Istituto Nazionale di Fisica Nucleare
Sezione di Cagliari

DIPARTIMENTO DI FISICA
UNIVERSITÀ DEGLI STUDI DI CAGLIARI

CAGLIARI 3 - 5 APRILE

IFAE

XII INCONTRI DI FISICA DELLE ALTE ENERGIE

2013

Overview of Physics at the Large Hadron Collider

Aleandro Nisati
INFN – Roma

April 3rd, 2013

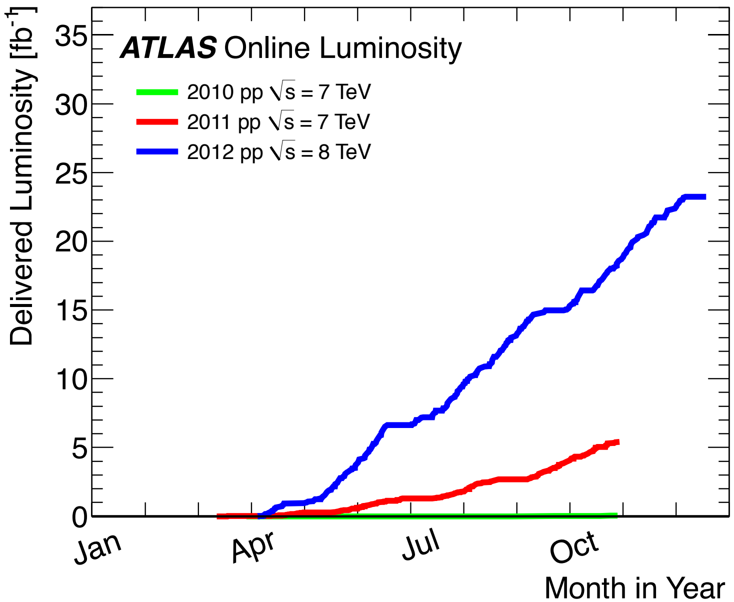
Introduction

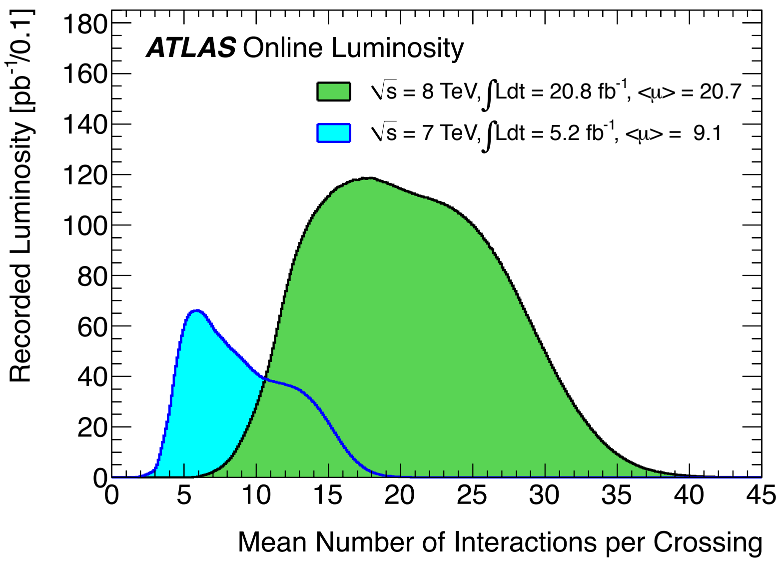
- Standard Model
  - W and Z boson physics
  - Diboson physics
  - QCD studies
  - Top quark physics
  - B-physics
- SUSY
- Exotics
- Higgs boson discovery and properties measurement
- Next steps

- Will cover LHC results by ATLAS CMS and LHCB
- Very reach Heavy Ion physics programme:see talks by:
  - Chiara Oppedisano
  - Plumari Salvatore
  - Guerzoni Barbara
  - Gagliardi Martino
  - Marco Antonio Tangaro
- Several talks from theory and phenomenology

Success of 2010-2012 Run

- Excellent LHC performance
  - 23.3 fb^{-1} delivered in 2012
  - ~ 22 fb^{-1} recorded by ATLAS; similarly for CMS
- Excellent detector performance;
  - example: ATLAS operational officiency: ~ 96%
  - High reconstruction efficiency also in presence of large pileup



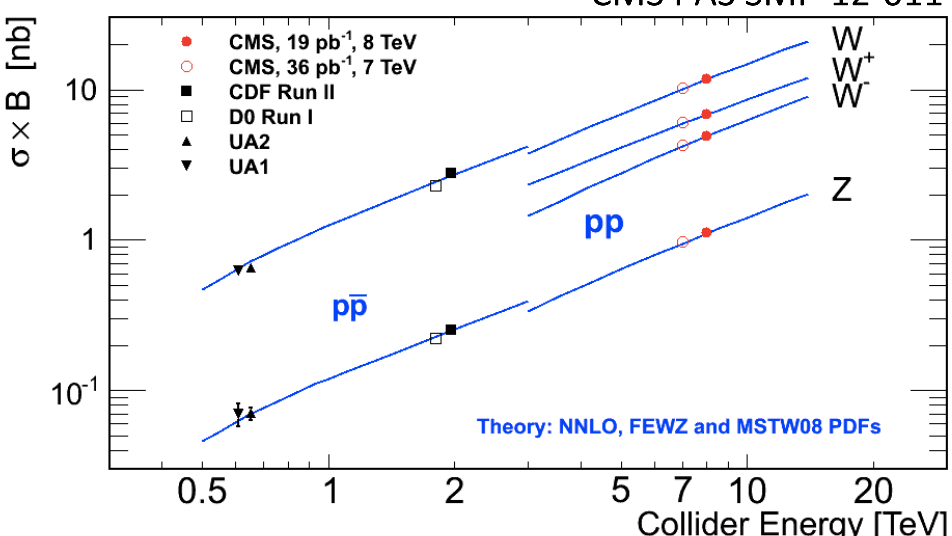


Standard Model

W e Z bosons

- Vector boson production important important benchmark for QCD and EWK. Deviations from SM would expectations would indicate New Physics

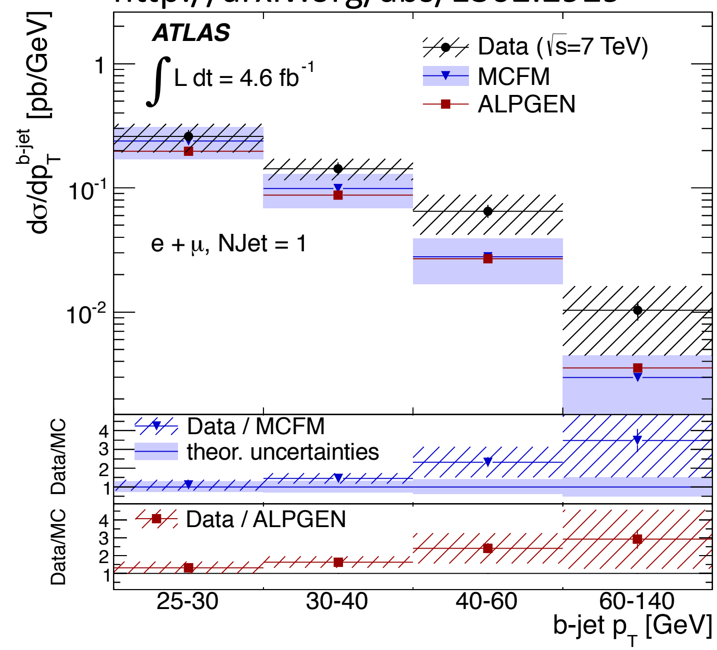
CMS PAS SMP-12-011



- at √s=7 TeV (36/pb): experimental precision ~**1% level**, especially for ratio-observables
- **new √s=8 TeV results from dedicated low-pile up run early in 2012**
- total uncert. 2-5 % (4.4 % lumi, 2-3% acceptance, 1.1-1.7% exp)
- good agreement with NNLO QCD, both at 7 and 8 TeV

- Long list of measurements on V+jets, **V+heavy flavours**, differential cross sections, W polarization, etc etc

http://arxiv.org/abs/1302.2929



Measured differential W+b-jets cross-sections

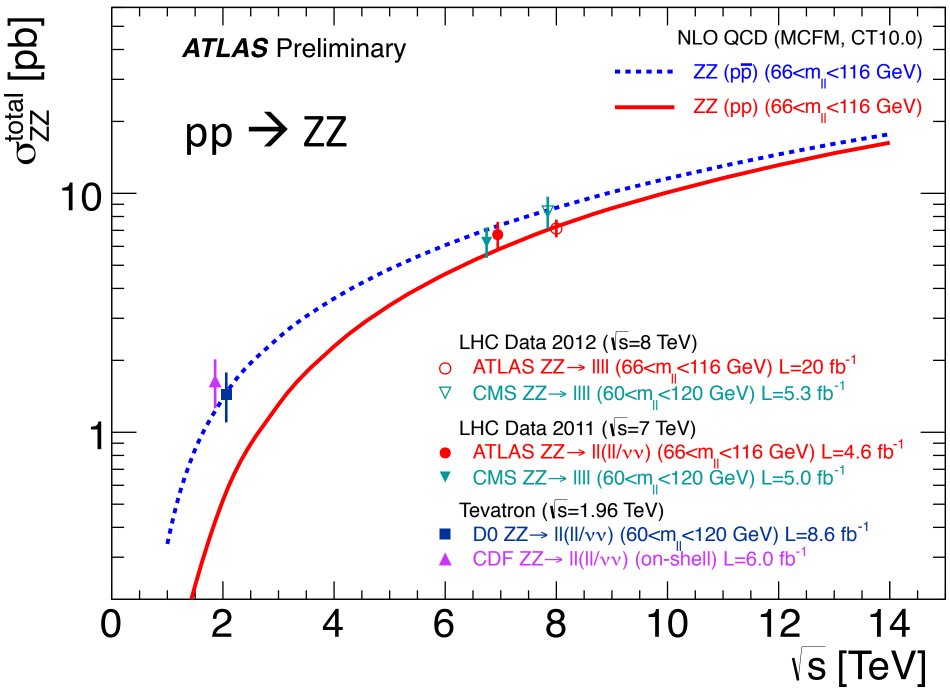
W charge asymmetry important to constraint PDFs

Dibosons

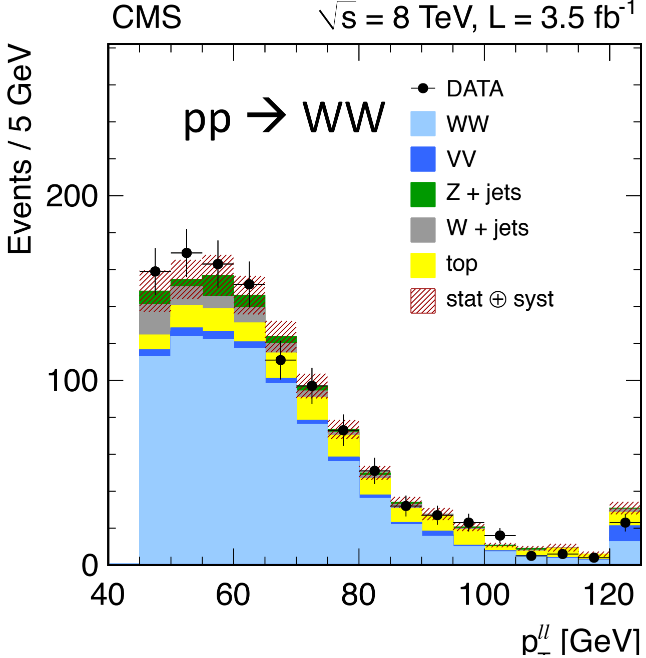
- Test of SM with NLO prediction in process relevant for EWSB
- Irreducible background to Higgs searches

$$\sigma_{ZZ}^{tot} = 7.1^{+0.5}_{-0.4}(\text{stat.}) \pm 0.3(\text{syst.}) \pm 0.2(\text{lumi.})\ \text{pb}$$

ATLAS-CONF-2013-020



arXiv:1301.4698v1



$$\sigma(pp \to W^+W^-) = 69.9 \pm 2.8\,(\text{stat.}) \pm 5.6\,(\text{syst.}) \pm 3.1\,(\text{lum.})\ \text{pb}$$

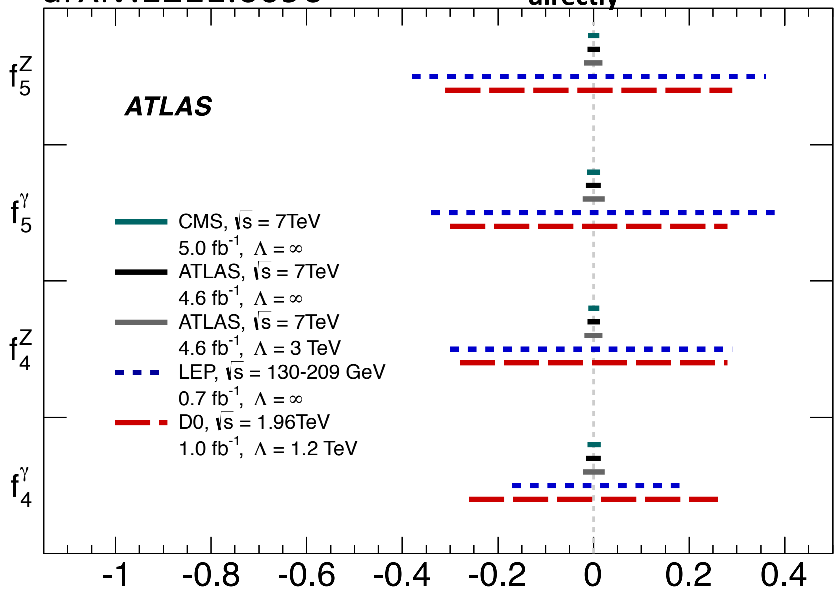
Distributions for W+W− candidate events of the dilepton transverse momentum p_T^{ll}. Points represent the data, and shaded histograms represent the WW signal and the background processes. The last bin includes the overflow. The W W signal is scaled to the measured cross section, and the background processes are normalized to the corresponding estimated values

TGCs

- Triple Gauge Couplings in ZZ processes: zero in SM. Non-zero value would indicate signals from BSM physics

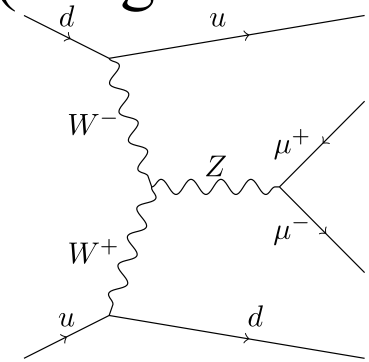
Λ is the scale at which New Physics would be observed directly

arXiv:1211.6096

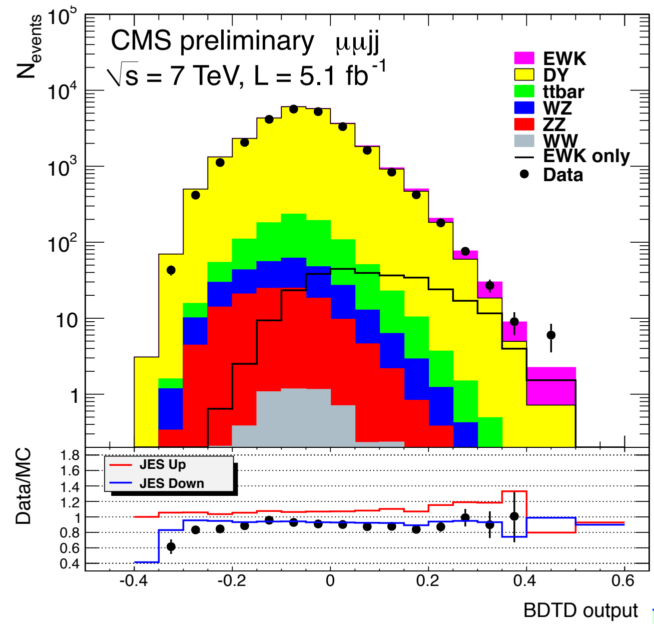


Anomalous nTGC 95% confidence intervals from ATLAS CMS, LEP and D0. For on-shell ZZ production can be parameterized by two CP-violating (f4V) and by two conserving CP (f5V) accounting for a scale dependence at which NP could show up

- First results on Z electroweak production (3-sigma evidence)



CMS-PAS-FSQ-12-019

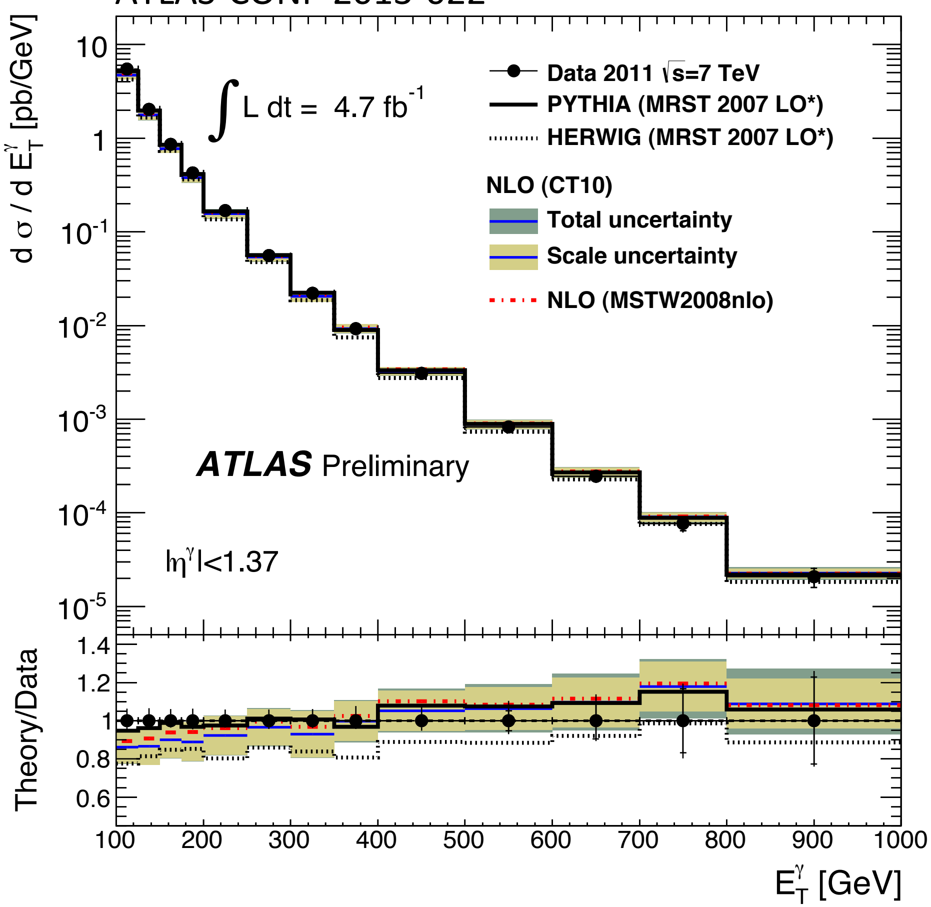


see EW talk by Antonio Tropiano

QCD studies

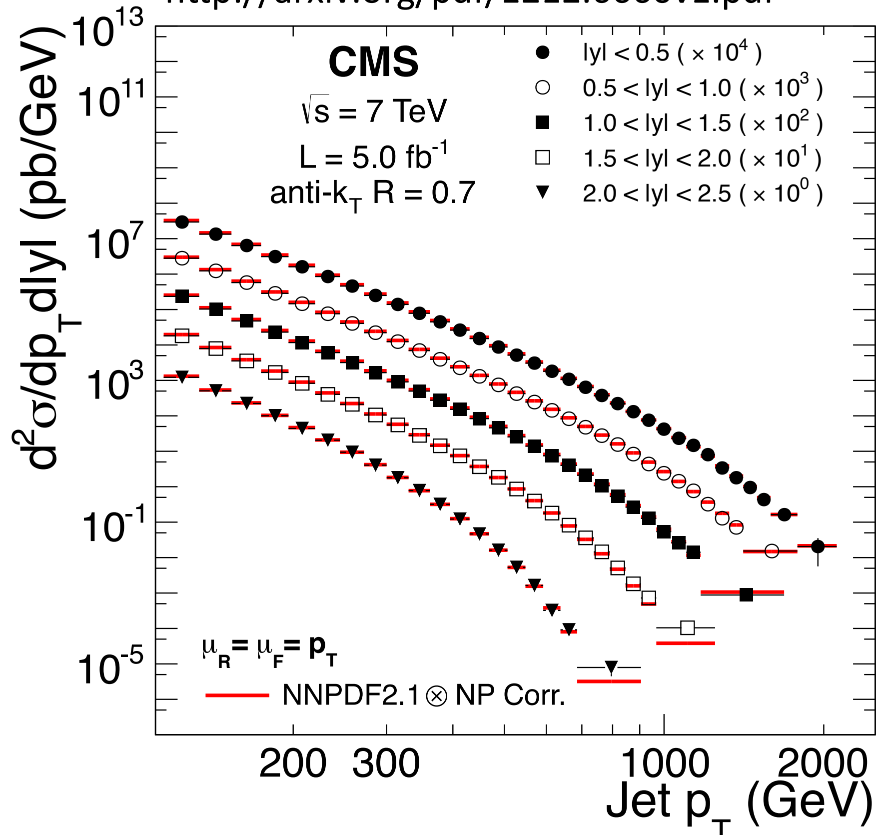
Direct photon production

ATLAS-CONF-2013-022



Inclusive jet production

http://arxiv.org/pdf/1212.6660v1.pdf

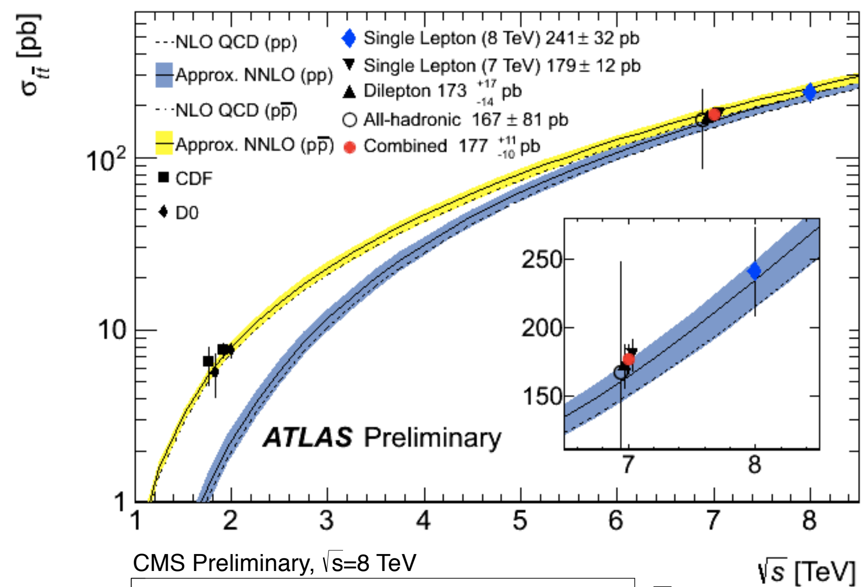


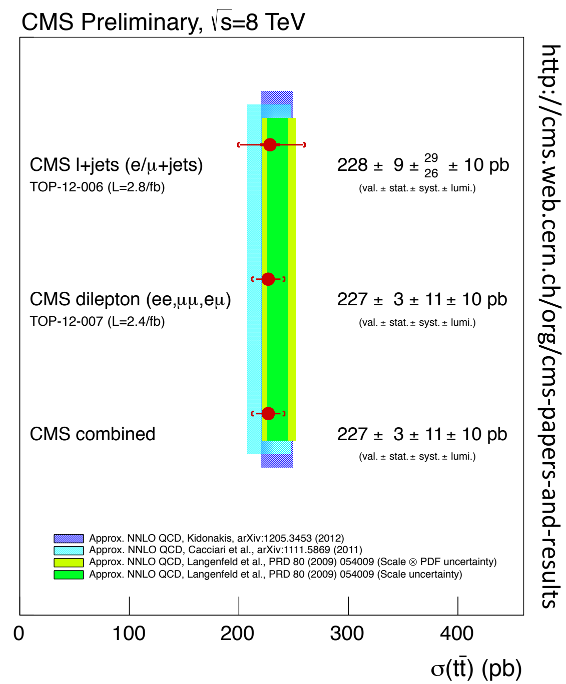
- NLO QCD describes data over ~9 orders of magnitude.
- excellent exp. progress: jet energy scale uncertainties at the **few %** level
- for central rapidities: similar exp. and theo. uncertainties, **5 - 10%**
- inclusive jet data : start to be important tool for constraining PDFs

Top quark production cross section

- As heaviest quark, it may play an important role in EletcroWeak Symmetry Breaking
- ttbar and single top processes are the among the main backgrounds to Higgs and New Physics searches
- Study top production probing different final states and using complementary techniques
  - single lepton; dilepton, full hadronic final states
- Measured ttbar production cross-section with < 7% uncertainty
  - in agreement with SM predictions within uncertainties

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



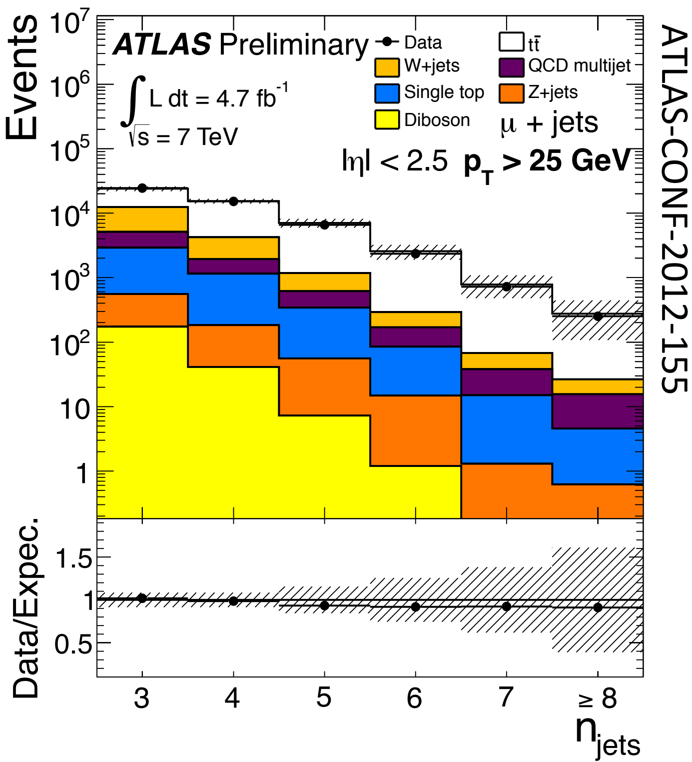


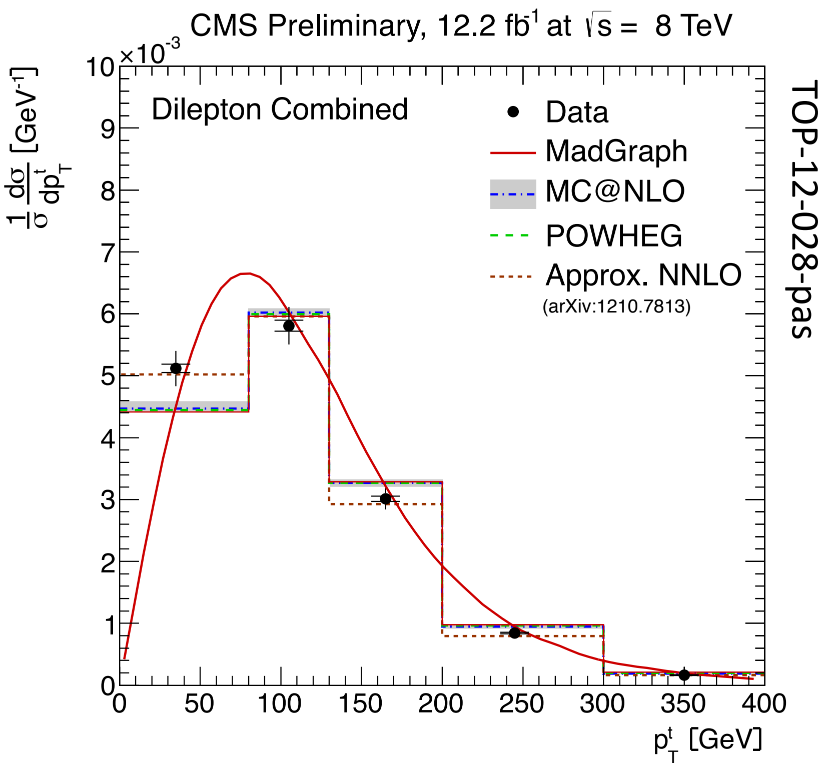
http://cms.web.cern.ch/org/cms-papers-and-results

ttbar production topologies

- A measurement of the ttbar production with additional jets and as a function of the jet transverse momentum useful to constrain models of initial and final state radiation (ISR/FSR) at the scale of the top quark mass,
- provides a test of perturbative QCD in the LHC energy regime.

- Normalised differential ttbar production cross section as a function of the p_T of the top/antitop quark
- The inner (outer) error bars indicate the statistical (combined statistical and systematic) uncertainty.

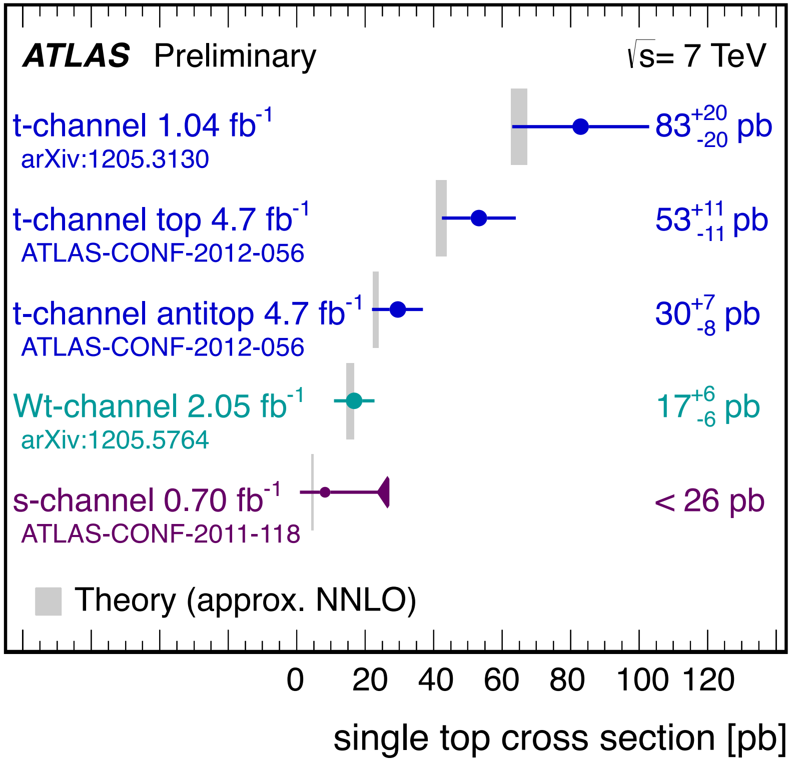


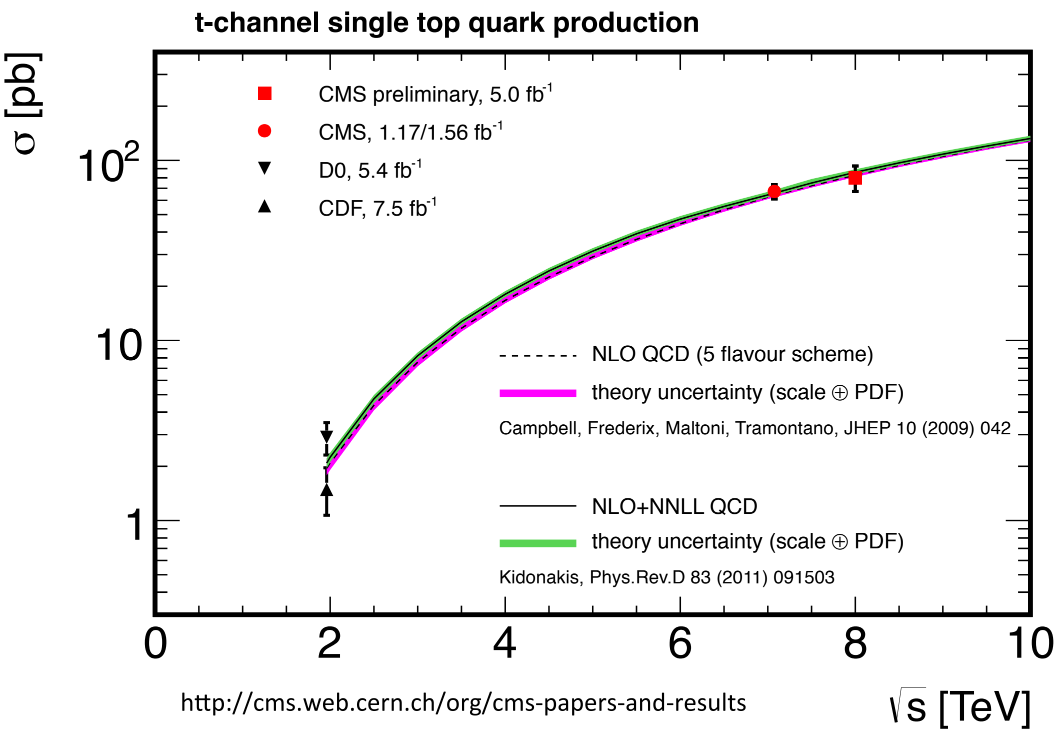


Single top production

- The single top-quark final state provides a direct probe of the Wtb coupling and is sensitive to many models of new physics. The measurement of the production cross-section constrains the absolute value of the quark-mixing matrix element without assumptions about the number of quark generations.

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





http://cms.web.cern.ch/org/cms-papers-and-results

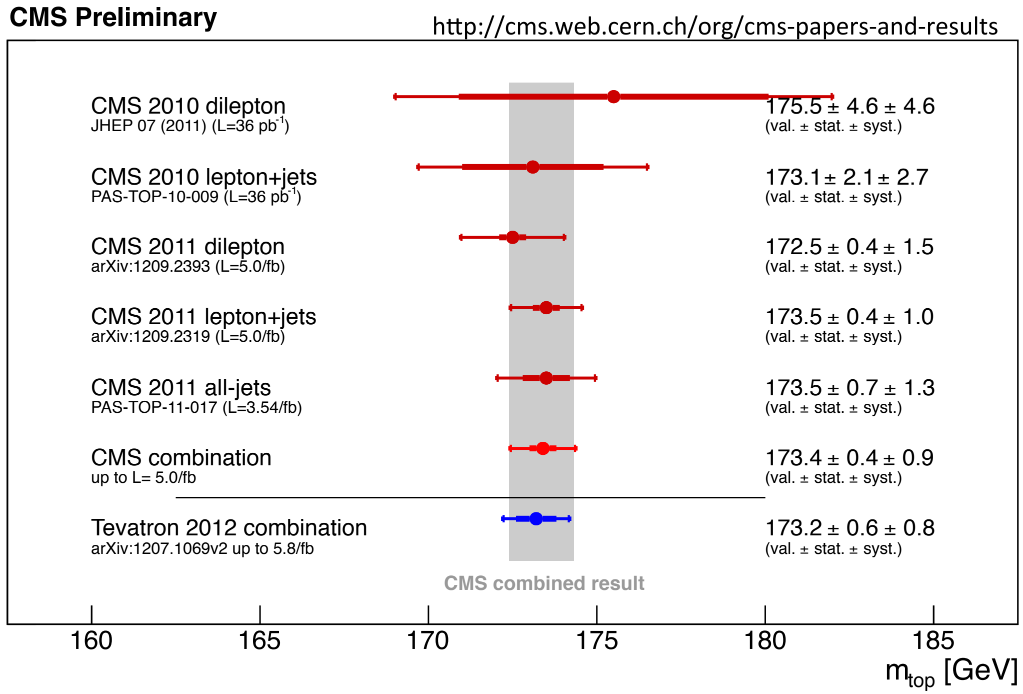
V_{tb} is measured to be 1.020 ± 0.046 (exp.)±0.017 (theor.)

Evidence of Wt production also by CMS (4σ): 16 $^{+5}_{-4}$ pb

Top quark mass

see talk by
- Michele Pinamonti

- The top-quark mass is an important parameter of the Standard Model as it affects predictions observables via radiative corrections. Precise measurements of the top-quark mass are critical inputs to global electroweak fits which provide constraints on the properties of the Higgs boson.



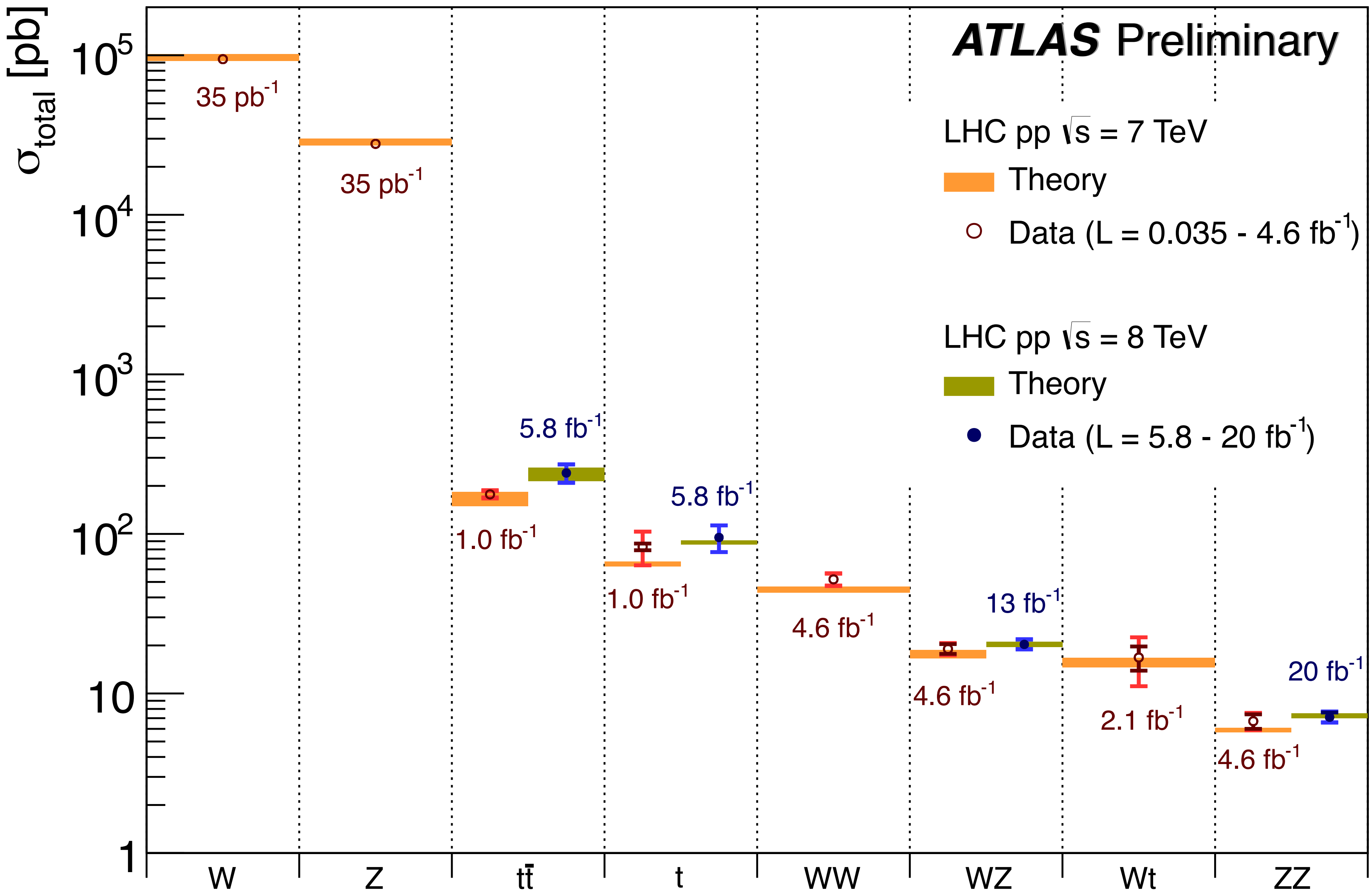
$$\mathbf{m_t = 173.4 \pm 0.4 \pm 0.9\ GeV}$$

$$\Delta m_t = -272 \pm 196\ \text{(stat.)} \pm 122\ \text{(syst.)}\ \text{MeV}$$

Study also the top antitop mass difference; in SM CPT invariance imposes $m_t = m_{tbar}$
- Best measurement to date

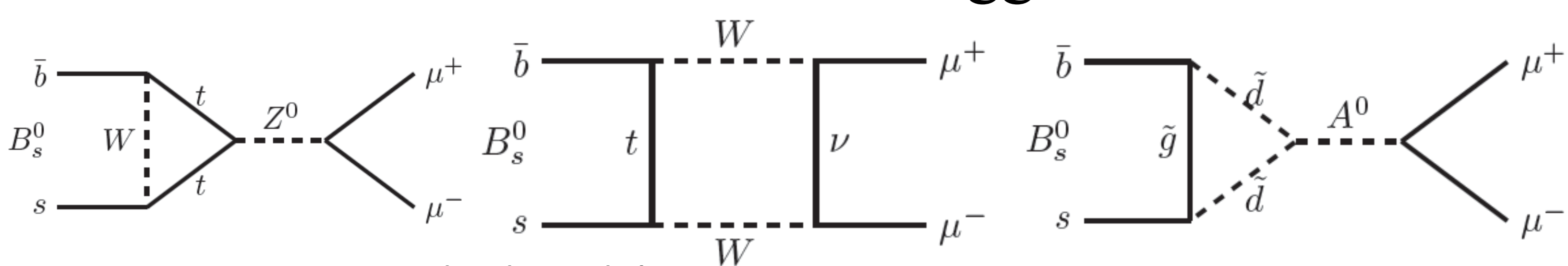
Study the top mass as a function of different kinematic variables
- Help reducing theory uncertainties on the measured top mass such as those from color reconnection [PAS-TOP-2012-029]

Standard Model: the big picture



B-Physics at LHC

- Very rich and important Heavy Flavour programme at LHC
  - LHCb, ATLAS, CMS
- Heavy flavour investigations are crucial to test Standard Model predictions
- **Rare decays** such us $\mathbf{B^0_{(s)} \rightarrow \mu^+\mu^-}$ are highly suppressed in SM; precise BR predictions make these modes powerful probes in the search for deviations from the SM, especially in models with a non-standard Higgs sector.



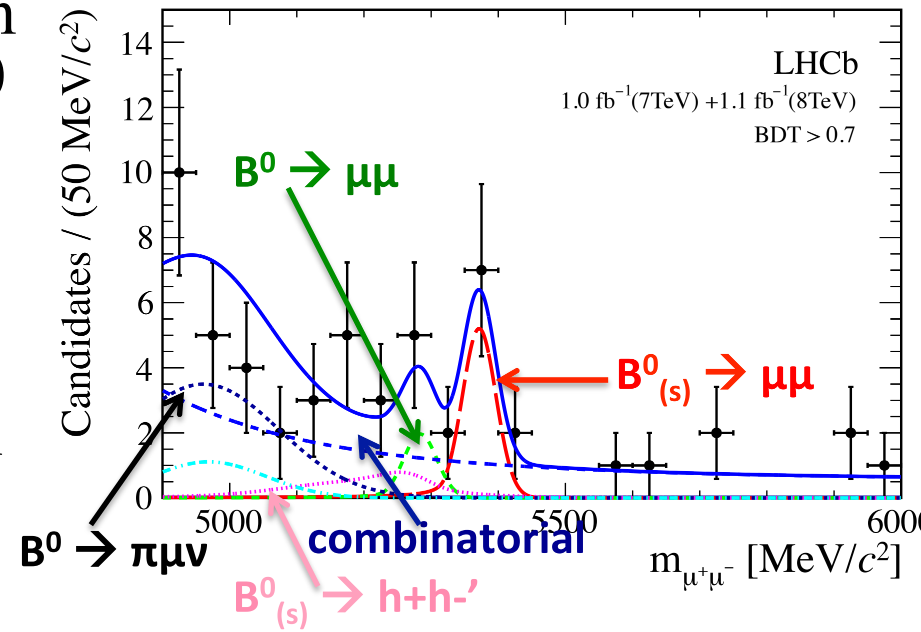
Standard Model SUSY

$BR(B^0_s \rightarrow \mu^+\mu^-) = (3.23 \pm 0.27) \times 10^{-9}$

- LHCb Studies based on a multivariate classifier and on invariant mass analysis

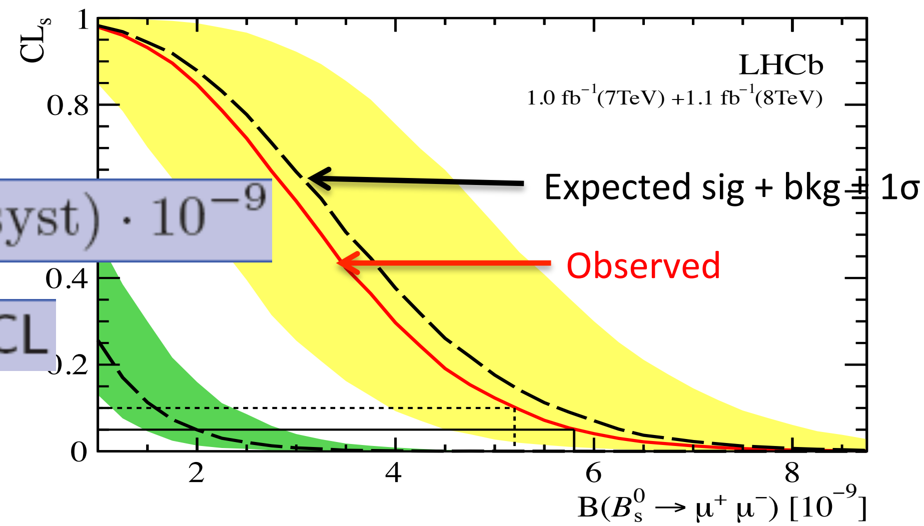
$B^0_{(s)} \to \mu^+\mu^-$

- BDT signal output flat between 0 and 1; background peaks at 0
- Mass sideband fit to obtain the number of background events expected in the signal region
- Signal mass central value from $B \to K^+\pi^-$, $B \to \pi^+\pi^-$ and $B^0_s \to K^+K^-$; shape based on data (in part. from the mentioned B channels)
- Results:



$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = 3.2^{+1.4}_{-1.2}(\text{stat})^{+0.5}_{-0.3}(\text{syst}) \cdot 10^{-9}$$

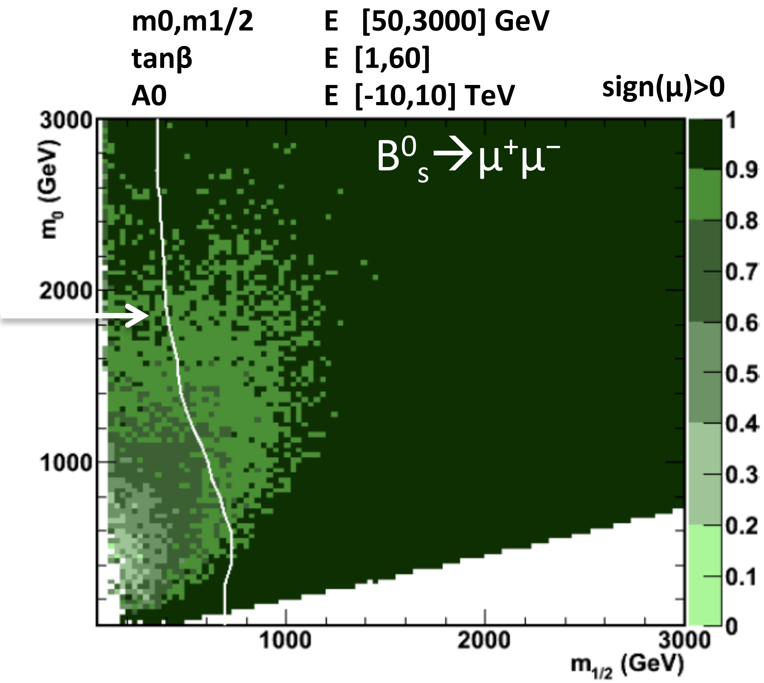
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 9.4 \cdot 10^{-10} \text{ at } 95\% \text{ CL}$$

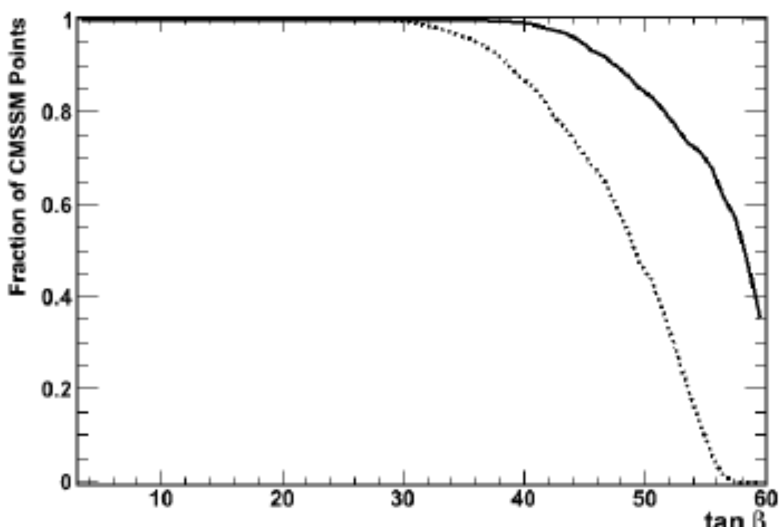


$B^0_{(s)} \rightarrow \mu^+\mu^-$ implications

- Constraints from 1.0 fb^{-1} ($\sqrt{s}$=7 TeV) + 1.1 ($\sqrt{s}$=8 TeV) fb^{-1} limit for cMSSM/mSUGRA

ATLAS limit





Fraction of CMSSM points obtained through a 4-parameter flat scan passing the LHC SUSY constraints and in agreement with the present $B^0_{(s)} \rightarrow \mu^+\mu^-$ measurement of (continuous line), and with the prospective range (uncertainty ~halved - dotted line), as a function of tanβ .

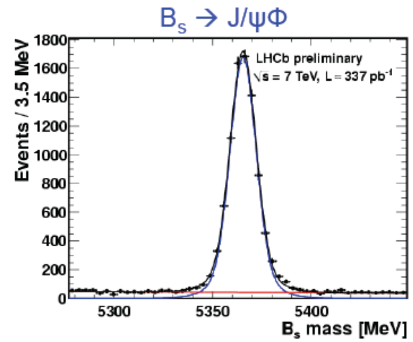
A. Arbey et al.: arxiv:1212.4487v2

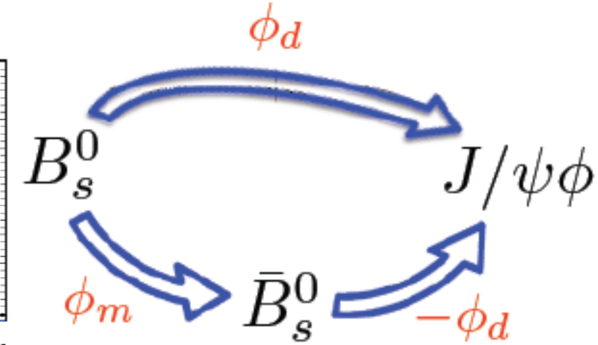
Fraction of CMSSM points compatible with the current 95% C.L. constraints on $B^0_{(s)} \rightarrow \mu^+\mu^-$ in the $m_{1/2}$,m_0 parameter plane.

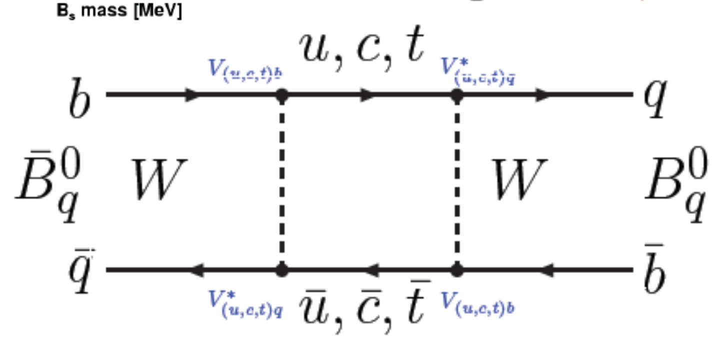
- $B^0_s \rightarrow \mu^+\mu^-$ measurement strongly constraints cMSSM at large values of tanβ

Mixing induced CP violation

- Consider here the decay B0s→J/ψφ
- Interference between mixing and decay givesrise to a CPV phase: $\phi_s = \phi_m - 2\phi_d$



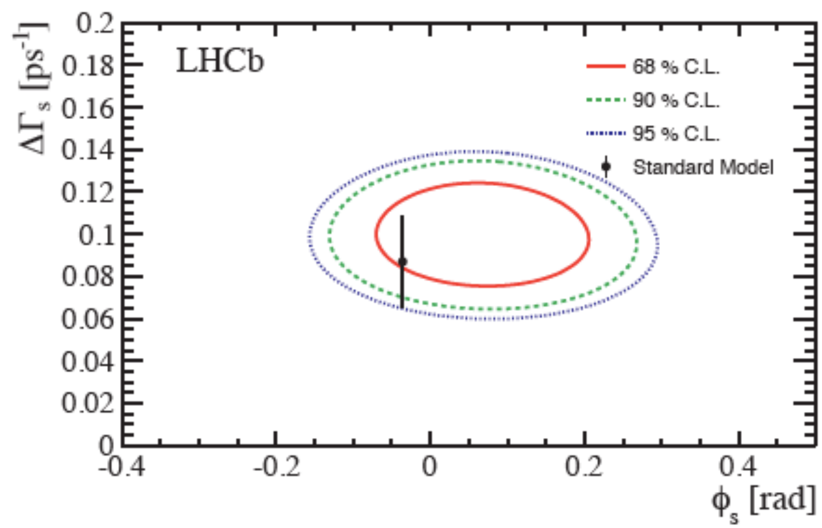




- Mixing phase ϕ_m from ΔB=2 box diagram → sensitive to New Physics

$$\phi_s^{SM} = -2arg\left(\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right) = -0.036 \pm 0.002\,\mathrm{rad}$$

Result in agreement with SM within current uncertainties



B-Physics in ATLAS and CMS

- $B^0_{(s)} \rightarrow \mu^+\mu^-$ searches
- Observation of a new χ_b state in radiative transitions to $\Upsilon(1s)$ and $\Upsilon(2s)$ [interpreted as $\chi_b(3P)$]
- measurements of production cross sections of $pp \rightarrow B^+X$, $pp \rightarrow B^0X$, $pp \rightarrow B^0_s \rightarrow J/\psi\ \varphi$
- measurement of the X(3872) production cross section
- measurement of Λ_b lifetime
- studies of Y(1s), Y(2s), Y(3s) cross section and polarization
- observation of $B^+_c \rightarrow J/\psi\ \pi^+$ and $B^+_c \rightarrow J/\psi\ \pi^+ \pi^-$
- observation of structures in $B^+ \rightarrow J/\psi\ \varphi\ K^+$
- …

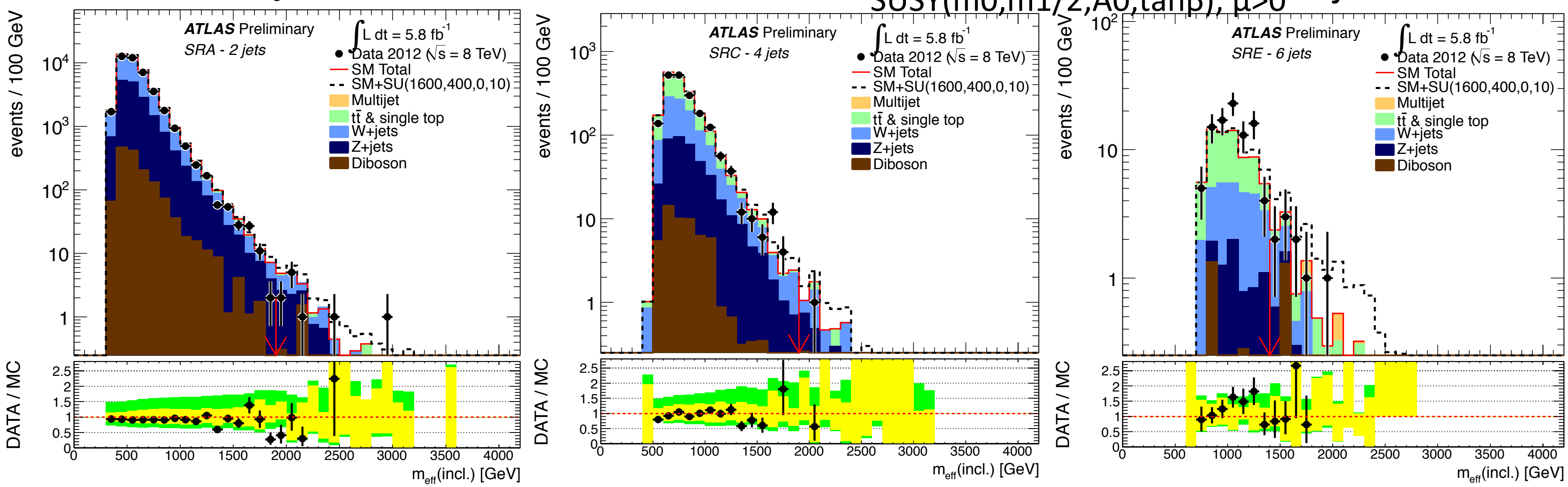
- Flavour Physics: see talks by:
  - Paul Ayan - Mauro Piccini
  - Flavio Archilli - Roberta Cardinale
  - Stefano Perazzini - Antonio Falabella

SUSY

Strong production 1^{st} 2^{nd} generation of Squarks and Gluinos

- Classic signature: large Missing Transverse Energy (MET) and 2 to 6 high-p_T jets
- Background composition depends on number of required jets
  - Model dependent limits in many scenarios (TeV scale)

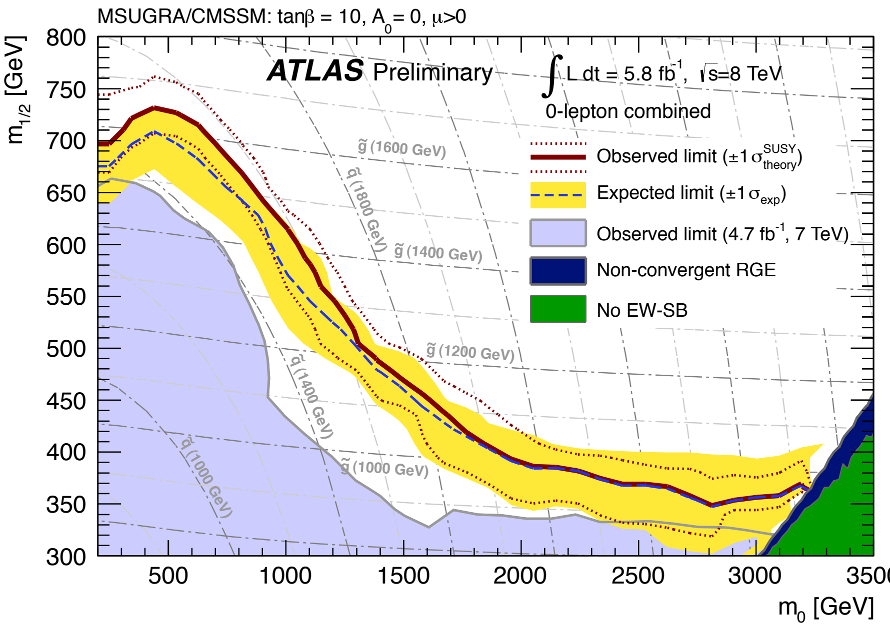
2 jets ATLAS-CONF-2012-109 4 jets SUSY(m0,m1/2,A0,tanβ); μ>0 6 jets

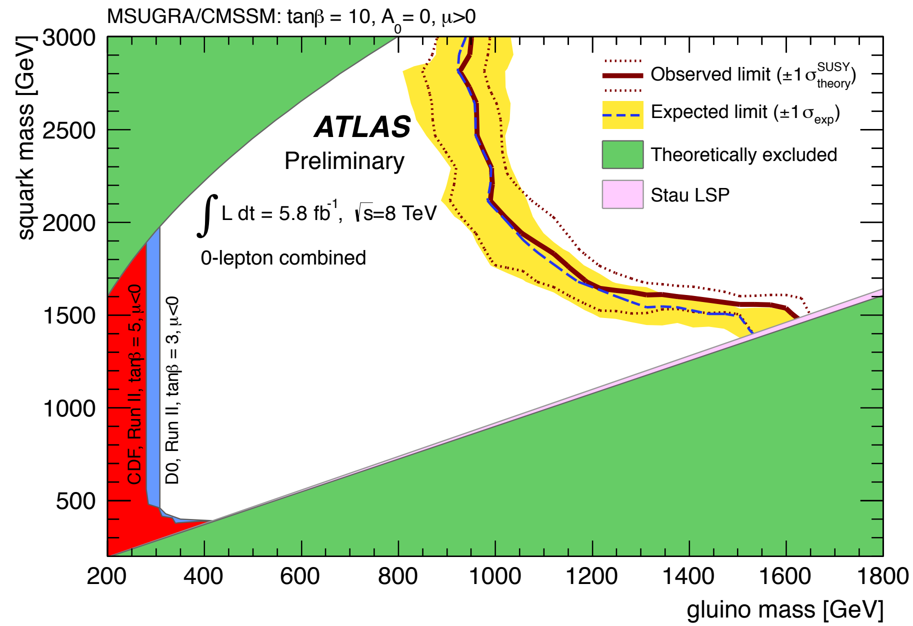


Effective mass (m_{eff}) distribution

m_{eff} = scalar sum of the transverse momenta of the leading N jets together with E_T^{miss}.

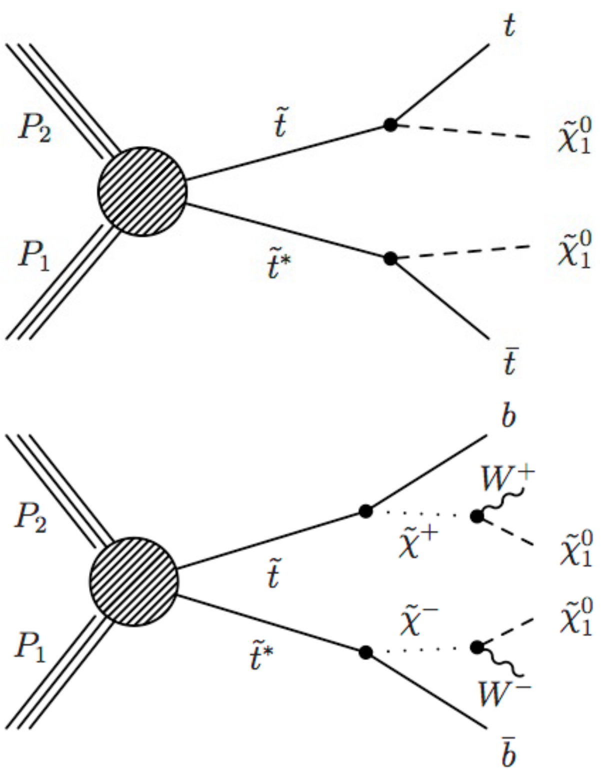
Strong production 1st 2nd generation of Squarks and Gluinos





- 95% CL exclusion limits for MSUGRA/CMSSM models with tanβ=10, A_0=0 and μ>0 presented (left) in the m_0—$m_{1/2}$ plane and (right) in the m_{gluino}— m_{squark} plane. The blue dashed lines show the expected limits at 95% CL, with the light (yellow) bands indicating the 1σ excursions due to experimental uncertainties.

SUSY: 3rd generation searches



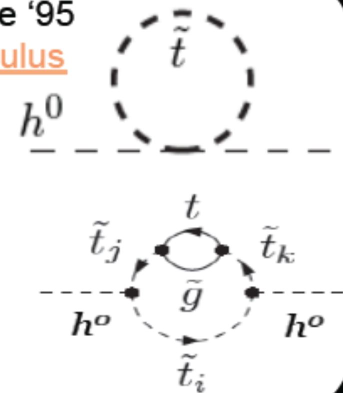
Direct stop production

For 10% tuning:

Giudice '95
Dimopulus

one loop: stops<600GeV

two loops: gluinos<1400GeV



Naturalness arguments require the light top squark mass eigenstate to be significantly below 1 TeV, which now appears to be significantly lighter than the other squarks.

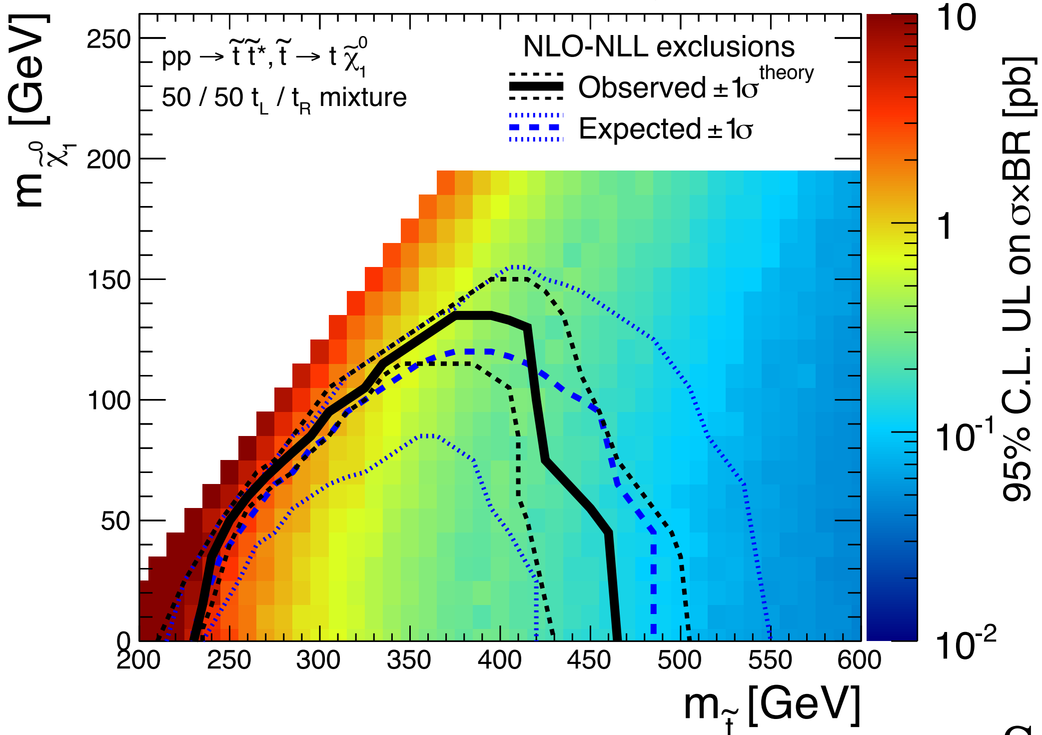
Focus on a scenario very stop/sbottom are "light" and the other squarks and gluinos are heavy

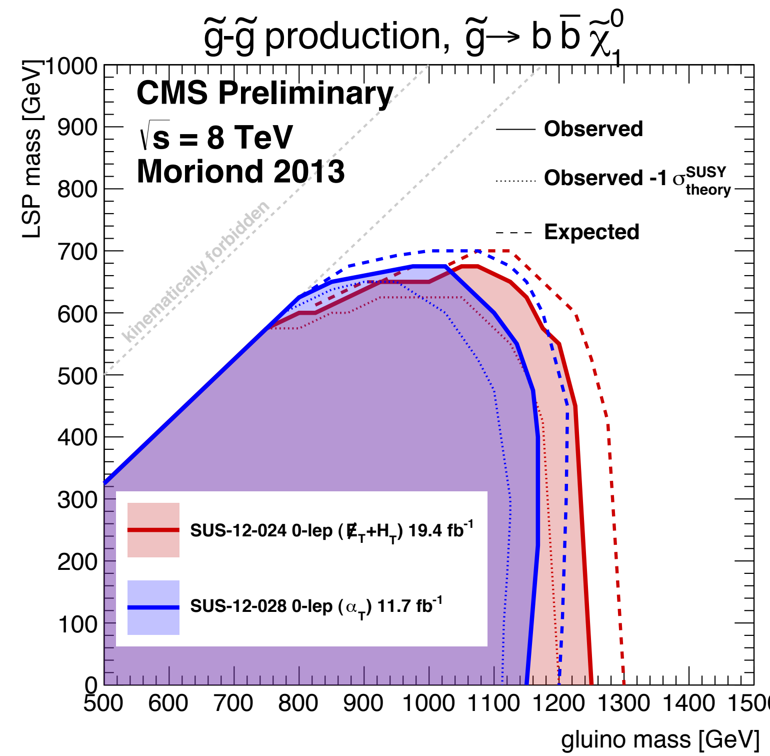
- Targeting direct and indirect stop/sbottom production
- E.g. extending generic searches adding b-tags, or applying ttbar + MET searches

- **Significant background expected (tt, ..)**
- **Background predictions need to be precise!**

SUSY: 3rd generation searches

SUS-12-023-pas



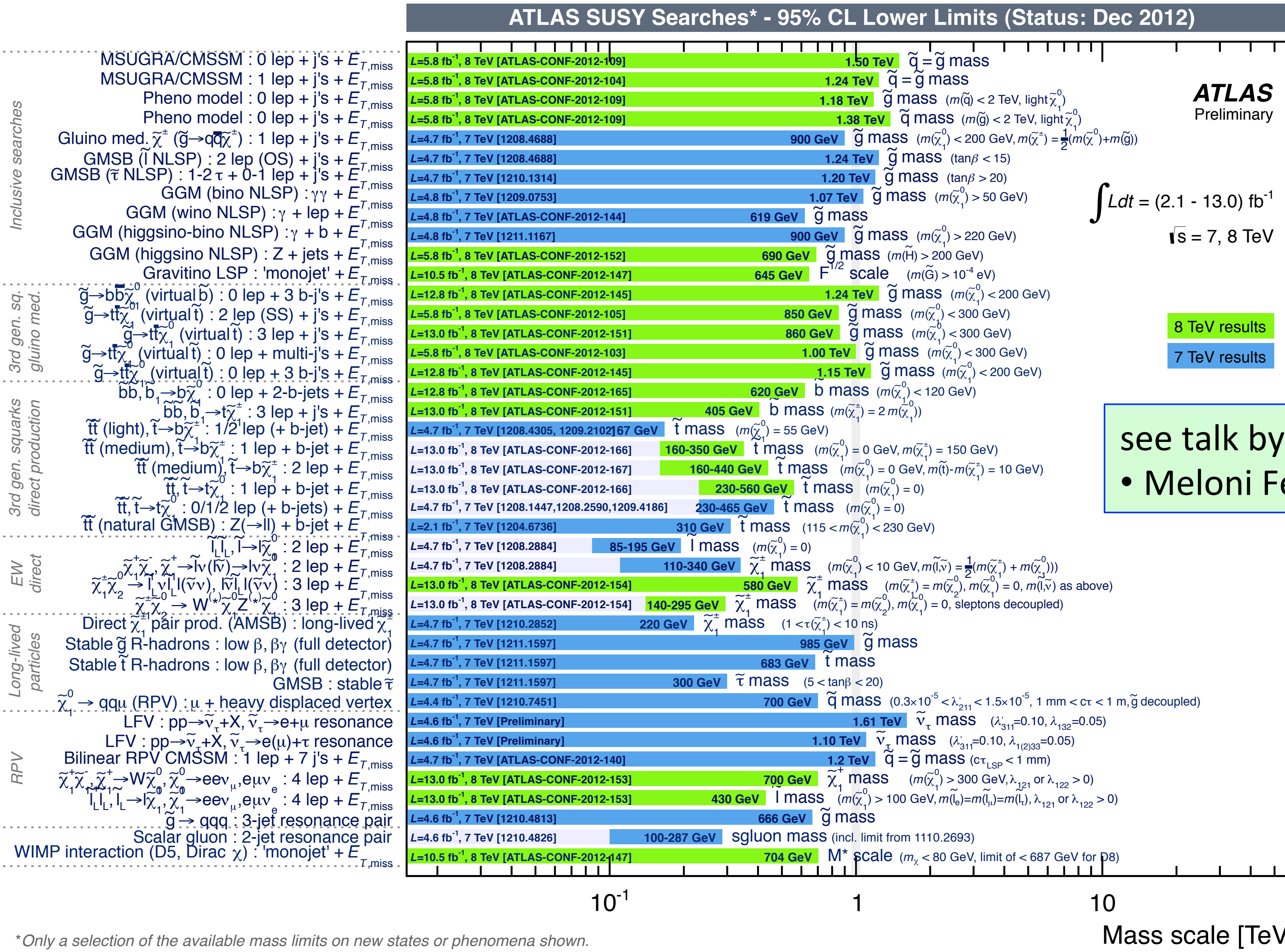


- Interpretation in the top squark pair production model stop→top+χ^0_1, in the plane of $m\chi^0_1 - m_{stop}$. The shading indicates the upper limit on the signal cross section.

- Summary of observed and expected limits for gluino pair production with gluino decaying via the 3-body decay beauty anti-beauty neutralino

stop mass > ~ 460 GeV for a light neutralino mass

Desperately searching for SUSY



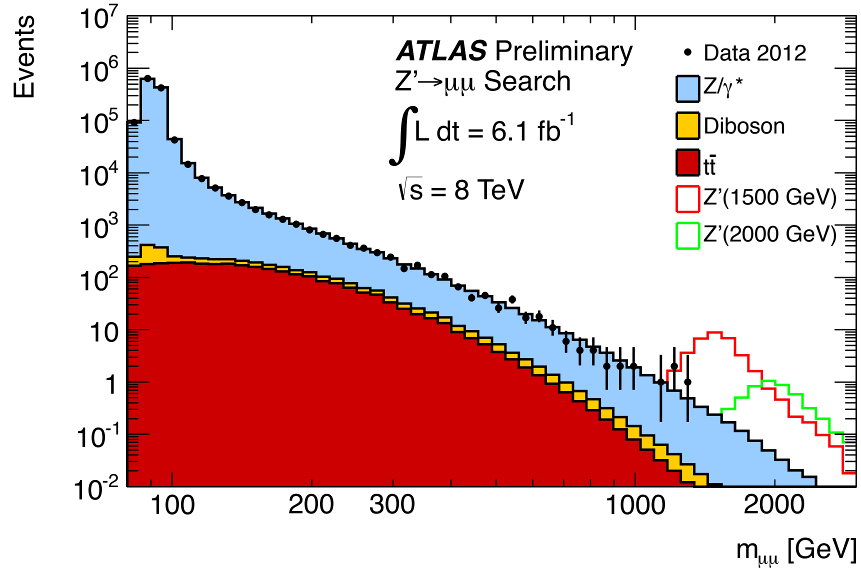
*Only a selection of the available mass limits on new states or phenomena shown.
All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

see talk by
- Meloni Federico

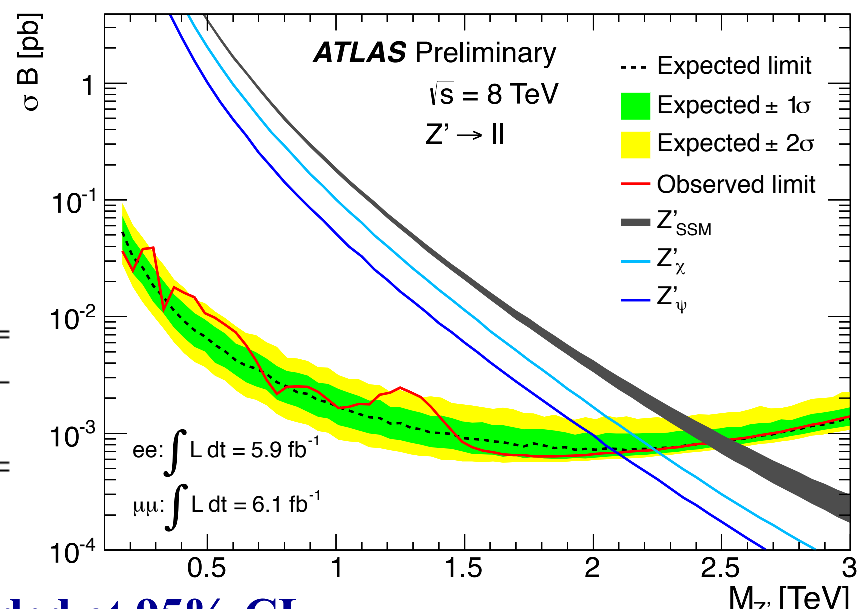
Exotics

Search for high-mass dilepton resonances

- In several BSM models heavy mass resonances decaying to dilepton final states are predicted
  - The benchmark model is the SSM Z'→ll;
- A more theoretically-motivated model is a Grand Unification model in which the E6 gauge group is broken into SU(5) and two additional U(1). Several models are based on this approach



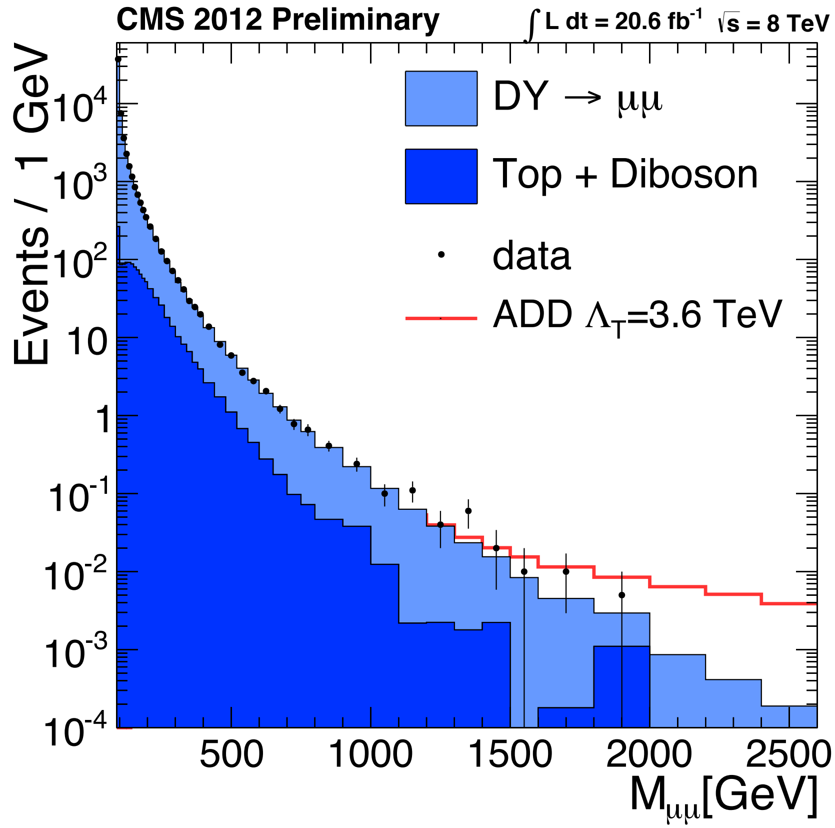
Model	Z'_ψ	Z'_N	Z'_η	Z'_I	Z'_S	Z'_χ
Observed mass limit [TeV]	2.09	2.10	2.15	2.14	2.18	2.24
Expected mass limit [TeV]	2.07	2.08	2.14	2.13	2.17	2.23



New Z' resonances with mass > 2.1 TeV are excluded at 95% CL

Extra-Dimensions

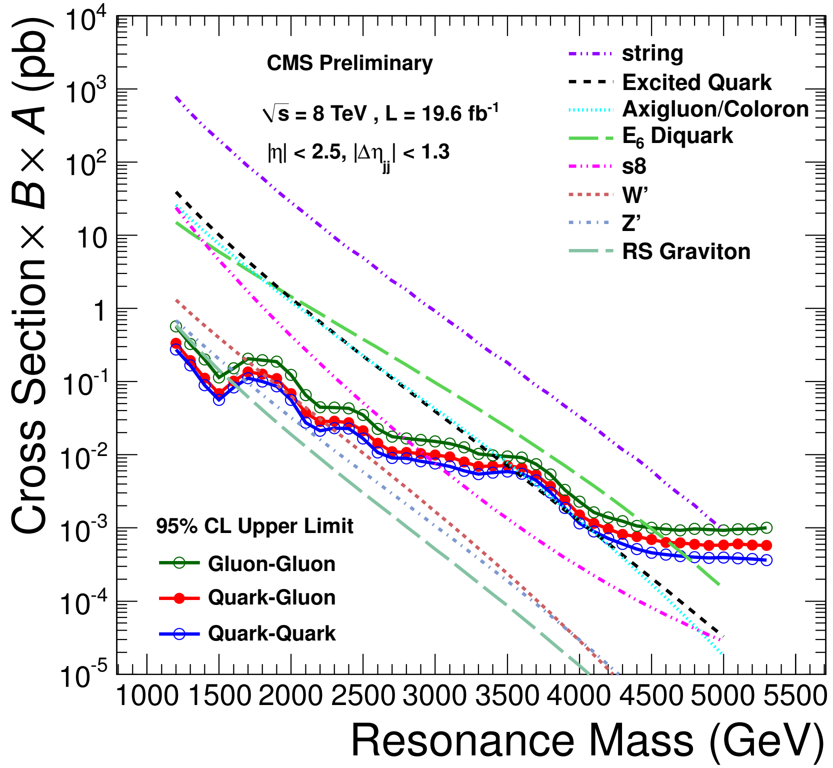
- Large Extra dimensions have (also) been proposed as a possible solution to the hierarchy problem in the Standard Model (SM) of particle physics.
- The ADD model postulates the existence of additional compactified extra dimensions. Gravity is assumed to propagate in the entire higher-dimensional space while particles of the standard model are confined to a 3+1 dimensional subspace, a brane.

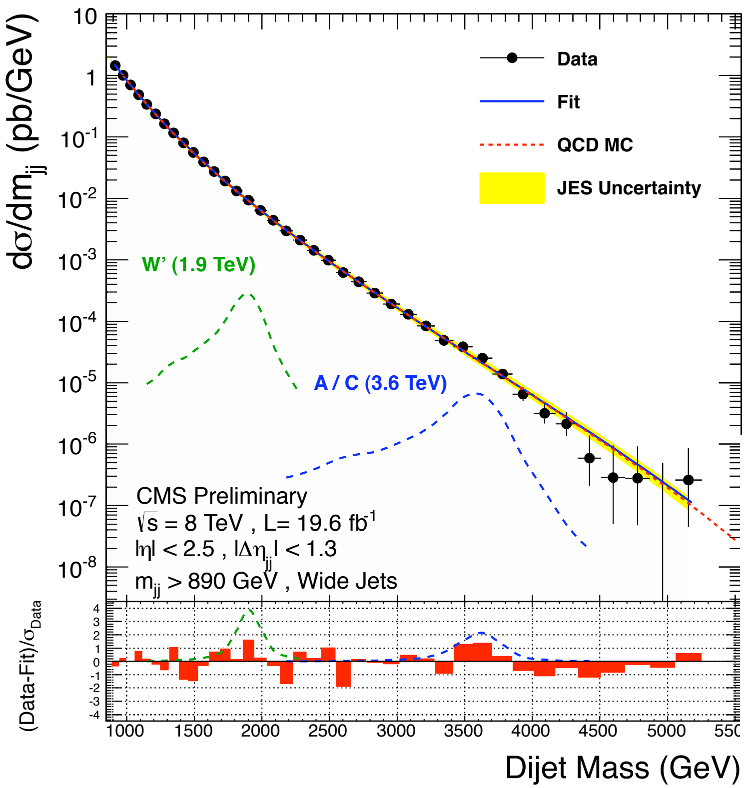


- Because of the exchange of virtual gravitons coupled to SM fermions at the LO of the perturbation theory, enhancement of the Drell-Yan spectrum predicted by SM is expected (depending on the number of extra-dimensions and on their size)
- **CMS and ATLAS data allow to set limits on the main parameters of the model**

Search for dijet resonances

- Many extensions of the Standard Model predict the existence of new massive objects that couple to quarks or antiquarks (q) and gluons (g), thus resulting in resonances in the dijet mass spectrum.

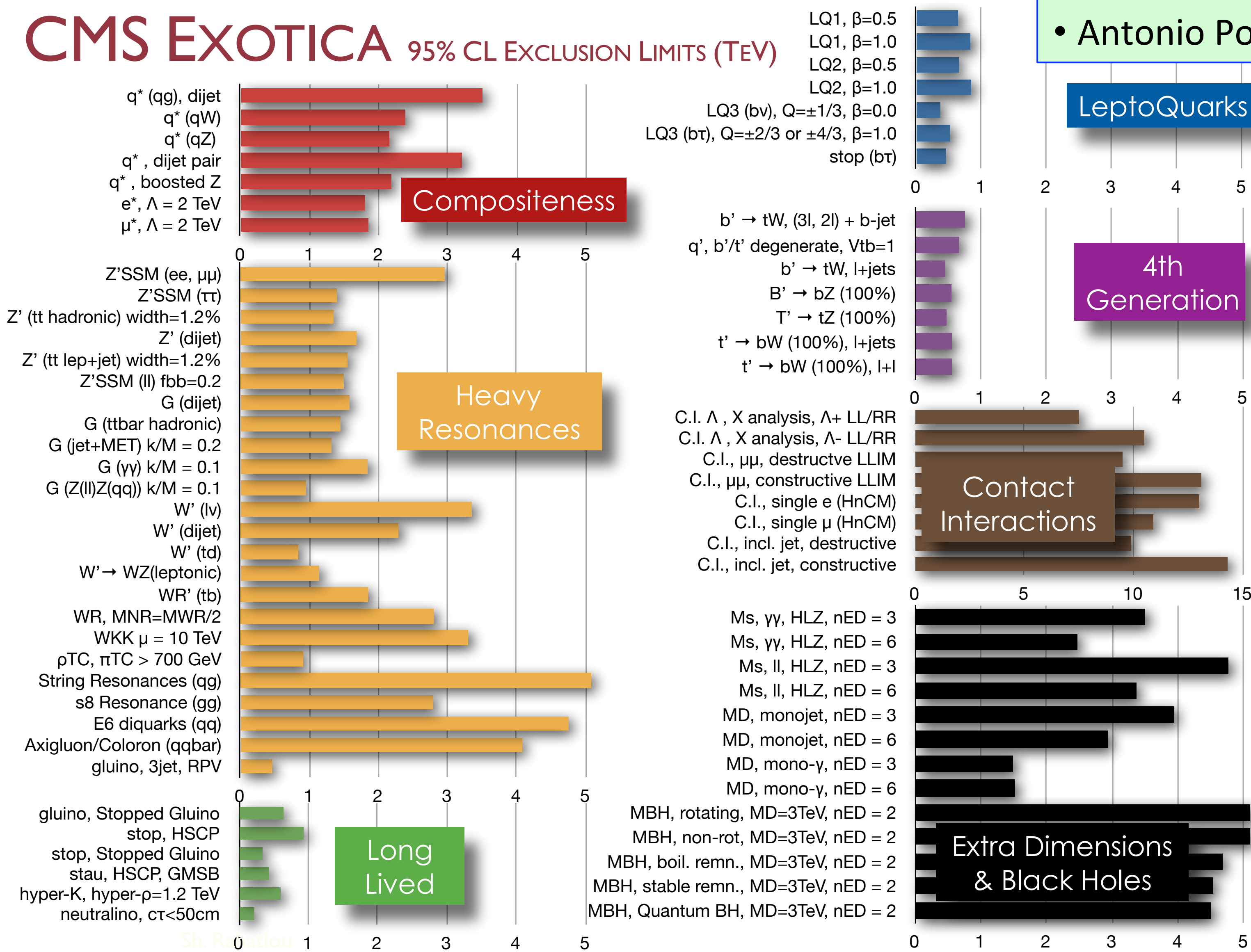




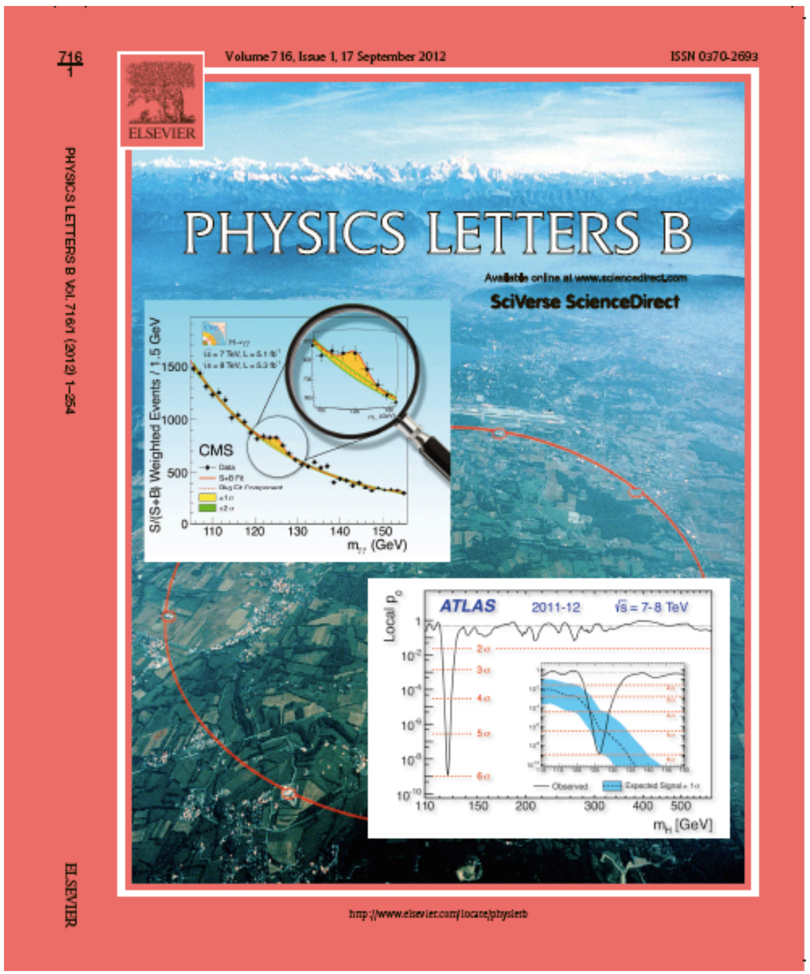
Observed and expected 95% CL exclusions on the mass of various resonances

Model	Final State	Obs. Mass Excl. [TeV]	Exp. Mass Excl. [TeV]
String Resonance (S)	qg	[1.20,5.08]	[1.20,5.00]
Excited Quark (q^*)	qg	[1.20,3.50]	[1.20,3.75]
E_6 Diquark (D)	qq	[1.20,4.75]	[1.20,4.50]
Axigluon (A)/Coloron (C)	$q\bar{q}$	[1.20,3.60] + [3.90,4.08]	[1.20,3.87]
Color Octet Scalar (s8)	gg	[1.20,2.79]	[1.20,2.74]
W′ Boson (W′)	$q\bar{q}$	[1.20,2.29]	[1.20,2.28]
Z′ Boson (Z′)	$q\bar{q}$	[1.20,1.68]	[1.20,1.87]
RS Graviton (G)	$q\bar{q}$+gg	[1.20,1.58]	[1.20,1.43]

see talks by
- Alessio Bonato
- Antonio Policicchio



Search for the SM Higgs boson



ATLAS

Physics Letters B
Volume 716, Issue 1, 17
September 2012, Pages 1–29

Results based on:

- 4.8 fb-1 of data at √s = 7 TeV
- 5.9 fb-1 of data at √s = 8 TeV

CMS

Physics Letters B
Volume 716, Issue 1, 17
September 2012, Pages 30–61

Results based on:

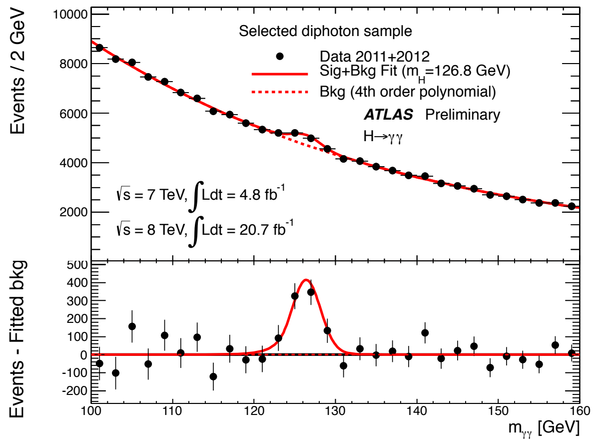
- 5.1 fb-1 of data at √s = 7 TeV
- 5.3 fb-1 of data at √s = 8 TeV

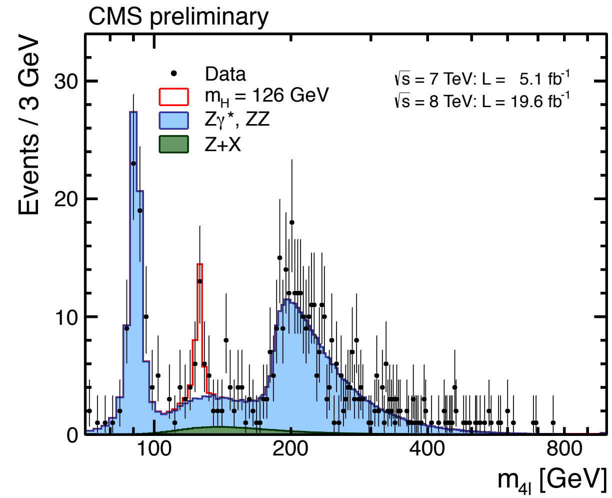
Higgs boson in ATLAS and CMS

channel	signature	S/B	Mass res.	ATLAS 2011+2012 (fb^{-1})	CMS 2011+2012 (fb^{-1})
$H \rightarrow \gamma\gamma$	Two high-p_T photons; Peak in inv. mass	few 10^{-2}	1-2%	5+20	5+20
$H \rightarrow ZZ^* \rightarrow 4l$	Four high-p_T leptons; Peak in inv. mass	≥ 1	1-2%	5+20	5+20
$H \rightarrow WW^* \rightarrow l\nu l\nu$	two high-p_T leptons + MET; Transverse mass	few 10^{-1}	-	5+20	5+20
$H \rightarrow \tau\tau$	2 high-p_T leptonts/ hadronic-τs + MET; inv. mass	few 10^{-2}	~20%	5+13	5+20
$H \rightarrow bb$	Two high-p_T b-jets in assoc. with W or Z; Inv. mass	few 10^{-2}	10-16%	5+13	5+12

ATLAS-CONF-2013-012,013,030
ATLAS-CONF-2012-060,061
CMS-PAS-HIG-13-001,002,003,004
CMS-PAS-HIG-12-019

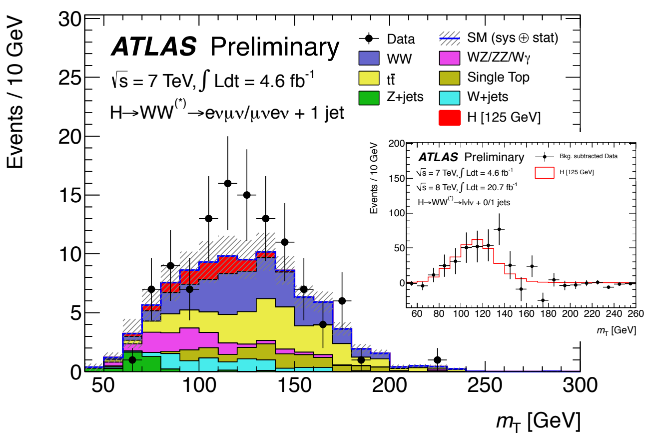
Higgs boson overview

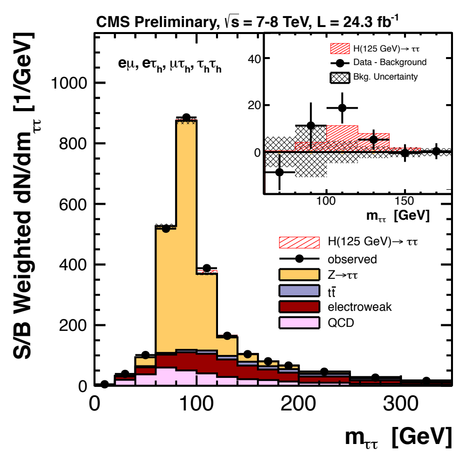


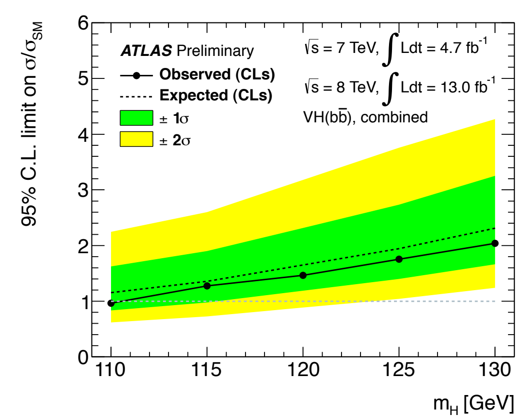


ATLAS: $\mu=1.65 \pm 0.24^{+0.25}_{-0.18}$ @ m=126.8 GeV
$m = 126.8 \pm 0.2 \pm 0.7$ GeV
CMS: $\mu=0.78 \pm 0.27$ @ m=125 GeV
$m = 125.4 \pm 0.5 \pm 0.6$ GeV

ATLAS: $\mu=1.7^{+0.5}_{-0.4}$ @ m=124.3 GeV
$m = 124.3\ ^{+0.6}_{-0.5}\ ^{+0.5}_{-0.3}$ GeV
CMS: $\mu=0.91^{+0.30}_{-0.24}$ @ m=125.8 GeV
$m = 125.8 \pm 0.5 \pm 0.2$ GeV





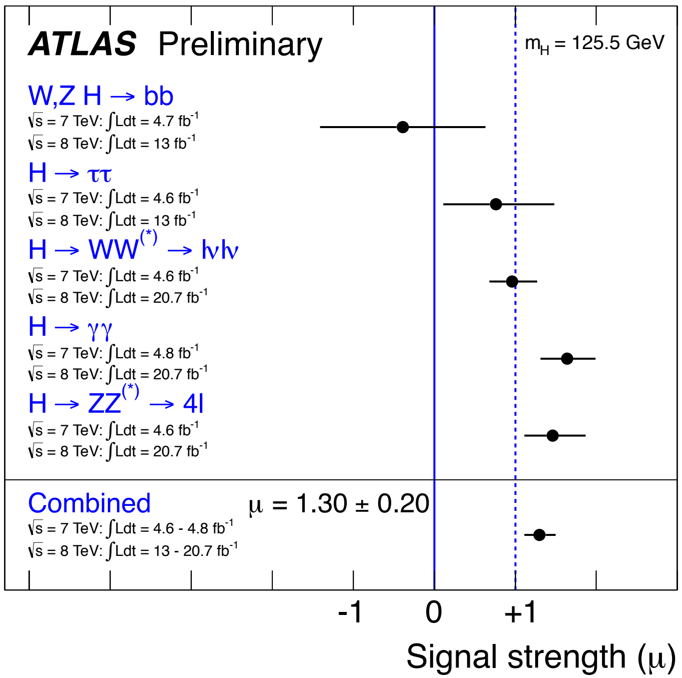


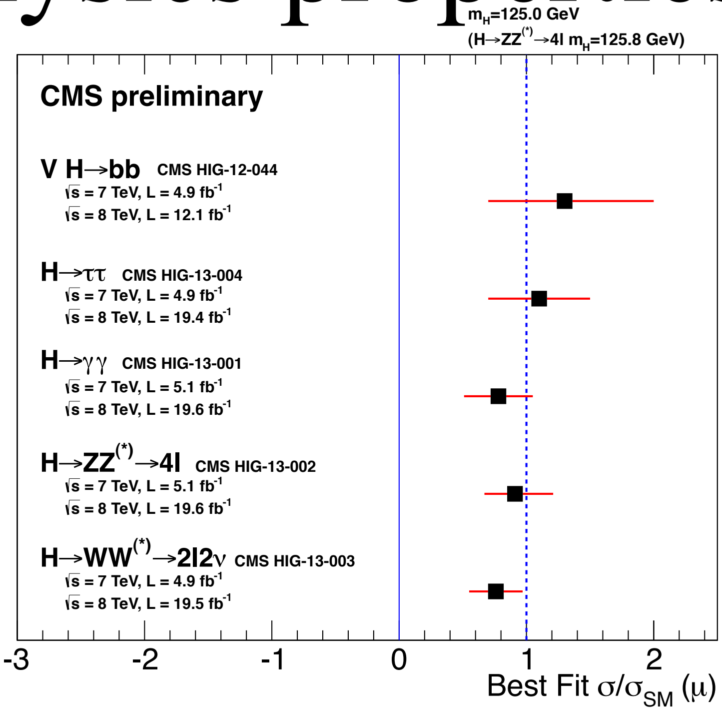
ATLAS: $\mu=1.01 \pm 0.31$ (@ m=140 GeV)
CMS: $\mu=0.76 \pm 0.21$ (@ m=125 GeV)

ATLAS: $\mu=0.7 \pm 0.7$ (@ m=125 GeV)
CMS: $\mu=1.1 \pm 0.4$ (@ m=125 GeV)

ATLAS: no excess
CMS: excess ~ 2.2 σ

Higgs boson: physics properties





Measurements of the signal strength parameter μ for m_H = 125.5 GeV for the individual channels and their contribution.

ATLAS μ = 1.30 ± 0.20 (5+≤21 fb^{-1})

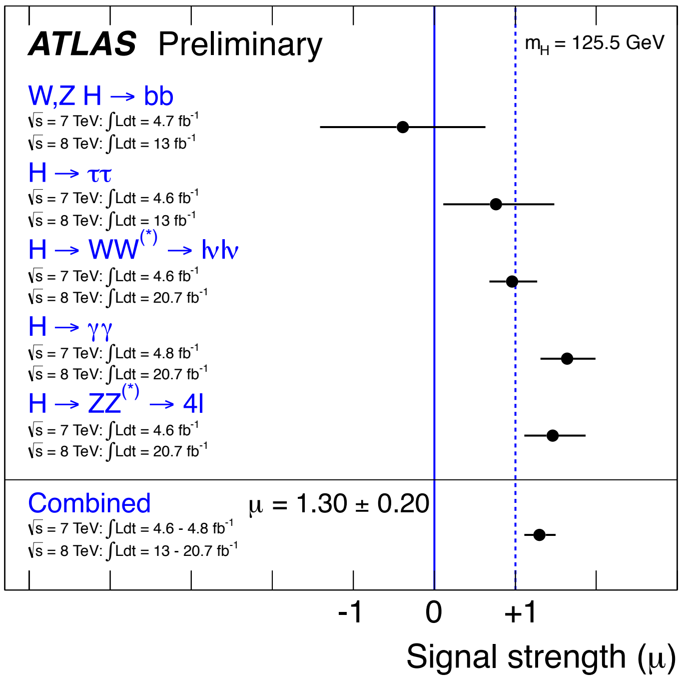
CMS μ = 0.88 ± 0.21 (5+12 fb^{-1}) (pre-Moriond; to be updated with latest results)

ATLAS mass = 125.5±0.2(stat)$^{+0.5}_{-0.6}$(sys)GeV

CMS mass = 125.8 ± 0.4 (stat) ± 0.4 (syst) GeV

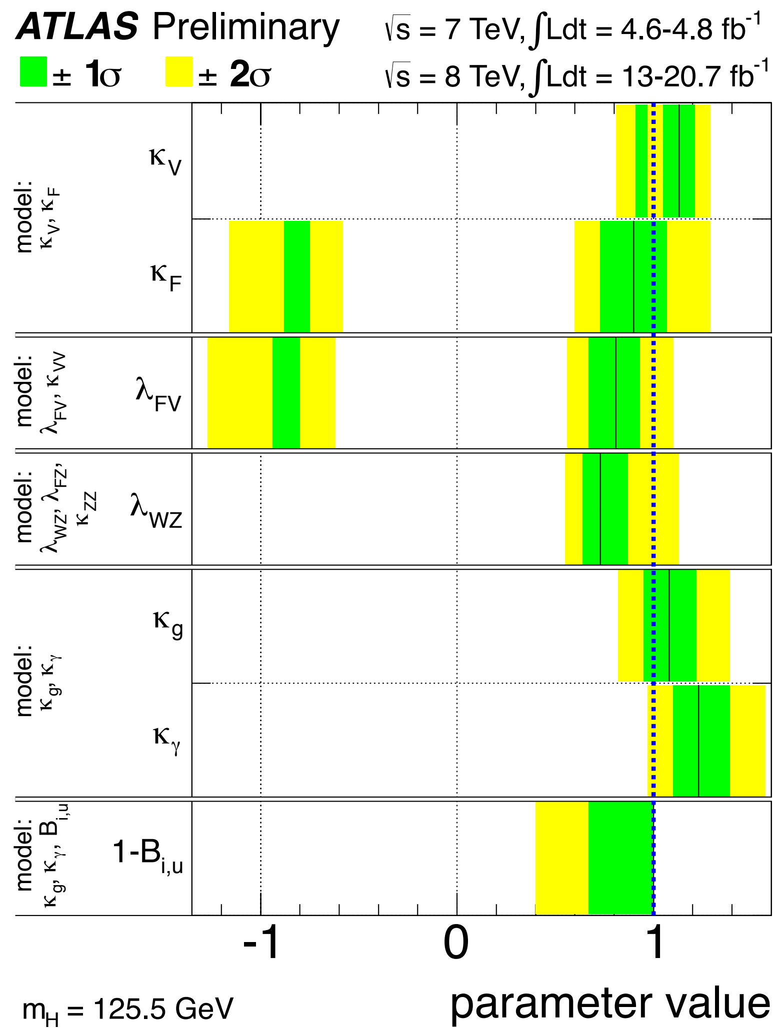
ATLAS-CONF-2013-014 ; ATLAS-CONF-2013-034 ; CMS-PAS-HIG-12-045

Higgs boson: physics properties



$k_V = c_V/c_V^{SM}$
$k_F = c_F/c_F^{SM}$

$\lambda_{FV} = k_F/k_V$
$\lambda_{WZ} = k_W/k_Z$



Measurements of the signal strength parameter μ for m_H = 125.5 GeV for the individual channels and their contribution.

ATLAS $\mu = 1.30 \pm 0.20$ (5+≤21 fb^{-1})
CMS $\mu = 0.88 \pm 0.21$ (5+12 fb^{-1})

ATLAS mass = $125.5 \pm 0.2(stat)^{+0.5}_{-0.6}(sys)$ GeV
CMS mass = 125.8 ± 0.4 (stat) ± 0.4 (syst) GeV

- **Summary of the coupling scale factor measurements for m_H = 125 GeV**

ATLAS-CONF-2013-014 ; ATLAS-CONF-2013-034 ; CMS-PAS-HIG-12-045

Many more Higgs boson studies…

- Spin studies using $H \rightarrow \gamma\gamma$, $H \rightarrow ZZ^* \rightarrow 4l$, $H \rightarrow WW^* \rightarrow l\nu l\nu$ final states
- $WH, H \rightarrow WW^*$
- $H \rightarrow Z\gamma$
- $H \rightarrow \mu\mu$
- ZH, $H \rightarrow$ Invisible decays
- 2HDM WW ($l\nu l\nu$)
- MSSM Higgs boson searches

see talks by
- Elvira Rossi
- Marianna Testa
- Emanuele Di Marco
- Michele De Gruttola
- Leonardo Carminati
- Andrea Benaglia
- Marcello Fanti
- Mario Pellicciorni
- Sommario Teorico

➔ detailed discussion on Higgs boson searches & studies during this Workshop

Implications of a Higgs boson discovery

- Higgs boson properties consistent with Standard Model
  - But cannot rule our other possibilities
- Mass ~ 125 GeV excludes large regions of MSSM SUSY parameter space
- EW-scale SUSY still possible with
  - Large mixing in the stop sector, or
  - Extra matter or gauge fields (extra gauge bosons,…)
- Two possible path to (new) discoveries:
  - Exploration of Higgs boson properties
  - Direct observation of the new particles or phenomena

The priorities for energy frontier physics after July 4th

- The recently discovered new particle drives to a number of fundamental open points that are top priority for the physics programme for the LHC and future energy frontier accelerators:
  1. Precision measurement of the mass and of the natural width of this new particle
  2. Determination of the quantum numbers spin and parity, J^P, and CP properties
  3. Precise measurement of couplings to elementary fermions and bosons
  4. Access Higgs boson self-coupling strength
  5. Comparison of these physics properties with those predicted by Standard Model
  6. Search for possible partners (neutral/charged) of this boson
  7. Is this particle a fundamental object, or it is composite?

The priorities for energy frontier physics after July 4th

8. Analyse the Vector Boson scattering cross section to study whether the cross-section regularization is operated by the Higgs boson (as predicted by SM) or (also) by other processes associated to physics beyond SM;
9. Continue the search for SUSY particles, in particular search for third generation squarks: to be effective, the mass of the stop quark cannot be too different from the on of the top quark; also continue the search for gauginos and for 1st and 2nd generation squarks;
10. Continue the search for heavy resonances decaying to photon, lepton or quark pairs, and for deviations from SM of physics distributions highly sensitive to New Physics (di-jet angular distribution,…)

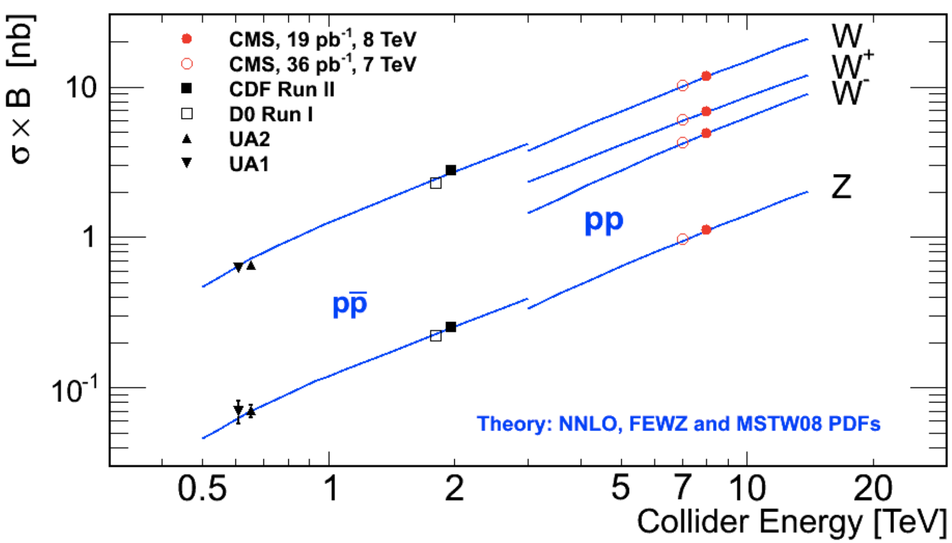
conclusions

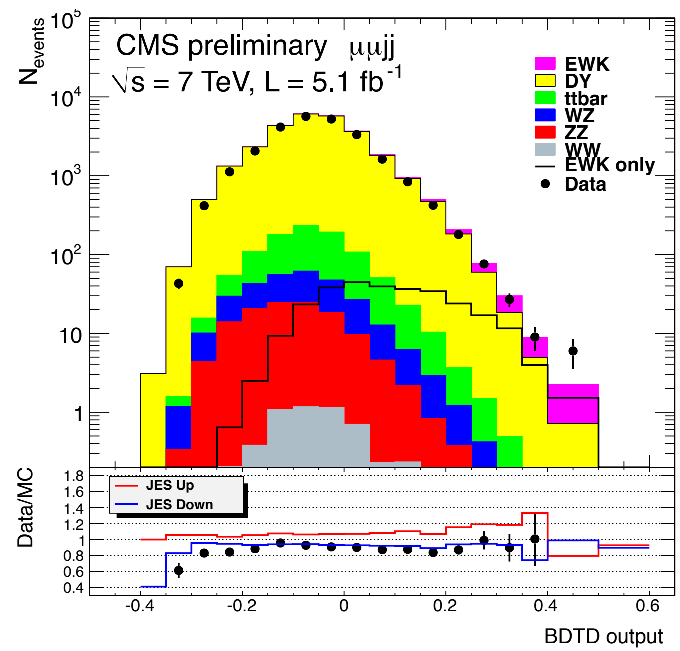
- A new resonance at m~125 GeV discovered with ~ 10 fb-1 of data at $\sqrt{s}$=7 and 8 TeV
  - With present uncertainties, it is consistent with the SM Higgs boson
- The Standard Model explains the pp LHC data analysed so far
- However we have analysed < 10% of the data that LHC will produce at significantly larger collision energy
- We are just at the beginning of the "TeV" scale exploration:
  - Study with the ultimate accuracy the properties of the Higgs boson recently discovered: extraordinary test of SM!
  - Continue SM measurements and BSM searches at the highest energy that LHC will provide

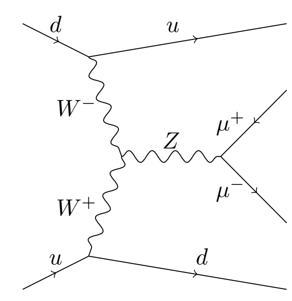
backup

W e Z bosons

- Vector boson production important because it is an important benchmark for QCK and EWK. Deviations from SM would expectations would indicate New Physics
- Long list of measurements on V+jets, V+heavy flavours, differential cross sections, W polarization, etc etc
- First results on Z electroweak production

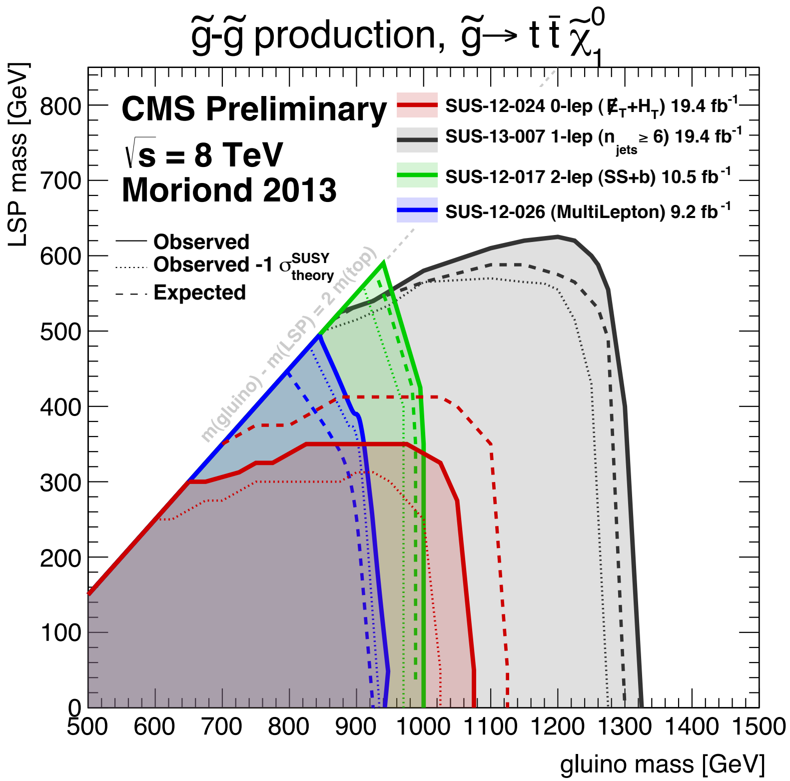


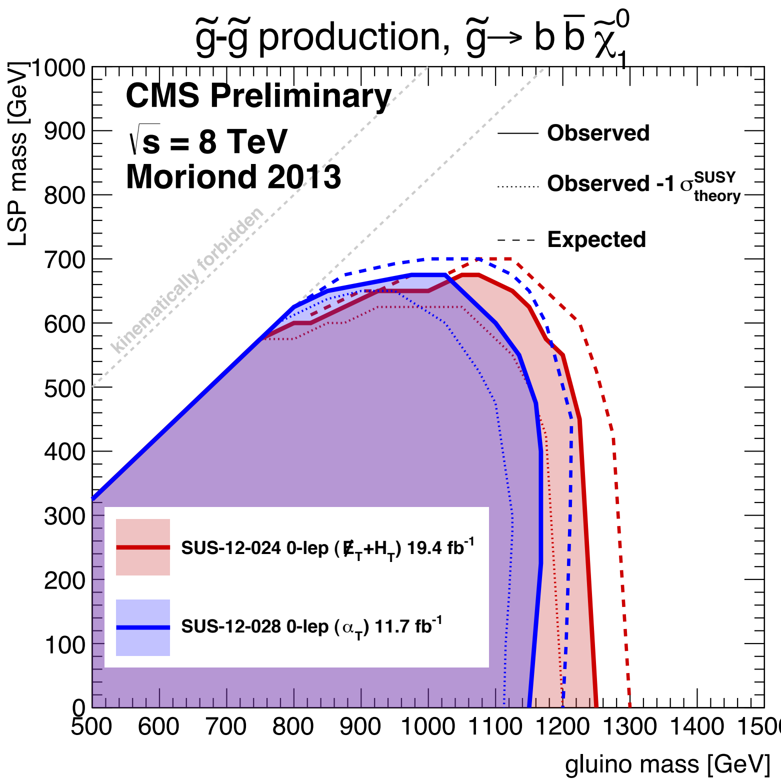


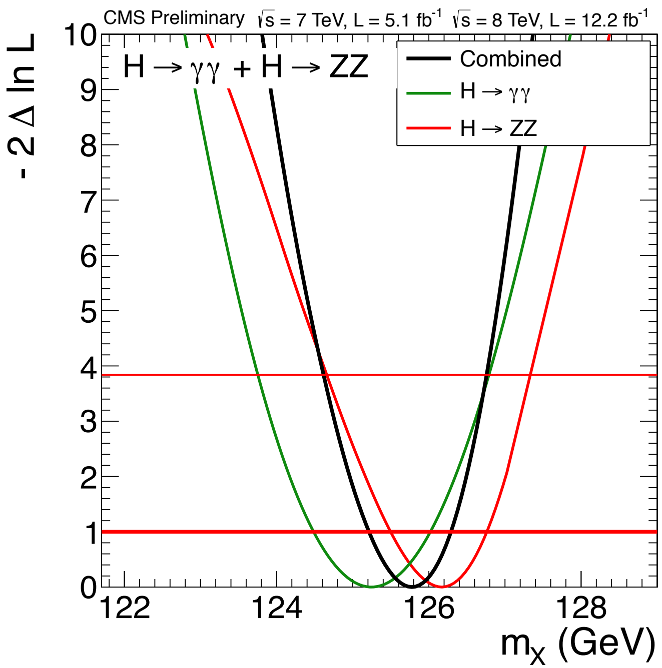


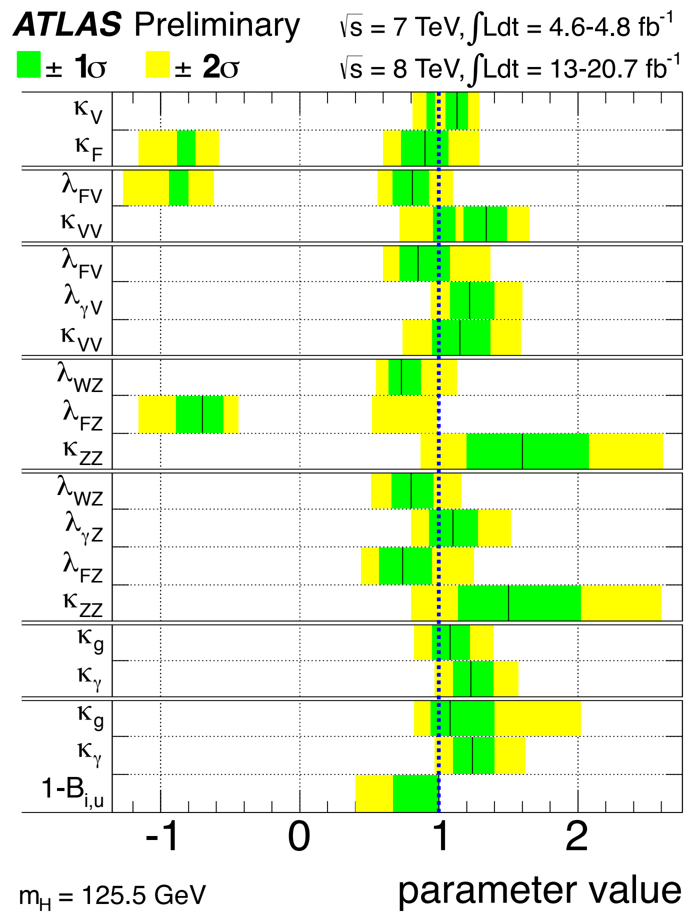
- at 7 TeV (36/pb): experimental precision ~**1% level**, especially for ratio-observables
- **new 8 TeV results from dedicated low-pile up run early in 2012**
- total uncert. 2-5 % (4.4 % lumi, 2-3% acceptance, 1.1-1.7% exp)
- good agreement with NNLO QCD, both at 7 and 8 TeV

SUSY: 3rd generation searches

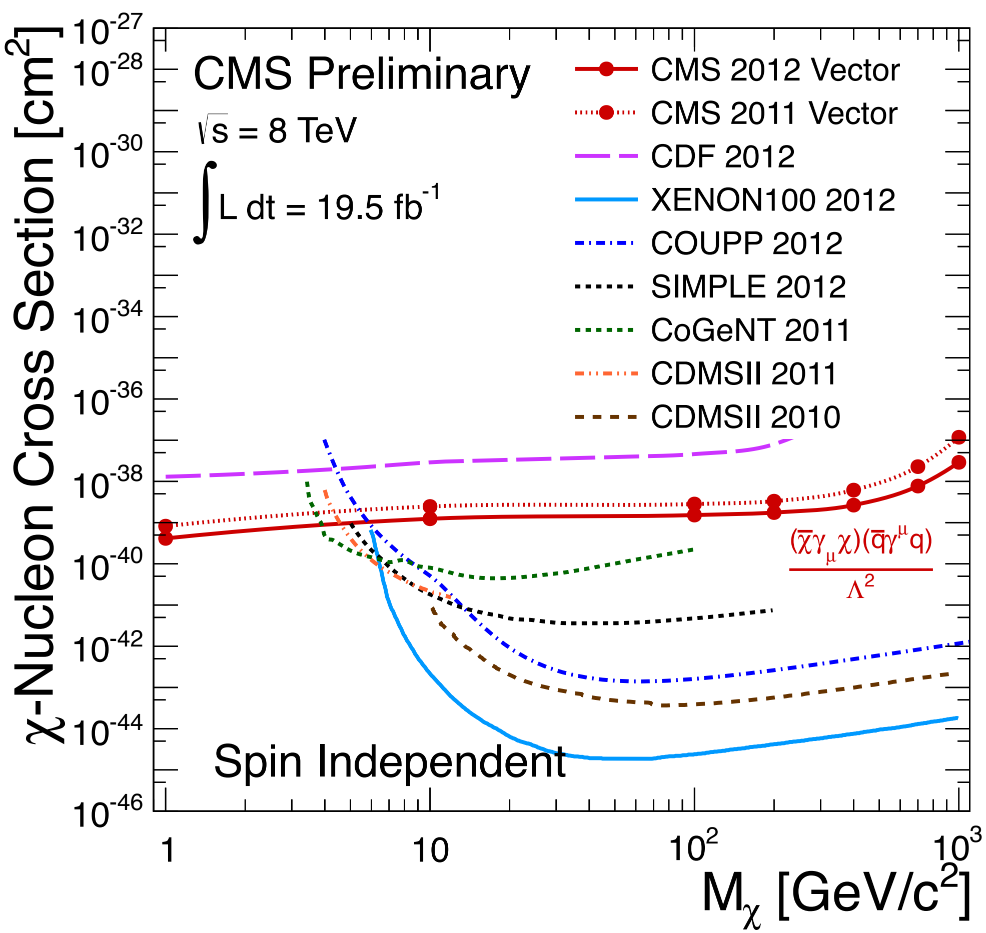




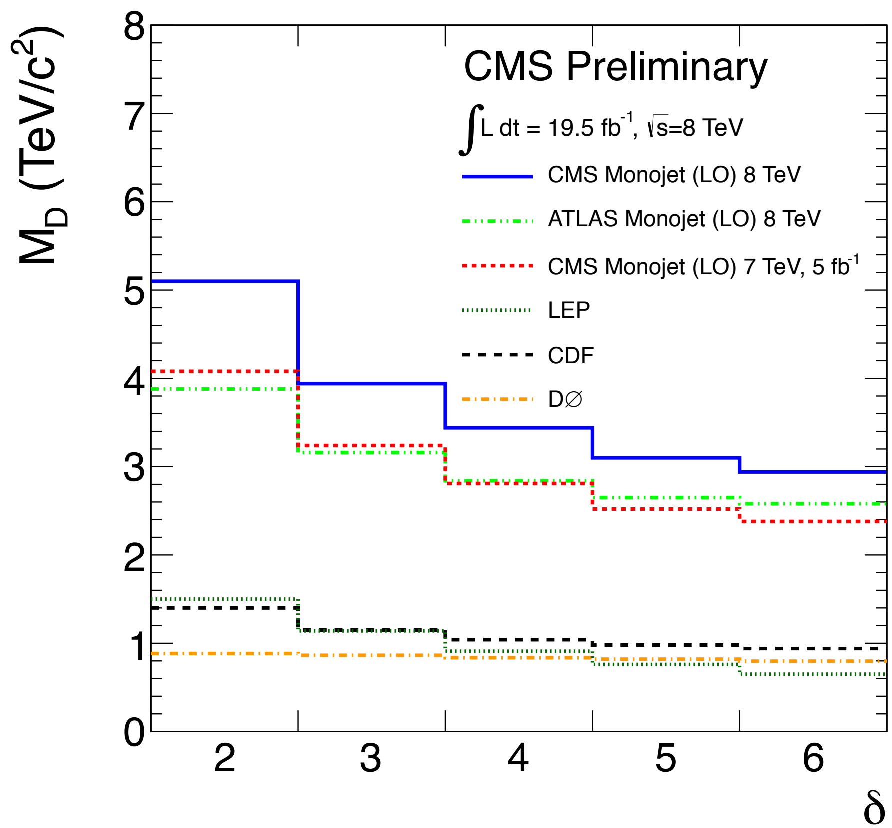

CMS Preliminary √s = 7 TeV, L = 5.1 fb-1 √s = 8 TeV, L = 12.2 fb-1
H → γγ + H → ZZ
Combined
H → γγ
H → ZZ
- 2 Δ ln L
mX (GeV)


ATLAS Preliminary
√s = 7 TeV, ∫Ldt = 4.6-4.8 fb-1
√s = 8 TeV, ∫Ldt = 13-20.7 fb-1
± 1σ
± 2σ
κV
κF
λFV
κVV
λFV
λγV
κVV
λWZ
λFZ
κZZ
λWZ
λγZ
λFZ
κZZ
κg
κγ
κg
κγ
1-Bi,u
parameter value
mH = 125.5 GeV

New Physics in monojet events in pp collisions



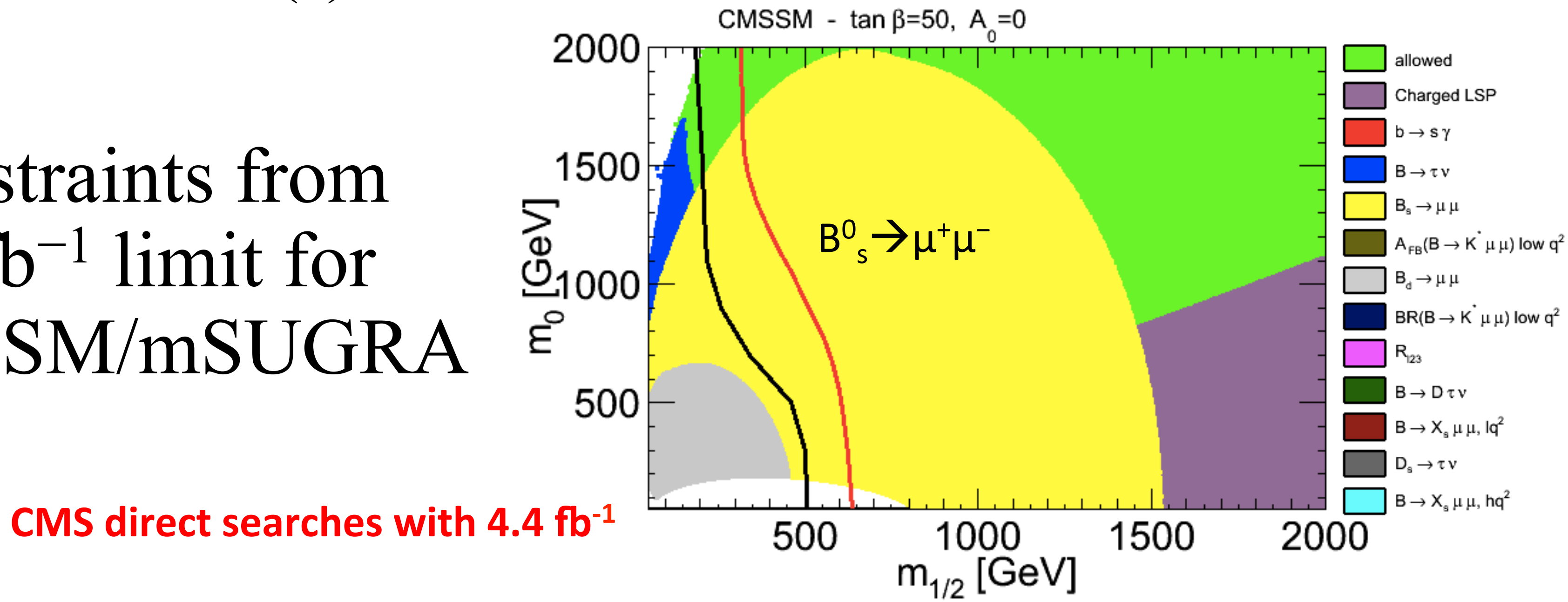
95% CL limits on Dark Matter – Nucleon interaction cross section



95% CL limits on the ADD model parameters M_D and δ

$B^0_{(s)} \rightarrow \mu^+\mu^-$ implications

- Constraints from 1.0 fb^{-1} limit for cMSSM/mSUGRA

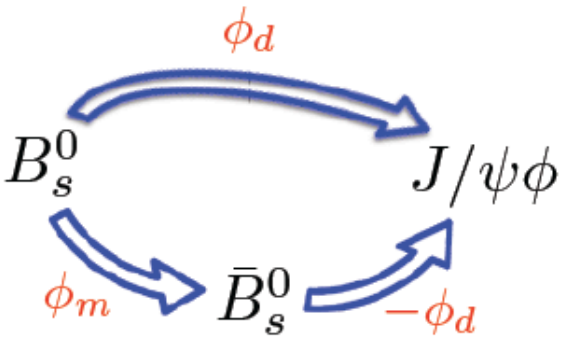


F. Mahmoudi arxiv:1205.3099

- $B^0_{(s)} \rightarrow \mu^+\mu^-$ limit strongly constraints CMSSM at large values of tanβ

Mixing induced CP violation in B_s^0-system

- Interference between mixing and decay gives rise to a $\not{C}\not{P}$ phase: $\phi_s = \phi_m - 2\phi_d$.
- For $B_s^0 \to J/\psi\,\phi$, $\phi_d = -2\arg(V_{cs}V_{cb}^*) \approx 0$ and

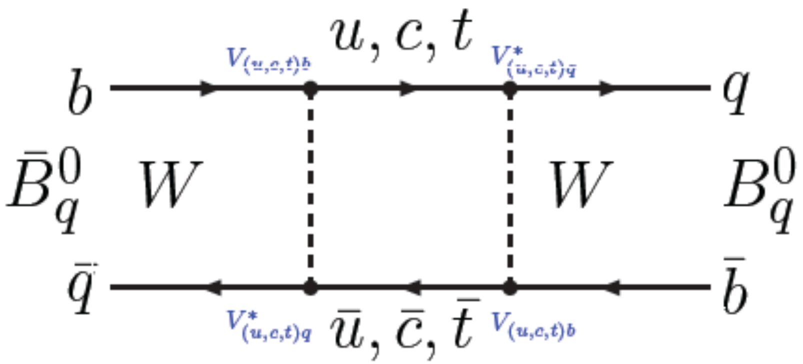


$$\phi_s^{\text{SM}} = -2\arg\left(\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right) = -0.036 \pm 0.002\,\text{rad}$$

Charles et al. [Phys. Rev. D84 (2011) 033005]

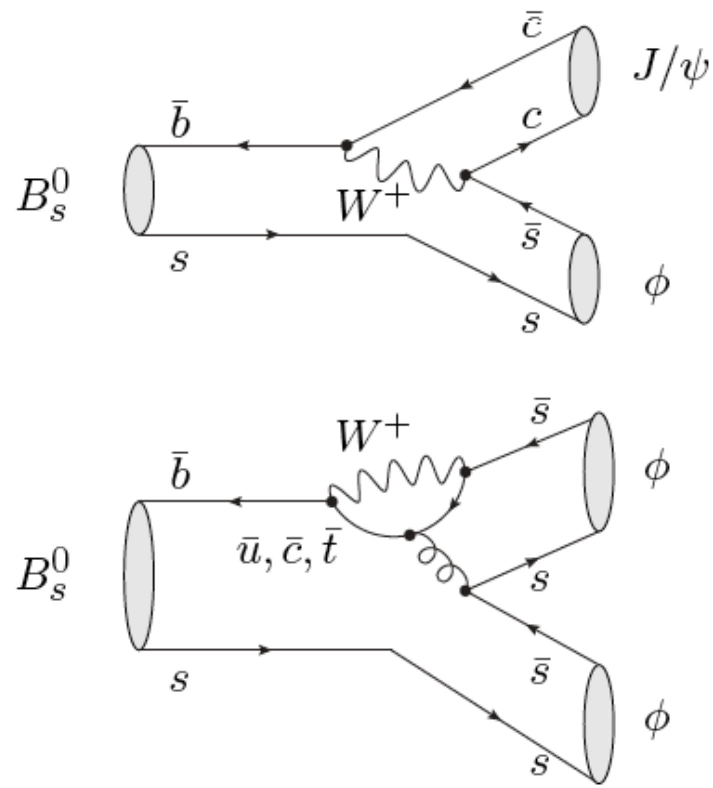
- Mixing phase, ϕ_m, from $\Delta B = 2$ box diagram.

→ Sensitive to NP contributions.



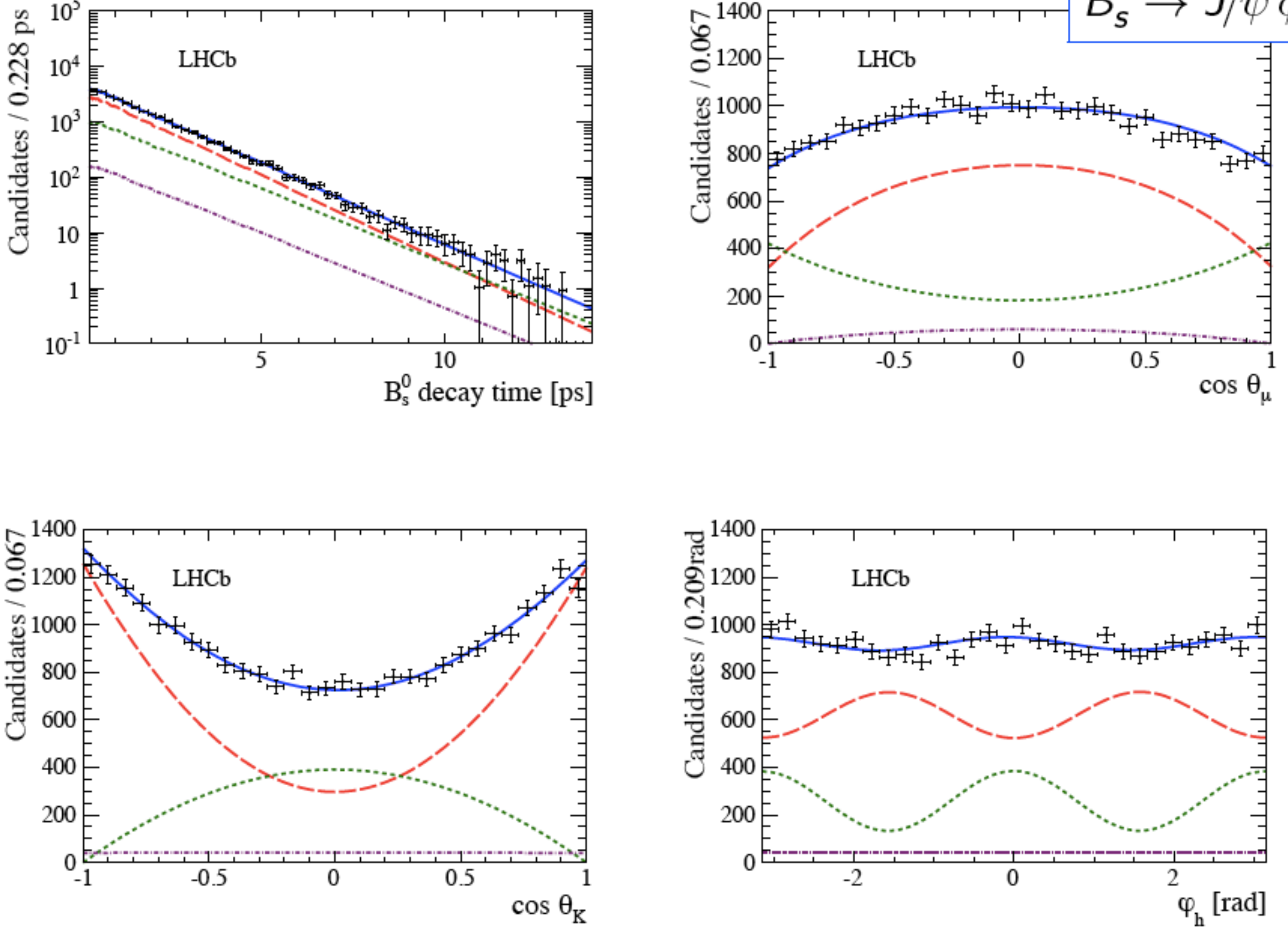
Mixing induced CP violation in B_s^0-system

- Can also look at $B_s^0 \to \phi\phi$ decays (gluonic penguin).
- Loop suppressed $\to 880 \pm 31$ candidates. Can also receive NP contribution to the decay.
- In the SM, partial cancellation between ϕ_m and ϕ_d $\to$ expect $\phi_s^{s\bar{s}s} \sim 0$.



- In both cases, perform a time dependent, flavour tagged, angular analysis to separate the CP-odd and CP-even final states.

$B_s^0 \to J/\psi\,\phi$



CP even, CP odd, S-wave

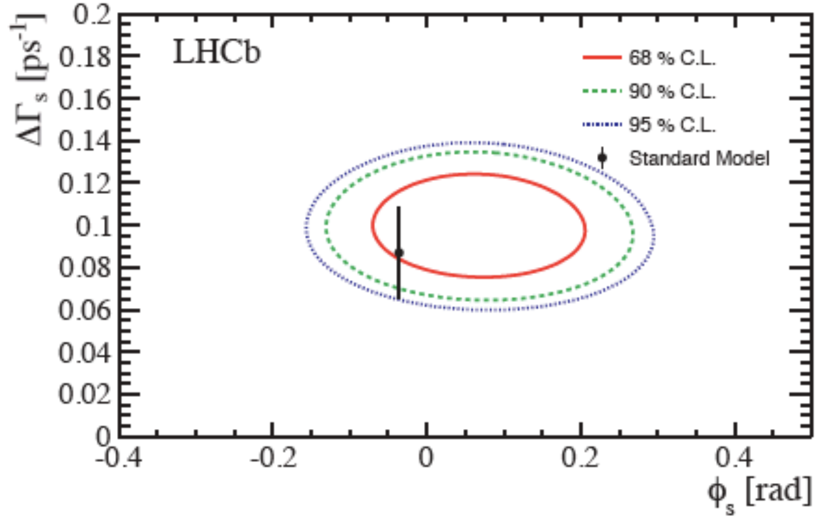
Mixing induced CP violation in $B_s^0 \to J/\psi\,\phi$

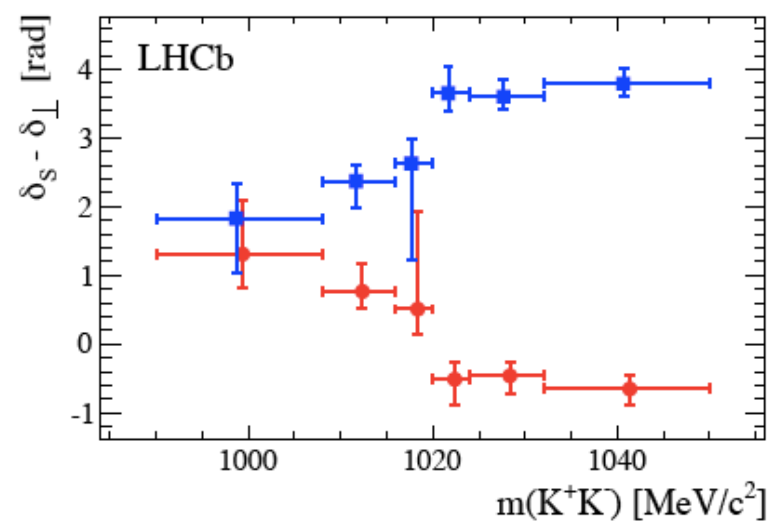
- Several improvements in the analysis from the preliminary result:

1. Added same-side kaon tagging, $\varepsilon\mathcal{D}^2 = (0.89 \pm 0.17)\%$.
2. Simultaneous fit in six bins of $m_{K^+K^-}$. The strong phase dependence across the ϕ pole-mass is used to resolve the sign of $\Delta\Gamma_s$.
3. Allow for CP violation in the decay,

$$|\lambda| = |\frac{q}{p}\frac{\bar{A}_f}{A_f}| = 0.94 \pm 0.03 \pm 0.02.$$

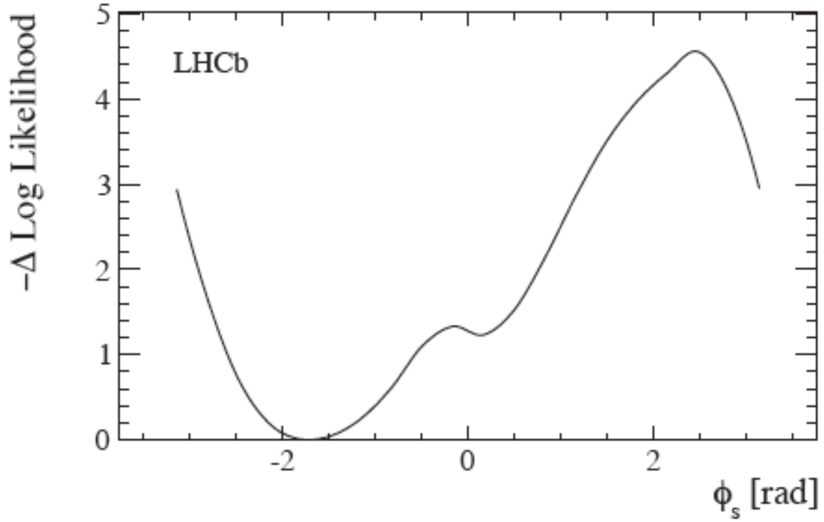
- Dominant source of systematic uncertainty arises from the angular acceptance (limited MC statistics).





Mixing induced CP violation in $B_s^0 \to \phi\phi$

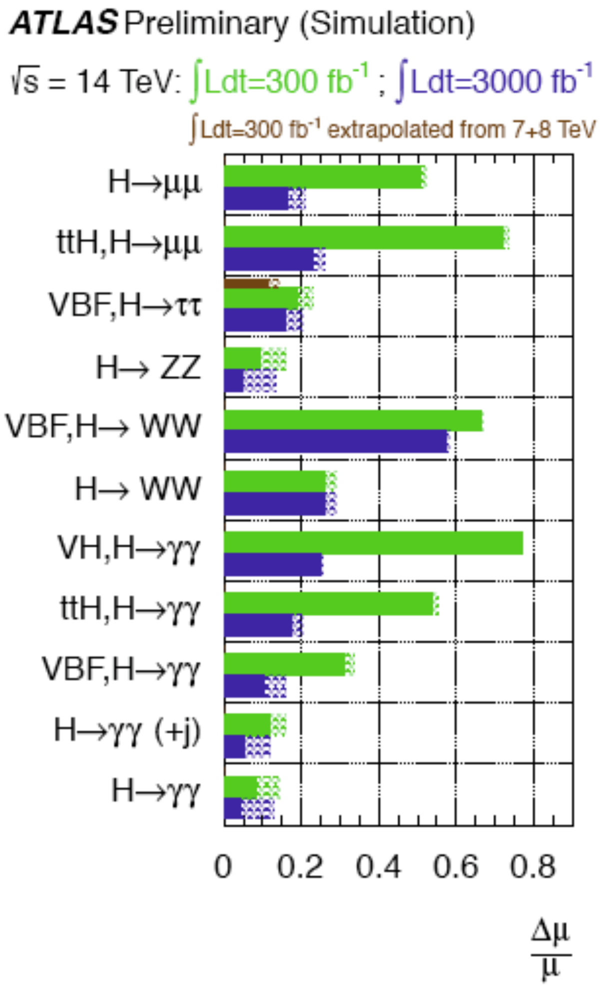
- Small dataset $\to$ Feldman Cousins (pseudo-experiments) are used to provide the correct coverage.
- The result is statistically limited.

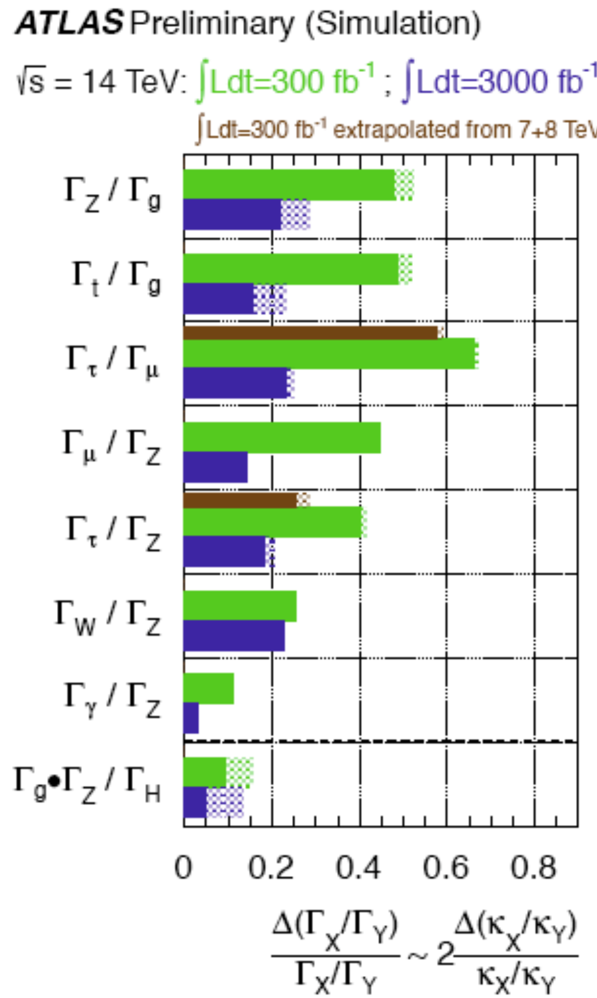


ϕ_s in interval $[-2.46, -0.76]\,\mathrm{rad}$ at 68% CL.

- p-value of $\phi_s = 0$ is 16%.
- The dominant sources of systematic uncertainty arise from:
  - the description of the decay time acceptance;
  - the knowledge of the S-wave contamination from $B_s^0 \to f^0\phi$ and $B_s^0 \to f^0 f^0$.
- Interesting analysis to pursue with larger datasets (NB: we have an additional $2\,\mathrm{fb}^{-1}$ on tape).

Higgs Couplings at the HL-LHC





Left: Expected measurement precision on the signal strength $\mu = (\sigma\times BR)/(\sigma\times BR)_{SM}$ in all considered channels.

Right: Expected measurement precisions on ratios of Higgs boson partial widths without theory assumptions on the particle content in Higgs loops or the total width.

	$300\ \mathrm{fb}^{-1}$	$3000\ \mathrm{fb}^{-1}$
κ_V	3.0% (5.6%)	1.9% (4.5%)
κ_F	8.9% (10%)	3.6% (5.9%)

Expected precision for the determination of the coupling scale factors k_V and k_F. No additional BSM contributions are allowed in either loops or in the total width (numbers in brackets include current theory systematic uncertainties).

Higgs Couplings at the HL-LHC

CMS Coupling	Uncertainty (%)			
	300 fb^{-1}		3000 fb^{-1}	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2
κ_γ	6.5	5.1	5.4	1.5
κ_V	5.7	2.7	4.5	1.0
κ_g	11	5.7	7.5	2.7
κ_b	15	6.9	11	2.7
κ_t	14	8.7	8.0	3.9
κ_τ	8.5	5.1	5.4	2.0

- Coupling CMS projection: In the first one (Scenario 1) all systematic uncertainties are kept unchanged. In the second one (Scenario 2) the theoretical uncertainties are scaled by a factor of 1/2, while other systematical uncertainties are scaled by the square root of the integrated luminosity.

Couplings can be measured at the level of few %