CMS results in H^+ and Φ^{++} searches

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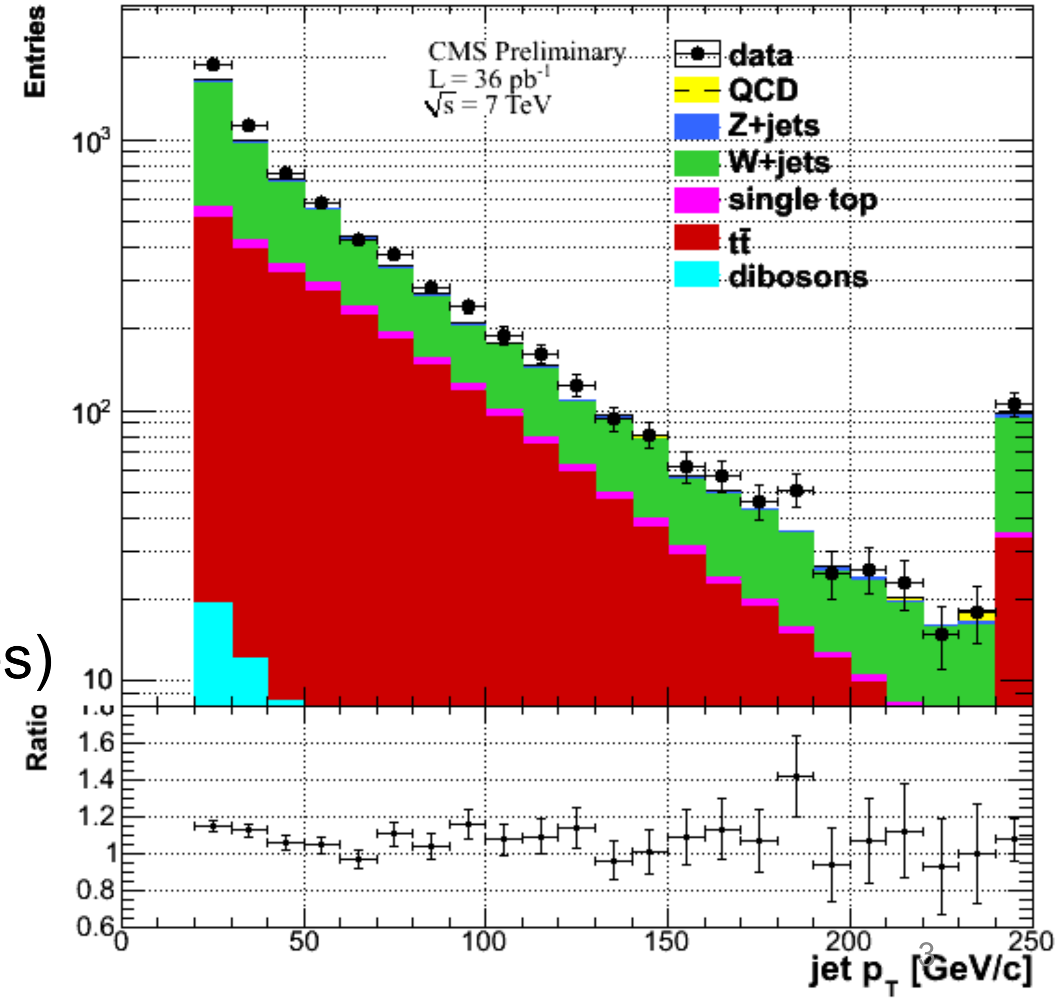
Introduction

- The are ordinary and standard searches
- And then there are non-standard/exotic searches
- Today we cover two of them:
  - MSSM H^{+} in top pairs
  - Doubly charged Higgs (Φ^{++})

Charged Higgs (H^+) CMS-PAS-HIG-11-002

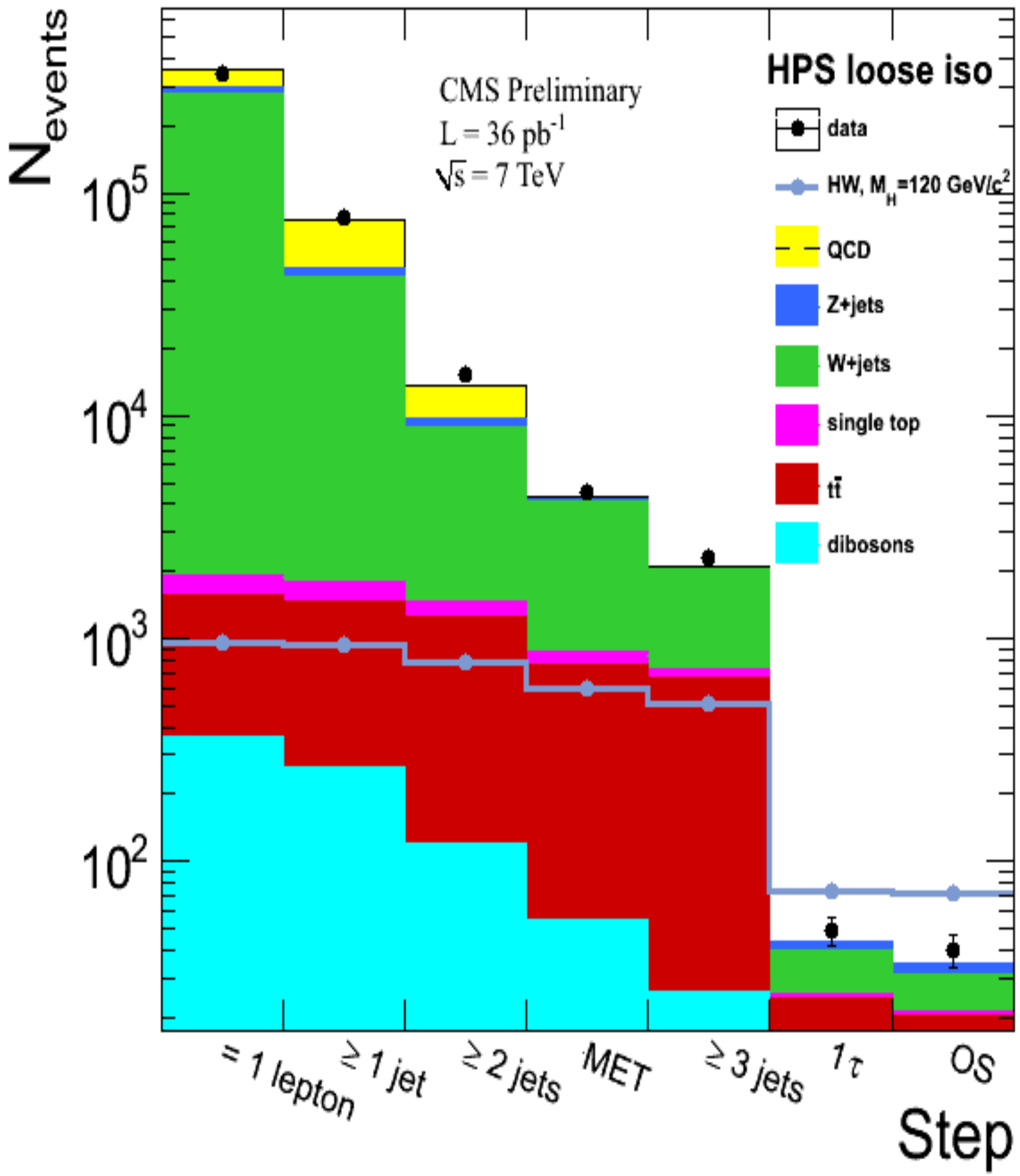
- If the H^+ is lighter than top, then we could witness anomalous top decays
- Assuming H^+ decays 100% to $\tau\nu$ this would show up as excess in τ channel

Channel	Signature	BR
Dilepton	ee, $\mu\mu$, eμ + 2b-jets	4/81
Single lepton	e, μ + jets + 2b-jets	24/81
All-hadronic	jets + 2b-jets	36/81
Tau+lepton	eτ, $\mu\tau$ + 2b-jets	4/81
Tau+jets	τ + jets + 2b-jets	12/81



- The dominant background is from W+3jets and $t\bar{t}$, where one of the jets fakes a τ (τ-fakes)
- In addition contributions come from $Z\rightarrow\tau\tau$+jets, single top and di-boson

Event selection



Similar to CMS top pair cross section measurement in lepton+jets channel (CMS-PAS-TOP-10-002)

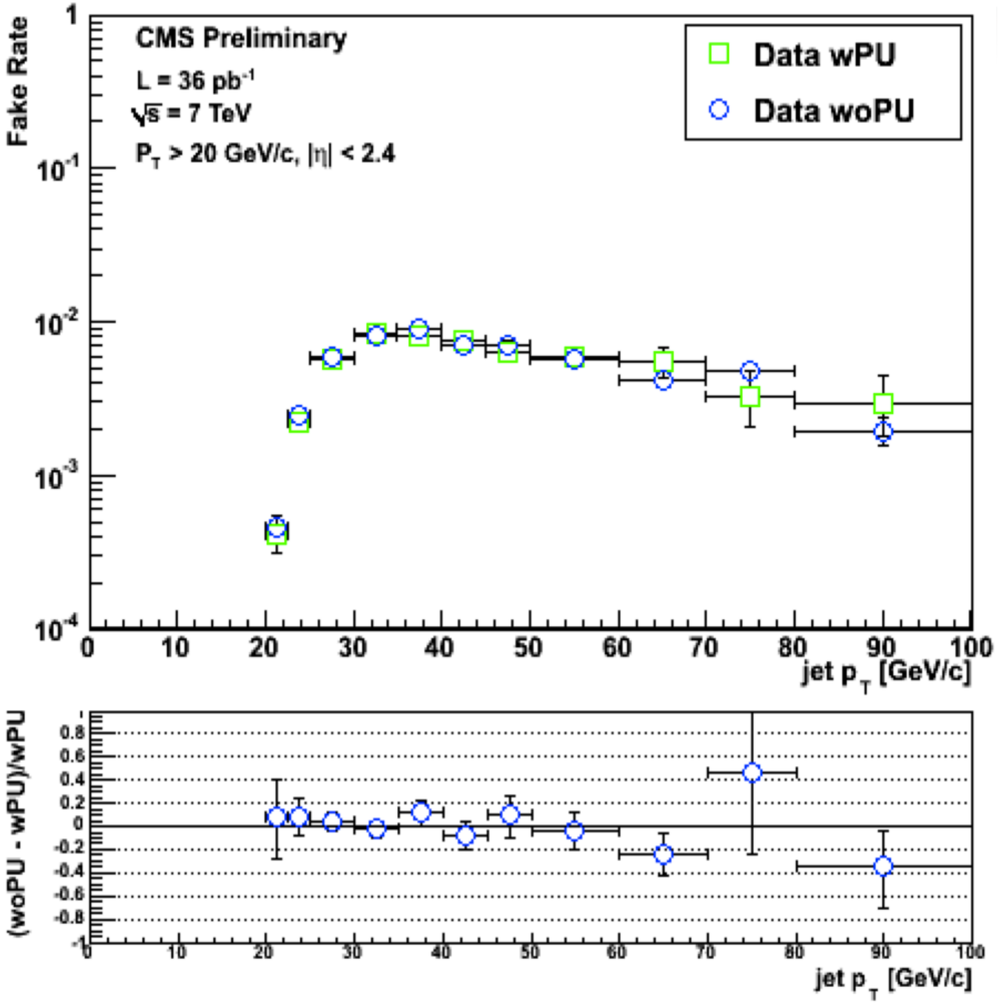
- Trigger selection: single lepton triggers
- 1 hard and isolated e or μ with E_T>30 GeV (p_T>20 GeV/c for μ)
- 2 hard jets, p_T > 30 GeV/c: no b-tag
- MET > 40 GeV
- 1 τ with p_T > 20 GeV/c (HPS loose isolation)
- The lepton and τ have to be of opposite sign

No significant excess of events in data is found with respect to Standard Model expectations

Background from jets faking τ

Dominated by W+jets and ttbar → l + jets

- Data driven background estimation :
  - Select jets in events with :
    1 lepton + MET + ≥3 jets
  - Apply to every jet the "jet→tau probability"



Probability that a jet fakes a *tau*-jet as obtained from the QCD multi-jet events taken during runs with and without pileup.

Systematic Uncertainty

- Jet → τ probability evaluated from QCD multi-jets (gluon dominated) and W+jet type events (quark dominated)
- Jets in lepton+MET+ ≥ 3jets events have a gluon/quark composition between the two samples
- Take average between W+jet and QCD values and assign half the difference between the two as the systematic uncertainty

Systematic Uncertainty is measured to be ~ 25 – 30%

Systematic uncertainties

Theoretical uncertainty on the cross section

Luminosity uncertainty

Electron/Muon trigger & ID & isolation

Uncertainty on jet energy scale and resolution as well as missing transverse momentum

Uncertainty of a lepton faking τ

Uncertainty on τ ID efficiency

Source	$\varepsilon_{\tau-fakes}$ (%)	$\varepsilon_{\tau-ID}$ (%)	$\varepsilon_{\tau\ mis-ID}$ (%)	$\varepsilon_{JES+JER+MET}$ (%)	$\varepsilon_{e,\mu\ eff}$ (%)	$\varepsilon_{\sigma(th.)}$ (%)	ε_{Lumi} (%)
HH, M_{H^+}=120 GeV/c^2	–	8	–	9	3	7	4
HW, M_{H^+}=120 GeV/c^2	–	8	–	6	3	7	4
τ fakes	26	–	–	–	–	–	–
$t\bar{t} \to WbWb \to \ell\nu b\ \tau\nu b$	–	8	–	6	3	7	4
$t\bar{t} \to WbWb \to \ell\nu b\ \ell\nu b$	–	–	15	13	3	7	4
$Z/\gamma^* \to \tau\tau$	–	8	–	16	3	4	4
Single top	–	8	–	10	3	8	4
WW,WZ,ZZ	–	8	–	12	3	4	4

Evaluation of exclusion limits

A Bayesian method with flat signal strength prior is used to obtain the upper limits

The background and signal uncertainties modeled with lognormal pdf's, correlations taken into account.

Upper limit on excess of events on top of the SM backgrounds (N_{up}), which is then translated to the limit on branching ratio

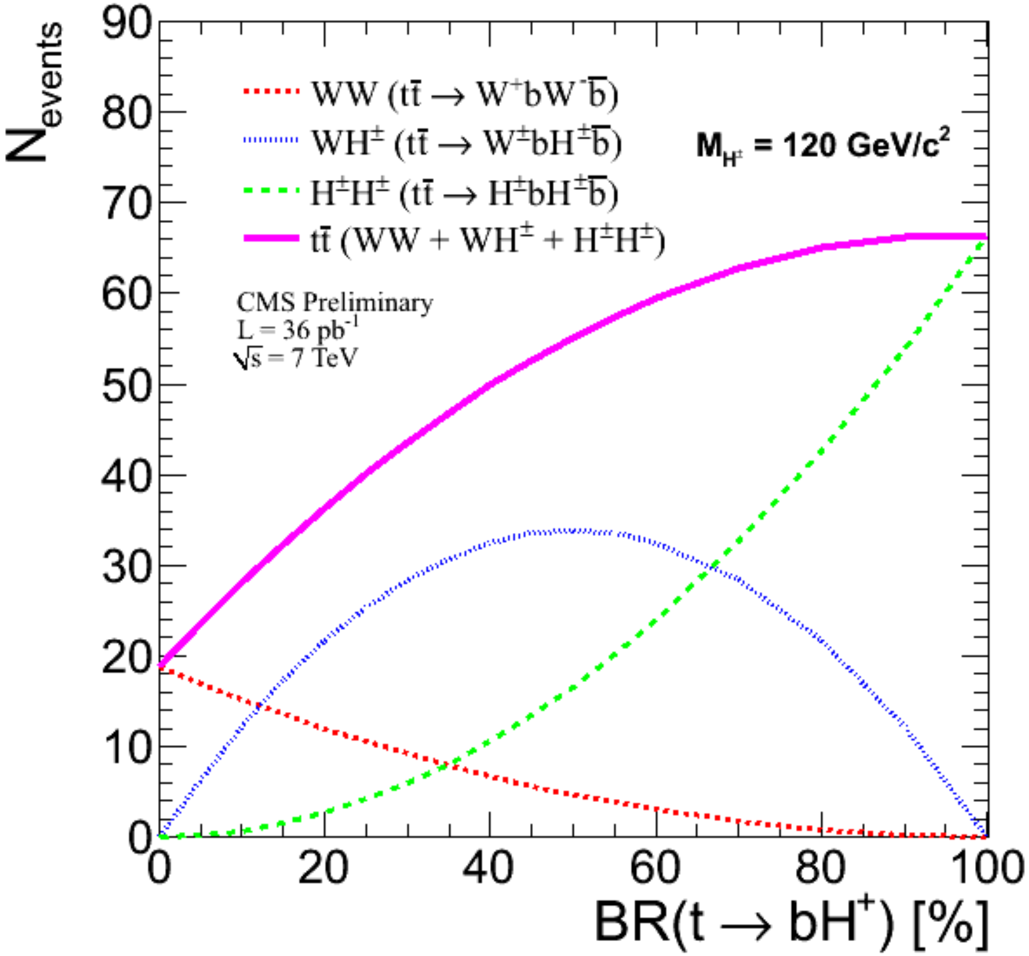
Source	N_{events}
HH, M_{H^+}=120 GeV/c^2	$66.5 \pm 1.8 \pm 9.7$
HW, M_{H^+}=120 GeV/c^2	$68.1 \pm 1.9 \pm 9.1$
τ fakes	$21.3 \pm 2.5 \pm 5.6$
$t\bar{t} \to WbWb \to \ell\nu b\ \tau\nu b$	$10.7 \pm 0.2 \pm 1.4$
$t\bar{t} \to WbWb \to \ell\nu b\ \ell\nu b$	$1.6 \pm 0.1 \pm 0.3$
$Z/\gamma^* \to ee, \mu\mu$	$0.3 \pm 0.1 \pm 0.2$
$Z/\gamma^* \to \tau\tau$	$3.0 \pm 0.3 \pm 0.6$
Single top	$1.0 \pm 0.0 \pm 0.2$
WW,WZ,ZZ	$0.5 \pm 0.0 \pm 0.1$
Expected from SM	$38.3 \pm 2.5 \pm 5.8$
Data	40

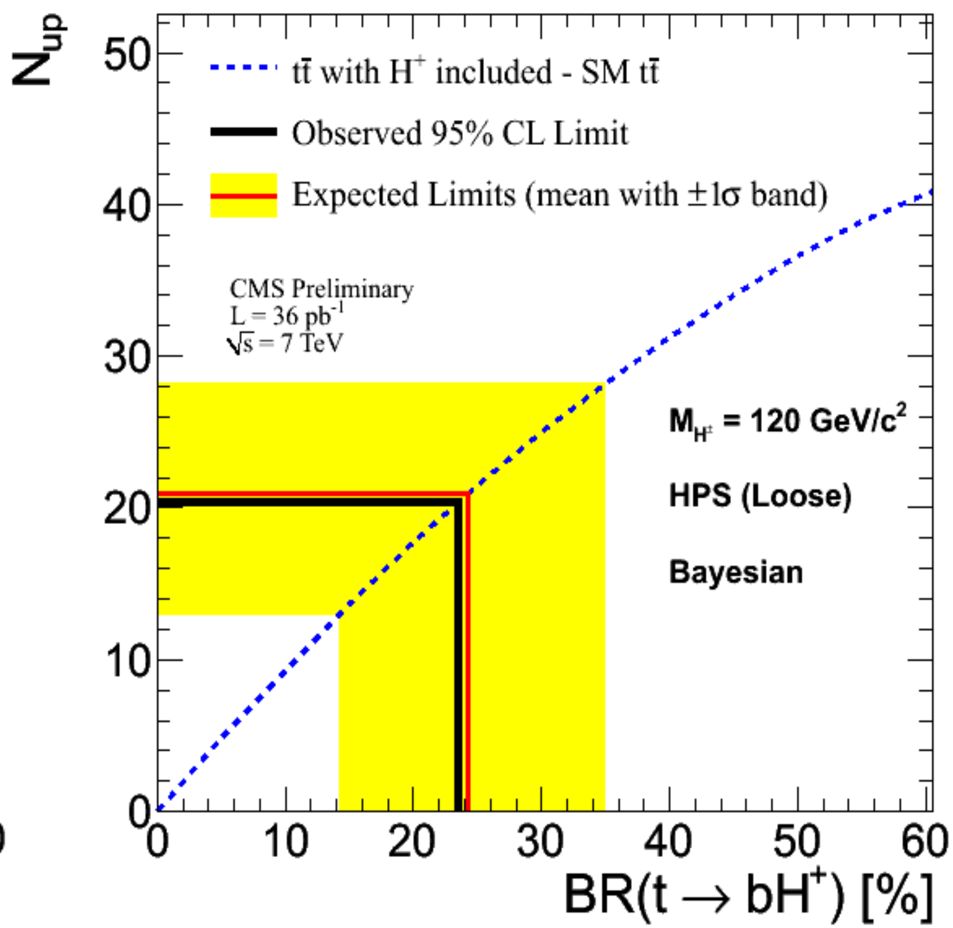
$$N_{up} = N_{WH} \cdot 2(1-x) \cdot x + N_{HH} \cdot x^2 + (N^{\ell\tau}_{SM\ tt} + N^{\ell\ell}_{SM\ tt} + N^{\ell qq'}_{SM\ tt}) \cdot (1-x)^2 - (N^{\ell\tau}_{SM\ tt} + N^{\ell\ell}_{SM\ tt} + N^{\ell qq'}_{SM\ tt}),$$

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

Branching ratio exclusion limits

Expected $t\bar{t}$ events

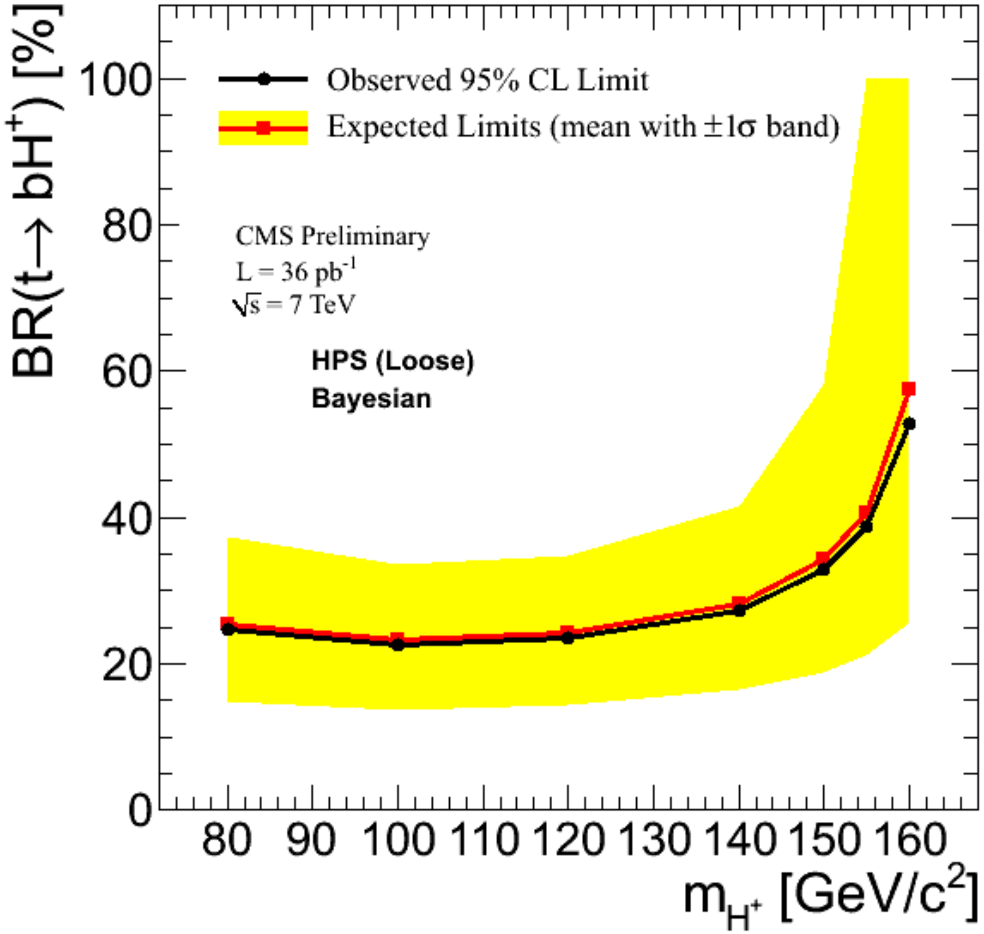


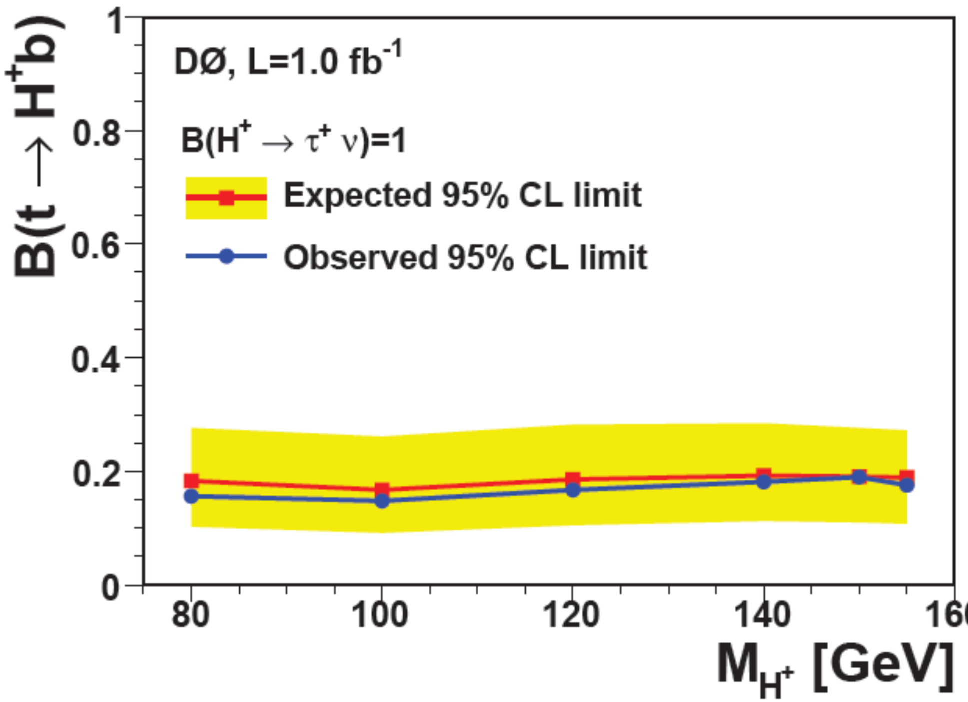


Branching ratio exclusion limits

Beginning to get interesting!

And that's with just 36 pb^{-1}





H^+ summary

- Search for charged Higgs boson in Top quark events was performed using 36 pb^{-1}

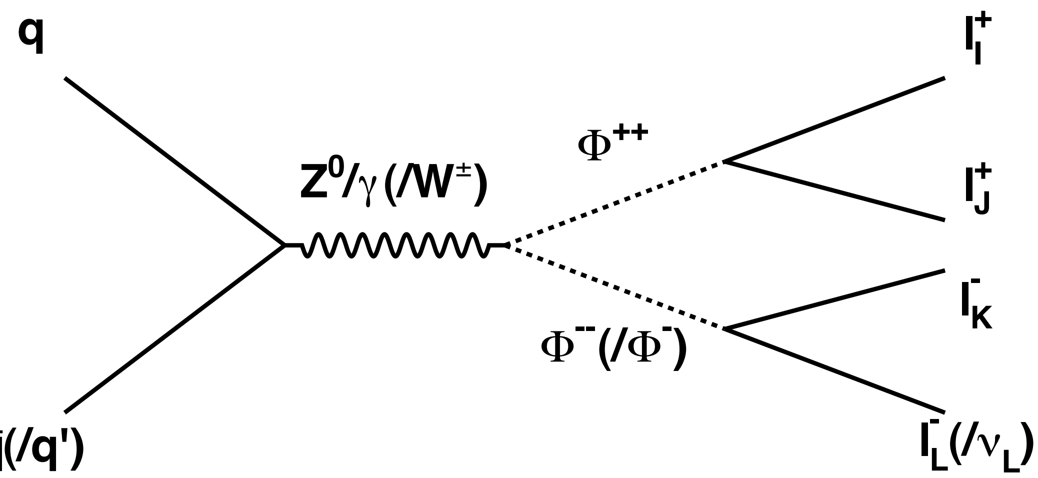
- Data is consistent with standard model expectation

- The largest background contributions come from
  a) the irreducible ttbar τ dilepton channel
  b) from τ-fakes where one jet fakes the τ

- Limits almost competitive with Tevatron ones, additional luminosity already on the way

Doubly charged Higgs (Φ^{++})
CMS-PAS-HIG-11-001

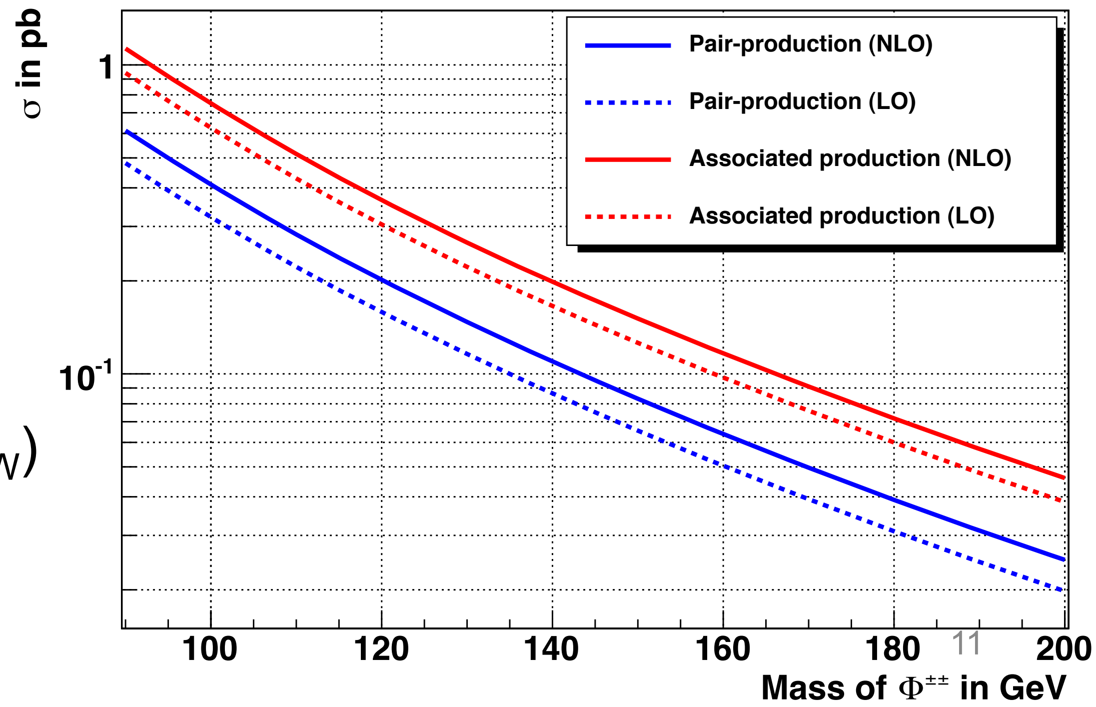
- Standard model extension by a scalar triplet adding three new particles
  - Φ^{++}, Φ^{+}, Φ^{0}



- The triplet is responsible for neutrino masses, the couplings being directly linked to the mass matrix
  - $M_{ij} = k\ Y_{ij}$

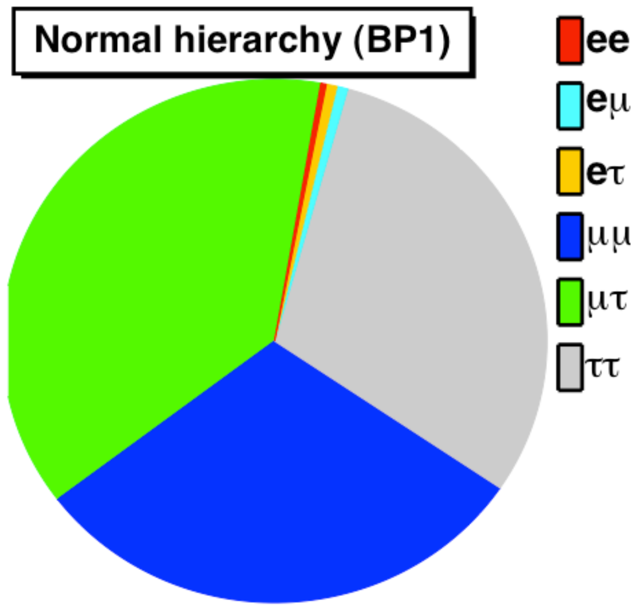
- Unknown neutrino mass matrix → unknown branching ratios

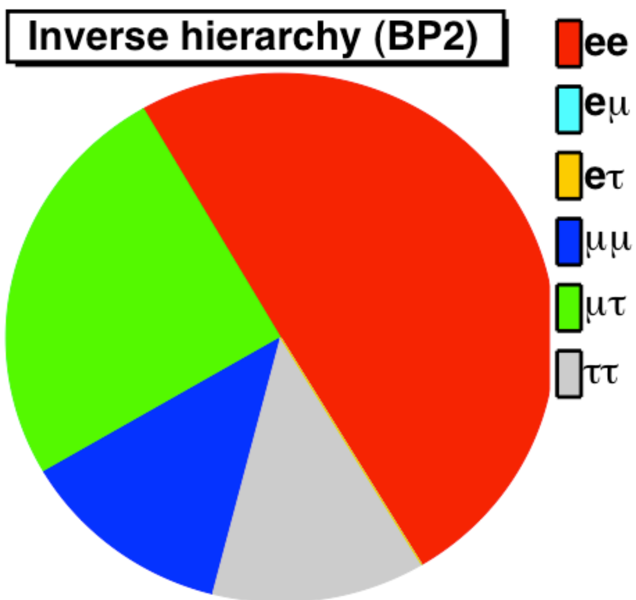
- below a mass of 160 GeV ($2M_W$) only leptons

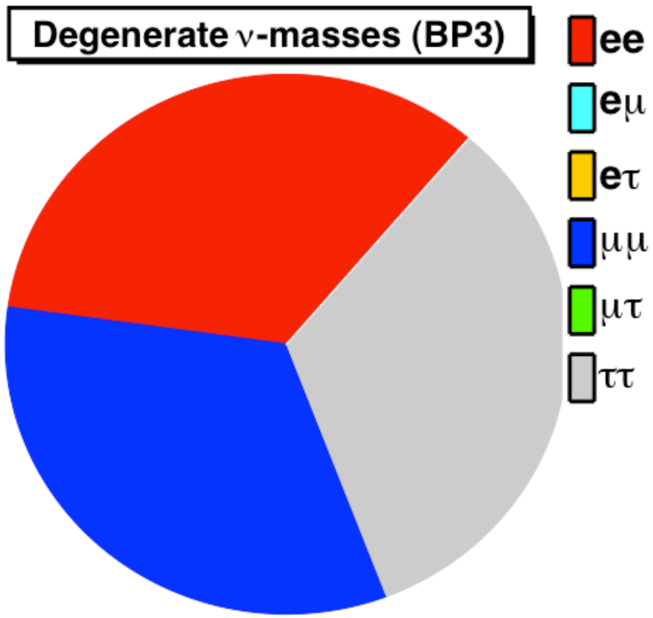


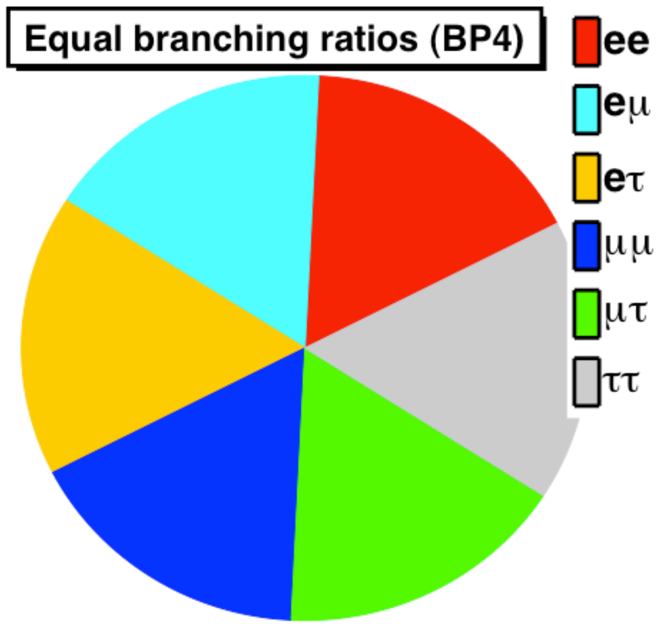
Model points

- Six standard searches, where BR($\Phi^{++} \rightarrow l^+l^+$)=100%
- 100% BR scenarios only cover 6 / 21 final states
- Four additional model dependent points that try to describe best the neutrino sector
- To cover the whole phase space **we perform an inclusive search**
- Cuts are optimized for inclusive results, not separately for each model point



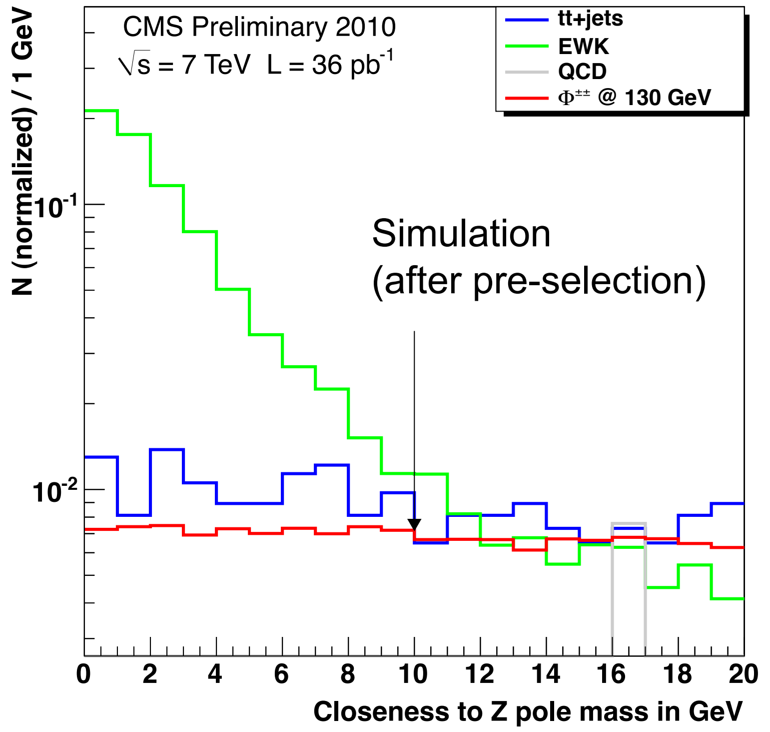


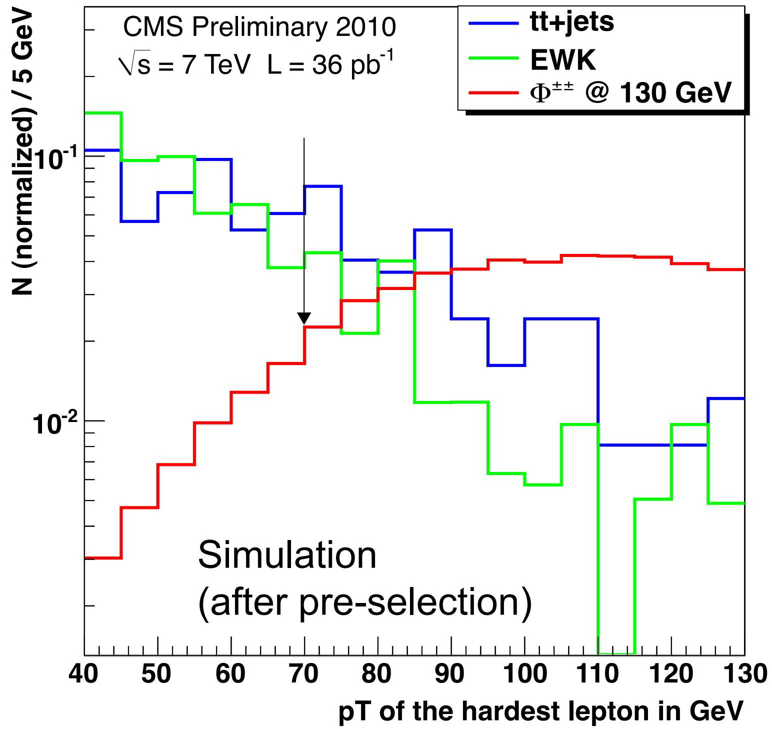




Experimental signature

- We consider both pair-production and associated production to enhance sensitivity
  - Three or four prompt isolated leptons in the final state
- The di-lepton combination is that of same charge
- Due to flavor non-conservation the final states can be combinations of all possible leptons
- The dominant backgrounds are di-boson, $t\bar{t}$ and Z+jets, all of which are reducible

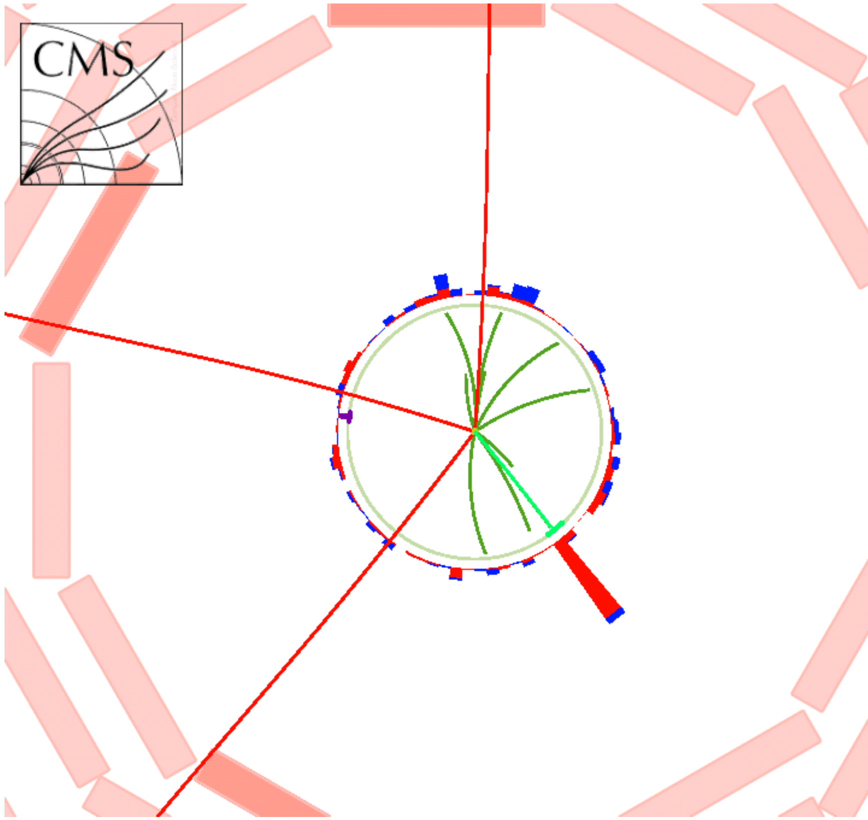




Event selection

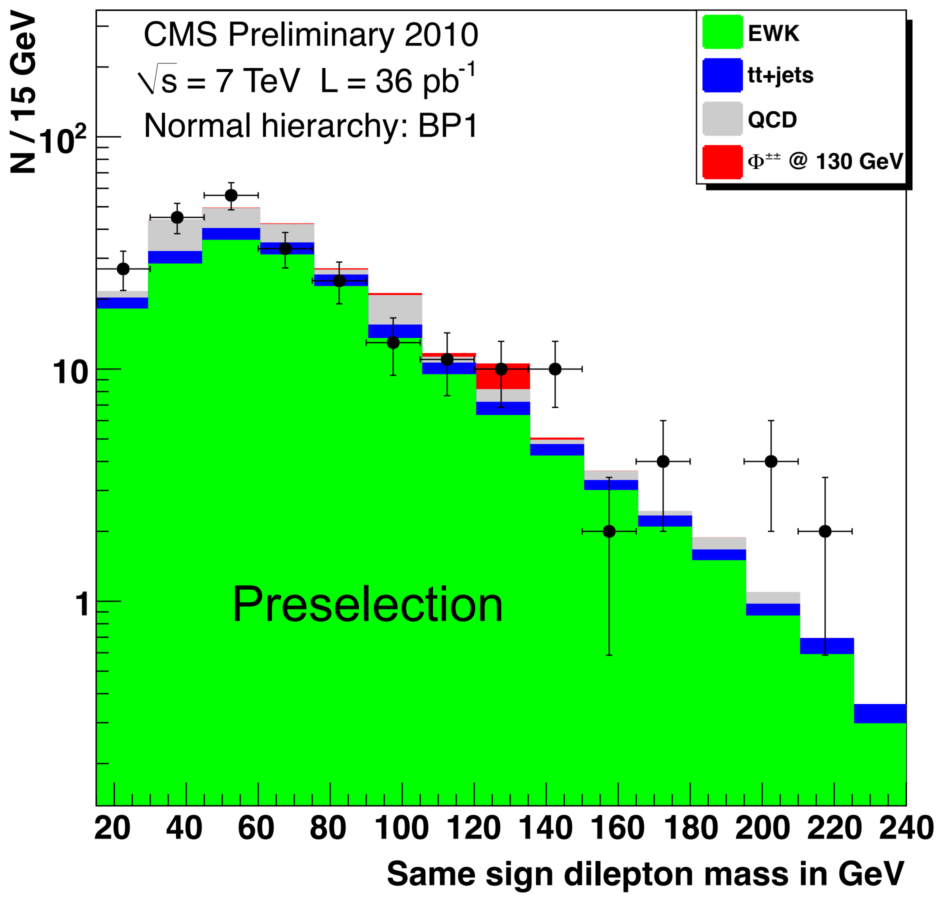
- Trigger: single lepton triggers
- Lepton ID:
  - Electrons: pT>15 GeV, |n|<2.5 and strong charge check with three different methods to reduce charge mis-identification to negligible levels
  - Muons: pT>5 GeV, |n|<2.5
  - Tau jets: p_T>15 GeV, |n|<2.1, HPS Loose selection

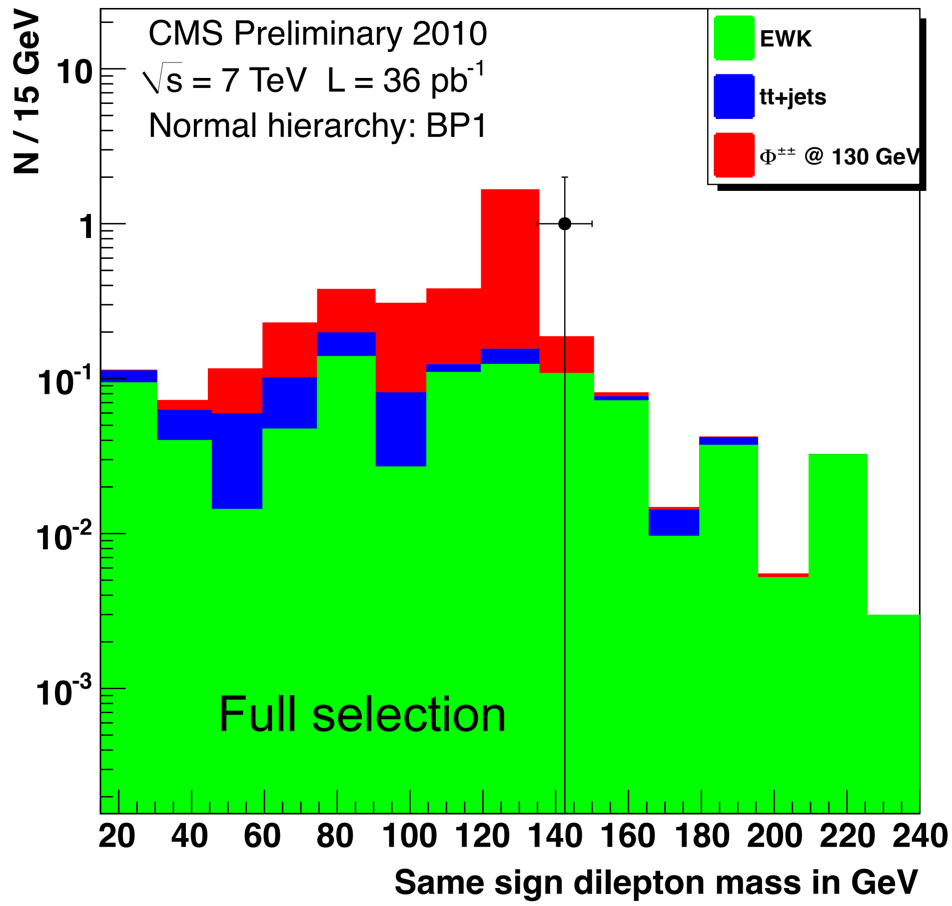
- τ-jets overlapping with an e or μ in a cone of 0.1 are vetoed
- To suppress low mass resonances any pair with mass less than 12 GeV is removed
- At least three leptons are required and the workflow is separated to three and four or more lepton final states



Three lepton final state

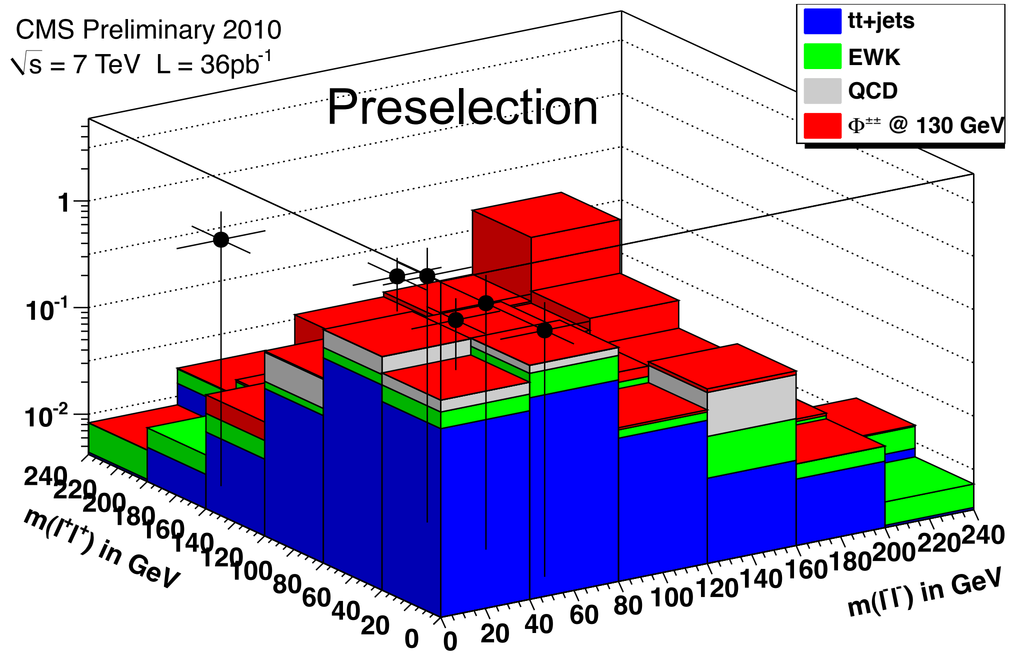
- Leptons are required to be isolated
- Z veto: $|m(l^+l^-)-91.18\ \text{GeV}| > 10\ \text{GeV}$
- Opening angle between same sign leptons less than 2.5
- p_T cuts on the three leptons as a function of search mass

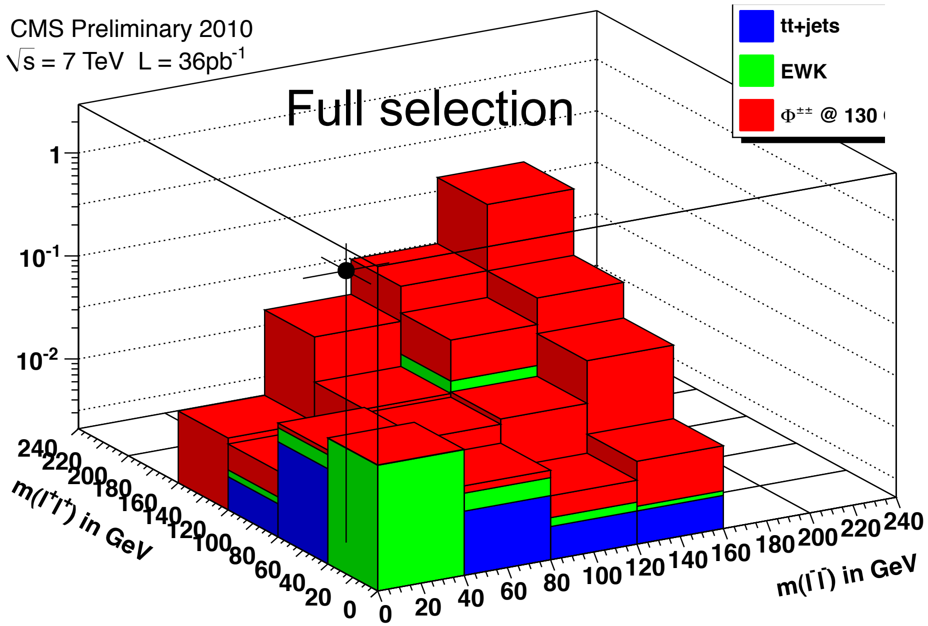




Four lepton final state

- Loose isolation required
- Z veto required
- Negligible background
  → no kinematic cuts





Model point shown: BP4

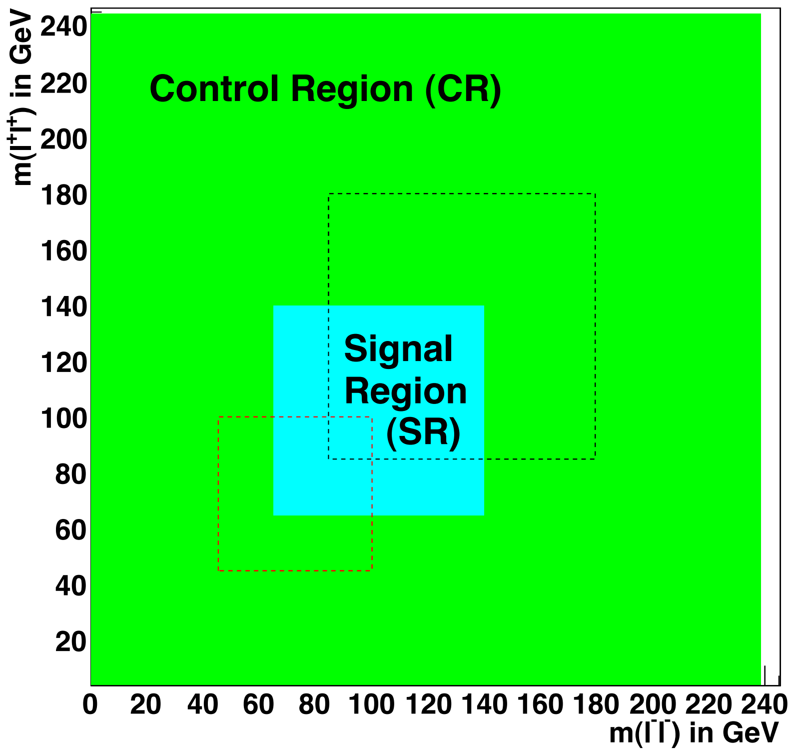
Background estimation

- Background is driven from data using the sidebands method
- Mass window: $(m(\Phi)/2; m(\Phi)+10)$
- 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

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

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

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

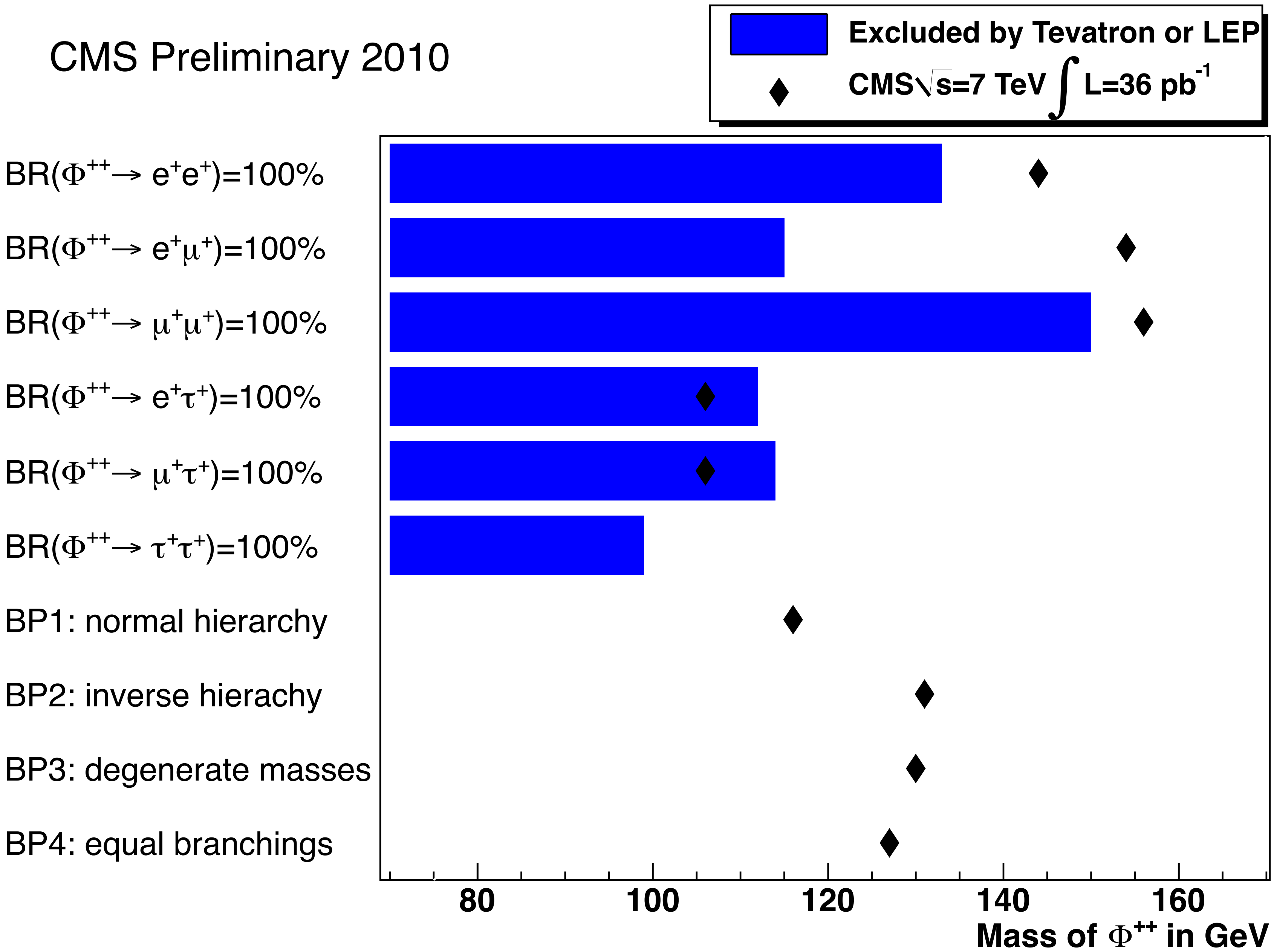


Systematic uncertainties and limit calculation

Source	Uncertainty
Lepton (e and μ unified) ID+isolation	2%
Tau jet	24%
Trigger + primary vertex finding	1.5%
Signal cross section	10%
Luminosity	4%
Uncertainty on α, comes from PDF, QCD scale and lepton energy scale	5%
Statistical uncertainty of signal MC	1-7%
Statistical uncertainty on observed events in control region	10-100%

- We use Bayesian method with a flat prior
- Limits are calculated in five different topologies (3l 0τj, 2l 1τj, 4l 0τj, 3l 1τj, 2l 2τj)
- For each scenario the corresponding control region is used to estimate background

Results



CMS Preliminary 2010
Excluded by Tevatron or LEP
CMS $\sqrt{s}$=7 TeV $\int$ L=36 pb^{-1}
BR($\Phi^{++} \rightarrow e^+e^+$)=100%
BR($\Phi^{++} \rightarrow e^+\mu^+$)=100%
BR($\Phi^{++} \rightarrow \mu^+\mu^+$)=100%
BR($\Phi^{++} \rightarrow e^+\tau^+$)=100%
BR($\Phi^{++} \rightarrow \mu^+\tau^+$)=100%
BR($\Phi^{++} \rightarrow \tau^+\tau^+$)=100%
BP1: normal hierarchy
BP2: inverse hierachy
BP3: degenerate masses
BP4: equal branchings
80
100
120
140
160
Mass of Φ^{++} in GeV

Φ^{++} summary

- A fully inclusive search has been performed with no excess observed
- The inclusion of singly charged component has significantly boosted sensitivity
- This is the first FULLY inclusive search and the first time both production mechanisms have been considered
- New world limits have been set in seven out of ten considered model points with just 36 pb^{-1}

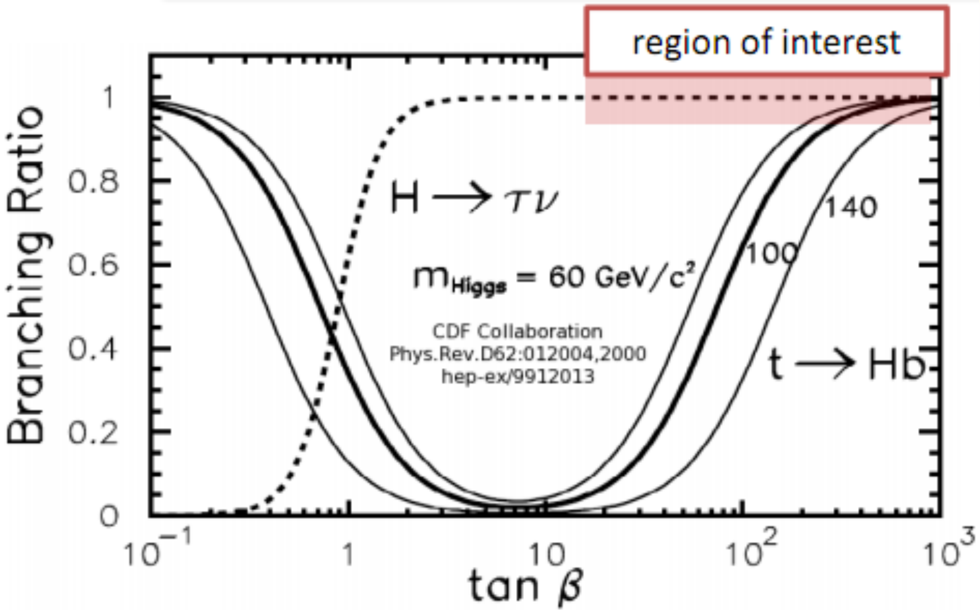
Backup

Introduction (II)

- BR (t →H^+b) could be large...

- $H^+ \rightarrow \tau^+ \nu$ enhanced if tanβ large
  $\tan\beta > 10 \Rightarrow$ BR ($H^+ \rightarrow \tau^+ \nu$) ~ 1

(tan β : ratio of vaccum expectation value)



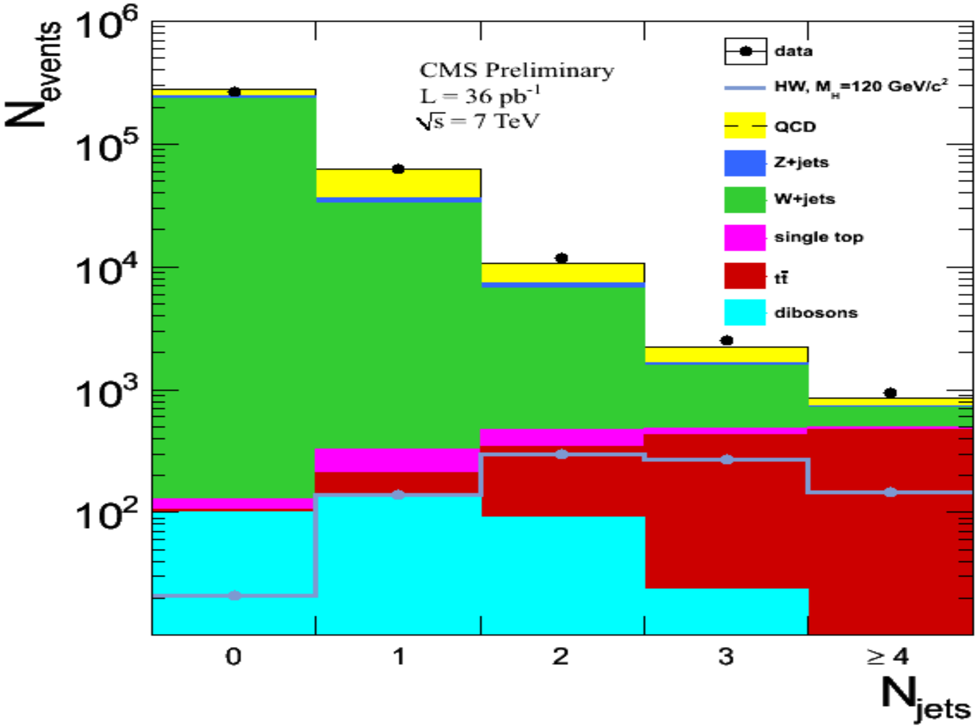
Taus in Top decays :
in SM BR for tau dilepton = BR dilepton channel

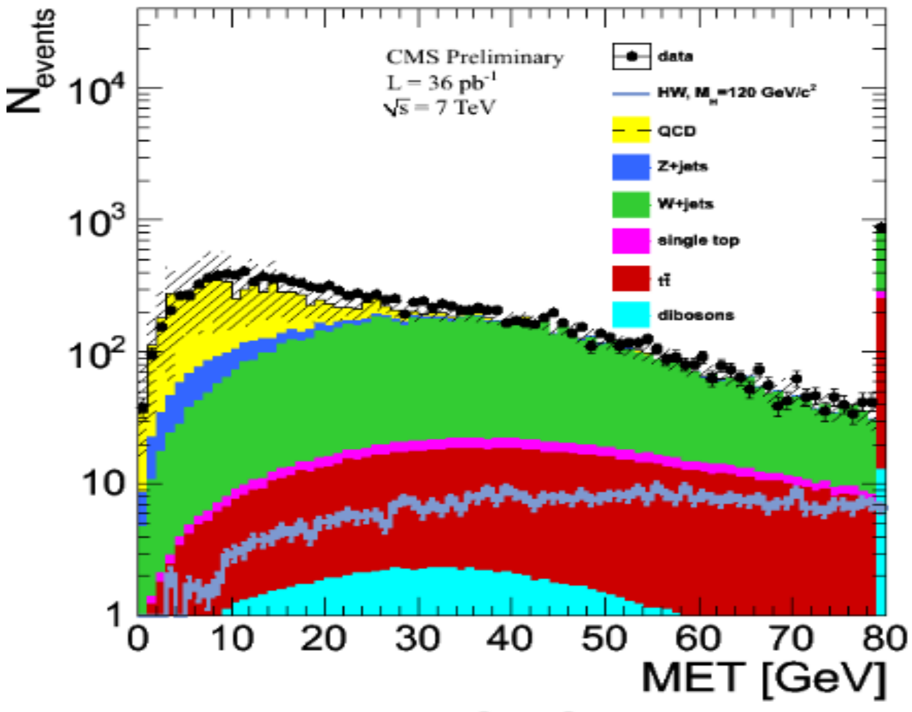
Channel	Signature	BR
Dilepton(e/μ)	*ee*,μμ,*e*μ + 2*b*-jets	4/81
Single lepton	*e*,μ + jets + 2*b*-jets	24/81
All-hadronic	jets + 2*b*-jets	36/81
Tau dilepton	*e*τ, μτ +2 *b*-jets	4/81
Tau+jets	τ + jets + 2*b*-jets	12/81

⇨number of tau dilepton events can potentially be large

Goal:
set limits/observe Higgs boson

Control Distributions

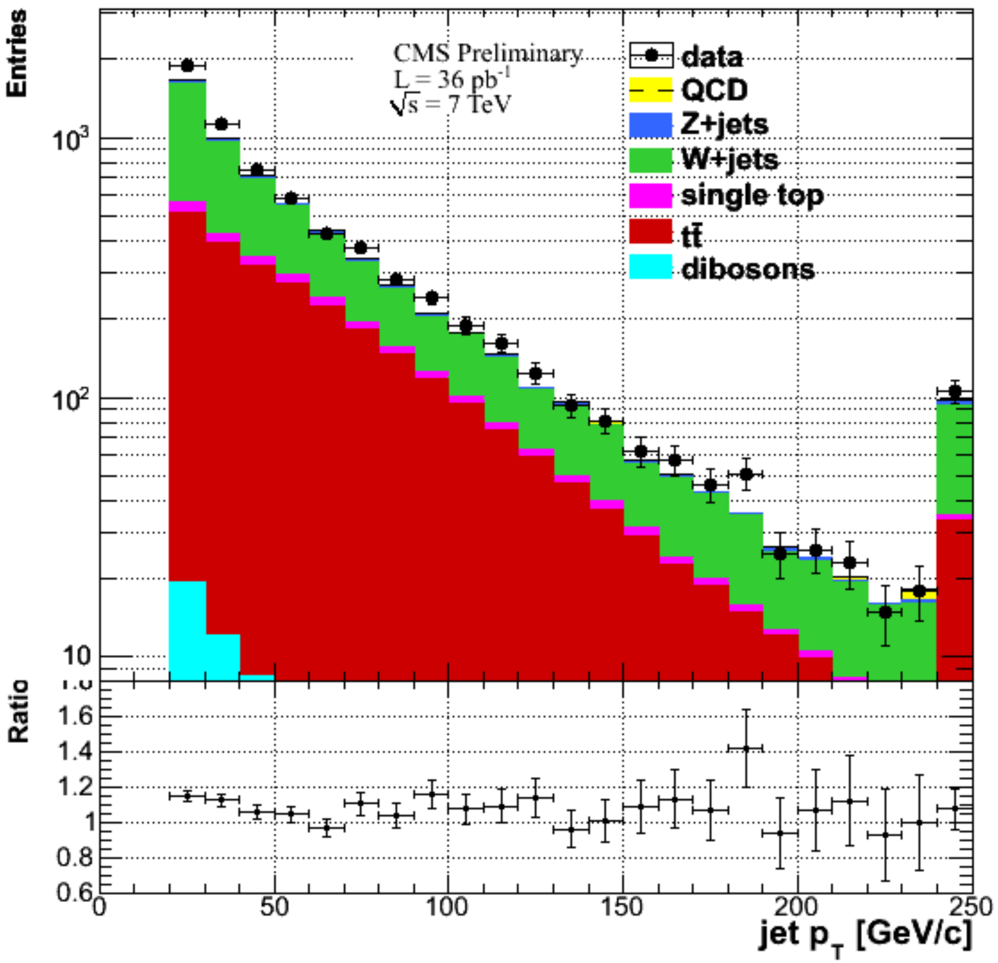




Selection :
isolated lepton + ≥2 jets

Selection :
+ MET>40 GeV

Inclusive Jet p_T distribution in lepton+MET+≥3jets events



Jets that can fake taus in events with :

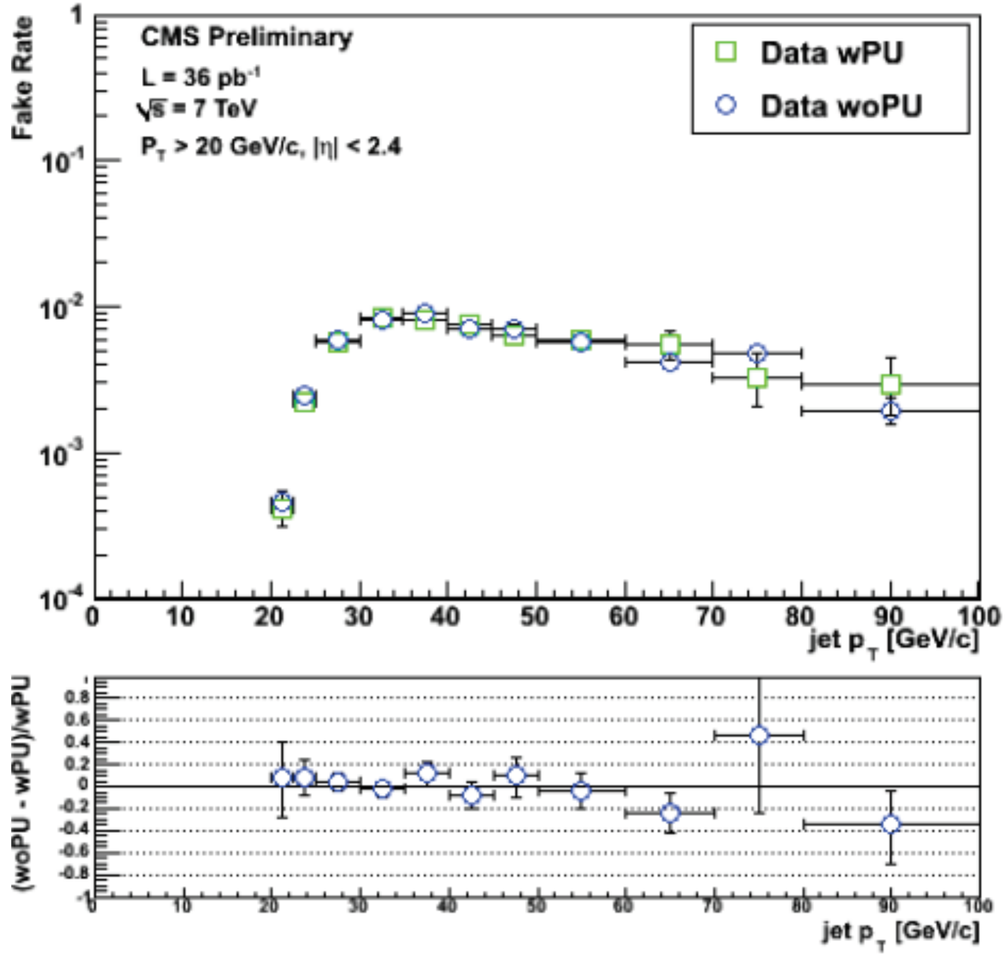
- 1 isolated lepton
  E_T>30GeV for electrons and
  p_T>20 GeV/c for muons
- At least 2 jets with p_T>30 GeV/c
  + at least one jet with p_T>20GeV/c
- MET > 40 GeV

Fake background is estimated using data

Data driven τ-fake background

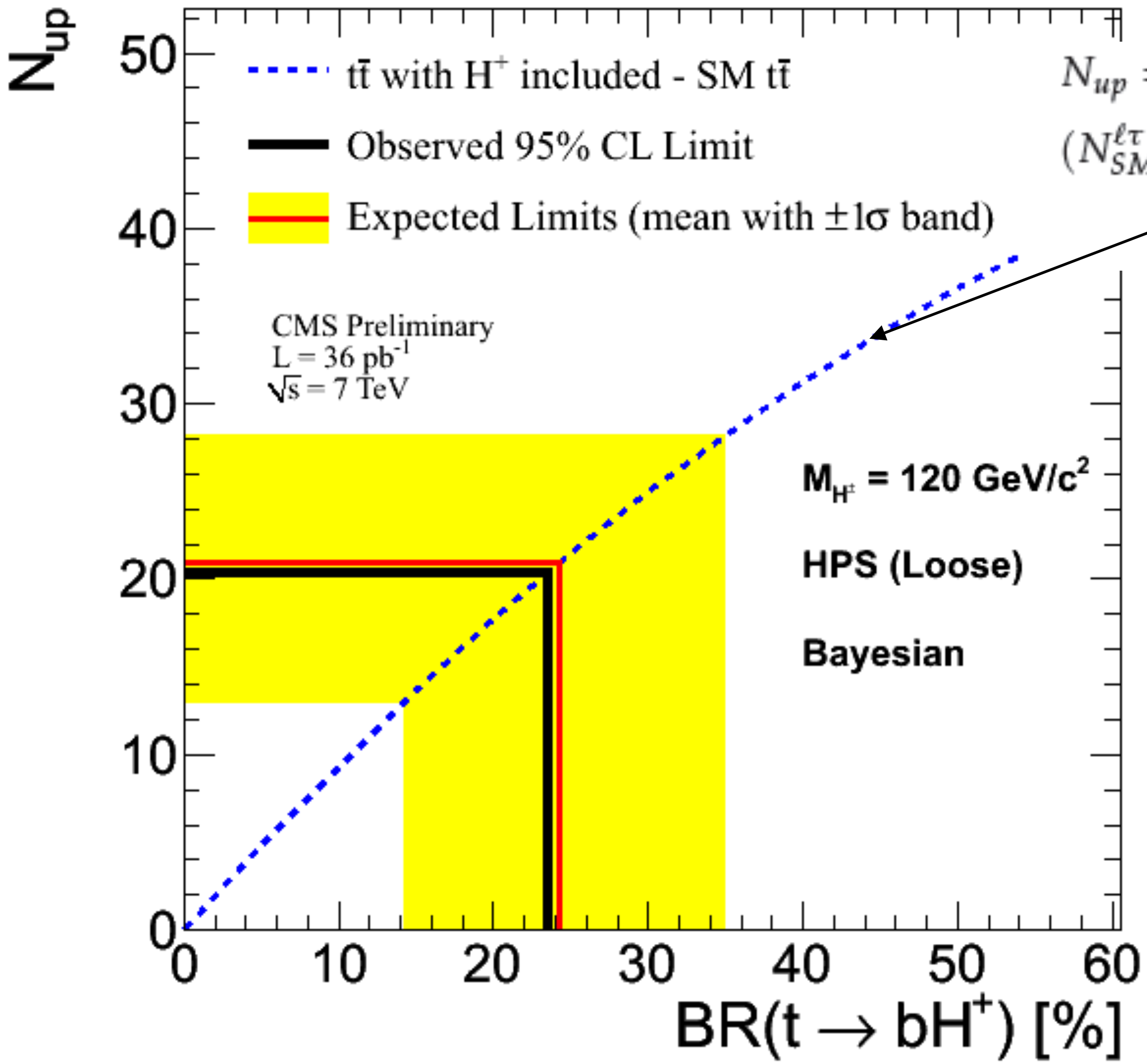
Dominated by W+jets and ttbar → l + jets

- Data driven background estimation :
  - Select jets in events with :
    1 lepton + MET + ≥3 jets
  - Apply to every jet the "jet→tau probability"



Probability that a jet fakes a *tau*-jet as obtained from the QCD multi-jet events taken during runs with and without pileup.

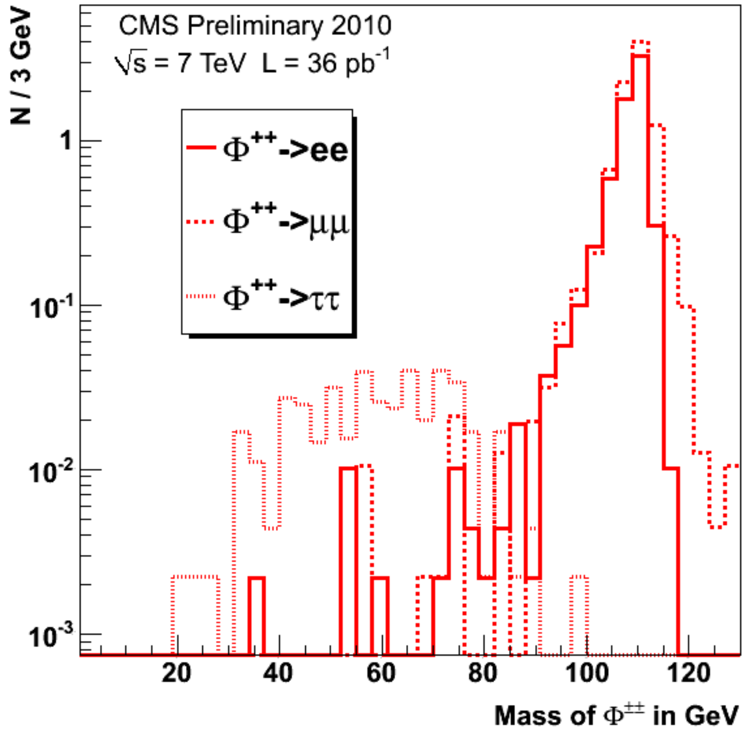
N_{up}

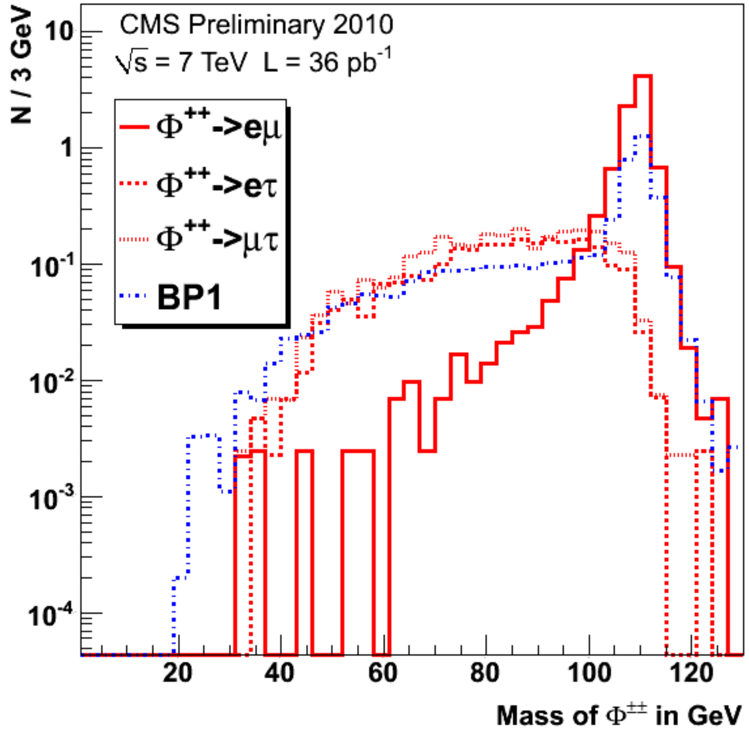


$$N_{up} = N_{WH} \cdot 2(1-x) \cdot x + N_{HH} \cdot x^2 + (N^{\ell\tau}_{SM\ tt} + N^{\ell\ell}_{SM\ tt} + N^{\ell qq'}_{SM\ tt}) \cdot (1-x)^2 - (N^{\ell\tau}_{SM\ tt} + N^{\ell\ell}_{SM\ tt} + N^{\ell qq'}_{SM\ tt}),$$

Mass window choice

- Branching fractions unknown, optimized for common case
- Window is same for purely leptonic and lepton+tau final states to accept tau leptonic decays
  - can contribute up to 40% of total signal yield (e.g. 100% branching to $\mu\tau$ final state)
- Choice of mass window: from half of search mass to search mass + 10 GeV





Event yields (3 lepton final state)

Mass	ttbar	VV	DY	W	QCD	Total (MC)	Total (Data)	Data
90	0.45	0.19	1.49	<0.02	0.09	2.23±0.35	3.24 ± 0.43 ± 0.16	5
110	0.29	0.13	0.75	<0.02	<0.03	1.17±0.20	1.39 ± 0.18 ± 0.07	1
130	0.17	0.09	0.33	0.07	<0.03	0.65±0.12	0.66 ± 0.08 ± 0.03	1
150	0.07	0.06	0.20	0.07	<0.03	0.39±0.09	0.38 ± 0.05 ± 0.02	1
170	0.02	0.04	0.15	<0.02	<0.03	0.21±0.09	0.25 ± 0.03 ± 0.001	1

Mass	ee	eμ	eτ	μμ	μτ	ττ	BP1	BP2	BP3	BP4
90	10.9	15.3	5.0	14.8	6.5	0.52	7.2	10.1	9.6	9.0
110	5.7	7.5	2.7	7.7	3.4	0.23	3.7	5.1	4.8	4.8
130	3.4	4.2	1.5	4.0	1.9	0.14	2.0	2.9	2.7	2.6
150	2.0	2.4	0.9	2.4	1.1	0.07	1.2	1.7	1.6	1.6
170	1.3	1.5	0.6	1.5	0.7	0.05	0.7	1.1	1.0	1.0

Event yields (4 lepton final state)

Mass	Total BG (MC)	Total BG (Data)	Data	ee	eμ	eτ	μμ	μτ
90	0.00 ± 0.06	0.22 ± 0.17 ± 0.01	0	3.3	6.0	1.0	6.2	1.2
110	0.00 ± 0.06	0.40 ± 0.30 ± 0.02	0	1.9	3.0	0.61	3.3	0.78
130	0.00 ± 0.06	0.32 ± 0.24 ± 0.02	0	1.2	1.8	0.32	1.9	0.48
150	0.00 ± 0.06	0.25 ± 0.19 ± 0.01	0	0.8	1.1	0.23	1.2	0.27
170	0.00 ± 0.06	0.22 ± 0.16 ± 0.01	0	0.5	0.7	0.17	0.7	0.17

Mass	BP1	BP2	BP3	BP4
90	1.87	3.12	3.32	2.84
110	1.04	1.72	1.79	1.54
130	0.61	1.02	1.02	0.90
150	0.37	0.62	0.63	0.55
170	0.23	0.40	0.39	0.35

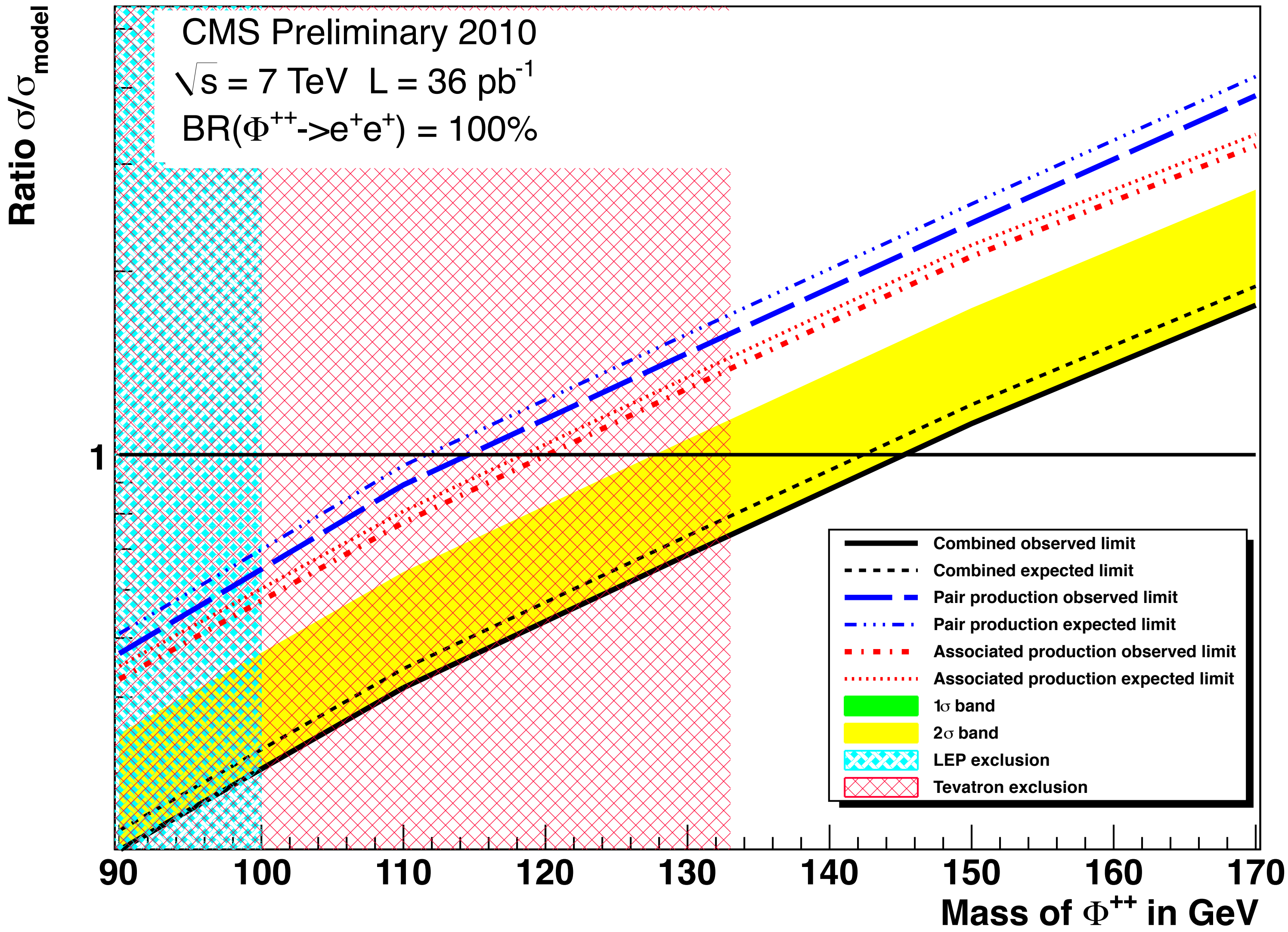
Limit calculation

- We use Bayesian method with a flat prior
- Results were cross-checked between L&S and RooStats
- Limits are calculated in five different topologies:
  - three leptons with no tau jets
  - three leptons including one tau jet
  - four leptons with no tau jets
  - four leptons including one tau jet
  - four leptons including two tau jets
- For each scenario the corresponding control region is used to estimate background

Summary of results

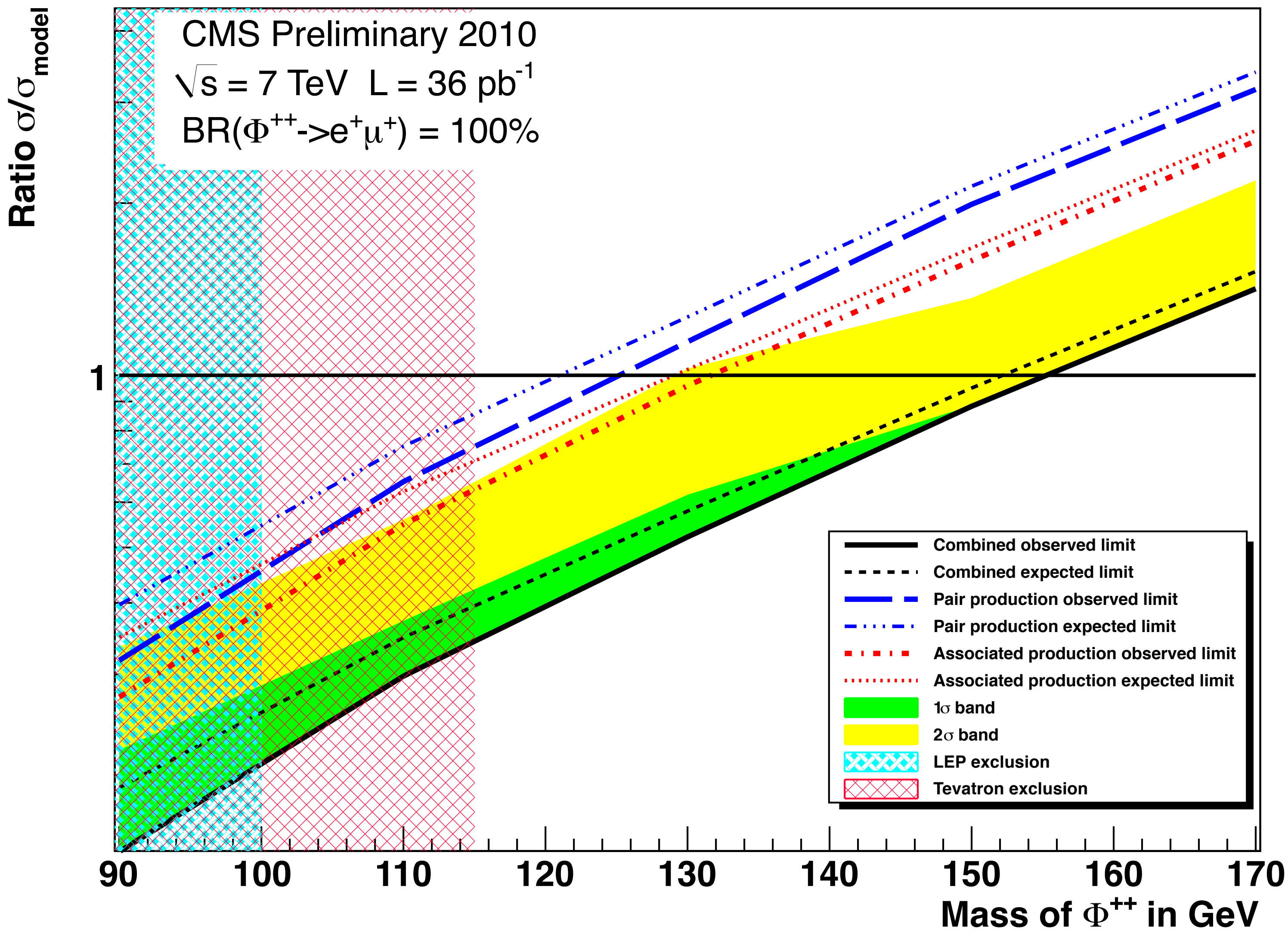
Model point	Former limit	CMS
BR(Φ^{++}->ee)=100%	133 GeV	144 GeV
BR(Φ^{++}->eμ)=100%	115 GeV	154 GeV
BR(Φ^{++}->$\mu\mu$)=100%	150 GeV	156 GeV
BR(Φ^{++}->eτ)=100%	112 GeV	106 GeV
BR(Φ^{++}->$\mu\tau$)=100%	114 GeV	106 GeV
BP1		116 GeV
BP2		131 GeV
BP3		130 GeV
BP4		127 GeV

Limits

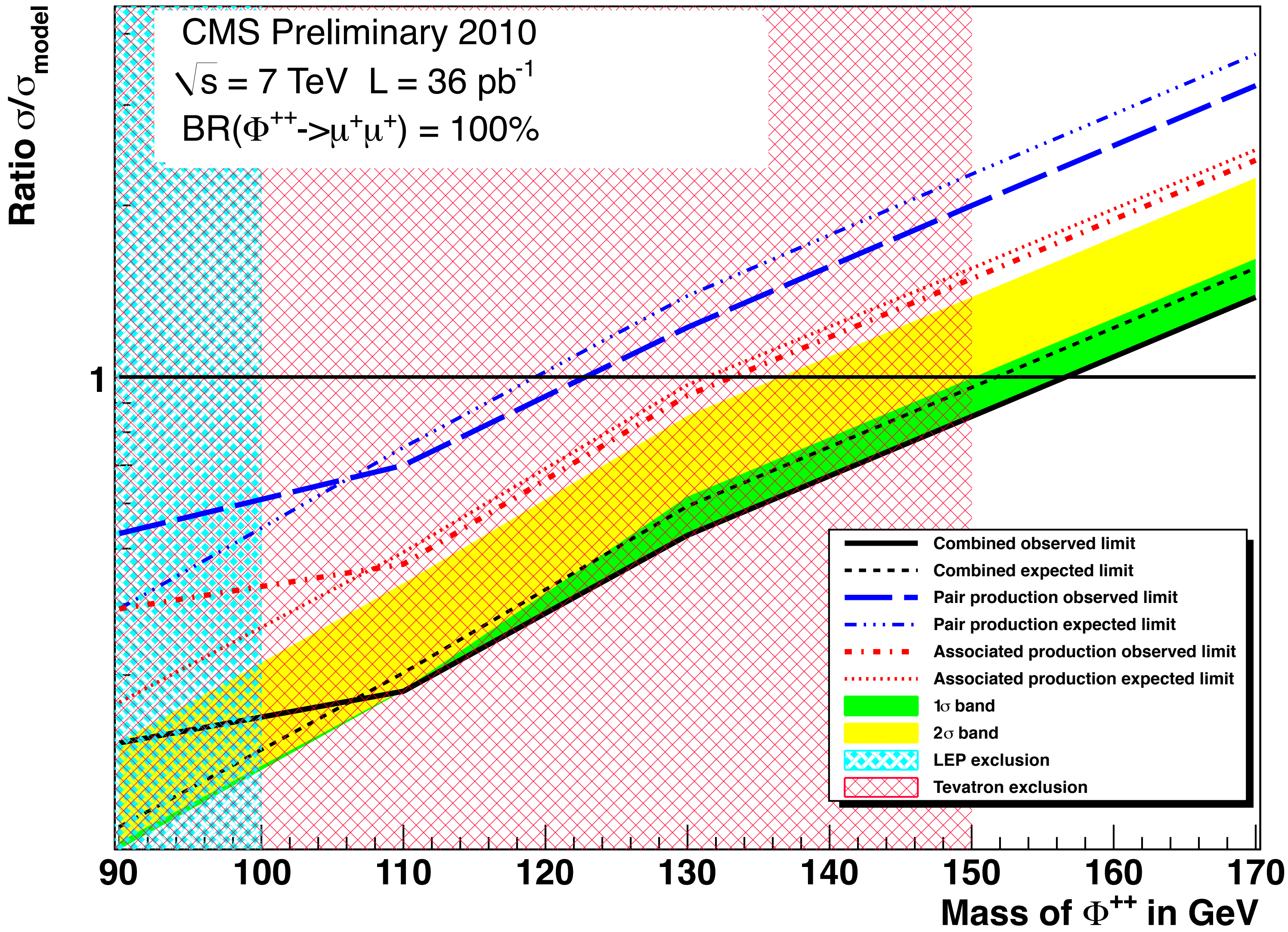


CMS Preliminary 2010
$\sqrt{s}$ = 7 TeV L = 36 pb^{-1}
BR(Φ^{++}->e^{+}e^{+}) = 100%
Ratio σ/σ_{model}
1
90
100
110
120
130
140
150
160
170
Mass of Φ^{++} in GeV
Combined observed limit
Combined expected limit
Pair production observed limit
Pair production expected limit
Associated production observed limit
Associated production expected limit
1σ band
2σ band
LEP exclusion
Tevatron exclusion

Limits

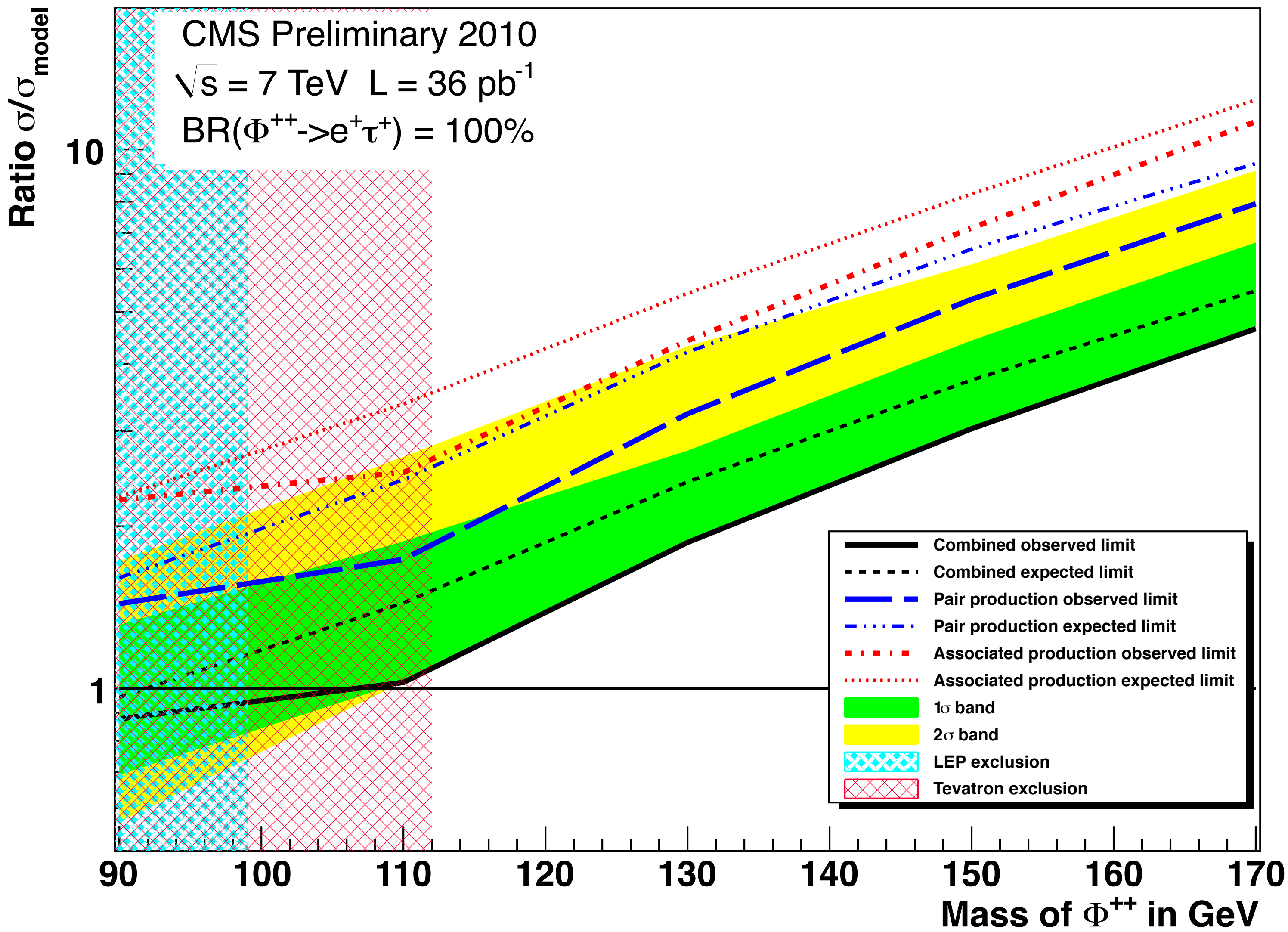

CMS Preliminary 2010
$\sqrt{s}$ = 7 TeV L = 36 pb^{-1}
BR(Φ^{++}->$e^{+}\mu^{+}$) = 100%
Ratio σ/σ_{model}
1
90
100
110
120
130
140
150
160
170
Mass of Φ^{++} in GeV
Combined observed limit
Combined expected limit
Pair production observed limit
Pair production expected limit
Associated production observed limit
Associated production expected limit
1σ band
2σ band
LEP exclusion
Tevatron exclusion

Limits



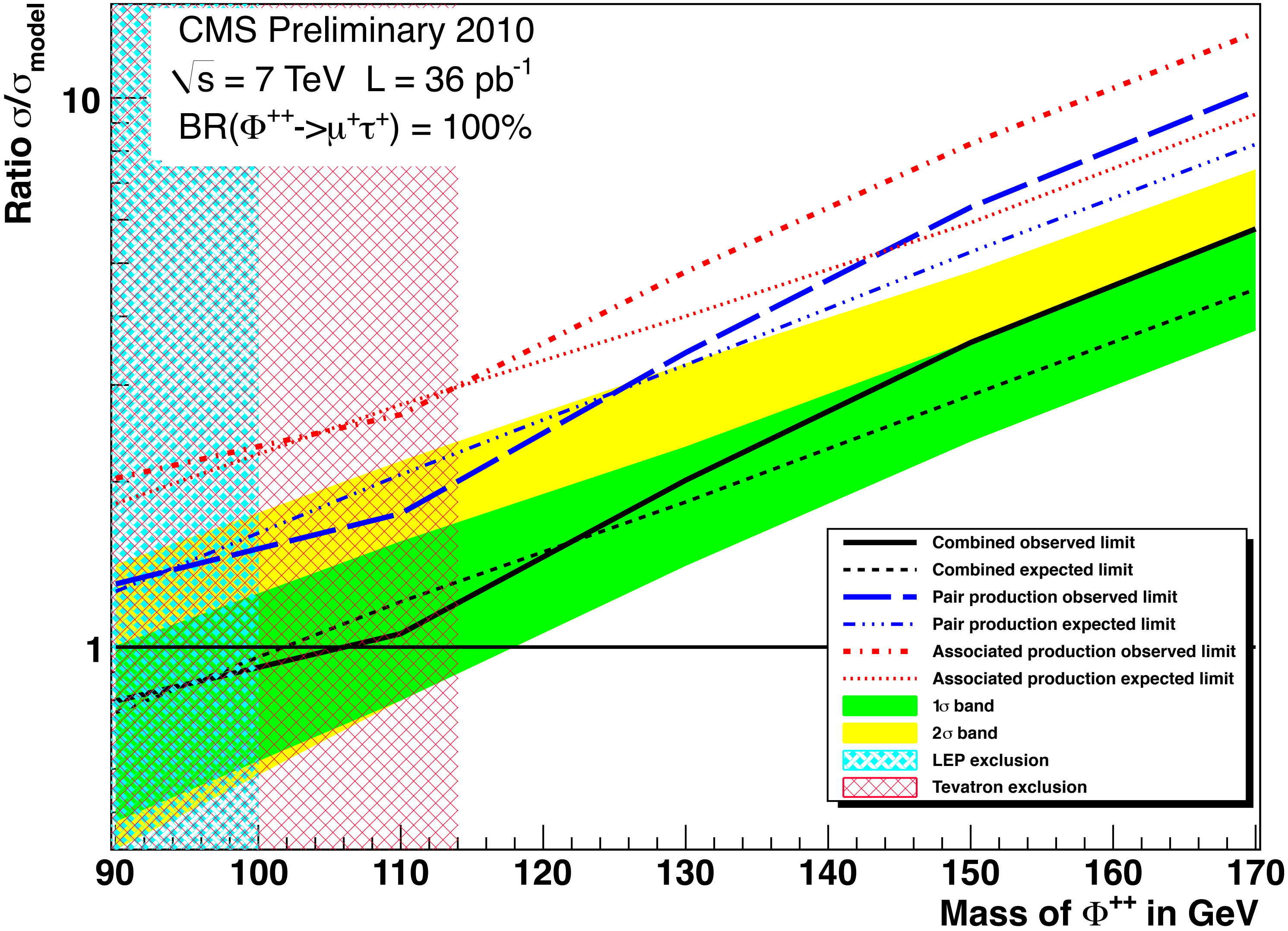
CMS Preliminary 2010
$\sqrt{s}$ = 7 TeV L = 36 pb^{-1}
BR(Φ^{++}->$\mu^+\mu^+$) = 100%
Ratio σ/σ_{model}
1
90
100
110
120
130
140
150
160
170
Mass of Φ^{++} in GeV
Combined observed limit
Combined expected limit
Pair production observed limit
Pair production expected limit
Associated production observed limit
Associated production expected limit
1σ band
2σ band
LEP exclusion
Tevatron exclusion

Limits



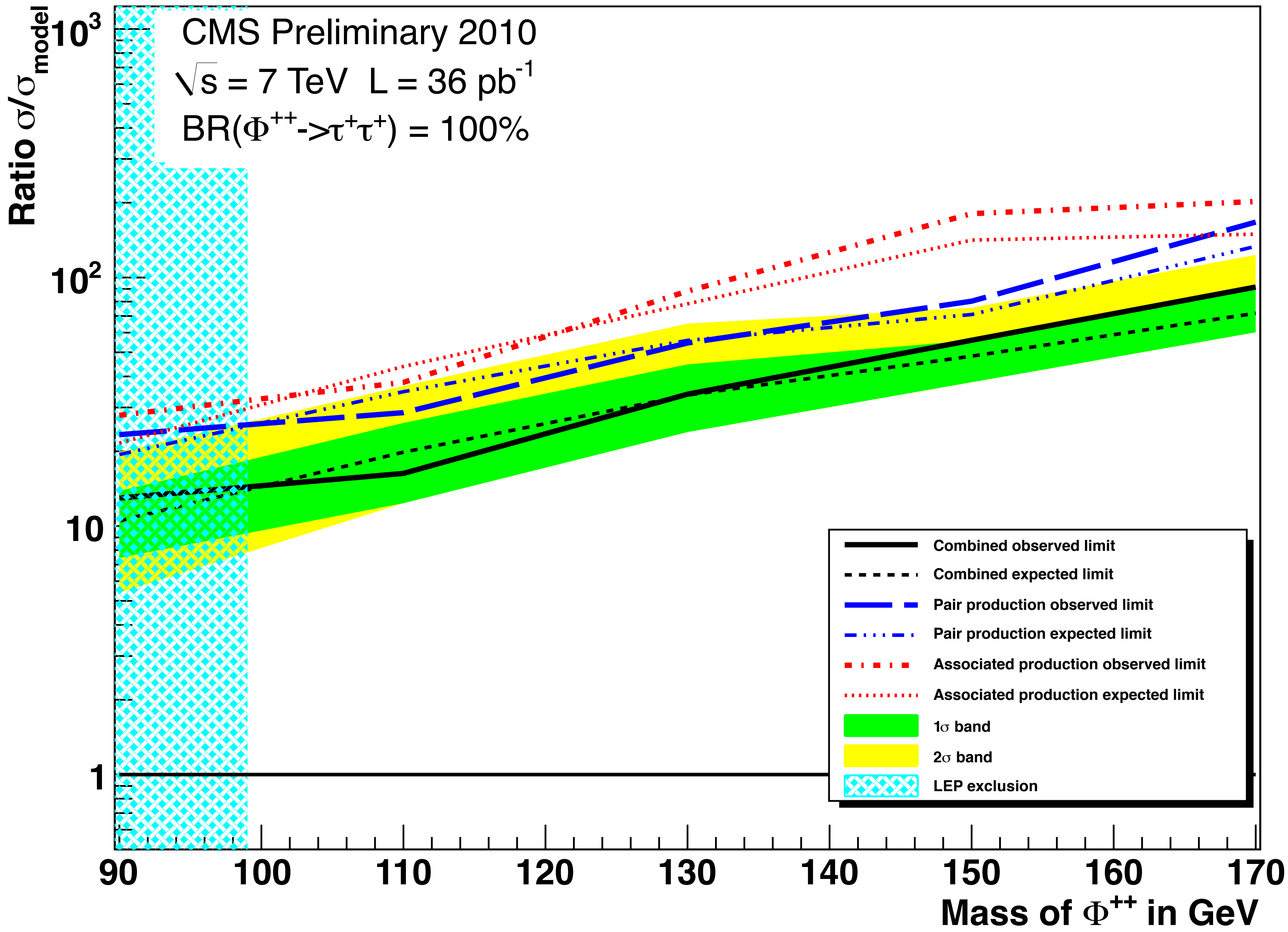
CMS Preliminary 2010
$\sqrt{s}$ = 7 TeV L = 36 pb^{-1}
BR(Φ^{++}->$e^{+}\tau^{+}$) = 100%
Ratio σ/σ_{model}
10
1
90
100
110
120
130
140
150
160
170
Mass of Φ^{++} in GeV
Combined observed limit
Combined expected limit
Pair production observed limit
Pair production expected limit
Associated production observed limit
Associated production expected limit
1σ band
2σ band
LEP exclusion
Tevatron exclusion

Limits

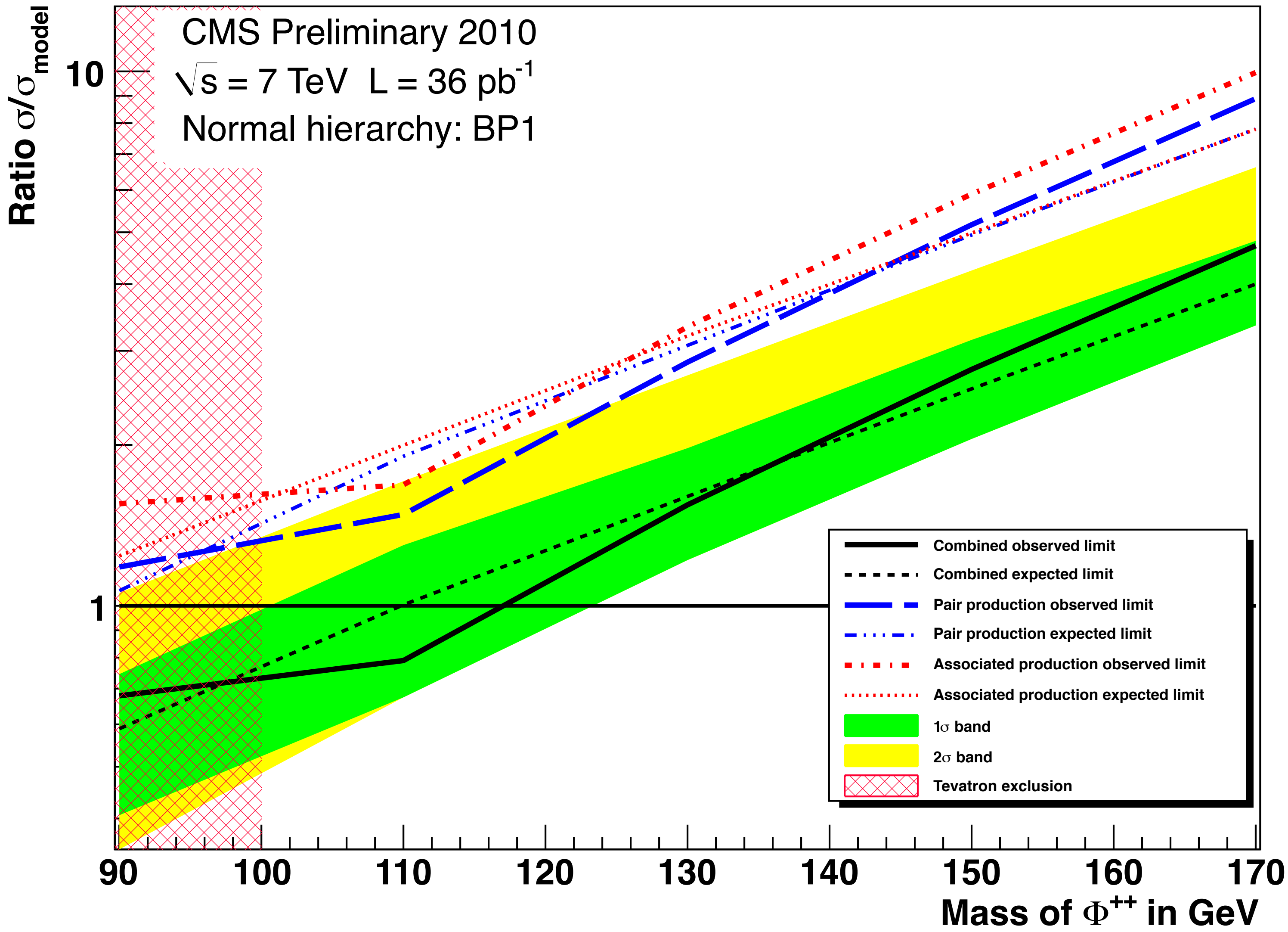


CMS Preliminary 2010
$\sqrt{s}$ = 7 TeV L = 36 pb^{-1}
BR(Φ^{++}->$\mu^+\tau^+$) = 100%
Ratio σ/σ_{model}
10
1
90
100
110
120
130
140
150
160
170
Mass of Φ^{++} in GeV
Combined observed limit
Combined expected limit
Pair production observed limit
Pair production expected limit
Associated production observed limit
Associated production expected limit
1σ band
2σ band
LEP exclusion
Tevatron exclusion

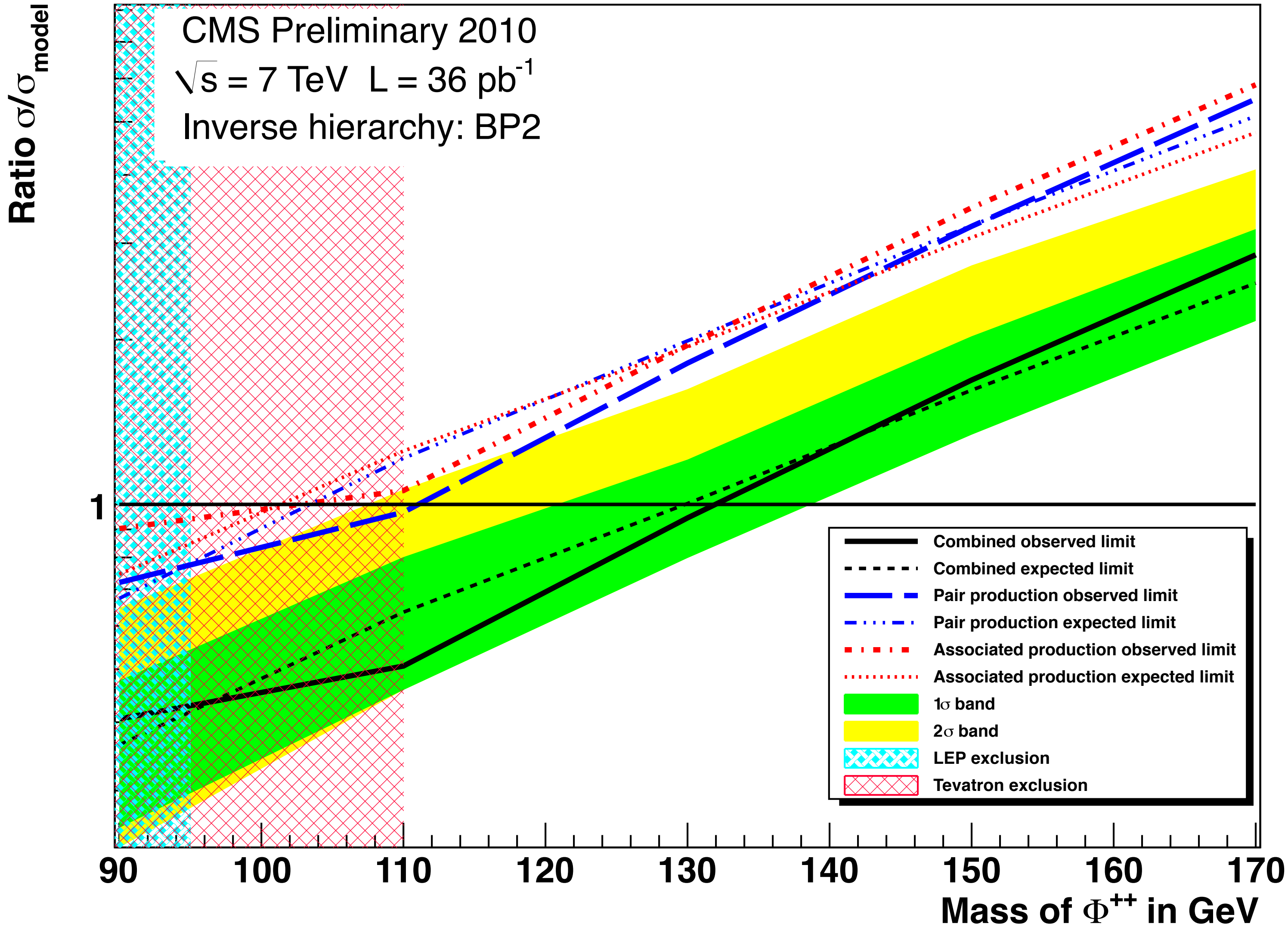
Limits


CMS Preliminary 2010
√s = 7 TeV L = 36 pb-1
BR(Φ++->τ+τ+) = 100%
Ratio σ/σmodel
10³
10²
10
1
90
100
110
120
130
140
150
160
170
Mass of Φ++ in 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

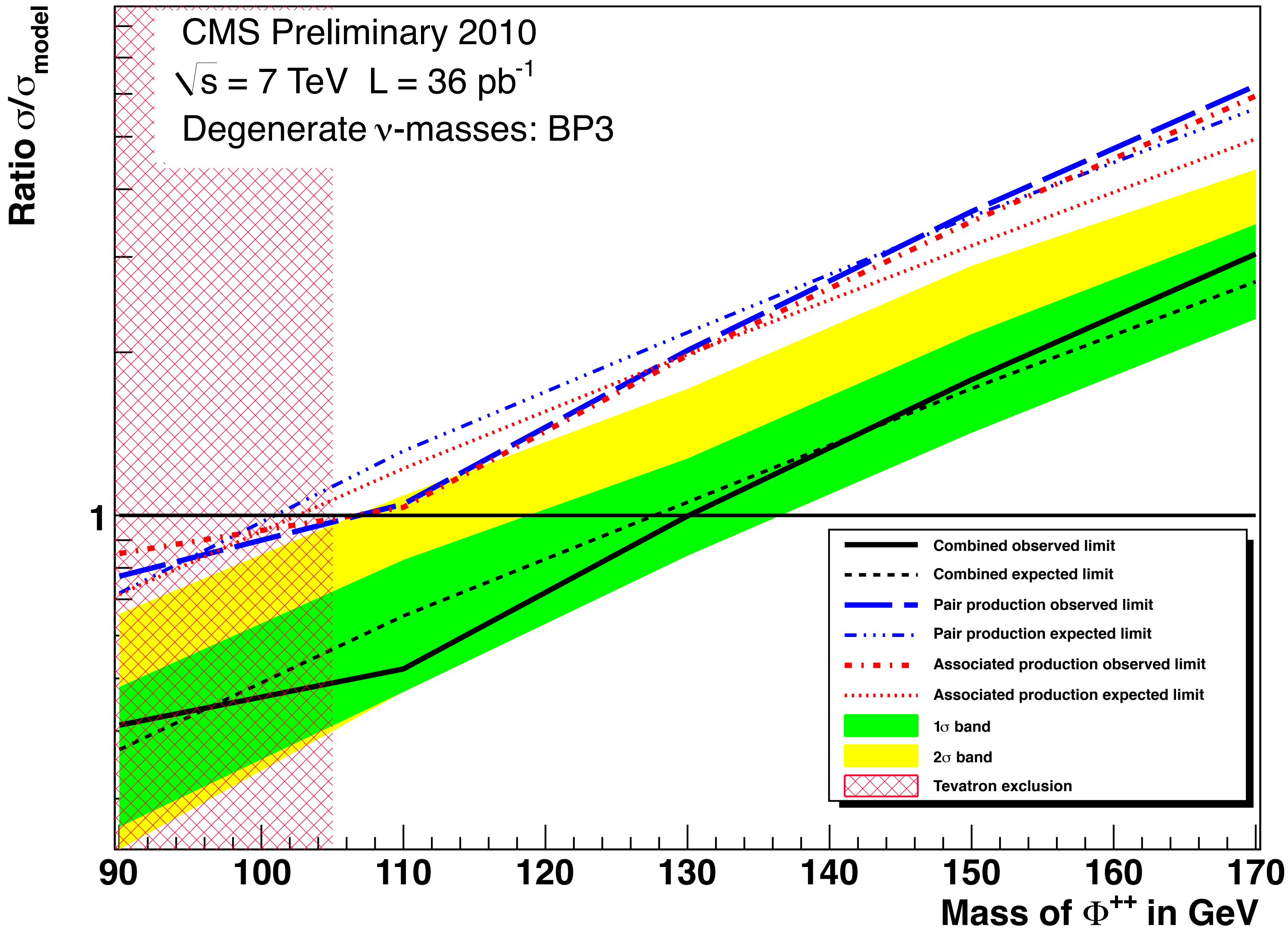
Limits


CMS Preliminary 2010
√s = 7 TeV L = 36 pb-1
Normal hierarchy: BP1
Ratio σ/σmodel
10
1
90
100
110
120
130
140
150
160
170
Mass of Φ++ in 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
Tevatron exclusion

Limits

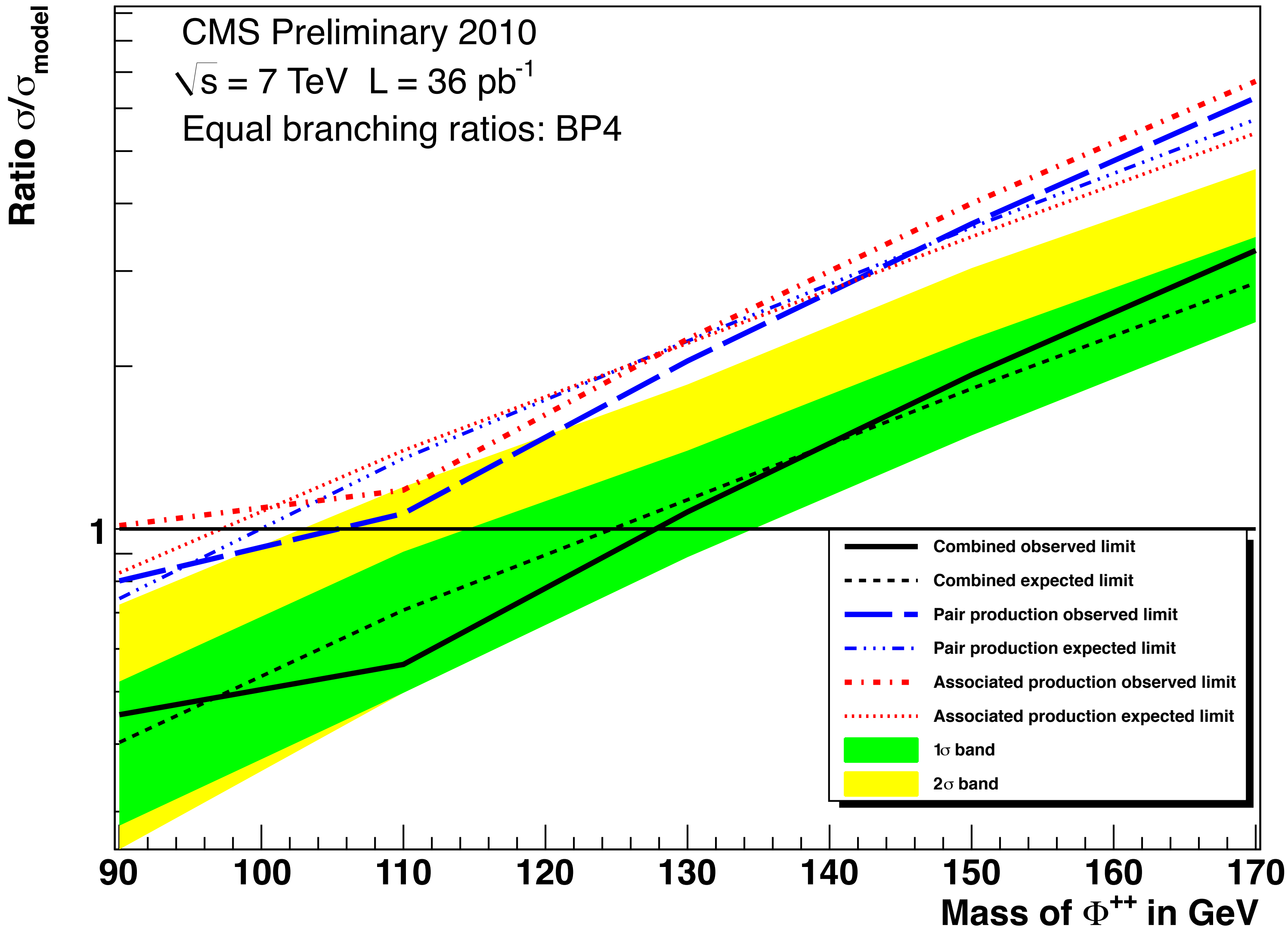

CMS Preliminary 2010
$\sqrt{s}$ = 7 TeV L = 36 pb^{-1}
Inverse hierarchy: BP2
Ratio σ/σ_{model}
1
90
100
110
120
130
140
150
160
170
Mass of Φ^{++} in GeV
Combined observed limit
Combined expected limit
Pair production observed limit
Pair production expected limit
Associated production observed limit
Associated production expected limit
1σ band
2σ band
LEP exclusion
Tevatron exclusion

Limits



CMS Preliminary 2010
√s = 7 TeV L = 36 pb-1
Degenerate ν-masses: BP3
Ratio σ/σmodel
1
90
100
110
120
130
140
150
160
170
Mass of Φ++ in 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
Tevatron exclusion

Limits



CMS Preliminary 2010
√s = 7 TeV L = 36 pb⁻¹
Equal branching ratios: BP4
Ratio σ/σ_model
1
90
100
110
120
130
140
150
160
170
Mass of Φ⁺⁺ in 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