Highlights from recent CMS results

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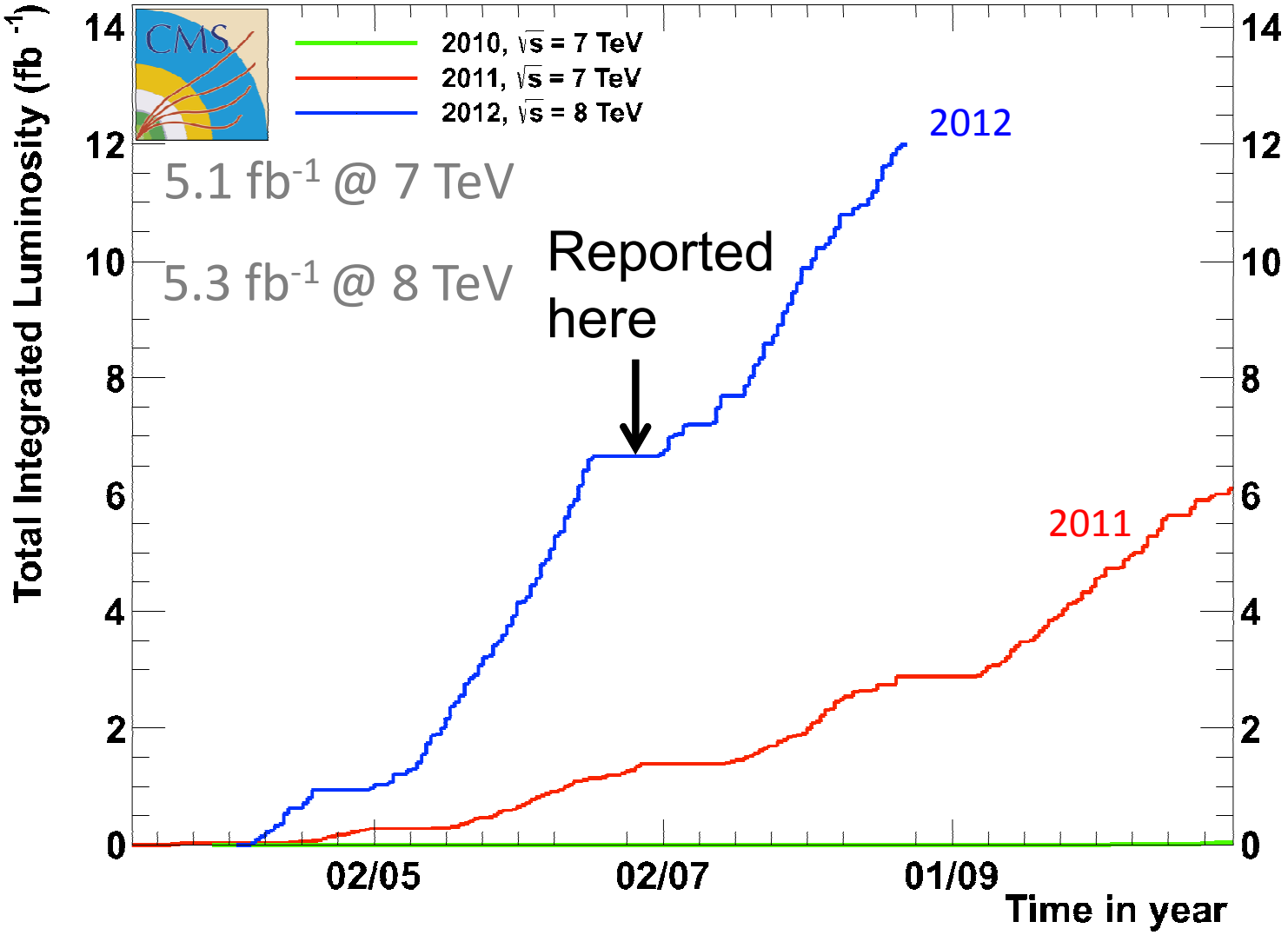
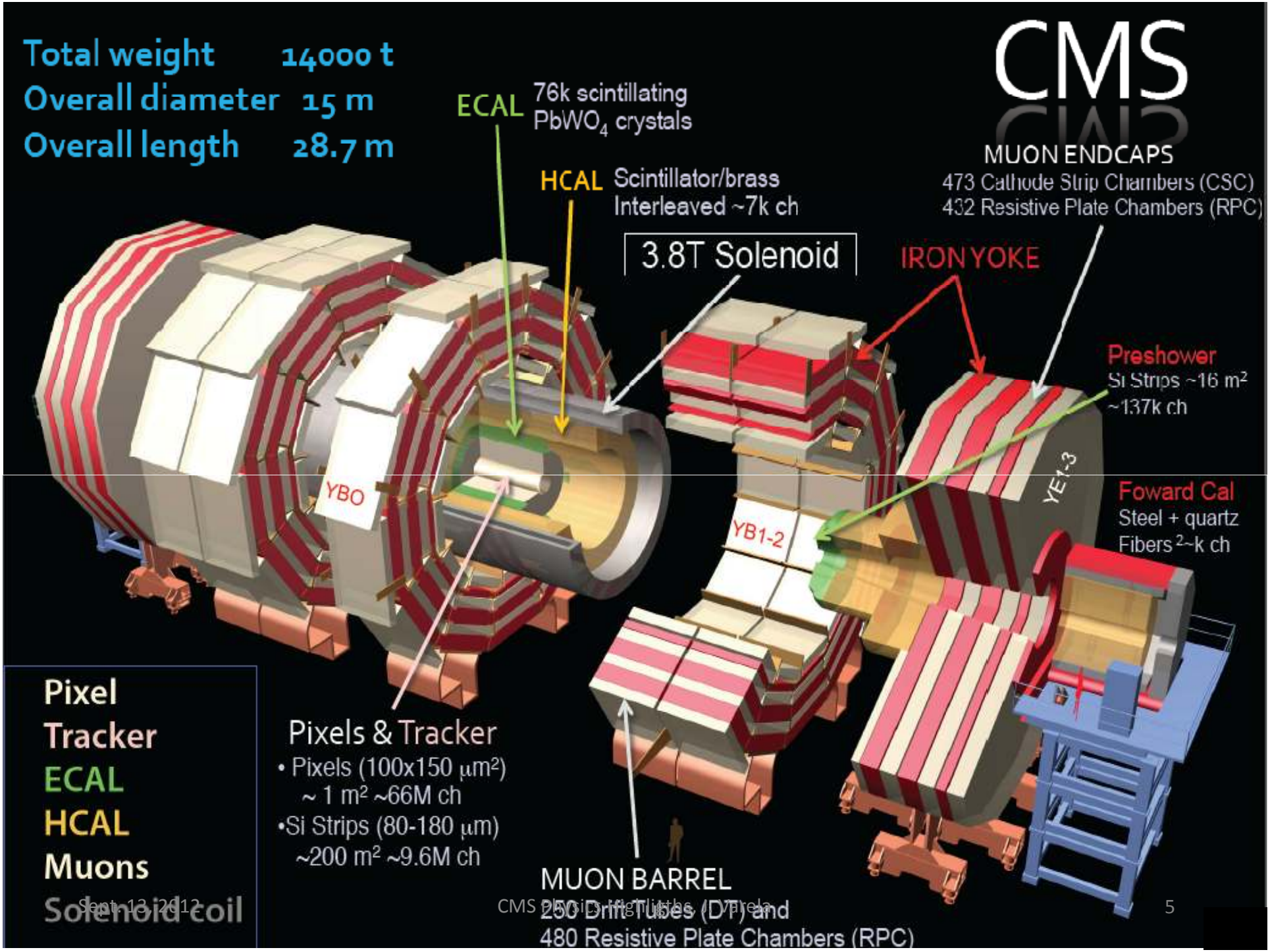
Outline

- Jets, W&Z, top
- Higgs
- SUSY
- Other searches
- Prospects

On behalf of the CMS Collaboration

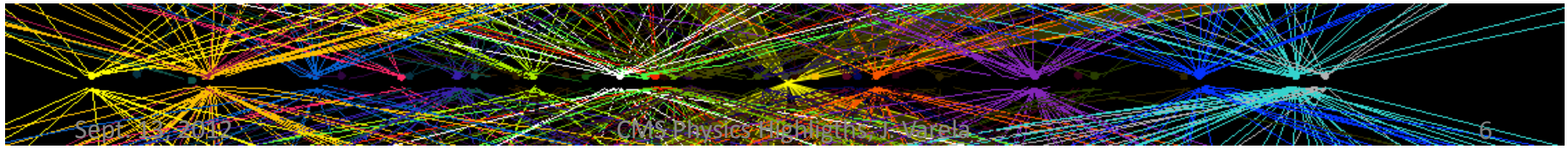
CMS total integrated luminosity




Total weight 14000 t
Overall diameter 15 m
Overall length 28.7 m
CMS
ECAL 76k scintillating PbWO4 crystals
HCAL Scintillator/brass Interleaved ~7k ch
3.8T Solenoid
IRON YOKE
MUON ENDCAPS
473 Cathode Strip Chambers (CSC)
432 Resistive Plate Chambers (RPC)
Preshower
Si Strips ~16 m2
~137k ch
Foward Cal
Steel + quartz Fibers
~k ch
YBO
YB1-2
YE1-3
Pixel
Tracker
ECAL
HCAL
Muons
Solenoid coil
Pixels & Tracker
• Pixels (100x150 μm2) ~ 1 m2 ~66M ch
•Si Strips (80-180 μm) ~200 m2 ~9.6M ch
MUON BARREL
250 Drift Tubes (DT) and
480 Resistive Plate Chambers (RPC)

Collisions pileup

- Bunch crossing events have ~30 p-p collisions
  - p-p inelastic ~ 70 mb x Inst luminosity 7 Hz/nb = 5E8 collisions/s
  - ~ 1400/3600*4E7= 1.5E7 crossings/s
- High multiplicity
  - ~1-2 thousand low energy charged particles per crossing
  - ~1-2 thousand low energy photons per crossing
- Challenge to reconstruction of hard collisions
  - jets and missing ET reconstruction
  - lepton isolation
- Assignment of particles to primary vertex:
  - particle flow reconstruction
  - neutral energy: event-by-event energy subtraction

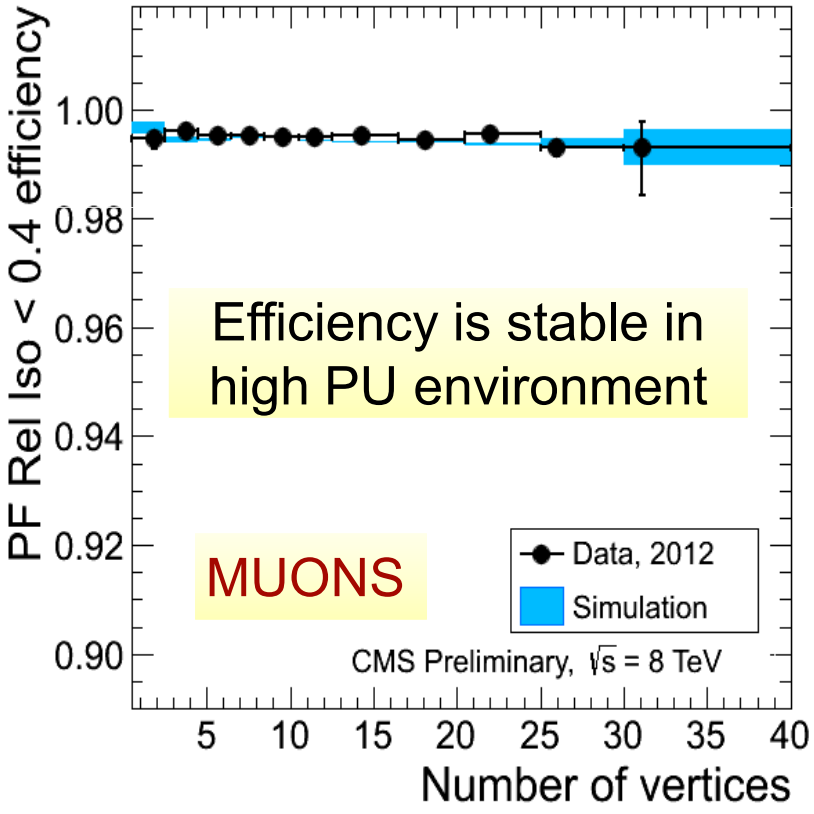


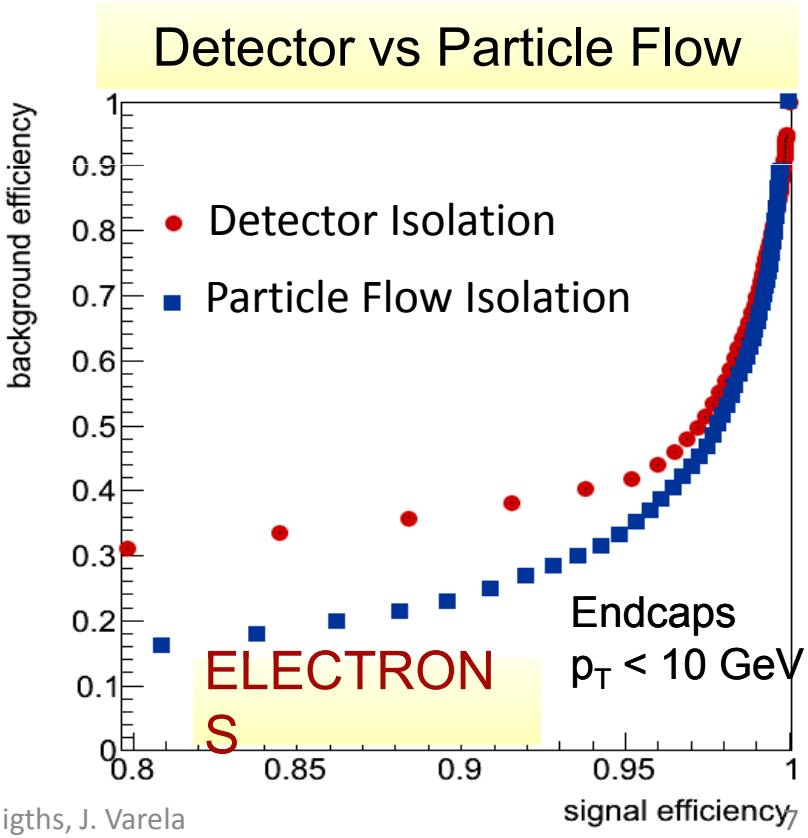
Particle-based isolation

Sum energy of particles in ΔR cone around the lepton

Pile-up contribution:

- Negligible for charged hadrons (vertexing)
- Neutrals corrected w/global energy density (ρ)

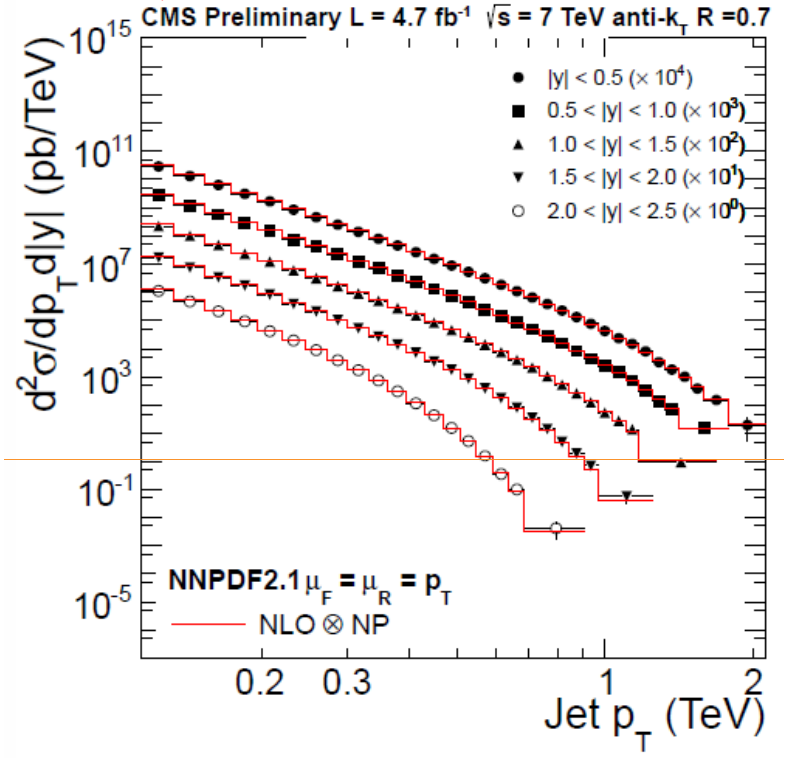




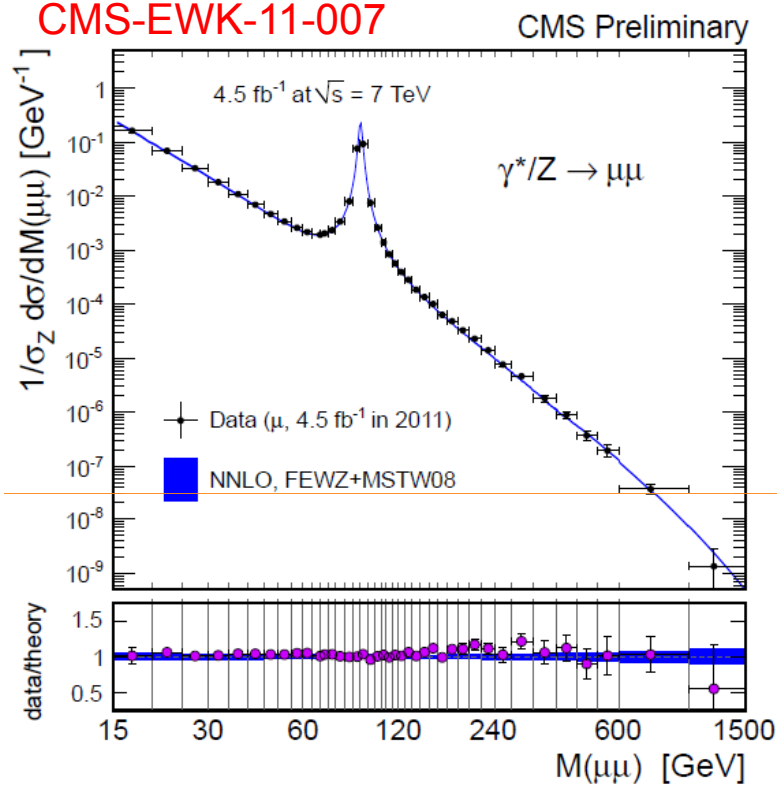
2011-12 Datasets: Standard Model

Standard model: Jets, γ^*/Z

CMS-QCD-11-004



CMS-EWK-11-007



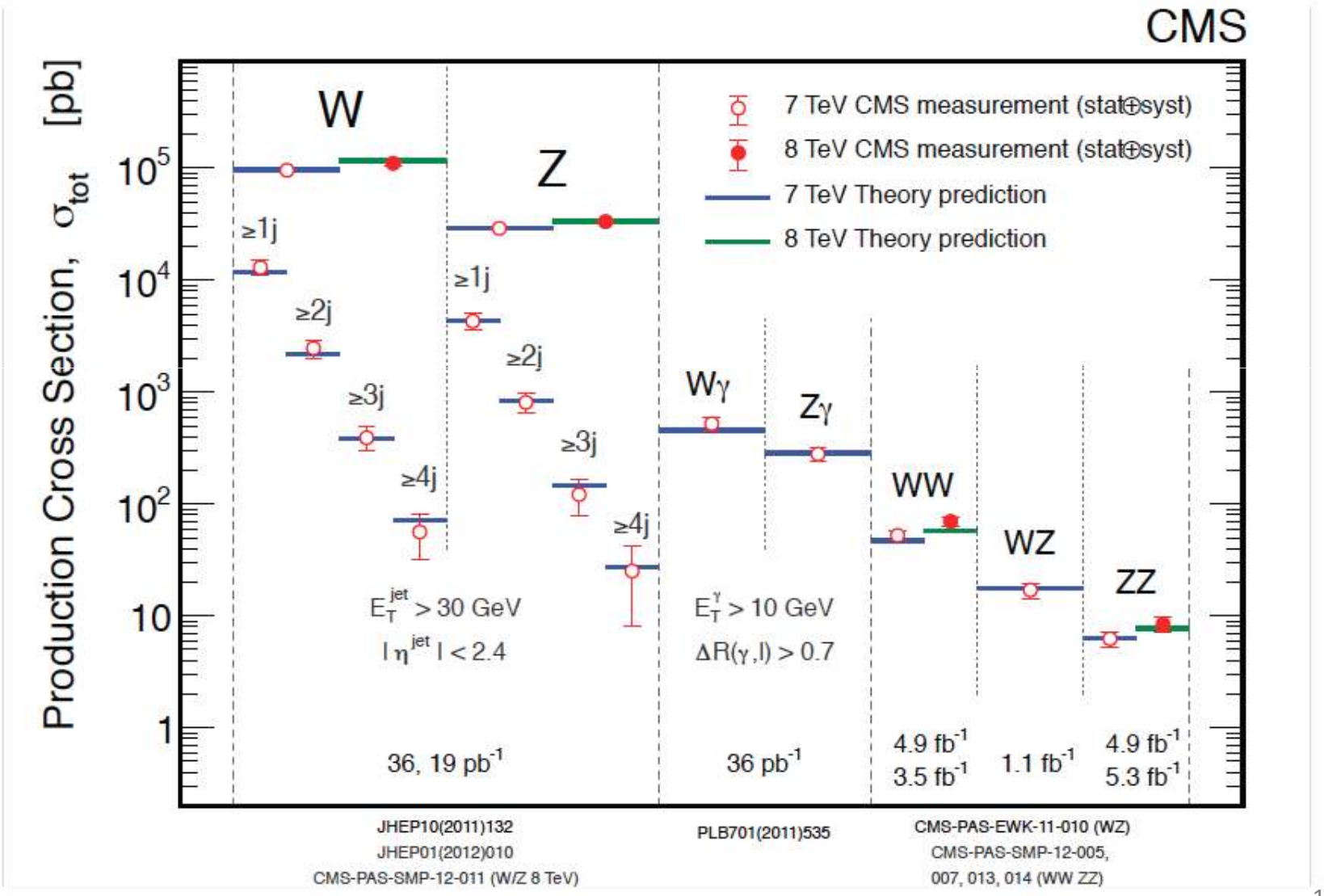
Inclusive jet and dijets:

- NLO QCD describes data over ~9 orders of magnitude!
- 1-2% JES.
- Constrains gluon PDF up to x=0.6

Differential Drell-Yan cross section:

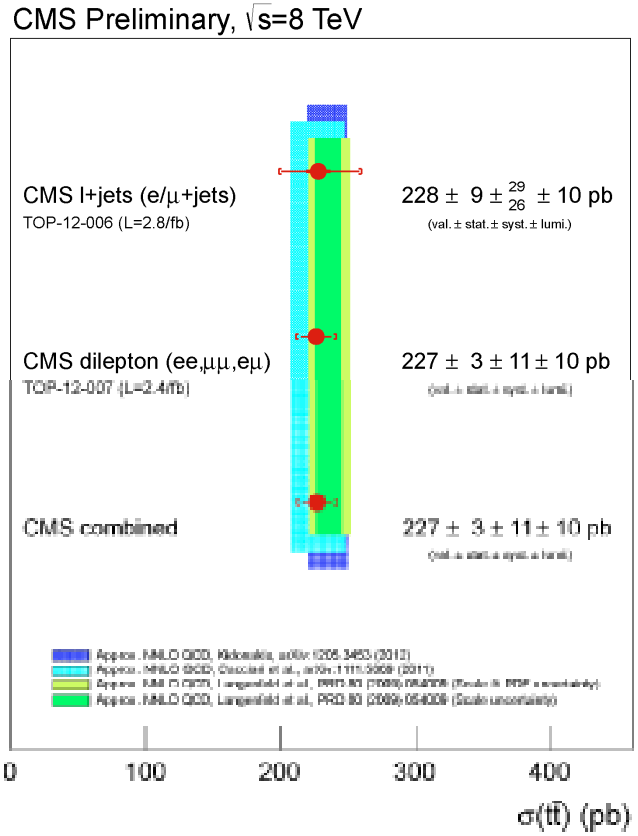
- 2.5M μμ pairs tests NNLO cross sections and PDFs

Standard model: W, Z, dibosons



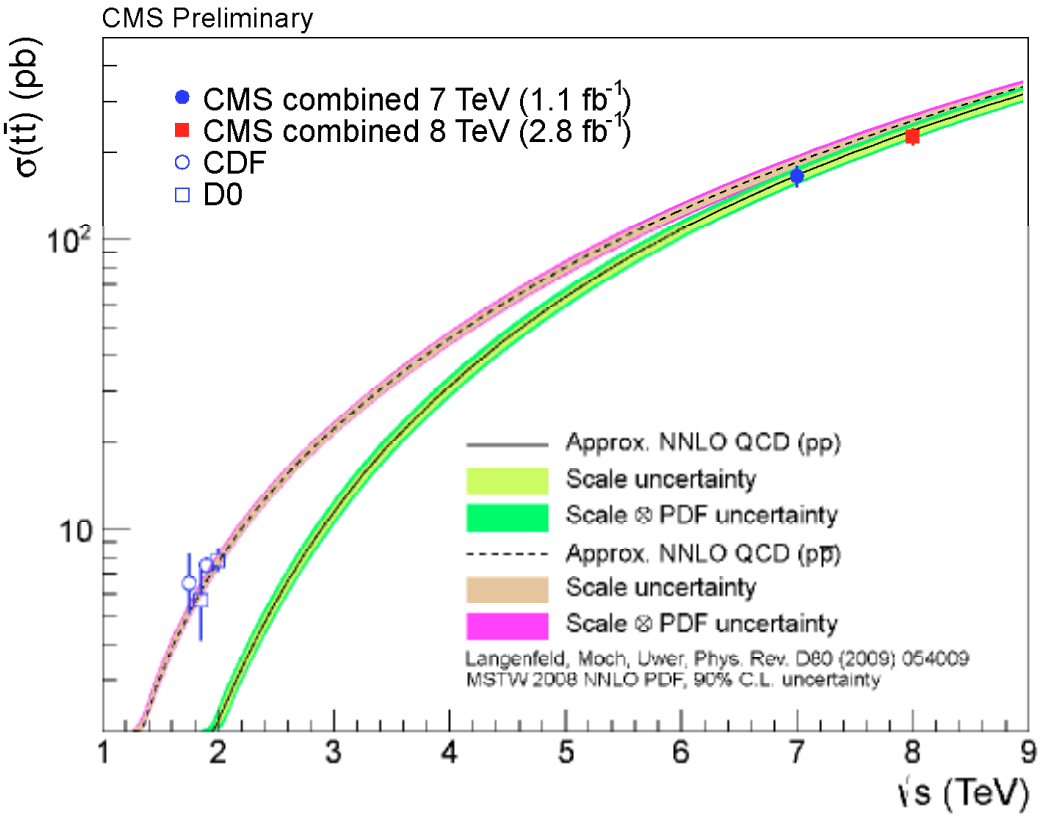
Top pair production at 8 TeV

CMS-TOP-12-006/7



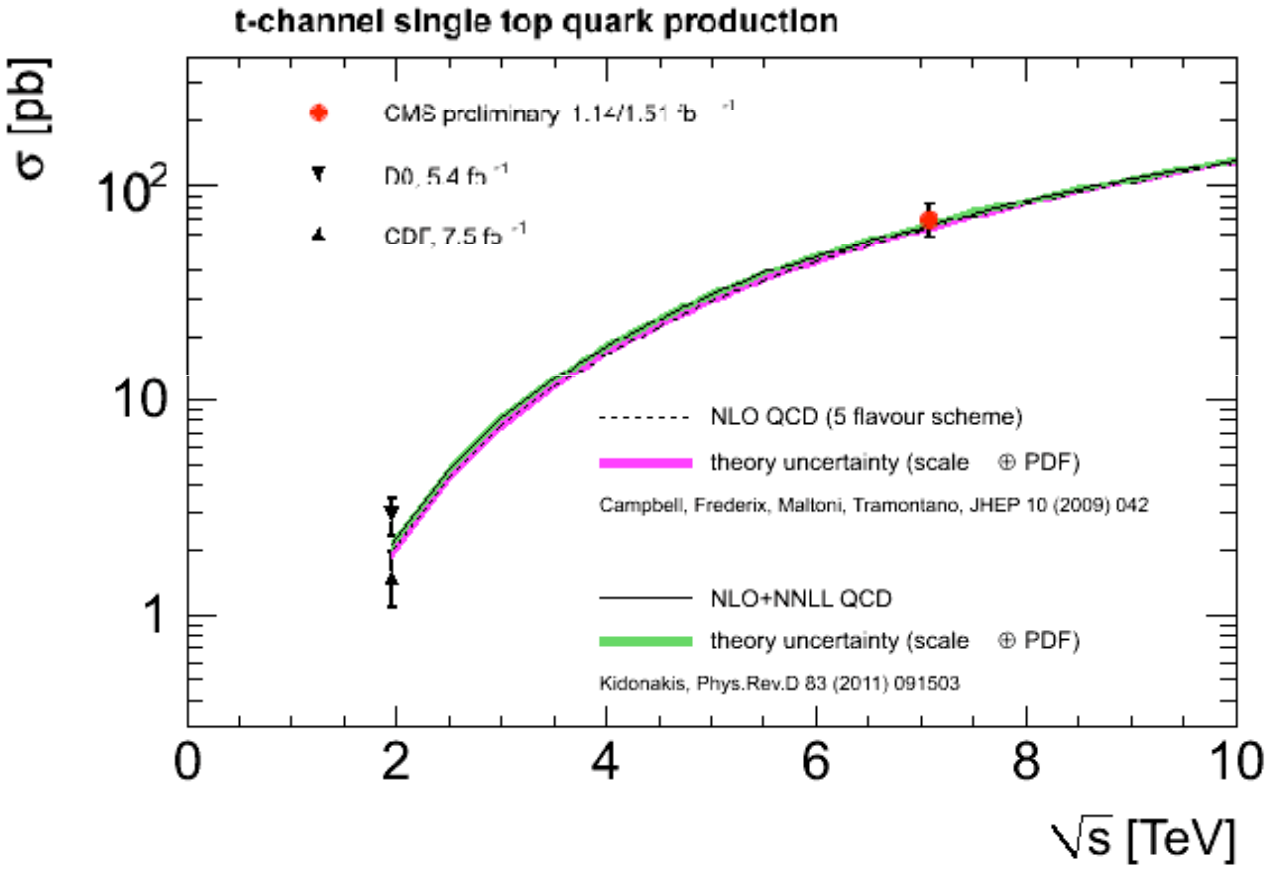
σ = 227 ± 3 (stat) ± 11 (syst.) ± 10 (lum.) pb

σ(8TeV)/σ(7TeV) = 1.41 ± 0.11; no correlation assumed

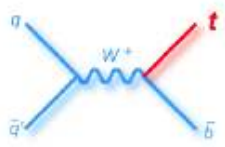


Single top production

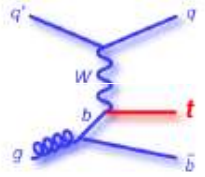
CMS-TOP-11-021



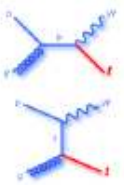
s-channel



t-channel



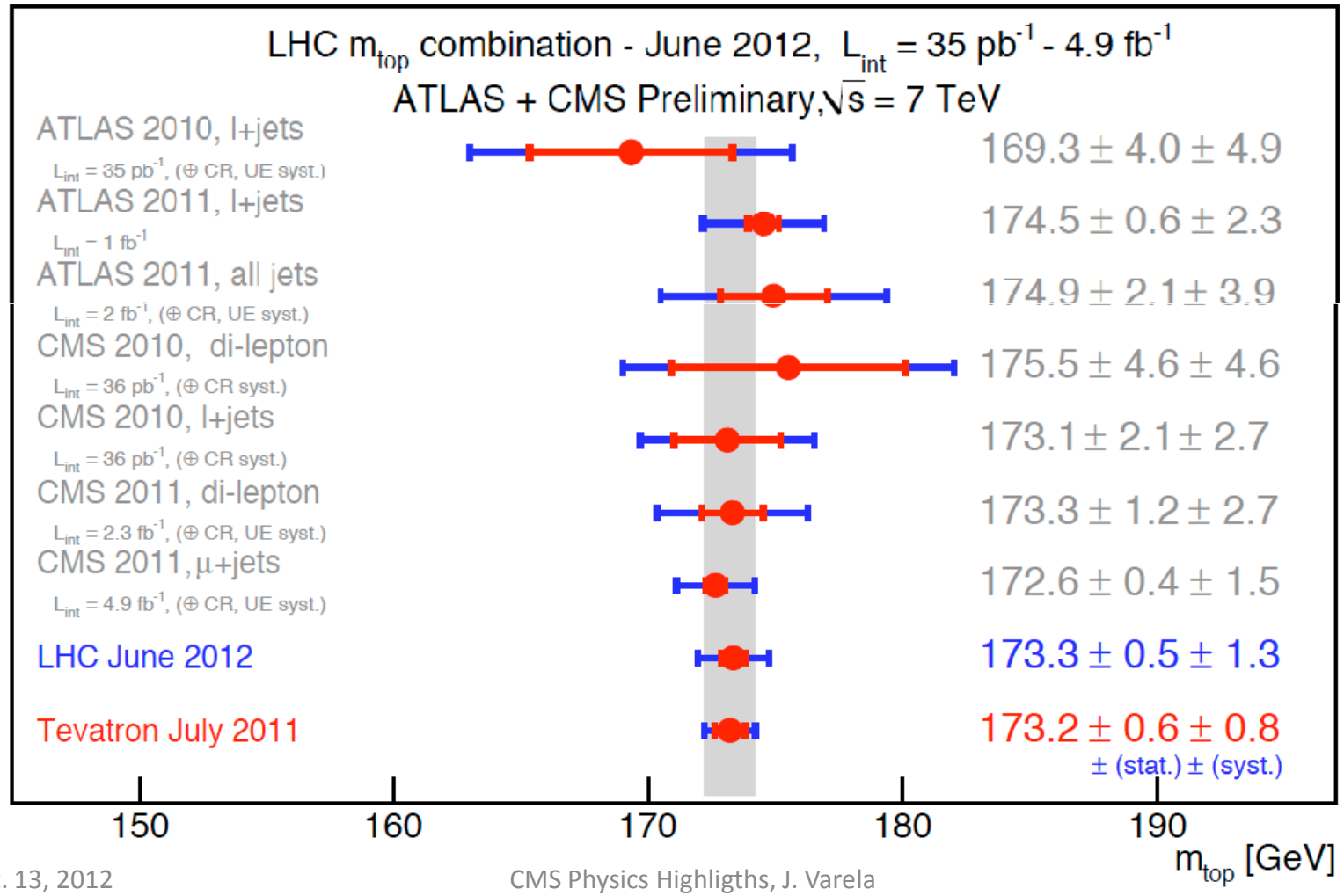
Wt-channel



CMS: s = 70.2 ± 5.2 (stat.) ± 10.4(syst.) ± 3.4(lumi.) pb

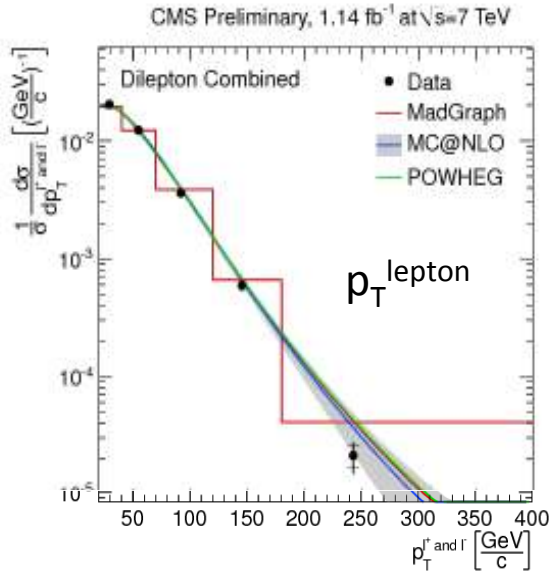
Top quark mass: LHC combination

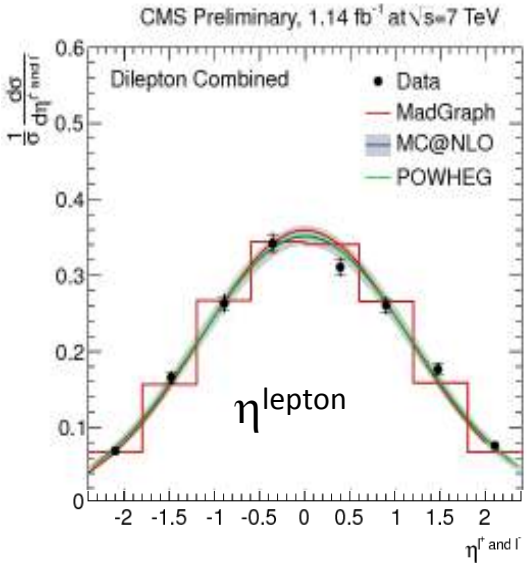
m_{top} = 173.3 ± 0.5 (stat) ± 1.3 (syst) GeV

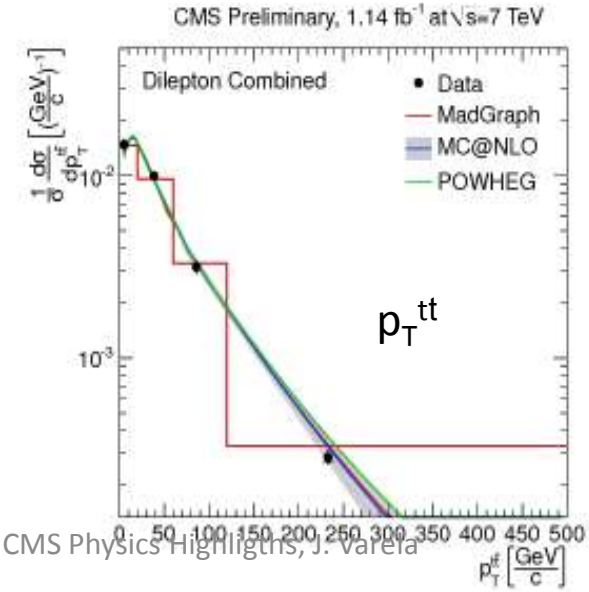


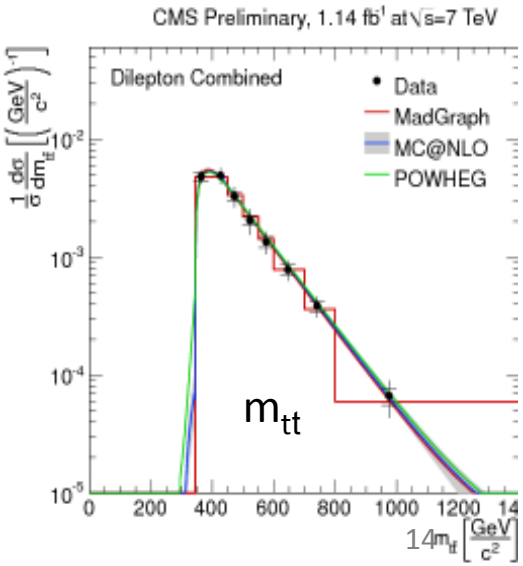
Differential cross section in top pairs

- Test SM predictions in differential distributions
  - Constrain MC predictions
  - Sensitivity to new physics
- New in 2012
  - Unfold detector effects
  - MC describes data well
  - Both l+jets and dilepton channels









TOP-11-013

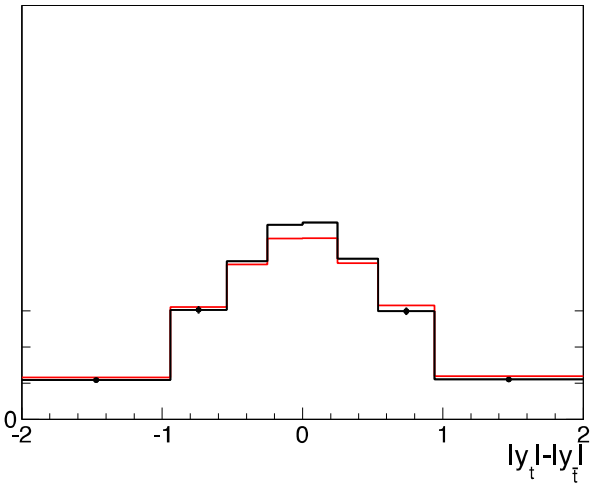
Top Charge Asymmetry

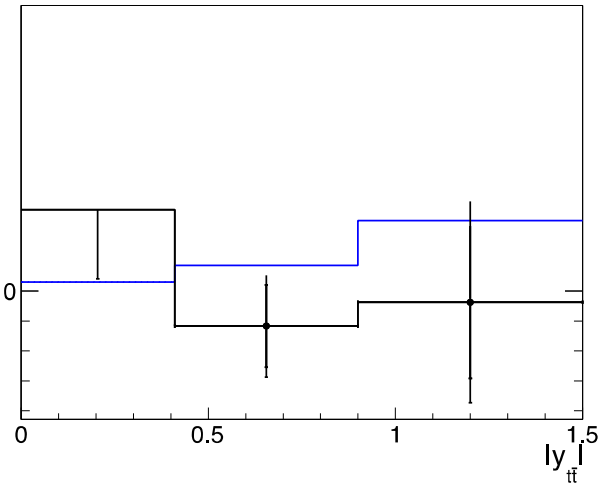
- Differential measurement of top charge asymmetry at the LHC; no evidence for deviations from the SM

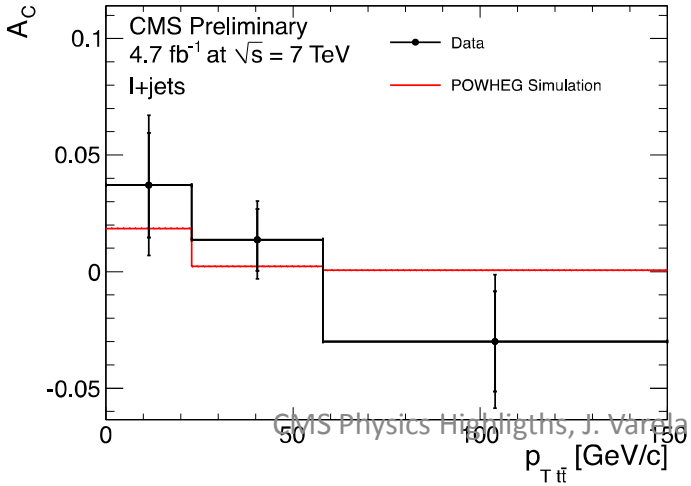
A = 0.004 ± 0.016

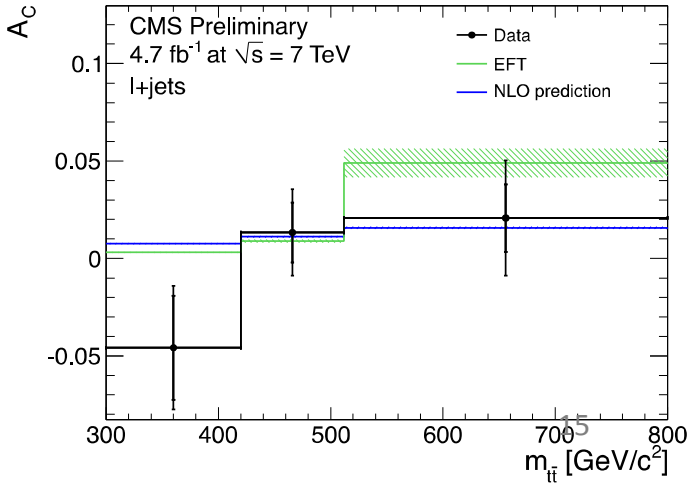
SM: 0.012 ± 0.001

TOP-11-030









Top quark branching fraction

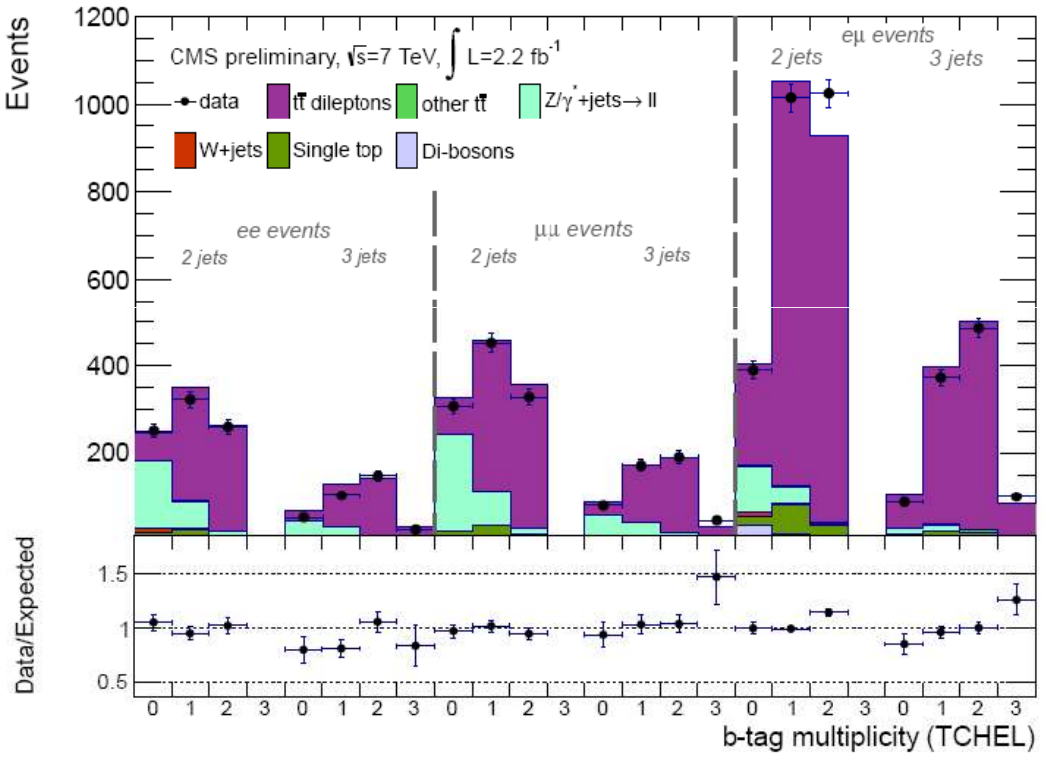
R=B(t→Wb)/B(t→Wq)

- Number of b-tagged jets depend on R and b-tagging efficiency
- Measurement is fully data-driven
  - b-tagging multiplicity is parametrized as function of R, ε_b, ε_q, top contributions
  - fraction of well reconstructed t → Wq is estimated from lepton-jet invariant mass spectrum
- Result

  R=0.98±0.04

  95% CL R>0.85

TOP-11-029

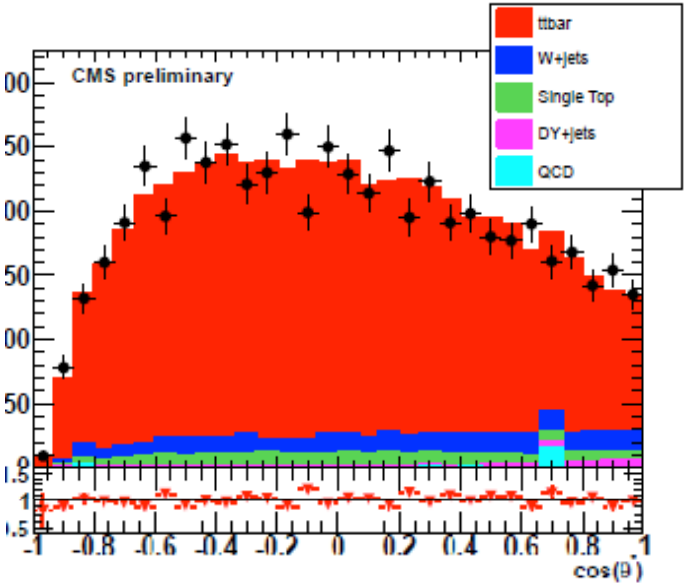


$$P_k = R^2\varepsilon_b^2 + 2R(1-R)\varepsilon_b\varepsilon_q + (1-R)^2\varepsilon_q^2$$

W helicity and constraints on the Wtb vertex

- Measure the W helicity fractions in tt lepton+jets
  - Use the cos(θ*) distribution
    - θ* = angle between the charged lepton in the W rest frame and the W in the top rest frame

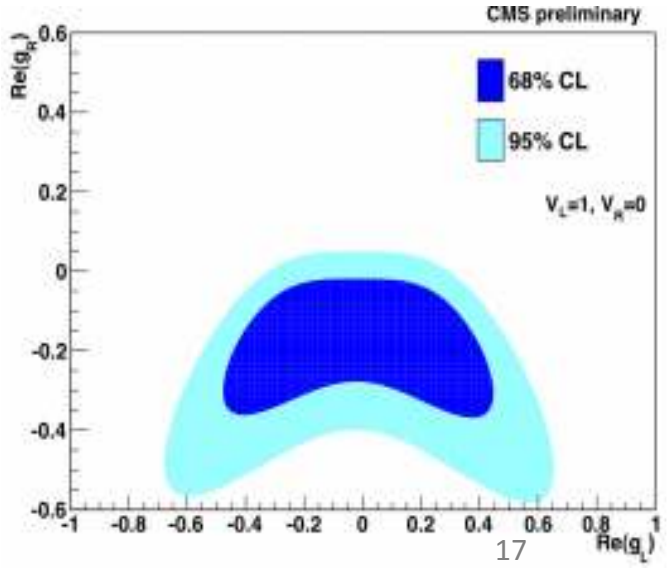
TOP-11-020



$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*} = \frac{3}{8}(1-\cos\theta^*)^2 F_L + \frac{3}{8}(1+\cos\theta^*)^2 F_R + \frac{3}{4}\sin^2\theta^* F_0.$$

  - Sensitive to anomalous couplings in the Wtb vertex

- CMS results
  - Use 2.2fb^{-1} and μ+jets events
  - Set limits on anomalous couplings in the Wtb vertex



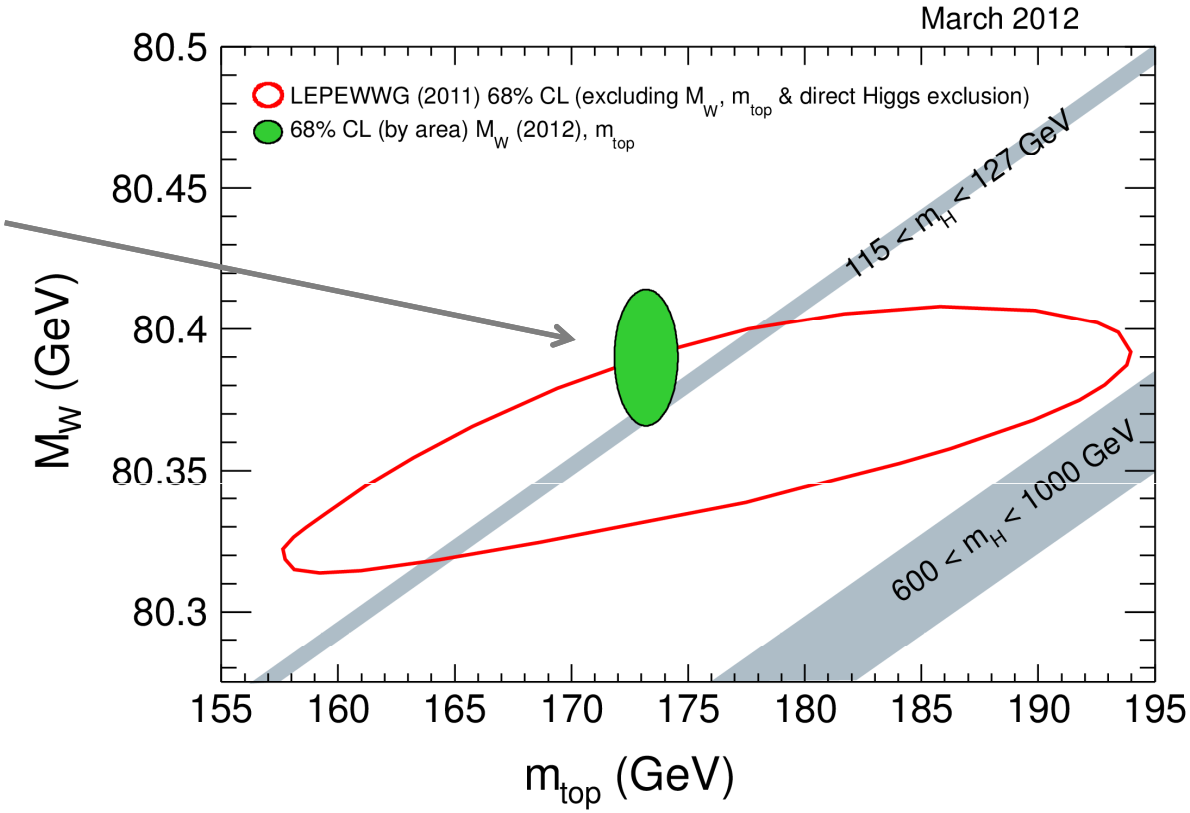
2011-12 Datasets: Higgs

Situation in early 2012

Very precise measurement of M_W = 80.390 ± 0.016 GeV, driven mainly by the Tevatron.

Much of the SM Higgs range had been ruled out by 2011 LHC running.

Excess of events in the low mass region seen in ATLAS and CMS

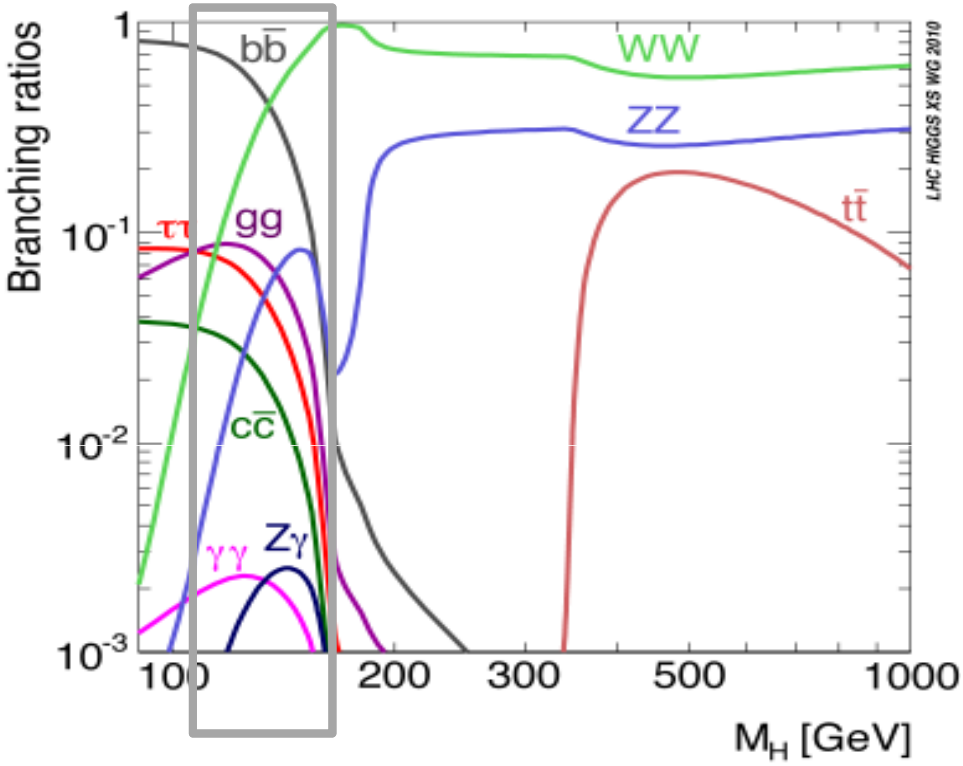


Exclusions of M_H:
- LEP < 114 GeV (arXiv:0602042v1)
- Tevatron [156,177] GeV (arXiv:1107.5518)
- LHC [~127, 600] GeV arXiv:1202.1408 (ATLAS) arXiv:1202.1488 (CMS)

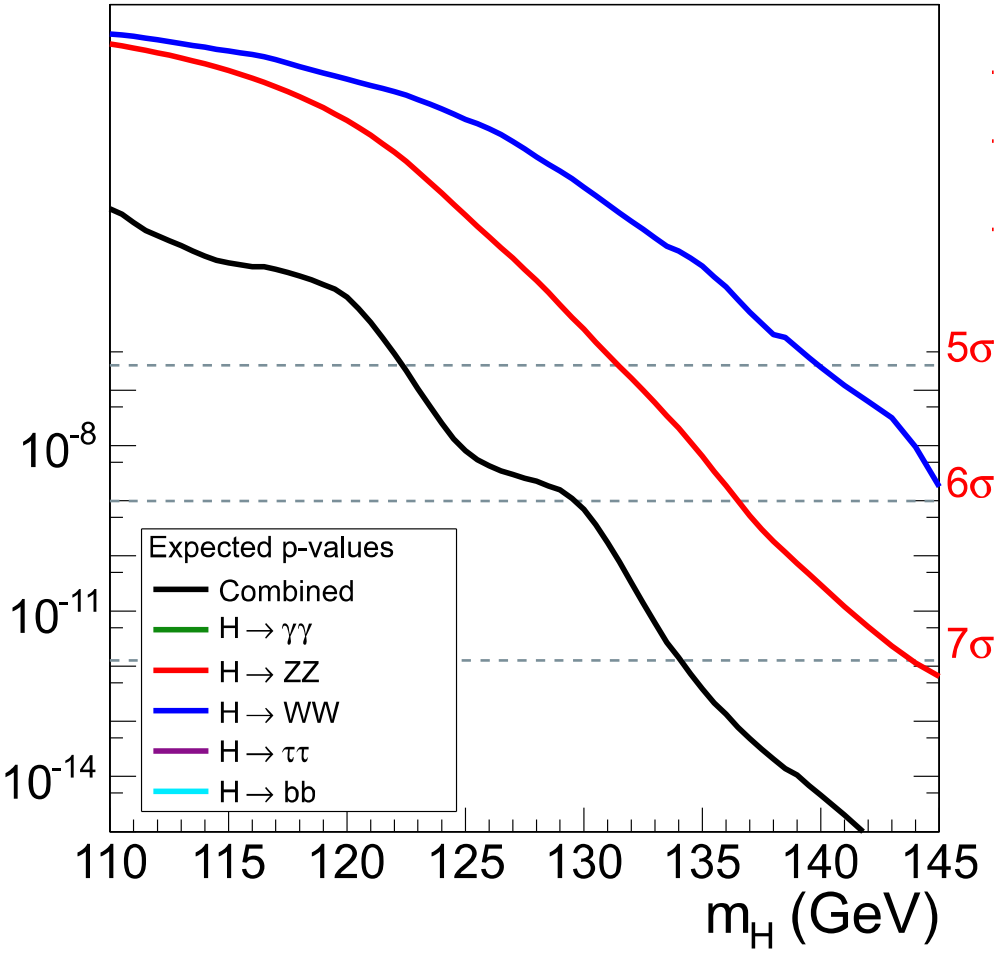
Higgs boson decays

5 decay modes exploited

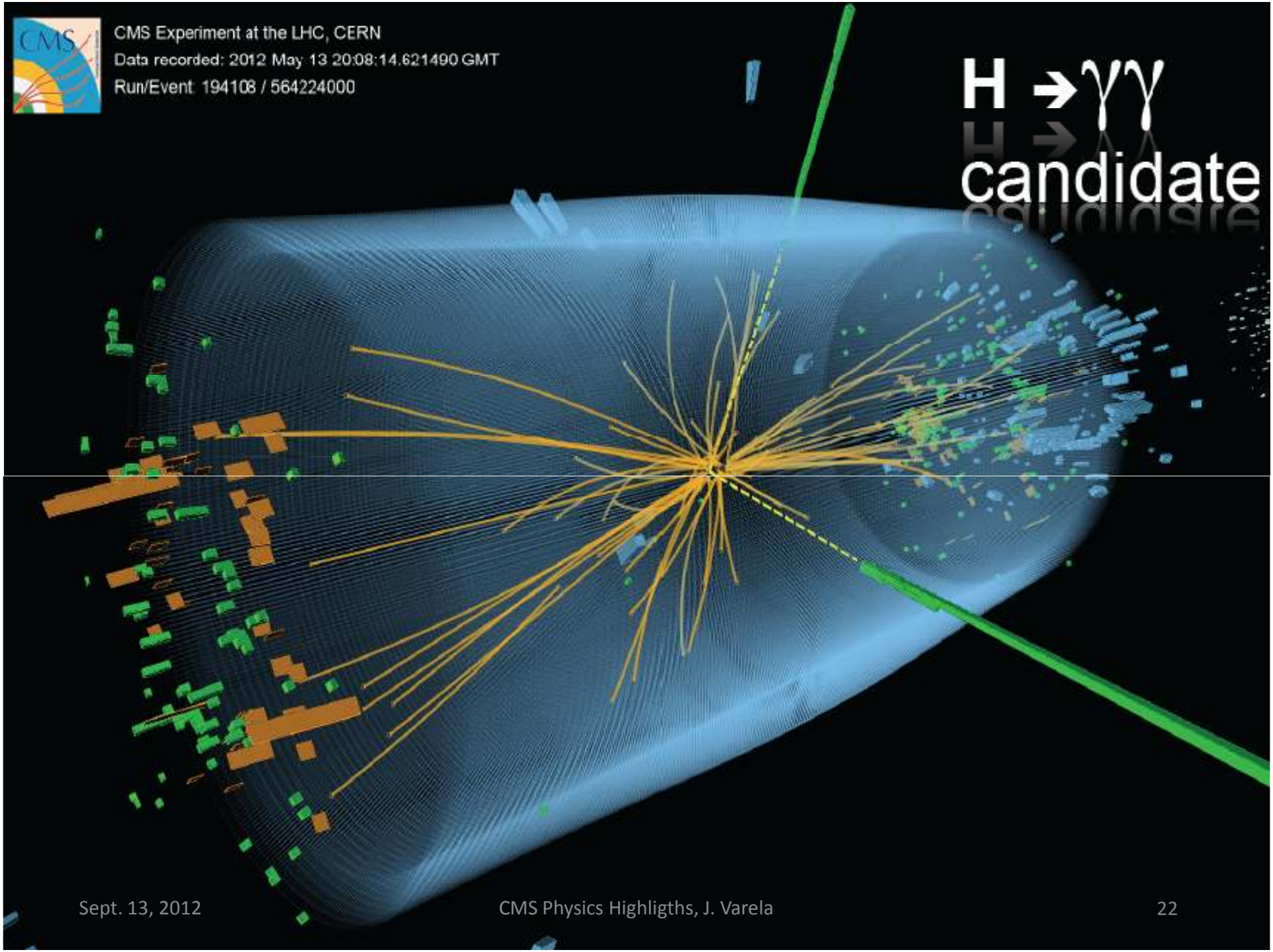
- High mass: WW, ZZ
- Low mass: bb, ττ, WW, ZZ, γγ
- Low mass region is very rich but also very challenging:
  main decay modes (bb, ττ) are hard to identify in the huge background
- Very good mass resolution (1%): H→γγ and H→ZZ→4l



Higgs expected sensitivity



Highest sensitivity in γγ and ZZ, since those modes exploit the excellent mass resolution (~1%) of CMS.


CMS Experiment at the LHC, CERN
Data recorded: 2012 May 13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000
H → γγ
candidate

H→γγ Strategy

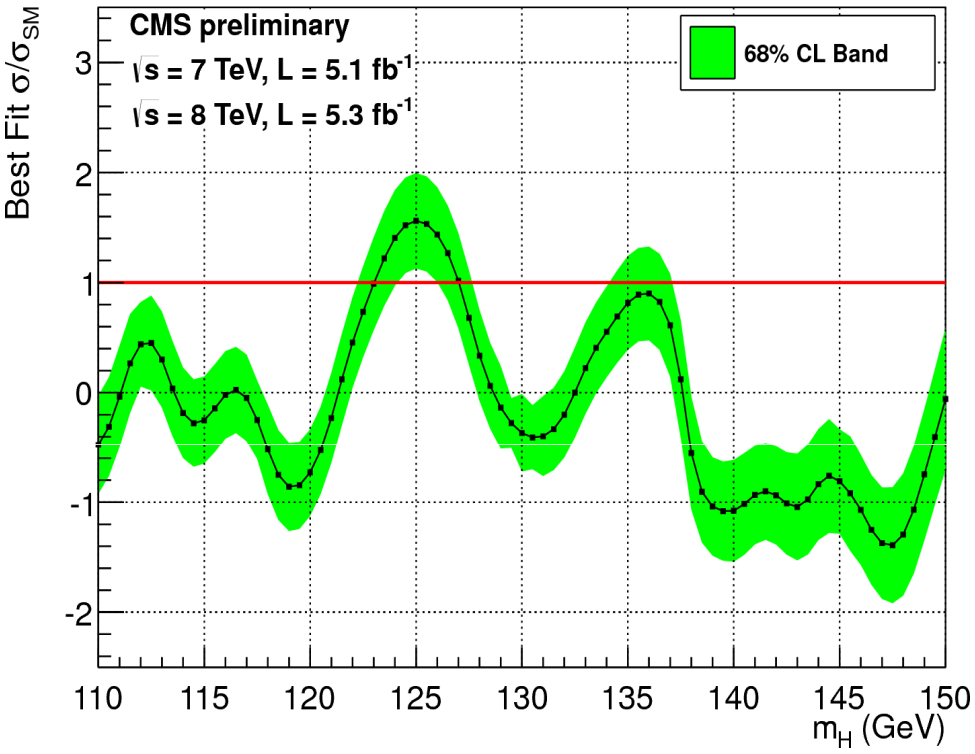
- Multi-Variate Analysis (MVA) for photon ID and event classification
  - Divide events into non-overlapping samples of varying S/B based on properties of the reconstructed photons and presence of di-jets from VBF process

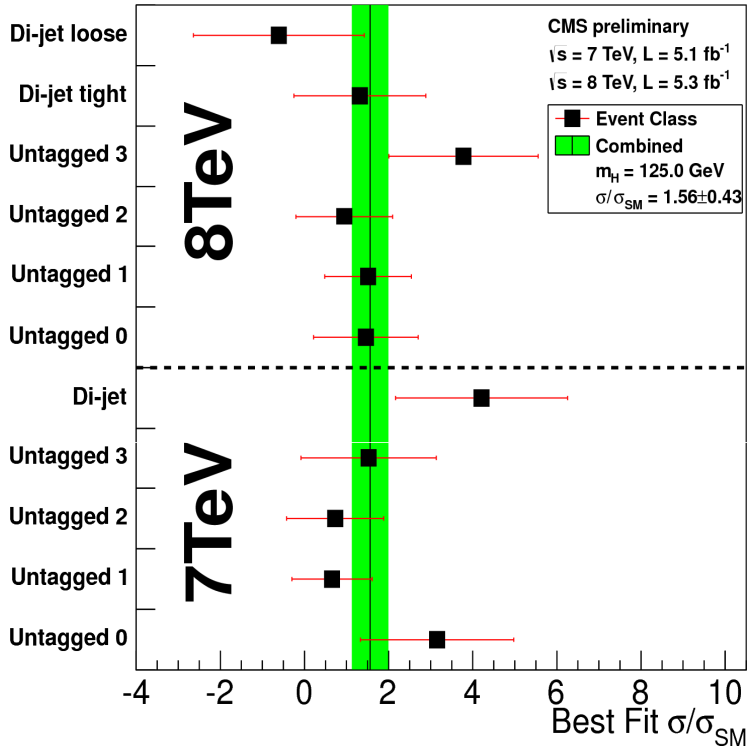
- Cross check with cut-based analysis
  - MVA and cut-based results consistent
  - MVA gives 15% better sensitivity

Expected Yield for SM Higgs

Event categories		SM Higgs boson expected signal ($m_H = 125$ GeV)							Background $m_{\gamma\gamma} = 125$ GeV (events/GeV)
		Events	ggH	VBF	VH	ttH	σ_{eff} (GeV)	FWHM/2.35 (GeV)	
7 TeV, 5.1 fb^{-1}	BDT 0	3.2	61%	17%	19%	3%	1.21	1.14	3.3 ± 0.4
	BDT 1	16.3	88%	6%	6%	–	1.26	1.08	37.5 ± 1.3
	BDT 2	21.5	92%	4%	4%	–	1.59	1.32	74.8 ± 1.9
	BDT 3	32.8	92%	4%	4%	–	2.47	2.07	193.6 ± 3.0
	Dijet tag	2.9	27%	72%	1%	–	1.73	1.37	1.7 ± 0.2
8 TeV, 5.3 fb^{-1}	BDT 0	6.1	68%	12%	16%	4%	1.38	1.23	7.4 ± 0.6
	BDT 1	21.0	87%	6%	6%	1%	1.53	1.31	54.7 ± 1.5
	BDT 2	30.2	92%	4%	4%	–	1.94	1.55	115.2 ± 2.3
	BDT 3	40.0	92%	4%	4%	–	2.86	2.35	256.5 ± 3.4
	Dijet tight	2.6	23%	77%	–	–	2.06	1.57	1.3 ± 0.2
	Dijet loose	3.0	53%	45%	2%	–	1.95	1.48	3.7 ± 0.4

Fitted Signal Strength



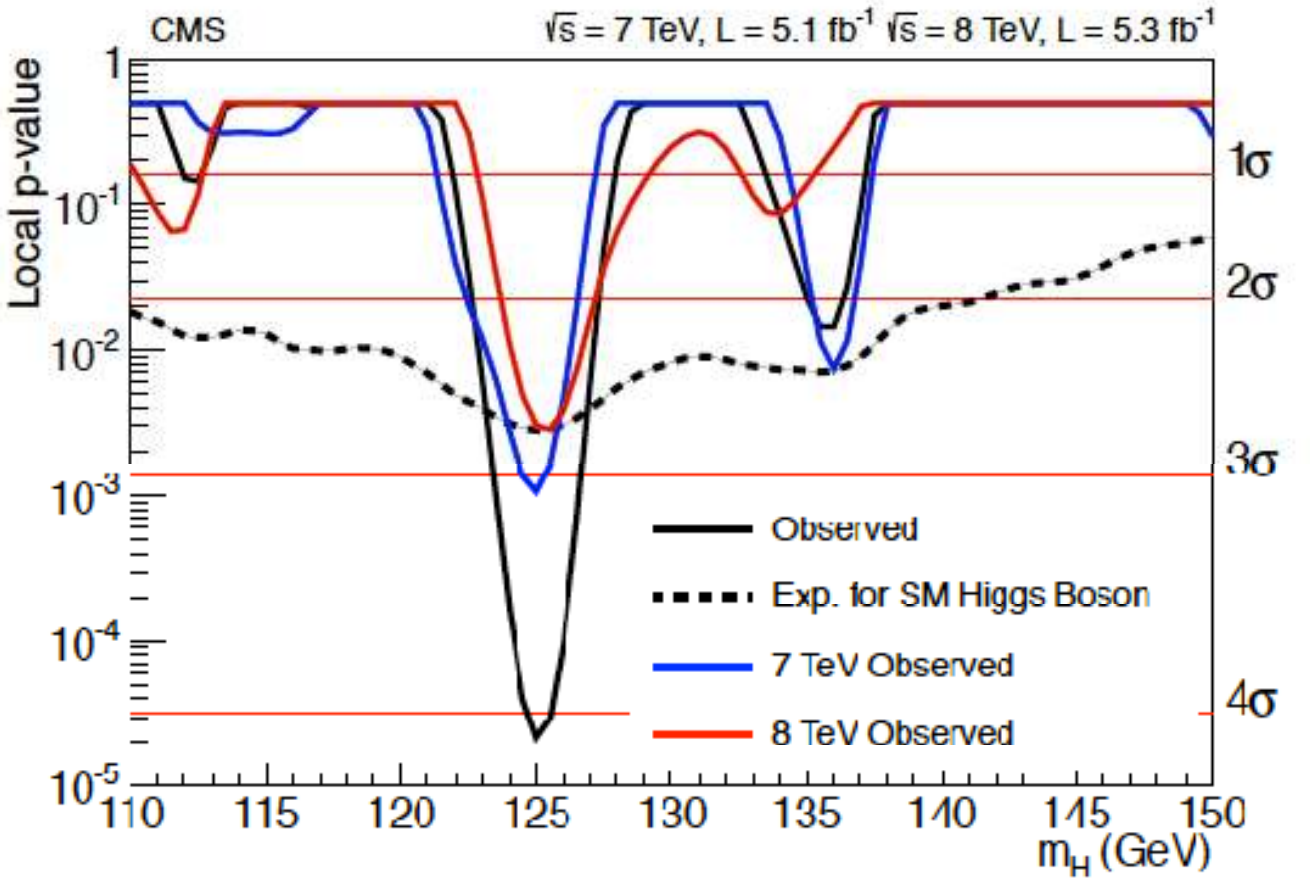


Combined best fit signal strength (m_H=125 GeV):

σ/σ_{SM} = 1.56±0.43 x SM

Best fit signal strength consistent between different classes

p-values

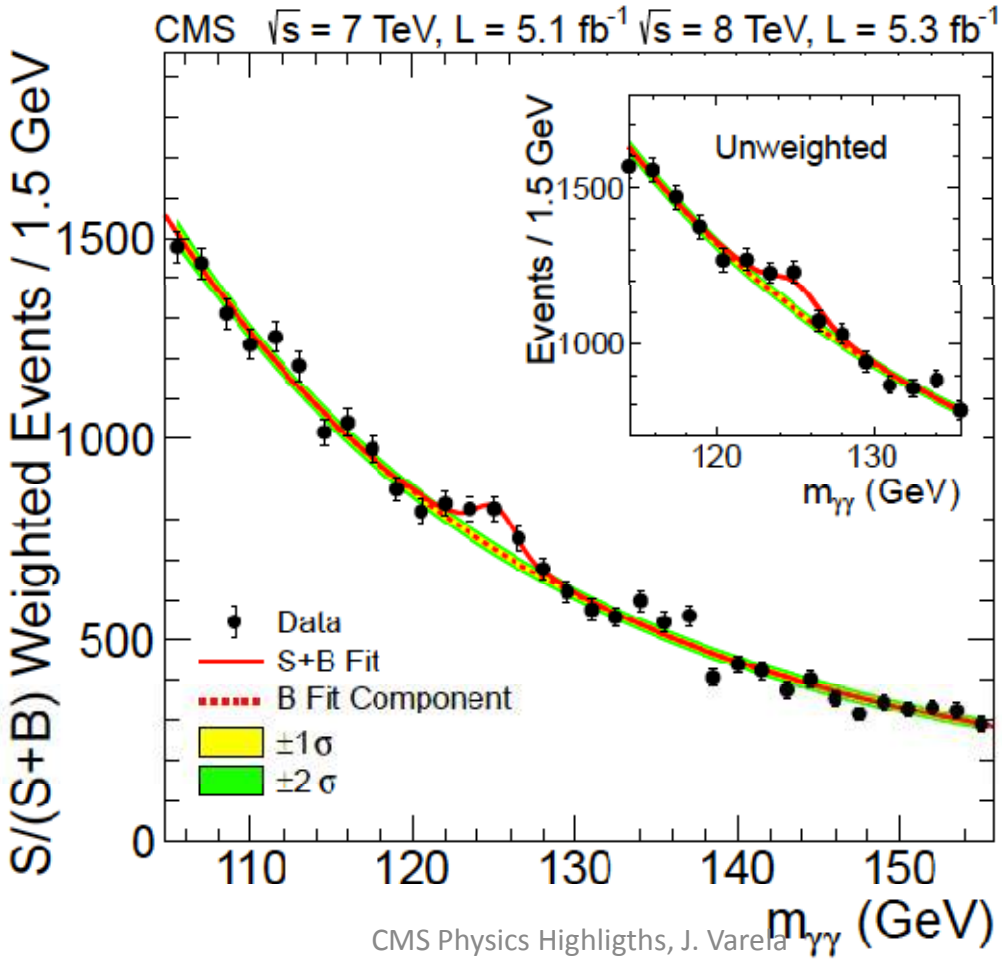


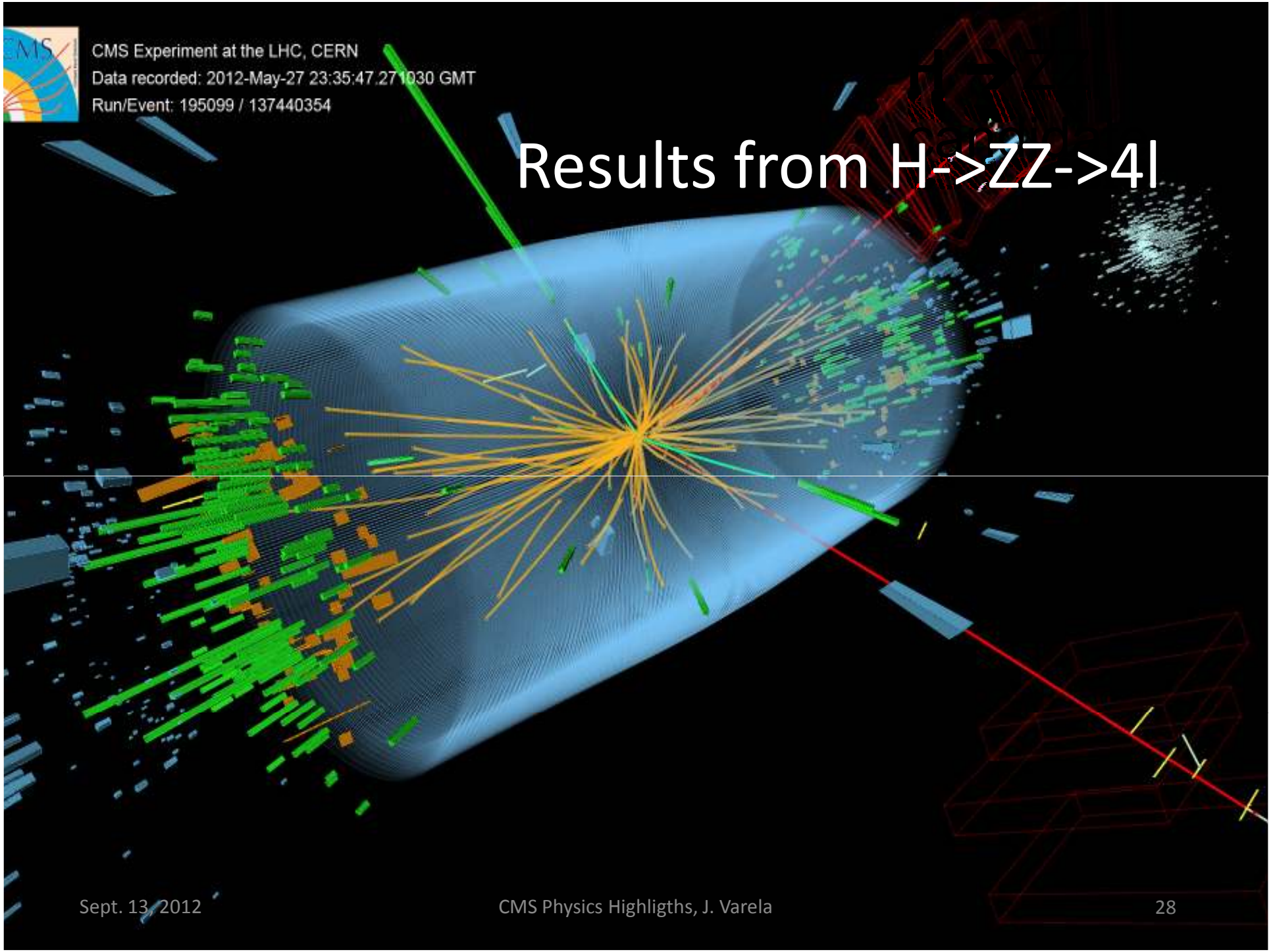
Significance based on local p-value: 4.1σ

Significance based on global p-value: 3.2σ (110-150) GeV

Weighted Mass Spectrum

- Sum of mass distributions for each event class, weighted by S/(S+B)





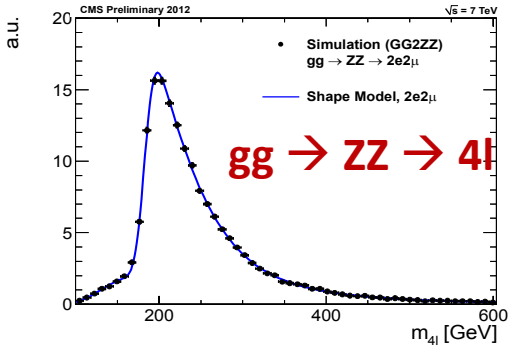
Results from H->ZZ->4l

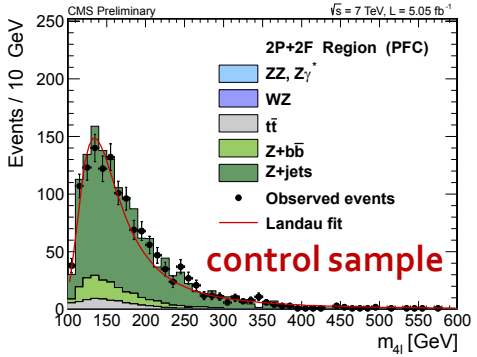
$H \rightarrow ZZ^{(*)} \rightarrow 4l$ (l = e,μ)

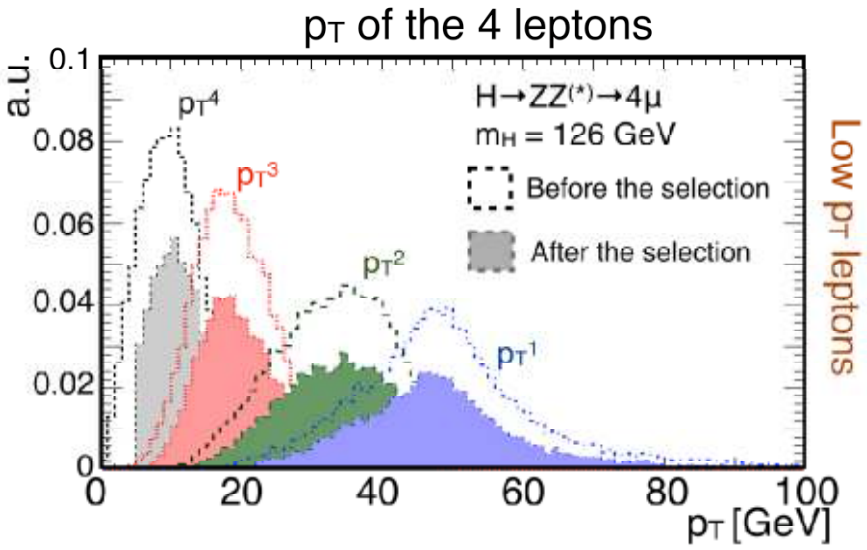
- Background models:
  - irreducible $ZZ^{(*)}$
    - Estimated using simulation
    - Corrected for data/simulation scale
  - reducible Z+jets, ttbar, WZ
    - Estimated from control samples

Event selection:

requires the highest possible efficiencies (lepton Reco/ID/Isolation).



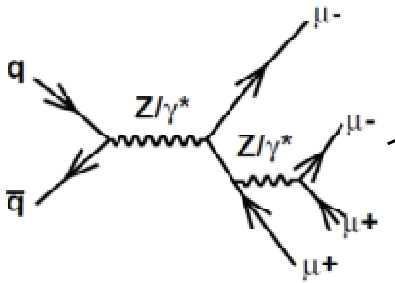


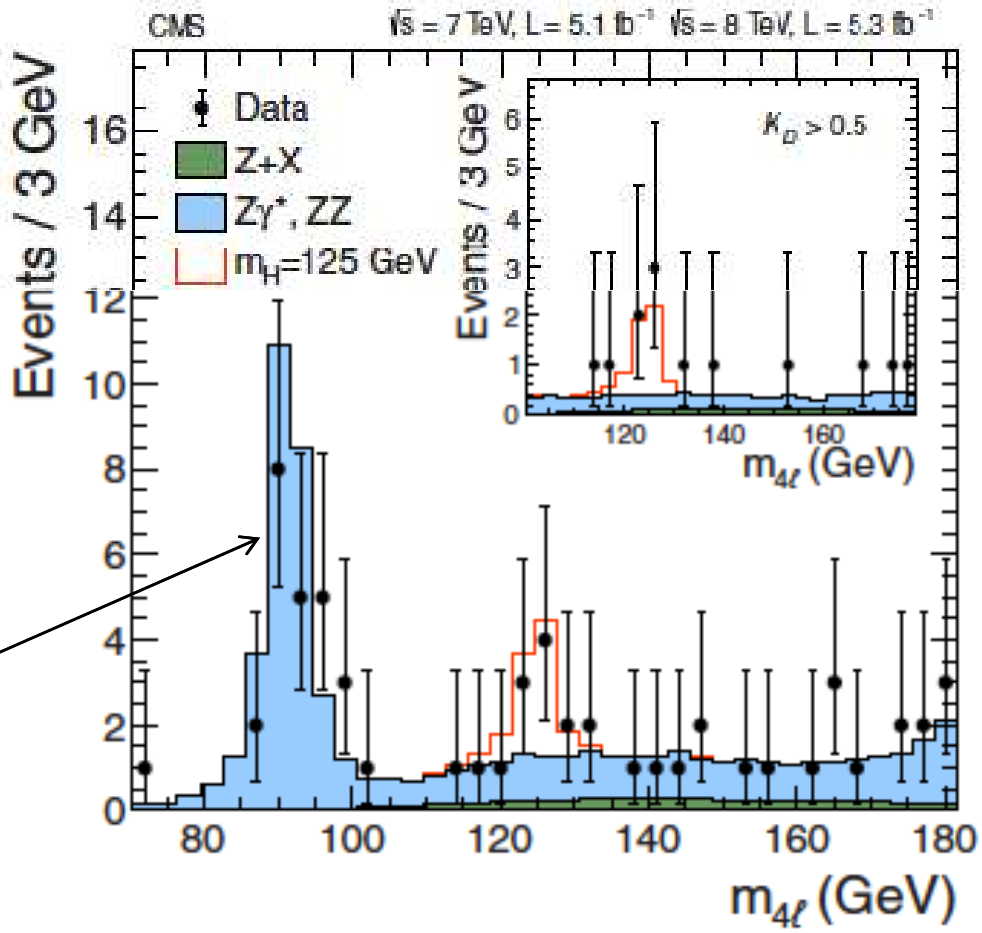


4 lepton mass spectrum

Mass distribution for the four leptons (two pairs of electrons, or two pairs of muons, or the pair of electrons and the pair of muons).

Accounting also for the decay angle characteristics, it yields an **excess of 3.1 sigma above background at a mass of 125.6 GeV.**

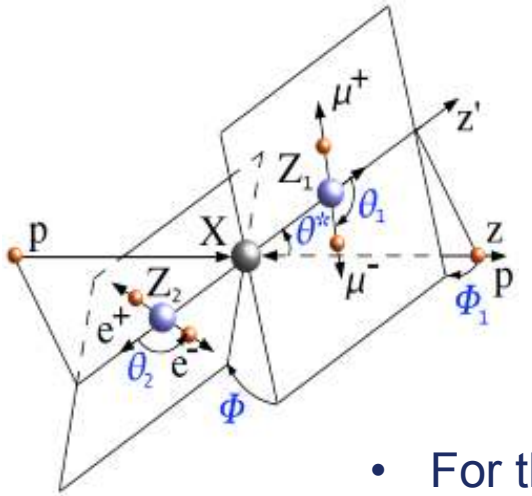




H→ZZ Signal and Background

Channel	4e	4μ	$2e2\mu$	4ℓ
ZZ background	2.7 ± 0.3	5.7 ± 0.6	7.2 ± 0.8	15.6 ± 1.4
$Z + X$	$1.2^{+1.1}_{-0.8}$	$0.9^{+0.7}_{-0.6}$	$2.3^{+1.8}_{-1.4}$	$4.4^{+2.2}_{-1.7}$
All backgrounds ($110 < m_{4\ell} < 160$ GeV)	4.0 ± 1.0	6.6 ± 0.9	9.7 ± 1.8	20 ± 3
Observed ($110 < m_{4\ell} < 160$ GeV)	6	6	9	21
Signal ($m_H = 125$ GeV)	1.36 ± 0.22	2.74 ± 0.32	3.44 ± 0.44	7.54 ± 0.78
All backgrounds (signal region)	0.7 ± 0.2	1.3 ± 0.1	1.9 ± 0.3	3.8 ± 0.5
Observed (signal region)	1	3	5	9

Matrix Element Likelihood Analysis



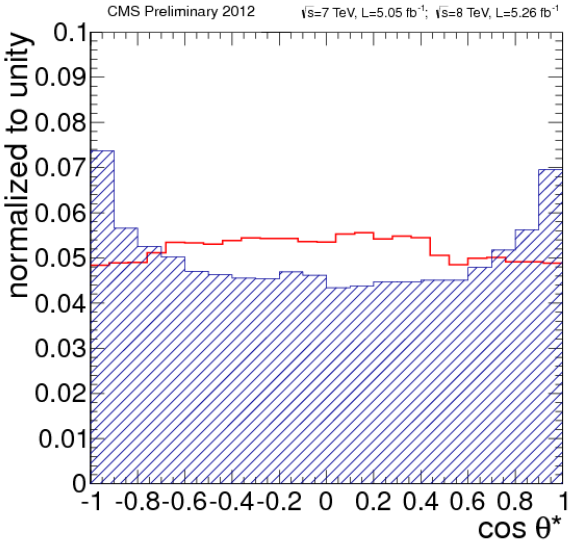
Matrix Element Likelihood Analysis:

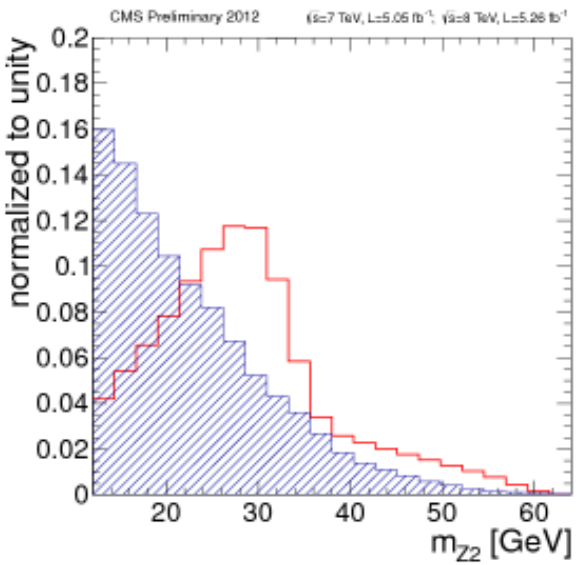
uses kinematic inputs for signal to background discrimination

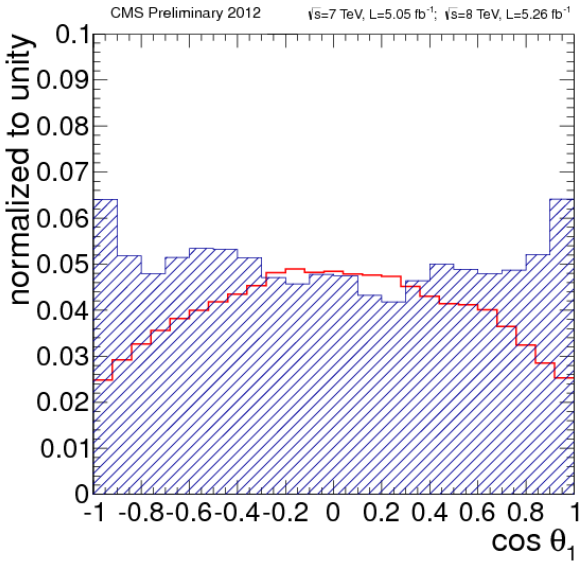
$$\{m_1, m_2, \theta_1, \theta_2, \theta^*, \Phi, \Phi_1\}$$

$$K_D = \left[1 + \frac{\mathcal{P}_{\rm bkg}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}{\mathcal{P}_{\rm sig}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}\right]^{-1}$$

- For the signal, use a fully analytic parameterization
- For the use a simulation of the process $q\bar{q} \rightarrow ZZ/Z\gamma$



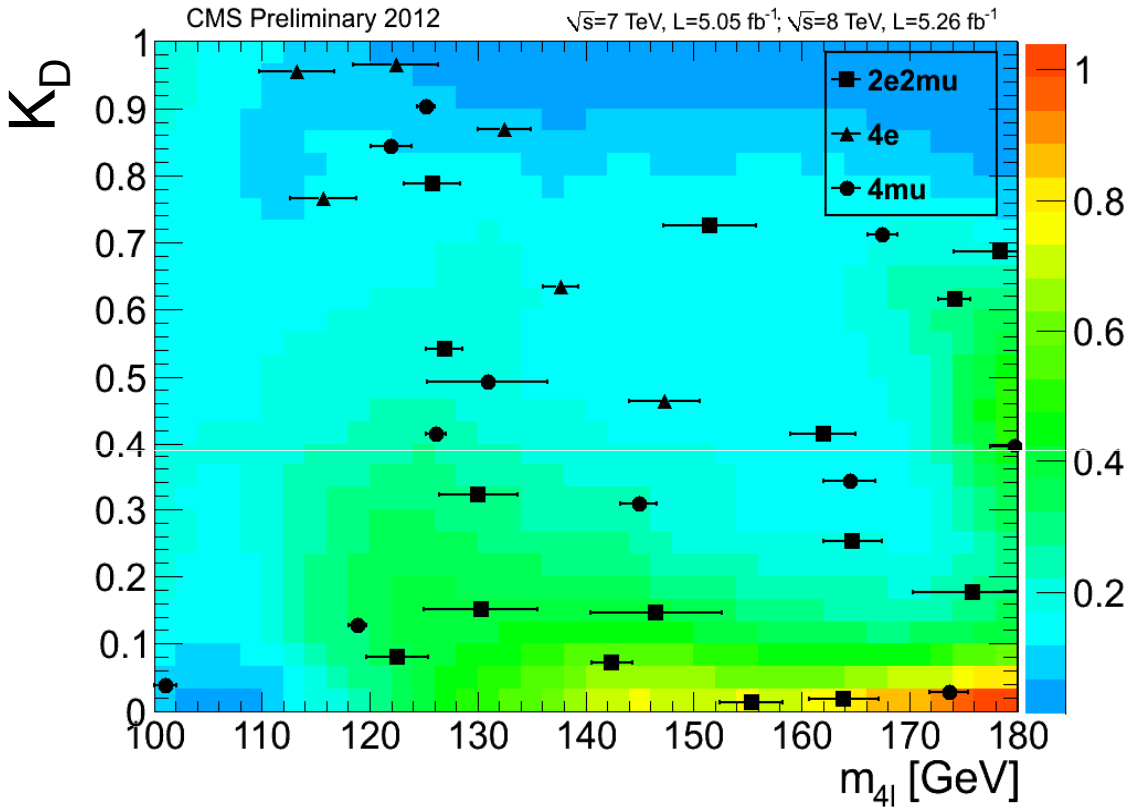




Results from 2D distributions

K_D discriminant versus m_{4l}

- Data points shown with per-event mass uncertainties
- Six simultaneous two-dimensional maximum likelihood fits for each value of m_H , in the variables m_{4l} and K_D .

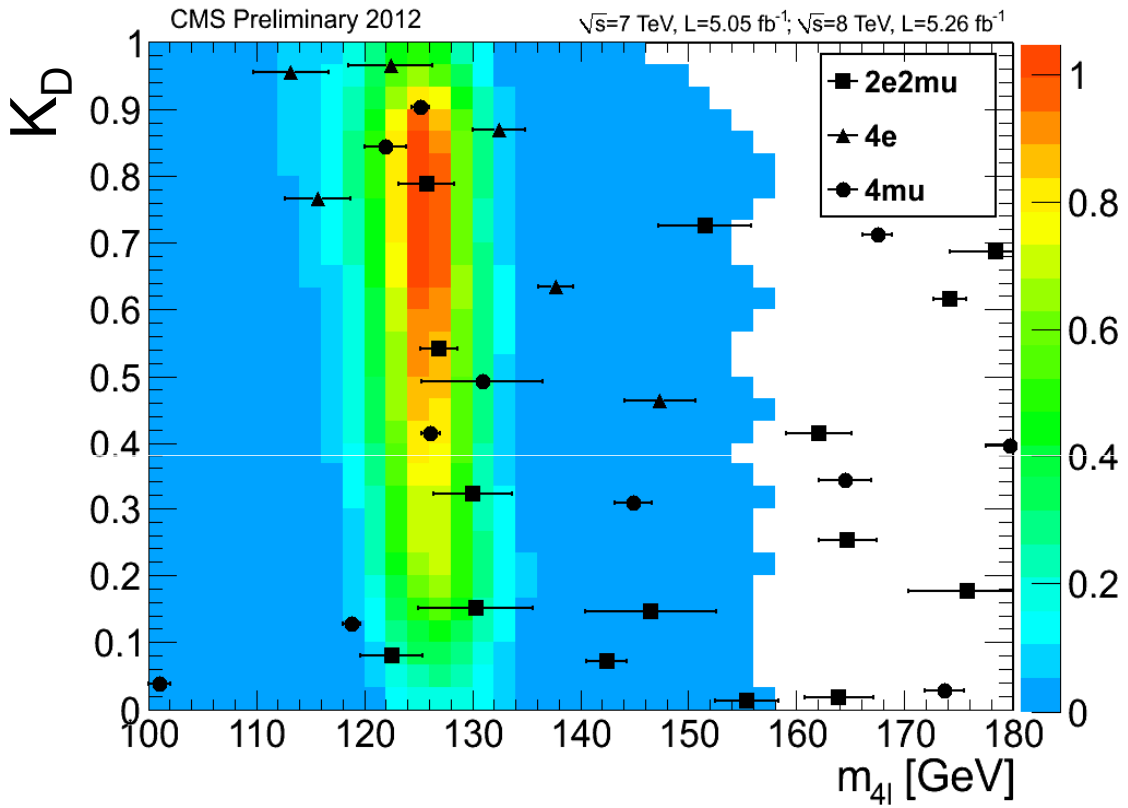


Data w.r.t. background expectation

Results from 2D distributions

2D fit results:

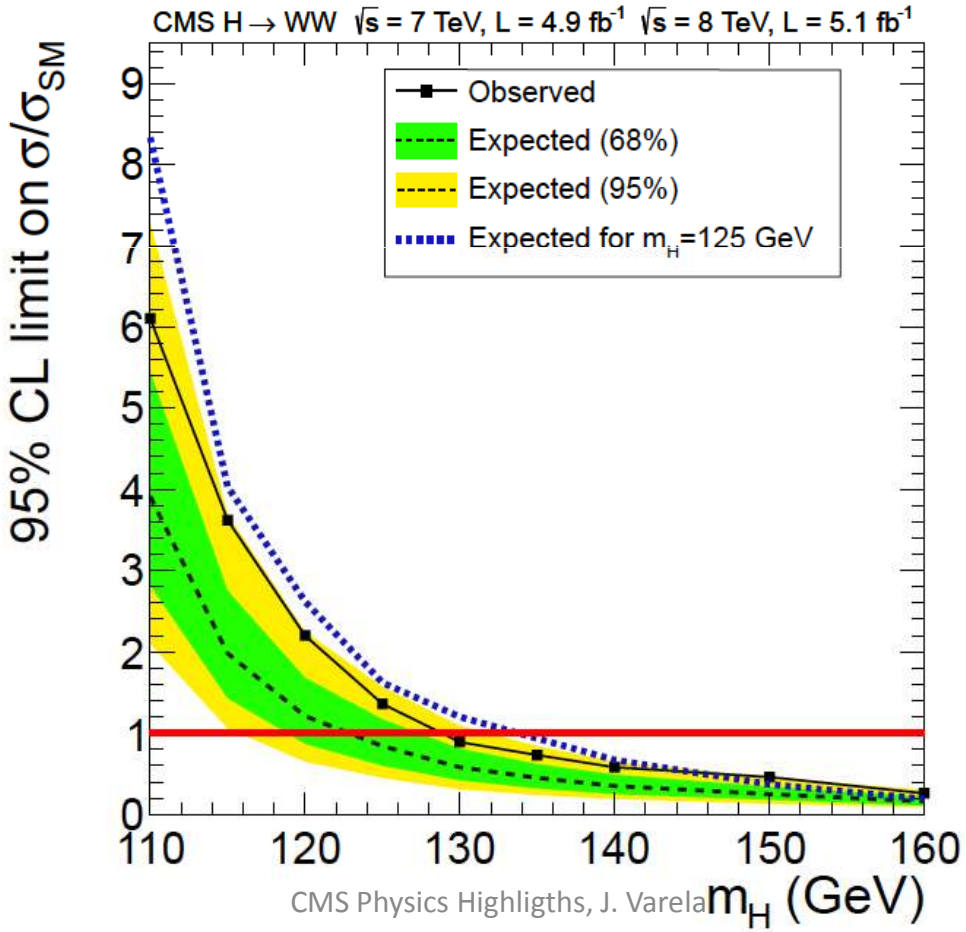
- The minimum local p - value occurs at m_{H}= 125.6 GeV and has a significance of 3.2 (expected 3.8).
- The best-fit signal strength for a SM Higgs boson mass hypothesis of 125.6 GeV is 0.7+0.4-0.3



Data w.r.t 126 GeV Higgs Expectation

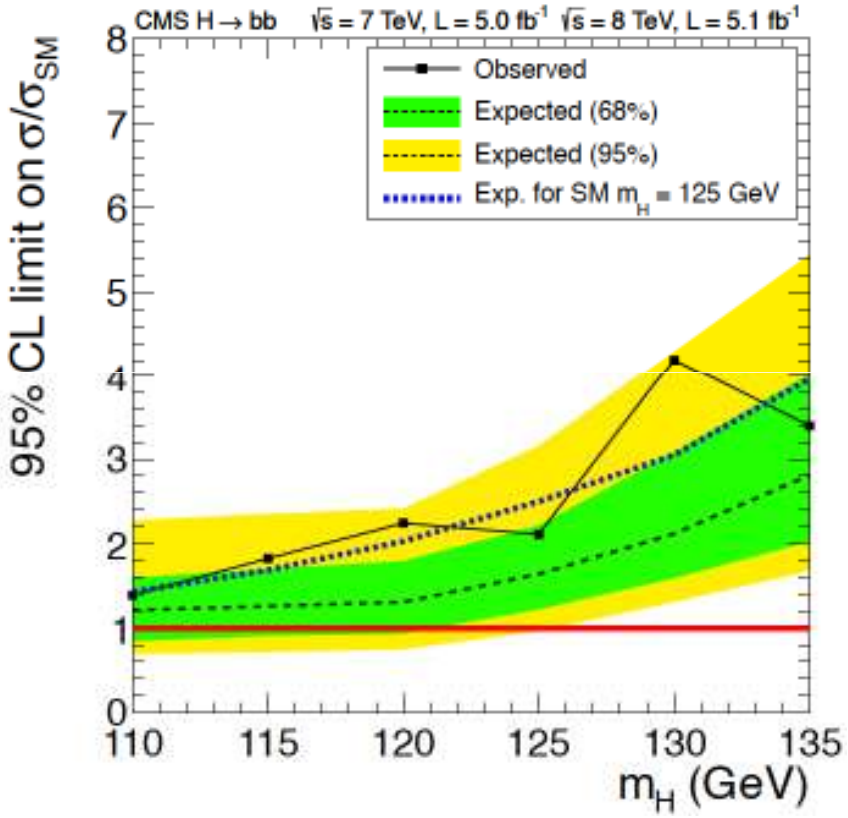
Results from H->WW

WW->llvv channel: a broad excess in the mass distribution of 1.5 sigma is observed.

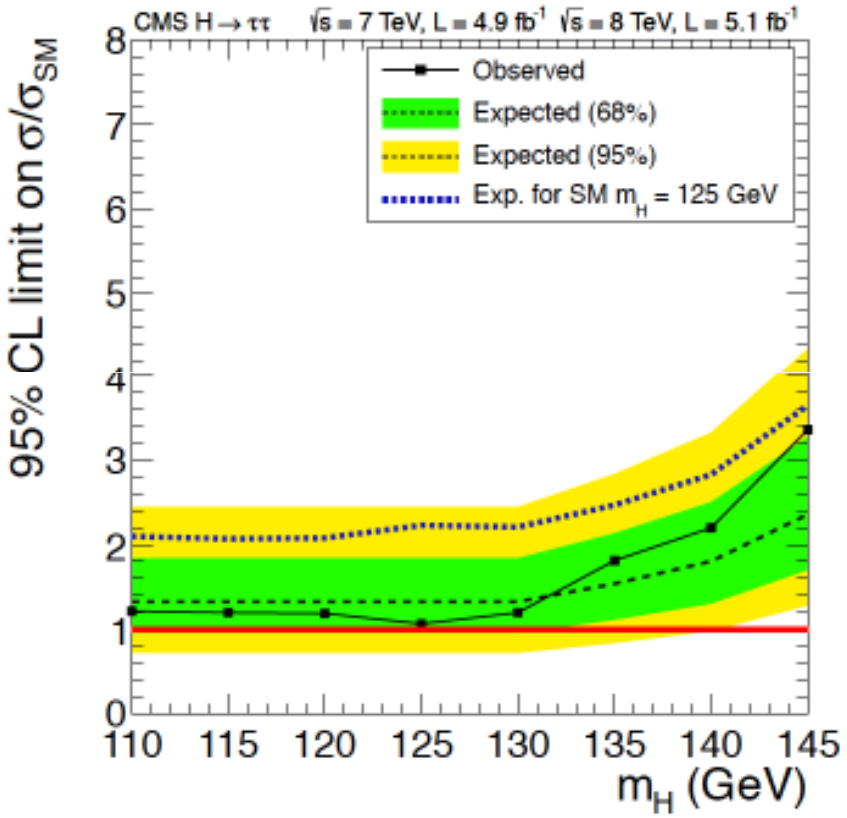


Results from low-sensitivity channels

VH->Vbb



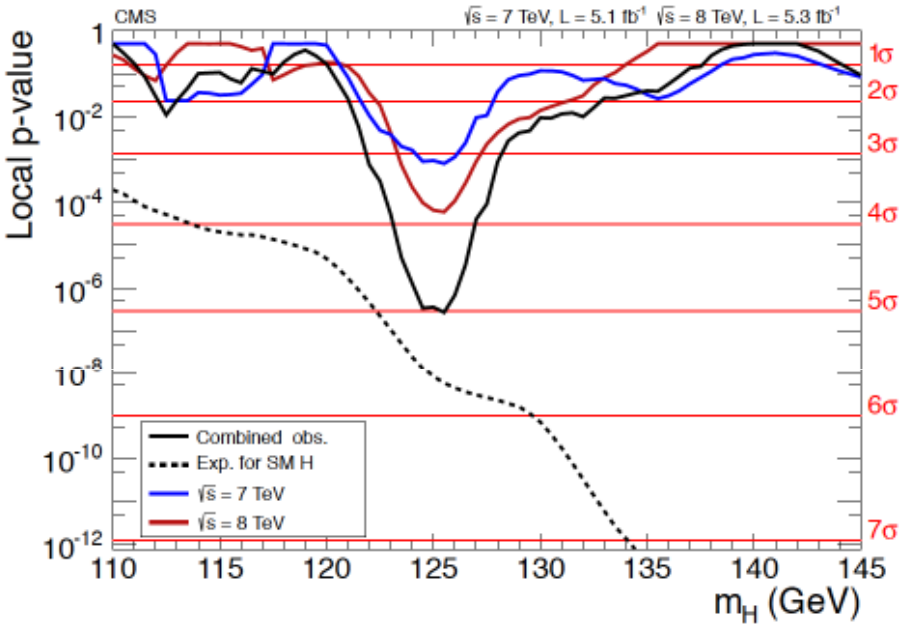
H->ττ



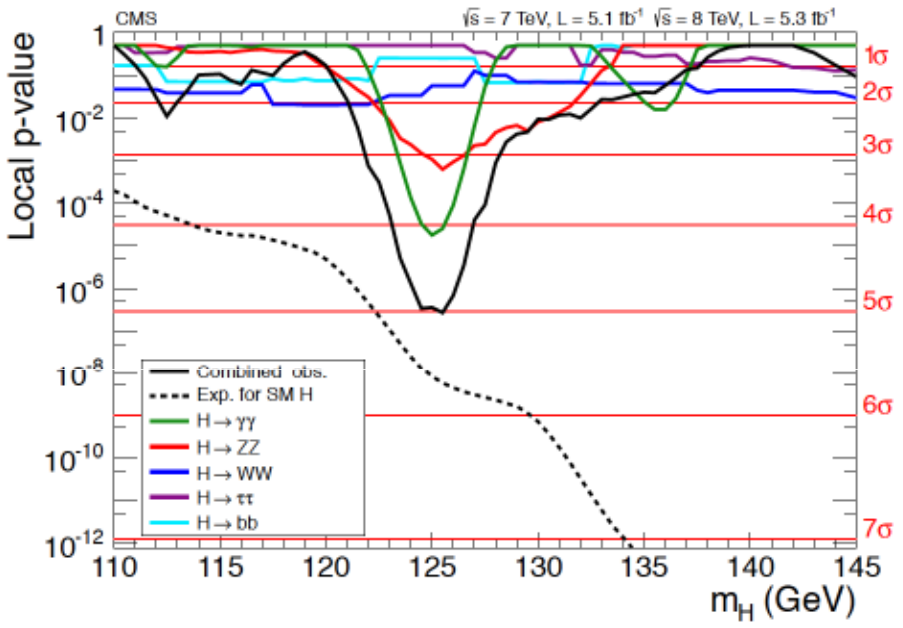
Compatible with either background or signal from a 125 GeV Higgs

No significant departure from SM background-only expectation

Combined results



By dataset



By mode

Combined Results

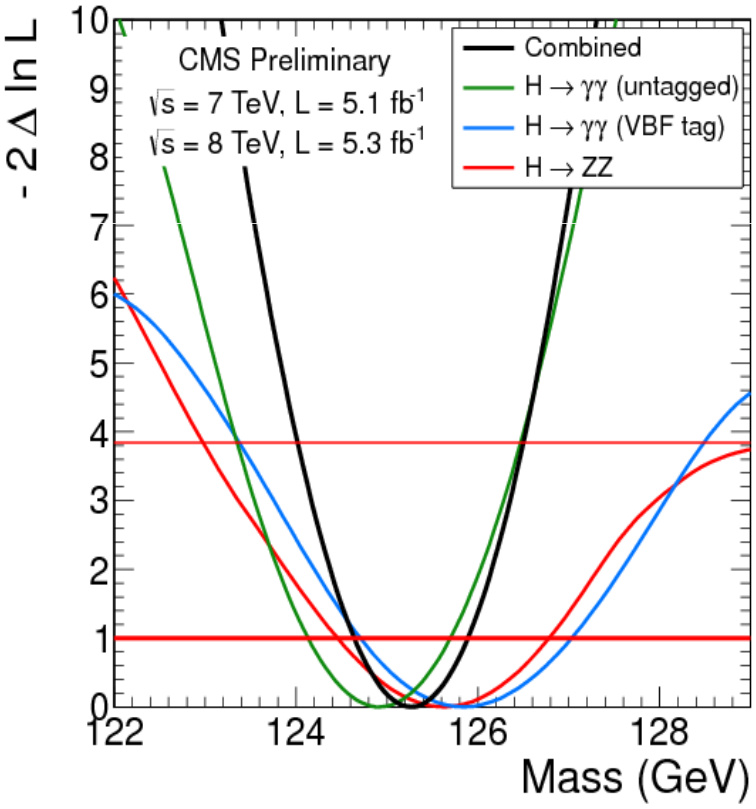
Decay mode/combination	Expected (σ)	Observed (σ)
$\gamma\gamma$	2.8	4.1
ZZ	3.6	3.1
$\tau\tau$ + bb	2.4	0.4
$\gamma\gamma$ + ZZ	4.7	5.0
$\gamma\gamma$ + ZZ + WW	5.2	5.1
$\gamma\gamma$ + ZZ + WW + $\tau\tau$ + bb	5.8	5.0

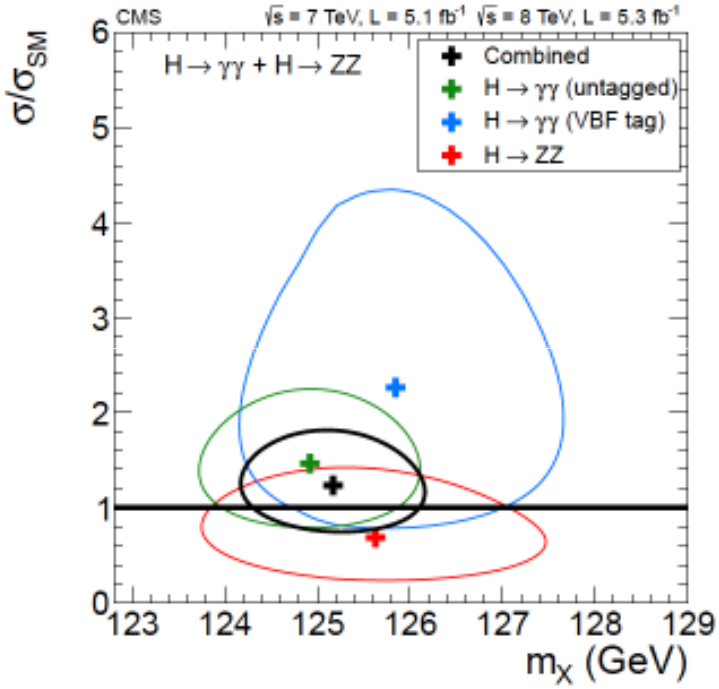
Overall significance 5.0σ versus 5.8σ expected.

Mass of the new resonance

Model independent mass measurement from the two high-resolution channels:

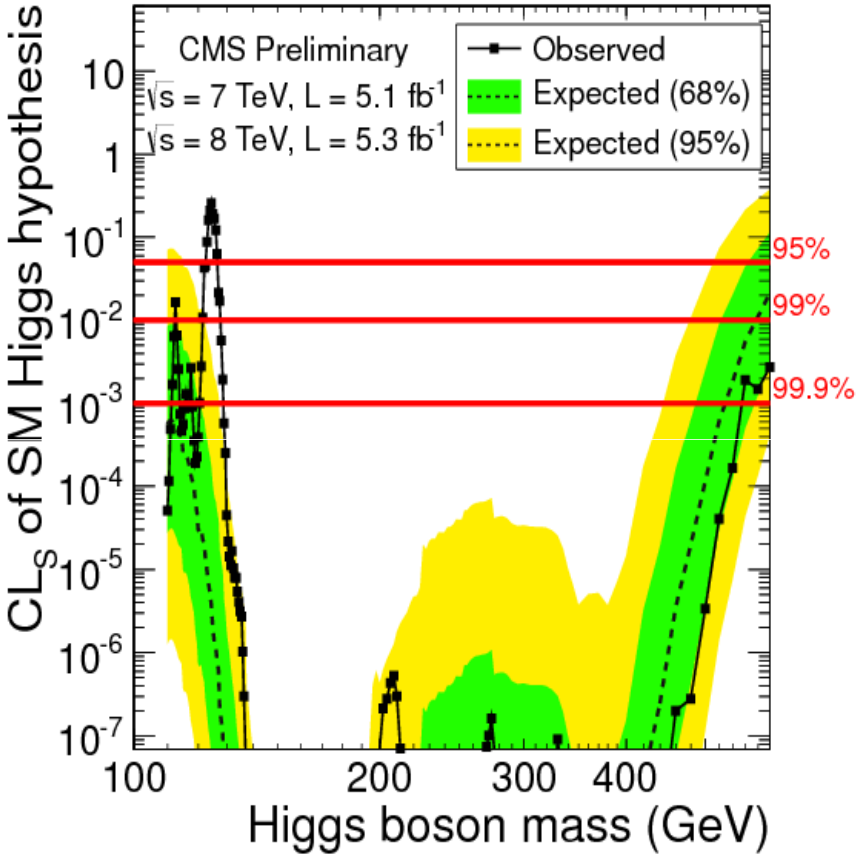
$m_X = 125.3 \pm 0.6$ GeV

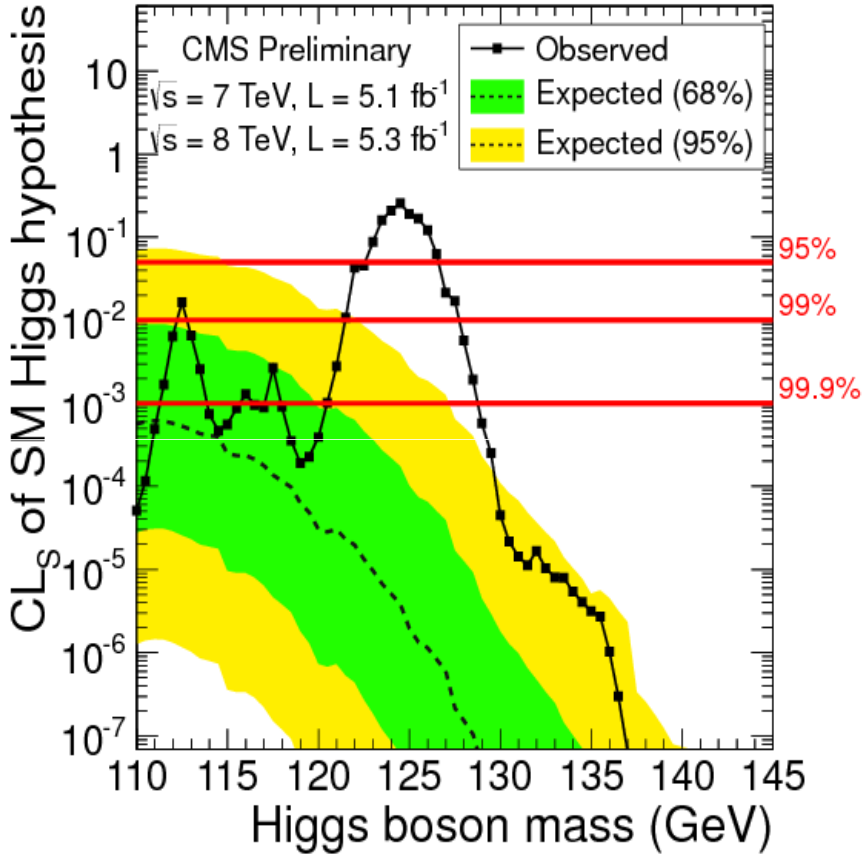




The combined 68% CL contour assumes that the relative event yields among the three channels are those expected from the standard model

SM Higgs exclusion

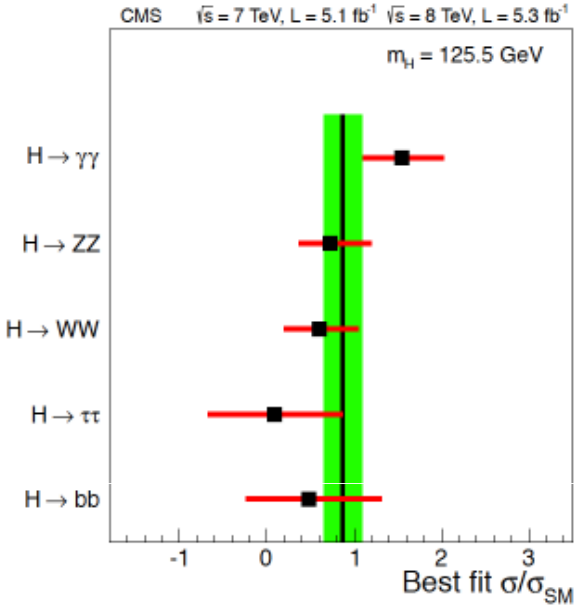




Excluded regions: 110 – 122.5 [...] 127 – 600 GeV **at 95% CL**

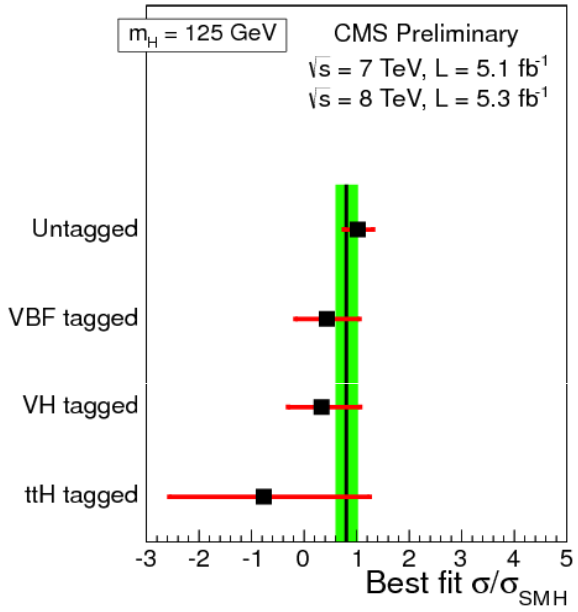
110—112 .. 113 – 121.5 [...] 128 – 600 GeV **at 99% CL**

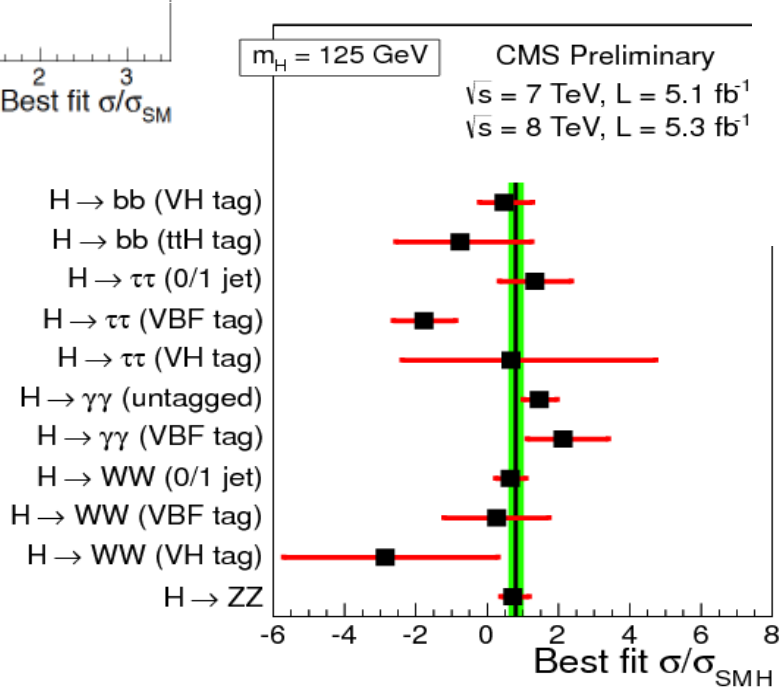
Compatibility with SM Higgs boson



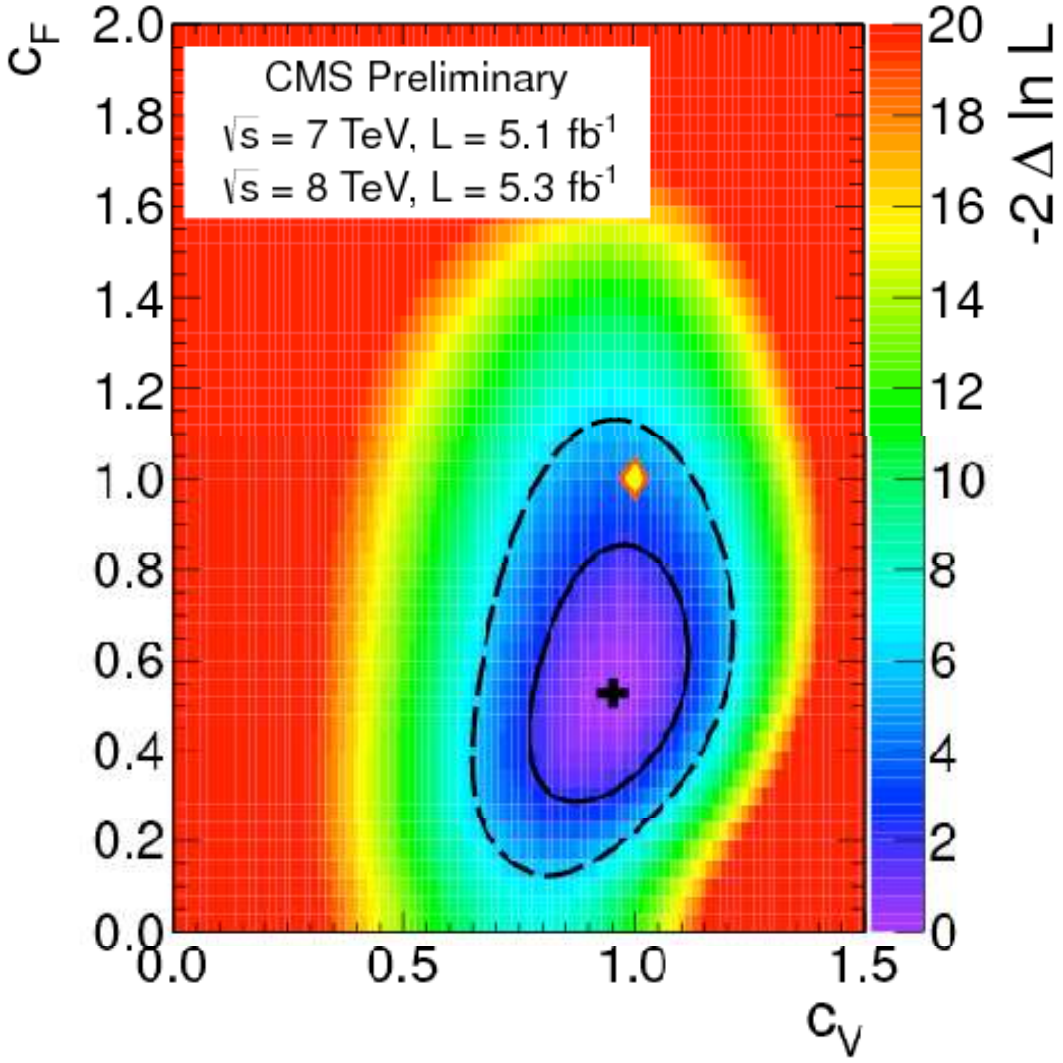
Overall best-fit signal strength in the combination:

$\sigma/\sigma_{SM} = 0.87 \pm 0.23$





Couplings Cv-Cf



2011-12 Datasets: SUSY

SUSY searches at 7 TeV

The initial SUSY program at CMS was designed to be

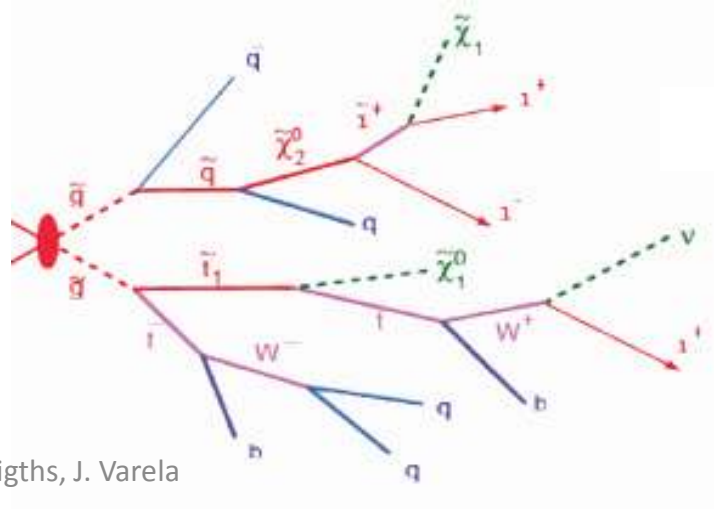
1. Generic
   - Signature based searches not tuned to a particular SUSY model
2. Broad
   - Cover many possible signatures
   - Use different methods
     - eg: 4 methods/variables for the all hadronic channel (α_T, MHT, MT2, razor)
     - Counting as well as shapes
3. Robust
   - Background estimated from data as much as possible

Final states studied

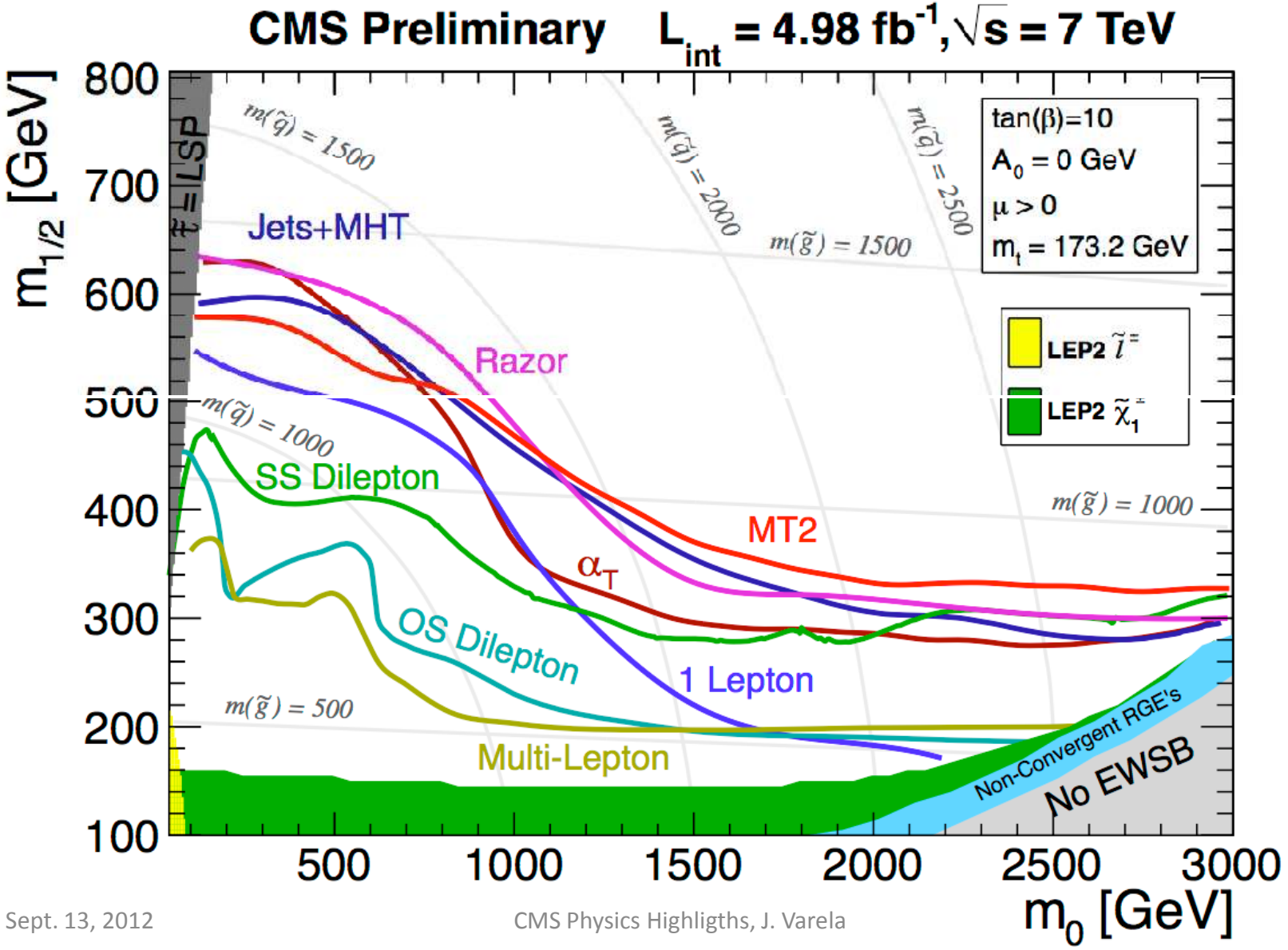
Generic approach: search for strongly produced (heavy) sparticles, which decay via cascades

- Fully hadronic final state
- Final states with leptons
  - 1 lepton
  - 2 leptons
    - Same-sign
    - Opposite sign, but not Z
    - Z
  - Multileptons
- Final states with photons
  - 1 photon
  - 2 photons

- Assume stable LSP: all final states with E_t^{miss}
- In almost all cases “lepton” also means τ
- Most of these searches have a version with b-tags

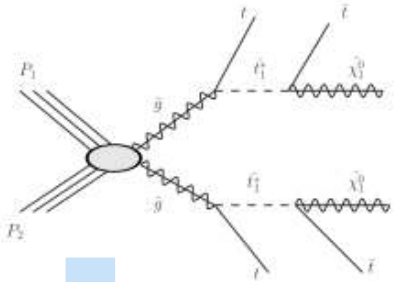


CMSSM interpretation

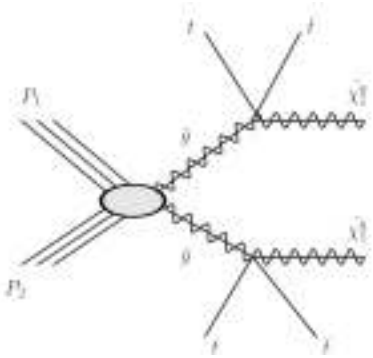


SMS interpretation

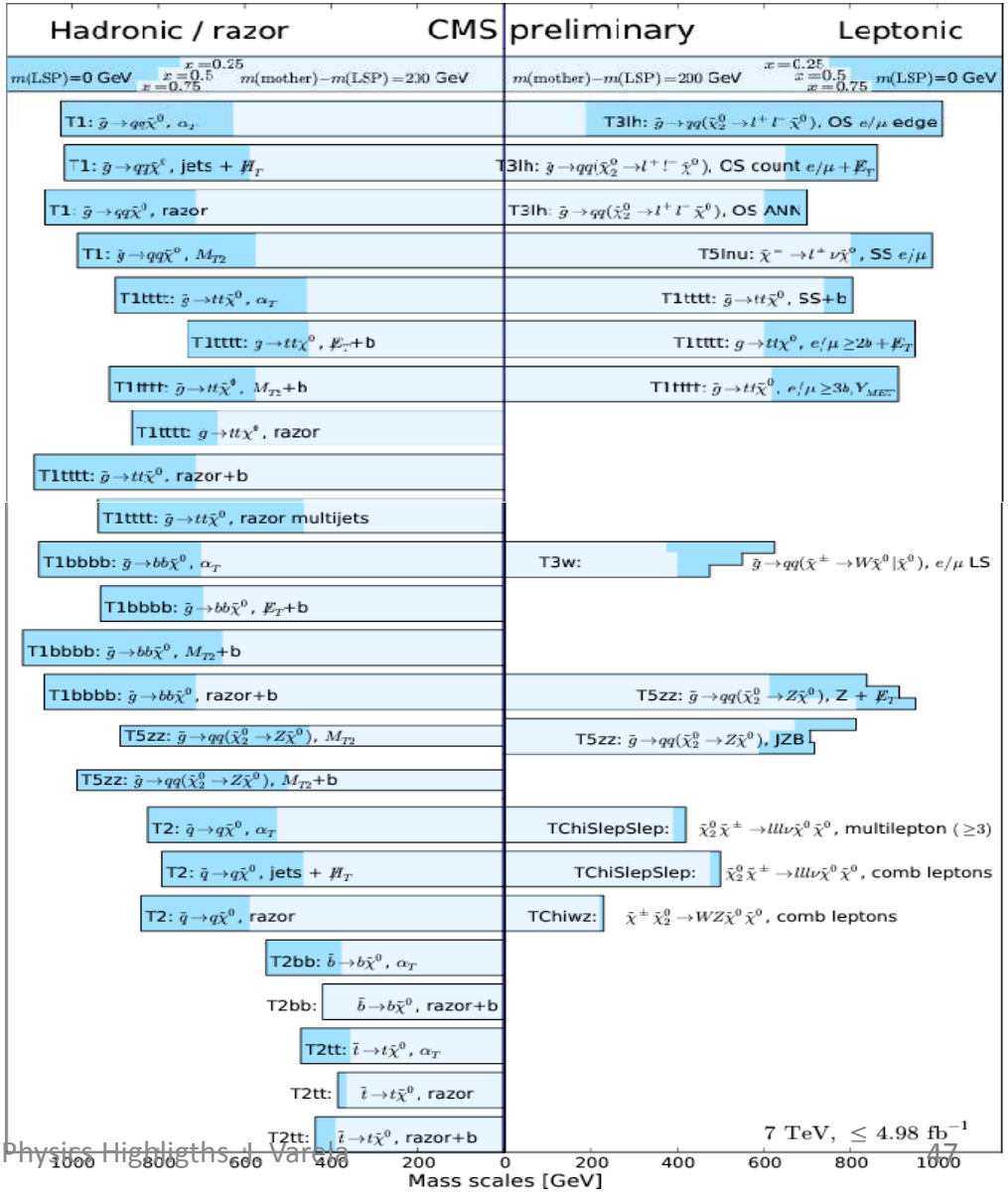
Simplified models:



Stop from gluino decays



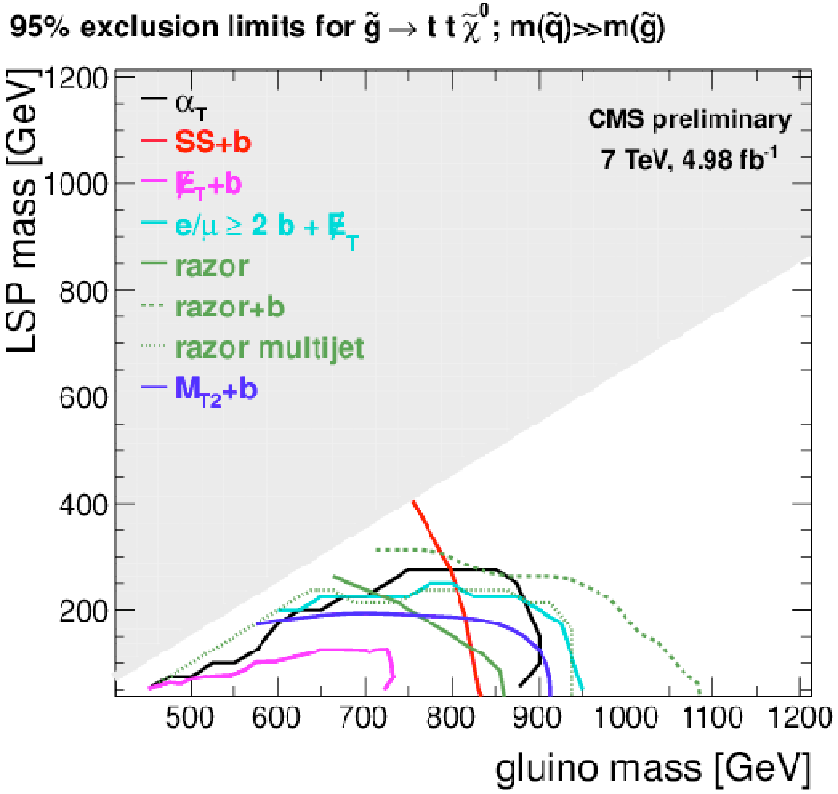
CMS searches have excluded light squarks and gluinos up to ~ 1 TeV

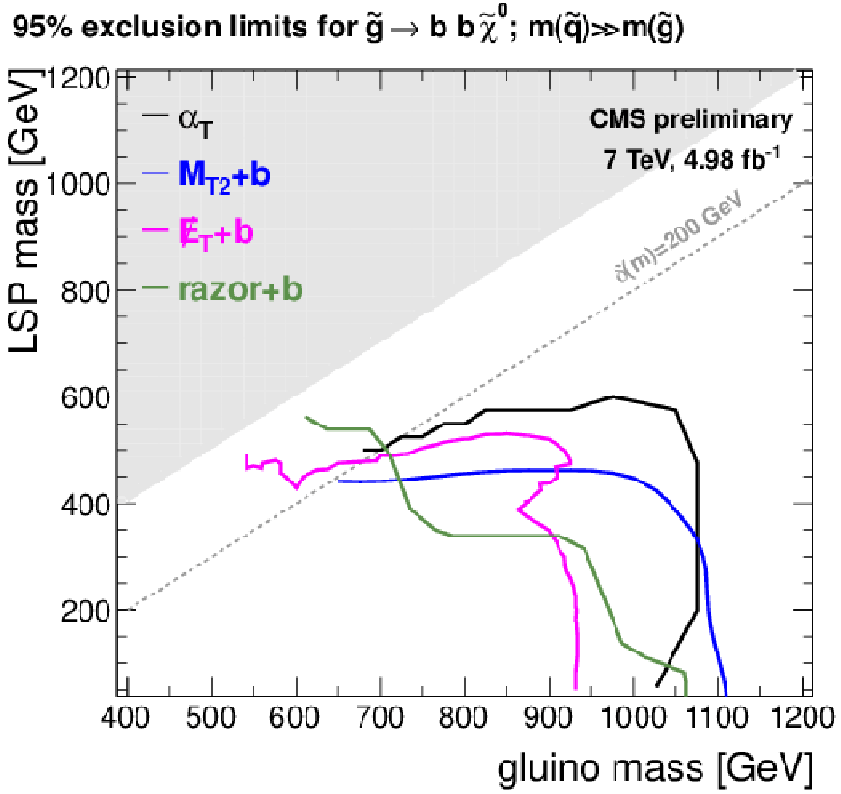


Looking for natural SUSY

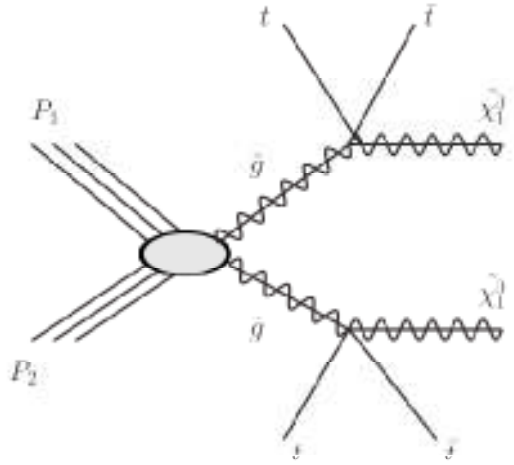
- Search for stops and sbottoms in gluino decays
  - Relatively light stops are needed for naturalness
  - In natural SUSY the gluino cannot be too heavy
  - If the other squarks are very heavy, then the gluino will decay into sbottoms and stops with high BR
- Search for direct stop and sbottom pair production
  - To close the loophole that the “gluino is too heavy”
- Existing “generic” searches can be re-interpreted in this context
- New targeted searches are being developed for pair production

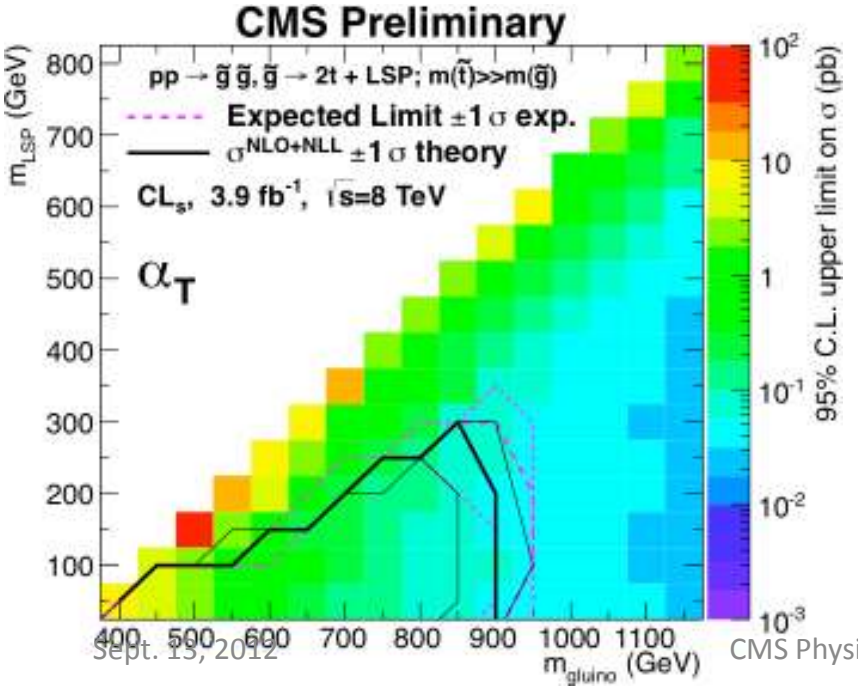
Stop and sbottom in gluino decays

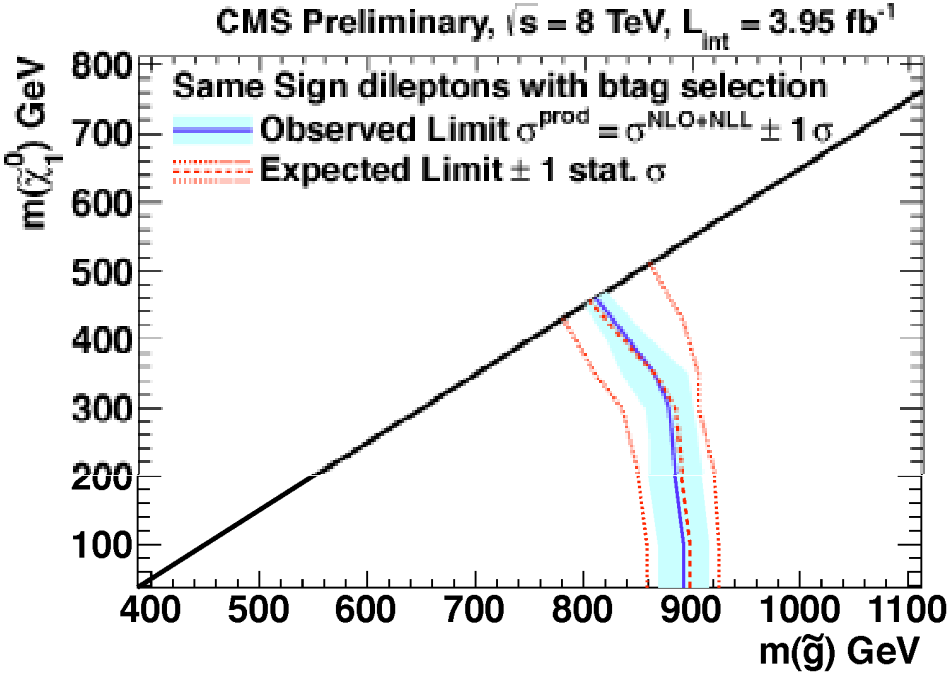




Stop in gluino decays at 8 TeV



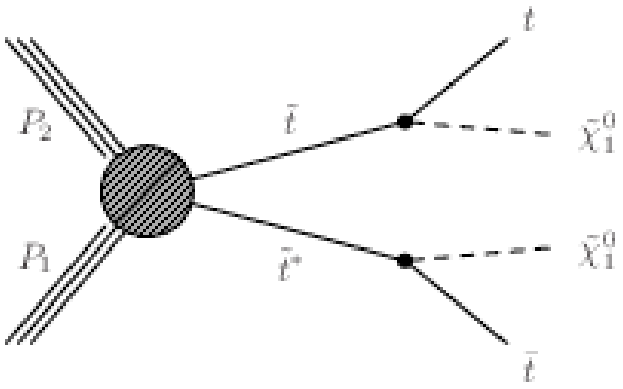




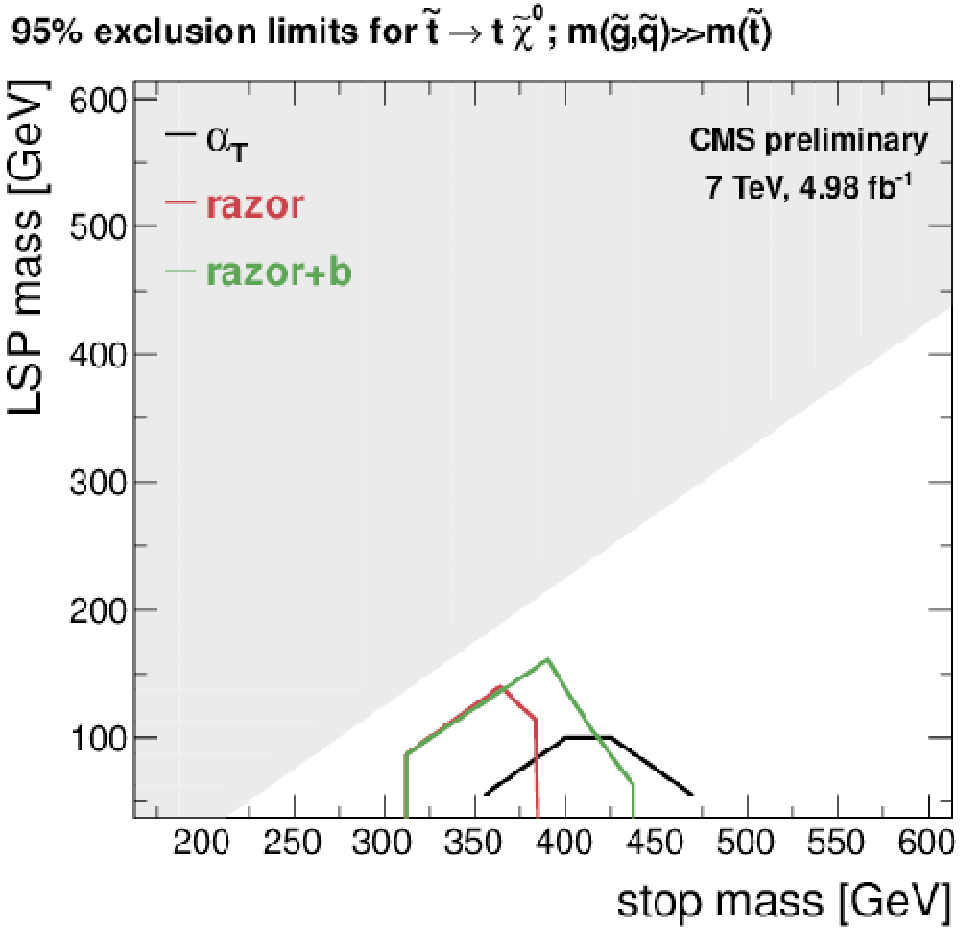
Extend the gluino exclusion in these scenarios by ~ 60 GeV

Early 8 TeV results

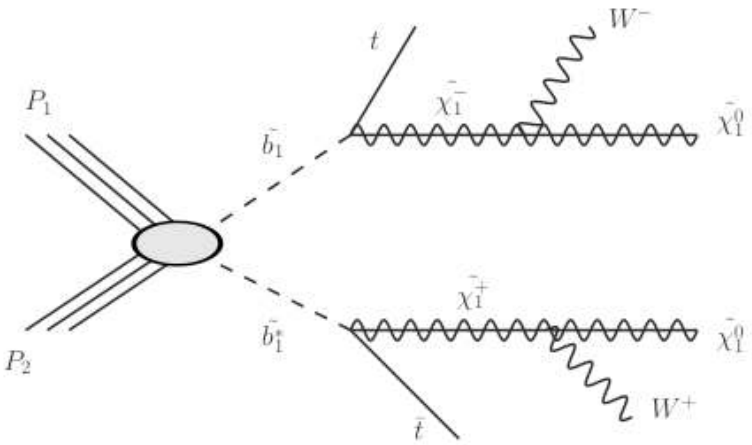
Stop Pair Production

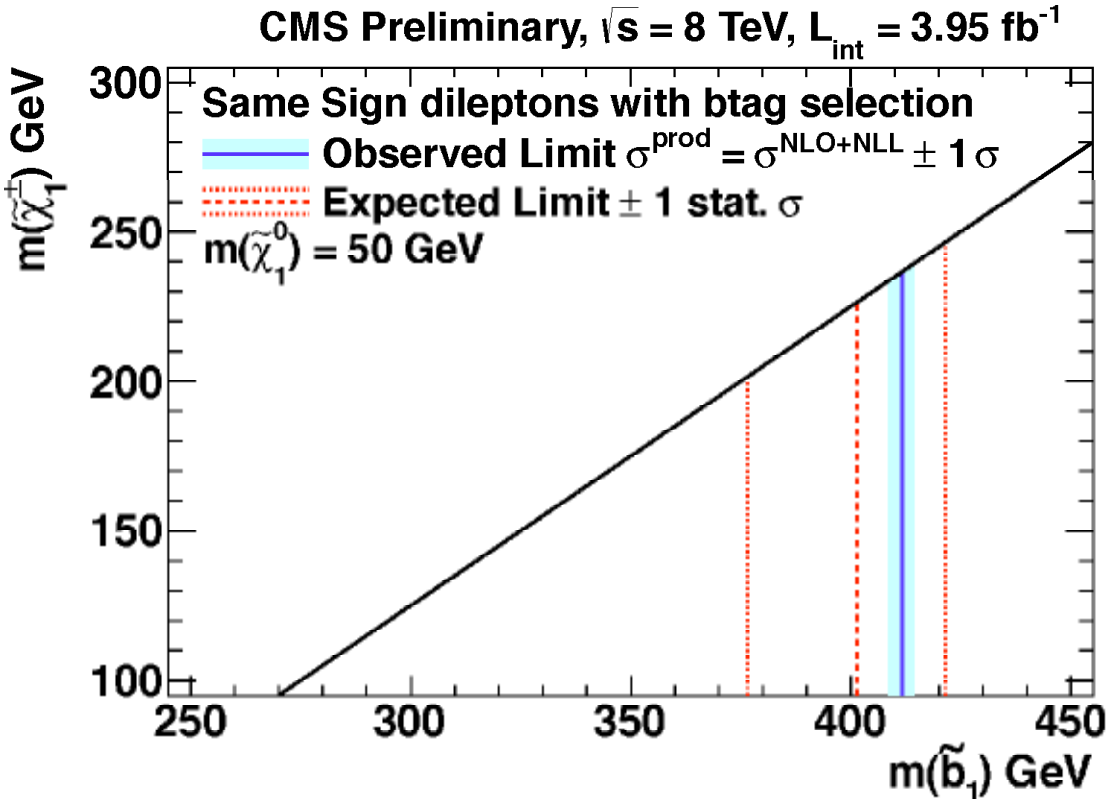


More dedicated searches in the works



Sbottom pair production

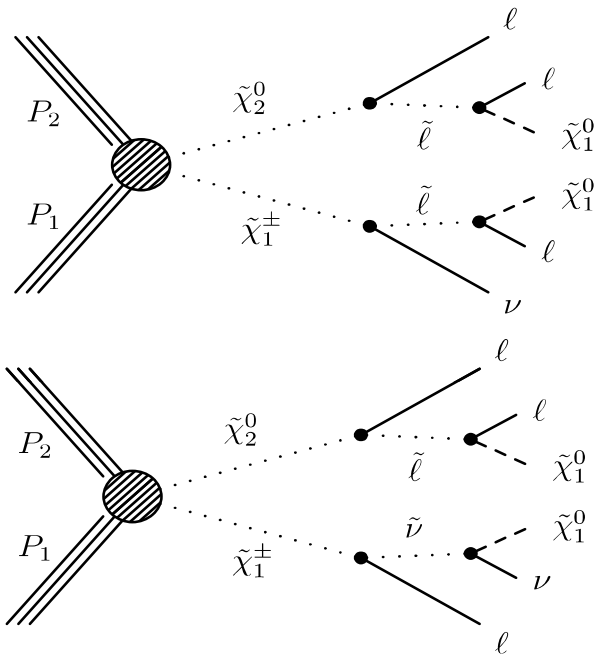




Early 8 TeV result

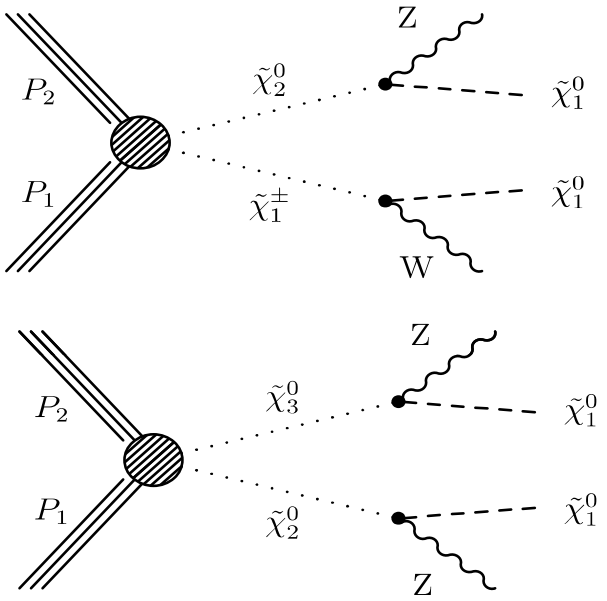
EWK production

Models with decays into sleptons



- Trilepton + MET final states
- Same-sign dileptons

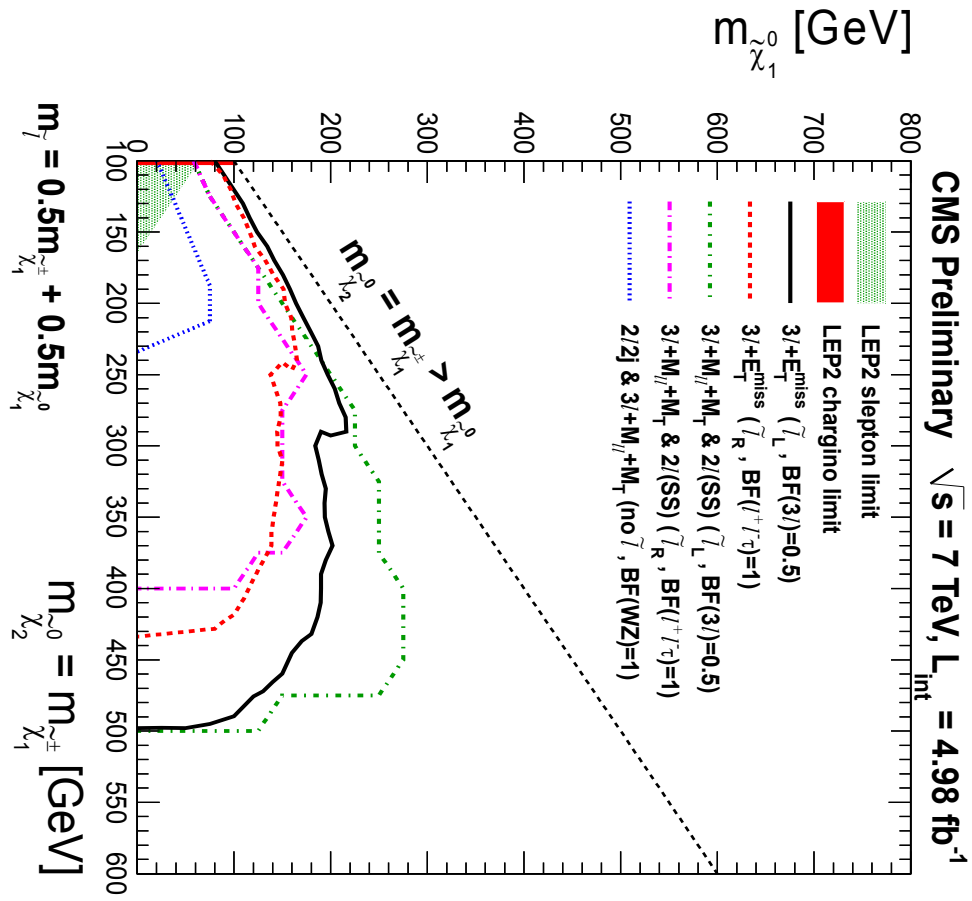
Models with decays into W and Z



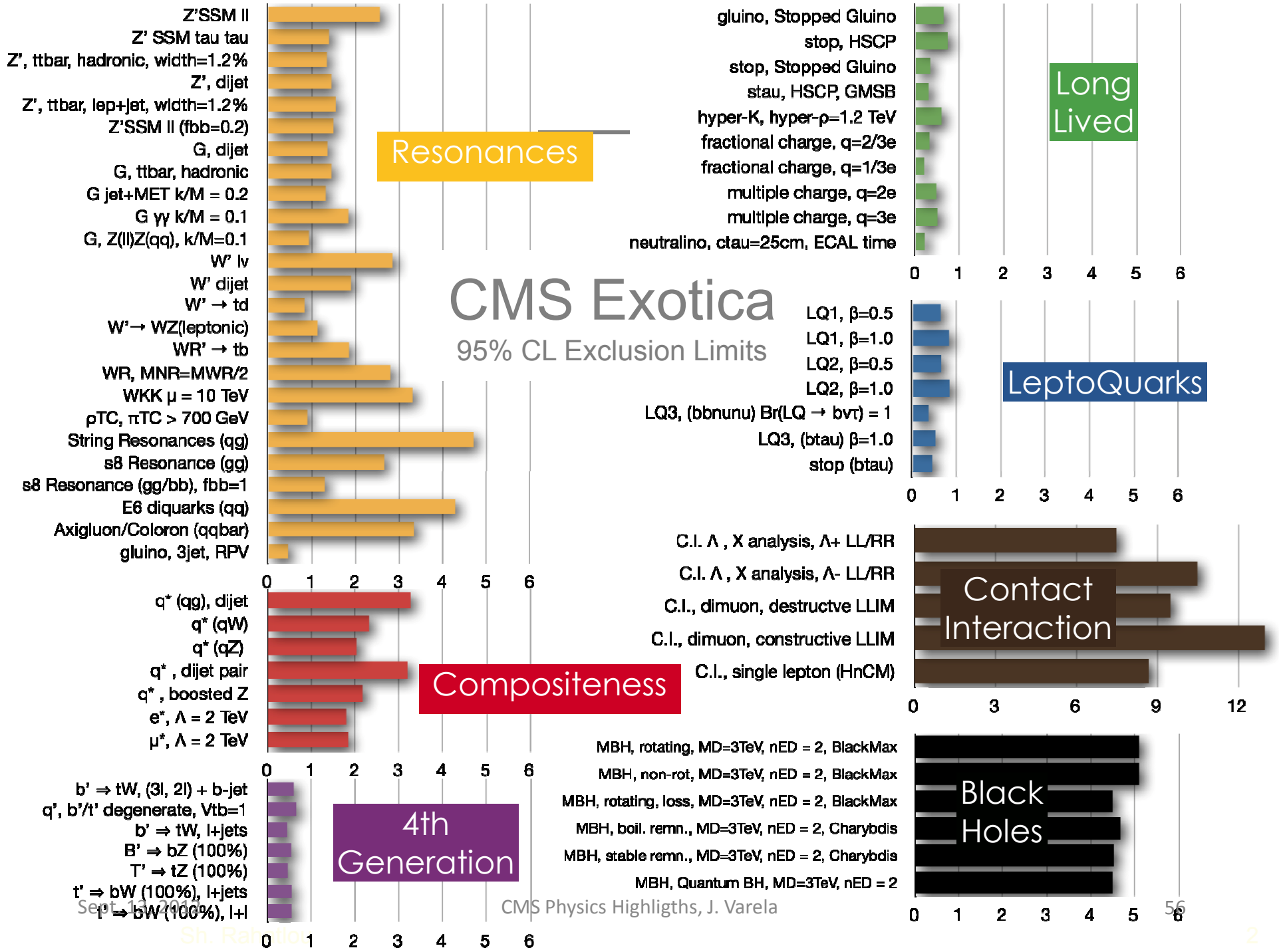
- Z→ℓℓ + ℓ + MET
- Z→ℓℓ + W/Z→jet-jet + MET
- Four leptons

$\chi^+\chi^0$ Limits

New 7 TeV result



2011-12 Datasets: Exotica

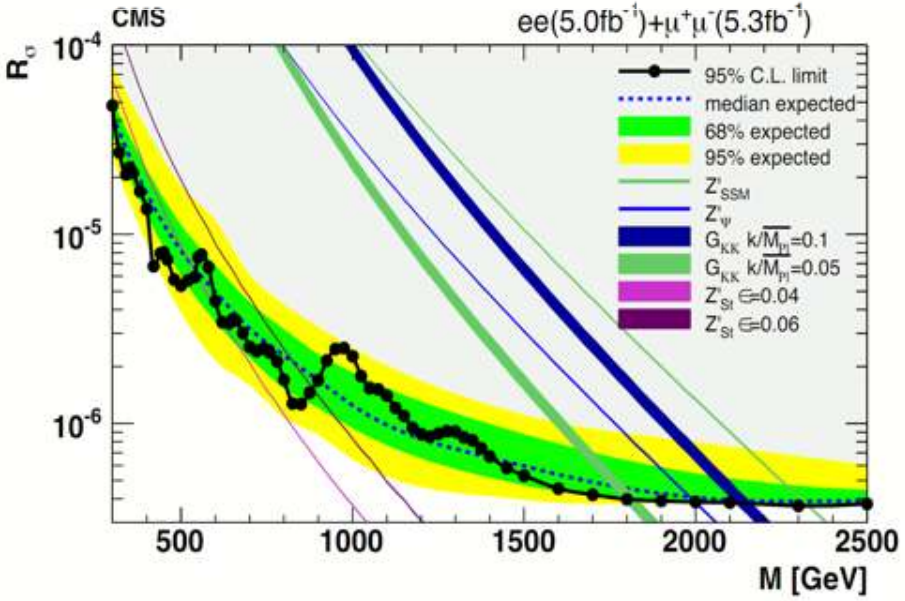

Z'SSM ll
Z' SSM tau tau
Z', ttbar, hadronic, width=1.2%
Z', dijet
Z', ttbar, lep+jet, width=1.2%
Z'SSM ll (fbb=0.2)
G, dijet
G, ttbar, hadronic
G jet+MET k/M = 0.2
G γγ k/M = 0.1
G, Z(ll)Z(qq), k/M=0.1
W' lν
W' dijet
W' → td
W'→ WZ(leptonic)
WR' → tb
WR, MNR=MWR/2
WKK μ = 10 TeV
ρTC, πTC > 700 GeV
String Resonances (qg)
s8 Resonance (gg)
s8 Resonance (gg/bb), fbb=1
E6 diquarks (qq)
Axigluon/Coloron (qqbar)
gluino, 3jet, RPV
Resonances
0 1 2 3 4 5 6
q* (qg), dijet
q* (qW)
q* (qZ)
q* , dijet pair
q* , boosted Z
e*, Λ = 2 TeV
μ*, Λ = 2 TeV
Compositeness
0 1 2 3 4 5 6
b' ⇒ tW, (3l, 2l) + b-jet
q', b'/t' degenerate, Vtb=1
b' ⇒ tW, l+jets
B' ⇒ bZ (100%)
T' ⇒ tZ (100%)
t' ⇒ bW (100%), l+jets
t' ⇒ bW (100%), l+l
4th Generation
0 1 2 3 4 5 6
CMS Exotica
95% CL Exclusion Limits
gluino, Stopped Gluino
stop, HSCP
stop, Stopped Gluino
stau, HSCP, GMSB
hyper-K, hyper-ρ=1.2 TeV
fractional charge, q=2/3e
fractional charge, q=1/3e
multiple charge, q=2e
multiple charge, q=3e
neutralino, ctau=25cm, ECAL time
Long Lived
0 1 2 3 4 5 6
LQ1, β=0.5
LQ1, β=1.0
LQ2, β=0.5
LQ2, β=1.0
LQ3, (bbnunu) Br(LQ → bντ) = 1
LQ3, (btau) β=1.0
stop (btau)
LeptoQuarks
0 1 2 3 4 5 6
C.I. Λ , X analysis, Λ+ LL/RR
C.I. Λ , X analysis, Λ- LL/RR
C.I., dimuon, destructve LLIM
C.I., dimuon, constructive LLIM
C.I., single lepton (HnCM)
Contact Interaction
0 3 6 9 12
MBH, rotating, MD=3TeV, nED = 2, BlackMax
MBH, non-rot, MD=3TeV, nED = 2, BlackMax
MBH, rotating, loss, MD=3TeV, nED = 2, BlackMax
MBH, boil. remn., MD=3TeV, nED = 2, Charybdis
MBH, stable remn., MD=3TeV, nED = 2, Charybdis
MBH, Quantum BH, MD=3TeV, nED = 2
Black Holes
0 1 2 3 4 5 6

Z’ in 2011 Data?

- Search for Z-like narrow resonances decaying to dileptons
- Interesting features in dilepton spectra
  - around 2σ each for CMS & ATLAS in e+μ
  - similar in scale to 2011 Higgs excess

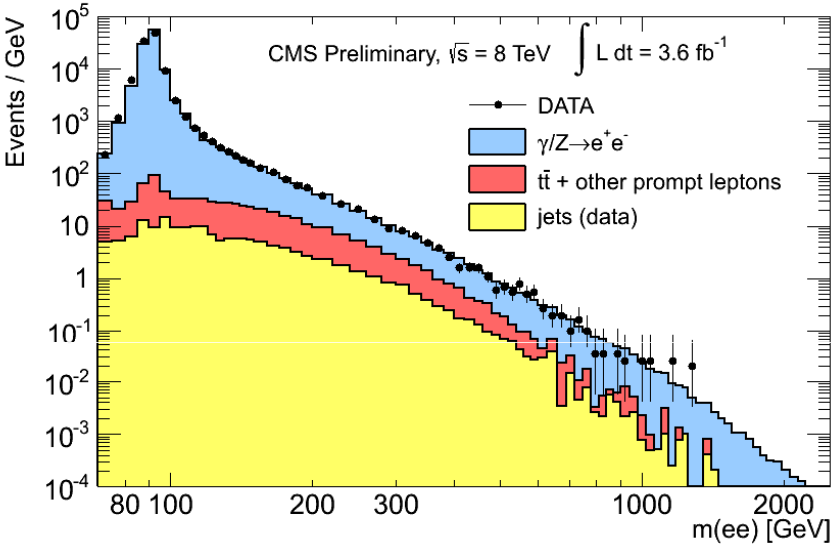
[hep-ex 1206.1849]

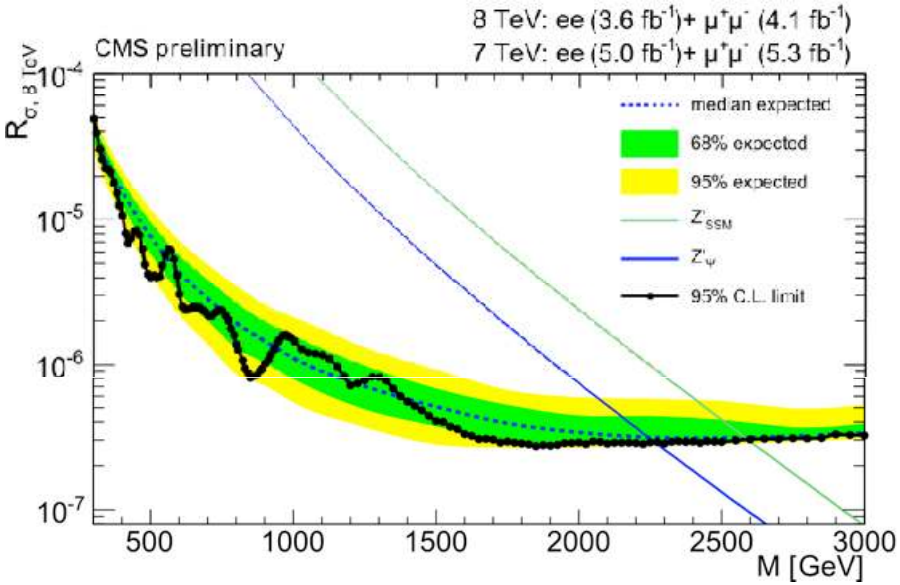
$$R_\sigma = \frac{\sigma(pp \to Z' + X \to \ell\ell + X)}{\sigma(pp \to Z + X \to \ell\ell + X)}$$



Today: Z’ in 8 TeV Data

CMS EXO-12-015





Limits on the combined 7 TeV and 8 TeV data from 2011+2012

- $M(Z'_{SSM}) > 2590$ GeV at 95% C.L.
- $M(Z'_{\psi}) > 2260$ GeV at 95% C.L.

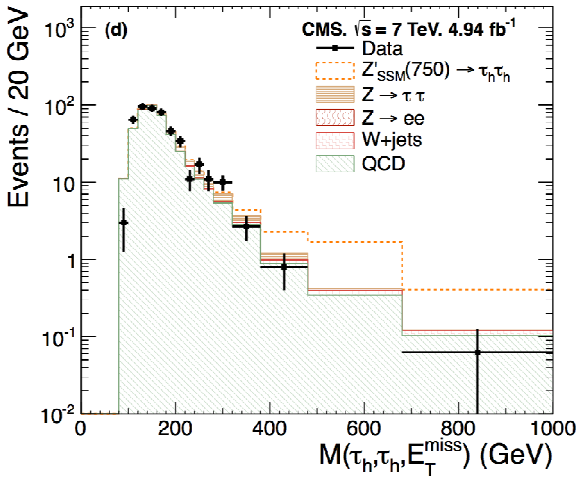
Excess just below 1 TeV all but gone in CMS data

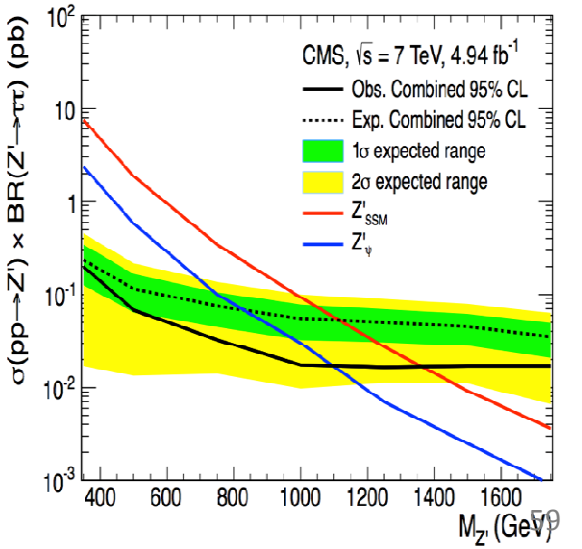
Z' → | | (7 TeV data)

[CMS EXO-11-031, hep-ex 1206.1725]

- Z' might couple preferentially to third-generation fermions
  - 5 fb-1 at √s = 7 TeV
  - Study: |e|μ, |e|h, |μ|h, |h|h
  - plot effective (visible) mass
- Backgrounds:
  - DY Z → | |, W+jets, tt, VV, QCD
  - estimated from data where possible

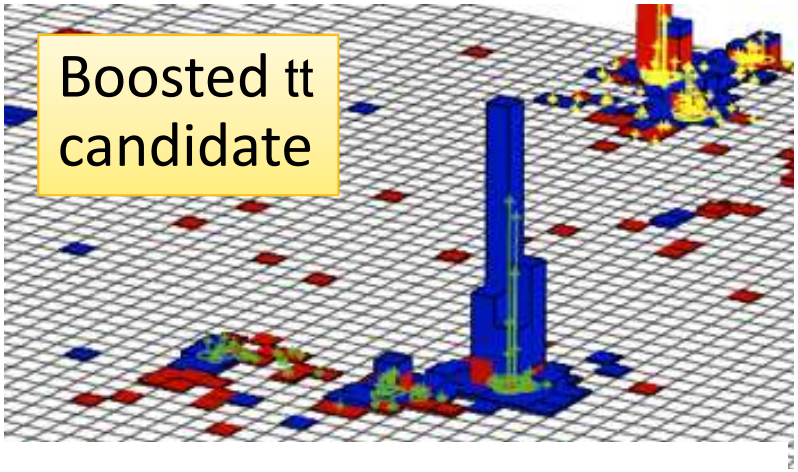
M(Z'$_{SSM}$)	expected	observed
CMS	> 1.1 TeV	> 1.4 TeV
ATLAS	> 1.4 TeV	> 1.3 TeV

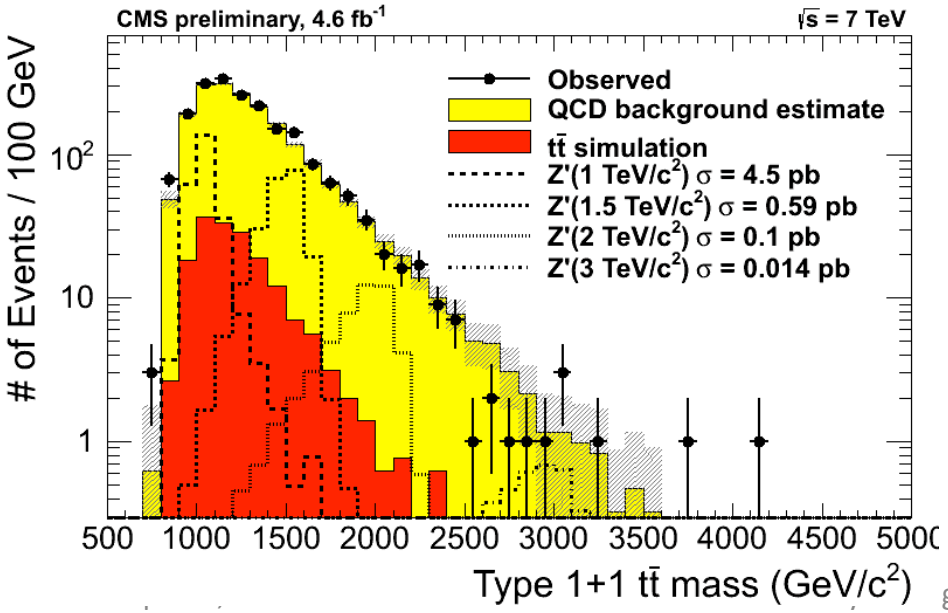


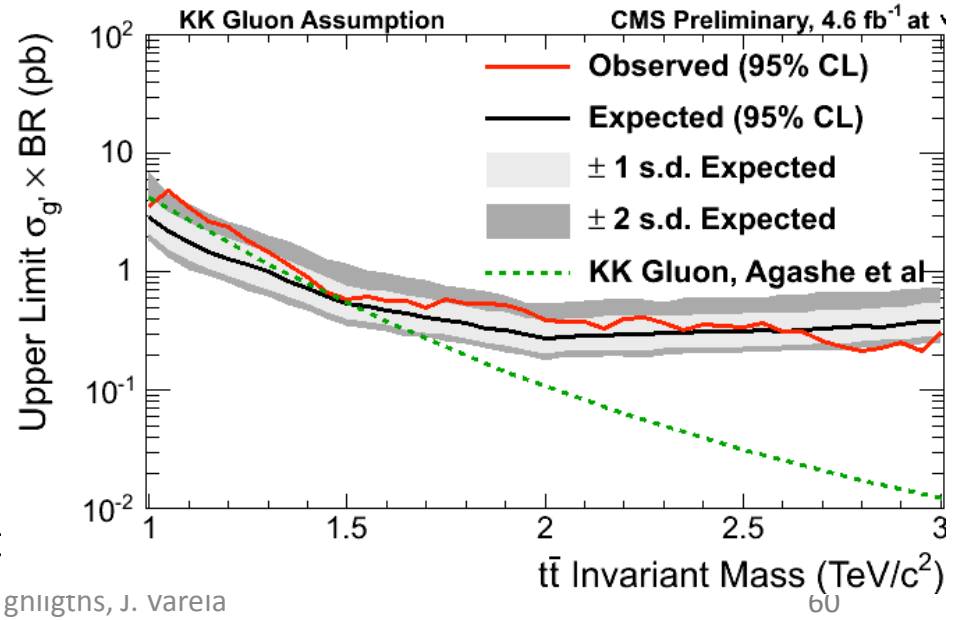


Boosted top pairs

- Boosted top events
  - Pioneered by CMS
  - Strong limits on Kaluza-Klein gluons and Z' -like objects decaying to top pairs



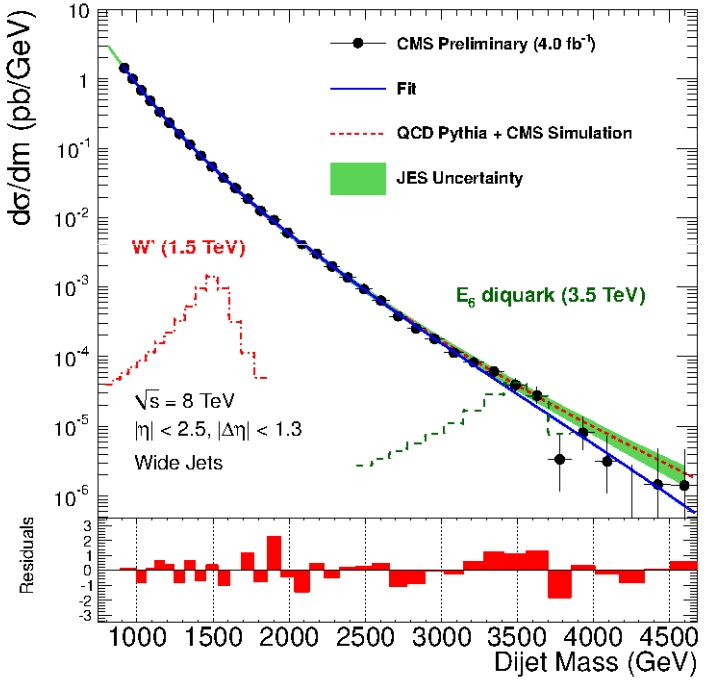




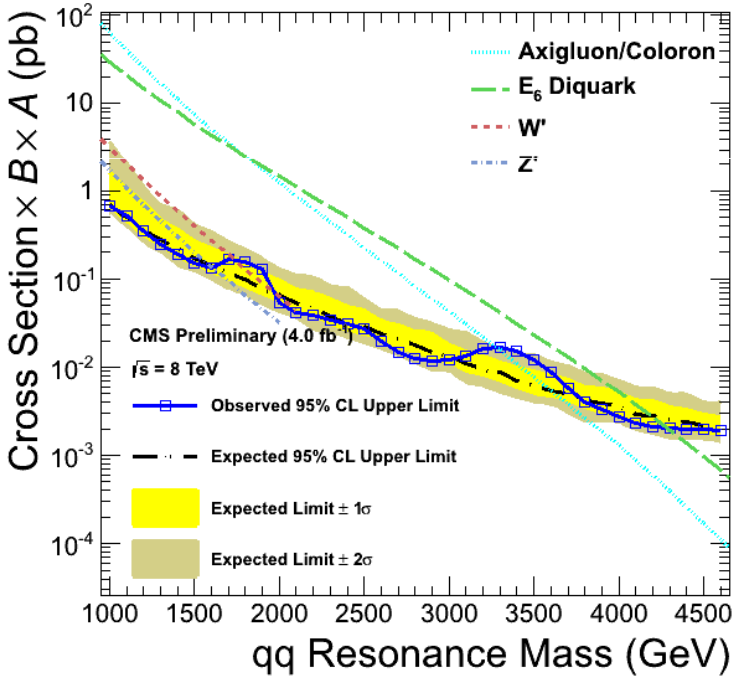
Dijets in 8 TeV Data

- Search for dijet resonance in smoothly falling mass spectrum
  - leading jet mass m_{jj} > 0.9-1 TeV from trigger and other constraints
  - Background estimated from smooth functional fit

[CMS PAS EXO-12-016]

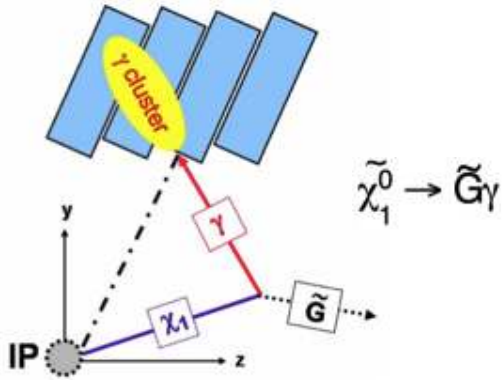


$$\frac{d\sigma}{dm_{jj}} = \frac{P_0(1-x)^{P_1}}{x^{P_2+P_3\ln(x)}}$$

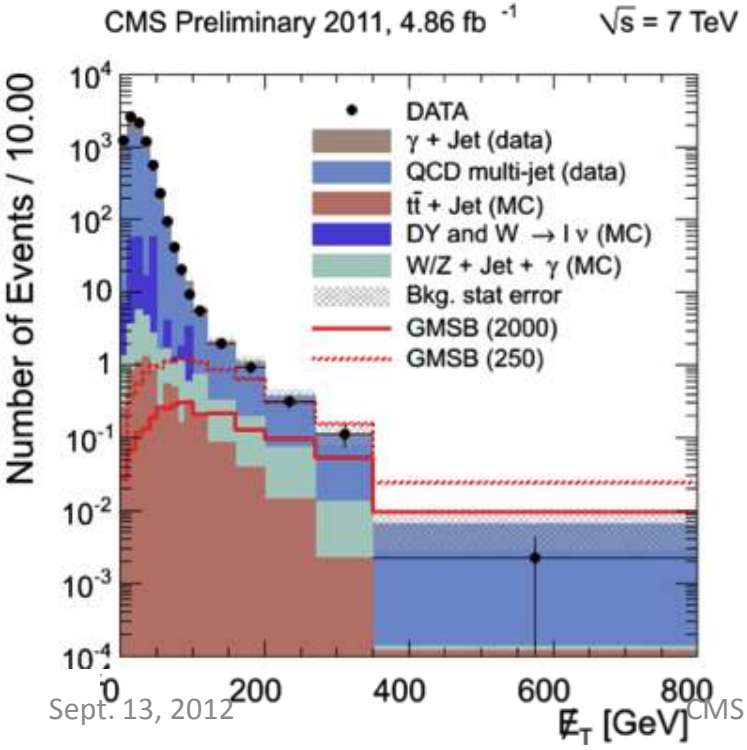


GMSB with Displaced Photon

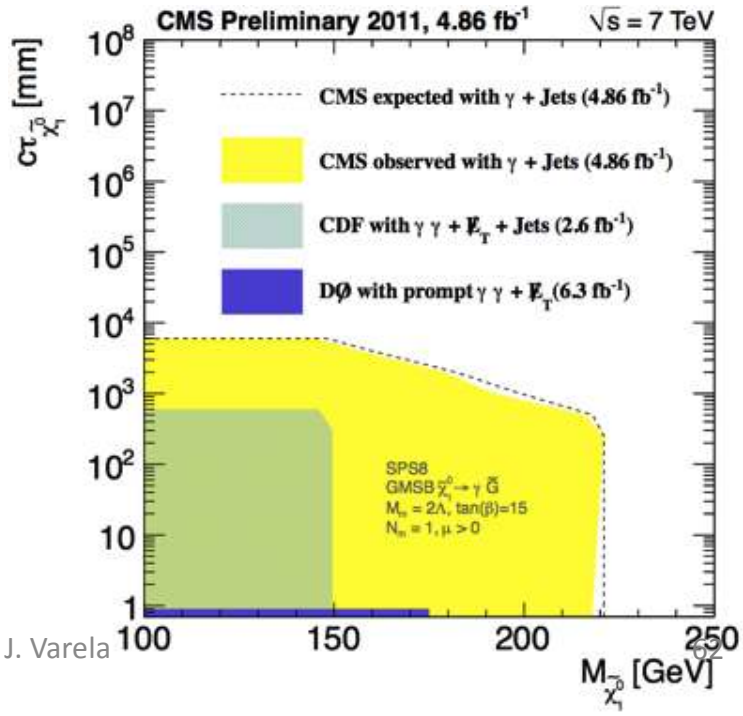
- GMSB (SUSY) decays typically include many jets
- Selection: photon with $E_T > 100$, three jets with $p_T > 35$
  - relaxed ECAL timing and shower-shape cuts
  - E_T^{miss} and ECAL timing main discriminants



Much-improved sensitivity to long-lived neutralino

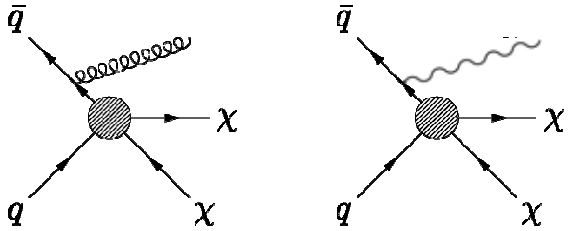


[CMS PAS EXO-11-035]



Monojet and Monophoton

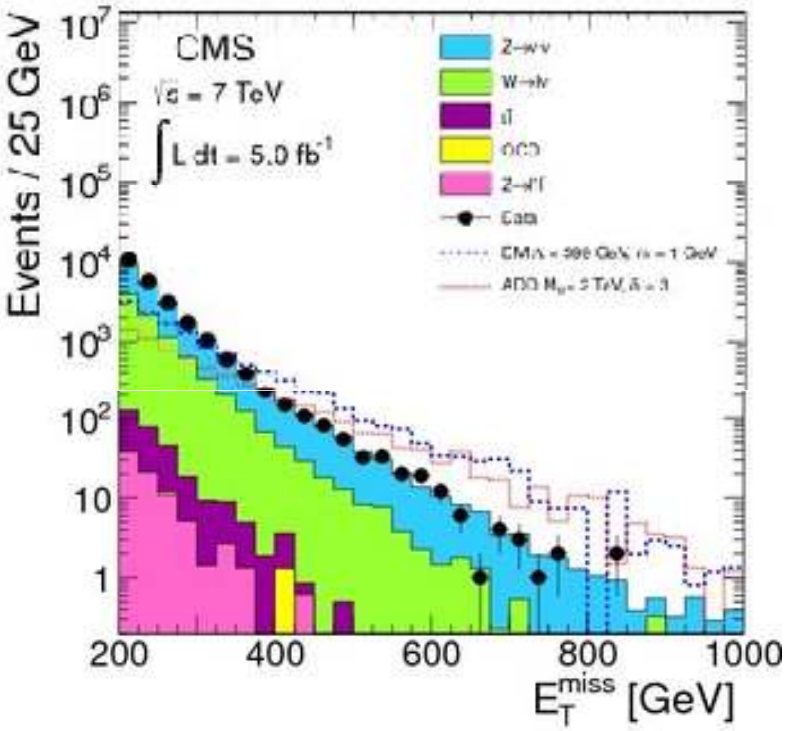
- Look for missing energy and radiated jet (photon)



- Monojet Selection:
  - Leading jet pT > 120 GeV, |η| < 2
  - allow a second jet if not back-to-back
  - veto isolated leptons

- Backgrounds and Uncertainties
  - Z + (jets/γ) --> νν+(jets/γ)
  - W + (jets/γ) --> lν+(jets/γ)
  - smaller backgrounds from top, QCD, non-collision

- Missing Energy (ETmiss) to distinguish signal



Dark Matter and Monojets

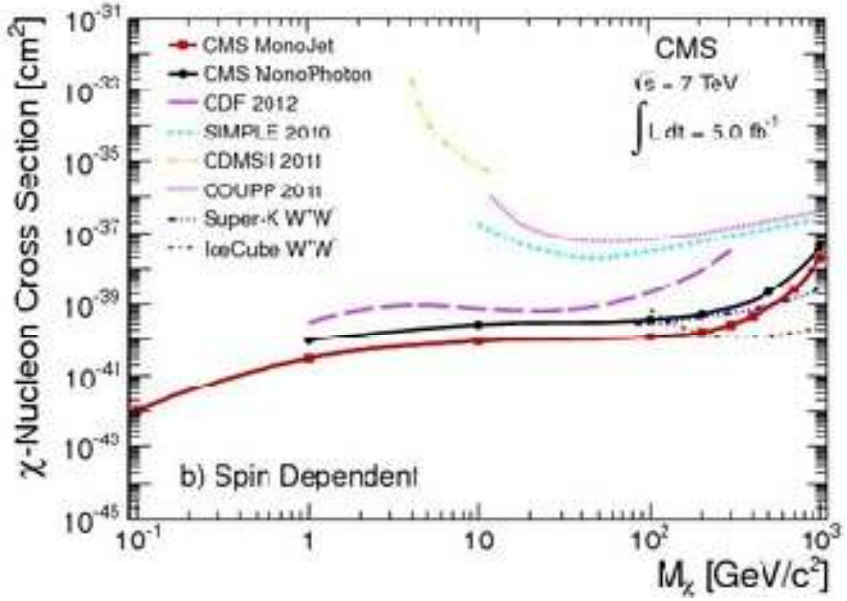
Spin-dependent couplings

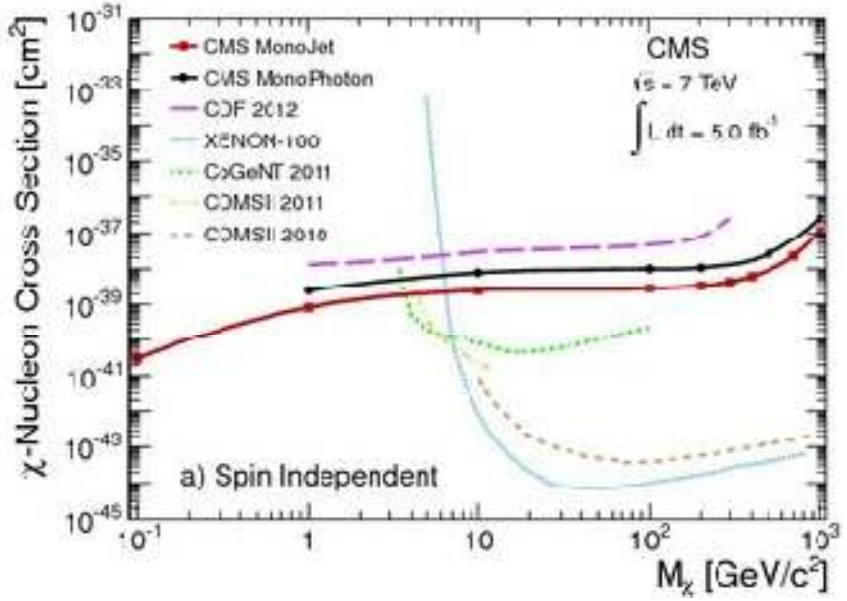
- Limits extend well below Direct DM (DD) searches

Spin-independent couplings

- competitive at low masses where nuclear recoil imposes a threshold for detection in DD case

[CMS EXO-11-059]



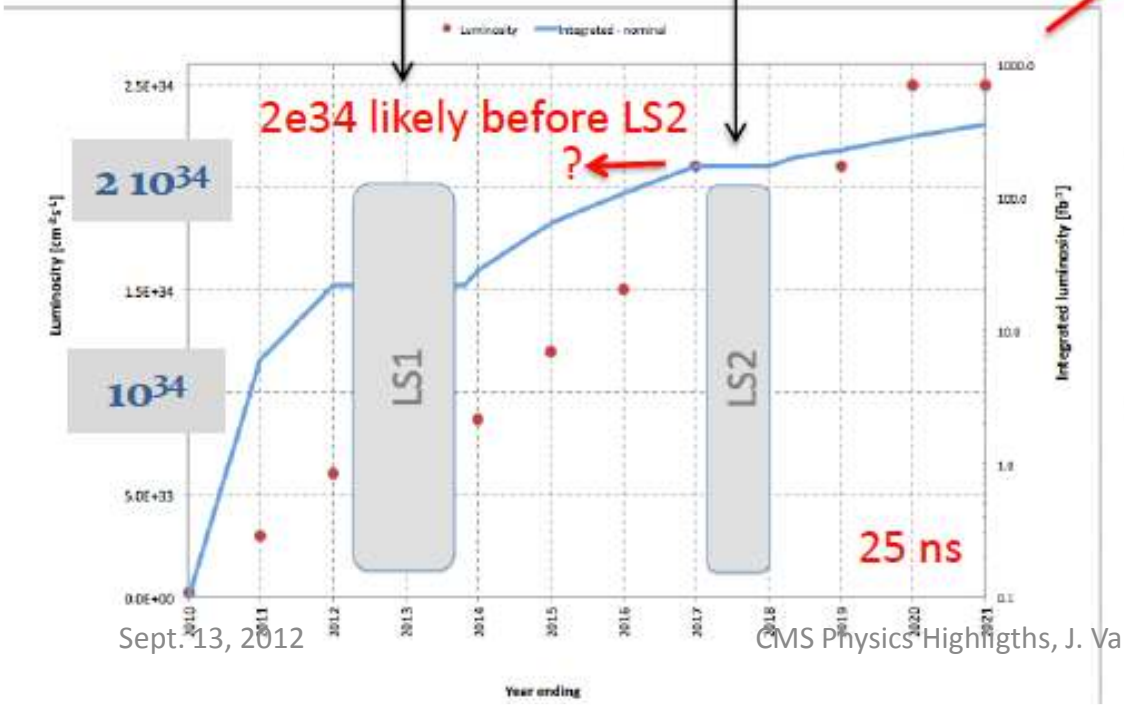


Prospects

LHC Schedule

25-30 fb^{-1} — **Phase 1 : 13/14 TeV 3-500 fb^{-1}** — **Phase 2 : 13/14 TeV - 3000fb^{-1}**

12	LS1 13-14	LS2 18 (19?)	LS3 22-23	>30…
7 10^{33}Hz/cm^2 @50 ns	8→13/14 TeV Injection upgrade: PS batch compression SPS scrubbing	Injection upgrade: Linac4 (H^-) PSB-PS 1.4→2GeV RF upgrades PS - SPS aC coating SPS (?)	LHC Interaction region upgrade: Triplets (lower β*) Crab cavities (beam crossing leveling) b-b compensation (lower beam loss) L_{peak} 10^{35} Hz/cm^2 $L_{leveled}$ 5 10^{34} Hz/cm^2	



- Goal is 25ns, 50ns not ruled out
- Performance projection and schedule will likely not be well known before restarting in 2015
- Leveling mitigates pile-up but integrated luminosity could be limited due to SEE & UFOs effects

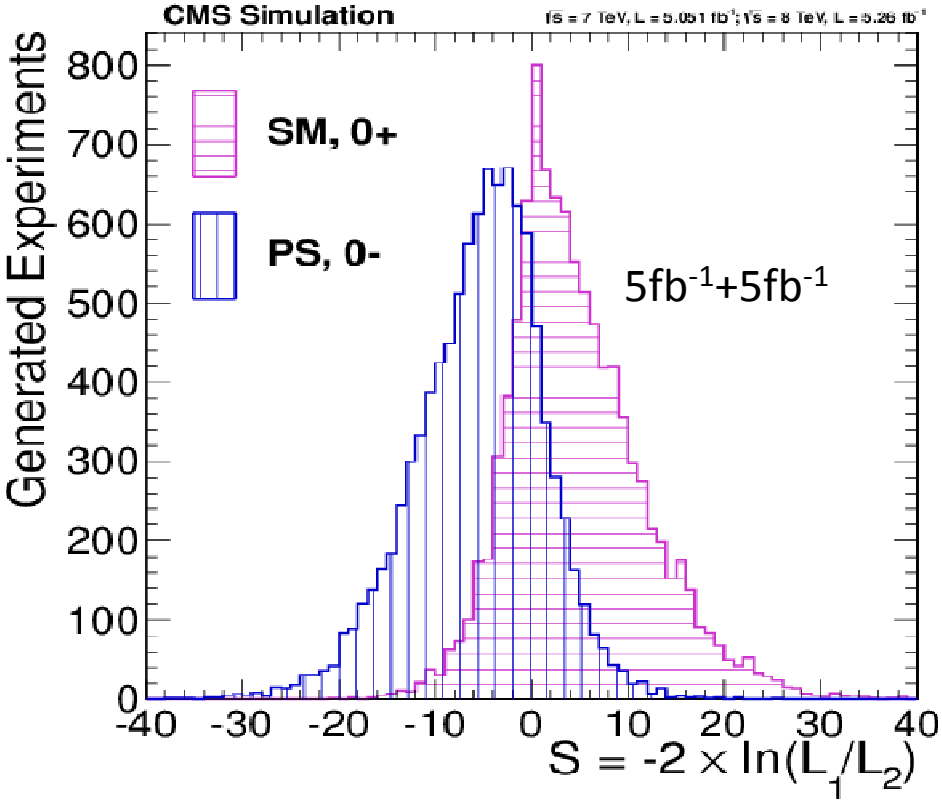
LHC phases

Scenario	L (fb^{-1})	E (TeV)
LHC (2012)	30	8
LHC (2021)	300	14
HL-LHC	3000	14
HE-LHC	300	33

Expectations on parity analysis

$$\mathrm{psMELA} = \left[1 + \frac{\mathcal{P}_{0^-}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}{\mathcal{P}_{0^+}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}\right]^{-1}$$

LHC 2012

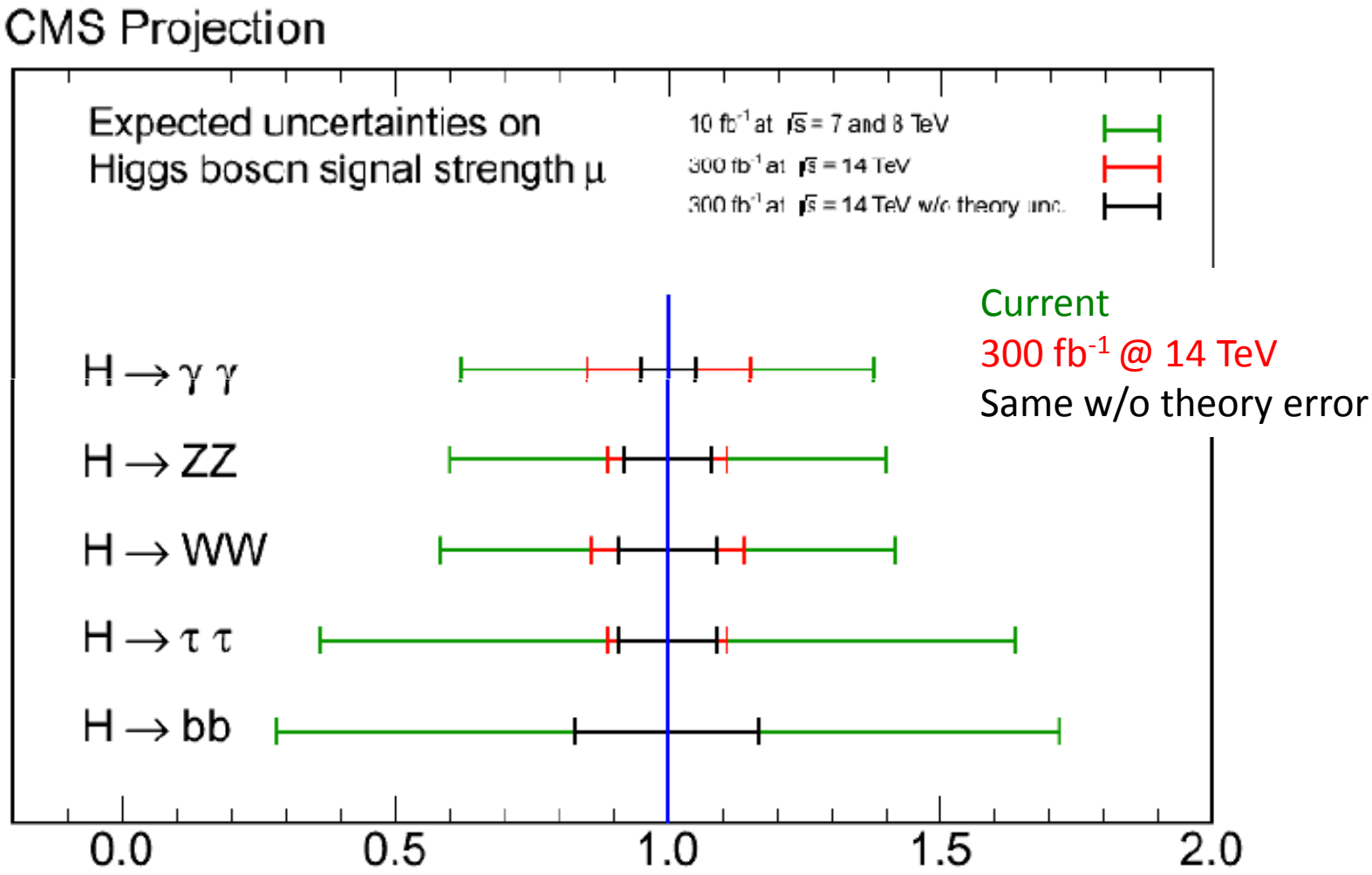


Very preliminary!

Expected separation between 0^+ and 0^- hypotheses:

- 1.6σ with July 2012 sample
- 3.1σ with 5+30 fb^{-1} sample expected by end of 2012 run
- 4.4σ combining ATLAS and CMS

Projected Signal Strength Precision

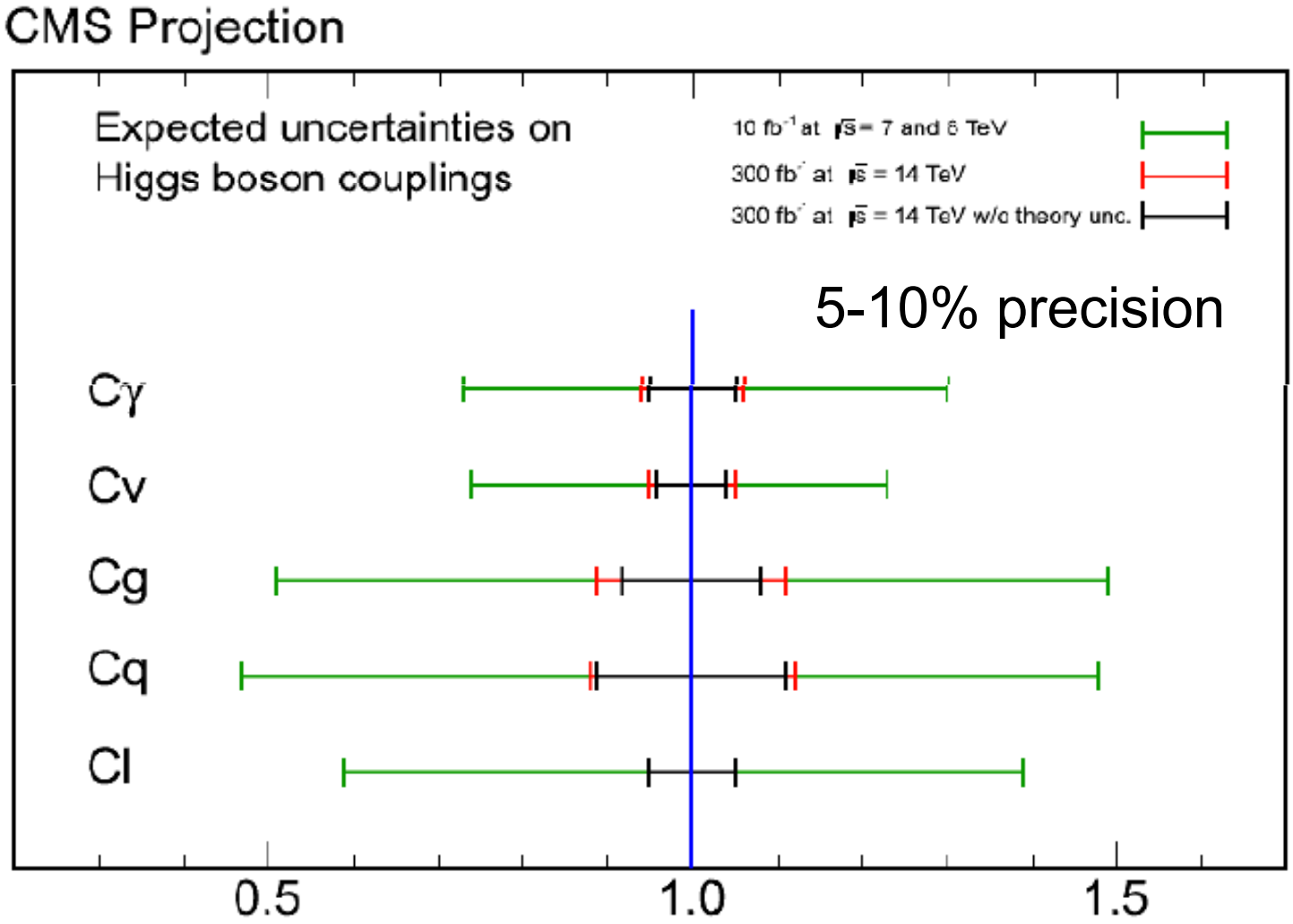


Current

300 fb^{-1} @ 14 TeV

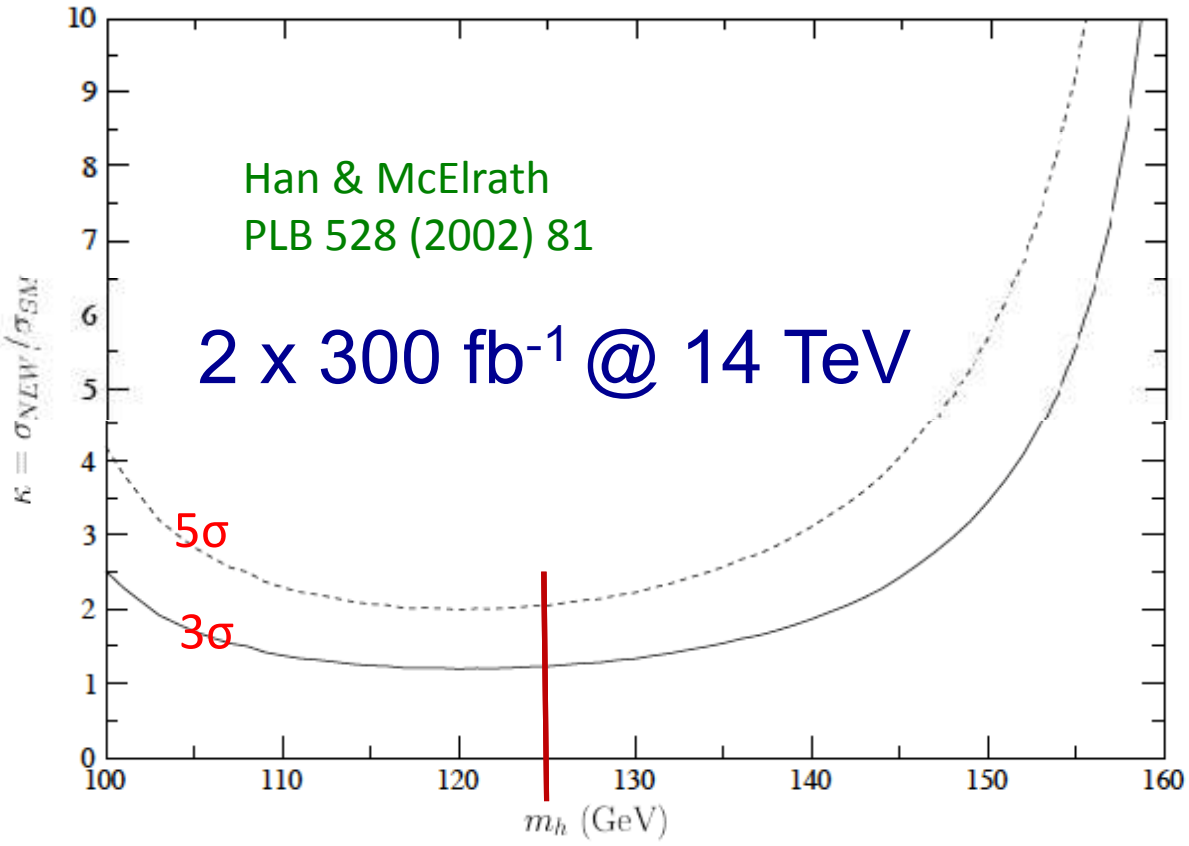
Same w/o theory error

Higgs couplings



H→μμ

Would like to see example of Higgs coupling to a 2nd generation fermion.



Enhancement relative to SM needed to see signal in H→μμ

Higgs Self Coupling

- Probing the Higgs potential itself is an essential piece of the future program.
- Do this through the study of multiple Higgs production.
- Most straightforward approach uses

$$gg \to HH \to W^+W^-W^+W^- \to \ell^\pm \nu jj \ell^\pm \nu jj$$

but this runs out of gas for $M_H < 140$ GeV

- For lower M_H=125 GeV use

$$gg \to HH \to \begin{array}{l} b\bar{b}\gamma\gamma \\ \\ b\bar{b}\mu\mu \end{array}$$

Likely needs the 33 TeV machine

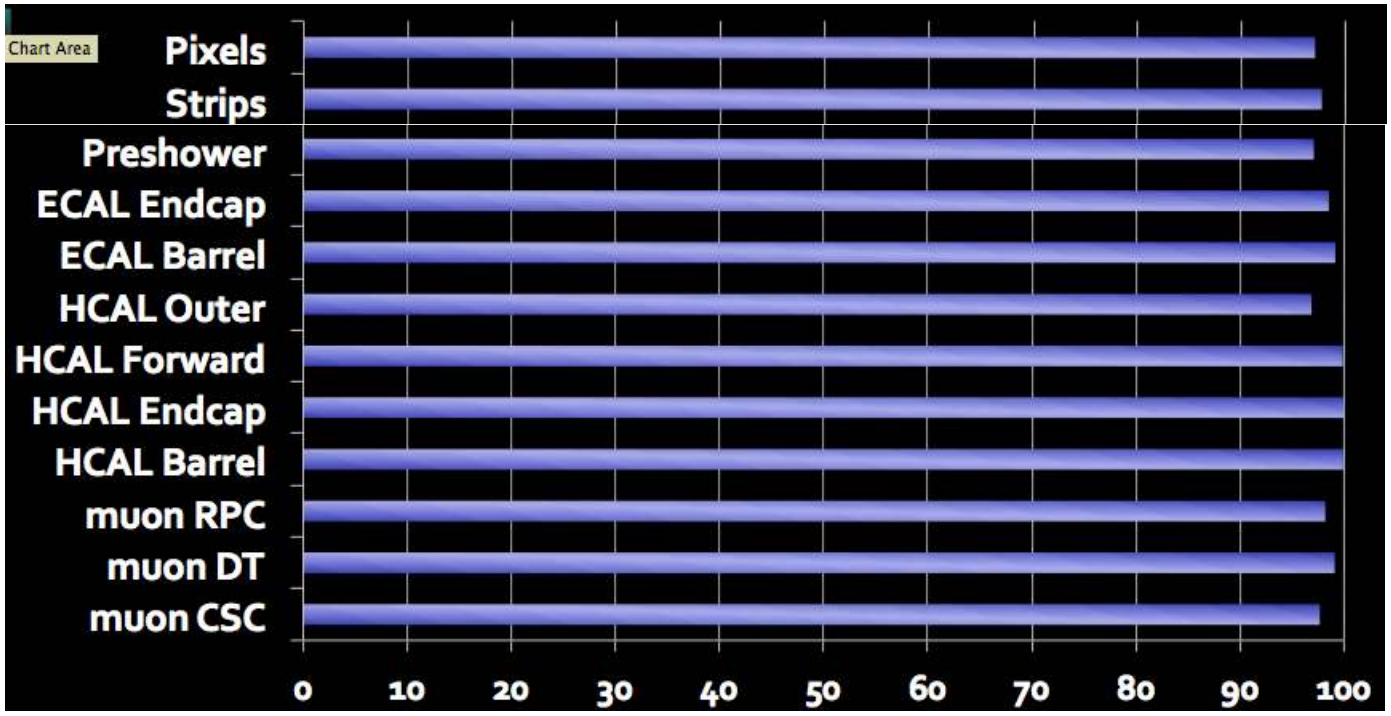
Conclusions

- Impressive performance of the standard model describing the LHC data. This is a tribute to decades of hard and rigorous theoretical work.
- Discovery of new boson with Higgs-like properties at 125 GeV is a major accomplishment for the field. Much remains to be done to confirm (or refute) the Higgs interpretation.
- CMS probed a wide variety of SUSY-motivated final states. Nothing found so far, but developed detailed understanding of BG. Transitioning to targeted searches optimized for specific models (e.g. natural SUSY, RPV)
- Nothing found either in many other searches for new physics.
- CMS will work hard to exploit every possible corner of phase space: no stone should be left unturned.

BACKUP

Operational Efficiency

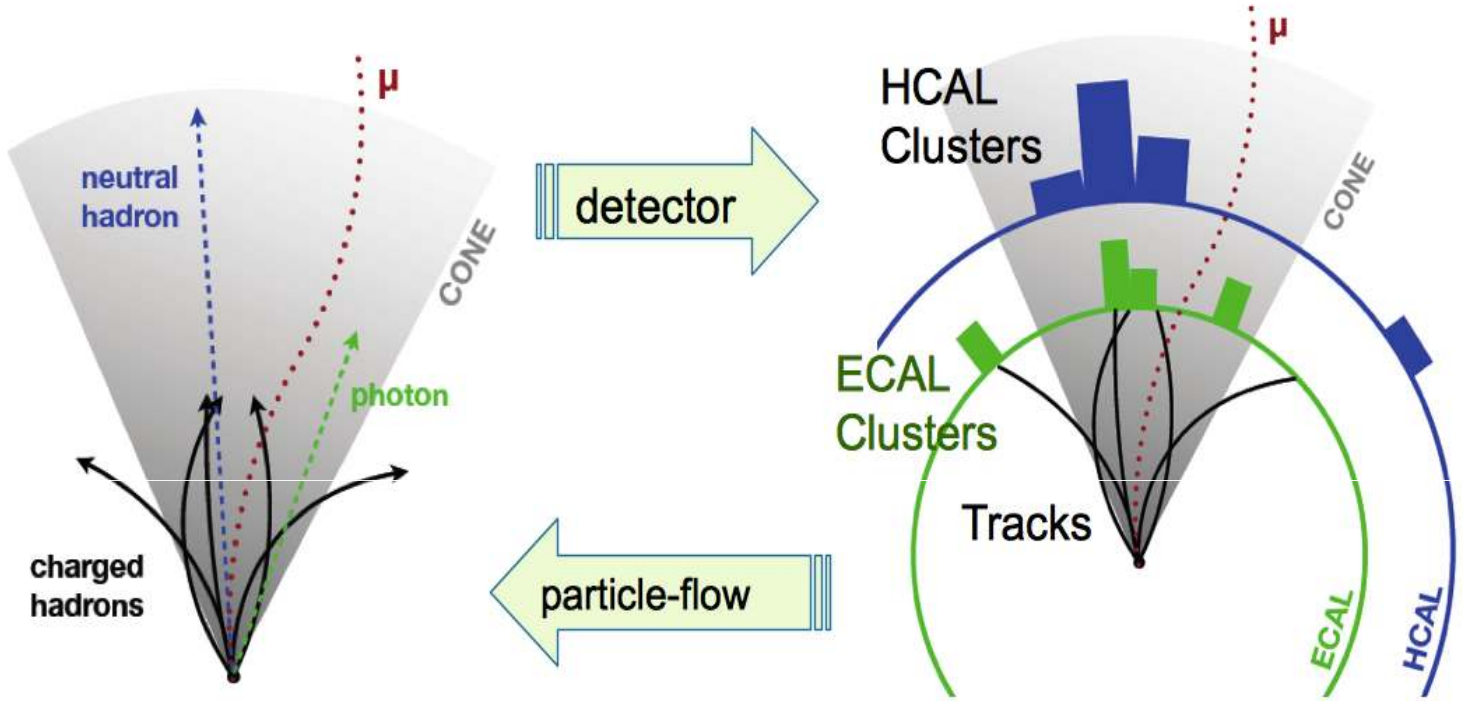
- Thus far in 2012, CMS has recorded 93% of the luminosity delivered by the LHC. Of that 85% is certified as “golden” (good for physics).



The fraction of working channels is >98%

Event Reconstruction

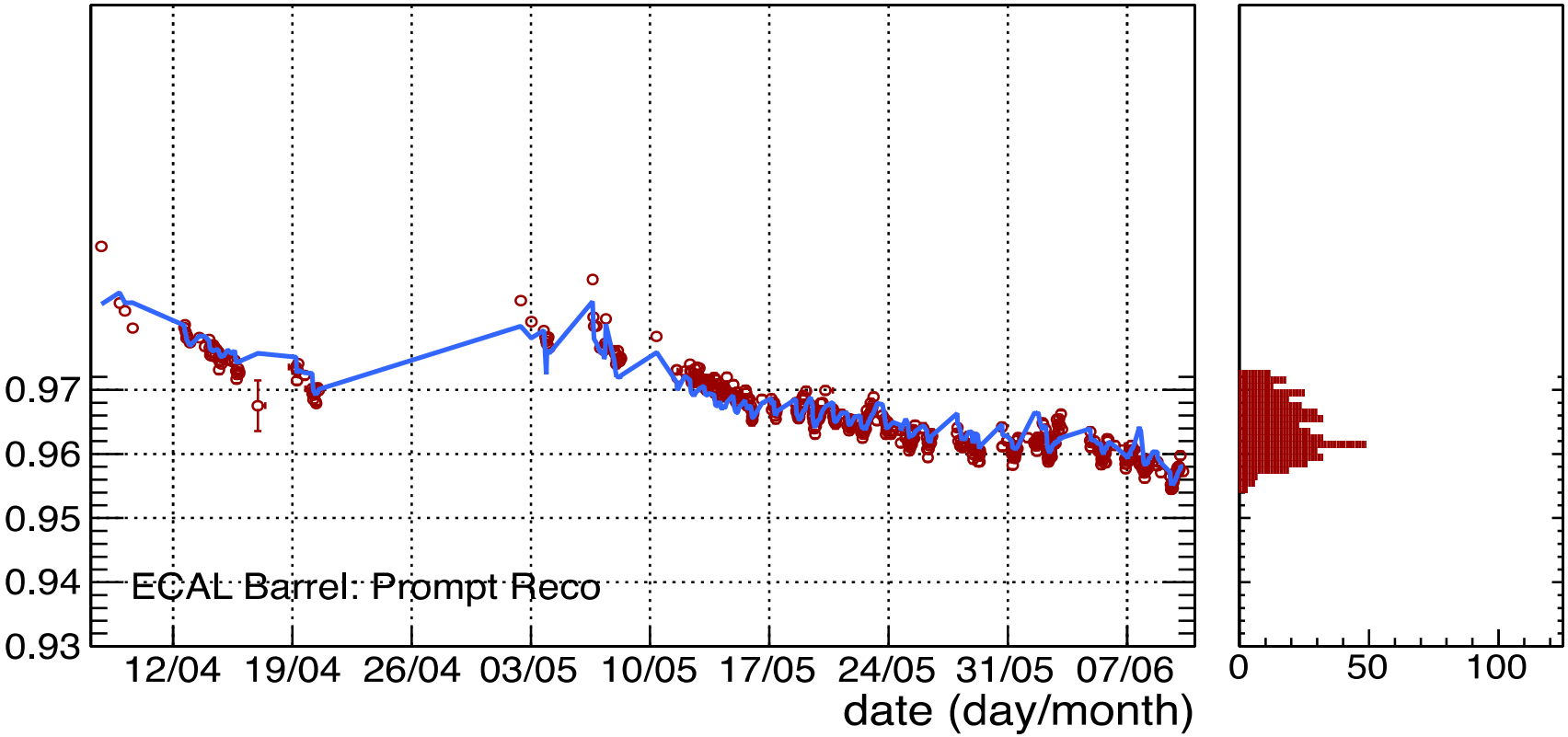
Particle Flow



Stable particles in the event are reconstructed by a sophisticated algorithm that combines information from all sub-detectors.

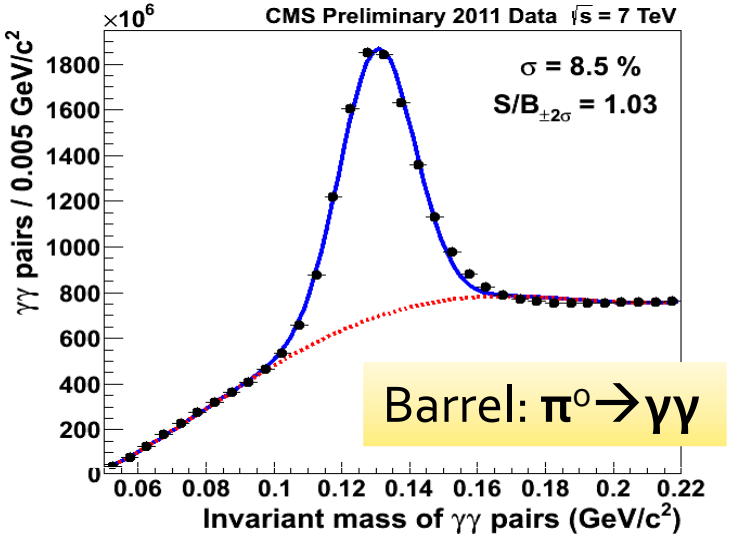
This exploits the fine-grained nature of CMS.

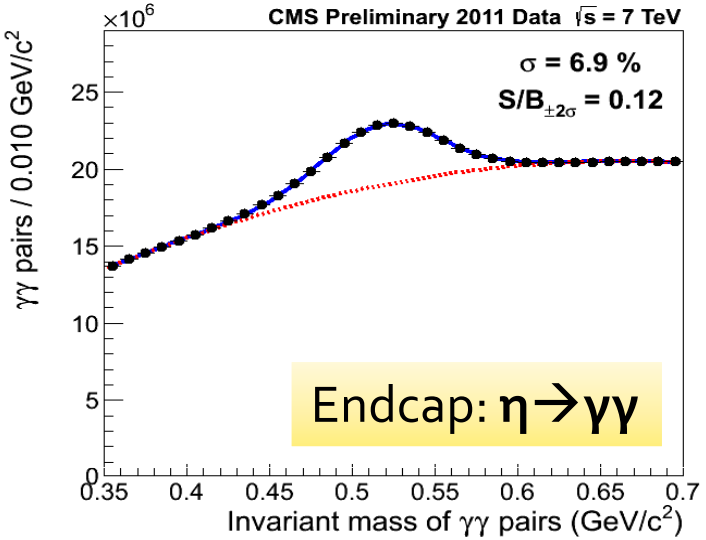
EM Calorimetry

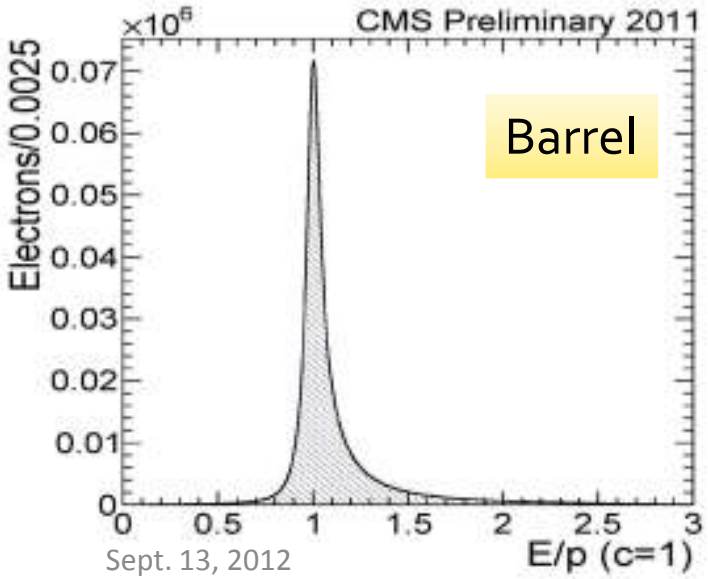


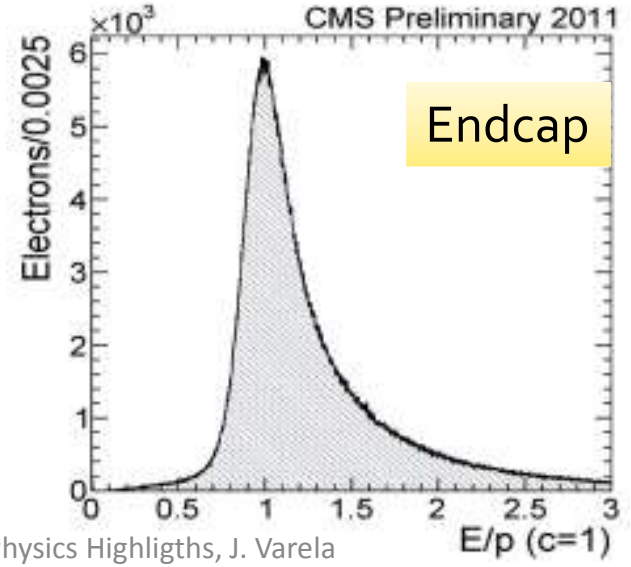
Light monitoring corrections are used to greatly improve the temporal stability.

Photons (EM Calorimetry)





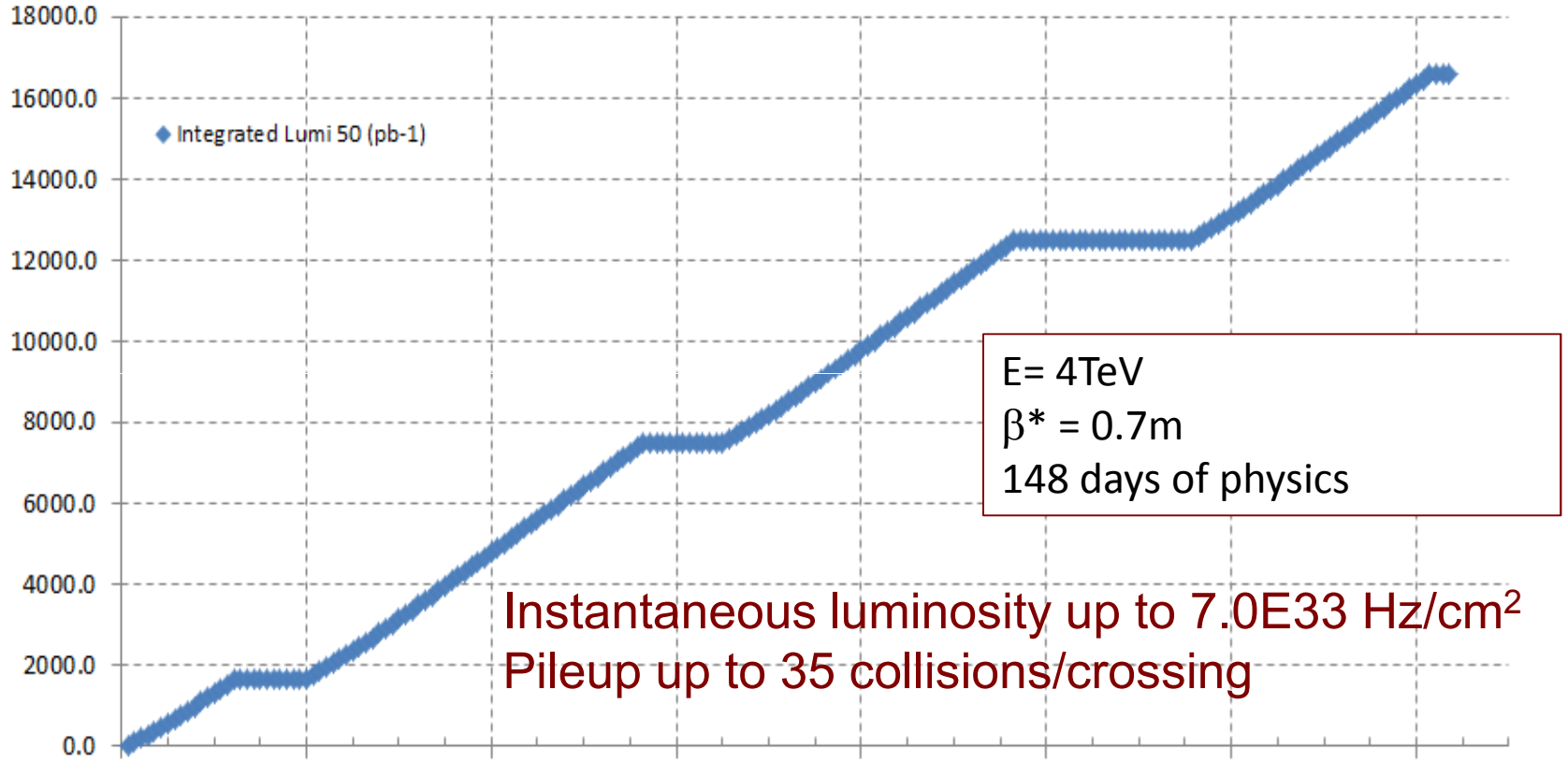




Calibration is a key issue for $H \rightarrow \gamma\gamma$

Expected Integrated Luminosity in 2012

Steve Myers

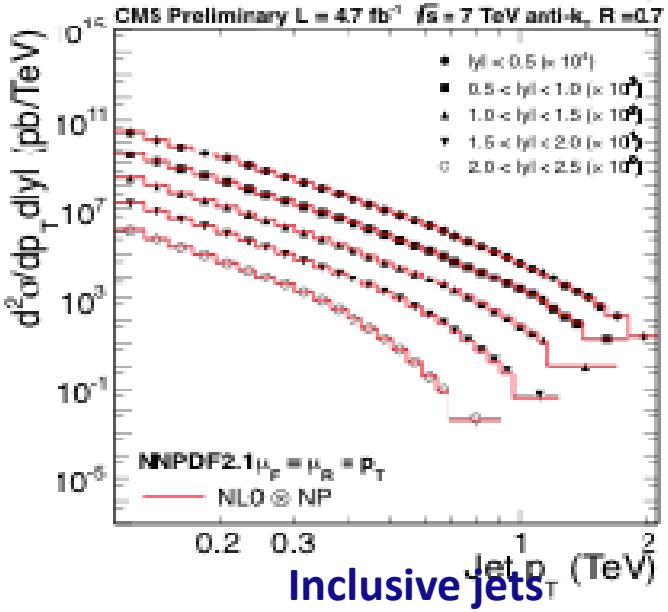


Reasonable to expect that the integrated luminosity estimate is conservative
(β^*=0.6 m may be possible, other improvements)

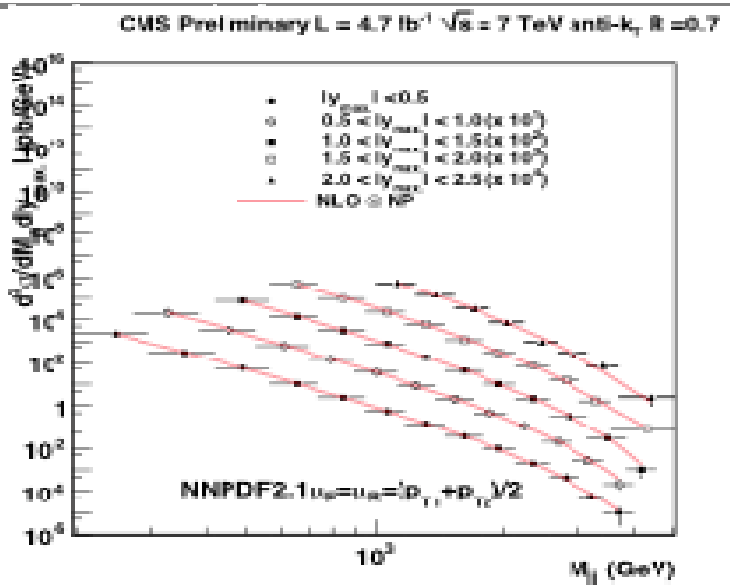
2012 HLT 5E33 Menu Highlights

(Unprescaled) Object	Trigger Threshold (GeV) @ 5E33
Single Muon	40 (|eta| < 2.1)
Single Isolated muon	24 (|eta| < 2.1)
Double muon	(17, 8)
Single Electron	80 (30 GeV for “parked” data)
Single Electron +pfMHT	32
Double Electron	(17, 8)
Single Photon	135
Double Photon	(36, 22)
Muon + Ele x-trigger	(17, 8), (5, 5, 8), (8, 8, 8)
Single PFJet	320
QuadJet	80
Six Jet	(4 x 60, 2 x 20)
PFMET	150
HT	750

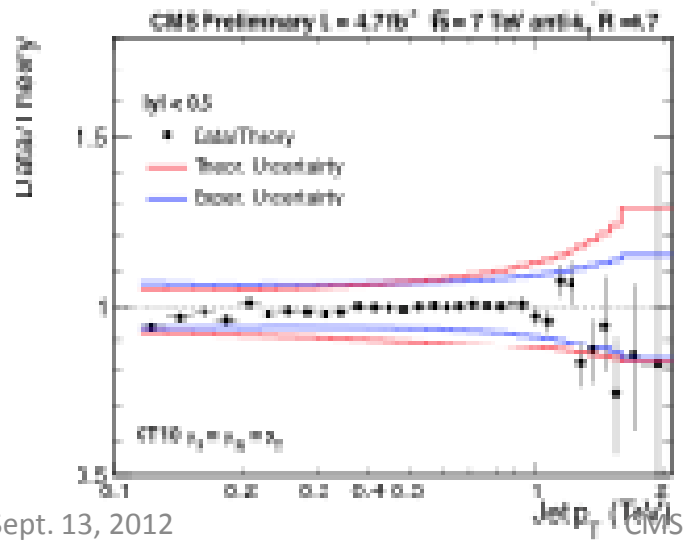
Jet Studies with 2011 Dataset

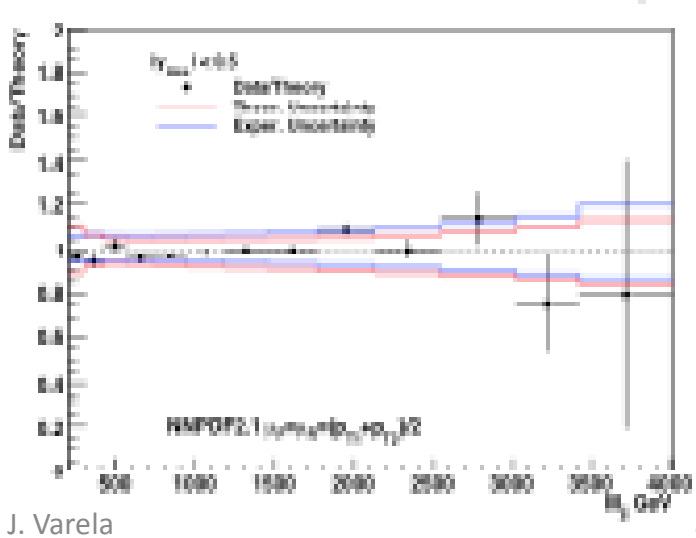


Inclusive jets

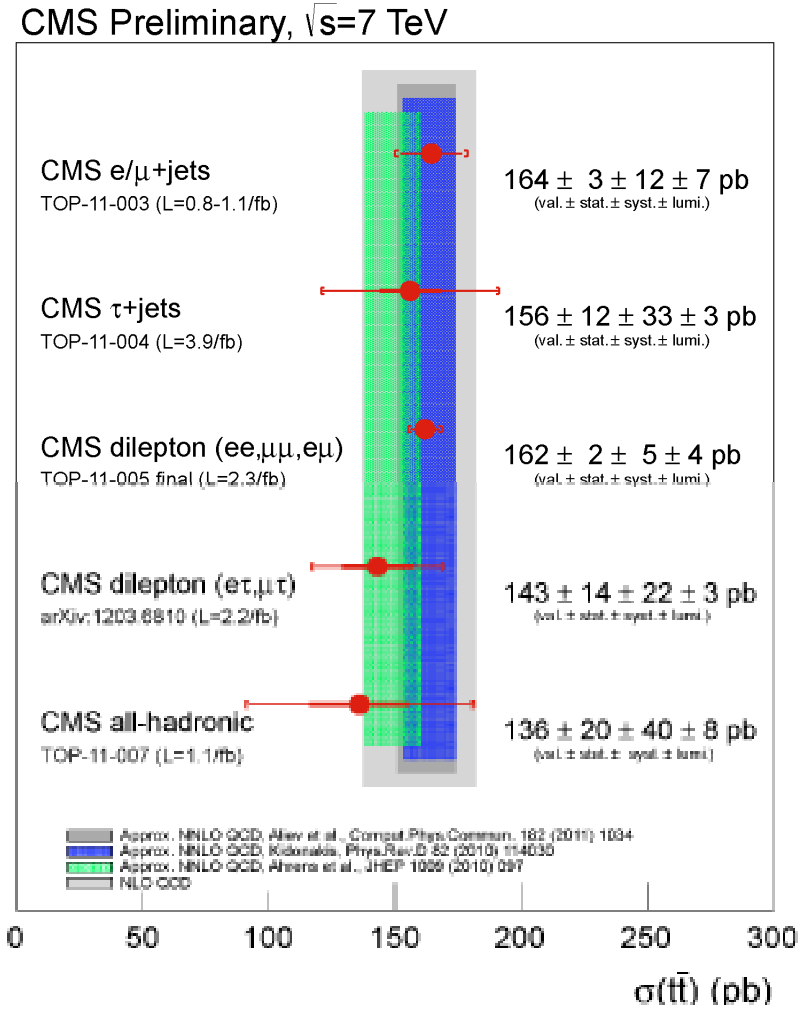


Dijets





Top pair production at 7 TeV



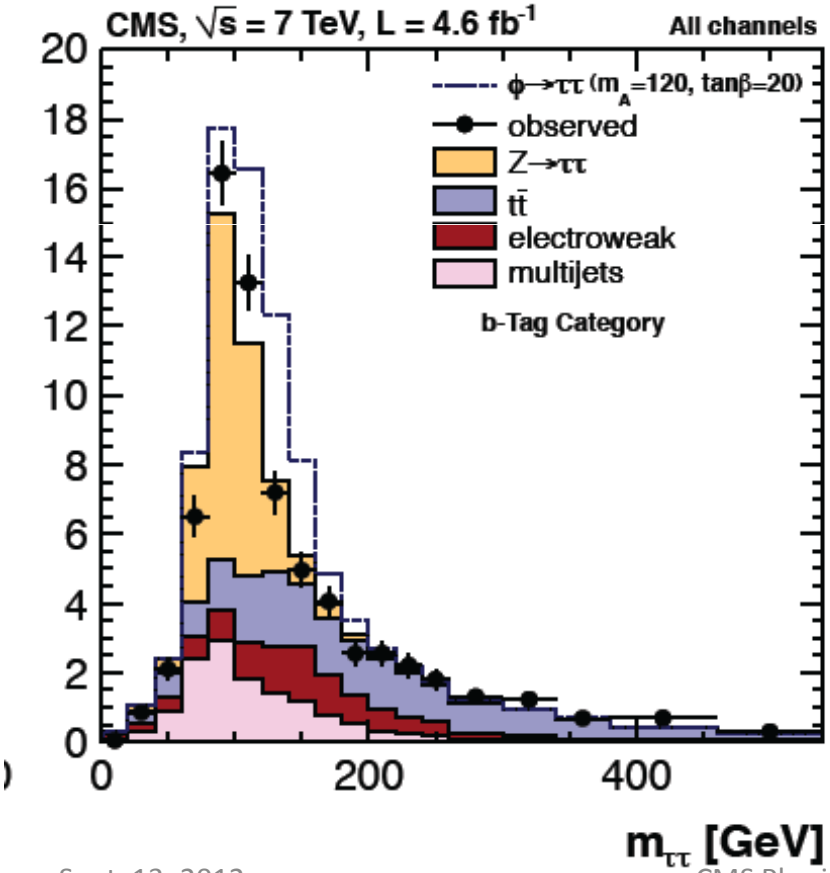
$\sigma = 165.8 \pm 2.2(\text{stat}) \pm 10.6(\text{syst.}) \pm 7.8(\text{lum.})\text{pb}$

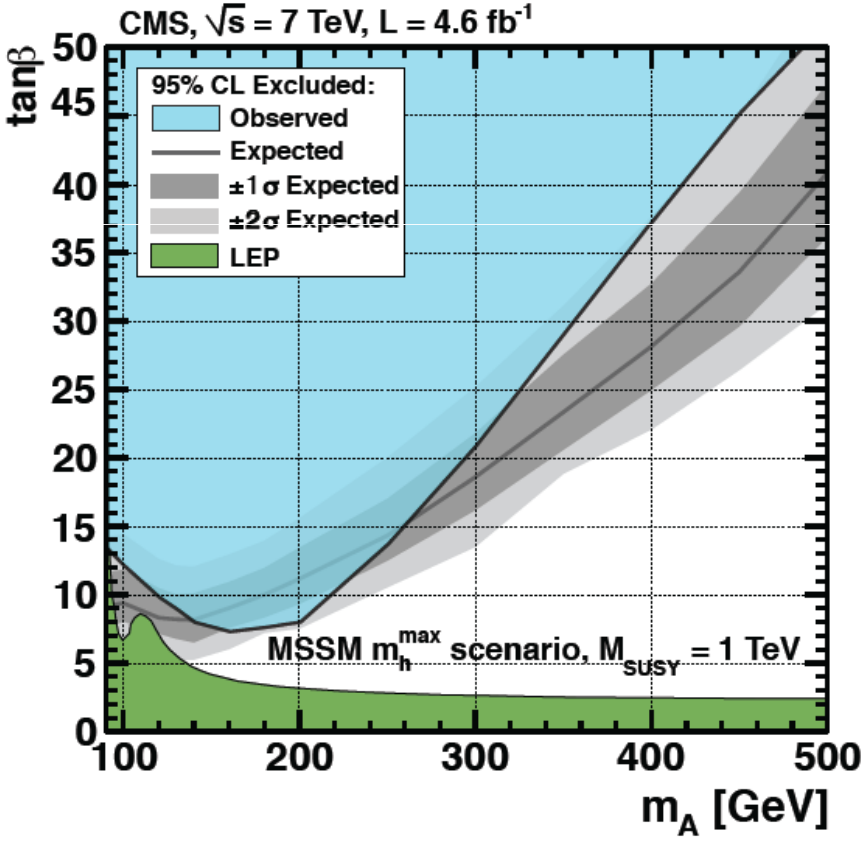
H→γγ Strategy

- Multi-Variate Analysis (MVA) for photon ID and event classification
  - Divide events into non-overlapping samples of varying S/B based on properties of the reconstructed photons and presence of di-jets from VBF process
- Cross check with cut-based analysis
  - MVA and cut-based results consistent
  - MVA gives 15% better sensitivity
- Primary vertex selection (needed for $M_{\gamma\gamma}$ calculation)
  - Highest sum of associated tracks PT
  - Consistency with di-photon kinematics (p_T balance etc.)
  - reconstructed from photon conversion into e^+e^- pair

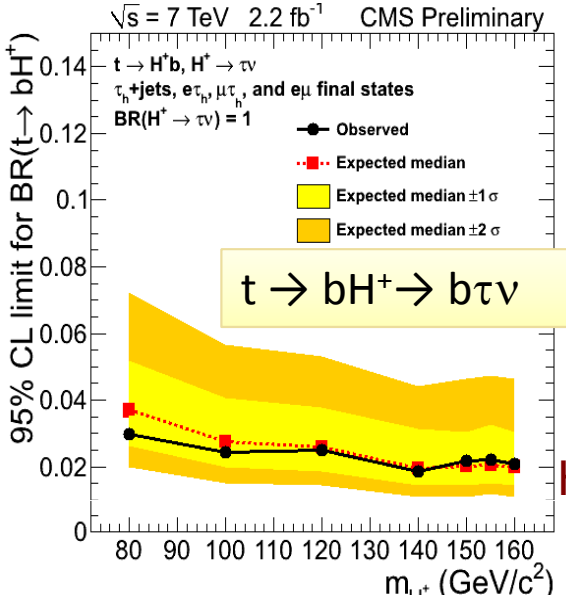
MSSM Higgs in tau pairs

- Tau pair mass (l+h and ll decays)
- Two categories: non-b-tagged and b-tagged (to enhance bbΦ)

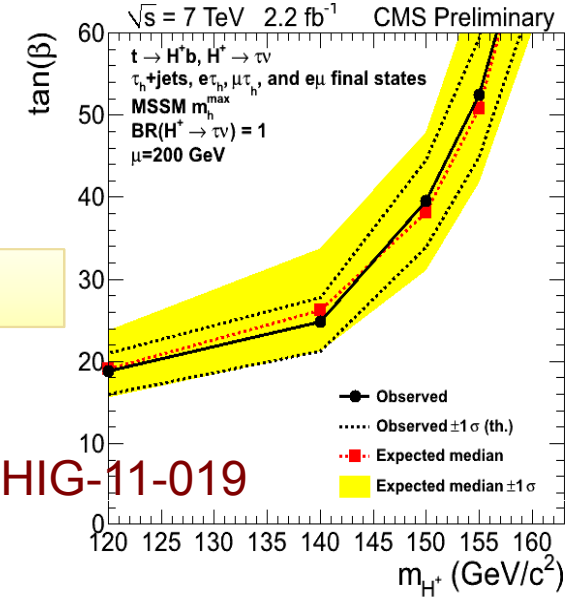




Charged and doubly charged Higgs



$t \rightarrow bH^{+} \rightarrow b\tau\nu$

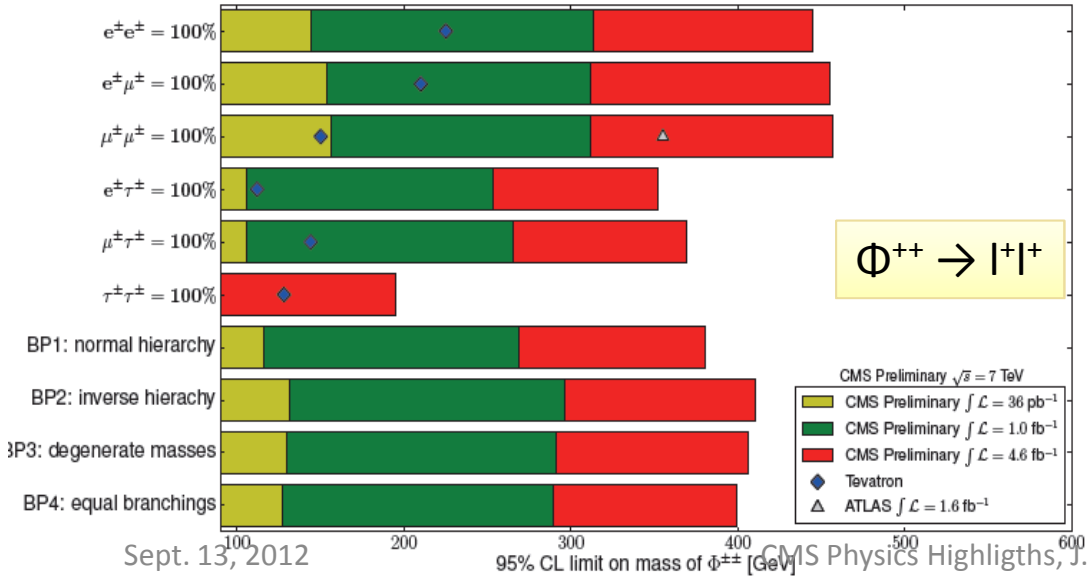


HIG-11-019

$tt \rightarrow H^{+}bW^{-}b$, $H^{+}bH^{-}b$
With $H^{+} \rightarrow \tau\nu$
Search channels

1. τ_h + jets
2. τ_h + e, τ_h + μ
3. eμ

Systematics limited
$\Rightarrow$ only 2.2 fb^{-1} used



$\Phi^{++} \rightarrow l^{+}l^{+}$

HIG-12-005

- Doubly charged Higgs
  - No signal unfortunately
    - But in all channels CMS has world's best limits
    - New: $\Phi^{++} \rightarrow \tau^{+}\tau^{+}$ decay

CMS Inclusive Razor

- **Razor variables:**
  - Form 2 mega-jets: j1 and j2
  - Boost to Razor "R" frame: $p_z = 0$
  - Define M_R, M_T^R and R

Search in 0,1,2 lepton events

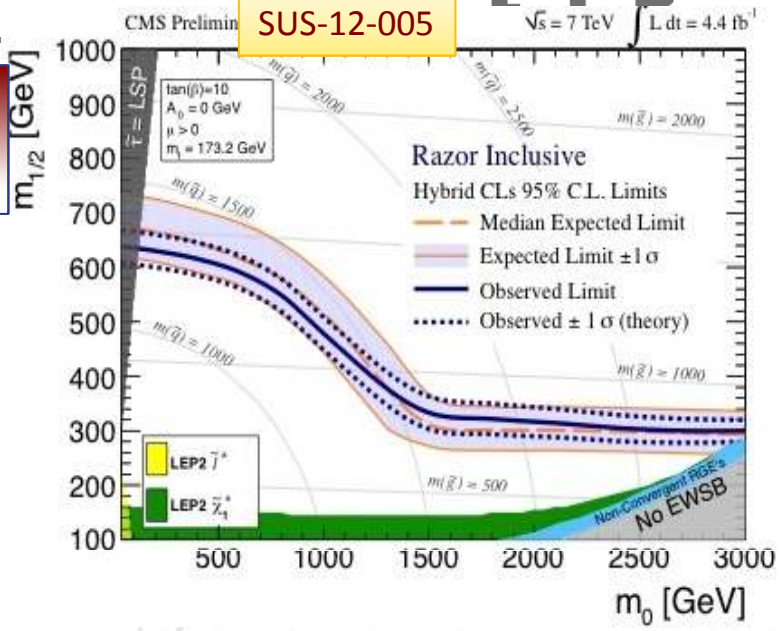
SUS-12-005

$$M_R \equiv \sqrt{(E_{j1} + E_{j2})^2 - (p_z^{j1} + p_z^{j2})^2}$$

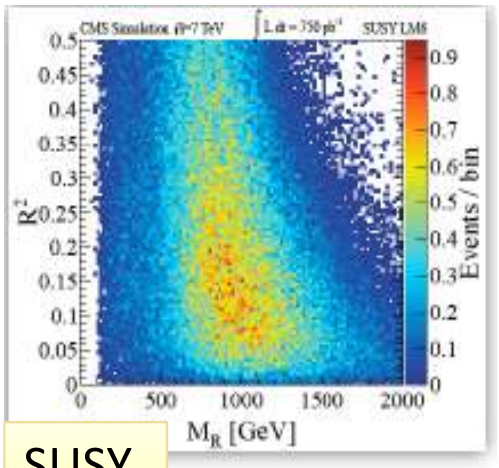
$$M_T^R \equiv \sqrt{\frac{E_T^{miss}(p_T^{j1} + p_T^{j2}) - \vec{p}_T^{\,miss} \cdot (\vec{p}_T^{\,j1} + \vec{p}_T^{\,j2})}{2}}$$

$$R \equiv \frac{M_T^R}{M_R}$$

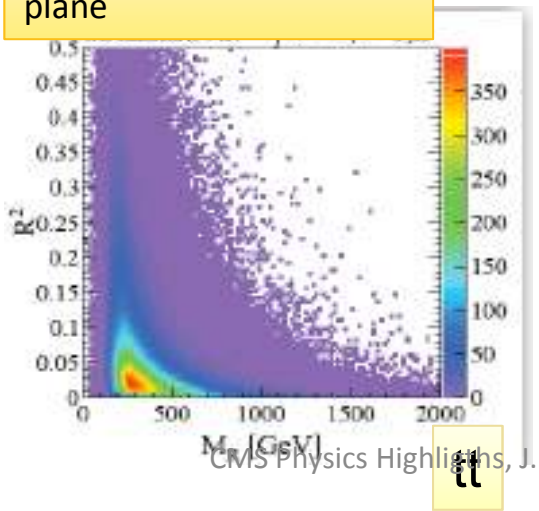
- $M_R \approx$ Energy of the 2 LSP's in rest frame of the mother sparticle
- $M_T^R \approx$ Average transverse mass of LSP's



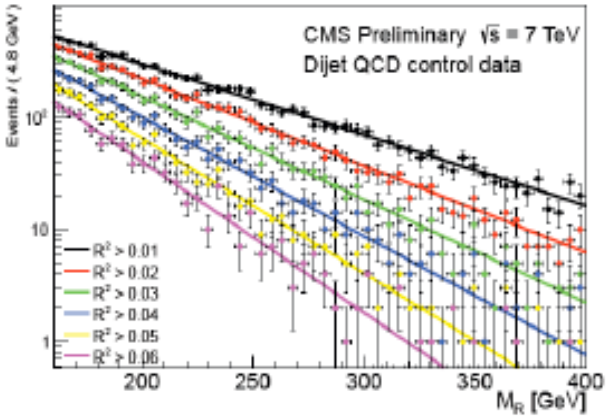
Great Signal/Background Separation in (R^2,M_R) plane



SUSY



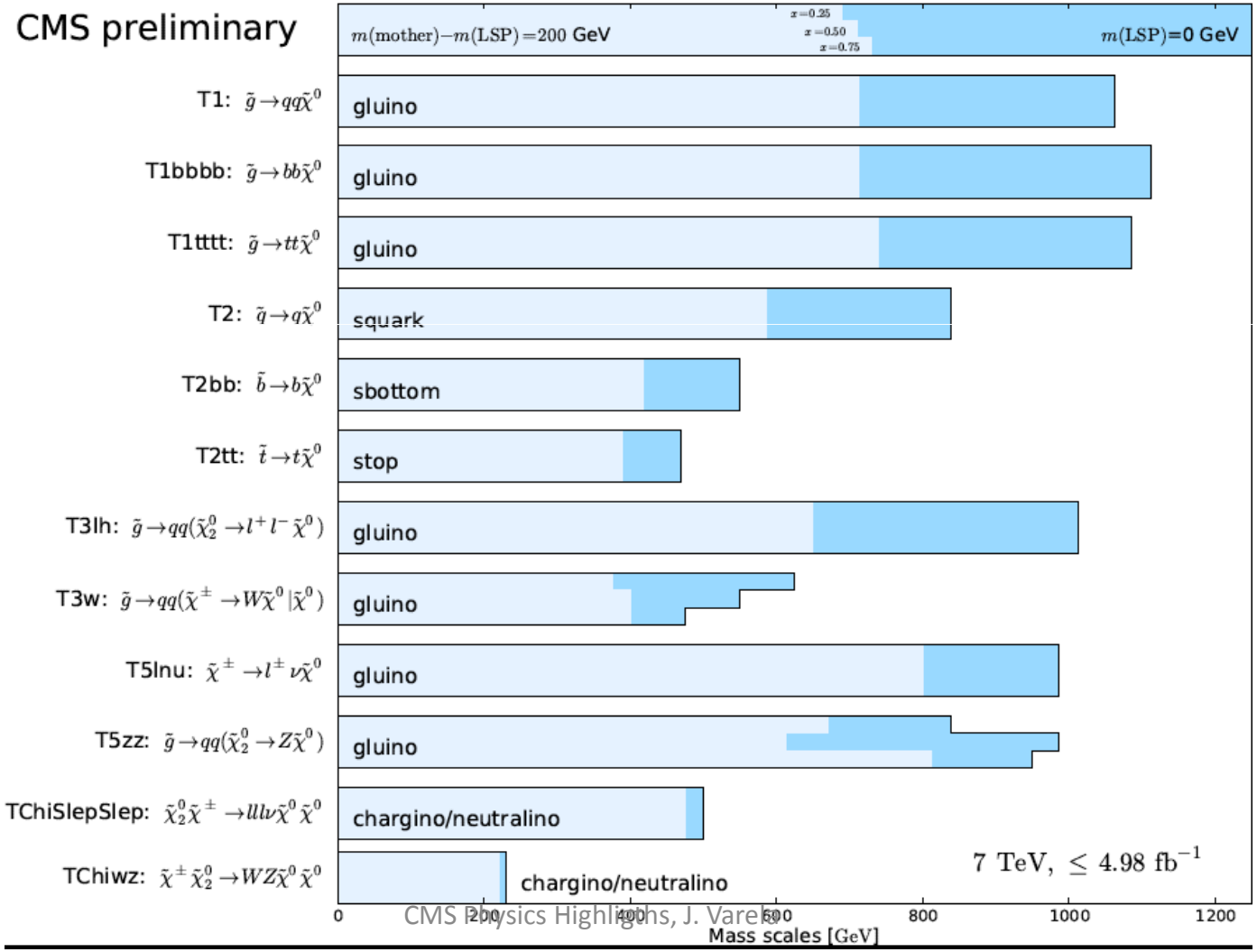
$t\bar{t}$



For various cuts on M_R (R), the differential distribution of R (M_R) has simple single or double exponential shape for backgrounds

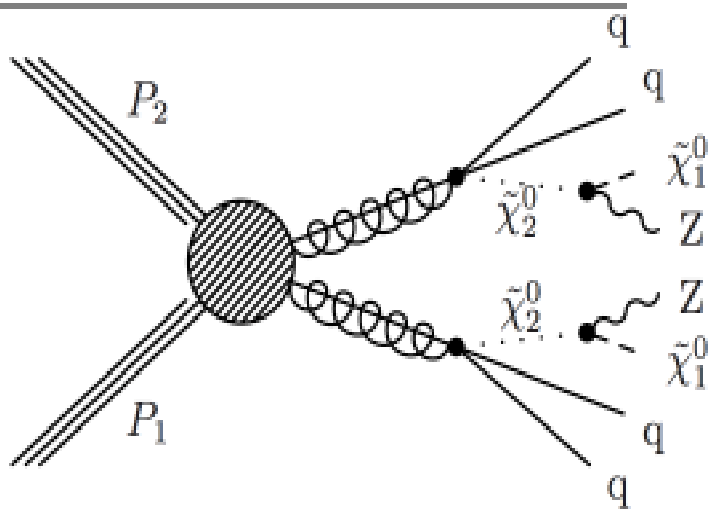
SMS interpretation

CMS searches have excluded light squarks and gluinos up to ~ 1 TeV



Search for SUSY in Z+jets events

- Dilepton analyses split into off and on Z resonance:
  - Different backgrounds and different model sensitivity

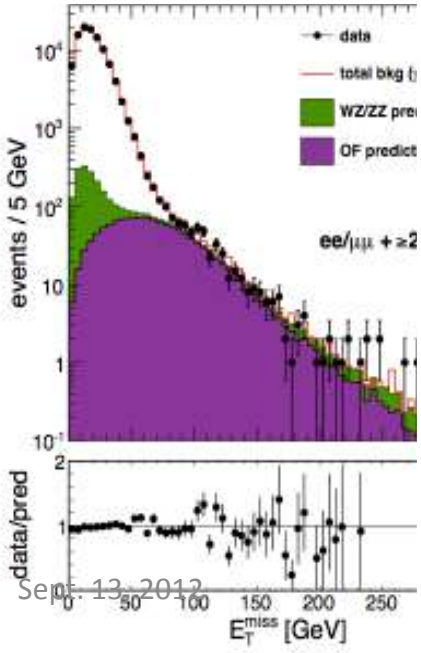


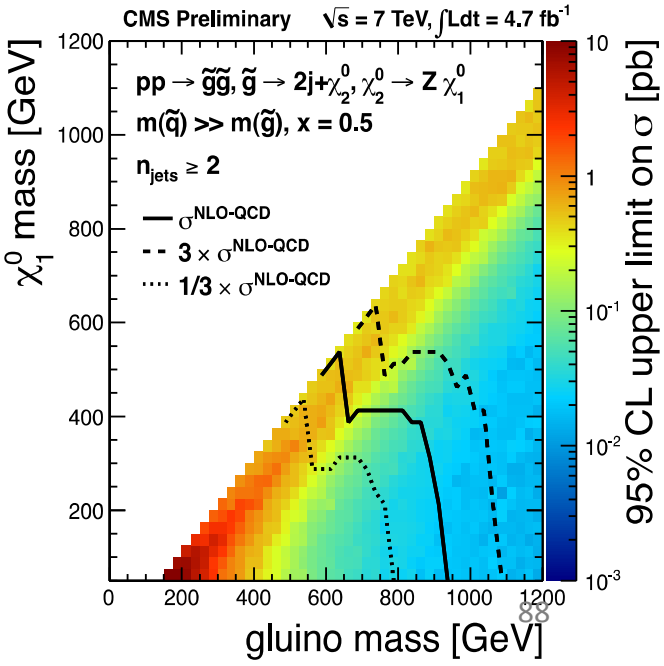
Complementary search methods based on orthogonal data control samples:

MET and; Jet-Z-Balance $= \left|\sum_{\text{jets}} \vec{p}_T\right| - \left|\vec{p}_T^{(Z)}\right| = \left|-\vec{E}_T^{\text{miss}} - \vec{p}_T^{(Z)}\right| - \left|\vec{p}_T^{(Z)}\right|$

tt background predicted from shapes in eμ events and M(ee)/M(μμ) sideband data
Z+artificial MET predicted from data-derived MET resolution templates.
Z+artificial JZB predicted from symmetry in negative→positive tails of JZB.

CMS Preliminary

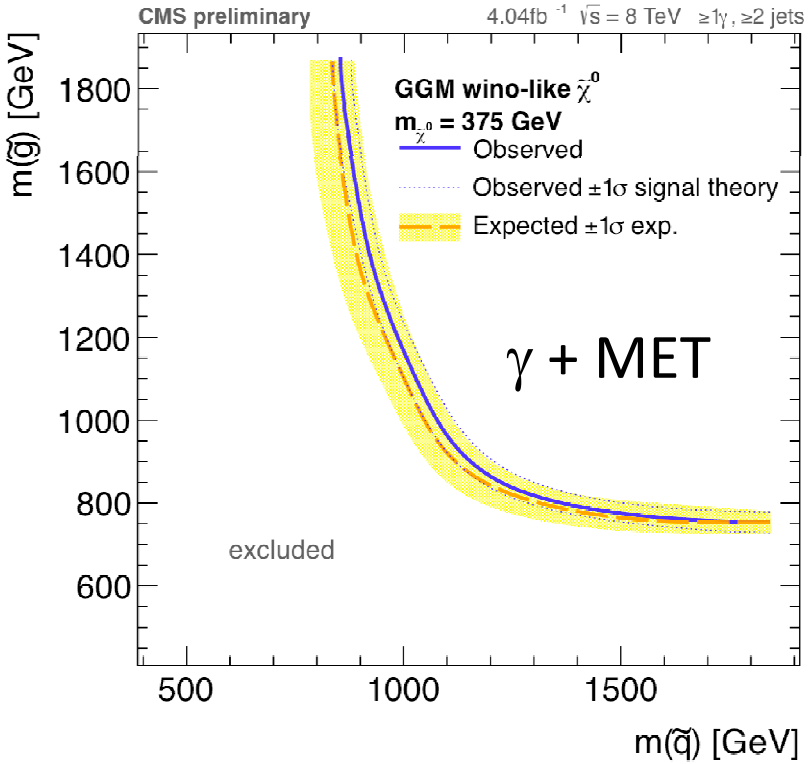


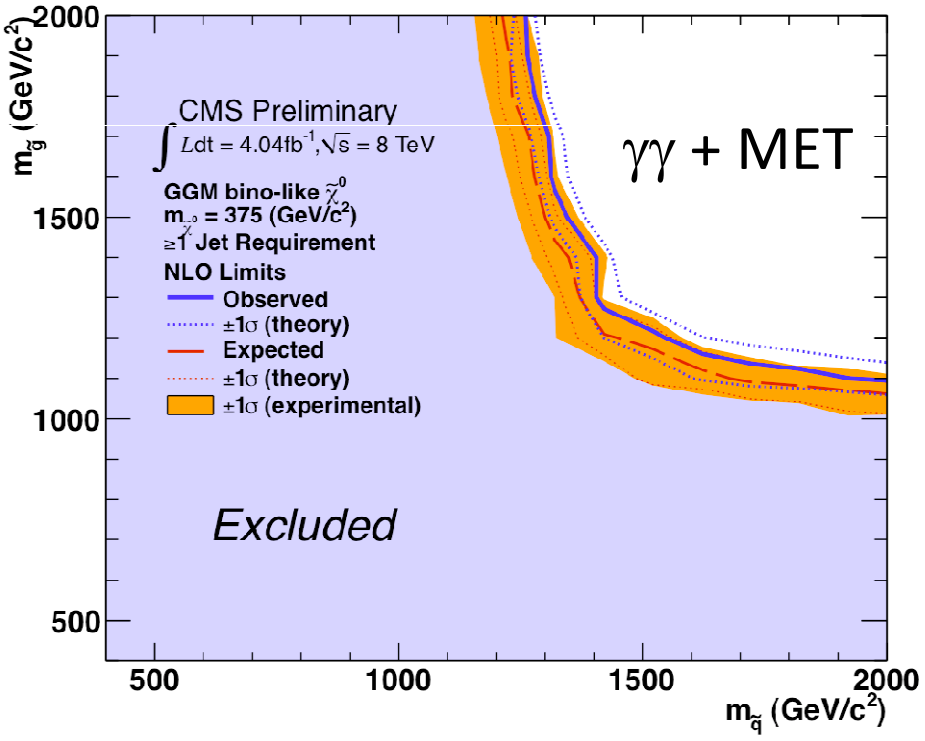


Gauge-mediated SUSY breaking scenarios

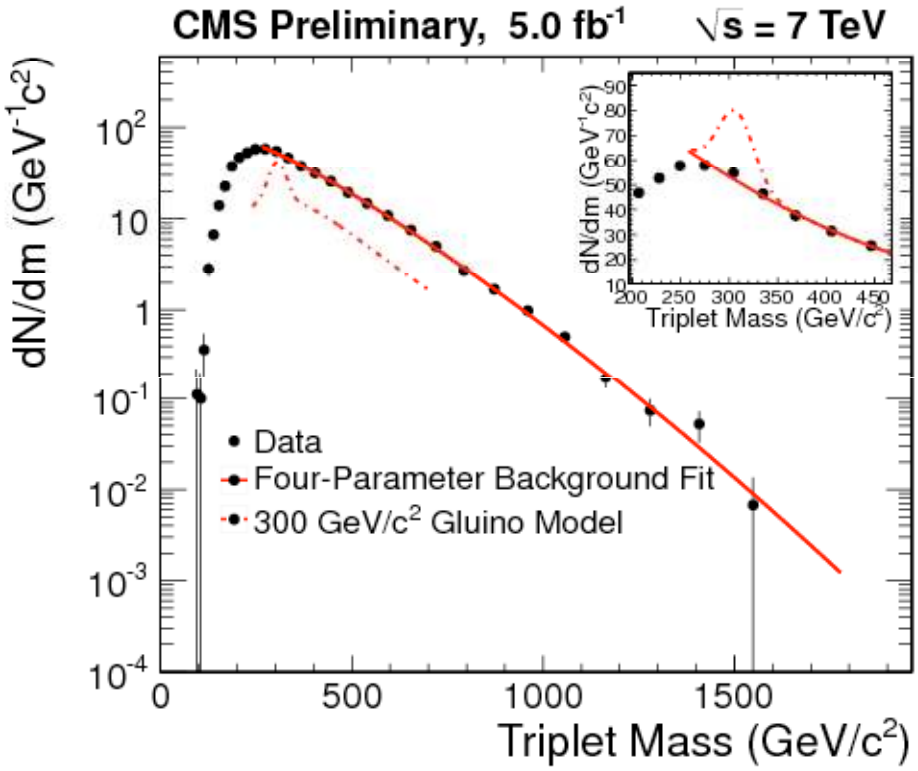
Depending on the nature of χ^0, single or double photon final states can dominate

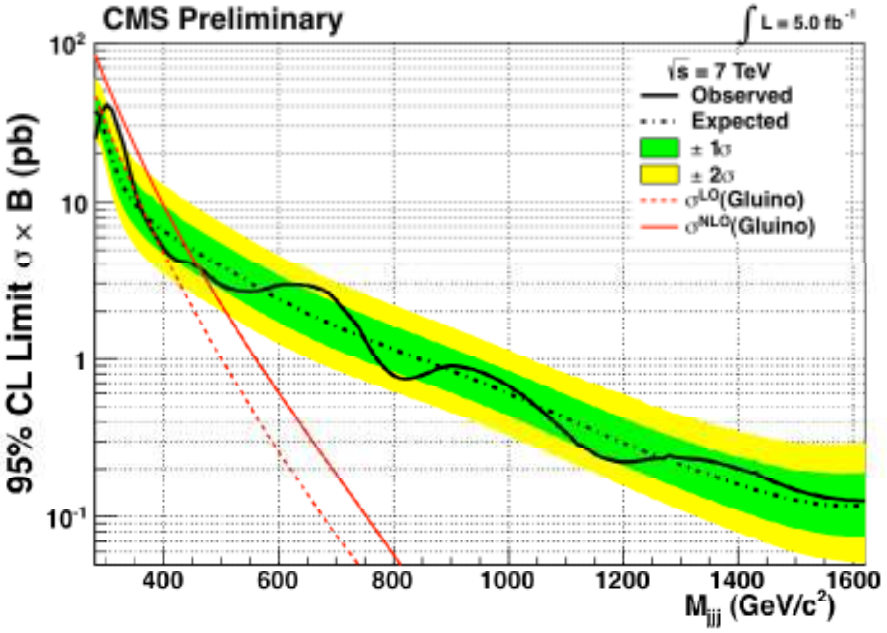
Early 8 TeV results





An RPV example: gluino→3 quarks





Exclude gluino masses below 460 GeV (assuming 100% BR into three jets)

W' → lν in 8 TeV Data

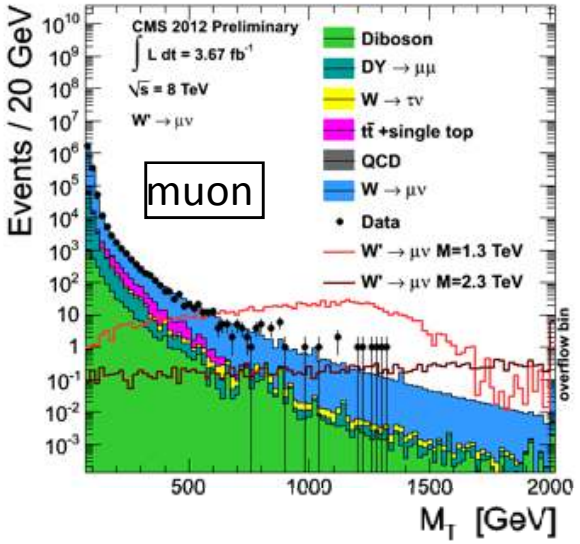
[CMS PAS EXO-12-010]

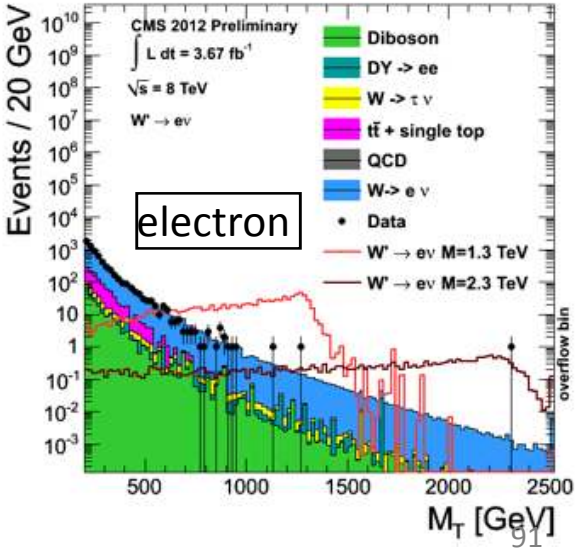
- Search for a new heavy gauge boson W' decaying to a charged lepton (μ or e) and ν

$$M_{\mathrm{T}} = \sqrt{2 \cdot p_{\mathrm{T}}^{\ell} \cdot E_{\mathrm{T}}^{\mathrm{miss}} \cdot (1 - \cos \Delta\phi_{\ell,\nu})}$$

- Many models possible
  - right-handed W' bosons with standard-model couplings
  - left-handed W' bosons including interference
  - Kaluza-Klein W'_{KK}-states in split-UED
  - Excited chiral boson (W*)

$M(W'_{SSM})$ 95% CL	Luminosity	Expected	Observed
ATLAS e+μ, 2011	4.7	> 2.55 TeV	> 2.55 TeV
CMS e+μ, 2012	3.7	> 2.80 TeV	> 2.85 TeV
CMS e+μ, 2011+2012	5.0 + 3.7	> 2.85 TeV	> 2.85 TeV

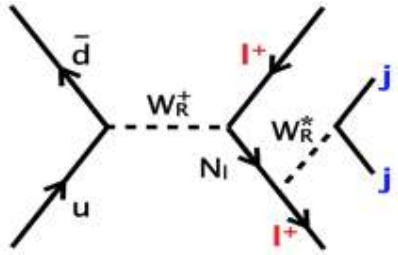




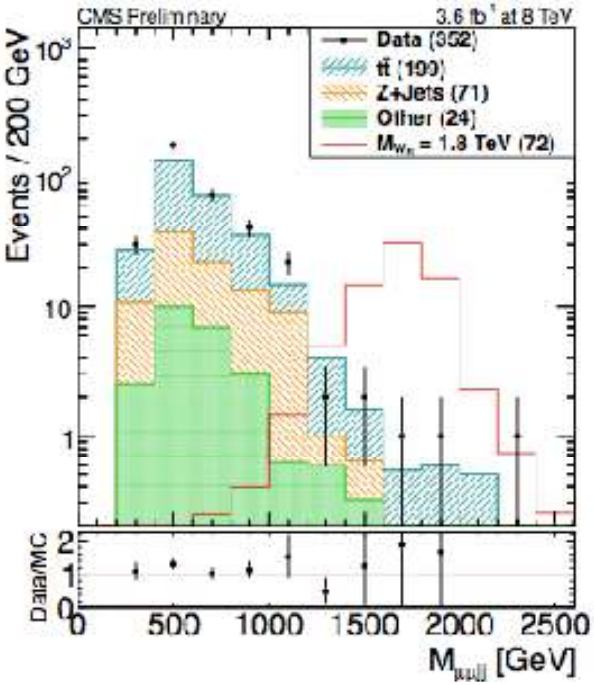
Heavy Neutrino in 8 TeV

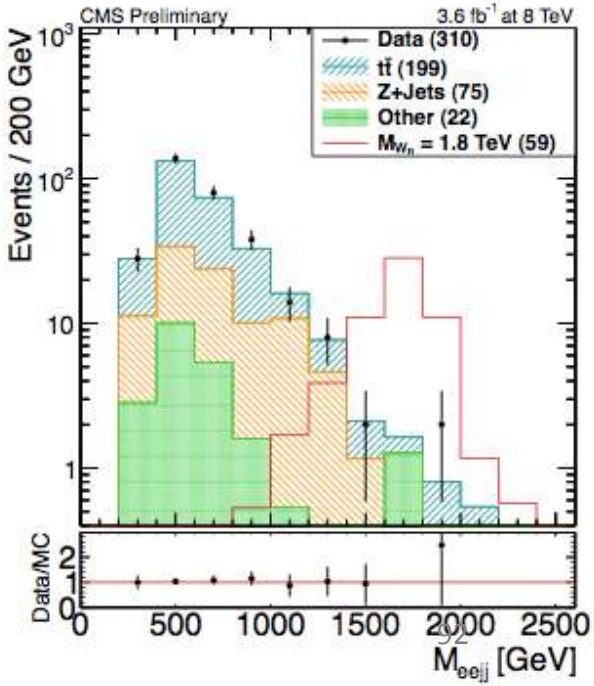
[CMS PAS EXO-12-017]

- We search for the decay of $W_R \rightarrow \mu\mu jj$ and eejj, as in a Left-Right Symmetric Model



- Selection
  - Lepton p_T >60/40 GeV, motivated by W decay
  - Jet p_T > 40 GeV
  - M(ll) > 200 GeV to reduce DY+jets.
- Background
  - Top: data-driven from eμjj
  - DY+jets: normalised to data, MC shape in Z peak
  - QCD: data-driven fake rate
  - VV, Single top: from MC



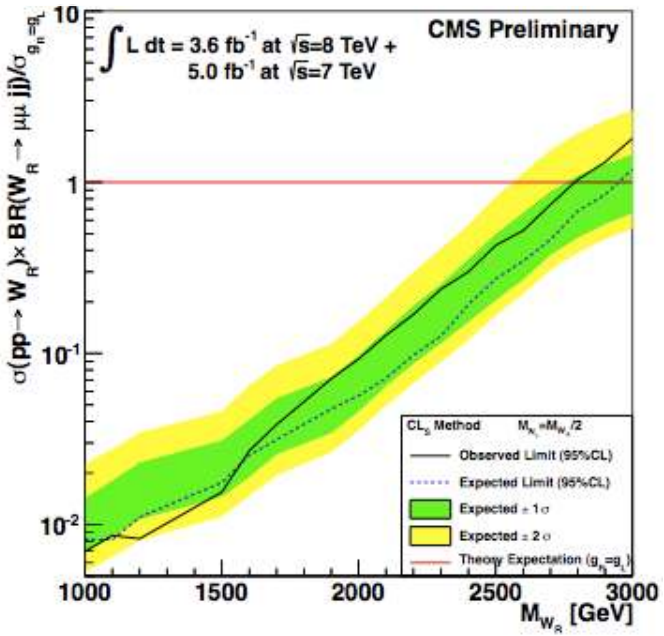


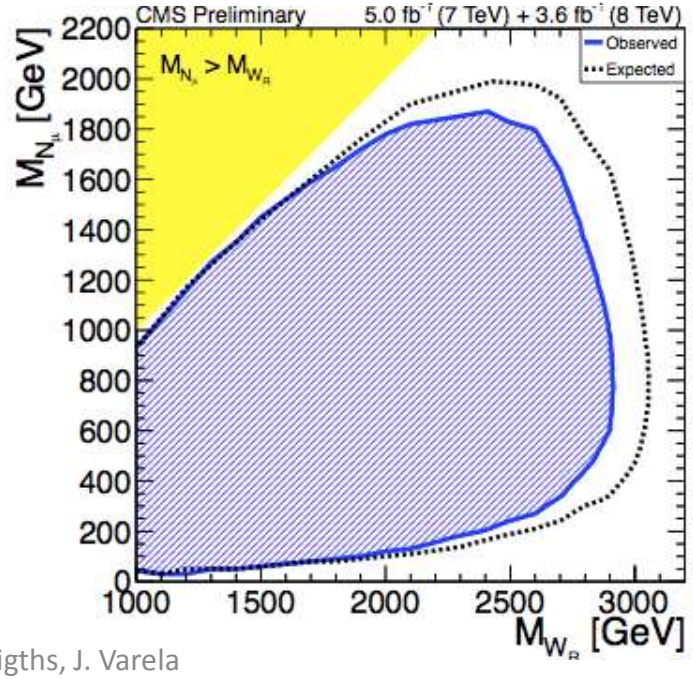
Heavy Neutrino in 8 TeV Data

- Search assumes small W_R-W_L and N_l-$N_{l'}$ mixing angles, only one lepton channel kinematically accessible
- Primary Systematic Uncertainties
  - Signal Eff.: 6-10% from lepton
  - Background: ~50% from DY+jets shape, ~16% from top shape

For M(N)=M(W_R)/2; M(W_R) > 2.8 TeV

[CMS PAS EXO-12-017]





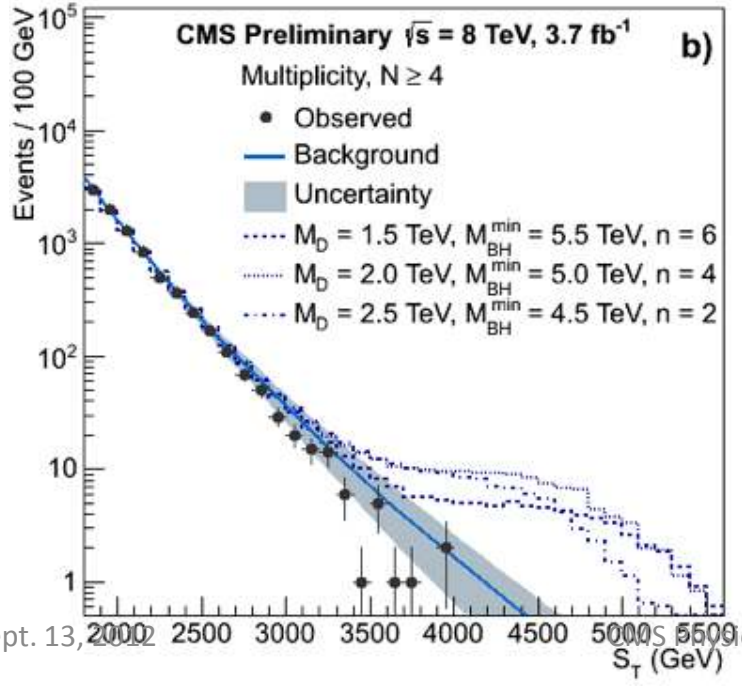
Black Holes in 8 TeV Data

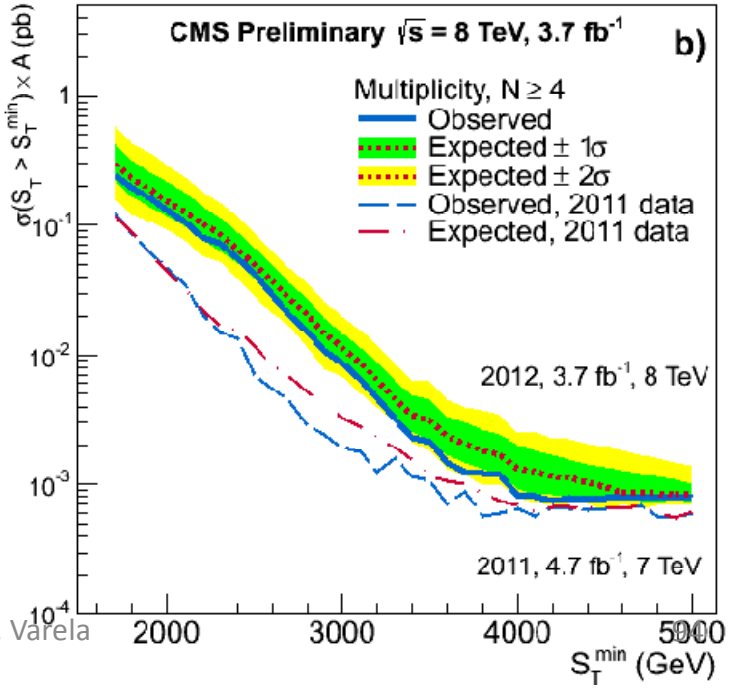
- Hypothetical BH would evaporate into many high-p_T objects
  - Estimate by S_T, the p_T sum of physics objects with p_T > 50 GeV
- Main background of QCD estimated by fit to n=2 distribution
  - Normalised for each multiplicity bin separately at S_T = 1.8–2.2 TeV
  - Model-independent limits vs S_T and multiplicity

$$S_T = \sum_{j,e,\mu,\gamma,MET}^{N} p_T$$

Large improvement in sensitivity (~10-20%) with respect to 2011 analysis

[CMS PAS EXO-12-009]





Parton Luminosities