

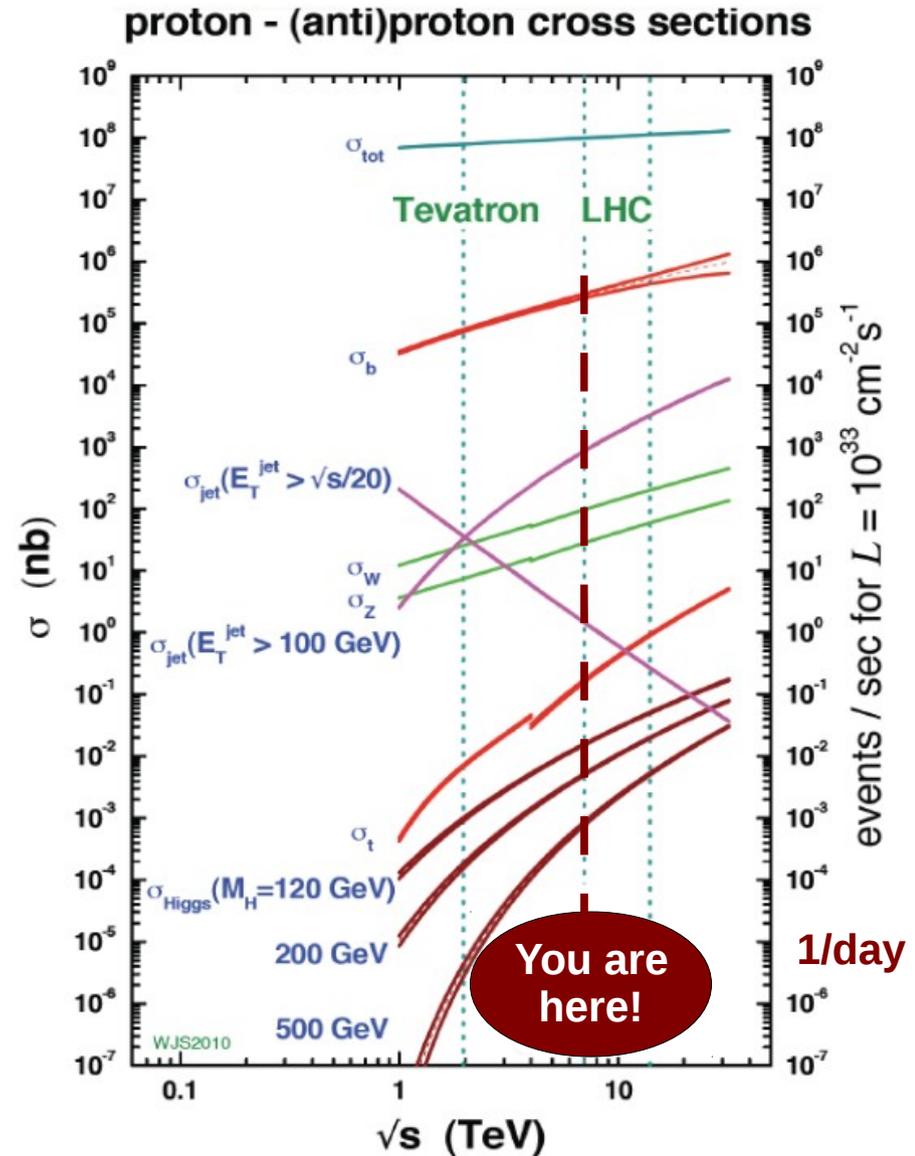
Status of CMS and Recent Highlights



Markus Klute (MIT) for the CMS Collaboration

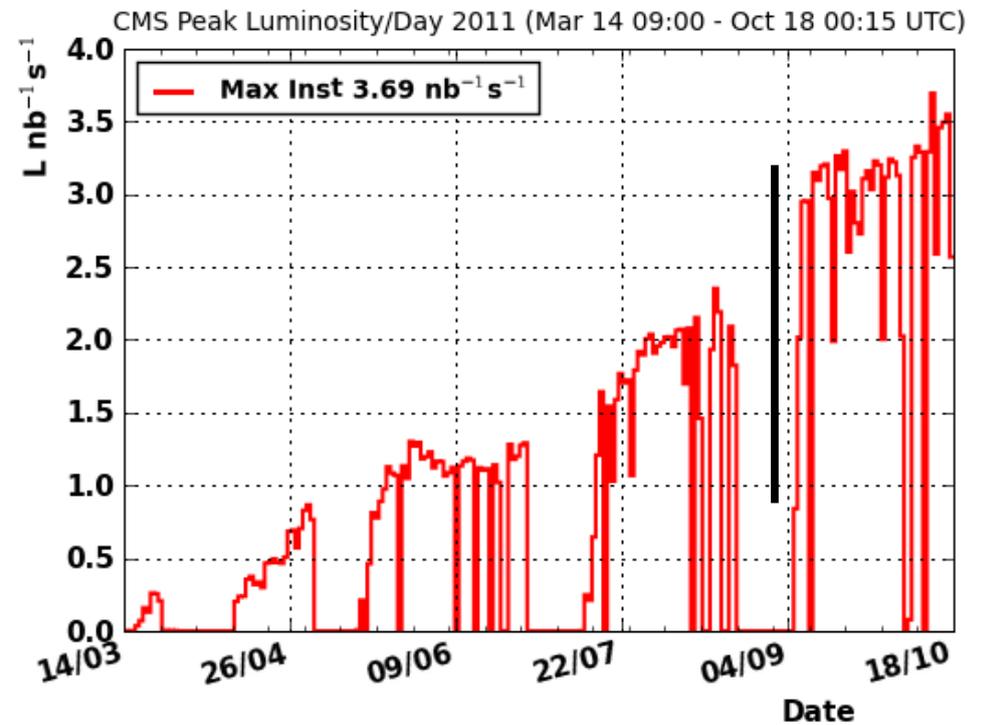
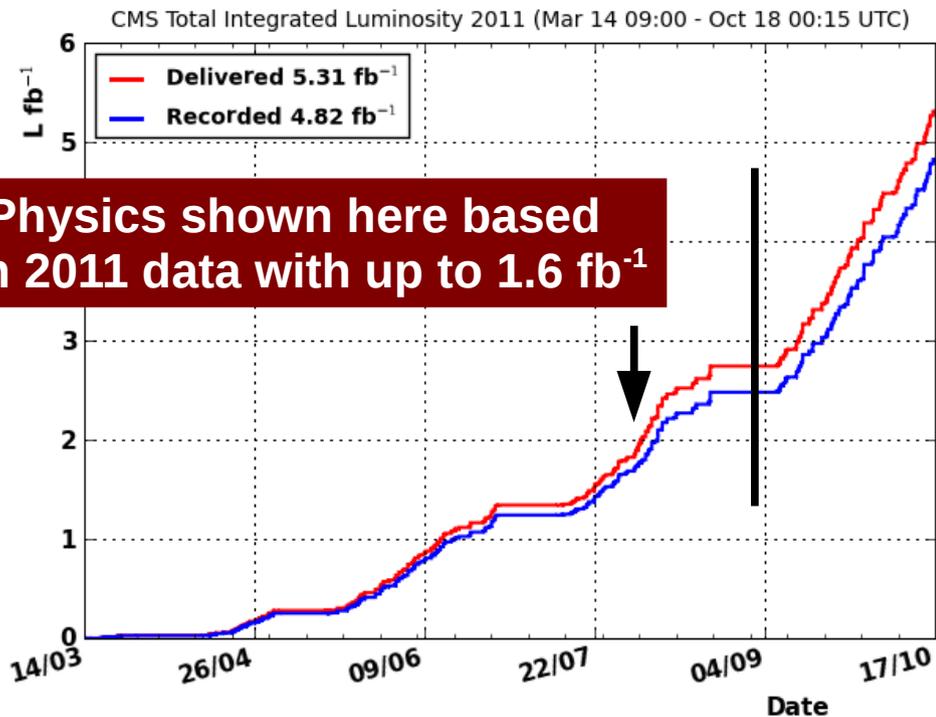
Outline

- **Introduction**
 - LHC Performance
 - CMS Performance
- **Selected Physics Results**
 - **W/Z Bosons**
 - **Top Quark Physics**
 - **Higgs Boson Searches**
 - **Beyond the Standard Model**
- **Conclusion**



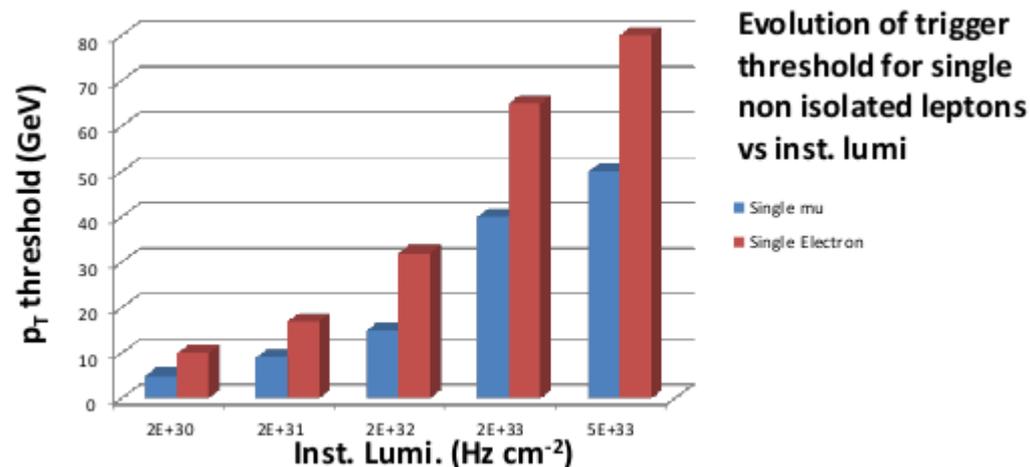
LHC Performance

- 2010 pp @ 7 TeV: $\sim 47\text{pb}^{-1}$ delivered, $L = 2 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$
- 2010 PbPb: $\sim 10\mu\text{b}^{-1}$ delivered
- 2011 pp @ 7 TeV: $> 5 \text{ fb}^{-1}$ delivered, $L = 3.7 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$, $550 \text{ pb}^{-1} / \text{week}$



Challenges of High Luminosity

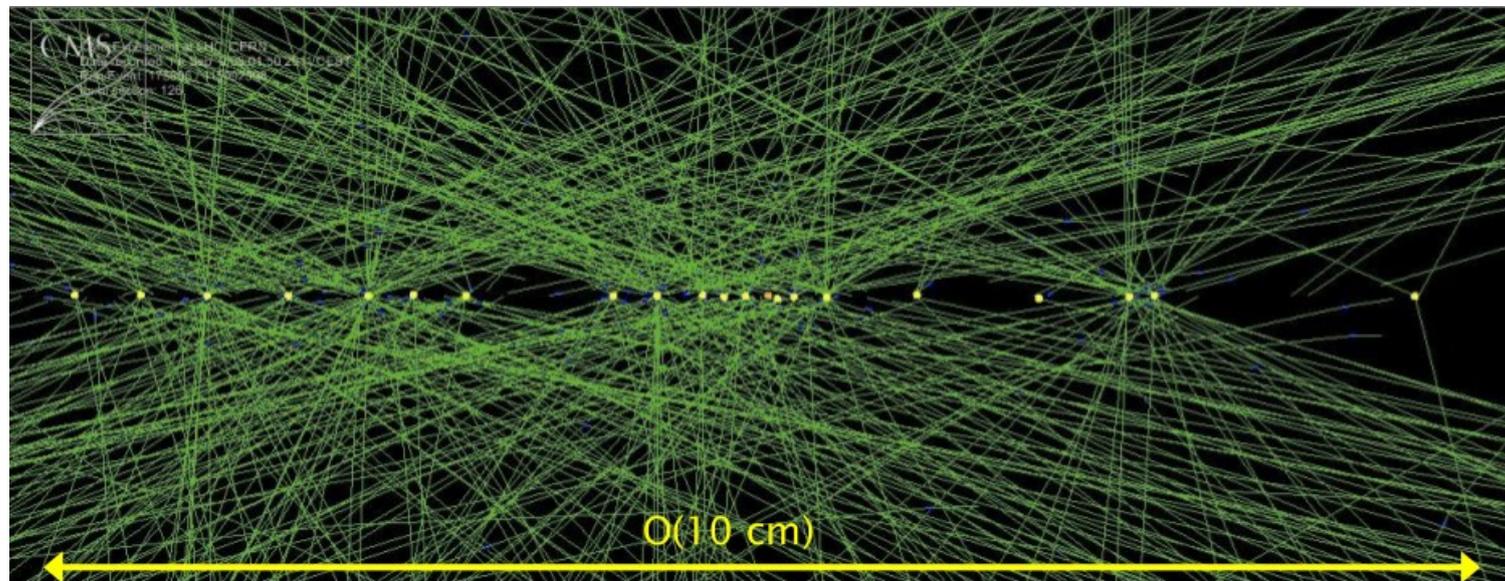
- Trigger



- Inclusive trigger threshold too high for many Higgs and SUSY analysis
- Dedicated signature trigger designed. Over 200 multi-object trigger including tau and b-jet trigger. Successfully deployed algorithm such as particle flow in tau reconstruction
- Challenging for low mass Higgs or SUSY searches

Challenges of High Luminosity

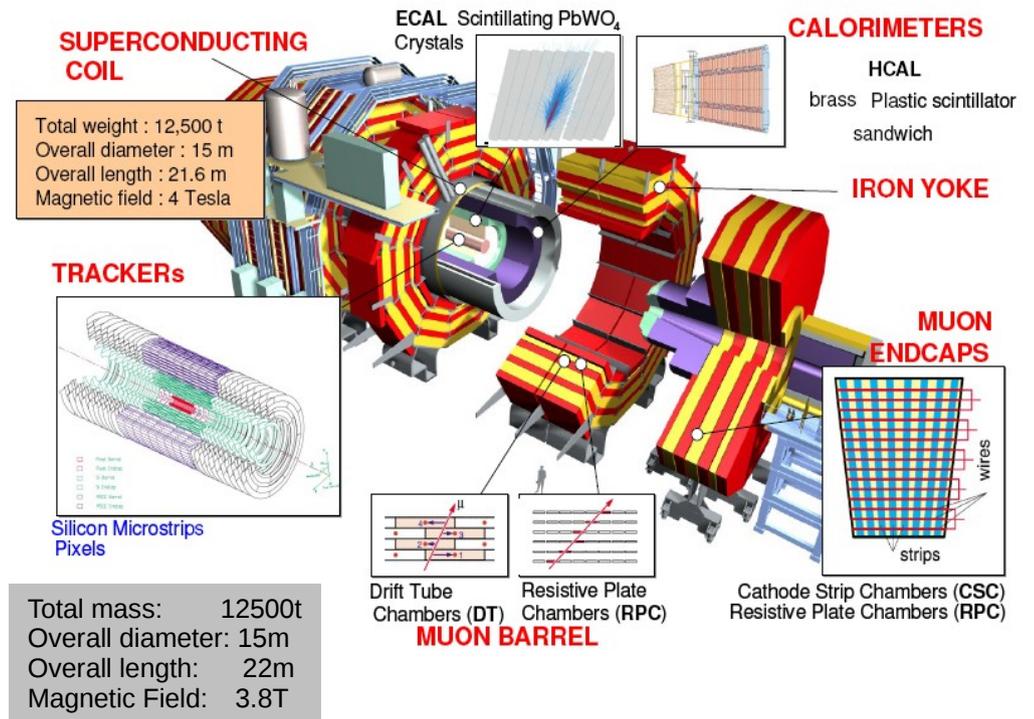
- Pile-up



- Additional pile-up interactions substantially affect
 - MET resolution, jet energy scale/resolution and multiplicity, lepton isolation, vertex reconstruction
 - Developed several techniques to address pile-up
- Increased processing time (trigger, offline)

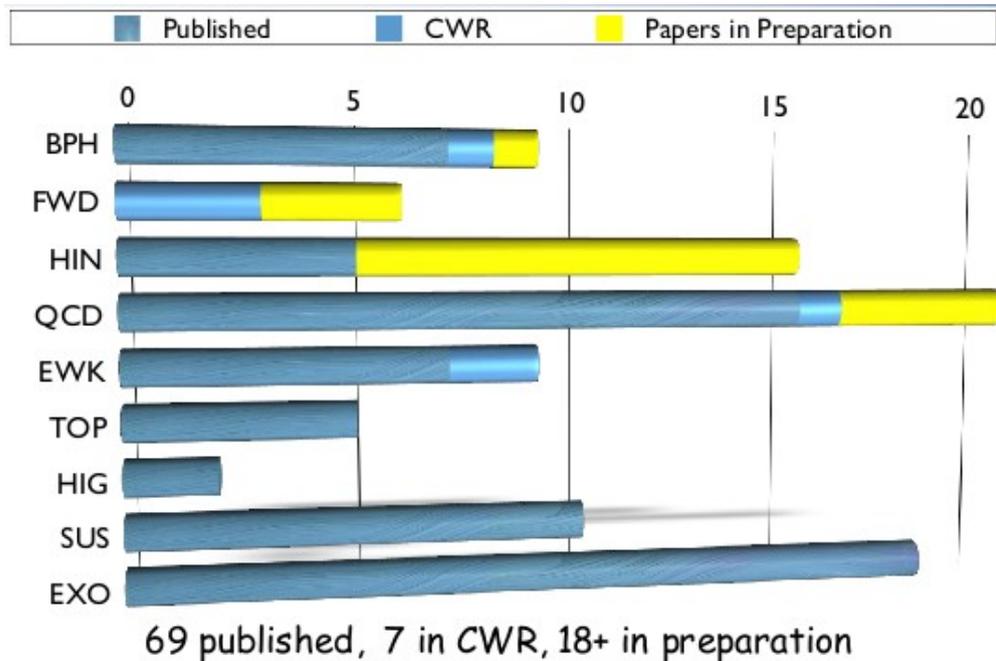
CMS Performance

- Operational fraction per sub-detector ~ 99%
- Overall data taking efficiency ~91%, ~84% with all systems perfect
- Improved uncertainty on pp luminosity measurement ~4.5%
- Detector performance is approaching expectation

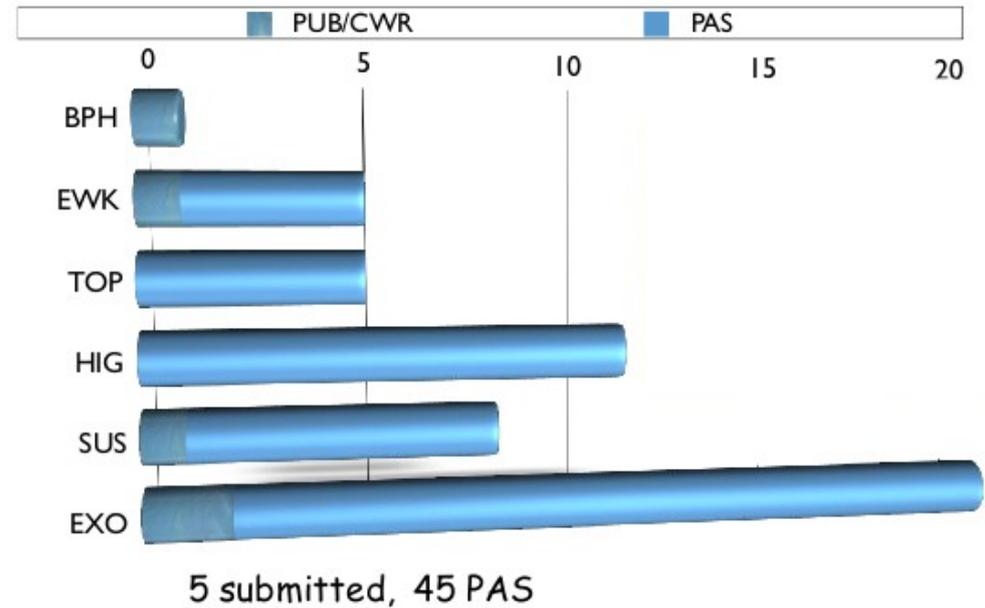


CMS Publications

2010 Data

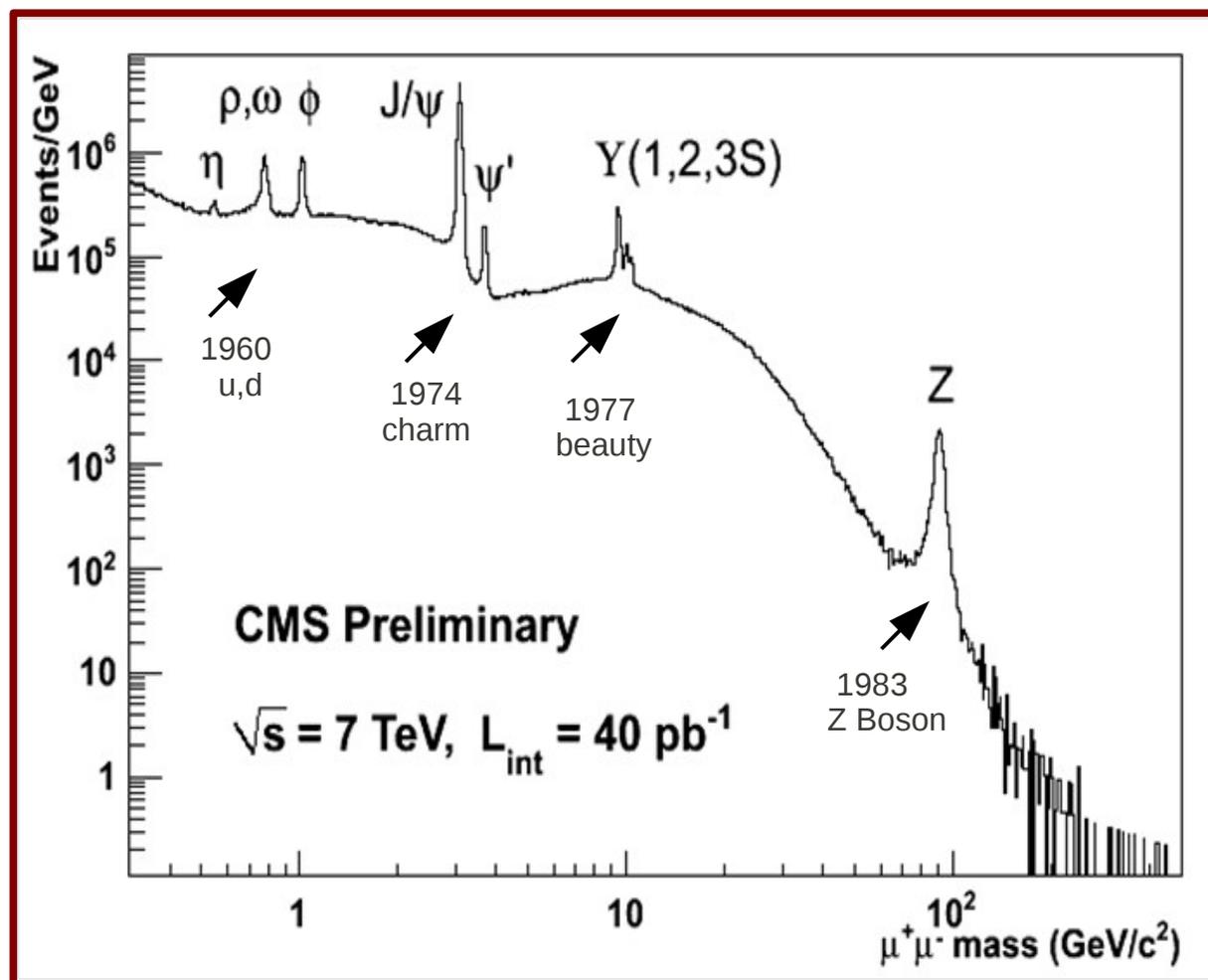


2011 Data



- CMS reached **100 publications** August 3rd
 - <https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults>
 - <http://cdsweb.cern.ch/collection/CMS>

Re-Discovery of SM in 2010/11 Data



no evidence for new physics yet

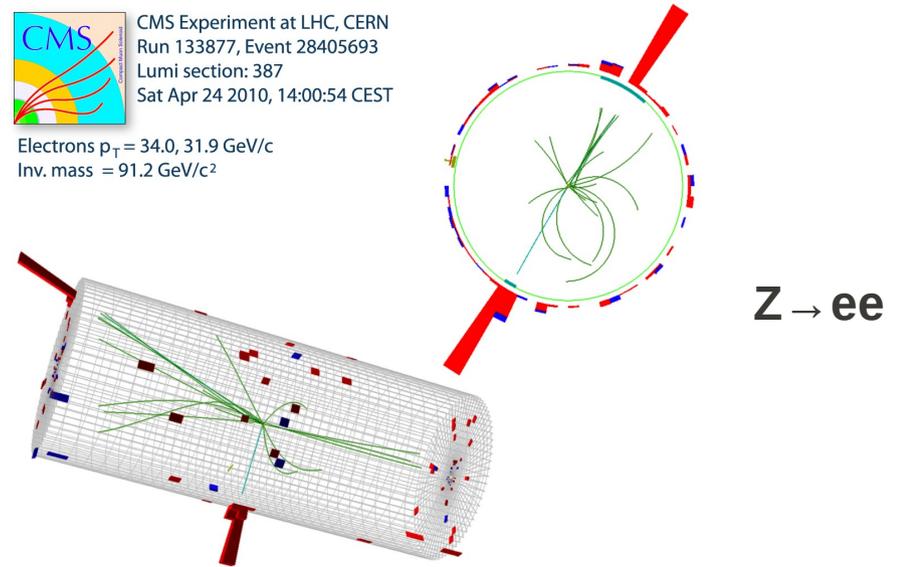
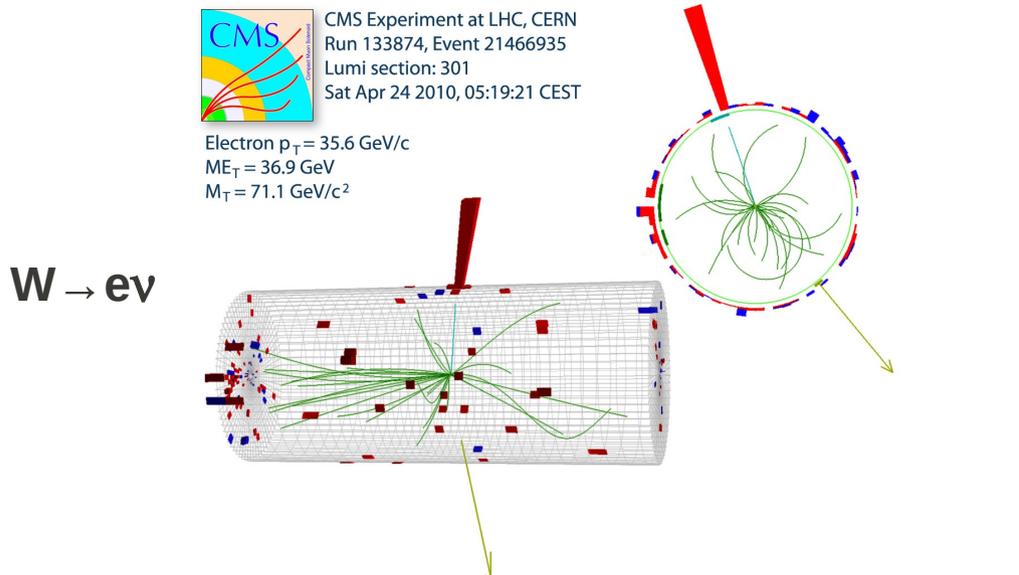
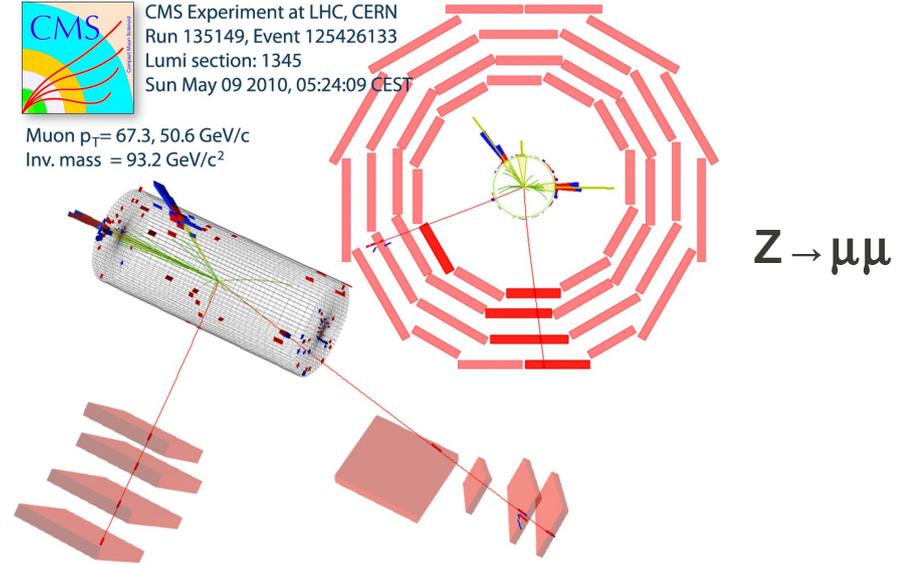
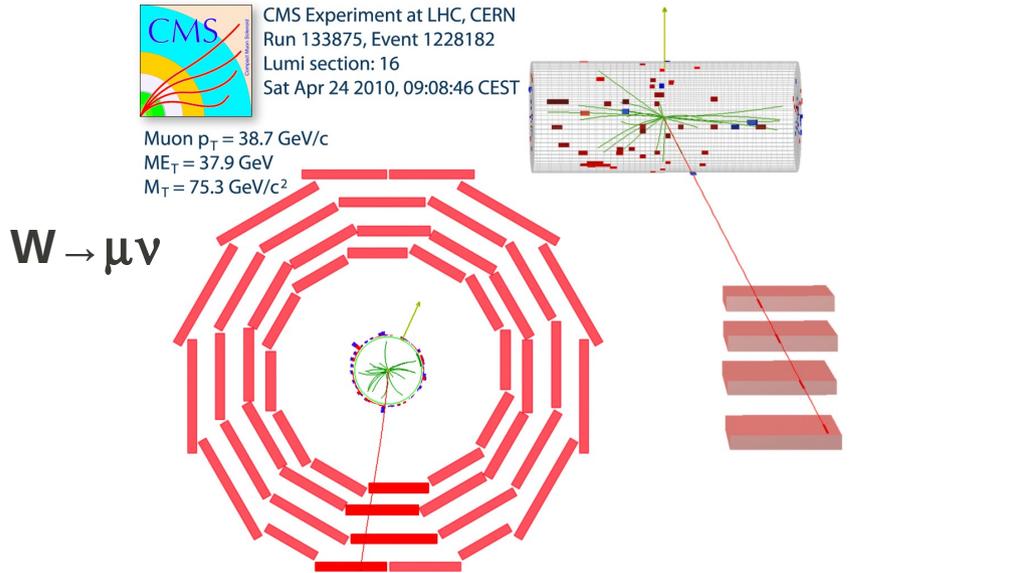
Presentations at this Workshop (Team CMS)

- Gheorghe Lungu: Searches for Jets + missing Et with no leptons at CMS
- Warren Andrews: Searches for Jets + missing Et with leptons at CMS
- Fedor Ratnikov: Searches for multi-lepton Production in CMS
- Joshua Thompson: SUSY Searches with b-jets in CMS
- Ulla Gebbert: SUSY Searches with Photons at CMS
- Maxwell Chertok: SUSY Searches with tau-leptons at CMS
- Jeff Temple: Stopped Gluino and Longlived Charged Sparticle Searches in CMS
- Hongliang Liu: SUSY Searches with Displaced Vertices in CMS
- Richard Carl Gray: CMS Searches for R-parity violating SUSY
- Hugues Louis Brun: Standard Model Higgs Boson Searches from CMS
- Roger Wolf: Beyond the SM Higgs Searches at CMS
- Eva Halkiadakis: Searches for New Physics at CMS

Can only show highlights here!

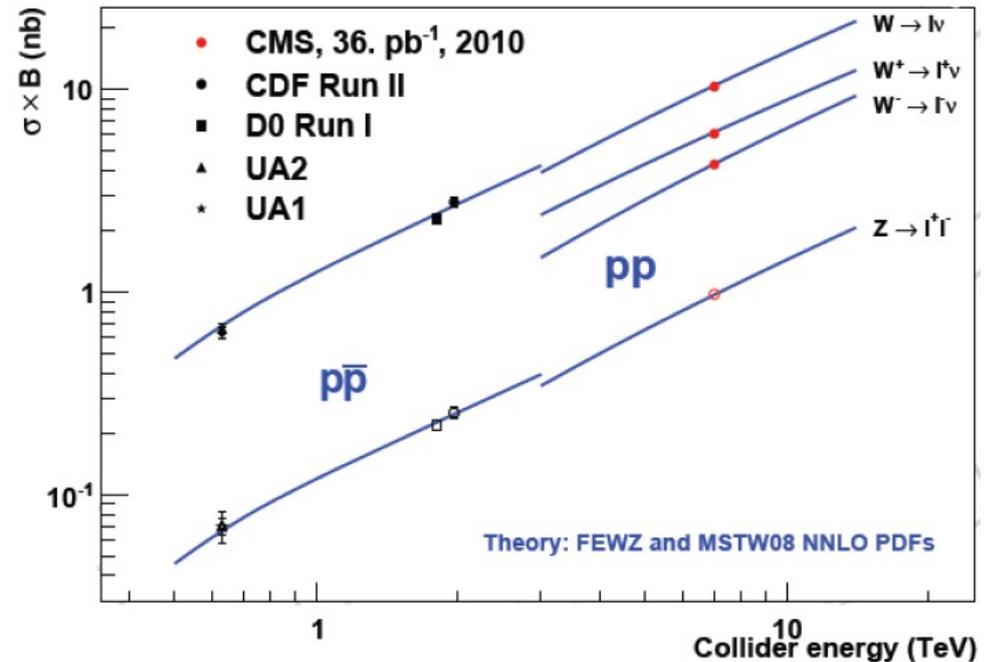
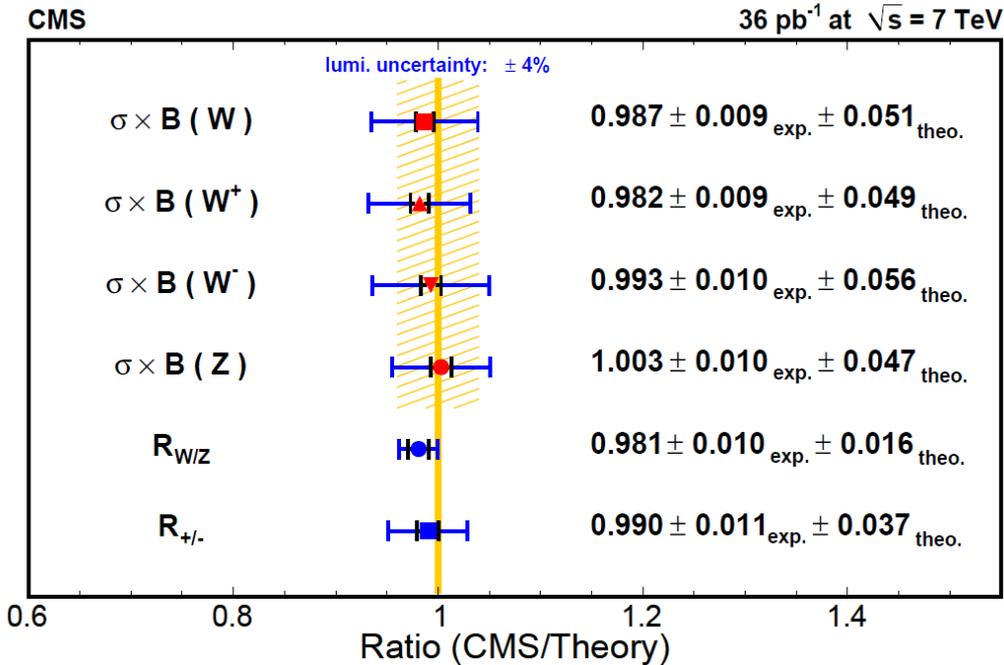


LHC Standard Candles



Vector Boson Production

- Results consistent with NNLO calculations (qQCD+PDF)
- Experimental accuracy about 1%
- 4% luminosity largest uncertainty
- Most stringent test of theory comes from ratios of cross sections



Lepton Charge Asymmetry

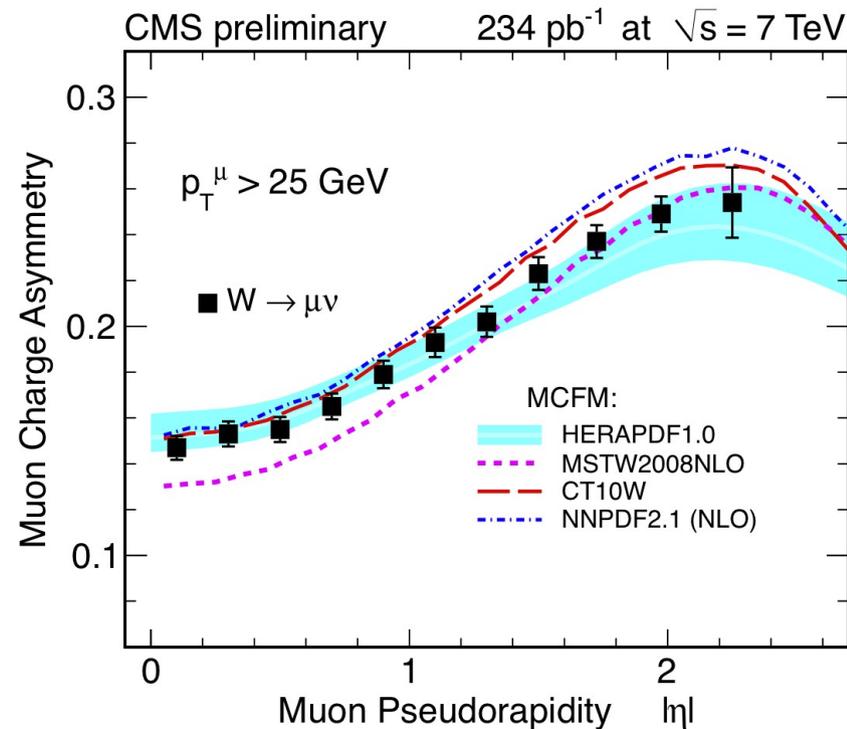
- Measured with electrons and muons
- Electron channel allows larger η coverage; charge confusion due to bremsstrahlung more challenging
- Updated measurement in muon channel
- Results provide **new constraints** on PDFs

$$\frac{\sigma(W^+)}{\sigma(W^-)} = 1.43 \pm 0.05$$

Experimental quantity :

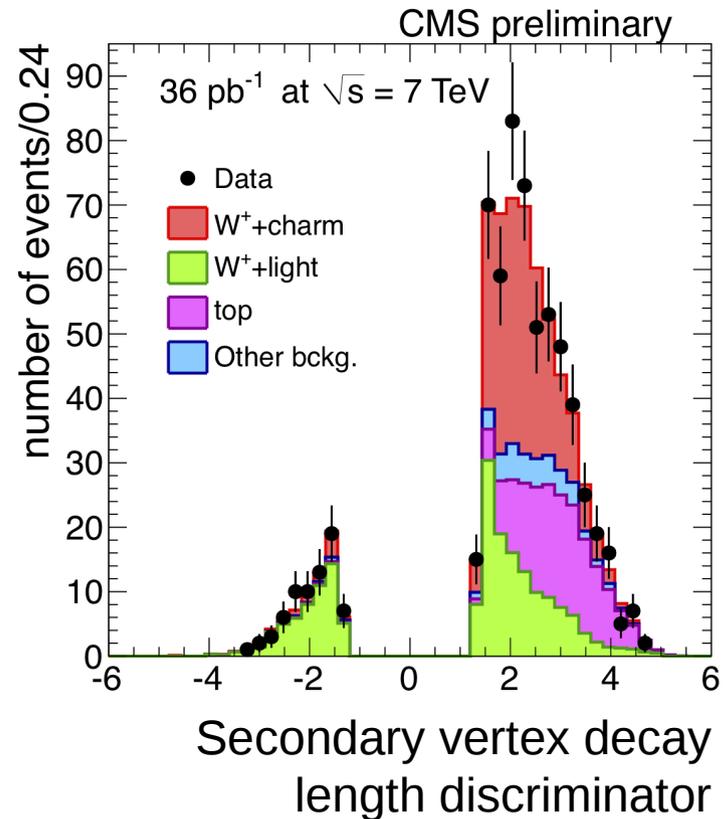
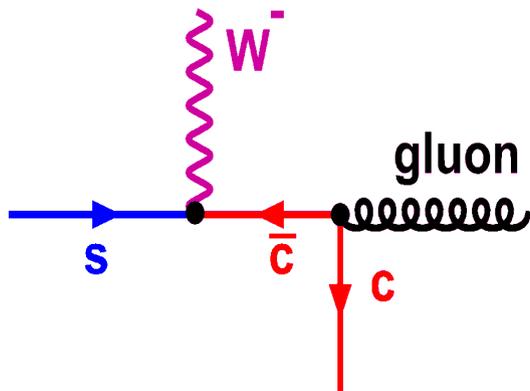
$$\mathcal{A}(\eta) = \frac{d\sigma/d\eta(W^+ \rightarrow \ell^+\nu) - d\sigma/d\eta(W^- \rightarrow \ell^-\bar{\nu})}{d\sigma/d\eta(W^+ \rightarrow \ell^+\nu) + d\sigma/d\eta(W^- \rightarrow \ell^-\bar{\nu})}$$

PAS EWK-11-005



Access to Proton PDFs

- W+c PAS EWK-11-013
- Probing strange quark PDF



$$R_{\pm c} = \sigma(W^+c) / \sigma(W^-c) = 0.92 \pm 0.19(\text{stat.}) \pm 0.04(\text{syst.})$$

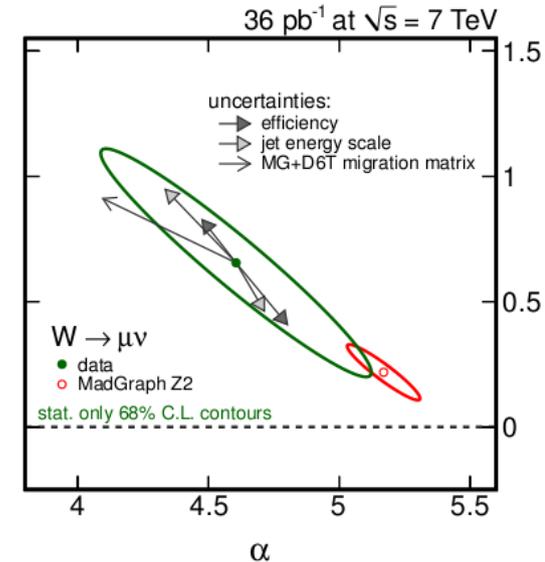
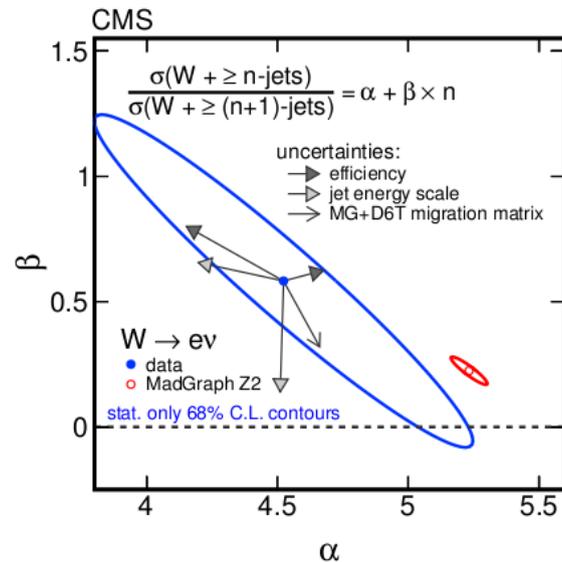
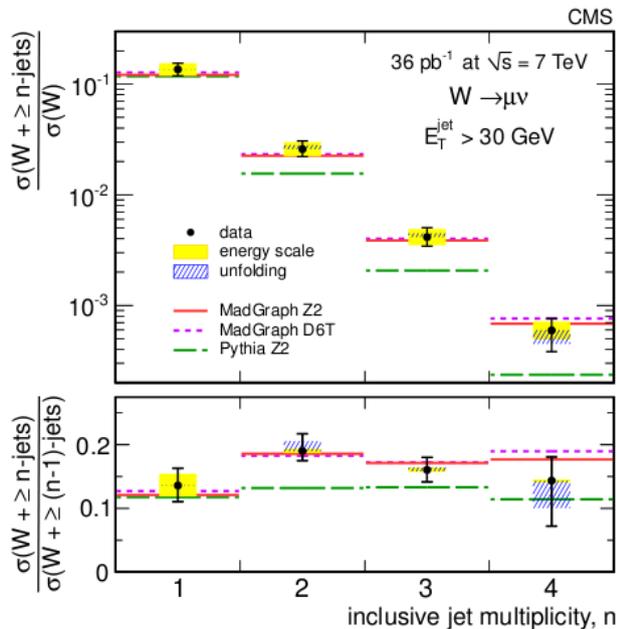
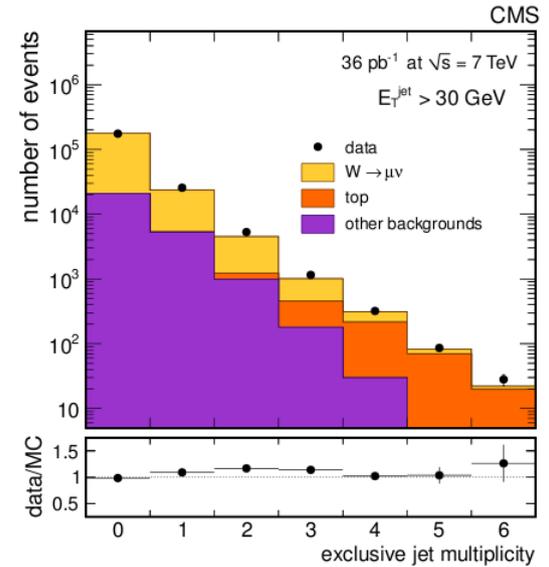
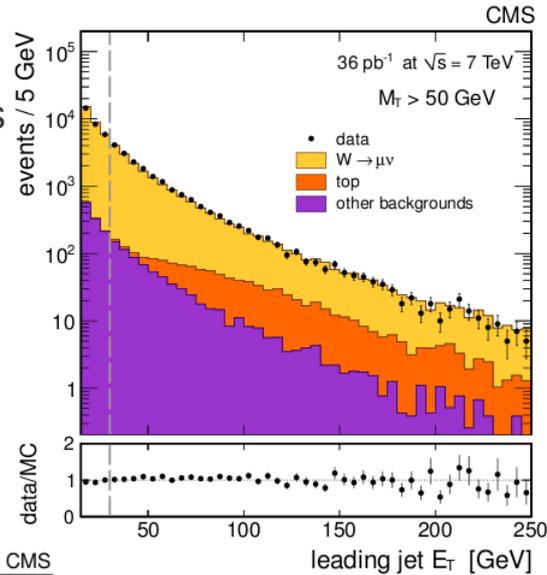
$$R_c = \sigma(Wc) / \sigma(W+\text{jets}) = 0.143 \pm 0.015(\text{stat.}) \pm 0.024(\text{syst.})$$

NLO predictions:

$$R_{\pm c} = 0.91 \pm 0.04 \quad R_c = 0.13 \pm 0.02$$

Vector Bosons Plus Jets

- Test perturbative QCD
- Important background to SM Higgs boson and new physics searches
- Measure for W and Z in electron and muon final state
- Measured rates and cross section ratios
- Test Berends-Giele scaling

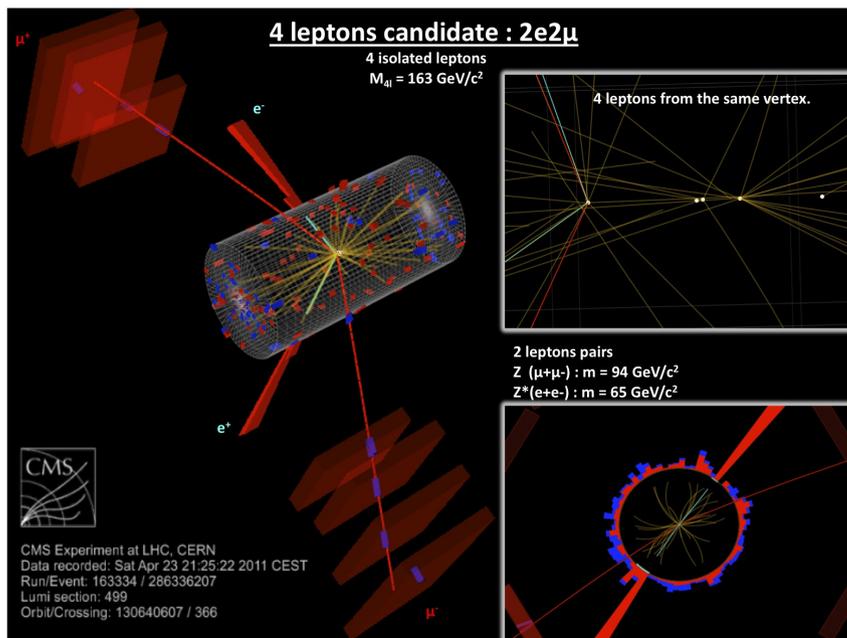


Vector Boson in Pairs

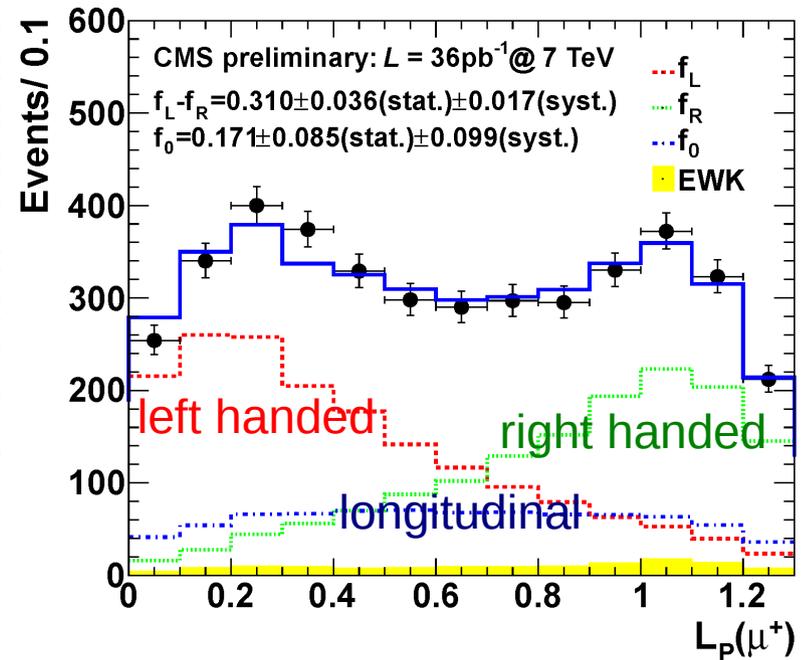
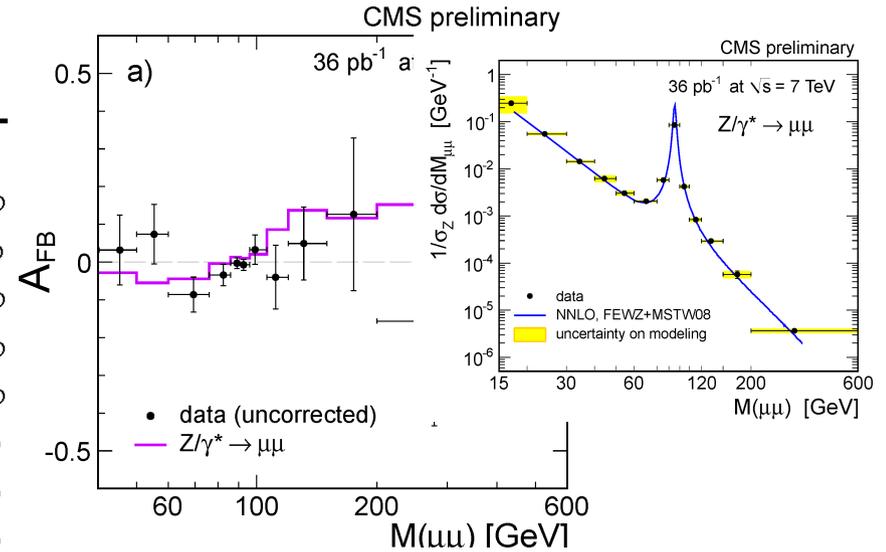
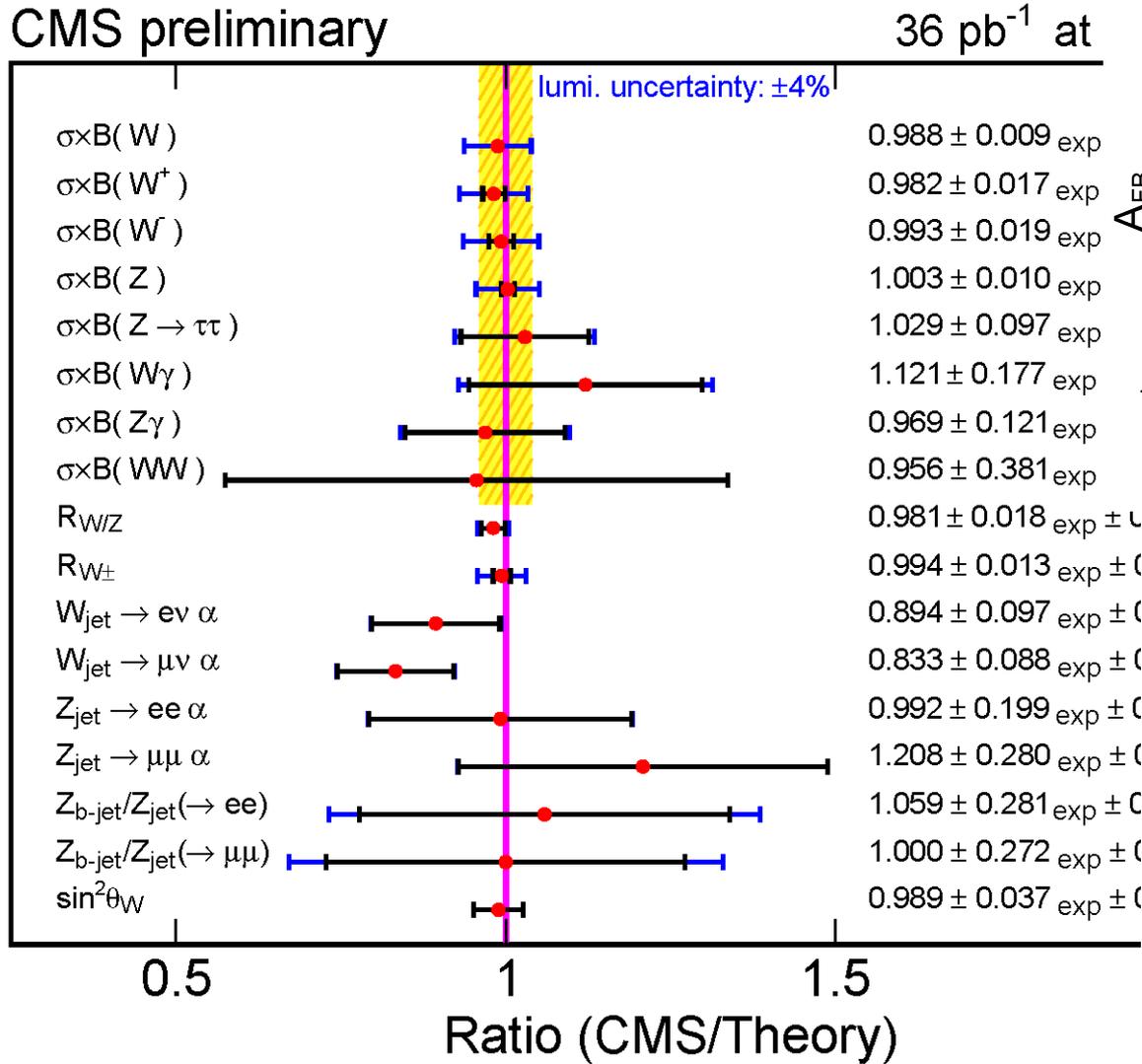
- Probe tri-linear gauge coupling
- Indirect probe for New Physics
- Broad agreement with theory
- Shares final states with Higgs searches

channel	CMS	theory
WW	626 events 68% purity $55.3 \pm 3.3 \pm 6.9 \pm 3.3$ (6% prec)	46 ± 3 pb
WZ	75 events 89% purity $17.0 \pm 2.4 \pm 1.1 \pm 1.0$	17 ± 1 pb
ZZ	9 events 93% purity $3.8 \pm 1.4 \pm 0.2 \pm 0.2$	6.5 ± 0.3 pb

PAS EWK-11-010



More Results with W and Z's

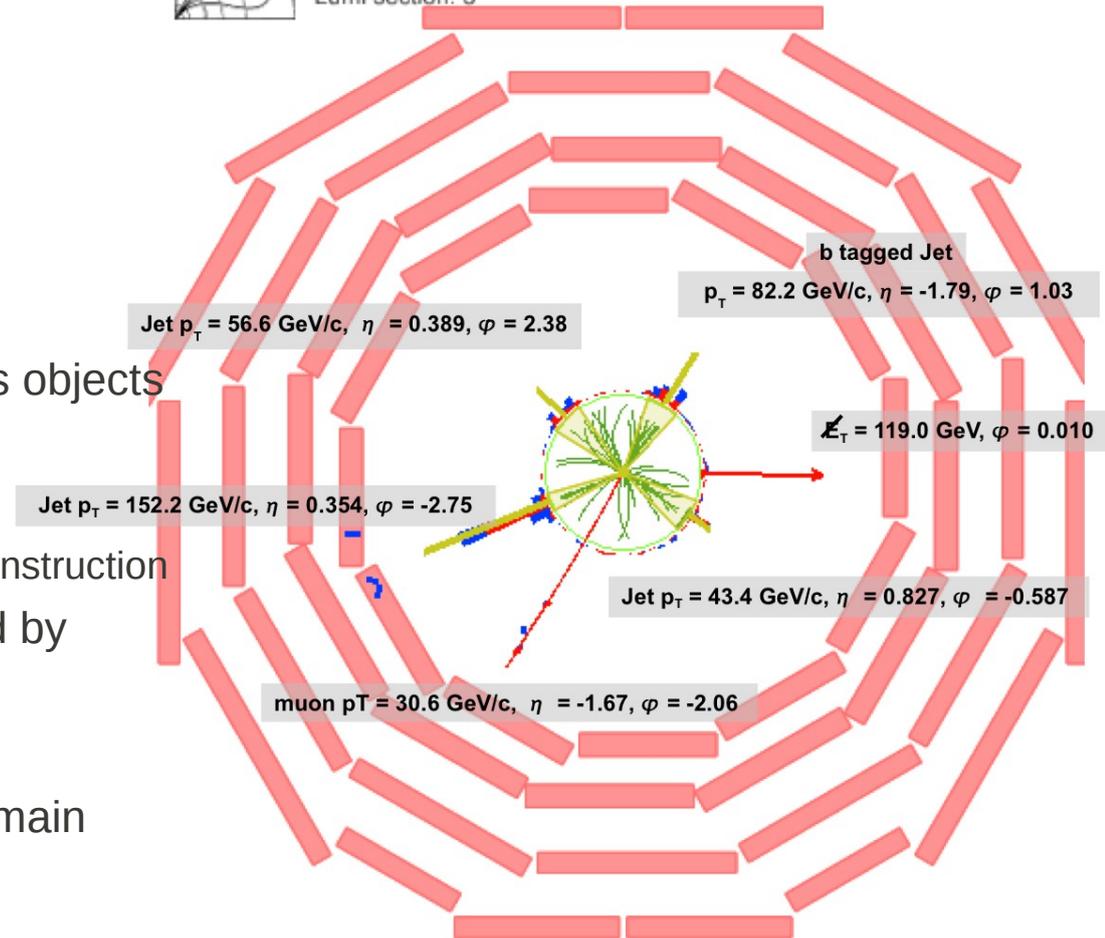


Top Quark Physics

- LHC is a **factory of top quarks**
 - Cross section $\sim 160\text{pb}$
- Multiple final states used in measurements
 - di-lepton
 - lepton+jets
 - **lepton+jets+b-tag**
 - all hadronic
- Top quark measurements use most physics objects
 - Leptons
 - Jets and missing ET
 - Primary and secondary vertex (b-tagging) reconstruction
- Systematic uncertainties usually dominated by
 - JET/MET energy scale
 - b-tagging efficiency
- Top quark used as standard candle and is main background to many searches



CMS Experiment at LHC, CERN
Data recorded: Wed Jul 14 03:32:41 2010 CEST
Run/Event: 140124 / 1749068
Lumi section: 3



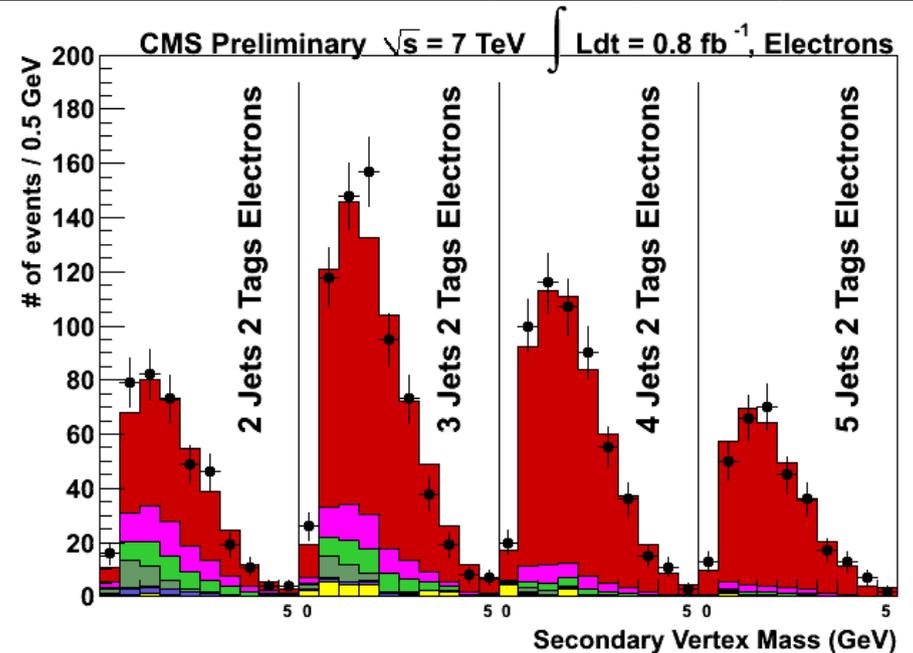
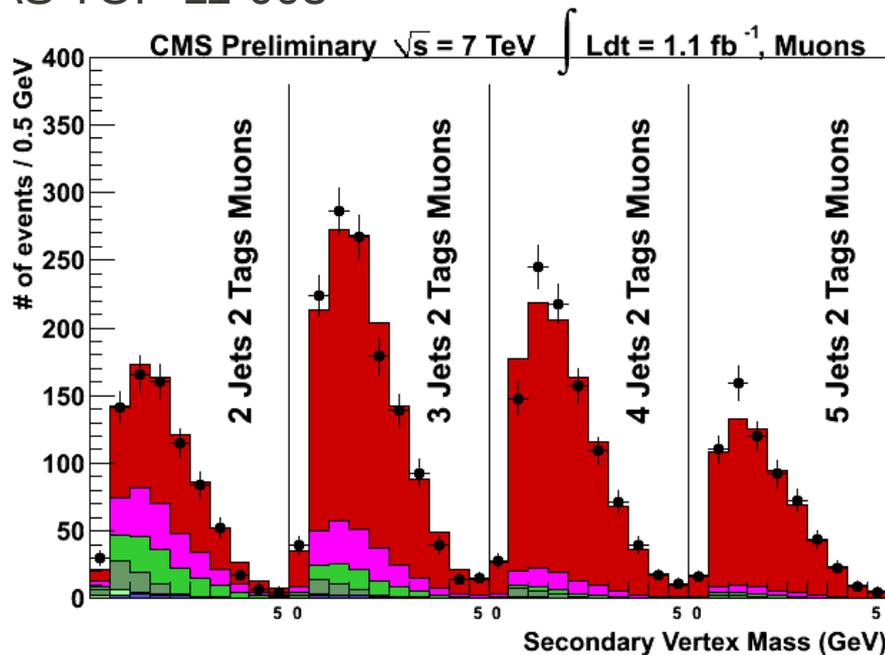
Top Quark Cross Section

- Lepton + jets channel with b tagging
 - Binned likelihood with secondary vertex mass in categories of jets and jets with b-tag
 - Clean signal observed
 - 7.5% uncertainty

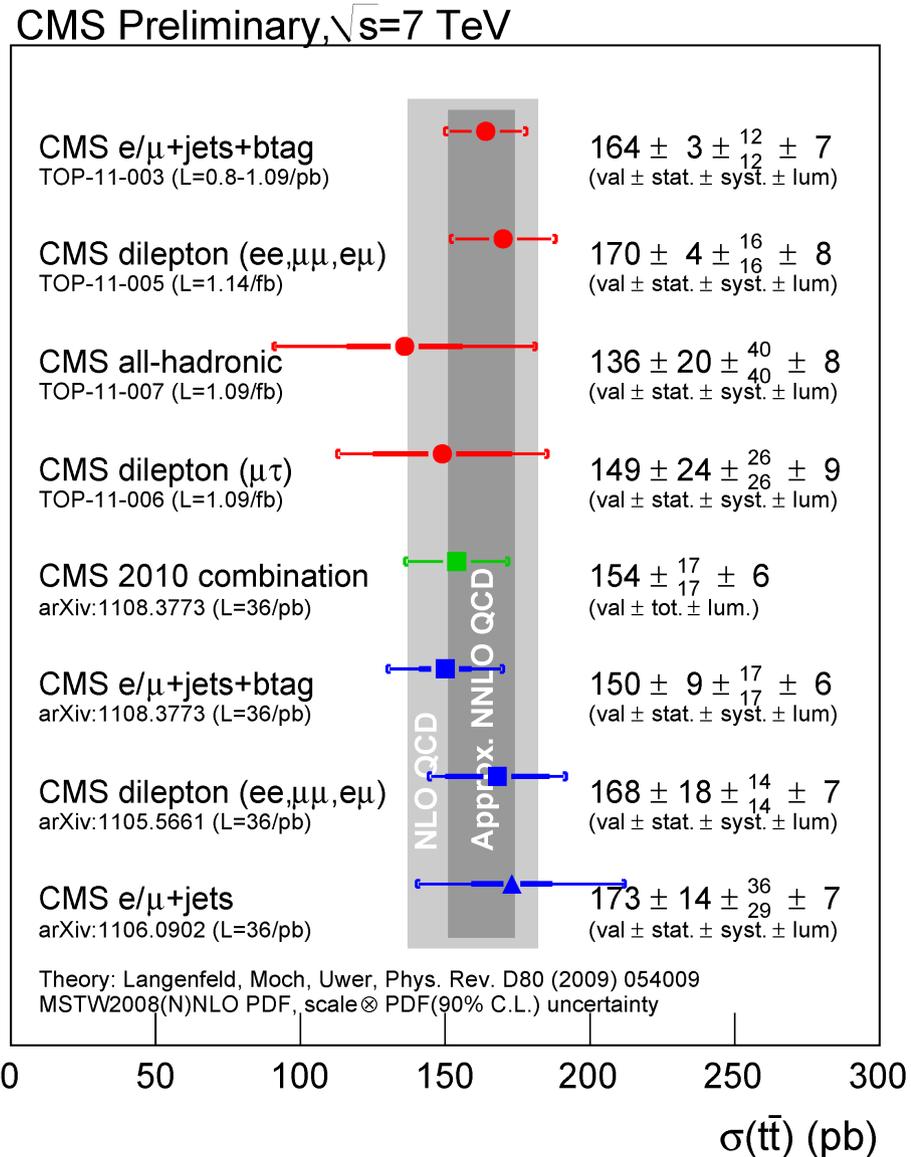
$$\sigma_{t\bar{t}} = 164.4 \pm 2.8(\text{stat.}) \pm 11.9(\text{syst.}) \pm 7.4(\text{lum.}) \text{ pb}$$

Source	Muon Analysis	Electron Analysis	Combined Analysis
Quantity	Uncertainty (%)		
Lepton ID/reco/trigger	3.4	3	3.4
E_T resolution due to unclustered energy	< 1	< 1	< 1
$t\bar{t}$ +jets Q^2 scale	2	2	2
ISR/FSR	2	2	2
ME to PS matching	2	2	2
Pile-up	2.5	2.6	2.6
PDF	3.4	3.4	3.4
Profile Likelihood Parameter	Uncertainty (%)		
Jet energy scale and resolution	4.2	4.2	3.1
b -tag efficiency	3.3	3.4	2.4
W +jets Q^2 scale	0.9	0.8	0.7
Combined	7.8	7.8	7.3

PAS TOP-11-003



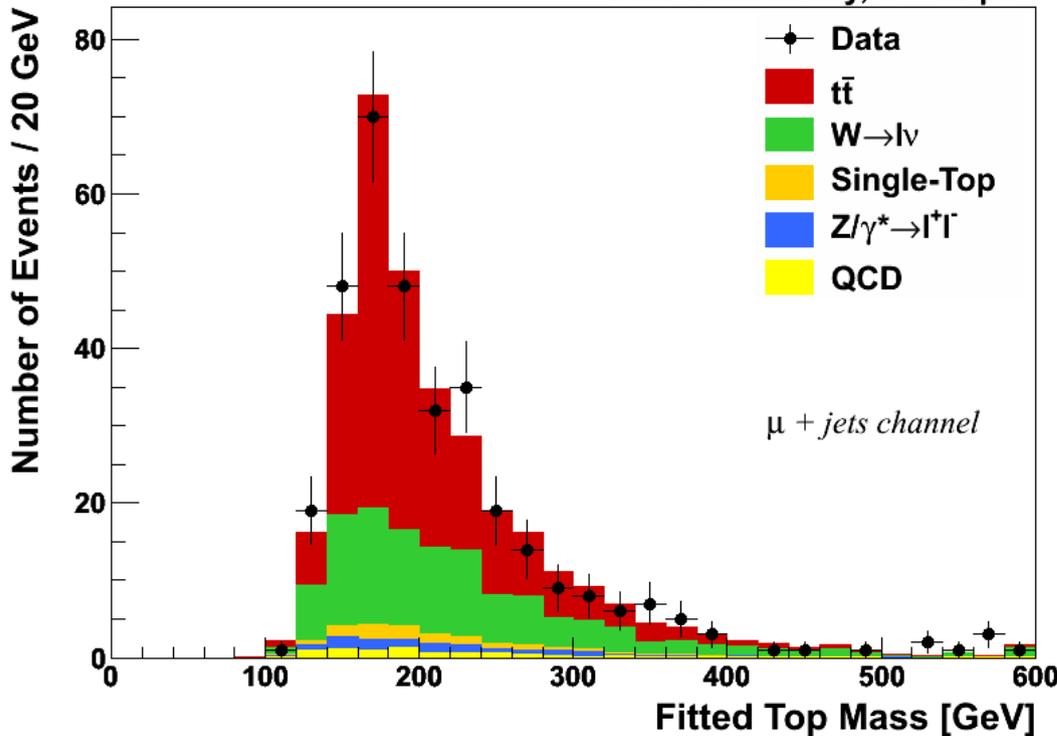
Top Quark Cross Section



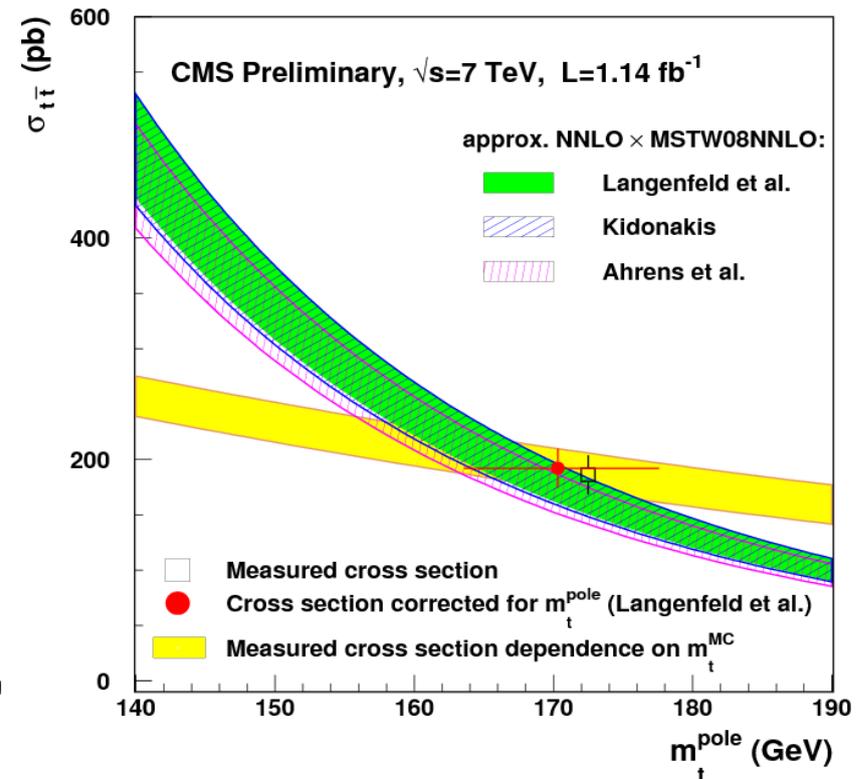
Top Quark Properties

- Early top mass measurements
 - Combined top mass measurement ($m_{\text{top}} = 173.7 \pm 1.9 \pm 2.7 \text{ GeV}$)
 - Top mass from cross section measurement
 - Consistent with Tevatron measurements

PAS TOP-10-009 CMS Preliminary, $L = 36 \text{ pb}^{-1}$

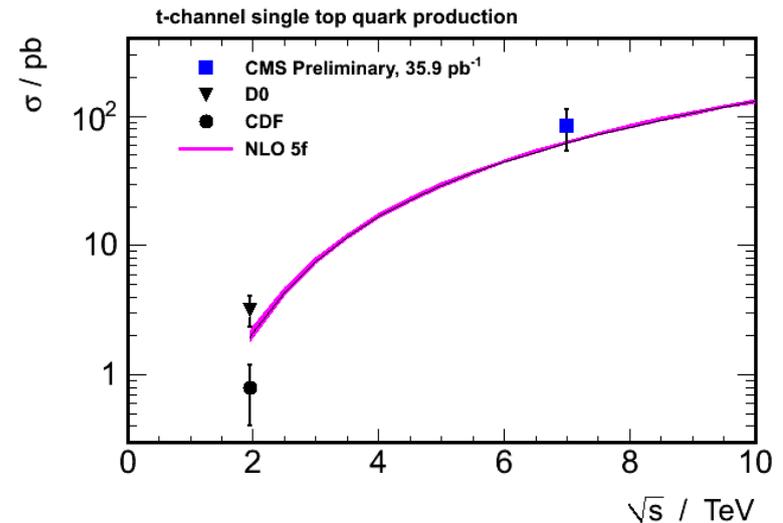
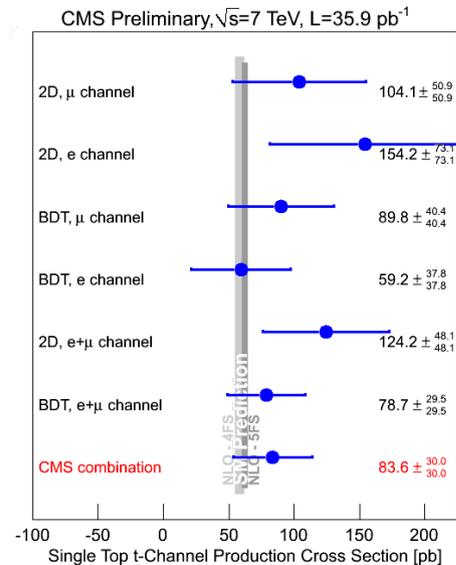
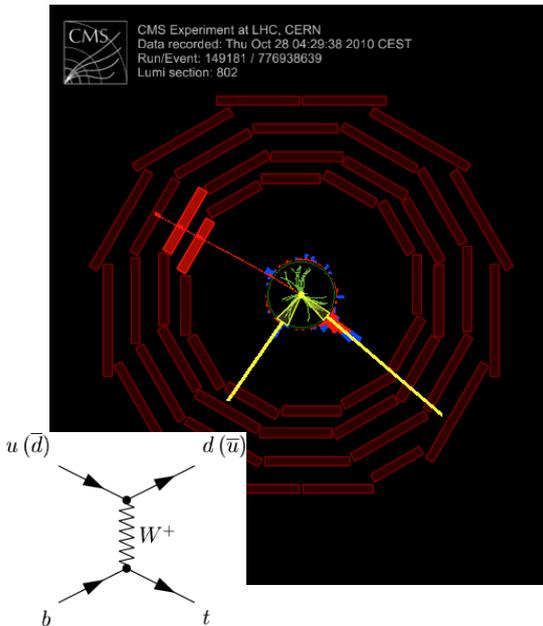
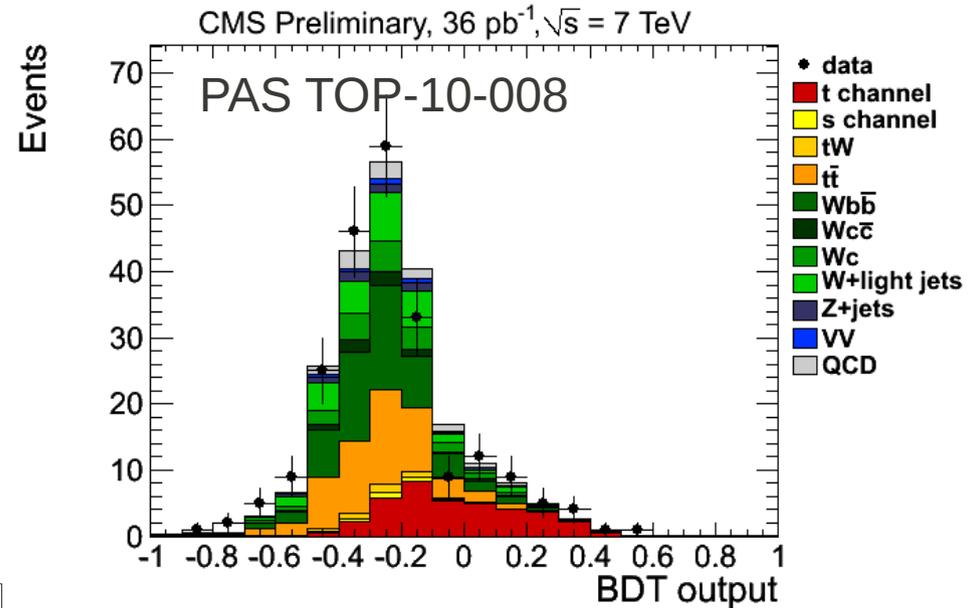


PAS TOP-11-008



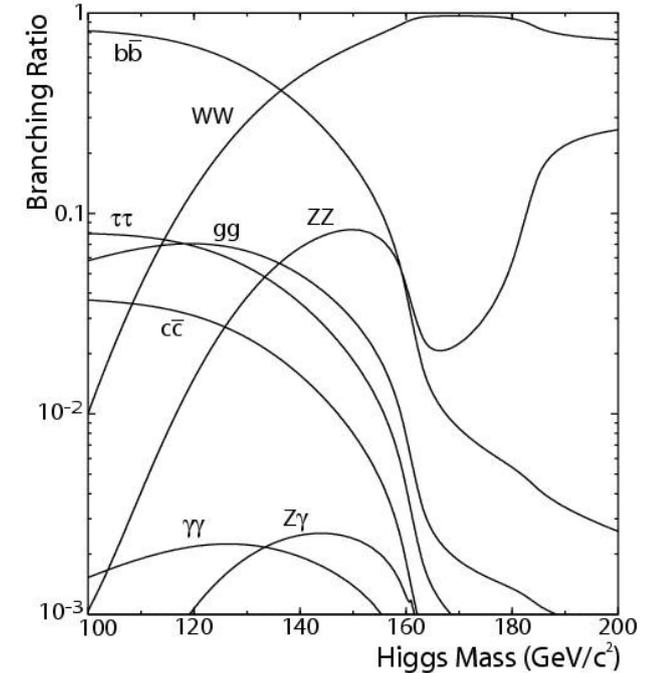
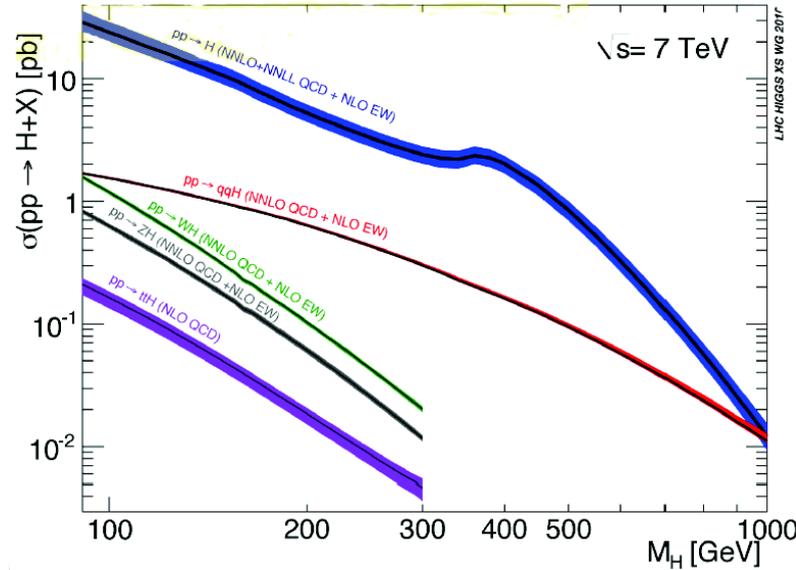
Single Top Quarks

- Observation of single top t-channel production
- $\sigma = 86.3 \pm 30$ pb
- Cross sections in agreement with expectation
- Signature: lepton + E_T^{miss} + b-jet + jet
- Small signal extracted from large background with multivariate analysis technique
- Wt channel added ($\sigma = 22^{+9}_{-7}$ pb) with 2.1 fb⁻¹ PAS TOP-11-022



Higgs Searches at the LHC

- Combined effort by ATLAS, CMS and theory
“Handbook of LHC Higgs Cross Sections”
arXiv:1101.0593
- 2nd part in works to discuss differential cross sections



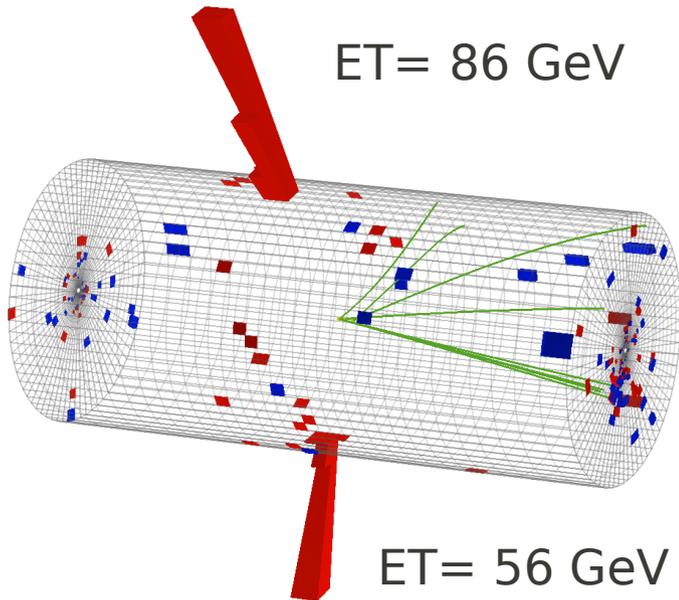
Channels included	≈ Mass range (GeV)	Status, Comments
$H \rightarrow \gamma\gamma$	115-150	Challenging.
VBF $H \rightarrow \tau\tau$	115-145	Results with 2010 data. Breaking new ground
VH, $H \rightarrow bb$ (highly boosted)	115-125	
VH, $H \rightarrow WW \rightarrow l\nu jj$	130-200	Results with 2010 data. Work horse for 120-200 GeV, large yield
$H \rightarrow WW \rightarrow 2l2\nu + 0/1$ jets	120-600	
VBF $H \rightarrow WW \rightarrow 2l2\nu$	130-500	
$H \rightarrow ZZ \rightarrow 4l$	120-600	The golden channel. Low bkgr but low yield
$H \rightarrow ZZ \rightarrow 2l2\nu$	200-600	Major bkgr is diboson and top.
$H \rightarrow ZZ \rightarrow 2l2b$	300-600	Profits from jet, MET reco and good b-tagging

modified from K. Hoepfner

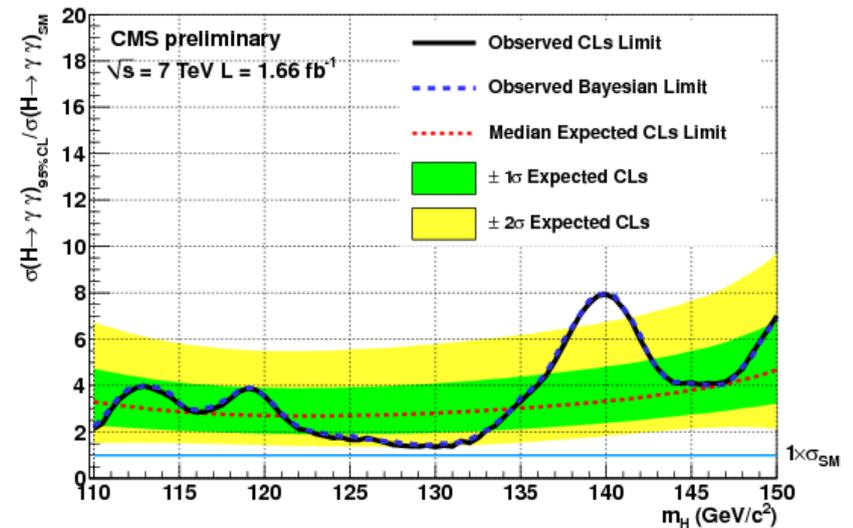
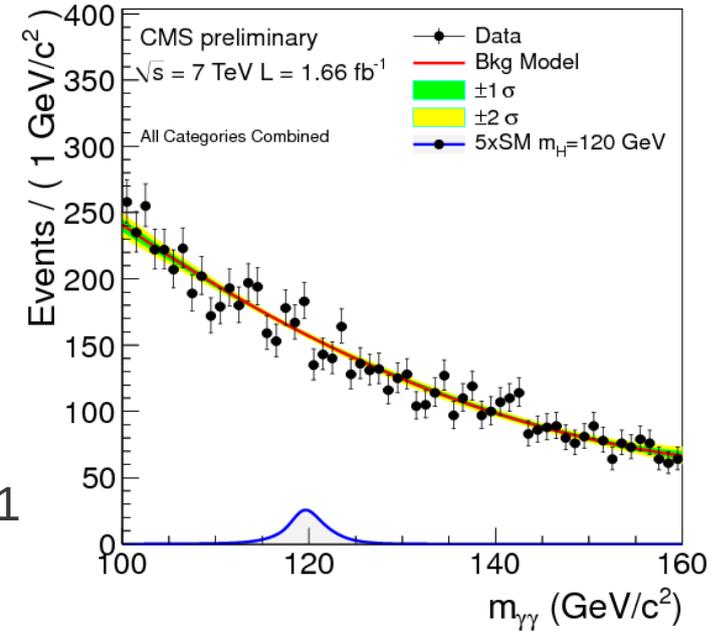
- Event yields can be modified and additional channels are possible in models beyond the SM
 - Modified particle content can change production or decay of the Higgs boson (e.g. 4th generation models)
 - Couplings can be modified (e.g. fermiophobic models)
 - Higgs sector is modified
 - Two Higgs doublet models (2HDM)
 - More complex models

$$H \rightarrow \gamma\gamma$$

- 2 isolated photons with $P_T > 40, 30$ GeV
- Divide data in categories based on mass resolution
- Background shape fitted in each category

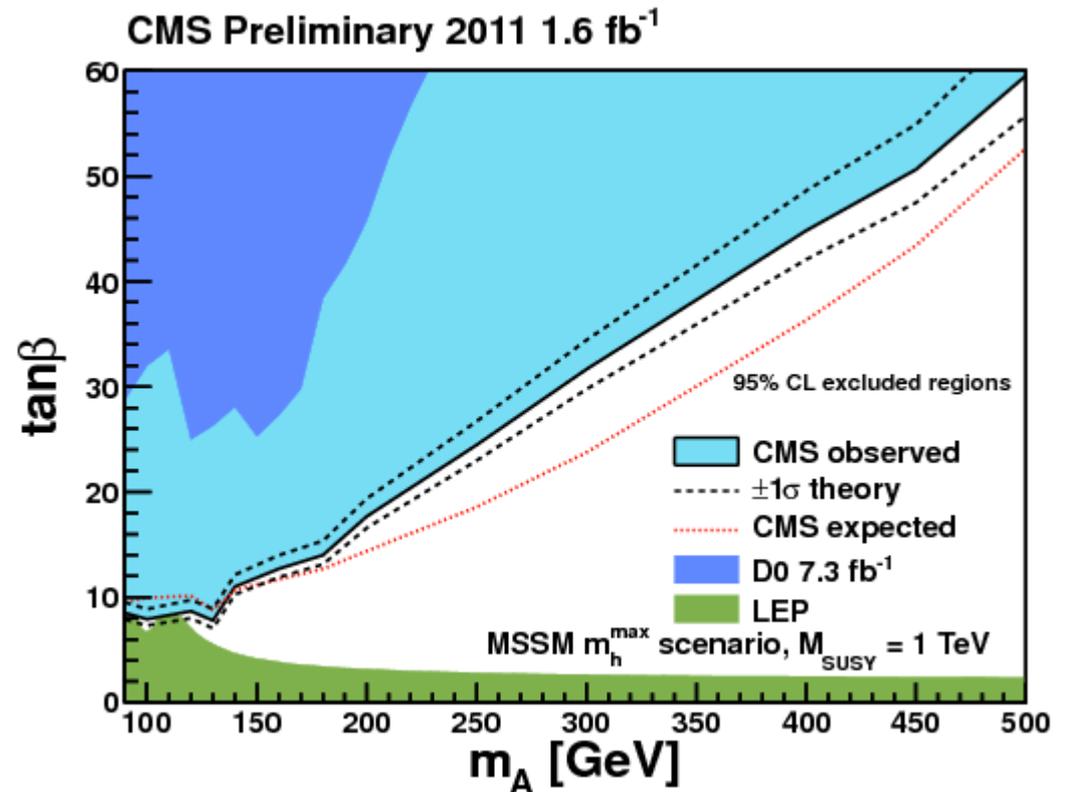
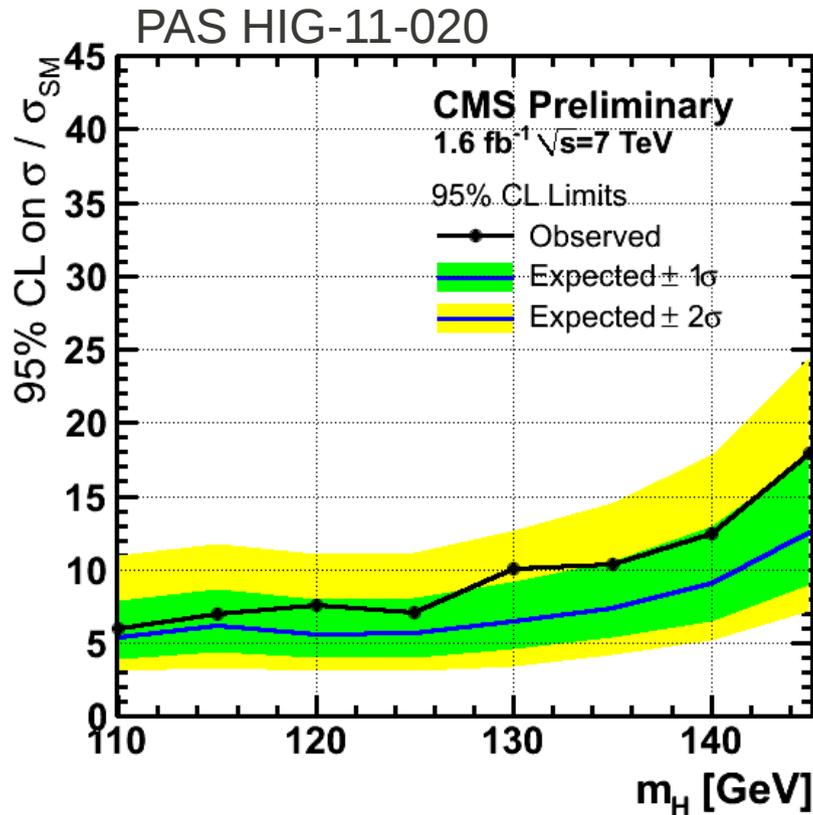
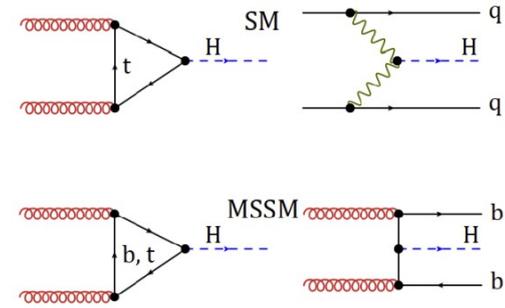


PAS HIG-11-021

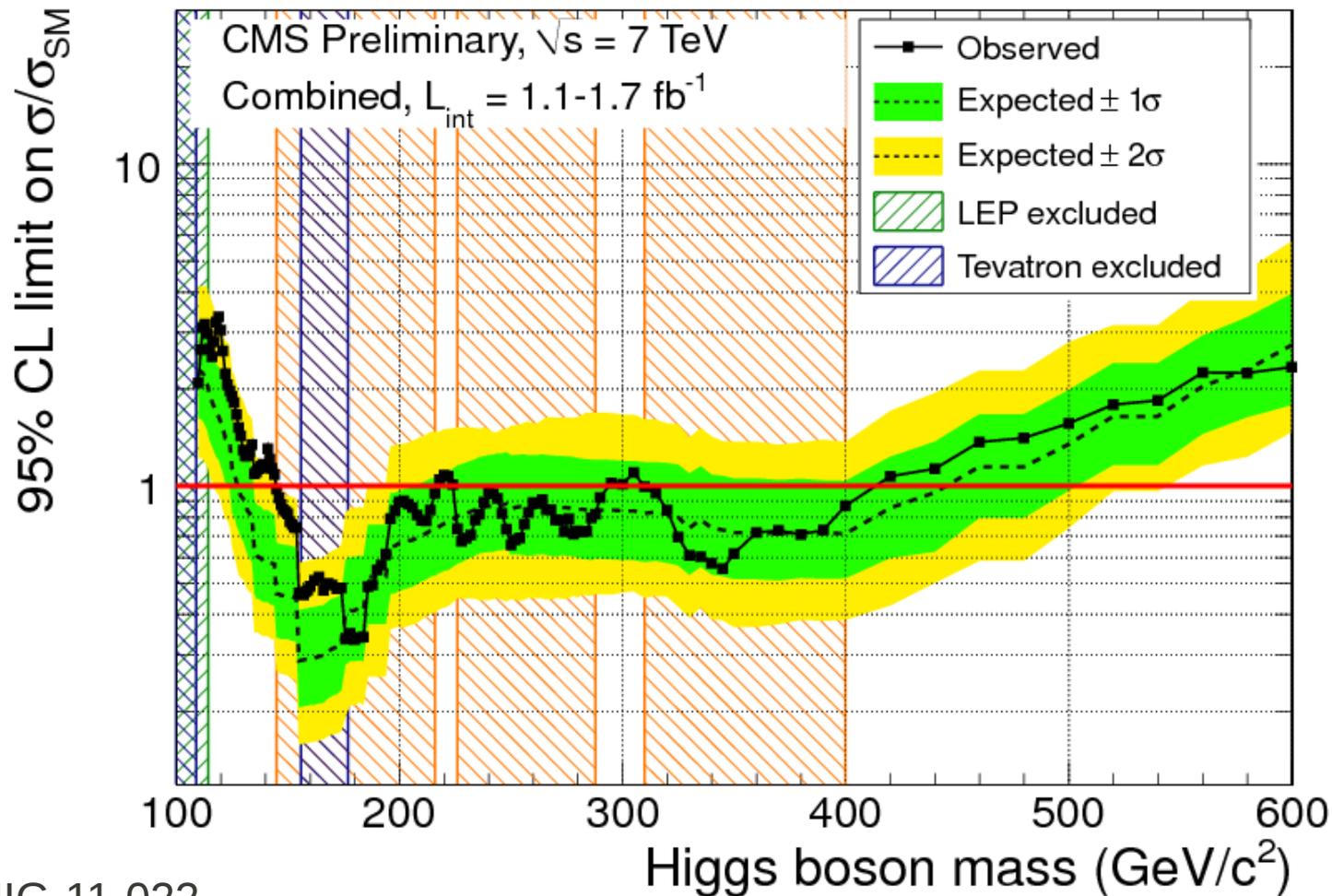


$$\phi \rightarrow \tau\tau$$

- Studied $\tau_\mu + \tau_{had}$, $\tau_\mu + \tau_e$ and $\tau_e + \tau_{had}$ channels
- No excess observed in visible di- τ mass spectrum
- Z boson production irreducible background
- Limits on cross section and MSSM $[\tan\beta, m_A]$ exclusion



Grand SM Combination

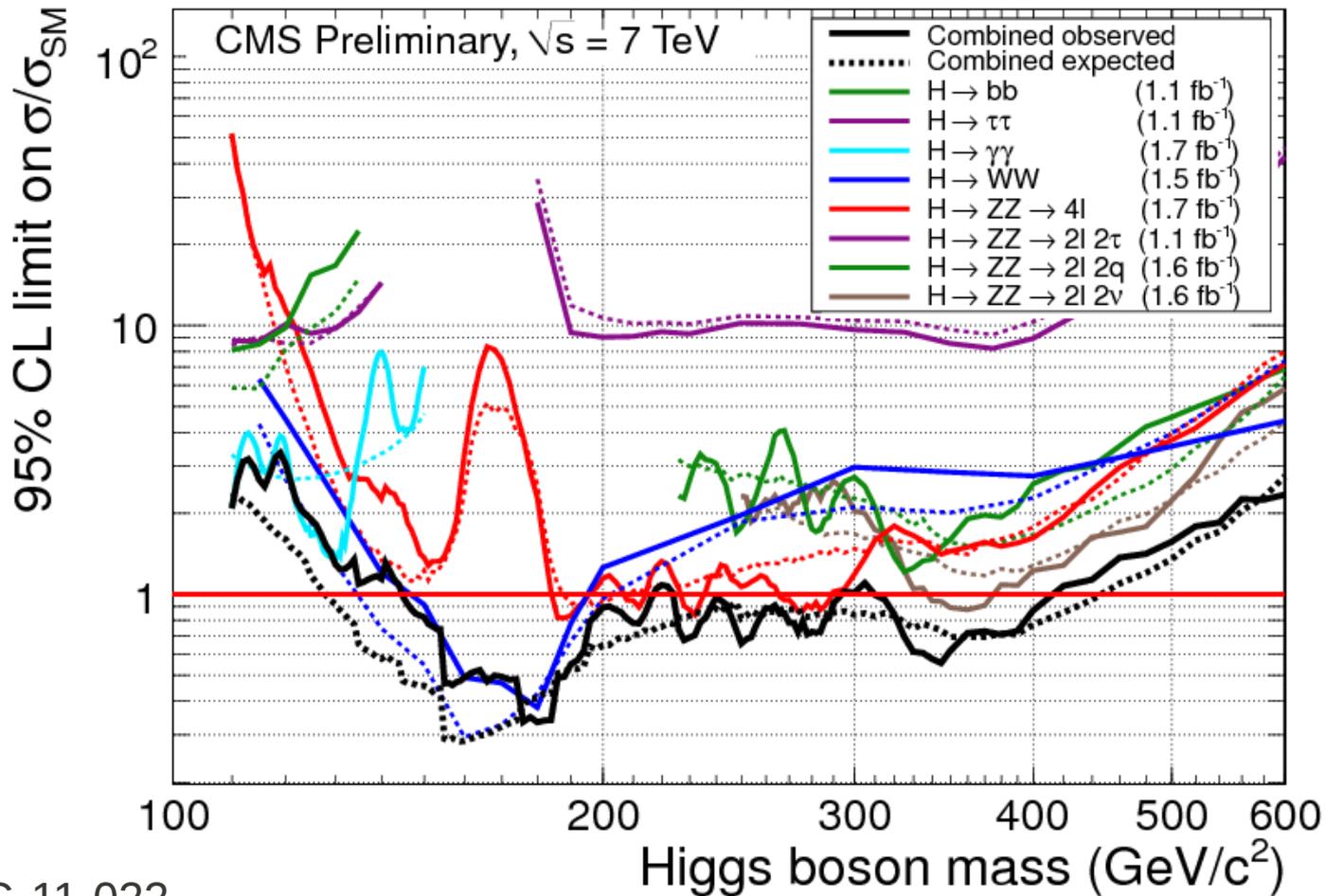


PAS HIG-11-022

* not yet updated for $H \rightarrow \tau\tau$

Low mass region extremely challenging

Grand SM Combination



PAS HIG-11-022

* not yet updated for $H \rightarrow \tau\tau$

Higgs Summary

- CMS searches for the Higgs boson in many different channels
- No SM Higgs signal observed in the [110-600] GeV mass range
- A wide range of mass **excluded at 95% CL**:
 - SM: [145-216], [226-288] & [310-400] GeV
 - Fermiophobic: [110-112] GeV
 - 4th generation SM: [250-550] GeV
 - MSSM [$\tan\beta$, m_A]
- The expected SM exclusion range is [130-440] GeV
- The experimentally difficult low mass region not fully probed

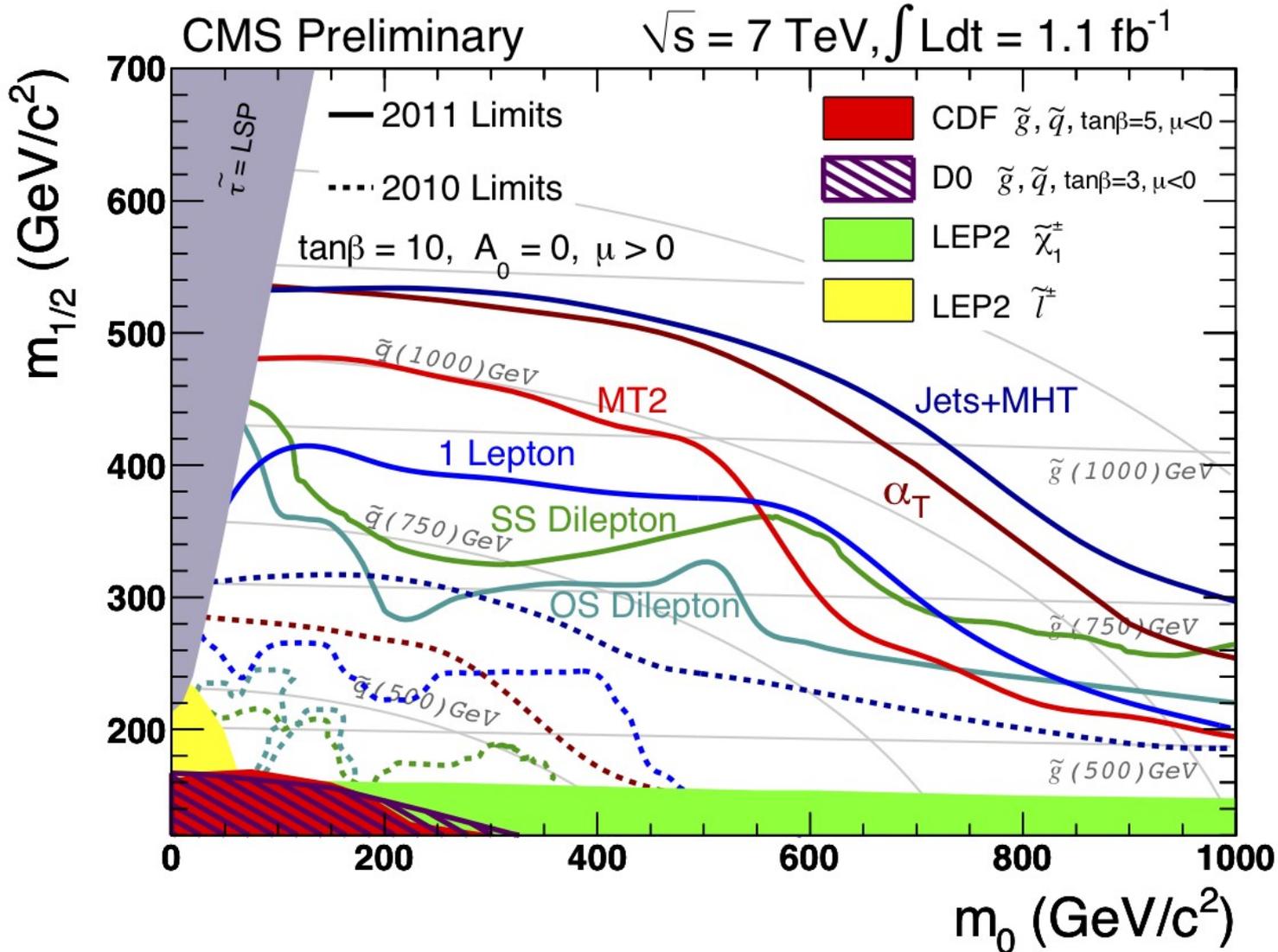
Beyond the Standard Model

- SUSY search strategy uses inclusive topology

0-leptons	1-lepton	OSDL	SSDL	≥ 3 leptons	2-photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	Di-photon + jet + MET	Photon + lepton + MET

- Multiple approaches within each category, as well as several search regions
- We do not know where SUSY is hiding, so we look everywhere
- Establish data driven estimates of backgrounds
- Interpretation model dependent

Interpretation in the CMSSM

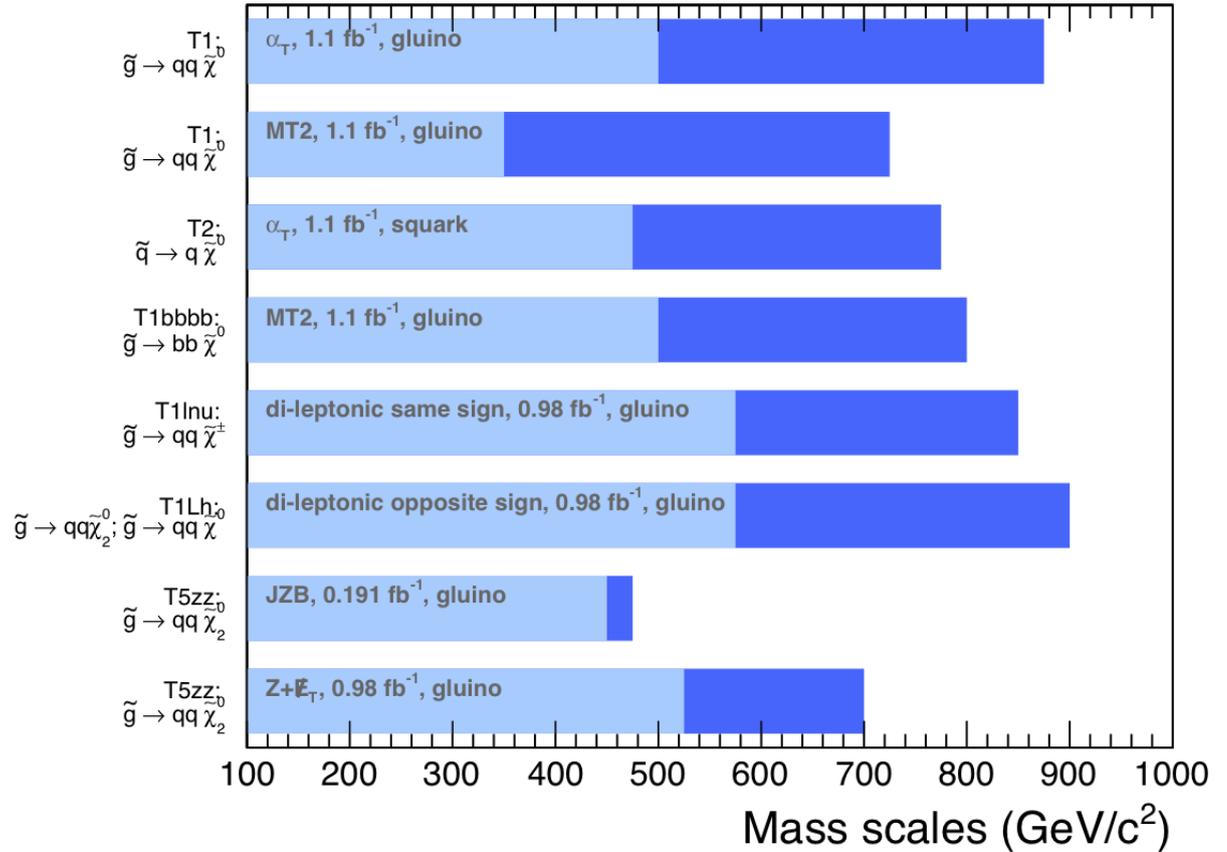
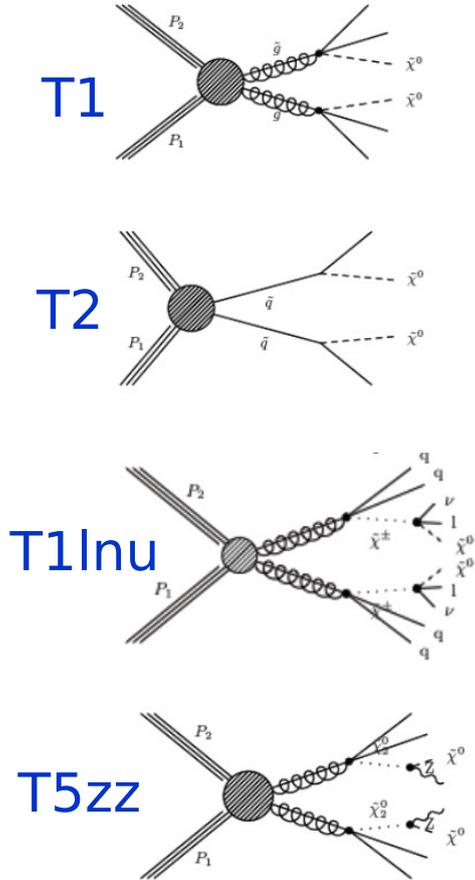


For equal squark and gluinos masses, this plot excludes $\sim 1.2 \text{ TeV}$

Simplified Models

arXiv:1105.2838

Ranges of exclusion limits for gluinos and squarks, varying $m(\tilde{\chi}^0)$
 CMS preliminary



For limits on $m(\tilde{g}), m(\tilde{q}) \gg m(\tilde{g})$ (and vice versa). $\sigma^{\text{prod}} = \sigma^{\text{NLO-QCD}}$.

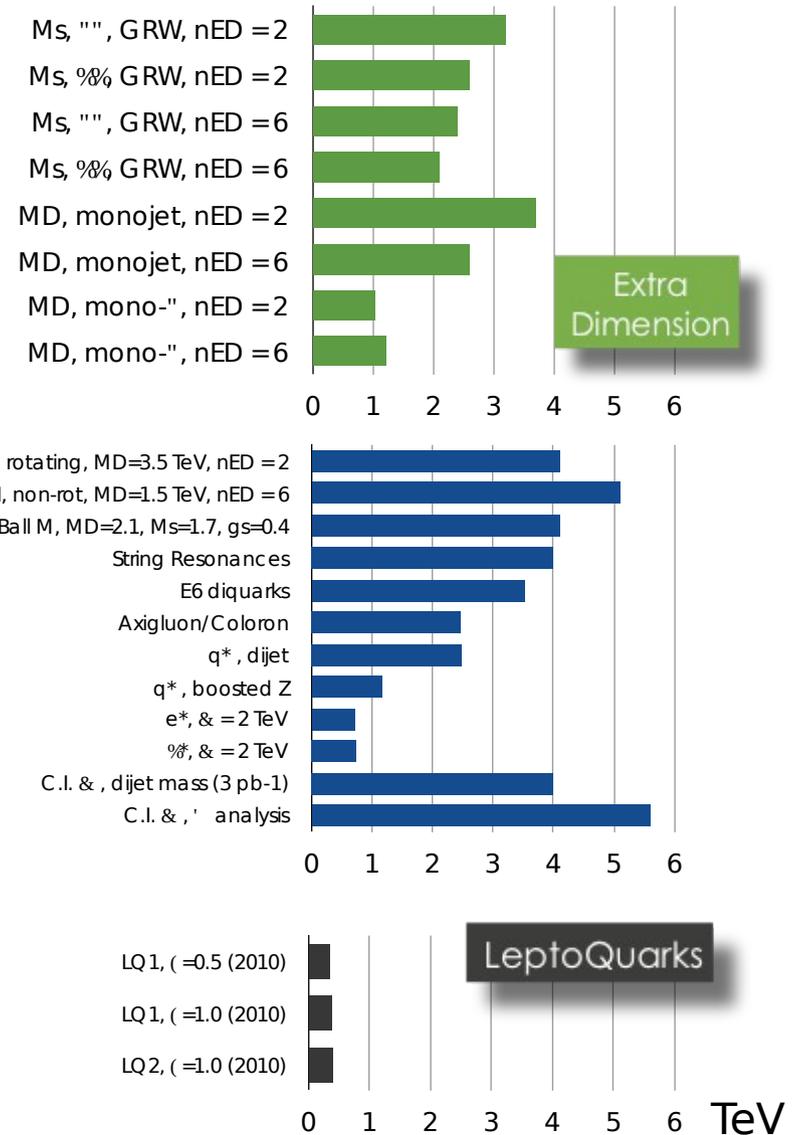
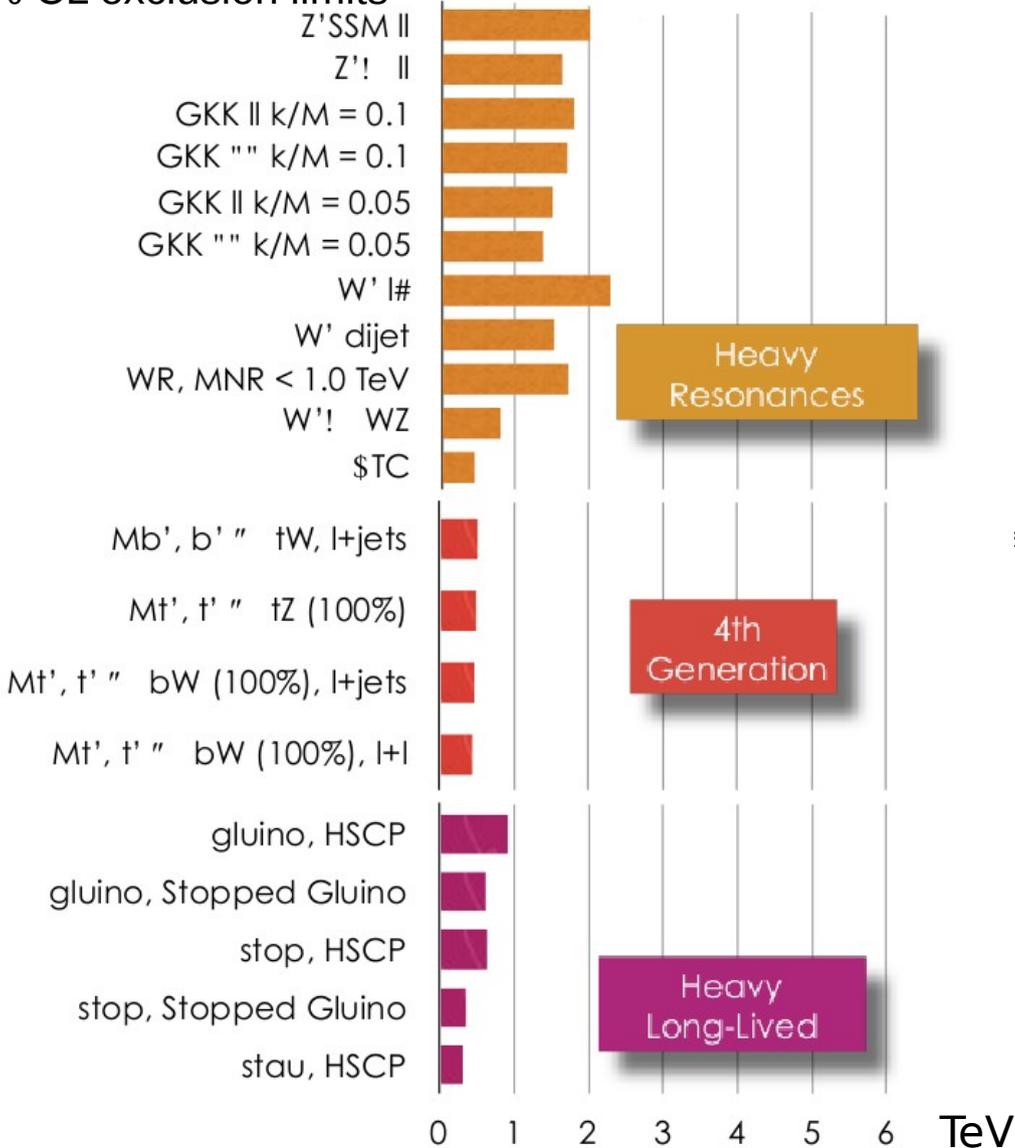
$$m(\tilde{\chi}^\pm), m(\tilde{\chi}_2^0) \equiv \frac{m(\tilde{g}) + m(\tilde{\chi}^0)}{2}$$

$m(\tilde{\chi}^0)$ is varied from 0 GeV/c² (dark blue) to $m(\tilde{g}) - 200$ GeV/c² (light blue).

Sensitivity varies based on assumption and analysis

Further Beyond the Standard Model

95% CL exclusion limits



Conclusion

- LHC and CMS performance is spectacular
- Very rich physics program with first fb^{-1}
 - SM: reaching precision era, inclusive measurements, complemented by differential and double-differential measurements
 - Higgs: no evidence so far
 - SUSY and Exotica: sensitivity to squark and gluinos mass in range of 0.5-1 TeV, many resonant and non-resonant signals sought
- Unfortunately, with 1fb^{-1} no new physics was found
- **Keep your seatbelt fastened. Already $\sim 5\text{fb}^{-1}$ delivered to CMS**
- Many interesting results not mentioned, i.e B-physics, QCD, forward physics, heavy ions. See complete list and references at
 - <https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults>