The Search for Higgs Bosons

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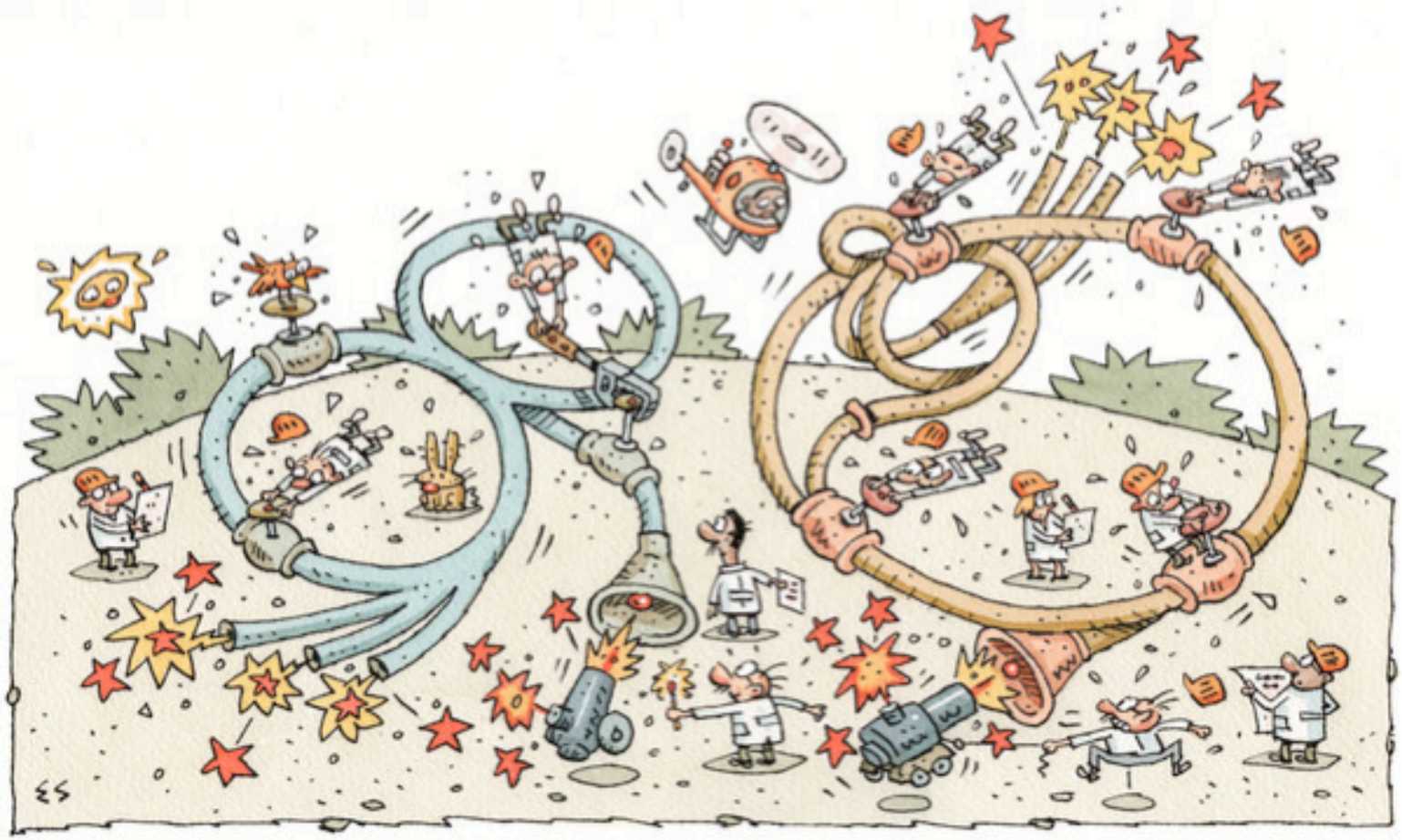
Aug 2, 2011

NEWS ANALYSIS

Particle Accelerators Full of Spin and Fury, Signifying Something



Elwood H. Smith

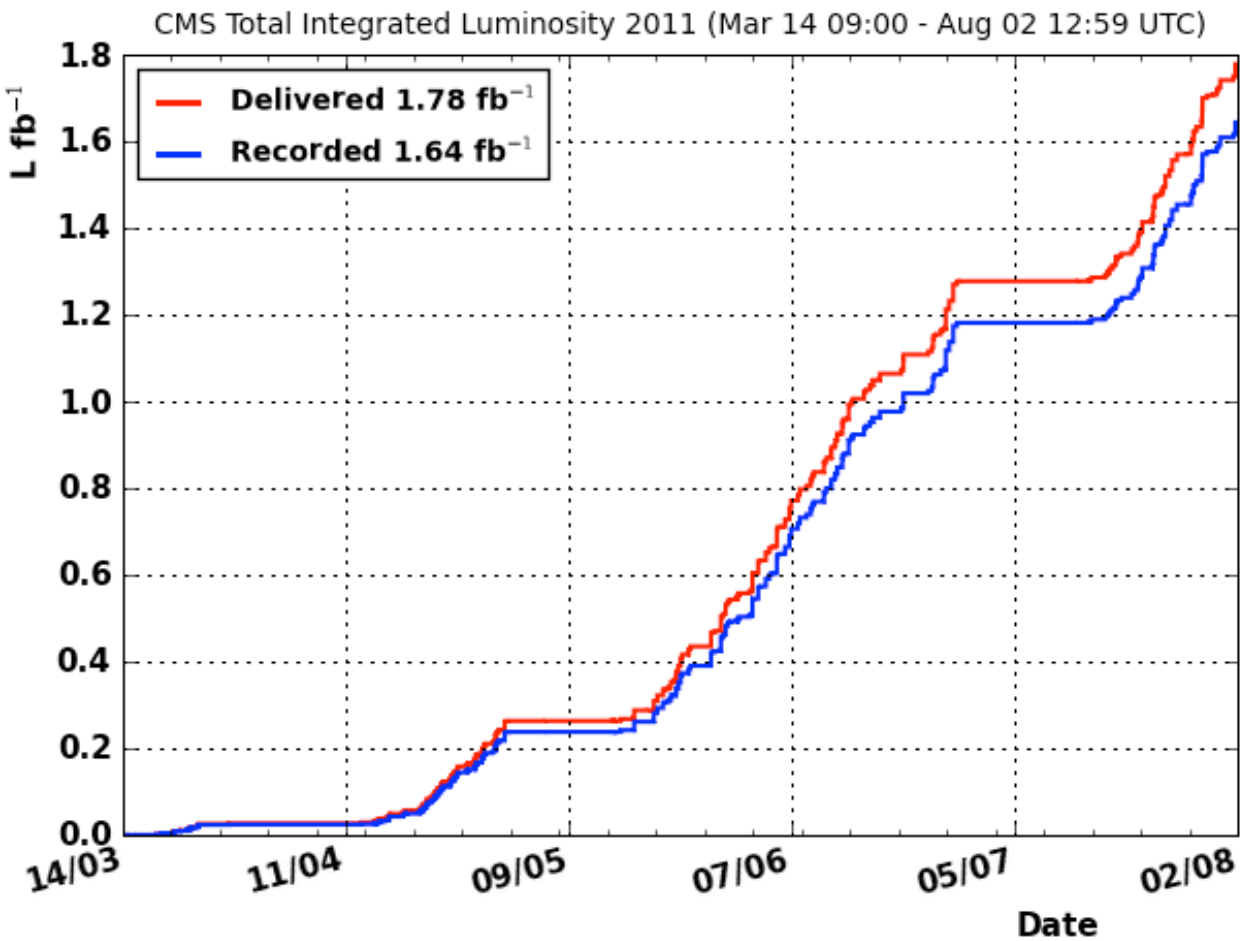
By DENNIS OVERBYE

Published: August 1, 2011

- This talk came from my PANIC 11 talk on SM Higgs at CMS

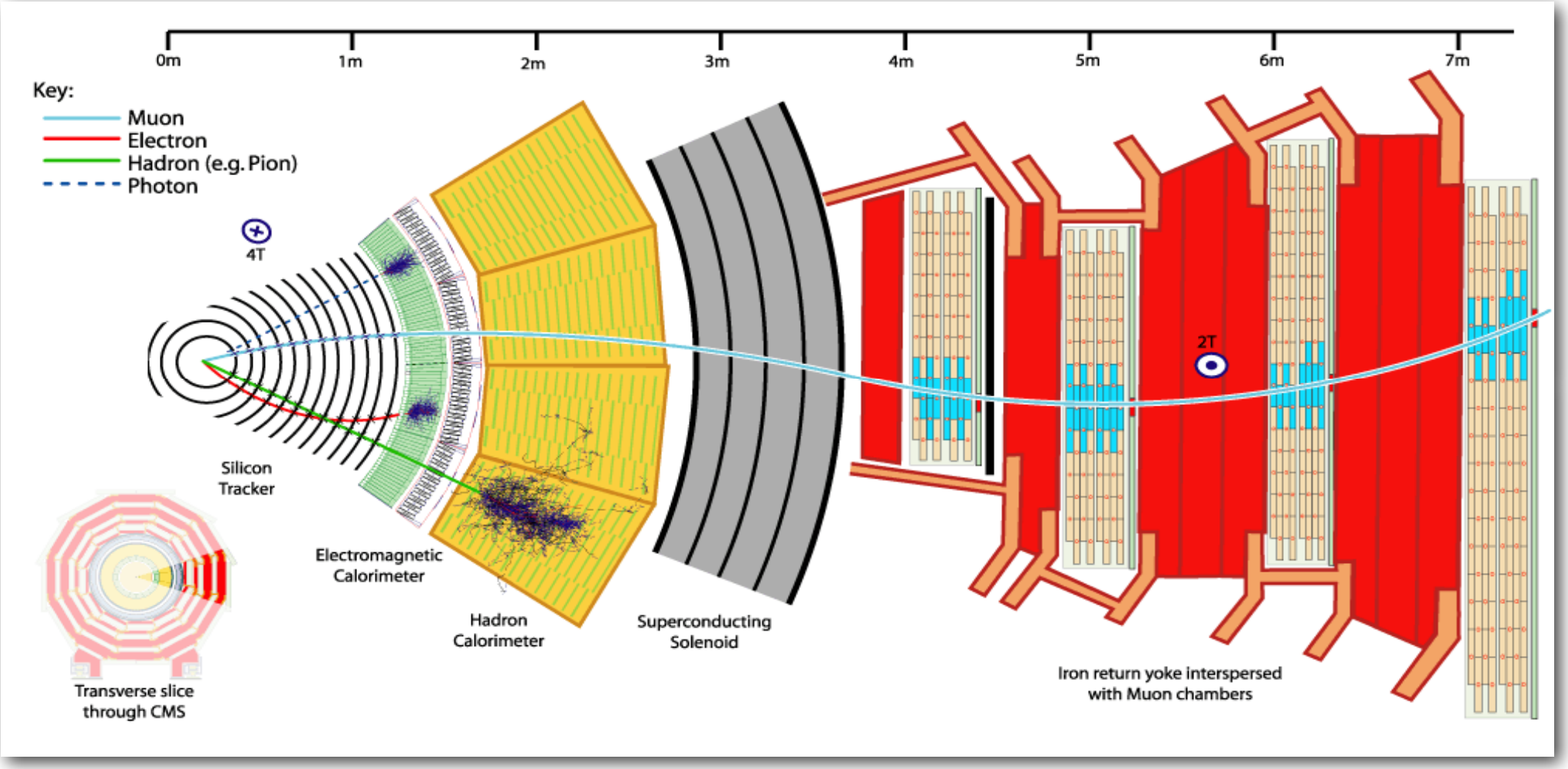
- To this I have added more material:

  - ATLAS combined SM Higgs result
  - Tevatron combined SM Higgs result
  - MSSM Higgs from CMS



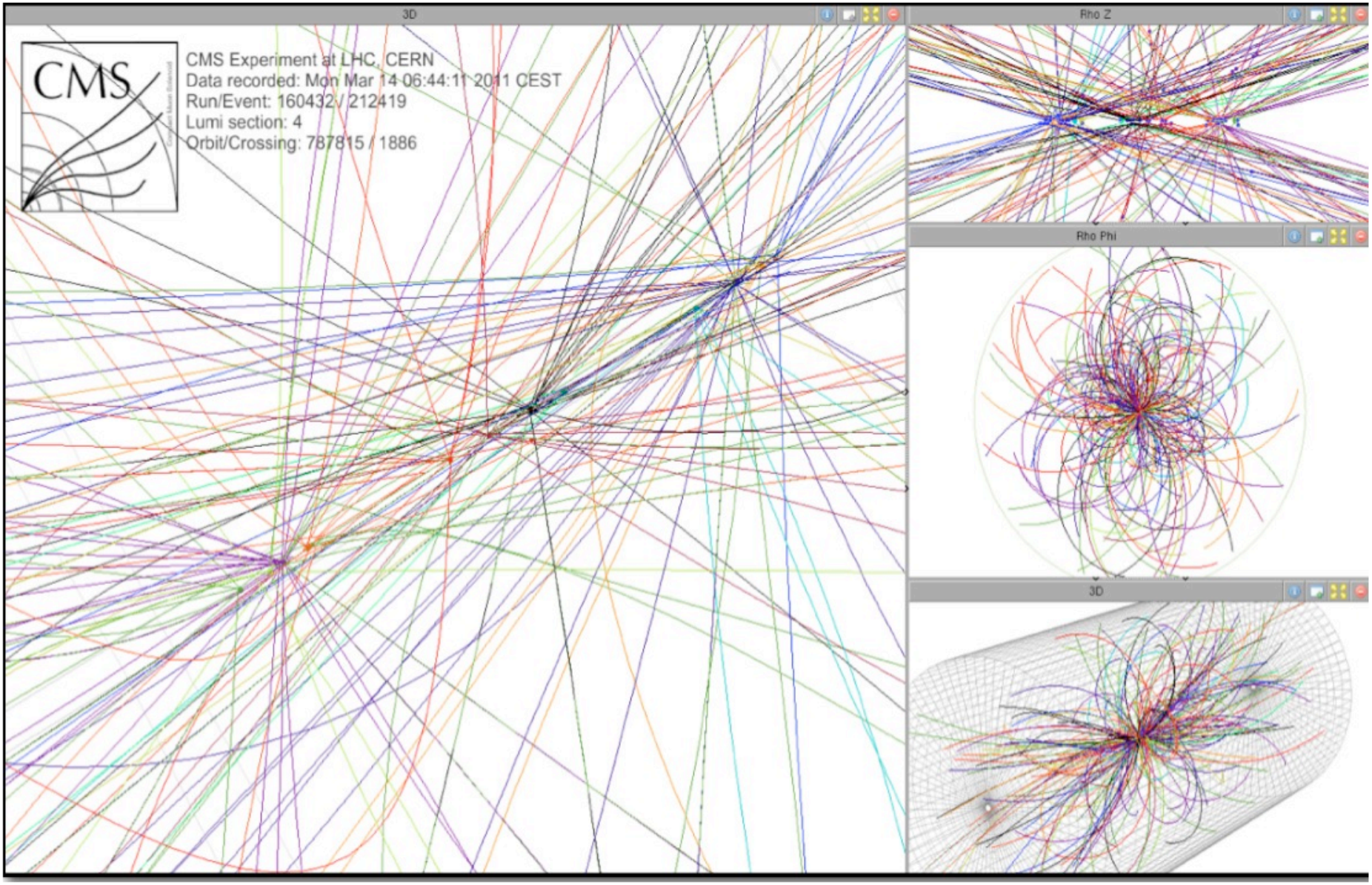
EPS/PANIC: 1.1 fb^{-1}

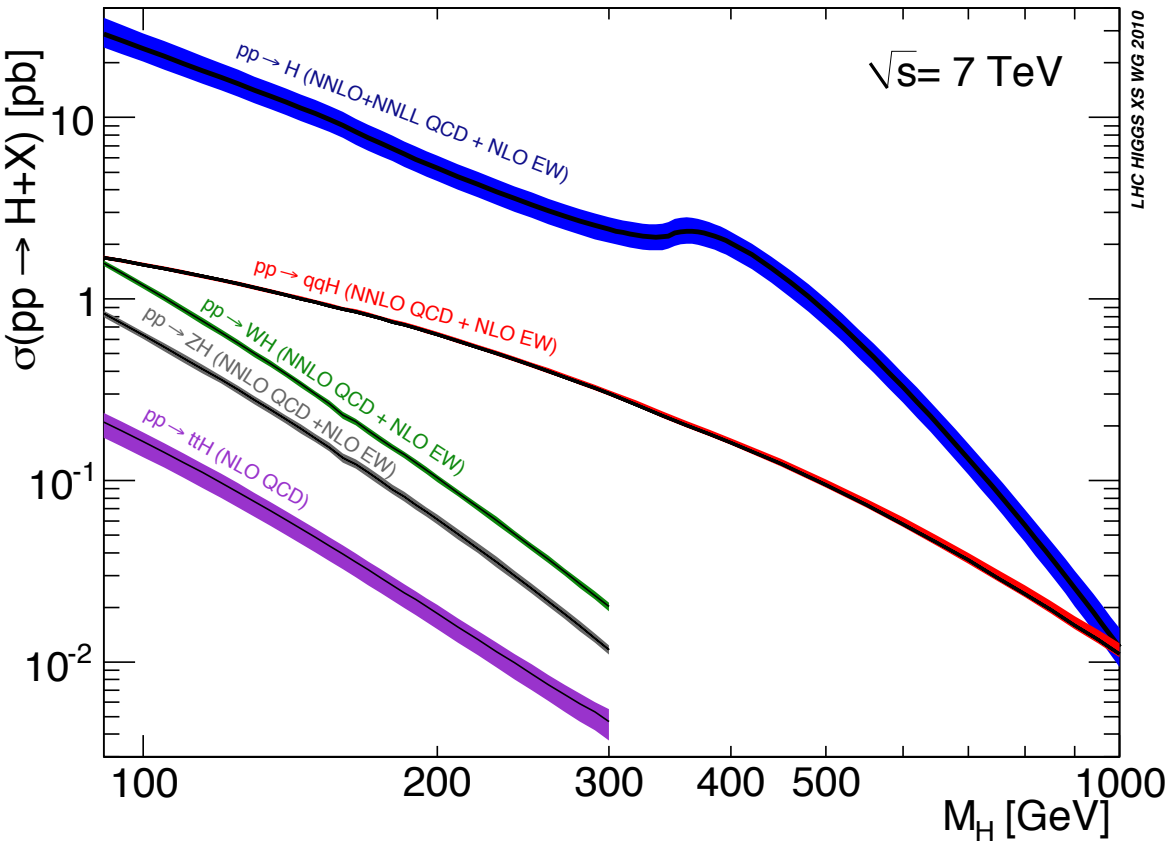
Search for SM Higgs is on with the first fb^{-1}

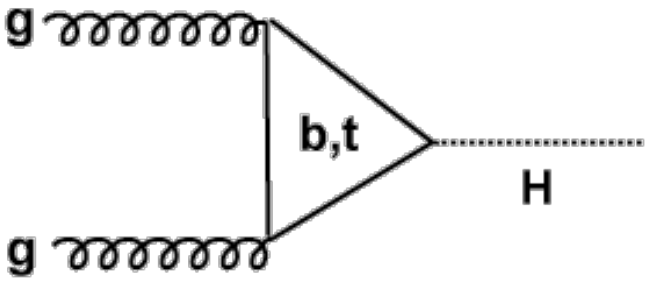


- large radius tracking, 4T field
- $PbWO_4$ crystal ECAL

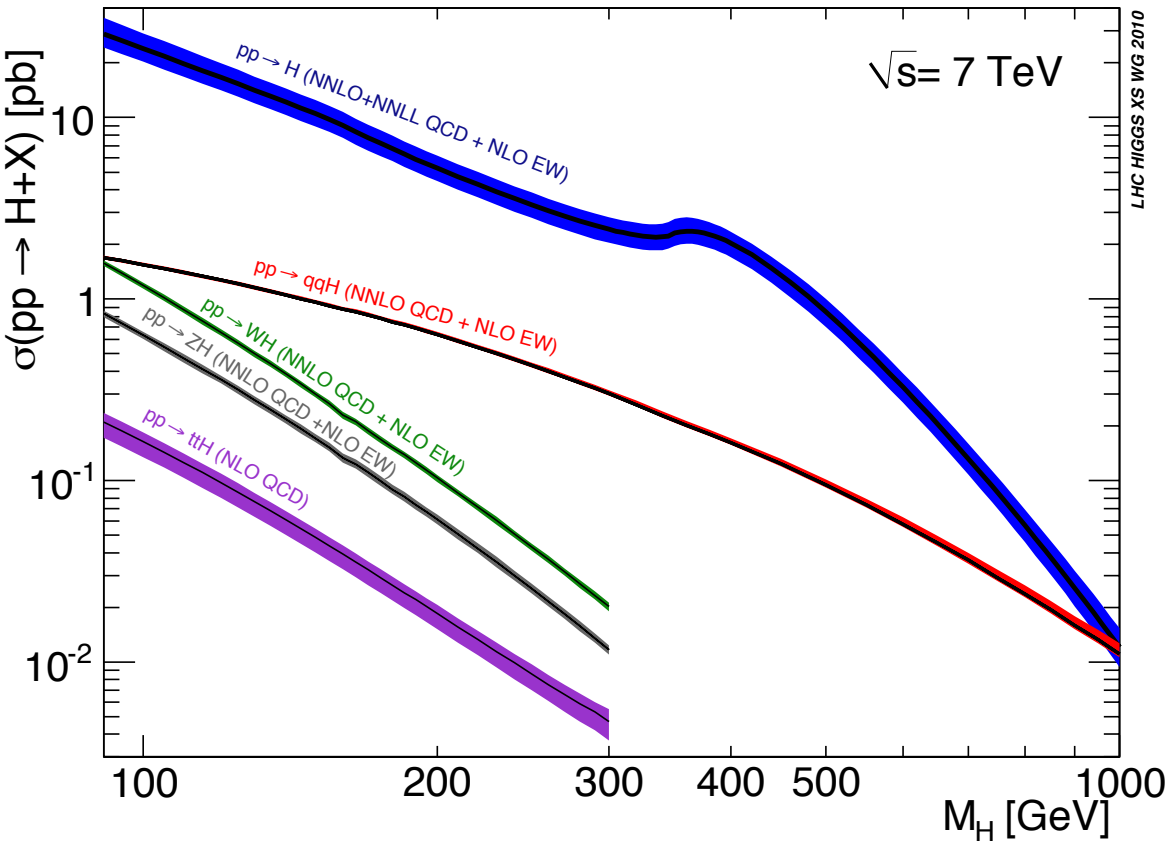
major challenge in 2011: multiple pp interactions ("pileup")

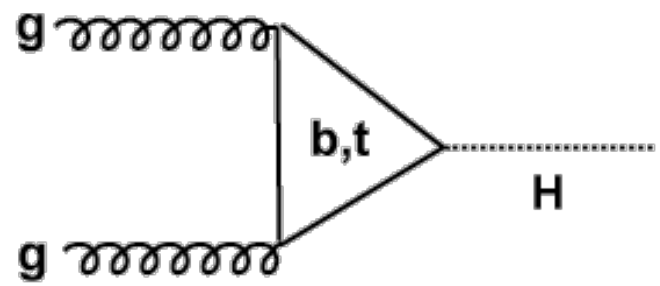






20 pb at 120 GeV





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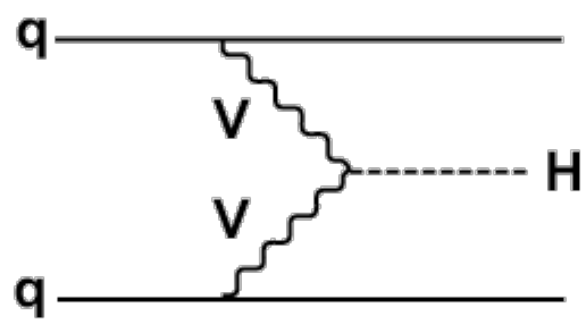
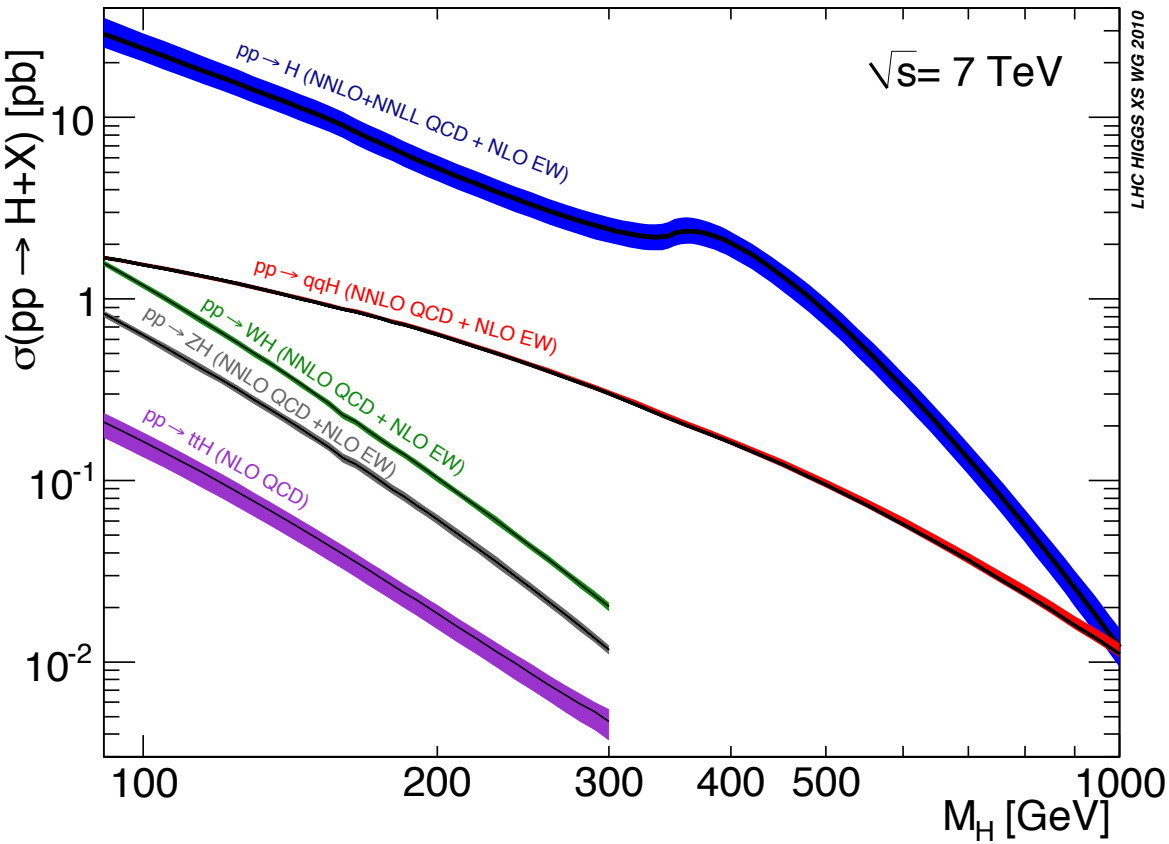
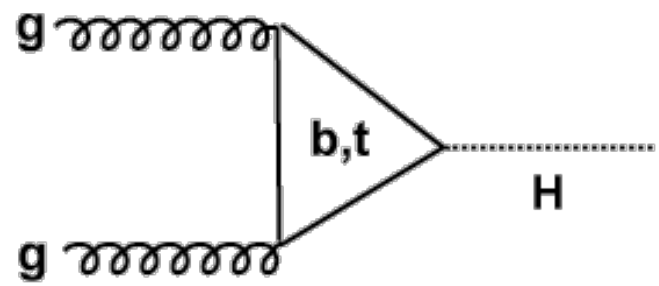


vector boson fusion





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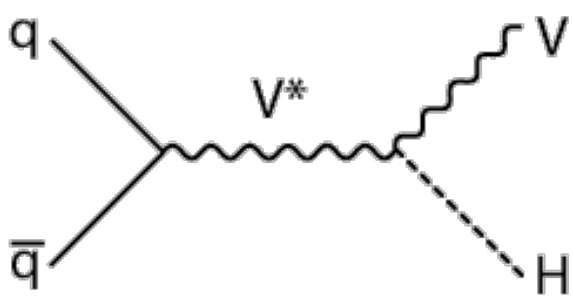
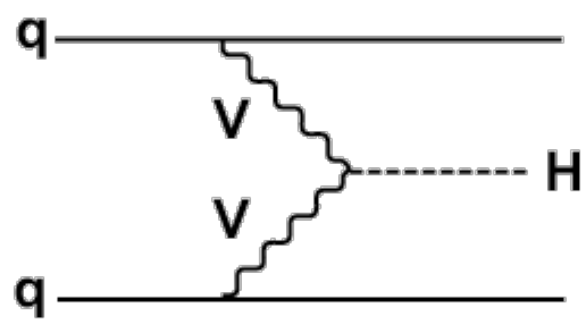
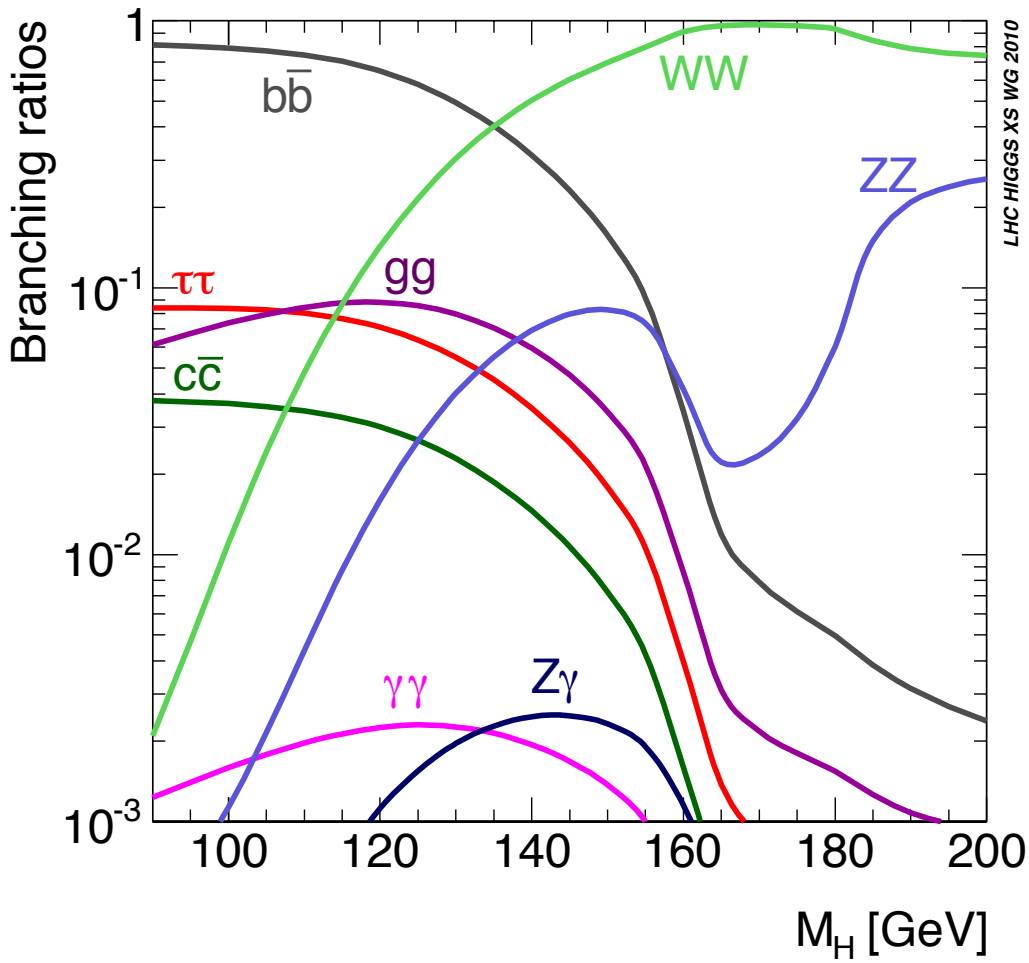
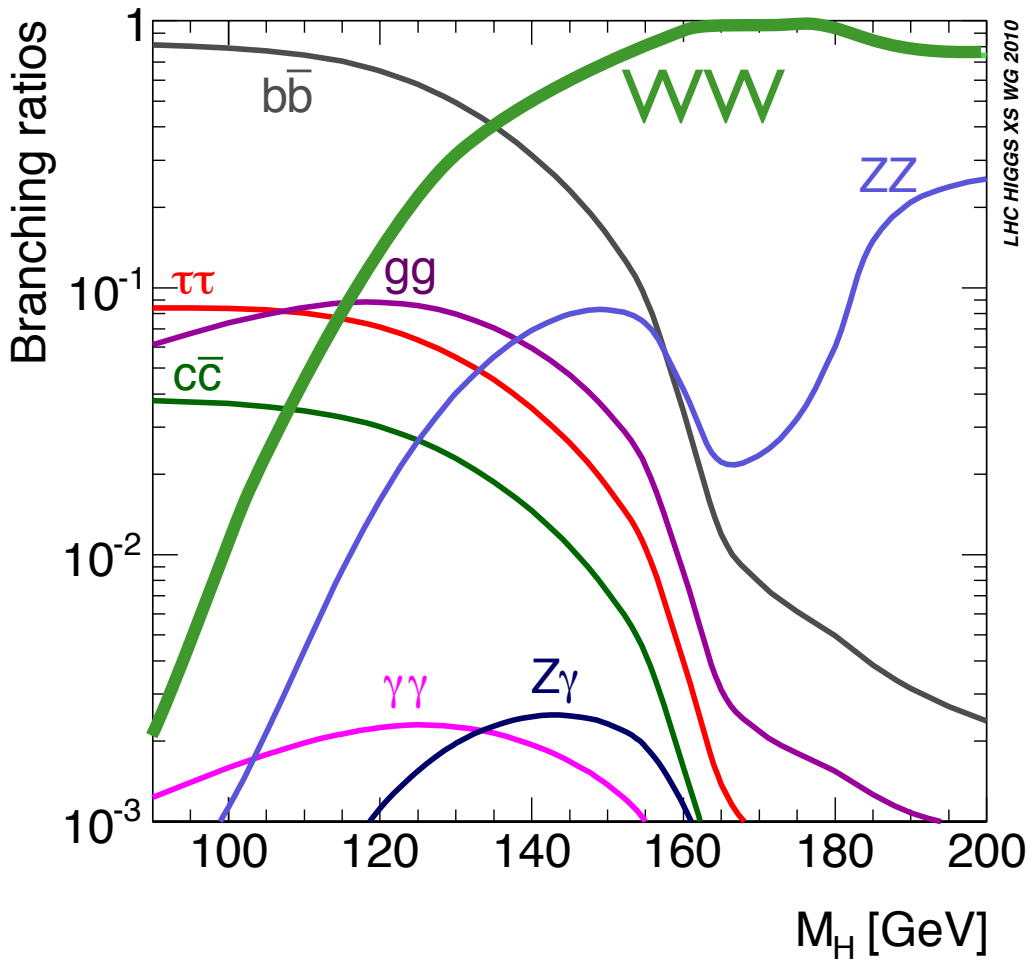


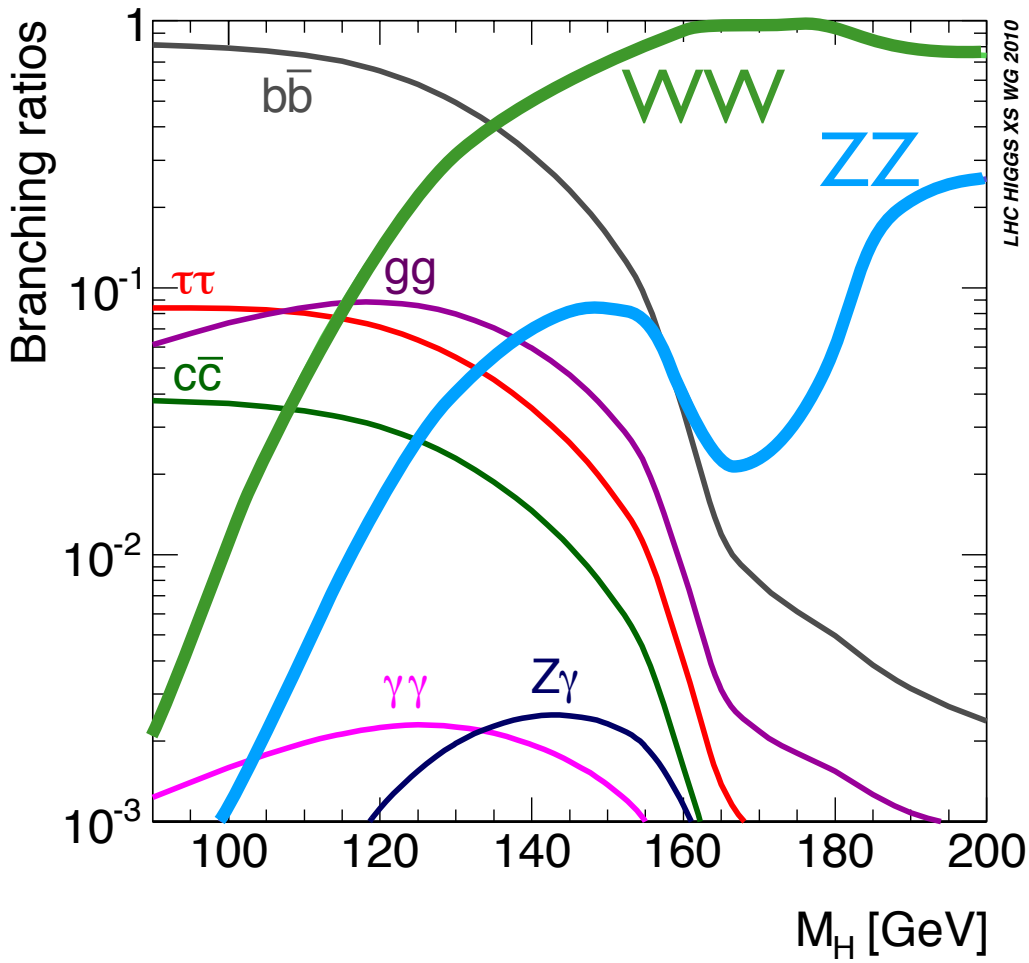


vector boson fusion


Branching ratios
1
10^{-1}
10^{-2}
10^{-3}
100
120
140
160
180
200
M_H [GeV]
$b\bar{b}$
WW
ZZ
ττ
gg
$c\bar{c}$
γγ
Zγ
LHC HIGGS XS WG 2010

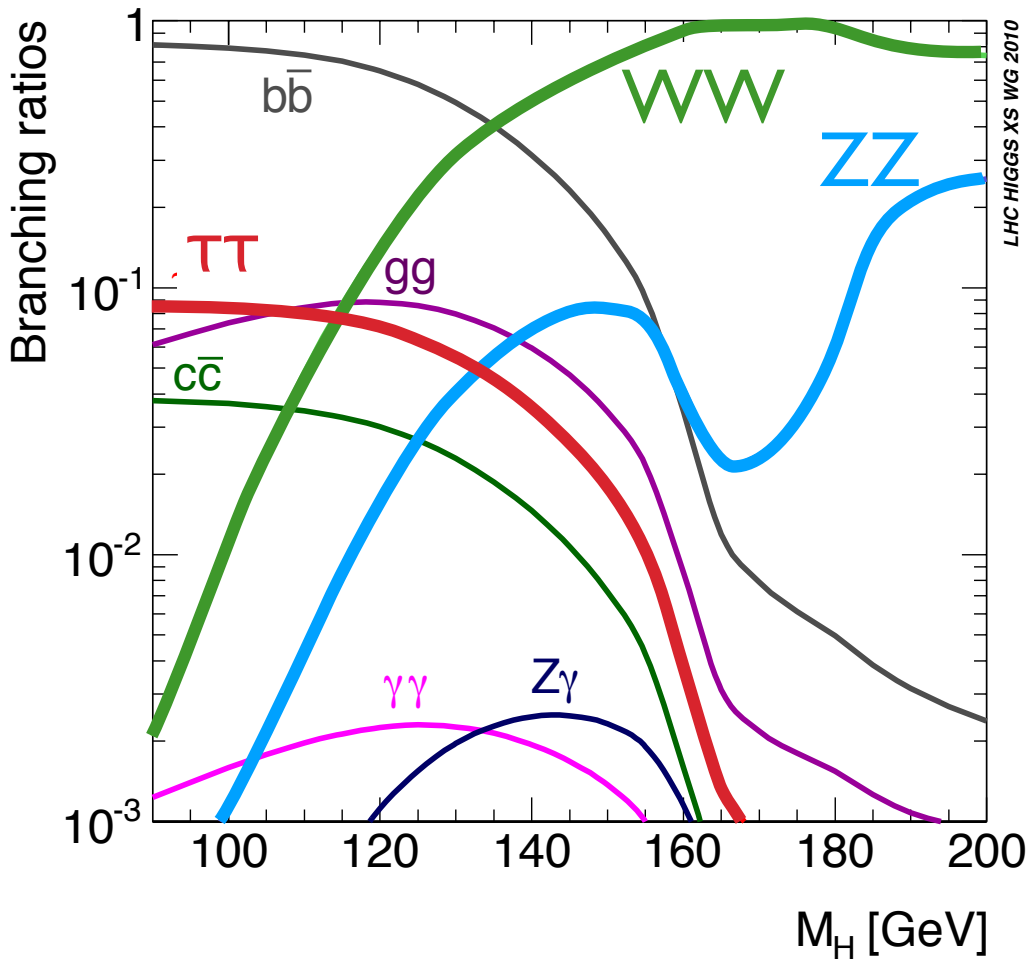


WW: dominates over wide mass range, clean final state ($\ell\nu\ell\nu$)



WW: dominates over wide mass range, clean final state ($\ell\nu\ell\nu$)

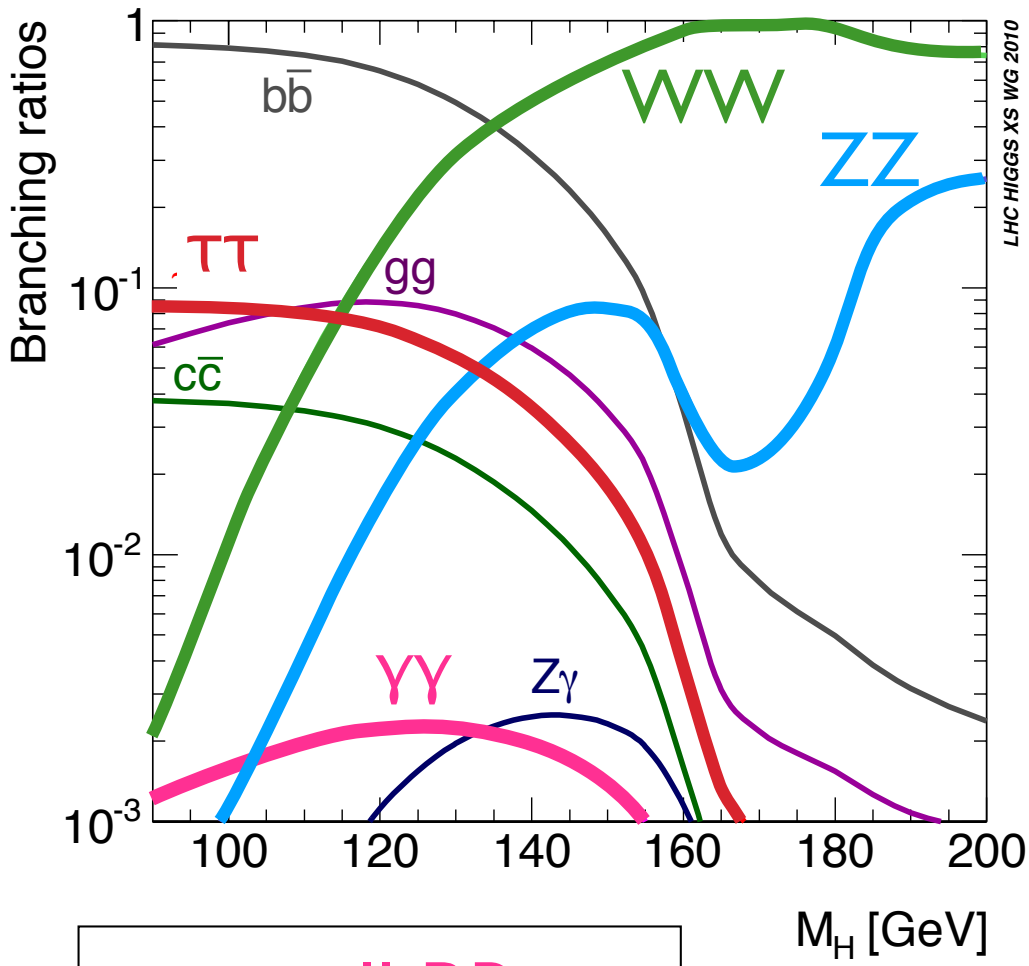
ZZ: three channels, sharp resolution



WW: dominates over wide mass range, clean final state ($\ell\nu\ell\nu$)

ZZ: three channels, sharp resolution

ττ: four channels, can use VBF production

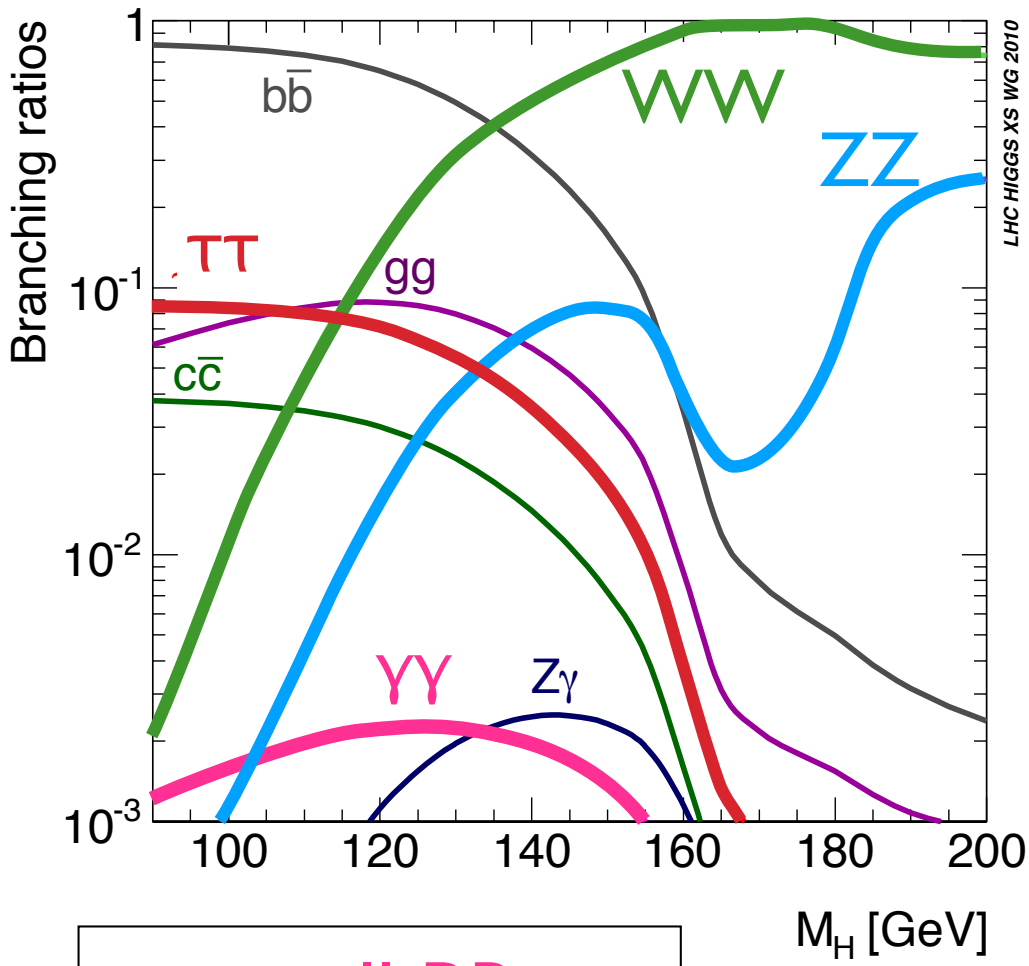


WW: dominates over wide mass range, clean final state ($\ell\nu\ell\nu$)

ZZ: three channels, sharp resolution

ττ: four channels, can use VBF production

γγ: small BR, sharp resolution



WW: dominates over wide mass range, clean final state ($\ell\nu\ell\nu$)

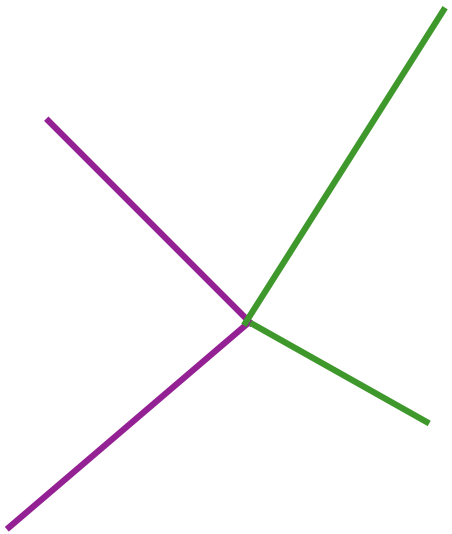
ZZ: three channels, sharp resolution

ττ: four channels, can use VBF production

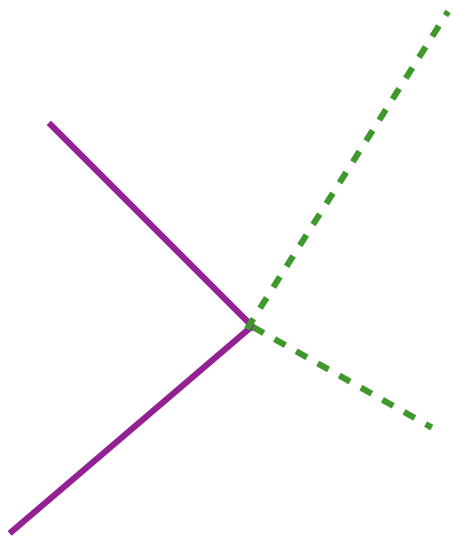
γγ: small BR, sharp resolution

bb mode will play role in future: boosted Higgs

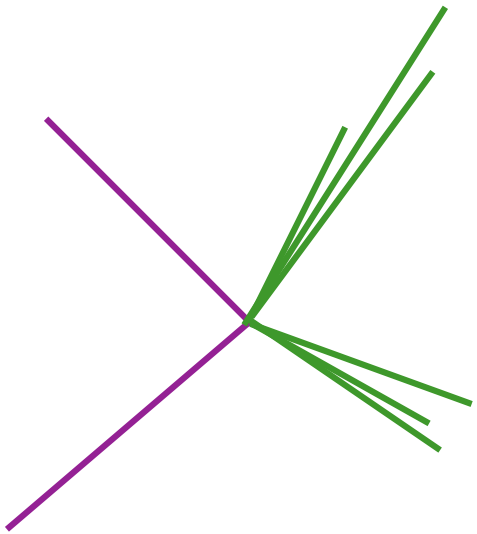
Three useful H→ZZ final states:



$Z \to \ell\ell$
$Z \to \ell\ell$



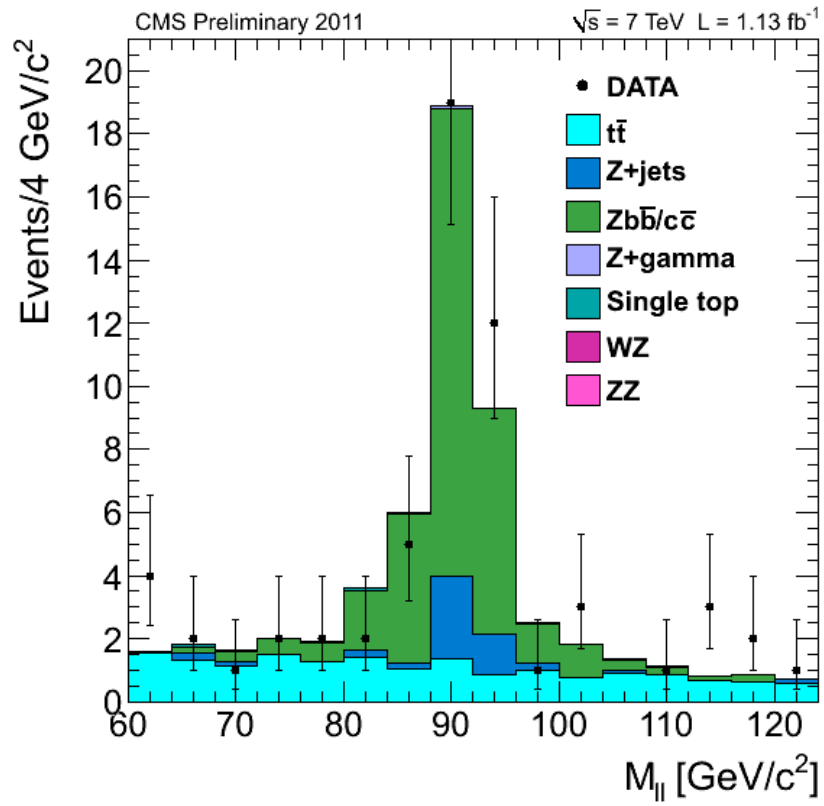
$Z \to \ell\ell$
$Z \to \nu\nu$



$Z \to \ell\ell$
$Z \to qq$

H → ZZ → 4 ℓ

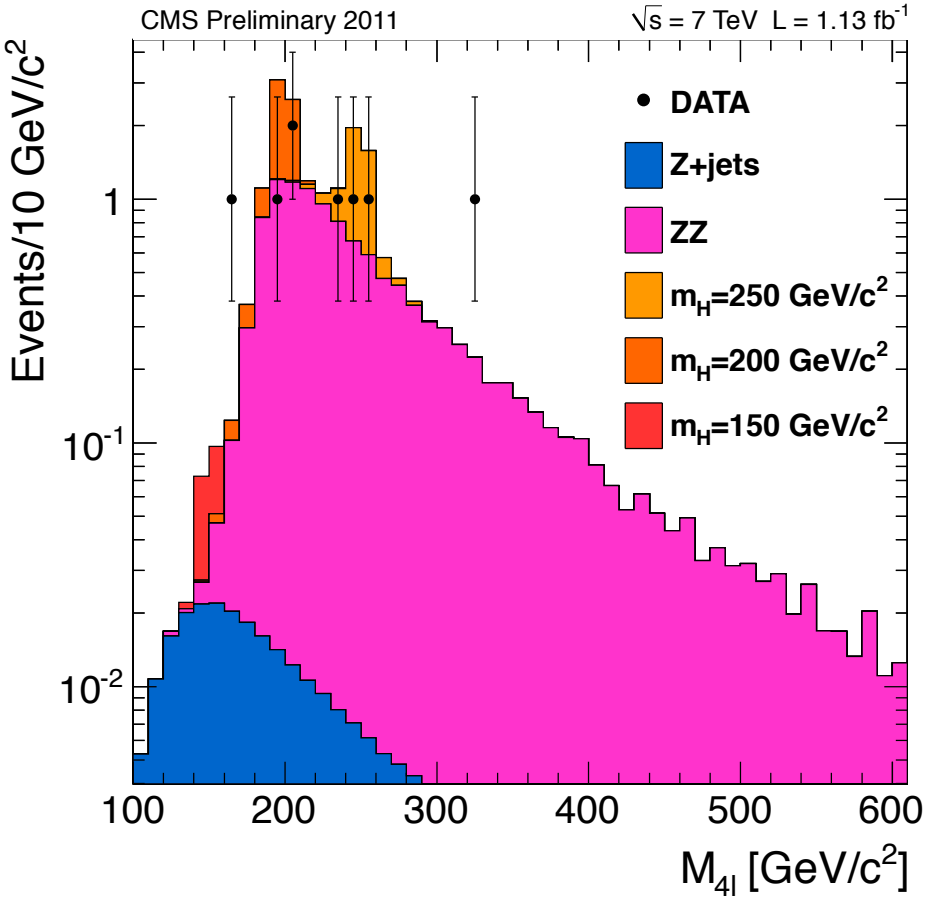
- look for best reconstructed Z → ee, μμ ($M_{\ell\ell}$ > 60 GeV)
- find second lepton pair
  - baseline selection: M_{Z2} > 20 GeV
  - high-mass selection: M_{Z2} > 60 GeV
- main background: continuum ZZ (estimate from data)



baseline

	eeee	μμμμ	eeμμ
ZZ	2.76±0.18	4.10±0.27	6.72±0.45
Z+jets	0.37±0.07	0.06±0.01	0.39±0.07
Z+bb,cc, tt	0.01±0.02	0.01±0.01	0.02±0.02
H (200 GeV)	0.82±0.01	1.16±0.01	1.91±0.02
observed	3	6	6

H → ZZ → 4 ℓ



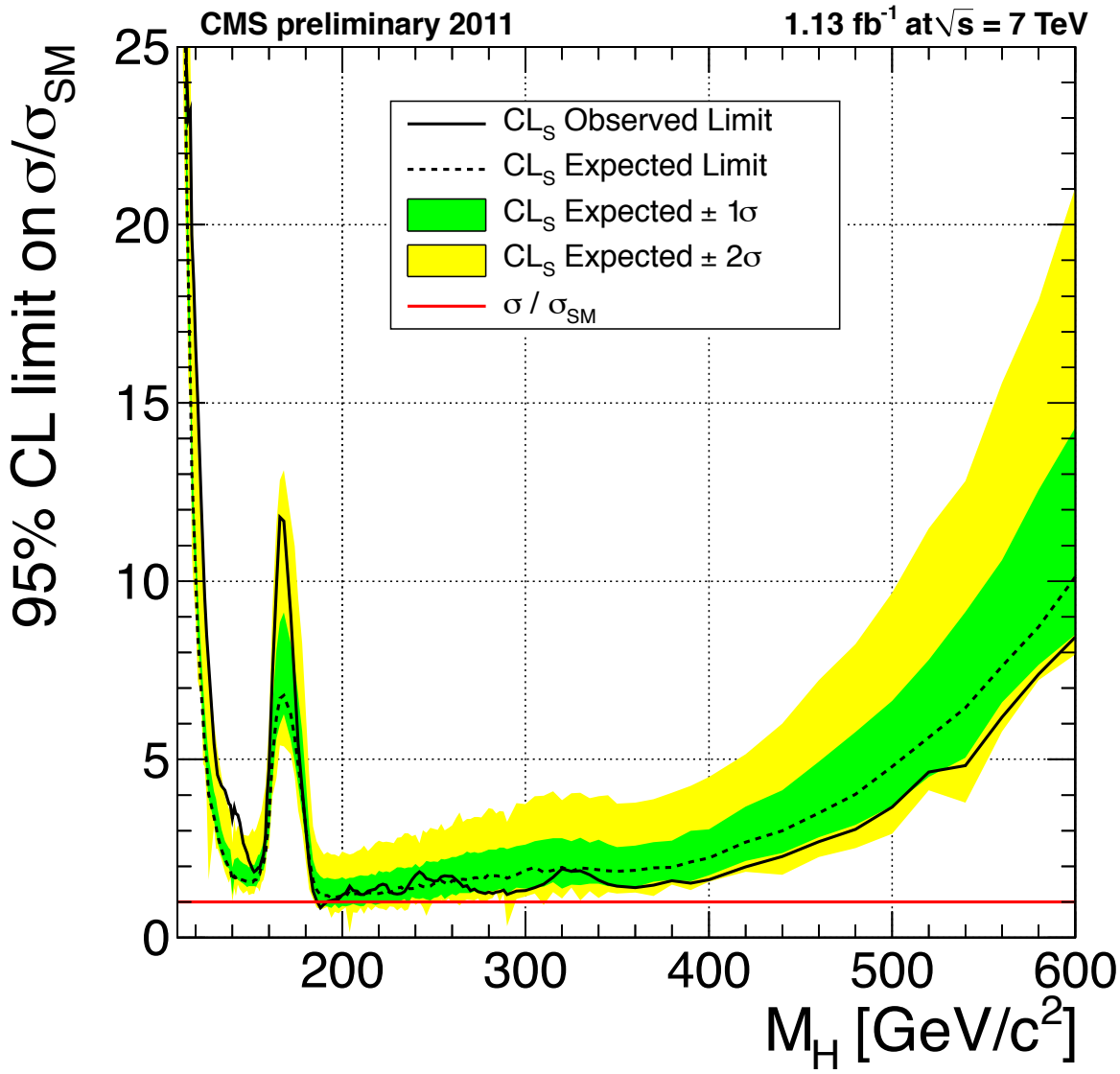
For high-mass selection, see good agreement with ZZ background prediction.

Signal: sharp peak

high-mass

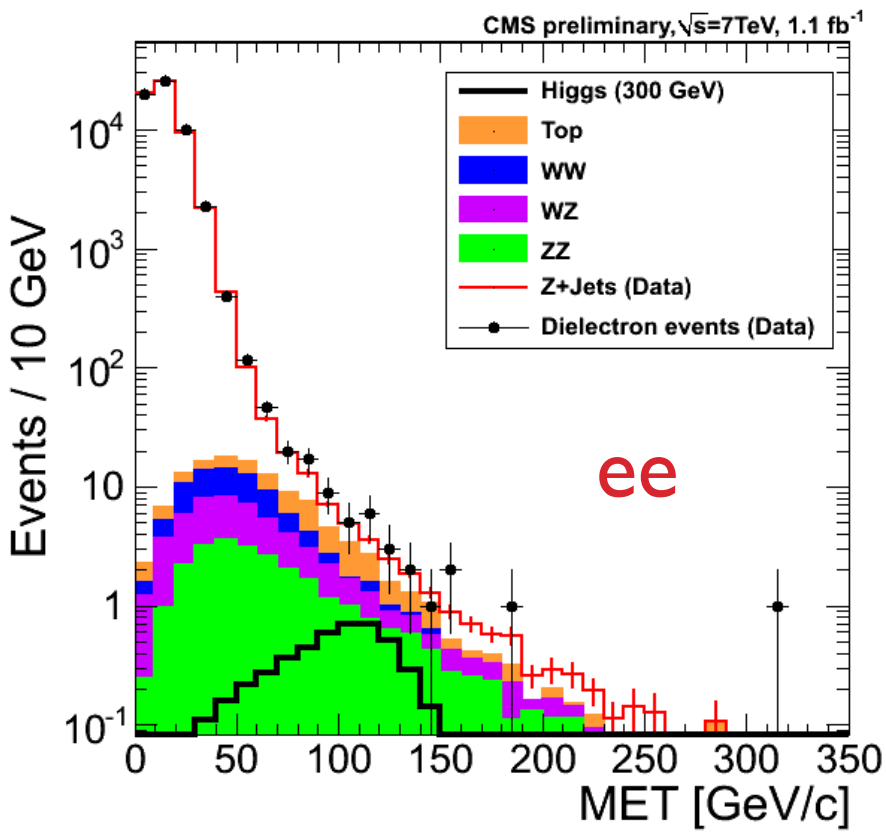
	eeee	μμμμ	eeμμ
ZZ	2.50±0.17	3.55±0.23	6.10±0.40
Z+jets	0.14±0.06	0.004±0.004	0.15±0.06
H (200 GeV)	0.76±0.01	1.08±0.01	1.80±0.02
observed	0	2	6

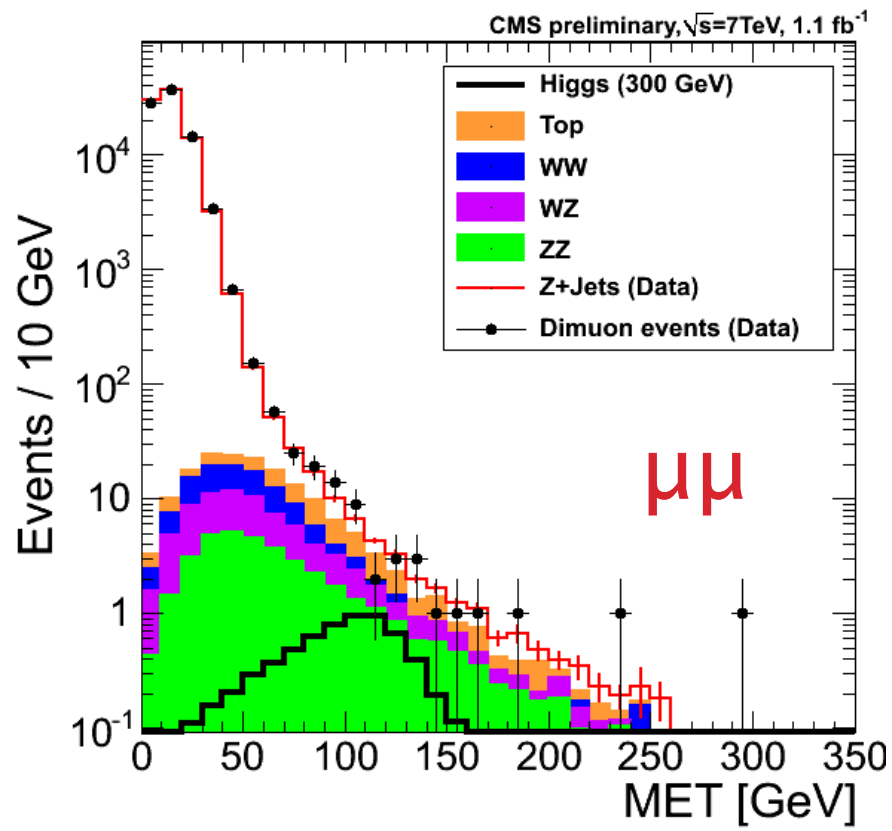
H → ZZ → 4 ℓ


CMS preliminary 2011
1.13 fb^{-1} at $\sqrt{s}$ = 7 TeV
95% CL limit on σ/σ_{SM}
CL_S Observed Limit
CL_S Expected Limit
CL_S Expected ± 1σ
CL_S Expected ± 2σ
σ / σ_{SM}
0
5
10
15
20
25
200
300
400
500
600
M_H [GeV/c^2]

H → ZZ → 2 ℓ 2ν

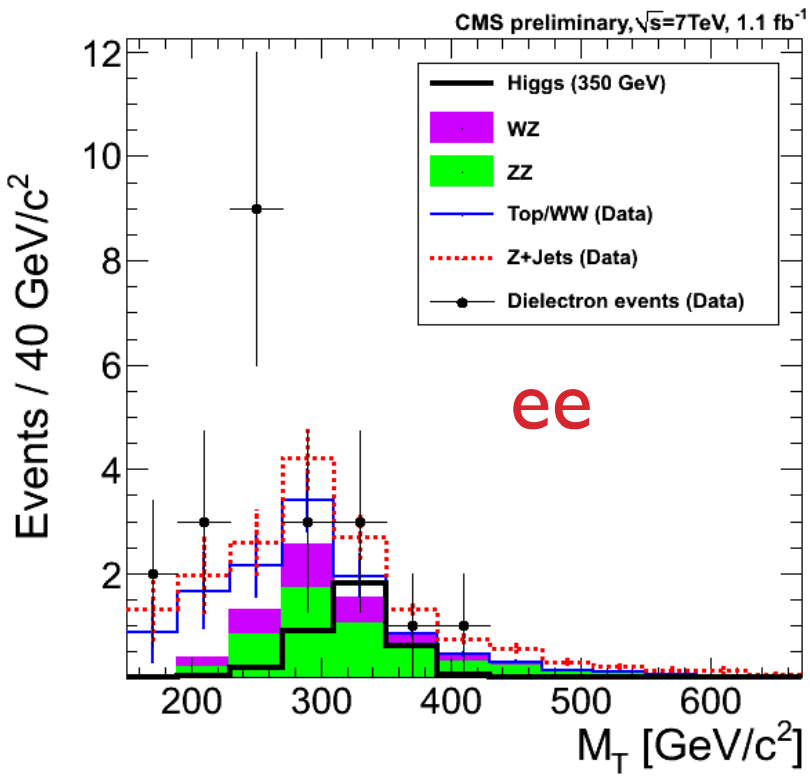
- two opposite-sign leptons, $|M_{\ell\ell}-M_Z| < 15$ GeV
- MET > 69-170 GeV (slides up with M_H)

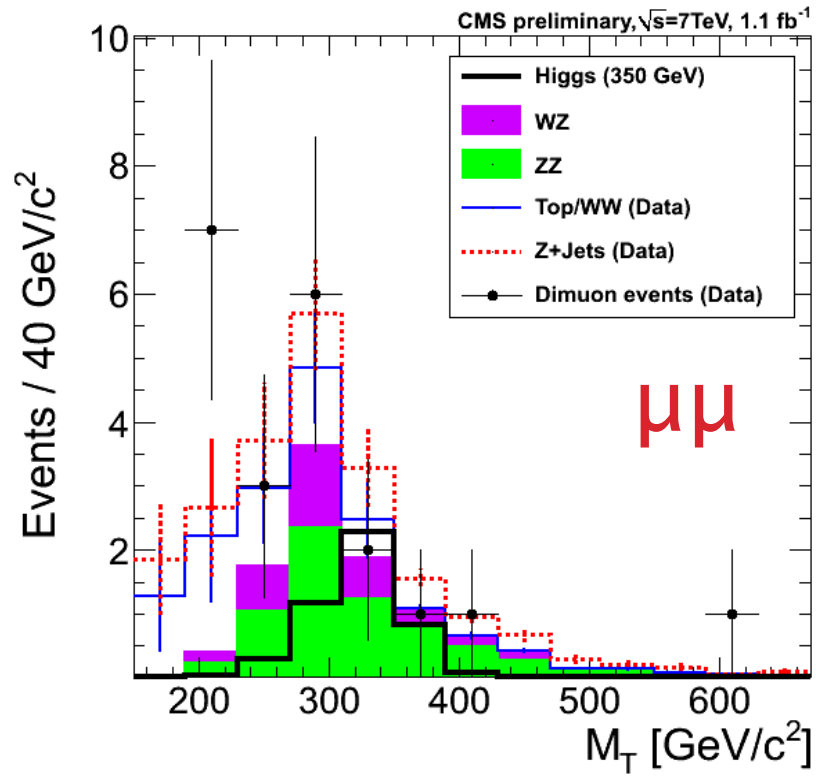




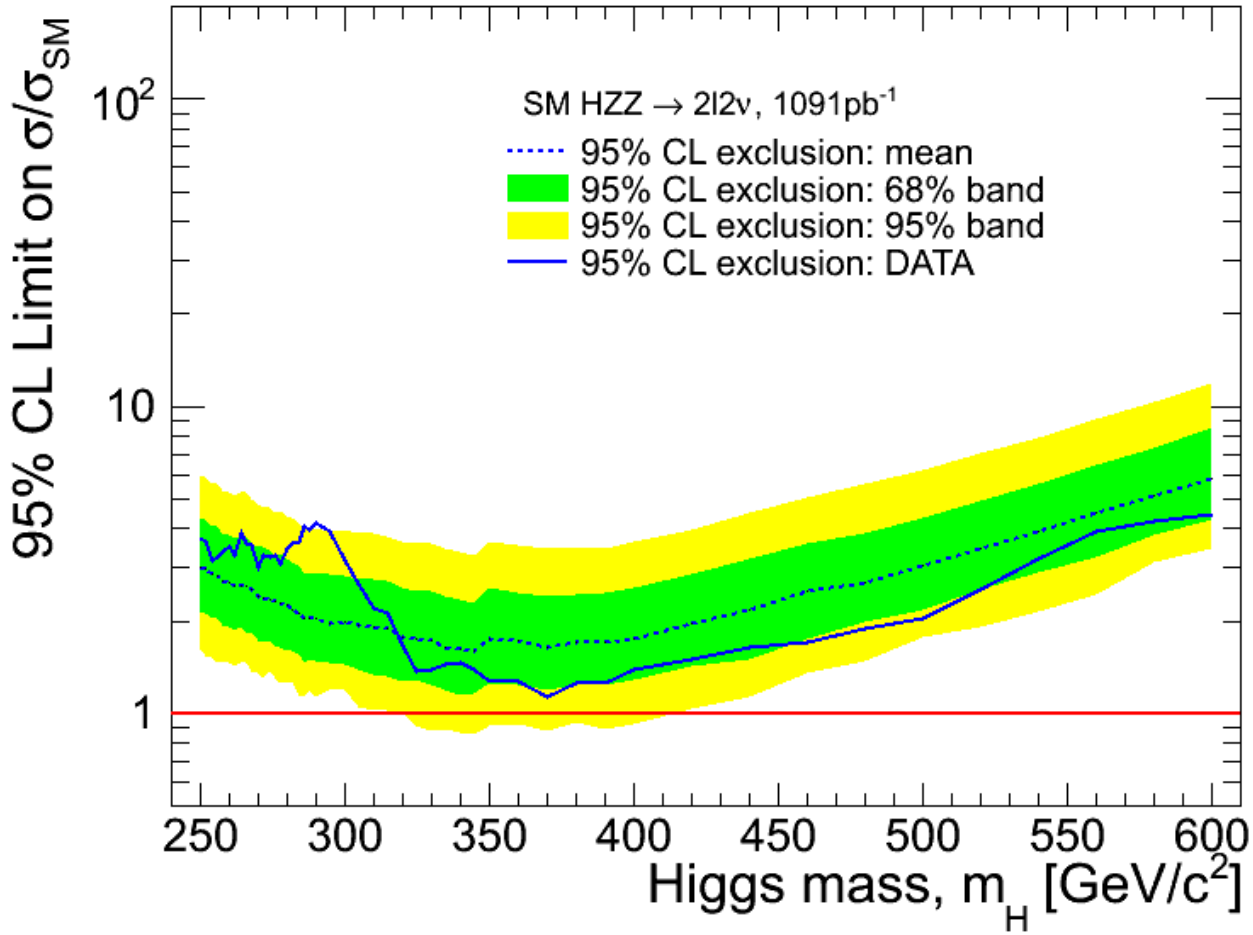
H → ZZ → 2 ℓ 2ν

- two opposite-sign leptons, $|M_{\ell\ell}-M_Z| < 15$ GeV
- MET > 69-170 GeV (slides up with M_H)
- M_T window cut (slides up with M_H)



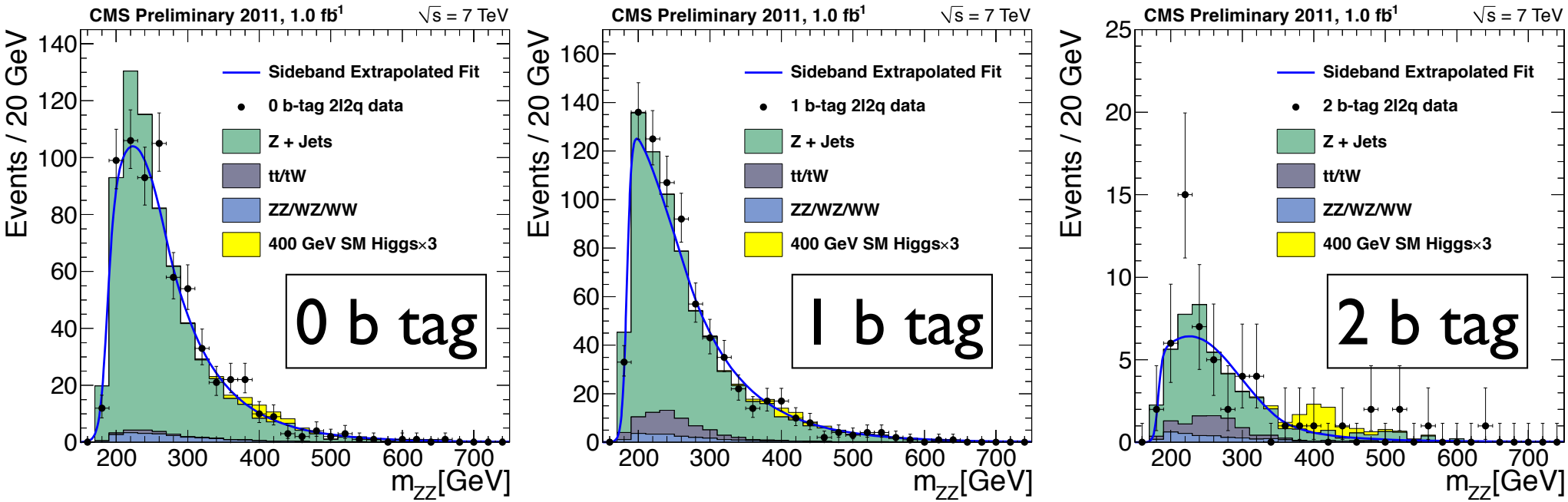


H → ZZ → 2 ℓ 2ν

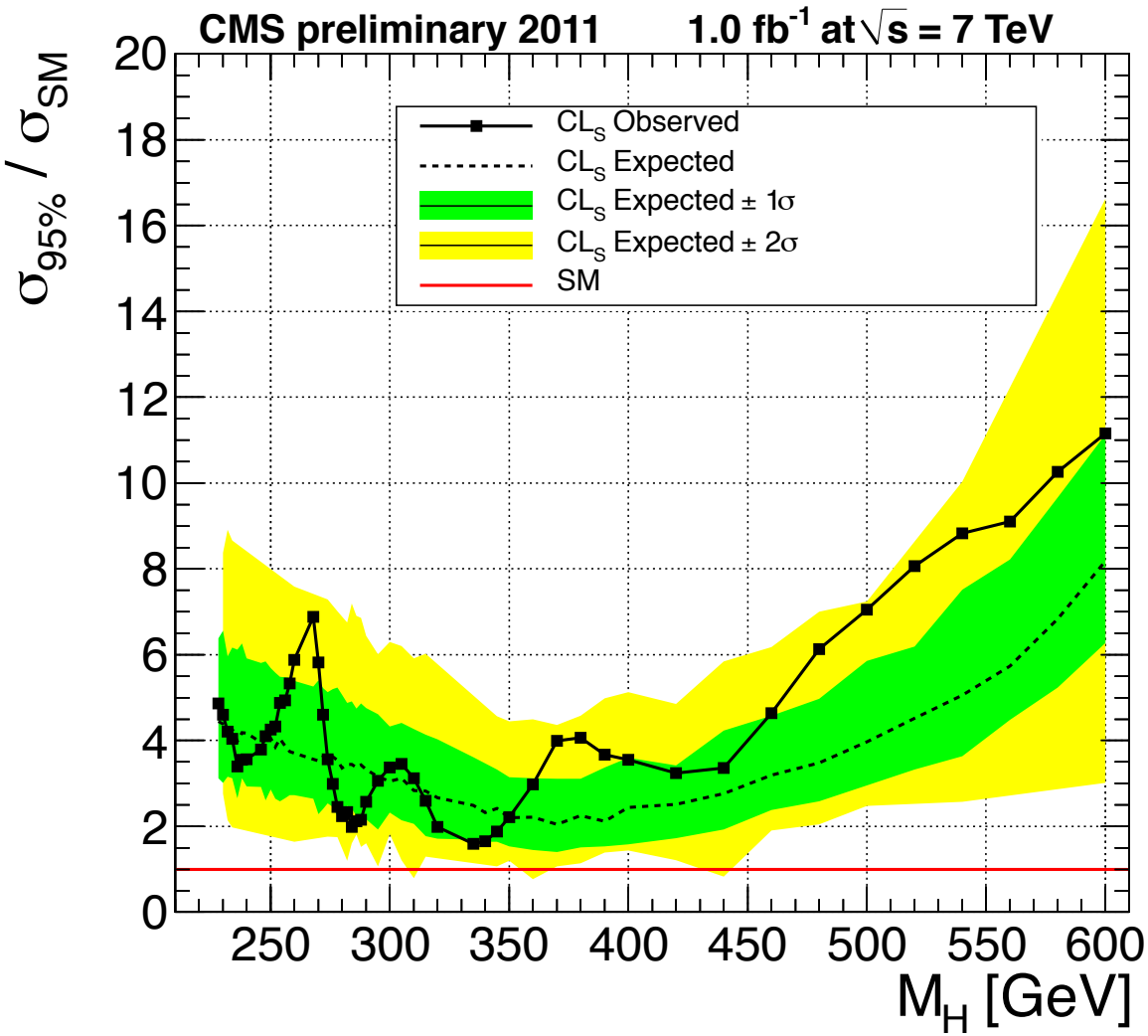

SM HZZ → 2l2ν, 1091pb^{-1}
95% CL exclusion: mean
95% CL exclusion: 68% band
95% CL exclusion: 95% band
95% CL exclusion: DATA
95% CL Limit on σ/σ_{SM}
10^2
10
1
250
300
350
400
450
500
550
600
Higgs mass, m_H [GeV/c^2]

H → ZZ → 2 ℓ 2j

- two opposite-sign leptons $70 < M_{\ell\ell} < 110$ GeV
- two jets $75 < M_{jj} < 105$ GeV
- $M_{ZZ} \in [183,800]$ GeV

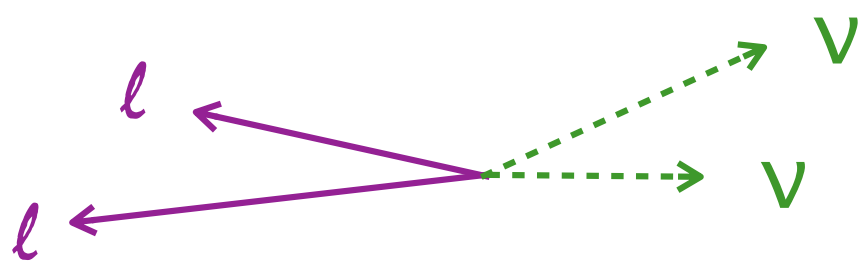


H → ZZ → 2 ℓ 2j


CMS preliminary 2011
1.0 fb^{-1} at $\sqrt{s}$ = 7 TeV
$\sigma_{95\%} / \sigma_{SM}$
CL_S Observed
CL_S Expected
CL_S Expected ± 1σ
CL_S Expected ± 2σ
SM
0
2
4
6
8
10
12
14
16
18
20
250
300
350
400
450
500
550
600
M_H [GeV]

- in H → WW decays the W spins are anti-aligned:

- in the decays of both W's to ℓν, the leptons tend to come out in the same direction



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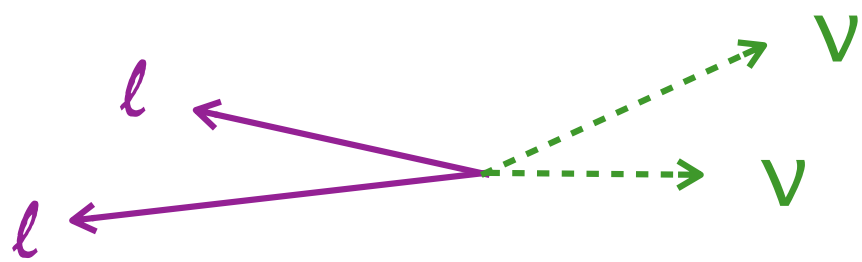
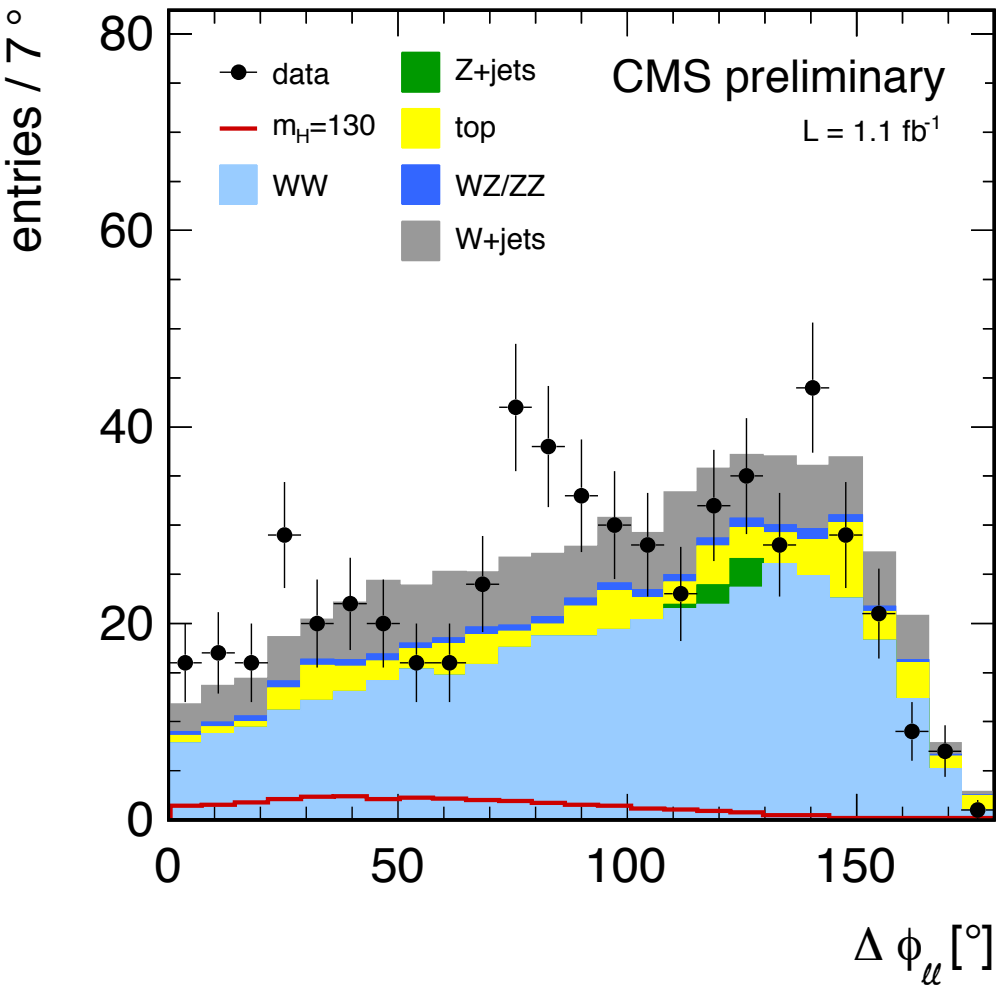
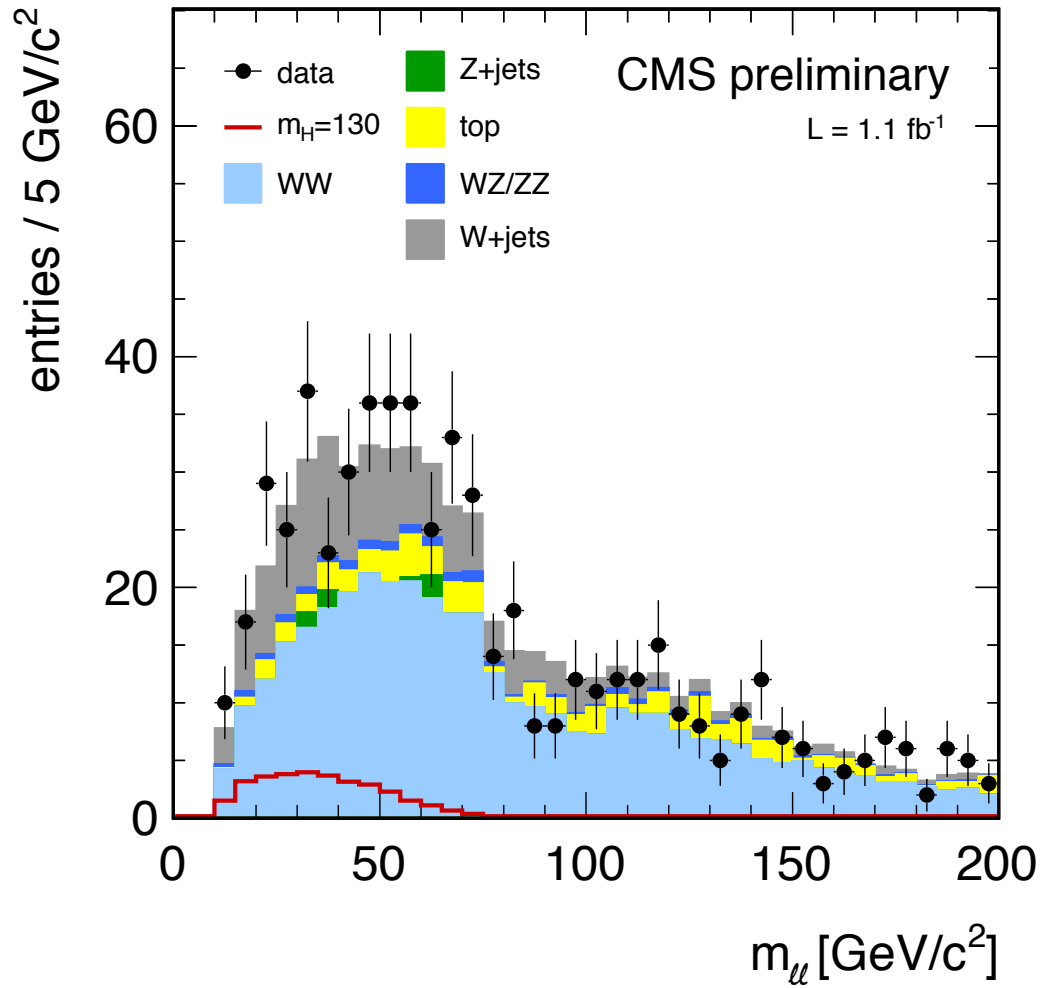


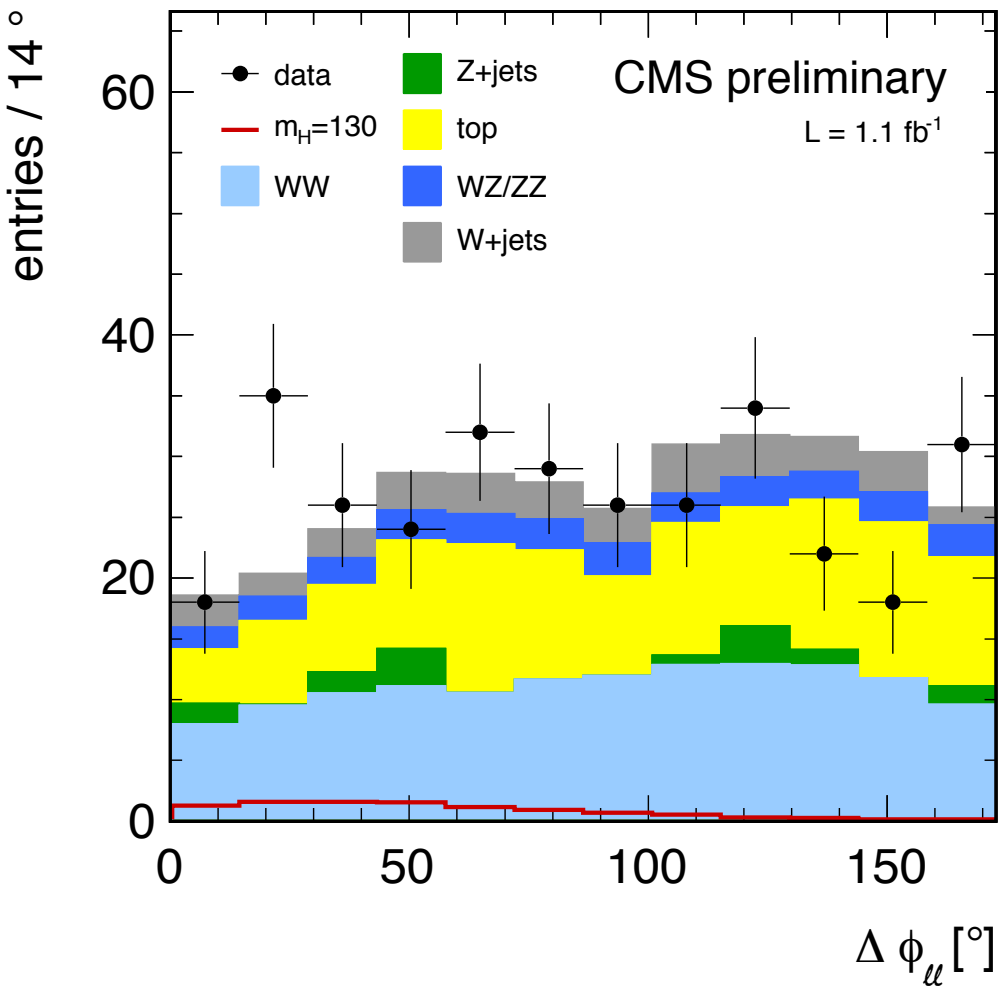
- use this and other kinematic variables in BDT

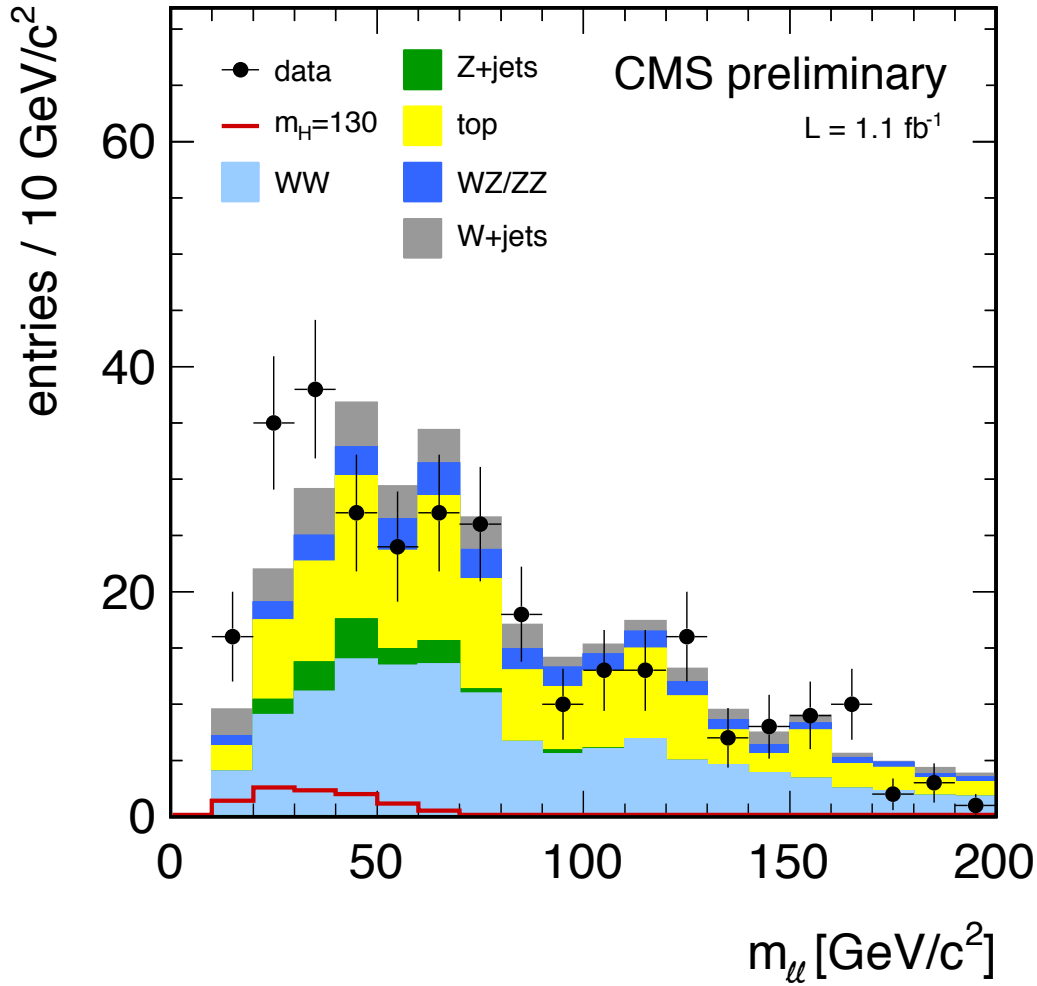
WW + 0 jets category



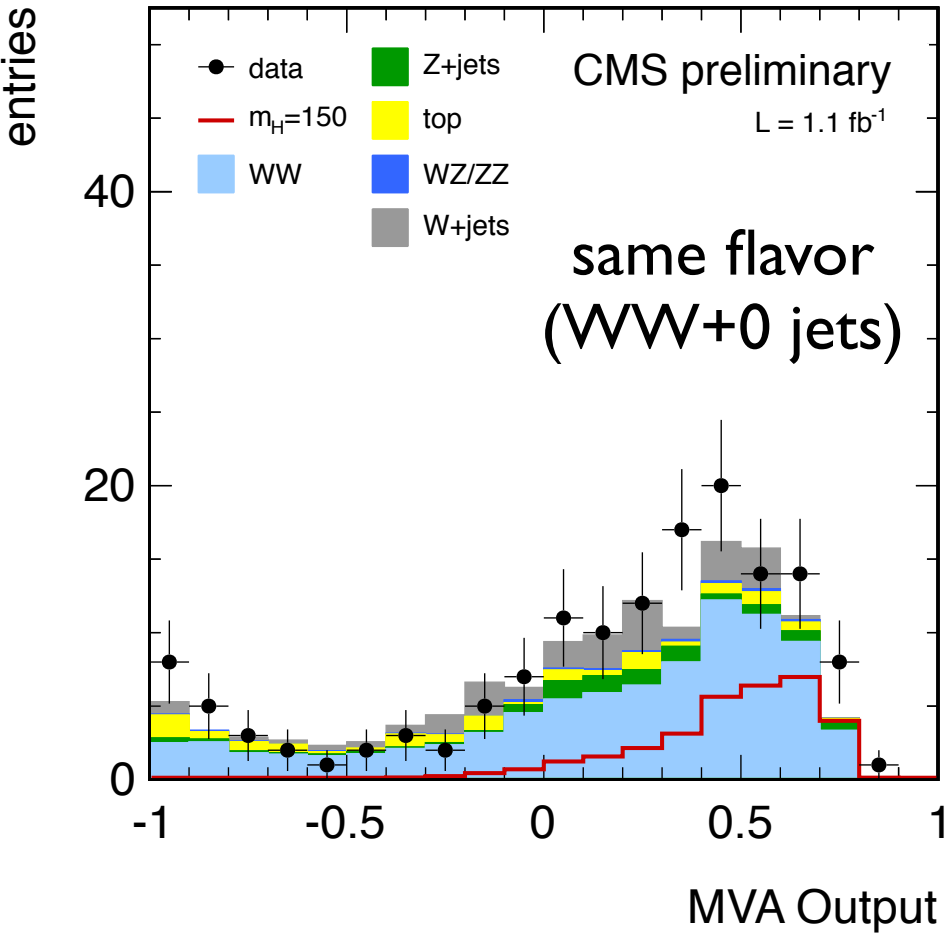


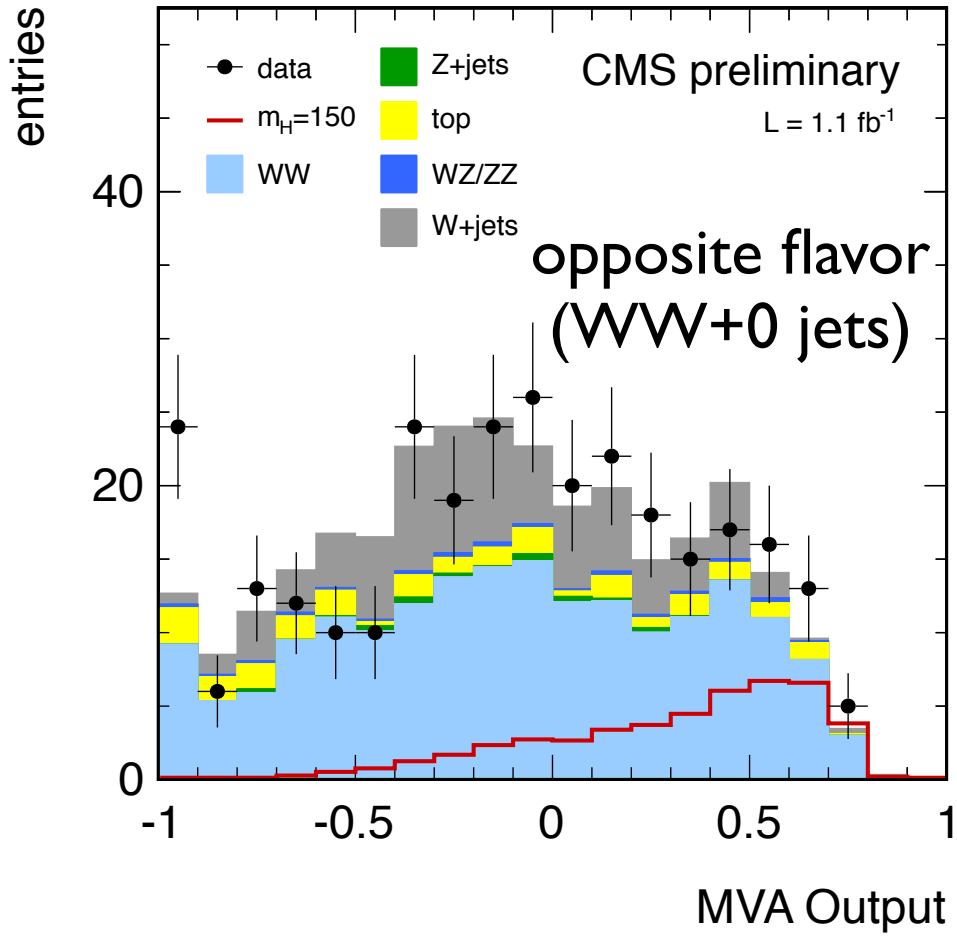
WW + 1 jets category





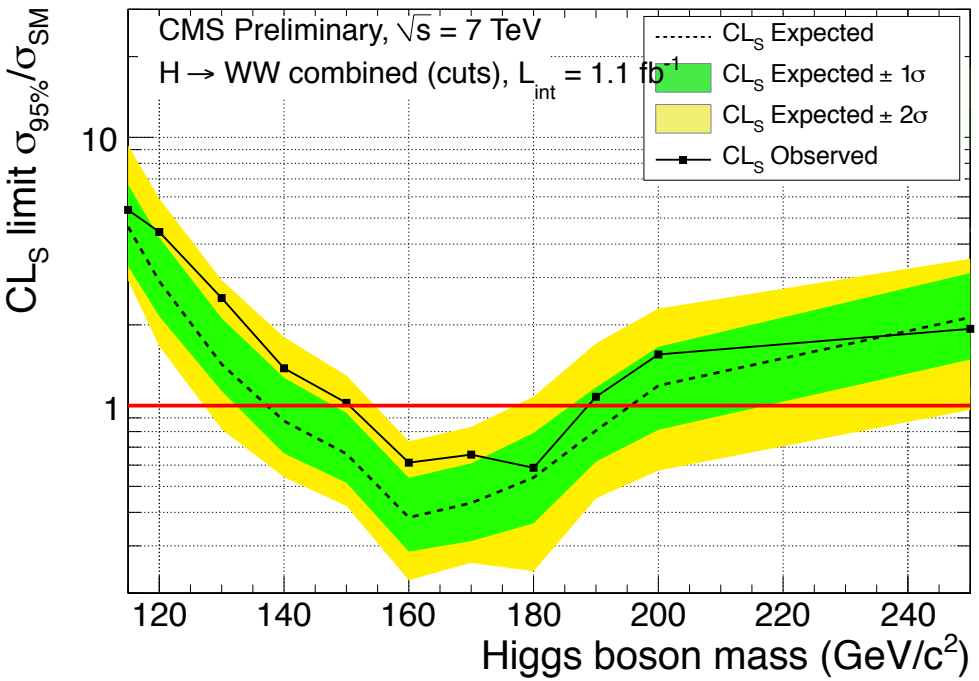
also split into same-flavor and opposite-flavor:



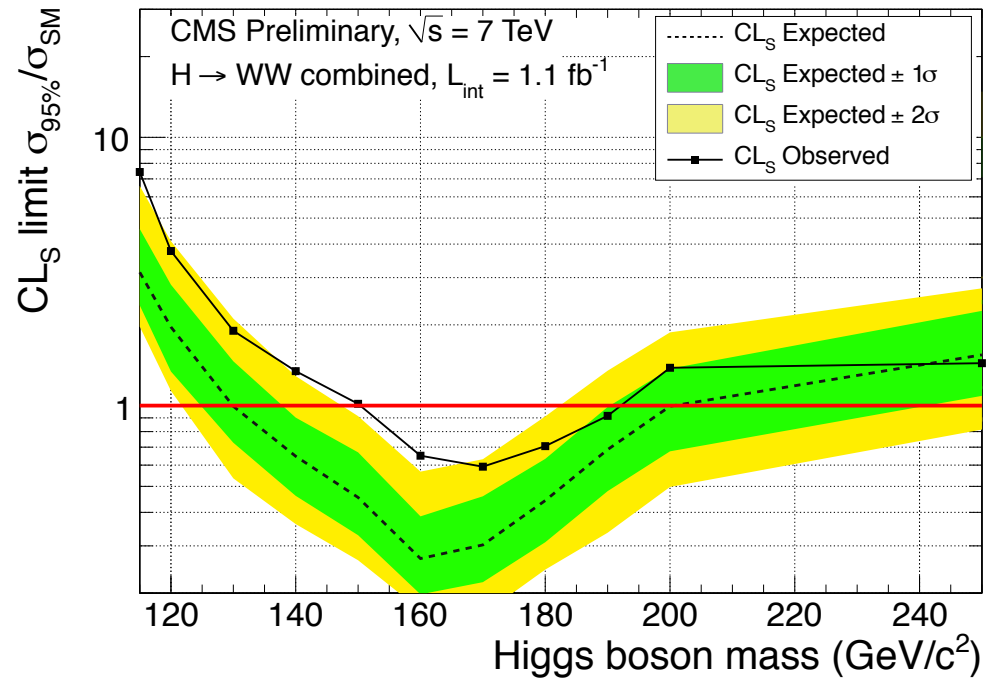


also include WW + 2 jets channel...

cut based



BDT based

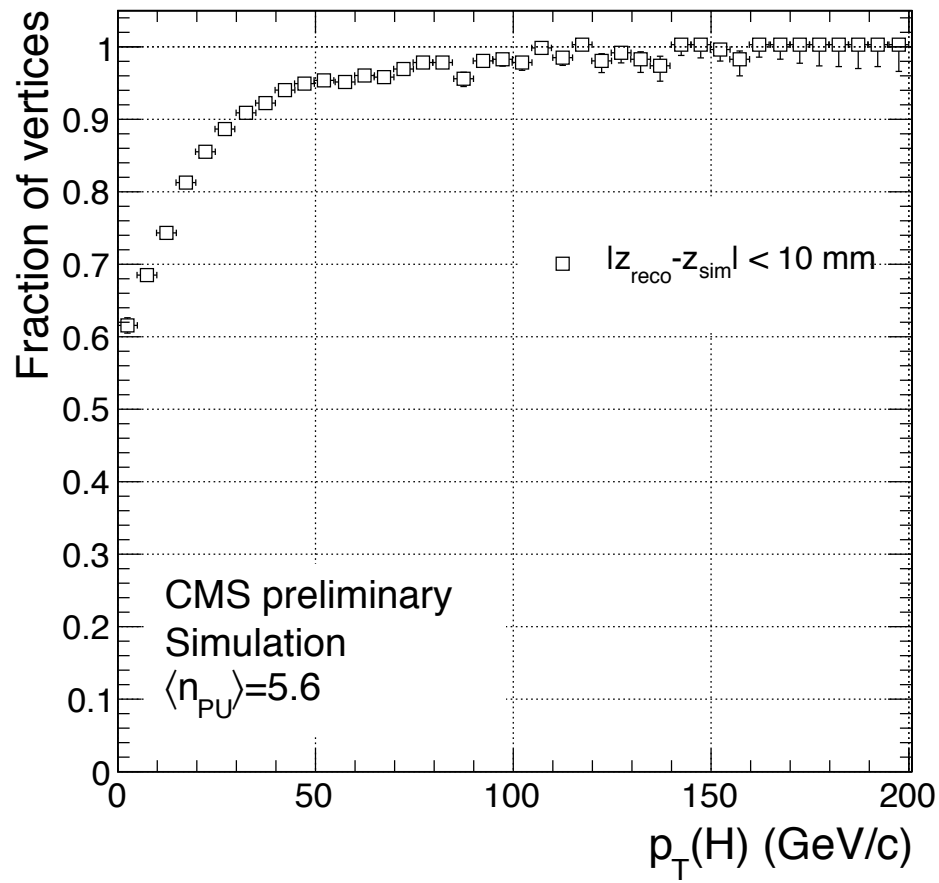


Exclude SM Higgs in range $150 < M_H < 193$ GeV

"Interesting" excess in low mass range!

H → γγ

- e.m. calorimeter designed with this mode in mind!
- γγ resolution: 2.4 GeV

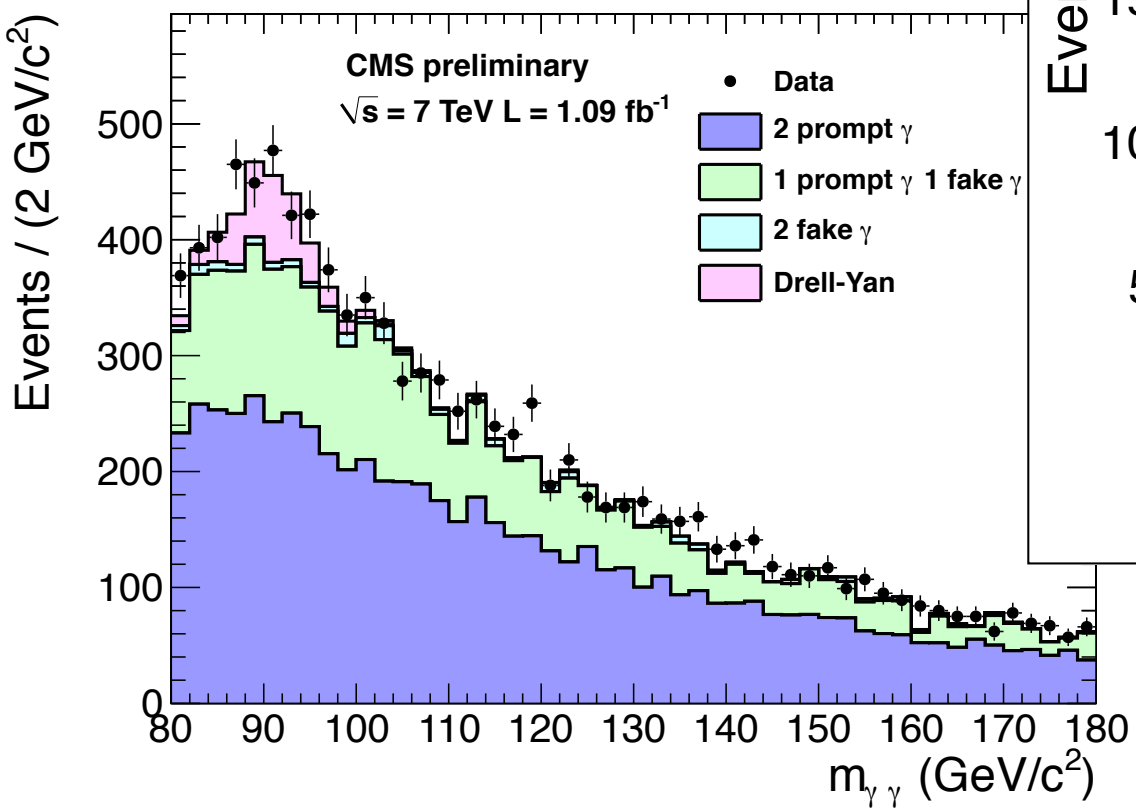


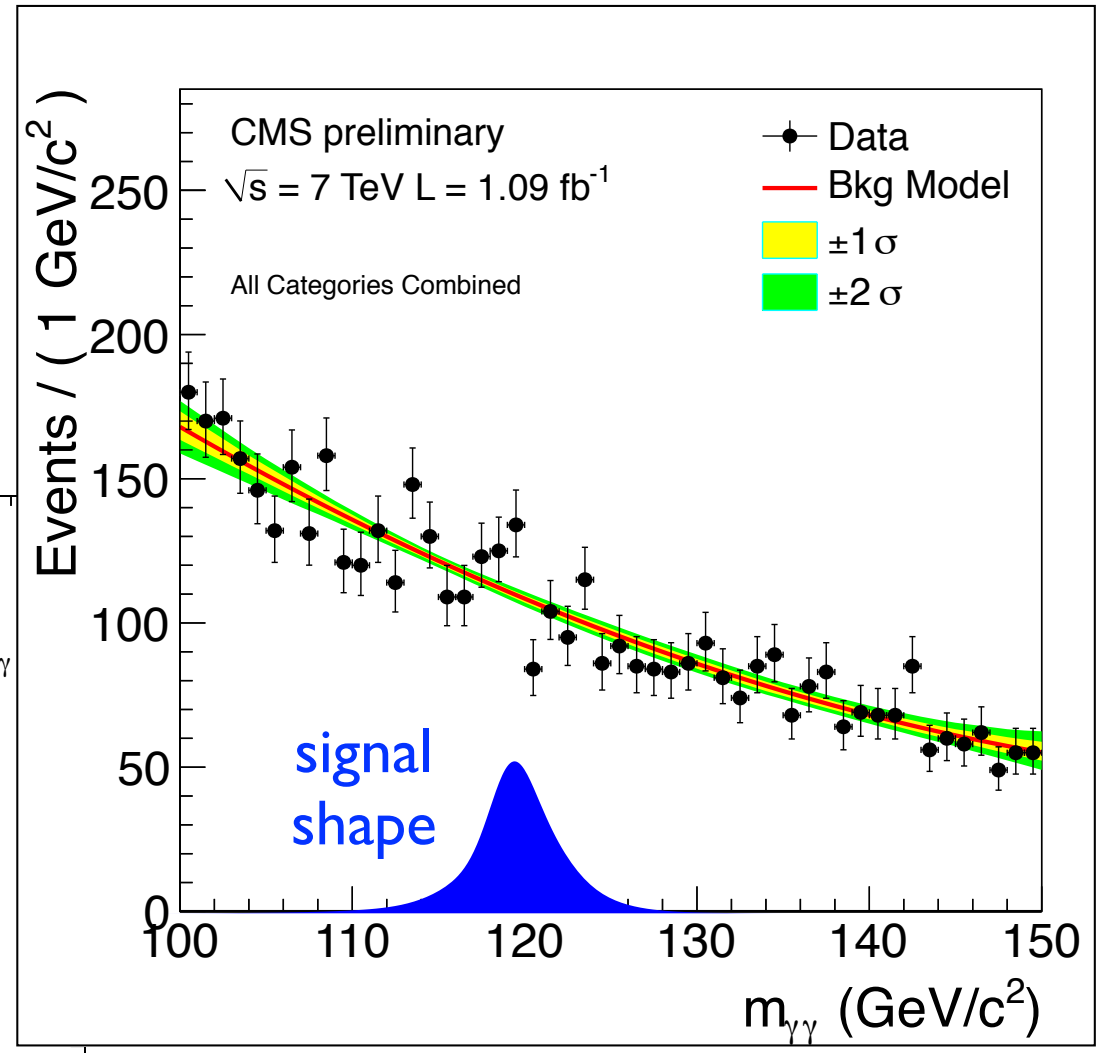
<u>event selection</u>

- two photons with at least 40, 30 GeV p_T
- choose vertex based on PV tracks or conversions

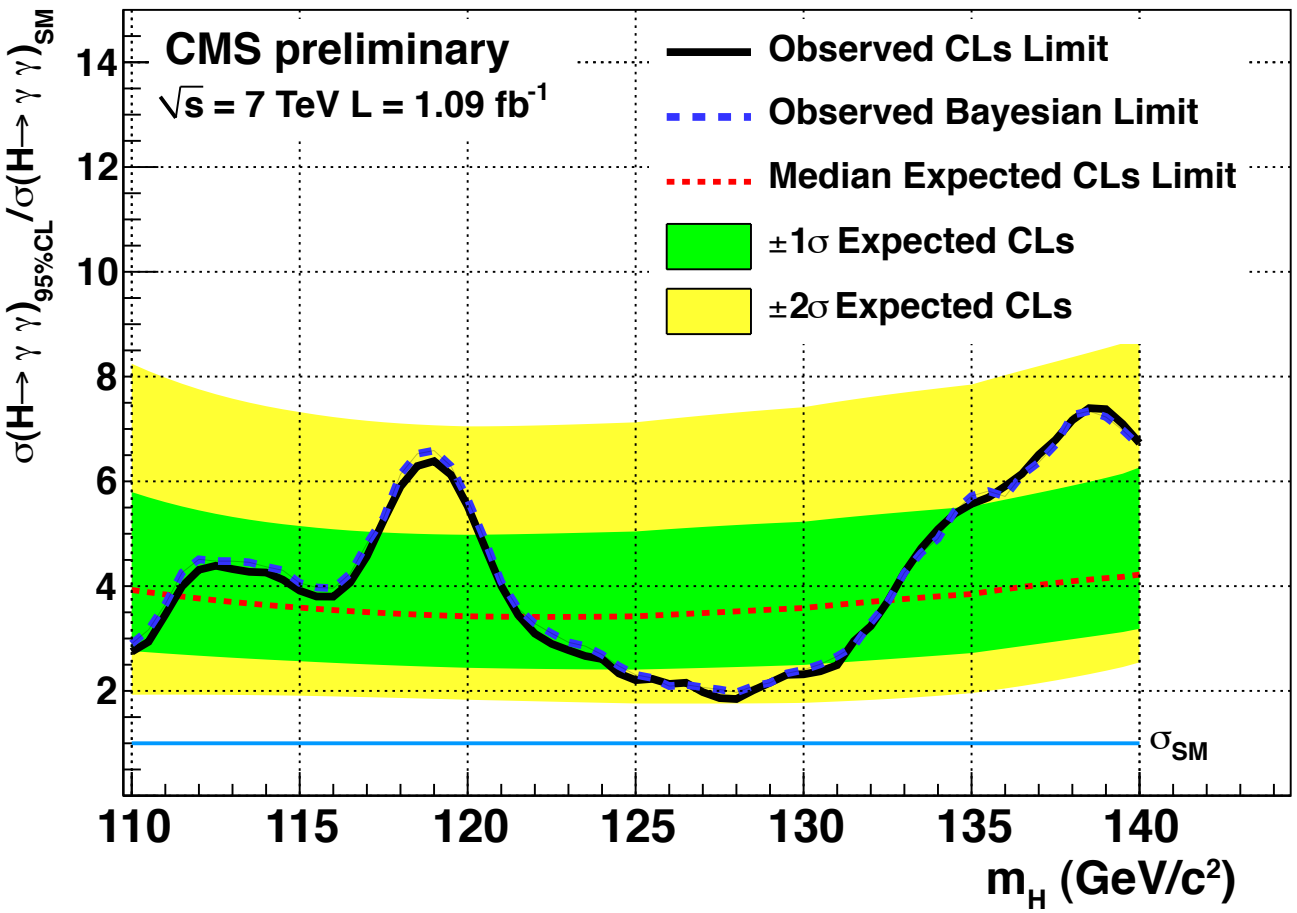
- 8 classes: barrel/endcap ⊗ $p_T^{\gamma\gamma}$ > 40 GeV ⊗ iso (R_9)

mass spectrum showing background sources





zoomed in, compared with background fit



expected limit at ~4x SM

Main focus of H → ττ: MSSM Higgs at large tanβ

Can exploit VBF production of SM Higgs by requiring two forward "tagging" jets in addition to tau decay channels (eτ, μτ, eμ, μμ)

$e^- \nu\nu$	17.8%
$\mu^- \nu\nu$	17.4%
$h^- \nu$	49%
$\pi^- \nu$	11%
$K^- \nu$	0.7%
$\rho^- \nu$	25.4%
$h^+h^-h^-\nu$	15%

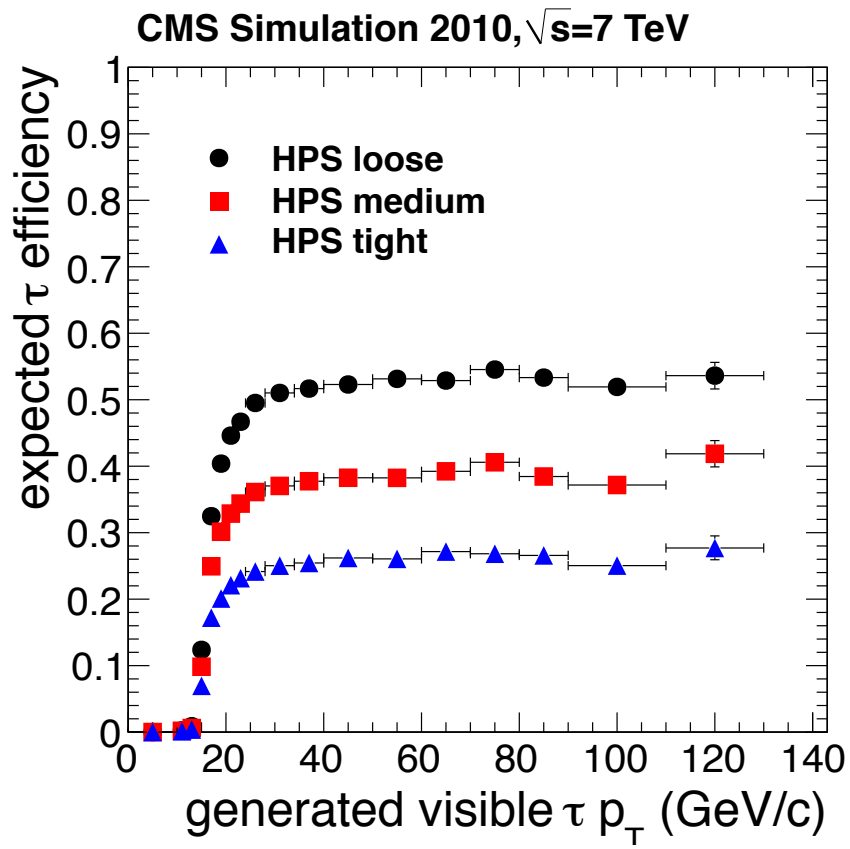
Tau ID classes:

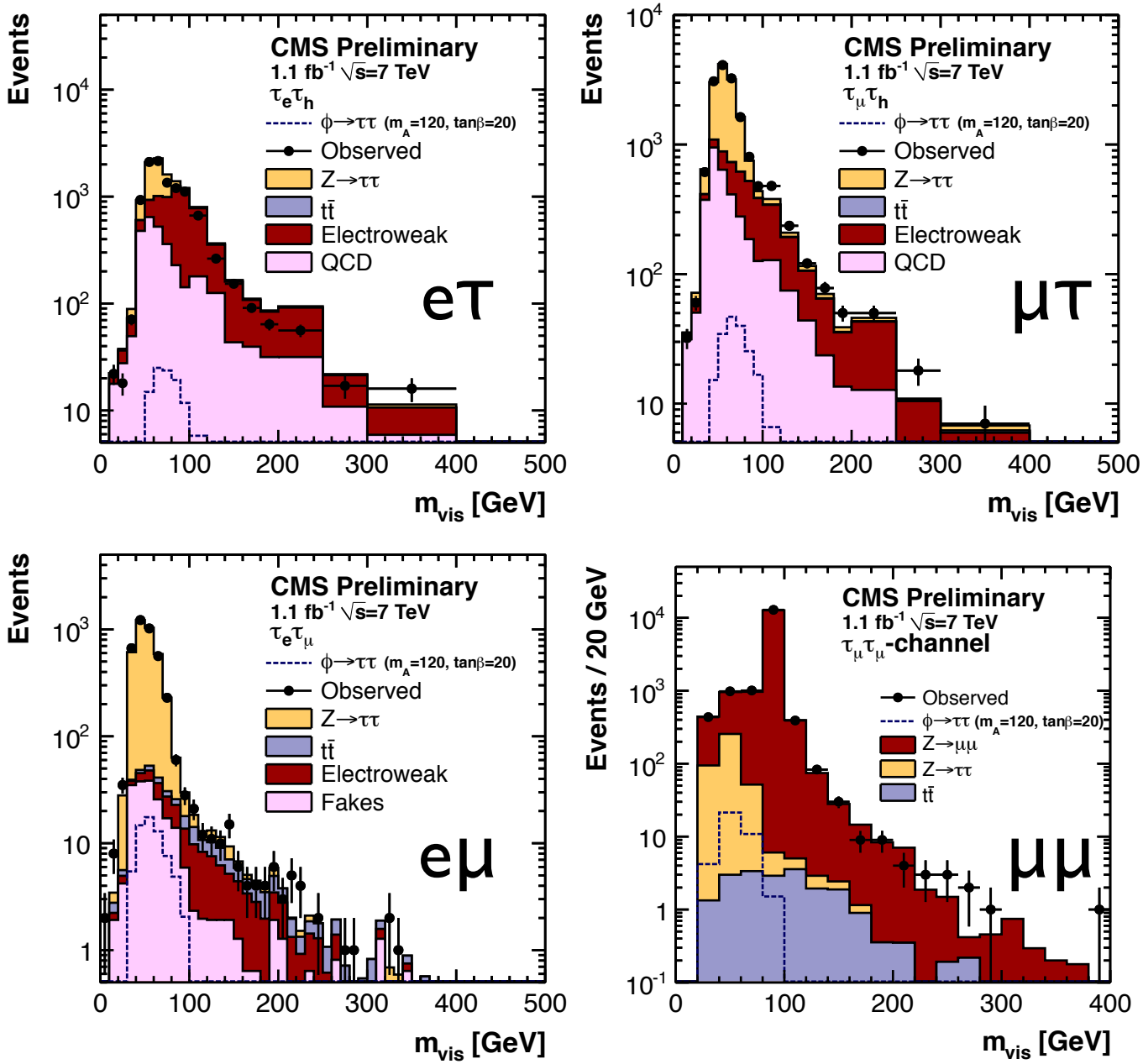
$\pi^\pm/K^\pm$

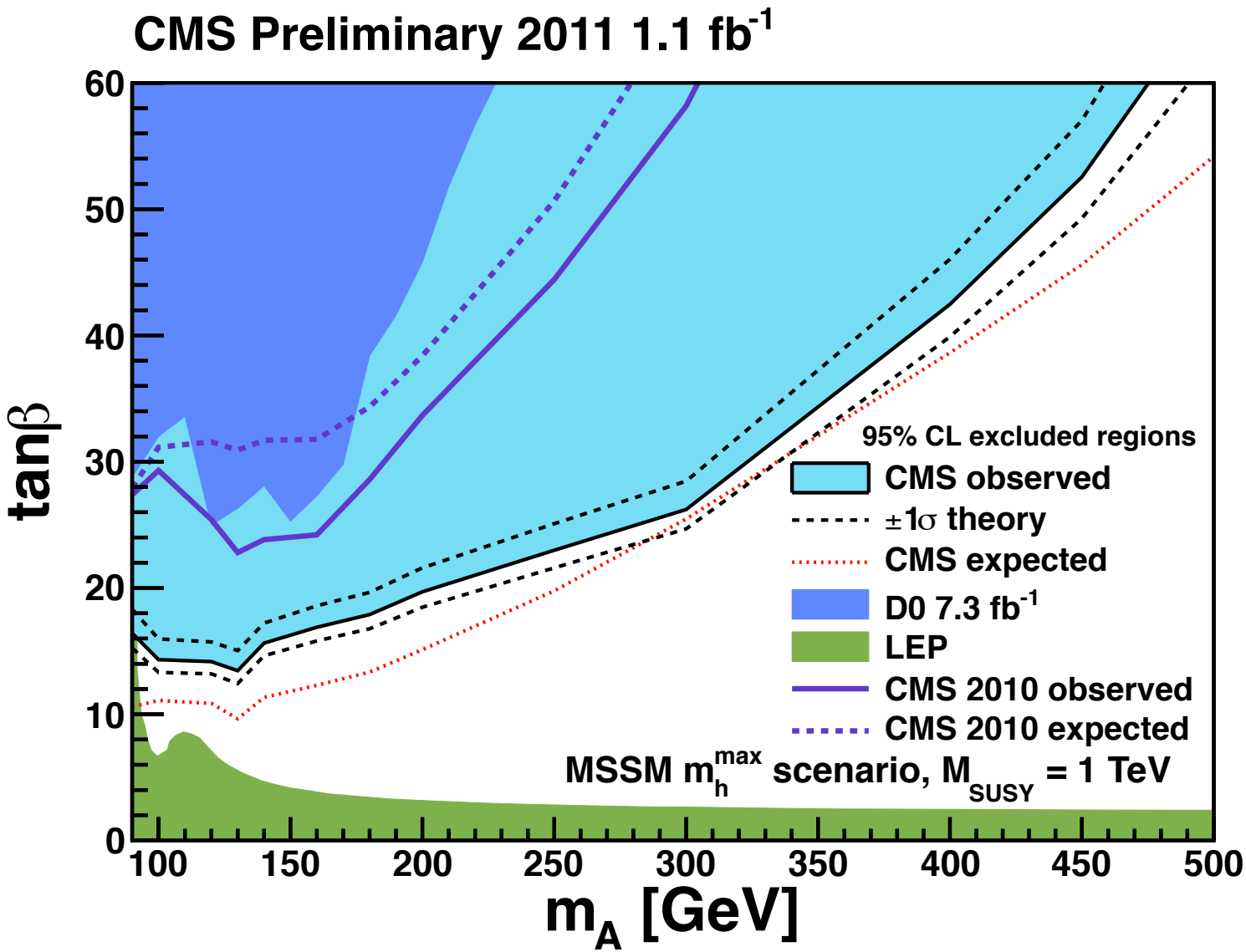
$\pi^\pm\ \pi^0$

$\pi^\pm\ \pi^0\ \pi^0$ ...

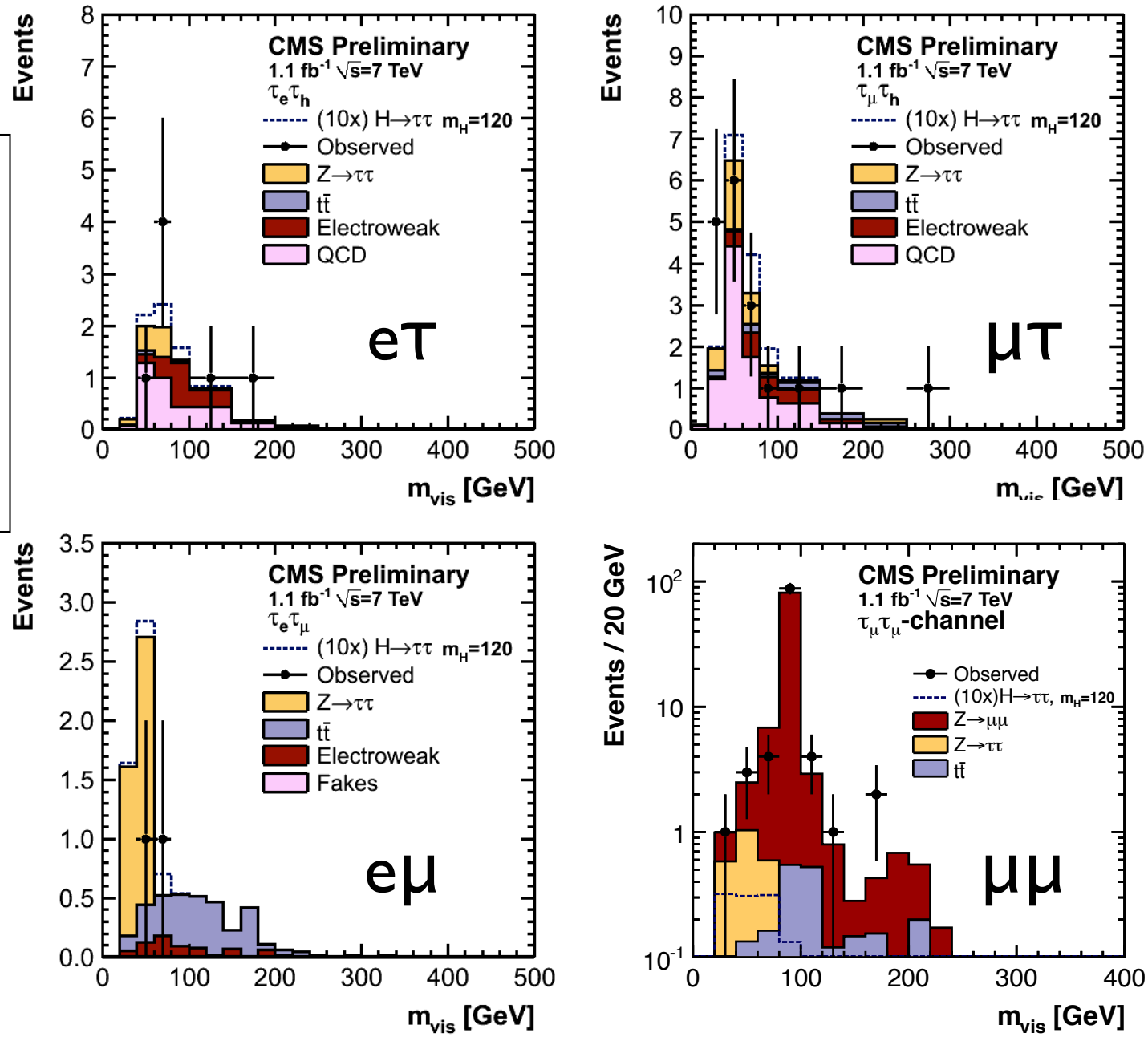
$\pi^+\ \pi^-\ \pi^\pm$

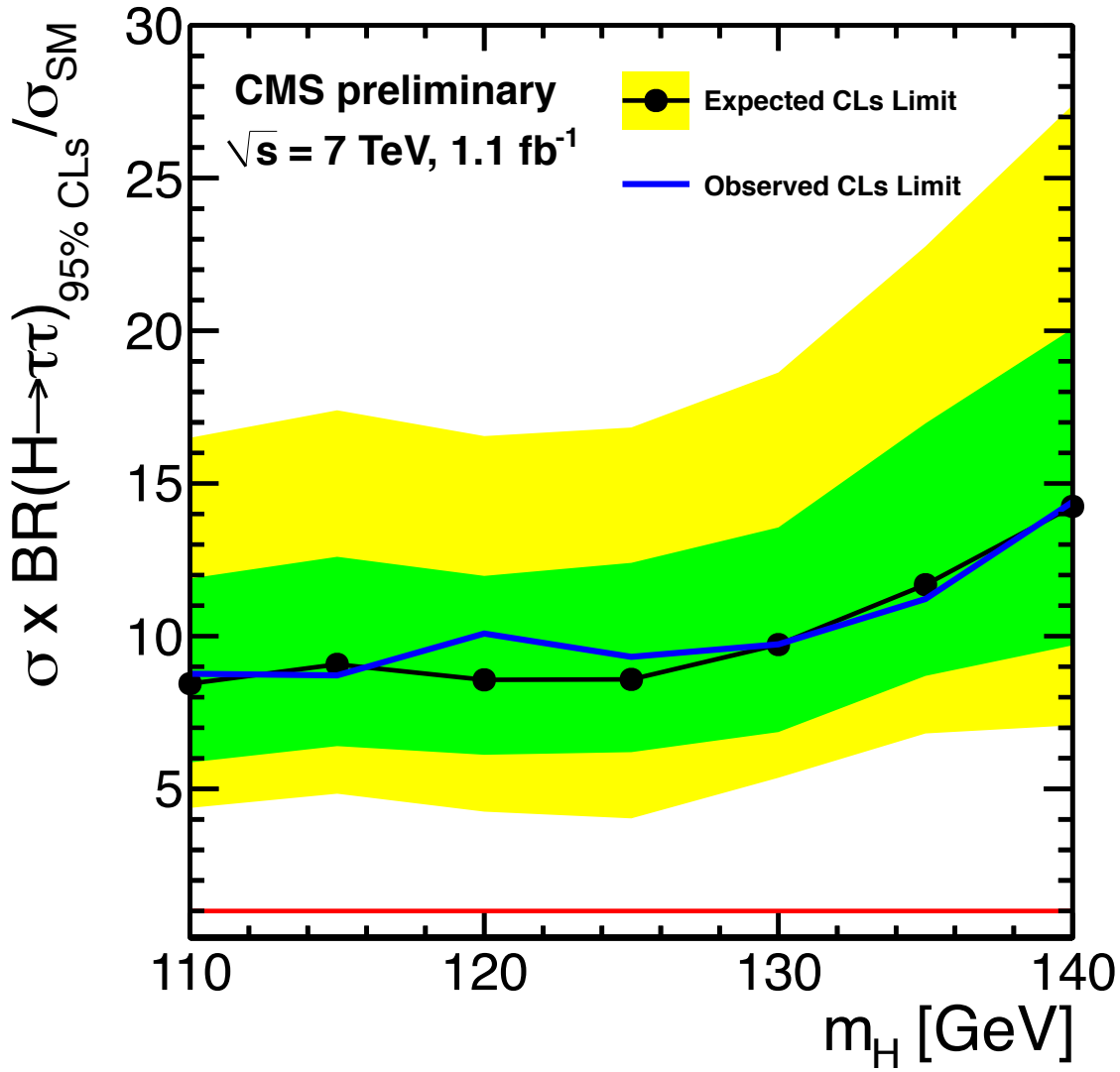



CMS Preliminary
1.1 fb^{-1} $\sqrt{s}$=7 TeV
$\tau_e\tau_h$
$\phi\to\tau\tau$ (m_A=120, tanβ=20)
Observed
$Z\to\tau\tau$
$t\bar{t}$
Electroweak
QCD
eτ
Events
m_{vis} [GeV]
CMS Preliminary
1.1 fb^{-1} $\sqrt{s}$=7 TeV
$\tau_\mu\tau_h$
$\phi\to\tau\tau$ (m_A=120, tanβ=20)
Observed
$Z\to\tau\tau$
$t\bar{t}$
Electroweak
QCD
μτ
Events
m_{vis} [GeV]
CMS Preliminary
1.1 fb^{-1} $\sqrt{s}$=7 TeV
$\tau_e\tau_\mu$
$\phi\to\tau\tau$ (m_A=120, tanβ=20)
Observed
$Z\to\tau\tau$
$t\bar{t}$
Electroweak
Fakes
eμ
Events
m_{vis} [GeV]
CMS Preliminary
1.1 fb^{-1} $\sqrt{s}$=7 TeV
$\tau_\mu\tau_\mu$-channel
Observed
$\phi\to\tau\tau$ (m_A=120, tanβ=20)
$Z\to\mu\mu$
$Z\to\tau\tau$
$t\bar{t}$
μμ
Events / 20 GeV
m_{vis} [GeV]

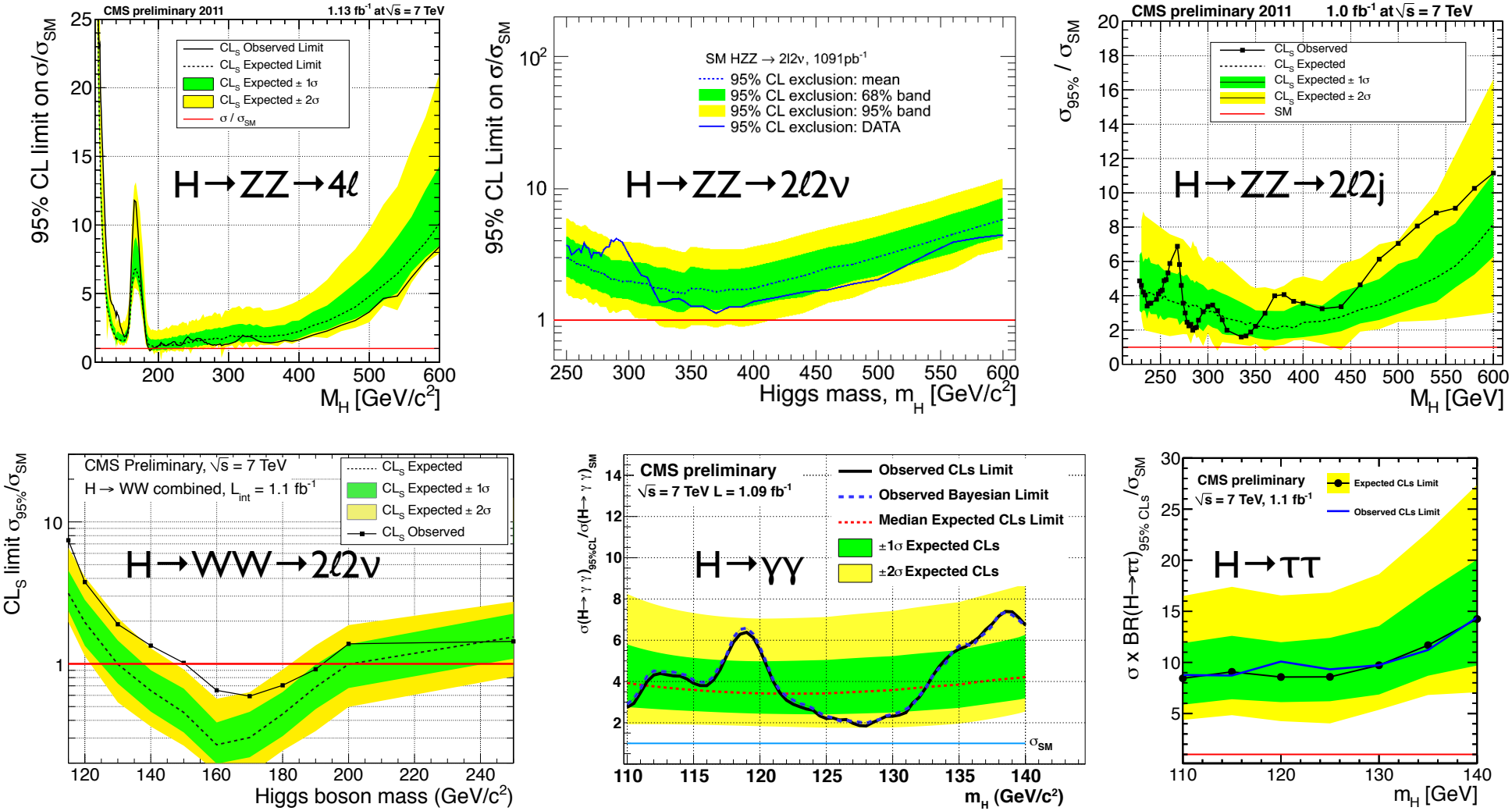

CMS Preliminary 2011 1.1 fb-1
tanβ
m_A [GeV]
95% CL excluded regions
CMS observed
±1σ theory
CMS expected
D0 7.3 fb-1
LEP
CMS 2010 observed
CMS 2010 expected
MSSM m_h^max scenario, M_SUSY = 1 TeV

Here we require two forward jets, tagging the vector boson fusion process





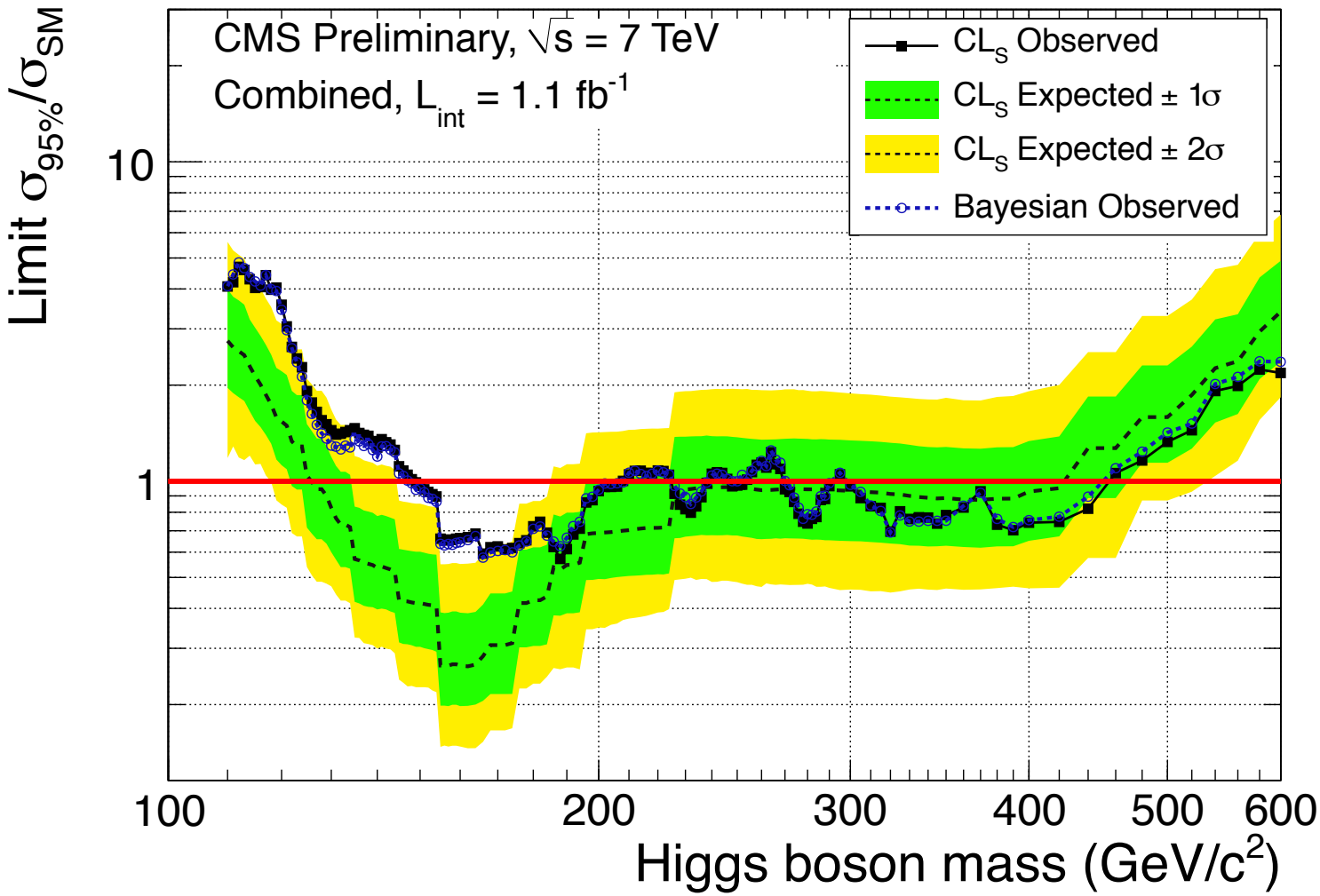
expected limit at ~9x SM



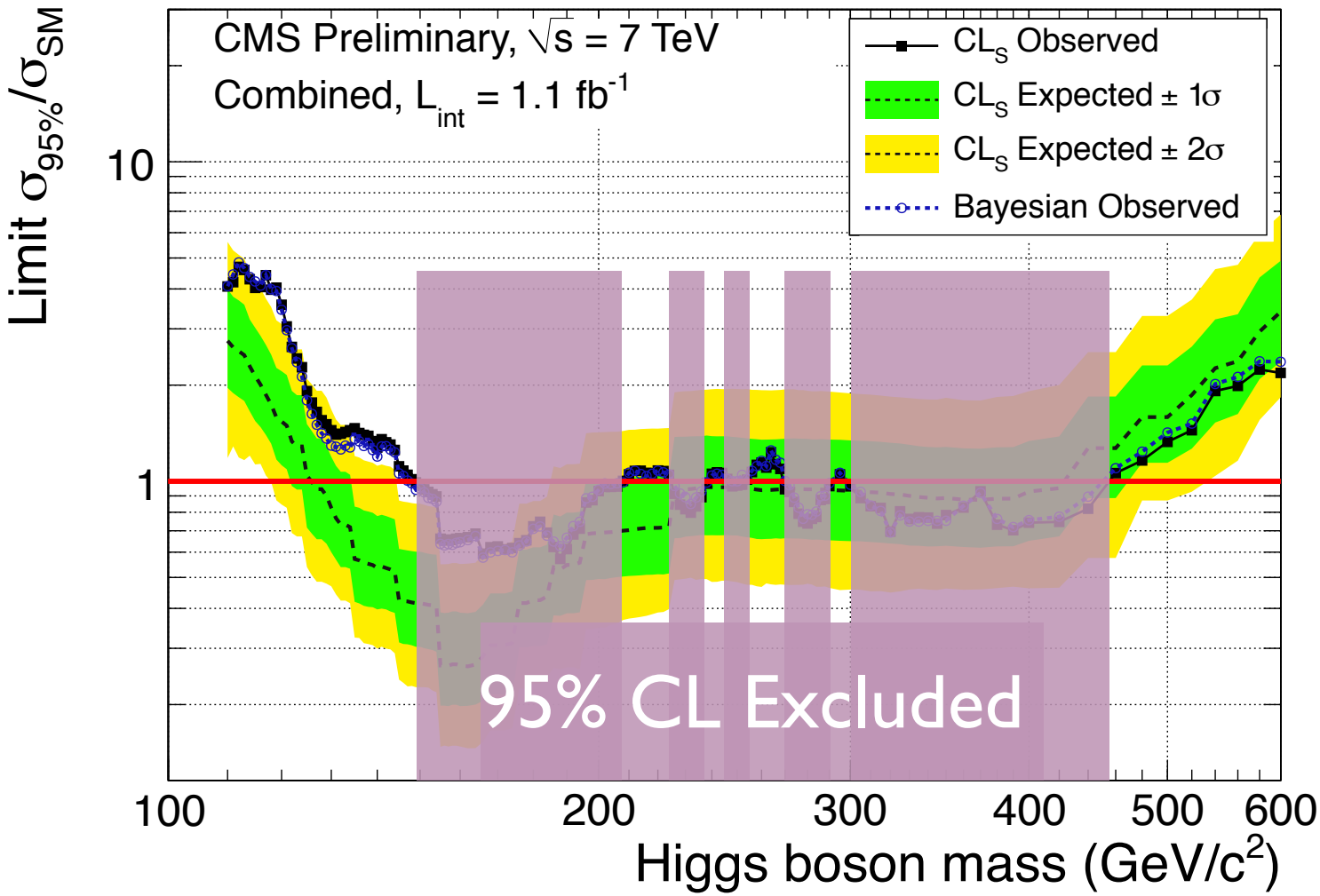
Goal: combine results of all six search channels

- form joint likelihood from all channels
- include correlated and uncorrelated systematic uncertainties represented by nuisance parameters
- use CL_s method to quote final limits
- (agrees very well with Bayesian)

channel	mass range (GeV/c^2)	luminosity (fb^{-1})	number of sub-channels	type of analysis	number of nuisances
$H \to \gamma\gamma$	110-140	1.1	8	mass shape (unbinned)	3+40=43
$H \to \tau\tau$	110-140	1.1	6	mass shape (binned)	10+21=31
$H \to WW \to 2\ell 2\nu$	110-600	1.1	5	MVA (binned); cut&count	16+36=52
$H \to ZZ \to 4\ell$	110-600	1.1	3	mass shape (unbinned)	14+8=22
$H \to ZZ \to 2\ell 2\nu$	250-600	1.1	2	cut&count	14+4=18
$H \to ZZ \to 2\ell 2q$	226-600	1.0	6	mass shape (unbinned)	13+10=23
TOTAL (6)	**110-600**	**1.0-1.1**	**30**		**24+119=143**



These are the first CMS results to exclude a SM Higgs boson!



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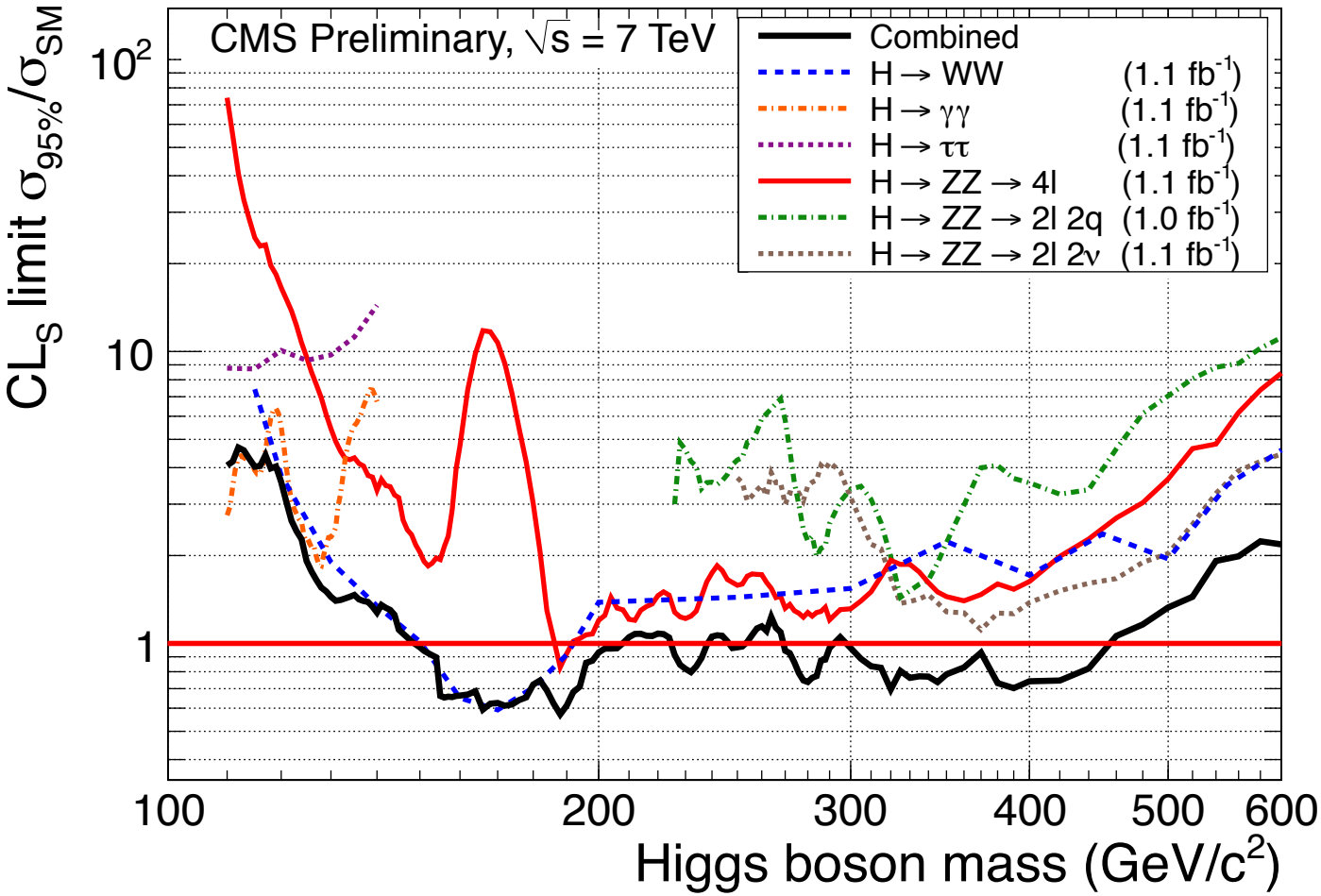

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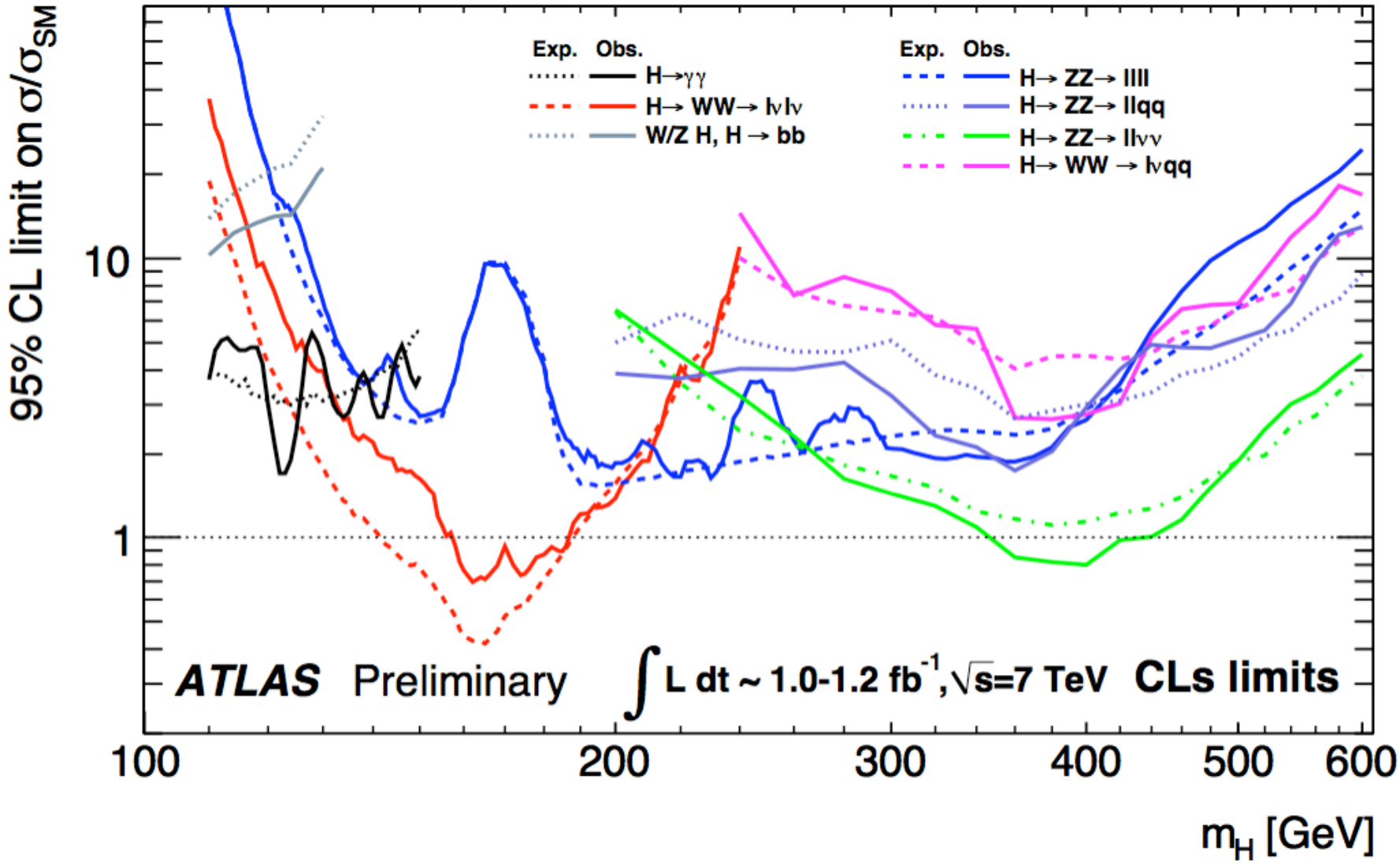
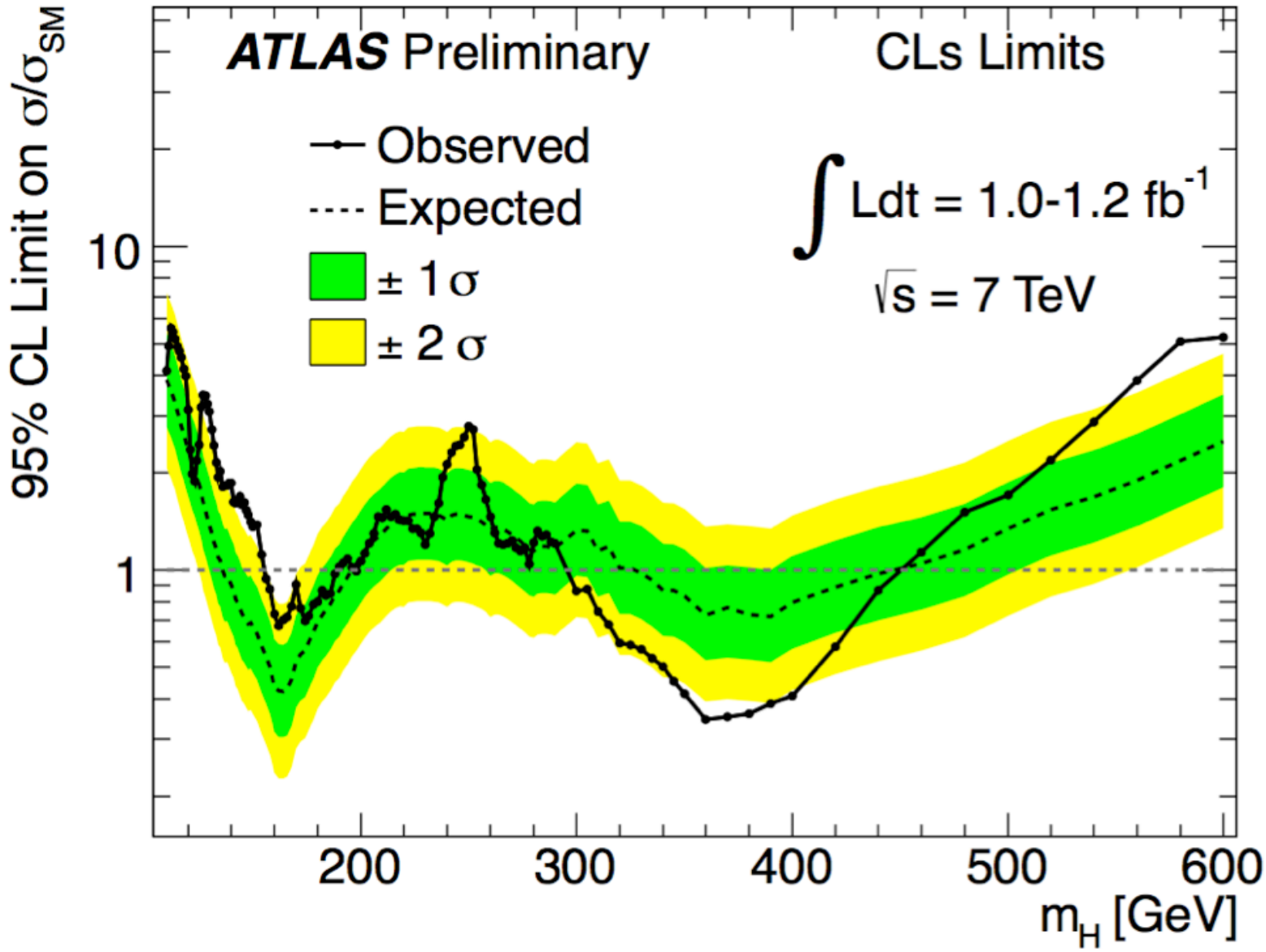
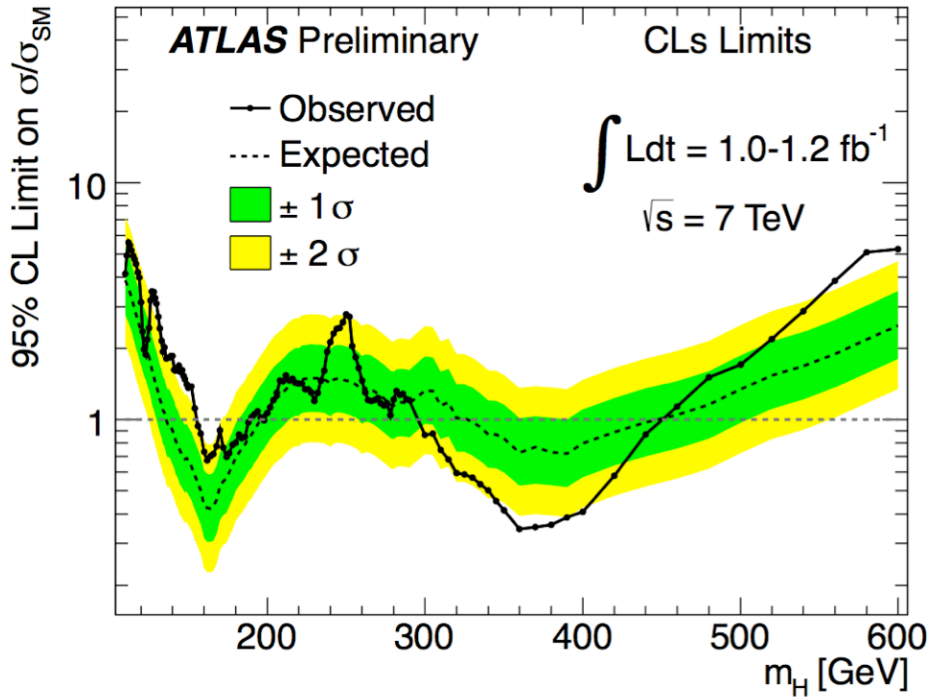
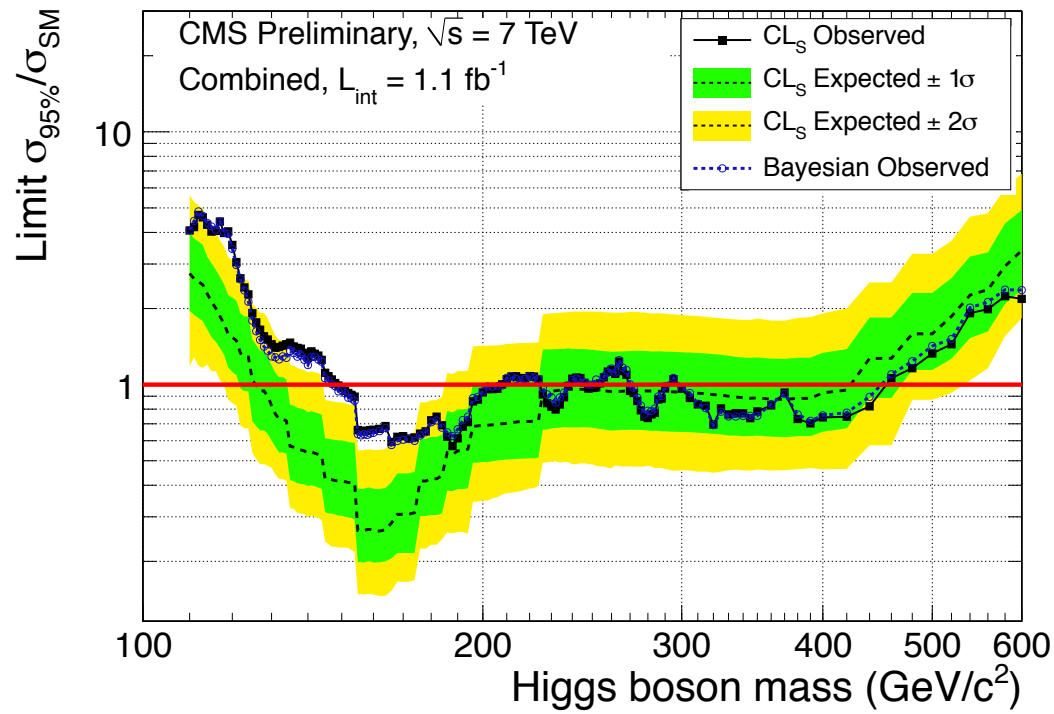
ATLAS - various channel results:

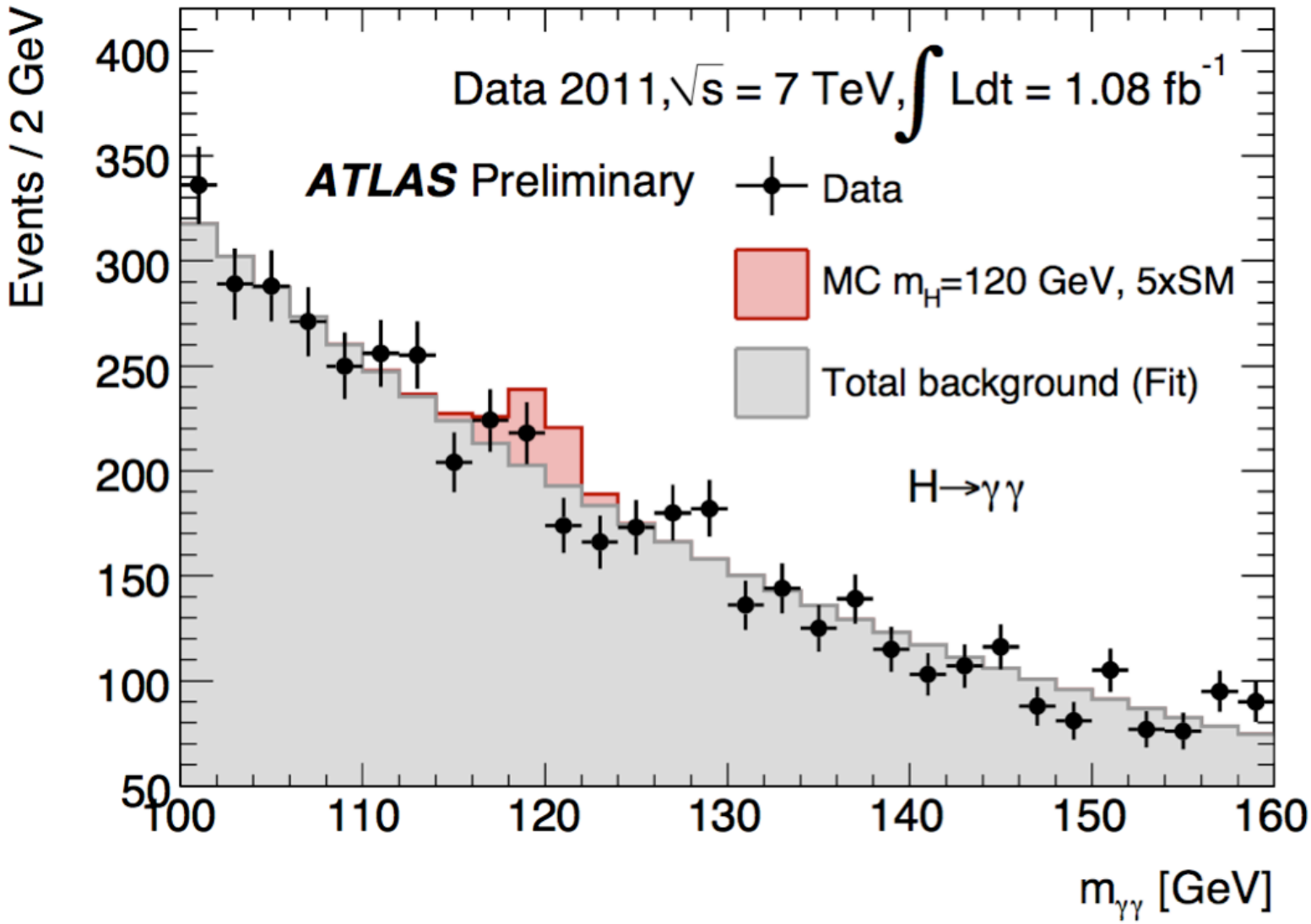



ATLAS Preliminary
CLs Limits
Observed
Expected
± 1 σ
± 2 σ
∫ Ldt = 1.0-1.2 fb-1
√s = 7 TeV
95% CL Limit on σ/σSM
10
1
200
300
400
500
600
mH [GeV]

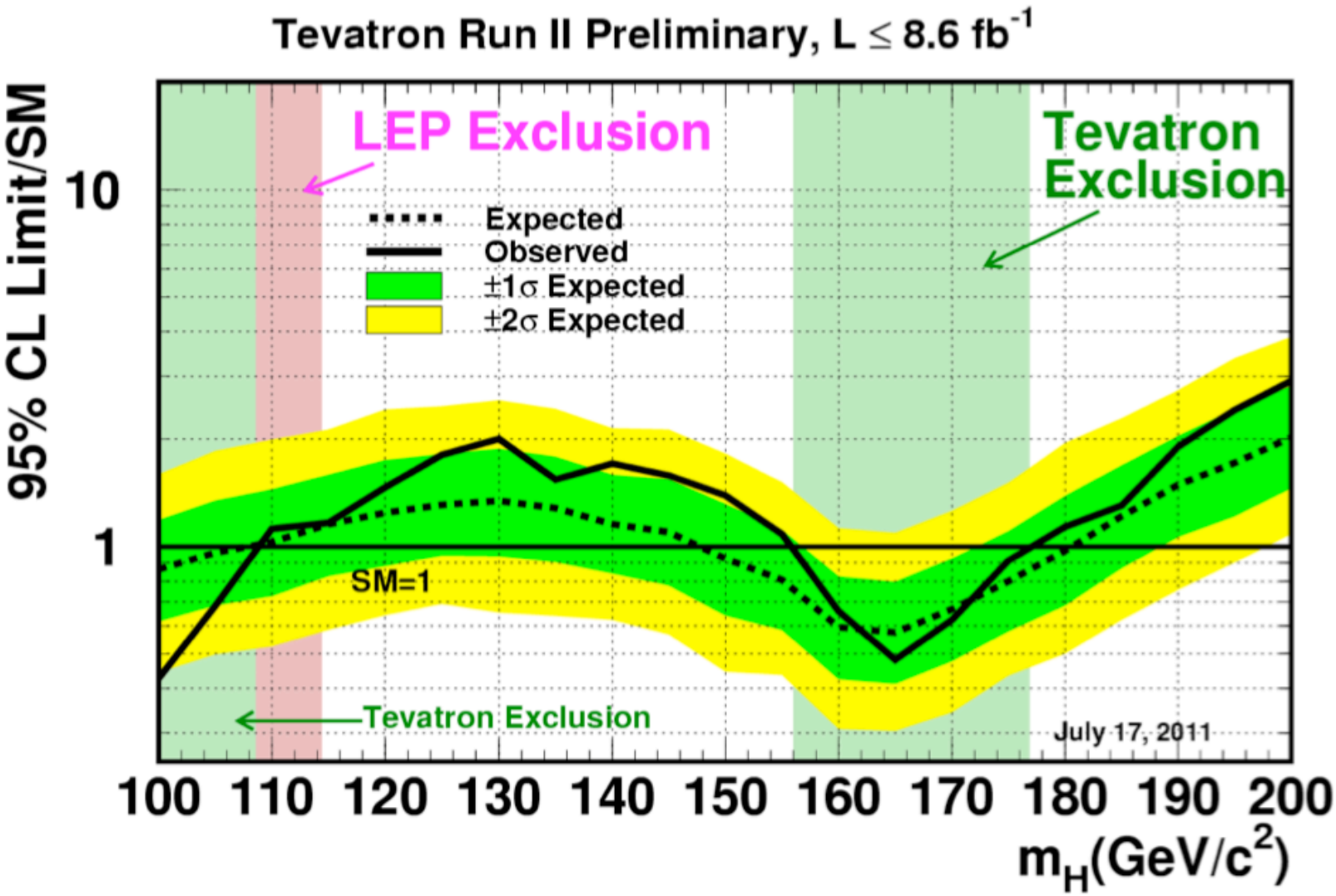




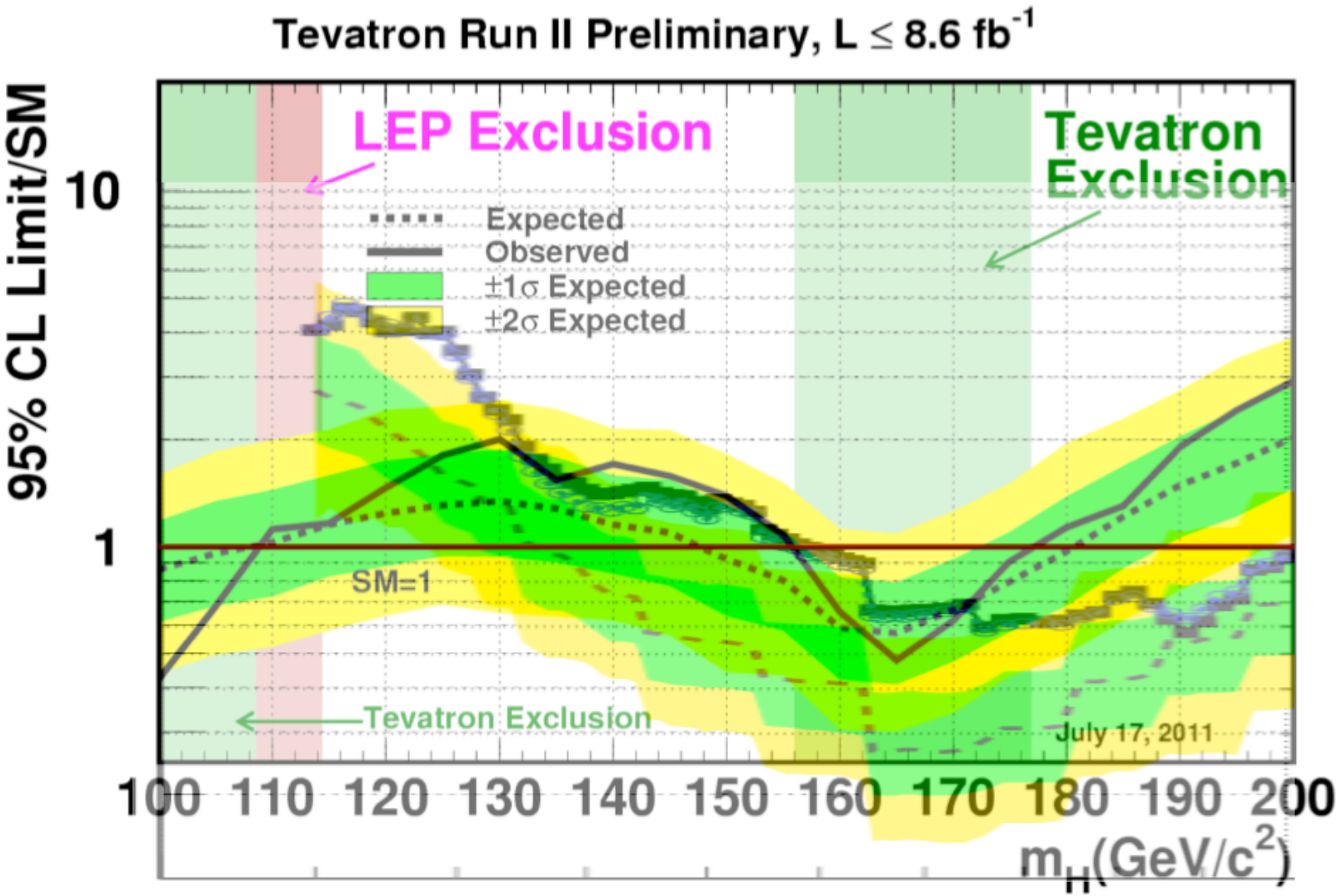
- both experiments exclude 300-450 GeV
- CMS excludes 150-200 GeV, other
- CMS: better sensitivity (125-425 GeV)
- both experiments have low mass excess
- ATLAS+CMS combination coming (LP?)



ATLAS low mass wiggles coming from γγ



Tantalizingly close to SM sensitivity!
Exclude 2x SM @ 130 GeV: LHC excess



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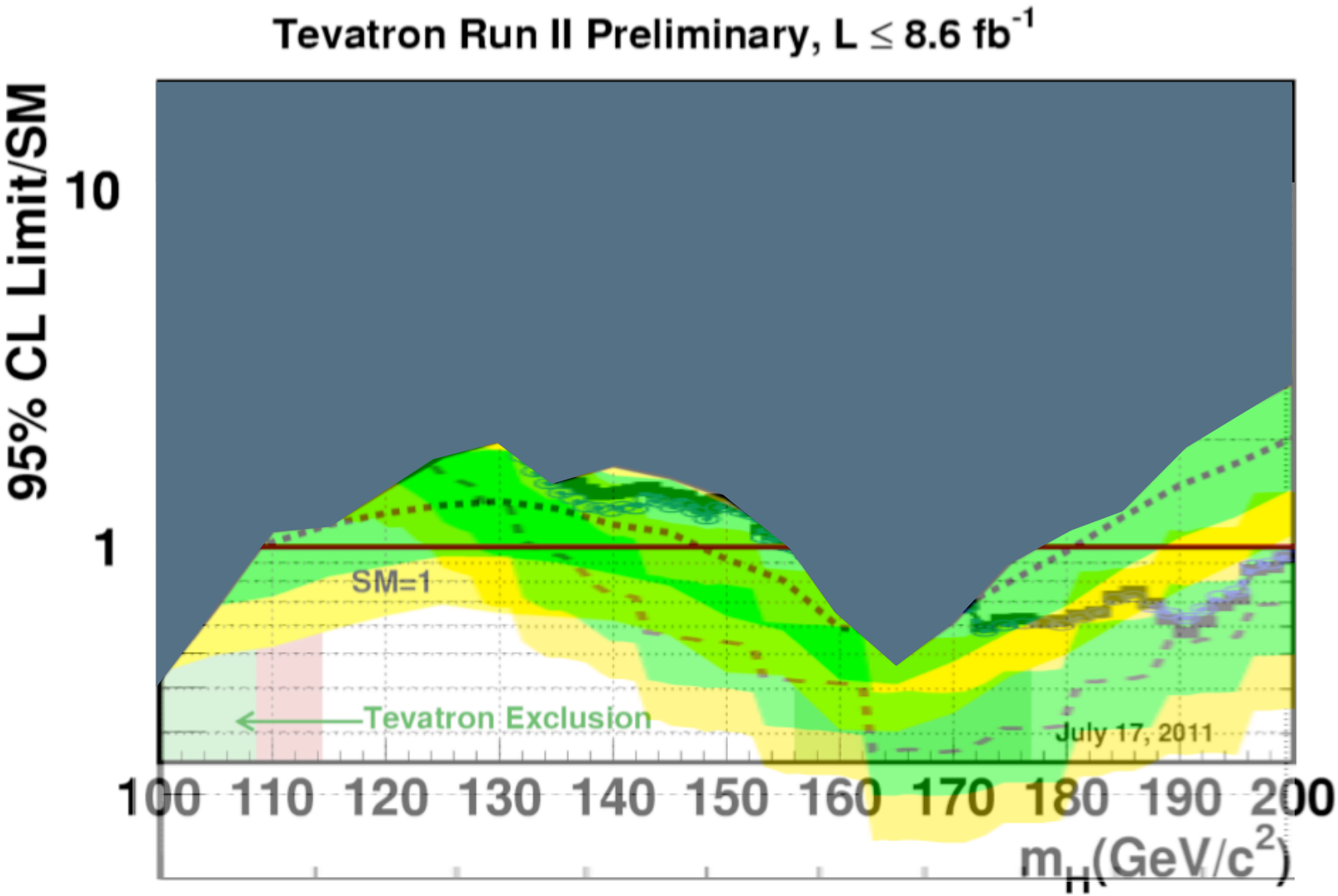

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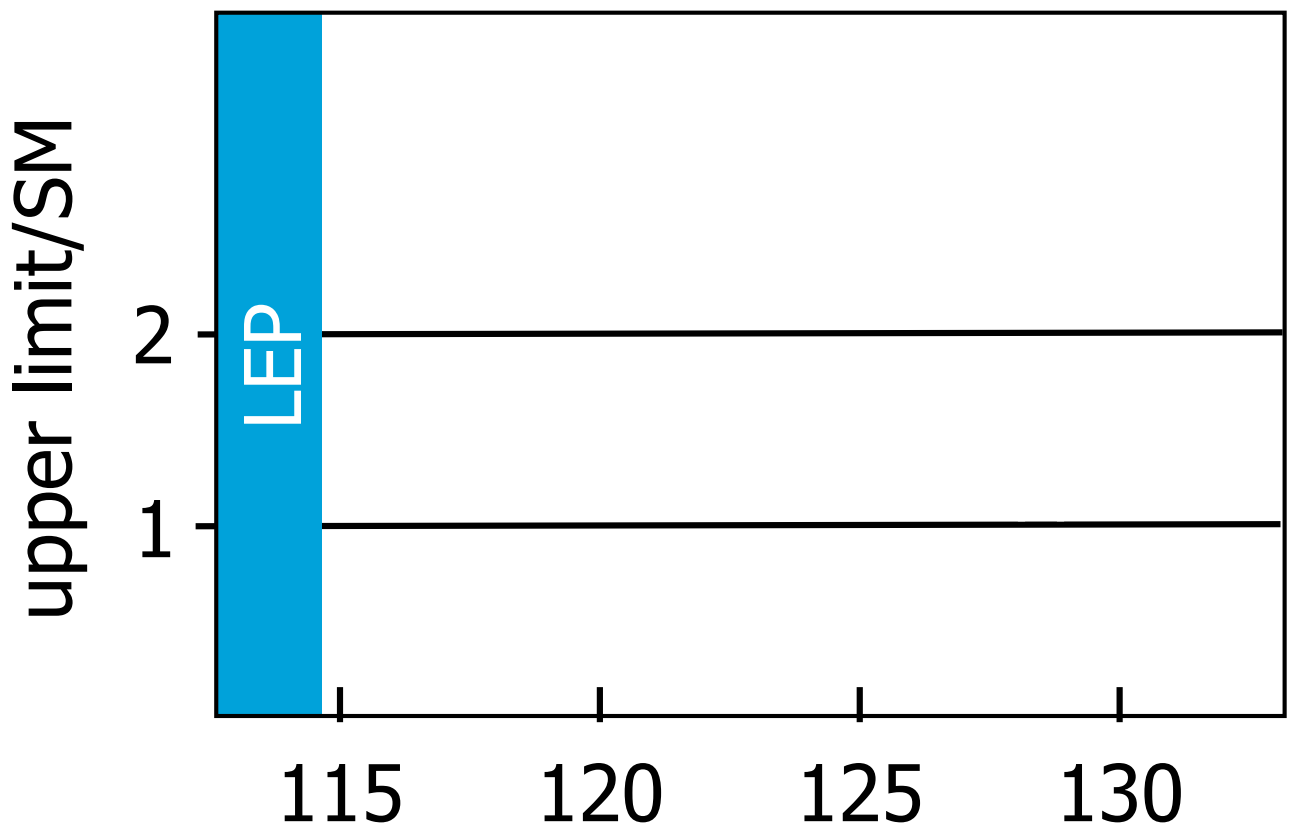
Tevatron is not out of the game yet - the next few months should be interesting! Very schematically:



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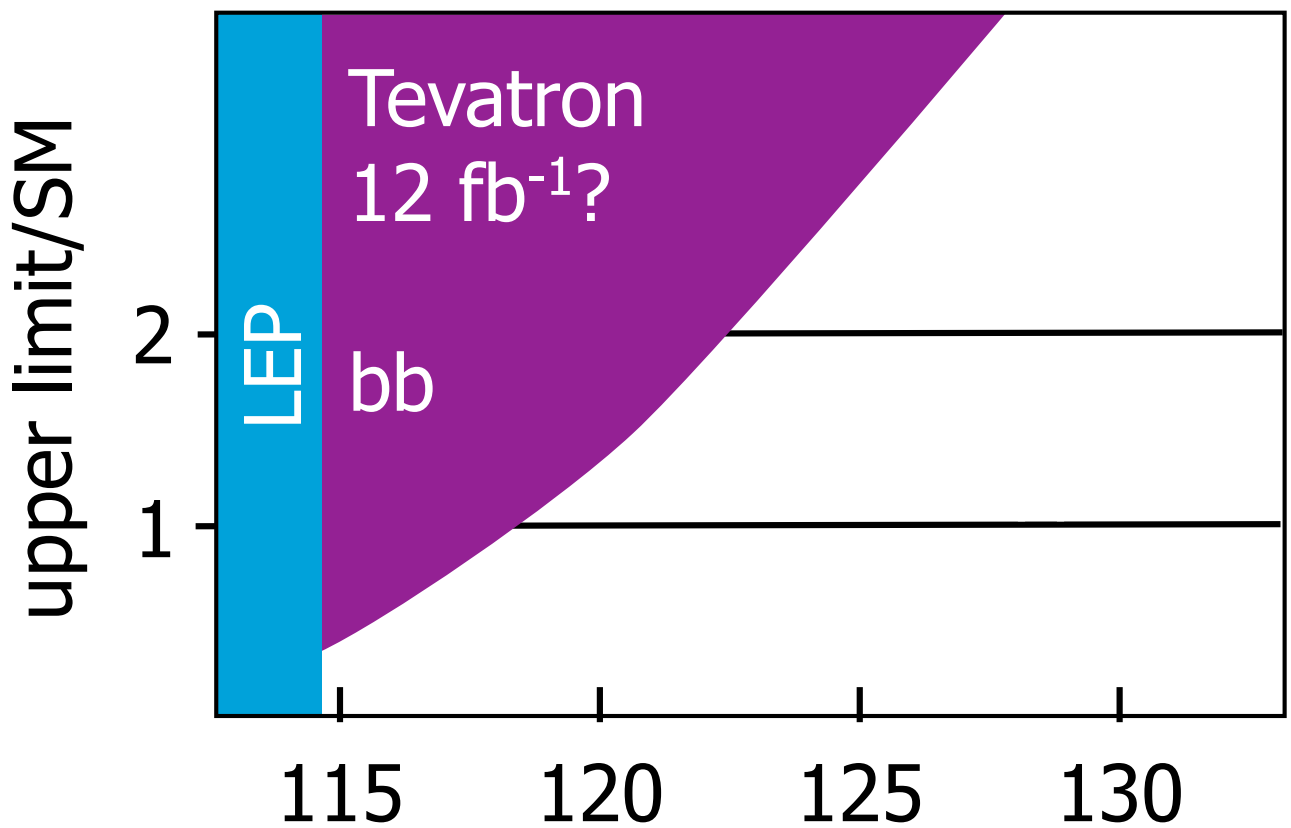

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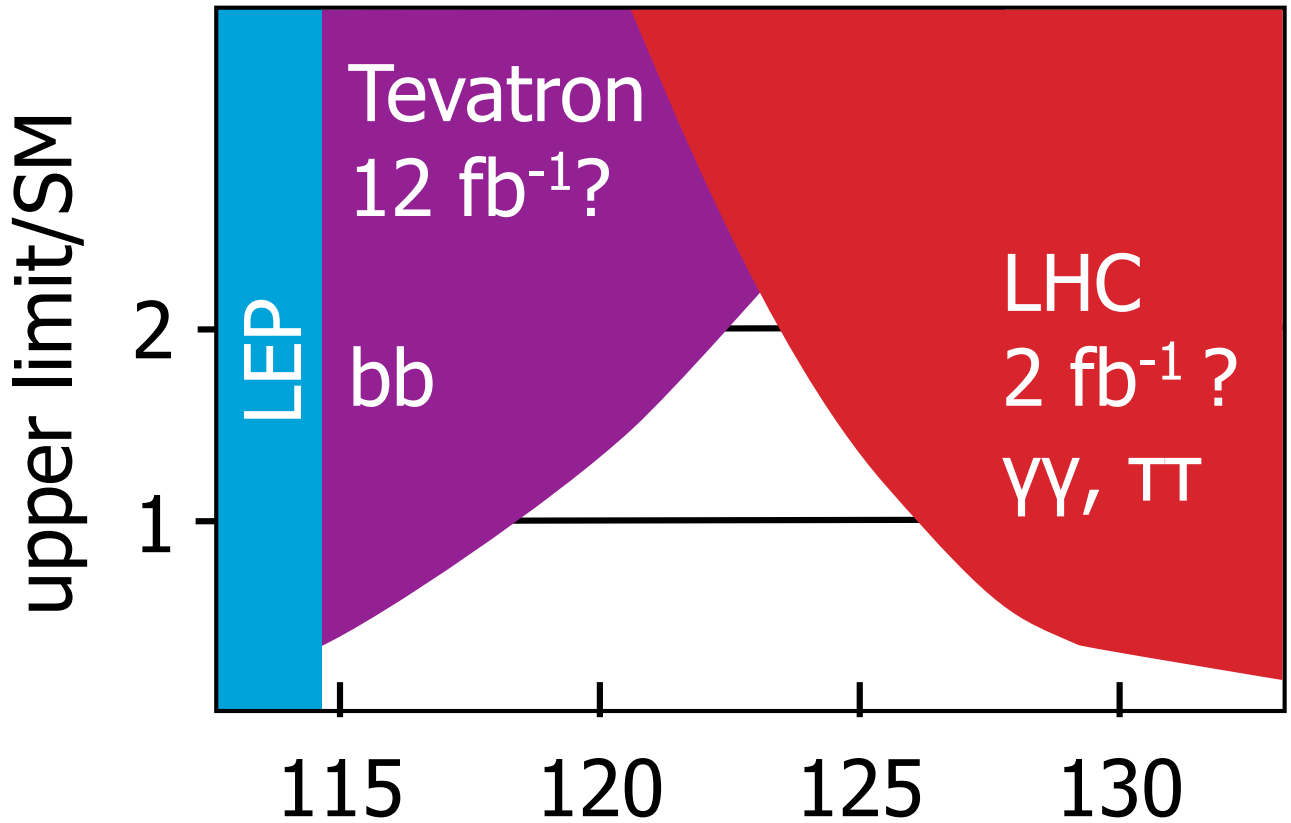

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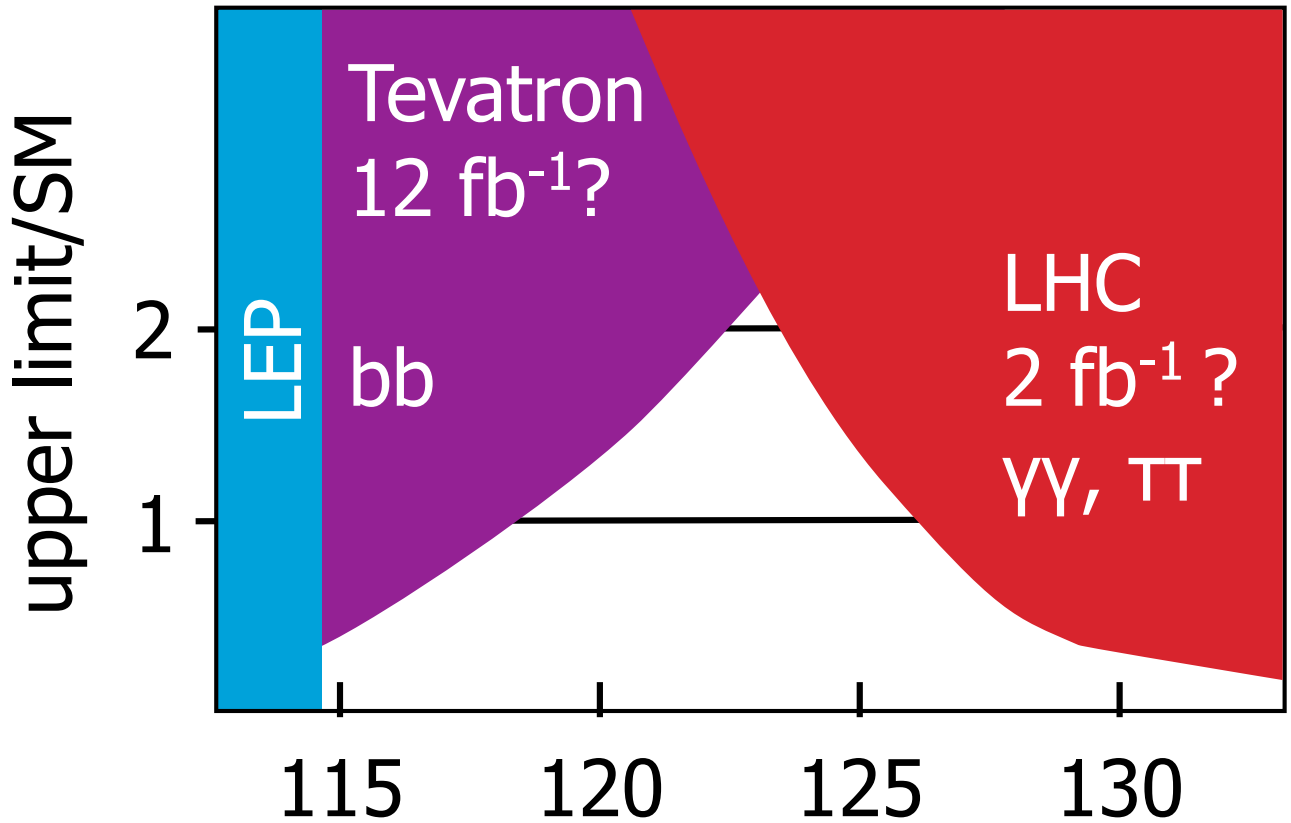

Combining LHC and Tevatron possible...can it happen?