Experiments at LHC and Bulgarian Participation

OUTLINE

Short introduction to the physics goals of LHC

Design and preliminary results of the experiments:

Bulgarian Participation at LHC experiments - CMS

We are trying to solve some of the main puzzles of nature

What is the origin of mass
- What could be the dark matter that keeps together the clusters of galaxies
- Why the main interactions are so different in strenght
- Why gravity is not included so far in our picture
- How many are really the dimensions of our world

The answer to some of these questions is probably hidden in the so far unexplored TeV region

CMS Compact Muon Solenoid

ATLAS A Toroidal LHC Apparatus

LHCb LHC*b*eauty experiment

ALICE - A Large Ion Collider Experiment

Precision (1%) measurement of total cross section (and more) TOTEM
Study of forward π^0 production LHCf
Search for magnetic monopoles MoEDAL

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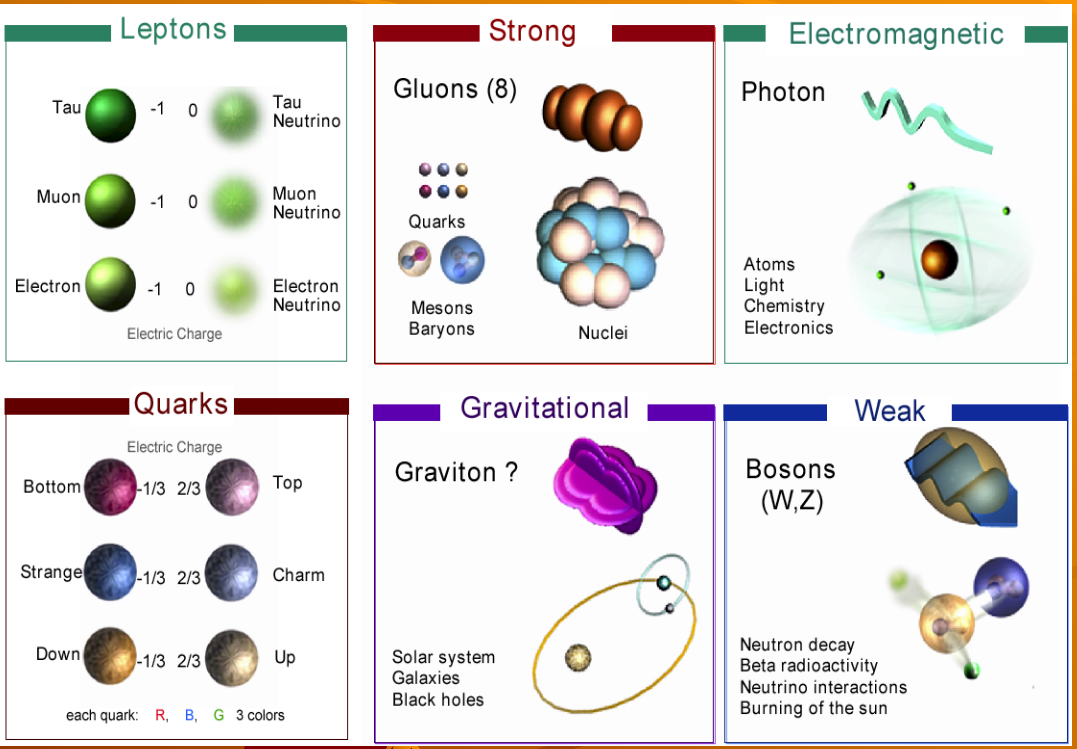


The Standard Model is still among the most successfull theories tested so far (accuracy <10^{-4} in hundreds of measurements up to an impressive 10^{-12} in electron g-2).
LEP, CDF&D0: we really understand physics up to ~100GeV.
It is sort of a monument of the physics of the 20° century: it brings together quantum mechanics and special relativity.
It is simple and elegant: it explains a huge amount of data using only 19 parameters.
Why we are not happy with it ?

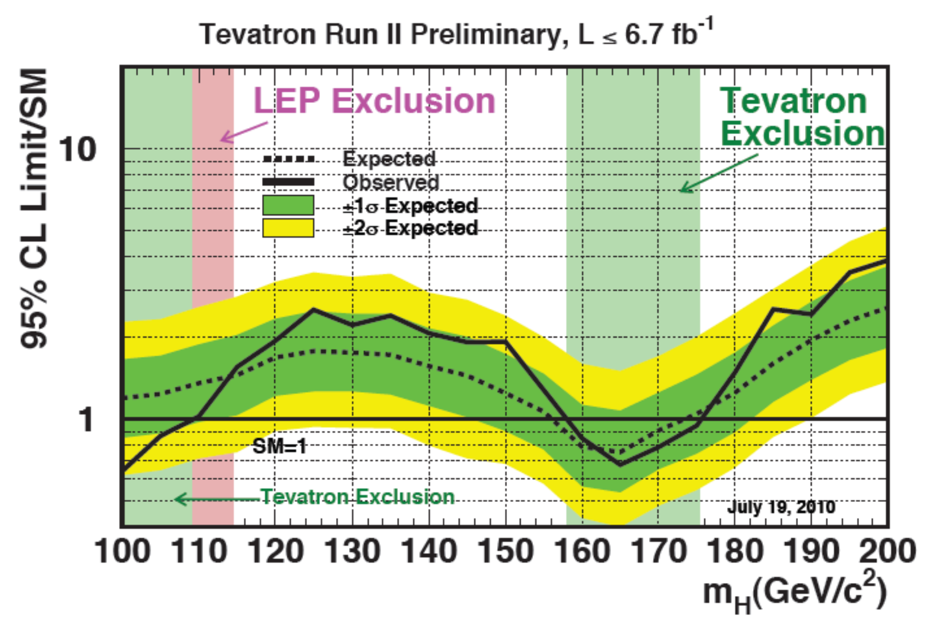
The bare SM could be consistent with massless particles **but** matter particles range from almost 0 to about 170GeV while force particles range from 0 to about 90GeV.
How can it be that a massless photon can carry the same electroweak interaction
of a 80-90 GeV W or Z?
The simplest solution (Higgs, Kibble, Brout, Englert 1960’s)
All particles are massless !! A new scalar field pervades the universe.
Particles interacting with this field acquire mass: the stronger the interaction the larger the mass.

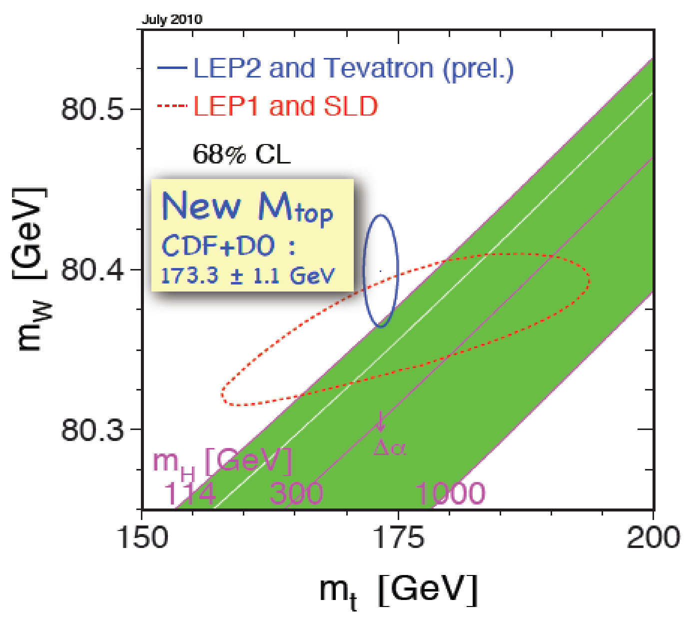
The Higgs mechanism

How heavy is the Higgs: the TeV scale

Today the Higgs is directly excluded in a small region of mass.
To be sure to be able to catch it (if it does exist) a safe attitude
is to explore the entire region between 100 and 1000GeV.

ICHEP 2010





Electroweak constraints

$\ln M_H \propto \Delta M_W \propto M_t^2$

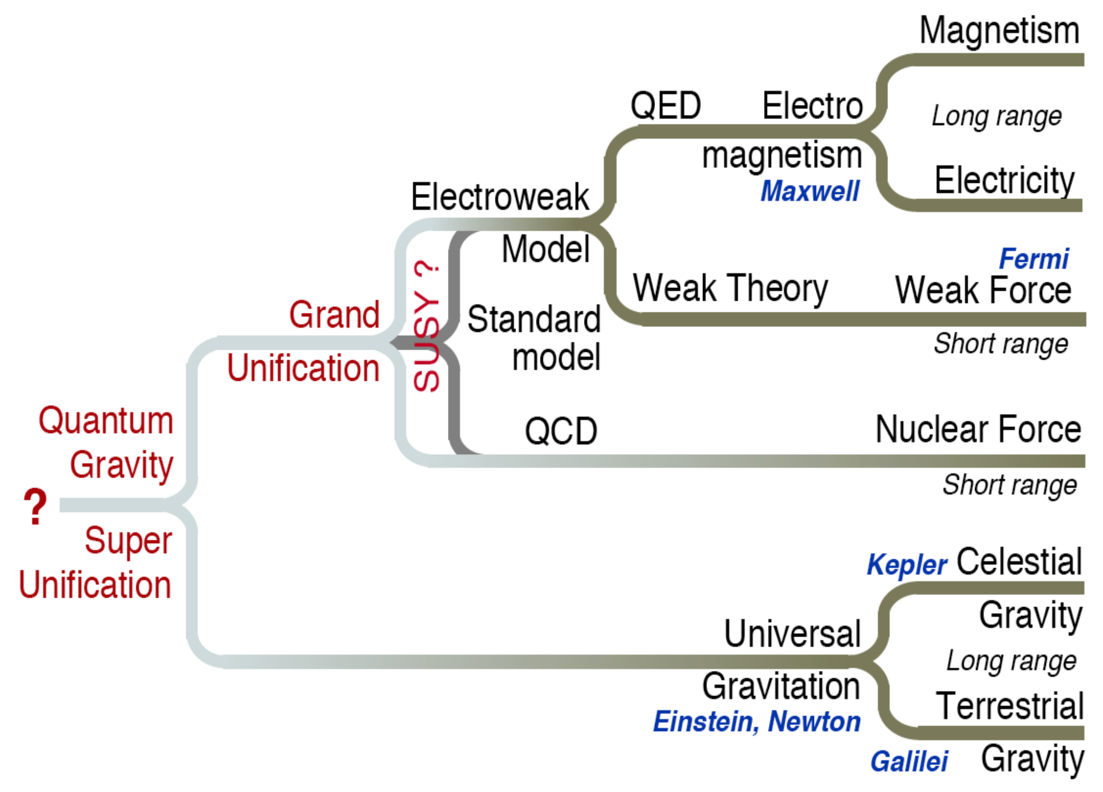
The theory is elegant, coherent, and consistent with all observations…..
but nobody has been able so far to identify this new particle.

Unfortunately the theory does not constrain significantly the mass of the boson.
M_H can be considered as a free parameter.

The Higgs boson can live anywhere between a few 10 GeV and many 100 GeV.

A definitive answer can come only from careful experiments.

The unification of all forces of nature. The dream of all physicists, the“mother” of all challenges



All these are elegant theories →

But to verify them we need to discover the Higgs, the supersymmetric particles and the very massive particles predicted by extradimensional theories (100GeV to severalsTeV)

All these particles have escaped detection so far.
This could be due to the fact that:

a)The theories are wrong or

b)We have not been able to produce them so far because the energy of previous accelerators was not high enough.

We should remember that to produce a mass m we need an energy $E=mc^2$. So far the modern experiments have produced and studied particles up to masses ~100GeV.

Let’s try to produce and study masses ~TeV

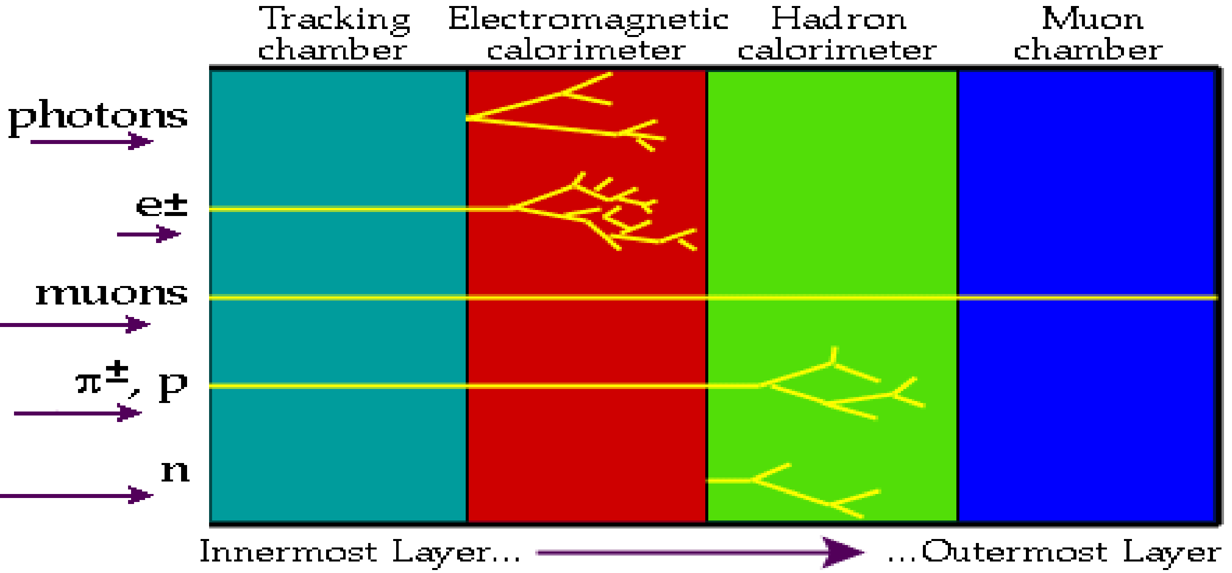
Experiments at LHC and Bulgarian Participation

Theory and Experiments

- Exp: Particles have masses: …..why ?
- Theo: Mass is given by the interaction with the Higgs field
- Exp: Find the Higgs Boson

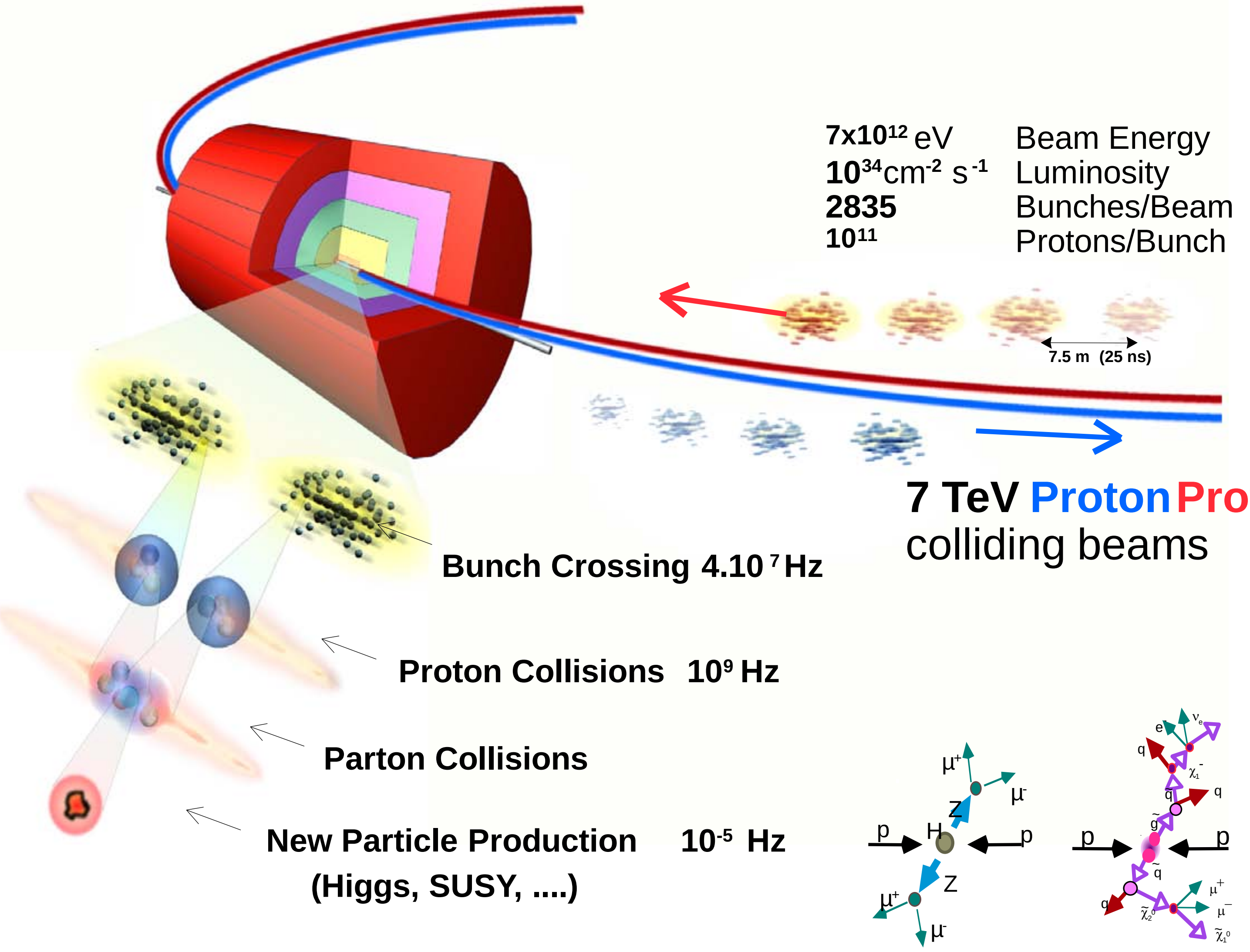
- Exp: There are 3 Forces: ……why ?
- Theo: Super Symmetry unifies the Forces
- Exp: Find the signals of Super Symmetry

Basic detector



New physics will be detected by the production of NEW PARTICLES. These particles will disintegrate in very short time (10^{-24} s) and we will detect their decay products. The particles that we will detect are particles with "long-life-time". The LHC detectors are designed to record the largest possible amount of information about these final state particles.

What is needed for TeV physics?



$7x10^{12}$ eV	Beam Energy
10^{34}cm^{-2} s^{-1}	Luminosity
2835	Bunches/Beam
10^{11}	Protons/Bunch

7 TeV Proton Proton colliding beams

Bunch Crossing 4.10 ^{7} Hz

Proton Collisions 10^{9} Hz

Parton Collisions

New Particle Production 10^{-5} Hz

(Higgs, SUSY, ...)

Selection of 1 event in 10,000,000,000,000

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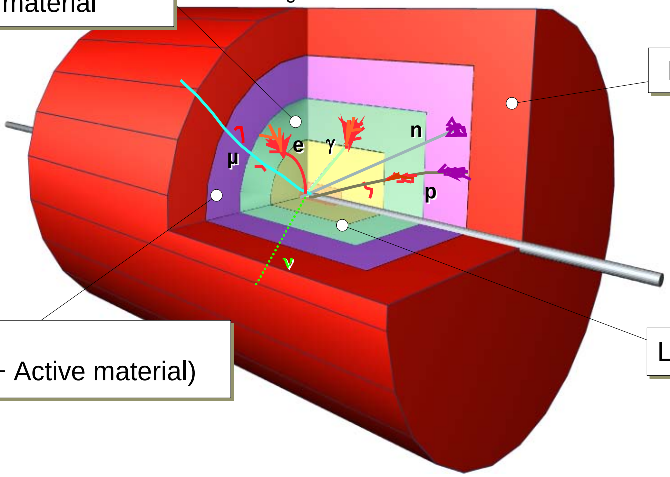
Typical elements of a collider detector



Materials with high number of protons + Active material

Hermetic calorimetry
- Missing Et measurements

Electromagnetic and Hadron calorimeters
- Particle identification (e, γ Jets, Missing E_T)
- Energy measurement

Heavy materials

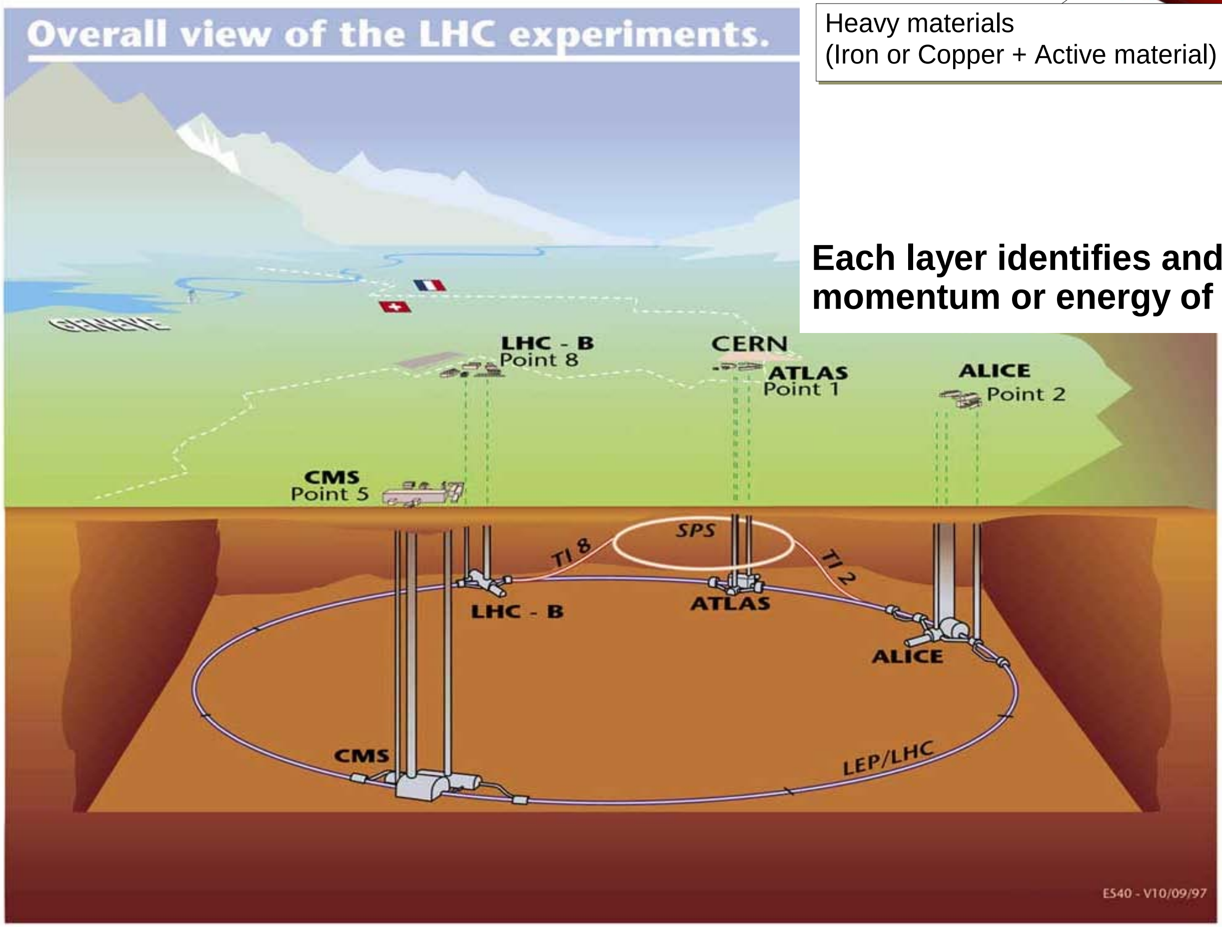
Muon detector
- μ identification

Heavy materials (Iron or Copper + Active material)

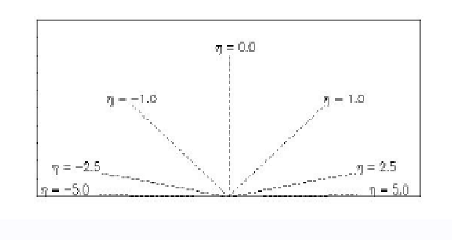
Light materials

Central detector
- Tracking, p_T, MIP
- Em. shower position
- Topology
- Vertex

Each layer identifies and enables the measurement of the momentum or energy of the particles produced in a collision



Ha



ples

pseudorapidity, η, is a commonly used spatial coordinate describing the angle of a particle relative to the beam axis.

$$\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right],$$

θ = 90⁰ → η = 0
θ = 10⁰ → η ≅ 2.4
θ = 170⁰ → η ≅ -2.4

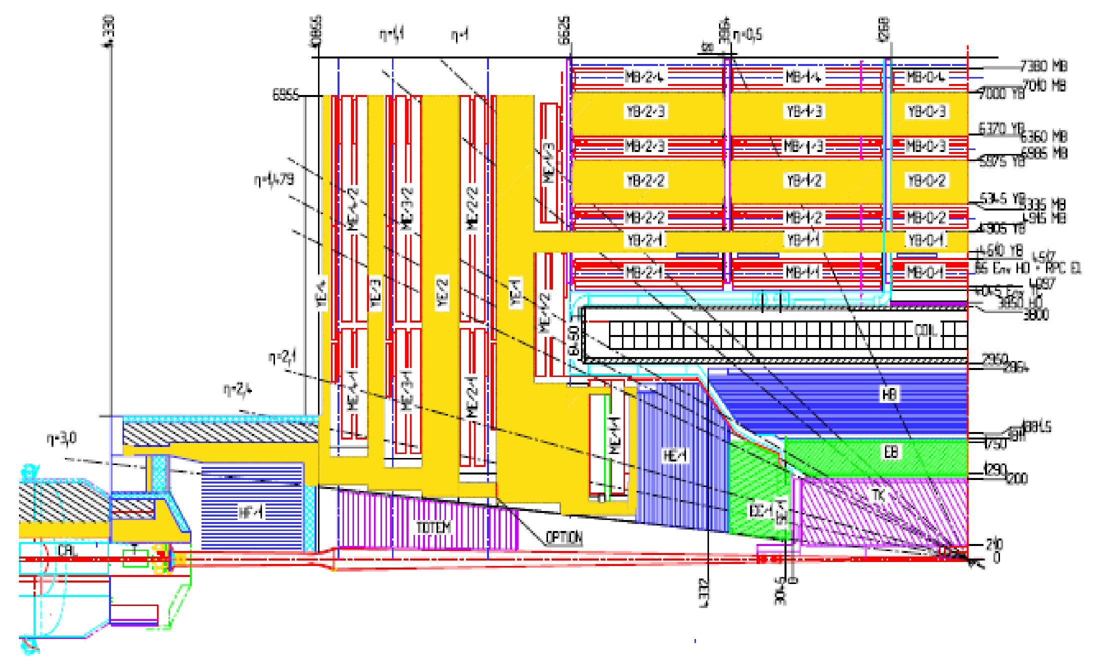


Figure CP 1: One quarter longitudinal view of the CMS Experiment. Dimensions are in units of mm.

Collider Luminosity

$$R = \mathscr{L}\sigma_{\text{int}} \ .$$

$$L = \frac{N_b^2 n_b f_{\text{rev}} \gamma_r}{4\pi\varepsilon_n \beta*} F$$

N_b = number of proton per bunch
n_b = number of bunches

f_{rev} = revolution frequency
F = crossing angle factor

Rms transverse beam size = √εβ/γ
ε_n = normalized transverse emittance
β* = optics at beam crossing (m)
γ_r = relativistic factor

Luminosity is measured in units of length^{-2} * time^{-1}
Typical collider values are in the range of $10^{30\pm\text{units}}$ cm^{-2} sec^{-1}

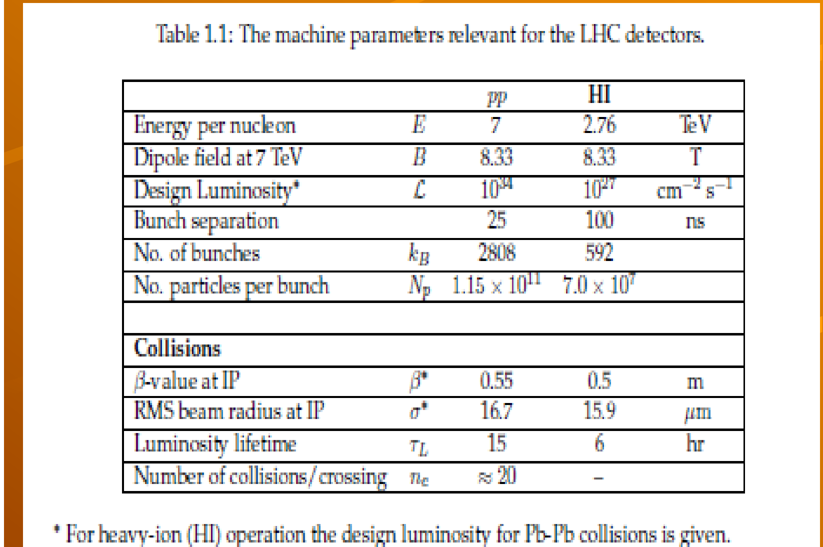
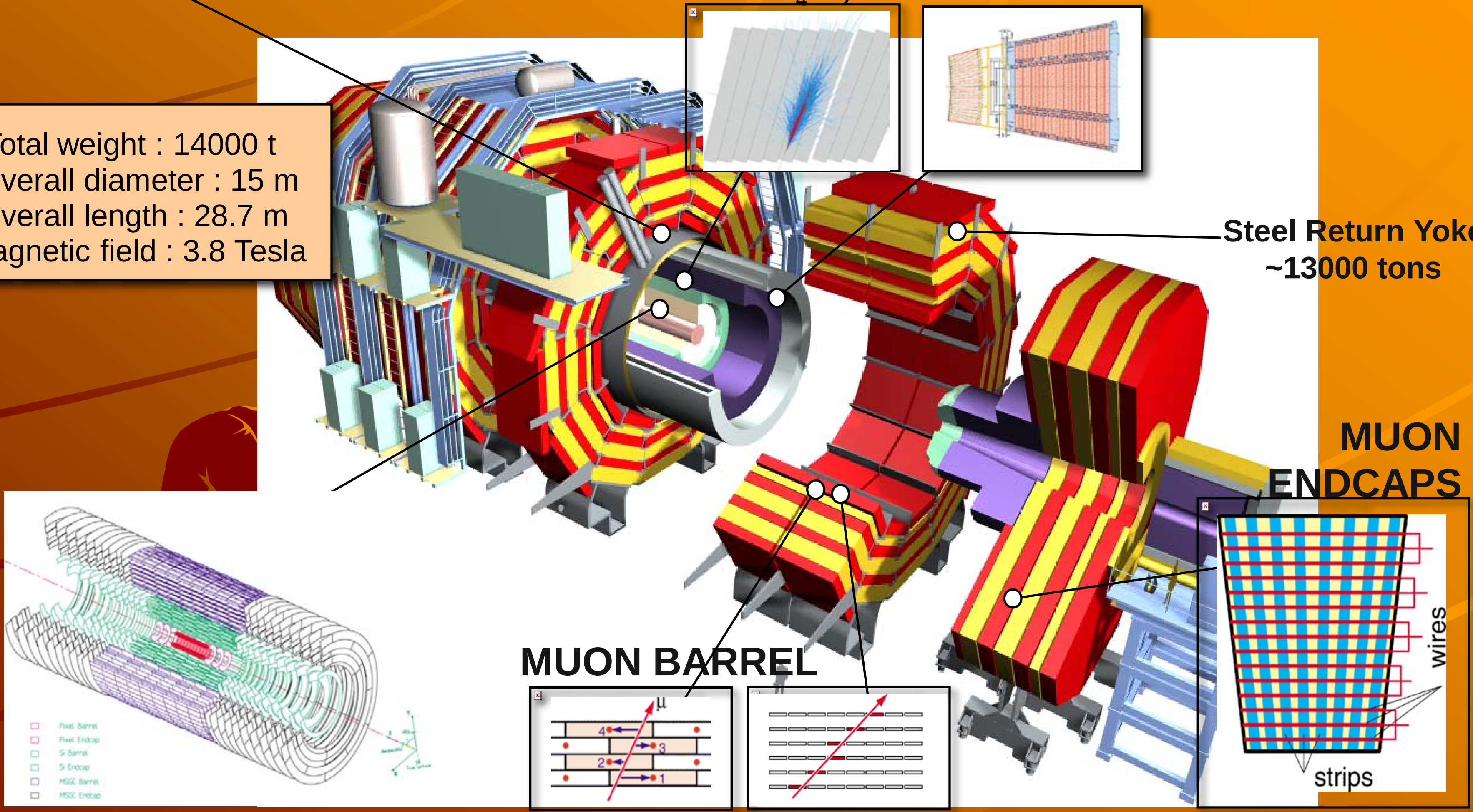


Table 1.1: The machine parameters relevant for the LHC detectors.

		pp	HI	
Energy per nucleon	E	7	2.76	TeV
Dipole field at 7 TeV	B	8.33	8.33	T
Design Luminosity*	$\mathcal{L}$	10^{34}	10^{27}	cm^{-2} s^{-1}
Bunch separation		25	100	ns
No. of bunches	k_B	2808	592	
No. particles per bunch	N_p	1.15×10^{11}	7.0×10^{7}	
Collisions				
β-value at IP	β^*	0.55	0.5	m
RMS beam radius at IP	σ^*	16.7	15.9	μm
Luminosity lifetime	τ_L	15	6	hr
Number of collisions/crossing	n_c	≈ 20	–	

* For heavy-ion (HI) operation the design luminosity for Pb-Pb collisions is given.

The Compact Muon Solenoid (CMS)



CALORIMETERS

ECAL ~76K Scintillating PbWO$_4$ crystals

HCAL Brass + Plastic Scintillator ~ 7K channels

SUPERCONDUCTING SOLENOID
Niobium Titanium coil carrying 18000 A

Total weight : 14000 t
Overall diameter : 15 m
Overall length : 28.7 m
Magnetic field : 3.8 Tesla

Steel Return Yoke
~13000 tons

MUON ENDCAPS

MUON BARREL

Silicon Tracker Pixels 100x150 μm^2
~ 1m^2 ~ 66M channels
Microstrips 80x180 μm, 200m^2
9.6M channels

250 Drift Tube Chambers

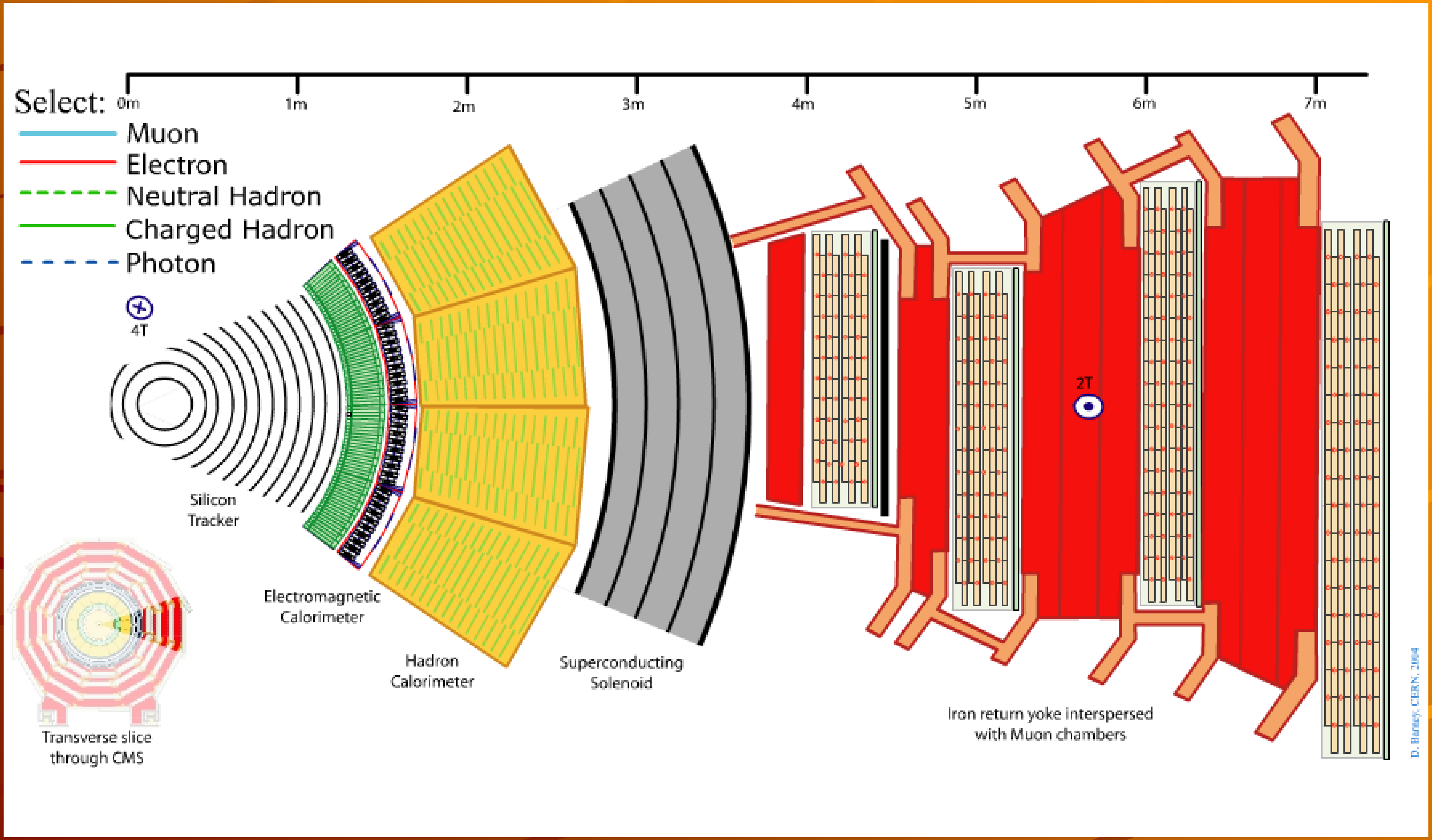
480 Resistive Plate Chambers

473 Cathode Strip Chambers (**CSC**)
432 Resistive Plate Chambers (**RPC**)

Transverse slice through CMS detector

Click on a particle type to visualise that particle in CMS

Press “escape” to exit



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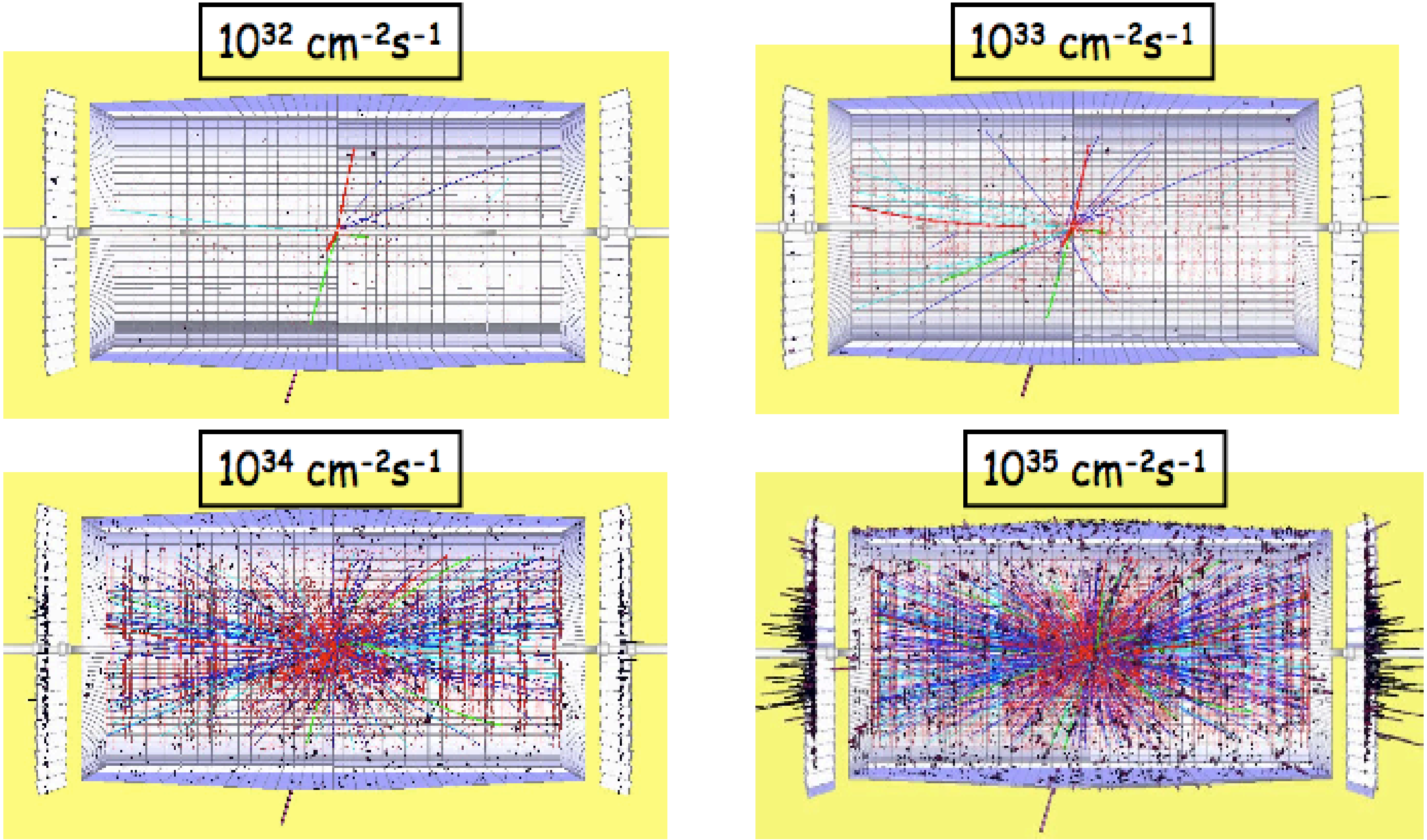
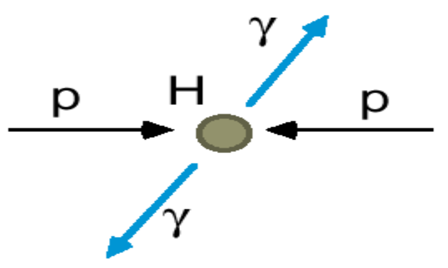
$H \to ZZ \to \mu\mu ee$ event with $M_H = 300$ GeV for different luminosities

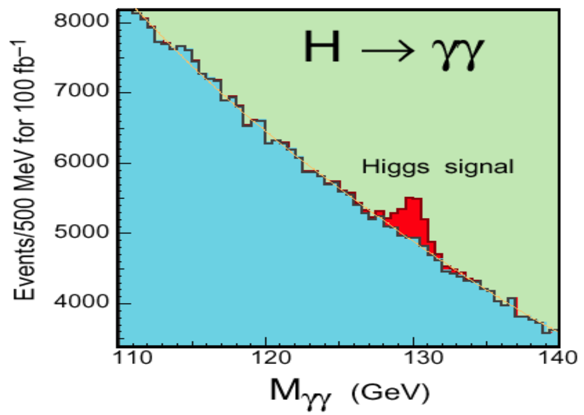


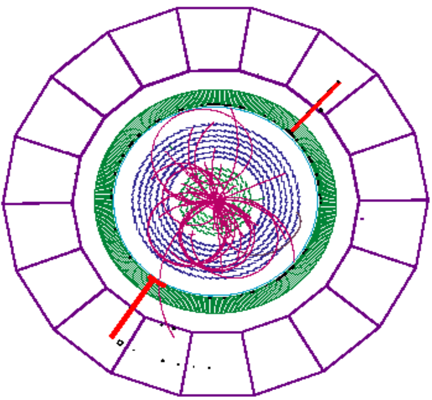
Experiments at LHC and Bulgarian Participation

For Higgs signals in CMS we need to be patient. Very likely 14 TeV will be needed

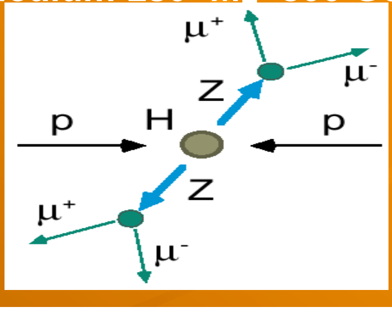
Low M_H < 150 GeV

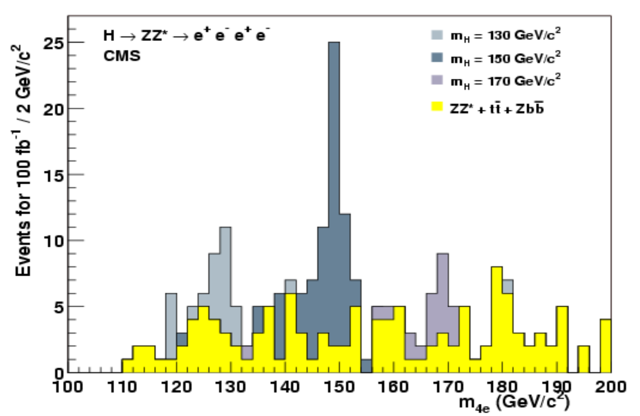


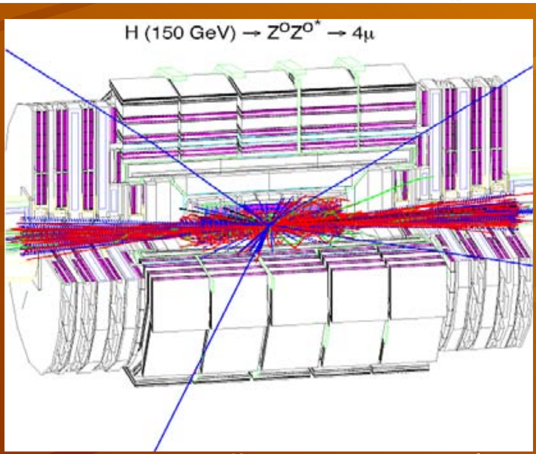




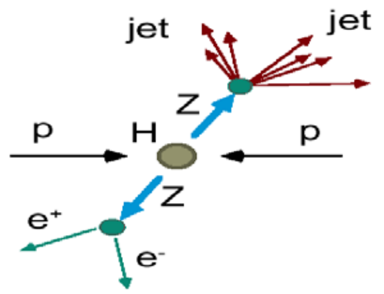
Medium 130<M_H<500 GeV

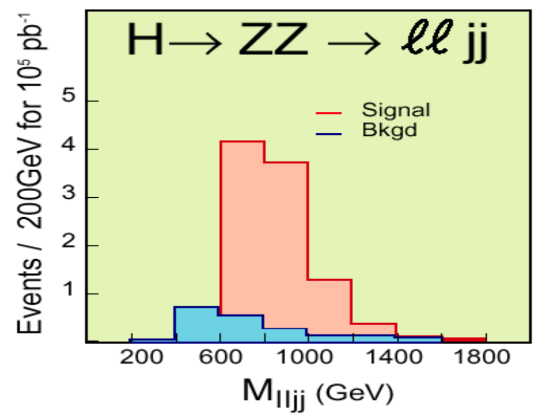


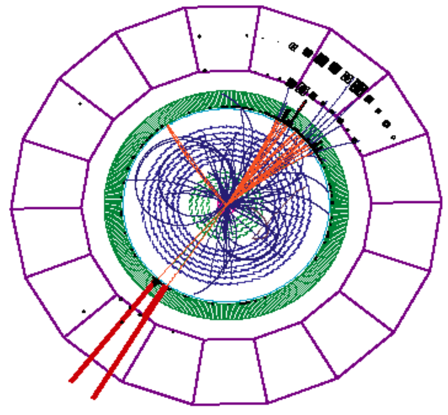




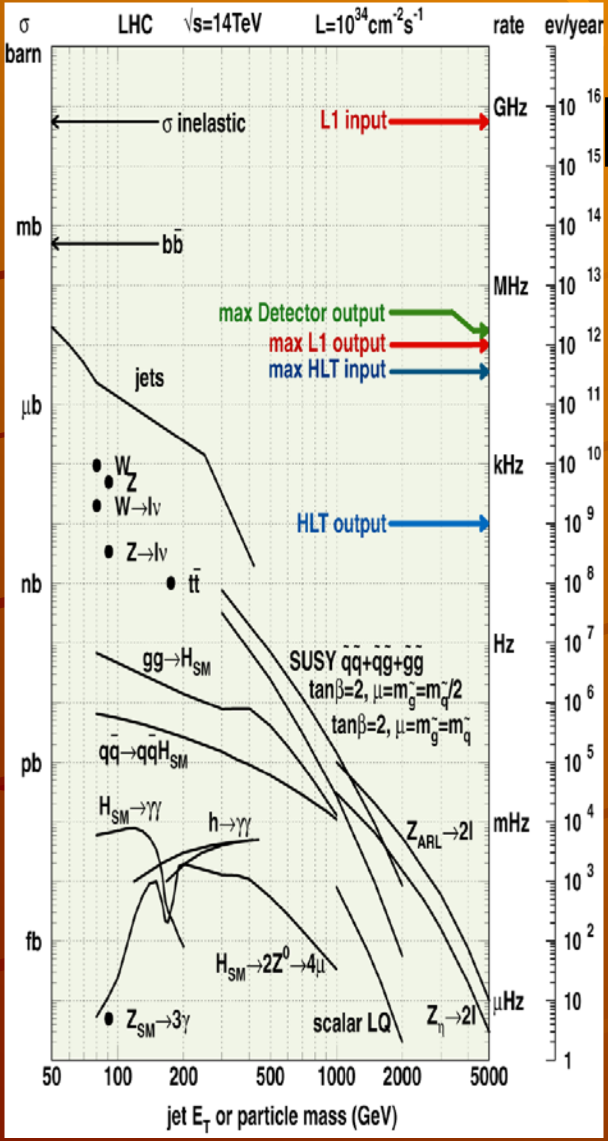
High M_H > ~500 GeV

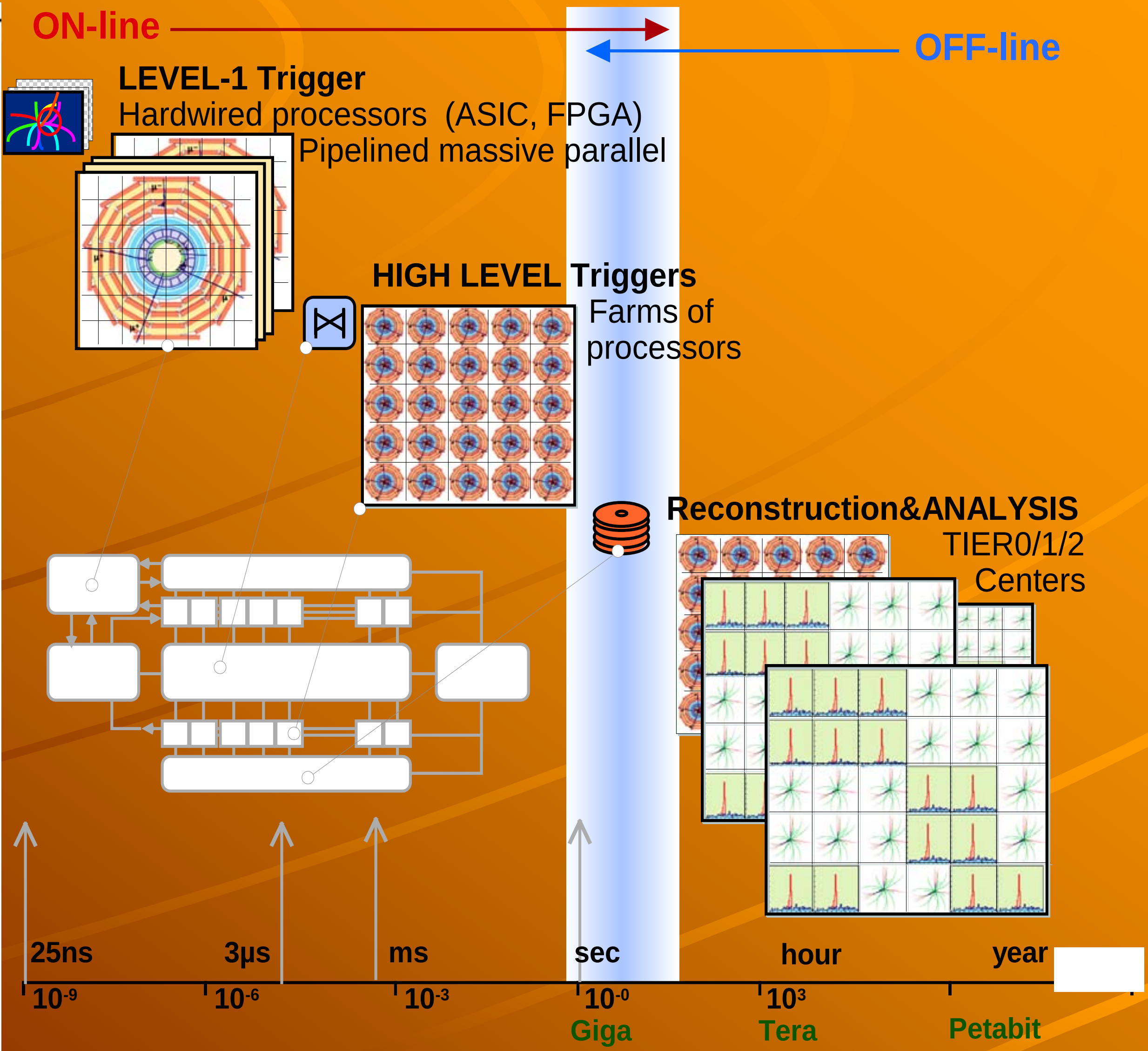






A high granularity device is needed to reconstruct hundreds of tracks per event





ON-line

OFF-line

LEVEL-1 Trigger
Hardwired processors (ASIC, FPGA)
Pipelined massive parallel

HIGH LEVEL Triggers
Farms of
processors

Reconstruction&ANALYSIS
TIER0/1/2
Centers

25ns	3μs	ms	sec	hour	year
10^{-9}	10^{-6}	10^{-3}	10^{-0}	10^{3}	
			Giga	Tera	Petabit

Imagine CMS as a huge and very fast digital camera

The interesting events are very rare. An incredibly high number of collisions is needed to be able to identify particles like the Higgs boson.

CMS can be compared to a huge digital camera of 100Megapixel which can take **40 millions pictures per second.**

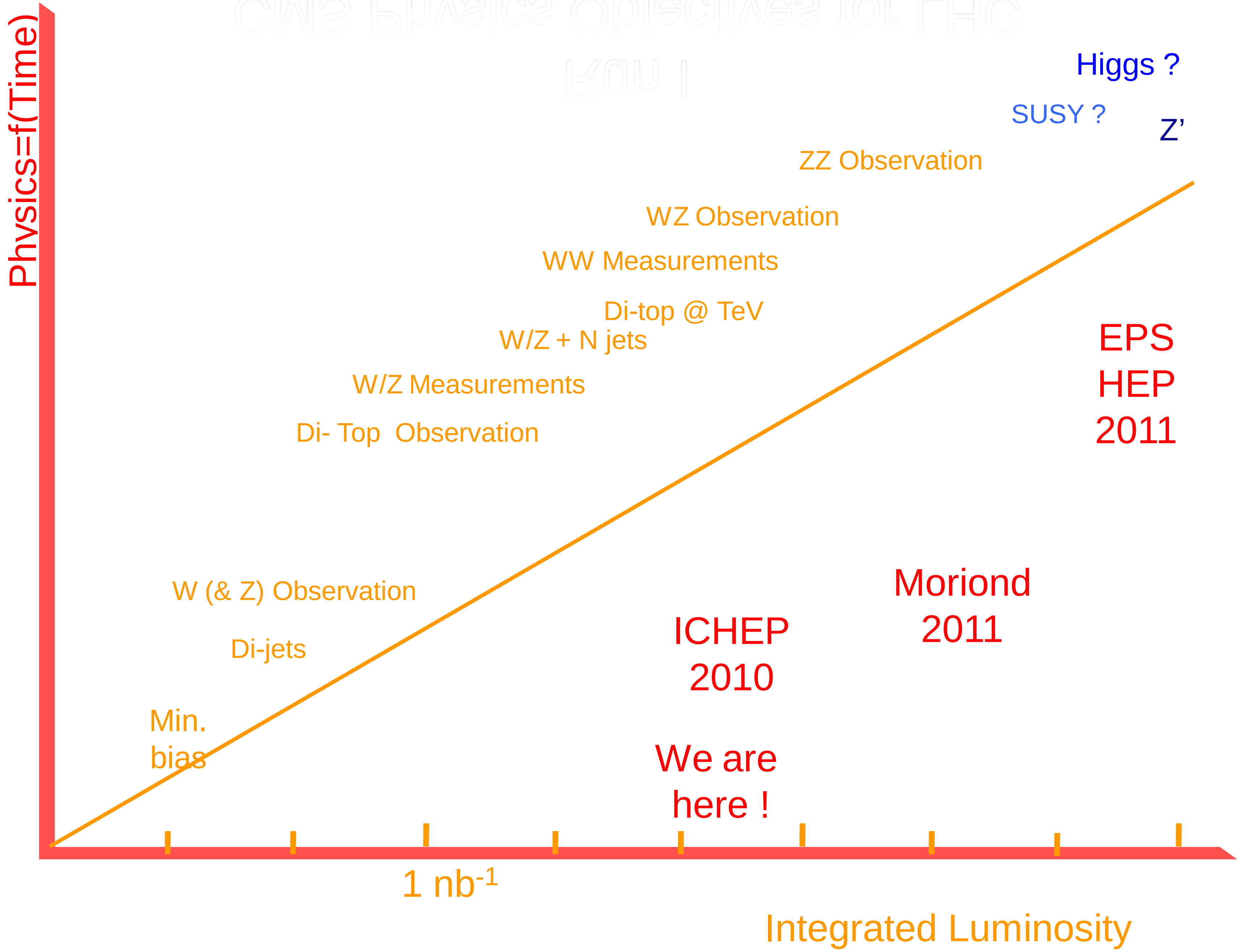
The pictures are quickly scanned and **after a first look, that takes about 3 millionths of a second, 100.000 pictures are preliminary selected: L1 Trigger**

In about 50-100 milliseconds a more detailed scan of the pre-selected pictures will discard most of the 100.000 pictures **(HLT: High Level Trigger) to record permanently on disk the 100-400 really promising.**

The operation will be repeated every second for the whole data taking period**:**
~ several PB of data/year

Grid Computing bringing together many powerful computing centers will be needed to store/re-reconstruct/analyze the data

CMS Physics Objectives for LHC Run I



Physics=f(Time)

Higgs ?

SUSY ?

Z’

ZZ Observation

WZ Observation

WW Measurements

Di-top @ TeV

W/Z + N jets

W/Z Measurements

Di- Top Observation

W (& Z) Observation

Di-jets

Min.
bias

EPS
HEP
2011

Moriond
2011

ICHEP
2010

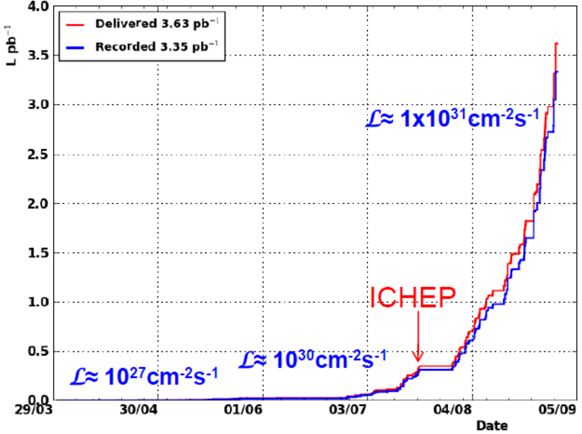
We are
here !

1 nb^{-1}

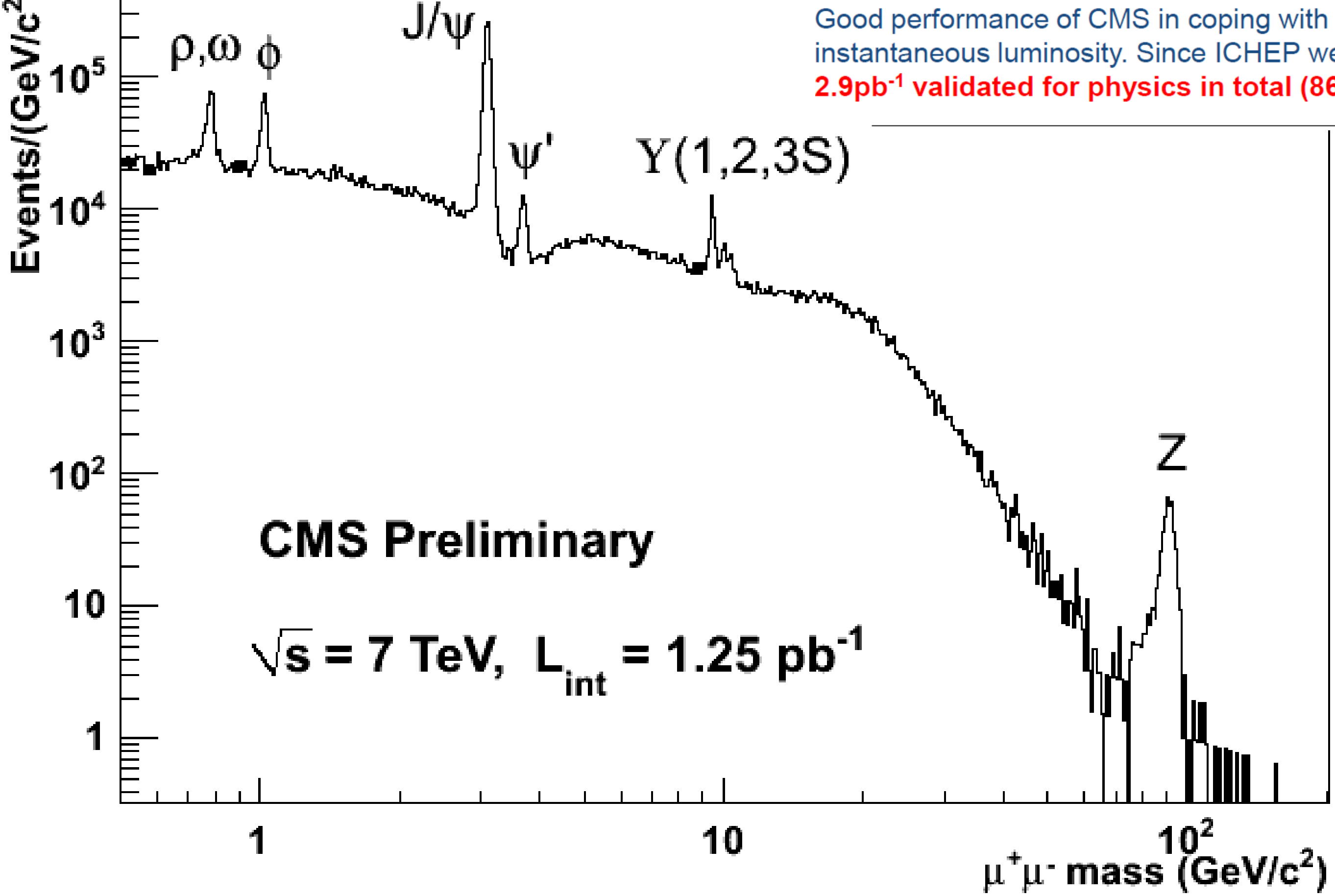
Integrated Luminosity

Here is the Compact Muon Solenoid

About **3.6pb^{-1}** delivered by LHC and **~3.3pb^{-1}** of data collected by CMS. Overall data taking efficiency **>92%.**



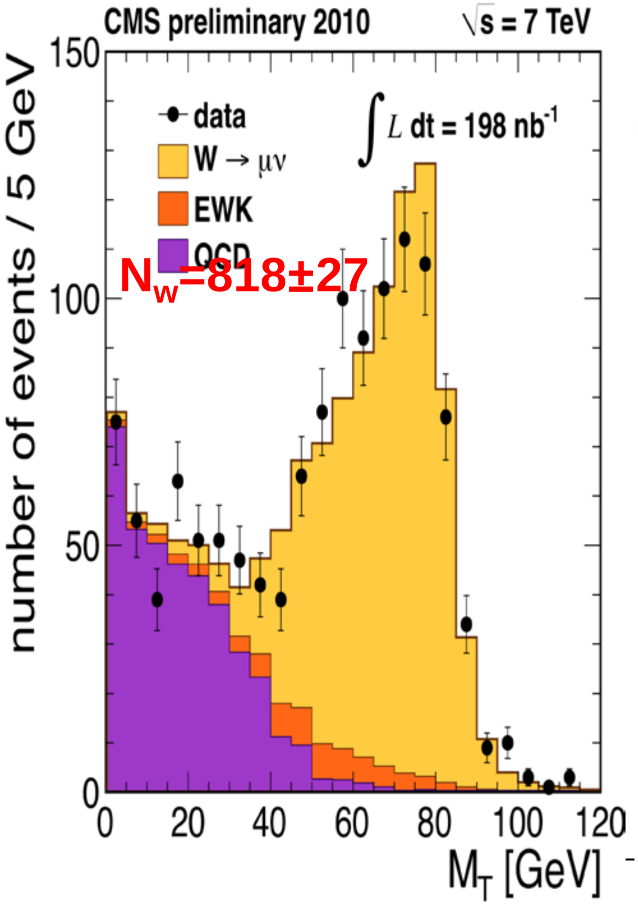
Good performance of CMS in coping with 4 orders of magnitude increase in instantaneous luminosity. Since ICHEP we have recorded another **3.0pb^{-1}** of data: **2.9pb^{-1} validated for physics in total (86% of the recorded data)**



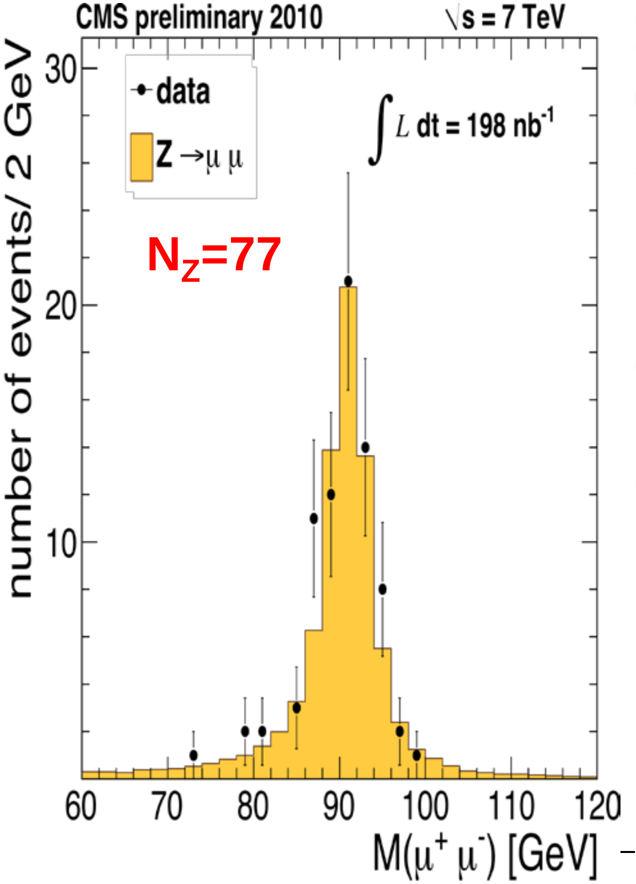
Extraction of the $W^\pm$ (Z^0)$\rightarrow\mu^\pm\nu$ ($\mu^+\mu^-$) yield signal

Trigger HLT path: μ+X(p_T>9GeV/c) |η|<2.

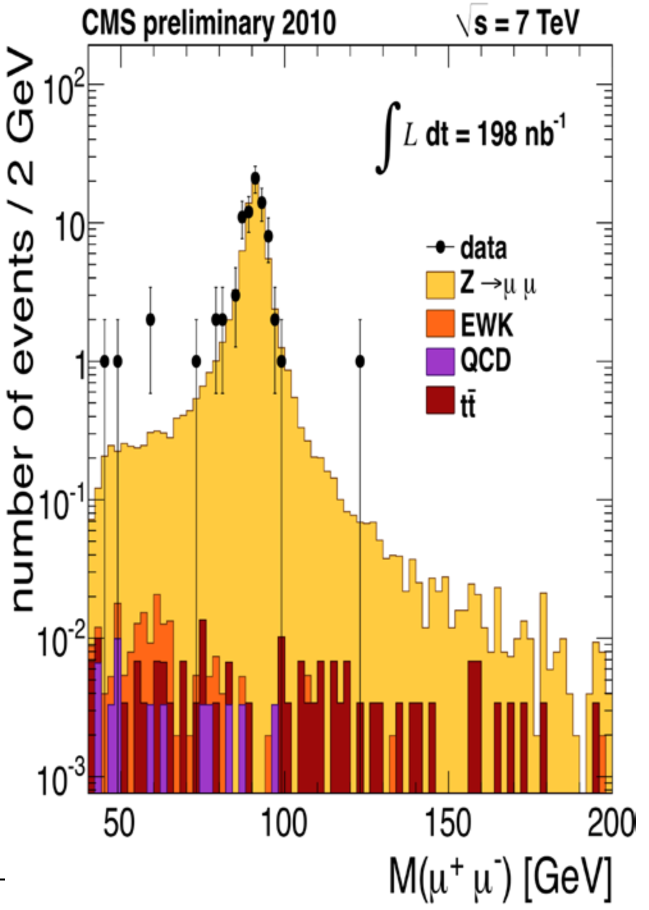
Good quality muon track (hits in pixels, strip tracker, muon system and χ^2/dof <10). For the W: relative isolation ≤0.15 in a cone of ΔR<0.3 around the muon. For the Z: looser quality criteria on the second muon, opposite charge and |η|<2.4; both muons isolated, p_T>20GeV and invariant mass 60<$m_{\mu\mu}$<120GeV/c^2. Simultaneous fits to backgrounds and signal contributions. QCD background shapes obtained using data. EWK background shapes and signal from MonteCarlo.



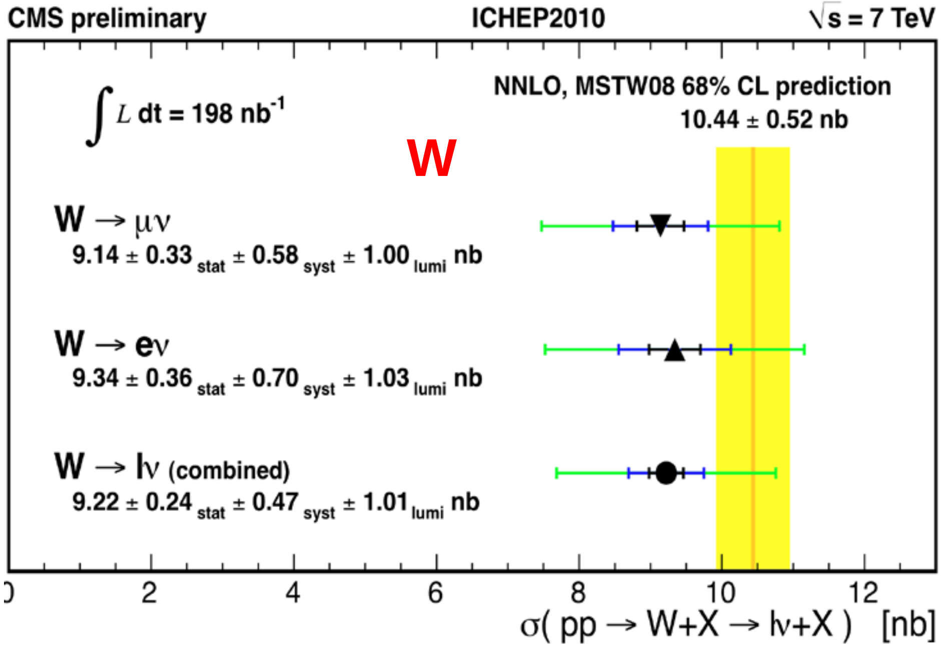
N_w=818±27



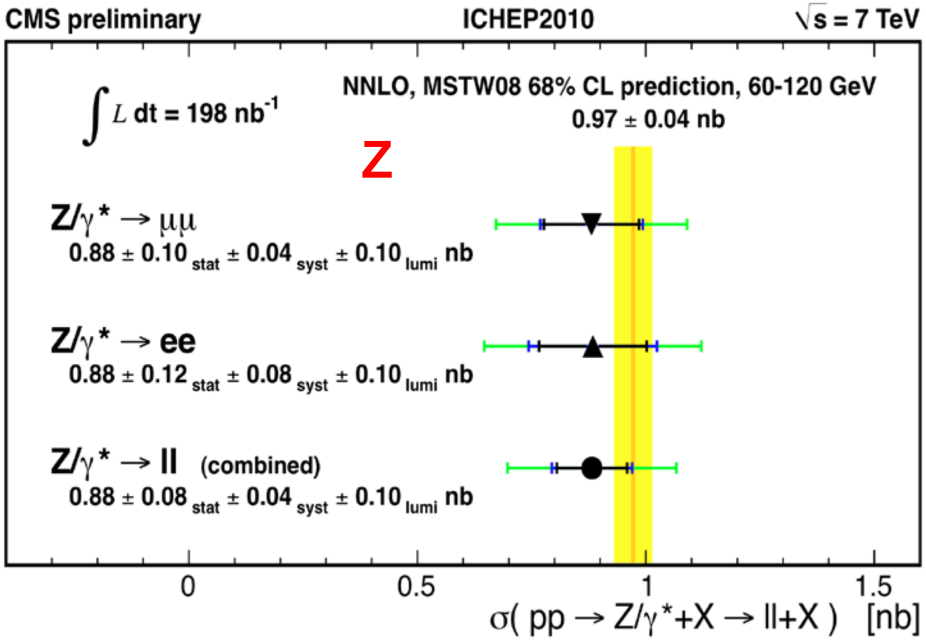
N_Z=77



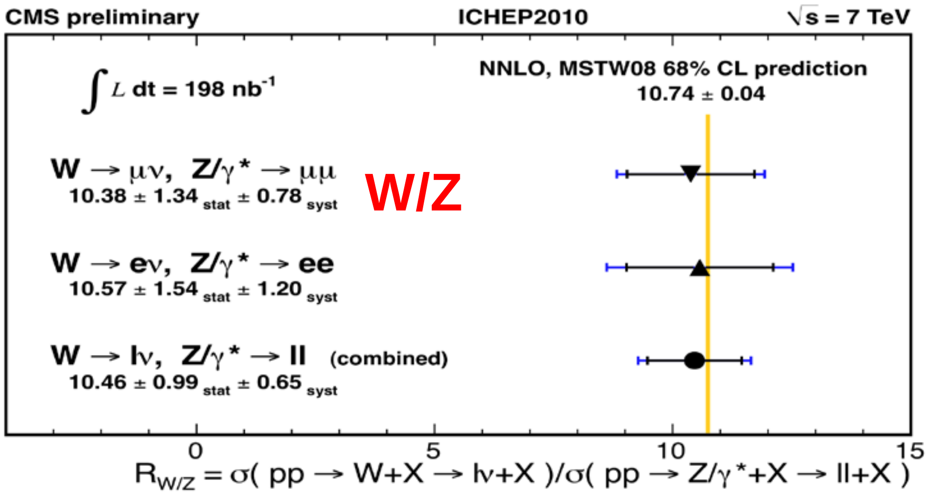
Results



W



Z

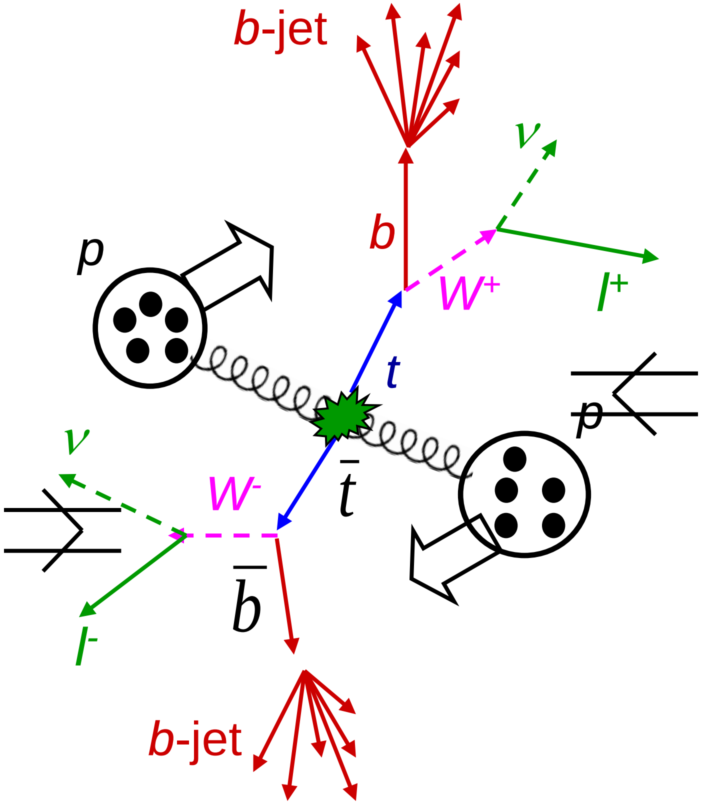


W/Z

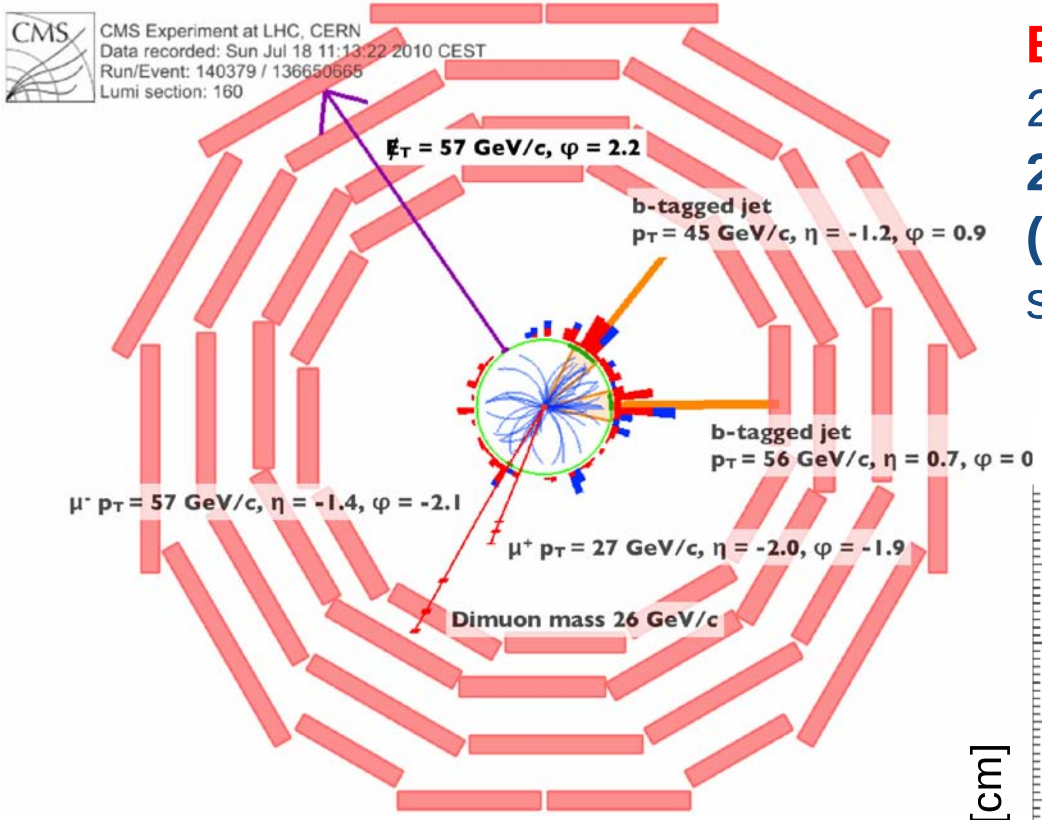
Notice: ~all major components of the measurements (efficiency, background, systematic errors etc) are carefully evaluated using data driven methods.

Dileptonic channels: *ee*, *μμ*, *eμ* + *X*

- Triggers: μ+X (p_T > 9 GeV/c) or e/γ+X (E_T > 15 GeV)
- 2 isolated, prompt, oppositely charged leptons (l = e,μ) of good quality
  - p_T(l) > 20 GeV/c
  - $|\eta_\mu| < 2.5$, $|\eta_e| < 2.4$
  - Relative isolation <15%.
- Missing transverse energy (MET)
  - using calorimeter⊕tracking
  - MET > 30 (20) GeV (in $e\mu$+X)
- *Z*-boson veto:
  - $76 < M_{ee,\mu\mu} < 106$ GeV/c^2
- Count additional jets:
  - anti-k_T jets, R = 0.5
  - using calorimeter⊕tracking info
  - $|\eta| < 2.4$, p_T > 30 GeV/c
  - ≥ 2 jets typical for ttbar



μμ +Jets Candidate Event

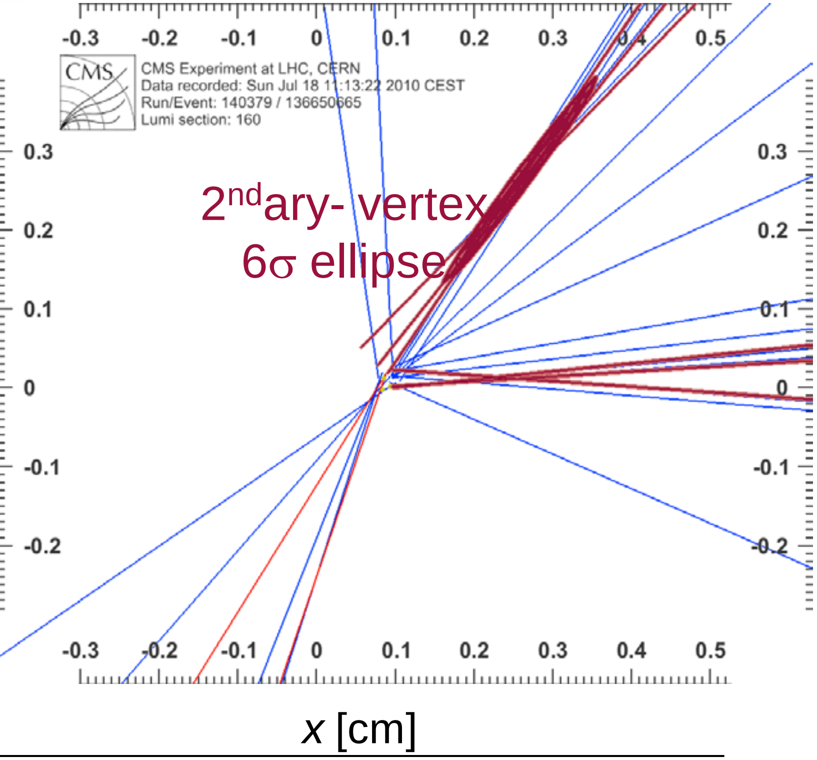


Event passes all cuts of full selecti

2 muons with opposite charge

2 jets, both w/ good/clear *b*-tags (and secondary vertices!)

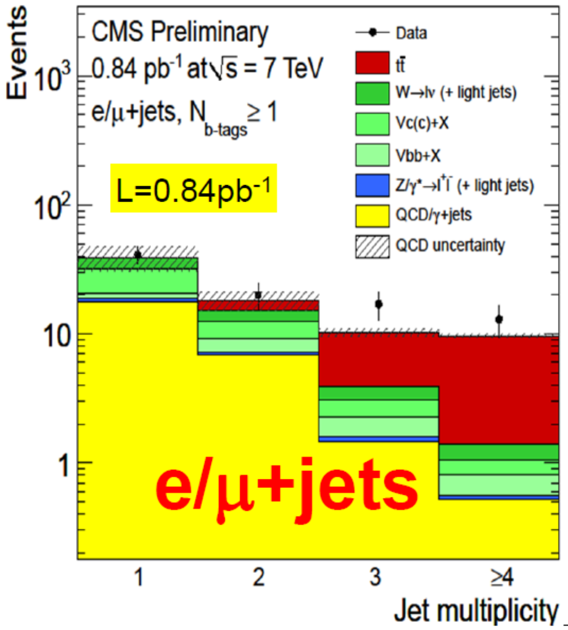
significant MET (>50 GeV)



m(μμ) = 26 GeV/c^2

Preliminarily reconstr. mass is in the range 160–220 GeV/c^2 (consistent with m_{top})

Using the full statistics currently validated (0.84pb^{-1}) and **requiring at least 1 jet b-tagged** (secondary vertex tagger with ≥2 tracks; high efficiency with ~1% fake rate)

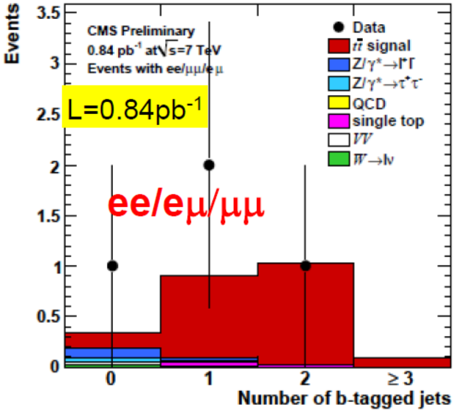


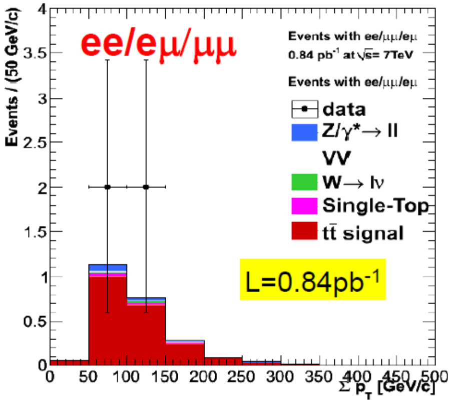
For N(jets)≥3 we count **30 signal candidates over a predicted background of 5.3**

t-tbar events are observed in CMS at a rate consistent with NLO cross section, considering experimental (JES, b-tagging) and theoretical (scale, PDF, HF modelling, …) uncertainties.

Di-lepton+jets top selection

- Full selection applied: Z-bosonVeto, |M(ll)-M(Z)|>15 GeV
- MET >30 (20) GeV in ee,μμ, (eμ); N(jets)≥2





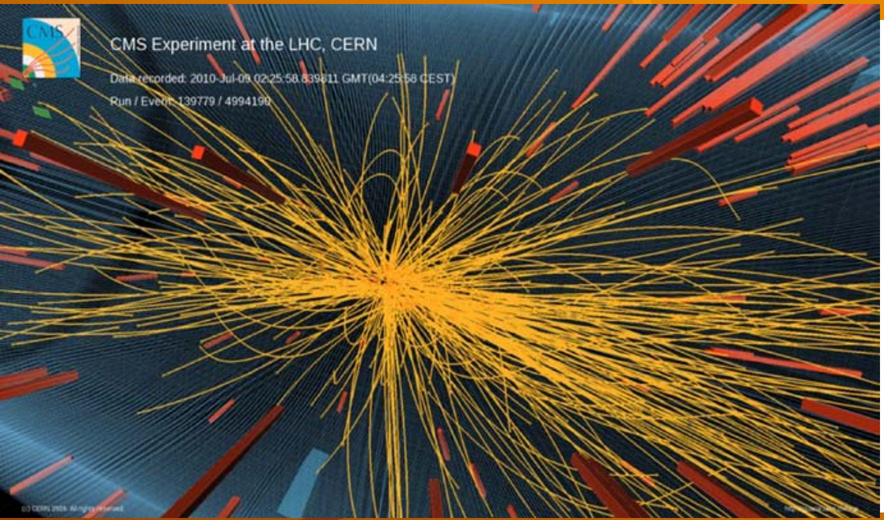
4 ttbar candidates (1eμ, 1ee, 2μμ) over a negligible background.
Top signal at LHC established.
First cross sections will come soon!

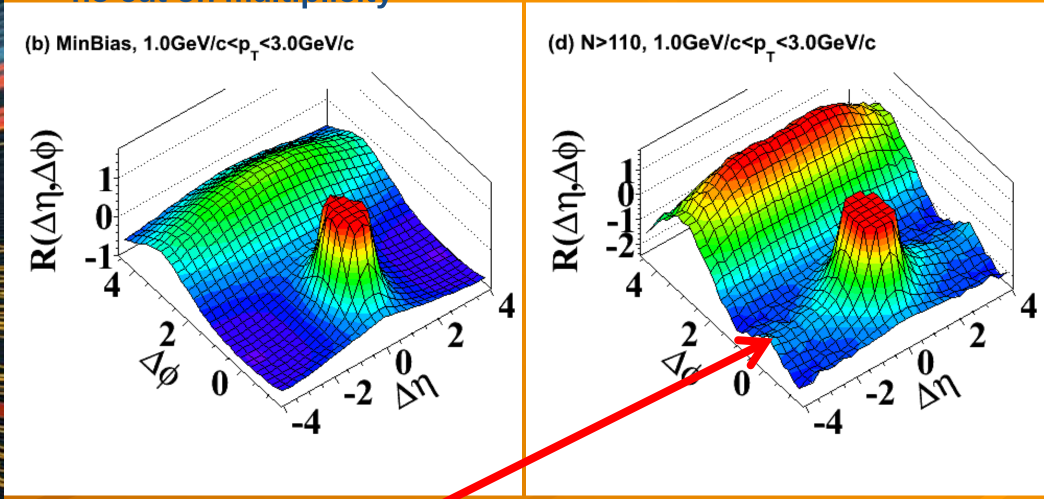
High multiplicity events at 7 TeV

Results for intermediate p_T:1-3GeV/c

Minimum Bias
no cut on multiplicity

High multiplicity data set
and N>110





New "ridge-like" structure extending to large $\Delta\eta$ at $\Delta\phi \sim 0$

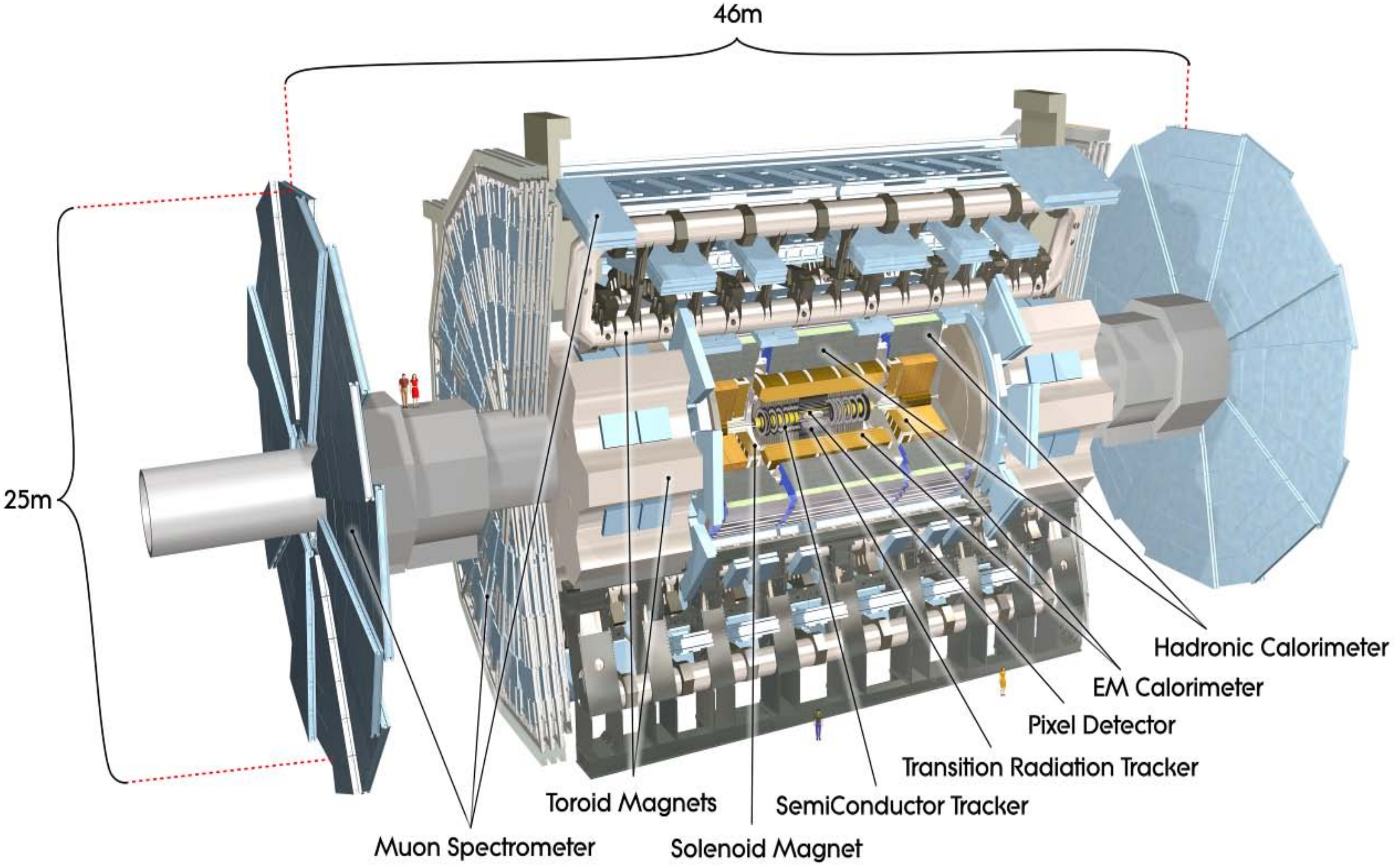
The new feature has appeared in our analysis around middle of July in the hottest days of the preparation for ICHEP.
We have immediately set-up an independent analysis (control group) and organized a full set of tests and cross-checks to kill the effect.
We didn't succeed to kill it.
We have therefore submitted the paper to expose our findings to the scrutiny of the scientific community at large.
Since there are a number of potential explanations, today's presentation is focussed on the experimental evidence in the interest of fostering a broader discussion on the subject.
We are planning many additional studies aimed at producing a better understanding of the dynamics of the effect. The incoming Heavy Ion run will be an additional important test bench.

The new feature is clearly seen for large rapidity differences $2 < |\Delta\eta| < 4.8$ in events with N ~ 90 or higher. The enhancement is most evident in the intermediate p_T range $1 < p_T < 3$ GeV/c.

This is the first observation of such a long-range, near-side feature in two-particle correlation functions in pp or p-pbar collisions.

Experiments at LHC and Bulgarian Participation

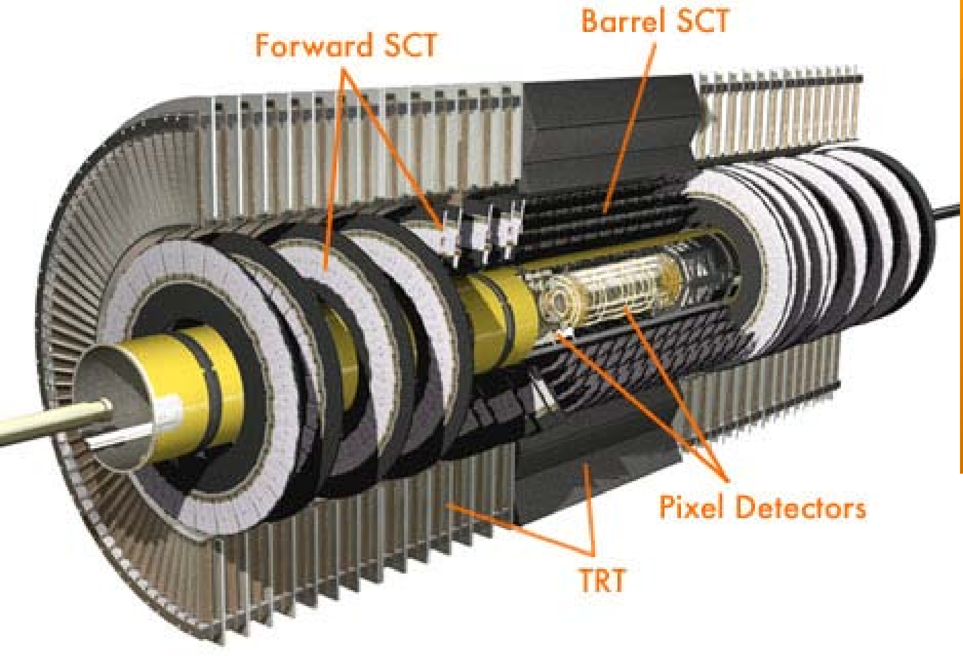
ATLAS



Diameter	*25 m*
Barrel toroid length	*26 m*
End-cap end-wall chamber span	*46 m*
Overall weight	*7000 Tons*

Experiments at LHC and Bulgarian Participation

The Inner Detector

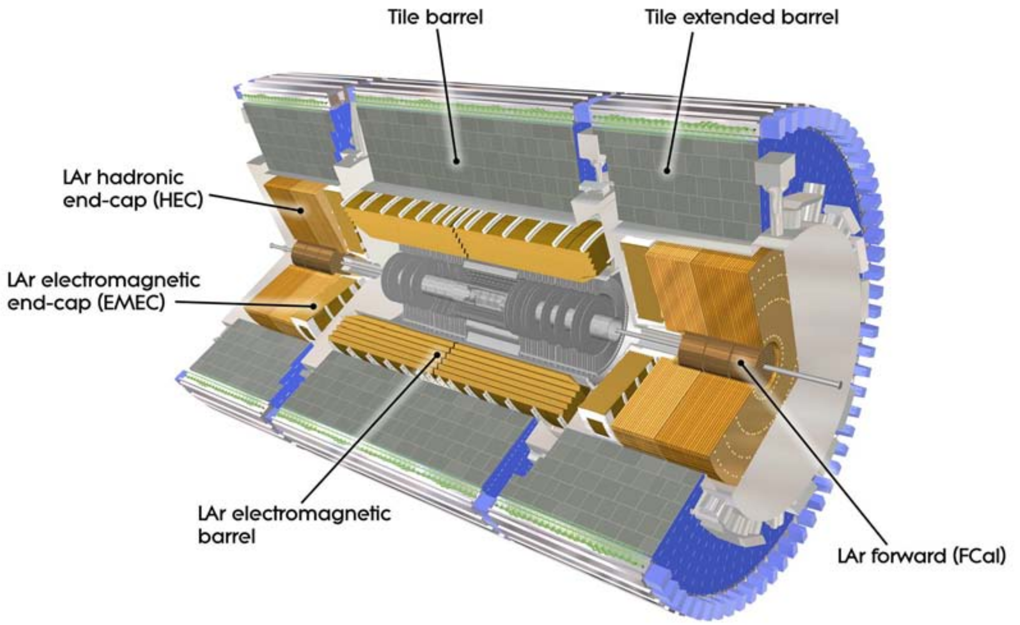


Silicon pixels (**Pixel**): 0.8 10^8 channels
Silicon strips (**SCT**) : 6 10^6 channels
Transition Radiation Tracker (**TRT**) :
straw tubes filled Xe gas, 4 10^5 channels

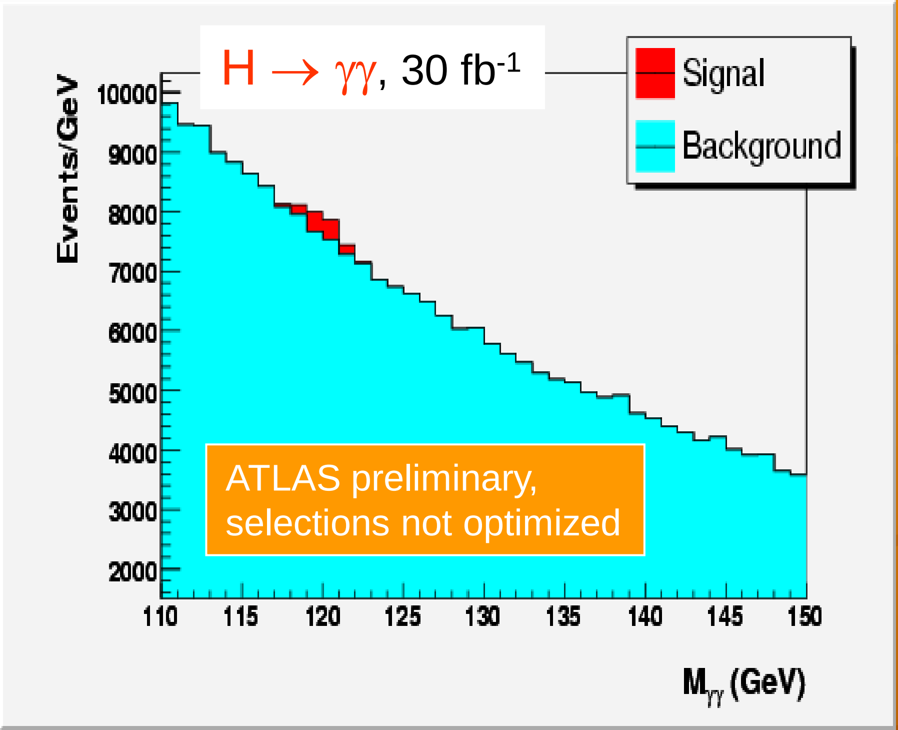
Calorimetry

Electromagnetic Calorimeter
barrel,endcap: Pb-LAr
$\sim 10\% / \sqrt{E}$ energy resolution e/γ
180000 channels: longitudinal segmentation
Hadron Calorimeter
barrel Iron-Tile EC/Fwd Cu/W-LAr (~20000 channels)
$\sigma / E \sim 50\% / \sqrt{E} \oplus 0.03$ pion (10 λ)

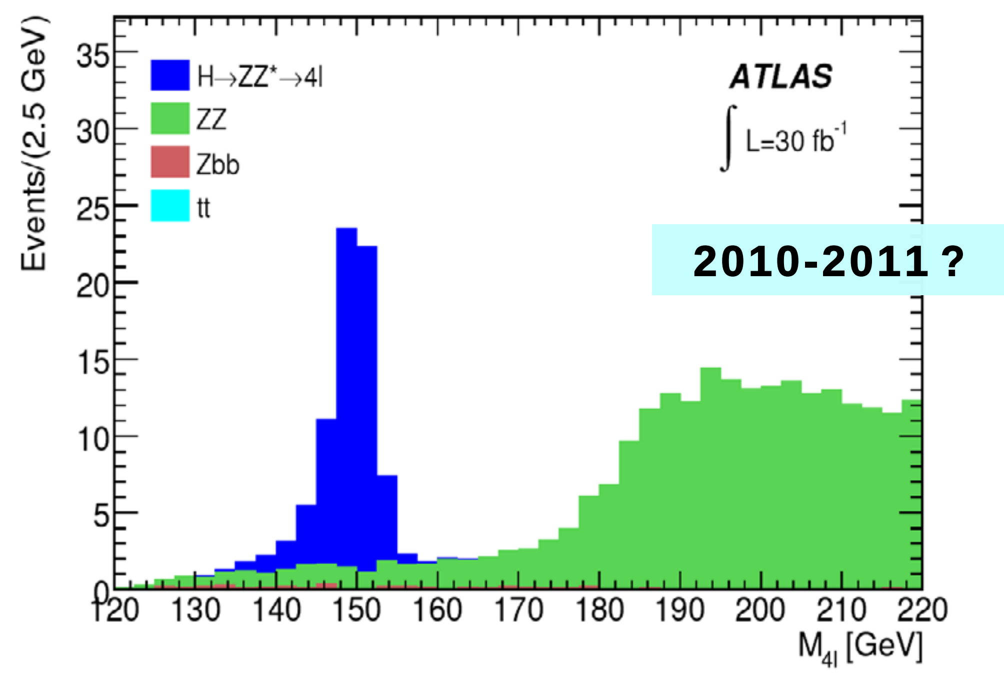
Trigger for **e/γ** , **jets, Missing E_T**



Experiments at LHC and Bulgarian Participation



ATLAS preliminary, selections not optimized



2010-2011 ?

The "golden" channel **H → ZZ* → 4l**

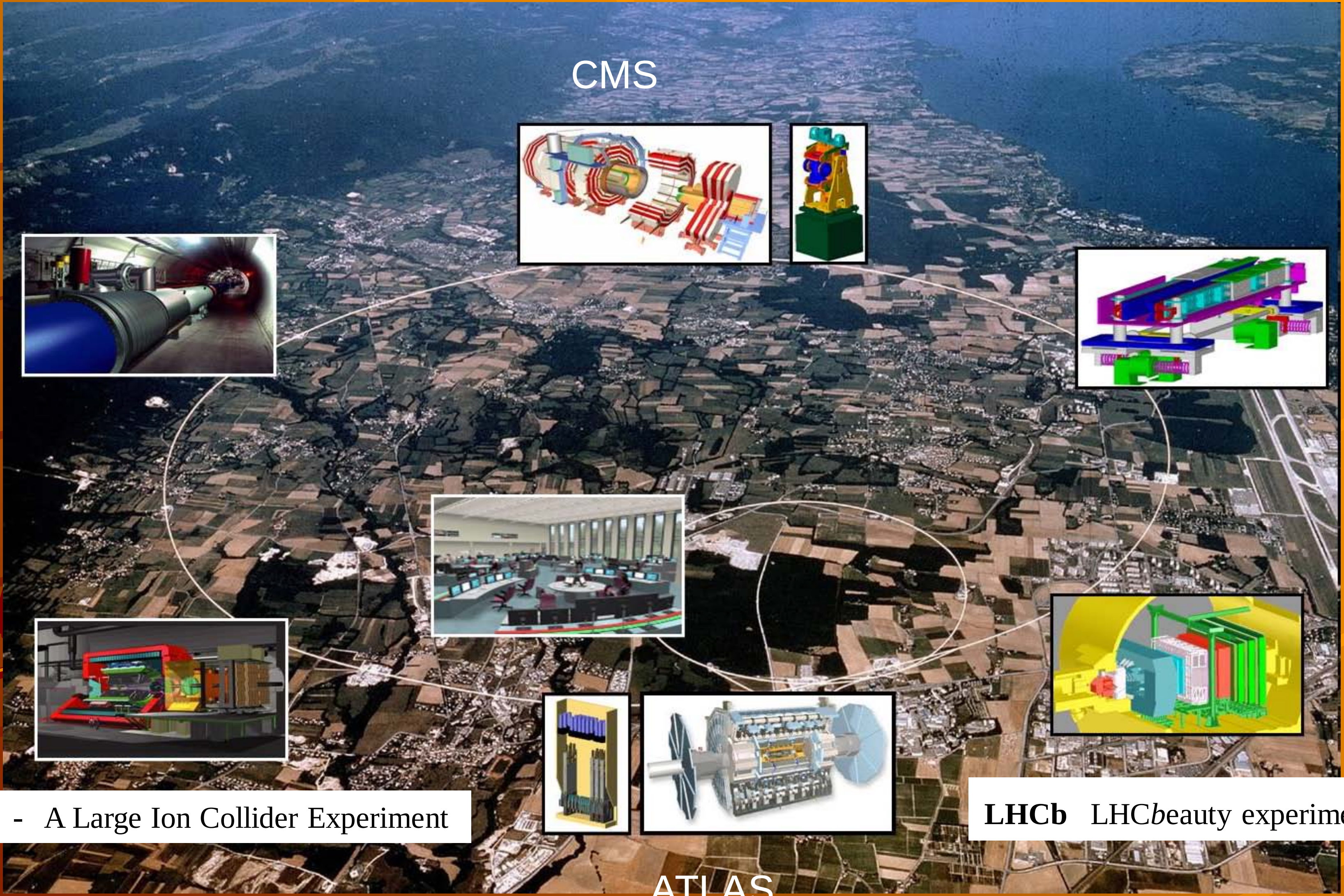
- **Higgs discovery channel in the mass range from 130-500 GeV with 30fb^{-1}**
- **A 150 GeV Higgs could be discovered with 5 fb^{-1}**

H → γγ : to observe a signal peak on top of a huge background need

- energy/mass resolution ~ 1%

- rejection of $\pi^0 \to \gamma\gamma$ faking single γ

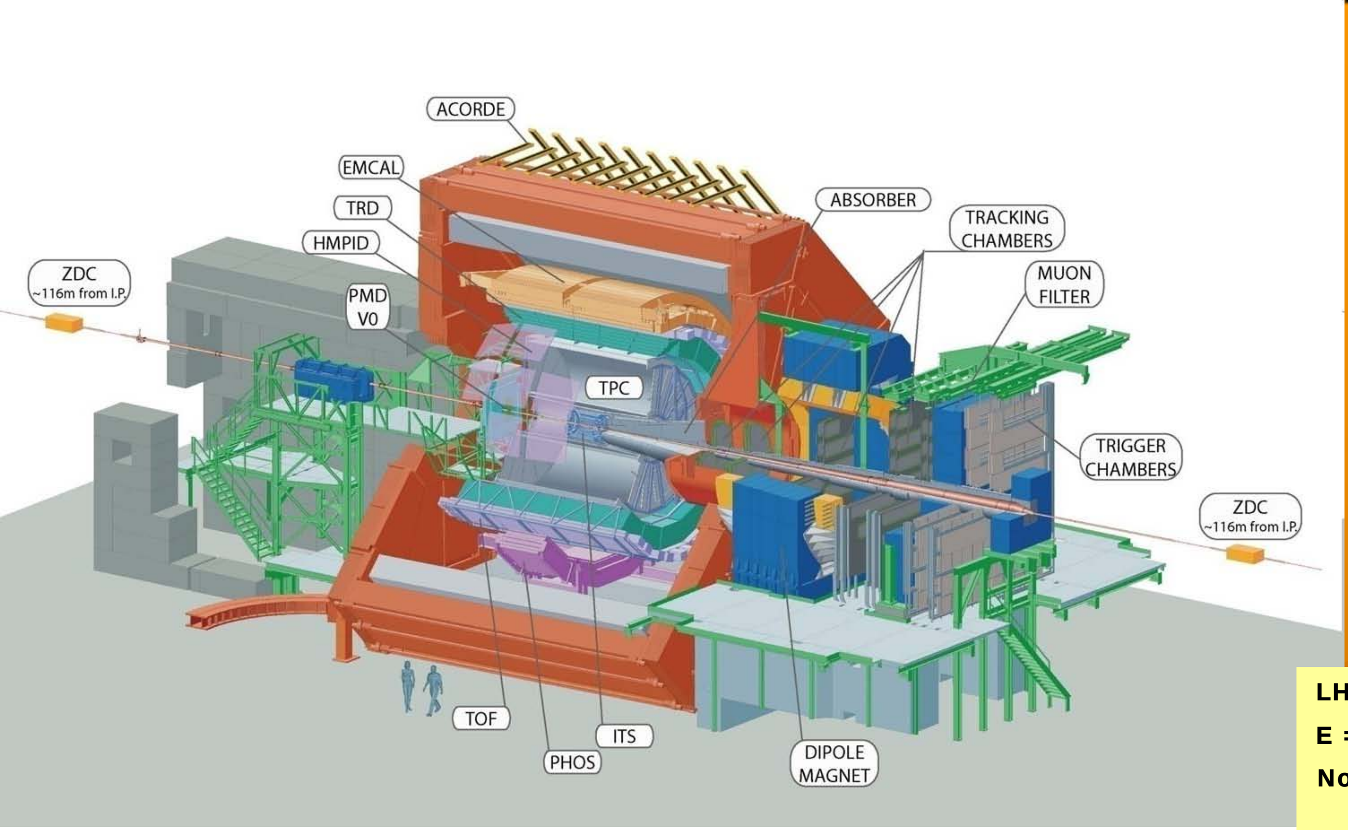
Experiments at LHC and Bulgarian Participation



ALICE - A Large Ion Collider Experiment

LHCb LHC*b*eauty experiment

Experiments at LHC and Bulgarian Participation



The ALICE Experiment is going in search of answers to fundamental questions, using the extraordinary tools provided by the LHC:
What happens to matter when it is heated to 100,000 times the temperature at the centre of the Sun ?
Why do protons and neutrons weigh 100 times more than the quarks they are made of ?
Can the quarks inside the protons and neutrons be freed ?

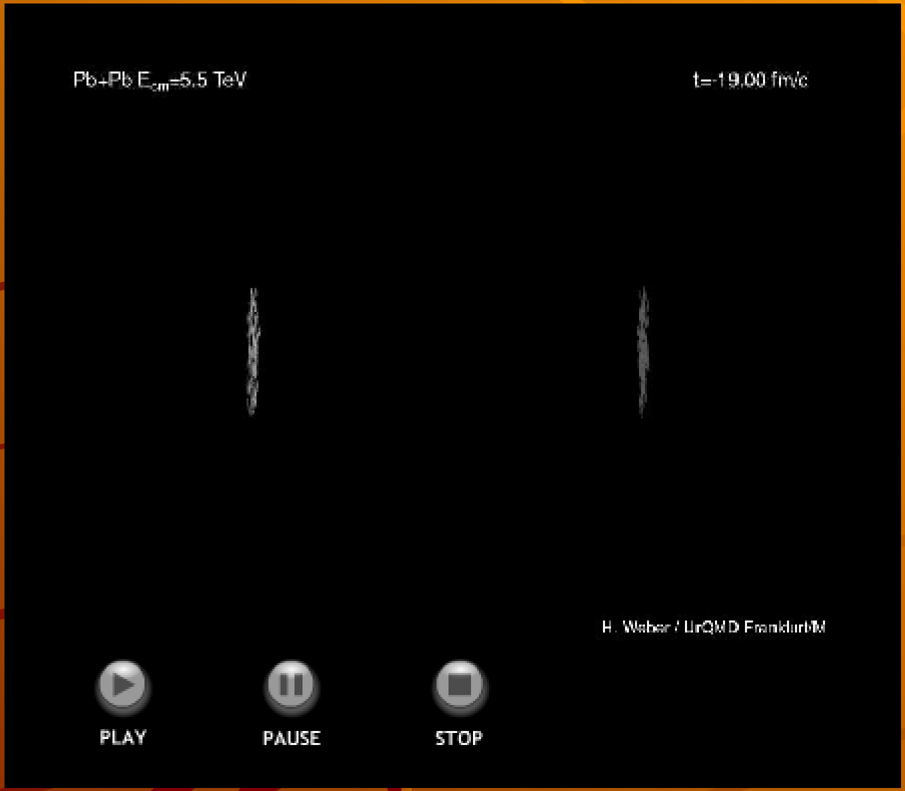
LHC Pb design luminosity L = 10^{27} cm^{-2} s^{-1}

E = 2.96 TeV, No of bunches = 592,

No of particles per bunch = 7×10^{7}

The final ALICE detector configuration[3], consists of a central detector system, covering about two units of rapidity, embedded in a very large solenoid with a field of 0.5T, a one-arm **forward muon spectrometer** and **forward multiplicity and centrality detectors**.
From the inside out, the barrel contains an **Inner Tracking System** (ITS) of six layers of high-resolution silicon pixel (SPD), drift (SDD), and strip (SSD) detectors, a **cylindrical Time-Projection Chamber** (TPC), three particle identification arrays of **Time-of-Flight** (TOF), **Ring Imaging Cherenkov** (HMPID) and Transition Radiation (TRD) detectors, and two **electromagnetic calorimeters** (PHOS and EMCal). All detectors except HMPID, PHOS, and EMCal cover the full azimuth. The TPC and the ITS contribute to the particle identification via the measurement of specific energy loss. An array of scintillators (ACORDE) on top of the L3 magnet is used to trigger on cosmic rays.

Experiments at LHC and Bulgarian Participation



Free Quarks and Gluons

The current theory of the strong interaction (called Quantum Chromo-Dynamics) predicts that at very high temperatures and very high densities, quarks and gluons should no longer be confined inside composite particles. Instead they should exist freely in a new state of matter known as quark-gluon plasma.

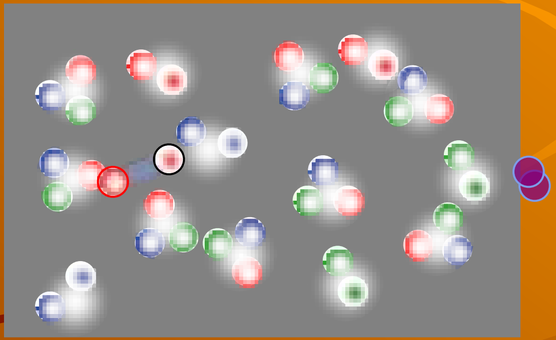
Such a transition should occur when the temperature exceeds a critical value estimated to be around 2 000 billion degrees... about 100 000 times hotter than the core of the Sun! Such temperatures have not existed in Nature since the birth of the Universe. We believe that for a few millionths of a second after the Big Bang the temperature was indeed above the critical value, and the entire Universe was in a quark-gluon plasma state.

The two heavy nuclei approach each other at a speed close to that of light. According to Einstein's theory of relativity, they appear as very thin discs.

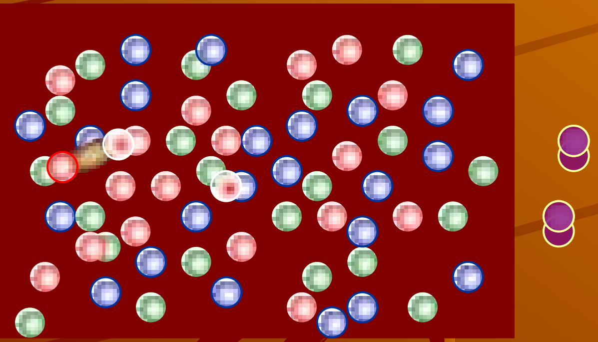
The nuclei collide and the extreme temperature releases the quarks (red, blue and green) and the gluons.

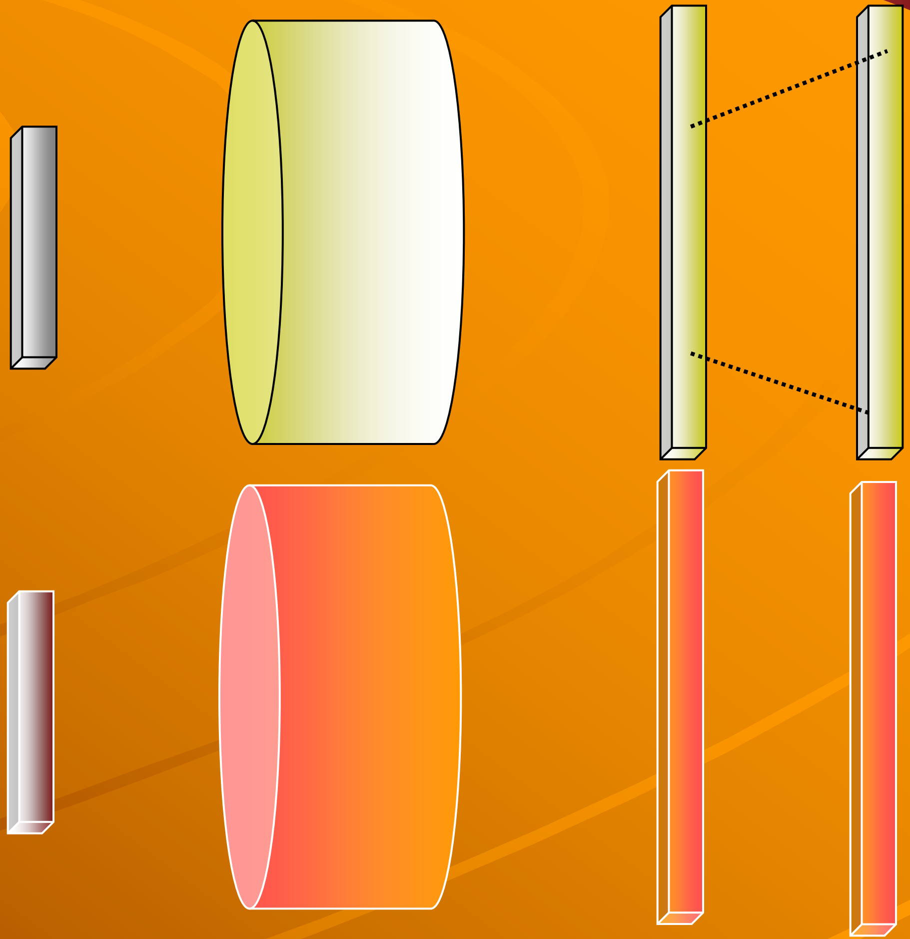
Quarks and gluons collide with each other creating a thermally equilibrated environment: the quark–gluon plasma.

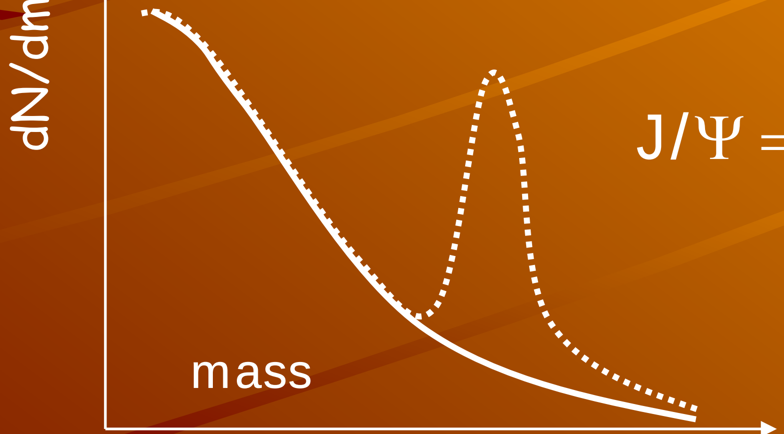
1. Quark Matter



2. QGP







$J/\Psi = c\bar{c}$

Experiments at LHC and Bulgarian Participation

LHCb: dedicated b-physics experiment at LHC that will search for NP beyond the SM through the study of very rare decays of b-flavoured (and c) hadrons and precision measurements of CP-violating observables

Enormous progress in recent years from the B factories and Tevatron, far beyond expectations.

Clear demonstration of the SM CKM mechanism as dominant source of CP violation.

Advantages of beauty physics at hadron colliders:

High value of beauty cross section expected at 14 TeV: $\sigma_{bb} \sim 0.5$ mb

(e+e- cross section at Y(4s) is 1 nb)$\sigma_{cc} \sim 3.6$ mb

Access to all b-hadrons: $B^{\pm}$, B^0, B_s, B_c, b baryons

In particular can study the B_s (bs) system, not studied at the B factories, but measured by CDF/D0.

The challenges:

Rate of background events: $\sigma_{inel} \sim 80$ mb

→Trigger is essential!

→Multiplicity of tracks (~30 tracks per rapidity unit)

Baryogenesis

Big Bang (~ 14 billion years ago) → matter and antimatter equally produced; followed by annihilation → nbaryon/ng ~ 10^{-10}

Why didn't all the matter annihilate (luckily for us)?

No evidence found for an "antimatter world" elsewhere in the Universe

One of the requirements to produce an asymmetric final state (our world) from a symmetric matter/antimatter initial state (the Big Bang) is that CP symmetry must be violated [Sakharov, 1967]

CP is violated in the Standard Model, through the weak mixing of quarks. For CP violation to occur there must be at least 3 generations of quarks.

So problem of baryogenesis may be connected to why three generations exist, even though all normal matter is made up from the first (u, d, e, νe)

However, the CP violation in the SM is not sufficient for baryogenesis

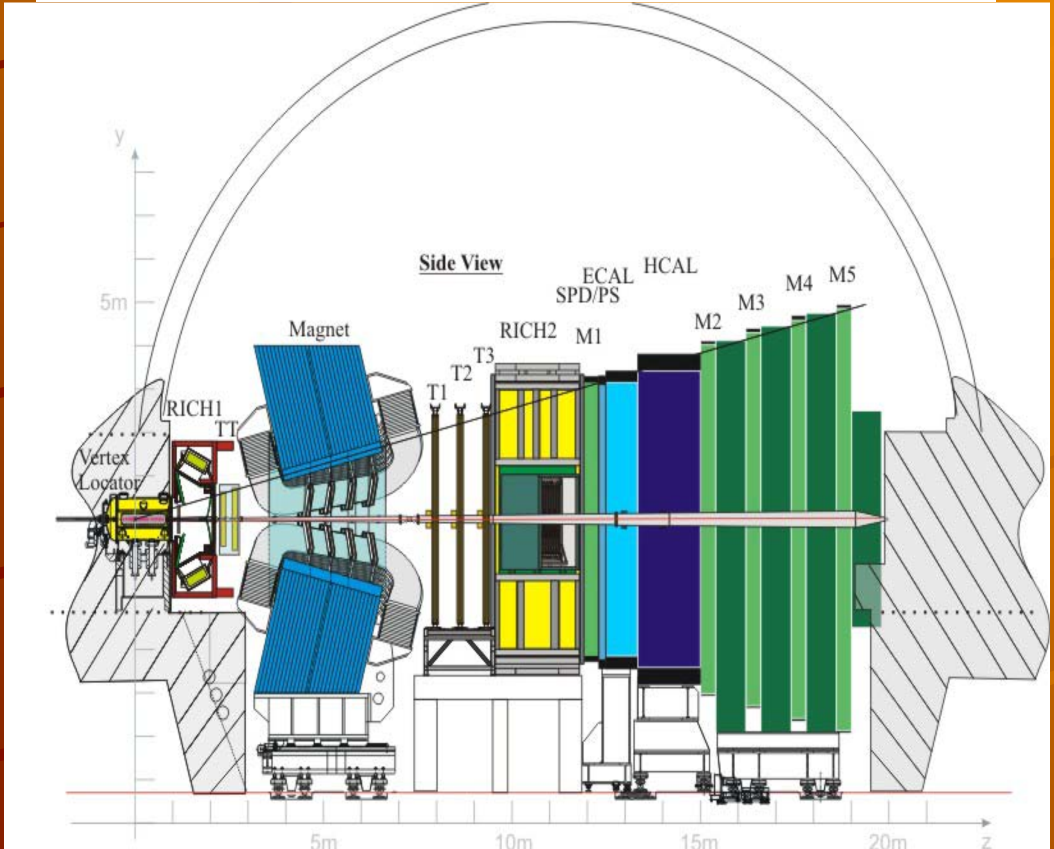
Other sources of CP violation expected → good field to search for new physics

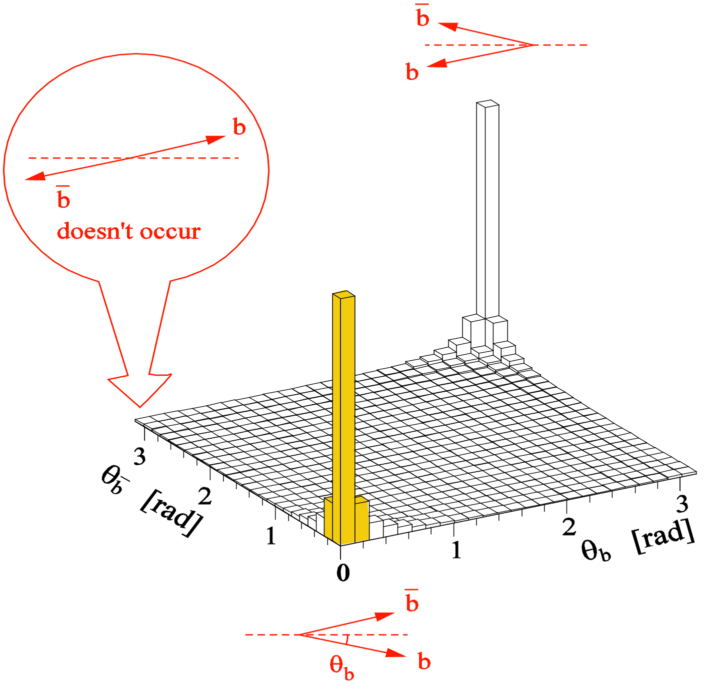
LHCb

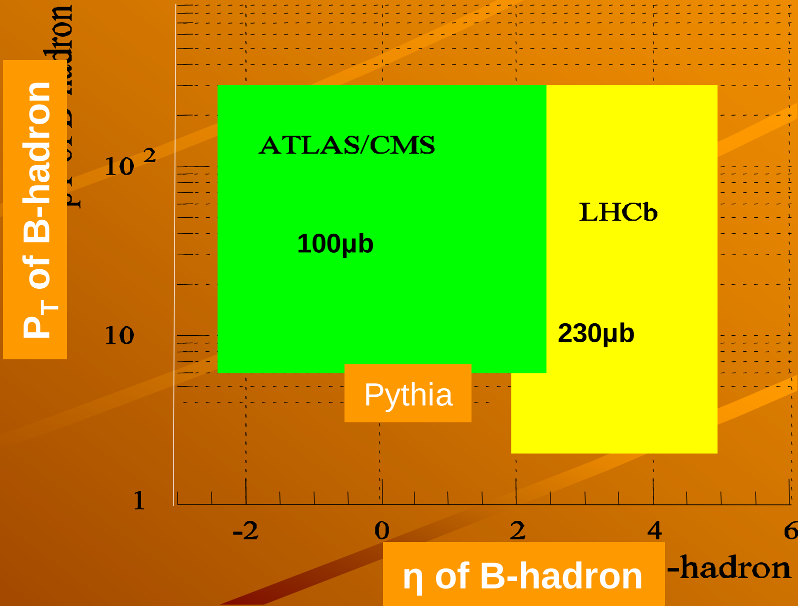
Detector designed to maximize b acceptance (against cosθ)

Forward spectrometer 1.9<η<4.9

- b-hadrons produced at low angle
- Single arm OK as b quarks are produced in same fwd or backward cone







vertices and momenta reconstruction

effective particle identification (π, Κ, μ, e, γ)

triggers

Experiments at LHC and Bulgarian Participation

Bulgaria – CERN membership from 11.06.1999

Participation in CMS at LHC

Institute for Nuclear Research
and Nuclear Energy

Bulgarian academy of Science

University of Sofia
Faculty of Physics

Central Laboratory of Mechatronics
and Instrumentation

Bulgarian academy of Science

Experiments at LHC and Bulgarian Participation

CMS ECAl – assembling and testing supemodules – INRNE, CLMI

Full size prepoduction prototype of HCAL - INRNE

The Compact Muon Solenoid Experiment

CMS Bulletin

CERN, CH-1211 GENEVA 23, Switzerland

Date of publication: 07-12-98
CMS internal information server: http://cmsdoc.cern.ch/cms.html

Number 98-04
7 December 1998

Full Size Pre-production Prototypes of HCAL

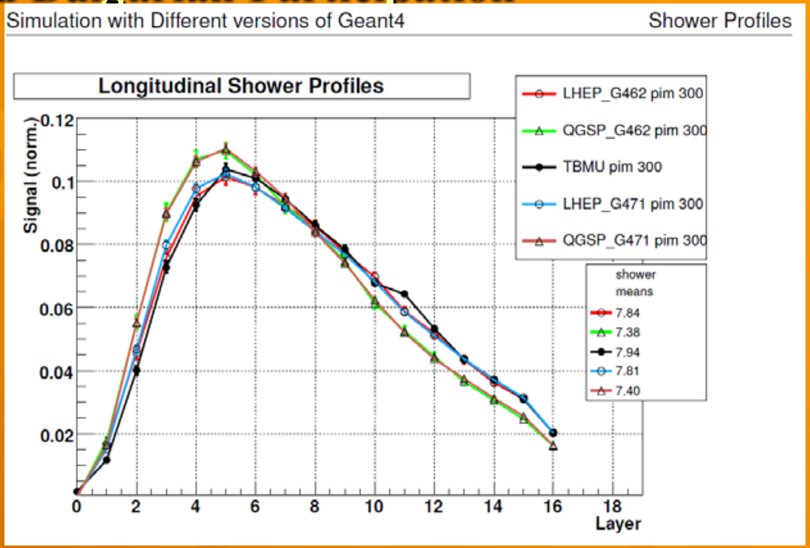
Pre-production prototypes of a barrel wedge and endcap sector have been manufactured in industry. The barrel wedge was manufactured by Felguera in Spain using brass plates procured in Bulgaria under the responsibility of HCAL-US groups. The endcap sector was manufactured by MZOR in Belarus using brass plates procured in Bulgaria and St. Petersburg under the responsibility of HCAL-RDMS groups. The scintillators trays have been installed in the prototypes and the HCAL system will be tested in 1999.

HV supply for CSC and HCAL for CMS – INRNE, Sofia

Experiments at LHC and Bulgarian Participation

RPC assembled at INRNE, Sofia, transported and installed in CMS – INRNE, Sofia University

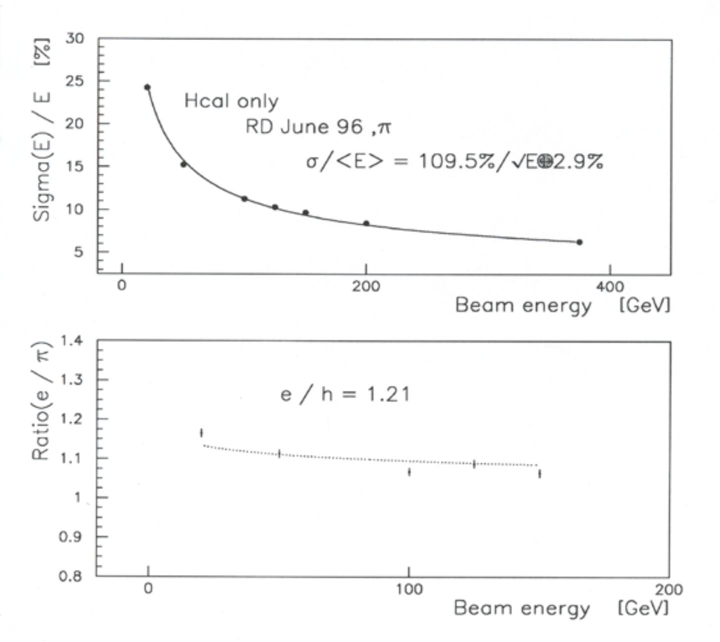
Experiments at LHC and Bulgarian Participation

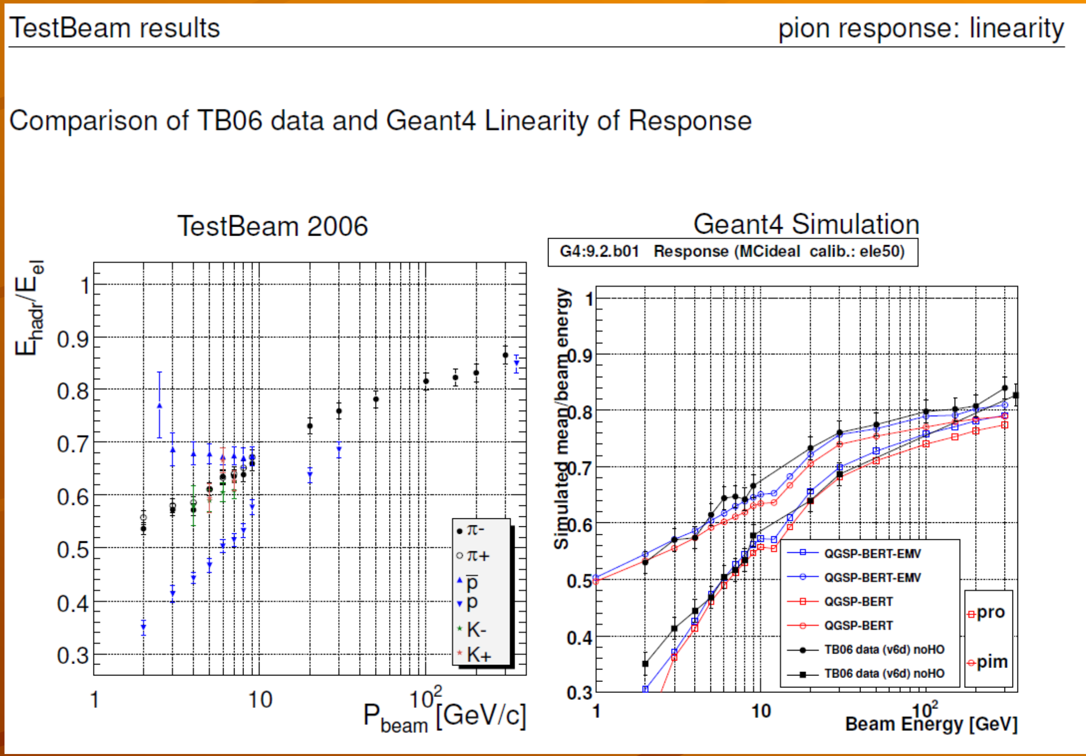


Simulation with Different versions of Geant4

Shower Profiles

CMS HCAL design, calibration and prototype testing – INRNE, Sofia University



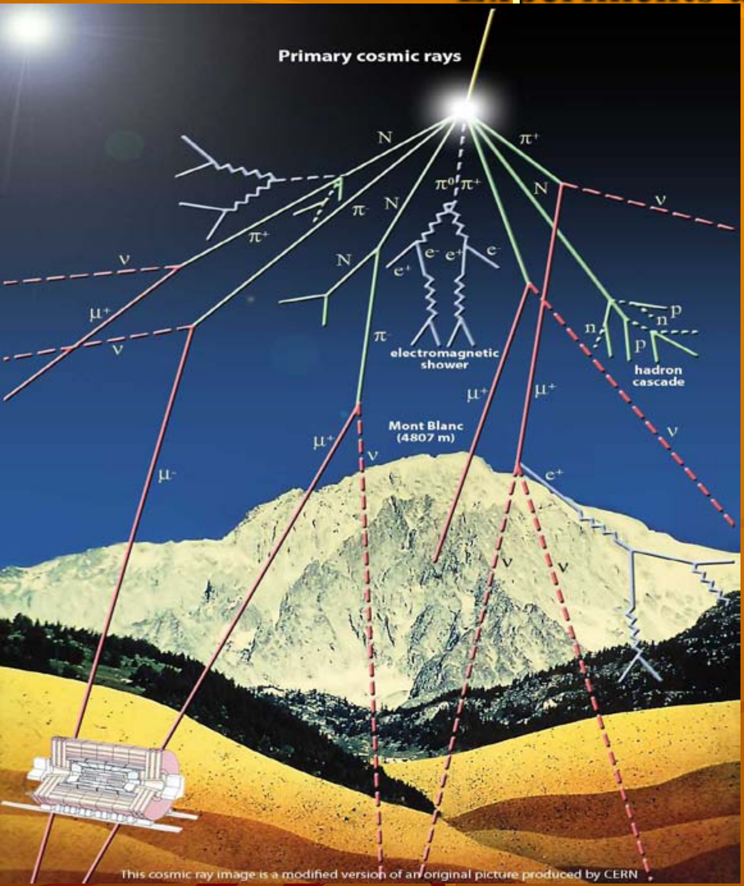


TestBeam results

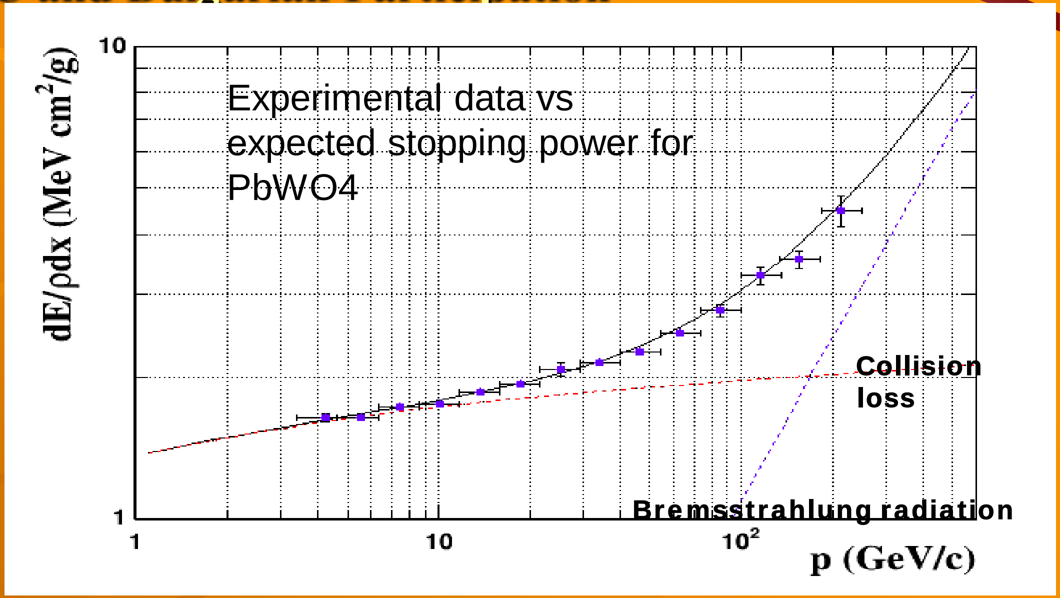
pion response: linearity

Comparison of TB06 data and Geant4 Linearity of Response

Experiments at LHC and Bulgarian Participation



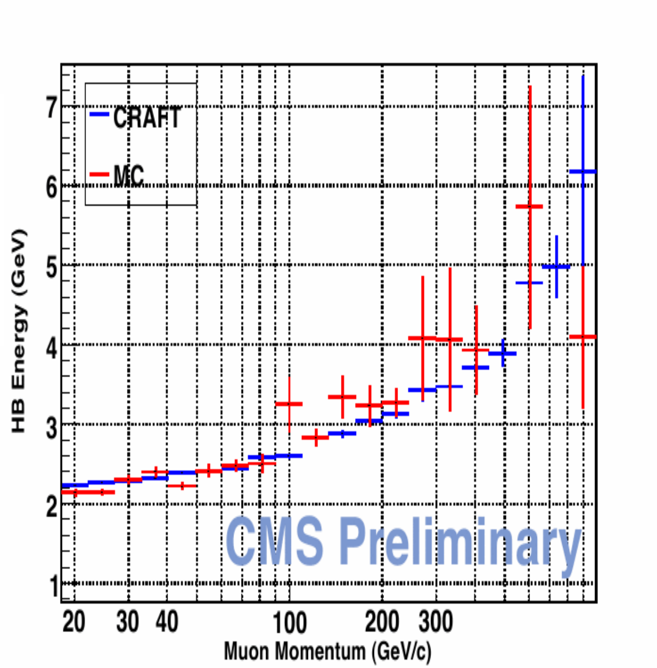
This cosmic ray image is a modified version of an original picture produced by CERN

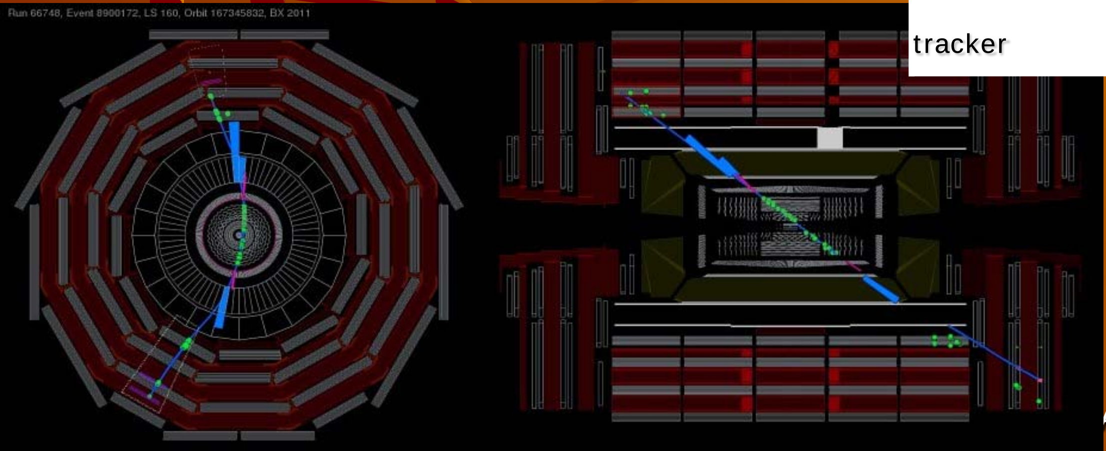


Experimental data vs expected stopping power for PbWO4

Substantial Rates for E_μ>10 GeV

$N_{HIT}\geq 1$	Rate[Hz]
CMS tot	~1800
Muon only	~1800
calorimeter	~ 700
tracker	~ 60

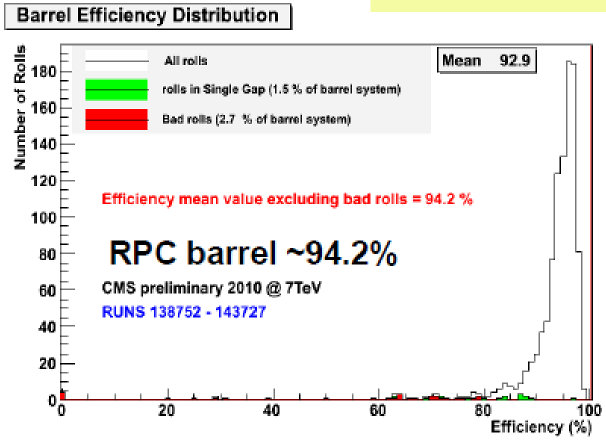


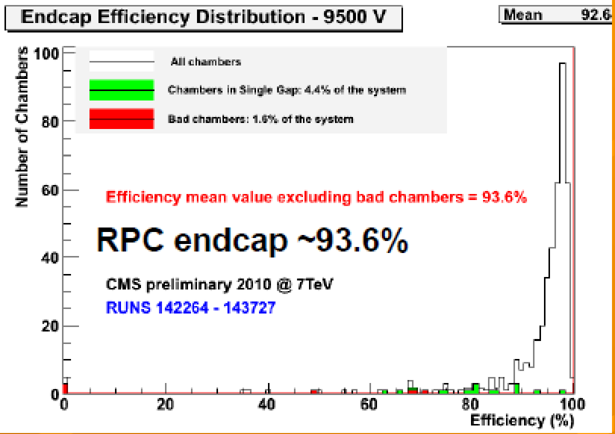

Run 66748, Event 8900172, LS 160, Orbit 167345832, BX 2011

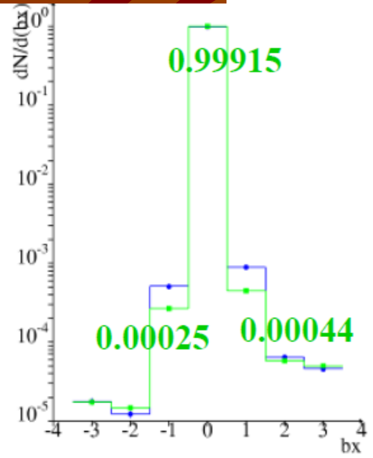
RPC

- RPC efficiency and cluster size are estimated from data using DT/CSC segment extrapolations or reconstructed muons
  - Data collected are now enough to produce efficiency table chamber-by-chamber and new condition DB tags should be available soon
  - Cluster size is at the moment modeled as a function of the local impact point on the strip. Present data will be used to model it as function of slope as well
- Dead and masked strips are monitored run by run but still not in DB. All the software infrastructure in ready to handle them.

RPC – high rechit efficiency (~94%) for all chambers in both barrel and endcap







RPC hit-time relative to L1A

RPC hit synchronization

- excellent time synchronization achieved (>99% of RB+RE has ΔBX=0)
- Some fine tuning still possible (~1-2 ns) for a fraction of the LB at BX=0

Experiments at LHC and Bulgarian Participation

With the Large Hadron Collider
at the Terascale now entering the ’Dark Universe’

Key Questions of Particle Physics

Origin of mass/matter

Origin of electroweak symmetry breaking

Unification of forces

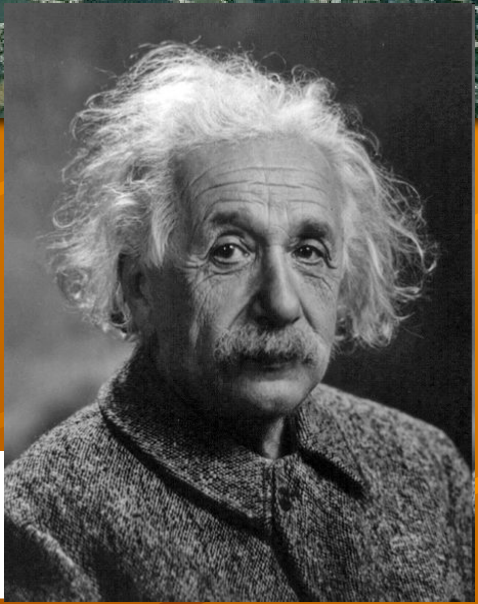
Fundamental symmetry of forces and matter

Unification of quantum physics and general relativity

Number of space/time dimensions

What is dark matter

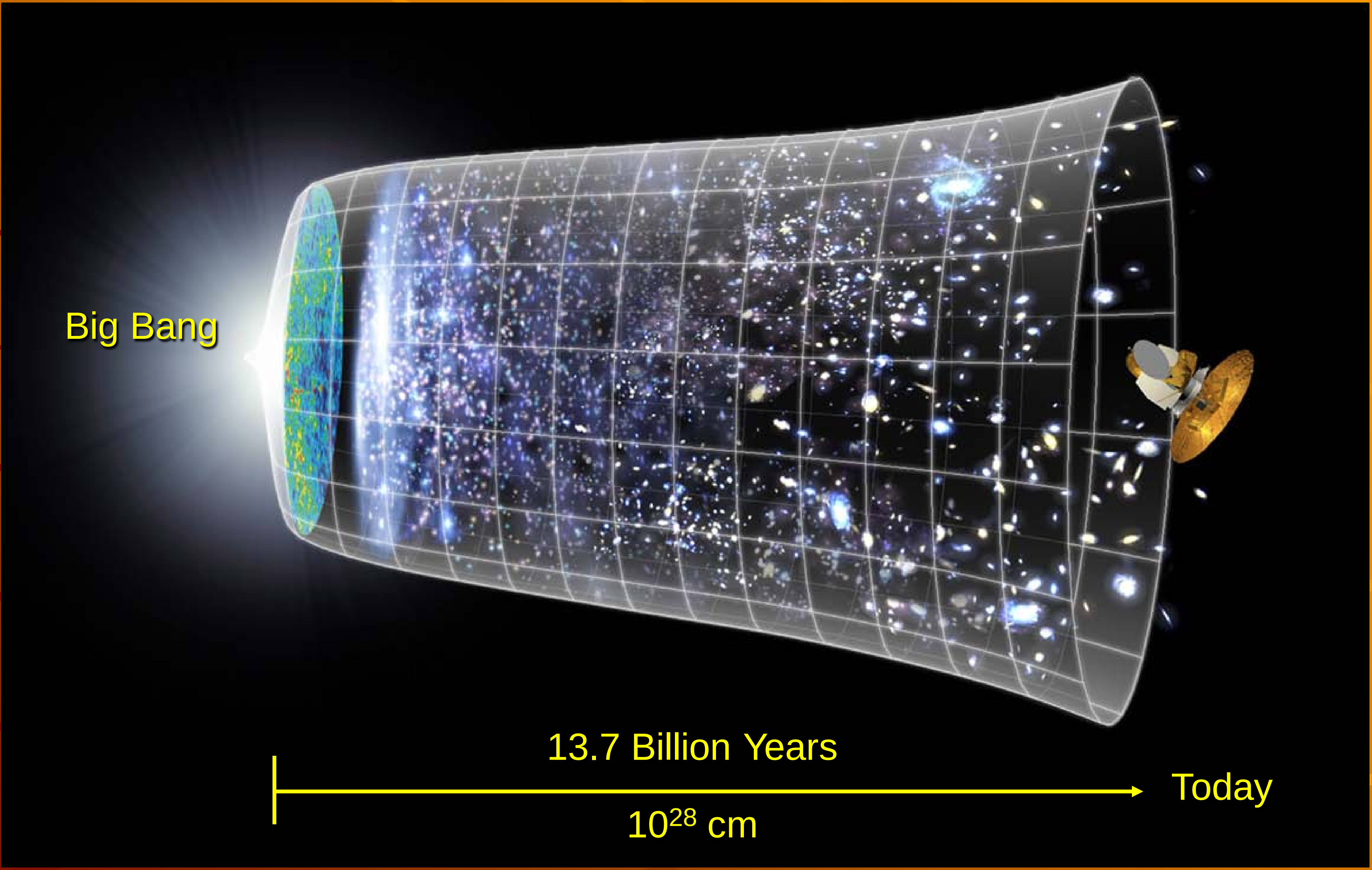
What is dark energy



The most incomprehensible thing about the world is that it is at all comprehensible.

Backup slides

Today's Universe: very old and very cold



Big Bang

13.7 Billion Years

10^{28} cm

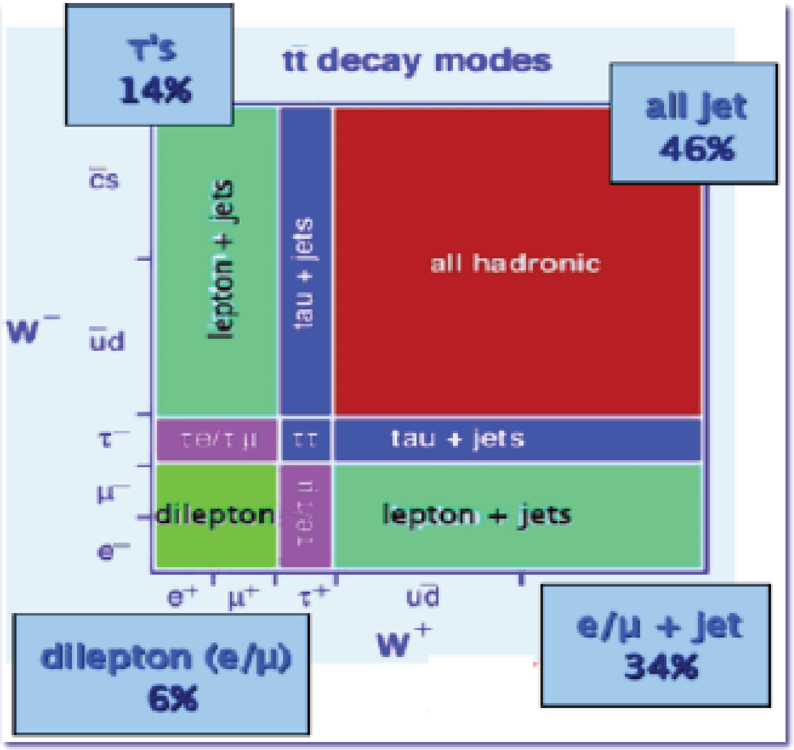
Today

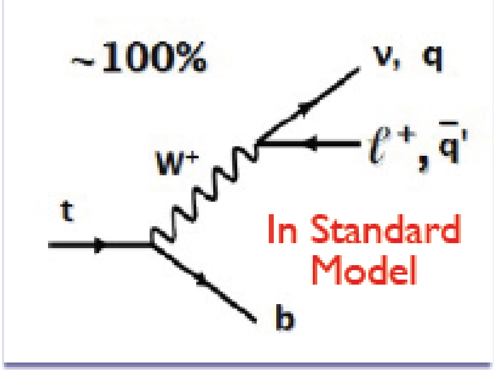
Top quark production and decay

- Main mechanism: pair production via strong interaction
  - Tevatron: $q\bar{q}$ (85%), σ=7.46 pb
  - LHC@7 TeV: gg (~90%), σ=160.8 pb
  - theoretical uncertainty ~9%

NNLO$_{\mathrm{approx}}$ for m_t = 172.5 GeV

PRD 80, 054009 (2009)





In Standard Model

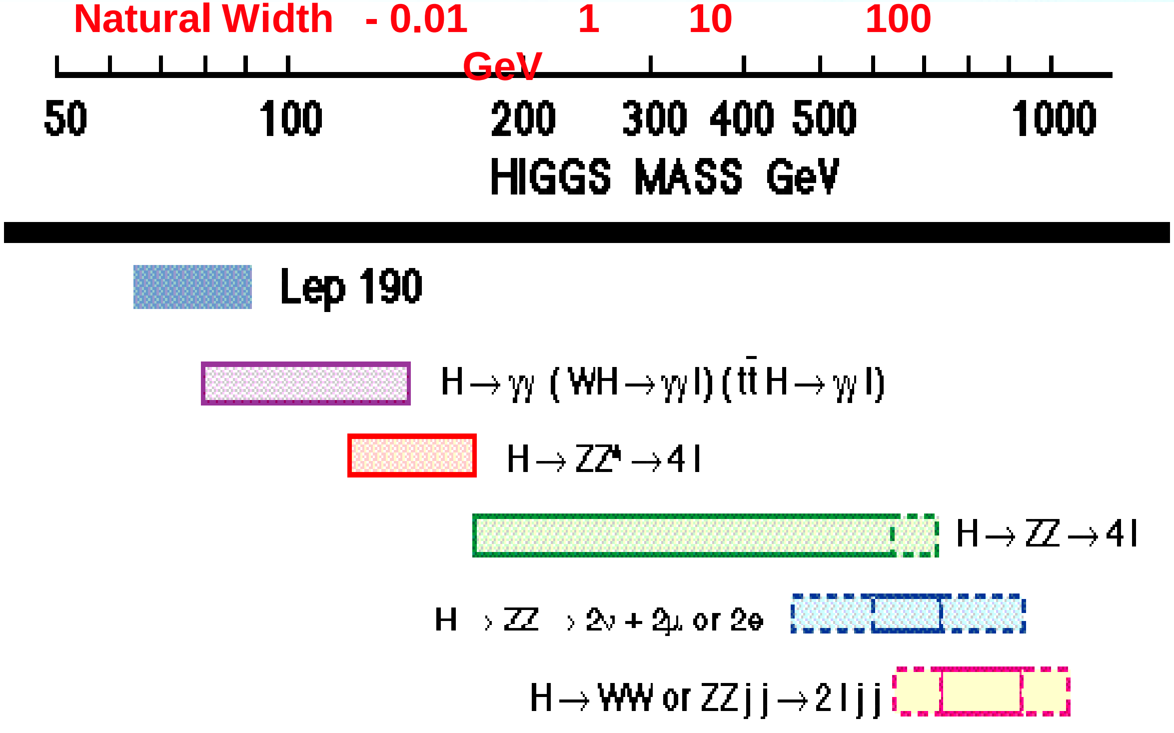
W decay mode defines top pair final state

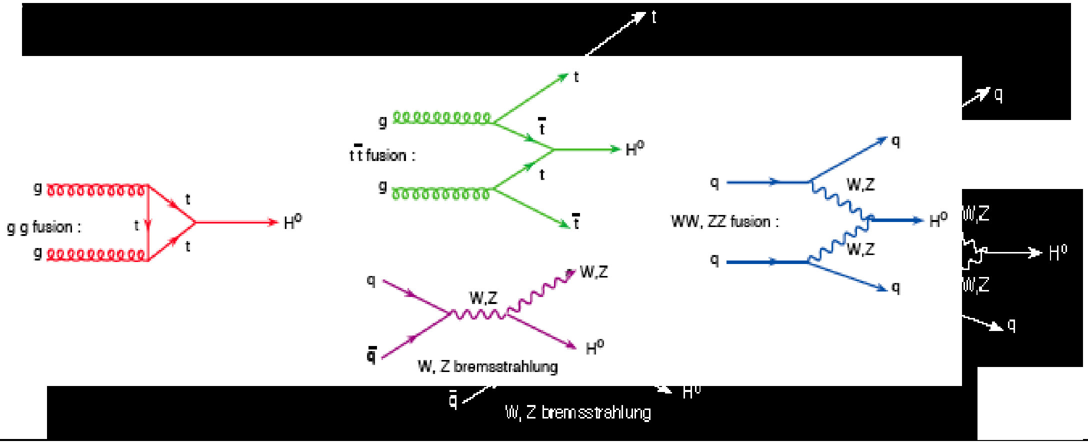
>5 fb^{-1} of data, ~3,000 b-tagged top candidates per Tevatron experiment

Experiments at LHC and Bulgarian Participation

me Electron mass 511 keV
mμ Muon mass 105.7 MeV
mτ Tau mass 1.78 GeV
mu Up quark mass 1.9 MeV
md Down quark mass 4.4 MeV
ms Strange quark mass 87 MeV
mc Charm quark mass 1.32 GeV
mb Bottom quark mass 4.24 GeV
mt Top quark mass 172.7 GeV
θ12 CKM 12-mixing angle 13.1°
θ23 CKM 23-mixing angle 2.4°
θ13 CKM 13-mixing angle 0.2°
δ CKM CP-violating Phase 0.995
g1 U(1) gauge coupling 0.357
g2 SU(2) gauge coupling 0.652
g3 SU(3) gauge coupling 1.221
θQCD QCD vacuum angle ~0
μHiggs quadratic coupling Unknown
λ Higgs self-coupling strength Unknown

The benchmark reactions





Experiments at LHC and Bulgarian Participation

Event rate = LσBr

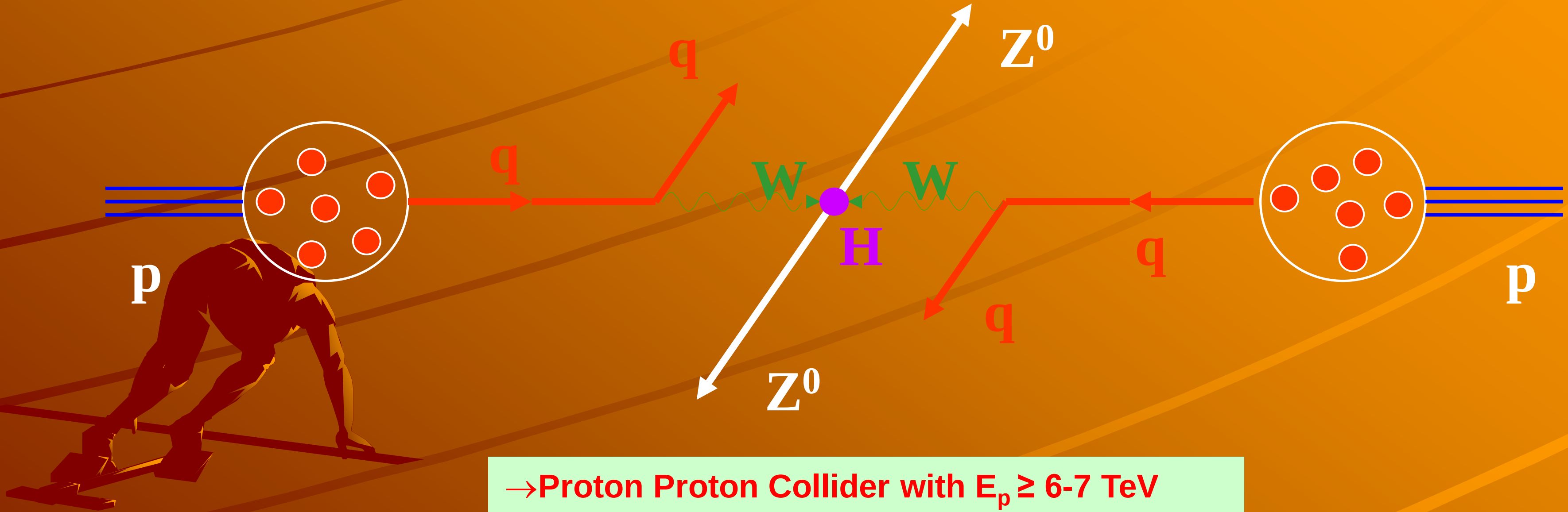
e.g. H ~ 0.8 TeV; H → ZZ → 4l

Events/year ≥ 10 ⇒ $(10/10^7) \times 1/(10^{-37}\ 10^{-3})$ =

L~10^{34}cm^{-2} s^{-1}

M_H ~ 1000 GeV

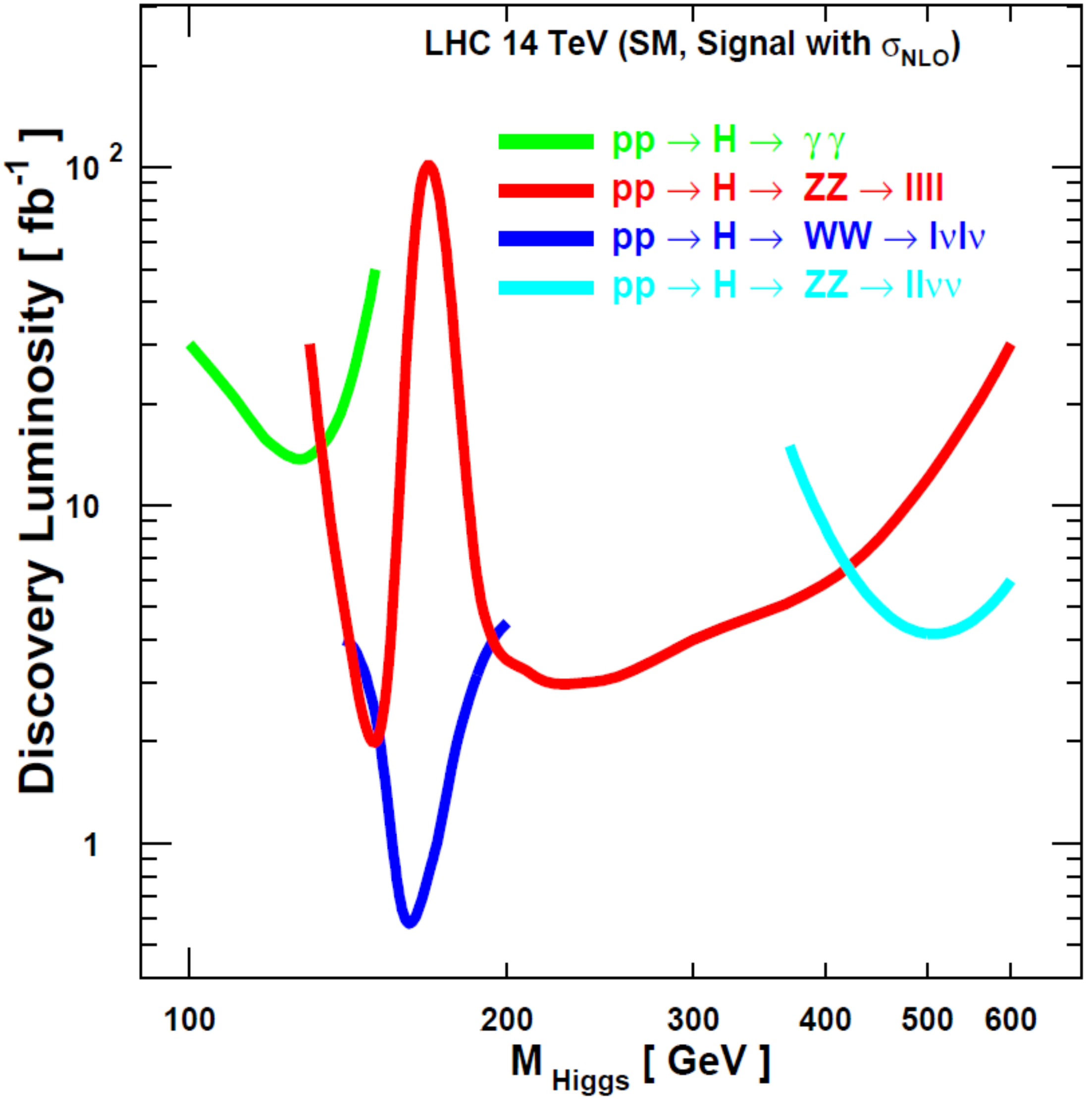
E_W ≥ 500 GeV; E_q ≥ 1000 GeV (1 TeV); **E_p ≥ 6000 GeV (6 TeV)**



→Proton Proton Collider with E_p ≥ 6-7 TeV

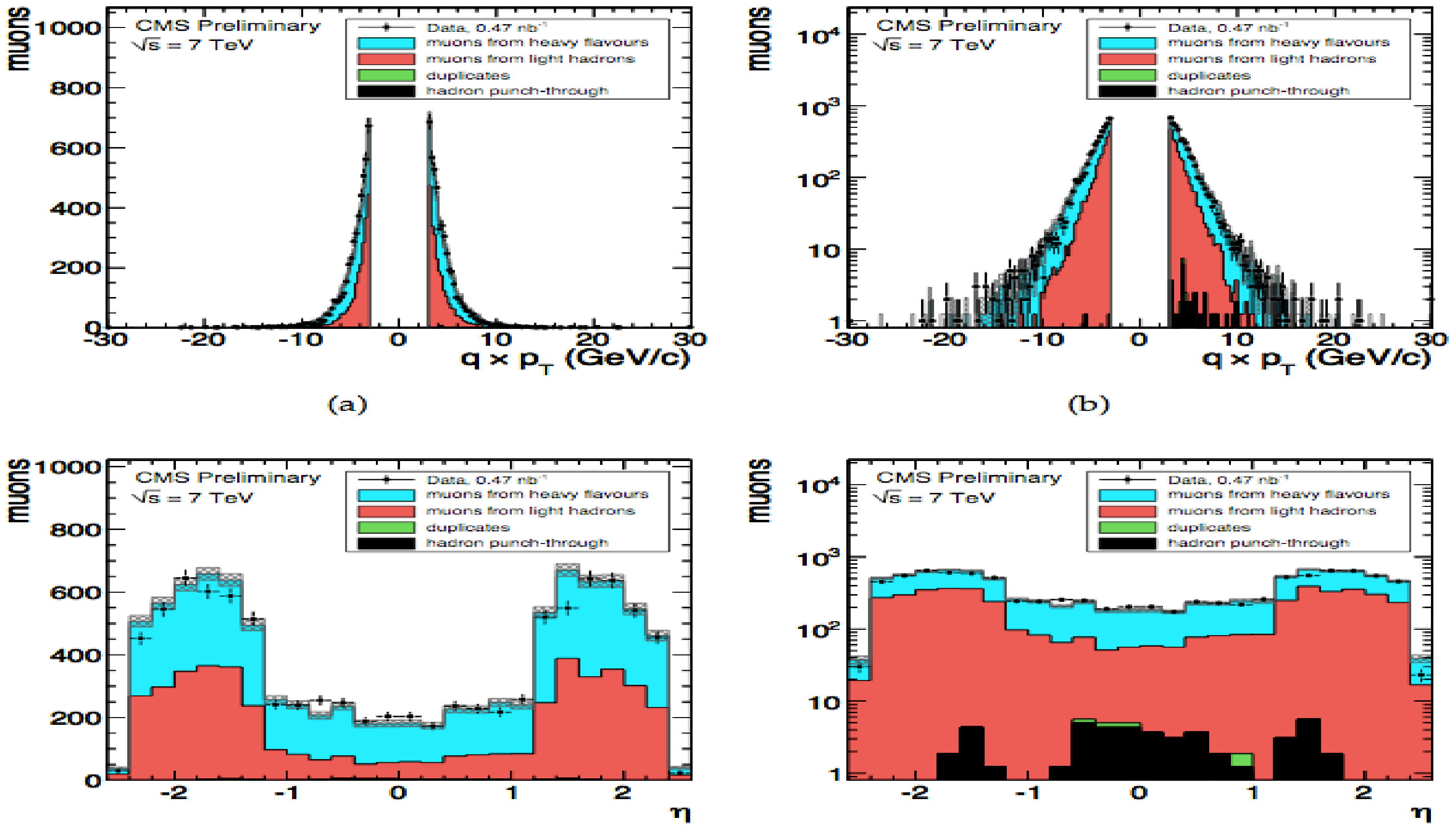
→L ~ 10^{33}-10^{34}cm^{-2} s^{-1}

5 σ Higgs Signals (statistical errors only)



Muons

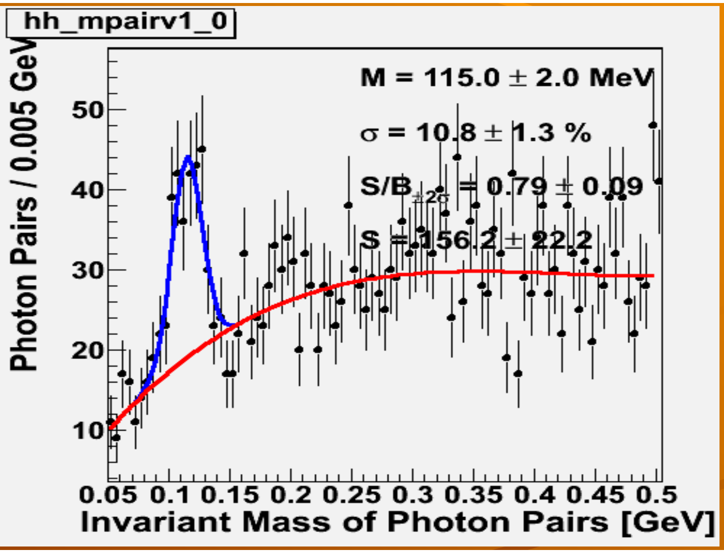
Muons identification efficiencies and kinematic variables have been studied in detail using minimum bias events and dimuon resonances.



(a) (b)

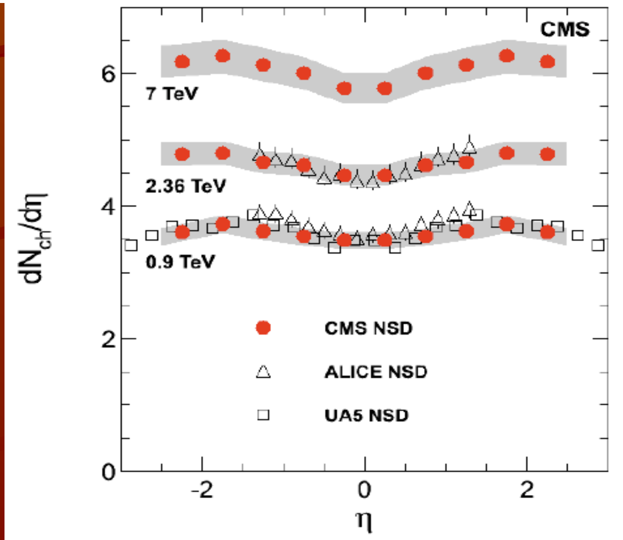
Distributions dominated by light hadron decay (red); excellent agreement with MC prediction including heavy flavor decays (blue); small fraction of punch-through (black) and fakes (green).

- π^0 peak reconstructed offline 200 seconds into 7 TeV run

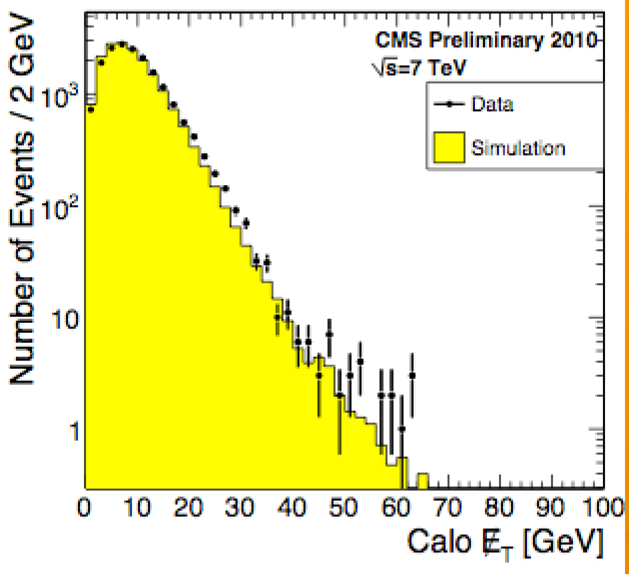


Calibration triggers have access to full L1 rate, and they output small fraction of event

“Transverse Momentum and Pseudorapidity Distributions of Charged Hadrons in pp Collisions at √s=7TeV”, ***Phys. Rev. Lett. 105, 2010.***



Calorimetry: Missing E_T



Jets reconstructed with the anti-k_T $R=0.5$ algorithm

Dijet selection : Jet $P_T > 25$ GeV, $\Delta\varphi > 2.1$, $|\eta| < 3$

Loose ID cuts on number of components and neutral/charged energy fraction

Calorimetric di-jet events