CMS Status and Recent Results

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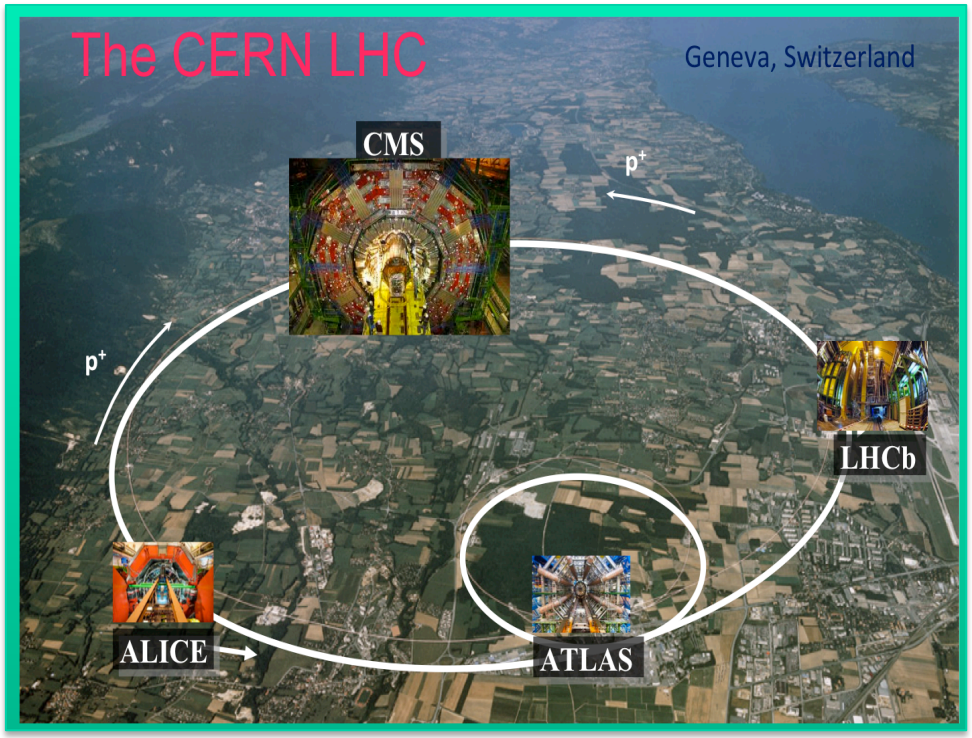
BERKELEY WORKSHOP ON
HEAVY FLAVOR PRODUCTION AT HADRON COLLIDERS

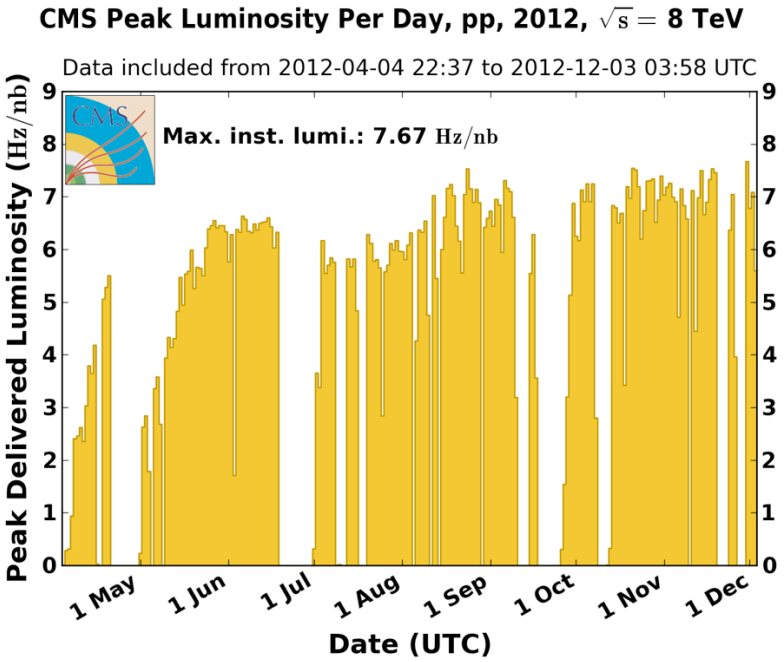
LBL, January 14-16, 2013

LHC Accelerator Status



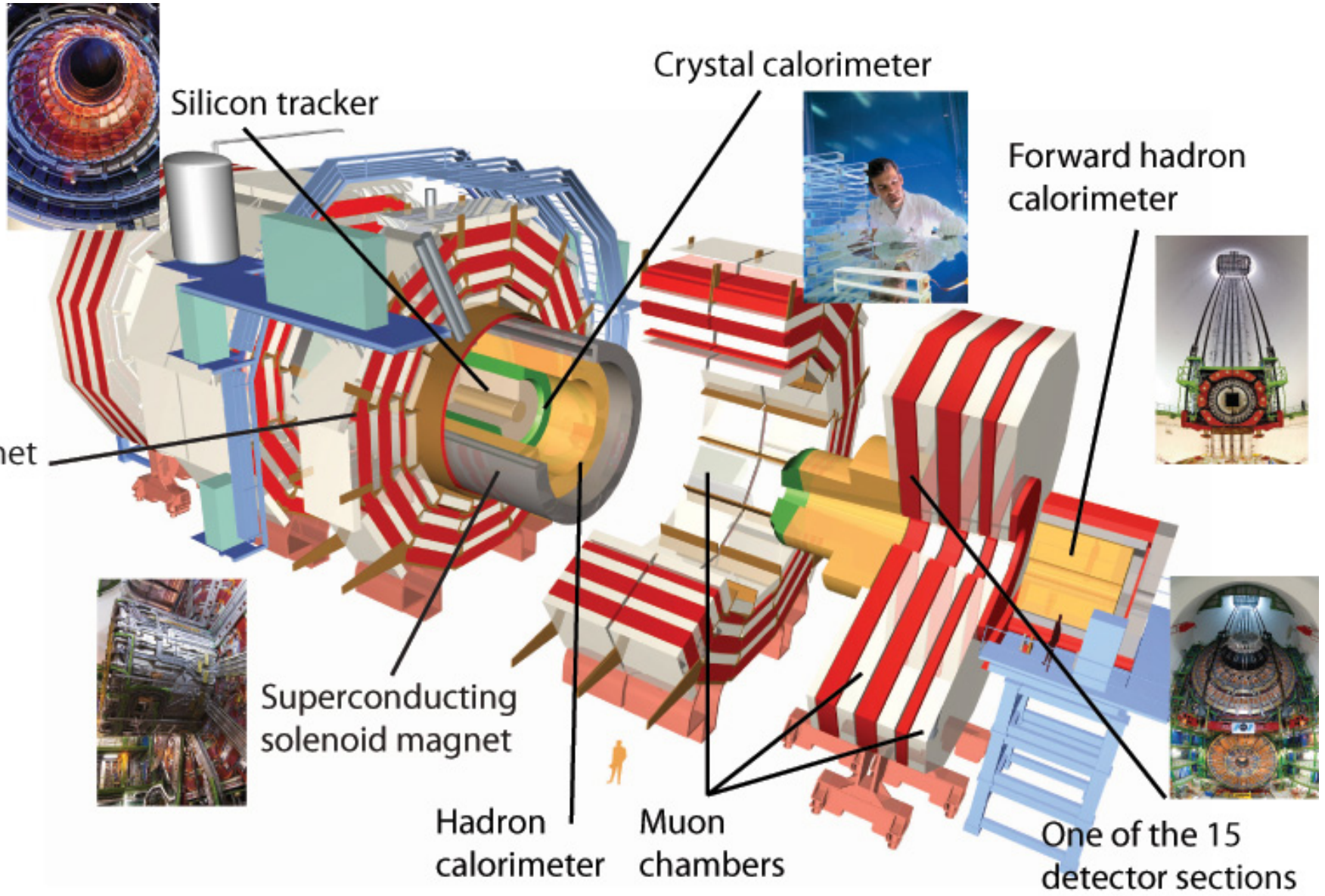
- 2010 $\sqrt{s}$=7 TeV, 36pb^{-1}
- 2011 $\sqrt{s}$=7 TeV, 5fb^{-1}
- 2012 $\sqrt{s}$=8 TeV, 20fb^{-1}
- Upgrade to ~14 TeV in 2015

Peak luminosity in CMS reached 0.77 x 10^{34} cm^{-2}s^{-1} with average PU of 21



Parked data increases the available luminosity.

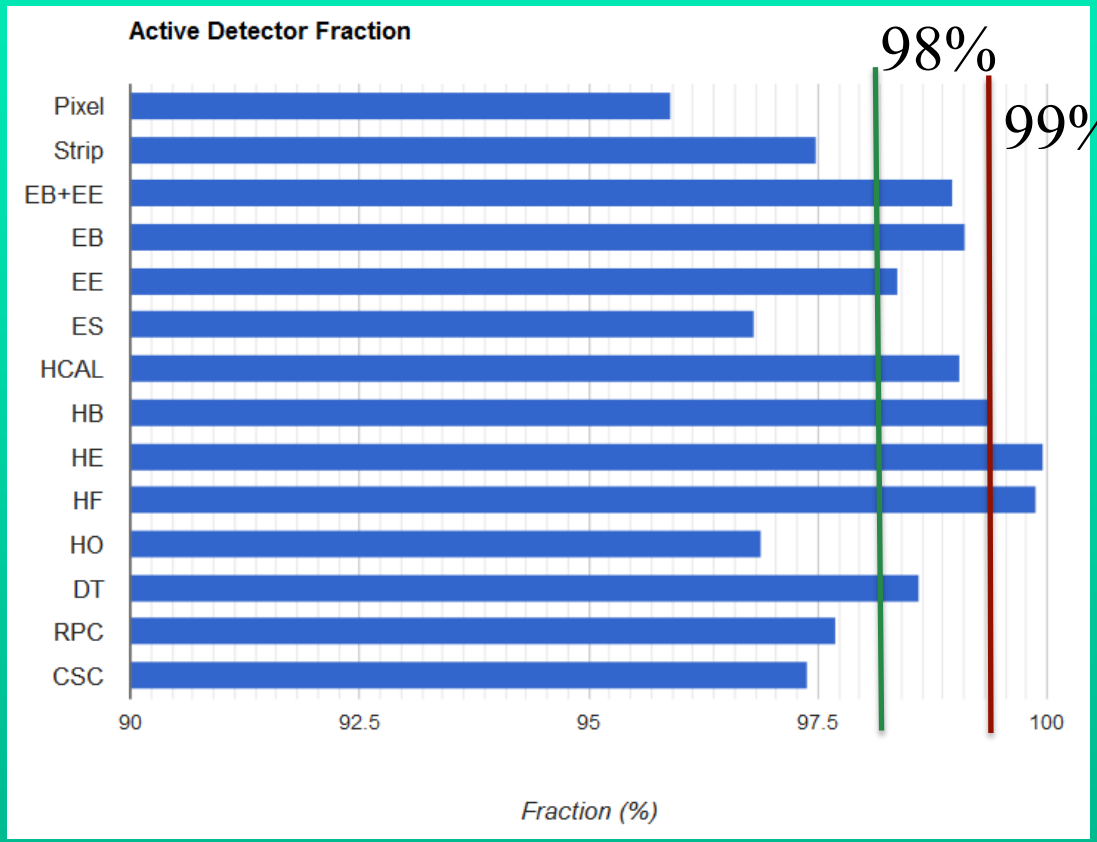
CMS Detector



CMS Detector Status

Crystal calorimeter

Fraction of Life Channels Dec 2012



hadron
eter

Magnet
yoke

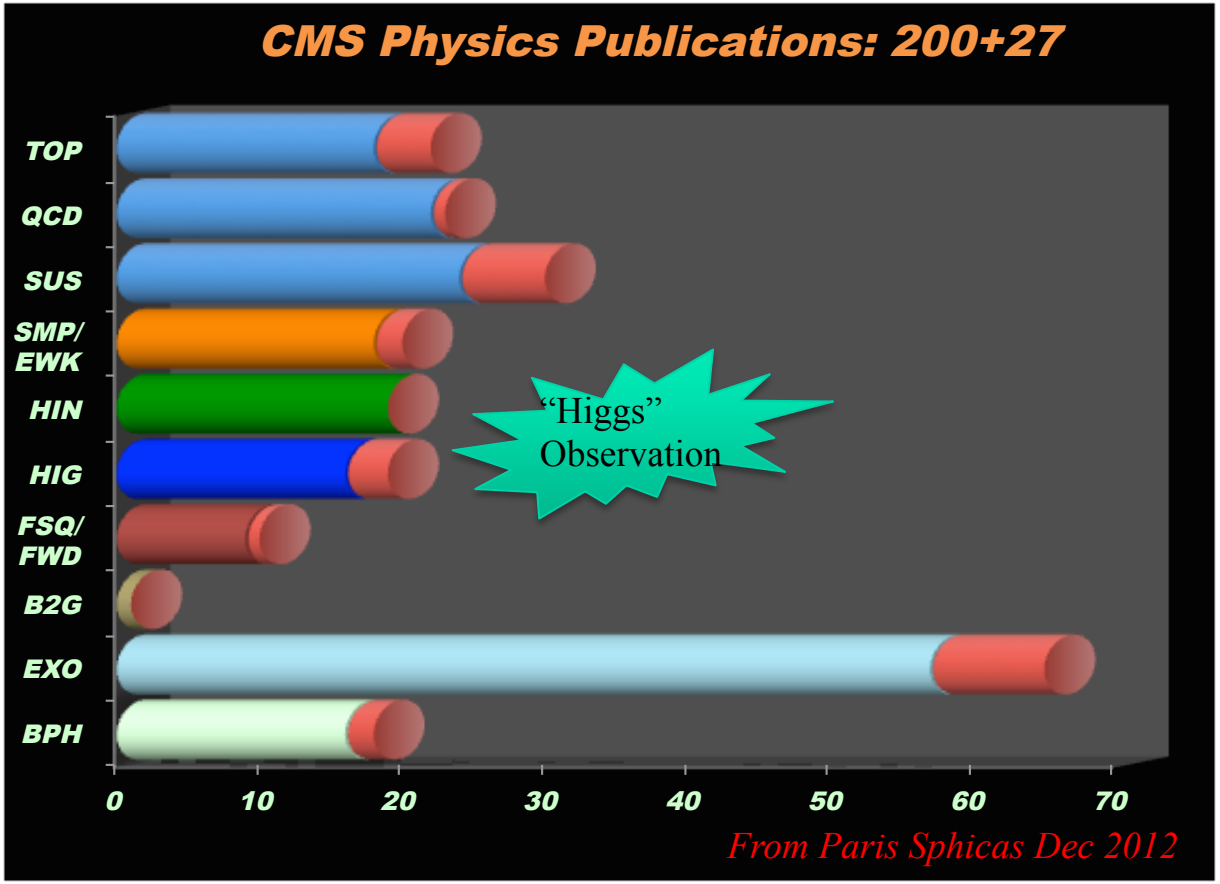
Hadron
calorimeter

Muon
chambers

One of the 15
detector sections

CMS Publications

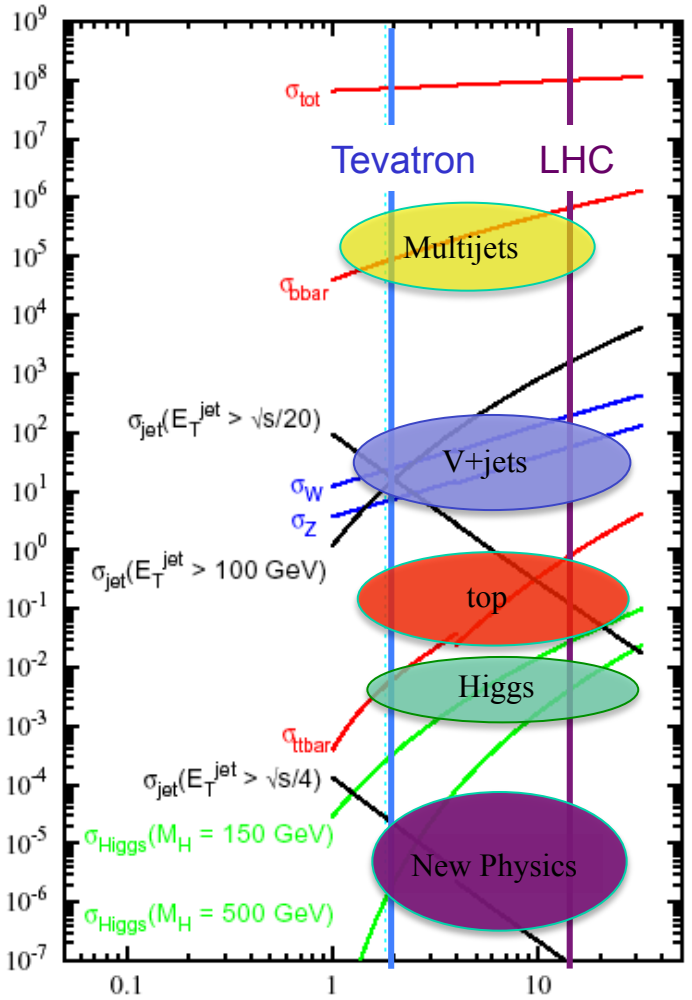
200 publications based on data (+ performance and detector)



Will cover a selection of recent (Nov 2012-now) results

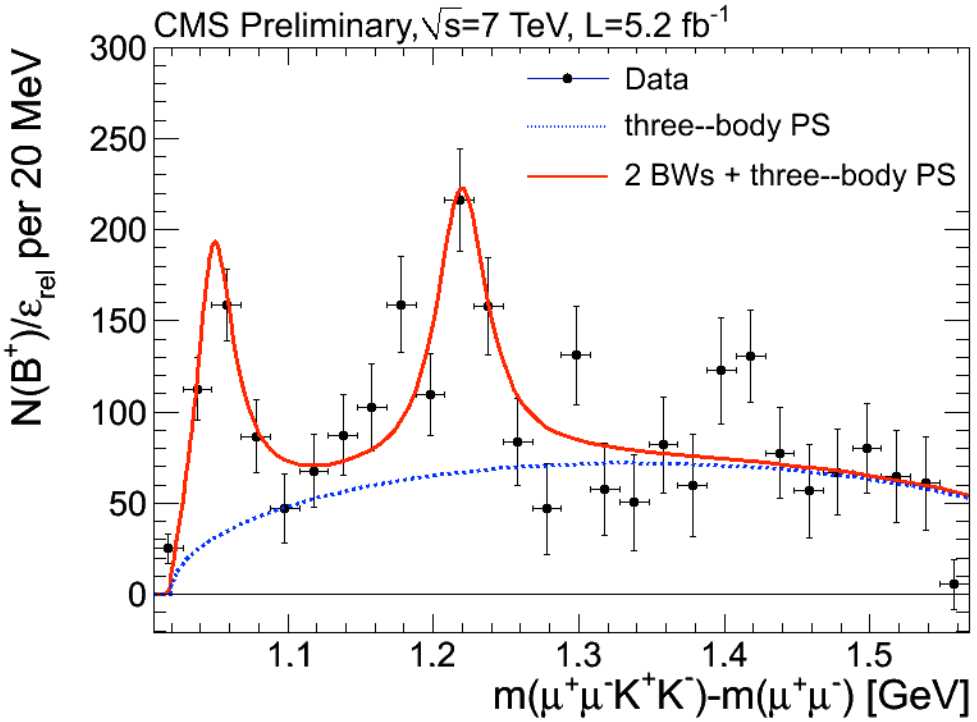
All public results available at
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

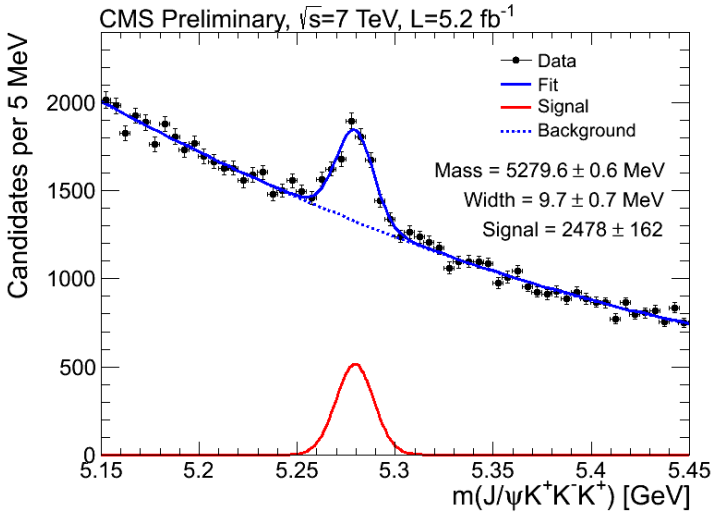
Hadronic Cross Sections



- Production Cross Sections span 12-13 orders of magnitude
  - Collision rate overwhelmed by mundane processes
  - Background discrimination and modeling crucial
- Wide variety of processes produced
  - Enables rich physics program
- Searches for New Physics
  - Direct
    - model driven or independent
  - Indirect through precision tests of SM

Observation of two structures in the J/Ψ K^+K^- spectrum





Candidate for an exotic state?

Fitted mass

$M_1 = 4148.2 \pm 2.0$ (stat.) ± 4.6 (syst.) MeV

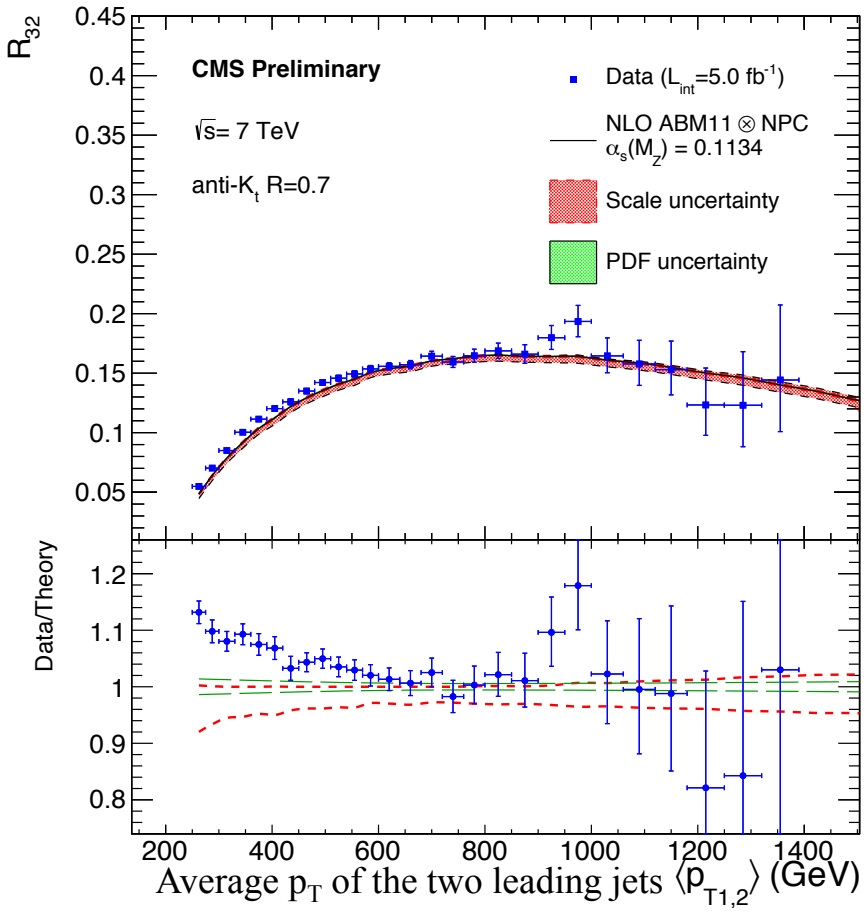
$M_2 = 4316.7 \pm 3.0$ (stat.) ± 7.3 (syst.) MeV

S-wave relativistic Breit-Wigner lineshape over a 3-body phase-space non-resonant component

Angular analyses of the two structures might help elucidate their nature. This may become feasible with more data.

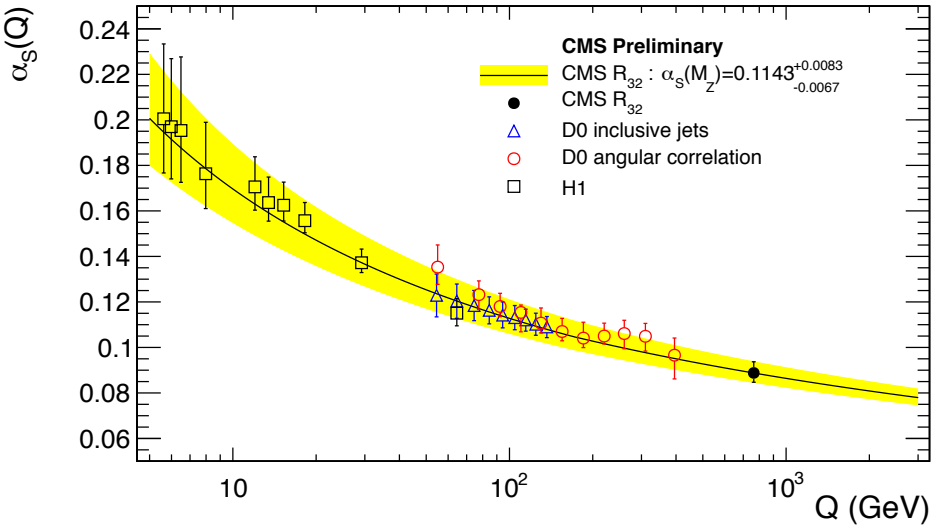
CMS-PAS-BPH-11-026

Inclusive 3-jet to 2-jet x-sections ratio



NLO using NNPDF2.1, MSTW2008 and CT10 PDF sets are in agreement with data. ABM11 PDF sets underestimates data in the $p_{T1,2} < 600$ GeV.

R_{32} (in the 400-1400 GeV range) is used to measure α_s at the Z mass scale, stringent test of QCD.



$$\alpha_S(M_Z) = 0.1143 \pm^{0.0083}_{0.0067}$$

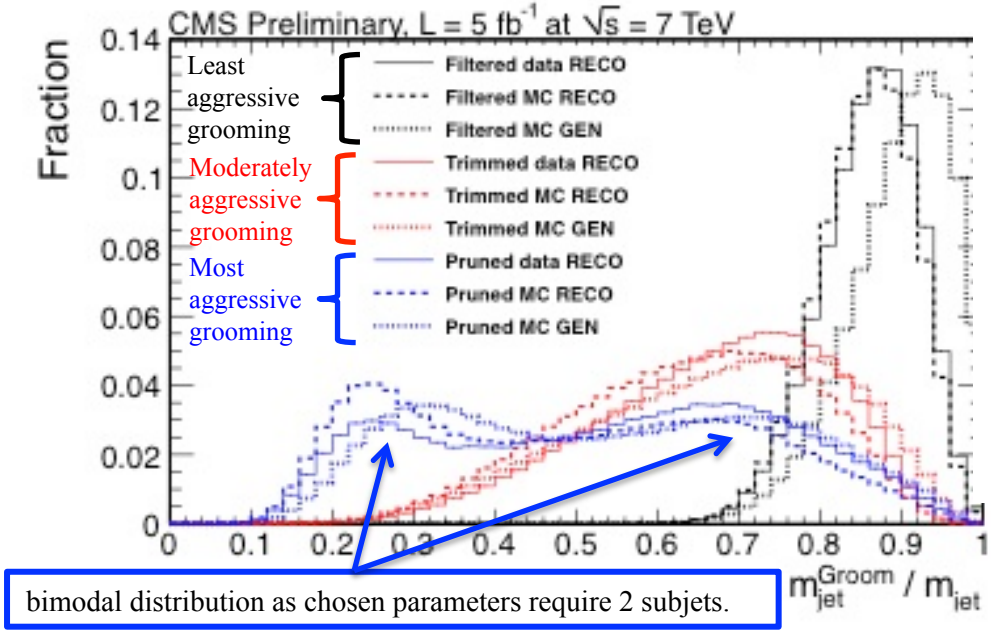
First derivation of $\alpha_S(M_Z)$ from momentum scales > 0.4TeV

CMS-PAS-QCD-11-003

Jet Mass and Substructure Studies

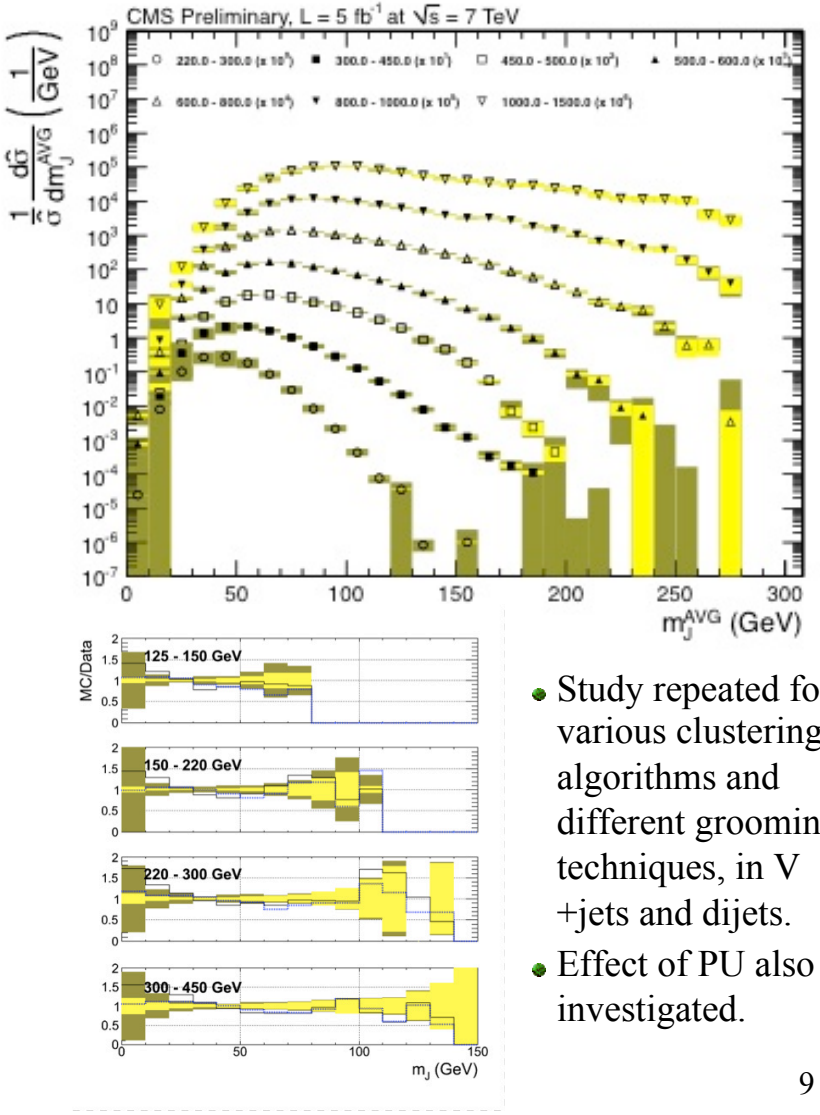
Use jets from di-jet and W/Z(➞ℓ)+ jets events

CMS-PAS-SMT-12-019



bimodal distribution as chosen parameters require 2 subjets.

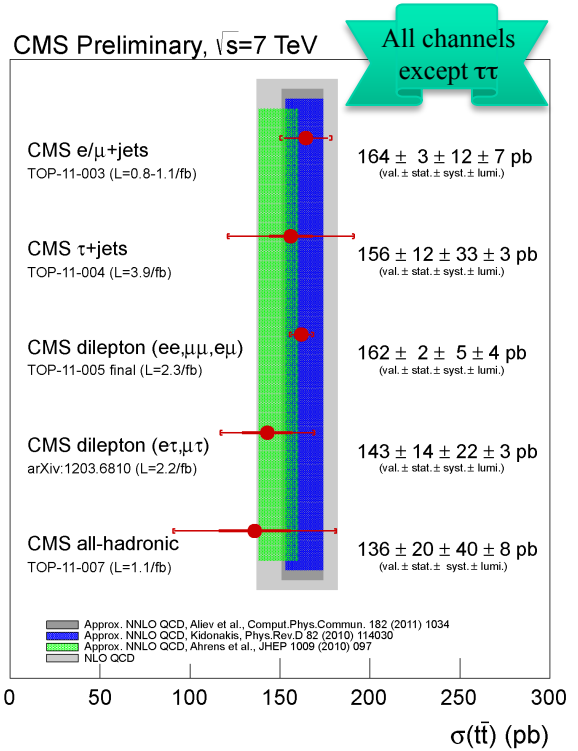
Unfolded jet mass distribution ungroomed AK7 jets inW+jets

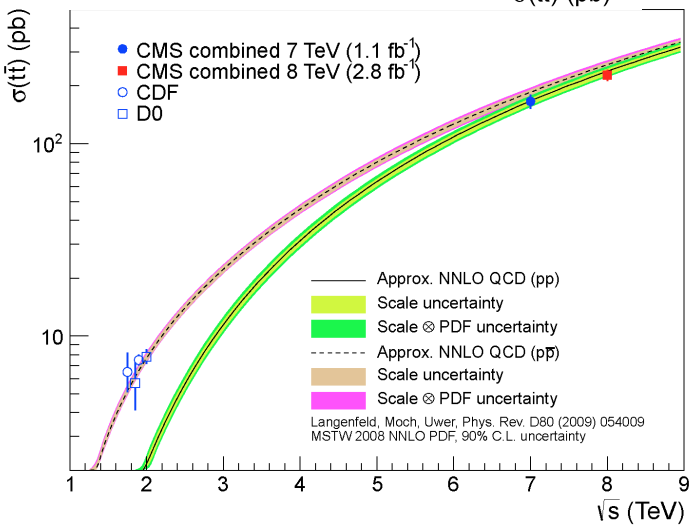


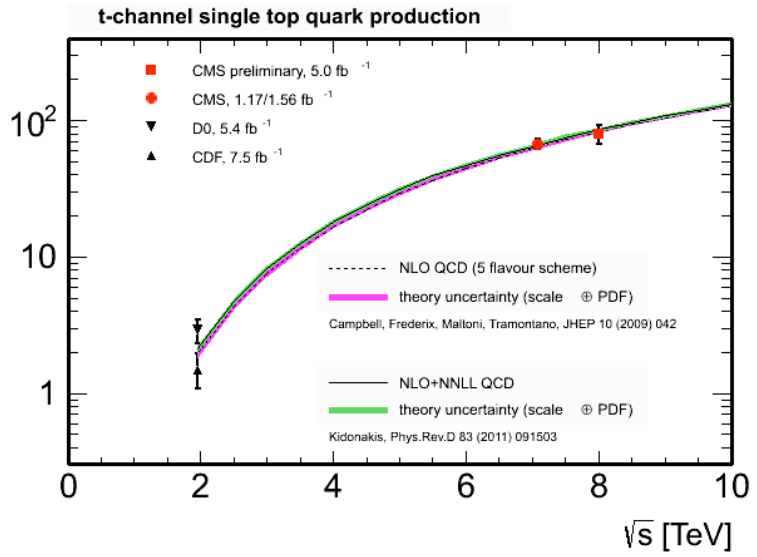
- Study repeated for various clustering algorithms and different grooming techniques, in V +jets and dijets.
- Effect of PU also investigated.

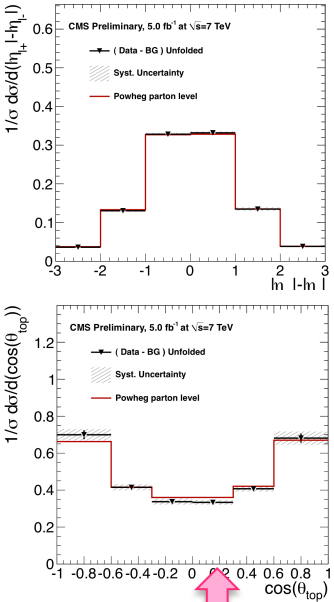
Leading-order parton-shower MC predictions found to be in good agreement with the data. Important benchmark studies toward the use of jet substructure tools in new physics searches

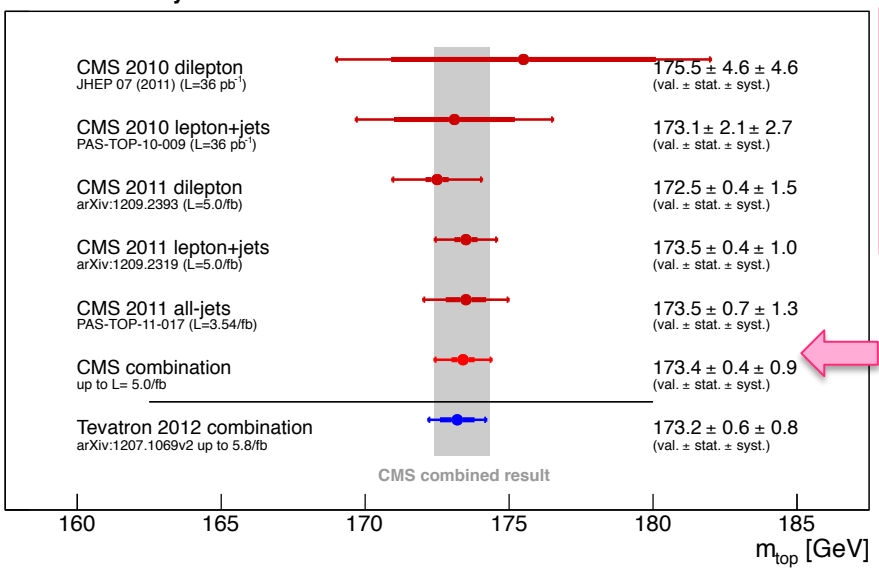
Studies of top quarks: precision!







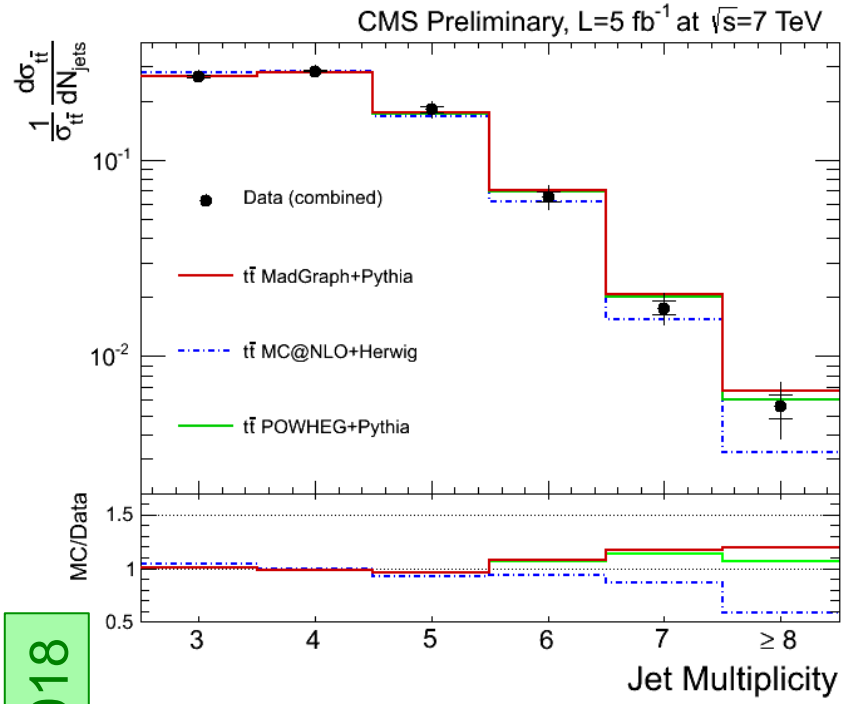


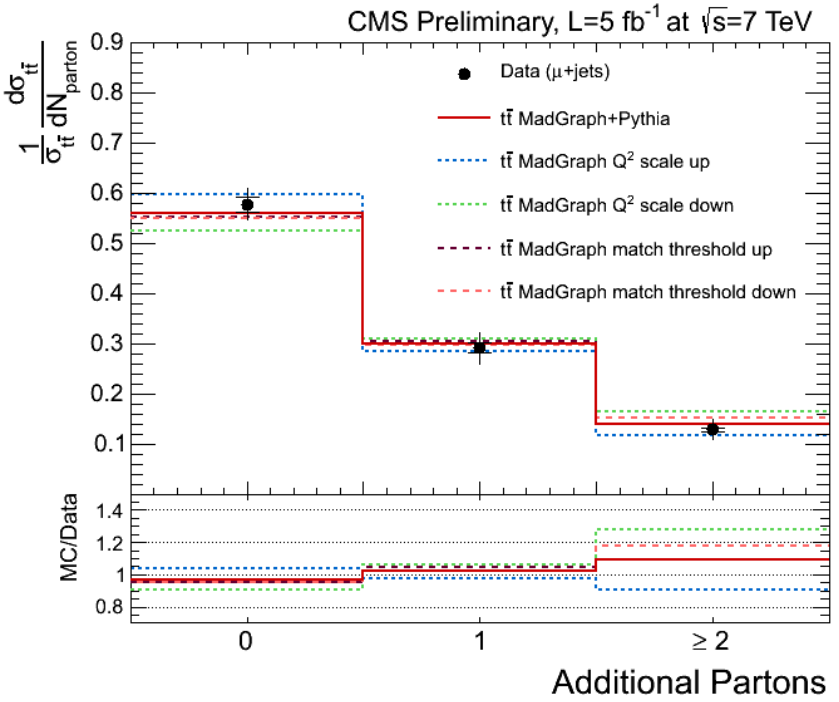


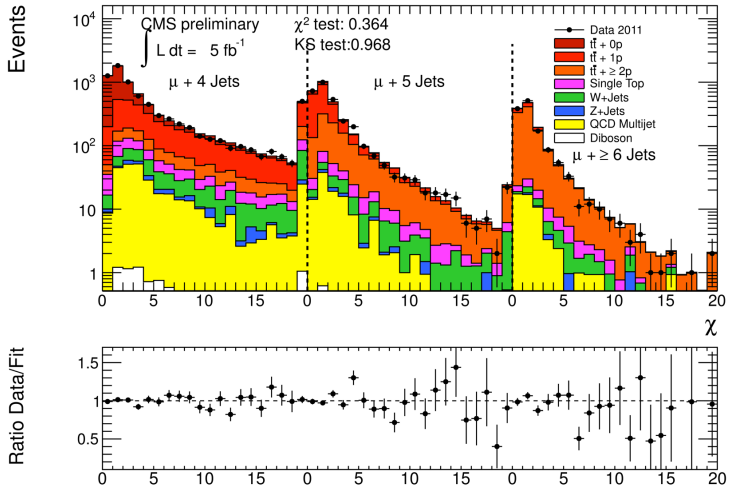
Top charge asymmetry in dileptons agrees with predictions.

Top mass in all 3 channels are single most precise to date

Jet multiplicity in $t\bar{t} \to \ell$+jets







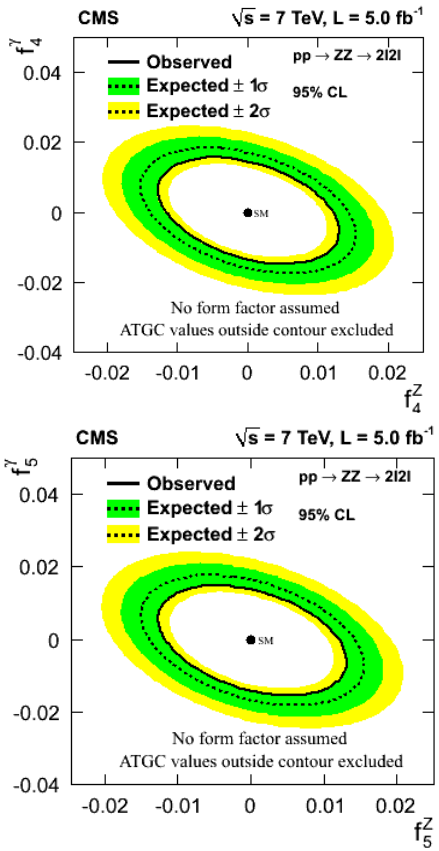
- Simulated events are classified according to the amount of additional radiation they contain (reduces detector effects).
- Fractions of events with 0, 1, and 2 extra hard partons are extracted from a binned maximum likelihood fit.
- Excellent agreement with MADGRAPH and POWHEG

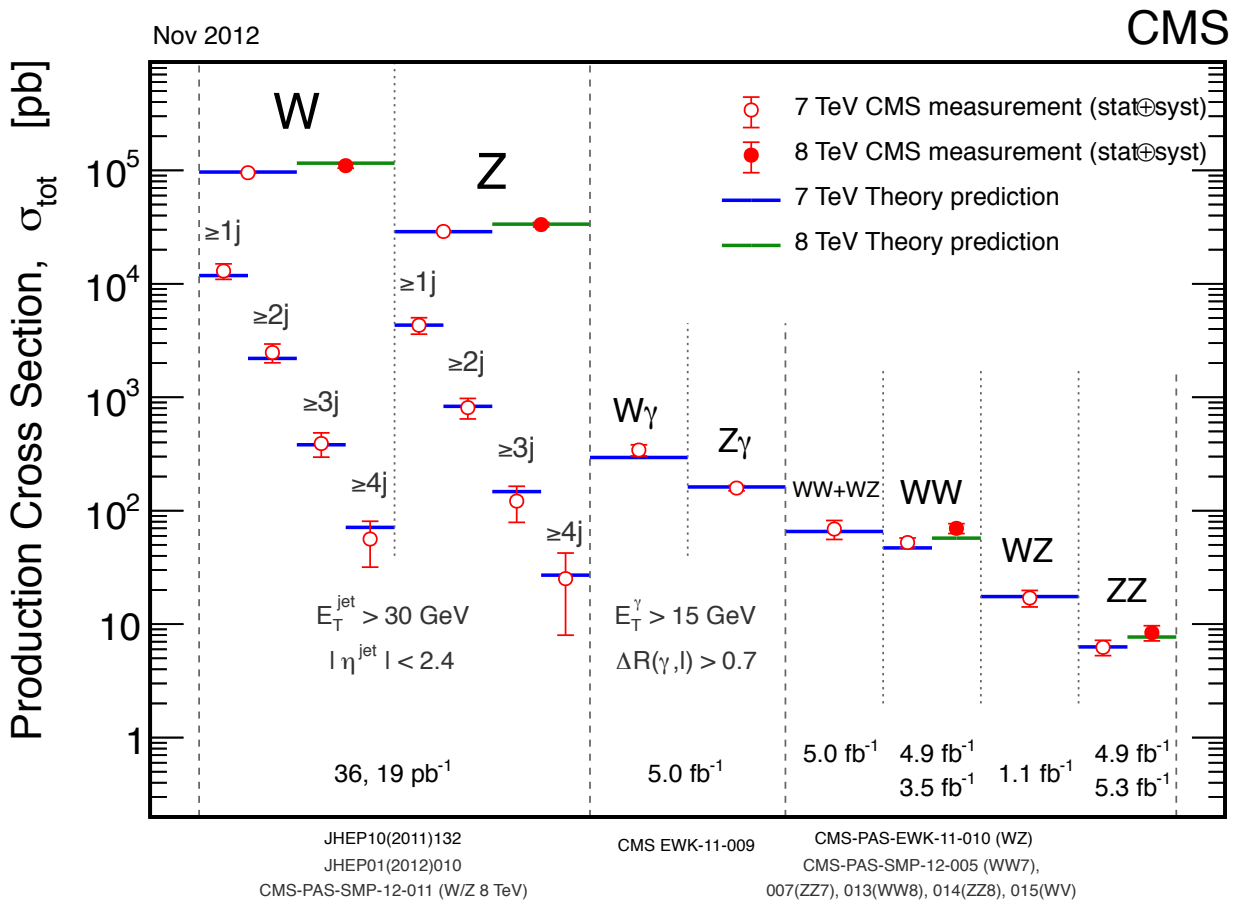
Experimental precision better than variations in theory scales, expect to be able to constrain these in the future.

CMS-PAS-TOP-12-018

Multi-Boson Production

- Diboson measurements are a crucial test of the gauge structure of the SM

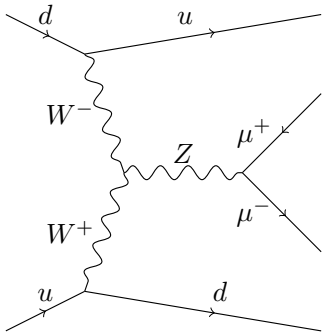




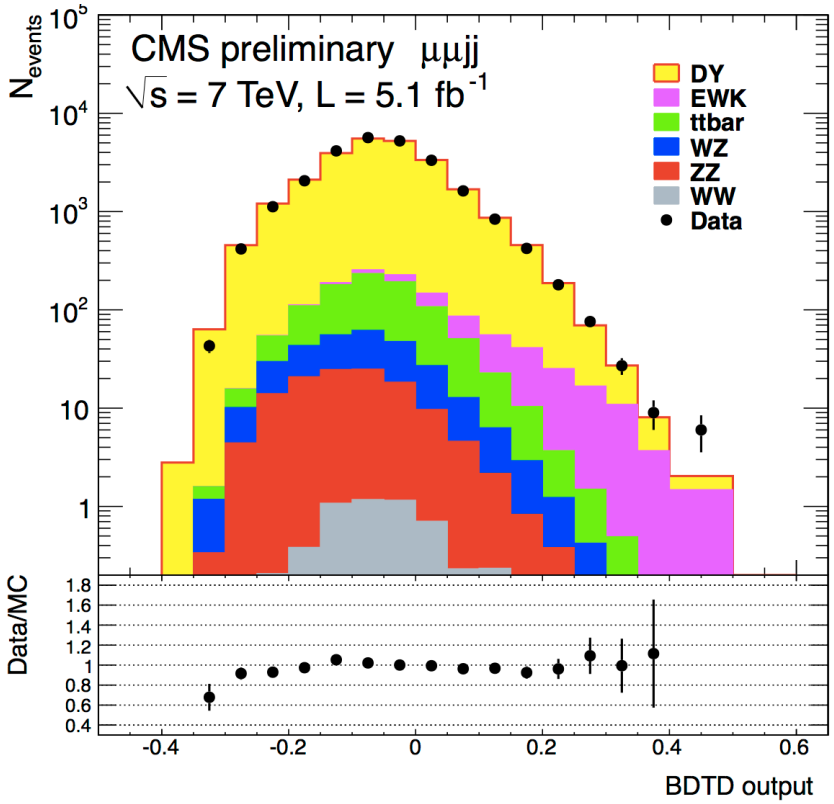
Limits on anomalous ZZZ/ ZZγ couplings:

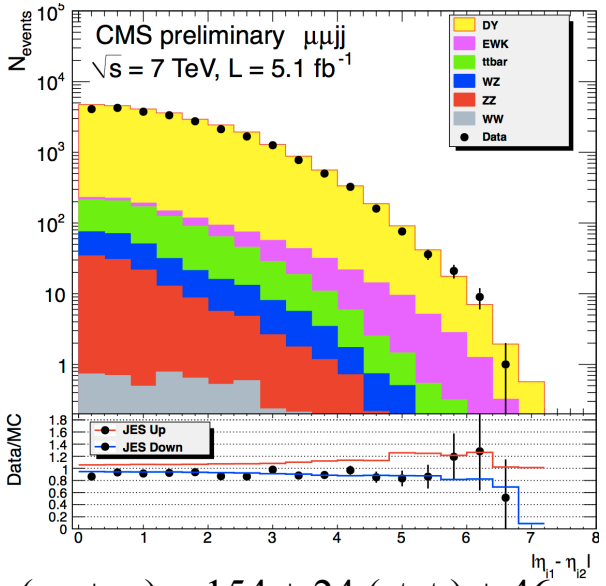
CMS-PAS-SMP-12-007, 011, 012, 014

Evidence for VBF Z production



- EW production of Z + jets – with the two jets well separated in rapidity – important benchmark in the searches for VBF Higgs
- Very hard due to dominant DY production, uses advanced multivariate techniques (BDT) to extract signal





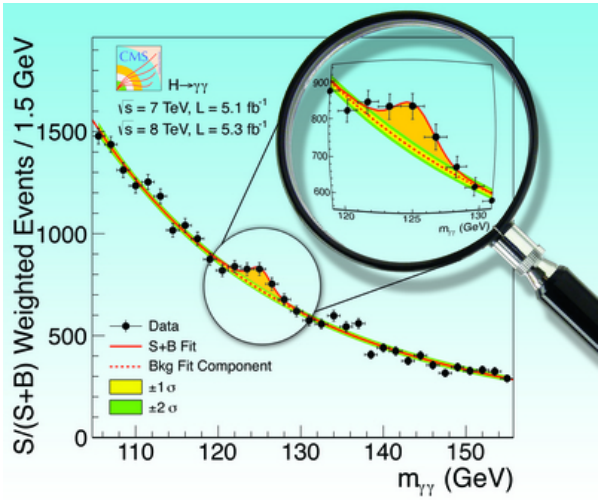
σ(μμ+ee) = 154 ± 24 (stat.) ± 46 (syst.) ± 27 (th.) ± 3 (lum.)fb
(Theory: 166fb)

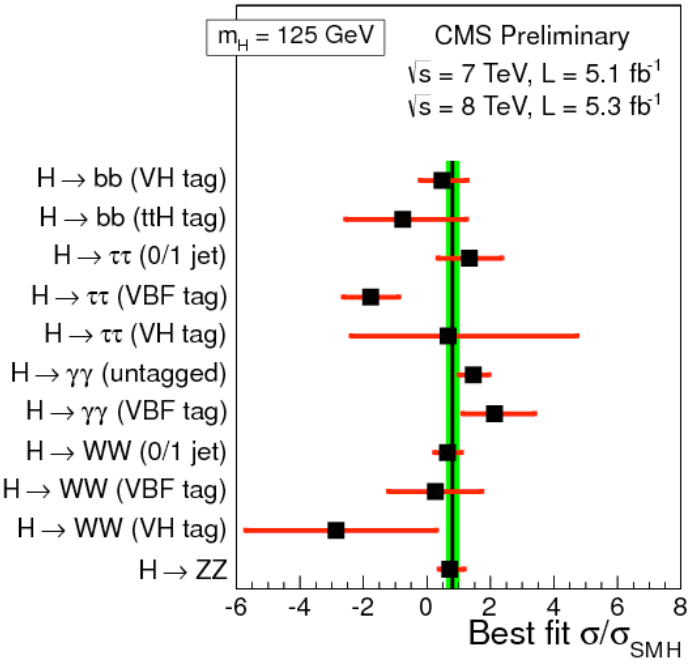
CMS-PAS-FSQ-12-019

See ~3σ evidence for EW production of the Z

Higgs Updates post-observation

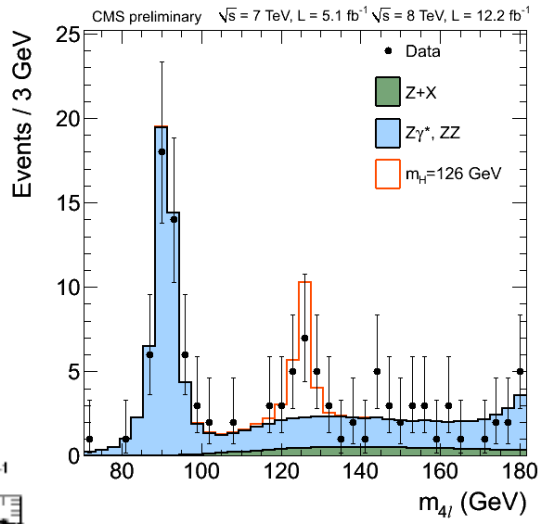
- ZZ, WW, bb, and ττ channels updated with 17fb^{-1} and refined analyses
  - In some cases substantial improvement in the sensitivity has been achieved
- First measurement of the spin-parity properties of the new particle
- Information on the mass and couplings
- Results extended to high masses, using an improved lineshape of the signal
- New MSSM Higgs search based on the ττ channel

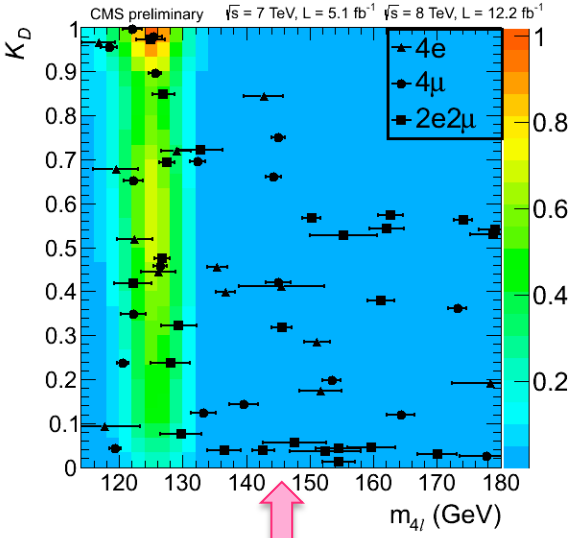


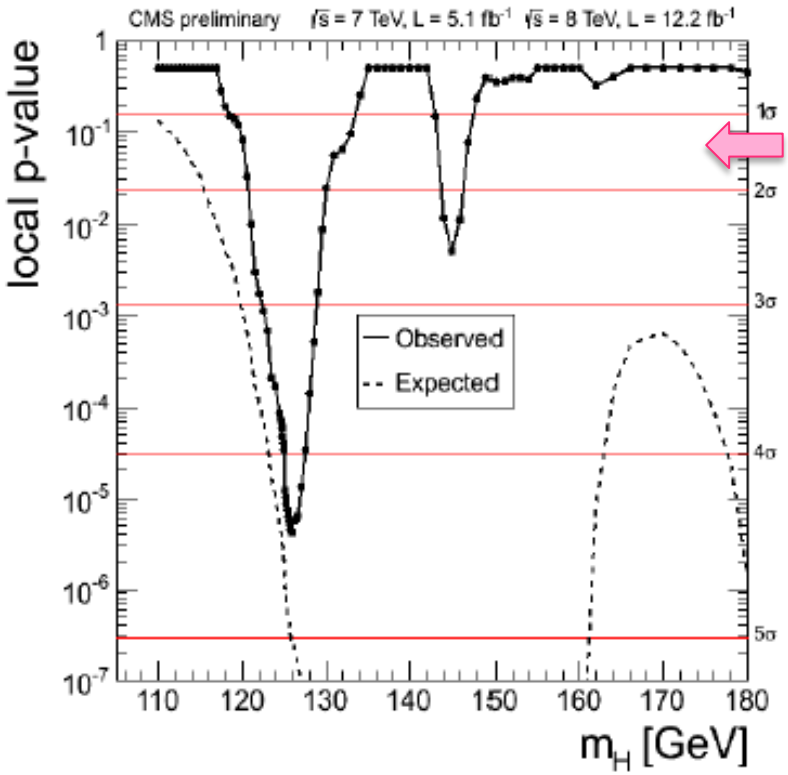


H → ZZ → ℓℓℓℓ

- Use MELA kinematic discriminant based on the probability ratio of the signal and background hypotheses vs 4 lepton invariant mass.







p-values for SM Higgs for ZZ to 4e, 4μ, 2e2μ and 2e2τ.

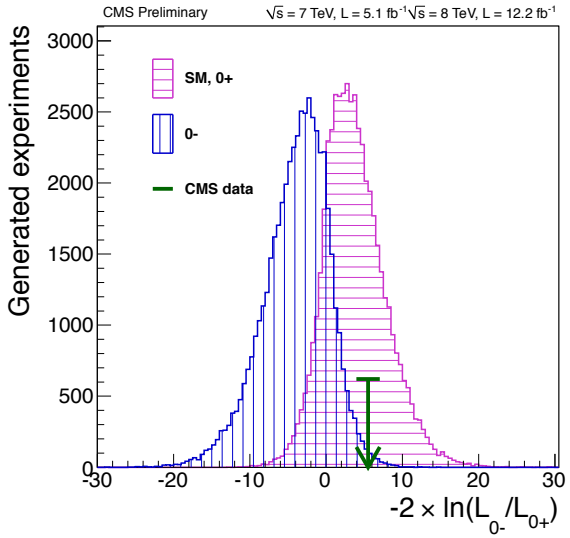
Points represent individual events. Contours show signal expectation.

Observed significance is 4.5σ (5σ expected).

CMS-PAS-HIG-12-041

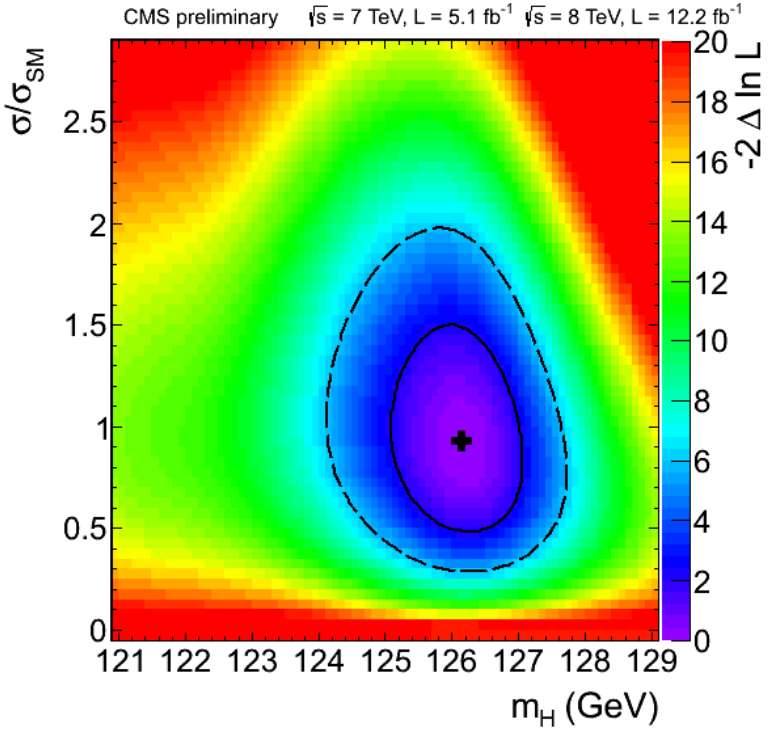
Higgs Properties: Spin Parity and Mass

- Based on H→ZZ→ 4ℓ channel
- Use MELA with probability ratio for two signal hypotheses: SM and pure pseudo-scalar state $J^P = 0^-$



The pseudoscalar (vs. scalar) hypothesis is excluded at the 97.6% level. Need more data to distinguish 0^+ from 2^+

Mass obtained from a simultaneous fit of the mass and of signal strength

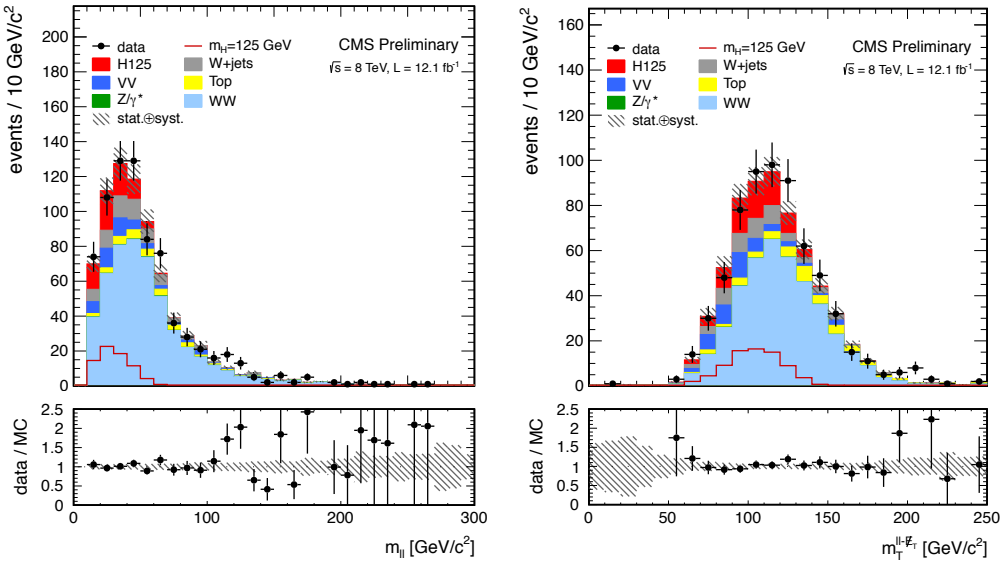


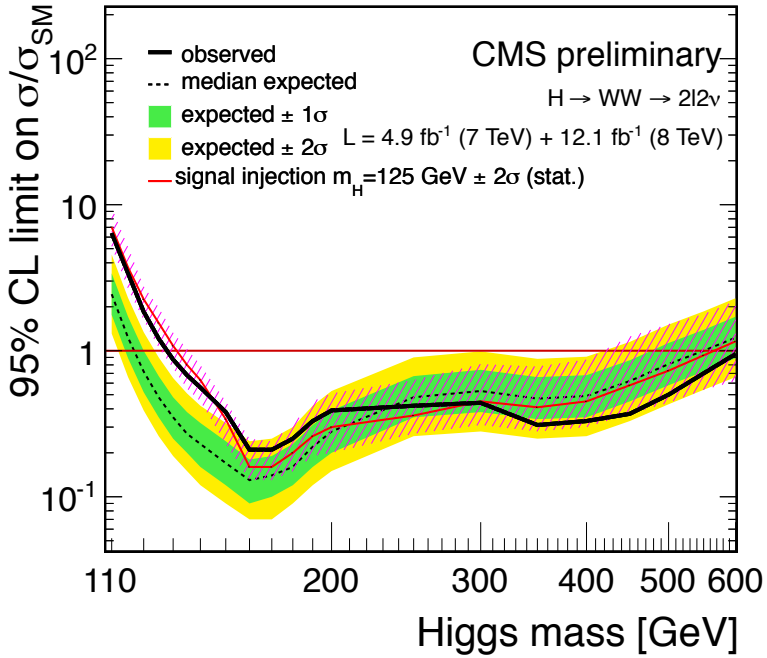
Measured mass
126.2 ± 0.6 (stat) ±0.2 (syst) GeV

CMS-PAS-HIG-12-041

$H \rightarrow WW \rightarrow \ell\ell\nu\nu$

- Updated the different lepton flavor analysis using M_{ll} and M_T as two discriminant variables.
- Results are consistent with the $m_H = 125$ GeV signal



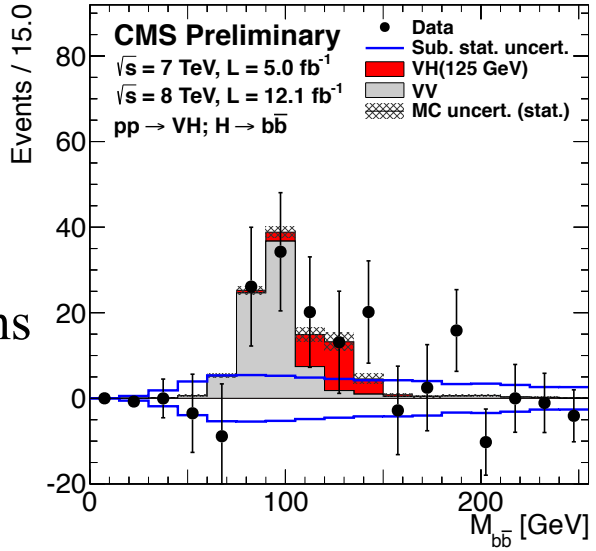


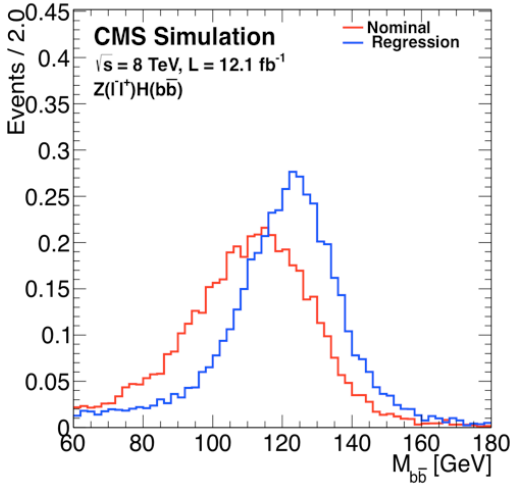
Observed significance is 3.1σ (4.1σ expected)

CMS-PAS-HIG-12-042

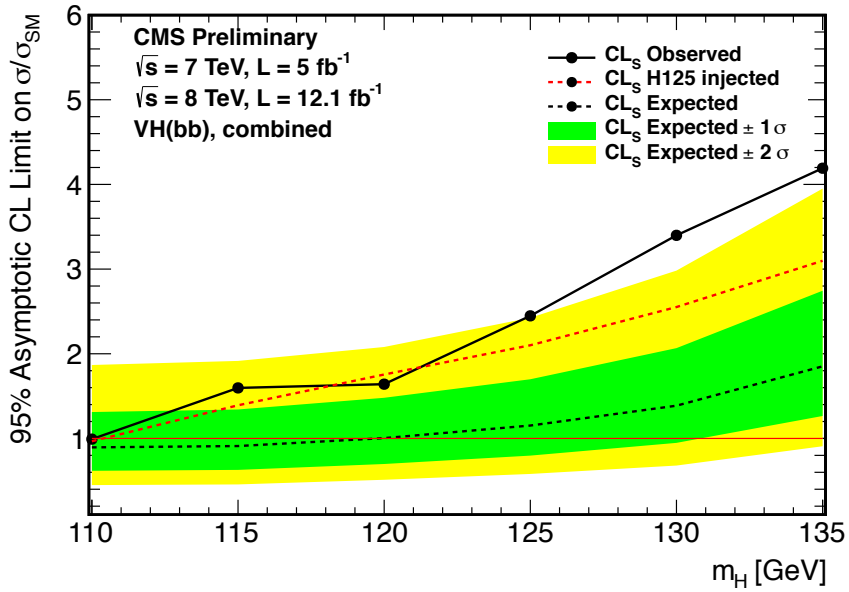
VH → bb

- Combines W(μν), W(eν), Z(μμ), Z(ee) and Z(νν), all Higgs to bb.
- Results are obtained from fits to the BDT output distributions trained separately for each channel
- b-jet energy recalibrated to true parton energy (regression)





Improvement in the bb mass resolution due to regression

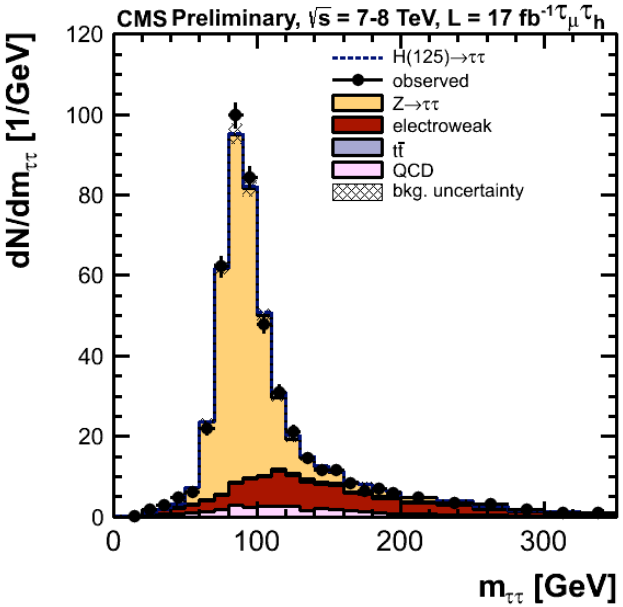


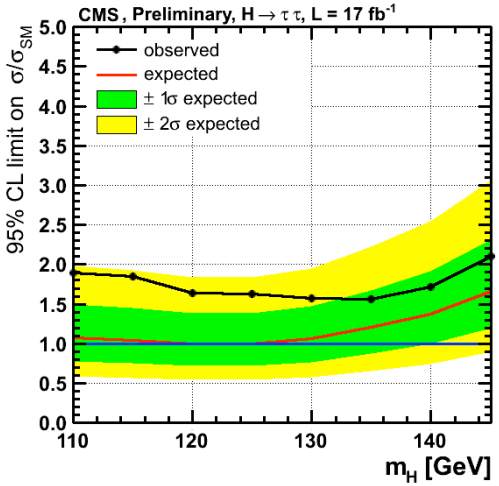
Observed upper limit on σ/σ_{SM}=2.5 (1.2 expected) at 125GeV. Local significance 2.2 S.D.

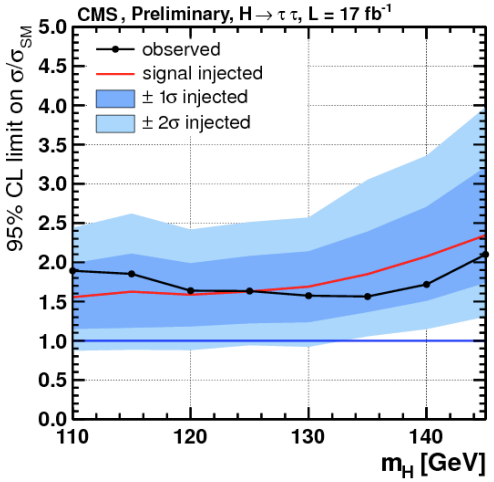
CMS-PAS-HIG-12-044

$H \rightarrow \tau\tau$

- Combines $\mu\tau_h$, $e\tau_h$, $e\mu$, $\tau_h\tau_h$, and $\mu\mu$.
- τ pair mass reconstruction is used as discriminant.
- Events are classified by the number of jets and p_T of τ decay products to increase sensitivity.







Limits obtained for a combined search for HV, with H to tt and V decaying leptonically.

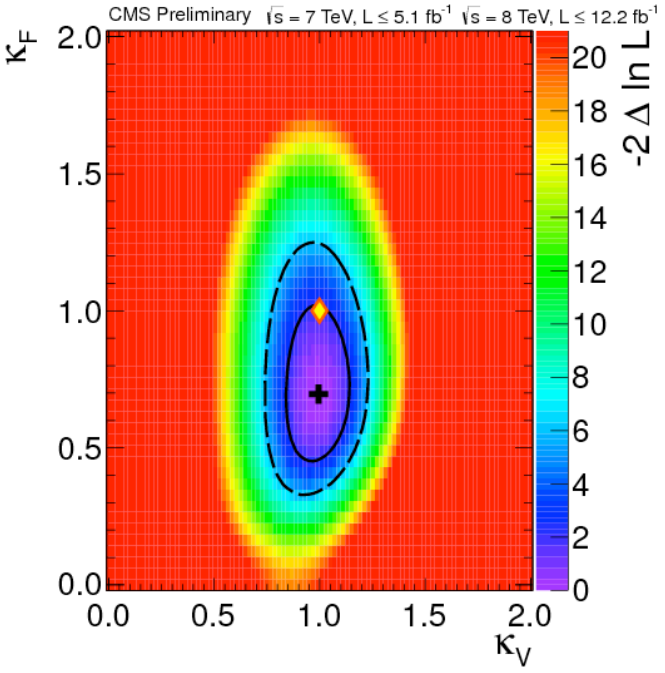
Observed upper limit on σ/σ_{SM}=1.63 (1 expected) at 125GeV.

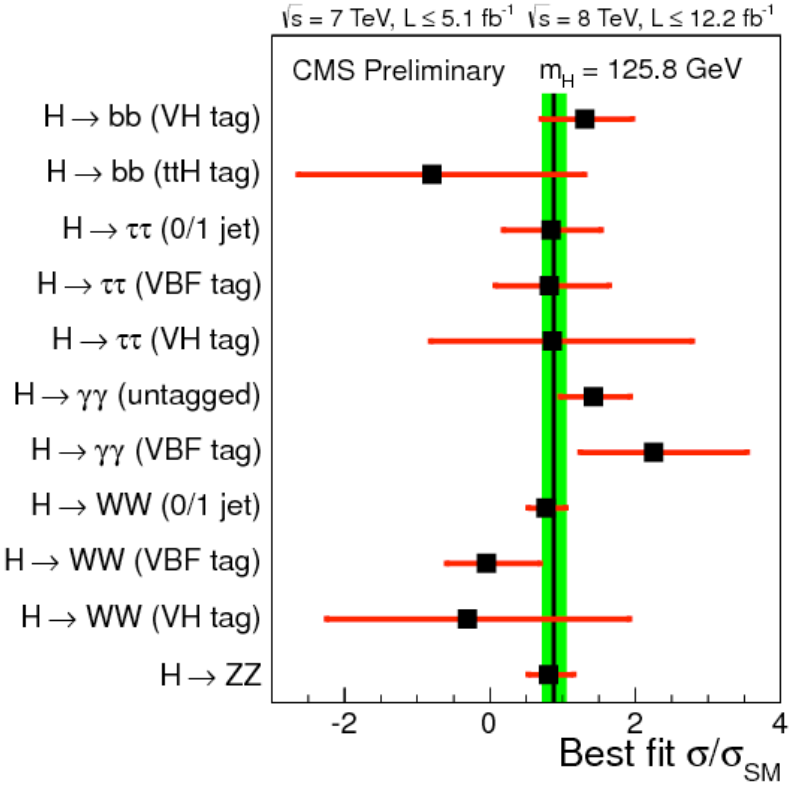
CMS-PAS-HIG-12-043

Higgs Combination

- Combines γγ, ZZ, WW, ττ and bb.

Test of Couplings: Fermion vs Vector





CMS-PAS-HIG-12-045

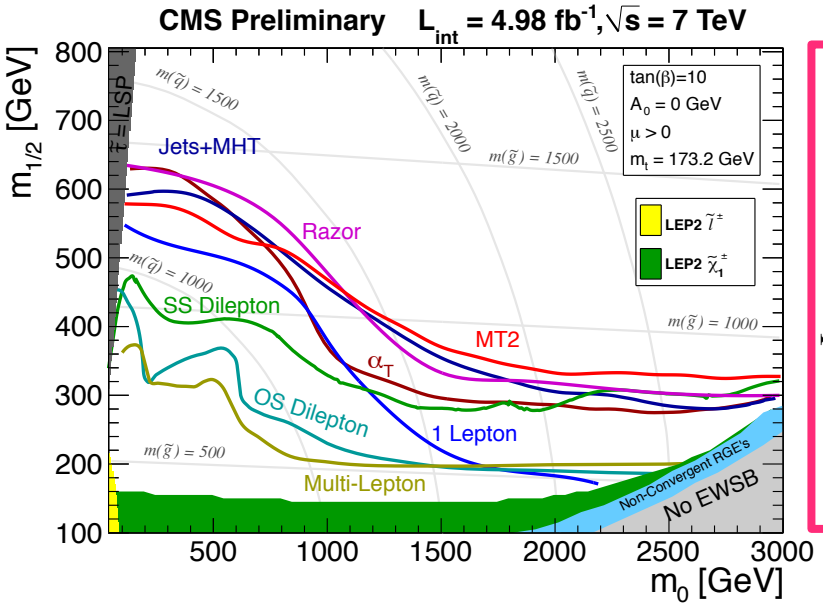
Decay mode or combination	Expected (σ)	Observed (σ)
ZZ	5.0	4.4
$\gamma\gamma$	2.8	4.0
WW	4.3	3.0
bb	2.2	1.8
$\tau\tau$	2.1	1.8
$\gamma\gamma$ + ZZ	5.7	5.8
$\gamma\gamma$ + ZZ + WW + $\tau\tau$ + bb	7.8	6.9

Observed significance is 6.9 σ (7.8 σ expected).
Measured Mass:
125.8 ± 0.4 (stat) ± 0.4 (syst) GeV

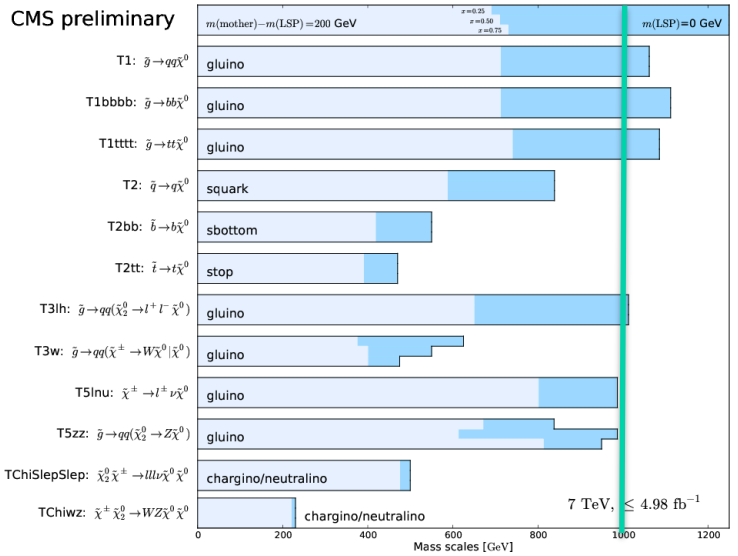
The Hierarchy Problem

- We discovered a new boson with mass ~ 126GeV
  - What is stabilizing its mass?
- Loop corrections diverge quadratically
  - Either there is some new physics which naturally solves the problem
  - Or the universe if fine tuned (i.e. it is a coincidence)
- 2011 CMS Searches
  - not tuned to particular model
  - cover many possible final states.

Now focusing on natural SUSY



CMSSM interpretation



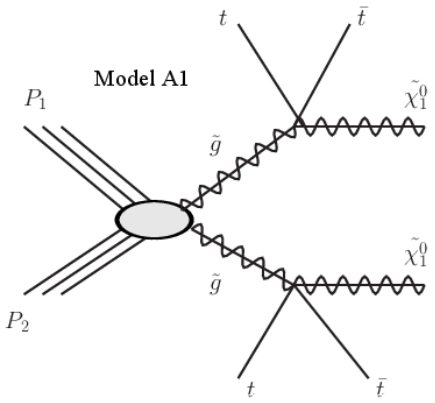
SMS interpretation

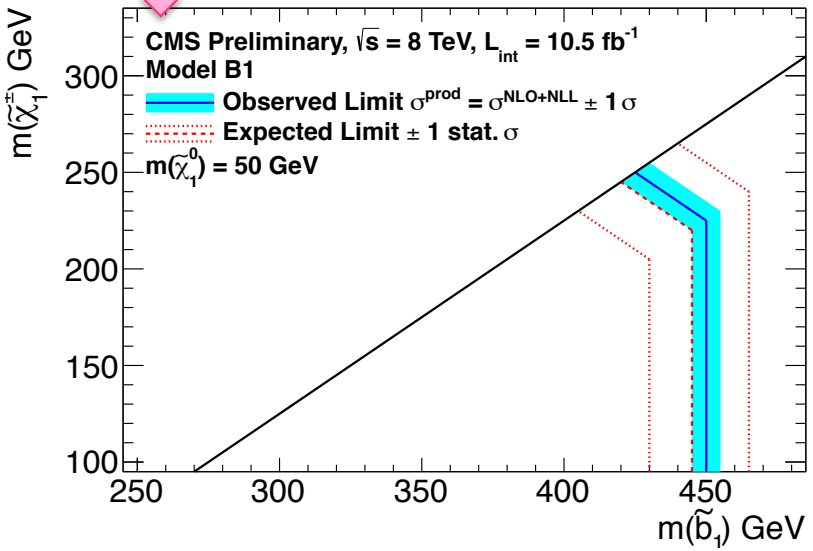
CMS-PAS-SUS-11-016

3rd Generation Searches

direct sbottom (SS diletons + b)

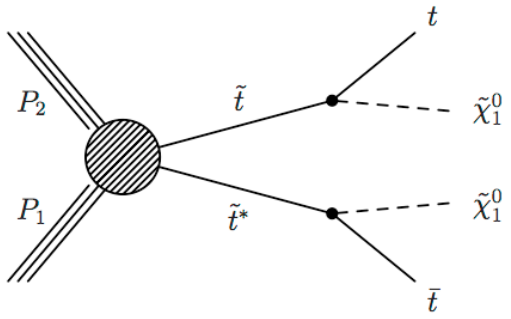
Exclusion shown for A1 model: gluino decay via virtual stop quarks

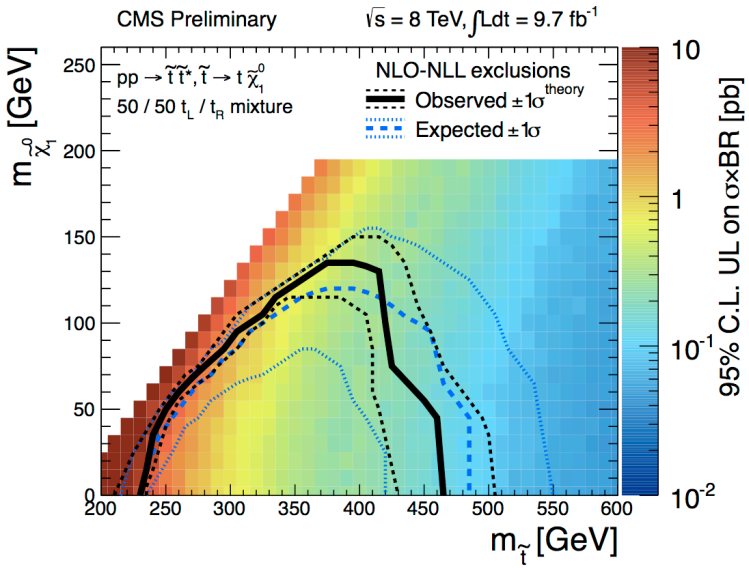




CMS-PAS-SUS-12-029

stop pairs (l + jets + ME_T)

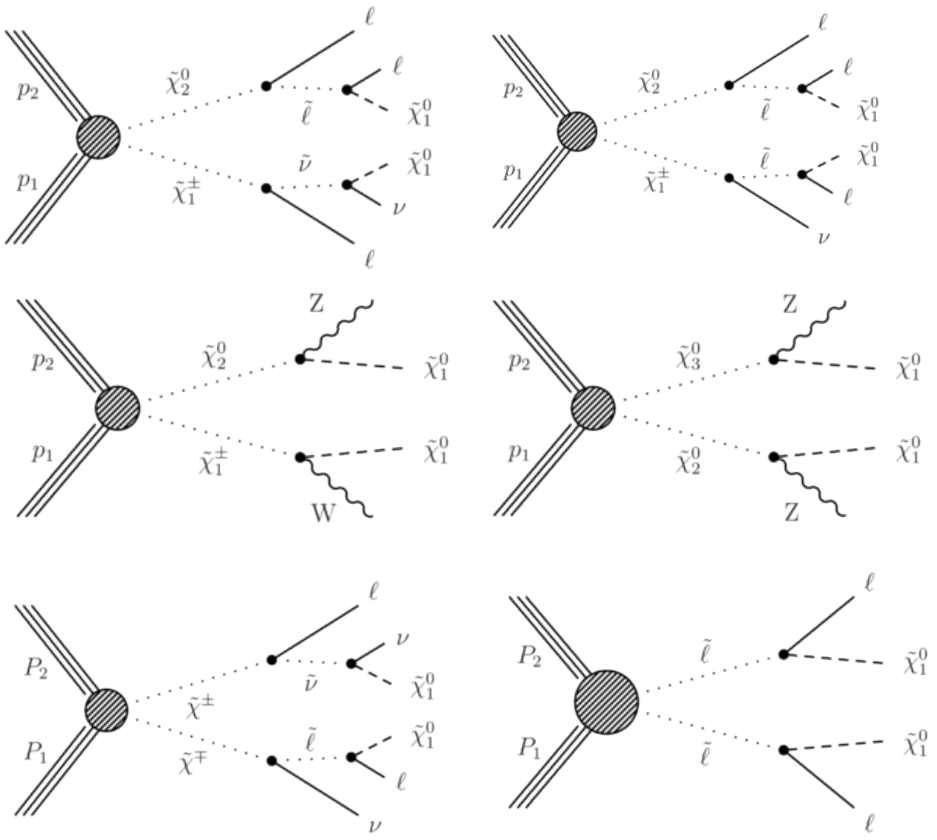


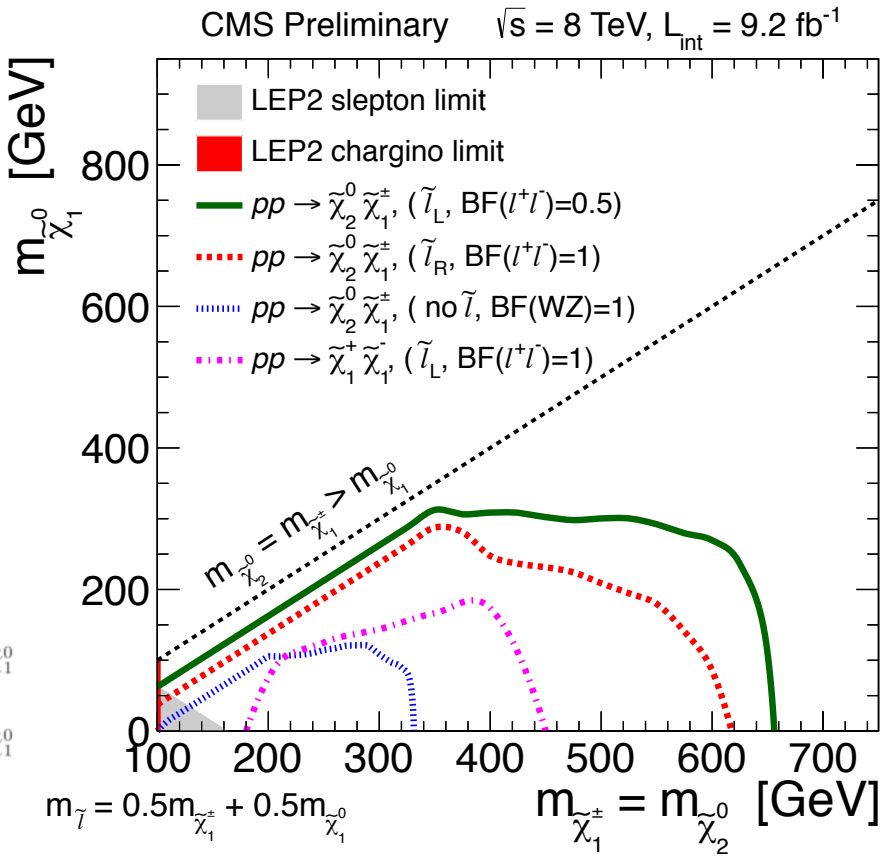


CMS-PAS-SUS-12-023

SUSY Electroweak Production

- charginos, neutralinos and sleptons in leptonic final states:
  - 2,3,4 leptons +MET
  - 2 SS leptons +MET
  - 2 leptons, 2 jets + MET





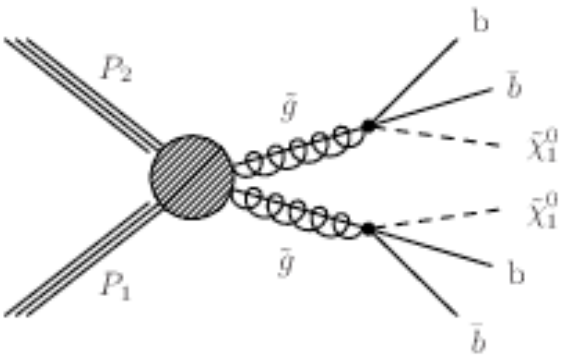
Limits on chargino, neutralino and slepton masses &
Limits on production cross sections ~01.-0.01 pb

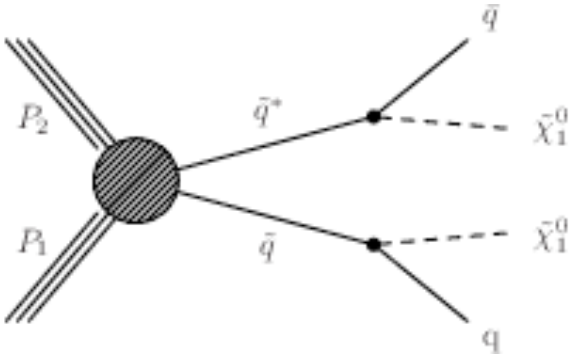
CMS-PAS-SUS-12-022

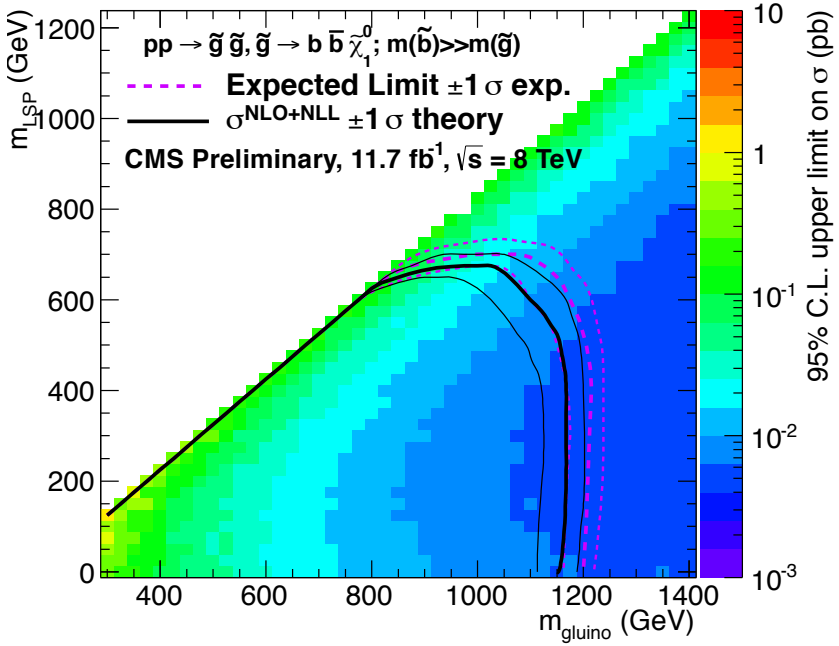
Searches in MET+0 to ≥4 b-jets

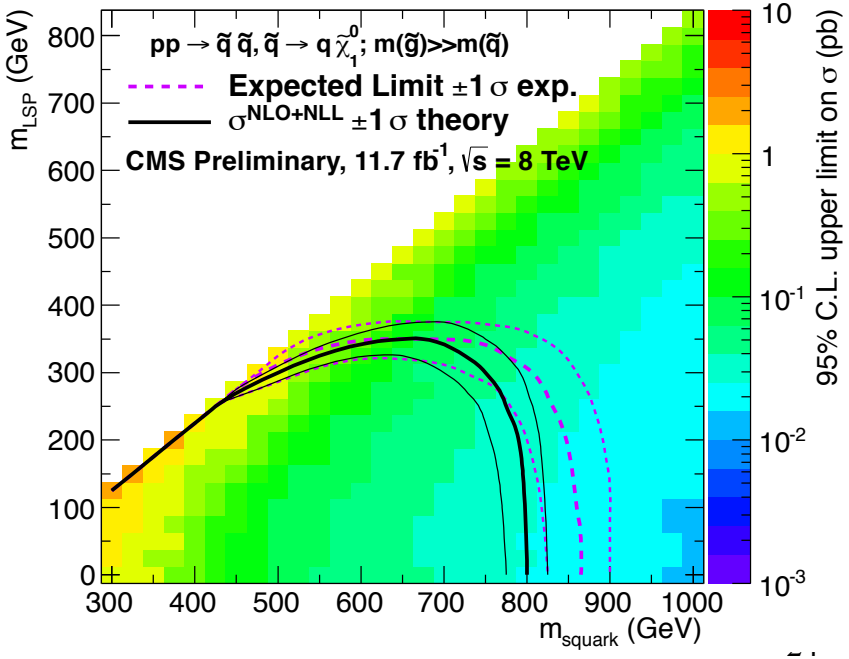
- Signal regions optimized in bins of N_{jet}, N_{bjet} and H_T
  - improving sensitivity to a wide range of strongly-produced SUSY

CMS-PAS-SUS-12-028





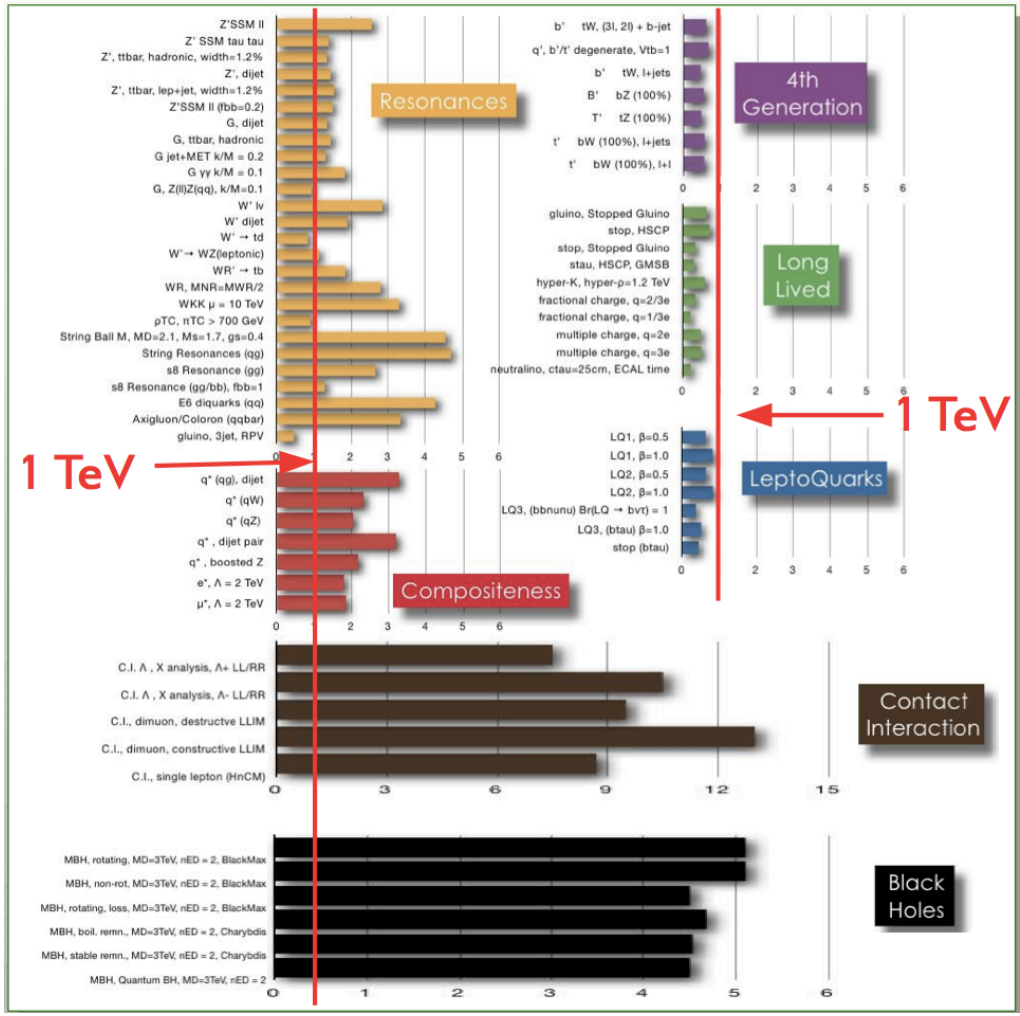




SUSY Alternatives

- SUSY is not the only natural solution to the hierarchy problem
  - Extra dimensions
    - Large volume (ADD)
    - Compact ED, curvature (RS)
    - Kaluza-Klein gravitons
    - Black Holes
  - Hidden Sectors
  - New forces (Z', W')

Studied at CMS within the EXOtica group and B2G groups (exotica searches with top quarks in the final state).



EXOTICA Summary

Microscopic Black Holes

- Focus on black hole production in a model with n large, flat, extra spatial dimensions (ADD model)
  - Search for the presence of multiple energetic jets, leptons, and photons in events with large total transverse energy S_T.
  - Uses 4fb^{-1} of 8TeV data & variety of models.

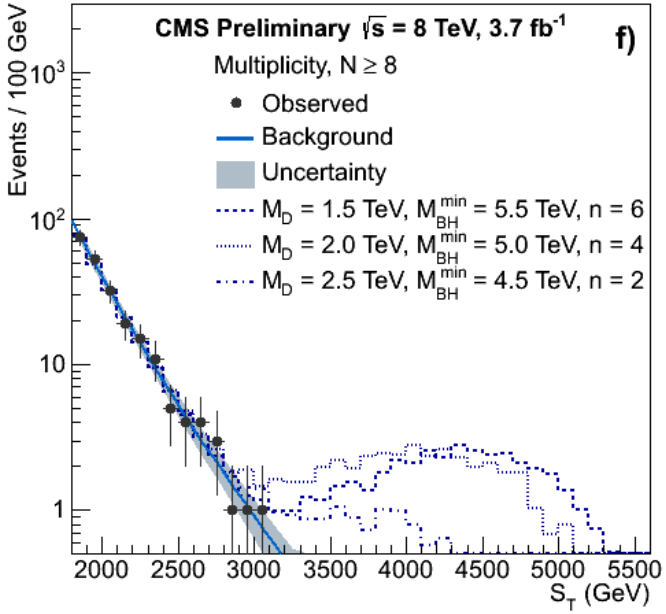
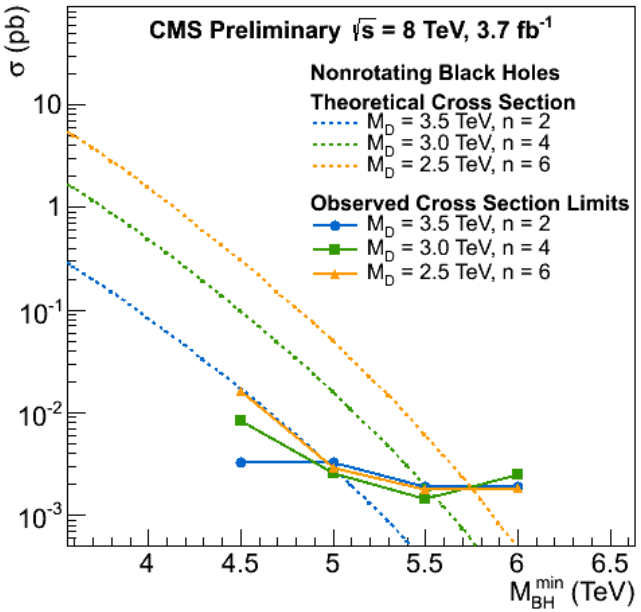


Table 1: Signal Monte Carlo samples and generators used in the analysis.

Sample description	BLACKMAX	CHARYBDIS
Non-rotating BH	YES	YES
Rotating BH	YES	YES
Rotating BH with M/J loss	YES (10 % loss)	YES (18-30 % loss)
Rotating BH, low multiplicity regime	NO	YES
Boiling remnant	NO	YES
Stable remnant	NO	YES

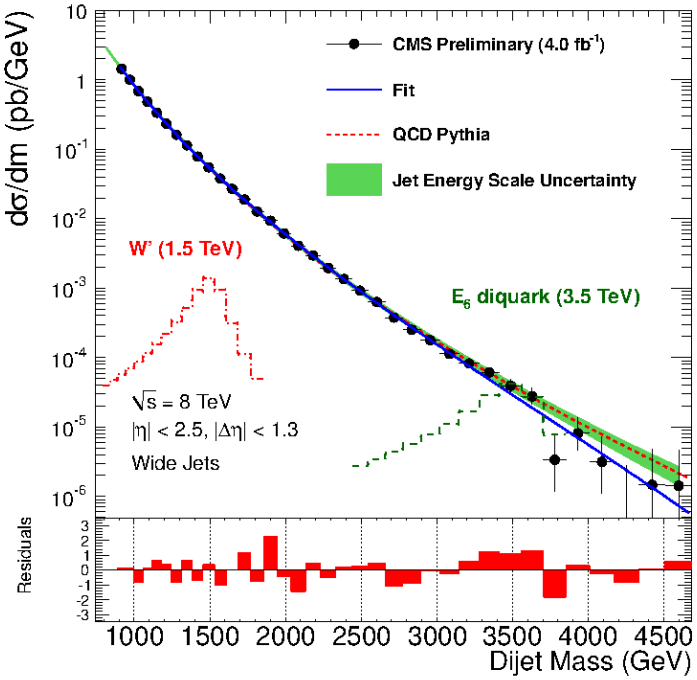


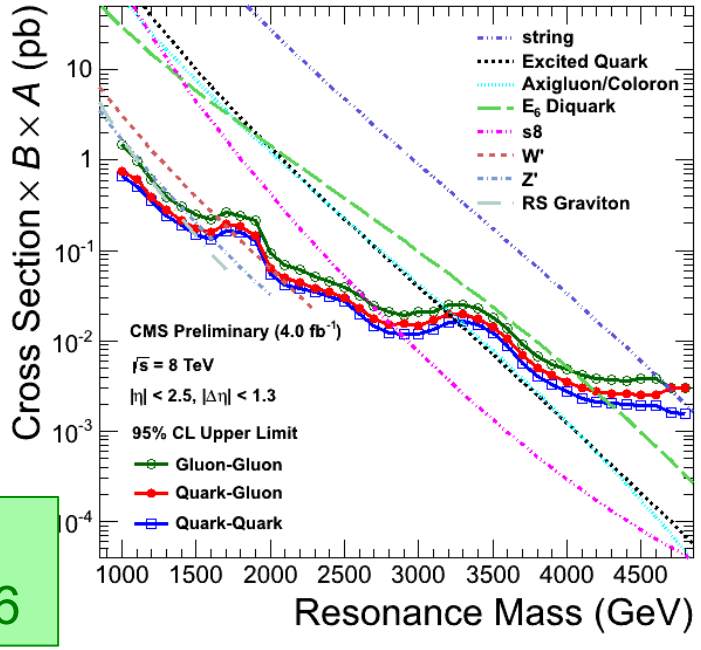
CMS-PAS-EXO-12-009

Set stringent model-independent limits on BSM production in high-multiplicity energetic final states, along with model-specific limits on semiclassical black hole masses in the 4.1 – 6.1TeV range for a variety of model parameters.

DiJet Resonances

- Set generic limits on the production of resonances with two spatially- separated jets over non-resonant QCD background
  - Uses 4fb^{-1} of 8 TeV data
- Compare limits with theoretical predictions for various models:
  - String resonances,
  - Scalar di-quarks
  - Exited quarks
  - Axial-vector particles (axigluons)
  - Colorons, s8 resonances
  - New gauge bosons (W', Z'), and RS gravitons



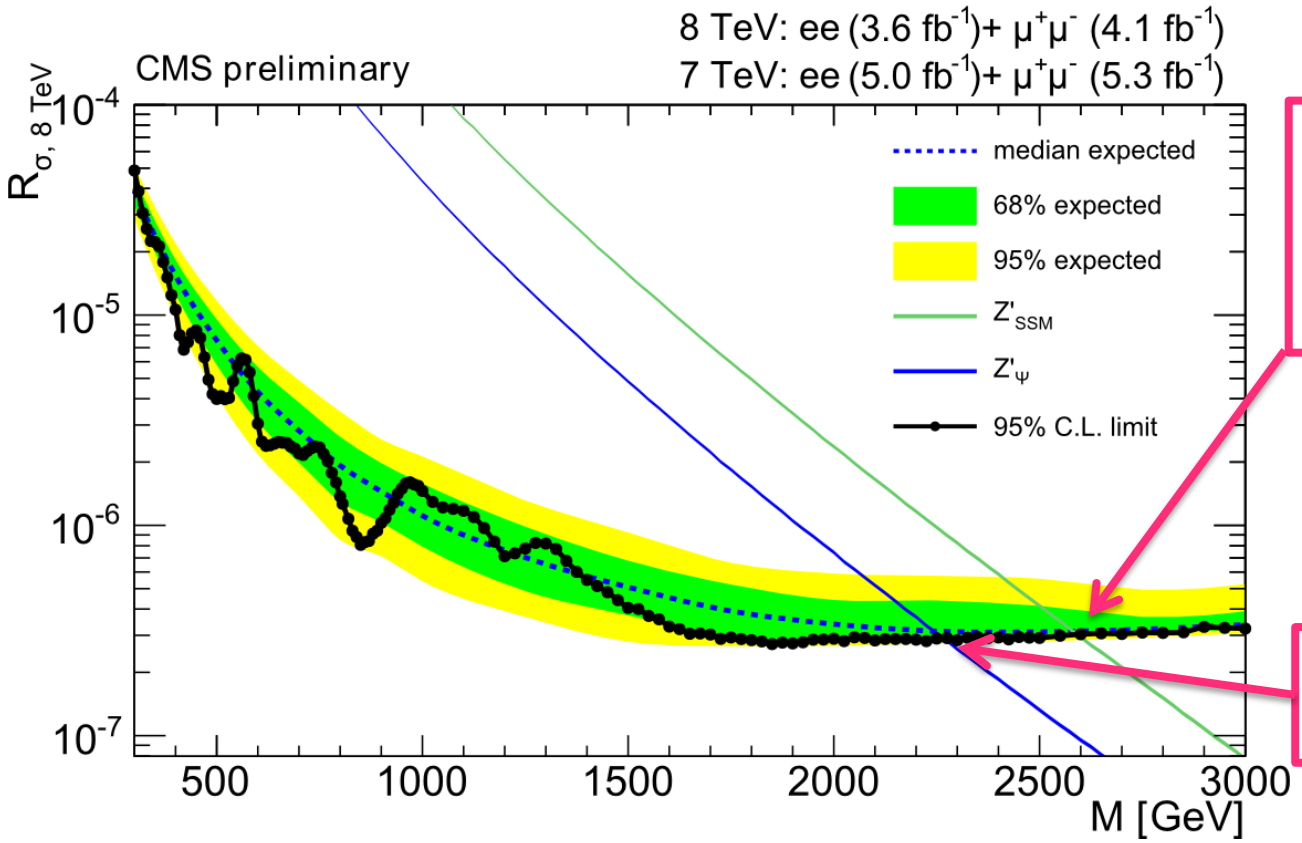


Data agrees with SM prediction. Set lower limits on the mass of specific resonances in the 1 to 4.7 TeV range.

CMS-PAS-EXO-12-016

DiLepton Resonances

- Search for narrow high-mass resonances to $\mu^+\mu^-$ or e^+e^-.
  - Uses $4fb^{-1}$ of 8TeV & 7TeV data.
- Upper limits are interpreted in the context of two Z' models
  - Most stringent to-date.

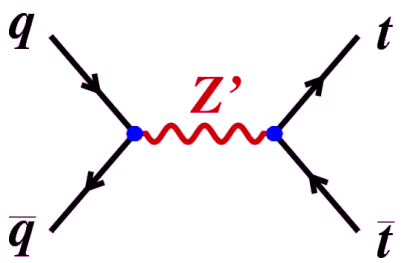


Sequential Standard Model with SM-like couplings
$m_{\ell\ell} > 2590$ GeV

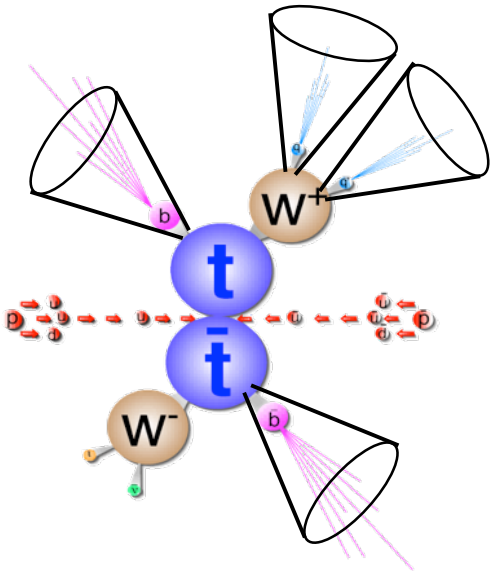
CMS-PAS-EXO-12-015

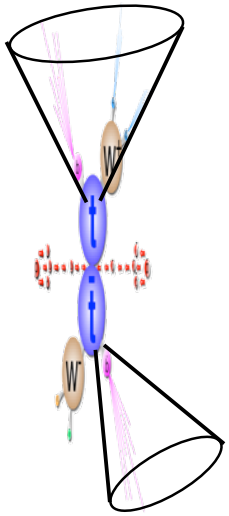
Superstring-inspired Z'_{ψ}.
$m_{\ell\ell} > 2260$ GeV

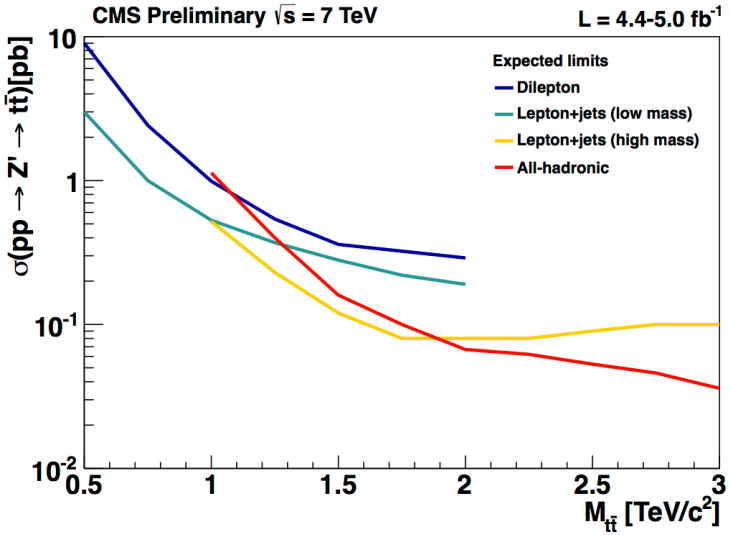
Top Quark Pair Resonances

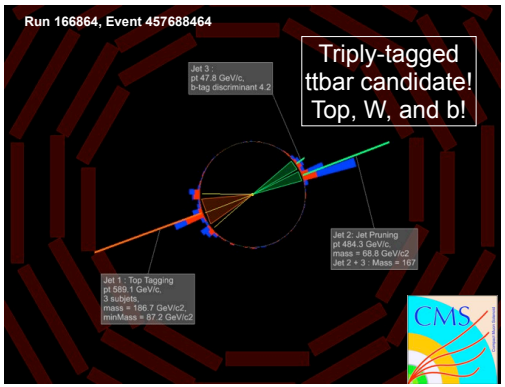


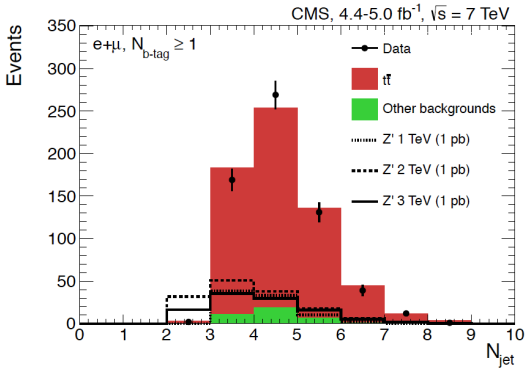
- Studied in the all hadronic, ℓ+jets and dilepton channels.

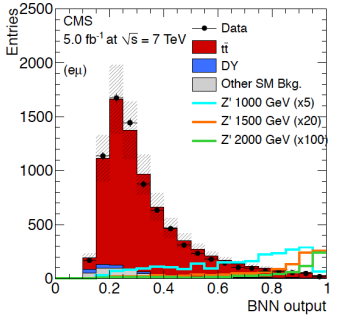










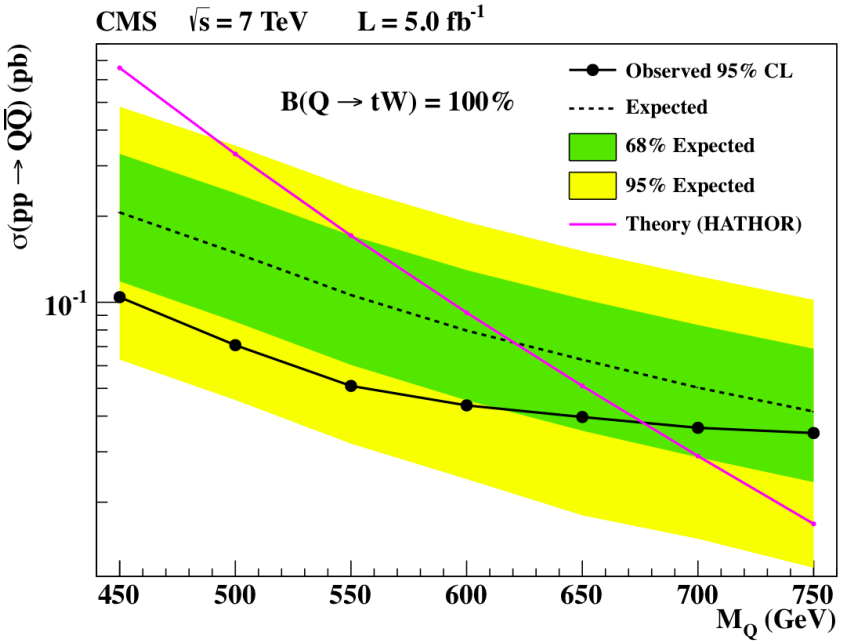


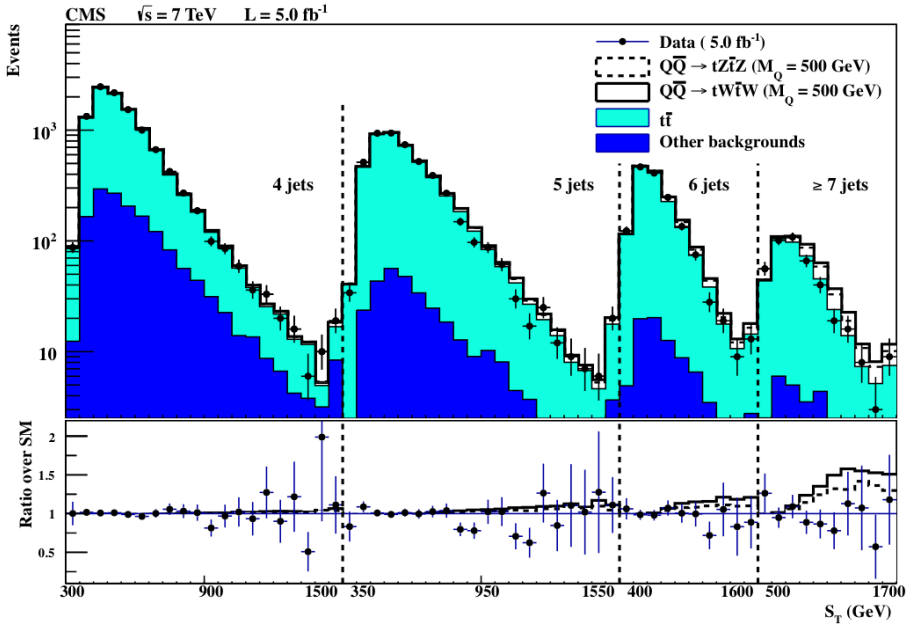
Data agrees with SM prediction in all channels. Set limits on mass in the 2-3TeV range.

JHEP09(2012)029
arXiv:1209.4397
arXiv:1211.3338

Pair Production of Heavy Quarks

- Search motivated by sequential fourth generation model
  - Concentrate on new Q quark cases d-type → tW or u-type → tZ
  - Select events containing an isolated electron or muon, missing E_T, and 4 jets, of which one is a b-jet.





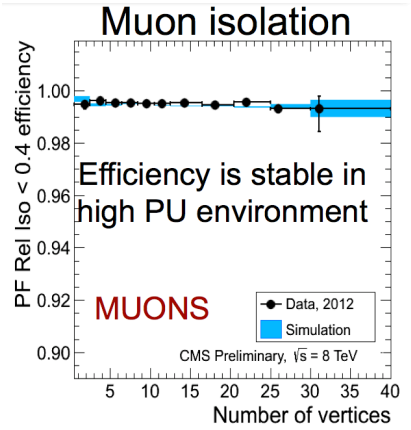
Search is performed by fitting the data to the distribution of S_T as a function of jet multiplicity.

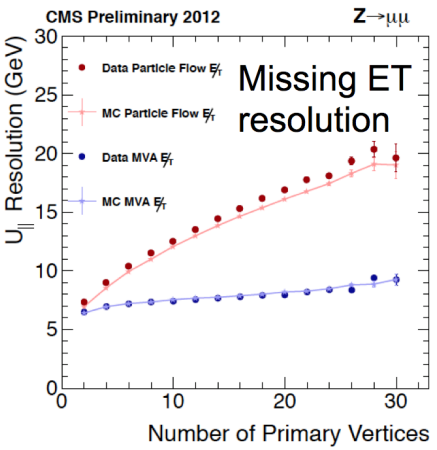
Data agrees with SM prediction. Assuming strong production, exclude quark masses below 675 (625) GeV decaying into tW (tZ).

arXiv:1210.7471

Summary and Short Term Plans

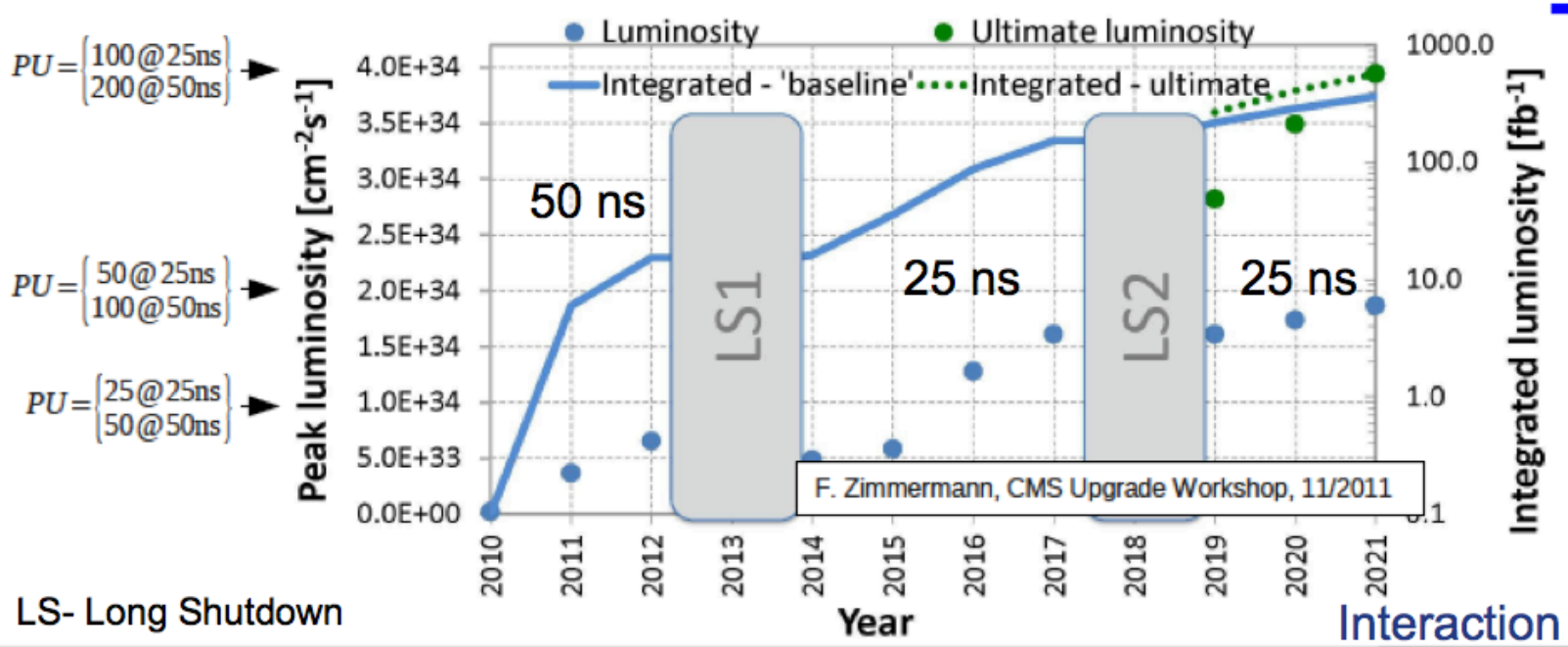
- Following the discovery of a Higgs-like particle the focus is shifting from search to measurements of the properties.
  - Measure the spin parity of the particle
  - Probe the fermionic couplings: H(ττ), VH(bb), ttH
- We have not observed any BSM physics yet
  - Searches are focusing on finding or excluding SUSY and non-SUSY natural models.
- We continue looking for deviations to the SM with our high-precision measurements program
  - Exceeded design performance, demonstrating that precision physics can be done at high luminosity and pileup.
  - Will continue after data-taking ends and also benefit from parked data.





LHC machine Projections

LHC | Energy increase 8 TeV to 13/14 TeV | Injection upgrade | **HL-LHC**



LS- Long Shutdown

Luminosity-leveled at 5×10^{34} cm^{-2}s^{-1} in HL-LHC

Interaction region upgrade

8×10^{33} Hz/cm^2
30 fb^{-1}

LS1

2×10^{34} Hz/cm^2
300 fb^{-1}

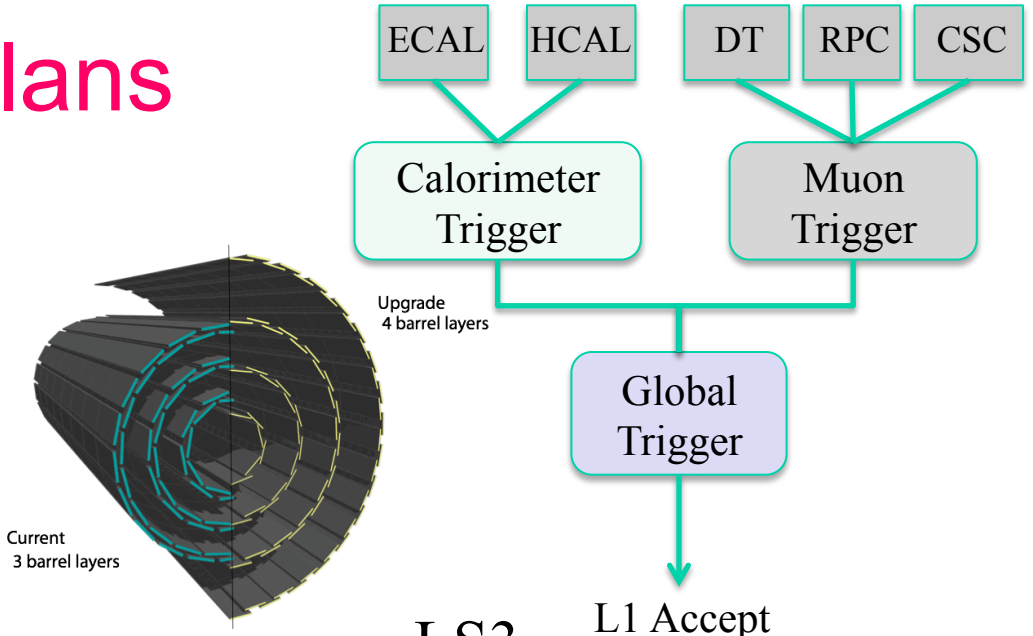
LS3

10^{35} Hz/cm^2
3000 fb^{-1}

Phase 1 Upgrade

Phase 2 Upgrade

CMS Upgrade Plans



LS1 Projects (in production)

- Completion of muon coverage & improved muon operation
- Replace HCAL photo-detectors

LS1 LS2 LS3

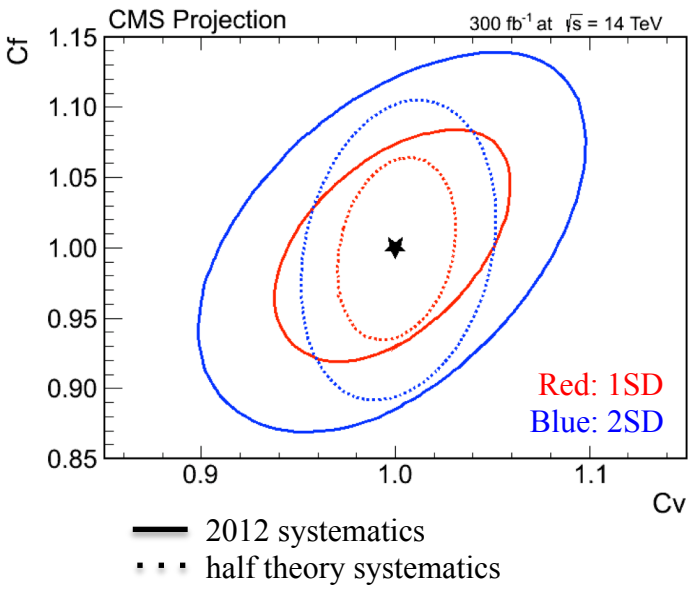
Phase 1 Upgrades (TDRs)

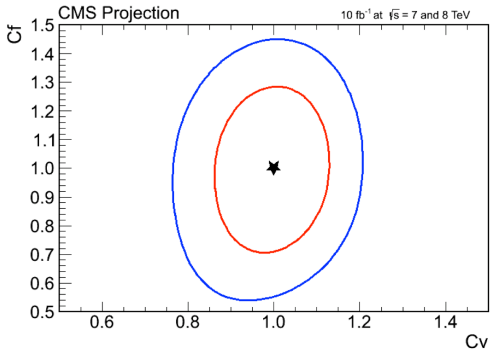
- Pixel detector replacement
- HCAL electronics upgrade
  - Both received CD0 from DOE
  - Preparatory work during LS1
- L1-Trigger upgrade

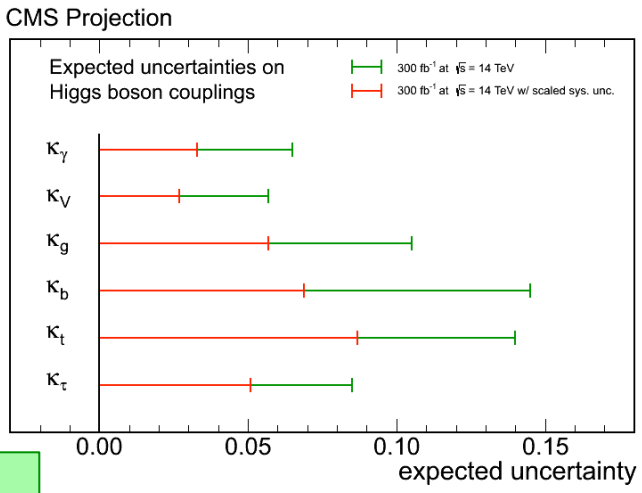
Phase 2: scope to be defined

- Tracker Replacement
- Track Trigger
- ForwardRegion: Calorimetry and Muons and tracking
- Further Trigger upgrade

Physics Reach Projections



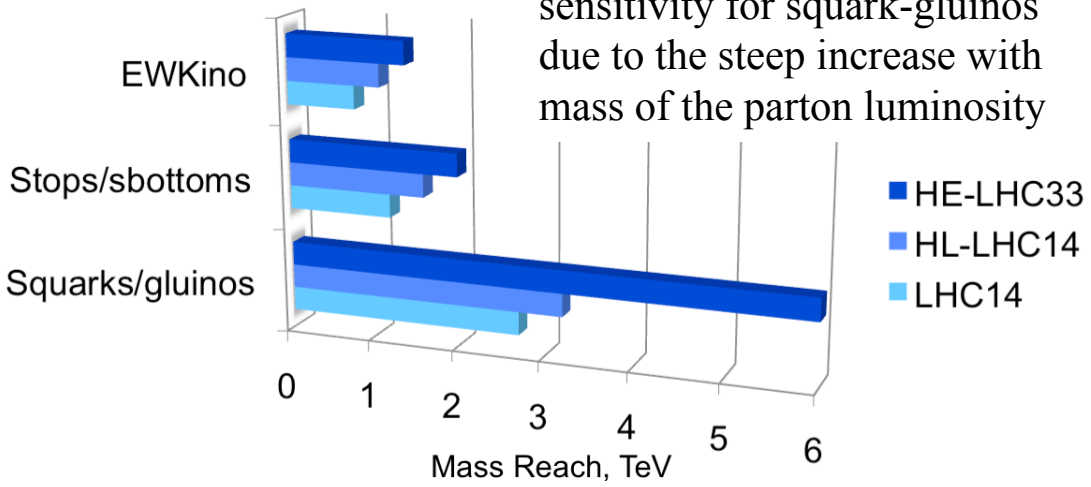




CERN-CMS-NOTE-2012-006

coupling	LHC	HL-LHC	HE-LHC
g_1^Z	0.0030	0.0019	0.0013
λ_γ	0.0009	0.0004	0.0004
λ_Z	0.0023	0.0014	0.0014
κ_γ	0.026	0.016	0.019
κ_Z	0.037	0.031	0.022

Predicted 95% confidence level constraints on anomalous triple-gauge couplings.



More pronounced increase of sensitivity for squark-gluinos due to the steep increase with mass of the parton luminosity

Conclusions

- CMS physics output has exceeded all expectations
  - Observed ~126GeV boson consistent with SM Higgs Boson
  - No evidence for new physics
- Physics Goals goals
  - Characterization of the Higgs-like boson by precision measurements of its mass and tree-level couplings to fermions, W and Z bosons, as well as self-coupling. Is it the SM Higgs?
  - Continue SUSY searches. Is SUSY responsible for EWSB?
  - Extend search for massive resonances predicted in various BSM models.
  - Precision EW measurements in the top and multi-gauge boson sectors. Provide constraints on the Higgs boson mass and sensitivity to BSM effects.
  - Precise determination of the parton distribution functions, particularly at very small and large x.