The physics programme of the LHC

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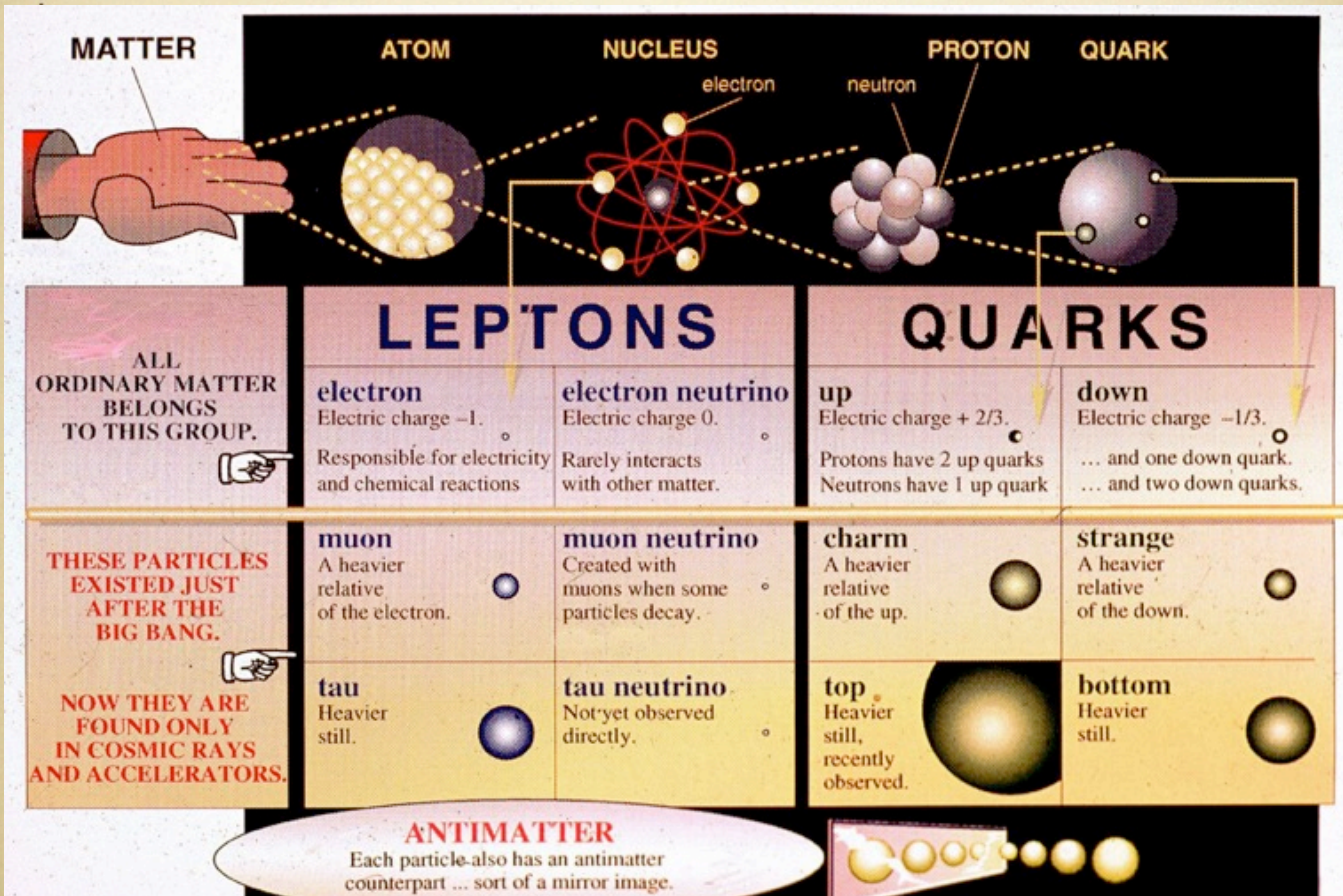
The Standard Model of fundamental interactions: MATTER



The Standard Model of fundamental interactions:

INTERACTIONS

FORCE	COUPLES TO:	FORCE CARRIER:
Electromagnetism	electric charge	photon (m=0)
"weak" force	"weak" charge	$W^{\pm}$ (m=80) Z^{0} (m=91)
"strong" force	"colour"	8 gluons (m=0)
gravity	energy	graviton (m=0)

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"strong" force	"colour"	8 gluons (m=0)
gravity	energy	graviton (m=0)

.... plus a scalar boson, to break electroweak symmetry and give particles their mass

	mass	**Higgs (m=??)**

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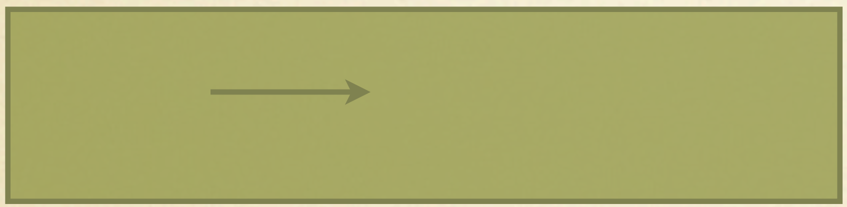

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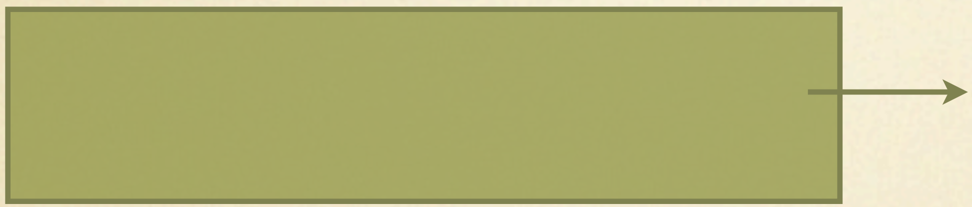

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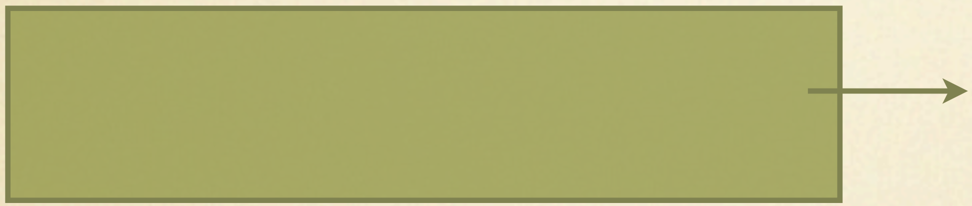

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$\Rightarrow c_{medium} < c_{vacuum}$

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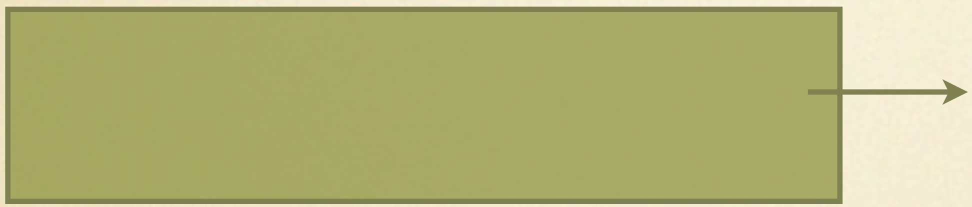

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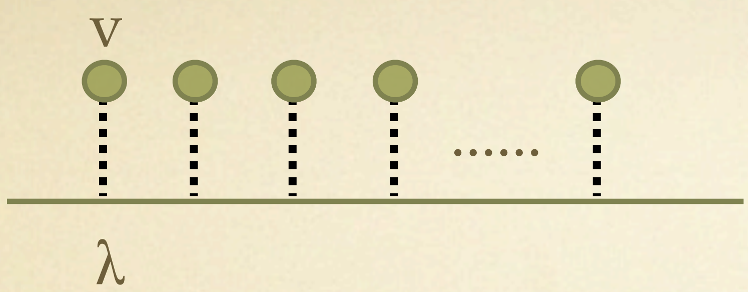
Think of the Higgs field as being a continuum embedding the whole Universe. Particles interacting with it will undergo a similar "slow-down" phenomenon. Rather than "slowing down", however, the interaction with the Higgs medium gives them "inertia" => mass



$m \propto \lambda v$

The number "v" is a universal property of the Higgs field background. The quantity "λ" is characteristic of the particle moving in the Higgs field. Particles which have large λ will have large mass, with $m \propto \lambda v$

Now the question of "why does a given particle have mass m" is replaced by the question "why does a given particle couple with the Higgs field with strength $\lambda \propto m / v$"

However at least now we have a mathematical model to understand how particles acquire a mass.

Detecting the Higgs boson

Like any other medium, the Higgs continuum background can be perturbed. Similarly to what happens if we bang on a table, creating sound waves, if we "bang" on the Higgs background (something achieved by concentrating a lot of energy in a small volume) we can stimulate "Higgs waves". These waves manifest themselves as particles, the so-called Higgs bosons

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What is required is that the energy available be sufficient ⇒ LHC !!!

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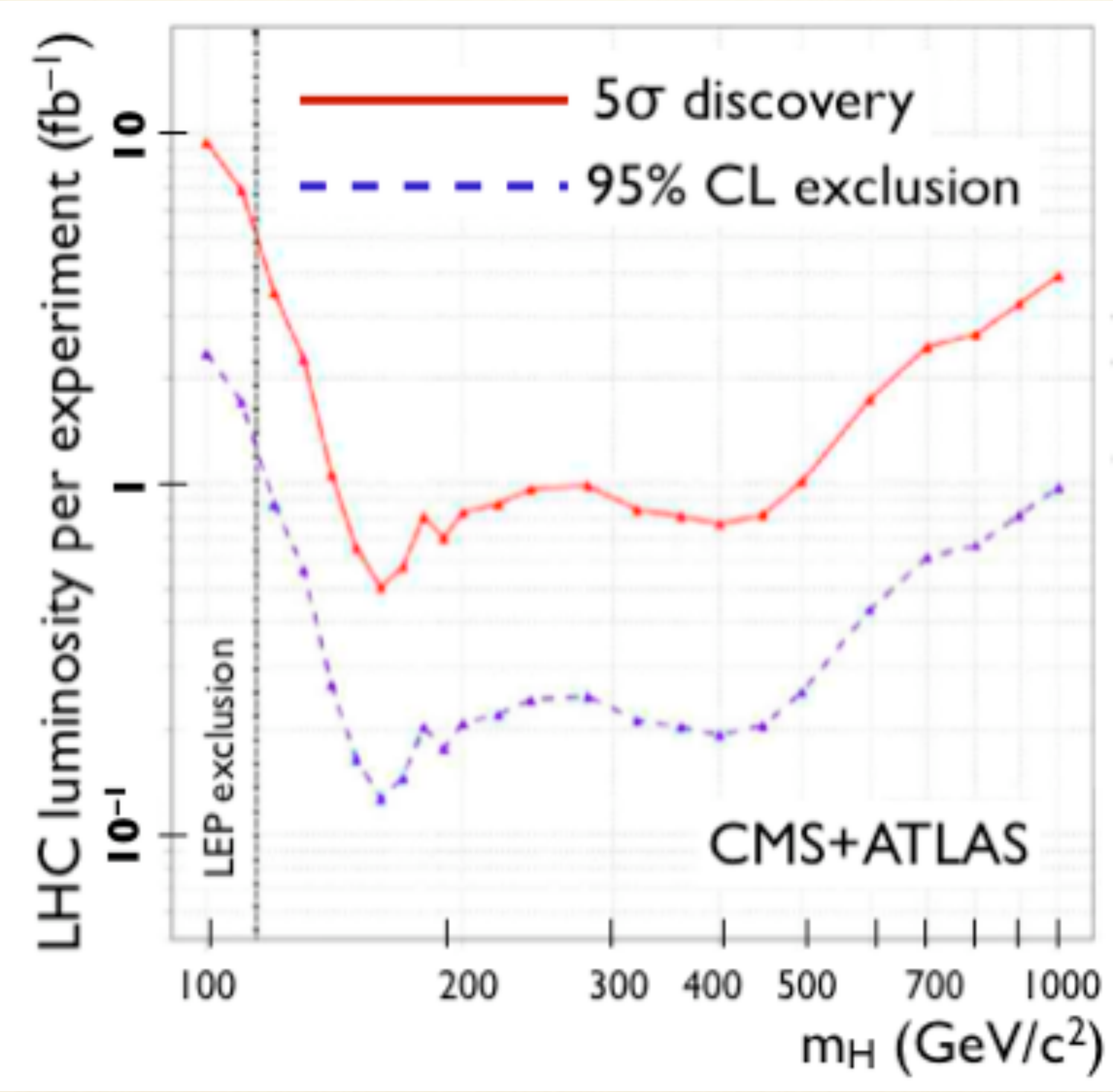
is electroweak symmetry broken as postulated in the Higgs mechanism of the SM?

- SM production and decay rates well known
- Detector performance for SM decays well understood
- $115 < m_H < 200$ from LEP and EW fits in the SM (LEP/SLC/Tevatron)

Summary of SM Higgs discovery potential



Within 2-3 yrs of effective running we should have an answer

IF Higgs seen with SM production/decay rates, but outside SM mass range:

- new physics to explain EW fits, or
- problems with LEP/SLD data

In either case,

- easy prey with low luminosity up to ~ 800 GeV, but more lum is needed to understand why it does not fit in the SM mass range!

IF NOT SEEN UP TO m_H ~ 0.8-1 TeV GEV:

$\sigma < \sigma_{SM}$: $\Rightarrow$ **new physics**

or

BR(H→visible) < BR_{SM}: $\Rightarrow$ **new physics**

or

m_H>800 GeV: expect WW/ZZ resonances at $\sqrt{s}$ ~ TeV $\Rightarrow$ **new physics**

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The precise identification of the cause of electroweak symmetry breaking phenomenon, of its dynamics and of the origin of the flavour structure, are therefore crucial goals for the progress of our understanding of Nature

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ALICE
TOTEM
CMS
The 15-m long LHC cryodipole
LHCf
LHCb
Calorimeters
Shielding plate
Yoke
Tracker
Coil
RICH-1
RICH-2
Vertex
Muon
ATLAS
MoEDAL

ATLAS, CMS, LHCb

- what is **Dark Matter** ?
- what is the origin of the matter-antimatter asymmetry of the Universe?
- what is the origin of neutrino masses?
- ......

questions driven by experimental facts: **proven** shortcomings of the SM

- why SU(3)xSU(2)xU(1)? are there new forces? GUT?
- why 3 generations, why their properties?
  - mass spectra
  - mixing patterns
- pointlike? substructures? strings?
- ....

questions driven by theoretical curiosity, will evolve with new data

- why D=3+1?
- what is **Dark Energy** ?

questions still lacking a solid, calculable theoretical framework for their formulation

Furthermore:

ALICE

- Detailed studies of high-density and high-temperature QCD matter, using Pb-Pb collisions at $\sqrt{S}$=5.5 TeV/nucleon (2.75 TeV in the 2010-2011 runs)
  - nuclear matter in a deconfined phase, eqn of state of quark-gluon matter
  - production/propagation/evolution of "high-Q^2" probes

TOTEM

- Measurement of total, elastic and diffractive proton-proton cross sections

LHCf

- Measurement of forward particle production (of relevance for the modeling of cosmic ray showers in the atmosphere)

MoEDAL

- Search for magnetic monopoles

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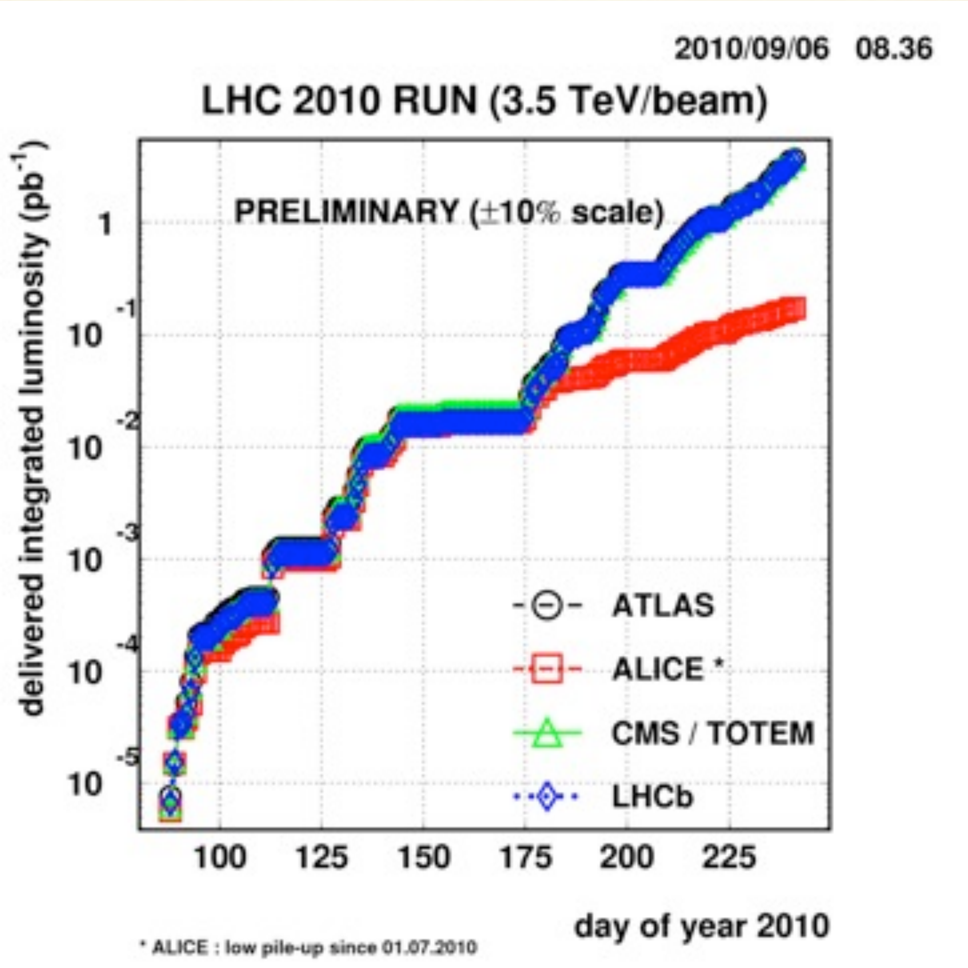
- **New dimensions of space-time:** modifications of Newton's law, new picture of Big Bang in its early evolution

Status of LHC operations



For comparison:

- at the SppS collider, the first run (1982) was a few 10^{-3} nb^{-1}, followed 1 year later by 20 nb^{-1} (W discovery)
- at the Tevatron collider, the first run (1985) was a few 10^{-3} nb^{-1}, followed 2 years later by 20 nb^{-1}

The LHC has surpassed this after few months of operations, and is still on an exponential ramp!

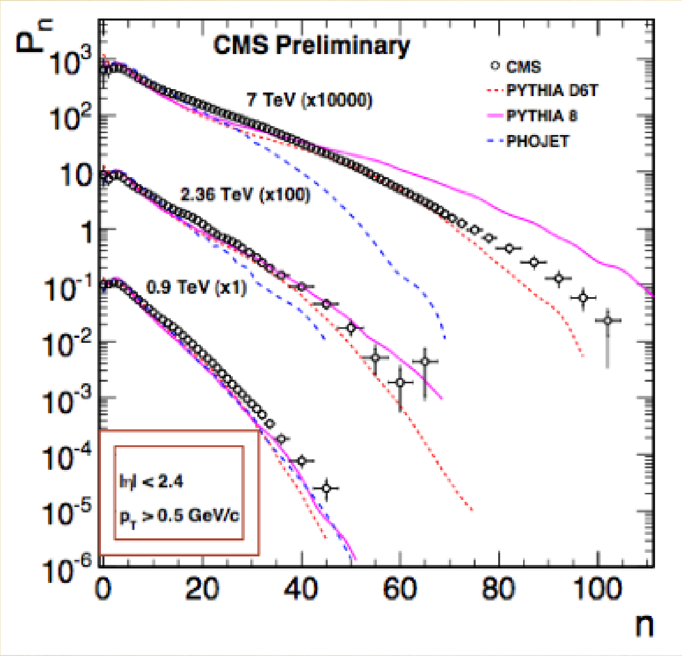
Plans for the 2010-11 data taking

- Run at half maximum energy, namely 3.5 TeV/beam
- Increase luminosity up to $10^{32}cm^{-2}s^{-1}$ (now: 10^{31}) by early November
- Switch to Pb-Pb collisions (~4 weeks) in mid-November
- ~2 months technical stop over Xmas
- Restart, run steady at ~$10^{32}cm^{-2}s^{-1}$ through 2011, to collect $1fb^{-1}$
- 4-week Pb-Pb run at end 2011

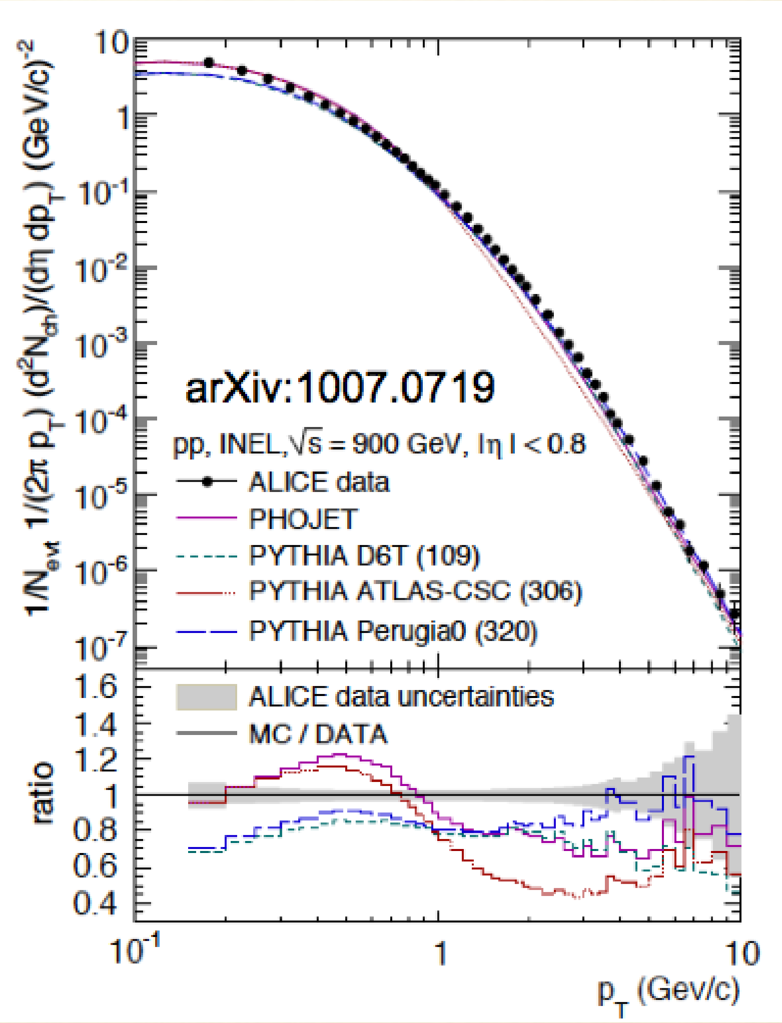
First LHC results

- 13 journal publications, by all 4 large experiments
- 100s of analysis notes detailing public results presented to International Conferences
- Much improved determination of general properties of proton-proton collisions at 900 GeV, 2.7 TeV and 7 TeV
- First challenges for MC event generators and modeling of pp collisions at 7 TeV
- Rediscovered the full SM particle content (including W/Z bosons, top quark)
- Crossed over into the territory of sensitivity to new-physics phenomena beyond the reach of any previous experiment

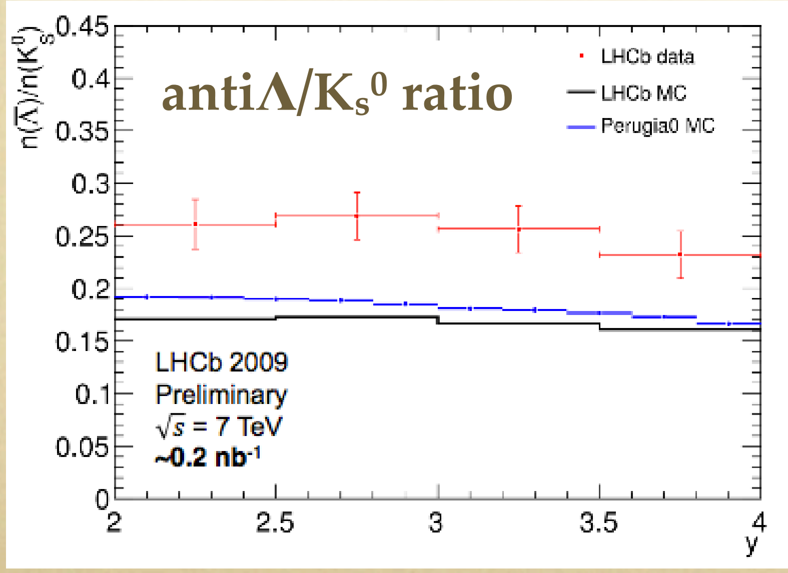
Modeling of inclusive properties of pp collisions



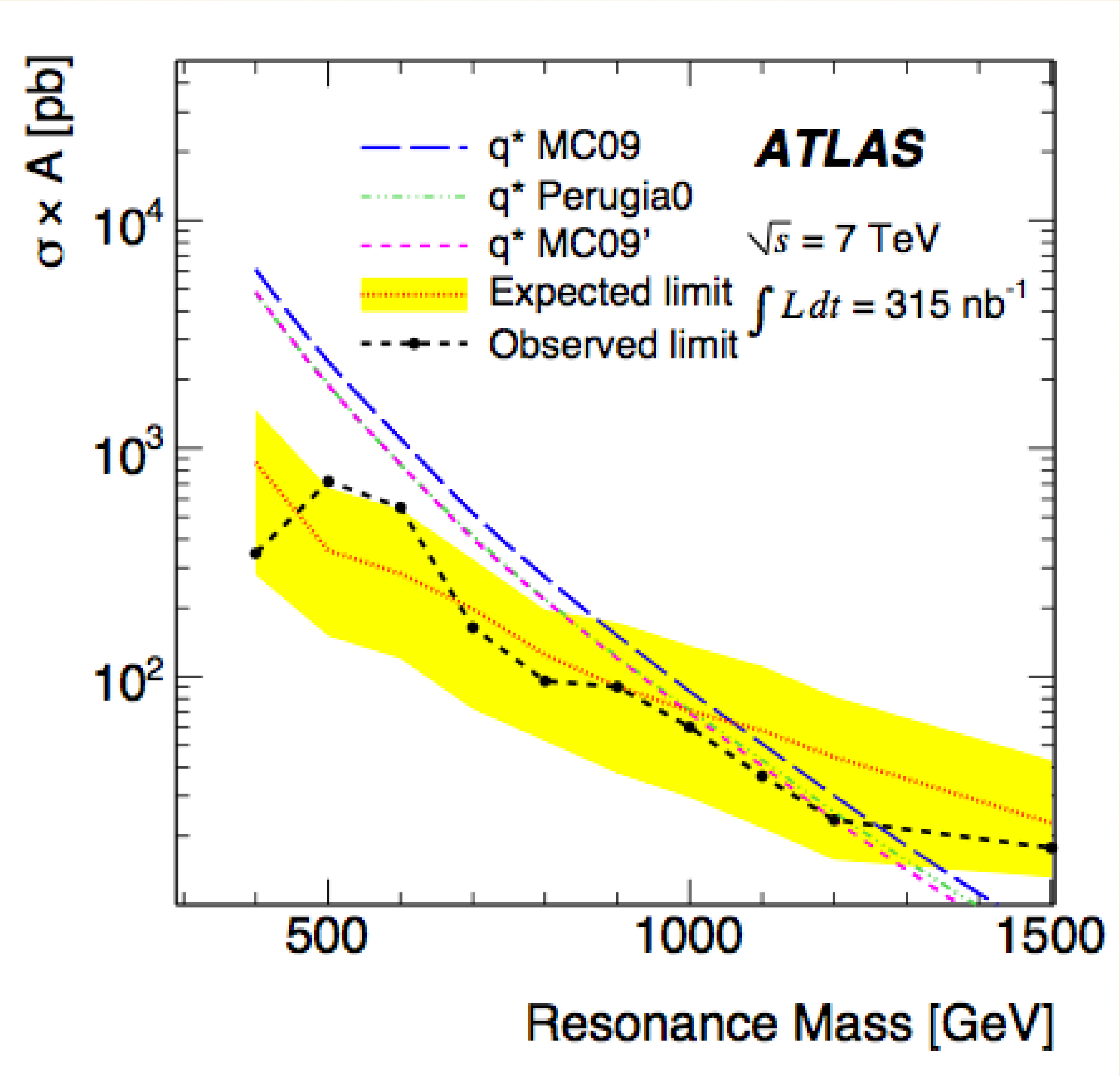
Multiplicity distributions



Momentum spectra



Probing the quark structure: limits on the mass of possible excited quarks

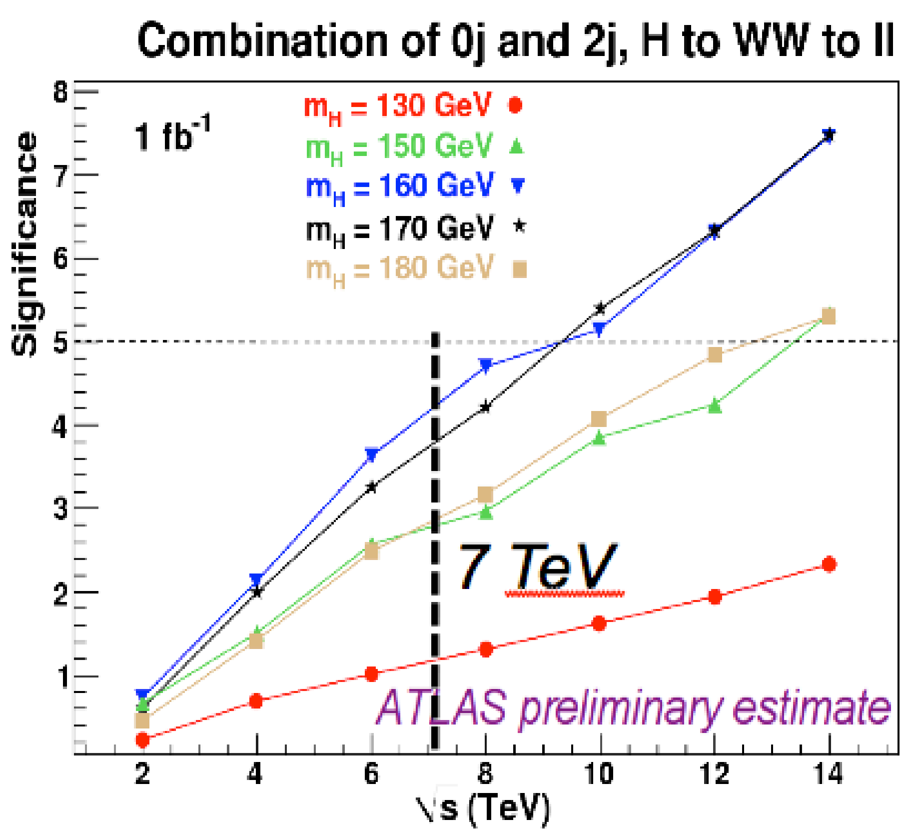


m[q*] > 1.26 TeV

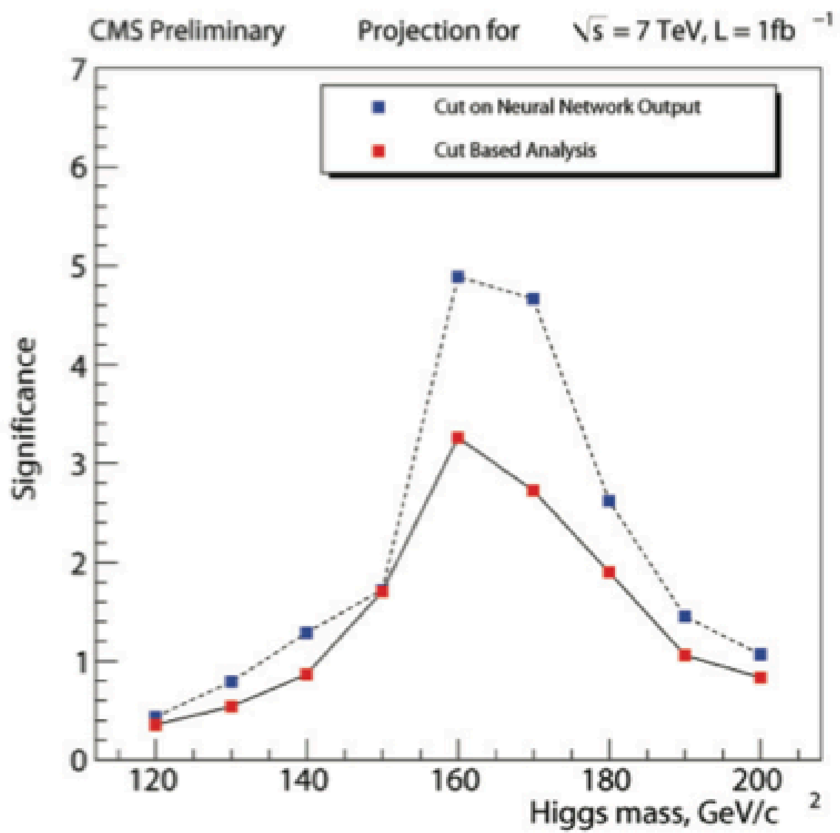
(best previous limit, from the Tevatron, was 0.87 TeV)

Prospects for 2011 run: Higgs

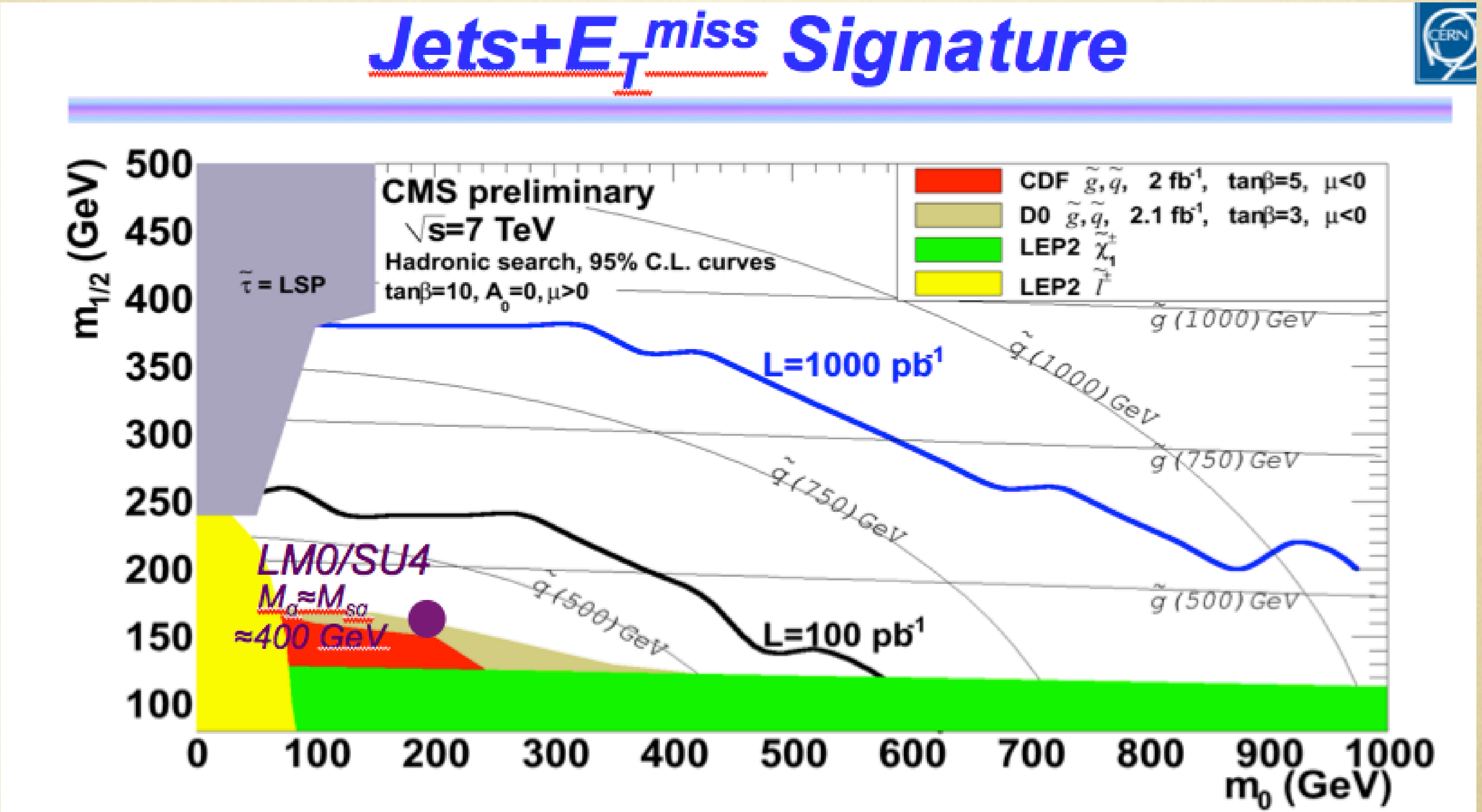
1fb^{-1} **ATLAS H→WW→ll**



CMS H→WW→ll



Prospects for 2011 run: Supersymmetry



The steps after 2011, in a nutshell

- At least 1 year shut-down in 2012, to prepare the LHC for 14 TeV:
    - consolidate the protection against quenches
    - test the ability of dipoles to sustain the maximum current, and re-train the weak ones
- 2-3 year run from 2013, at 14 TeV and L=few x 10^{33} $cm^{-2}s^{-1}$, i.e. O(10 fb^{-1}/yr)
- Shut down to prepare the LHC for L=few x 10^{34} $cm^{-2}s^{-1}$

- **< 1973: theoretical foundations of the Standard Model**
  - renormalizability of SU(2)xU(1) with Higgs mechanism for EWSB
  - asymptotic freedom, QCD as gauge theory of strong interactions
  - KM description of CP violation
- **Followed by 30 years of consolidation:**
  - **technical theoretical advances** (higher-order calculations, lattice QCD, ...)
  - **experimental** verification, via **discovery** of
    - **Fermions**: charm, 3rd family (USA)
    - **Bosons**: gluon, W and Z (Europe; .... waiting to add the Higgs ....)
  - **experimental** consolidation, via **measurement** of
    - EW radiative corrections
    - running of α_S
    - CKM parameters

It's unlikely it will take less than 30 yrs to clarify and consolidate the understanding of new phenomena to be unveiled by the LHC!

The LHC is ready for this exciting new era in particle physics!