Jornadas 2014

21 a 22 de Março de 2014

Pavilhão do Conhecimento Lisboa

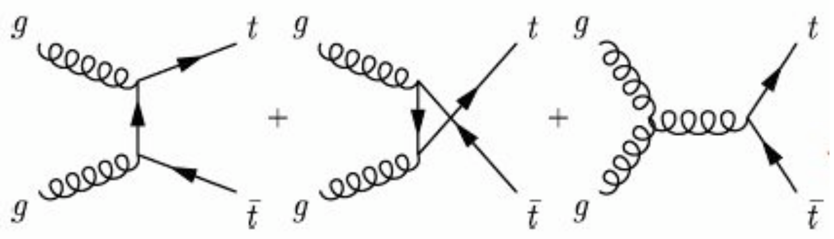
Top quark related physics

Federico Nguyen

on behalf of the CMS@LIP-Lisboa Group

March 21st, 2014

An outline



- ✓ Introduction
- ✓ Particle reconstruction of interest for top quark physics
- ✓ $\sigma(pp \rightarrow t\bar{t} \rightarrow l\,\tau_h)$ measurement and search for H^+ in top decays
- ✓ Measurement of $B_{t\rightarrow Wb}/B_{t\rightarrow Wq}$ and $|V_{tb}|$ determination
- ✓ Summary

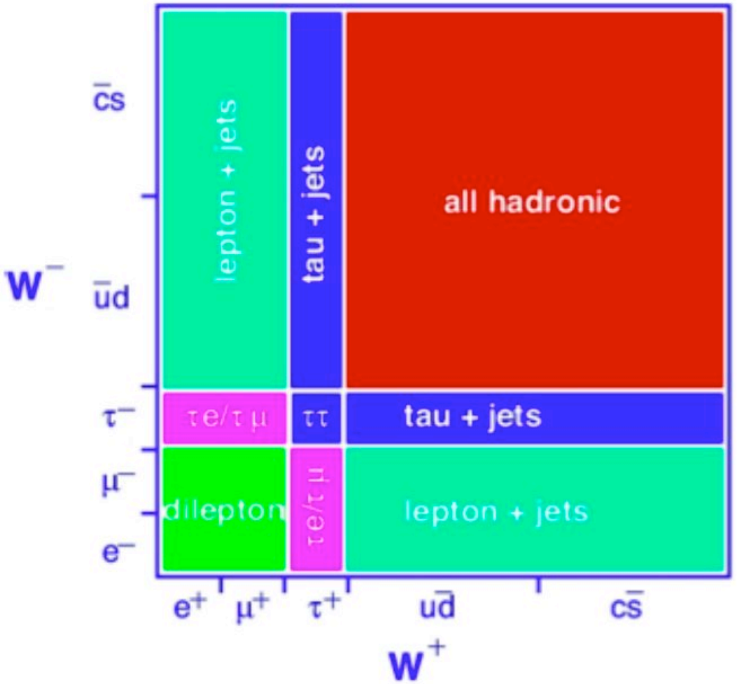
Why top quark activities after H(125) discovery?

✓ the heaviest elementary particle (m_{top} ~ 173 GeV/c^2, such as the ^{74}W)

✓ Yukawa top-Higgs coupling, $y_t = \sqrt{2}\, m_t / \langle \phi^0 \rangle \simeq 1$

✓ only quark with properties fully predictable in Perturbation Theory:

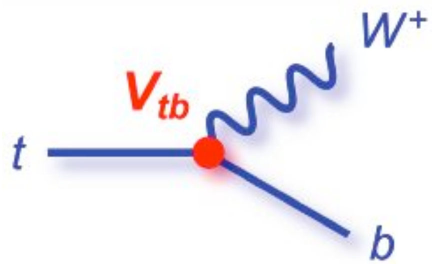
$$\tau_{top} \sim 5 \times 10^{-25}\,s < \hbar/\Lambda_{QCD} \sim 2 \times 10^{-24}\,s$$



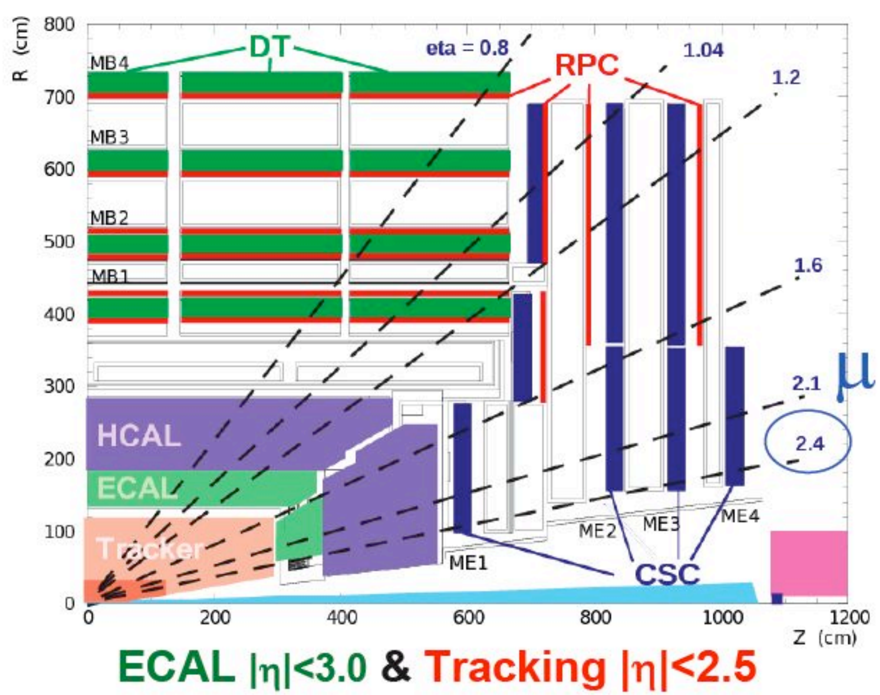
a) Precision measurements of SM properties (*e.g.* cross sections, m_{top})

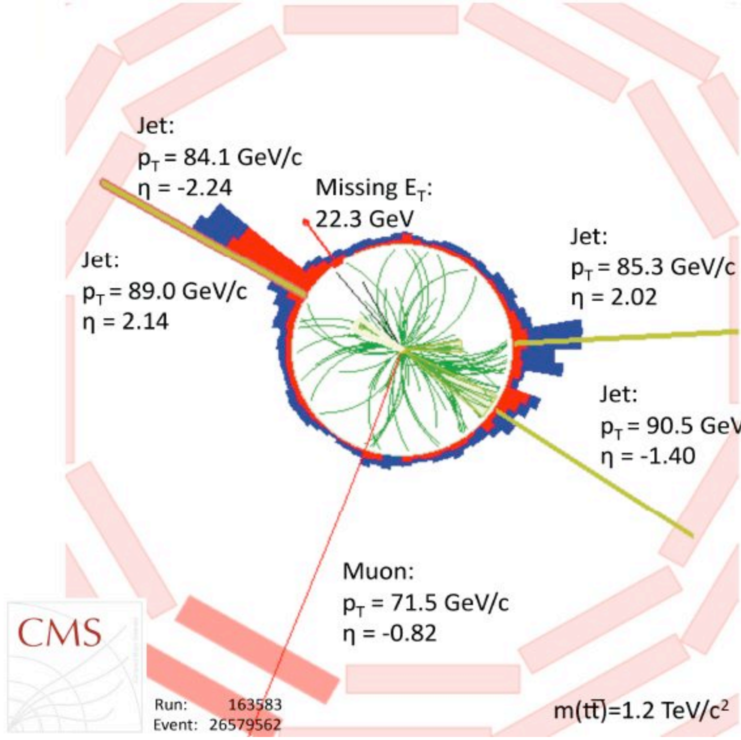
b) Test deviations from SM in many observables

c) Most relevant background process to New Physics searches



Selection of top quark events





Trigger:
- single or double (isolated) leptons

Leptons:
- $e/\mu/\tau_h$, p_T > 20-30 GeV/c
- identification/reconstruction
- tracker/calorimeter isolation

Jets:
- at least 2 jets, p_T > 30 GeV
- anti-kT algorithm, with cone 0.5
- b-tagging

Missing Transverse Energy:
- typically E_T > 30-40 GeV

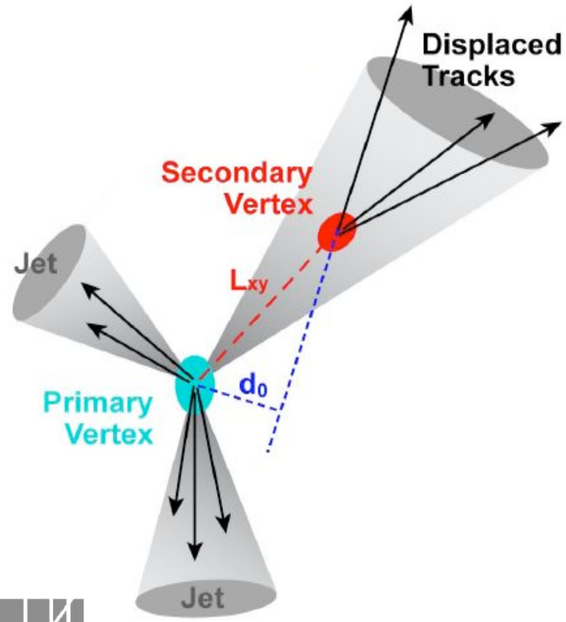
Reconstruction of b jets

JINST 8 (2013) P04013,
CMS PAS BTV-13-001

b-tagging: crucial for accurate searches & property measurements in top quark decays

Input observables:

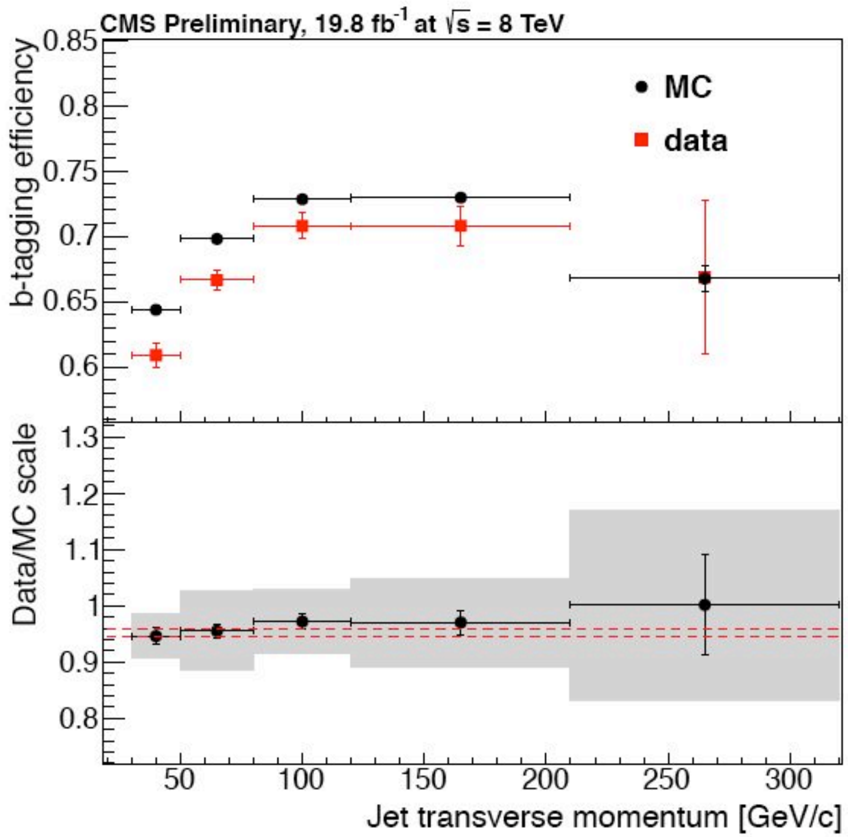
- **impact parameter, secondary vertices (b-hadron lifetime ~ 1.6 ps)**
- **transverse momentum relative to the jet axis (b-hadron mass ~ 4.8 GeV/c^2)**
- **lepton within the jet (semileptonic decay)**



✓ eff. directly measured on $t\bar{t}$ data events

✓ isolated leptons guarantee high purity

✓ methods based on consistency fits, observed vs. expected → syst. from th. shape

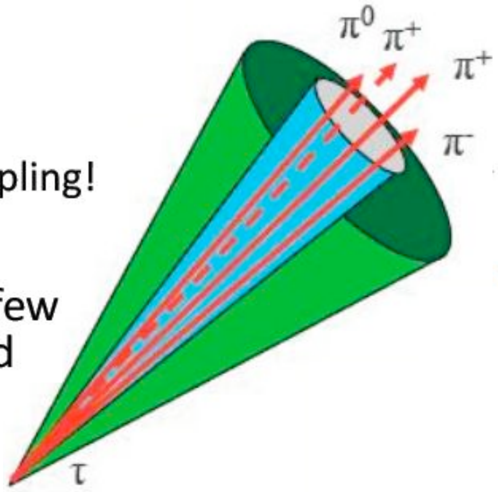


Reconstruction of τ_h

JINST 7 (2012) P01001, arXiv:1401.5041

m = 1.78 GeV/c^2
- Largest Higgs-lepton coupling!

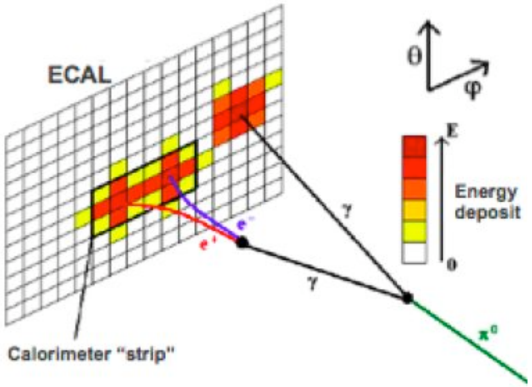
Narrow "jet" with only a few particles, typically isolated

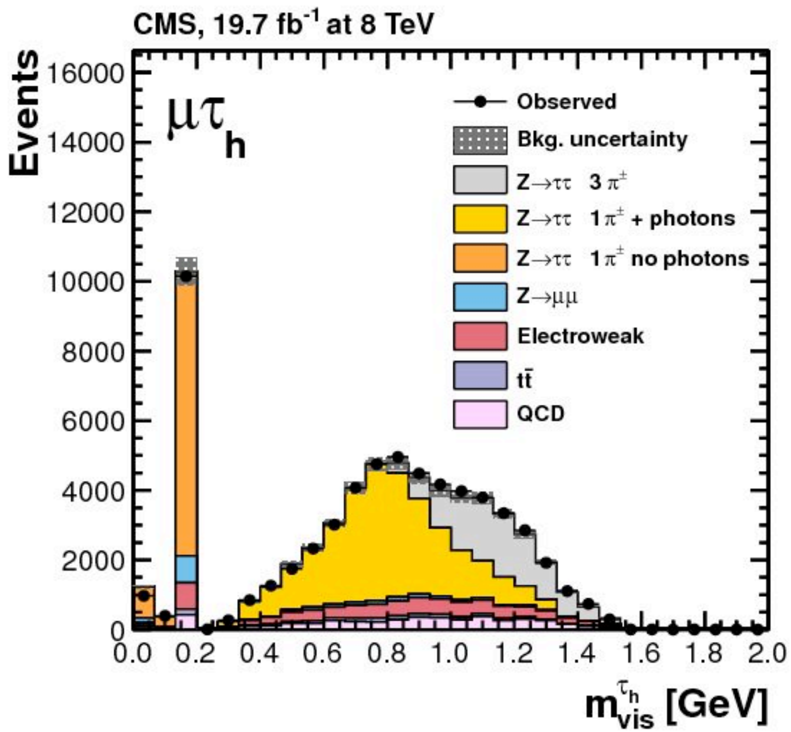


- Branching ratios:
  - 65% $\tau^\pm \rightarrow \tau_{had}^\pm \nu_\tau$
    - 75% , $\tau^\pm \rightarrow 1\pi^\pm + [\pi^0('s)] + \nu_\tau$ (**1 prong**)
    - 23% , $\tau^\pm \rightarrow 3\pi^\pm + [\pi^0('s)] + \nu_\tau$ (**3 prongs**)
  - 35% $\tau^\pm \rightarrow l^\pm \nu_l \nu_\tau$

γ conversions in the tracker
- ✓ low p_T "strips" in the ECAL
- ✓ charged hadrons
- ✓ decay modes

reconstruction



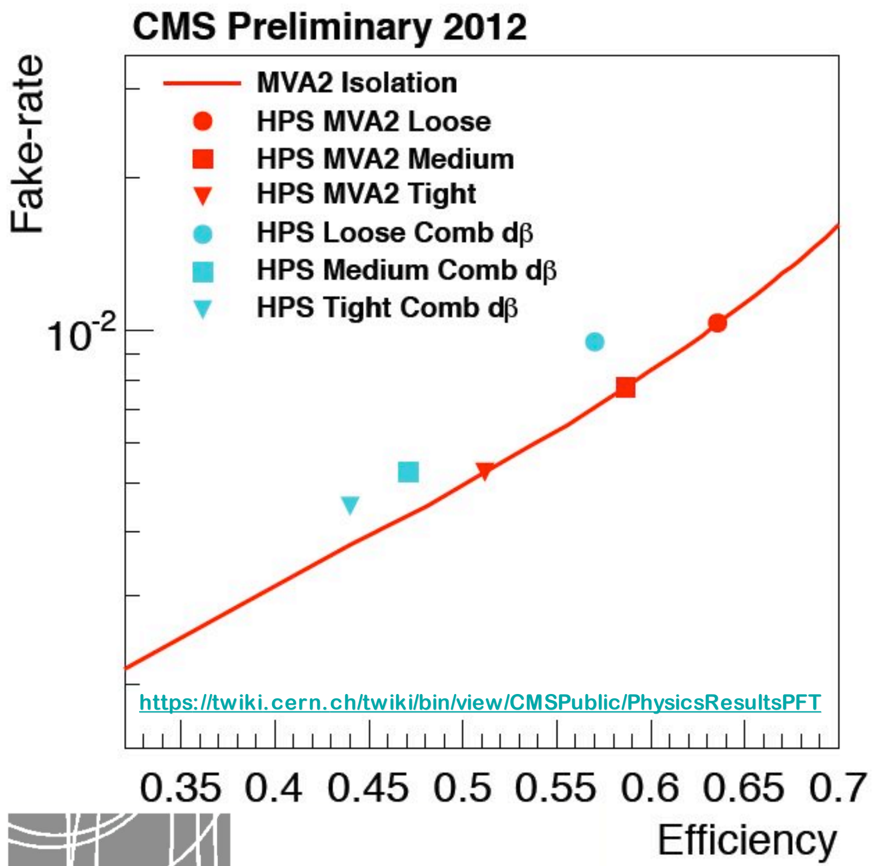


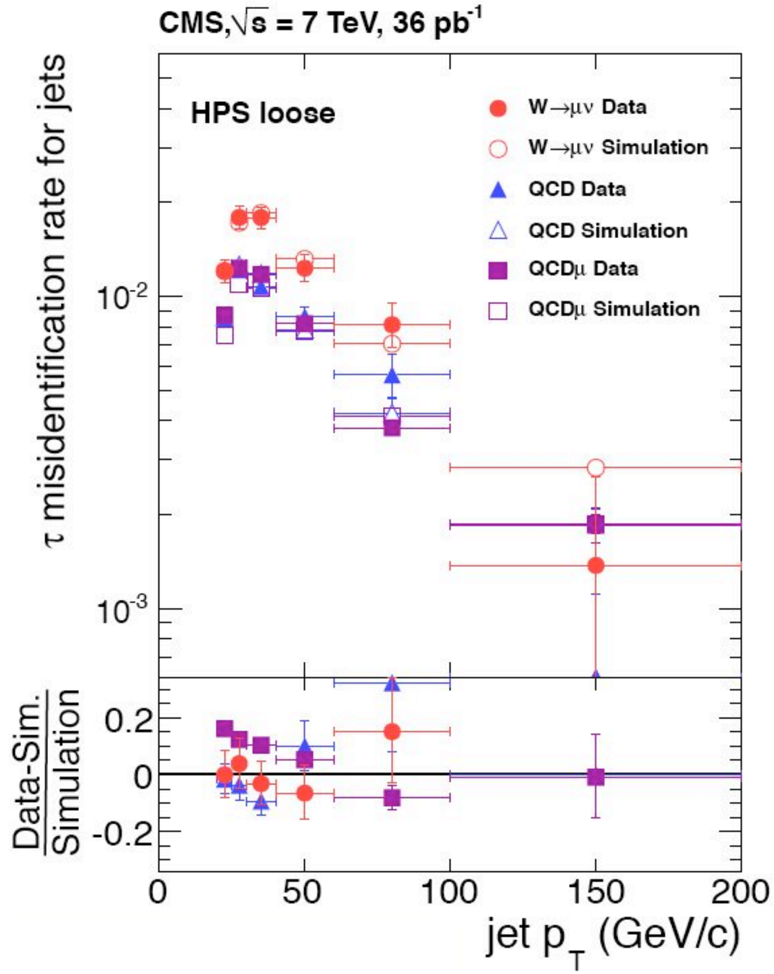
τ_h efficiency and fake rate

JINST 7 (2012) P01001, arXiv:1401.5041

✓ fake jet → τ rate measured both in QCD multijet and W(→μν)+jets events

✓ different parton compositions: analyses must account for both → systematics



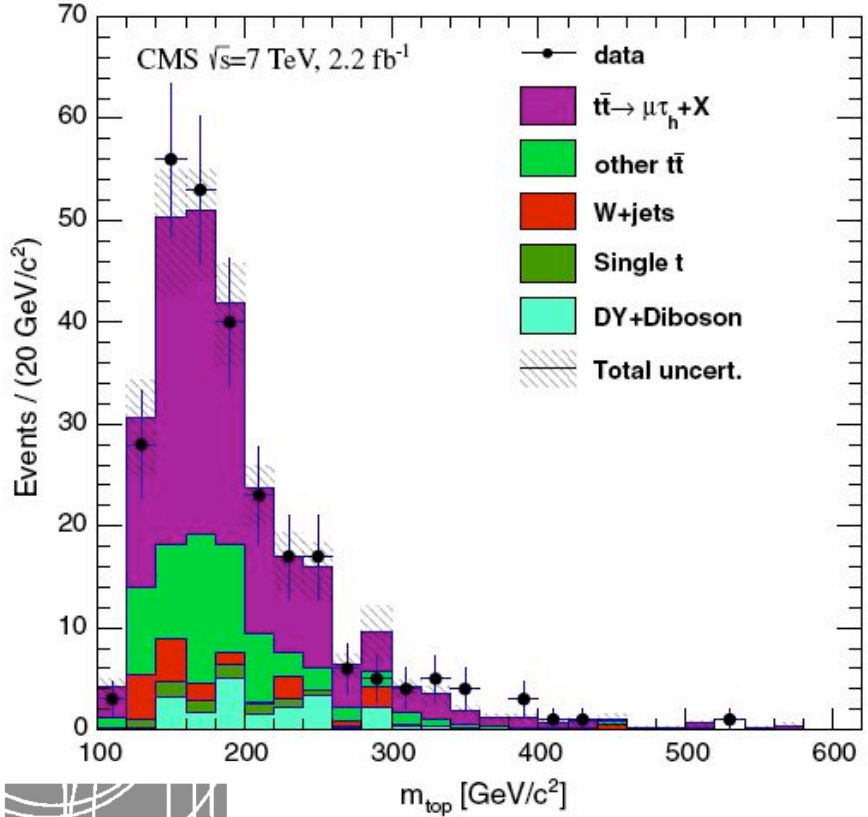


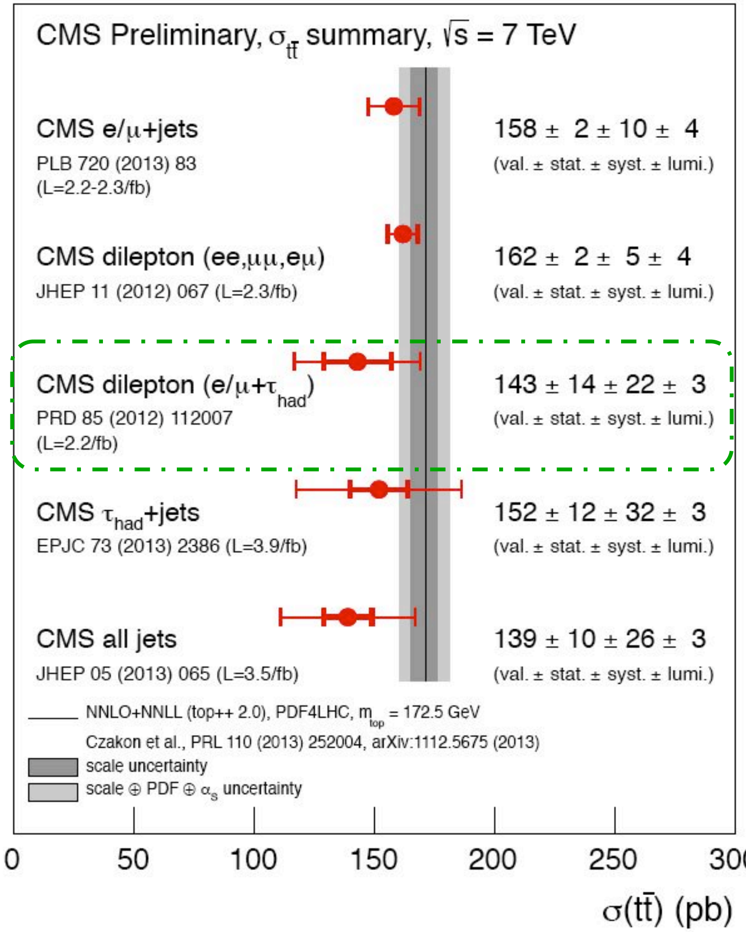
- ❑ Efficiency computed using Tag and Probe technique, using Z->ττ->μτ events
- ❑ Fit mass distribution for passing and failing TauID probes.

Measurement of $\sigma(pp \rightarrow t\bar{t} \rightarrow l\,\tau_h)$

PRD85 (2012) 112007

- ✓ 1 isolated lepton (e/μ) + 1 OS τ_h with p_T > 20 GeV
- ✓ MET > 30 (45) GeV + at least 2 jets (at least 1 btag)
- ✓ W+jets, $t\bar{t}$ → lep+jets are the dominant background with jet → τ_h fake
- ✓ the knowledge of this rate is the main measurement uncertainty = 10.8%



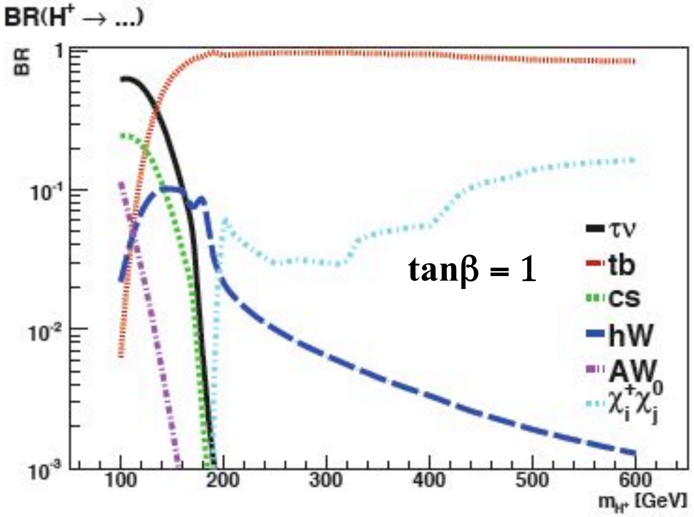


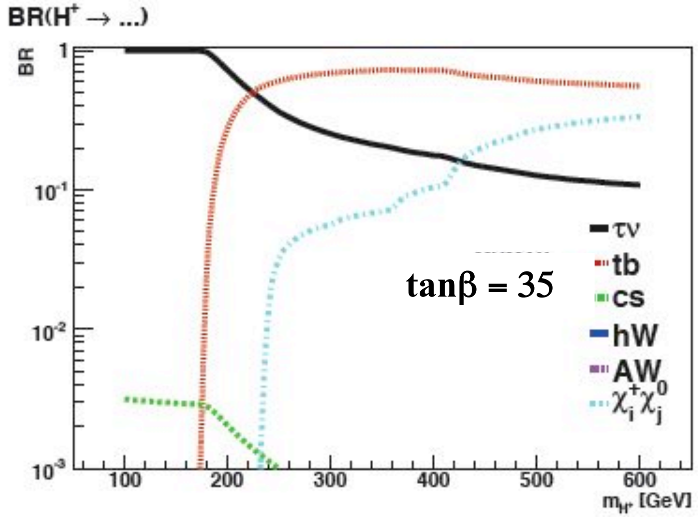
Search for the H^+ boson

JHEP 1207 (2012) 143,
CMS PAS HIG-12-052

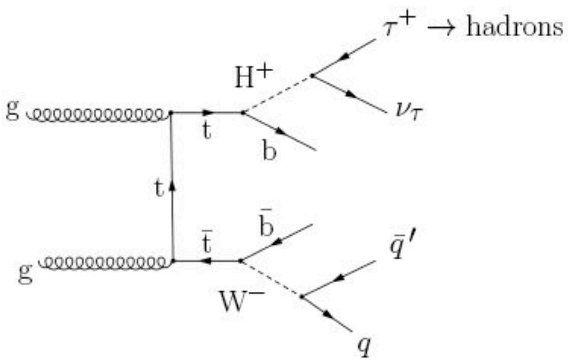
Decays of the charged Higgs boson:

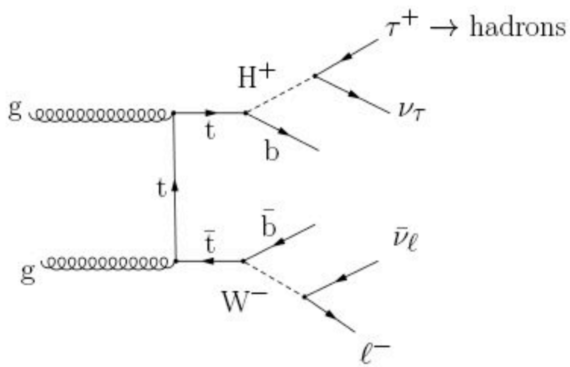
- light H^+ ($m_{H+} < m_{top}$) decays primarily to $\tau^+\nu_\tau$
- heavy H^+ ($m_{H+} > m_{top}$) decays primarily to $t\bar{b}$ and $\tau^+\nu_\tau$

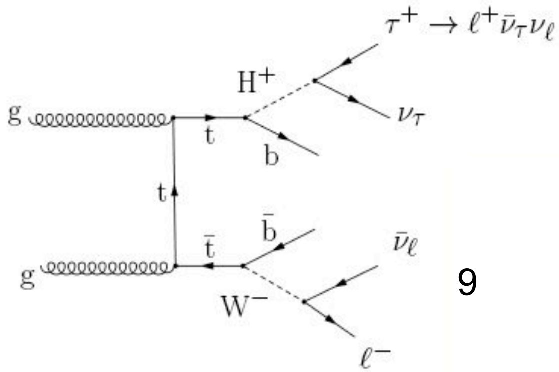




focus on the light H^+ produced in top decays







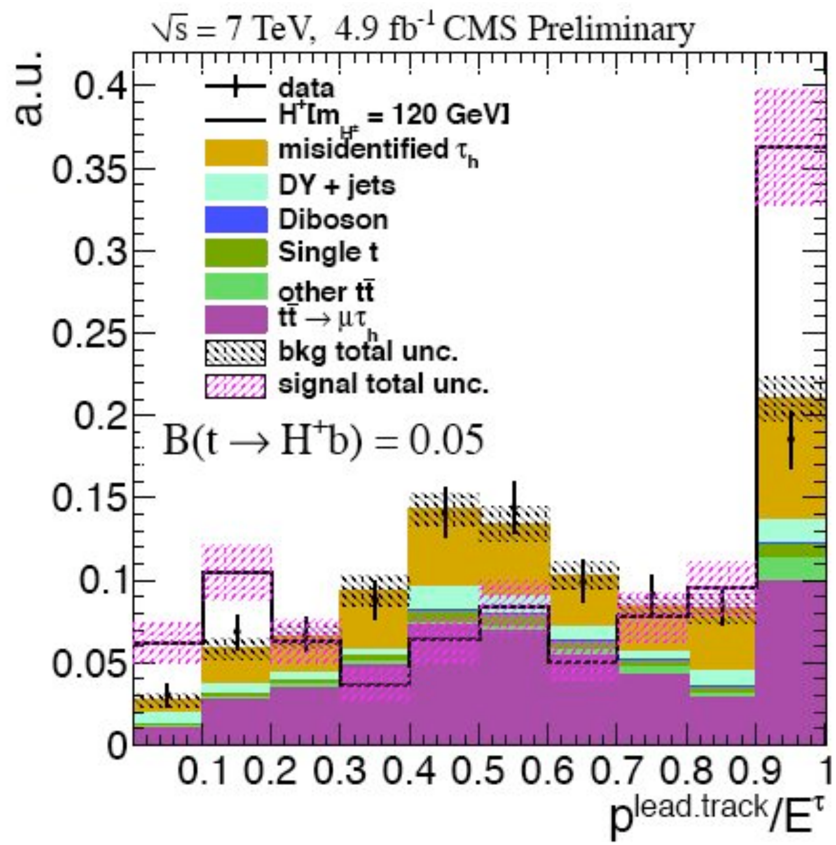
JHEP 1207 (2012) 143,
CMS PAS HIG-12-052

H+ search strategy

- ✓ lepton+τ_h and muon+electron final states (e.g. e + $\tau \to \mu$) are studied
- ✓ improved strategy in $\mu+\tau_h$ exploiting τ features in hadronic products
- ✓ dominant systematics due to $t\bar{t}$ background events

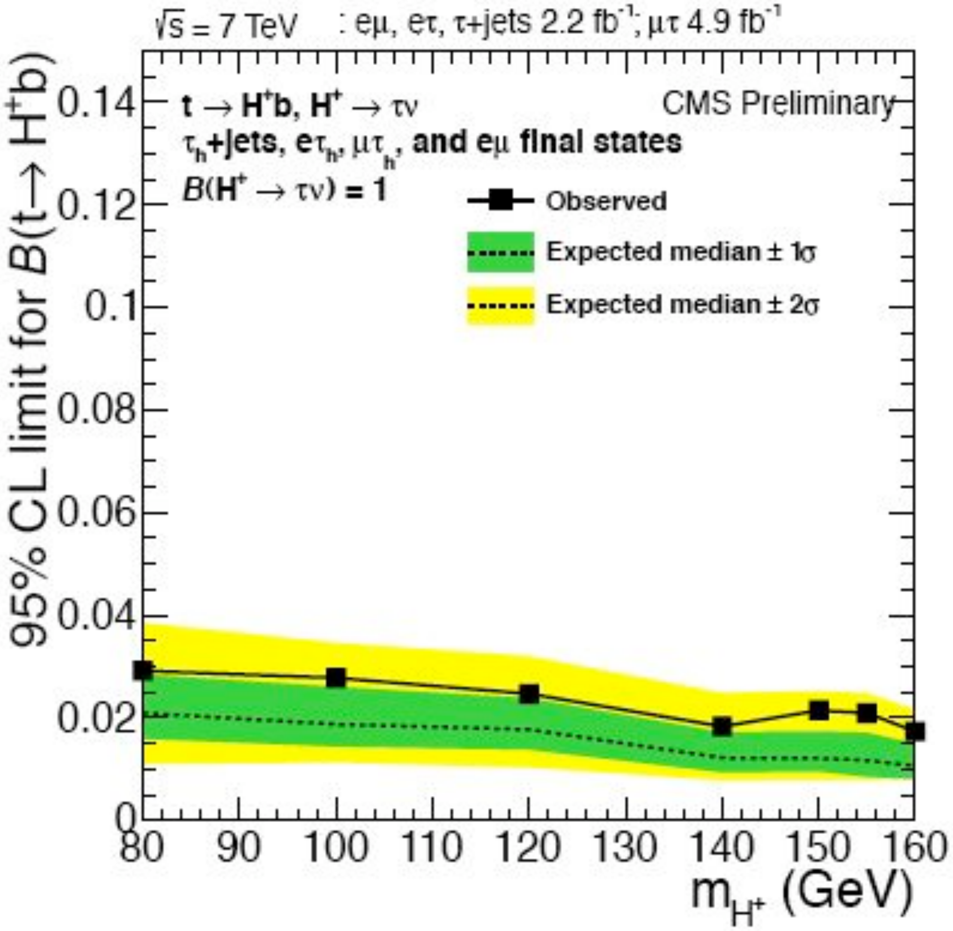
$$\tau^+ \leftarrow W^+ \rightarrow \nu_\tau$$
$$\bar{\nu}_\tau \leftarrow \tau^+ \rightarrow \text{hadrons}$$

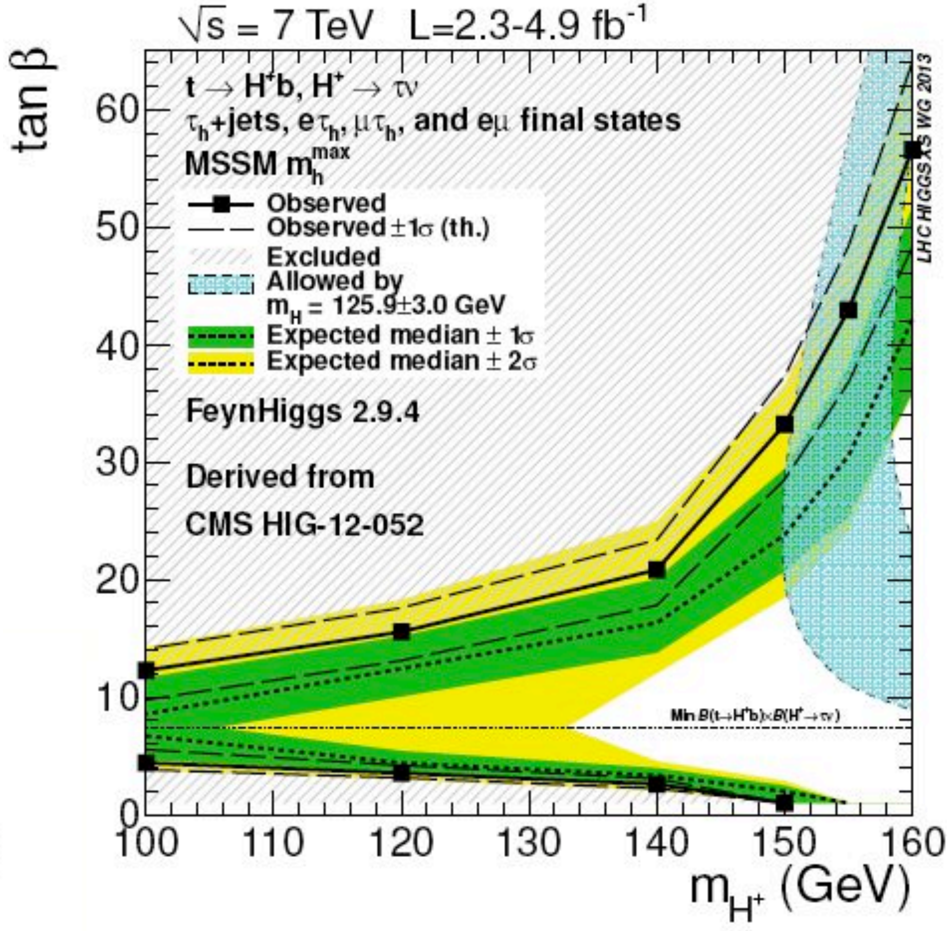
the leading track (from τ)
p_T spectrum is studied
to infer a charged Higgs signal



H+ search limits

JHEP 1207 (2012) 143, CMS PAS HIG-12-052





Handbook of LHC Higgs Cross Sections: 3. Higgs Properties - arXiv:1304.1347

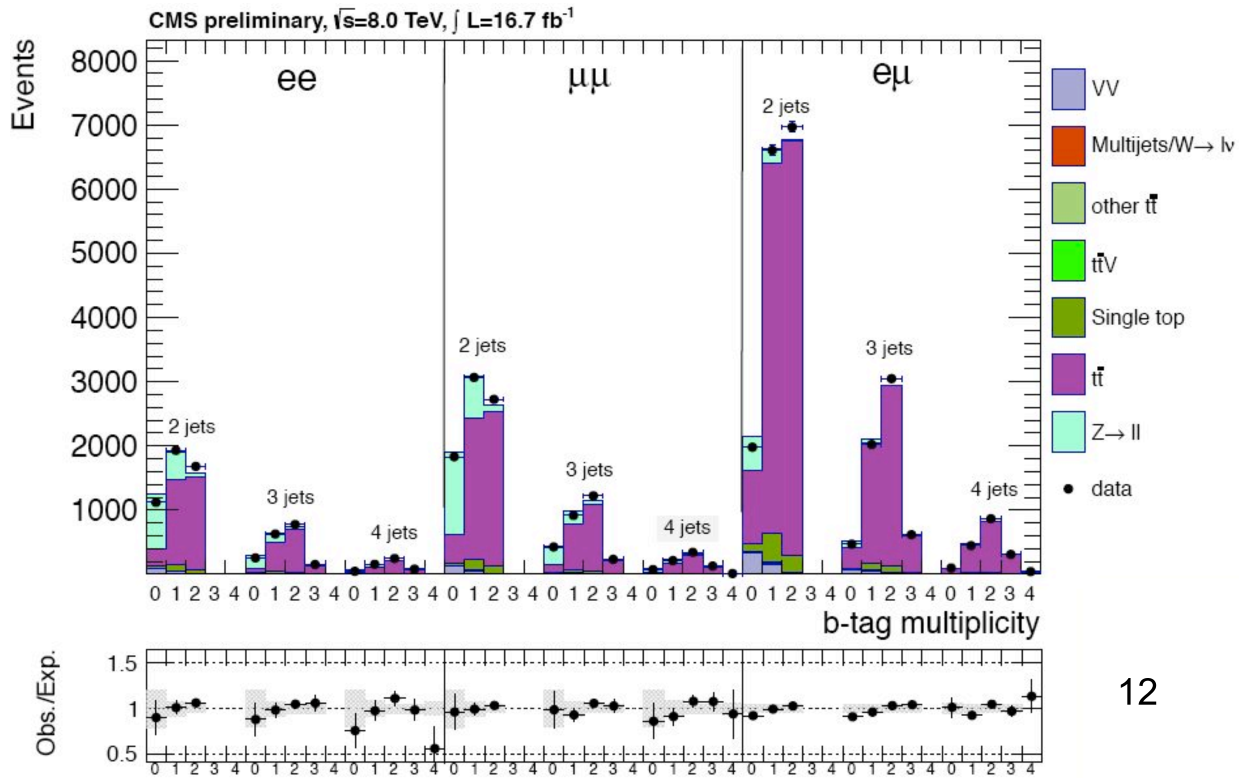
Measurement of $B_{t\rightarrow Wb}/B_{t\rightarrow Wq}$

- **An indirect $|V_{tb}|$ measurement and a search for the 4th generation fermions**

$$R \equiv \frac{Br(t \rightarrow Wb)}{Br(t \rightarrow Wq)} \xrightarrow[\text{Standard Model}]{\text{3 quark generations}} \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2}$$

$$R_{SM} = 0.998$$

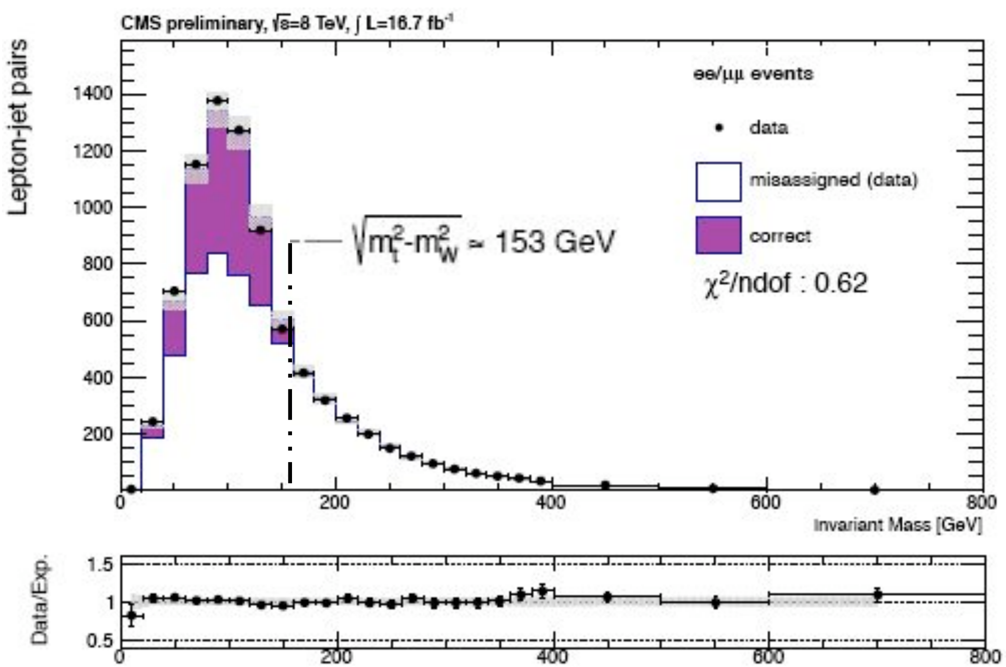
- **Analysis performed in (2,3,4) jets × (3) dilepton flavour categories**

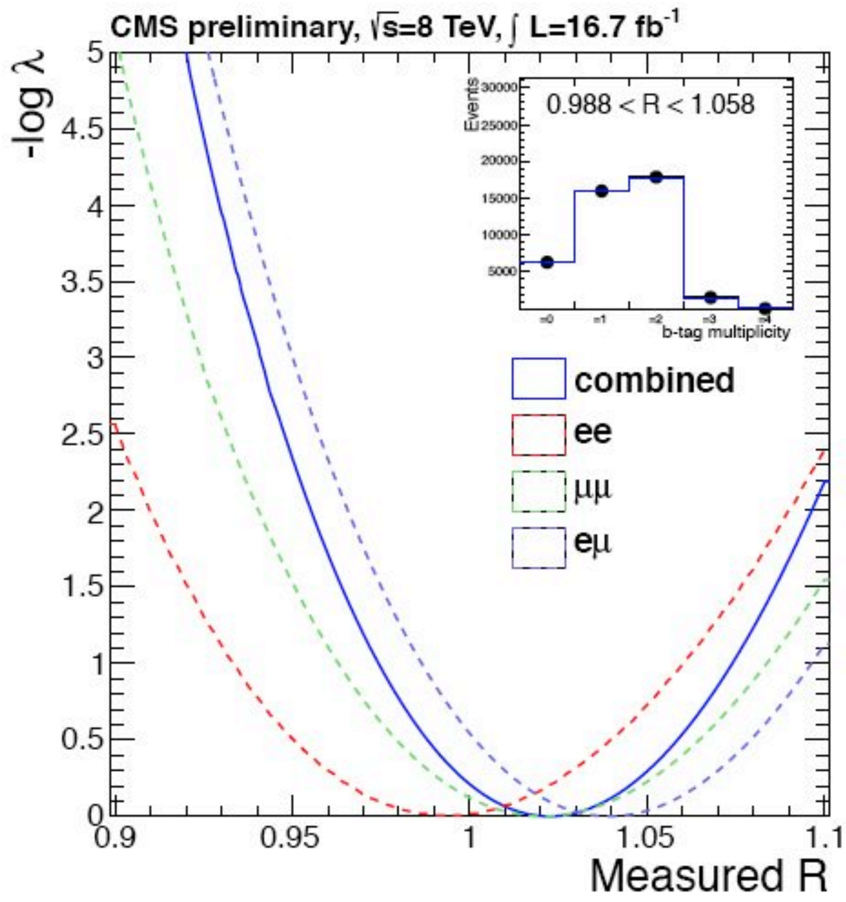


CMS PAS TOP-12-035

Data driven inputs

- jet-top assignment probability from data
- b-tagging and mistag efficiencies from data
- Measured signal and background normalization from data
- Systematic uncertainties as nuisance parameters

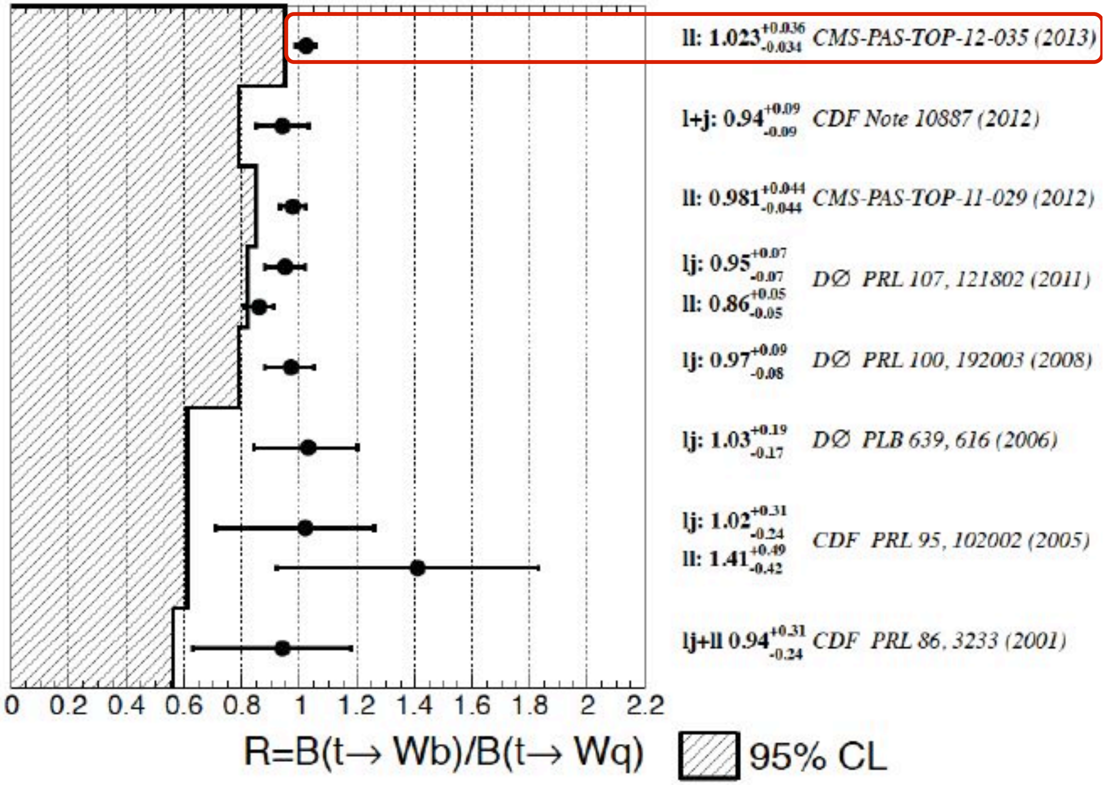




R is measured using a profile likelihood based on # of b-tags in each dilepton category

Results

Source	Uncertainty (%)
Statistical	0.4
Systematic	3.4
Individual contributions:	
b-tagging efficiency	1.9
$f_{t\bar{t}}^{stat}$	0.5
Mistag rate	0.9
$B(W \to \ell\nu)$	0.2
DY	0.3
Fake leptons	0.1
JER	0.9
JES	1.0
Luminosity	0.2
ME-PS	1.2
Pileup	0.2
Q^2	1.1
Selection efficiency	0.2
Signal	0.2
Simulation stat.	0.2
Single top cross section	0.1
$f_{correct}^{stat}$	1.1
Extra sources of heavy flavors	0.9
Total	**3.4**



$$R = \frac{B(t \to Wb)}{\sum_{q=d,s,b} B(t \to Wq)} = |V_{tb}|^2$$

$$|V_{tb}| = 1.011^{+0.018}_{-0.017}\,(stat. + syst.)$$

$$|V_{tb}| > 0.972 \text{ @ } 95\% \ CL$$

$$R = 1.023^{+0.036}_{-0.034}\,(stat. + syst.)$$

$$R > 0.945 \text{ @ } 95\% \text{ CL}$$

Summary

- ✓ top (tau) is the heaviest elementary particle (lepton) → most sensitive particles to eventual BSM states

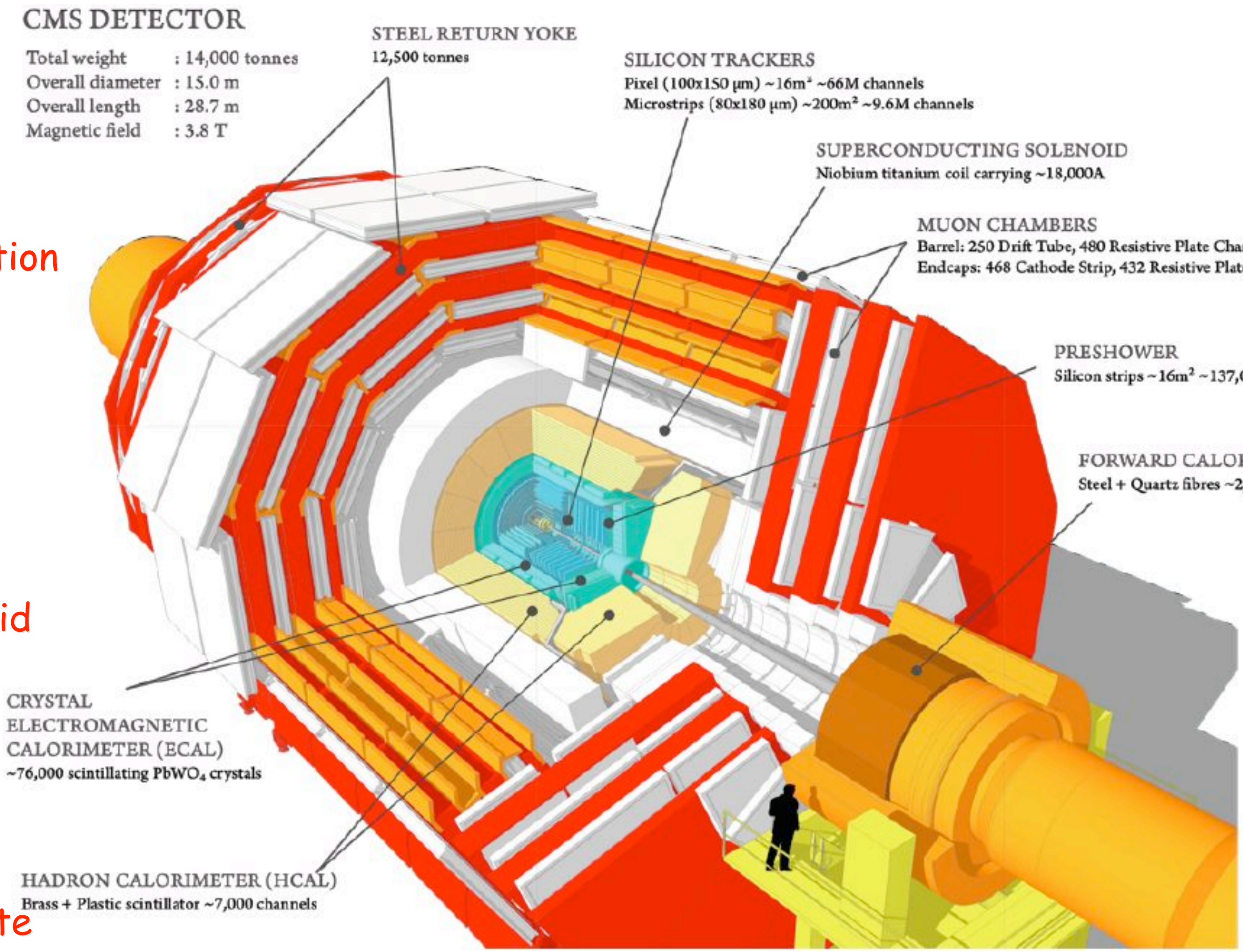
- ✓ deep understanding of the CMS detector and improved analysis algorithms allow for accurate studies in the sector of top couplings

- ✓ with the tools developed for the $\sigma(pp \rightarrow t\bar{t} \rightarrow l\,\tau_h)$ measurement: stringent limits have been put on the MSSM parameters space in the search for the H^+ in top decays

- ✓ world's most precise measurement of the b-quark content in top decays has been performed, assuming 3 fermion generations → the best CKM $|V_{tb}|$ determination

Spare Slides

The CMS detector



Large gas tracking system for μ detection

All Si tracker (area ~ 200 m^2)

Calorimeters inside 3.8 T, r = 3m solenoid

Hermetic up to ~ 5 η units

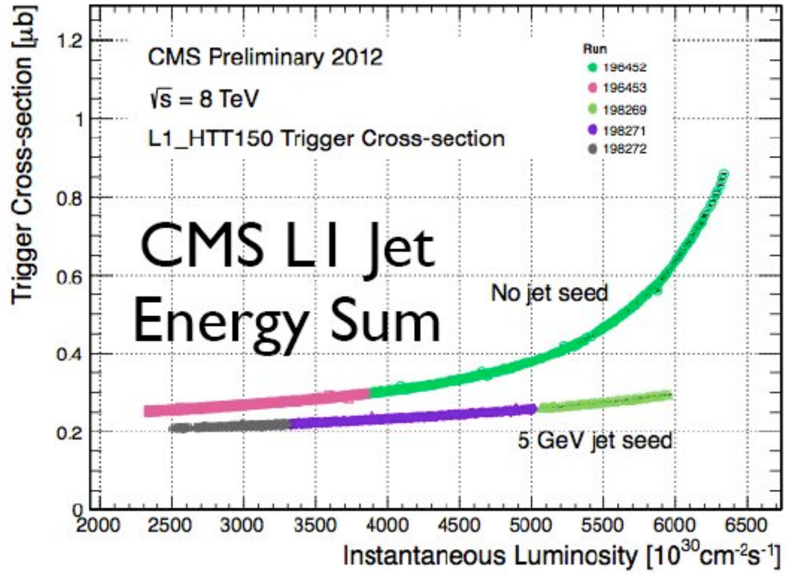
100 kHz readout rate (~1 MB event size)

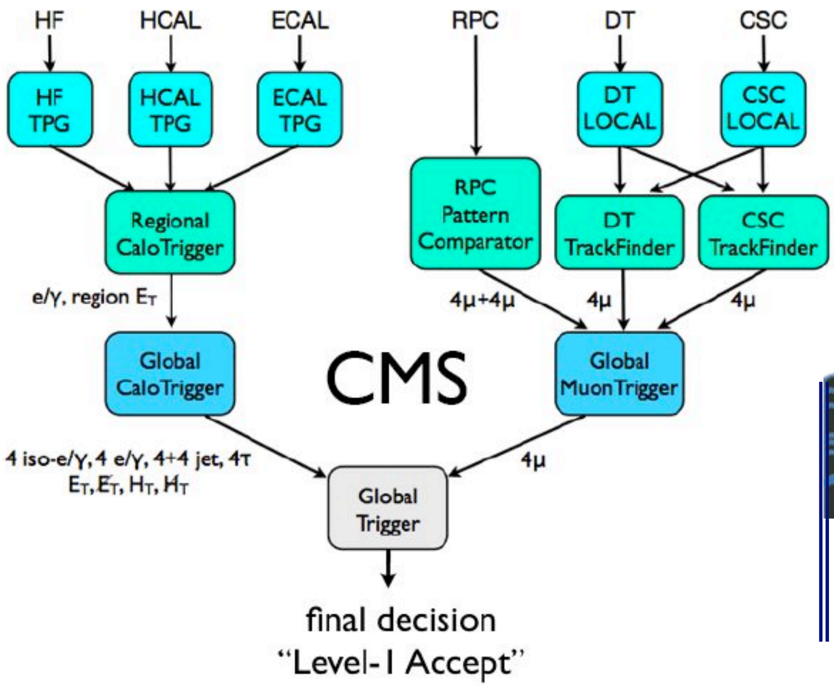
Federico Nguyen
Jornadas 2014

CMS in action: L1 trigger system

✓ goal: must keep high & redundant efficiency for interesting signals (leptons, MET, high p_T jets) against QCD processes

✓ pileup rates ~ 2× the design expectations: improved cuts already at L1





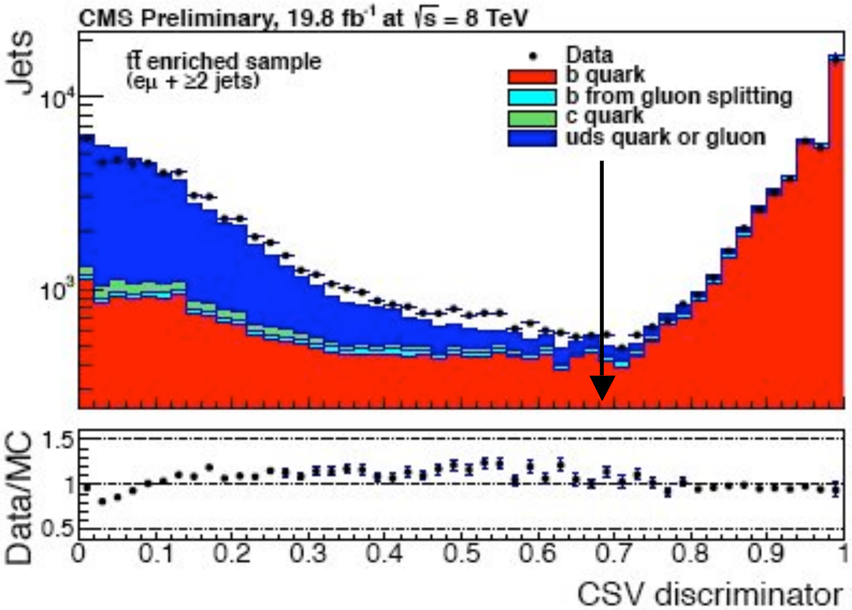
- L1 Trigger
  - 40 MHz input from calo and muon
  - dead-time free
  - 100 kHz selected events

L1 Trigger:
- commissioning,
- Run1 operations,
- Run2 perf. & data quality,
- Upgrade (see J.Carlos' talk)

Reconstruction of b jets

JP, Jet Probability:
likelihood evaluated per jet with associated tracks, those with IP are given larger weight

CSV, Combined Secondary Vertex:
secondary vertices and track-based lifetime combined into a discriminator



The Particle Flow Algorithm

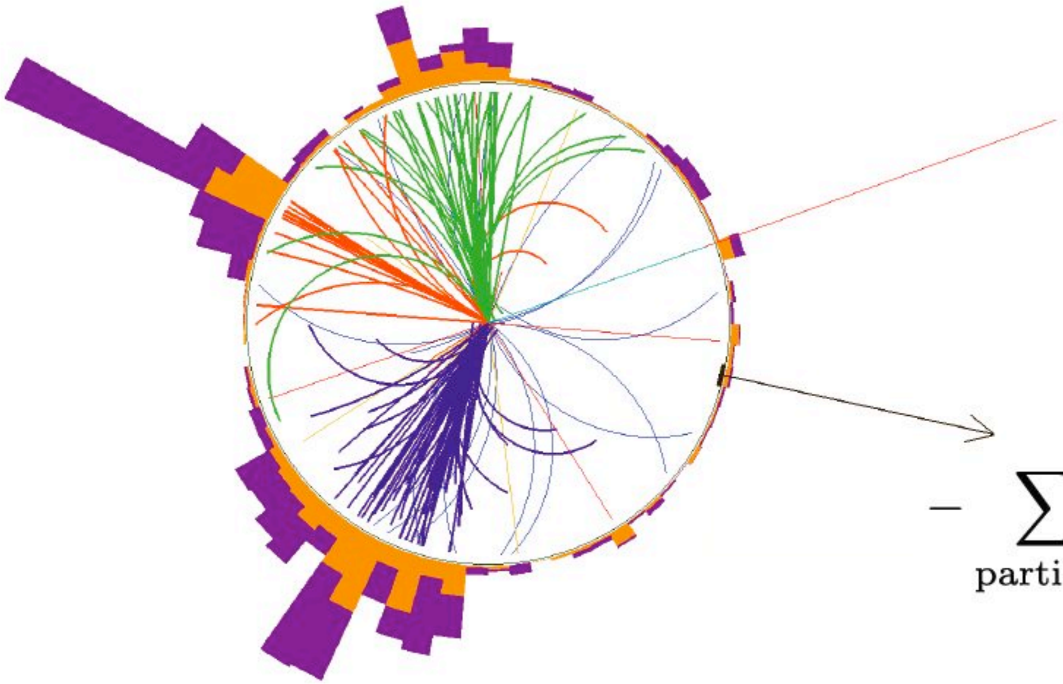
Calorimeter jet:

- $E = E_{HCAL} + E_{ECAL}$
- σ(E) ~ calo resolution to hadron energy: 120 % / √E
- direction biased (B = 3.8 T)

vs.

Particle flow jet:

- 65% charged hadrons
  - σ(pT)/pT ~ 1%
  - direction measured at vertex
- 25% photons
  - σ(E)/E ~ 1% / √E
  - good direction resolution
- 10% neutral hadrons
  - σ(E)/E ~ 120 % / √E



$$-\sum_{\text{particles}} \vec{p}_T$$