Search for H^+ and H^{++} at CMS

Aruna Kumar Nayak

LIP, Lisbon
(On behalf of CMS Collaboration)

Outline

- Theoretical overview
- Search for singly charged Higgs boson
- Search for doubly charged Higgs boson
- Summary

H^+ search in Top quark decay

CMS-PAS-HIG-11-008

Charged Higgs boson is predicted by extensions of Standard Model with two Higgs doublets, such as MSSM.

Production and decay at tree level depends on M_A and $\tan\beta = v_1/v_2$ (ratio of the v.e.vs)

Light charged Higgs ($M_{H+} < M_{top}$) : $pp \rightarrow t\bar{t} \rightarrow H^{\pm}bW^{\mp}\bar{b}$

Heavy charged Higgs ($M_{H+} > M_{top}$) : $pp \rightarrow tH^{\pm}$ $(tbH^{\pm})$

Search assumption :

$m_{H+} < m_t$, $t \rightarrow H^+b$, $H^+ \rightarrow \tau\nu$, $BR(H^+ \rightarrow \tau\nu) = 1$ (high $\tan\beta$)

Three channels included

1) Hadronic tau decay, hadronic W decay (τ + jets) : $H^{\pm} \rightarrow \tau_h\nu, W^{\mp} \rightarrow q_i\bar{q}_j$

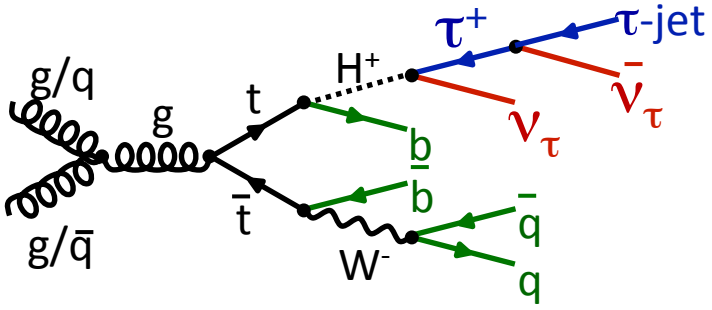
2) Hadronic tau decay, leptonic W decay (μ + τ) : $H^{\pm} \rightarrow \tau_h\nu, W^{\mp} \rightarrow \mu\nu$

3) Leptonic tau decay, leptonic W decay (e + μ) : $H^{\pm} \rightarrow \tau\nu, \tau \rightarrow e(\mu)\nu, W^{\mp} \rightarrow \mu(e)\nu$

Fully Hadronic final state

1.08 fb-1 of data used

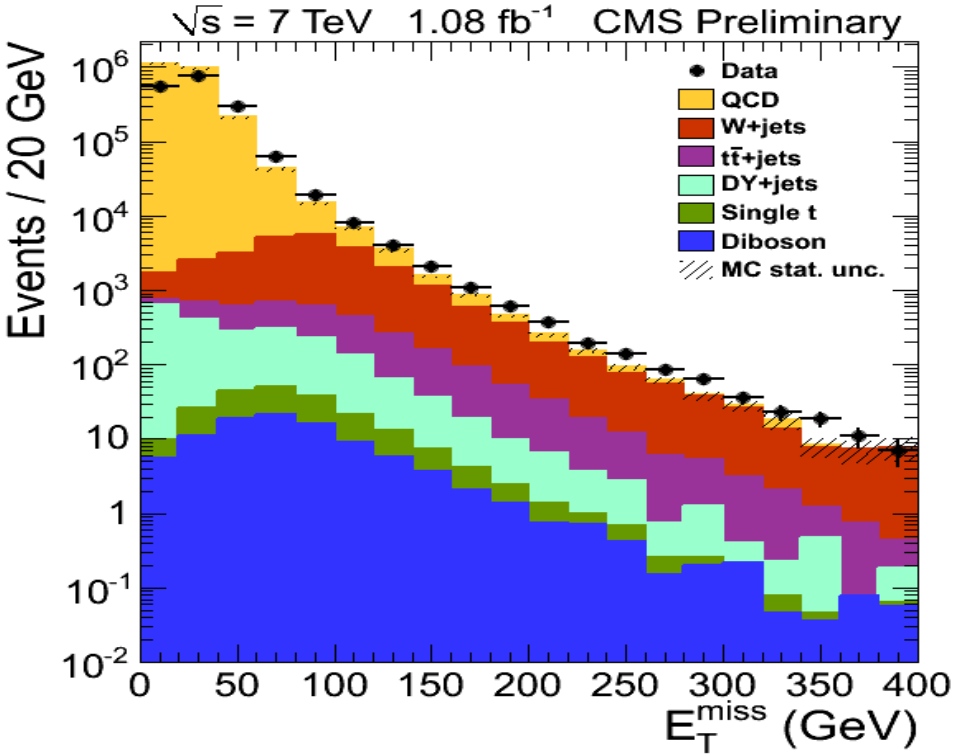
- Main backgrounds: QCD multi-jet, ttbar, W+jets



- General selection strategy is to suppress QCD multi-jet background below ttbar and other backgrounds

➢ Event Selection :

- Trigger: Single tau + E_T^{miss} trigger
- Require one τ jet $p_T > 40$ GeV/c, p_T(leading particle)>20 GeV/c
- $E_T^{miss} > 70$ GeV
- At least 3 jets, $p_T > 30$ GeV/c, $|\eta| < 2.4$
- At least one b-jet

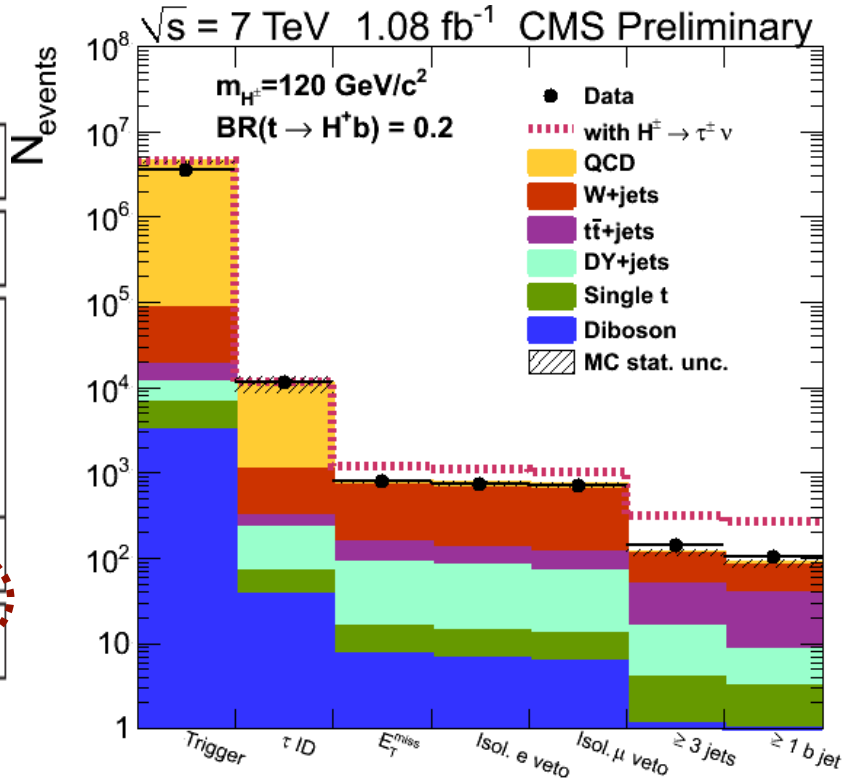


After all selections except tau isolation and b-tagging

Fully Hadronic Event Yields

Summary of event yields after final selection

Source	N_{events}
HH+HW, $m_{H^\pm} = 120\ GeV/c^2$, BR=0.2	121 ± 6 (stat.) ± 39 (syst.)
QCD multi-jets	7.5 ± 0.5 (stat.+syst.)
EWK+$t\bar{t}$ τ	71 ± 5 (stat.) ± 16 (syst.)
EWK+$t\bar{t}$ τ fakes	3.5 ± 0.8 (MC stat.) ± 1.0 (syst.)
Total expected from the SM	82 ± 5 (stat.) ± 16 (syst.)
Data	104



The major backgrounds are measured from data

Data agrees well with the SM expectations within the uncertainty
NO excess observed

Muon + Hadronic tau decay

1.09 fb-1 of data used

- Main backgrounds : $t\bar{t}$, W+jets

- Event Selection :

Isolated single muon trigger (p_T > 17 GeV/c)

One isolated muon p_T >20 GeV/c

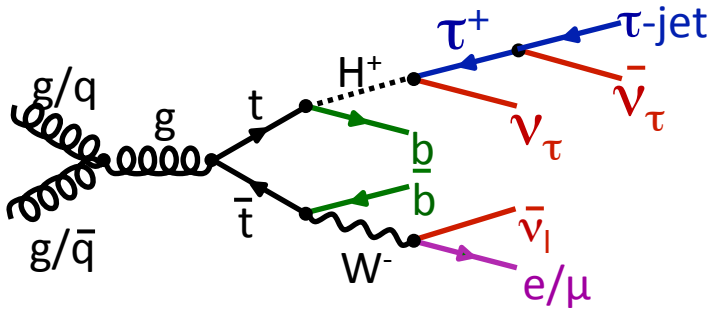
At least 2 jets p_T>30 GeV/c

E_T^{miss} > 40 GeV

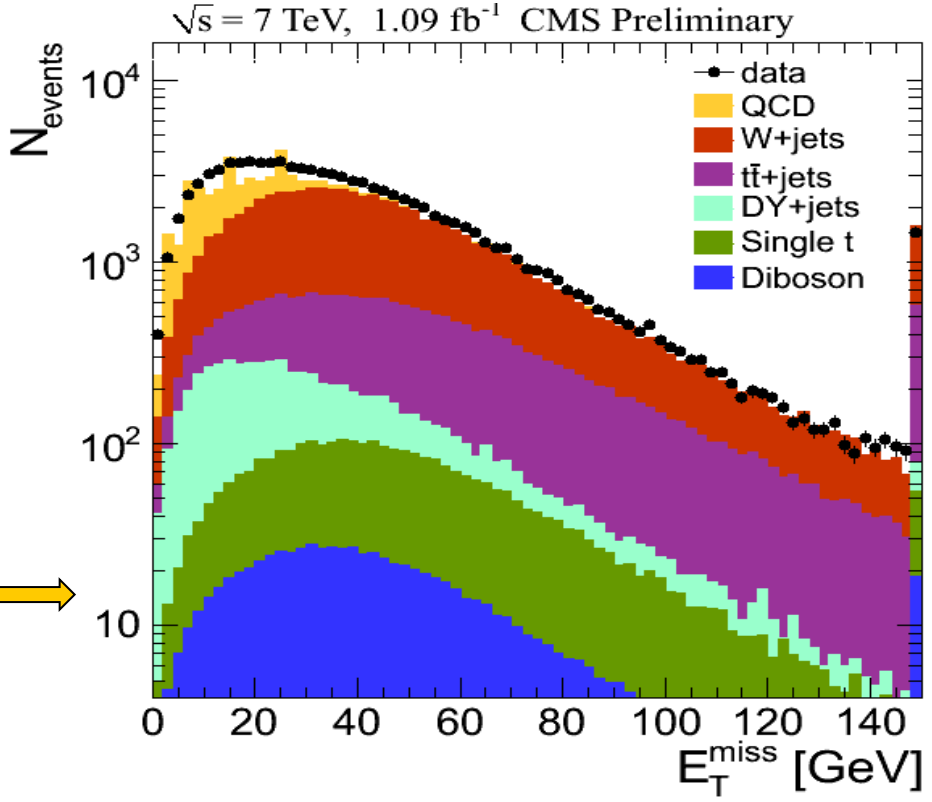
One tau p_T >20 GeV/c

Opposite-Sign between muon and tau

At least one b-jet



After selections of one muon and 2 jets

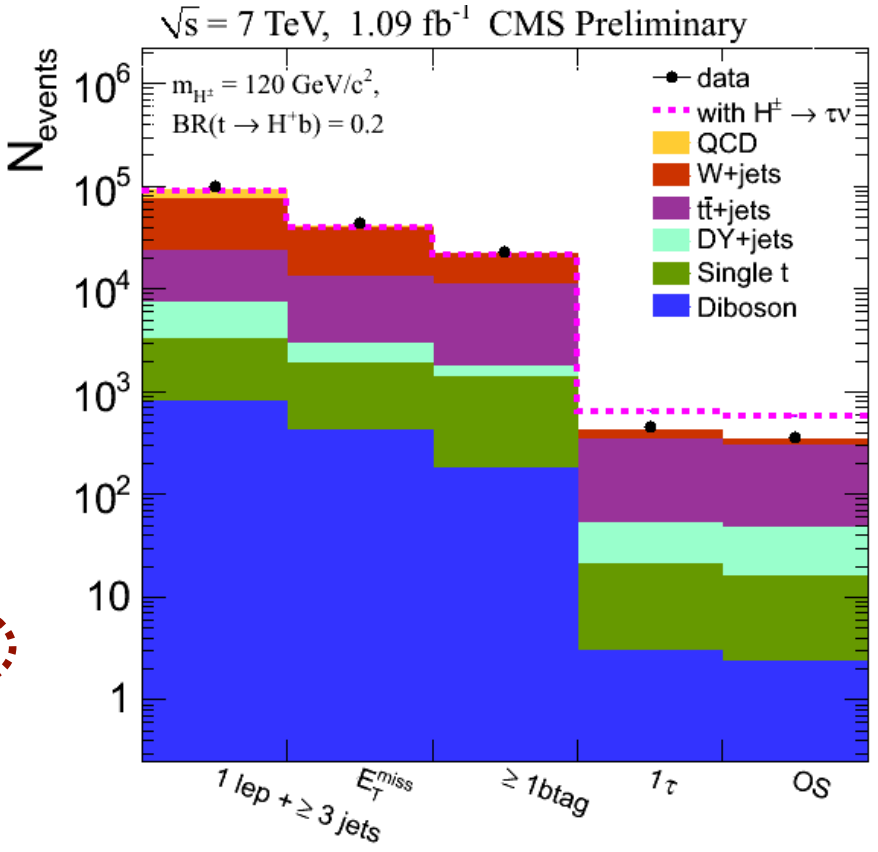


Muon + Tau event yields

Summary of event yields after final selection

Source	N_{events} ($\pm$ stat $\pm$ syst)
HH+HW, m_{H^+}=120 GeV/c^2, BR=0.2	323 $\pm$ 8.7 $\pm$ 67
τ fakes	163.0 $\pm$ 9.7 $\pm$ 17.3
$t\bar{t} \to WbWb \to \ell\nu b\, \tau\nu b$	152.7 $\pm$ 2.8 $\pm$ 35.0
$t\bar{t} \to WbWb \to \ell\nu b\, \ell\nu b$	13.2 $\pm$ 0.8 $\pm$ 3.5
$Z/\gamma^* \to ee, \mu\mu$	0.7 $\pm$ 0.5 $\pm$ 0.5
$Z/\gamma^* \to \tau\tau$	30.9 $\pm$ 3.6 $\pm$ 6.0
Single top	13.8 $\pm$ 0.7 $\pm$ 2.1
VV	2.4 $\pm$ 0.2 $\pm$ 0.4
Total expected from the SM	376.7 $\pm$ 10.8 $\pm$ 39.7
Data	361

Background measured from data

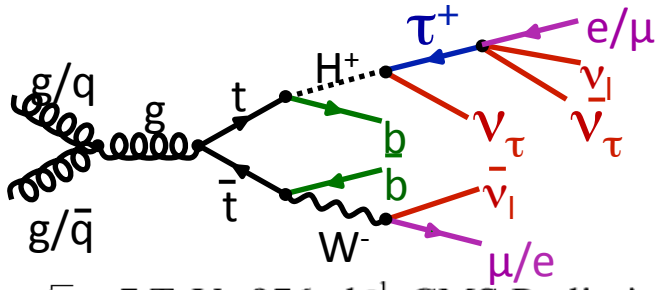


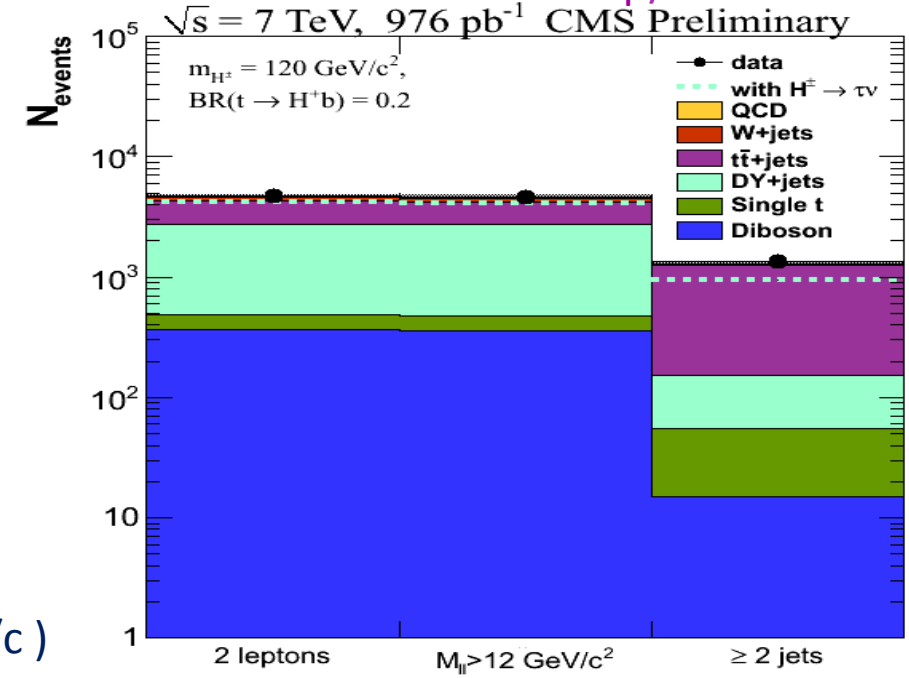
Data agrees well with the SM expectations within the uncertainty
NO excess observed

eμ final state

0.98 fb-1 of data used

Source	N_{events} (± stat. ± syst.)
HH+HW, m_{H^+}=120 GeV/c^2, BR=0.2	219 ± 7 ± 43
$t\bar{t}$	1094 ± 6 ± 219
$Z/\gamma^* \to ll$	98 ± 3 ± 12
W+jets	18 ± 3 ± 2
Single top	40 ± 1 ± 4
VV	14.7 ± 0.4 ± 1
Total expected from SM	1264 ± 7 ± 219
Data	1340





- Tau decays leptonically
- Main background: $t\bar{t}$
- Event selection:

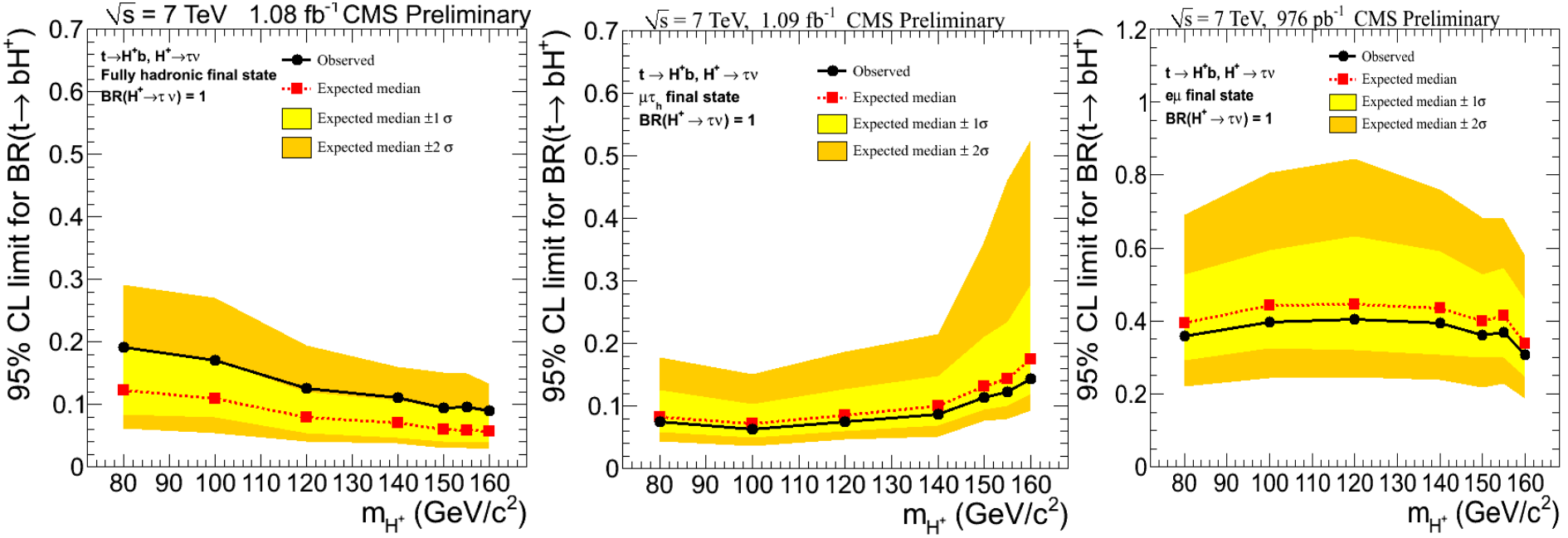
e-μ trigger
one e (p_T>20 GeV/c), one μ (p_T>20 GeV/c)

At least 2 jets (p_T>30 GeV/c)

Deficit of total events expected in the presence of charged Higgs boson, because e/μ from τ decay become soft

Upper limit on BR ($t \rightarrow H^+b$)

fully hadronic **muon+tau** **electron+muon**



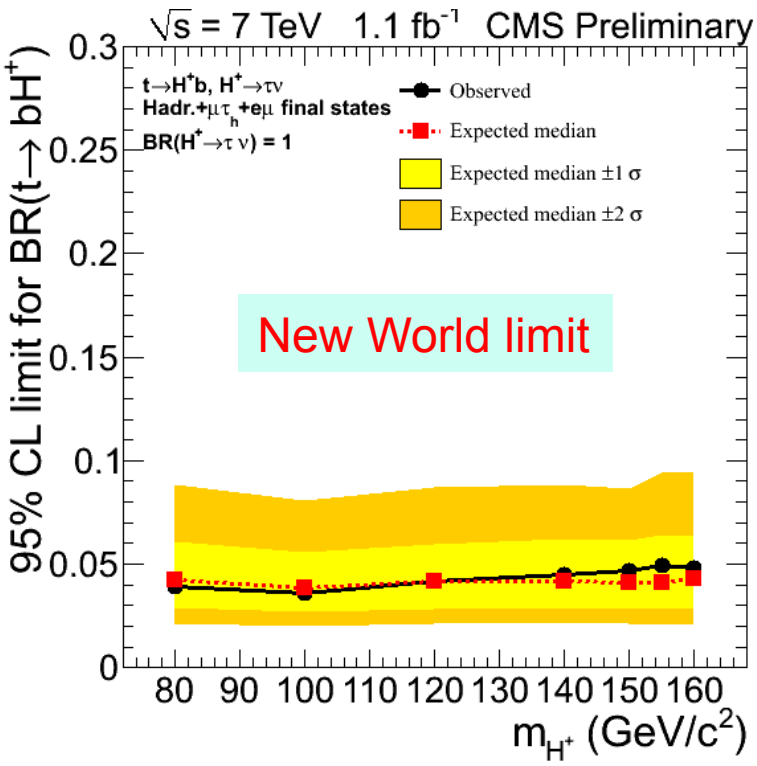
95 % CL upper limit on BR($t \rightarrow H^+b$) using CLs method.

The signal is modelled as the excess (or deficit) of events yields in presence of H^+

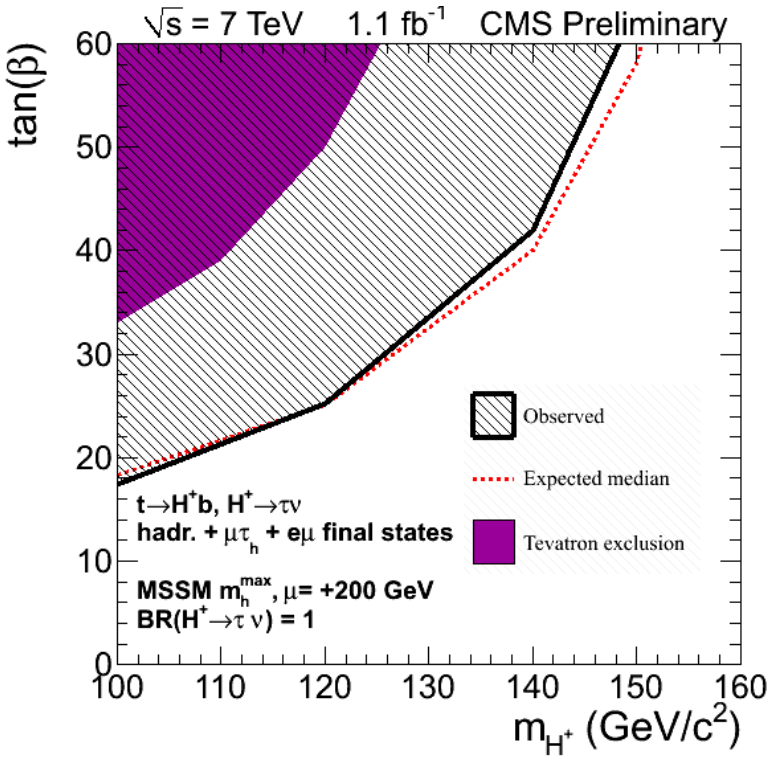
$N_{excess\ (deficit)} = N_{tt}^{SUSY} - N_{tt}^{SM} = N_{WH}\ 2(1-x)x + N_{HH}\ x^2 + N_{tt}^{SM}\ ((1-x)^2 - 1)$, $x = BR(t \rightarrow H^+b)$

Results from Combination of three channels

combination of the fully hadronic, muon + tau and electron + muon channels



Tevatron limit : 0.15 – 0.2



exclusion region in MSSM (m_h^{max})
MH^+-tanβ parameter space

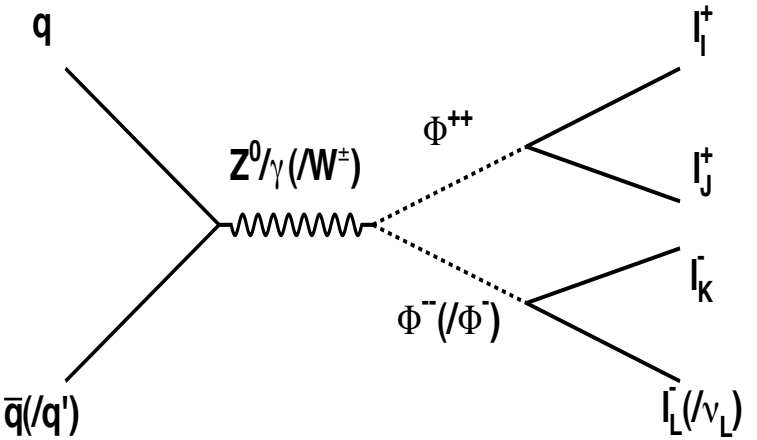
Doubly charged Higgs boson (Φ^{++})

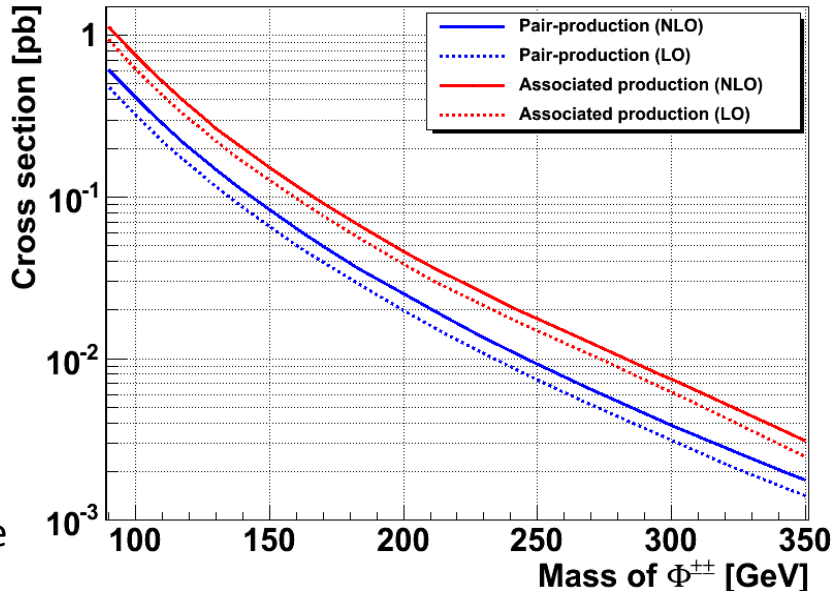
CMS-PAS-HIG-11-007

- Standard model extension by a scalar triplet adding three new particles
  - Φ^{++}, Φ^{+}, Φ^{0} (e.g. Type-|| seesaw model)
- The triplet is responsible for neutrino masses, the couplings being directly linked to the mass matrix
  - $M_{ij} = k\, Y_{ij}$
- Unknown neutrino mass matrix → unknown branching ratios
- We assume branching ratios to leptons only

➢ Six standard searches covered, where **BR($\Phi^{++} \rightarrow l^+l^+$) =100%**

➢ Four additional model dependent points to describe the neutrino sector





Φ^{++} analysis in a nutshell

- Signatures: **3 or 4 leptons** in the final state, dilepton made by same sign lepton
- Backgrounds:
  - ZZ, WZ , Z+jets, tt+jets, (W+jets, QCD)
- Selection strategy:
  - dilepton triggers
  - lepton id and charge matching
  - Σp_T cuts on leptons
  - tight isolation of leptons
  - Z veto
  - cut on $\Delta\phi$ between leptons

- Pre-selection:
  - At least two leptons with pT > 35 / 10 GeV
  - Loose isolation requirement
  - Veto of low invariant mass resonances (< 12 GeV)

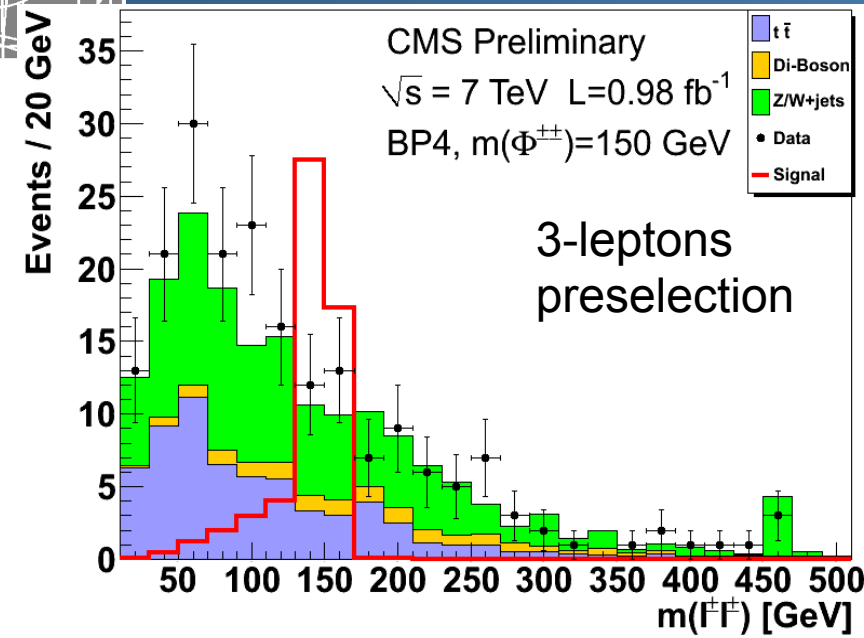
❑ Additional topological cuts on leptons depending on final states
Three OR four leptons

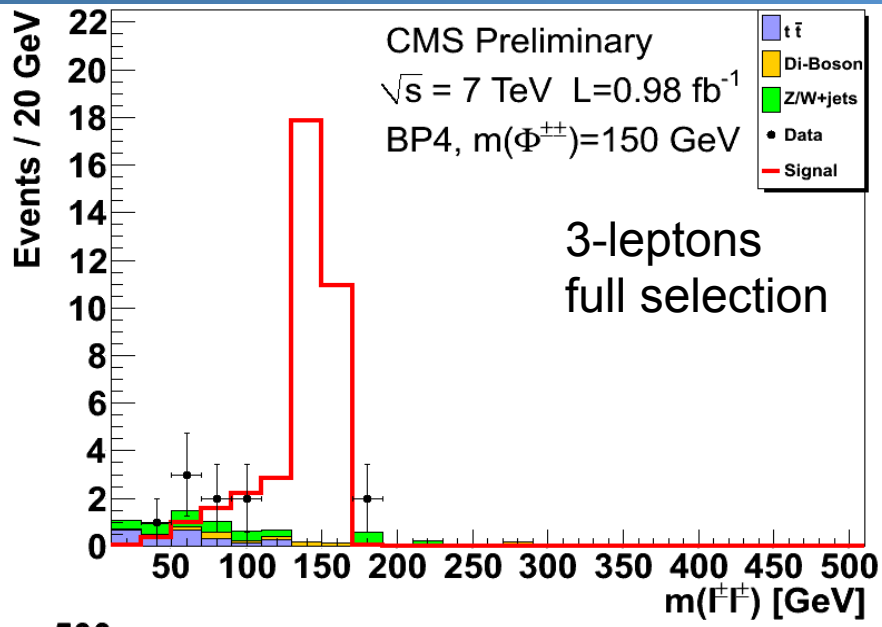
- Control from real data of
  - the lepton-related efficiencies
  - the estimation of background rate

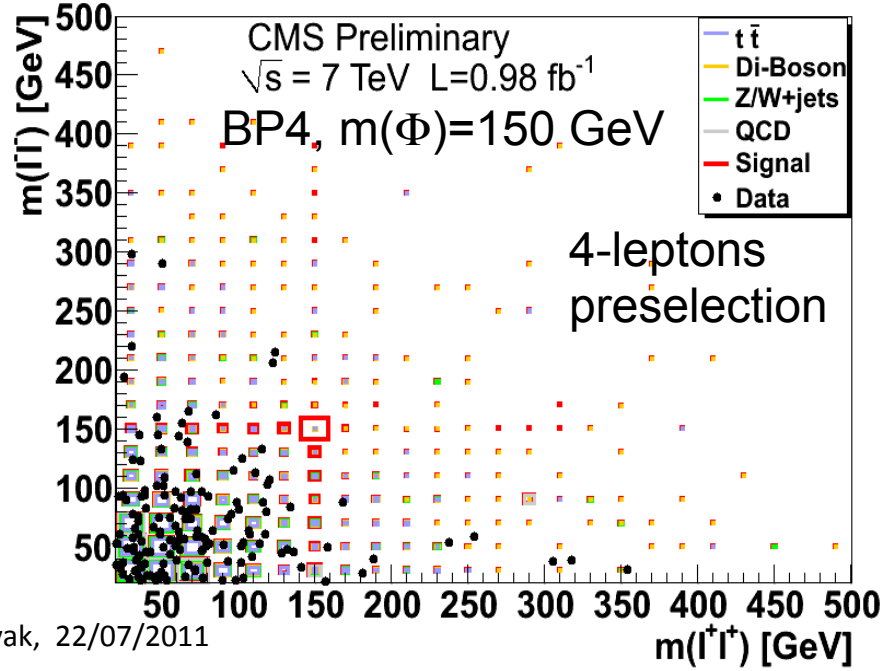
❑ Events are counted in the mass window depending on the Higgs boson mass considered

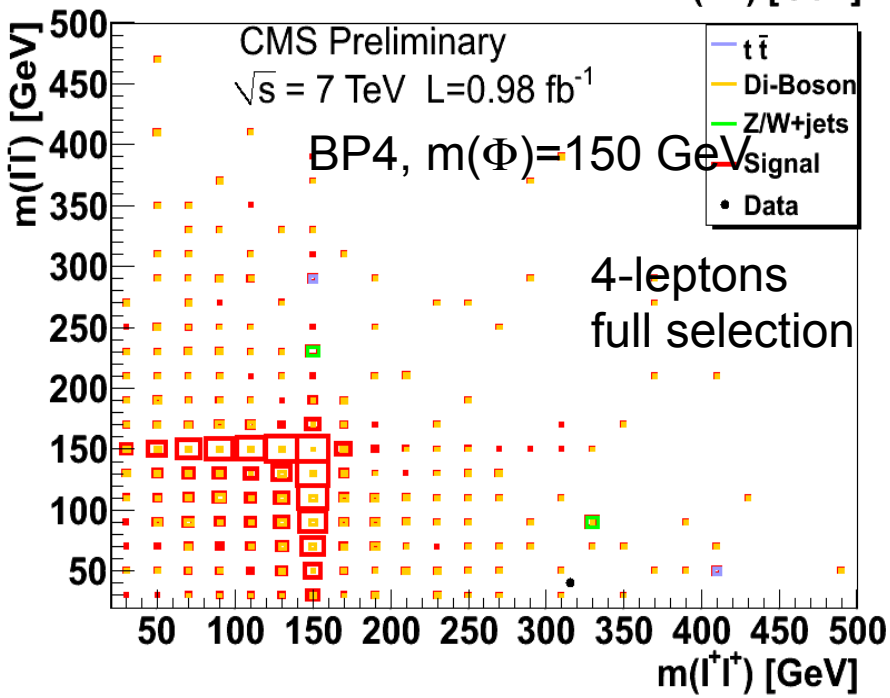
- Inclusive search in order to cover the whole phase space
- **Results provided for integrated lumi = 0.98 fb^{-1}**

Results

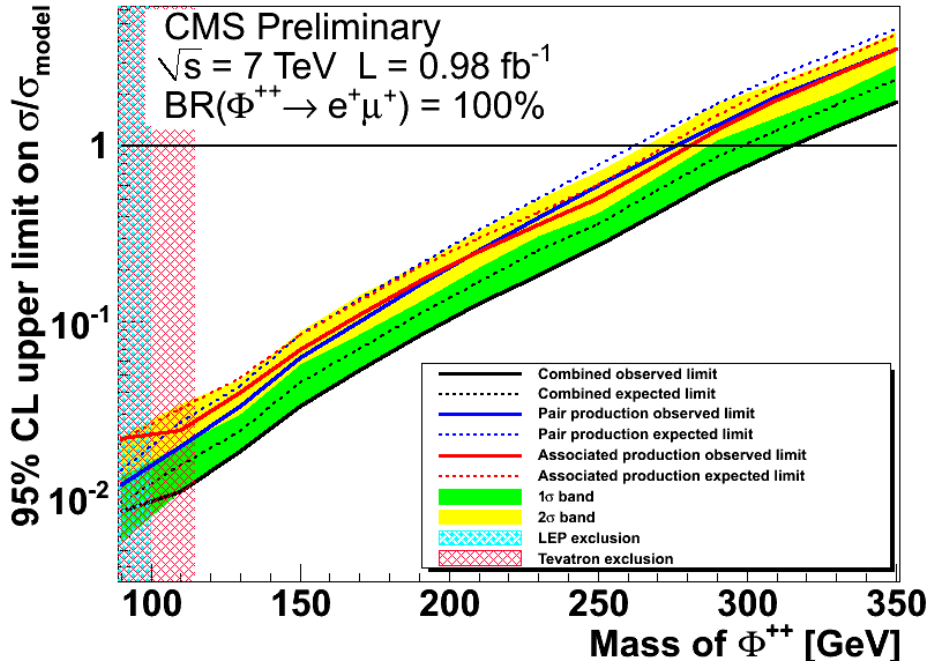

CMS Preliminary
√s = 7 TeV L=0.98 fb-1
BP4, m(Φ++)=150 GeV
3-leptons
preselection
Events / 20 GeV
m(l+l+) [GeV]
tt̄
Di-Boson
Z/W+jets
Data
Signal

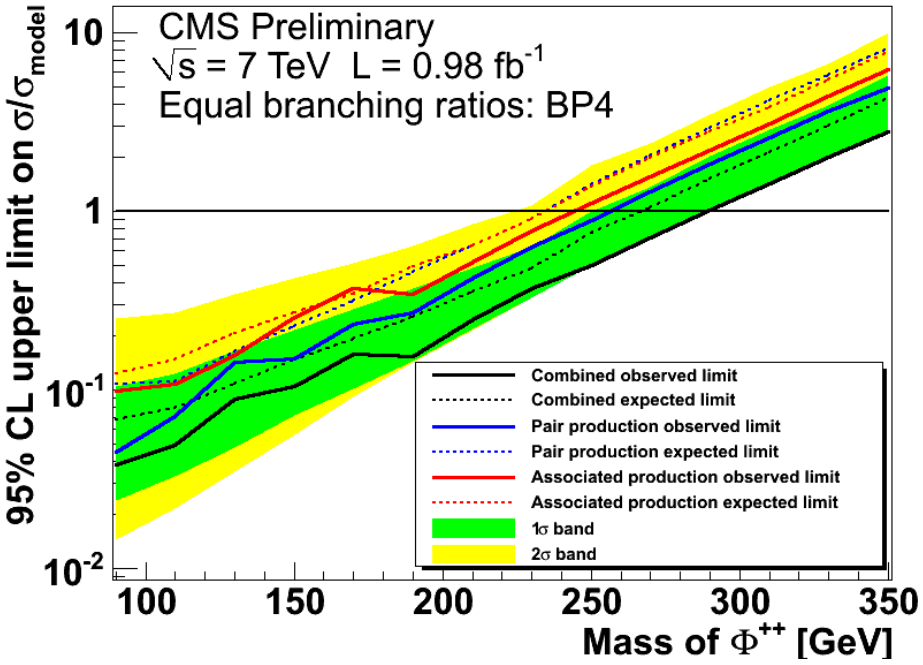

CMS Preliminary
√s = 7 TeV L=0.98 fb-1
BP4, m(Φ++)=150 GeV
3-leptons
full selection
Events / 20 GeV
m(l+l+) [GeV]
tt̄
Di-Boson
Z/W+jets
Data
Signal


CMS Preliminary
√s = 7 TeV L=0.98 fb-1
BP4, m(Φ)=150 GeV
4-leptons
preselection
m(l+l-) [GeV]
m(l+l+) [GeV]
tt̄
Di-Boson
Z/W+jets
QCD
Signal
Data


CMS Preliminary
√s = 7 TeV L=0.98 fb-1
BP4, m(Φ)=150 GeV
4-leptons
full selection
m(l+l-) [GeV]
m(l+l+) [GeV]
tt̄
Di-Boson
Z/W+jets
Signal
Data

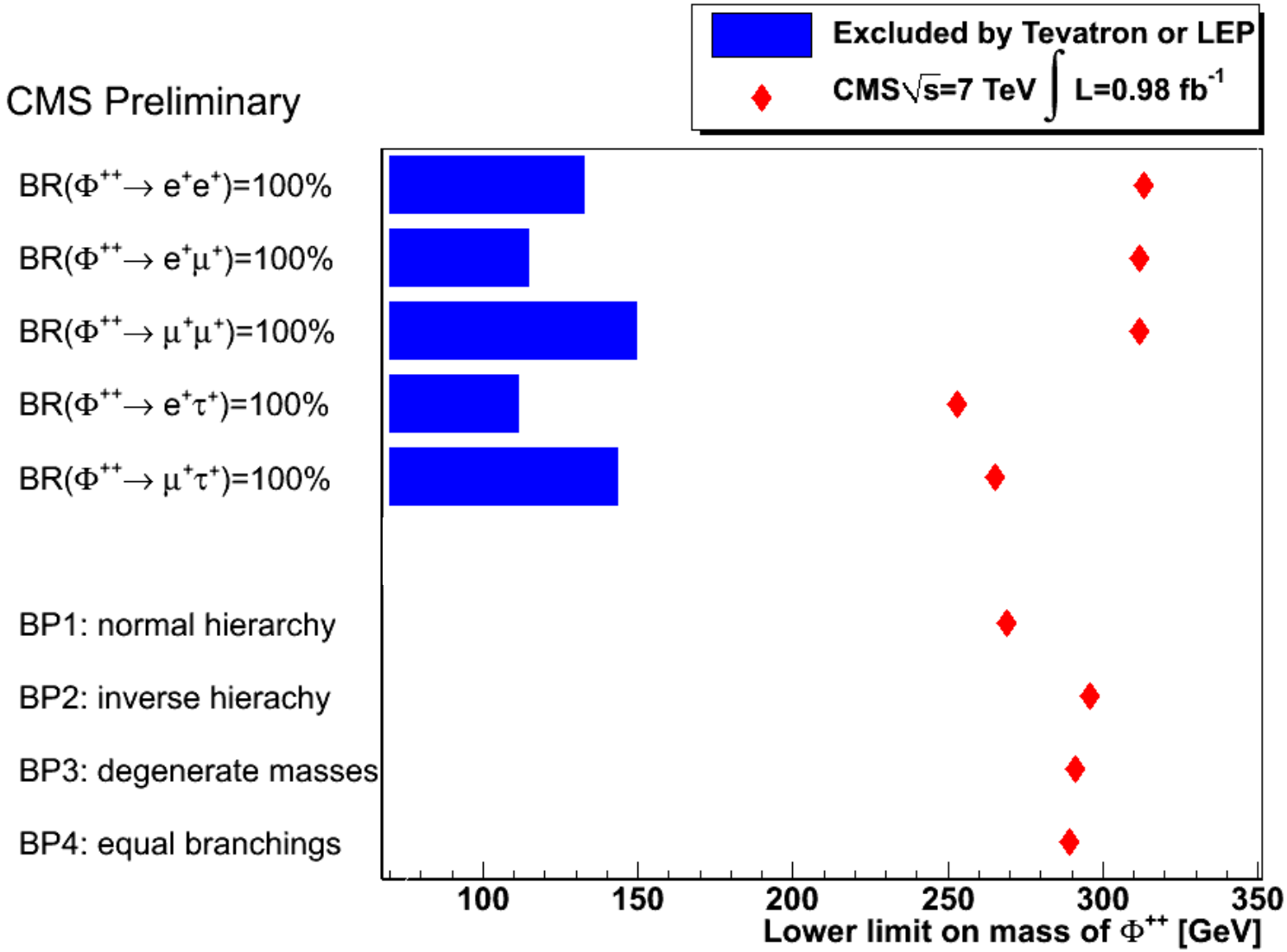
Lower limit on Φ^{++}





95% CL lower Limits obtained using CLs method

Lower limit on Φ^{++}



Summary

➢ H^+ search :

- The charged Higgs boson in the decay of Top quark is searched assuming BR($H^+ \rightarrow \tau\nu$) = 1
- Upper limit on BR($t \rightarrow H^+b$) = 0.04 – 0.05 (new world limit) depending on H^+ mass

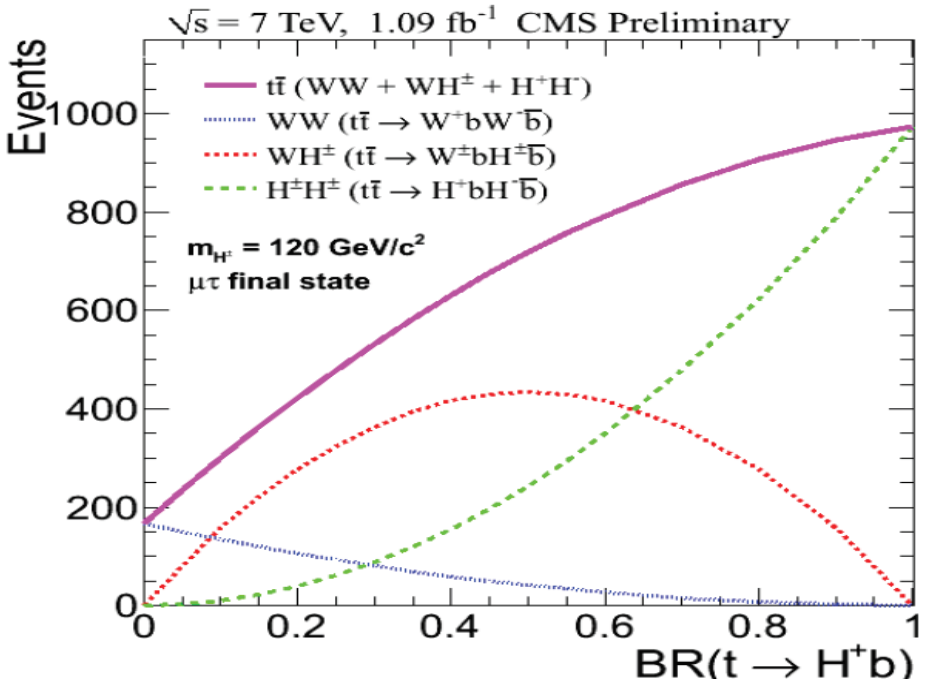
➢ Φ^{++} search :

- A fully inclusive search has been performed with no excess observed
- CMS now has the best limit by a large margin in most of channels.

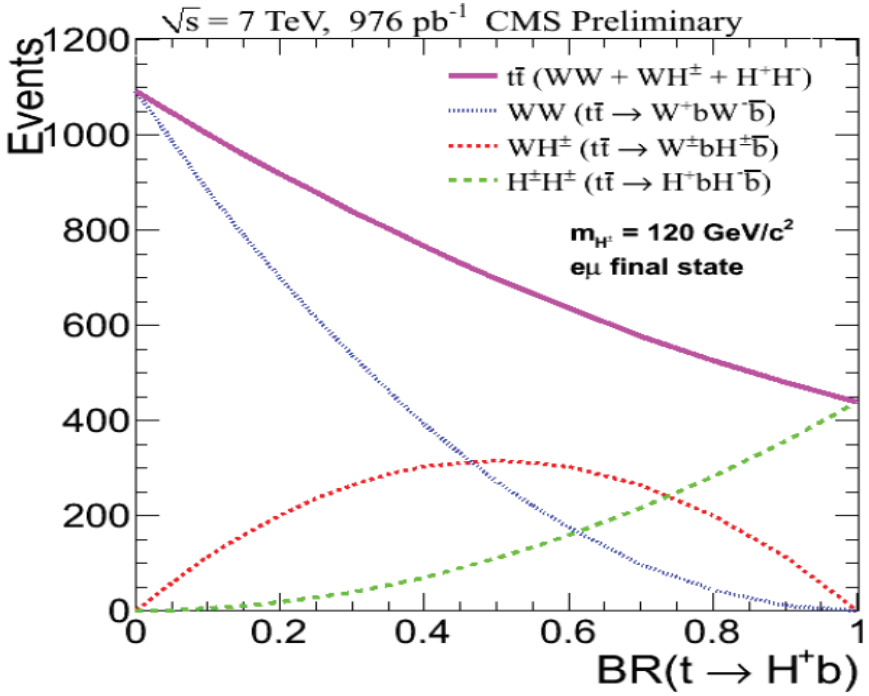
Thank You

Expected events vs BR

muon+tau

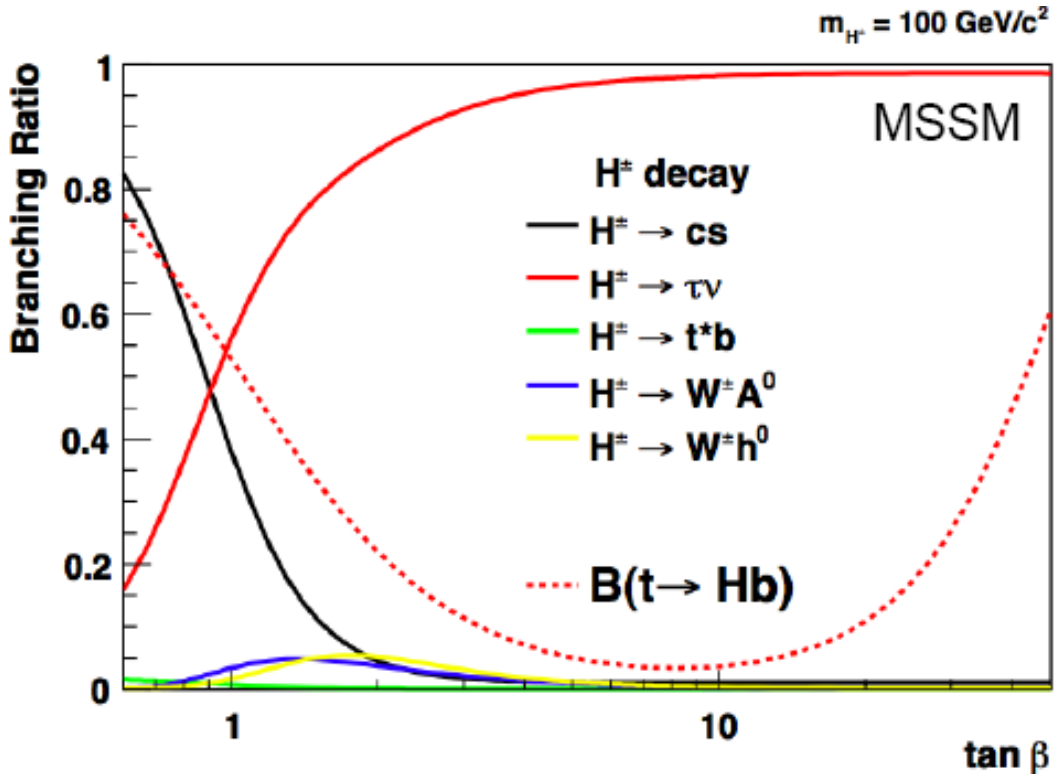


e+muon



$x = BR(t \rightarrow bH^+)$

N_{tt} (in presence of H^+) = $N_{WH}\, 2(1-x)x + N_{HH}\, x^2 + N_{tt}^{SM}\, (1-x)^2$



D0 Note 5715-CONF

Background measurements in fully hadronic final state

- QCD multi-jet background, **measured from data**

Method based on factorisation of E_T^{miss} + b-tagging from other selections

Apply same selections like signal analysis but in different order.

Factorize $\varepsilon(E_T^{miss}$ + b-tagging) at a selection level where QCD contribution dominates.
ε (E_T^{miss} + b-tagging) estimated in bin of τ p_T.

- Non QCD Type I background (genuine taus within p_T, η acceptance), **measured from data**

Based on tau embedding method

Select events with only one isolated lepton (p_T > 40 Gev/c, $|\eta|$ < 2.1) and 3 jets (p_T > 30 GeV/c, $|\eta|$ < 2.4). Replace the muon by a fully simulated and reconstructed tau with same momentum.

- Non QCD Type II background (e/μ/jets mis-identified as taus, or genuine taus outside p_T, η acceptance)

Expected to be small, **estimated from simulation**

QCD multi-jet background

- Same selections like in signal analysis, but applied in different order to select from data sample where QCD multi-jets dominate
- Number of events in signal region estimated with
  $N_{QCD} = \Sigma_i N_{selected,i}^{data} \times f_{presel,i} \times \varepsilon_{MET+b,i}^{data}$,
  where i is tau p_T bin and f fraction of QCD multi-jet events

	Number of events
MC expectation	7.4 ± 0.3
data estimate	7.5 ± 0.5 (stat.+syst.)

- **Tau+MET trigger**
- **Tau candidate selection**
  - Trigger matching, jet p_T>40 GeV/c, $|\eta|$<2.1, ldg. track p_T>20 GeV/c, e/μ veto, select exactly one tau cand.
- **Veto of isolated electrons muons (p_T>15 GeV/c) and muons (p_T>15 GeV/c)**
- **Jet selection:**
  - $N_{jets} \geq 3$ with E_T>30 GeV and $|\eta|$<2.4 in addition to the tau candidate, $\Delta R(\tau, jet)$<0.5

$\varepsilon_{MET+b\text{-}tag,i}^{data}$
- Factorize out MET+ b-tagging cuts in bins of tau candidate p_T (MET>70)
- Sample purity 60-90 %

- tau ID (HPSTight isolation && Nprongs=1)

$N_{selected,i}^{data}$
- Number of events after tauID
- Sample purity 50-90 %

Non QCD Type I background (genuine taus) data-driven

- **Control sample selection**
  - → One muon, $p_T > 40$ GeV/c, $|\eta| < 2.1$
    - •Isolation by requiring no HPSTight-quality PFCandidates in $0.1 < \Delta R < 0.4$
  - → Veto of isolated electrons and other muons, $p_T > 15$ GeV/c
  - → At least 3 PF jets, $p_T > 30$ GeV/c, $|\eta| < 2.4$
- **Tau embedding at PF level**

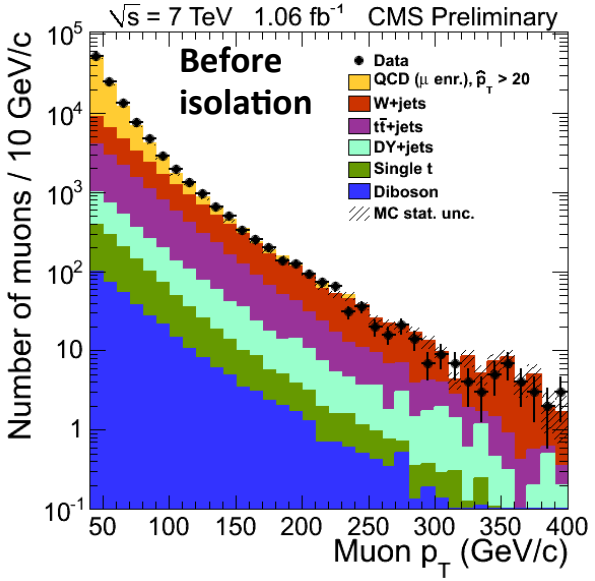
Simulate and reconstruct tau with same momentum as muon

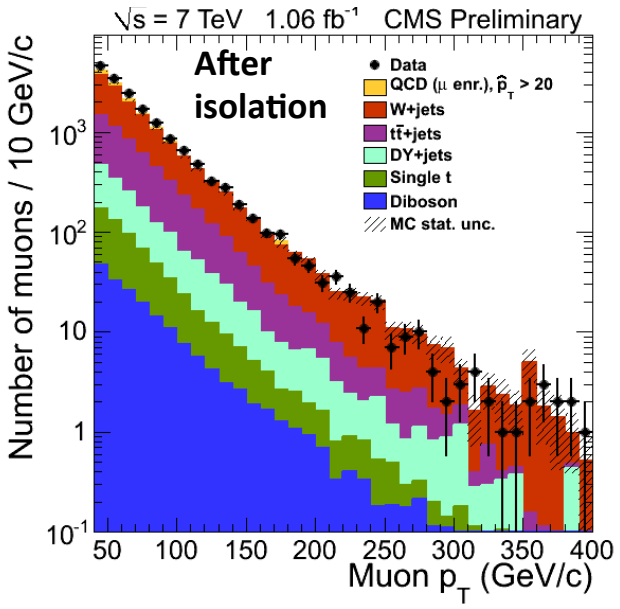
- **Normalisation**
  - → Tau trigger efficiency with weighting by efficiency
  - → MET trigger efficiency with

”vector sum caloMETnoHF” > 60 GeV

  - → Muon trigger and ID efficiency with Tag and Probe

Result: 71 ± 5 (stat) ± 15 (syst)
MC expectation: 78 ± 7 (stat)





Systematics (Fully Hadronic)

Table 1: The systematic uncertainties (in %) for the backgrounds and the signal from $t\bar{t} \rightarrow H^{\pm}bH^{\mp}\bar{b}$ (HH) and $t\bar{t} \rightarrow W^{\pm}bH^{\mp}\bar{b}$ (WH) processes at $m_{H^{\pm}}$=80-160 GeV/c^2.

	HH	WH	QCD	non QCD Type 1	non QCD Type 2				
					$t\bar{t}$	tW	W+jets	Z+jets	VV
$\tau - p_T^{miss}$ trigger	24–26	24–25		9.6	22	22	22	24	23
τ-jet id	7.0	7.0		7.0					
jet, $\ell \rightarrow \tau$ mis-id					15	15	15	15	15
JES+JER+MET	13–17	14–19		18	17	25	14	19	22
lepton veto	0.2–0.3	0.3–0.4			1.5	0.6	0.6	0.6	0.7
b-jet tagging	12–15	14-16			16	17			
jet$\rightarrow$b mis-id							13	10	11
QCD stat.+syst.			7.1						
Non QCD Type 1 stat.				6.8					
$f_{W\rightarrow\tau\rightarrow\mu}$				0.7					
muon selections				0.6					
MC stat	4.1–7.0	4.8–7.2			16.3	56	100	100	90
cross-section	20	20			20	8	5	4	4
luminosity	6.0				6.0				

Background estimate in muon + tau final state

Main background from "fake" tau jet

major contribution : W+jets, $t\bar{t} \rightarrow \ell$ + jets

Data driven background estimation :

- Select jets in events with :

  1 lepton + MET + ≥3 jets

  + ≥ 1 b-tagged jet

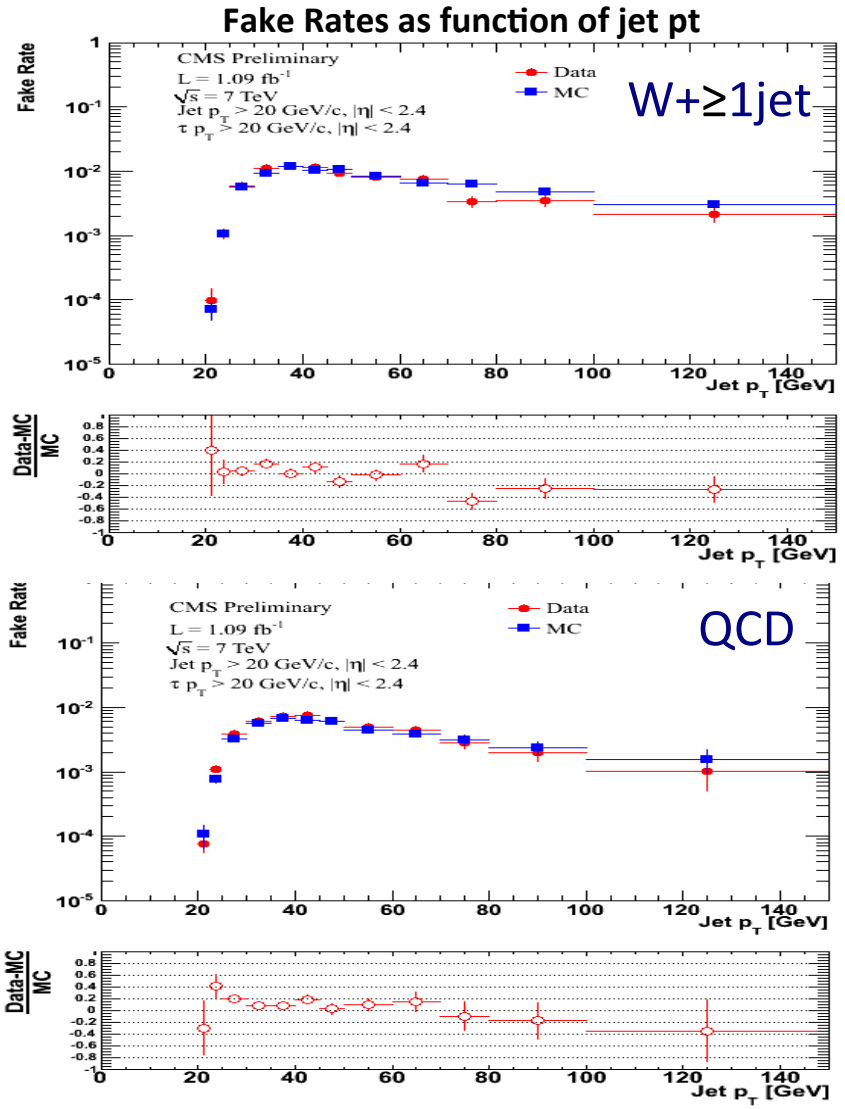
- Apply to every jet a

  "jet→ τ probability (pt,eta,jet width)"

Jet width = $\sqrt{(\sigma_{\eta\eta}^2 + \sigma_{\phi\phi}^2)}$

Jet → τ probability measured from data from different type of samples

(QCD dijets, W + ≥1 jets)



Systematics

mu+tau channel

	HH	WH	$t\bar{t}_{\ell\tau}$	$t\bar{t}_{\ell\ell}$	τ fakes	Single top	VV	DY($\mu\mu$)	DY($\tau\tau$)
τ-jet id	7.0	7.0	7.0			7.0	7.0		7.0
jet, $\ell \rightarrow \tau$ mis-id				15.0				15.0	
JES+JER+MET	6.0	4.0	3.0	3.0		8.0	8.0	71.0	14.0
b-jet tagging	6.0	6.0	5.0	5.0		8.0			
jet$\rightarrow$b mis-id							8.0	9.0	9.0
muon selections	1.0	1.0	1.0	1.0		1.0	1.0	1.0	1.0
τ fakes (stat)					6.0				
τ fakes (syst)					11.0				
cross-section	20.0					8.0	4.0	4.0	
MC stats	3.0	3.0	2.0	6.0		5.0	8.0	71.0	12.0
luminosity	6					6			

e-mu channel

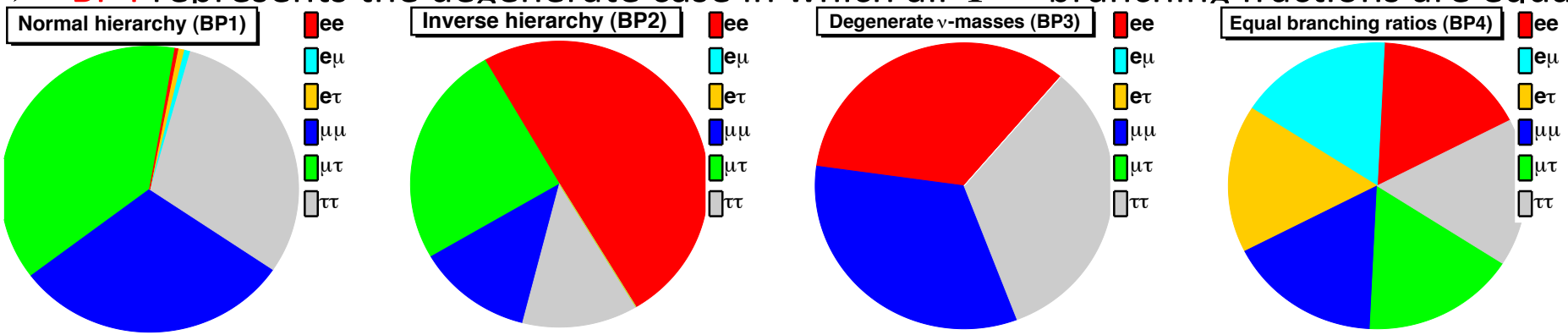
	HH	WH	$t\bar{t}$	DY(ll)	W+jets	Single top	VV
JES+JER+MET	2.8	2.8	2.8	7.0	6.0	4.9	4.8
dilepton selection	2.5	2.5	2.5	2.5	2.5	2.5	2.5
cross section	20.0	20.0	20.0	4.0	5.0	8.0	4.0
MC stats	7.5	3.4	0.5	3.2	16.0	2.5	2.7
luminosity	6						

Summary of results (95% CL upper limits)

Model point	Former limit	CMS @ 36 pb^{-1}	CMS @ 0.98 fb^{-1}	Only pair-production
BR(Φ^{++}->ee)=100%	133 GeV	144 GeV	313 GeV	274 GeV
BR(Φ^{++}->eμ)=100%	115 GeV	154 GeV	313 GeV	275 GeV
BR(Φ^{++}->$\mu\mu$)=100%	150 GeV	156 GeV	313 GeV	277 GeV
BR(Φ^{++}->eτ)=100%	112 GeV	106 GeV	254 GeV	211 GeV
BR(Φ^{++}->$\mu\tau$)=100%	144 GeV	106 GeV	266 GeV	219 GeV
BP1	N/A	116 GeV	269 GeV	236 GeV
BP2	N/A	131 GeV	297 GeV	263 GeV
BP3	N/A	130 GeV	291 GeV	258 GeV
BP4	N/A	127 GeV	289 GeV	255 GeV

Model points chosen

- Six standard searches covered, where **BR($\Phi^{++} \rightarrow l^+l^+$)=100%**
- Four additional model dependent points to describe the neutrino sector
- BP1 describes the neutrino sector with normal mass hierarchy and a massless lightest neutrino, $m_1 = 0$ eV.
- BP2 describes the same but with the inverse mass hierarchy
- BP3 represents a degenerate neutrino mass spectrum with $m_1 = 0.2$ eV
- BP4 represents the degenerate case in which all Φ++ branching fractions are equal.



Selection strategy

- Pre-selection:
  - At least two leptons with pT > 35 / 10 GeV
  - Loose isolation requirement
  - Veto of low invariant mass resonances (< 12 GeV)

- Three lepton final state:

Label	Selection
Pre-selection	Correct topology (++- or - -+)
Scalar sum of p_T	$\sum p_T > m(\Phi) + 80\,\text{GeV}$
Relative isolation	$\sum relIso_{lepton} < 0.1$
Veto of events containing a Z boson	$\min\lvert m(\ell^+\ell^-) - m_Z\rvert > 6\,\text{GeV}$
Opening angle between same-sign leptons	$\phi(\ell^\pm\ell^\pm) < 1.8\text{rad}$
Counting of events in a mass window	$m(\ell^\pm\ell^\pm) \in (m_{lower}, m(\Phi)+10\ \text{GeV})$

- Four lepton final state:

Label	Selection
Pre-selection	Correct topology (++- - or - -++) + optional extra leptons
Relative isolation	$\sum relIso_{lepton} < 0.125$
Scalar sum of p_T	$\sum p_T > m(\Phi) + 80\,\text{GeV}$
Counting of events in a mass window	$m(\ell^+\ell^+) \in (m_{lower}, m(\Phi)+10\ \text{GeV})$
	$m(\ell^-\ell^-) \in (m_{lower}, m(\Phi)+10\ \text{GeV})$

The backgrounds have been measured from data extrapolating from sidebands

Background estimation

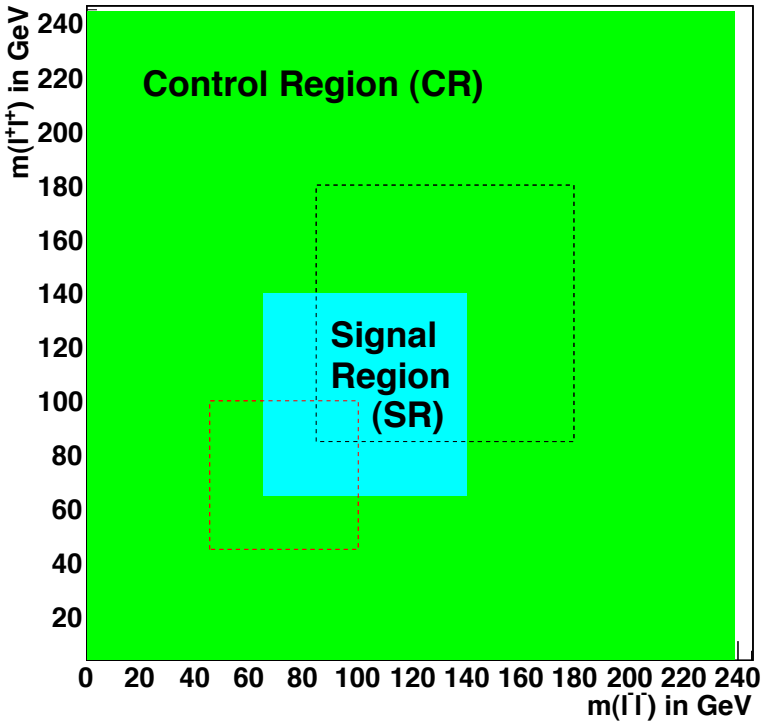
- Background is driven from data using the sidebands method
- Control region is the 1D or 2D (depending if it's 3- or 4-lepton analysis) region in the invariant mass distribution outside search mass window after the tight isolation requirements

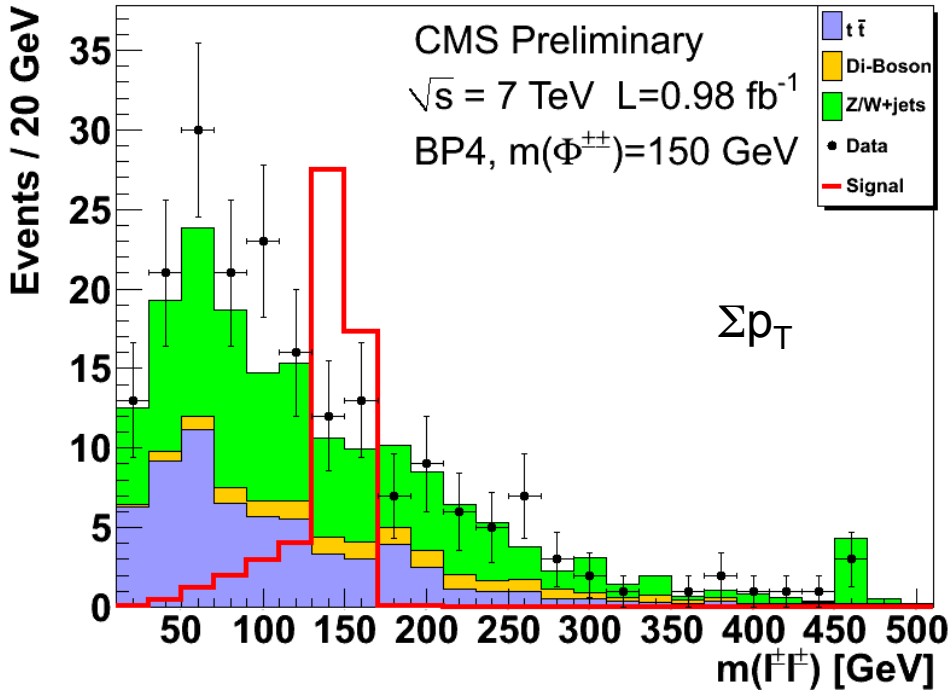
$$\alpha = N_{SR} / N_{CR} \text{ in MC}$$

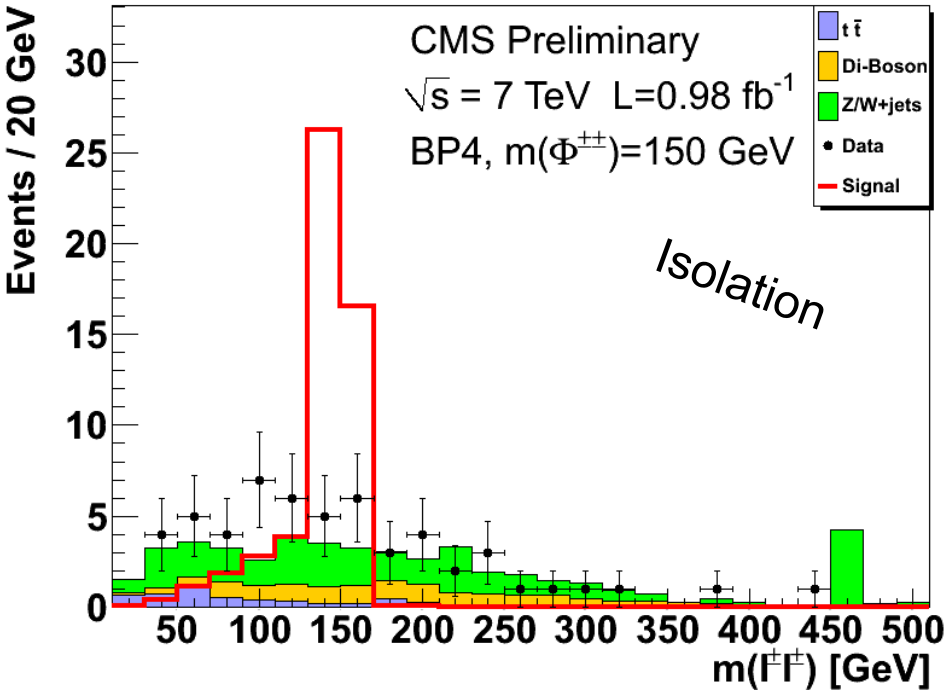
$$N_{BG} = \alpha \, (N_{CR}^{Data}+1)$$

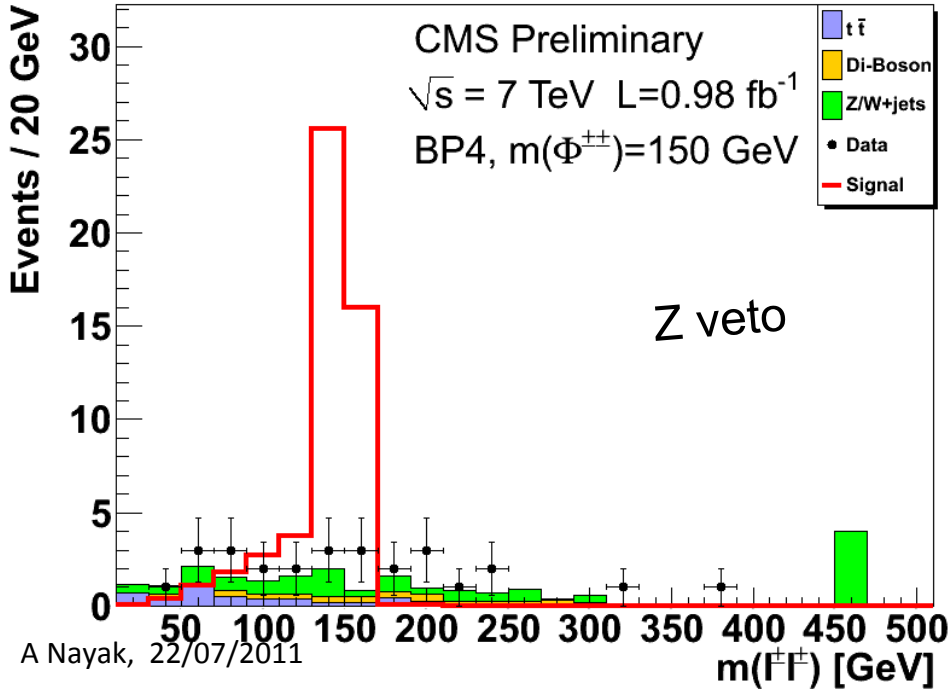
$$\Delta N_{BG} = 1/\mathrm{sqrt}(N_{CR}^{Data}+1)$$

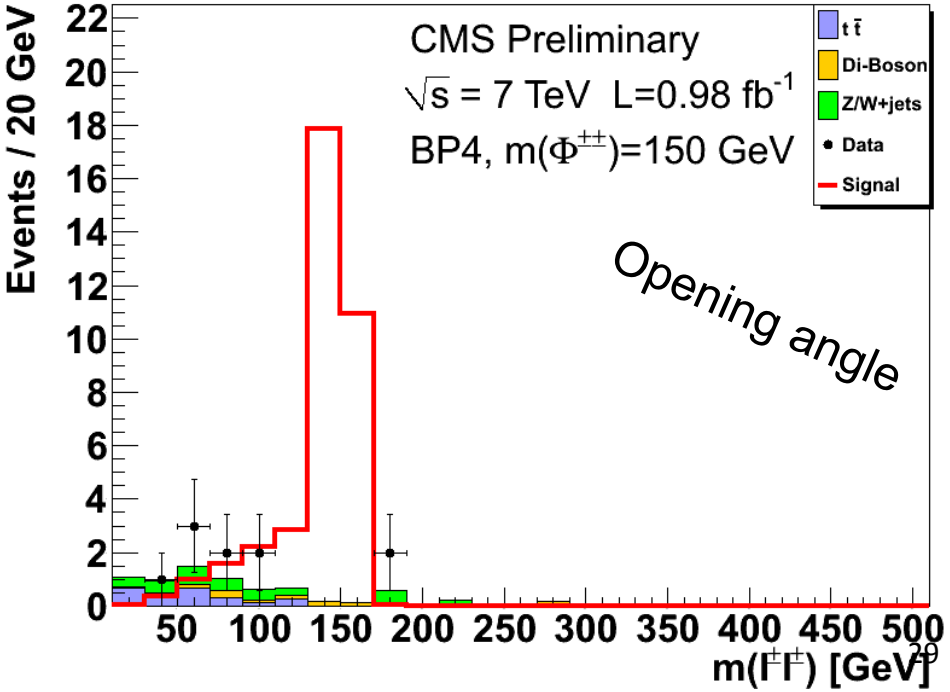
- If not enough statistics available in SR or CR the MC statistical uncertainty is used and a 100% error is attached



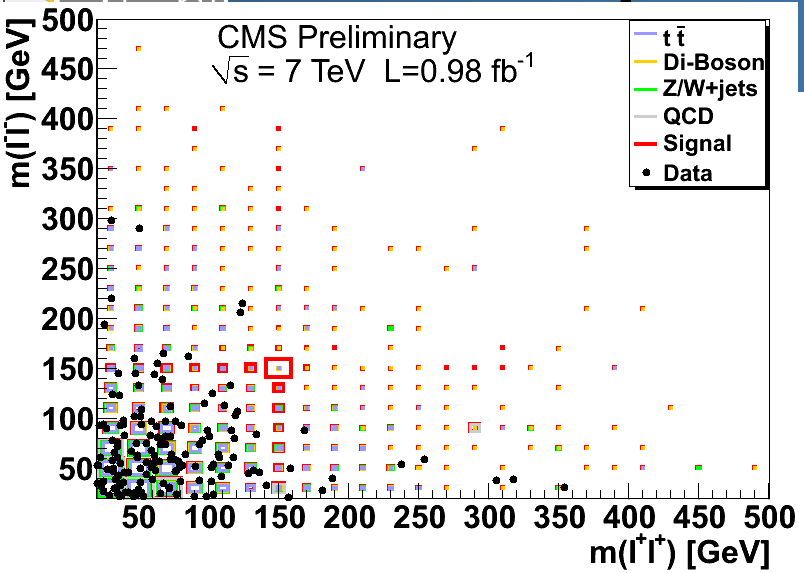

CMS Preliminary
$\sqrt{s}$ = 7 TeV L=0.98 fb^{-1}
BP4, m($\Phi^{\pm\pm}$)=150 GeV
$t\bar{t}$
Di-Boson
Z/W+jets
Data
Signal
Σp_T
Events / 20 GeV
m($l^{\pm}l^{\pm}$) [GeV]

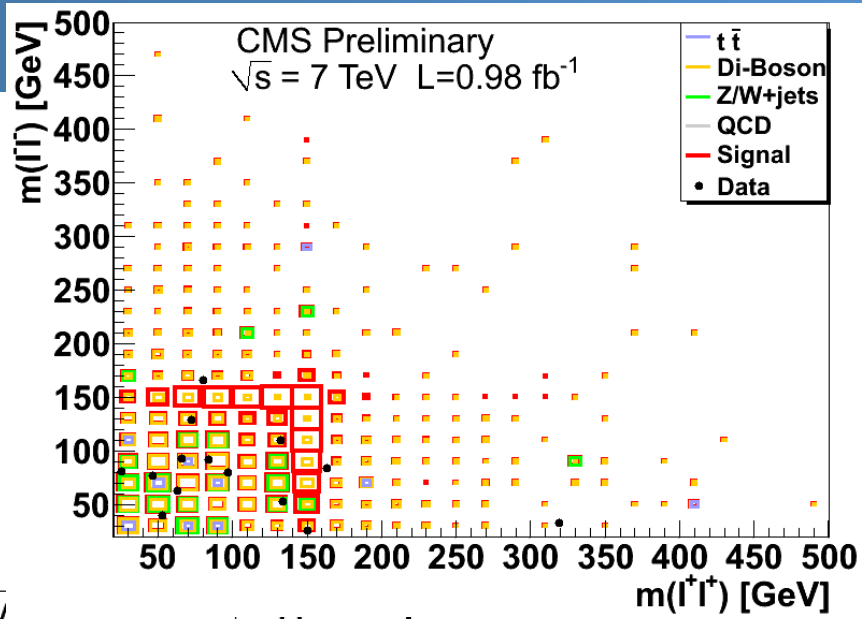

CMS Preliminary
$\sqrt{s}$ = 7 TeV L=0.98 fb^{-1}
BP4, m($\Phi^{\pm\pm}$)=150 GeV
$t\bar{t}$
Di-Boson
Z/W+jets
Data
Signal
Isolation
Events / 20 GeV
m($l^{\pm}l^{\pm}$) [GeV]

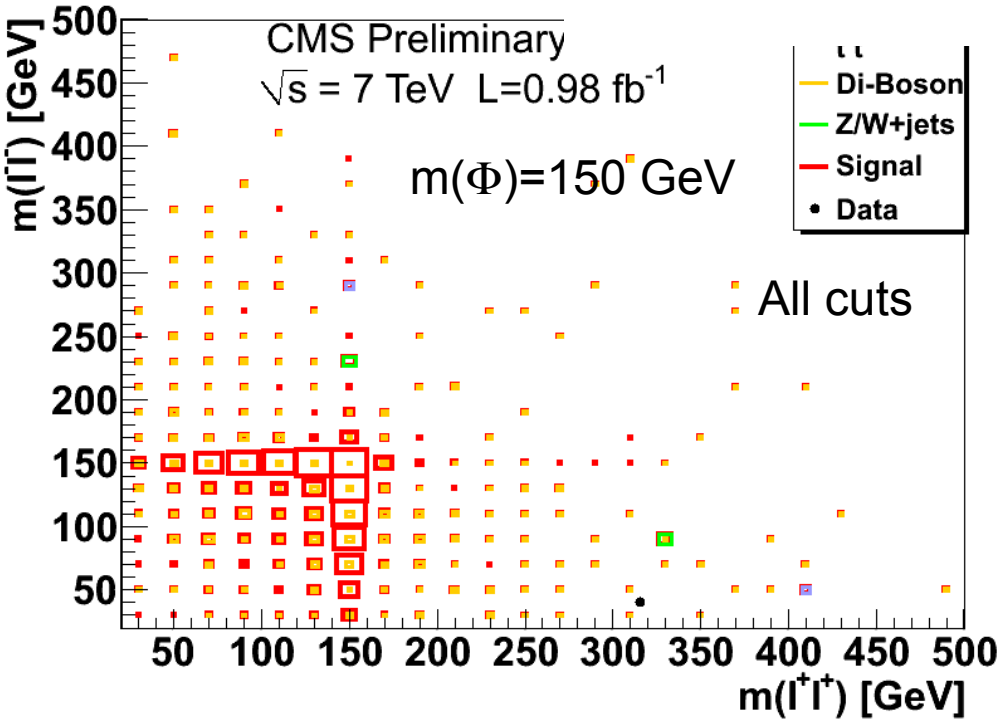

CMS Preliminary
$\sqrt{s}$ = 7 TeV L=0.98 fb^{-1}
BP4, m($\Phi^{\pm\pm}$)=150 GeV
$t\bar{t}$
Di-Boson
Z/W+jets
Data
Signal
Z veto
Events / 20 GeV
m($l^{\pm}l^{\pm}$) [GeV]


CMS Preliminary
$\sqrt{s}$ = 7 TeV L=0.98 fb^{-1}
BP4, m($\Phi^{\pm\pm}$)=150 GeV
$t\bar{t}$
Di-Boson
Z/W+jets
Data
Signal
Opening angle
Events / 20 GeV
m($l^{\pm}l^{\pm}$) [GeV]

Four lepton final state







Systematic uncertainties

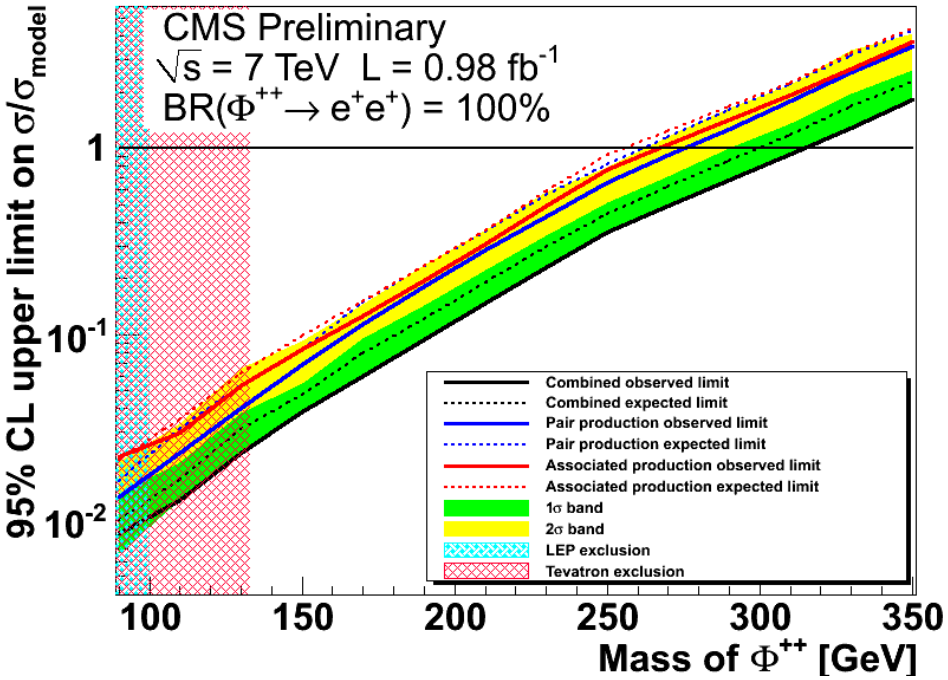
Source	Uncertainty
Lepton ID+RECO+Isolation+k-factors (e and μ unified)	2%
Tau jet ID+RECO+Isolation	8%
Trigger + primary vertex finding	1.5%
Signal cross section	10%
Luminosity	6%
Uncertainty on α, comes from PDF, QCD scale and lepton energy scale	5% / 100%*
Statistical uncertainty of signal MC	1-7%
Statistical uncertainty on observed events in control region	5-100%**

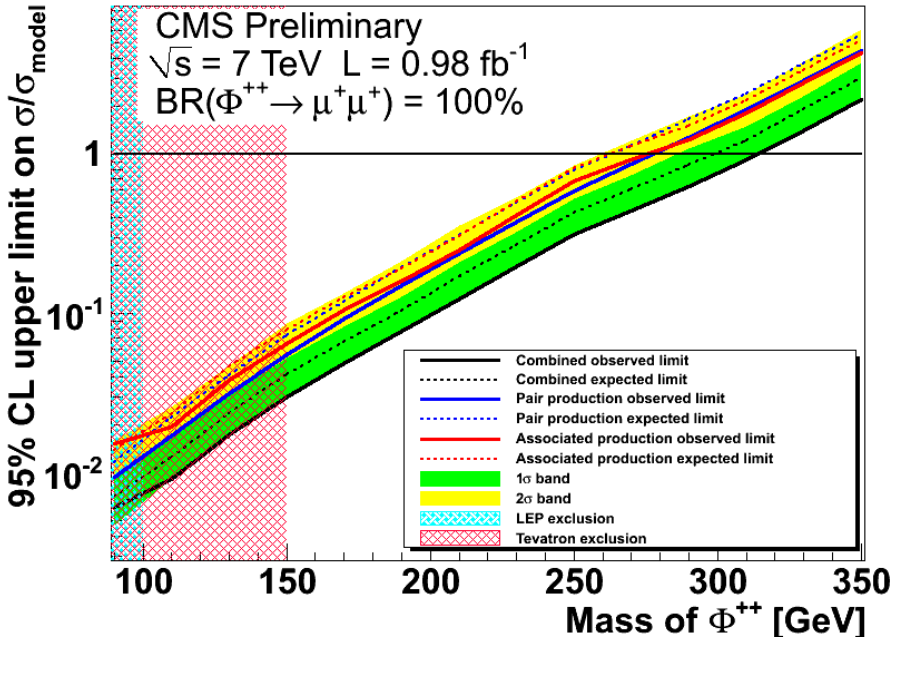
* If not enough statistics in MC are available and statistical uncertainty is used, then 100% is used as the uncertainty on the ratio

** Varies by channel, background topology and search mass

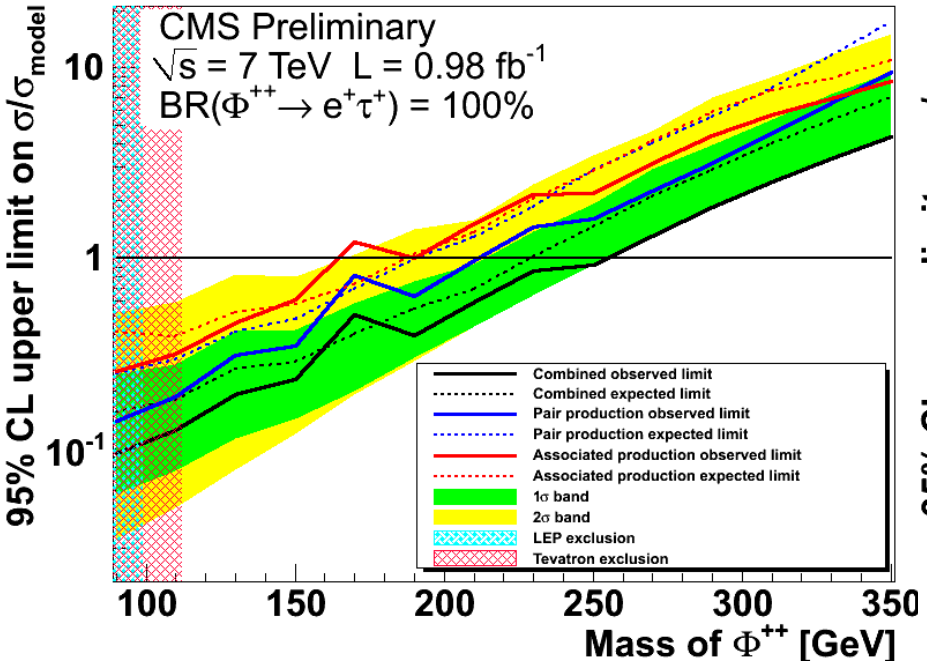
Limits are calculated with the CLs method in five categories based on lepton count and number of tau jets in the final state

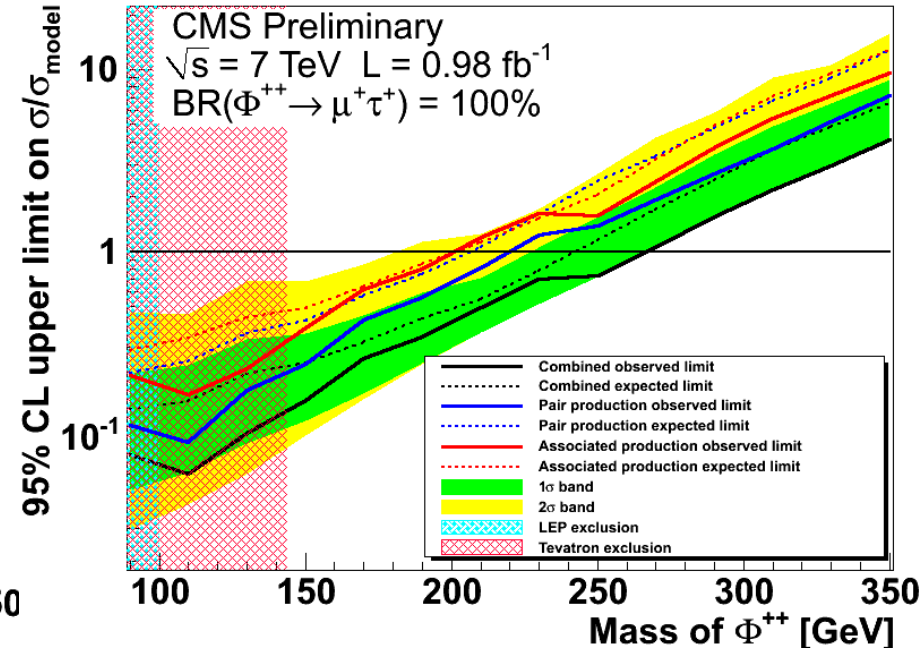
Limits


CMS Preliminary
√s = 7 TeV L = 0.98 fb-1
BR(Φ++→ e+e+) = 100%
95% CL upper limit on σ/σmodel
Mass of Φ++ [GeV]
Combined observed limit
Combined expected limit
Pair production observed limit
Pair production expected limit
Associated production observed limit
Associated production expected limit
1σ band
2σ band
LEP exclusion
Tevatron exclusion

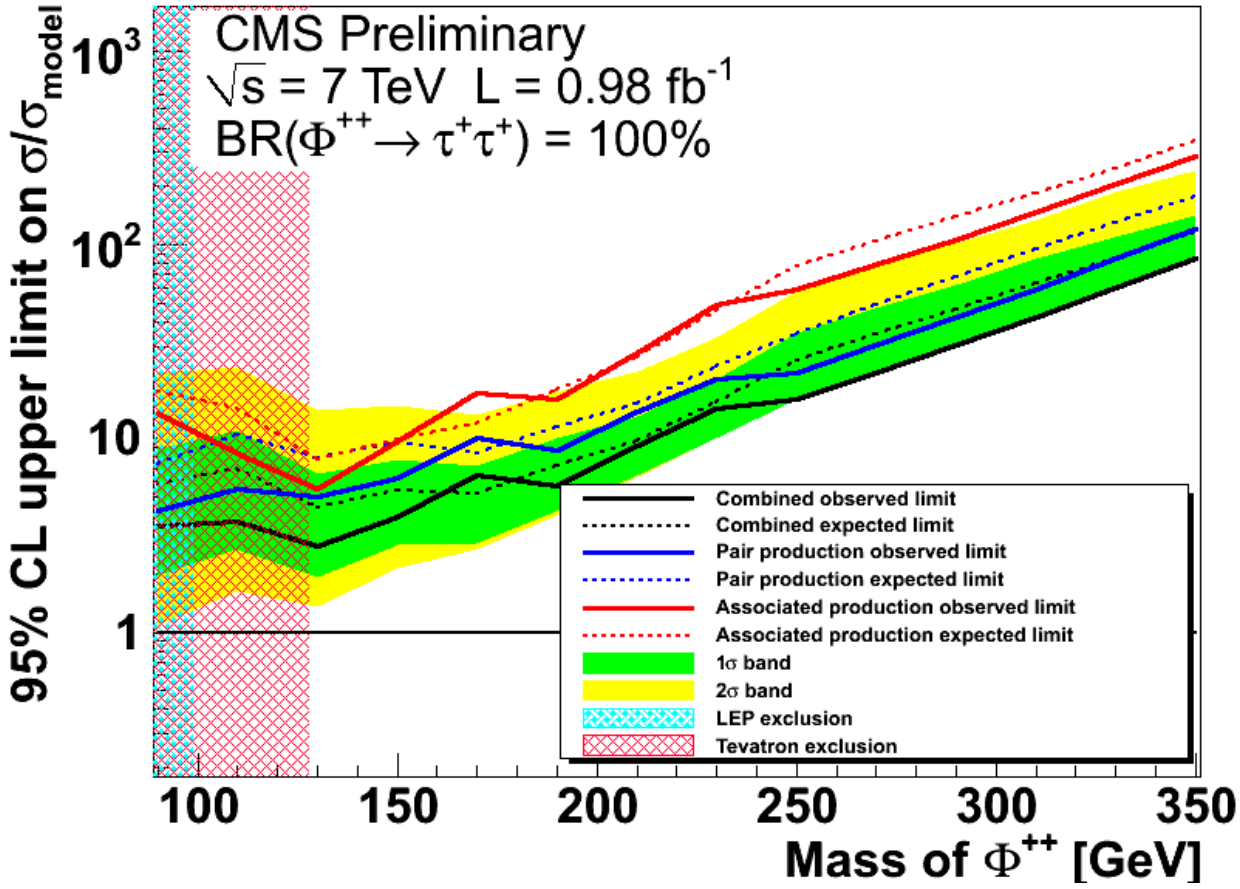

CMS Preliminary
√s = 7 TeV L = 0.98 fb-1
BR(Φ++→ μ+μ+) = 100%
95% CL upper limit on σ/σmodel
Mass of Φ++ [GeV]
Combined observed limit
Combined expected limit
Pair production observed limit
Pair production expected limit
Associated production observed limit
Associated production expected limit
1σ band
2σ band
LEP exclusion
Tevatron exclusion

Limits

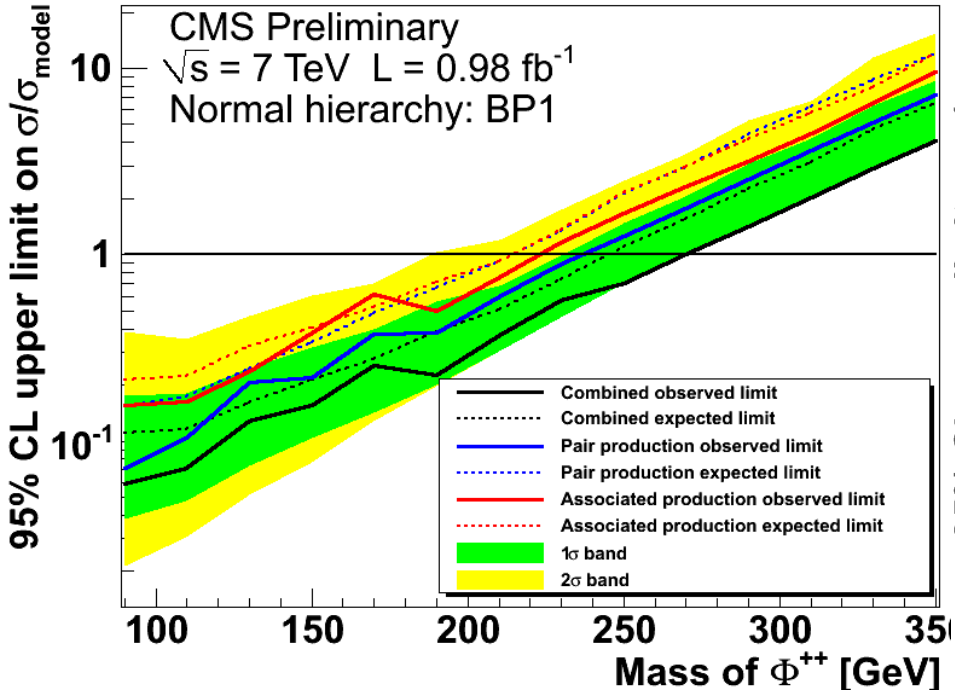

CMS Preliminary
√s = 7 TeV L = 0.98 fb-1
BR(Φ++→ e+τ+) = 100%
95% CL upper limit on σ/σmodel
Mass of Φ++ [GeV]
Combined observed limit
Combined expected limit
Pair production observed limit
Pair production expected limit
Associated production observed limit
Associated production expected limit
1σ band
2σ band
LEP exclusion
Tevatron exclusion

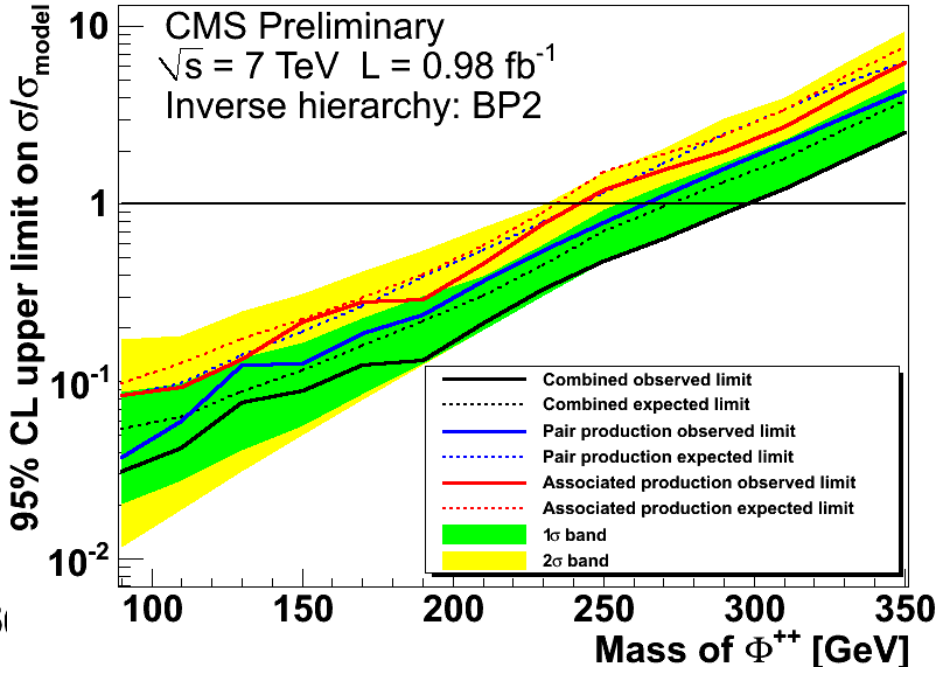

CMS Preliminary
√s = 7 TeV L = 0.98 fb-1
BR(Φ++→ μ+τ+) = 100%
95% CL upper limit on σ/σmodel
Mass of Φ++ [GeV]
Combined observed limit
Combined expected limit
Pair production observed limit
Pair production expected limit
Associated production observed limit
Associated production expected limit
1σ band
2σ band
LEP exclusion
Tevatron exclusion

Limits

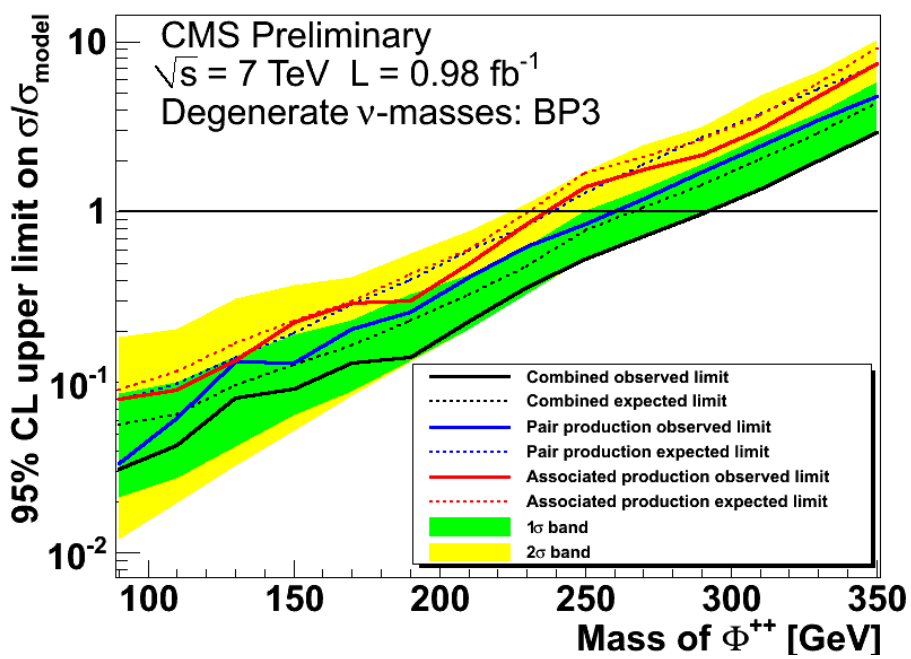

CMS Preliminary
√s = 7 TeV L = 0.98 fb-1
BR(Φ++ → τ+τ+) = 100%
95% CL upper limit on σ/σmodel
10³
10²
10
1
100
150
200
250
300
350
Mass of Φ++ [GeV]
Combined observed limit
Combined expected limit
Pair production observed limit
Pair production expected limit
Associated production observed limit
Associated production expected limit
1σ band
2σ band
LEP exclusion
Tevatron exclusion

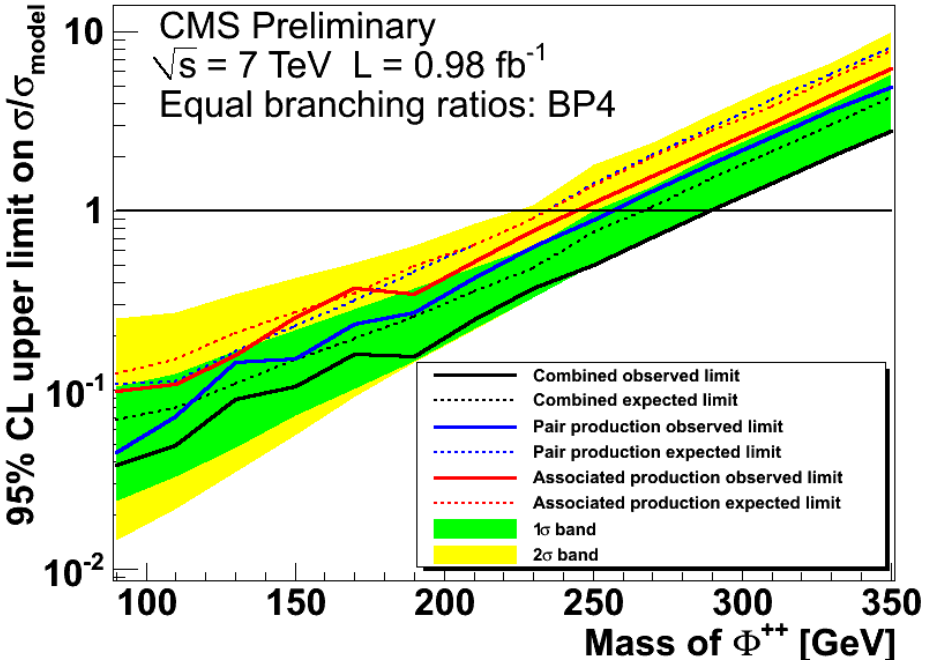
Limits


CMS Preliminary
√s = 7 TeV L = 0.98 fb-1
Normal hierarchy: BP1
95% CL upper limit on σ/σmodel
Mass of Φ++ [GeV]
Combined observed limit
Combined expected limit
Pair production observed limit
Pair production expected limit
Associated production observed limit
Associated production expected limit
1σ band
2σ band

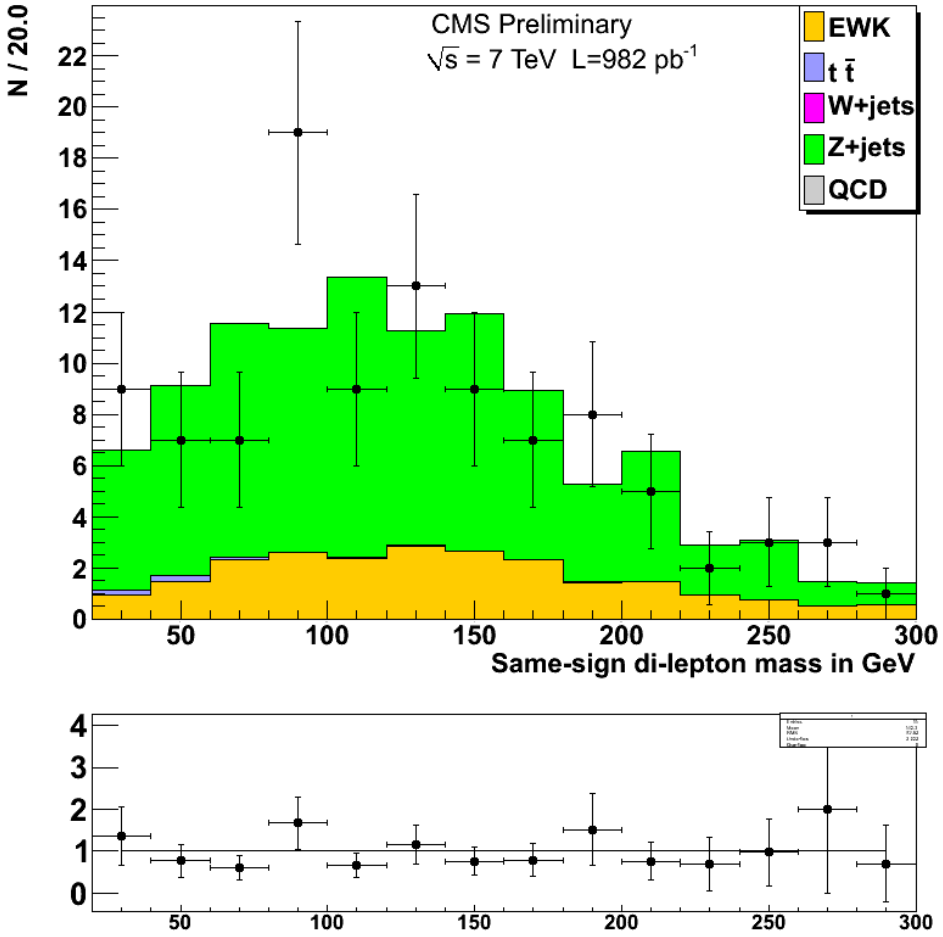

CMS Preliminary
√s = 7 TeV L = 0.98 fb-1
Inverse hierarchy: BP2
95% CL upper limit on σ/σmodel
Mass of Φ++ [GeV]
Combined observed limit
Combined expected limit
Pair production observed limit
Pair production expected limit
Associated production observed limit
Associated production expected limit
1σ band
2σ band

Limits

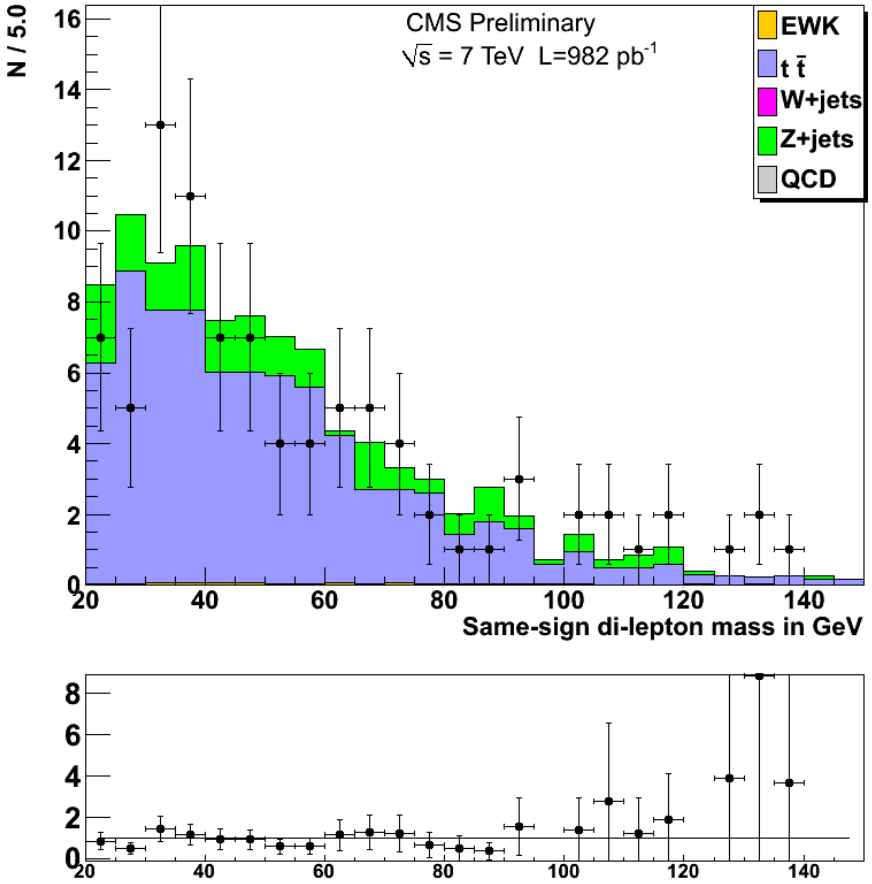

CMS Preliminary
√s = 7 TeV L = 0.98 fb-1
Degenerate ν-masses: BP3
95% CL upper limit on σ/σmodel
Mass of Φ++ [GeV]
Combined observed limit
Combined expected limit
Pair production observed limit
Pair production expected limit
Associated production observed limit
Associated production expected limit
1σ band
2σ band


CMS Preliminary
√s = 7 TeV L = 0.98 fb-1
Equal branching ratios: BP4
95% CL upper limit on σ/σmodel
Mass of Φ++ [GeV]
Combined observed limit
Combined expected limit
Pair production observed limit
Pair production expected limit
Associated production observed limit
Associated production expected limit
1σ band
2σ band

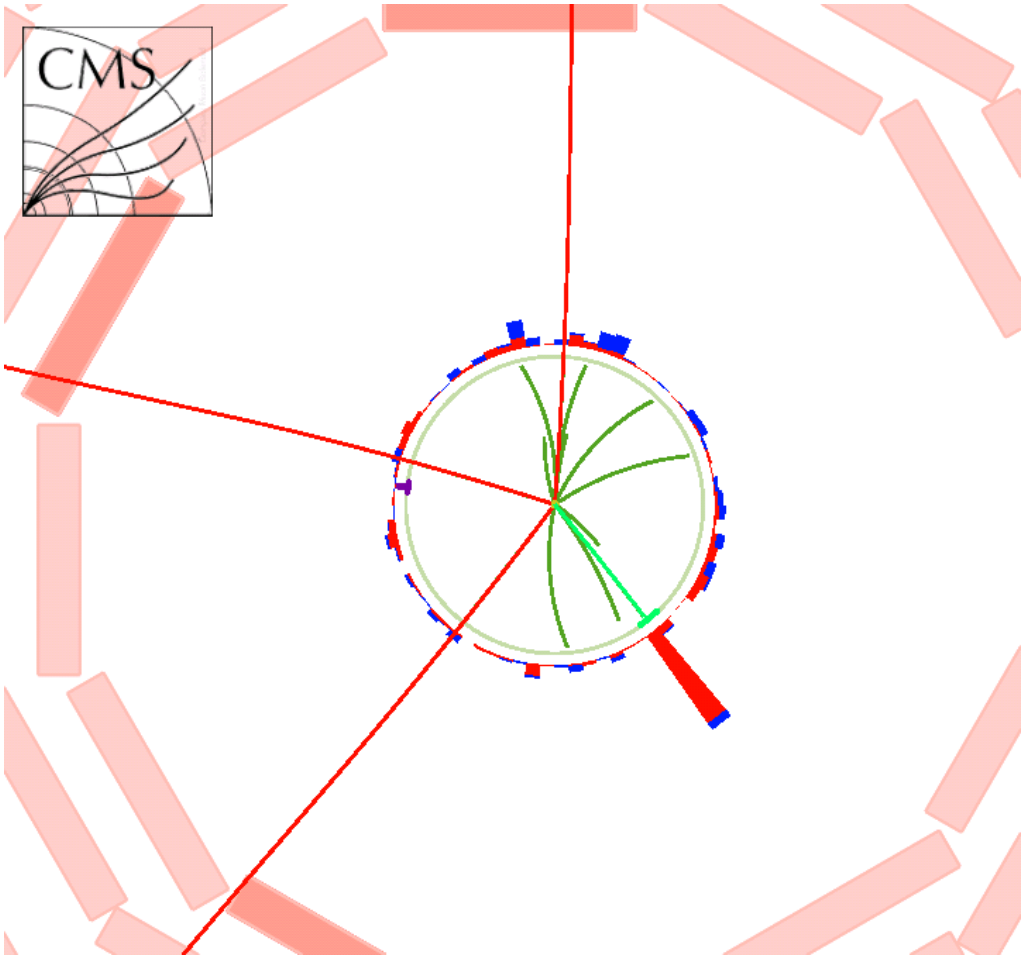
Background check plots



Reversed Z veto after isolation + Σp_T



Preselection, Z veto, reversed isolation + Σp_T, opening angle


CMS