Higgs Boson Search Results from CMS and Prospects for 2011-2012

Fermilab Users' Meeting
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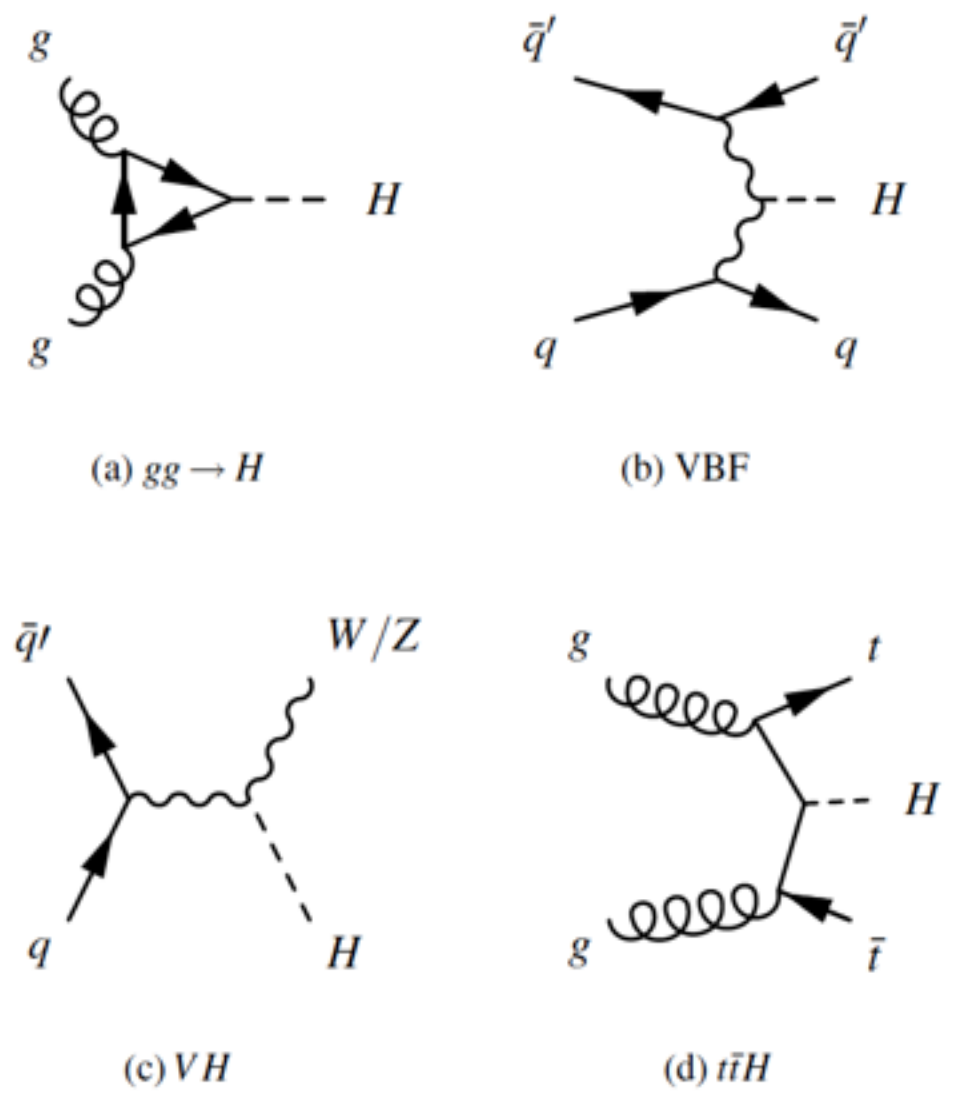
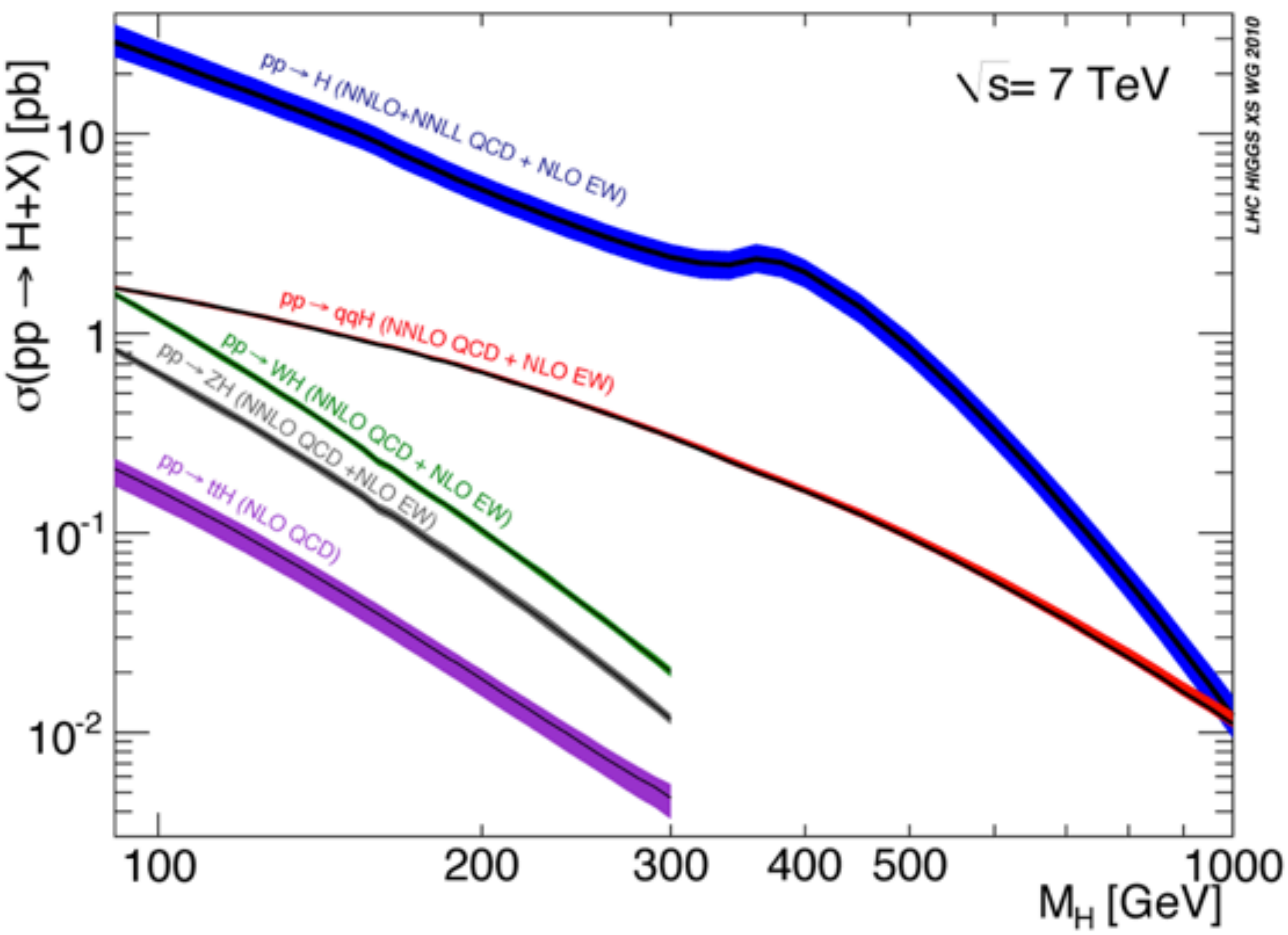
On behalf of the CMS Collaboration

Outline

- Higgs Production at the LHC
- Standard Model Higgs Searches
- BSM Higgs Searches
- Prospects for Higgs Search/Discovery in 2011-2012
- Conclusions

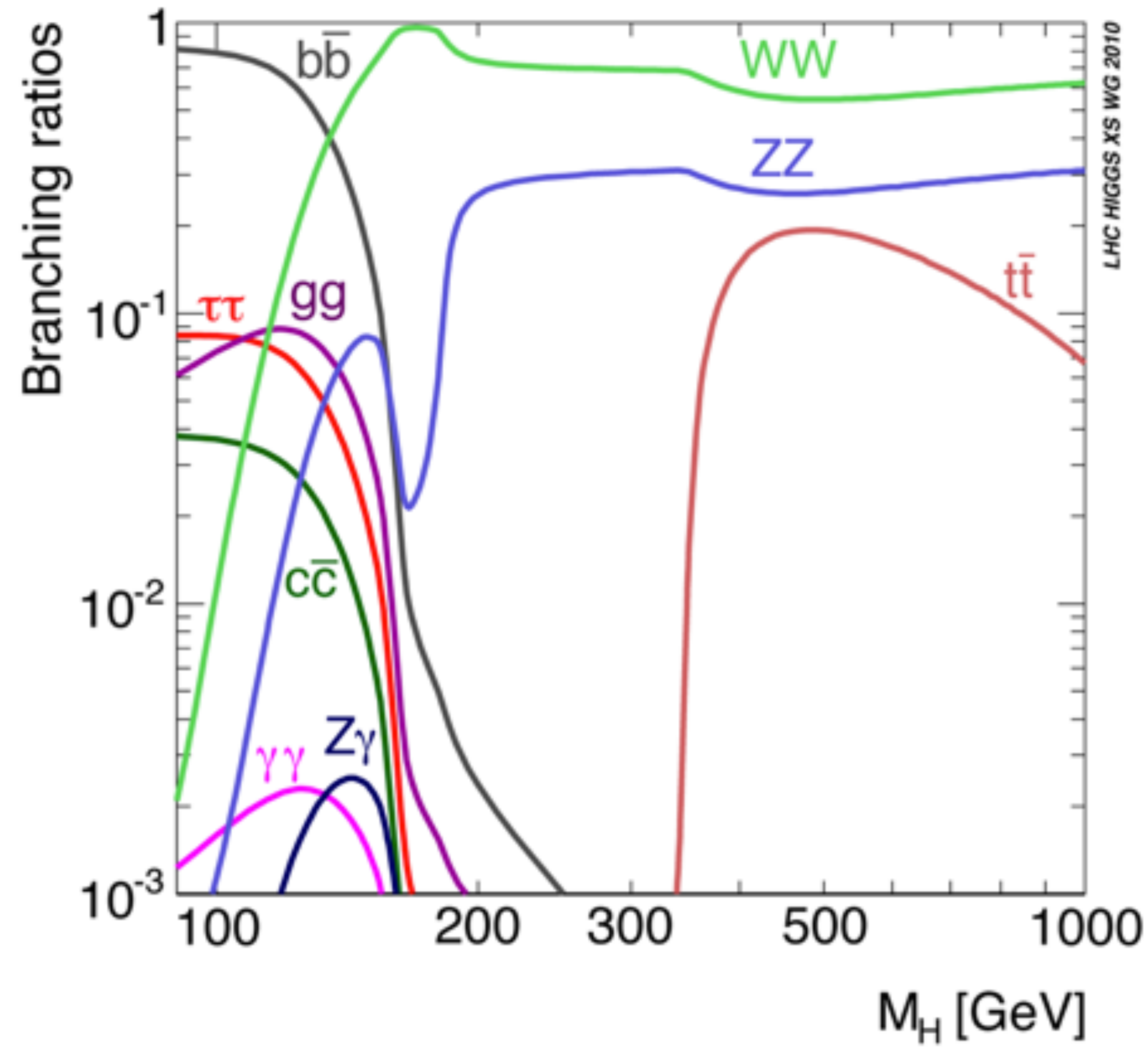
While there are several diagrams that contribute to Higgs production, at the LHC gluon fusion dominates





SM Higgs Production at the LHC

- A comprehensive strategy for the SM Higgs search includes multiple channels to cover the full mass range
  - $m_H \sim 120$ GeV/c^2
    - $H \rightarrow \gamma\gamma$
    - VH with $H \rightarrow bb$ (Boosted)
    - $H \rightarrow WW \rightarrow l\nu l\nu$ + 0/1 jets
  - $m_H \sim 160$ GeV/c^2
    - $H \rightarrow WW \rightarrow l\nu l\nu$ + 0/1 jets, $l\nu jj$
    - $H \rightarrow ZZ \rightarrow 4l$
  - $m_H > 200$ GeV/c^2
    - $H \rightarrow WW \rightarrow l\nu l\nu$ + 0/1 jets + VBF
    - $H \rightarrow ZZ \rightarrow 4l, 2l2\nu, 2l2b$

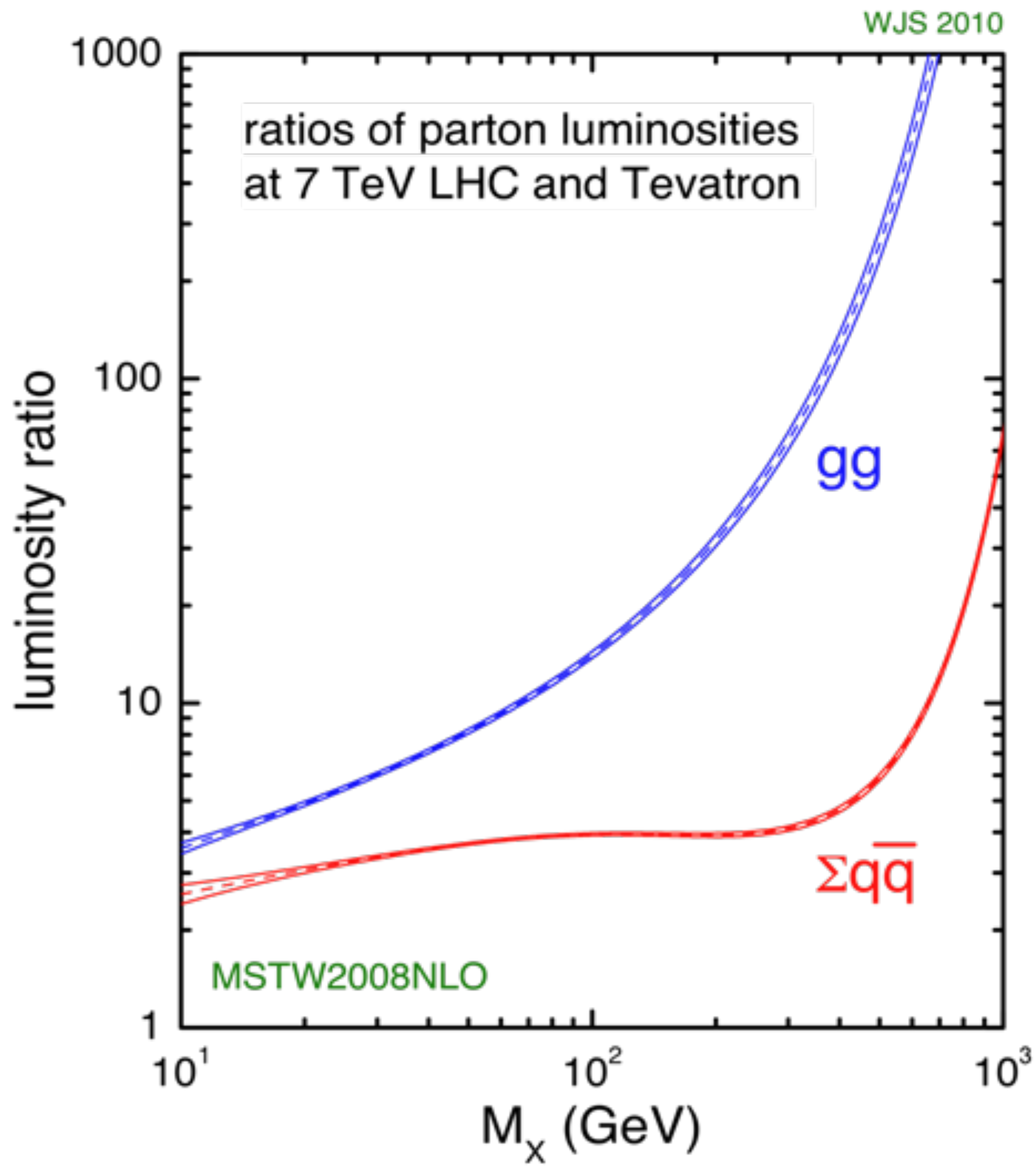


- Coverage of all these channels implies efficient and accurate reconstruction of leptons, jets, missing E_T, b-tags

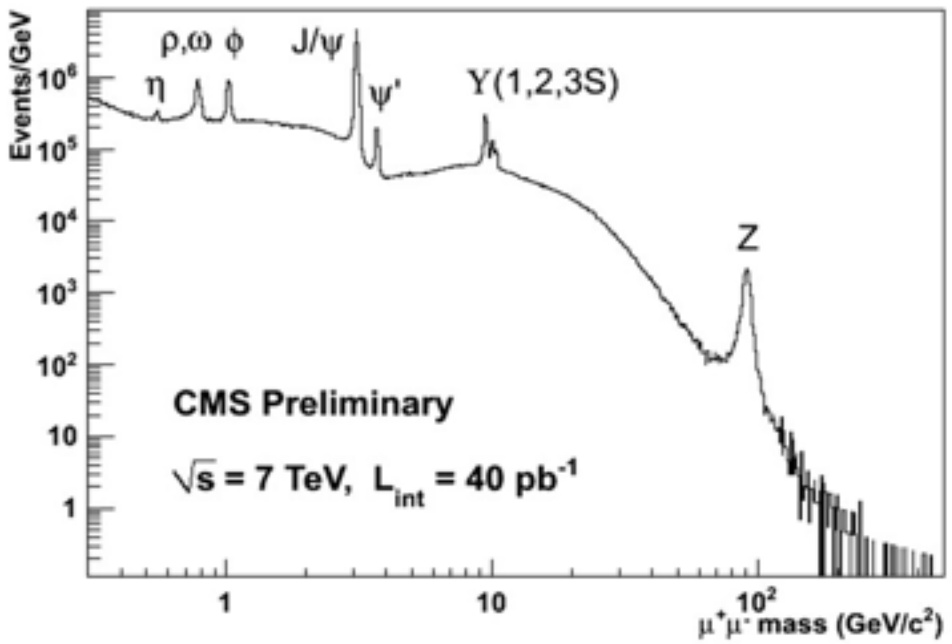
Comparison to Higgs Production at the Tevatron

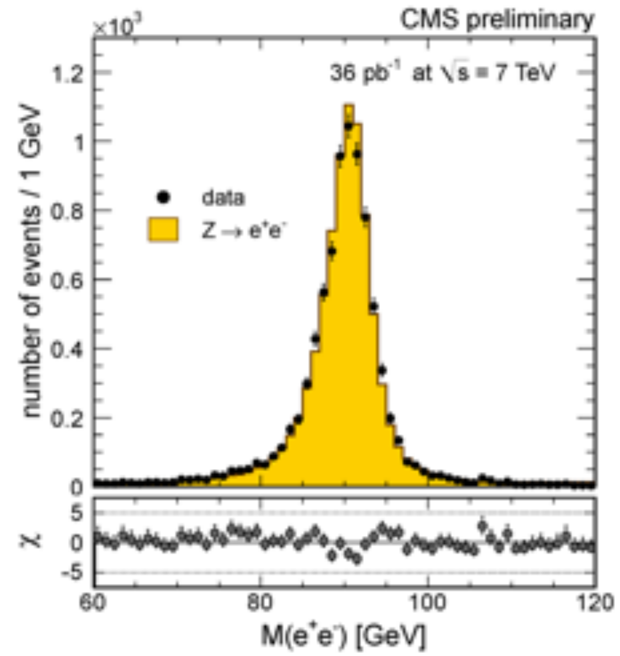
Depending on the production mechanism and the dominant backgrounds, there is a larger/smaller advantage for the LHC relative to the Tevatron

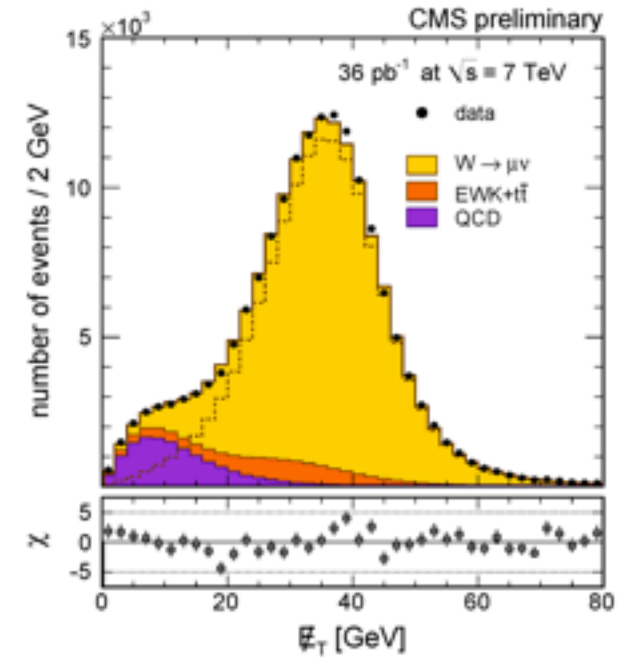
- $m_H < 130$ GeV/c^2
  - pp→VH only 3x larger at LHC
  - Dominant backgrounds from W/Z+bb and top production which increase more due to the rise in gg cross section
- $m_H > 140$ GeV/c^2
  - gg→H ~15x larger at LHC
  - Dominant backgrounds from WW and ZZ production, from qqbar production which increases by a smaller factor

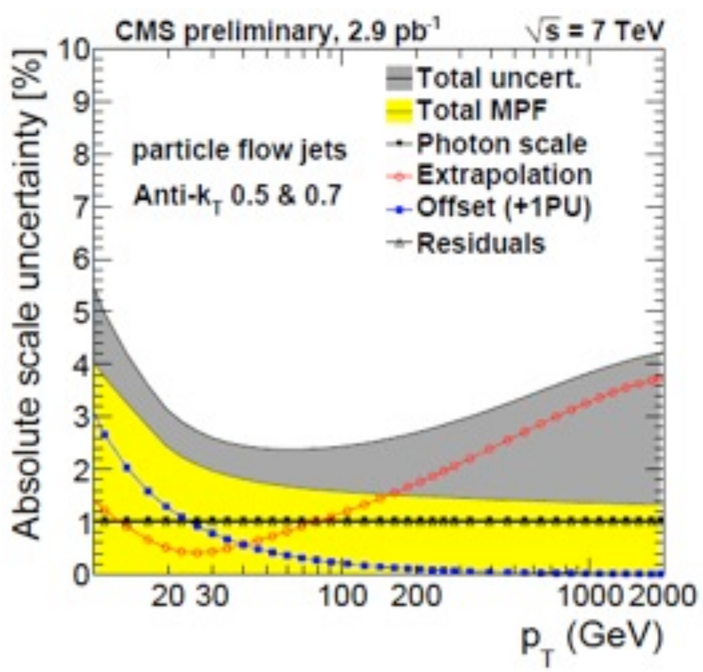


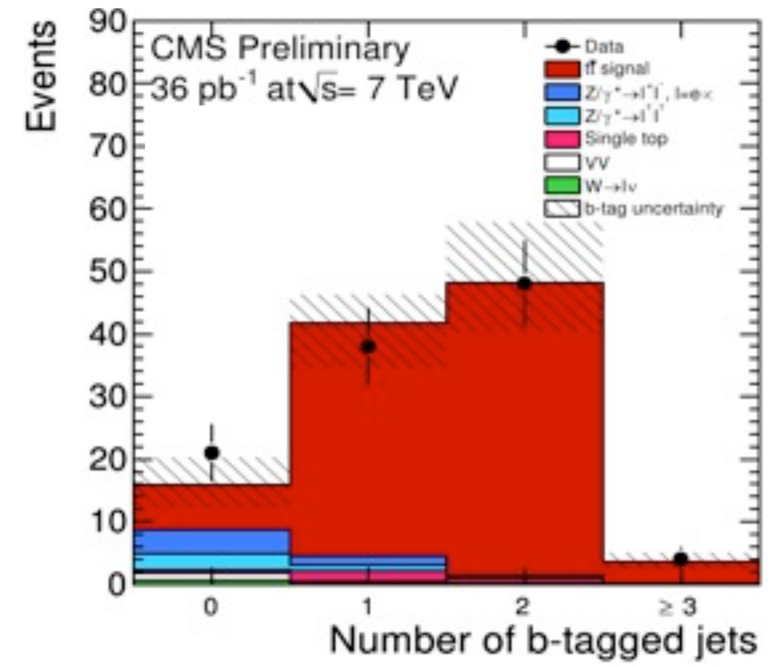
CMS Performance in 2010





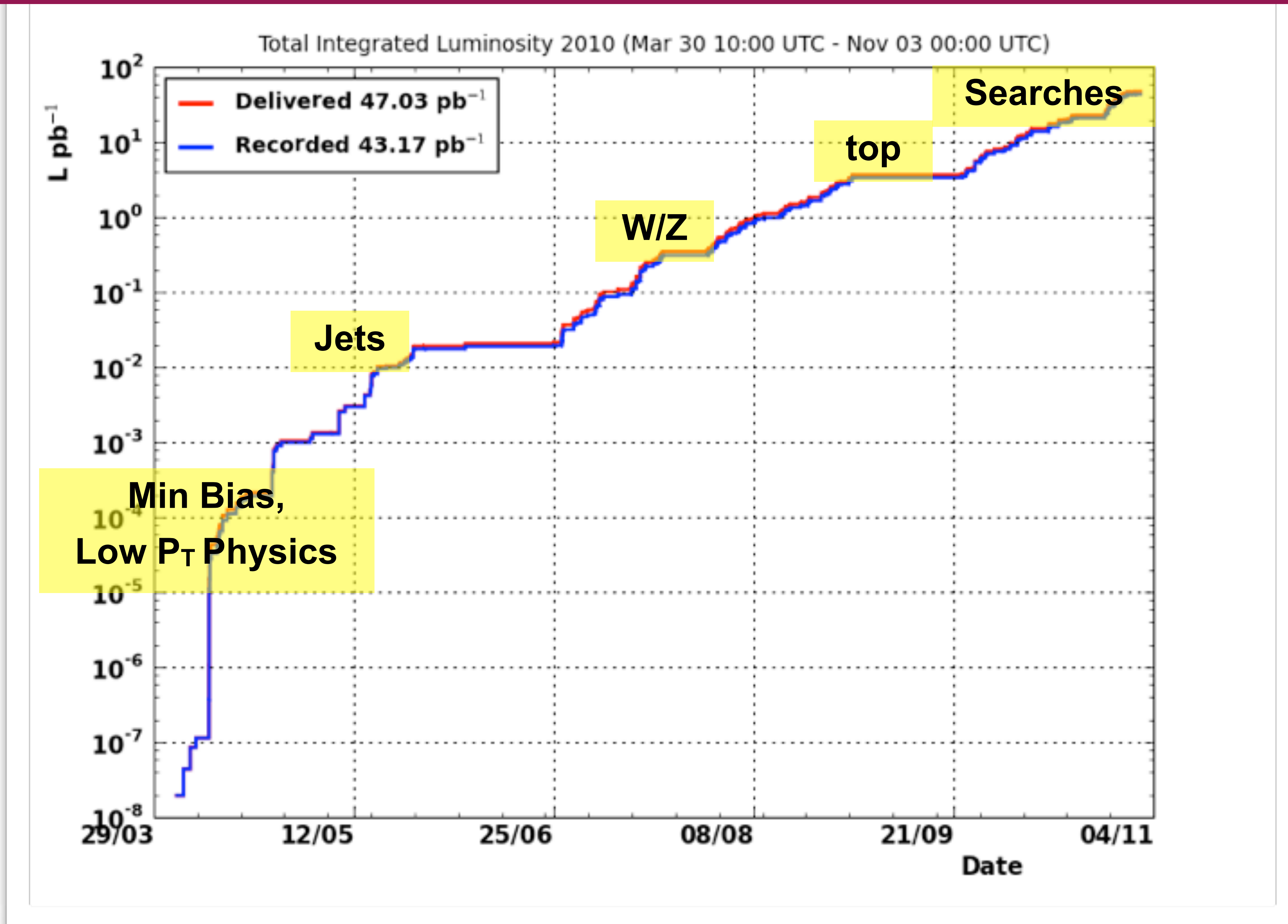






- Analysis of 2010 data demonstrated very good performance of detector and reconstruction, excellent data/MC agreement
- See earlier talks from Jim Pivarski, Rahmat Rahmat, Michele De Gruttola

CMS Performance in 2010

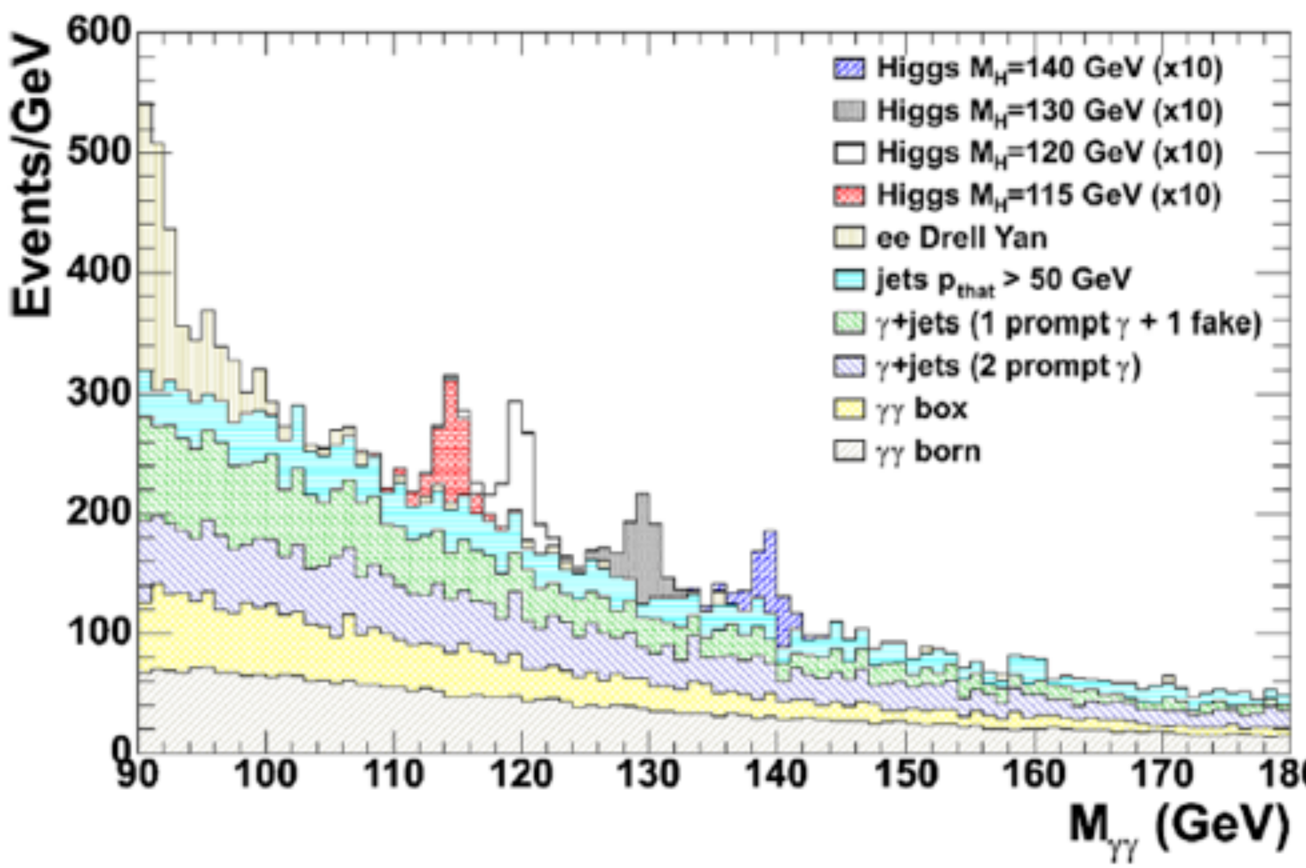


- Recorded 92% of delivered luminosity
- Efficiency with all systems good ~84%
- Results shown today use 36 pb^{-1}

Standard Model Higgs Searches

$H \rightarrow \gamma\gamma$

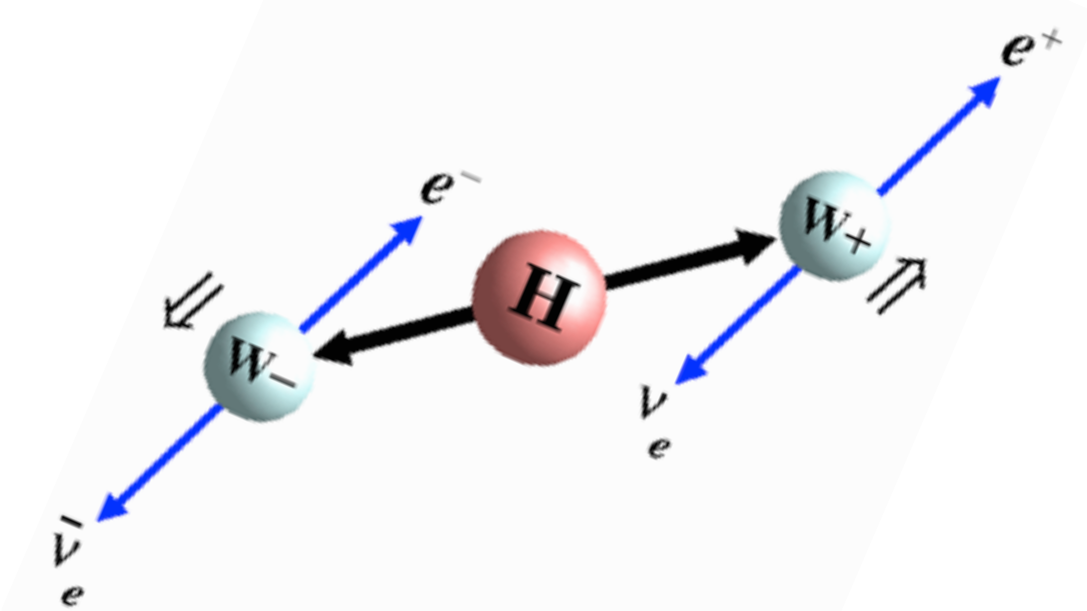
- Important channel at low m_H
- Signature is two isolated photons
  - Should create a narrow peak in the diphoton mass distribution
- Background from continuum diphoton production as well as fake photons ⇒ Will be measured with data
- Count events in mass window optimized vs. m_H
- Challenges:
  - Background shape
  - Understanding $m_{\gamma\gamma}$ resolution
  - Identification of primary vertex, esp. with pileup



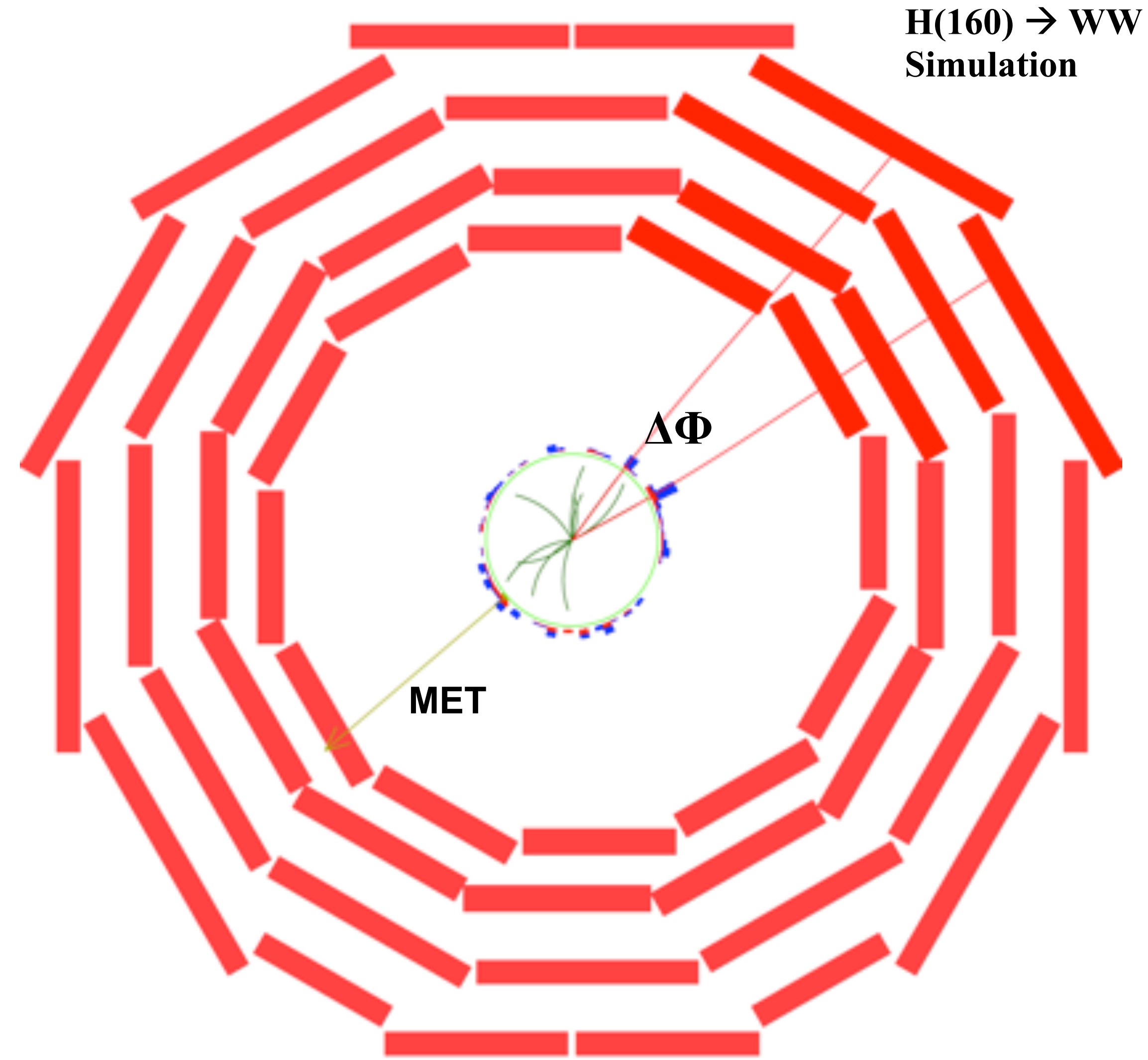
First result should be ready for EPS

H→WW→$l\nu l\nu$

- Key channel for early analyses, especially for m_H=120-250 GeV
- Signature:
  - Two high p_T isolated leptons with small opening angle and significant MET
- Main background is SM WW production, plus top and Drell-Yan

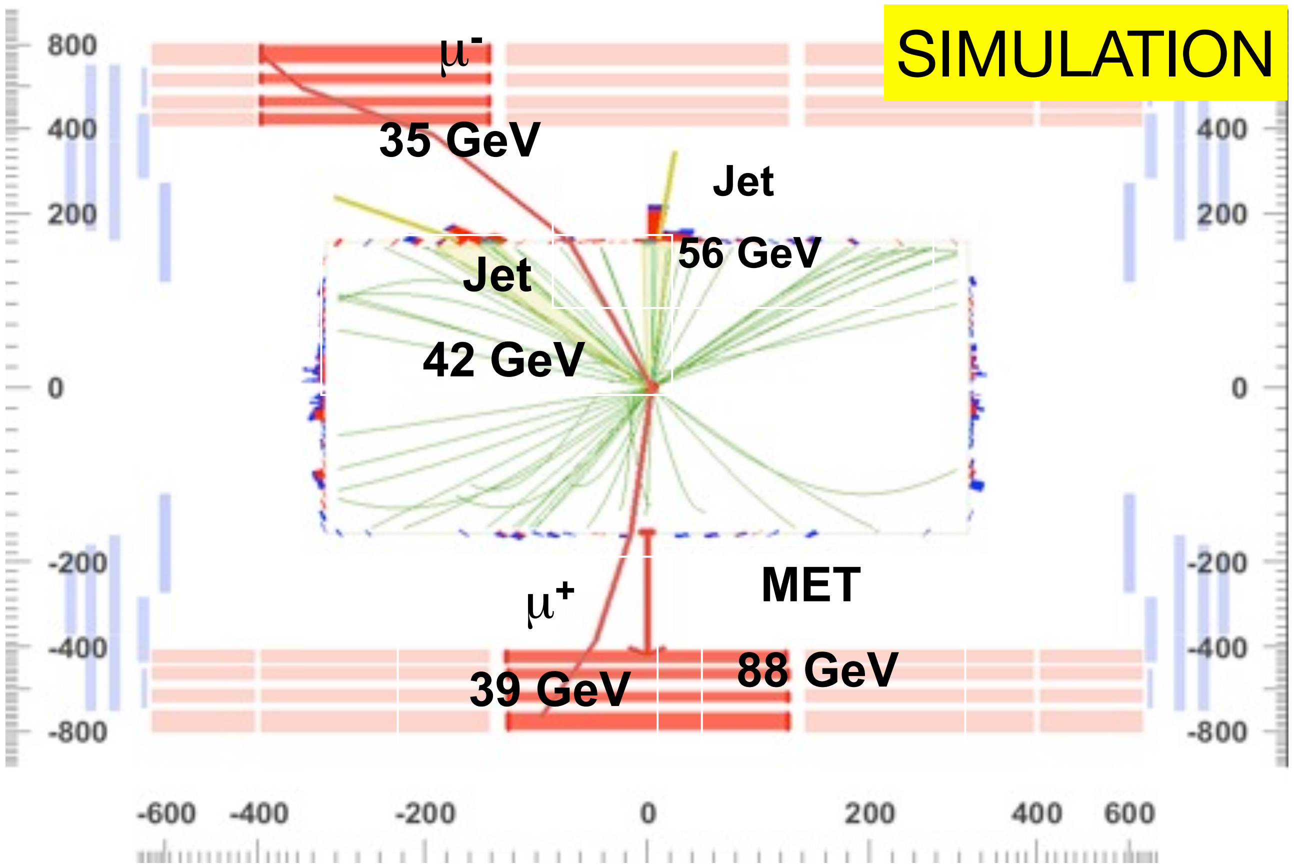


Small opening angle due to spin correlations → Can be used to suppress WW background



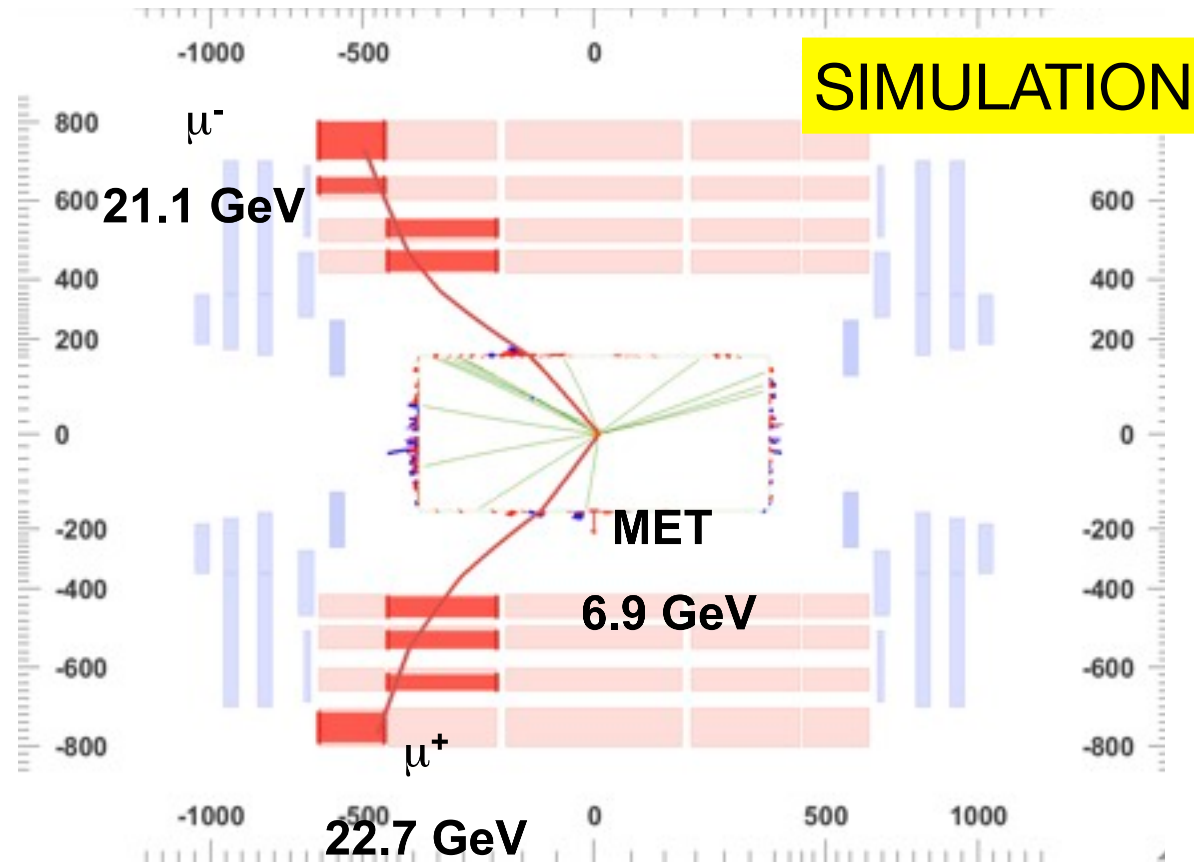
H→WW Backgrounds

ttbar



Reduce by vetoing on b-tags (and additional jets)

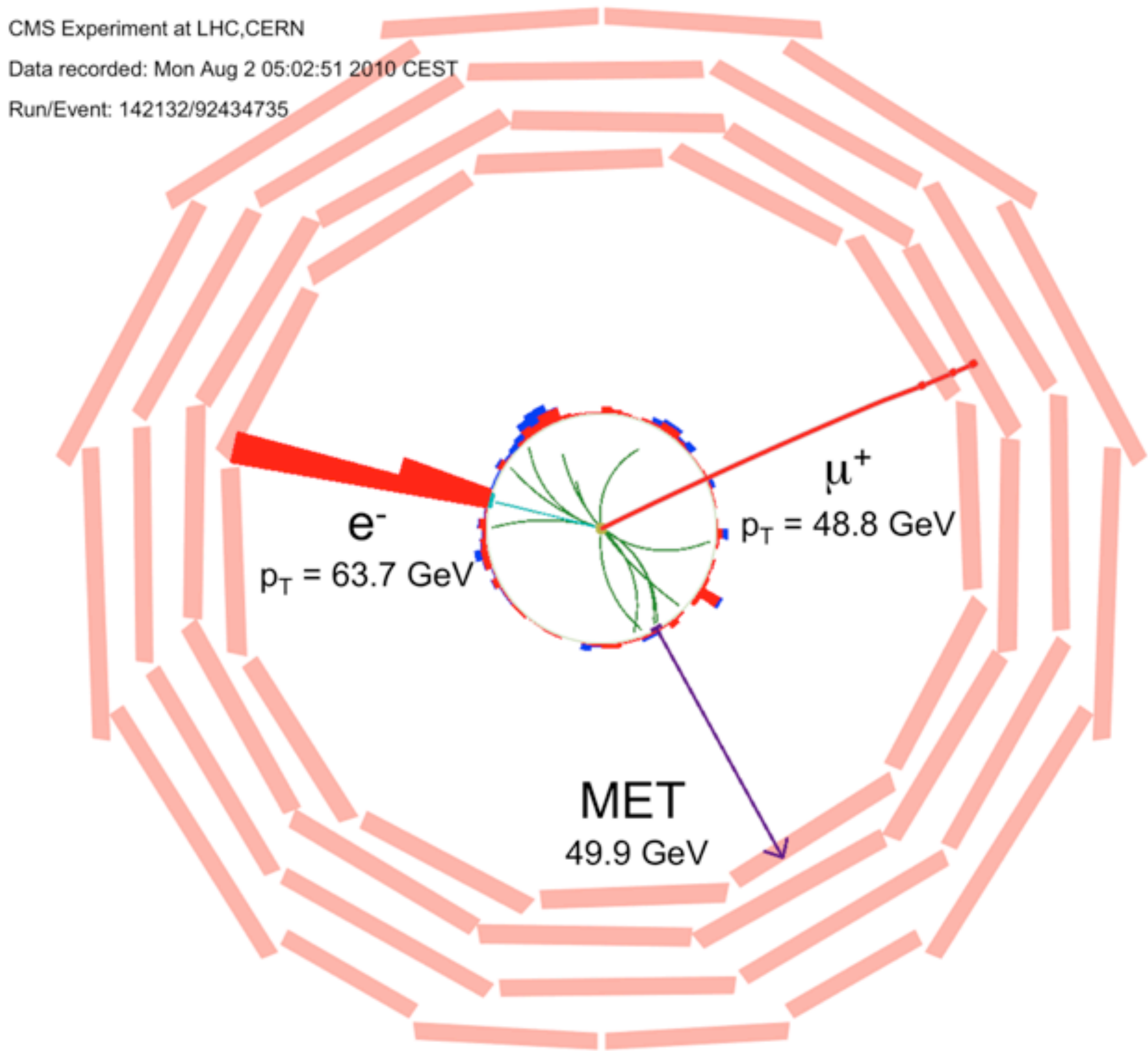
Drell-Yan



Reduce by requiring signifcant MET in the event

H→WW Backgrounds

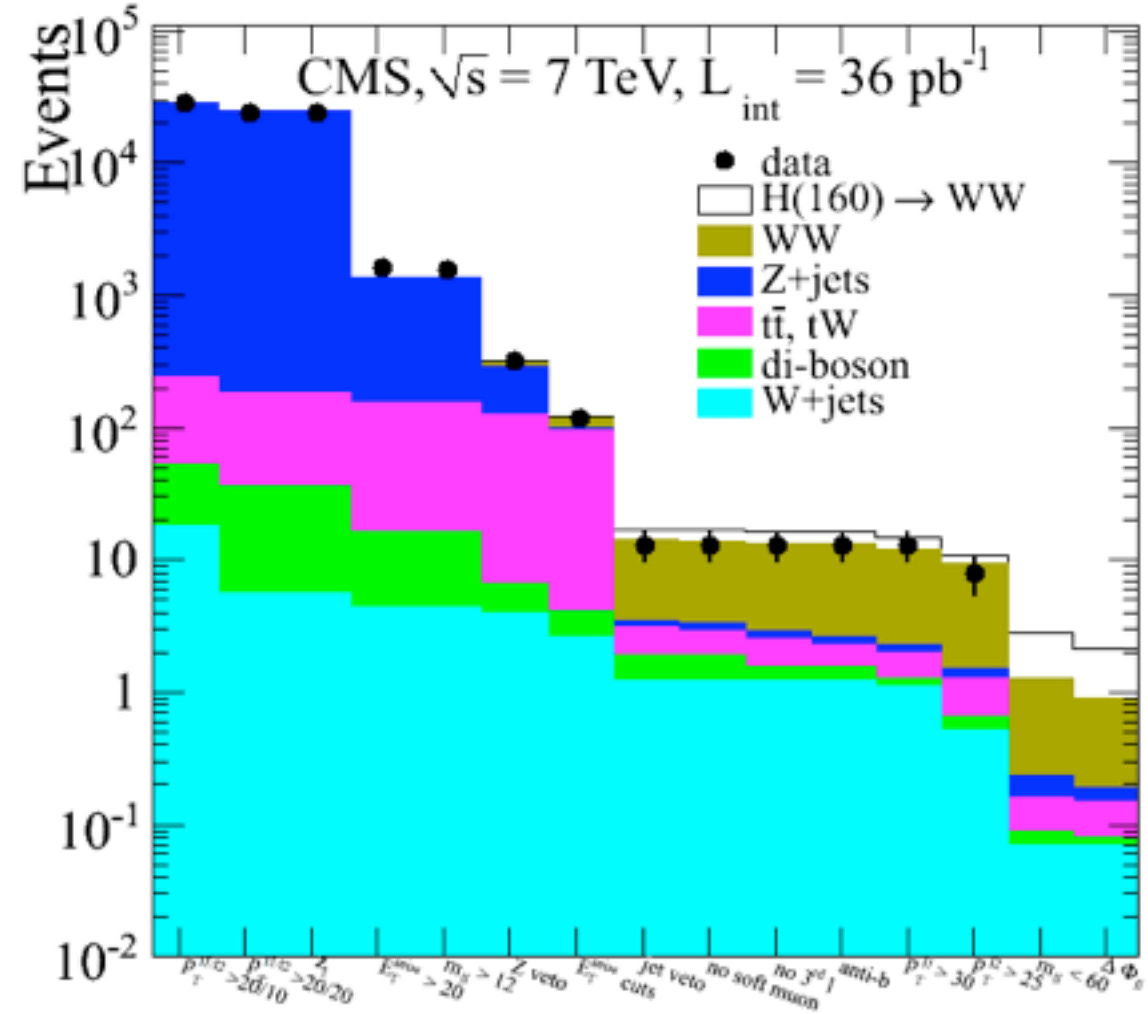
pp→WW candidate in 2010 data



H→WW→$l\nu l\nu$

- 2010 Analysis restricted to 0-jet bin
- Treatment of non-WW backgrounds
  - W+jets
    - Apply tight lepton ID and use data-driven method to estimate residual background
  - Drell-Yan
    - Use tight MET cut for ee/μμ
  - ttbar, single top
    - Veto on jets and b-tags
- Reduce WW with m_H-dependent cuts on $p_T(l)$, $m(ll)$, and $\Delta\varphi(ll)$

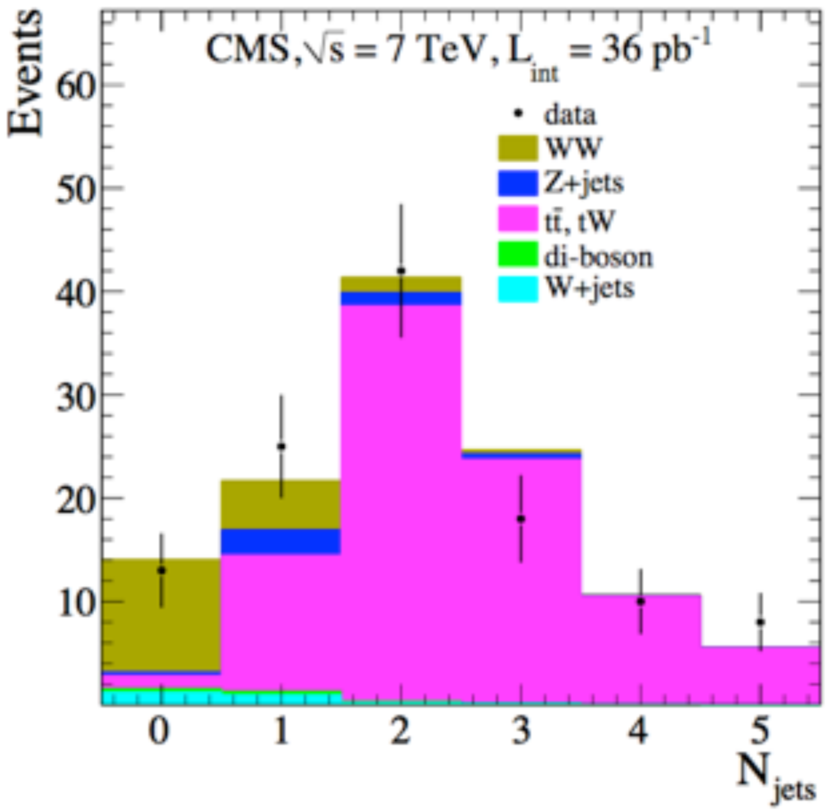
Cut Flow: Data vs. MC



(arXiv:1102.5429)

Measurement of WW→*lvlv*

Before searching for H→WW, measure SM WW production



Process	Events
W+jets + QCD	$1.70 \pm 0.40 \pm 0.70$
$t\bar{t}$ + tW	$0.77 \pm 0.05 \pm 0.77$
$W\gamma$	$0.31 \pm 0.04 \pm 0.05$
$Z + WZ + ZZ \to e^+e^- / \mu^+\mu^-$	$0.20 \pm 0.20 \pm 0.30$
$WZ + ZZ$, leptons not from the same boson	$0.22 \pm 0.01 \pm 0.04$
$Z/\gamma^* \to \tau^+\tau^-$	$0.09 \pm 0.05 \pm 0.09$
Total	$3.29 \pm 0.45 \pm 1.09$

13 events observed in 36 pb^{-1}

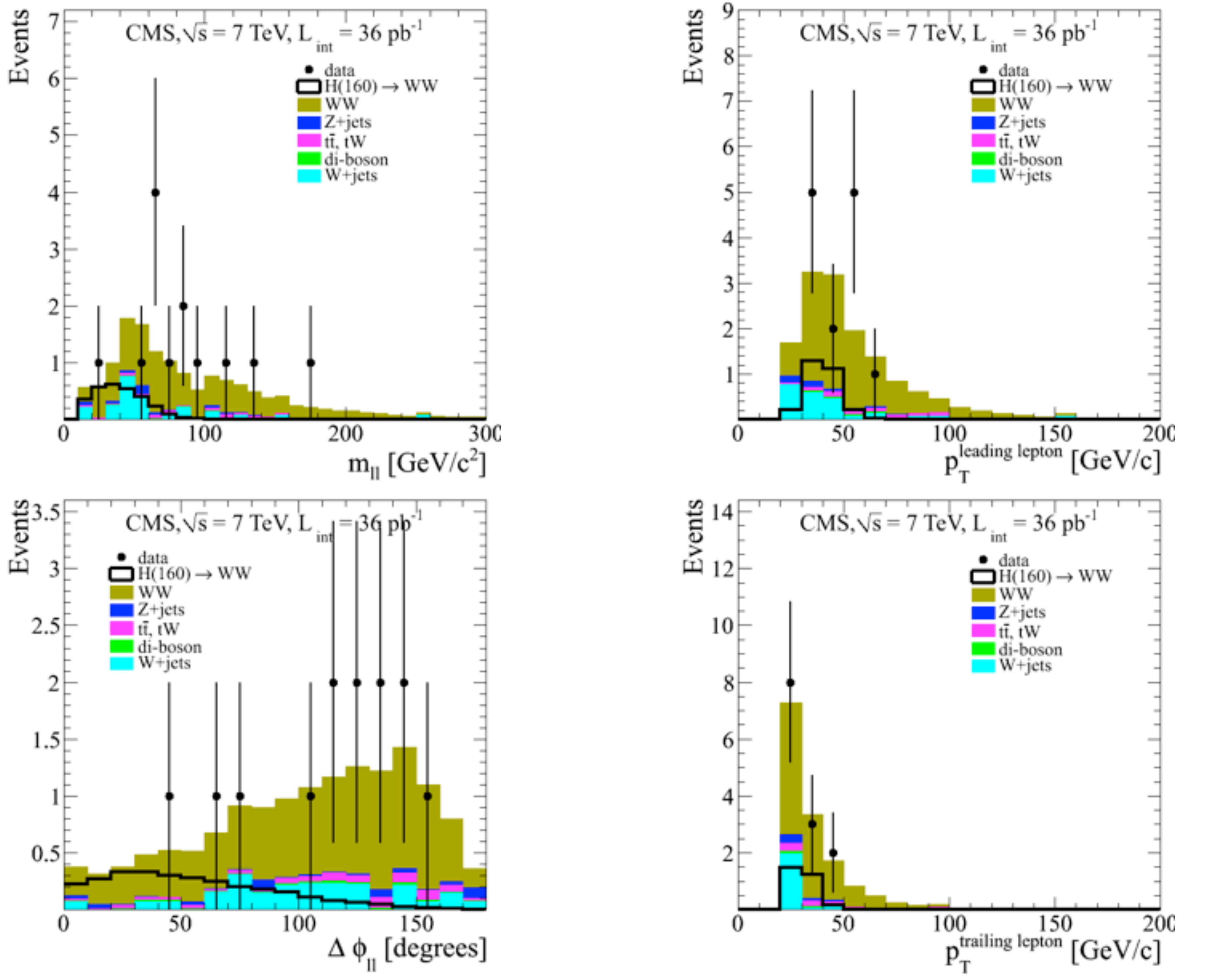
$$\sigma_{W^+W^-} = 41.1 \pm 15.3\,(\text{stat}) \pm 5.8\,(\text{syst}) \pm 4.5\,(\text{lumi})\ \text{pb}$$

Good agreement with NLO prediction of 43.0 ± 2.0 pb

(arXiv:1102.5429)

H→WW→$l\nu l\nu$

Comparison of key kinematic observables after WW selection

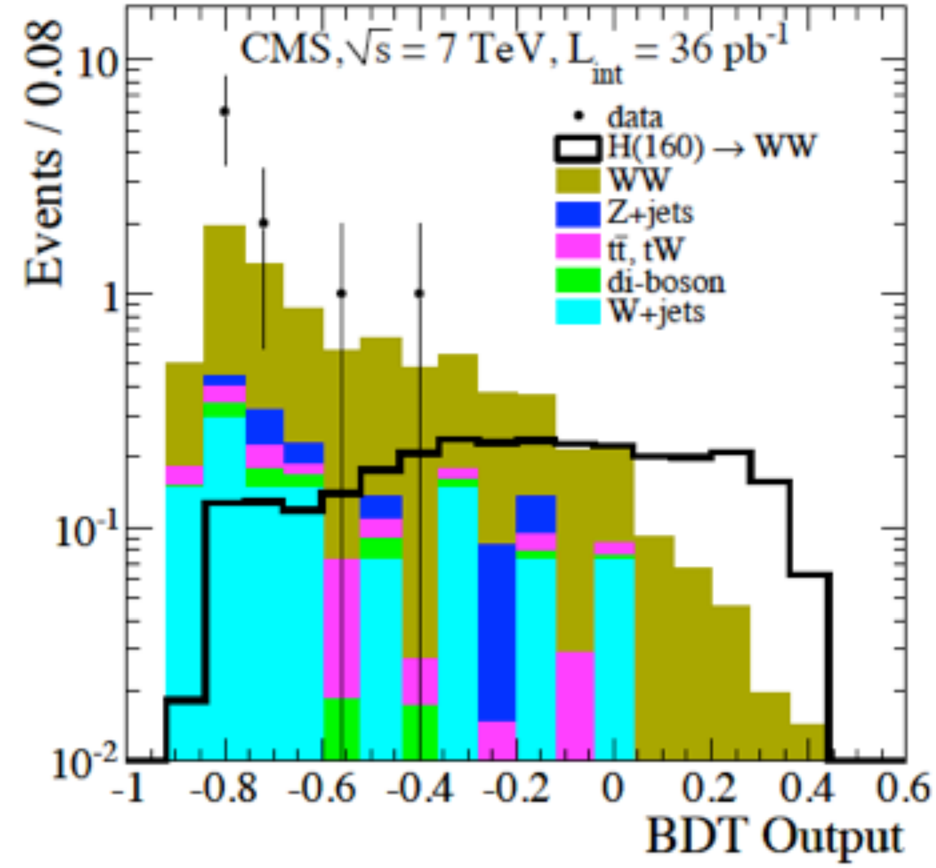


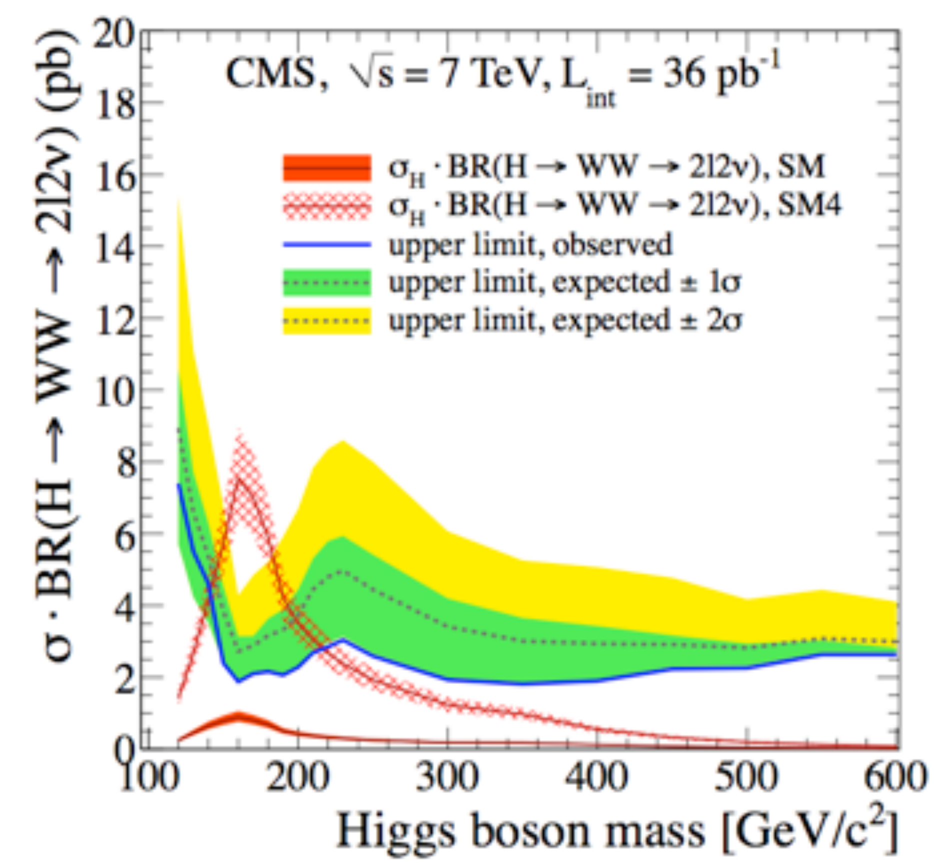
H→WW→$l\nu l\nu$

- Use BDT for improved sensitivity, with the following inputs
  - ΔR(*ll*), Δη(*ll*)
  - Δφ(*l*-MET)
  - Projected MET
  - Transverse mass of *l*-MET pairs
  - lepton flavor
- Count excess above BDT cut

➡ Not yet sensitive to SM

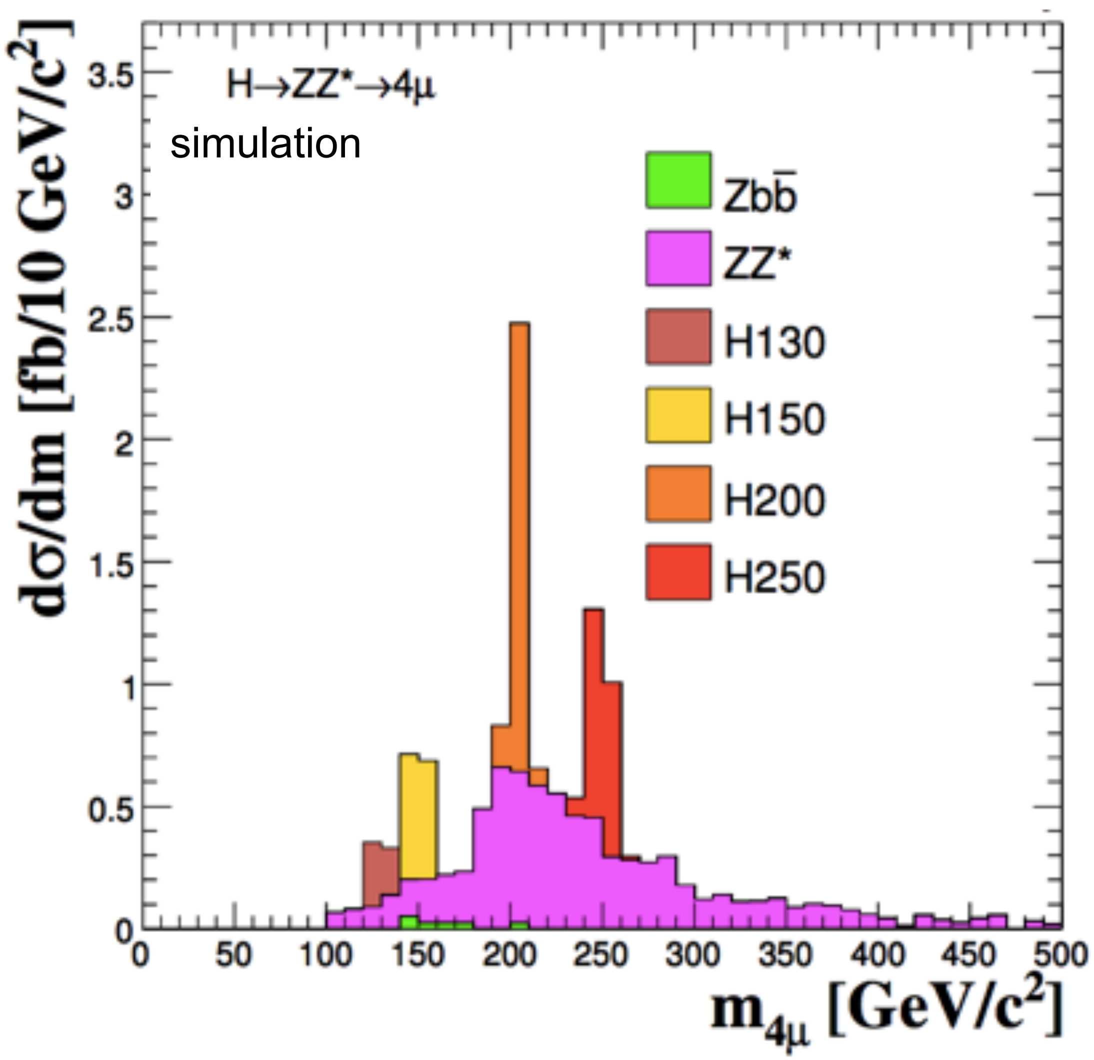
➡ In the context of a SM extension by a sequential fourth family of fermions with very high masses, exclude $144 < m_H < 207$ GeV/c²



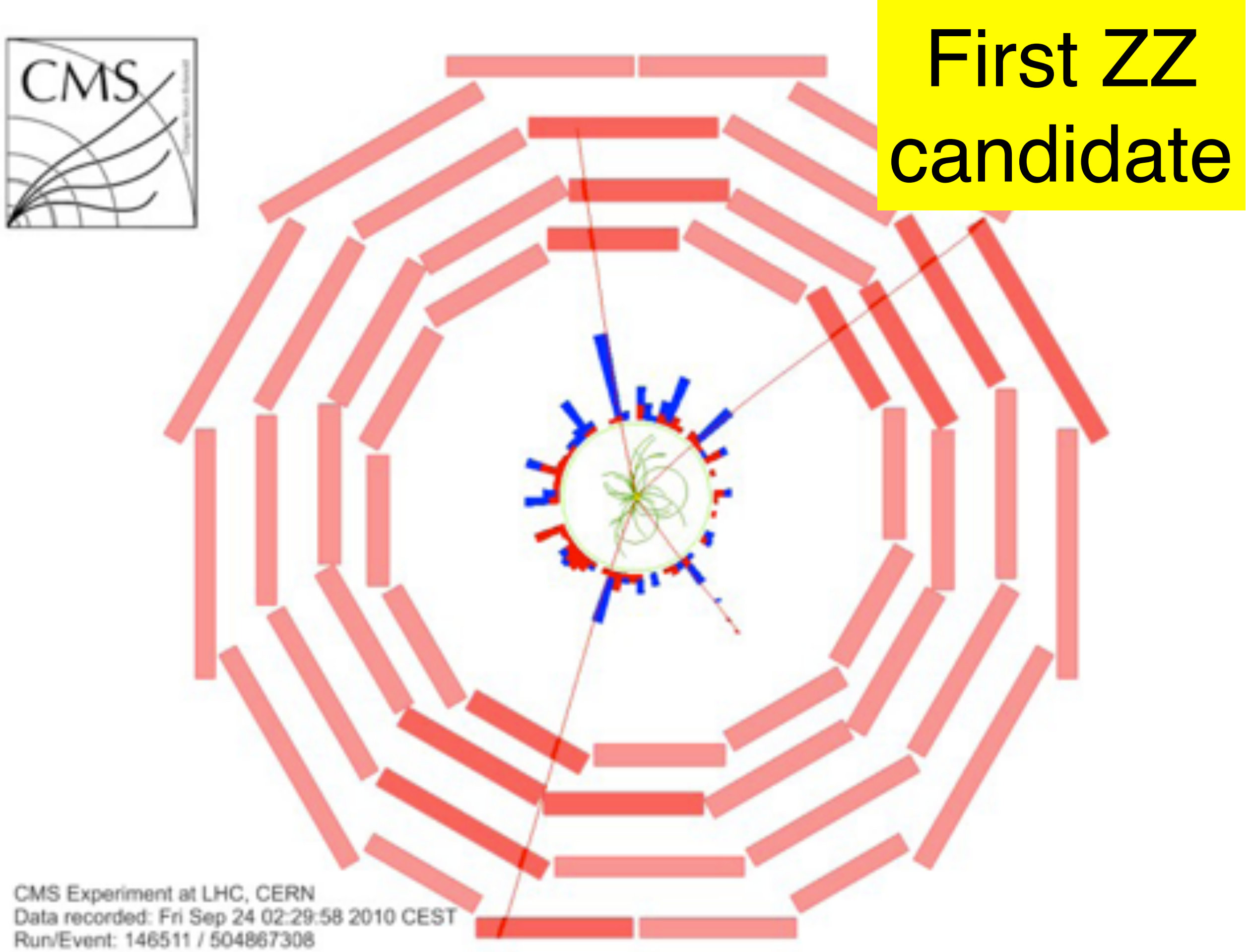


H→ZZ→4l

- H→ZZ→4l is the "golden channel"
  - narrow mass peak from 4 isolated leptons
  - irreducible background from SM ZZ, plus Zbb and top
- Use 4e, 2e2μ, and 4μ final states



First result expected for EPS



$m_{\mu1\mu2}$ = 92.15 GeV
$m_{\mu3\mu4}$ = 92.24 GeV
$m_{4\mu}$ = 201 GeV

BSM Higgs Searches

MSSM $H \to \tau^+\tau^-$ and $Z \to \tau^+\tau^-$

- In MSSM, 5 physical Higgs Bosons
  - 2 CP even: h, H
  - 1 CP Odd: A
  - 2 Charged: H^+, H^-

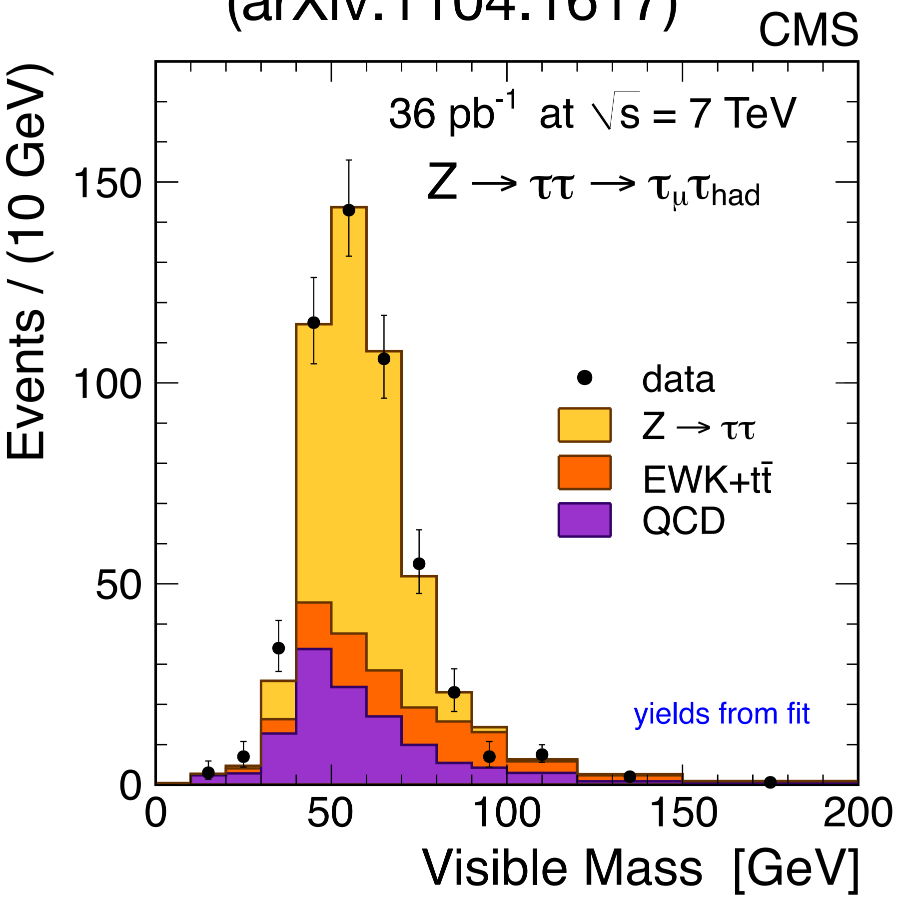
A degenerate with h or H

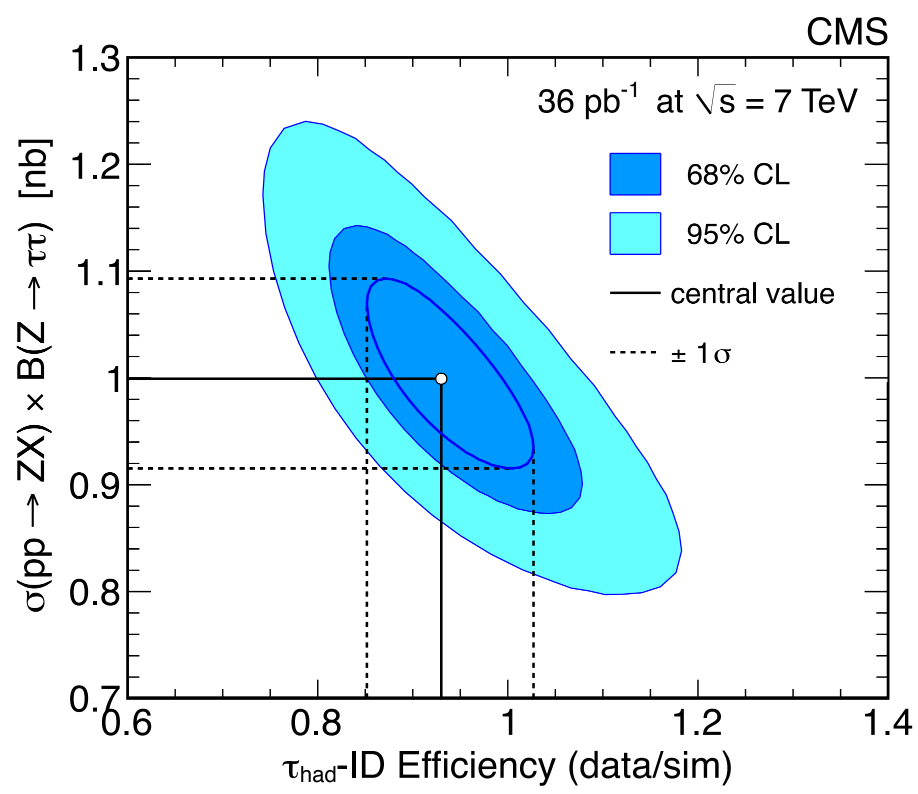
- $B(H \to \tau^+\tau^-)$ enhanced at large tanβ

- Measurement of $Z \to \tau^+\tau^-$ validates the reconstruction of τ_{HAD}
  - Analysis includes $\mu+\tau_{HAD}$, $e+\tau_{HAD}$, $e+\mu$, and $\mu+\mu$ final states
  - Global fit of all channels plus τ_{HAD} efficiency scale factor provides a check on the τ_{HAD} reconstruction

$\sigma(pp \to ZX) \times B(Z \to \tau^+\tau^-) = 1.00 \pm 0.05$ (stat.) ± 0.08(syst.) ± 0.04(lumi.) nb

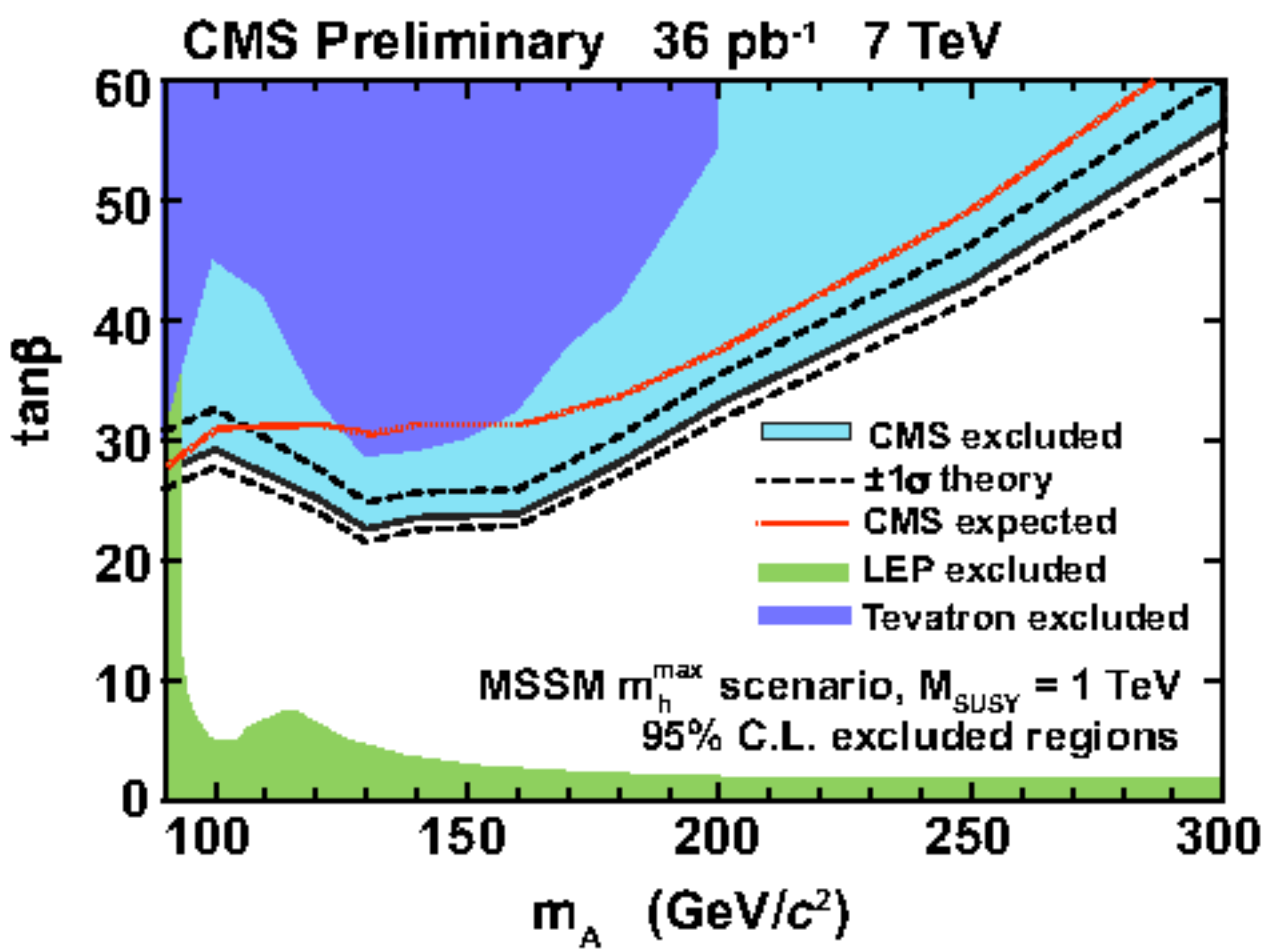
(arXiv:1104.1617)

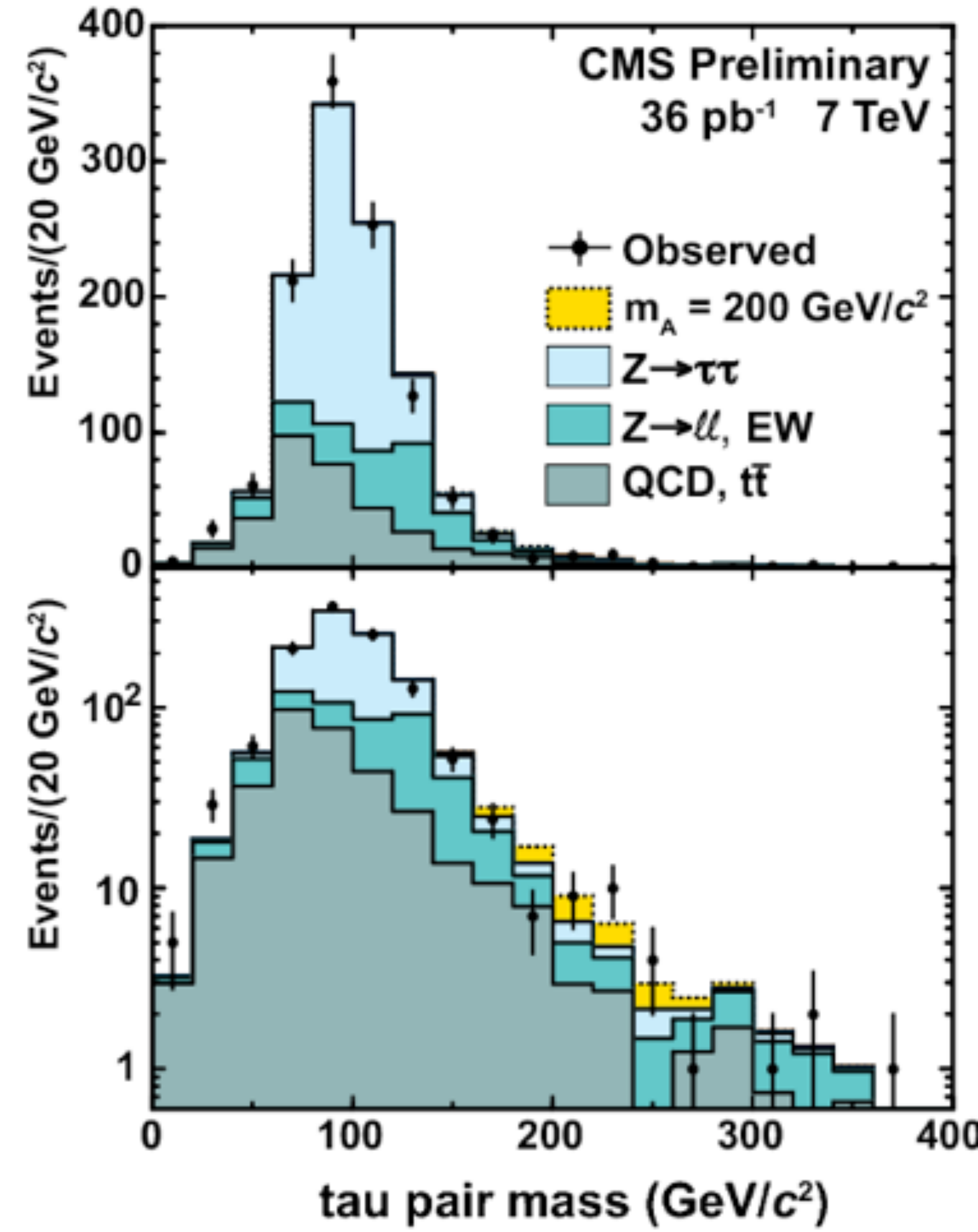




MSSM $H \to \tau^+\tau^-$ and $Z \to \tau^+\tau^-$

- Extend $Z \to \tau^+\tau^-$ analysis to search for $H \to \tau^+\tau^-$
- Set limits on $\sigma(pp \to \Phi X) \times B(\Phi \to \tau^+\tau^-)$
- Exclude regions of SUSY parameter space for large m_A
- Exclude $\tan\beta$=23 as low as m_A =130 GeV/c^2

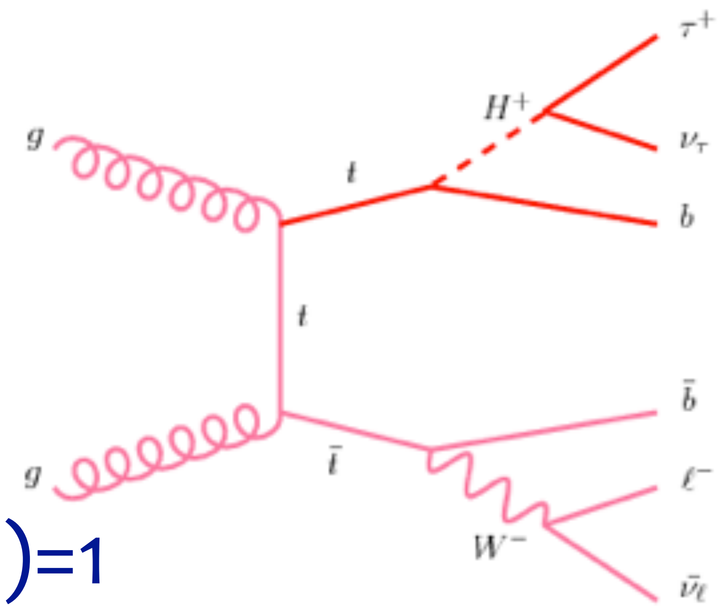




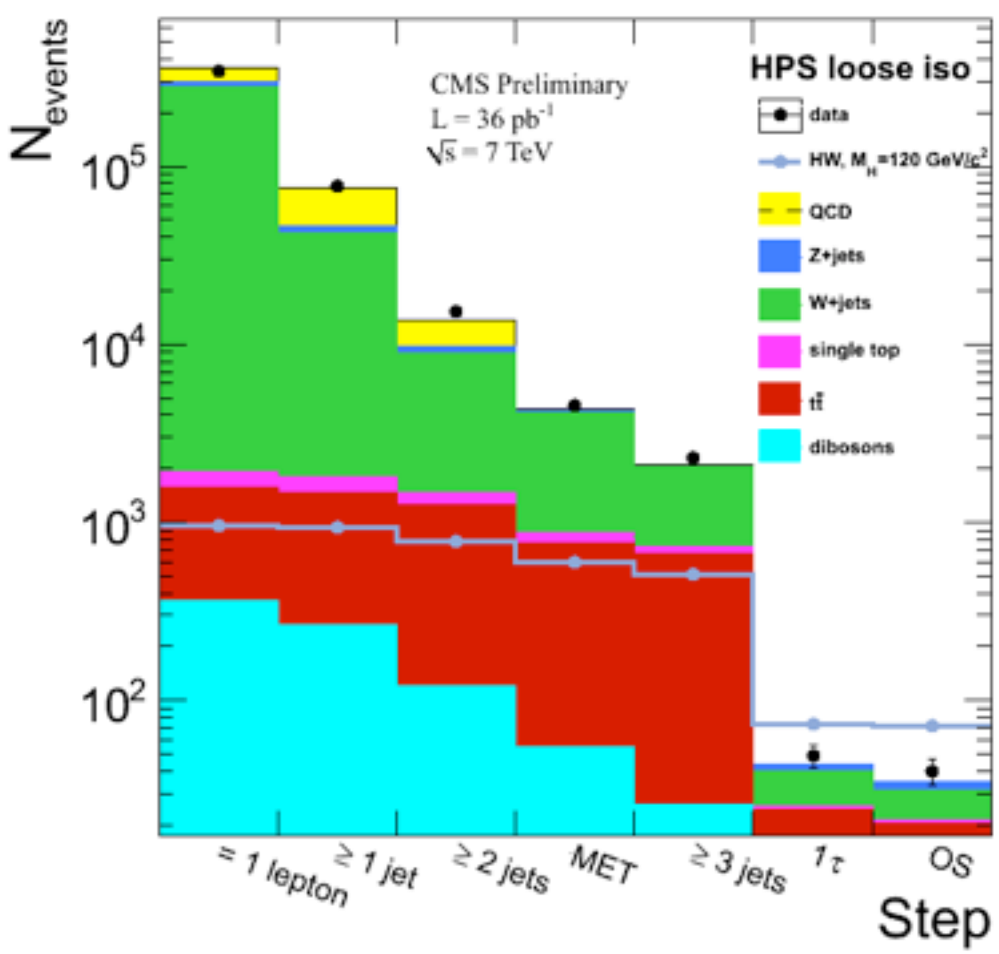
(arXiv:1104.1619)

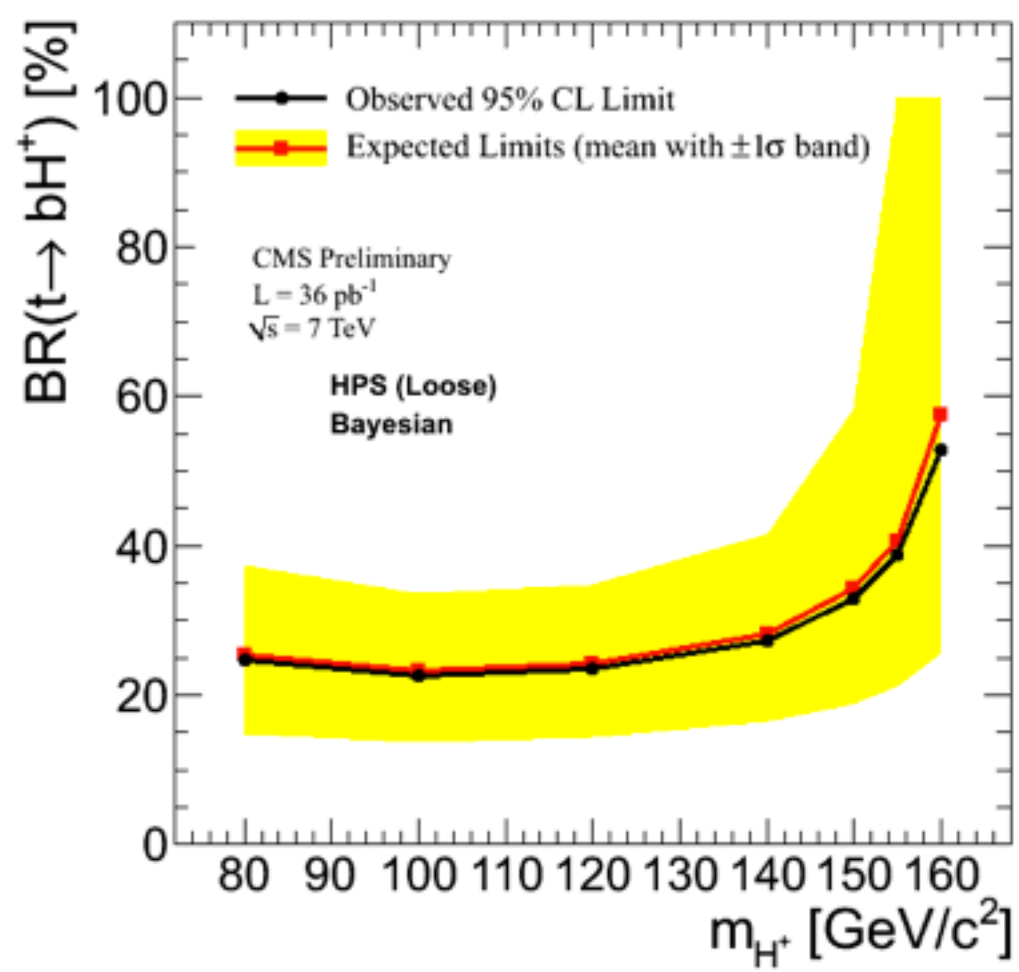
Exotic Higgs: $H^+ \to \tau^+ \upsilon$

- Search for H^+ in top quark decays: $t \to H^+ b \to \tau^+ \upsilon b$
- Require one lepton (e or μ), ≥2 jets, significant MET and one τ_{HAD}
- Background from fake τ and real top
- Derive limit on $BR(t \to H^+ b)$, assuming $BR(H^+ \to \tau^+ \upsilon)=1$



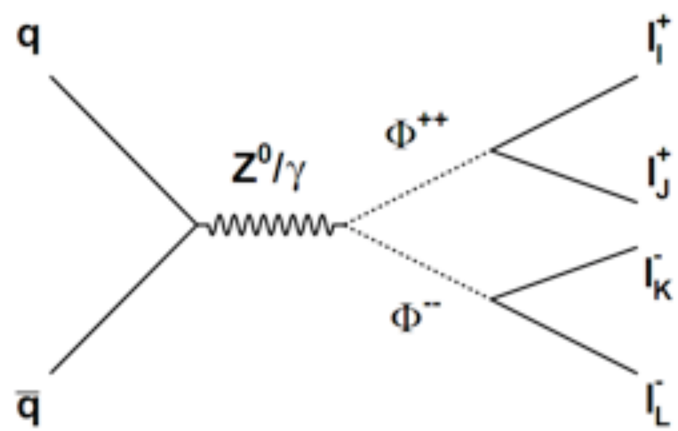
(CMS-PAS-HIG-11-002)

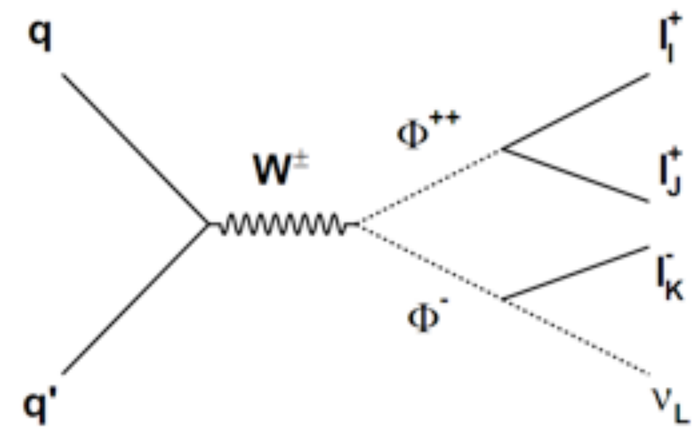




Exotic Higgs: $\Phi^{++} \rightarrow l^{+}l^{+}$

- Search in 3 and 4 lepton final states, using all lepton flavors





- Small background due to tt+jets, VV(+jets), as well as charge-misID and fake lepton backgrounds
- Set limits for different scenarios of BR($\Phi^{++} \rightarrow l^{+}l^{+}$)

Benchmark point	Former limit	New result
$BR(\Phi^{++} \rightarrow e^{\pm}e^{\pm}) = 100\%$	133 GeV [31]	144 GeV
$BR(\Phi^{++} \rightarrow e^{\pm}\mu^{\pm}) = 100\%$	115 GeV [31]	154 GeV
$BR(\Phi^{++} \rightarrow e^{\pm}\tau^{\pm}) = 100\%$	112 GeV [32]	106 GeV
$BR(\Phi^{++} \rightarrow \mu^{\pm}\mu^{\pm}) = 100\%$	150 GeV [33]	156 GeV
$BR(\Phi^{++} \rightarrow \mu^{\pm}\tau^{\pm}) = 100\%$	114 GeV [32]	106 GeV

(CMS-PAS-HIG-11-001)

Projections for 2011-2012

Higgs Sensitivity Projections

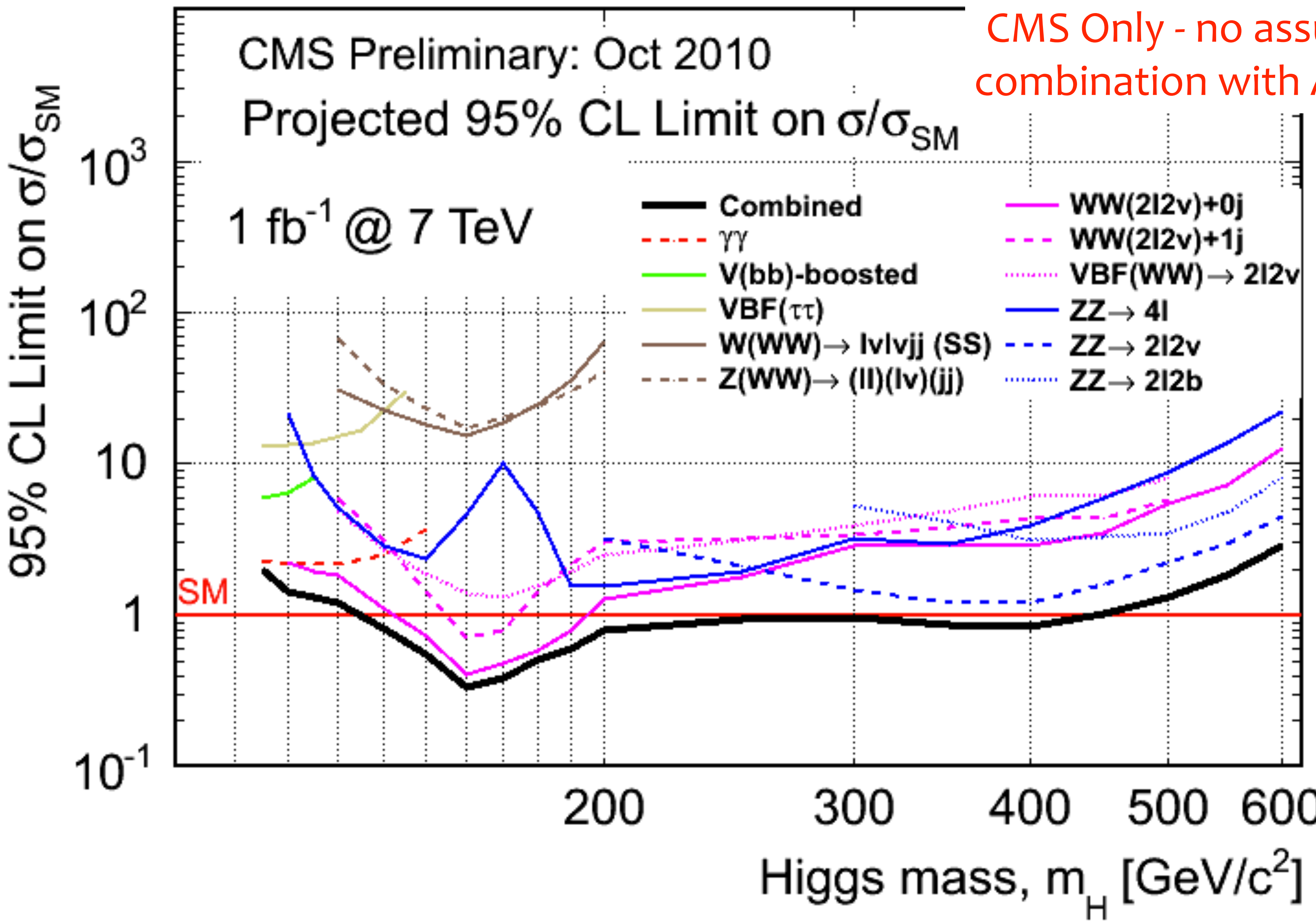
- What has gone into the projections:
  - Best available cross sections
    - signal: gg-fusion at NNLO+NNLL, VBF and VH at NLO, ttH at LO
    - all backgrounds at NLO
  - Full GEANT-based detector simulation
  - Only cut-based analyses considered - no shape analysis
  - Conservative estimates of systematic uncertainties
  - Estimates validated by measurements in the 2010 data
- Channels considered (depending on m_H):
  - $H \to \gamma\gamma$
  - VBF $H \to \tau\tau$
  - VH with $H \to bb$ (Boosted)
  - $H \to WW \to l\nu l\nu$ + 0/1 jets, VBF $H \to WW \to l\nu l\nu$
  - $VH \to WW \to l\nu jj$
  - $H \to ZZ \to 4l$, $2l2\nu$, $2l2b$

Projections based on conditions of 2010 data

Projected Exclusion with 1 fb^{-1}

Contributions from many channels to cover a wide range of Higgs masses

CMS Only - no assumed combination with ATLAS

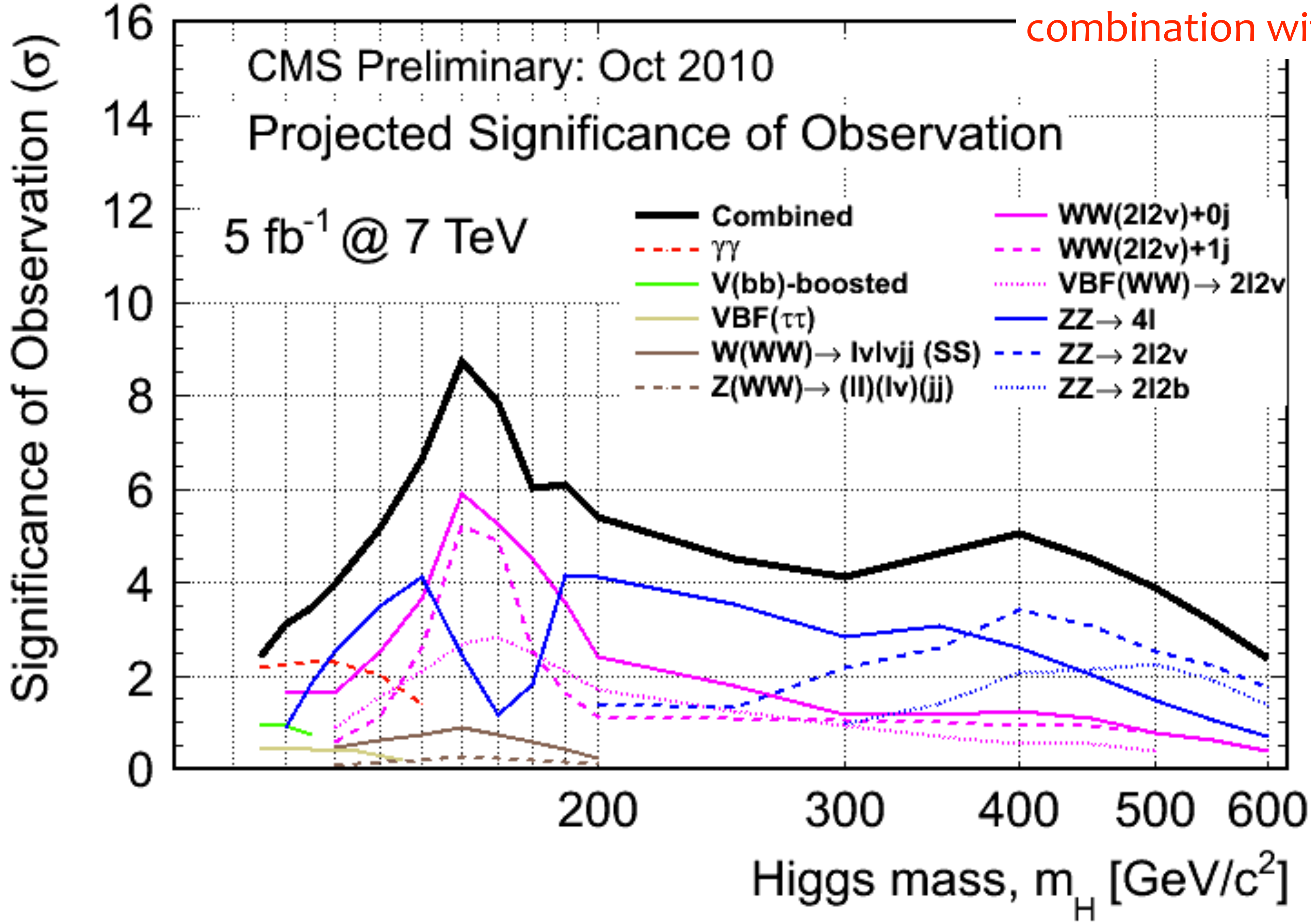


With 1 fb^{-1}, exclude m_H in the range 135-450 GeV/c^2

Projected Sensitivity with 5 fb^{-1}

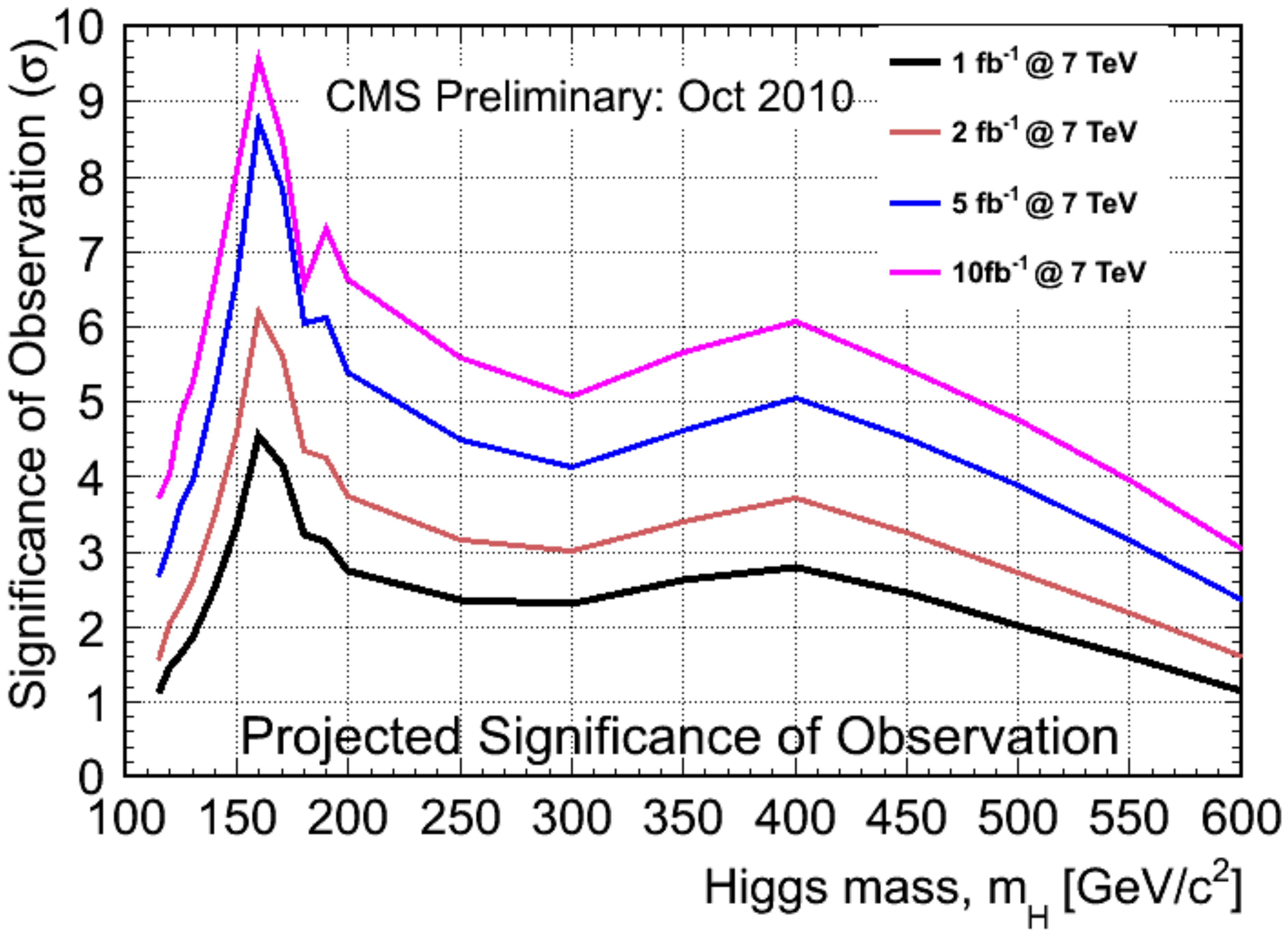
Contributions from many channels to cover a wide range of Higgs masses

CMS Only - no assumed combination with ATLAS



With 5 fb^{-1}, 4σ sensitivity for m_H in the range 130-500 GeV/c²

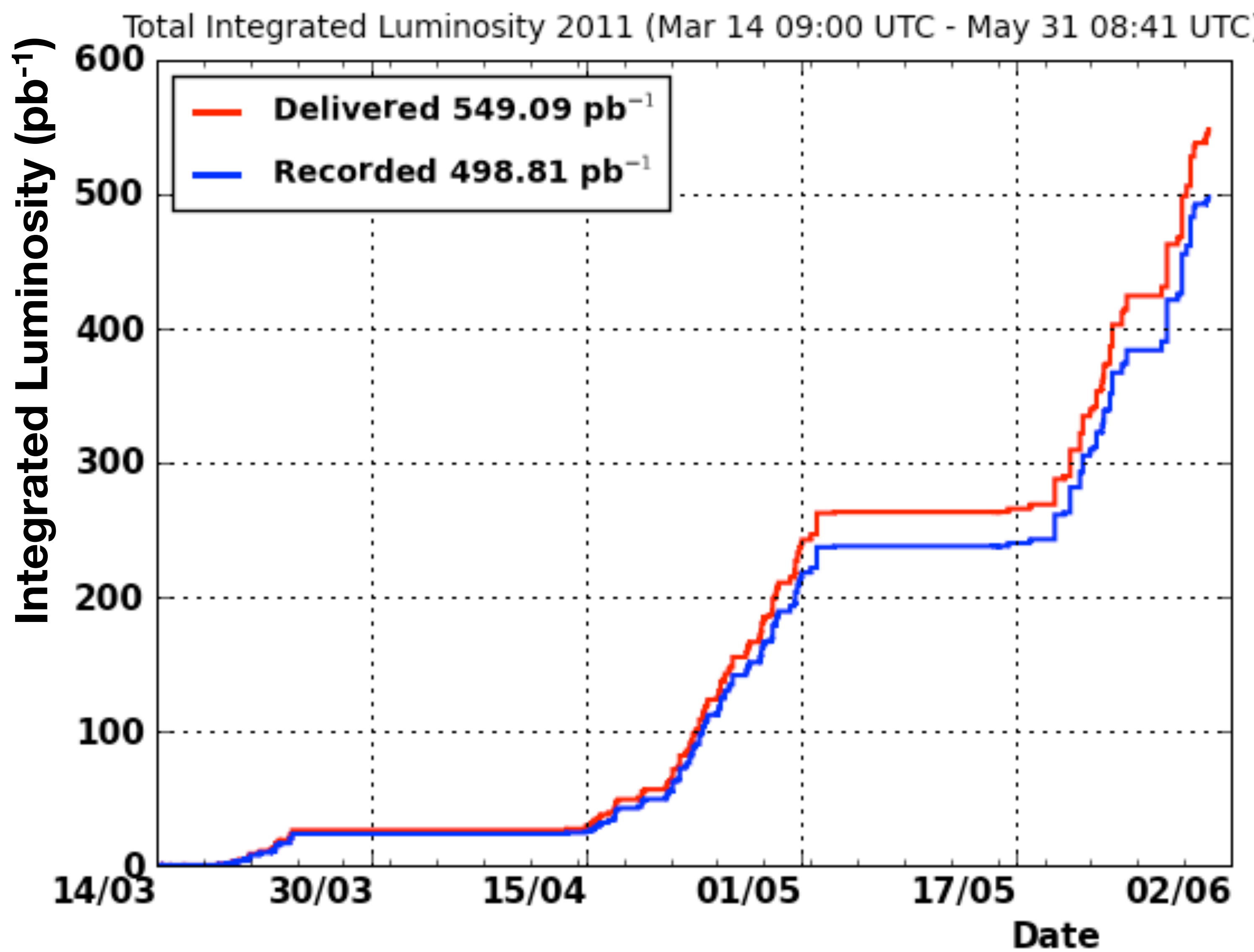
Higgs Sensitivity with 1-10 fb^{-1}



Assuming combination with ATLAS yields 2xCMS with 1 fb^{-1}, 3σ sensitivity 135-475 GeV/c^2

LHC Performance in 2011

- $>0.5\ fb^{-1}$ delivered by LHC to each experiment
- Should have one more month of data-taking before EPS
- EPS results will likely be based on $\sim 1\ fb^{-1}$ samples



Higher luminosity comes with its own set of challenges, such as managing trigger rates and dealing with higher pileup

Conclusions

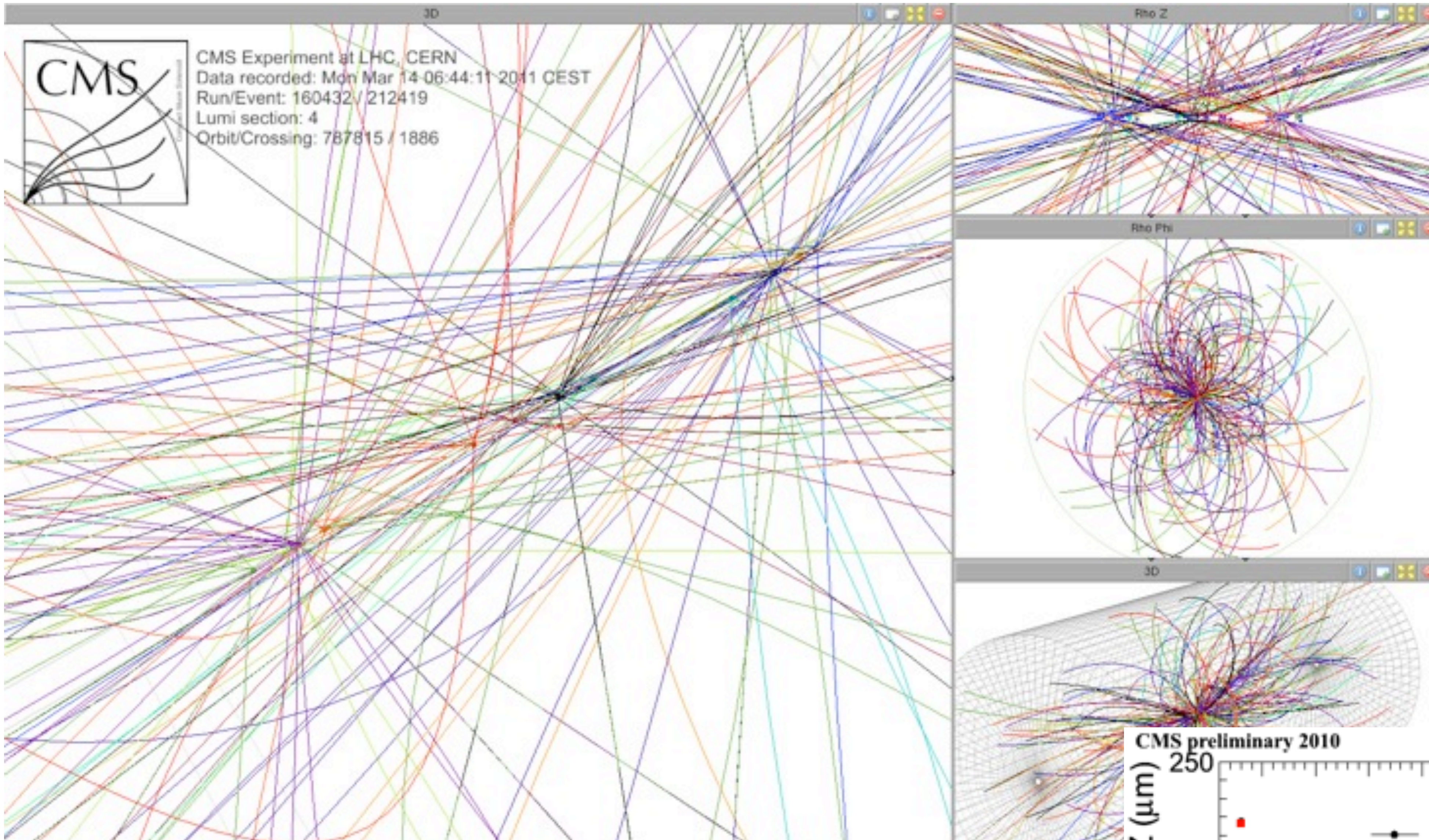
- First Higgs limits from CMS produced using 2010 data
  - Already competitive with Tevatron in some scenarios
- Projected Higgs sensitivity with 1 fb^{-1}:
  - CMS alone could possibly exclude 135-450 GeV/c^2
  - Results from 2010 data support sensitivity projections
  - LHC is performing well $\Rightarrow$ We will have the data in hand
- Expect first Higgs results with ≥1 fb^{-1} at EPS and Lepton-Photon in the next two months
- The next two years should be very exciting!

Backup

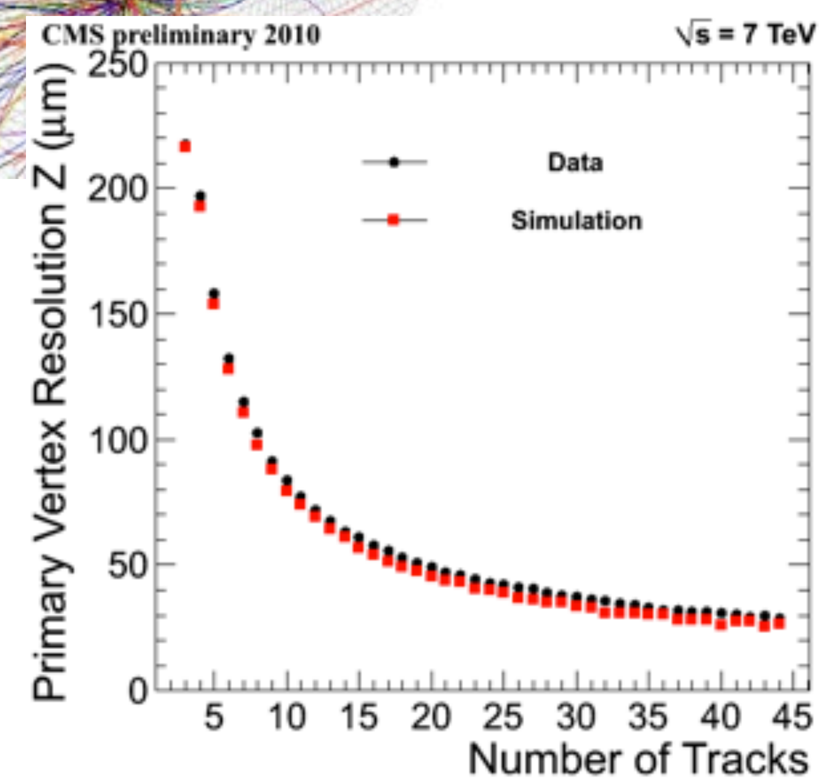
Sensitivity Projections

Channels included	Higgs mass range used in analyses (GeV)
$H \rightarrow \gamma\gamma$	115-150
VBF $H \rightarrow \tau\tau$	115-145
VH, $H \rightarrow bb$ (highly boosted)	115-125
VH, $H \rightarrow WW \rightarrow l\nu jj$	130-200
$H \rightarrow WW \rightarrow 2l2\nu$ + 0/1 jets	120-600
VBF $H \rightarrow WW \rightarrow 2l2\nu$	130-500
$H \rightarrow ZZ \rightarrow 4l$	120-600
$H \rightarrow ZZ \rightarrow 2l2\nu$	200-600
$H \rightarrow ZZ \rightarrow 2l2b$	300-600

Pileup Treatment



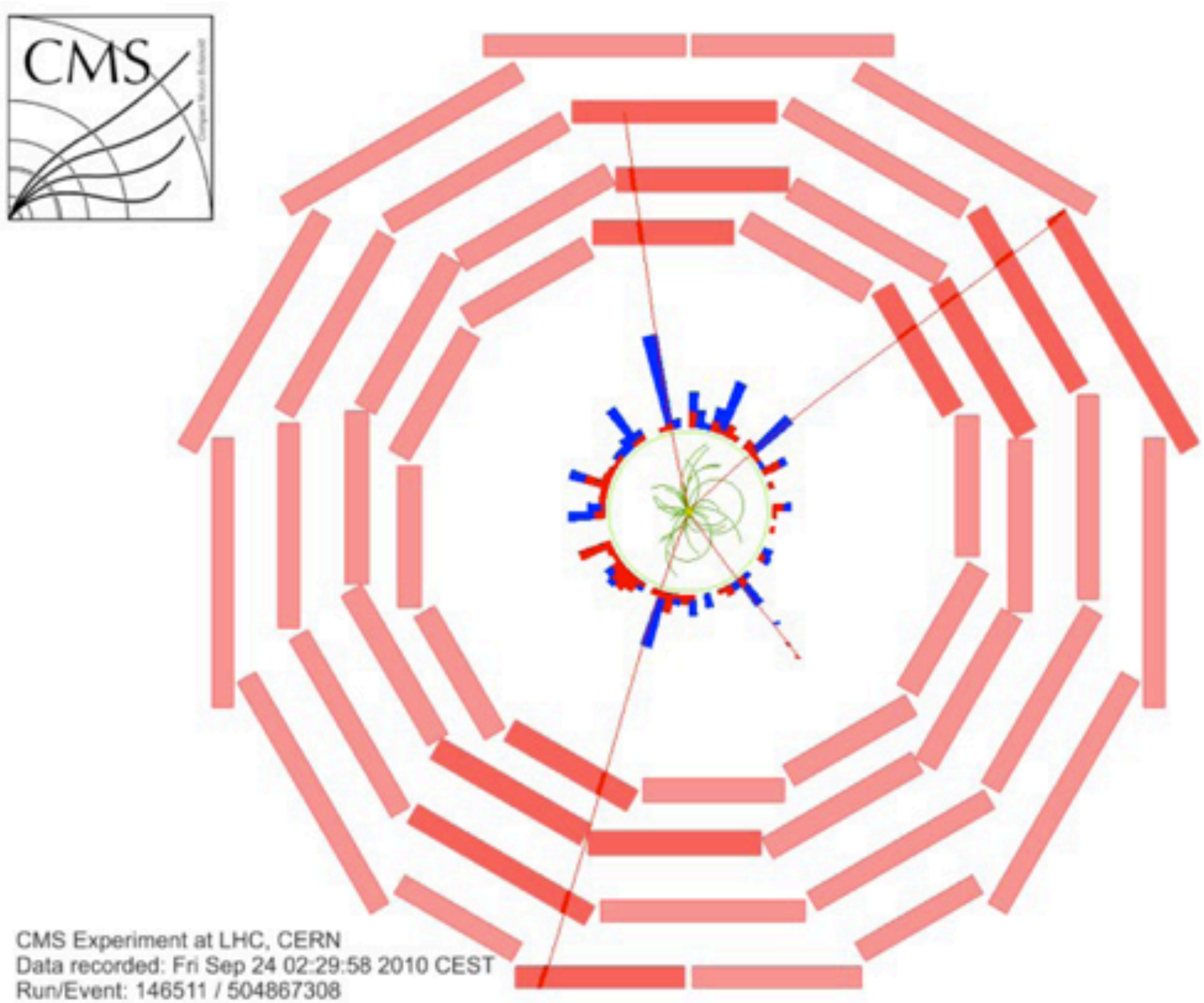
- Pileup has an effect on quantities we use for event selection
  - Lepton Isolation
  - Measurement of Jet ET and MET
  - Primary vertex identification
- Tools to handle high pileup
  - Precise reconstruction of primary vertex position
  - Average event activity calculation for Jets and MET

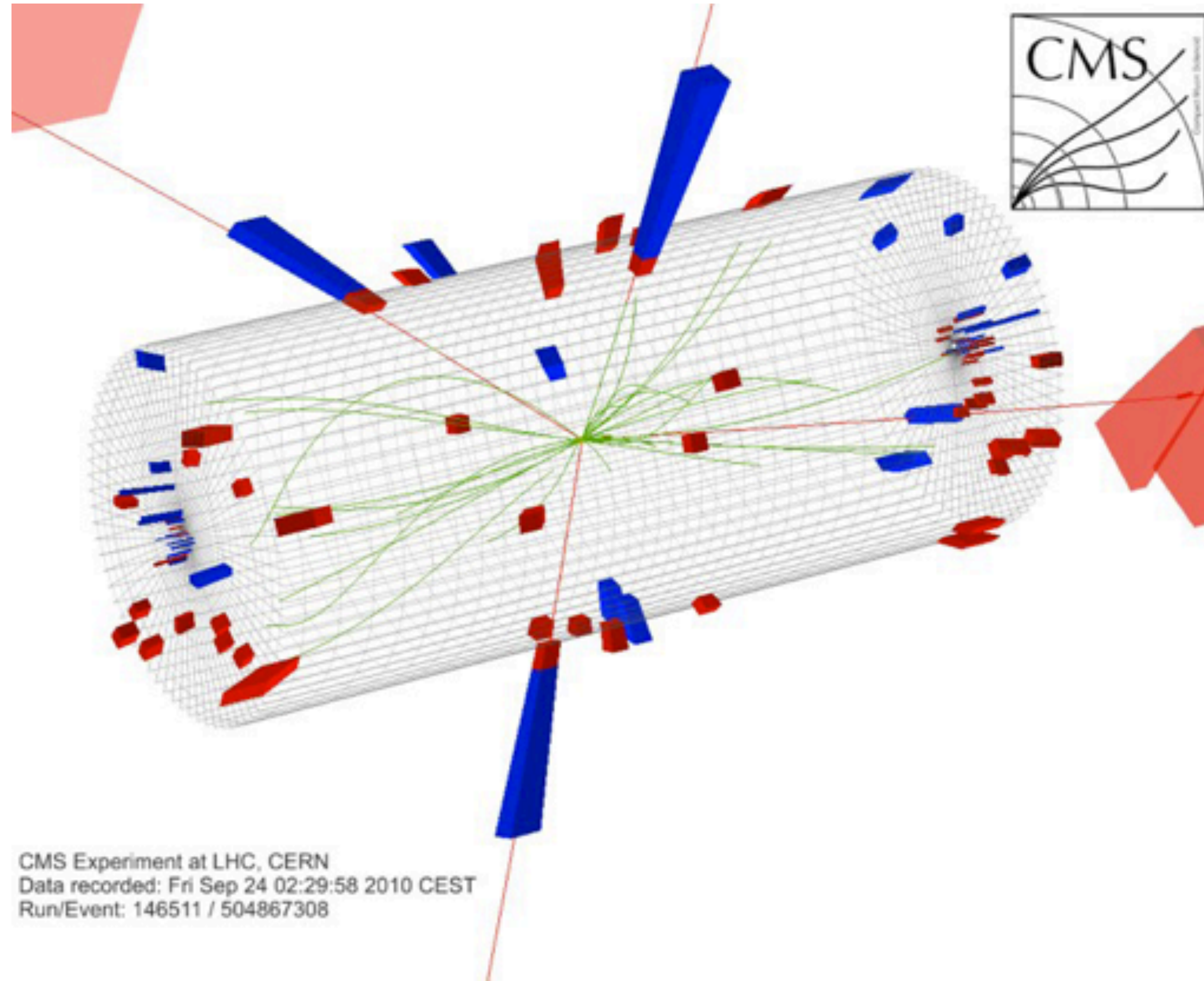


$H \to WW \to l\nu l\nu$

m_H (GeV/c^2)	data	SM $H \to W^+W^-$	SM with 4th gen. $H \to W^+W^-$	all bkg.	qq$\to W^+W^-$	gg$\to W^+W^-$	all non-W^+W^-
cut-based approach							
130	1	0.30 ± 0.01	1.73 ± 0.04	1.67 ± 0.10	1.12 ± 0.01	0.10 ± 0.01	0.45 ± 0.10
160	0	1.23 ± 0.02	10.35 ± 0.16	0.91 ± 0.05	0.63 ± 0.01	0.07 ± 0.01	0.21 ± 0.05
200	0	0.47 ± 0.01	3.94 ± 0.07	1.47 ± 0.09	1.13 ± 0.01	0.12 ± 0.01	0.23 ± 0.09
210	0	0.34 ± 0.01	2.81 ± 0.07	1.49 ± 0.05	1.09 ± 0.01	0.10 ± 0.01	0.30 ± 0.05
400	0	0.19 ± 0.01	0.84 ± 0.01	1.06 ± 0.03	0.79 ± 0.01	0.04 ± 0.01	0.23 ± 0.03
multivariate approach							
130	1	0.34 ± 0.01	1.98 ± 0.04	1.32 ± 0.18	0.75 ± 0.01	0.04 ± 0.00	0.53 ± 0.18
160	0	1.47 ± 0.02	12.31 ± 0.17	0.92 ± 0.10	0.63 ± 0.01	0.06 ± 0.00	0.22 ± 0.10
200	0	0.57 ± 0.01	4.76 ± 0.07	1.47 ± 0.07	1.07 ± 0.01	0.13 ± 0.00	0.27 ± 0.07
210	0	0.42 ± 0.01	3.47 ± 0.07	1.44 ± 0.07	1.03 ± 0.01	0.12 ± 0.00	0.29 ± 0.07
400	0	0.20 ± 0.01	0.90 ± 0.01	1.09 ± 0.07	0.75 ± 0.01	0.04 ± 0.00	0.30 ± 0.07

First ZZ Candidate





$P_t^{\mu 1} = 48.1$ GeV

$P_t^{\mu 2} = 43.4$ GeV

$P_t^{\mu 3} = 25.9$ GeV

$P_t^{\mu 4} = 19.6$ GeV

$M_{\mu 1 \mu 2} = 92.15$ GeV

$M_{\mu 3 \mu 4} = 92.24$ GeV

$M_{4\mu} = 201$ GeV

MET

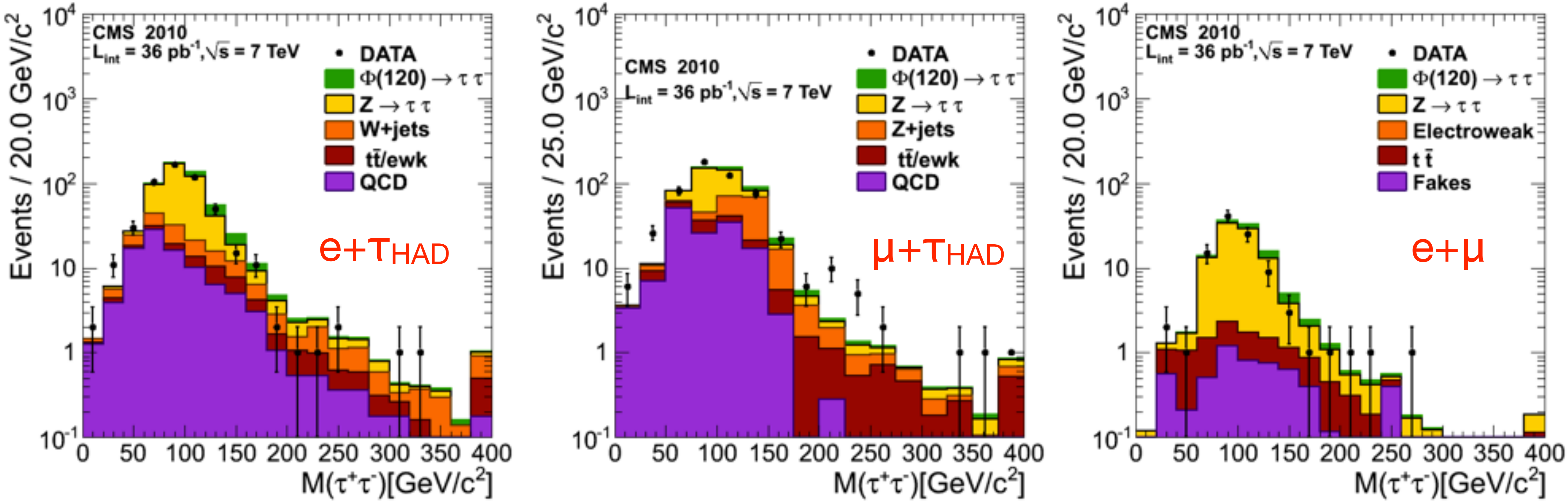
- MET is computed as a negative vector sum of calorimeter energy depositions (E_T), corrected for muons and tracks.
  - The track correction substitutes the expected energy deposition for each tracks with the Pt measured by the tracker
- Projected MET helps to reject Drell-Yan to tau-tau decays that tend to have MET aligned with one of the leptons:

$$\Delta\phi_{min} = min(\Delta\phi(\ell_1, E_T^{miss}), \Delta\phi(\ell_2, E_T^{miss}))$$

$$\text{projected } E_T^{miss} = \begin{cases} E_T^{miss} & \text{if } \Delta\phi_{min} > \frac{\pi}{2}, \\ E_T^{miss}\sin(\Delta\phi_{min}) & \text{if } \Delta\phi_{min} < \frac{\pi}{2} \end{cases}$$

- For ee/μμ: projected MET > 35 GeV
- For eμ: projected MET > 20 GeV

H→WW→$l\nu l\nu$



Process	$\mu+\tau_h$	$e+\tau_h$	$e+\mu$
$Z \to \tau\tau$	329 ± 77	190 ± 44	88 ± 5
TTBar	6 ± 3	2.6 ± 1.3	7.1 ± 1.3
$Z \to ee/\mu\mu$ +jets , jet fakes tau	6.4 ± 2.4	15 ± 6.2	-
$Z \to ee/\mu\mu$	12.9 ± 3.5	109 ± 28	2.4 ± 0.3
$W \to e/\mu\ \nu$ + jets	54.9 ± 4.8	30.6 ± 3.1	
$W \to \tau\ \nu$	14.7 ± 1.3	7.0 ± 0.7	1.5 ± 0.5
QCD	132 ± 14	181 ± 23	
Di bosons	1.6 ± 0.8	0.8 ± 0.4	3.0 ± 0.4
Total	**557 ± 79**	**536 ± 57**	**102 ± 5**
Observed	**517**	**540**	**101**