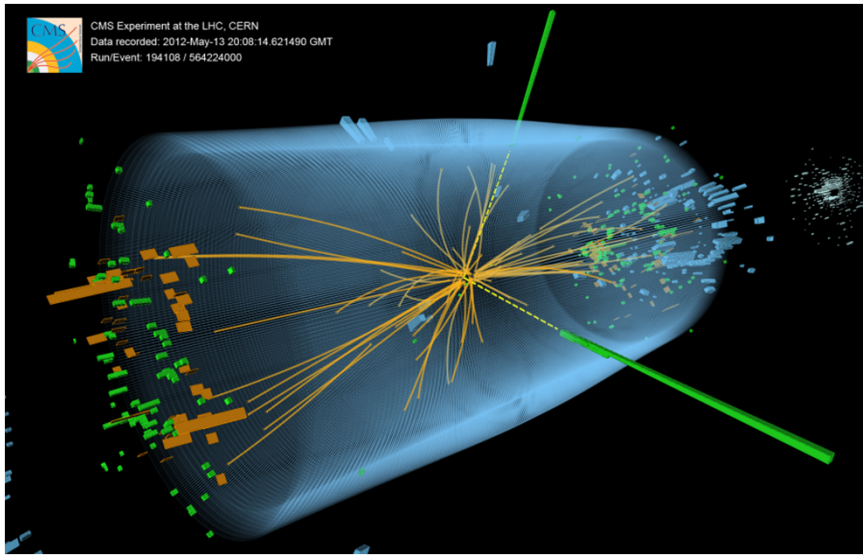
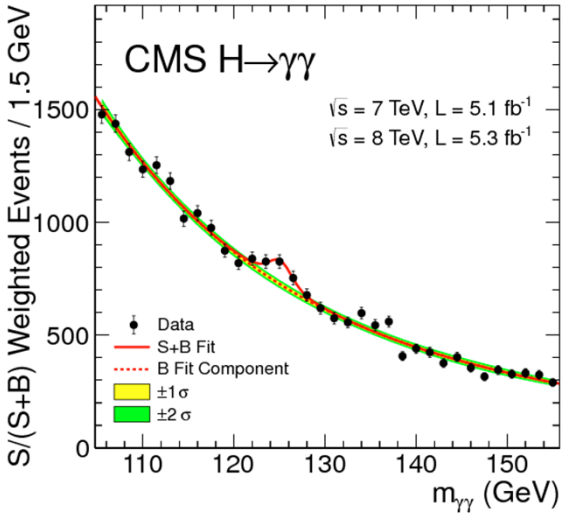




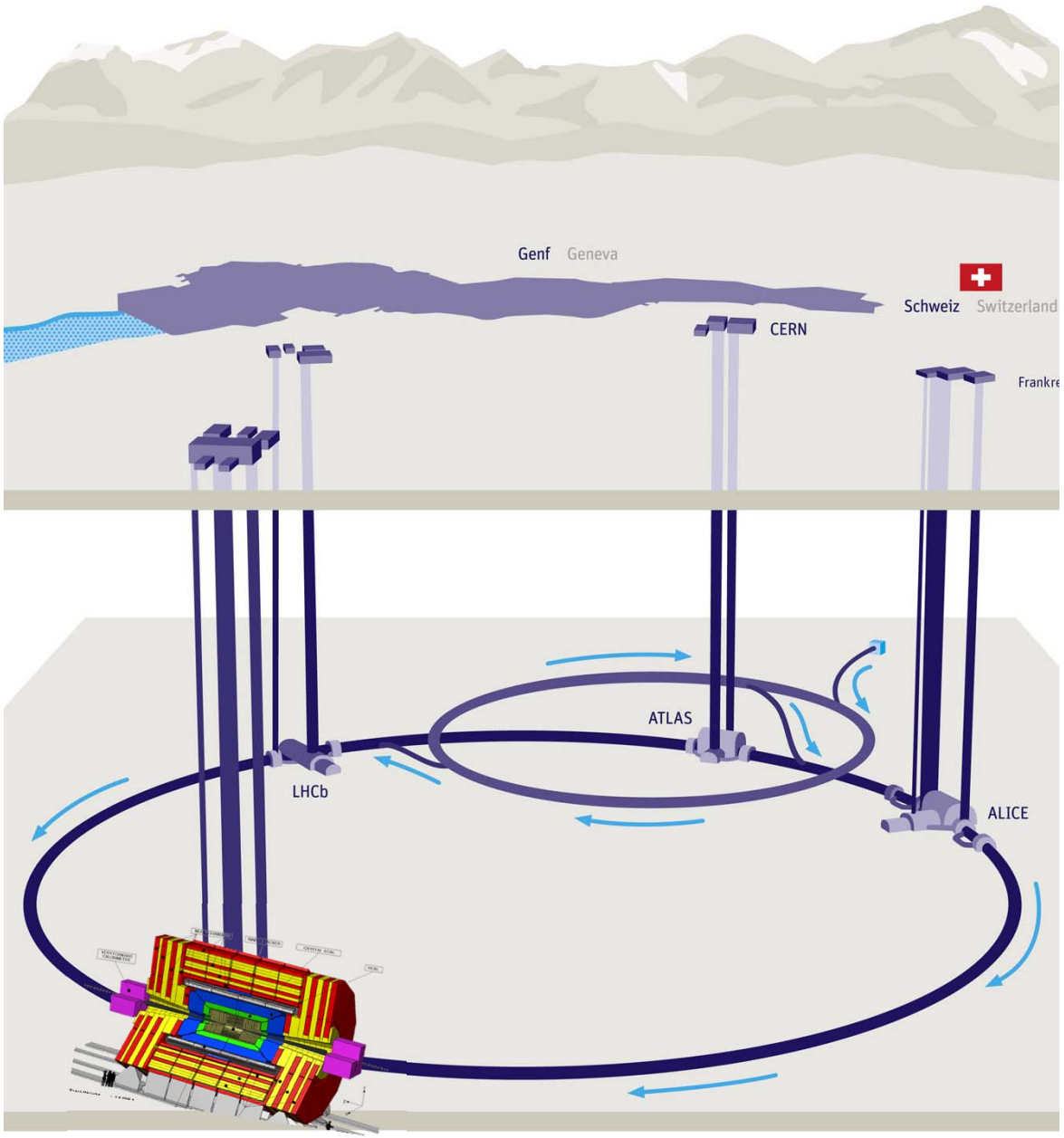
News from the CMS Experiment at LHC

Lutz Feld
1. Physikalisches Institut
RWTH Aachen

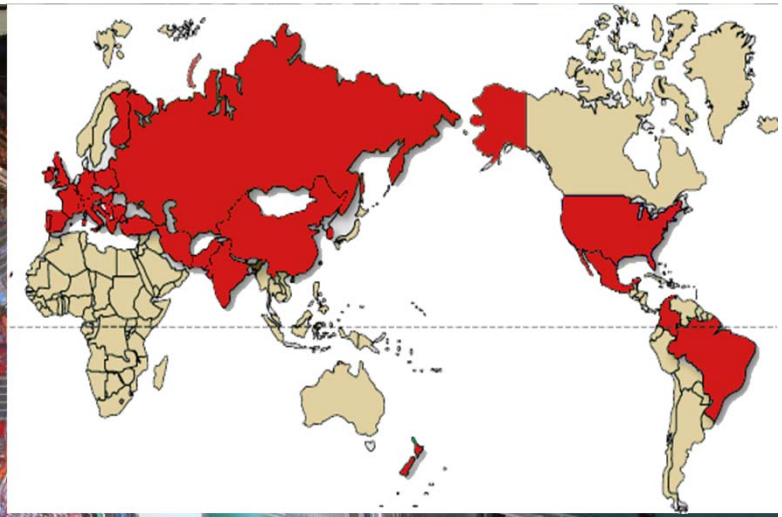
IceCUBE Collaboration Meeting
4.10.2012

Overview

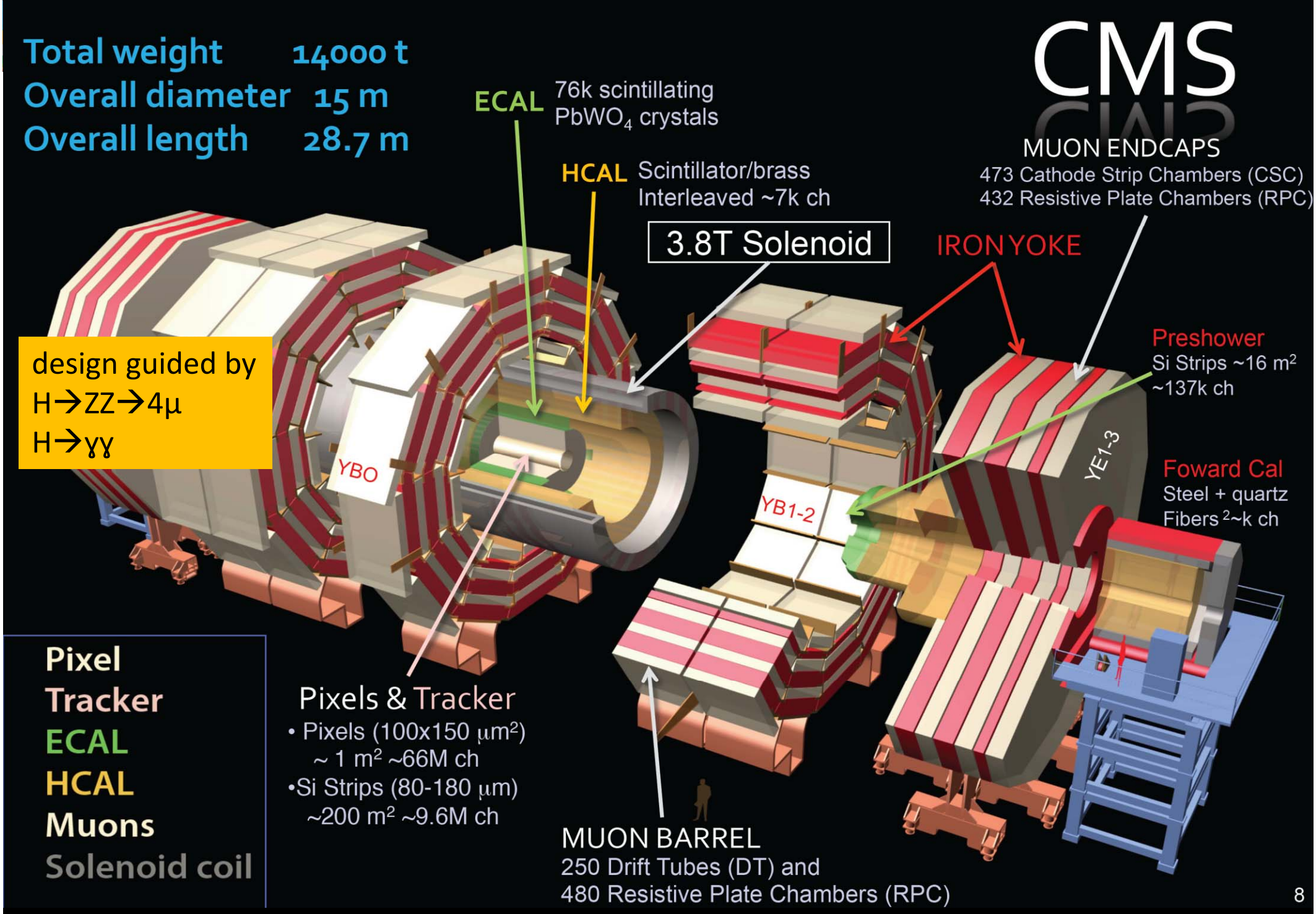
- Introduction to CMS and the LHC
- LHC Physics Program
- Observation of a new Boson
- Searches beyond the Standard Model
- Summary



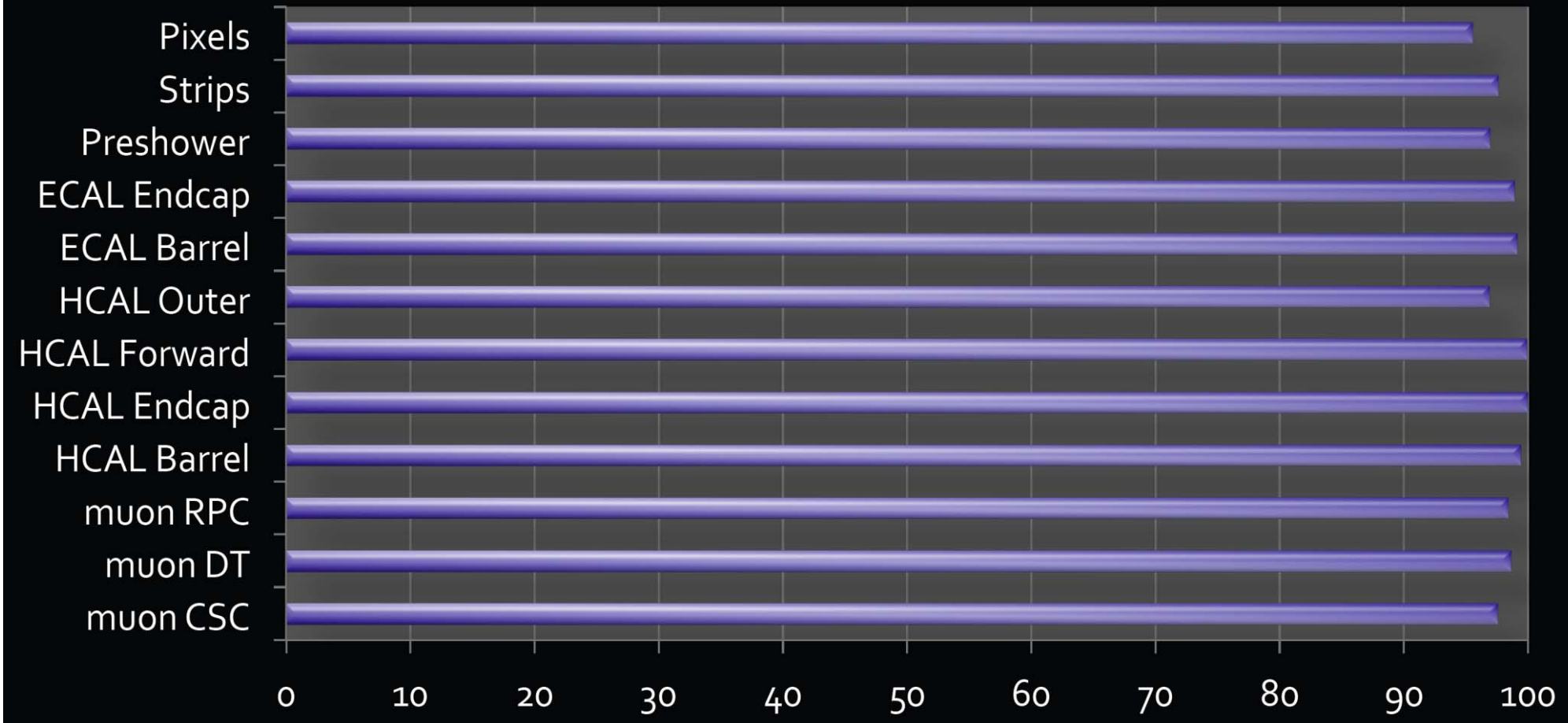
CMS Collaboration



2500 Scientists incl. 500 students
183 Institutes
38 Countires


Total weight 14000 t
Overall diameter 15 m
Overall length 28.7 m
CMS
ECAL 76k scintillating PbWO4 crystals
HCAL Scintillator/brass Interleaved ~7k ch
3.8T Solenoid
IRON YOKE
MUON ENDCAPS
473 Cathode Strip Chambers (CSC)
432 Resistive Plate Chambers (RPC)
Preshower
Si Strips ~16 m2
~137k ch
Foward Cal
Steel + quartz Fibers
2~k ch
design guided by
H→ZZ→4μ
H→γγ
YBO
YB1-2
YE1-3
Pixel
Tracker
ECAL
HCAL
Muons
Solenoid coil
Pixels & Tracker
• Pixels (100x150 μm2) ~ 1 m2 ~66M ch
•Si Strips (80-180 μm) ~200 m2 ~9.6M ch
MUON BARREL
250 Drift Tubes (DT) and
480 Resistive Plate Chambers (RPC)
8

Detector Performance



CMS Subsystem	muon CSC	muon DT	muon RPC	HCAL Barrel	HCAL Endcap	HCAL Forward	HCAL Outer	ECAL Barrel	ECAL Endcap	Preshower	Strips	Pixels
%Operational	97.55	98.6	98.4	99.4	99.96	99.88	96.88	99.11	98.89	96.9	97.61	95.5

October 3, 2012 CMS Wedi

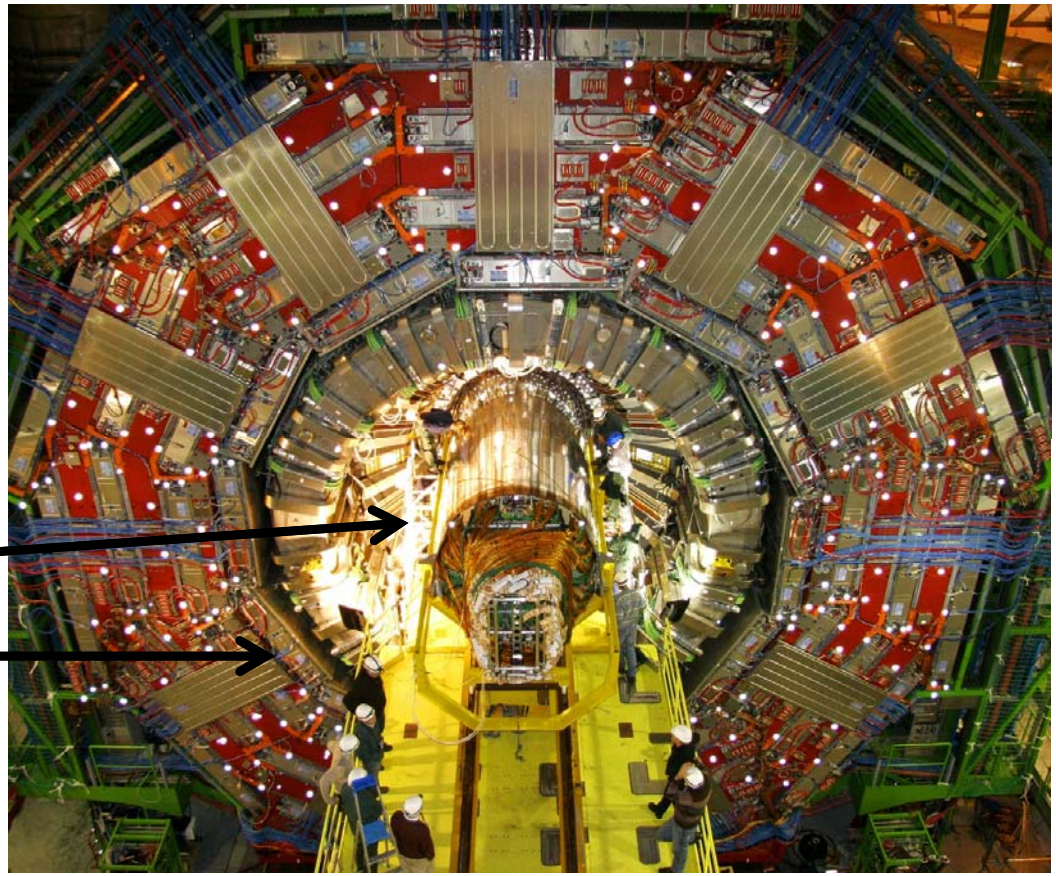
Aachen in CMS

1. + 3. Physikalisches Institut: Profs. Erdmann, Feld, Hebbeker, Schael, Stahl

+ 26 physicists
+ 9 engineers
+ 24 PhD students
+ 27 students
+ 12 technicians

since 1994

R&D and construction of
Silicon Tracker
and Myon Chambers



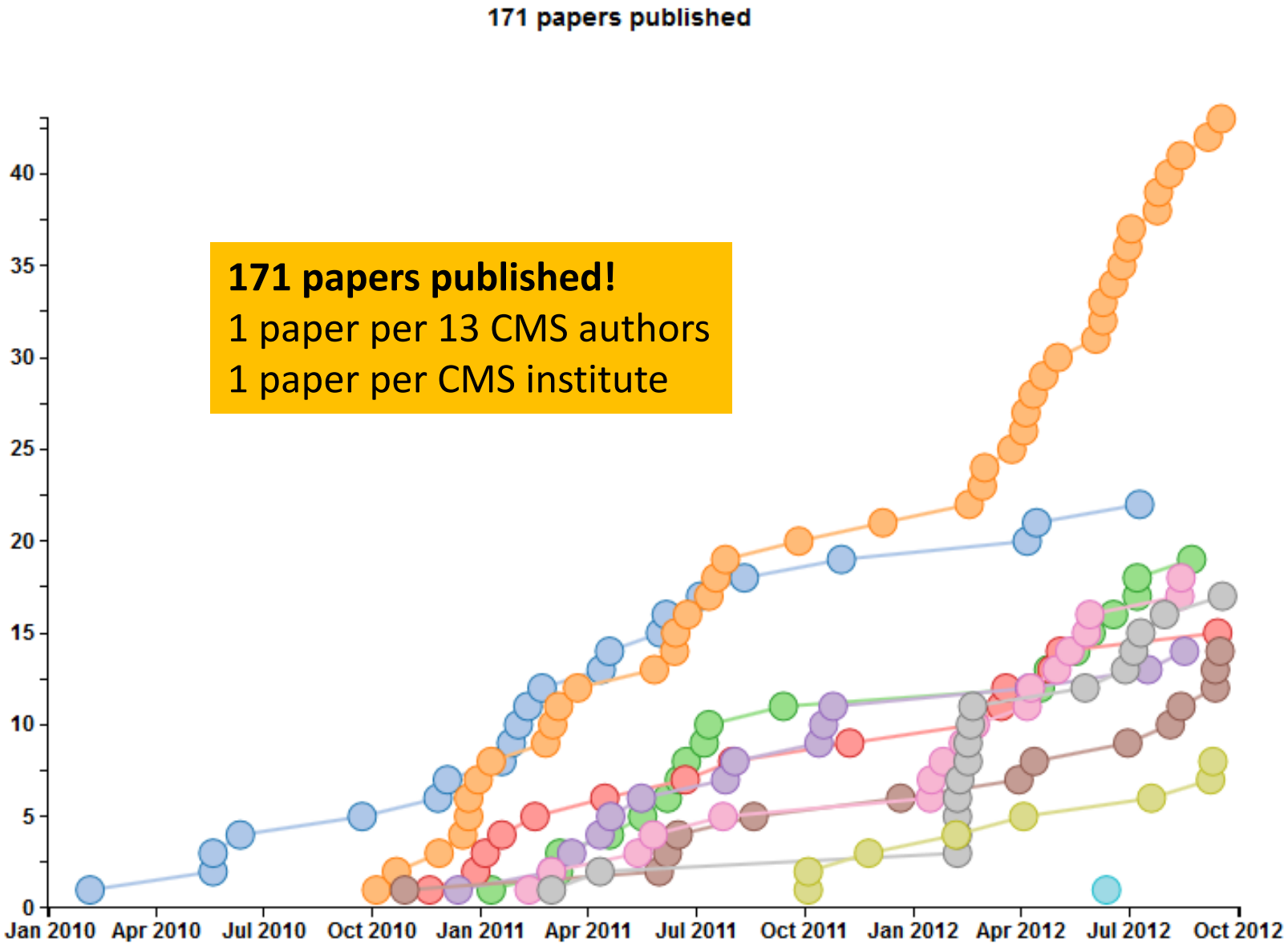
Tier-2 Computing Centre

Data analysis: Top-Quarks, Higgs, Supersymmetry, …

Upgrades of Pixel, Tracker and Myon System

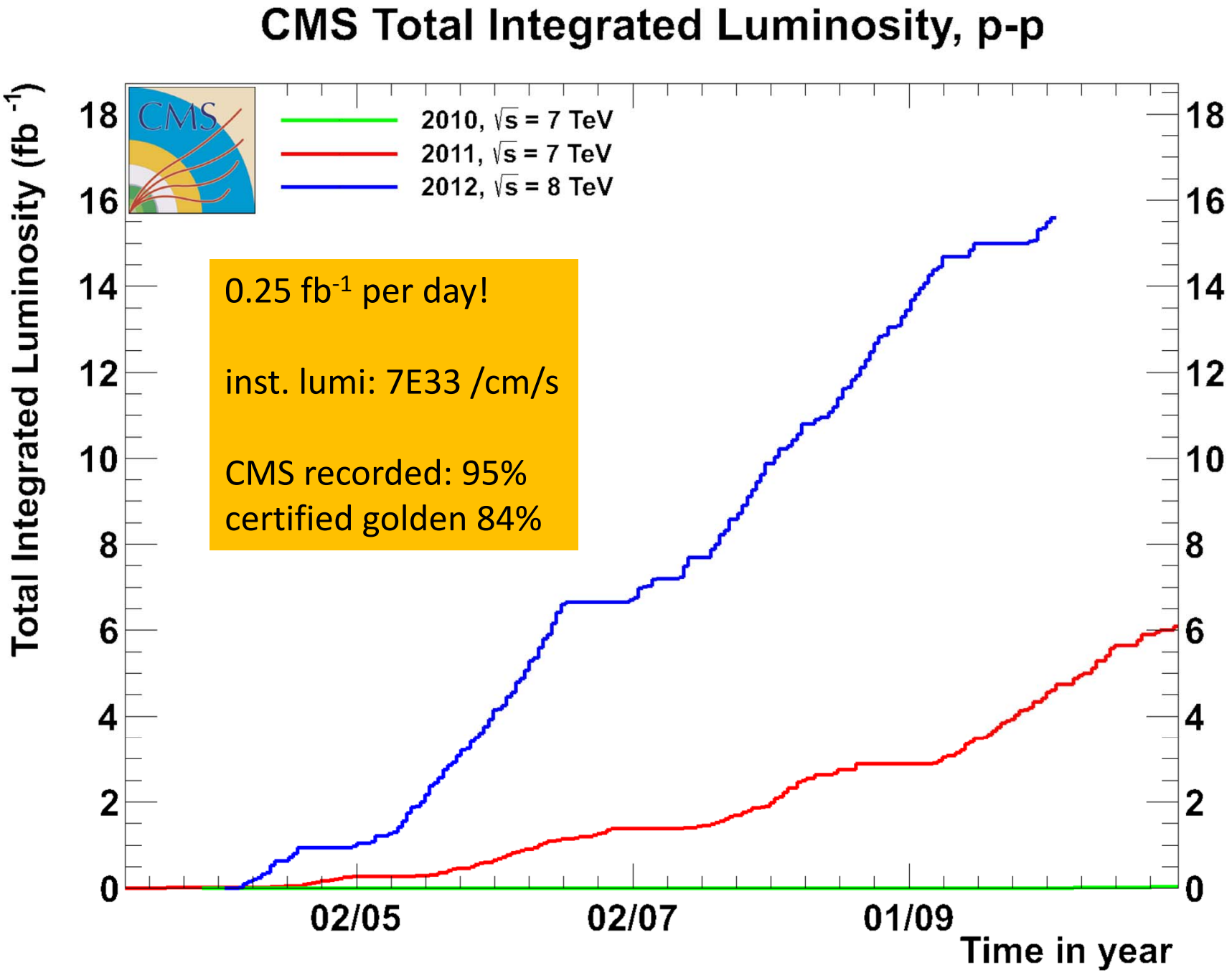
CMS Publications

Show all | Total | QCD Physics | Exotica Searches | Supersymmetry | B Physics | Electroweak | Top Physics | Heavy Ion | Higgs | Forward Physics | Standard Model



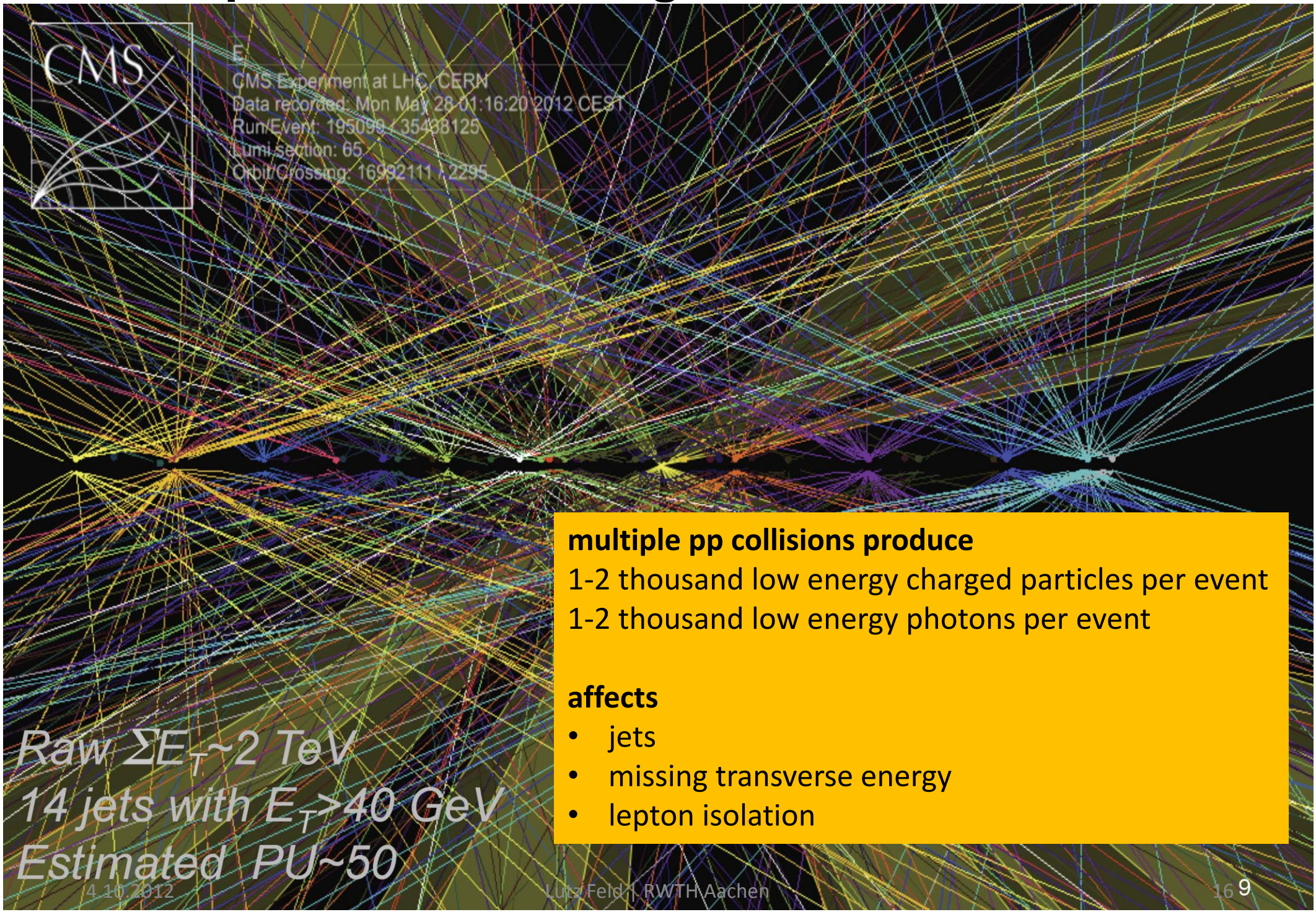
[http://cmsdoc.cern.ch/~mccauley/cmsphysics/]

Luminosity



[https://twiki.cern.ch/twiki/bin/view/CMSPublic/LumiPublicResults]

Pile-up is a real challenge!



multiple pp collisions produce

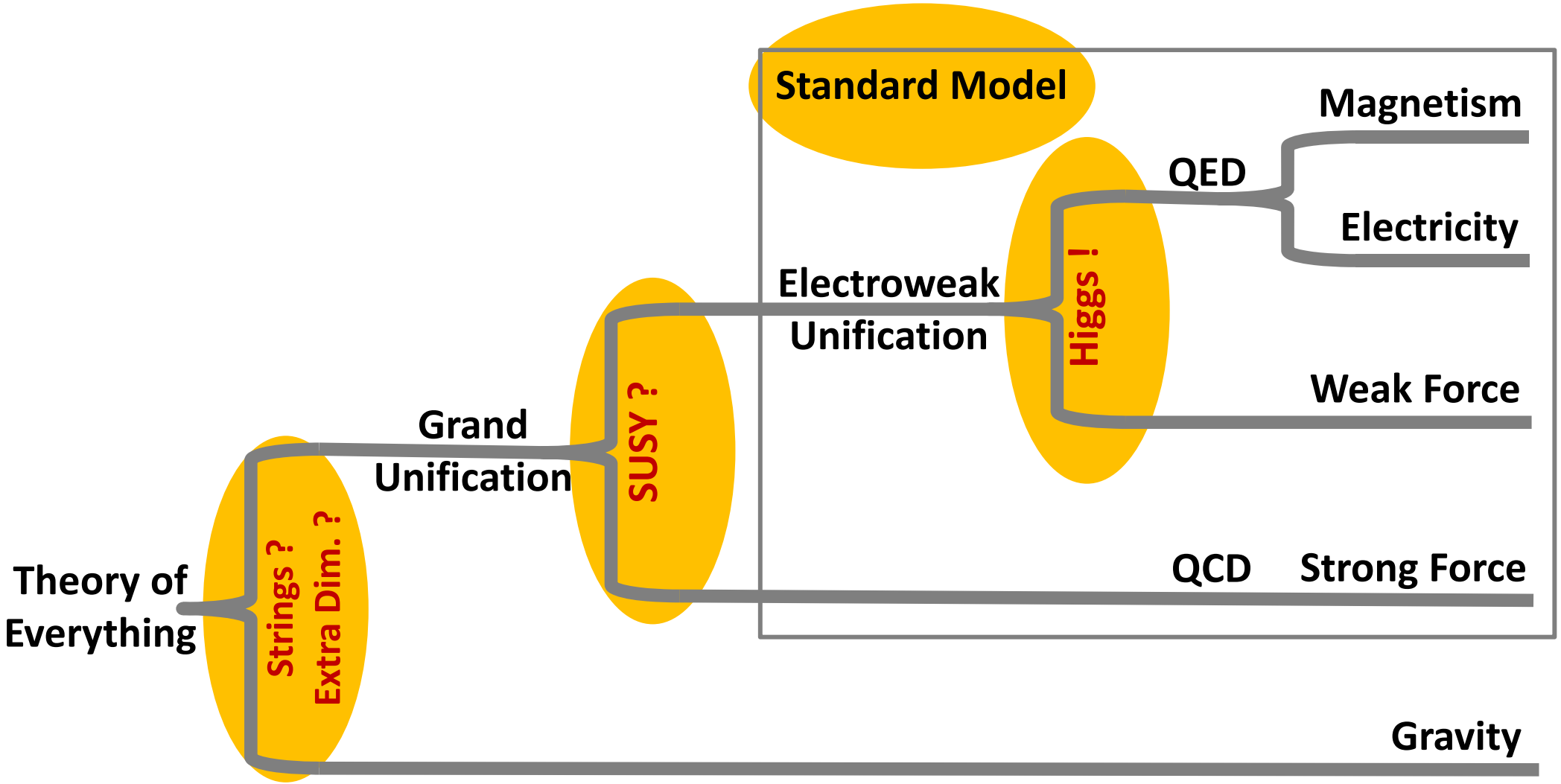
1-2 thousand low energy charged particles per event

1-2 thousand low energy photons per event

affects

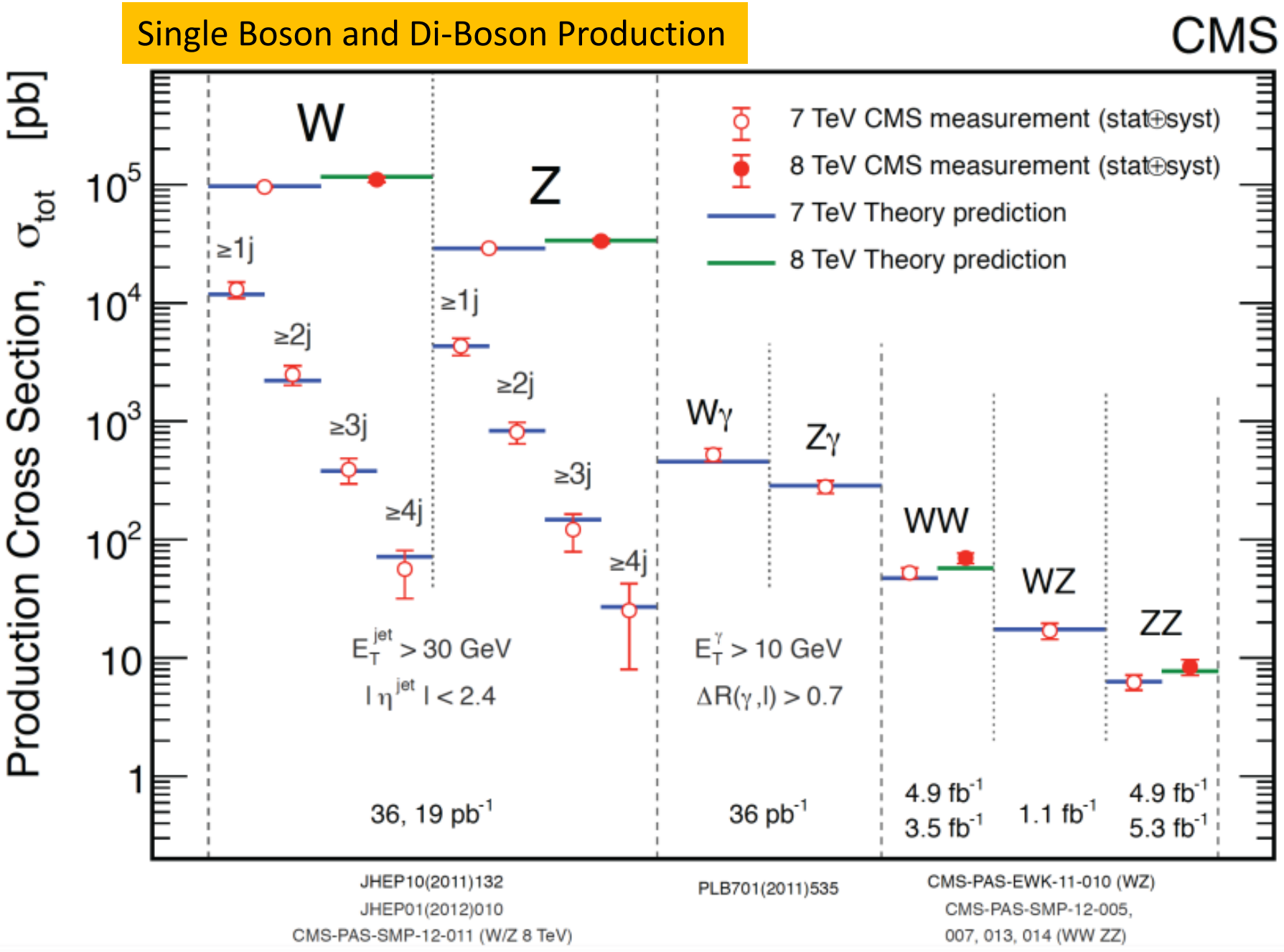
- jets
- missing transverse energy
- lepton isolation

LHC Physics Goals

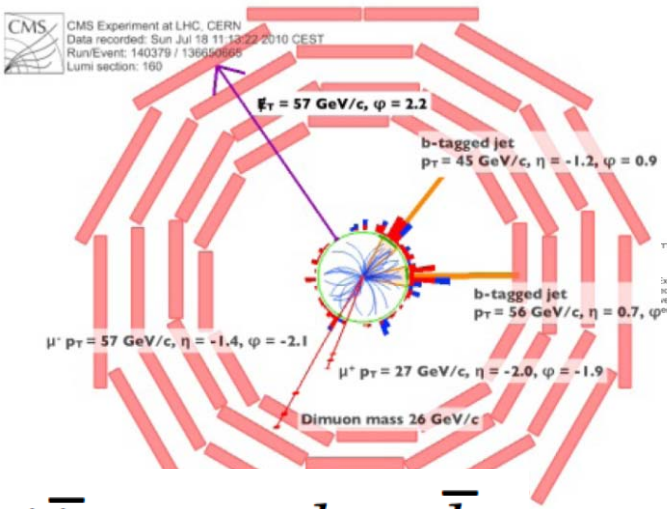


Vector Boson Cross Section Measurements

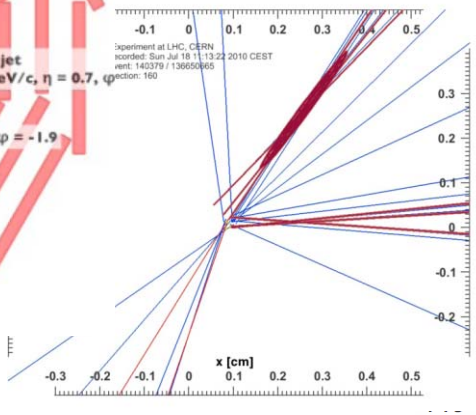
Single Boson and Di-Boson Production



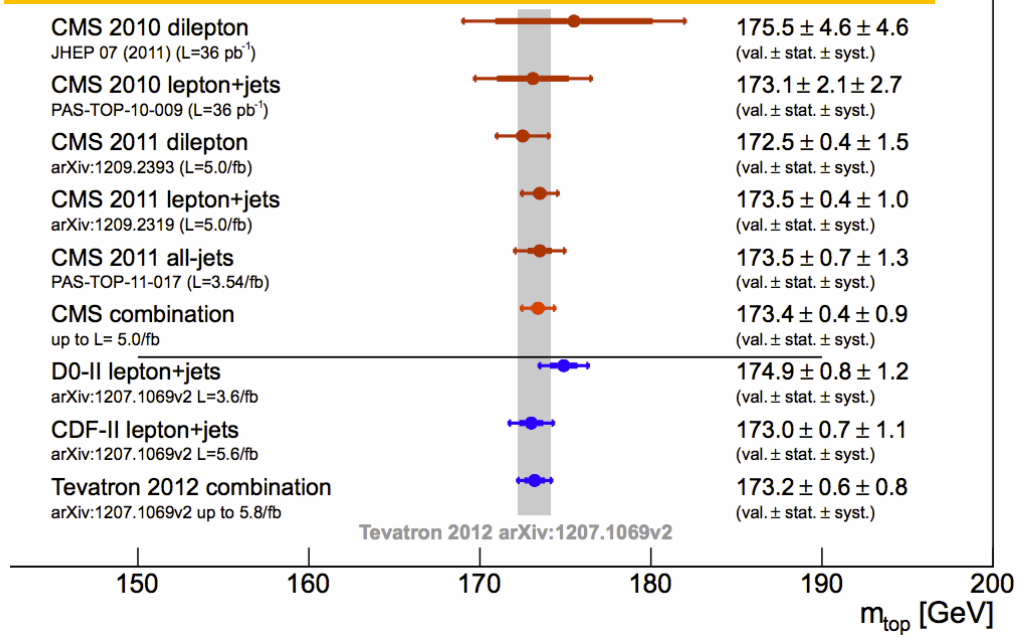
Top Quark Cross Section and Mass



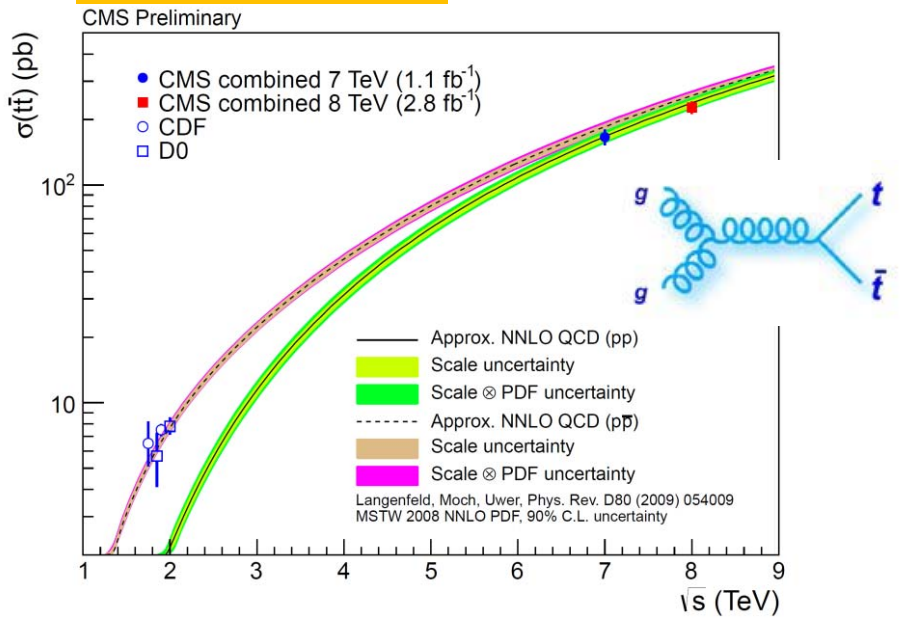
$$t\bar{t} \rightarrow \mu\nu b \mu\nu \bar{b}$$



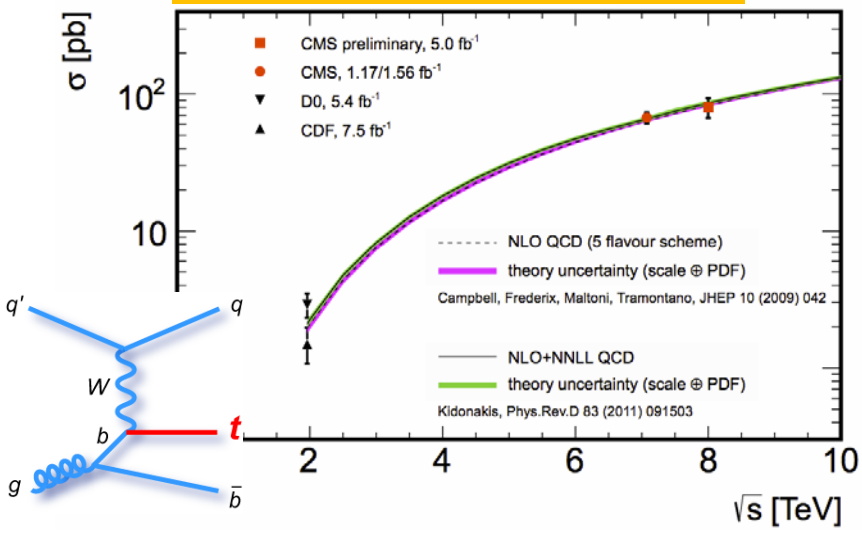
top mass mt = 173.36 ± 0.38 (stat.) ± 0.91 (syst.)GeV



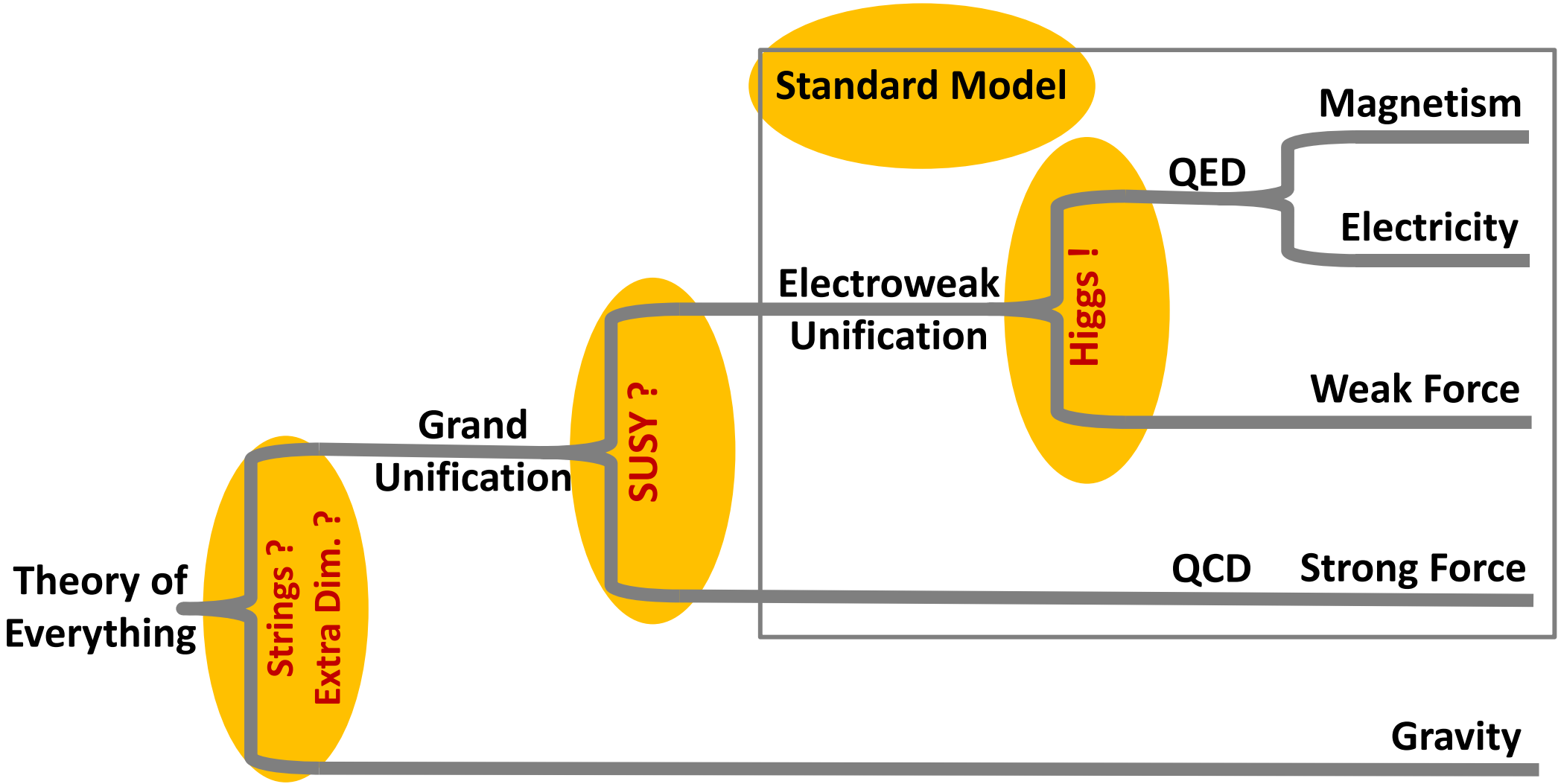
top pair production



t-channel single top production

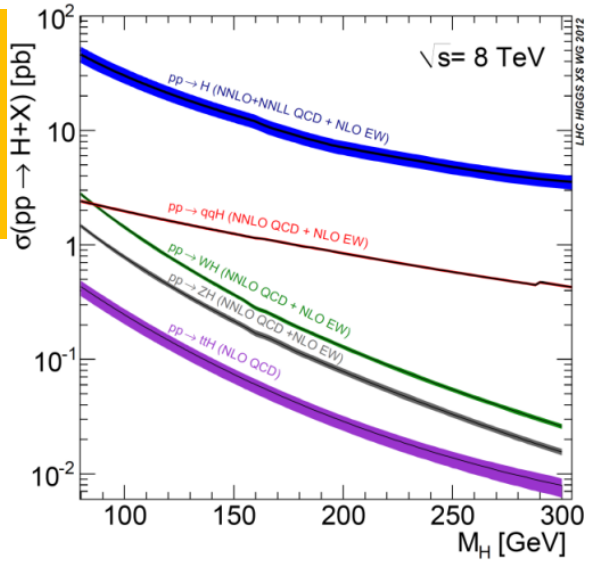


LHC Physics Goals



The Higgs Boson

production



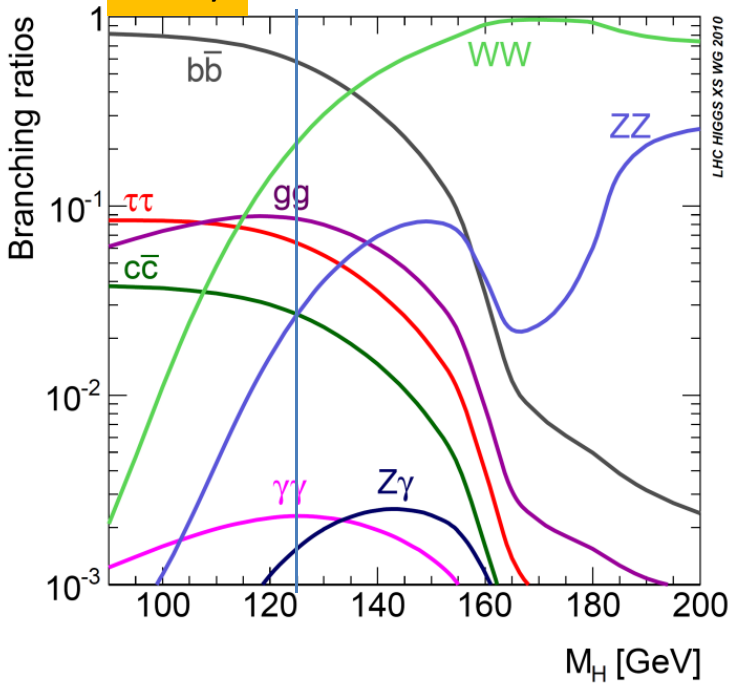
if $m_H \approx 125$ GeV then

$\sigma(pp \to H + X) \approx 15$ pb

$\to$ in $L = 5$ fb^{-1}: 75'000 higgs bosons

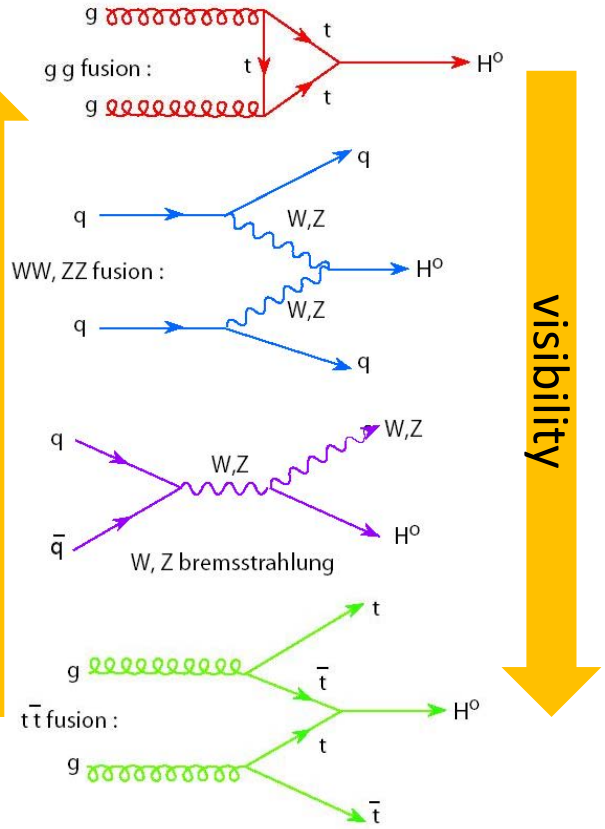
$\Gamma(H) \approx 4$ MeV

decay



cross section

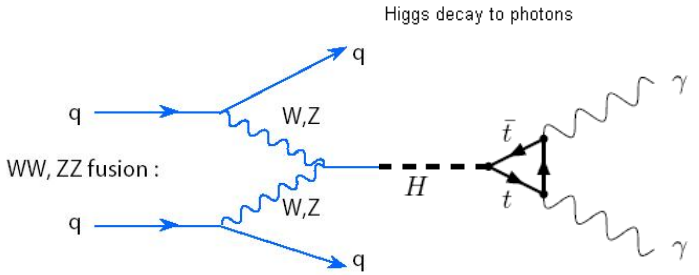
visibility

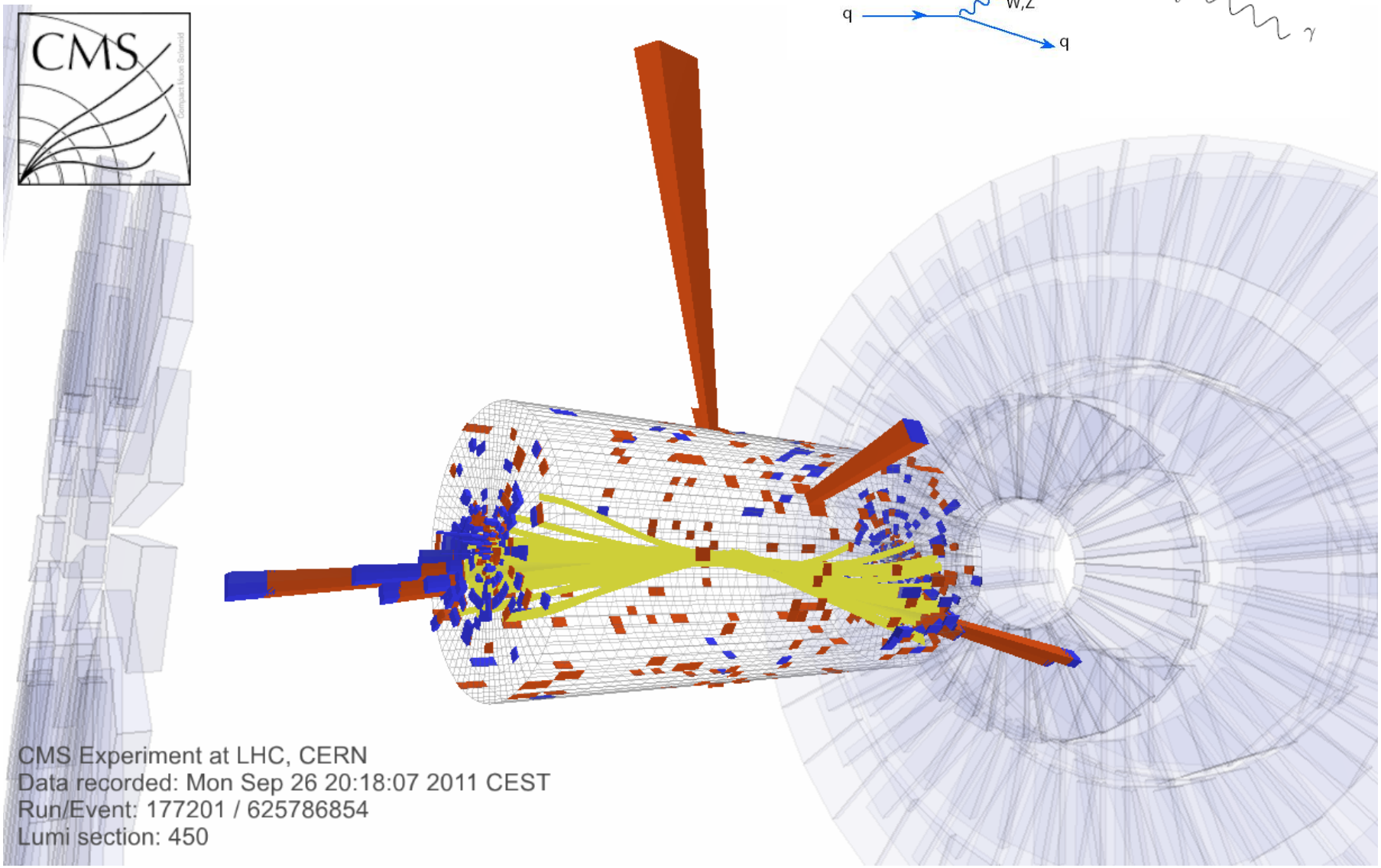


	H→γγ	H→ZZ	H→WW	H→bb	H→ττ
gg→H	+	+	+	-	+
qq→qqH	+		+		+
qq→VH				+	
gg→ttH					

mass resolution	1-3%	1-7%	20%	10%	20%

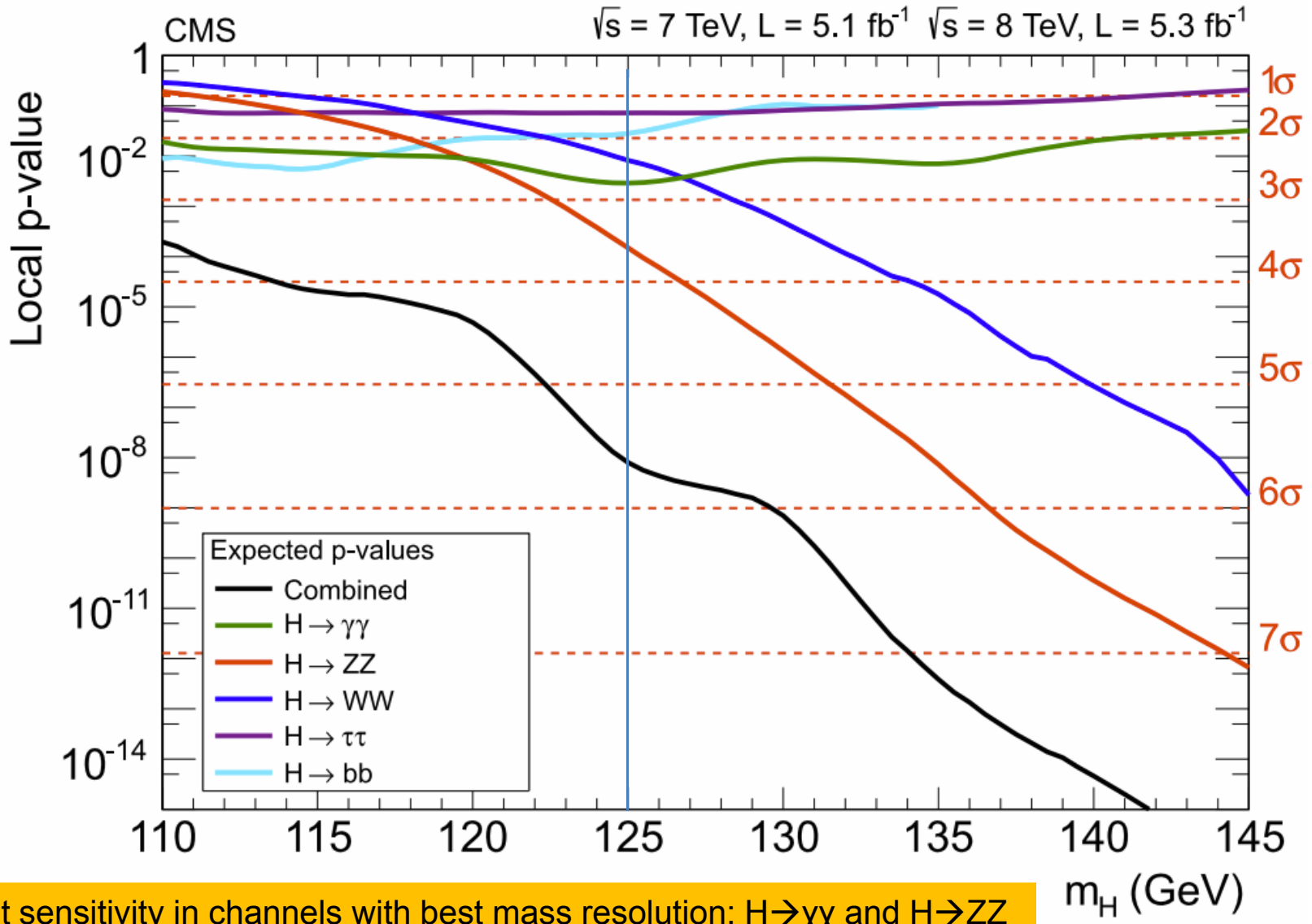
di-jet tagging: qq→qqH→qqɣɣ



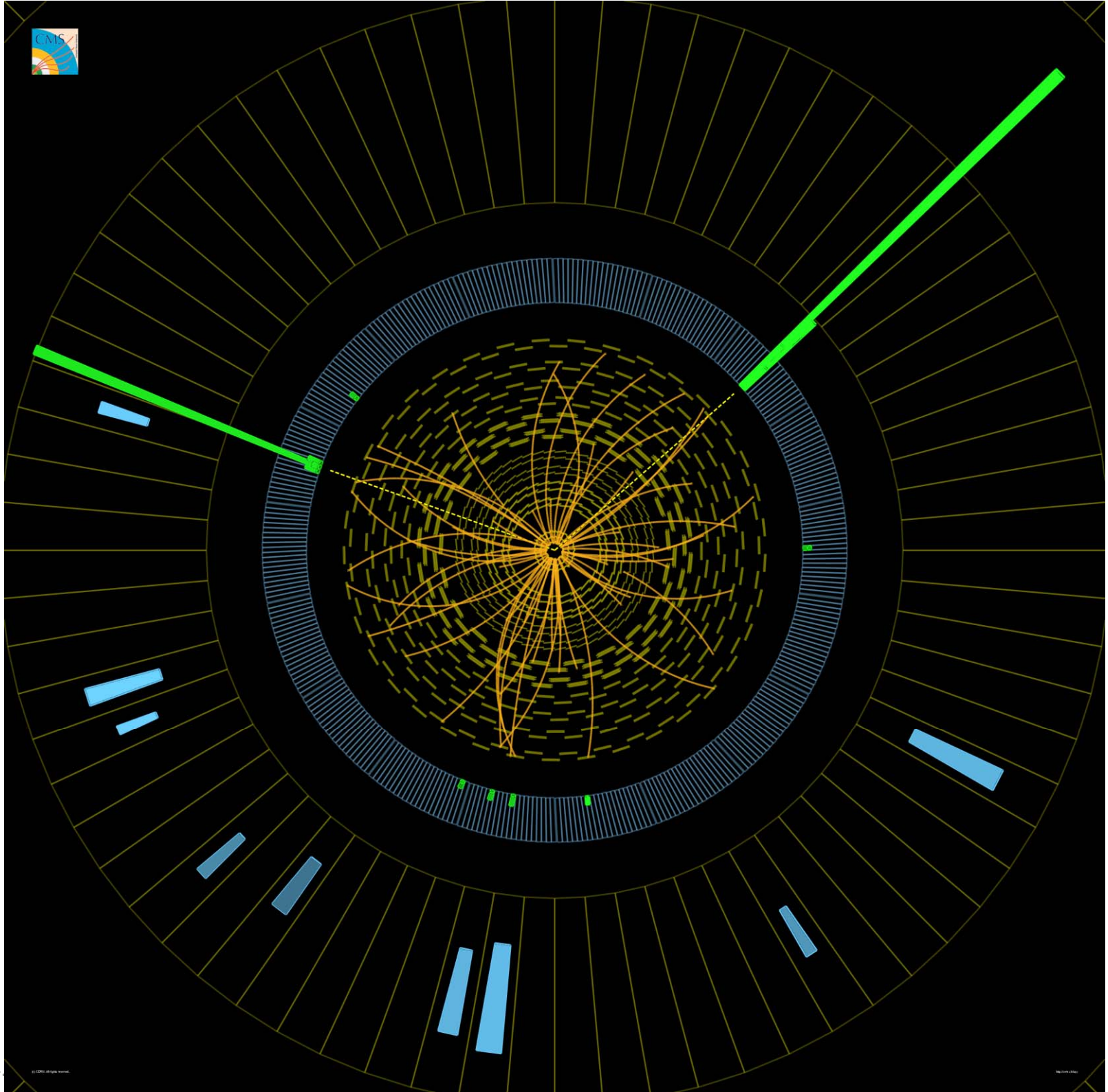


Sensitivity of different channels

p-value: probability that background fluctuates to an excess as large as expected from the SM higgs

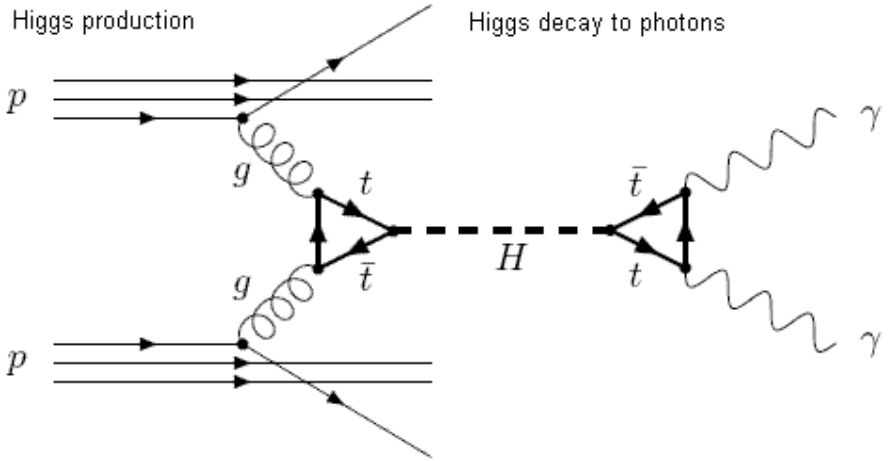


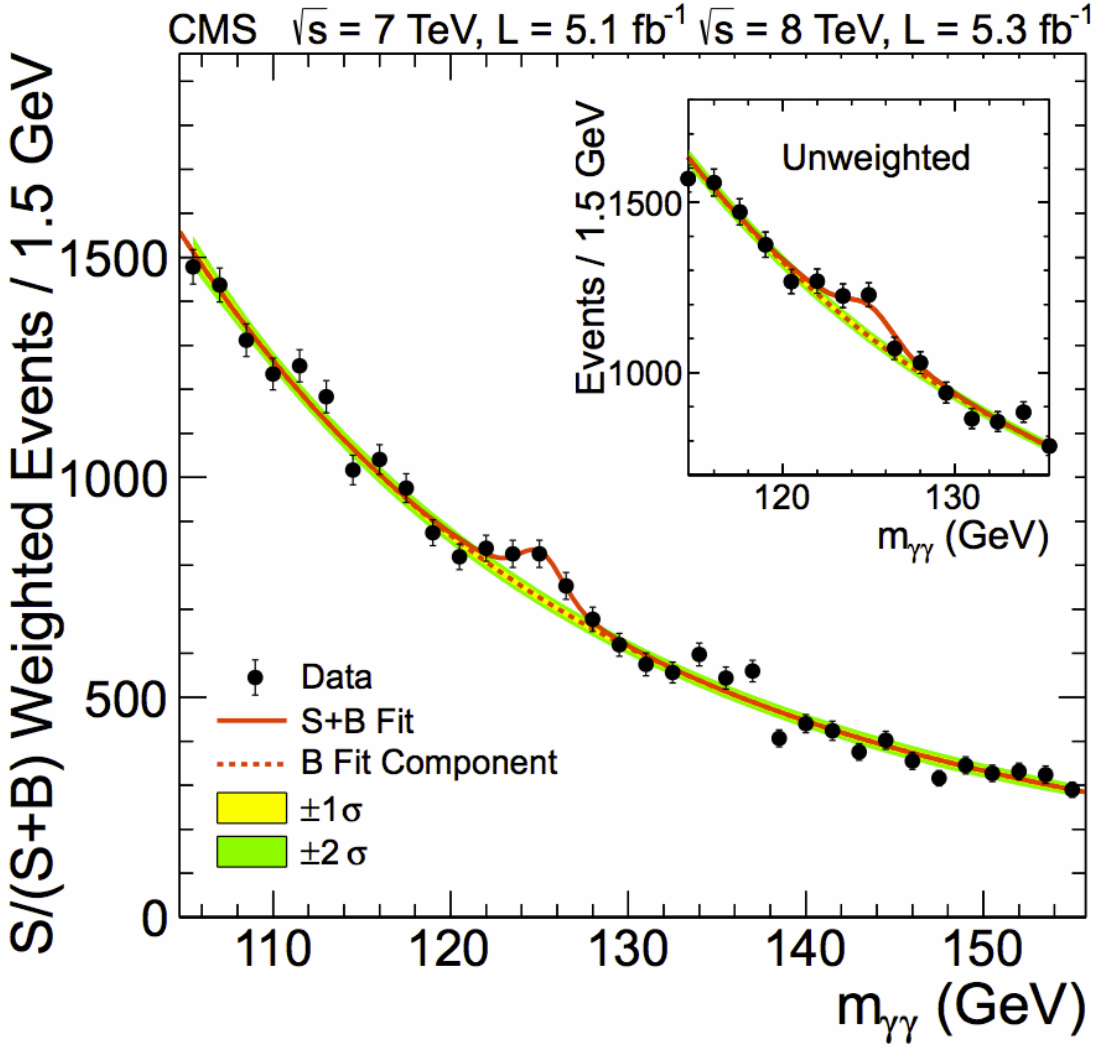
highest sensitivity in channels with best mass resolution: H→γγ and H→ZZ
mass resolution = significance!

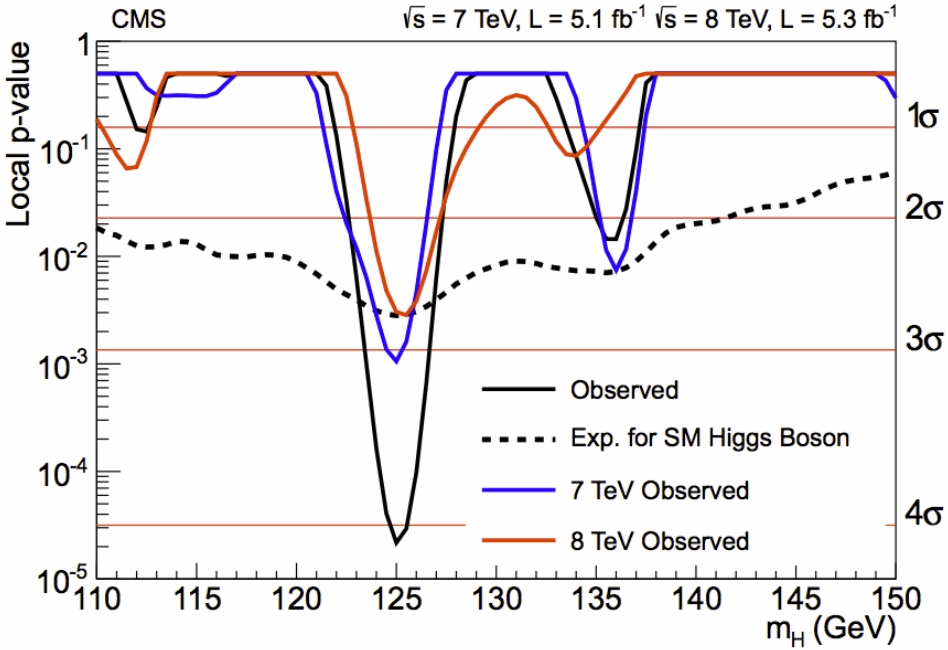


H→γγ

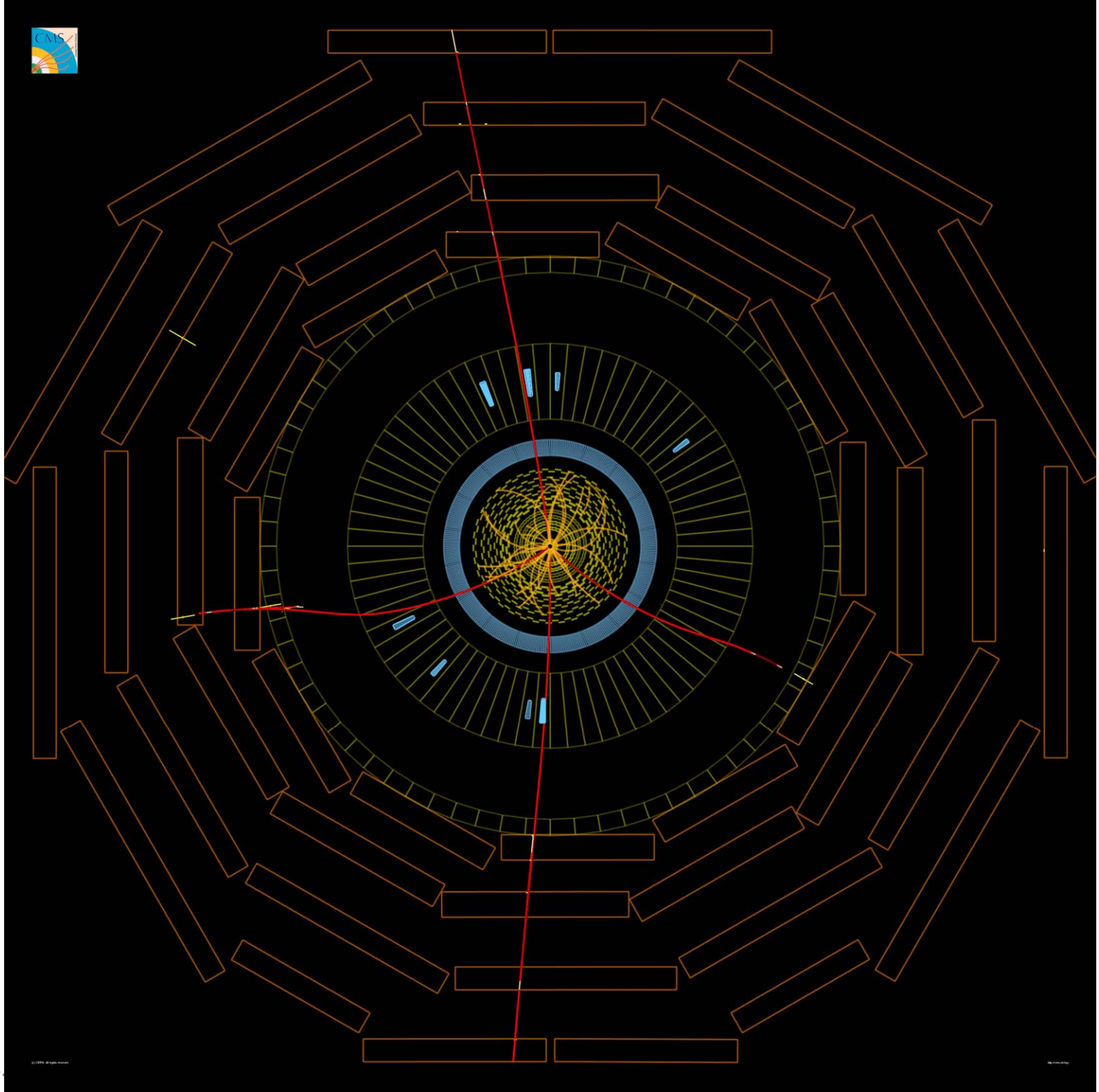
- ECAL energy resolution decides
- γγ mass resolution 3-4 GeV
- multi-variate analysis for photon ID and event classification



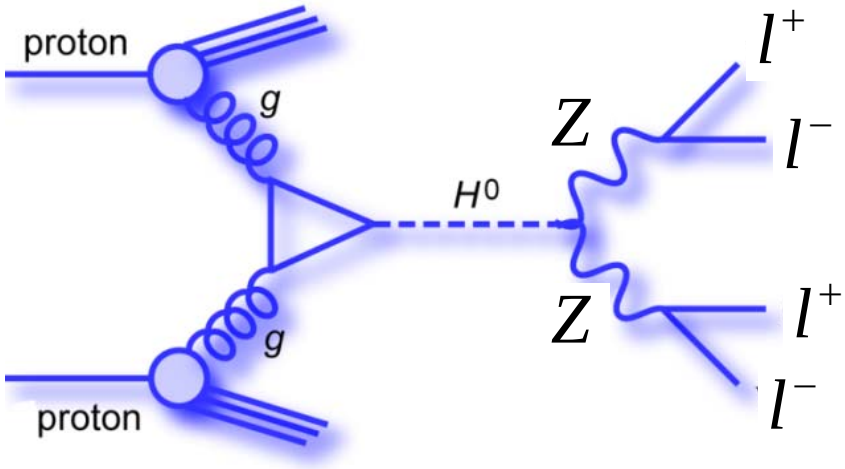


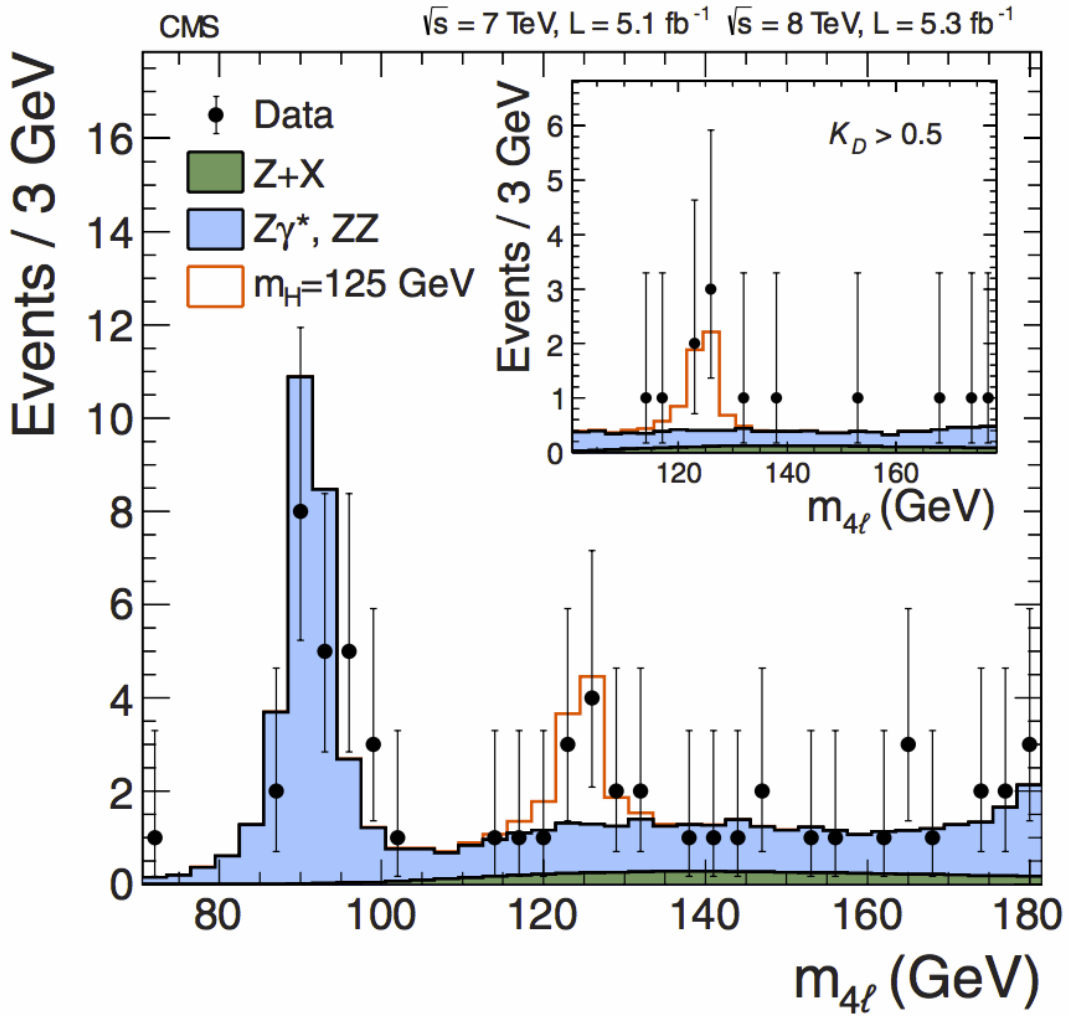


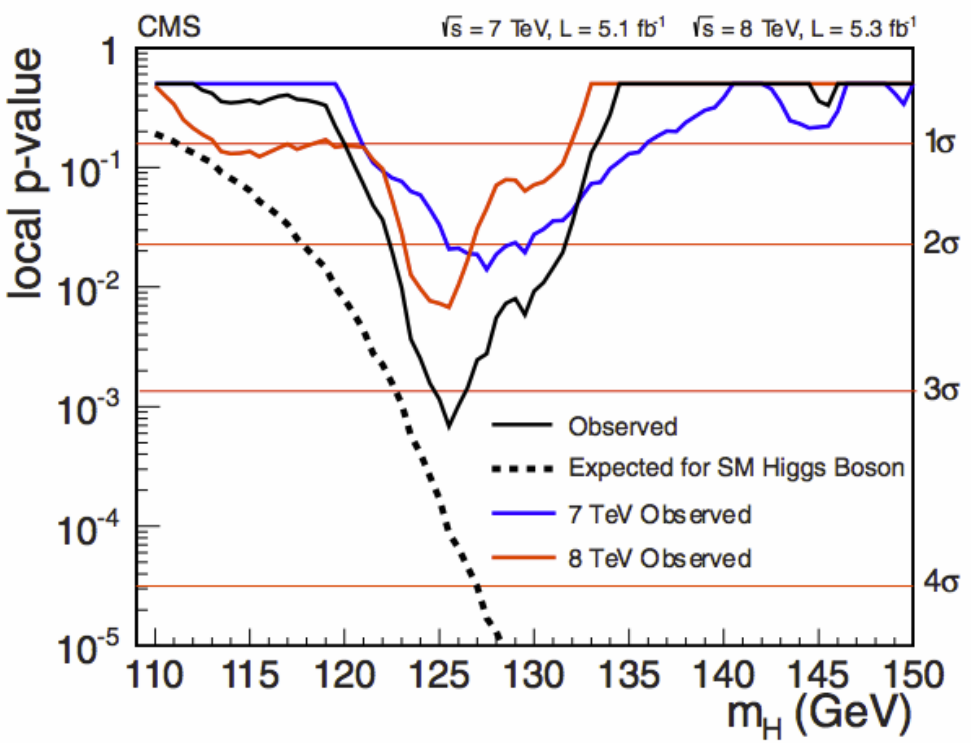
significance 4.1σ



H→ZZ



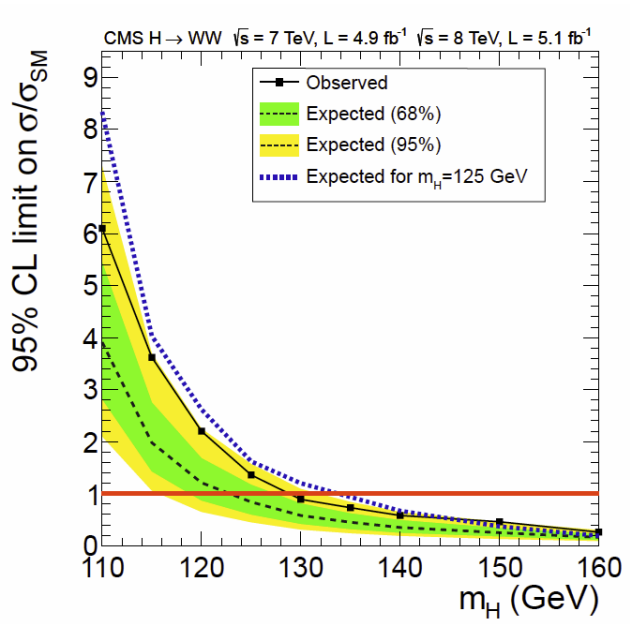




significance 3.1σ

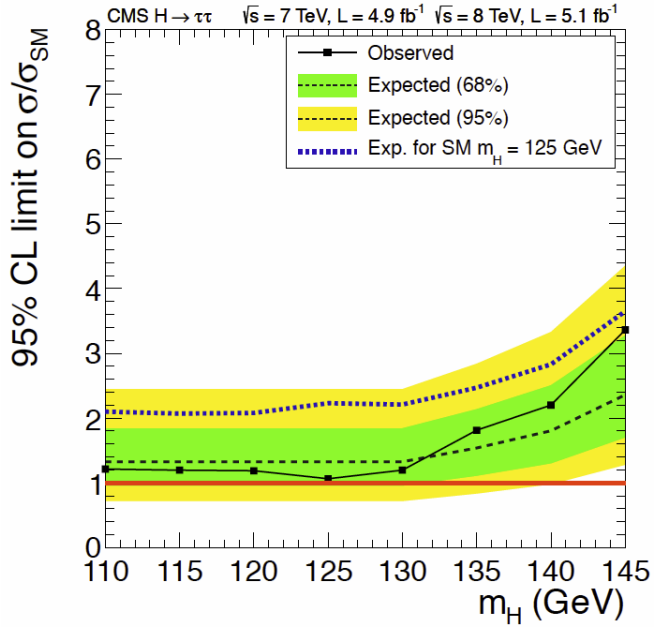
The low mass resolution channels

H→WW (gg→H, qq→qqH)



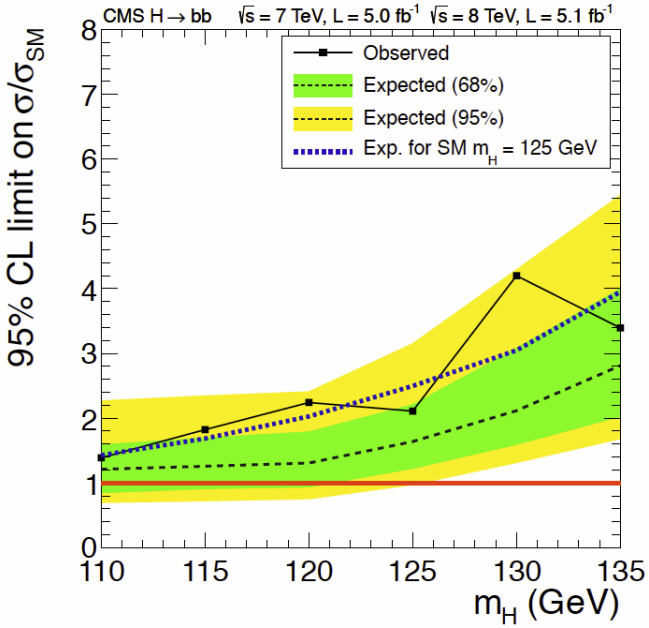
broad excess

H→ττ (gg→H, qq→qqH)



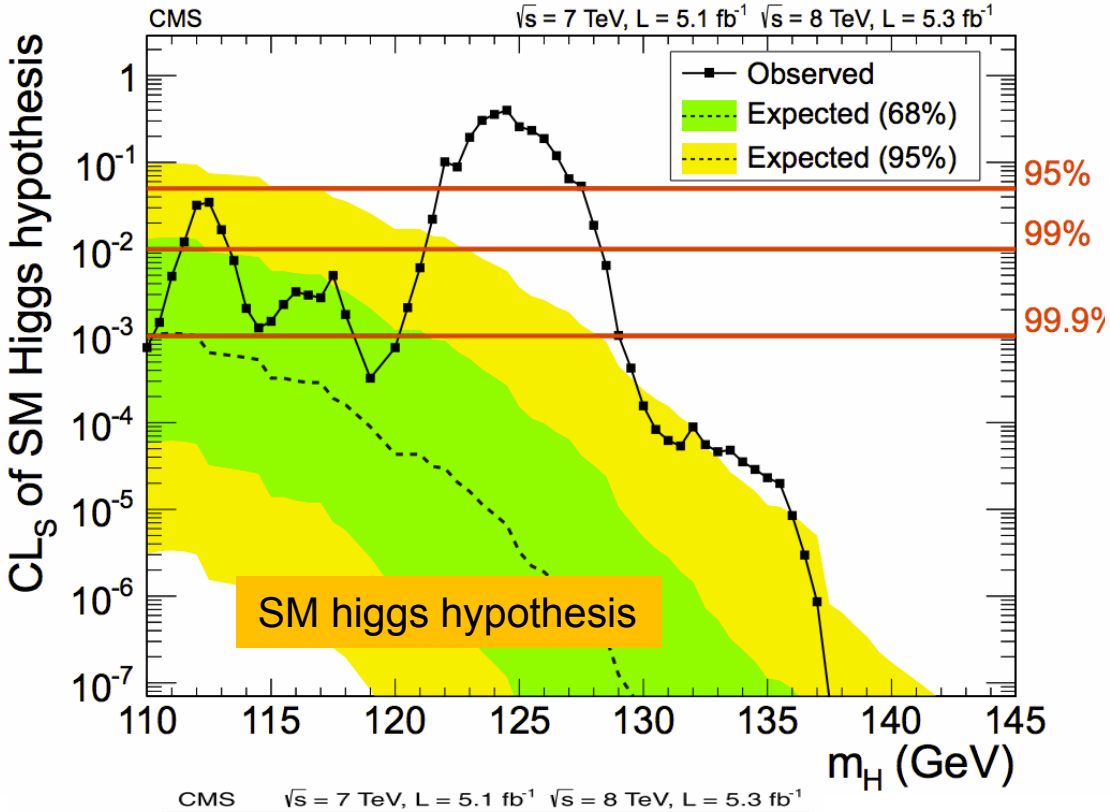
‚background like'

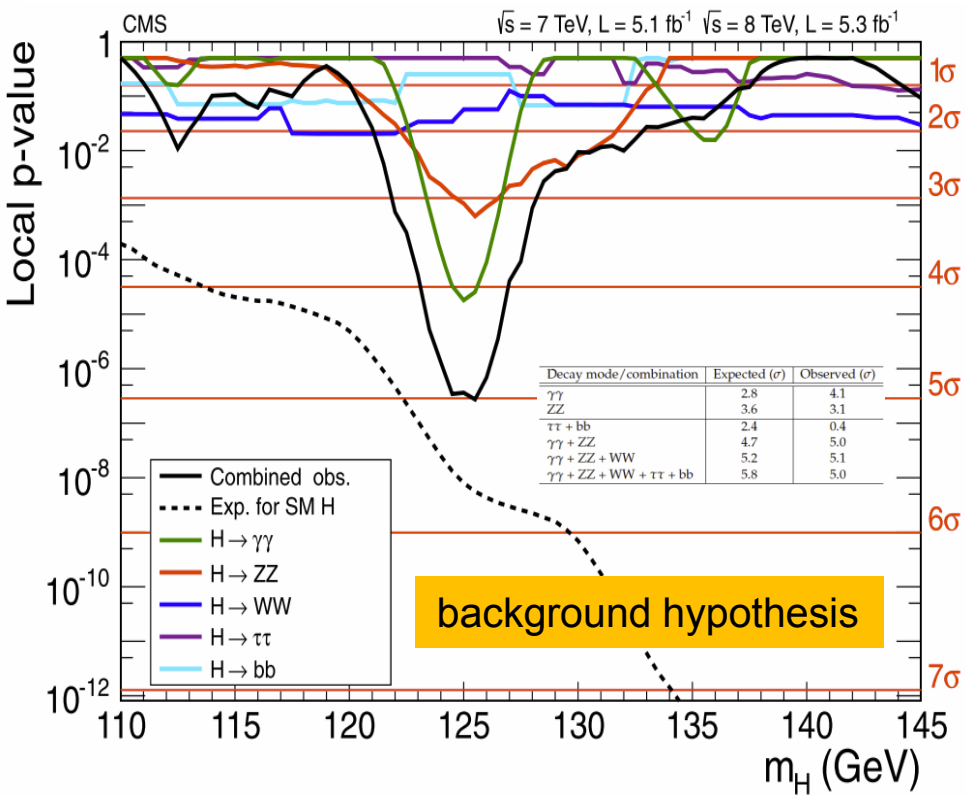
H→bb (qq→VH)

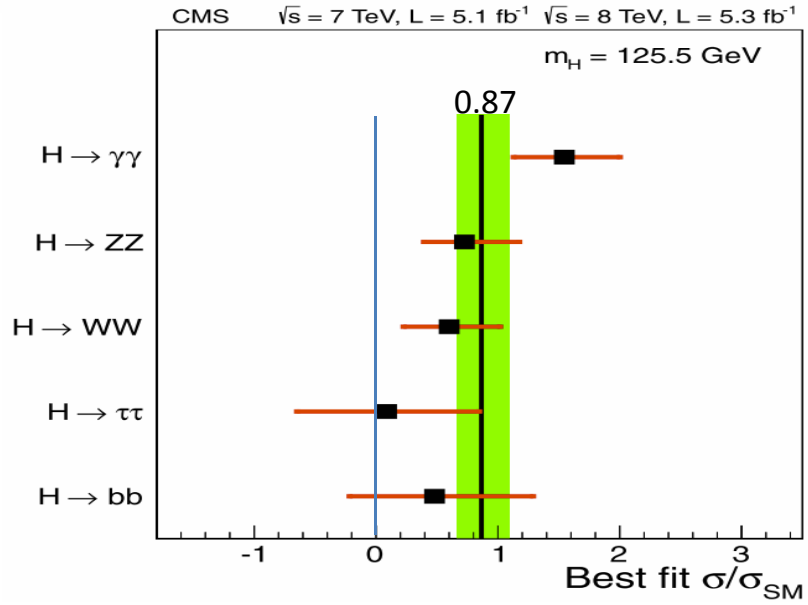


broad excess

Observed Yields







higgs boson excluded at 95% CL everywhere up to 600 GeV except around 125 GeV

at 125 GeV we observe a 5 sigma deviation from the background hypothesis

yields in all channels (still) consistent with SM higgs

ratio of couplings to Z and W consistent with SM

good agreement between 2011 and 2012 data

CERN-PH-EP/2012-220
2012/08/01

CMS-HIG-12-028

Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC

The CMS Collaboration*

Abstract

Results are presented from searches for the standard model Higgs boson in p
proton collisions at $\sqrt{s} = 7$ and 8 TeV in the CMS experiment at the LHC,
data samples corresponding to integrated luminosities of up to 5.1 fb^{-1} at 7 Te
5.3 fb^{-1} at 8 TeV. The search is performed in five decay modes: $\gamma\gamma$, ZZ, WW,
and $b\bar{b}$. An excess of events is observed above the expected background, a local s
icance of 5.0 standard deviations, at a mass near 125 GeV, signalling the produ
of a new particle. The expected significance for a standard model Higgs bos
that mass is 5.8 standard deviations. The excess is most significant in the two
modes with the best mass resolution, $\gamma\gamma$ and ZZ; a fit to these signals gives a m
$125.3 \pm 0.4\,(\text{stat.}) \pm 0.5\,(\text{syst.})$ GeV. The decay to two photons indicates that th
particle is a boson with spin different from one.

This paper is dedicated to the memory of our colleagues who worked on CMS but have since passed away.

In recognition of their many contributions to the achievement of this observation

we have observed a new particle!

it decays to γγ and ZZ

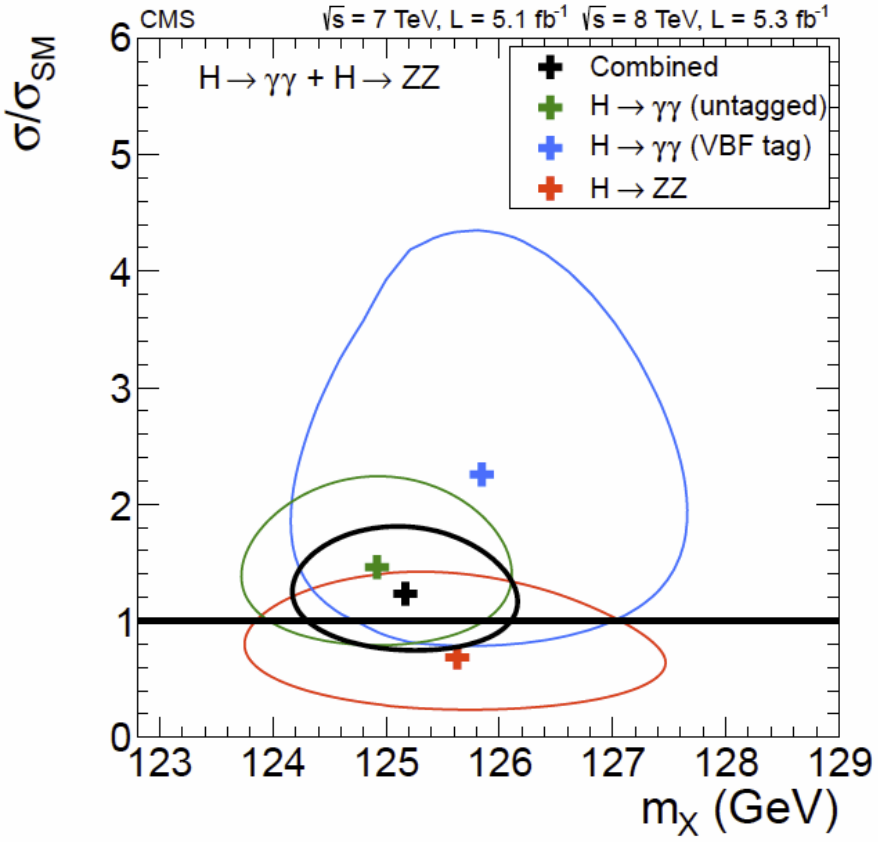
→ spin 0 or 2
(spin 1 forbidden by Landau Yang theorem)

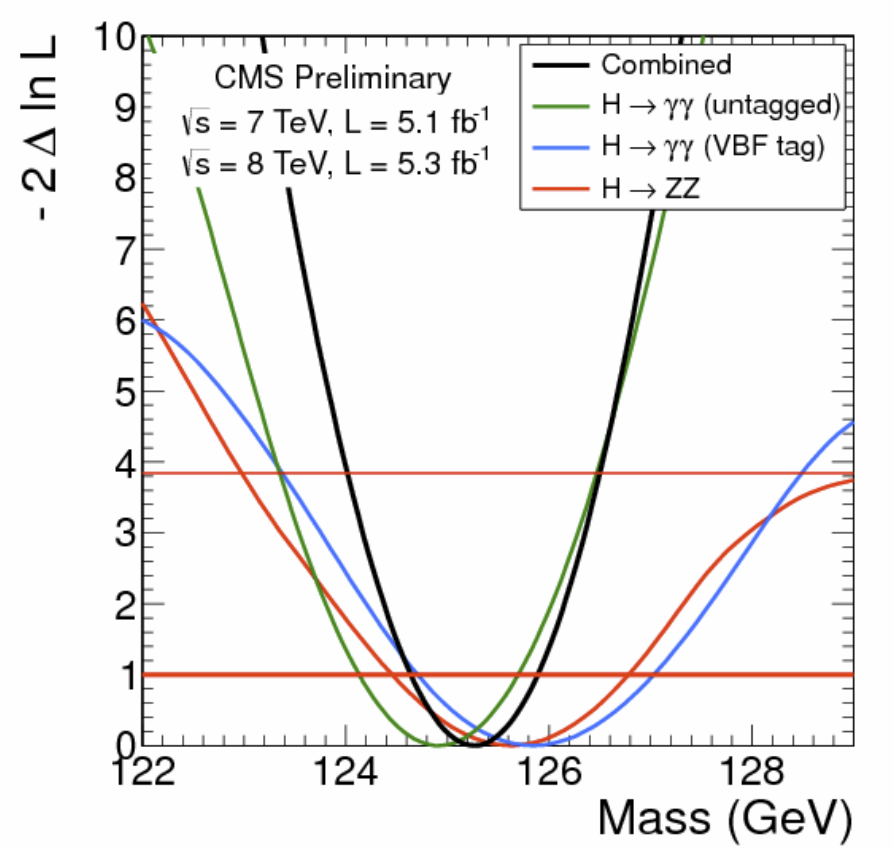
→ it is a boson

→ it is a new kind of particle
the first with this spin value

→ **the LHC has achieved one of it‘s main goals (either the higgs or new physics!)**

Observed Mass

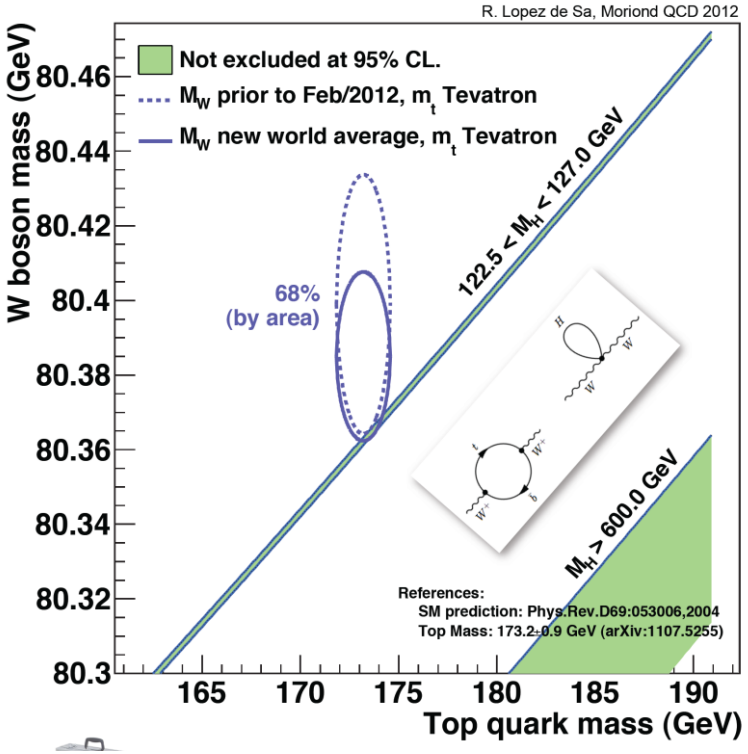


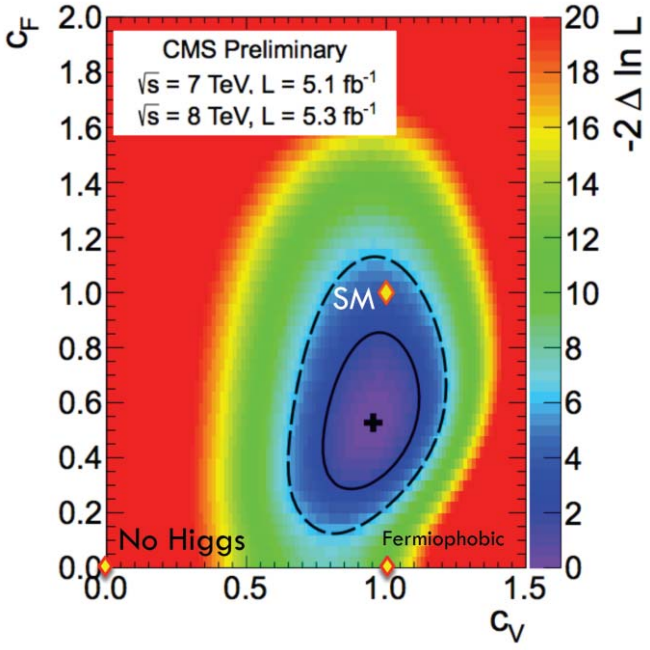


m = 125.3 +/- 0.6 GeV

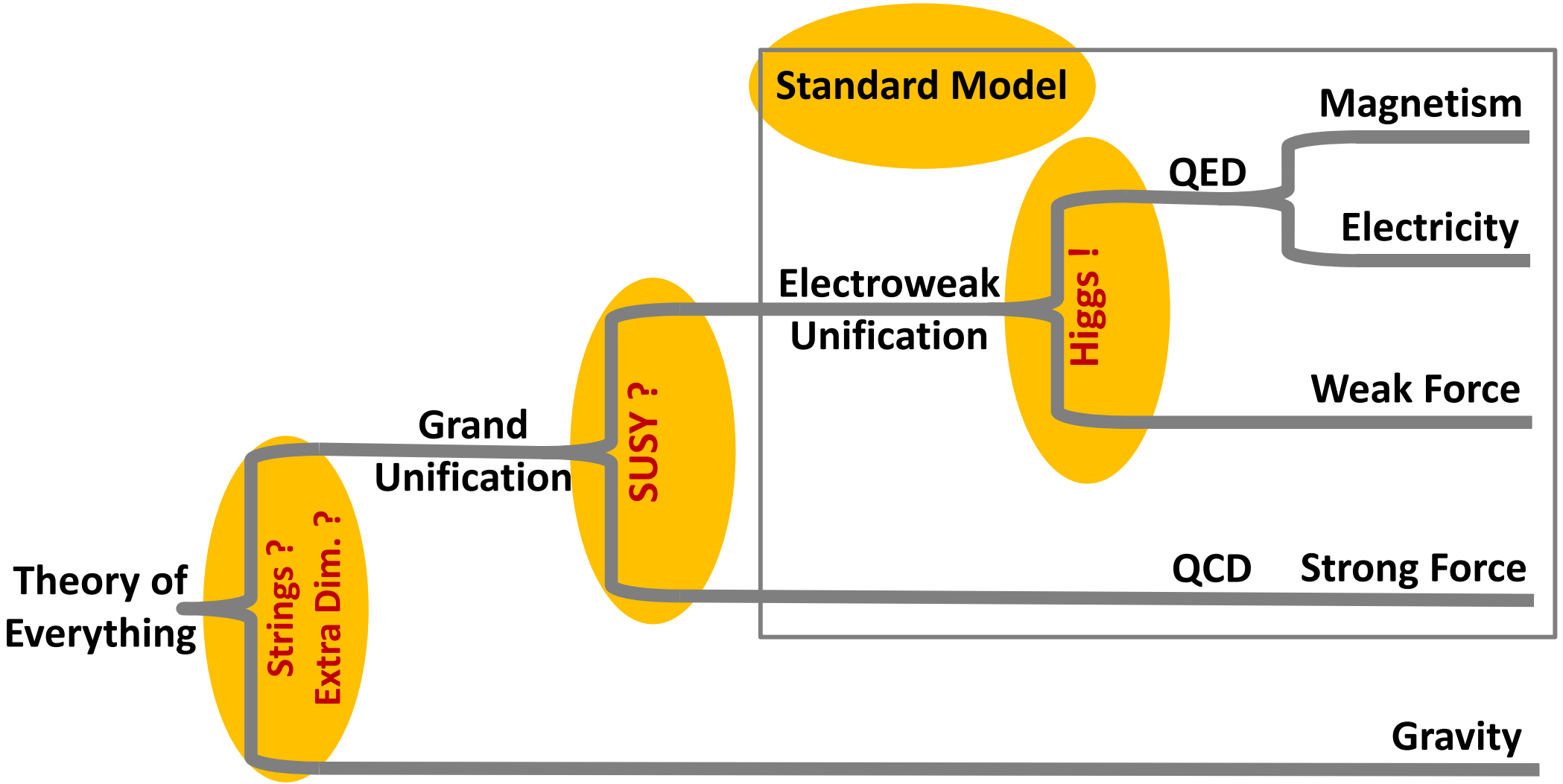
Higgs Outlook

- a higgs mass of 125 GeV is fully consistent with the standard model fit
- **but is the new boson the standard model higgs?**
- investigate couplings to as many particles as possible!
- measure spin and parity from angular distributions in H→ZZ, H→WW and H→γγ
  4 σ separation expected between 0^+ vs. 0^- and 0^+ vs. 2^+ for 35/fb per experiment
- more channels will be analysed (e.g. gg→ttH with H→bb)
- existing analyses are still being improved
- more data to come this year
- with a lot more data: WW scattering



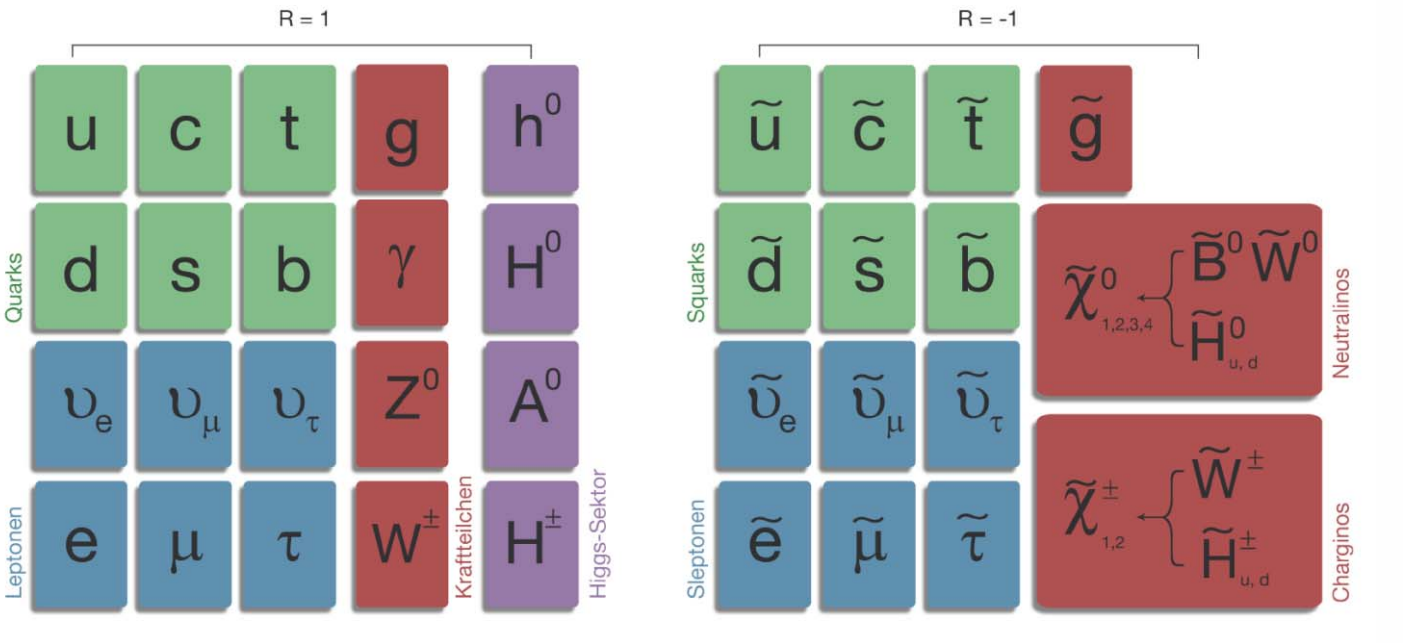


LHC Physics Goals



higgs discovery → hierarchy problem

Supersymmetry



well known motivations

- stabilization of higgs mass
- unification of couplings
- dark matter candidate
- dynamic generation of EWSB
- max. symmetry of S matrix
- connection to gravity
- …

MSSM

minimal extension of the SM (105 free parameters)

cMSSM (aka MSUGRA)

unification of masses at the GUT scale

4.5 free parameters: m_0, $m_{1/2}$, tanβ, A_0, sign(μ)

SUSY Signatures

0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	2-photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	Di-photon + jet + MET	Photon + lepton + MET

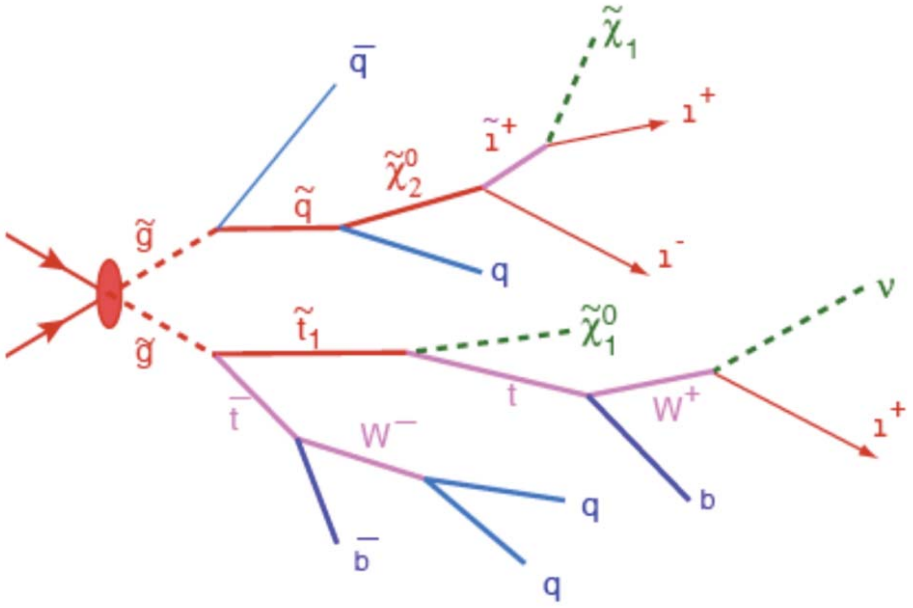
similar signatures in other BSM scenarios (e.g. extra dimentions)

$$MET = E_T^{miss} = \left| \sum_{i=1}^{n_{jet}} \vec{p}_T(j_i) \right|$$

many observables to distinguish true missing transverse energy from QCD background:

MET, α_T, Razor, MT2, MHT

b-tags used to search for 3rd generation squarks



data-driven background estimation

A hadronic search: α_T

[CMS PAS SUS-12-016]

Selection: $3.9\ \text{fb}^{-1}$ of 2012 data

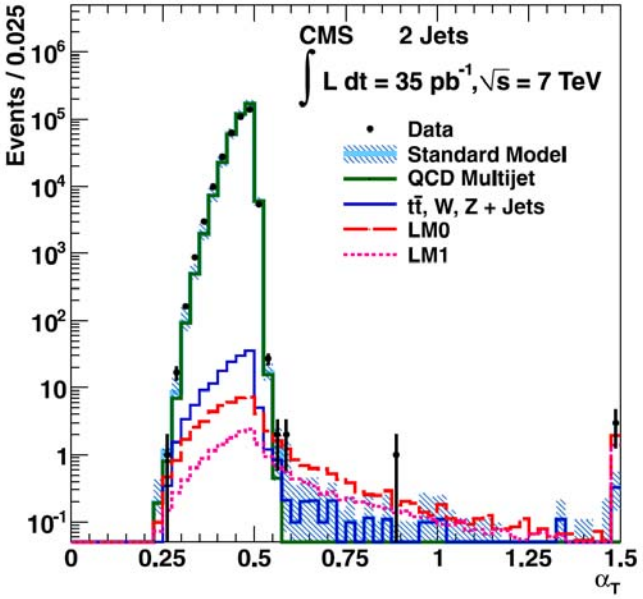
two jets with $E_T > 100$ GeV

$$H_T = \sum_{i=1}^{N_{jet}} E_T(j_i) > 275\ \text{GeV}$$

lepton veto

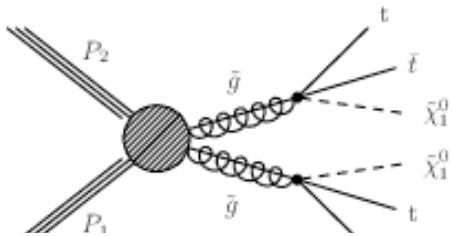
$$\alpha_T = \frac{E_T(j_2)}{M_T} > 0.55 \quad \text{with} \quad M_T = \sqrt{\left(\sum_{i=1}^{2} E_T(j_i)\right)^2 - \left(\sum_{i=1}^{2} p_x(j_i)\right)^2 - \left(\sum_{i=1}^{2} p_y(j_i)\right)^2}$$

$0, 1, 2$ or 3 b-tagged jets

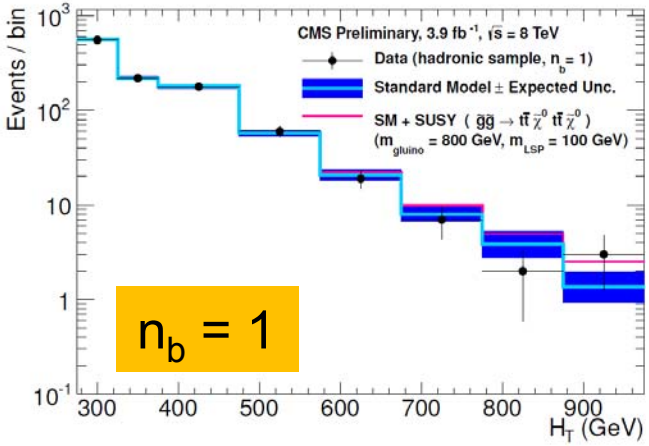


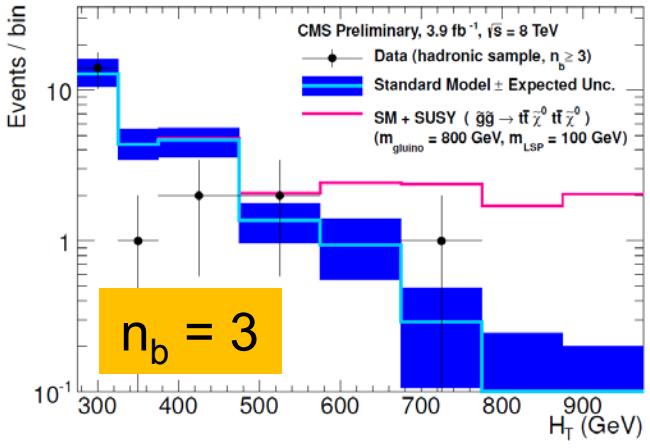
results consistent with SM prediction (data driven)

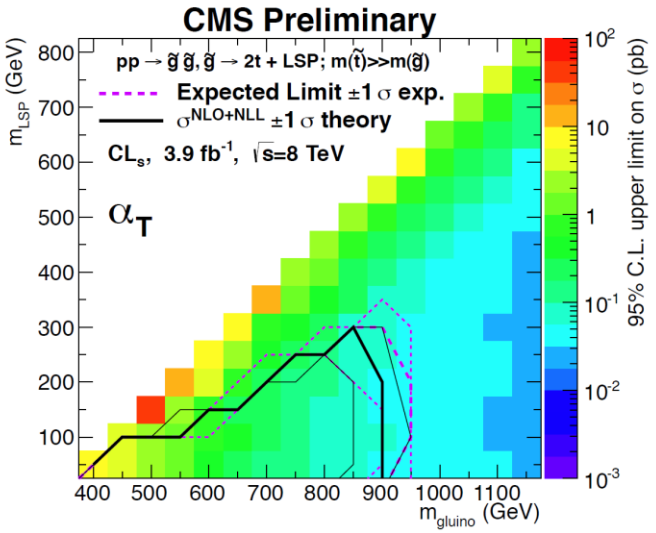
→ limits in cMSSM and in simplified model



2012 data







A leptonic search: opposite sign di-leptons

[arXiv:1206.3949v1]

Selection: $5\ \text{fb}^{-1}$ of 2011 data

two opposite-sign leptons

at least 2 jets

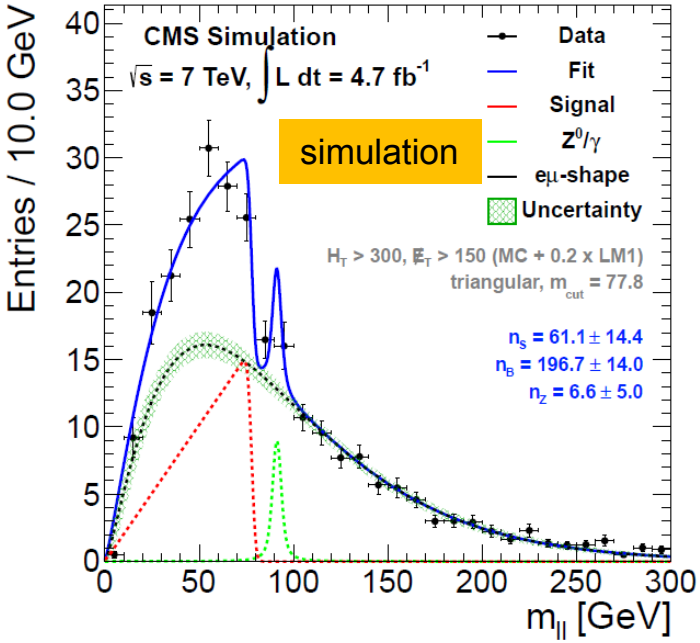
$H_T > 300$ GeV

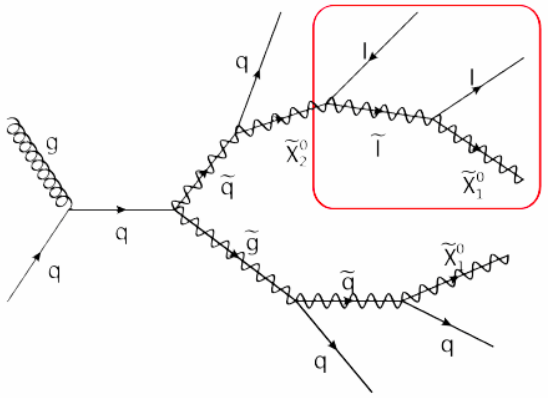
$E_T^{miss} > 150$ GeV

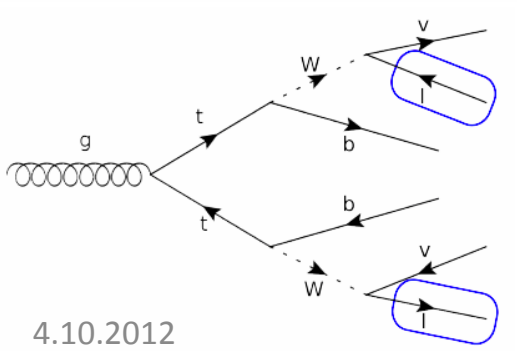
measure flavour-symetric back-ground ($t\bar{t}$,..) from $e\mu$ events

$\rightarrow$ monte-carlo free analysis

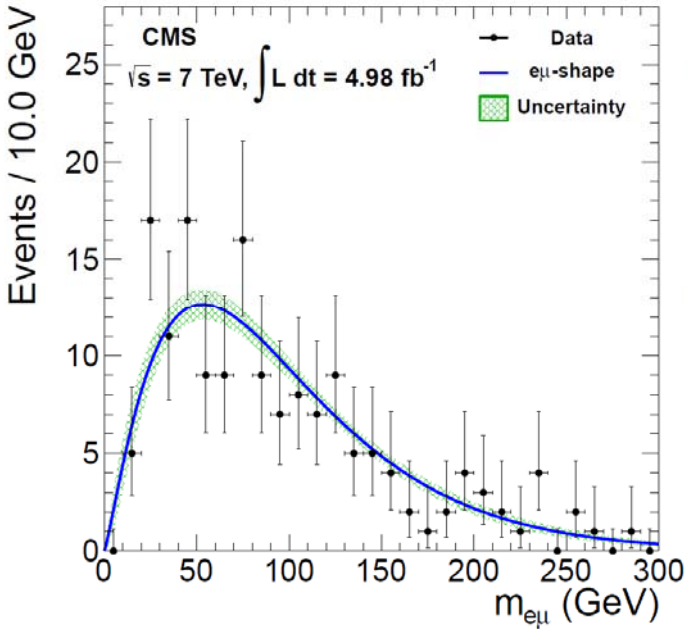
measurement consistent with SM background

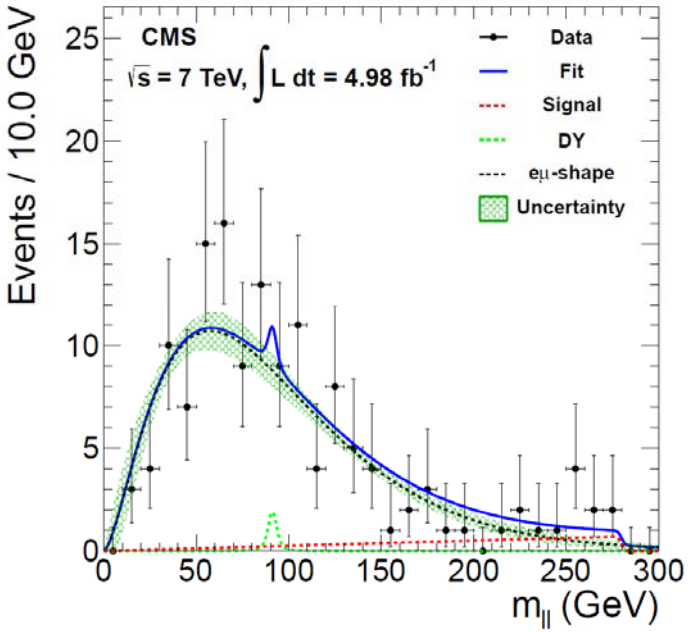




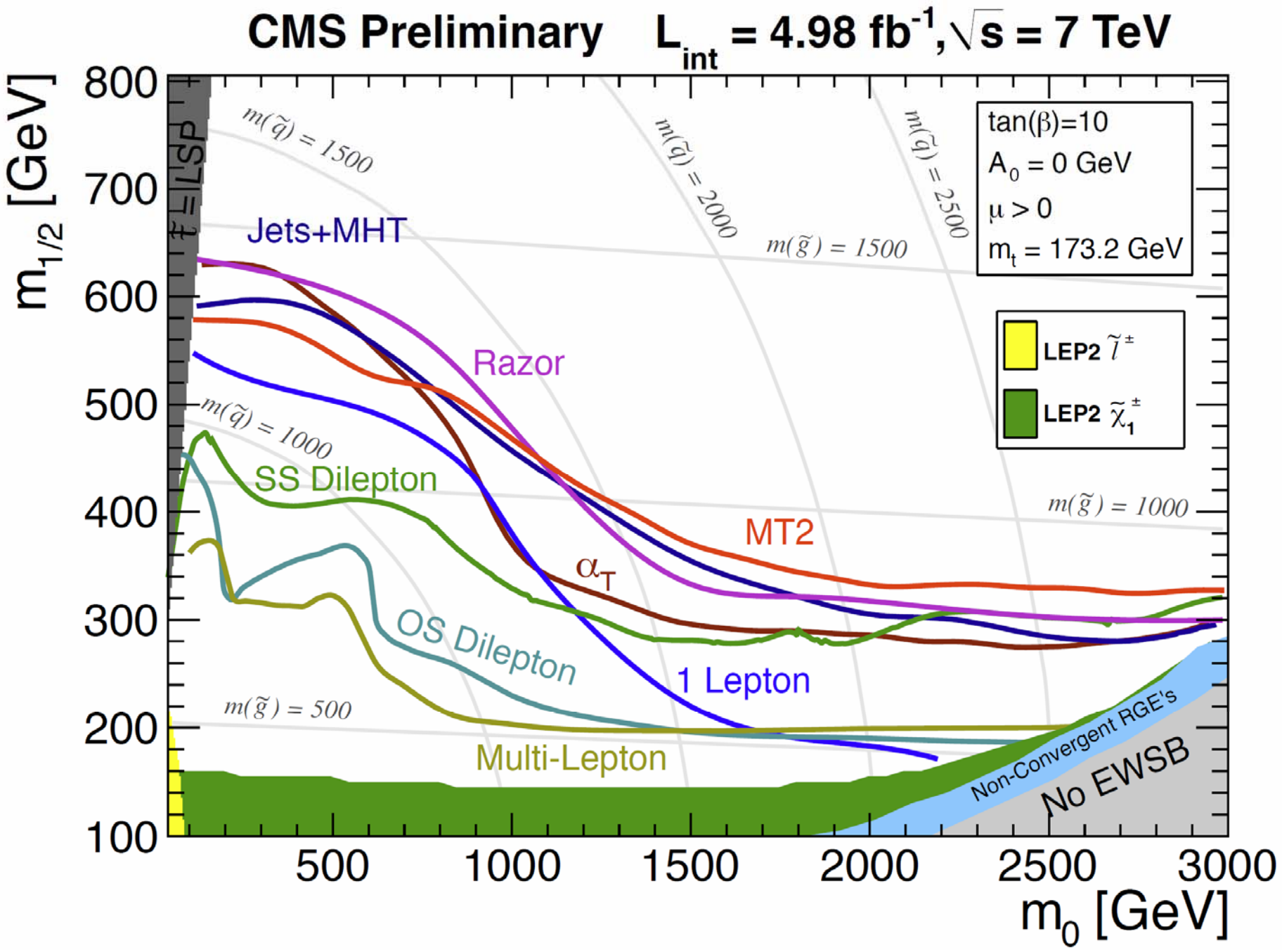


2011 data





Interpretation in the cMSSM



Search for the invisible

[arXiv:1206.5663v1]

Selection:

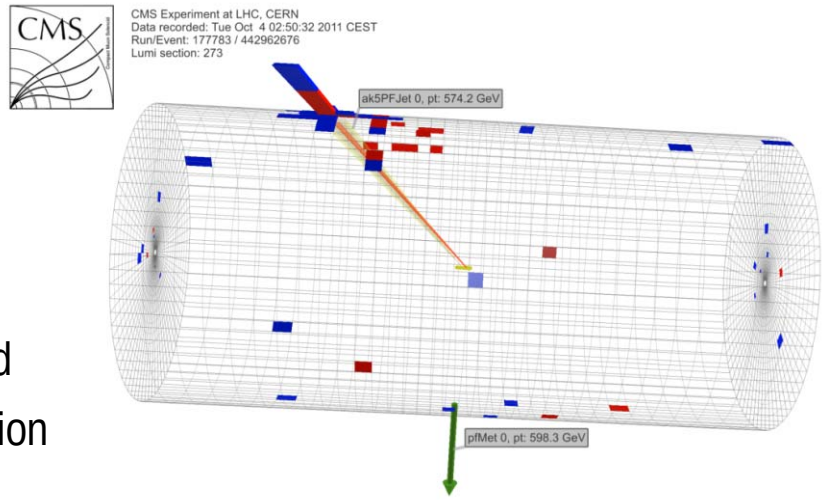
$E_T^{miss} > 200$ GeV

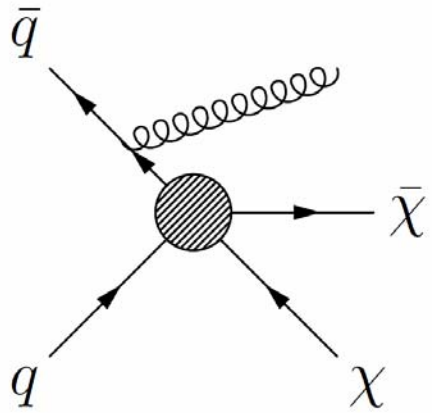
a jet with $E_T > 110$ GeV

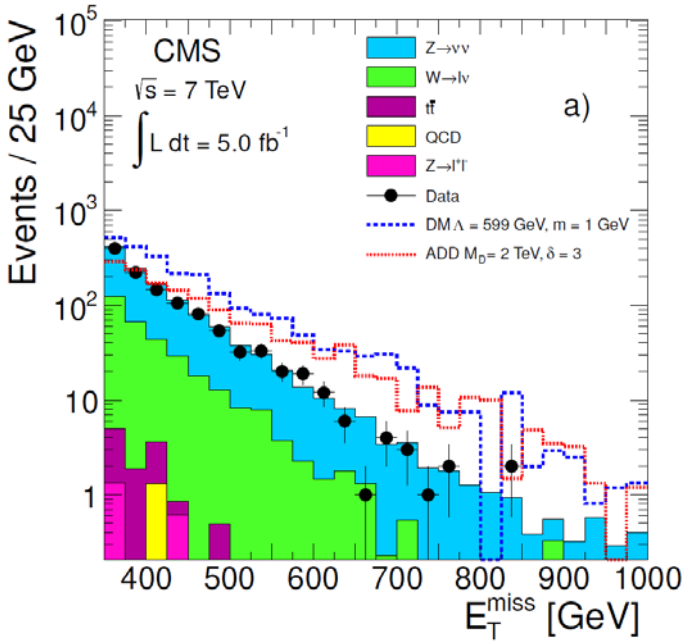
limits on:

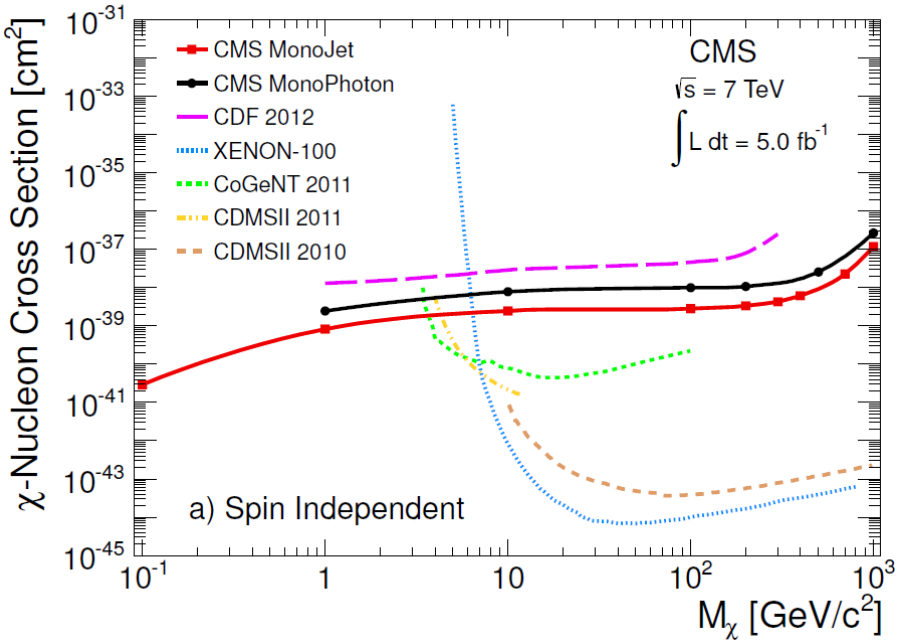
dark matter pair production and

on mass scale in extra dimension models

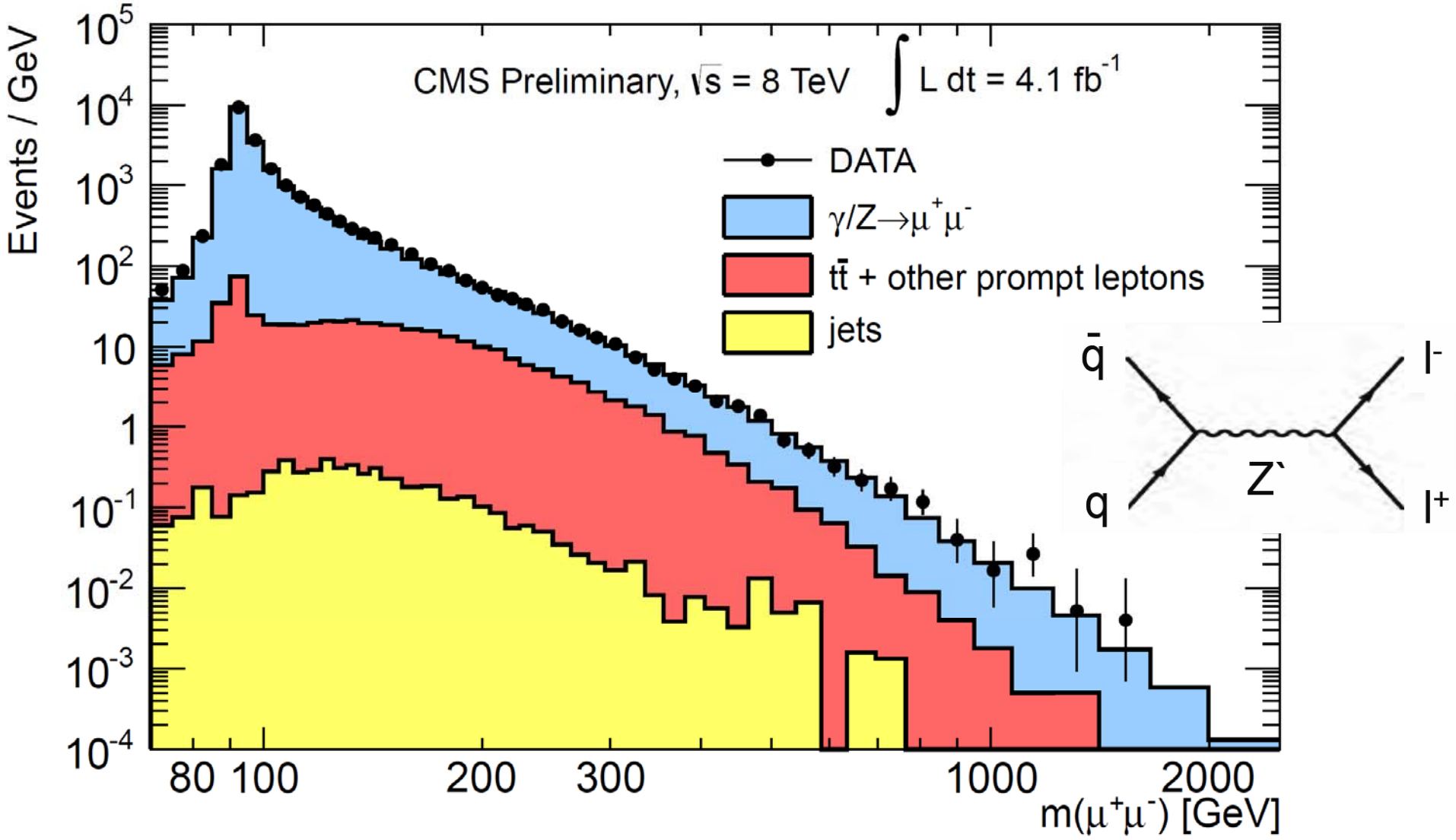








Heavy resonances: Z‘



Z‘ with SM-like couplings: m>2.59 TeV (95% CL) CMS-PAS-EXO-12-015

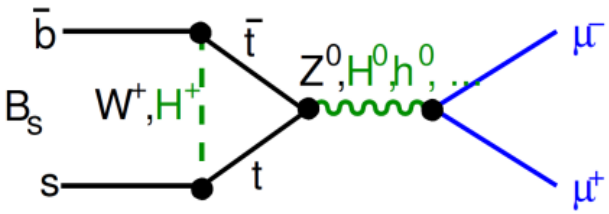
$B_s \to \mu\mu$

$B_s \to \mu^+\mu^-$ und $B_d \to \mu^+\mu^-$

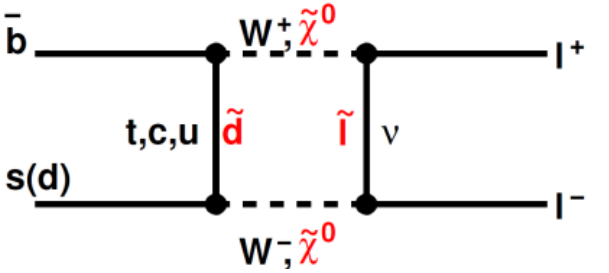
are highly suppressed in the standard model (FCNC, helicity suppression):

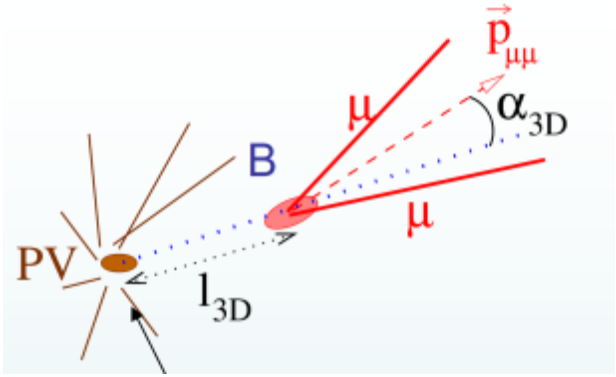
$$BR\left(B_s \to \mu^+\mu^-\right) = \left(3.2 \pm 0.2\right) \times 10^{-9}$$

$$BR\left(B_d \to \mu^+\mu^-\right) = \left(1.0 \pm 0.1\right) \times 10^{-10}$$



modifications are predicted in extensions to the standard model





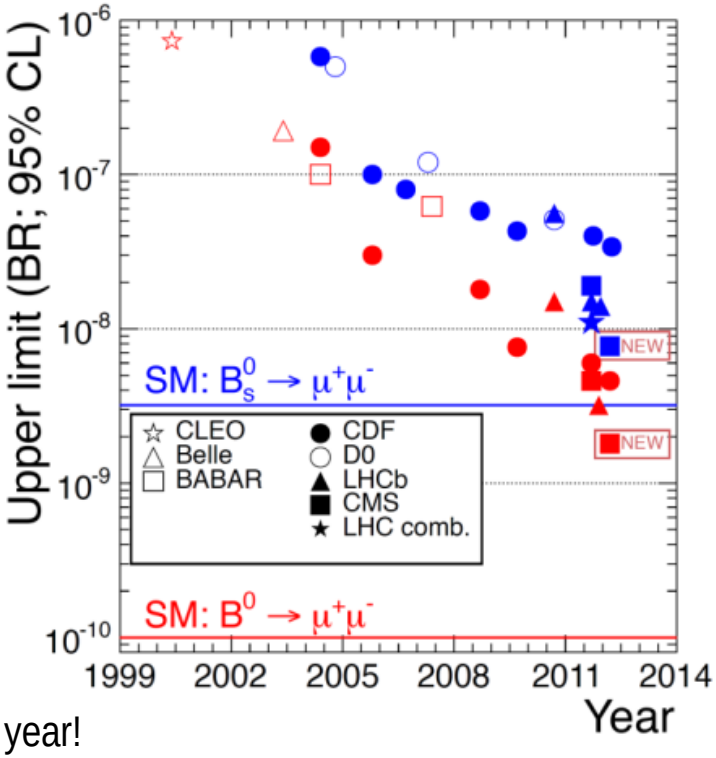
Observed limit in 5 fb^{-1} (95% CL):

$$BR\left(B_s \to \mu^+\mu^-\right) < 7.7 \times 10^{-9}$$

$$BR\left(B_d \to \mu^+\mu^-\right) < 18 \times 10^{-10}$$

LHC combination:

$$BR\left(B_s \to \mu^+\mu^-\right) < 4.2 \times 10^{-9}$$



→ we are very close to the SM value, the definitive answer will come this year!

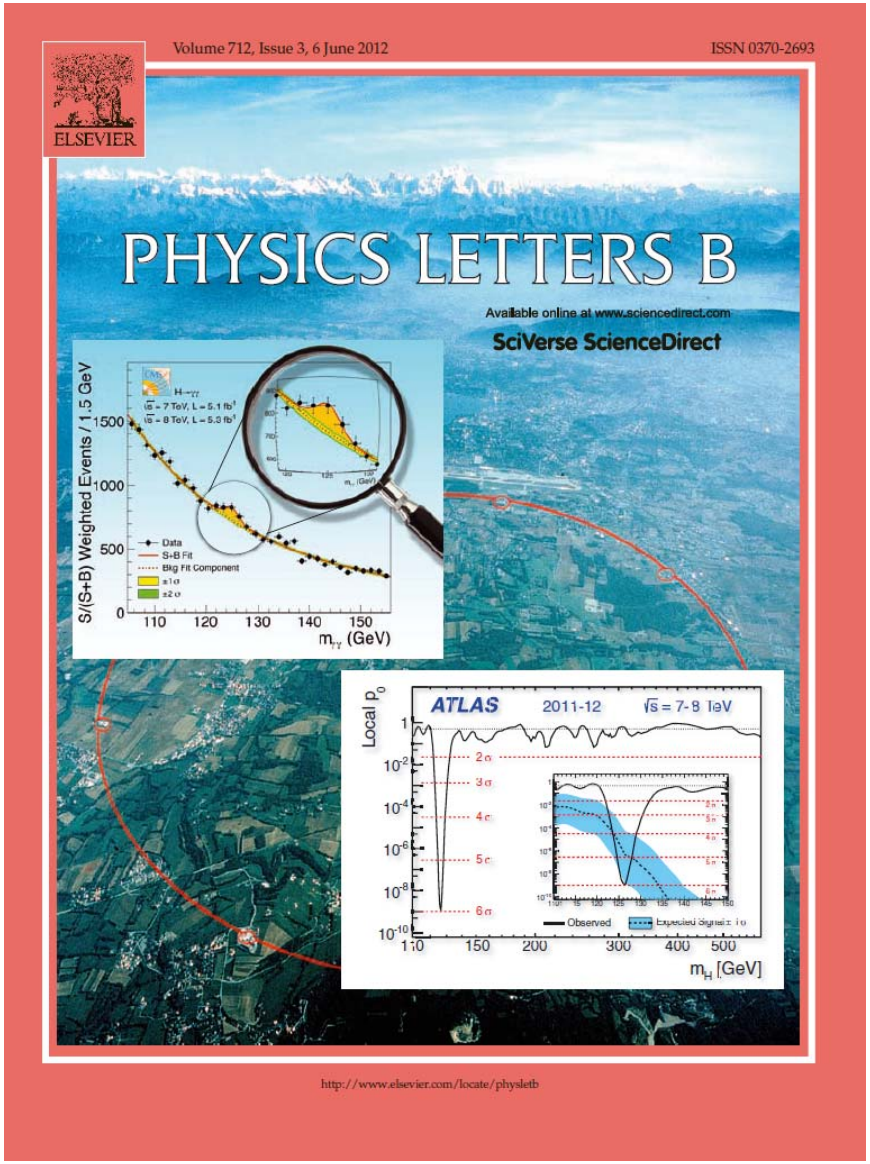
CMS Outlook

- about 25 fb^{-1} in 2012 (results shown here used at most 5 fb^{-1} at 8TeV)
- many new results to come
- 2013/14 LHC shut-down
- 2015 - …. data taking at 13.x TeV
- luminosity will increase to $2x10^{34}cm^{-2}s^{-1}$ (factor 2 beyond specs)

  →detector upgrade program under way, e.g. new pixel detector in 2016
- beyond 2020: luminosity increase to $5x10^{34}cm^{-2}s^{-1}$
  → new tracker, trigger etc.

Summary

- LHC delivers a lot of luminosity
- CMS covers a broad physics program
  cms.web.cern.ch/org/cms-papers-and-results
- A new boson has been discovered
- Searches for New Physics provide stringent limits
- Many SM measurements in pp and heavy ion collisions
- Exploration of the Terascale is in full swing



[http://www.sciencedirect.com/science/journal/03702693/716/1]