Beyond Standard Model Higgs at CMS

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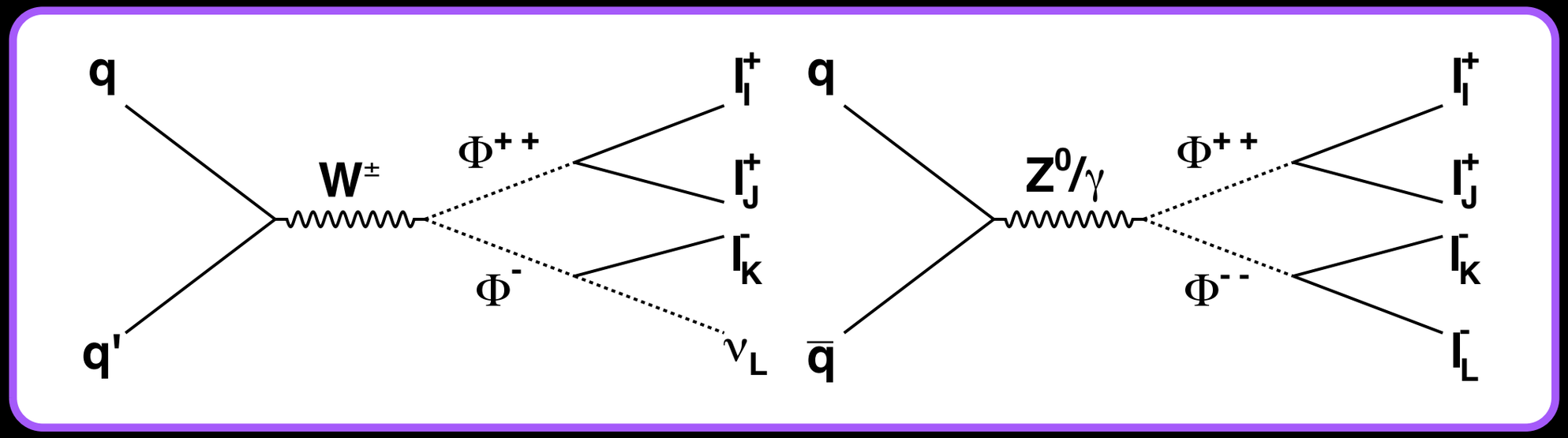
Overview

in this talk we present three CMS analyses using 1.1 fb^{-1} of 2011 data

- Doubly charged Higgs search
- MSSM Higgs analyses
  - $H \rightarrow \tau\tau$ search
  - Charged Higgs BR($t \rightarrow H^{+}b$)
- Interpretation of results in the MSSM

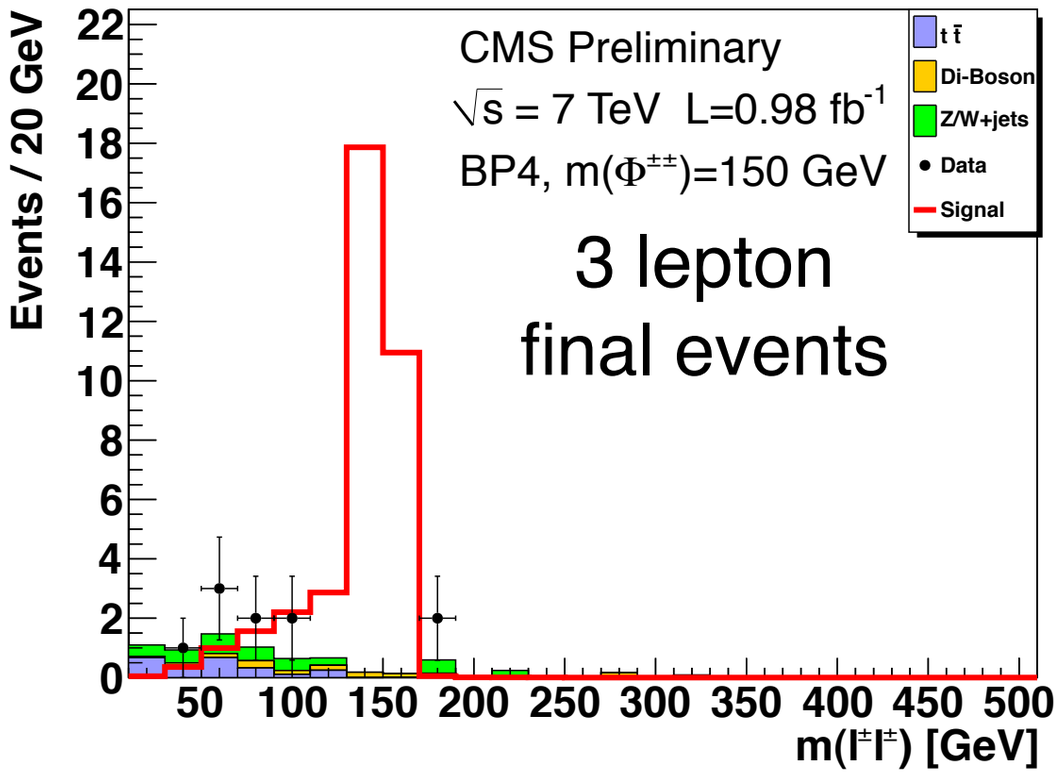
Doubly Charged Higgs

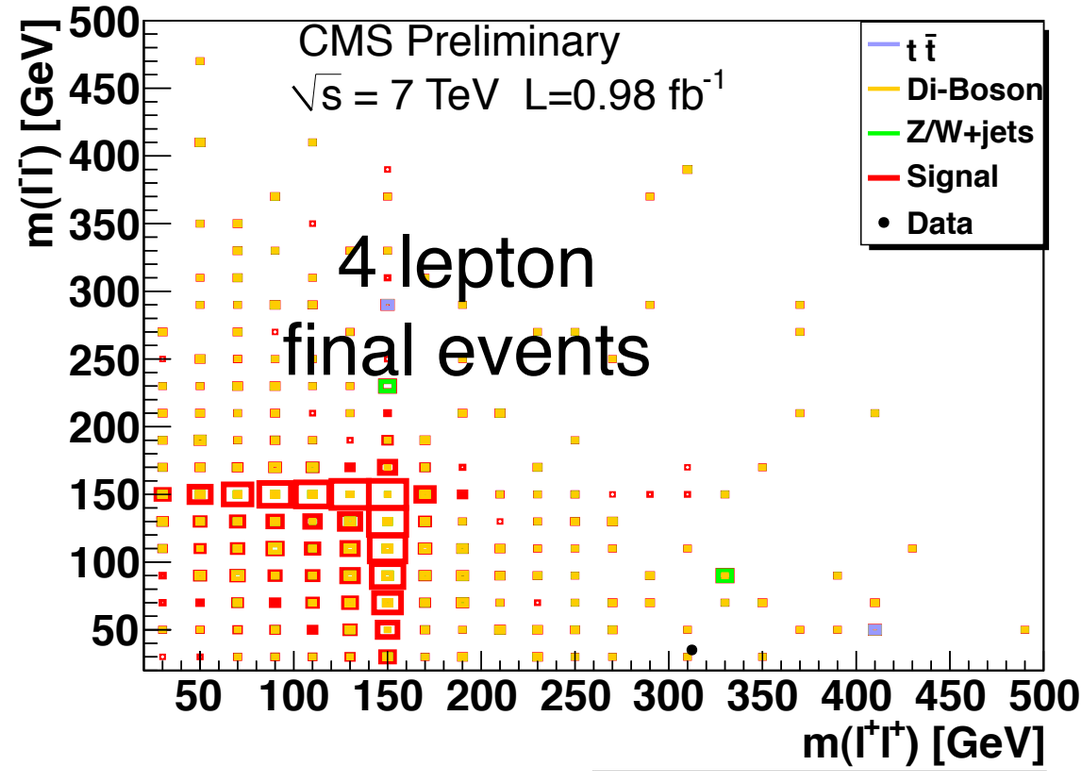
- Extend standard model with scalar triplet:
  - ϕ^{++}, ϕ^{+}, ϕ^{0} (type II seesaw model)
- Triplet responsible for neutrino masses
- Unknown neutrino mass matrix
  - We assume decays to leptons only
- Signature: 3 or 4 final state leptons
- Dilepton made by same sign leptons
- Backgrounds: ZZ, WZ, Z/W+jets, top anti-top
- Lepton efficiencies and backgrounds from data

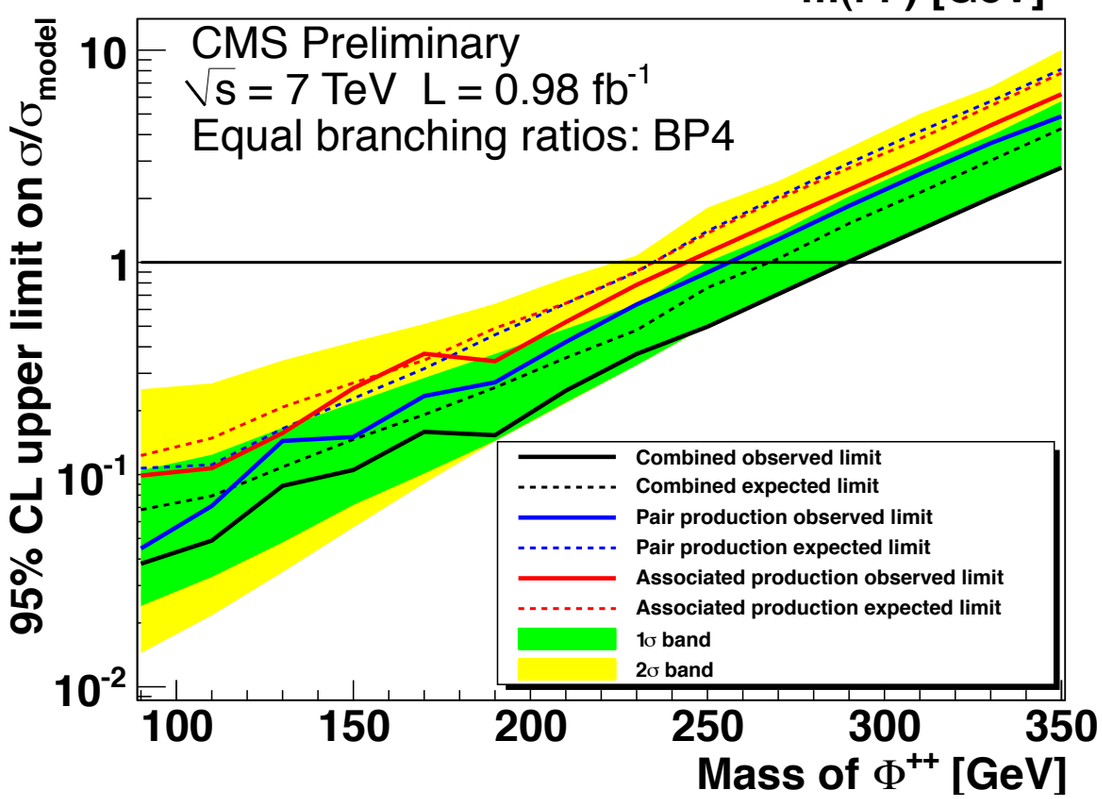


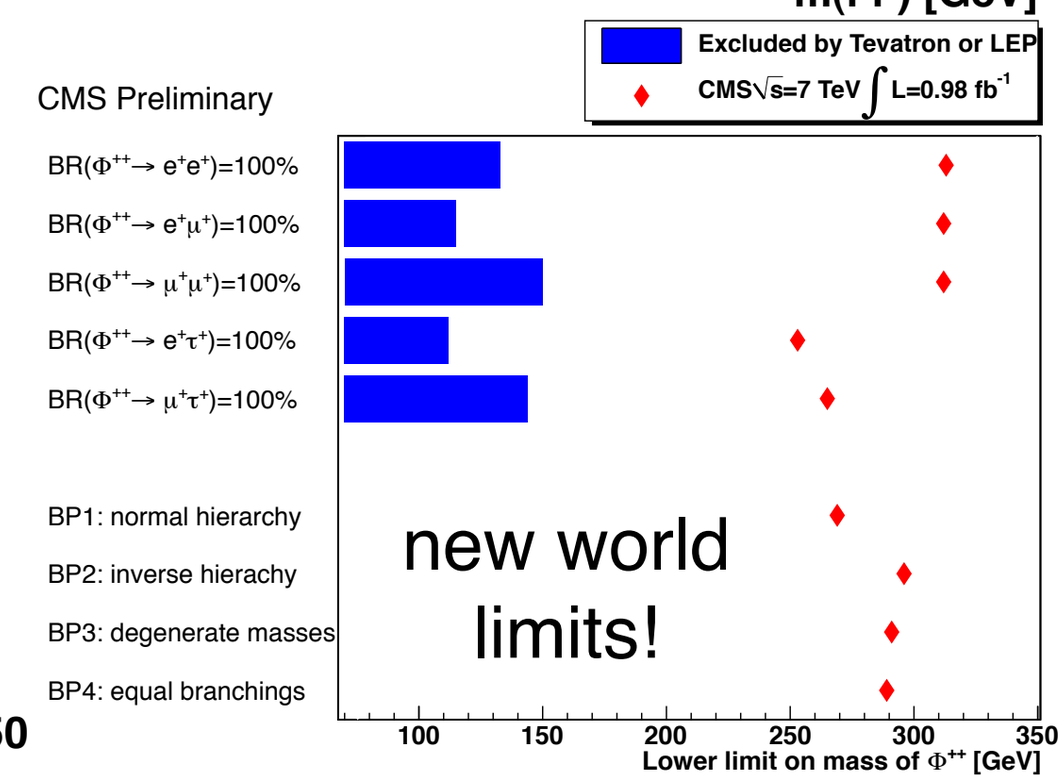
Doubly Charged Higgs

results



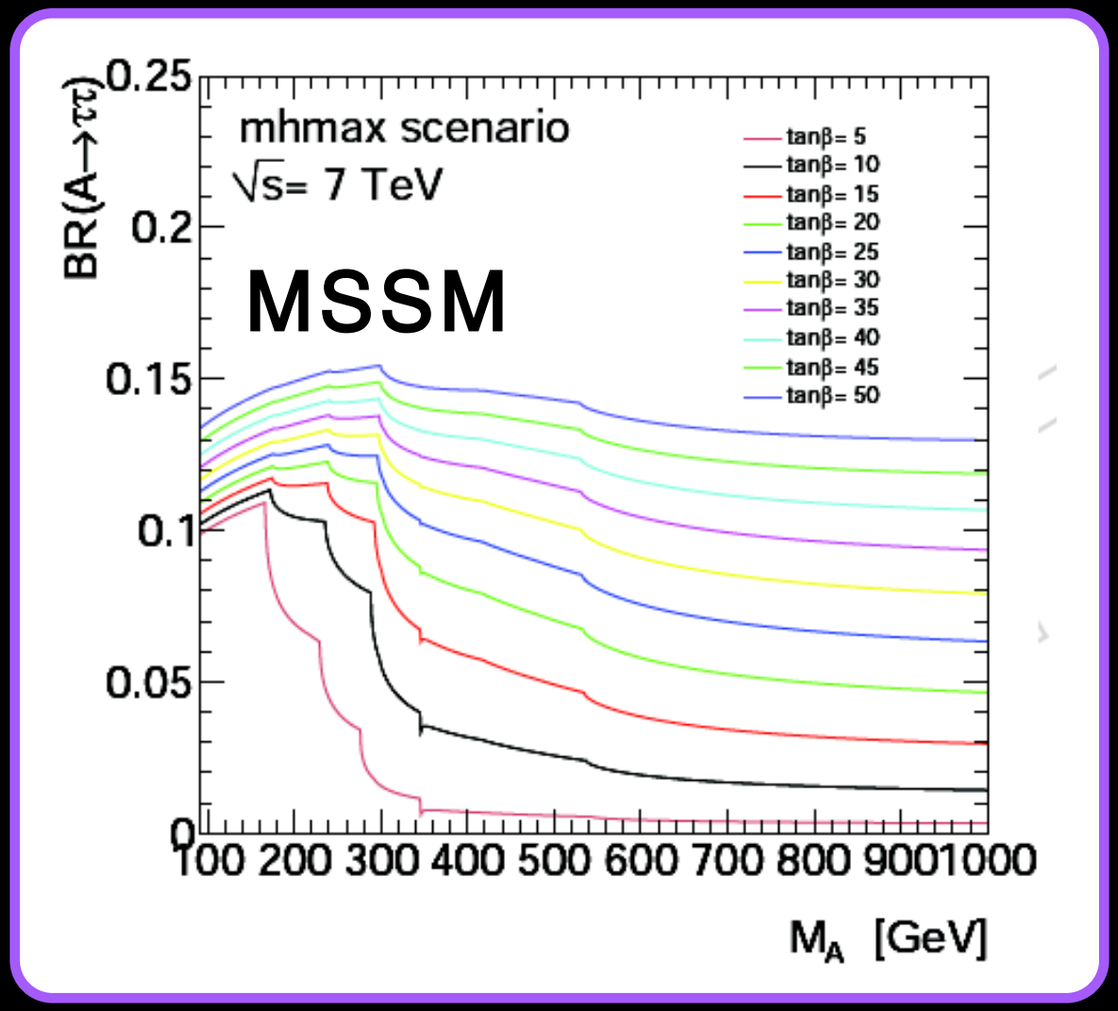






MSSM Higgs and Tau

- Minimal Supersymmetric Standard Model
- Higgs to τ/b couplings enhanced by tanβ
- Higgs → τ discovery channel in full mass range
- Two Higgs doublet model:
  - Includes charged Higgs



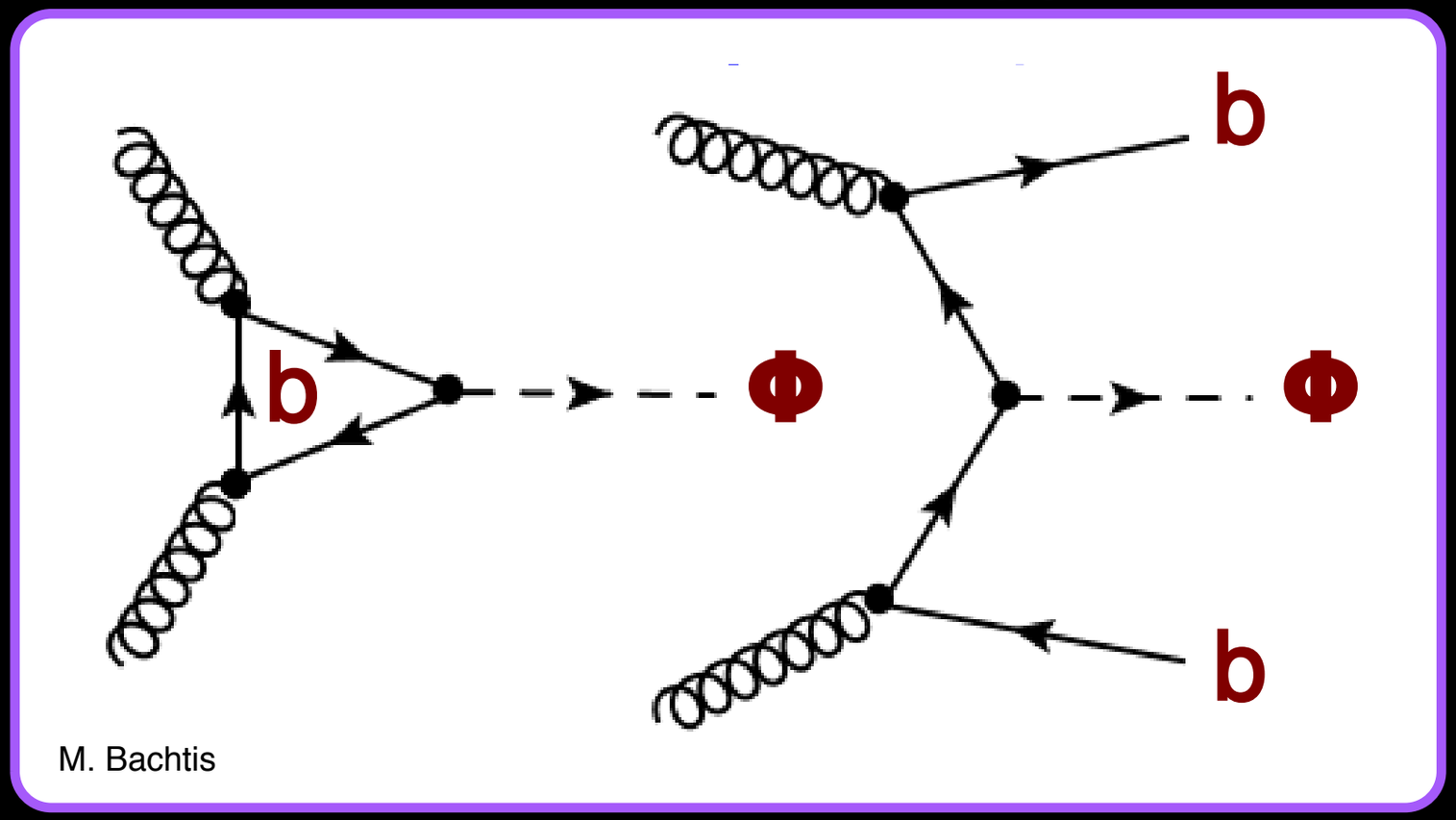
two MSSM analyses using 1.1 fb^{-1} of CMS data

search for neutral MSSM Higgs bosons in di-tau events

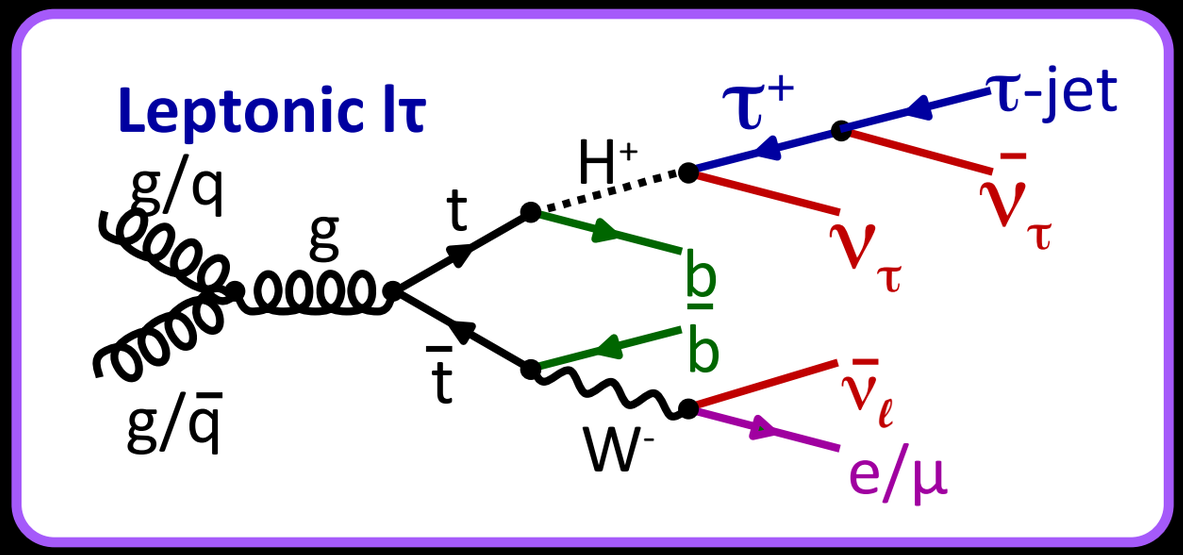
measurement of BR($t \rightarrow H^+ b$)

MSSM Production at the LHC

neutral MSSM Higgs



charged MSSM Higgs



$H \to \tau\tau$ Analysis Strategy

Analysis Channels

$\mu + \tau_h$	High statistics, clean
$e + \tau_h$	High statistics, larger background
$e + \mu$	Low statistics, very clean
$\mu + \mu$	Large Drell-Yan background

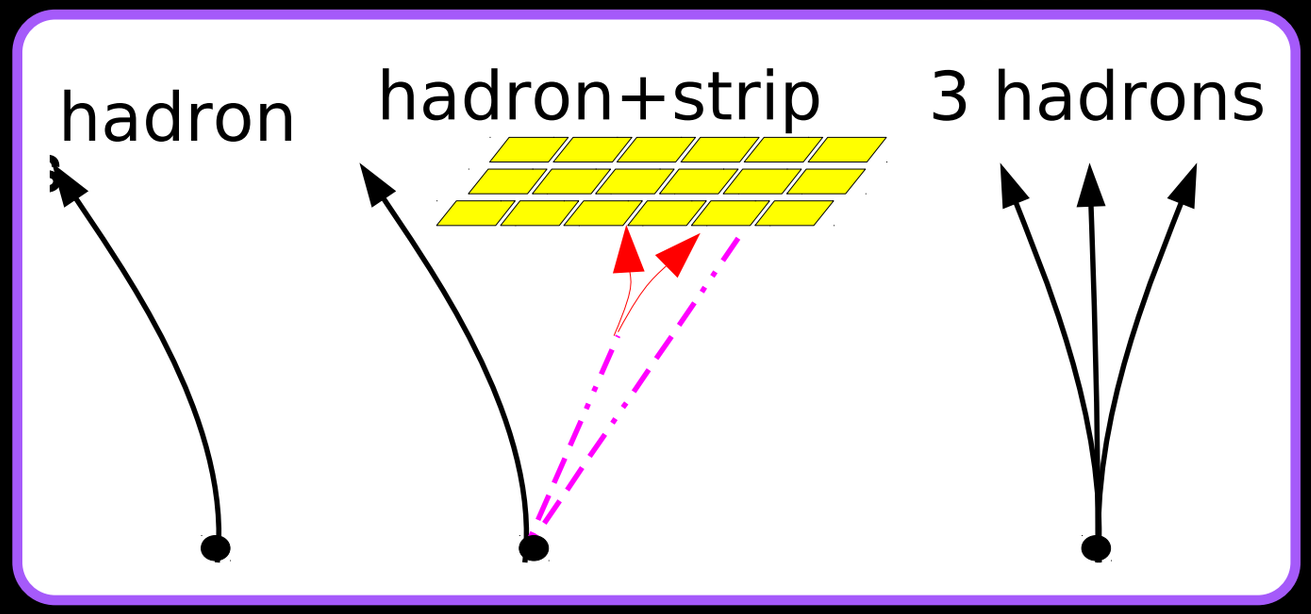
τ_h = hadronic tau decay

selected events are divided into two categories: events with and without b-tagged jets

M_{vis} spectrum is fitted simultaneously in all channels and categories

Tau Reconstruction at CMS

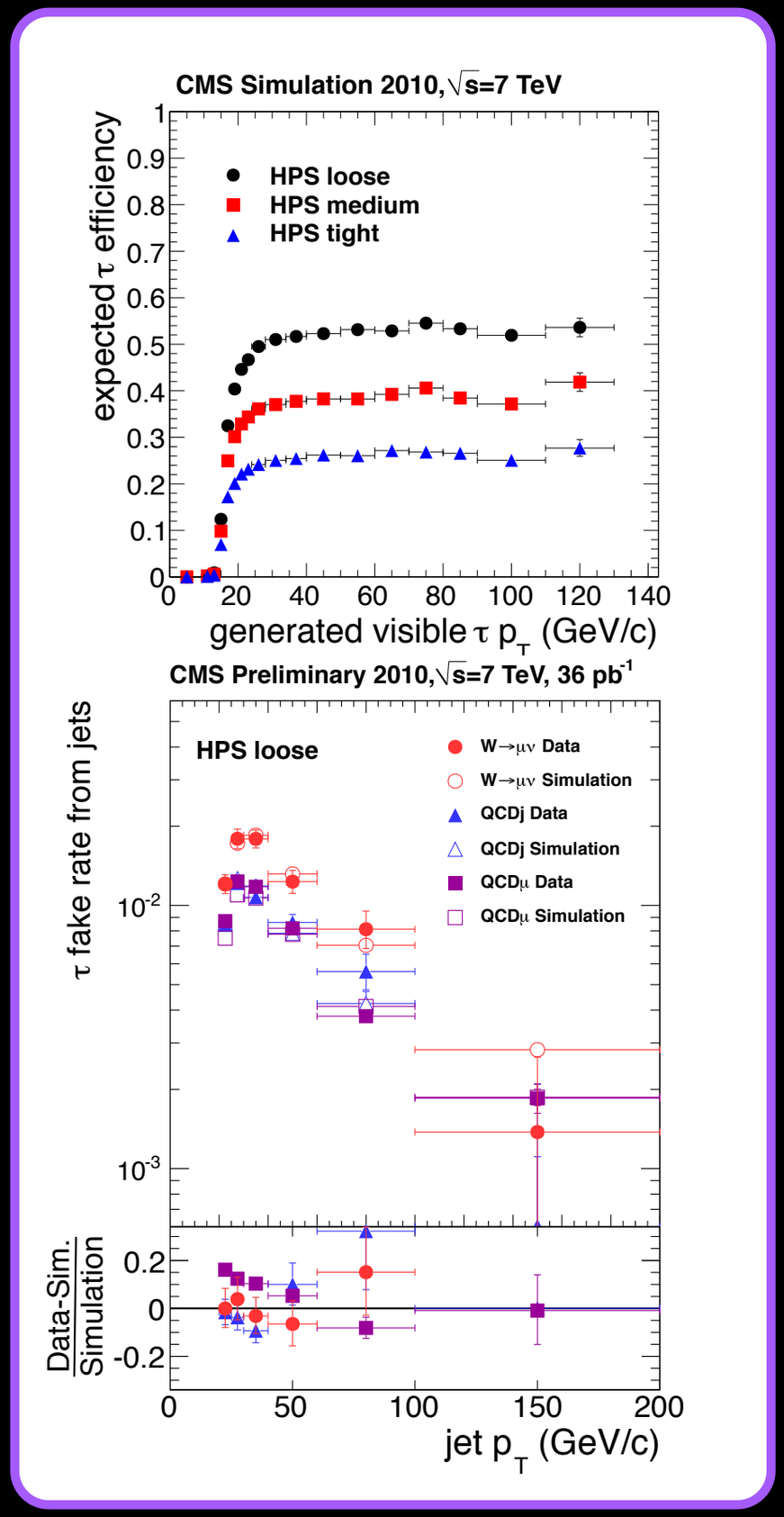
Hadrons + Strips (HPS) Algorithm



taus use CMS Particle Flow algorithm objects

selections applied on isolation, mass, collimation

efficiency measured to 6% in data



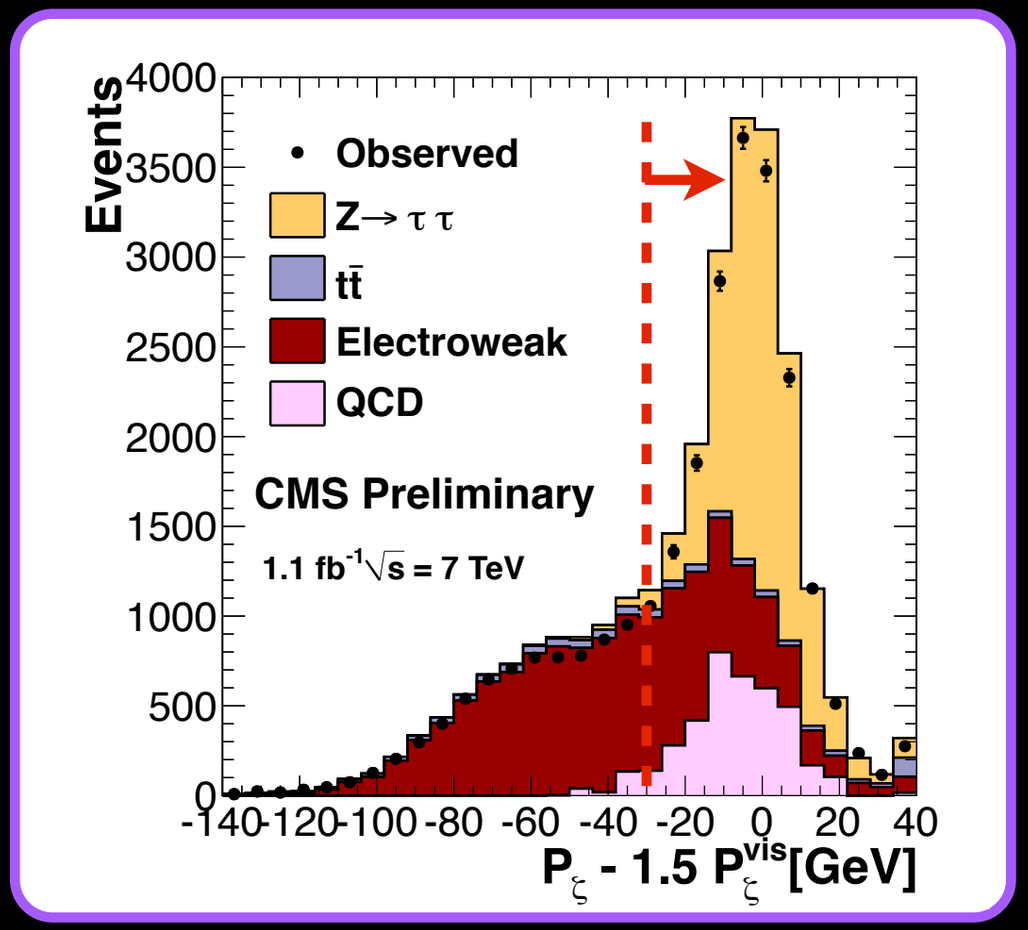
$H \rightarrow \tau\tau$ Event Selection

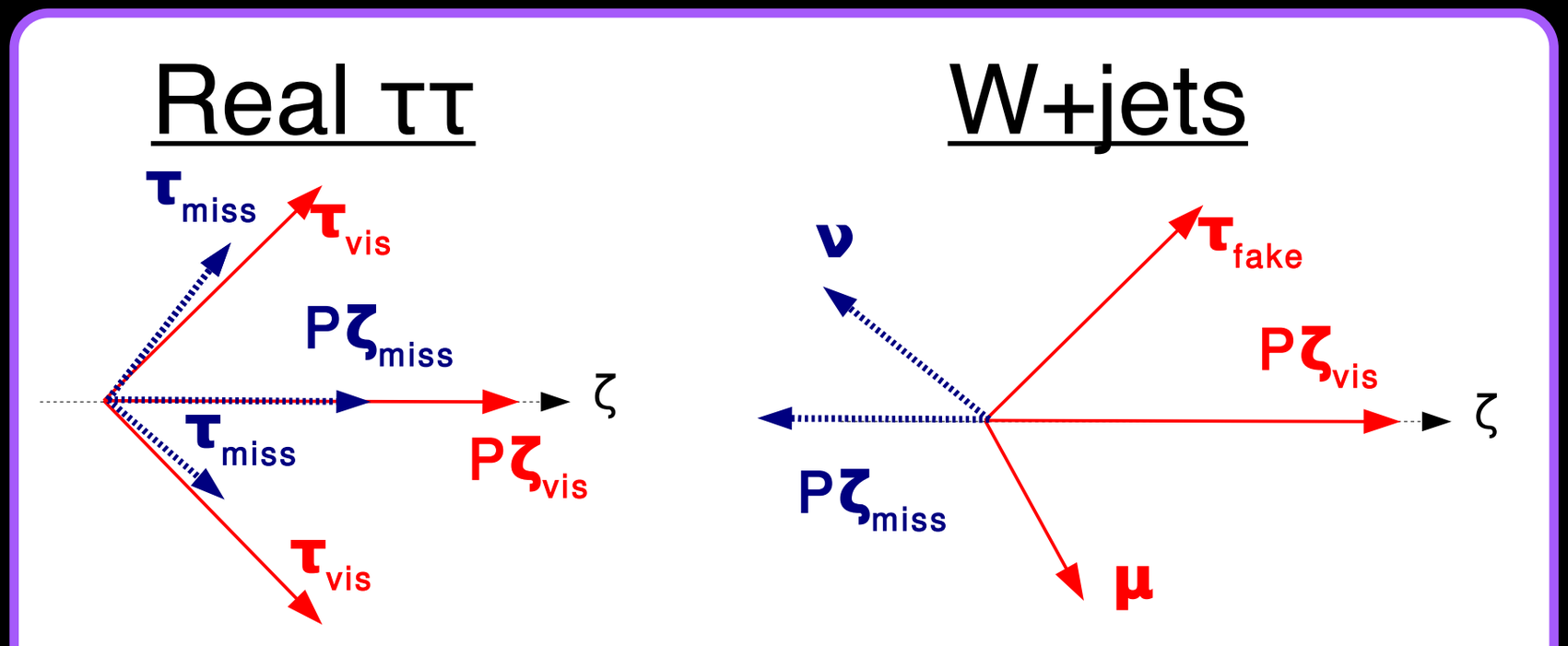
trigger and kinematic selections

Channel		Trigger	Offline
$\mu + \tau_h$	μ	$p_T > 15$ GeV	$p_T > 15$ GeV, $\eta < 2.1$
	τ	pt > 15,20 GeV	$p_T > 20$ GeV, $\eta < 2.3$
$e + \tau_h$	e	$p_T > 18$ GeV	$p_T > 20$ GeV, $\eta < 2.1$
	τ	pt > 20 GeV	$p_T > 20$ GeV, $\eta < 2.3$
$e + \mu$	e	$p_T > 8/17$ GeV	$p_T > 20/10$ GeV, $\eta < 2.1$
	μ	pt > 17/8 GeV	$p_T > 10/20$ GeV, $\eta < 2.5$
$\mu + \mu$	μ_1	$p_T > 17$ GeV	$p_T > 20$ GeV, $\eta < 2.1$
	μ_2		$p_T > 10$ GeV, $\eta < 2.4$

H→ττ Event Selection

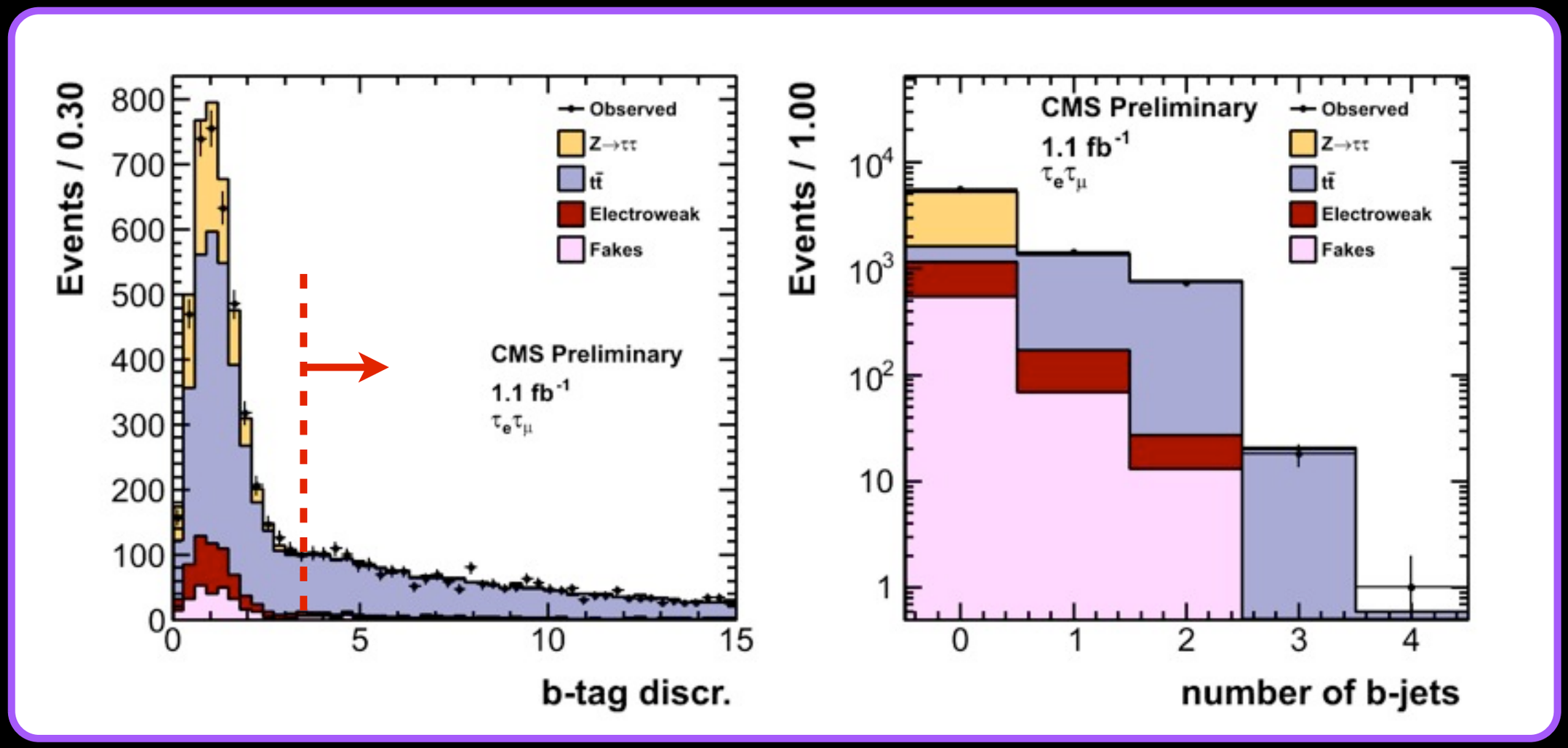
- P_ζ selection introduced at CDF
- Effective against W+jets and top
- Leptons required to have opposite charge
- Less than 2 jets with $p_T > 30$ GeV
- $\mu + \mu$ requires $ME_T < 65$ GeV
- $\mu + \mu$ channel has additional likelihood based selection





H→ττ Event Categorization

MSSM enhances associated b-quark production

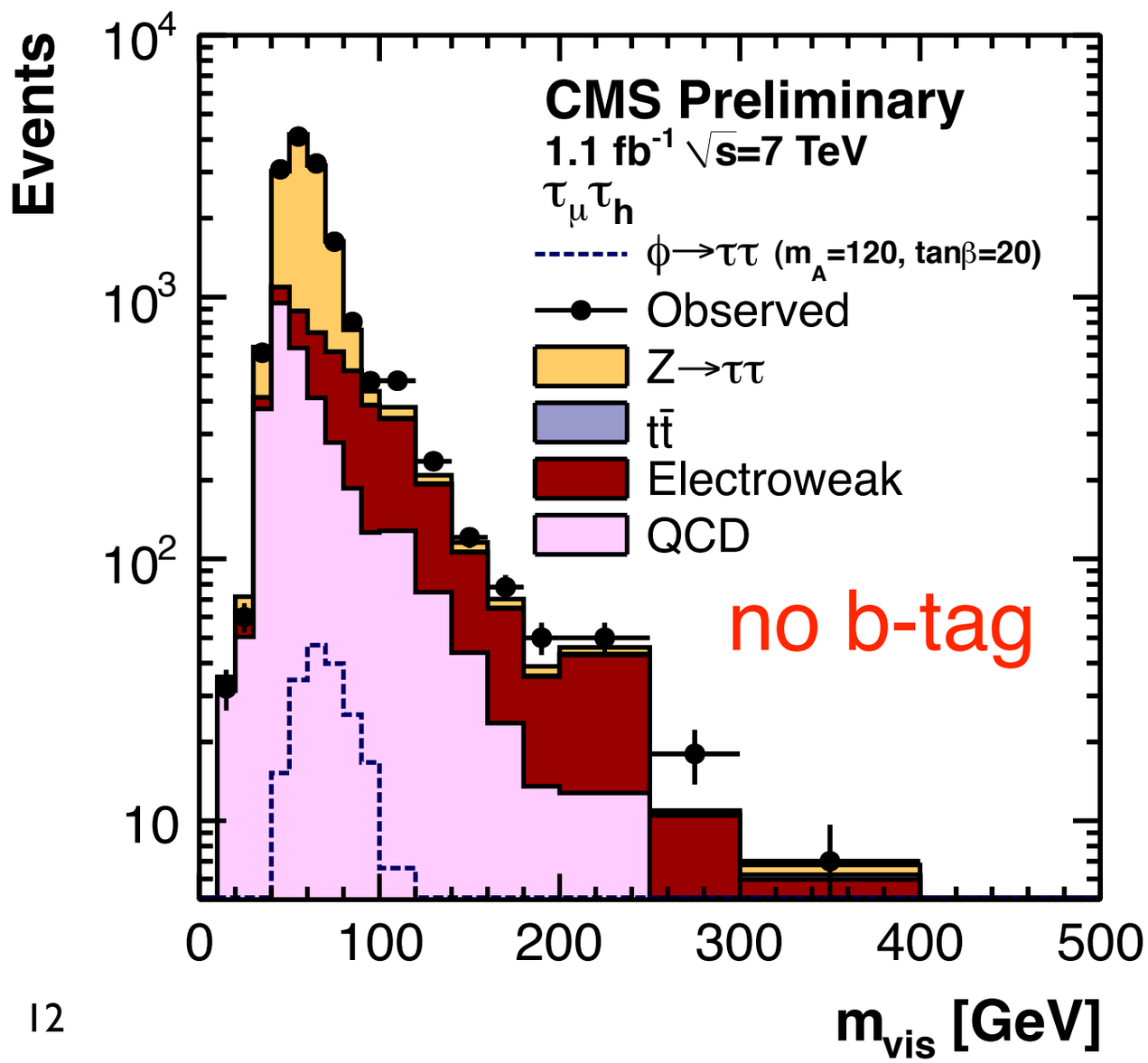


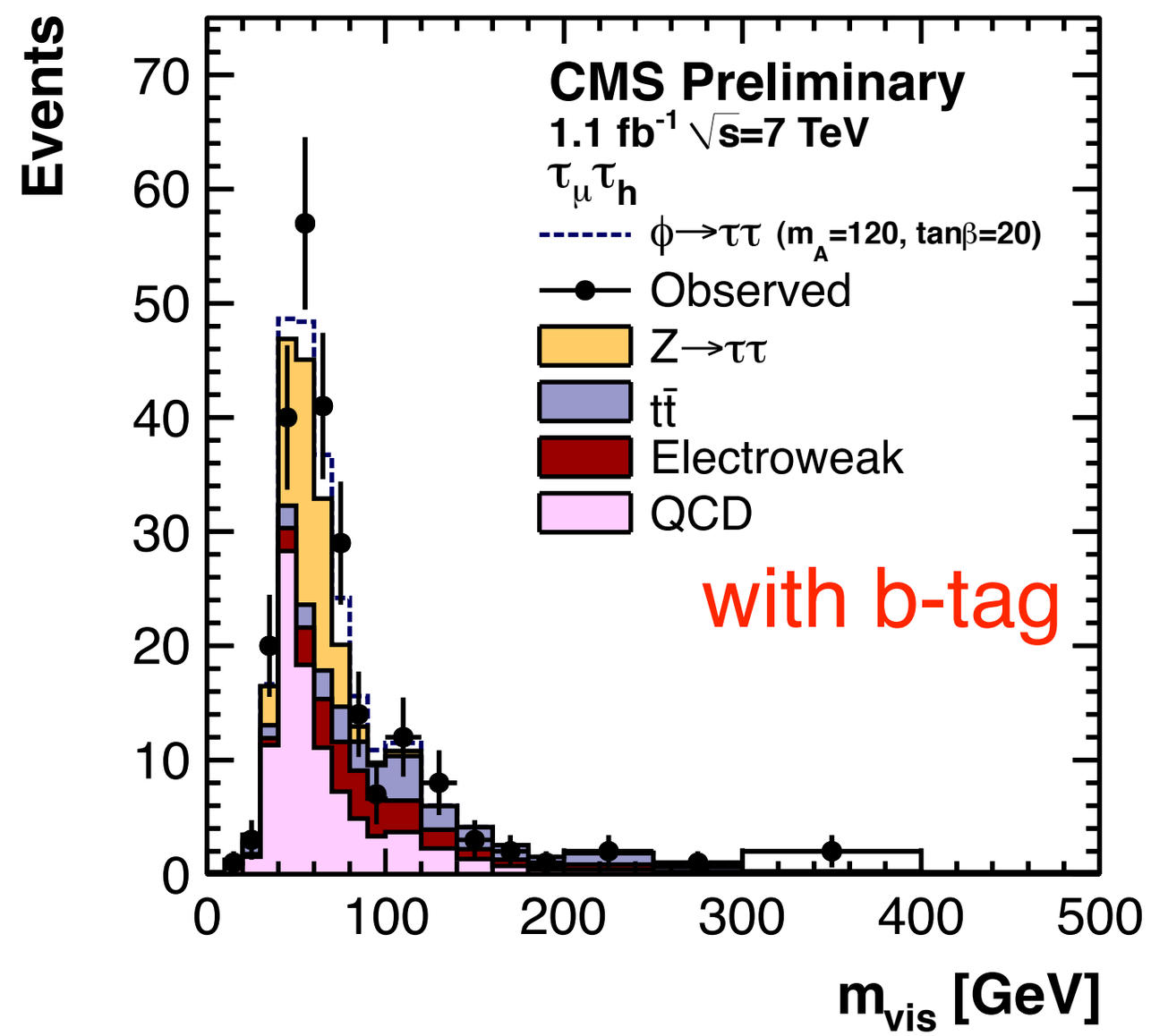
selected events divided exclusively:
with/without at least one b-tagged jet (p_T > 20 GeV)

H→ττ Selected Events

μ + τ_h final state

	no b-tag	b-tag
background	14514±640	193±13
data	15057	243

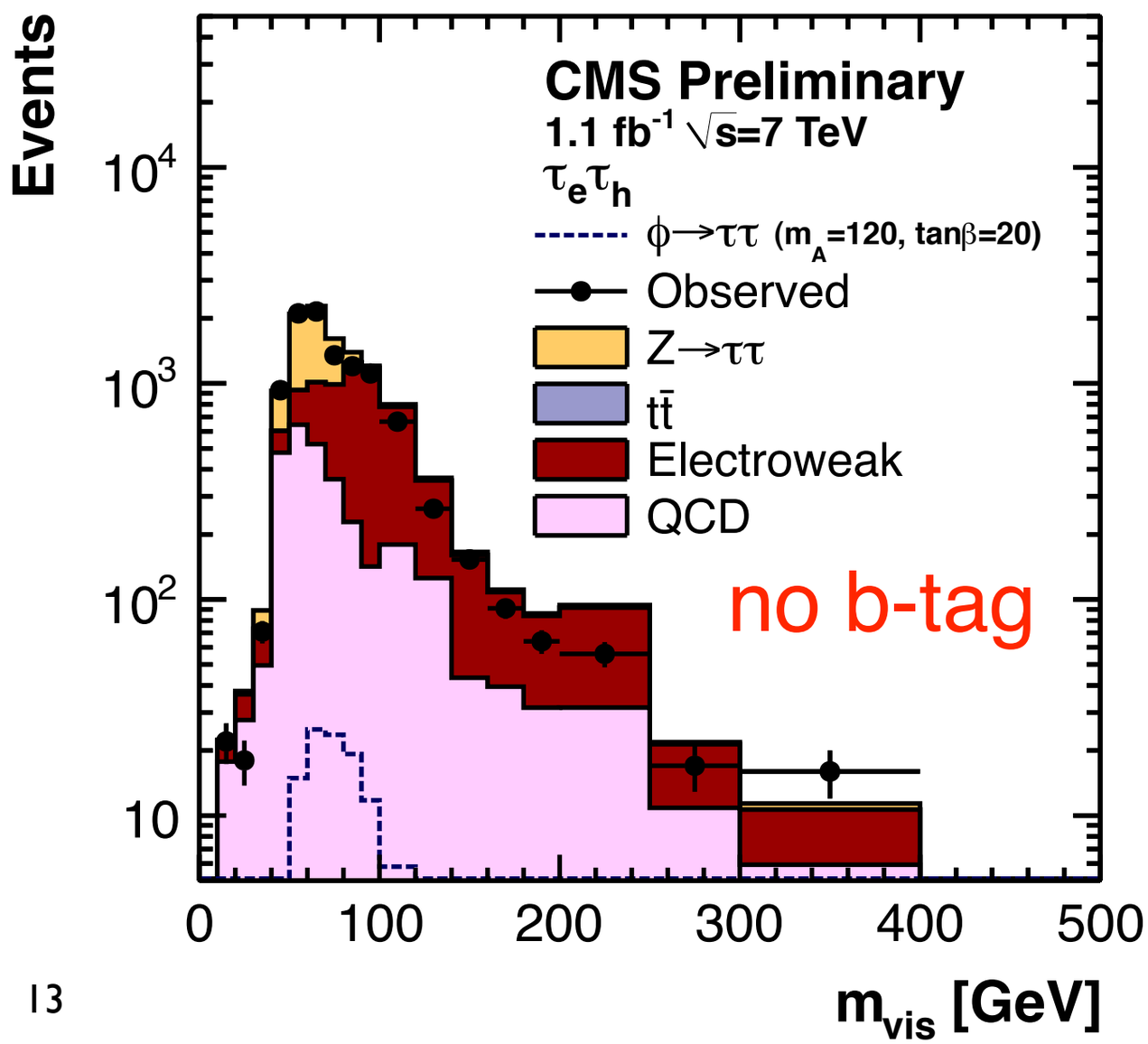


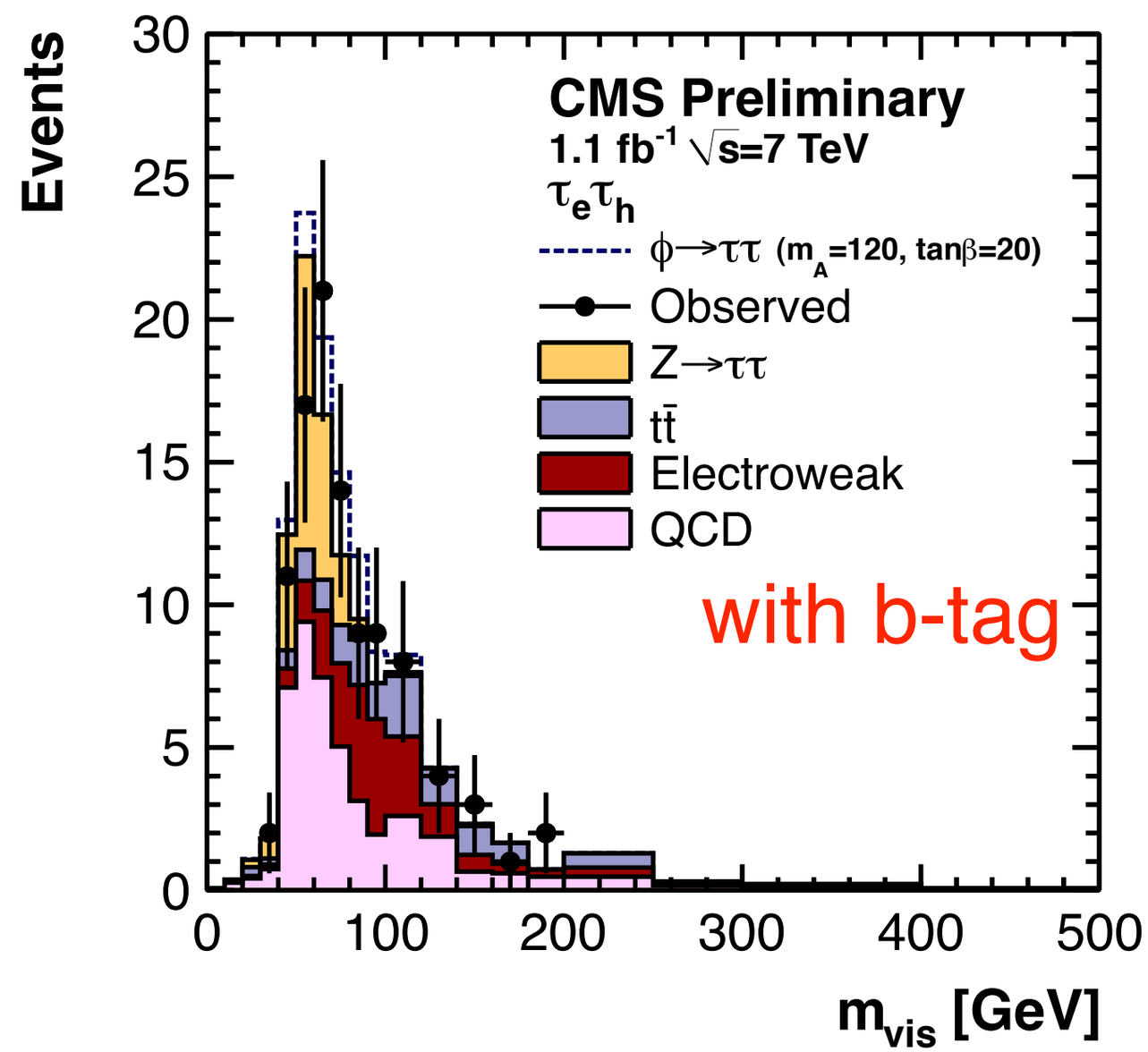


H→ττ Selected Events

e + τ_h final state

	no b-tag	b-tag
background	9398±320	105±9
data	10283	101

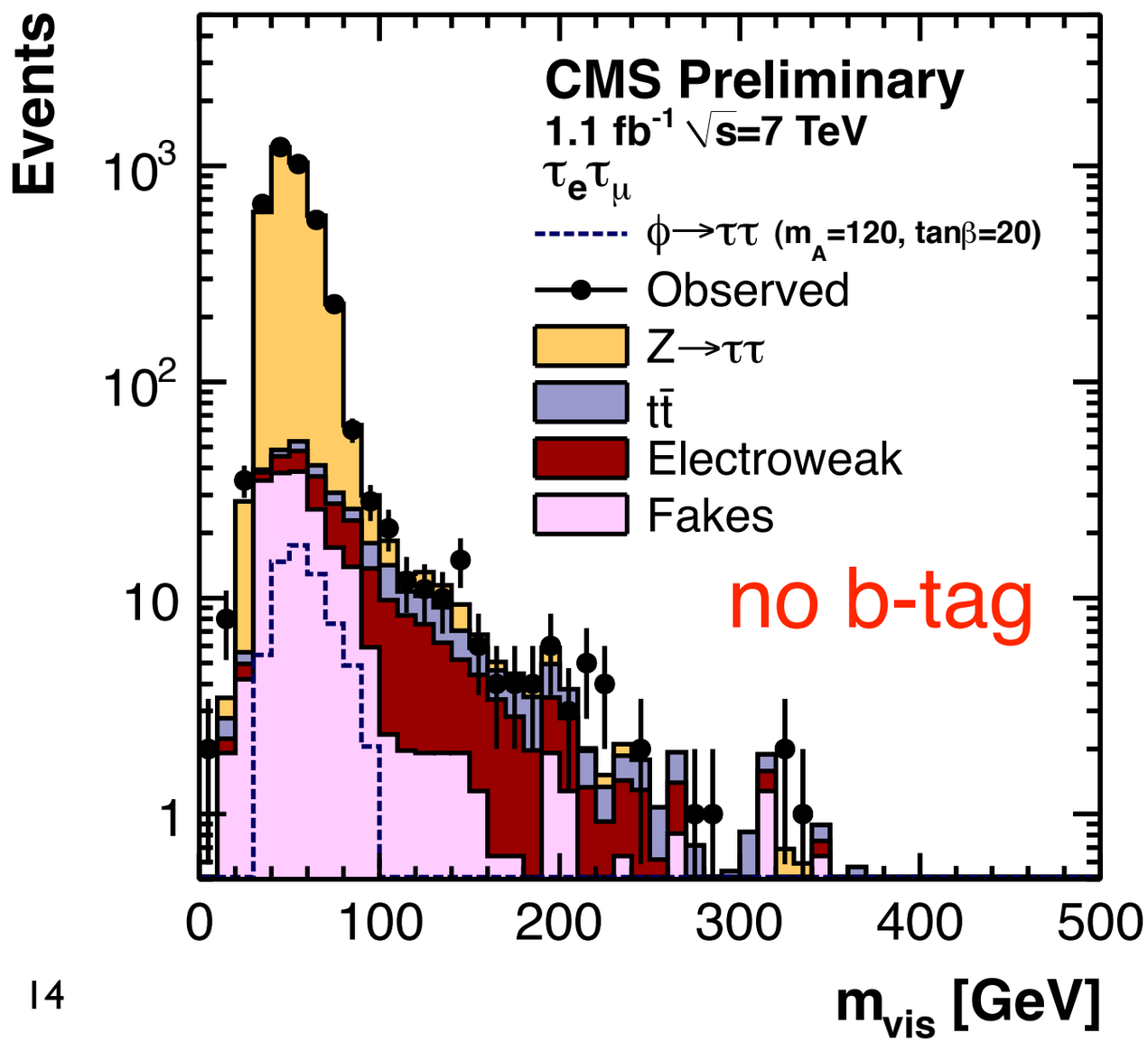


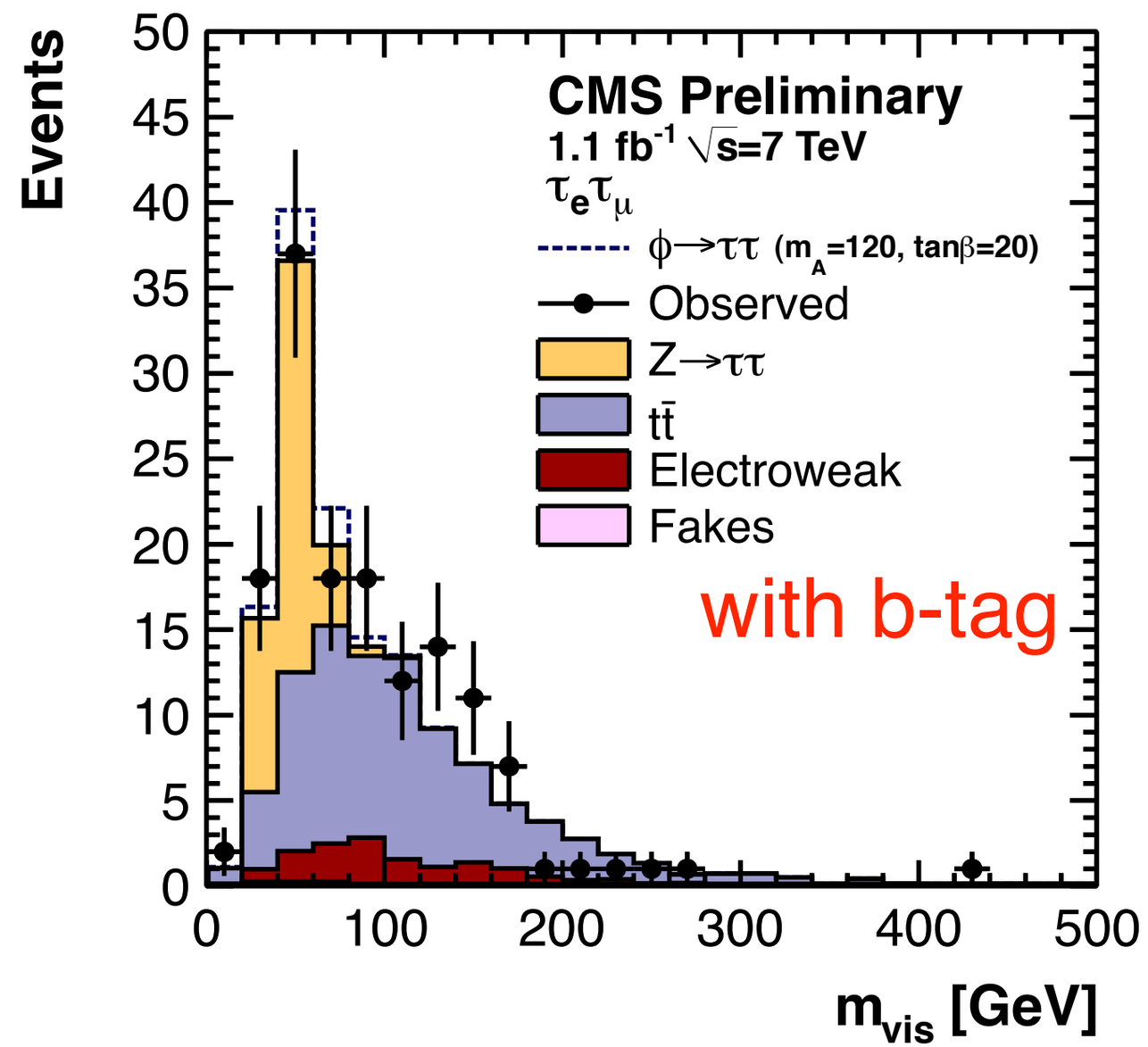


H→ττ Selected Events

e + μ final state

	no b-tag	b-tag
background	3643±131	150±12
data	3942	143

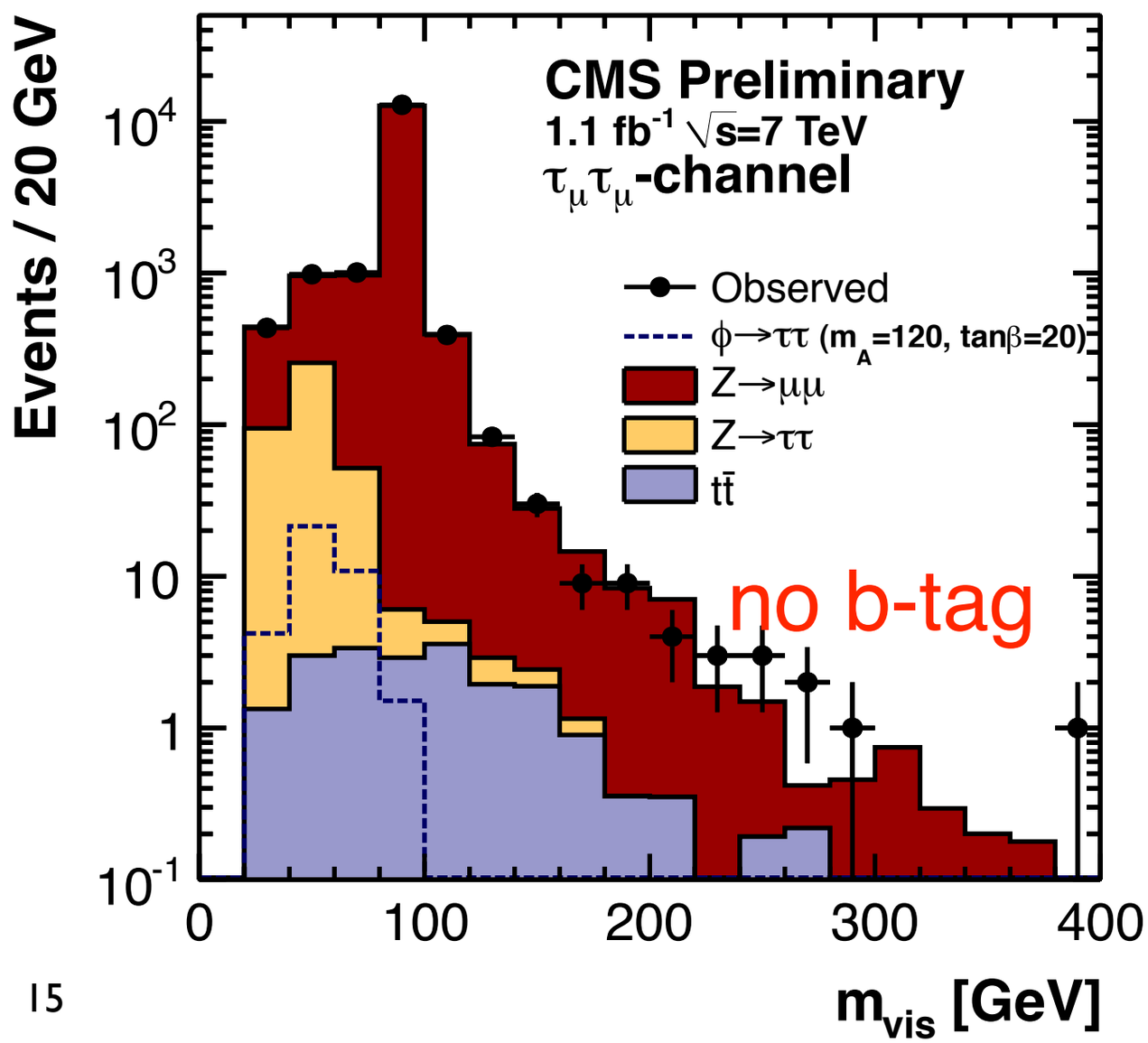


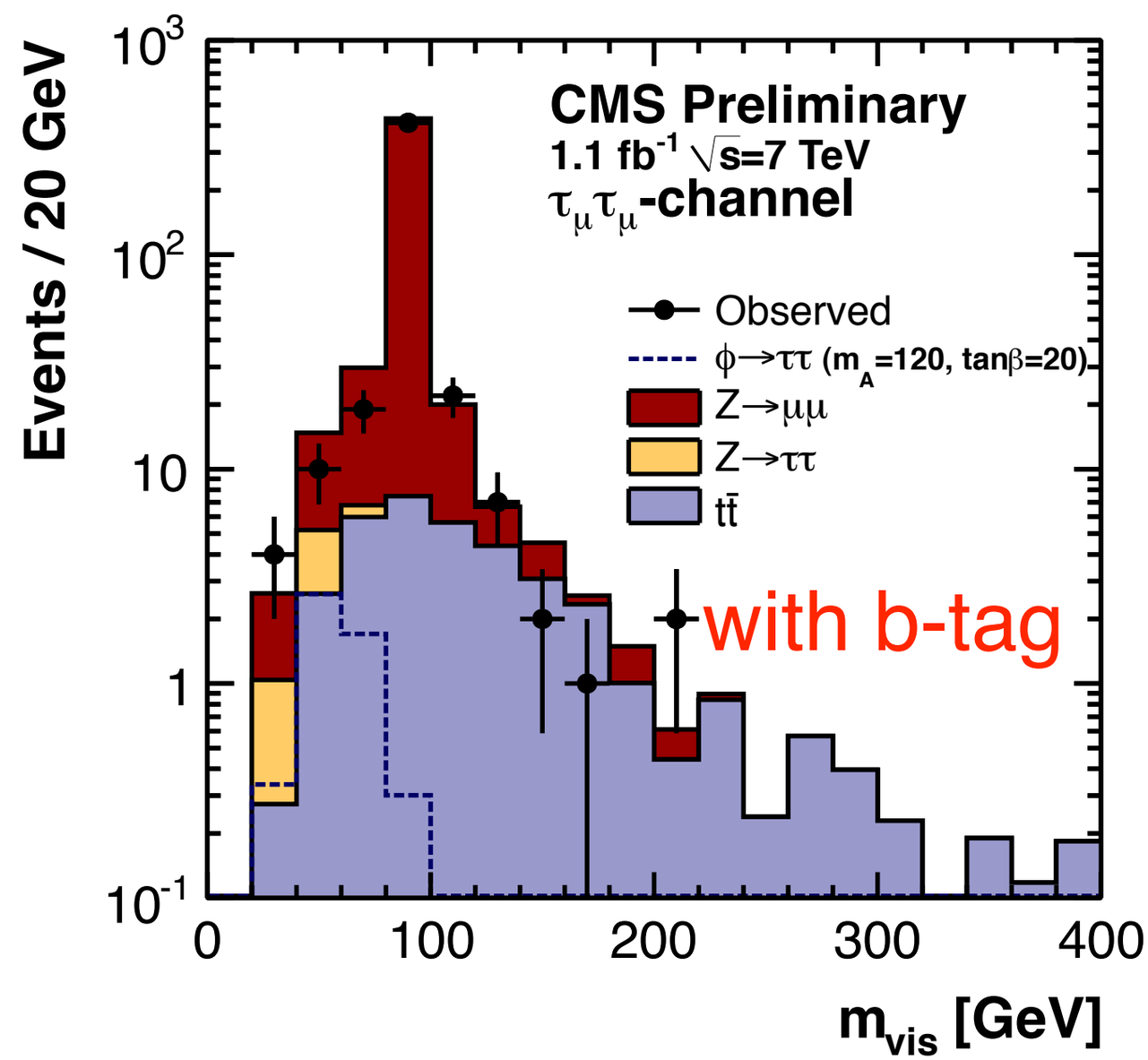


H→ττ Selected Events

μ + μ final state

	no b-tag	b-tag
background	15645±105	460±12
data	15711	479





$H \rightarrow \tau\tau$ Backgrounds

background	affects	strategy
$Z \rightarrow \tau\tau$	all	normalized to CMS 2010 $Z\mu\mu$
QCD	$\mu + \tau_h$, $e + \tau_h$	estimated from OS/SS data
W+jets	all	shape from MC normalization from P_ζ sideband
fake electrons	$e + \mu$	fake rate method* using data
top anti-top	all	shape from MC normalization: CMS 2010 $\sigma(tt)$
di-boson	all	taken from MC (negligible)
$Z \rightarrow \mu\mu$	$\mu + \mu$	taken from likelihood variable sidebands

*described in backup

H→ττ Systematics

uncertainties either effect normalization or shape

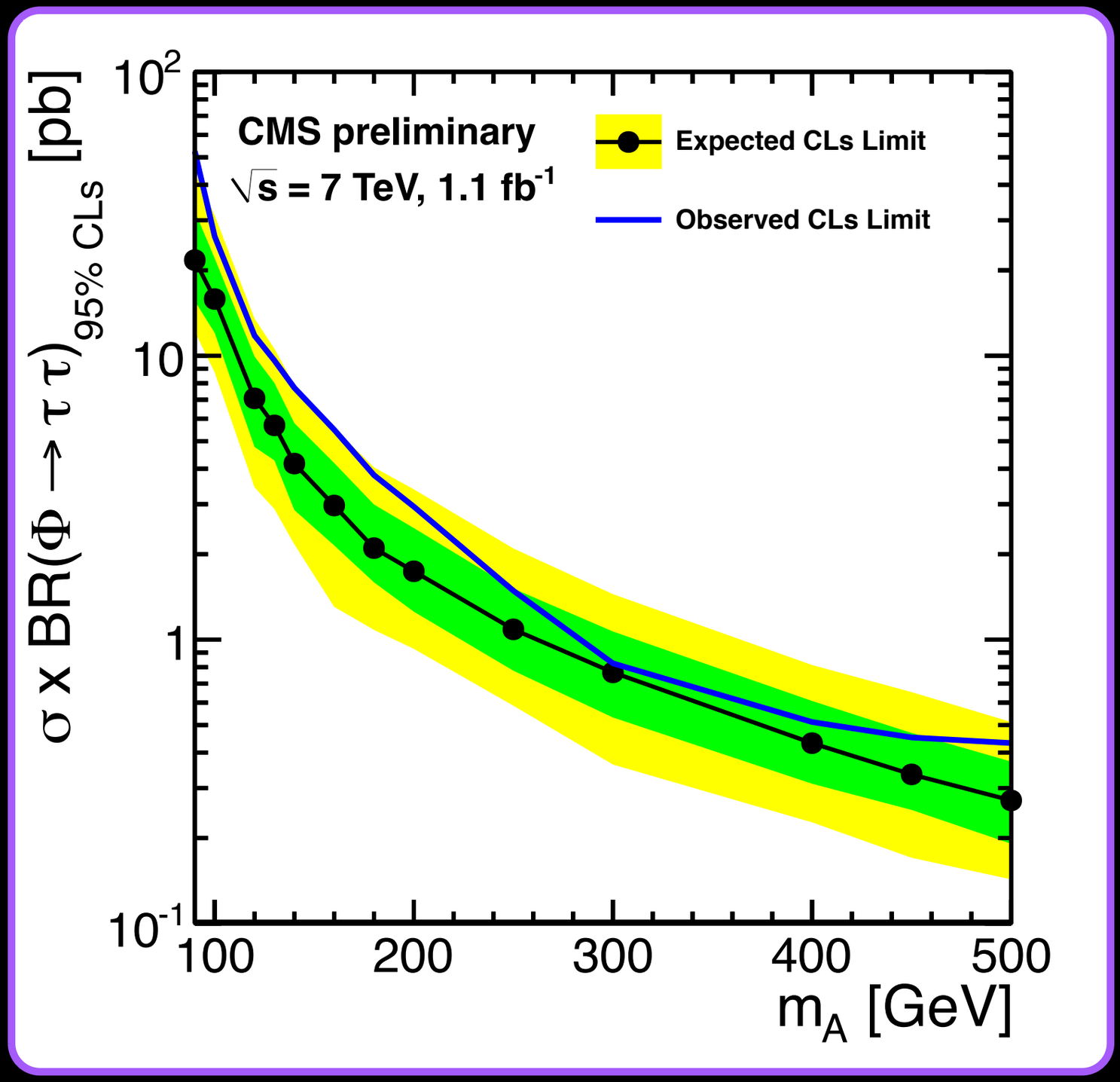
numbers shown here are **input** uncertainties

source	uncertainty
lepton ID/trigger	1%
tau ID efficiency	6%
tau energy scale	3% (shape)
σ (Z→ee/μμ)	3%
σ (top anti-top)	12%
b-tag efficiency	10%
b-tag mistag rate	14%
jet energy scale	2-5%
PDFs	3%
UE/parton shower	4%
QCD scale	4-12%
luminosity	6%

H→ττ Yield Limit

limit on
$\sigma_\phi \times BR_{\phi\to\tau\tau}$

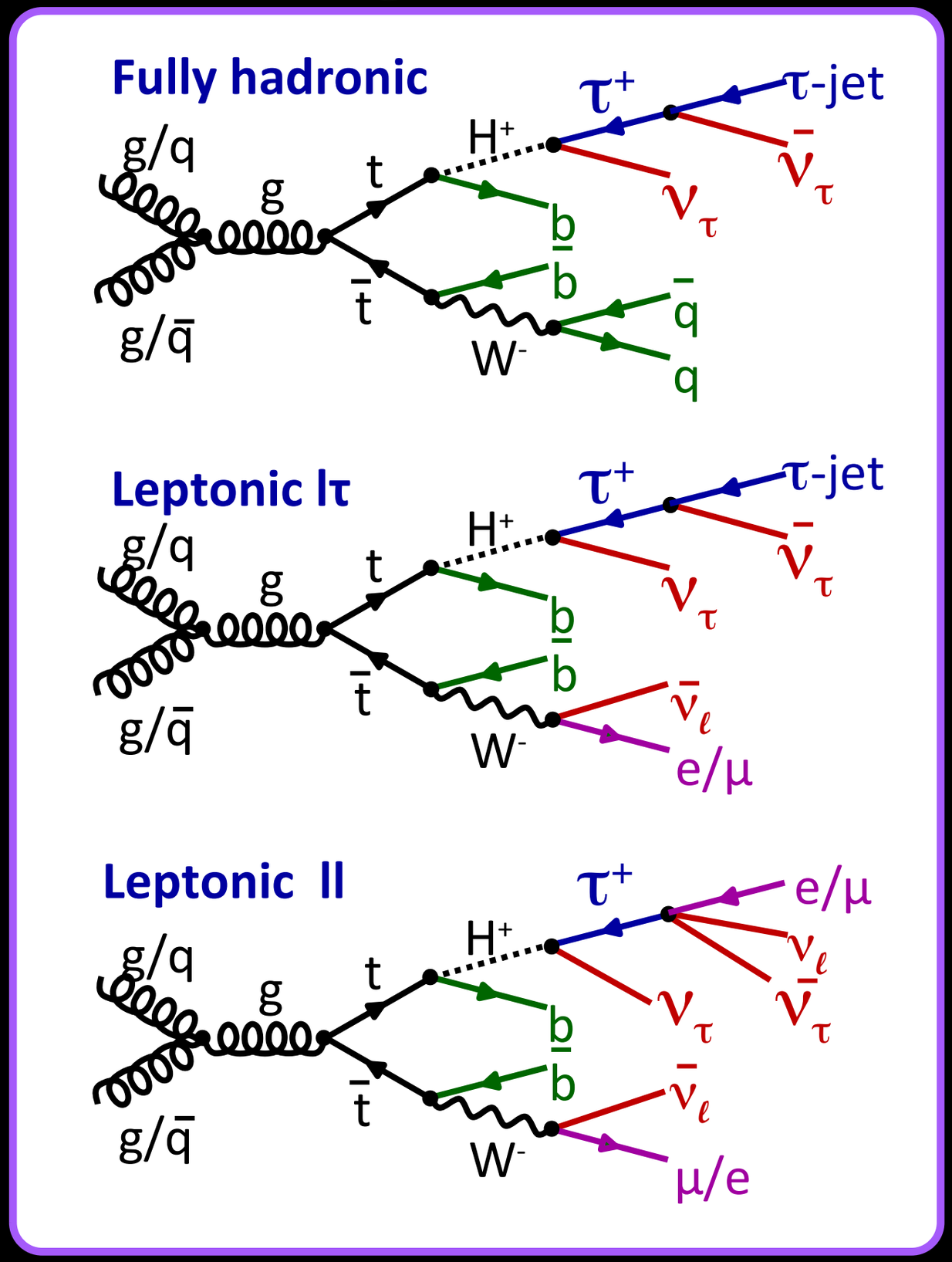
- Not model independent
- gg/bb cross section ratio assumes MSSM and tanβ = 30



Uses CL_s method

Charged Higgs Strategy

- Measurement of branching fraction of $H^+ \rightarrow \tau^+ \nu$
- Three final states considered



Charged Higgs Selection

all hadronic

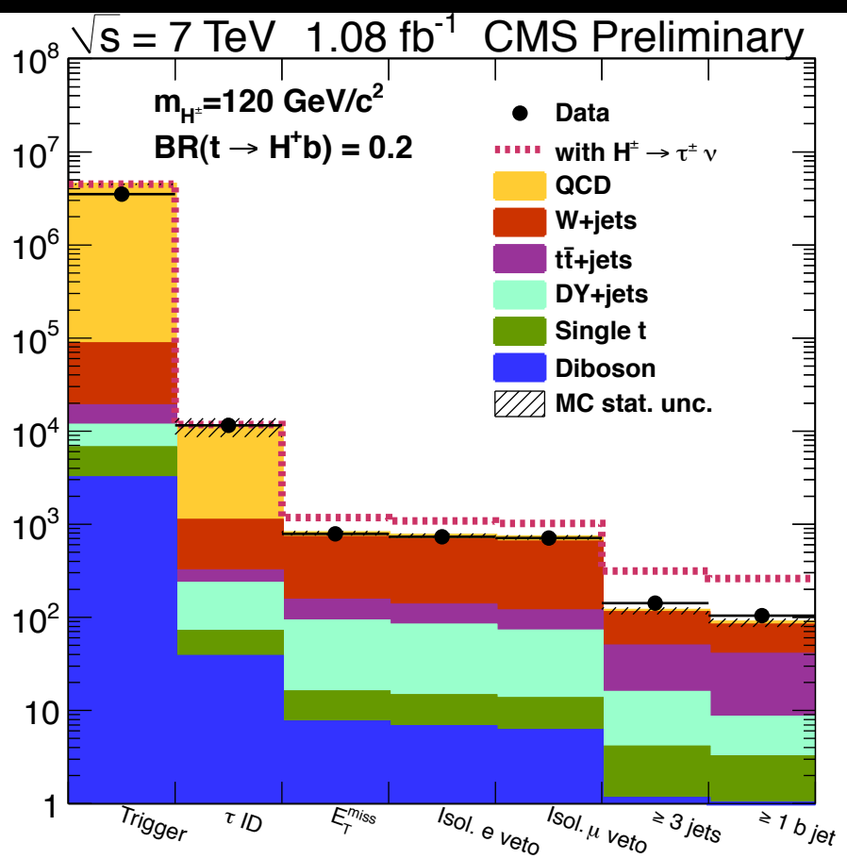
- tau + ME_T trigger
- τ $p_T > 40$ GeV, $\eta < 2.3$
- 1 prong taus
- ≥ 3 jets $p_T > 30$ GeV
- $ME_T > 70$ GeV
- 1 b-tag

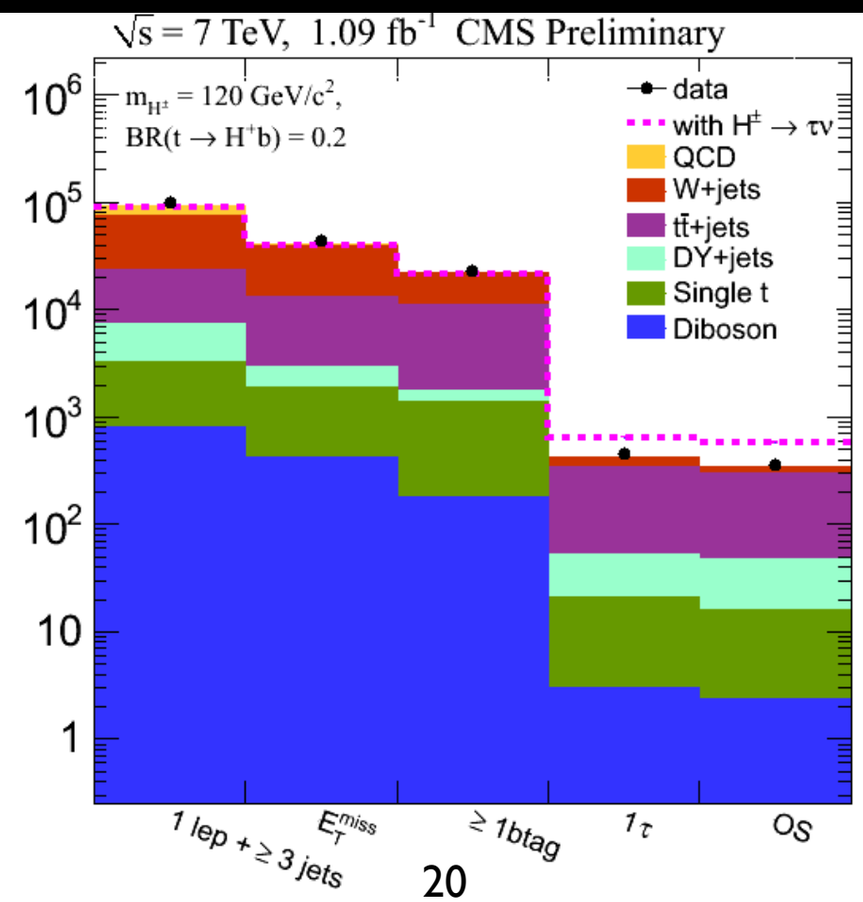
$\mu + \tau_h$

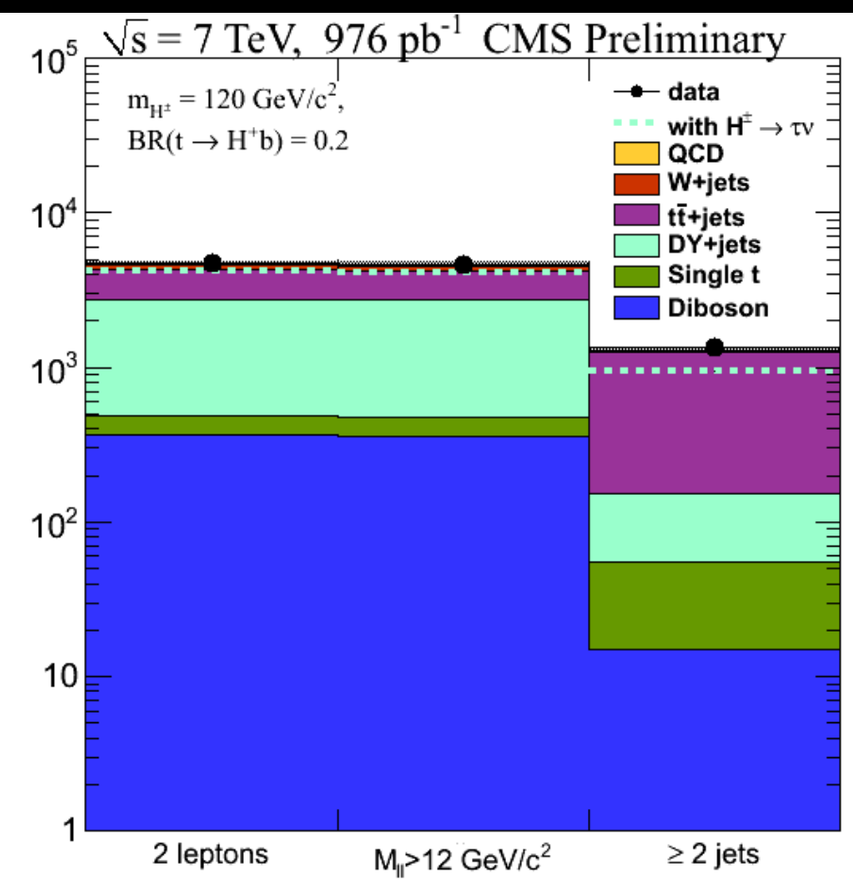
- single muon trigger
- τ $p_T > 20$ GeV, $\eta < 2.4$
- μ $p_T > 20$ GeV, $\eta < 2.1$
- ≥ 2 jets $p_T > 30$ GeV
- $ME_T > 40$ GeV
- 1 b-tag

$\mu + e$

- e (8) + μ (17)
e (17) + μ (8) trigger
- lepton $p_T > 20$ GeV, $\eta < 2.4$
- ≥ 2 jets $p_T > 30$ GeV







Charged Higgs Backgrounds

fully hadronic

QCD multijet background taken from data
EWK + top anti-top estimated by embedding simulated taus in muon events
EWK + top anti-top + fake taus from MC

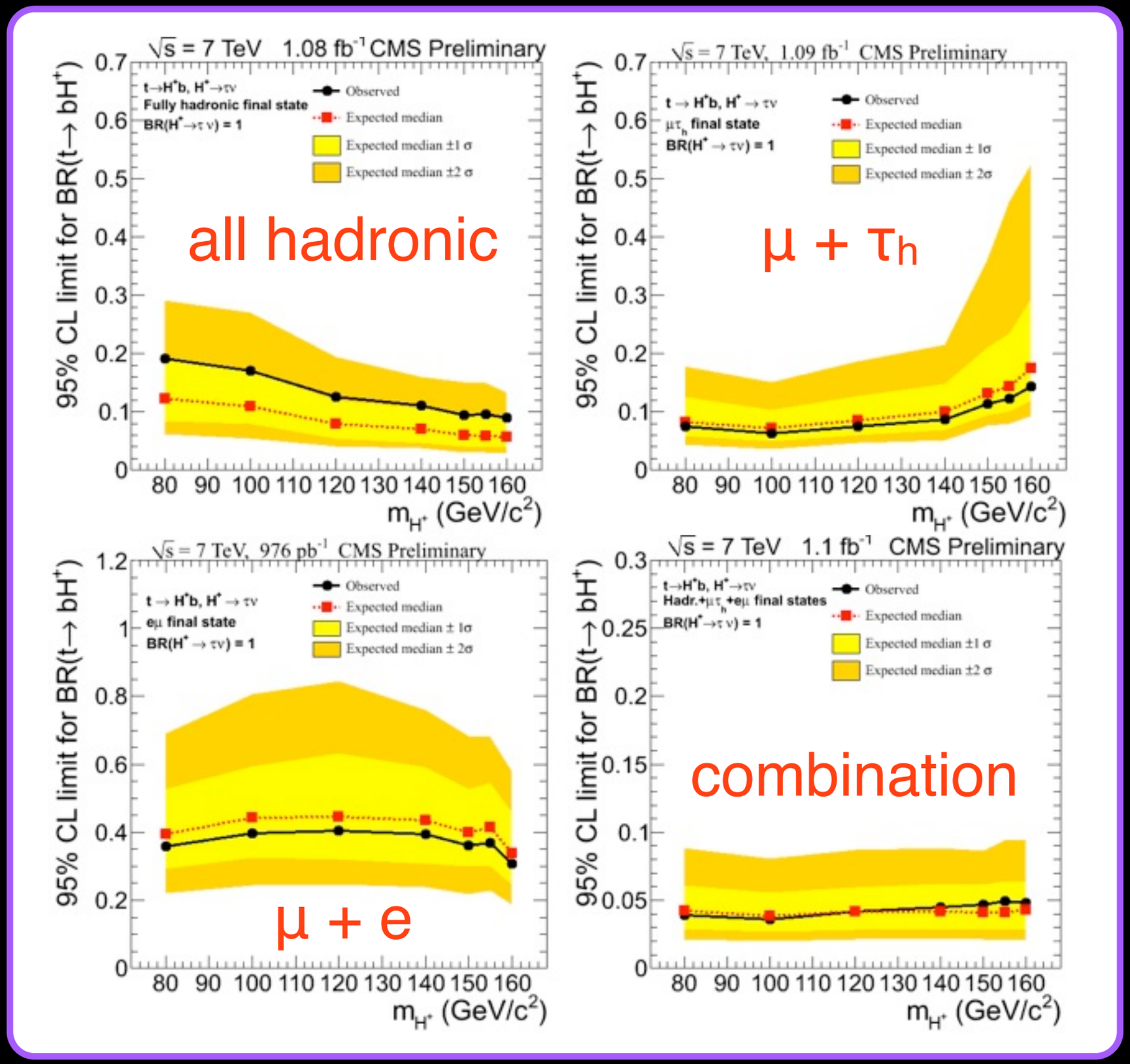
$\mu + \tau$

QCD tau fakes estimated with fake rate method
other backgrounds from simulation

$e + \mu$

top anti-top background estimated from simulation

Charged Higgs Limits



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

assumes
$B(H^+ \rightarrow \tau^+ \nu) = 1$

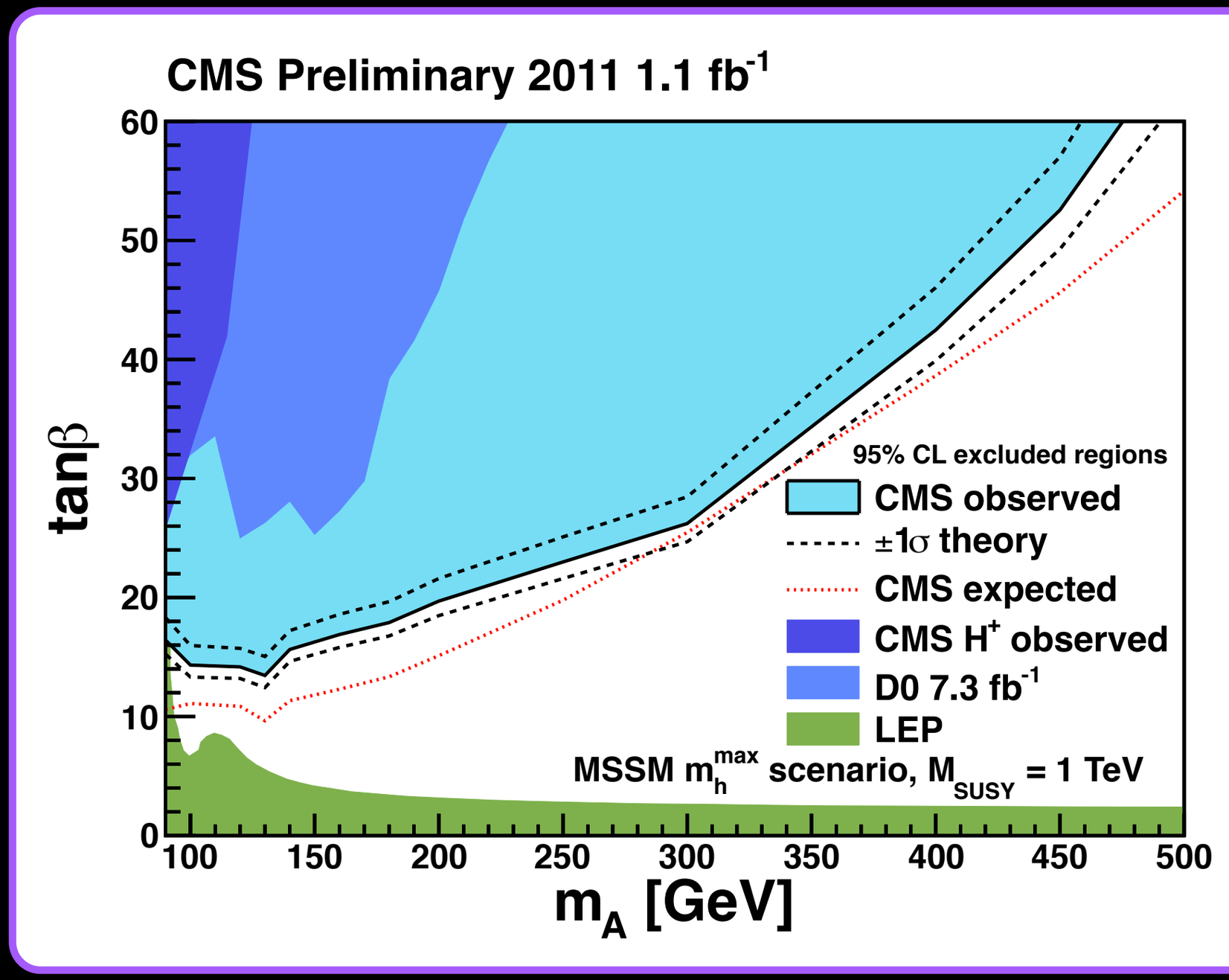
BR > 5%
excluded!

Interpretation in MSSM

Santander matching
for mapping σ → tanβ

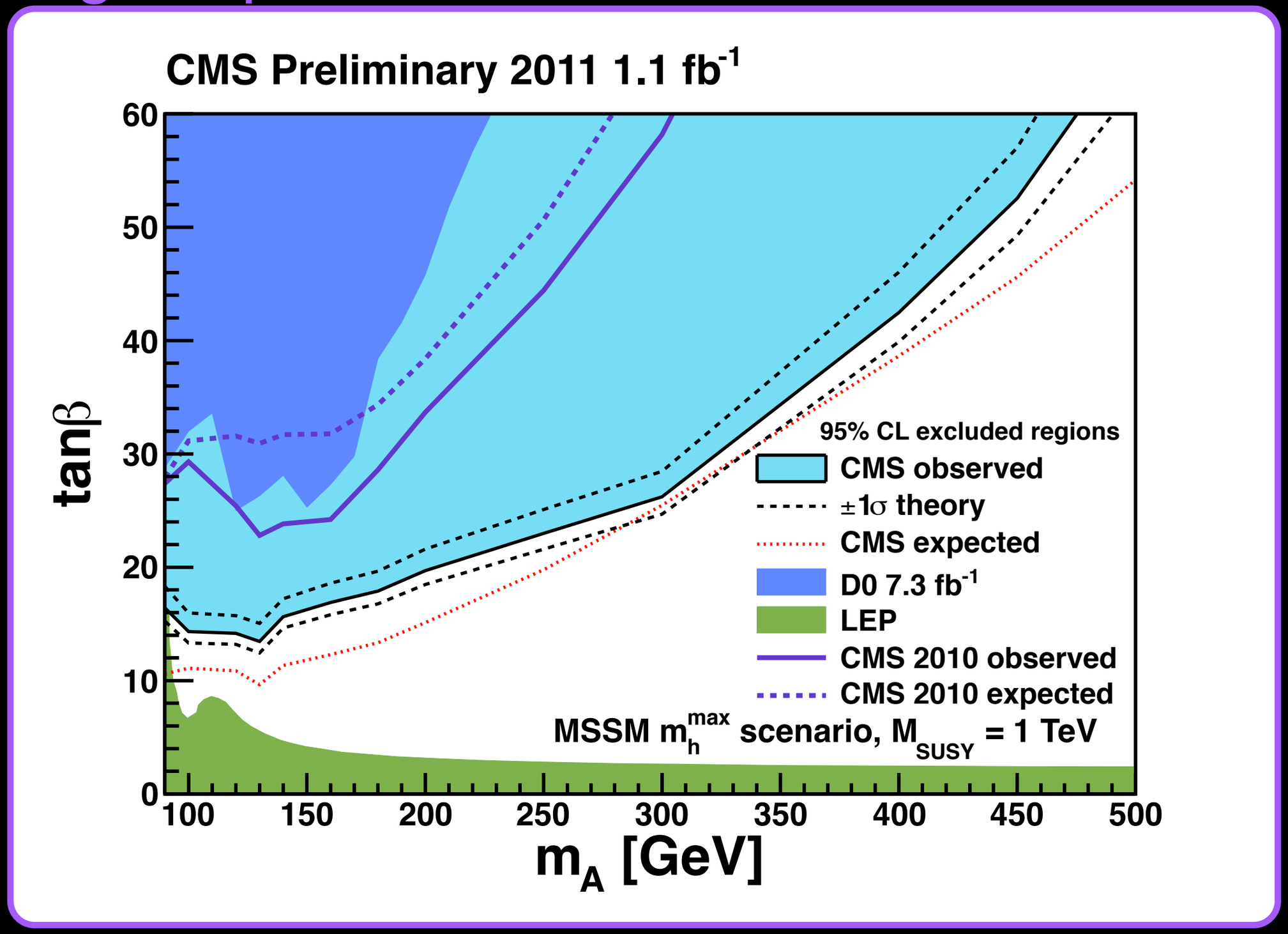
H→ττ drives limit
H^+ contributes
at low mass

Theory uncertainties:
PDF + α_s + μ scale



Interpretation in MSSM

huge improvement w.r.t. CMS winter result!



more data, b-tagging, and τ-ID systematics

Summary

- Inclusive search for ϕ^{++} performed
  - No excess observed, new world limits
- Search for neutral MSSM Higgs performed
  - No excess observed
- Upper limit of 5% placed on $BR(t \rightarrow H^{+}b)$
- Large new region of MSSM parameter space excluded by these results

backup

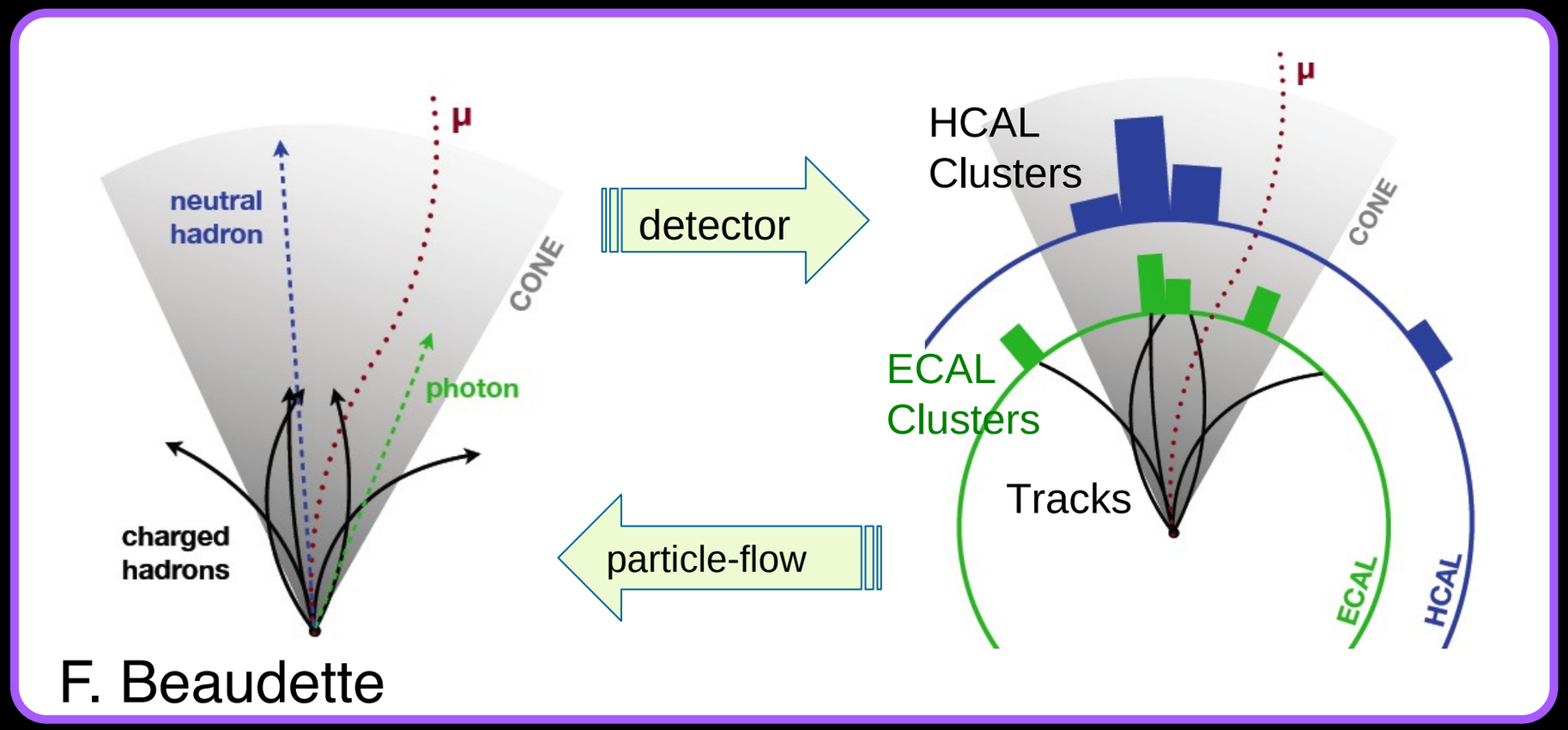
Particle Flow Algorithm

taus in CMS are built using Particle Flow objects

- Clusters and links signals from all subdetectors
- Produces a list of particle candidates

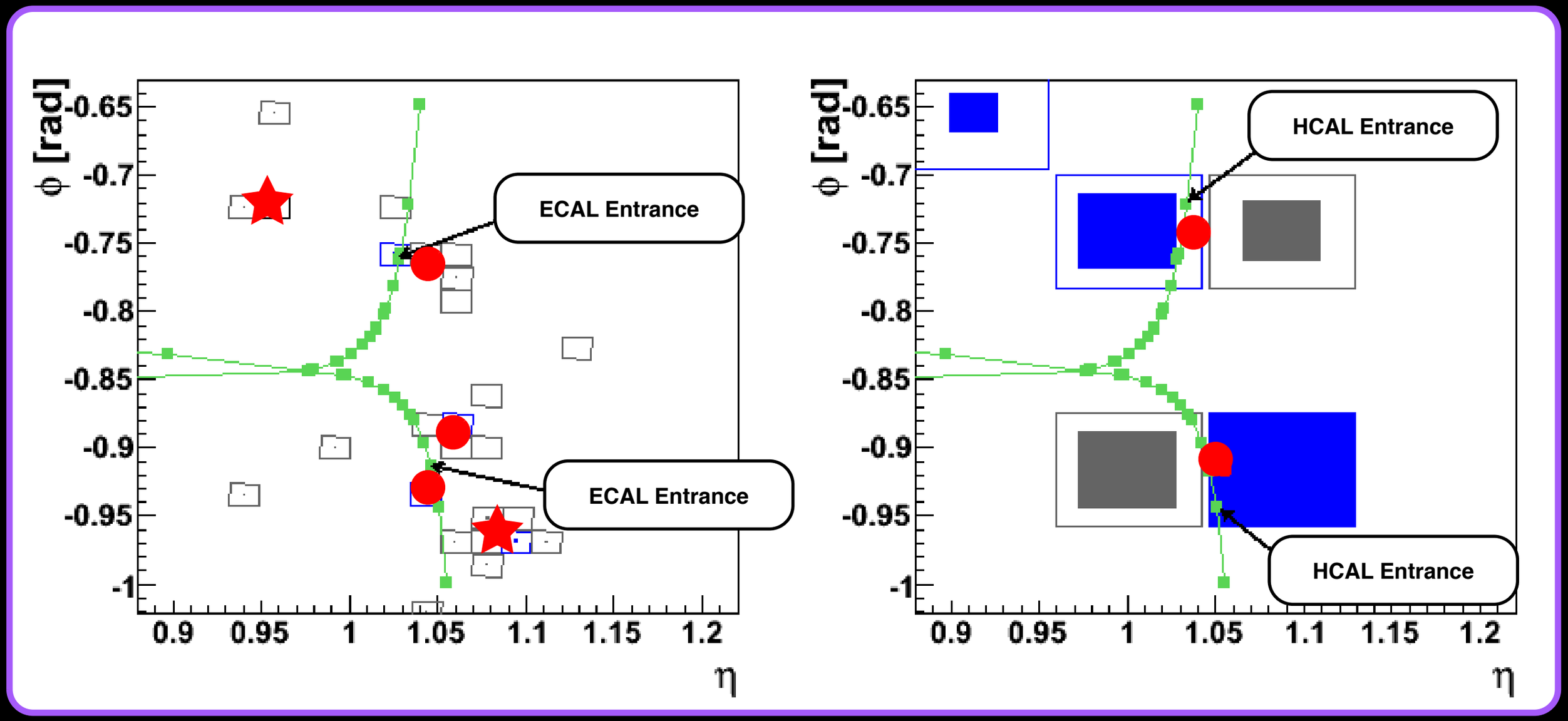
$h\ h^0\ e\ \mu\ \gamma$

- To the user looks just like Monte Carlo



F. Beaudette

Particle Flow Algorithm



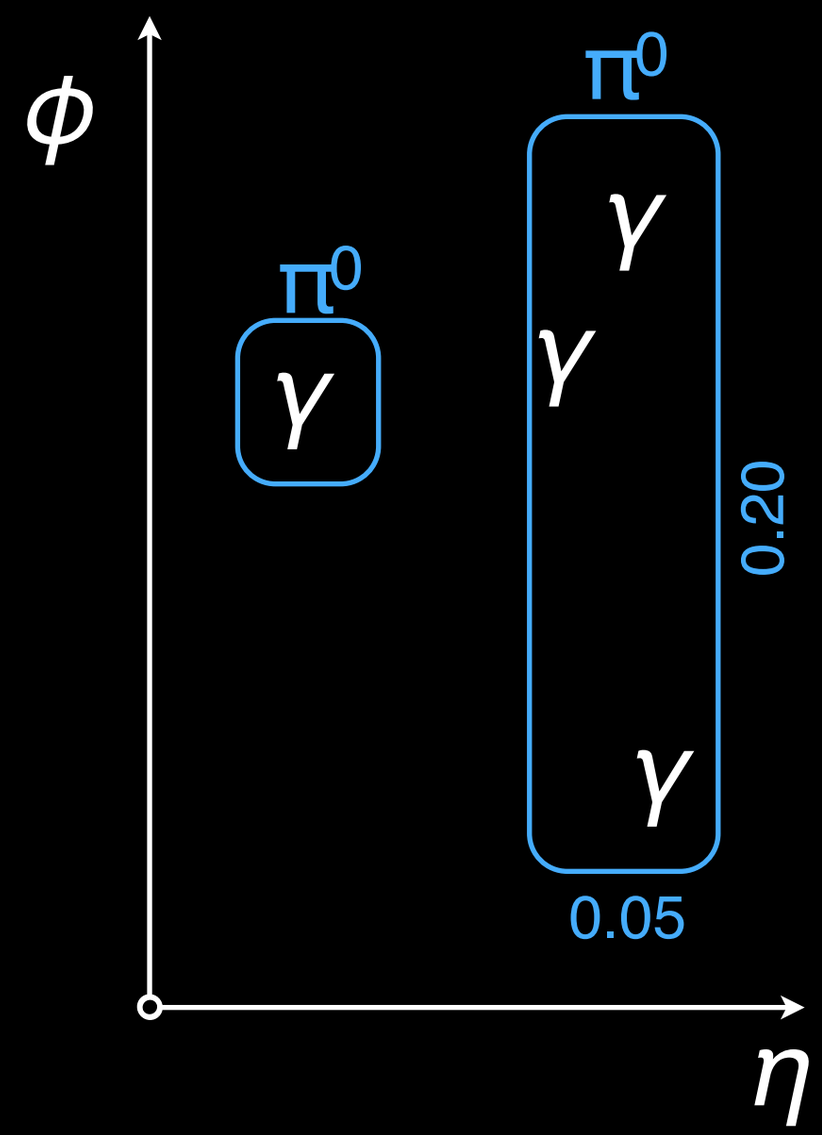
- ● cluster linked to track
- ★ unlinked cluster
- ■ tracker hit

see CMS PAS PFT-10-002

Hadrons Plus Strips Algorithm

build signal components combinatorially

cluster gammas into π^0 candidates using η-ϕ strips



build all possible taus that have a 'tau-like' multiplicity from the seed jet

π^+

$\pi^+ \pi^0$

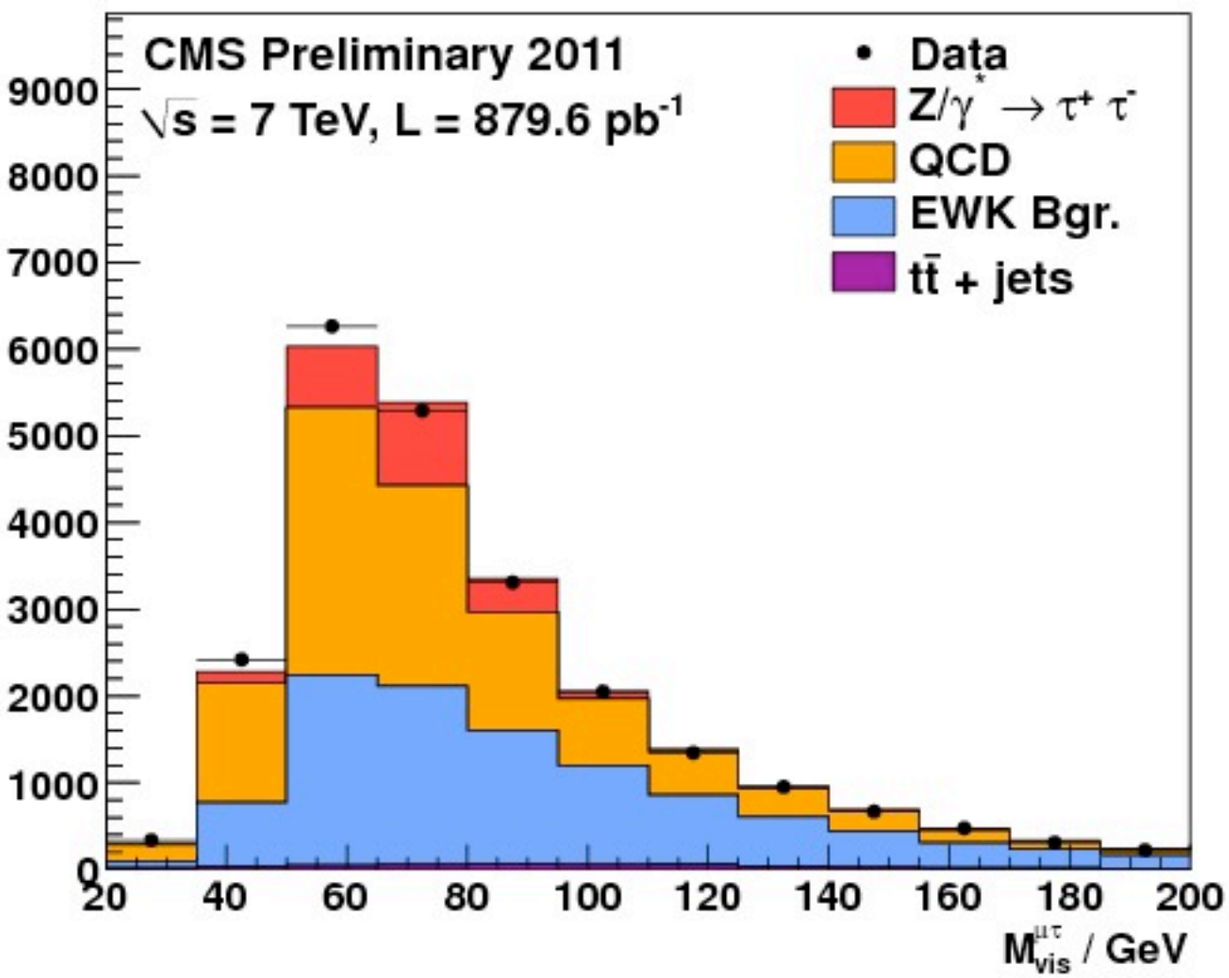
$\pi^+ \pi^+ \pi^-$

tau that is 'most isolated' with compatible m_{vis} is the final tau candidate associated to the seed jet

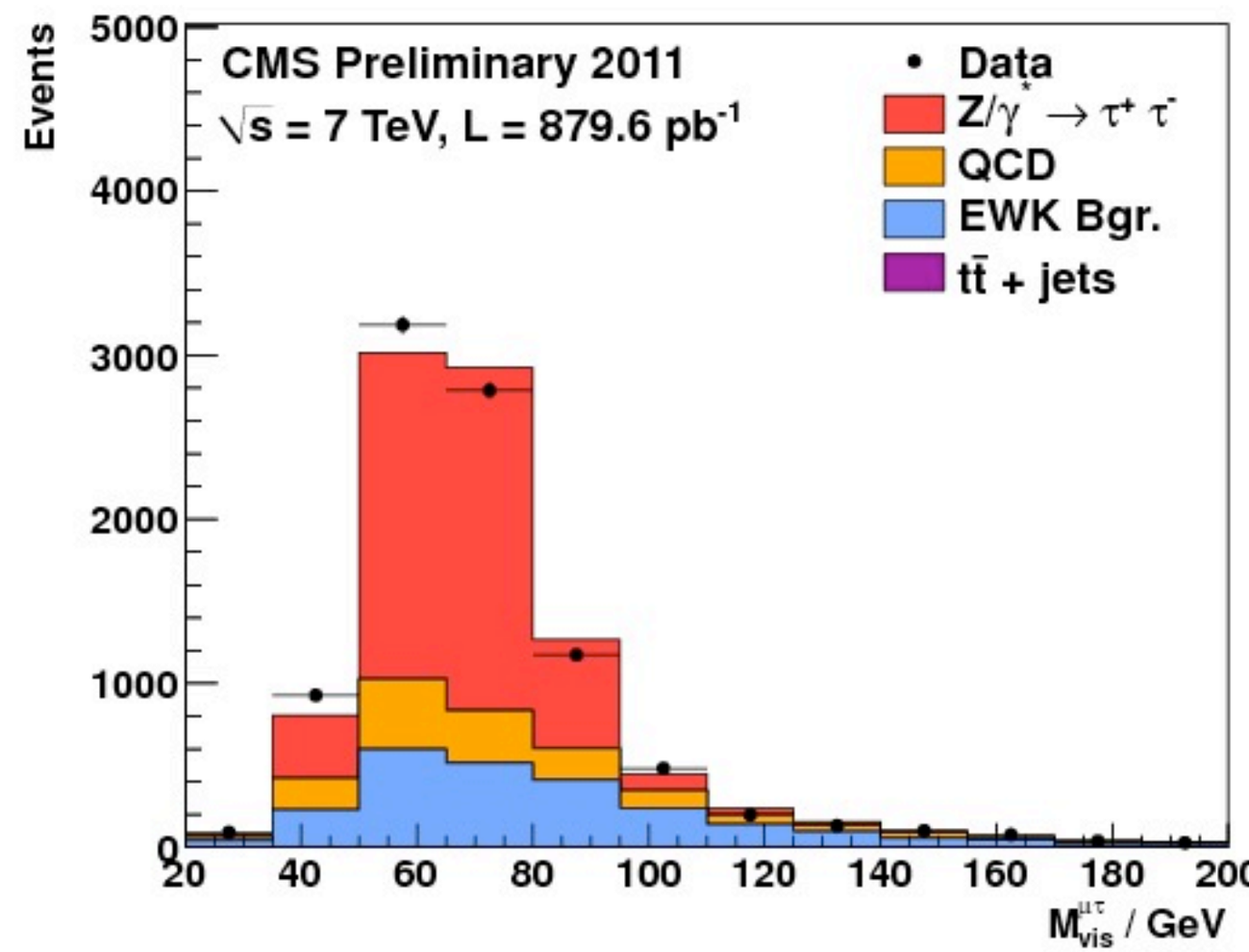
Tau ID Efficiency

measured in data by fitting tau-ID passed and failed M_{vis} spectrum for loosely selected taus

tau ID failed

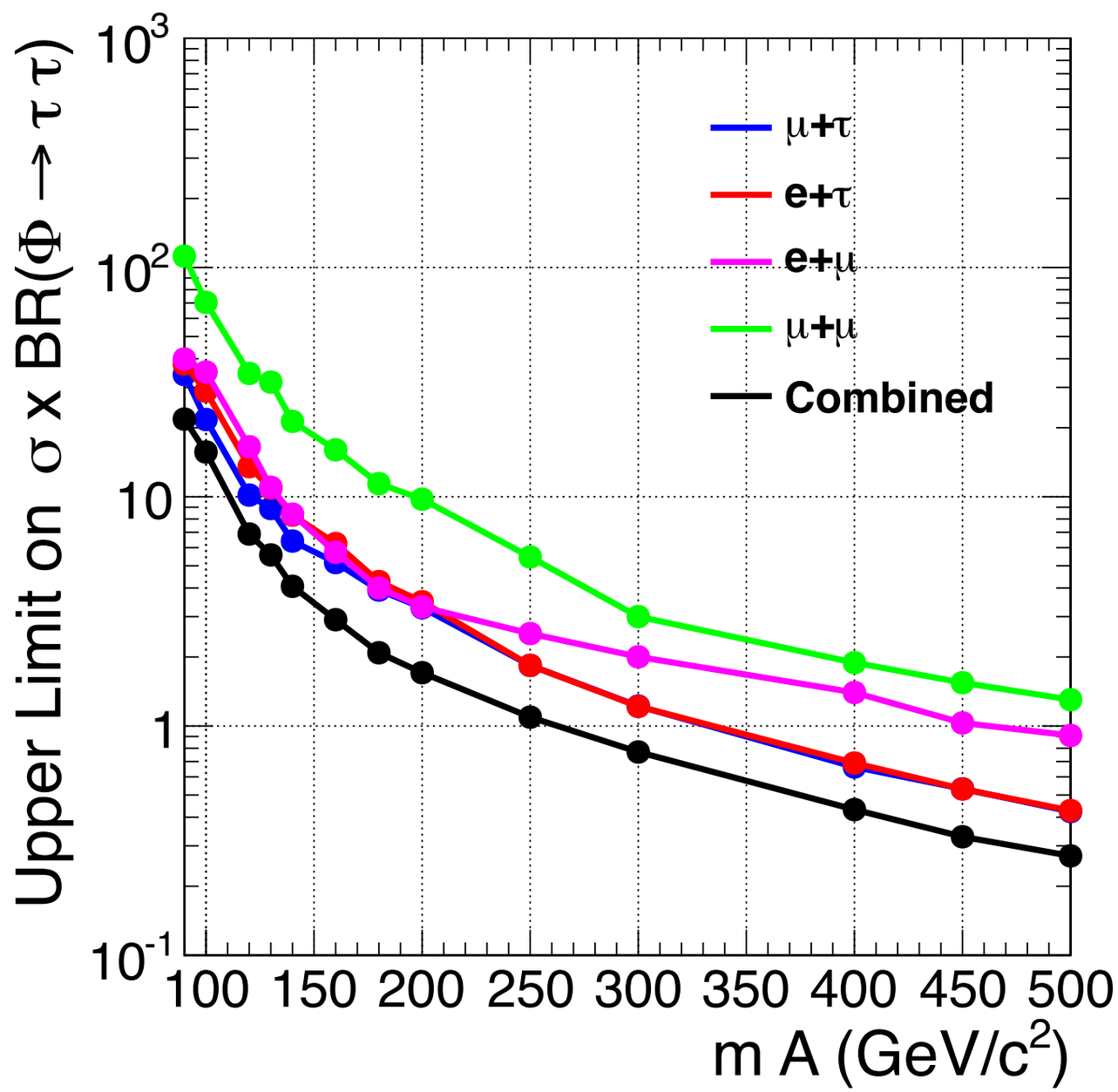


tau ID passed

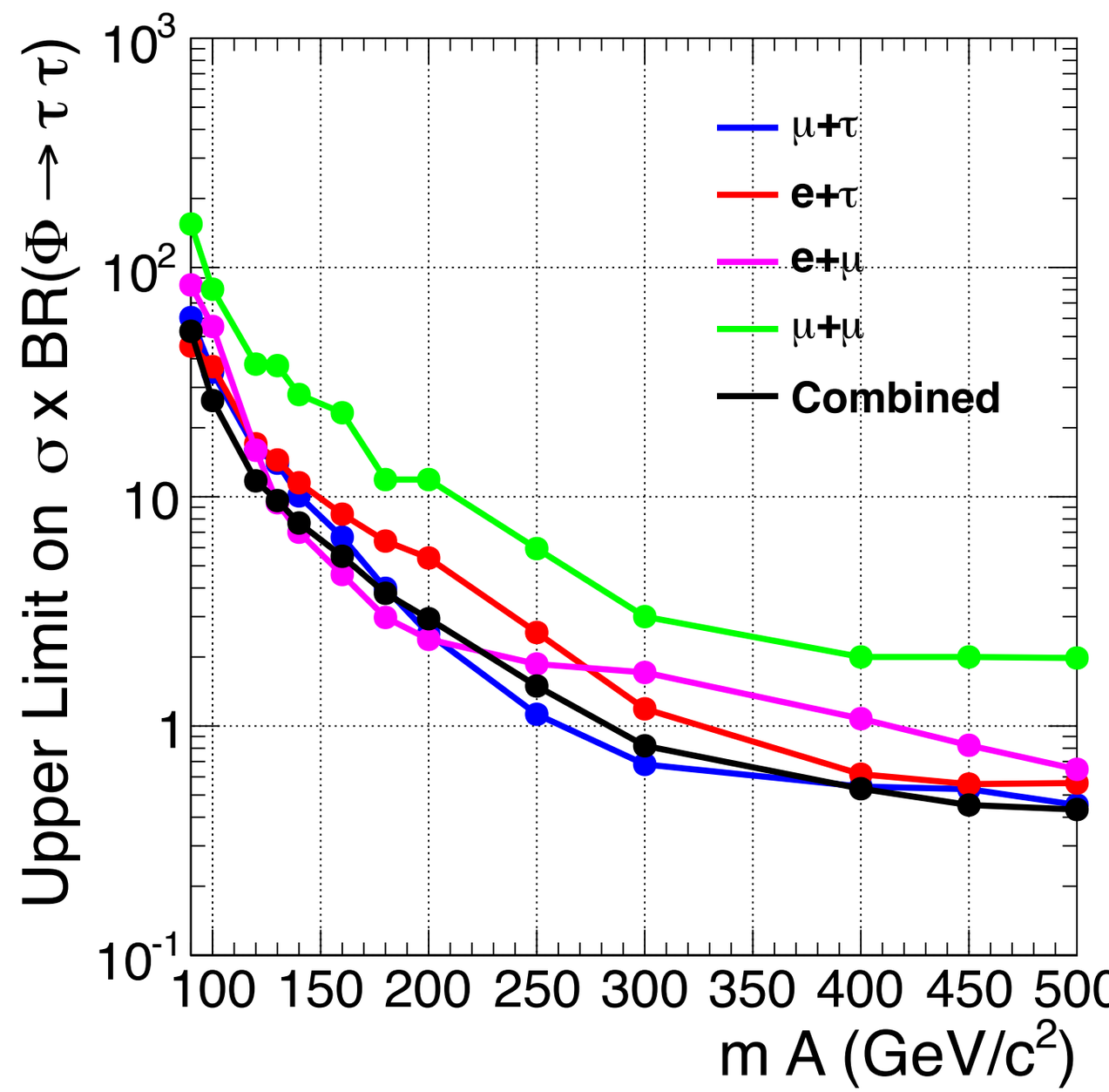


H→ττ Limits per Channel

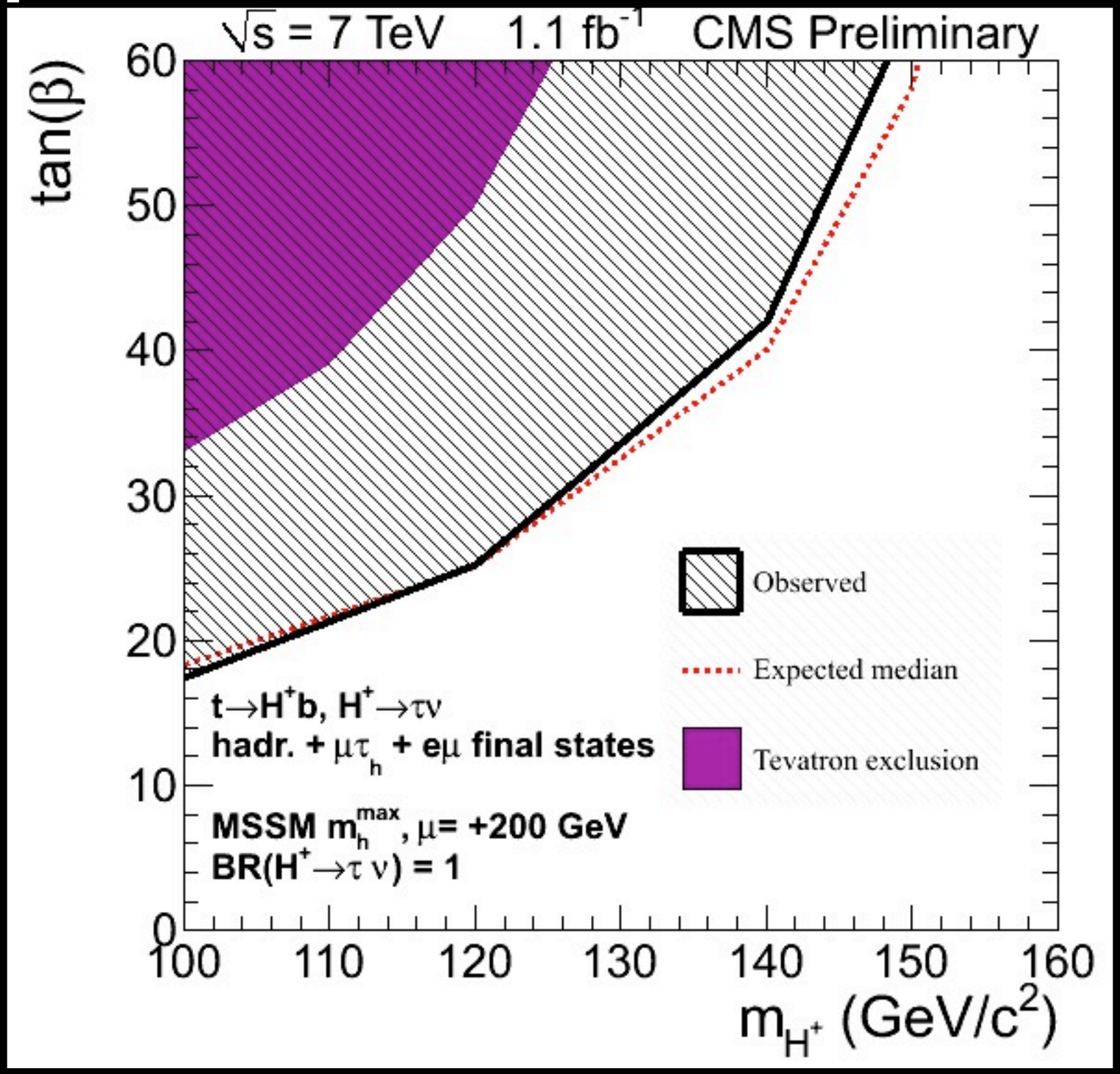
expected



observed

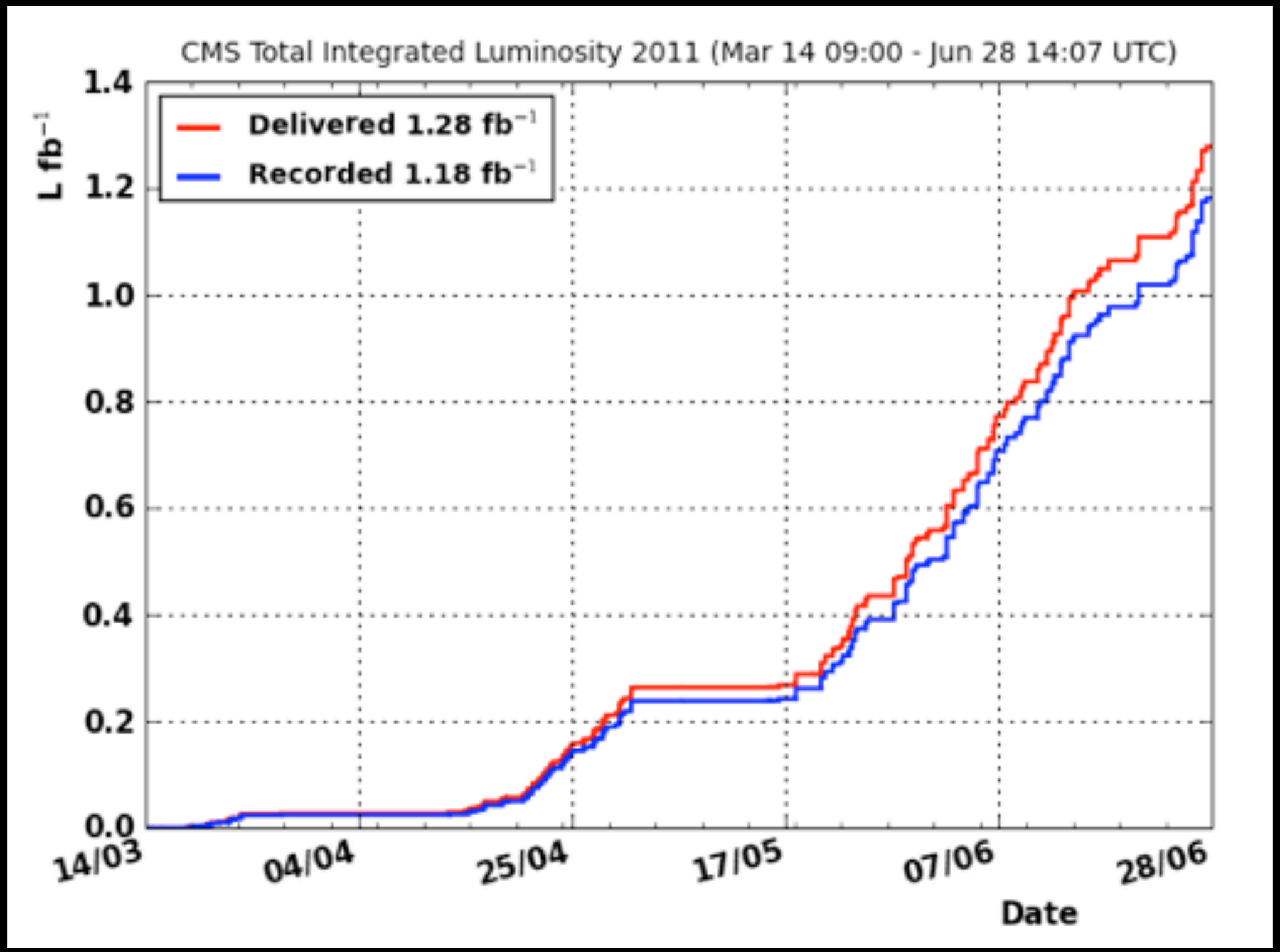


H^+ tanβ Limit

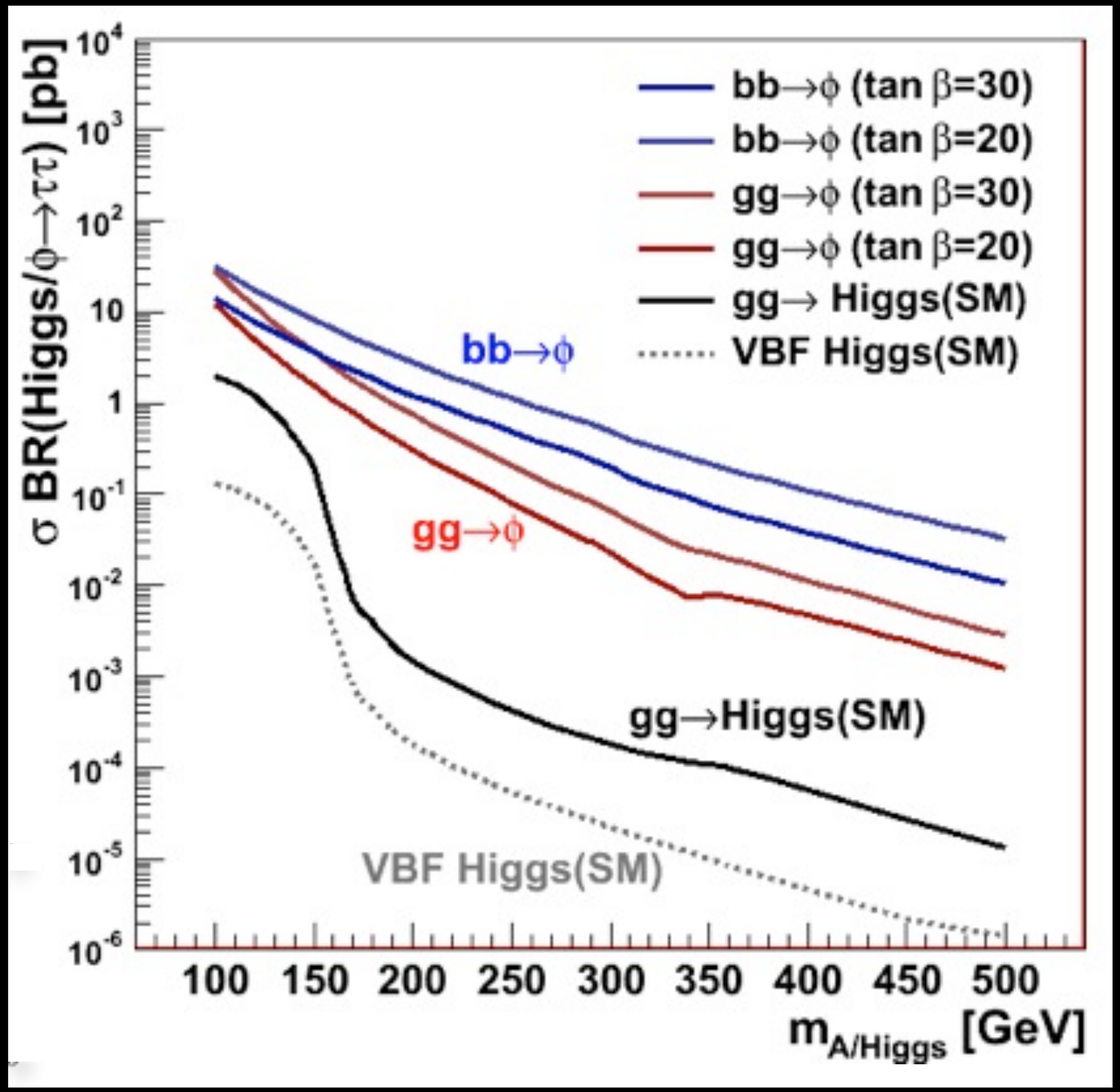


NB: $(m_{H^+})^2 = (m_A)^2 + (m_W)^2$

CMS Luminosity



MSSM Cross Sections



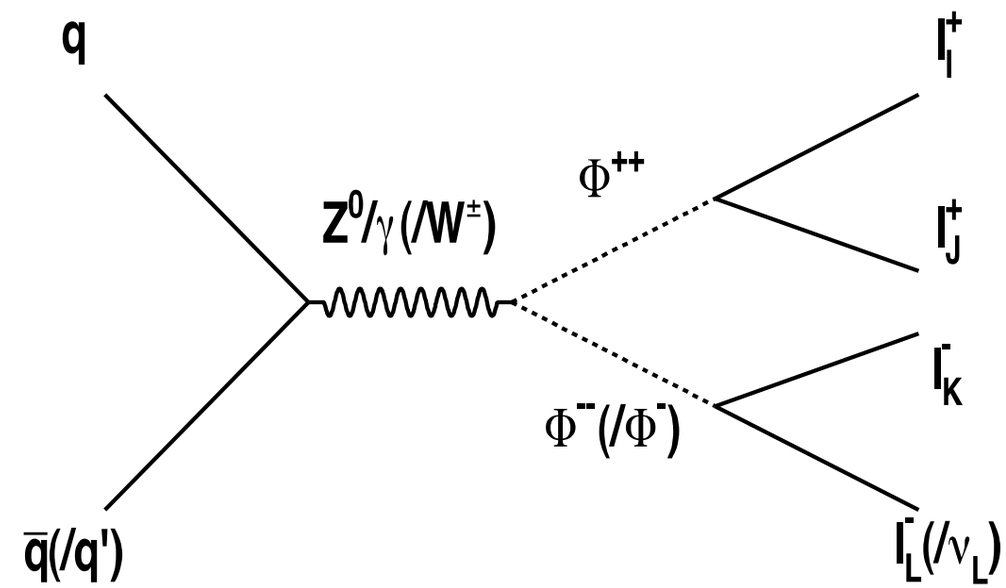
Doubly charged Higgs boson (Φ^{++})

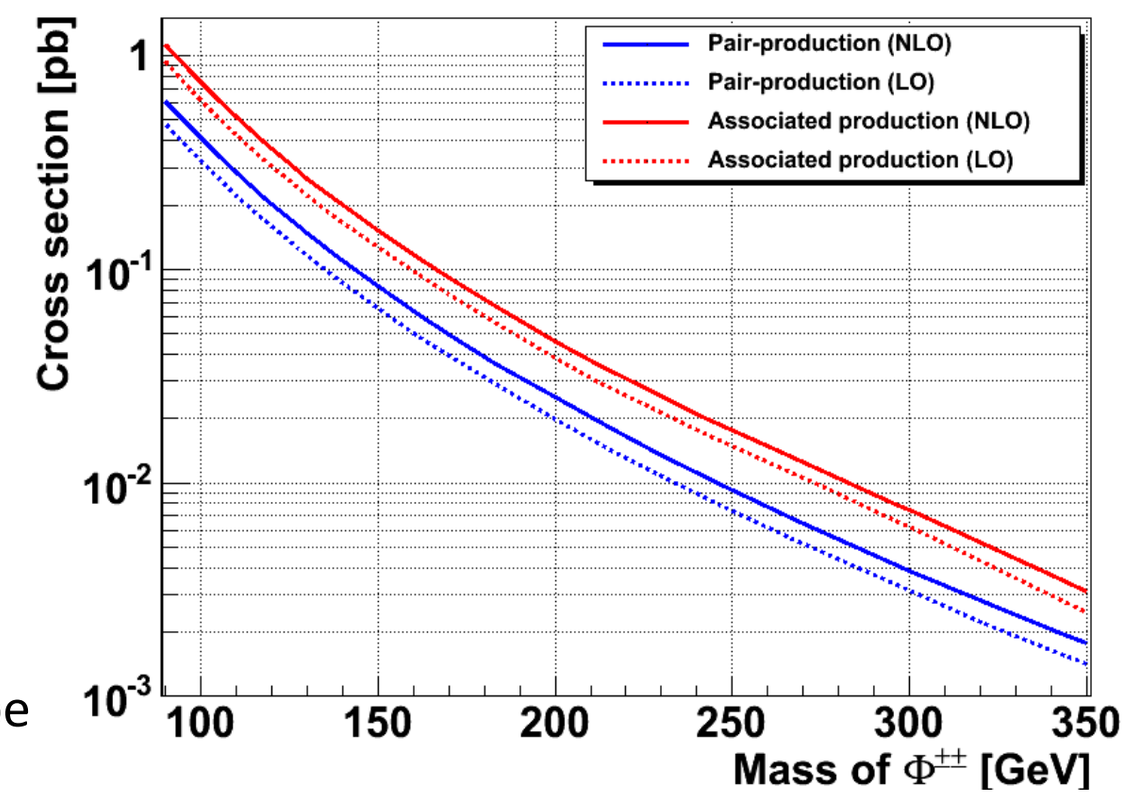
CMS-PAS-HIG-11-007

- Standard model extension by a scalar triplet adding three new particles
  - $\Phi^{++}, \Phi^{+}, \Phi^{0}$ (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)

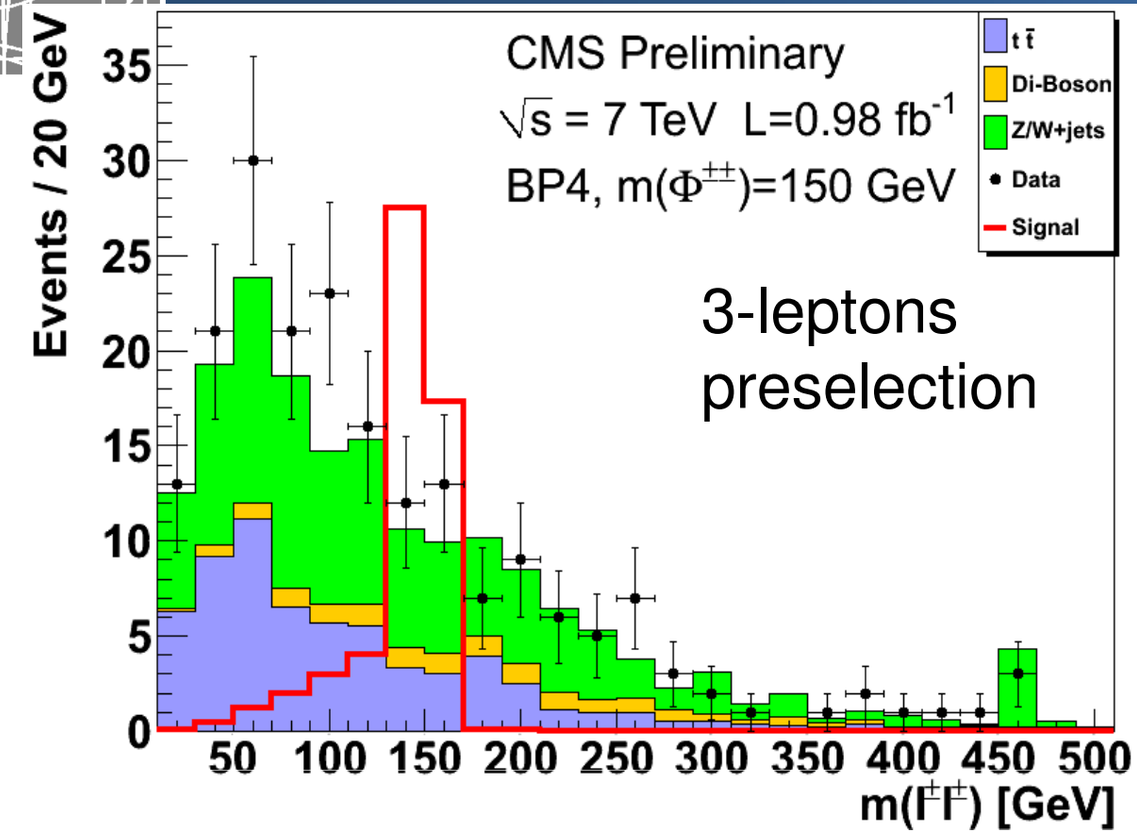
❑ Additional topological cuts on leptons depending on final states
Three OR four leptons

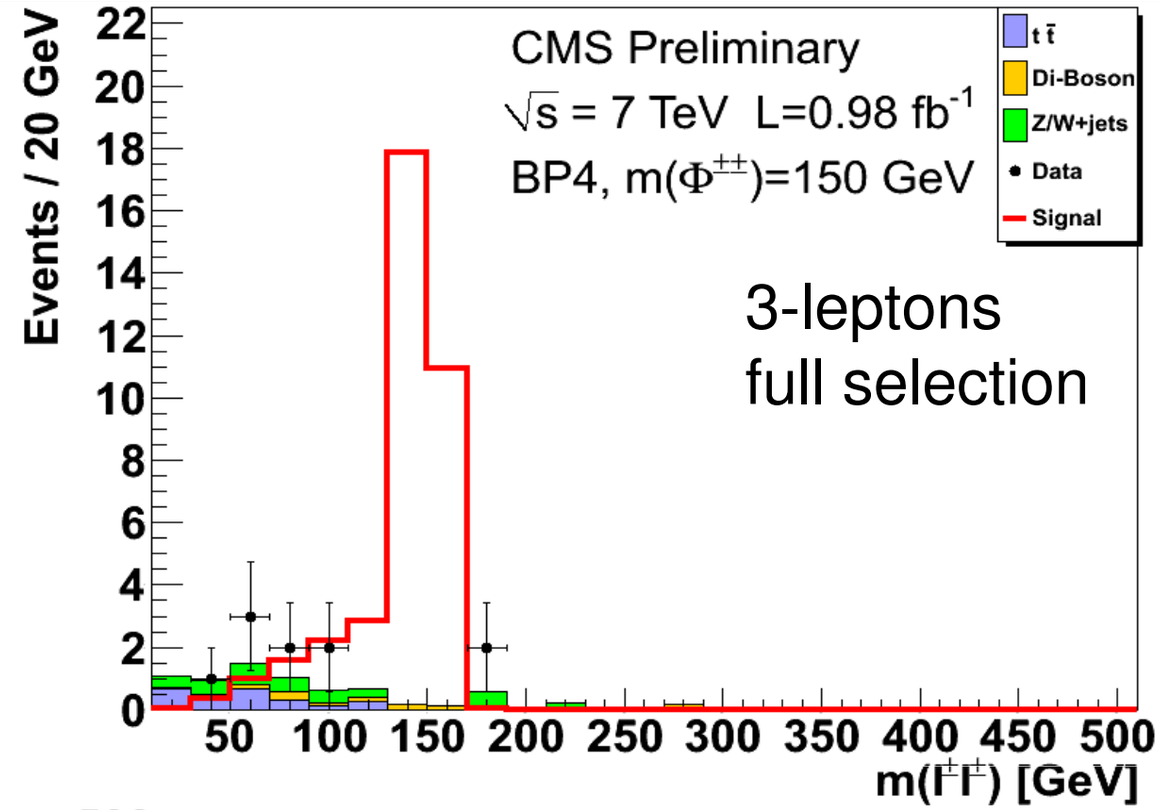
❑ Events are counted in the mass window depending on the Higgs boson mass considered

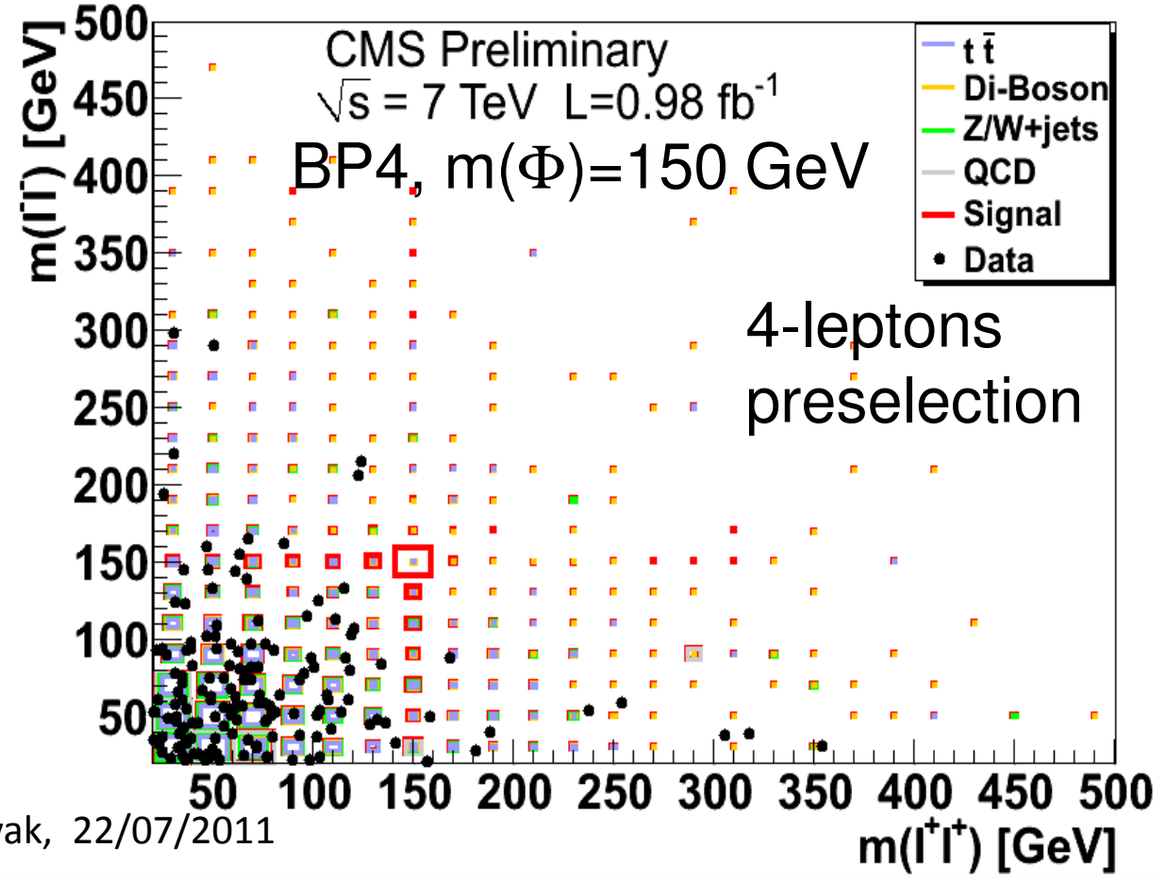
- Control from real data of
  - the lepton-related efficiencies
  - the estimation of background rate

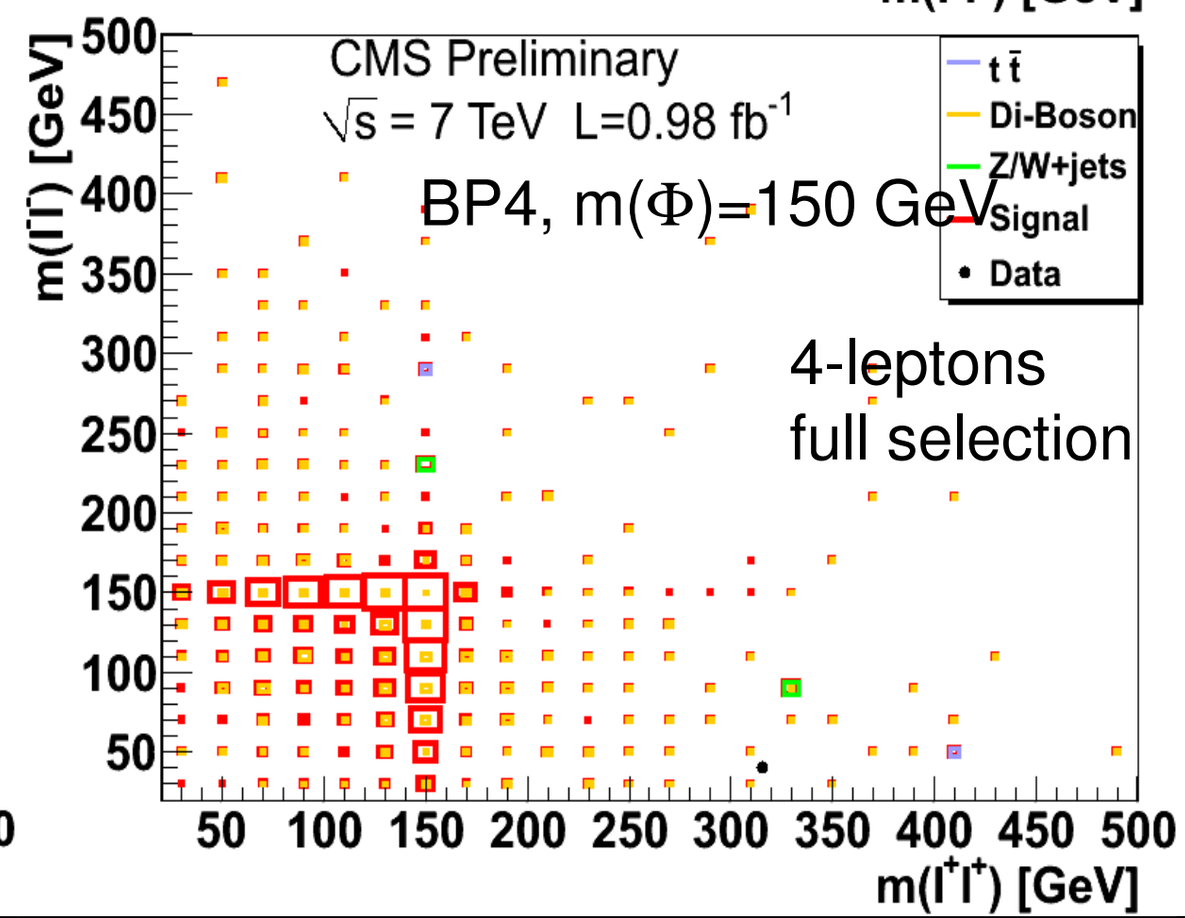
- Inclusive search in order to cover the whole phase space
- **Results provided for integrated lumi = 0.98 fb^{-1}**

Results

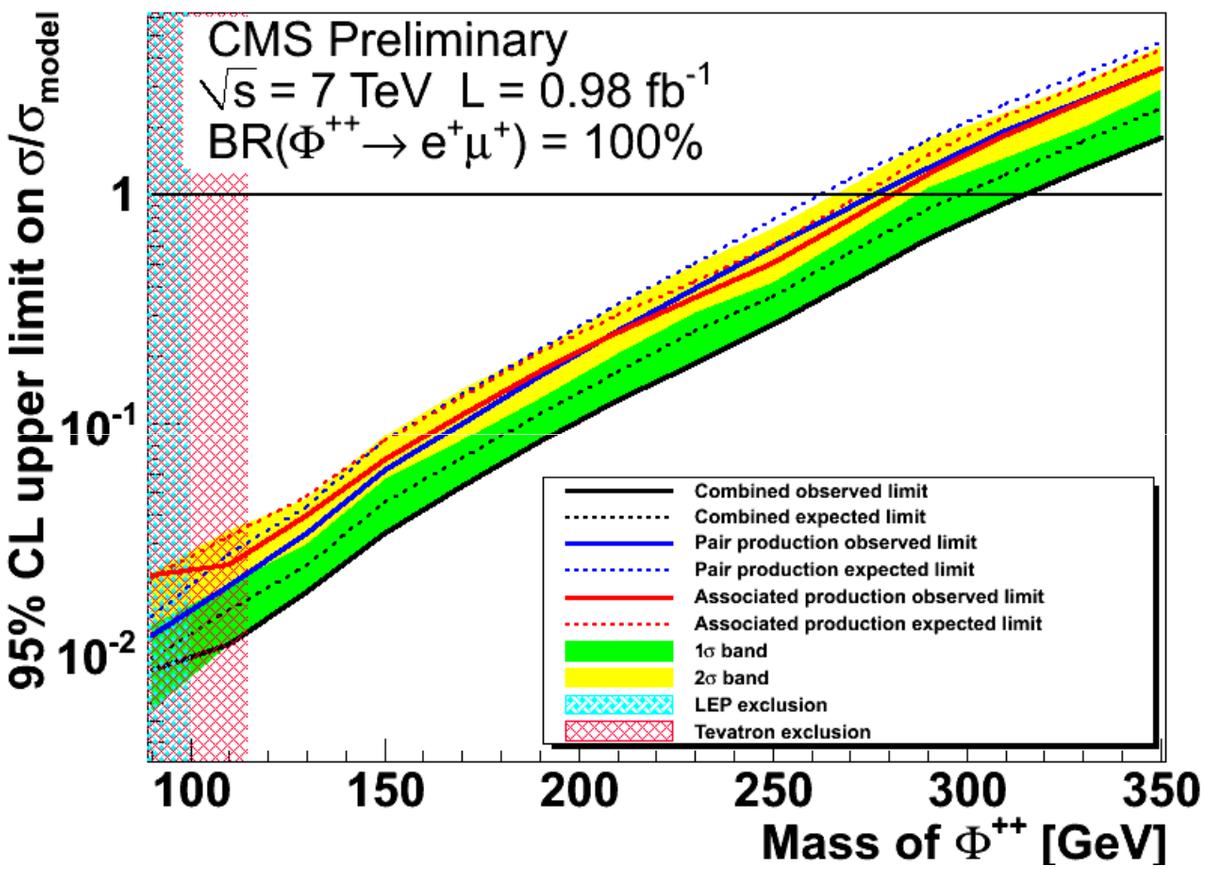

CMS Preliminary
√s = 7 TeV L=0.98 fb-1
BP4, m(Φ±±)=150 GeV
t t̄
Di-Boson
Z/W+jets
Data
Signal
3-leptons
preselection
Events / 20 GeV
m(l±l±) [GeV]

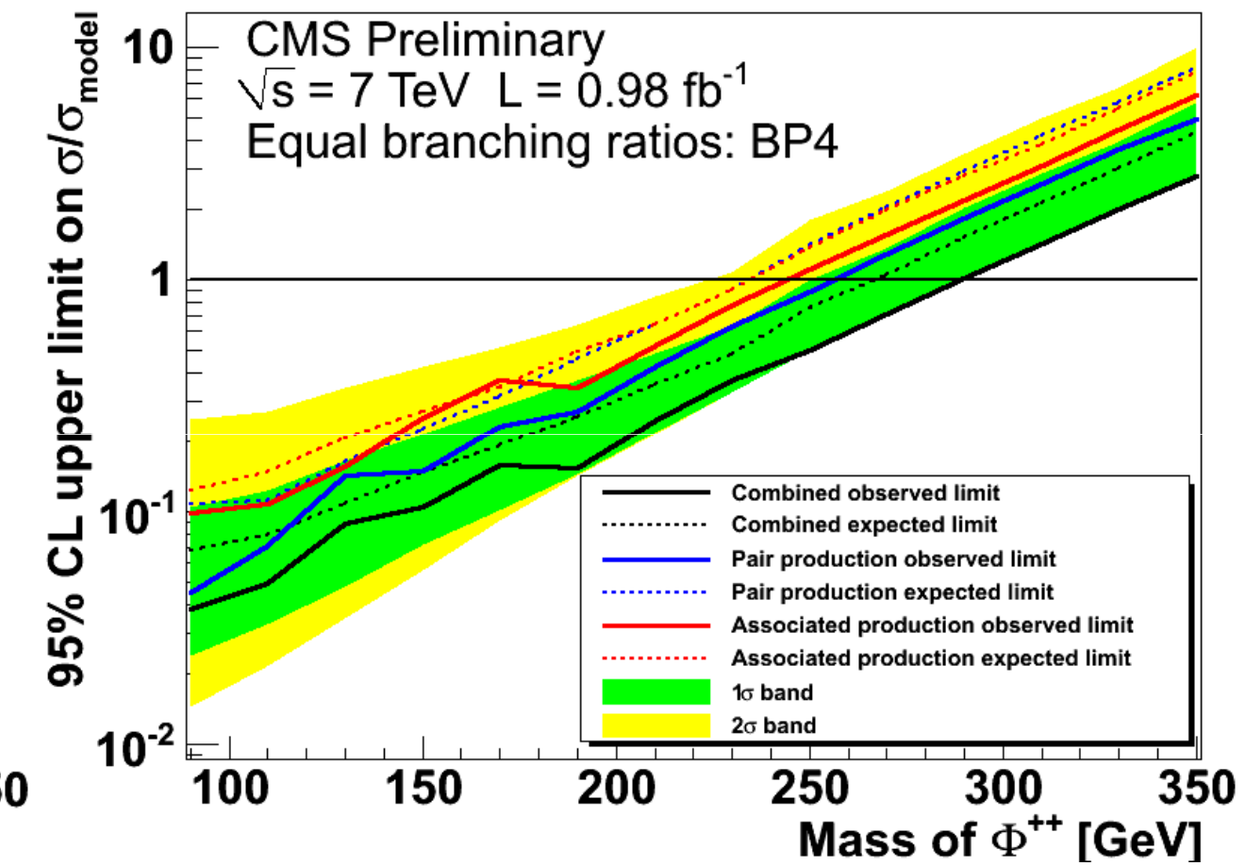

CMS Preliminary
√s = 7 TeV L=0.98 fb-1
BP4, m(Φ±±)=150 GeV
t t̄
Di-Boson
Z/W+jets
Data
Signal
3-leptons
full selection
Events / 20 GeV
m(l±l±) [GeV]


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


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

Lower limit on Φ^{++}





95% CL lower Limits obtained using CLs method

ϕ^{++} Benchmark Points

In addition to the model independent search, the type II seesaw model is tested in four benchmark points (BP) [8] that characterize different characteristic neutrino mass matrix structures. 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. Those three benchmark points are the extremes allowed by varying the neutrino mass and hierarchy in the allowed ranges without consideration for θ_{13} or CP phases and cover a large region of the parameter space. The fourth benchmark point BP4 represents the case in which all Φ^{++} branching fractions are equal. This is achieved with the following values of Majorana phases: $\alpha_1 = 0$, $\alpha_2 = 1.7$. In all benchmark points an exact tri-bi-maximal neutrino mixing matrix and vanishing CP-phases is assumed except in BP4, where α_2 is nonvanishing. The branching fractions of the benchmark points are summarized in Table 1.

Table 1: Branching fractions of Φ^{++} to the various final states (τ means a τ lepton before decay) in the four benchmark point models.

Benchmark point	ee	eμ	eτ	$\mu\mu$	$\mu\tau$	$\tau\tau$
BP1	0	0.01	0.01	0.30	0.38	0.30
BP2	0.50	0	0	0.125	0.25	0.125
BP3	1/3	0	0	1/3	0	1/3
BP4	1/6	1/6	1/6	1/6	1/6	1/6

Fake Rate Method

goal: estimate fake background contribution

- Measure object fake rate in data in background enriched control regions
  - W+jets, QCD μ enriched, etc
- Disable object-ID in analysis
- Final events now ~pure background
- Weight each event by probability to fake identification