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 strength
  • 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

Design and preliminary results of the experiments:

Bulgarian Participation at LHC experiments - CMS

Precision (1%) measurement of total cross section (and more) TOTEM
Study of forward n° production LHCf
Search for magnetic monopoles MoEDAL
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 $\sim$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.
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 1000 GeV.

The Higgs mechanism

How heavy is the Higgs: the TeV scale

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.
Experiments at LHC and Bulgarian Participation

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

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

All these are elegant theories
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

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?

- **Beam Energy**: $7 \times 10^{12}$ eV
- **Luminosity**: $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
- **Bunches/Beam**: 2835
- **Protons/Bunch**: $10^{11}$

7 TeV Proton Proton colliding beams

- **Bunch Crossing**: $4 \times 10^7 \text{ Hz}$
- **Proton Collisions**: $10^8 \text{ Hz}$
- **Parton Collisions**
- **New Particle Production**: $10^{-5} \text{ Hz}$ (Higgs, SUSY,...)

Selection of 1 event in $10,000,000,000,000$
Typical elements of a collider detector

- **Central detector**
  - Tracking, \( p_T \), MIP
  - Identification of jets, Missing \( E_T \)
  - Topology
  - Vertex

- **Electromagnetic and Hadron calorimeters**
  - Particle identification (\( e, \gamma, \text{jets}, \text{Missing } E_T \))
  - Energy measurement

- **Heavy materials**
  - Iron or Copper + Active material

- **Light materials**
  - Materials with high number of protons + Active material

- **Muon detector**
  - \( \mu \) identification

- **Hermetic calorimetry**
  - Missing \( E_T \) measurements

Each layer identifies and enables the measurement of the momentum or energy of the particles produced in a collision.
pseudorapidity, \( \eta \), is a commonly used spatial coordinate describing the angle of a particle relative to the beam axis.

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

- \( \theta = 90^\circ \rightarrow \eta = 0 \)
- \( \theta = 10^\circ \rightarrow \eta \approx 2.4 \)
- \( \theta = 170^\circ \rightarrow \eta \approx -2.4 \)

Collider Luminosity

\[
L = \frac{N_p^2 n_b f_{\text{rev}} \gamma_r}{4\pi \epsilon_n \beta^* F}
\]

- \( N_p \) = number of proton per bunch
- \( n_b \) = number of bunches
- \( f_{\text{rev}} \) = revolution frequency
- \( F \) = crossing angle factor
- \( \beta^* \) = optics at beam crossing (m)
- \( \gamma_r \) = relativistic factor

Rms transverse beam size = \( \sqrt{\epsilon \beta / \gamma} \)

\( \epsilon_n \) = normalized transverse emittance

Luminosity is measured in units of length\(^{-2}\) * time\(^{-1}\)

Typical collider values are in the range of \( 10^{30} \) units \( \text{cm}^{-2} \text{sec}^{-1} \)

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy per nucleon</td>
<td>( E )</td>
</tr>
<tr>
<td>Dipole field at 7 TeV</td>
<td>( B )</td>
</tr>
<tr>
<td>Design Luminosity(^*)</td>
<td>( L )</td>
</tr>
<tr>
<td>Bunch separation</td>
<td>25 ns</td>
</tr>
<tr>
<td>No. of bunches</td>
<td>( k_B )</td>
</tr>
<tr>
<td>No. particles per bunch</td>
<td>( N_p )</td>
</tr>
<tr>
<td>RMS beam radius at IP</td>
<td>( \sigma )</td>
</tr>
<tr>
<td>Lifetime</td>
<td>( \tau_L )</td>
</tr>
<tr>
<td>Number of collisions/crossing</td>
<td>( n_c )</td>
</tr>
</tbody>
</table>

\(* \) For heavy-ion (HI) operation the design luminosity for Pb-Pb collisions is given.
The Compact Muon Solenoid (CMS)

**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

**Calorimeters**

- **ECAL**
  - ~76K Scintillating PbWO$_4$ crystals

- **HCAL**
  - Brass + Plastic Scintillator
  - ~7K channels

**Muon Barrels**

- 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

**Muon Endcaps**

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

- Steel Return Yoke
  - ~13000 tons
Transverse slice through CMS detector
Click on a particle type to visualise that particle in CMS
Press “escape” to exit
H→ZZ → μμee event with $M_H = 300$ GeV for different luminosities

$10^{32}$ cm$^{-2}$s$^{-1}$

$10^{33}$ cm$^{-2}$s$^{-1}$

$10^{34}$ cm$^{-2}$s$^{-1}$

$10^{35}$ cm$^{-2}$s$^{-1}$
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 $M_H > \sim 500$ GeV
A high granularity device is needed to reconstruct hundreds of tracks per event.

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

HIGH LEVEL Triggers
Farms of processors

Reconstruction & Analysis
TIER 0/1/2 Centers

ON-line
OFF-line

25 ns 3 µs ms sec
Giga Tera Petabit
10^-9 10^-6 10^-3 10^0 10^3 10^6 10^9
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.
Physics = f(Time)

Integrated Luminosity

1 nb^{-1} 1 pb^{-1} 1 fb^{-1}

W (& Z) Observation
Di-top @ TeV
W/Z + N jets
Di-jets
Min. bias

W/Z Measurements

WZ Observation

ZZ Observation

We are here!

ICHEP 2010

EPS HEP 2011

Moriond 2011

Higgs?
SUSY?
Z'

Di-Top Observation
WW Measurements
WZ Observation

We are here!
Here is the Compact Muon Solenoid

About $3.6\text{pb}^{-1}$ delivered by LHC and $\sim 3.3\text{pb}^{-1}$ of data collected by CMS. Overall data taking efficiency $\geq 92\%$.

Good performance of CMS in coping with 4 orders of magnitude increase in instantaneous luminosity. Since ICHEP we have recorded another $3.0\text{pb}^{-1}$ of data: $2.9\text{pb}^{-1}$ validated for physics in total ($86\%$ of the recorded data).
Trigger HLT path: $\mu^+X(p_T>9\text{GeV/c})$ $|\eta|<2$. Good quality muon track (hits in pixels, strip tracker, muon system and $|\eta|/\text{dof}<10$). For the W: relative isolation $\leq 0.15$ in a cone of $|\Delta R|<0.3$ around the muon. For the Z: looser quality criteria on the second muon, opposite charge and $|\Delta R|<2.4$; both muons isolated, $p_T>20\text{GeV}$ and invariant mass $60<m_{\mu\mu}<120\text{GeV}/c^2$. Simultaneous fits to backgrounds and signal contributions. QCD background shapes obtained using data. EWK background shapes and signal from MonteCarlo.

$N_W=818\pm27$

$N_Z=77$
Results

**Results**

\[ \int L \, dt = 198 \, \text{nb}^{-1} \]

- **W → μν**
  \[ 9.14 \pm 0.33_{\text{stat}} \pm 0.58_{\text{syst}} \pm 1.00_{\text{lumi}} \, \text{nb} \]

- **W → eν**
  \[ 9.34 \pm 0.36_{\text{stat}} \pm 0.70_{\text{syst}} \pm 1.03_{\text{lumi}} \, \text{nb} \]

- **W → lν (combined)**
  \[ 9.22 \pm 0.24_{\text{stat}} \pm 0.47_{\text{syst}} \pm 1.01_{\text{lumi}} \, \text{nb} \]

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

---

G. Tonelli, CERN/INFN/UNIPI 2010

ICHEP10 Paris July, 26 18
Dileptonic channels: $ee, \mu\mu, e\mu + X$

- Triggers: $\mu+X$ ($p_T > 9$ GeV/c) or $e/\gamma+X$ ($E_T > 15$ GeV)

- 2 isolated, prompt, oppositely charged leptons ($l = e,\mu$) 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$\oplus$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$\oplus$tracking info
  - $|\eta| < 2.4$, $p_T > 30$ GeV/c
    - $\geq 2$ jets typical for $t\bar{t}$
Event passes all cuts of full selection:
- 2 muons with opposite charge
- 2 jets, both with good/clear $b$-tags (and secondary vertices!)
- Significant MET (>50 GeV)

Preliminarily reconstructed mass is in the range 160–220 GeV/c$^2$ (consistent with $m_{\text{top}}$)

$m(\mu\mu) = 26$ GeV/c$^2$
Using the full statistics currently validated (0.84 pb⁻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(III)-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!
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 $N \sim 90$ 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

Plamen Iaydjiev – INRNE, Sofia, CERN Accelerator School, Varna 2010

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

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

The Inner Detector
- Pixel Detectors
- Forward SCT
- Barrel SCT

Calorimetry

Electromagnetic Calorimeter
barrel, endcap: Pb-LAr
$\sim 10\%/\sqrt{E}$ energy resolution $e/\gamma$
180000 channels: longitudinal segmentation

Hadron Calorimeter
barrel Iron-Tile EC/Fwd Cu/W-LAr ($\sim 20000$ channels)
$\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$ pion ($10 \lambda$)

Trigger for $e/\gamma$, jets, Missing $E_T$
H → γγ : to observe a signal peak on top of a huge background need
- energy/mass resolution ~ 1%
- rejection of π⁰ → γγ faking single γ

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
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 $L = 10^{27} \text{ cm}^{-2} \text{ s}^{-1}$

$E = 2.96 \text{ TeV}$, No of bunches = 592,
No of particles per bunch = $7 \times 10^7$

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.
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.

**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
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, K, μ, e, γ)
triggers

Pythia

100μb

230μb

LHCb

ATLAS/CMS

P_T of B-hadron

η of B-hadron

30
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

University of Sofia

Central Laboratory of Mechatronics and Instrumentation

Bulgarian academy of Science

Faculty of Physics

Bulgarian academy of Science
Experiments at LHC and Bulgarian Participation

CMS ECA1 – assembling and testing supemodules – INRNE, CLMI

Full size preproduction prototype of HCAL - INRNE

The Compact Muon Solenoid Experiment

CMS Bulletin

Full Size Pre-production Prototypes of HCAL
HV supply for CSC and HCAL for CMS – INRNE, Sofia
RPC assembled at INRNE, Sofia, transported and installed in CMS – INRNE, Sofia University
CMS HCAL design, calibration and prototype testing – INRNE, Sofia University
Experimental data vs expected stopping power for PbWO4

Substantial Rates for $E_\mu > 10$ GeV

<table>
<thead>
<tr>
<th>$N_{\text{HIT}} \geq 1$</th>
<th>Rate [Hz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMS tot</td>
<td>$\sim 1800$</td>
</tr>
<tr>
<td>Muon only</td>
<td>$\sim 1800$</td>
</tr>
<tr>
<td>calorimeter</td>
<td>$\sim 700$</td>
</tr>
<tr>
<td>tracker</td>
<td>$\sim 60$</td>
</tr>
</tbody>
</table>
**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.

**Experiments at LHC and Bulgarian Participation**

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

**RPC barrel ~94.2%**

CMS preliminary 2010 @ 7TeV
RUNS 138732 - 143727

** RPC endcap ~93.6%**

CMS preliminary 2010 @ 7TeV
RUNS 142254 - 143727

**RPC hit synchronization**

- excellent time synchronization achieved (>99% of RB+RE has \(\Delta BX=0\))
- Some fine tuning still possible (~1-2 ns) for a fraction of the LB at \(BX=0\)
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
Main mechanism: pair production via strong interaction
- Tevatron: $q\bar{q}$ (85%), $\sigma=7.46$ pb
- LHC@7 TeV: $gg$ (~90%), $\sigma=160.8$ pb
- theoretical uncertainty ~9%

$\text{NNLO}_{\text{approx}}$ for $m_t = 172.5$ GeV
PRD 80, 054009 (2009)

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

- $m_e$ Electron mass 511 keV
- $m_\mu$ Muon mass 105.7 MeV
- $m_\tau$ Tau mass 1.78 GeV
- $m_u$ Up quark mass 1.9 MeV
- $m_d$ Down quark mass 4.4 MeV
- $m_s$ Strange quark mass 87 MeV
- $m_c$ Charm quark mass 1.32 GeV
- $m_b$ Bottom quark mass 4.24 GeV
- $m_t$ Top quark mass 172.7 GeV

- $\theta_{12}^{\text{CKM}}$ 12-mixing angle 13.1°
- $\theta_{23}^{\text{CKM}}$ 23-mixing angle 2.4°
- $\theta_{13}^{\text{CKM}}$ 13-mixing angle 0.2°
- $\delta^{\text{CKM}}$ CP-violating Phase 0.995

- $g_1$ U(1) gauge coupling 0.357
- $g_2$ SU(2) gauge coupling 0.652
- $g_3$ SU(3) gauge coupling 1.221

- $\theta_{\text{QCD}}$ QCD vacuum angle $\sim$ 0

- $\mu_{\text{Higgs}}$ Higgs quadratic coupling Unknown
- $\lambda_{\text{Higgs}}$ Higgs self-coupling strength Unknown
The benchmark reactions

<table>
<thead>
<tr>
<th>Natural Width</th>
<th>0.01</th>
<th>1</th>
<th>10</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>GeV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HIGGS MASS GeV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Lep 190**
  - $H \rightarrow \gamma \gamma$ (WH→γγl) (t̄t H→γγl)
  - $H \rightarrow ZZ^* \rightarrow 4l$
  - $H \rightarrow ZZ \rightarrow 2\nu + 2\mu$ or $2\nu$ or $2\mu$
  - $H \rightarrow WW$ or $ZZjj \rightarrow 2ljj$

---

G. Tonelli, CERN/INFN/UNIPI
July, 9 2010
Event rate = $L \sigma \text{Br}$
e.g. $H \sim 0.8$ TeV; $H \rightarrow ZZ \rightarrow 4l$
Events/year $\geq 10 \Rightarrow (10/10^7) \times 1/(10^{-37} \times 10^{-3}) = L \sim 10^{34} \text{cm}^{-2} \text{s}^{-1}$

$M_H \sim 1000$ GeV
$E_W \geq 500$ GeV; $E_q \geq 1000$ GeV (1 TeV); $E_p \geq 6000$ GeV (6 TeV)

→Proton Proton Collider with $E_p \geq 6-7$ TeV
→$L \sim 10^{33}-10^{34} \text{cm}^{-2} \text{s}^{-1}$
$5\sigma$ Higgs Signals (statistical errors only)

LHC 14 TeV (SM, Signal with $\sigma_{\text{NLO}}$)

- $pp \rightarrow H \rightarrow \gamma\gamma$
- $pp \rightarrow H \rightarrow ZZ \rightarrow ll\nu\nu$
- $pp \rightarrow H \rightarrow WW \rightarrow l\nu l\nu$

Discovery Luminosity [fb$^{-1}$]

$M_{\text{Higgs}}$ [GeV]
Muons identification efficiencies and kinematic variables have been studied in detail using minimum bias events and dimuon resonances.

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).
- $\pi^0$ peak reconstructed offline 200 seconds into 7 TeV run

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


Jets reconstructed with the anti-$k_T$ $R=0.5$ algorithm
Dijet selection: Jet $P_T > 25$ GeV, $\Delta\phi > 2.1$, $|\eta| < 3$
Loose ID cuts on number of components and neutral/charged energy fraction

Calorimetric di-jet events