Recent Results from CMS

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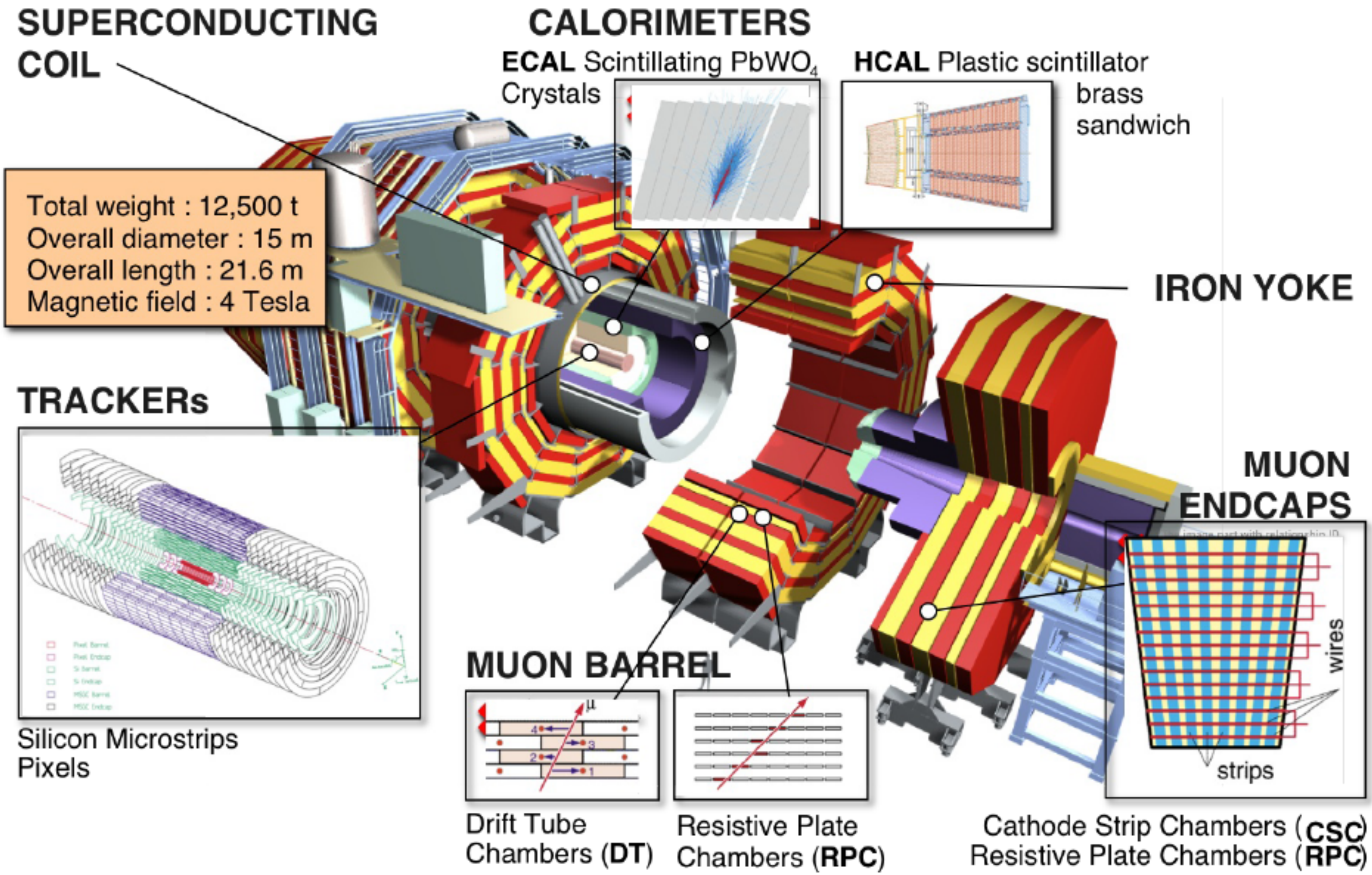
Outline

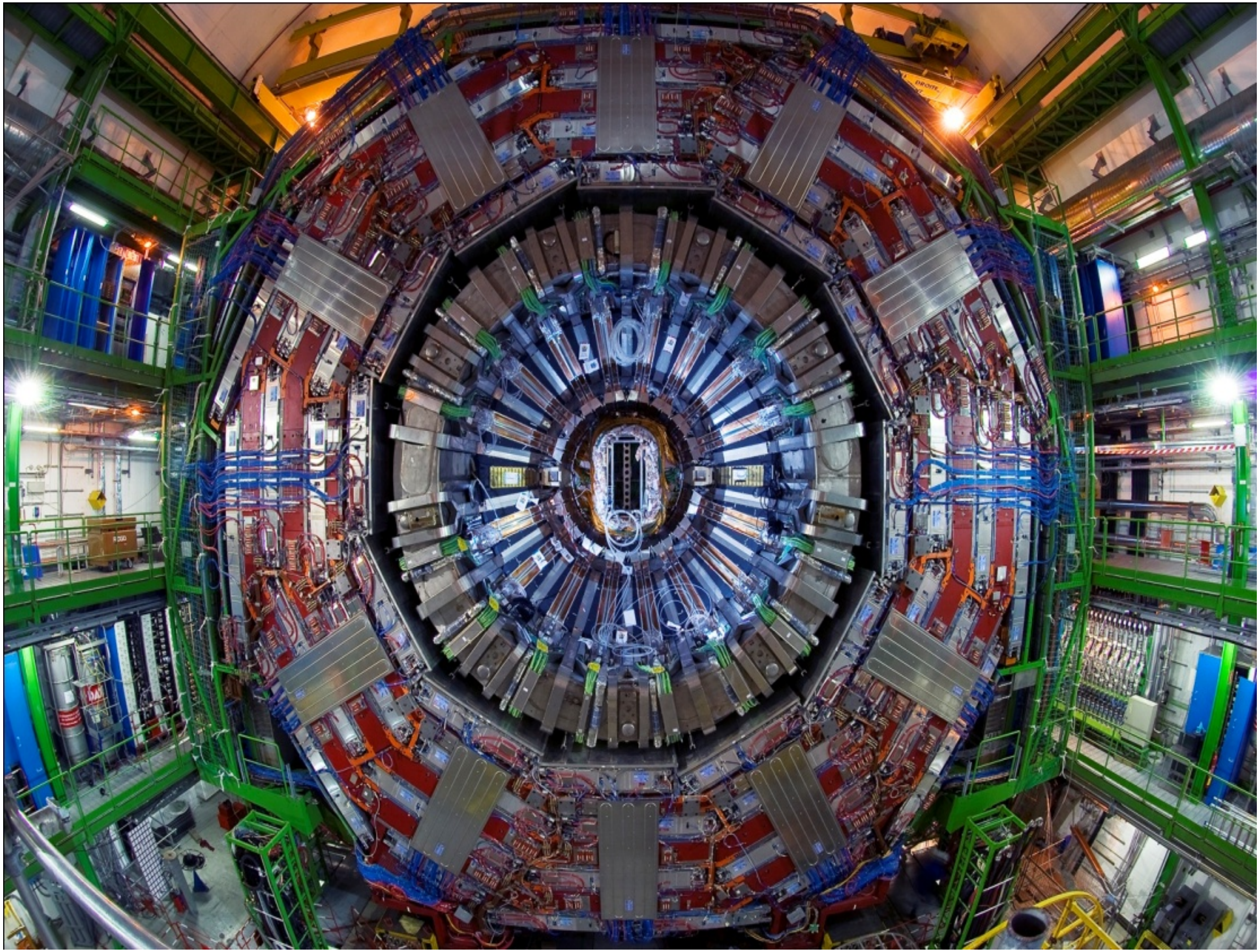
- Introduction
- SM Measurements
- Higgs Searches
  - Most sensitive channels for SM Higgs: $H \to \gamma\gamma$, $H \to ZZ$, $H \to WW$
  - Combined results for SM Higgs
  - Searches for MSSM Higgs Bosons
- SUSY Searches
- Other BSM Searches
- Heavy Ions
- Summary and Outlook

Only part of the results will be covered in this talk
For all CMS public results see:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

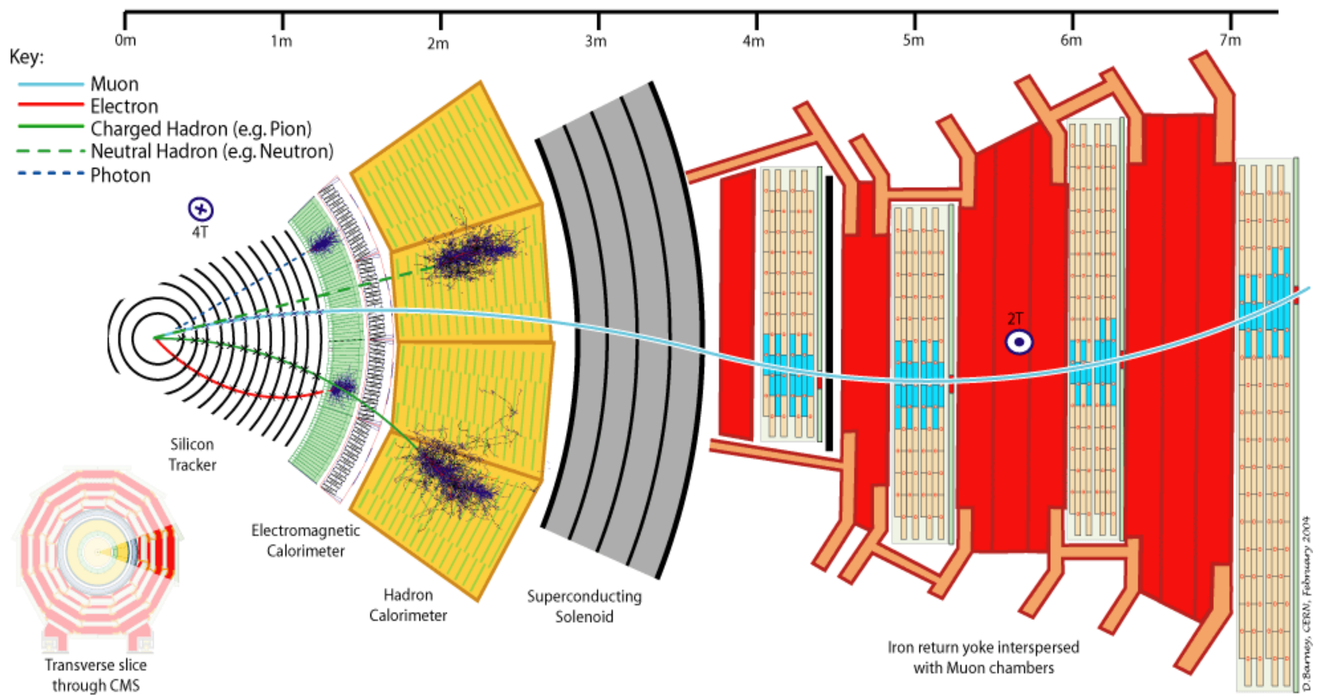
The CMS Detector



Picture of CMS

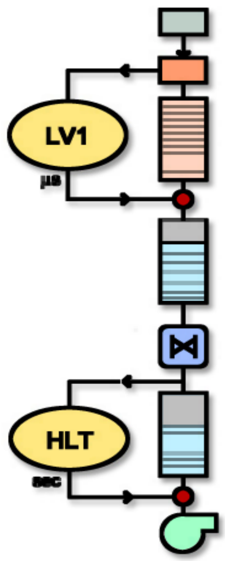


Measurement of Particles in CMS



- Particle Flow algorithm has been developed
  - It combines and links signals from the different sub-detectors
  - It provides the optimal event description in form of a list of particles: electron, muons, charged hadrons, photons and neutral hadrons
- τ lepton reconstruction and MET are based on Pflow
- Large improvements obtained

Trigger

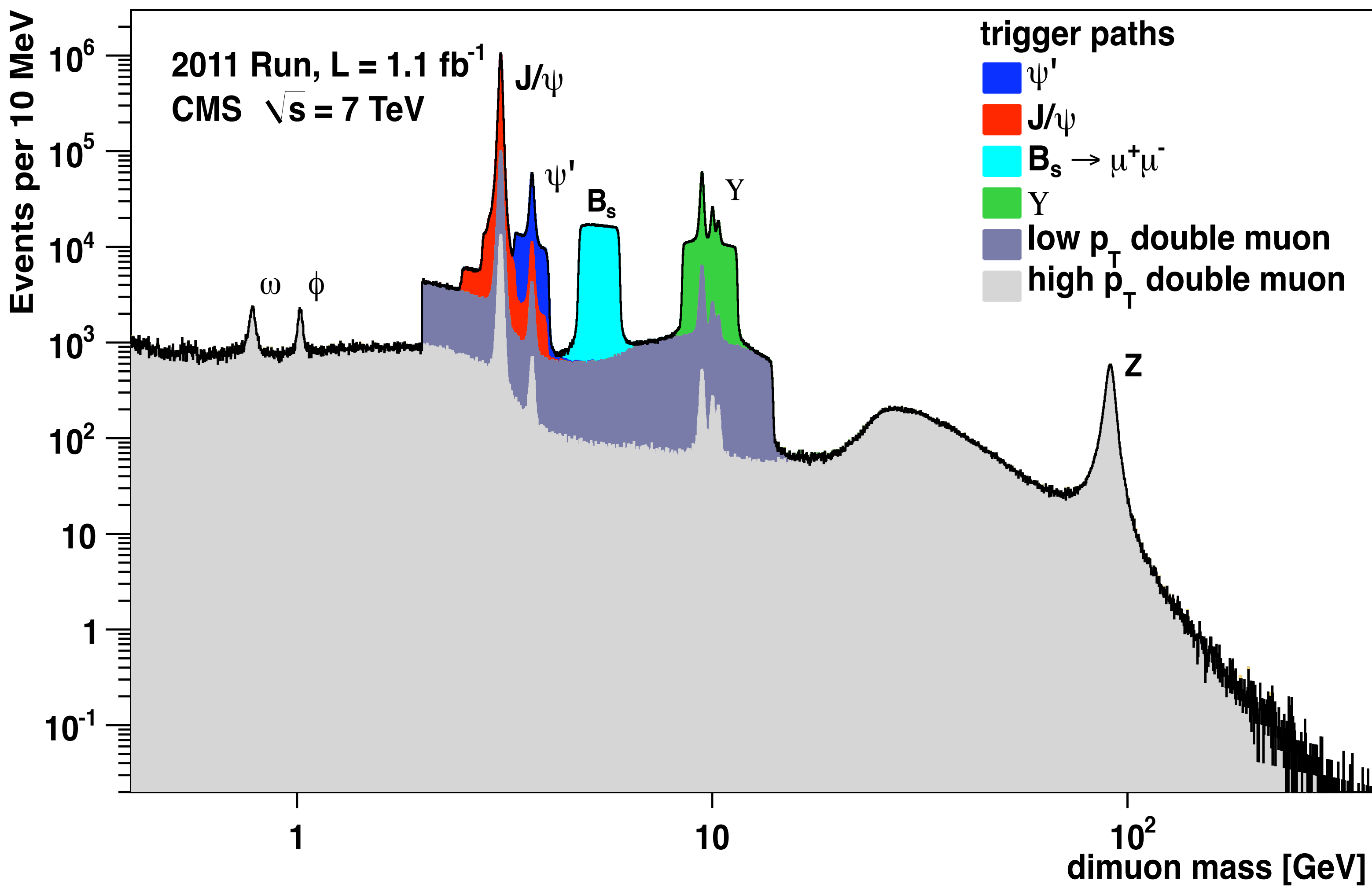


- 2-level trigger system
  - Input: 40 MHz
  - Level1 Trigger output 100 KHz
  - All events fully built and sent to the online Filter Farm
  - High Level Trigger (HLT)output ~300 Hz (saved for physics analysis)

- The HLT has access to the full event information and runs the offline reconstruction only optimized for speed
- ~300 HLT paths select events for all analyses
  - Single object triggers: e, γ, μ, MET, …
  - Multi object triggers: ee, γγ, μμ, ee+MET, …
  - Prescaled triggers used for control samples and to measure efficiencies, including trigger efficiency

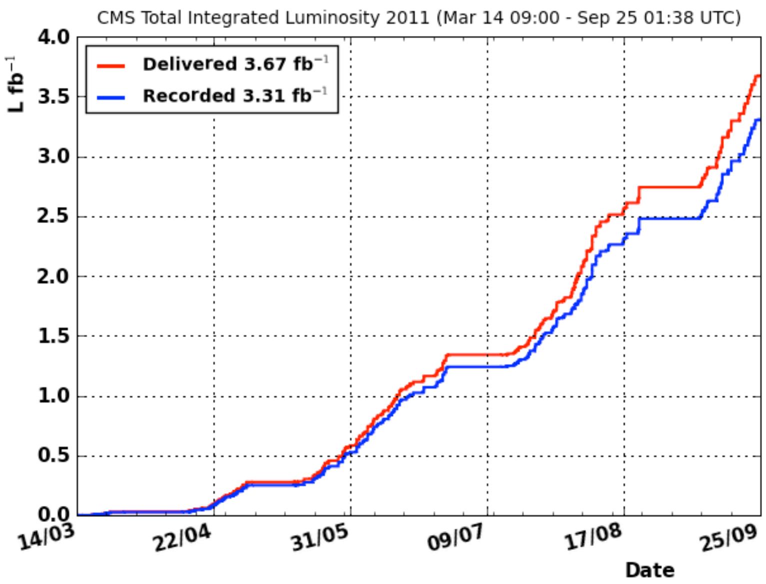
Dimuon Mass Spectrum

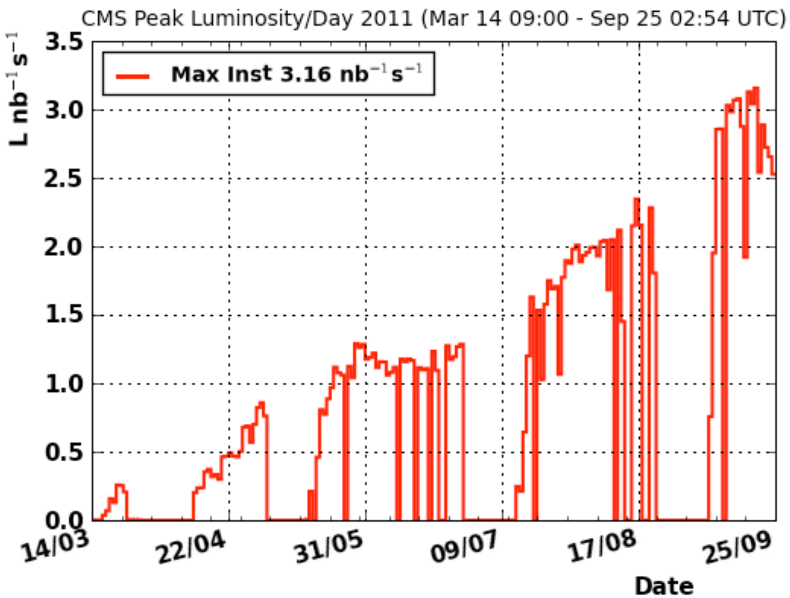
- Di-muon mass distribution from several trigger paths



Data: pp Collision at 7 TeV

- Excellent performance of LHC and CMS in 2011
- ~3 fb^{-1} IntL pp collisions collected at 7 TeV CM energy
  - Analyzed ~1.7 fb^{-1}
- Peak luminosity 3.2 x 10^{33} $cm^{-2}s^{-1}$
- Data taking efficiency 90%

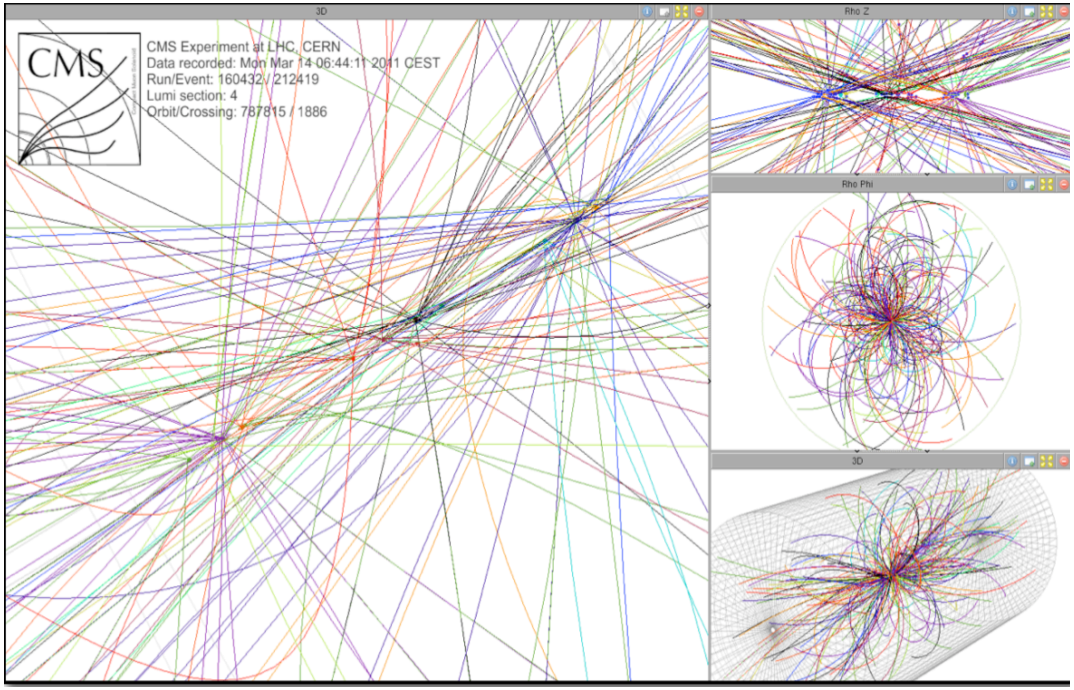




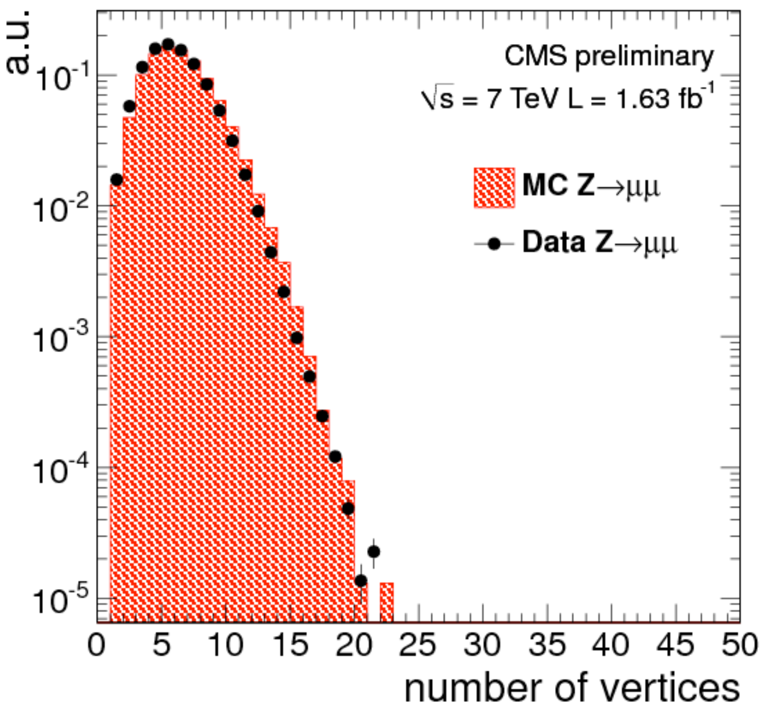
Number of interactions per bunch crossing at the beginning of fills is about 20 at 3 x 10^{33} $cm^{-2}s^{-1}$

Pileup

- Multiple interactions occur for each bunch crossing
  - In-time and out-of-time pileup
- Vertexing algorithm is capable of efficiently reconstruct vertices separated in z by less than 1 mm
- Jets and energy in isolation cones is corrected for pileup energy estimated event by event

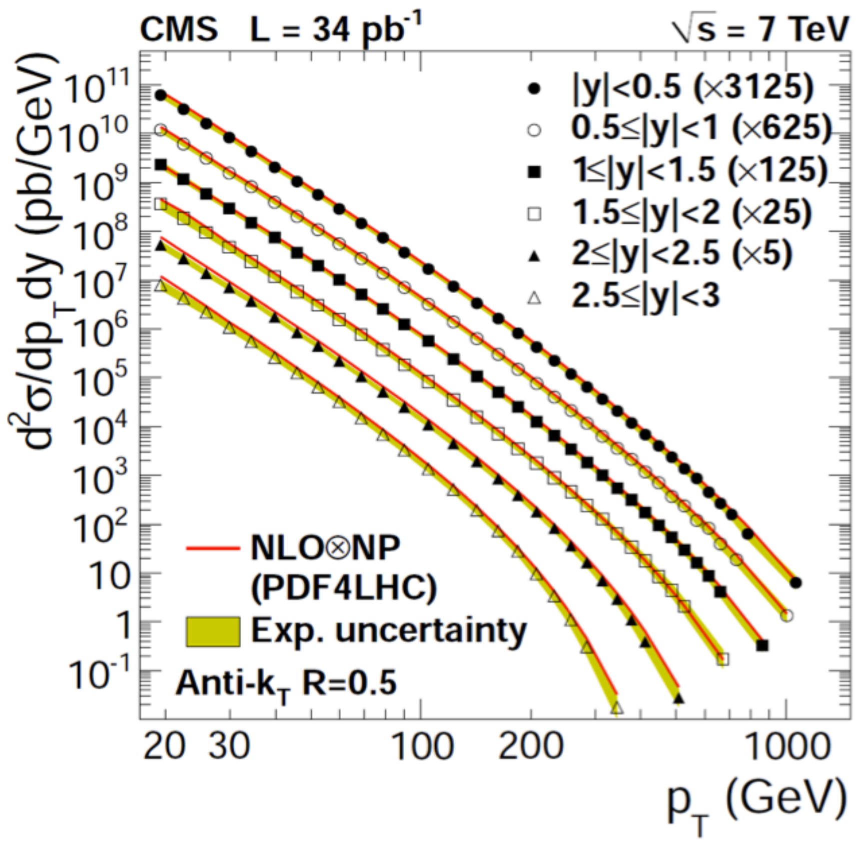


Number of vertices in the analyzed dataset

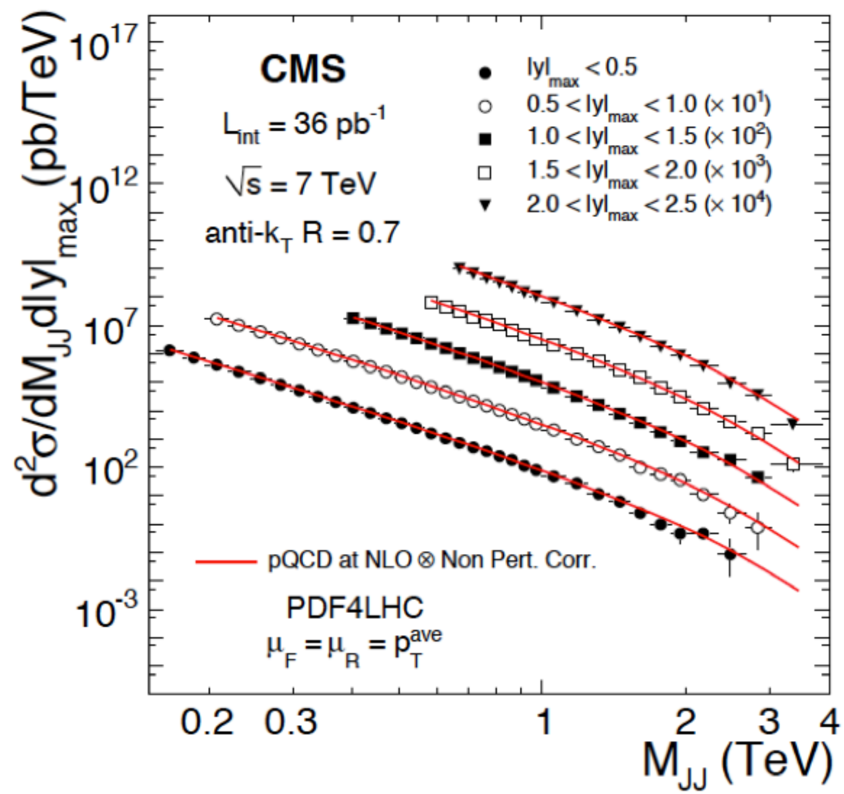


QCD Measurements

Inclusive jet cross sections
Phys. Rev. Lett. 107 (2011) 132001



Di-jet mass spectra
Phys. Lett. B 700 (2011) 187–206



- Many other measurements for hard and soft QCD have been carried out
- Observed general agreement with MC predictions

Di-hadron Correlations

- CMS observed for the first time at hadron colliders long range di-hadron correlations

Signal distribution (same event):

$$S_N(\Delta\eta,\Delta\phi) = \frac{1}{N(N-1)}\frac{d^2N^{\text{signal}}}{d\Delta\eta d\Delta\phi}$$

Background distribution (different events):

$$B_N(\Delta\eta,\Delta\phi) = \frac{1}{N^2}\frac{d^2N^{\text{mixed}}}{d\Delta\eta d\Delta\phi}$$

Two dimensional correlation function for particle pairs

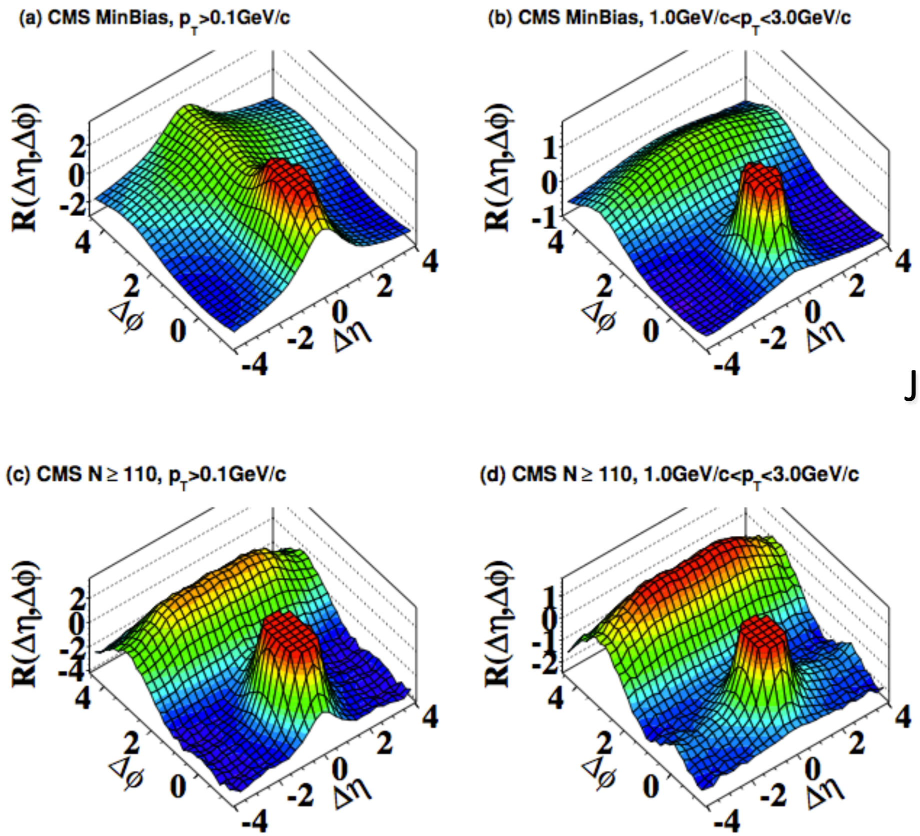
$$R(\Delta\eta,\Delta\phi) = \left\langle (N-1)\left(\frac{S_N(\Delta\eta,\Delta\phi)}{B_N(\Delta\eta,\Delta\phi)} - 1\right)\right\rangle_N$$

- Measurements in minimum bias triggers and in special high multiplicity triggers (980 nb^{-1} at 7 TeV)
- Measurements for different multiplicities and in different ranges of hadron P_T

Observation of the Ridge

$P_T > 0.1$ GeV — $1\text{ GeV} < P_T < 3$ GeV

MinBias
<N> ~15



JHEP 09 (2010) 091

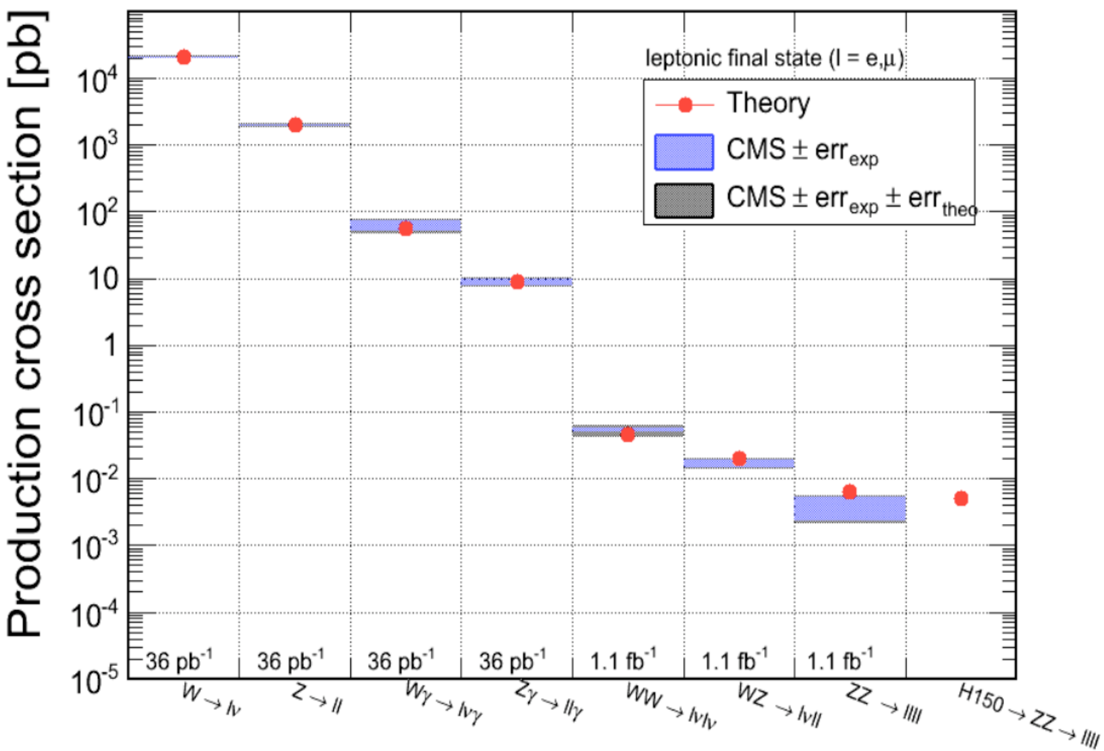
High Multiplicity
N>110

Peak
is truncated

- Near side long range correlations at $\Delta\phi$ near 0 and $\Delta\eta$ 2-4 observed in high multiplicity events for intermediate hadron P_T [1-3] GeV
- This effect is not predicted by existing MC programs (Pythia, Herwig, Madgraph)

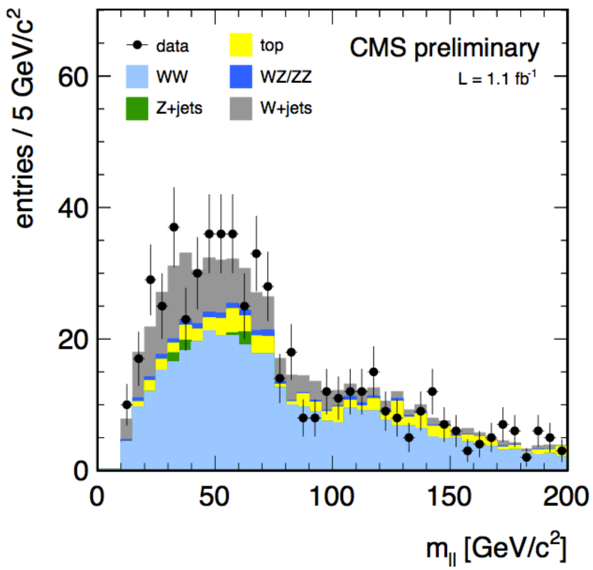
EW Measurements

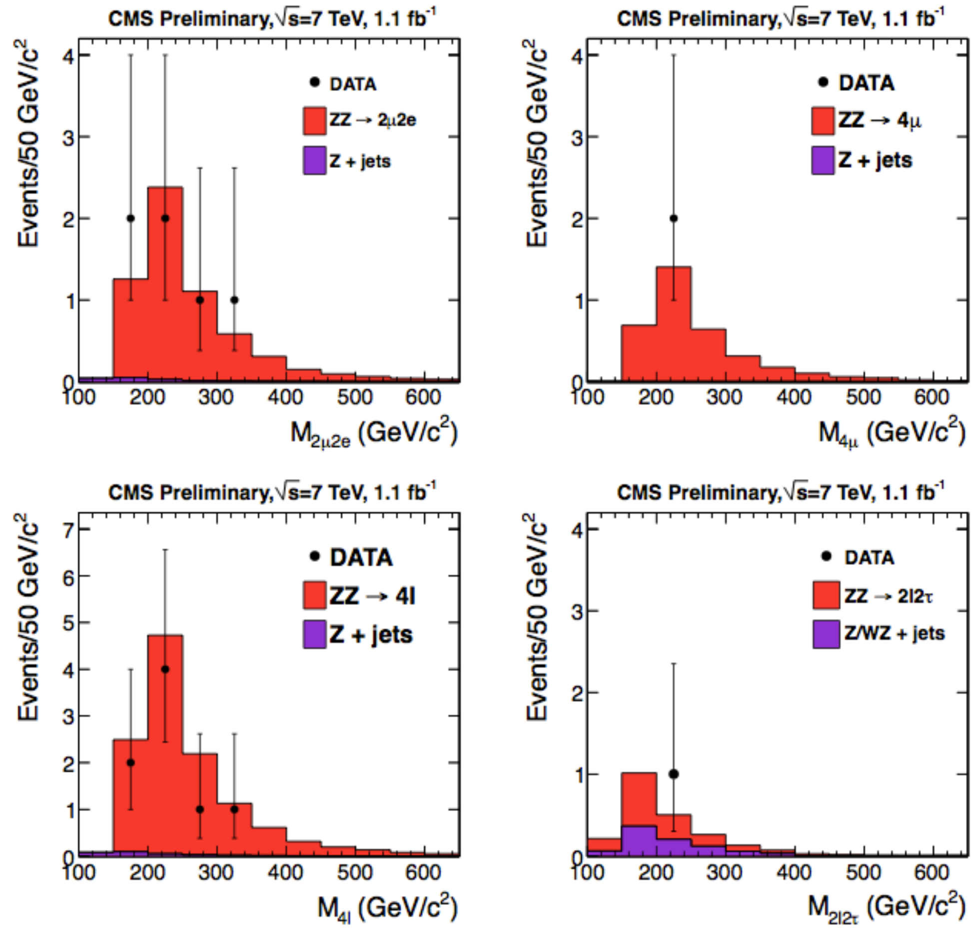
- Measurement of EWK bosons (single and pair production) also important to understand performance of:
  - Electrons, muons, taus, MET, …
- And background to searches for Higgs and New Physics



- All measurement found to be consistent with theory predictions

WW, WZ, ZZ



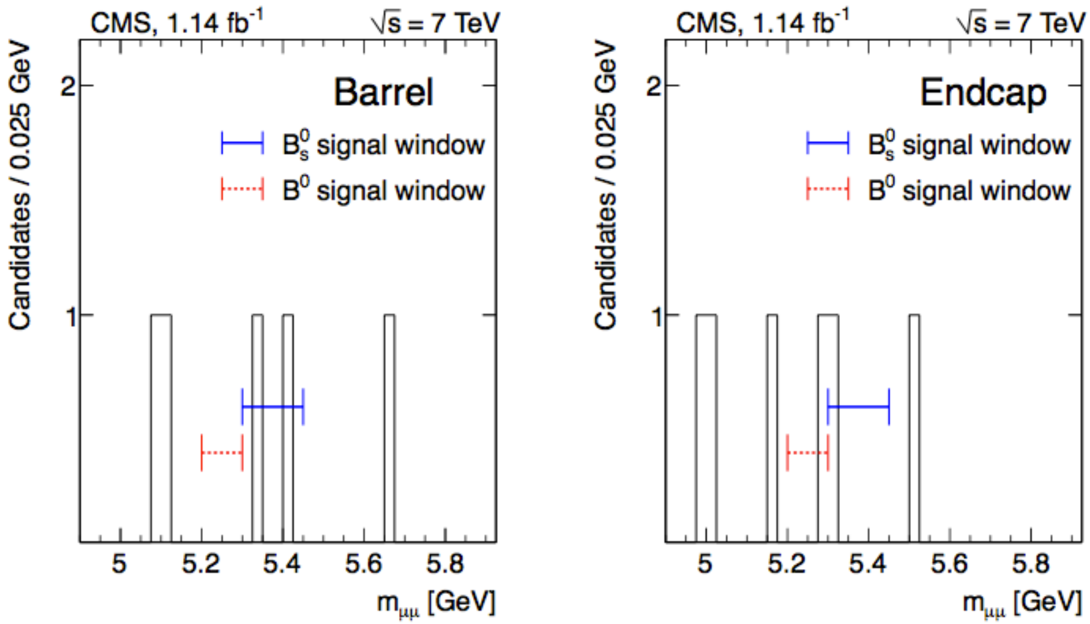


- Measured the WW, WZ and ZZ production cross sections at 7 TeV
- Results are consistent with the standard model predictions

$$\sigma(pp \to W^+W^- + X) = 55.3 \pm 3.3\,(\text{stat.}) \pm 6.9\,(\text{syst.}) \pm 3.3\,(\text{lumi.})\text{ pb.}$$
$$\sigma(pp \to WZ + X) = 17.0 \pm 2.4\,(\text{stat.}) \pm 1.1\,(\text{syst.}) \pm 1.0\,(\text{lumi.})\text{ pb.}$$
$$\sigma(pp \to ZZ + X) = 3.8^{+1.5}_{-1.2}\,(\text{stat.}) \pm 0.2\,(\text{syst.}) \pm 0.2\,(\text{lumi.})\text{ pb.}$$

$B_s \rightarrow \mu^+\mu^-$

- BR($B \rightarrow \mu^+\mu^-$) expected to be very small in SM
  - $B_s \rightarrow \mu^+\mu^- = (3.2\pm0.2)\times10^{-9}$
  - $B_d \rightarrow \mu^+\mu^- = (1.0 \pm0.1)\times10^{-10}$
- Selection:
  - Low mass trigger
  - Isolated muon
  - Impact parameter significance
- Sensitivity to new Physics:
  - Supersymmetry
  - Leptoquarks,
  - …



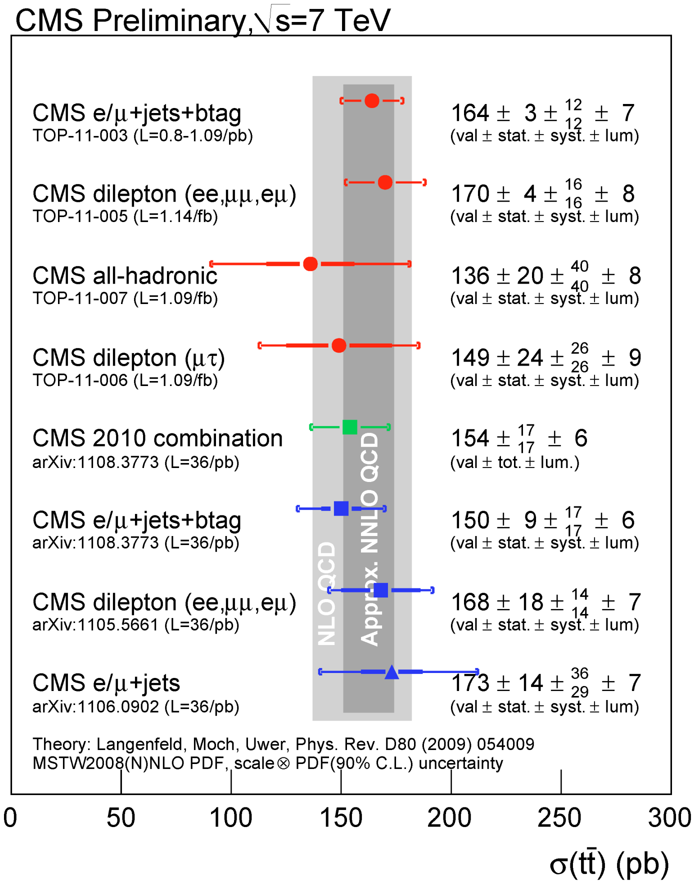
- Events observed in the search windows consistent with background plus SM expectations
- $B_s \rightarrow \mu^+\mu^- < 1.9\times10^{-8}$ (95% CL)
- $B_d \rightarrow \mu^+\mu^- < 4.6\times10^{-9}$ (95% CL)

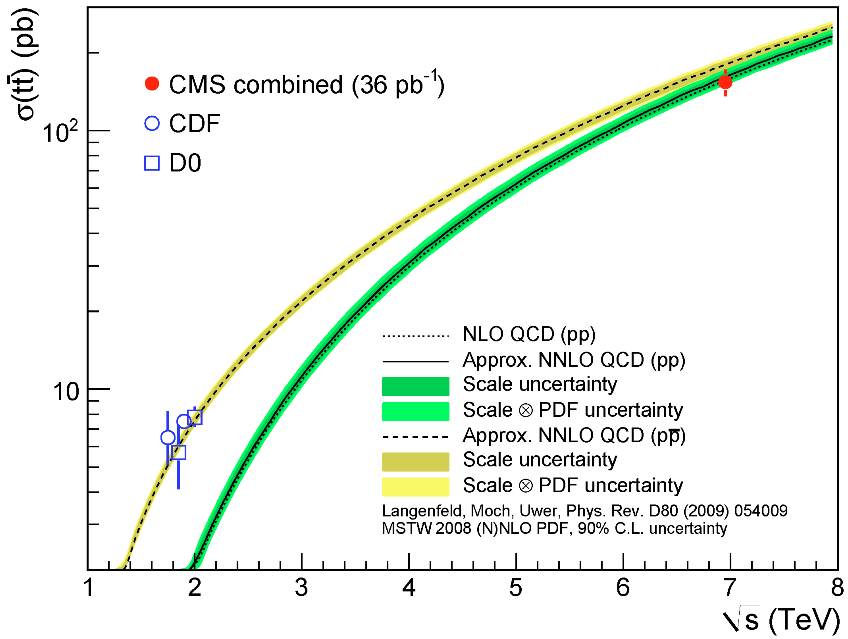
Combination with LHCB:

arXiv:1107.5834

$$\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-) \quad < \quad 1.1\times10^{-8} \text{ at } 95\,\% \text{ CL}$$
$$\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-) \quad < \quad 0.9\times10^{-8} \text{ at } 90\,\% \text{ CL}$$

Top Measurements





Theory predictions

$$\sigma_{t\bar{t}}^{\mathrm{NLO}}(\mathrm{MCFM}) = 158^{+23}_{-24}\ \mathrm{pb}$$

$$\sigma_{t\bar{t}}^{\mathrm{app.\ NNLO}}(\mathrm{HATHOR}) = 164^{+11}_{-13}\ \mathrm{pb}$$

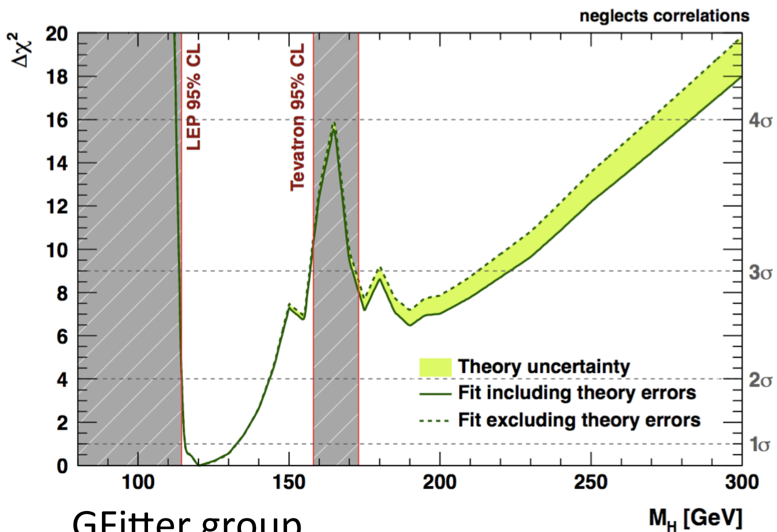
$$\sigma_{t\bar{t}}^{\mathrm{app.\ NNLO}}(\mathrm{Kidonakis}) = 163^{+11}_{-10}\ \mathrm{pb}$$

- Other measurements with top
  - Top charge asymmetry
    - Lower sensitivity than at p-pbar collider
    - Measurements consistent with SM
  - Top-antitop mass difference
    - -1.2+-1.21 (stat) +- 0.47 (syst) GeV
  - Single top production cross section

SM Higgs Boson

- Minimal Standard Model requires 1 Higgs doublet that predicts the existence of one scalar Higgs boson

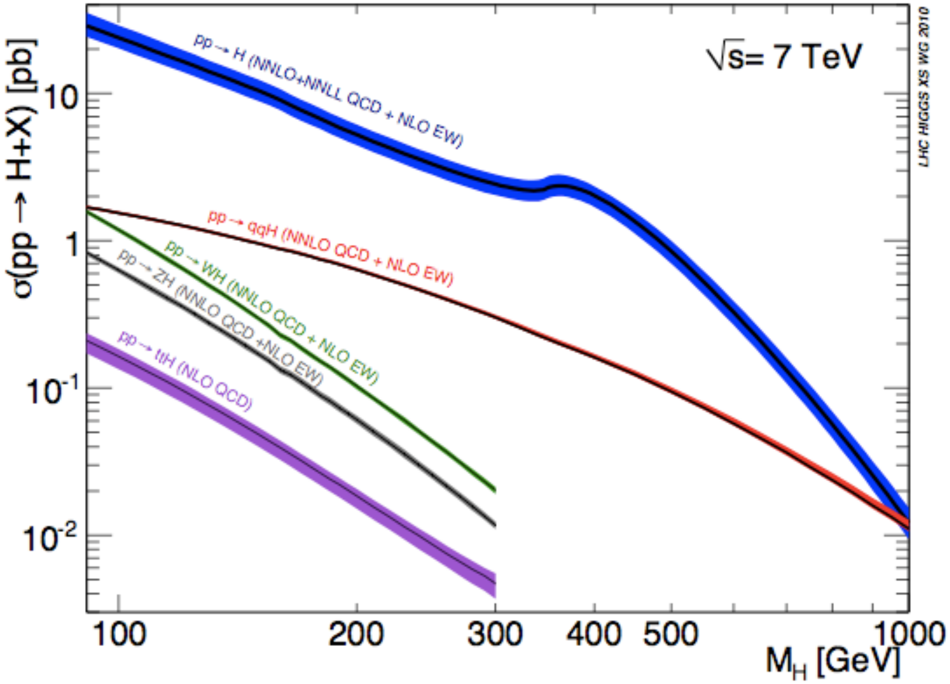
Status before LHC for the SM Higgs boson

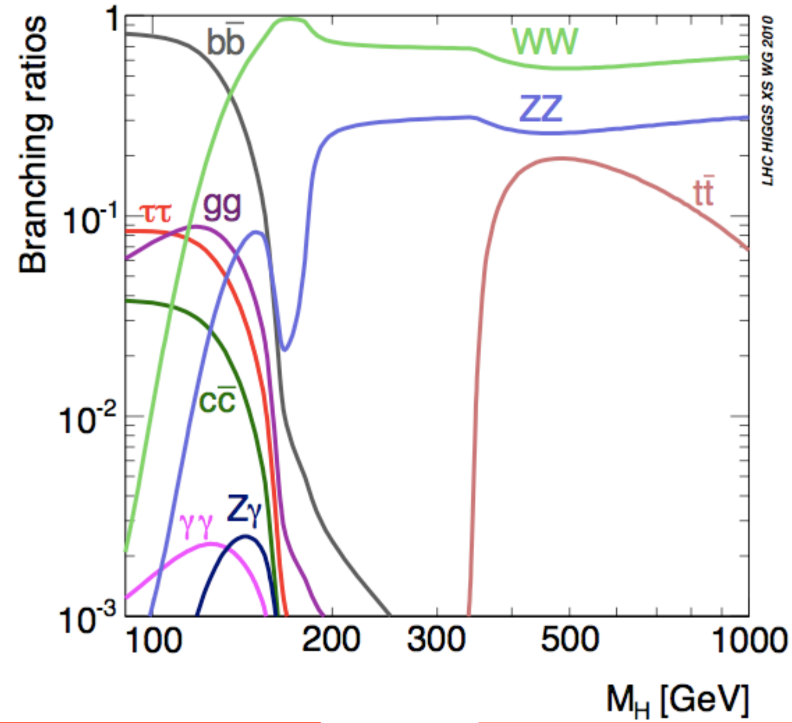


GFitter group
http://arxiv.org/abs/1107.0975

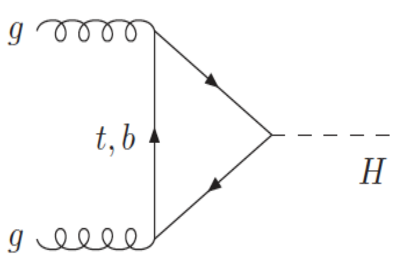
- Direct searches (95% CL exclusion)
  - LEP: $M_H < 114.4$ GeV excluded
  - Tevatron: $156 < M_H < 176$ GeV excluded
- Indirect constraints from precision EW measurements
  - $M_H < 169$ GeV at 95% CL (standard fit)
  - $M_H < 143$ GeV at 95% CL (including direct searches)

SM Higgs Production and Decay

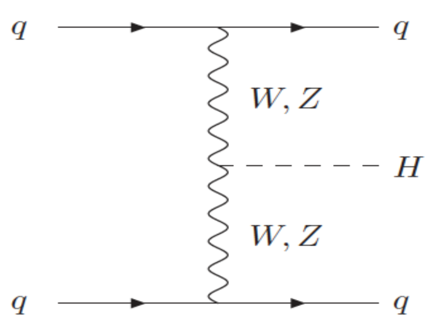




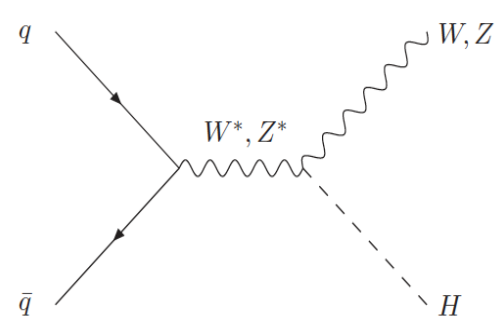
gluon-fusion



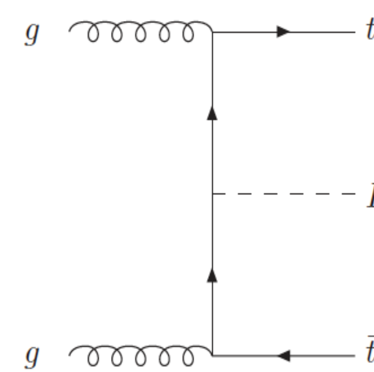
VBF



VH



ttH



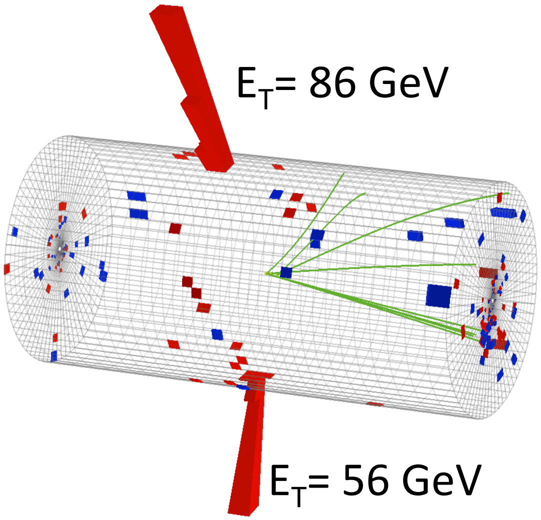
SM Higgs Channels

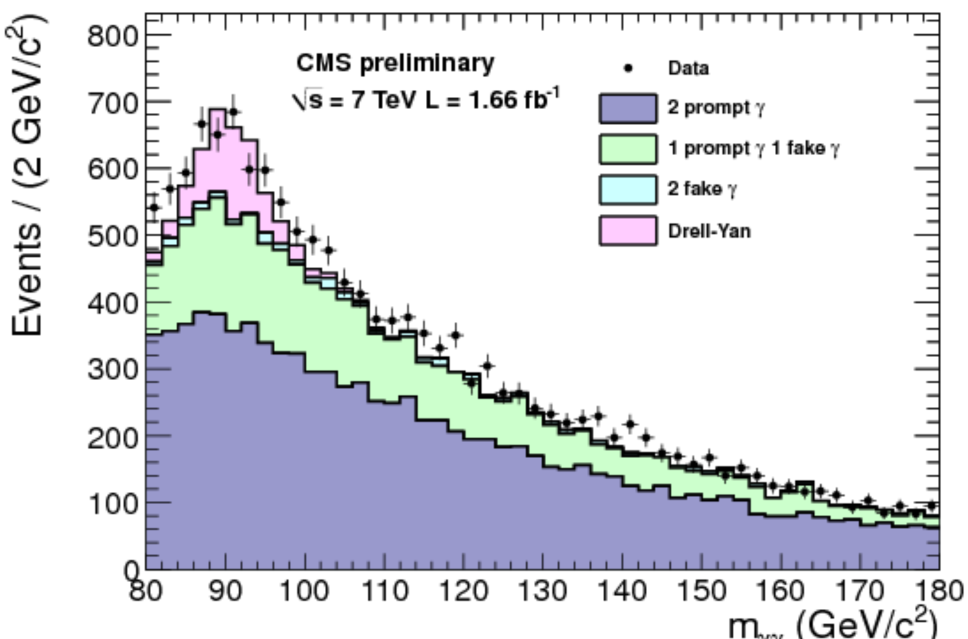
Channel	Mass Range (GeV)	Dataset (fb^{-1})
$H \rightarrow \gamma\gamma$	[110-150]	1.7
$qq \rightarrow VH$; $H \rightarrow bb$	[110-135]	1.1
$H \rightarrow \tau\tau$	[110-145]	1.6
$H \rightarrow WW \rightarrow 2l\,2\nu$	[110-600]	1.5
$H \rightarrow ZZ \rightarrow 4l$	[110-600]	1.7
$H \rightarrow ZZ \rightarrow 2l2\tau$	[180-600]	1.1
$H \rightarrow ZZ \rightarrow 2l2j$	[226-600]	1.6
$H \rightarrow ZZ \rightarrow 2l2\nu$	[250-600]	1.5

The most sensitive channels for discovery and exclusion, **in red in the table**, will be described

$H \rightarrow \gamma\gamma$

- BR rather small ~ 0.002
- Very good mass resolution ~1%
- Signature: small, narrow peak over large smooth background
  - Irreducible: 2γ QCD production
  - Reducible: γ+jet with 1 additional fake photon, DY with fake photons
- Studied mass range: 110-150 GeV
- Photon E_t required to be > 40, 30 GeV



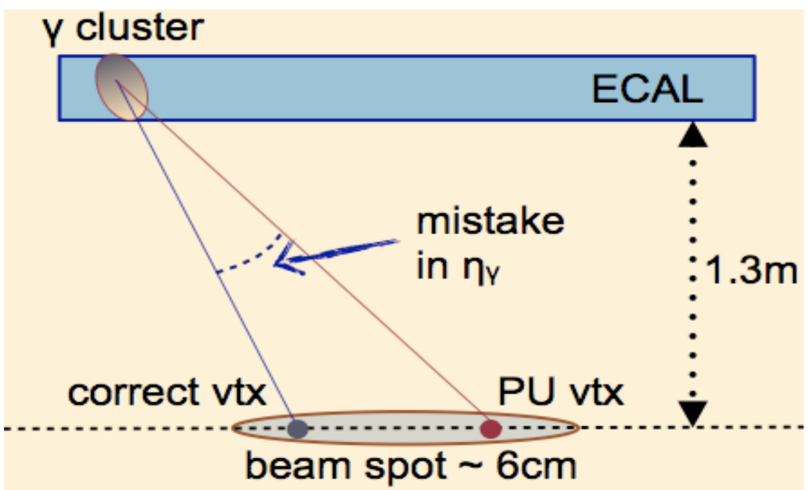


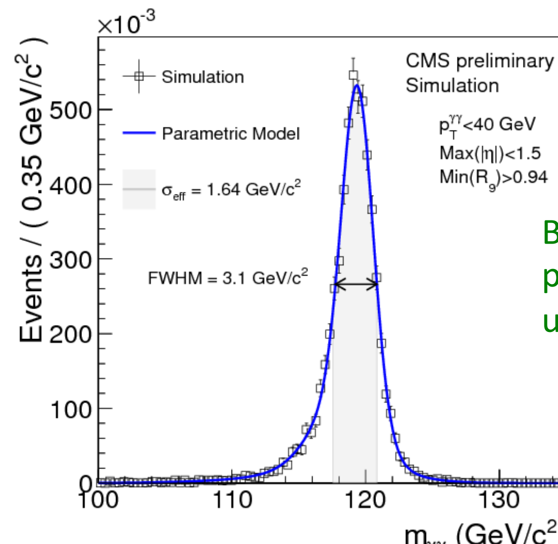
Ingredients of the Analysis

- **Photon Selection**
  - Based on isolation, shower shape and electron rejection, is optimized in different categories (different BG levels)
    - Barrel/endcap
    - Converted/unconverted identified with shower shape in ECAL

- **Primary Vertex Identification**
  - Primary Vertex is identified using tracks from recoiling jets and underlying event + conversion
  - Found correct in ~83% of cases for pileup in analyzed sample

- **Mass resolution**
  - Most important aspect of analysis
  - ECAL response calibrated with $\pi^0 \rightarrow \gamma\gamma$, $W \rightarrow e\nu$ (E/p), $Z \rightarrow ee$
  - Laser corrections measuring transparency loss are applied



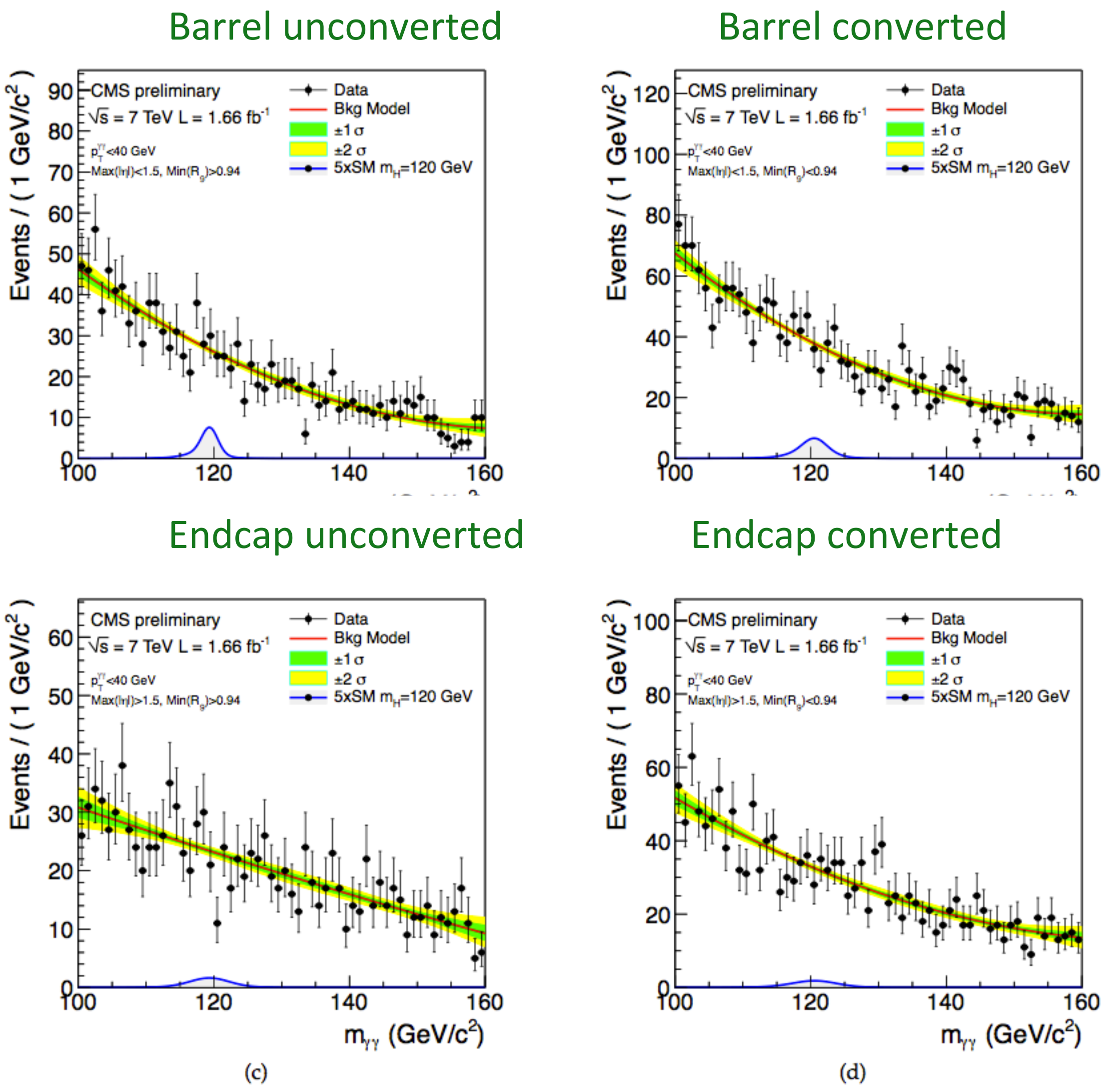


Barrel, both photons unconverted

Categorization and BG Estimate

- Events are classified in 8 categories:
  - Both photons in barrel / at least one photon in endcaps
  - Both photons unconverted / at least one converted
  - Di-photon P_T
    - Splitting categories at 40 GeV allows common analysis between SM and Fermiophobic
  - BG is estimated from data sidebands (no use of BG MC)
    - 2^{nd} order polynomial is fit to the data distribution in 100 – 160 GeV Mass range
  - Signal shape taken from MC after applying all known effects

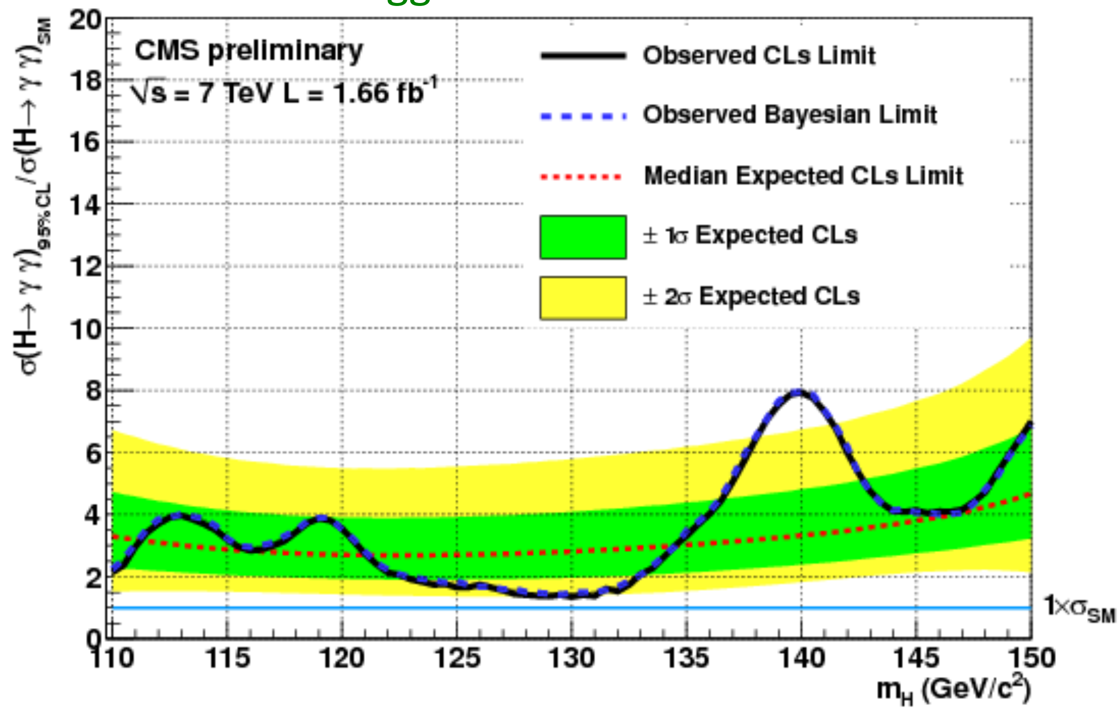
Low $P_{T\gamma\gamma}$ categories



H→γγ Results

- 1.5 to 8 x SM cross section excluded at 95% C.L. in 110-150 GeV mass range
- Slight excess around 140 GeV
  - local significance 2.8 σ, LEE reduces significance to 1.7 σ

SM Higgs 95% CL Exclusion

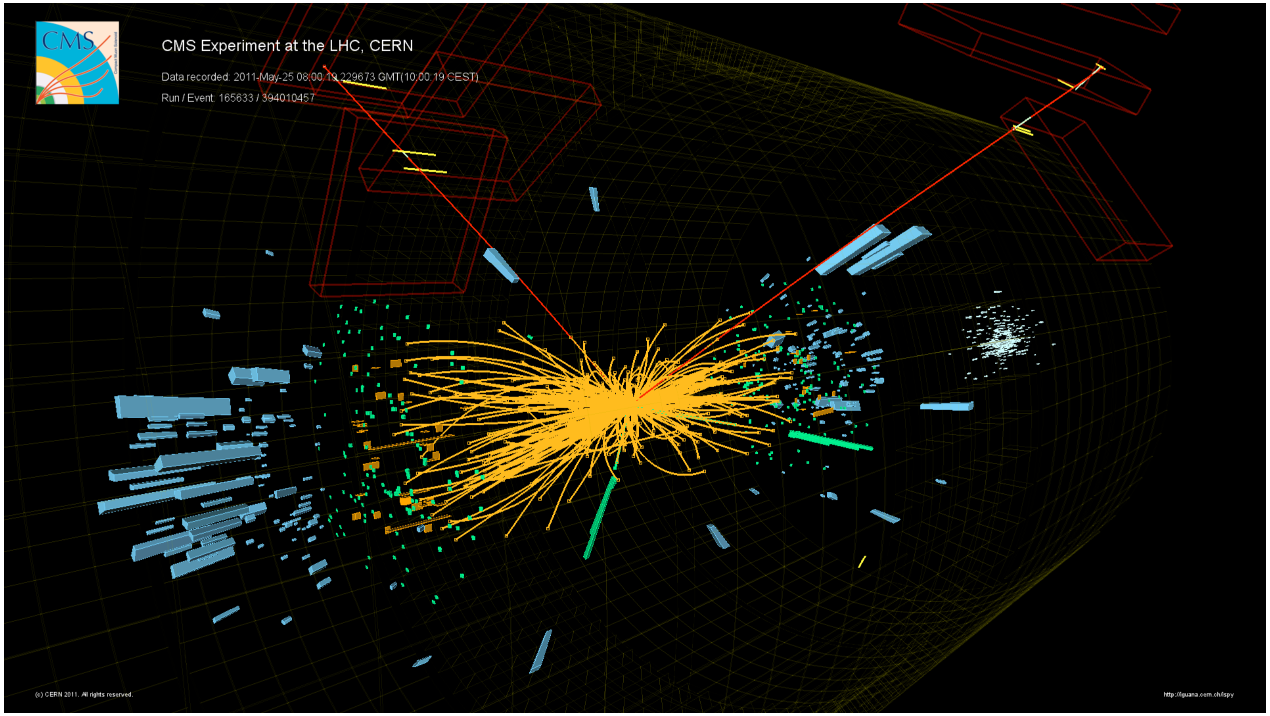


Fermiophobic Higgs exclusion in γγ channel: M_H > 112 at 95% C.L.

H → ZZ → 4 Leptons (4μ, 4e, 2e2μ)

- Also very clean signature: 2 pairs of high Pt electrons or muons
- At least one pair consistent with Z mass
- **Narrow mass peak, resolution 2-4 GeV**
- Br(ZZ→llll) =0.5% → BR(H->ZZ->llll) ~ 1E-3
- **Small background**:
  - Irreducible
    - ZZ
  - Reducible
    - Z+jets
    - Zbb,
    - tt,
    - WZ

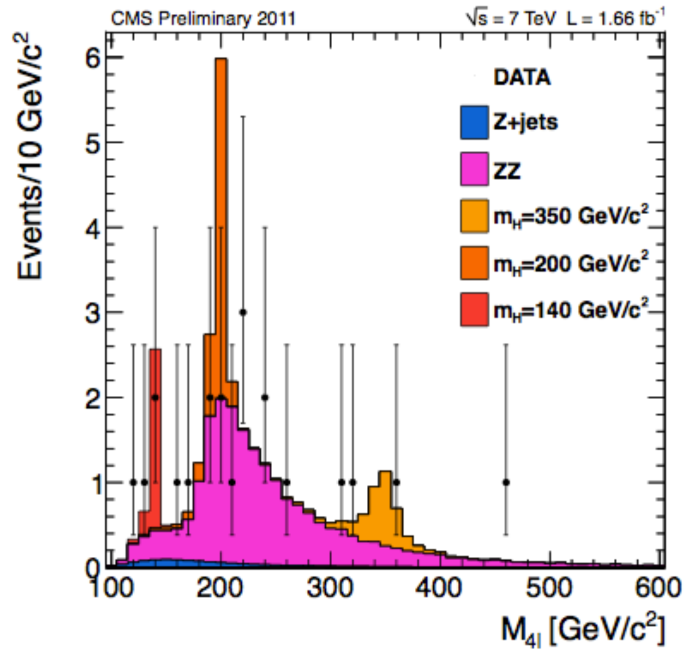
H->eeμμ candidate



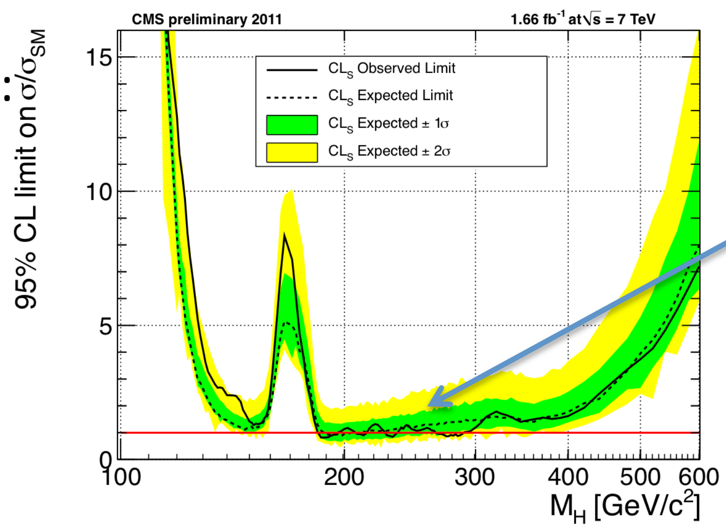
- **Sensitive in mass range 130-600 GeV except the region around 160 GeV**

H→ZZ→4l Results

- Selection
  - 2 pairs of opposite charge isolated electrons or muons
  - At least one on-shell Z
  - All leptons should come for a common vertex
- BG estimation
  - ZZ BG estimated using Z→ll measurement
  - Other BG from control regions



- Expected events from BG: 21.2+-0.8
- Observed in data: 21
- No significant excess

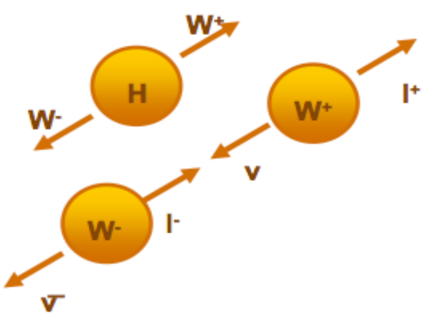


~ 1xSM cross section excluded At 95% CL In region: 200-300 GeV

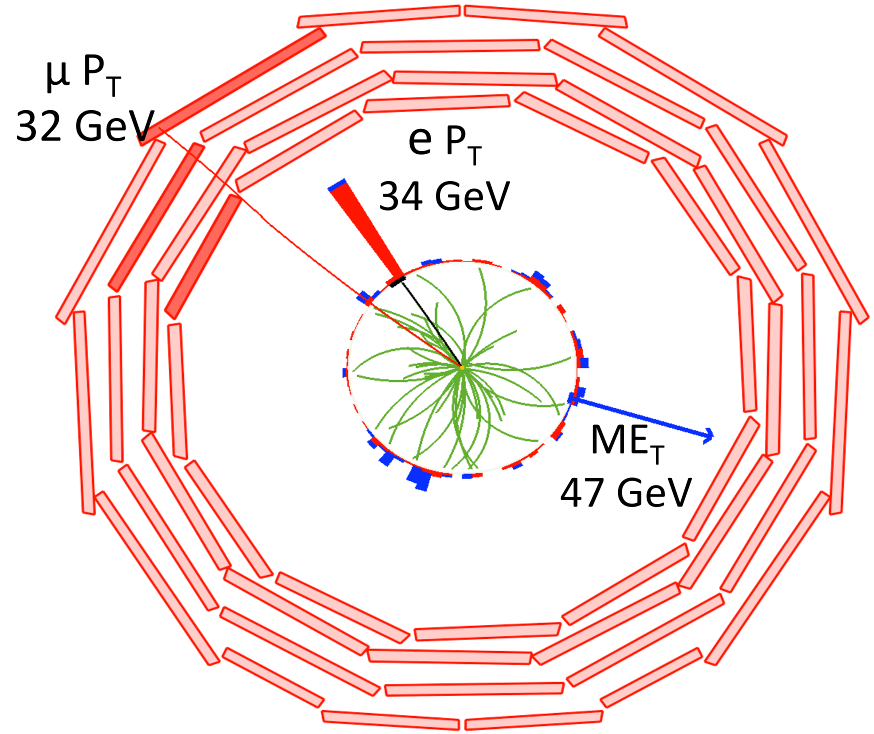
H→WW→$l^+ \nu l^- \nu$

- Most sensitive channel around $2M_W$ (130 < MH < 200 GeV)
- 2 high P_T isolated leptons + MET
- No narrow mass peak

Scalar Higgs +
V-A structure of W decay
favors small opening angle
between the 2 charged leptons
(Small Δϕ)



H→WW→eμνν candidate



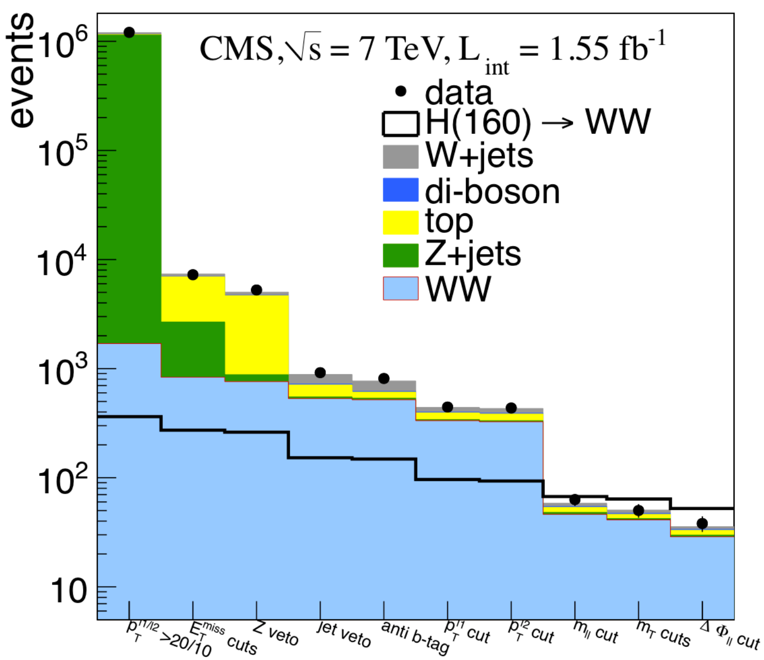
- **MET is affected by pileup, special treatment**
  - Use minimum between MET with all particles and charged met only from identified PV to reduce effect of pileup
  - Use projected MET: Transverse to nearest lepton if <90°, full MET otherwise

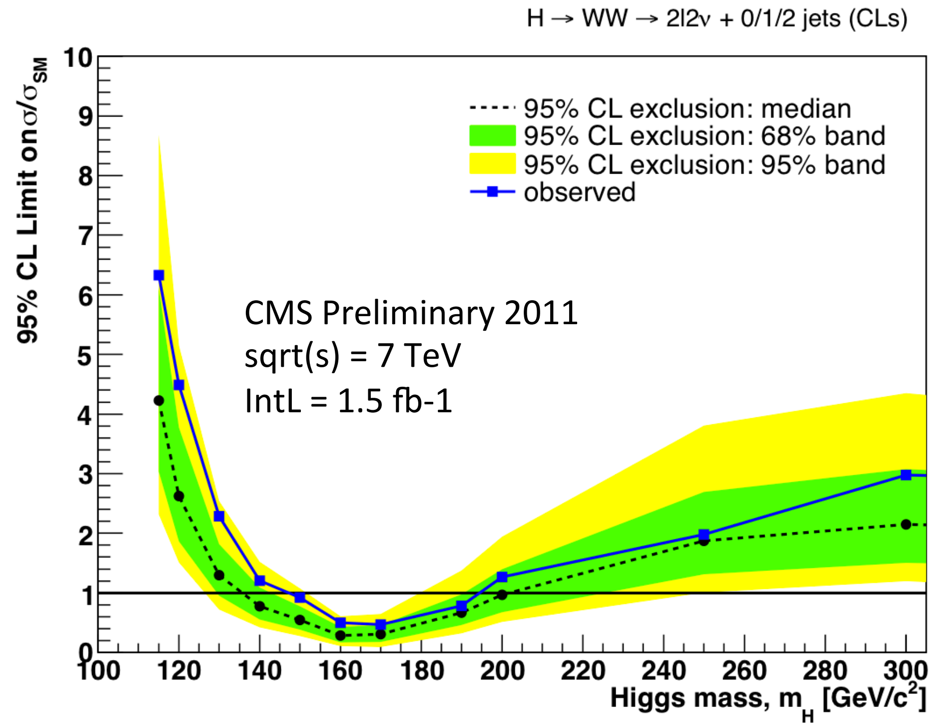
H→WW Results

- Cut and count analysis
- **BG estimation crucial**
- Main backgrounds estimated from data

- No significant excess in the full mass range
- 95% C.L. Exclusion for M_H in [147-193] GeV
  - Expected [136-200] GeV

Effect of sequential cuts, M_H=160 GeV

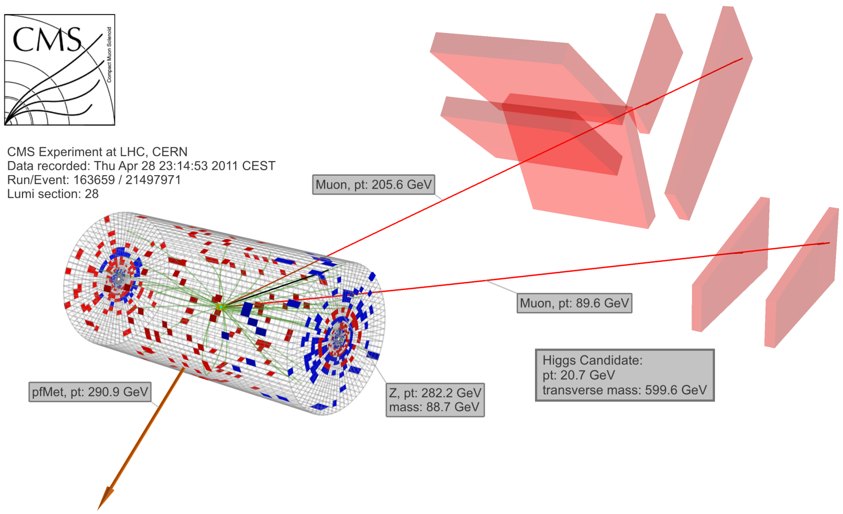


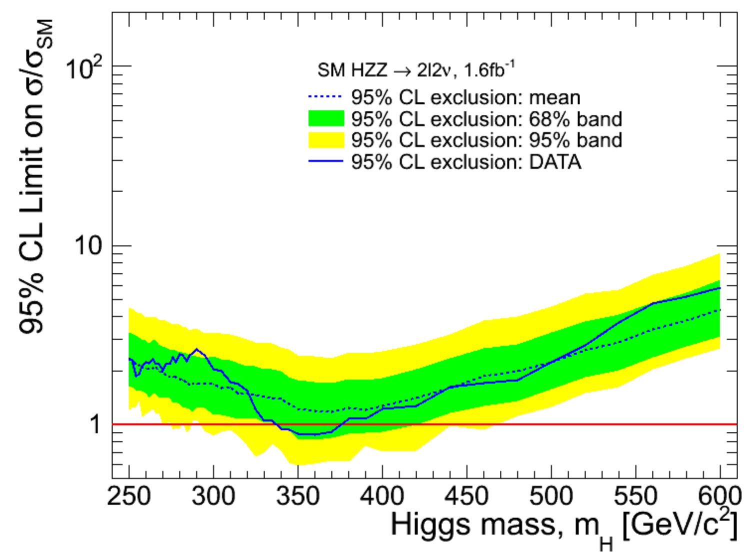


ZZ→llνν

- Most sensitive channel for high mass search, mass range 250-600 GeV
  - BR 6 times larger than ZZ→4l but no mass measurement
- When Higgs mass is large the two Z bosons are boosted → Large MET
- Background
  - ZZ (irreducible), Z+jets, tt, WZ
- Cut and count analysis

- No excess seen in data
- 95% CL exclusion for masses 340-375 GeV

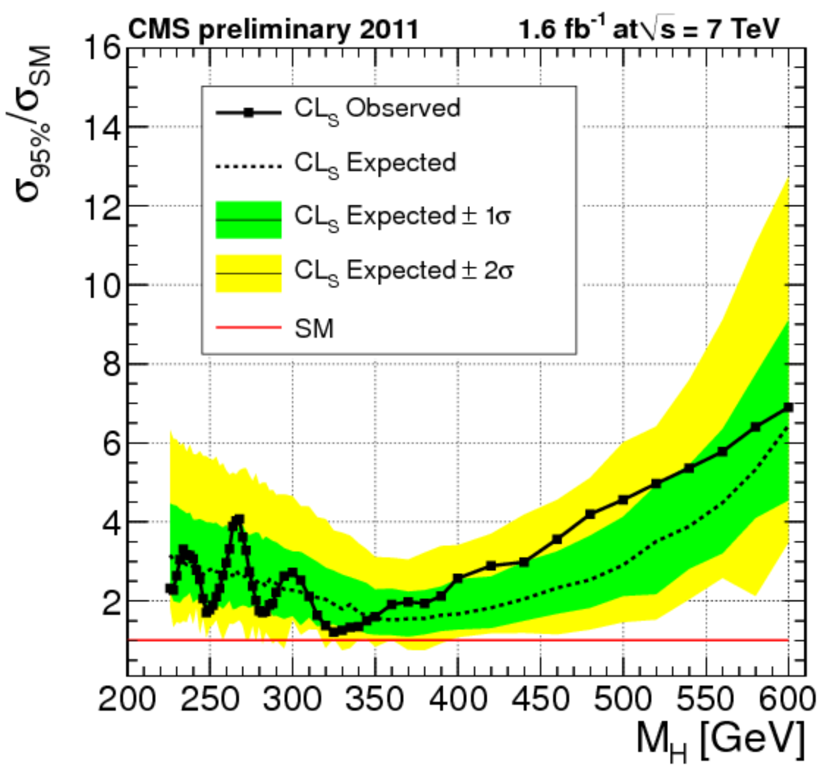




Other SM Channels

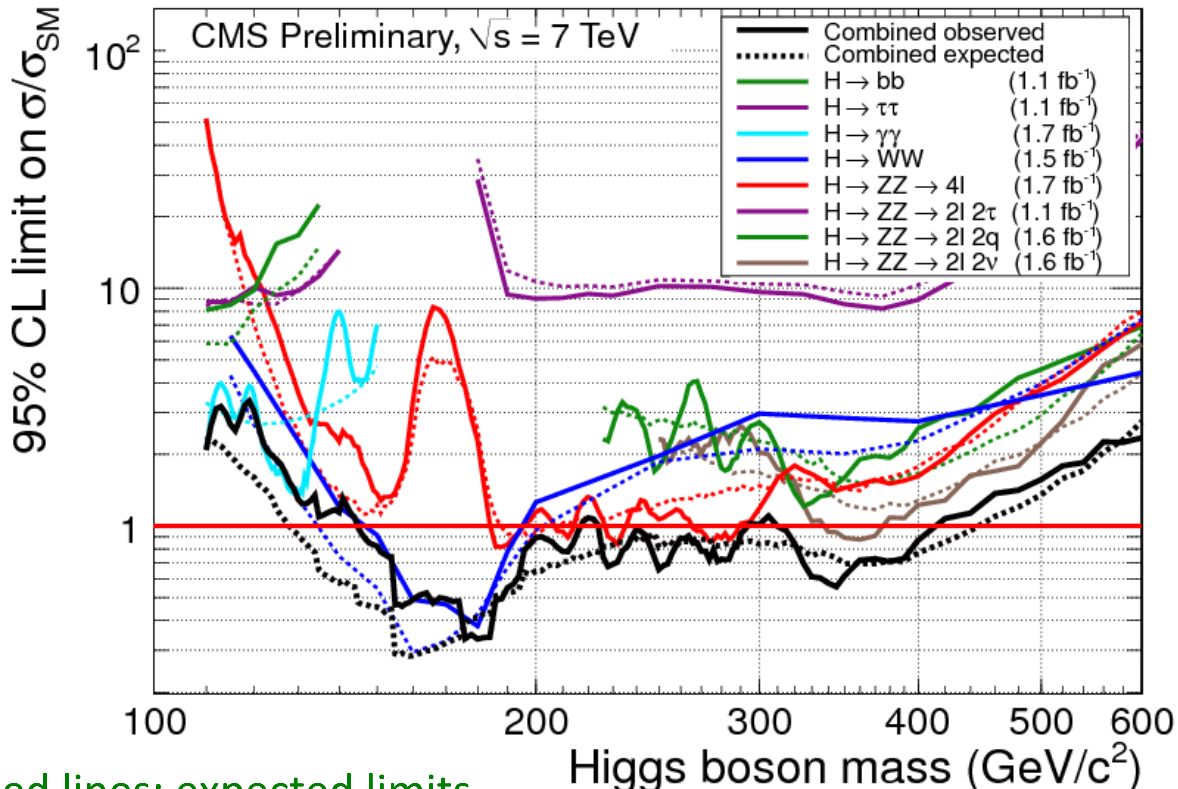
- H → ZZ → llqq
  - Similar sensitivity as other ZZ decays
- H → bb, H → ττ
  - Not very sensitive for discovery but important when/if Higgs boson will be found at low mass to measure its couplings
  - Also important for 2HDM and MSSM
- H → ZZ → llττ
  - All decay channels searched for
  - Low sensitivity (~10xSM)

95% Exclusion from H→ZZ→llqq



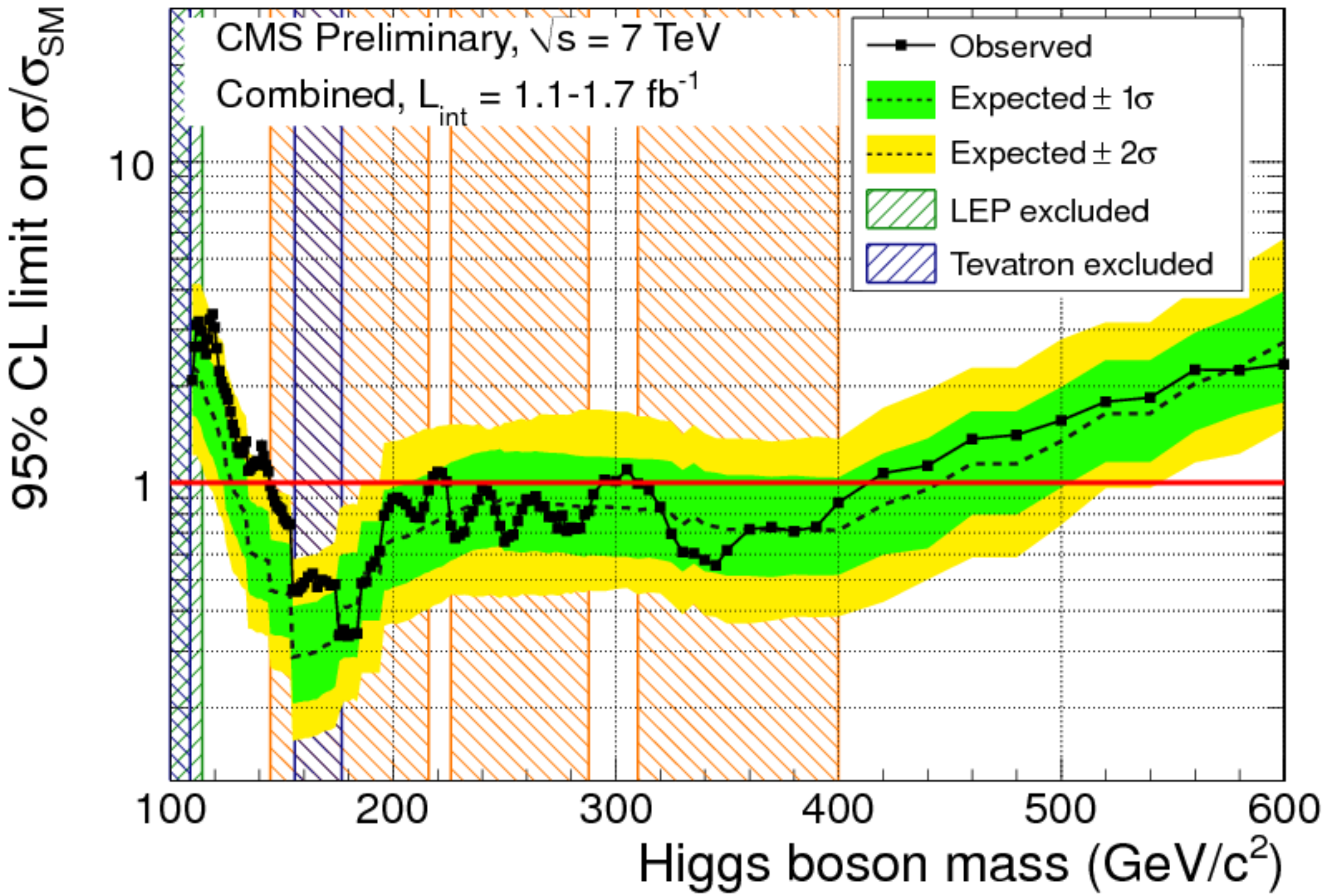
SM Higgs Combined Results

- All channels are combined to obtain the final Confidence Level for exclusion/discovery
- SM cross sections and Branching Ratios are assumed
- Baseline method for CL evaluation is modified frequentist (CLs)



Dotted lines: expected limits
Solid lines: observed limits

SM Higgs 95% Exclusion Limits

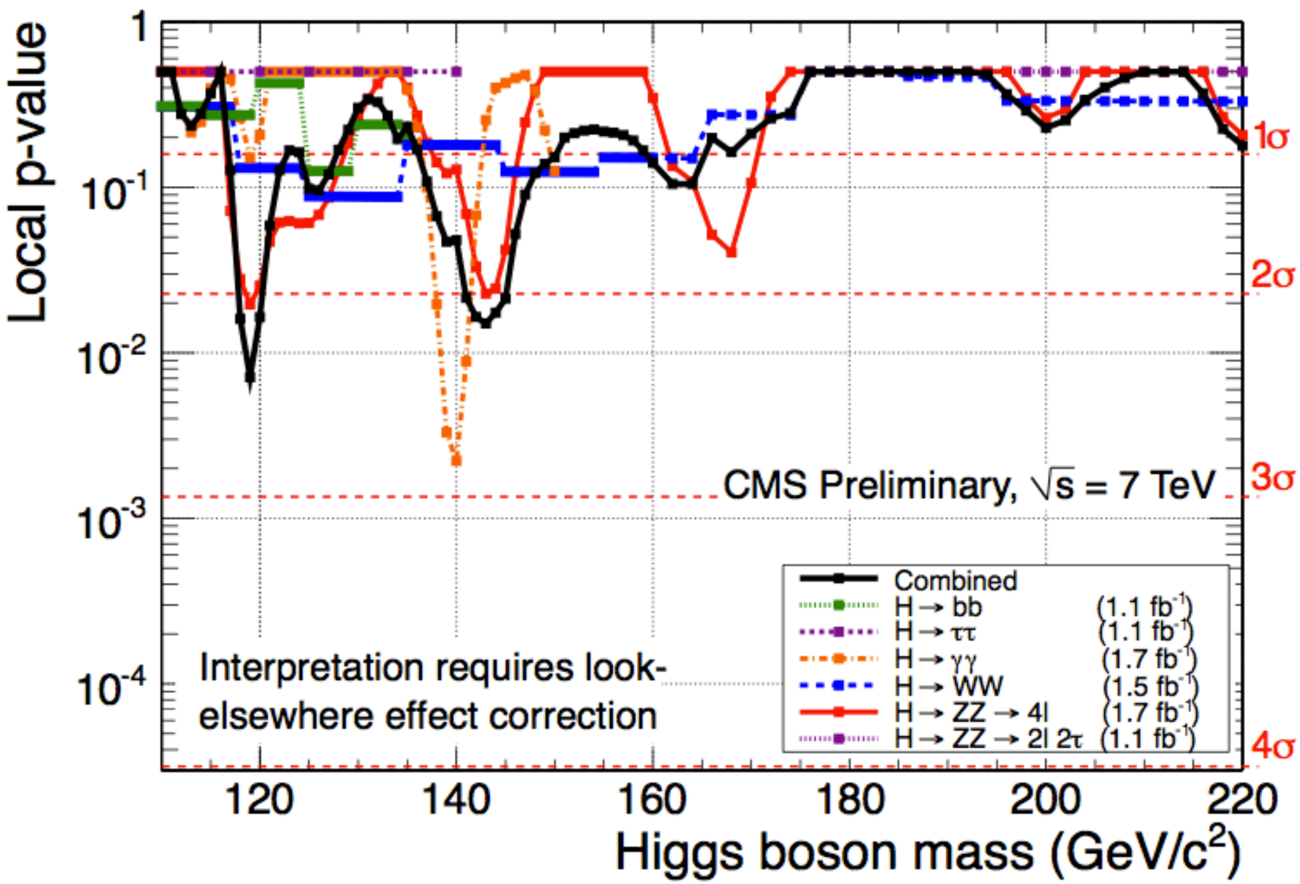


Expected 95% CL exclusion M_H 130 – 440 GeV

Observed 95% CL exclusion M_H 145-216, 226-288, 310-400 GeV

Local p-values

- P-values measure the probability of observing a fluctuation from BG only larger that the one observed in the data
- Given that we searched in many different mass points the p-value should be corrected by the Look Elsewhere Effect (LEE)



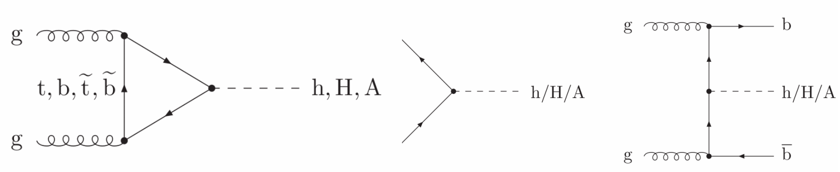
Min p-value of ~1% min p-value becomes ~40% with LEE

MSSM Higgs Bosons

- Minimal SuperSymmetric Model requires at least 2 Higgs doublets and predicts 5 Higgs bosons:
  - 2 Neutral scalars h, H
  - 1 Neutral pseudo-scalar A
  - 2 Charged scalars $H^{\pm}$
- All masses and couplings are determined by 2 independent parameters: for example M_A, tanβ
  - MSSM usually predicts the existence of one Higgs boson similar to SM Higgs
  - For large tanβ, h to WW, ZZ is suppressed and main decays are to bb and ττ
  - Most important channels for large tanβ are Higgs decays to τ leptons

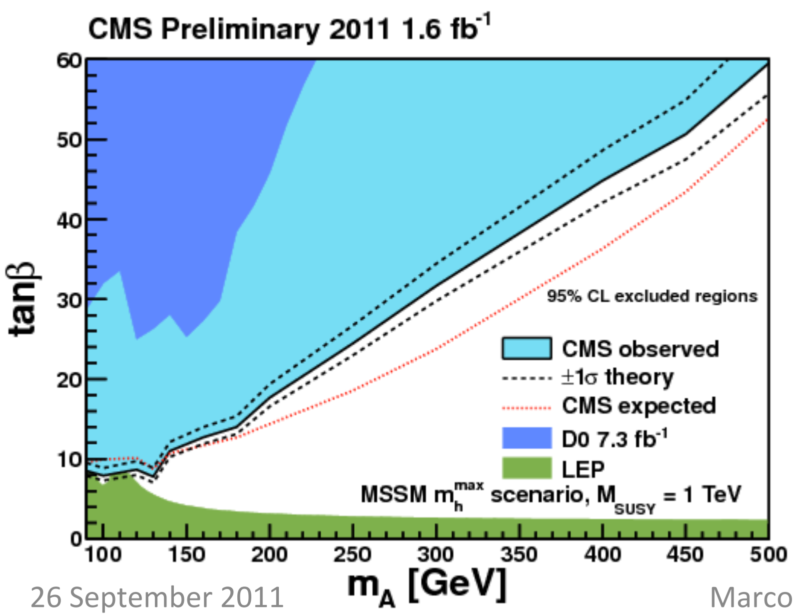
Φ (h,H,A) and $H^{\pm}$ of MSSM

- In MSSM Φ can be produced by gg fusion or bbbar annihilation
- Search channels are μ-τ_{had}, e-τ_{had}, e-μ

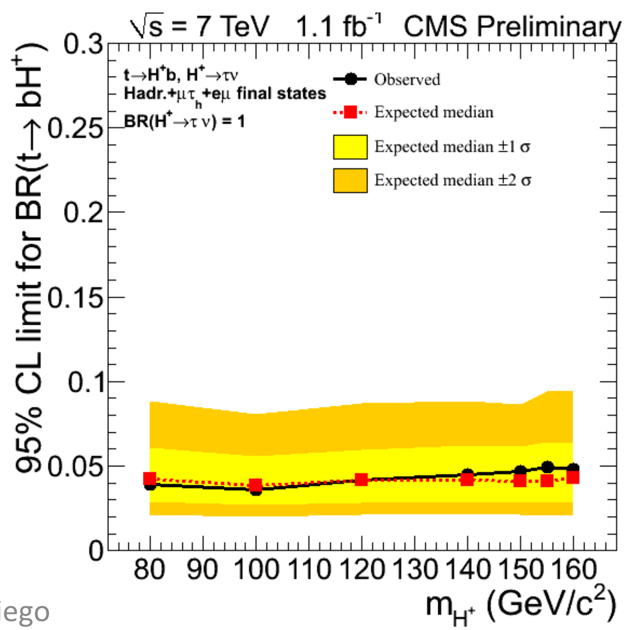


Often at least one b jet produced in the central detector

- No significant excess observed
- MSSM, excluded region at large tanβ. Large improvements in exclusion



- Charged Higgs are searched for in top decays for M_{H^+} in the range 80-160 GeV ($M_{H^+} < M_{top}$)
  - $t\bar{t} \to H^{\pm}W^{\mp}b\bar{b}$, $t\bar{t} \to H^{\pm}H^{\mp}b\bar{b}$
- Search for $H^{\pm} \to \tau\nu$
- No signal observed
- 95% CL limit on BR($t \to bH^+$) of 4-5% assuming BR ($H^+ \to \tau\upsilon$) =1
- Extended limits in tanβ vs M_{H^+} plane in MSSM

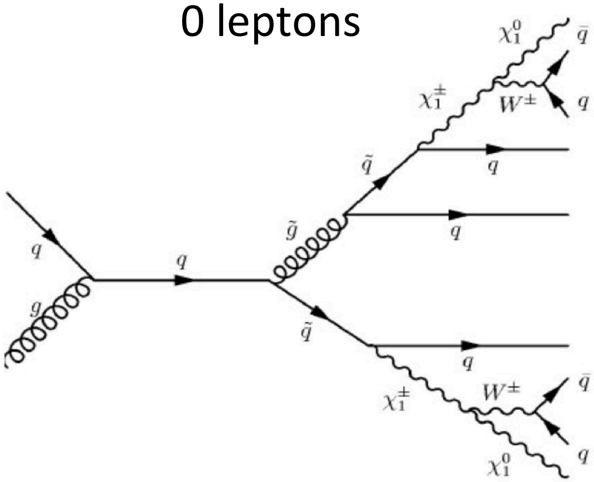


SUSY Searches

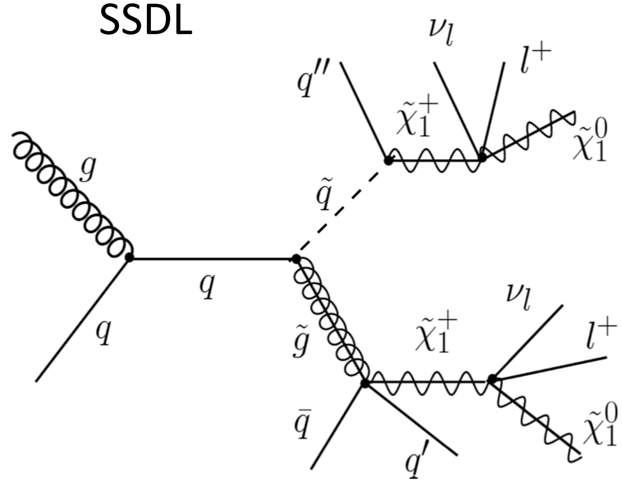
- Search for squark and gluino production
- Missing energy from undetected LSP
- Multiple search channels

0 leptons	**1 lepton**	**OSDL**	**SSDL**	**≥3 leptons**	**2γ**	**1 γ+ 1 lep.**
Jets + ETmiss (+special variables)	Single lepton+ jets+ETmiss	Opposite sign di-leptons+ jets +ETmiss	Same-sign di-leptons + jets + Etmiss	Multi- leptons	Di-photon + jets + Etmiss	Photon + lepton + Etmiss

0 leptons

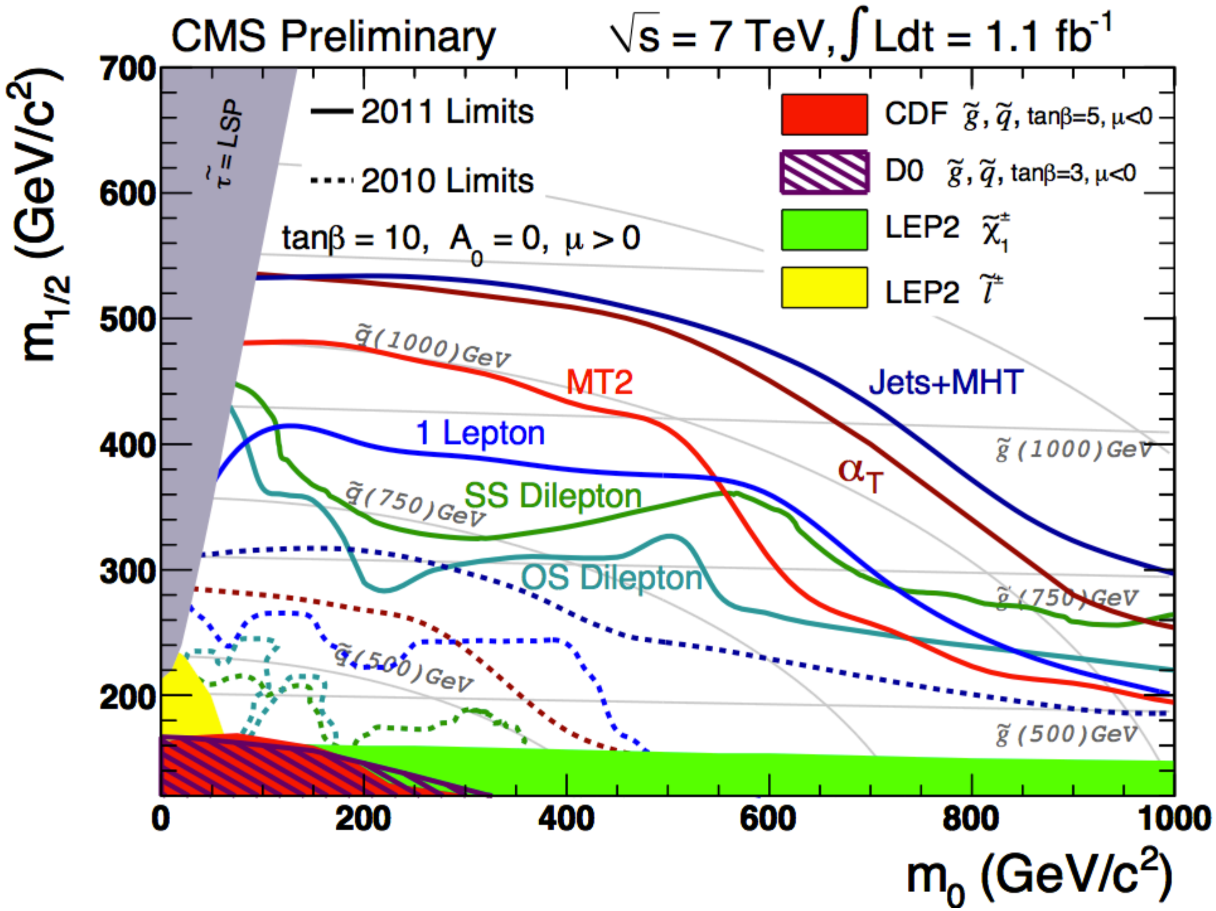


SSDL



Exclusion limits in CMSSM

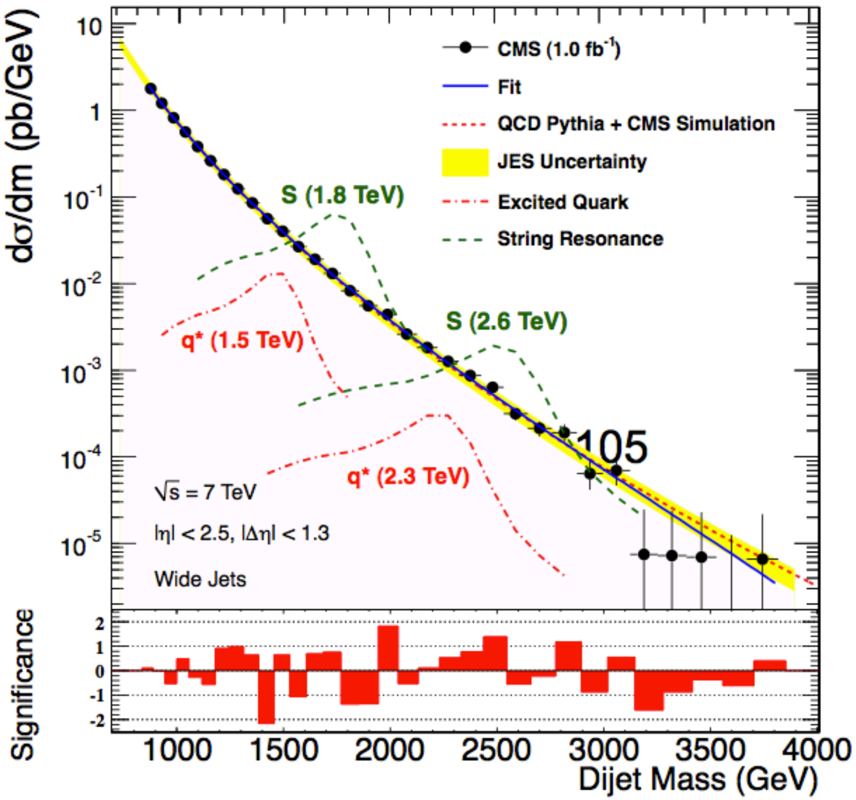
- Limits have been obtained in the constrained MSSM



- Squarks and gluinos up to 1 TeV and beyond are excluded at 95% CL

Search for Di-jet Resonances

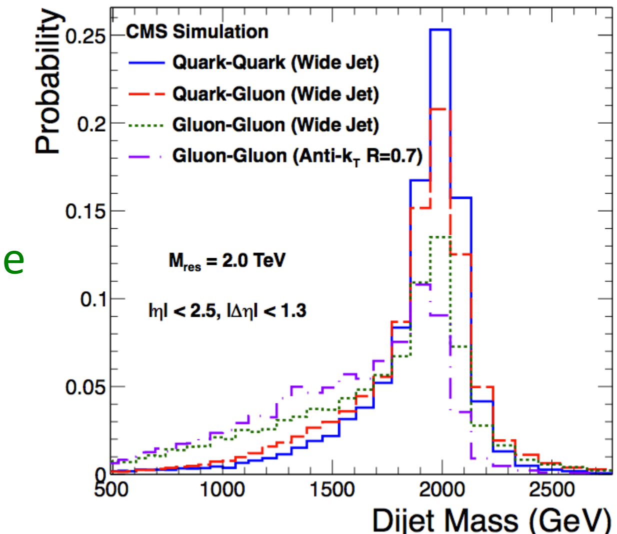
arXiv:1107.4771



Parametrization of the data:

$$\frac{d\sigma}{dm} = \frac{P_0(1 - m/\sqrt{s})^{P_1}}{(m/\sqrt{s})^{P_2 + P_3 \ln(m/\sqrt{s})}}$$

Signal shape

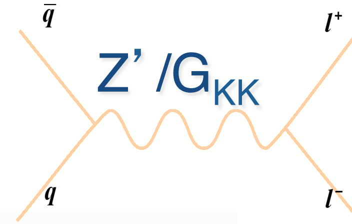


Lower limit on the mass in different models

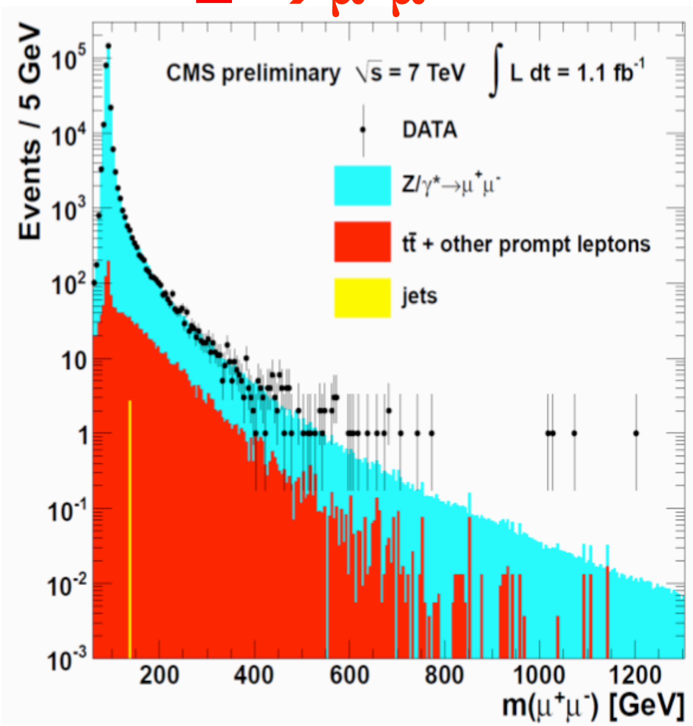
Model	Excluded Mass (TeV)	
	Observed	Expected
String Resonances	4.00	3.90
E_6 Diquarks	3.52	3.28
Excited Quarks	2.49	2.68
Axigluons/Colorons	2.47	2.66
W′ Bosons	1.51	1.40

Search for Z' and Graviton

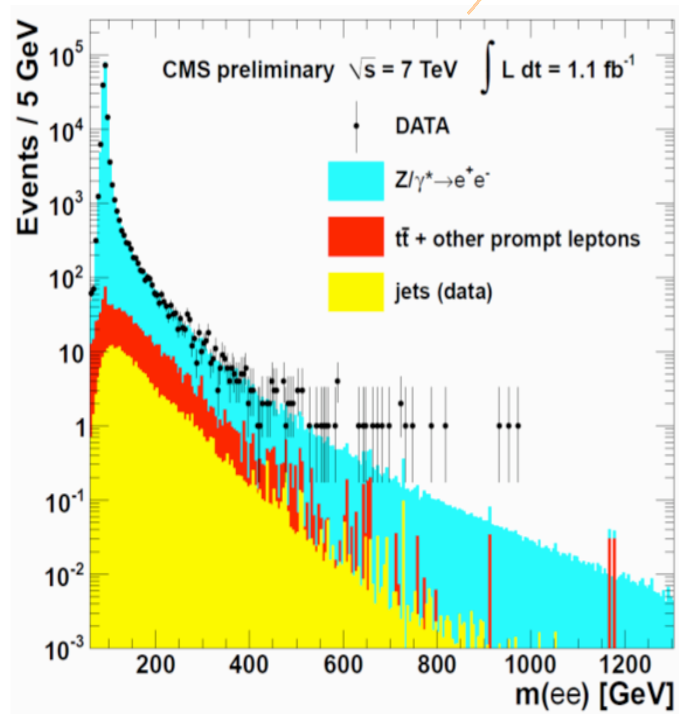
- Di-muon and di-electron mass spectra



Z' → $\mu^+\mu^-$



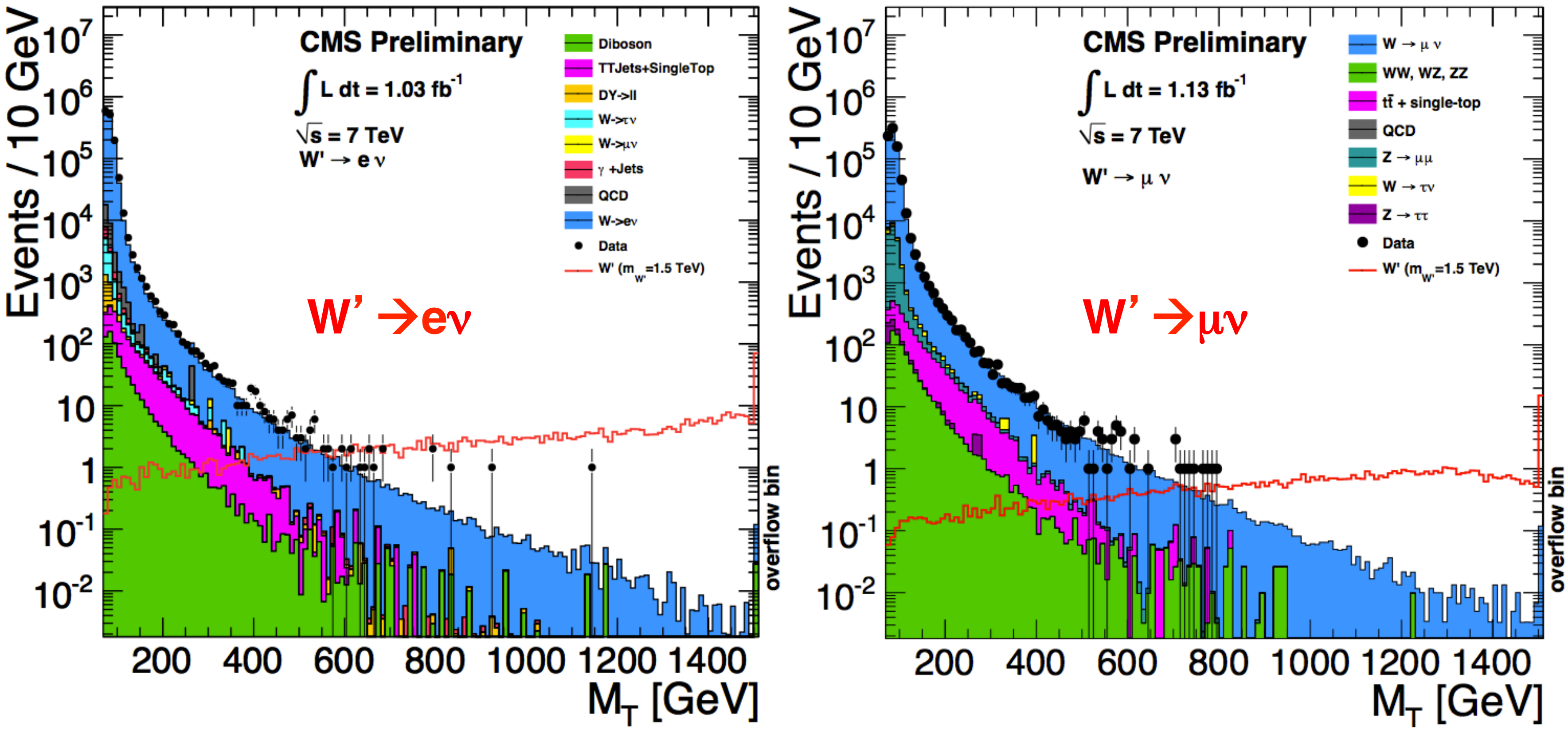
Z' → e^+e^-



Model	95% CL lower limit on the mass
Sequential Standard Model Z'_{SSM}	1940 GeV
Super-String inspired models, Z'_{ψ}	1620 GeV
RS Kaluza-Klein Gravitons for (k/M_{Pl}) 0.05-0.1	1450-1780 GeV

Search for W'

- Electron or μ + Missing E_T



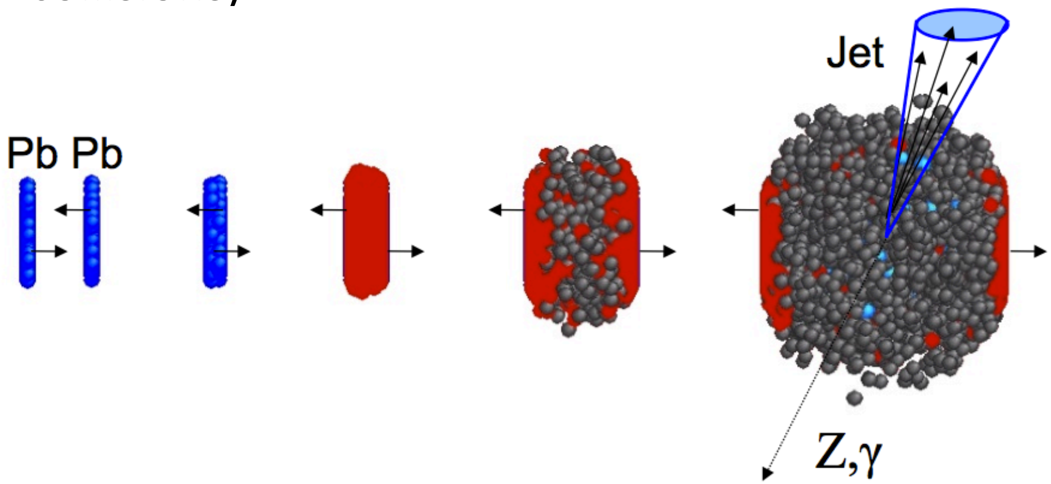
- Assuming SM-like couplings and BR, SSM W' with mass < 2.27 TeV is excluded at 95% C.L.

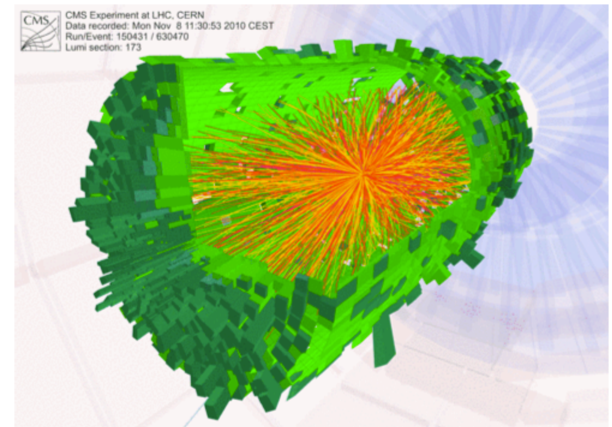
Other Searches

- Many other searches have been carried out, we searched for:
  - 4th Generation quarks t’ and b’
  - Leptoquarks
  - Excited leptons e* and μ
  - Heavy Charged Stable Particles (HSCP)
  - …
- Unfortunately we found no positive signals and we obtained exclusions
- In any case, we will keep searching, we are only at the beginning

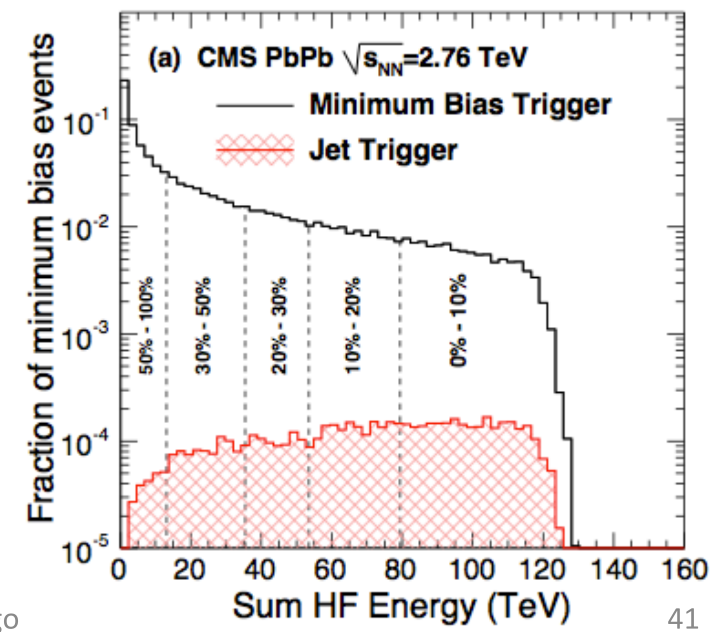
Heavy Ions

- LHC can also collide heavy ions (Pb-Pb) collisions)





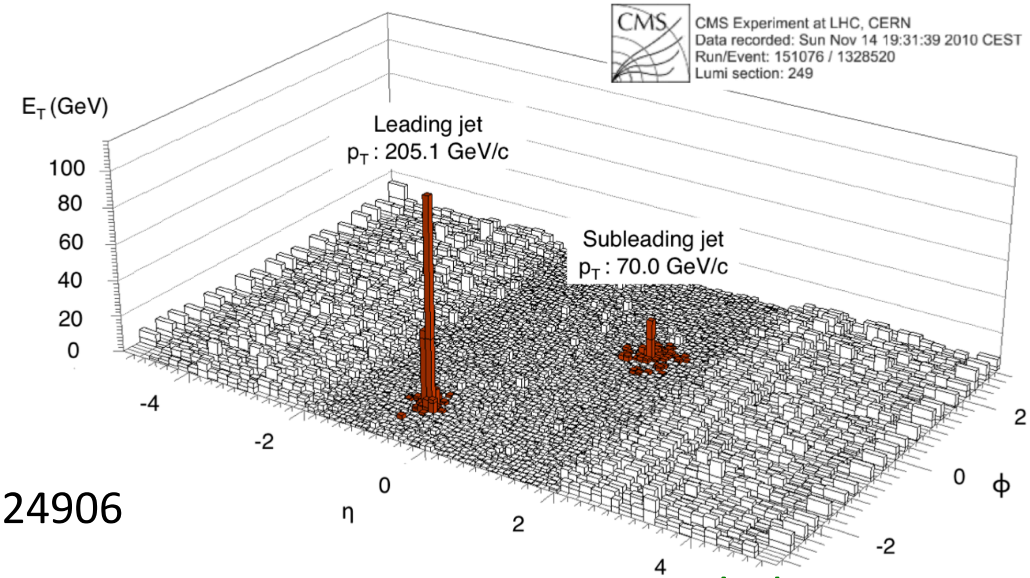
Centrality bins



- Heavy Ion run for about 1 month in November 2010 at 2.76 TeV nucleon-nucleon CM energy
- Trigger on minimum bias, jets, muons and photons
- Recorded luminosity Pb-Pb 8.7 μb^{-1}
- In 2011 we had a special pp run at 2.76 TeV 241 nb^{-1}

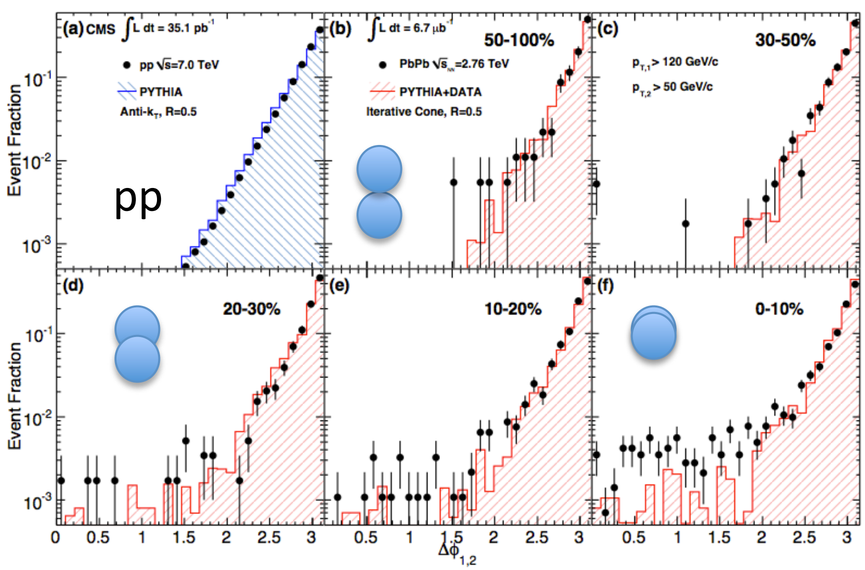
Observation of Jet Quenching

- Jet loose energy passing through the nuclear medium
- Observed momentum imbalance
- Direction is mostly unchanged
- Energy appears to be lost in particles at low P_T and large ΔR from jet core

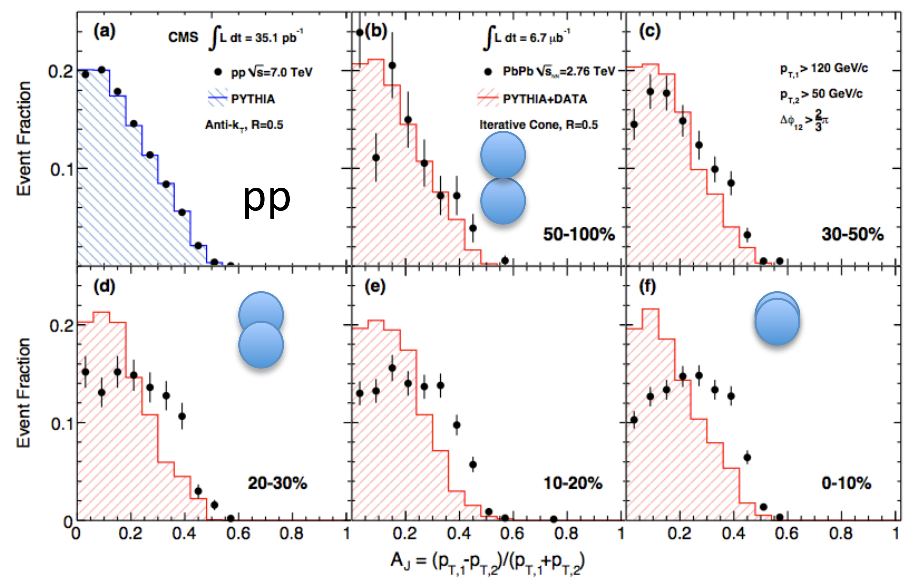


Phys, Rev. C 84 (2011) 024906

Δϕ



Di-jet momentum imbalance

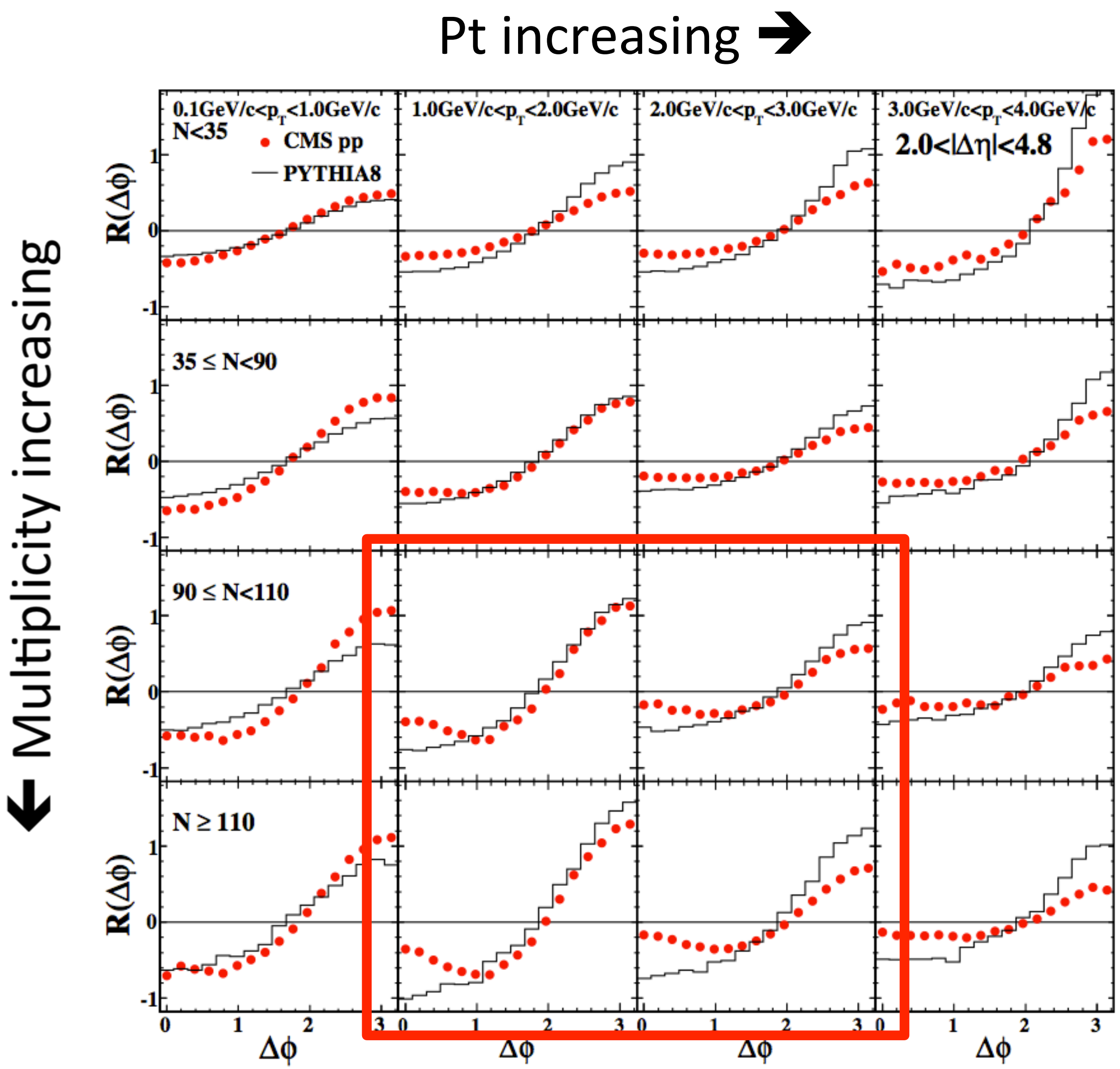


Summary and Outlook

- LHC and CMS performance in 2011 was excellent
  - Peak luminosity now > $3x10^{33}$ $cm^{-2}s^{-1}$
  - Large pileup 20 collisions per bunch crossing
- ~ 1.5 fb^{-1} of data collected before the Summer Conferences have been analyzed
  - Many different measurement have been carried out
  - No evidence of new physics
  - New 95% exclusion limits for the SM and MSSM Higgs have been produced
  - Most theoretically favored low mass range needs some more time
- Expect a total of ~5 fb^{-1} by the end of this year and another ~10 fb^{-1} in 2012 (perhaps at slightly higher CM energy)
  - Looking forward to collect and analyze the data
  - SM Higgs boson could be observed or excluded
- Many thanks to:
  - the LHC team for the impressive performance of the machine
  - you for your attention

Backup

Long Range Near-Side Correlations



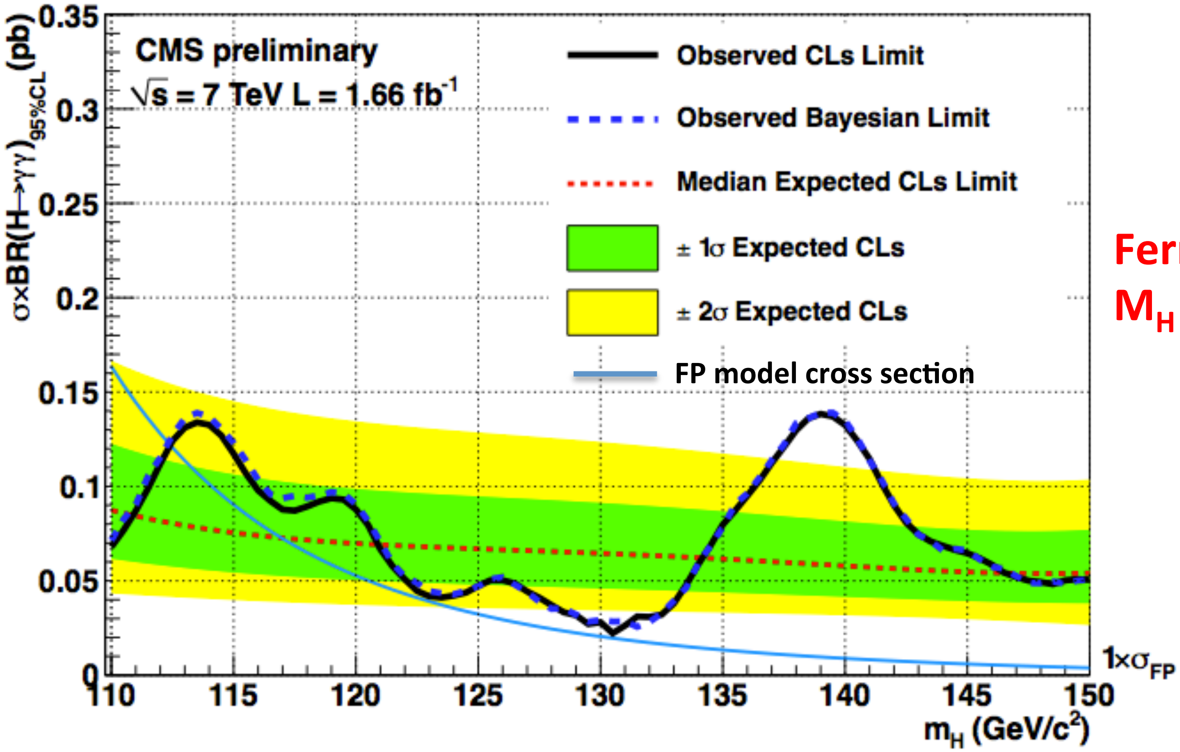
Trigger for Higgs

- Trigger for Higgs is relatively easy for most sensitive channels
- Main triggers:
  - Di-photon E_T > 26, 18 GeV
  - ee, eμ: E_T > 17, 8 GeV
  - μμ: E_T > 13, 8 GeV
  - Single isolated muon: E_T > 17 GeV
- Trigger efficiency after selection larger than 99% after selection for most channels and masses
- More complicated and less efficient for bb and ττ
- With the increase of luminosity rejection will have to increase in future

H→γγ Fermiophobic

- Fermiophobic model:
  - Higgs boson does not couple to fermions
  - Only VBF and VH production modes
  - H->γγ BR enhanced for low mass (no bb decay)

95% CL upper limit on sigma times BR

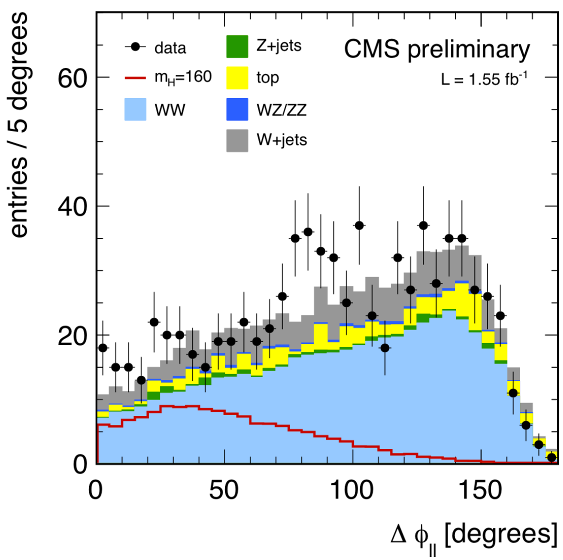


Fermiophobic Exclusion
M_H > 112 at 95% C.L.

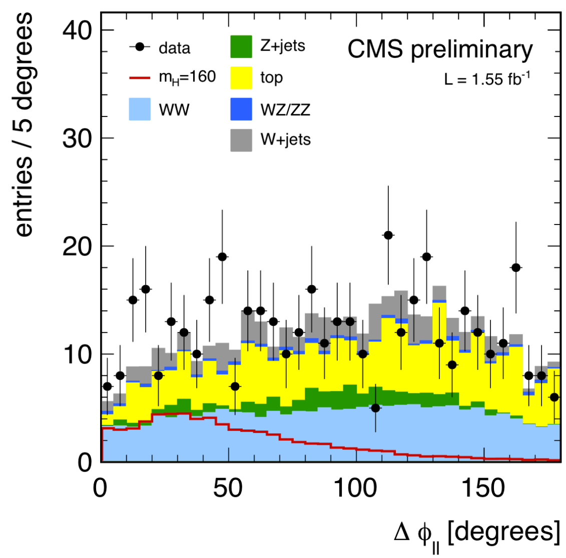
H→WW Selection

- Analysis is performed in exclusive jet multiplicities (0, 1, 2-jet bins), different BG contributions
  - WW BG contributes more to the 0 jet bin
  - ttbar BG contributes more to the 2 jet bin
- Apply cuts on PT leptons, Mll, MT, Δϕ, btag veto (top BG rejection)
- For Two jet bin 2 VBF jets selection
  - $M_{jj} > 450$ GeV, $\Delta\eta_{jj} > 3.5$

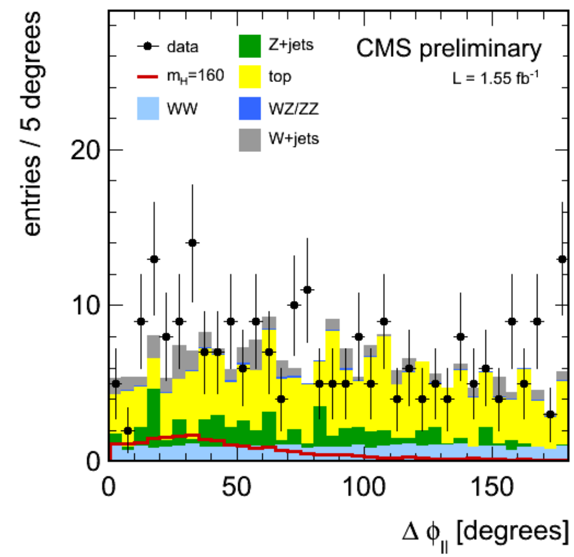
0 jet channel



1 jet channel



2 jet channel



M_H 160 GeV

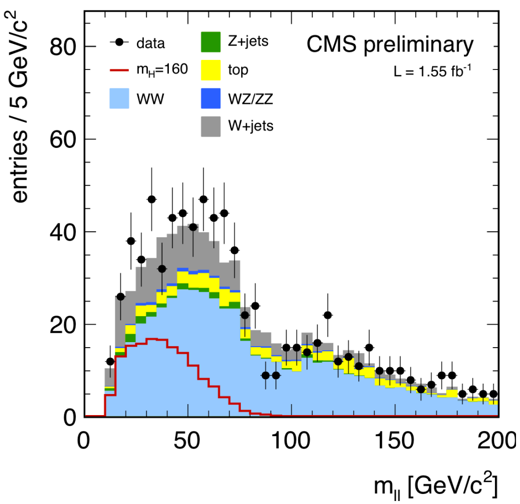
Background Estimation in the H→WW Channel

- BG estimation is crucial for this channel
- Main BG are estimated from data

process	Higgs	$qq \to WW$	$gg \to WW$	VV	top	$Z/\gamma^* \to \ell^+\ell^-$	W + jets	∑Bkg	data
0-jet bin, SF	18.8 ± 4.2	31.5 ± 5.5	1.5 ± 0.8	0.8 ± 0.1	3.1 ± 1.1	0.1 ± 0.0	5.6 ± 2.3	44.0 ± 6.2	46
0-jet bin, OF	15.9 ± 3.6	29.1 ± 5.1	1.3 ± 0.7	0.5 ± 0.1	1.4 ± 0.5	3.1 ± 4.2	5.3 ± 2.2	40.6 ± 7.0	41
1-jet bin, SF	6.6 ± 2.2	8.3 ± 3.1	0.5 ± 0.3	0.5 ± 0.1	5.6 ± 1.2	0.2 ± 0.1	2.4 ± 1.1	17.8 ± 3.5	23
1-jet bin, OF	4.6 ± 1.5	5.8 ± 2.2	0.3 ± 0.2	0.3 ± 0.1	3.2 ± 0.8	1.2 ± 2.7	1.5 ± 0.9	12.6 ± 3.7	23
2-jet bin	0.5 ± 0.1	0.6 ± 0.2	0.1 ± 0.1	0.0 ± 0.0	2.6 ± 1.5	0.8 ± 0.6	1.0 ± 0.6	5.3 ± 1.7	7

WW for low mass:
control region MT>100 GeV
Extrapolate to lower masses
Using MC

Z+jets, WZ, ZZ
Extrapolated using MC
From control region
with Z mass veto inverted



Top BG
Using btag
efficiency measured
In top enriched
control sample

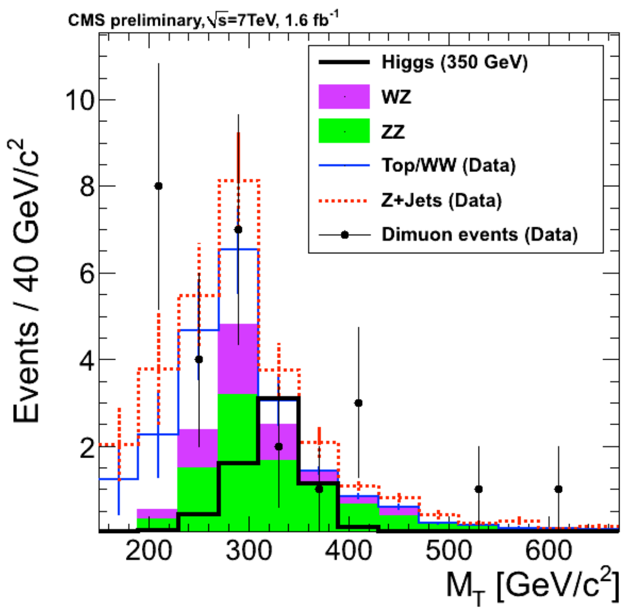
W+jets
Using 'fake rate' method
Looser, non-overlapping
lepton id on one lepton
Misidentification
probability applied

ZZ→llνν Selection

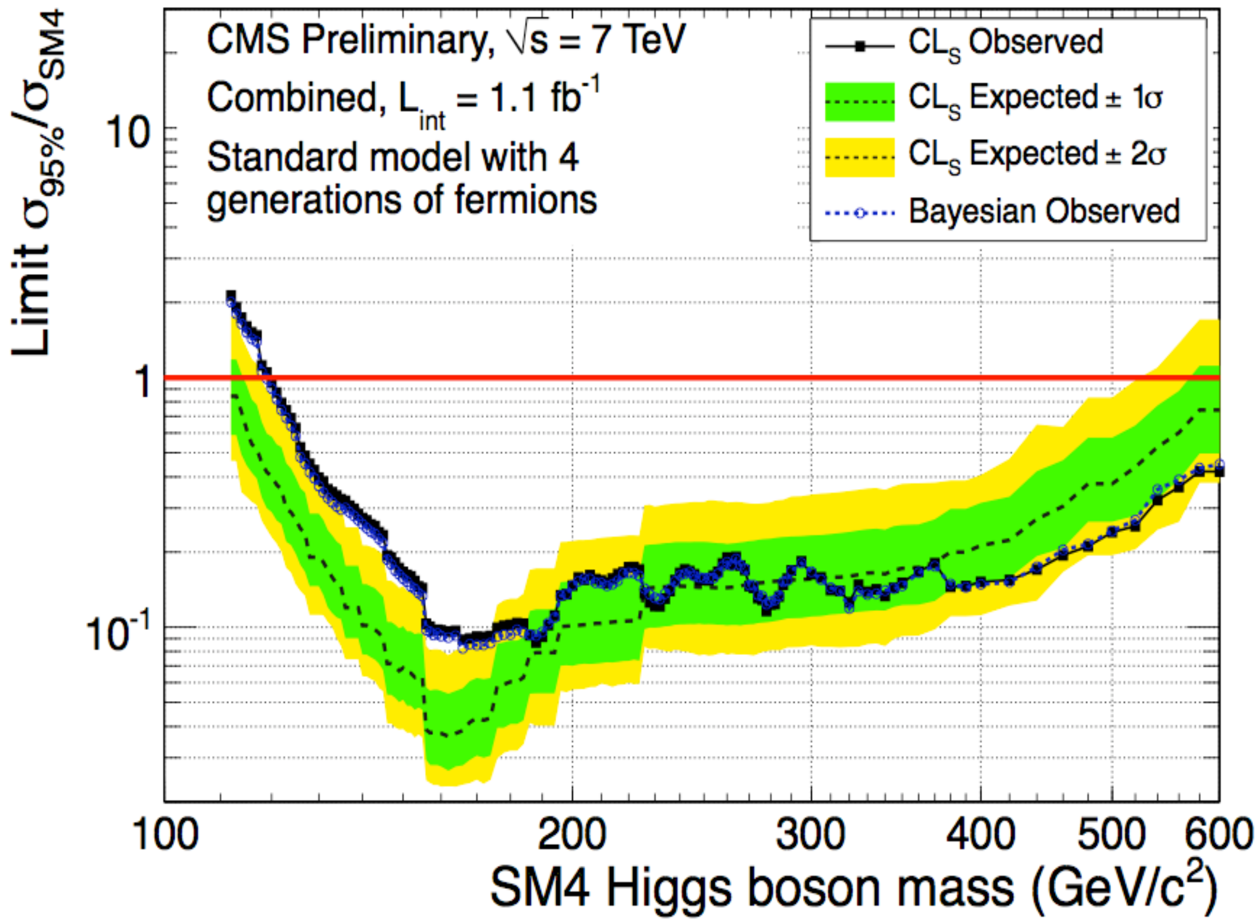
- Selection
  - Dilepton mass consistent with Z, P_{tZ}
  - Veto b-jet and soft muons to reduce top BG
  - Veto 3rd lepton to reduce WZ
- BG estimation
  - Z+jets estimated using γ+jet to model the MET distribution
  - Non resonant BG normalization from eμ events
  - ZZ and WZ from MC
- Mass dependent optimized selection
  - MET, Δϕ(MET,jet), Transverse Mass M_T

$$M_T{}^2 = (\sqrt{P_{TZ}{}^2 + M_Z{}^2} + \sqrt{MET^2 + M_Z{}^2})^2 - (\vec{P_{TZ}} + \vec{MET})^2$$

μμ channel, M_H = 350 GeV



SM4G Higgs



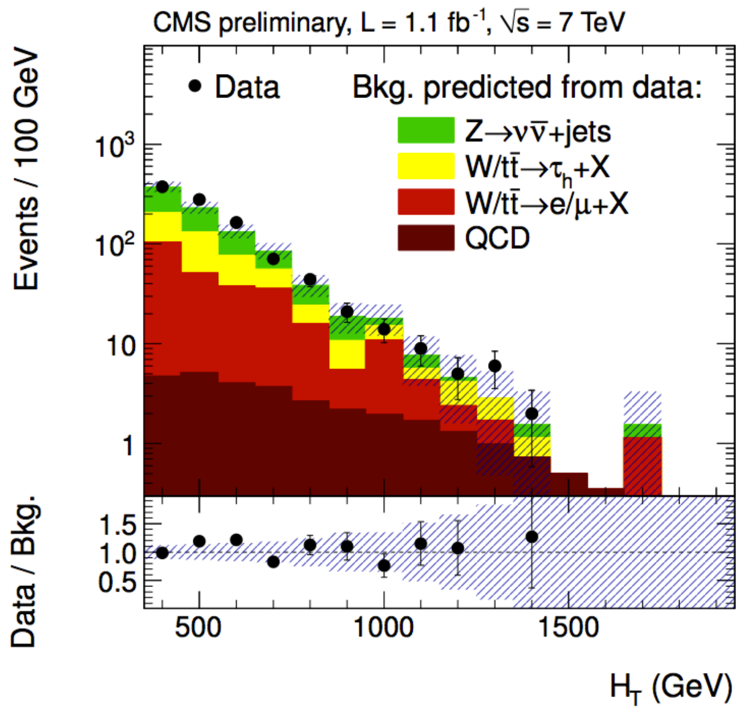
In the SM with 4 generations, production cross section much larger
SM4G Higgs with a mass between 120 and 600 GeV is excluded at 95% CL

SUSY: Jets + MHT Search

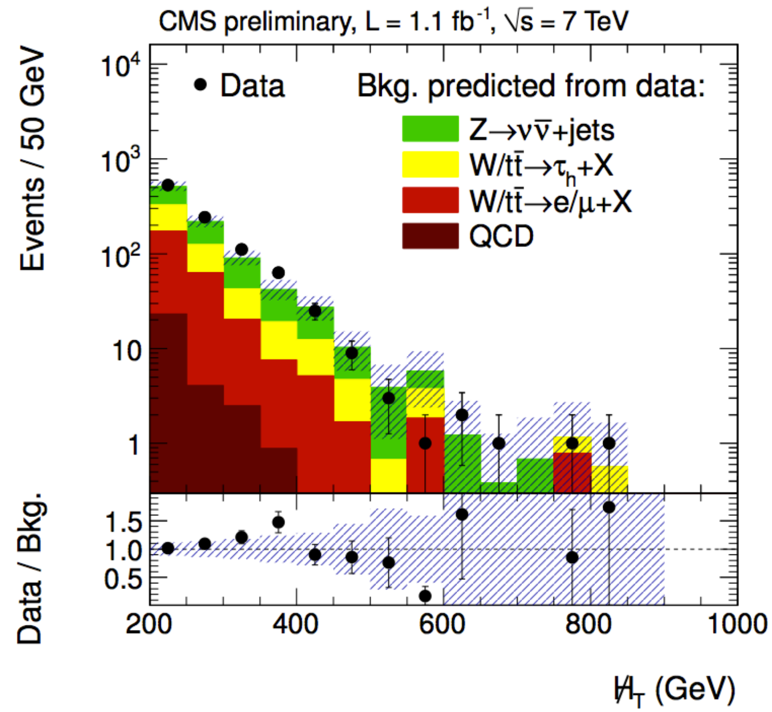
- Selection based on:
  - HT, MHT
  - Δϕ(jet,MHT)
  - Veto isolated muons or electrons

	Baseline (H_T >350 GeV) ($\not{H}_T$ >200 GeV)	Medium (H_T >500 GeV) ($\not{H}_T$ >350 GeV)	High H_T (H_T >800 GeV) ($\not{H}_T$ >200 GeV)	High $\not{H}_T$ (H_T >800 GeV) ($\not{H}_T$ >500 GeV)
$Z \to \nu\bar{\nu}$ from γ+jets	$376 \pm 12 \pm 79$	$42.6 \pm 4.4 \pm 8.9$	$24.9 \pm 3.5 \pm 5.2$	$2.4 \pm 1.1 \pm 0.5$
$t\bar{t}/W \to e,\mu$+X	$244 \pm 20^{+30}_{-31}$	$12.7 \pm 3.3 \pm 1.5$	$22.5 \pm 6.7^{+3.0}_{-3.1}$	$0.8 \pm 0.8 \pm 0.1$
$t\bar{t}/W \to \tau_h$+X	$263 \pm 8 \pm 7$	$17 \pm 2 \pm 0.7$	$18 \pm 2 \pm 0.5$	$0.73 \pm 0.73 \pm 0.04$
QCD	$31 \pm 35^{+17}_{-6}$	$1.3 \pm 1.3^{+0.6}_{-0.4}$	$13.5 \pm 4.1^{+7.3}_{-4.3}$	$0.09 \pm 0.31^{+0.05}_{-0.04}$
Total background	928 ± 103	73.9 ± 11.9	79.4 ± 12.2	4.6 ± 1.5
Observed in data	986	78	70	3

HT



MHT



Summary of Exotica Searches

	Limits in TeV	
		Heavy Bosons
Z'_{SSM} ll	1.94	2011
Z'_{Ψ} ll	1.62	2011
G_{KK} ll k/M = 0.1	1.78	2011
W' lν	2.27	2011
W' dijet	1.51	2011
G_{KK} γγ k/M = 0.1 (2010)	0.945	2010
		4th Generation
$M_{b'}$, b' ⇒ tW (2010)	0.361	2010
$M_{t'}$, t' ⇒ tZ (100%)	0.417	2011
$M_{t'}$, t' ⇒ bW (100%), l+jets	0.45	2011
		Heavy Stable Particles
M_{gluino}, HSCP	0.899	2011
M_{gluino}, Stopped Gluino	0.601	2011
M_{stop}, HSCP	0.620	2011
M_{stop}, Stopped Gluino	0.337	2011
M_{stau}, HSCP	0.293	2011
		Large Extra Dimensions
M_s, γγ, GRW (2010)	1.89	2010
M_s, μμ, GRW (2010)	1.75	2010
M_D, monojet, n_{ED} = 2 (2010)	2.56	2010
M_D, monojet, n_{ED} = 6 (2010)	1.68	2010
M_{BH}, rotating, M_D=3.5 TeV, n_{ED} = 2	4.1	2011
M_{BH}, non-rot, M_D=1.5 TeV, n_{ED} = 6	5.1	2011
String Ball M, M_D=2.1, M_s=1.7, g_s=0.4	4.1	2011
		Compositeness and Contact Interactions
String Resonances	4.0	2011
E_6 diquarks	3.52	2011
Axigluon/Coloron	2.47	2011
q* , dijet	2.49	2011
q* , boosted Z	1.17	2010
e*, Λ = 2 TeV	0.720	2010
μ*, Λ = 2 TeV	0.745	2010
C.I. Λ , dijet mass (3 pb^{-1})	4.0	2010
C.I. Λ , X analysis	5.6	2010
		LeptoQuark
LQ1, β=0.5 (2010)	0.340	2010
LQ1, β=1.0 (2010)	0.384	2010
LQ2, β=1.0 (2010)	0.394	2010