

Highlights from the LHC

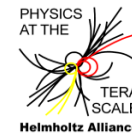


A. Straessner



TECHNISCHE
UNIVERSITÄT
DRESDEN

on behalf of
the ATLAS and CMS Collaborations



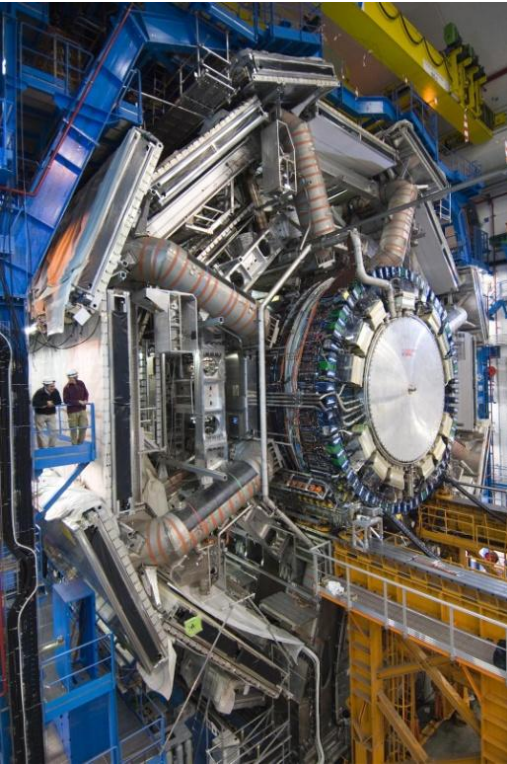
FSP 101

ATLAS

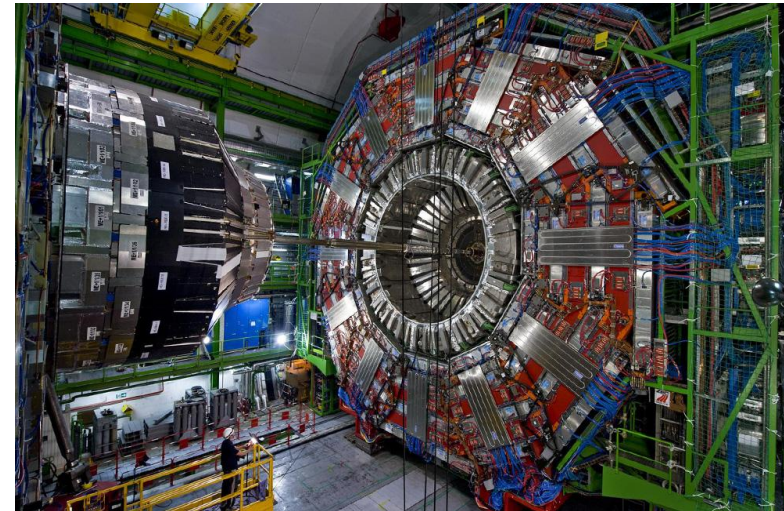


Bundesministerium
für Bildung
und Forschung

Vulcano Workshop 2012
Frontier Objects in Astrophysics and Particle Physics
May 28 – June 2, 2012



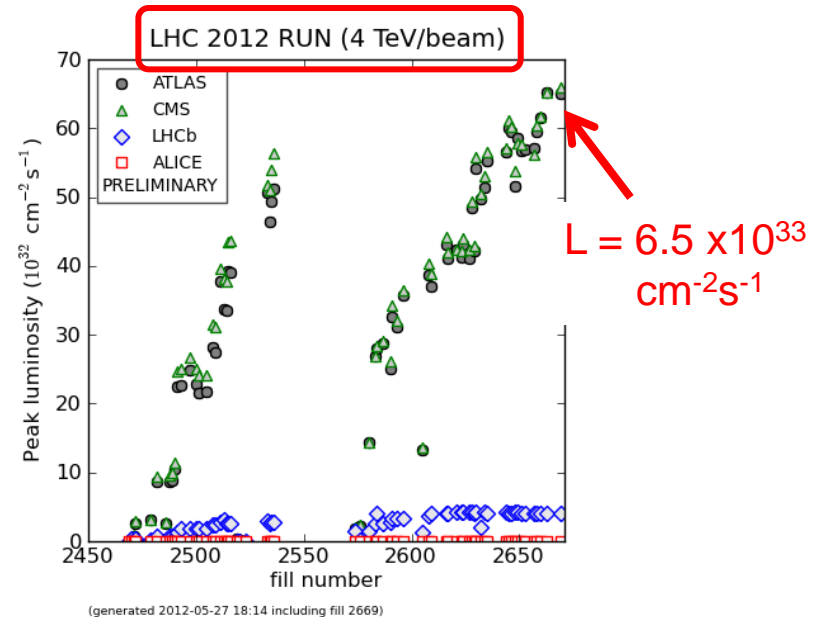
- Introduction:
 - Performance of LHC, ATLAS and CMS
- Recent Results:
 - Standard Model Measurements
 - Searches for Higgs Bosons
 - Supersymmetry Searches
 - Exotic Particles
- Summary and Outlook



LHC Performance and Plans

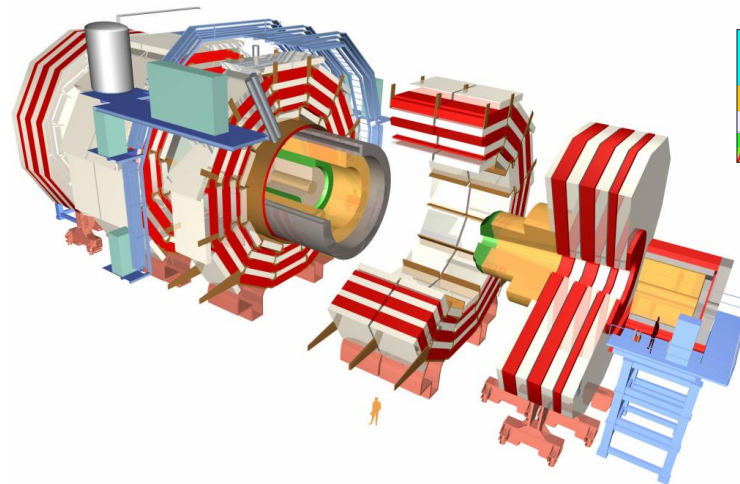
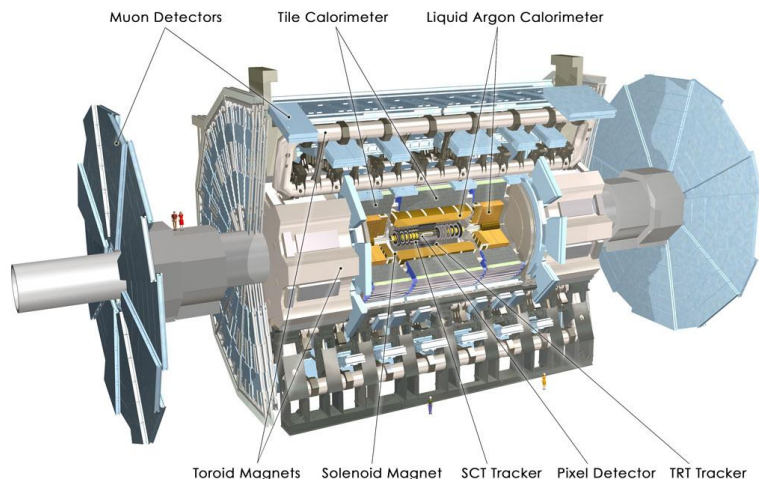


- Large Hadron Collider (LHC): proton-proton collisions at 7-13 TeV
- 4 main particle detectors:
 - ATLAS, CMS: general purpose
 - LHCb: B-physics
 - ALICE: heavy-ion physics

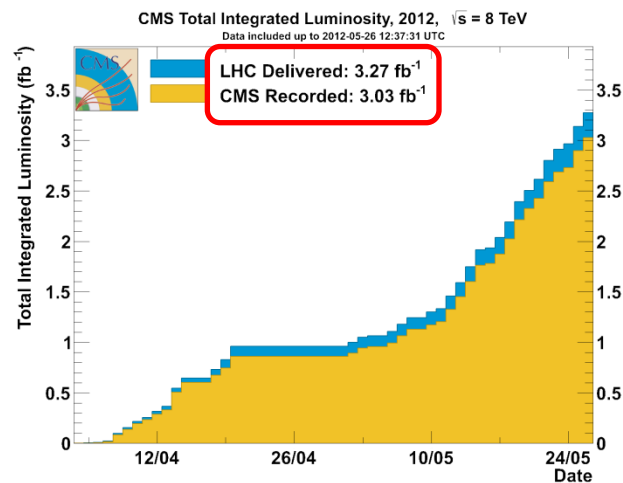
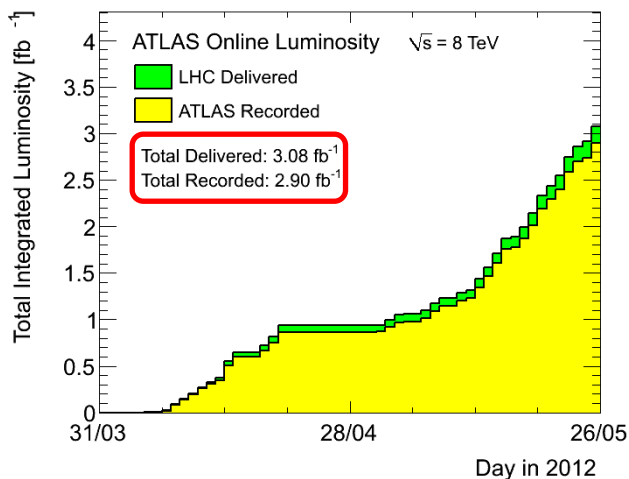


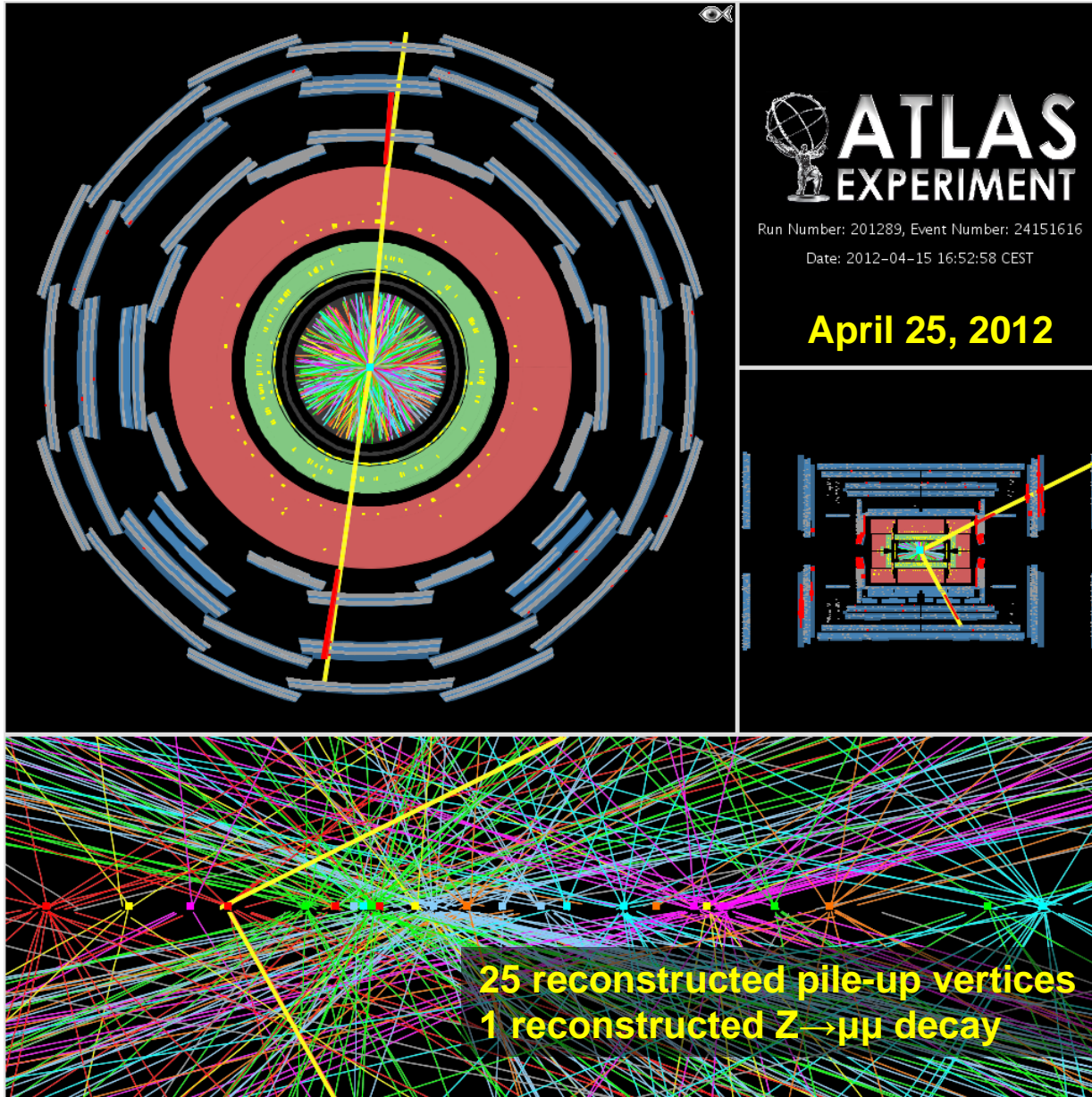
- Further LHC plans:
 - Long shut down in 2013/14 to repair magnet splices to prepare for 13 TeV running
 - Expect $L=2 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ after long shut-down (= $2 \times L_{\text{nominal}}$!)

ATLAS and CMS Detectors at the LHC

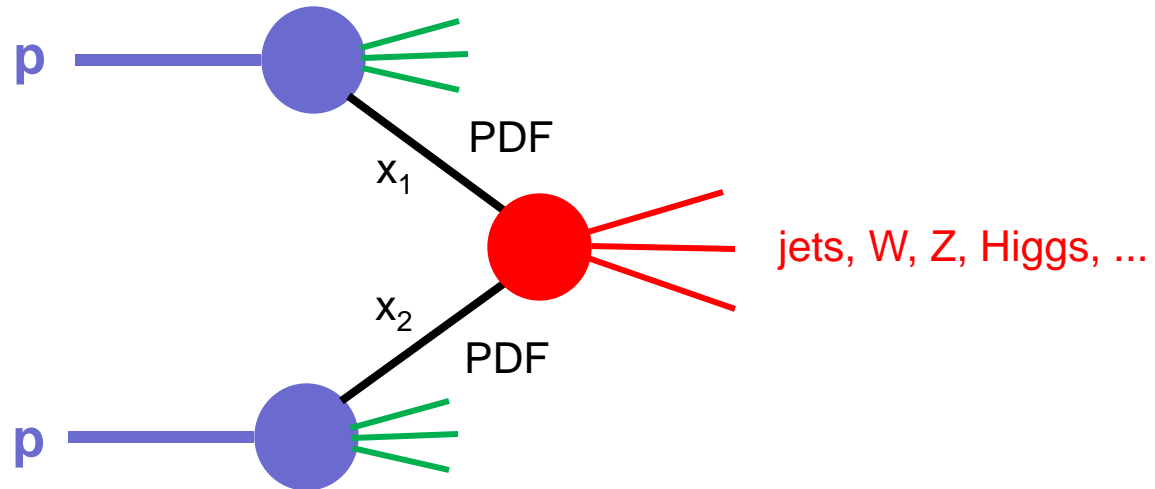


- ATLAS and CMS detectors performed well in 2011 with efficient data taking:
 - 97% - 100% of detector channels operational
 - 91% - 93% data taking efficiency
- Luminosity recorded at 7 TeV centre-of-mass energy : $\sim 5.3 \text{ fb}^{-1}$ per experiment \rightarrow **this talk**
- 2012 run at 8 TeV: $\sim 3 \text{ fb}^{-1}$ per experiment collected \rightarrow aiming for a total of 20 fb^{-1} per experiment





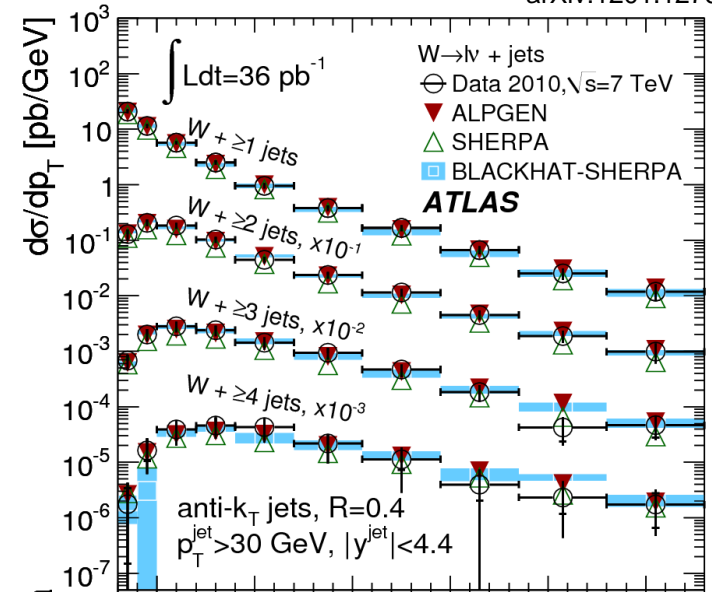
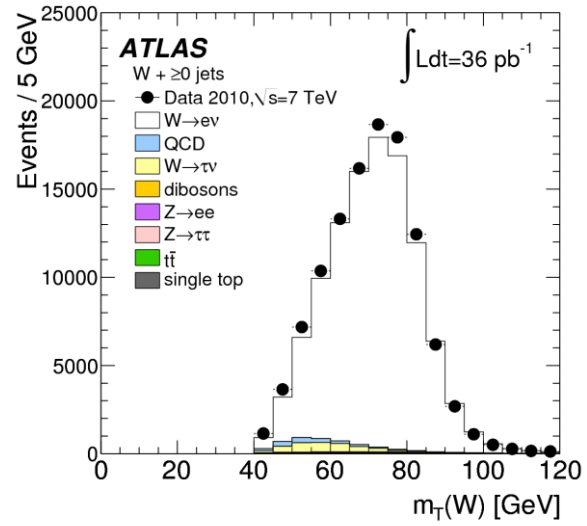
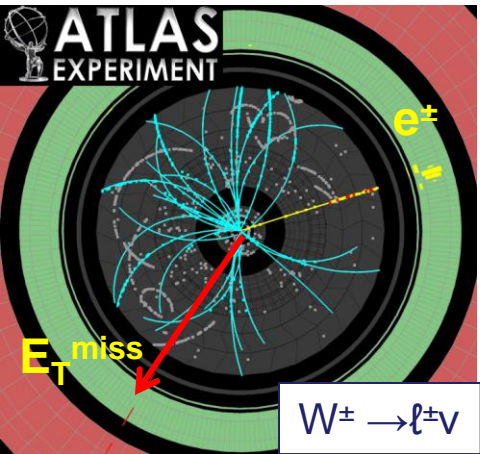
Standard Model Measurements



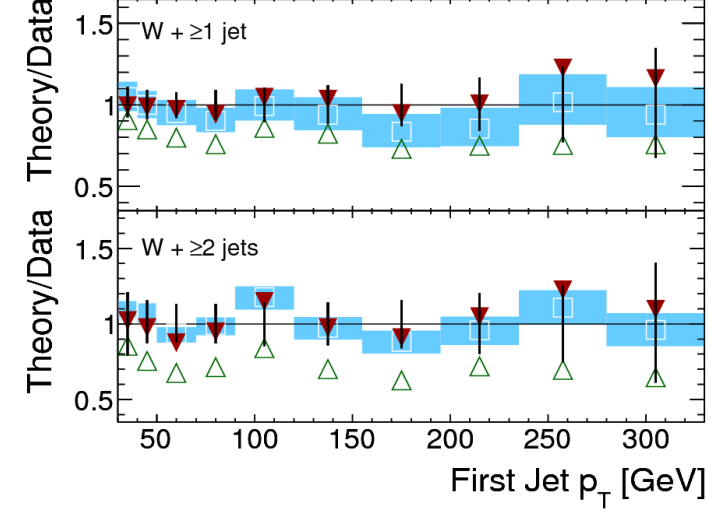
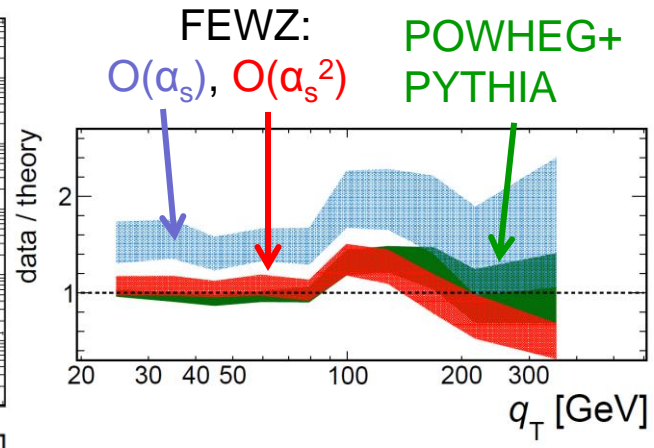
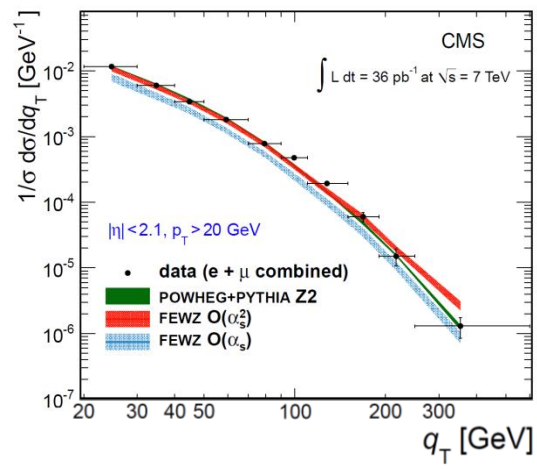
W and Z + Jets Production

- Measurement of $W \rightarrow \ell\nu$ and $Z \rightarrow \ell\ell$ cross-sections in agreement with Standard Model predictions
- Many detailed studies of W/Z+jet production \rightarrow background to New Physics signatures

arXiv:1201.1276

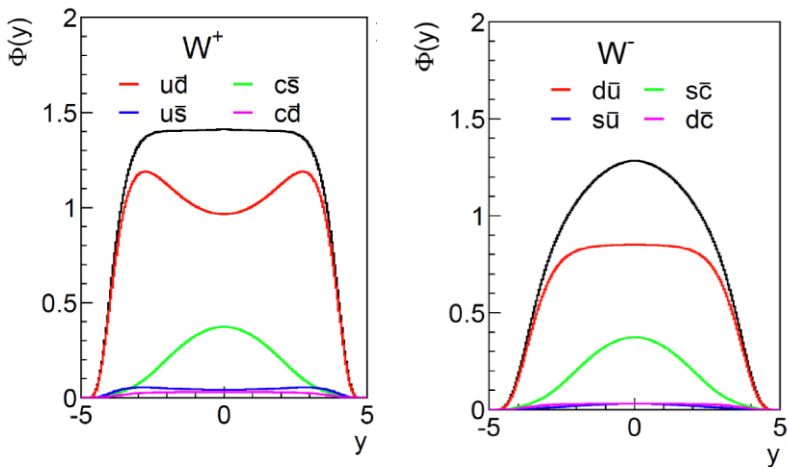


- Measurement of $p_T = q_T$ distribution of W- and Z-bosons \rightarrow preparation for precision M_W measurement,...

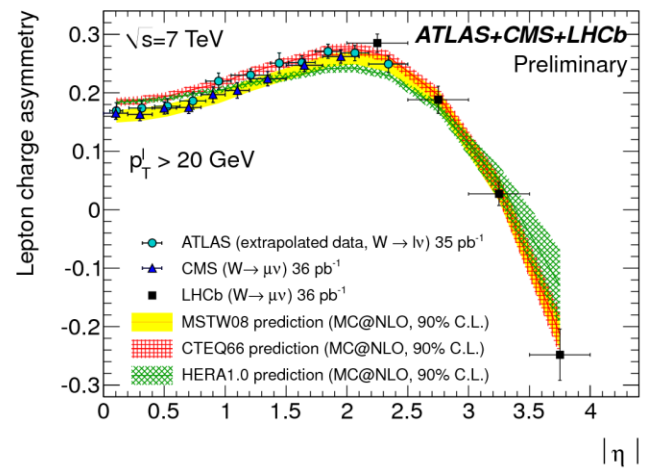


W± Charge Asymmetry and Strange Quarks

- Different quark flavor contributions in $d\sigma/dy(W^\pm) \rightarrow$ leptonic charge asymmetry in $W^\pm \rightarrow \ell^\pm \nu$ decays

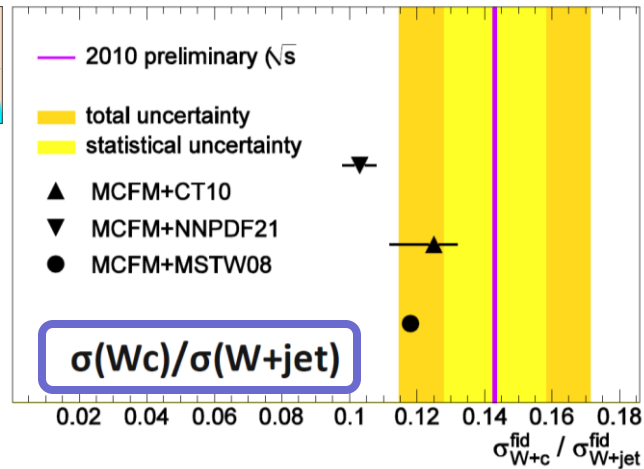
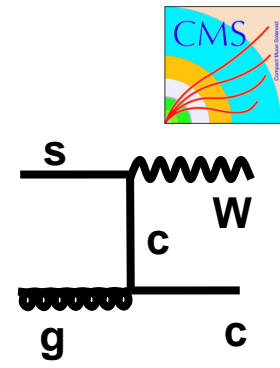
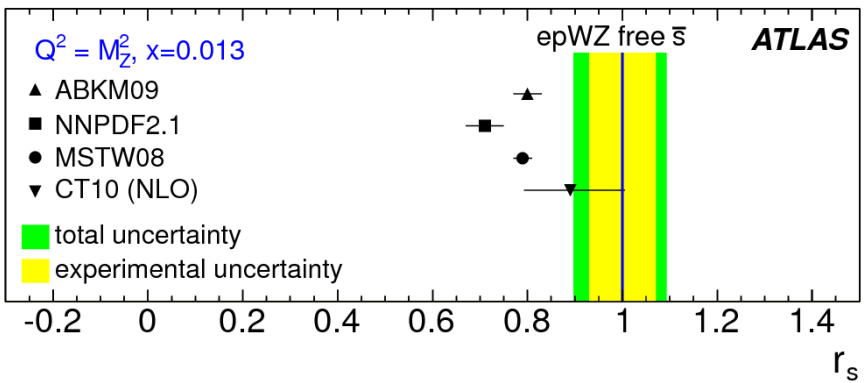


$$A_\ell(\eta) = \frac{N_\ell^+(\eta) - N_\ell^-(\eta)}{N_\ell^+(\eta) + N_\ell^-(\eta)}$$



- Combined with $Z \rightarrow \ell\ell$ rapidity distribution \rightarrow sensitive to strange quark PDF

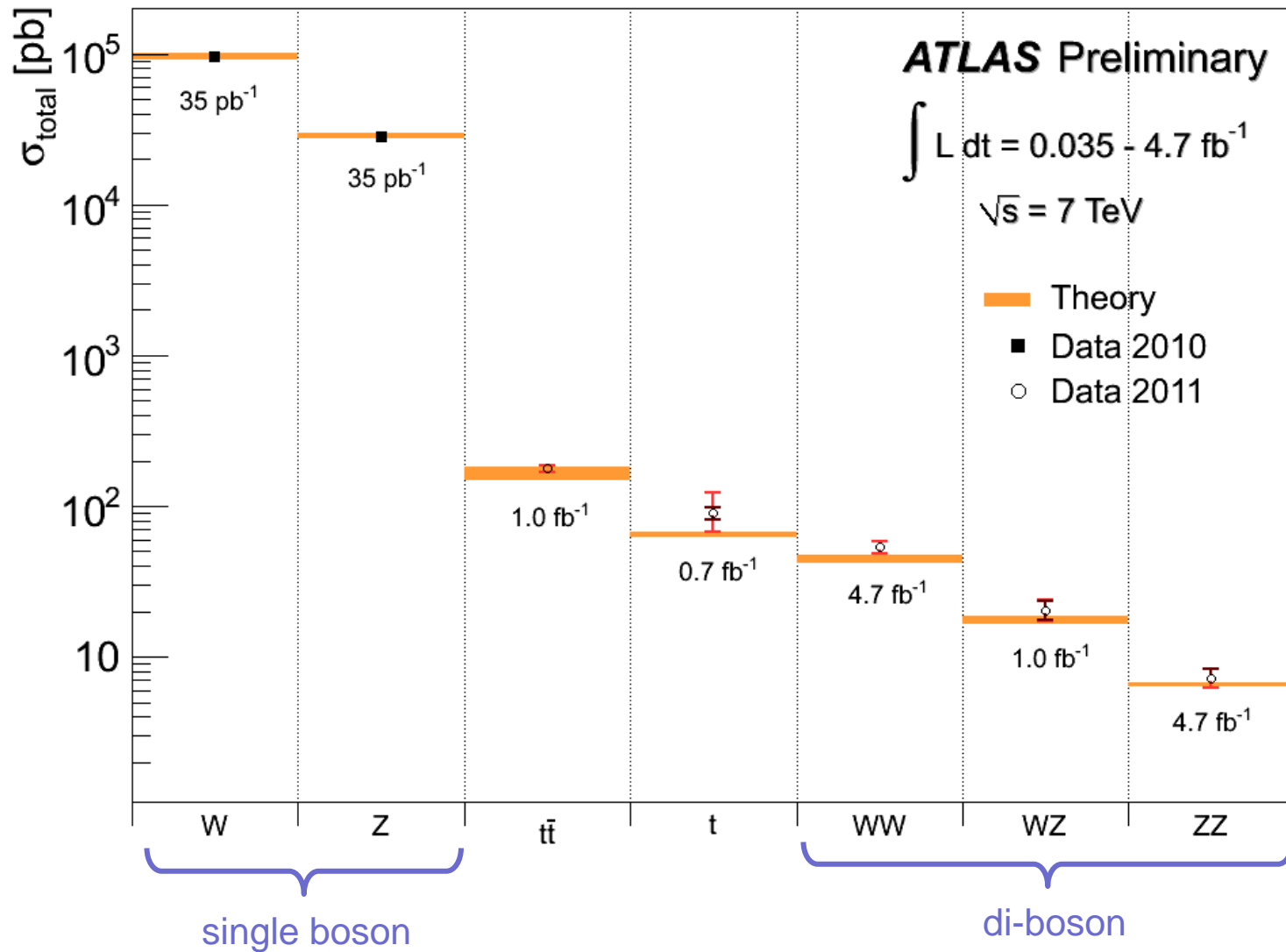
NNLO pQCD analysis of the ratio $r_s = \frac{1}{2}(s + \bar{s})/\bar{d}$



- Data support symmetric strange-to-down sea quark distributions (ATLAS)
- Similar trend in direct measurement of $W^\pm +$ charm production (CMS)

arXiv:1203.4051v1
 ATLAS-CONF-2011-129
 CMS PAS EWK-11-013

Summary of W, Z, and Top Production

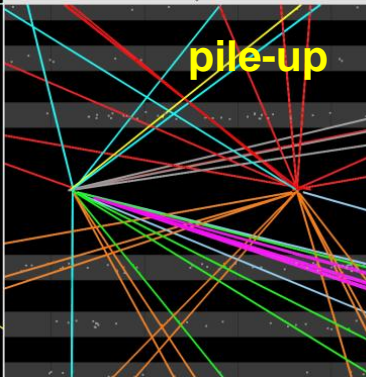
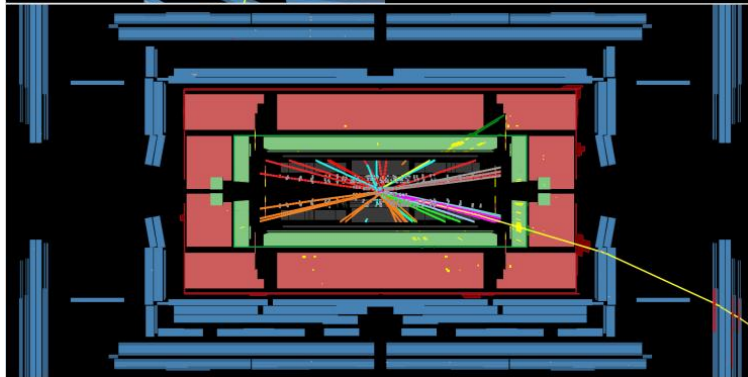
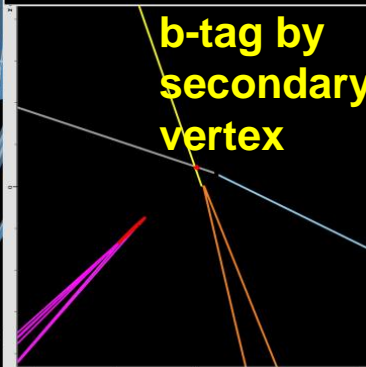
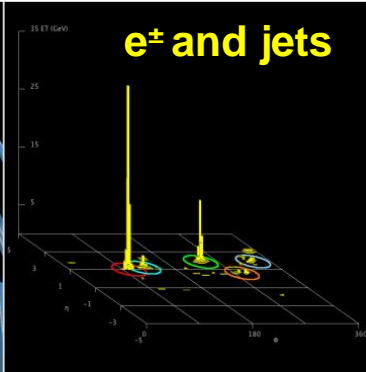
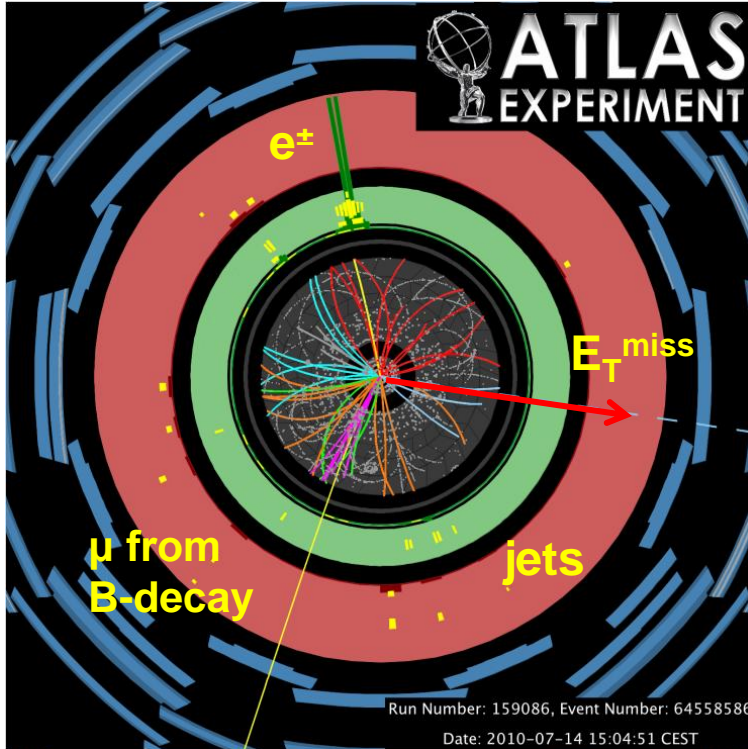


- Very similar agreement with (N)NLO predictions is observed by CMS

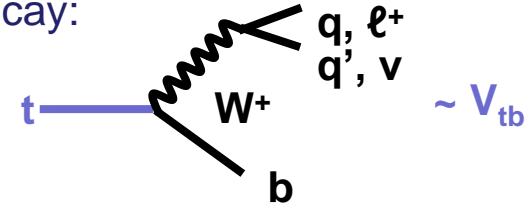
Top Quark Physics



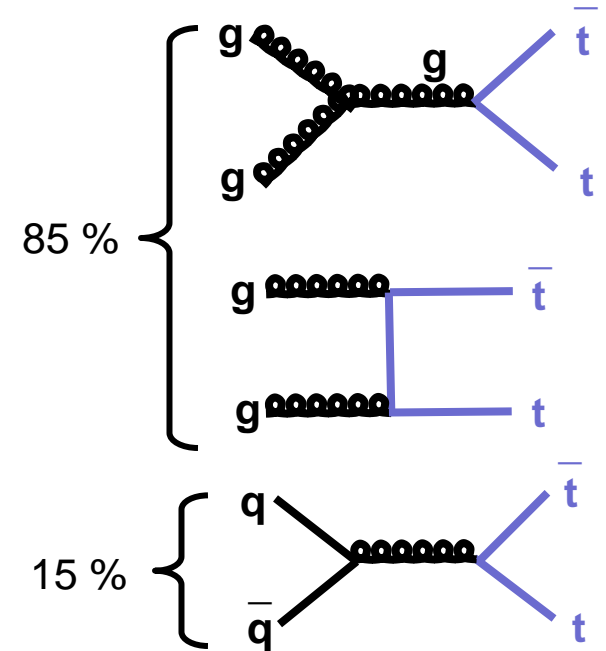
- Top quarks produced in pairs and as single-top



- Top decay:



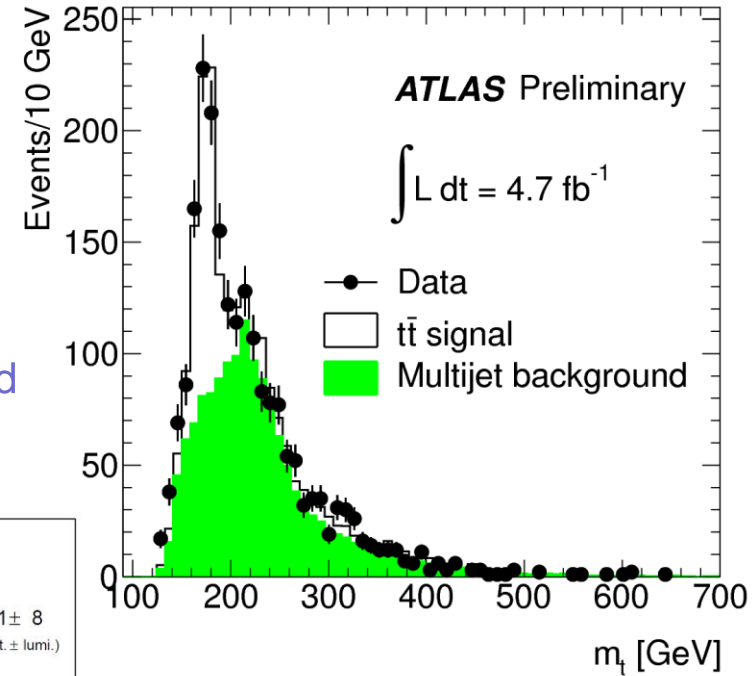
- Top pair production



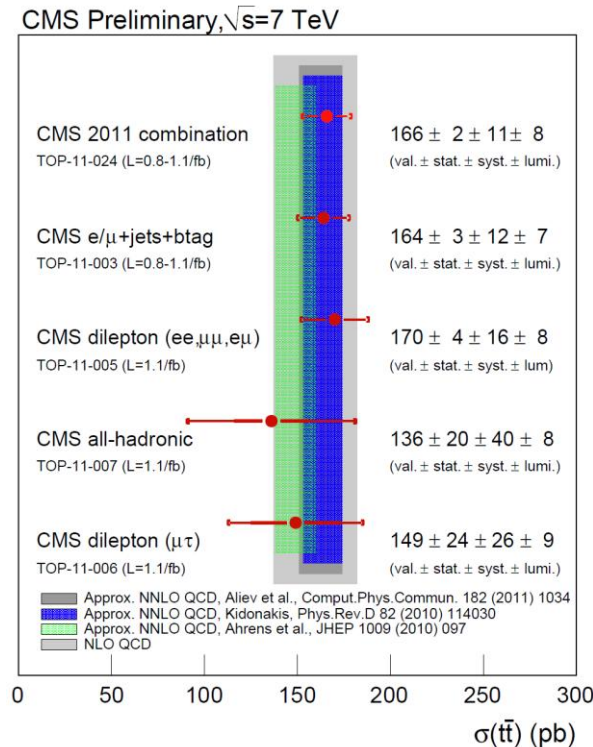
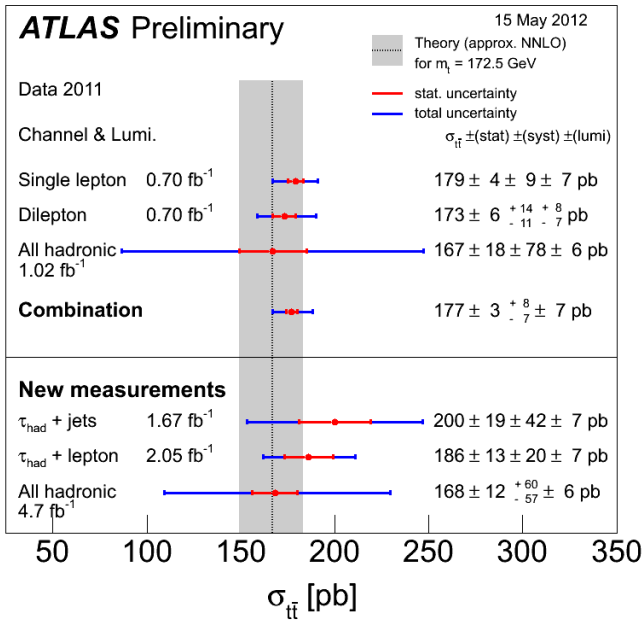
Top-Pair Cross-Section



- Several channels have been analysed:
single lepton, dilepton, tau+leptons, tau+jets, all hadronic
- Selection motivated by decay topology
- Example: m_{top} after kinematic fit in all-hadronic analysis
- Main systematics (channel dependent):
jet energy scale, b-tag, pileup, signal modeling, background
- Results:



- Relative precision
 $\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}} \approx 6-8\%$
- Full theoretical NNLO calculations needed

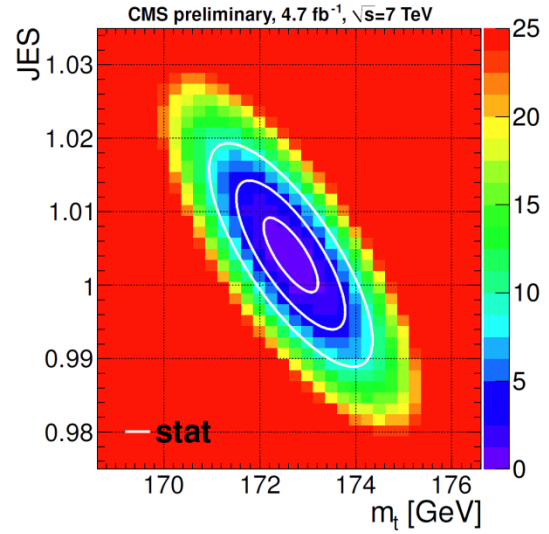
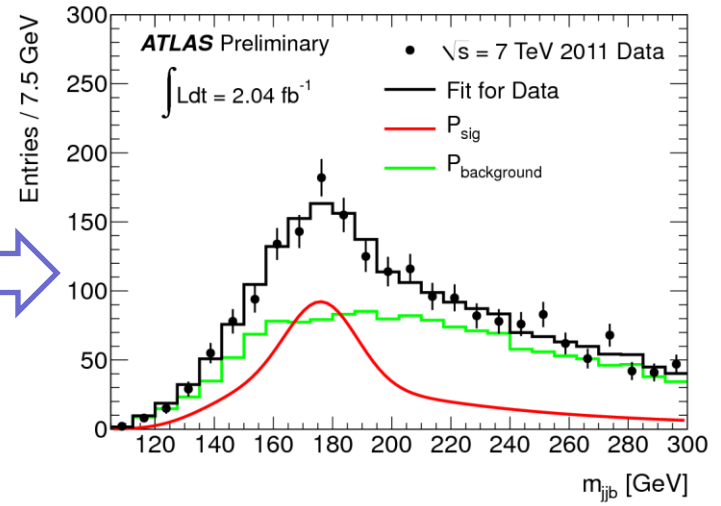
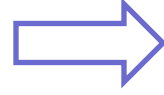
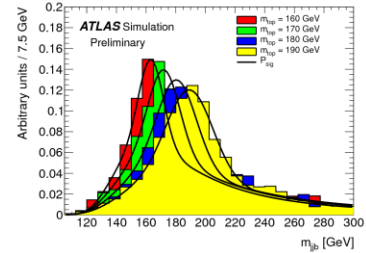


ATLAS-CONF-2012-024, 031, 032
 arXiv:1205.2067
 CMS PAS TOP-11-024, 007, 005, 004, 003
 arXiv:1203.6810

Mass of the Top Quark



- Top mass from reconstructed mass spectrum in di-lepton, lepton+jets and all-hadronic channels
- Mass-dependent signal templates are fit to data
- Lepton+jets channel: W-mass constraint is used to simultaneously determine the jet energy scale (JES)



CMS:
 $m_{top} \text{ (di-lepton, lepton+jets)} = 172.6 \pm 0.4 \pm 1.2 \text{ GeV}$
 (underlying event and colour reconnection systematics to be evaluated)

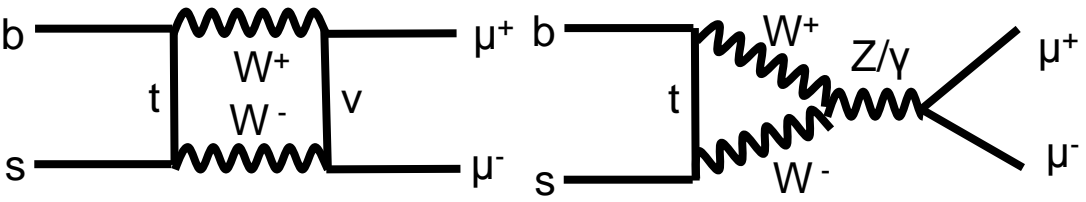
ATLAS
 $m_{top} \text{ (all-hadronic)} = 174.9 \pm 2.1 \text{ (stat.)} \pm 3.8 \text{ (syst.) GeV}$
 $m_{top} \text{ (lepton+jets)} = 174.5 \pm 0.6 \text{ (stat.)} \pm 2.3 \text{ (syst.) GeV}$

- Main systematics (channel dependent): jet energy scales, signal and background modeling, ...
- For comparison: CDF+D0: $m_{top} = 173.2 \pm 0.9 \text{ GeV}$

arXiv:1203.5755
 ATLAS-CONF-2012-031
 CMS-PAS-TOP-11-015
 CMS-PAS-TOP-11-018
 arXiv:1204.2807

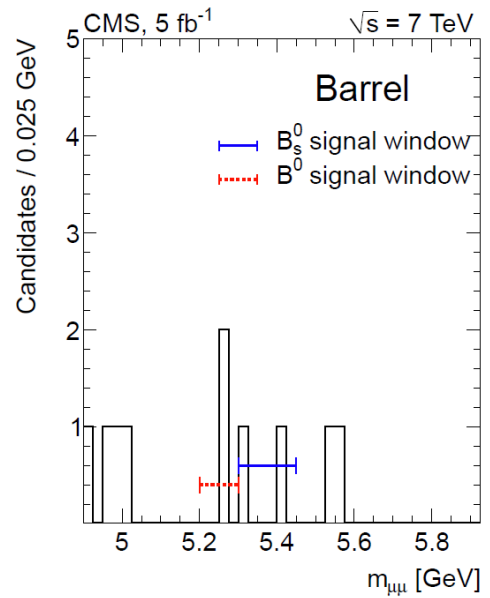
Rare B-Decay $B_s \rightarrow \mu^+ \mu^-$

- Standard Model FCNC decay is highly suppressed:
 $BR_{SM}(B_s \rightarrow \mu^+ \mu^-) = (3.5 \pm 0.3) \times 10^{-9}$ [arXiv:1012.1447]



- New Physics (2HDM, SUSY, ...) appears in loop
 \rightarrow enhances $BR(B_s \rightarrow \mu^+ \mu^-)$ by orders of magnitude

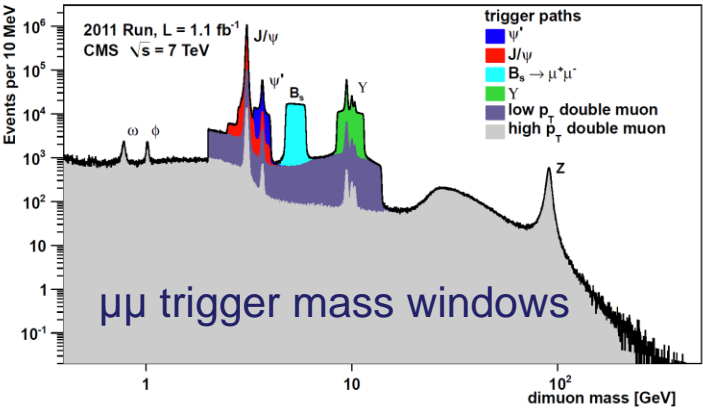
- Isolated $B_s \rightarrow \mu^+ \mu^-$ decays are selected
- Remaining backgrounds:
 - $B_s \rightarrow hh', h\nu$ with misidentified hadrons (h, h')
 - combinatorial background
- Reference is $B^+ \rightarrow J/\psi K^+ \rightarrow \mu^+ \mu^- K^+$



Variable	$B_s^0 \rightarrow \mu^+ \mu^-$ Barrel	$B_s^0 \rightarrow \mu^+ \mu^-$ Endcap
ϵ_{tot}	0.0029 ± 0.0002	0.0016 ± 0.0002
N_{signal}^{exp}	2.70 ± 0.41	1.23 ± 0.18
N_{peak}^{exp}	0.18 ± 0.06	0.08 ± 0.02
N_{comb}^{exp}	0.59 ± 0.50	1.14 ± 0.53
N_{total}^{exp}	3.47 ± 0.65	2.45 ± 0.56
N_{Obs}	2	4

arXiv: 1203.3976
 ATLAS-CONF-2012-010
 arXiv:1203.4493

CMS: $BR(B_s \rightarrow \mu^+ \mu^-) < 7.7 \times 10^{-9}$ (4.9 fb^{-1})
 ATLAS: $BR(B_s \rightarrow \mu^+ \mu^-) < 2.2 \times 10^{-8}$ (2.4 fb^{-1})
 LHCb: $BR(B_s \rightarrow \mu^+ \mu^-) < 4.5 \times 10^{-9}$ (1.0 fb^{-1}) } 95% CL



- soon sensitivity to Standard Model rates

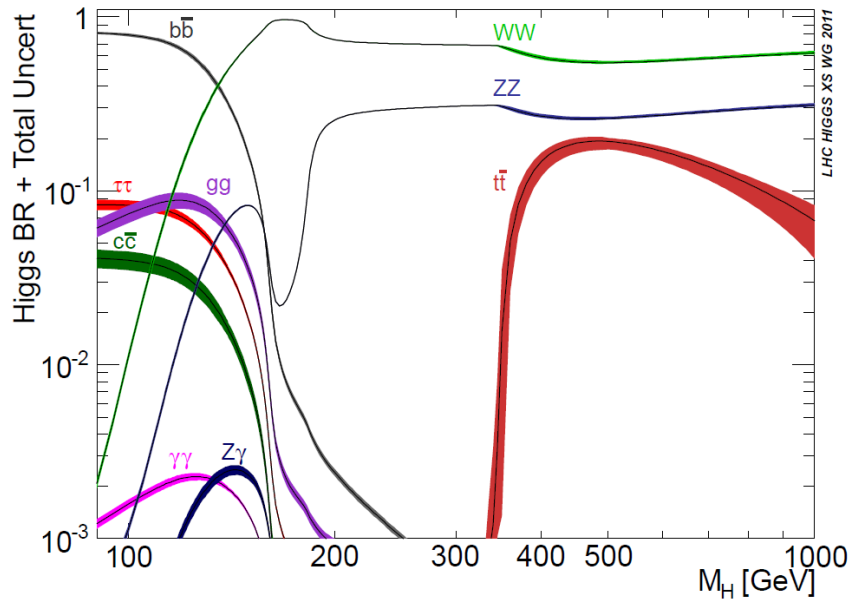
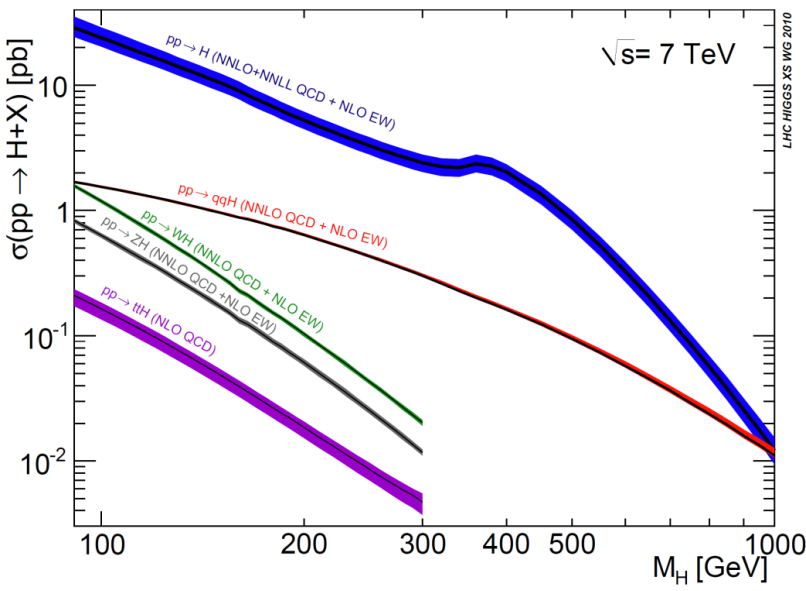
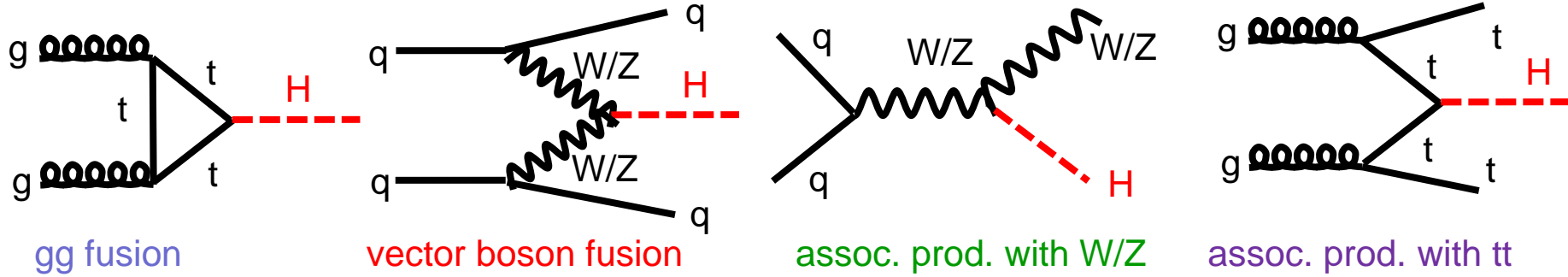
Higgs Searches



Standard Model Higgs at the LHC

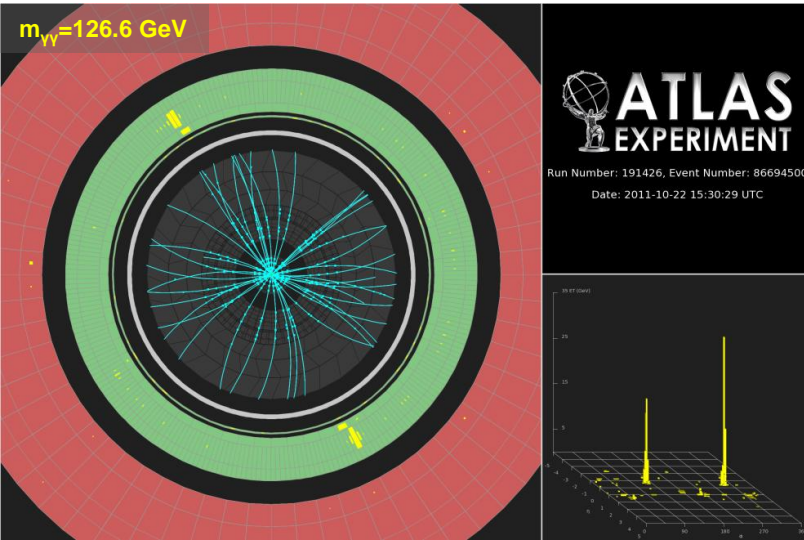


- Standard Model Higgs production and decay:



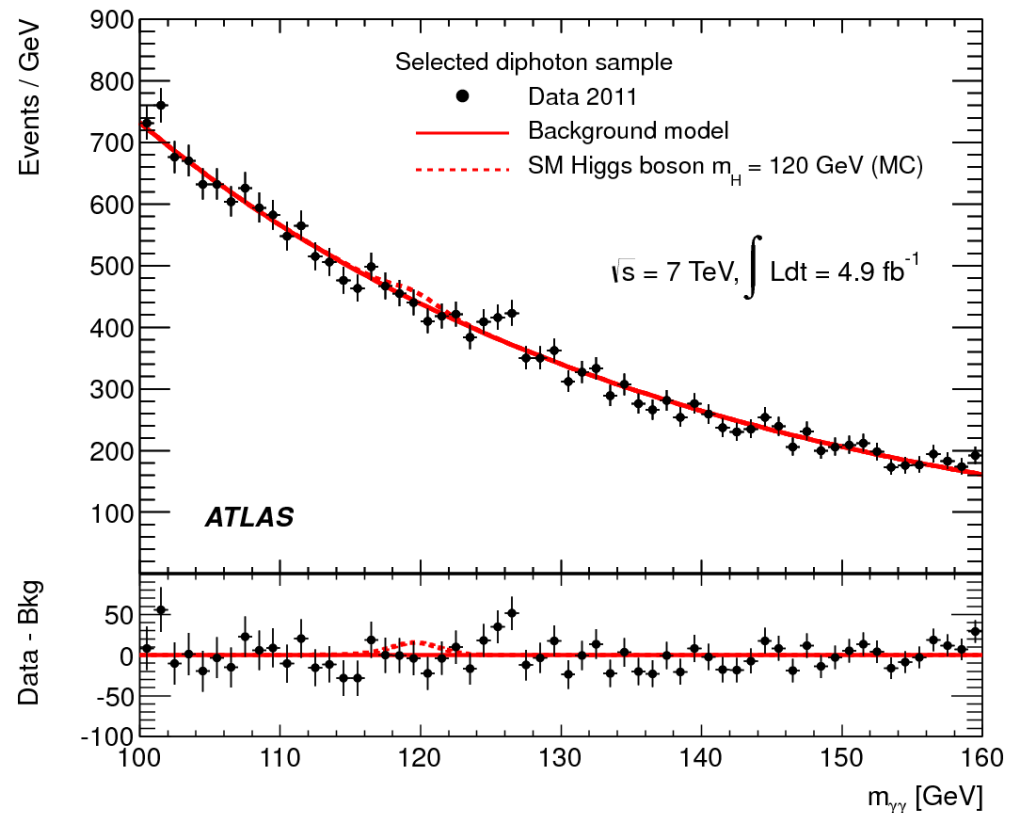
arXiv:1101.0593
arXiv:1201.3084

- excellent mass resolution: $H \rightarrow \gamma\gamma$ $H \rightarrow ZZ^* \rightarrow \ell\ell\ell$
- limited mass resolution, low m_H : $H \rightarrow WW^* \rightarrow \ell\nu\ell\nu$ $H \rightarrow \tau\tau \rightarrow \ell\ell 4\nu, \ell h 3\nu, h h 2\nu$ $W/Z + (H \rightarrow b\bar{b})$
- large m_H : $H \rightarrow ZZ \rightarrow \ell\nu\nu, \ell\ell q\bar{q}$ $H \rightarrow WW \rightarrow \ell\nu q\bar{q}$

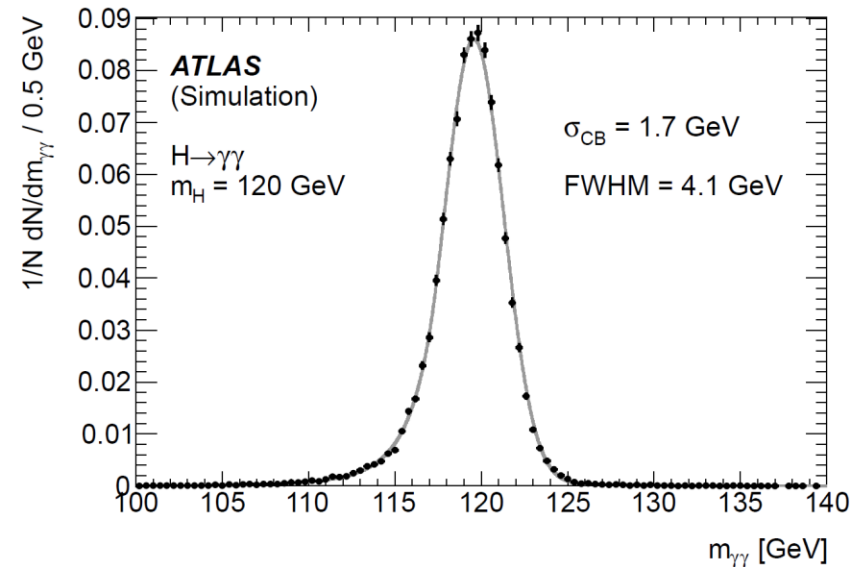


- $H \rightarrow \gamma\gamma$ events selected with $E_T(\gamma_{1,2}) > 40$ (25) GeV
- Analysis in 9 categories of different $m_{\gamma\gamma}$ resolutions according to: $\eta(\gamma)$, $\gamma \rightarrow ee$ conversions, $p_{T,thrust}^{\gamma\gamma}$
- Final combined mass spectrum:

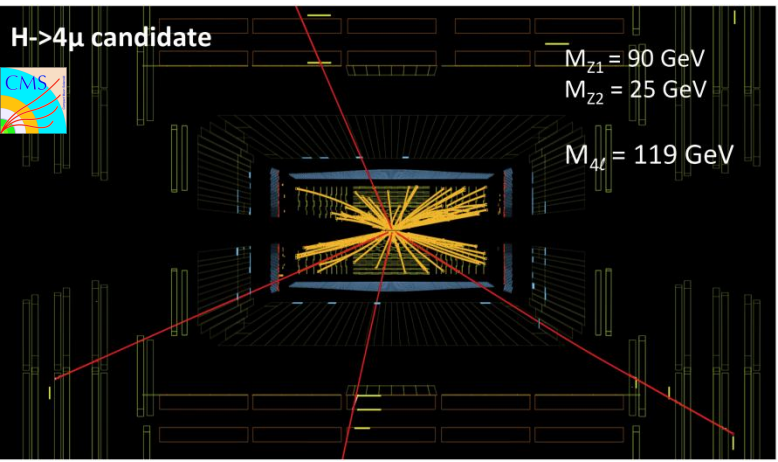
arXiv:1202.1414



- Combined $m_{\gamma\gamma}$ resolution:



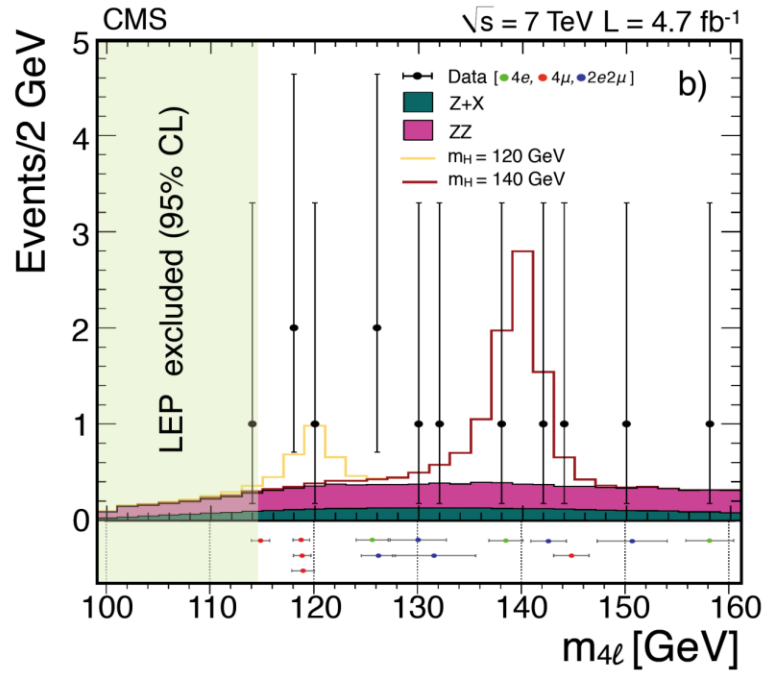
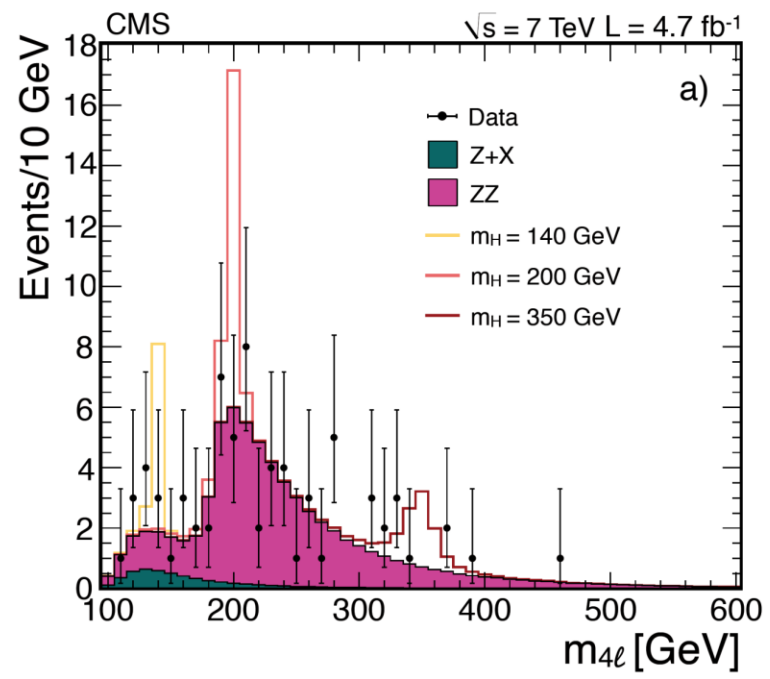
Golden Channel: $H \rightarrow ZZ^* \rightarrow \ell\ell\ell\ell$



- $H \rightarrow ZZ^*$ events selected in 4 final states: 4e, 2e2 μ , 2 μ 2e, 4 μ
- High lepton efficiency down to low p_T of ~ 7 GeV
- Opposite-sign lepton pairs, one $m_{\ell\ell}$ compatible with m_Z
- Main backgrounds:
 - ZZ^* , Z+jets, $t\bar{t}$, WZ production
 - estimated from simulation and using data in control regions

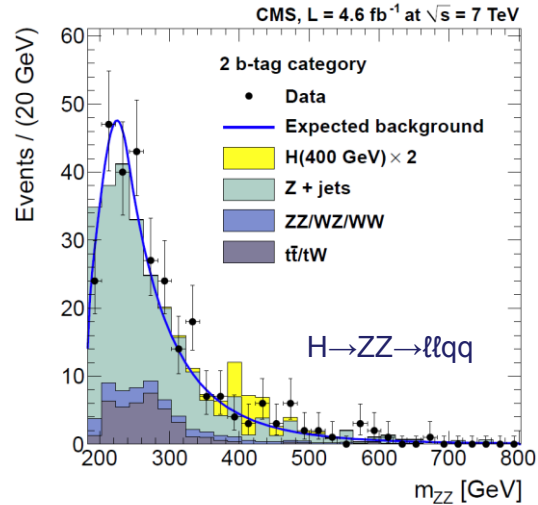
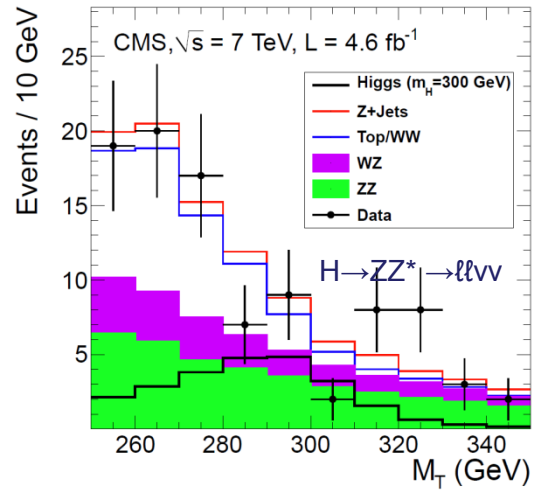
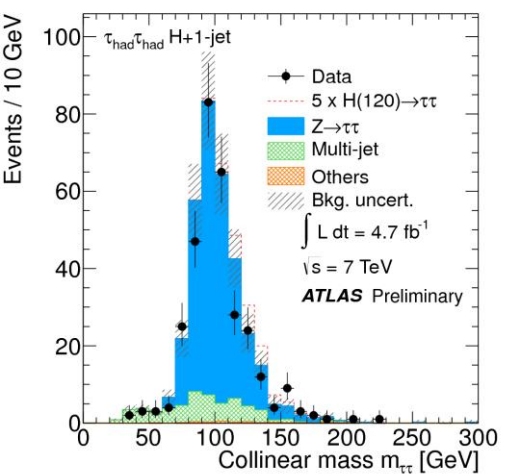
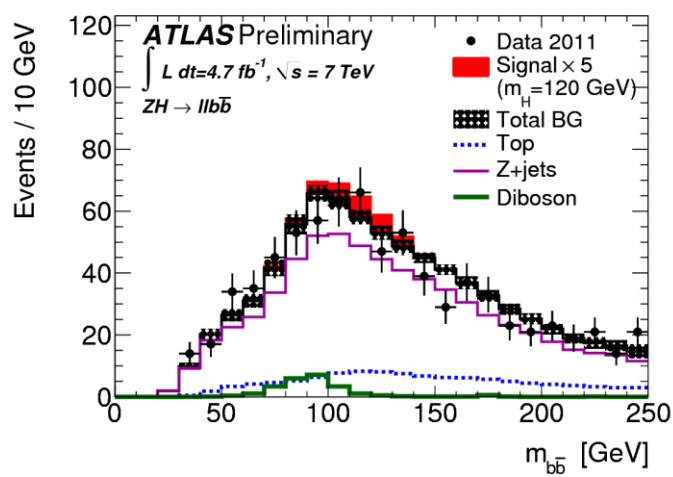
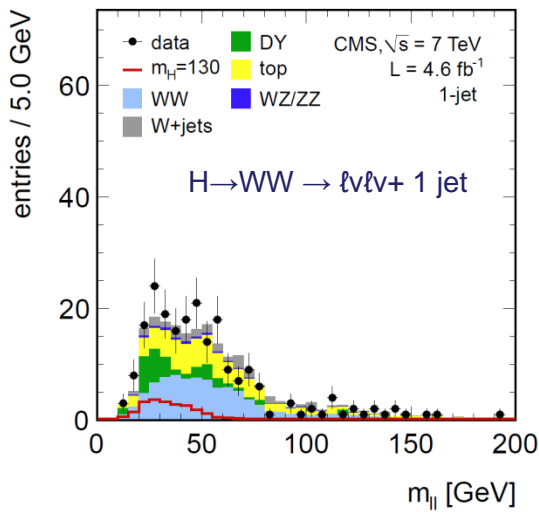
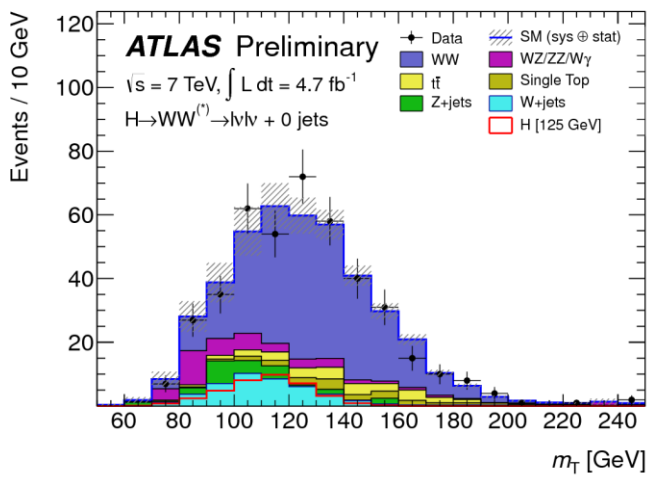
arXiv: 1202.1997

Final mass spectrum:



More Higgs Decay Channels

- Example mass spectra of $H \rightarrow WW^*$, $\tau\tau$, ZZ decays accompanied by jets and in different production modes (gg-fusion, VBF, W/Z associate production) :

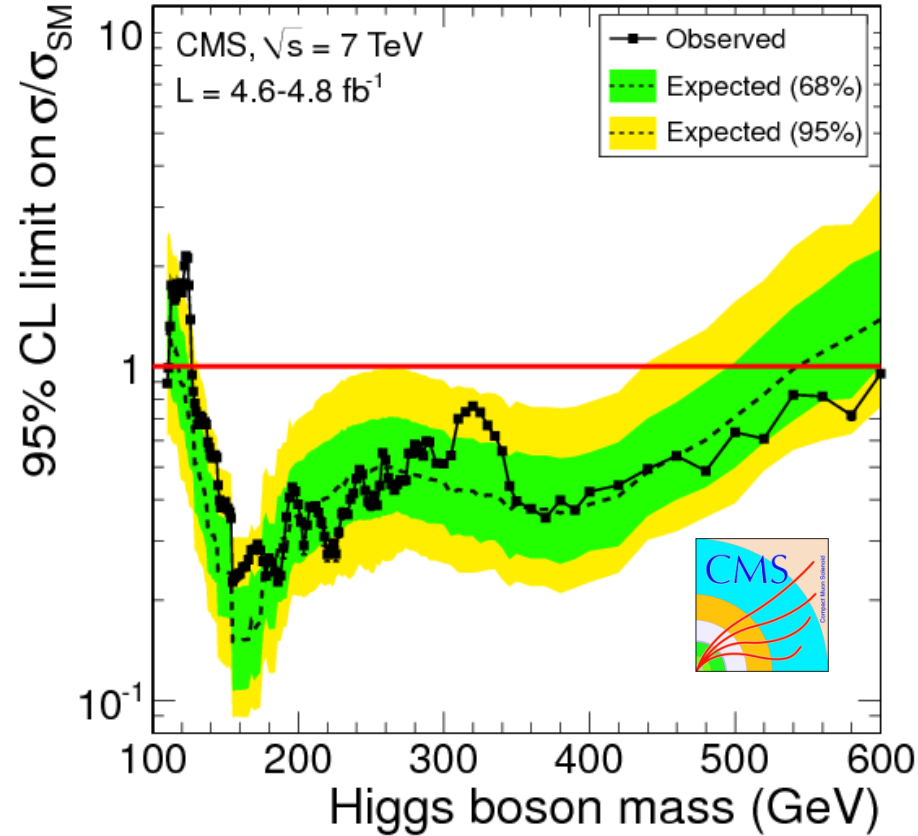
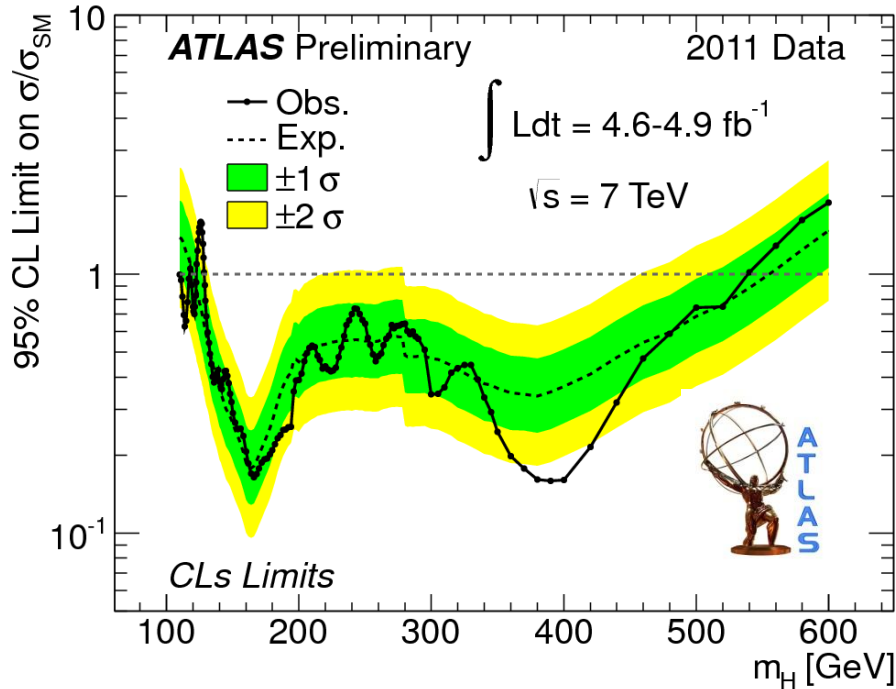


ATLAS-CONF-2012-012, 014, 015, 016, 017, 018
 arXiv:1202.1489, 1202.1997, 1202.3617, 1202.3478, 1202.1416, 1202.1487, 1202.4083, 1202.4195, 1202.1488

ATLAS and CMS - SM Higgs Search Results



- Observed and expected 95% CL combined upper limits on the SM Higgs production cross section:

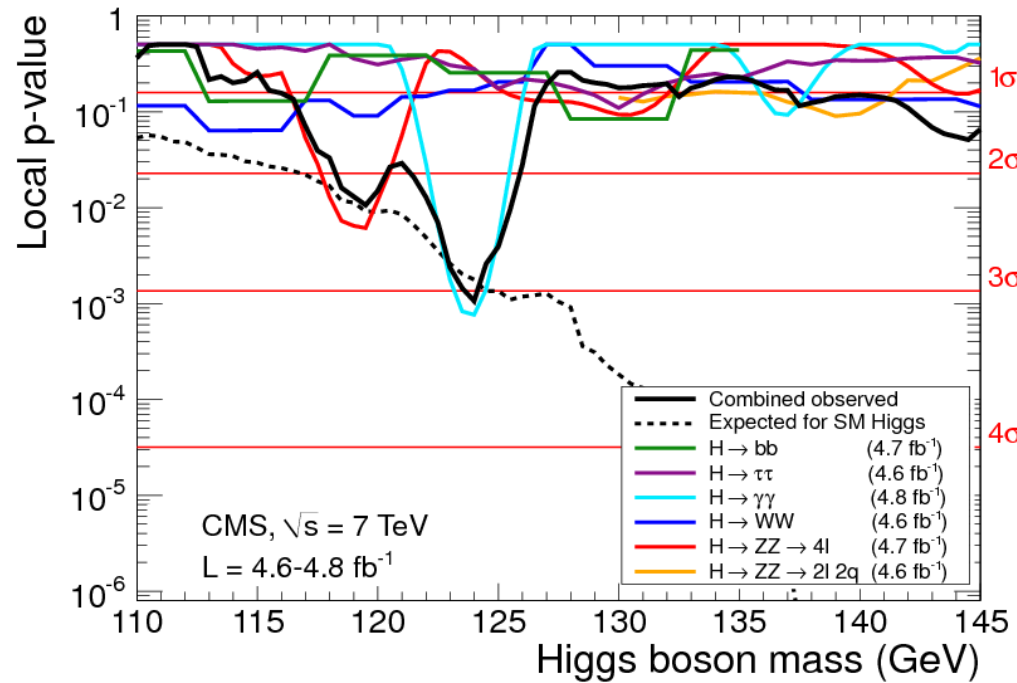
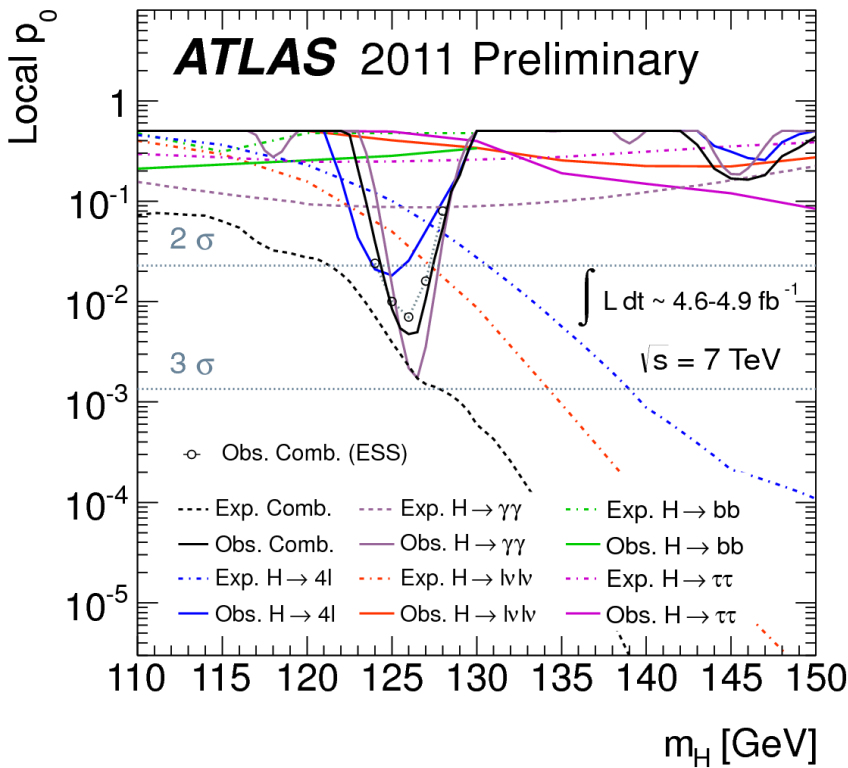


- Excluded regions at 95 % CL:
- ATLAS expected: $m_H = 120-555$ GeV observed: $m_H = 110-117.5, 118.5-122.5, 129-539$ GeV
- CMS expected: $m_H = 114.5-543$ GeV observed: $m_H = 127.5-600$ GeV

SM Higgs Search Results



- Local probability p_0 for a background-only experiment to be more signal-like than the observation:



ATLAS-CONF-2012-019
arXiv:1202.1488

- ATLAS and CMS excess in $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ^*$ search channels

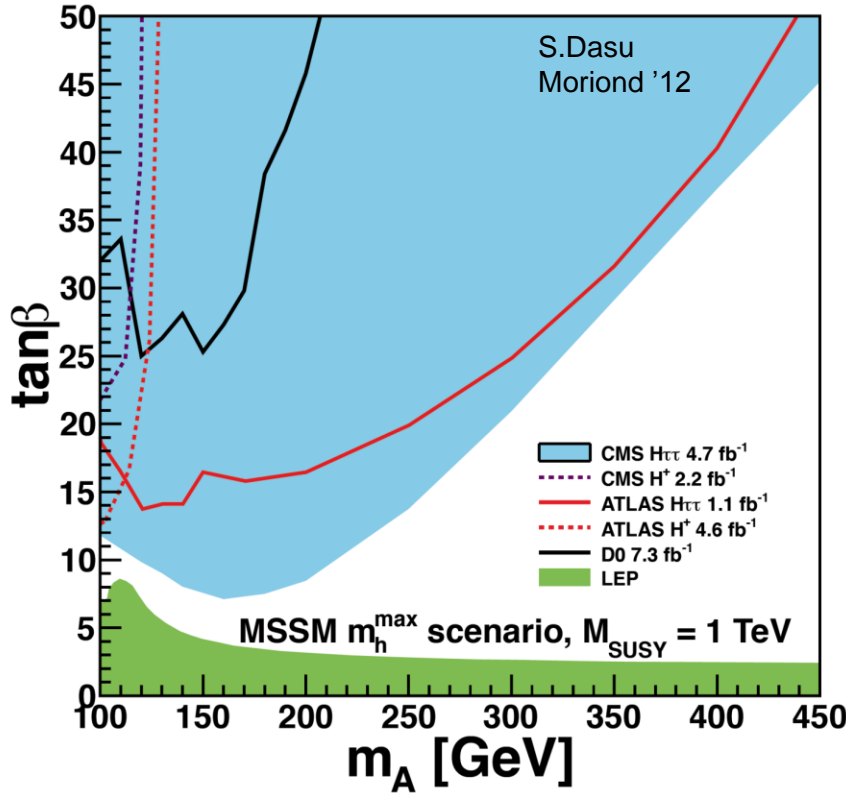
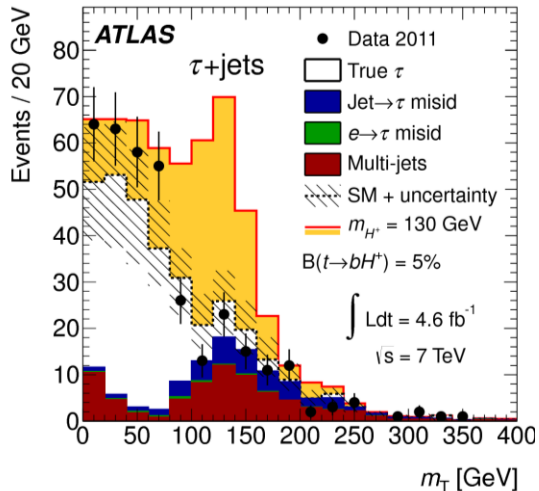
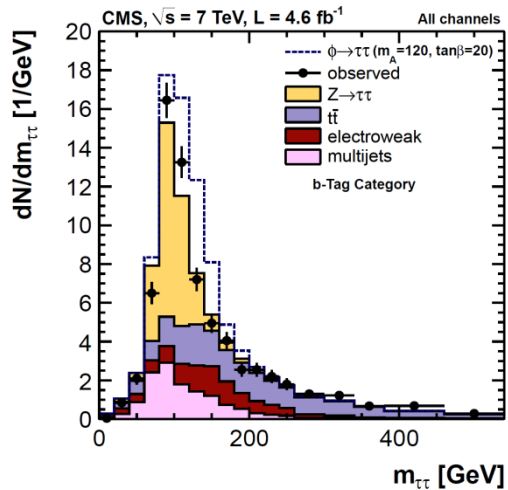
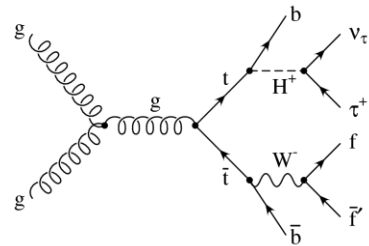
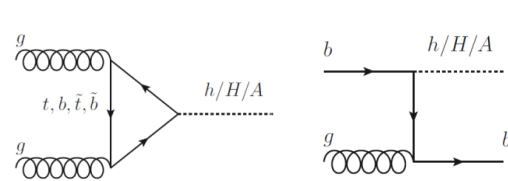
Data of 2012 with additional 15 fb^{-1} may bring the conclusion on the Standard Model Higgs boson

MSSM Higgs Boson Search

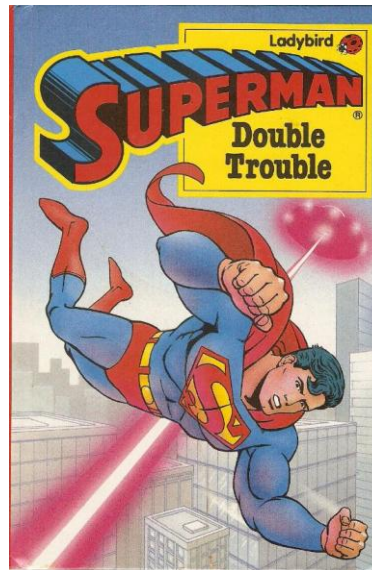


- Minimal supersymmetric extension of the Standard Model:
 - 2 Higgs doublets with VEV v_1 and v_2 giving mass to up- and down-type fermions
 - 5 physical Higgs bosons: $h/H/A$ and H^\pm
 - Couplings to down-type fermions are enhanced $\sim \tan\beta$
 - Higgs masses and cross-sections predicted by 2 main parameters: m_A and $\tan\beta = v_2 / v_1$

- Neutral $h/H/A$ searches in $\tau^+\tau^-$ final state
- Light charged H^\pm searches in top pairs with $t \rightarrow H^\pm b$ and decay $H^\pm \rightarrow \tau^\pm \nu$ and $H^\pm \rightarrow cs$



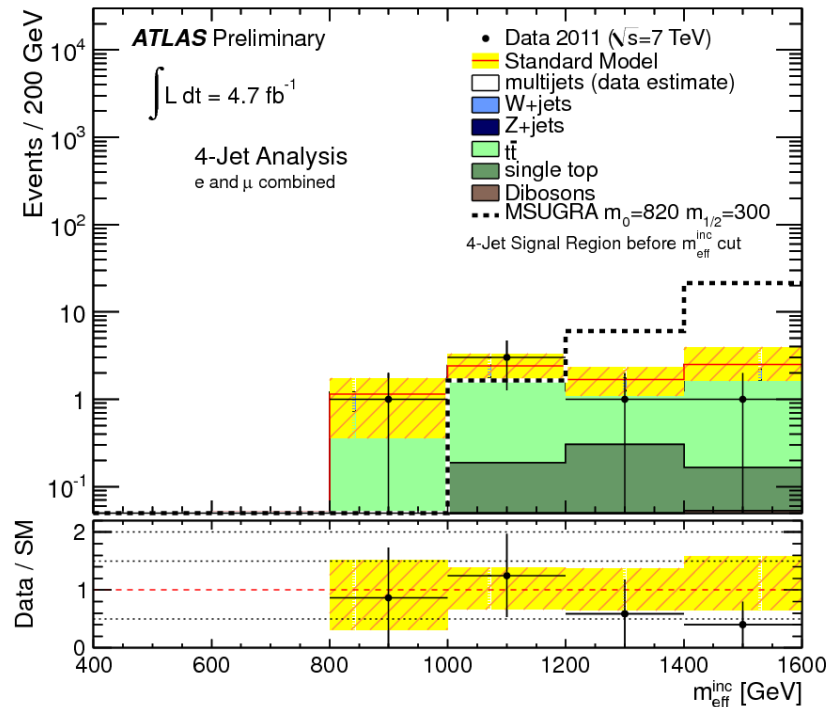
Searches for Supersymmetry



Example: 1 Lepton + Jets Signature



- High p_T electron or muon selected: $p_T > 20(30)$ GeV or soft lepton $6 < p_T < 20$ GeV
- 3-4 jets with $p_T > 25 \dots 100$ GeV and $E_T^{\text{miss}} > 250$ GeV
- Transverse mass of lepton and missing momentum, $m_T > 100$ GeV
- Scalar sum of all lepton and p_T and E_T^{miss} : $m_{\text{eff}}^{\text{inc}} > 800$ (1200) GeV and $E_T^{\text{miss}} / m_{\text{eff}}^{\text{inc}} > 0.3$ (0.2)



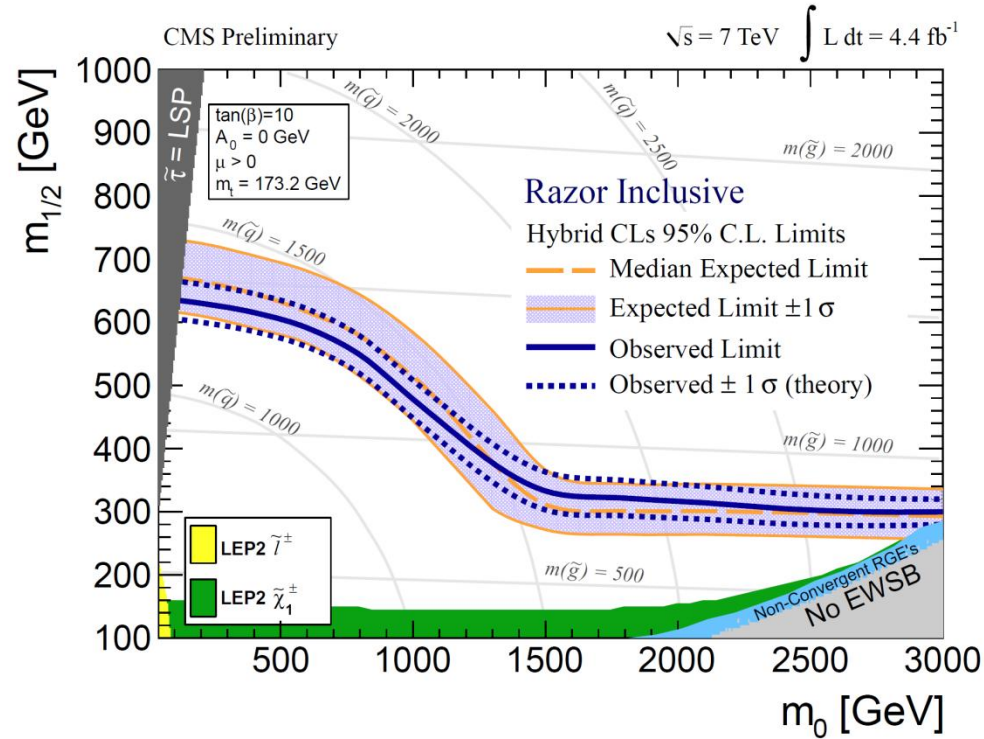
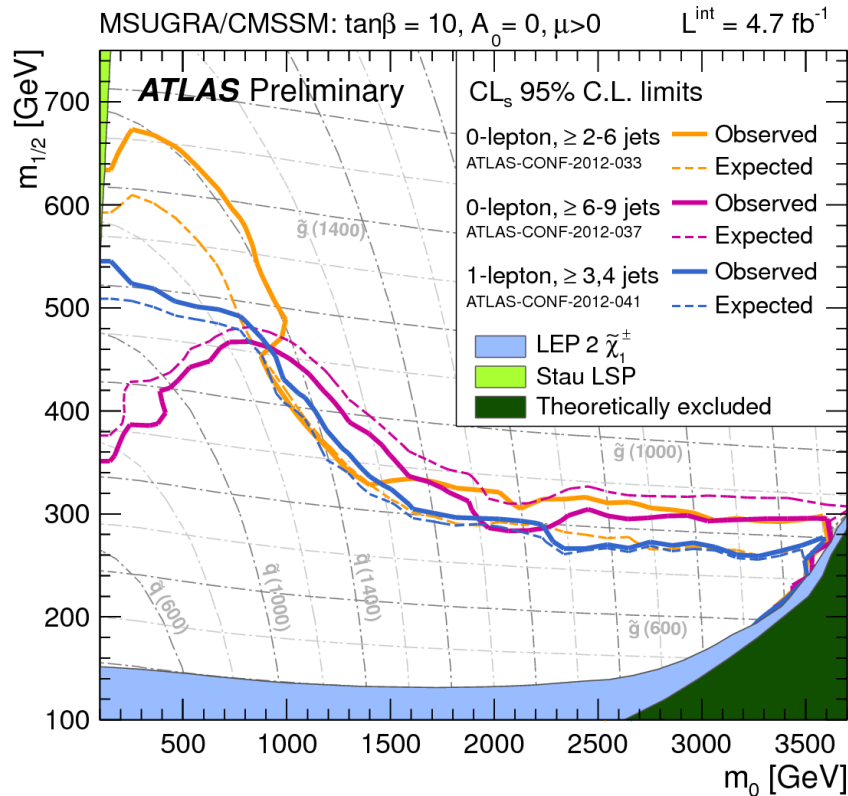
ATLAS-CONF-2012-041

- Data driven background estimations → no significant excess observed in data
- Further signatures with E_T^{miss} : photons+jets, disappearing tracks, hadronic multi-jets, same-sign dileptons, multi-leptons, same-sign dileptons with b-jets, ...

Exclusion in SUSY Parameter Space



• Examples:



• within mSUGRA/CMSSM:

• $m(\text{gluino}) < 800 \text{ GeV}$ (CMS), 850 GeV (ATLAS) can be excluded at 95 % CL

• for $m(\text{squark}) = m(\text{gluino})$ exclusion limits are 1.2 TeV (ATLAS) and 1.35 TeV (CMS) at 95 % CL

CMS PAS SUS-12-005

ATLAS-CONF-2012-037

ATLAS-CONF-2012-041

CMSSM under pressure!

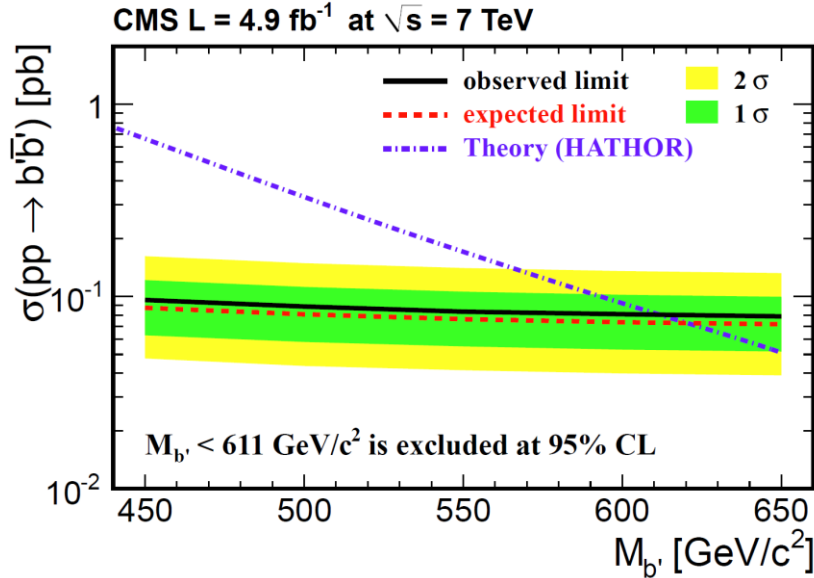
Exotics Searches



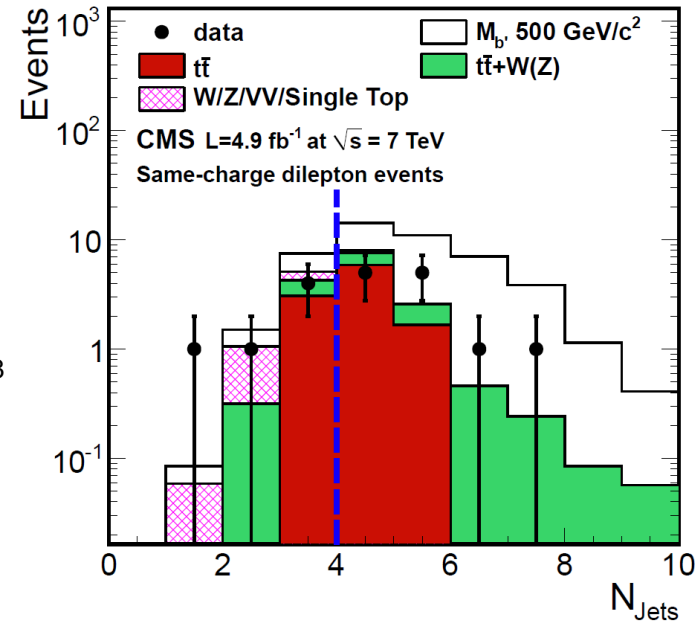
4th Generation Quarks



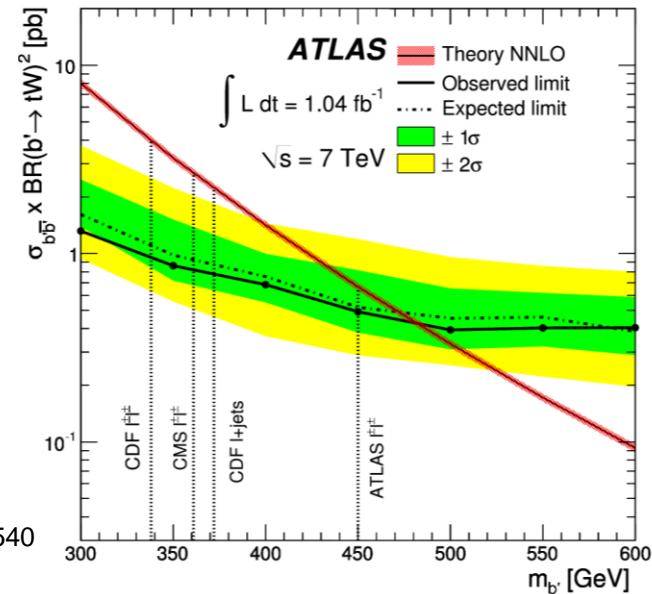
- CMS search for down-type heavy quarks:
 $b'b' \rightarrow Wt Wt \rightarrow WWb WWb$
- Same-sign leptons and 3-lepton final state with b-jets and light-flavour jets
- b' masses below 611 GeV are excluded at 95% CL



arXiv:1204.1088



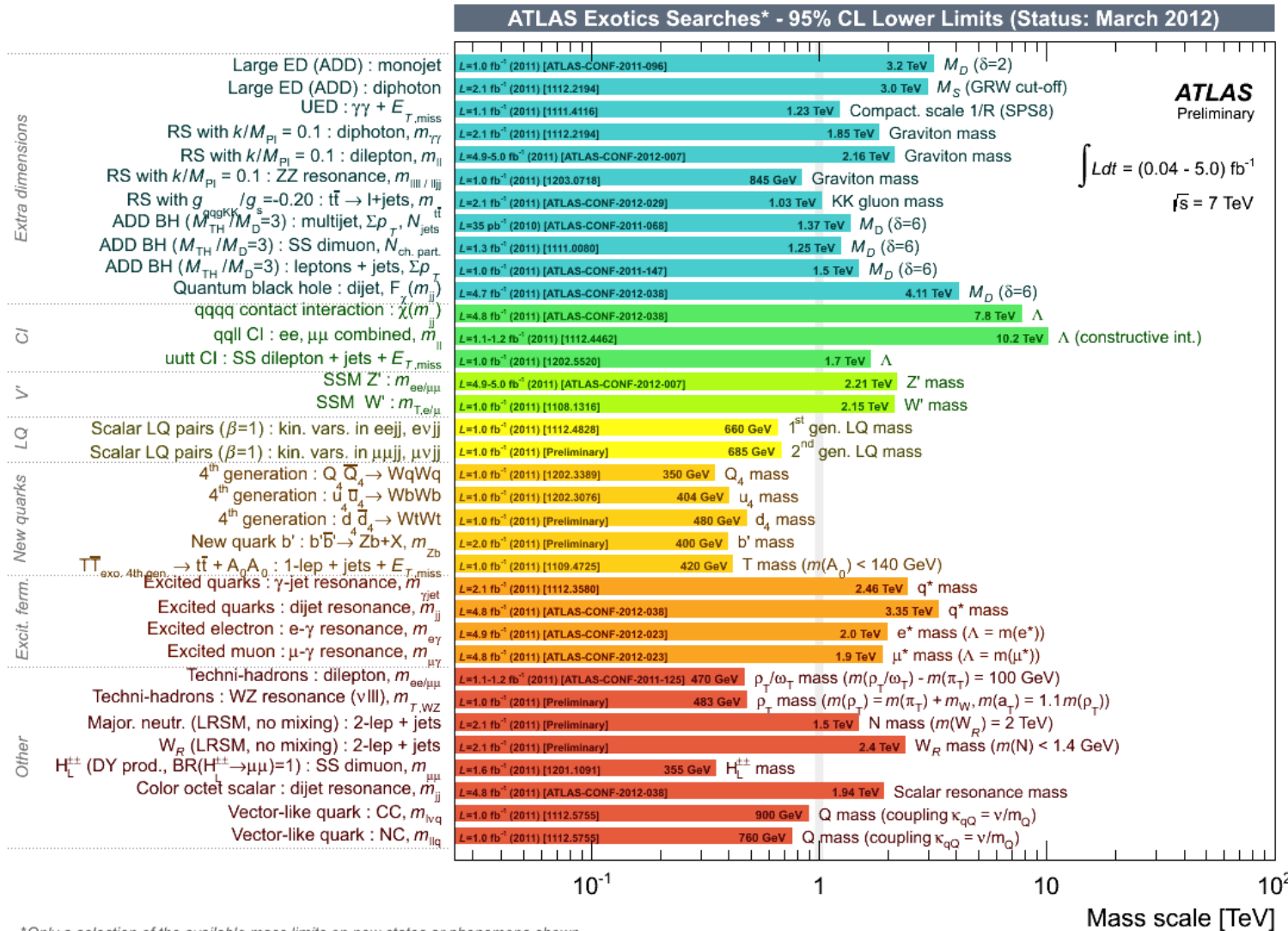
- ATLAS search in 1-lepton decay channel:
 $b'b' \rightarrow Wt Wt \rightarrow WWb WWb \rightarrow \ell\nu qqb qqqqb$
- Highly-boosted hadronic W decays are selected
- b' masses below 480 GeV are excluded at 95% CL



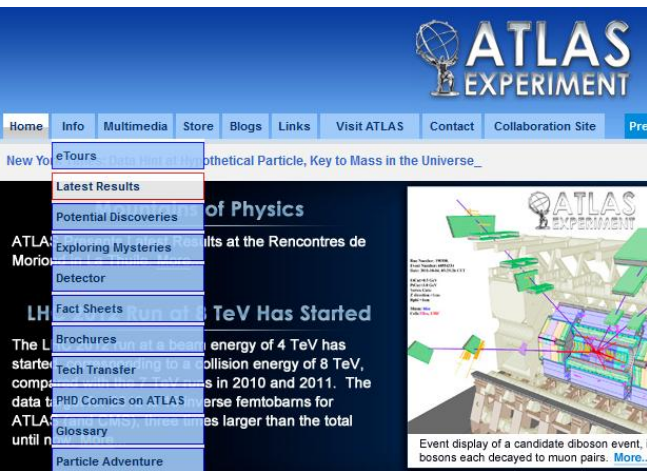
arXiv:1202.6540

Example Summary of Exotics Searches

- Searches for new particles covers mass range from 300 GeV to 10 TeV



*Only a selection of the available mass limits on new states or phenomena shown



- Standard Model measurements in very good agreement to (N)NLO predictions
- Standard Model Higgs Boson searches
 - excess of events in low- m_H region
- MSSM Higgs and SUSY searches
 - no signs of SUSY yet
- Exotics
 - no deviation from SM processes
- Expectations for 2012:
 - exciting news from SM Higgs searches
- All ATLAS and CMS measurements at:
 - atlas.ch → Info → Latest Results
 - cms.web.cern.ch → Physics → Papers and Results

- Acknowledgements:
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