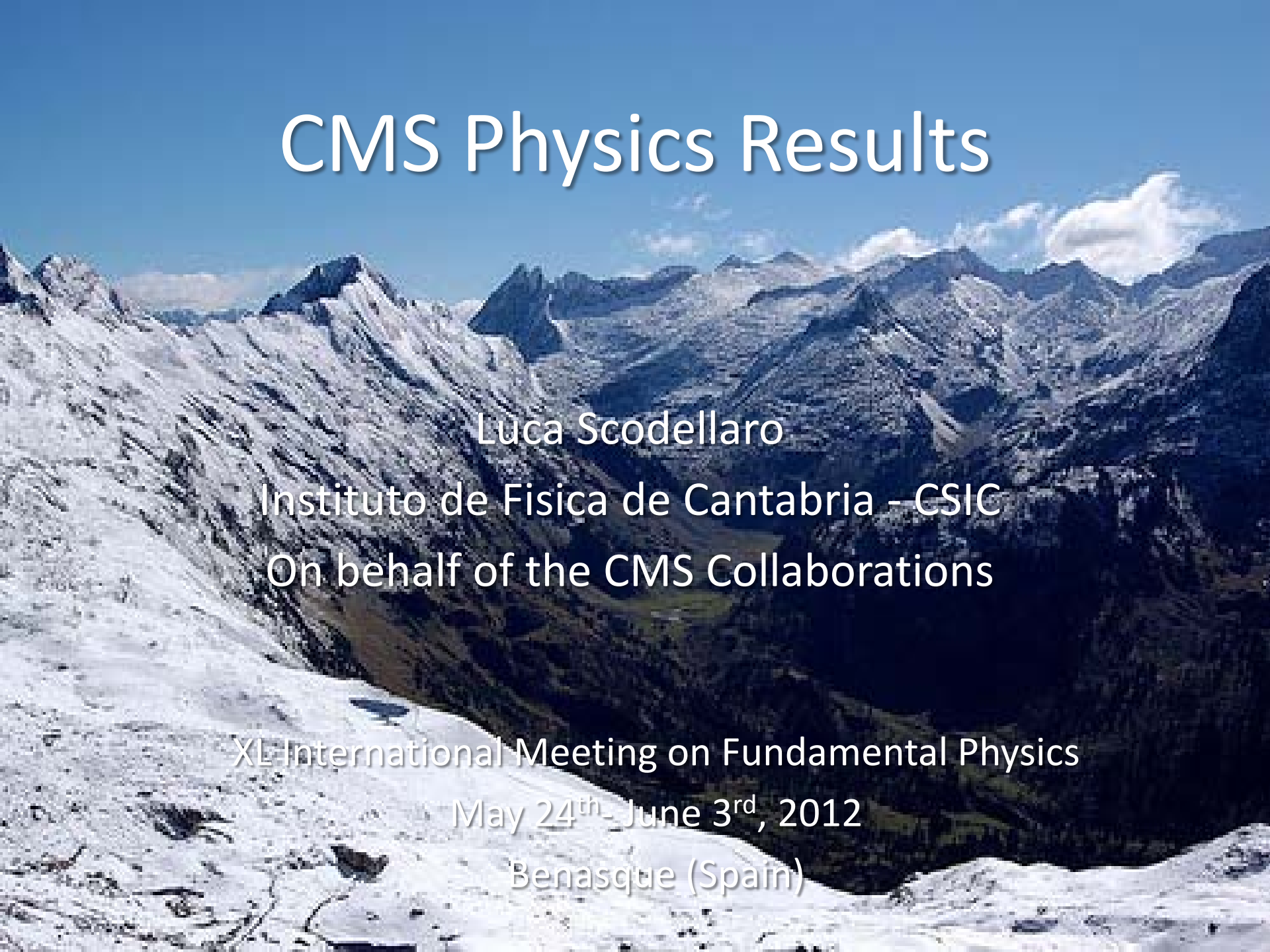
CMS Physics Results



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On behalf of the CMS Collaborations

XL International Meeting on Fundamental Physics
May 24th - June 3rd, 2012
Benasque (Spain)

Introduction

- Physics Results from CMS will be presented
- There are hundreds of interesting analyses to show
  - ◇ To summarize them in half an hour is a frustrating task!
- This selection is based on the following criteria:
  - ◇ Covering (if possible) all the research fields investigated
  - ◇ Emphasizing hottest topics and more recent results
- A complete review is available at the experiment's web page:
  - ◇ https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

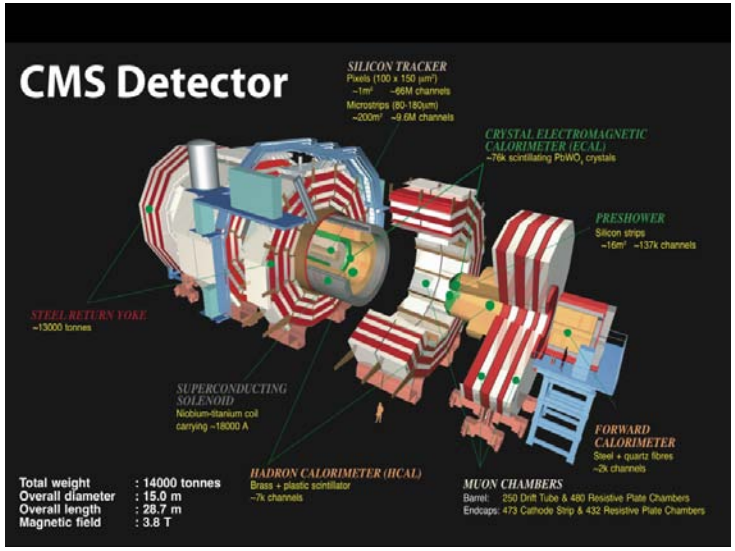
Outline

- Cross section measurements for SM processes
- Precision tests to the Standard Model:
  - ◇ Top properties
  - ◇ Rare baryons' decays
- Higgs boson searches
- Searches for new physics
  - ◇ Supersymmetry
  - ◇ Exotic physics


Cross Section Measurements
for SM Processes

The CMS Experiment

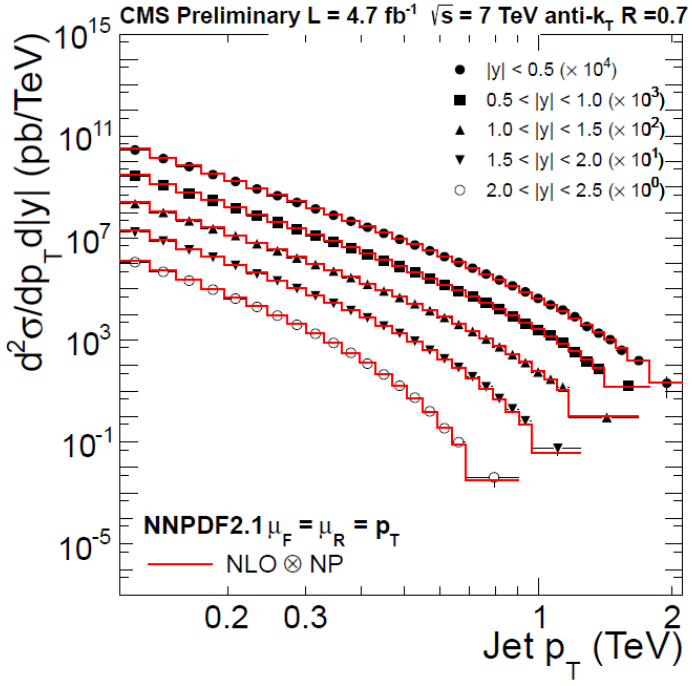
- General-purpose detector at the Large Hadron Collider
  - ◇ Designed around a solenoid magnet capable of 4T (curr. 3.8T)

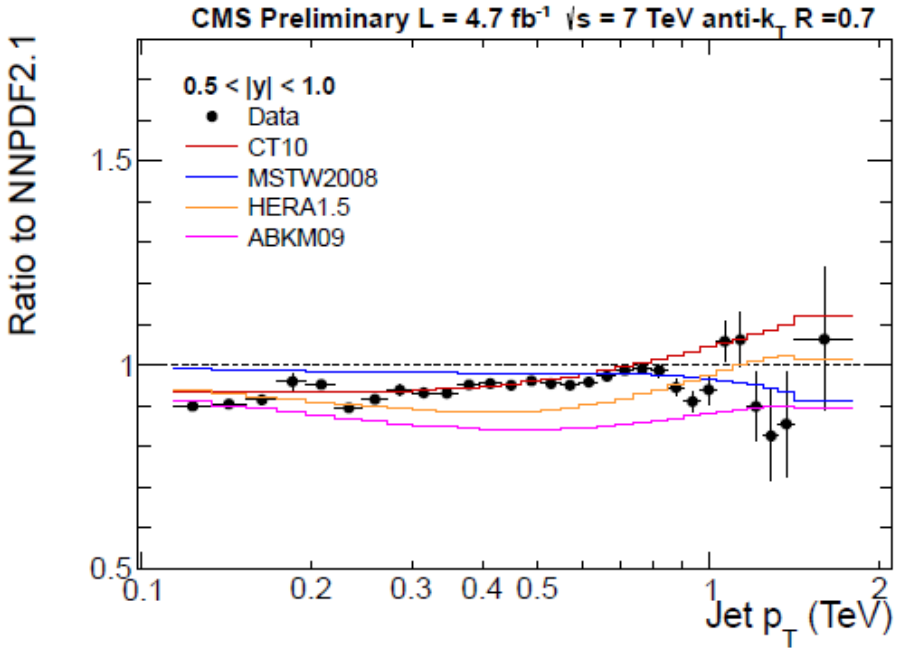


- About 3400 scientists and engineers (including ~840 students) from 173 institutes in 40 countries
  - ◇ Details on data taking and detector performance in Jesus' talk

Jet Production and PDF

- Differential cross section for jet inclusive production
  - ◇ Agreement with NLO⊗NP QCD over ≥7 orders of magnitude
  - ◇ CMS data can be used to constrain the fits of the PDFs



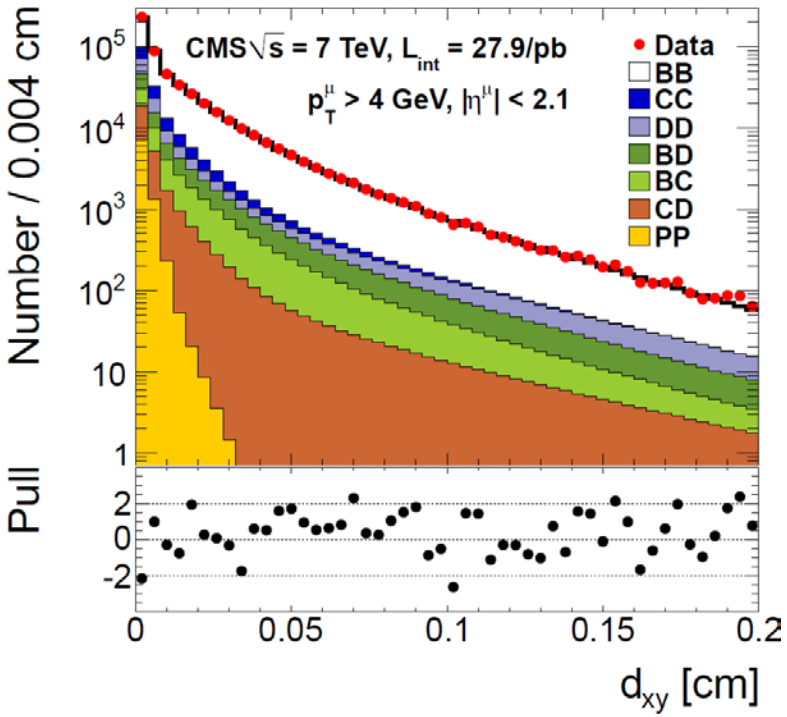


Heavy Flavor Production

- $\sigma(pp \rightarrow b\bar{b}X \rightarrow \mu\mu\Upsilon)$:

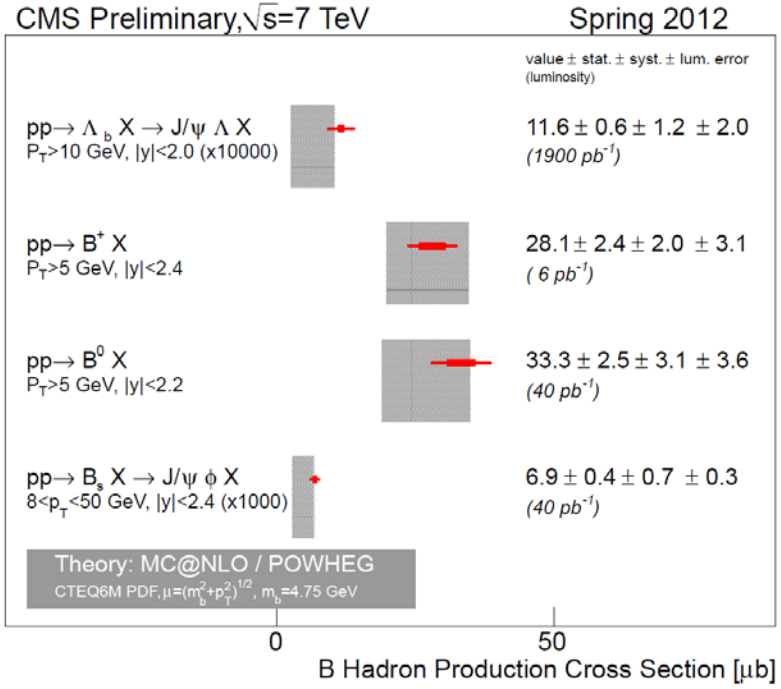
  26.4±0.1(stat)±2.4(syst)±1.1(lum)nb

  $\sigma_{MC@NLO}$=19.7±0.37(stat)$^{+6.5}_{-4.1}$(syst) nb



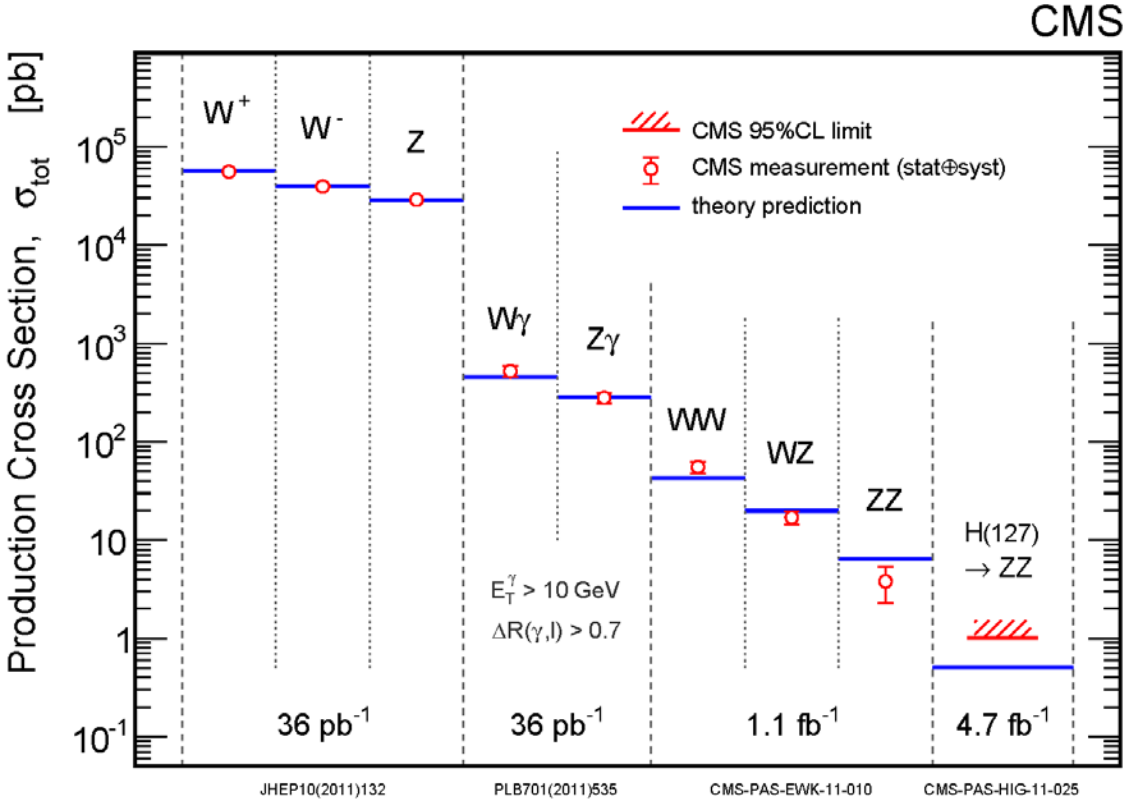
- B hadron production:

  ◇ Measured cross sections agree with MC@NLO calculations



EWK Boson Production

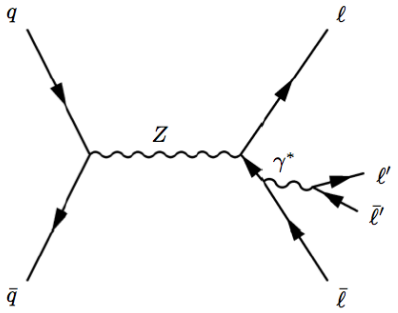
- Cross sections for boson and diboson productions:
  - ◇ Good agreement over ~4 order of magnitude: ready for new physics!



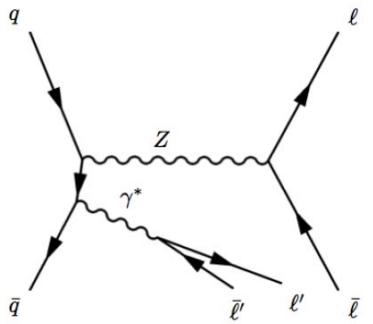
Z⟶4l Decay

- First observation of the Z boson decay to 4 leptons in pp collisions

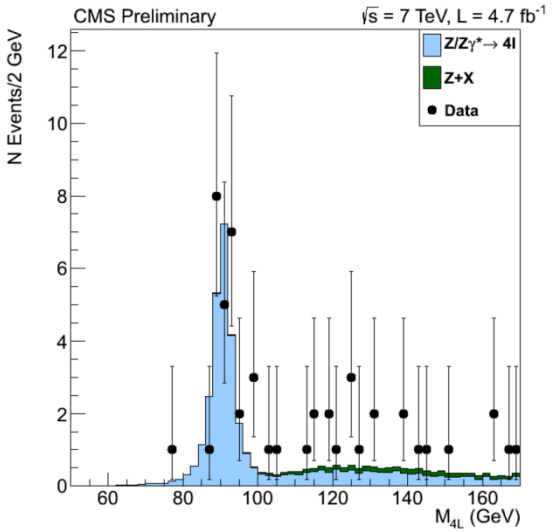
Signal



Irreducible background

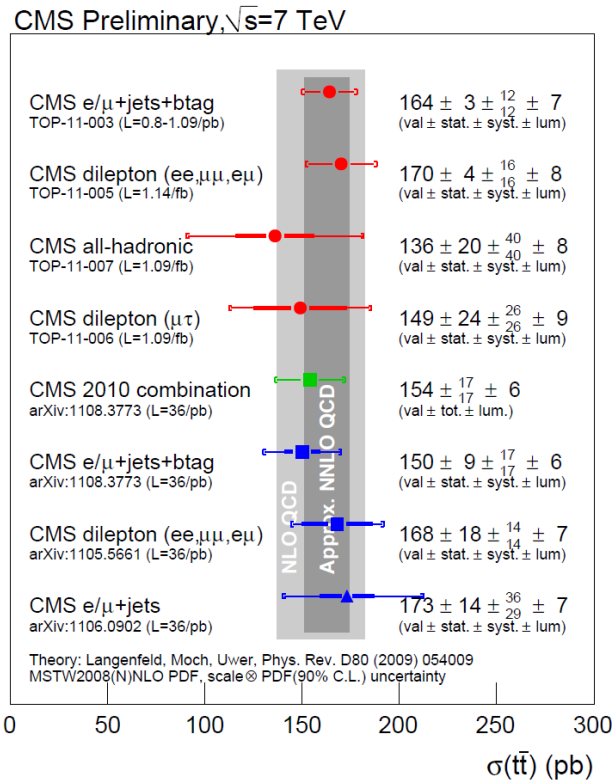


- Clear peak in 4 leptons invariant mass:
  - ◇ BR(Z⟶4l) = $4.4^{+1.0}_{-0.8}$(stat) $\pm$0.2(syst) x 10^{-6}
  - ◇ SM prediction: 4.45 x 10^{-6}
  - ◇ Standard candle for H⟶WW⟶4l analysis

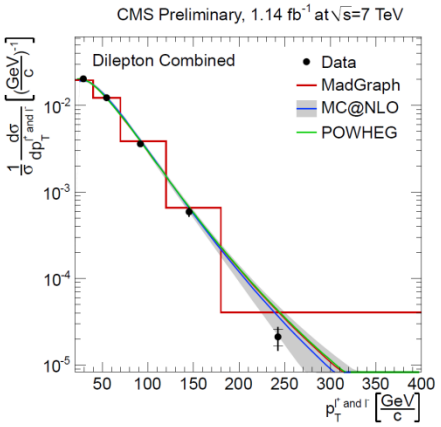


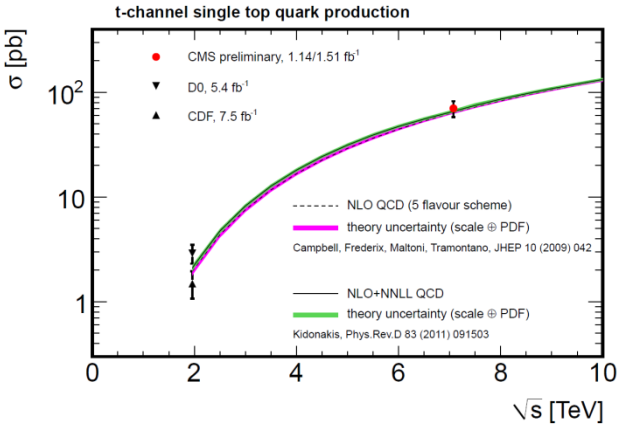
Top Quark Production

- Top pair production cross section measured in four decay channels
  - ◇ Good agreement with approx. NNLO QCD calculations



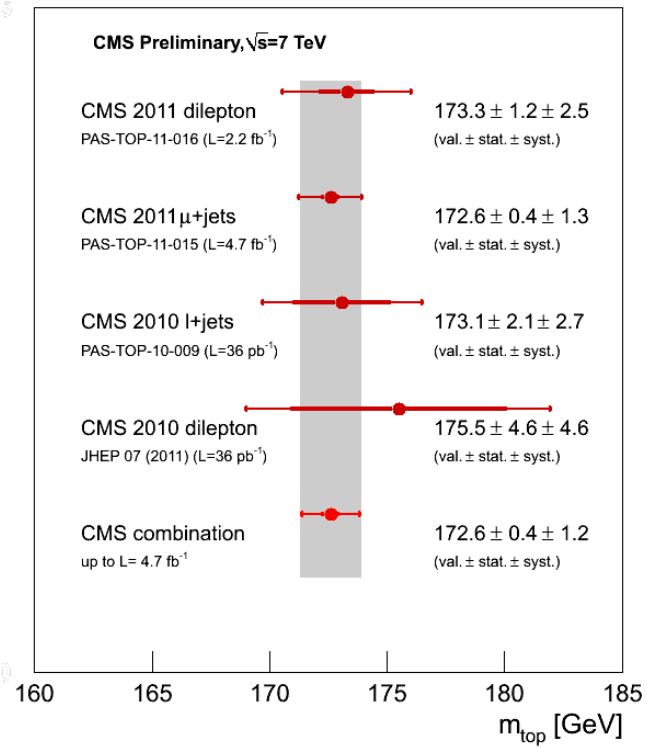
- Shapes of differential cross section well described by theory
- Single top quark production consistent with NLO+NNLL QCD predictions






Precision Tests to the SM

Top Quark Mass

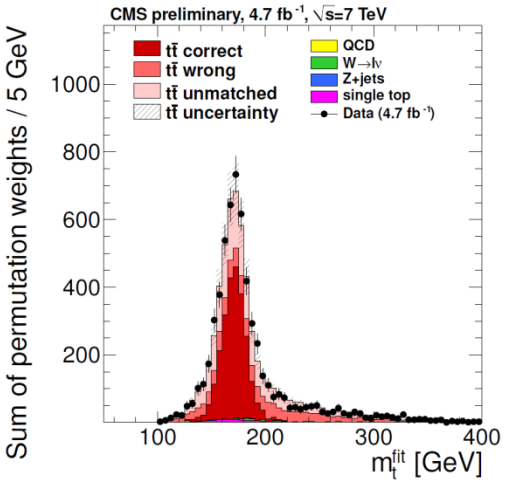


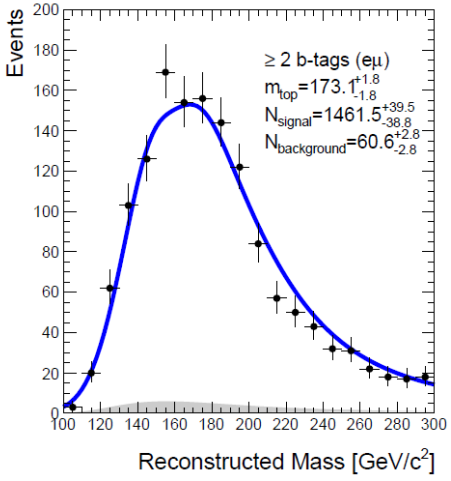
- CMS μ+jets and dilepton combination:

  $m_t = 172.6 \pm 0.4\ (stat) \pm 1.2\ (syst)\ GeV/c^2$

- Approaching Tevatron sensitivity:

  $m_t = 172.7 \pm 0.6\ (stat) \pm 0.9\ (syst)\ GeV/c^2$

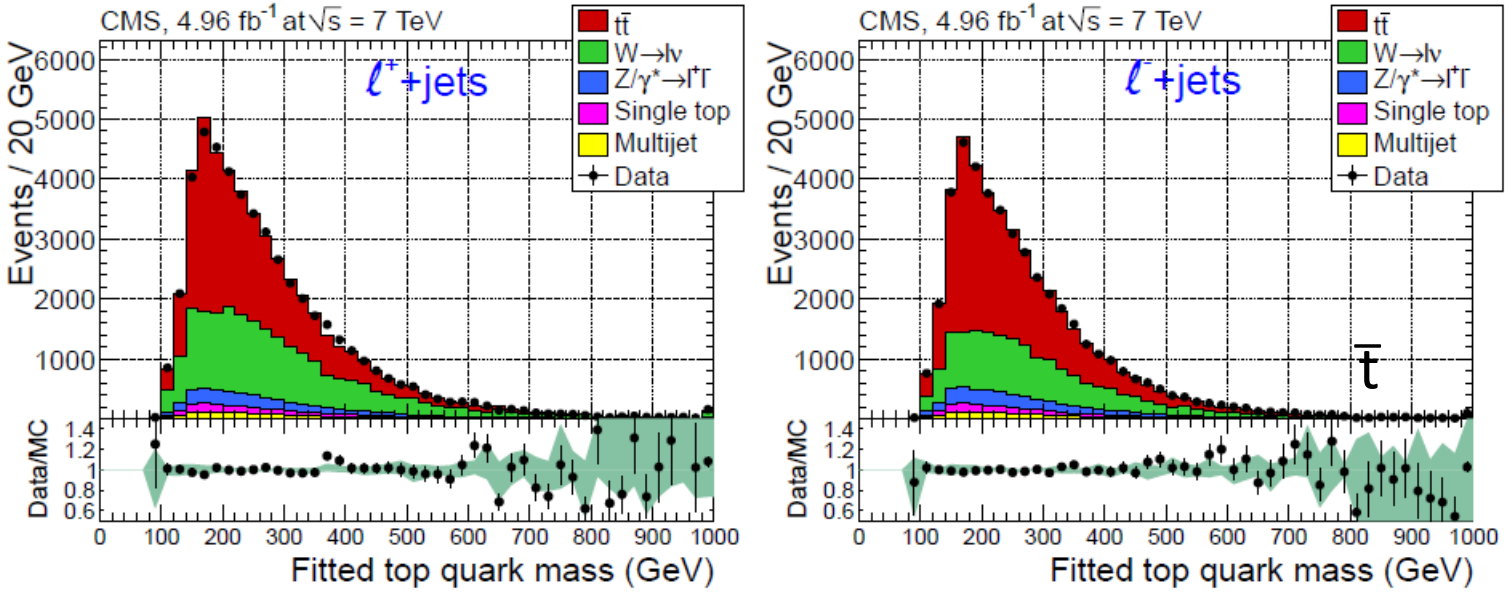




Top-Antitop Mass Difference

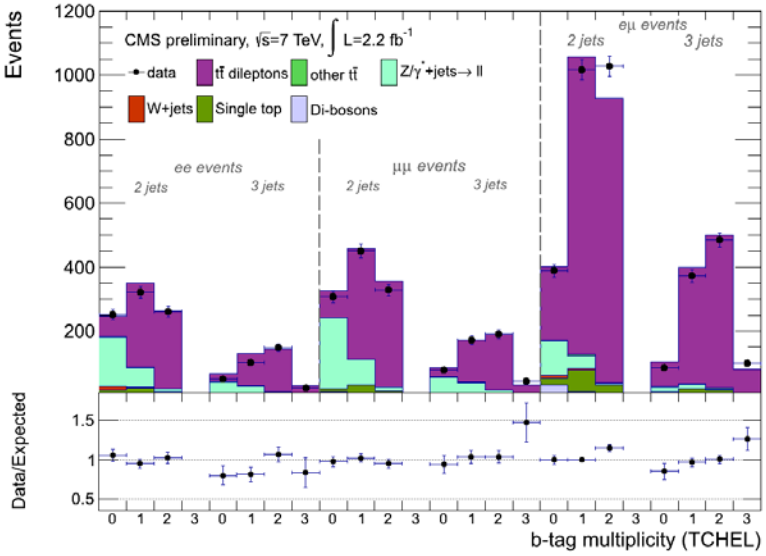
- If CPT is conserved, particle and antiparticle must have same mass
  - ◇ The top quark is the only one with which we can test this directly
- CMS: reconstruct t ($\bar{t}$) mass in had. decay in $l^-(l^+)$+jets events:

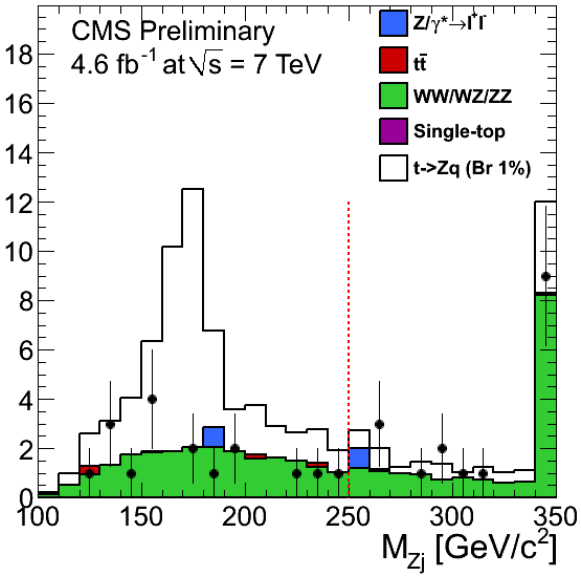
$$\Delta m_t = -0.44 \pm 0.46\ (\text{stat.}) \pm 0.27\ (\text{syst.})\ \text{GeV}$$



Top Quark Decays

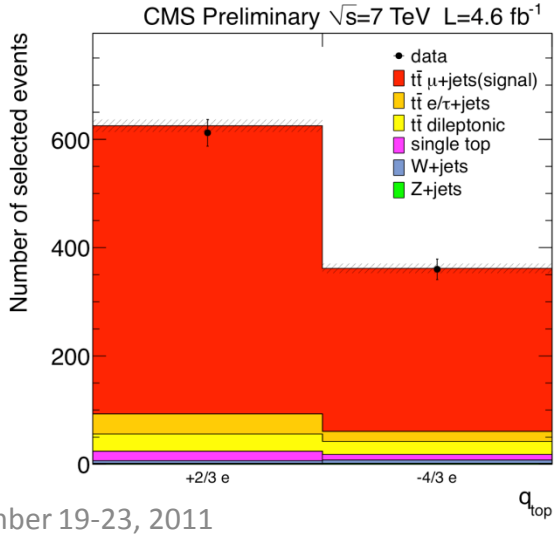
- Measurement of decay ratio R=BR(t→Wb)/BR(t→Zq):
  - ◇ Fit to b-tag multiplicity in ttbar dilepton decays
  - ◇ R=0.98±0.04, R>0.85 @95% CL
- Search for FCNC top decays into a Z boson t→Zq:
  - ◇ Look for events with three leptons from $t\bar{t}$→WbZq→lllυbq decays
  - ◇ BR(tWb)<0.0034 @95% CL





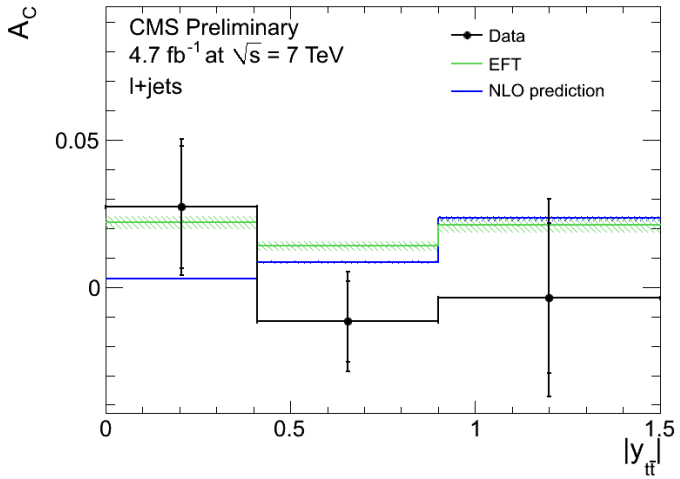
Top Quark Charge

- Constraints on top charge:
  - ◇ Top charge from decay products
    - W: muon in $W^{\pm} \rightarrow \mu^{\pm} \upsilon$ decay
    - b: muon in semileptonic decay
  - ◇ q_t=+2/3 vs q_t=-4/3 hypotheses: Good agreement with SM



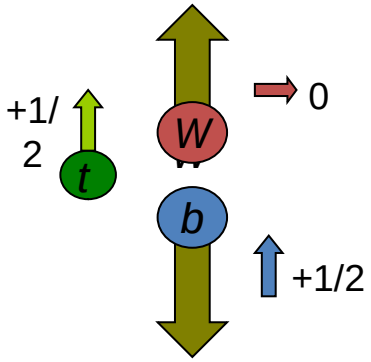
- Charge asymmetry in ttbar pair:
  - ◇ Sensitive to BSM top production
  - ◇ In pp collisions, antitop expected to be produced more centrally
  - ◇ Measurements in agreement to SM

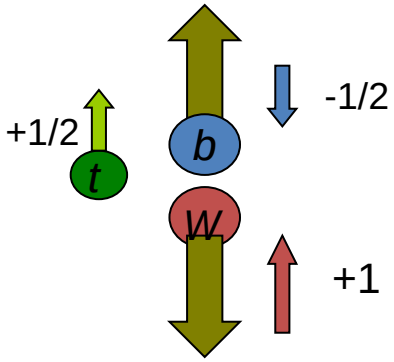
$A_C^y = 0.004 \pm 0.010(stat) \pm 0.012(syst)$

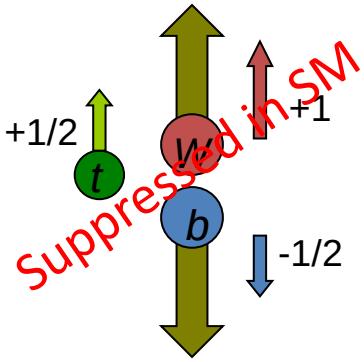


W Boson Polarization

- W boson polarization tests V-A coupling in top decays:

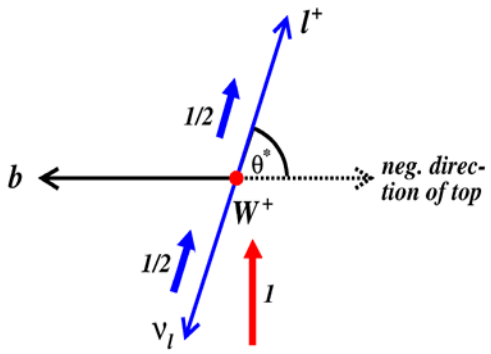


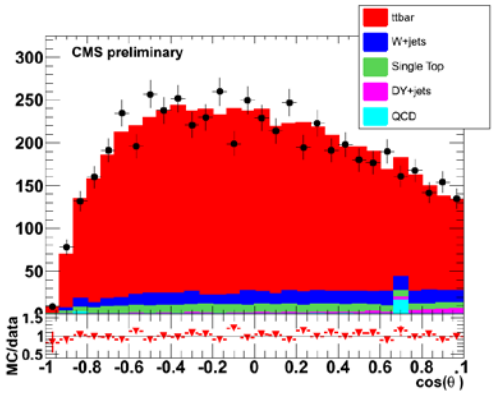




W_0 longitudinal: $F_0 = 0.7$ W_- left-handed: $F_- = 0.3$ W_+ right-handed: $F_+ \approx 0.0$

- CMS measured the W helicity fractions in the l+jets channel:





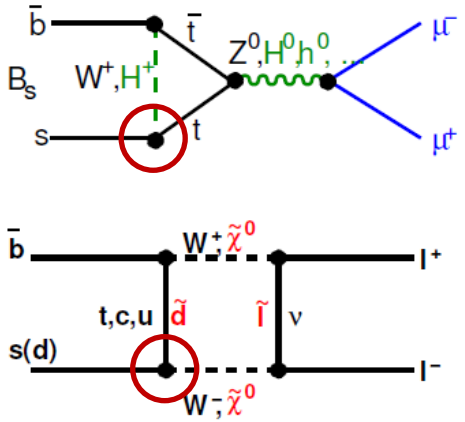
◇ $F_0 = 0.567 \pm 0.074 \pm 0.047$

◇ $F_- = 0.393 \pm 0.045 \pm 0.029$

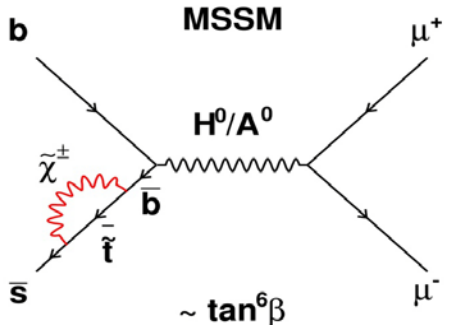
◇ $F_+ = 0.040 \pm 0.035 \pm 0.044$

Rare Decays of B Hadrons

- FCNC decay $B_{s(d)} \rightarrow \mu^+\mu^-$ highly suppressed in SM:
  - ◇ Helicity suppressed by a factor $(m_\mu/m_B)^2$
  - ◇ Higher order loop diagrams suppressed by CKM couplings
  - ◇ $BR(B_s \rightarrow \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$
  - ◇ $BR(B_d \rightarrow \mu^+\mu^-) = (1.0 \pm 0.1) \times 10^{-10}$

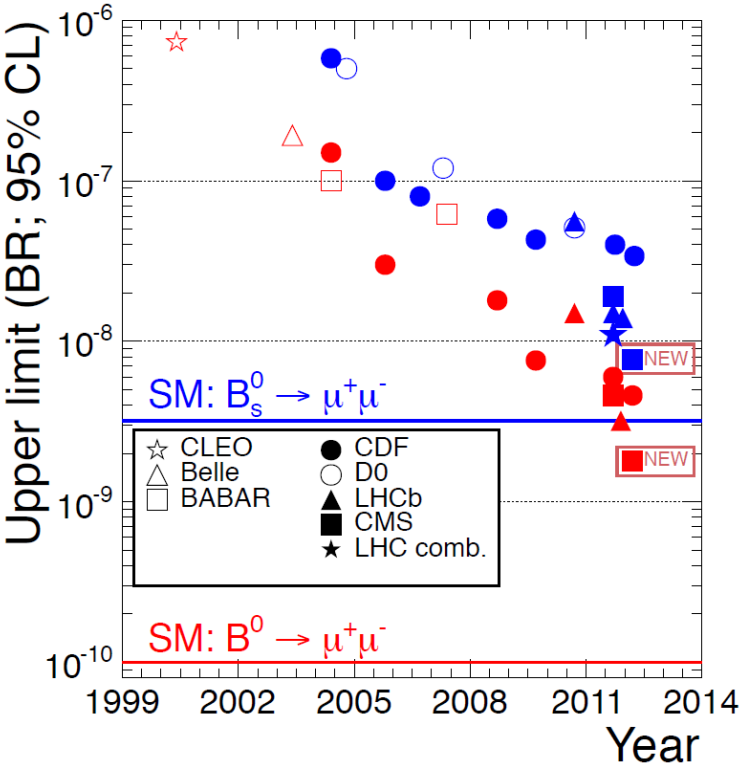


- SUSY scenarios can significantly boost the BR:
  - ◇ Within MSSM: BR ∝ $\tan^6\beta$



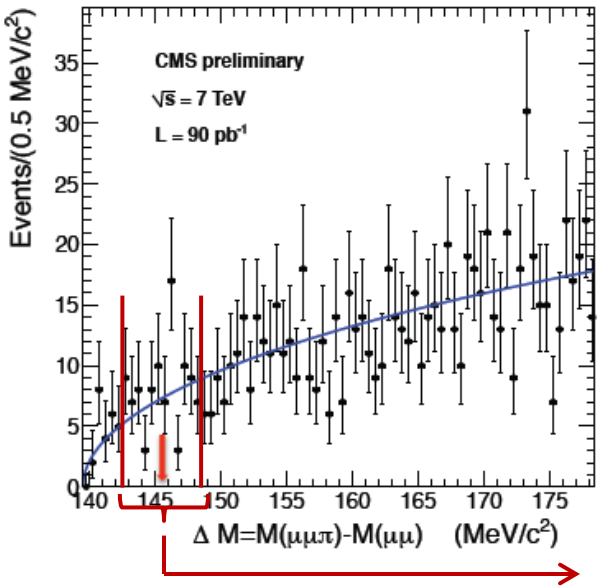
FCNC Decay $B_{s(d)} \rightarrow \mu^+\mu^-$

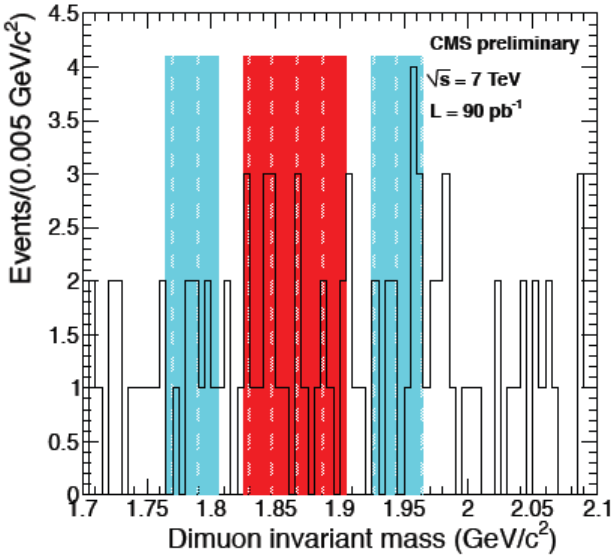
- Blind analysis searching for $B_s \rightarrow \mu^+\mu^-$ and $B_d \rightarrow \mu^+\mu^-$:
  - ◇ Normalization sample: $B^+ \rightarrow J/\psi K^+$
  - ◇ Control sample: $B_s \rightarrow J/\psi K^+ \Phi$
- Observed upper limits at 95% CL:
  - ◇ BR($B_s \rightarrow \mu^+\mu^-$) <7.7 x 10^{-9} (expected 8.4 x 10^{-9})
  - ◇ BR($B_d \rightarrow \mu^+\mu^-$) <1.8 x 10^{-9} (expected 1.6 x 10^{-9})
- Strong bounds for BSM theories



FCNC Decay $D^0 \longrightarrow \mu^+\mu^-$

- Charm is an up-type quark: complementary to B decay searches
- Measuring ratio $BR(D^{*+} \longrightarrow D^0(\mu^+\mu^-)\pi^+)/BR(D^{*+} \longrightarrow D^0(K^-\mu^+\nu)\pi^+)$
  - ◇ Most of systematic uncertainties cancel out
- No evidence for $D^0 \longrightarrow \mu^+\mu^-$ from D^{*+}:





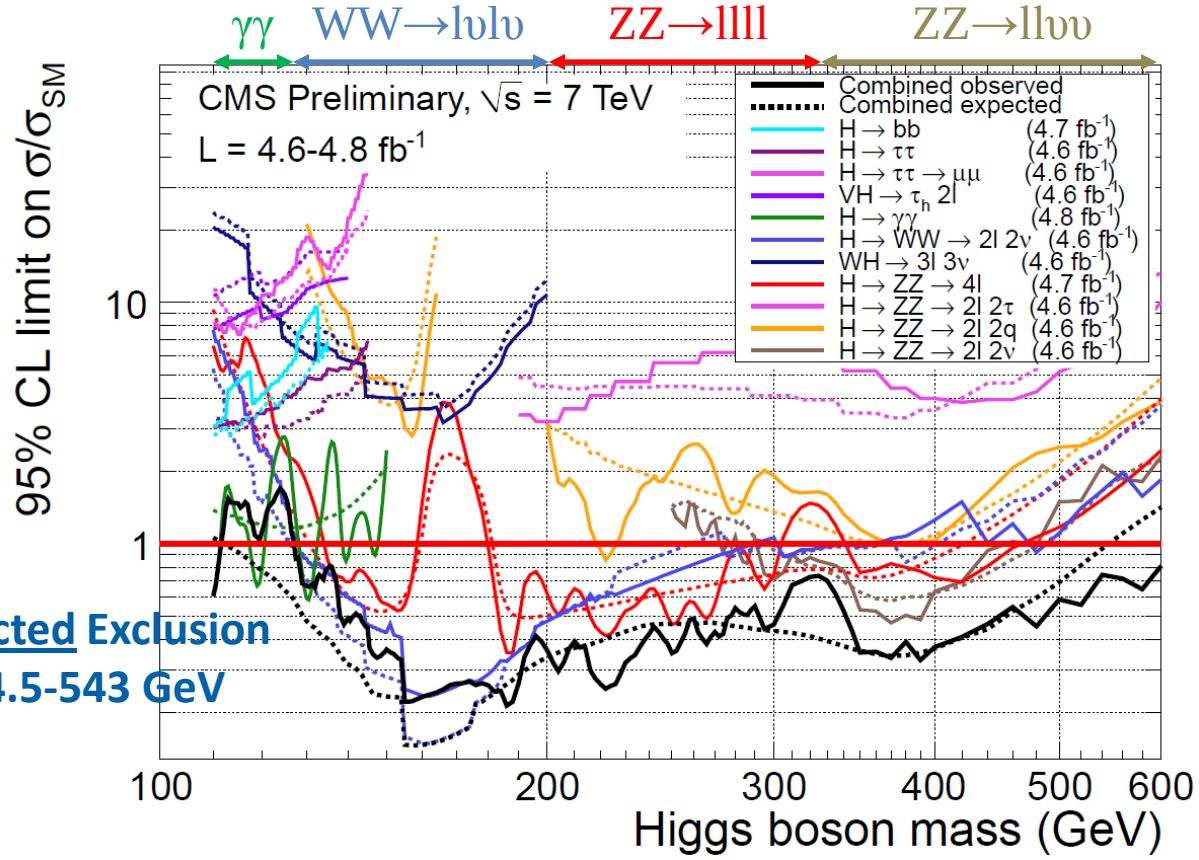
M(μμ) for $|\Delta M(D^0,D^{*+})-\Delta M_{PDG}|<3$MeV

Exp.	Limit 90%CL
BABAR	$<1.3\times10^{-6}$
CDF	$<2.1\times10^{-7}$
BELLE	$<1.4\times10^{-7}$
CMS	$<5.4\times10^{-7}$
SM	$\sim10^{-13}$


Searches for Higgs Boson

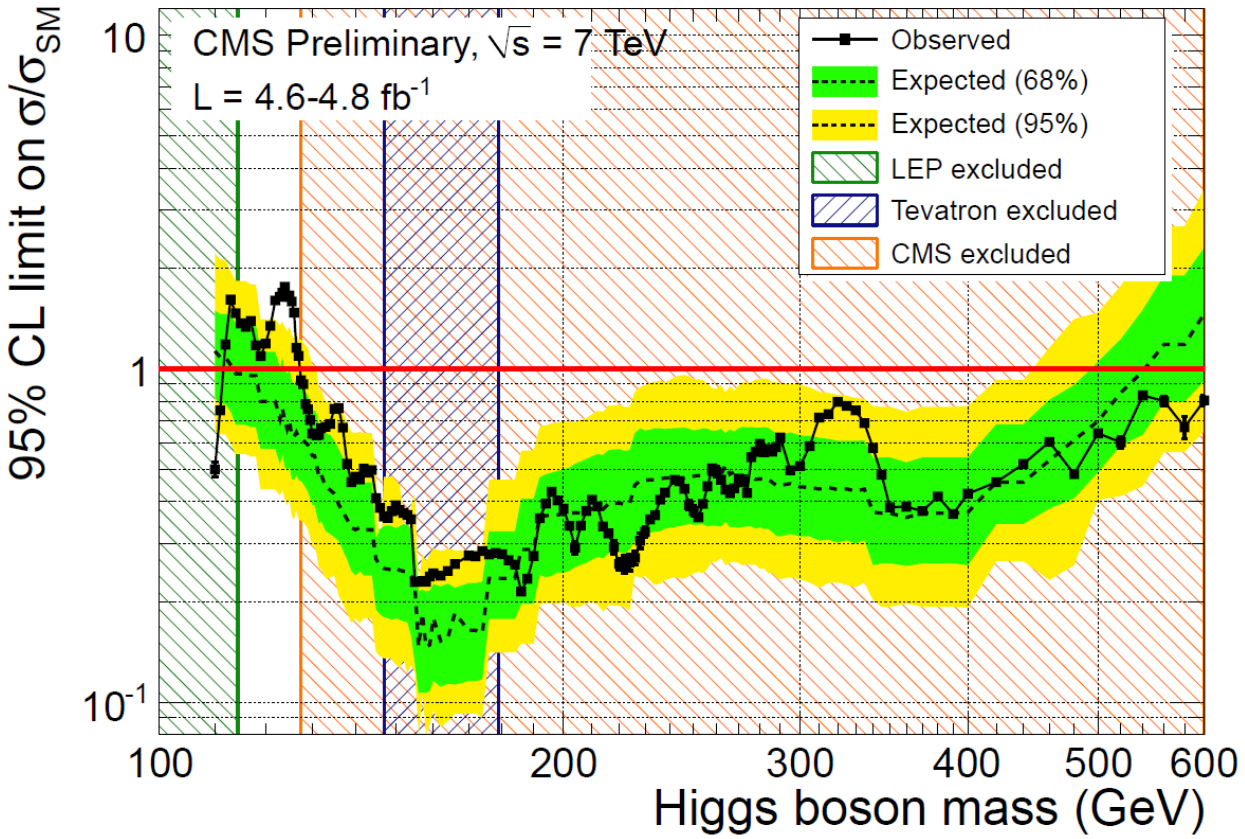
Standard Model Higgs Boson

- CMS searches for the SM Higgs boson in eleven different decay channels in the mass range 110-600 GeV



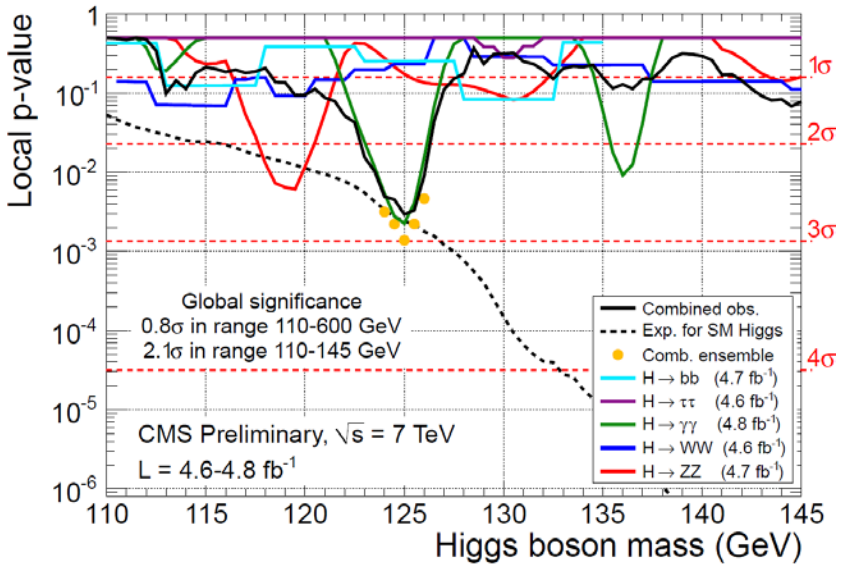
95% Expected Exclusion Range 114.5-543 GeV

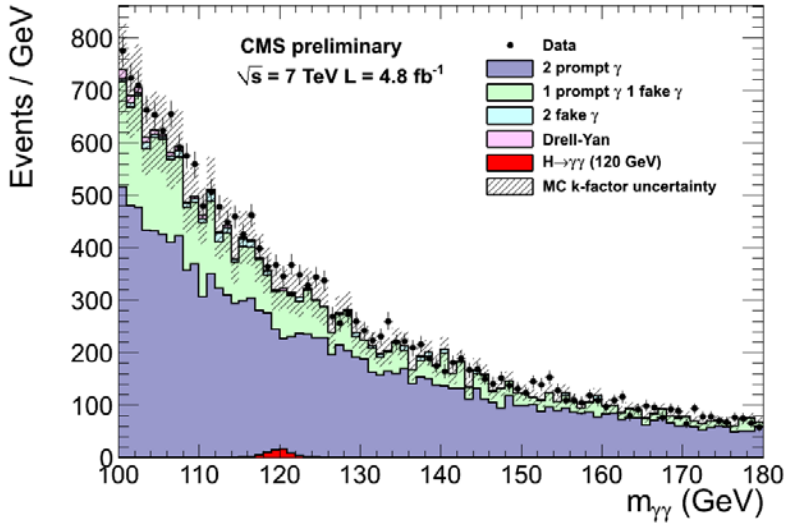
Standard Model Higgs Boson



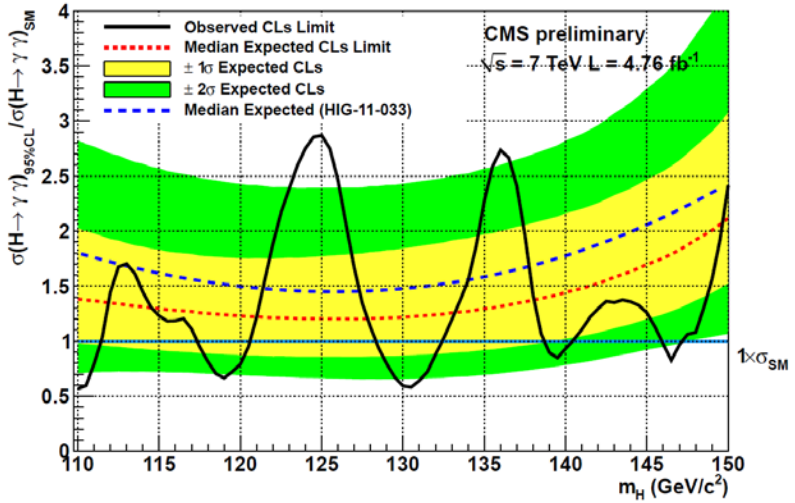
- SM Higgs boson in mass range 127.5-600 GeV excluded @95% CL
  - ◇ Excess of events at low mass makes the limit weaker then expected

Standard Model Higgs Boson

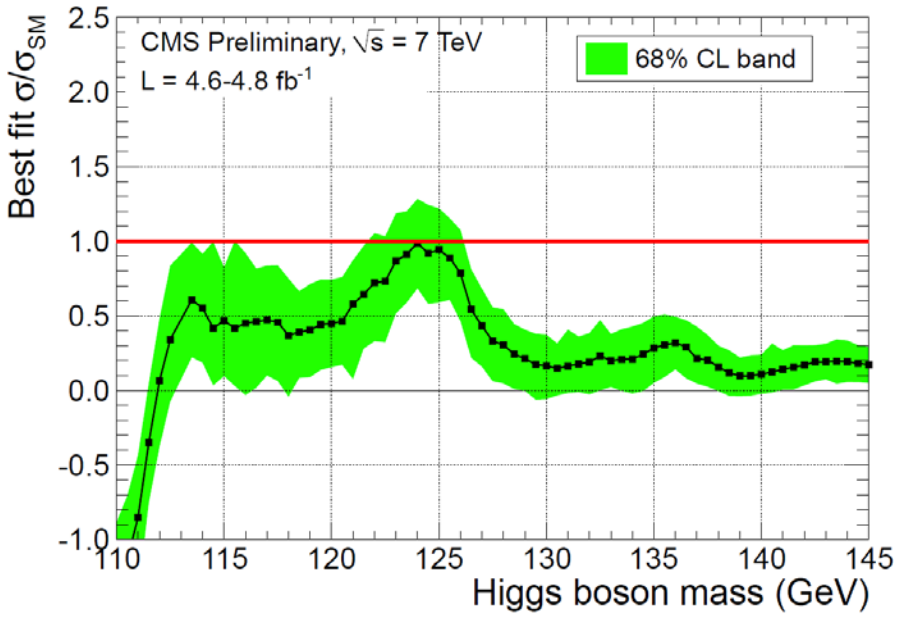


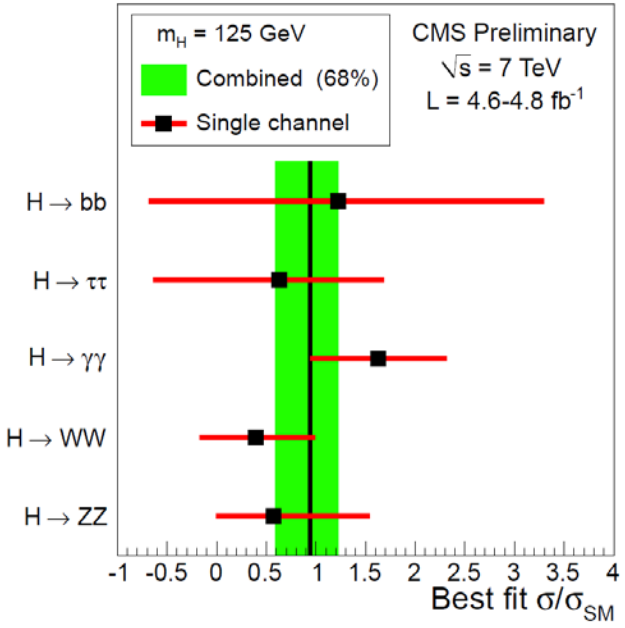


- Minimum p-value for M_H = 125 GeV:
  - ◇ Local significance: 2.8σ
  - ◇ Estimated global significance:
    - 0.8σ in [110-600] GeV
    - 2.1σ in [110-145] GeV



Standard Model Higgs Boson

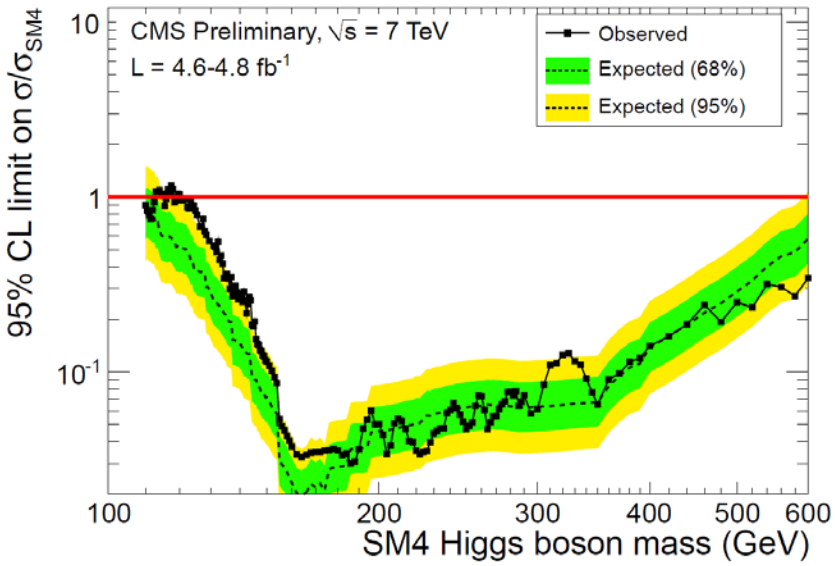


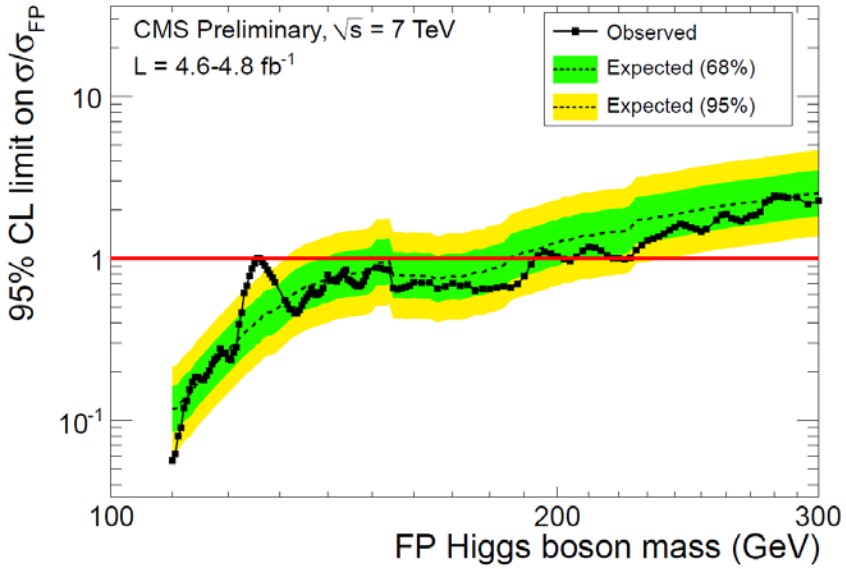


- Best fit to signal strength $\mu=\sigma/\sigma_{SM}$ as a function of the Higgs mass
- At low mass several channels show modest excess:
  - ◇ For M_H=125 GeV, sensitive channels show consistent excess
  - ◇ More data needed to exclude background-only hypothesis

BSM Higgs Boson

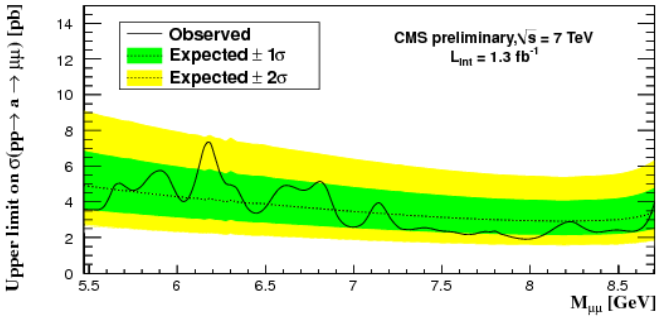
- Interpreting SM Higgs boson search's results in BSM scenarios
- SM with fourth generation:
  - ◇ Higgs boson excluded in mass range [120-600]GeV @95% CL
- Fermiophobic Higgs boson:
  - ◇ Higgs boson excluded in mass range [110-192]GeV @95% CL

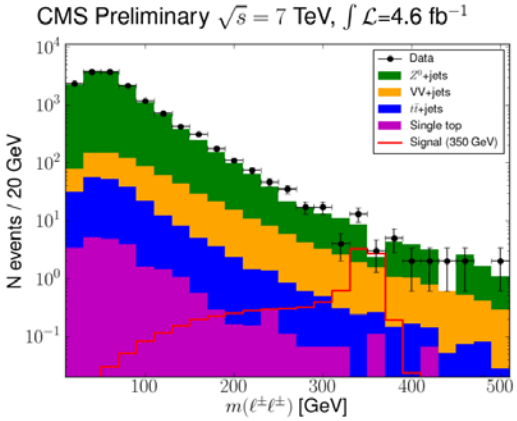




BSM Higgs Boson

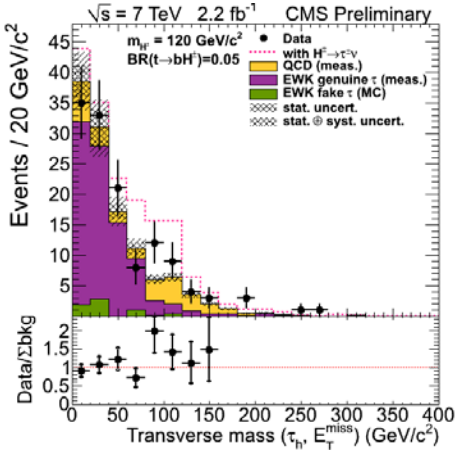
- Light pseudoscalar Higgs boson a_0:
  - ◇ Dimuon decay channel
  - ◇ Limit on production rates in NMSSM





- Doubly charged Higgs boson H^{++}:
  - ◇ Pair production: ≥3 leptons in final states
  - ◇ $M_{H^{++}}$>[380-410] GeV for a type-II seesaw model

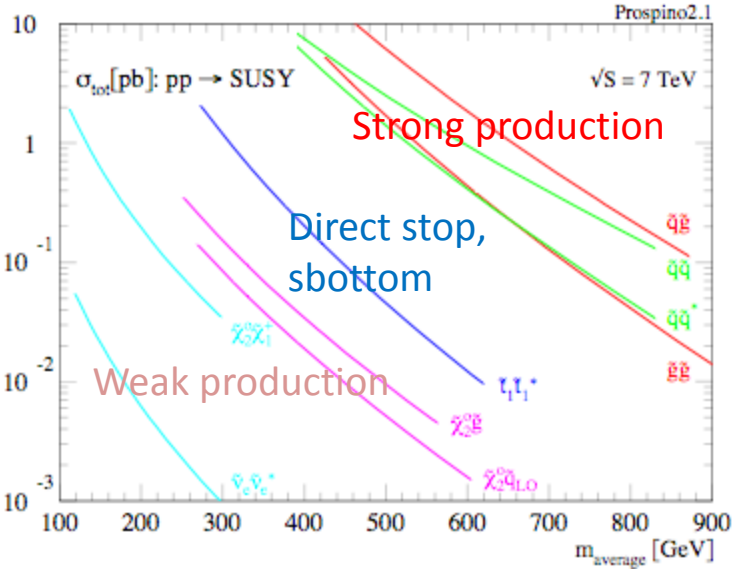
- Light charged Higgs boson ($M_{H^+}<m_t$):
  - ◇ $t\bar{t}\rightarrow H^+bW^-\bar{b}$, $H^+\rightarrow\tau^+\upsilon$
  - ◇ BR($t\rightarrow H^+b$)<2-3% for 80<M_{H^+}<160 GeV

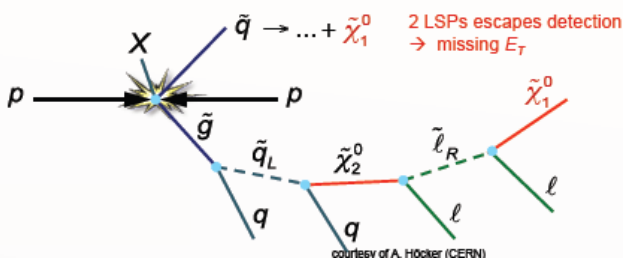



Searches for BSM Physics

Supersymmetry Searches at CMS

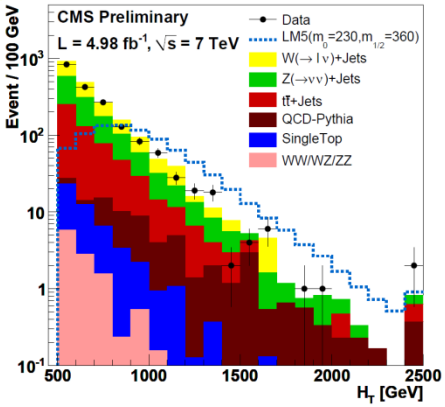
- Highest production cross sections for squarks and gluinos:
  - ◇ Production rate depend on model
  - ◇ R-parity conserved: pair production
- Squarks and gluinos are often the heaviest SUSY particles:
  - ◇ Long cascades of decays
  - ◇ Details depend on SUSY masses
- Large missing E_T from LSPs:
  - ◇ Research channels categorized by the number of jets or leptons in final states
  - ◇ Gauge Mediated SUSY also predicts final states with photons

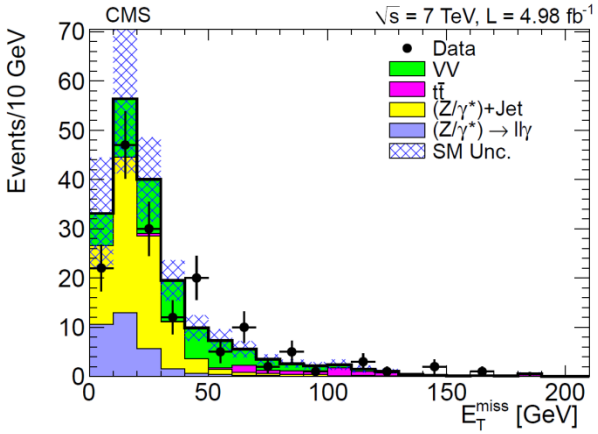




Sample of SUSY Searches

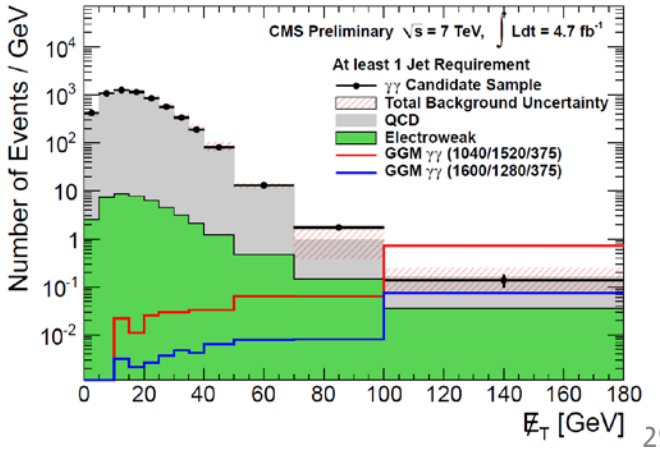
- Fully hadronic final states:
  - ◇ Three jets and large missing E_T
  - ◇ High signal rate, large SM backgrounds





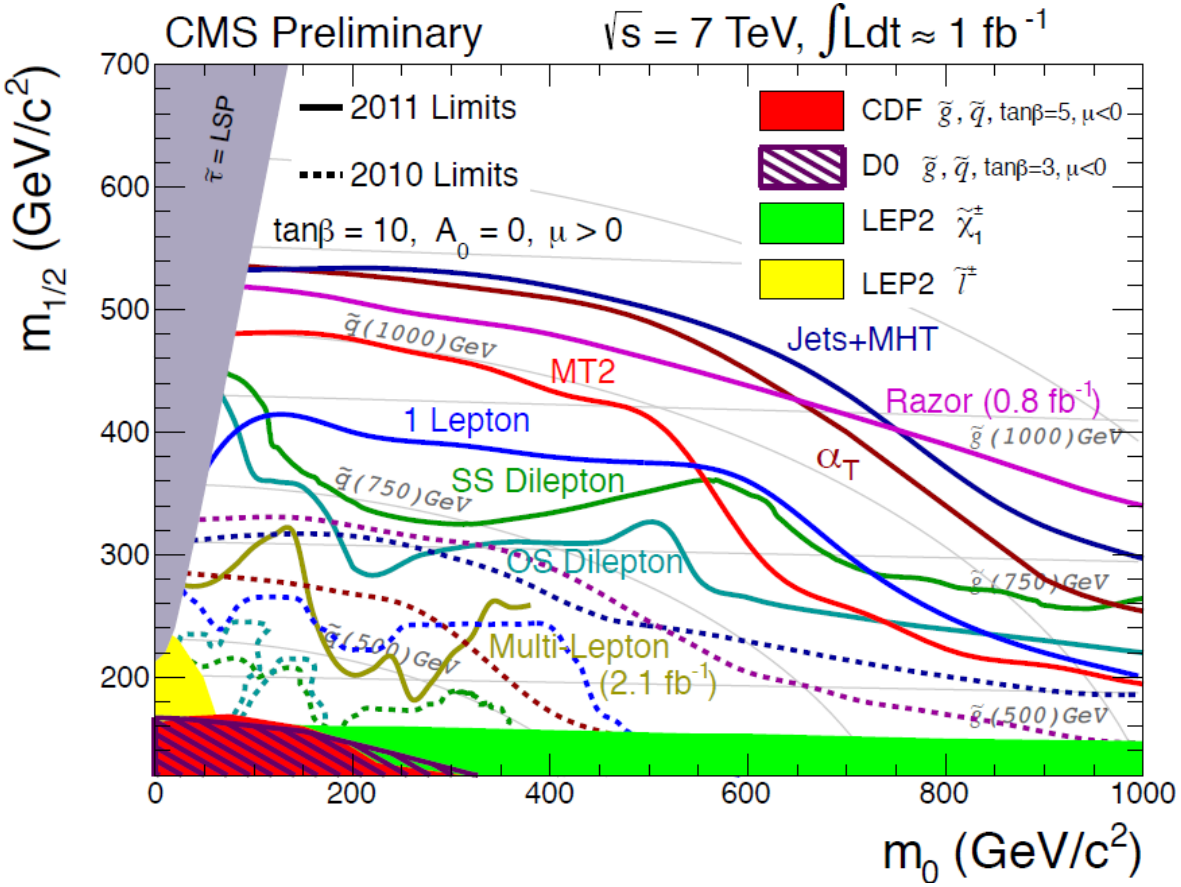
- Multilepton final states:
  - ◇ No missing E_T cut (R-parity violating models)
  - ◇ Low signal rate, small SM backgrounds

- Final states with photons:
  - ◇ 1(2) photon, 2(1) jets + large missing E_T
  - ◇ Limits on Gauge Mediated SUSY model



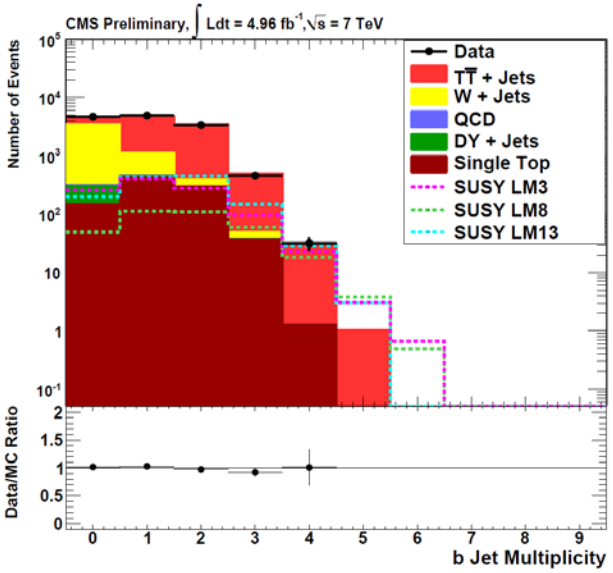
SUSY Limits

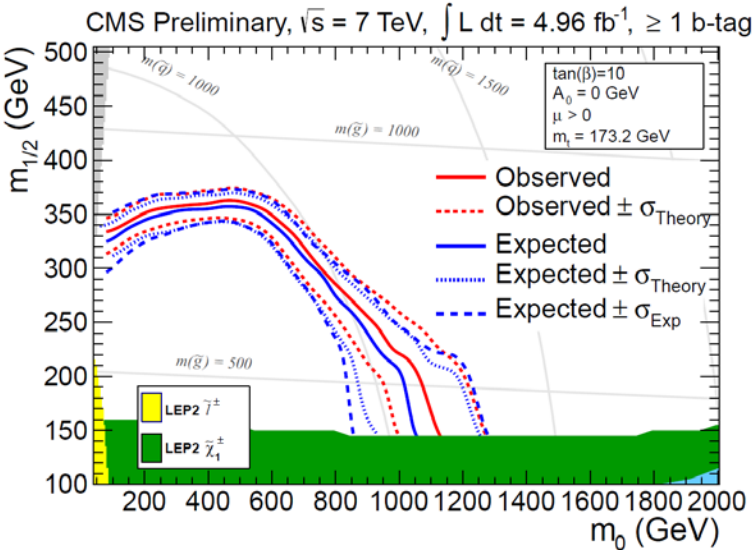
- Exclusion regions in the $[m_0, m_{1/2}]$ plane for the Constrained MSSM



Third Generation Squarks

- Large luminosity allows to study more exclusive production modes
  - ◇ Electroweak production of charginos and neutralinos
  - ◇ Direct stop and sbottom production
- SUSY naturalness suggests light 3th generation
- Search for SUSY in final states with a lepton, b-jets and missing E_T





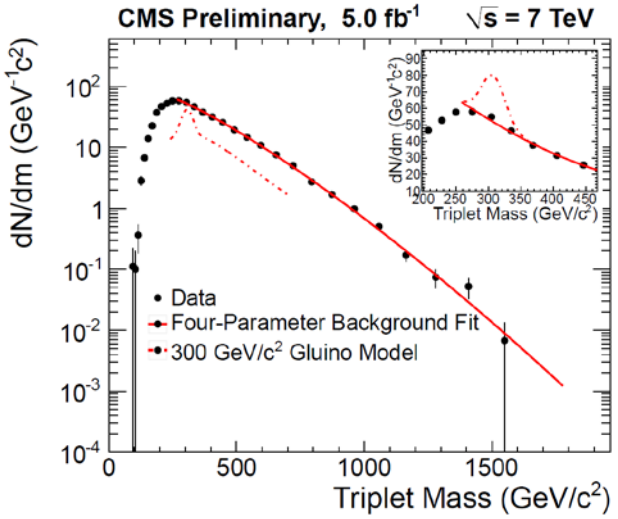
Exotic Physics at CMS

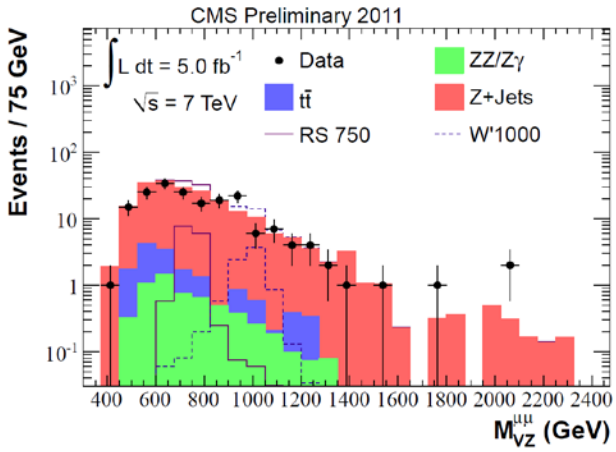
- Many new results with ~5 fb^{-1} presented at winter conferences:

Heavy bosons	W' →WZ, tb, td, l+MET	EXO-11-041/001/056/024	Right-handed W' mass>2.5 TeV, Left-handed W' mass>2.43-2.63 TeV
	Z' (KK g)→ttbar	EXO-11-006/092	Limits on cross section x BR
4^{th} generation fermions	b'b' →tWtW	EXO-11-036	b' mass>611 GeV
	t't' →bWbW	EXO-11-050/051	t' mass>560 GeV
Compositeness	Dimuons	EXO-11-009	Limits on fermion contact interaction scale Λ
Black holes	Multiple energetic objects	EXO-11-071	Model dependent black hole mass>3.8-5.3TeV,string ball mass>4.6-4.8TeV
Long-lived particles	HSCPs	EXO-11-022	gluino mass>1091 GeV, stop mass>735 GeV, stau mass>232 GeV
Resonances	Three-Jet	EXO-11-060	R-parity violating SUSY gluino mass ≠ 280-460 GeV
	WZ/ZZ→qqll	EXO-11-081	SSM W' mass≠700-929 GeV, RS graviton mass≠700-924 GeV (k/M_{Pl}=0.05)
	ttbar	TOP-11-009/010	Limits on cross section x BR of Z' and KK gluon
	Ditaus	EXO-11-031	SSM Z' mass>1.36 TeV, E6 model Z'_{ψ} mass> 1.10 TeV
	Dileptons	EXO-11-019	SSM Z' mass>2.32 TeV, E6 model Z'_{ψ} mass> 2.00 TeV, KK graviton mass>1.81 TeV (k/M_{Pl}=0.05), >2.135 TeV (k/M_{Pl}=0.1)
	ZZ	EXO-11-061	Limits in the (KK graviton mass, k/M_{Pl}) plane
Dark matter and large extra dimensions	Monojets + MET	EXO-11-059	Constraints on the dark matter-nucleon scattering cross sections
	Photon + MET	EXO-11-096	Constraints on the dark matter-nucleon scattering cross sections
Anomalous production	Multilepton events	EXO-11-045	Limits on production rates, interpretations for SUSY models
	Boosted Z→dimuons	EXO-11-025	Limits on excited quark production and decay

Resonances

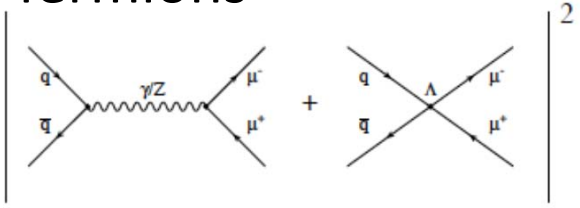
- Three-Jet resonances:
  - ◇ High jet multiplicity: $N_{jet} \geq 6$ ($E_T^j > 45$ GeV)
  - ◇ Large transverse energy: $\sum E_T^j > 900$ GeV
- Limits set on gluino pair production in SUSY model with R-parity violation
  - ◇ $M_{\tilde{g}} \neq 280\text{-}460$ GeV @ 95% CL
- Diboson resonances:
  - ◇ $X \rightarrow WZ/ZZ \rightarrow qql^+l^-$
- Several theoretical models considered
  - ◇ Sequential SM W': $M_{W'} \neq 884\text{-}929$ GeV
  - ◇ RS graviton: $M_{G_{RS}} \neq 700\text{-}924$ GeV($k/M_{Pl}=0.05$)



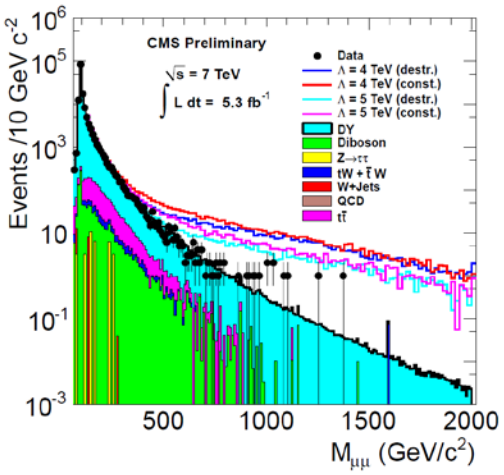


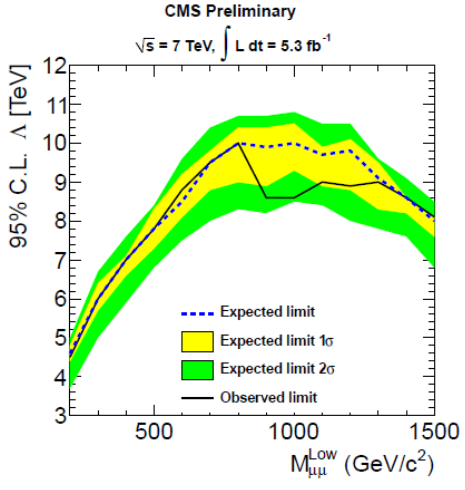
Lepton-Quark Compositeness

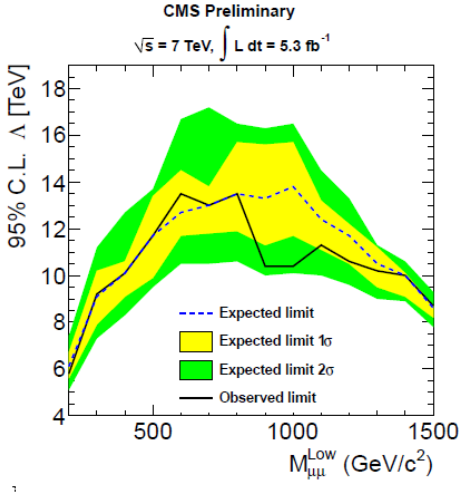
- Search for contact interaction between fermions
  - ◇ Look for effect of interference with Standard Model Drell-Yan production



- No significant effect is observed in 5.3 fb^{-1} of data
- Limits on interaction scale Λ for destructive and constructive interference

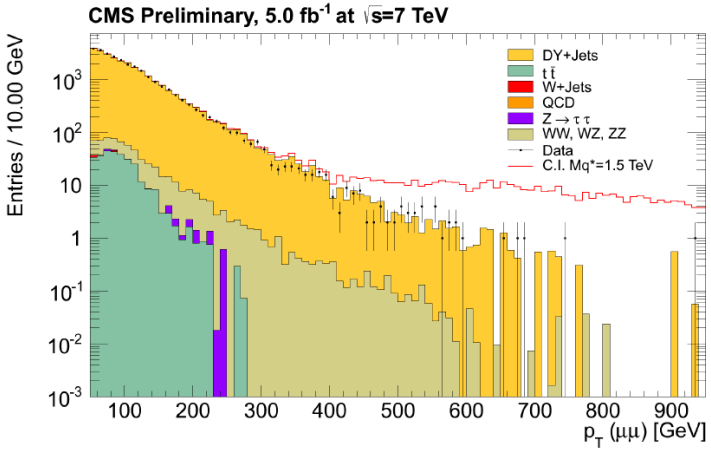


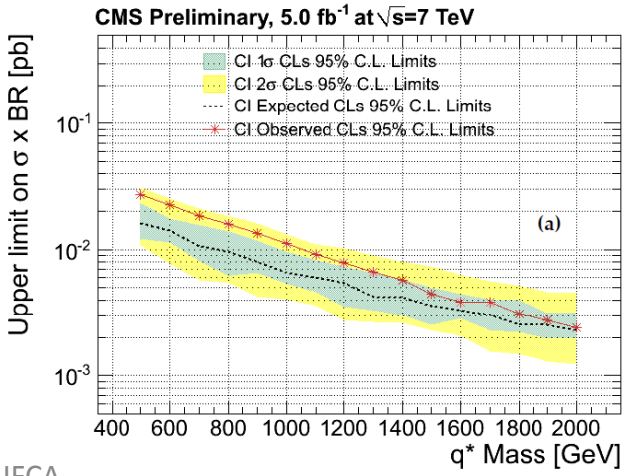




Highly Boosted Z

- Anomalous Z bosons production from heavy particle decays:
  - ◇ Identifying the Z bosons from Z → μμ decays
  - ◇ Look for events with very large $p_T(\mu\mu)$
- No deviation from SM predictions is observed
- Limits on excited quark q* production and decay are derived
  - ◇ Translate to lower limits on M_{q^*} at about 2 TeV for several models





Conclusions

- CMS reached excellent results with 2011 data taking at 7 TeV:
  - ◇ Excellent control of Standard Model processes
  - ◇ Challenging precision tests to the Standard Model
  - ◇ SM Higgs boson cornered in the mass range 115-127.5 GeV
  - ◇ Probed new phenomena at the TeV scale

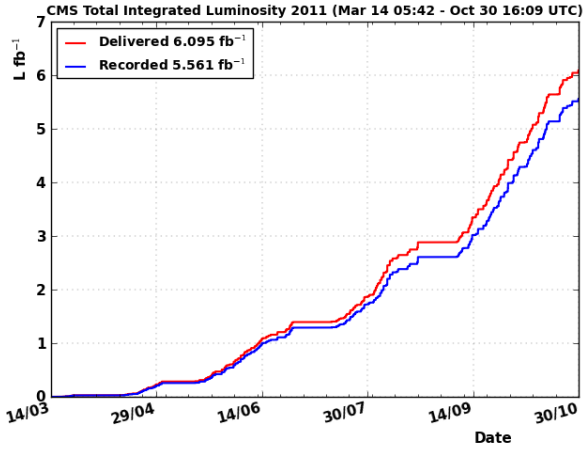
- Already recorded 2.61 fb^{-1} at 8 TeV

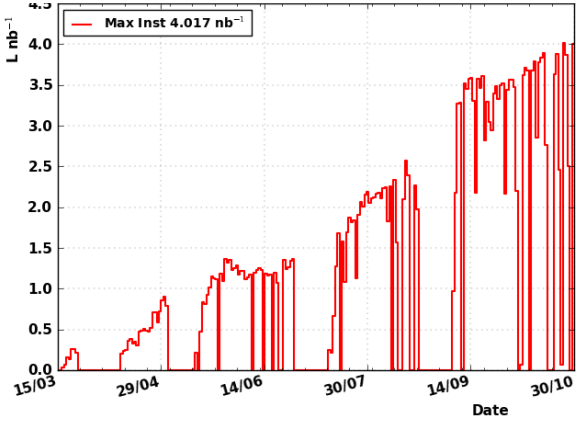
Working very hard to provide new results for the summer


Backup Material

LHC and CMS Operations in 2011

- Proton-proton collisions at a center-of-mass energy of 7 TeV
- Integrated luminosity:
  - ◇ 6.10 fb^{-1} delivered by LHC
  - ◇ 5.56 fb^{-1} recorded by CMS
- Increasing instantaneous luminosity:
  - ◇ Record $\mathcal{L}$ = 4.02x10^{33} $cm^{-2}s^{-1}$



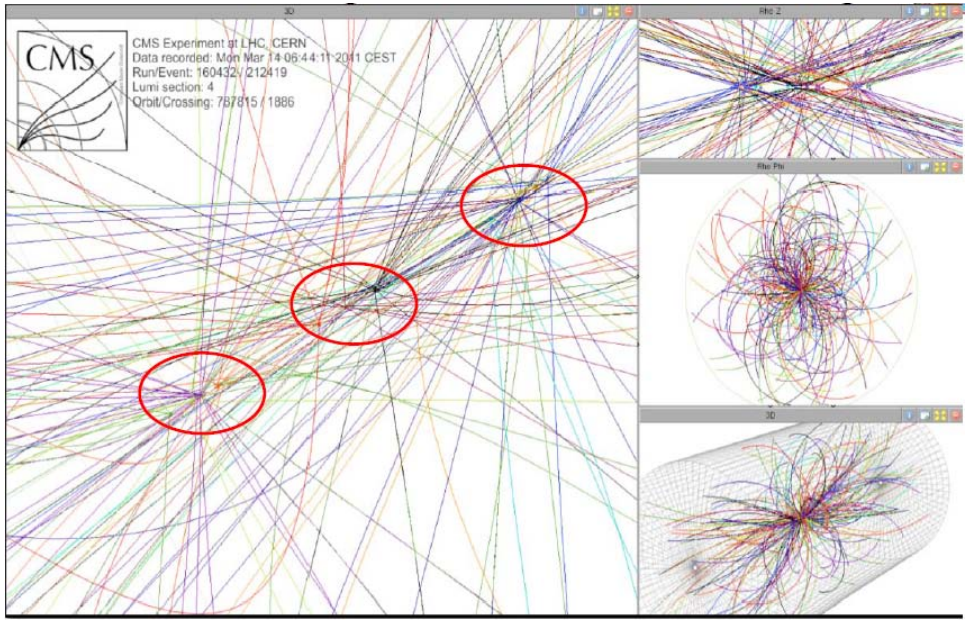


The Challenge of 2011 Data Taking

- High multiplicity of interactions in a single collision of two proton bunches (pileup):

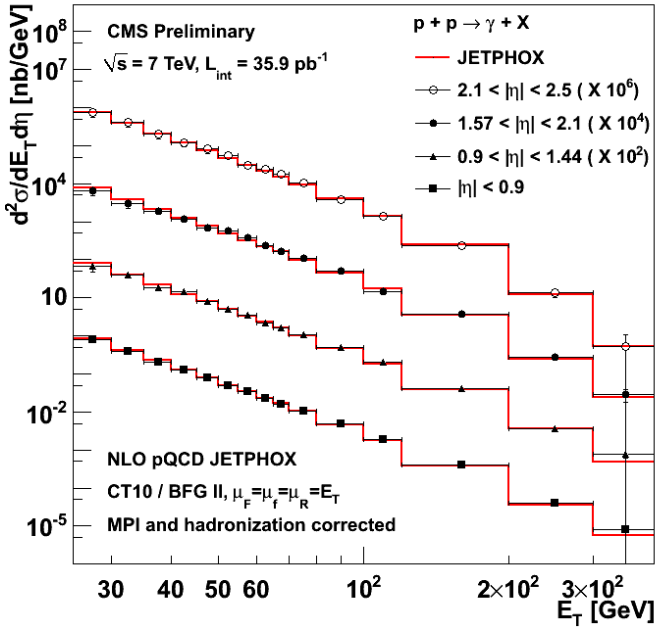
$$\langle N_{PU} \rangle \sim 6 \text{ at } 2.4 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$$

- Effects on the reconstruction of the produced events:
  - ◇ Jet energy and Missing E_T
  - ◇ Lepton isolation
  - ◇ Tagging of heavy quark
- Algorithms developed to subtract activity not coming from the event primary vertex



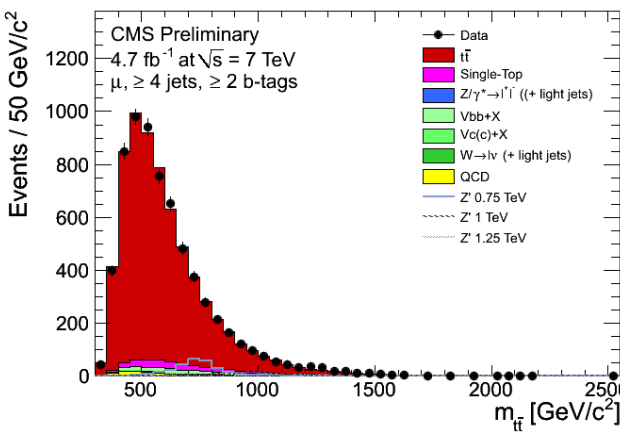
Photon Production

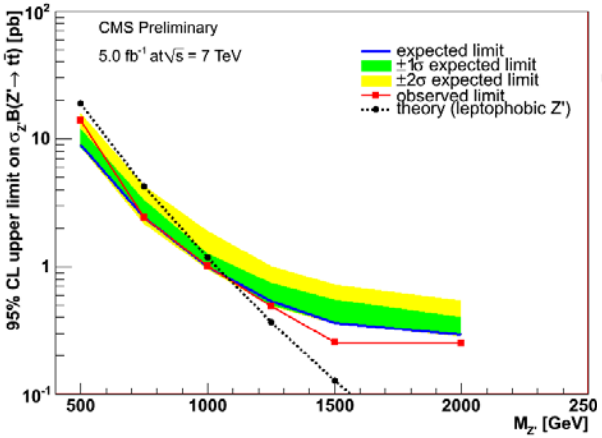
- Differential isolated prompt photon production:
  - ◇ Photon selection: E_T>25 GeV, |η|<2.5
  - ◇ Comparing to NLO perturbative QCD

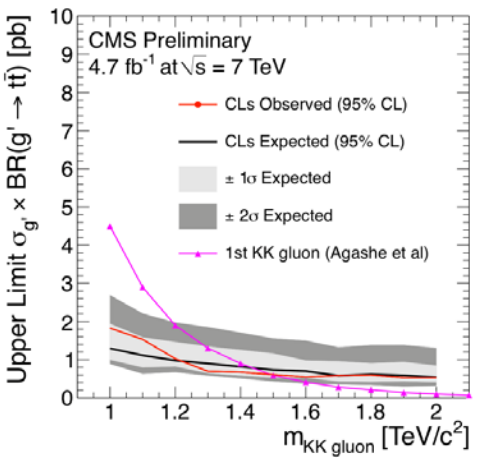


$t\bar{t}$ Resonances

- Searches for heavy neutral boson decaying into ttbar pairs
  - ◇ Both l+jets and dilepton decay channels explored
- No deviation from SM predictions is observed
  - ◇ Set upper limits on the production cross section as a function of the boson mass in several BSM theories

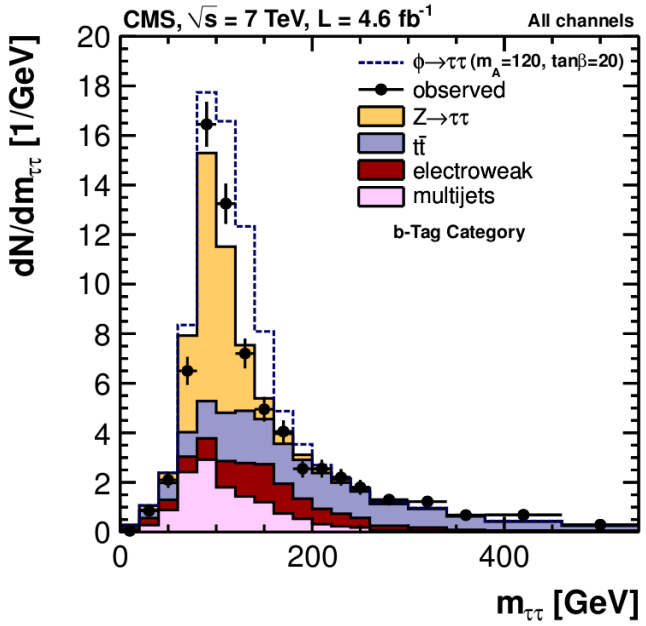


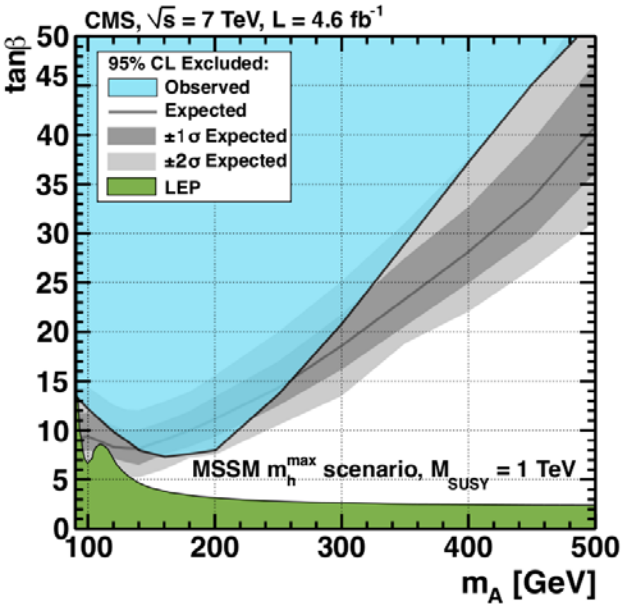




MSSM Neutral Higgs Bosons

- Search for a neutral Higgs boson $pp \rightarrow \varphi(b) \rightarrow \tau\tau(b)$
  - ◇ Fit to reconstructed visible mass
  - ◇ Additional b-tagged jet can be required
  - ◇ Limits in the context of the MSSM





Summary of SUSY Searches

- Excluded mass scale in Simplified Model Spectra
  - ◇ CMS is reaching gluinos and squarks mass exclusion up to 1 TeV/c^2