

# Exotic Charmonium- and Bottomonium-like states



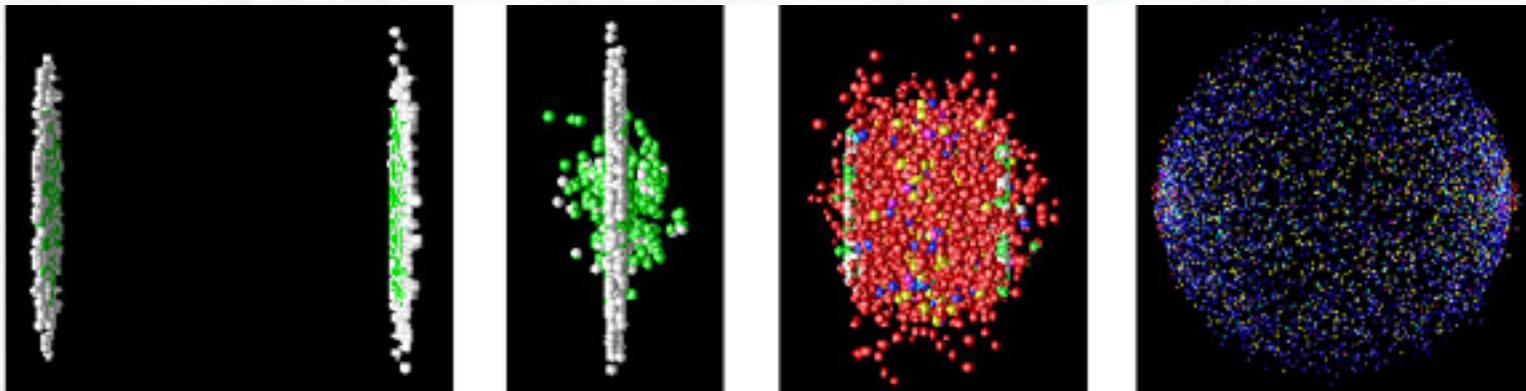
State	Mass (MeV)	Width (MeV)	Decay	Production
$Y_s(2175)$	$2175 \pm 8$	$58 \pm 26$	$\phi f_0$	ISR
$X(3872)$	$3871.84 \pm 0.33$	$< 0.95$	$J/\psi \omega, J/\psi \pi$	B decay
$X(3872)$	$3872.8 + 0.7/-0.6$	$3.9 + 2.8/-1.8$	$D^* D^0, J/\psi \omega$	B decay
$Y(3915)$	$3915 \pm 4$	$17 \pm 10$	$J/\psi \omega$	$\Upsilon \Upsilon$
$Z(3940)$	$3929 \pm 5$	$29 \pm 10$	DD	$\Upsilon \Upsilon$
$X(3940)$	$3942 \pm 9$	$37 \pm 17$	DD*	Double-charm
$Y(3940)$	$3942 \pm 17$	$87 \pm 34$	$J/\psi \omega$	B decay
$Y(4008)$	$4008 + 82/-49$	$226 + 97/-80$	$J/\psi \omega$	ISR
$Z(4051)^*$	$4051 + 24/-43$	$82 + 51/-28$	$\pi \chi_{c1}$	B decay
$X(4160)$	$4156 \pm 29$	$139 + 113/-65$	$D^* D^*$	Double-charm
$Z(4248)^*$	$4248 + 185/-45$	$177 + 320/-72$	$\pi \chi_{c1}$	B decay
$Y(4260)$	$4264 \pm 12$	$83 \pm 22$	$J/\psi \omega$	ISR
$X(4350)$	$4350 + 4.7/-5.1$	$13 + 18/-14$	$J/\psi \phi$	$\Upsilon \Upsilon$
$Y(4350)$	$4361 \pm 13$	$74 \pm 18$	$\psi' \pi \pi$	ISR
$Z(4430)^*$	$4433 \pm 5$	$45 + 35/-18$	$\psi' \pi$	B decay
$Y(4660)$	$4664 \pm 12$	$48 \pm 15$	$\psi' \pi \pi$	ISR
$Y_b(10890)$	$10889.6 \pm 2.3$	$54.7 + 8.9/-7.6$	$\pi \pi \Upsilon(nS)$	$e^+e^-$ annihilation
$Z_b(10610)$	$10608.4 \pm 2.0$	$15.6 \pm 2.5$	$(\Upsilon(nS) \text{ or } h_b) \pi$	$\Upsilon(5S) / \Upsilon_b$ decay
$Z_b(10650)$	$10653.2 \pm 1.5$	$14.4 \pm 3.2$	$(\Upsilon(nS) \text{ or } h_b) \pi$	$\Upsilon(5S) / \Upsilon_b$ decay

- Many new states (X,Y,Z) discovered at high-lumi  $e^+e^-$  B-factories
- Detailed investigations ongoing to clarify the nature of these states (more data needed for solid determination of spin, parity and decay modes)

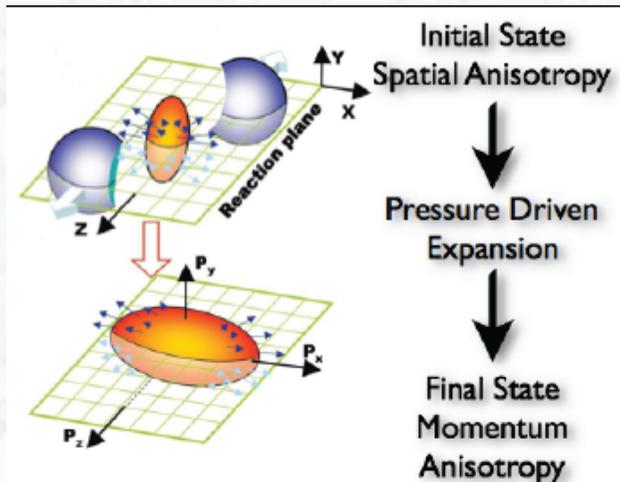
# Heavy Ions

- Experiments at the RHIC collider have established a “New State of Matter”
- The matter
  - shows a hydro-dynamical behaviour (like a nearly ideal fluid)
  - opaque to coloured partons,
  - transparent to el.magnetic and weakly interacting particles
- The LHC experiments ALICE, ATLAS and CMS have impressively confirmed the properties seen at RHIC in the first heavy ion runs in 2010/11;

Impressive results on “jet quenching” right after first collisions

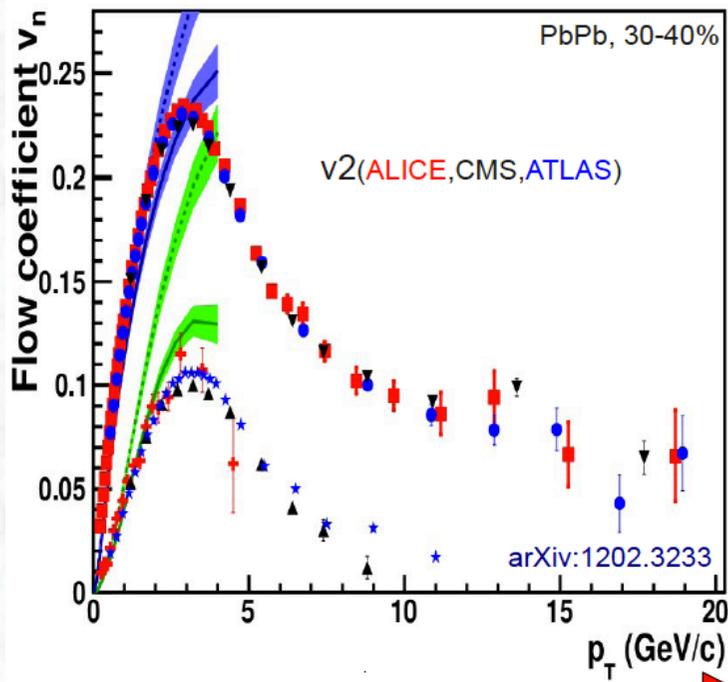


# Flow Measurements:



$$E \frac{d^3 N}{d^3 p} = \frac{1}{2\pi} \frac{d^2 N}{p_T dp_T dy} \left( 1 + \sum_{n=1}^{\infty} 2v_n \cos [n (\varphi - \Psi_R)] \right)$$

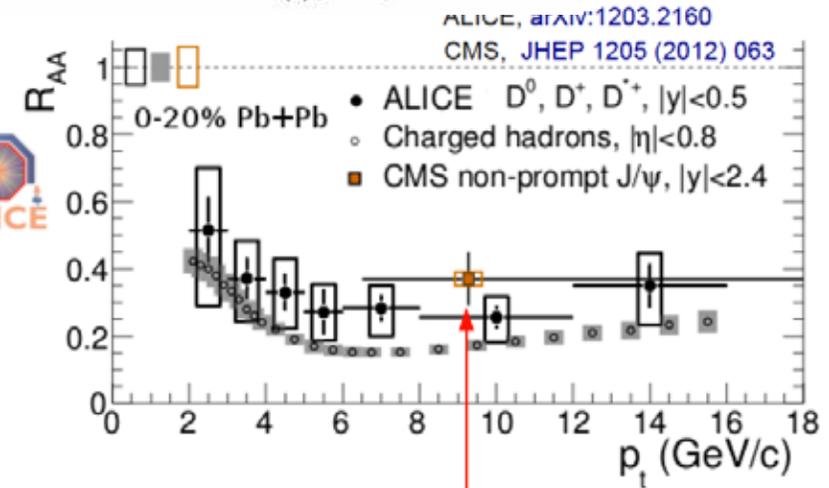
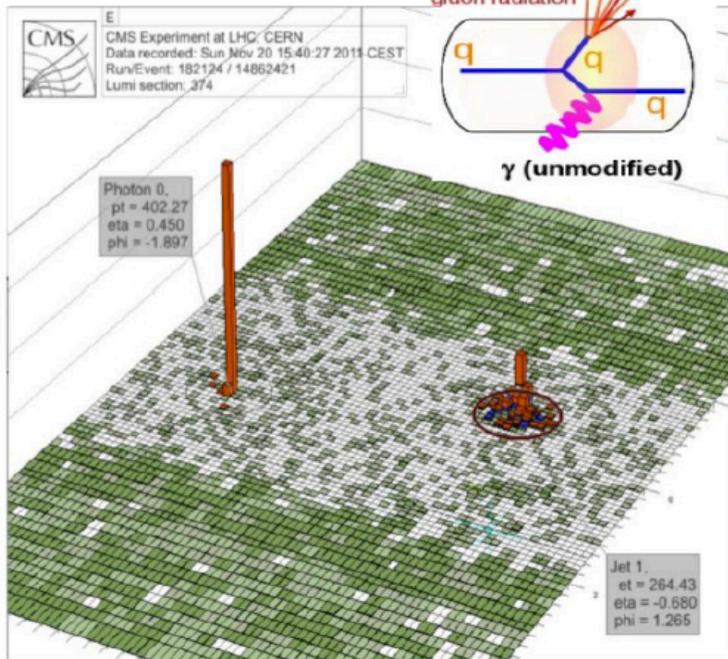
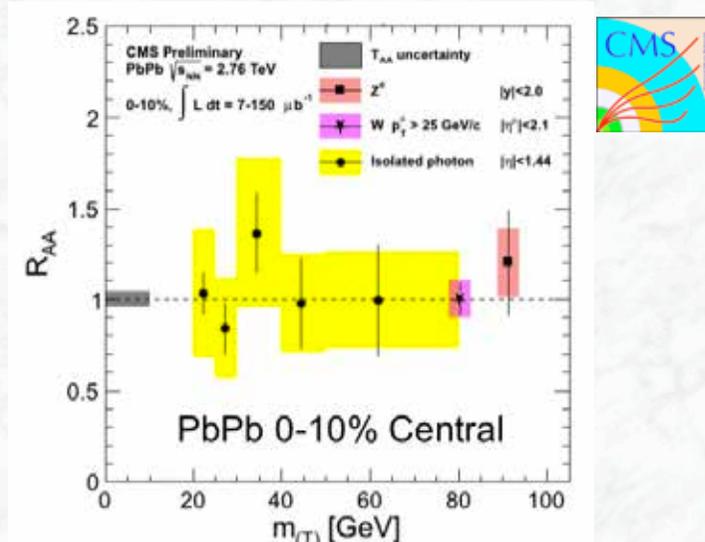
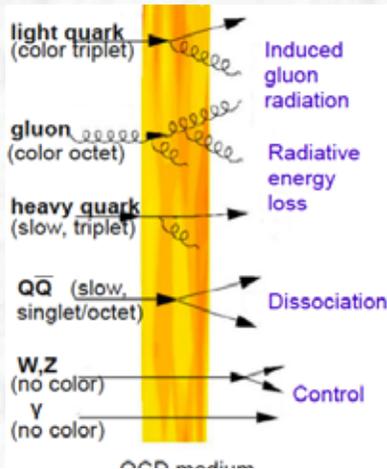
$\Psi_R$  : angle of reaction plane  
 $v_2$  : known as elliptic flow



- LHC measurements confirm the hydrodynamical behaviour;  
 $v_2(p_T)_{\text{LHC}} \approx v_2(p_T)_{\text{RHIC}}$
- Low viscosity, nearly a perfect liquid
- Measurements extended to high  $p_T$
- Flow measured for identified hadrons, including D mesons

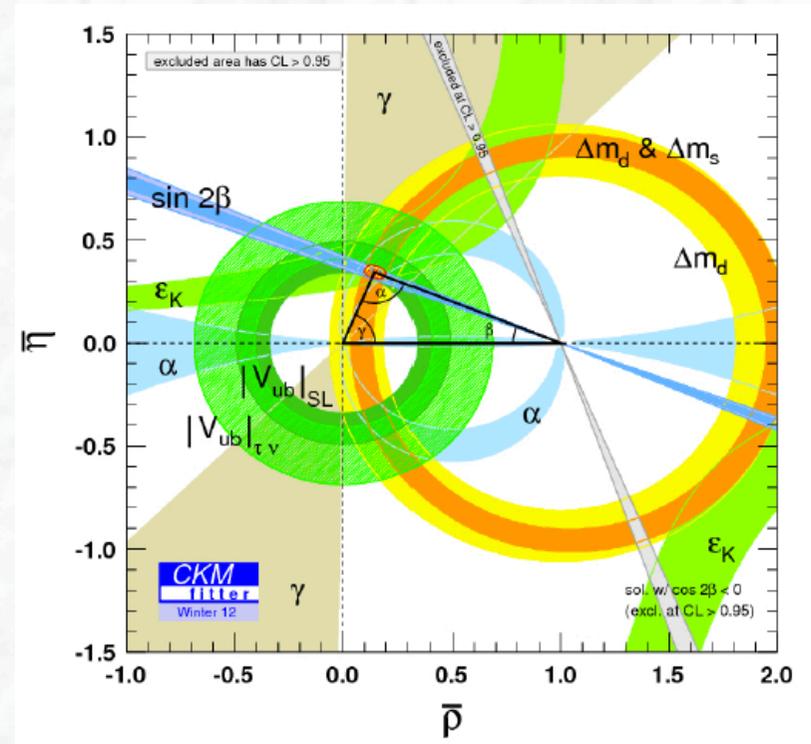
# Matter effects, jet quenching:

$$R_{AA}(p_T) = \frac{1}{N_{\text{coll}}} \times \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T} = \frac{dN_{AA}/dp_T}{T_{AA} d\sigma_{pp}}$$



- Expected behaviour seen (hadrons, jets, photons, W and Z particles)
- Heavy mesons/quarks are less suppressed

# B physics



“Early hints of news from “Beyond the Standard Model” physics may come from “beautiful” flavour physics  
(P. Jenni, PLHC Summary DESY-2010)

# Highlights from LHCb and other Flavour Experiments:

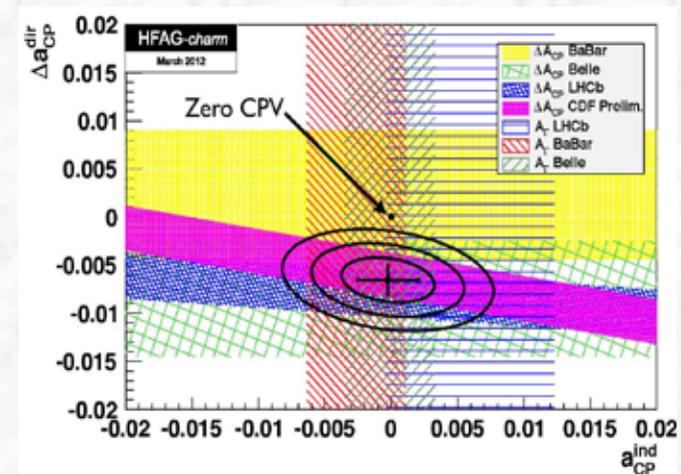
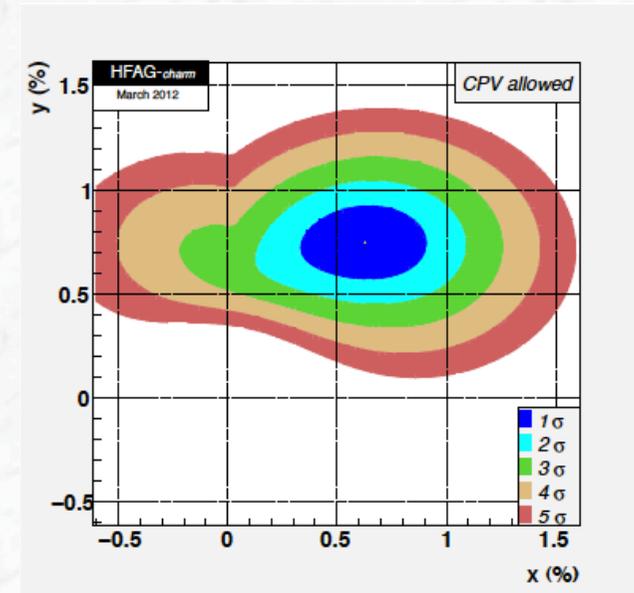
## Lot of impressive results

- Charm mixing has been well established (combination of many experiments)
- Large CP violation effects emerge in the charm system (larger than expected)

LHCb measures difference in CP asymmetry for  $D^0 \rightarrow K^+K^-$  and  $D^0 \rightarrow \pi^+\pi^-$

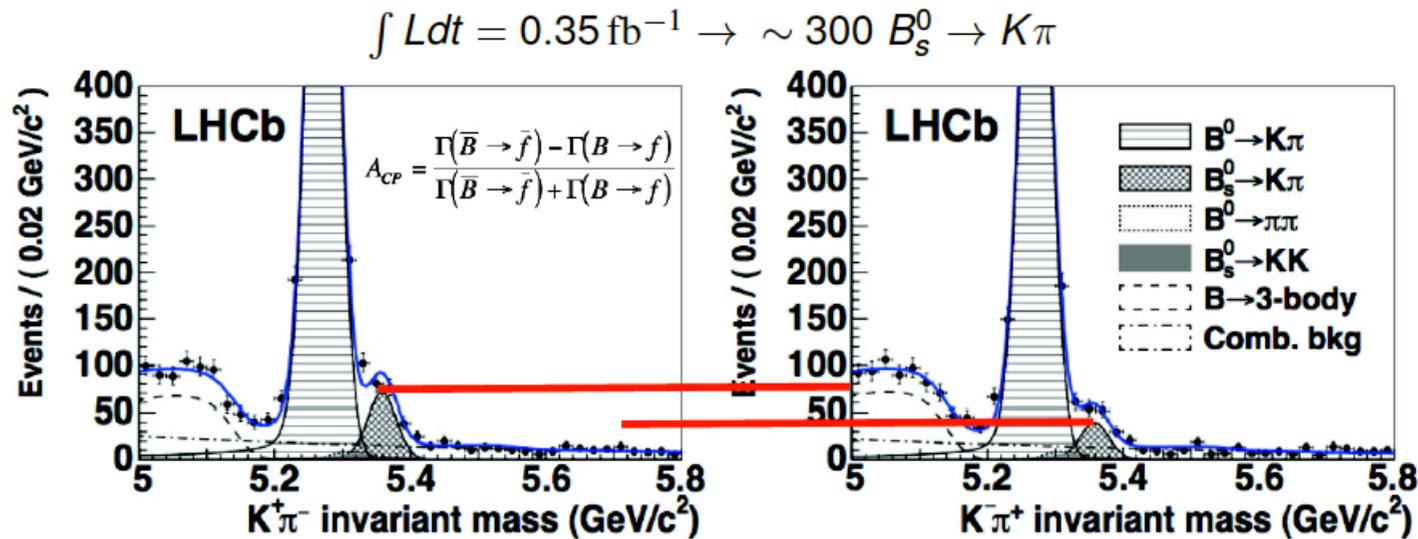
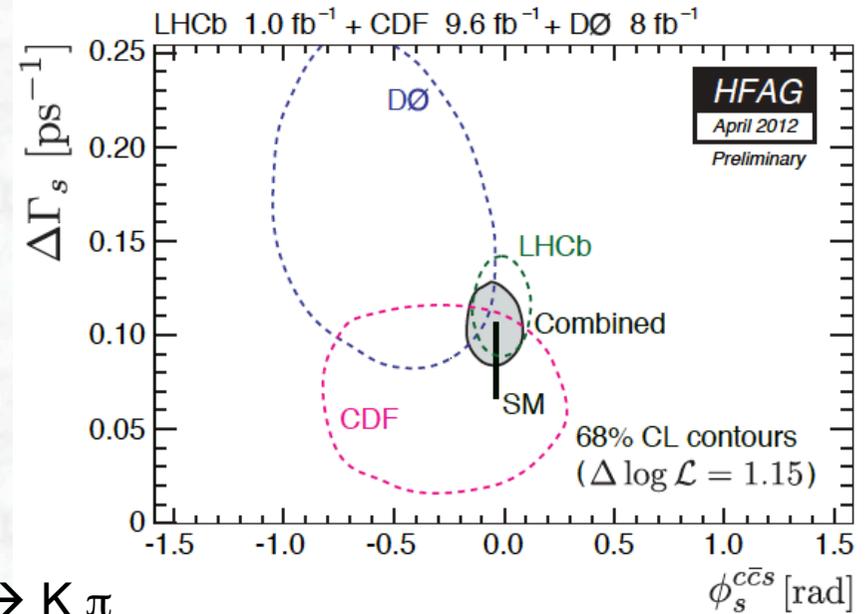
Zero CP violation is excluded at the  $3.5\sigma$  level (LHCb only)

Theoretical work needed and ongoing to disentangle possible new physics effects from SM hadronic effects.



# CP violation in B decays

- Precise measurement of CP phase  $\phi_s$  :  
LHCb result consistent with Standard Model
- First significant direct measurement of  
 $\Delta\Gamma_s = 0.116 \pm 0.018 \pm 0.006 \text{ ps}^{-1}$
- First evidence for direct CP violation in  $B_0^s \rightarrow K\pi$



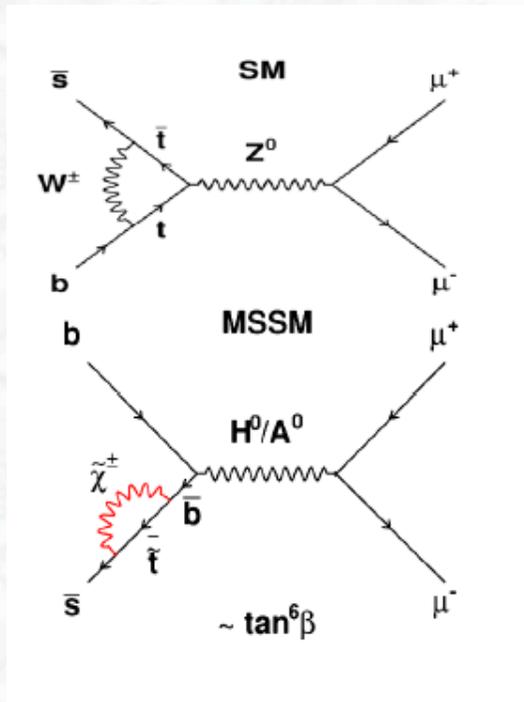
LHCb:  $A_{CP}(B_s^0 \rightarrow K\pi) = 0.27 \pm 0.08(\text{stat}) \pm 0.02(\text{syst})$

CDF:  $A_{CP}(B_s^0 \rightarrow K\pi) = 0.39 \pm 0.15(\text{stat}) \pm 0.08(\text{syst})$

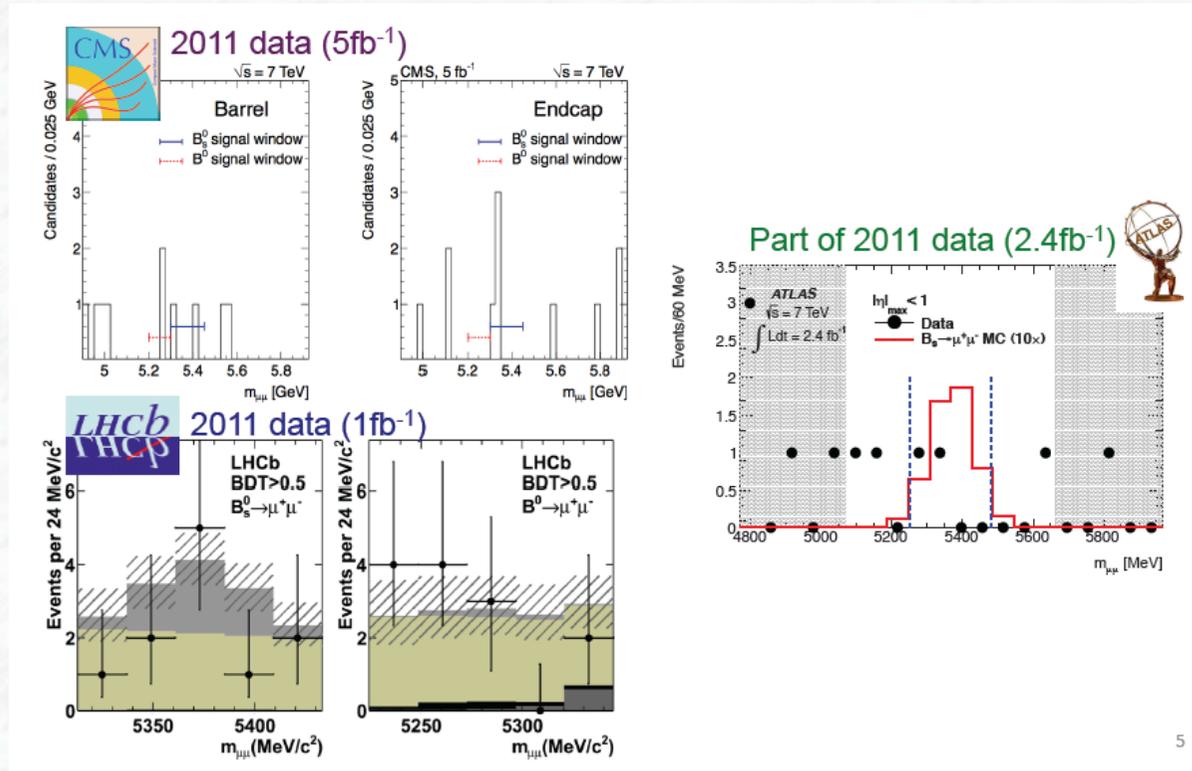


# Search for the decays $B_0 \rightarrow \mu^+\mu^-$ and $B_0^s \rightarrow \mu^+\mu^-$

The motivation:

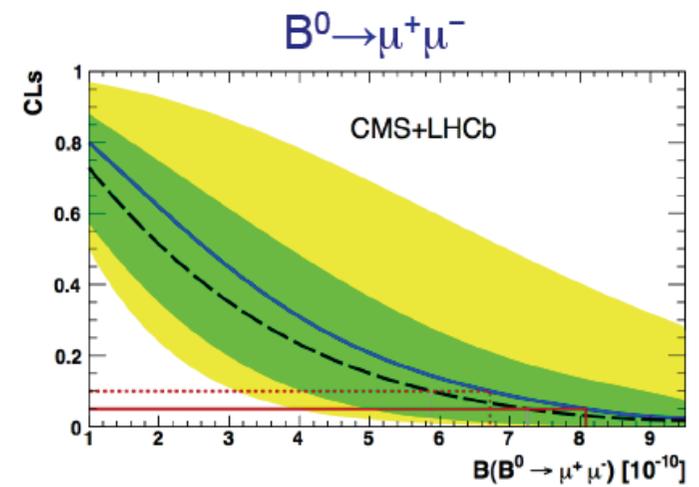
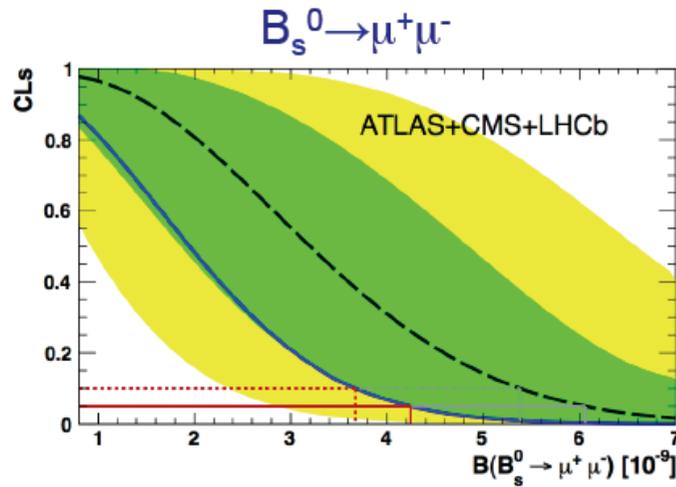
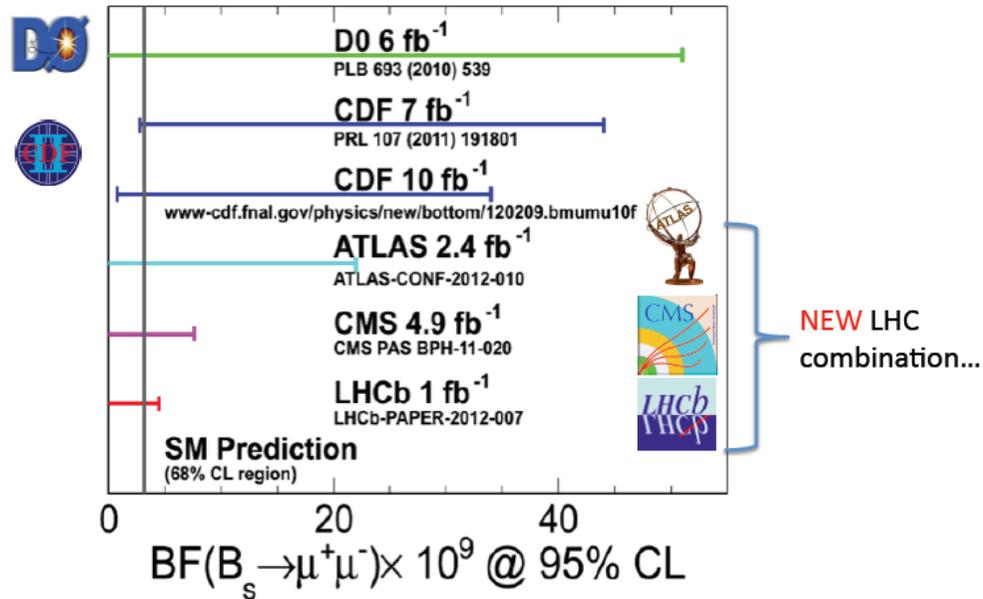


The data:



$$B(B_s^0 \rightarrow \mu^+\mu^-) = 1.1 \times (3.2 \pm 0.2) \times 10^{-9}$$

# The limits:



$B(B_s^0 \rightarrow \mu\mu) < (3.7 (4.2)) \times 10^{-9}$  at 90(95) % C.L.

- Excess over background at  $\sim 2\sigma$  level ( $1-CL_b$  (p-value)=5%)
- Compatible with SM at  $1\sigma$  ( $1-CL_{s+b}$ =84%)

$B(B^0 \rightarrow \mu\mu) < (0.67 (0.81)) \times 10^{-9}$  at 90(95) % C.L.

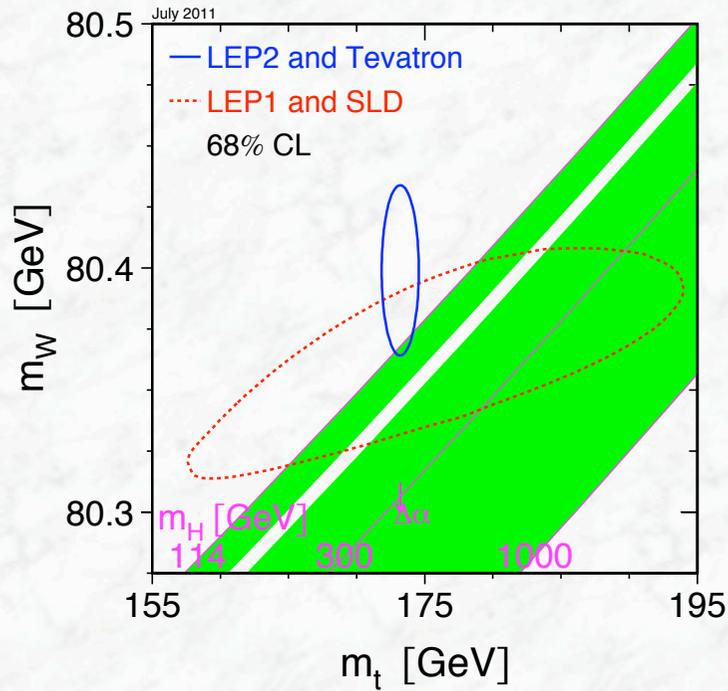
## My summary on B physics

- Beautiful results are coming out !
- LHCb has taken a leading role in many areas, but Tevatron is still nicely in the game
- $e^+e^-$  machines complementary ( $\tau$  decays)
- LHCb appears as an “Anomaly terminator”  
( $\phi_s$ , BR ( $B_s \rightarrow \mu \mu$ ) approaching Standard Model prediction)
- Some remaining “tensions”:
  - large CP violation in charm  $\rightarrow$  LHCb, Theory
  - $\sin 2\beta$  vs. BR ( $B \rightarrow \tau \nu$ )  $\rightarrow$  BELLE
  - Asymmetry in semileptonic B decays from D0  $\rightarrow$  CDF, D0

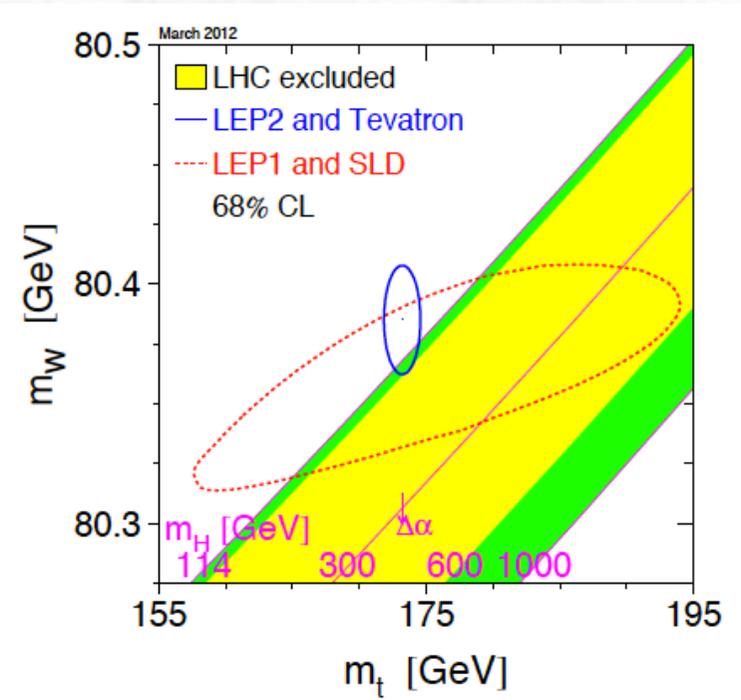


G. Dissertori, Moriond

# V. Electroweak parameter



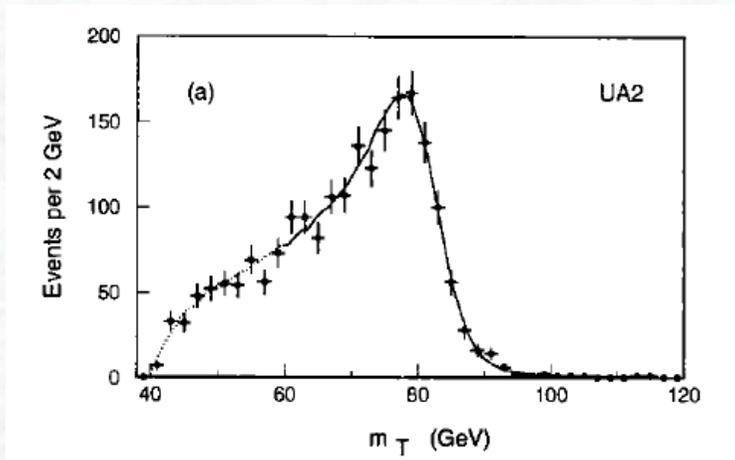
July 2011



today

# W mass measurements

## The beginning



$$m_W = 80.35 \pm 0.33 \pm 0.17 \text{ GeV}$$

W MASS

For each value of  $M_W$  generate  $dn/dp_T^e d\theta_e$  using  
 parametrisation of  $p_L^W$  from Glück et al.  
 - - -  $p_T^W$  from Halzen et al.

V-A production and decay  
 $\Gamma(W) = 3 \text{ GeV}$

Maximum likelihood for events with  $p_T^e > 25$ :

$$M_W = 82.5 \pm 1.5 \pm 1.3 \text{ GeV}/c^2$$

Same result from fit to  $M_T$ -dist  
 for events with  $p_T^W < 5 \text{ GeV}/c$ :

$$M_T = (2 p_T^e p_T^v (1 - \cos \Delta\phi))^{1/2}$$

generated with  $M_W = 82.5 \text{ GeV}$

D. Froidevaux, Blois 2012

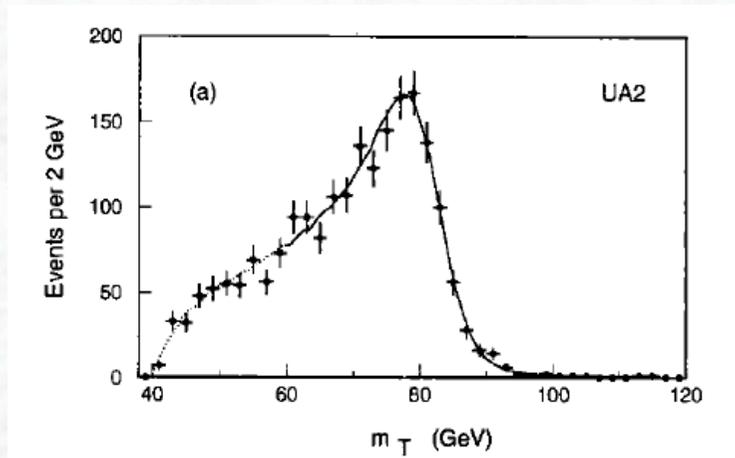
# W mass measurements

The beginning

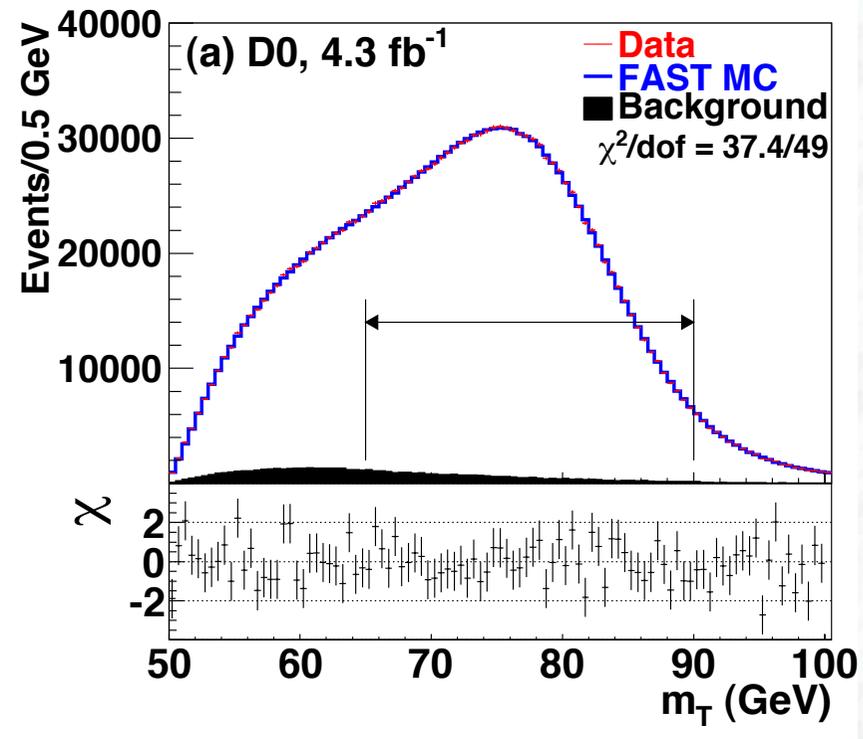


State of the art, today

1.68 M events, electrons  $|\eta| < 1.05$



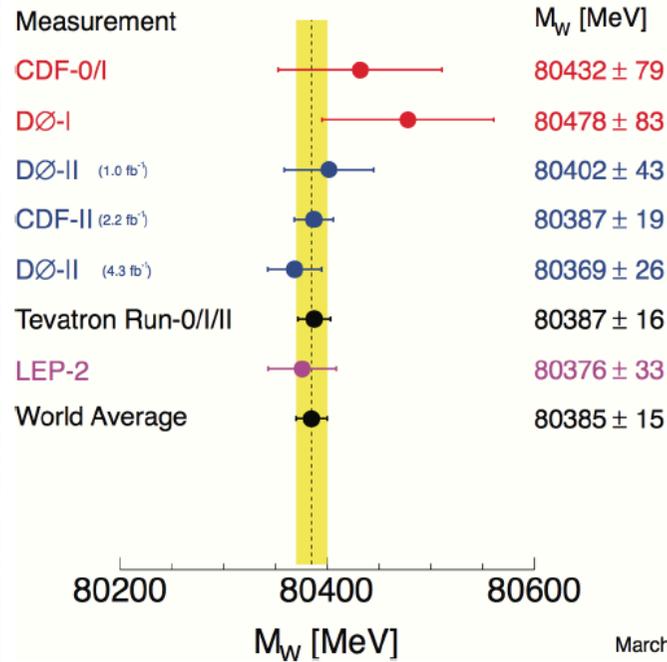
$$m_W = 80.35 \pm 0.33 \pm 0.17 \text{ GeV}$$



$$m_W = 80.371 \pm 0.013 \text{ (stat.) GeV}$$



### Mass of the W Boson



### Systematic uncertainties:

#### New CDF Result (2.2 fb<sup>-1</sup>) Transverse Mass Fit Uncertainties (MeV)

	<i>electrons</i>	<i>muons</i>	<i>common</i>
W statistics	19	16	0
Lepton energy scale	10	7	5
Lepton resolution	4	1	0
Recoil energy scale	5	5	5
Recoil energy resolution	7	7	7
Selection bias	0	0	0
Lepton removal	3	2	2
Backgrounds	4	3	0
pT(W) model	3	3	3
Parton dist. Functions	10	10	10
QED rad. Corrections	4	4	4
Total systematic	18	16	15
Total	26	23	

Can the LHC improve on this?

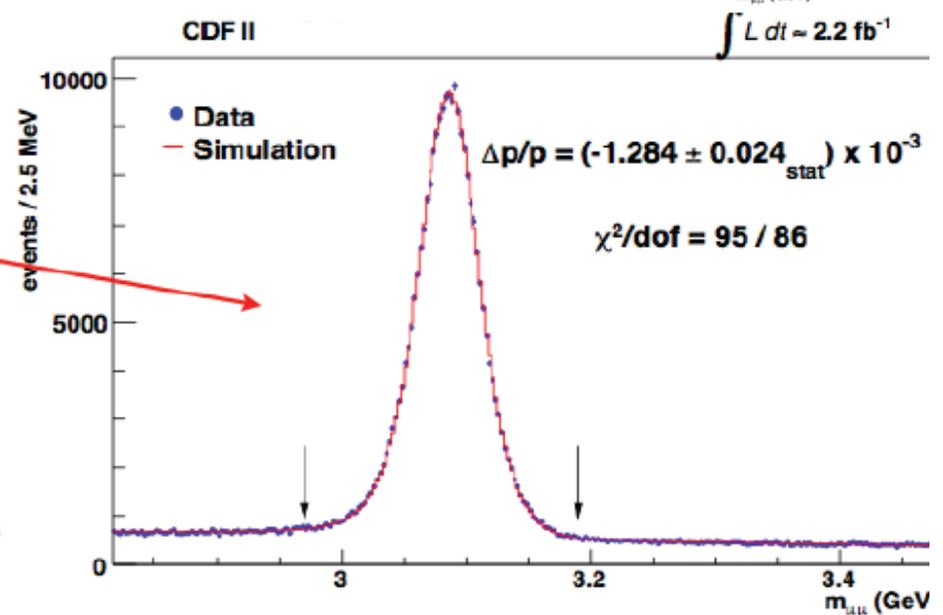
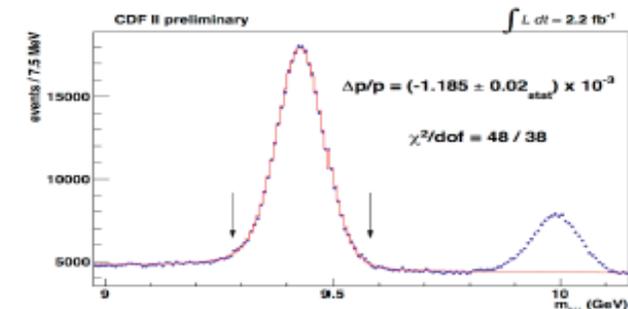
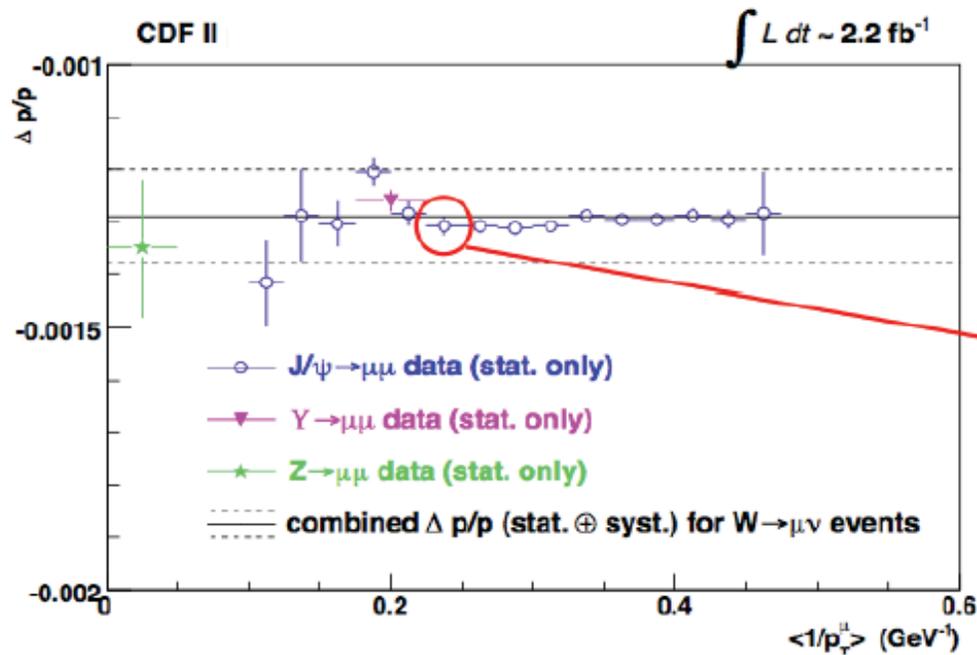
In principle yes, but probably not soon .and. not with 30 pileup events

- Very challenging (e-scale, hadronic recoil,  $p_T(W)$ ,... )
- However there is potential for reduction of uncertainties
  - statistics
  - statistically limited systematic uncertainties (marked in green above)
  - pdfs, energy scale, ....., recoil(?)

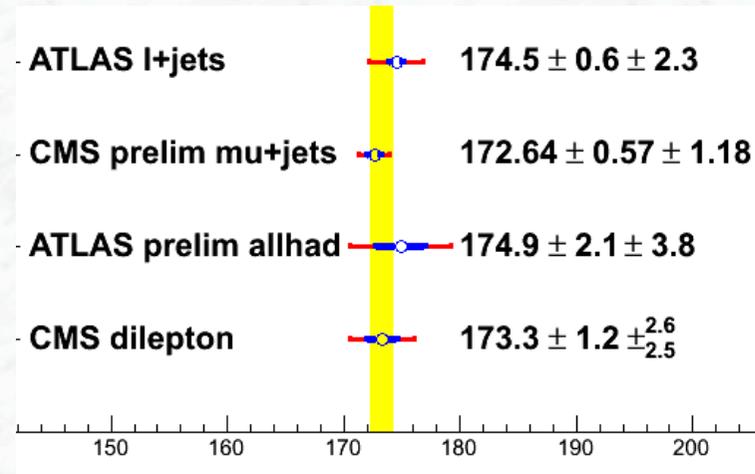
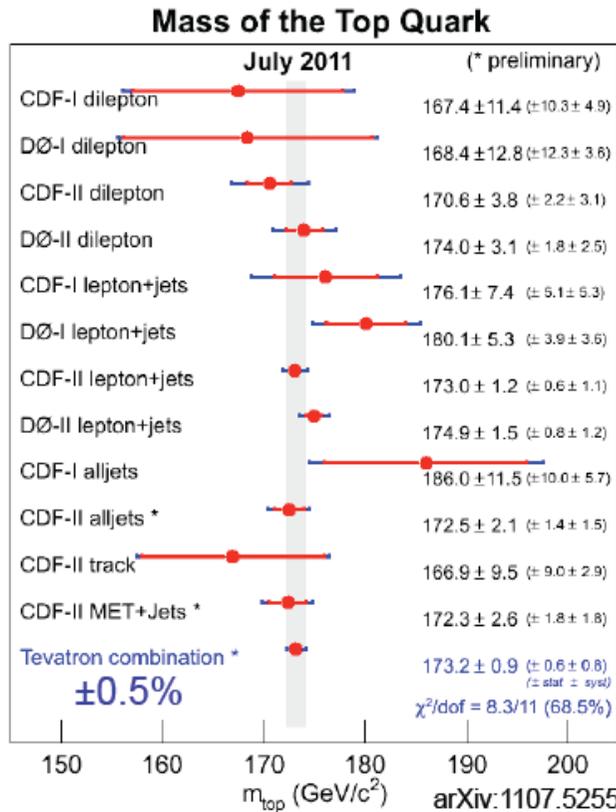
# Momentum Scale Calibration



- “Back bone” of CDF analysis is track  $p_T$  measurement in drift chamber (COT)
- Perform alignment using cosmic ray data:  $\sim 50\mu\text{m} \rightarrow \sim 5\mu\text{m}$  residual
- Calibrate momentum scale using samples of dimuon resonances ( $J/\psi$ ,  $Y$ ,  $Z$ )
  - Span a large range of  $p_T$
  - Flatness is a test of  $dE/dx$  modeling
- Final scale error of  $9 \times 10^{-5}$ :  $\Delta m_W = 7 \text{ MeV}$



# Top quark mass

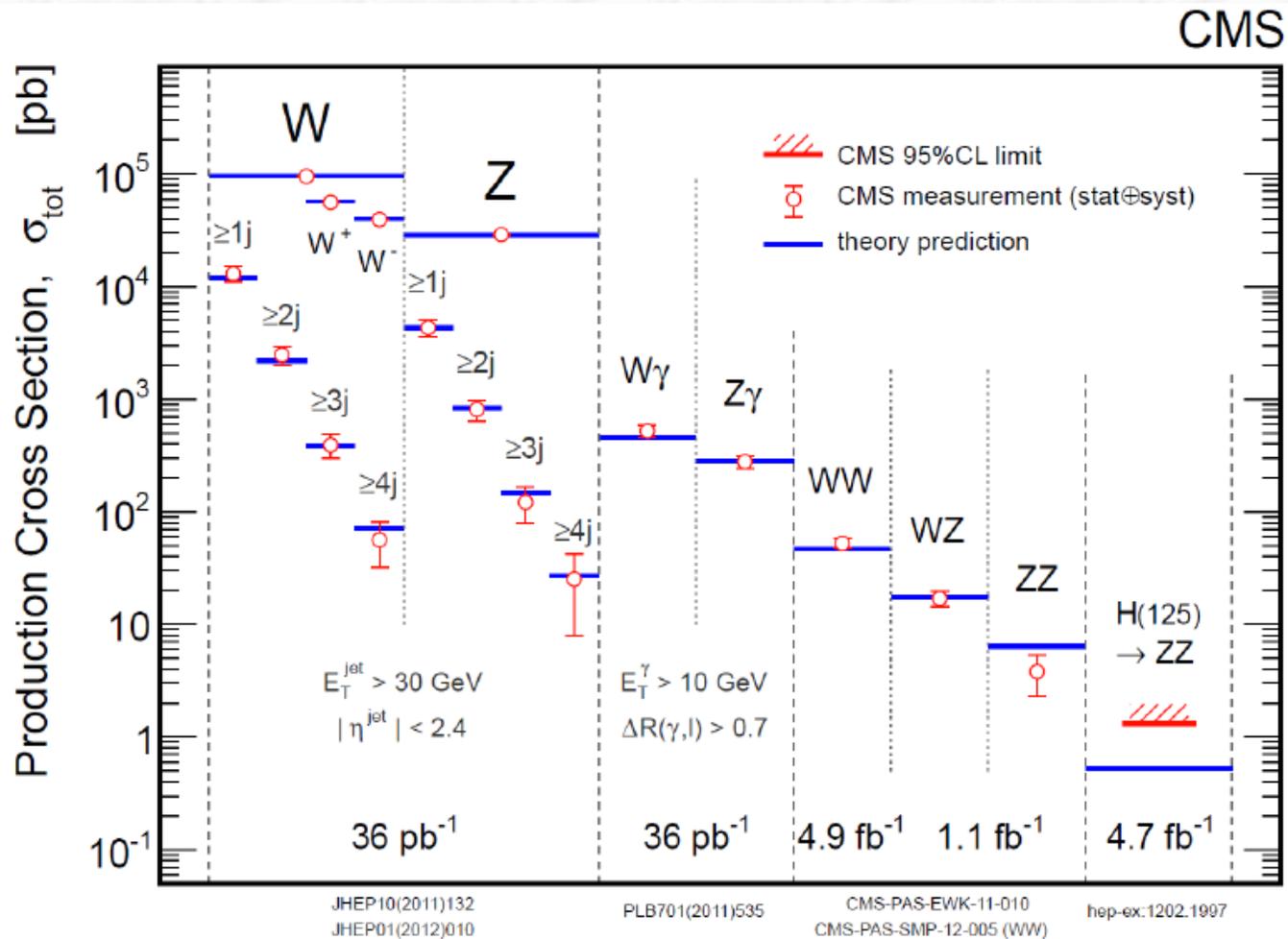


without uncertainties due to underlying event and colour reconnection

- Still dominated by the Tevatron experiments
- However, first competitive LHC results appear; CMS measurement in (l-jet)-channel claims a precision of 1.2 GeV;

Uncertainties need to be analyzed / understood

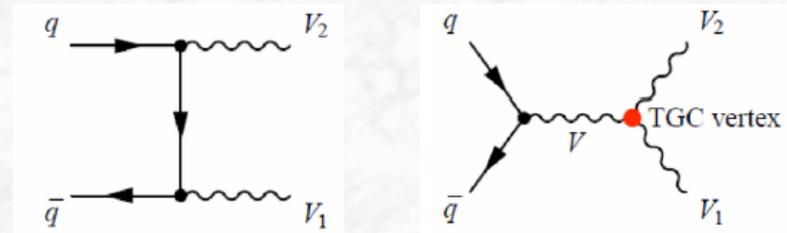
# Di-boson production: $W\gamma$ , $WW$ , $WZ$ , $ZZ$



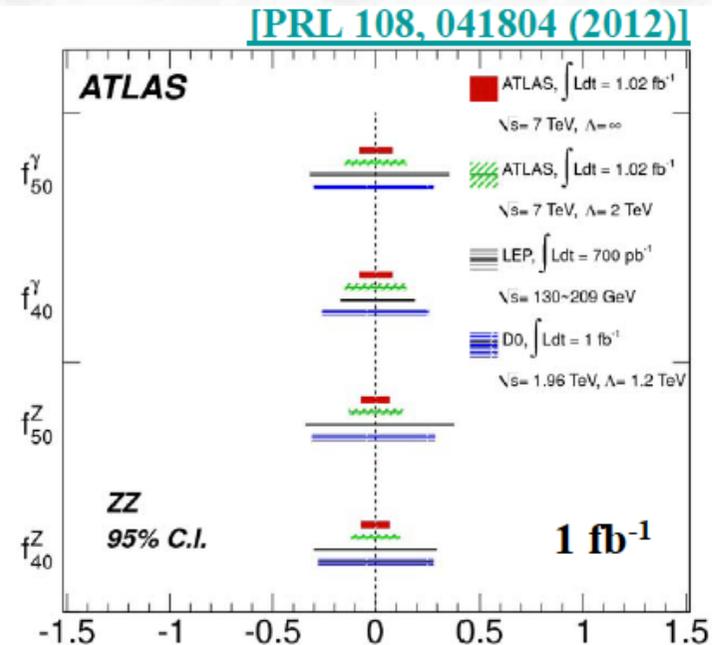
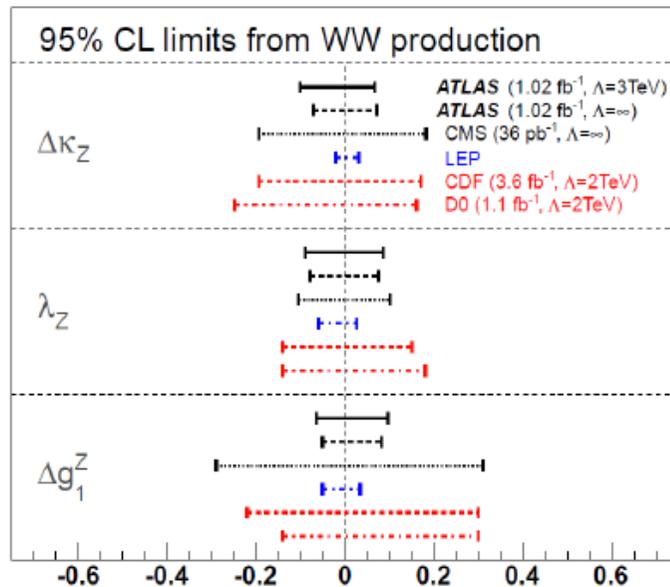
- All di-boson processes have been measured by both ATLAS and CMS
- Good agreement with expected Standard Model cross sections

# → Constraints on anomalous Triple Gauge Couplings

Coupling	Parameters	Channel
WW $\gamma$	$\lambda_\gamma, \Delta\kappa_\gamma$	WW, W $\gamma$
WWZ	$\lambda_Z, \Delta\kappa_Z, \Delta g_1^Z$	WW, WZ
ZZ $\gamma$	$h_3^Z, h_4^Z$	Z $\gamma$
Z $\gamma\gamma$	$h_3^\gamma, h_4^\gamma$	Z $\gamma$
ZZZ	$f_{40}^Z, f_{50}^Z$	ZZ
Z $\gamma$ Z	$f_{40}^\gamma, f_{50}^\gamma$	ZZ



- Anomalous coupling modify production rates (cross sections) and kinematics
- So far, limits extracted from production cross sections
- Start to be competitive with limits from LEP and Tevatron (process dependent)



## Some numerology:

Frequently mentioned numbers at this conference ?

125

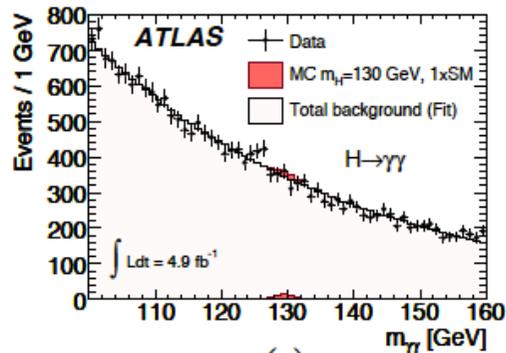
95

$3 \cdot 10^{-9}$

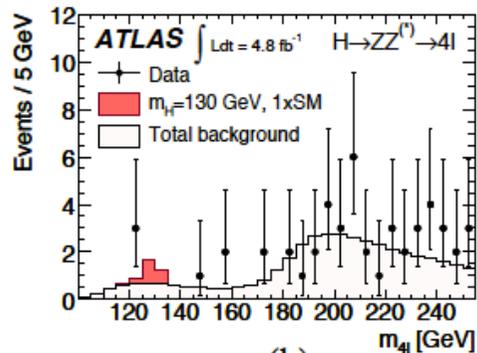
# Where is the Higgs boson ?



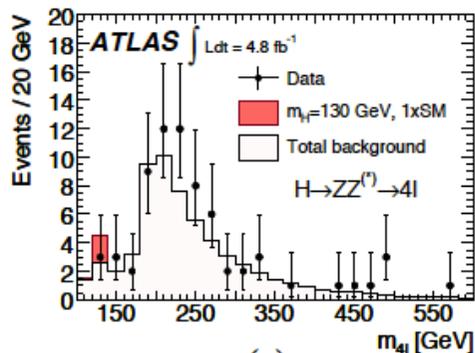
- The Higgs boson has been searched for in both experiments, ATLAS and CMS, in a large mass range and in many channels
- Example: Some ATLAS search channels



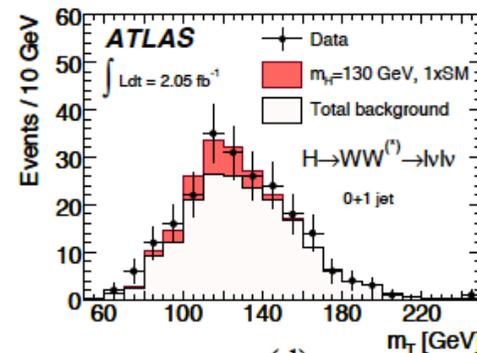
(a)



(b)



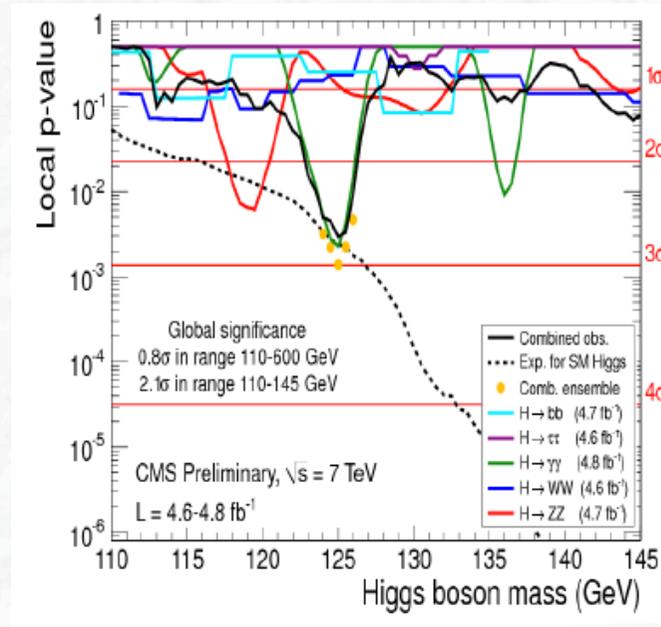
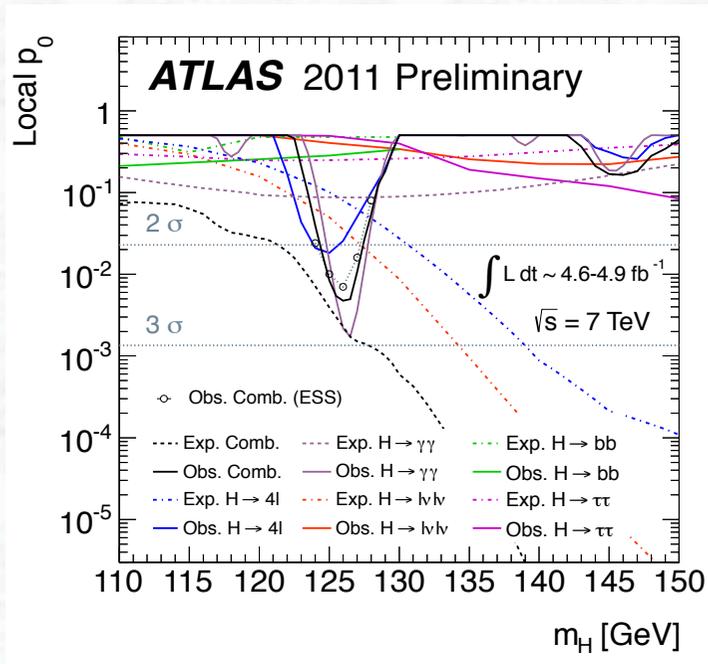
(c)



(d)

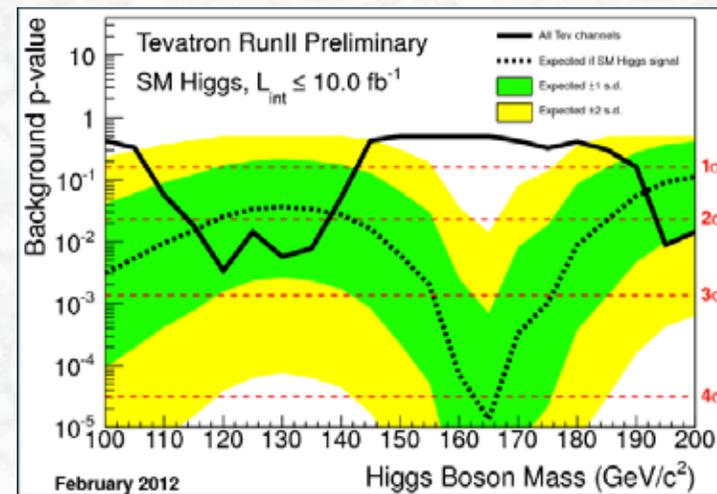
- Data are largely consistent with the expectations from Standard Model background processes ...  
 use statistical methods to quantify this statement

# Compatibility with the background-only hypothesis

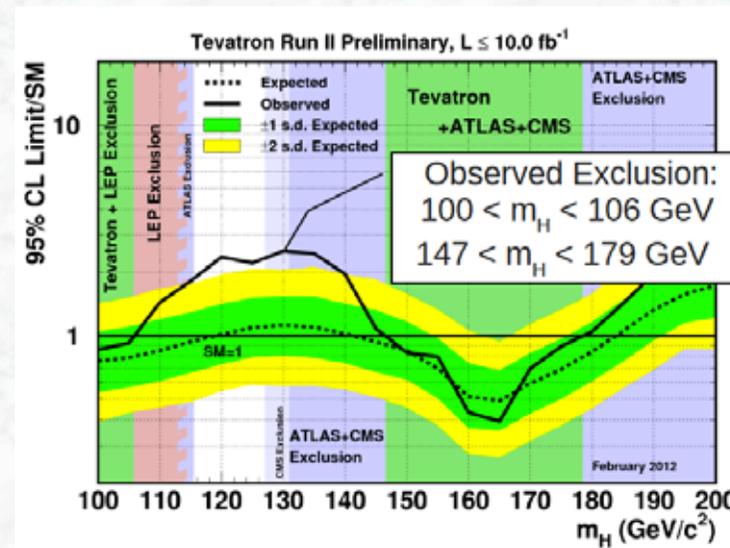
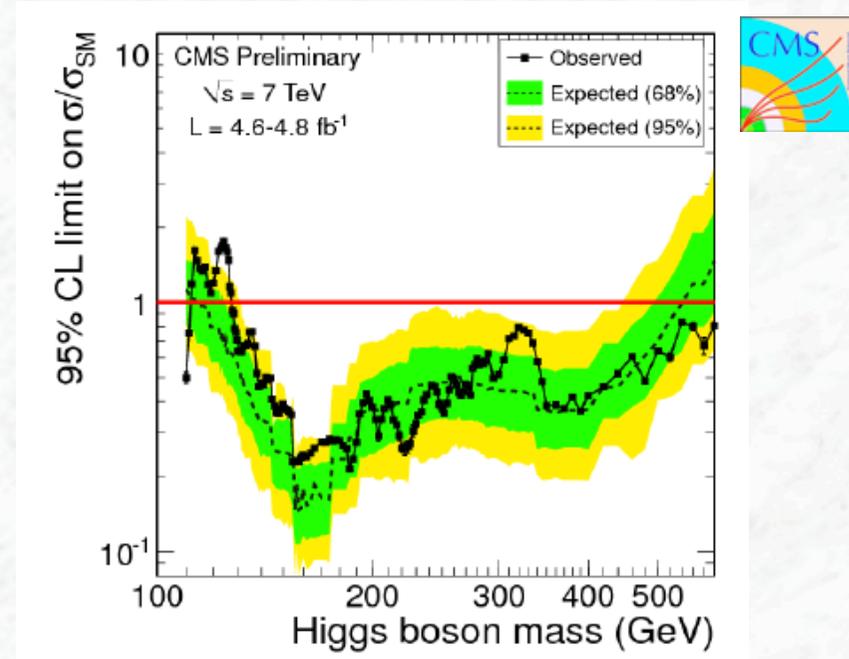
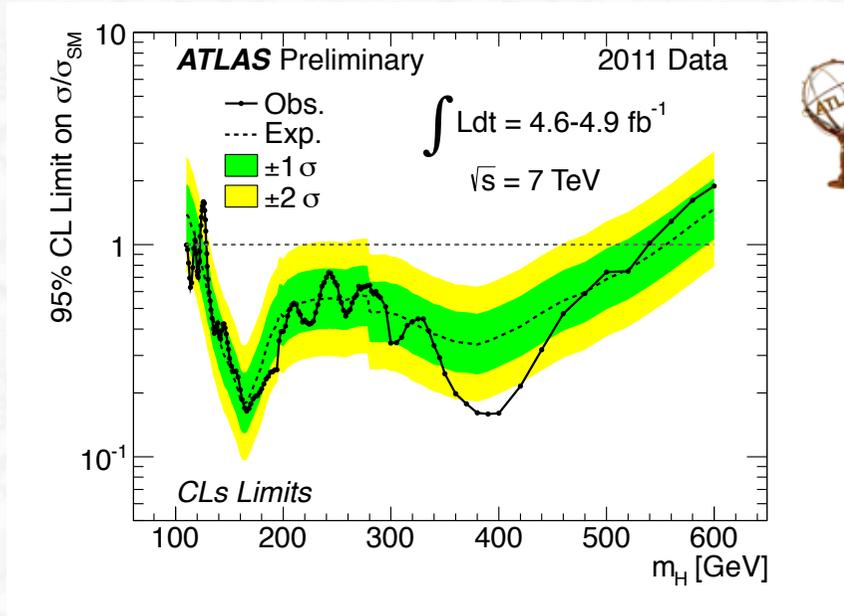


## Comments:

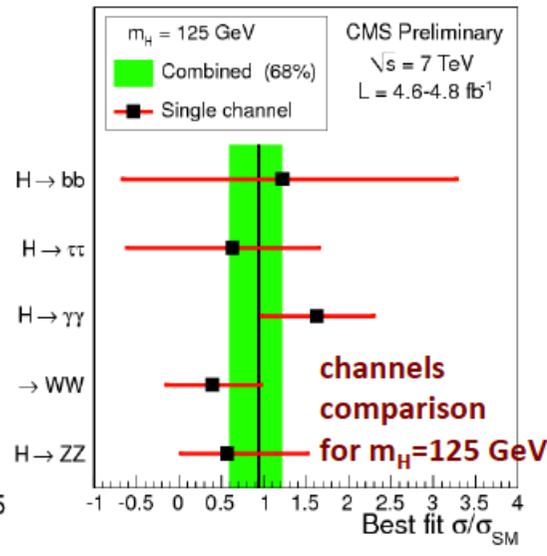
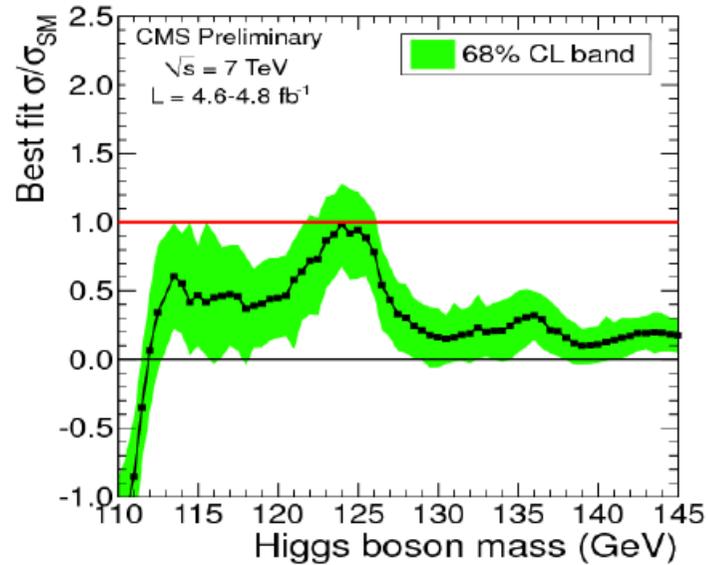
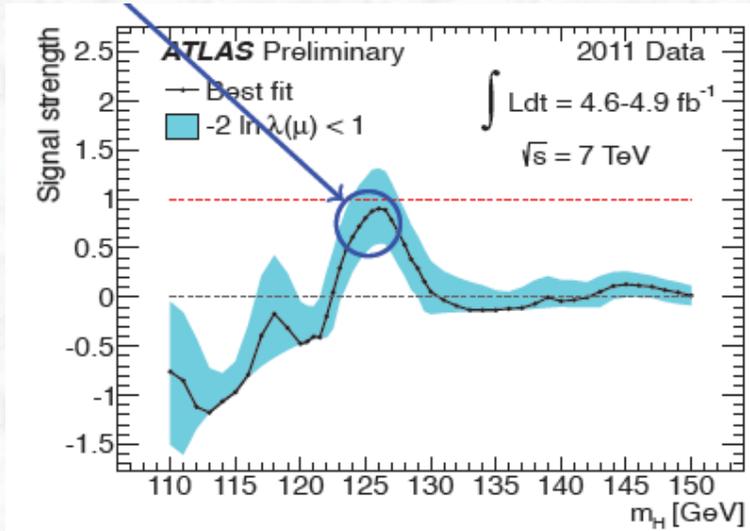
- ATLAS: low  $p_0$  value around 126 GeV driven by  $\gamma\gamma$  and ZZ channels
- CMS:  $\gamma\gamma$  channel is dominant
- $WW \rightarrow l\nu l\nu$  contributes little in both experiments



# Exclusion limits on Higgs boson cross sections



# Fitted signal strength



My personal comments:

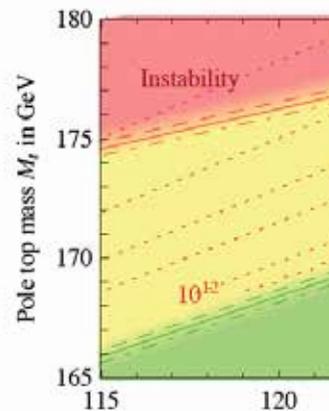
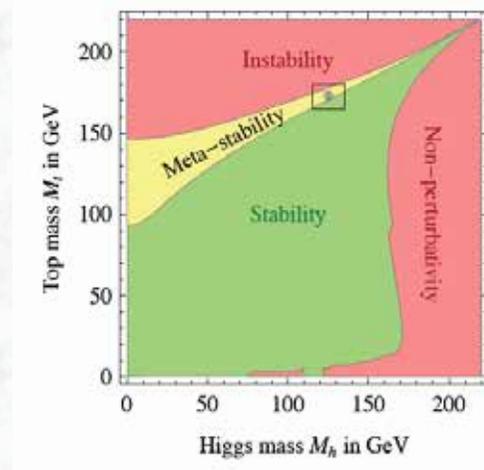
- It is impressive to see what Higgs boson mass range the LHC experiments were able to explore after just two years of running !!

Many beloved plots (blue-band,  $m_W$  vs.  $m_t$ ) have drastically changed

- But: the Higgs boson has not yet been discovered !

[ For many many theorists it seems obvious that  $m_H = 125$  GeV ]

*Due to  $m_H = 125$  the fate of the universe now seems to depend critically on the top mass and 1 GeV can make an enormous difference*



beware !

H. Murayama, Blois 12



Picked up for you in the parallel sessions:

still early... lets not get carried away

J. Galloway



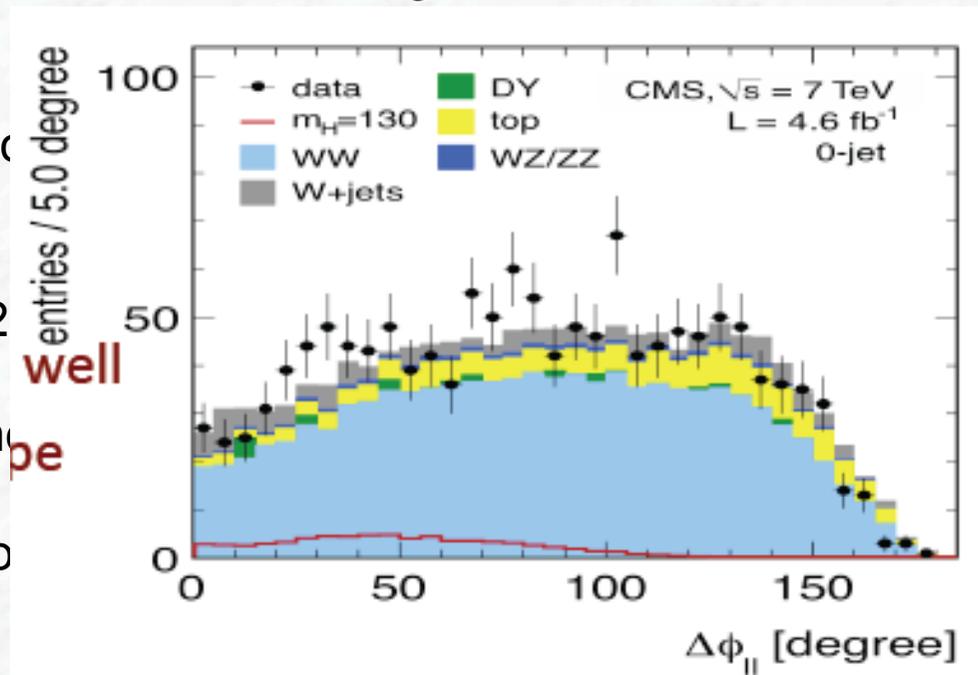
A. Martin

My personal comments (part II, more positive):

- The two experiments have sensitivity to exclude the existence of the SM Higgs boson over the entire mass range [114 – 600 GeV]
- But they don't ! .... and leave the same mass window open !
- There are interesting events in both experiments in the high resolution  $\gamma\gamma$  and  $ZZ^*$  channels;

but the significances are low (in particular after correcting for the famous “look-elsewhere effect”)

- The WW channel does not seem to be the most sensitive channel in the ATLAS experiment  
 But: - this is a challenging channel  
 - this channel is not made for 12 TeV
- More data and careful analyses are needed
- $\tau\tau$  and  $bb$  decay modes will come into play (challenging as well)

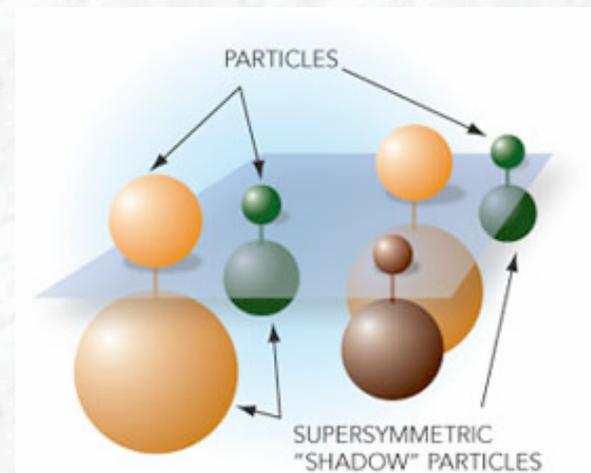


# Searches for

## Physics Beyond the Standard Model

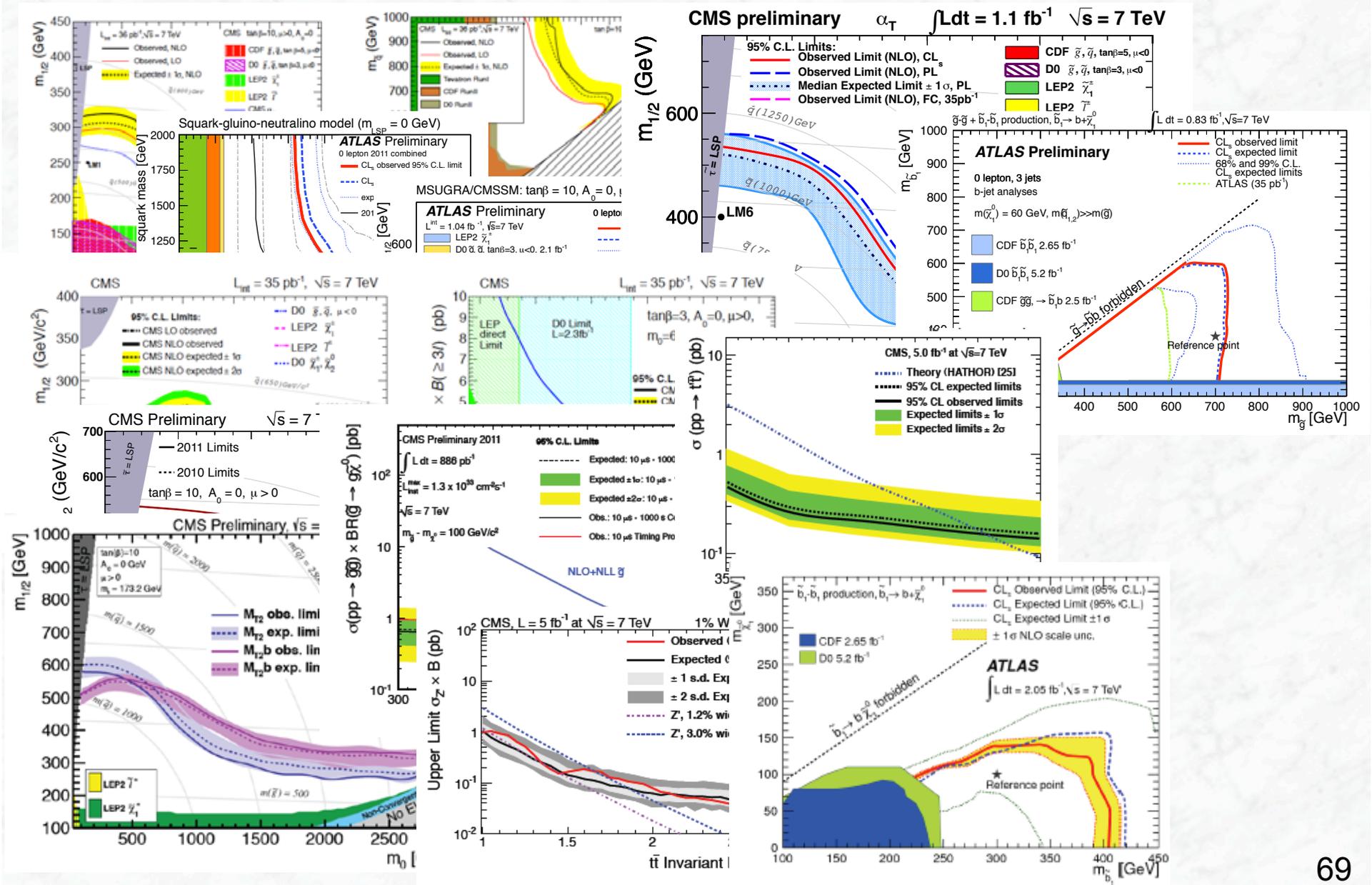
The story in short:

- Many searches, many papers,  
even more exclusion plots
- Nothing found ...  
.... and frustration increased
- There are not even the “Zoo” events that appeared at any collider so far



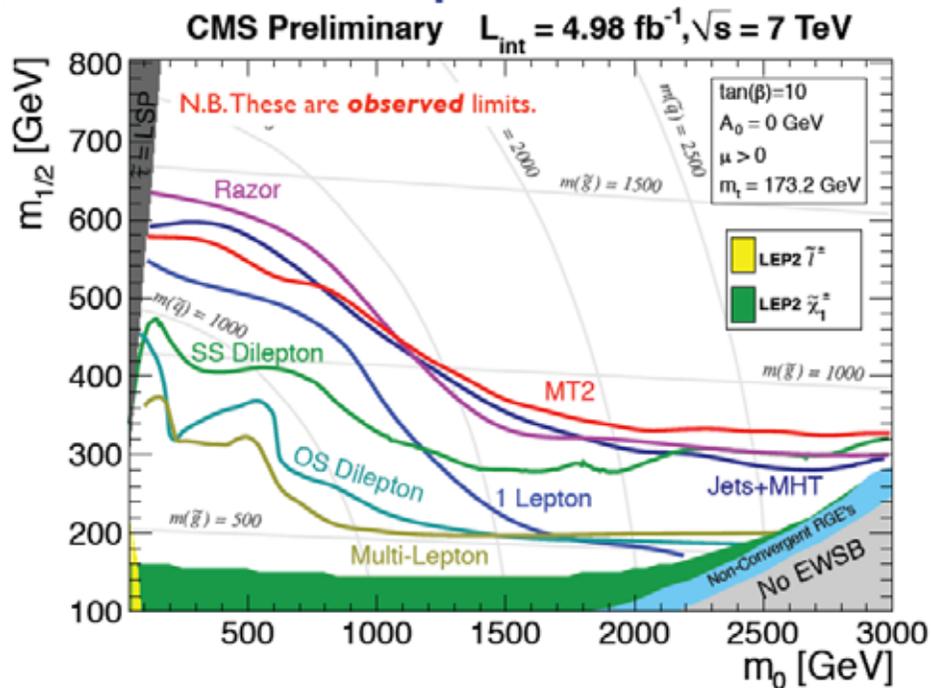
95

# Some exclusion plots show at this conference



.... a few selected ones

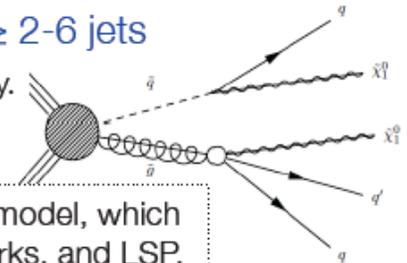
mSUGRA interpretation



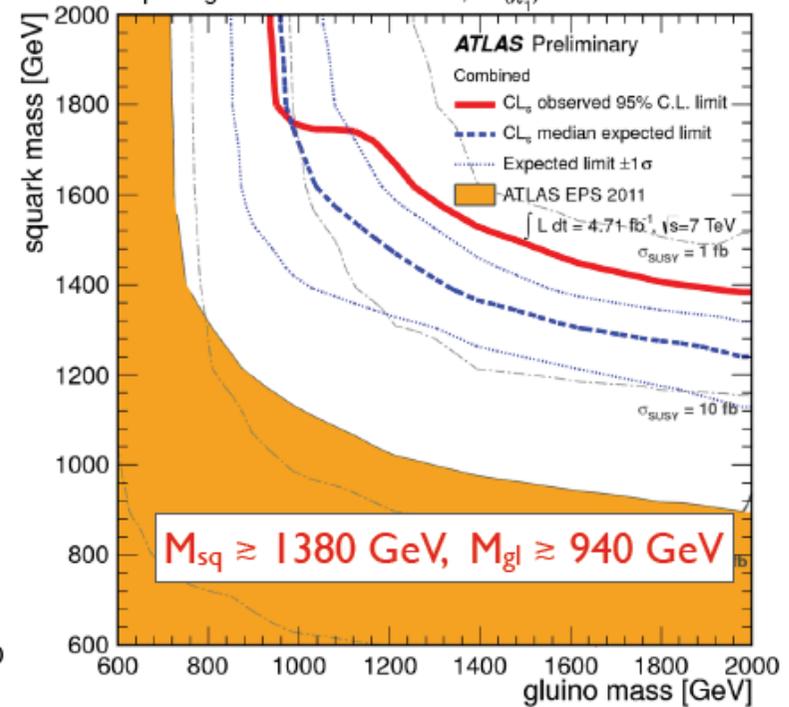
**Search channels:**

1. veto leptons +  $E_T^{\text{miss}} + \geq 2-6$  jets

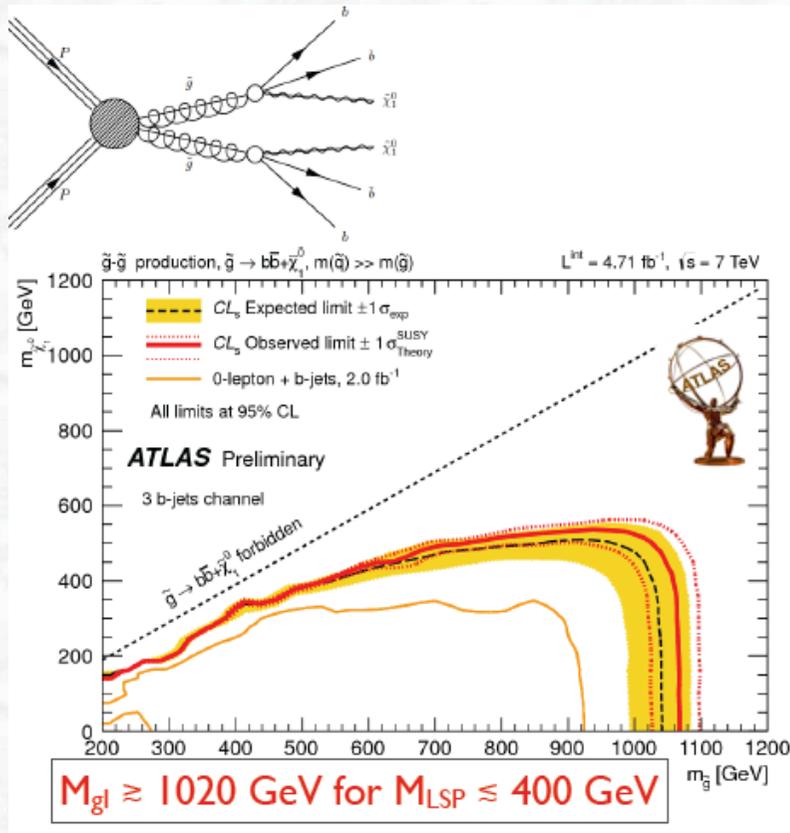
Results compatible with SM only.



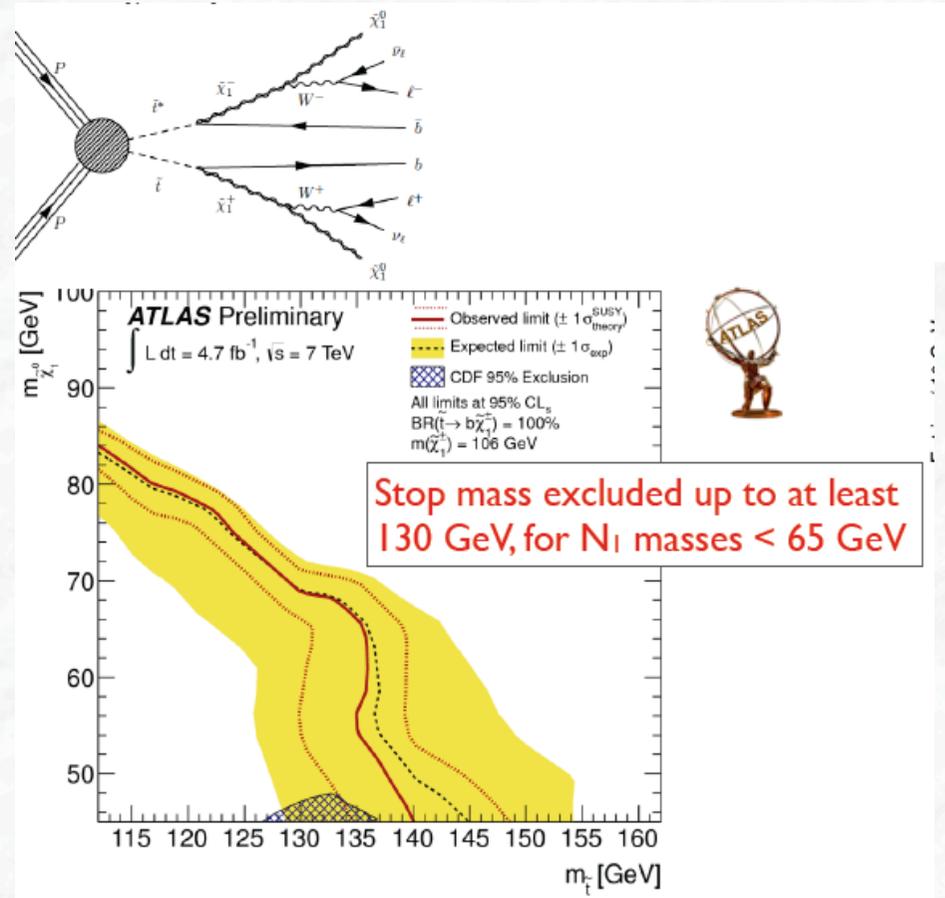
Squark-gluino-neutralino model,  $m(\tilde{\chi}_1^0) = 0 \text{ GeV}$



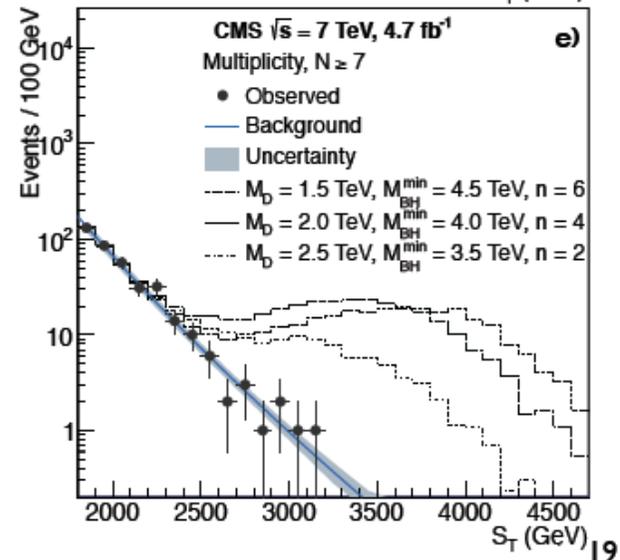
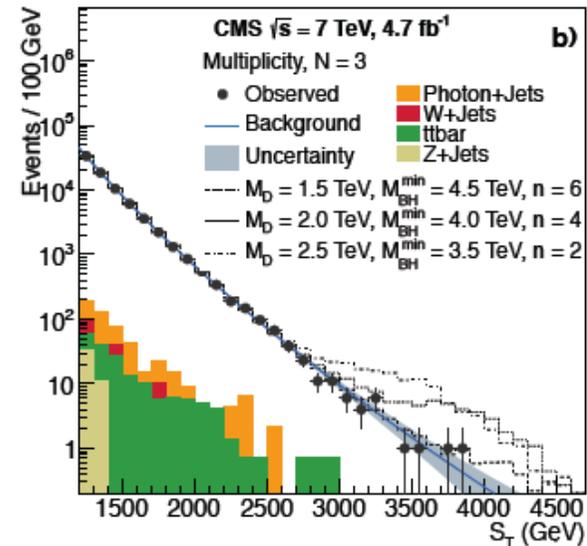
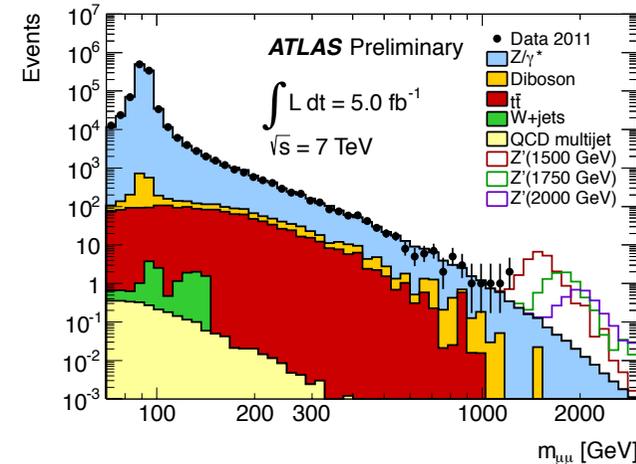
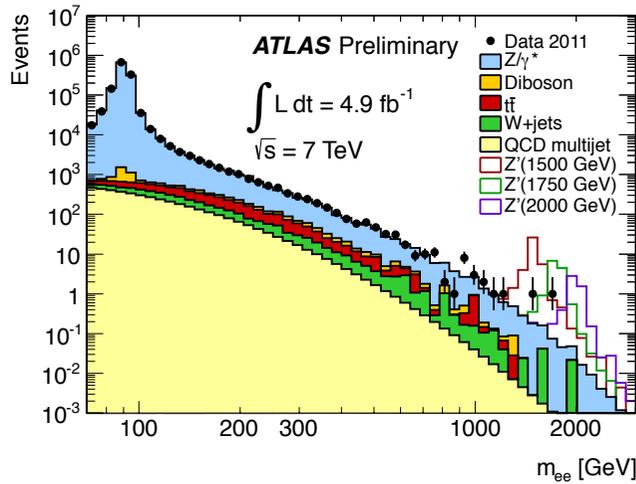
limits from 3<sup>rd</sup> generation squarks  
(gluon mediated sbottom production)



first limits on stop quarks from the LHC



# ... a few more selected ones (Exotics)



No Black holes (so far)

# What are the main messages ?

- **“Low energy SUSY”** in its minimal version with  $E_T^{\text{miss}}$  signatures is in trouble
  - squark and gluino limits for sparticles of first two generations at TeV scale
- Limits do not hold for third generation squarks, in particular the light stop window is not yet closed

# What are the main messages ?

- **“Low energy SUSY”** in its minimal version with  $E_T^{\text{miss}}$  signatures is in trouble
  - squark and gluino limits for sparticles of first two generations at TeV scale
- Limits do not hold for third generation squarks, in particular the light stop window is not yet closed
- There might be more complicated realizations of SUSY (R-parity violation, long-lived sparticles, ...multileptons, ...)
- Goto MMSSM, NMSSM, NMSSM,....., NNNNNNNNNN
- We had an excellent talk on such **“escape roads”** by Csaba Csaki yesterday...

and I am confident that Gian Giudice will come up with further ideas to keep the experimentalists' motivation for the search for BSM physics high

→ The experimentalists program: we will continue to study as many final state topologies as precisely as possible and confront the data to the predictions of the model that seem to survive all attacks (even those from LHCb)

## 2012/13 are exciting years for particle physics:

- Final word on the existence of the Standard Model Higgs boson ?
- There might be surprises in searches  
(more data, slightly higher energy, not yet looked in all corners ...)
- LHCb will challenge the Standard Model at the precision frontier
- ALICE will measure more parameters of the Quark-Gluon-Plasma



**PLHC**  
2012

**June 4 - 9, 2012**

**Physics at LHC -2012**

**Vancouver, BC**

THANKS to the Organizers of the Conference for the fantastic meeting !

... and to all Speakers for presenting such a wealth of interesting and exiting results !