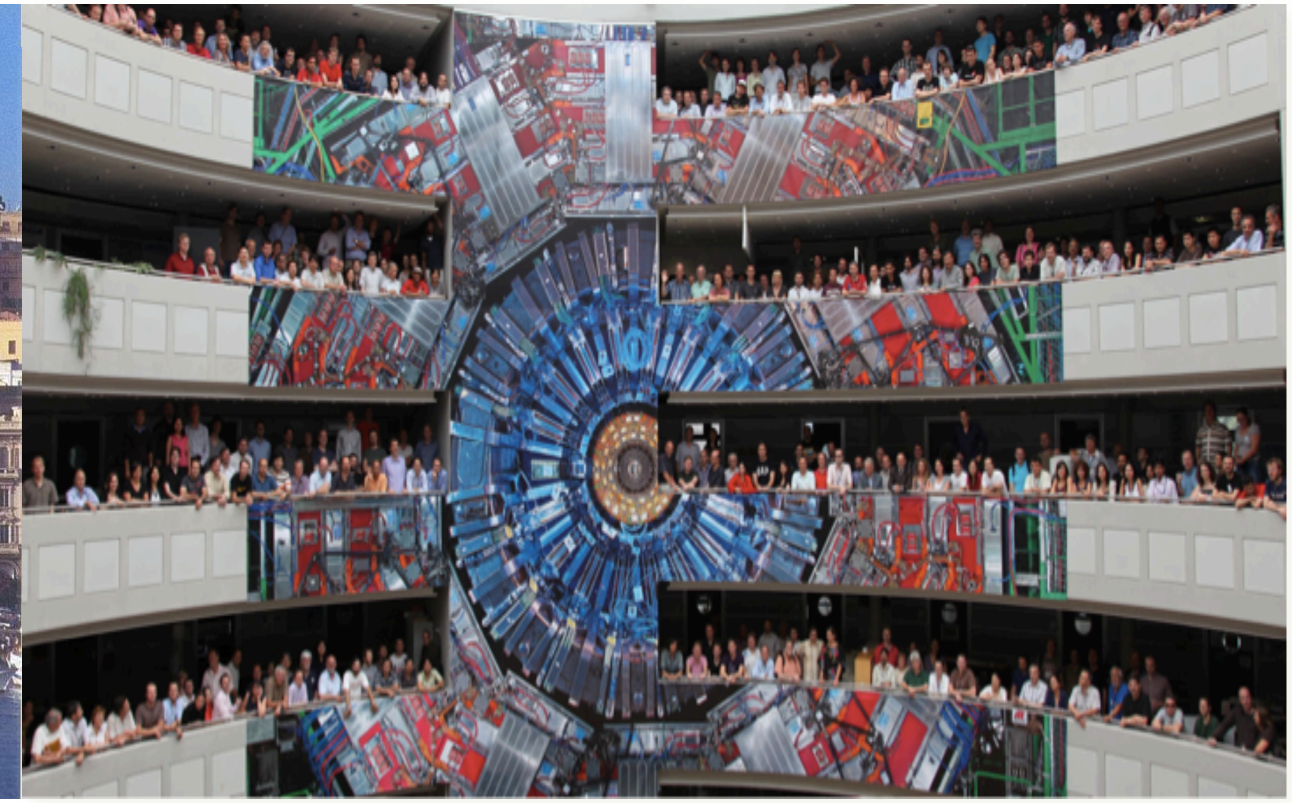


CMS Higgs search in fermions final states

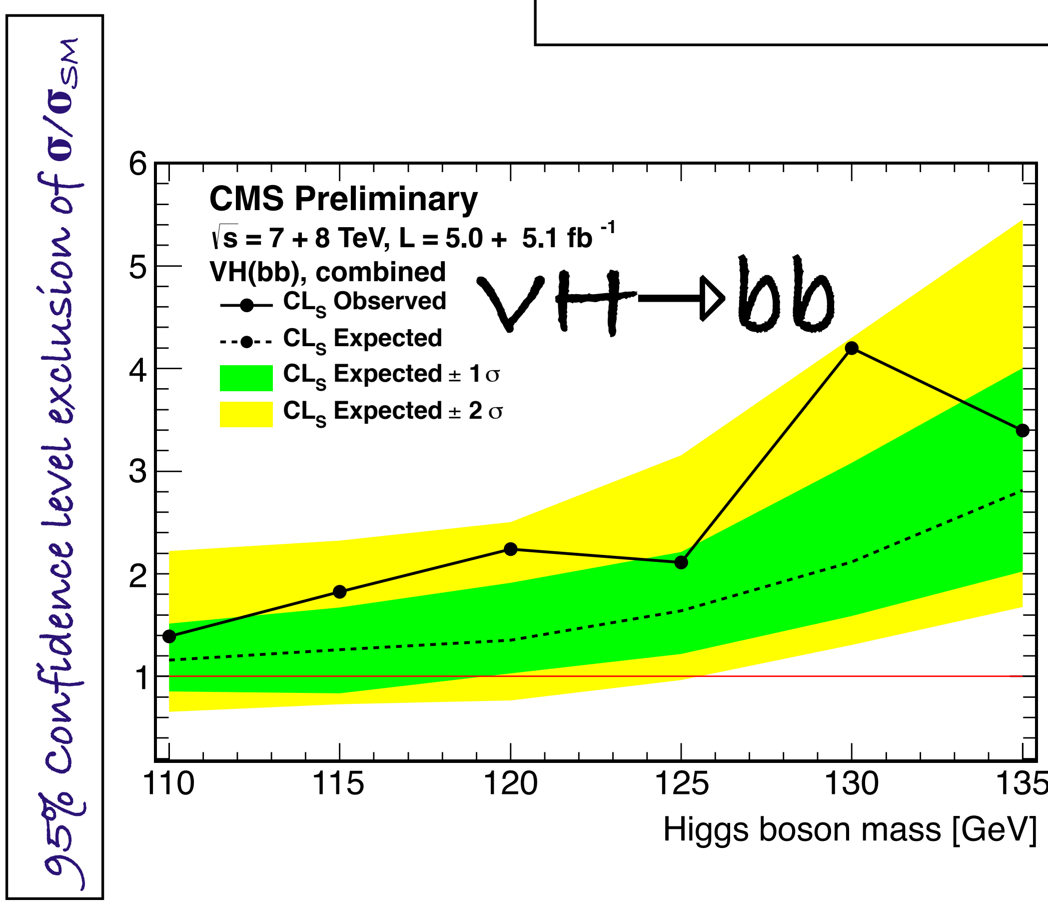
Michele de Gruttola (U of Florida)
on behalf of CMS collaboration

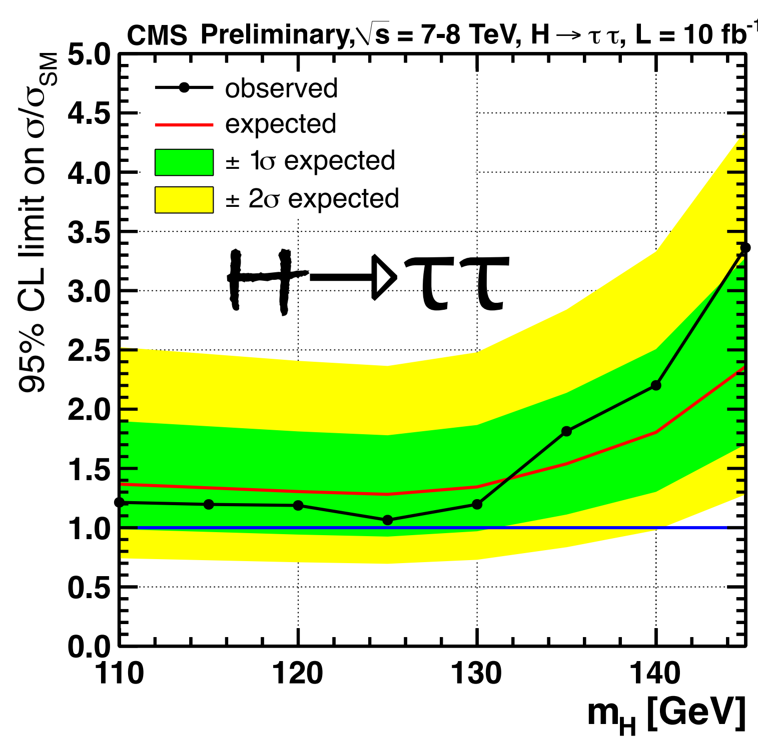
IFAE Cagliari April 5 2013

A little bit of history

- July 4th revolution: CMS and ATLAS reported the observation of a new boson with mass around 125 consistent with Standard
  - driven by bosonic decay: $H \to ZZ \to 4l$, $H \to \gamma\gamma$ and supported by $H \to WW \to l\nu l\nu$
  - what about fermions?

Shown at ICHEP Jul'12





- Sensitivity at that time not yet at the level of SM
- Compatible with either background or signal from a 125 GeV Higgs
- Analysis have been updated since then with more data and new techniques

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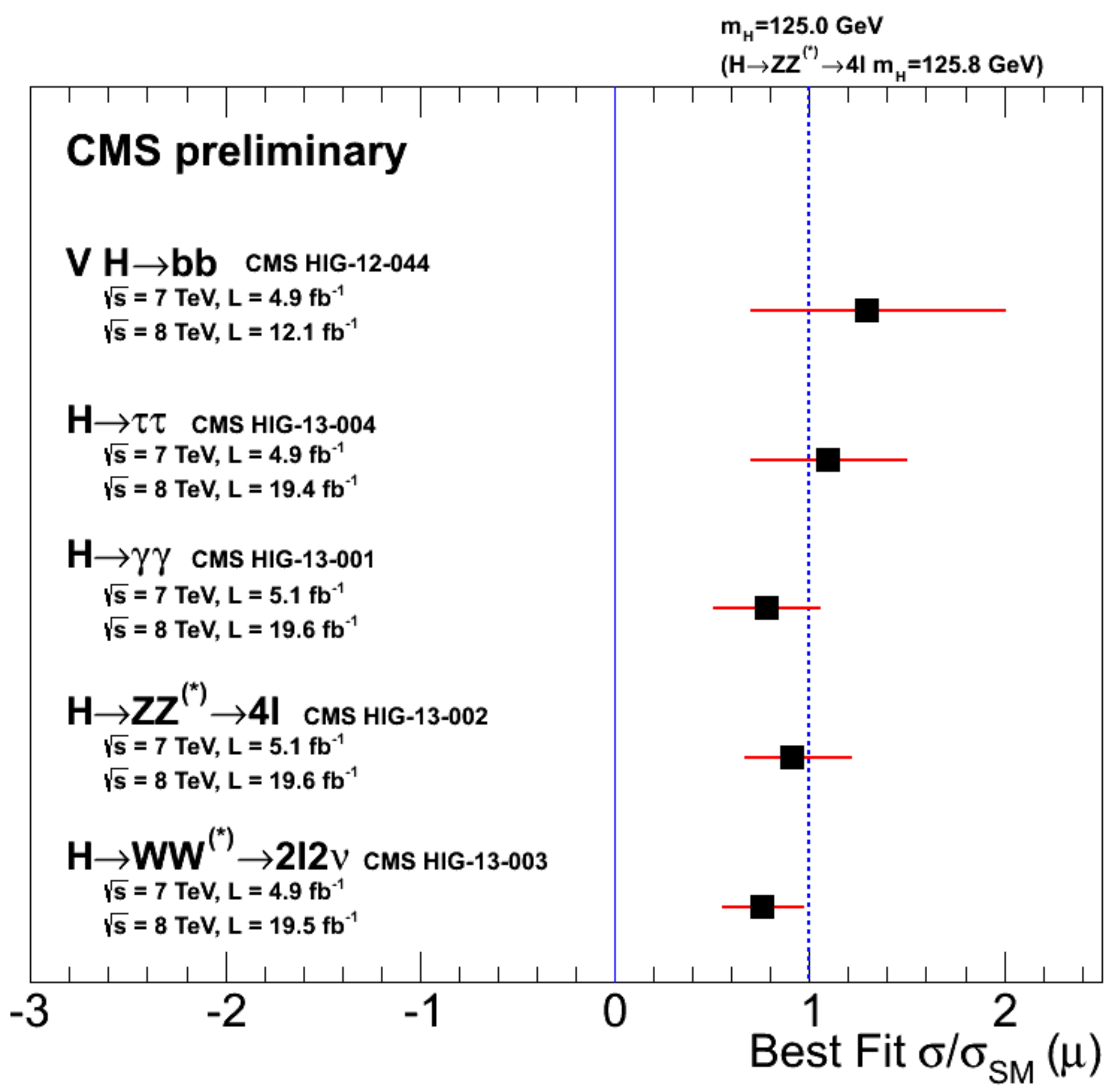
Out of the press!

- most recent updated on 2011+2012 data for all sub-channels
  - "reinforcing" the compatibility with SM Higgs



Out of the press!

- most recent updated on 2011+2012 data for all sub-channels
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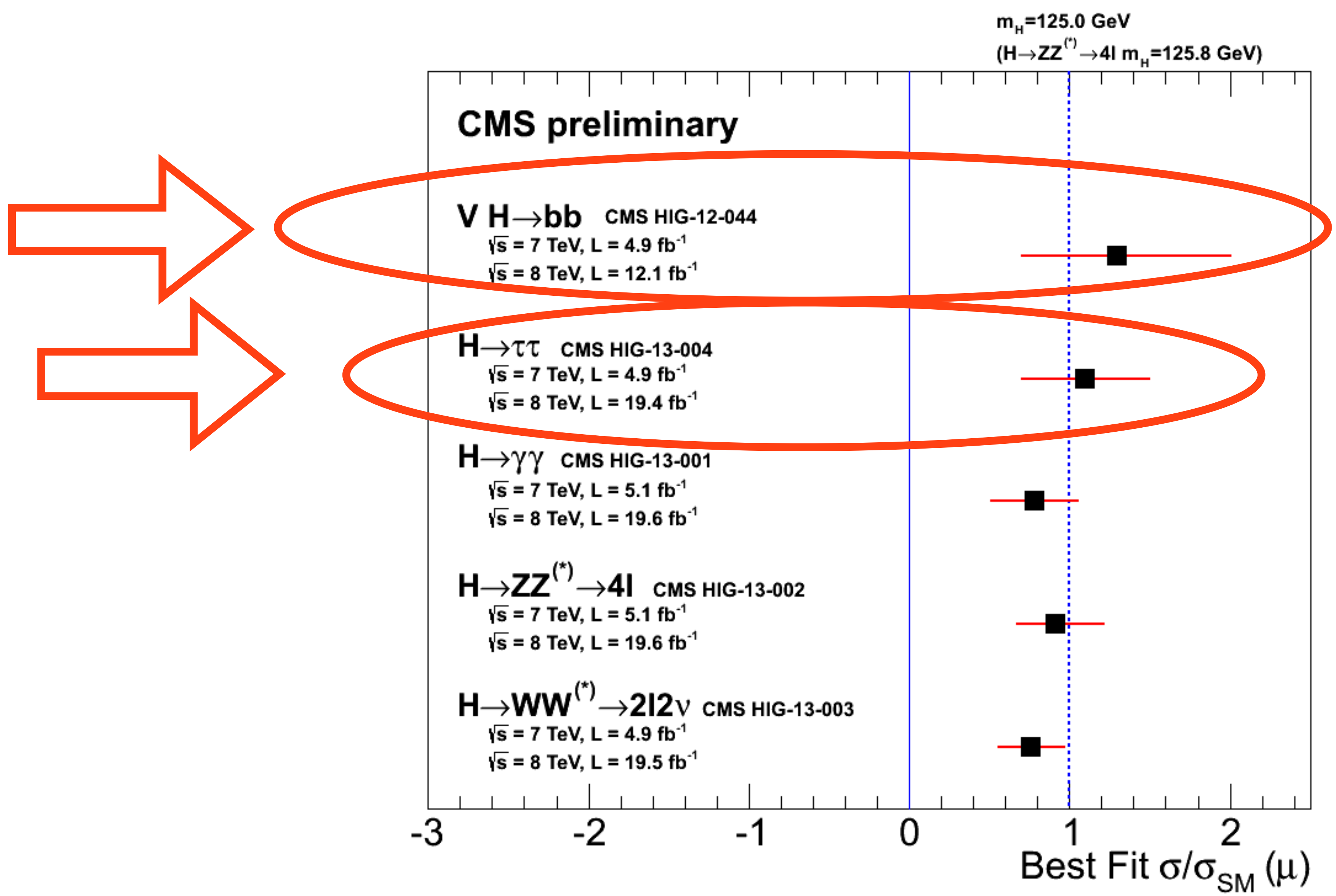


@125:

BR(H→bb) ~ 58%

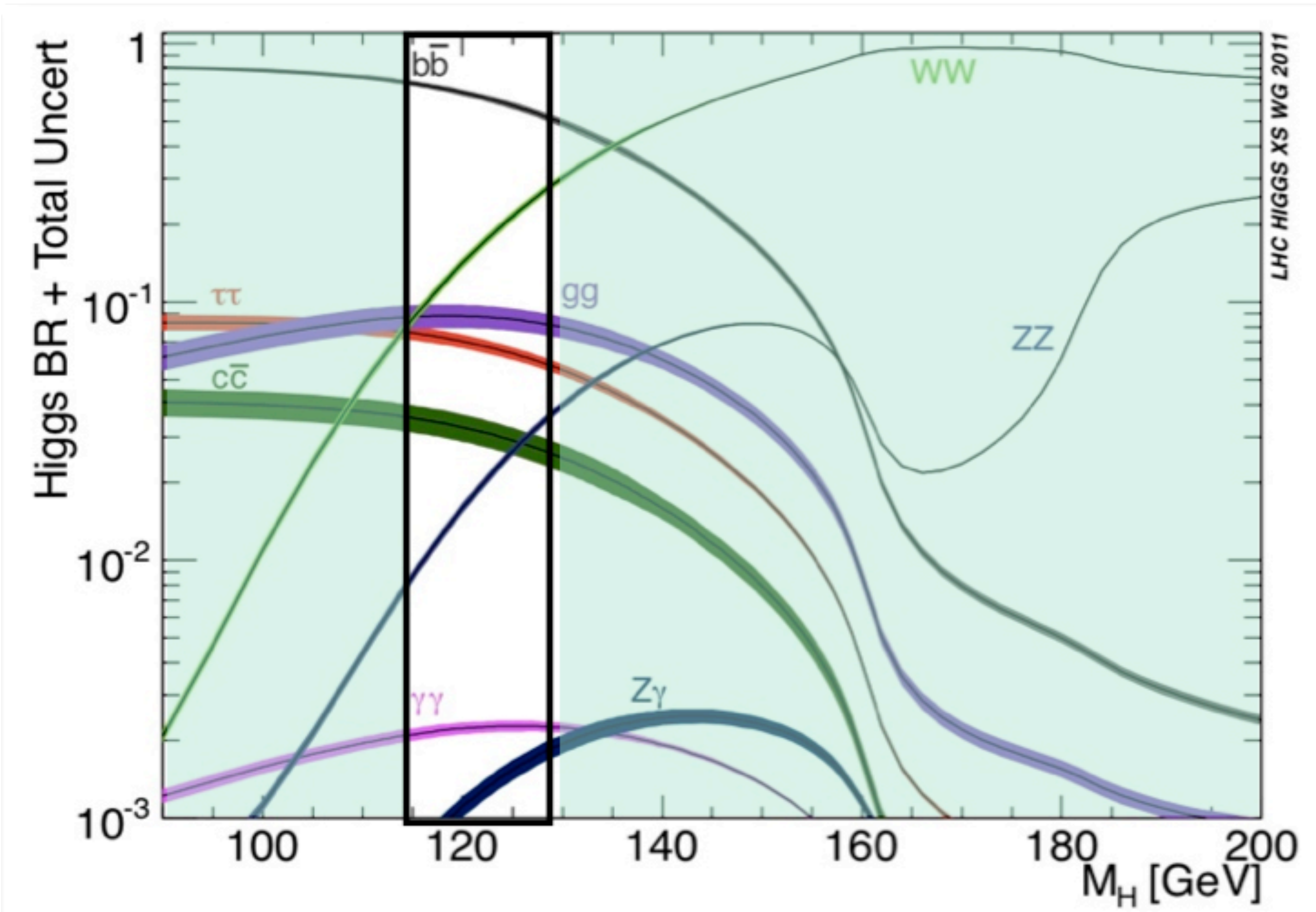
BR(H→WW) ~ 22%

BR(H→ττ) ~ 6%

BR(H→ZZ*) ~ 3%

BR(H→γγ) ~ 0.22%

Region of interest



@125:

BR(H=>bb) ~ 58%

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BR(H=>γγ) ~ 0.22%

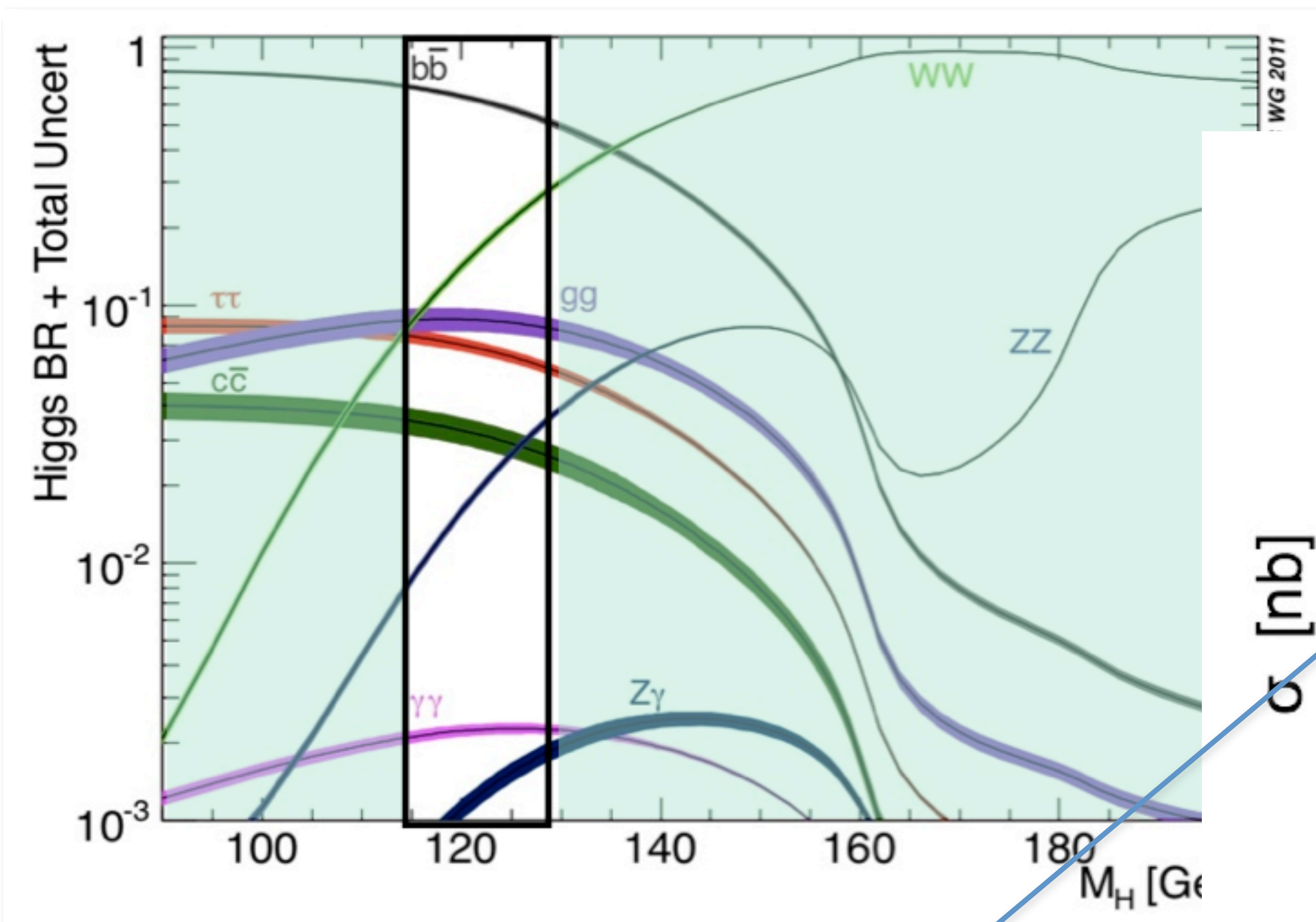
b's and tau's ← test the Higgs couplings to fermions vs bosons

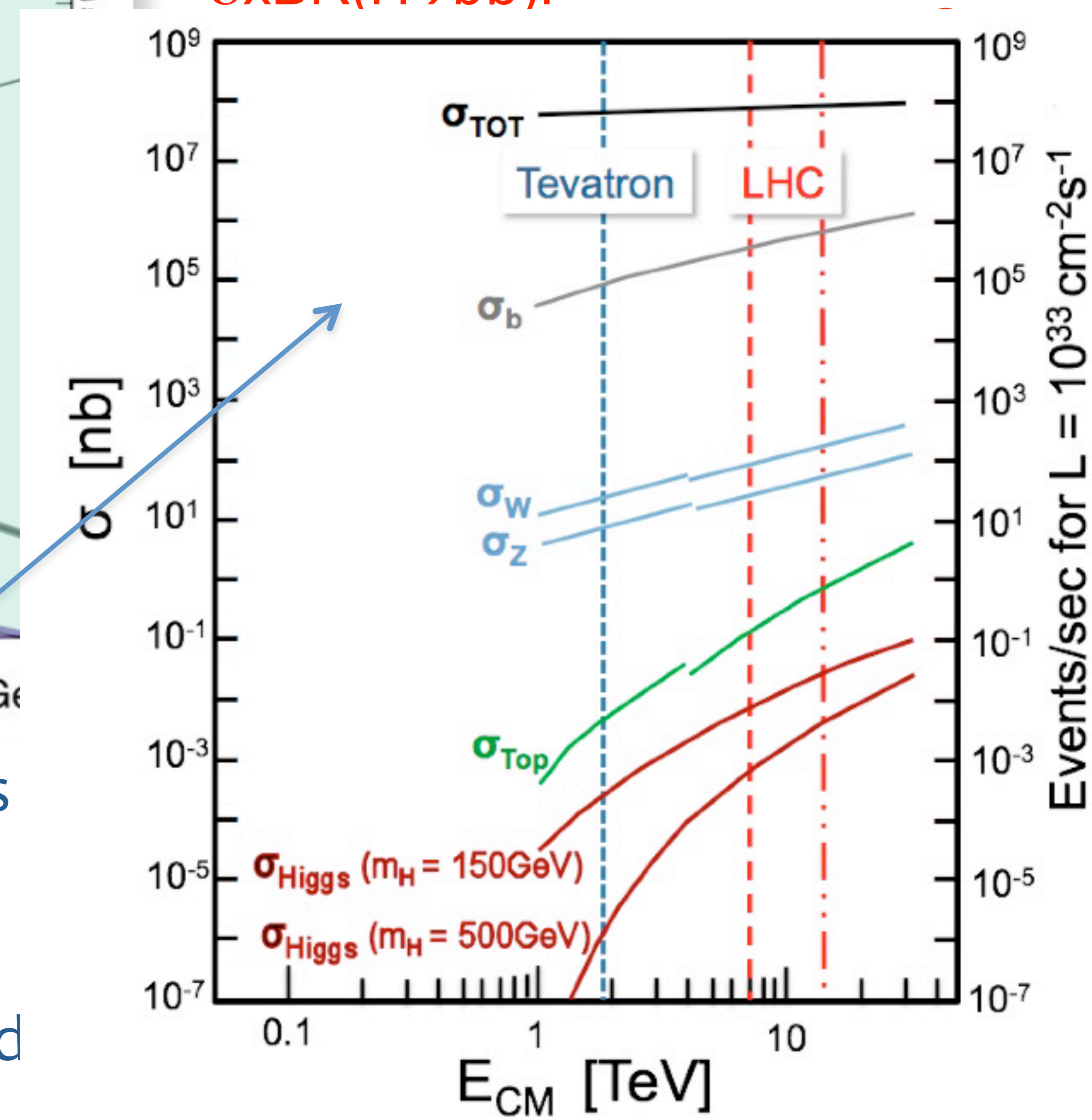
Vital part of the Higgs identification and Higgs property studies

But life is hard…

Region of interest

But σ_{bb}(QCD) ~ 10^7 σxBR(H→bb)!





b's and tau's ← test the Higgs couplings to fermions vs bosons

Vital part of the Higgs identification and Higgs property studies

But life is hard…

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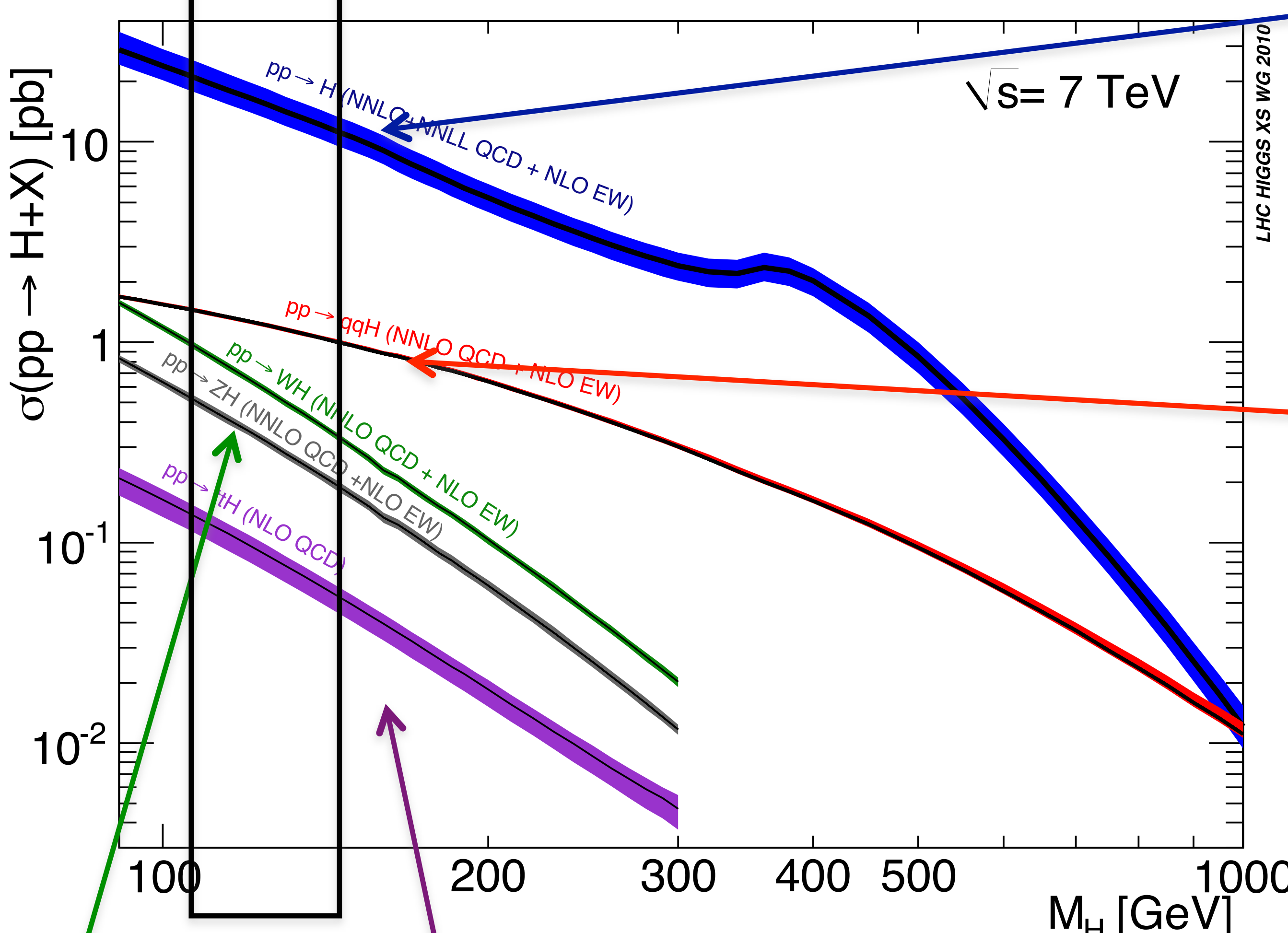
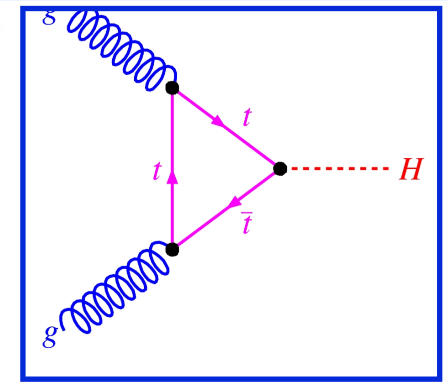
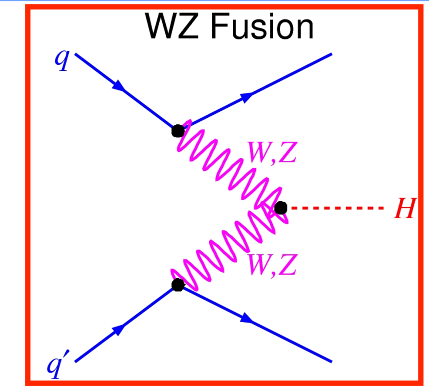
func(Xsection * BR, eff, bkgs)





g-g fusion



Vector boson fusion

H→ττ

- gluon fusion difficult but possible(can use association with jets or go to high pt regime)
- VBF cleaner
- VH also added recently

very important for study Higgs properties!

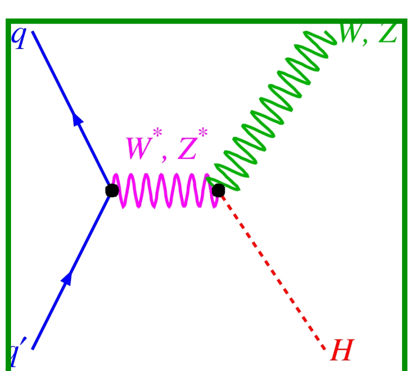
Association with Z/W

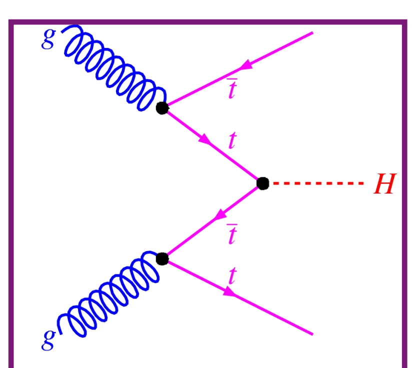
Association with tt^bar

H→bb

overwhelming QCD: need to go with associated production,

- VH - can use lepton/MET and topology
- ttH - even less rate, look at topology, but ttbar bkg well understood





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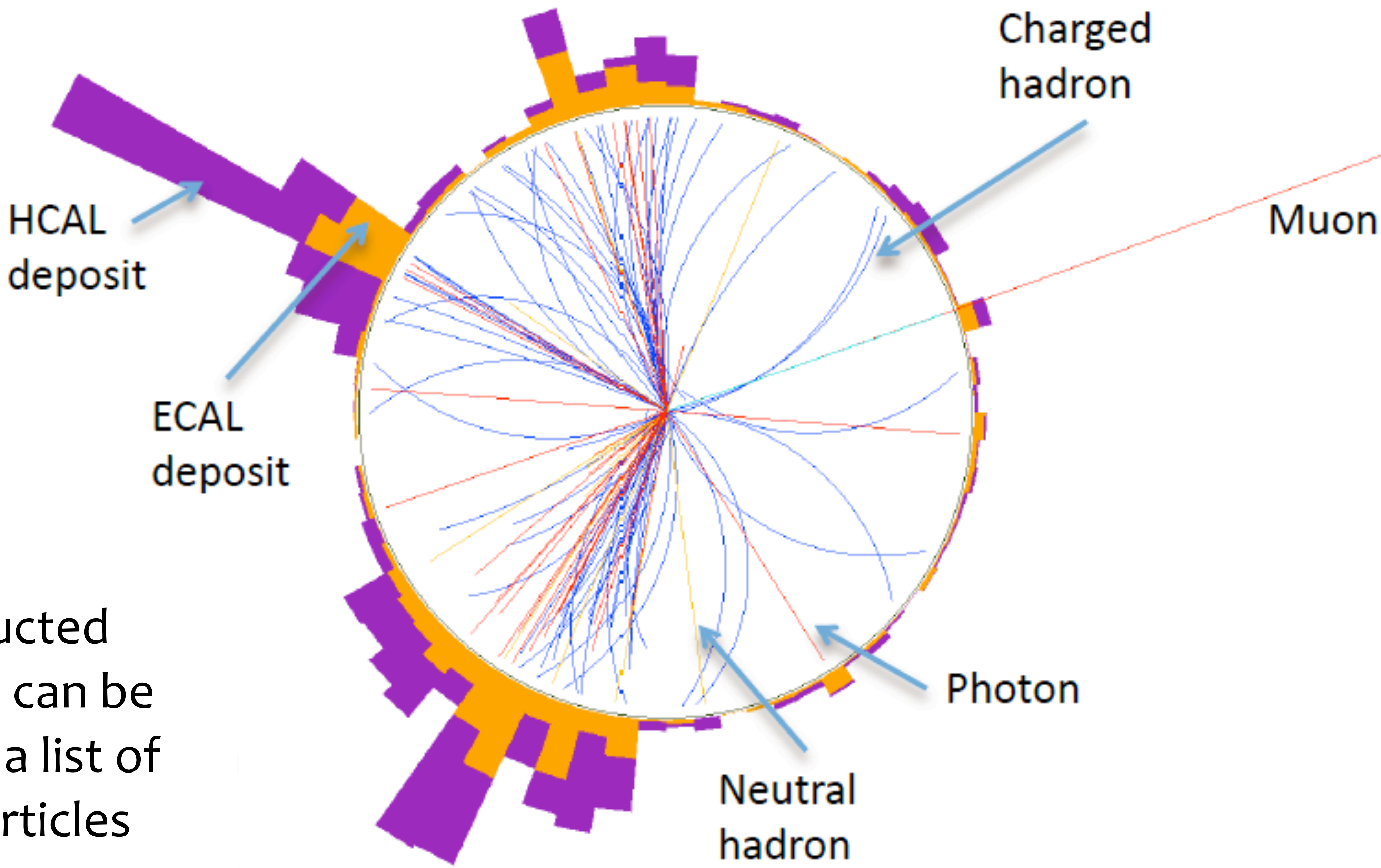
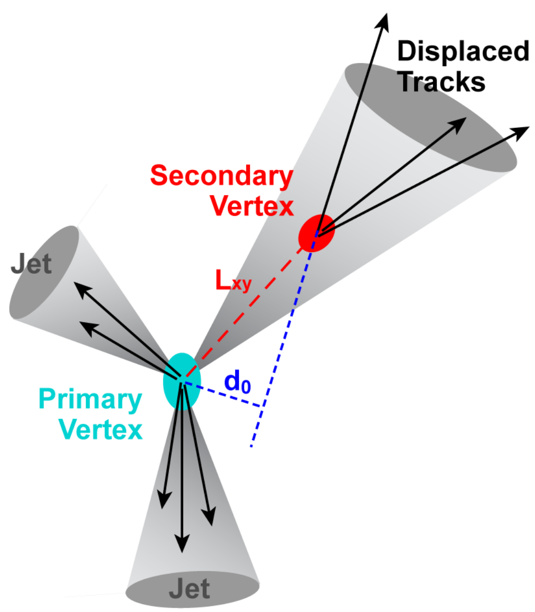
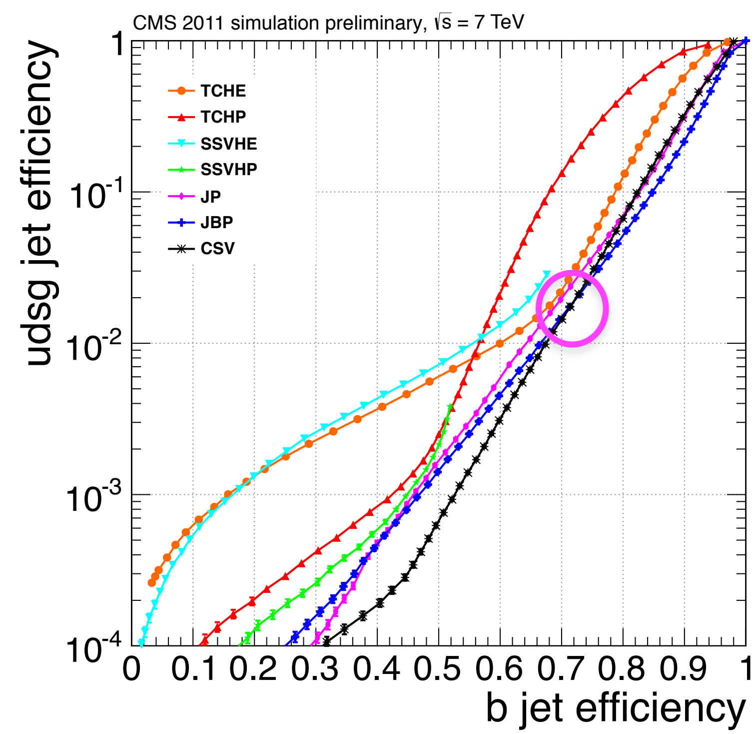
- CMS Particle flow reconstruction

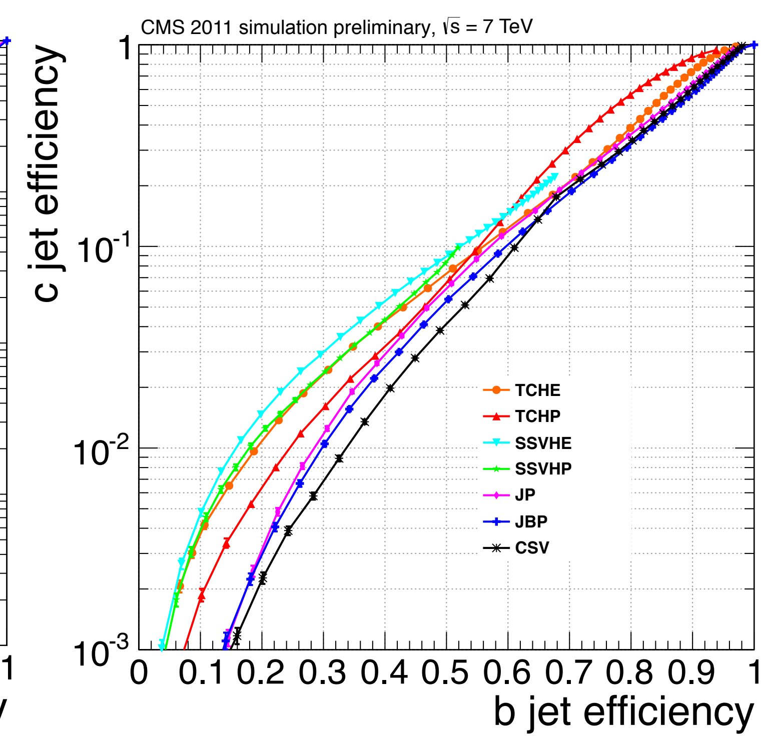


List of reconstructed particles: can be used like a list of stable particles from a generator

B-jets at CMS

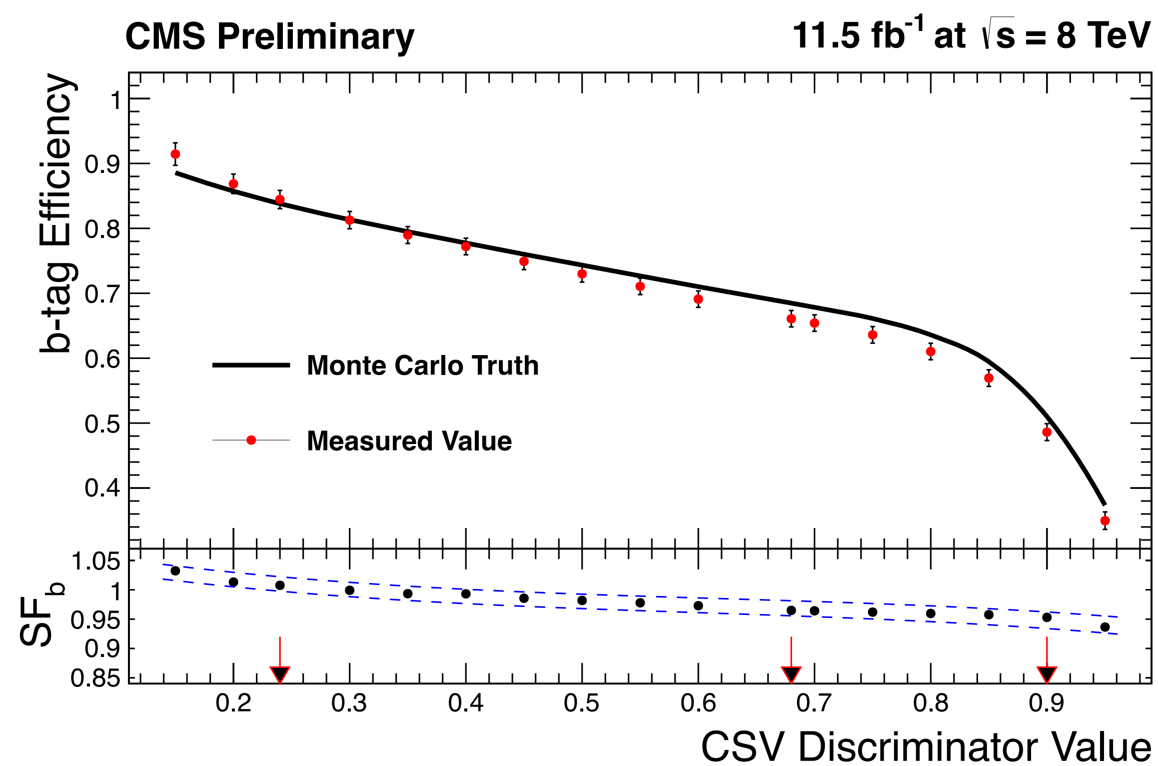






- Many algorithms deployed at CMS
- Best separation from udscg and c jets
  - **CSV**: likelihood tagger using many jet properties: secondary vertex (if any), tracks impact parameters, etc.

Eff of ~70% for a fake-rate of ~2%

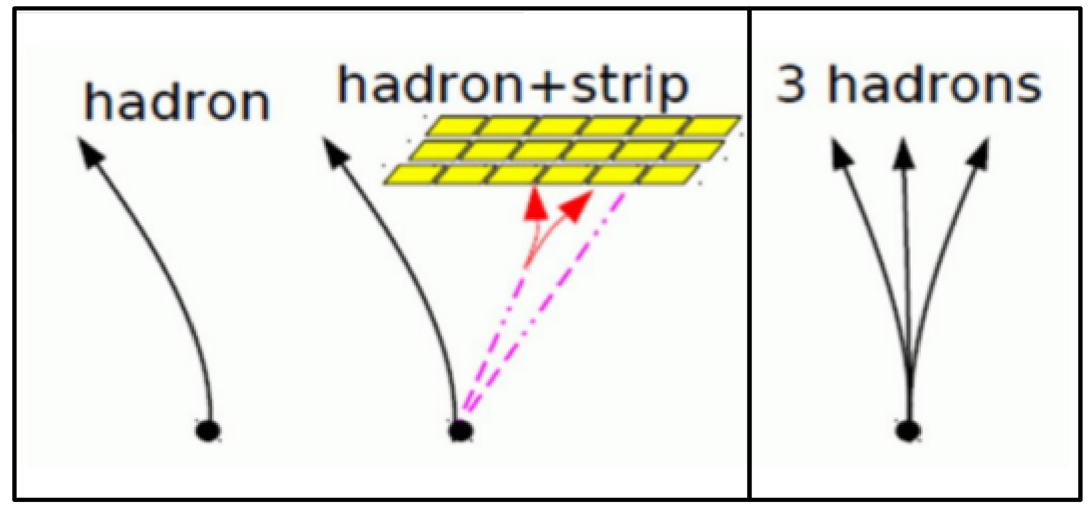


eff and fake-rate from ttbar samples and muon plus jets

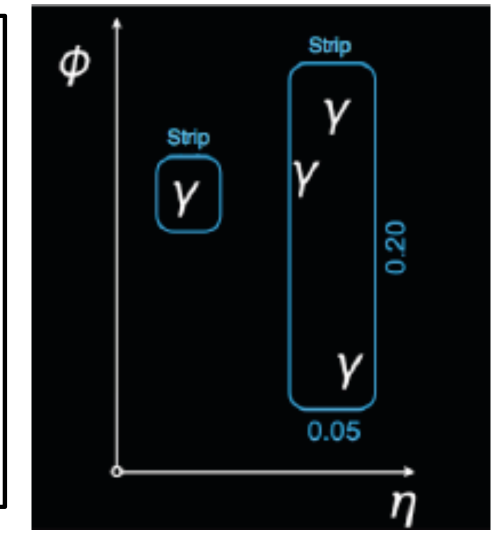
τ's at CMS

Hadronic Tau identification:

- Reconstruct individual decay modes
- Charged hadrons + electromagnetic obj arranged in strips or single photons



$\tau \rightarrow \pi\nu$ $\tau \rightarrow \rho\nu$ $\tau \rightarrow a_1\nu$

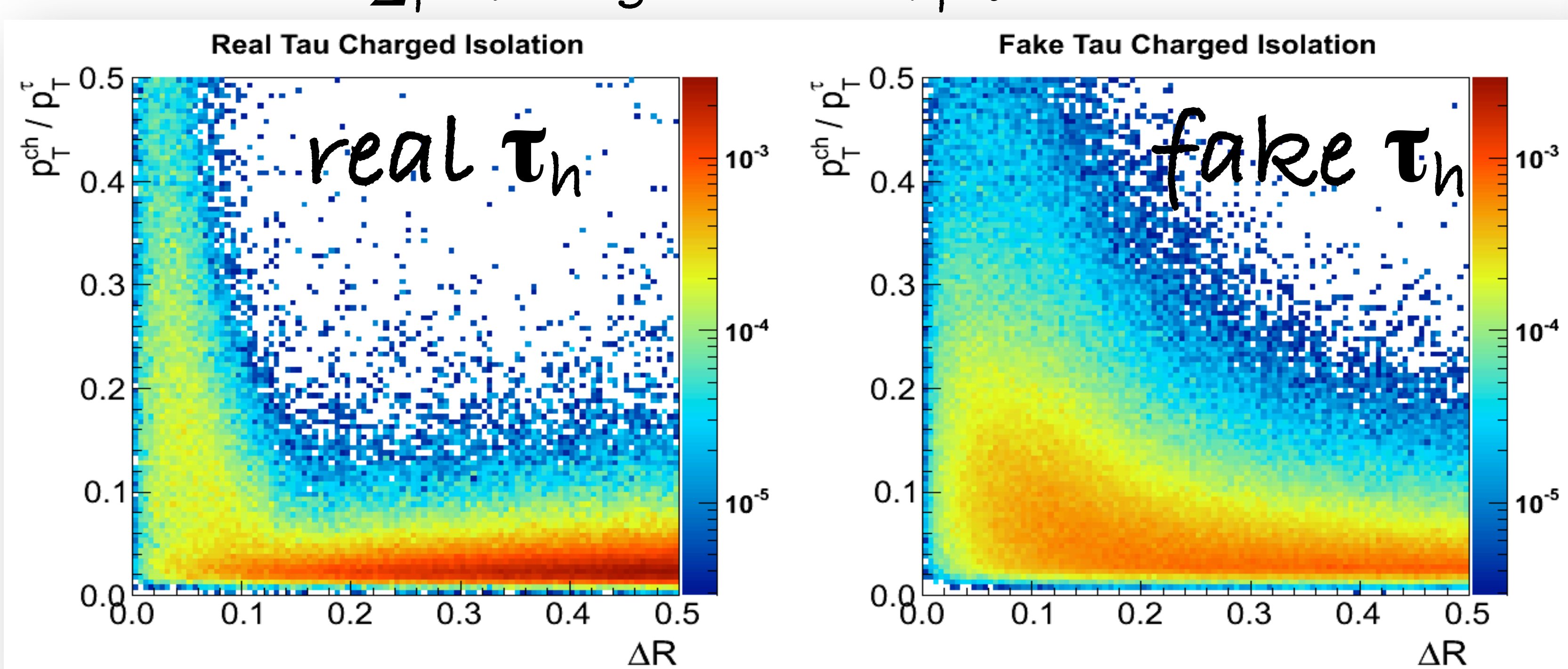


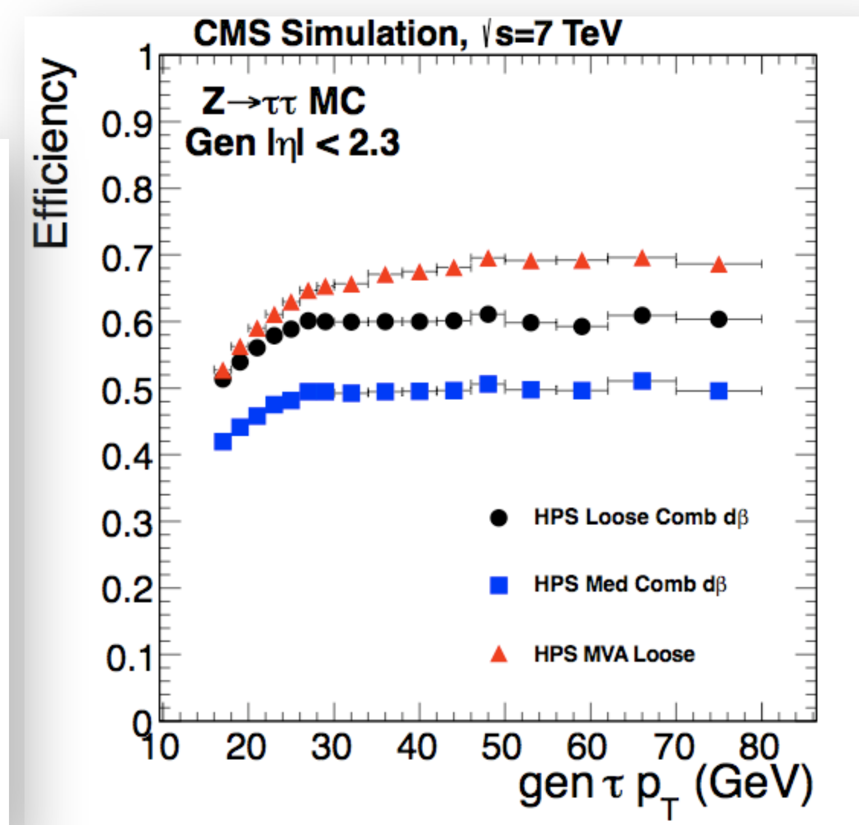
Tau Isolation:

- Multivariate discriminator using sum of energy deposits in dR rings around the tau (from 0.1 to 0.5)

eff ~62% for a fake rate of ~6%

$\sum pt$ (charged hadron)pt_τ vs DR





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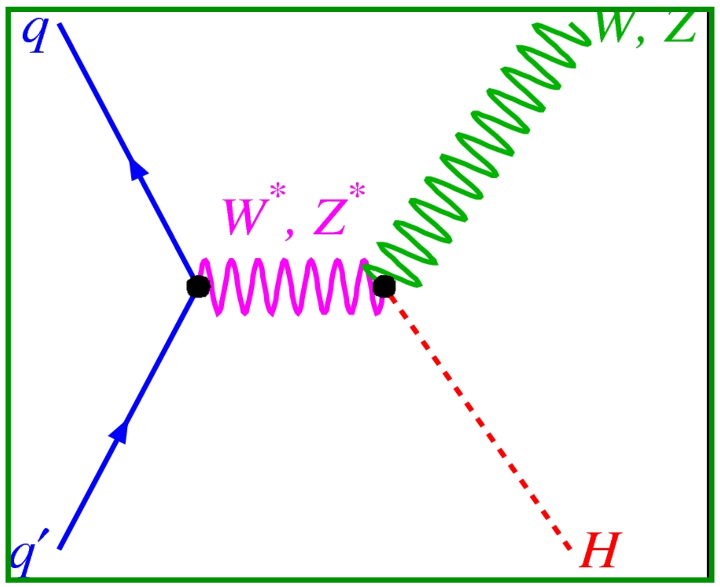
SM Higgs search



VH → Vbb

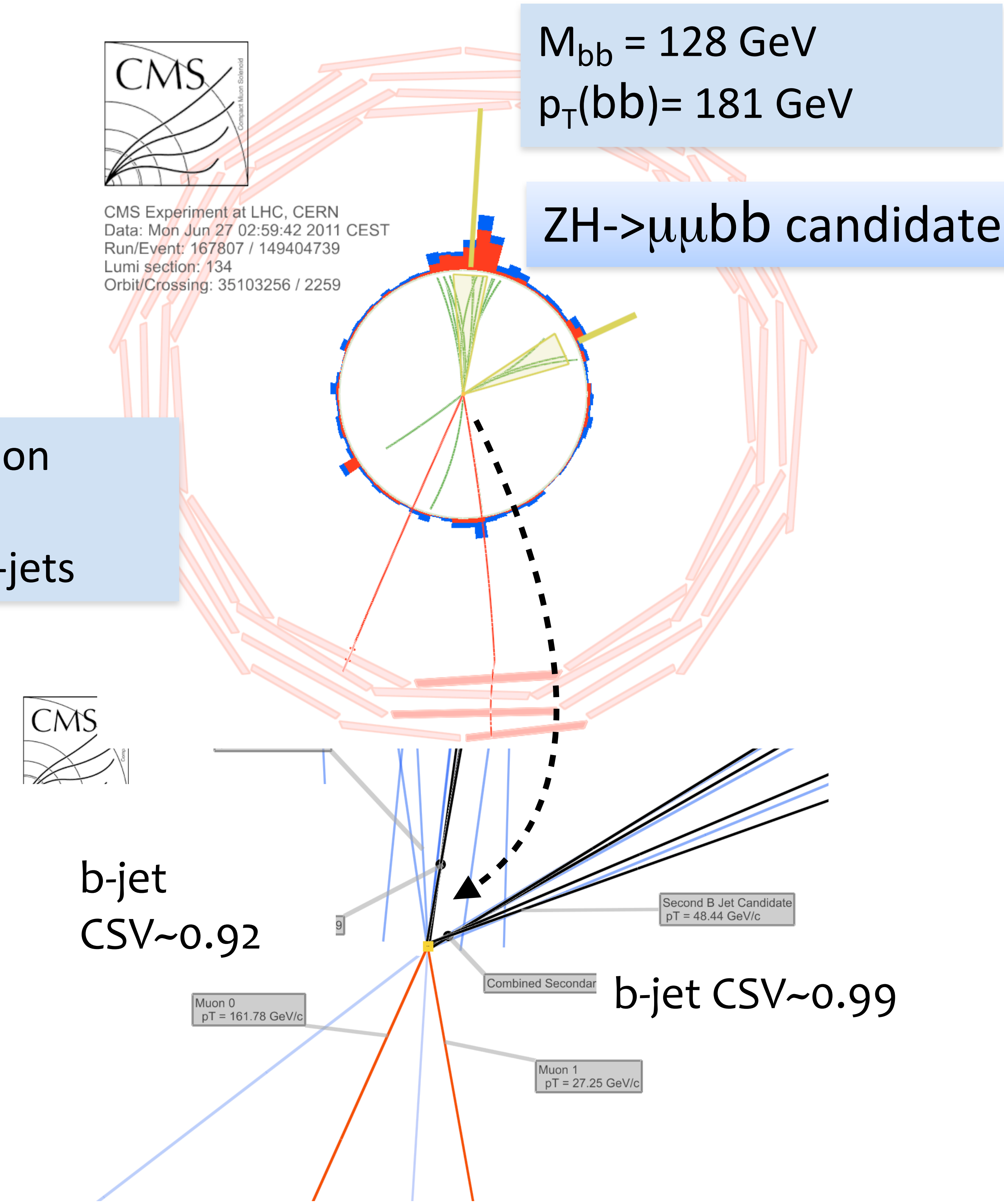
V→lν,ll,νν

Most sensitive channel with b as final state, also interesting to compare with Tevatron results

First CMS VHbb 2011 analysis
Phys. Lett. B 710(2012) 284-306

- 5 channels:
  - Z(ll)Hbb
  - Z(νν)Hbb
  - W(lν)Hbb

Associated Production
→ final states with leptons, MET and b-jets



General strategy:

(a) High boosted vector boson and dijet,
(b) 2 b-tagged jets,
(c) back-to-back V & H
(d) Reconstruct m_{bb}

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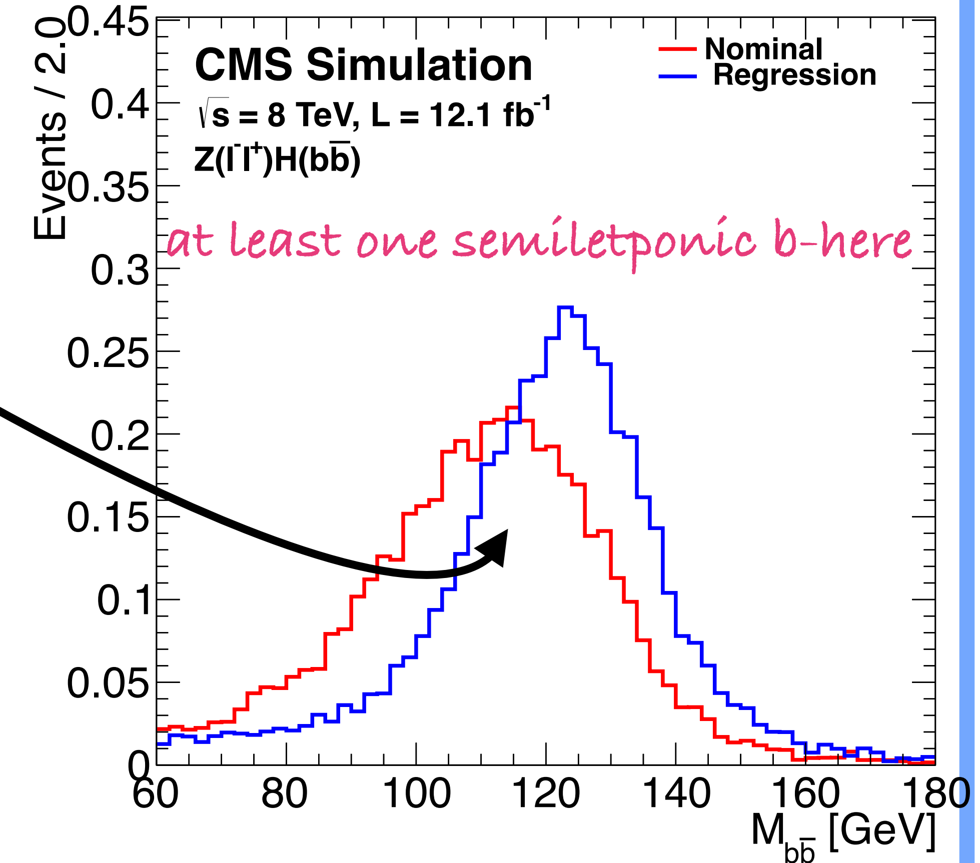
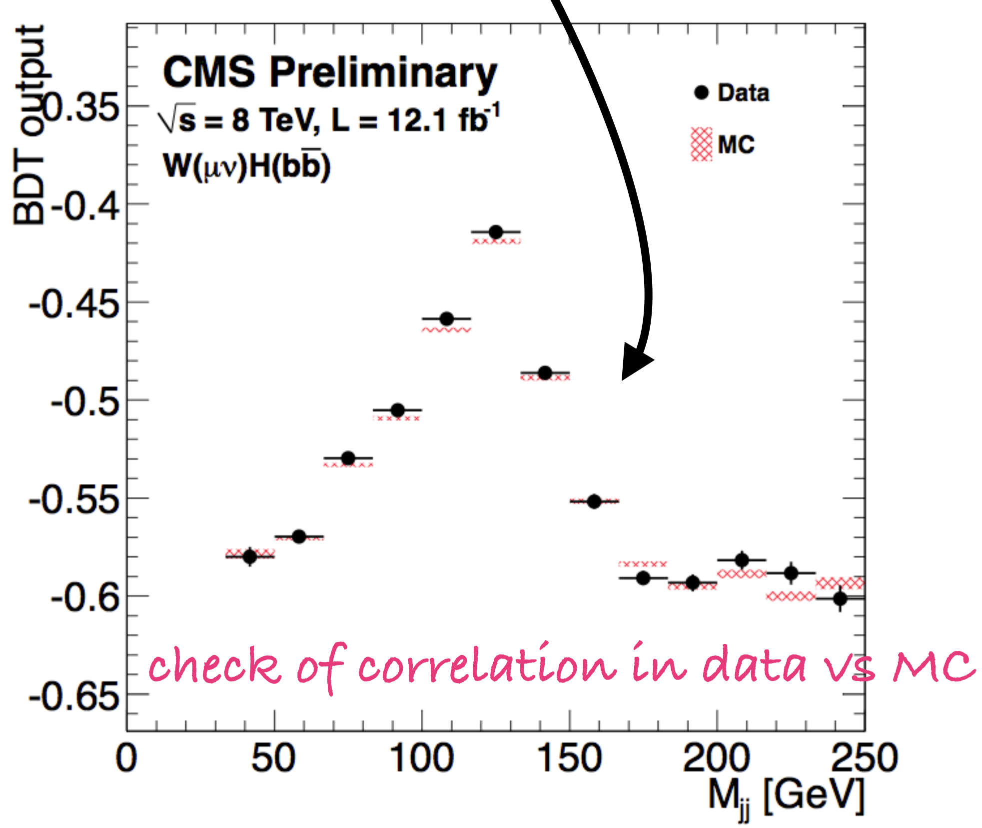
H -> bb further ingredients

- Main backgrounds (V+jets, $t\bar{t}$) normalized from data control regions to signal region
- b-jet energy regression to improve jet pt and hence mass
- Discriminate signal from bkgs using
  - categorization in pt bins
  - Boosted Decision trees (BDTs)





No update since HCP'12

7 TeV(2011)	8TeV(2012)
5 fb^{-1}	12 fb^{-1}

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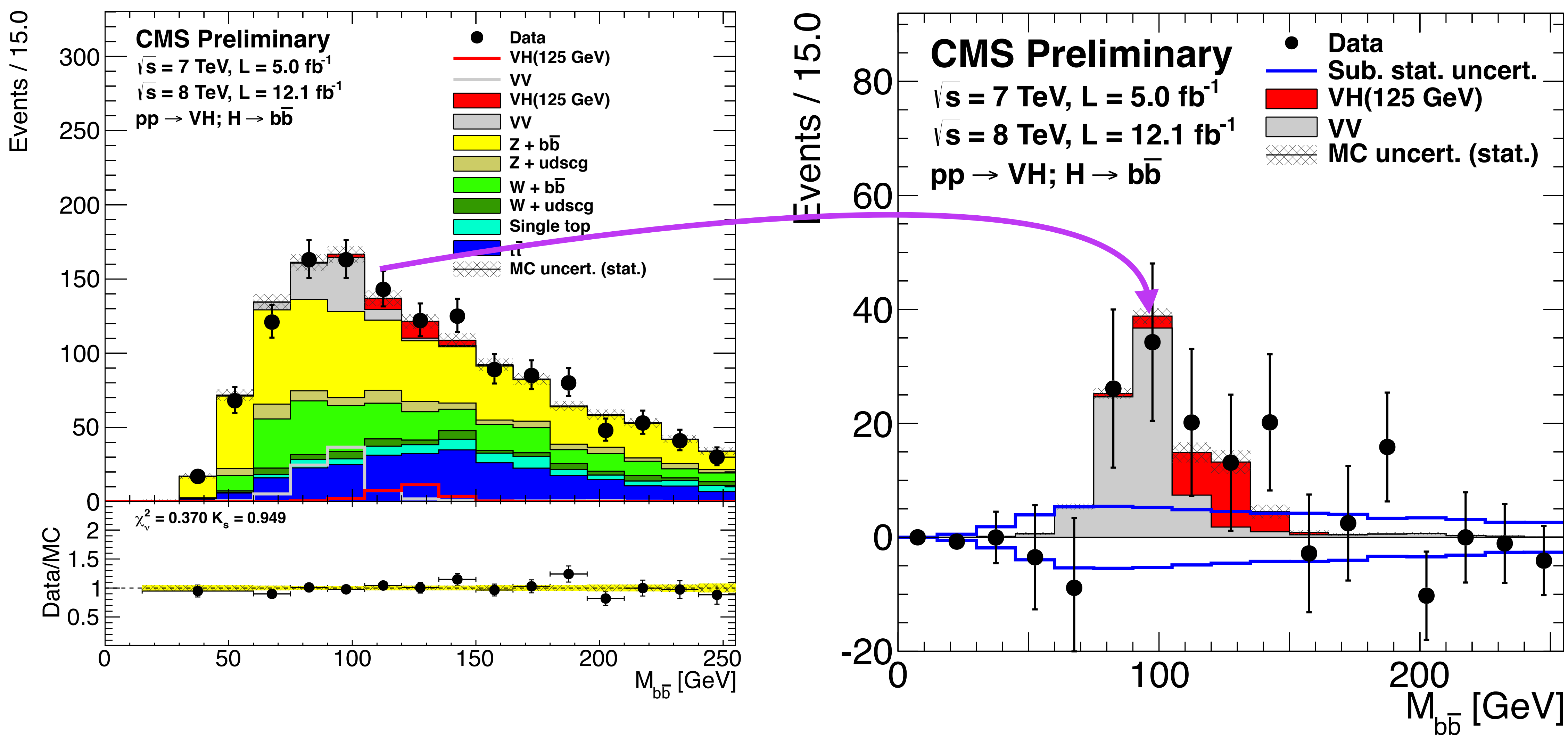
H -> bb M_{bb} distribution

all channels

bkg except VV subtracted



- Tighter selection than used in BDT analysis
- consistent with diboson expectation + small excess in signal region

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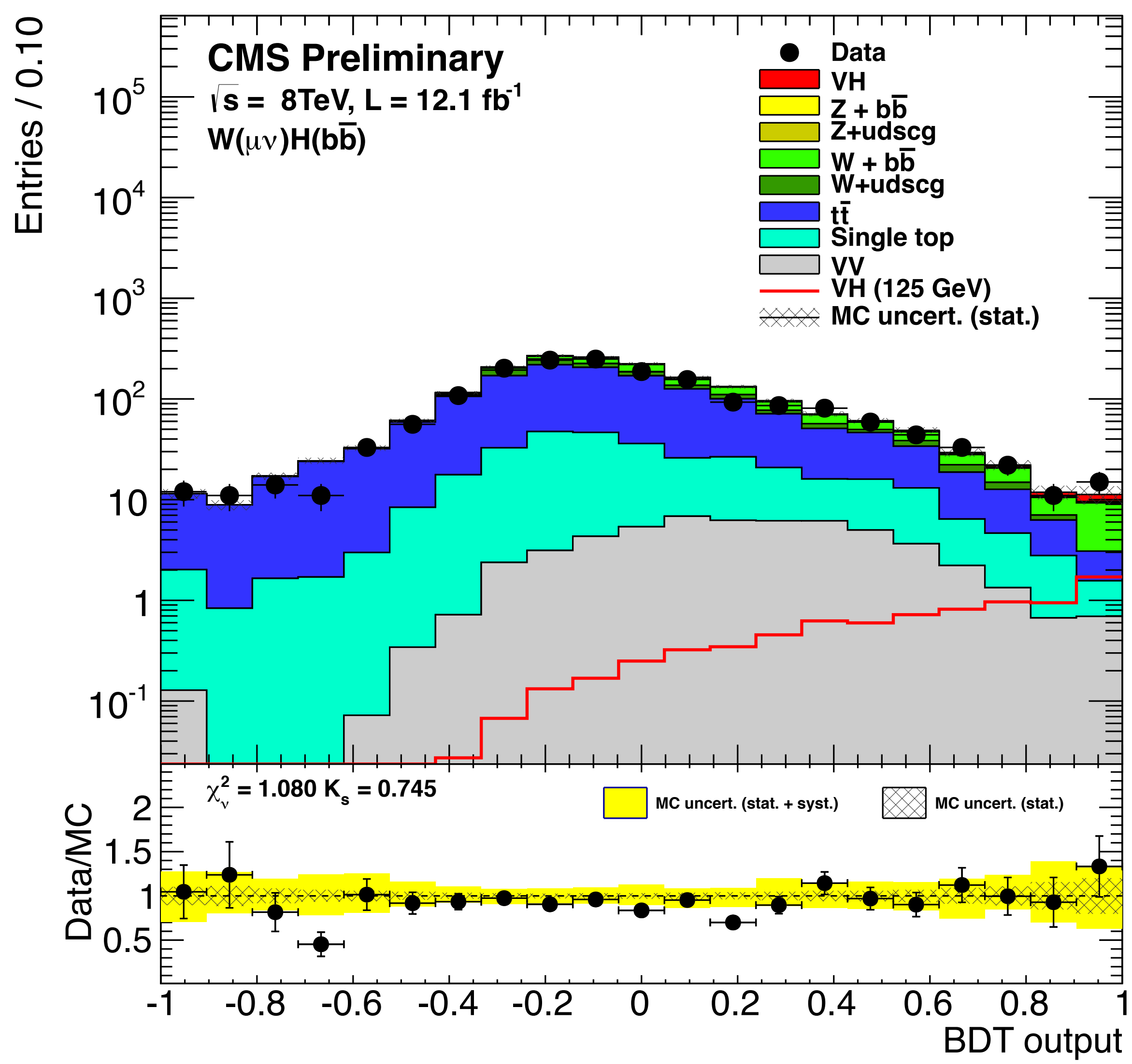
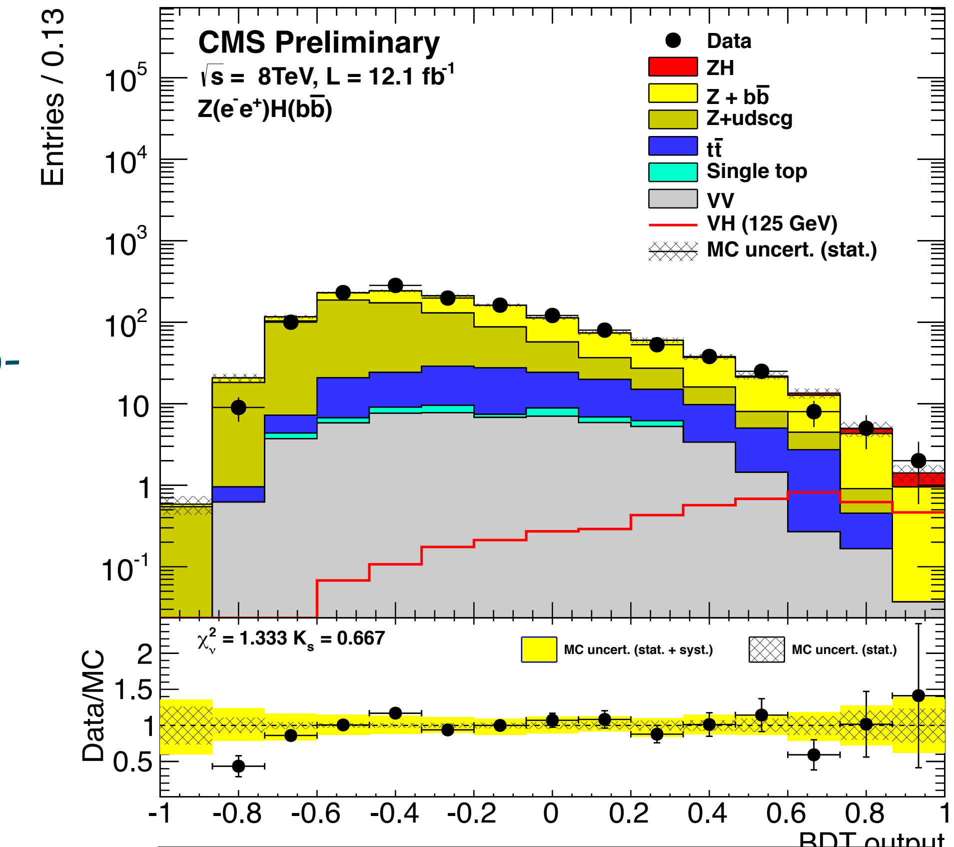
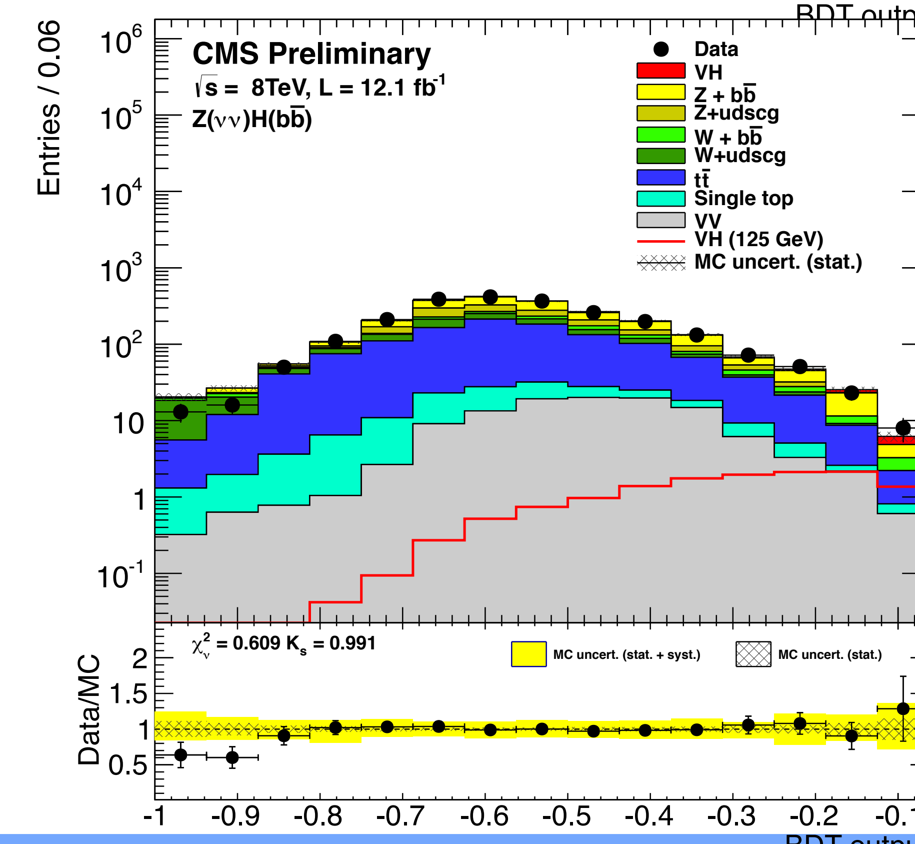
H -> bb BDT analysis

- Fit to BDT gives 20% improvements on mass fit
- using kinematics, b-tag, angles as inputs
- categorize into low-high Vpt + high Vpt with looser b-tag for some channels







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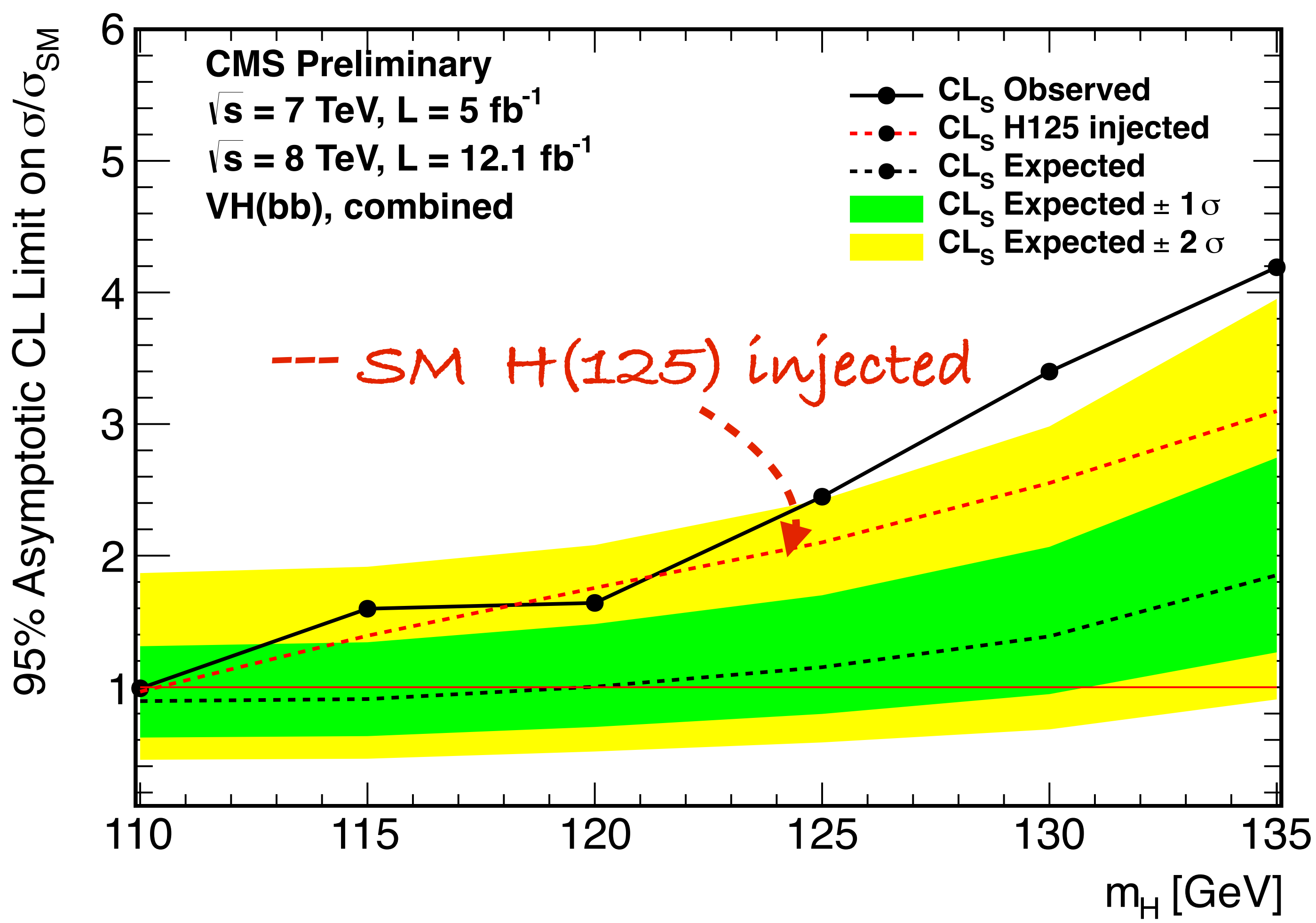
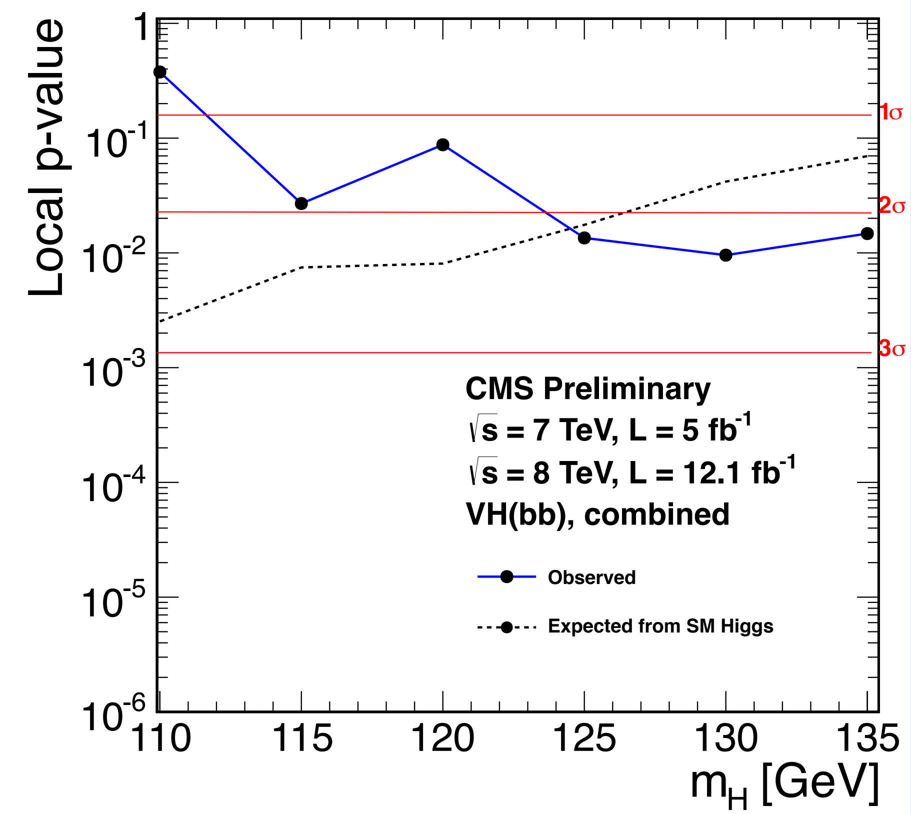
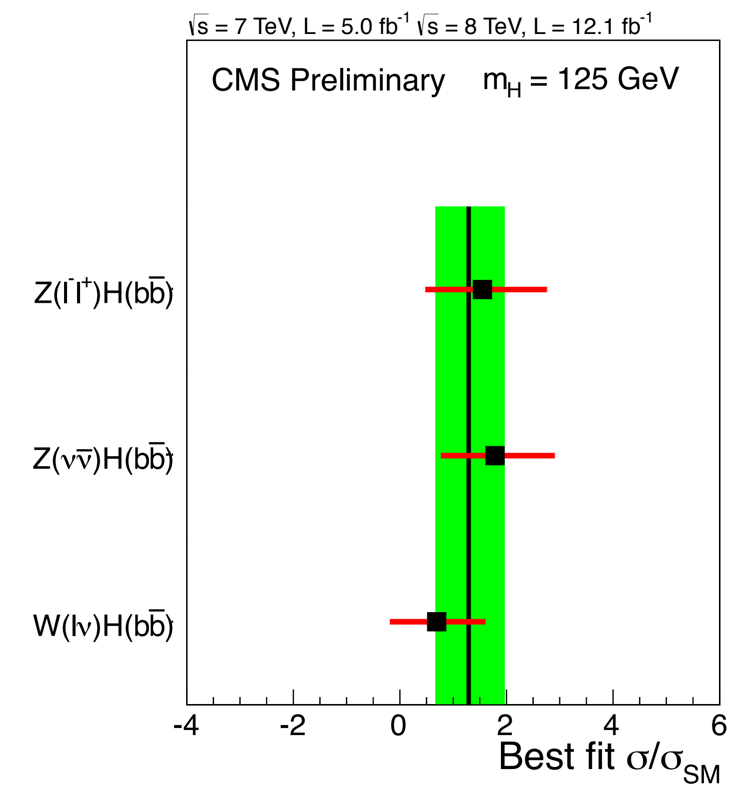
H -> bb Results







- Observed (expected) limit of 2.5(1.2)xSM at 125 GeV
- Observed (expected) local significance of 2.2σ (2.1σ) for mH=125 GeV

- Combined best-fit $\mu=1.3^{+0.7}_{-0.6}$

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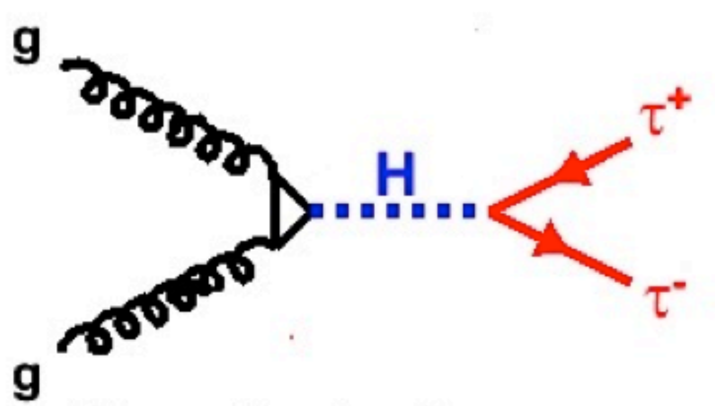
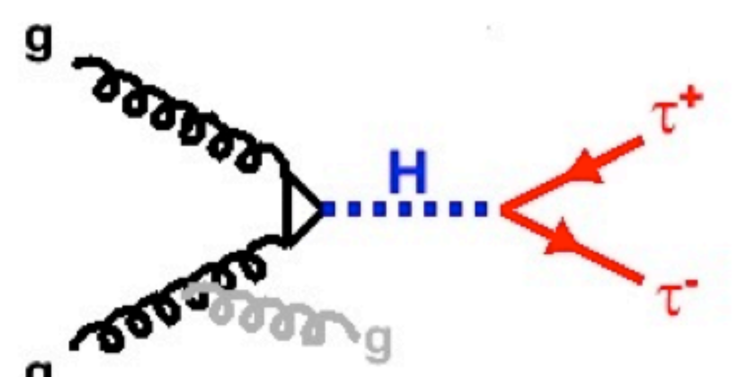
H → $\tau\tau$ → $\mu\tau_h$, $e\tau_h$, $e\mu$, $\mu\mu$

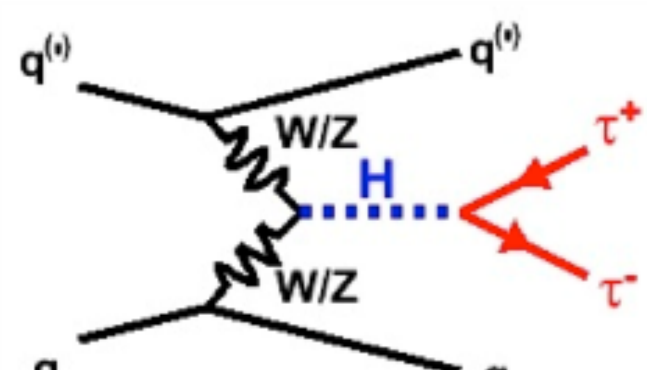
- Sensitive to all production modes
- Probes coupling to leptons
- Enhanced σ x BR in MSSM



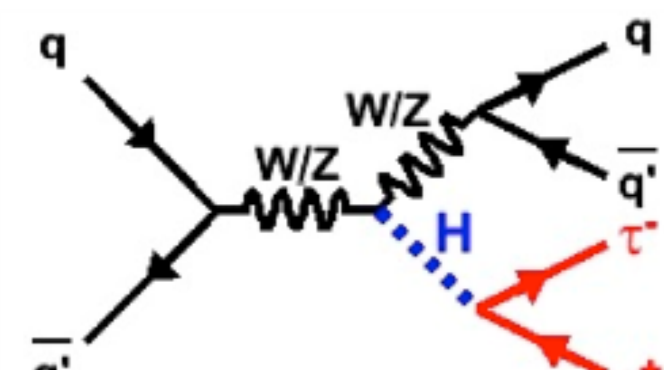
Gluon Fusion Process



Boosted Gluon Fusion Process



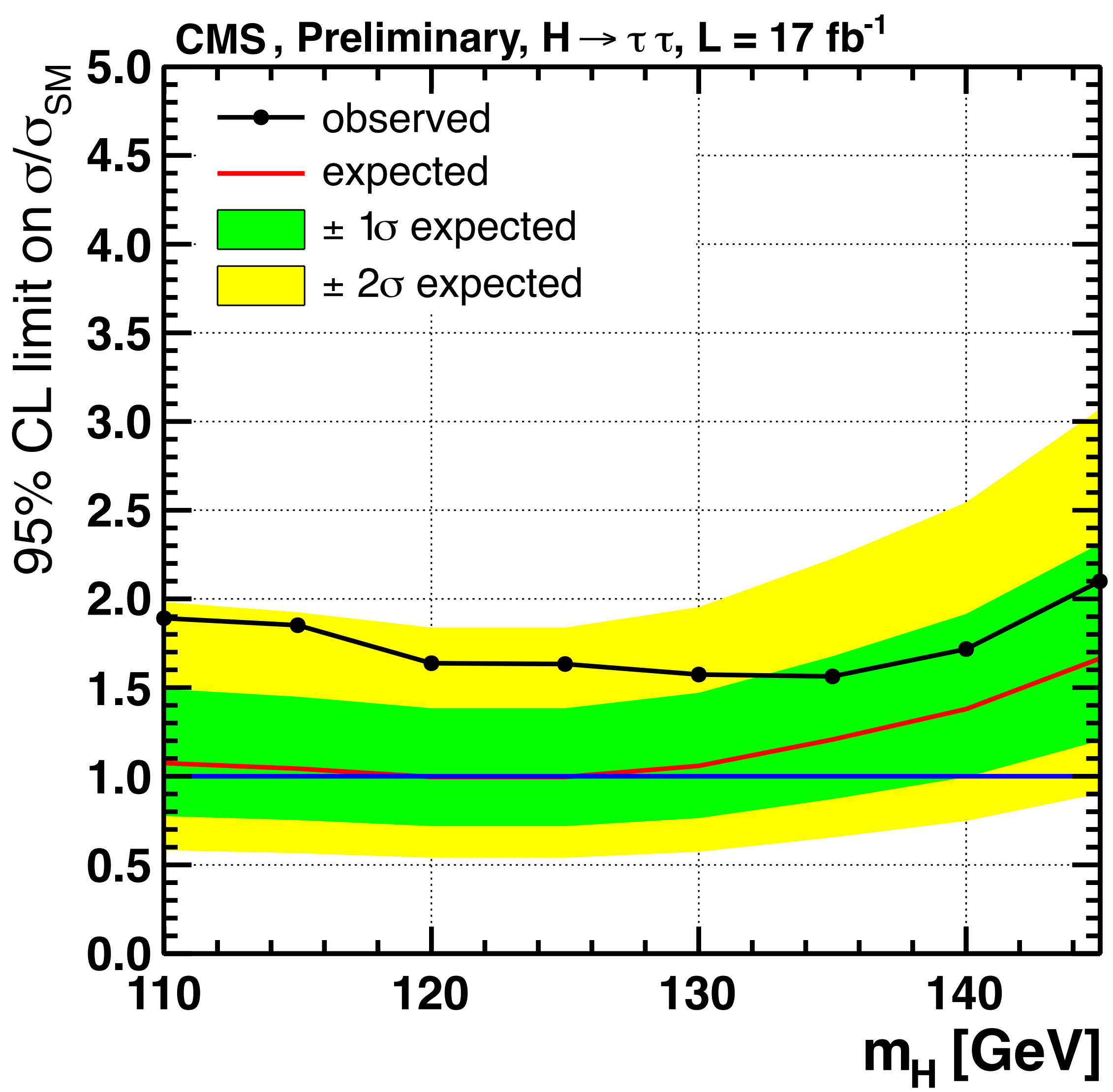
VBF Process



VH Process

- Last but one public results (the first after iCHEP show)

HIG-12-043



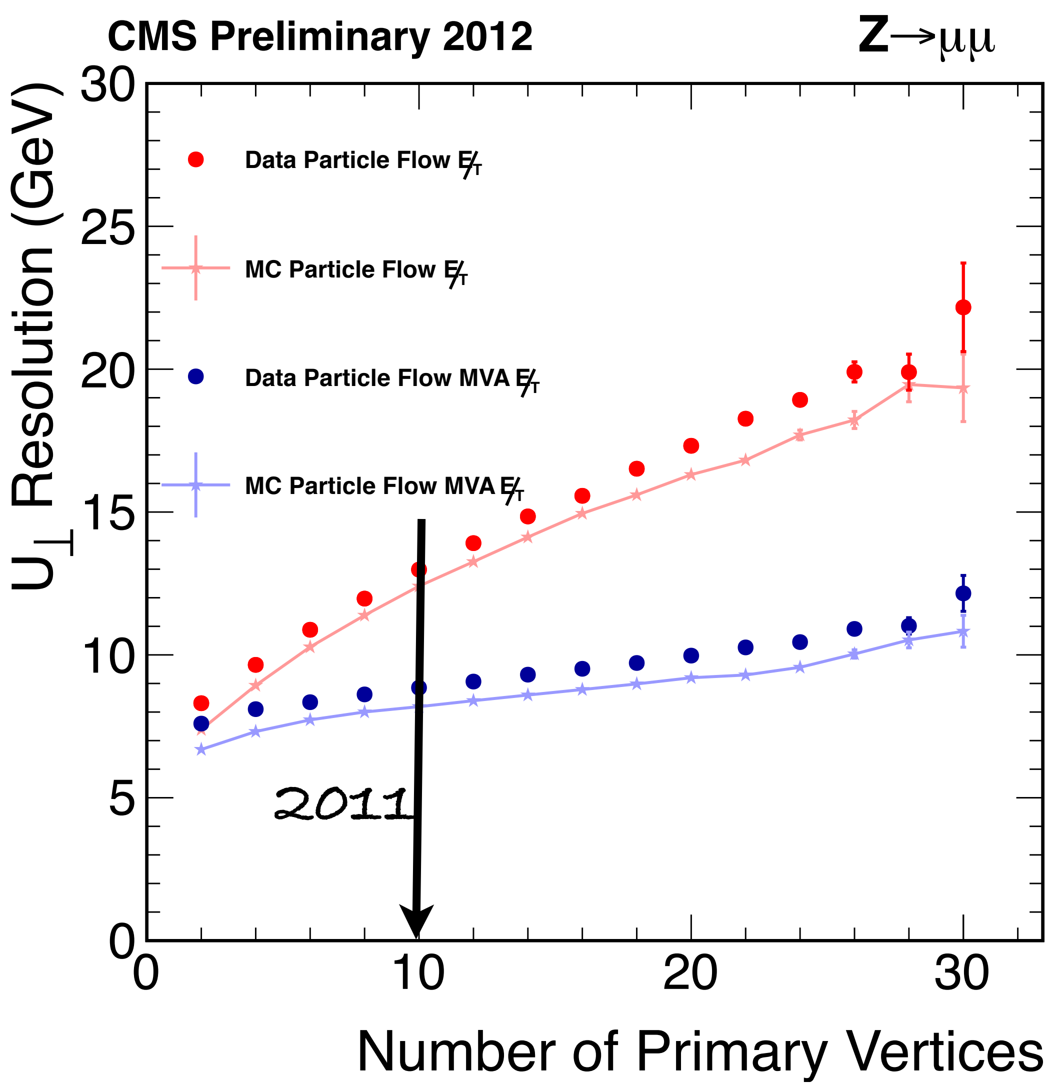
All channels combined,
Best fit $\mu=0.7\pm0.5$

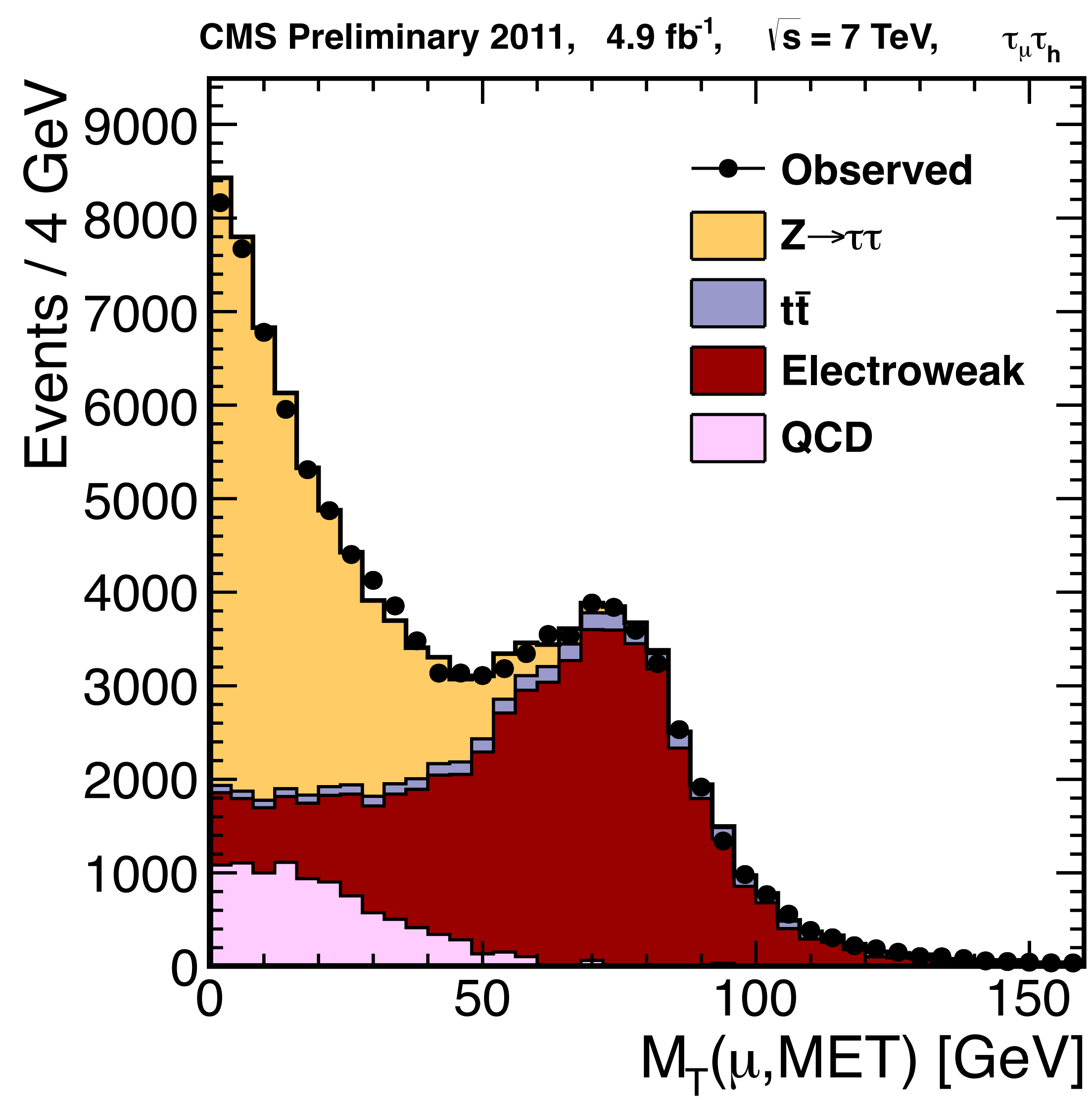
Sensitivity improves thanks to:

- addition of events
- revised MET reconstruction
- optimization of selections (<50% overlap with previous analysis for same data period)

H -> ττ MVA MET regression

$$m_T = \sqrt{2 p_T E_T^{miss}(1 - \cos(\Delta\phi))}$$

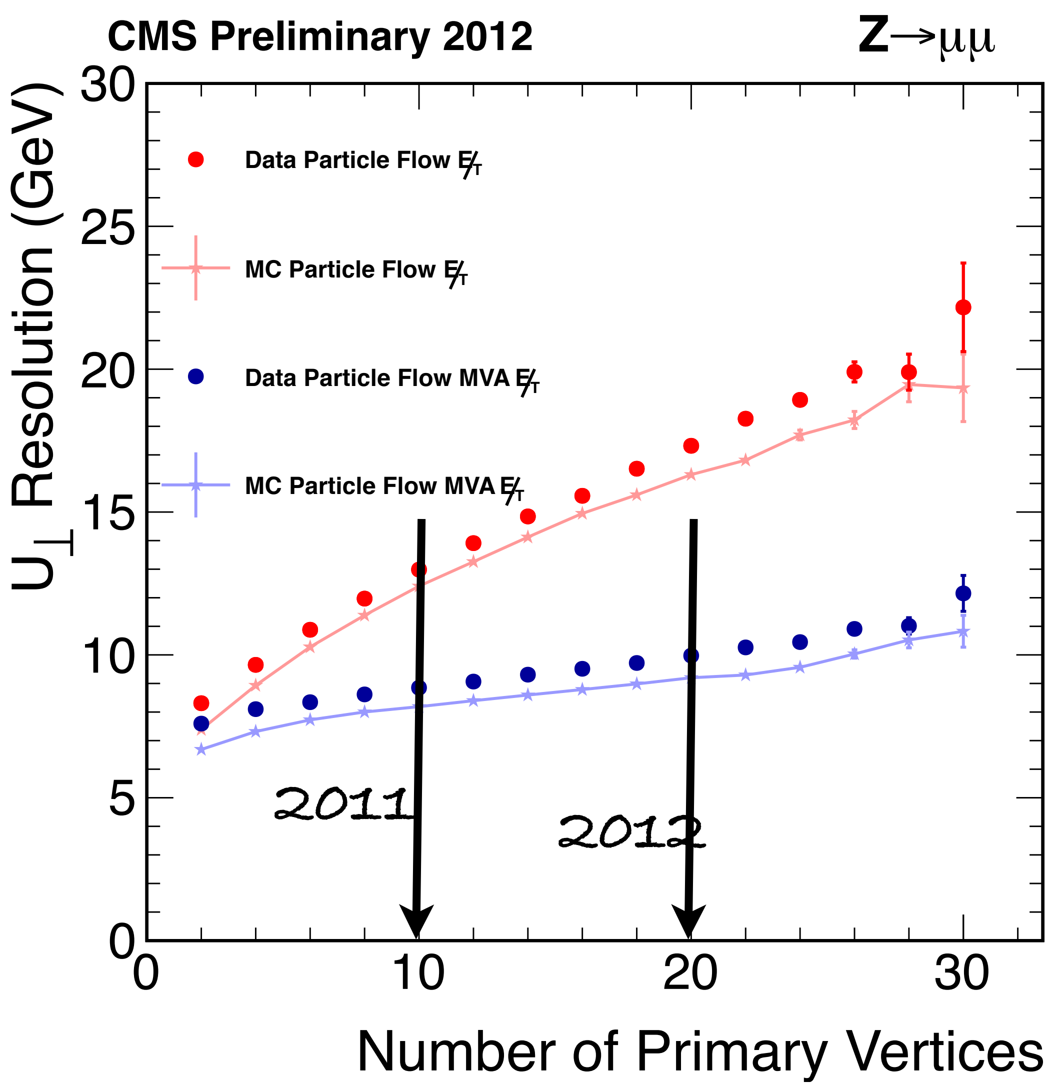


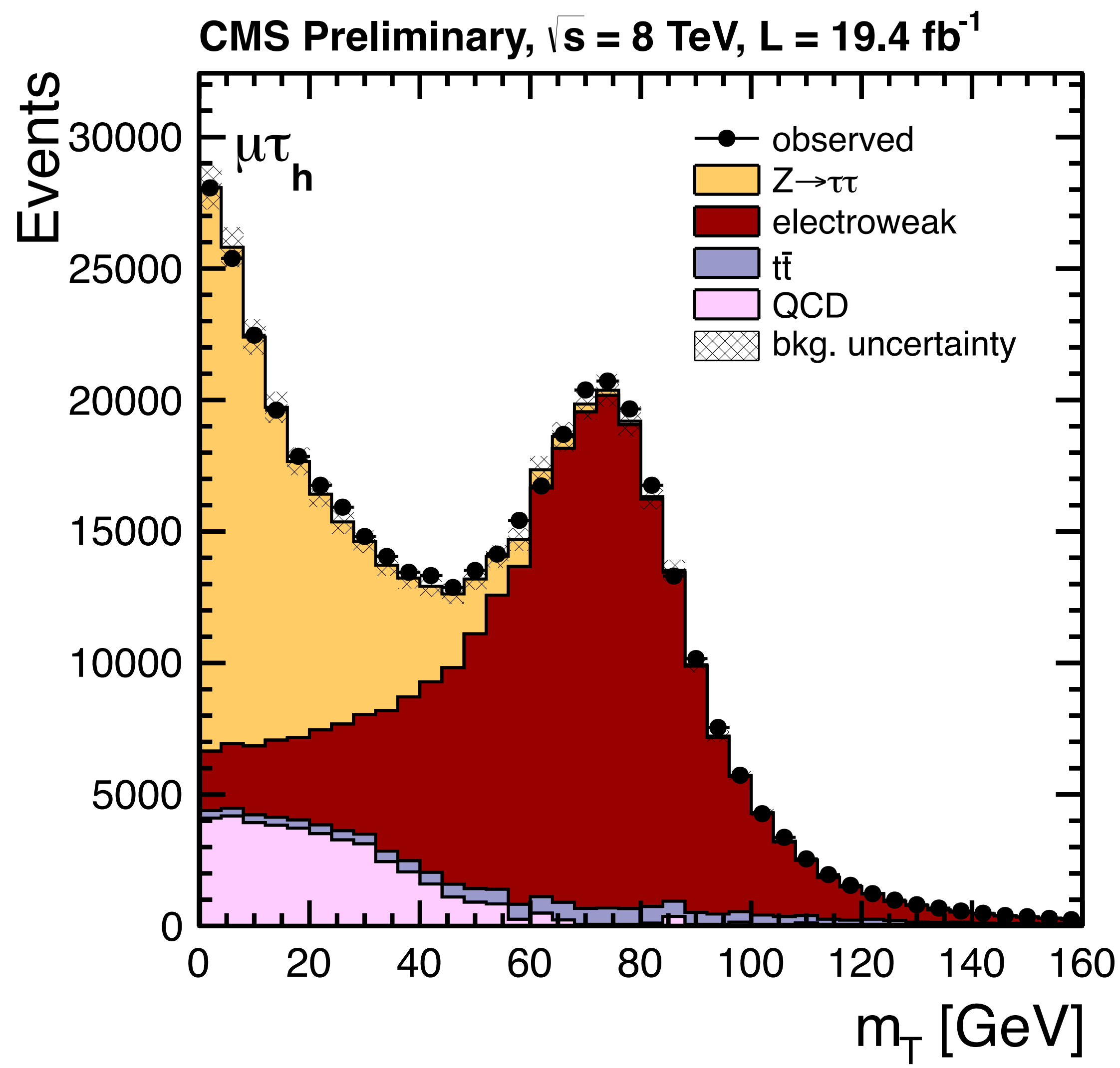


- significant improvement in resolution and pileup dependence
- crucial for H->ττ: best separation of signal from W+jets

MVA MET regression

$$m_T = \sqrt{2 p_T E_T^{miss}(1-\cos(\Delta\phi))}$$



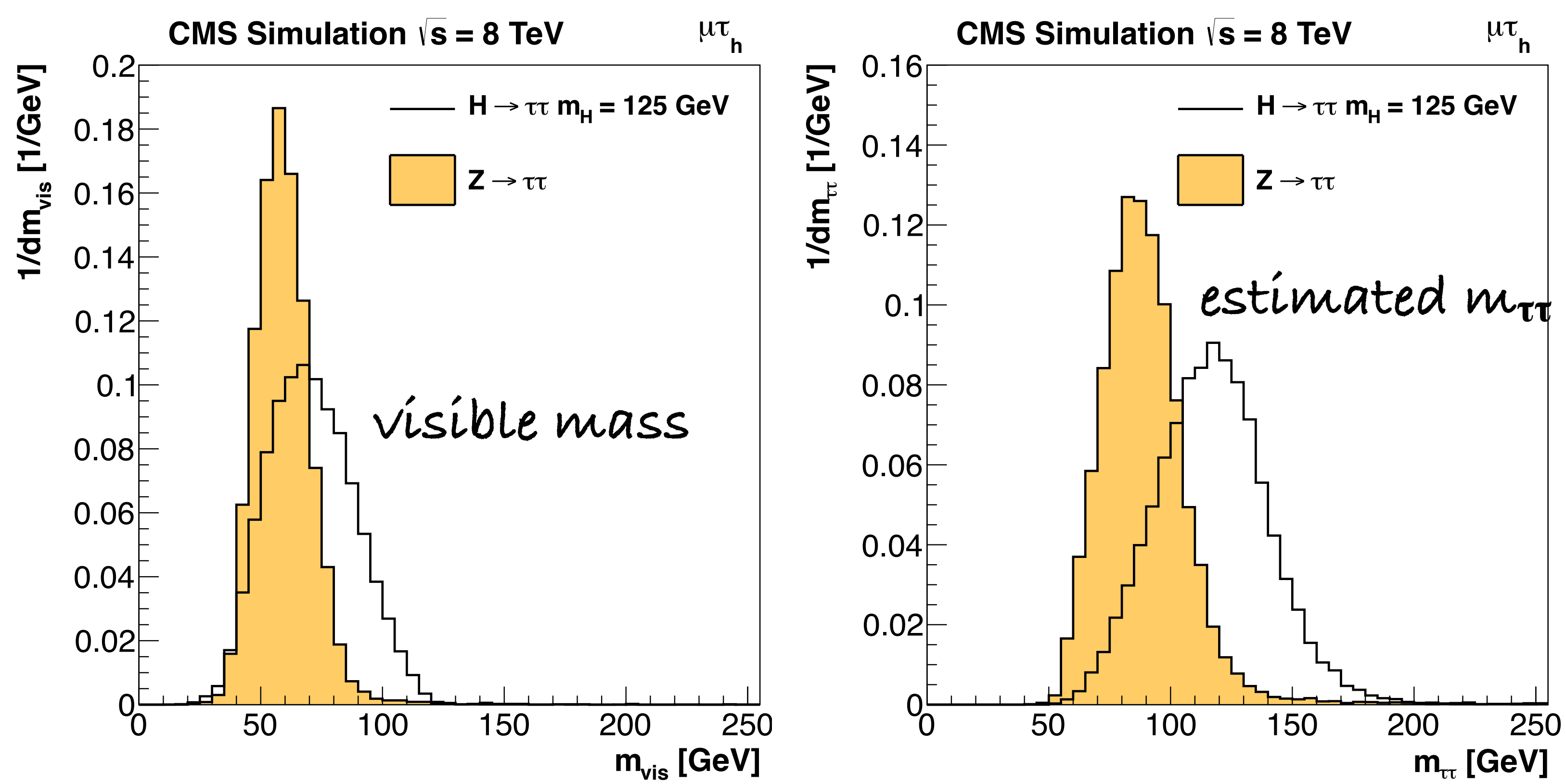


- significant improvement in resolution and pileup dependence
- crucial for H->ττ: best separation of signal from W+jets

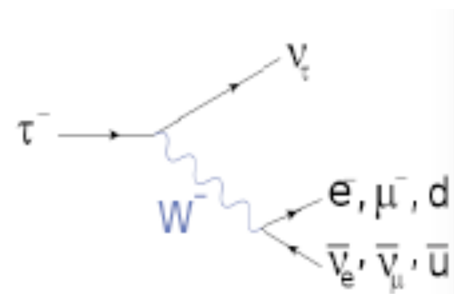
H -> ττ   Mττ resolution

2011 analysis in PLB: Phys. Lett. B 713(2012) 68-90

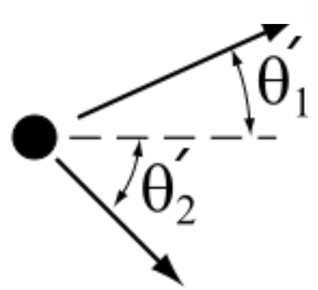
H/Z separation



- also new 2012
  - Improved tau ID new mass reconstructions better mass resolution)



$\mathcal{L}$ =



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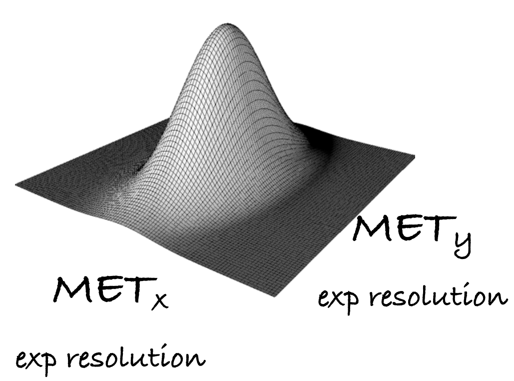

- Event-by-event estimator of true m(ττ) likelihood using momenta of visible decay products, angles and MET directions and expected resolution

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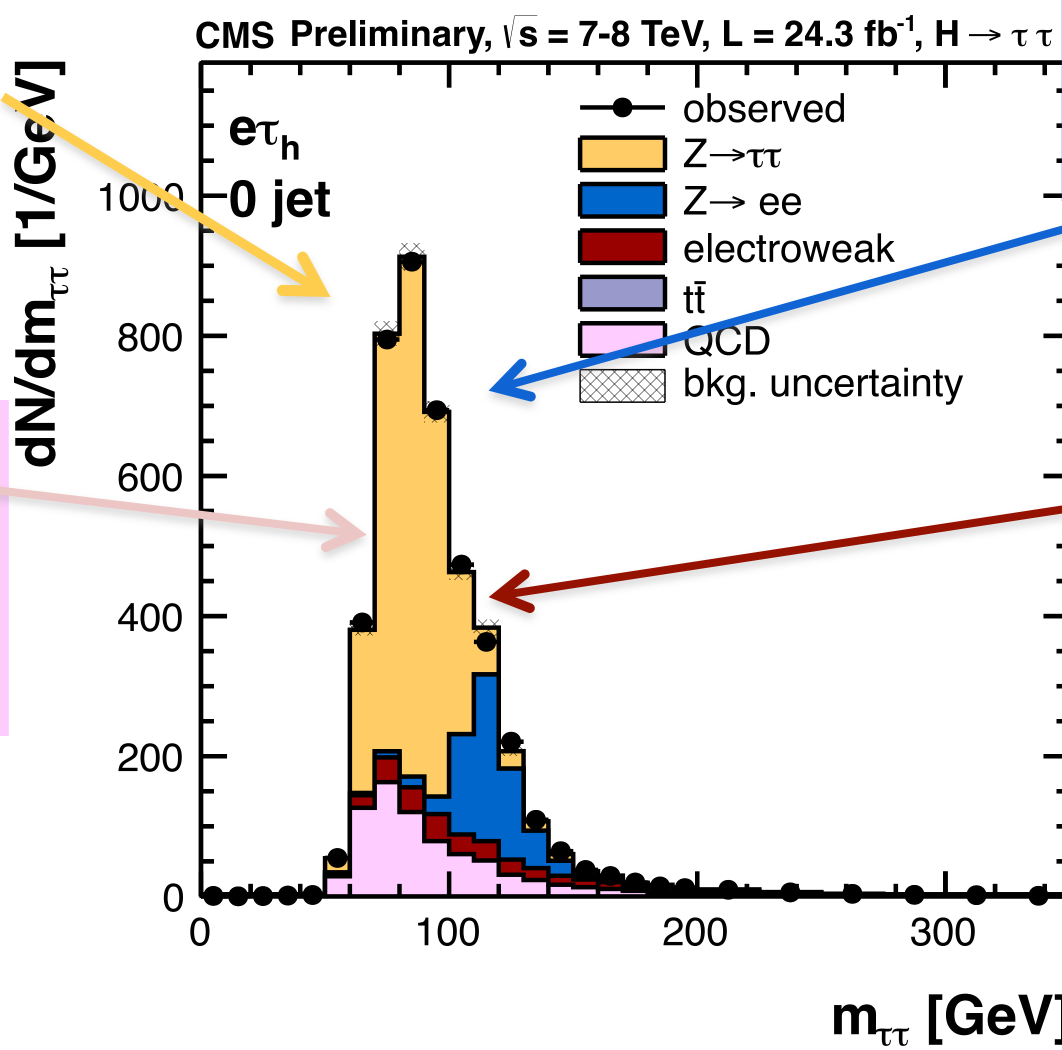
H -> ττ Backgrounds

- Backgrounds measured as much as possible form data

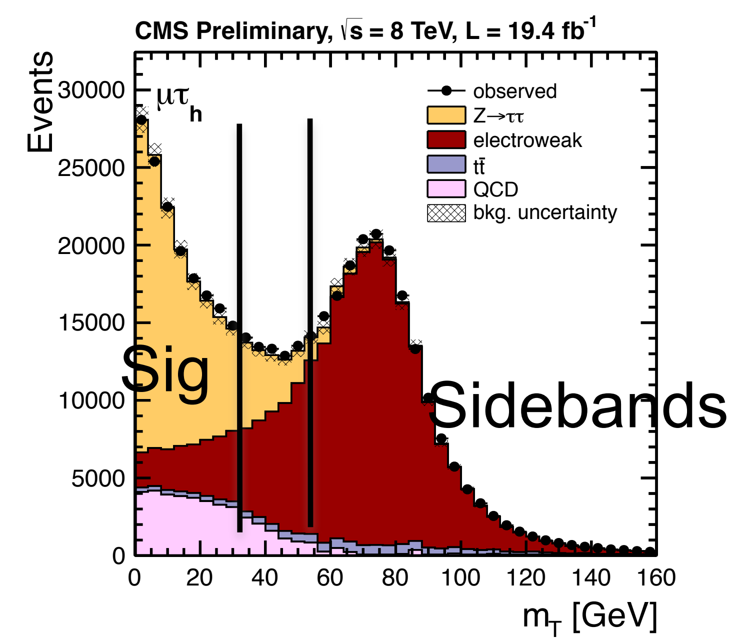
Z→ττ
Embedding: Z→$\mu\mu$ data, replace μ with simulated τ decay
Normalization from Z→$\mu\mu$ data

QCD - estimated from same sign data, corrected for SS/OS ratio



DY→ll – from MC but correcting the l→ τ fake rate

EWK – mostly W+jets: using M_T sidebands and angles between MET and τs



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$H \to \tau\tau$ Analysis strategy

number of jets (p_T>30) — $\mu\tau_h$, $e\tau_h$, $e\mu$, $\mu\mu$

τ p_T

0 Jet, Low p_T
High background

1 Jet, Low p_T
Enhancement from jet requirement

VBF
2 jets, no jets in rapidity gap
mjj>500

0 Jet, High pT
Lepton p_T spectrum harder from H

1 Jet, High p_T
Enhancement from p_T and jet requirement

$\tau_h\tau_h$ **1 Jet**
high p_T(H) requirement

$\tau_h\tau_h$ **2 Jet (VBF)**
high p_T(H) requirement
mjj>250

- Search performed in 5 tau-pair final states: $\mu\tau_h$, $e\tau_h$, $e\mu$, $\mu\mu$, $\tau_h\tau_h$
- Select isolated, well-identified leptons, τ_h + topological cuts (e.g. m_T in $l\tau_h$) to suppress backgrounds
- Categorize events based on number of jets, τ p_T
- Template fit to $m_{\tau\tau}$ shape

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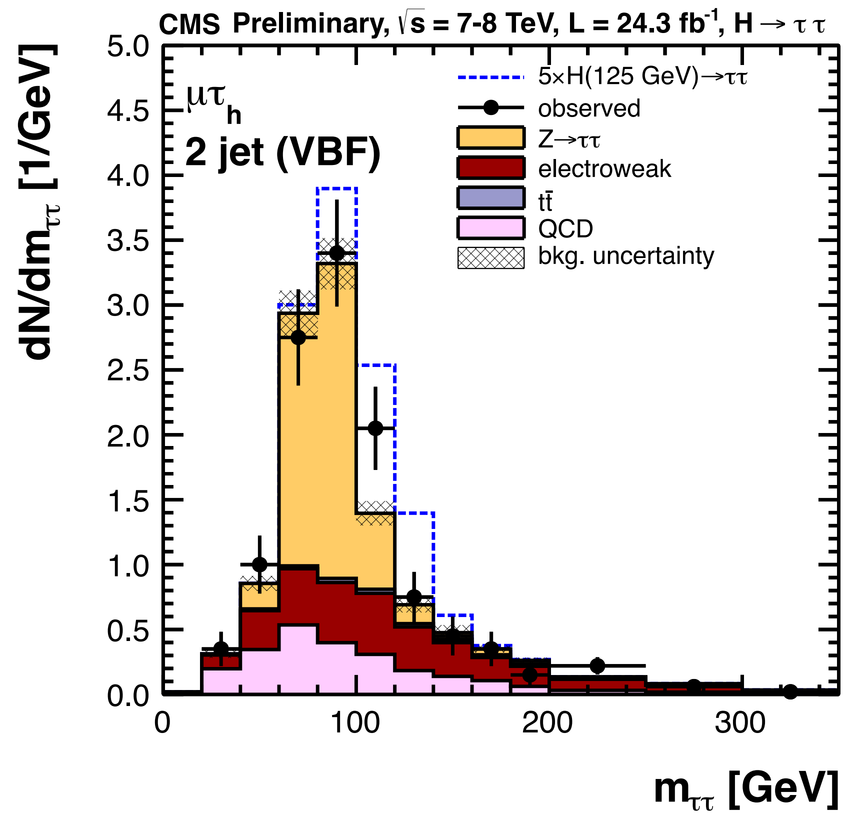
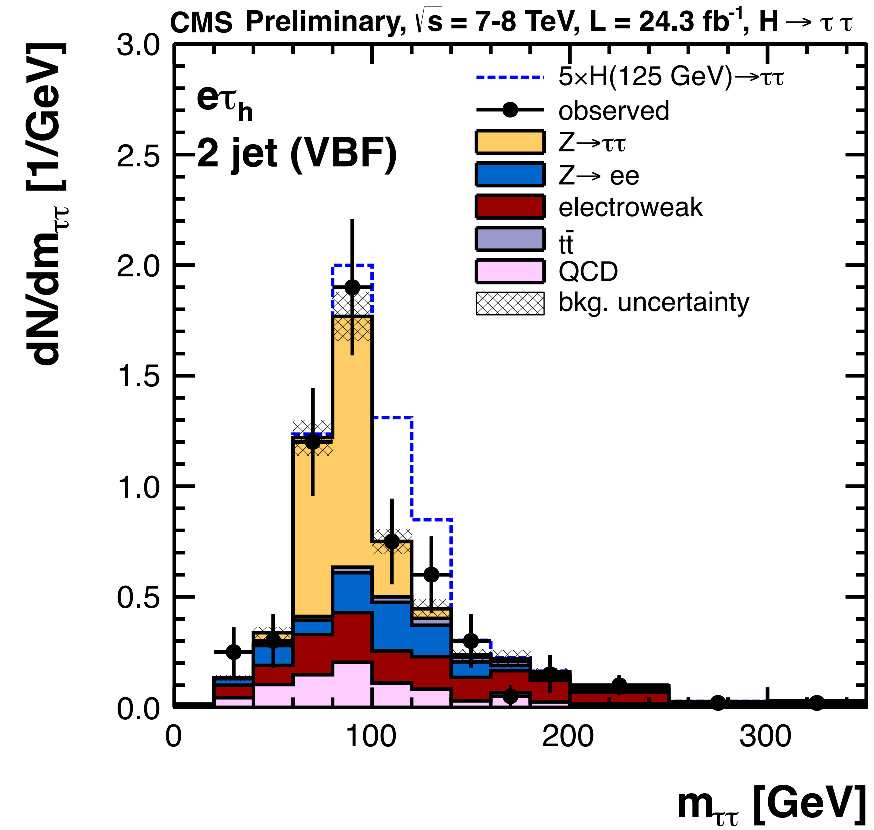
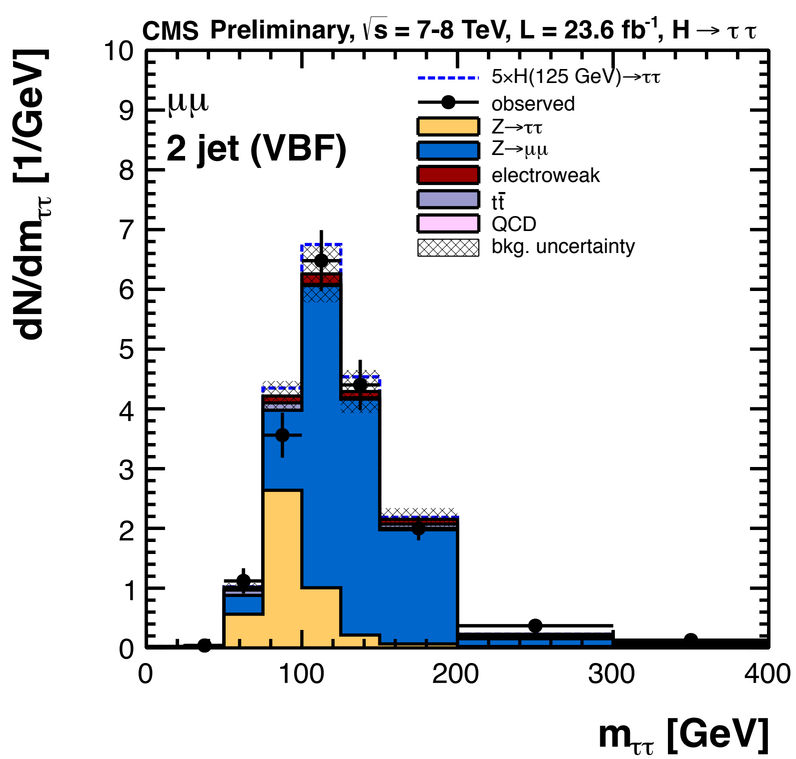
$H \to \tau\tau$ $m_{\tau\tau}$ distributions

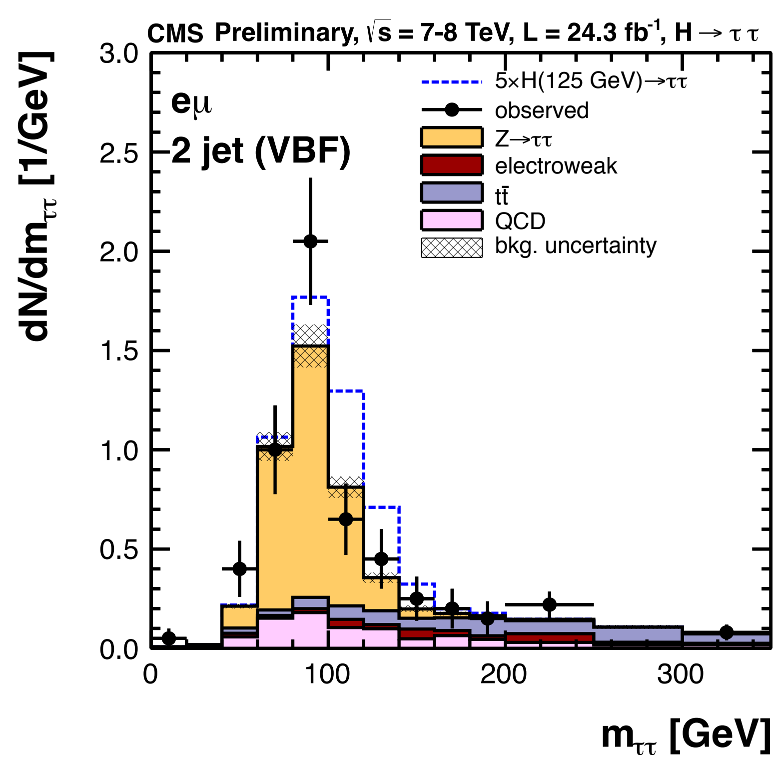
7 TeV(2011)	8TeV(2012)
5 fb^{-1}	19 fb^{-1}

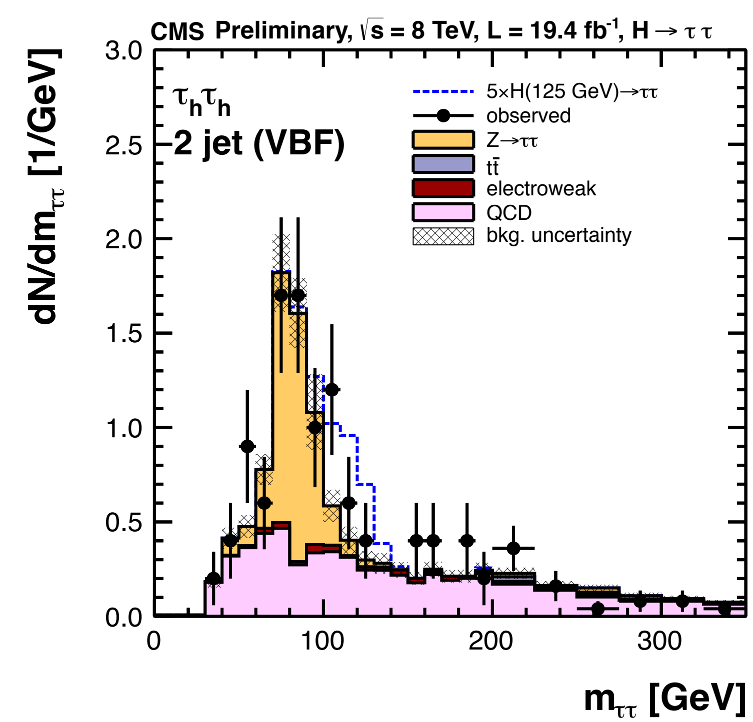
2-jet (VBF)
category with best S/B











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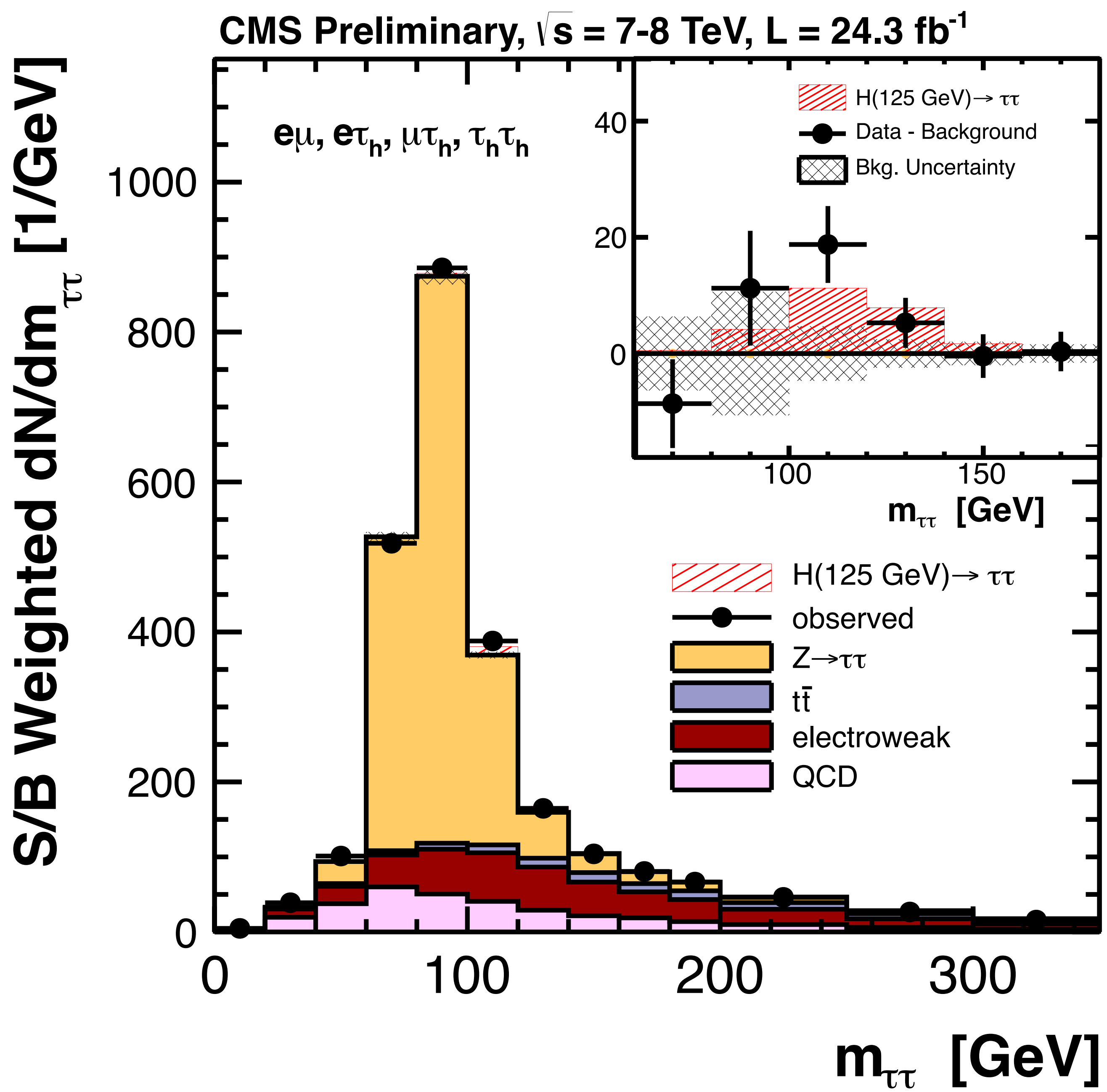
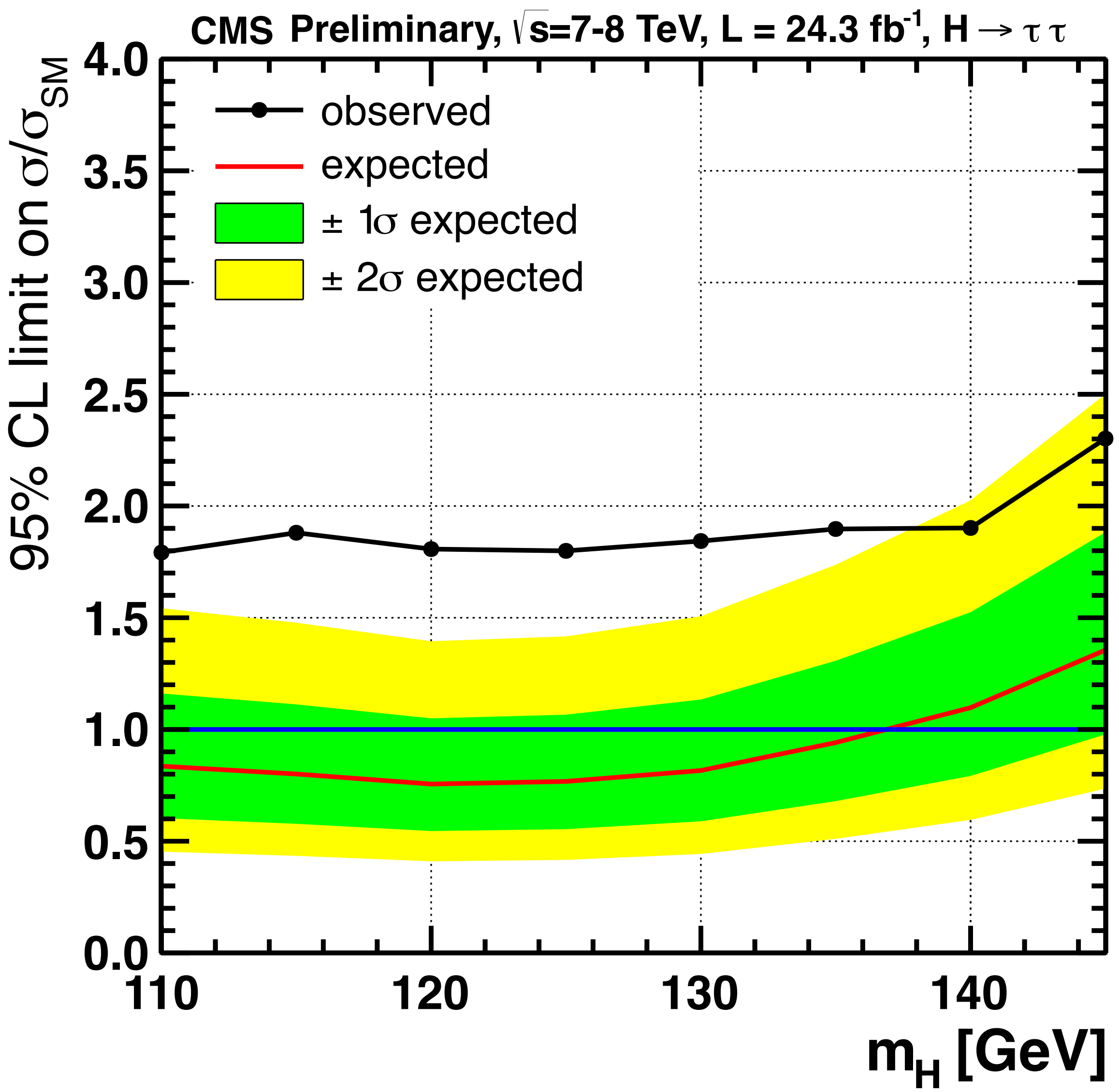
H -> ττ combined $m_{\tau\tau}$

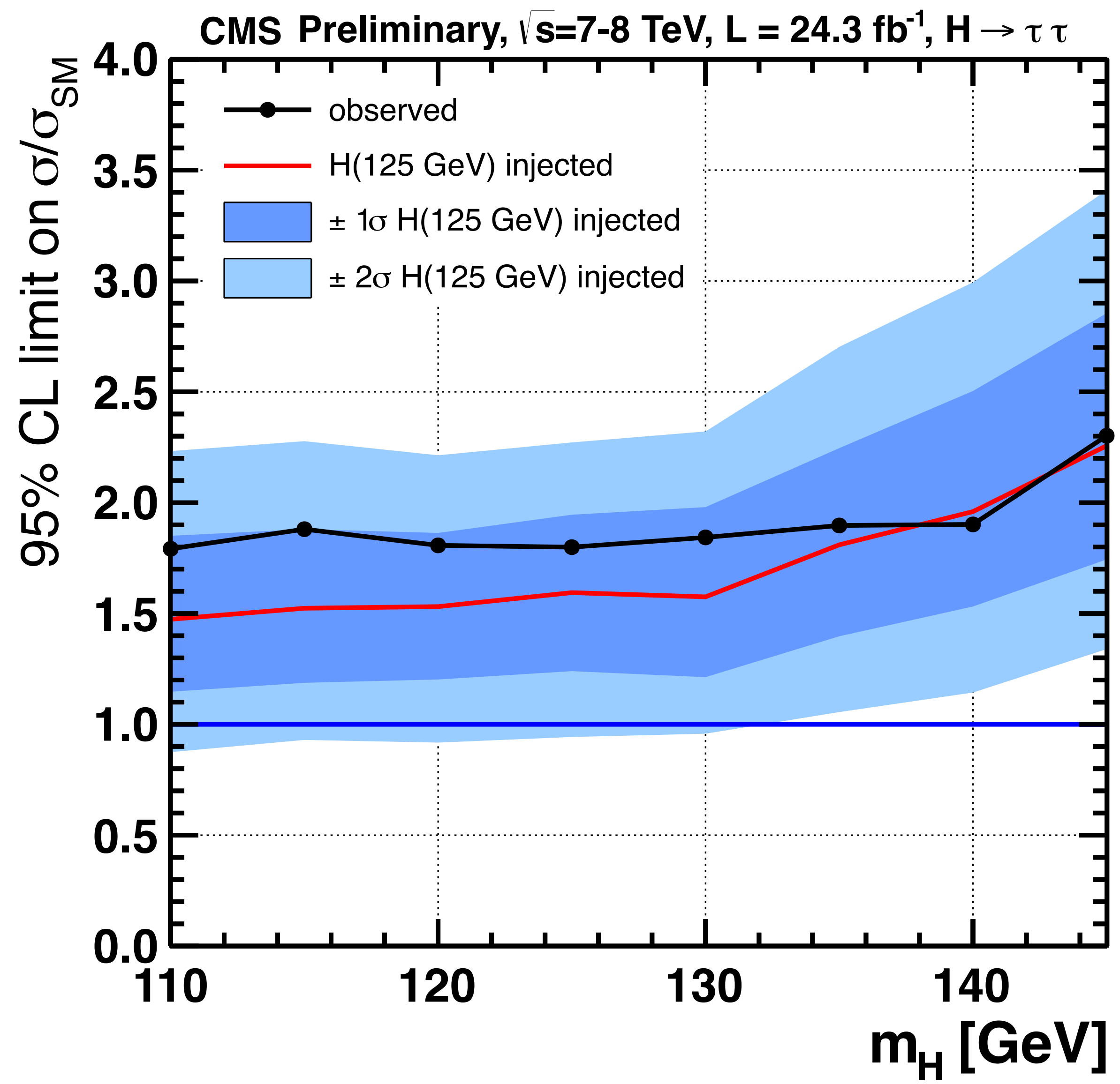
- 1jet + VBF



Combined channels and categories, each category in each channel weighted by its S/B

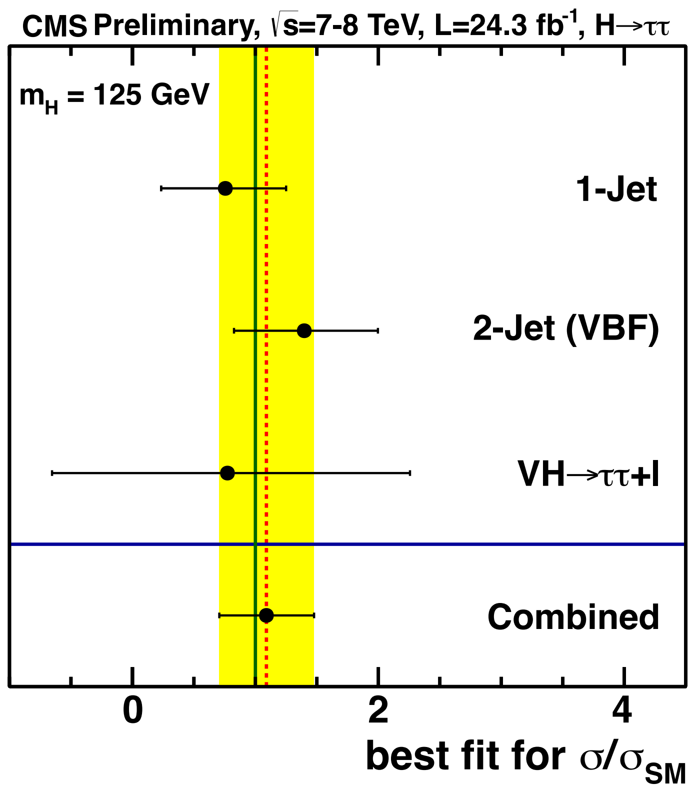
H -> ττ Limits



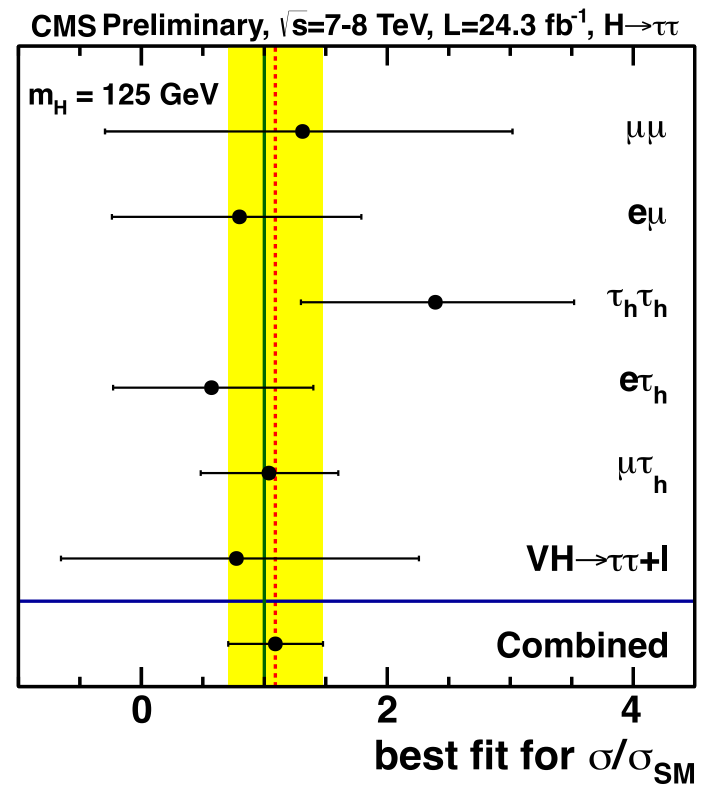


- Results consistent with expectation for background + SM scalar at 125 GeV

H -> ττ Signal strength and significance

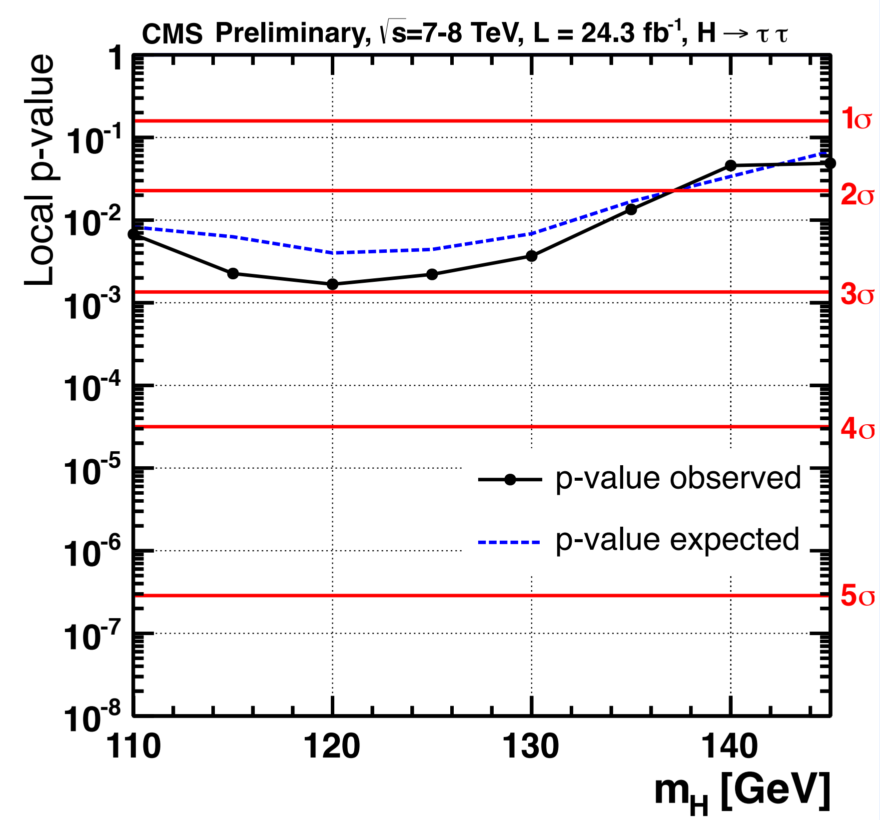


by category



by channel

- Broad excess observed over range of *m*H
- Maximum local significance of **2.93σ** at 120 GeV, compatible with presence of 125 GeV SM scalar boson
- Observed (expected) significance of **2.85σ** (**2.62σ**) for *m*H = 125 GeV



- Consistent picture across channels and categories
- Combined best-fit $\hat{\mu}$ of **1.1±0.4**

Michele de Gruttola

Conclusions

Conclusions

METRO

News Sport Guilty Pleasures Ents & Tech Life & Style

UK World Weird Money

'God particle' found by Large Hadron Collider scientists, hours after new Pope elected

Thursday 14 Mar 2013 10:57 am

But they remain unsure whether it might be the most-prized 'super-Higgs', which would transform previous ideas of how the universe began, or a 'mere' Standard Model boson – which would at least confirm existing theories.

Michele de Gruttola

Conclusions

- CMS showed preliminary results on taus with full 2011 + 2012 data (~23 fb-1) and the majority of the dataset (19 fb-1) for VH->bb
- Strong indication that the new discovered boson at 125 GeV decays to taus
  - Obs significance of H->ττ 2.85σ and signal strengh 1.1 ± 0.4
- broad excess also in VHbb
  - Obs significance of H->bb 2.2σ and signal strengh 1.3 ± 0.7
- Public results based on partial statistics on ttH and exclusion of MSSM Φ->bb and Φ->ττ (see back-up)

CMS is working to analyze all data and/or finalize the analysis for final publication on 7+8 TeV data, stay tuned for Summer Conferences

BACK UP

VHbb: Bkg Control Regions

Definition of Control Regions (CR) crucial element of the analysis

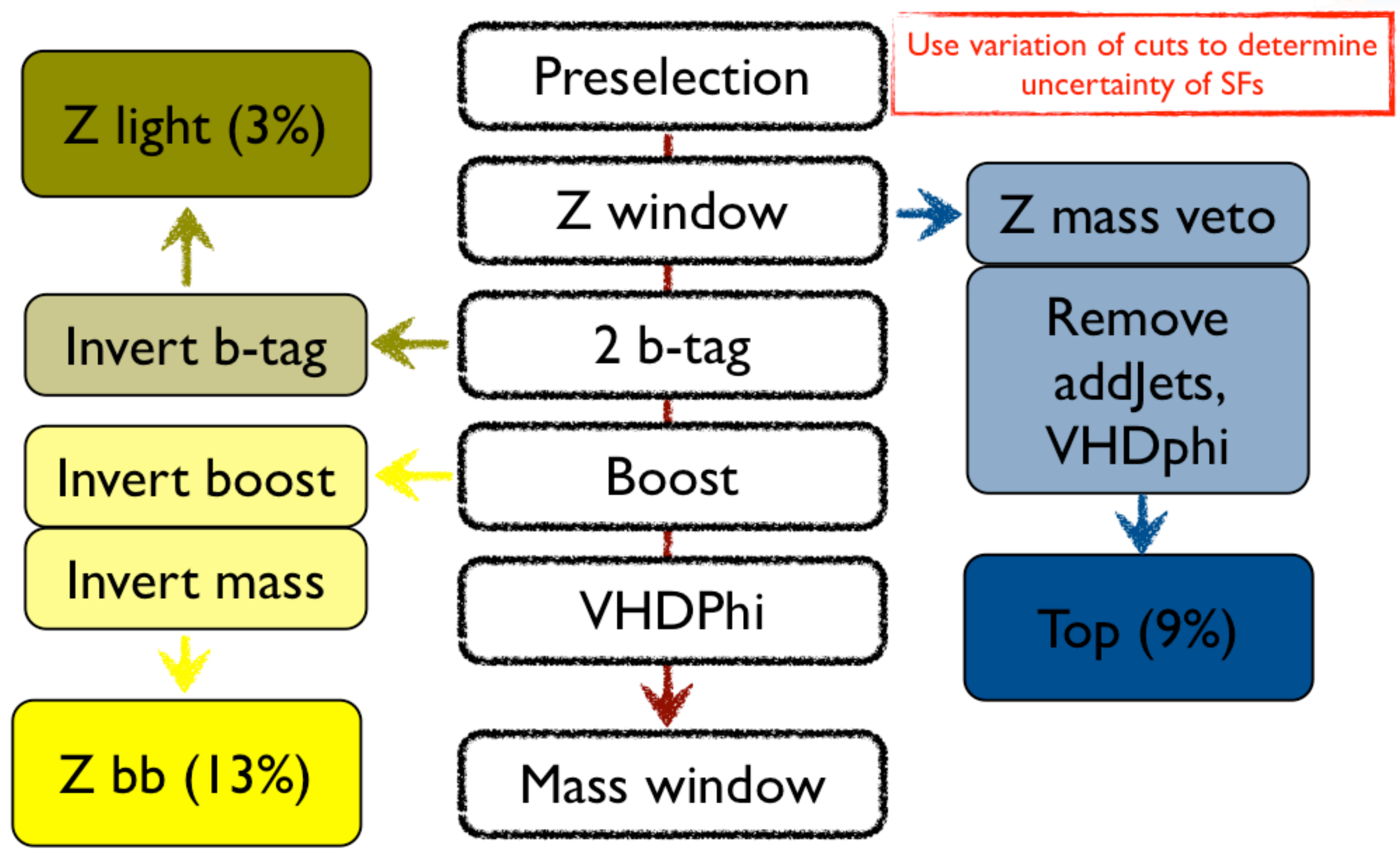
Define several CR enriched in different background components:

Control regions cuts as close as possible to the signal region

Renormalize MC simulation yields and extrapolate to signal region

Account for associated stat. and syst. uncertainties

Example: Zee control region definition



(%)= uncertainty

VHbb

BDT input variables	
p_{Tj}	transverse momentum of each Higgs daughter
m(jj)	dijet invariant mass
p_T(jj)	dijet transverse momentum
p_T(V)	vector boson transverse momentum (or E_T^{miss})
CSV_{max}	b-tag disc. value for Higgs daughter with largest value
CSV_{min}	b-tag disc. value for Higgs daughter with second largest value
$\Delta\phi$(V, H)	azimuthal angle between V (or E_T^{miss}) and dijet
$\lvert\Delta\eta(jj)\rvert$	difference in η between Higgs daughters
ΔR(jj)	difference in η-ϕ between Higgs daughters
N_{aj}	number of additional jets
$\Delta\phi(E_T^{miss}$, jet)	azimuthal angle between E_T^{miss} and closest jet (only for Z(vv)H)
$\Delta\theta_{pull}$	color pull angle

H->bb systematics

Source	Range
Luminosity	2.2%
Lepton efficiency and trigger (per lepton)	3%
$Z(\nu\nu)H$ triggers	2%
Jet energy scale	2–3%
Jet energy resolution	3–6%
Missing transverse energy	3%
b-tagging	3–15%
Signal cross section (scale and PDF)	4%
Signal cross section (p_T boost, EWK/QCD)	5–10% / 10%
Signal Monte Carlo statistics	1-5%
Backgrounds (data estimate)	$\approx$ 10%
Diboson and single-top (simulation estimate)	30%

4.4% at 8 TeV

M. Ciccolini et al., "Strong and electroweak corrections to the production of Higgs+2jets via weak interactions at the LHC", Phys. Rev. Lett. 99 (2007) 161803, doi:10.1103/PhysRevLett.99.161803, arXiv:0707.0381.

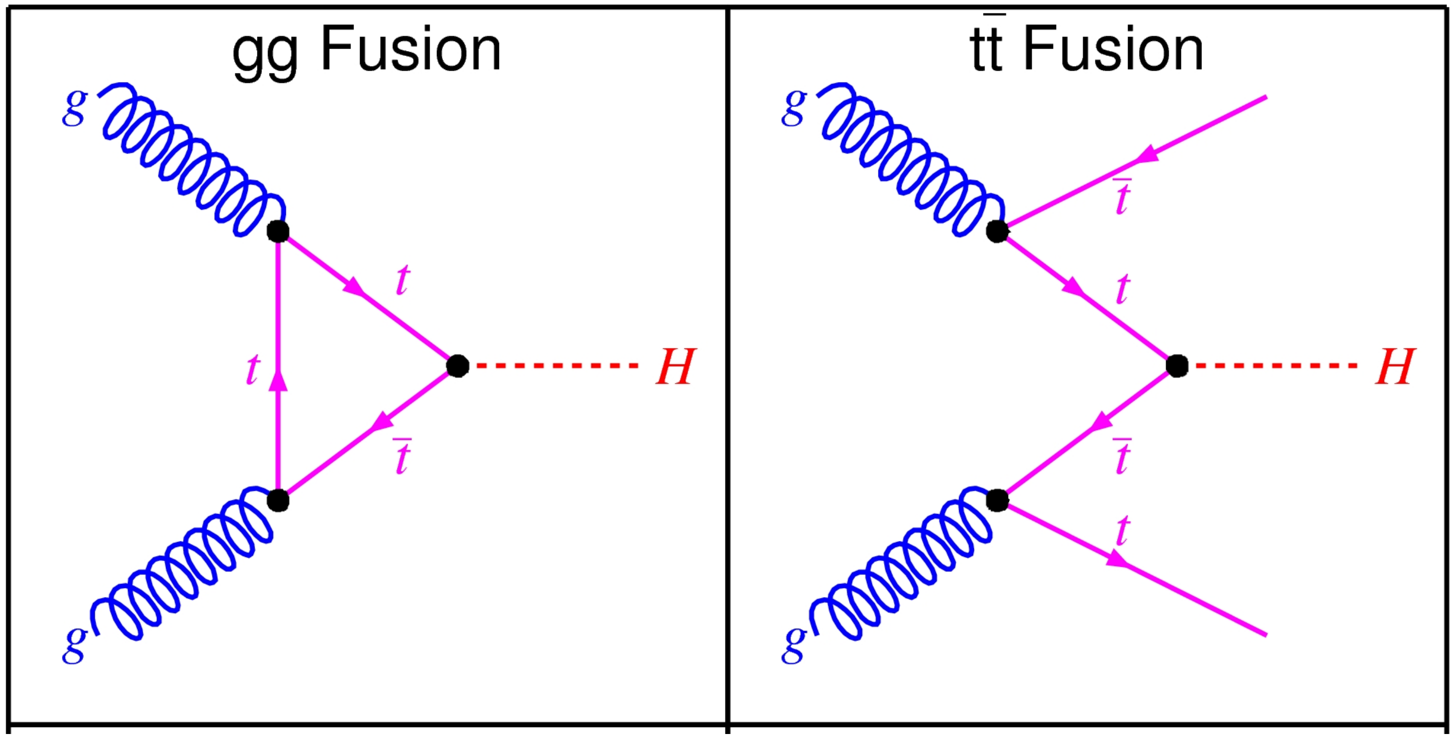
M. Ciccolini, A. Denner, and S. Dittmaier, "Electroweak and QCD corrections to Higgs production via vector-boson fusion at the LHC", Phys. Rev. D 77 (2008) 013002, doi:10.1103/PhysRevD.77.013002, arXiv:0710.4749.

A. Denner, S. Dittmaier, S. Kallweit et al., "Electroweak corrections to Higgs-strahlung off W/Z bosons at the Tevatron and the L HC with HAWK", (2011). arXiv:1112.5142.

Brand new

gg→tt(H)bb

Higgs fermions coupling both in production and decay



[CERN-PH-EP-2013-027]

$ttH \rightarrow ttbb$

*tt*H analysis and results

Directly probe *tt*H vertex

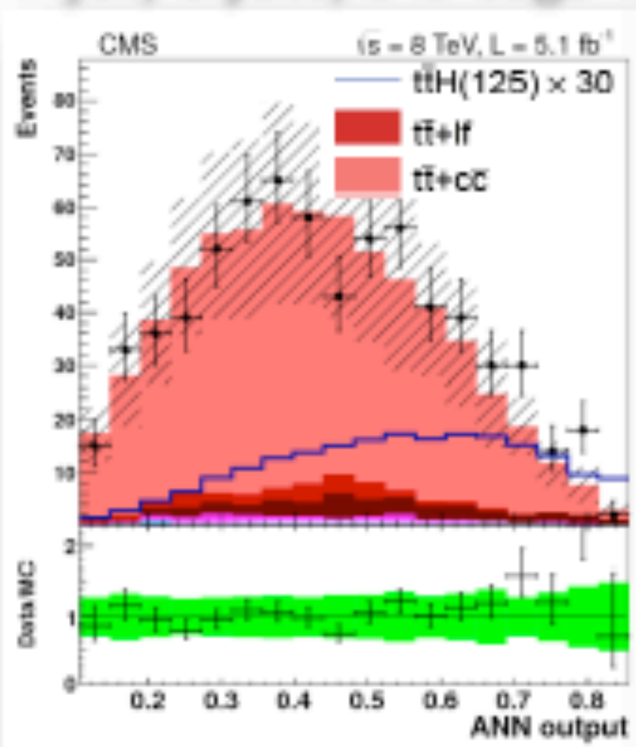
Dominant background: *tt*+jets

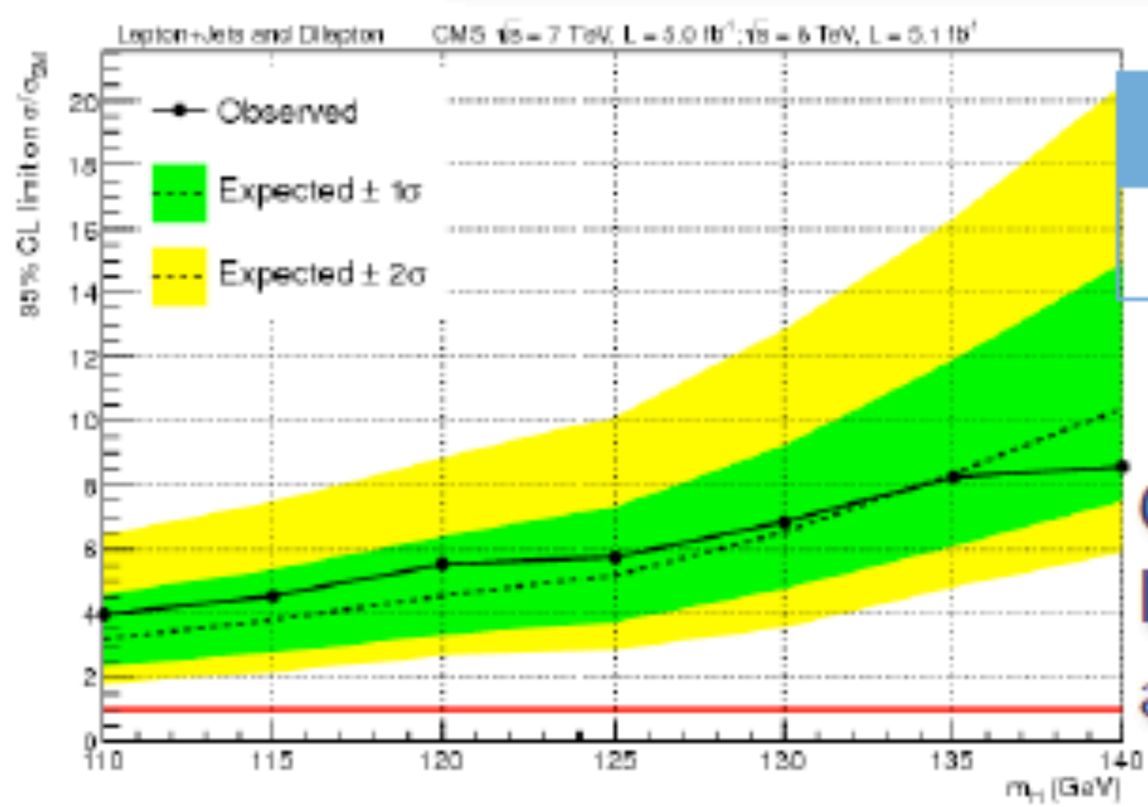
Search done for lepton+jets and dilepton final states

Strategy:

- 1-2 leptons + ≥ 2 jets + ≥ 2 b-tagged jets
- Categorize based on number of jets and number of b-tags
- Fit to output of neural network (ANN), inputs are b-tag information, kinematics and angular correlations

l+jet, 6 jets, 3 b-tags





7TeV (2011)	8TeV (2012)
5 fb^{-1}	5 fb^{-1}

Observed (expected) limit of **5.8** (**5.2**) x SM at 125 GeV

ttH

Source	Rate Uncertainty	Shape	Remarks
Luminosity (7 TeV)	2.2%	No	All signal and backgrounds
Luminosity (8 TeV)	4.4%	No	All signal and backgrounds
Lepton ID/Trig	4%	No	All signal and backgrounds
Pileup	1%	No	All signal and backgrounds
Additional Pileup Corr.	–	Yes	All signal and backgrounds
Jet Energy Resolution	1.5%	No	All signal and backgrounds
Jet Energy Scale	0-60%	Yes	All signal and backgrounds
b-Tag SF (b/c)	0-33.6%	Yes	All signal and backgrounds
b-Tag SF (mistag)	0-23.5%	Yes	All signal and backgrounds
MC Statistics	–	Yes	All backgrounds
PDF (gg)	9%	No	For gg initiated processes ($t\bar{t}$, $t\bar{t}Z$, $t\bar{t}H$)
PDF ($q\bar{q}$)	4.2-7%	No	For $q\bar{q}$ initiated processes ($t\bar{t}W$, W, Z).
PDF (qg)	4.6%	No	For qg initiated processes (single top)
QCD Scale ($t\bar{t}H$)	15%	No	For NLO $t\bar{t}H$ prediction
QCD Scale ($t\bar{t}$)	2-12%	No	For NLO $t\bar{t}$ and single top predictions
QCD Scale (V)	1.2-1.3%	No	For NNLO W and Z prediction
QCD Scale (VV)	3.5%	No	For NLO diboson prediction
Madgraph Scale ($t\bar{t}$)	0-20%	Yes	$t\bar{t}$+jets/$b\bar{b}$/$c\bar{c}$ uncorrelated. Varies by jet bin.
Madgraph Scale (V)	20-60%	No	Varies by jet bin.
$t\bar{t} + b\bar{b}$	50%	No	Only $t\bar{t} + b\bar{b}$.

H ->ττ

Table 2: Main systematic uncertainties entering the analysis. The ∓ symbol indicates that the uncertainty is anti-correlated with respect to other categories. The (*) symbol indicates correlation between separate channels. The (†) symbol indicates correlation between separate categories. In the instance where "ex. vbf" is indicated, an additional uncorrelated nuisance is added to account for statistical uncertainties.

Experimental Uncertainties		Propagation into Event Categories		
Uncertainty	Uncert.	*0-Jet*	*1-Jet*	*VBF*
Electron ID & Trigger (†*)	±2%	±2%	±2%	±2%
Muon ID & Trigger (†*)	±2%	±2%	±2%	±2%
Tau ID & Trigger (†)	±8%	±8%	±8%	±8%
Tau Energy Scale (†)	±3%	±3%	±3%	±3%
Electron Energy Scale (†)	±1%	±1%	±1%	±1%
JES (Norm.) (†*)	±2.5 – 5%	∓3 – 15%	±1 – 6%	±5 – 20%
MET (Norm.) (†*)	±5%	±5 – 7%	±2 – 7%	±5 – 8%
b-Tag Efficiency (†*)	±10%	∓2%	∓2 – 3%	∓3%
Mis-Tagging (†*)	±30%	∓2%	∓2%	∓2 – 3%
Norm. Z production (†*)	±3%	±3%	±3%	±3%
$Z \to \tau\tau$ Category	±3%	±0 – 5%	±3 – 5%	±10 – 13%
Norm. $t\bar{t}$ (†* ex.vbf)	±10%	±10%	±10%	±12 – 33%
Norm. Diboson (†* ex. vbf)	±15 – 30%	±15 – 30%	±15 – 30%	±15 – 100%
Norm. QCD Multijet	±6 – 32%	±6 – 32%	±9 – 30%	±19 – 35%
Lumi 7 TeV (8 TeV)	±2.2(4.2)%	±2.2(4.2)%	±2.2(4.2)%	±2.2(4.2)%
Norm. W+jets	±10 – 30%	±20 – 27%	±10 – 33%	±12.4% – 30%
Norm. $Z \to \ell\ell$: e fakes τ_h (†)	±20%	±20%	±36%	±22%
Norm. $Z \to \ell\ell$: μ fakes τ_h (†)	±30%	±30%	±30%	±30%
Norm. $Z \to \ell\ell$: jet fakes τ_h	±20%	±20%	±20%	±40%

MSSM search overview

CMS-PAS-HIG-12-050

Higgs sector: 2 Higgs doublets, 5 observable Higgs bosons

- 3 neutral: **H**, **h** (CP-even); **A** (CP-odd)
- 2 charged: **$H^{\pm}$**

Coupling to down-type fermions enhanced for large tanβ

- current best sensitivity from $\Phi \rightarrow \tau\tau$

Production mechanisms: gluon fusion, associated production with *b* quarks

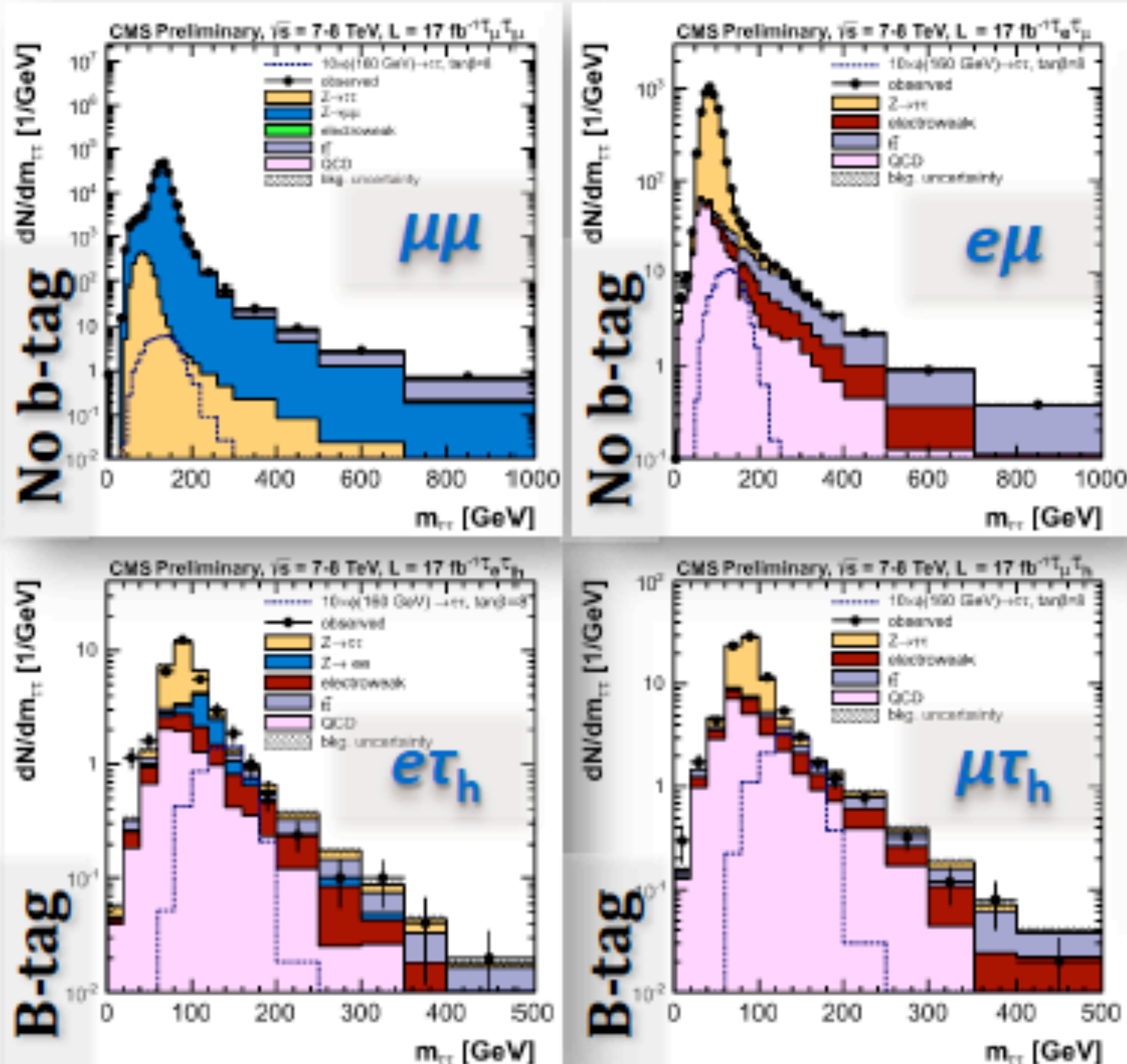
Strategy:

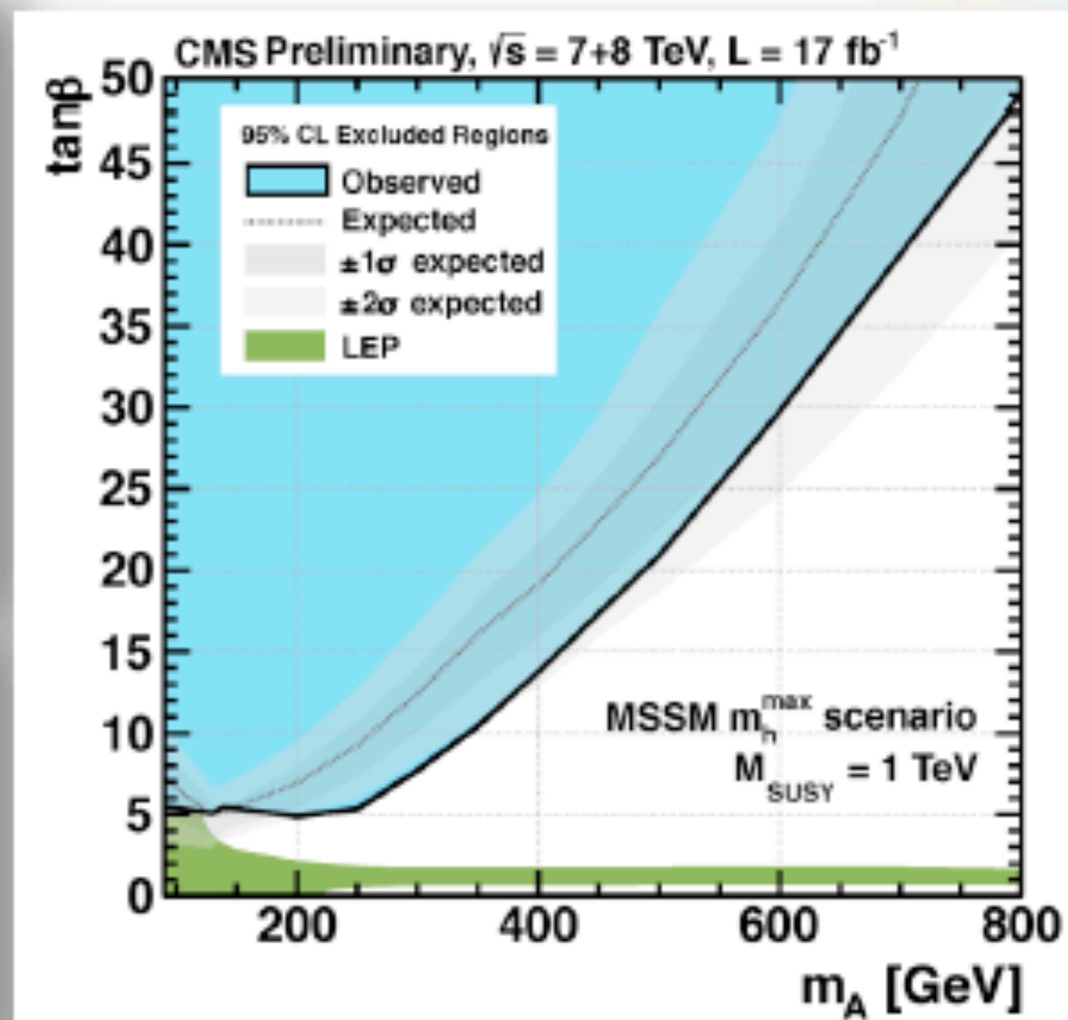
- Same object and topological selection as for SM search
- 2 event categories: b-tag (≥1 b-tagged jet, p_T > 20 GeV) and no b-tag
- Template fit to $m_{\tau\tau}$ shape

7TeV (2011)	8TeV (2012)
5 fb^{-1}	12 fb^{-1}

Φ -> ττ

Results



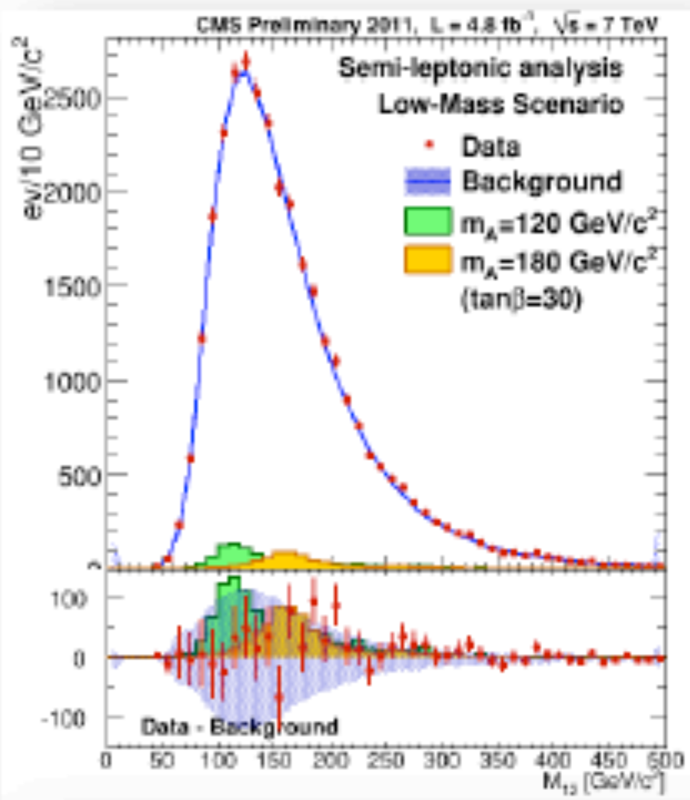


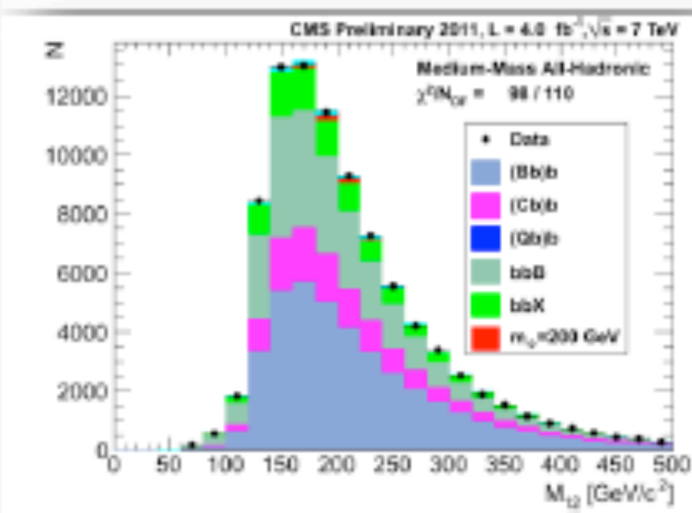
- Interpretation in m_h^{max} benchmark scenario
- Exclusion limit in m_A-tanβ parameter space

Φ -> bb

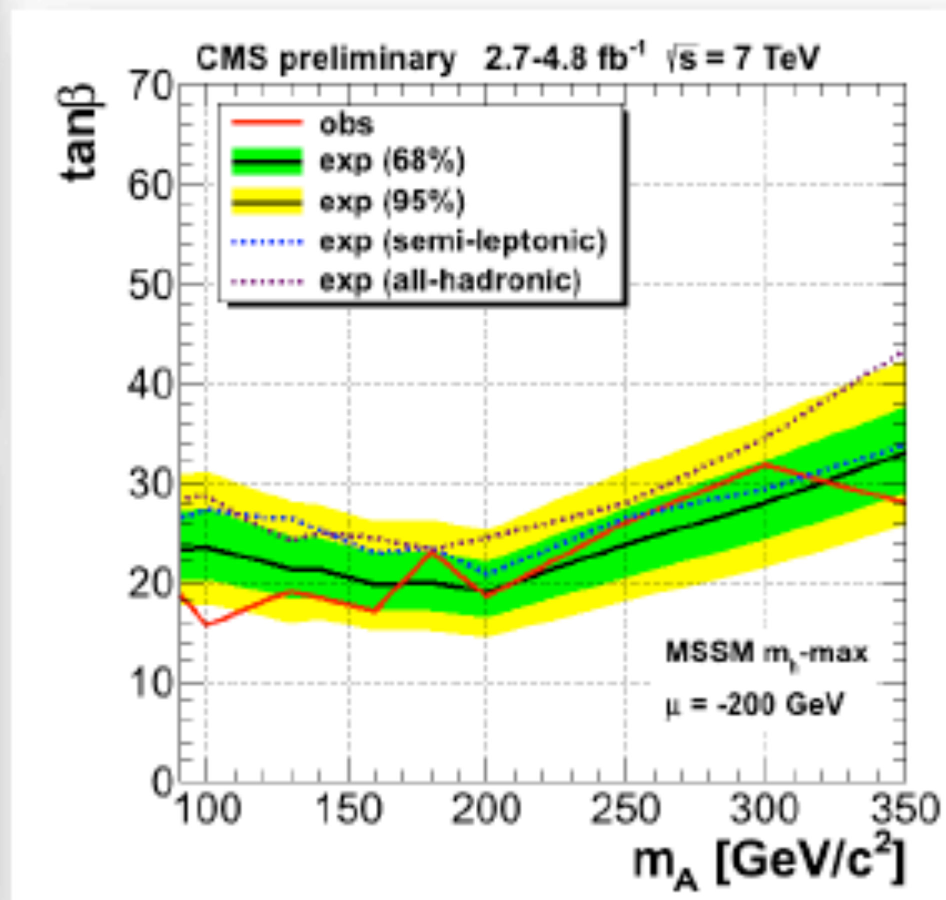
MSSM $b(b)\Phi$, $\Phi \rightarrow bb$

- Multijet final states with 3 b-tagged jets (one of which may include a non-isolated muon)
- Fit mass of 2 leading b-jets





CMS-PAS-HIG-12-026 CMS-PAS-HIG-12-027

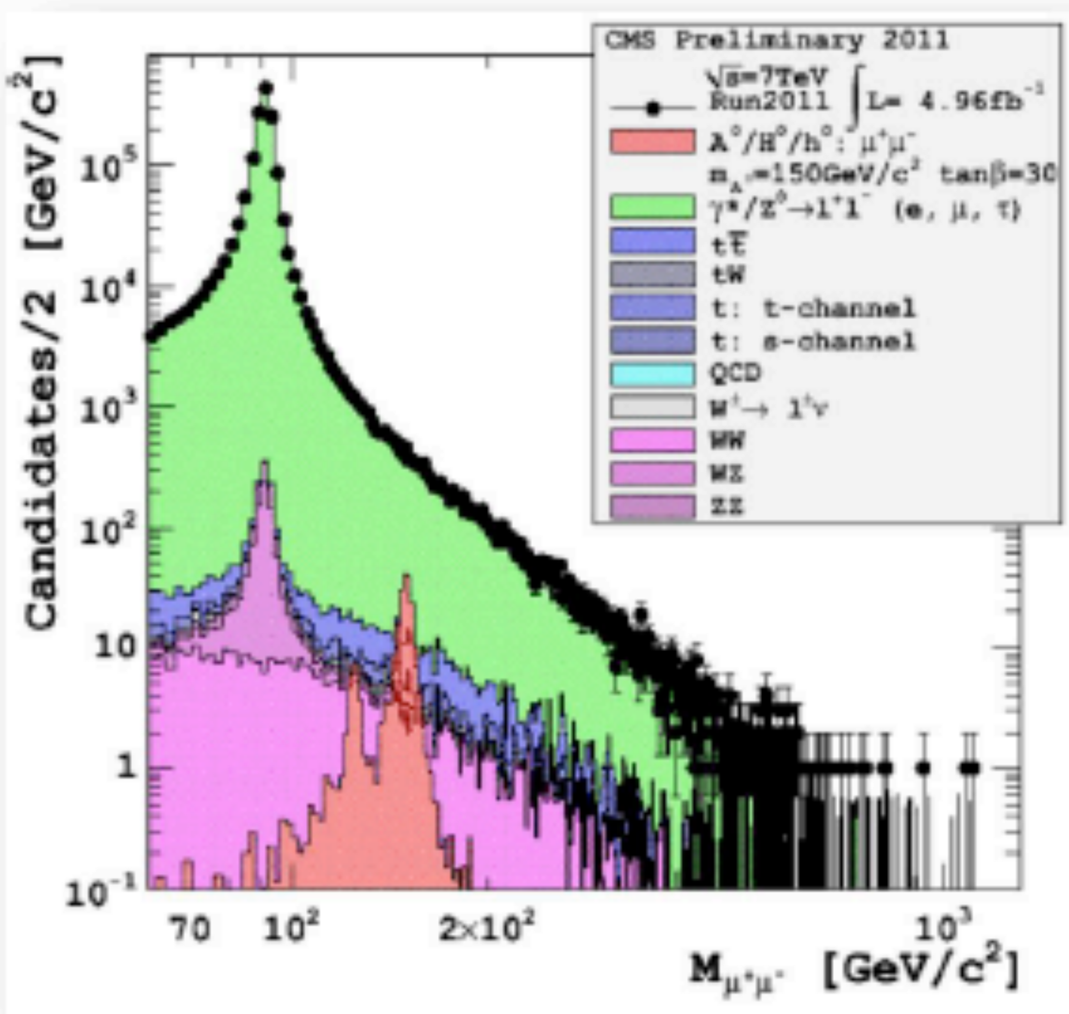


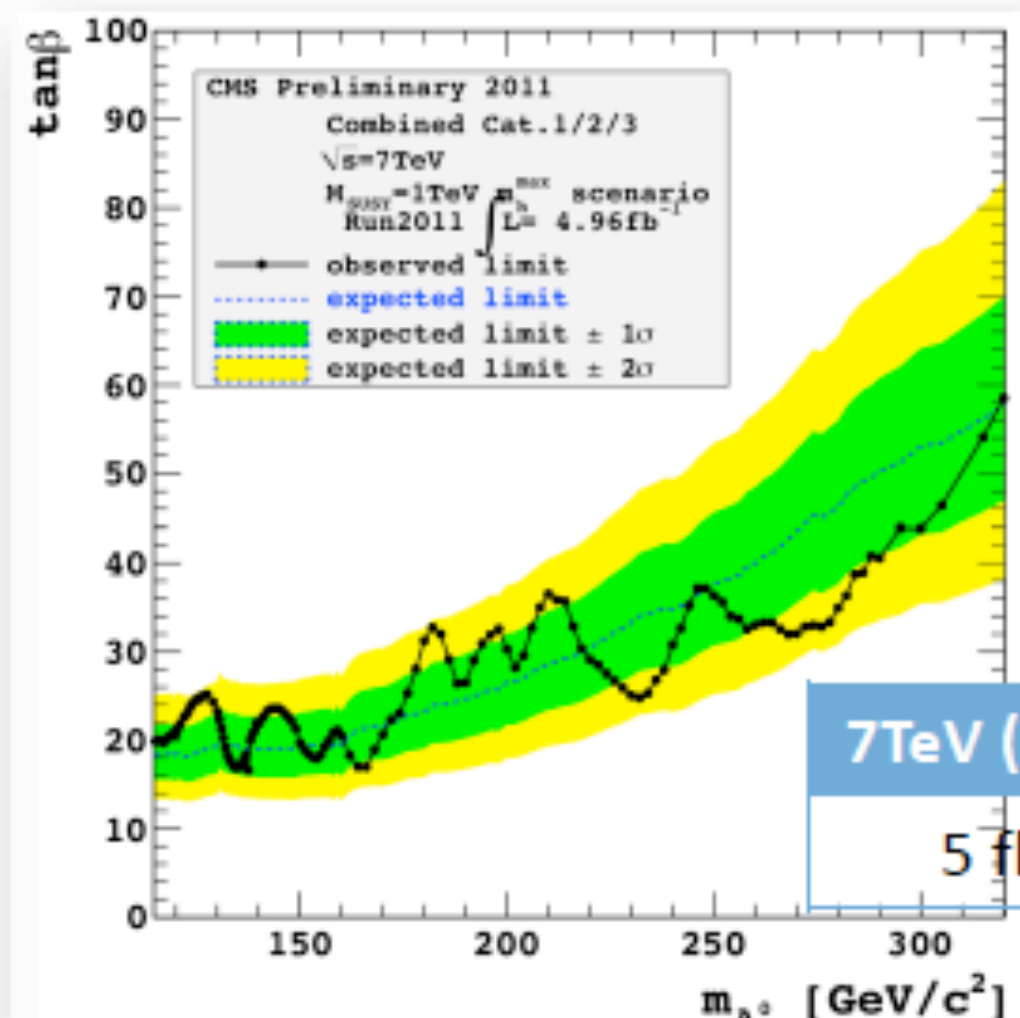
7TeV (2011)
3-5 fb^{-1}

MSSM Φ→μμ

CMS-PAS-HIG-12-011

- Sensitive to gluon-fusion, associated production with b-quarks
- Fit $m_{\mu\mu}$ in 3 categories: with a b-tagged jet, no b-tag but with additional muon from b decay, everything else





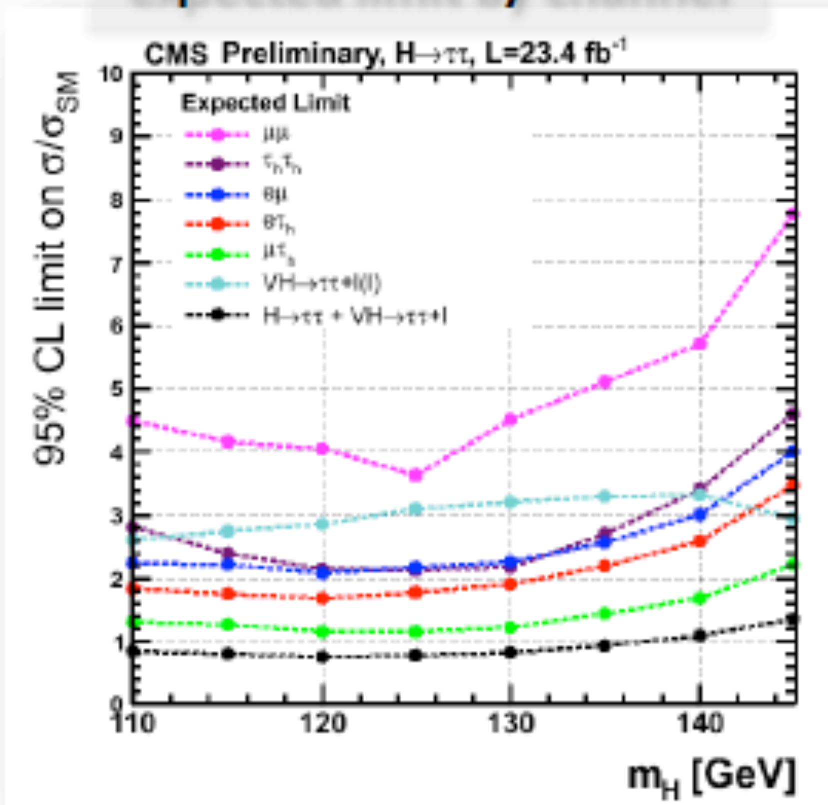
7TeV (2011)

5 fb^{-1}

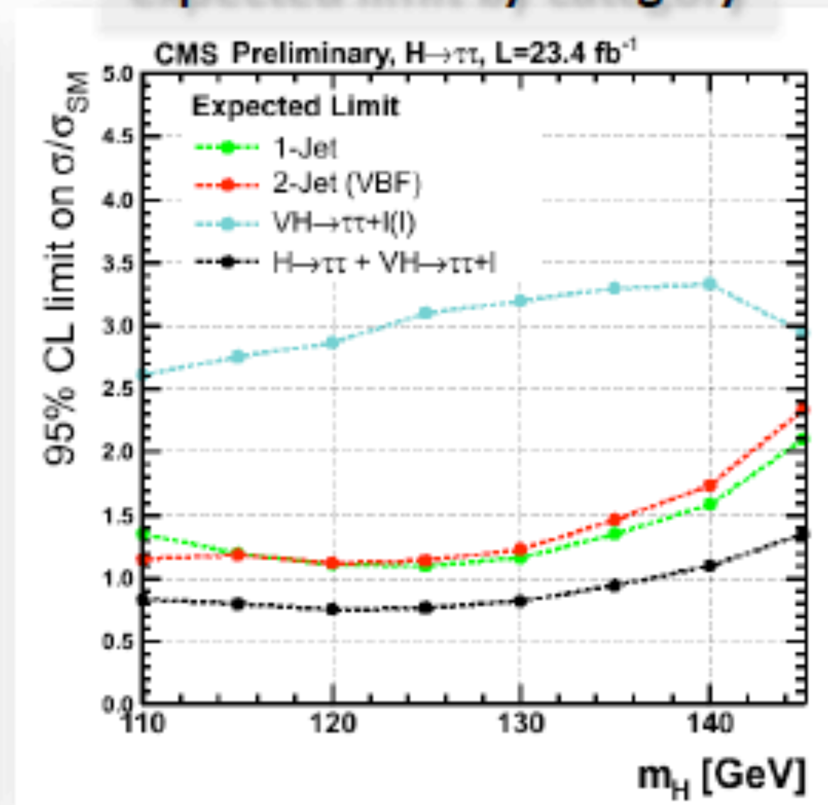
H -> ττ

Sensitivity break-down

expected limit by channel



expected limit by category

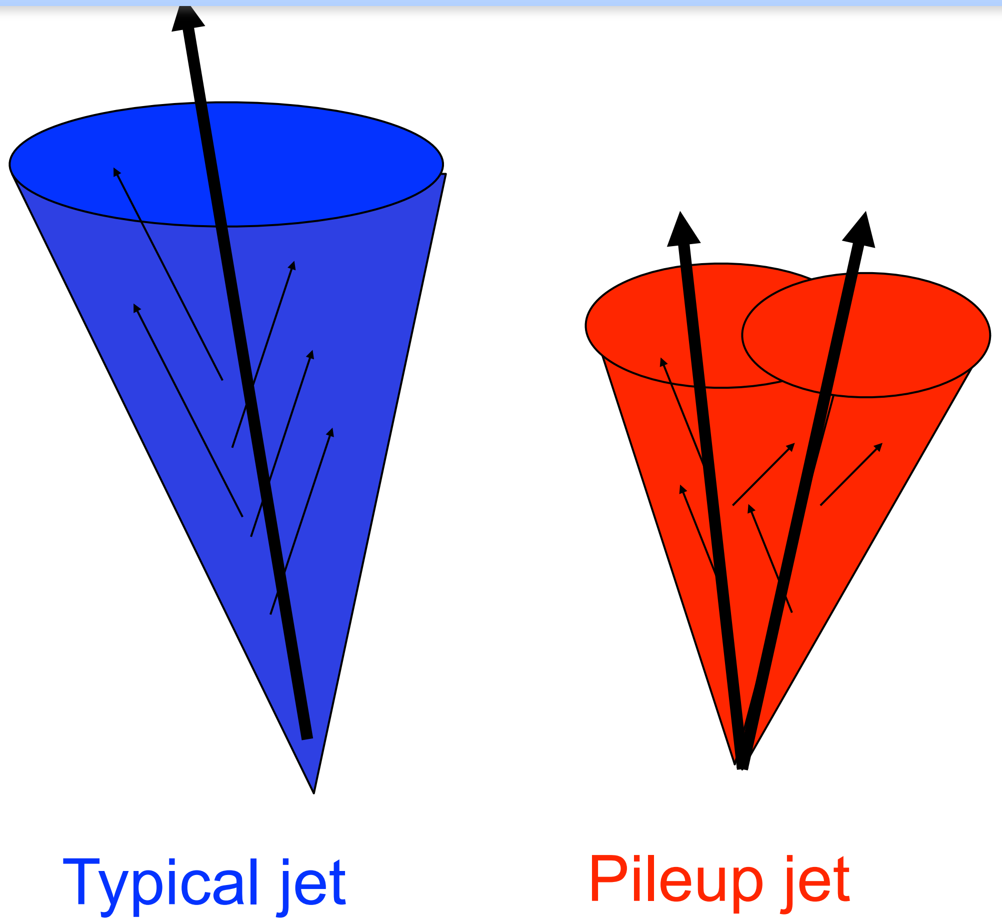


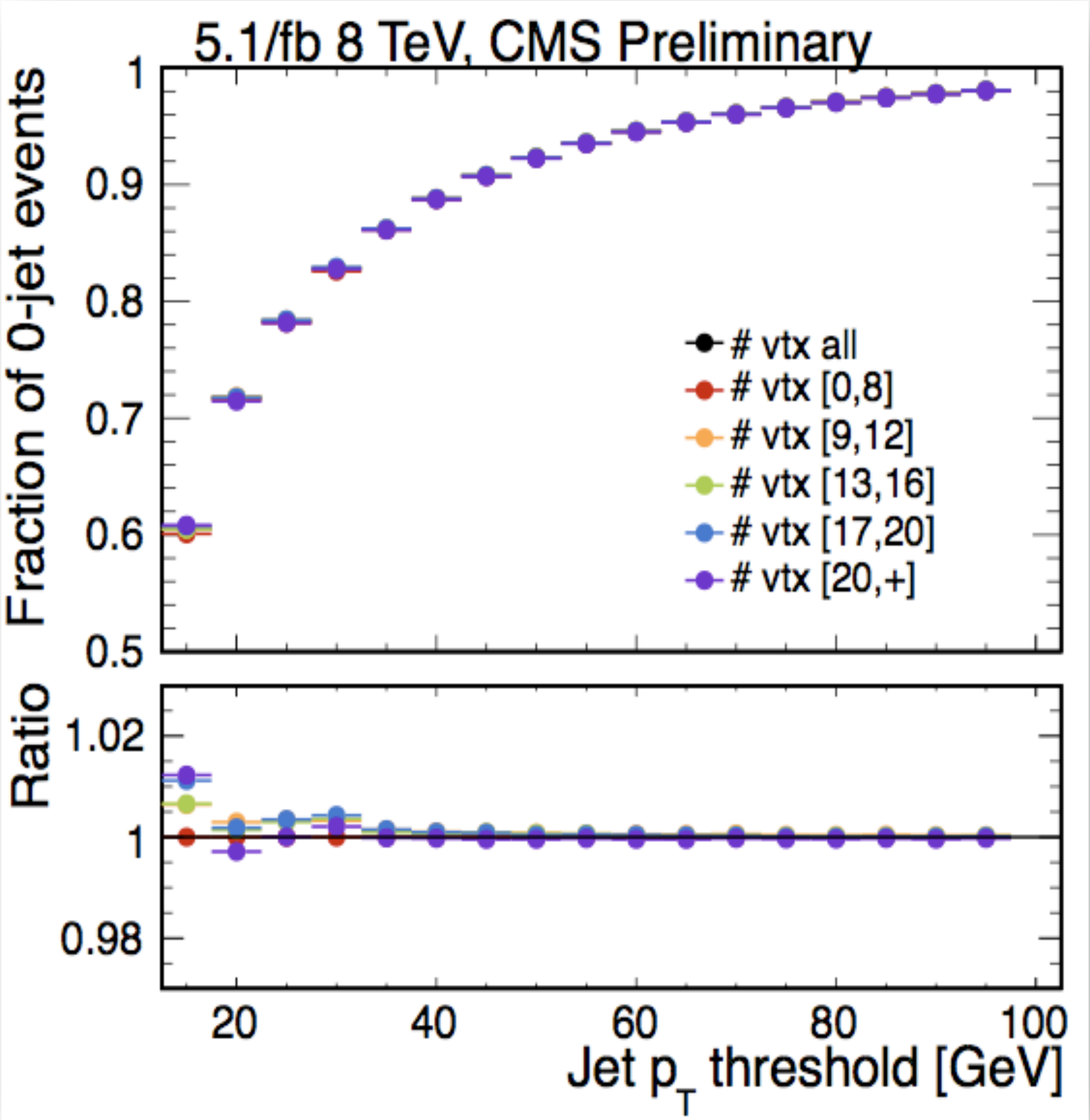
- Results updated with full 2011+2012 dataset
- Sensitivity of **0.77** x SM at 125 GeV

7TeV (2011)	8TeV (2012)
5 fb^{-1}	**19 fb^{-1}**

Jet Identification

- Jet reconstruction
  - Reconstruction with particle flow objects



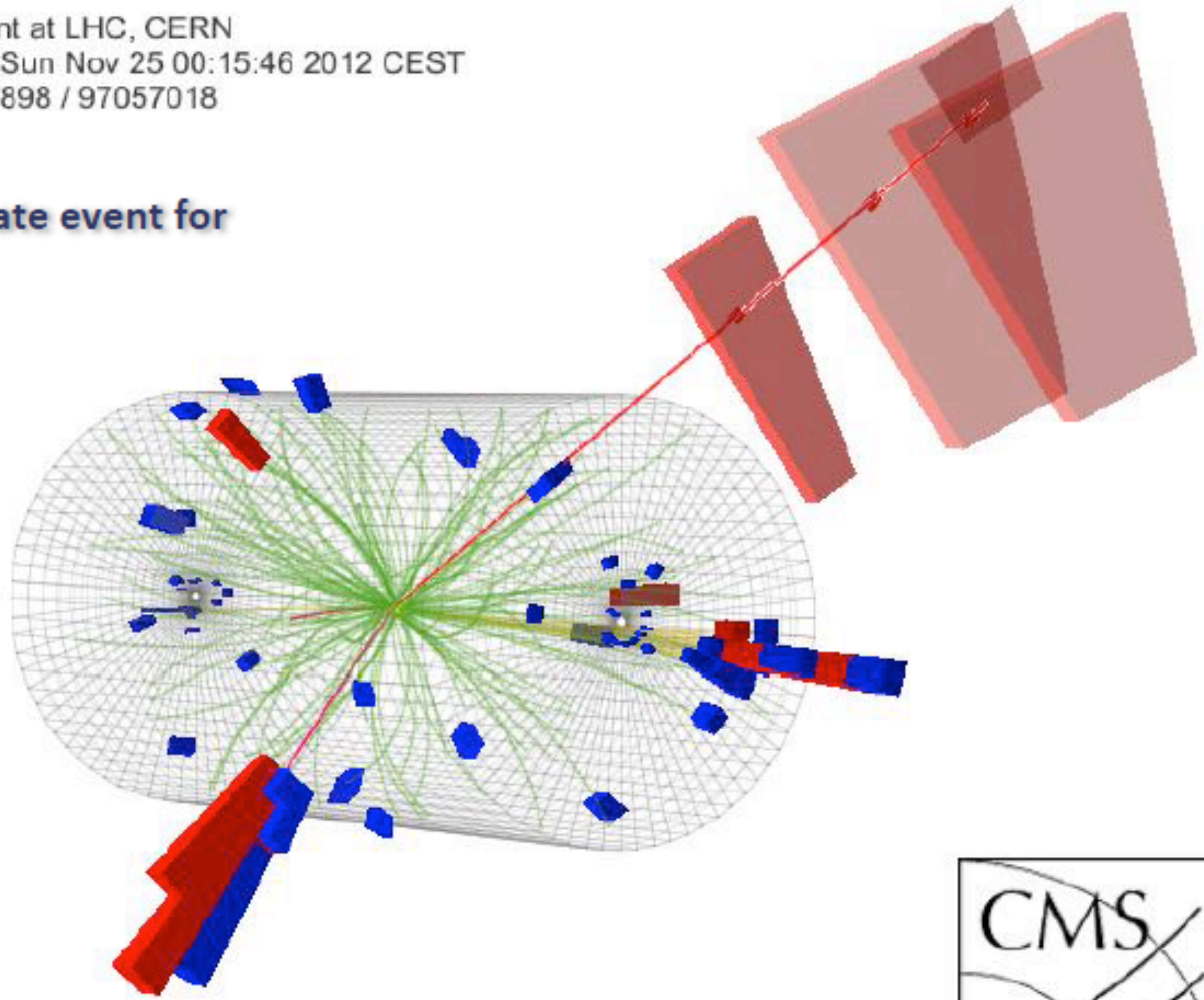


- Pileup jets structure differs wrt regular jets:
  - Pileup jets originate from several overlapping jets which merge together
  - Likelihood grows rapidly with high pileup
- Discriminant exploits shape and tracking variables
  - discrimination both inside and outside tracker acceptance

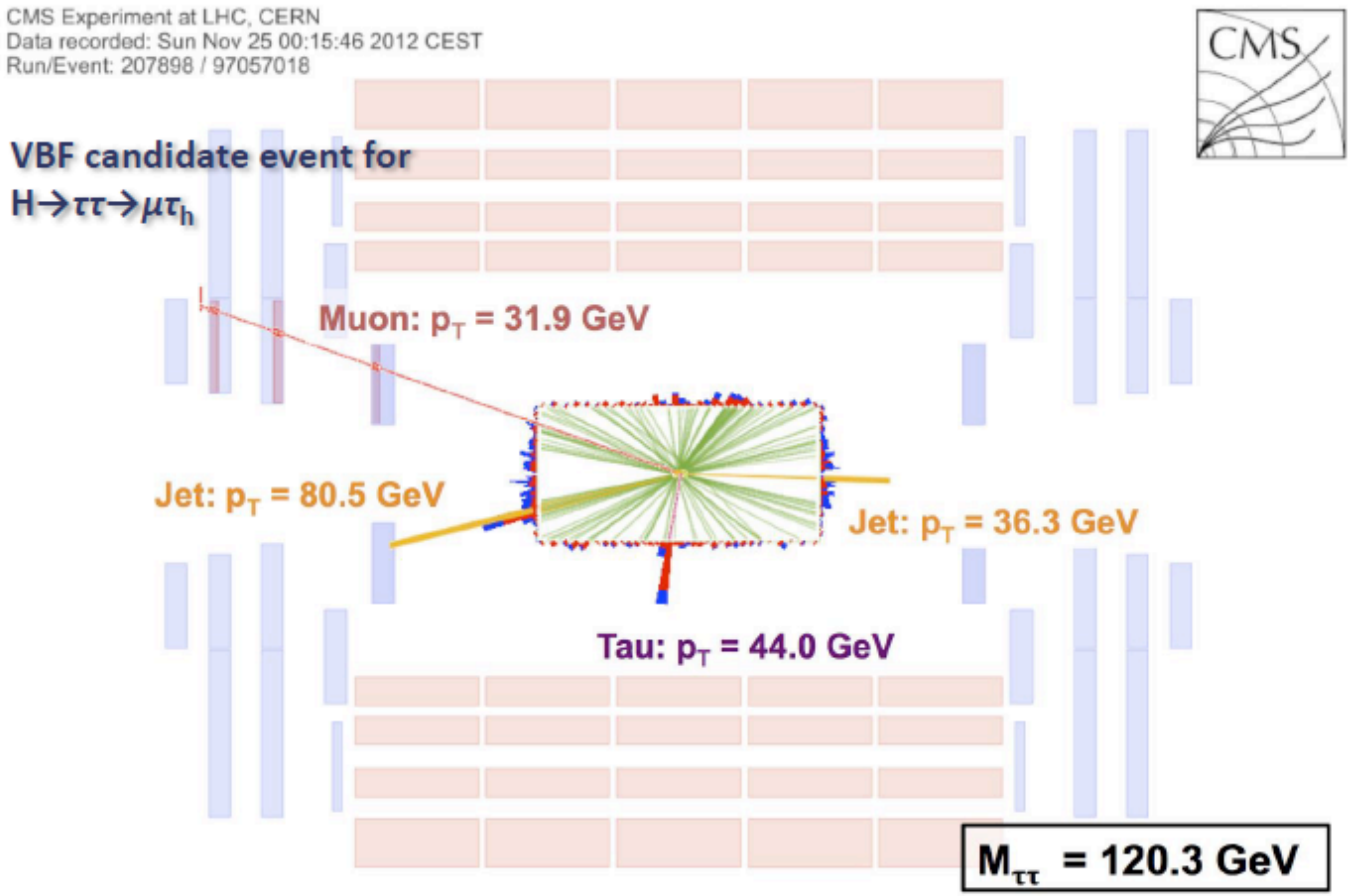
H -> ττ

CMS Experiment at LHC, CERN
Data recorded: Sun Nov 25 00:15:46 2012 CEST
Run/Event: 207898 / 97057018

VBF candidate event for
$H \to \tau\tau \to \mu\tau_h$



H -> ττ


CMS Experiment at LHC, CERN
Data recorded: Sun Nov 25 00:15:46 2012 CEST
Run/Event: 207898 / 97057018
VBF candidate event for
H→ττ→μτh
Muon: pT = 31.9 GeV
Jet: pT = 80.5 GeV
Jet: pT = 36.3 GeV
Tau: pT = 44.0 GeV
Mττ = 120.3 GeV