Results on the Search for MSSM Neutral and Charged Higgs bosons

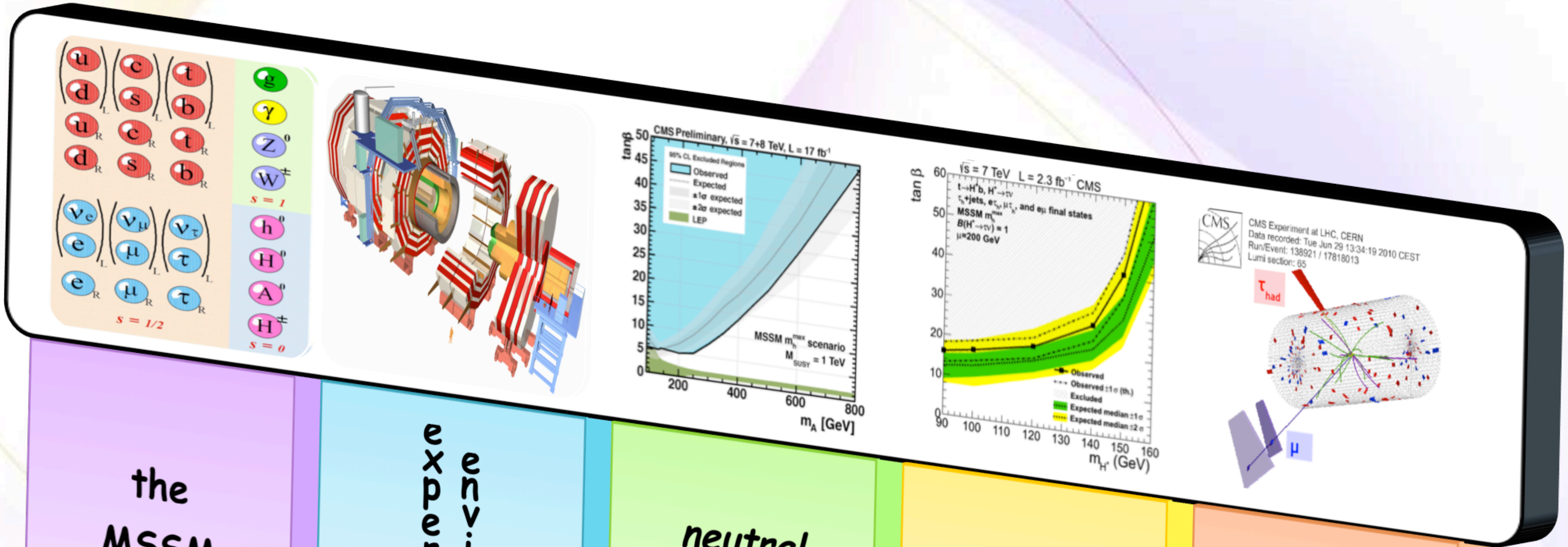
Mia Tosi
Universita' degli Studi di Padova & INFN

on behalf of the CMS collaboration

DISCRETE 2012

- Lisbon December 3rd÷7th-

outline

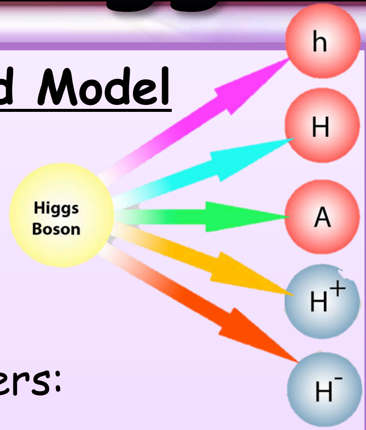


- the MSSM Higgs sector
- experimental environment
- neutral Higgs $\phi \to \tau^+\tau^-$ $\phi \to bb$ $\phi \to \mu^+\mu^-$
- light charged Higgs
- conclusions

the MSSM Higgs sector

Minimal Supersymmetric Standard Model

- 2 isospin Higgs doublets
  - ➔ 5 physical Higgs Bosons



2	EM neutral CP even	h^0, H^0	scalar
1	EM neutral CP odd	A^0	pseudo-scalar
2	EM charged	H^+, H^-	

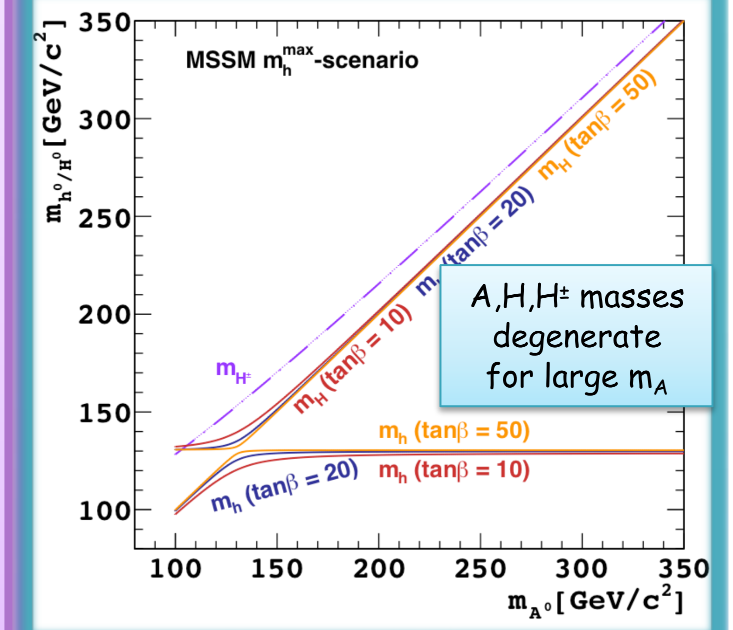
- @tree level
  - MSSM Higgs sector can be described by 2 parameters:
    - **tan β:=v_2/v_1**
    - **m_A**
  - $m_h < m_Z$ ⟶ already excluded by LEP
    $m_A < m_H$
    $m_W < m_{H^\pm}$ ⟶ $m_{H\pm}$ > 80 GeV/c² [LEP]

  but huge radiative corrections

  → **m_h < 135 GeV/c²**

  fixed in benchmark scenarios

  (m_h-max used in most of the results)



Carena, Heinemeyer, Wagner, Weiglein Eur. Phys. J. C26 (2003) pp. 601-7

- couplings (for large tan β)
  - W/Z suppressed, absent for A
  - enhanced for 3rd generation and down type fermions
  - h is SM-like for large m_A

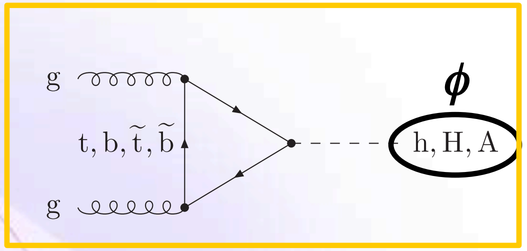
$$y_b \rightarrow y_b \frac{\tan\beta}{1+\Delta_b}$$

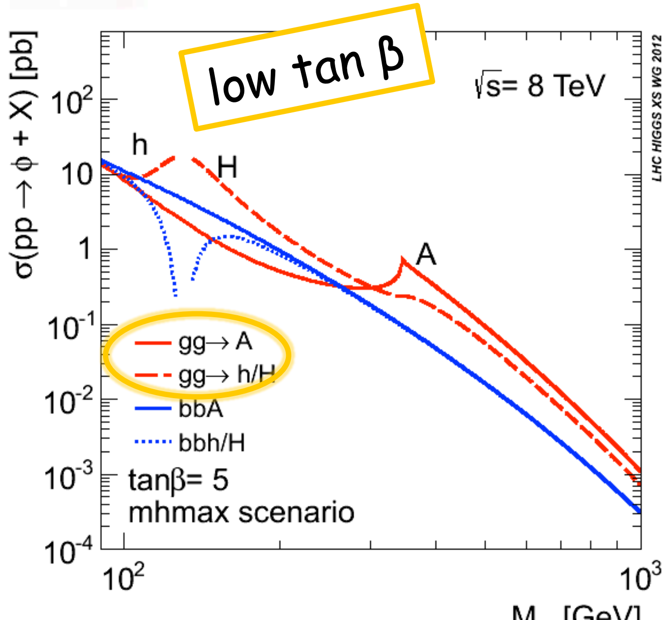
φ = **h,H,A** mass degenerate

depending on **tanβ** regime (h+A,H+A)

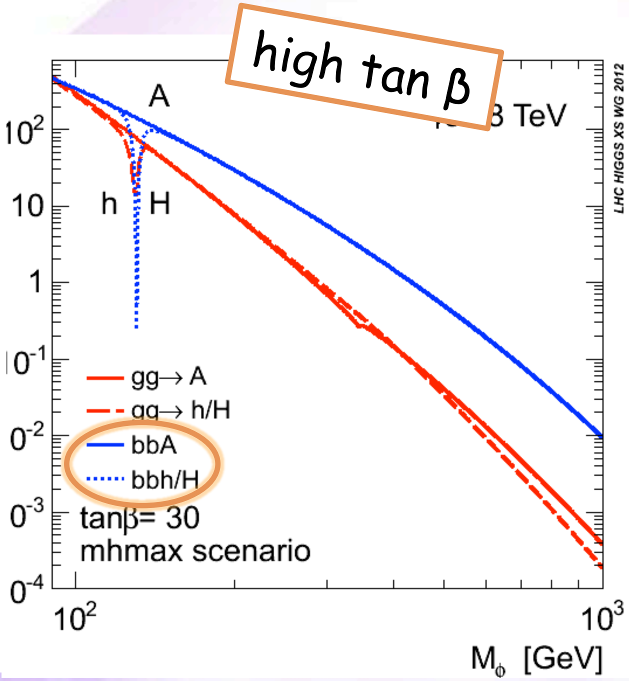
neutral Higgs @LHC

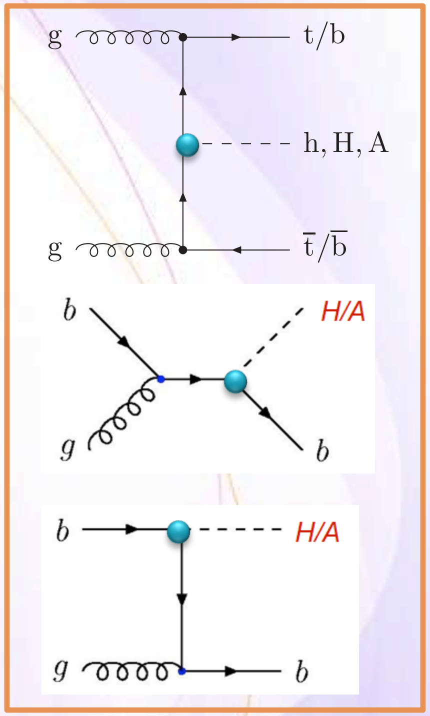
- search for **pp** → ϕ + X
- 2 main production processes @LHC
- dominant decay modes are **bb** (~85%) and ττ (~10÷15%)
  also μμ (~0.03%) channel analyzed





arXiv:1101.0593 [hep-ph]





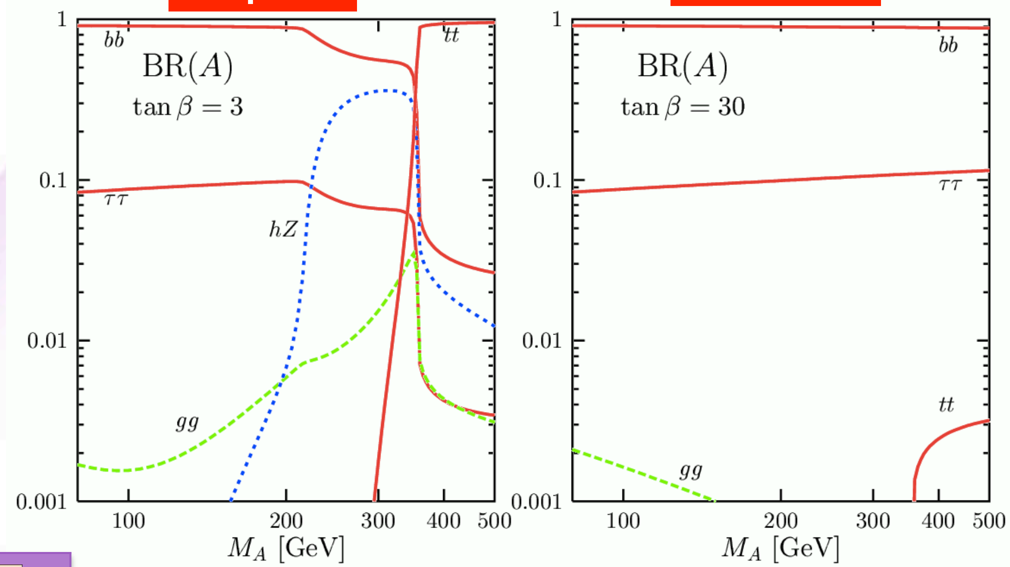
@large tan β
cross section enhanced [~tanβ²]
coupling to b quark is enhanced → tagging a jet as a ***b,*** is very important in MSSM search

neutral Higgs @CMS

MSSM Higgs production and decays can be significantly affected by **radiative corrections**

- ❑ the **bb channel is more sensitive** to these corrections (and therefore to the SUSY scenario)
- ❑ while the **ττ channel is more robust**

tanβ = 5 | tanβ = 30



ϕ→ττ

- ☑ sensitivity for both gluon fusion and b-associated production
- ☒ relatively small BR (9%)
- ☒ difficult reconstruct m_ϕ and Γ_ϕ
- ❑ backgrounds
  - Z → $\tau^+\tau^-$, tt, W + jets
  - QCD multi-jets in hadronic case
  - Z → e e /μ μ + jets for leptonic decay

CMS	
ϕ→ττ	~17fb^{-1}
ϕ→μμ	~5fb^{-1}
ϕ→bb	~3÷5fb^{-1}

ϕ→b$\bar{b}$

- ☑ SM cross section predicted to be small
- ☑ in MSSM production enhanced by $\tan^2\beta$
- ☑ high BR (~90%)
- ☑ sensitive mainly to b-associated production
- ☒ backgrounds
  - QCD multi-jets

ϕ→μμ

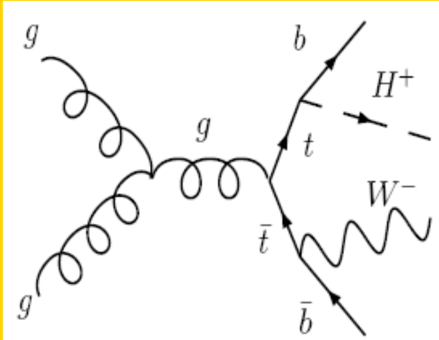
- ☑ clean signal w/ excellent mass resolution (0.03%)
  - ➡ potential to distinguish between h, H and A
  - ➡ provide measurement of tanβ (from width)
- ☑ sensitivity for both gluon fusion and b-associated production
- ☒ small BR (enhanced for high tan β)
- ❑ backgrounds
  - Drell-Yan Z (+ jets)
  - tt → bb$\mu^+\mu^-\nu\bar{\nu}$
  - WW / ZZ very small

  can be estimated from data using $\mu^+\mu^-$, e^+e^-, $e^\pm\mu^\mp$

charged Higgs @LHC

- ***light*** charged Higgs [$m_{H\pm}$ < m_{top}]
  dominant production mode:
  top decay **t→bH±**
  dominant decay:
  H±→τν

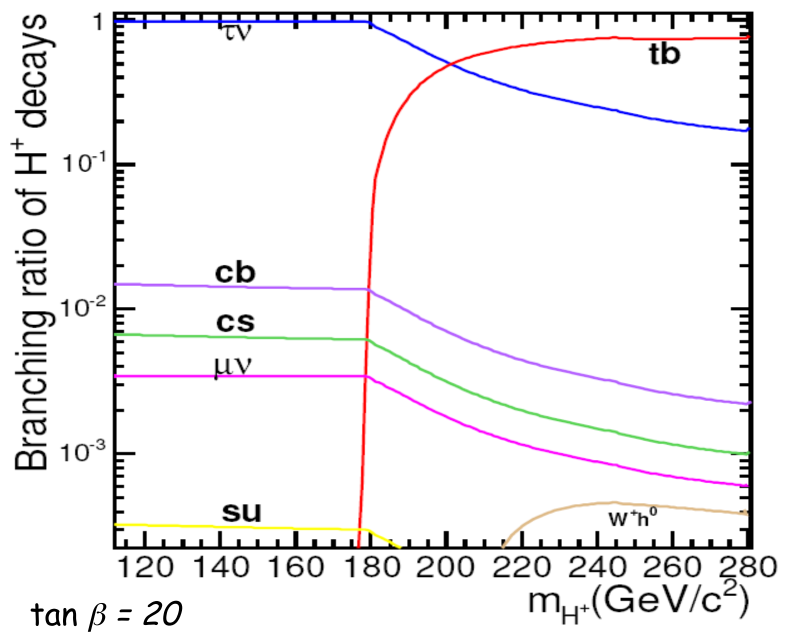
BR(t→bH±) depends on both tanβ and m_{H+}



the discovery of a charged Higgs boson would provide unambiguous evidence for an extended Higgs sector beyond the Standard Model

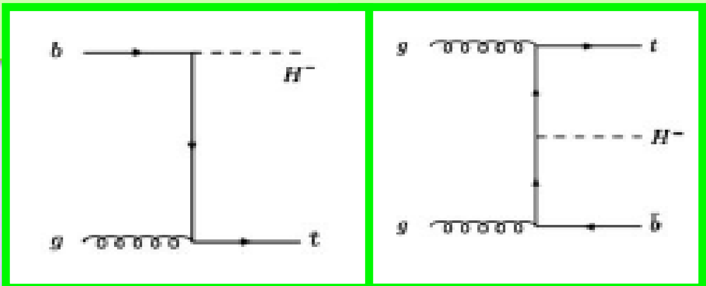
current upper limit on BR(t→bH±)≈0.15÷0.20 for $m_{H\pm}$=80÷155 GeV/c², assuming BR(H±→τν)=1 by CDF and D0

http://www-cdf.fnal.gov/physics/new/top/2005/ljets/charged_higgs/higgs/V2/HiggsAnalysis_publicV2.html



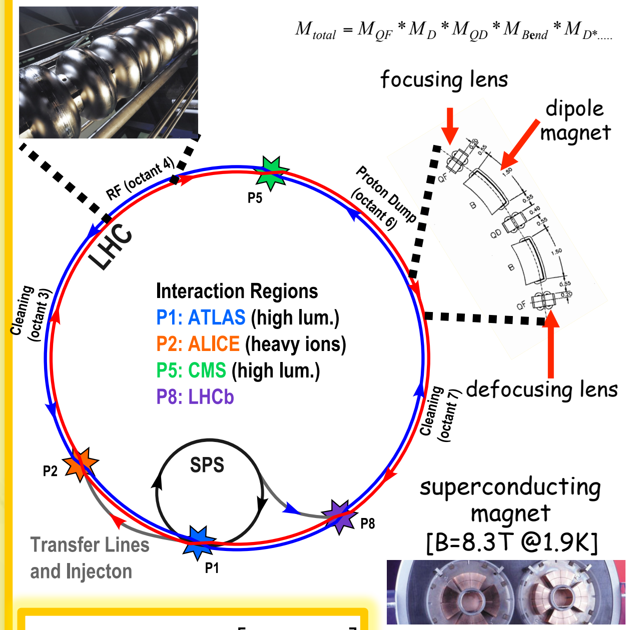
tan β = 20

- ***heavy*** charged Higgs [$m_{H\pm}$ > m_{top}]
  dominant production modes:
  gg→tbH± and **gb→tH±**
  dominant decays:
  H±→tb and **H→τν** no yet analyzed

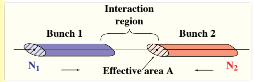


Large Hadron Collider (LHC)

$$M_{total} = M_{QF} * M_D * M_{QD} * M_{Bend} * M_{D*}.....$$

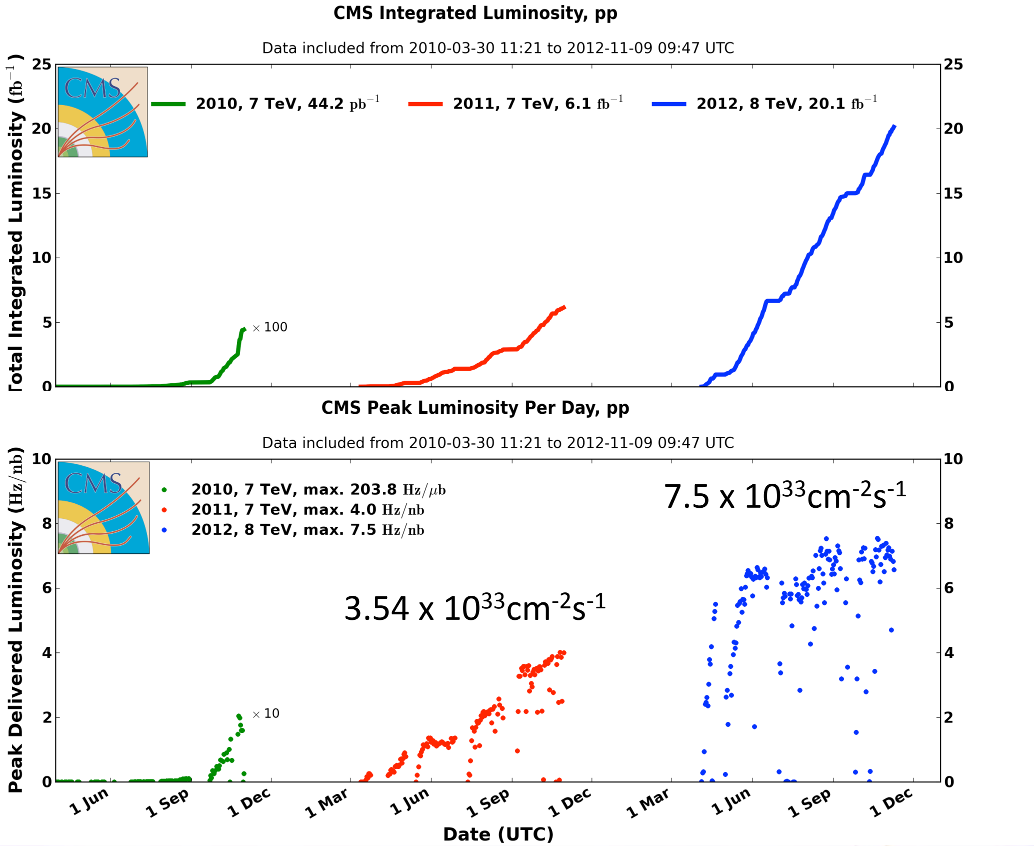


$$L = \left(\frac{\gamma f_{rev}}{4\pi}\right)\frac{n_b N_b}{\beta^*}\left[\left(\frac{N_b}{\varepsilon_N}\right)R_\varphi\right]$$



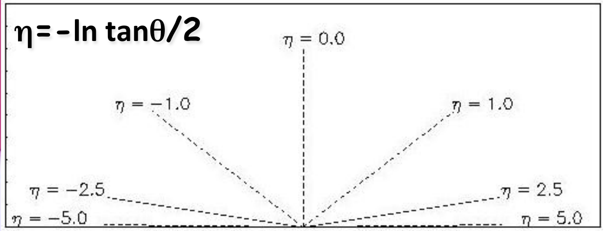
- proton-proton collider @CERN
  re-uses the LEP tunnel [~100m underground]
- accelerates protons
  from 450 GeV up to 7000/8000 GeV(*)
  PS/SPS used to accelerate protons upto 450 GeV
- 8 points,
  4 where the beams interact [experiments]
  2 for beam cleaning
  1 dedicated to beam dumper
  1 containing superconducting RF cavities [400MHz]
- 8 arcs with a regular lattice structure,
  containing 23 arc cells
  each arc cell has a FODO structure

(*) goal is $\sqrt{s}$=14TeV



- ☑ first collisions @7TeV (30/03/2010)
- ☑ first collisions @8TeV (05/04/2012)
- ☑ max peak luminosity $\mathcal{L}_{PEAK}$ **~7.5x10^{33} s^{-1}cm^{-2}**
- ☑ delivered luminosity: **~6 fb^{-1} (7TeV) + ~20 fb^{-1} (8TeV)**
- ☑ machine performs better than expected !!

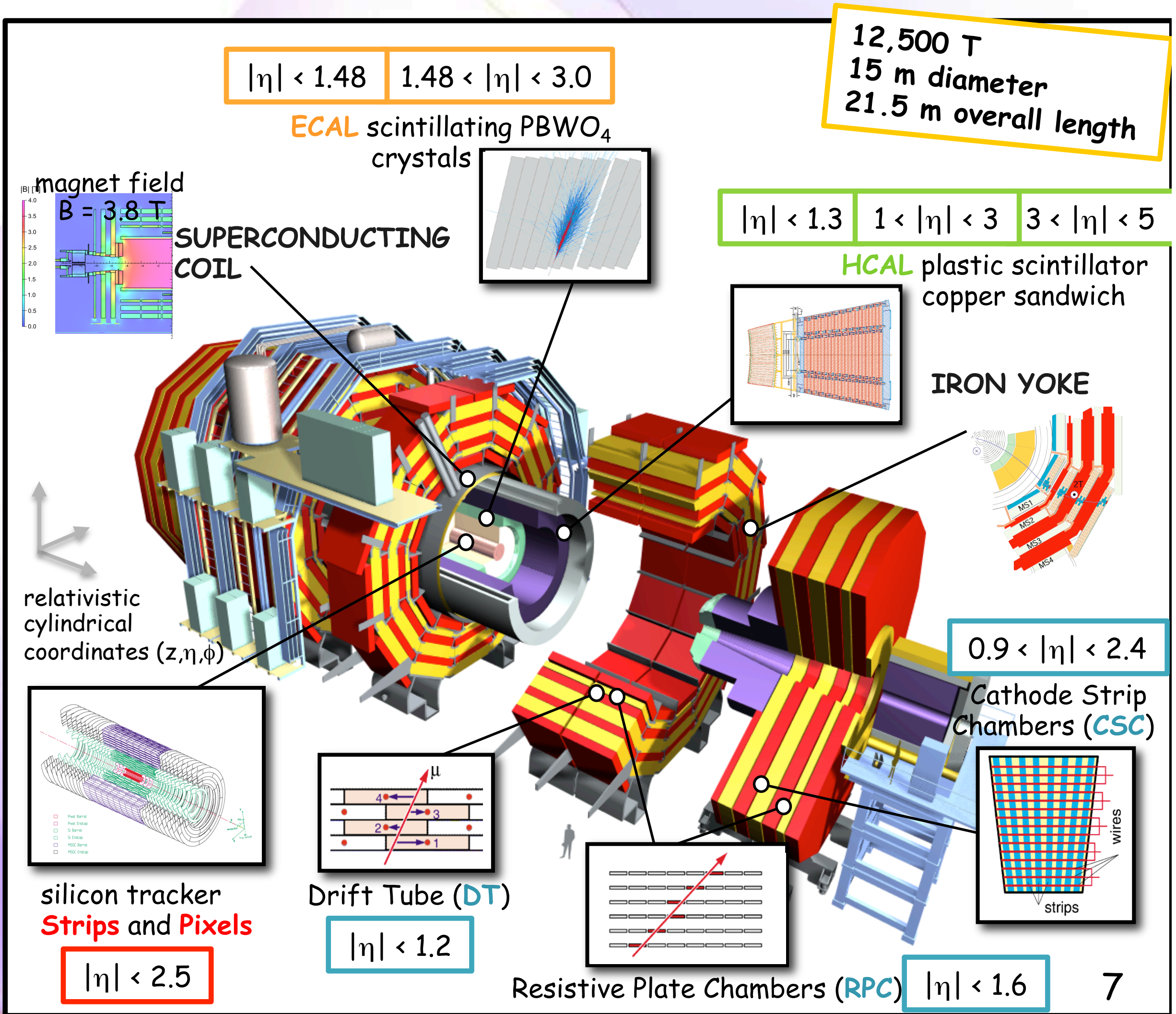
the CMS detector



Compact Muon Solenoid [compact 4π experiment]

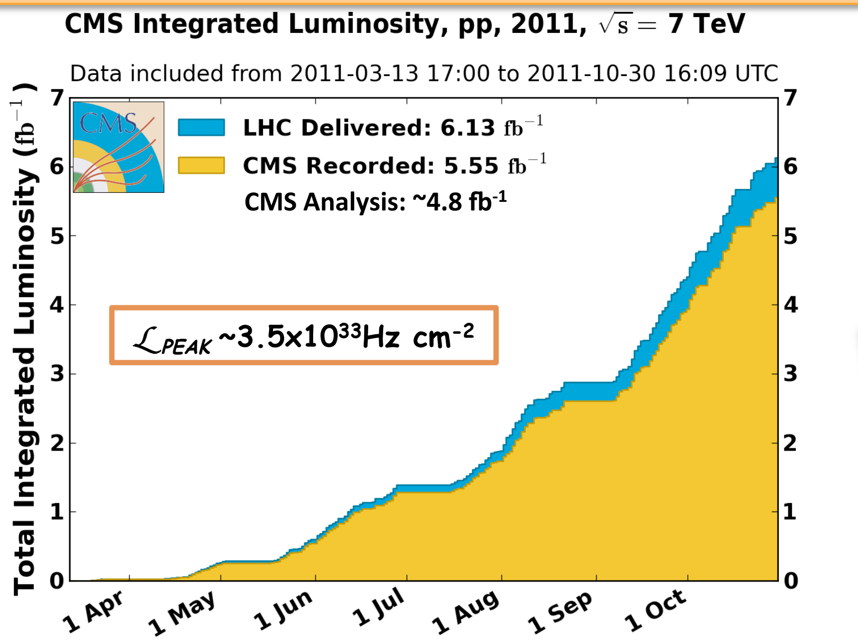
→ design based on:

- **high intensity B field**
  3.8T superconducting solenoid
- high precision **silicon tracker**
  ($\sigma/p_T \approx 1.5 \cdot 10^{-4}\, p_T \oplus 0.005$)
- high precision homogeneous **EM calorimeter**
  $\sigma/E \approx 2.8\%/\sqrt{E} \oplus 12\%/E \oplus 0.3\%$
- **hermetic calorimeter**
  $\sigma/E \approx 100\%/\sqrt{E} \oplus 5\%$
- redundant **muon spectrometer** (B=2T)
  $\sigma/p_T \approx 1\%$ @ 40 GeV

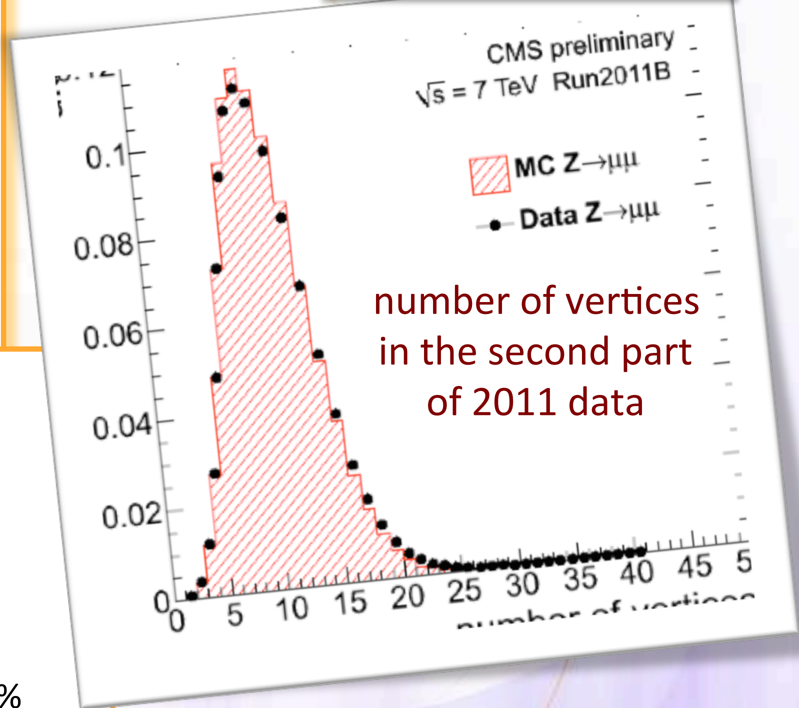


dataset

excellent performance of LHC and CMS in both 2011 and 2012



mean pileup:
10 vertices @7TeV
16 vertices @8TeV



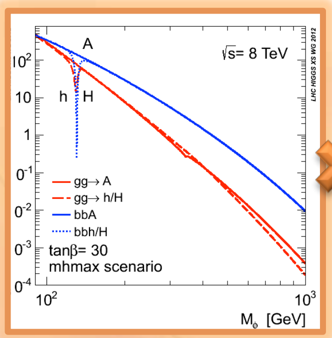
number of vertices in the second part of 2011 data

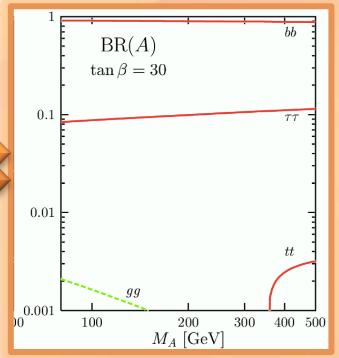
- ✓ more than **5 fb^{-1}** and **20 fb^{-1}** of pp collisions collected @7 TeV and 8 TeV CM energy, respectively
- ✓ peak luminosity:
  - $\mathcal{L}_{PEAK}$ ~ 3.5 x 10^{33} Hz cm^{-2} @7TeV
  - $\mathcal{L}_{PEAK}$ ~ 7.5 x 10^{33} Hz cm^{-2} @8TeV
- ✓ data taking efficiency: **~90%**
  - average fraction of operational channels per subsystem >98.5%
- ✓ ~85-90% of collected data good for all analyses
  - **searches based on ~5 fb^{-1}@7TeV** and **~18fb^{-1}@8TeV**

first step: online selection

collision rate is heavily <u>dominated</u>
by large cross section QCD <u>processes</u>
<u>not interesting</u> for the physics program o
production relative to σ_{tot}:

- bb @10^{-3}
- W→lν @10^{-6}
- **Higgs(M_ϕ=120GeV/c^2) @ 10^{-10} !**

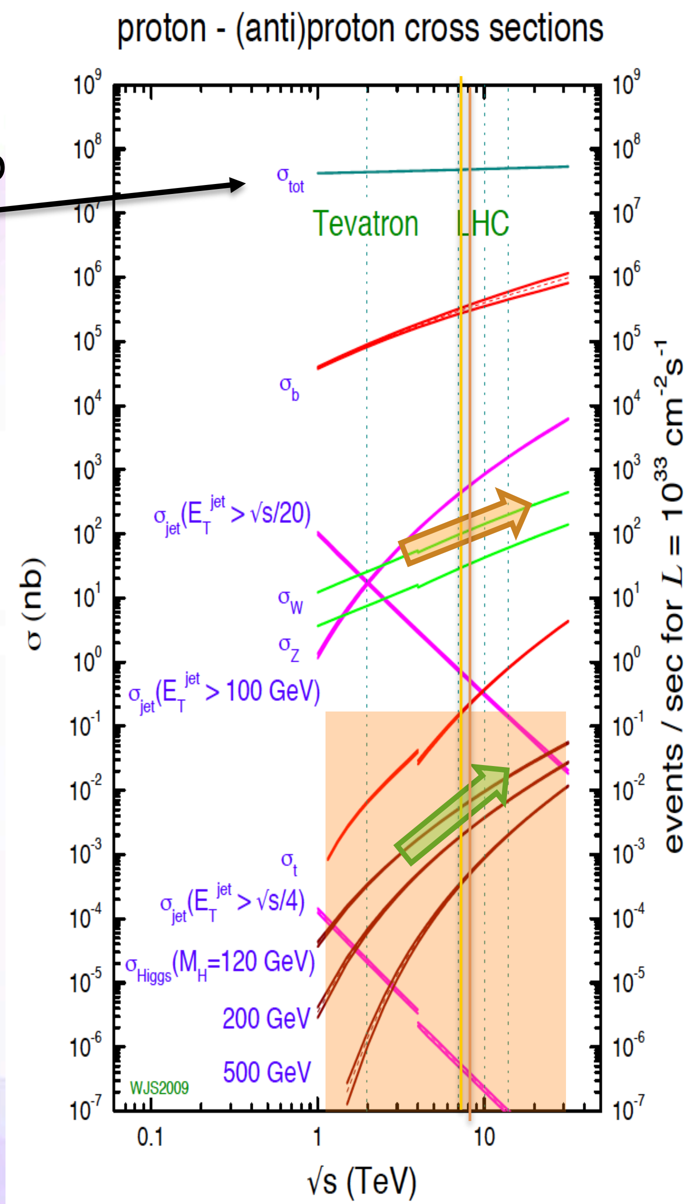


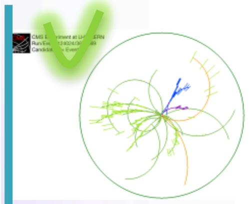


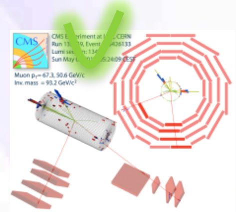
~15 MHz beam crossing,
but only ~300Hz tape writing: 1/10^5

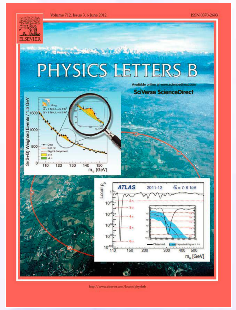
➨ <u>online</u> **fast and sophisticated** <u>selection</u>
is essential

1st & high level trigger algorithms exploit
main signatures of physics objects
[electron, muon, jet, b-jet, τ, energy]









physics objects

muon:
matching tracks in inner tracker and muon chambers
~97% efficiency

electron:
EM cluster with an associated track
~80% efficiency, fake rate 10^{-5}

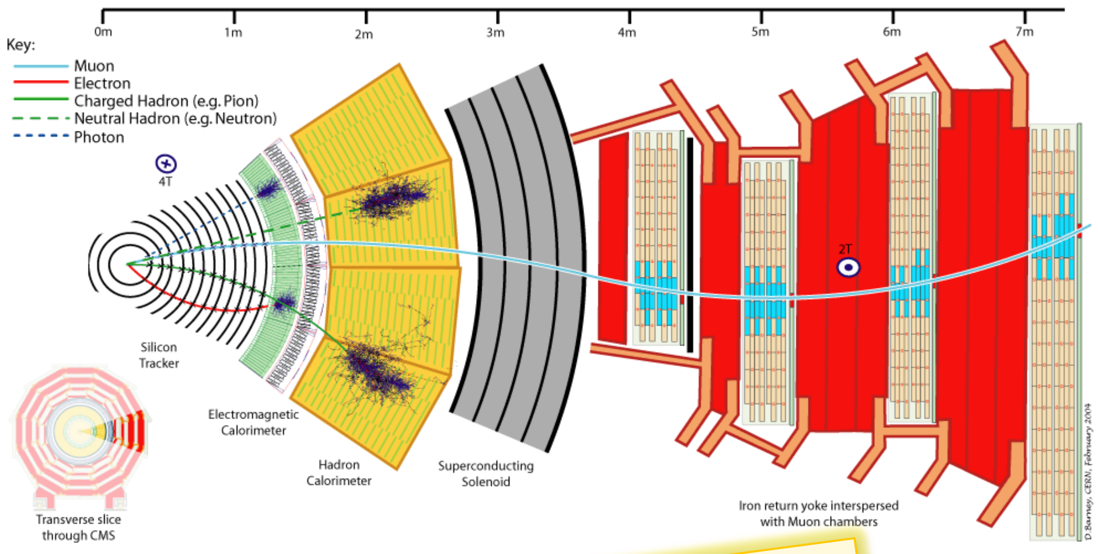
photon:
EM cluster without a matching track
~80% efficiency, fake rate 10^{-3}

jet:
cluster in EM and hadronic calorimeters (and inner tracker)
reconstruction up to $|\eta|<4.9$

b-tagging:
sophisticated algorithms which exploit b-quark properties
~60% efficiency, fake rate 10^{-2}

tau:
Narrow jet with matching track(s)
~60-70% efficiency, fake rate 10^{-2}

MET:
p_T required to balance all of these



on top of reconstruction of physics objects a **Particle Flow algorithm** (PF) has been developed
- provides **a global event description** in form of a list of particles
- ☑ large **improvements in measuring**
  - **τ** (ε~60%, fake rate ~1-3%, energy scale ~3%)
  - **jet** (energy resolution)
  - missing transverse energy (**MET**)

$\phi \rightarrow \tau^+\tau^-$ search @CMS

τ decay modes:
- **leptonical**: BR~35% $e\nu_e\nu_\tau$ and $\mu\nu_\mu\nu_\tau$
- **hadronical**: BR~65% dominantly via π/K, $\rho \rightarrow \pi\pi^0$ and $a_1 \rightarrow \pi\pi\pi(\pi\pi^0\pi^0)$

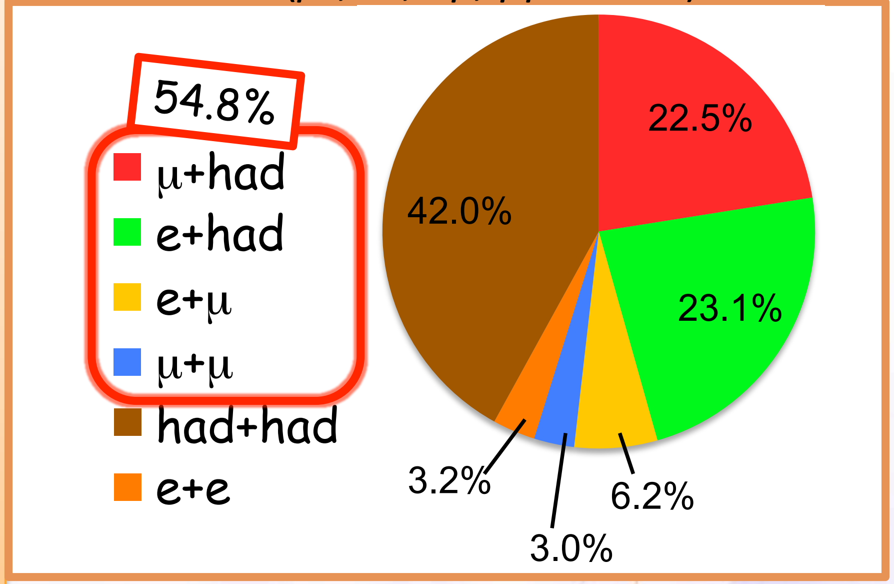
- search for **pp** → ϕ + **X** [inclusive]
- 2 main production processes @LHC
- Higgs decays to tau pairs w/ **BR($\phi \rightarrow \tau^+\tau^-$) ~10÷15%**

4 independent final states:
w/ at least 1 lepton
- ☑ easier to trigger
- ☑ lower QCD background

depending on final states, events are triggered by double lepton, lepton+tau or double tau
select isolated leptons, restict m_T<20 GeV (supp. W+jet, ttbar)
distinguish signal from background by
shape analysis of $m_{\tau\tau}$
(or the invariant mass of the visible decay products m_{vis})
selected events analyzed in 2 categories:
- b-tag
- non-b-tag

enhance bbΦ coupling

5 final states ($\mu\tau$, $e\tau$, $e\mu$, $\mu\mu$ and $\tau\tau$)



$Z \rightarrow \tau^+\tau^-$ standard candle
- measurement of τ **identification efficiencies**
- commissioning of τ **triggers**
- important **background** in searches for **beyond** the **SM**

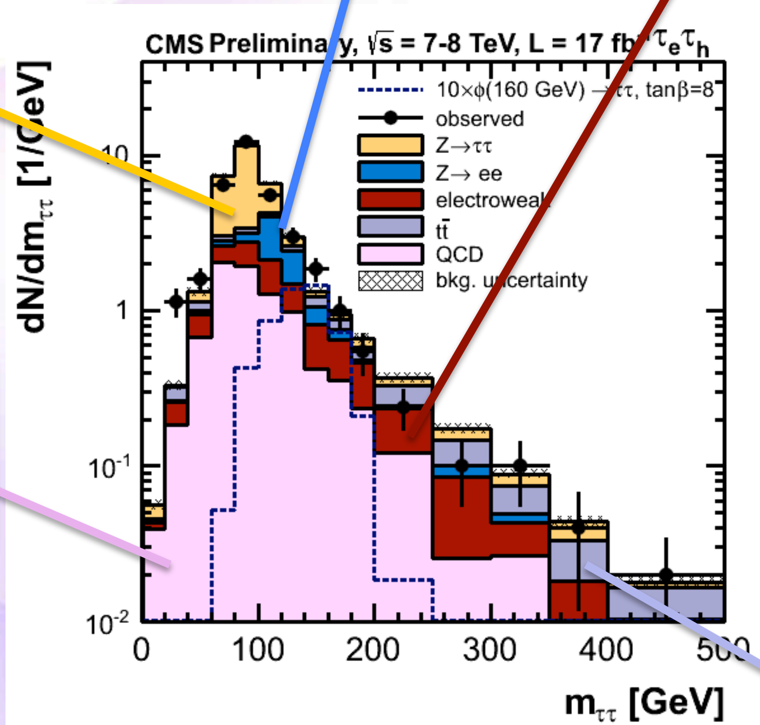
CMS-HIG-12-050

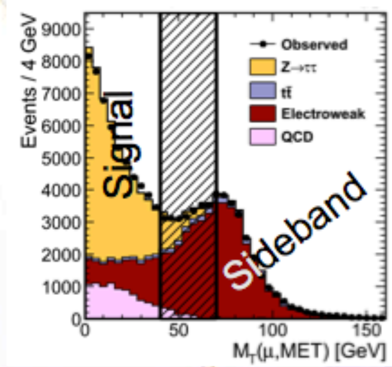
$\phi \rightarrow \tau^+\tau^-$: dominant backgrounds

$Z \rightarrow \tau\tau$:
- embedding: in $Z \rightarrow \mu\mu$ replace μ by simulated τ decay
- normalization from $Z \rightarrow \mu\mu$ events

$Z \rightarrow ee/\mu\mu$:
- shape from simulation
- corrected for SS/OS ratio and jet$\rightarrow\tau$ and $e/\mu\rightarrow\tau$ fake rate

diboson/W+jets
- shape from simulation
- normalization from sidebands





QCD:
- normalization & shape from SS/OS and fake rate

ttbar:
- shape from simulation
- normalization from sidebands

full $\tau^+\tau^-$ mass reconstruction

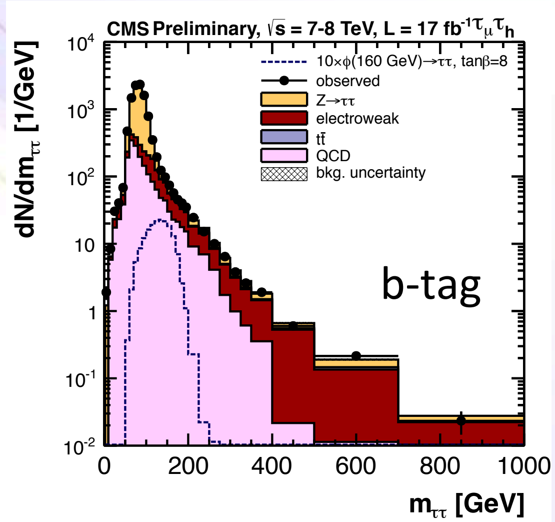
$Z \to \tau\tau$ is irreducible background
- di-tau **invariant mass** is the best discriminator

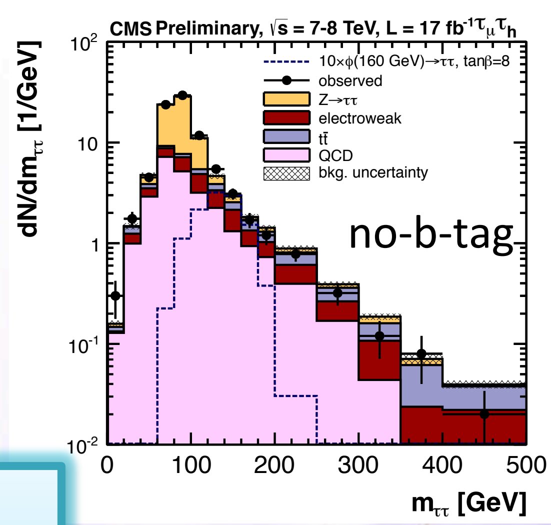
… but, 3 neutrinos in the final state
- **probabilistic approach** to estimate the full mass

$\sigma(m_{\tau\tau})$~21%
$\sigma(m_{vis})$~24%

likelihood fit technique [SVfit]
- ☑ visible τ momenta (decay products)
- ☑ neutrinos produced in τ decays (missing transverse energy)
- physical solution for every event

background expected number of events
[data driven background estimation]
- $Z \to \tau\tau$ is constrained by published CMS $Z \to \mu\mu/ee$ result
- QCD from ratio of OS/SS (~1) in di-lepton events and τ-fake rate in multi-jet events
- W+jets from W transverse mass shape [separately in OS,SS]
- ttbar and VV by MC
- $Z \to ee/\mu\mu$ from lepton fake rates





clear **Z mass peak** seen in CMS data
more than **600 events** observed in data

CMS-HIG-12-050

$\phi \to \tau^+\tau^-$ exclusion limit

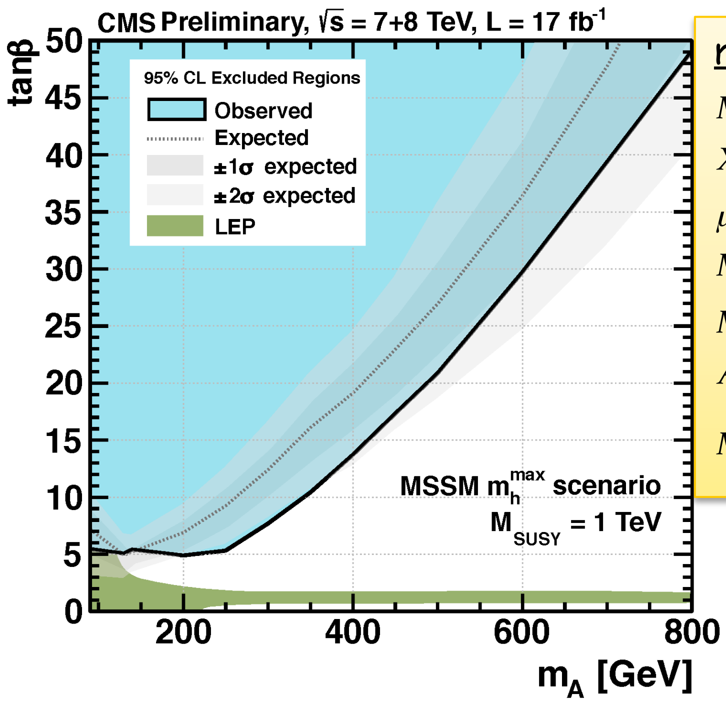
likelihood fit to the **$m_{\tau\tau}$ spectrum**
[sys. uncertainties are represented by nuisance parameters]
is performed using shape information

signal constraints
- ✓ $gg\Phi$ and $bb\Phi$ shape relative normalization [ratio constrained to the expected value @tanβ=30]
- ✓ Higgs width assumed for tanβ=30 [negligible w.r.t. experimental mass resolution (**~21%**)]

background constraints
- ✓ QCD and Z → ll shapes taken from data
- ✓ all other shapes from simulation data/MC agreement in sidebands

expecting ~100 Φ events in m_A=120 for tanβ = 30!

…but, no excess is observed in the di-tau mass spectrum
➡ 95% CL upper limit on σ×BR



m_h^{max} scenario

$M_{SUSY} = 1 TeV/c^2$

$X_{PQt} = 2M_{SUSY}$

$\mu = 200 GeV/c^2$

$M_{\tilde{g}} = 800 GeV/c^2$

$M_2 = 200 GeV/c^2$

$A_b = A_t$

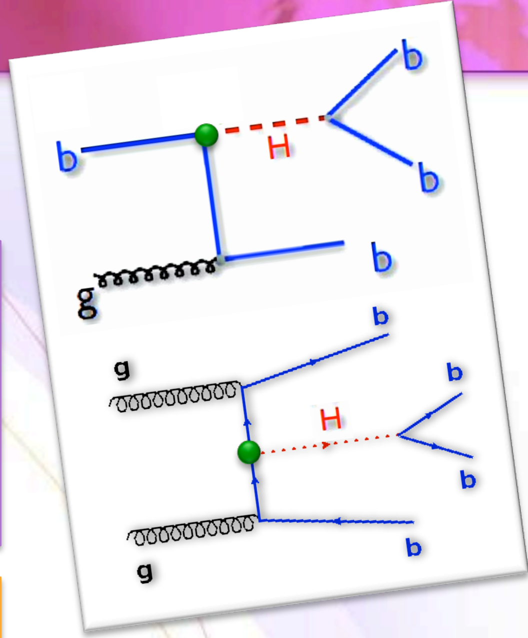
$M_1 = \frac{5}{3} M_2 \tan\theta_w$

observed and expected limit on σ×BR computed for different mass hypotheses m_A using Bayesian integration and assuming an uniform prior on σ×BR in $\mu+\tau_{had}$, $e+\tau_{had}$, $e+\mu$ channels

upper limit on σ×BR interpreted in MSSM parameter space (m_A,tanβ)

$\phi \rightarrow bb$ search @CMS

search for $\phi \rightarrow bb$ produced in association w/ b-quarks
signature: events w/ at least **3b-jets in the final state**



- major **background source is multi-jet QCD processes**
  - simulation are affected by large uncertainties both in terms of experimental observables and cross sections
    - **multi-jet background estimation from data is crucial**
  - contribution from tt, Z+jets is negligible

- **online selection is particularly challenging**
  - maintain a reasonable rate
    - multi-jet events w/ moderate jet multiplicity
      high total cross section, high luminosity, PU
  - maintaining sufficient signal efficiency
    - low threshold on object p_T
    - exploit b-tagging already online

2 independent and complementary approaches:
- **all-hadronic** final state:
  exploit the b-jets multiplicity
- **semi-leptonic** final state:
  exploit also the b-quark decay into muon (~20%)

overlap between sample is small: ~2% (already @trigger level)

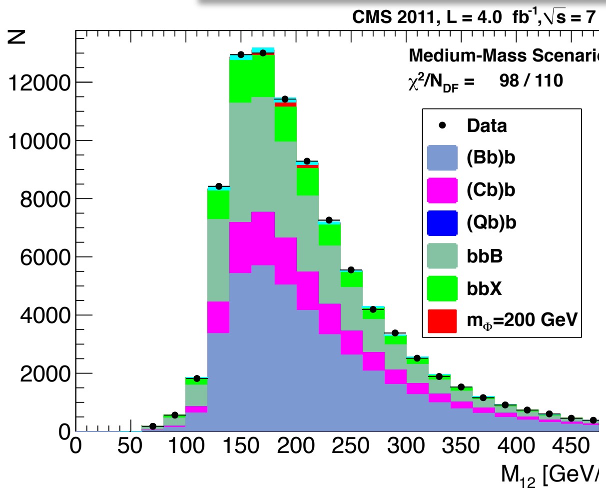
CMS-HIG-12-033, CMS-HIG-012-027, CMS-HIG-12-026

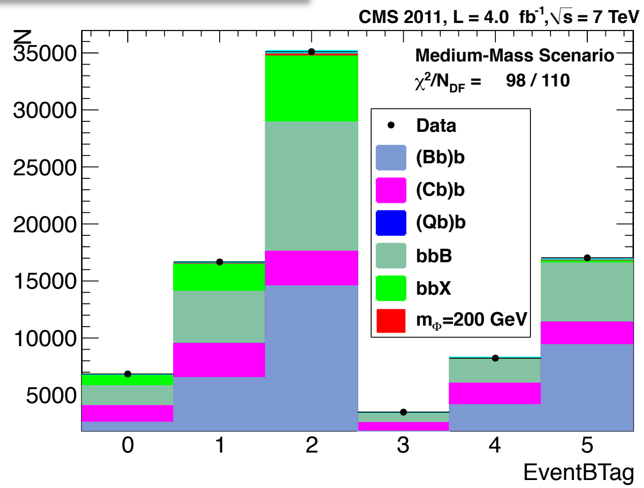
ϕ→bb all-hadronic

- 2011 data: 2.7fb^{-1} ÷ 4fb^{-1}
- use online b-tag

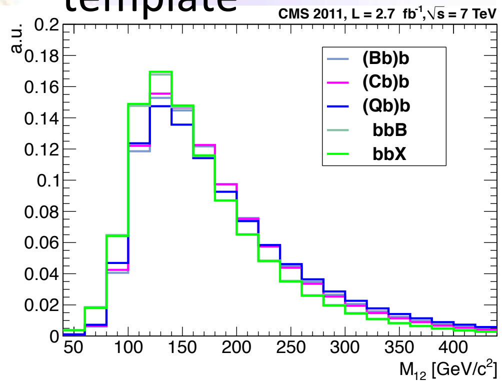
<u>OFFLINE selections</u>:
- 3jets (PFak5) $|\eta|<2.2$, p_T > 46,38,20 (60,53,20) GeV/c
- ΔR(jet1,jet2) > 1 (suppress gluon splitting)
- 3 leading jets w/ b-tag (CSVT)

signal yields obtained from a **2D fit** on **di-jet mass** (M_{12}) vs **EventBTag**





template



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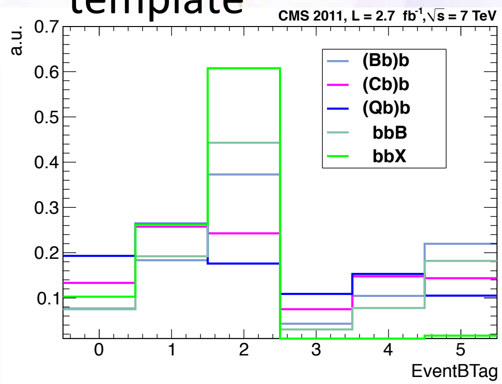


3 b-jets background estimate from data (à la CDF):
- 2D templates (M_{12},EventBTag) of different flavour contributions assessed from a 2 b-tagged sample from data (**bbj,bjb,jbb**)
- untagged jet weighted by the b-tag probability and the corresponding SV mass index probability
- corrections for non real b's in double b-tagged sample, and b-tag trigger corrections applied

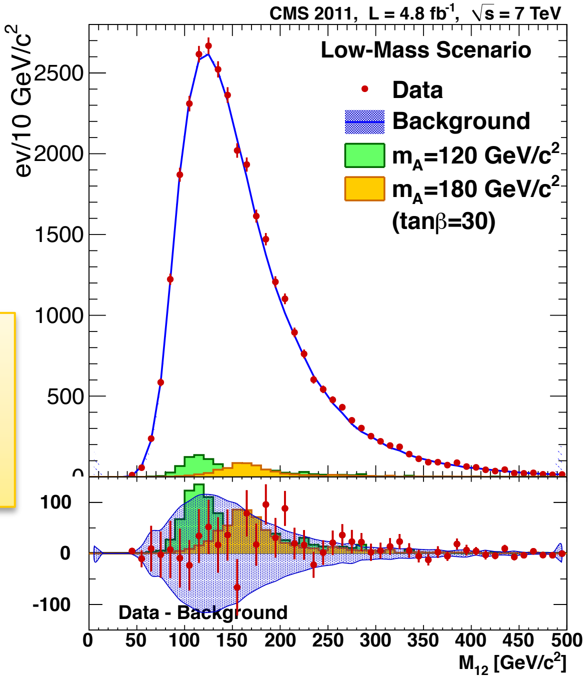
CMS-HIG-012-026

$\phi \rightarrow$bb semi-leptonic

- 1 muon p_T > 15GeV/c
- 3jets (PFak5) $|\eta|$<2.6, p_T > 30,30,20 GeV/c
- μ w/in one of the 2 leading jets
- b-tag CVS>0.8,0.8,0.7

- 2011 data: 4.8 fb^{-1}
- use semi-leptonic (muon) b decay for trigger interesting events: muon+jets+b-tagging

use **reconstructed mass of leading jets pair (M_{12})** as signal-sensitive variable in final fit

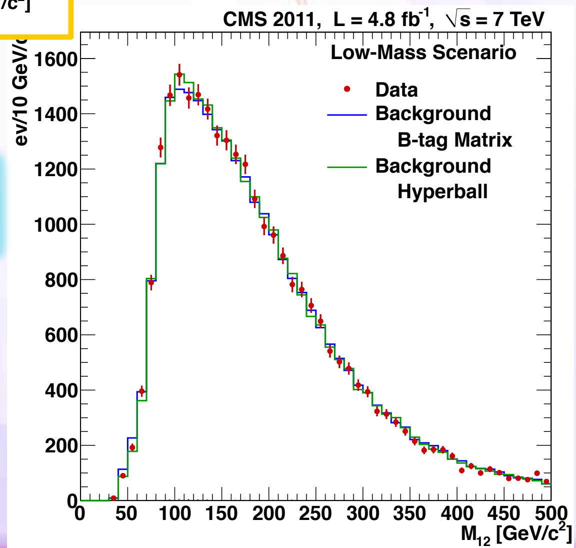


background estimate from **bbj** and **bjj** samples
- define signal-poor control sample;
- 2 independent methods:
  - **B-tagging Matrix**
  - nearest-neighbour (**Hyperball**)

$$F(x;bbb) = F(x;bbj) \otimes P_{b-tag}^{3^{rd}\ jet}(\ldots)$$

$$F(x;bbb) = F(bjj) \otimes f$$

➡ final <u>background shape from combination of the 2 methods</u>, using a bin-per-bin weighted average of the two predictions



CMS-HIG-012-027

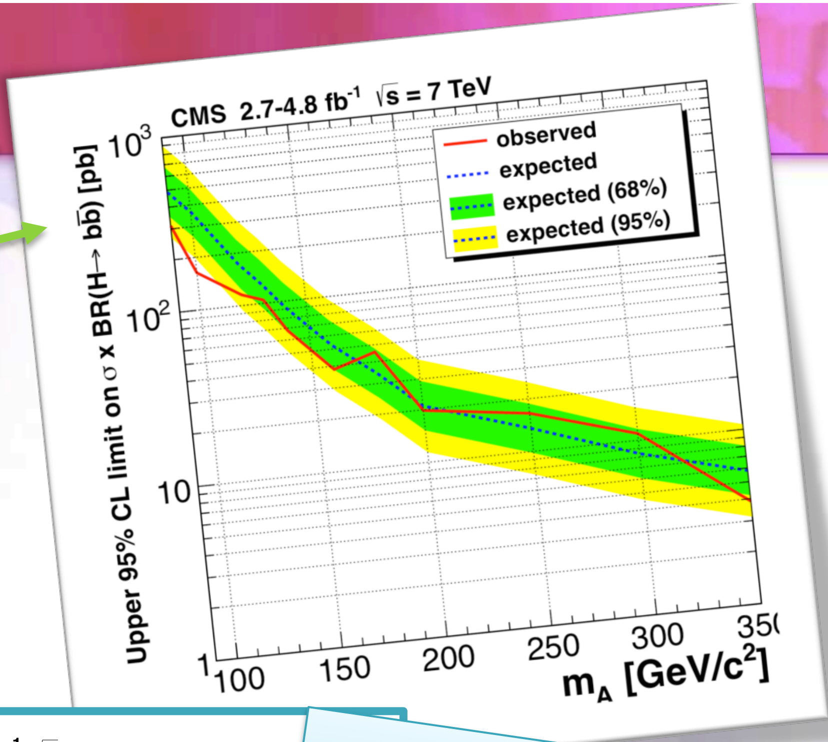
φ→bb combined

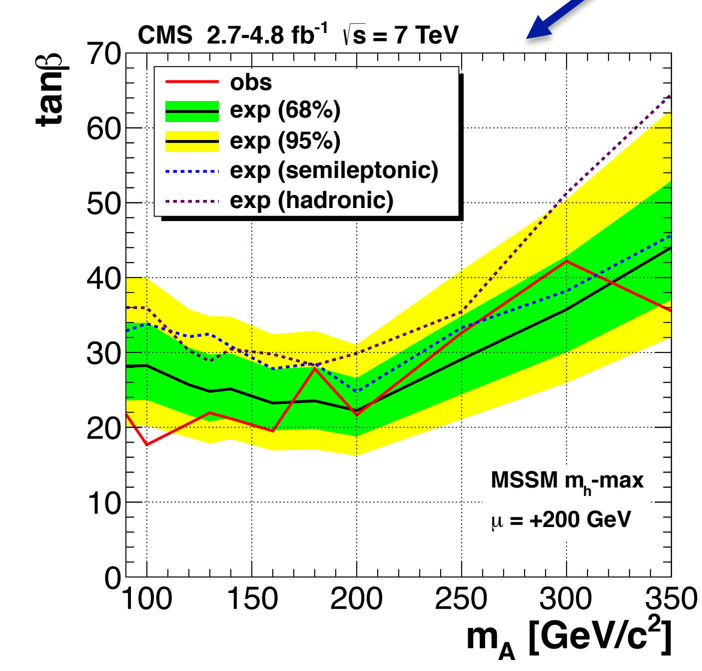
no excess observed

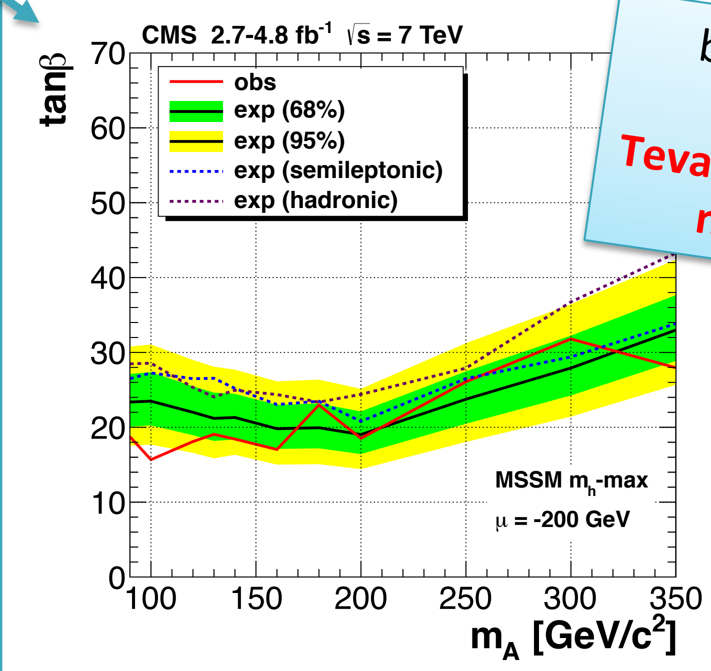
- set **upper limits on σ(bbφ)xBR(φ→bb)** as function of different φ mass hypothesis

fit linear combination
– background templates (b-only fit)
– background templates + signal (s+b fit)
shape altering uncertainties (JES, JER, b-tagging) via nuisances
no prior constraints on normalization of background templates!

- **interpreted in the MSSM m_ϕ-tanβ plane**







better sensitivity than Tevatron
Tevatron excesses (2σ) not confirmed

..published soon

CMS-HIG-012-033

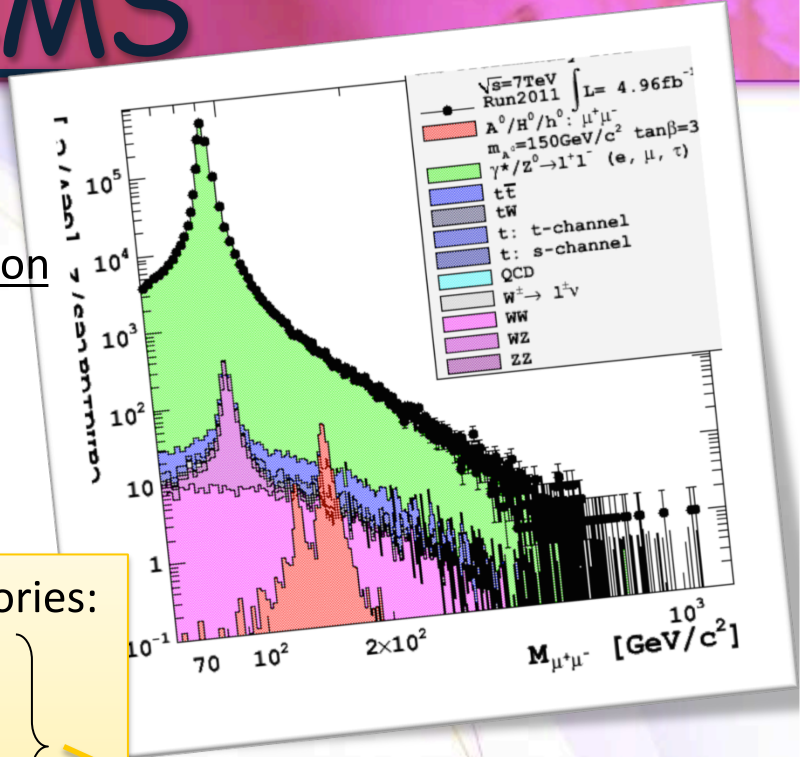
$\phi\rightarrow\mu\mu$ search @CMS

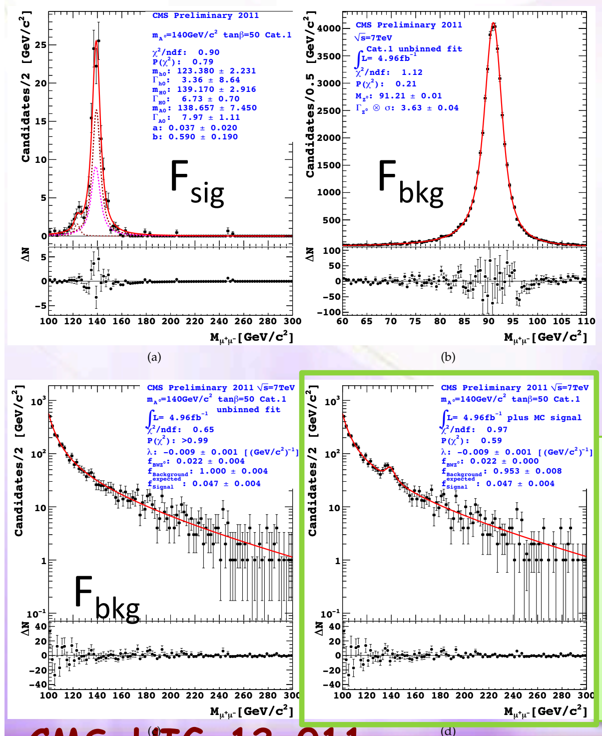
<u>h/H/A → $\mu^+\mu^-$</u>

sensitive to MSSM Higgs boson production

both in <u>association w/ a b-quarks pair</u> and via <u>gluon fusion</u>

- 2011 data: 4.96 fb^{-1}
- trigger on single high-p_T mu
- high-p_T isolated muons: p_T>30,20 GeV/c w/ |η| <2.1
- MET<30 GeV (against tt and WW)





events divided in 3 categories:

- **at least one b-tag jet, p_T > 20 GeV/c, |η|<2.4**
- **3rd muon (from b's) p_T > 3 GeV/c, |η|<2.4**

  (recover events were the b-tagging fails)

→ b-associated production

- **other events**

→ gluon-gluon fusion

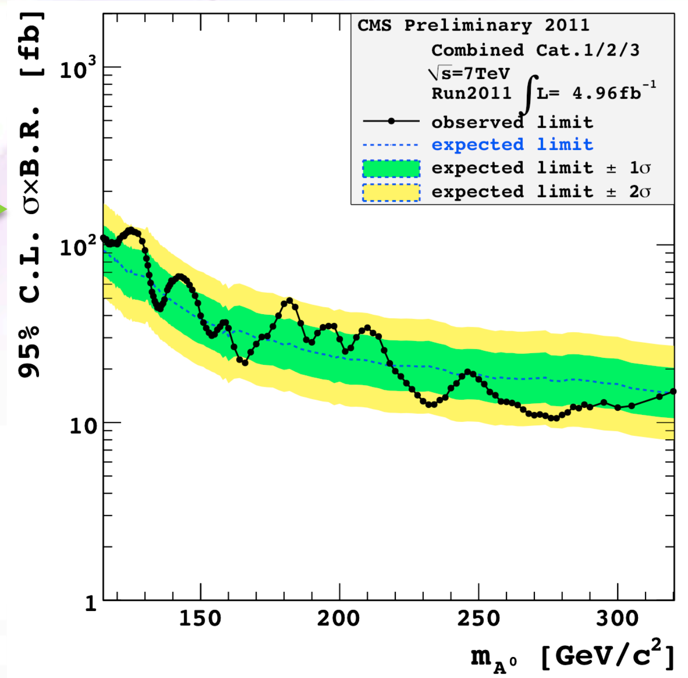
background shape and normalization determined by a simultaneous fit to data of signal and background hypothesis

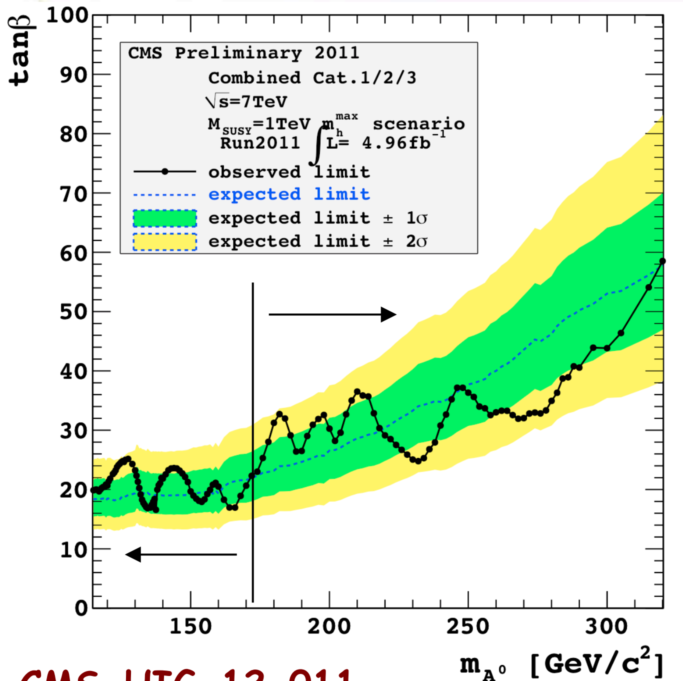
$$F = N \cdot \left[(1 - f_{Background}) \cdot F_{sig} + f_{Background} \cdot F_{bkg}\right]$$

CMS-HIG-12-011

limits from $\phi\rightarrow\mu\mu$

no excess is observed
in the di-muon mass spectrum
➡ 95% CL upper limit on σ×BR
observed and expected limit on σ×BR
computed for different mass hypotheses m_A
using Bayesian integration
and assuming an uniform prior on σ×BR



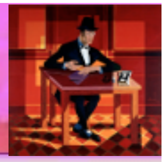


upper limit on σ×BR interpreted in MSSM parameter m_A,tanβ plane

in the m_h^{max} scenario,
this analysis @95% CL excludes values of tanβ
between 16 and 26 for m_A =115÷175 GeV/c²
between 26 and 40 for higher m_A up to 300 GeV/c²

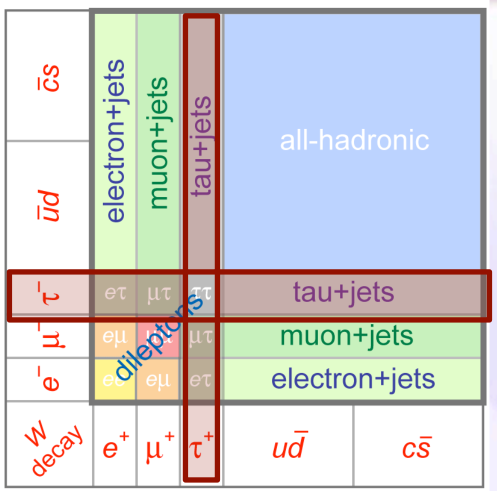
CMS-HIG-12-011

light charged Higgs search

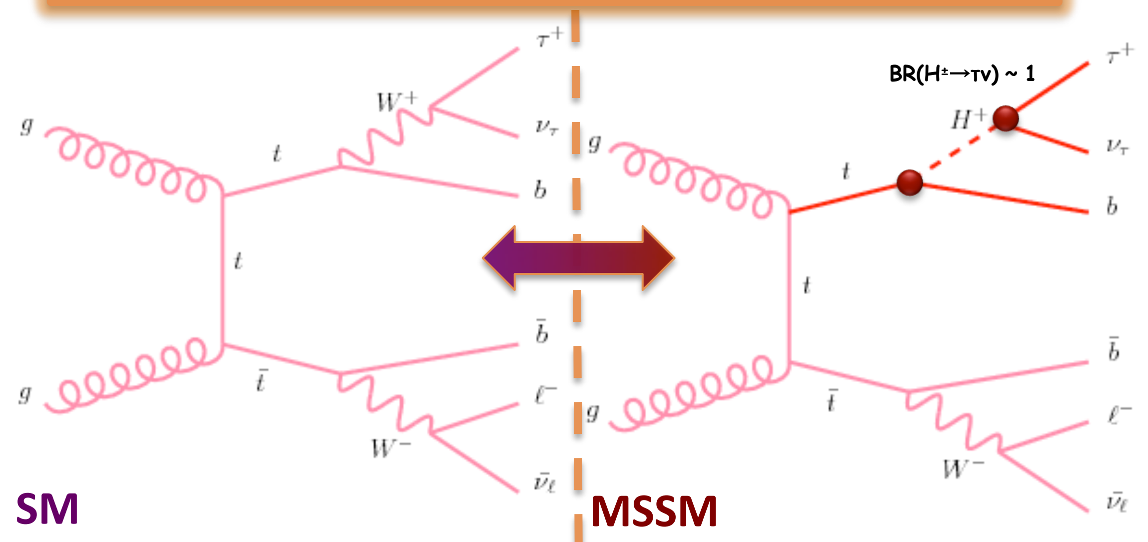


studied $H^{\pm}$

- ☑ in **ttbar events**
  - ❑ HH: both top decay into $H^{\pm}b$
  - ❑ WH: 1! top decays into $H^{\pm}b$
  - ➧ **80 ≤ m($H^{\pm}$) ≤ 160 GeV/c²**
- ☑ **BR($H^{\pm}\to\tau\nu$) ~ 1**



if the $H^{\pm}$ exists,
we may observe a **discrepancy**
in the events yield <u>of the ttbar's τ channel</u>
incompatible w/ the SM prediction



signature:

- E_T^{miss}
- 3jets+1btag / 1lepton+2jets+1btag
- one τ (τ to hadrons or leptons)
- W and top reconstructed masses consistent w/ measured values

backgrounds:

- ***irreducible***
  ttbar tau dilepton channel
- ***tau-fake***:
  W+3jets and lepton+jets (in ttbar)
- ***non tau-fake***:
  Z→ee,μμ,ττ, single-top, di-bosons

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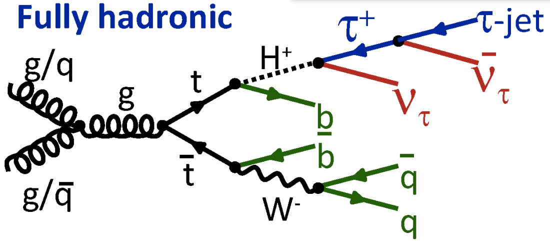
H⁺→τν: analyzed topology

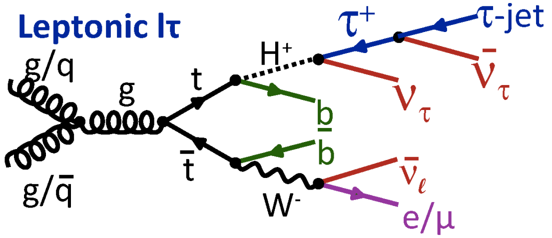
T_h+jets: 2.2fb^{-1}

Fully hadronic



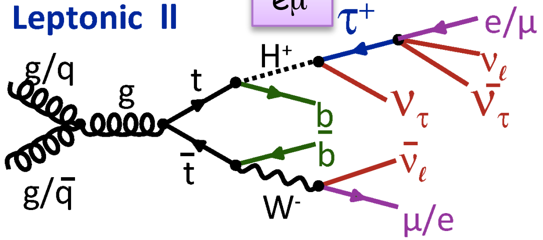
T_h+e/μ: 1.99/2.2 fb^{-1}

Leptonic lτ



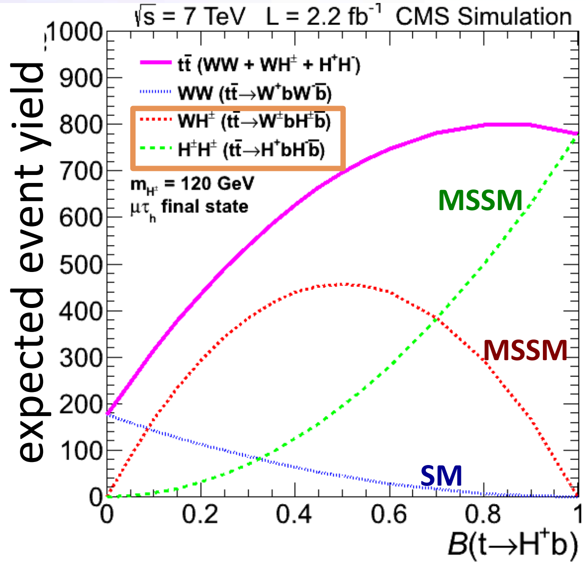
eμ

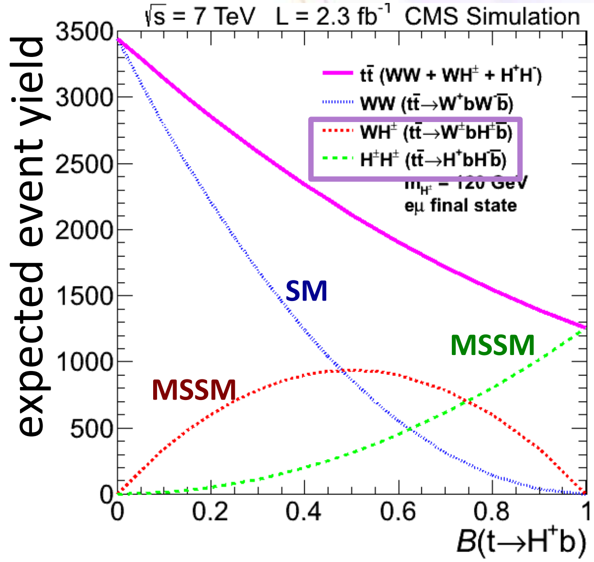
Leptonic ll



$N_{tt}^{SUSY} > N_{tt}^{SM}$
[BR(H→τν) > BR(W→τν)]

$N_{tt}^{SUSY} < N_{tt}^{SM}$





excess or deficit of events in data is related to the difference between MSSM and SM tt event yields:

$$\Delta N = N_{t\bar{t}}^{MSSM} - N_{t\bar{t}}^{SM} = 2x(1-x)N_{WH} + x^2 N_{HH} + [(1-x)^2 - 1]N_{t\bar{t}}^{SM}$$

x=BR(t→H⁺b)

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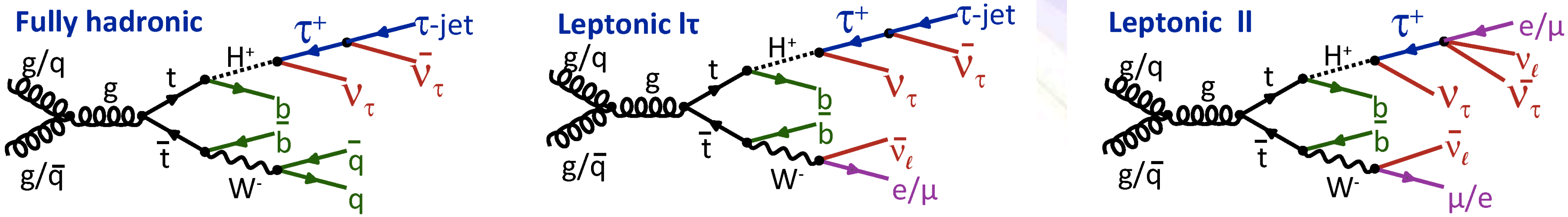
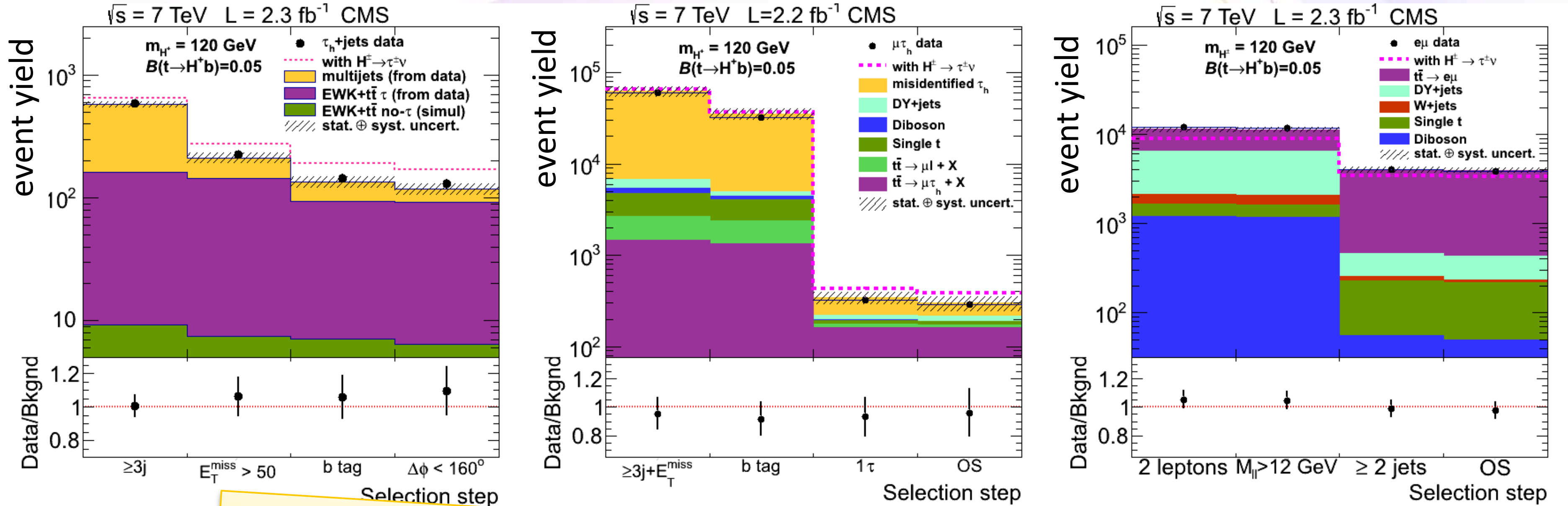
$H^+ \to \tau\nu$: analyzed topology

online selections

τ_{had}+ E_t^{miss}	electron+2 Jets single Muon	electron+muon



offline selections



event yields observed in τ_{had}+jets , τ_{had}+e/μ and e+μ channels in agreement w/ background expectation

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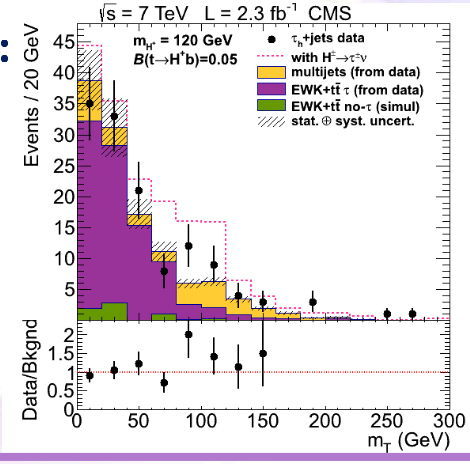
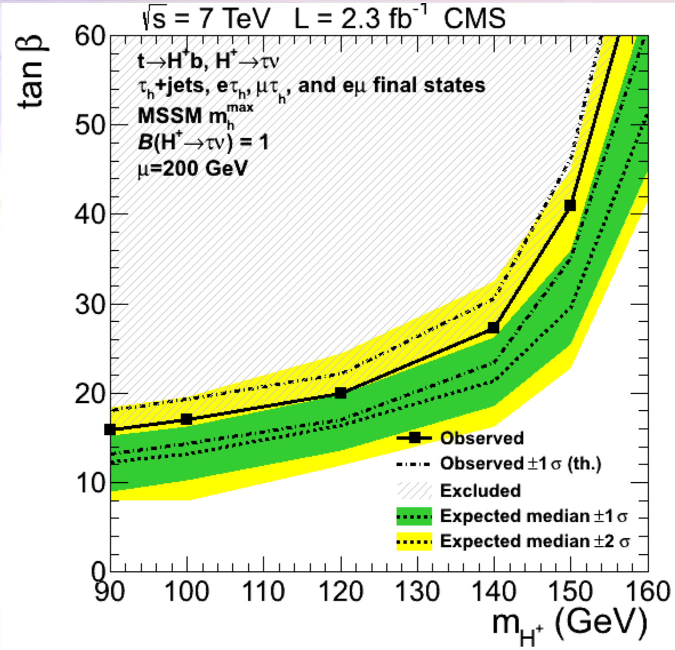
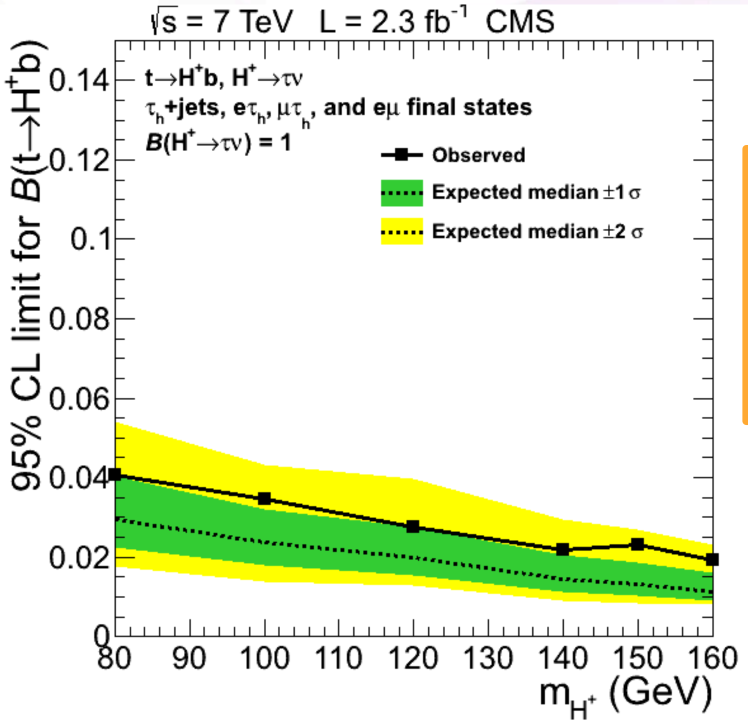
charged MSSM Higgs boson

τ_h+jets channel is most sensitive:
- the $t\bar{t}\rightarrow WbWb$ background is measured from the data
- shape analysis: m_T distribution

τ_h+e/μ and e/μ channels
- the $t\bar{t}\rightarrow WbWb$ background from simulation
- event count analysis







excess or deficit of events in data is related to the difference between MSSM and SM tt~ event yields:

$$\Delta N = N_{t\bar{t}}^{\mathrm{MSSM}} - N_{t\bar{t}}^{\mathrm{SM}} = 2x(1-x)N_{\mathrm{WH}} + x^2 N_{\mathrm{HH}} + [(1-x)^2 - 1]N_{t\bar{t}}^{\mathrm{SM}}$$

$x = BR(t\rightarrow H^+b)$

the upper limit 2-4 % on the $BR(t\rightarrow H^+b)$ has been obtained for the Higgs boson mass interval $80 < m_{H+} < 160$ GeV/c^2 assuming $BR(H^+\rightarrow \tau^+\nu)=1$

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conclusion…

- direct searches for MSSM Higgs have been performed in CMS w/ both 7TeV and 8TeV dataset
- no evidence of signal(s) observed so far

neutral Higgs:
search in the $\tau\tau$, bb and $\mu\mu$ channels
- **set 95% CL upper limit on $\sigma\times$BR**
- **exclusion limits** (m$_h^{max}$ scenario) **in the m_A–tanβ plane**

CMS results exclude previously unexplored region in MSSM parameter space
a small fraction of the phase-space is not excluded, now

excluded **tanβ>6**
for **m_A** up to **~250GeV/c^2**
w/in m_h^{max} scenario

charged Higgs:
search in the 80 < m_{H+} < 160 GeV/c^2 range
- in through the tt production mechanism

w/in the hypothesis BR($H^+\rightarrow\tau\nu$)=1
- significant constraint on **BR(t→bH$^\pm$) < 2÷4%**
- exclude a large region in the **m_{H+}–tanβ plane**

- full 2012 data sample will be analyzed soon
- new combination among different channels will be published soon
- channels analyzed for the SM Higgs measurements cover part of the remaining phase-space
  - might give more information

important to continue searches and extract model "independent" cross-sections in SUSY ϕ->$\tau\tau$, $\mu\mu$, bb analyses

BACKUP

event selection

trigger
- $\mu+\tau_{had}$ and μ+e: **single muon**
- e+τ_{had}: **single isolated electron**

  p_T thresholds 10÷20GeV/c

offline

	electron	muon	τ_{had}
p_T	15÷20 GeV/c		20 GeV/c
$\lvert\eta\rvert$	2.1 (2.3 for e+μ)	2.1	2.3
	isolated		tauID veto against e/μ

- opposite charge lepton pair
- transverse mass

reduce QCD contamination

reject W→lν and ttbar

	M_T (l+MET)
e+τ_{had} and $\mu+\tau_{had}$	<40 GeV/c^2
e+μ (both)	<50 GeV/c^2

- veto events w/ additional isolated leptons [for e/$\mu+\tau_{had}$]

reject Z→ll

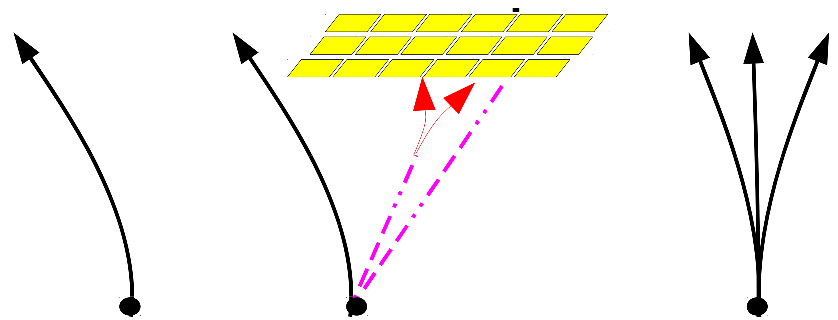
enhance bbΦ coupling

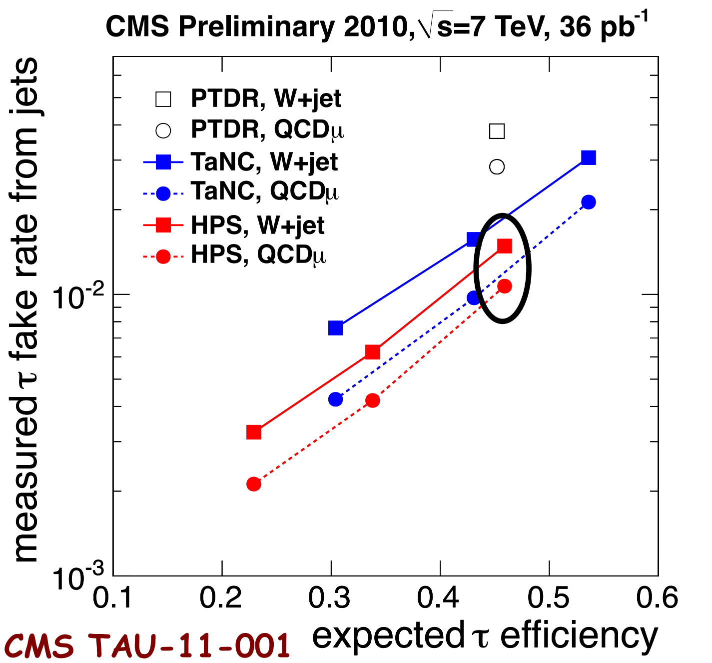
selected events analyzed in 2 categories:
- b-tag
- non-b-tag

b-tag	non-b-tag
≤ 1 jet w/ p_T > 30 GeV/c	
≥ 1 b-tagged jet w/ p_T > 20 GeV/c	NO b-tagged jet w/ p_T > 20 GeV/c

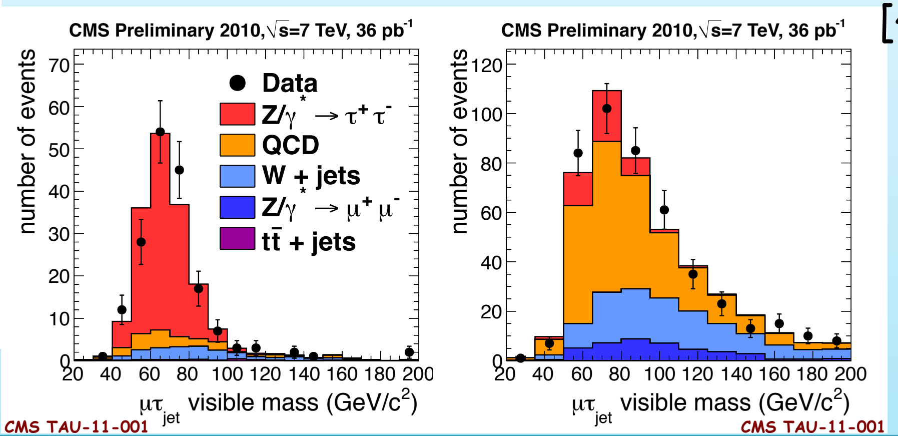
τ Identification [HPS]

tauID:
reconstruction of **individual decay modes**
combining **ParticleFlow** candidates
discrimination against μ's and e's
[based on shower shape info and E/p]





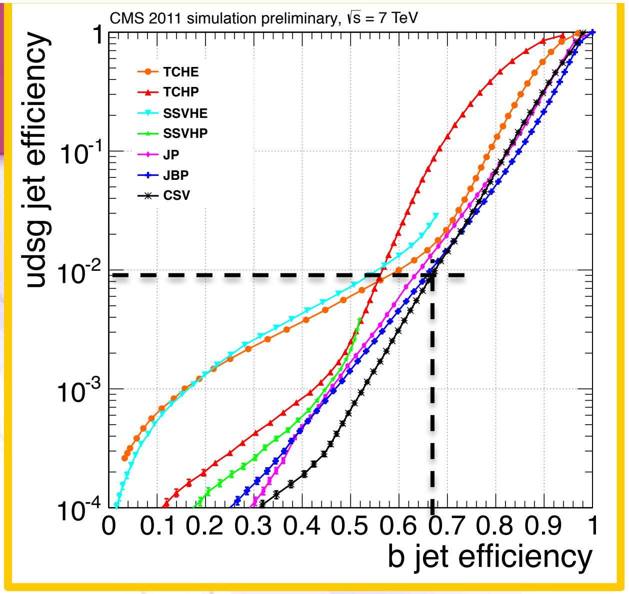
well commissioned in data
- ☑ fake rates in
  - ➢ di-jets
  - ➢ W + jets
  - ➢ inclusive muon sample
- ☑ efficiency on $Z \rightarrow \tau\tau \rightarrow \mu+\tau_{had}$ w/ tag and probe [~23%]



b-tagging

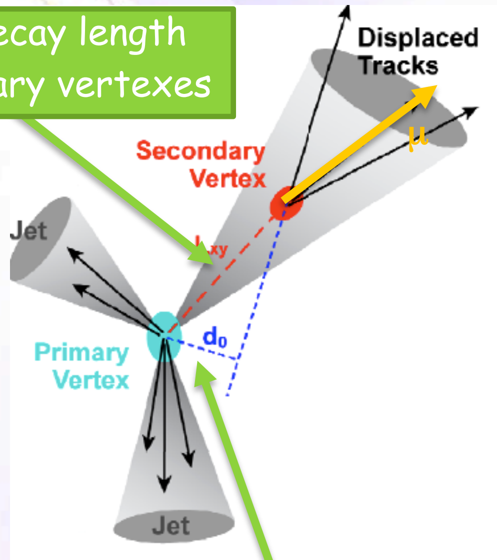
several *b*-tag algorithms have been developed which exploit some ***b* hadron characteristics** [w.r.t. light flavours and gluons]:

- **hard fragmentation**
- **mass** → high tracks multiplicity
- **long lifetime** → secondary vertex, track w/ large impact parameter
- **semi-leptonic decay** (BR~20%) → leptons w/ high p_T w.r.t. jet axis



for each jet, all algorithms produce a ***discriminator*** [simple or complex variable] on which one cuts more or less tightly, in order to distinguish *b*-jets [correspondently w/ different efficiency and purity]

signed decay length of secondary vertexes



signed impact parameter of tracks in the jet