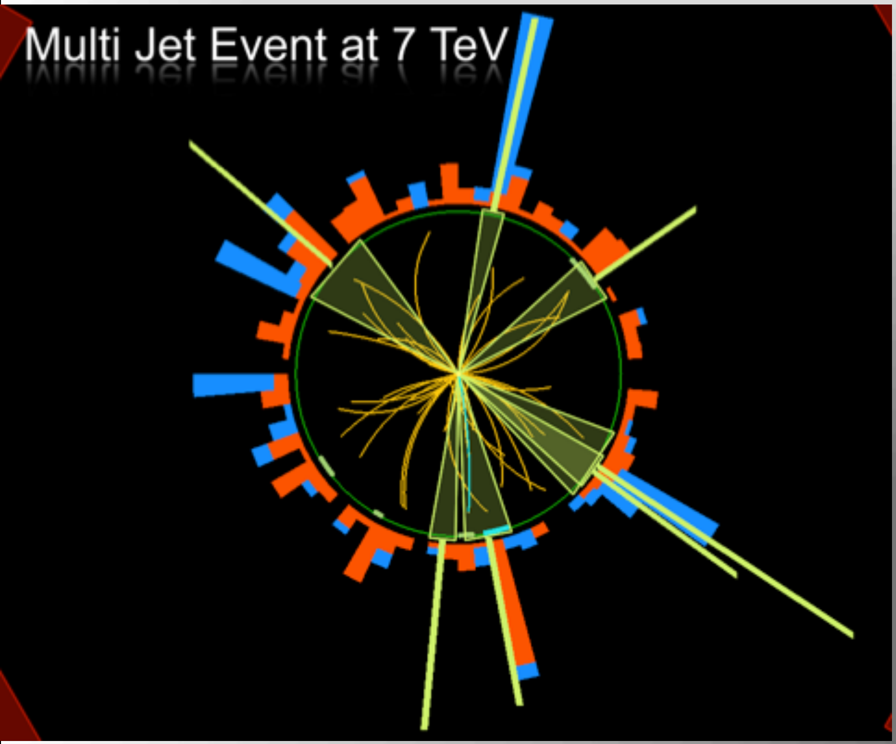
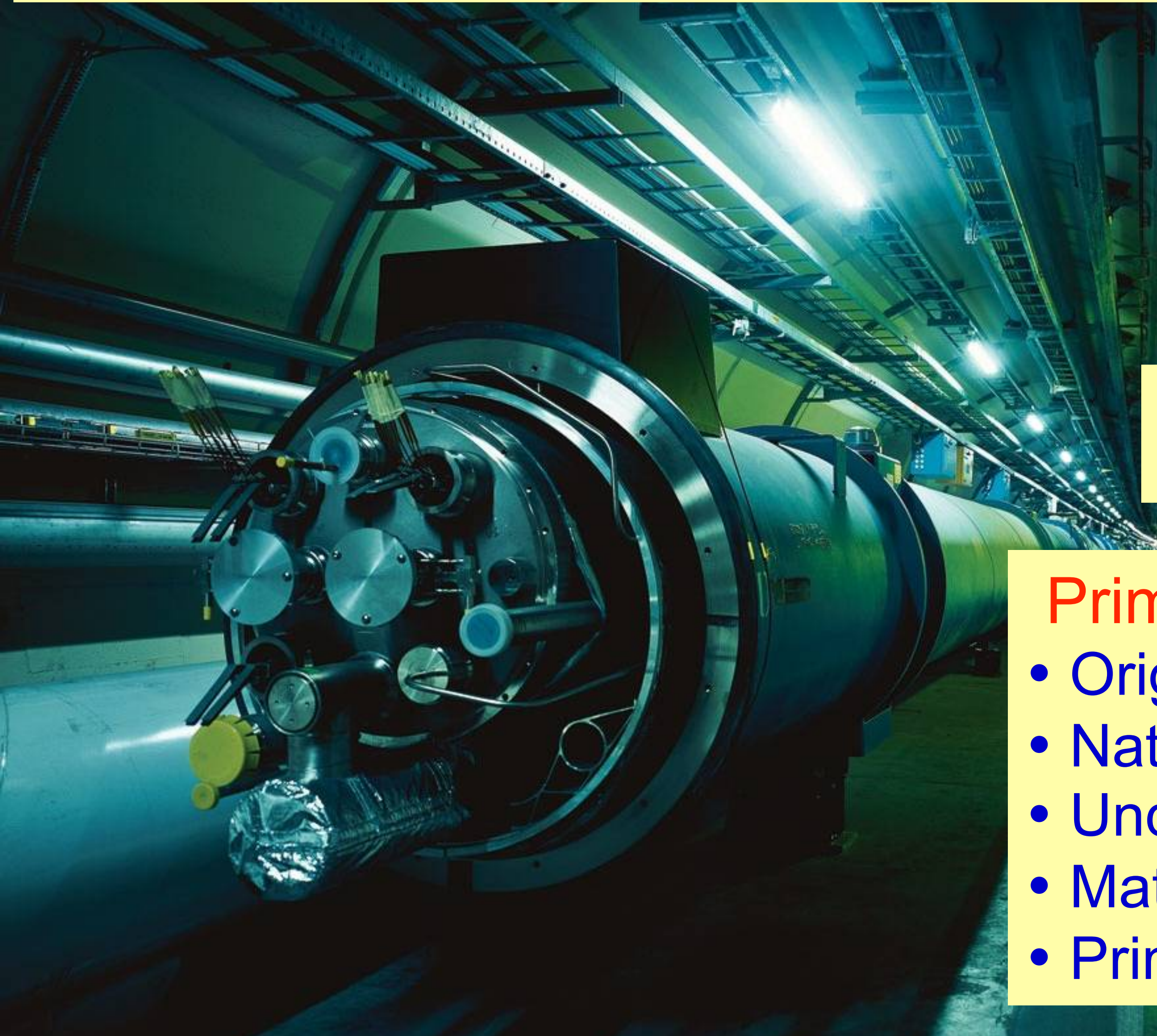
Outline



- Introduction: Searches
- Searching for the Higgs Boson
- Searches for Physics Beyond the Standard Model: Examples
  - Extra Dimensions and Dark Matter
  - Unusual Stable Particles

The Large Hadron Collider = a proton proton collider



7 TeV + 7 TeV
(3.5/4 TeV + 3.5/4 TeV)

1 TeV = 1 Tera electron volt
= 10^{12} electron volt

Primary physics targets

- Origin of mass
- Nature of Dark Matter
- Understanding space time
- Matter versus antimatter
- Primordial plasma

The LHC is a Discovery Machine
The LHC will determine the Future course of High Energy Physics

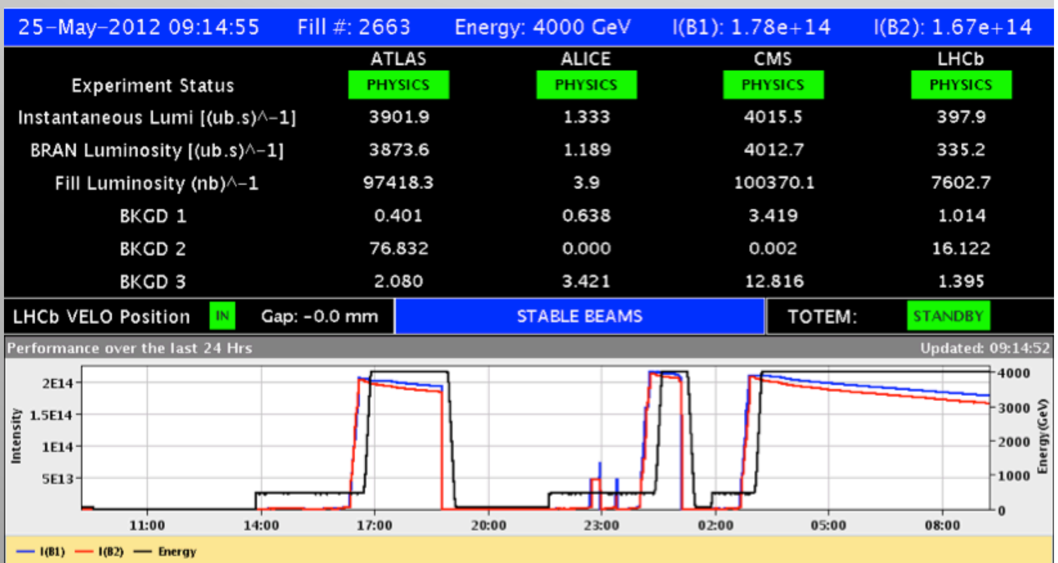
LHC Today

LHC is doing very well

Last year: luminosity $3 \cdot 10^{33}$ cm^{-2} s^{-1} ⇒ 5 fb^{-1} collected in total

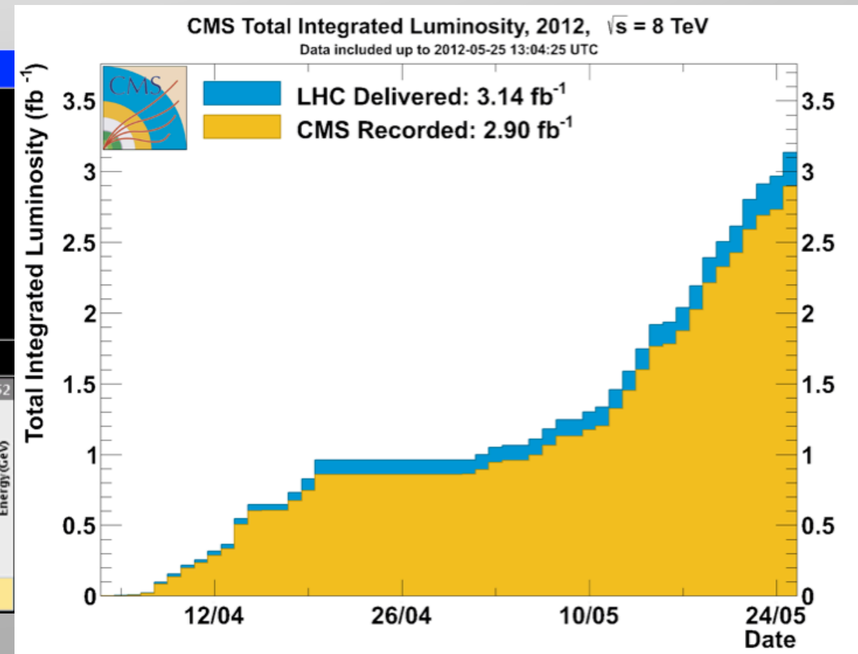
This year: luminosity $6.5 \cdot 10^{33}$ cm^{-2} s^{-1} ⇒ 3 fb^{-1} collected so far

~20 fb^{-1} expected end 2012


25–May–2012 09:14:55 Fill #: 2663 Energy: 4000 GeV I(B1): 1.78e+14 I(B2): 1.67e+14

	ATLAS	ALICE	CMS	LHCb
Experiment Status	PHYSICS	PHYSICS	PHYSICS	PHYSICS
Instantaneous Lumi [(ub.s)^–1]	3901.9	1.333	4015.5	397.9
BRAN Luminosity [(ub.s)^–1]	3873.6	1.189	4012.7	335.2
Fill Luminosity (nb)^–1	97418.3	3.9	100370.1	7602.7
BKGD 1	0.401	0.638	3.419	1.014
BKGD 2	76.832	0.000	0.002	16.122
BKGD 3	2.080	3.421	12.816	1.395

LHCb VELO Position IN Gap: -0.0 mm STABLE BEAMS TOTEM: STANDBY



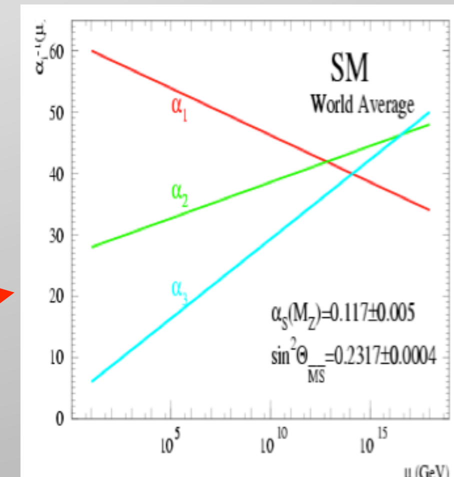
Luminosity = # events/cross section/time

Physics case for new High Energy Machines

Understand the mechanism Electroweak Symmetry Breaking

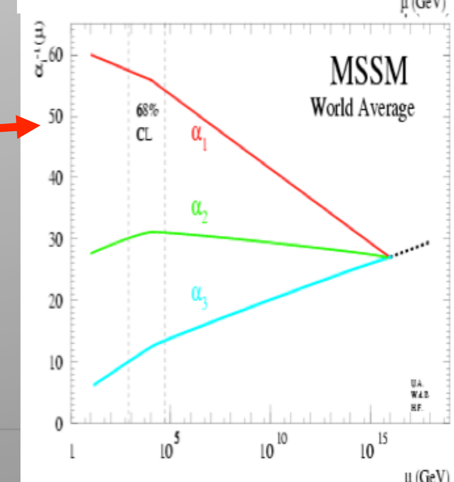
Discover physics beyond the Standard Model

Reminder: The Standard Model
- tells us how but not why
  3 flavour families? Mass spectra? Hierarchy?
- needs fine tuning of parameters to level of 10^{-30} !
- has no connection with gravity
- no unification of the forces at high energy



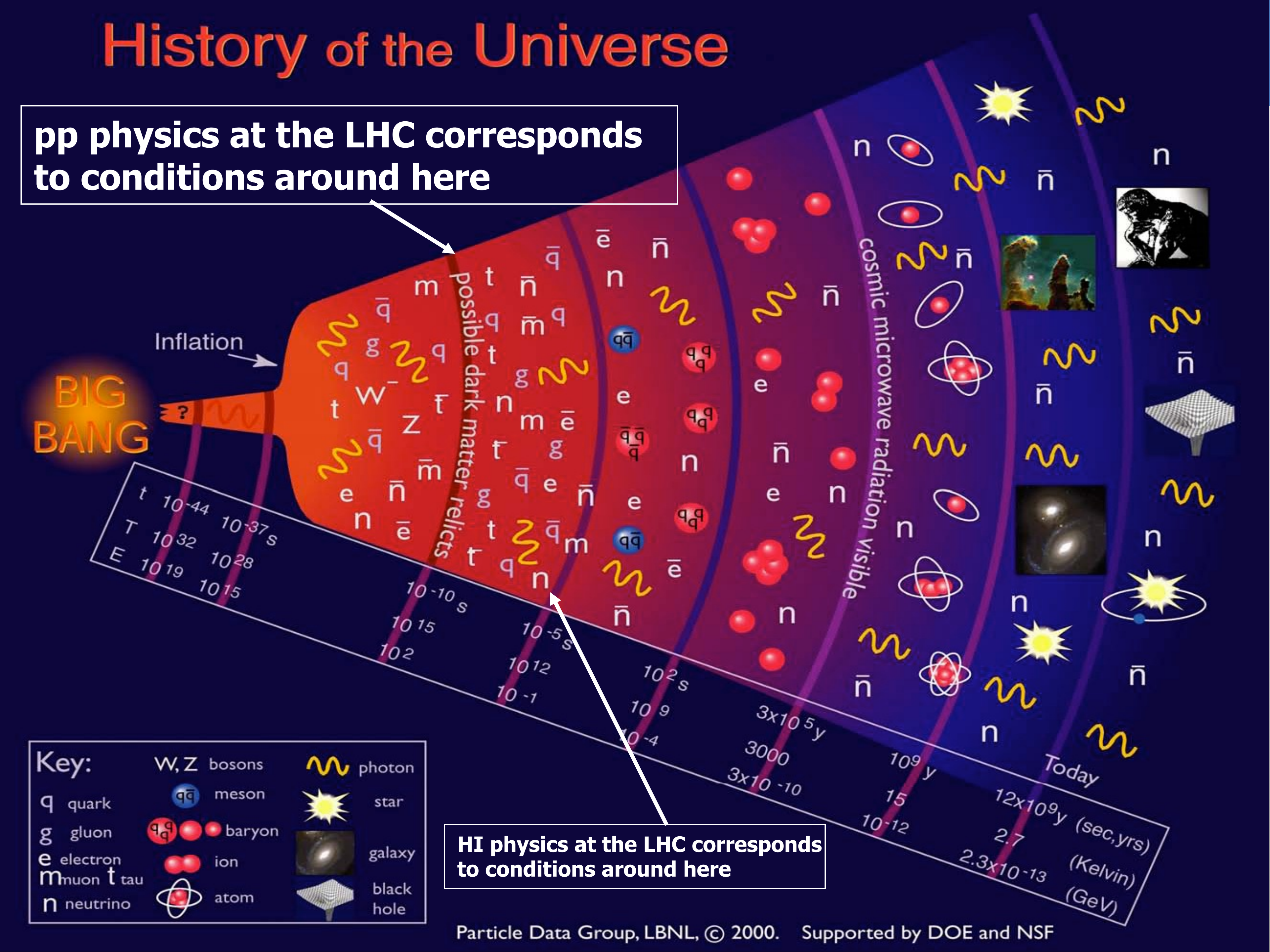
Most popular extensions these days

If a Higgs field exists:
- Supersymmetry
- Extra space dimensions



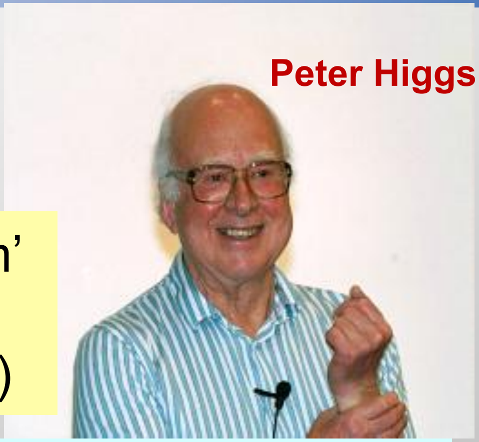
If there is no Higgs below ~ 700 GeV
- Strong electroweak symmetry breaking around 1 TeV

Other ideas: more symmetry & gauge bosons, L-R symmetry, quark & lepton substructure, Little Higgs models, Technicolor, Hidden Valleys…

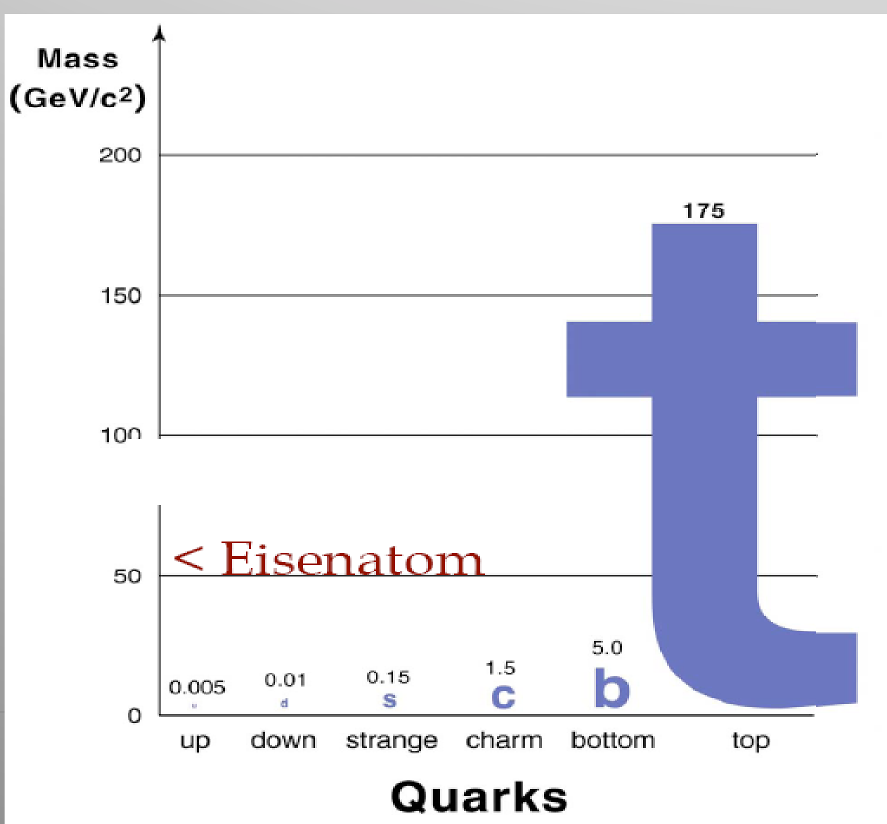

History of the Universe
pp physics at the LHC corresponds to conditions around here
HI physics at the LHC corresponds to conditions around here
BIG BANG
Inflation
possible dark matter relicts
cosmic microwave radiation visible
t 10-44 10-37 s 10-10 s 10-5 s 10 2 s 3x10 5 y 10 9 y Today 12x10 9 y (sec,yrs)
T 10 32 10 28 10 15 10 12 10 9 3000 15 2.7 (Kelvin)
E 10 19 10 15 10 2 10 -1 10 -4 3x10 -10 10 -12 2.3x10 -13 (GeV)
Key:
W, Z bosons
q quark
g gluon
e electron
m muon t tau
n neutrino
meson
baryon
ion
atom
photon
star
galaxy
black hole
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

The Origin of Particle Masses

A most basic question is why particles (and matter) have masses (and so different masses)



The mass mystery could be solved with the ‘Higgs mechanism’ which predicts the existence of a new elementary particle, the ‘Higgs’ particle (theory 1964, P. Higgs, R. Brout and F. Englert)



The Higgs (H) particle has been searched for since decades at accelerators, but not yet found…

The LHC will have sufficient energy to produce it for sure, if it exists

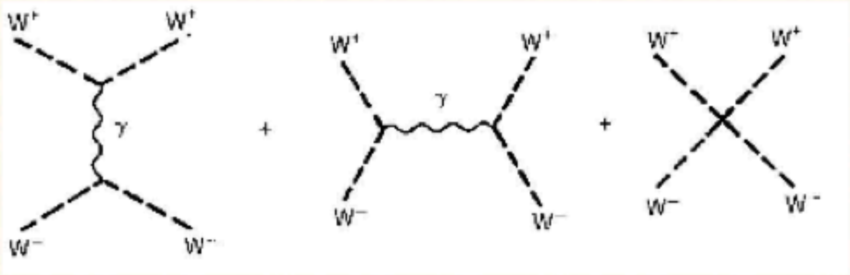
Standard Model: Problems

- **Masses of the vector bosons W and Z:**

Experimental results: $M_W = 80.399 \pm 0.023$ GeV / c^2
$M_Z = 91.1875 \pm 0.0021$ GeV / c^2

A local gauge invariant theory requires massless gauge fields

- **Divergences in the theory (scattering of W bosons)**



$$-iM(W^+W^- \to W^+W^-) \sim \frac{s}{M_W^2} \quad \text{for} \quad s \to \infty$$

Higgs Mechanism

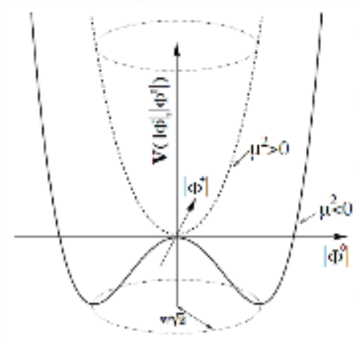
Standard Model

The Higgs mechanism

Spontaneous breaking of the SU(2) x U(1) gauge symmetry

- Scalar fields are introduced $$\phi = \frac{1}{\sqrt{2}}\begin{pmatrix}\phi_1 + i\phi_2 \\ \phi_3 + i\phi_4\end{pmatrix} = \begin{pmatrix}\phi^+ \\ \phi^0\end{pmatrix}$$

  Potential : $$V(\phi) = \mu^2(\phi^*\phi) + \lambda(\phi^*\phi)^2$$



- Lagrangian for the scalar fields:
  g, g' = SU(2), U(1) gauge couplings
  $$L_2 = \left|\left(i\partial_\mu - g\mathbf{T}\cdot\mathbf{W}_\mu - g'\frac{Y}{2}B_\mu\right)\phi\right|^2 - V(\phi)$$

- For $\mu^2 < 0$, $\lambda > 0$, minimum of potential:
  $$\phi_1^2 + \phi_2^2 + \phi_3^2 + \phi_4^2 = v^2 \qquad v^2 = -\mu^2/\lambda$$

- Perturbation theory around ground state:
  $$\phi_0(x) = \frac{1}{\sqrt{2}}\begin{pmatrix}0 \\ v + h(x)\end{pmatrix} \Rightarrow$$

Higgs Field → Scalar boson : Higgs Particle

The Seminal Papers

BROKEN SYMMETRY AND THE MASS OF GAUGE VECTOR MESONS*

F. Englert and R. Brout
Faculté des Sciences, Université Libre de Bruxelles, Bruxelles, Belgium
(Received 26 June 1964)

BROKEN SYMMETRIES, MASSLESS PARTICLES AND GAUGE FIELDS

P. W. HIGGS
Tait Institute of Mathematical Physics, University of Edinburgh, Scotland

Received 27 July 1964

VOLUME 13, NUMBER 16 PHYSICAL REVIEW LETTERS 19 OCTOBER 1964

BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

Peter W. Higgs
Tait Institute of Mathematical Physics, University of Edinburgh, Edinburgh, Scotland
(Received 31 August 1964)

GLOBAL CONSERVATION LAWS AND MASSLESS PARTICLES*

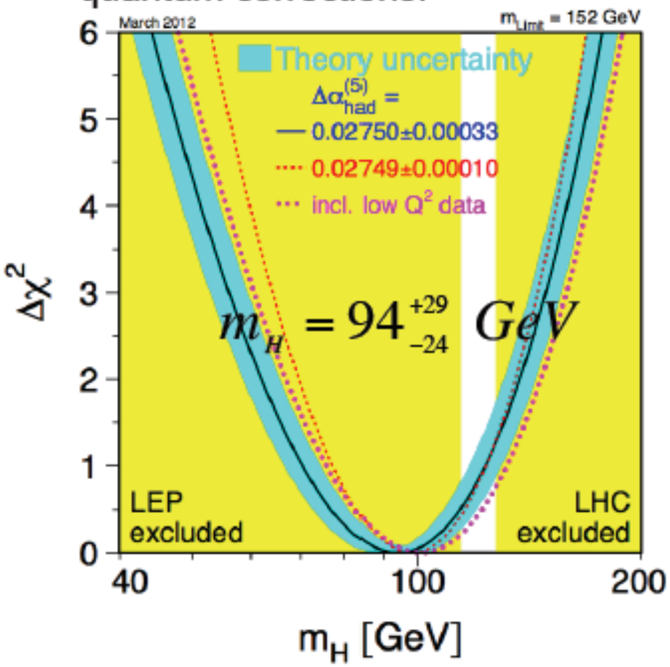
G. S. Guralnik,† C. R. Hagen,‡ and T. W. B. Kibble
Department of Physics, Imperial College, London, England
(Received 12 October 1964)

Information on the Higgs

Stalking the Higgs Boson

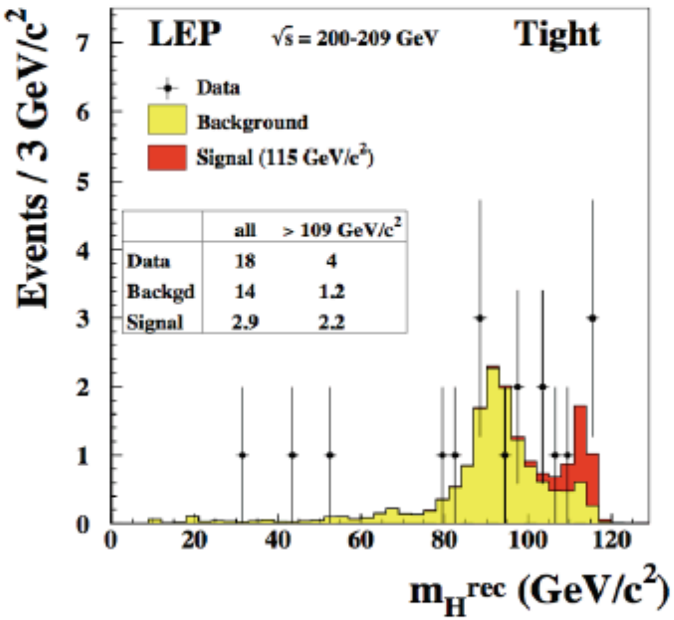
Indirect constraints

- Precision electroweak observables are sensitive to the Higgs boson mass via quantum corrections.



Direct searches at LEP

- Tantalizing hints (~1.7σ) of a SM-like Higgs boson with m_H~115 GeV:



	all	> 109 GeV/c^2
Data	18	4
Backgd	14	1.2
Signal	2.9	2.2

Combining indirect and LEP direct constraints

m_H< 152 GeV (95% CL) m_H> 114.4 GeV (95% CL)

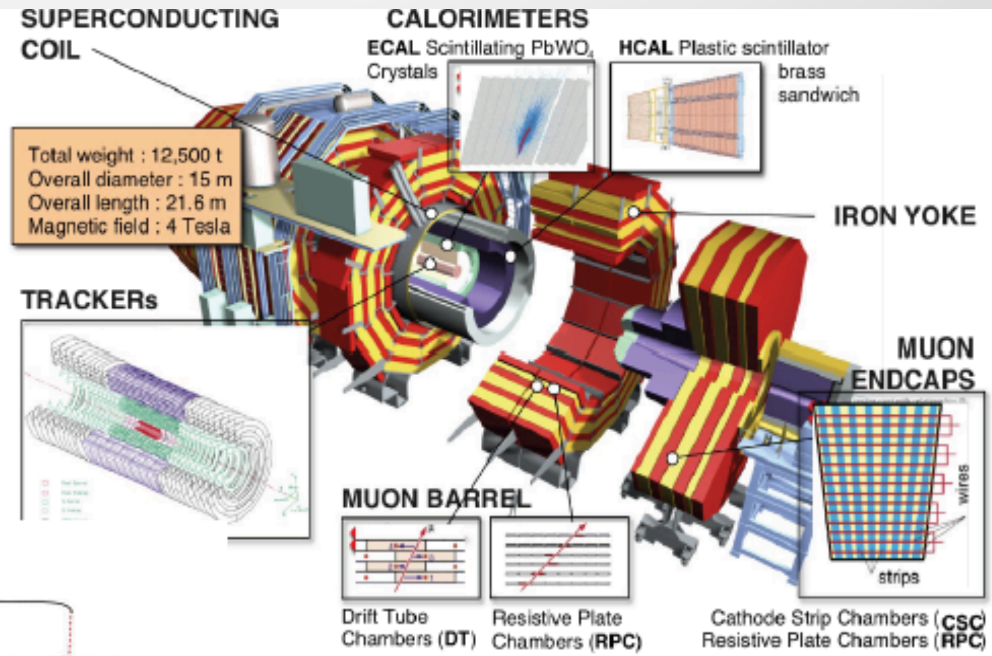
114.4 < m_H< 171 GeV (95% CL)

This is precisely the range where the Tevatron is sensitive!

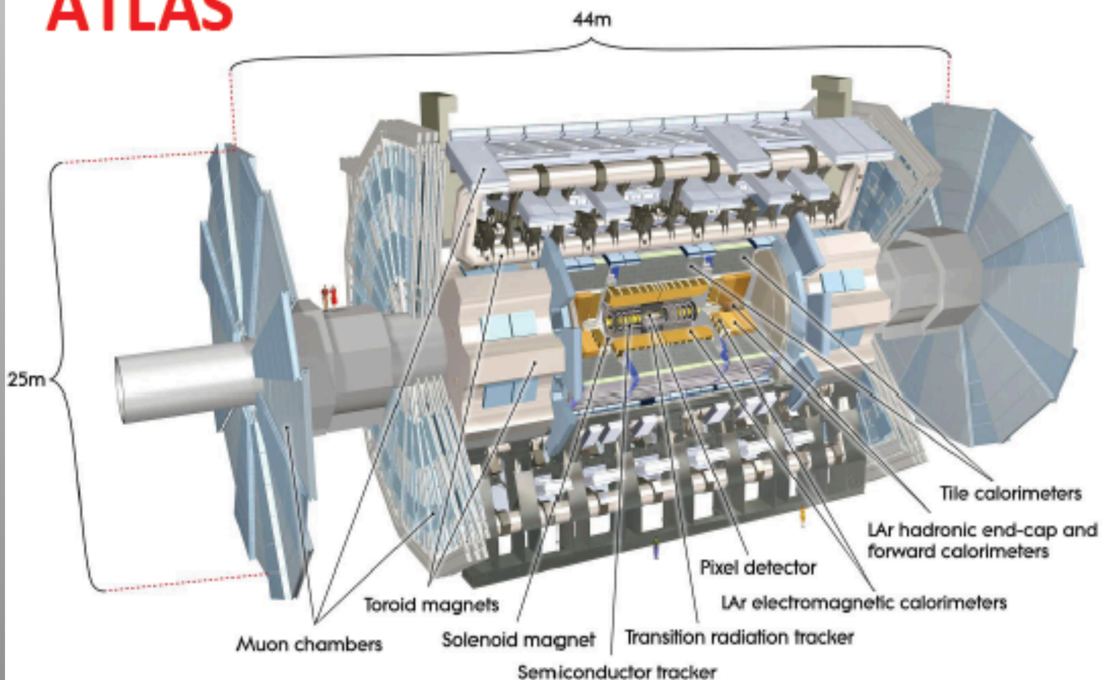
ATLAS and CMS

… The key players in this talk…

CMS



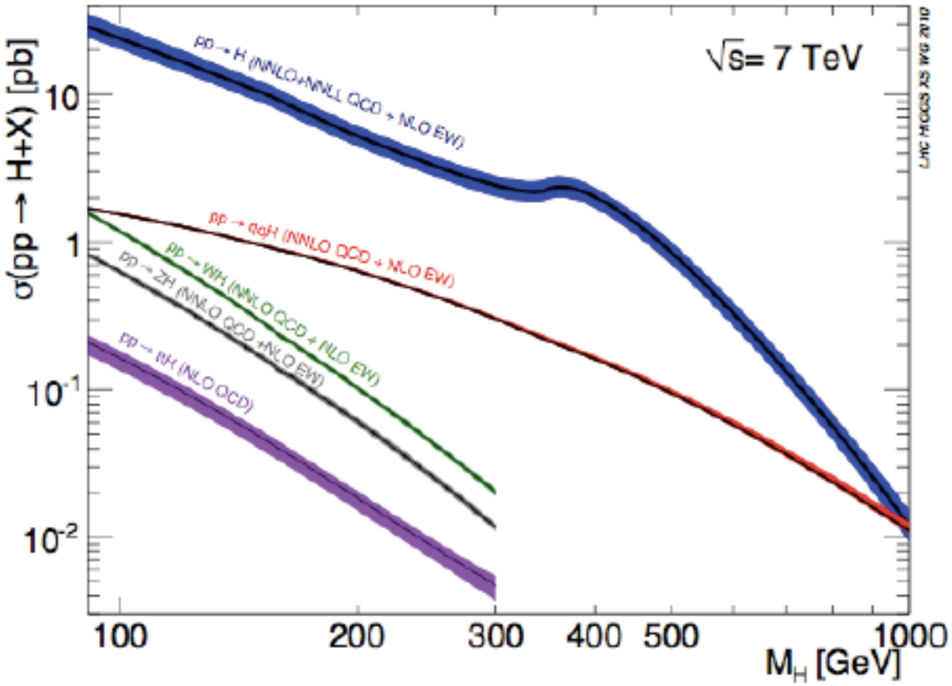
ATLAS



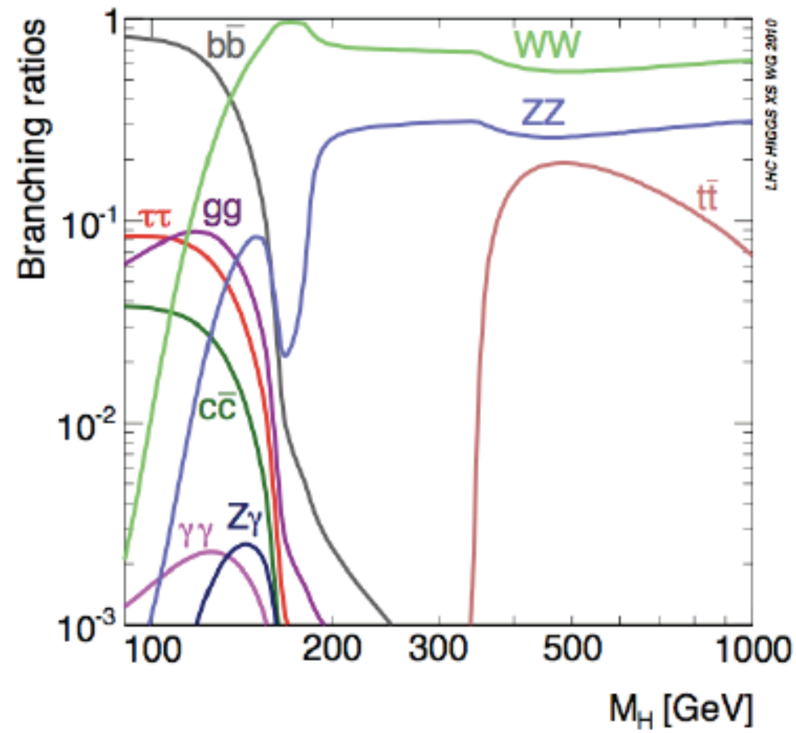
See lecture A. Hoecker

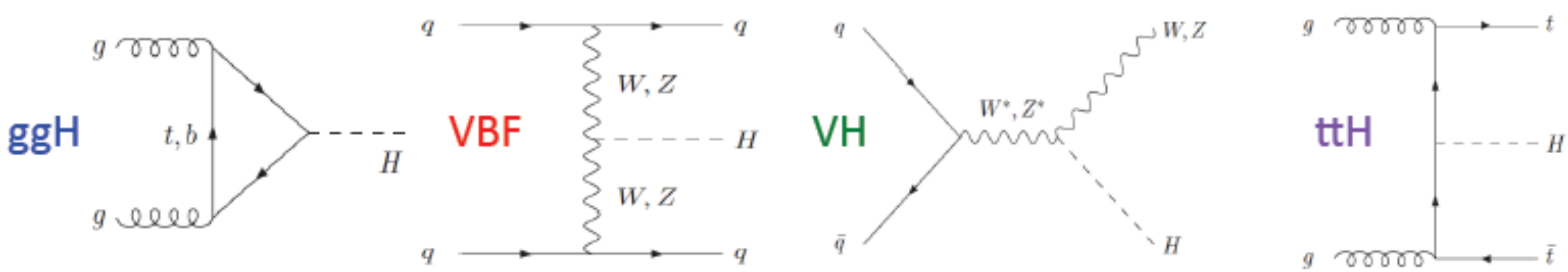
Higgs Production and Decays

Production



Decay





Cross sections and BR
from the LHC cross section working group

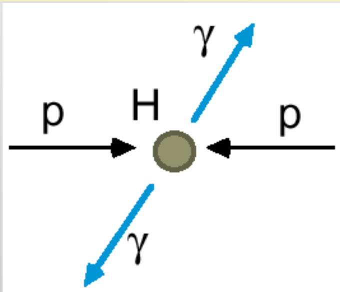
Decays Analysed by Experiments

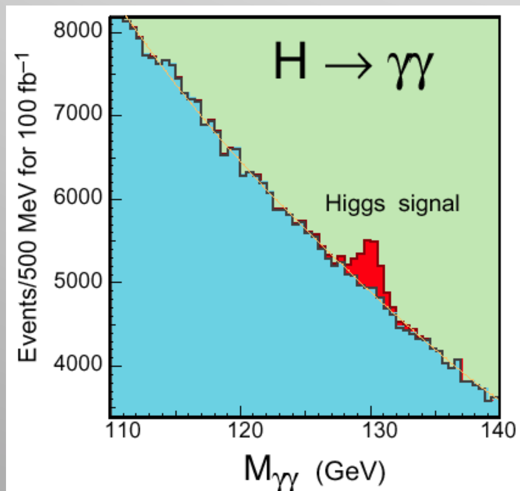
Channel	Mass range (GeV)	Production modes	Sensitivity range	Other comments
$H \to \gamma\gamma$	110-150 GeV	inclusive, VBF	Most sensitive at low mass	Good mass resolution
$H \to bb$	110-135 GeV	VH		
$H \to \tau\tau$	110-150 GeV	Inclusive, VBF, VH		
$WW \to l\nu l\nu$	110-600 GeV	gg-fusion, VBF, VH	Most sensitive at intermediate mass	
$ZZ \to 4l$	110-600 GeV	Inclusive		Good mass resolution
$ZZ \to$ other decays	~200-600 GeV	inclusive	Most sensitive at high mass	
$WW \to l\nu qq$	170-600 GeV	inclusive		

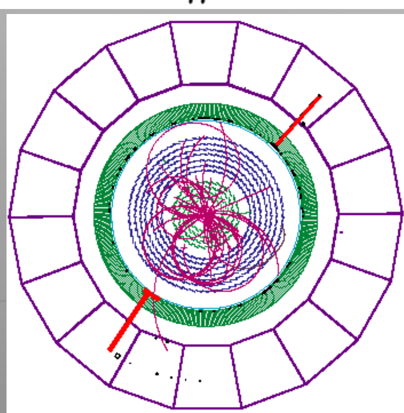
- Many published results

Higgs Boson Searches (Simulation)

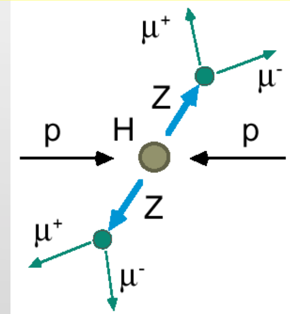
Low M_H < 140 GeV/c²

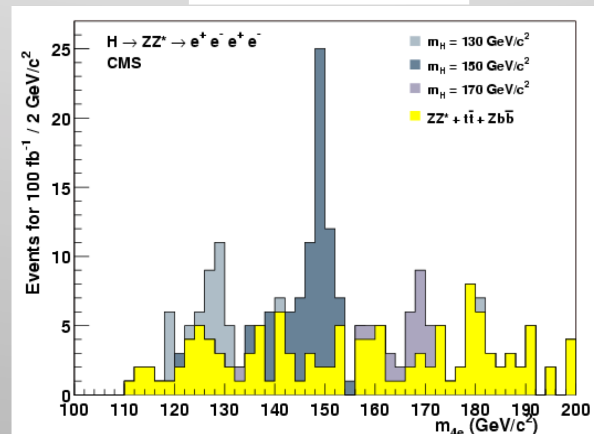


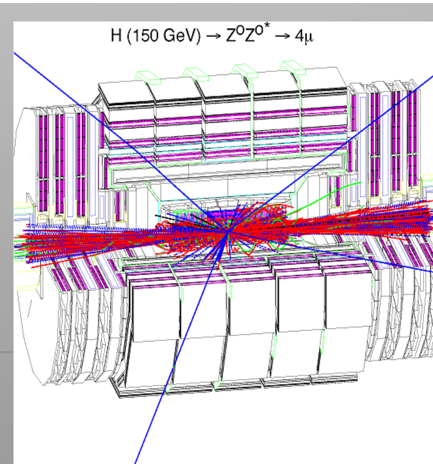




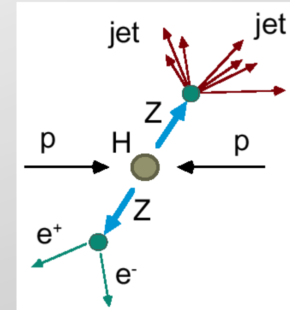
Medium 130<M_H<500 GeV/c²

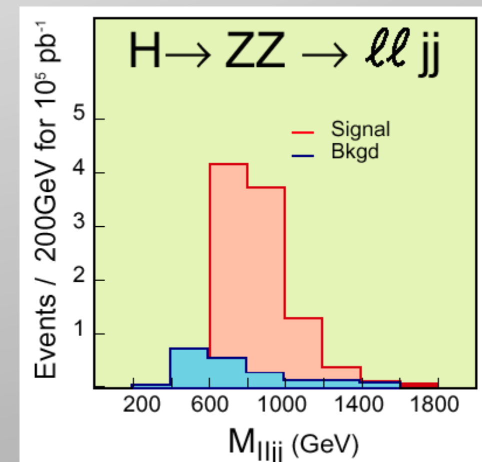


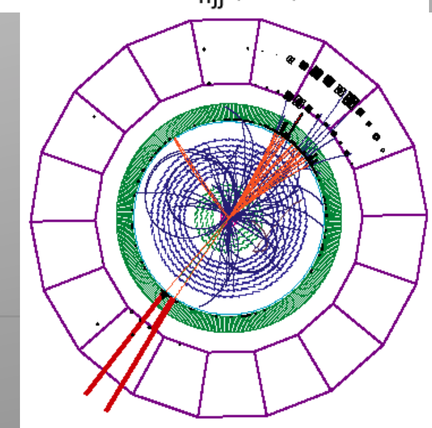




High M_H > ~500 GeV/c²







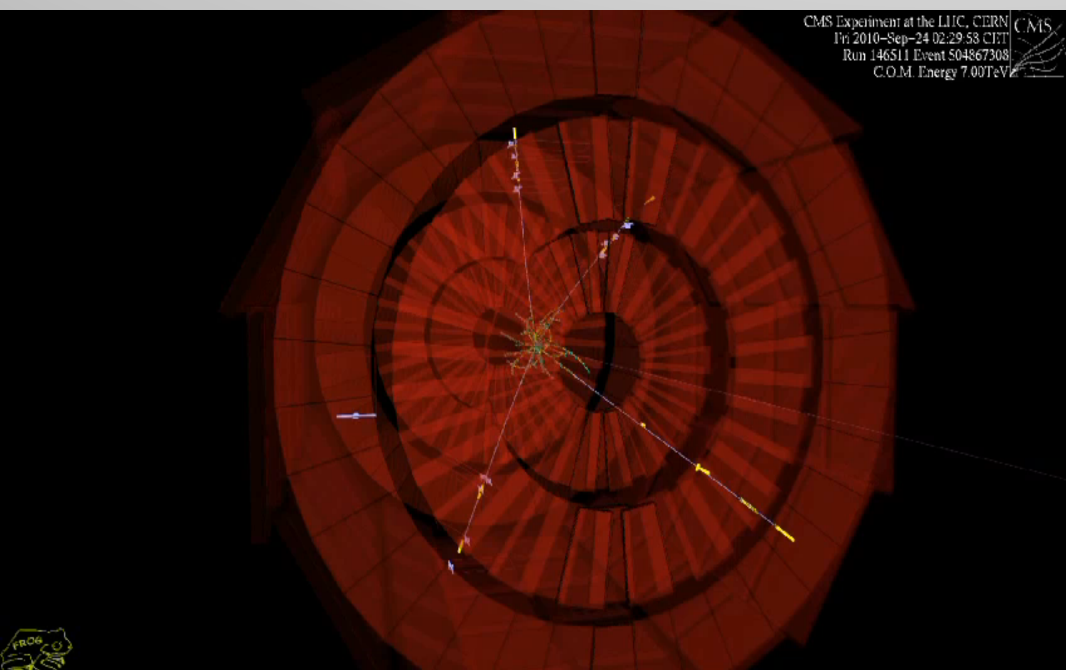
Searches for the Higgs Particle

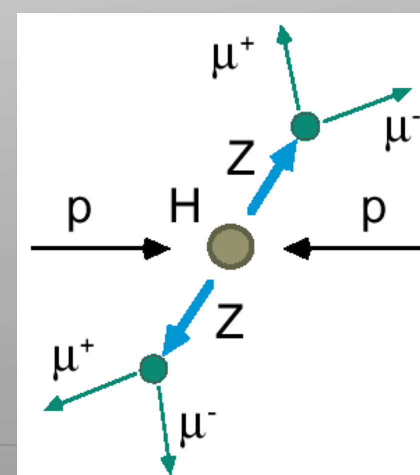
A Higgs particle will decay immediately, eg in two heavy quarks or two heavy (W,Z) bosons

Example: Higgs(?) decays into ZZ and each Z boson decays into μμ

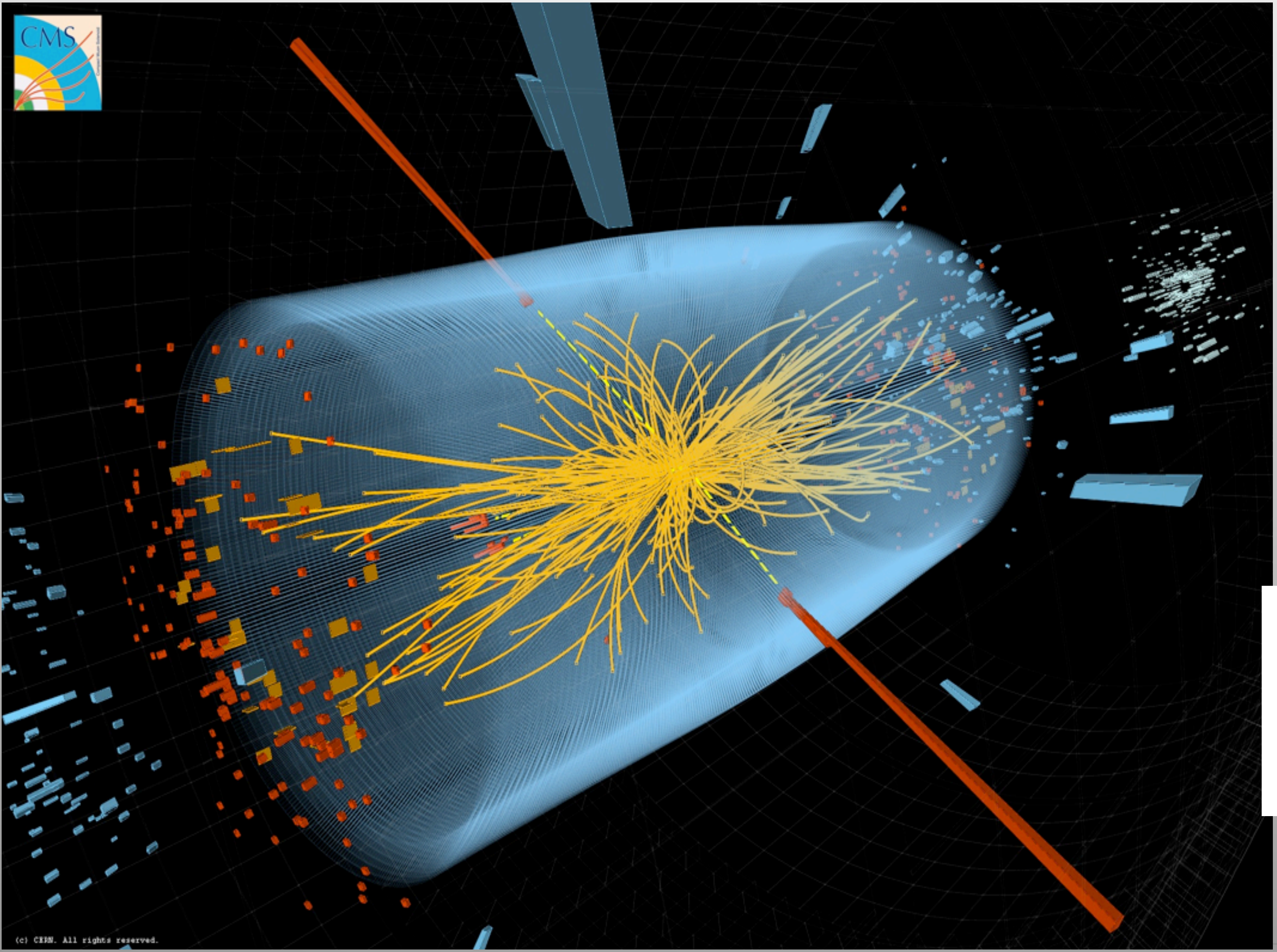
So we look for 4 muons in the detector

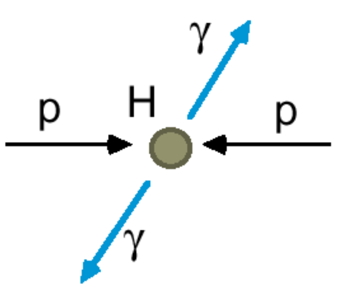
But two Z bosons can also be produced in LHC collisions, without involving a Higgs!
We cannot say for on event by event (we can use the total invariant mass of the 4 muons)





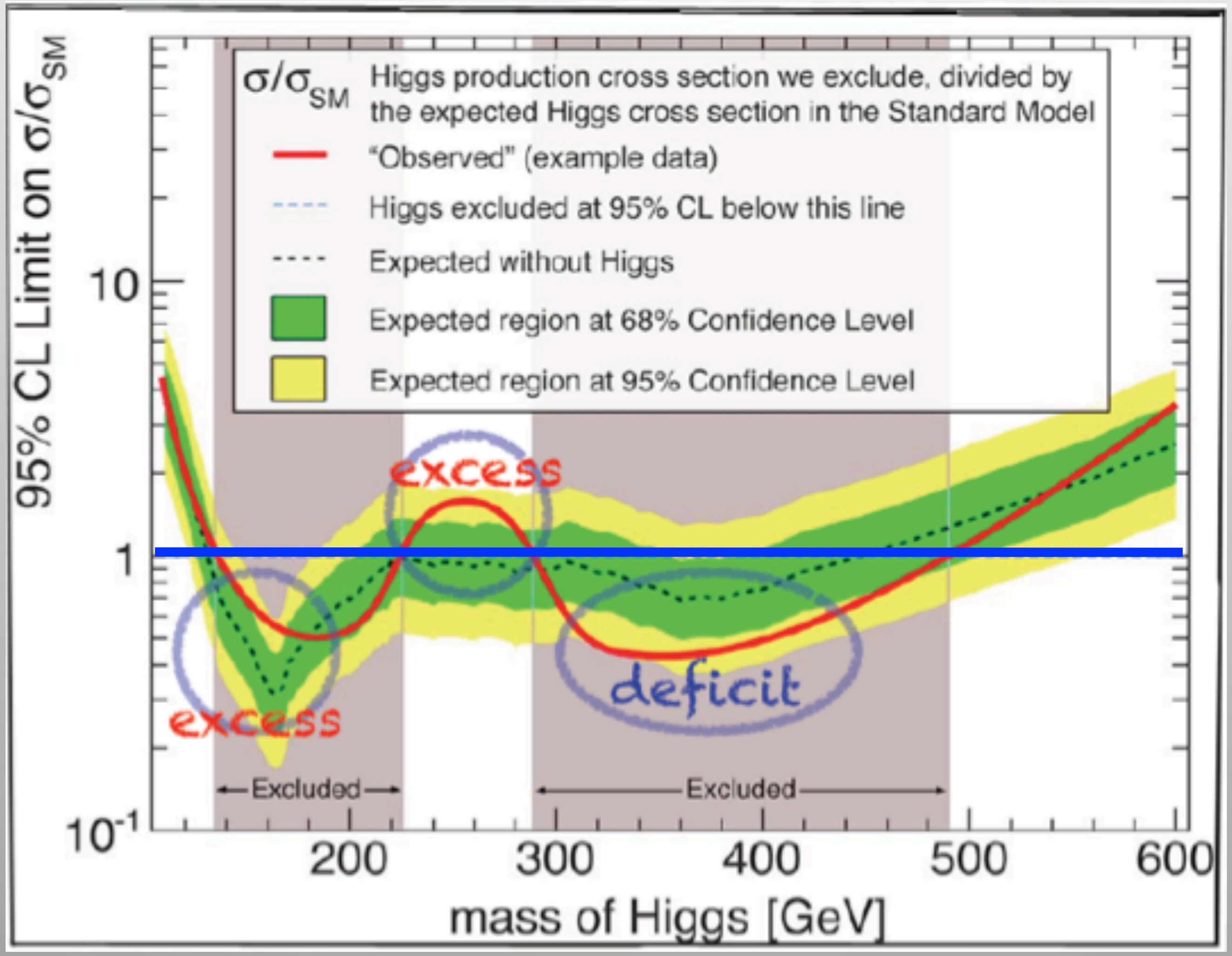
A Collision with two Photons





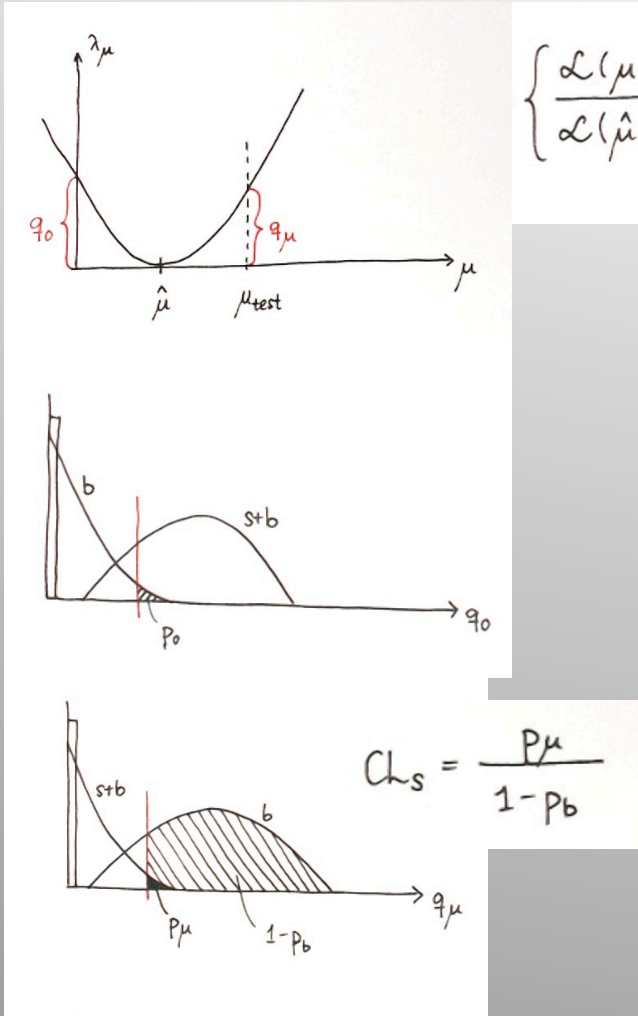
A Higgs or
a 'background' process without a Higgs?

Understanding the Higgs Search Plots



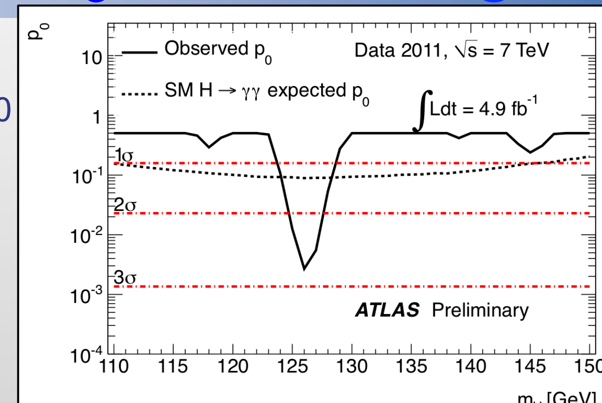
For a SM Higgs signal we need an excess above the blue line

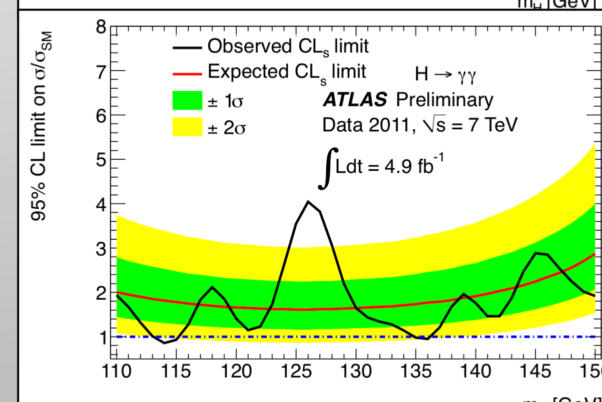
Profile Likelihood Ratio, p_0 and CL_s

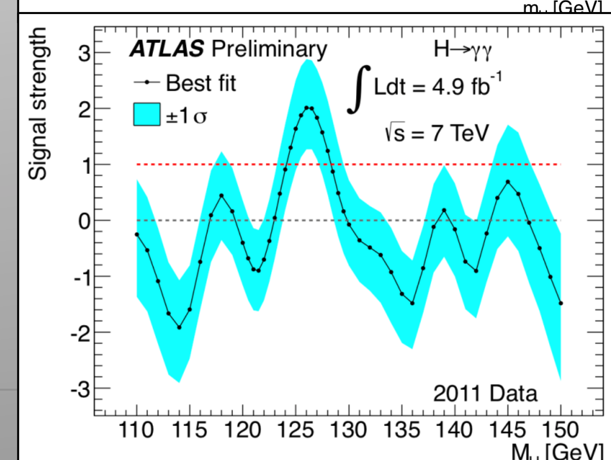


$$\left\{ \frac{\mathcal{L}(\mu, \hat{\hat{\theta}}_\mu)}{\mathcal{L}(\hat{\mu}, \hat{\theta})} \right\}$$

- Local significance p_0 to test background hypothesis
- $CL_s = CL_{s+b}/CL_b$ (log-likelihood ratio) to test signal hypothesis
- $\hat{\mu}$ to estimate signal strength (relative to expectation)



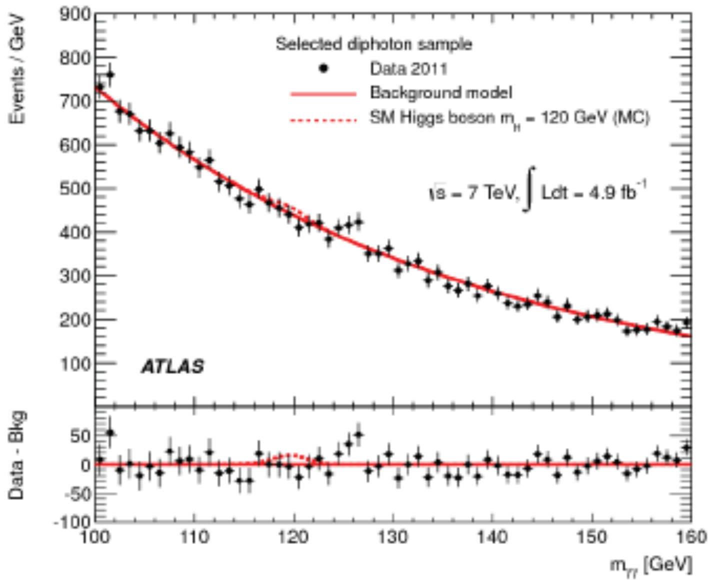


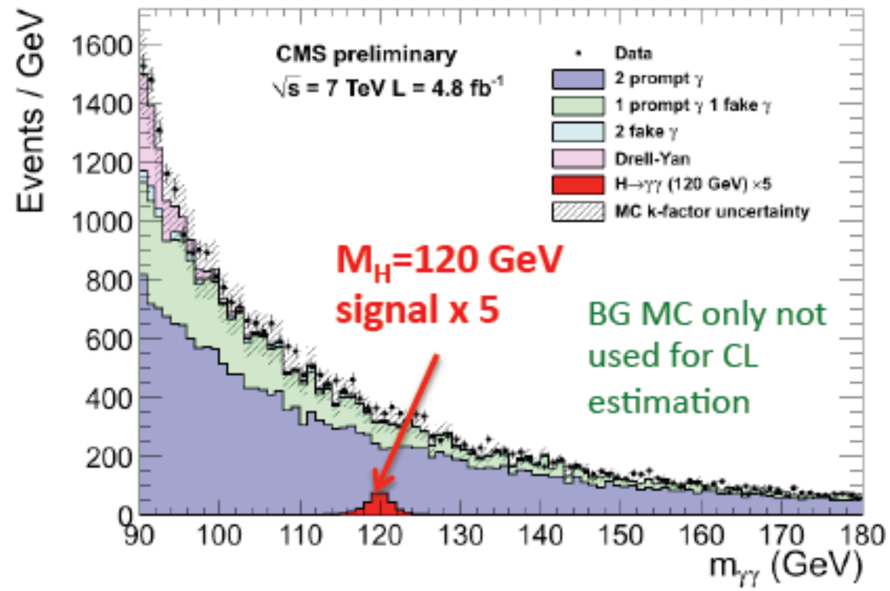


Follow LHCHCG Combination Procedures

H→γγ Analysis Strategy

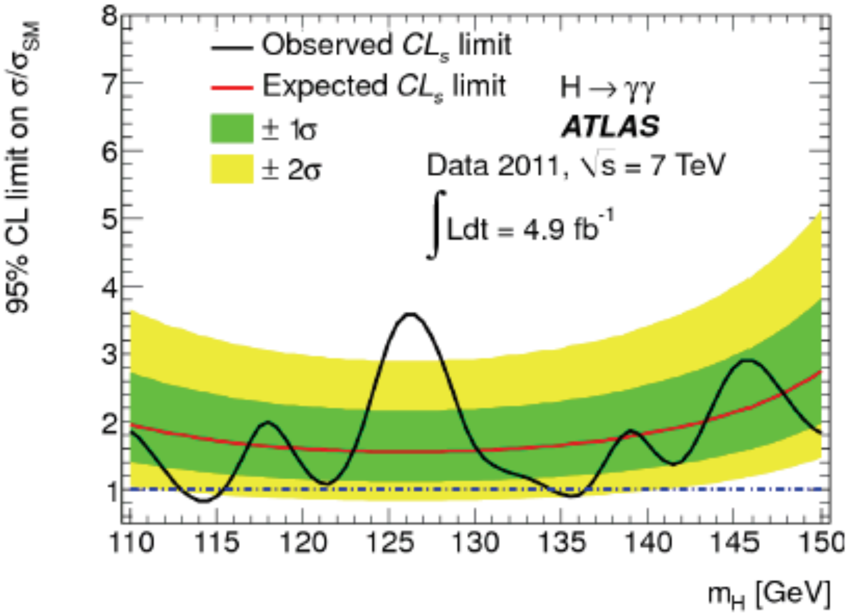
- Search for a small mass peak over large and smooth background
  - Irreducible: 2γ QCD production
  - Reducible: γ+jet with 1 additional fake photon, QCD with 2 fake photons, DY with electrons faking photons
- **Narrow mass peak**
  - mass resolution 1-2%

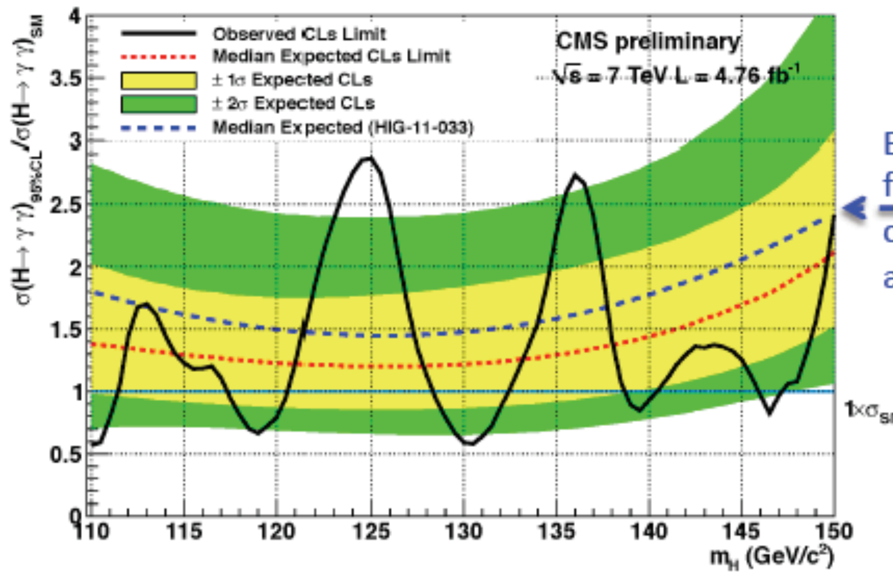




- Studied mass range: 110-150 GeV
- Split into event classes to enhance the sensitivity
- ATLAS
  - Split into 9 categories
  - Diphoton P_{Tt}, η, converted/unconverted
- CMS
  - Cut based and MVA based analyses
  - Split into 4 categories + VBF analysis

H→ γγ Result: Exclusion



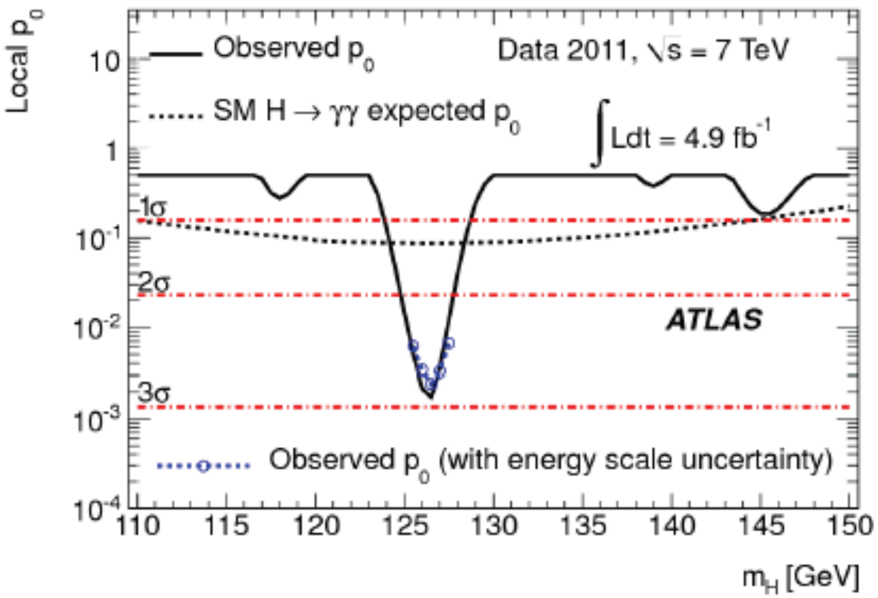


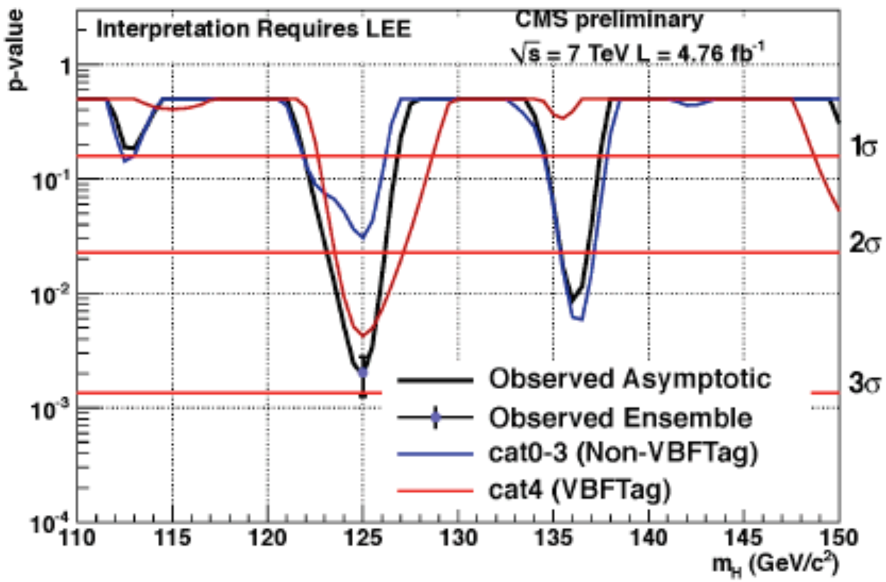
Expected from cut based analysis

	ATLAS	CMS
Expected exclusion 95% CL	1.5 - 2.9 x SM	1.2 - 2.1 x SM
Observed exclusion 95% CL	113-115, 134.5-136 GeV	110.0-111.0, 117.5-120.5, 128.5-132.0, 139.0-140.0, 146.0-147.0 GeV

H→γγ Results: p-values

- P-value: probability that a BG only fluctuation is more signal-like than observation

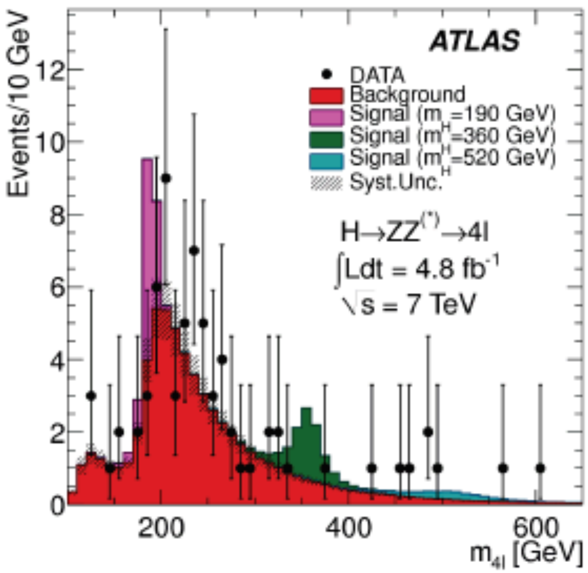




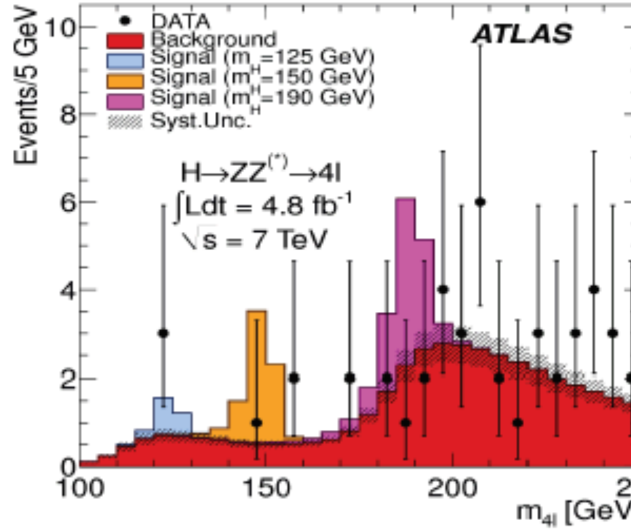
	ATLAS	CMS
Mass position of minimum local p-value	126.5 GeV	125 GeV
Local significance at minimum	2.8 σ	2.9 σ
Global significance in mass range 110-150 GeV	1.5 σ	1.6 σ

Higgs →ZZ →4 leptons

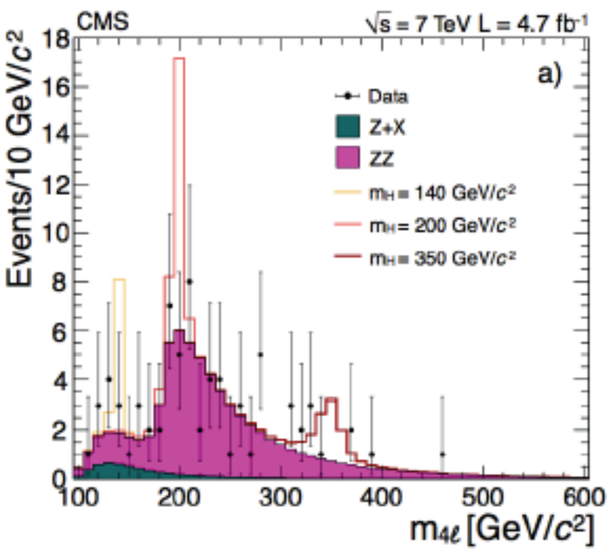
Full mass range

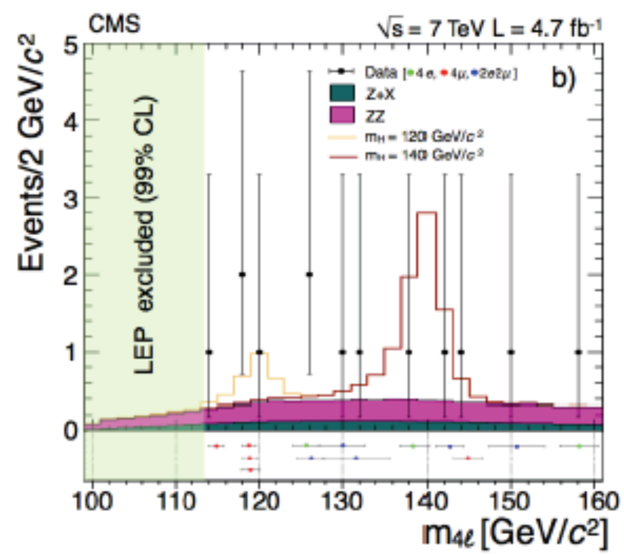


Low mass



ATLAS has 3 events at 125 GeV

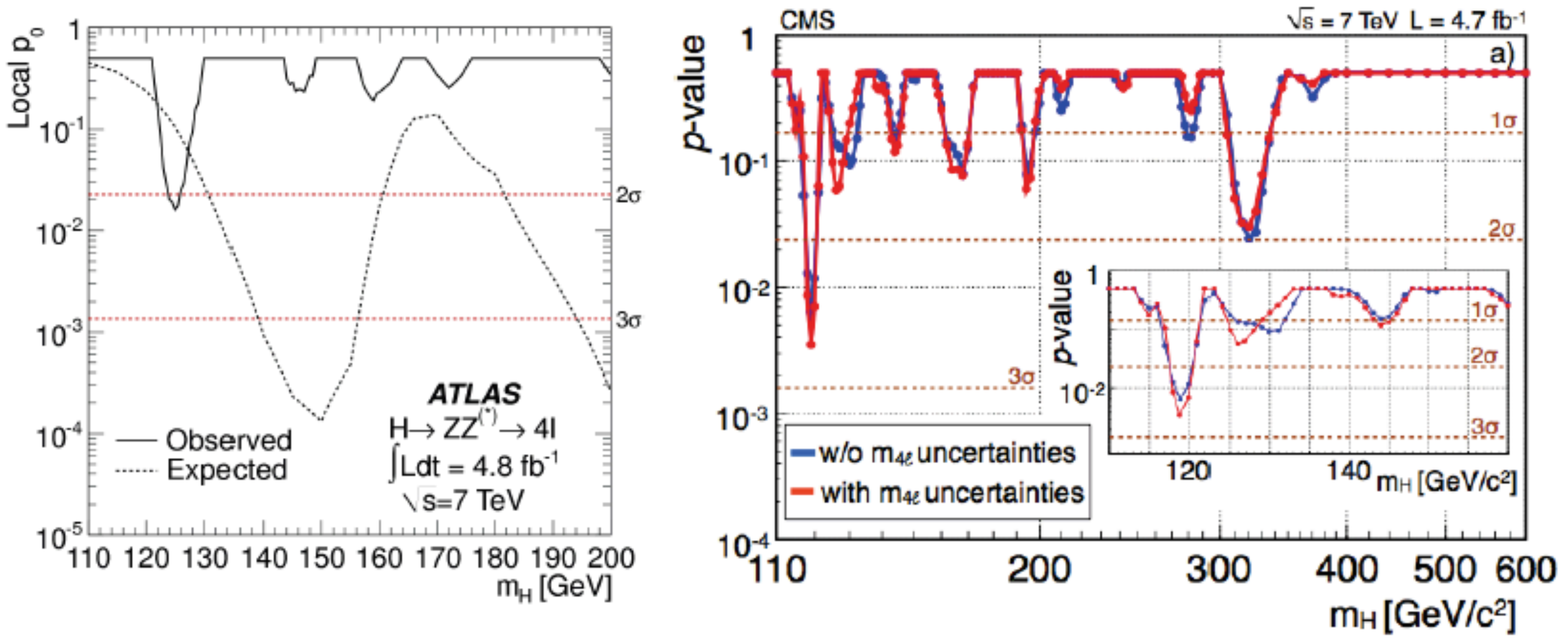




CMS has 3 events at 119.5 GeV

and 2 events ~ 126 GeV

Higgs → ZZ to → leptons



	ATLAS	CMS
Mass position of minimum local p-value	125 GeV	119.5 GeV
Local significance at minimum	2.1 σ	2.5 σ
Global significance in full mass range	O(50%)	1.0 σ

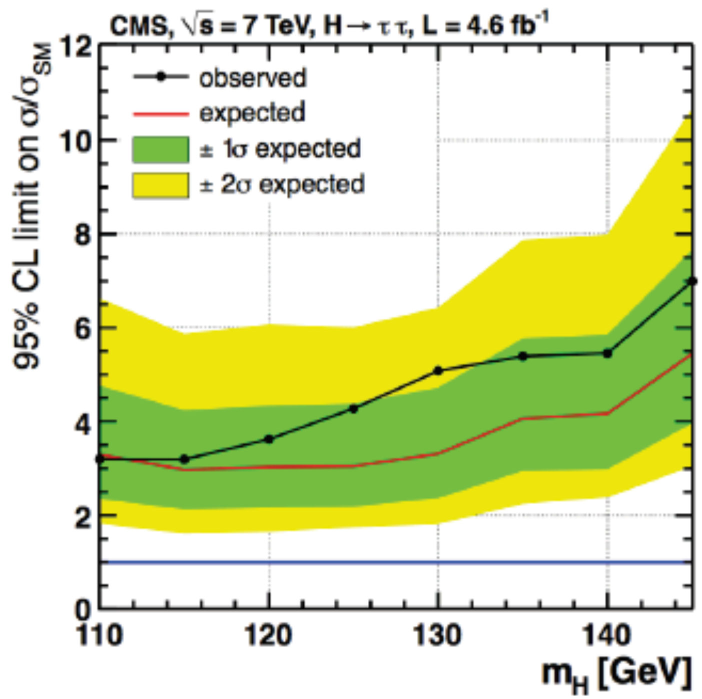
- ATLAS excess at 125 GeV in the same mass region as the excess in H->γγ channel

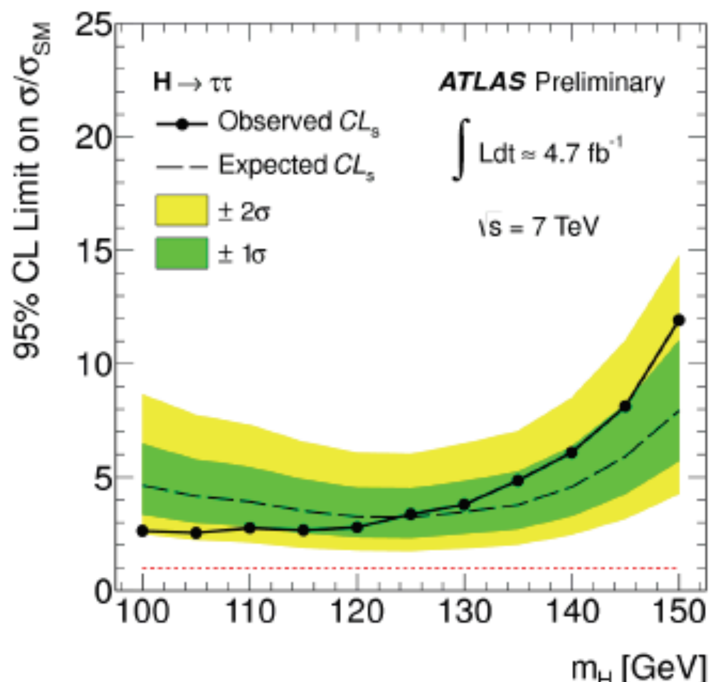
Higgs → tau tau Decays

- Complicated analysis, combination of many different subchannels

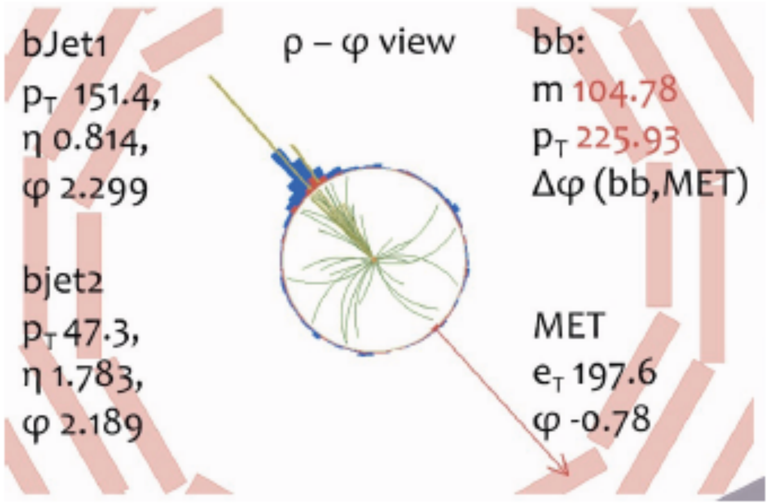
Decay		Production/signature
$H \to \tau\tau \to \ell\ell + 4\nu$ (12%)	$\otimes$	0-jet
$H \to \tau\tau \to \ell\tau_h + 3\nu$ (46%)		1-jet boosted
$H \to \tau\tau \to \tau_h\tau_h + 2\nu$ (42%)		2-jet VBF
		2-jet VH (ATLAS only)

- More than 10 sub-channels for each of the experiments





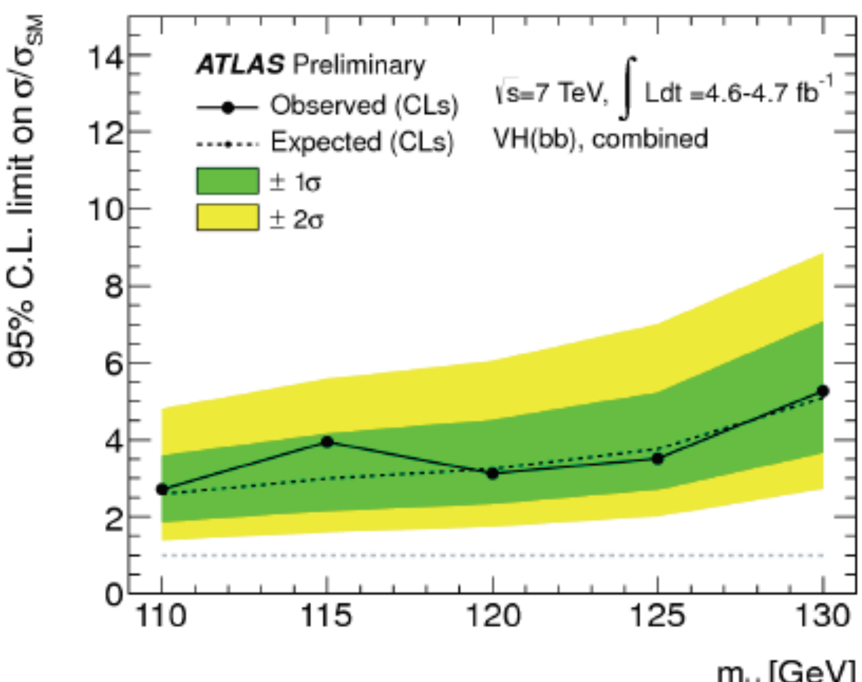
Higgs → b-quark Pairs

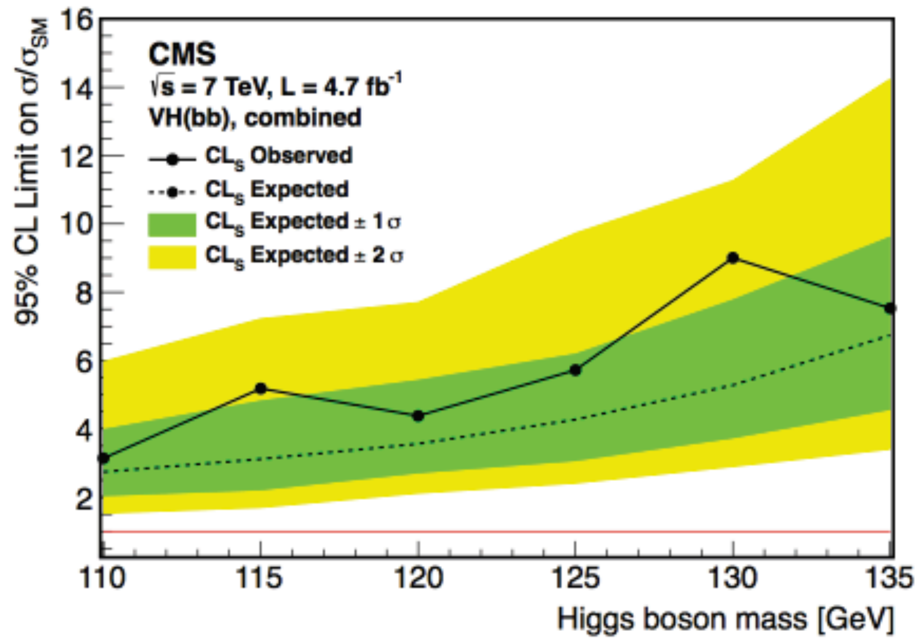


Challenging at the LHC!!
-> Huge QCD b-pair production background
-> Present solution: VH associated channel

Select events with two b-jets & lepton(s) or MET

- WH → μνbb, eνbb
- ZH → μμbb, eebb
- ZH → ννbb:



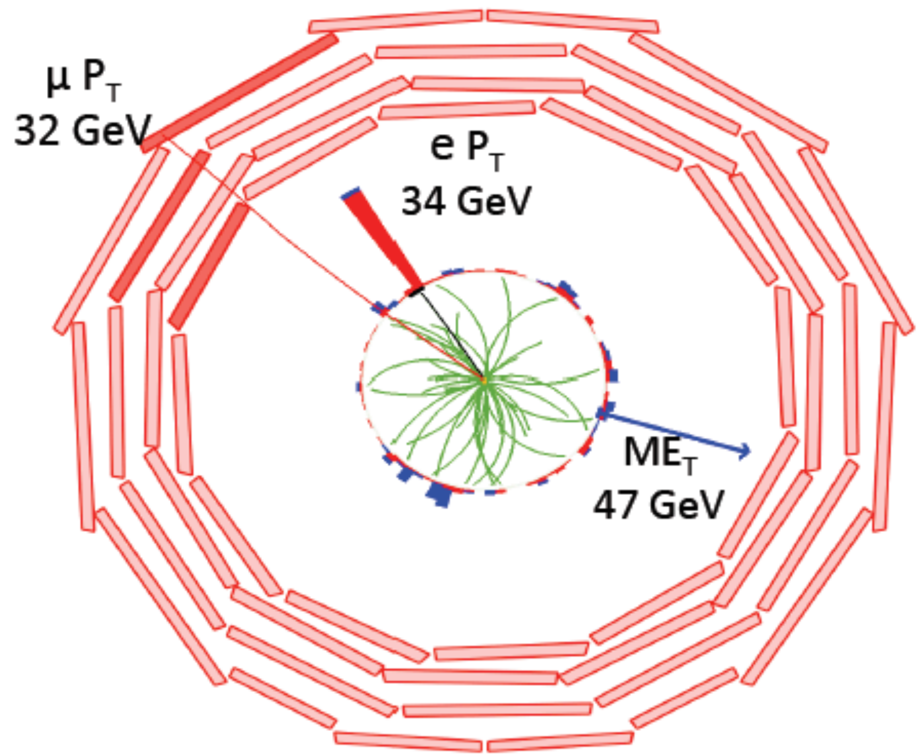


Higgs → WW→2 leptons & 2 neutrinos

- Most sensitive channel around 2 x M_W (125 <~ M_H <~ 200 GeV)
- **No narrow mass peak (mass resolution ~20%)**
- Main backgrounds
  - WW (irreducible but signal tends to have smaller angle between leptons)
  - Z+jets, WZ, ZZ, tt, W + jets

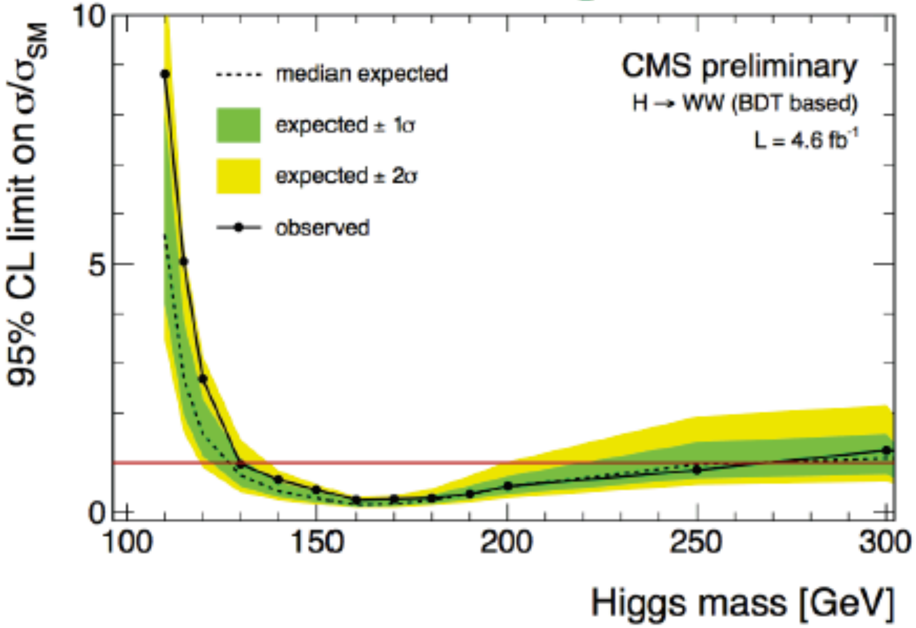
- Both ATLAS and CMS perform the analysis in exclusive jet multiplicities (0, 1, 2-jet bins) and flavour (ee, μμ, eμ)
  - Different BG
  - 2 jet bin corresponds to VBF dijet tag

H->WW->eμνν candidate in CMS

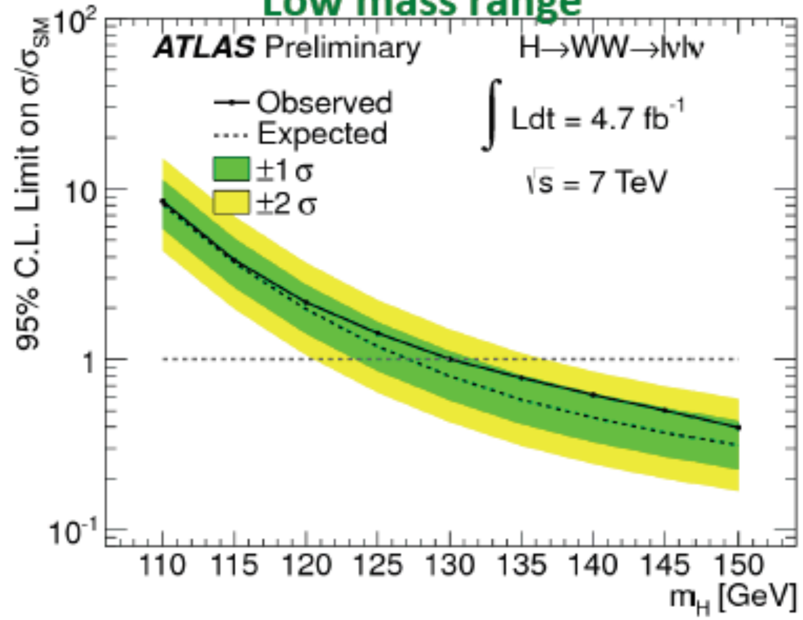


Higgs → WW low mass range

Low mass range



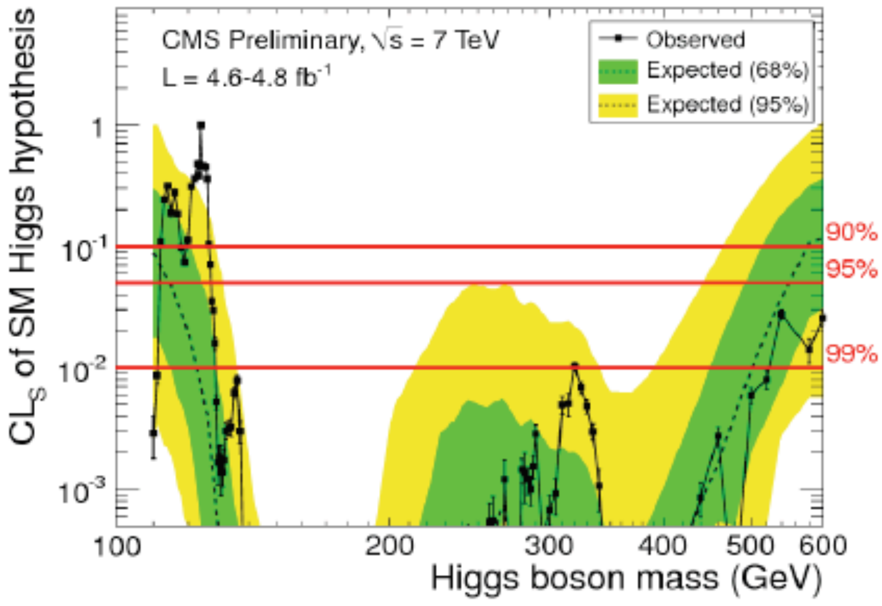
Low mass range

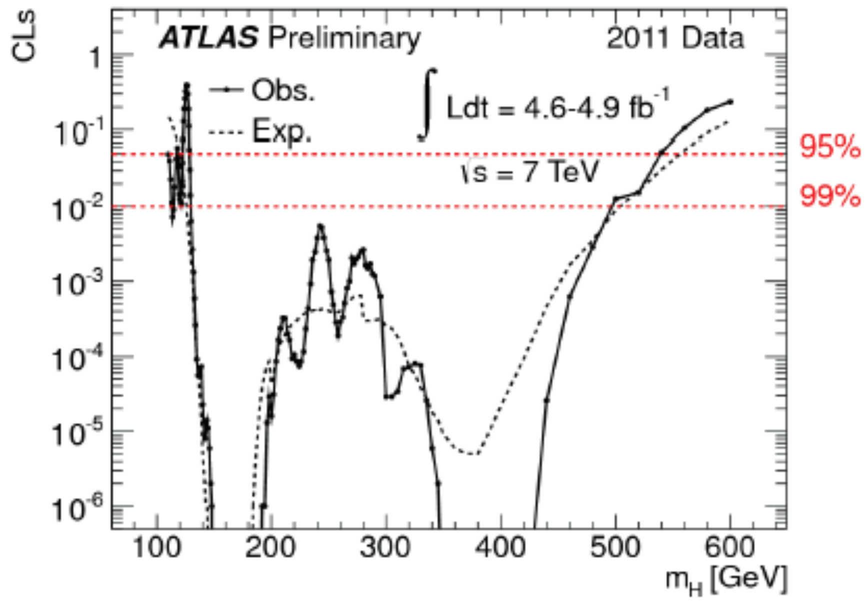


	ATLAS	CMS
Expected exclusion 95% CL	127-234 GeV	127-270 GeV
Observed exclusion 95% CL	130-260 GeV	129-270 GeV

Some excess in CMS, less in ATLAS

Combining all Search Channels

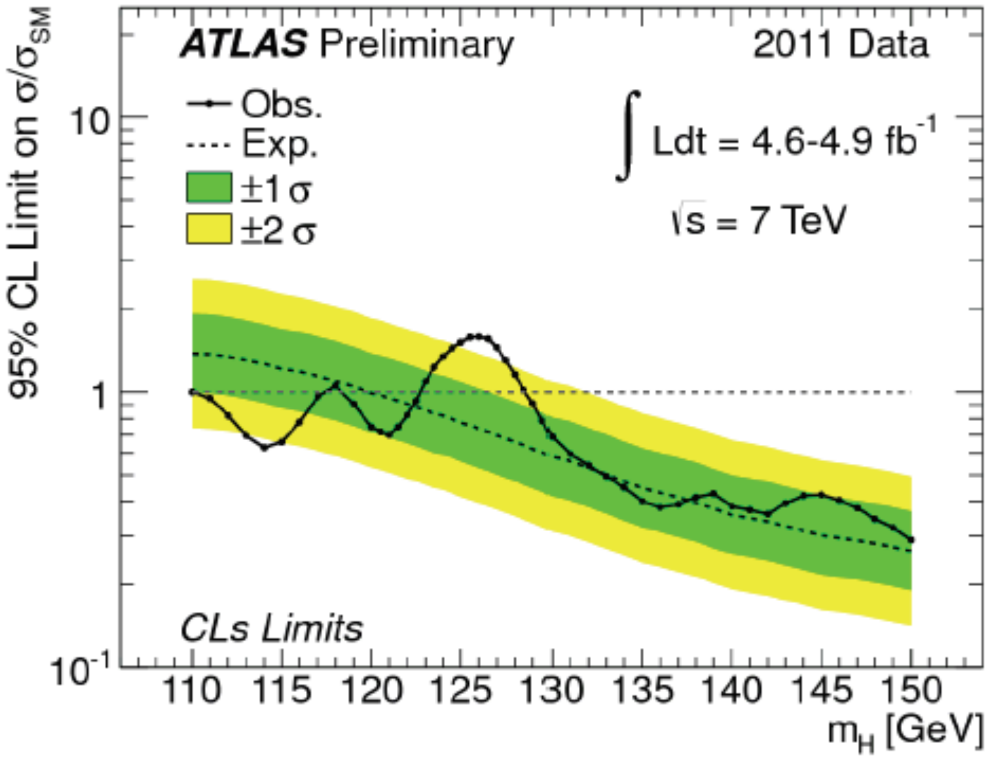


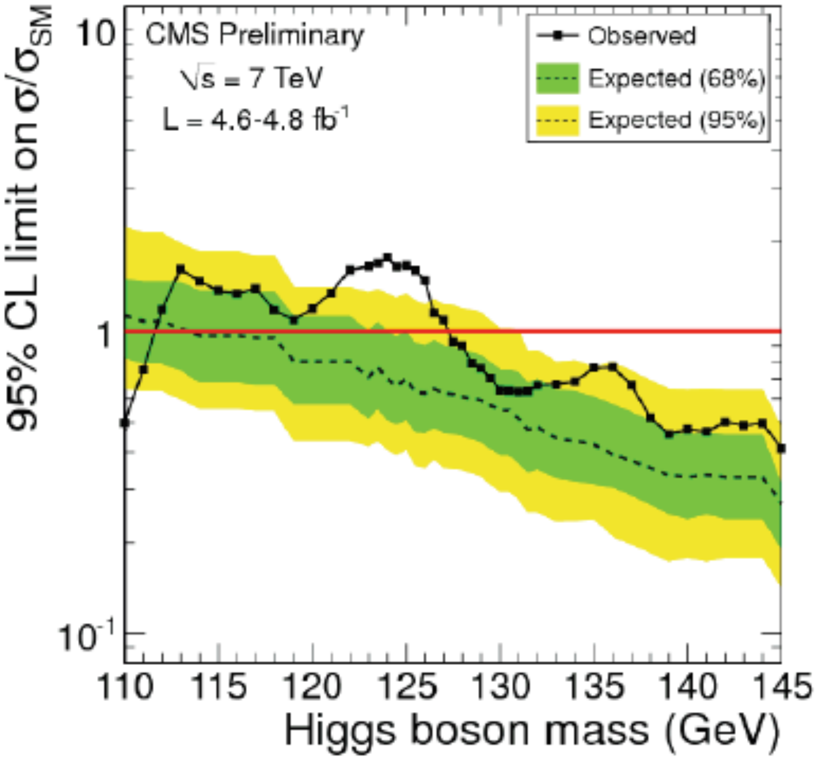


	ATLAS	CMS
Expected exclusion 95% CL	120-555 GeV	114.5-543 GeV
Observed exclusion 95% CL	110-117.5, 118.5-122.5, 129-539 GeV	127.5-600 GeV
Observed exclusion 99% CL	130-486 GeV	129-525 GeV

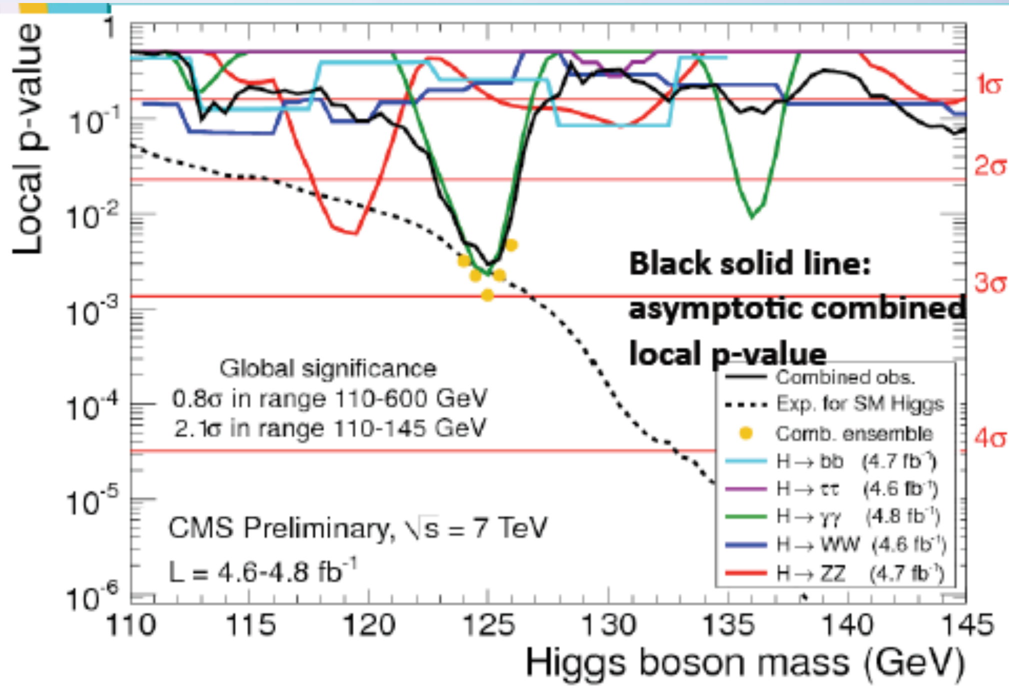
- Observed lower limit higher than expected because of excess in data at low mass
- $130 < M_H < 486$ GeV excluded by both at 99% CL

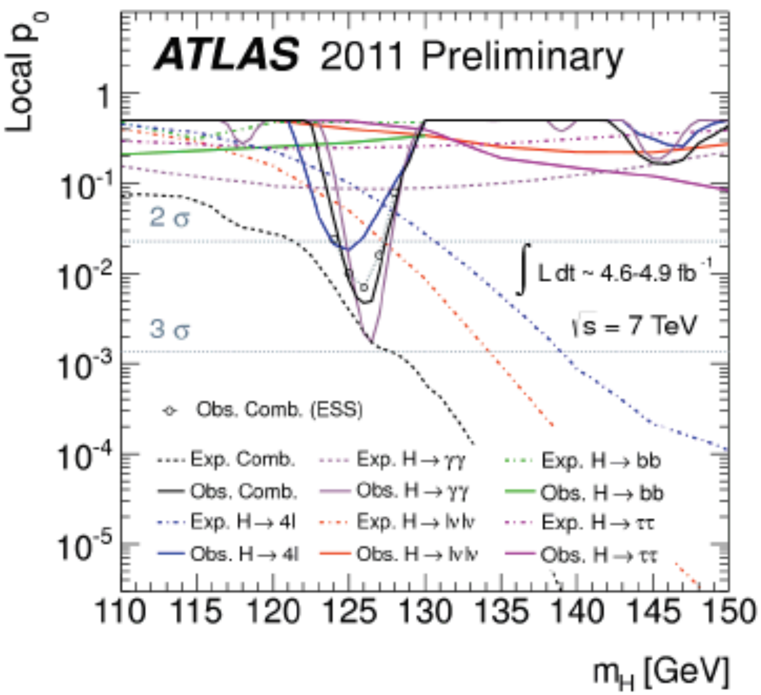
Exclusion in the Low Mass Range





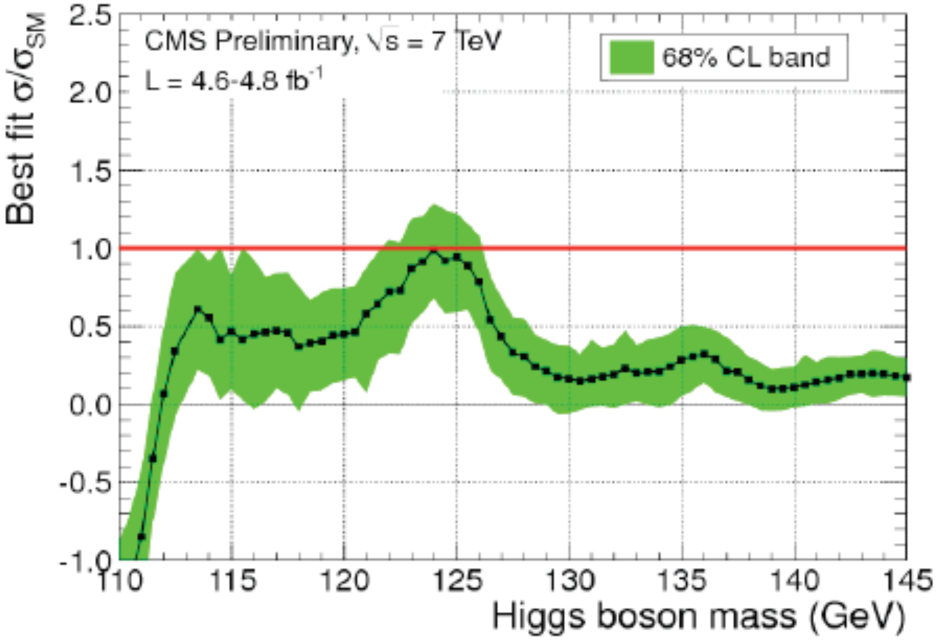
Combined p-values

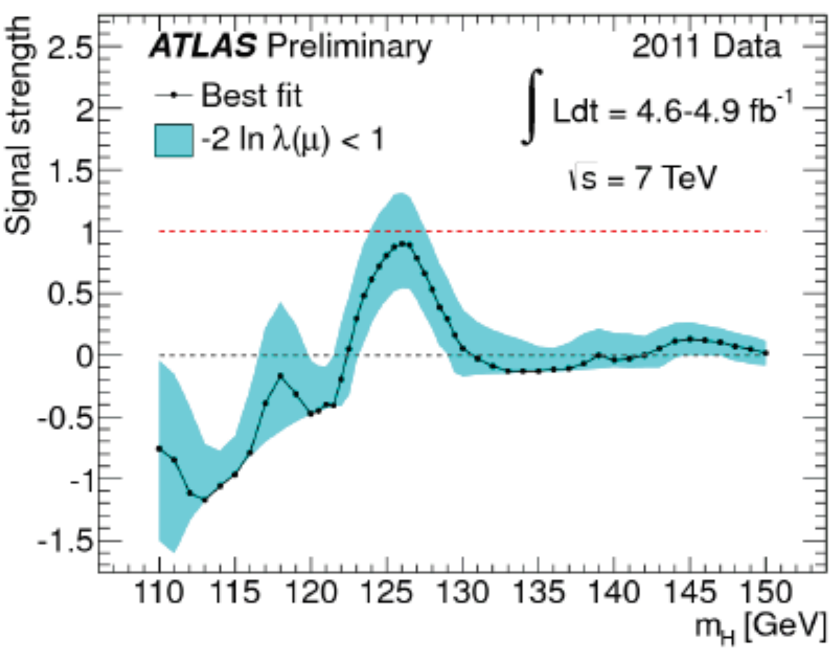




	ATLAS	CMS
Mass position of minimum local p-value	126 GeV	125 GeV
Local significance at minimum	2.5 σ	2.8 σ
Expected local significance at minimum from sm signal	2.9 σ	2.9 σ
Global significance in full mass range	0.8 σ	30%
Global significance in low mass range	2.1 σ (110-145 GeV)	10% (110-146 GeV)

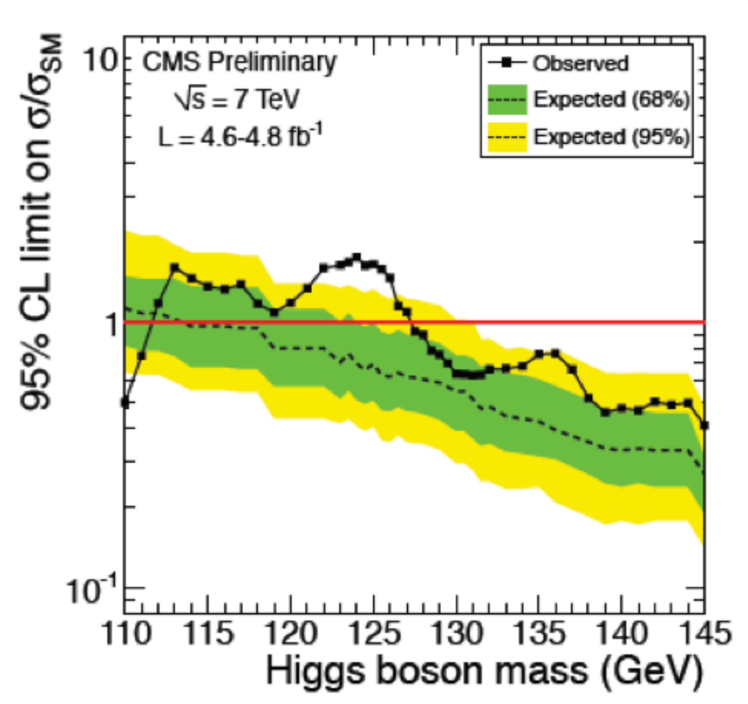
Fitted Signal Strength for SM Higgs

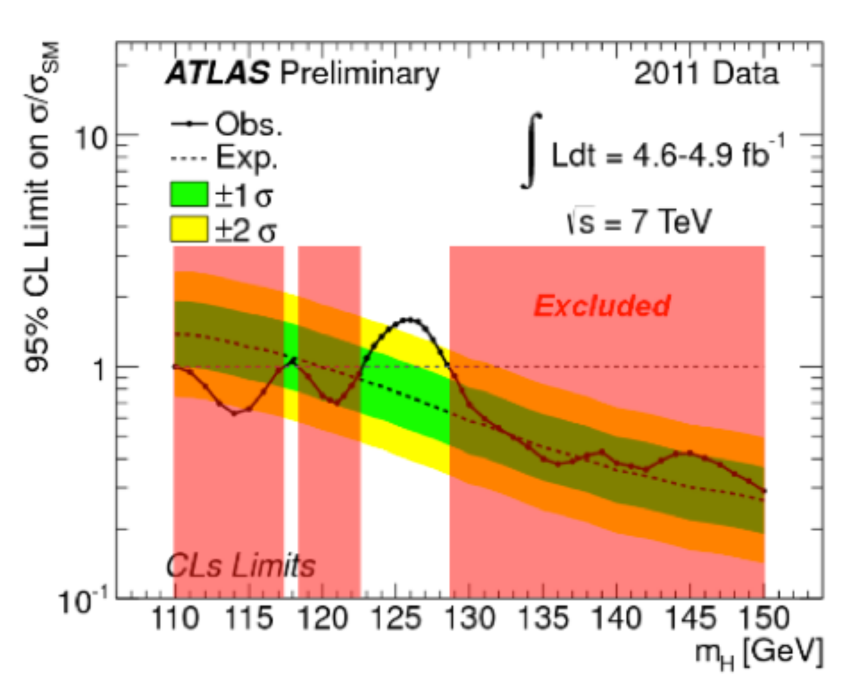




- ATLAS: $\mu(126\ \text{GeV}) = 0.9^{+0.4}_{-0.3}$
- CMS: $\mu(125\ \text{GeV}) = 0.9^{+0.3}_{-0.3}$
- Fitted values of μ are consistent with SM expectation
- ATLAS and CMS observe:
  - similar significance (~2.5)
  - similar expected local p-value (~3 σ)
  - similar fitted μ (~1)

The Results of the Higgs Search 2011





Results

1) The mass region where Higgs particle can possibly live has been reduced to very small mass range of 115-130 GeV (95% CL)
2) We see an excess of events in that region over expectation from pure background. Cool!

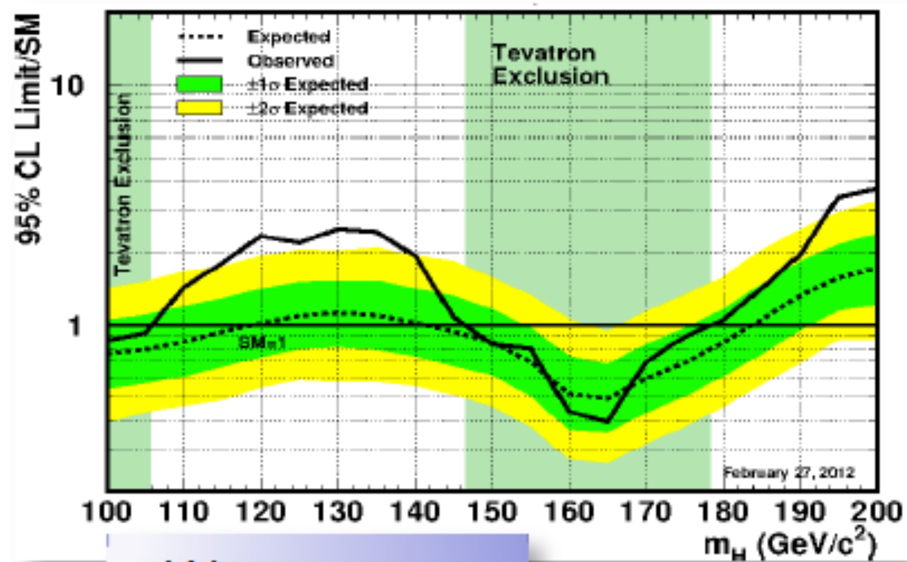
   Is this the first sign of the 'growing Higgs signal?

   Is it a statistical fluctuation in the background? We can't say for sure.

→These questions will be answered with the 2012 data (4 x 2011 data)

Tevatron 2012 Results

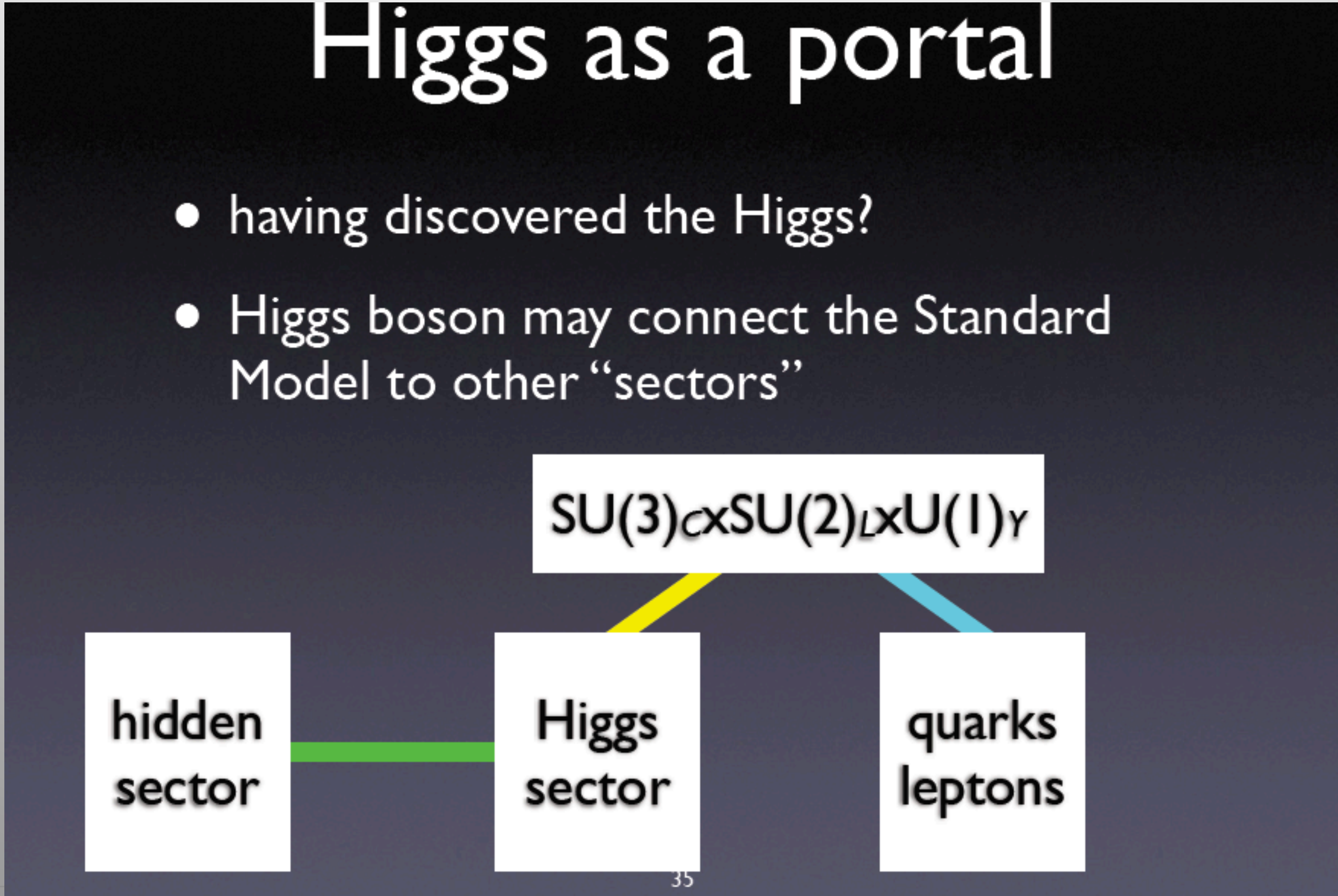
- Winter 2012 exclusions
  - *Expected: 100 – 120, 141 - 184 GeV*
  - *Observed: 100 – 106, 147 - 179 GeV*
    - *Broad >2σ excess 115-140 and above 194*
    - *Compatible with signal + background, not so compatible with background only*



Winter 2012

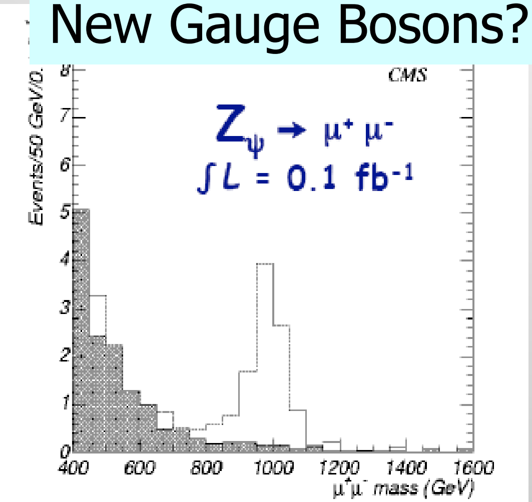
A < 0.5σ excess in mass range from 115 to 135 GeV has become > 2σ excess with 22% increase in data.

NOTE: The Higgs

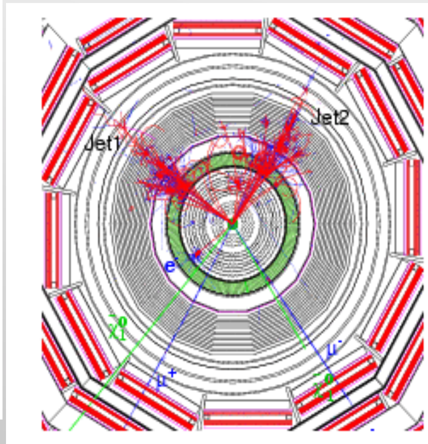


New Physics at High Energies?

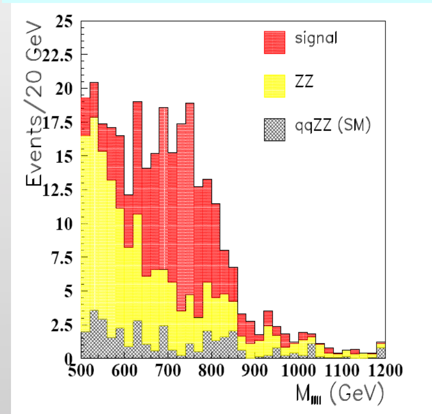
New Gauge Bosons?



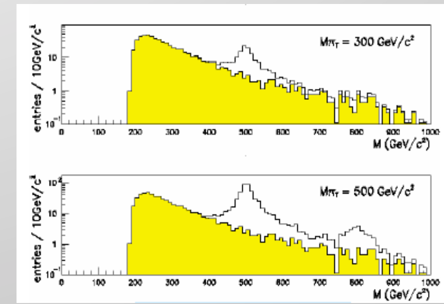
Supersymmetry



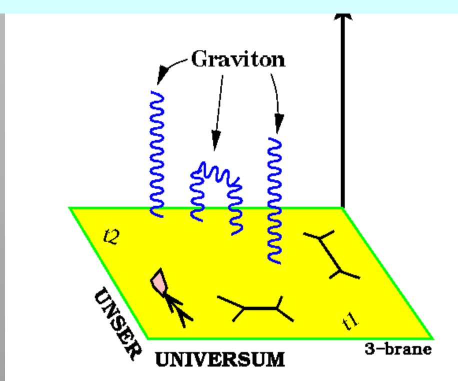
ZZ/WW resonances?



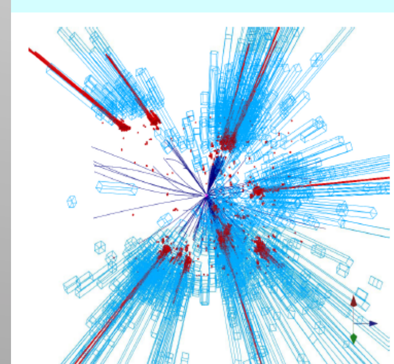
Technicolor?



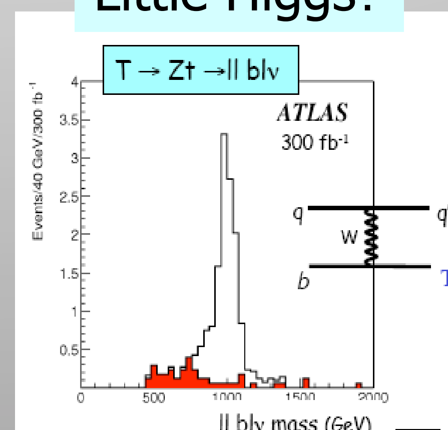
Extra Dimensions?



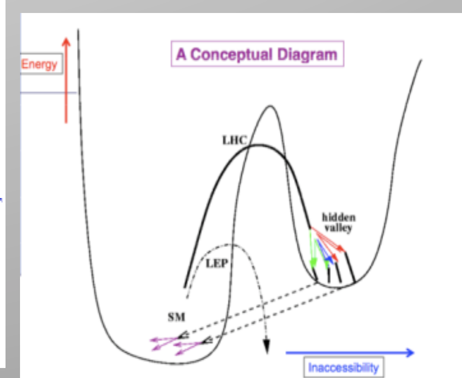
Black Holes???



Little Higgs?



Hidden Valleys?



We do not know what is out there for us…
A large variety of possible signals. We have to be ready for that

Large Extra Dimensions

February 1, 2008

SLAC-PUB-7769
SU-ITP-98/13

The Hierarchy Problem and New Dimensions at a Millimeter

Nima Arkani–Hamed[*], Savas Dimopoulos[**] and Gia Dvali[†]
[*] SLAC, Stanford University, Stanford, California 94309, USA
[**] Physics Department, Stanford University, Stanford, CA 94305, USA
[†] ICTP, Trieste, 34100, Italy

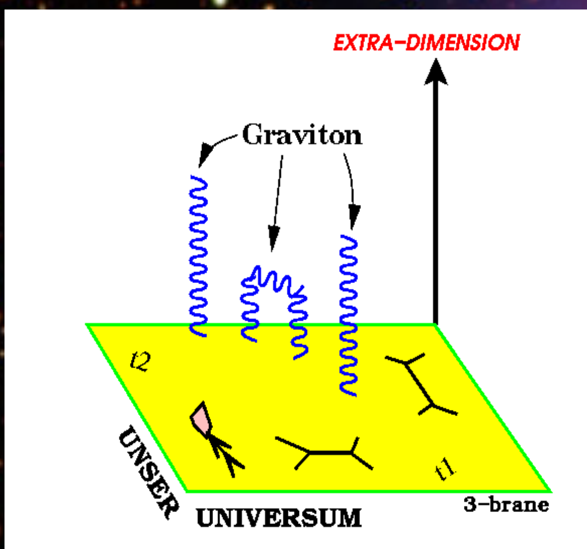
4519 citations

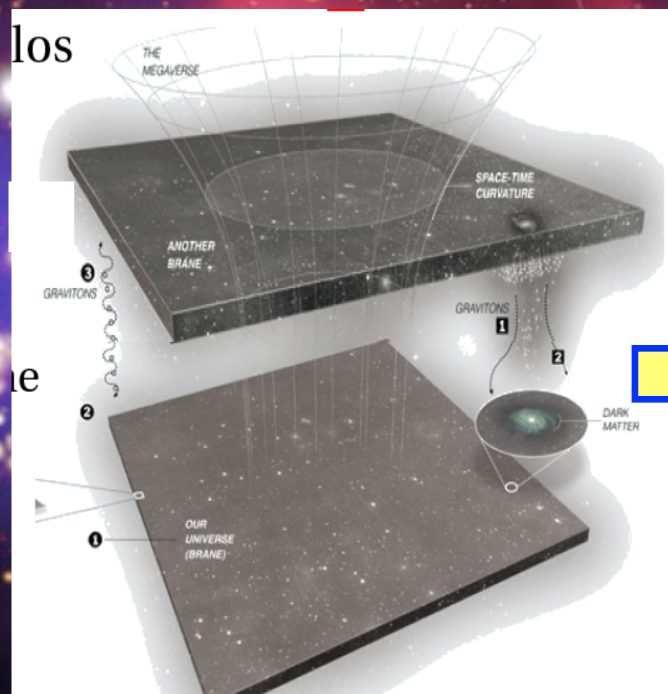
One of the key papers, that led a lot of experimental searches.

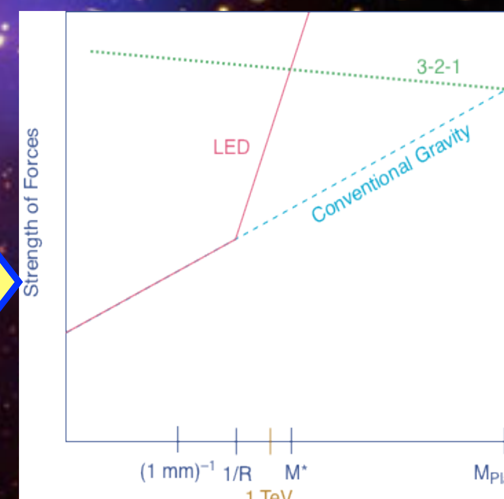
Extra Space Dimensions

Problem:

$$m_{EW} = \frac{1}{(G_F \cdot \sqrt{2})^{\frac{1}{2}}} = 246\ \text{GeV} \quad \Leftrightarrow \quad M_{Pl} = \frac{1}{\sqrt{G_N}} = 1.2 \cdot 10^{19}\ \text{GeV}$$







Gravity becomes strong!

Models with Extra Dimensions

Large Extra Dimensions

Planck scale (M_D) ~ TeV

Size: » TeV^{-1}; SM-particles on brane; gravity in bulk

KK-towers (small spacing); KK-exchange; graviton prod.

Signature: e.g. x-section deviations; jet+$E_{T,miss}$ ....

ADD

Arkani-Hamed Dimopoulos Dvali

Warped Extra Dimensions

RS

Randall Sundrum

5-dimensional spacetime with warped geometry

Graviton KK-modes (large spacing); graviton resonances

Signature: e.g. resonance in ee, μμ, γγ-mass distributions ...

TeV-Scale Extra Dimensions

look-like SUSY

SM particles allowed to propagate in ED of size TeV^{-1}

[scenarios: gauge fields only (nUED) or all SM particles (UED)]

Antoniadis

UED

Universal Extra Dimensions

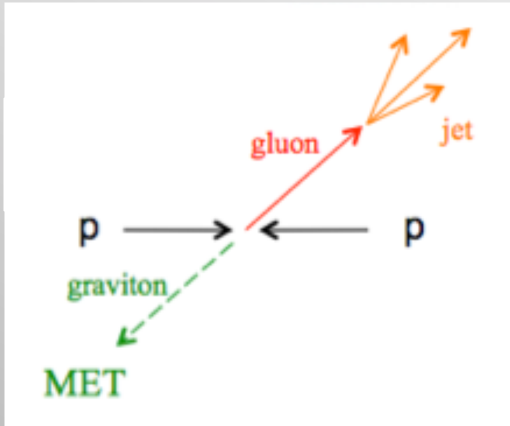
nUED : KK excitations of gauge bosons

UED : KK number conservation; KK states pair produced (at tree-level) ...

Signature: e.g. Z'/W' resonances, dijets+$E_{T,miss}$, heavy stable quarks/gluons...

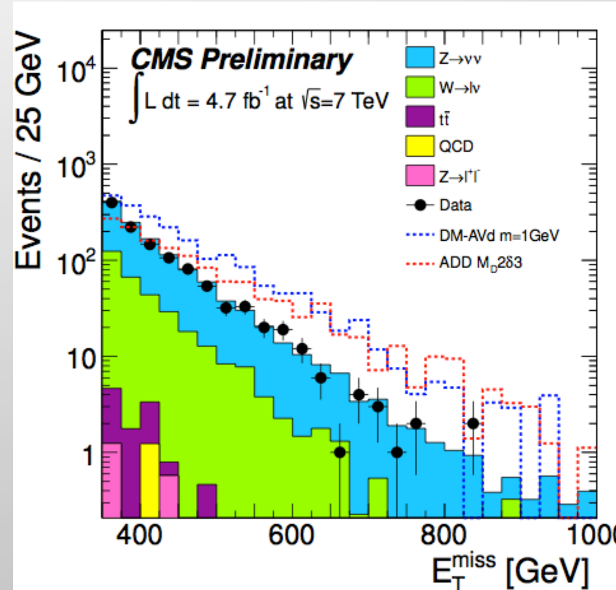
Search for Extra Dimensions

Mono-jet final state +Missing E_T (ADD)



p_T jet > 110 GeV
MET > 200 GeV

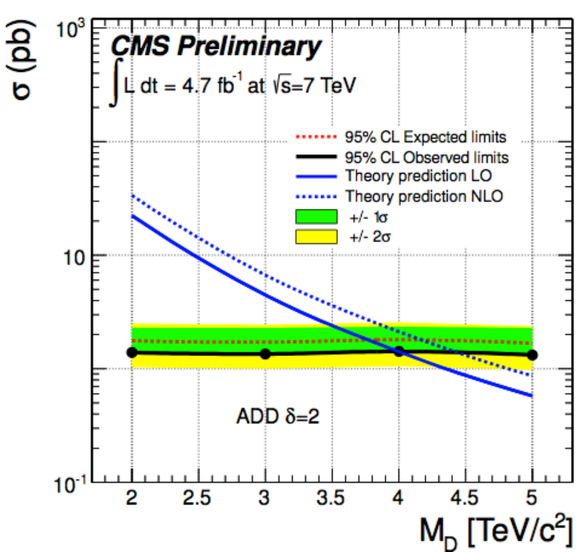
Limits on M_D between 2.5 and 4.5 TeV

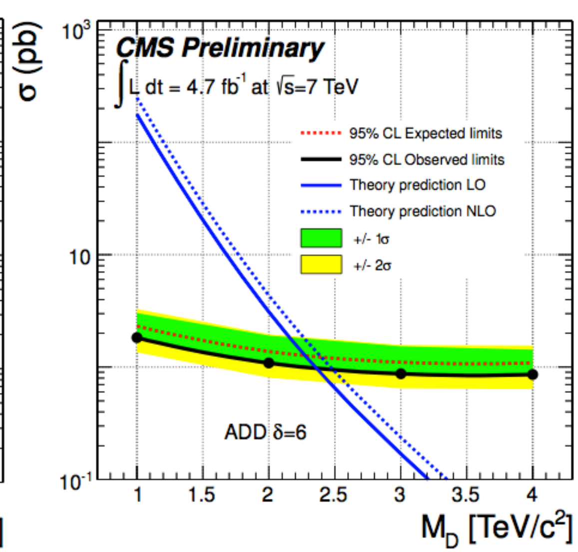


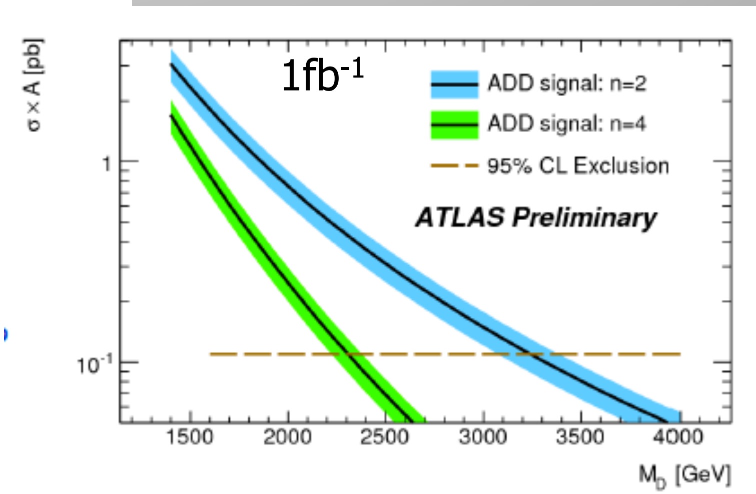
CMS-EXO-11-059

Lower Limit on the Planck Scale versus number of extra dimensions

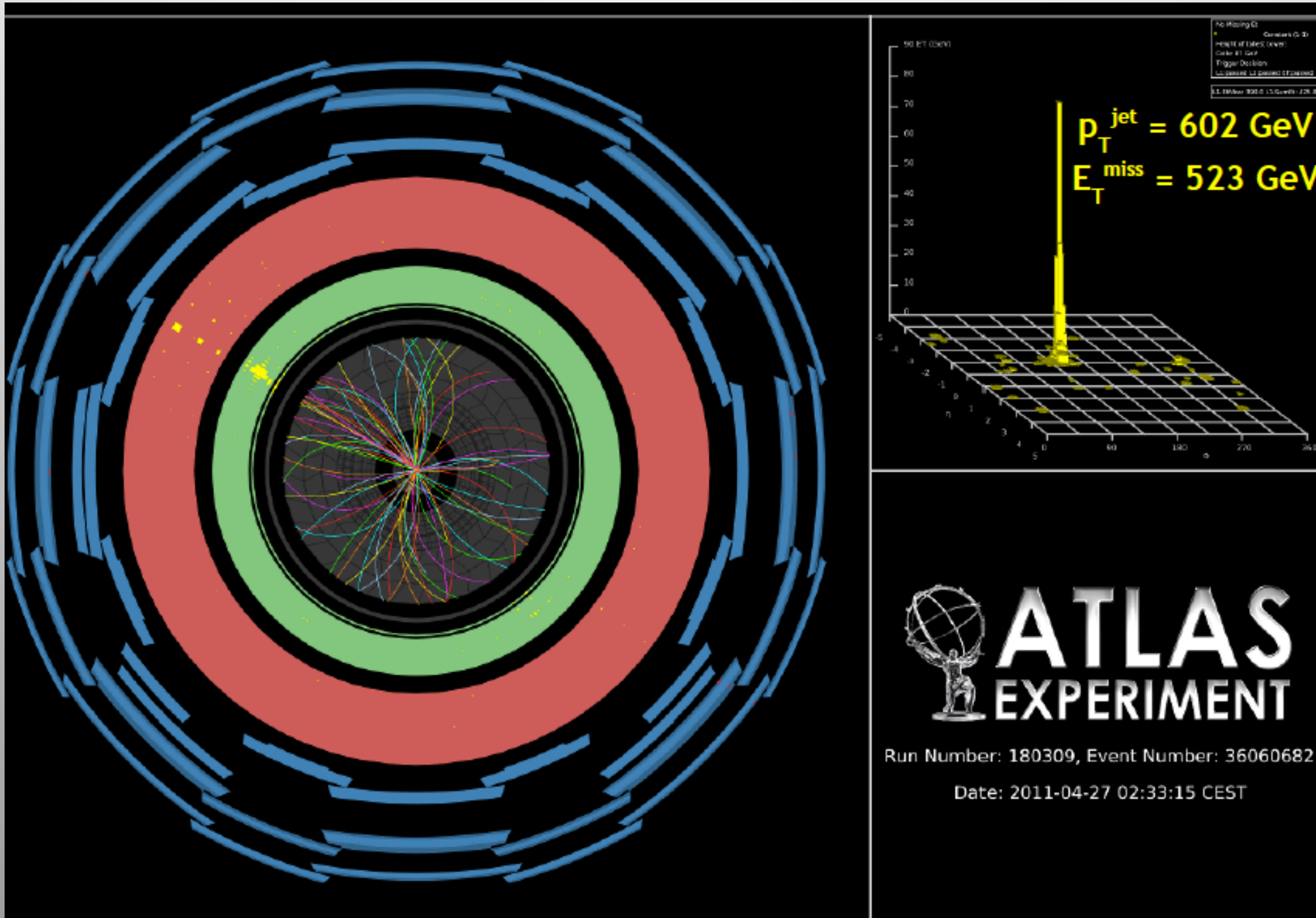
ATLAS-CONF-2011-096







A High p_T Mono-jet event

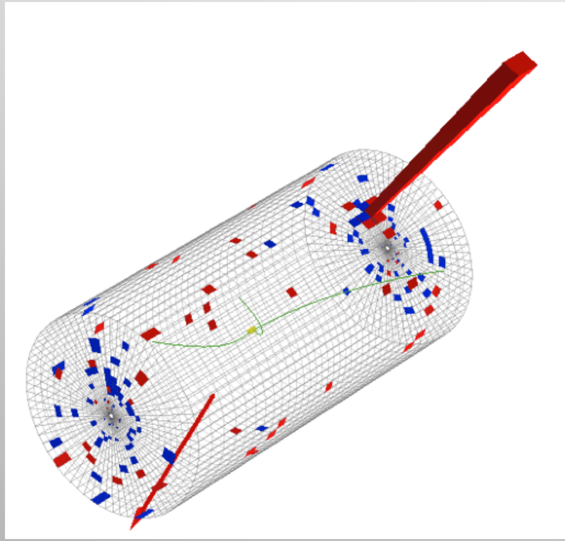


A high-p_T monojet event - SM interpretation $Z \rightarrow \nu\bar{\nu}$ + jet

21

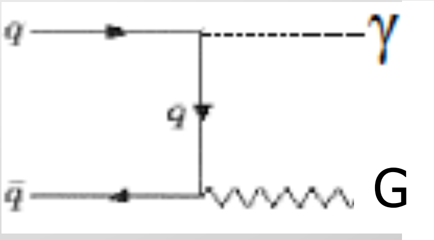
Search for Extra Dimensions

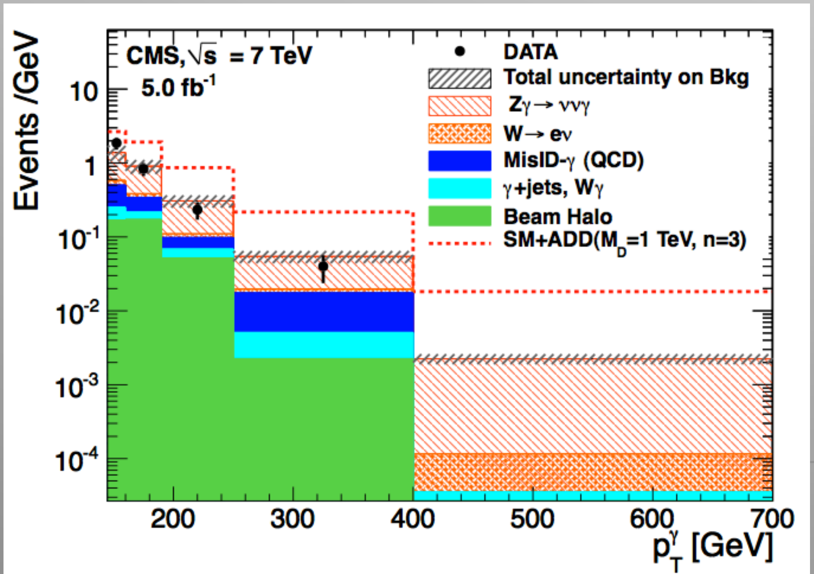
Mono-photon final state +Missing E_T (ADD)

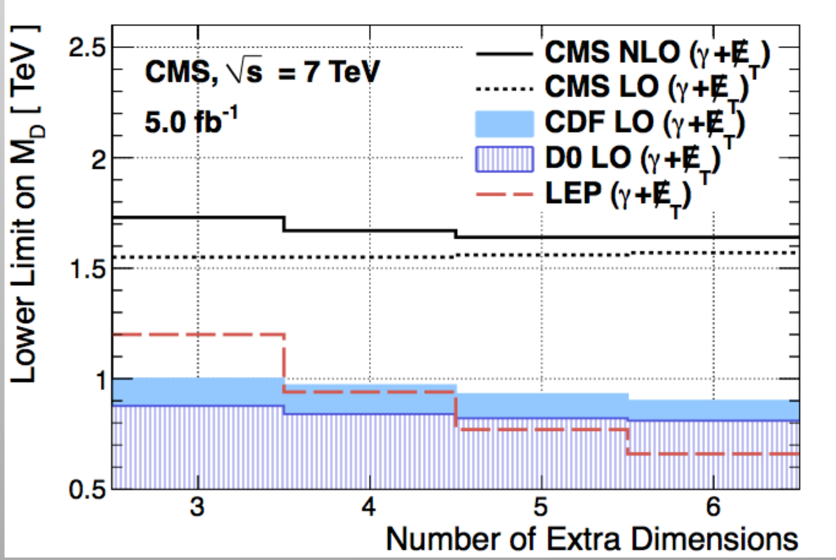


E_{γ} > 145 GeV & MET>130 GeV

CMS-EXO-11-096

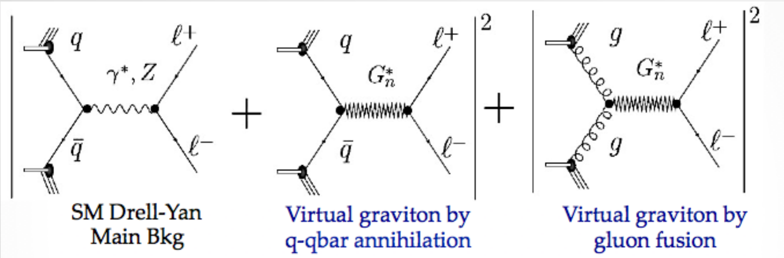






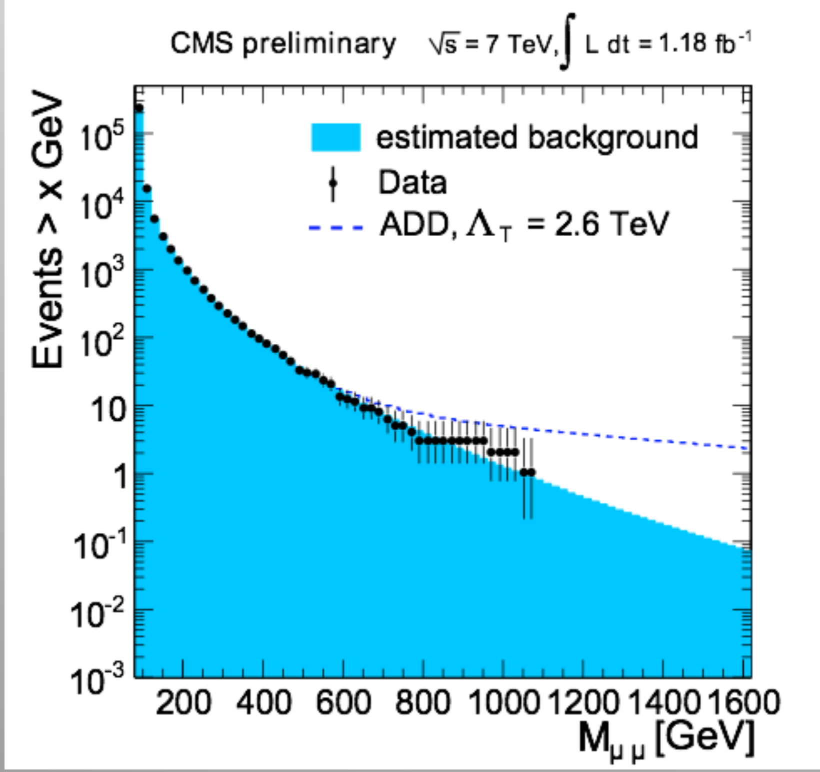
Limit: M_D> 1.5 TeV

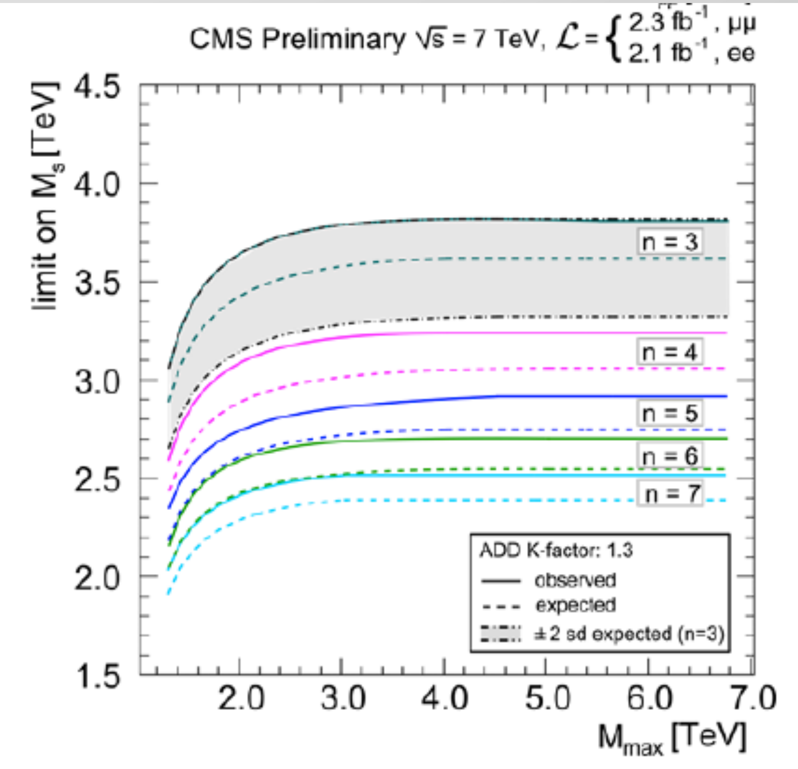
Search for Extra Dimensions



Pairs of electrons and muons at high invariant mass

arXiv:1202:3827



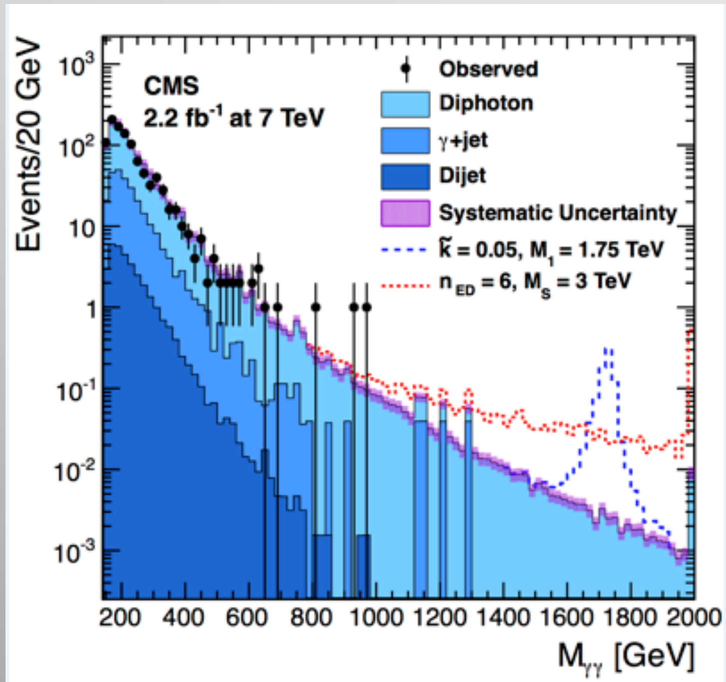


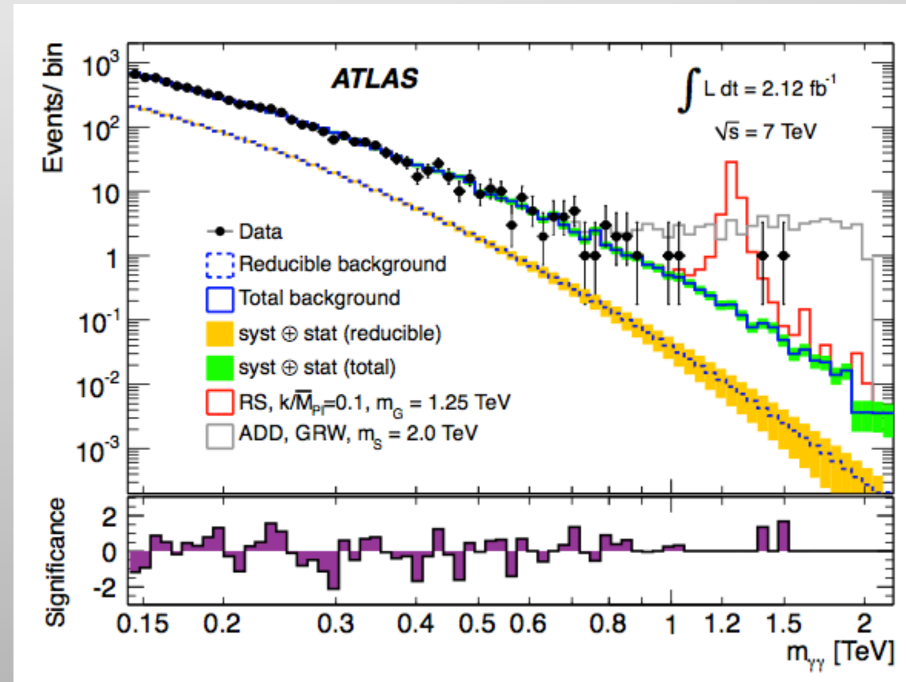
Limits on M_s ranging from 2.5 TeV to 3.8 TeV (HLZ convention)

Search for Extra Dimensions

Two Photons resonance (RS)
Select two photons with $M_{\gamma\gamma} > 140$ GeV

arXiv:1112:2194





arXiv:1112:0688

K factor	GRW	Hewett		HLZ (n_{ED})					
		pos.	neg.	2	3	4	5	6	7
1.0	2.94	2.63	2.28	3.29	3.50	2.94	2.66	2.47	2.34
1.6	3.18	2.84	2.41	3.68	3.79	3.18	2.88	2.68	2.53

ADD Limit: $M_s > 2.5$-3.8 TeV (HLZ)

Monojet/Monophoton Signatures

While used in the past 10 years mostly for ADD alike searches, there are important new spinoffs

- Supersymmetry searches (not new; UA1 already "detected" such signal)
- Dark Matter searches
- Unparticles… (?)
- Invisible Higgs searches (eg arXiv:1205. 3169): The sensitivity ~ SM total cross section

Direct detection of Higgs–portal dark matter at the LHC

Abdelhak Djouadi[a,b],[*] Adam Falkowski[a],[†] Yann Mambrini[a],[‡] and Jérémie Quevillon[a][§]

[a] *Laboratoire de Physique Théorique, Université Paris-Sud, F-91405 Orsay, France.*

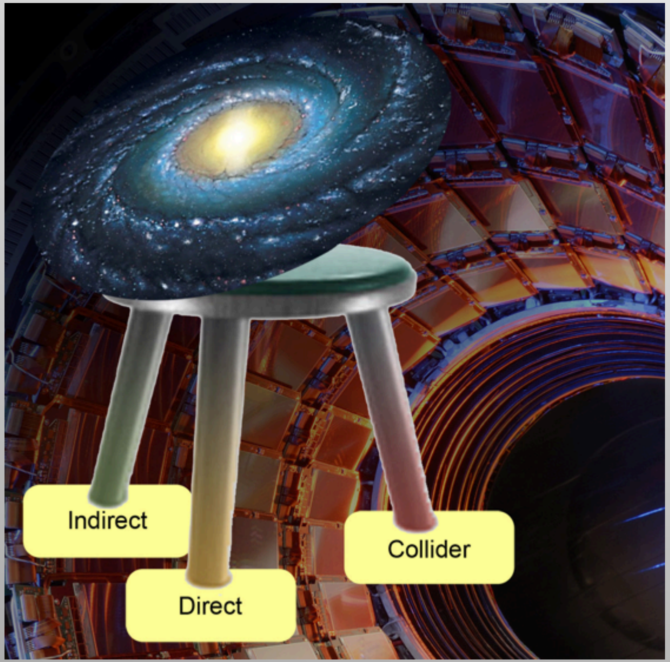
[b] *CERN, CH–1211, Geneva 23, Switzerland.*

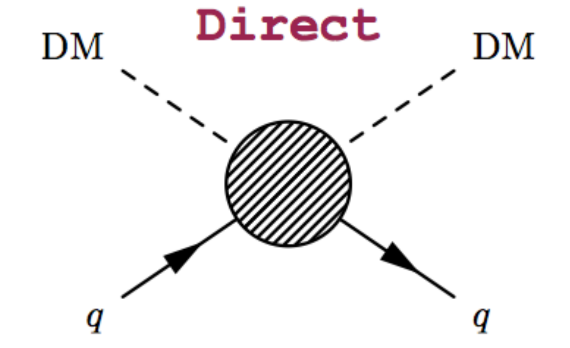
Last week

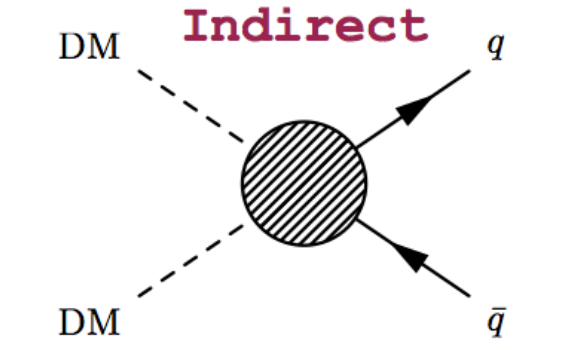
$$\mathrm{BR}_\chi^{\mathrm{inv}} \equiv \frac{\Gamma(H \to \chi\chi)}{\Gamma_H^{\mathrm{SM}} + \Gamma(H \to \chi\chi)} = \frac{\sigma_{\chi p}^{\mathrm{SI}}}{\Gamma_H^{\mathrm{SM}}/r_\chi + \sigma_{\chi p}^{\mathrm{SI}}}$$

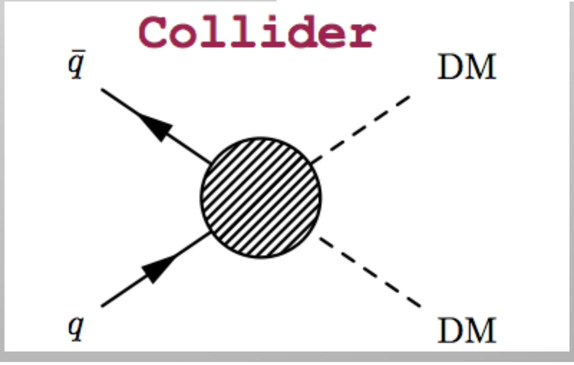
The Dark Matter Connection

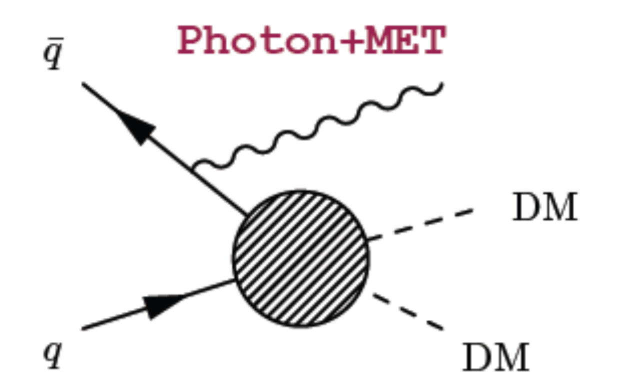
Searches for mono-jets and mono-photons can be used to search for Dark Matter (DM)

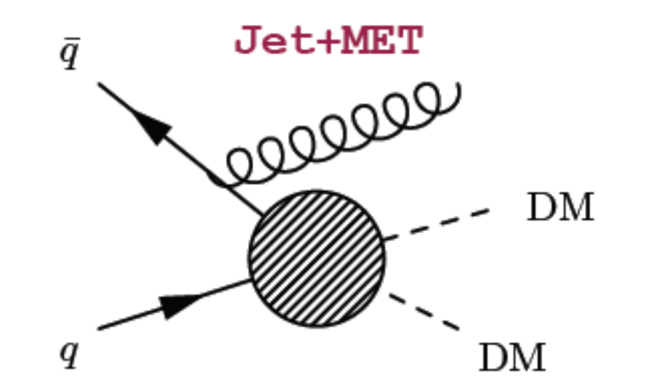












The Dark Matter Connection

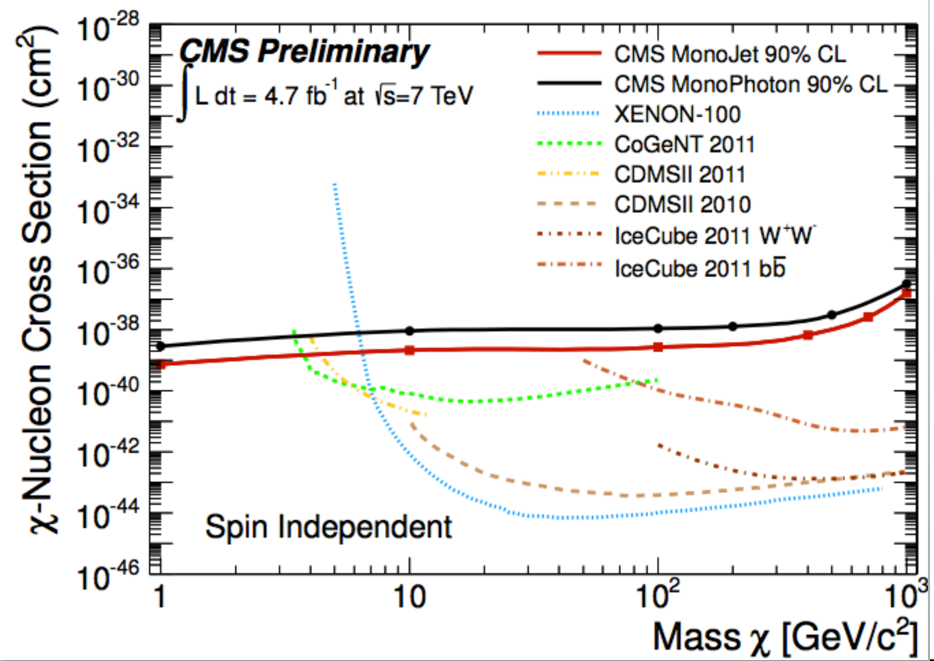
Results for direct searches and collider searches for Dark Matter
-> Spin dependent and spin independent cross sections of Dark Matter with ordinary matter

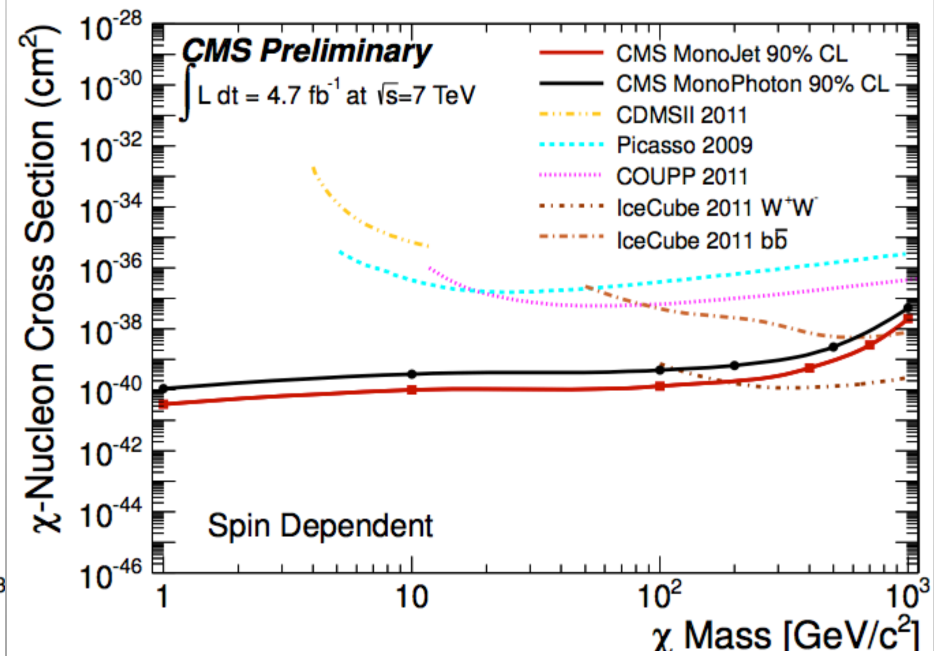
$$\mathcal{O}_V = \frac{(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)}{\Lambda^2}$$

Effective contact interaction approach

$$\mathcal{O}_{AV} = \frac{(\bar{\chi}\gamma_\mu\gamma_5\chi)(\bar{q}\gamma^\mu\gamma_5 q)}{\Lambda^2}$$

CMS-EXO-11-059

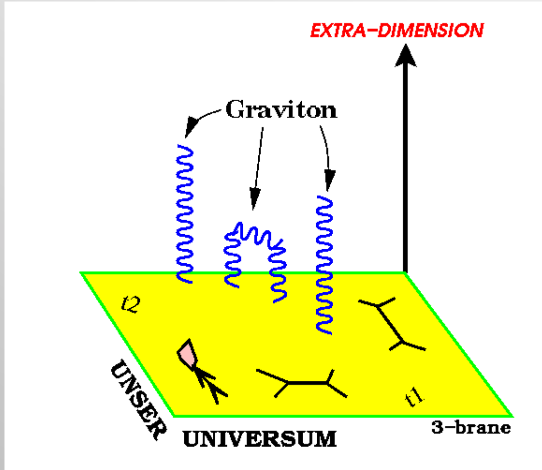




Collider searches are very competitive!!

[Bai, Fox and Harnik, JHEP 1012:048(2010)]

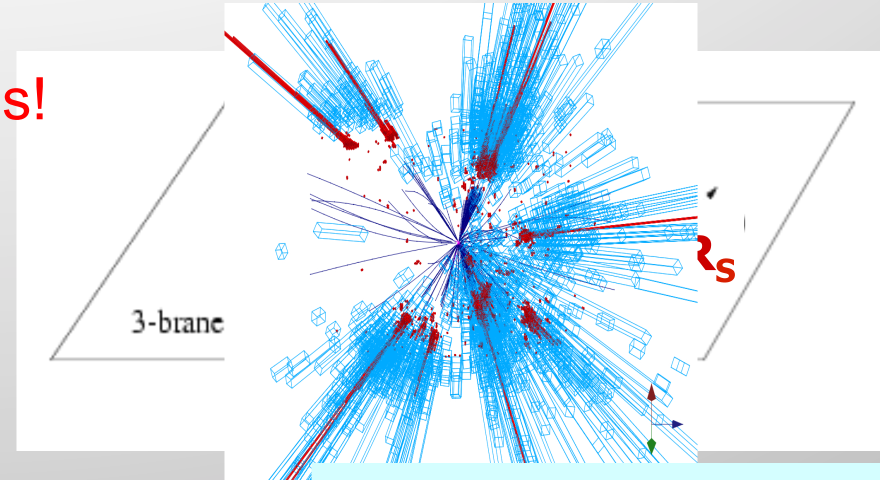
Search for Micro Black Holes



arXiv:1202.6396

Extra Dimensions!

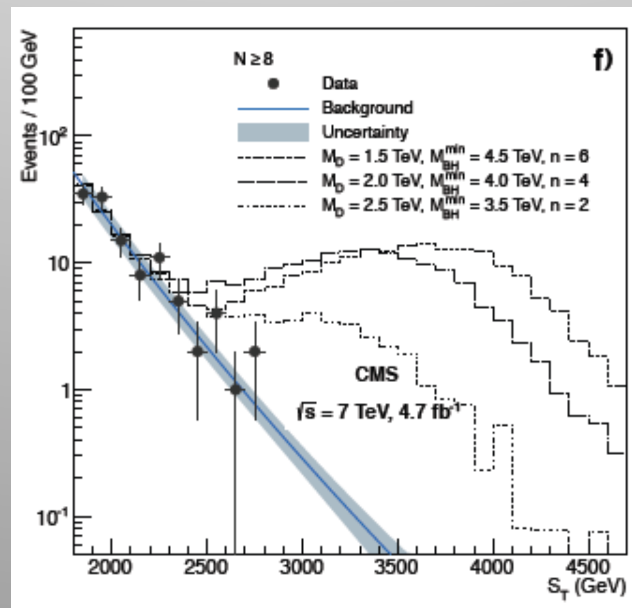
Planck scale
a few TeV?

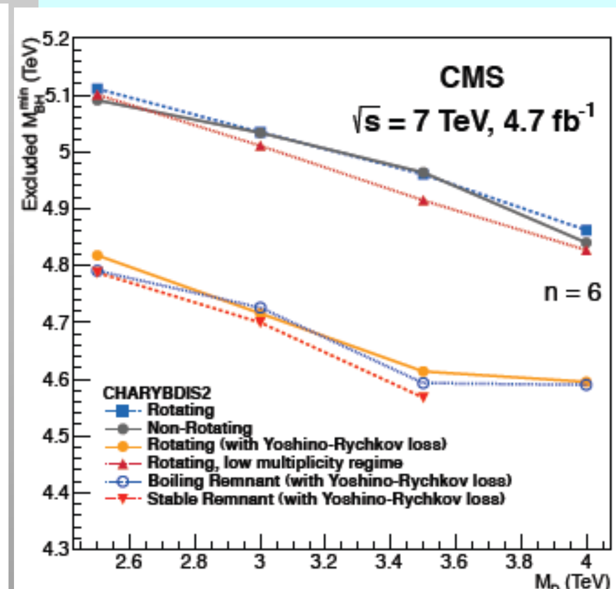


Evaporates in 10^{-27} sec

Look for the decay producs of an evaporating black hole

- Define S_T to be the scalar sum of all high p_T objects found in the event
- Look for deviations at high S_T

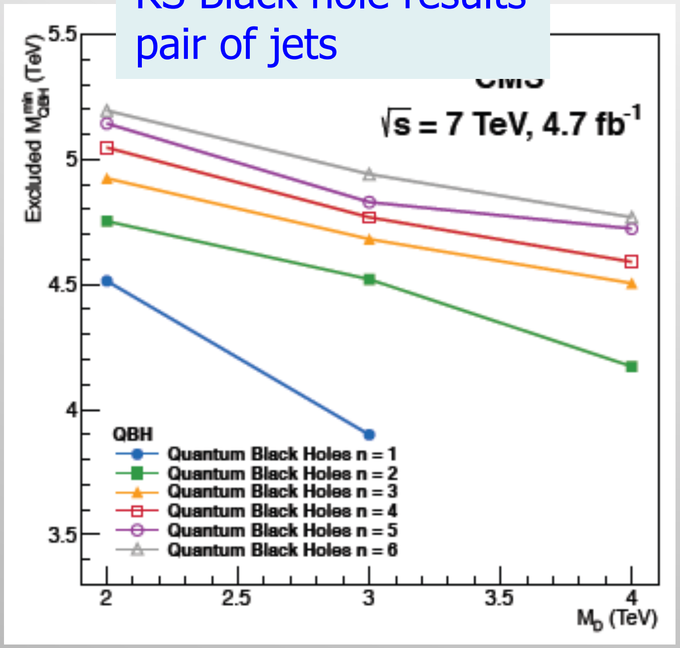




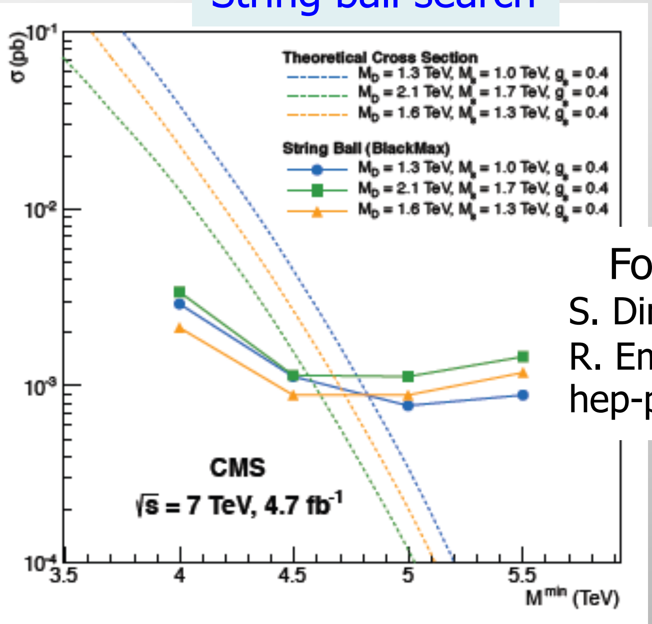
Black hole masses excluded in range ~5 TeV depending on assumptions

Search for Micro Black Holes

RS Black hole results
pair of jets

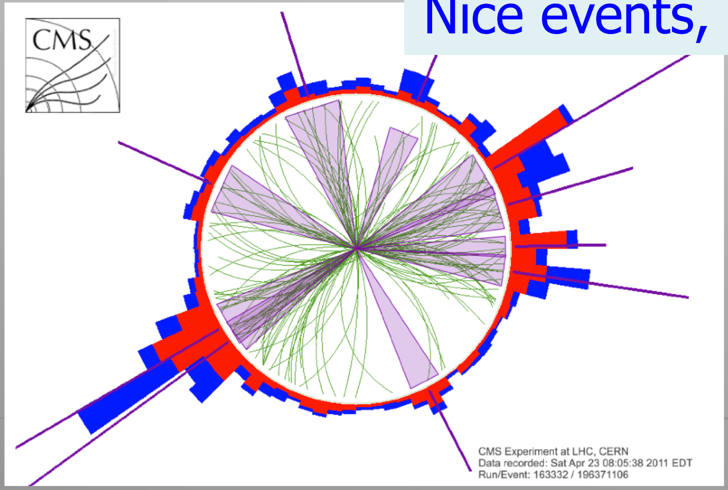


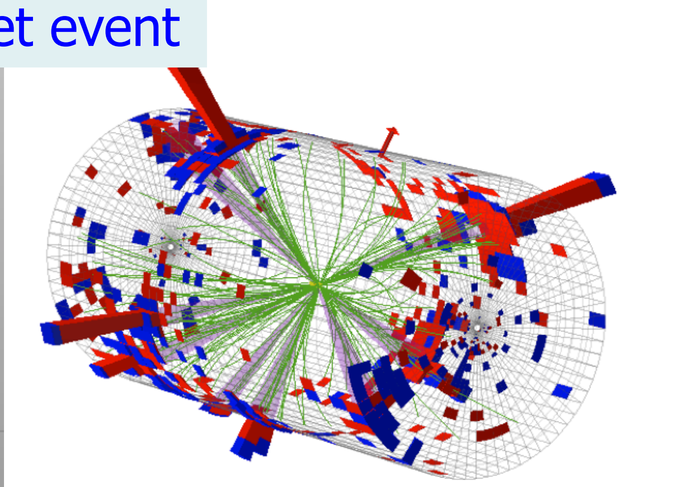
String ball search



Following
S. Dimopoulos
R. Emparan
hep-ph/0108060

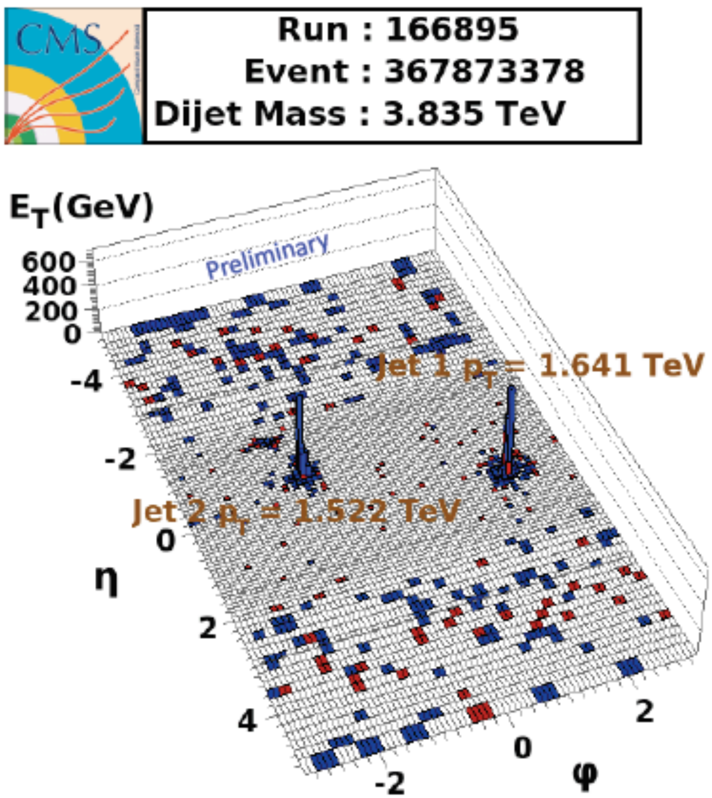
Nice events, eg this 10 jet event



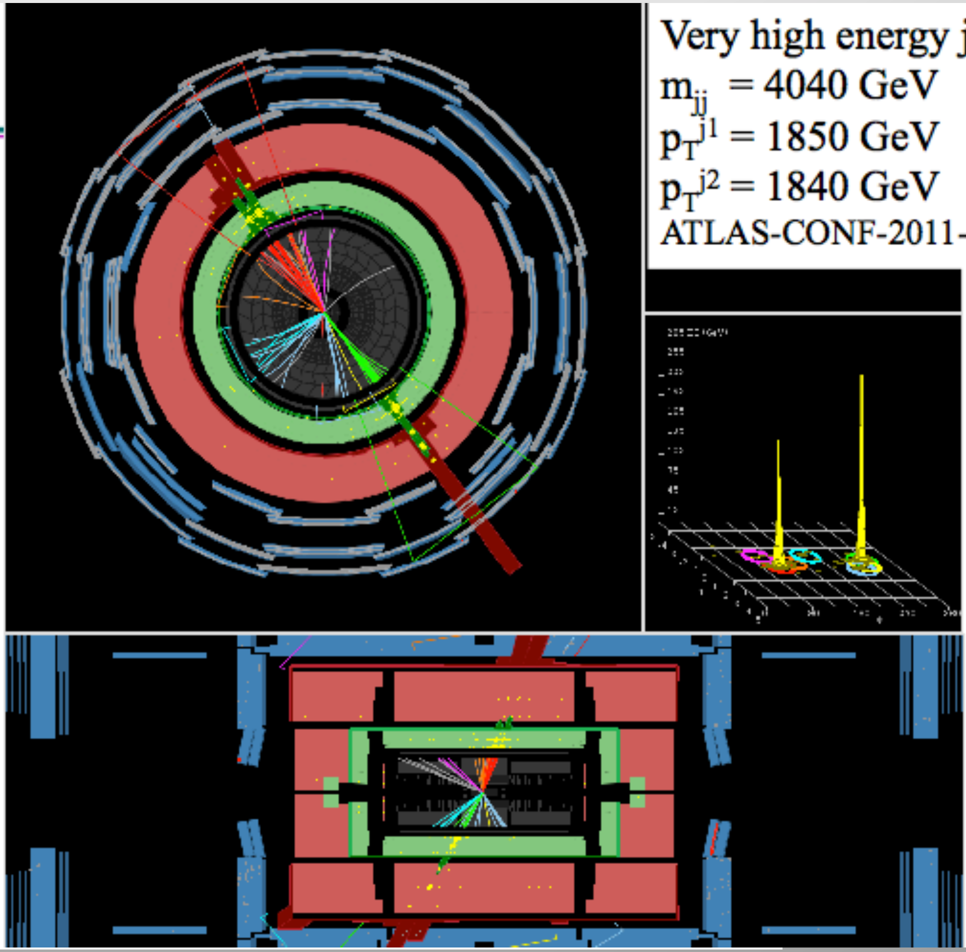


High p_T Dijet Events

Mostly QCD.. Also a signature for Quantum Black Holes?



- Well balanced dijet event

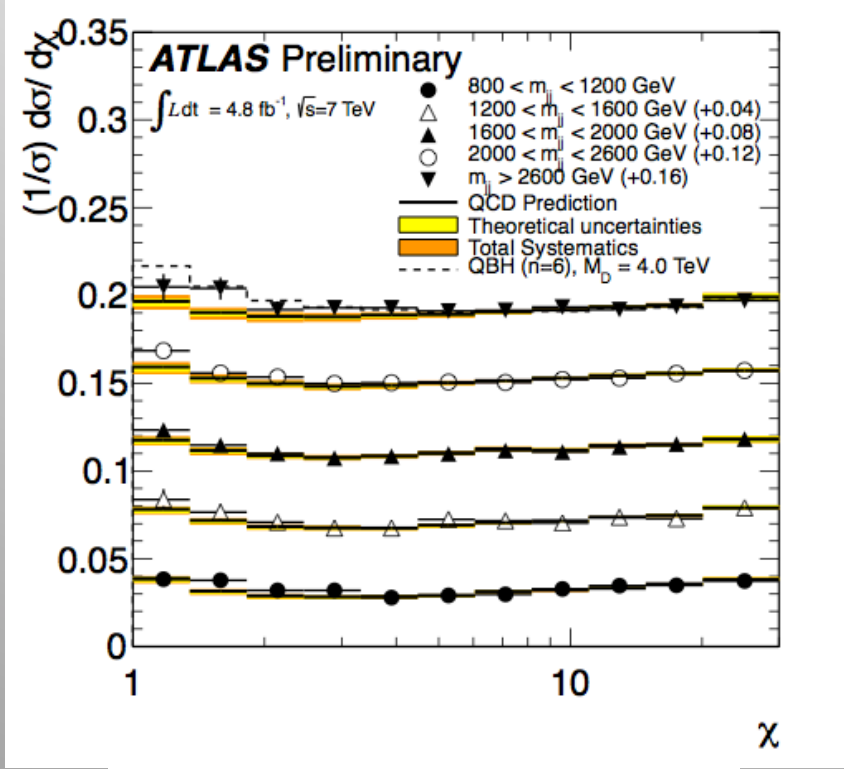


Very high energy jet event
m_{jj} = 4040 GeV
p_T^{j1} = 1850 GeV
p_T^{j2} = 1840 GeV
ATLAS-CONF-2011-081

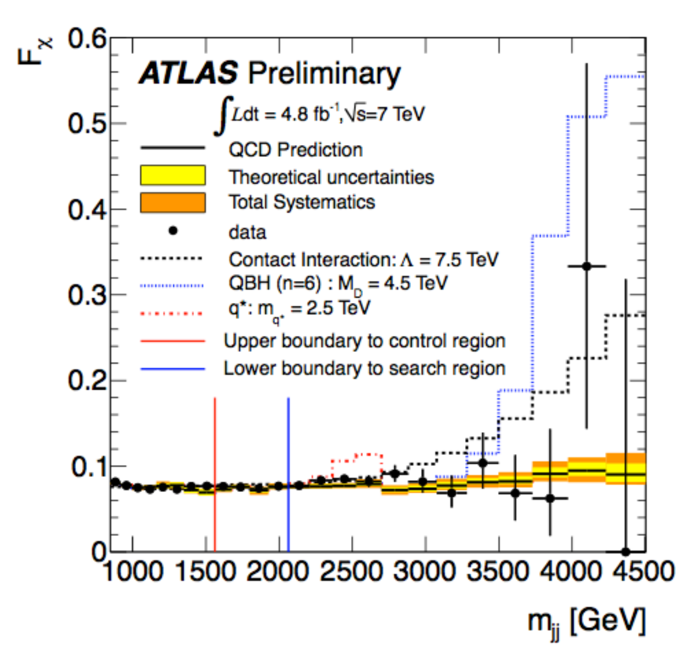
Quantum Black Holes

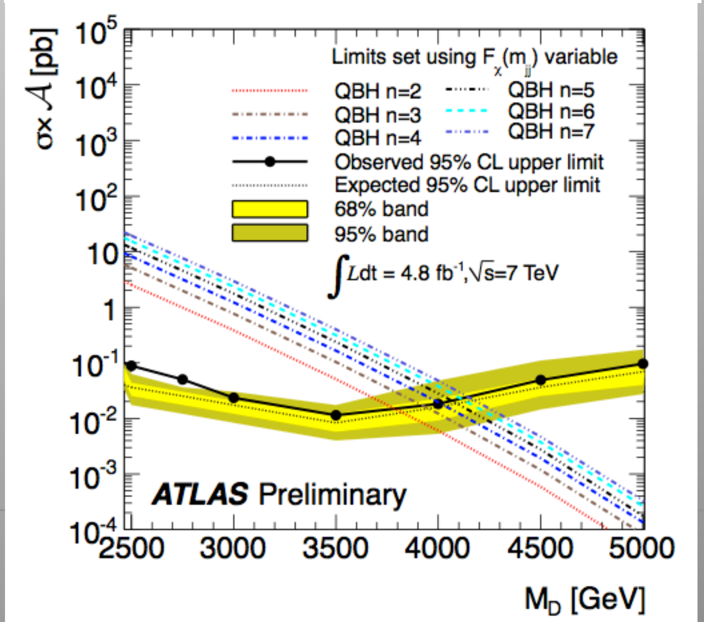
Di-jet events: angular correlation study

ATLAS-CONF-2012-038



$$\chi \equiv \exp(|y_1 - y_2|) = \exp(2|y^*|)$$



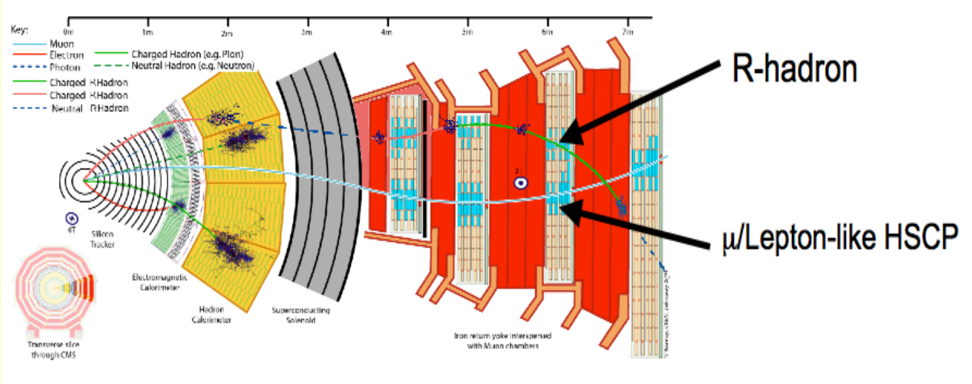


Exclude quantum black holes with mass ~ 4 TeV

Long Lived Particles

Split Supersymmetry

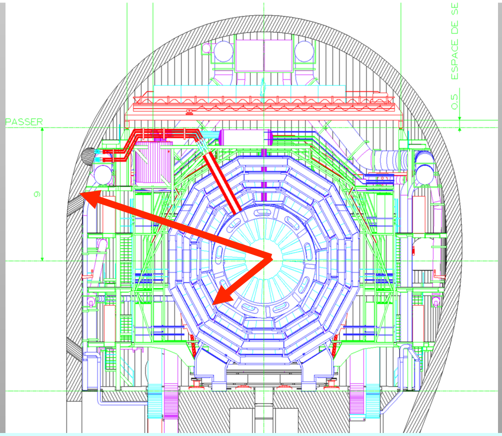
- The only light particles are the Higgs and the gauginos
  - Gluino can live long: sec, min, years!
  - R-hadron formation (eg: gluino+ gluon): slow, heavy particles



Gravitino Dark Matter and GMSB

- In some models/phase space the gravitino is the LSP
- ⇒ NLSP (neutralino, stau lepton) can live 'long'
- ⇒ non-pointing photons

EG: K. Hamaguchi,M Nojiri,ADR hep-ph/0612060
ADR, J. Ellis et al. hep-ph/0508198



Hidden Valley modes!…

Plethora of possibilities for long lived neutrals

Sparticles stopped in the detector,walls of the cavern, or dense 'stopper' detector. They decay after hours---months…

⇒Challenges to the experiments!

Stopped R-hadrons or Gluinos!

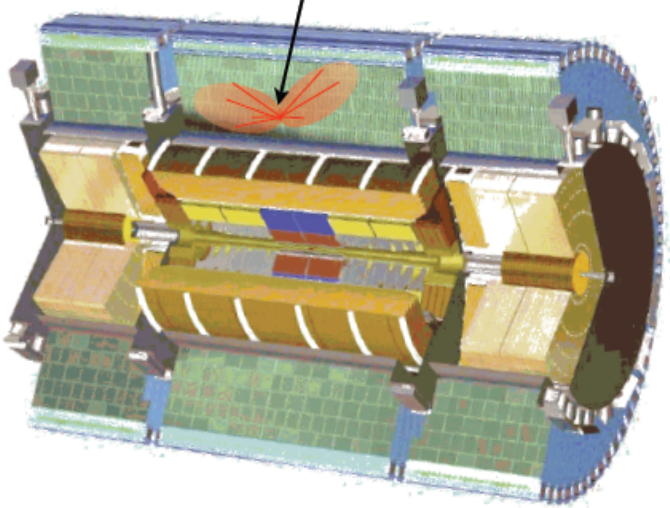
The R-hadrons may loose so much energy that they simply stop in the detector

Long Lived Gluinos

$\tau_{\tilde{g}} > 100$ ns

looking for stopped gluinos that later decay

100s GeV Unbalanced $= \not{E}_T$



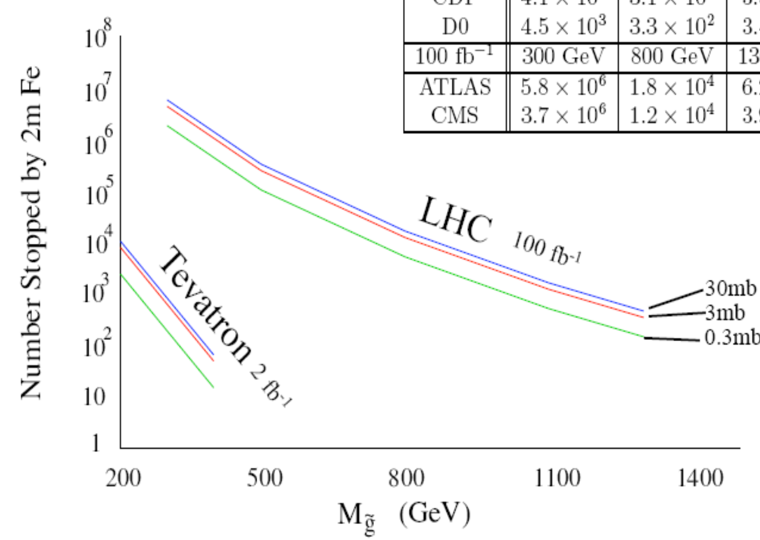
Uncorrelated with any beam crossing

No tracks going to or from activity

Total Number of Stopped Gluinos

Arvanitaki, Dimopoulos, Pierce, Rajendran, JW hep-ph/0506242

$2\ fb^{-1}$	200 GeV	300 GeV	400 GeV
CDF	4.1×10^3	3.1×10^2	3.3×10^1
D0	4.5×10^3	3.3×10^2	3.4×10^1
$100\ fb^{-1}$	300 GeV	800 GeV	1300 GeV
ATLAS	5.8×10^6	1.8×10^4	6.2×10^2
CMS	3.7×10^6	1.2×10^4	3.9×10^2

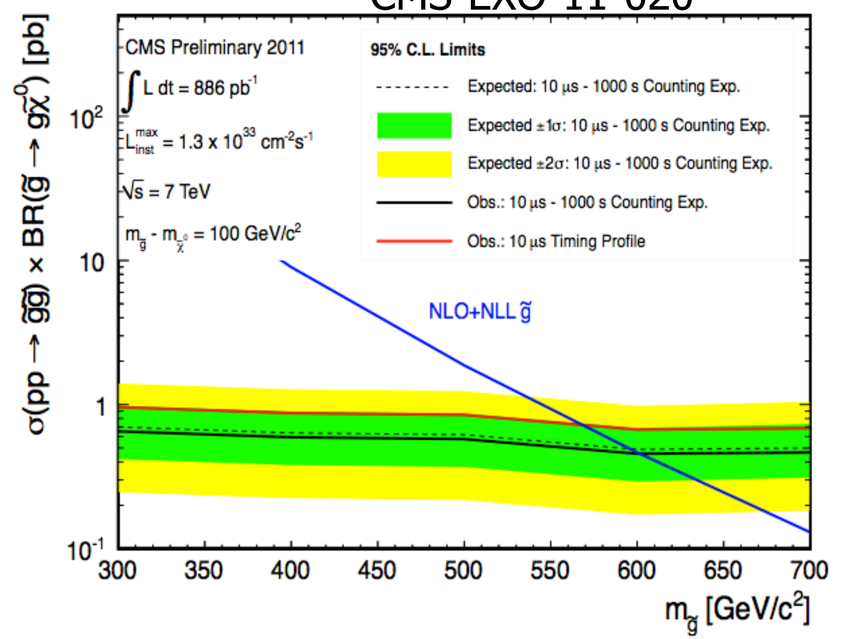


⇒ Special triggers needed, asynchronous with the bunch crossing

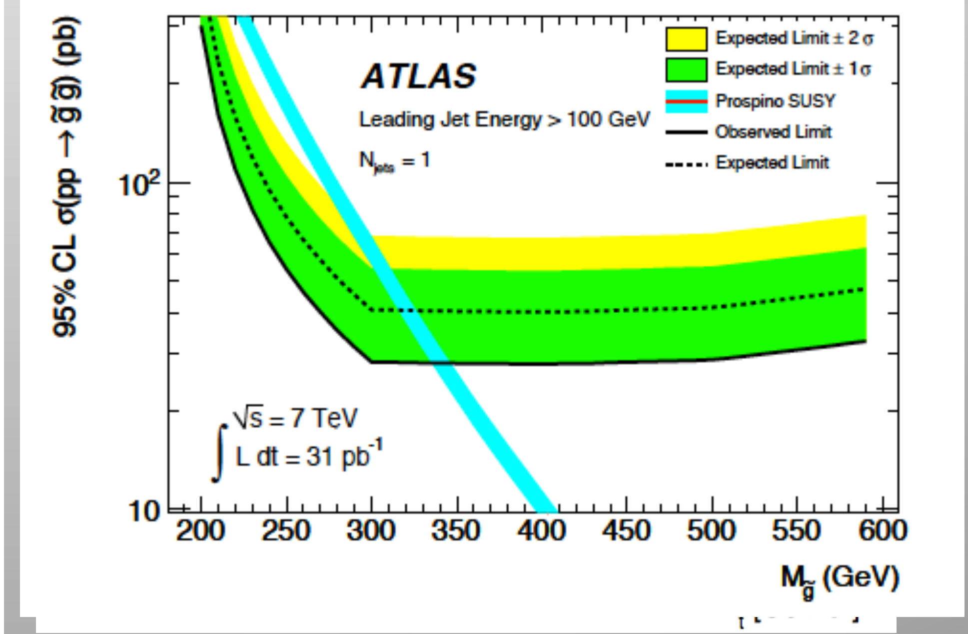
Search for Stopped Gluinos

Search for Heavy Stable Charged Particles that stop in the detectors and decay a long time afterwards (nsec, sec, hrs…)
Special data taking after the beams are dumped and during beam abort gap

CMS-EXO-11-020



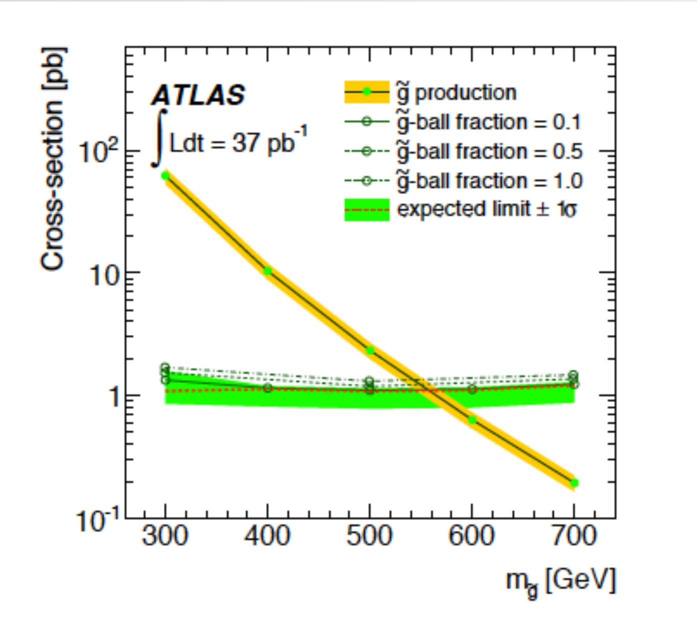
arXiv:1201.5595

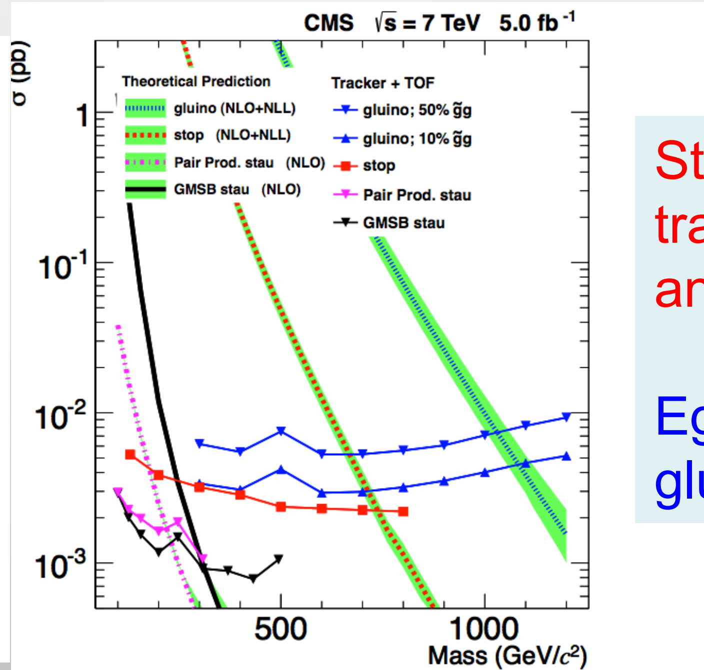


95% CL Limits: Stopped Gluinos > 600 GeV, Stopped Stop quarks> 337 GeV

Heavy Stable Charged Particles

CMS-EXO-11-022





Stable particles that traverse the detector, and move very slowly

Eg heavy stable gluino or stop/stau

Search limits using tracker de/dx and Muon Time of Flight information

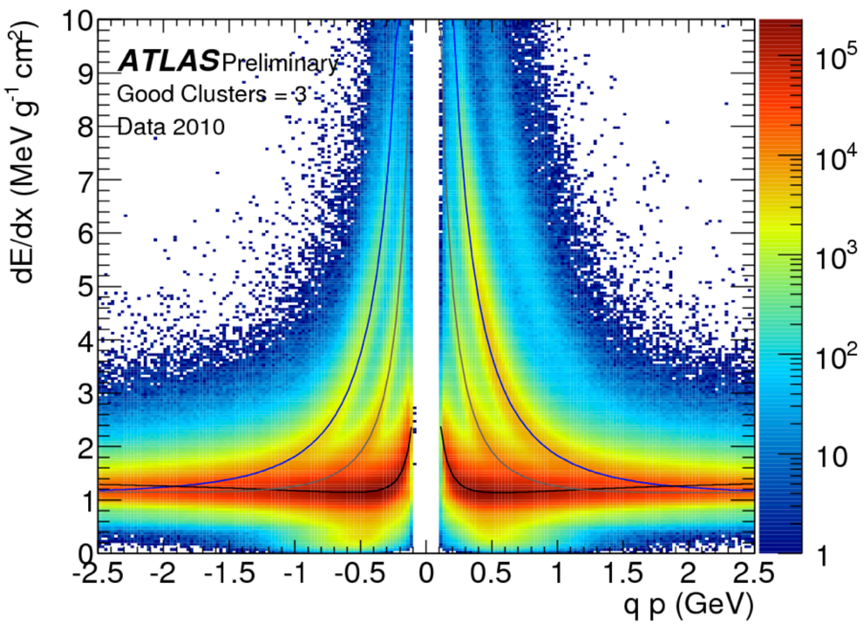
Result for 5 fb^{-1}: #Events consistent with estimated background

No gluinos (stop) found for masses up to about 1200 (800) GeV

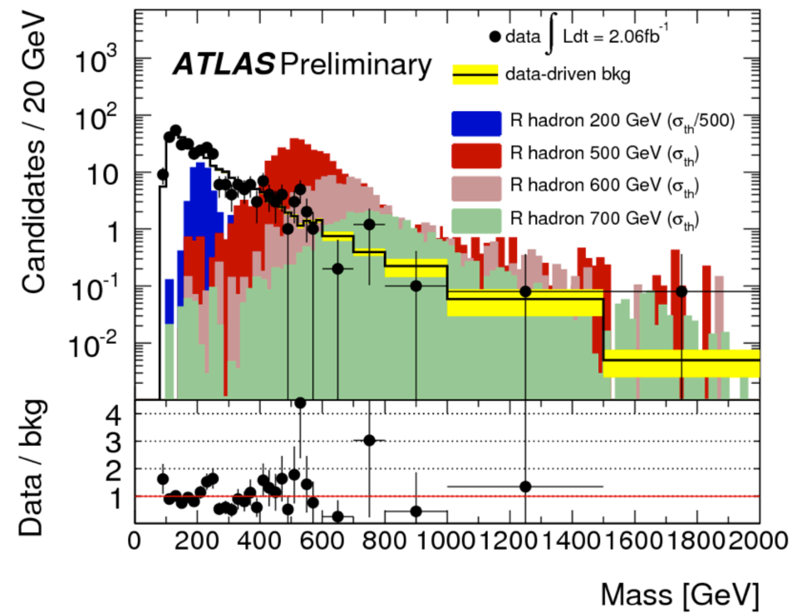
Search for R-hadrons

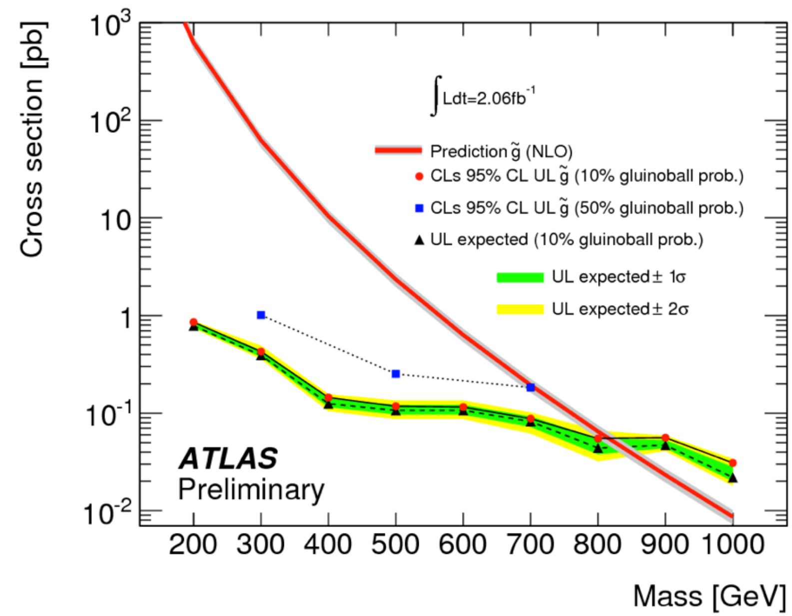
ATLAS-CONF-12-022

Search for particles with unusual ionization



Limit: Gluino mass > 810 GeV



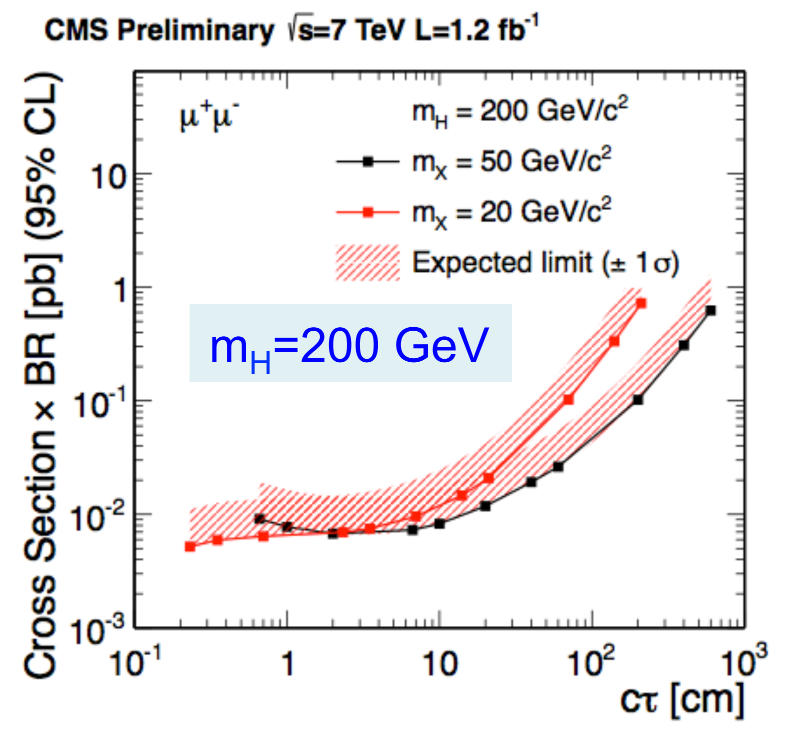


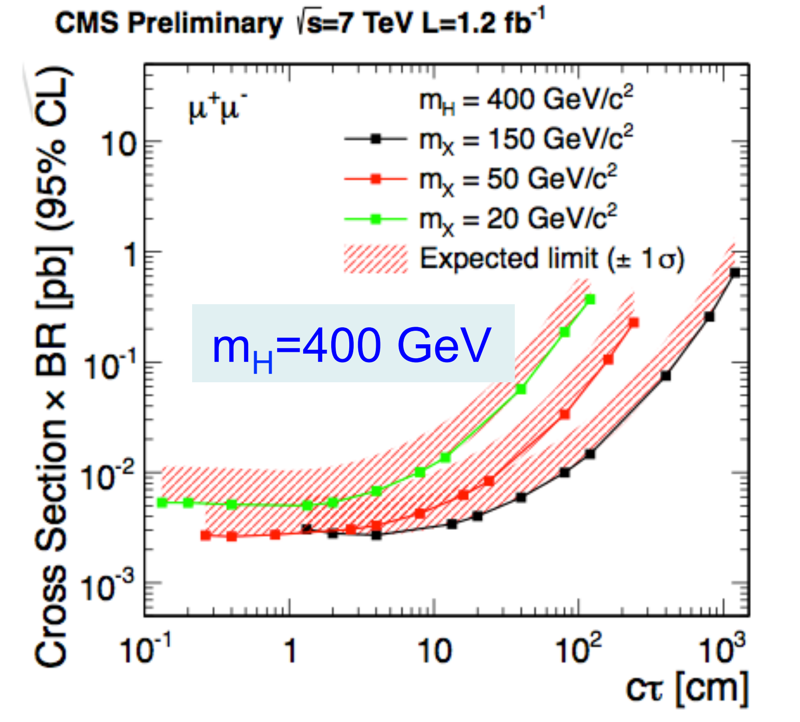
Long Lived Stable Particles

Long lived neutral particles like in Hidden Valley models

CMS-EXO-11-004

- Simple Example: Higgs→ X, where X decays into leptons
- Search for electrons from displaced vertices in the inner tracker
- Part of CMS tracking to find displaced vertices, for up to 50 cm displacement



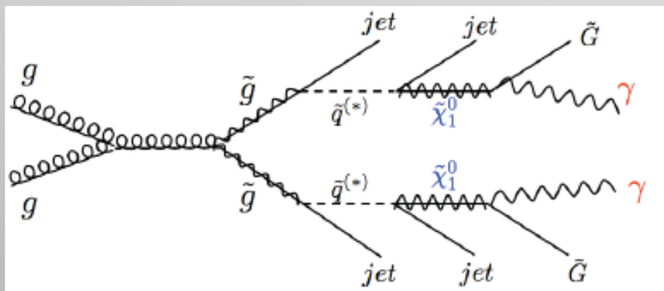


Upper limits on cross sections ~ 0.03-0.003 pb (if decay in detector)

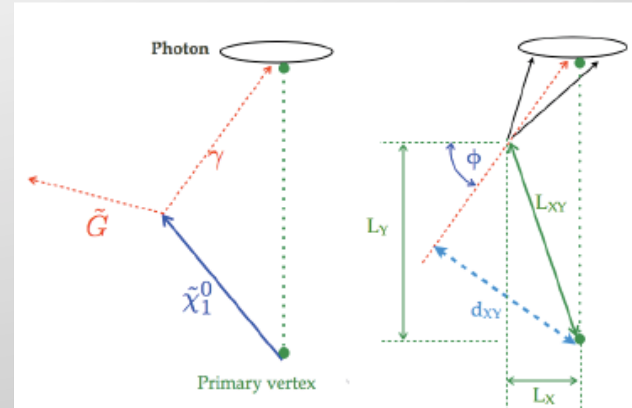
Displaced Photons

EG: GMSB models, Hidden Valleys

- Use photon conversions in CMS tracker
- Probe ~0.1-1.0 nsec lifetimes
  (2-25 cm displaced vertices)
- Select events with 2 jets, 2 photons and MET

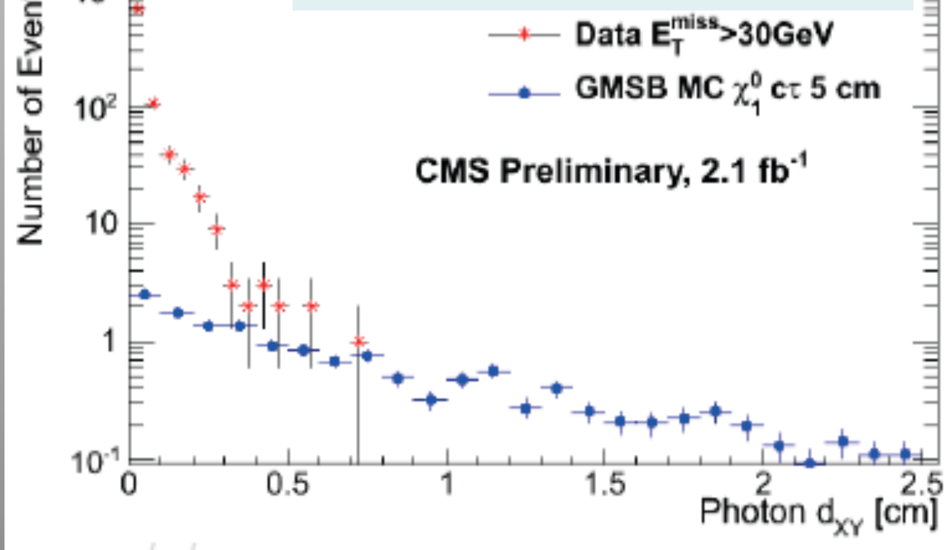


$$\tilde{\chi}_1^0 \to \tilde{G}\gamma$$

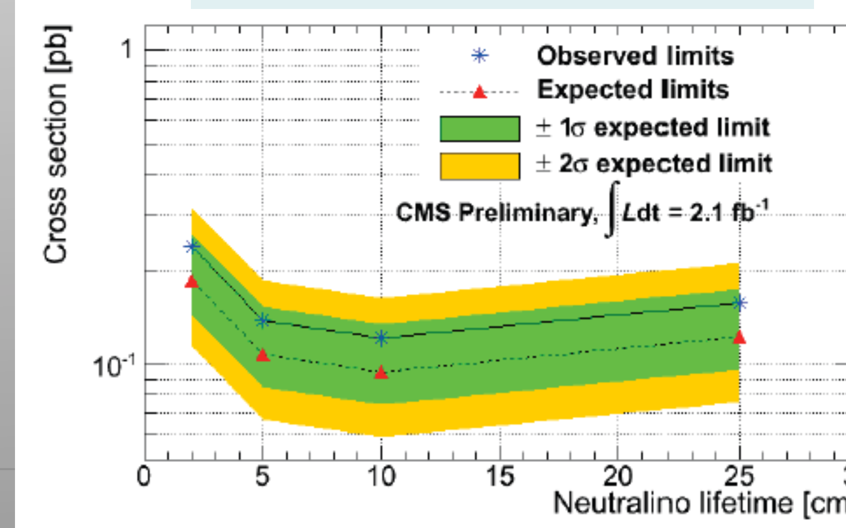


CMS-EXO-11-067

Transverse displacement



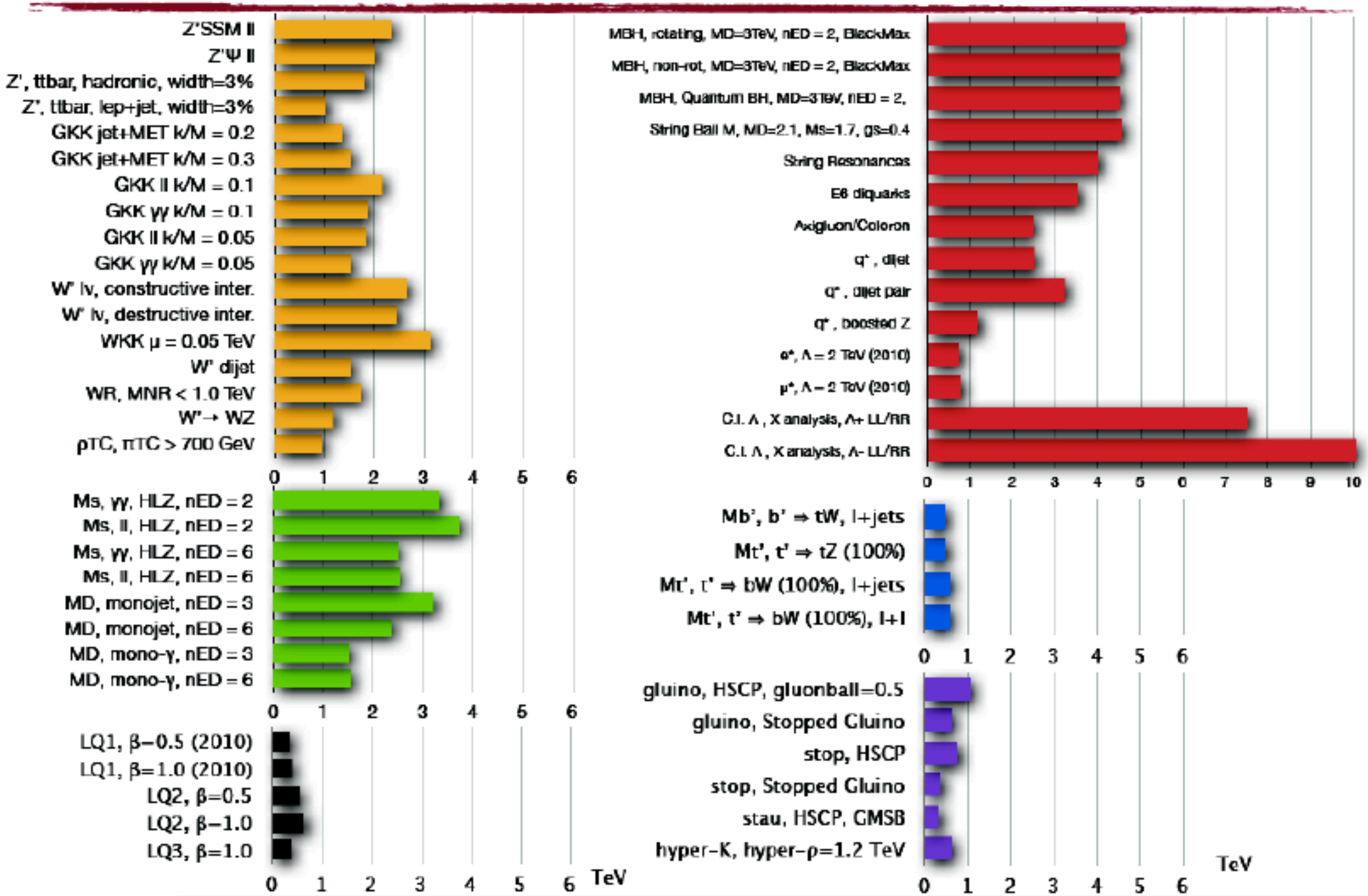
Cross section upper limit



Other Searches

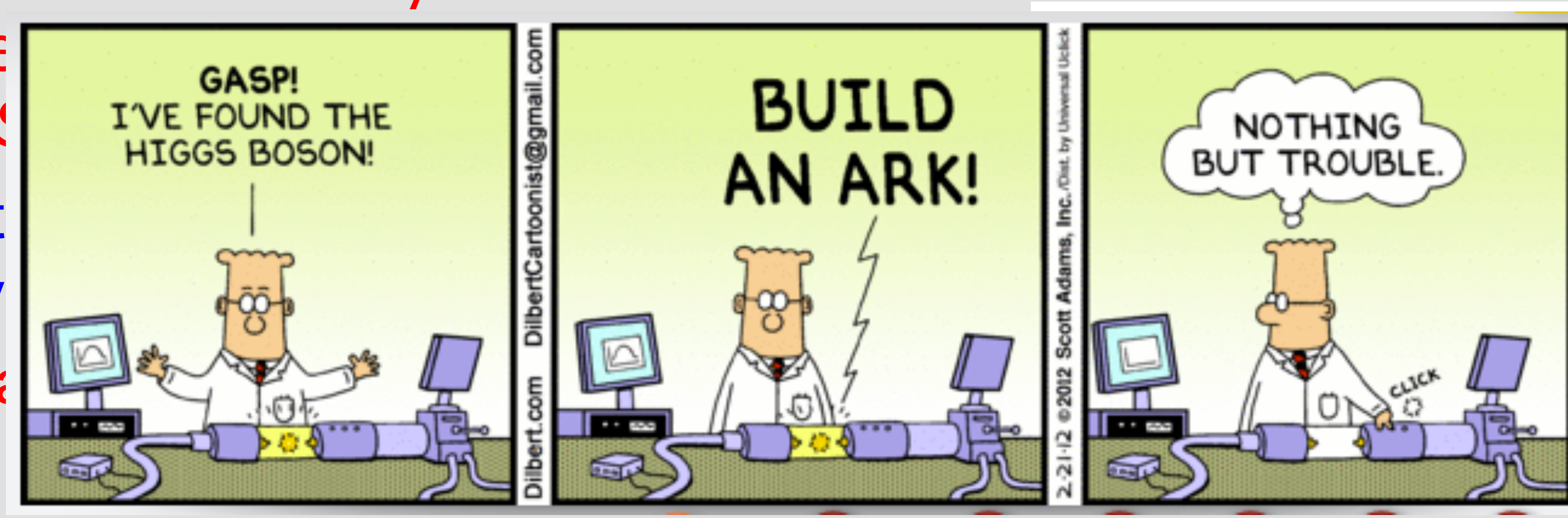
- New Gauge bosons
- Coloured resonances
- Objects decaying into top quarks
- Strong EW symmetry breaking eg topcolor
- 4th Generation of quarks and leptons
- Substructure /contact interactions
- Technicolor
- Long lived particles
- Dark/Hidden Sector particles
- …and more…

Example: CMS Results



Summary: The Searches are on!

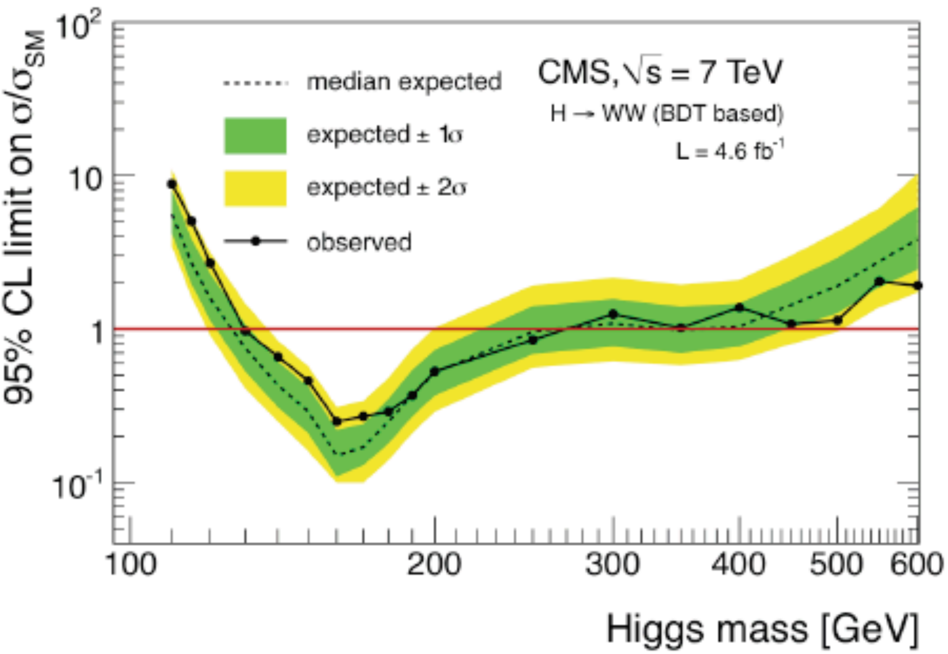
- The LHC has entered new territory. The ATLAS and CMS experiments are ready for searches for new physics. Very many New Physics searches are covered. No sign of new physics yet in the first 1-5 fb^{-1} at 7 TeV.
- Many channels available for the Higgs boson search. A small window is left for the Higgs. But a tantalizing excess is seen at ~ 125 GeV!! Watch the new 2012 data!
- With the data of this year ATLAS and CMS should be able to discove
Model
- Expect
energy
- And ma



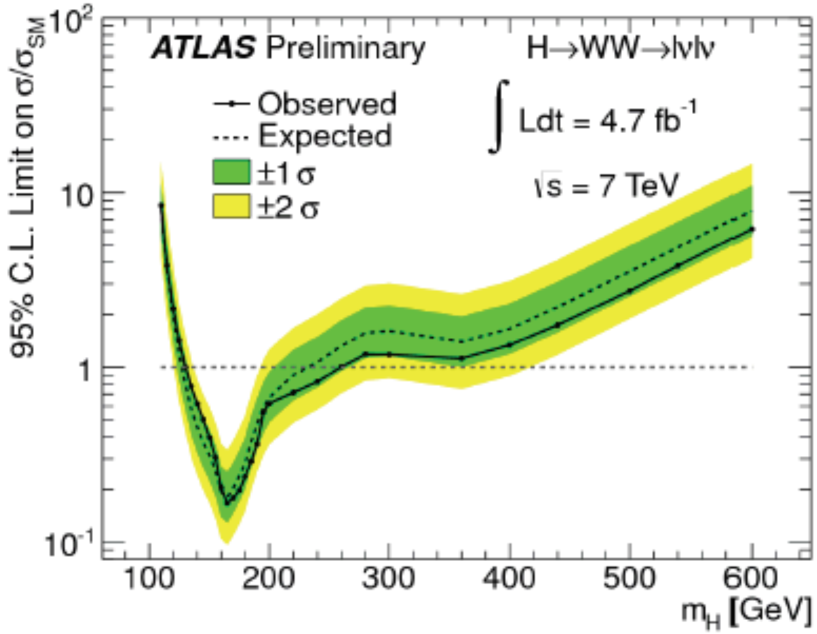
Backup

Higgs → WW: Full Range

Full mass range



Full mass range

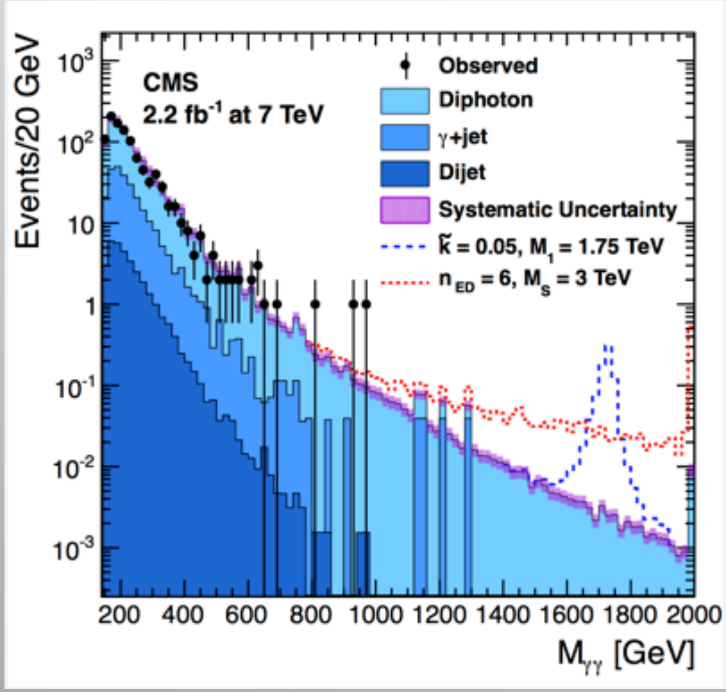


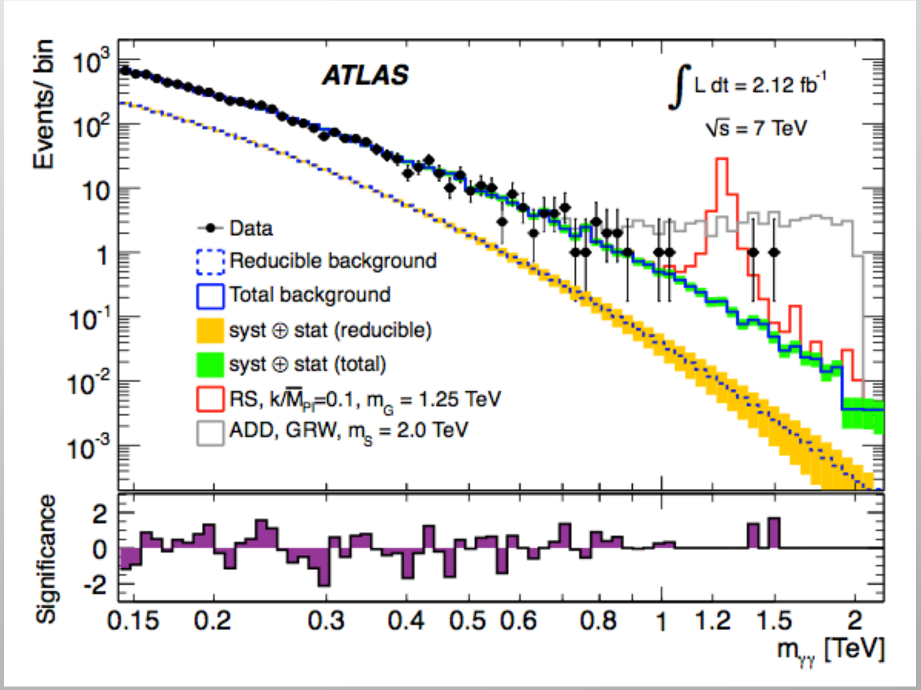
	ATLAS	CMS
Expected exclusion 95% CL	127-234 GeV	127-270 GeV
Observed exclusion 95% CL	130-260 GeV	129-270 GeV

Search for Extra Dimensions

Two Photons resonance (RS)
Select two photons with $M_{\gamma\gamma} > 140$ GeV

arXiv:1112:2194





arXiv:1112:0688

K factor	GRW	Hewett		HLZ (n_{ED})					
		pos.	neg.	2	3	4	5	6	7
1.0	2.94	2.63	2.28	3.29	3.50	2.94	2.66	2.47	2.34
1.6	3.18	2.84	2.41	3.68	3.79	3.18	2.88	2.68	2.53

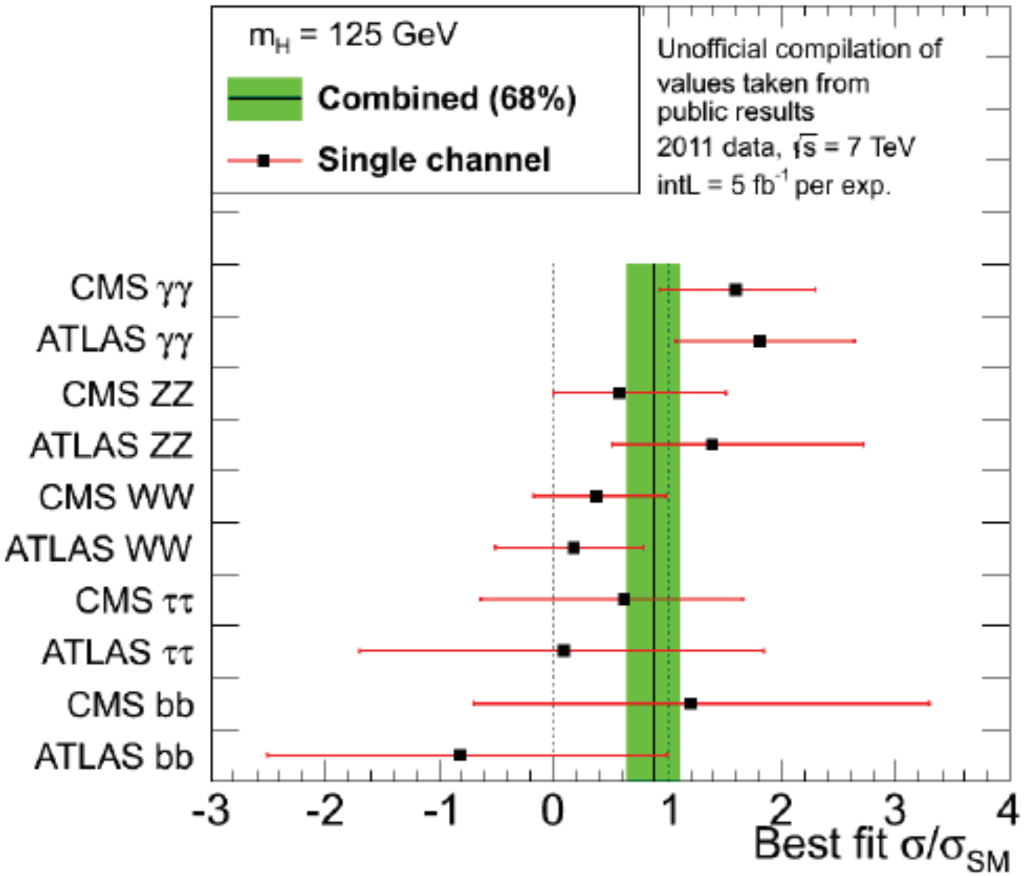
ADD Limit: $M_s > 2.5$-3.8 TeV (HLZ)

So, where is the Higgs Boson?

- The experiments analysed the new data, for the full year of 2011
- They can exclude an even larger range, and restrict the region for the Higgs to 115-130 GeV
- But.. they see a tantalizing excess in the “Higgs” mass range of 120-126 GeV. This is exciting!
- The significance of this excess is still far too low to claim a discovery, but a Higgs signal could just start to be seen just like that. The excess could still go away with more data.
- The LHC 2012 data will be the referee… Increase of factor 4 in the statistics expected

  The Higgs boson could well be showing signs of life already…

Individual Channels: Signal Strength

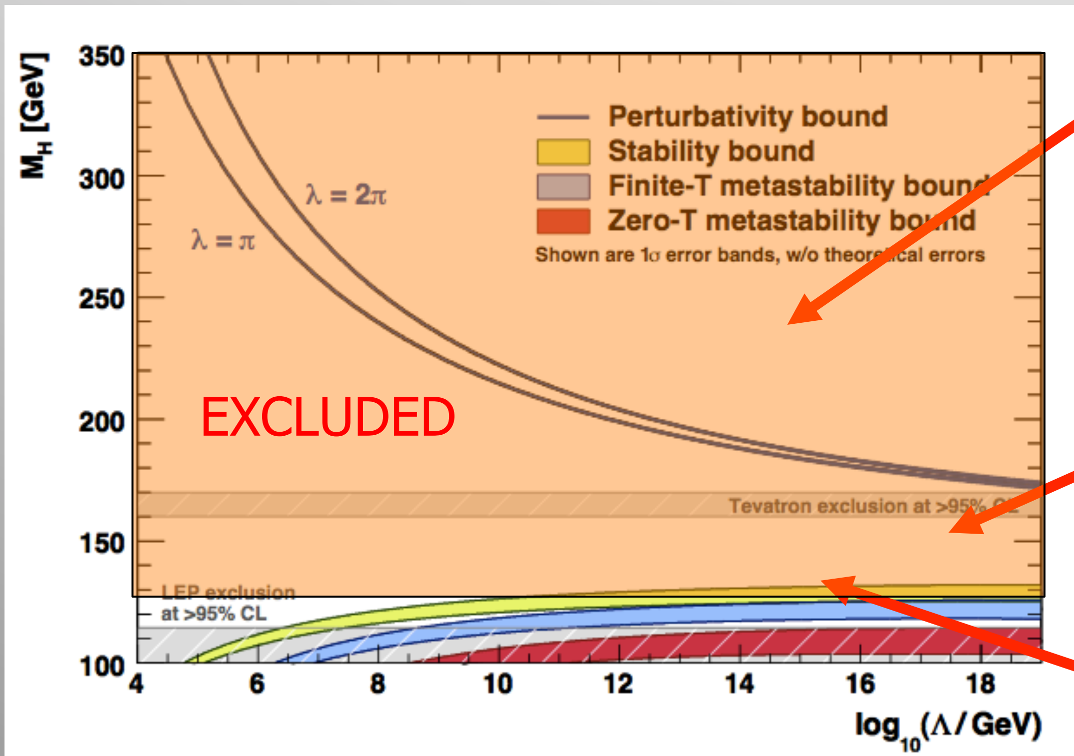


Comparison of channels from ATLAS and CMS for M_H=125 GeV

- The fitted σ of the excess near 125 GeV is consistent with the SM Higgs boson expectation
- More data are needed to investigate this excess

A Light Higgs: Consequences

A light Higgs implies that the Standard Model cannot be stable up to the GUT or Planck scale (10^{19} GeV)



The effective potential blows up, due to heavy top quark mass

Allowed corridor but needs strong fine-tuning…

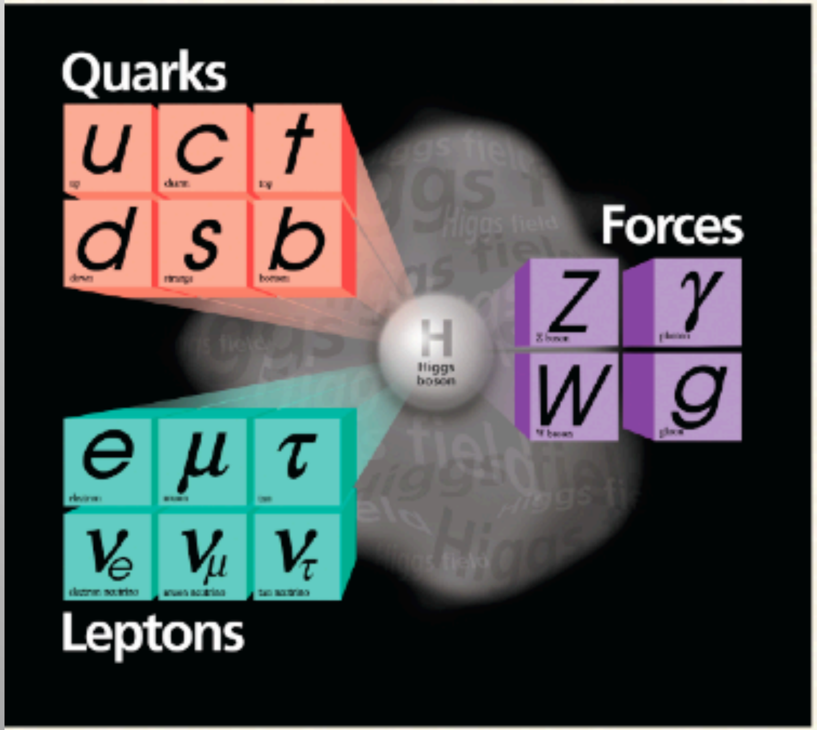
The electroweak vacuum is unstable to corrections from scales $\Lambda >> v= 246$ GeV

J. Ellis et al.

New physics expected in TeV range

Standard Model

Building blocks of the Standard Model



- **Matter**

  Made out of fermions

  (Quarks and Leptons)

- **Forces**

  Electromagnetism, weak and strong force

  + gravity

  (mediated by bosons)

- **Higgs field**

  Needed to break (hide) the electroweak symmetry and to give mass to weak gauge bosons and fermions

→ Higgs particle

Standard Model Problems

Solution to **both** problems:

- create mass via spontaneous breaking of electroweak symmetry

- introduce a scalar particle that regulates the WW scattering amplitude

→ Higgs Mechanism