Highlights from LHC

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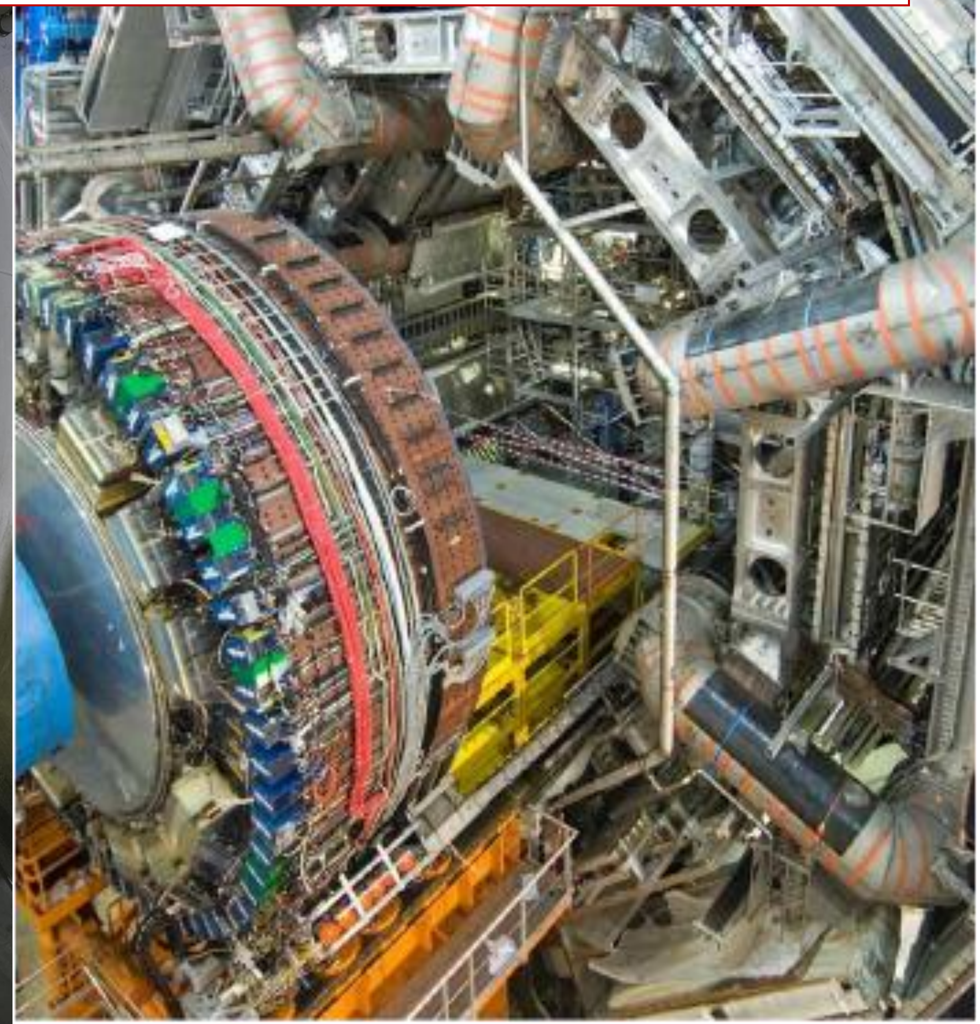
5-Nov-2012

Outline of Presentation

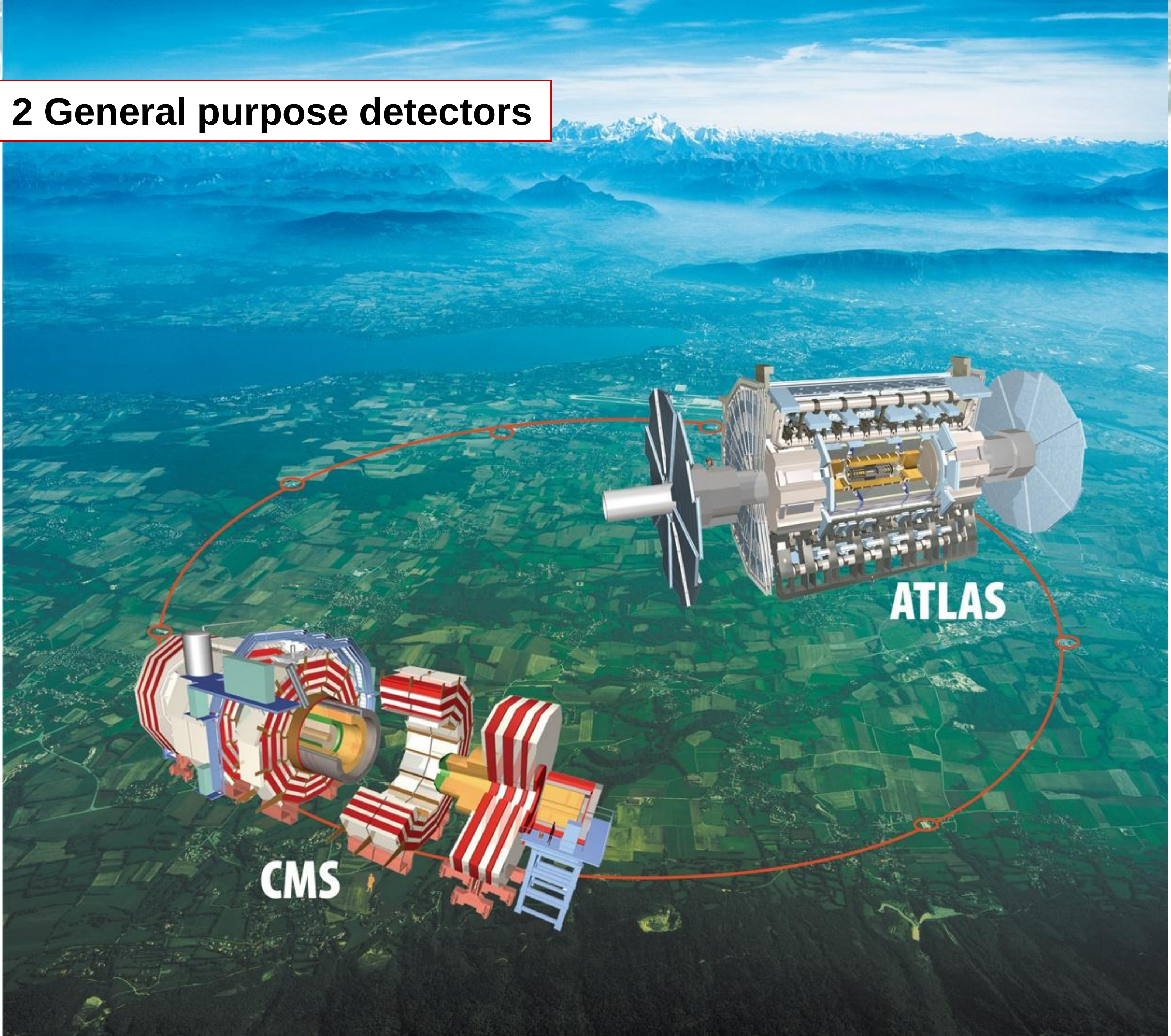
- LHC machine and performance
- Recent physics results
  - Standard Model Physics
  - Observation of a Higgs-like boson at 125 GeV/c^2
  - Search for Physics beyond the SM
  - CP violation
  - Measurements relevant for High Energy Cosmic Rays
- A short look at the near future

The Large Hadron Collider LHC

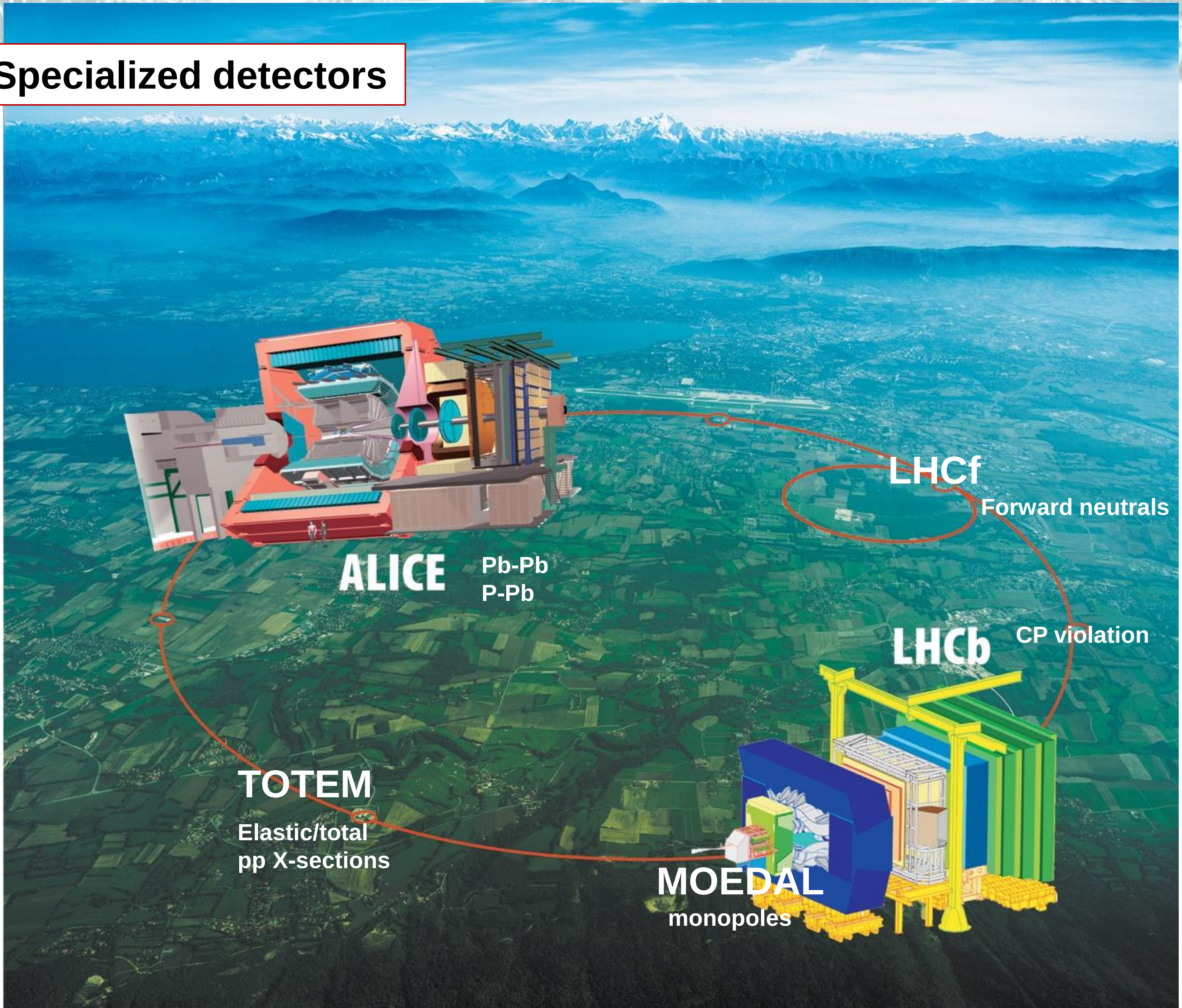
The Large Hadron Collider project is a global scientific adventure, combining the accelerator, a worldwide computing grid and the experiments, initiated more than 20 years ago



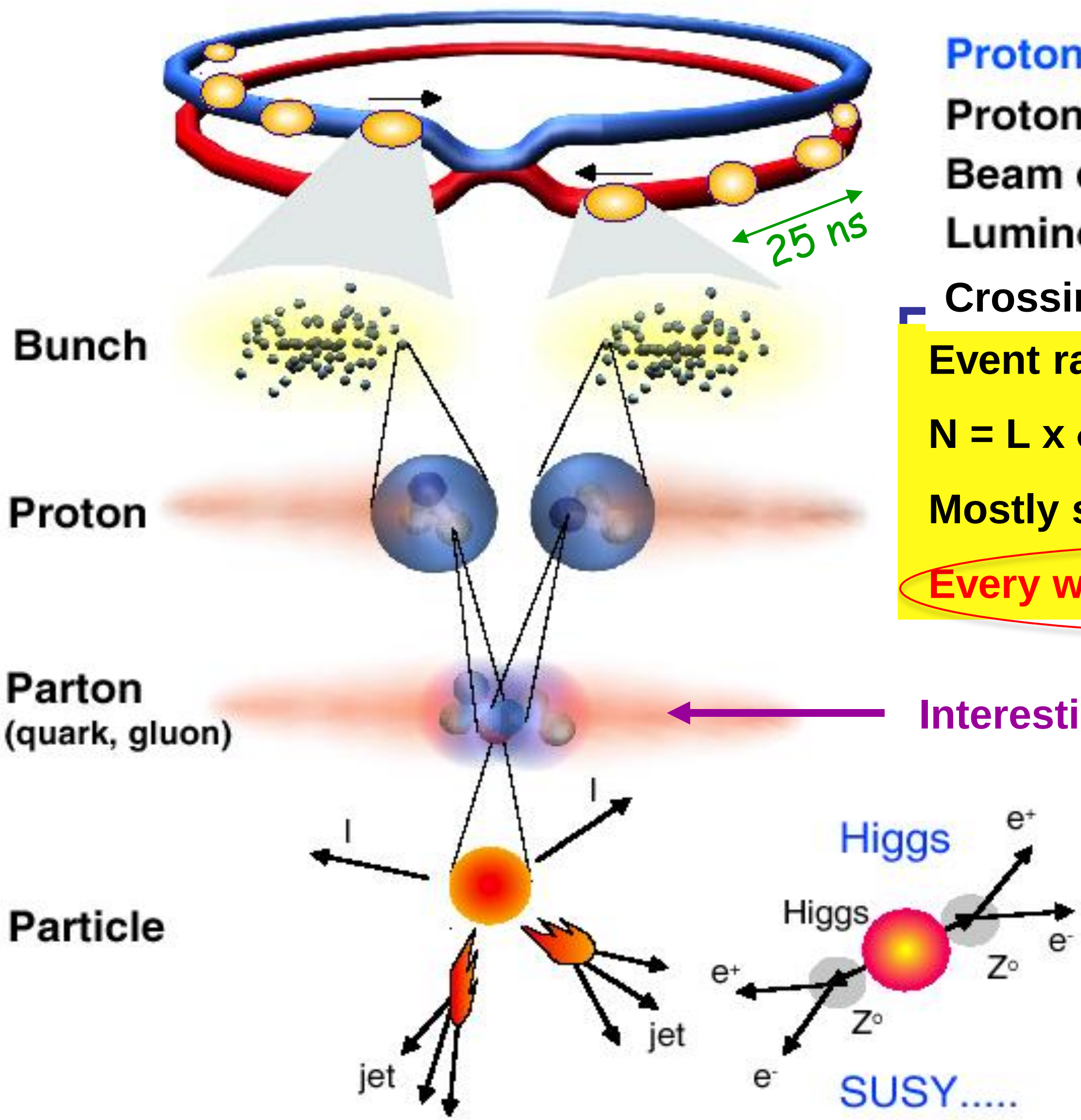
2 General purpose detectors



5 Specialized detectors



Current LHC performance



Proton-Proton	1368 bunch/beam
Protons/bunch	$1.6\ 10^{11}$
Beam energy	4 TeV (4×10^{12} eV)
Luminosity	$7.5\ 10^{33}\ cm^{-2}\ s^{-1}$ (peak)
Crossing rate	20 MHz

Event rate:

$N = L \times \sigma\ (pp) \approx$ **$7\ 10^{8}$ interactions/s (peak L)**

Mostly soft (low p_T) events

Every week ~ 1 fb^{-1} ~ 10^{14} interactions

Interesting hard (high-p_T) events are rare

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

→ very powerful detectors needed

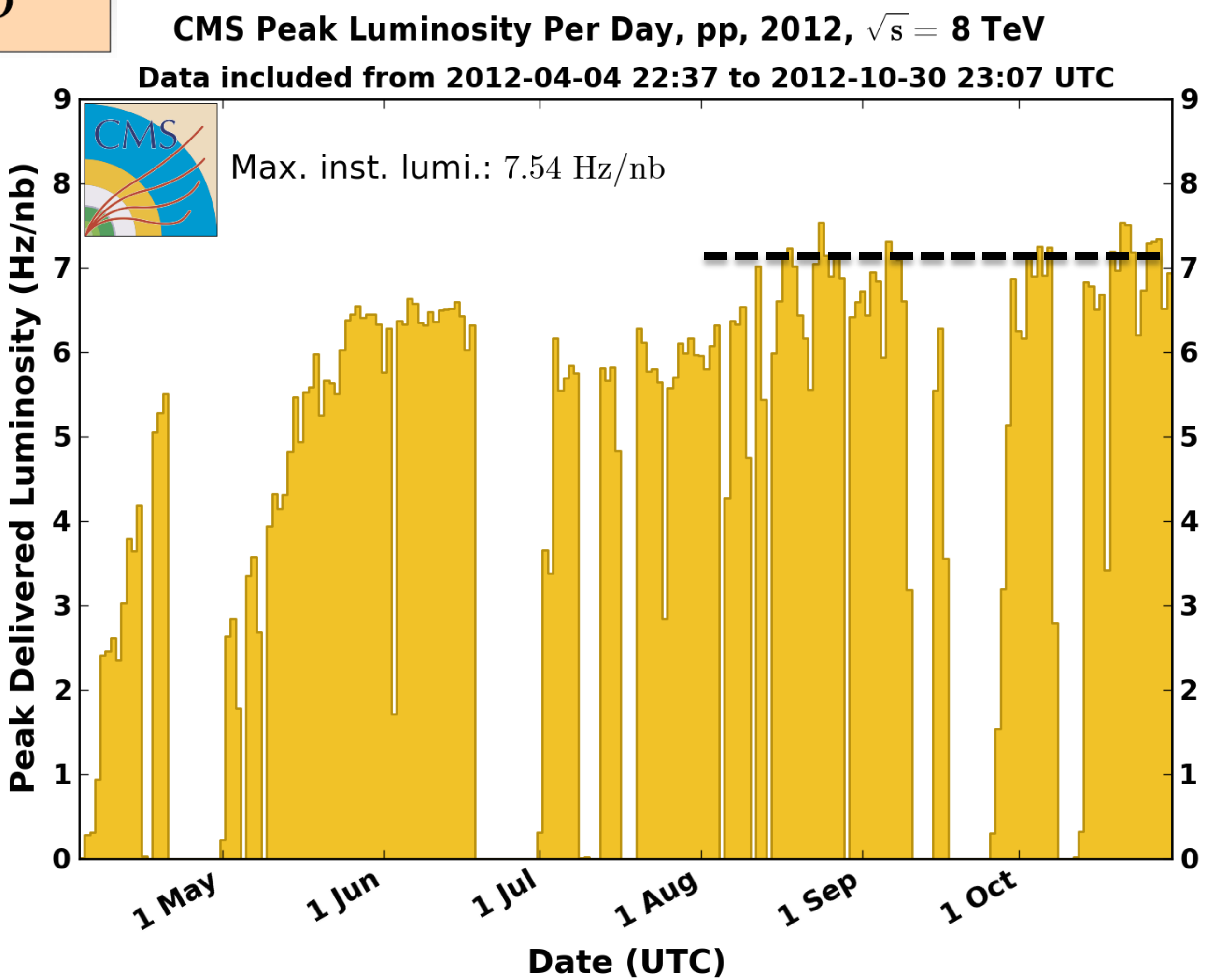
Peak luminosity

$$L = \frac{N^2 k_b f}{4\pi\sigma_x\sigma_y} F = \frac{N^2 k_b f \gamma}{4\pi\varepsilon_n\beta^*} F$$

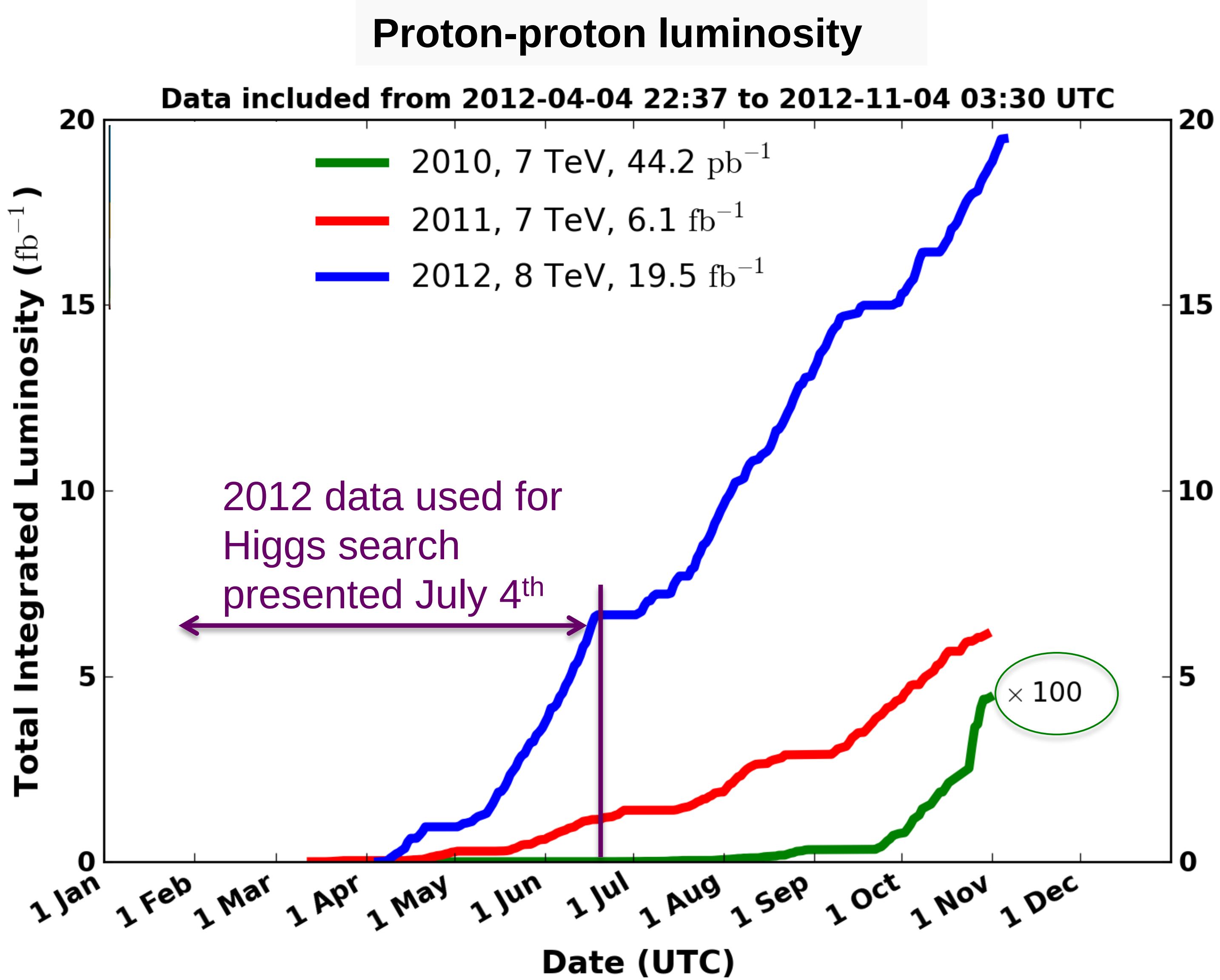
Close to nominal Lumi !

γ factor ½ (4 TeV)
k_b factor ½ (50ns)
compensated by

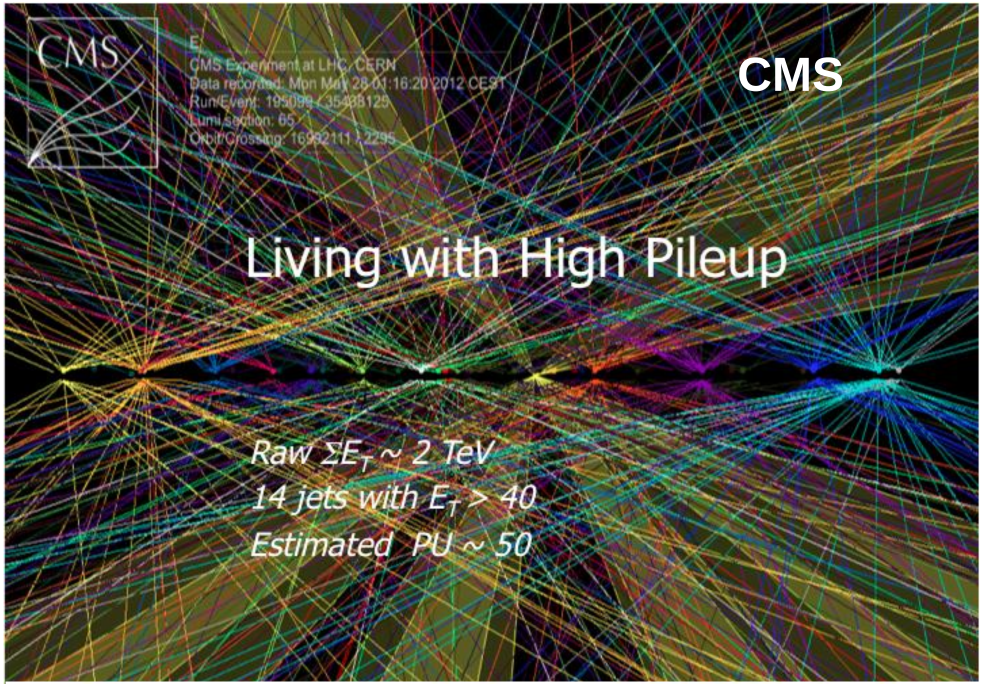
- Higher bunch intensity N
- Better emittance ε_n



Production Running : up to 4-11-2012



Experimental challenge in 2012

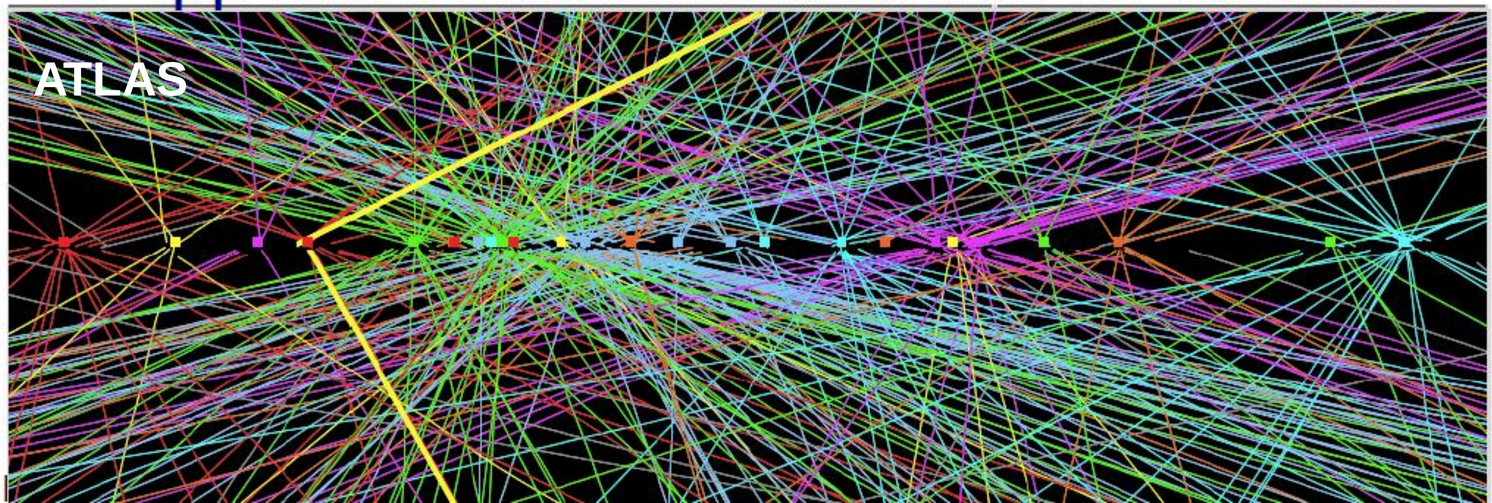


7x10^8 interactions/s
2 x10^7 bunch crossings/s

↓

At peak *L*, pileup of 35 events !

Z→μμ event from 2012 data with 25 vertices

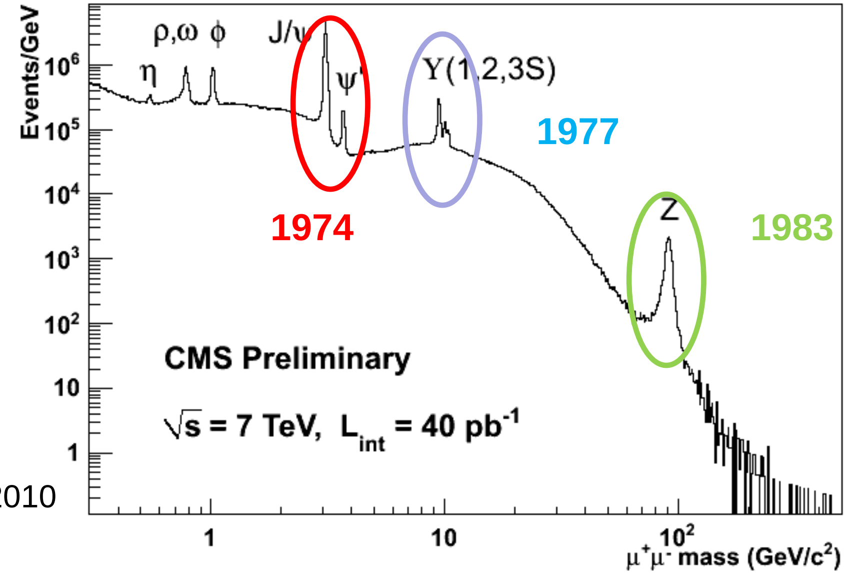


Testing every corner of the Standard Model

Understanding SM process which are background to Higgs and to New Physics discoveries is essential

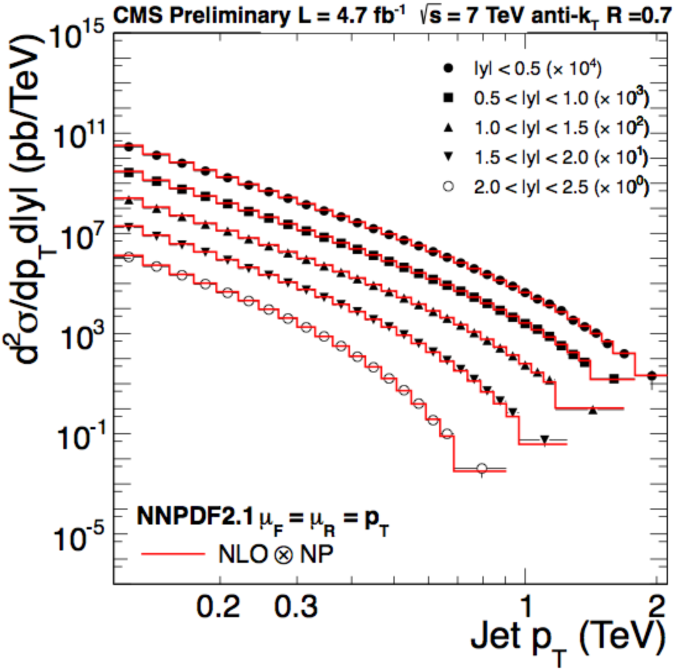
Precision tests of the SM may allow finding deviations linked to higher order processes involving New Physics

LHC experiments have "rediscovered" in a few months all the physics of the last 50 years, from low mass resonances to the heaviest (top) quark.

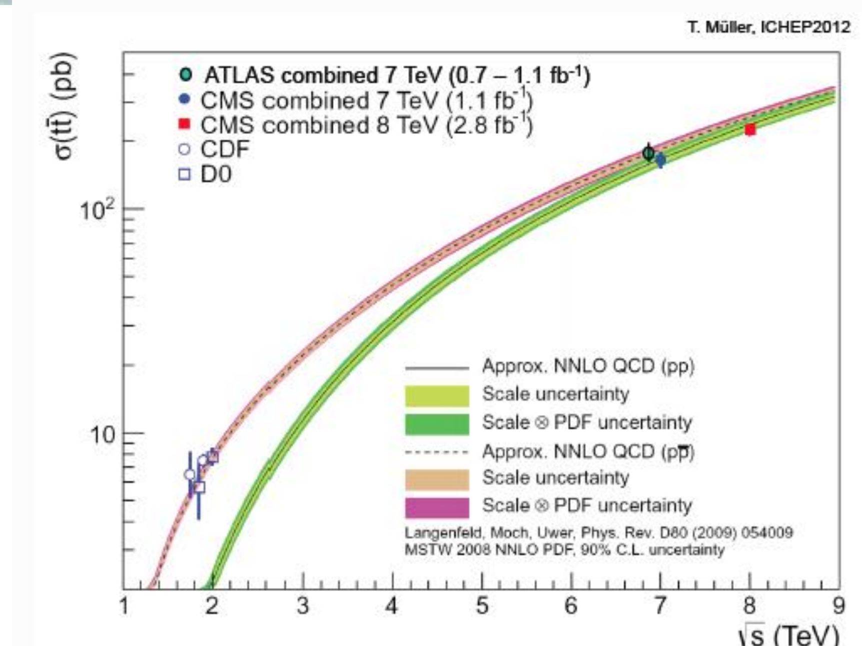


CMS Dimuons spectrum 2010

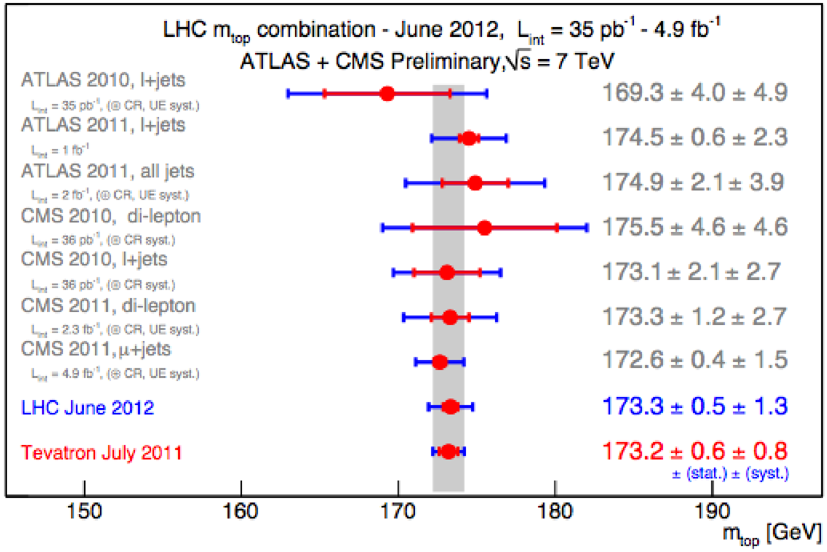
Example of Standard Model measurements



NLO QCD describes data over
9 orders of magnitude



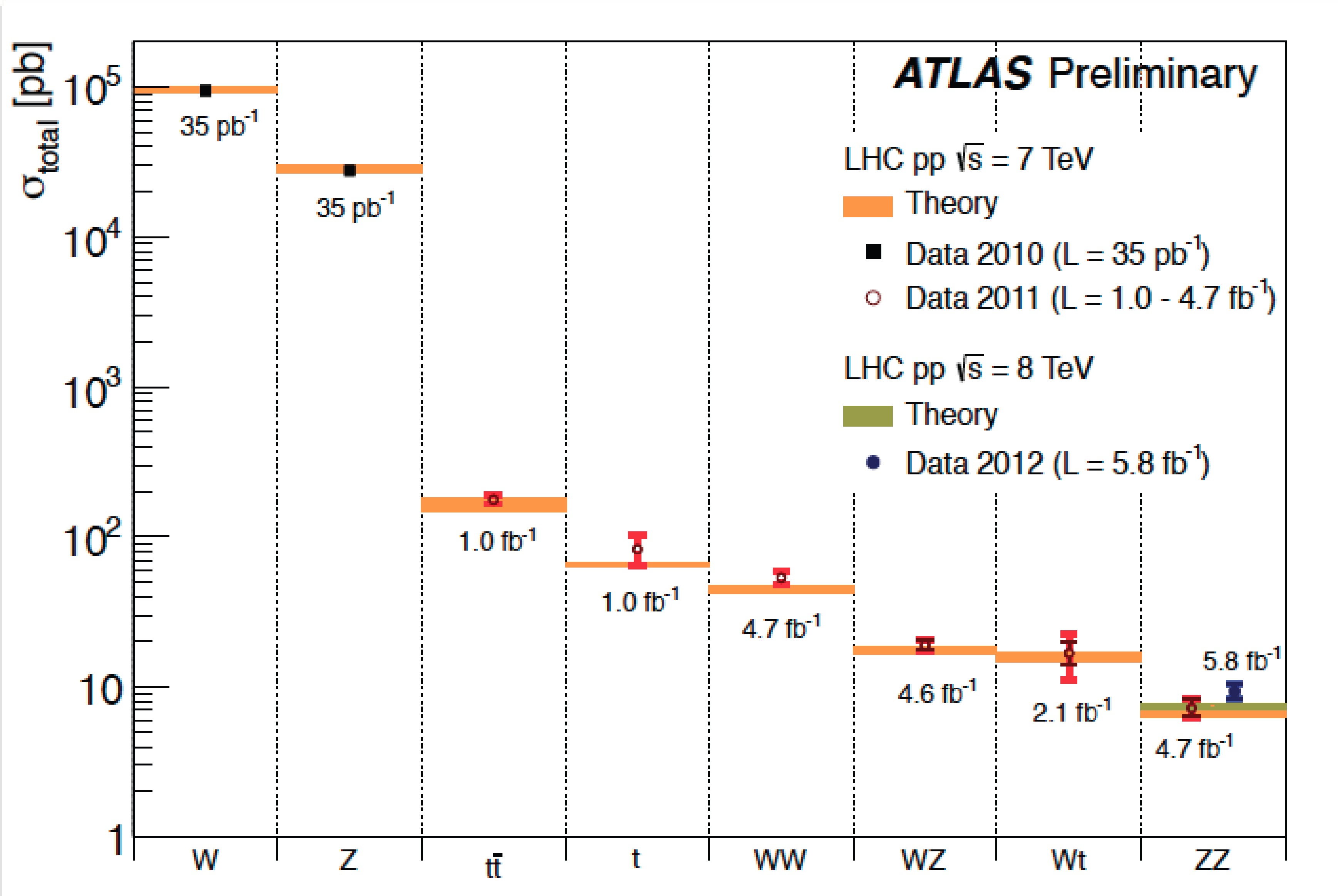
Top cross section exp error < 5%



Top mass at the GeV level,
in agreement with TeVatron

Weak Boson Production

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/CombinedSummaryPlots



Higgs Boson Search

The symmetry of electromagnetic and weak interactions is broken

$m_\gamma = 0 \qquad m_{W/Z} \sim 90\ \text{GeV}/c^2$

Mechanism proposed by Brout, Englert and Higgs in 1964 with a scalar field whose vacuum expectation breaks the EW symmetry.
Field excitation would give birth to the Higgs Boson.
Allows solving many problems:

- Mass to W and Z
- Mass to elementary fermions
- Regularisation of $W_L W_L$ scattering which increases with E

$m_H > 114\ \text{GeV}/c^2$ (LEP experiments, 2001)

Understanding electro-weak symmetry breaking (EWSB) was among the top physics motivations behind LHC construction.

P. Higgs

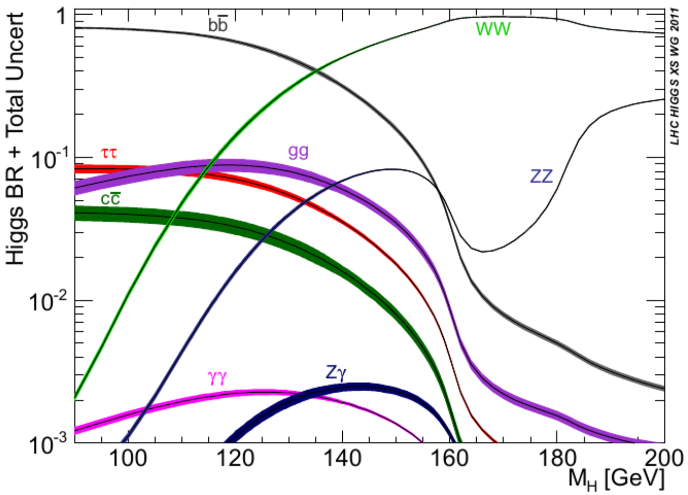
F.Englert

Caution:

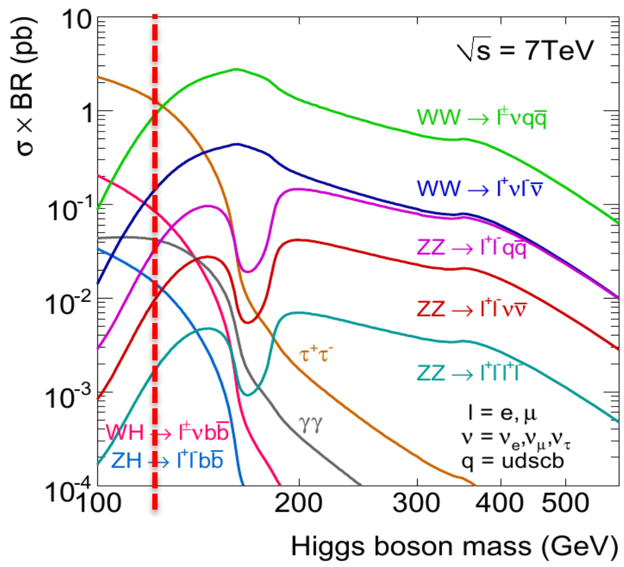
- This is not the only solution proposed to solve EWSB (ex: technicolor)
- The Higgs may not be a fundamental object but a composite one.
- Models with several Higgs !
- Does not solve the hierarchy problem (why is gravity so weak, why $m_H \ll M_{Pl}$?)

Higgs Search : Choice of decay channels

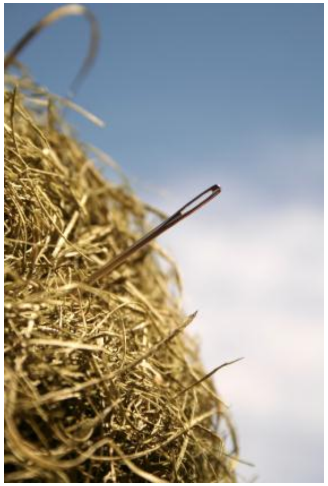
About 20000 Higgs of 125 GeV mass may be produced by fb^{-1}.
But most of them can not be detected due to background.
Only decays leading to isolated leptons or photons (+ possibly identified b meson jets) are candidates for identification.
The Branching Ratio (BR) to these decays is very small.



Decay channel	advantages	inconvenient
H➔γγ	V.Good Mass resolution 1 to 1.5 GeV/c^2	Large irreducible background
ZZ*➔ 4 charged leptons	Good mass resolution ~2 GeV/c2 Small background	Very few events σ*BR(125 GeV) few fb
H➔WW*➔lν lν	Larger σ*BR	Poor mass resolution due to missing neutrinos
W,Z/H➔bb	Large σ*BR	Medium mass resolution (jets) Huge background
H➔ττ	Large BR	Poor mass resolution Missing neutrinos. τ detection



Methodology and statistical analysis



- **Define cuts with simulation beforehand: blind analysis**
- **Estimate background from data driven methods + simulations**

- **Limits : for each hypothetical mass m_H**
  - **define maximal cross section σ_{lim} of a possible excess over background** at 95% CL (i.e. Prob($\sigma > \sigma_{lim}$) $\leq$ 0.05)
  - Divide by known Higgs cross section in SM.
  - **If less than 1, exclude mass m_H**

- **Signal:**
  - **Compatibility with background-only hypothesis quantified with local p_0**
    p_0 expressed as "number of σ" as in tail of a Gaussian distribution $3\sigma \sim 10^{-3}$ $5\sigma \sim 3\,10^{-7}$
  - **Look elsewhere effect:** if a large number of mass bins is looked at, the probability of a fluctuation in one of them is increasing . Global p0
  - **Best fit signal strength μ** for each m_H (fit signal + background) . μ_{SM}**=1**
    - **is $\mu \sim 1$?**
    - **are individual decay channels $\mu_{ind} \sim 1$**
- **In all cases (limits or signal) , compare with expectations for SM Higgs (simulation)**

Summer 2012 results

Based on data collected up to the Technical Stop 17/06/2012

Reanalysis of 2011 data at $\sqrt{s}$ = 7 TeV with optimized cuts

ATLAS	4.6 to 4.8 fb^{-1}
CMS	4.9 to 5.1 fb^{-1}

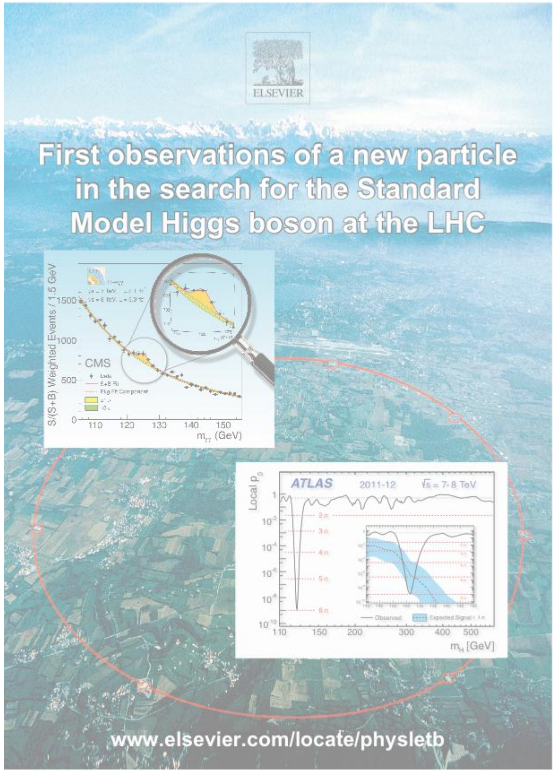
2012 data at $\sqrt{s}$ = 8 TeV (27% higher cross section than at 7 TeV)

ATLAS	5.8 to 5.9 fb^{-1}
CMS	5.1 to 5.3 fb^{-1}

Published in

Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC
Physics Letters B Volume 716, Issue 1, Pages 1-29

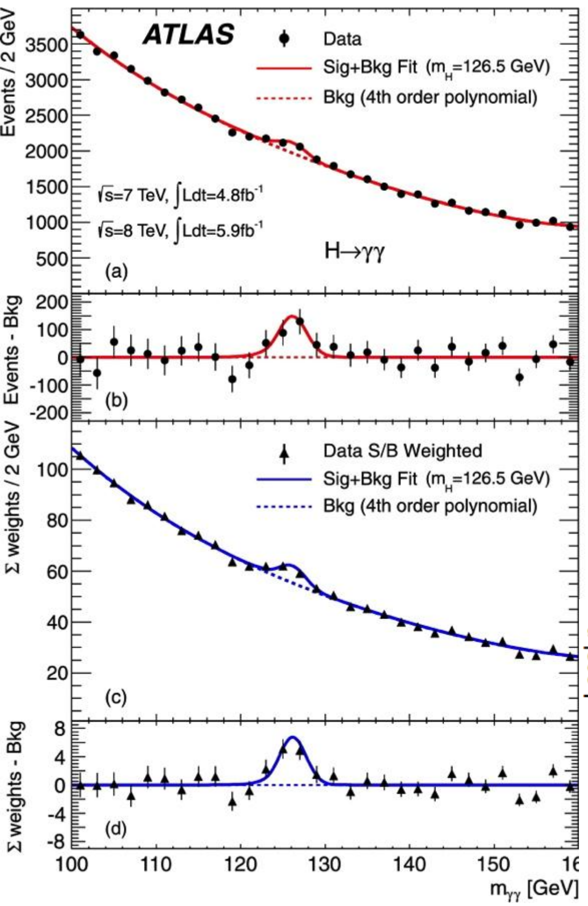
Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC
Physics Letters B Volume 716, Issue 1, Pages 30-61



$H \rightarrow \gamma\gamma$

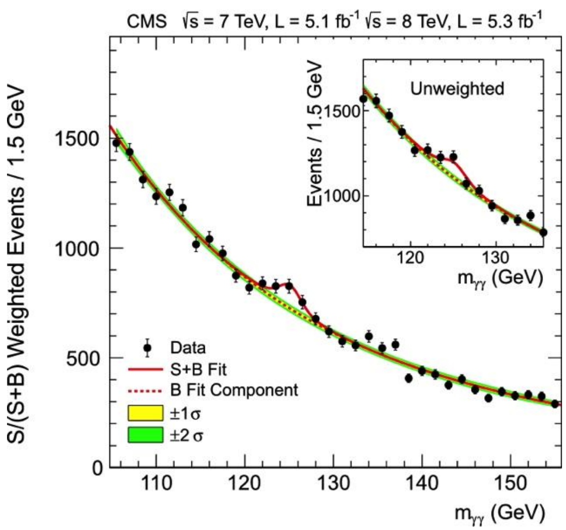
Events are split into categories depending on expected S/B.

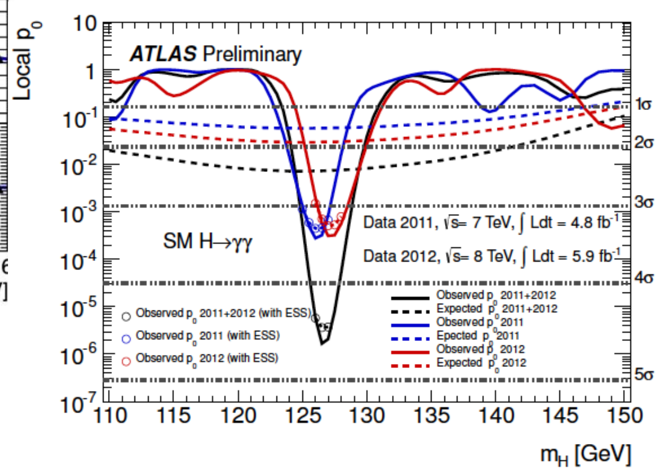
Plots with S/B weighting represent better the statistical analysis

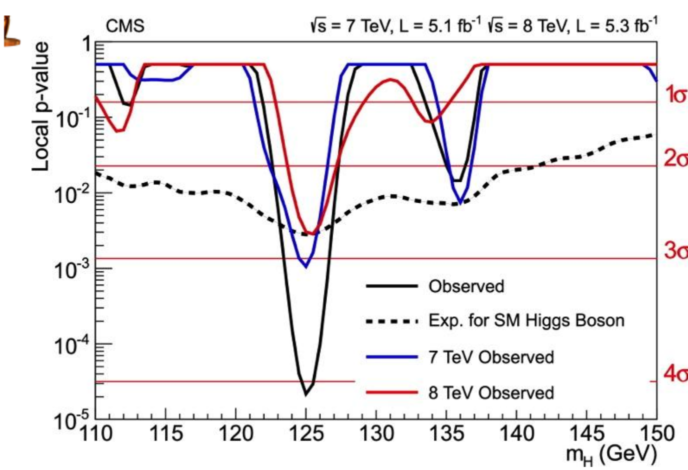


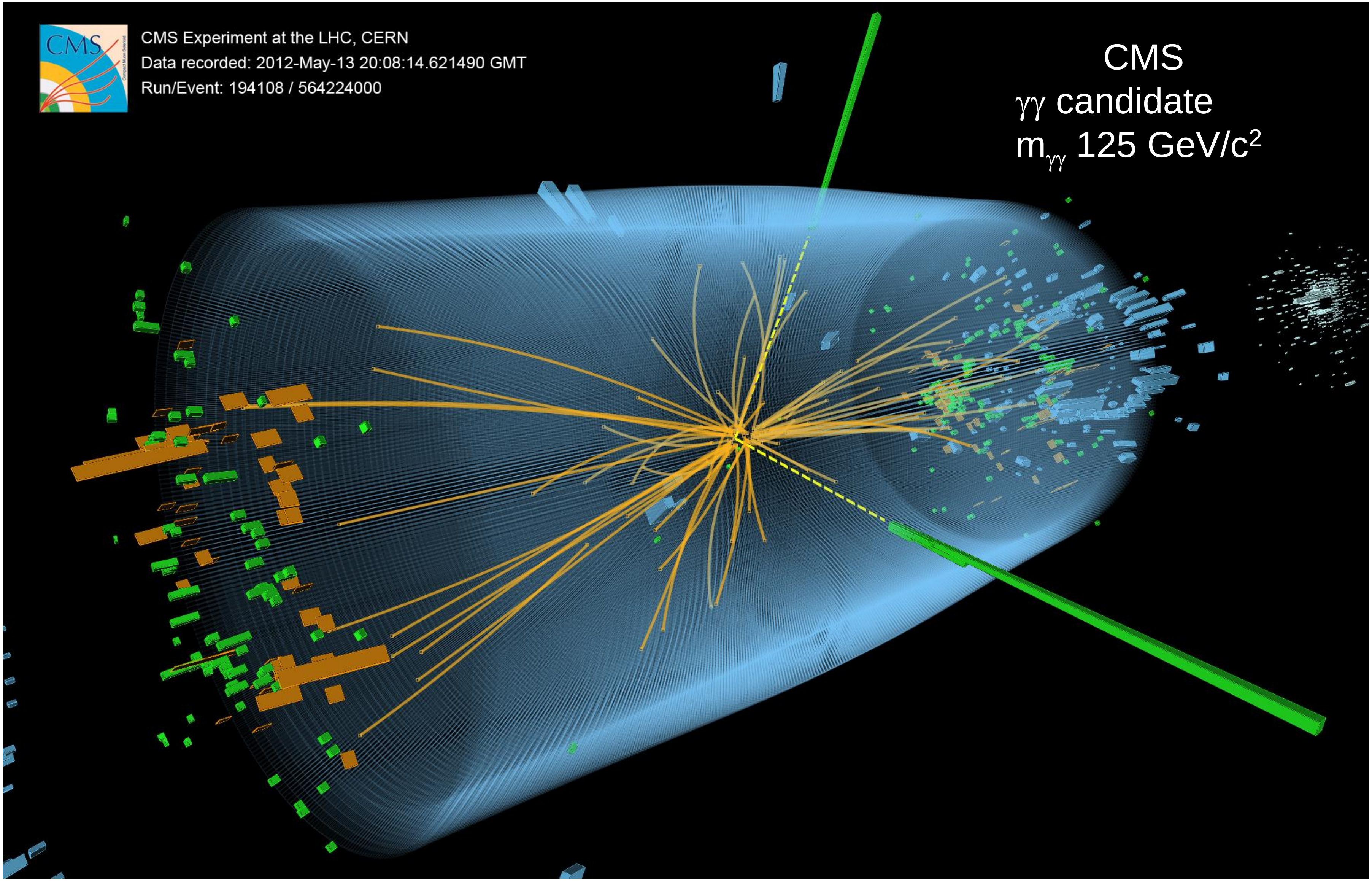
ATLAS:
m_H = 126.5 GeV (min p0)
Local sig 4.5 σ
Exp significance 2.4 σ

CMS:
m_H = 125 GeV (min p0)
Local sig 4.1 σ
Exp significance 2.8 σ

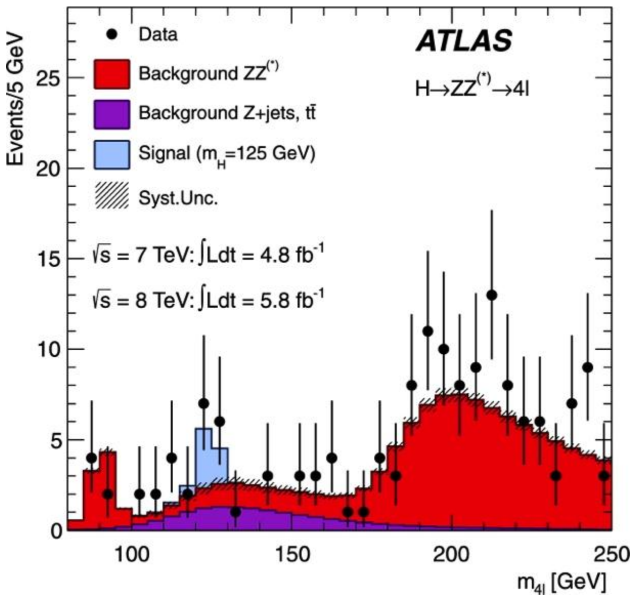






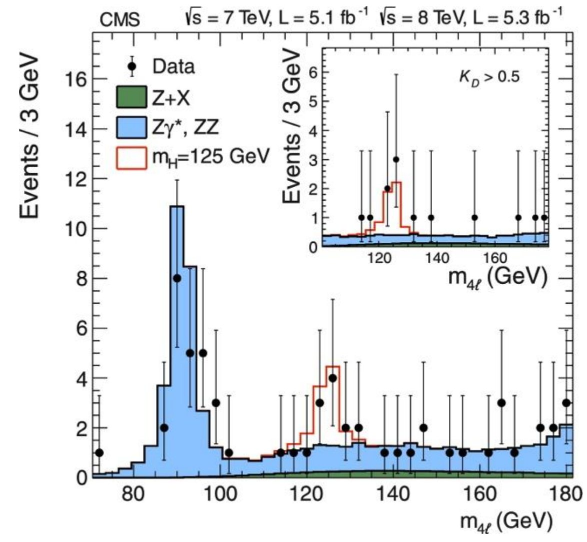

CMS Experiment at the LHC, CERN
Data recorded: 2012-May-13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000
CMS
$\gamma\gamma$ candidate
$m_{\gamma\gamma}$ 125 GeV/c^2

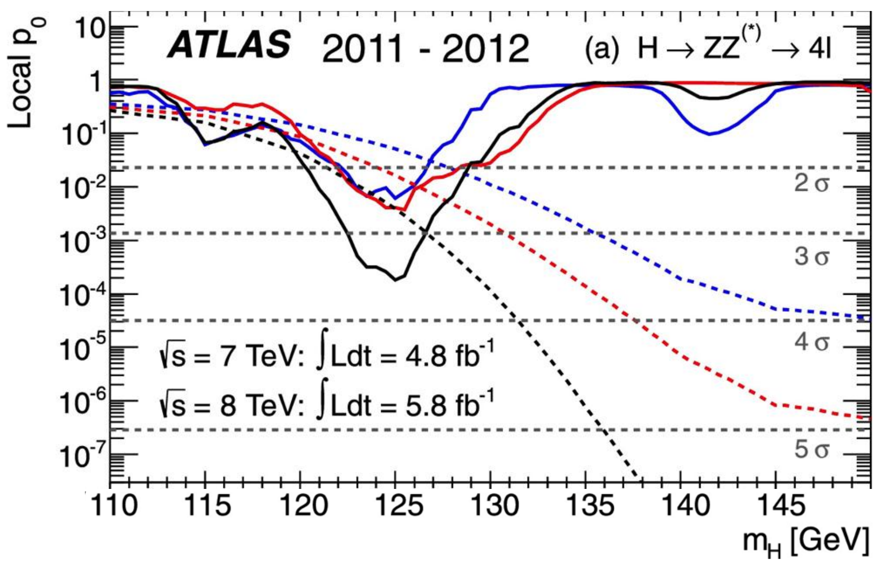
$H \to ZZ^* \to 4\ \mathrm{leptons}(e,\mu)$

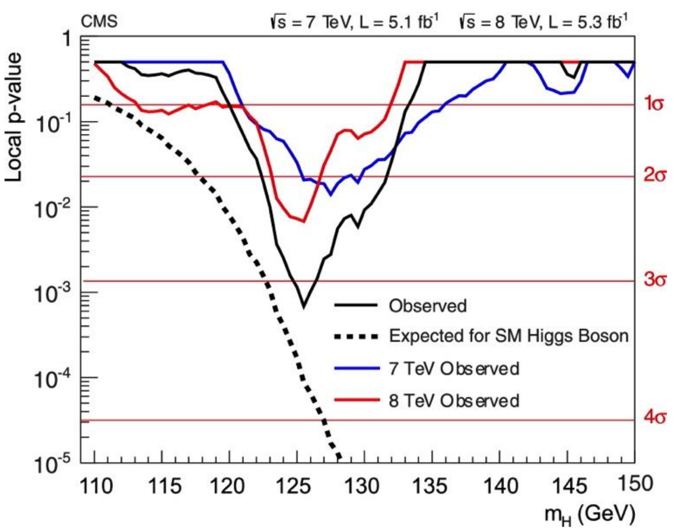


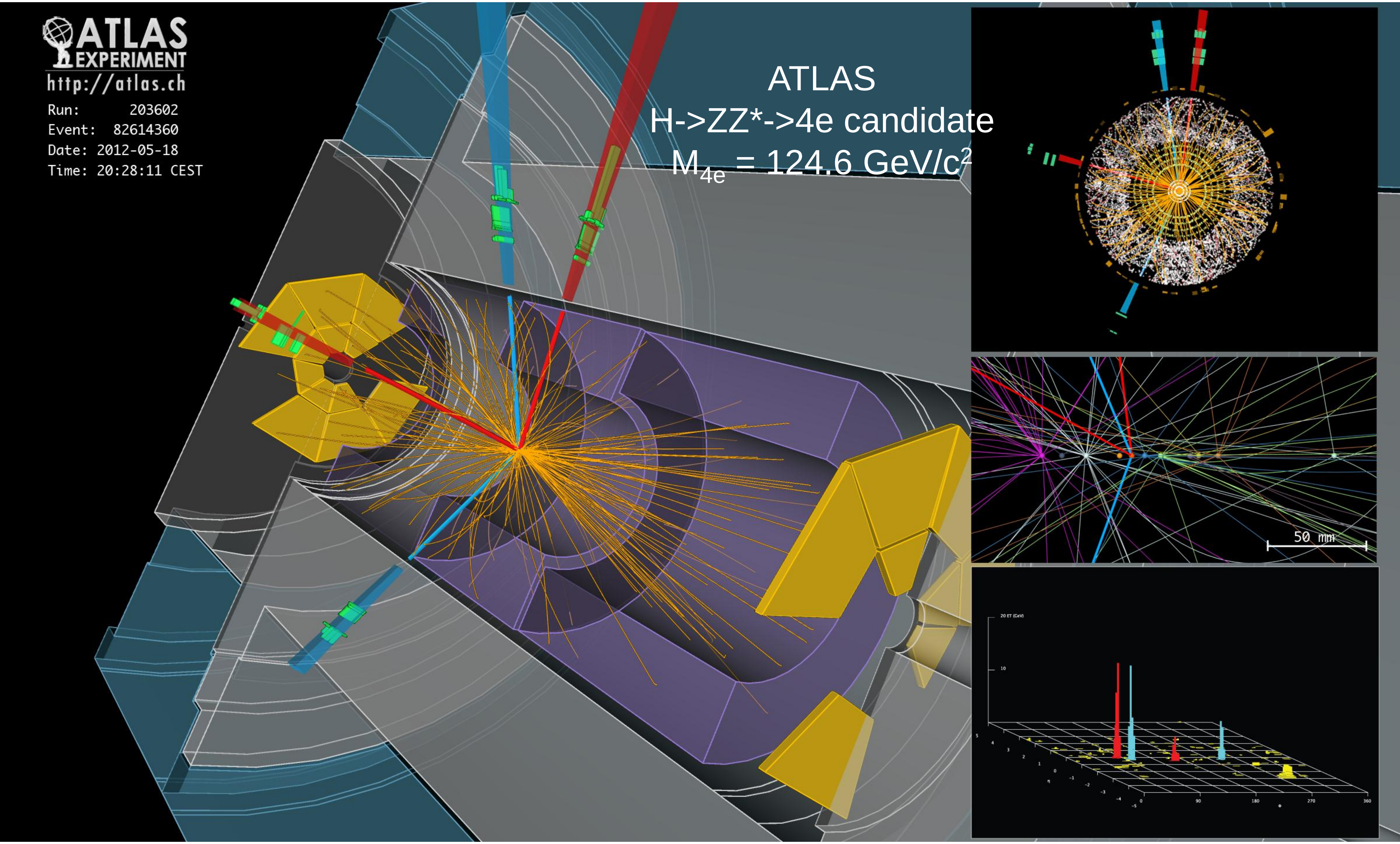
ATLAS:
m_H = 125 GeV (min p0)
Local sig 3.4 σ
Exp significance 2.6 σ

CMS:
m_H = 125.6 GeV (min p0)
Local sig 3.2 σ
Exp significance 3.8 σ

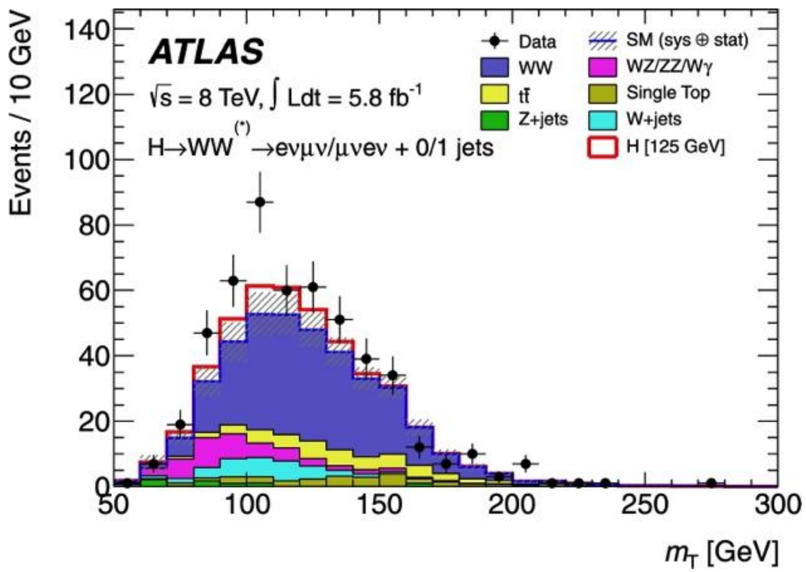






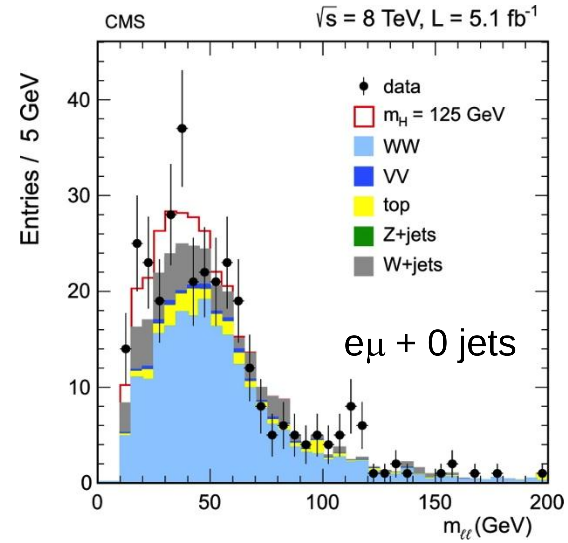

ATLAS
H->ZZ*->4e candidate
M4e = 124.6 GeV/c2
ATLAS EXPERIMENT
http://atlas.ch
Run: 203602
Event: 82614360
Date: 2012-05-18
Time: 20:28:11 CEST
50 mm

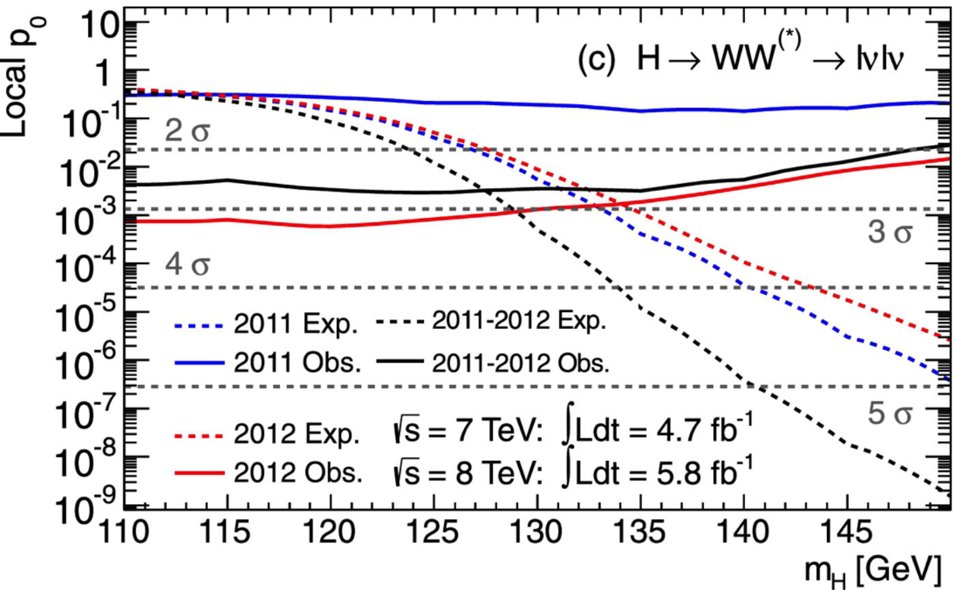
$H \to WW^* \to e\nu\mu\nu$ (ATLAS)
$\to l\nu l\nu$ (CMS)

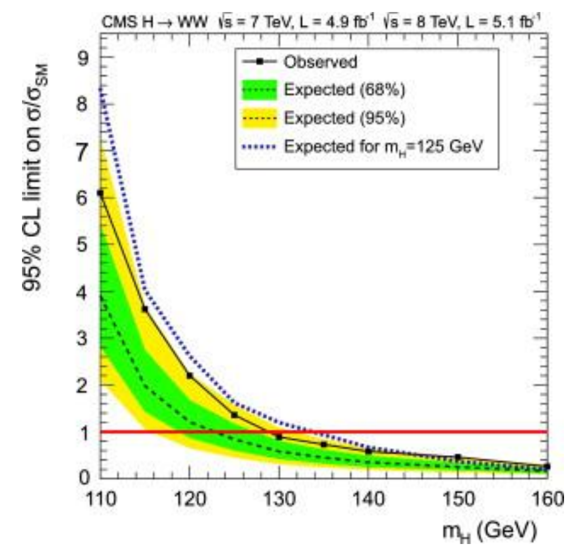


ATLAS:
At 125 GeV
Local sig 2.8 σ
Exp significance 2.6 σ

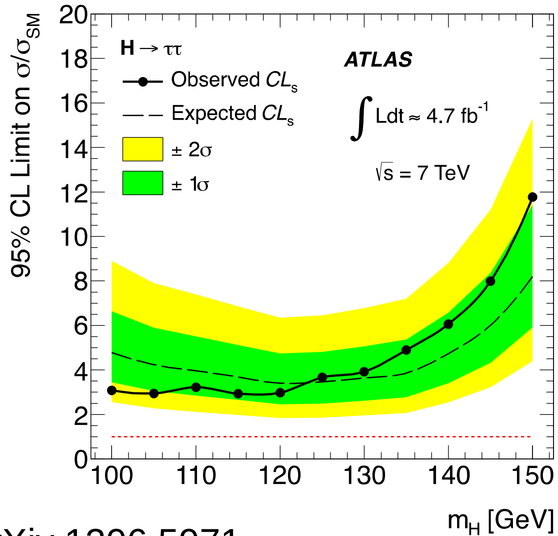
CMS:
At 125 GeV
Local sig 1.6 σ
Exp significance 2.4 σ



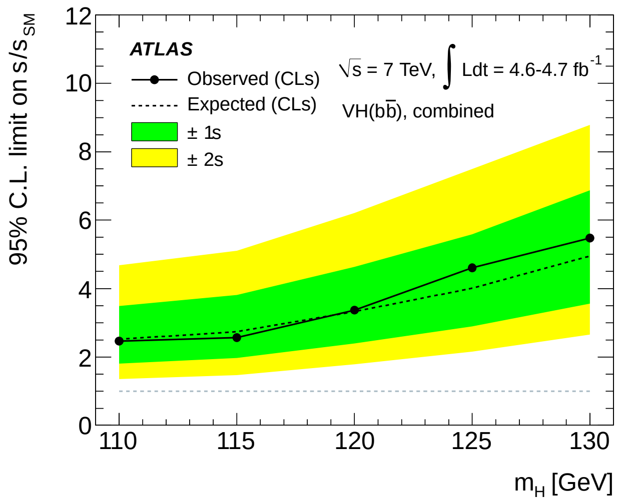




$H \to \tau^+\tau^-$ and $W/Z + H \to b\bar{b}$



ArXiv 1206.5971



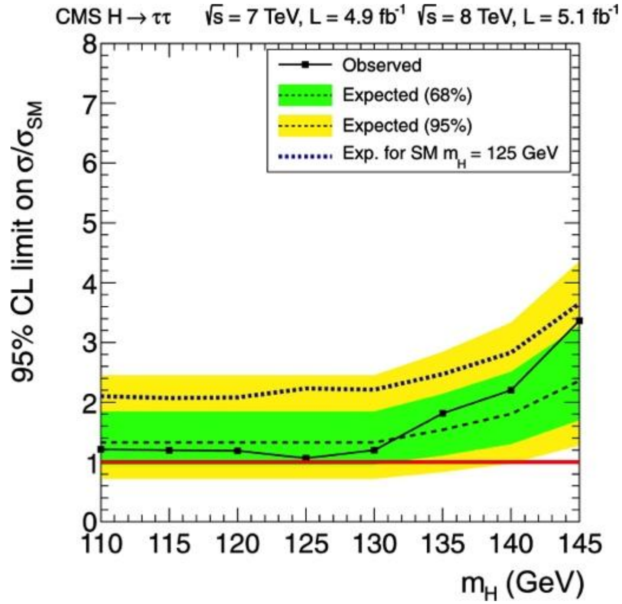
ArXiv 1207.0210

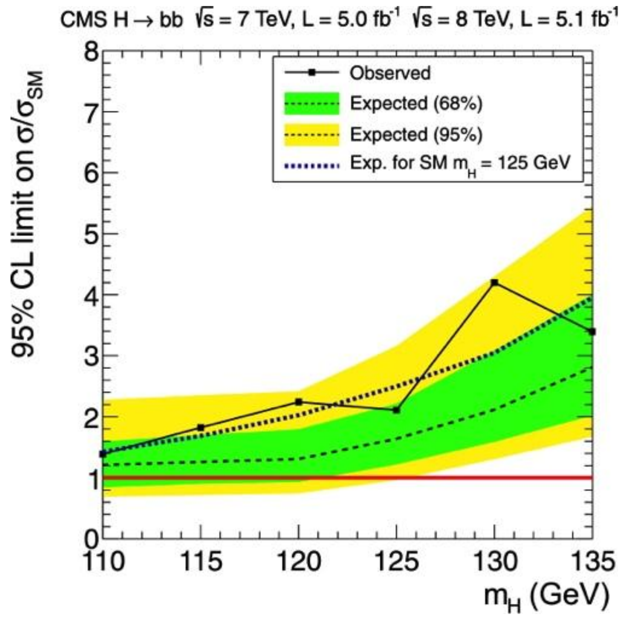
ATLAS:
Use recently published data at 7 TeV

CMS:
Preliminary analysis 7+8 TeV

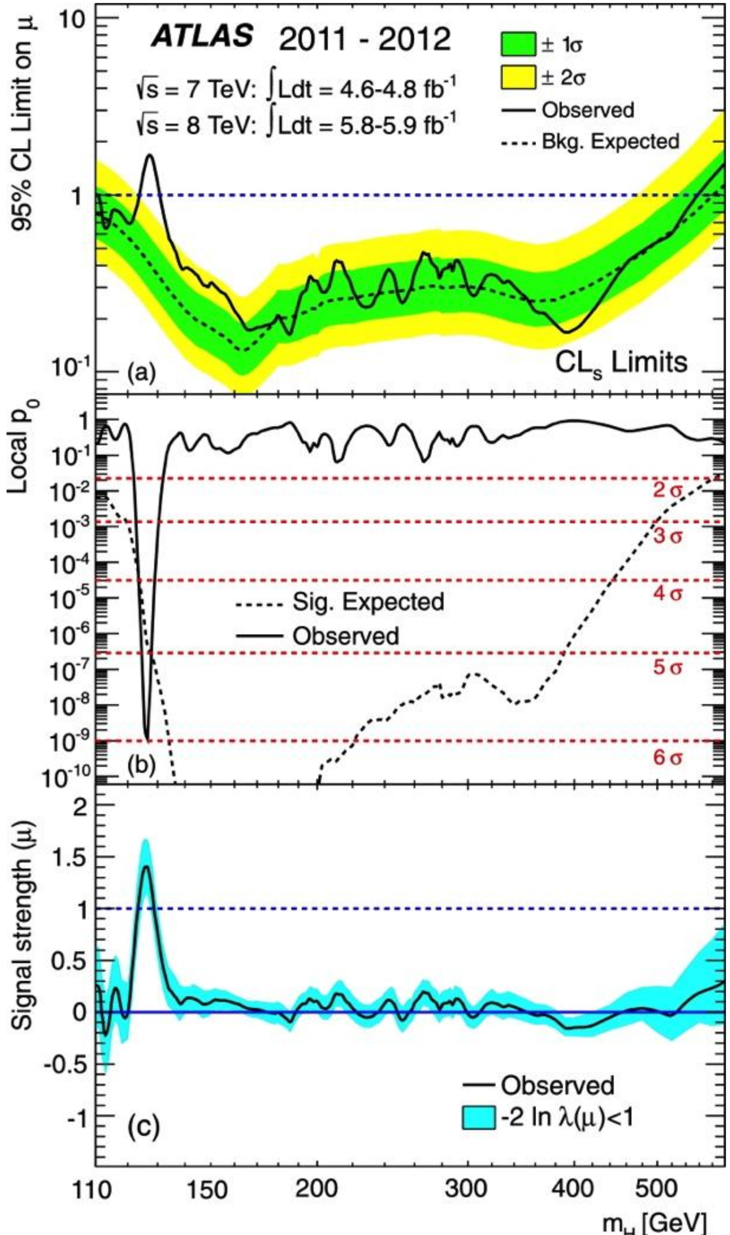
Not enough statistics

Very important question: coupling to <u>Fermions</u>





Combined Significance ATLAS

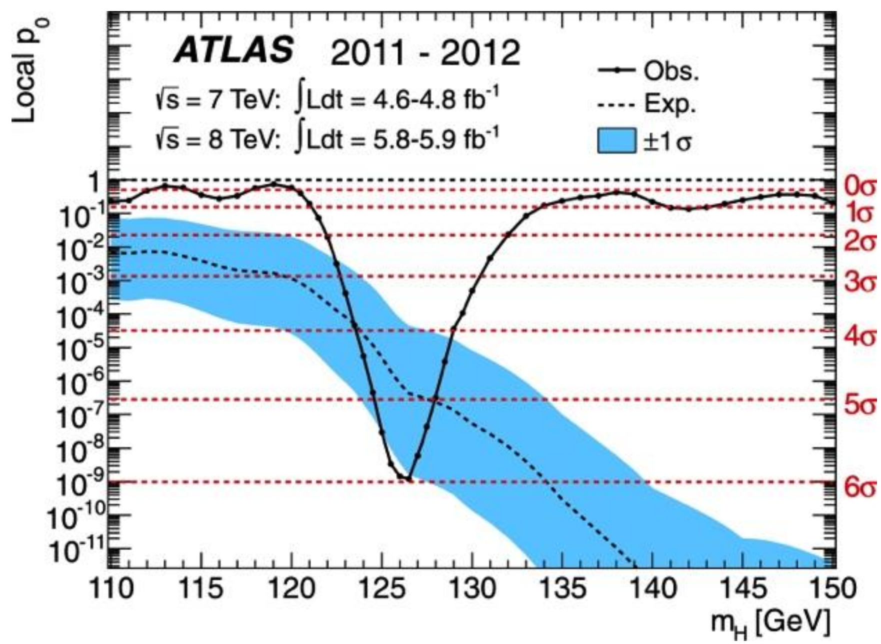


p_0 min at 126.5 GeV/c^2

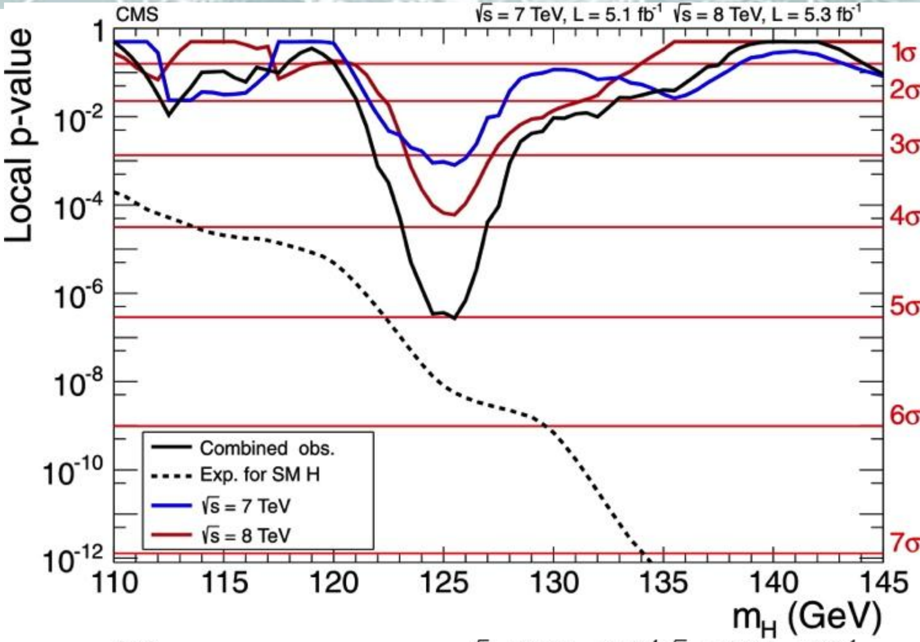
Local significance 6.0 σ

Exp. local significance 4.9 σ

Global significance: 5.3 σ in [110 –150] GeV/c^2



Combined Significance CMS

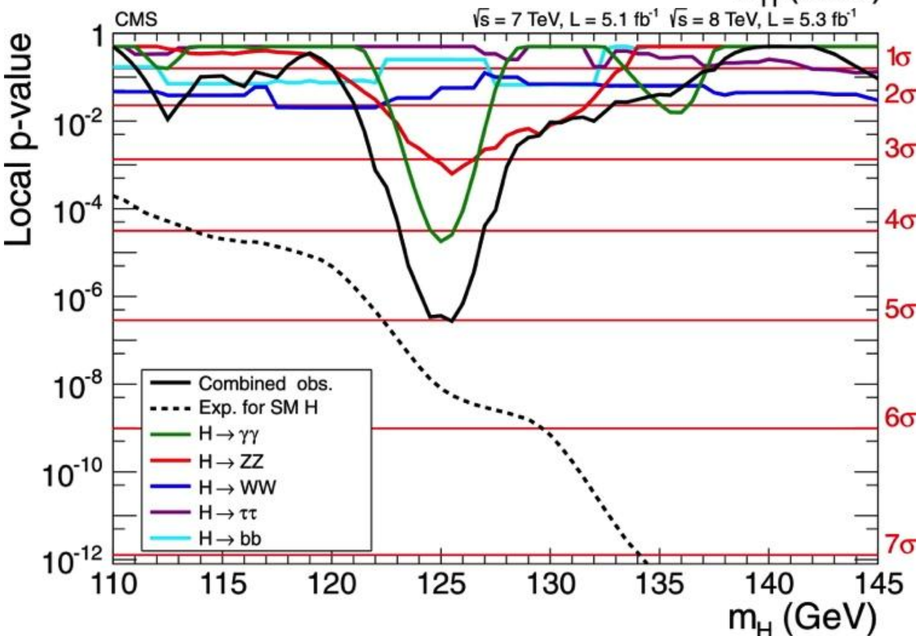


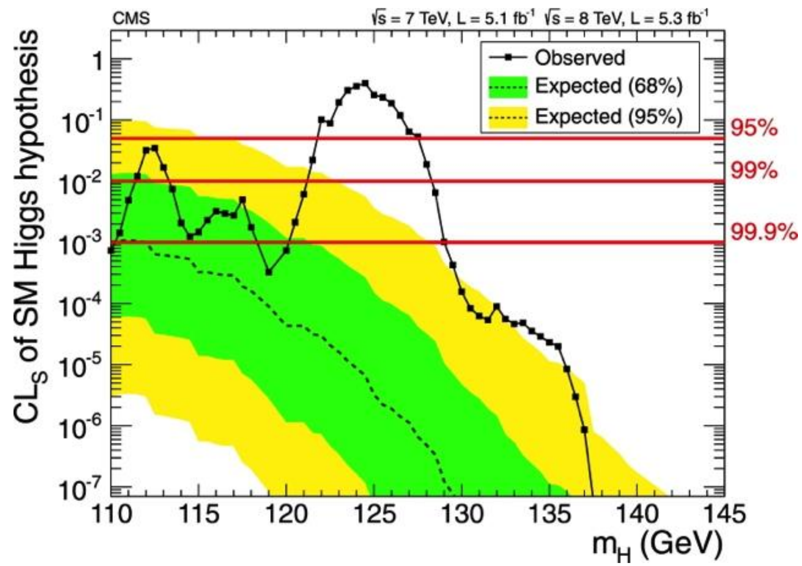
p_0 min at 125 GeV/c^2

Local significance 5.0 σ

Exp. local significance 5.8 σ

Global significance: 4.5 σ in [110 –145] GeV/c^2





Is it compatible with the SM Higgs ?

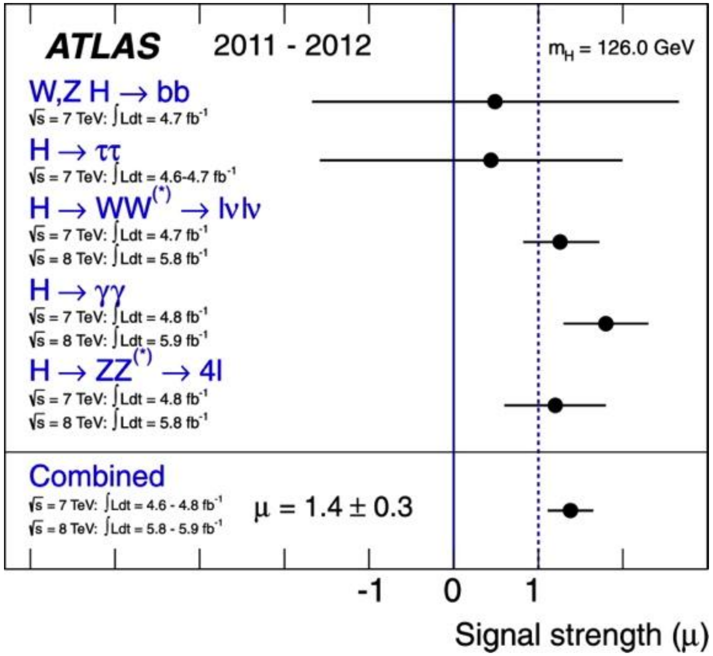
The overall excess is in both cases compatible with expectation from SM Higgs

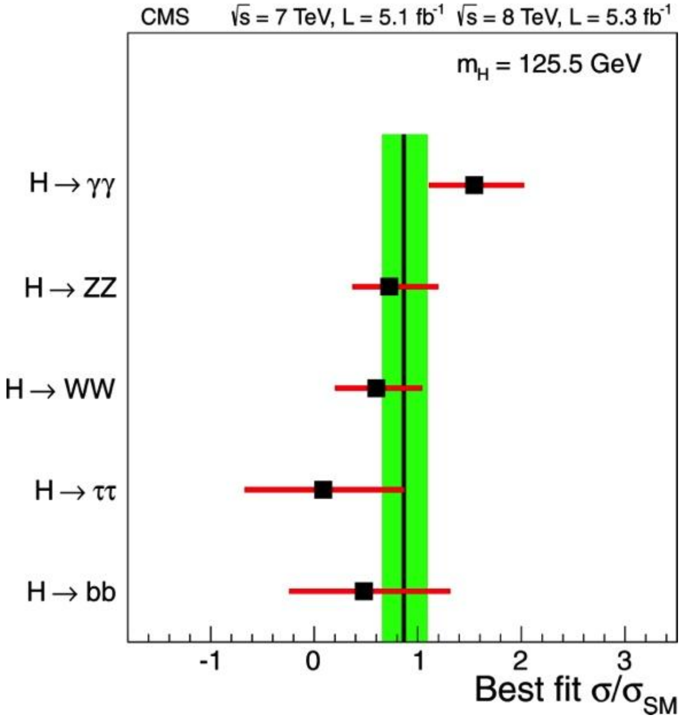
$\mu_{ATLAS} = 1.4 \pm 0.3$

$\mu_{CMS} = 0.87 \pm 0.23$

and the individual channels μ's are also compatible with 1

even if γγ is high is both experiments





Understanding the couplings to individual Bosons and Fermions is the key point to understand whether we see the SM Higgs Boson & whether there is New Physics

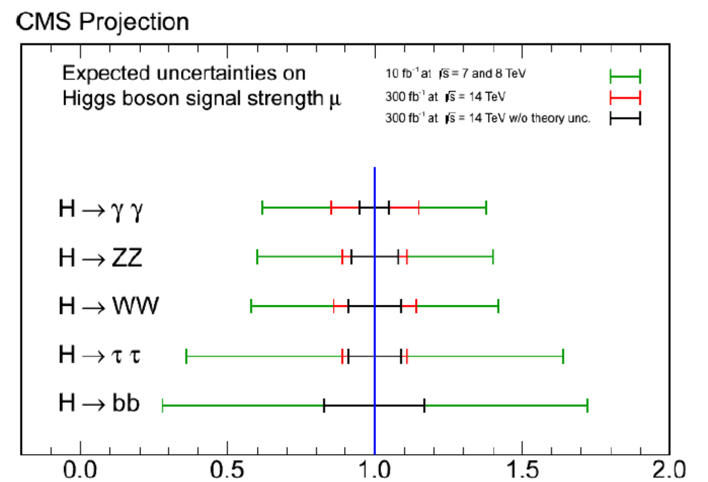
Conclusions and perspectives on the Higgs

- **Both ATLAS and CMS have independently observed an excess around 125 GeV.**
- **In both case, the probability that it comes from a background fluctuation is ≤ 3 x 10^{-7} (or ≥ 5 σ), which is enough to claim for a discovery.**
- **The new particle is a boson, since it decays into two photons. S=0 or 2**
- **Its yield and properties are so far compatible with the SM Higgs.**

More data have been accumulated:
pp run extended till 7/12/2012 will reach > 20 fb^{-1}

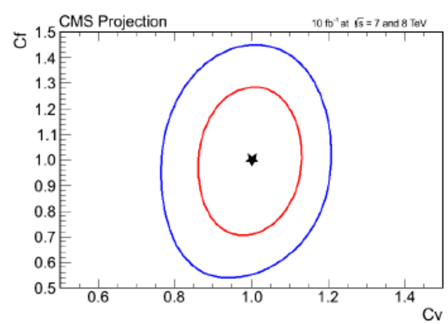
More news in a few days: HCP 2012 in Kyoto next week

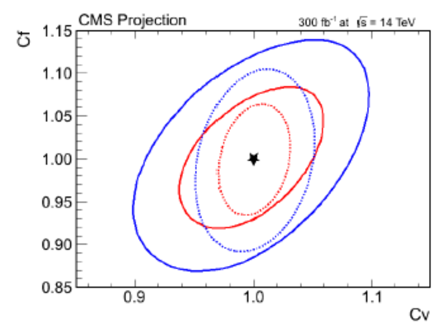
Should be able to measure the spin by end 2012



Longer term: √s=14 TeV
300 fb^{-1} by 2021
- yields and couplings to < 10%

3000 fb^{-1} by 2030
- di-Higgs production (self coupling)
- WW scattering





Searches for Physics Beyond SM

We know that even with the Higgs, the SM can not explain everything:

- Neutrino Masses are not included
- Hierarchy problem $m_H << M_{Pl}$ Fine tuning ?
- Dark Matter: electrically, color neutral particles with only weak and gravitational interactions
- Inclusion of Gravity in the picture

Many different possibilities to (partially) solve these issues have been proposed

Most popular is SuperSymmetry (SUSY) :

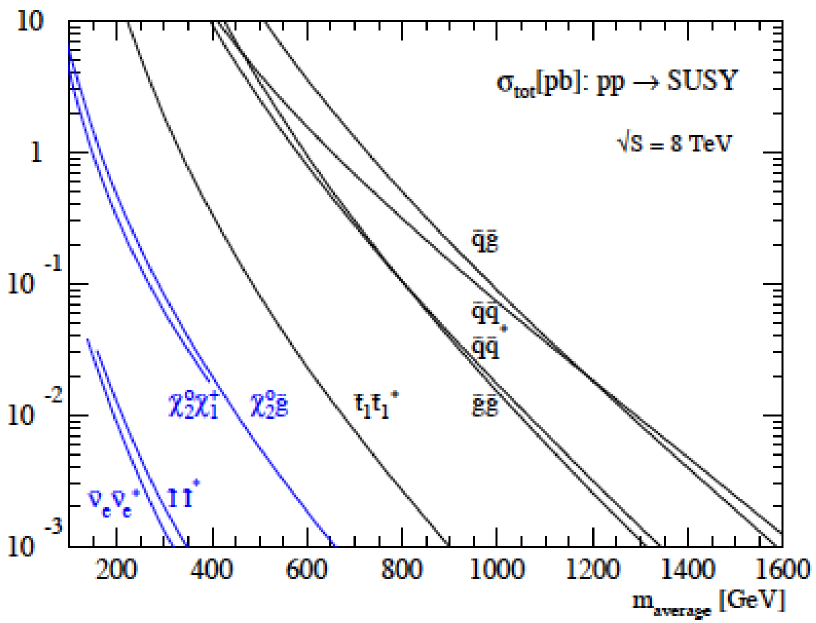
Lightest one (LSP) candidate for Dark Matter

Many others : extra dimensions, extdended gauge groups, ….

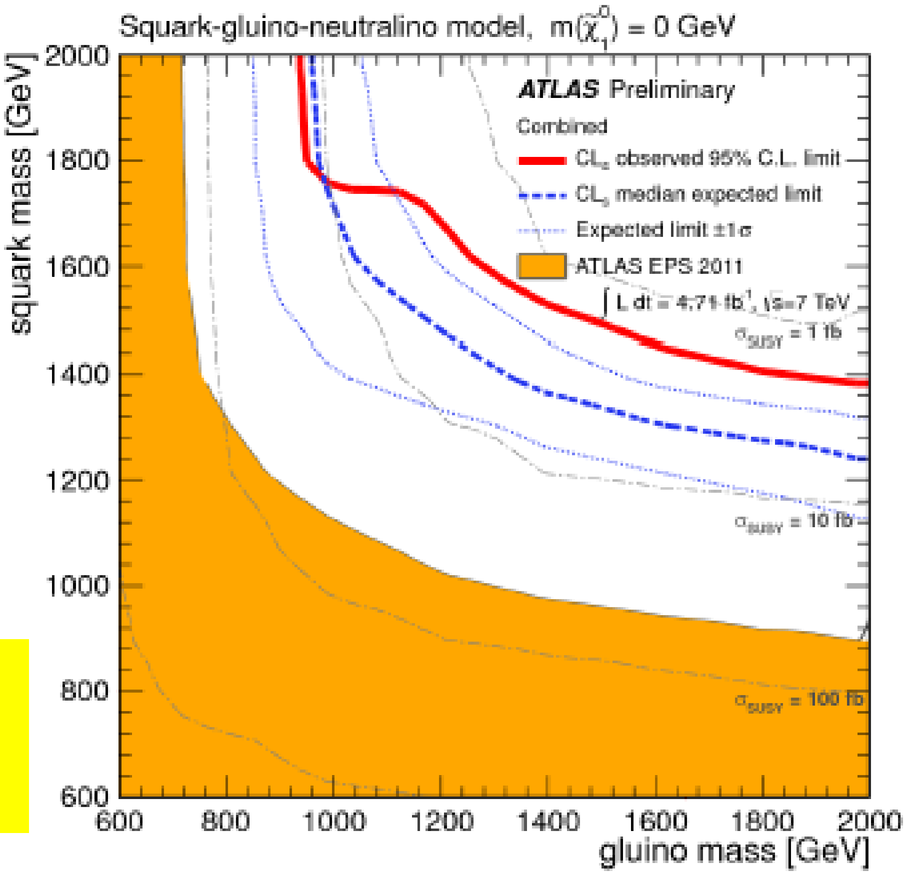
All give rise to new particles or interactions

"Leave no stone unturned"

Search for SUSY



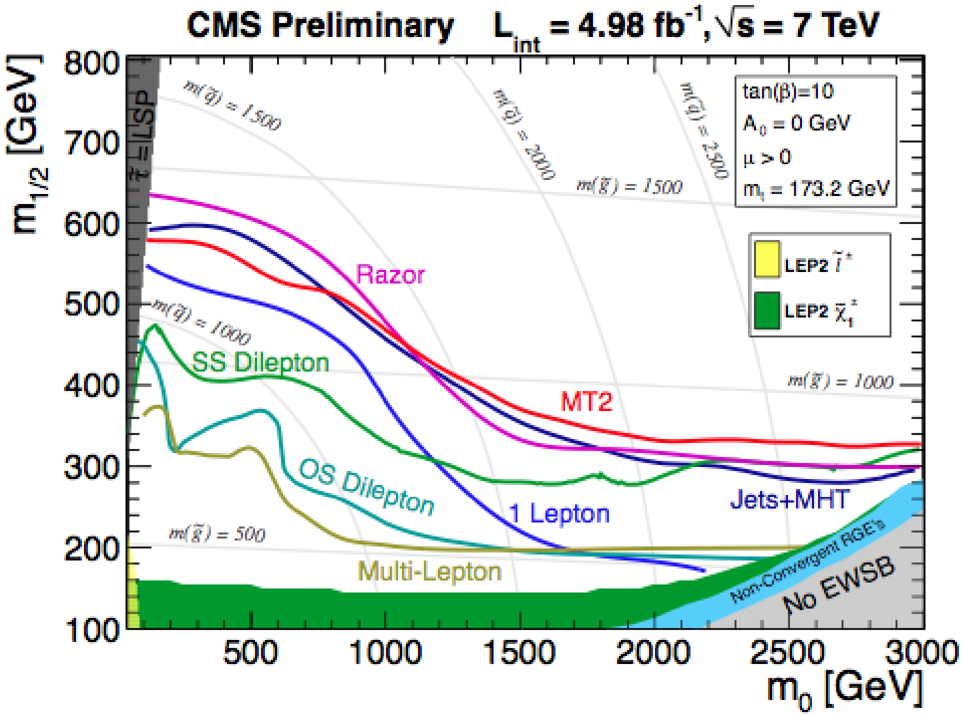
squarks and gluinos are the most abundantly produced in CMSSM
Followed by 3rd generation quark (stop)



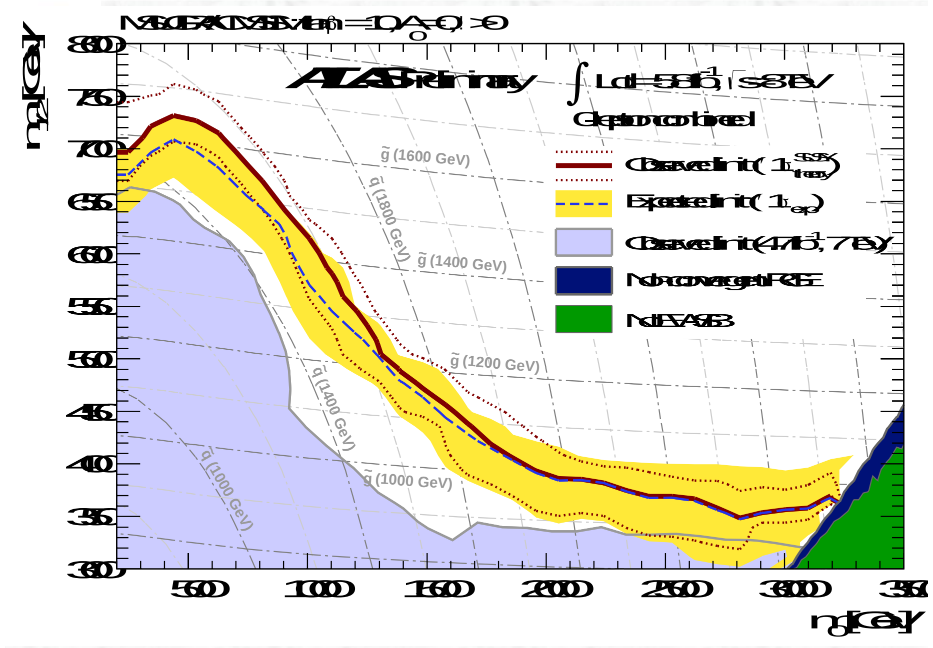
Degenerate 1st and 2nd generation squarks, and light LSP

$$\tilde{q} > 1.4 \mathrm{TeV}, \tilde{g} > 1 \mathrm{TeV}$$

SUSY : CMSSM



Minimal Models (e.g. cMSSM) under pressure ...



Most constrained model : CMSSM only 5 parameters,
Leads to rather low energy SUSY particles (<1.5 TeV)
Difficulty to accommodate 125 GeV Higgs

"Hardly tenable" (WG2 report on Implications of LHC results for TeV-Scale physics)

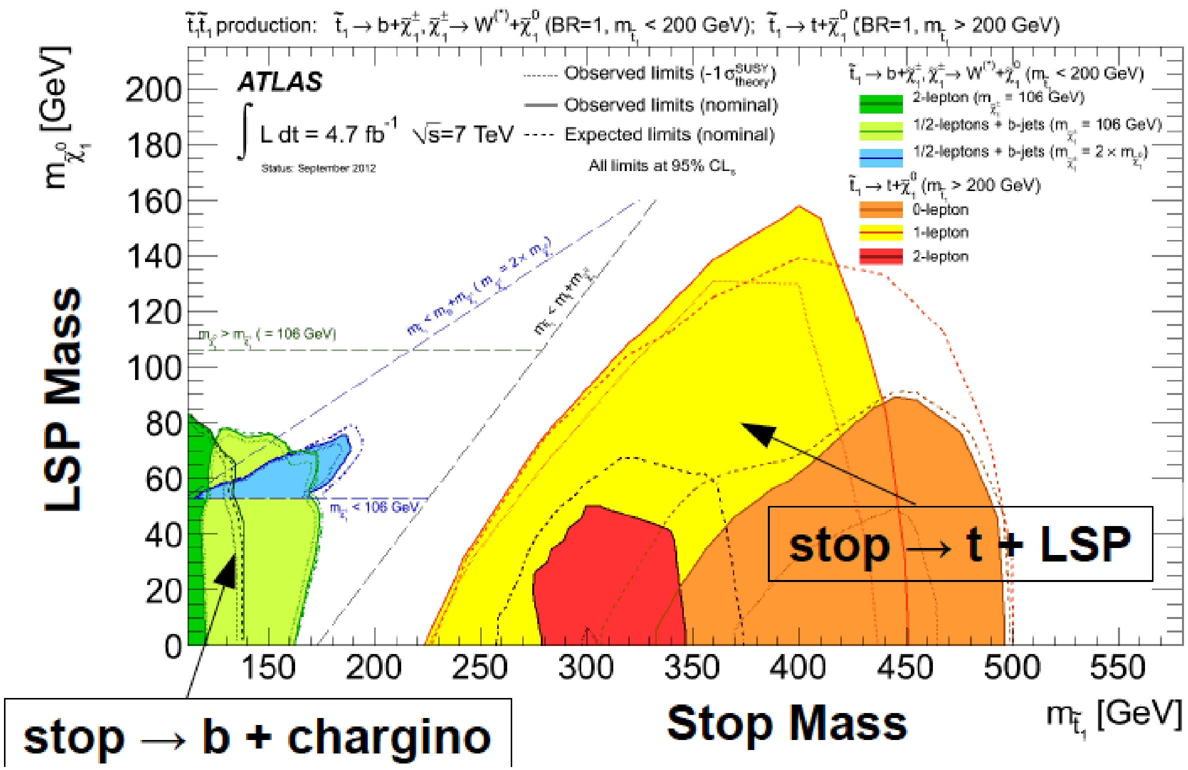
SUSY: 3rd generation

Naturalness advocates a rather light 3rd generation SUSY particles

Hunt for stop and sbottom has started !

Look for MET with bottom or even top quarks

ATLAS, LHCC 26/10/2012

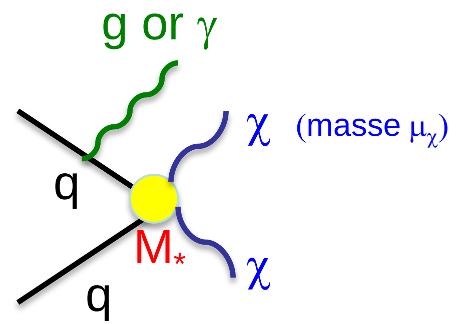


Search for (weakly) produced DM

Monojets or Mono photons +MET

- Invisible particles in final state
- Radiation for ISR/FSR

- Assume effective interaction with suppression scale M*
- Different type of interactions, either spin independent or independent
- Set limits in μ_χ-M*, translate into bounds in WIMP-nucleon X-sections directly comparable with direct searches



Name	Initial state	Type	Operator
D1	qq	scalar	$\frac{m_q}{M_*^3}\bar{\chi}\chi\bar{q}q$
D5	qq	vector	$\frac{1}{M_*^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$
D8	qq	axial-vector	$\frac{1}{M_*^2}\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$
D9	qq	tensor	$\frac{1}{M_*^2}\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$
D11	gg	scalar	$\frac{1}{4M_*^3}\bar{\chi}\chi\alpha_s(G^a_{\mu\nu})^2$

$$\sigma_0^{D1} = 1.60 \times 10^{-37}\ \mathrm{cm}^2\left(\frac{\mu_\chi}{1\ \mathrm{GeV}}\right)^2\left(\frac{20\ \mathrm{GeV}}{M_*}\right)^6, \quad (3)$$

$$\sigma_0^{D5,C3} = 1.38 \times 10^{-37}\ \mathrm{cm}^2\left(\frac{\mu_\chi}{1\ \mathrm{GeV}}\right)^2\left(\frac{300\ \mathrm{GeV}}{M_*}\right)^4, \quad (4)$$

$$\sigma_0^{D8,D9} = 9.18 \times 10^{-40}\ \mathrm{cm}^2\left(\frac{\mu_\chi}{1\ \mathrm{GeV}}\right)^2\left(\frac{300\ \mathrm{GeV}}{M_*}\right)^4, \quad (5)$$

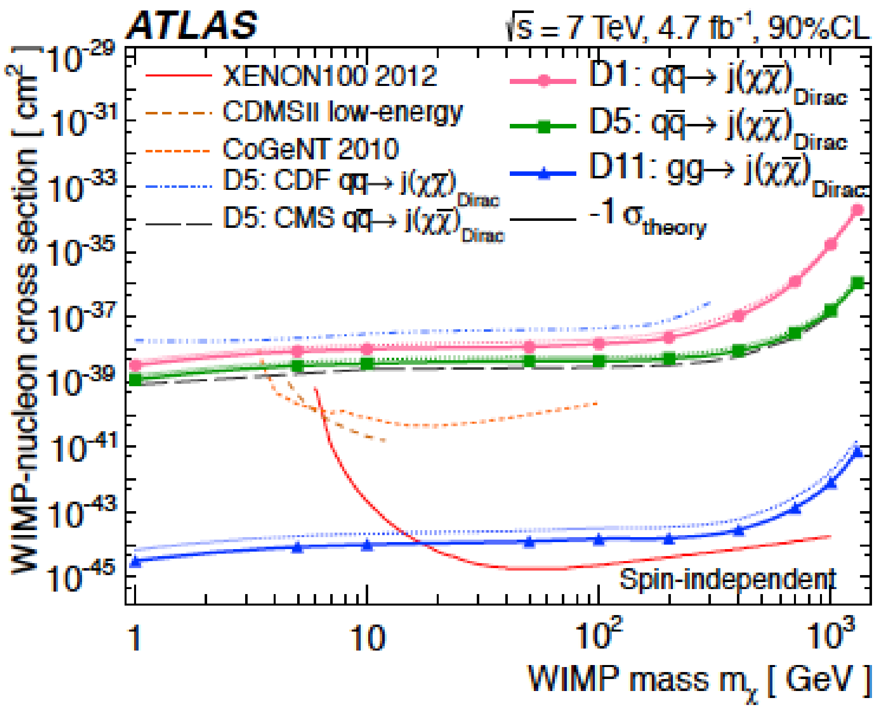
$$\sigma_0^{D11} = 3.83 \times 10^{-41}\ \mathrm{cm}^2\left(\frac{\mu_\chi}{1\ \mathrm{GeV}}\right)^2\left(\frac{100\ \mathrm{GeV}}{M_*}\right)^6, \quad (6)$$

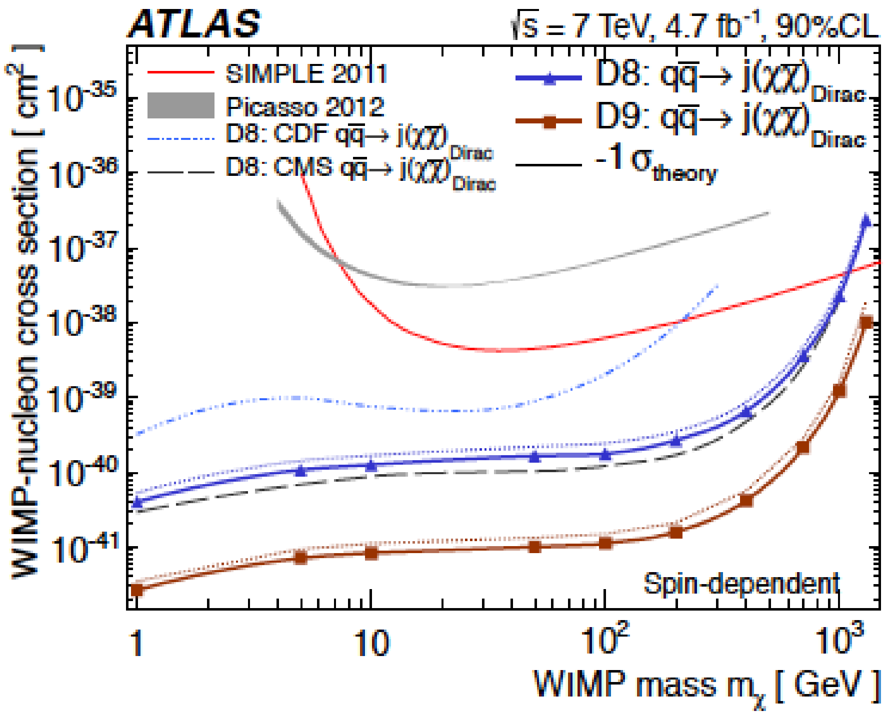
PHYSICAL REVIEW D 82, 116010 (2010)

Constraints on dark matter from colliders

Jessica Goodman, Masahiro Ibe, Arvind Rajaraman, William Shepherd, Tim M. P. Tait, and Hai-Bo Yu
Department of Physics and Astronomy, University of California, Irvine, California 92697
(Received 26 August 2010; published 27 December 2010)

Search for Dark Matter





ATLAS: ArXiv 1210.4491

CMS ~ similar result
arXiv 1206.5663

Exotica

Summary of results on searches for Physics Beyond the Standard Model in ATLAS in ATLAS

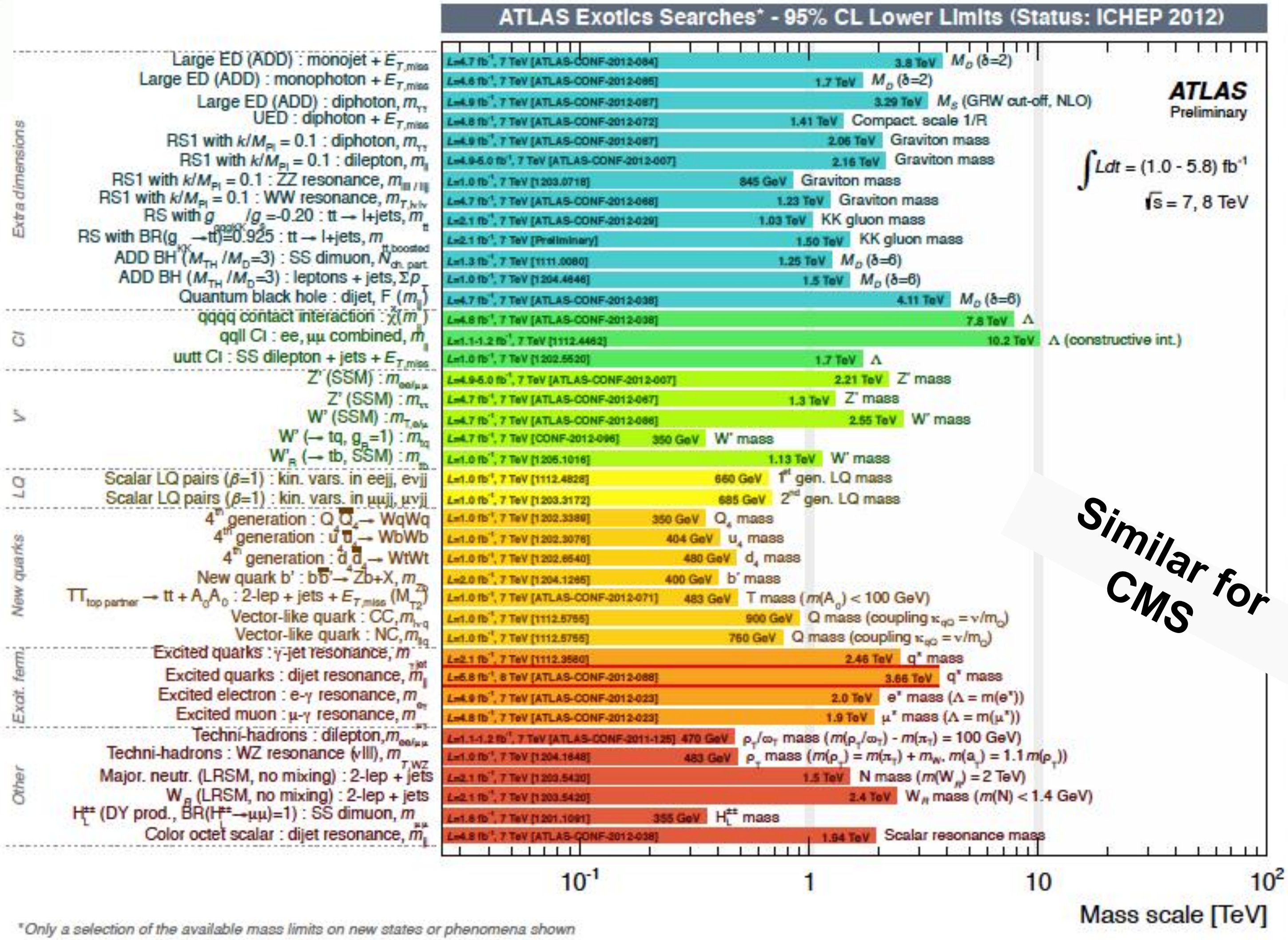
Extra dimensions

Compositeness

New gauge bosons Z' or W'

4th generation quarks

Excited states



Similar for CMS

CP Violation and rare decays

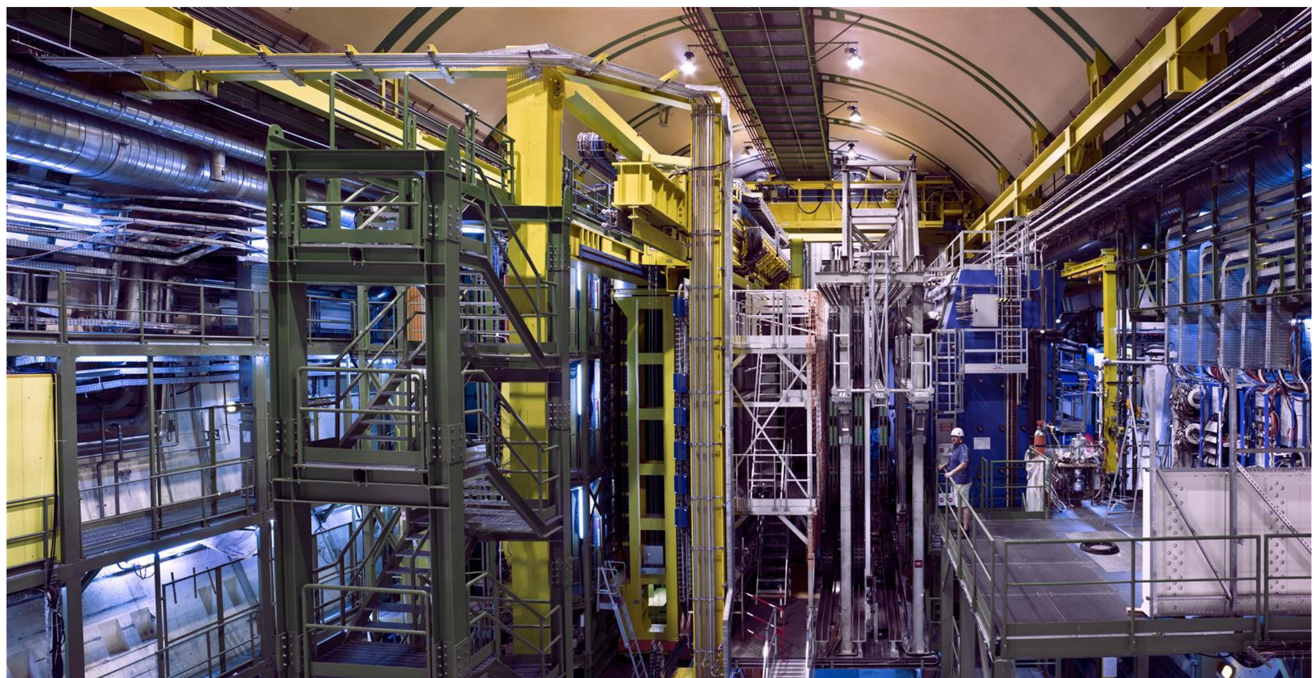
- The matter-antimatter asymmetry of the universe is still a big puzzle
- CP violation in the Standard Model to small to explain this effect
- Searching for new sources of CPV could reveal new physics
- Precision Flavour Physics is also a good way to test for New Physics at high scale through higher order loops (penguins etc…)

Mostly territory of LHCb

ATLAS & CMS contribute to specific channels with muons:

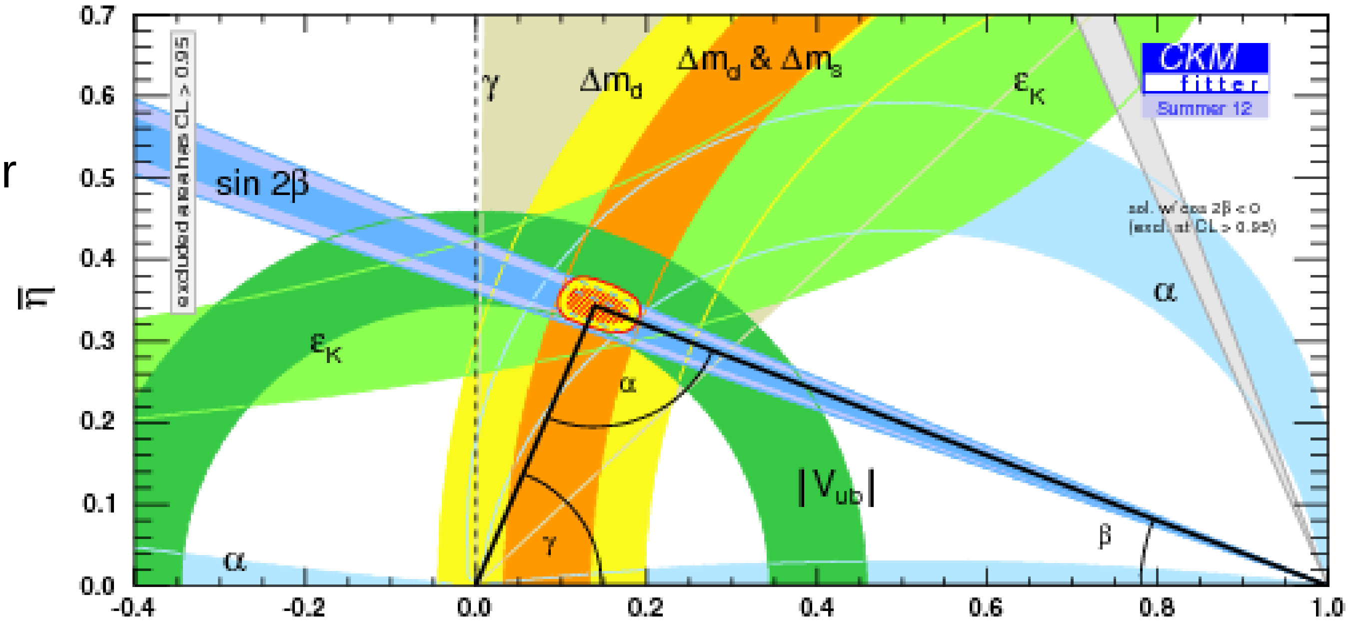
B_s-> $\mu\mu$

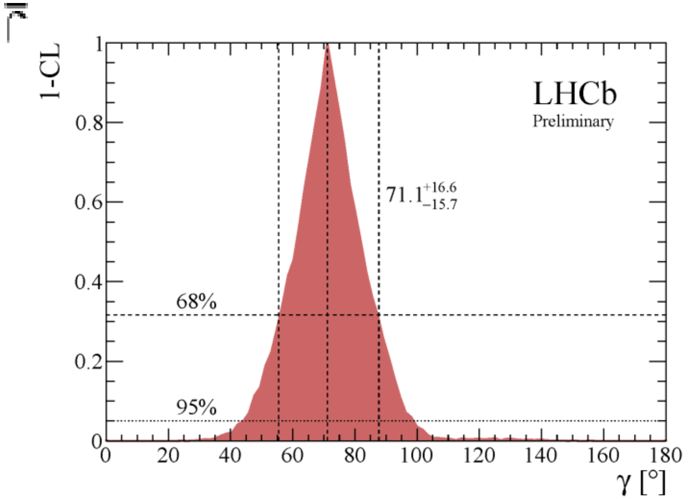
B_s->J/ψ ϕ



CP violation : closure of triangle

γ angle from other measurements
~ 67 ± 12 ^{o}





7th International Workshop on the CKM Unitarity Triangle
28th Sept-2nd October 2012 Cincinnati

$\gamma = (71.1^{+16.6}_{-15.7})^\circ$ $B^\pm \to DK$ decays

Surprises are not excluded !

Recent : huge CPV in charmless 3 body decays

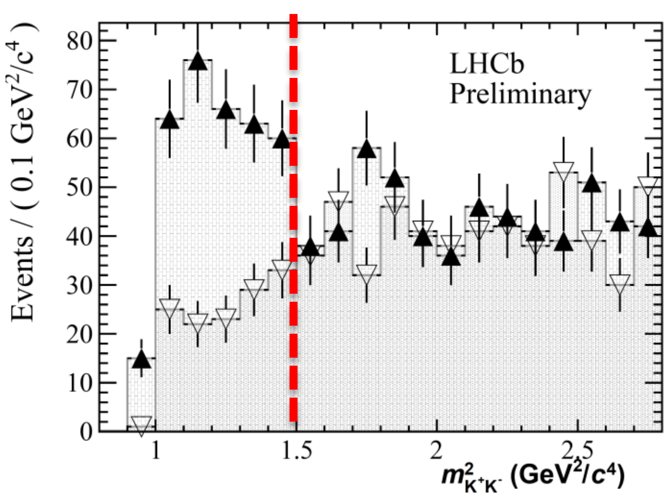
[$A_{CP}(B^{\pm}\rightarrow\pi^{\pm}\pi^{+}\pi^{-})$ = +0.120 ± 0.020 ± 0.019 ± 0.007]

[$A_{CP}(B^{\pm}\rightarrow\pi^{\pm}K^{+}K^{-})$ = -0.153 ± 0.046 ± 0.019 ± 0.007]

Broad structure below m_{KK} = 1.5 GeV/c^2 only in B^+

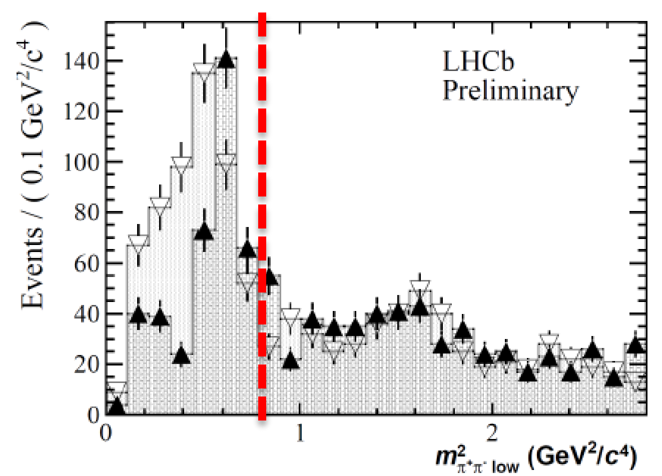
Need more data (amplitude analysis) + theory input !

A.Poluektov
On behalf of LHCb
7th Workshop on the CKM Unitarity Triangle



Low KK mass:

A_{CP} =−0.671±0.067±0.028±0.007(J/ψK)



Low ππ mass

A_{CP} =+0.622±0.075±0.032±0.007(J/ψK)

Rare decays

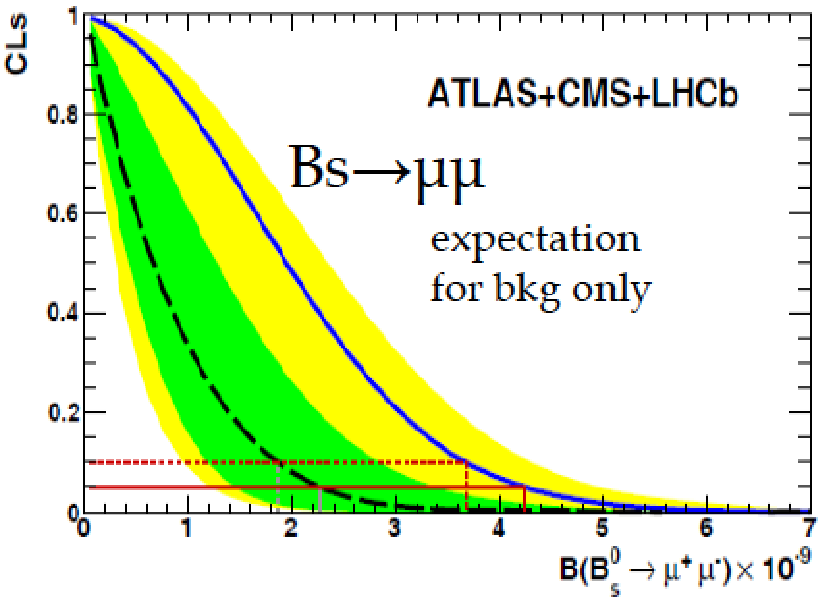
$B_s \to \mu^+\mu^-$ and $B_d \to \mu^+\mu^-$ strongly suppressed in SM
Very sensitive to new physics, in particular SUSY at high tanβ

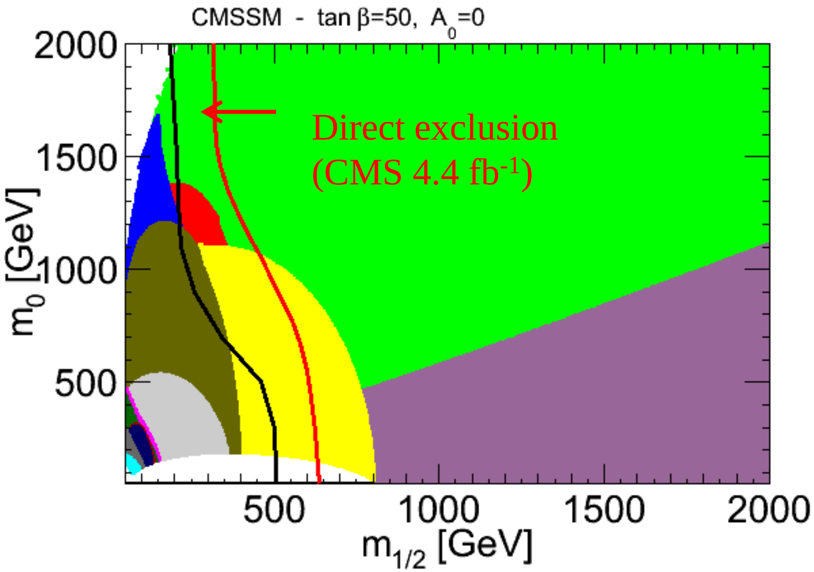
CMS-PAS-BPH-12-009
LHCb-CONF-2012-017
ATLAS-CONF-2012-061.

Combination of 3 LHC expts :

B_S: BR $< 4.2 \times 10^{-9}$ (at 95% CL) Stand Model: $(3.2 \pm 0.2) \times 10^{-9}$

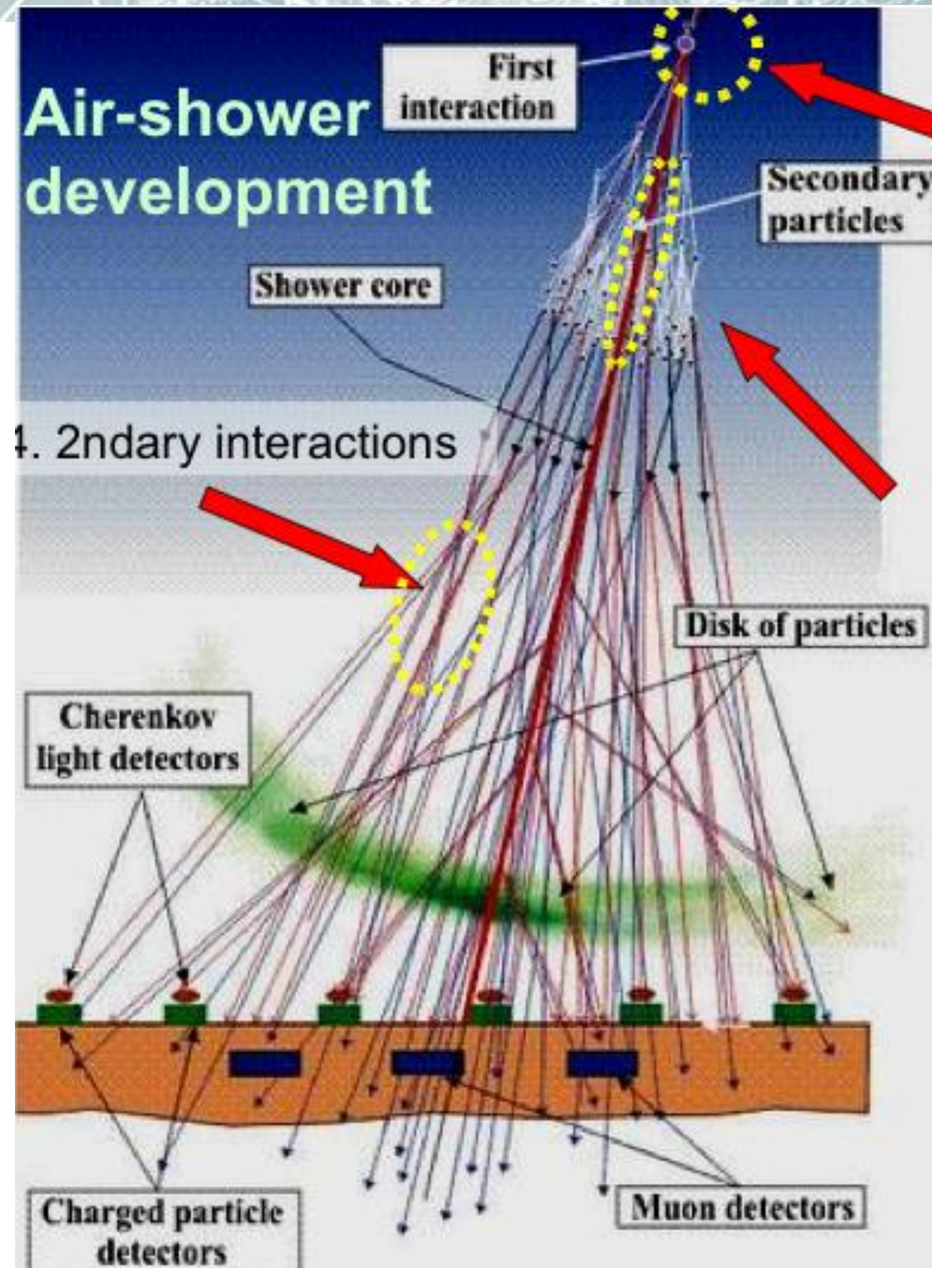
B_d: BR $< 0.81 \times 10^{-9}$ (at 95% CL) Stand Model: $(0.1 \pm 0.01) \times 10^{-9}$





[N. Mahmoudi, Moriond QCD]

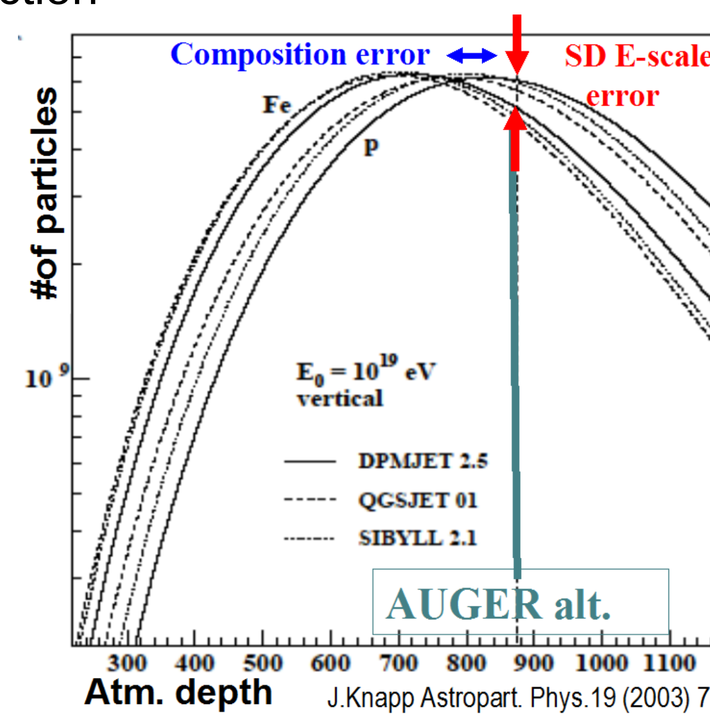
Data relevant for U.H.E. Cosmic Rays



Inelastic cross section

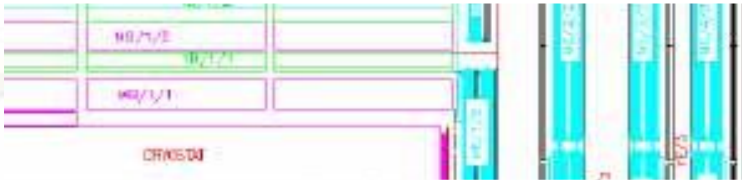
Forward production

LHC experiments can help reducing the Uncertainty on E scale and composition of air showers



J.Knapp Astropart. Phys.19 (2003) 77

TOTEM (P5) , ALPHA and LHCf (P1) detectors



14 m

T1: $3.1 < \eta < 4.7$

T2: $5.3 < \eta < 6.5$

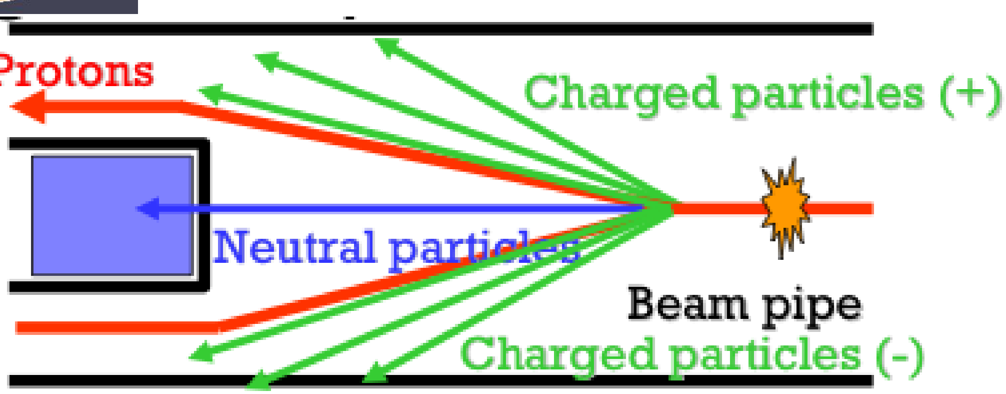
TOTEM

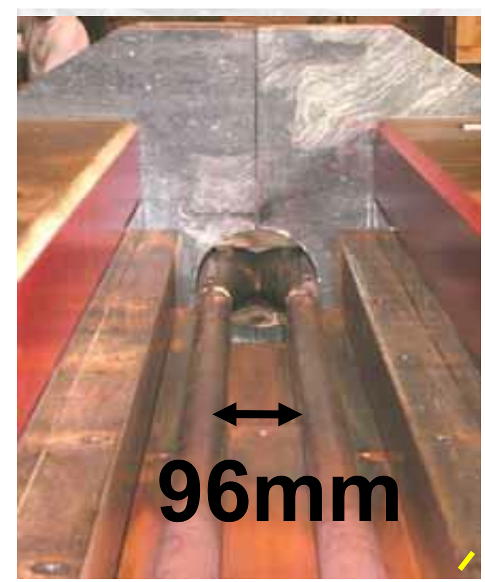
Roman Pot stations in the LHC tunnel

RP (147 m)

RP (220m)

(F.Ferro, Diffraction 2010)

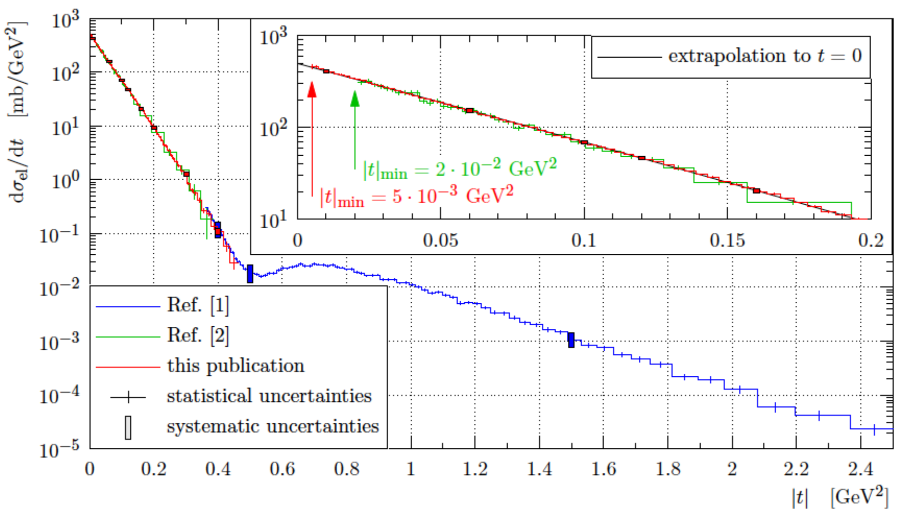




Inelastic and total p-p cross section at high E

TOTEM & ALPHA Experiments

Specific runs with high β* (90m, 500m, 1km in oct 2012) to measure elastic cross section



√s= 7 TeV
EPL 95 (2011) 41001

elastic observables only:

$$\sigma^2_{tot} = \frac{16\pi}{1+\varrho^2} \frac{1}{\mathcal{L}} \left.\frac{dN_{el}}{dt}\right|_0$$

June (EPL96): $\sigma_{tot} = (98.3 \pm 2.0)$ mb
October: $\sigma_{tot} = (98.6 \pm 2.3)$ mb

σ_{tot}

ϱ independent:

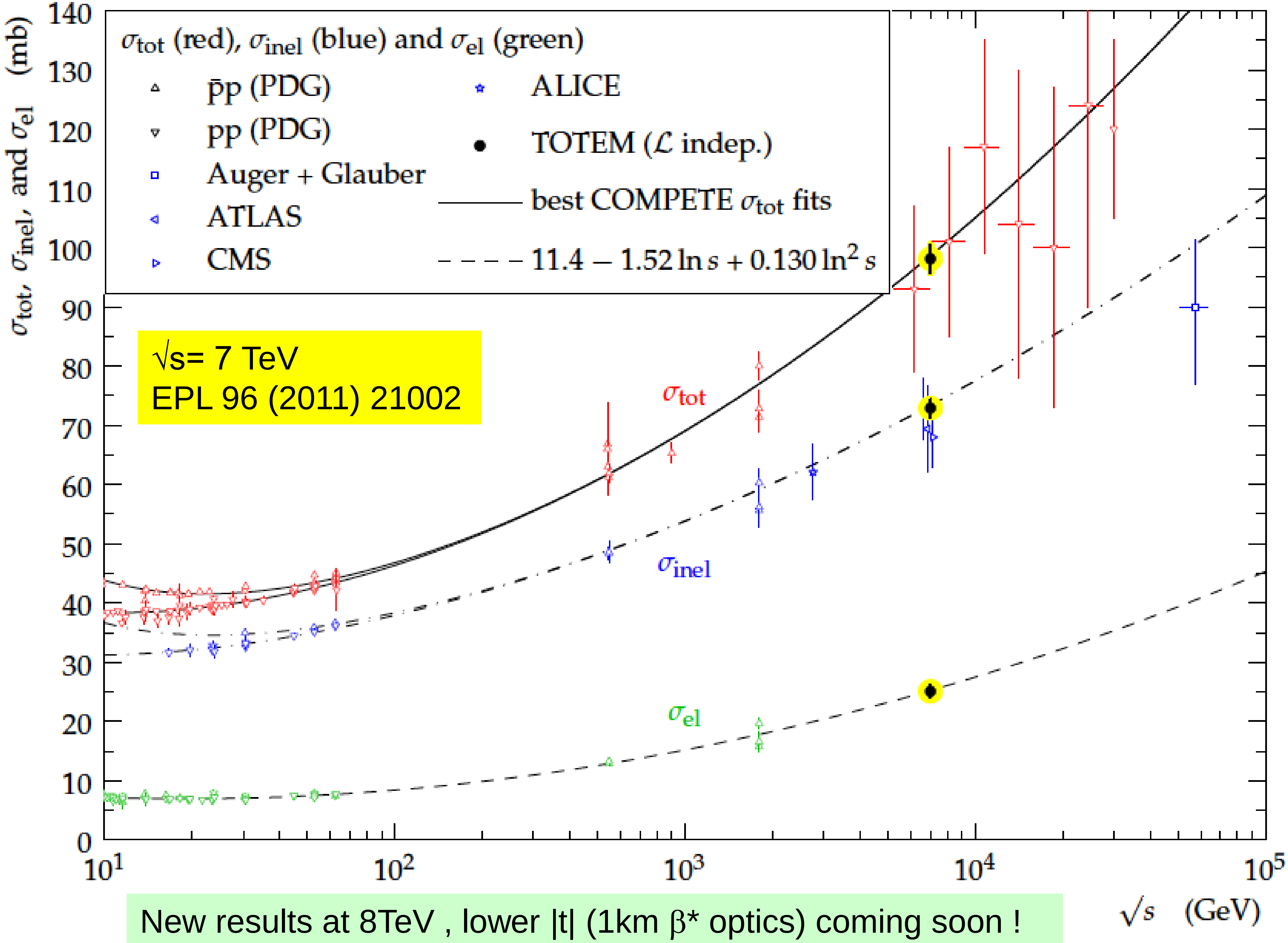
$$\sigma_{tot} = \frac{1}{\mathcal{L}} (N_{el} + N_{inel})$$

$\sigma_{tot} = (99.1 \pm 4.4)$ mb

luminosity independent:

$$\sigma_{tot} = \frac{16\pi}{1+\varrho^2} \frac{dN_{el}/dt|_0}{N_{el} + N_{inel}}$$

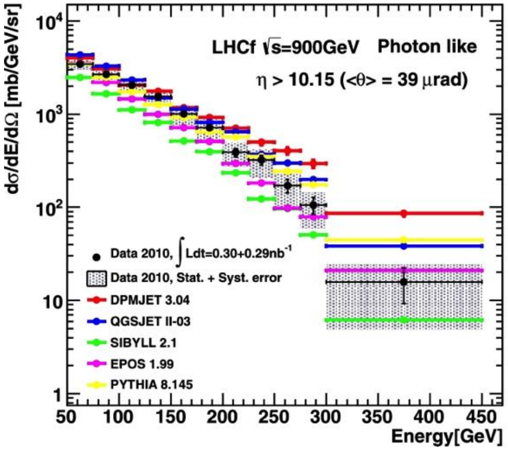
$\sigma_{tot} = (98.1 \pm 2.4)$ mb

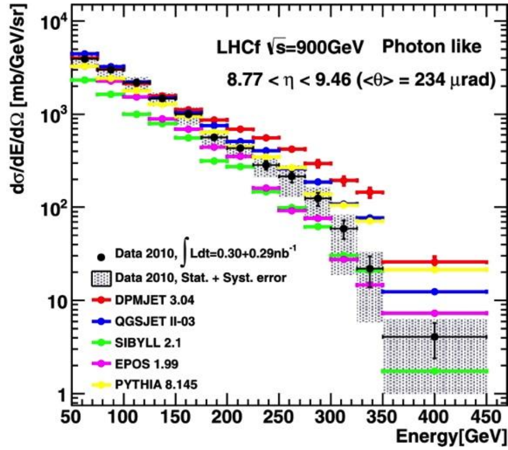


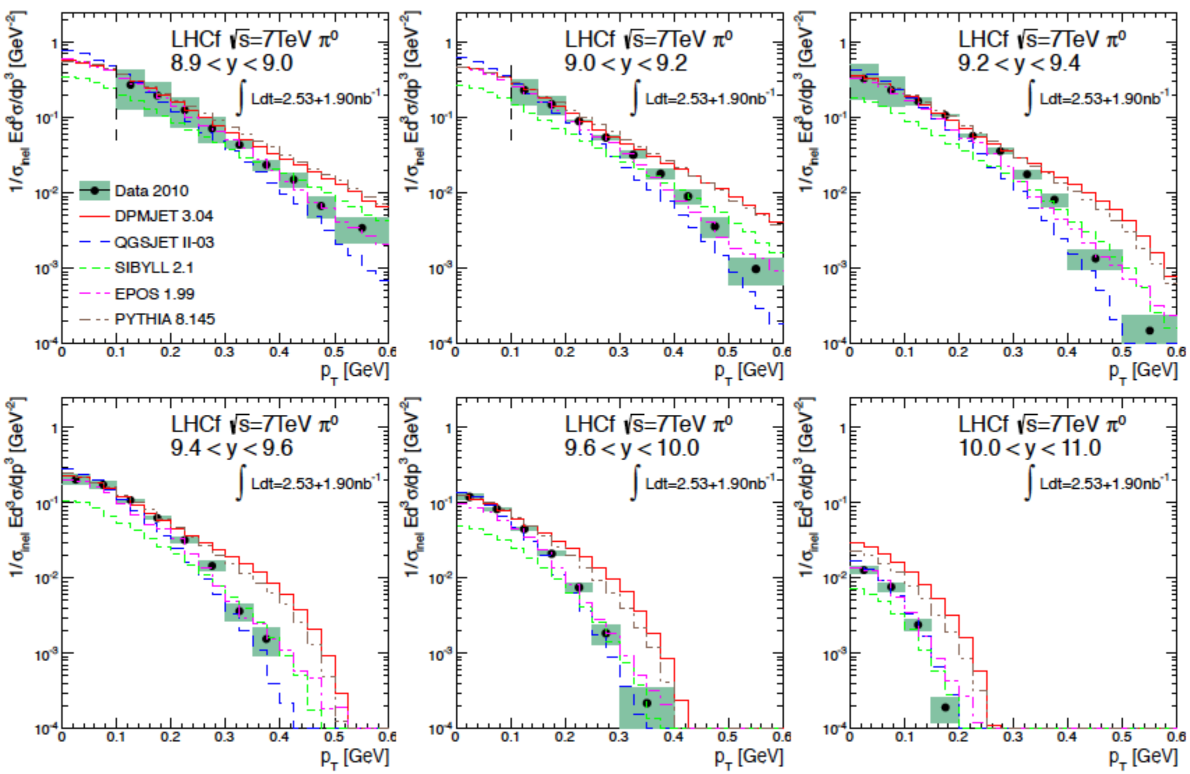
σ_{tot} (red), σ_{inel} (blue) and σ_{el} (green)
$\bar{p}p$ (PDG)
pp (PDG)
Auger + Glauber
ATLAS
CMS
ALICE
TOTEM ($\mathcal{L}$ indep.)
best COMPETE σ_{tot} fits
$11.4 - 1.52 \ln s + 0.130 \ln^2 s$
√s= 7 TeV
EPL 96 (2011) 21002
σ_{tot}
σ_{inel}
σ_{el}
σ_{tot}, σ_{inel}, and σ_{el} (mb)
$\sqrt{s}$ (GeV)
New results at 8TeV , lower |t| (1km β* optics) coming soon !

Forward production of π^0 and γ

$\sqrt{s}$= 0.9 TeV
Inclusive γ production 8.77<η<11.
Phys. Lett. B 715 (2012) 298-303







$\sqrt{s}$= 7 TeV
π^0 production 8.9<η<11.
arXiv:1205.4578

The predictable future: LHC Time-line

2009 — Start of LHC

Run 1: 7-8 TeV centre of mass energy, luminosity ramping up to 7 10^{33} cm^{-2} s^{-1},~25 fb^{-1} delivered

2013/14 — LHC shut-down to prepare machine for design energy and nominal luminosity

Run 2: Ramp up √s & luminosity to nominal (10^{34} cm^{-2} s^{-1}), ~50 to 60 fb^{-1}

2018 — Injector and LHC Phase-I upgrades to go to ultimate luminosity

Run 3: Ramp up luminosity to 2.2 x nominal, reaching ~100 fb^{-1} / year accumulate few hundred (~300) fb^{-1}

~2022 — Phase-II: High-luminosity LHC. New focussing magnets and CRAB cavities for very high luminosity with levelling

Run 4: Collect data until > 3000 fb^{-1}

2030 — Next machine ?

This requires a parallel work on detectors consolidations/upgrades

2009 — Start of LHC

2013/14
- Consolidation of Infrastructure for all
- CMS 4th Muon station forward
- New reduced diameter Be beam pipes CMS & ATLAS
- ATLAS : new pixel internal layer (IBL)

2018
- ATLAS: Upgrade Trigger, new small Muon wheels, FTK trigger, Forward physics
- CMS : Upgrade Trigger, New pixel detector, New photosensors for HCAL, Forward Muon chambers
- LHCb : Upgrade FE electronics: New 40 MHz readout, x10 luminosity !
- ALICE : New vertex detector (ITS), faster TPC, DAQ,….

~2022
- ATLAS: New central Tracker + …?
- CMS : New central Tracker + ….?
- LHCb : continue until 50 fb^{-1}
- ALICE : continue until 10 nb^{-1} PbPb

2030

Conclusions

- 2012 will be remembered as a milestone in the conquest of a new energy scale in physics:
  - Atomic scale 10^{-8} cm (1900)   Strong scale 10^{-13} cm (1970's)

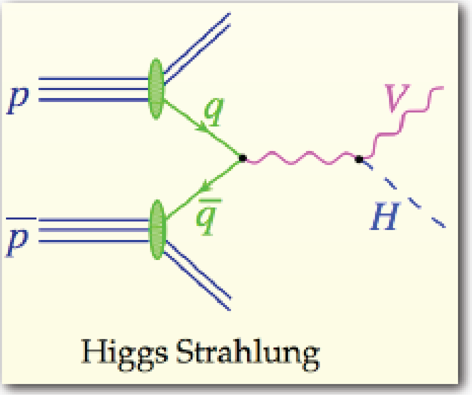
Weak scale 10^{-17} cm

- The LHC and the LHC detectors have shown to perform extremely well, even above expectations.

- **This just the beginning !**
  - The LHC has so far produced only 1% of its ultimate data sample. Furthermore, the operation at full energy (13 to14 TeV) will increase the power of searches by more than a factor x10.
  - This will allow us to go deeper and deeper in understanding what we just discovered and hopefully find sign of **New Physics** which is needed to complete the Standard Model.

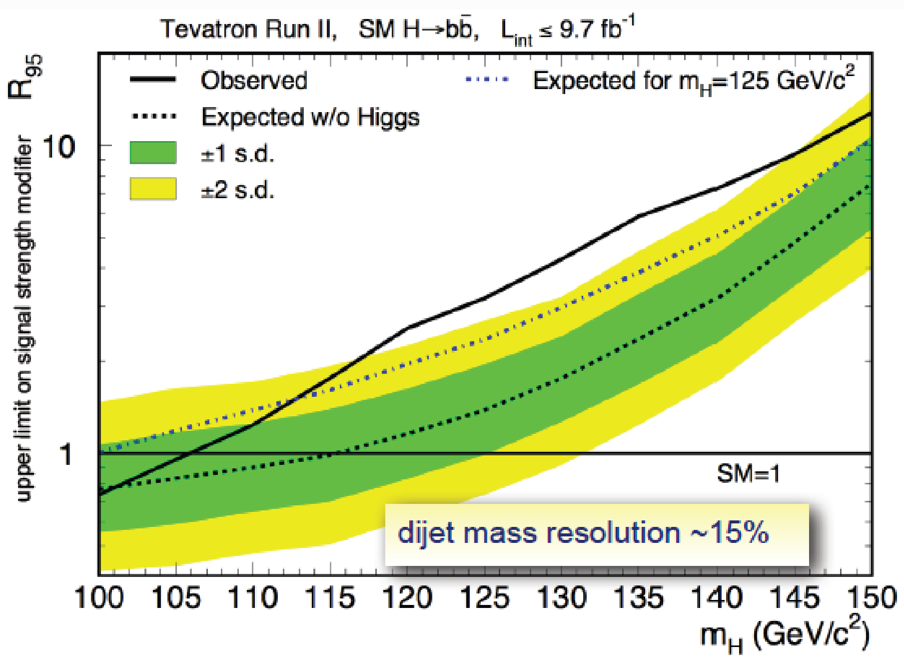
Backup slides

Tevatron (CDF+D0 combined) evidence



Z,W: lept. and inv. decays

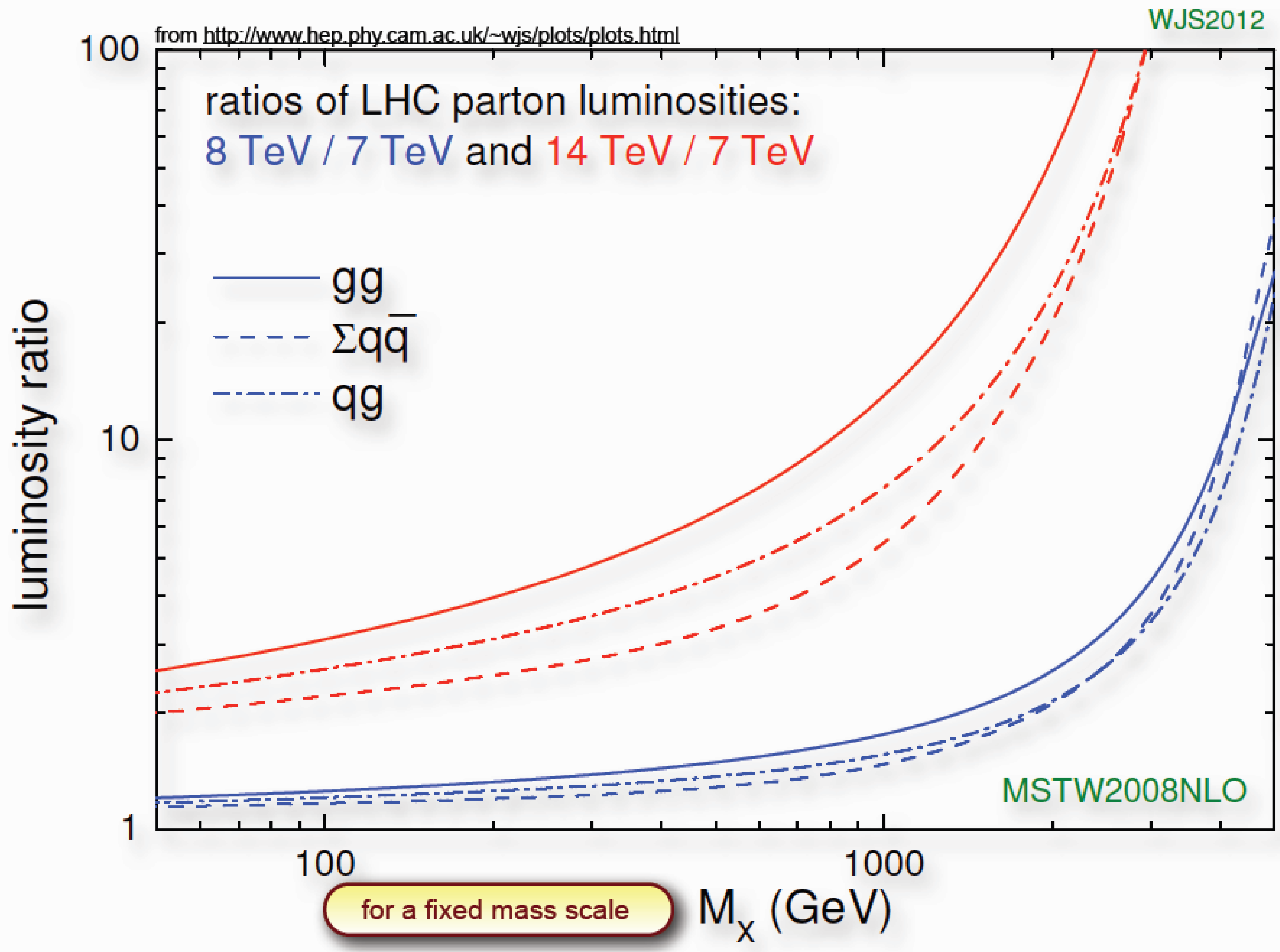
H→bb



Max local significance 3.3 σ at 135 GeV
Global significance 3.1 σ
σxBR factor 2 above SM expectation
So far only evidence for coupling to fermions

arXiv 1207.6436

Potential of 14 TeV LHC

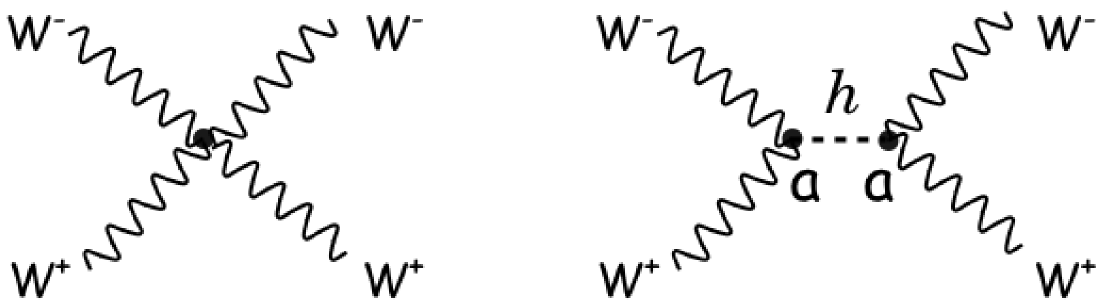


The perturbative unitarity conundrum

the Higgs plays a crucial in the UV behavior of massive state scattering

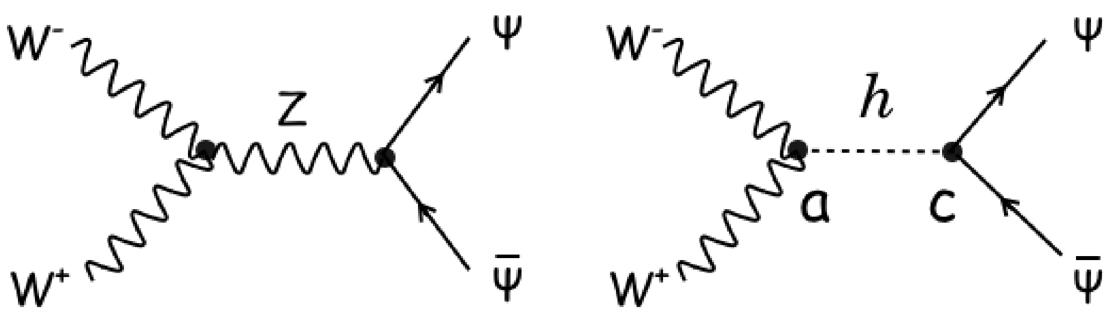
$$\mathcal{L}_{\rm EWSB} = -m_V^2 V_\mu V^\mu \left(1 + 2a\frac{h}{v}\right) - m_\psi \bar\psi\psi \left(1 + c\frac{h}{v}\right)$$

'a' and 'c' are arbitrary free couplings



$$\mathcal{A} = \frac{1}{v^2}\left(s - \frac{a^2 s^2}{s - m_h^2}\right)$$

For a=1: perturbative unitarity in elastic channels WW → WW



$$\mathcal{A} = \frac{m_\psi\sqrt{s}}{v^2}\left(1 - \frac{ac\, s}{s - m_h^2}\right)$$

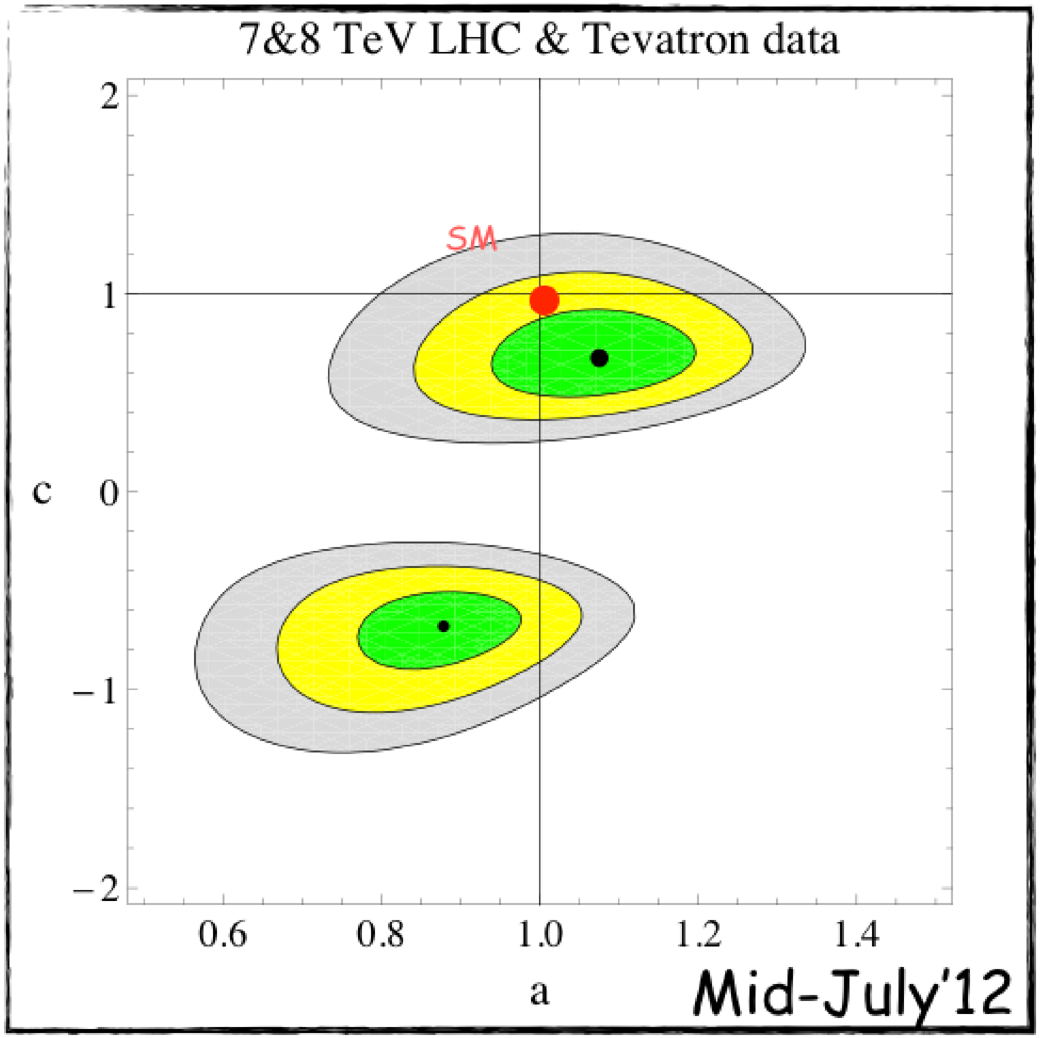
For ac=1: perturbative unitarity in inelastic WW → $\psi\,\psi$

Cornwall, Levin, Tiktopoulos '73

Contino, Grojean, Moretti, Piccinini, Rattazzi '1

Unitarity: χ^2 fit to the "125" excess

Espinosa, Grojean, Muhlleitner, Trott '12



note: a fermiophobic Higgs (c=0) is disfavored by data (mostly VBF channels) at 97%CL

for similar analyses, see also

Giardino, Kannike, Raidal, Strumia '12
Carni, Falkowski, Kuflik, Volansky, Zupan '12
Corbet, Eboli, Gonzalez-Fraile, Gonzalez-Garcia '12
Montull, Riva '12