Search strategy for charged Higgs in CMS

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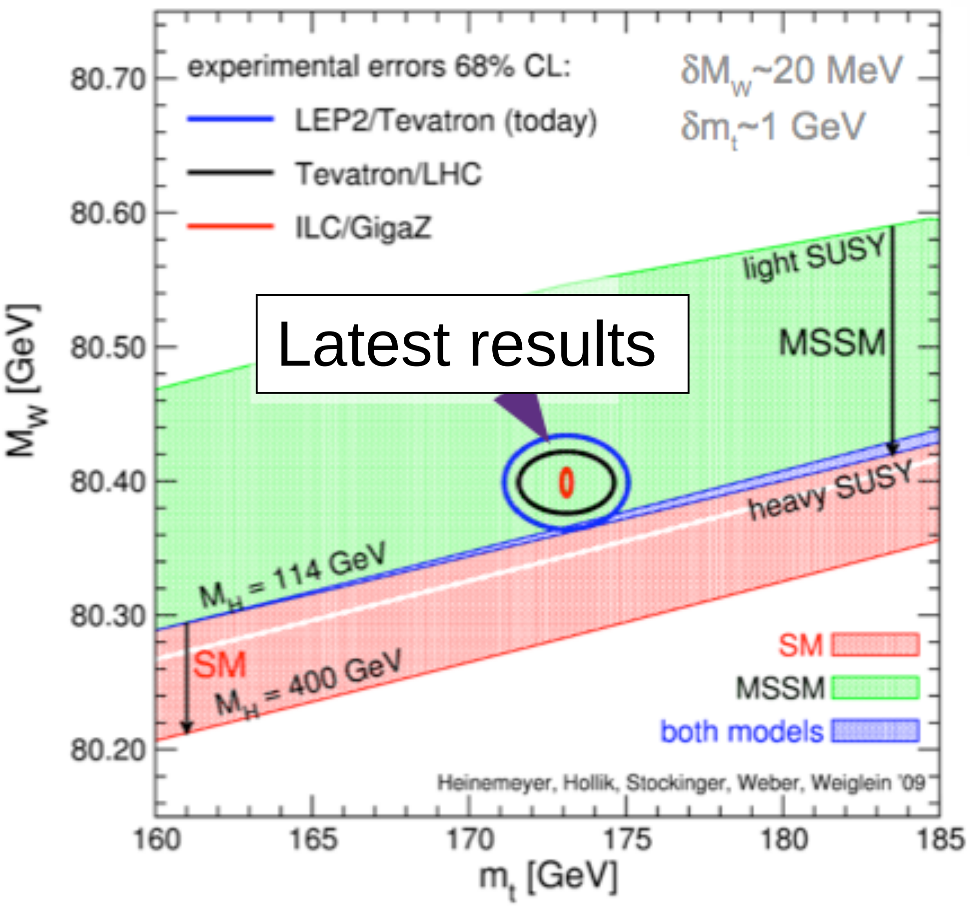
September 29, 2010

- Introduction
- Top and tau decays
- Backgrounds
- Summary

Introduction

- In the MSSM there are 5 Higgs bosons: h, H, A, $H^{\pm}$
- At the tree level the Higgs boson is described by tanβ, and m_A

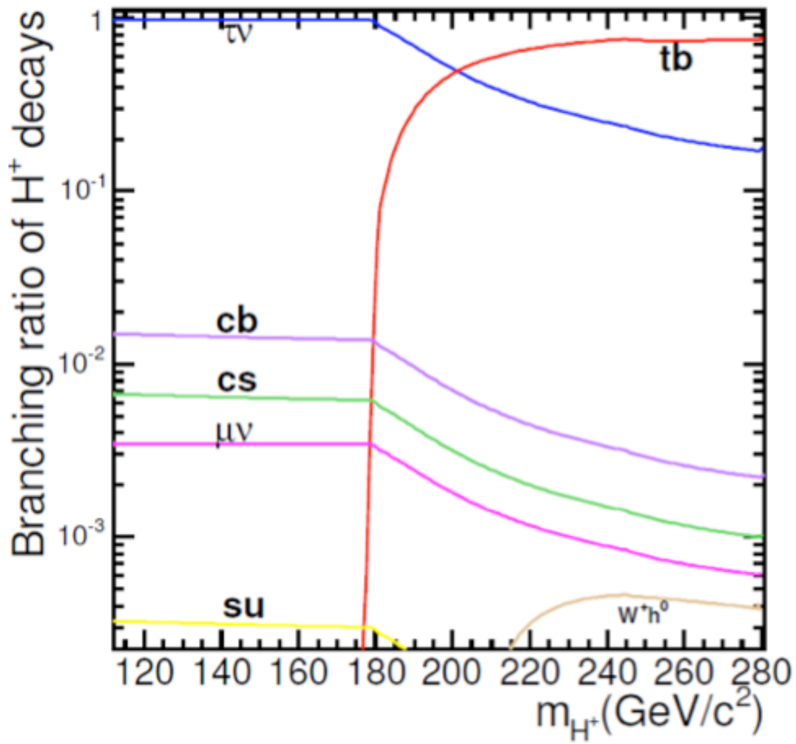


MSSM Higgs

- Study of non-SM Higgs

Two mass regimes:

- $m_H < m_{top}$
  - Mostly produced in Top decays
  - Large tanβ: $H^{\pm} \to \tau\nu$
  - Small tanβ (<1): $H \to cs$
- $m_H > m_{top}$
  - Produced in gluon-gluon fusion
  - Main decays: $H \to tb$, $H^{\pm} \to \tau\nu$
- Main backgrounds: ttbar, W+jets, QCD



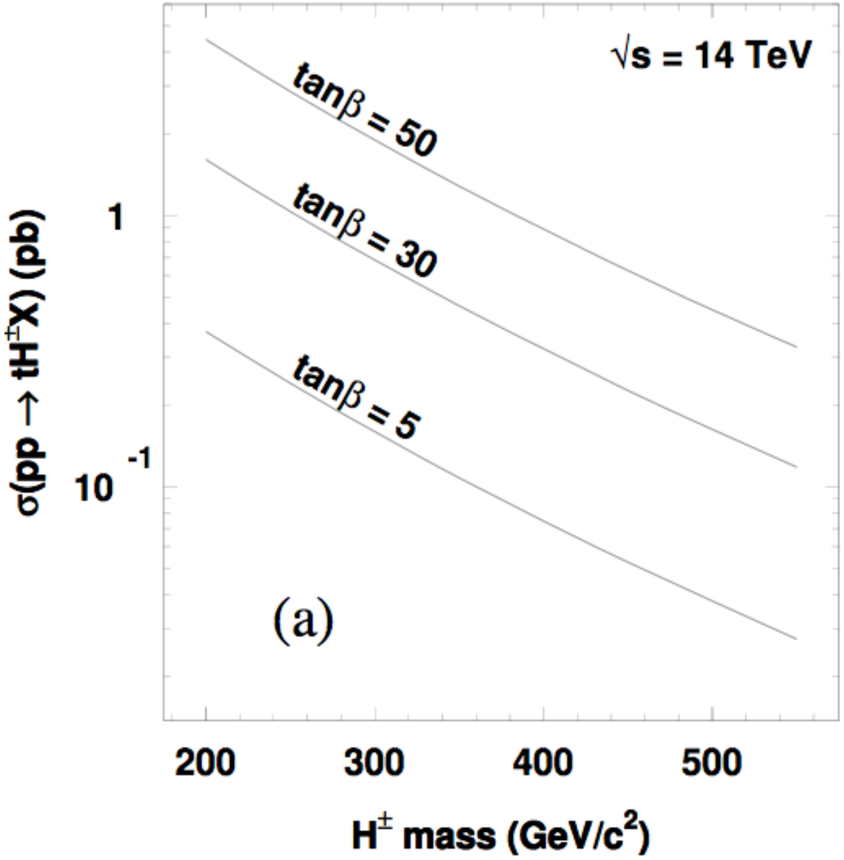
Search strategy

Light charged Higgs:

- Lepton from Top decays (W or tau) provides excellent signature
- Two b-jets (b-tag?)
- W may be used to reconstruct W→qq
- Large MET
- Tau lepton reconstruction (helicity?)
- Final state depends on tanβ:
  - Look at dilepton ttbar decays
  - In case of H→cs, may reconstruct H mass (final state is l+≥4 jets)

Heavy charged Higgs: $gg \longrightarrow tbH^{\pm}$

- H→τν strategy similar to light ch. Higgs
- H→tb requires ≥5 jets (≥2 b-jets)



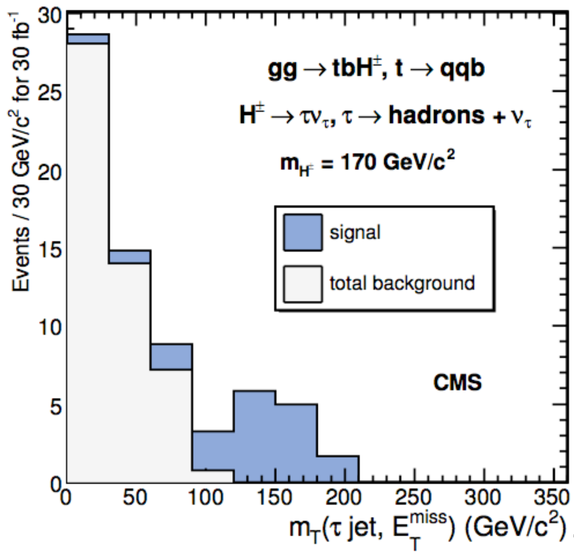
Heavy charged Higgs

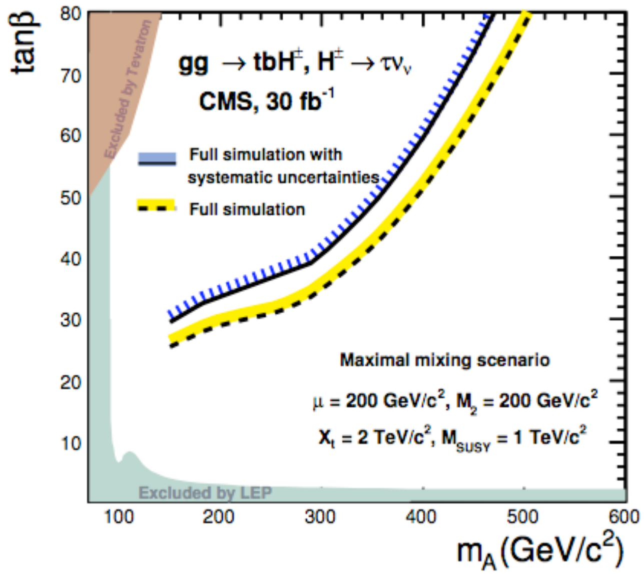
- $M_H > M_{top}$: studies done for LHC@14TeV

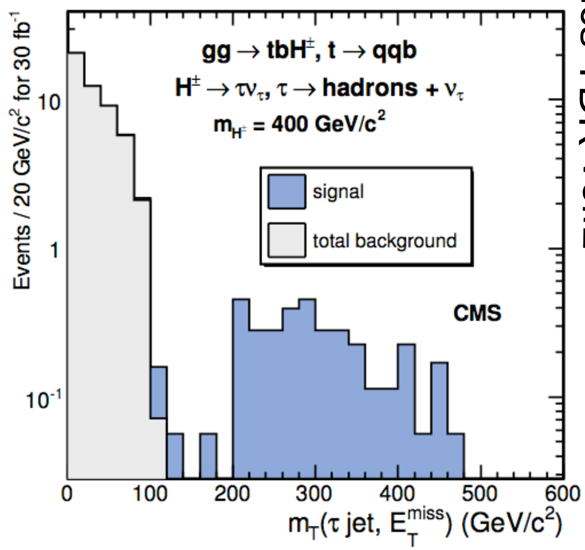
$$gg \rightarrow tbH^{\pm} \begin{cases} H^{\pm} \rightarrow tb \\ H^{\pm} \rightarrow \tau^{\pm}\nu_{\tau} \end{cases}$$

$$gb \rightarrow tH^{\pm} \rightarrow ttb \rightarrow W^+W^-bbb \rightarrow qq'\mu\nu_\mu bbb,$$
$$gg \rightarrow tH^{\pm}b \rightarrow ttbb \rightarrow W^+W^-bbbb \rightarrow qq'\mu\nu_\mu bbbb$$

- Low event yield



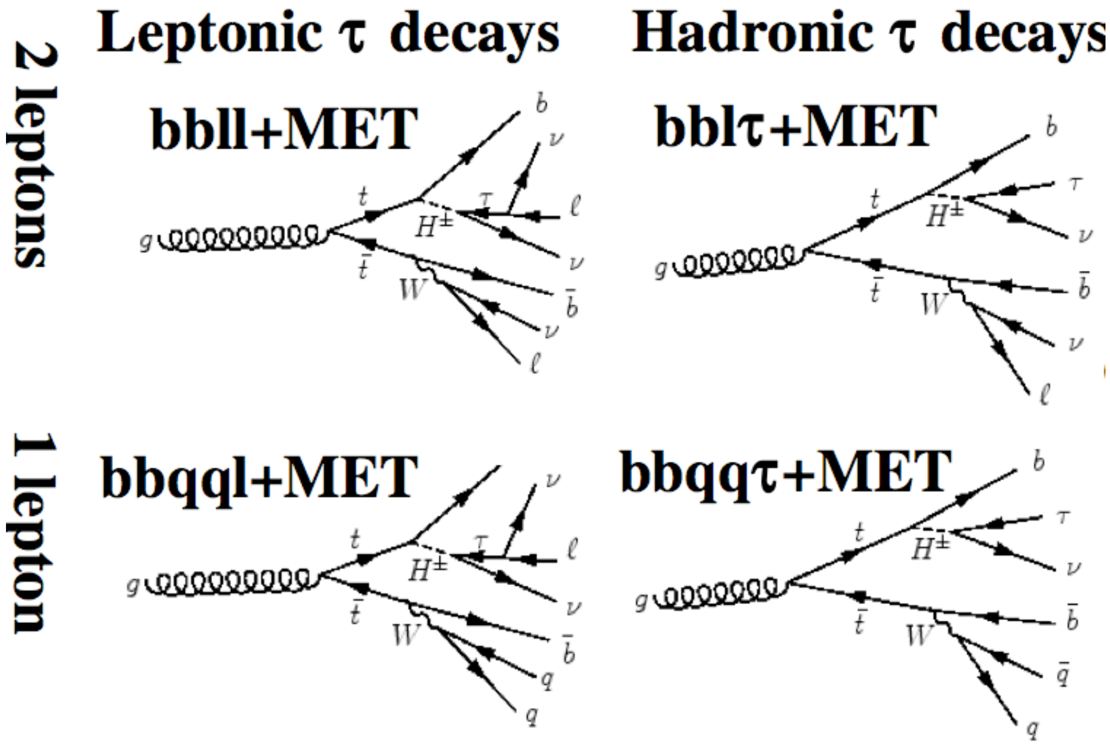




CMS Physics TDR vol.2

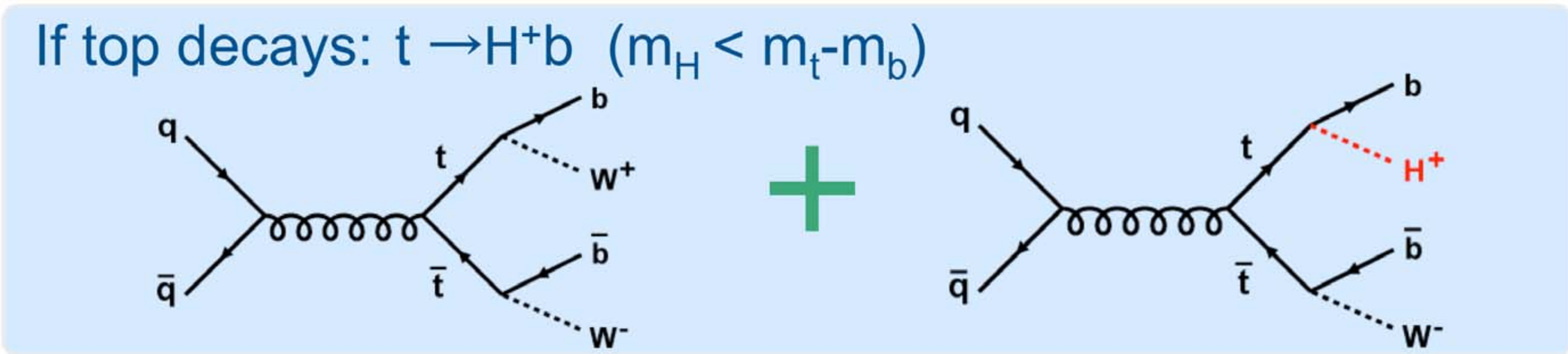
Light charged Higgs

- Different final states
  - Leptons, jets and MET
  - Hadronic tau decays
  - Leptonic tau decays (similar to prompt lepton final states)
- Background studies
- Combination?



Charged Higgs

- study $H^{\pm}$ in ttbar events: $100 \leq M(H^{\pm}) \leq 160$ GeV/c^2, BR($H \rightarrow \tau\nu$)=1
- if the $H^{\pm}$ exists we may observe an excess of events in the $l\tau$ channel incompatible with the SM
- decay of H to csbar will generate different final state



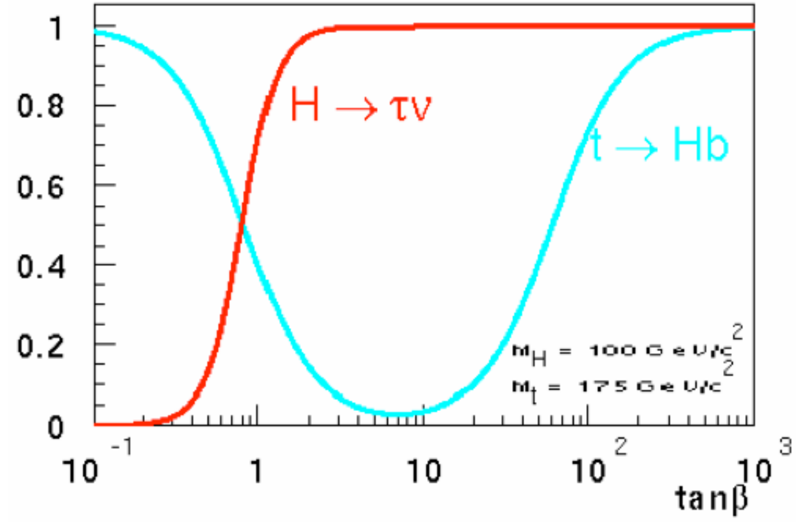
⇨probe non-standard physics ($t \rightarrow H^{\pm}b$, …)

Charged Higgs (cont.)

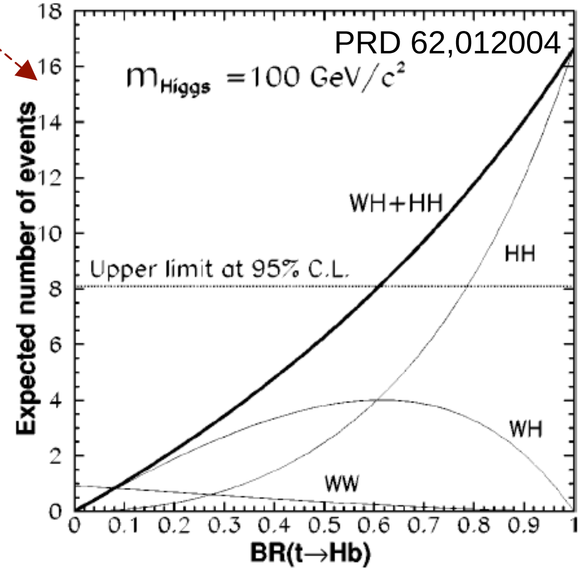
- BR($t \rightarrow H^{+}b$) could be large
- $H^{+} \rightarrow \tau^{+}\nu_{\tau}$ enhanced if tanβ large

⇨ **observe more taus**

(tanβ: ratio of vacuum expectation values)



x50-100 events @LHC



⇨number of tau dilepton events can potentially be large

Goal:
set limits/observe Higgs boson

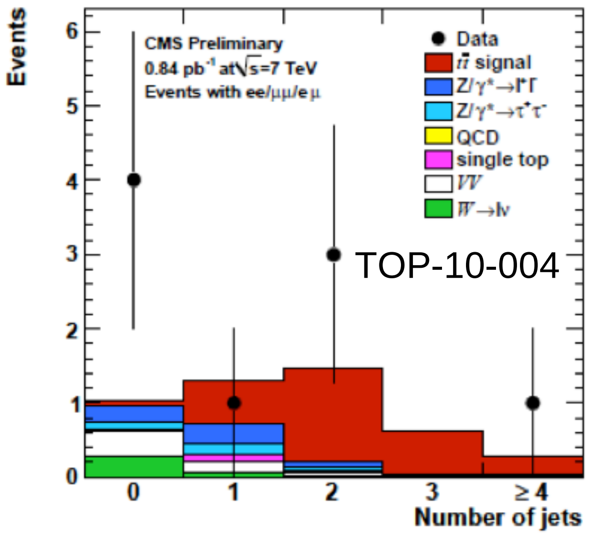
Top quark

- Understand Top quark decays/sample
  - Use all tools/objects
  - Study backgrounds
  - Measure cross-section

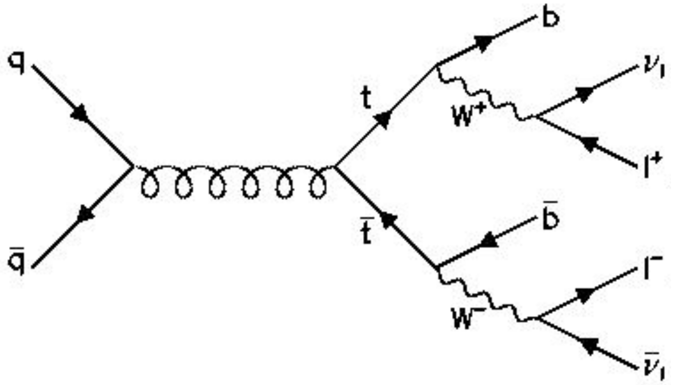
Apply Z-veto, $N_{jet} \geq 1$: $L=0.84pb^{-1}$

Sample	ee	$\mu\mu$	$e\mu$
Dilepton $t\bar{t}$	$0.63 \pm 0.09 \pm 0.12$	$0.70 \pm 0.11 \pm 0.13$	$1.70 \pm 0.26 \pm 0.32$
VV	0.05 ± 0.03	0.05 ± 0.03	0.12 ± 0.06
Single top - tW	0.04 ± 0.02	0.05 ± 0.03	0.12 ± 0.06
Drell-Yan $\tau\tau$	0.08 ± 0.04	0.13 ± 0.07	0.19 ± 0.09
Drell-Yan $ee, \mu\mu$	4.2 ± 1.1	5.0 ± 1.2	0.04 ± 0.02
Non-dilepton $t\bar{t}$	0.02 ± 0.01	0.003 ± 0.002	0.03 ± 0.02
W+jets	0.06 ± 0.03	$0.000\ ^{+0.002}_{-0.000}$	0.07 ± 0.04
QCD multijets	$0\ ^{+10}_{-0}$	$0\ ^{+10}_{-0}$	$0\ ^{+10}_{-0}$
Total simulated	5.1 ± 1.1	5.9 ± 1.2	2.3 ± 0.4
QCD data-driven	$0.0\ ^{+0.1}_{-0.0}\ ^{+0.1}_{-0.0}$	$0.0\ ^{+0.2}_{-0.0}\ ^{+0.2}_{-0.0}$	$0.0\ ^{+0.1}_{-0.0}\ ^{+0.1}_{-0.0}$
W+jets data-driven	$0.2\ ^{+0.2}_{-0.0}\ ^{+0.1}_{-0.0}$	$0.0\ ^{+0.4}_{-0.0}\ ^{+0.2}_{-0.0}$	$0.0\ ^{+0.4}_{-0.0}\ ^{+0.2}_{-0.0}$
Drell-Yan data-driven	$3.6 \pm 0.6 \pm 1.8$	$4.3 \pm 0.7 \pm 2.1$	N/A
Data	6	6	2

Apply Z-veto, MET cut:



Taus in Top decays



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

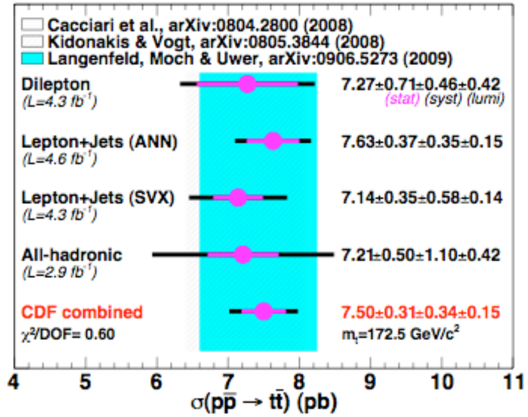
- should have same rate as *e*μ dilepton channel
- challenging (lower p_T than *e* or μ due to ν's)
- probe New Physics processes

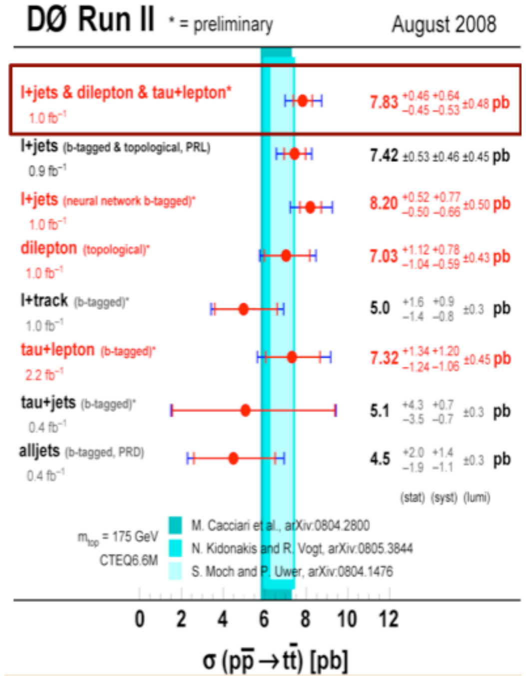
Taus in Top decays

- Measure: $R = \dfrac{BR(tt \to l\tau\nu\nu jj)}{BR(tt \to ll\nu\nu jj)}$ (l=e,μ)
- Measure cross section ratio to reduce systematic uncertainties

⇨ test lepton universality
⇨ probe non-standard physics ($t \to H^{\pm}b$, …)

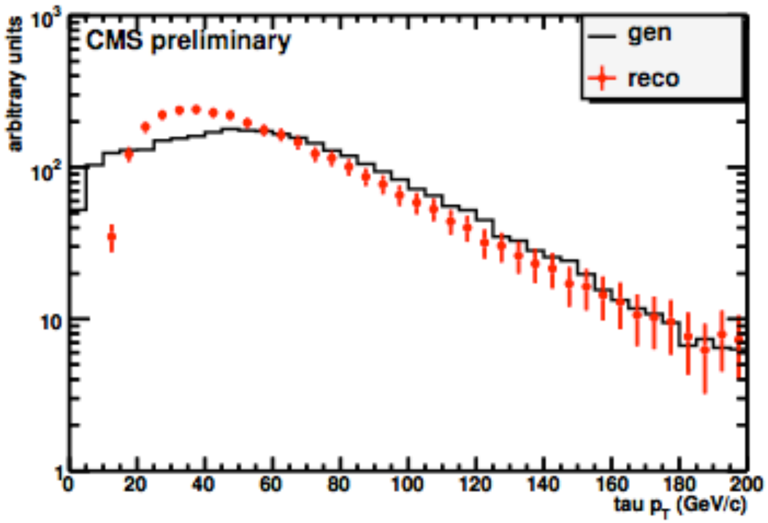
However…there are some caveats





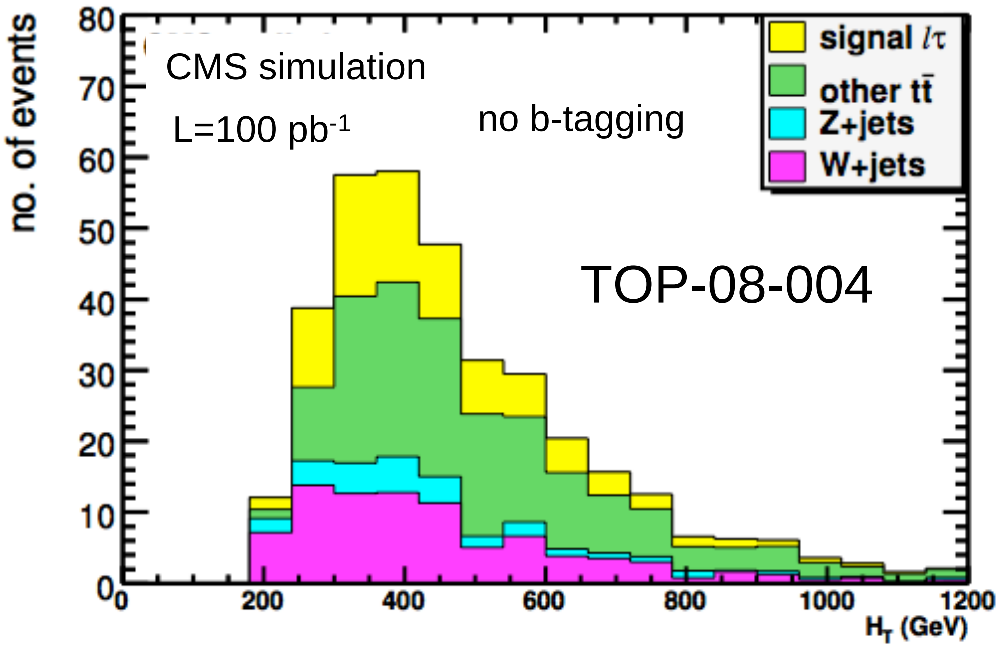
Tau dileptons

- Interesting:
  - SM predicts rate/cross section
  - increase ttbar acceptance
  - $t \to Wb \to \tau\nu_\tau b$ involves exclusively 3rd generation quarks and leptons
- Rare:
  - ttbar cross section is ~160pb at 7TeV
  - only ~5% of all ttbar decays
- Challenging:
  - tau ID is difficult at a hadron collider
    - lots of quarks and gluons can fake taus
    - softer p_T due to the neutrinos



Event selection

- Look at hadronic tau decays
- Event selection:
- Isolated lepton: p_T>20 GeV
- ≥2jets E_T>30 GeV $|\eta|$<2.4
- Missing E_T>40 GeV
- S/B~ almost 1



- measure cross section ratio to reduce systematic uncertainties
- expect ~100 events from ttbar (TOP-08-004)
- expect ~700 events from charged Higgs (mH=120 GeV)

For m_H=120 GeV, can reach large S/B

A word about QCD background

- QCD is a large background to Top events
- At CMS, QCD events (with 4 or more jets, E_T>30GeV) have similar MET of ttbar events
- From Tevatron to LHC(@14TeV)
  - σ(ttbar) increases by 100
  - σ(W) increases by 10

…however…

- σ(W+4 jets) increases 100 times

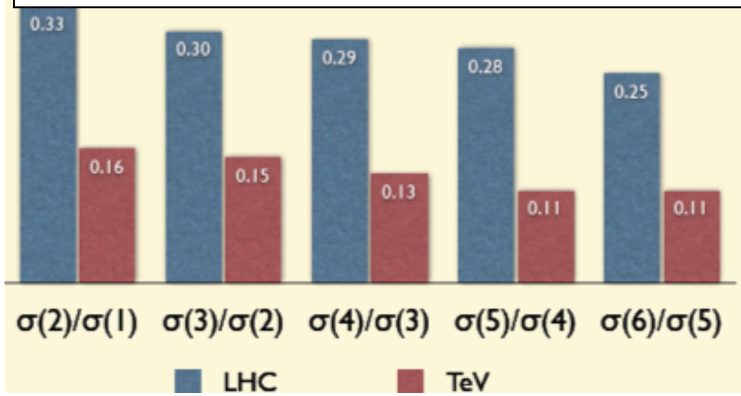
⇨W+jet background is large

Slide by Michelangelo Mangano

$\sigma \times B(W \to e\nu)$[pb]	N jet=1	N jet=2	N jet=3	N jet=4	N jet=5	N jet=6
LHC	3400	1130	340	100	28	7
Tevatron	230	37	5.7	0.75	0.08	0.009

E_T(jets) > 20 GeV , $|\eta|$<2.5 , ΔR>0.7

ratio:	15	30	60	130	350	800



- Ratios almost constant over a large range of multiplicities
- $O(\alpha_s)$ at Tevatron, but much bigger at LHC

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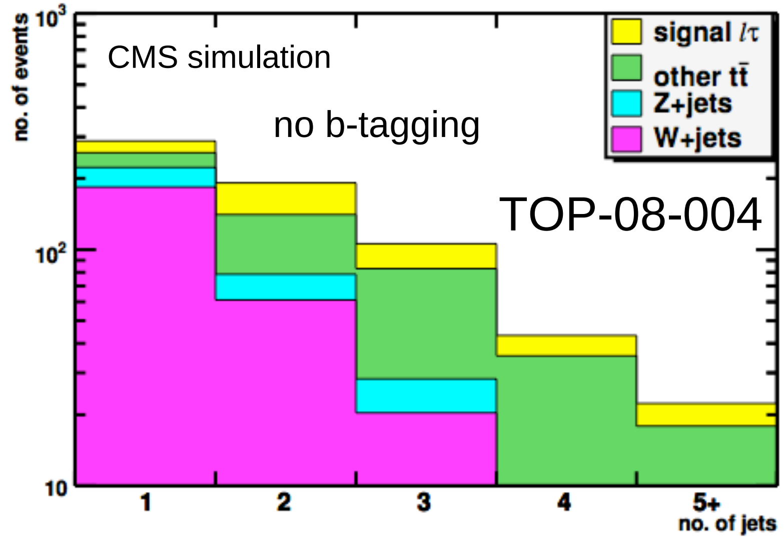
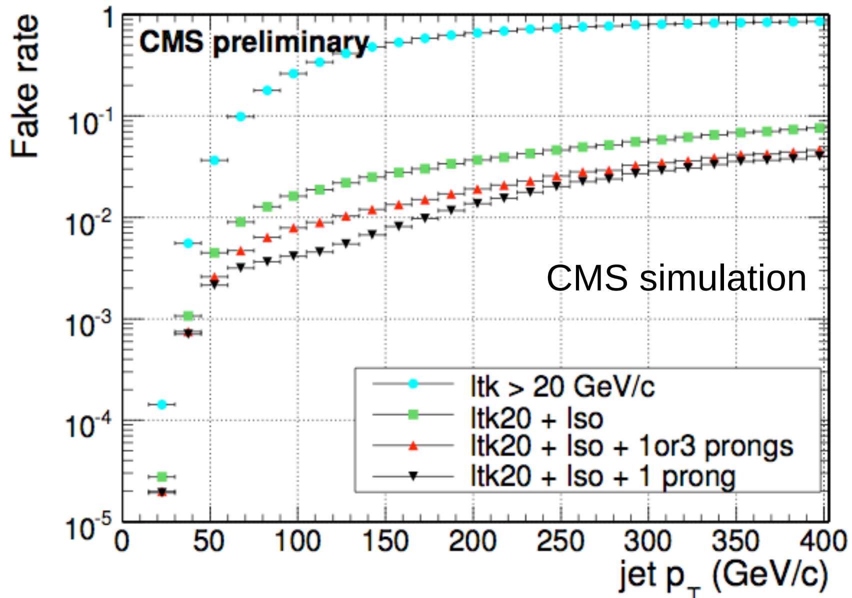
QCD background

- Jets may “fake” hadronic tau decays
  - from `W+jets’ and from `ttbar→l+jets’
- It is a large background
- Estimate background from data
  - inclusive jet pT distribution
  - jet identified as a tau
  - estimate “fake” probability from ratio
- Apply to W+≥3 jet distribution
- Estimates within 10-15% of expectations

<u>Early data:</u>

- look at low/high pT tracks
- Tau ID/PF
- validate bkg studies (fake rates, etc)

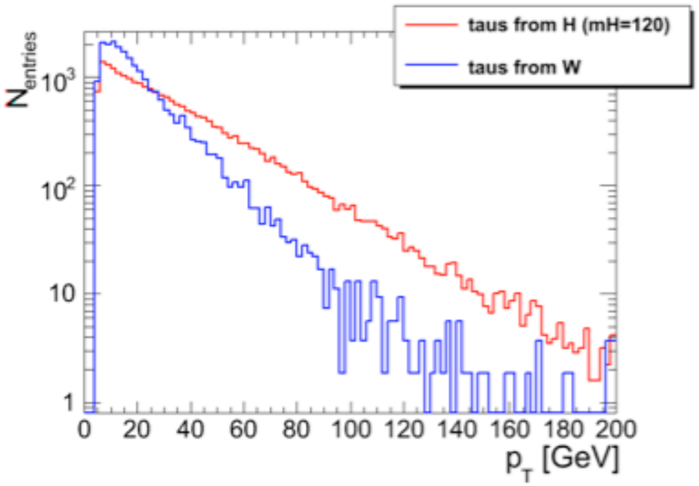




Other backgrounds

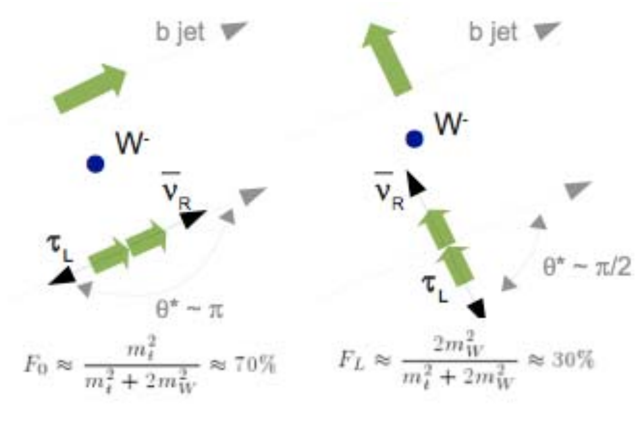
- DY$\rightarrow\tau\tau$ with additional jet production
- Model Z$\rightarrow\tau\tau$ from Z$\rightarrow\mu\mu$ data
  – Replace di-muons (data) with di-taus (from MC)
  – Correct for MET
  – Superimpose event
- Background due to multi-bosons is small

Distinct signature(s)

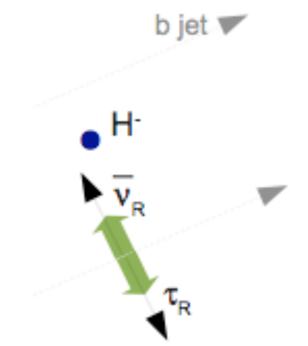


- $M_H > M_W$:
  - boosts the tau lepton
  - b-jets from $t \to Hb$ are softer than $t \to Wb$

- Charged Higgs signature:



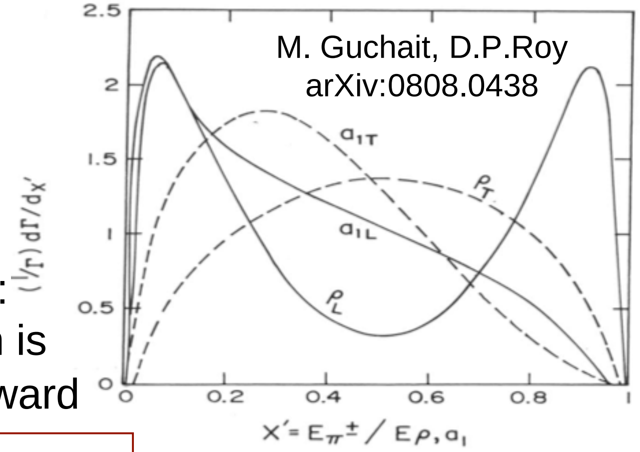
In the SM, all τ's are left-handed



In the MSSM, τ's become right-handed

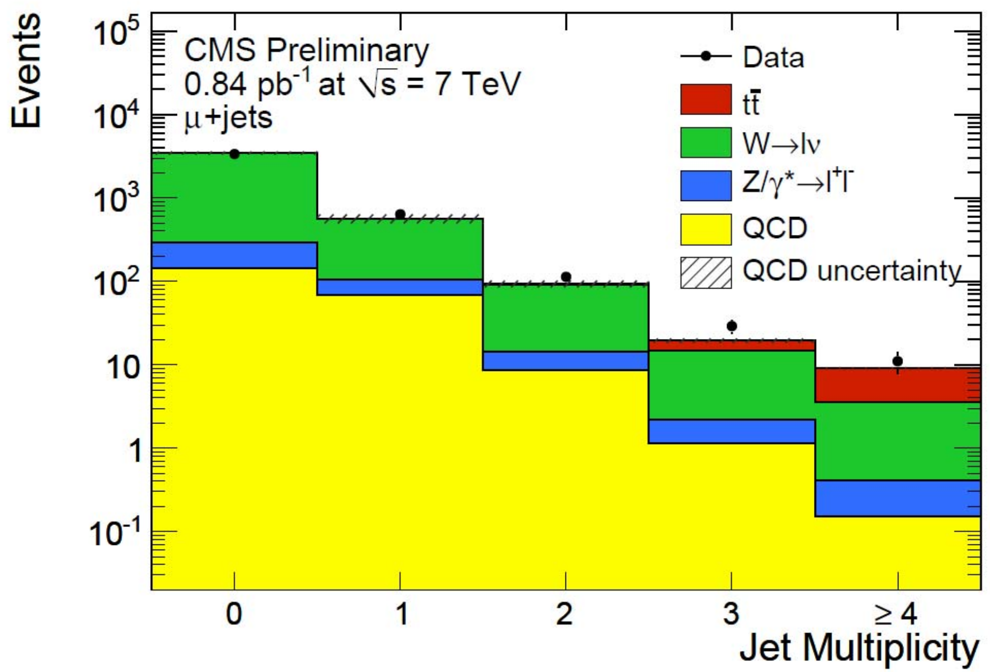
In τ decays: $\pi^{\pm}$ emission is favored forward

$$R = \frac{p_{\pi^\pm}}{p_{\tau-jet}} \rightarrow 1$$

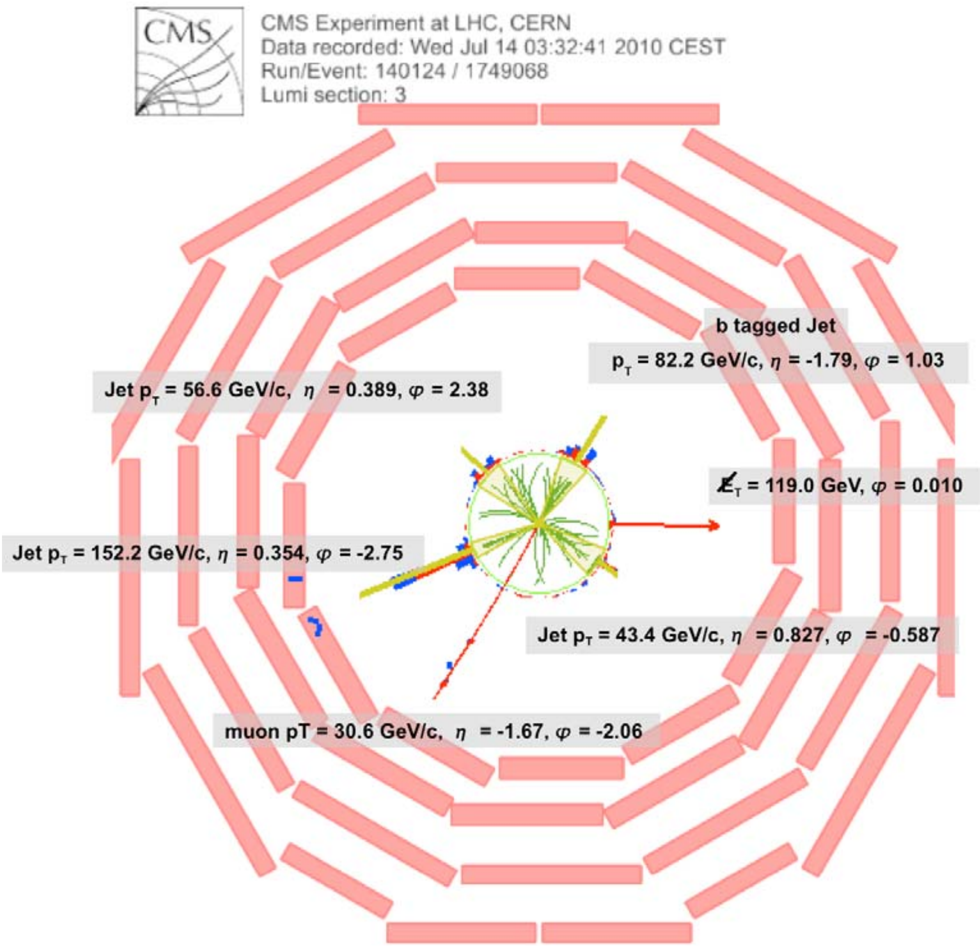


Plans for search

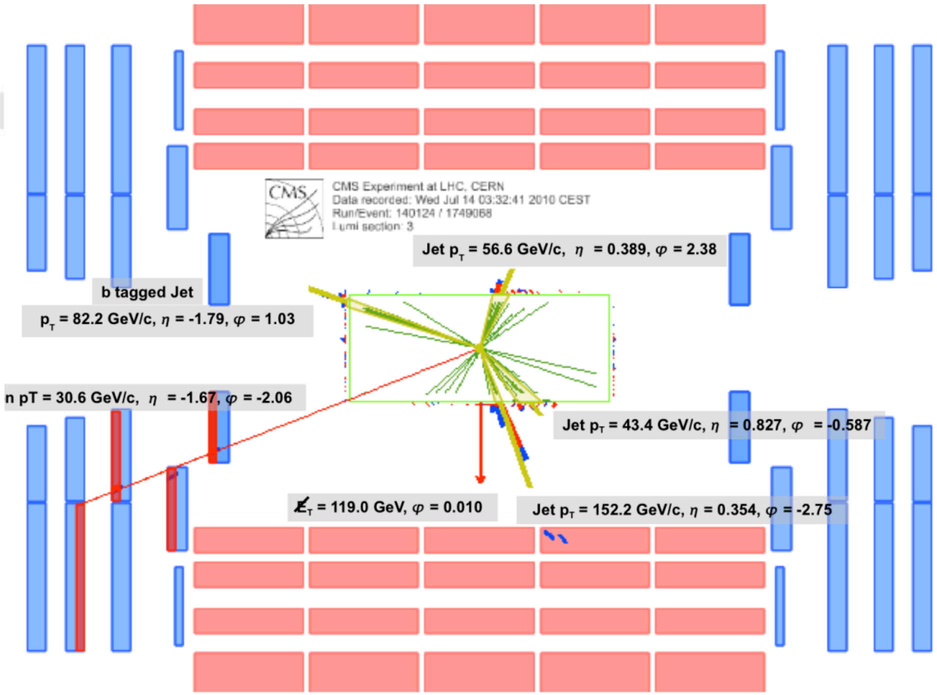
- 1-10 pb^{-1}:
  - study tau fake rates in multi-jet samples
  - leptons/jets/MET
  - validate data-driven background methods
- 10-100 pb^{-1}:
  - estimate tau fake background
  - look for ttbar events with taus
- 100-1000 pb^{-1}:
  - set limits/find signal



One “mu+4 jets” event

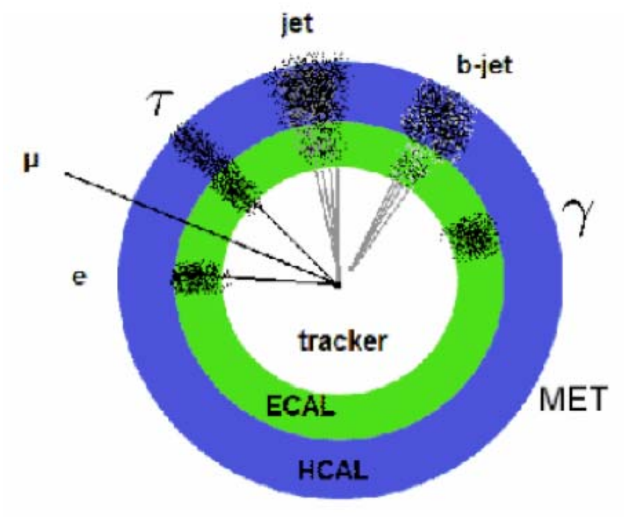


Event passes all ttbar selection cuts
1 high-momentum muon
significant MET (>100 GeV)
m_T(W) = 104 GeV/c^2
4 high-p_T jets,
one of which with good *b*-tag



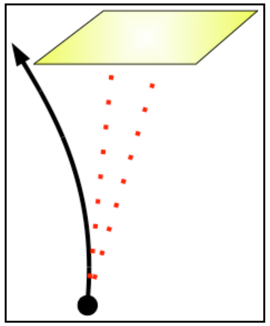
Hadronic tau decays

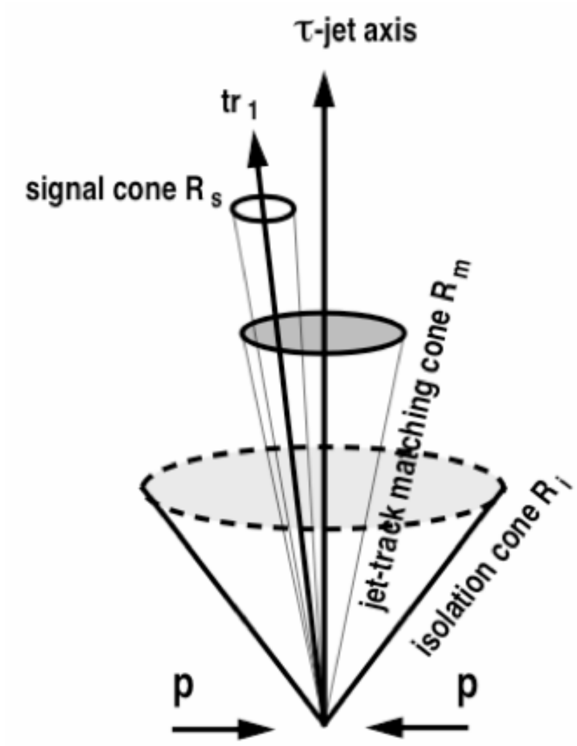
- Look for tau in their hadronic decay
  - $\tau \rightarrow$ 1charged hadron (BR~50%)
  - $\tau \rightarrow$ 3 charged hadrons (BR~14%)
- Hadronic taus are identified using combination of tracking and calorimeter information
  - search for isolated track(s)
  - powerful rejection against QCD background
  - tau leptons often produce neutral pions
  - identify tau decay products



Tau Identification

- Particle Flow (PF)
  - Examination of full event
- Cone algorithms
  - “Fixed” and “shrinking” cone cut-based
  - Cone around tau candidate and require low activity
  - Taus are more collimated than QCD jets
  - Require a leading candidate





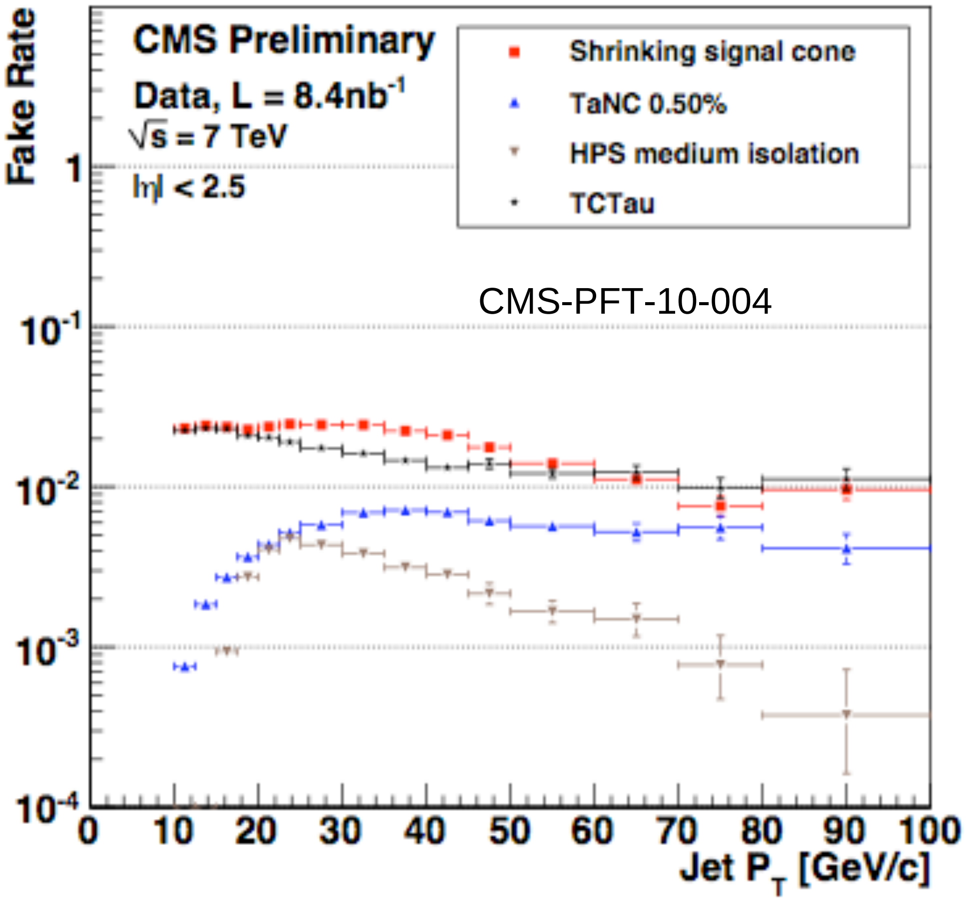
- Hadron Plus Strip (HPS)
  - Cluster gammas in pi0
  - Use $\eta - \phi$ strips
- Tau Neural Classifier (TaNC)
  - A neural network for each decay mode
- Performance studied in terms of efficiency and “fake” rate

Fake rates

- Main background from “fake” tau jets in events passing the W+≥3 jet selection
- Background can be estimated by applying tau fake rate to the inclusive jet distribution

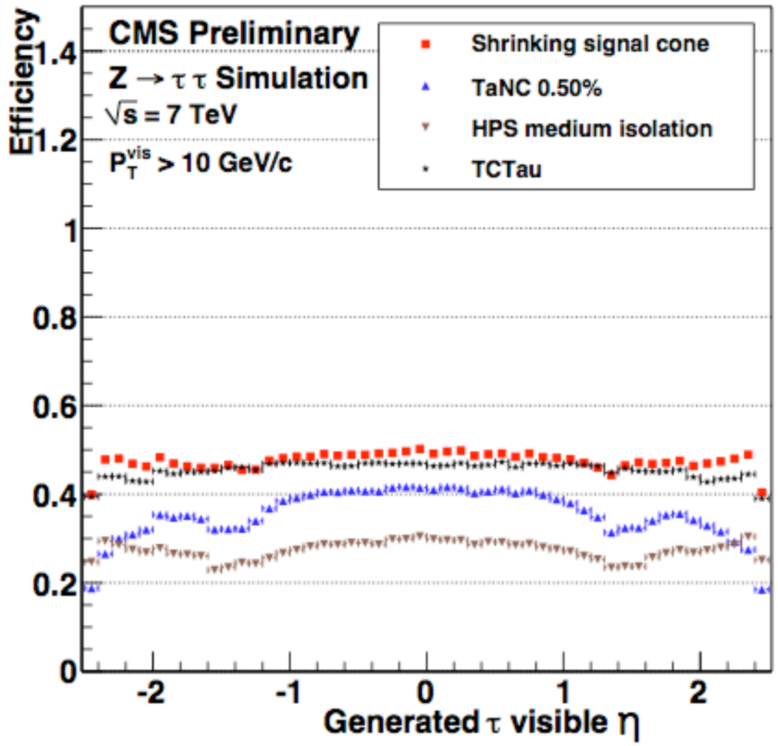
$$P_{fr}(\text{bin}) := \frac{N_{jets}(\text{bin})_{\text{passed tau identification}}}{N_{jets}(\text{bin})}$$

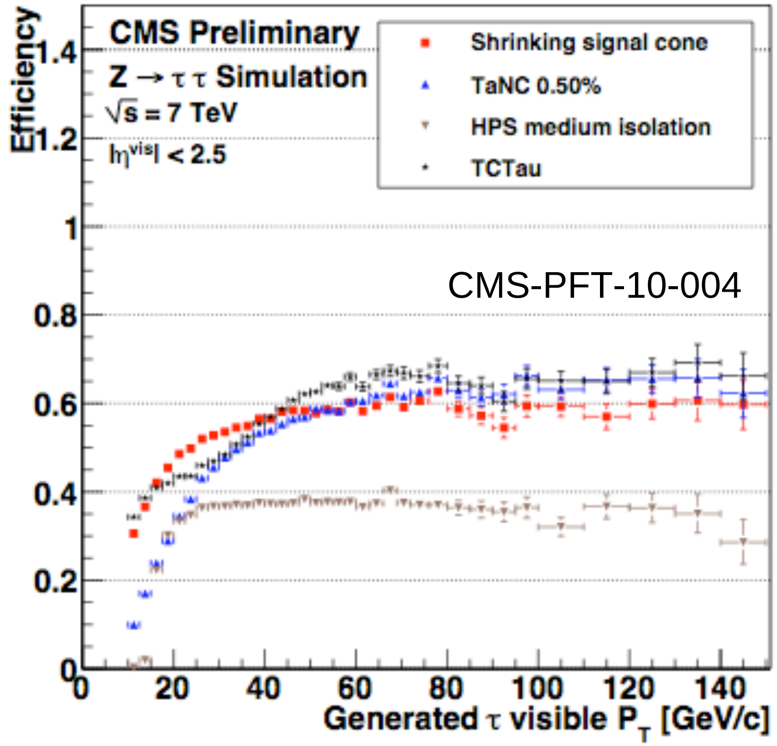
- Tau fake rate can be evaluated from data: QCD, γ+jets)
- Good agreement (within 10-20%)



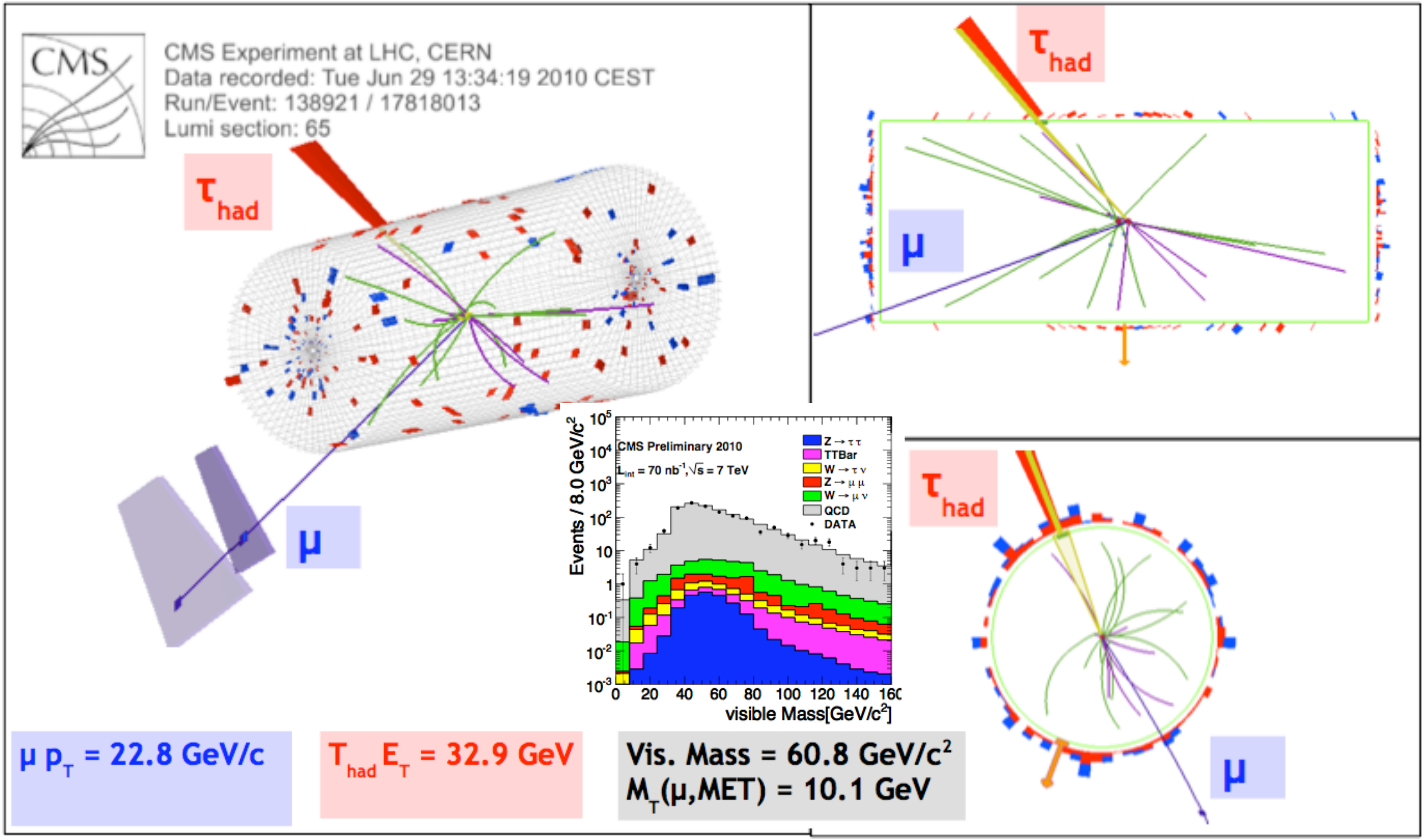
Efficiency

- Efficiency is estimated from simulation (Z→ττ events)





Z→ττ candidate event



Trigger considerations

- inclusive lepton trigger has “high” p_T threshold:
  - Pros: more reliable to estimate BRs
  - Cons: lower rate
- lepton+tau trigger?
  - $e\tau_{had}$: central electron + tau jet (20?)
  - $\mu\tau_{had}$: central muon + tau jet (20?)
- lepton+jets ?
  - Pros: lower threshold
  - Cons: need different trigger for “standard” dilepton (e/μ)

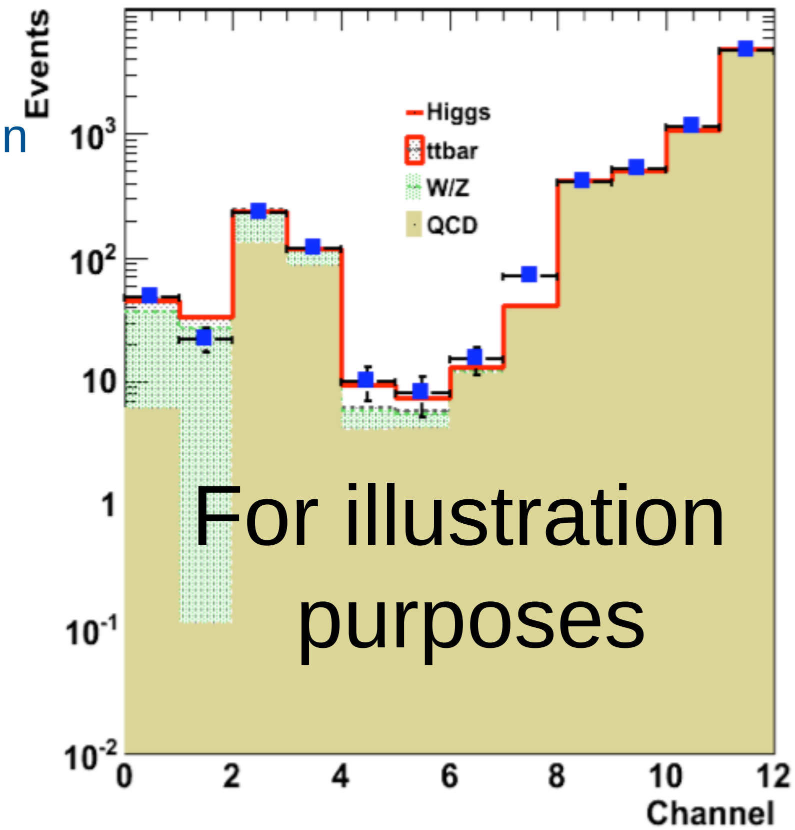
⇨keep it simple

Challenges

- low event yield
  – adjust cuts, simple selection, use kinematics
- large backgrounds
  – improve rejection
- multiple interactions spoil “cone isolation”
- measure cross section, mass (?)
- large QCD background at “low” p_T
- $Z \rightarrow \tau\tau$ (irreducible) background

Future plans

- Include tau leptons in top analysis
  - use isolation cone w/tracking&calo information
  - aim for simple selection
- Study/optimize τ-ID in ttbar events
  - relax and tune selection cuts
  - cone size/isolation
- Estimate efficiency/fakes
- Increase ttbar acceptance
- Global fit (including all channels)
- Trigger:
  - do we need a tau-specific trigger? (i.e. $e\tau/\mu\tau$, lepton+H_T, lepton+jets, or simply inclusive lepton?)



Summary

- LHC is delivering data fast
- CMS is working well, but still an infant detector
- Search for (light) charged Higgs is possible with current tools
- First results are encouraging but challenges ahead
  - Understanding of backgrounds (data-driven)
  - Understanding of systematics
- Looking forward to the near future

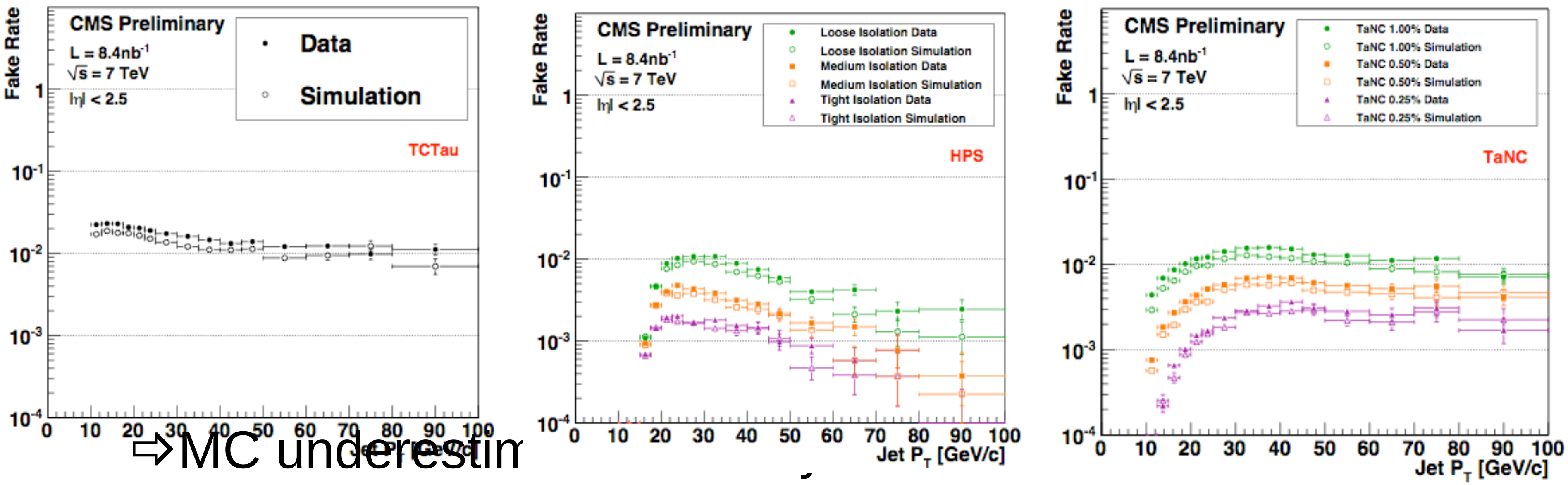
(no more soap bubbles!)

Two dedicated CMS talks:
“QCD backgrounds” by Alexandros Attikis
“Systematics studies” by Lauri Wendland

backup

Fake rate: data vs MC

Comparison to MC simulation



⇨MC underestim