SM H→ττ with ATLAS

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lapp seminar

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Subject of this talk

- **Search for the SM Higgs boson decaying into two tau leptons**

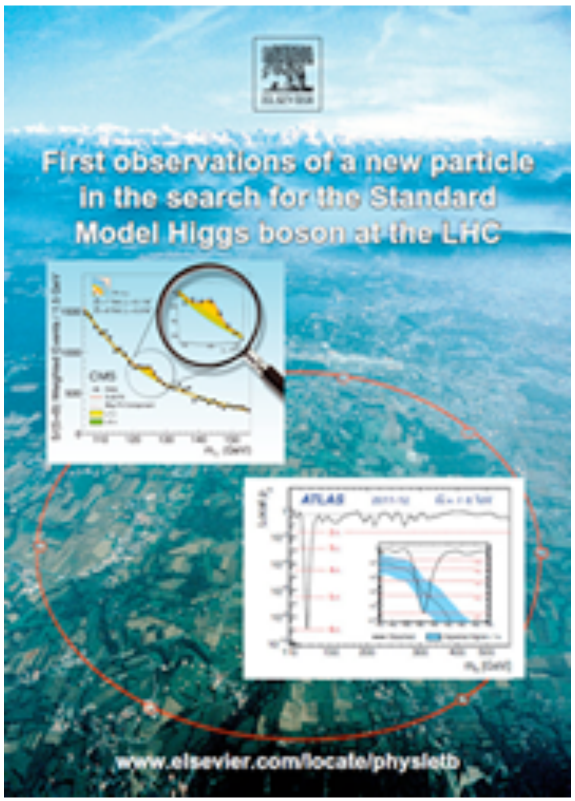
- ATLAS analysis combining 7 TeV (4.6 fb^{-1}) and 8TeV (13 fb^{-1})
- Preliminary result presented in HCP symposium (Kyoto Nov. 2012)
  - ATLAS-CONF-2012-160

- *Not discussed: Interpretation of the $H\rightarrow\tau\tau$ in the context of MSSM*

Why bother with H→ττ ?

- **Summer 2012: Historic observation of a new Higgs-like particle @ ~125 GeV**

Phys.Lett. B716 (2012) 1-29

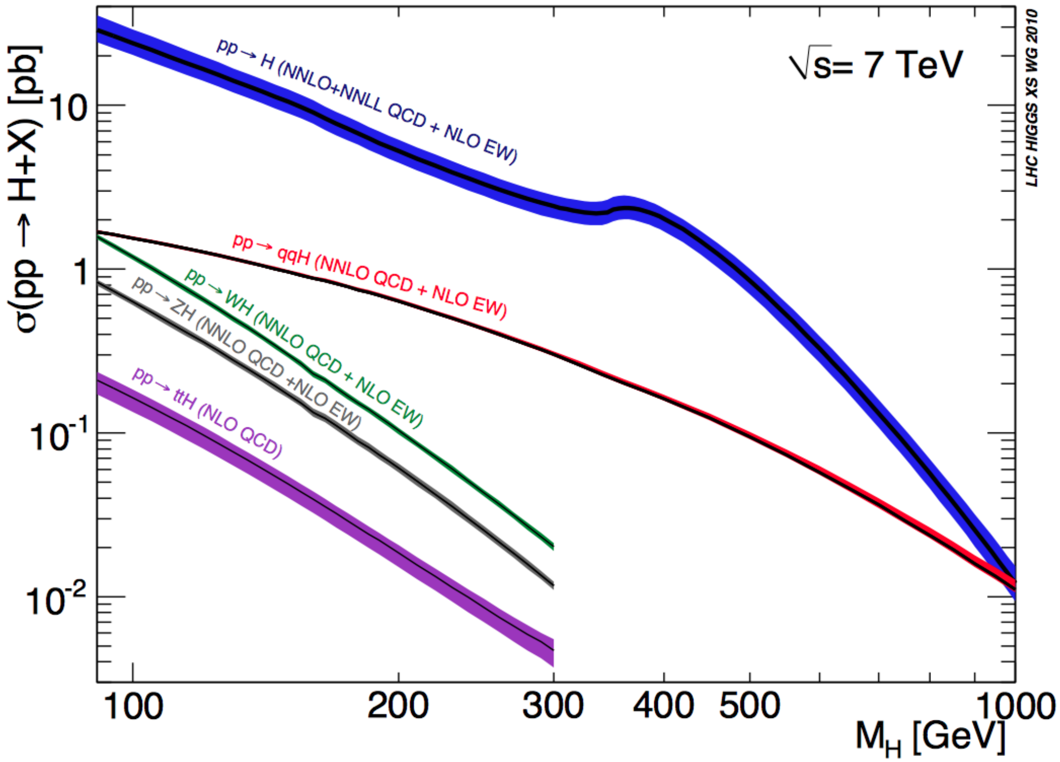


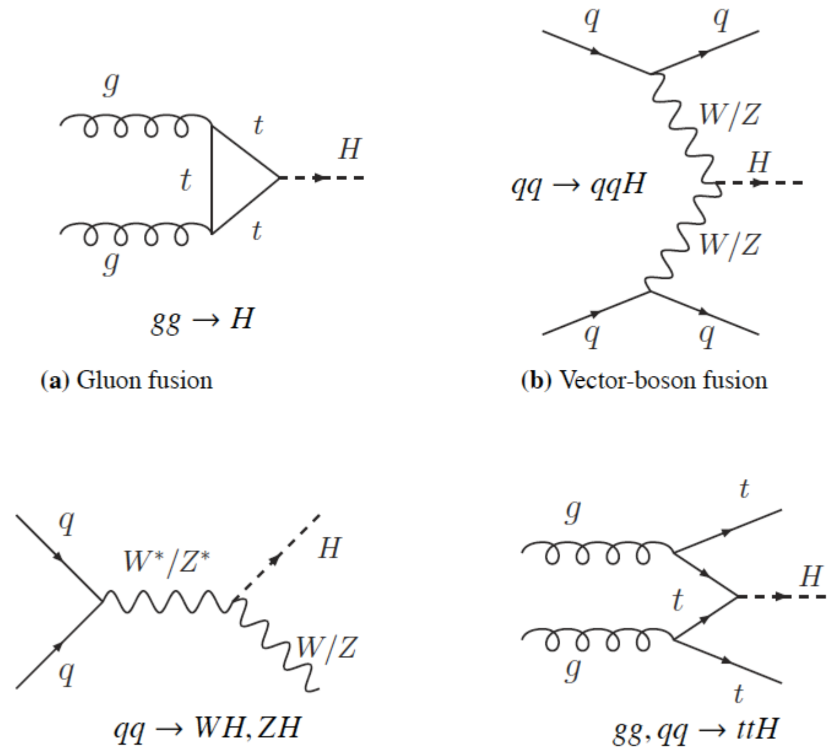
But.. What did we observe exactly?

- Too early for definitive answers
- Some facts:

- Couples to Vector Bosons
  - ZZ/WW
- Couples to fermions?
  - Probably yes: ggF production and γγ decay via quark loop.
- Couples to leptons?
  - ττ search is addressing this question

SM Higgs boson production in LHC





(a) Gluon fusion

(b) Vector-boson fusion

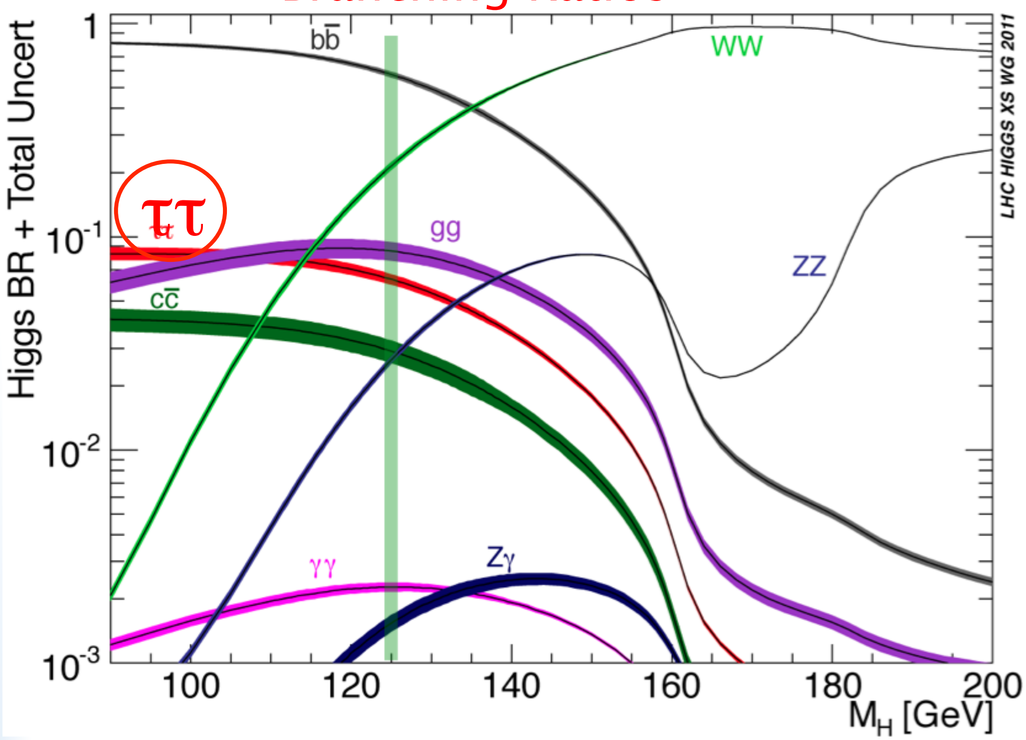
c) Higgsstrahlung of W/Z

(d) Associated production with a top quark pair

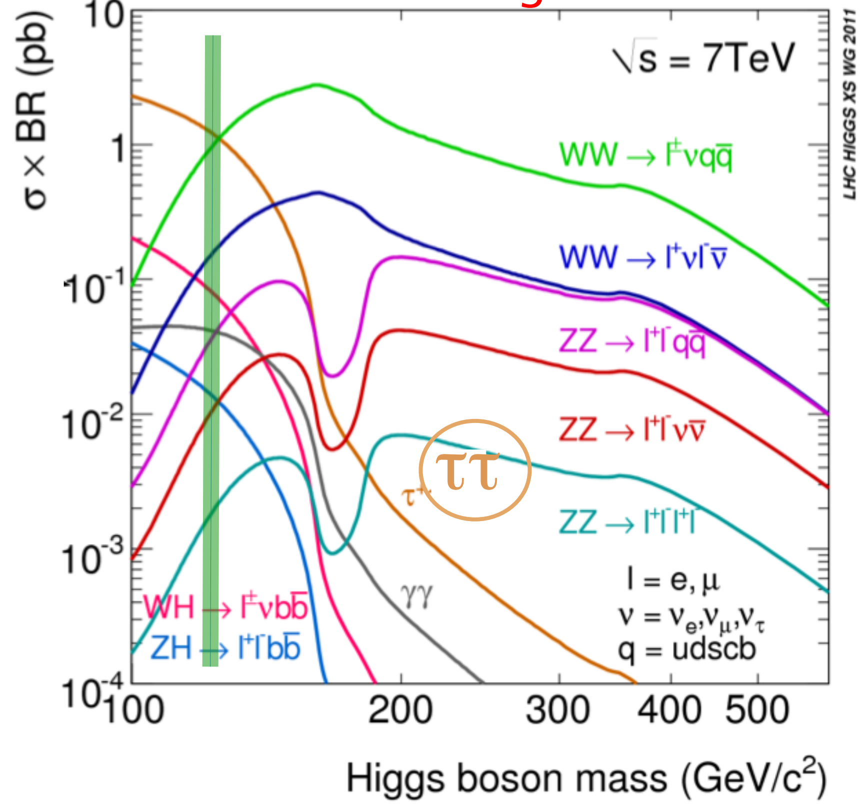
- Four production mechanisms
  - ggFusion the dominant one
- Top associated production is neglected for this analysis

SM Higgs boson decay modes

Branching Ratios

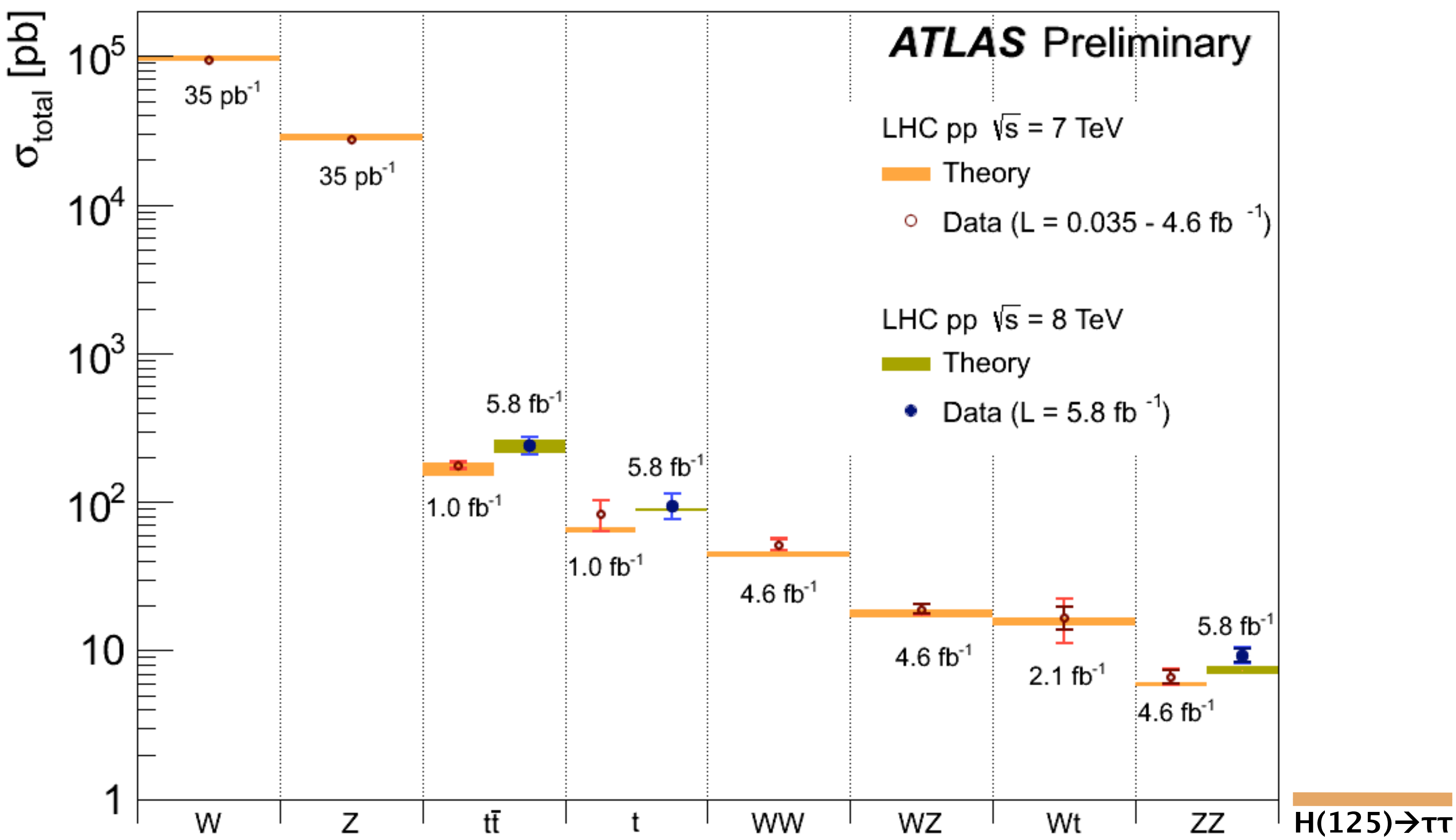


σ × Branching Ratio



- Higgs-like boson of m_H~125 GeV accessible
  - bb, **ττ**, WW*, ZZ*, γγ, Zγ, μμ
- **ττ**
  - With WW→lvqq, highest σ×BR ~ 1pb @ 7 TeV
  - Well motivated search, but experimentally very challenging

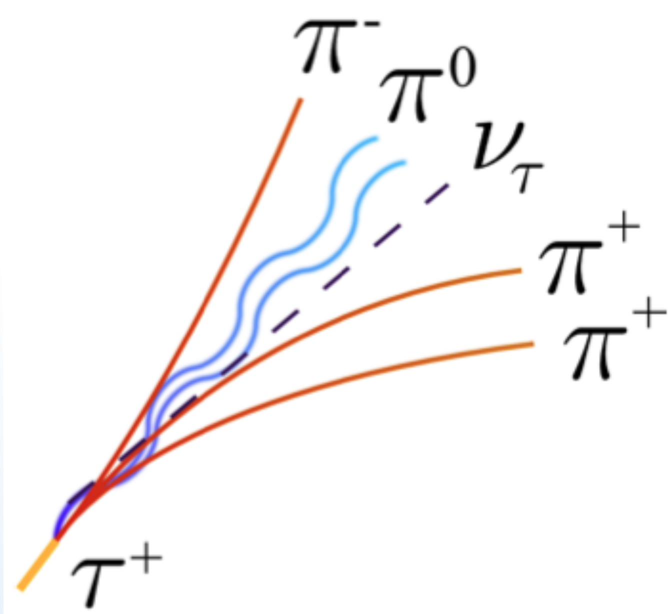
Large amount of SM backgrounds



- SM background cross-sections
  - Few to many orders of magnitude higher than expected signal cross-section

Tau lepton trivia in one slide

- Mass: 1.777 GeV/c^2
- cτ: ~87μm



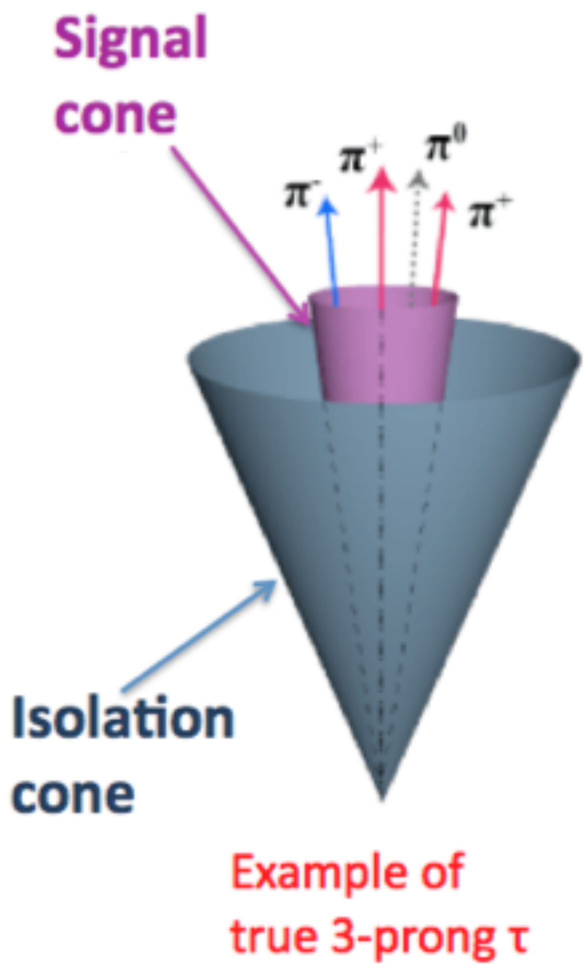
3prong hadronic tau decay

Most important decay modes

Decay Mode	Branching Fraction
Leptonic modes	**~35%**
$\tau^\pm \rightarrow e^\pm \nu_e \nu_\tau$	18%
$\tau^\pm \rightarrow \mu^\pm \nu_\mu \nu_\tau$	17%
Hadronic modes	**~65%**
1 prong (1 charged particle)	**46%**
$\tau^\pm \rightarrow \pi^\pm \nu_\tau$	11%
$\tau^\pm \rightarrow \pi^\pm \pi^0 \nu_\tau$	26%
$\tau^\pm \rightarrow \pi^\pm \pi^0 \pi^0 \nu_\tau$	9%
3 prong (3 charged particles)	**14%**
$\tau^\pm \rightarrow \pi^\pm \pi^\pm \pi^\mp \nu_\tau$	9%
$\tau^\pm \rightarrow \pi^\pm \pi^\pm \pi^\mp \pi^0 \nu_\tau$	5%

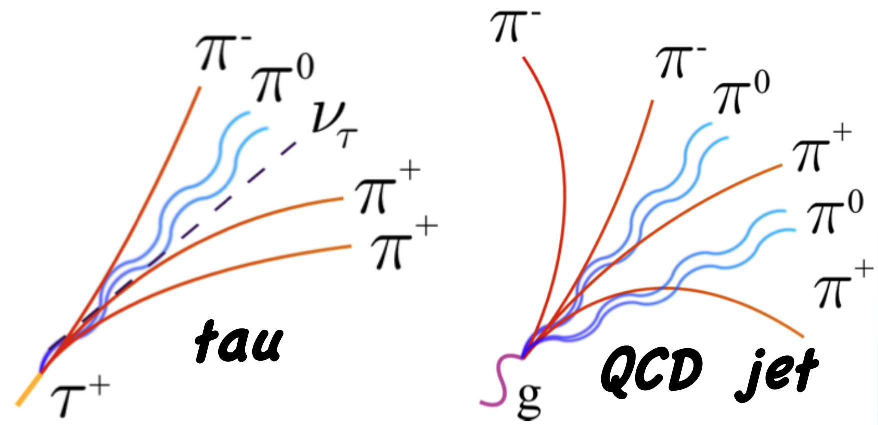
Tau Reco (τ_{had}) in ATLAS

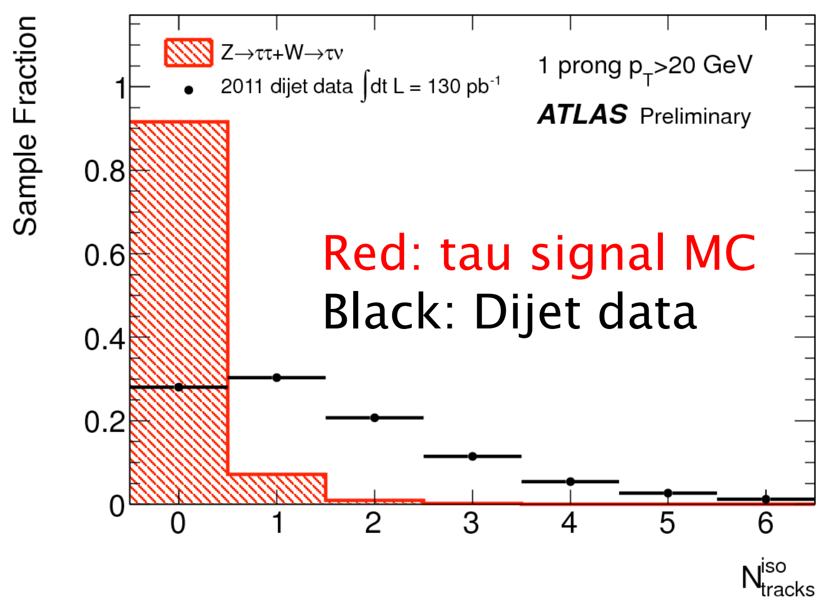
- τ_{had} appears as a narrow isolated jet
- τ_{had} seed: jet of cone $\Delta R<0.4$, $p_T>10$ GeV and $|\eta|<2.5$
- Classify τ_{had}: count number of tracks in signal cone of $\Delta R<0.2$ around the jet seed
- τ_{had} energy: Energy of calo topological clusters in $\Delta R<0.2$
- Isolation region: cone $0.2<\Delta R<0.4$

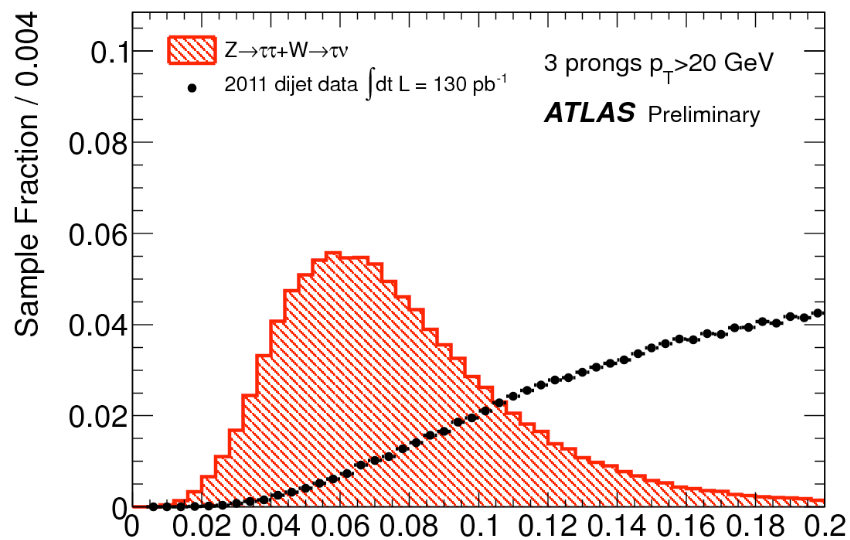


Tau Identification (TauID)

- **TauID: Distinguish τ_{had} jets from QCD jets and electrons**
- Use a number of discriminating variables based on tau properties: isolation, energy profiles, fractions of EM & Had energy, angular distances
- Combine all variables separately on 1p and 3p tau decays using MVA discriminator



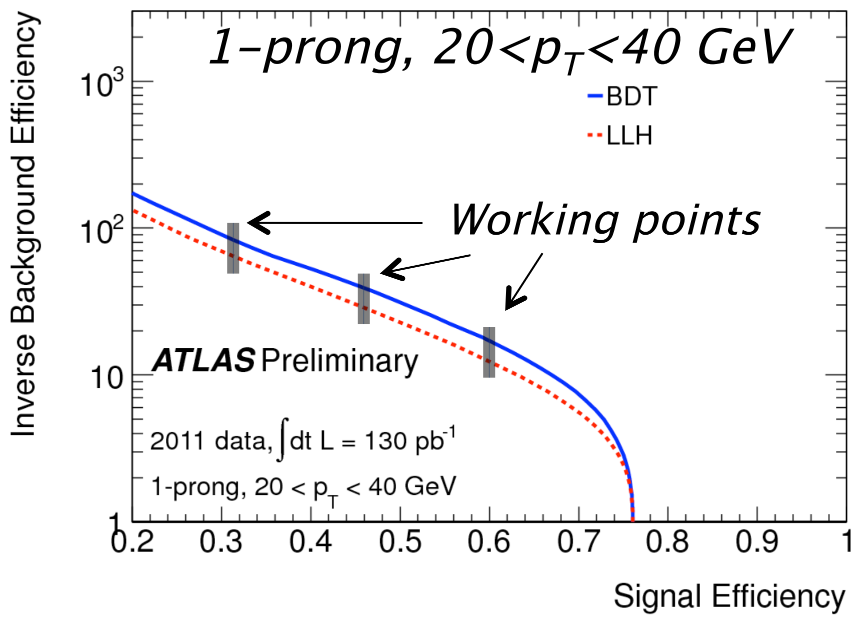


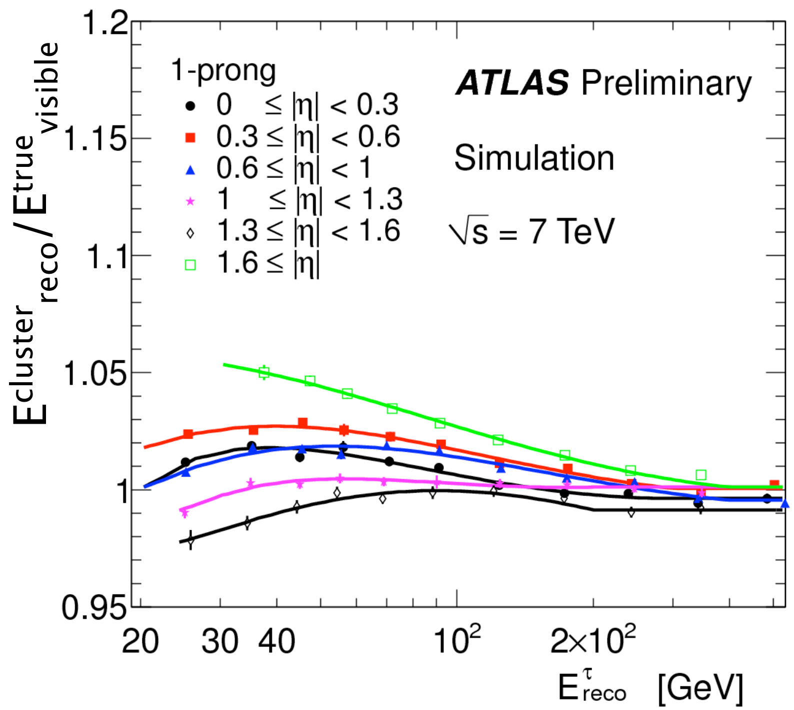


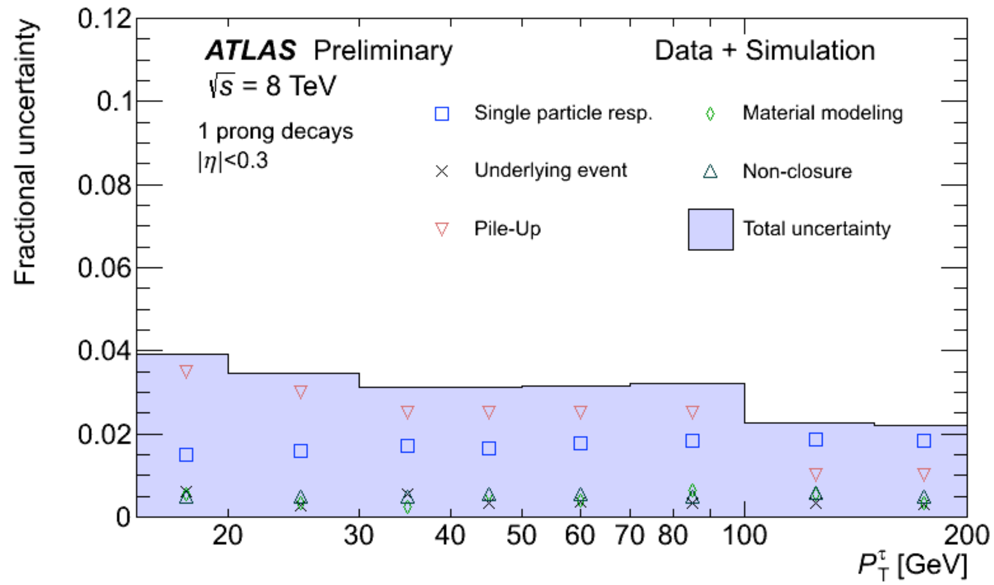
Maximal distance ΔR(core track,τ axis)

TauID efficiency, energy scale

- Every TauID available with predefined cuts, of signal efficiency:
  - Loose: ~60%
  - Medium: ~45%
  - Tight: ~30%
- 2012 Energy scale uncertainty
  - ~4%







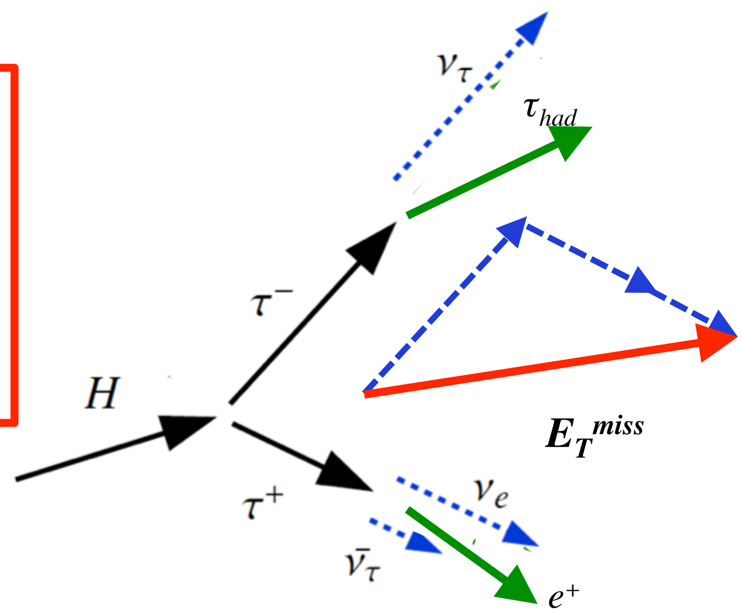
H→τ⁺τ⁻

- According to the decay of τ, split the analysis in 3 channels
  - *ll 4ν (**LepLep**)*
  - *$l\tau_{had}$ 3ν (**LepHad**)*
  - *$\tau_{had}\tau_{had}$ 2ν (**HadHad**)*

, *Lep : e or μ*
Had: hadronic decay of τ

- Neutrinos result into missing energy, thus missing information

→Main challenge: Separate signal from Z→τ⁺τ⁻
- Estimate mass of di-tau: $\boldsymbol{m_H}$
- Difficult due to the presence of neutrinos

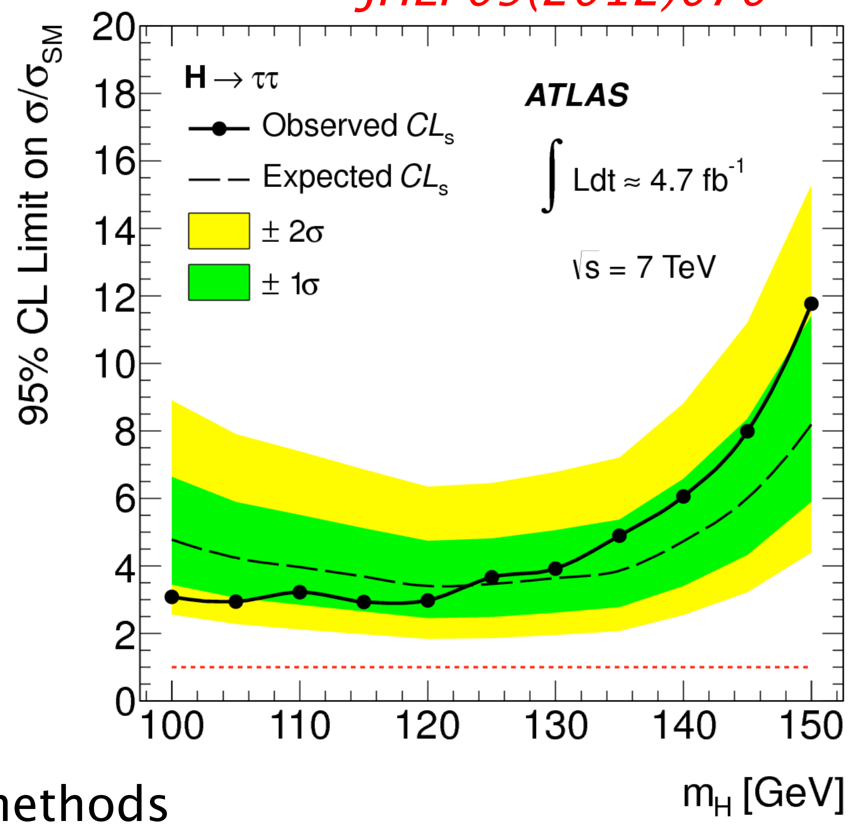


- Combine all three channels to search for H→ττ decays
- Show results with 4.6fb^{-1}(7TeV) and 13fb^{-1}(8TeV) data

Starting point: 7TeV Moriond2012

- *JHEP09(2012)070*: analysis of full 2011 (7TeV) data, presented in Moriond 2012
  - The observed (expected) limit 3.5 (3.3)$\times\sigma_{H\to\tau\tau}$ @ m_H=125 GeV

JHEP09(2012)070



- What we did..
  - Re-optimize 7 TeV analysis
    - Optimize event selection
    - Improve background estimation methods
    - Increase acceptance: Lepton-Tau combined triggers
    - Improve/Add categories: VBF - Boosted
  - Perform 8 TeV analysis based on 7 TeV re-optimization
    - Modulo some inevitable differences due to different conditions

Analysis strategy

➢ Split events in several categories to enhance signal sensitivity and reduce backgrounds

channels: **LepHad** **LepLep** **HadHad**

categories

VBF* Selection (2 high p_T jets with high $\Delta\eta_{jj}$ and m_{jj})

Non VBF | Non VBF | Non VBF

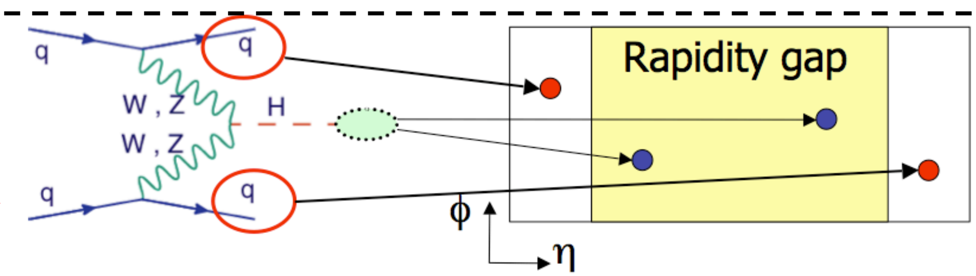
Boosted Higgs selection (high p_T jets and high p_T Higgs

Non boosted | Non boosted

2 HadHad categories

0jet | ≥1 jet

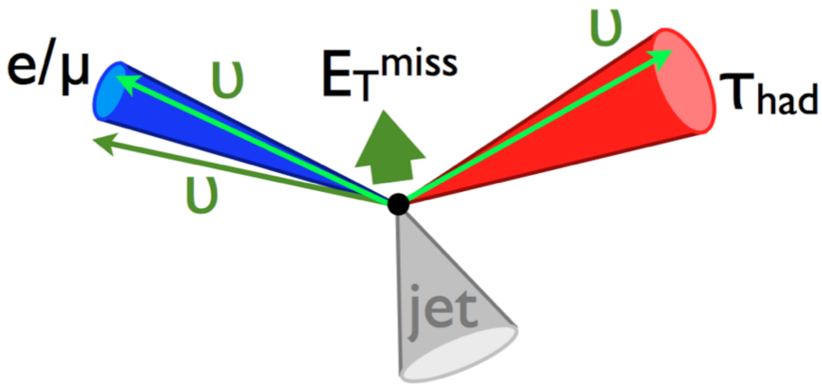
VH selection (m_{jj}~$m_{Z/W}$) → Non VH → ≥1 jet

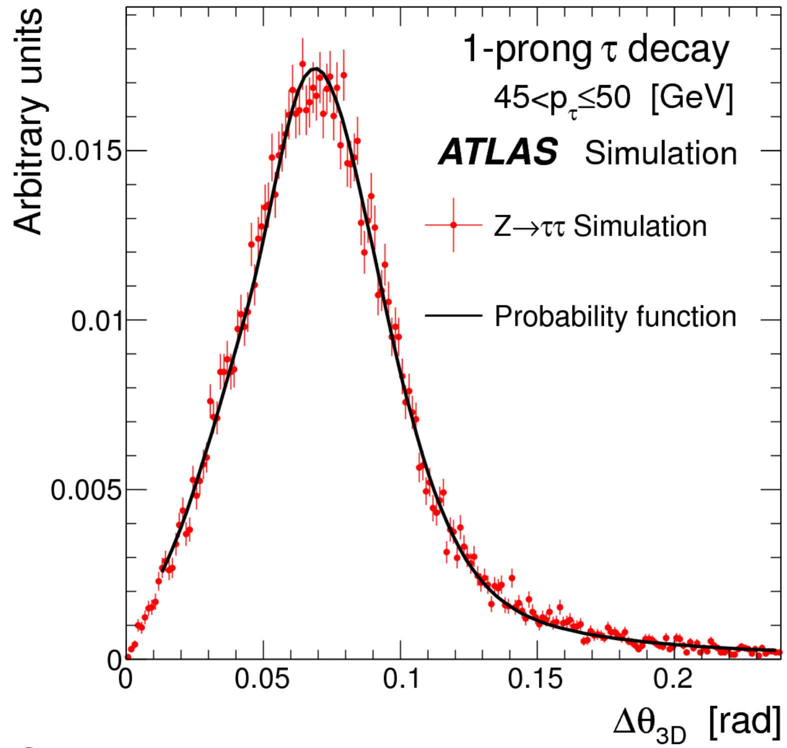


*: VBF, highest sensitivity

DiTau mass reconstruction: MMC

- Algorithm based on *Nucl. Inst. Meth. A 654 (2011) 481*
- **Missing Mass Calculator (MMC)**



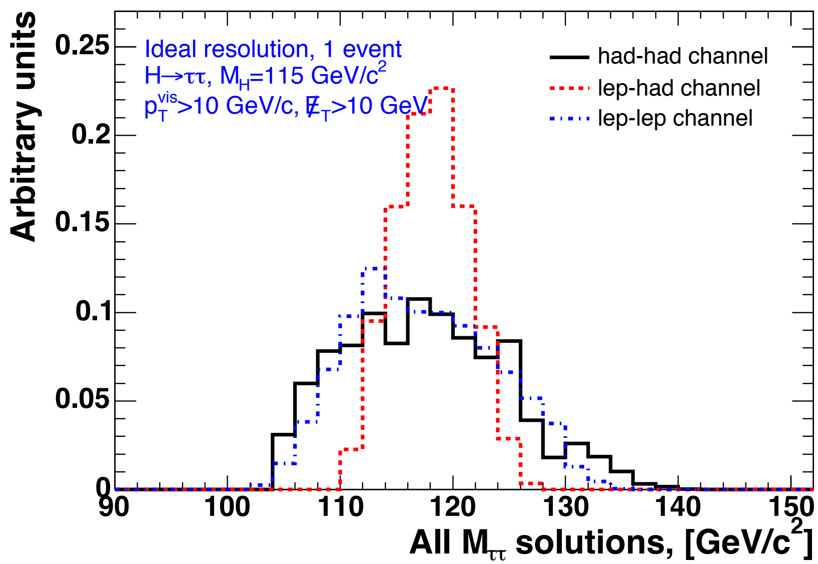


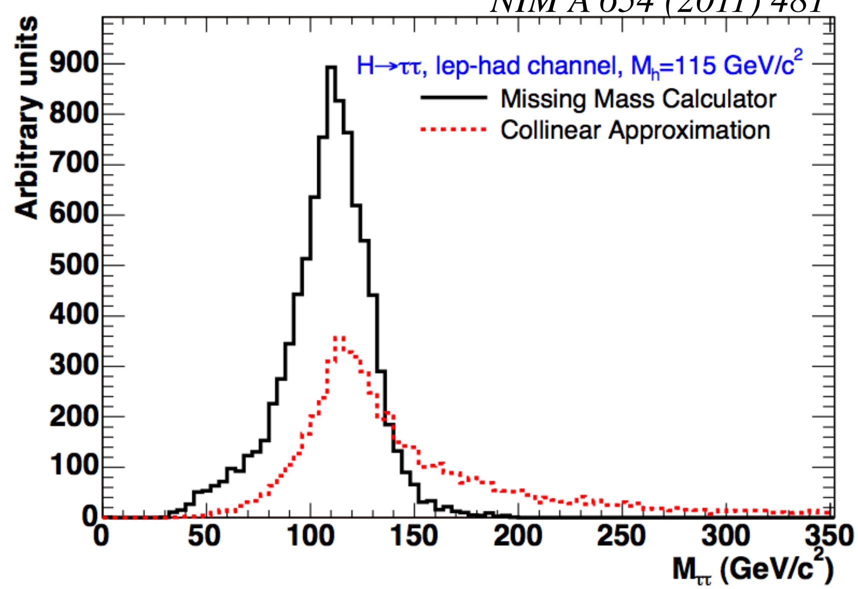
- System of kinematic equations has infinite solutions since number of unknowns > number of equations
- Solve equations for each point of grid[$\Delta\varphi(\tau_1,\nu\text{'s})$, $\Delta\varphi(\tau_2,\nu\text{'s})$]
- Weight solutions based on kinematic properties of tau lepton
  ➔ **Select more likely solution**

DiTau mass reconstruction: MMC

- Put all weighted solutions in a histogram
- **The most probable value is the $m_{\tau\tau}$ estimator**

NIM A 654 (2011) 481





- High efficiency for ττ resonances (>97%)
  - Works for back-to-back events as well
- More precise mass description
  - Reduced tails, resolution 13-20%, correct peak position

➢ MMC mass the final discriminating variable used in all 3 channels

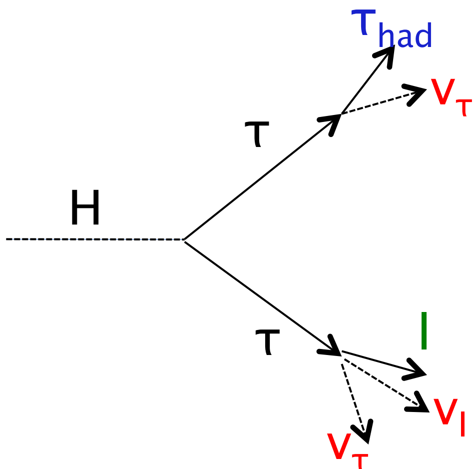
➢ The most powerful (and almost the only) way to enhance separation of signal against Z→ττ

- $H \to \tau(\mathit{lep})\ \tau(\mathit{had}) + 3\nu$'s final state

Trigger – preselection

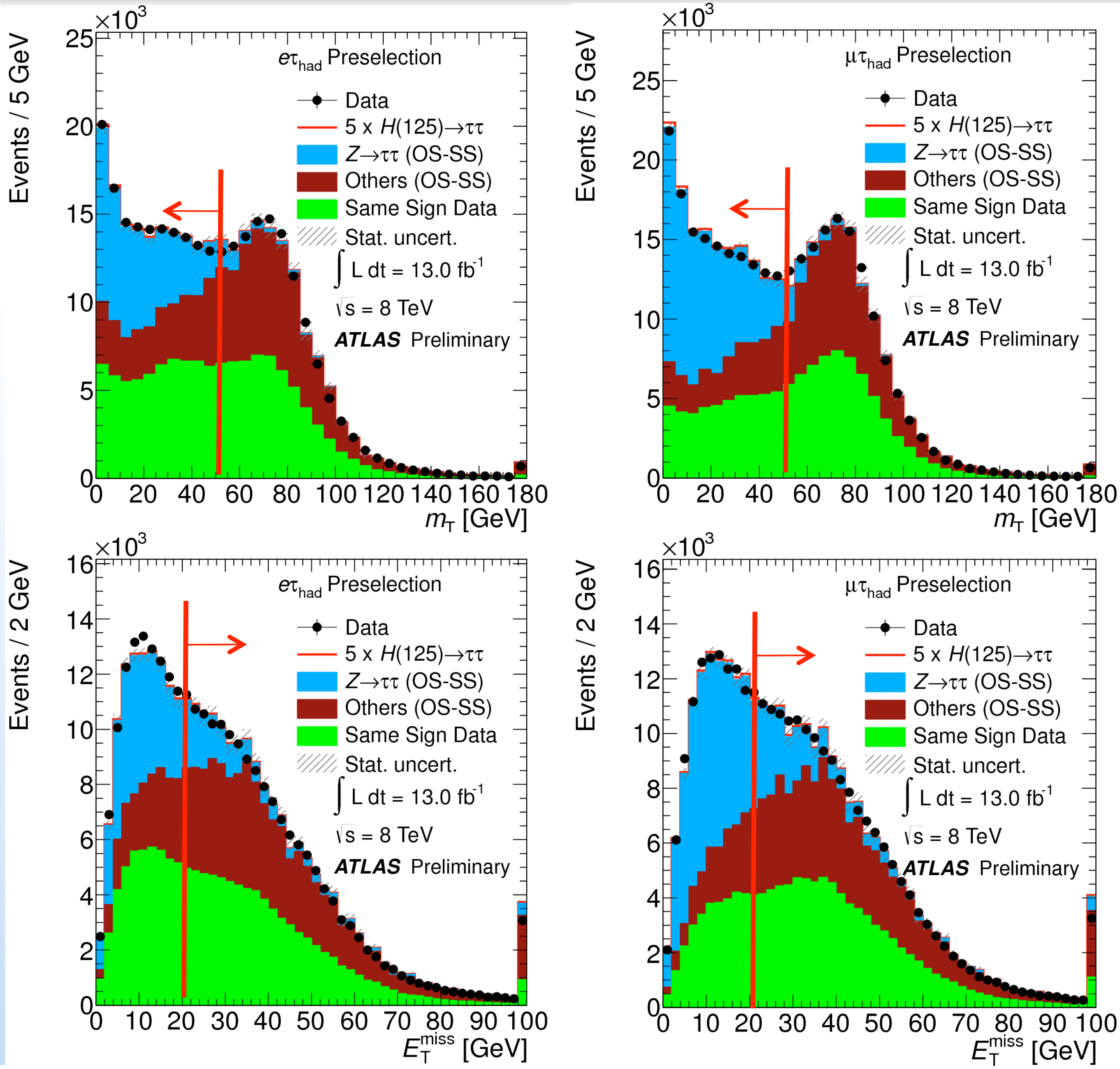
Channel	Trigger	Trigger p_T Threshold (GeV)	Offline p_T Threshold (GeV)
$H \to \tau_{lep}\tau_{had}$	single electron	$p_T{}^{e} > 24$ –	$p_T{}^{e} > 26$ $p_T{}^{\tau_{had\text{-}vis}} > 20$
	single muon	$p_T{}^{\mu} > 24$ –	$p_T{}^{\mu} > 26$ $p_T{}^{\tau_{had\text{-}vis}} > 20$
	combined $e + \tau_{had\text{-}vis}$	$p_T{}^{e} > 18$ $p_T{}^{\tau_{had\text{-}vis}} > 20$	$20 < p_T{}^{e} < 26$ $p_T{}^{\tau_{had\text{-}vis}} > 25$
	combined $\mu + \tau_{had\text{-}vis}$	$p_T{}^{\mu} > 15$ $p_T{}^{\tau_{had\text{-}vis}} > 20$	$17 < p_T{}^{\mu} < 26$ $p_T{}^{\tau_{had\text{-}vis}} > 25$

- Signature
  - One isolated lepton (e,μ)
  - One τ_{had} candidate
  - Real MET due to neutrinos



- Trigger – Preselection cuts
  - **Single lepton trigger – combined lepton tau trigger**
  - Require $N_{leptons}=1$ and $N_\tau=1$ and opposite sign (OS)

Background rejection

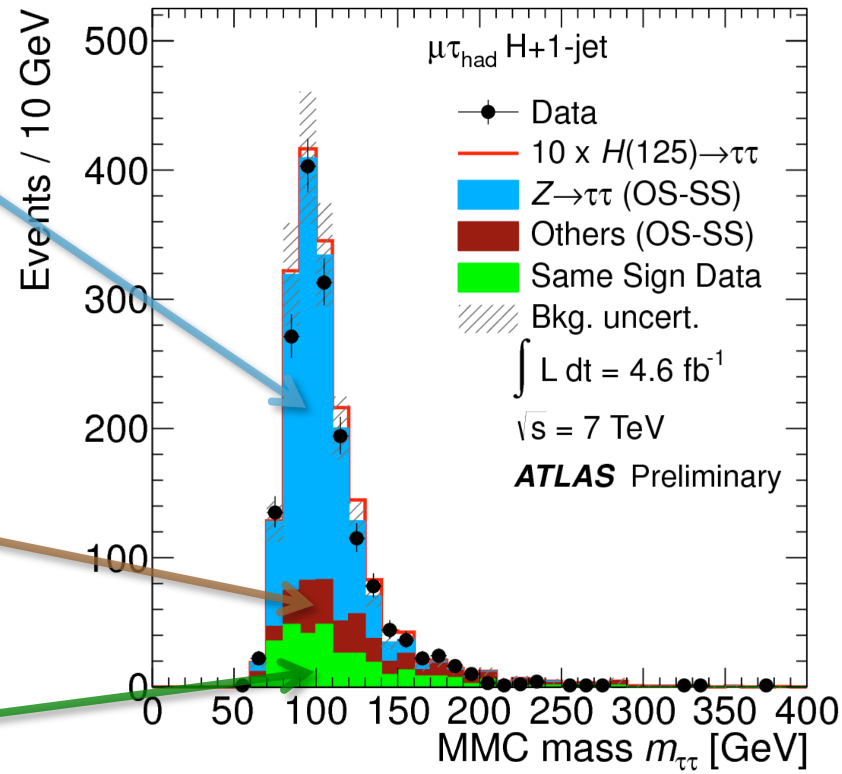


Apply m_T and E_T^{miss} cuts to reduce backgrounds

$$m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}}^{\ell} E_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos \Delta\phi)}$$

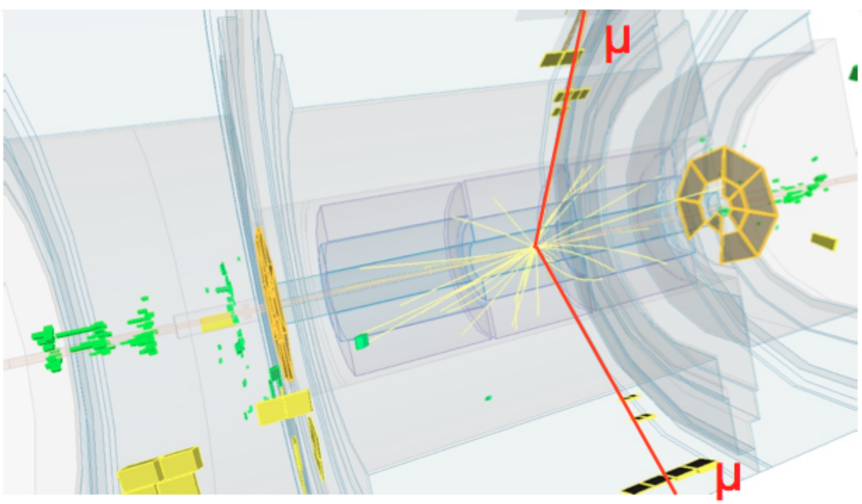
Background estimation

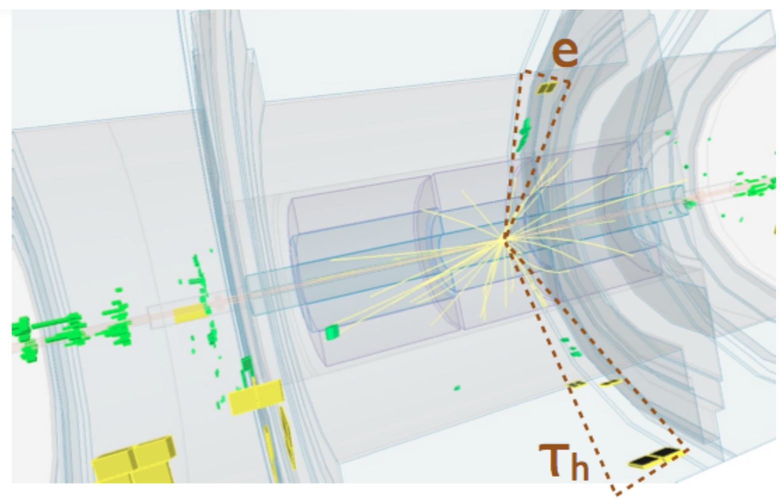
- Dominant Z→ττ
  - Almost data driven method: Embedding
  - Use high statistics MC for VBF category
  - **Same for all channels**
- Z→ll, top, Diboson
  - Shape from MC
  - Normalization from data CR
- QCD, W rich samples in fake tau's
  - Data driven methods



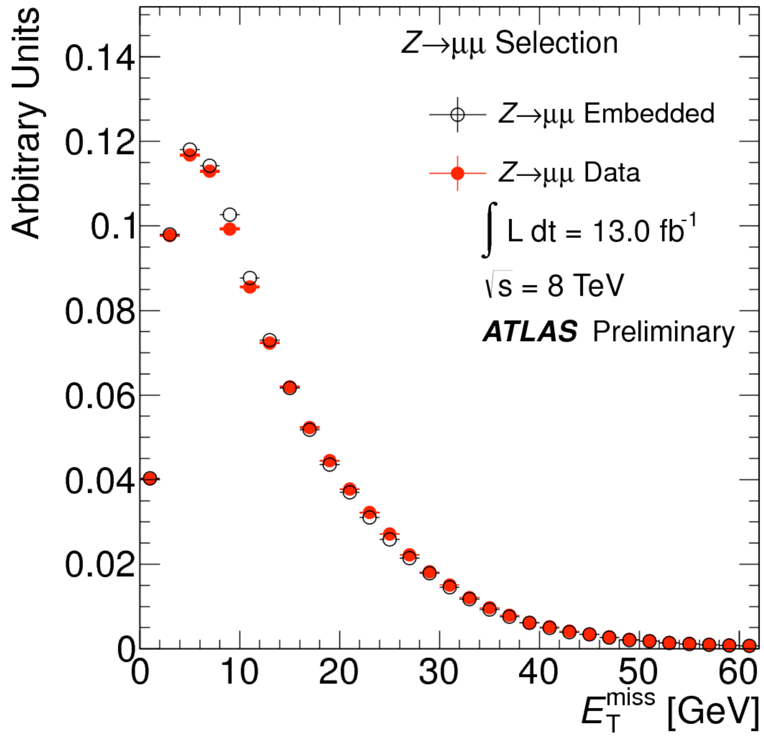
Background estimation: Z→ττ

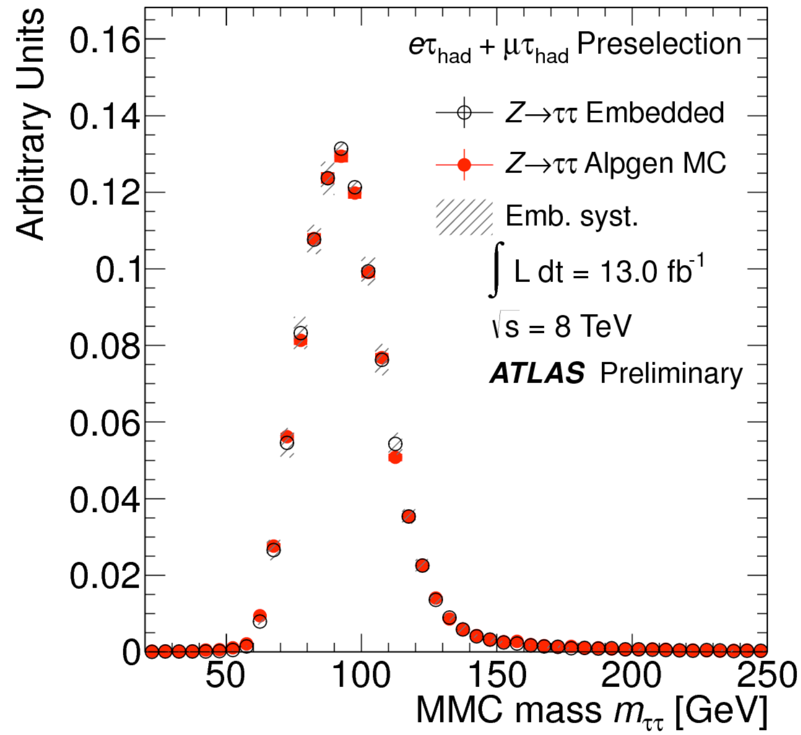
- Dominant background due to the same final state Z→ττ
- Shape estimation from Z→μμ data: "**Embedding**" technique
  - Delete μ tracks and deposited calorimeter energy from data events
  - Replace by full-simulated Z→ττ decays, generated with Tauola with identical kinematics
  - Almost a pure data-driven technique
    - Jet/MET/pile-up/UE/etc described by data
    - Only tau decays described by MC





Embedding validation





- Embedding procedure does not introduce any significant bias to the reconstruction of the event properties
- MMC mass shape validation against MC
- Key kinematic distributions are better described

Embedded samples are used for the $Z \rightarrow \tau\tau$ estimation in all 3 channels

Background estimation

- Uses the complete SS_{data} (lep,tau of same sign) and with add-on of all backgrounds

$$n_{OS}^{bckg} = r_{QCD} \cdot n_{SS}^{data} + N_{add-on}^{Z\to\tau\tau} + N_{add-on}^{Z\to ll} + N_{add-on}^{W+jets} + N_{add-on}^{others}$$

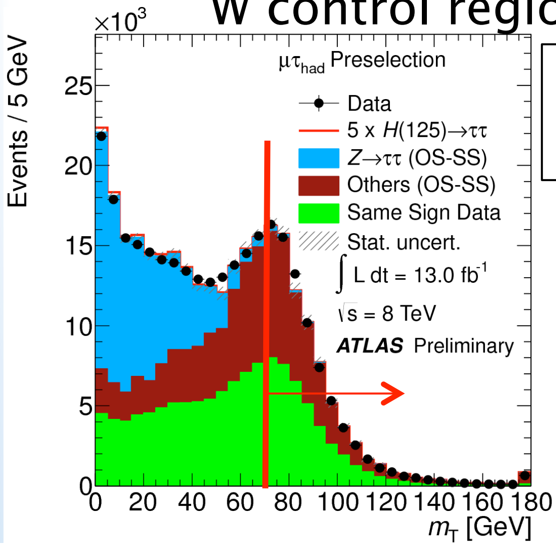
$$r_{QCD} = \frac{N_{OS}^{QCD}}{N_{SS}^{QCD}}$$

: Obtained from data QCD control region:

- E_T^{miss} < 15 GeV
- m_T < 30 GeV
- No lepton isolation
- BDTLoose TauID

N_{add-on} : OS-SS Background contributions estimated from MC or Embedded normalized to data CR

W control region



- High m_T region
- Relaxed cuts

top control region

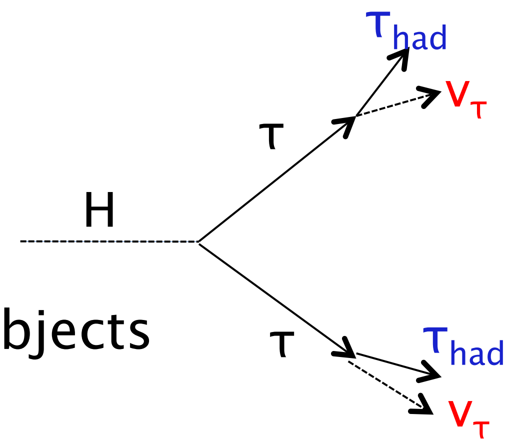
- High m_T region
- At least 2 jets
- 1b-tagged jet (70% efficiency)

- H→τ(*had*) τ(*had*) + 2*ν*'s final state

Trigger – preselection

Channel	Trigger	Trigger p_T Threshold (GeV)	Offline p_T Threshold (GeV)
$H \to \tau_{had}\tau_{had}$	combined two τ_{had}	$p_T{}^{\tau_{had\text{-}vis}} > 29$	$p_T{}^{\tau_{had\text{-}vis}} > 40$
		$p_T{}^{\tau_{had\text{-}vis}} > 20$	$p_T{}^{\tau_{had\text{-}vis}} > 25$

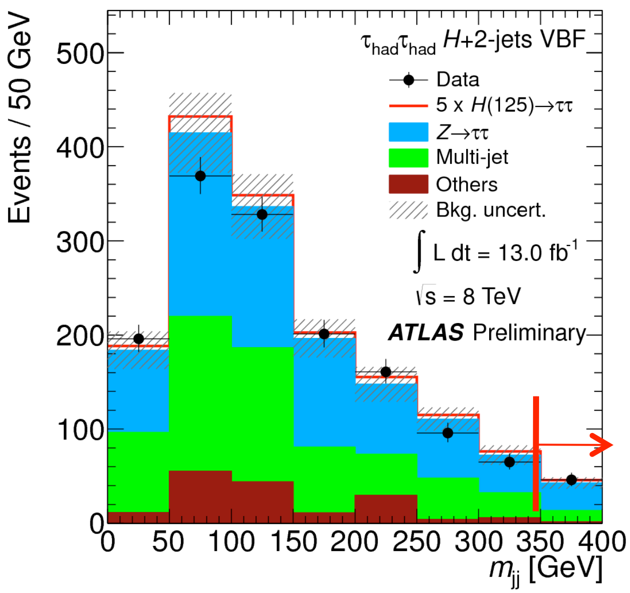
- Signature
  - Two τ_{had}
  - MET due to neutrinos
  - $N_{lep}=0$ and $N_\tau=2$ of opposite sign matched to the trigger objects

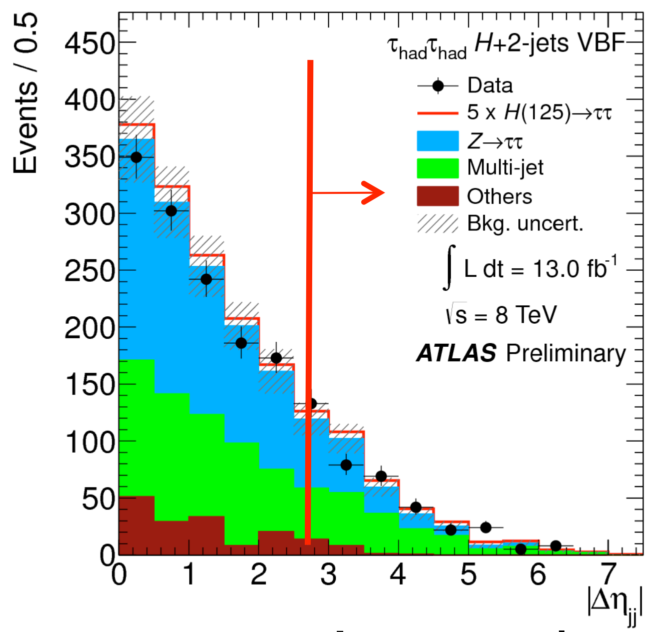


- Trigger – Preselection cuts
  - **Combined DiTau trigger, with trigger p_T thresholds: $p_T^{\tau1}>29$ GeV , $p_T^{\tau2}>20$ GeV**
  - Extensive studies of tau trigger objects allowed an accurate modeling of tau trigger efficiency turn-on curves
    - **Keep the offline p_T cut of one tau as low as 25 GeV**

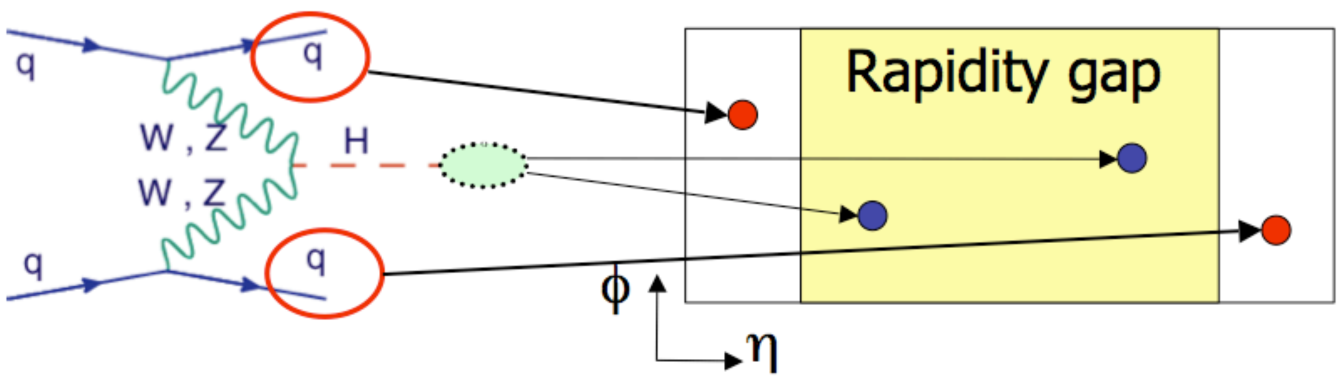
– CMS: offline tau p_T>45 GeV for **both** tau's, loosing in signal acceptance
– ATLAS: 2 times more sensitive in this channel

VBH in HadHad



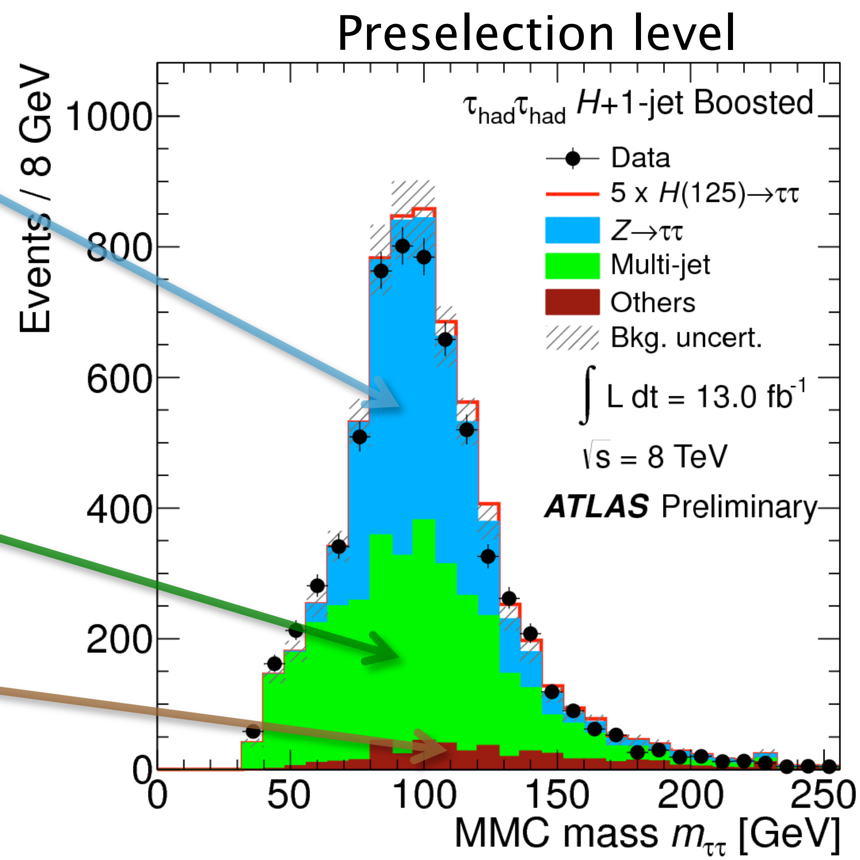


- $\Delta\eta_{jj}$>2.6 , m_{jj}>350 GeV, $\eta_{j1}\times\eta_{j2}$<0, tau's centrality



Background estimation

- Dominant Z→ττ
  - Embedding as in LepHad
- QCD
  - Data driven method, from looser tau selection
- W, top, Z→ll
  - Shape from MC
  - Normalization from data



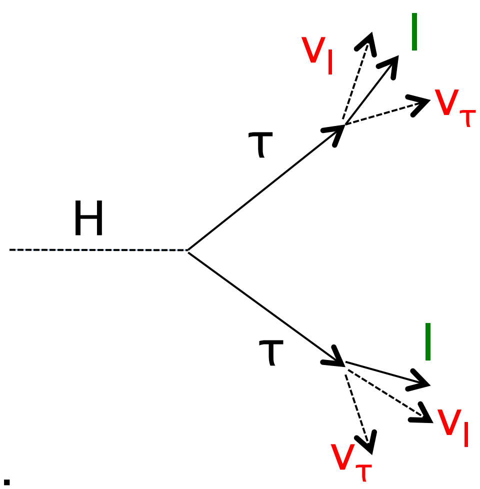
➔ QCD and Z→ττ backgrounds dominant backgrounds

- $H\rightarrow\tau$(*lep*) τ(*lep*) + 4ν's final state

Trigger – preselection

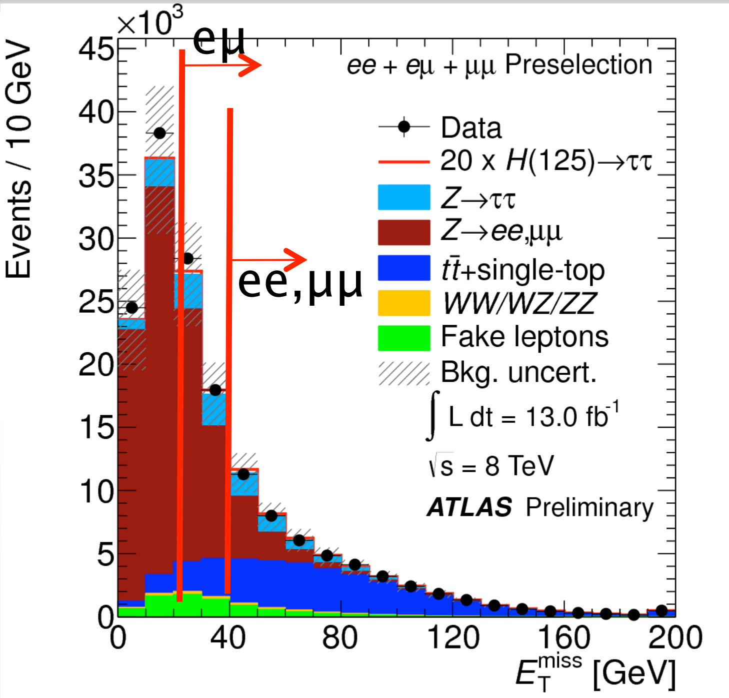
Channel	Trigger	Trigger p_T Threshold (GeV)	Offline p_T Threshold (GeV)
$H \rightarrow \tau_{lep}\tau_{lep}$	single electron	$p_T{}^e > 24$	$p_T{}^e > 25$ $p_T{}^\mu > 10$
	di-electron	$p_T{}^{e1} > 12$ $p_T{}^{e2} > 12$	$p_T{}^{e1} > 15$ $p_T{}^{e2} > 15$
	di-muon	$p_T{}^{\mu 1} > 18$ $p_T{}^{\mu 2} > 8$	$p_T{}^{\mu 1} > 20$ $p_T{}^{\mu 2} > 10$
	$e - \mu$ combined	$p_T{}^e > 12$ $p_T{}^\mu > 8$	$p_T{}^e > 15$ $p_T{}^\mu > 10$

- Signature
  - Two isolated lepton (e,μ)
  - Large MET due to neutrinos



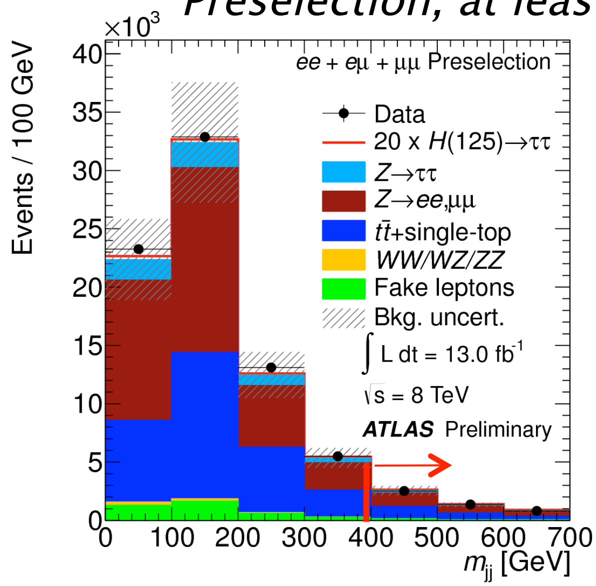
- Trigger – Preselection cuts
  - Require $N_{leptons}$=2 and opposite sign
  - Reduce the contamination of Z→ll
    - 30 GeV < m_{ee}, $m_{\mu\mu}$ < 75 GeV , 30 GeV < $m_{e\mu}$ < 100 GeV

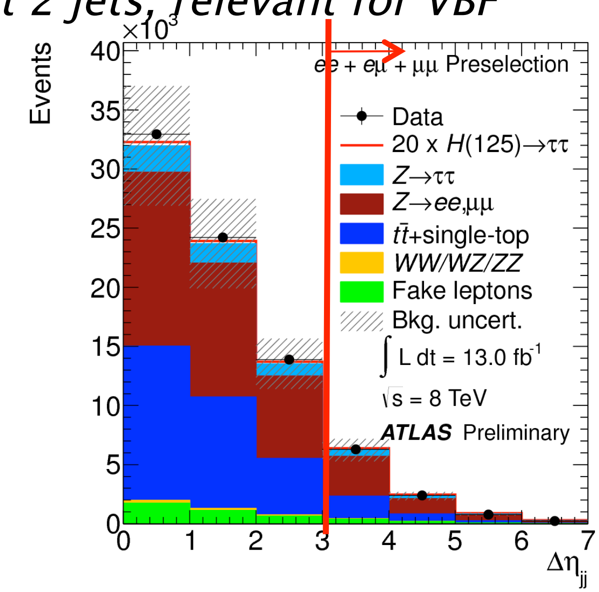
Background rejection



- E_T^{miss}>40 GeV in ee,μμ channels to reject Z→ee/μμ
- eμ channel is Z→ee/μμ, no need for such a hard cut in E_T^{miss}

Preselection, at least 2 jets, relevant for VBF

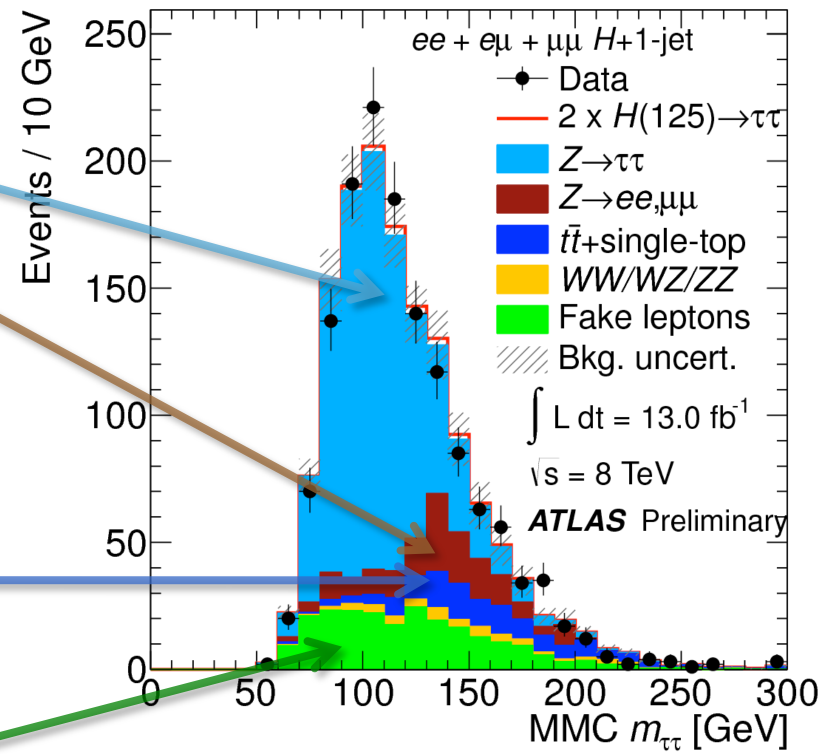




VBF category, very Tight cuts, selecting a small fraction of phase space

Background estimation

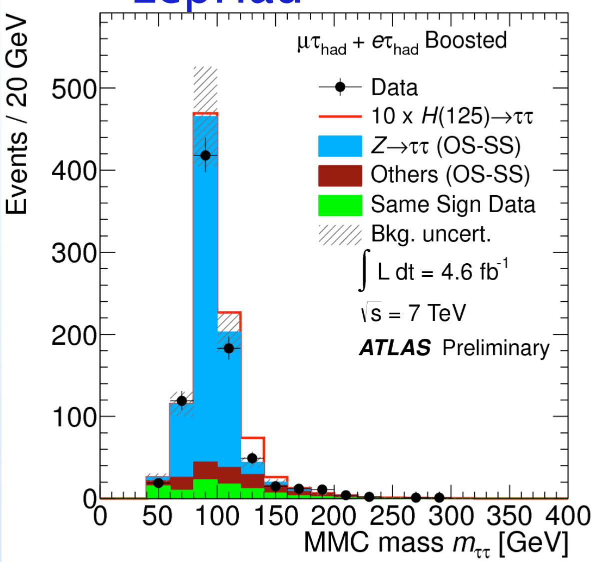
- $Z \rightarrow \tau\tau$
  - Embedding
- $Z \rightarrow ll$ (for ee/μμ channels)
  - MC simulation with control region normalization in data. ABCD metdod using E_T^{miss} and m_{ll}
- Top
  - MC simulation with control region normalization in data
- Fake leptons (QCD)
  - Estimate from signal free CR in data reversing lepton isolation for one of the two leptons



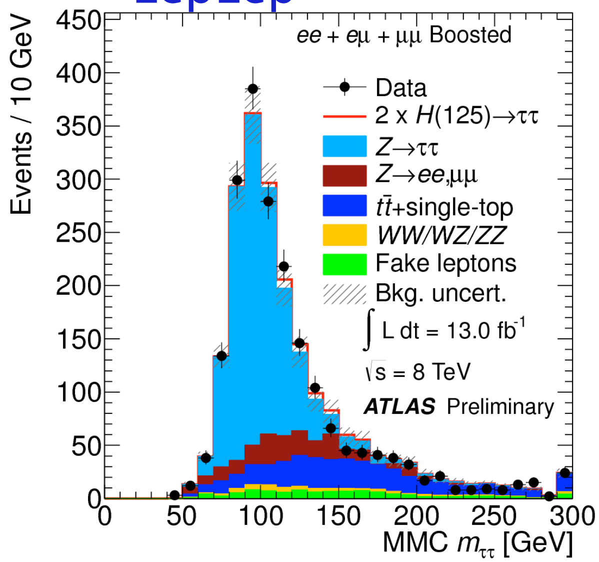
Results: ggF sensitive category

- Boosted: 2nd most sensitive category, large p_T^H or large jet p_T
- ggF has higher ISR than quark-initiated Z
  - p_T of the Higgs is slightly harder than Z, resulting into a higher boost
- Better mass resolution due to large E_T^{miss}
  - Higgs and Z better separated

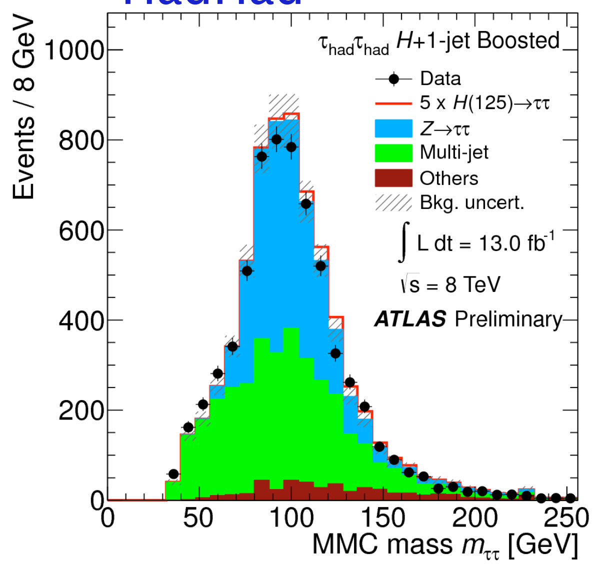
LepHad



LepLep

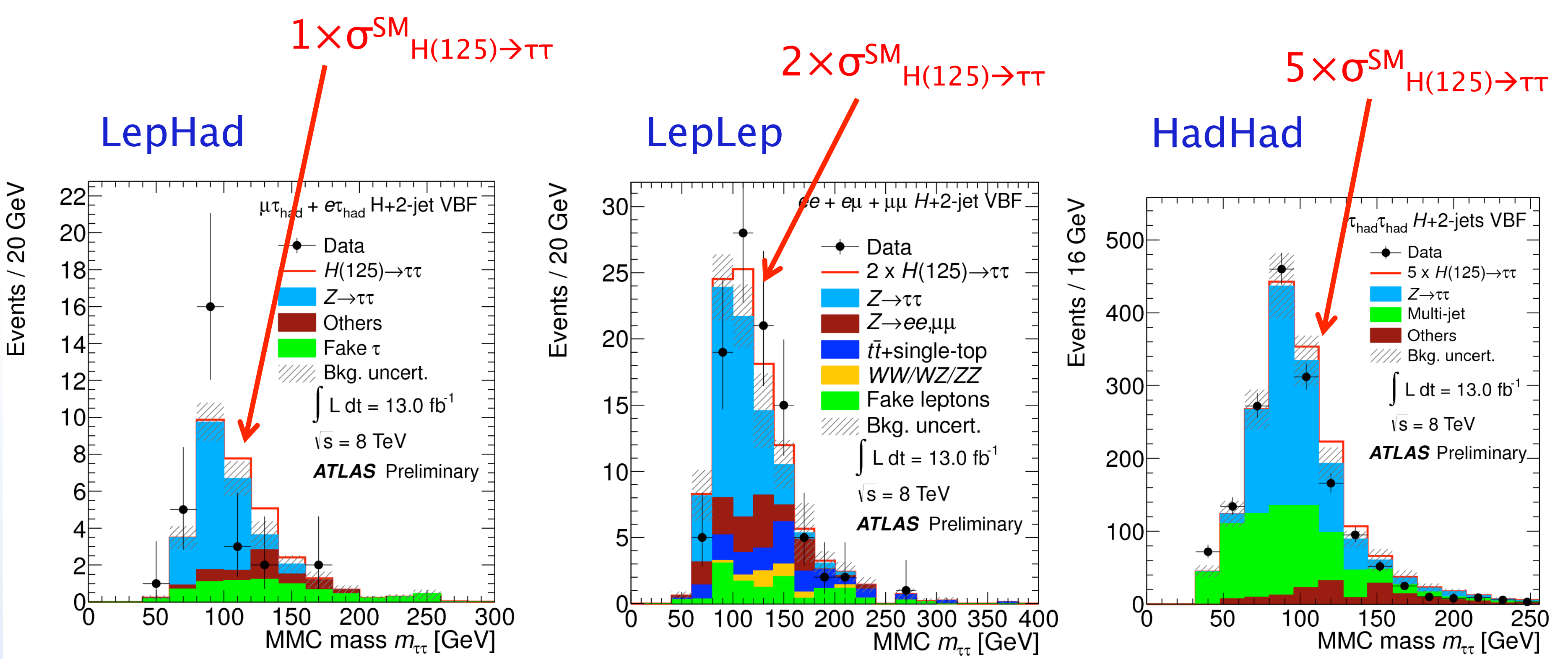


HadHad



Results: VBF category

- VBF: 1^{st} most sensitive category
- Limited statistics but best $S/\sqrt{B}$ ratio among all categories



Systematics

- Theory uncertainty on signal: 18 – 23%
  - QCD scale: ~1% for VBF, 8–12% for ggF
  - PDF: 8% for gluon processes, ~4% for quark processes

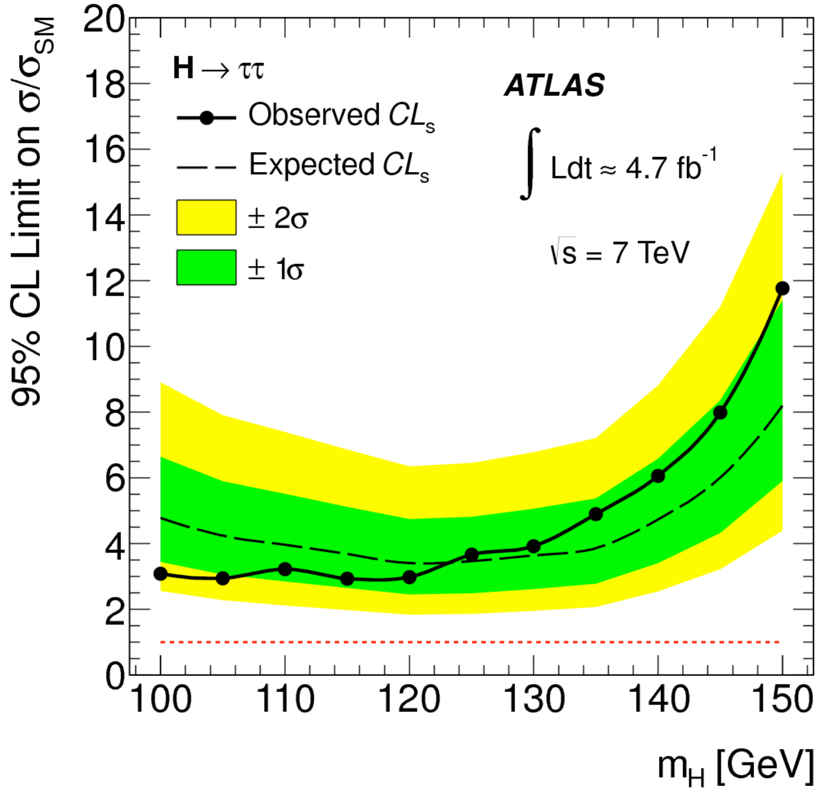
Dominant detector-related systematics:

	$Z \rightarrow \tau\tau$	*Signal*
Embedding	3%	---
JES	---	3–9%
TES	4–15%	2–9%
TauID	4–5%	
Luminosity	3.9% @ 7TeV 3.6% @ 8 TeV	

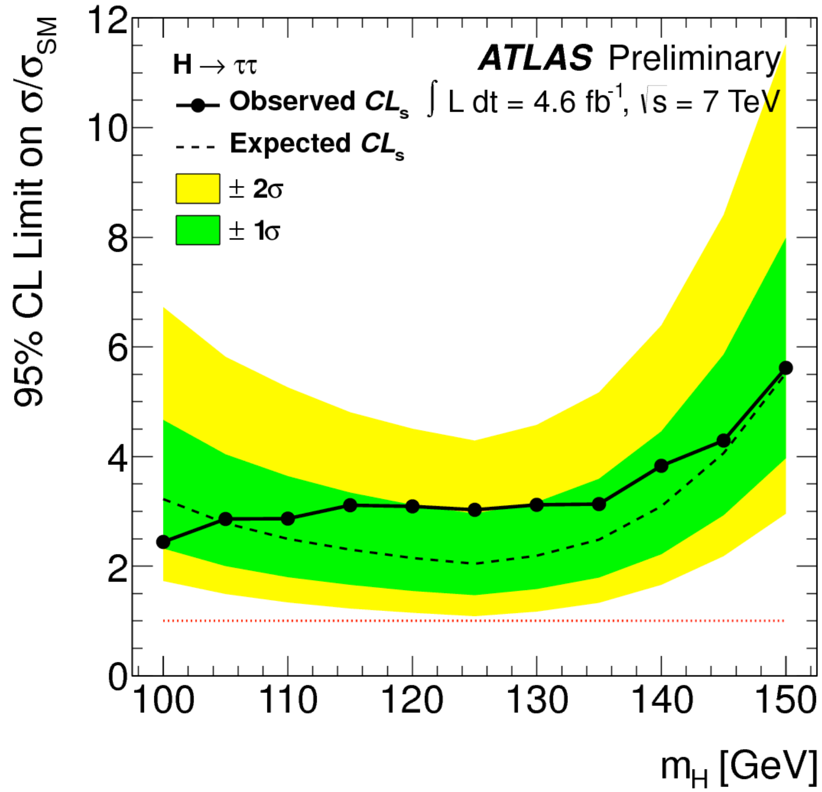
➢ Both Shape and Normalization variation taken into account

Limits @ 7 TeV only

Where we were for Moriond2012

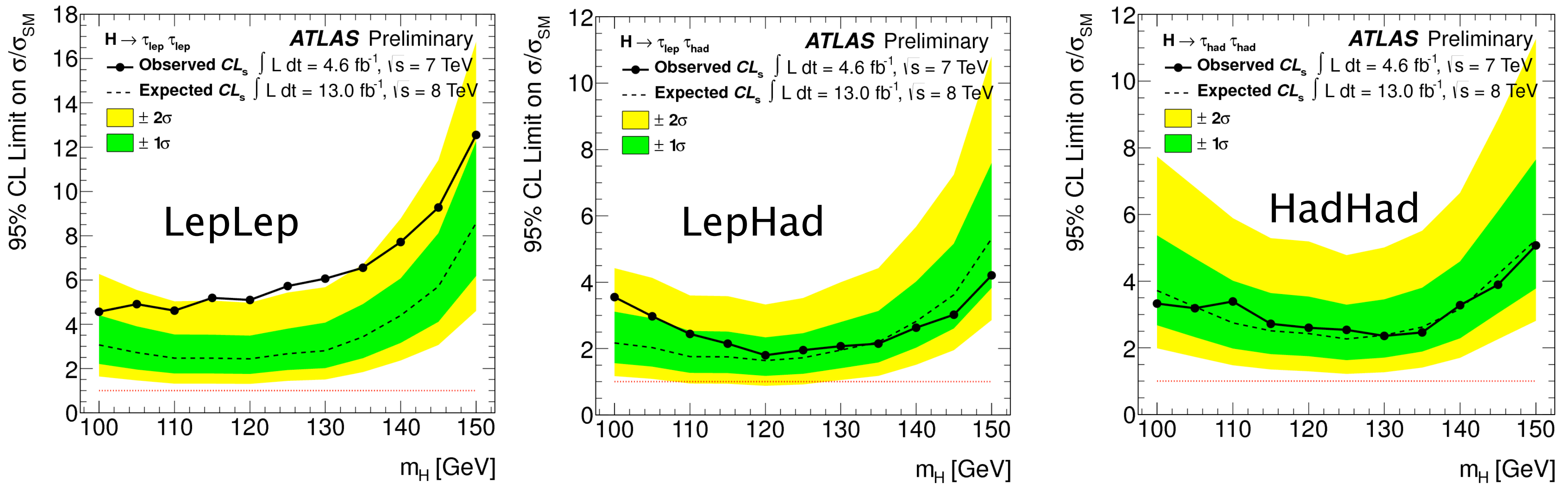


New result



- Watch out y-axis different scale!
- For the same dataset: new limit ~2 times better

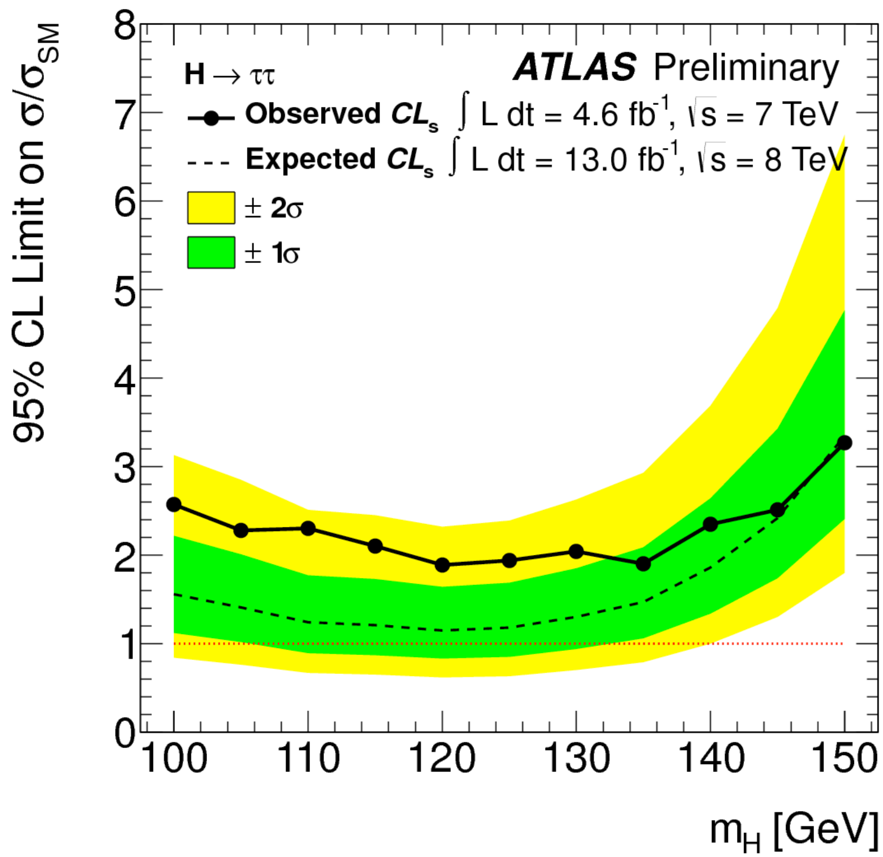
Limits @ 7&8 TeV, for the 3 channels

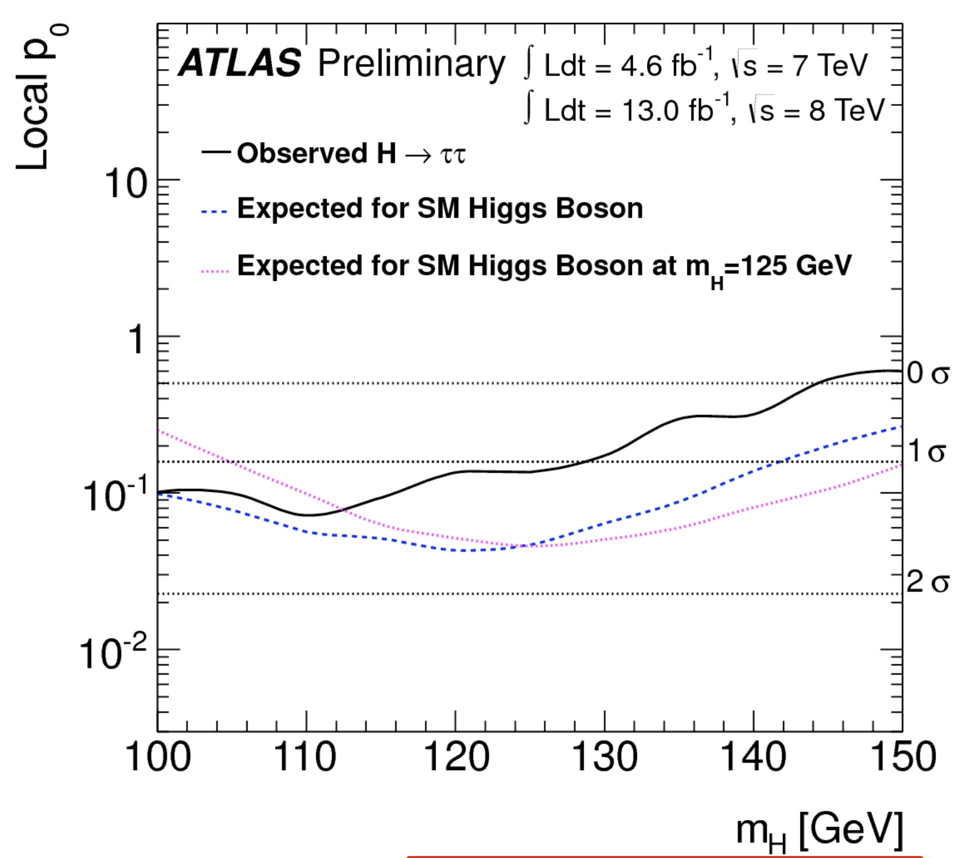


m_H=125 GeV	LepLep	LepHad	HadHad
Obs(Exp)×σ_{SM}	5.5(2.7)	2.0(1.7)	2.2(2.3)

- LepHad: most sensitive channel
- LepHad – HadHad: observed and expected limits are consistent
- LepLep: Small excess (1–2σ) of data, over the full mass range

Results: combined limit and p0

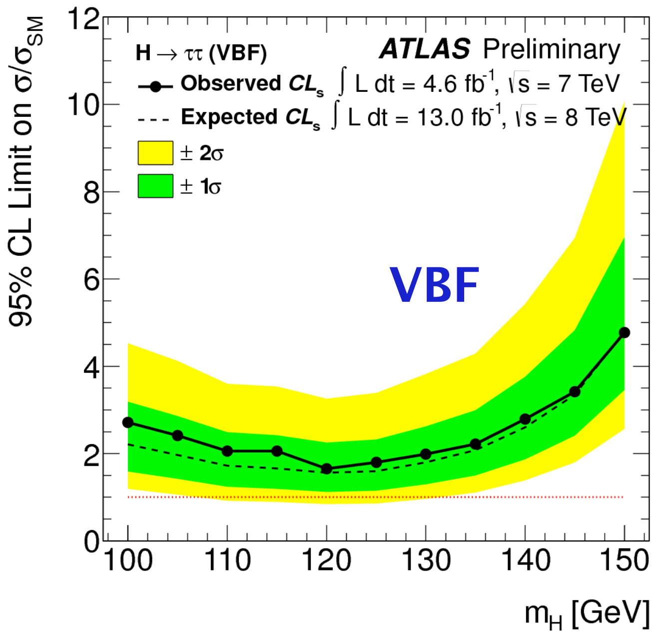


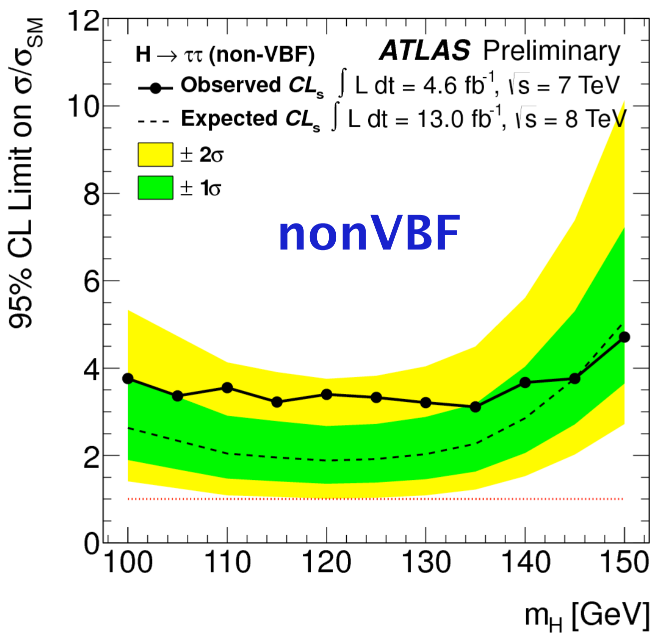


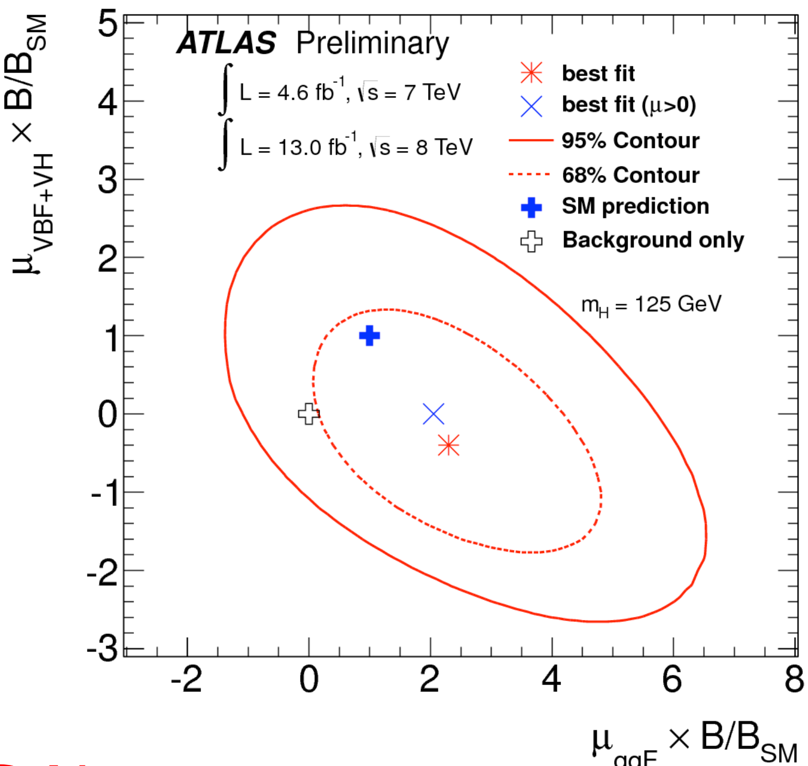
m_H=125GeV
Obs(Exp):1.9(1.2)

- Expected limit vary between 1.2 and 3.4 $\times\sigma_{SM}$
- Observed limit vary between 1.9 and 3.3 $\times\sigma_{SM}$
- Local p0: probability that background fluctuation mimics signal
  - **m_H=125 GeV:** observed **1.1σ**, highest expected sensitivity **1.7σ**
  - Signal strength μ= 0.7±0.7 consistent with both presence and absence of SM H→ττ signal

Result interpretation attempt





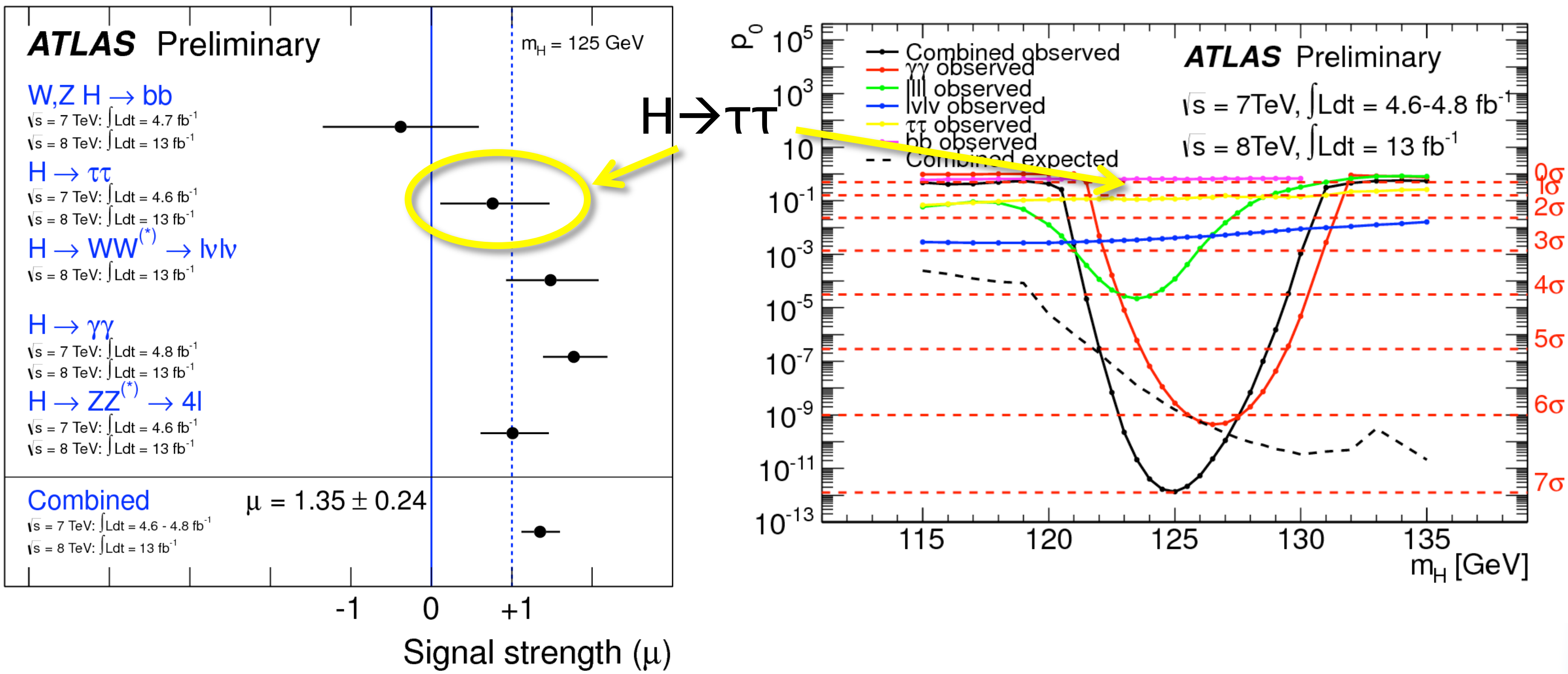


m_H=125 GeV :

- Consistent with background only hypothesis and SM Higgs signal
- Large uncertainties

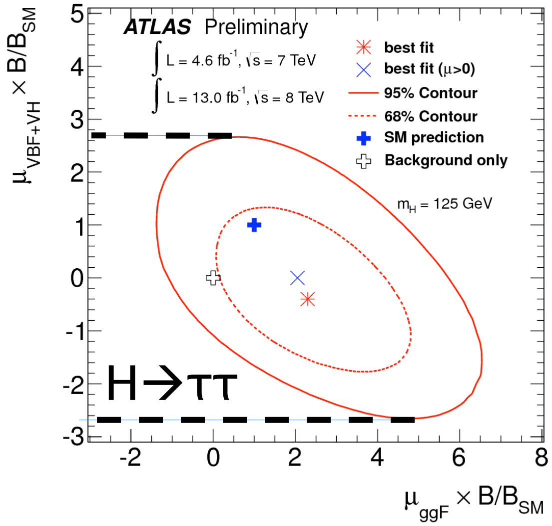
	VBF	nonVBF
Limit:	1.8(1.6)	3.3(1.9)

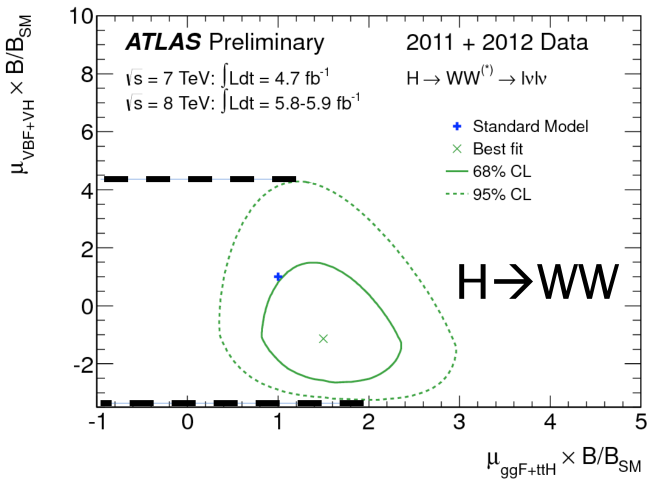
H→ττ in the overall picture

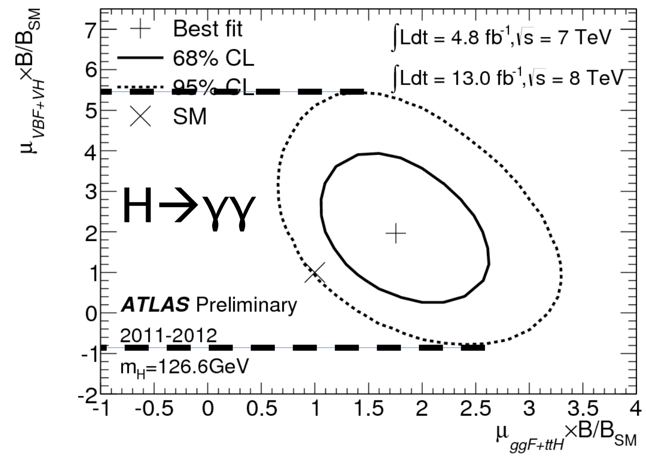


- Higgs combined excess 7σ, with H→ττ contribution of 1.1σ
- Very challenging and complicated analysis due to large amount of backgrounds, small S/√B, complexity of final state, large resolution effects
- Very important role in the SM Higgs searches, since provides direct measurement of the coupling to leptons

H→ττ uncertainty in VBF

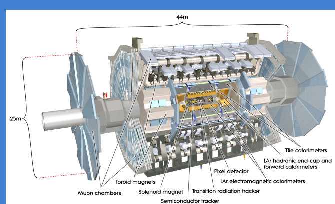


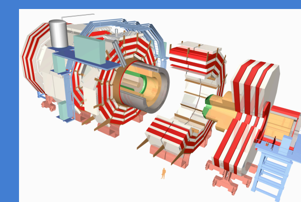




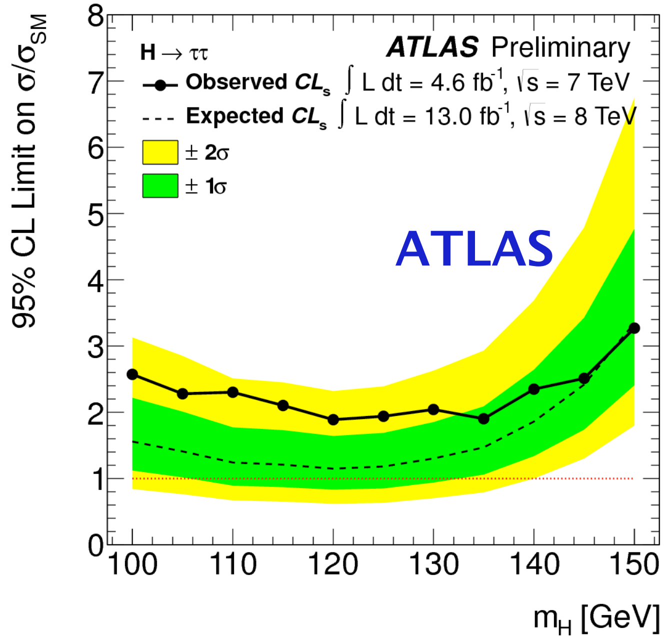
- Measure of the precision in probing VBF: projection in y-axis of 95% CL contour
  - H→ττ ~ 5.4μ
  - H→WW ~ 6.1μ
  - H→γγ ~ 6.4μ
- H→ττ has smaller uncertainty (better precision)
- Potential of contributing significantly in measuring VBF production mode of new boson

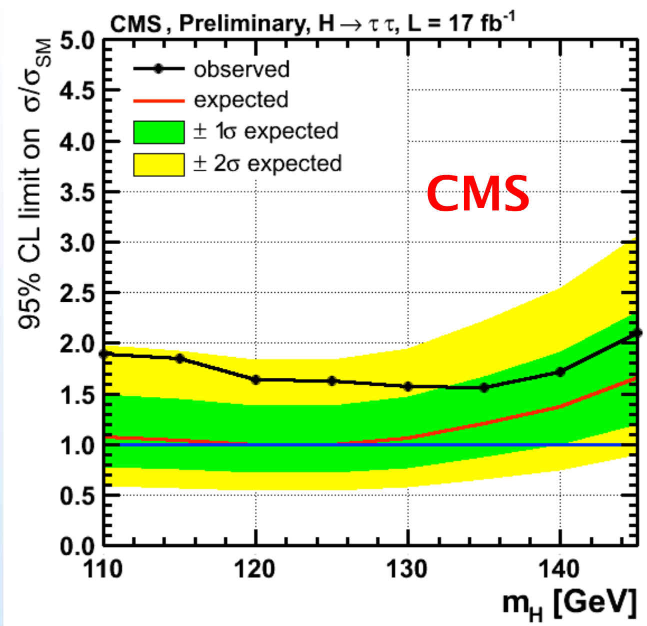
Bonus Level

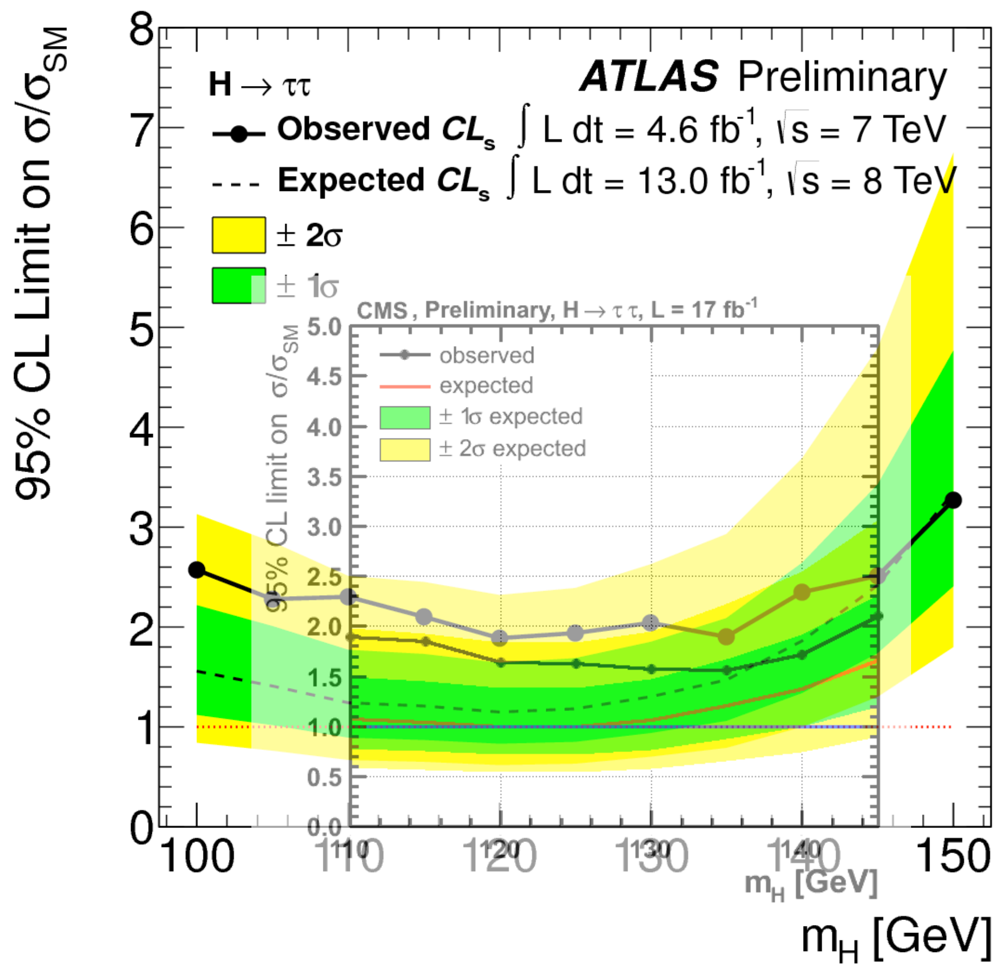

44m
25m
Tile calorimeters
LAr hadronic end-cap and forward calorimeters
Pixel detector
Toroid magnets
LAr electromagnetic calorimeters
Muon chambers
Solenoid magnet
Transition radiation tracker
Semiconductor tracker



Limits H→ττ ATLAS Vs CMS

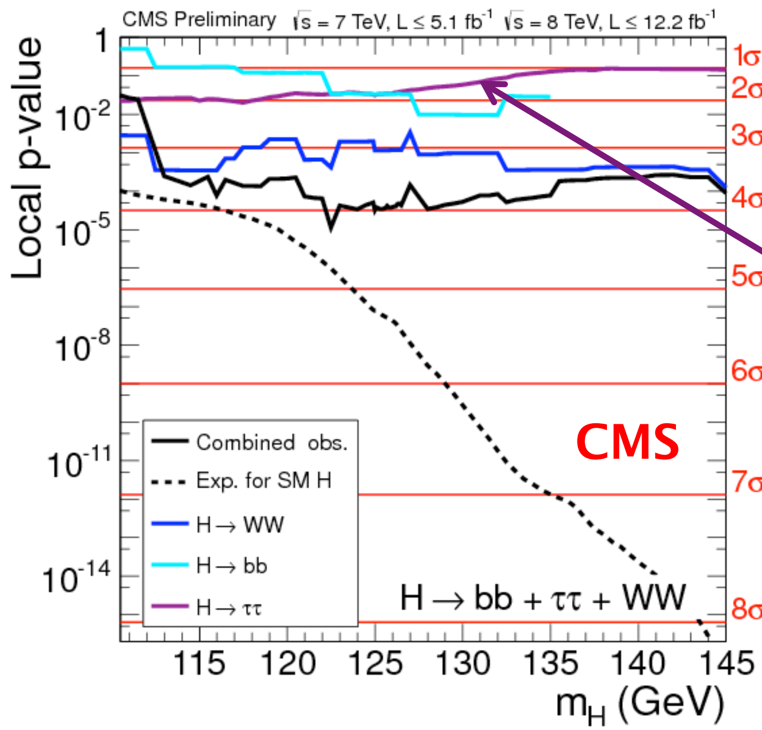




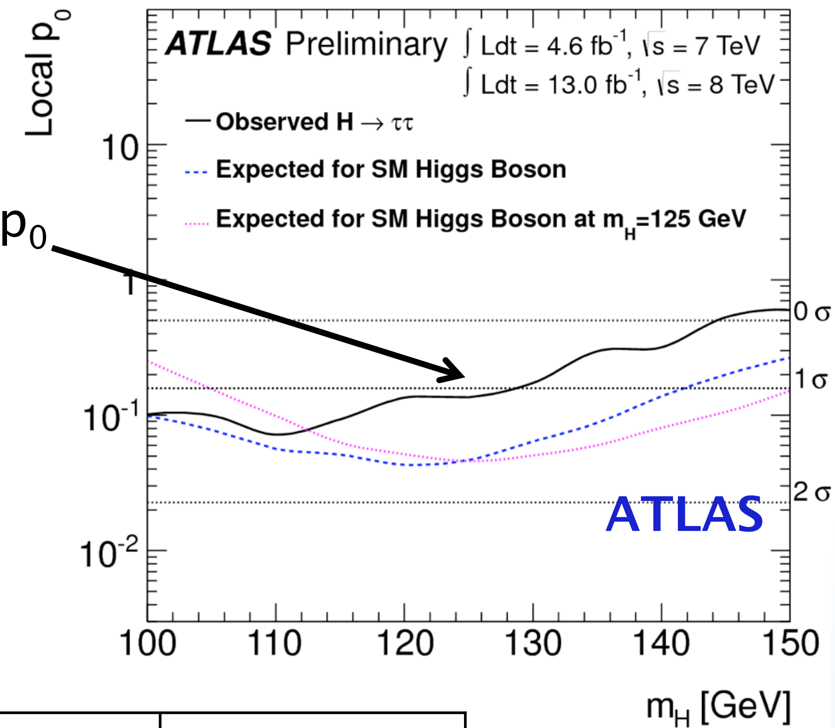


	CMS	ATLAS
	Observed (Expected) × σ_{SM}	
m_H=125 GeV	1.63(1.00)	1.94(1.18)

Limits H→ττ ATLAS Vs CMS



Observed p_0
H→ττ

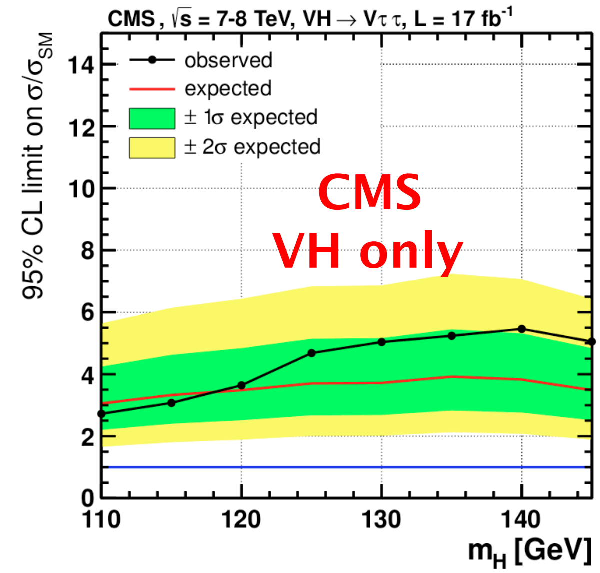


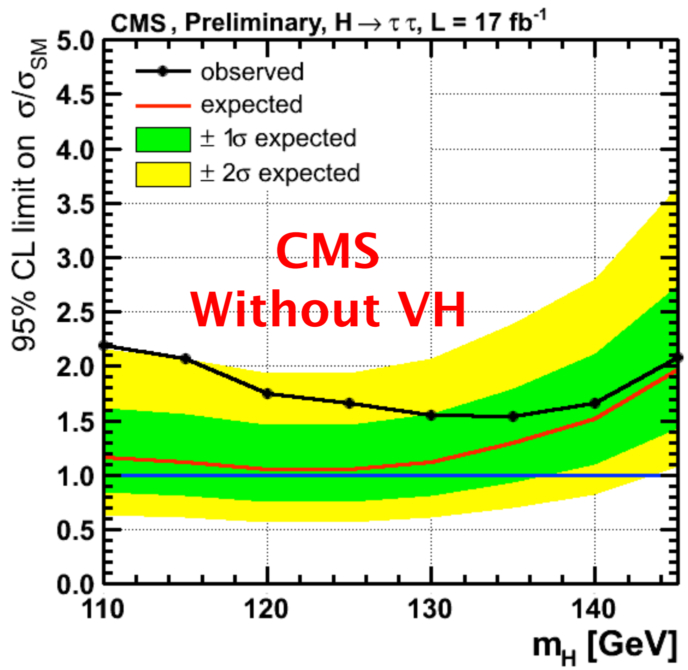
m_H=125 GeV	CMS	ATLAS
Local p_0 (observed)	1.8σ	1.1σ
Local p_0 (expected)	2.1σ	1.7σ
Signal strength μ	0.7 ± 0.5	0.7 ± 0.7

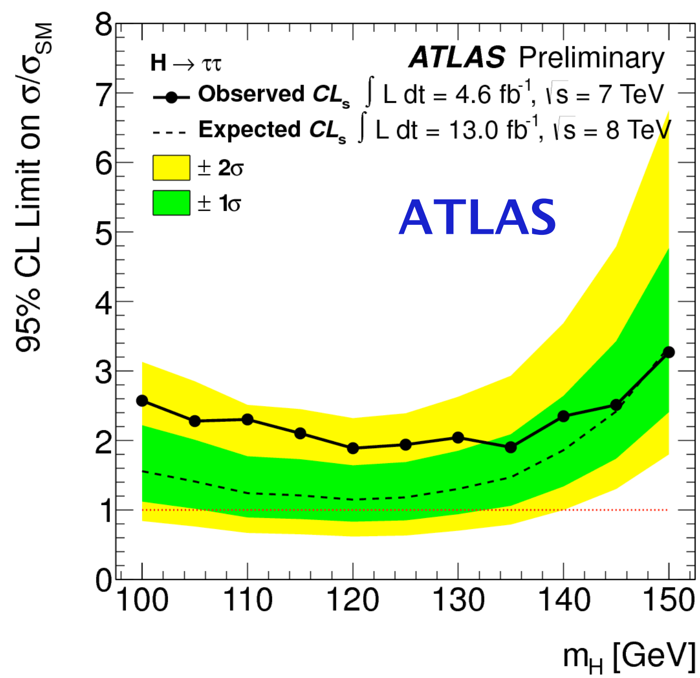
- CMS different event categorization low tau p_T Vs high tau p_T
  - 20% improvement with respect to previous analysis

Notable differences

- CMS has two additional explicit analyses to probe signal in the production mode of VH, where V decays in leptons
  - WH→lvττ
  - ZH→llττ

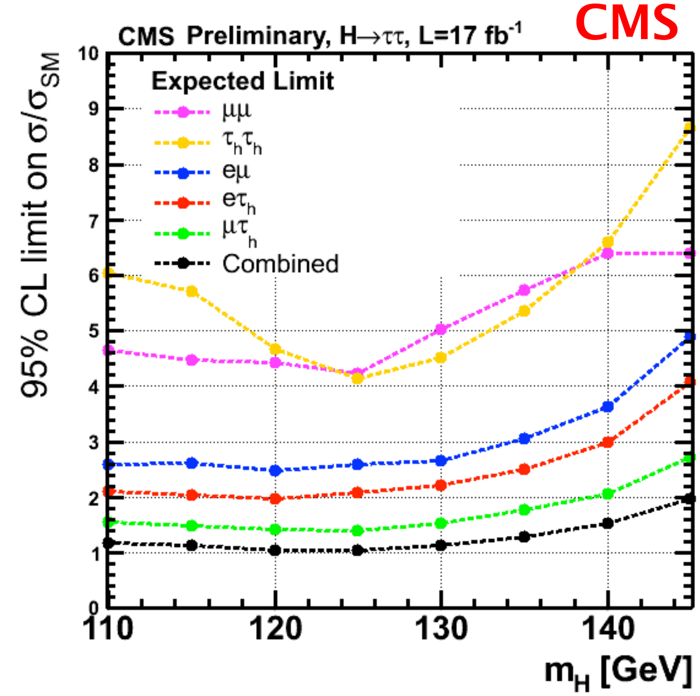




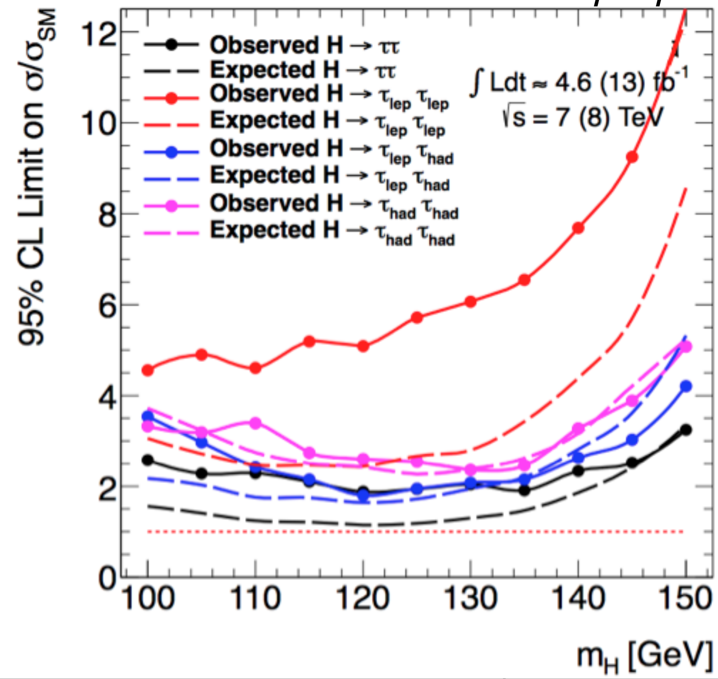


Notable differences

CMS



ATLAS *for illustration purposes*



m_H=125 GeV	CMS	ATLAS
HadHad	**4.1**	**2.3**
LepHad	**1.5**(mu-had) and 2.1 (e-had)	**1.8**
LepLep	2.6(e-mu) and 4.2 (mu-mu)	2.6

- CMS lepton/tau thresholds (lep-had):20/17/20 GeV for e/mu/tau
- ATLAS has 26/26/20 GeV for SLT, and 20/17/25 GeV for LTT events
  - Different p_T thresholds could affect sensitivities

ATLAS SM H→ττ perspective

- LHC 2 years shut-down period since a few days

H→ττ search in ATLAS:

- Analyze full 2012 dataset, additional ~7fb^{-1}
- Reminder, current result: expected sensitivity 1.7σ

- Goal of new analysis to push the sensitivity as much as possible towards 3σ and provide a more conclusive statement on whether H decays to ττ

- Explore and use the enhanced discrimination power of MVA techniques
- Optimizing basic objects such as TauID, MET, jets, mass reconstructions

- Next update will include the complete 2011+2012 dataset

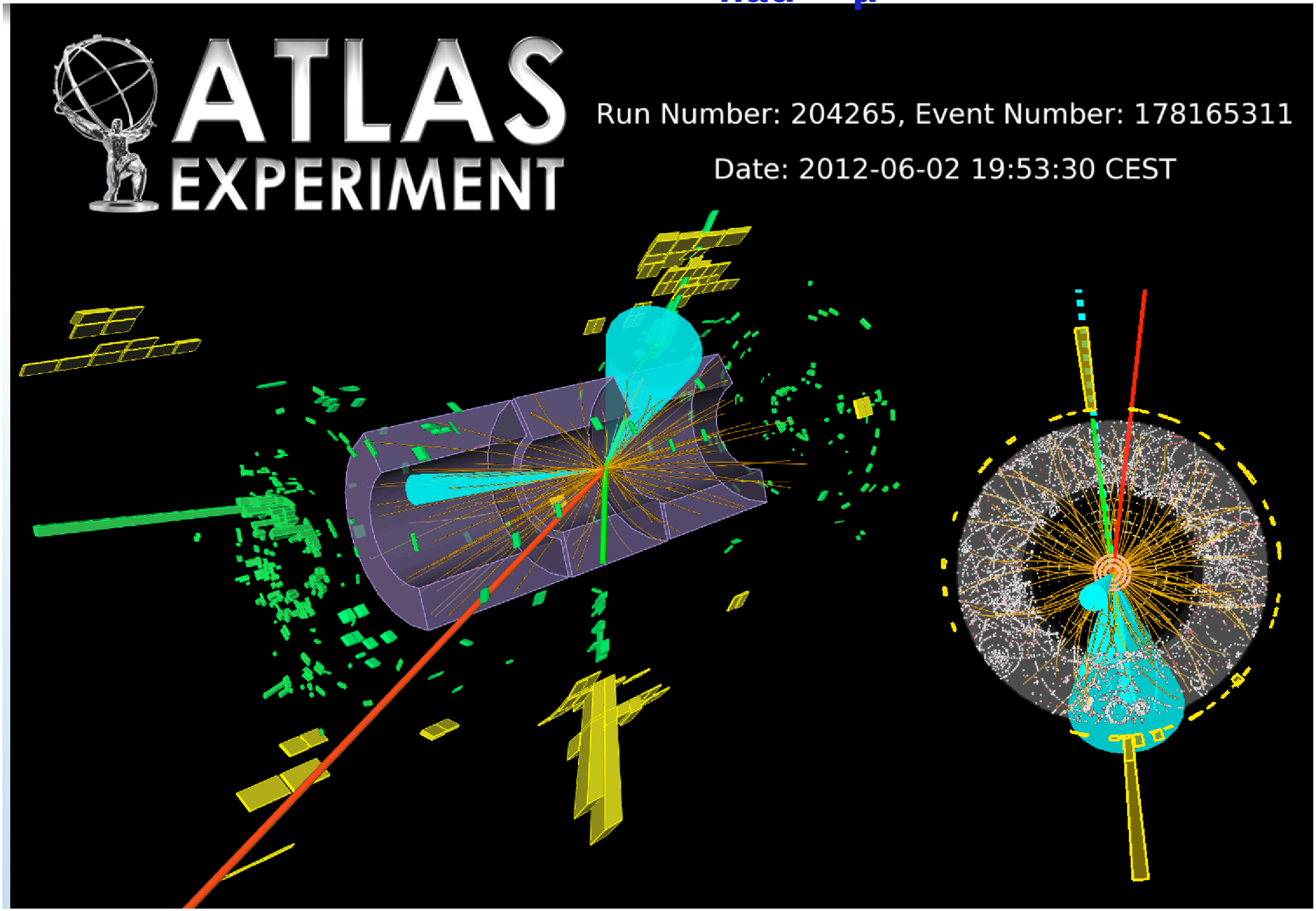
Conclusions

- SM $H \rightarrow \tau\tau$ in ATLAS up to now..
  - Analyzing 4.6(13) fb^{-1} @ 7(8) TeV
  - Combined limit:
    - Observed (expected): 1.9 (1.2)xσ_{SM} @ m_H=125 GeV
    - Excess of data driven by nonVBF, LepLep channels
  - Expected p_0 @ m_H=125 GeV: 1.7σ
  - Observed p_0 @ m_H=125 GeV: 1.1σ

- 7 additional fb^{-1} @ 8TeV are being analyzed

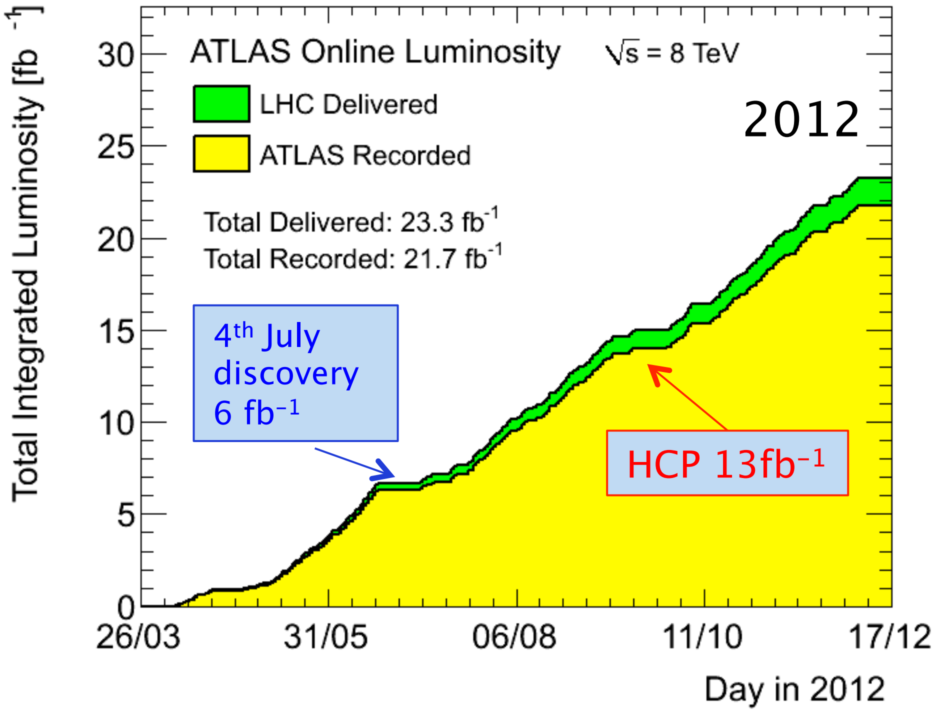
- Stay tuned for the next $H \rightarrow \tau\tau$ more sensitive update, coming soon…

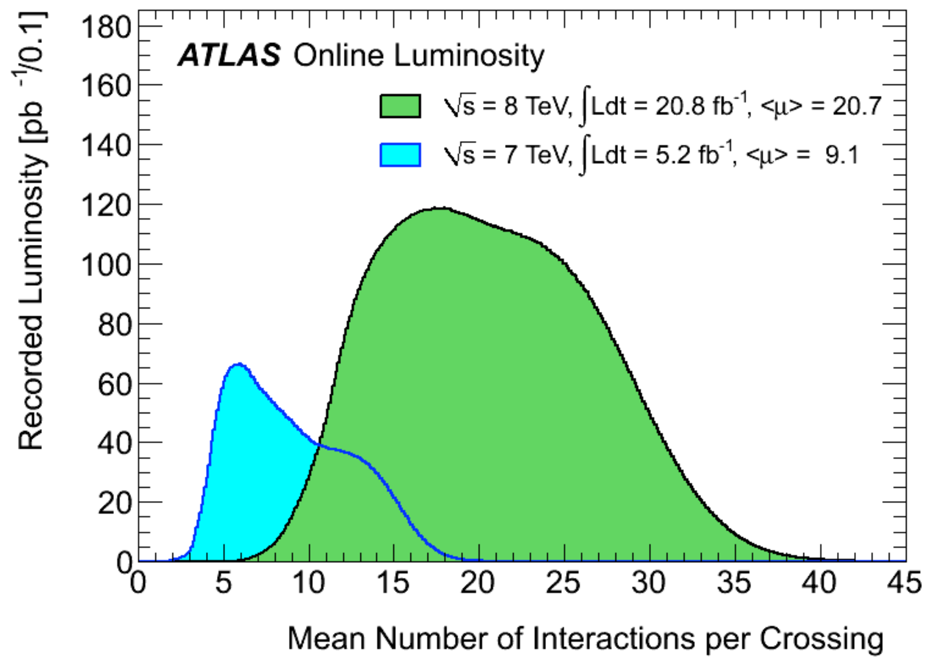
VBF $H \rightarrow \tau_{had}\ \tau_{\mu}$



Backup

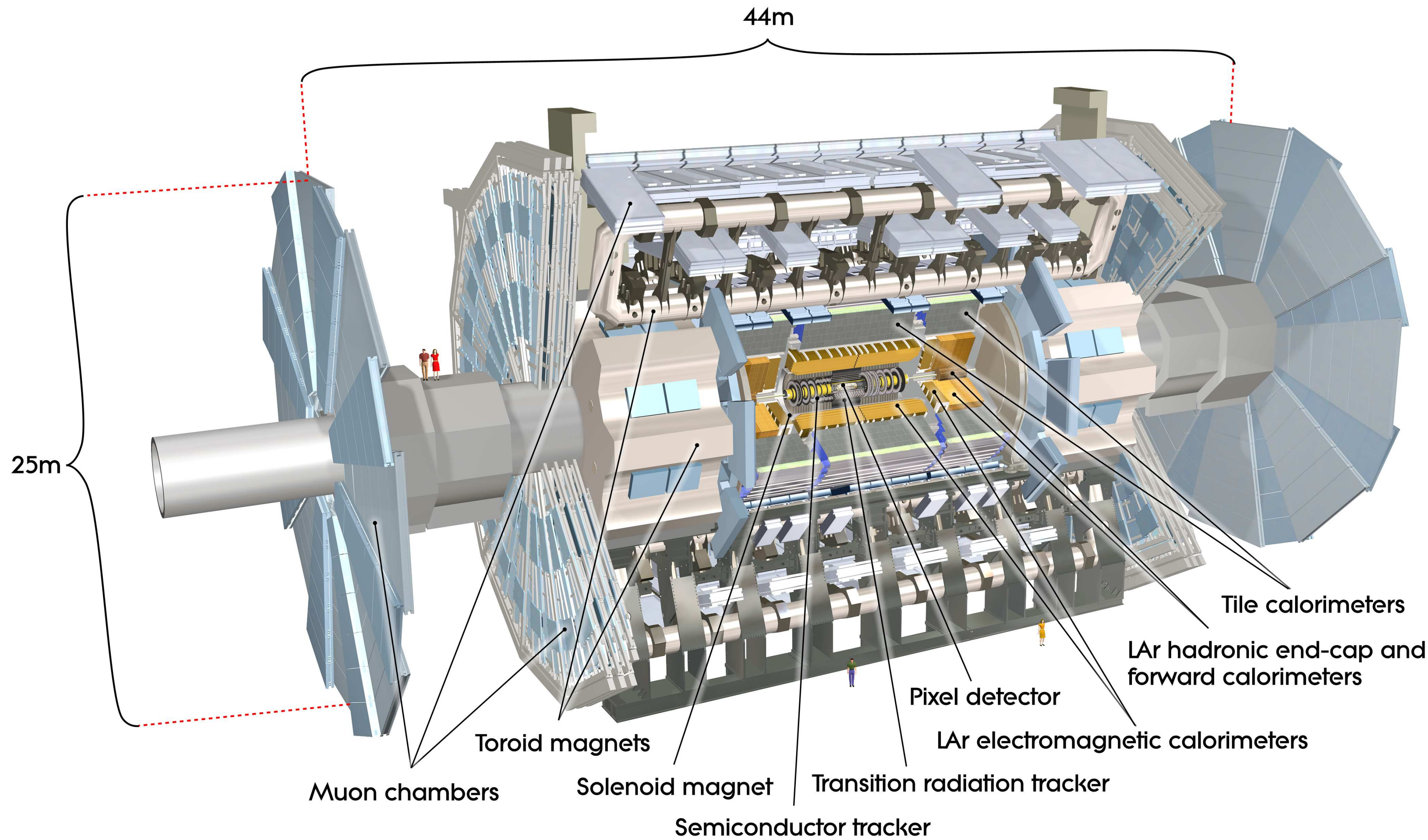
LHC operation





- Excellent LHC performance in 2012
  - $L_{integrated}$ ~ 23 fb^{-1} delivered
  - ATLAS data taking efficiency >93%
- Total 2011-2012 $L_{integrated}$~29 fb^{-1} delivered
- Increased number of pile-up events
  - Affecting trigger, computing, reconstruction, resolution, …
  - An important challenge for all analyses

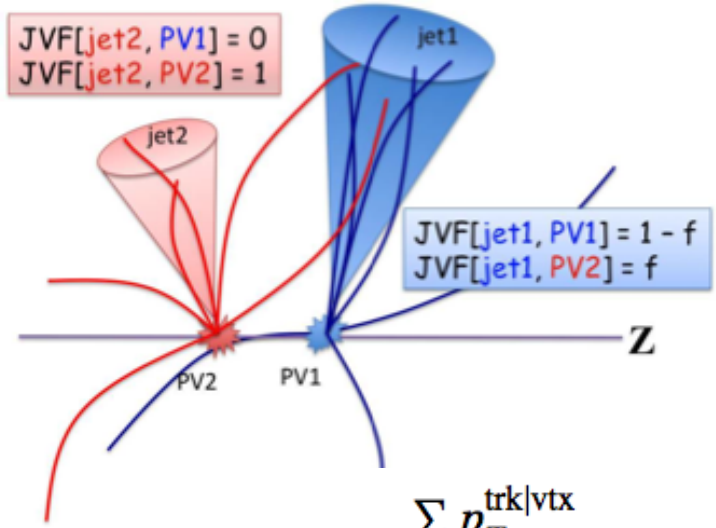
A Toroidal Large ApparatuS



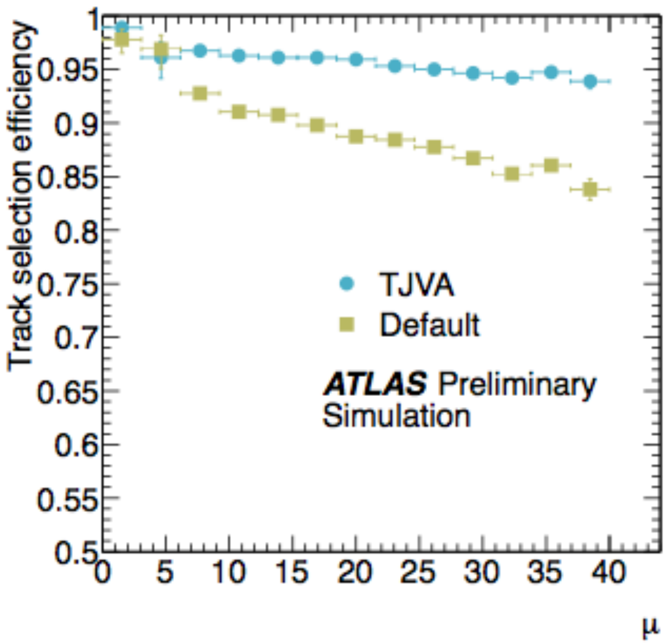
TauReco

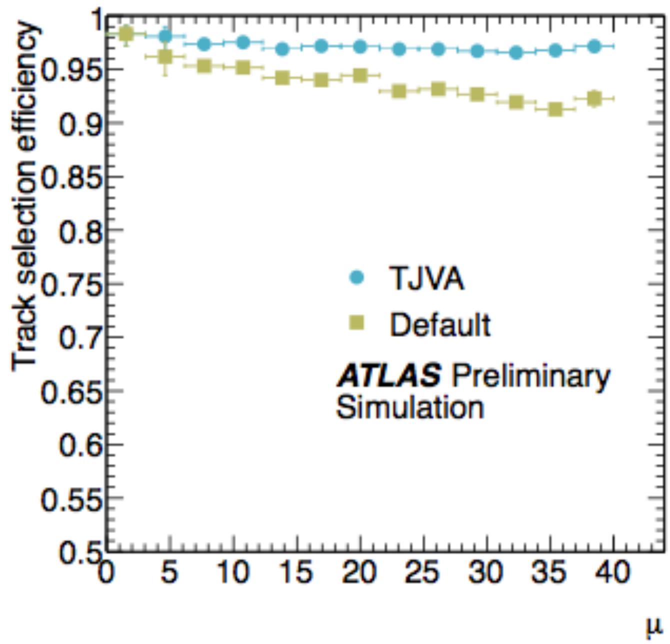
Track requirements

- *pT > 1 GeV,*
- *Number of pixel hits ≥ 2,*
- *Number of pixel hits + number of SCT hits ≥ 7,*
- *|d0|<1.0mm,*
- *|z0 sinθ| < 1.5 mm,*

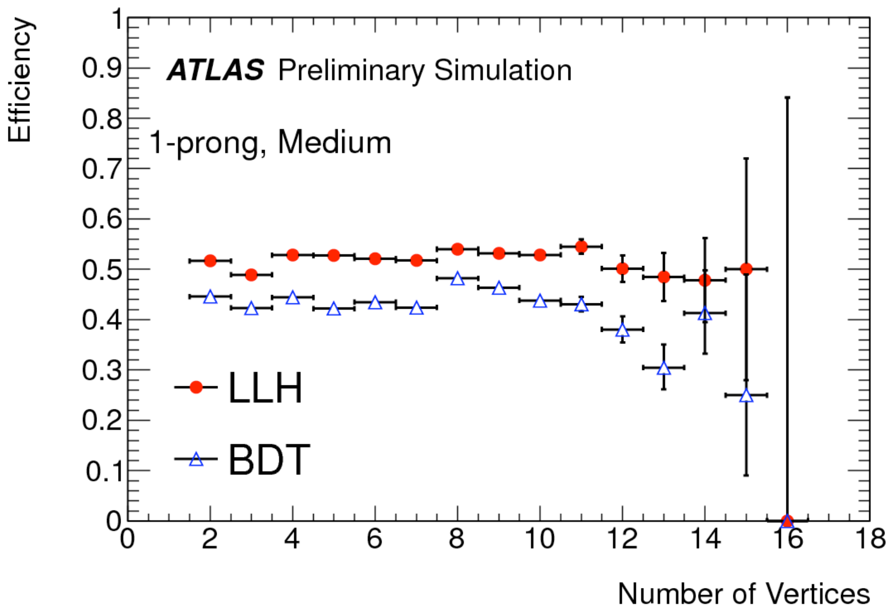


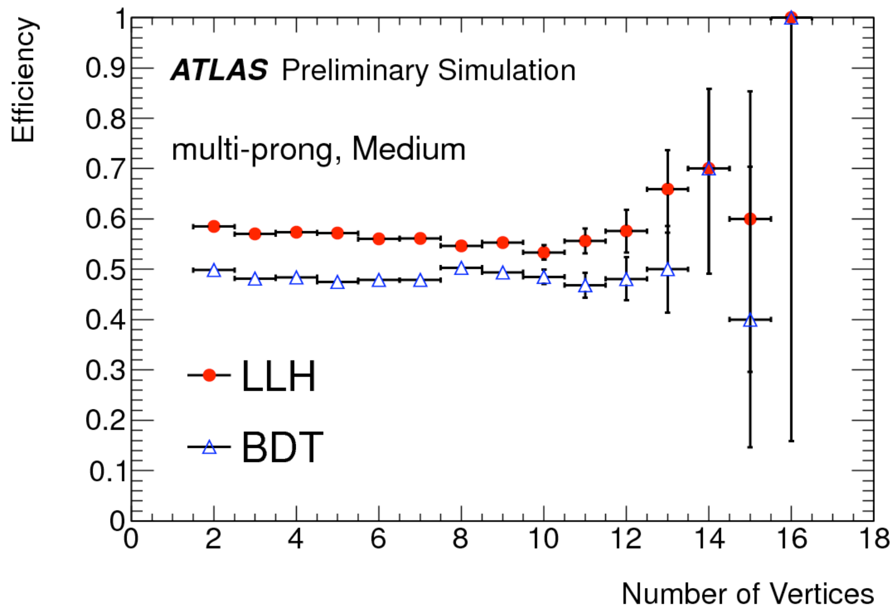
$$f_{\mathrm{JVF}}(\mathrm{jet}|\mathrm{vtx}) = \frac{\sum p_T^{\mathrm{trk}|\mathrm{vtx}}}{\sum p_T^{\mathrm{trk}}}$$





TauID against pile-up





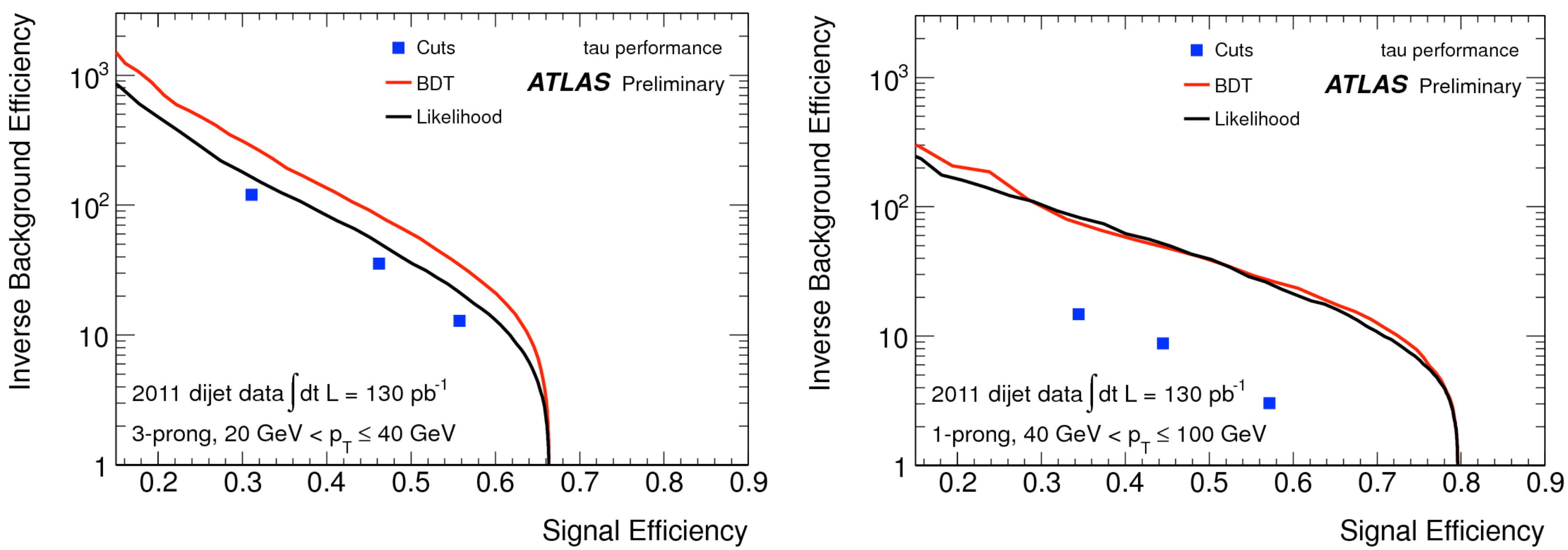
TauID Signal/Background Efficiency

Signal efficiency: MC: Z→τ , W→τν

$$\varepsilon_{\rm sig}^{n\text{-prong}} = \frac{(\#\text{ of tau candidates with } n \text{ reconstructed tracks, passing ID})}{(\#\text{ of true visible hadronic tau decays with } n \text{ prongs})}$$

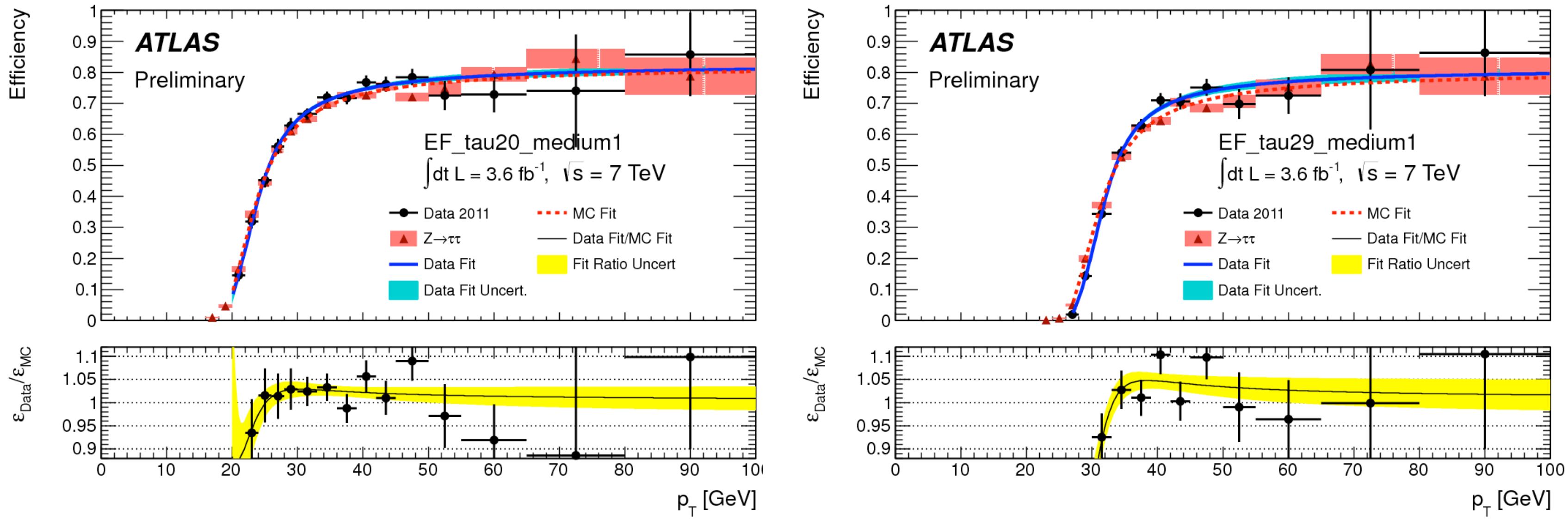
Background efficiency: Data: Dijet sample

$$\varepsilon_{\rm bkg}^{n\text{-prong}} = \frac{(\#\text{ of tau candidates with } n \text{ reconstructed tracks, passing ID})}{(\#\text{ of tau candidates with } n \text{ reconstructed tracks})}$$



Tau Trigger Efficiency

- Tag and probe: $Z \rightarrow \tau_{lep}\tau_{had}$, $W \rightarrow \tau\nu$
  - Tag: orthogonal trigger
    - Single lepton trigger
    - Missing ET trigger
  - Probe: Hadronic tau matched to a hadronic tau trigger

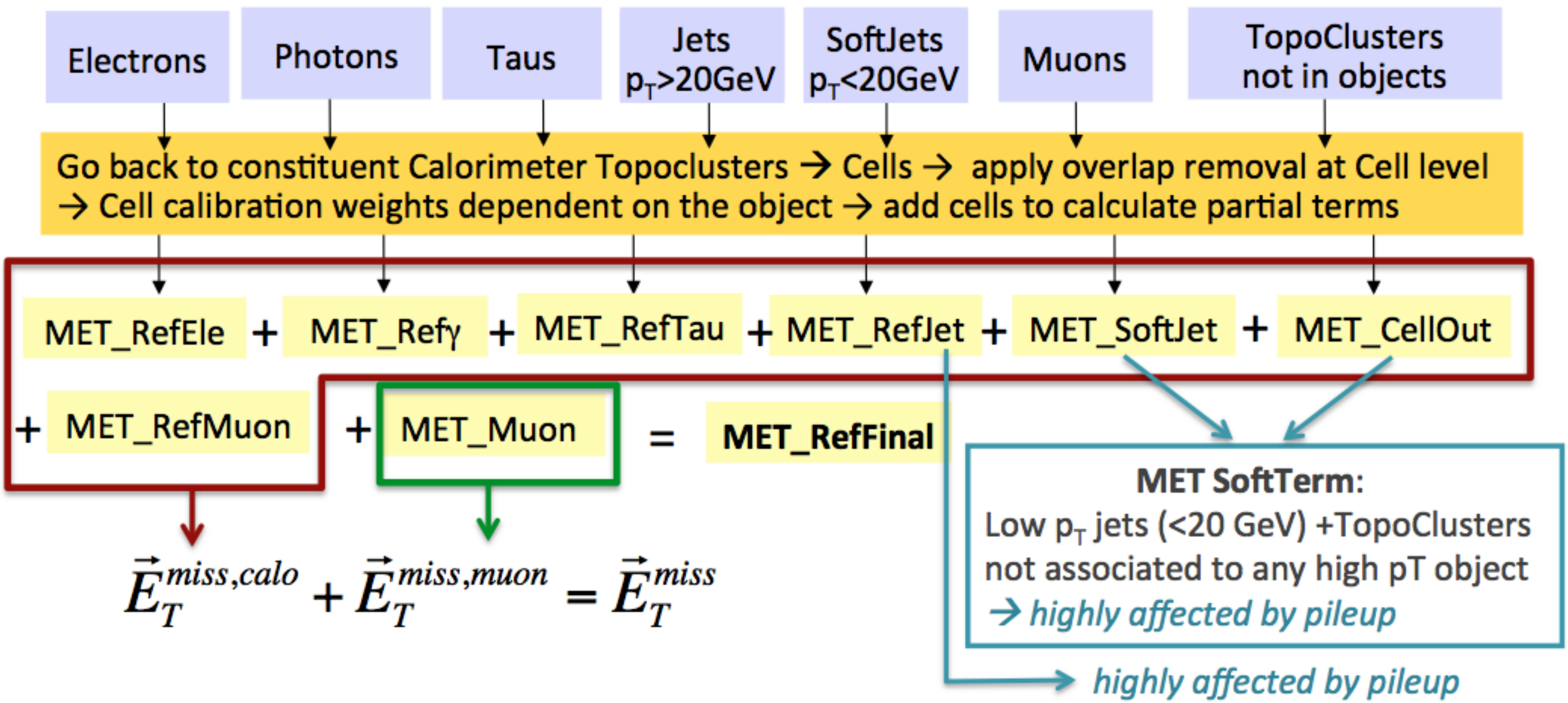


- Fit turn-on curve

$$f(p_T) = C_0 \tan^{-1}\left\{\frac{p_T - C_1}{C_2}\right\} + C_3$$

  - Efficiencies in data and MC in good agreement

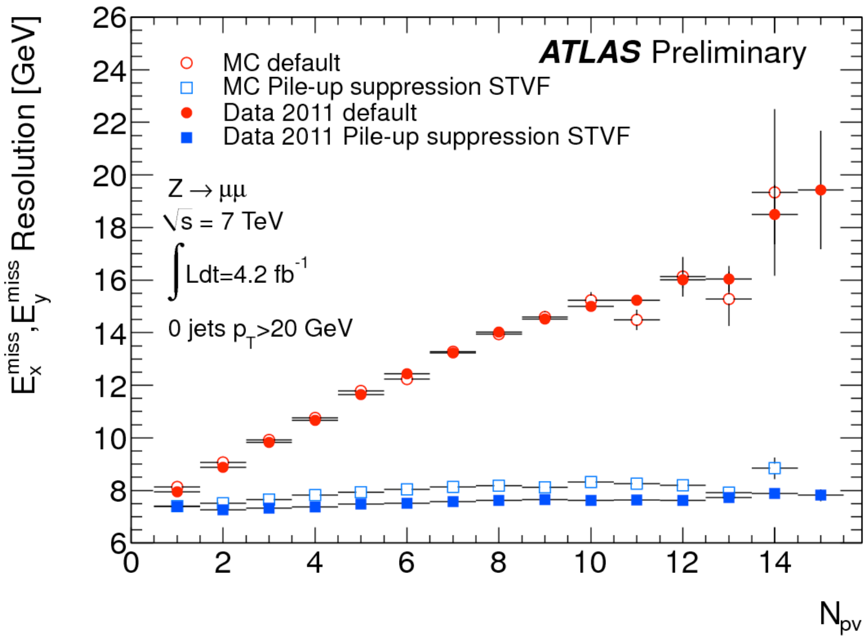
MET

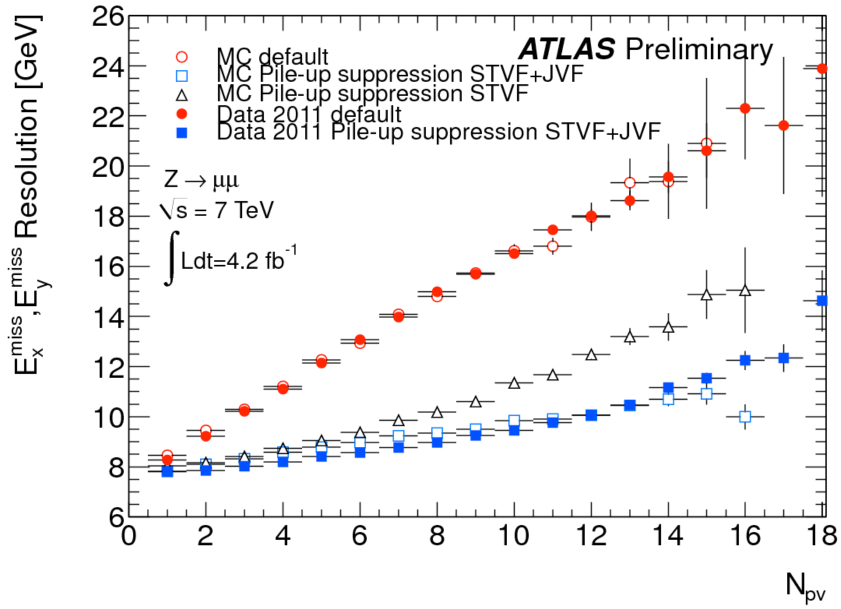


$$\vec{E}_T^{miss,calo} + \vec{E}_T^{miss,muon} = \vec{E}_T^{miss}$$

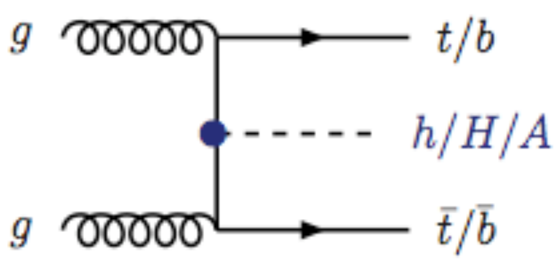
STVF+JVF	Correction based on the fraction of tracks from PV	STVF weight: $\left(\sum p_T^{track,PV} / \sum p_T^{track}\right)_{unmatched\ objects}$	Each jet p_T scaled by JVF $p_T^{jet.corr} = \begin{cases} 0 & JVF = -1 \,\&\, \lvert\eta\rvert < 2.5 \\ p_T^{jet}\lvert JVF\rvert & else \end{cases}$

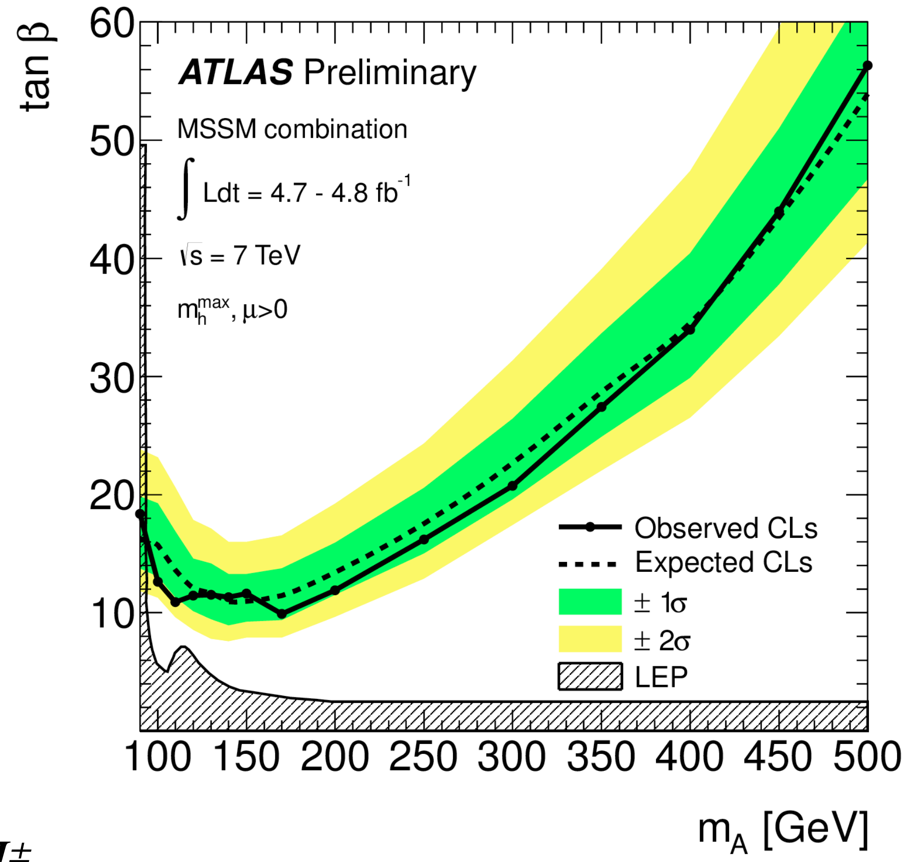
MET and pile-up





MSSM H→tau tau



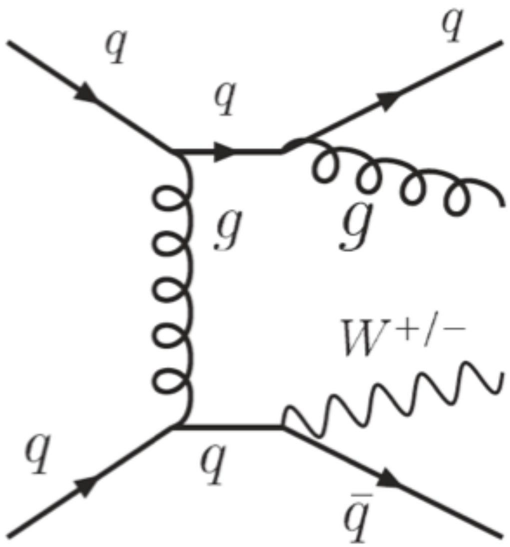


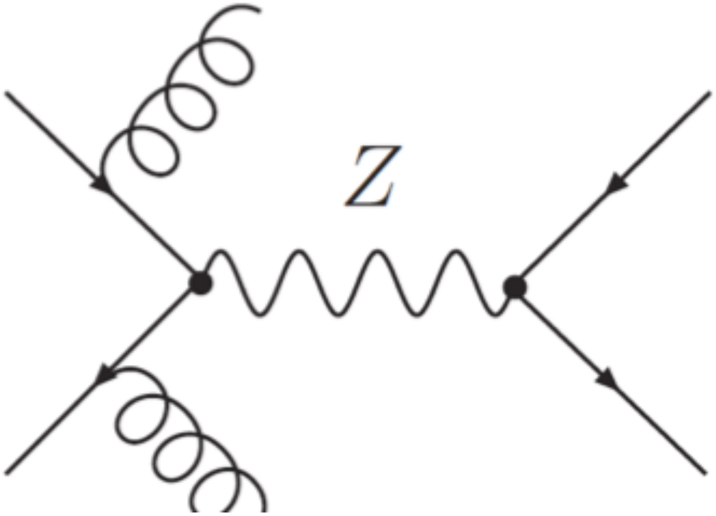
- *2 Higgs doublets : h, H, A, $H^{\pm}$*
- *At tree level Higgs properties are predicted in function of two parameters, often chosen us*

m_A : mass of CP-odd A

$\tan\beta$: the ratio of VEV of the 2 Higgs doublets

W / Z production tree level





H→tau tau BR's

Decay channels	Channel description	BR
lepton-lepton channel	$qq \to qqH \to qq\ \tau^{\pm}\tau^{\mp} \to qq\ e^{\pm}e^{\mp}v_{\tau}v_{\tau}v_{e}v_{e}$	$\sim 3.2\%$
	$qq \to qqH \to qq\ \tau^{\pm}\tau^{\mp} \to qq\ \mu^{\pm}\mu^{\mp}v_{\tau}v_{\tau}v_{\mu}v_{\mu}$	$\sim 3.0\%$
	$qq \to qqH \to qq\ \tau^{\pm}\tau^{\mp} \to qq\ e^{\pm}\mu^{\mp}v_{\tau}v_{\tau}v_{e}v_{\mu}$	$\sim 6.2\%$
lepton-hadron channel	$qq \to qqH \to qq\ \tau^{\pm}\tau^{\mp} \to qq\ e^{\pm}hadrons\ v_{\tau}v_{\tau}v_{e}$	$\sim 23.2\%$
	$qq \to qqH \to qq\ \tau^{\pm}\tau^{\mp} \to qq\ \mu^{\pm}hadrons\ v_{\tau}v_{\tau}v_{\mu}$	$\sim 22.6\%$
hadron-hadron channel	$qq \to qqH \to qq\ \tau^{\pm}\tau^{\mp} \to qq\ hadrons\ hadrons\ v_{\tau}v_{\tau}$	$\sim 42.3\%$

LepLep categories

<table>
<tr><th>2-jet VBF</th><th>Boosted</th><th>2-jet VH</th><th>1-jet</th></tr>
<tr><td colspan="4">Pre-selection: exactly two leptons with opposite charges</td></tr>
<tr><td colspan="4">30 GeV $< m_{\ell\ell} <$ 75 GeV (30 GeV $< m_{\ell\ell} <$ 100 GeV)
for same-flavor (different-flavor) leptons, and $p_{T,\ell 1} + p_{T,\ell 2} >$ 35 GeV</td></tr>
<tr><td colspan="4">At least one jet with $p_T >$ 40 GeV ($|JVF_{\mathrm{jet}}| > 0.5$ if $|\eta_{\mathrm{jet}}| < 2.4$)</td></tr>
<tr><td colspan="4">$E_{\mathrm{T}}^{\mathrm{miss}} >$ 40 GeV ($E_{\mathrm{T}}^{\mathrm{miss}} >$ 20 GeV) for same-flavor (different-flavor) leptons</td></tr>
<tr><td colspan="4">$H_{\mathrm{T}}^{\mathrm{miss}} >$ 40 GeV for same-flavor leptons</td></tr>
<tr><td colspan="4">$0.1 < x_{1,2} < 1$</td></tr>
<tr><td colspan="4">$0.5 < \Delta\phi_{\ell\ell} < 2.5$</td></tr>
<tr><td>$p_{T,j2} >$ 25 GeV (JVF)</td><td>excluding 2-jet VBF</td><td>$p_{T,j2} >$ 25 GeV (JVF)</td><td>excluding 2-jet VBF, Boosted and 2-jet VH</td></tr>
<tr><td>$\Delta\eta_{jj} > 3.0$</td><td>$p_{T,\tau\tau} >$ 100 GeV</td><td>excluding Boosted</td><td>$m_{\tau\tau j} >$ 225 GeV</td></tr>
<tr><td>$m_{jj} >$ 400 GeV</td><td>b-tagged jet veto</td><td>$\Delta\eta_{jj} < 2.0$</td><td>b-tagged jet veto</td></tr>
<tr><td>b-tagged jet veto</td><td rowspan="2">–</td><td>30 GeV $< m_{jj} <$ 160 GeV</td><td rowspan="2">–</td></tr>
<tr><td>Lepton centrality and CJV</td><td>b-tagged jet veto</td></tr>
<tr><td colspan="4">0-jet (7 TeV only)</td></tr>
<tr><td colspan="4">Pre-selection: exactly two leptons with opposite charges</td></tr>
<tr><td colspan="4">Different-flavor leptons with 30 GeV $< m_{\ell\ell} <$ 100 GeV and $p_{T,\ell 1} + p_{T,\ell 2} >$ 35 GeV</td></tr>
<tr><td colspan="4">$\Delta\phi_{\ell\ell} > 2.5$</td></tr>
<tr><td colspan="4">b-tagged jet veto</td></tr>
</table>

LepHad categories

7 TeV		8 TeV	
VBF Category	Boosted Category	VBF Category	Boosted Category
▸ $p_T^{\tau_{\text{had-vis}}}$ >30 GeV	–	▸ $p_T^{\tau_{\text{had-vis}}}$ >30 GeV	▸ $p_T^{\tau_{\text{had-vis}}}$ >30 GeV
▸ E_T^{miss} >20 GeV	▸ E_T^{miss} >20 GeV	▸ E_T^{miss} >20 GeV	▸ E_T^{miss} >20 GeV
▸ ≥ 2 jets	▸ $p_T^H > 100$ GeV	▸ ≥ 2 jets	▸ $p_T^H > 100$ GeV
▸ $p_T^{j1}, p_T^{j2} > 40$ GeV	▸ $0 < x_1 < 1$	▸ $p_T^{j1} > 40, p_T^{j2} >30$ GeV	▸ $0 < x_1 < 1$
▸ $\Delta\eta_{jj} > 3.0$	▸ $0.2 < x_2 < 1.2$	▸ $\Delta\eta_{jj} > 3.0$	▸ $0.2 < x_2 < 1.2$
▸ $m_{jj} > 500$ GeV	▸ Fails VBF	▸ $m_{jj} > 500$ GeV	▸ Fails VBF
▸ centrality req.	–	▸ centrality req.	–
▸ $\eta_{j1} \times \eta_{j2} < 0$	–	▸ $\eta_{j1} \times \eta_{j2} < 0$	–
▸ $p_T^{\text{Total}} < 40$ GeV	–	▸ $p_T^{\text{Total}} < 30$ GeV	–
–	–	▸ p_T^{ℓ} >26 GeV	–
• m_T <50 GeV	• m_T <50 GeV	• m_T <50 GeV	• m_T <50 GeV
• $\Delta(\Delta R) < 0.8$	• $\Delta(\Delta R) < 0.8$	• $\Delta(\Delta R) < 0.8$	• $\Delta(\Delta R) < 0.8$
• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 1.6$	• $\sum \Delta\phi < 2.8$	–
–	–	• b-tagged jet veto	• b-tagged jet veto
1 Jet Category	0 Jet Category	1 Jet Category	0 Jet Category
▸ ≥ 1 jet, p_T >25 GeV	▸ 0 jets p_T >25 GeV	▸ ≥ 1 jet, p_T >30 GeV	▸ 0 jets p_T >30 GeV
▸ E_T^{miss} >20 GeV	▸ E_T^{miss} >20 GeV	▸ E_T^{miss} >20 GeV	▸ E_T^{miss} >20 GeV
▸ Fails VBF, Boosted	▸ Fails Boosted	▸ Fails VBF, Boosted	▸ Fails Boosted
• m_T <50 GeV	• m_T <30 GeV	• m_T <50 GeV	• m_T <30 GeV
• $\Delta(\Delta R) < 0.6$	• $\Delta(\Delta R) < 0.5$	• $\Delta(\Delta R) < 0.6$	• $\Delta(\Delta R) < 0.5$
• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 3.5$
–	• $p_T^{\ell} - p_T^{\tau} < 0$	–	• $p_T^{\ell} - p_T^{\tau} < 0$

HadHad categories

Cut	Description
Preselection	No muons or electrons in the event
	Exactly 2 medium τ_{had} candidates matched with the trigger objects
	At least 1 of the τ_{had} candidates identified as tight
	Both τ_{had} candidates are from the same primary vertex
	Leading $\tau_{\text{had-vis}}$ $p_T > 40$ GeV and sub-leading $\tau_{\text{had-vis}}$ $p_T > 25$ GeV, $\lvert\eta\rvert < 2.5$
	τ_{had} candidates have opposite charge and 1- or 3-tracks
	$0.8 < \Delta R(\tau_1, \tau_2) < 2.8$
	$\Delta\eta(\tau, \tau) < 1.5$
	if $E_{\text{T}}^{\text{miss}}$ vector is not pointing in between the two taus, $\min\left\{\Delta\phi(E_{\text{T}}^{\text{miss}}, \tau_1), \Delta\phi(E_{\text{T}}^{\text{miss}}, \tau_2)\right\} < 0.2\pi$
VBF	At least two tagging jets, j_1, j_2, leading tagging jet with $p_{\text{T}} > 50$ GeV
	$\eta_{j1} \times \eta_{j2} < 0$, $\Delta\eta_{jj} > 2.6$ and invariant mass $m_{jj} > 350$ GeV
	$\min(\eta_{j1}, \eta_{j2}) < \eta_{\tau 1}, \eta_{\tau 2} < \max(\eta_{j1}, \eta_{j2})$
	$E_{\text{T}}^{\text{miss}} > 20$ GeV
Boosted	Fails VBF
	At least one tagging jet with $p_{\text{T}} > 70(50)$ GeV in the 8(7) TeV dataset
	$\Delta R(\tau_1, \tau_2) < 1.9$
	$E_{\text{T}}^{\text{miss}} > 20$ GeV
	if $E_{\text{T}}^{\text{miss}}$ vector is not pointing in between the two taus, $\min\left\{\Delta\phi(E_{\text{T}}^{\text{miss}}, \tau_1), \Delta\phi(E_{\text{T}}^{\text{miss}}, \tau_2)\right\} < 0.1\pi$.

LepLep event yields

	VBF category	$ee + \mu\mu + e\mu$ Boosted category	VH category	1-jet category
$gg \to H$ (125 GeV)	1.3 ± 0.2 ± 0.4	12.4 ± 0.6 ± 2.9	2.5 ± 0.3 ± 0.6	7.0 ± 0.5 ± 1.6
VBF H (125 GeV)	3.63 ± 0.10 ± 0.02	3.36 ± 0.09 ± 0.30	0.21 ± 0.03 ± 0.02	1.82 ± 0.07 ± 0.18
VH (125 GeV)	0.01 ± 0.01 ± 0.01	2.20 ± 0.05 ± 0.22	0.64 ± 0.03 ± 0.09	0.44 ± 0.02 ± 0.05
$Z/\gamma^* \to \tau\tau$ embedded	47 ± 2 ± 1	$(1.24 \pm 0.01 \pm 0.08)\times10^3$	393 ± 7 ± 26	$(0.86 \pm 0.01 \pm 0.06)\times10^3$
$Z/\gamma^* \to \ell\ell$	14 ± 3 ± 2	$(0.21 \pm 0.02 \pm 0.04)\times10^3$	$(0.08 \pm 0.01 \pm 0.02)\times10^3$	$(0.16 \pm 0.01 \pm 0.03)\times10^3$
Top	15 ± 2 ± 3	$(0.39 \pm 0.01 \pm 0.07)\times10^3$	87 ± 4 ± 23	117 ± 5 ± 18
Diboson	3.6 ± 0.8 ± 0.6	55 ± 3 ± 10	15 ± 1 ± 4	40 ± 3 ± 7
Backgrounds with fake leptons	12 ± 2 ± 3	102 ± 7 ± 23	86 ± 4 ± 16	230 ± 8 ± 52
Total background	91 ± 5 ± 5	$(2.01 \pm 0.03 \pm 0.12)\times10^3$	$(0.66 \pm 0.02 \pm 0.05)\times10^3$	$(1.40 \pm 0.02 \pm 0.08)\times10^3$
Observed data	98	2014	636	1405

LepHad event yields

Process	Events	
	0-Jet	1-Jet
$gg \to H$ (125 GeV)	25.9 ± 0.8 ± 6.1	37.3 ± 0.9 ± 8.4
VBF H (125 GeV)	0.30 ± 0.05 ± 0.04	7.8 ± 0.3 ± 0.5
VH (125 GeV)	0.27 ± 0.05 ± 0.03	3.5 ± 0.2 ± 0.2
$Z/\gamma^* \to \tau\tau$ (OS-SS)	$(3.59 \pm 0.03 \pm 0.278)\times10^3$	$(4.50 \pm 0.04 \pm 0.37)\times10^3$
Diboson (OS-SS)	9.9 ± 0.7 ± 0.9	27 ± 1 ± 2
$Z/\gamma^* \to \ell\ell$ (OS-SS)	$(0.41 \pm 0.04 \pm 0.13)\times10^3$	$(0.28 \pm 0.07 \pm 0.14)\times10^3$
Top (OS-SS)	8 ± 2 ± 1	$(1.00 \pm 0.02 \pm 0.03)\times10^3$
W boson + jets (OS-SS)	$(0.48 \pm 0.07 \pm 0.04)\times10^3$	$(1.32 \pm 0.12 \pm 0.12)\times10^3$
Same sign data	$(0.66 \pm 0.03 \pm 0.03)\times10^3$	$(3.68 \pm 0.06 \pm 0.18)\times10^3$
Total background	$(5.16 \pm 0.09 \pm 0.31)\times10^3$	$(10.8 \pm 0.2 \pm 0.5)\times10^3$
Observed data	5012	10409

electron

Process	Events	
	0-Jet	1-Jet
$gg \to H$ (125 GeV)	34.3 ± 0.9 ± 8.0	46 ± 1 ± 11
VBF H (125 GeV)	0.47 ± 0.06 ± 0.04	8.5 ± 0.3 ± 0.6
VH (125 GeV)	0.20 ± 0.05 ± 0.02	3.7 ± 0.2 ± 0.3
$Z/\gamma^* \to \tau\tau$ (OS-SS)	$(7.13 \pm 0.04 \pm 0.48)\times10^3$	$(6.14 \pm 0.04 \pm 0.45)\times10^3$
Diboson (OS-SS)	10.5 ± 0.7 ± 0.9	30 ± 1 ± 3
$Z/\gamma^* \to \ell\ell$ (OS-SS)	$(0.10 \pm 0.02 \pm 0.02)\times10^3$	$(0.12 \pm 0.02 \pm 0.03)\times10^3$
Top (OS-SS)	10.4 ± 2.3 ± 0.6	$(1.03 \pm 0.03 \pm 0.05)\times10^3$
W boson + jets (OS-SS)	$(0.51 \pm 0.09 \pm 0.04)\times10^3$	$(1.0 \pm 0.1 \pm 0.14)\times10^3$
Same sign data	$(1.03 \pm 0.03 \pm 0.07)\times10^3$	$(3.27 \pm 0.06 \pm 0.24)\times10^3$
Total background	$(8.8 \pm 0.1 \pm 0.5)\times10^3$	$(11.6 \pm 0.1 \pm 0.5)\times10^3$
Observed data	8300	11373

muon

LepHad event yields

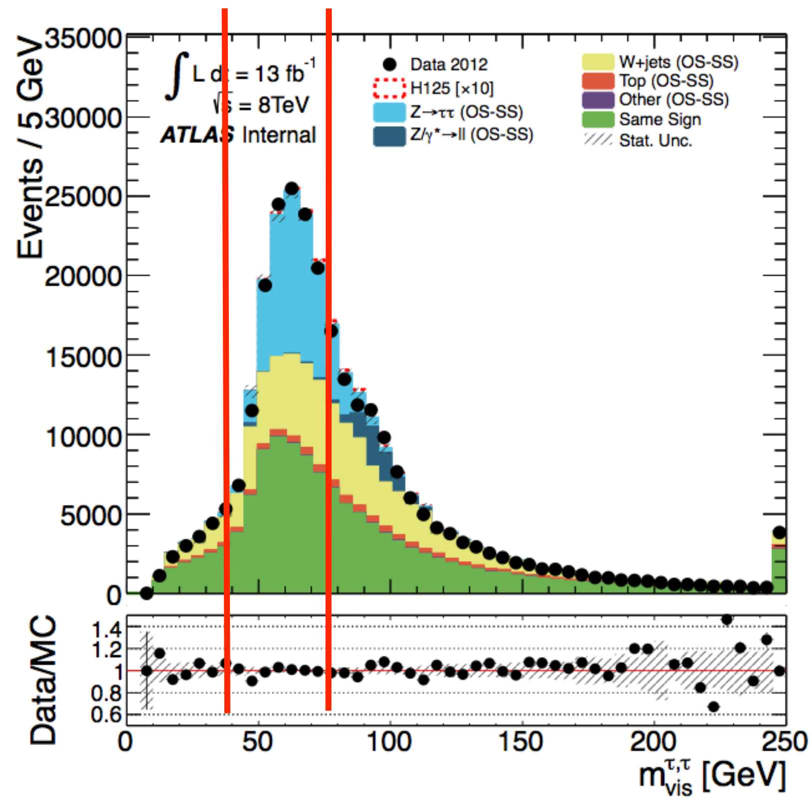
Process	Events	
	Boosted	VBF
$gg \to H$ (125 GeV)	$20.3 \pm 0.7 \pm 5.1$	$0.5 \pm 0.1 \pm 0.3$
VBF H (125 GeV)	$5.3 \pm 0.2 \pm 0.3$	$2.5 \pm 0.2 \pm 0.4$
VH (125 GeV)	$2.7 \pm 0.2 \pm 0.2$	<0.001
$Z/\gamma^* \to \tau\tau$ †	$(1.78 \pm 0.03 \pm 0.11)\times 10^3$	$17 \pm 2 \pm 6$
Diboson †	$12.2 \pm 0.9 \pm 1.0$	$0.6 \pm 0.3 \pm 0.4$
$Z/\gamma^* \to \ell\ell$ †	$18 \pm 9 \pm 4$	$1.7 \pm 0.5 \pm 1.2$
Top †	$111 \pm 8 \pm 33$	$2.0 \pm 0.7 \pm 1.0$
W boson + jets (OS-SS)	$(0.27 \pm 0.06 \pm 0.04)\times 10^3$	–
Same sign data	$(0.34 \pm 0.02 \pm 0.01)\times 10^3$	–
Fake-$\tau_{\text{had-vis}}$ backgrounds	–	$7.6 \pm 0.7 \pm 3.8$
Total background	$(2.53 \pm 0.07 \pm 0.13)\times 10^3$	$29 \pm 2 \pm 7$
Observed data	2602	29

HadHad event yields

$H \to \tau_{had}\tau_{had}$	7 TeV analysis (4.6 fb^{-1})		8 TeV analysis (13.0 fb^{-1})	
	VBF category	Boosted category	VBF category	Boosted category
$gg \to H$ (125 GeV)	0.36 ± 0.06 ± 0.12	2.4 ± 0.2 ± 0.7	1.0 ± 0.1 ± 0.3	8.2 ± 0.4 ± 1.8
VBF H (125 GeV)	1.12 ± 0.04 ± 0.18	0.68 ± 0.03 ± 0.07	3.01 ± 0.09 ± 0.48	1.98 ± 0.07 ± 0.30
VH (125 GeV)	<0.02	0.61 ± 0.05 ± 0.06	<0.05	1.4 ± 0.2 ± 0.2
$Z/\gamma^* \to \tau\tau$ embedded	20 ± 2 ± 3	392 ± 9 ± 12	50 ± 4 ± 6	1080 ± 20 ± 110
W/Z boson+jets	1.5 ± 0.7 ± 0.4	5 ± 1 ± 1	0.4 ± 0.4	90 ± 20 ± 30
Top	1.0 ± 0.2 ± 0.2	3.0 ± 0.3 ± 0.5	1.4 ± 1.0	21 ± 3 ± 5
Diboson	0.10 ± 0.07 ± 0.02	4.4 ± 0.6 ± 0.7	<0.01	<0.5
Multijet	10.2 ± 0.9 ± 5.0	156 ± 6 ± 30	44 ± 5 ± 7	420 ± 20 ± 60
Total background	32.5 ± 2.2 ± 5.9	561 ± 11 ± 32	96 ± 6 ± 9	1607 ± 37 ± 130
Observed data	38	535	110	1435

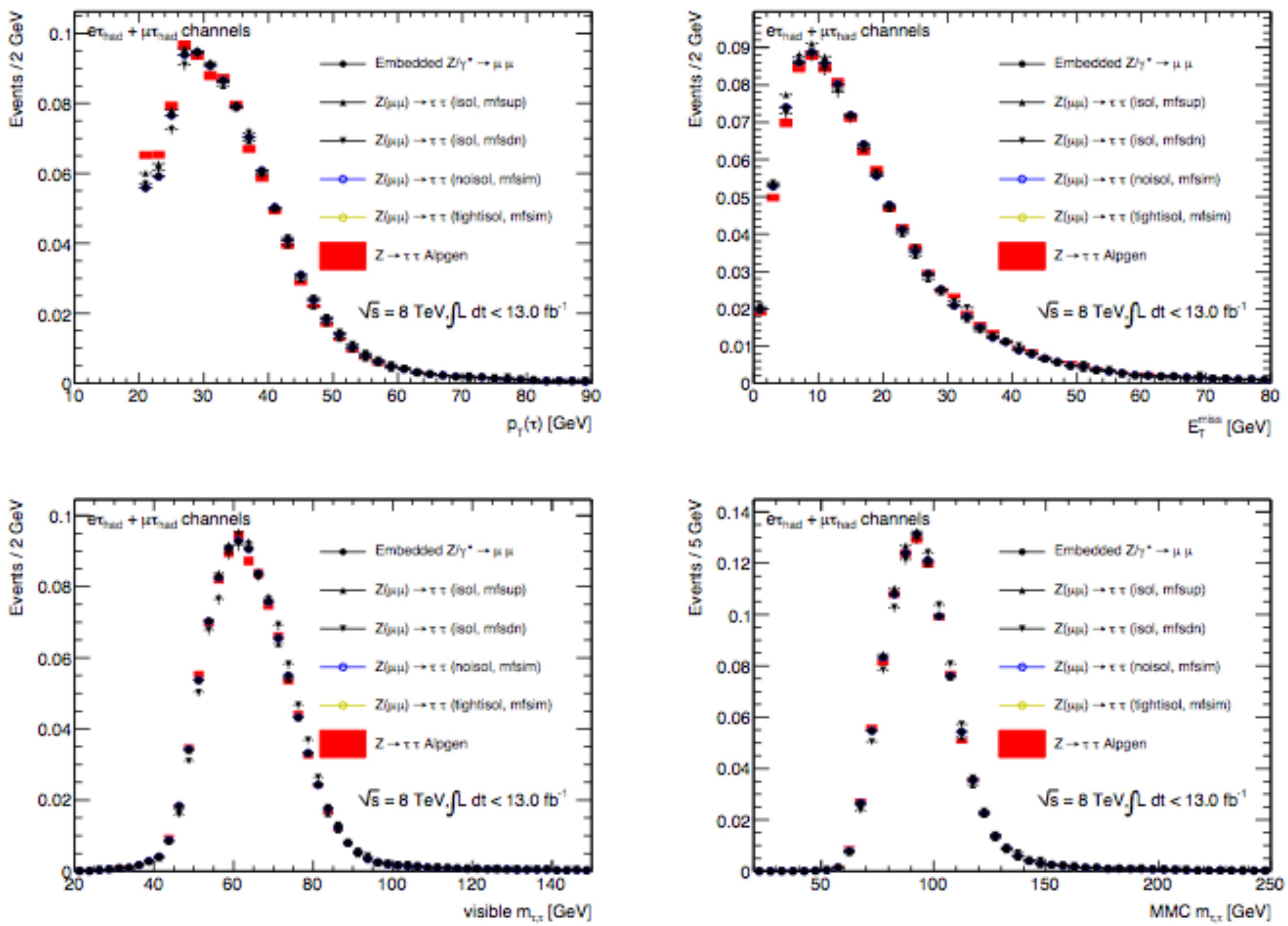
Embedding normalization

- Normalization obtained from data
  - $Z \rightarrow \tau\tau$-rich window
    $40 < m_{vis} < 70$ GeV
- Signal contamination < 0.1%
- Procedure done separately for SLT/LTT, $e\tau_{had}/\mu\tau_{had}$
- Avoid propagation of mis-modeling effects from MC (Alpgen) normalization
- Systematics reduced significantly



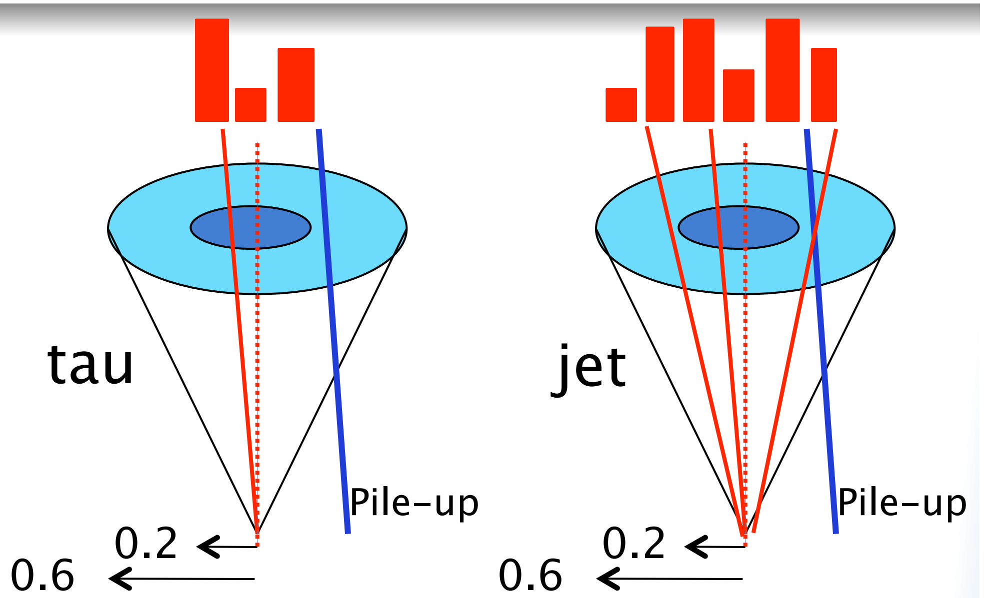
Embedded related systematics

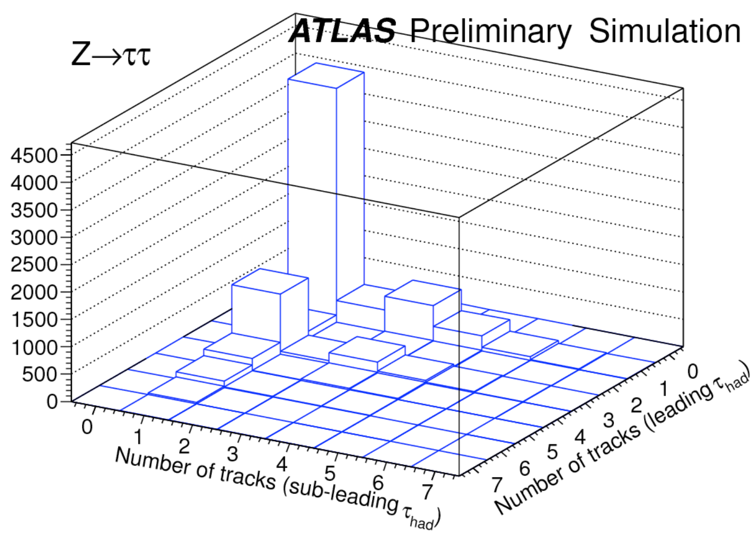
- Change muon isolation (tighter, or remove)
- Scale up/down muon energy 30%
- Normalization 45 <m_vis<75 GeV or 60 <m_mmc<100

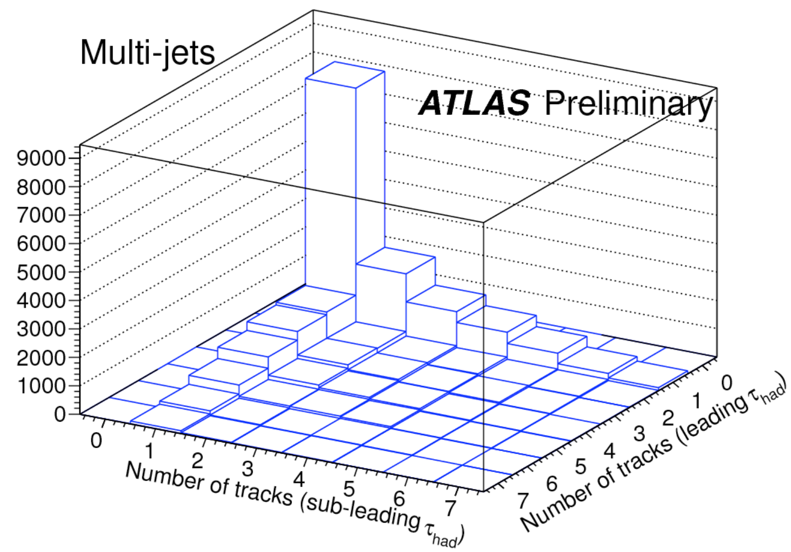


Background estimation

- Track counting method
  - Jet has larger spread than tau
  - Obtain 2-dim fit templates of tracks within ΔR<0.6 for the 2 tau's of the event
  - QCD template fit in SS events

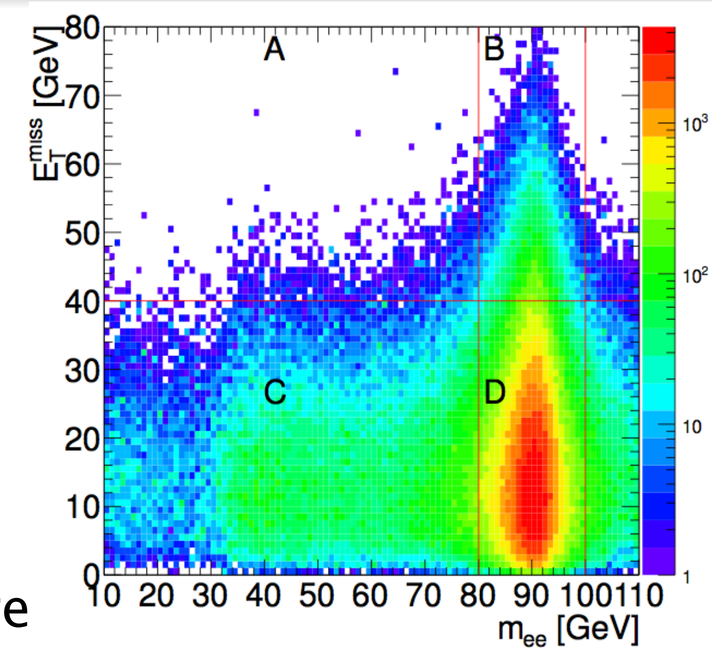






Background estimation

- Dominant Z→ττ
  - From embedded as in other channels
- Top, DiBoson
  - From MC
  - Validate Top in data top-rich CR
    - Invert b-Jet veto in jet categories
- Fake lepton background
  - Estimate from signal free CR in data re for one of the two leptons



- Z→ll background (only in jet ee,μμ categories)
  - Scale yield in MC by a MET mismodelling factor determined in CR of both data and MC

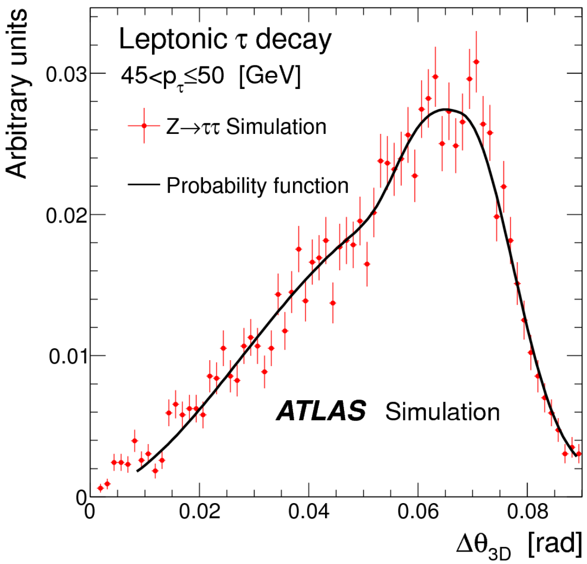
$$A_{MC}^{\text{corrected}} = A_{\mathrm{MC}} \times \frac{B_{\mathrm{data}}}{B_{\mathrm{data}} + D_{\mathrm{data}}} \frac{B_{\mathrm{MC}} + D_{\mathrm{MC}}}{B_{\mathrm{MC}}}$$

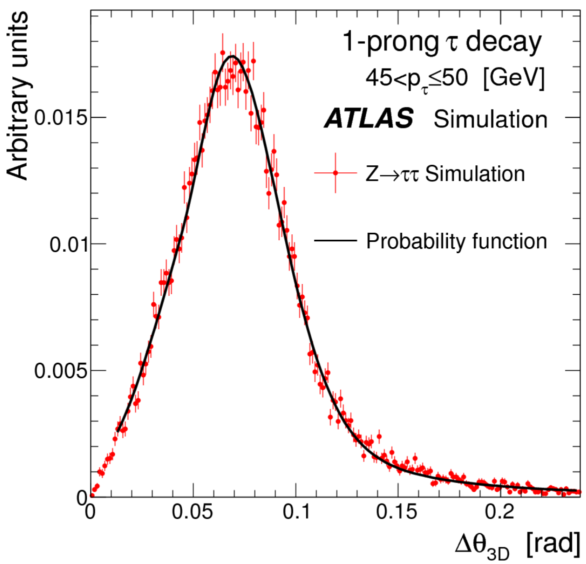
Systematics

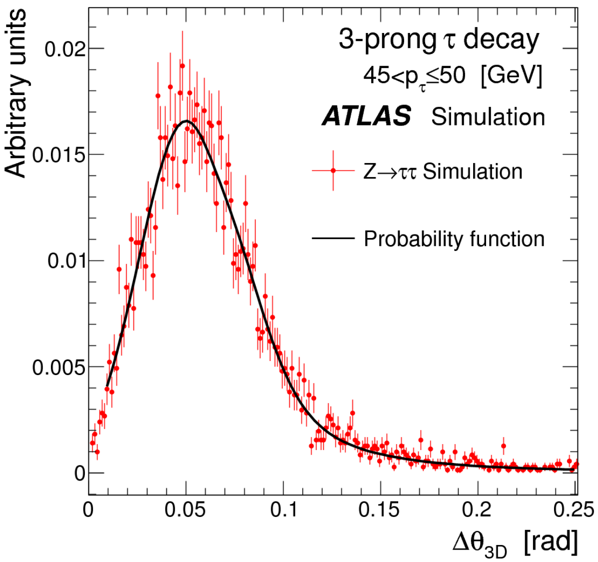
Uncertainty	$H \to \tau_{\text{lep}}\tau_{\text{lep}}$	$H \to \tau_{\text{lep}}\tau_{\text{had}}$	$H \to \tau_{\text{had}}\tau_{\text{had}}$
		$Z \to \tau^+\tau^-$	
Embedding	1–4%	2–4%	1–4%
Tau Energy Scale	–	4–15%	3–8%
Tau Identification	–	4–5%	1–2%
Trigger Efficiency	2–4%	2–5%	2–4%
Normalisation	5%	4% (non-VBF), 16% (VBF)	9–10%
		Signal	
Jet Energy Scale	1–5%	3–9%	2–4%
Tau Energy Scale	–	2–9%	4–6%
Tau Identification	–	4–5%	10%
Theory	8–28%	18–23%	3–20%
Trigger Efficiency	small	small	5%

Mass reconstruction: MMC

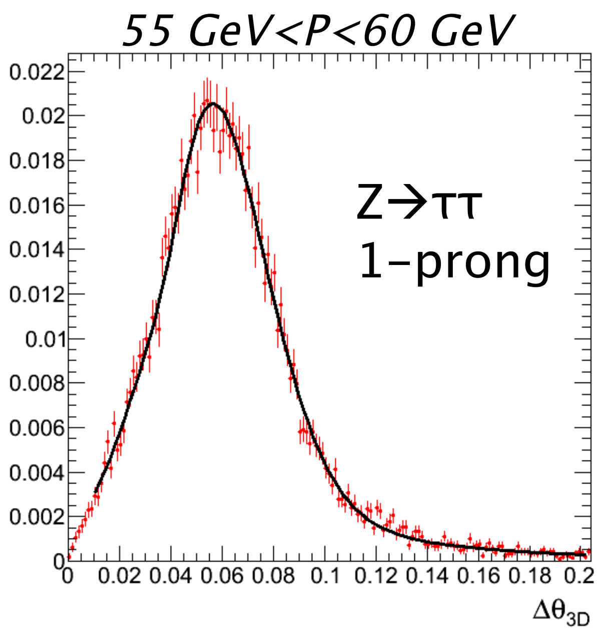
- Full reconstruction of original DiTau resonance, **high efficiency for signal and Z**, **resolution ~17%**, **rejects non-Z backgrounds**
  - Based on **Nucl.Instrum.Meth. A654:481-489,2011** Sasha Pranko et al. [arXiv:1012.4686]
  - Parameterize $\Delta\theta_{3D}$(visible τ,neutrino[s]) in MC
  - Solve τ, E_T^{miss} kinematics equations for each point of the $\Delta\varphi$(vis,neutrino[s]) parameter space
  - Use $\Delta\theta_{3D}$(vis,neutrino[s]) parameterization to weight the solutions in $\Delta\varphi$ (vis,neutrino[s]) grid, put weighted solutions to histogram
  - Peak most probable value as the $M_{\tau\tau}^{MMC}$ estimator
  - MMC dedicated bi-weekly meeting, mailing list, details here here







MMC Concept



Fit: Gauss × Landau
6 parameters

Basic idea

- $M_\tau << M_Z$ or M_H ⇒ τ's are heavily boosted
- $d\theta_{3D}(\nu\text{-}\tau_{vis})$ is very small, but non-zero !!
  - $d\theta_{3D}(\nu\text{-}\tau_{vis})$ distribution depends only τ–type and P(τ)

$$\not{E}_{T_x} = p_{mis_1}\sin\theta_{mis_1}\cos\phi_{mis_1} + p_{mis_2}\sin\theta_{mis_2}\cos\phi_{mis_2}$$

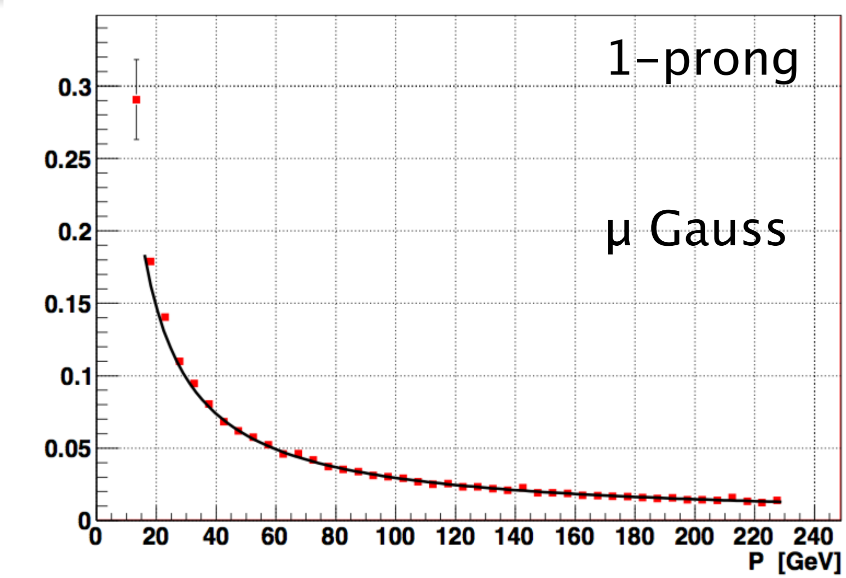
$$\not{E}_{T_y} = p_{mis_1}\sin\theta_{mis_1}\sin\phi_{mis_1} + p_{mis_2}\sin\theta_{mis_2}\sin\phi_{mis_2}$$

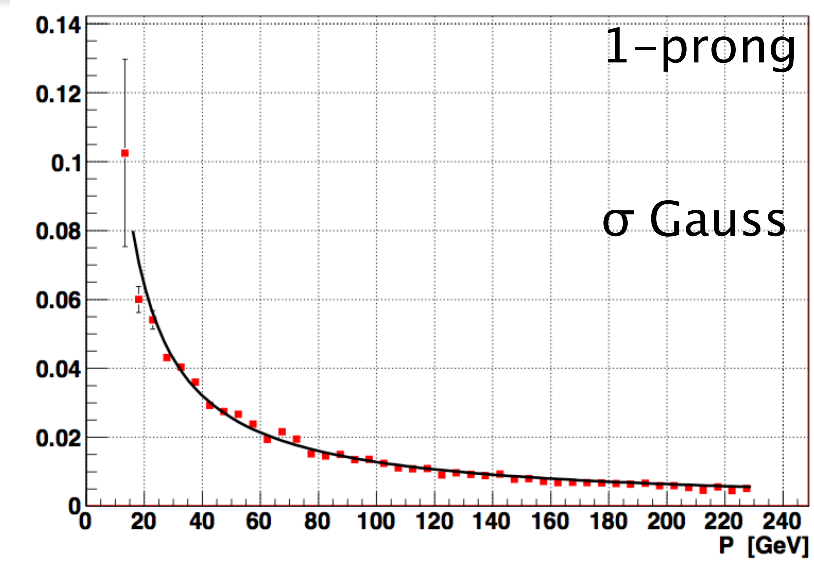
$$M^2_{\tau_1} = m^2_{mis_1} + m^2_{vis_1} + 2\sqrt{p^2_{vis_1} + m^2_{vis_1}}\sqrt{p^2_{mis_1} + m^2_{mis_1}} - 2p_{vis_1}p_{mis_1}\cos\Delta\theta_{vm_1}$$

$$M^2_{\tau_2} = m^2_{mis_2} + m^2_{vis_2} + 2\sqrt{p^2_{vis_2} + m^2_{vis_2}}\sqrt{p^2_{mis_2} + m^2_{mis_2}} - 2p_{vis_2}p_{mis_2}\cos\Delta\theta_{vm_2}$$

- Create a grid of points in $[\Delta\varphi_1; \Delta\varphi_2]$ space for each tau
  - $\Delta\varphi_i$: Azimuthal angle between neutrinos and visible taus
- Solve 4 equation for P(ν1) and P(ν2) for each point on the grid
- Choose best solution

$\Delta\theta(\nu\text{-}\tau_{vis})$ Parameterization



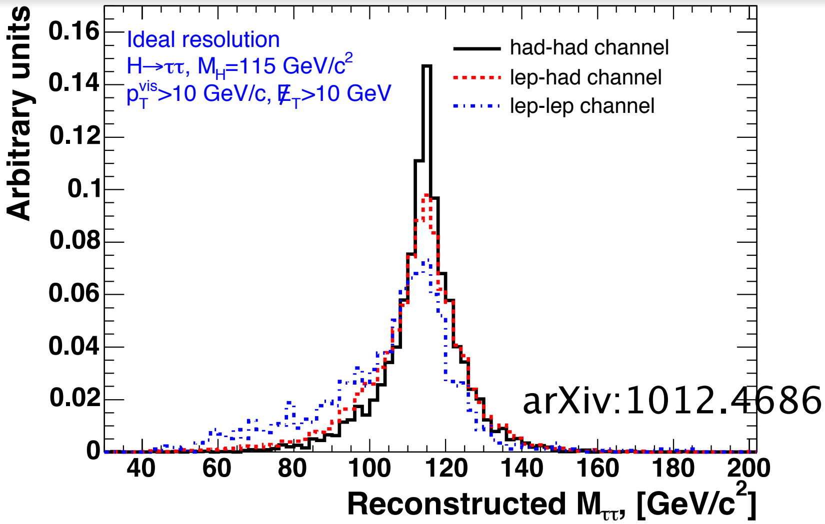


$$a_0(e^{-a_1 \cdot p_\tau} + a_2/p_\tau)$$

- Parameterize $\Delta\theta(\nu\text{-}\tau_{vis})$ as function of full τ-lepton momentum (P^τ) and decay type: $P(\Delta\theta,P,type)$
- Calculate solution probability:

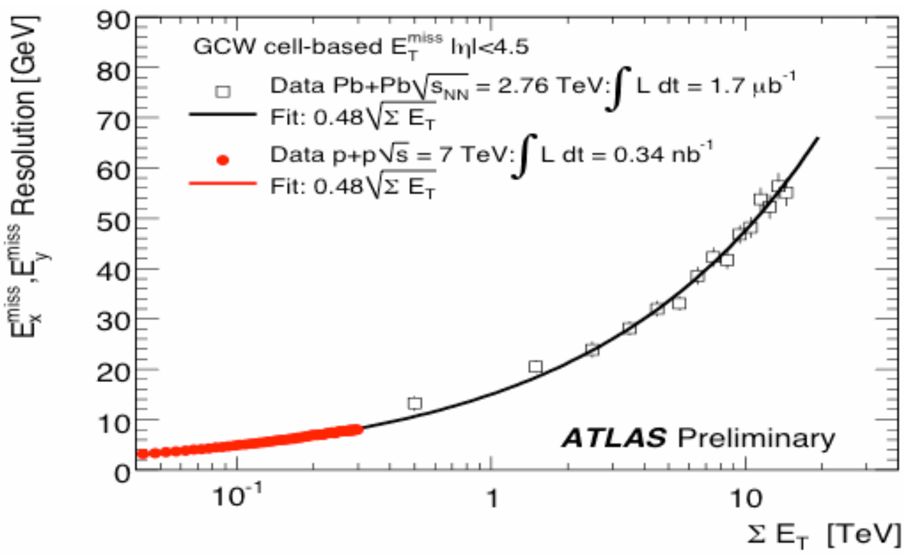
  $P_{solution}=P(\Delta\theta_1,P_1,type)\bullet P(\Delta\theta_2,P_2,type)$
- Fill histogram with $M_{\tau\tau}$ solutions for all grid points, weighted by corresponding $P_{solution}$
- Take the most probable $M_{\tau\tau}$ as best estimate for $M_{\tau\tau}$

MMC resolution



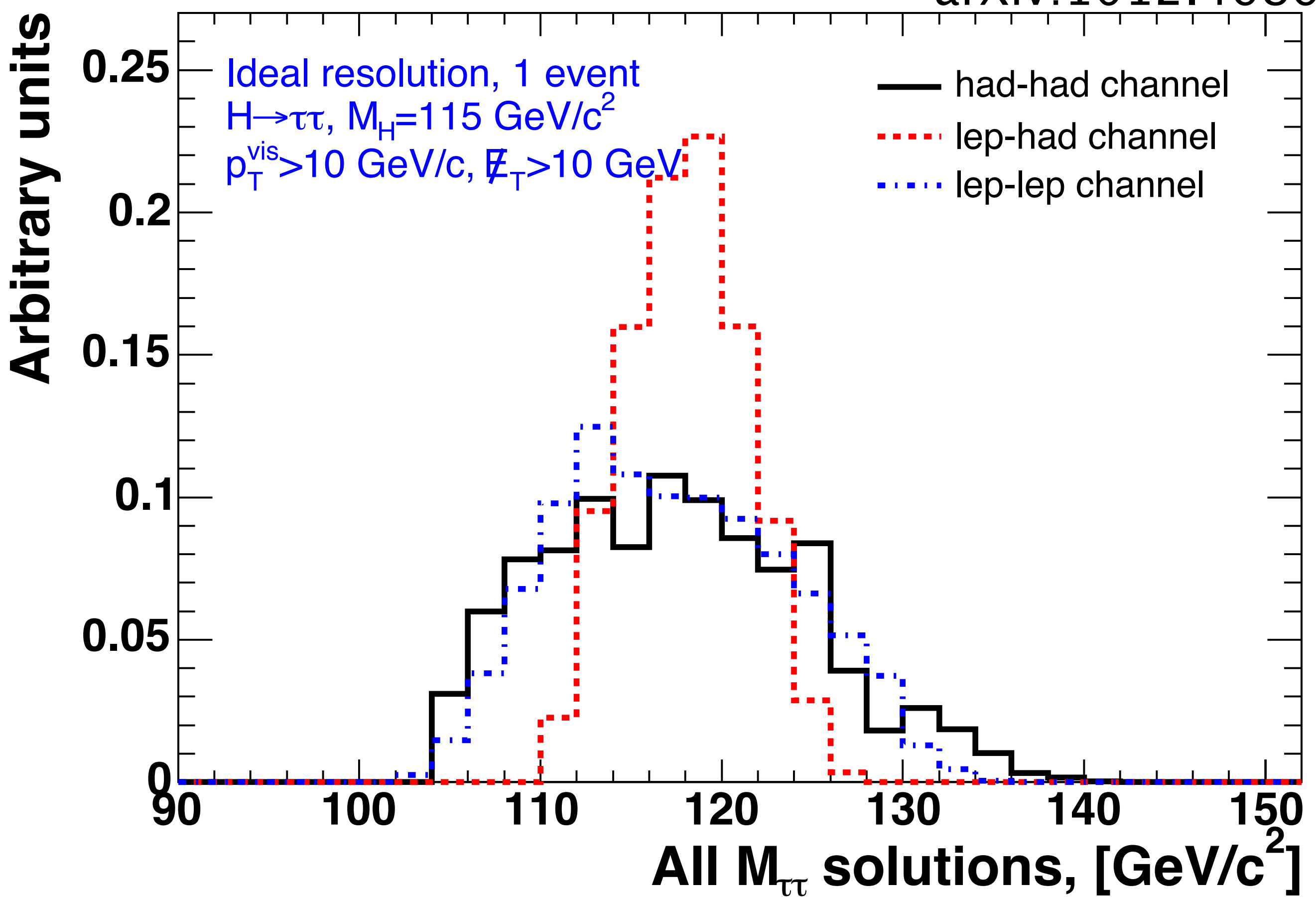
- MMC resolution in an ideal detector (histogram RMS) is 8%-13% (depending on decay channel) ⇒ demonstrates internal limitations
  - ~98% efficiency

- MET resolution drives final $M_{\tau\tau}$ resolution
- Introduce 2 additional scans for x- and y-components of MET
- Modify $P_{solution}$ to include MET resolution functions



Choosing Best Solution

arXiv:1012.4686



- Example of solutions for all points on $[\Delta\varphi_1; \Delta\varphi_2]$ grid for a single Higgs event
  - solutions weighted by corresponding $P_{solution}$ probabilities