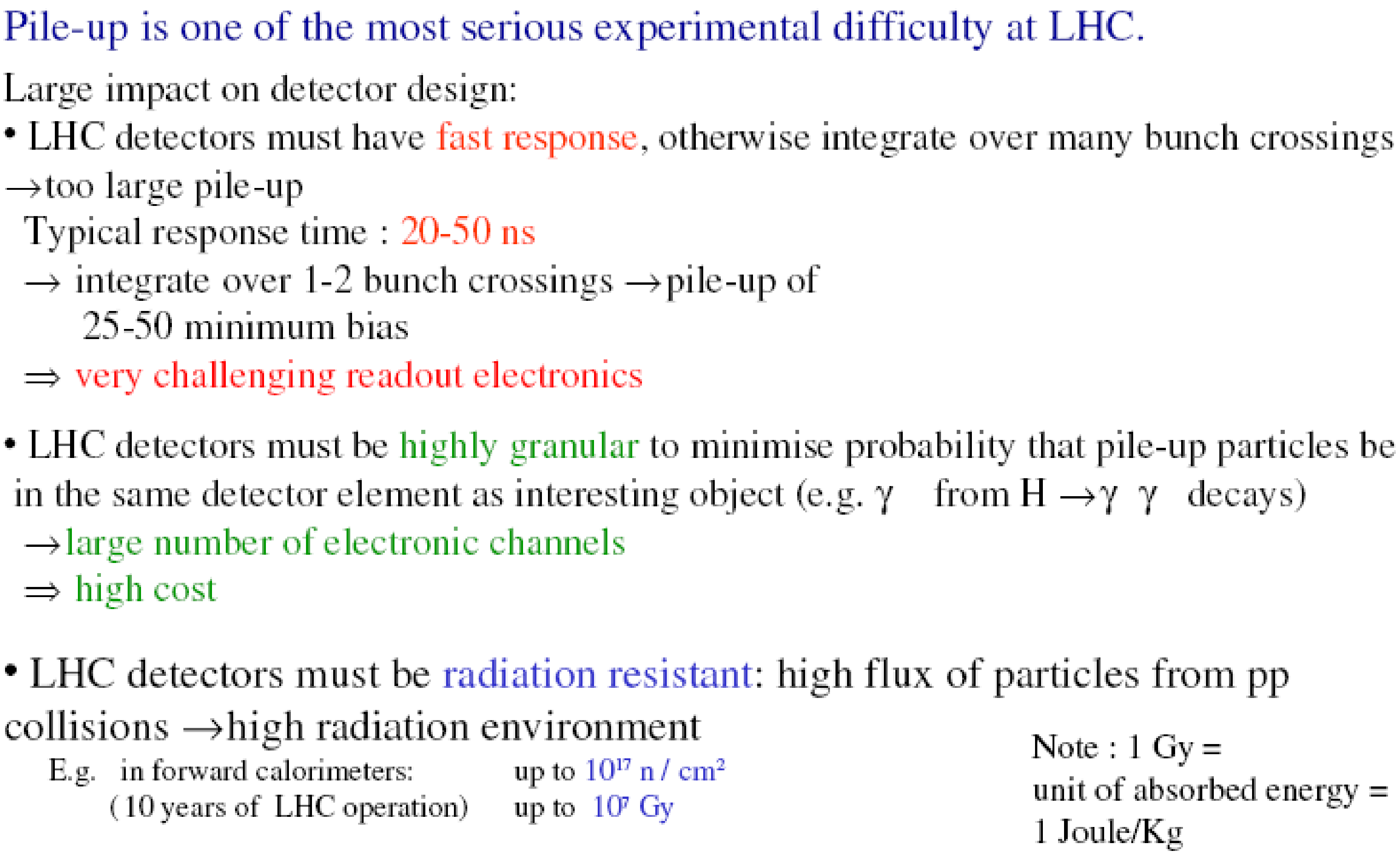


... still much more complex than a LEP event

- **n_{ch}** $= u_{ch} \times \eta = 6 \times 7$ **= 42**
- **N_{ch}** $= n_{ch} \times 22$ **= ~ 900**
- **N_{tot}** $= N_{ch} \times 1.5$ **= ~ 1400**

The LHC flushes each detector with ~1400 particles every 25 ns

Two main difficulties



Pile-up is one of the most serious experimental difficulty at LHC.

Large impact on detector design:

- LHC detectors must have fast response, otherwise integrate over many bunch crossings →too large pile-up

  Typical response time : 20-50 ns

  → integrate over 1-2 bunch crossings →pile-up of
  25-50 minimum bias

  ⇒ very challenging readout electronics

- LHC detectors must be highly granular to minimise probability that pile-up particles be in the same detector element as interesting object (e.g. γ from $H \rightarrow \gamma\gamma$ decays)

  →large number of electronic channels

  ⇒ high cost

- LHC detectors must be radiation resistant: high flux of particles from pp collisions →high radiation environment

  E.g. in forward calorimeters: up to 10^{17} n / cm^2
  (10 years of LHC operation) up to 10^{7} Gy

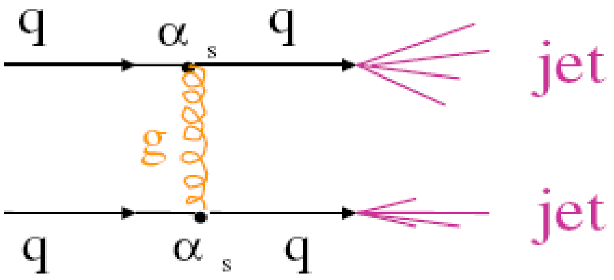
Note : 1 Gy =
unit of absorbed energy =
1 Joule/Kg

Two main difficulties:

QCD background

Common to all hadron colliders:

high-p_T events dominated by QCD jet production



- Strong production → large cross-section
- Many diagrams contribute: qq →qq, qg →qg, gg →gg, etc.
- Called “ QCD background “

Most interesting are rare processes:

- involve heavy particles
- weak-force mediated production mechanisms (e.g. W production)

Two main difficulties:

QCD background

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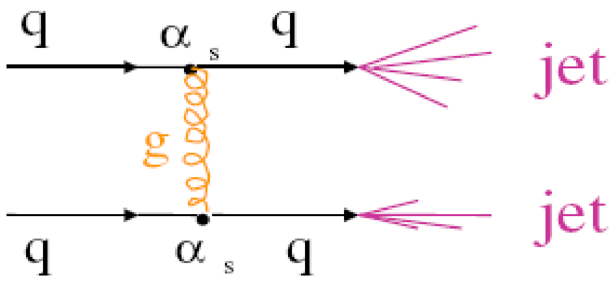

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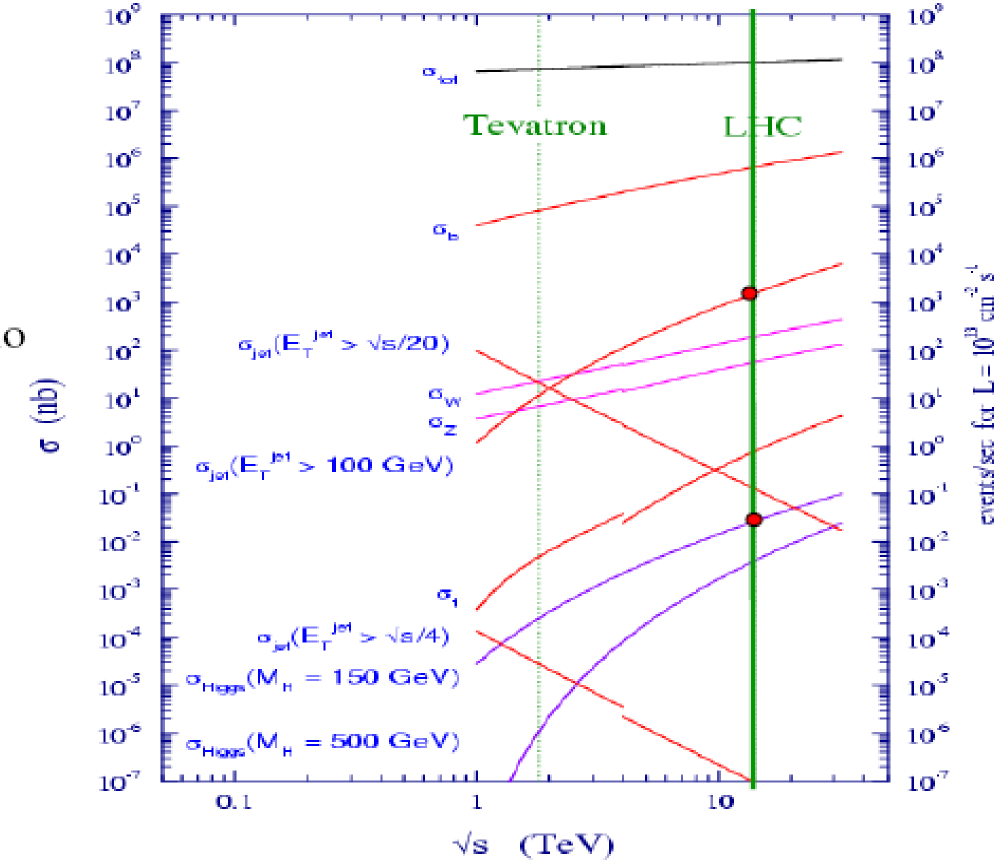
Proton – (anti) proton cross-section

To extract signal over QCD jet background must look at decays to photons and leptons
→pay a prize in branching ratio

Ex. BR (W →jet jet) ≈ 70%
BR (W →lν) ≈ 30%



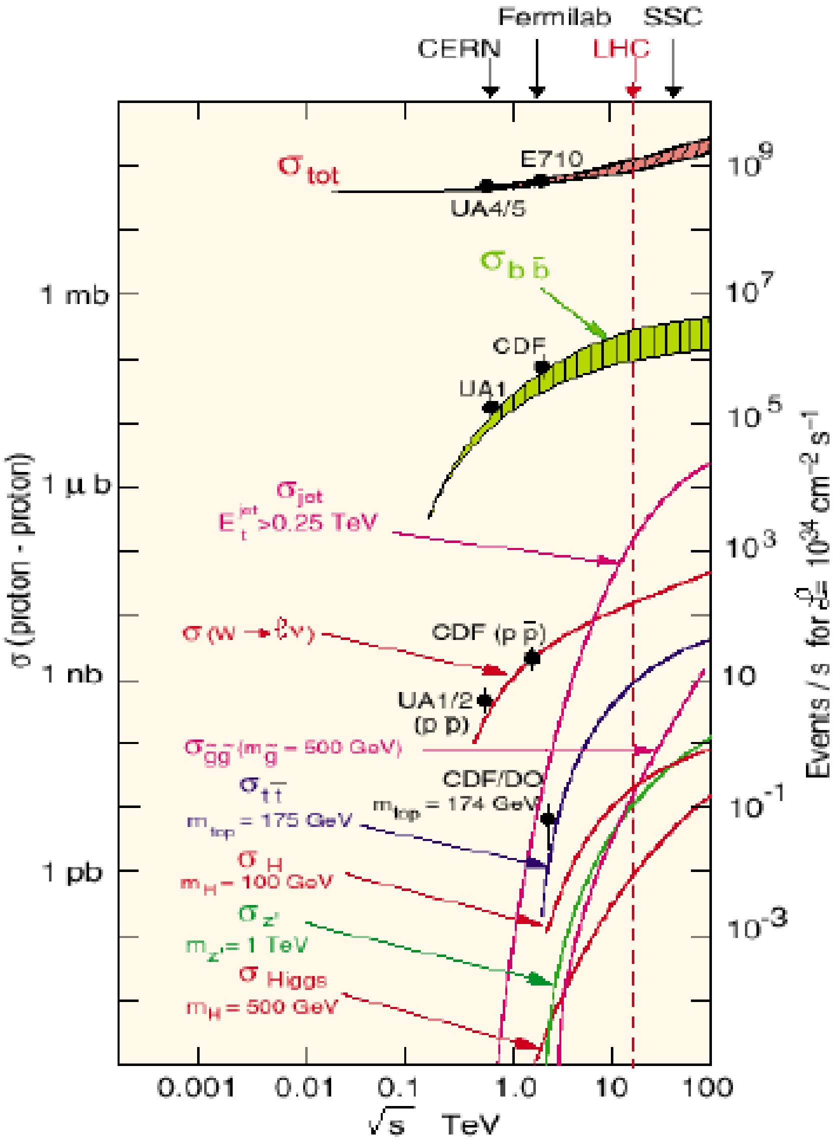
Cross-section

Orders of magnitude amongst x-sections of various physics channels:

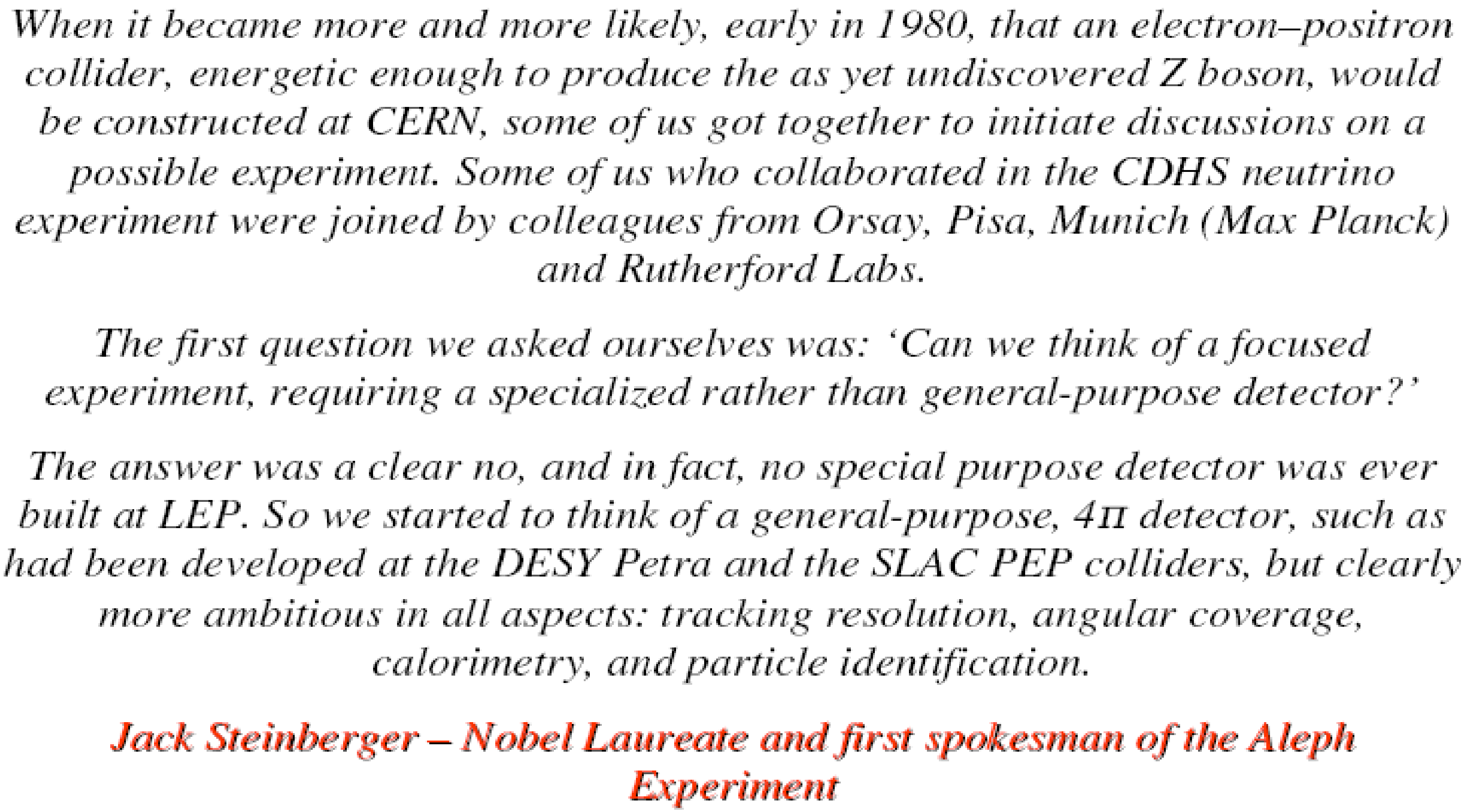
• Inelastic :	10^9 Hz
• W -> lν :	10^2 Hz
• t-t production :	10^1 Hz
• Higgs (m=100 GeV/c^2) :	10^{-1} Hz
• Higgs (m=600 GeV/c^2) :	10^{-2} Hz

==> selection power :	$10^{10\text{-}11}$
... lepton decay BR :	~ 10^{-2}

==> Selection power for Higgs discovery : 10^{13}



General Purpose Detectors



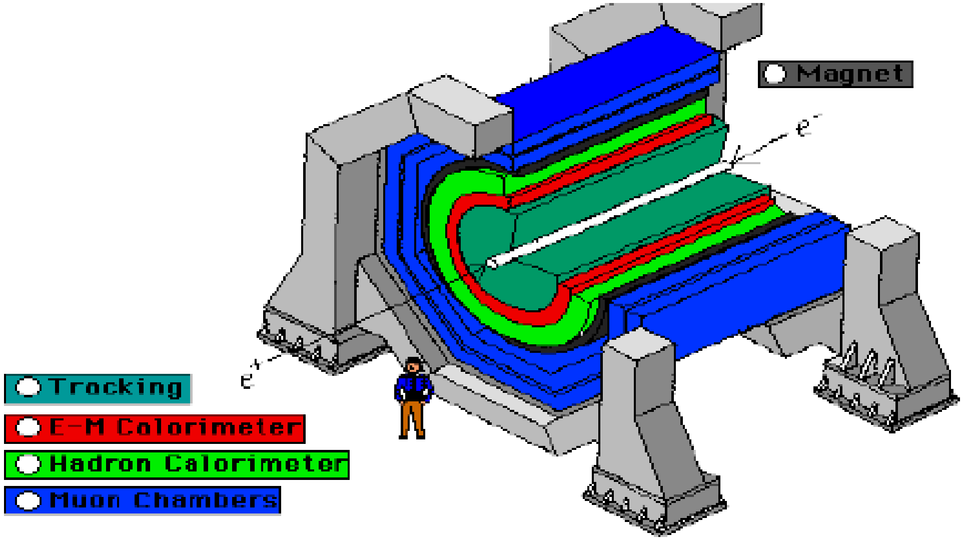
When it became more and more likely, early in 1980, that an electron–positron collider, energetic enough to produce the as yet undiscovered Z boson, would be constructed at CERN, some of us got together to initiate discussions on a possible experiment. Some of us who collaborated in the CDHS neutrino experiment were joined by colleagues from Orsay, Pisa, Munich (Max Planck) and Rutherford Labs.

The first question we asked ourselves was: 'Can we think of a focused experiment, requiring a specialized rather than general-purpose detector?'

The answer was a clear no, and in fact, no special purpose detector was ever built at LEP. So we started to think of a general-purpose, 4π detector, such as had been developed at the DESY Petra and the SLAC PEP colliders, but clearly more ambitious in all aspects: tracking resolution, angular coverage, calorimetry, and particle identification.

Jack Steinberger – Nobel Laureate and first spokesman of the Aleph Experiment

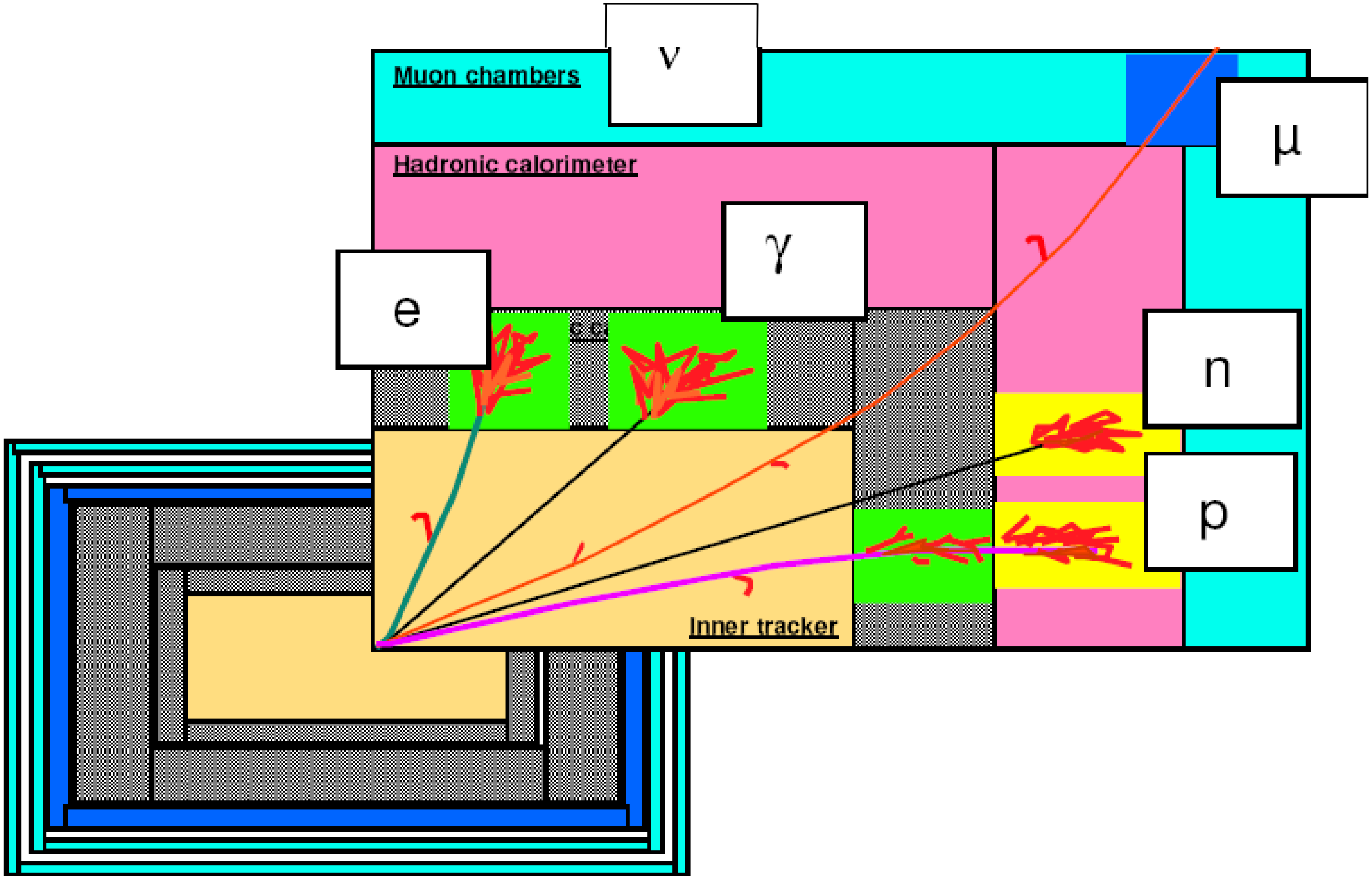
General Principle



Collider detectors look all similar since they must perform in sequence the same basic measurements.

The dimension of the detector are driven by the required resolution . The calorimeter thickness change only with the logarithm of the energy: for this reason the dimension of the detectors change only slightly with the energy.

Particle identification



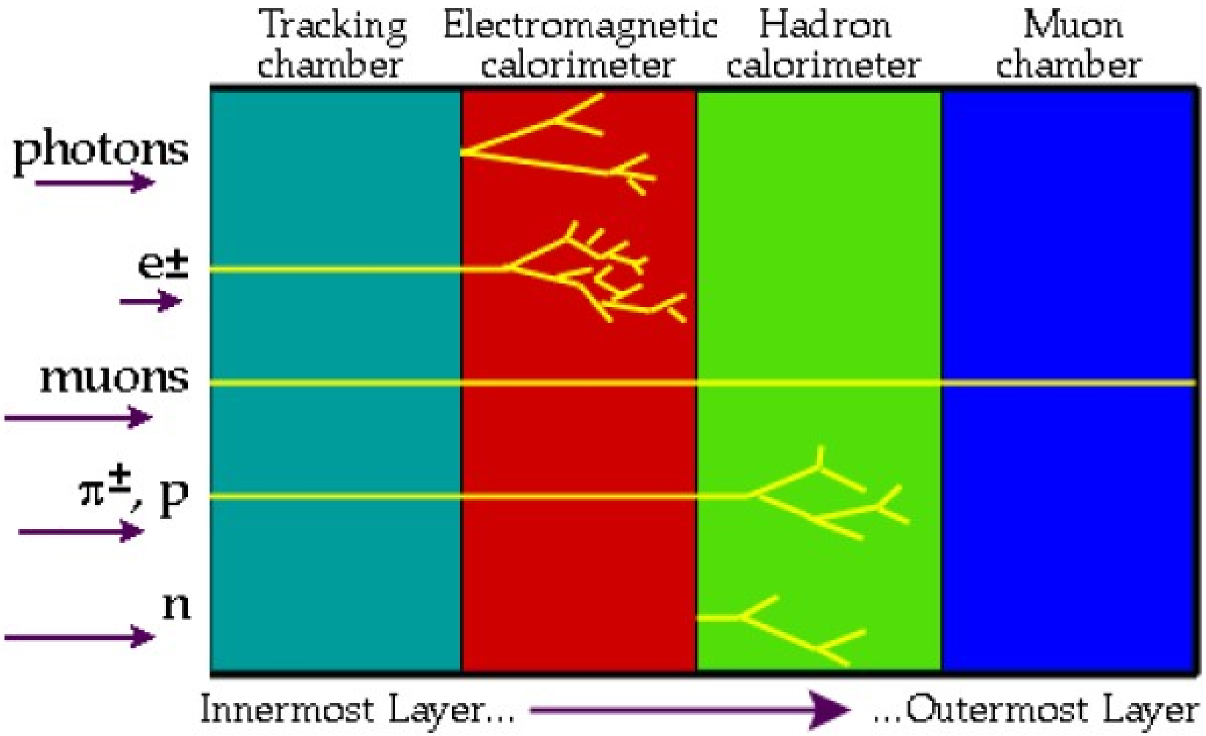
Particle measurement

- Detectors must be capable of
  - Resolving individual tracks, in-and-outside the calorimeters
  - Measuring energy depositions of isolated particles and jets
  - Measuring the vertex position.
- Detector size and granularity is dictated by

  … the required (physics) accuracy
  … the particle multiplicity.
- Size + granularity determine

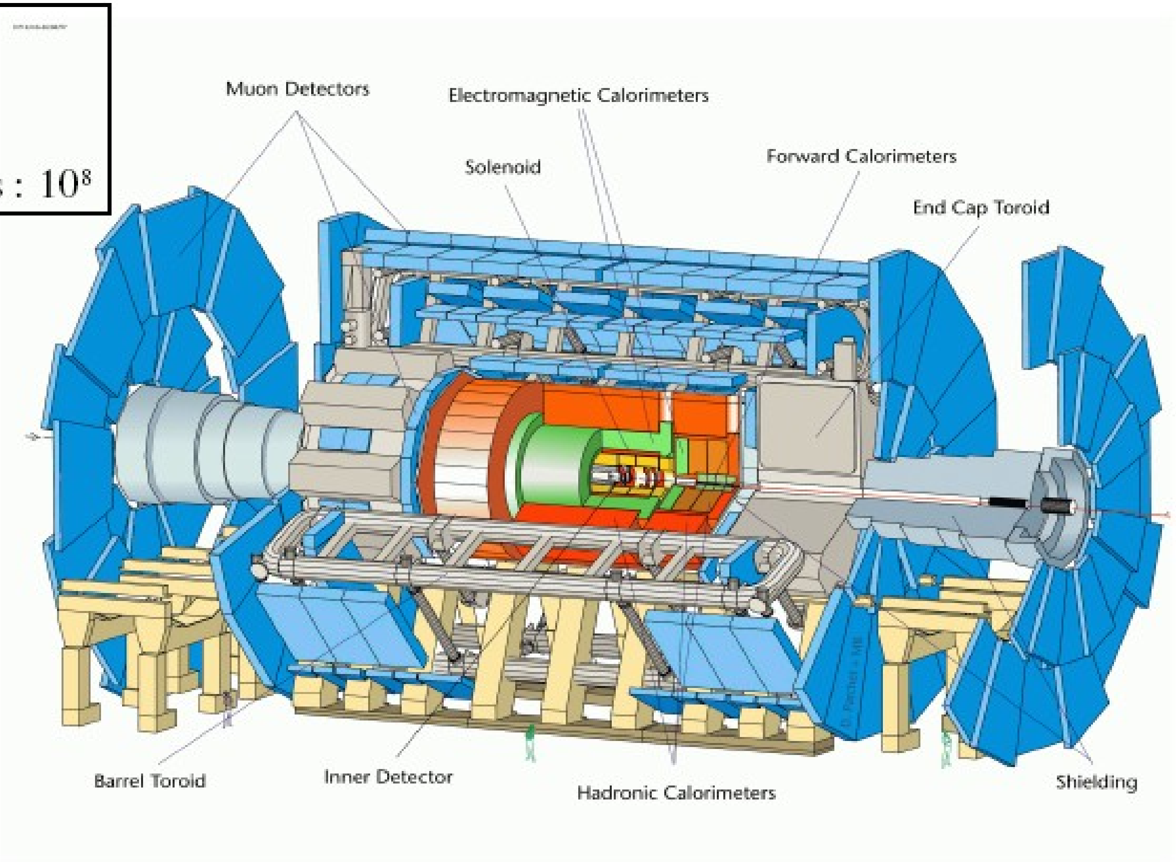
  … the no. of measuring elements
  … i.e. the no. of electronics channels.

ATLAS and CMS detectors



ATLAS (A Toroidal Lhc ApparatuS)

Length : 40 m
Radius : 10 m
Weight : 7000 tons
Electronics channels : 10^8



Few pictures from construction

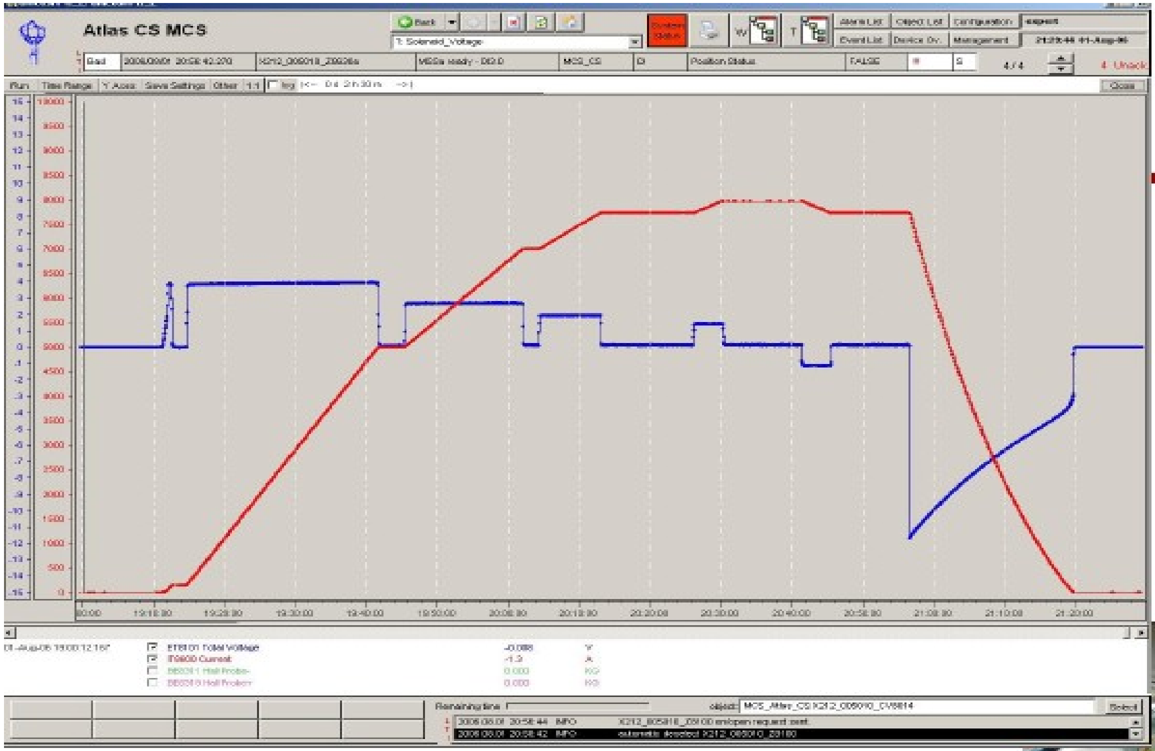
2004

ATLAS cavern

2006

Barrel calorimeter
(EM liquid-argon + HAD Fe/scintillator Tilecal)
in final position at Z=0. Barrel cryostat cold and
filled with Ar.

Few pictures from construction



Solenoid

July – August 2006:

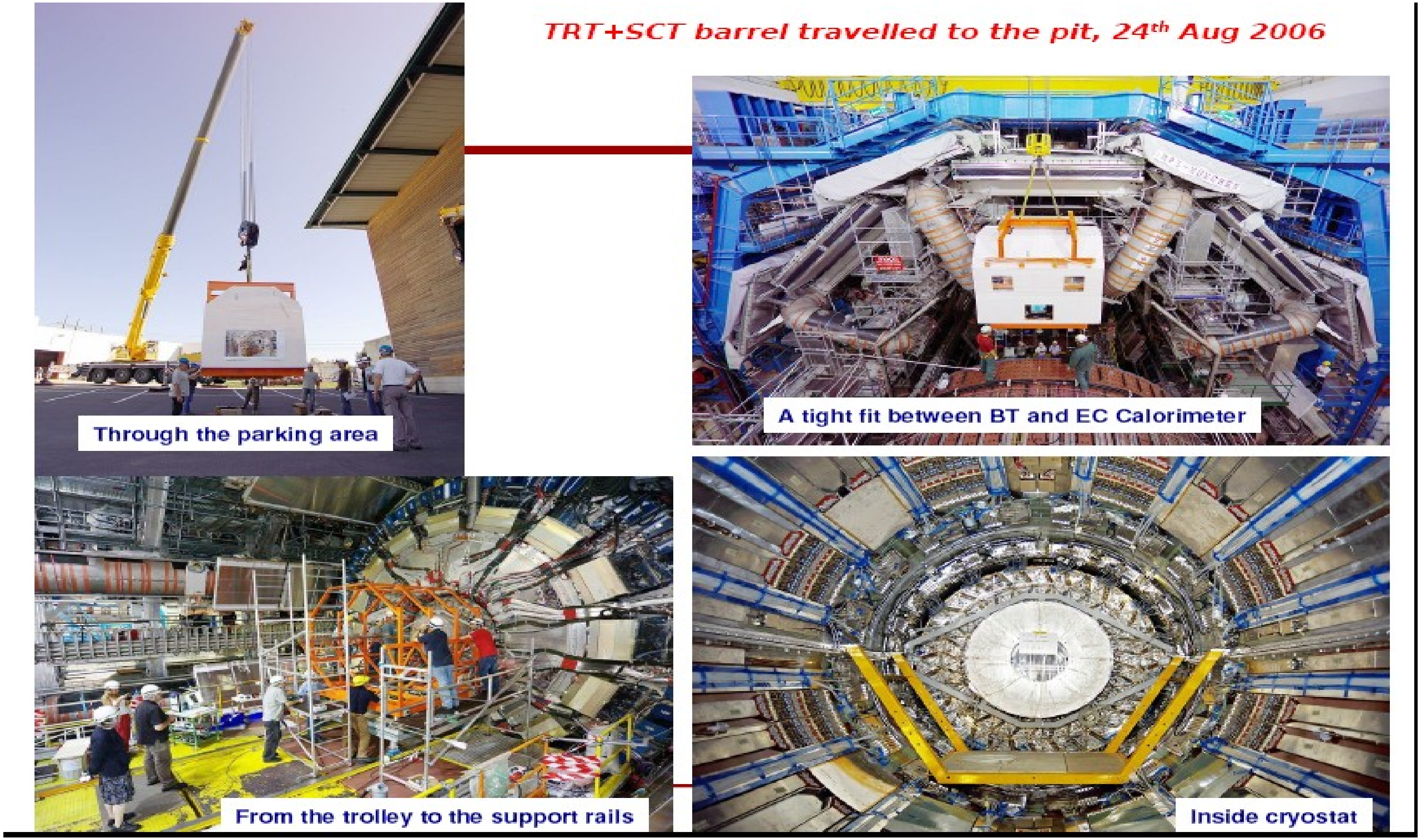
The solenoid has been fully commissioned *in-situ* up to 8.0 kA

The operation current is 7.73 kA for a field of 2.0 T

Successful accurate field mapping

1st August 2006: the solenoid is fully operational

Few pictures from construction



TRT+SCT barrel travelled to the pit, 24^{th} Aug 2006

Through the parking area

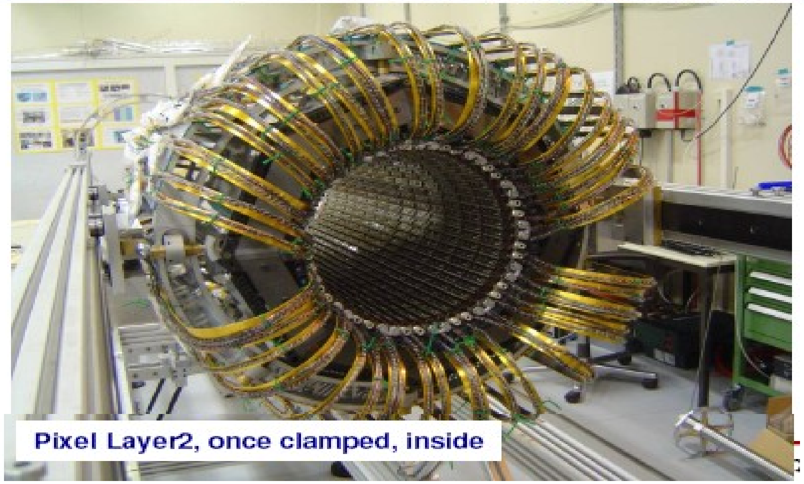
A tight fit between BT and EC Calorimeter

From the trolley to the support rails

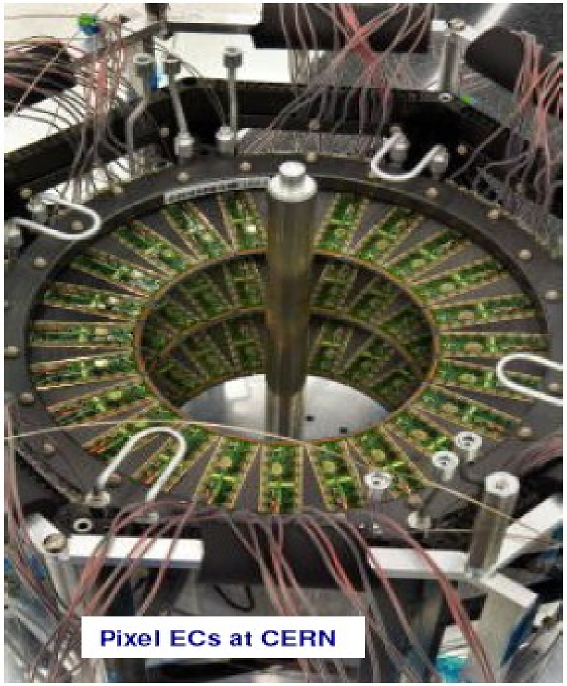
Inside cryostat

Few pictures from construction

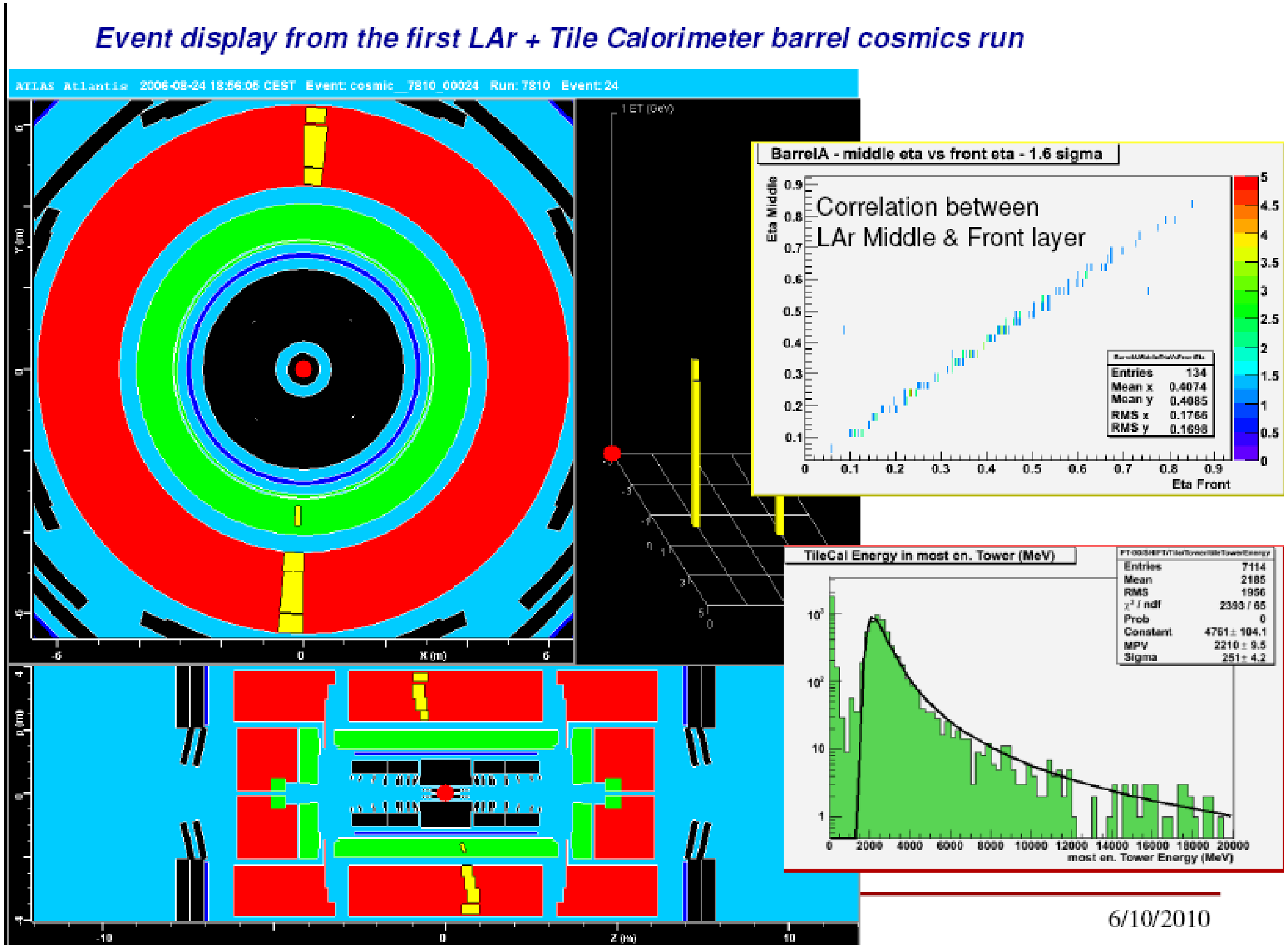

Pixel Layer-2 – half shell


Pixel Layer2, once clamped, inside

Lot of progress on the Pixels!


Pixel ECs at CERN

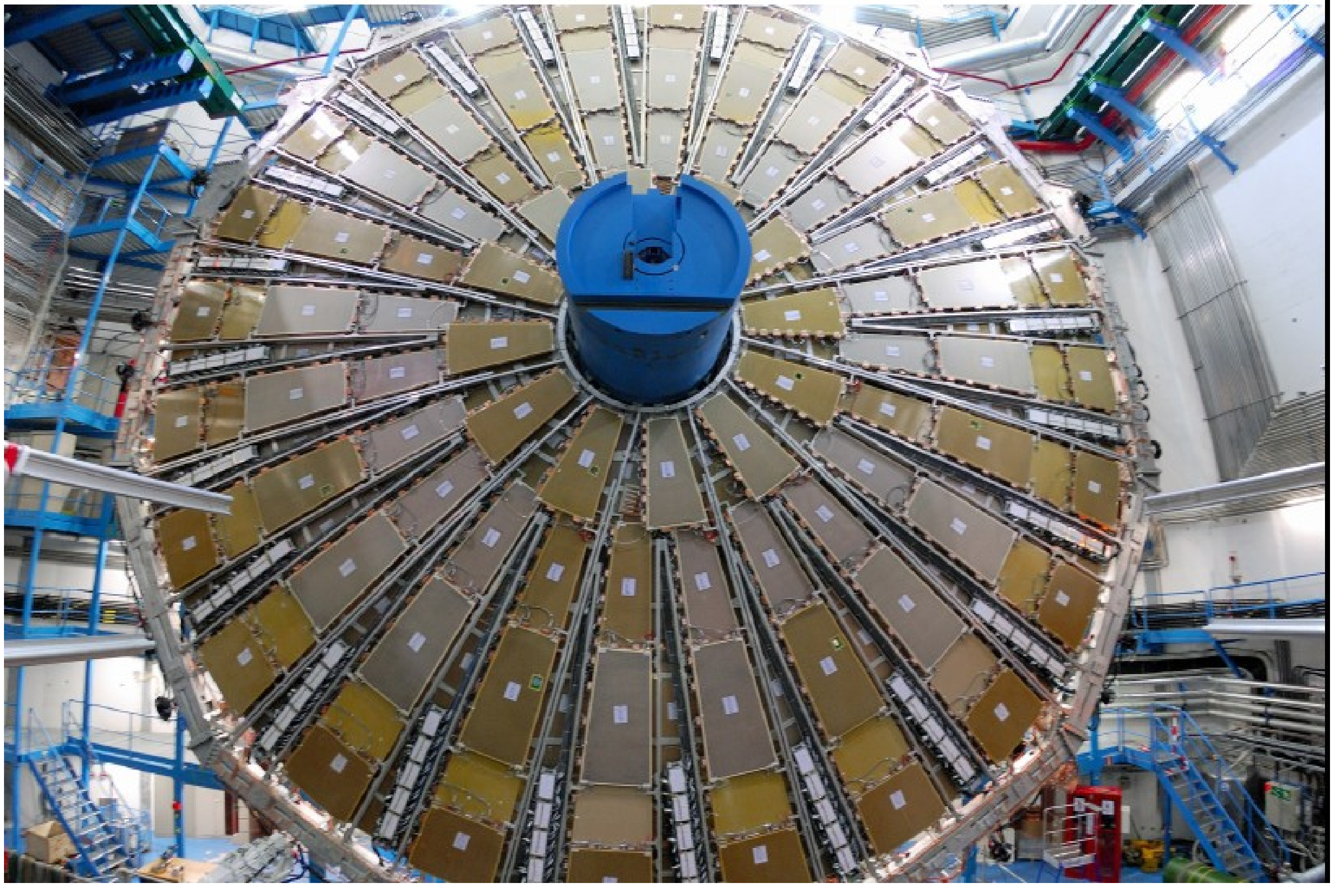
Few pictures from construction



Event display from the first LAr + Tile Calorimeter barrel cosmics run

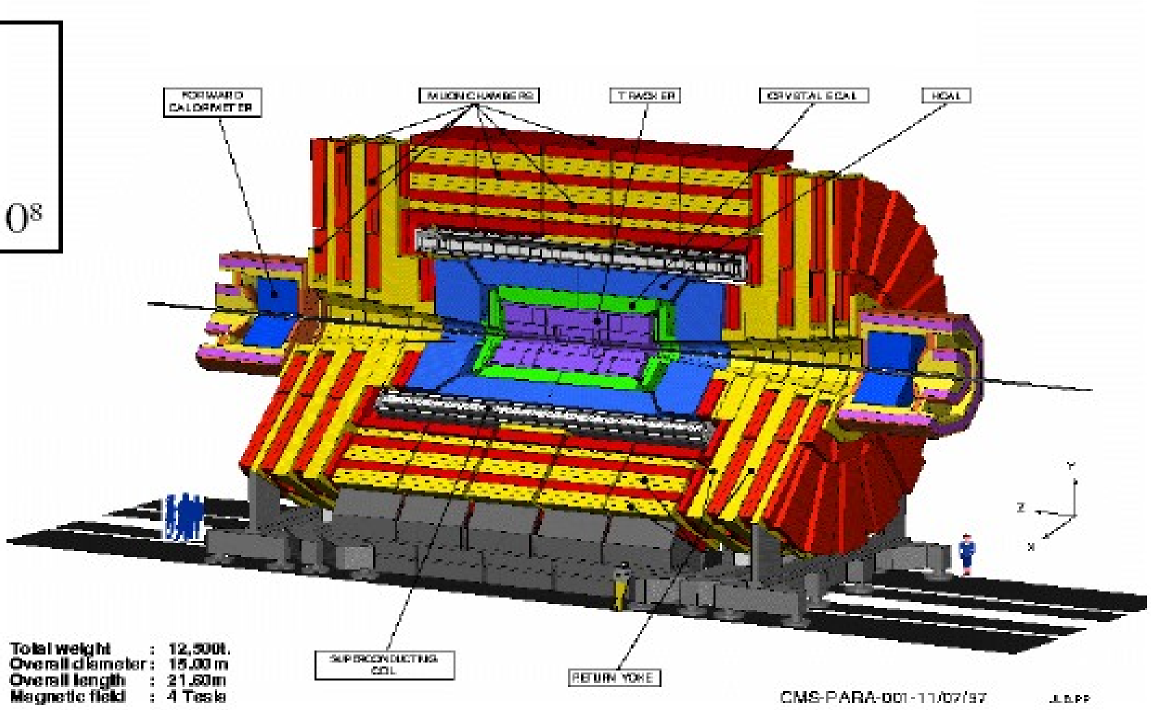
Few pictures from construction

One more view of the first installed TGC Big Wheel



CMS – a compact muon solenoid

Length : 20 m
Radius : 7 m
Weight : 14000 tons
Electronics channels : 10^8



CMS and ATLAS detectors

Don't know how New Physics will manifest →detectors must be able to detect as many particles and signatures as possible:

e, μ , τ , ν , γ , jets, b-quarks, ….

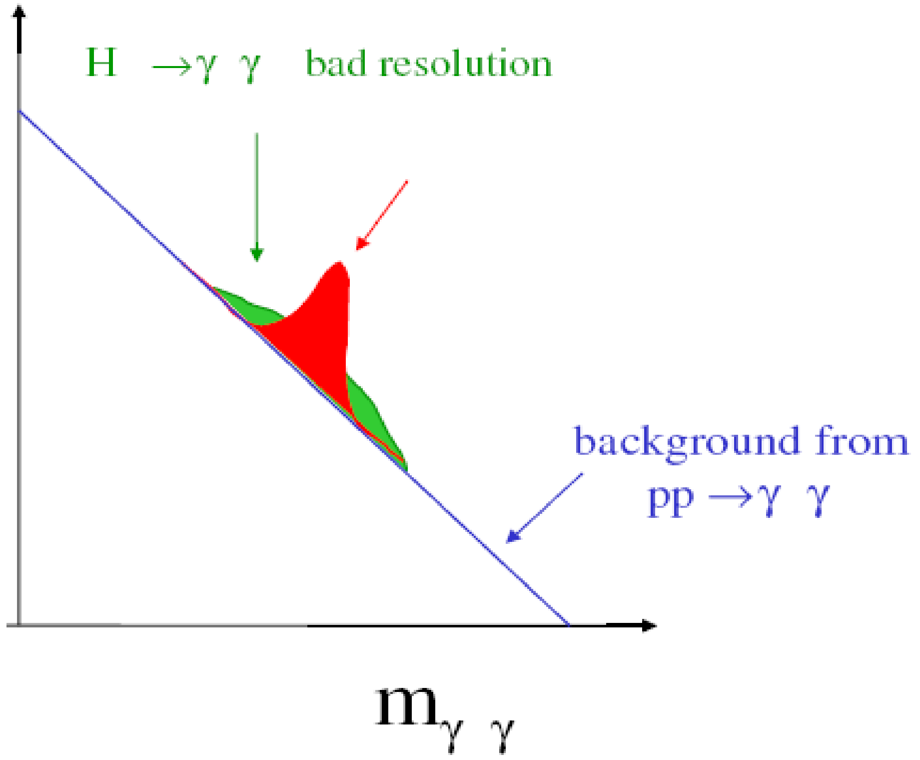
→" multi-purpose" experiments.

- Momentum / charge of tracks and secondary vertices (e.g. from b-quark decays) measured in central tracker. Excellent momentum and position resolution required.
- Energy and position of electrons and photons measured in electromagnetic calorimeters. Excellent resolution and particle identification required.
- Energy and position of hadrons and jets measured mainly in hadronic calorimeters. Good coverage and granularity are required.
- Muons identified and momentum measured in external muon spectrometer (+ central tracker). Excellent resolution over ~ 5 GeV $< p_T < \sim$ TeV required.
- Neutrinos "detected and measured" through measurement of missing transverse energy E_T^{miss}. Calorimeter coverage over $|\eta| < 5$ needed.

Example of performance requirements

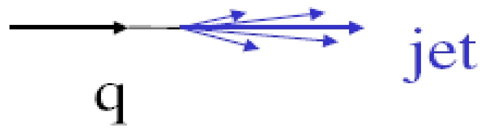
Excellent energy resolution of EM calorimeters for e/γ and of the tracking devices for μ in order to extract a signal over the backgrounds.

Example : H →γ γ

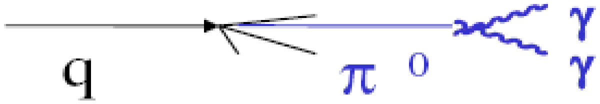


Example of performance requirements

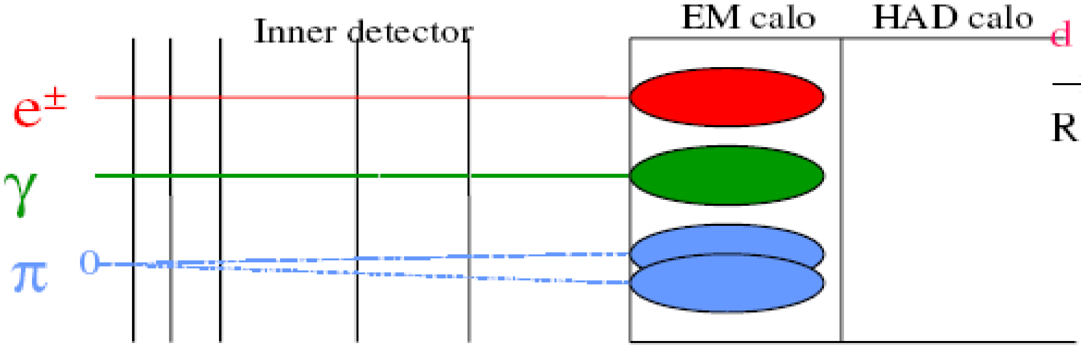
Excellent particle identification capability e.g. e/jet , γ /jet separation



number and p_T of hadron in a jet have large fluctuations



in some cases: one high-p_T π^0; all other particles too soft to be detected



$d(\gamma\gamma) < 10$ mm in calorimeter

→QCD jets can mimic photons.

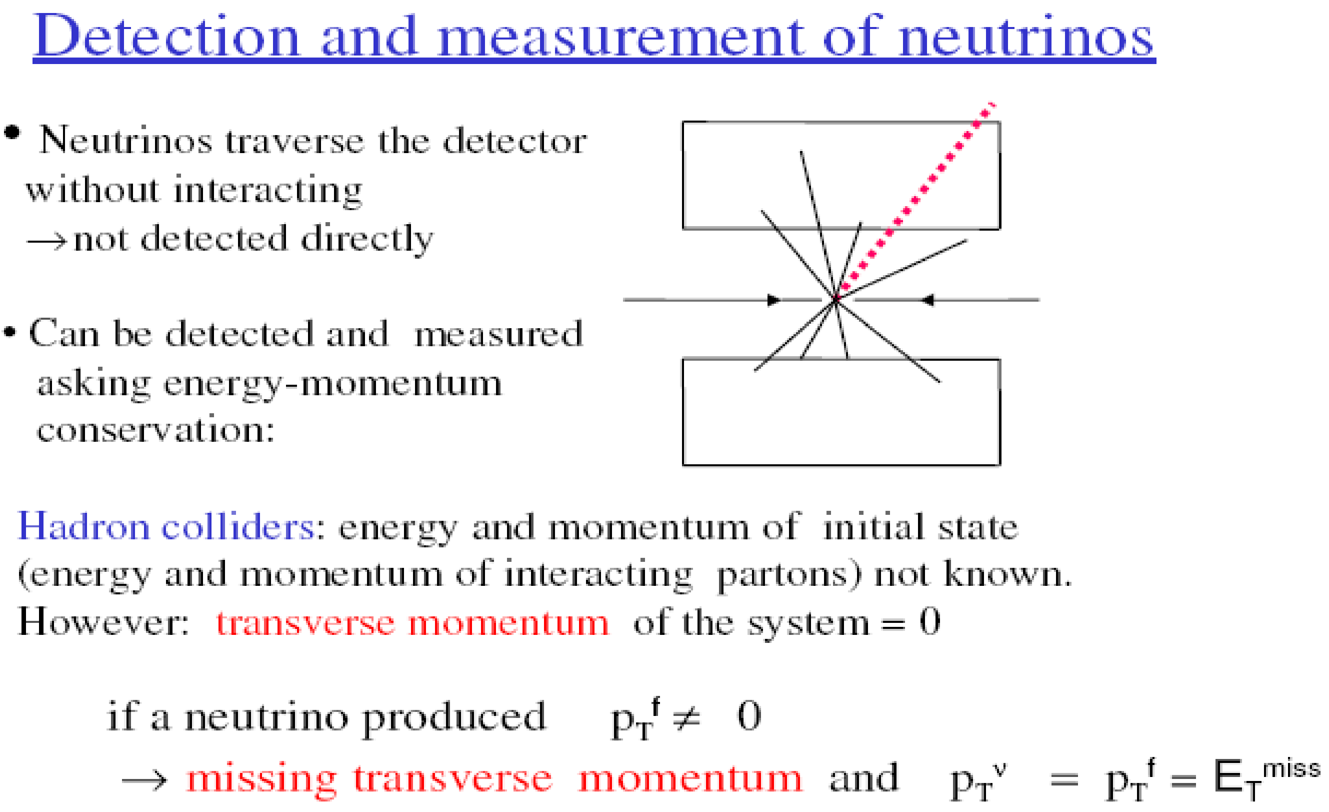
Rare cases, however:

$$\frac{\sigma_{jj}}{\sigma(H\to\gamma\gamma)} \sim 10^8$$

$m_{\gamma\gamma}$ ~ 100 GeV

need detector (calorimeter) with fine granularity to separate overlapping photons from single photons

ATLAS and CMS detectors



Detection and measurement of neutrinos

- Neutrinos traverse the detector without interacting → not detected directly
- Can be detected and measured asking energy-momentum conservation:

Hadron colliders: energy and momentum of initial state (energy and momentum of interacting partons) not known.
However: transverse momentum of the system = 0

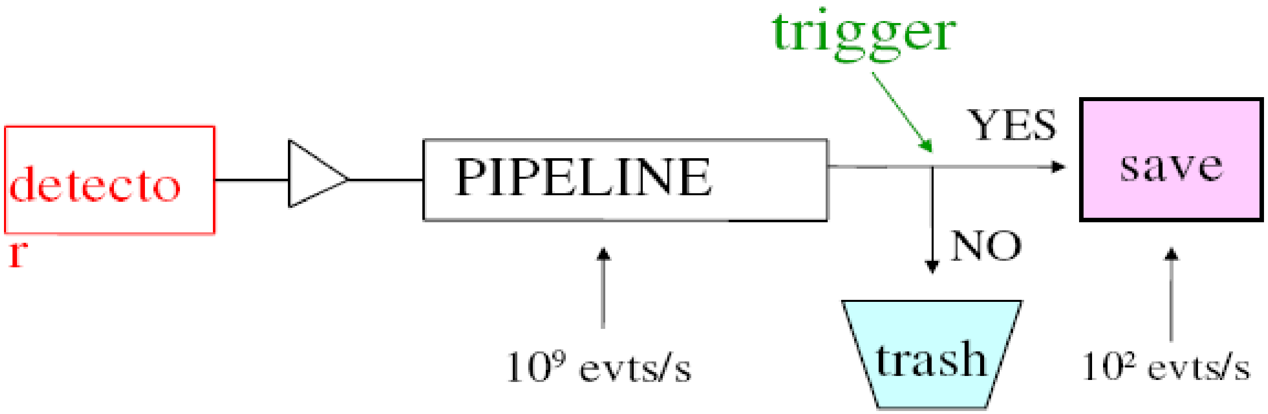
if a neutrino produced $p_T^f \neq 0$

→ missing transverse momentum and $p_T^\nu = p_T^f = E_T^{miss}$

Example of performance requirements

Trigger : much more difficult than at e^+e^- machines

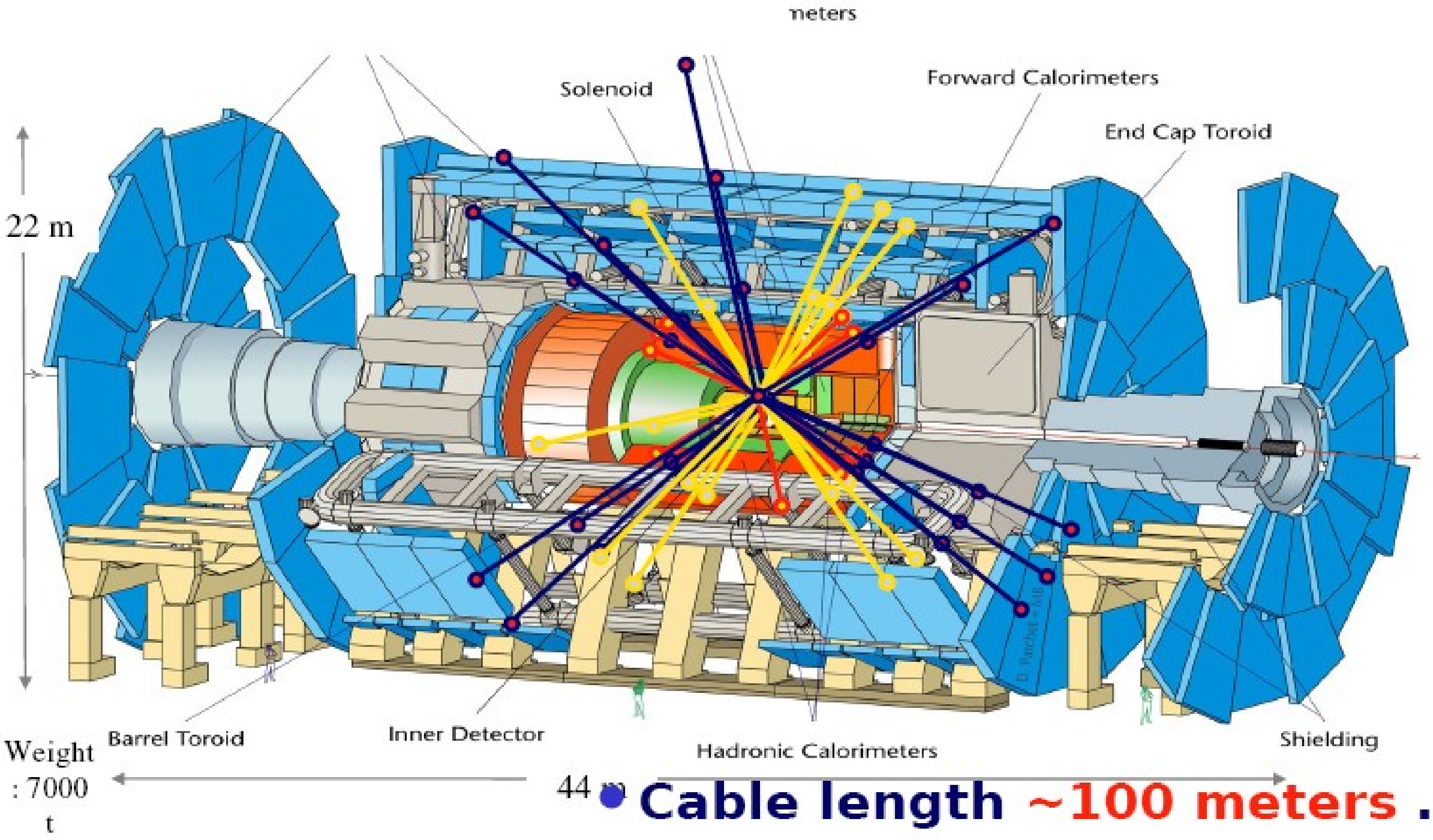
Interaction rate: ~ 10^9 events/second
Can record ~ 100 events/second
(event size 1 MB)
⇒ trigger rejection ~ 10^7
Trigger decision ≈ μ s → larger than interaction rate of 25 ns
store massive amount of data in pipelines while trigger performs calculations



trigger
detector
PIPELINE
YES
NO
save
trash
10^9 evts/s
10^2 evts/s

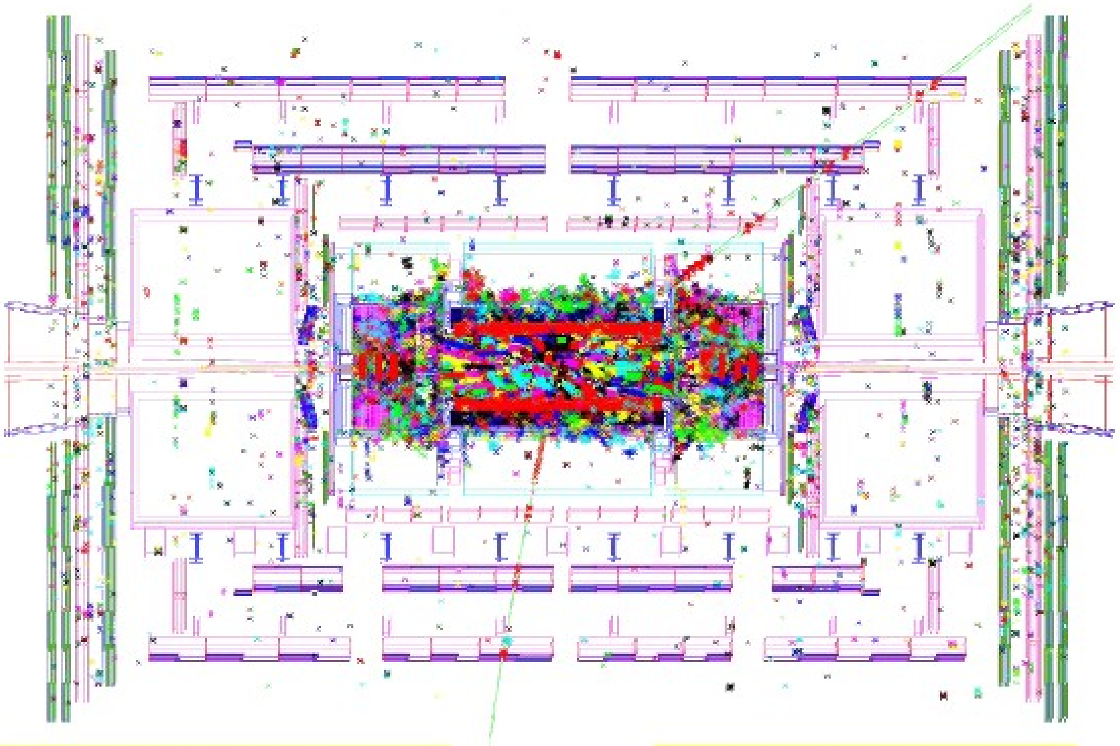
Trigger

- **Interactions every 25 ns …**
  - **In 25 ns particles travel 7.5 m**



- **Cable length ~100 meters ..**
  - **In 25 ns signals travel 5 m**

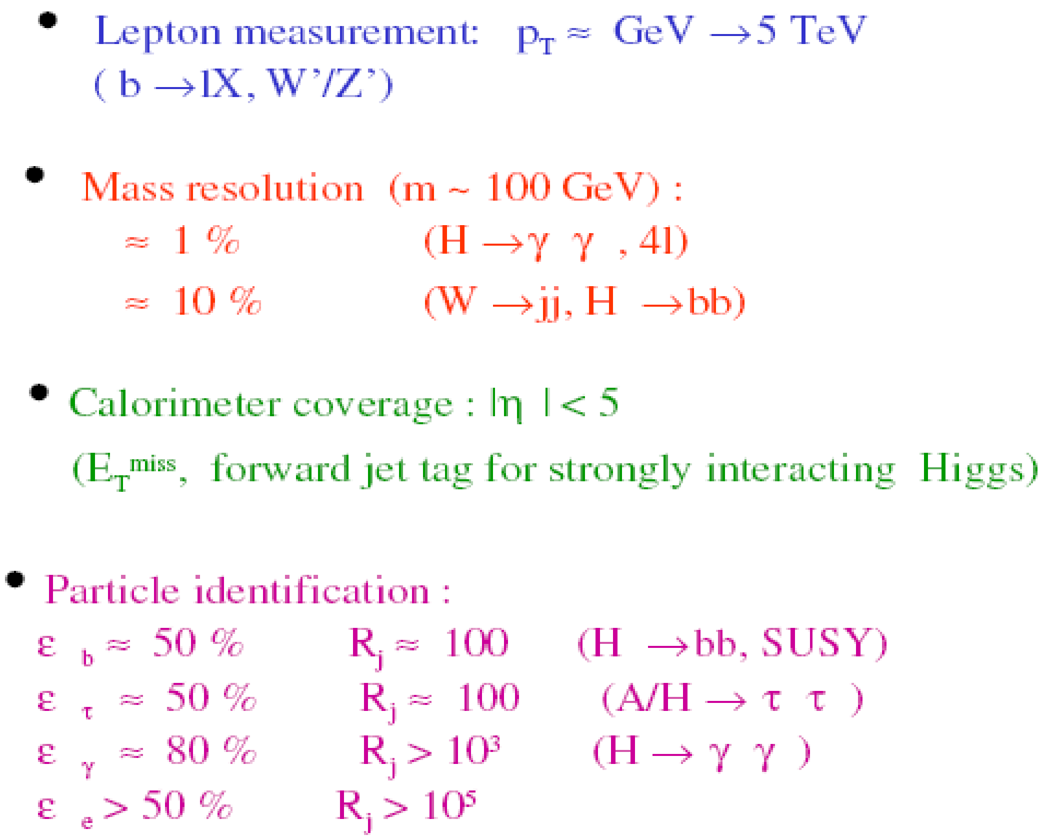
Looking for interesting event



Higgs → ZZ → 2e+2μ

23 min bias events

Basic design criteria



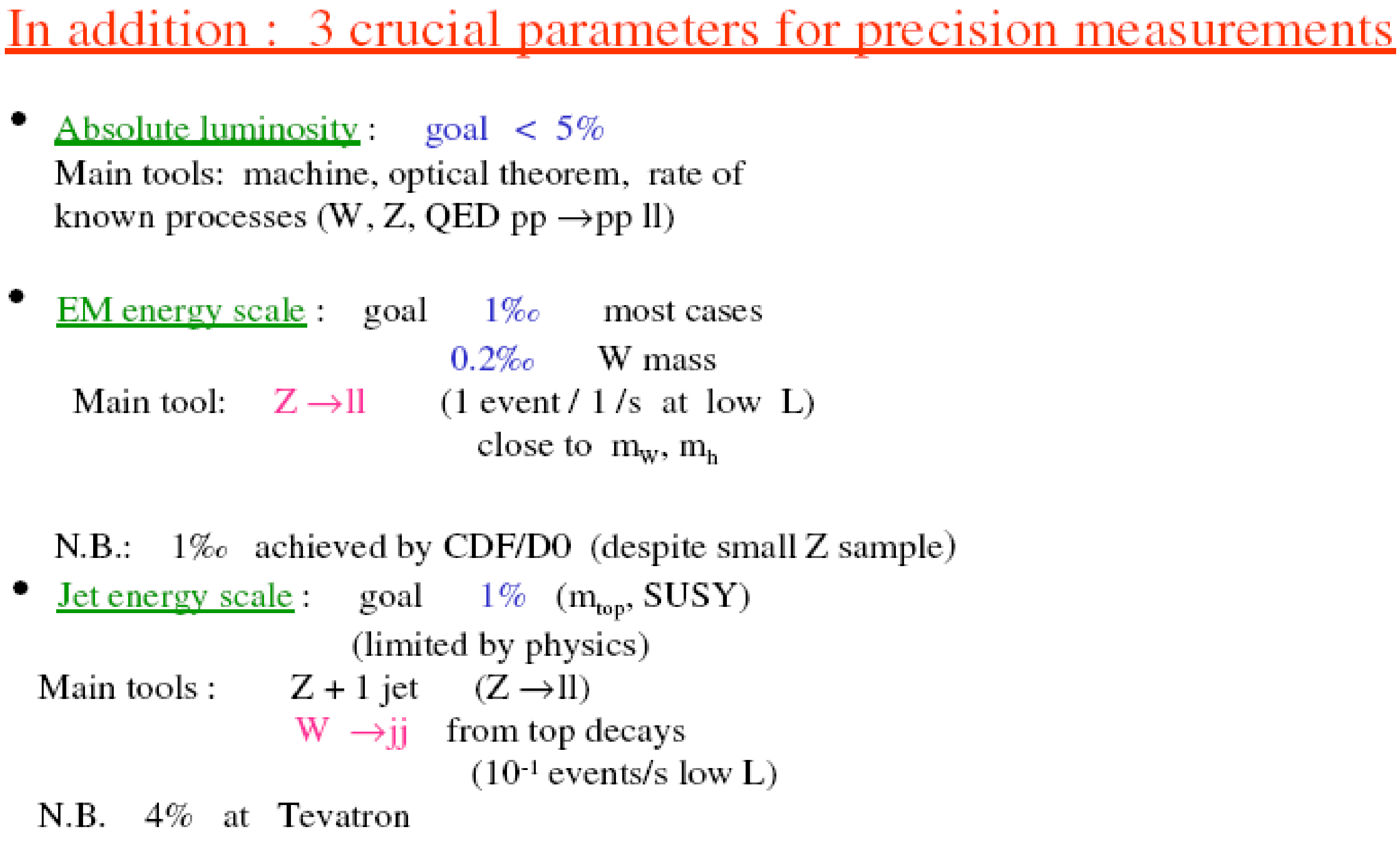
- Lepton measurement: $p_T \approx$ GeV $\rightarrow$ 5 TeV
  (b $\rightarrow$ lX, W'/Z')

- Mass resolution (m ~ 100 GeV) :
  $\approx$ 1 % (H $\rightarrow \gamma\ \gamma$, 4l)
  $\approx$ 10 % (W $\rightarrow$ jj, H $\rightarrow$ bb)

- Calorimeter coverage : $|\eta| < 5$
  (E_T^{miss}, forward jet tag for strongly interacting Higgs)

- Particle identification :
  $\varepsilon_b \approx 50\ \%$ $R_j \approx 100$ (H $\rightarrow$ bb, SUSY)
  $\varepsilon_\tau \approx 50\ \%$ $R_j \approx 100$ (A/H $\rightarrow \tau\ \tau$)
  $\varepsilon_\gamma \approx 80\ \%$ $R_j > 10^3$ (H $\rightarrow \gamma\ \gamma$)
  $\varepsilon_e > 50\ \%$ $R_j > 10^5$

Basic design criteria



In addition : 3 crucial parameters for precision measurements

- Absolute luminosity : goal < 5%
  Main tools: machine, optical theorem, rate of known processes (W, Z, QED pp →pp ll)

- EM energy scale : goal 1‰ most cases
  0.2‰ W mass
  Main tool: Z →ll (1 event / 1 /s at low L)
  close to m_W, m_h

  N.B.: 1‰ achieved by CDF/D0 (despite small Z sample)

- Jet energy scale : goal 1% (m_{top}, SUSY)
  (limited by physics)
  Main tools : Z + 1 jet (Z →ll)
  W →jj from top decays
  (10^{-1} events/s low L)
  N.B. 4% at Tevatron

Summary

LHC: **(nominal)**

pp machine (also Pb-Pb)

$\sqrt{s} = 14$ TeV

$L = 10^{33}\text{-}10^{34}\ \mathrm{cm^{-2}\ s^{-1}}$

Four large-scale experiments:

ATLAS, CMS	pp multi-purpose
LHCb	pp B-physics
ALICE	Pb-Pb

\+ dedicated small experiment
TOTEM

Very broad physics programme thanks to energy and luminosity: mass reach : ≤ 5 TeV