H→ττ at ATLAS

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Meeting of the APS Division of Particles and Fields
Santa Cruz Institute for Particle Physics
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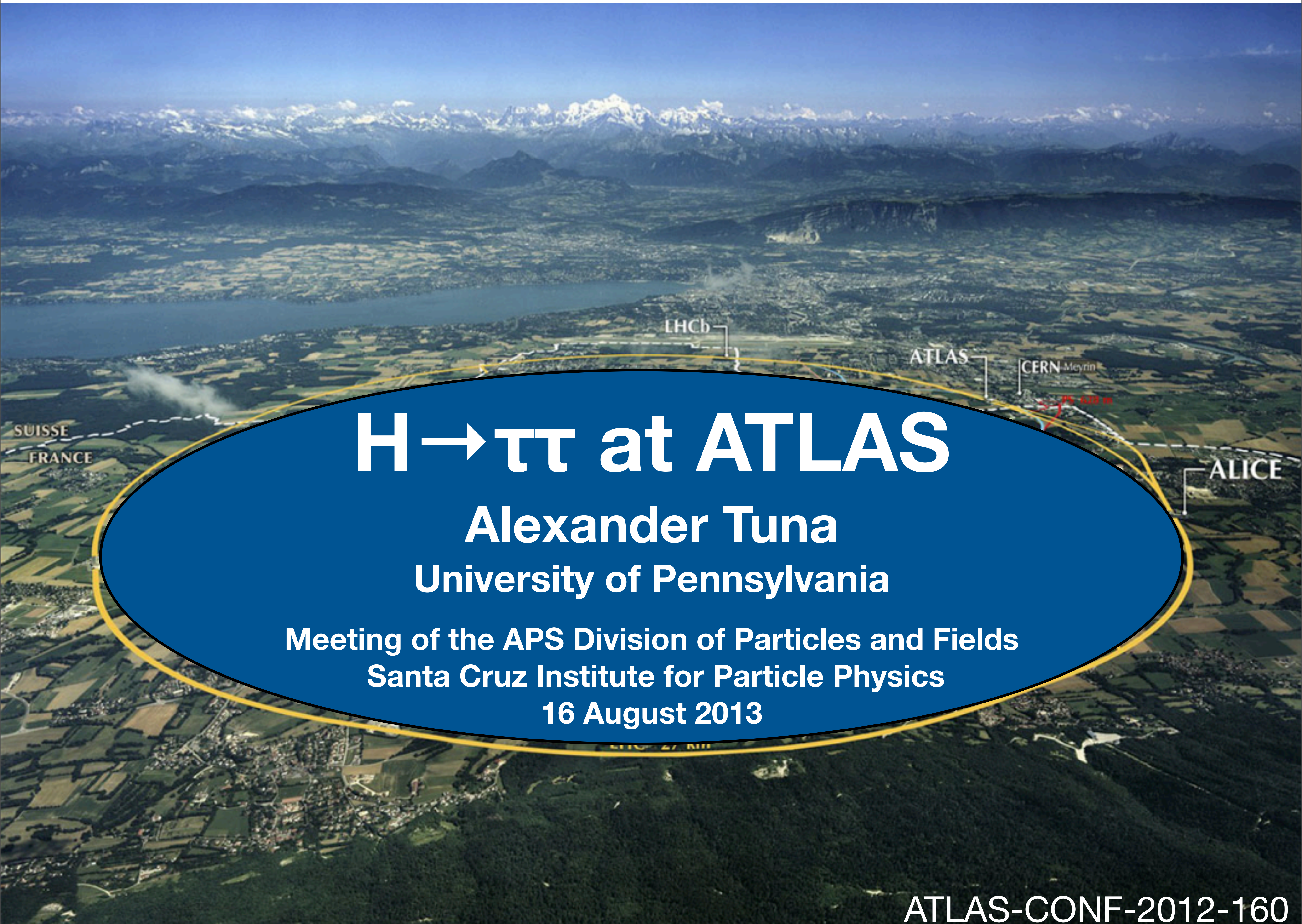


ATLAS-CONF-2012-160

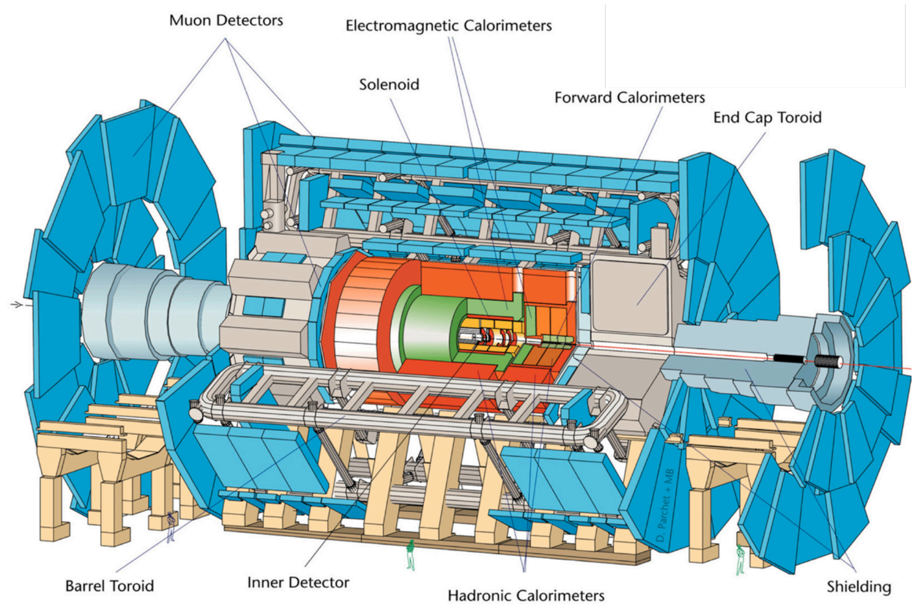
Outline

Introduction to H→ττ

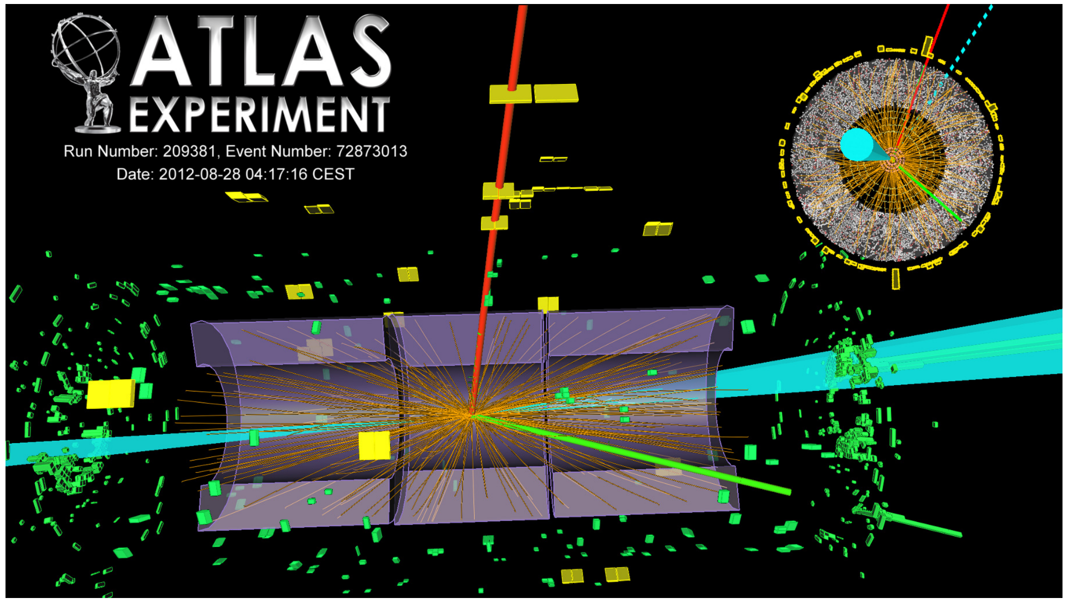
- ATLAS and the LHC
- Higgs searches at ATLAS
- Tau leptons at ATLAS

H→ττ at ATLAS

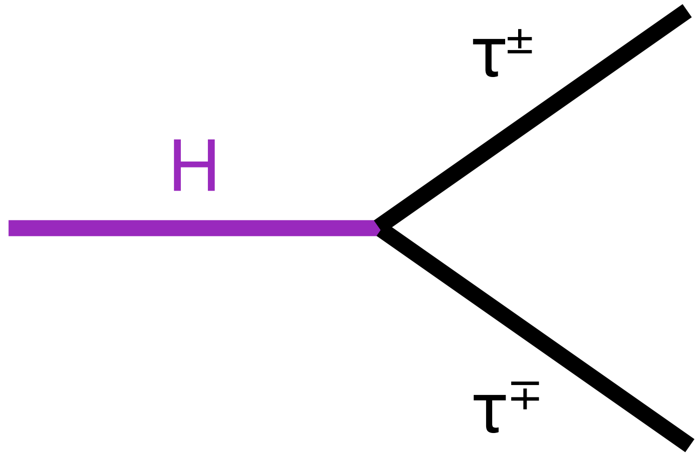
- Overview
- Common issues
- Snapshot of the final states
- Combination



ATLAS-CONF-2012-160



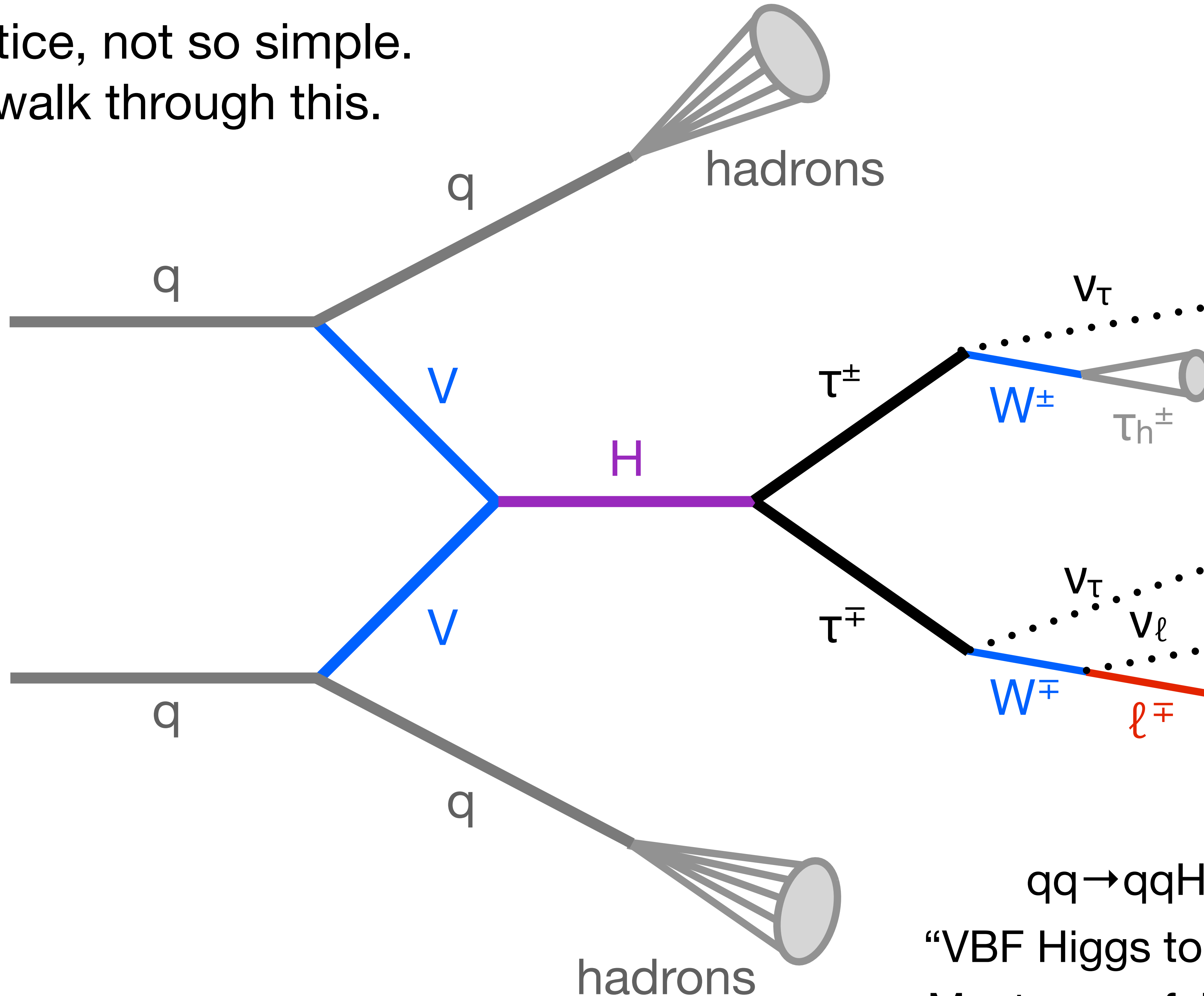
Picture of the analysis



Seems simple!

Picture of the analysis

In practice, not so simple.
Let's walk through this.

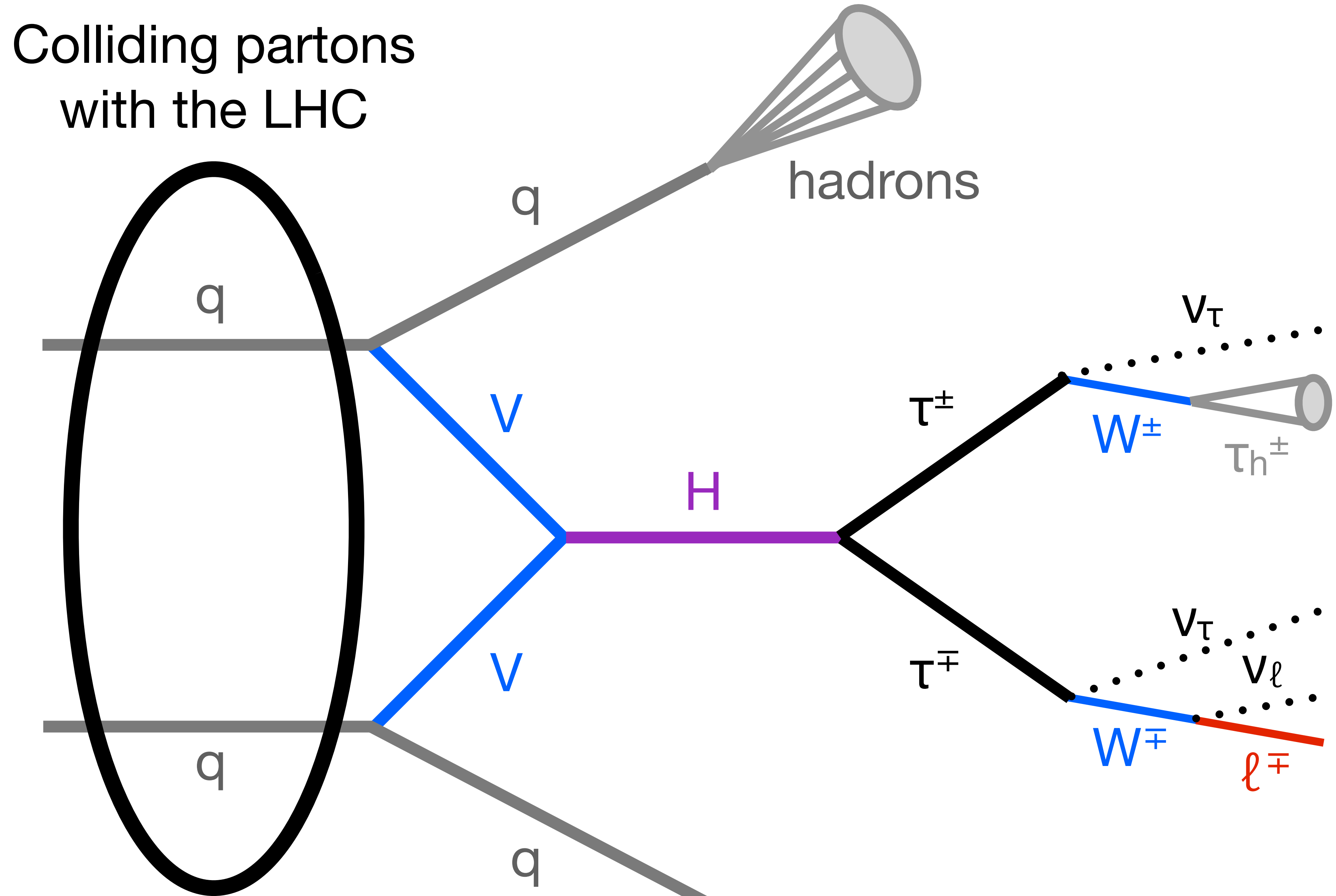


$qq \to qqH \to \tau\tau \to h\nu_\tau \ell \nu_\ell \nu_\tau$

"VBF Higgs to tau-tau to lep-had"

Most powerful category for $H \to \tau\tau$

Picture of the analysis



$qq \to qqH \to \tau\tau \to h\nu_\tau \ell \nu_\ell \nu_\tau$

"VBF Higgs to tau-tau to lep-had"

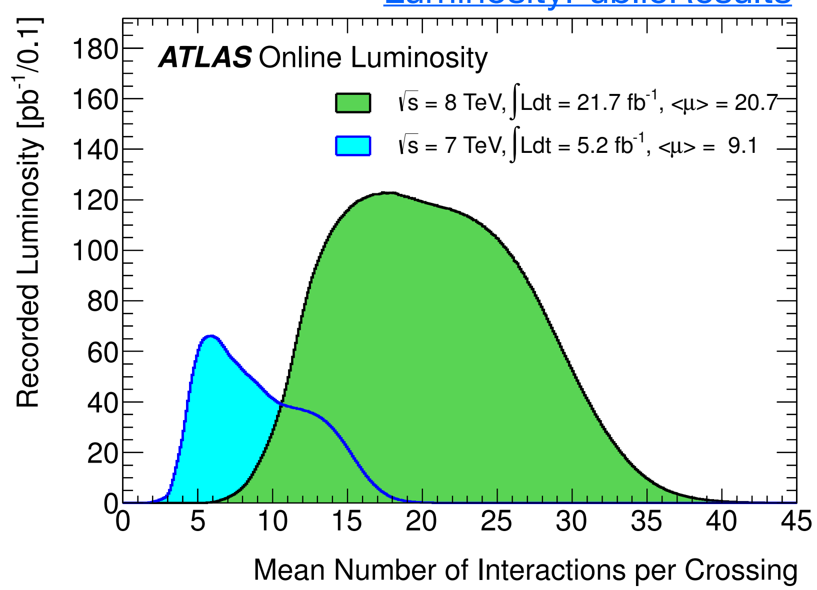
Most powerful category for $H \to \tau\tau$

ATLAS and the LHC

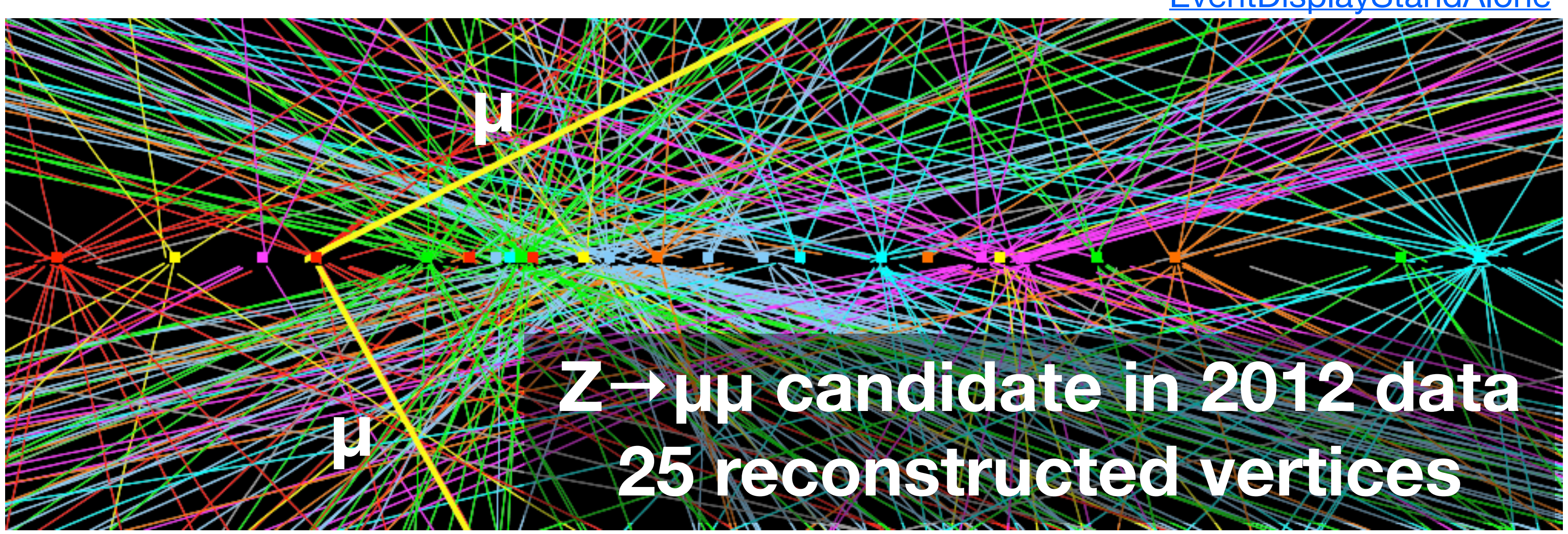
The LHC collides protons at high energy and events are observed with the ATLAS detector.

Many pp collisions occur in a single bunch crossing. This is challenging for analysis.

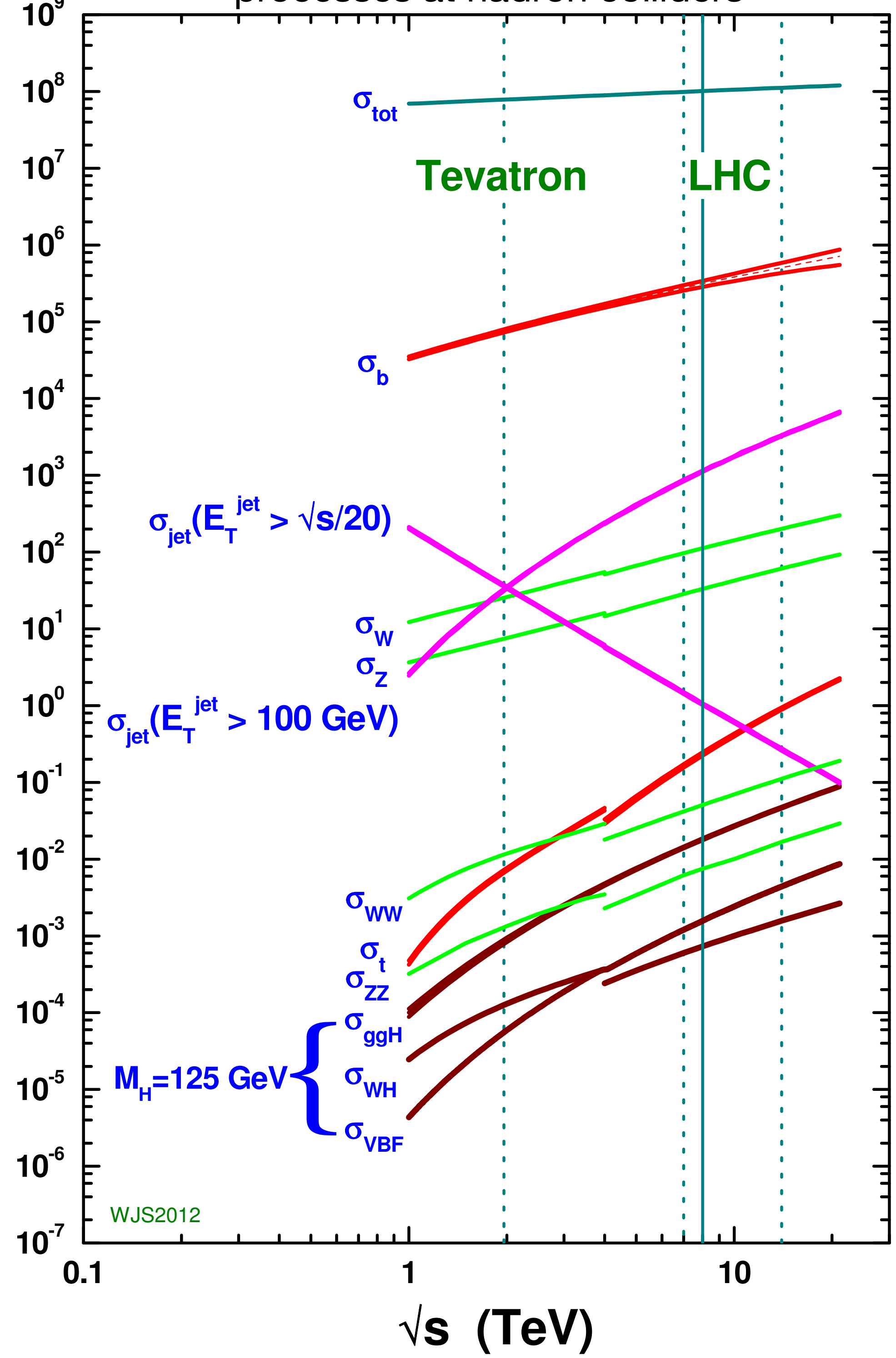
LuminosityPublicResults



EventDisplayStandAlone



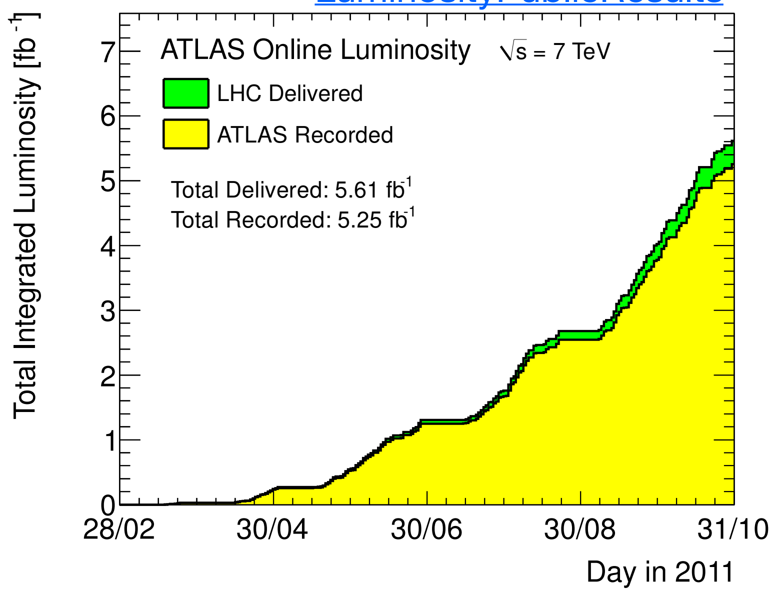
Cross-sections (nb) for SM processes at hadron colliders

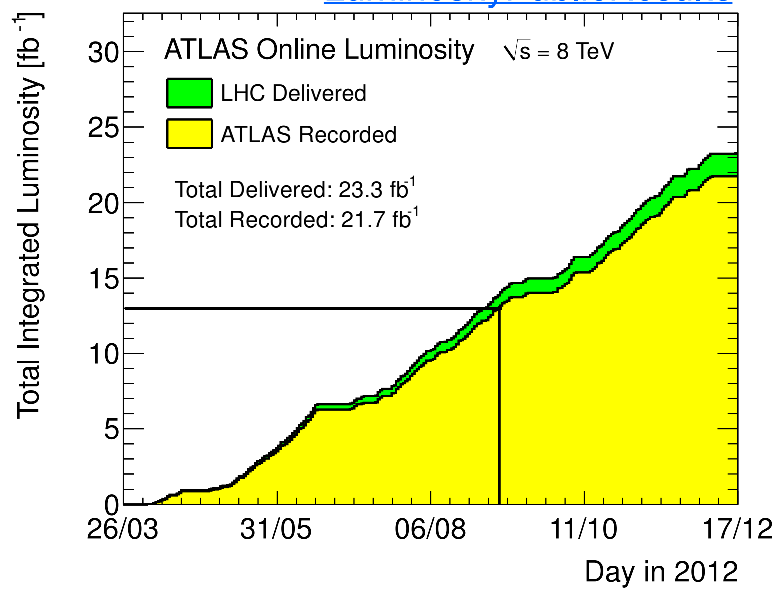


Parton Luminosity And Cross Section Plots

ATLAS and the LHC

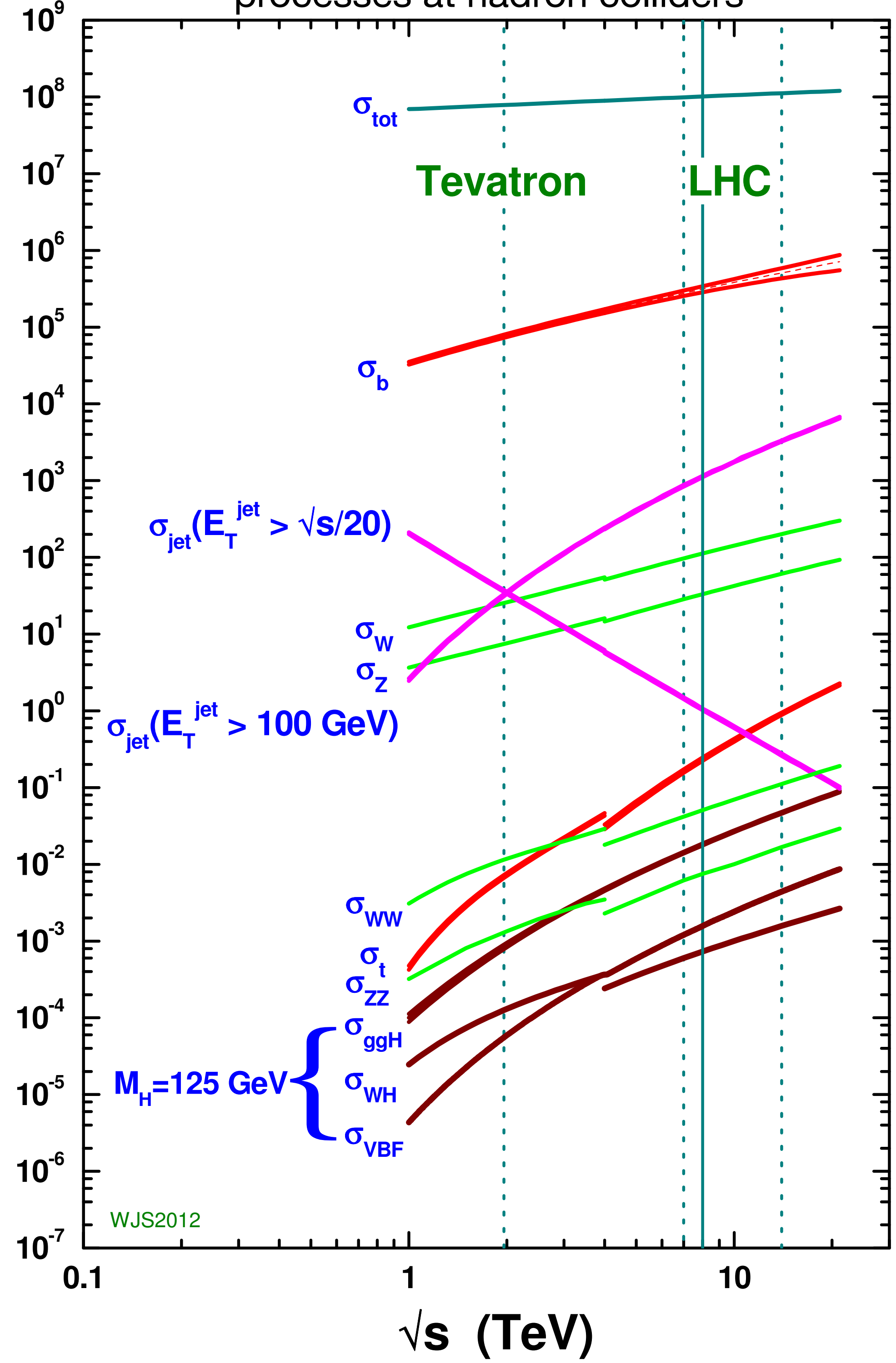
Results from today's talk use the full 2011 dataset and partial 2012 dataset.





All of 2011 data

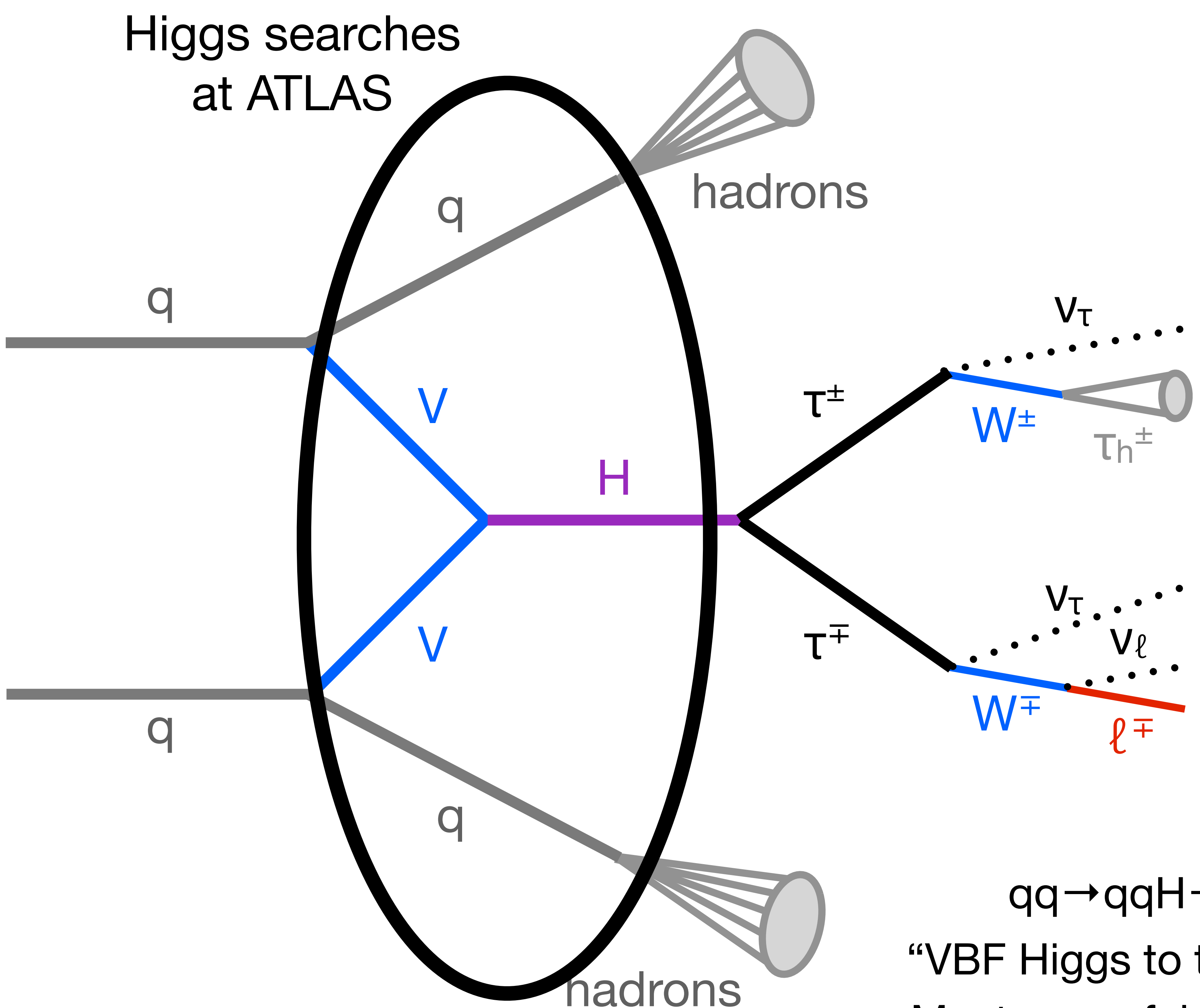
~65% of 2012 data



Parton Luminosity And Cross Section Plots

The $H\to\tau\tau$ analysis with the full 2011+2012 datasets is in progress now. We hope to release a new result soon!

Picture of the analysis



$qq \to qqH \to \tau\tau \to h\nu_\tau \ell \nu_\ell \nu_\tau$

"VBF Higgs to tau-tau to lep-had"

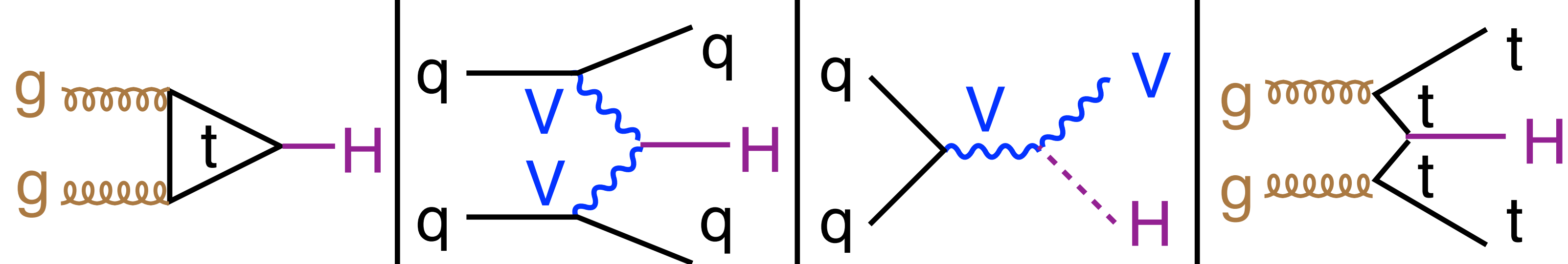
Most powerful category for $H \to \tau\tau$

Higgs @ ATLAS

The BEH electroweak symmetry breaking mechanism, and corresponding Higgs boson, were postulated in the 1960s. Searches for the Higgs boson are a major piece of the ATLAS program.

σ @ m_H = 125 GeV and $\sqrt{s}$ = 8 TeV

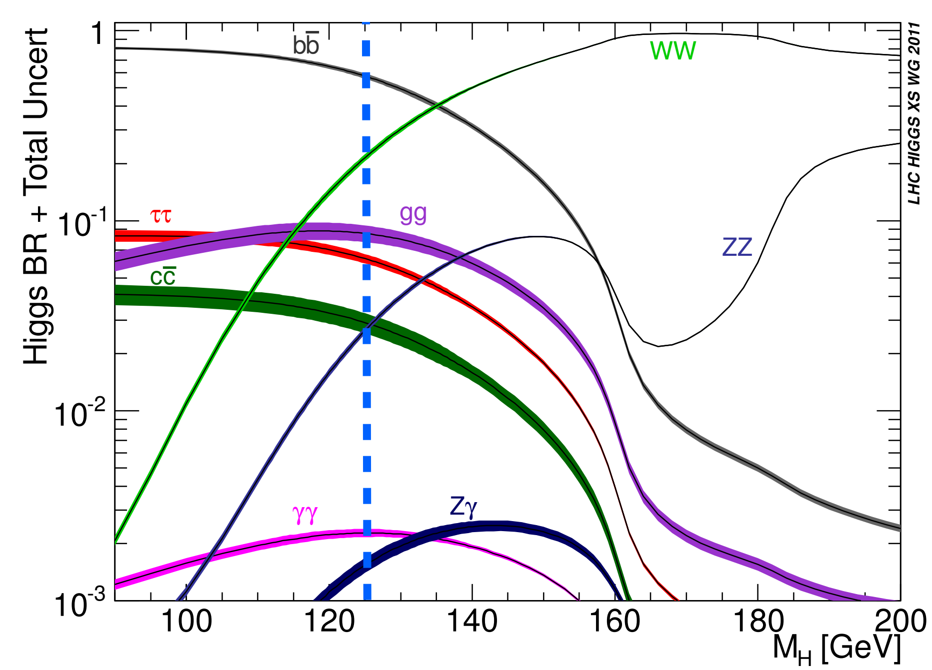
There are lots of ways to make Higgs bosons.



gluon-gluon fusion (“ggF”)	vector boson fusion (“VBF”)	associated production	“ttH”
19.5 pb	1.58 pb	1.09 pb	0.13 pb

And there are lots of ways for Higgs bosons to decay.

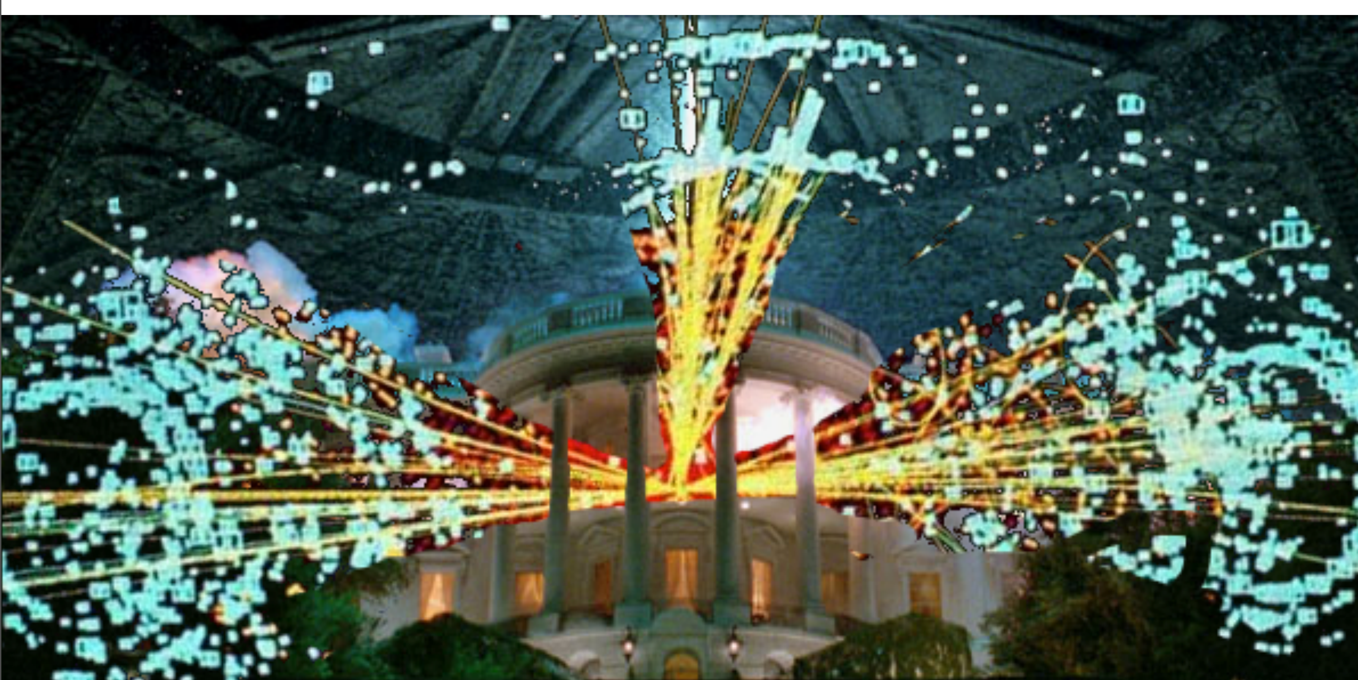
$H^{125}\rightarrow$...	BR (%)
bb	58
WW	22
ττ	6.3
ZZ	2.6
γγ	0.23



Higgs @ ATLAS

The Higgs program at ATLAS has been awesome.
Higgs searches have steadily improved since the observation of an excess on July 4, 2012, a.k.a. Higgsdependence Day.

CMS event display I photoshopped onto *Independence Day* image



http://www.imdb.com/title/tt0116629/

New York Times coverage of Higgsdependence day

http://www.nytimes.com/2012/07/05/science/cern-physicists-may-have-discovered-higgs-boson-particle.html

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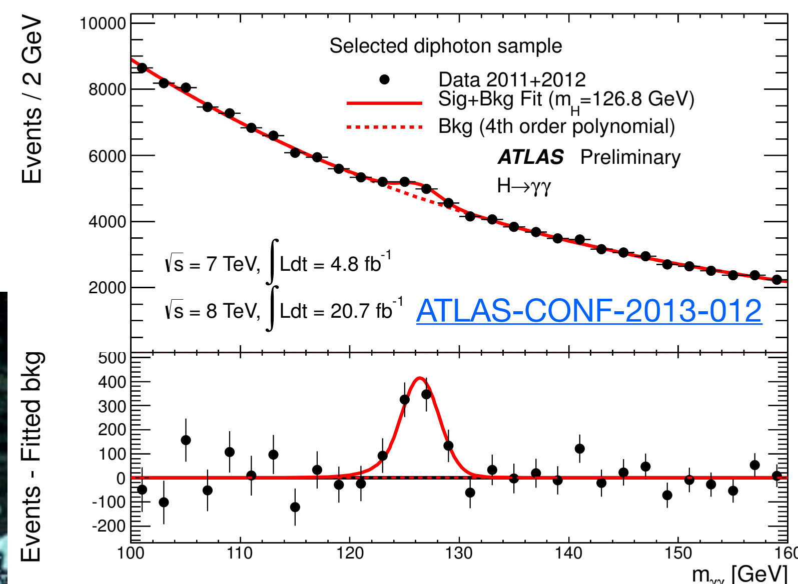

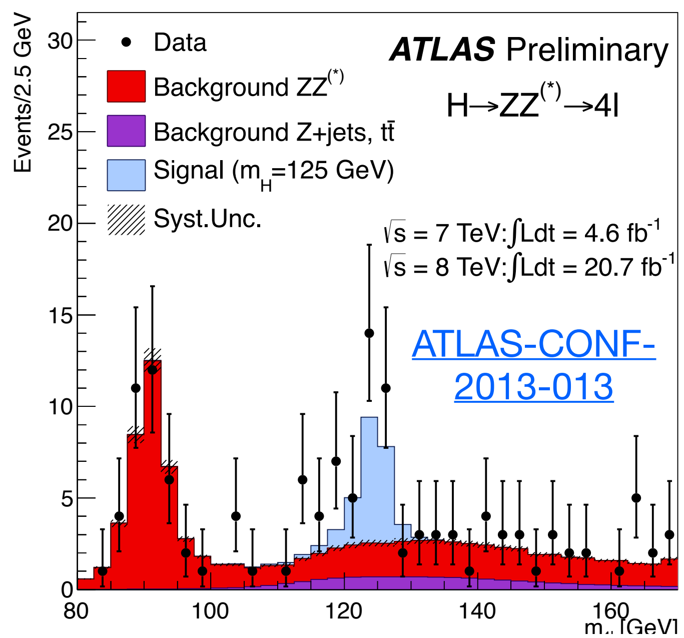

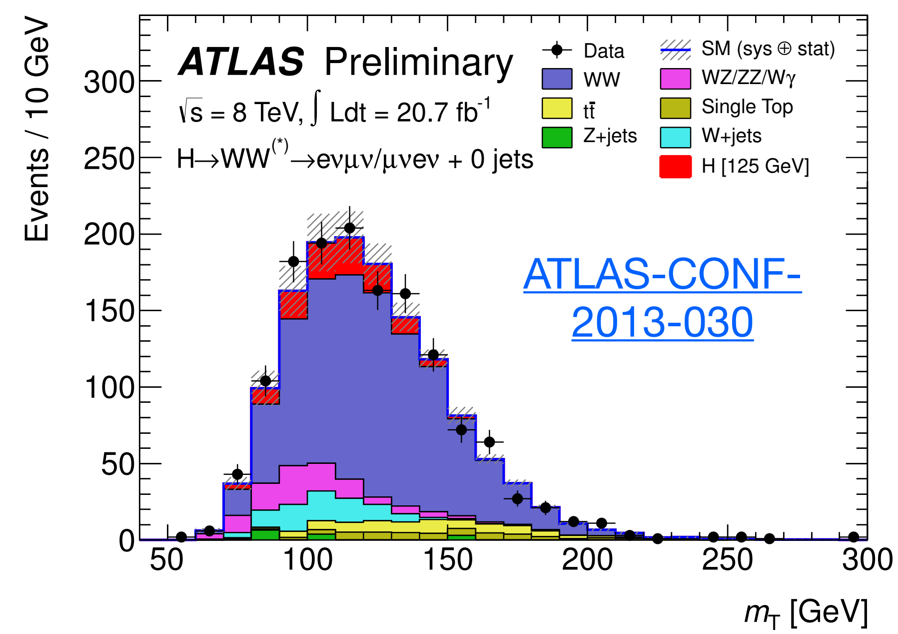

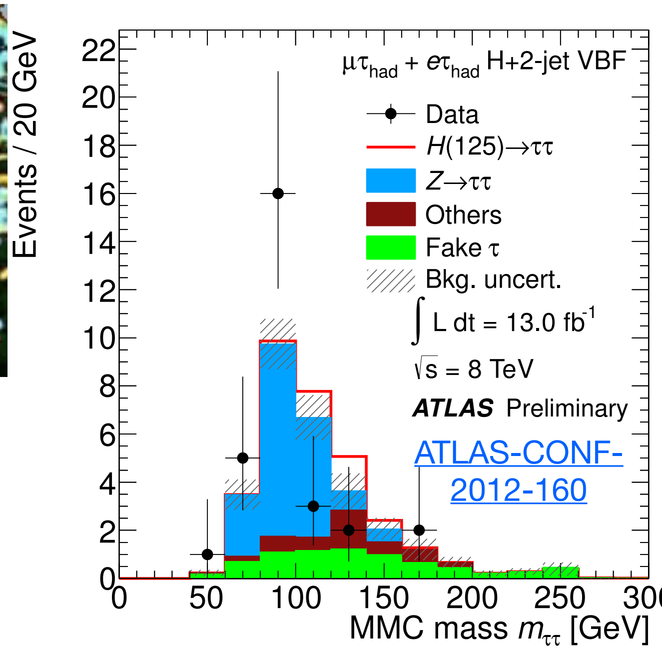

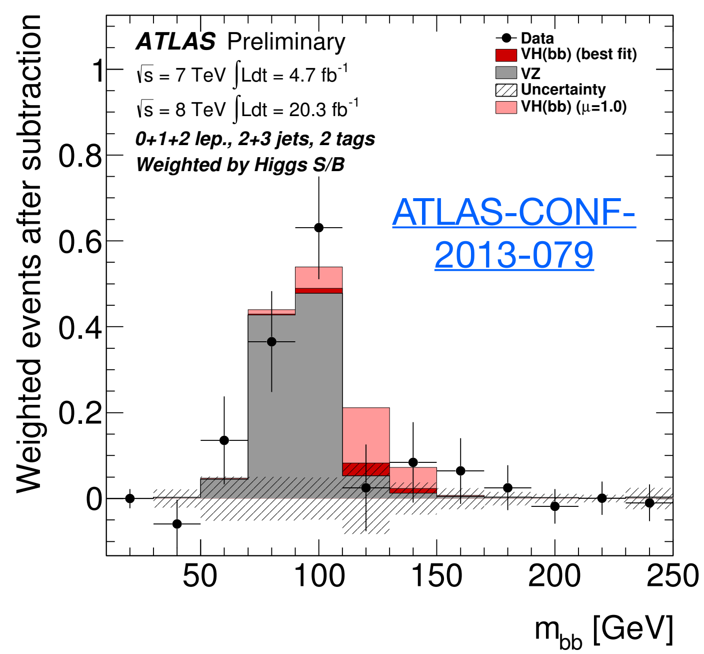

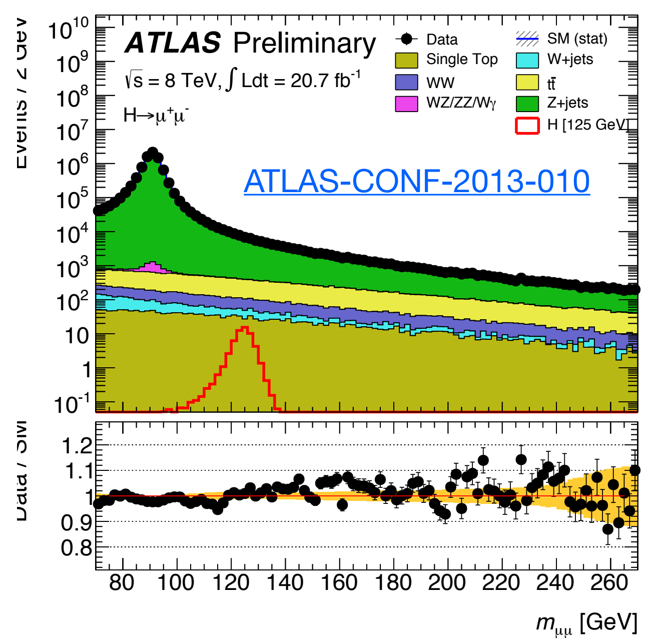

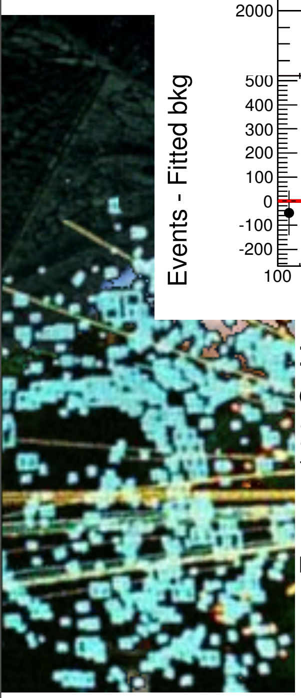

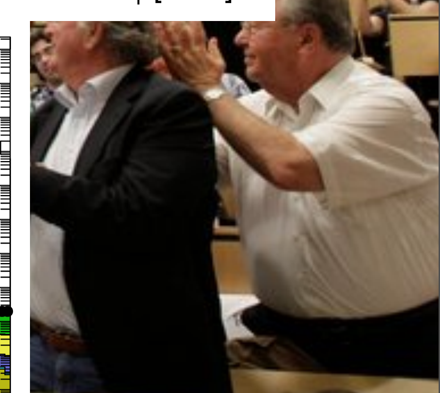

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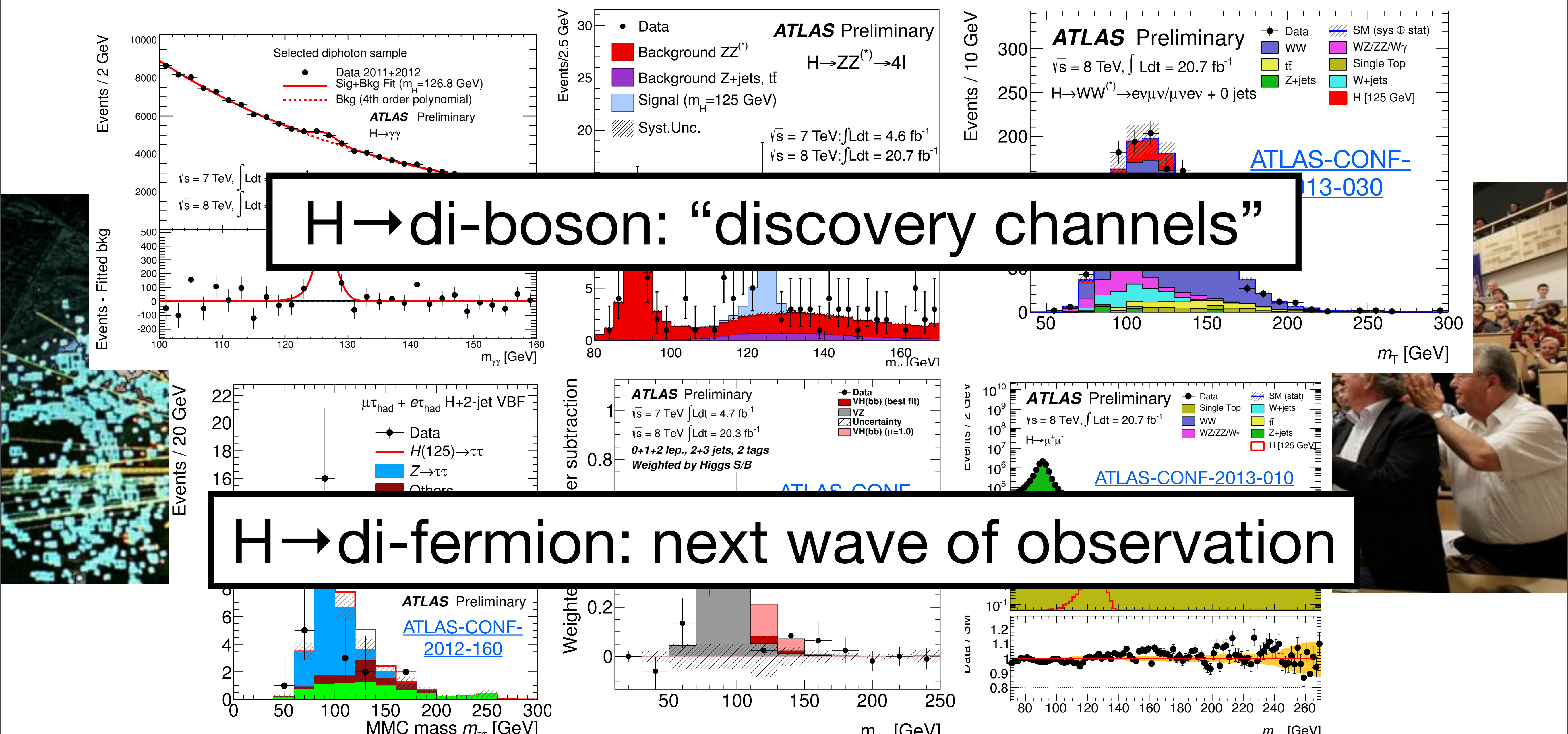
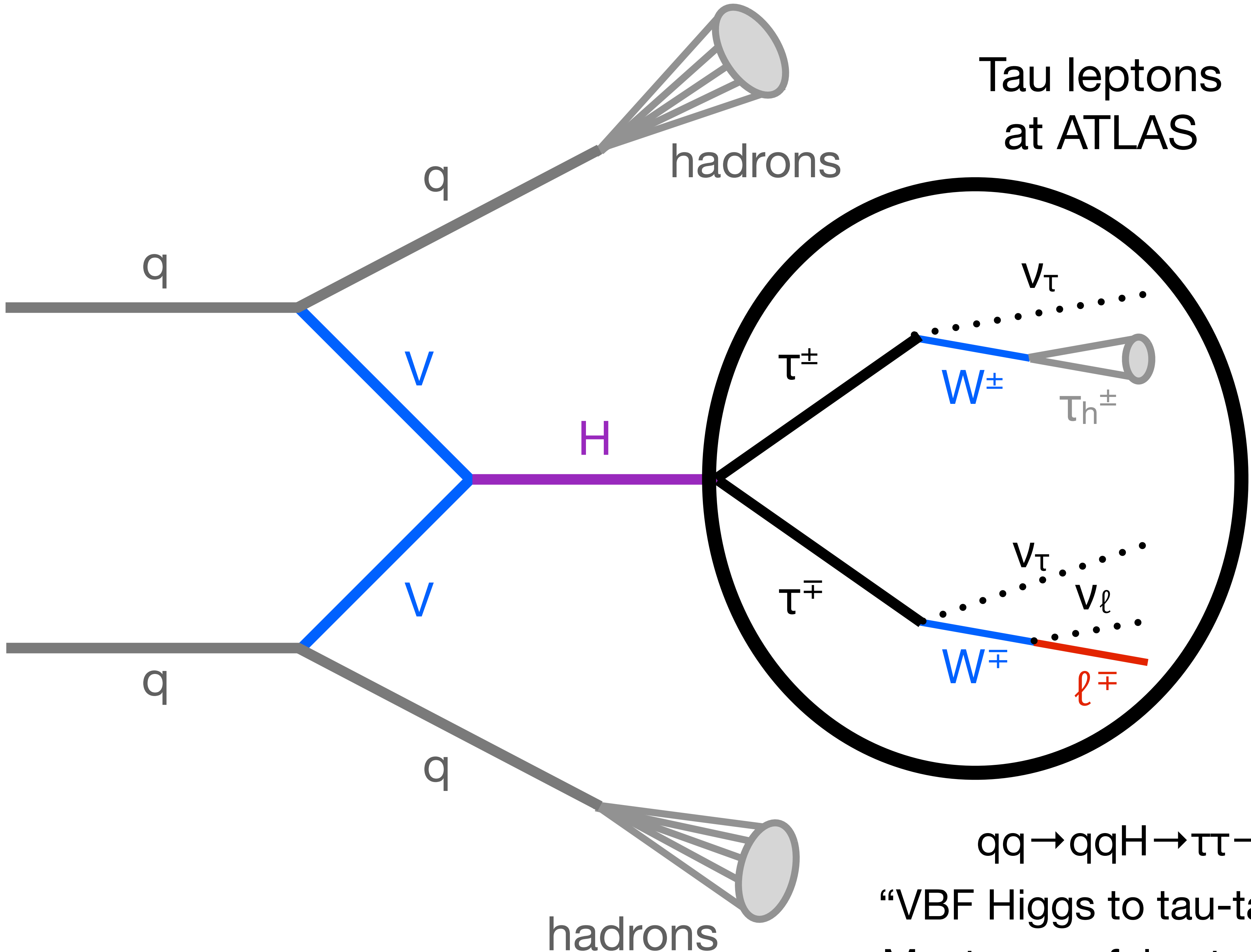


H→di-boson: "discovery channels"

H→di-fermion: next wave of observation

Picture of the analysis



$qq \rightarrow qqH \rightarrow \tau\tau \rightarrow h\nu_\tau \ell \nu_\ell \nu_\tau$

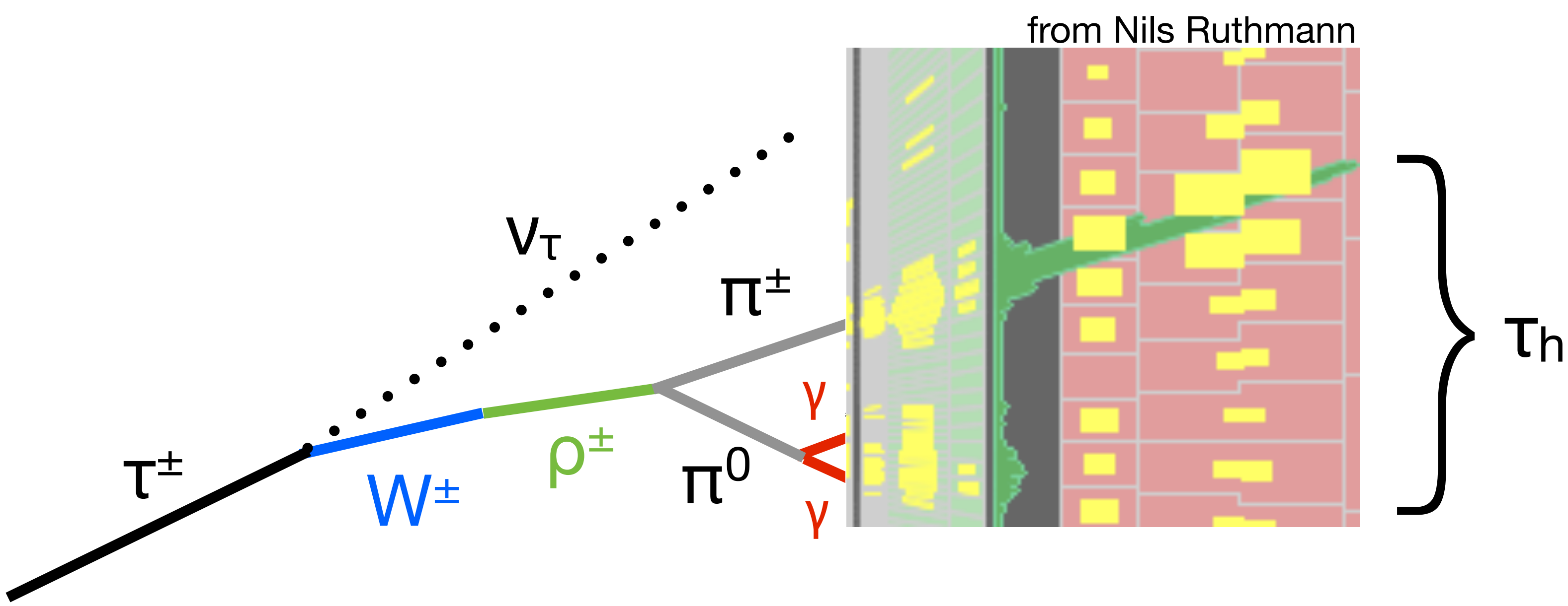
"VBF Higgs to tau-tau to lep-had"

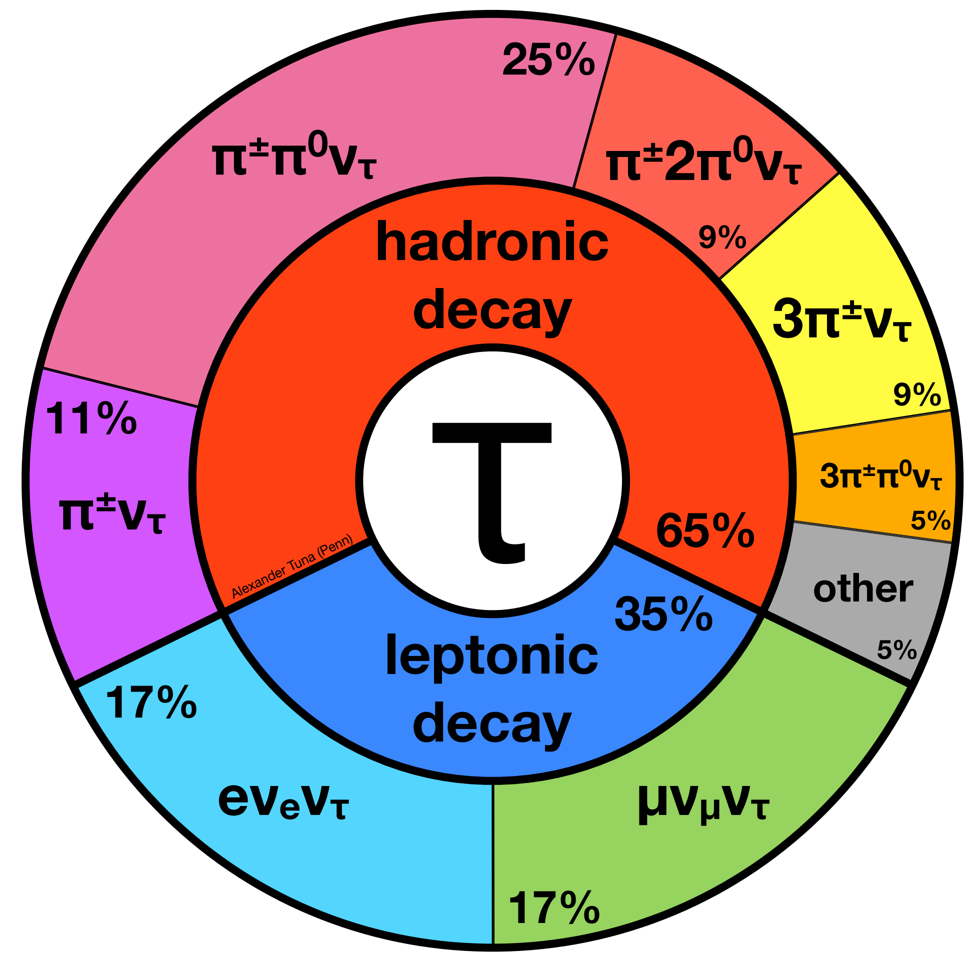
Most powerful category for $H \rightarrow \tau\tau$

Tau leptons @ ATLAS

Tau leptons are the 3rd and heaviest ($m_\tau \approx 1.8$ GeV) generation of leptons.

This large mass has two important consequences: tau leptons decay within the ATLAS beam pipe, and tau leptons can decay hadronically.





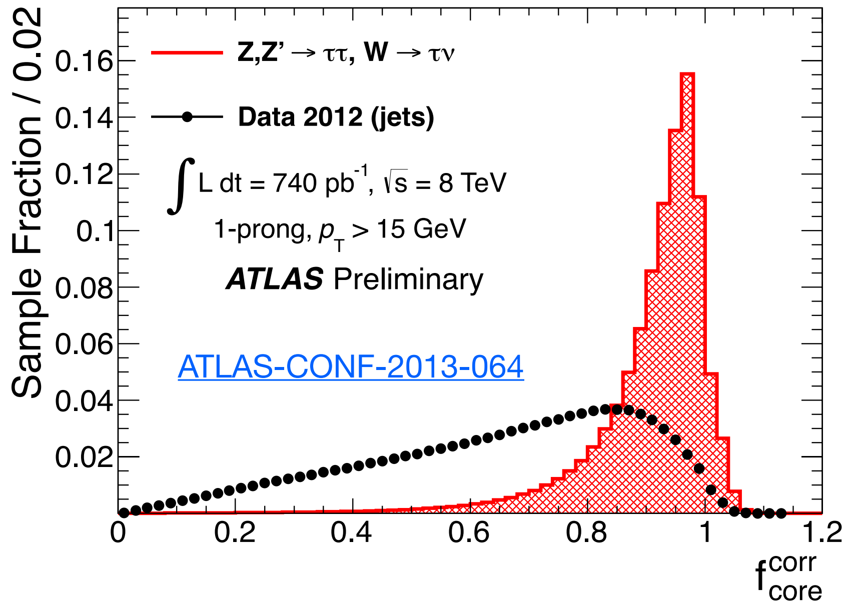
Identifying hadronic tau decays (τ_h: $\tau \rightarrow h\nu_\tau$) is challenging because hadrons (→"jets") are produced copiously at the LHC.

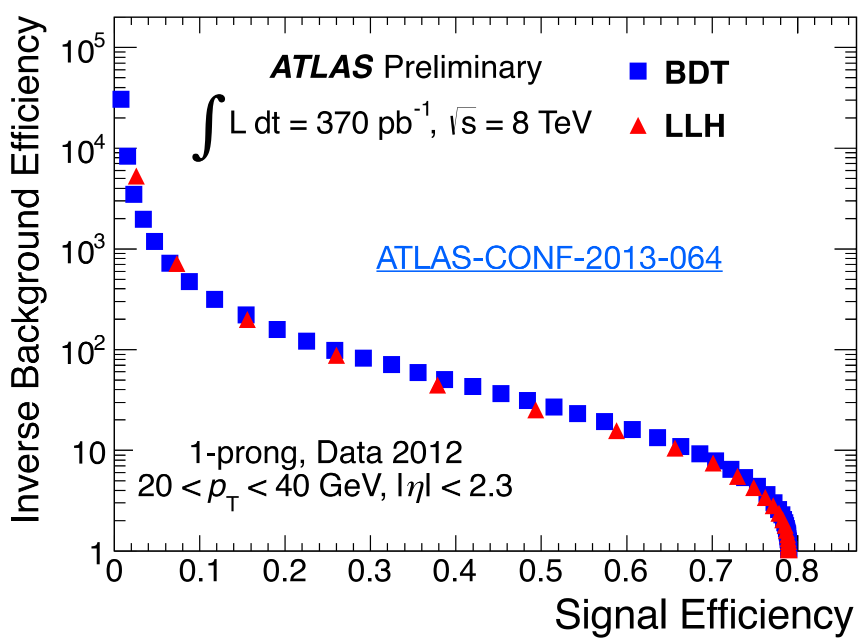
Identifying leptonic tau decays (τ_ℓ: $\tau \rightarrow \ell\nu_\ell\nu_\tau$) is easier because leptons are not hadrons, and we have great "standard candles": $W \rightarrow \ell\nu_\ell$ and $Z \rightarrow \ell\ell$.

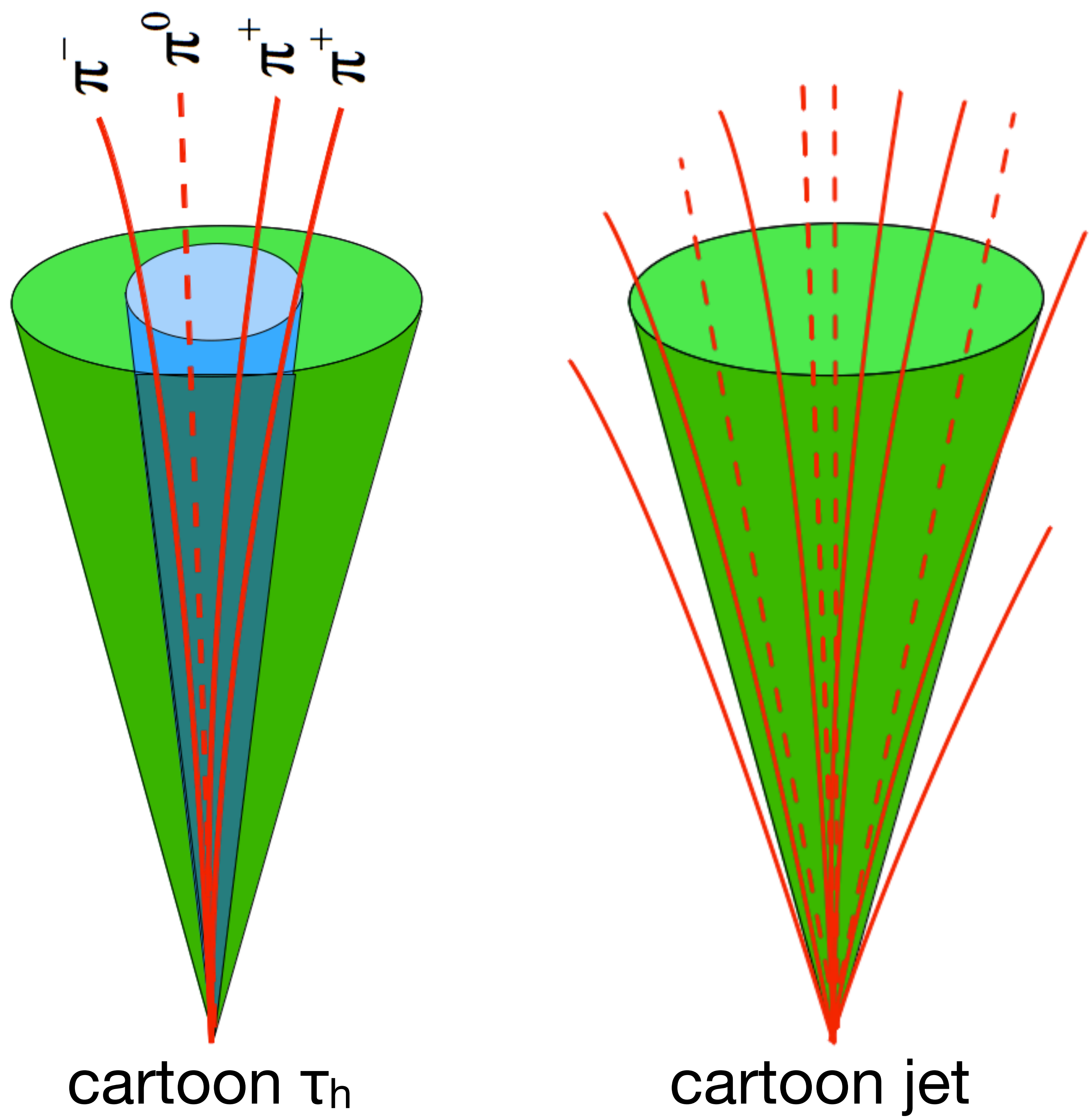
τ_h @ ATLAS

τ_h candidates are seeded by calorimeter clusters and tracks are associated to the candidates.

τ_h tend to have 1 or 3 tracks, narrow calorimeter showers, and a displaced vertex.





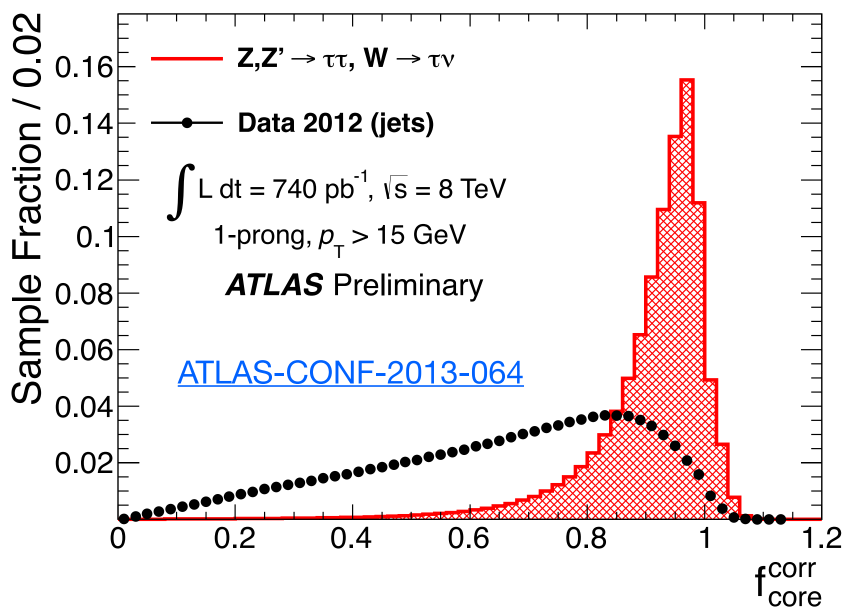


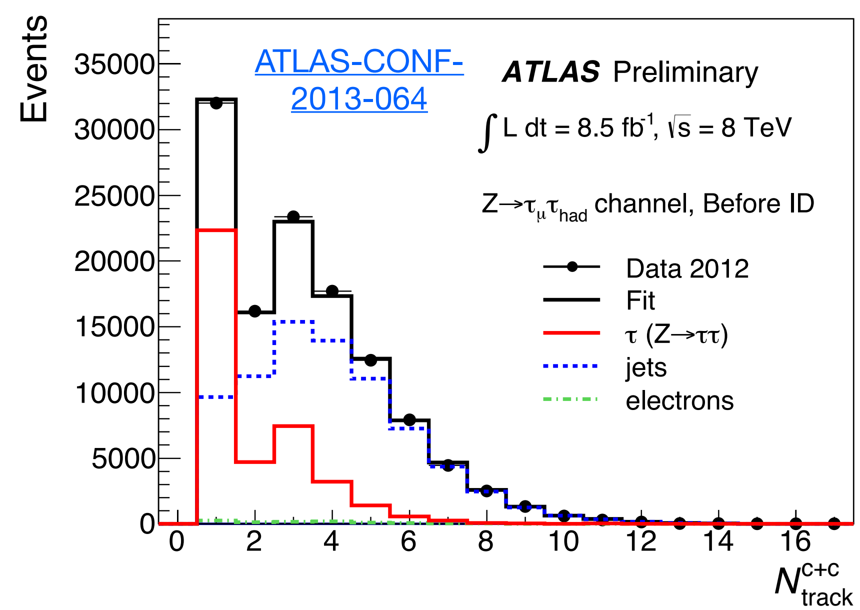
τ_h @ ATLAS

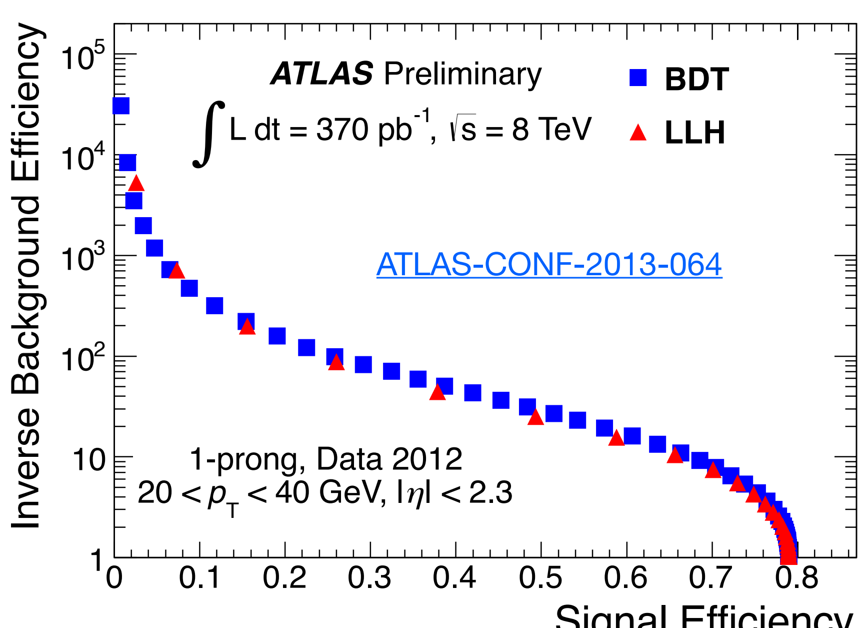
τ_h candidates are seeded by calorimeter clusters and tracks are associated to the candidates.

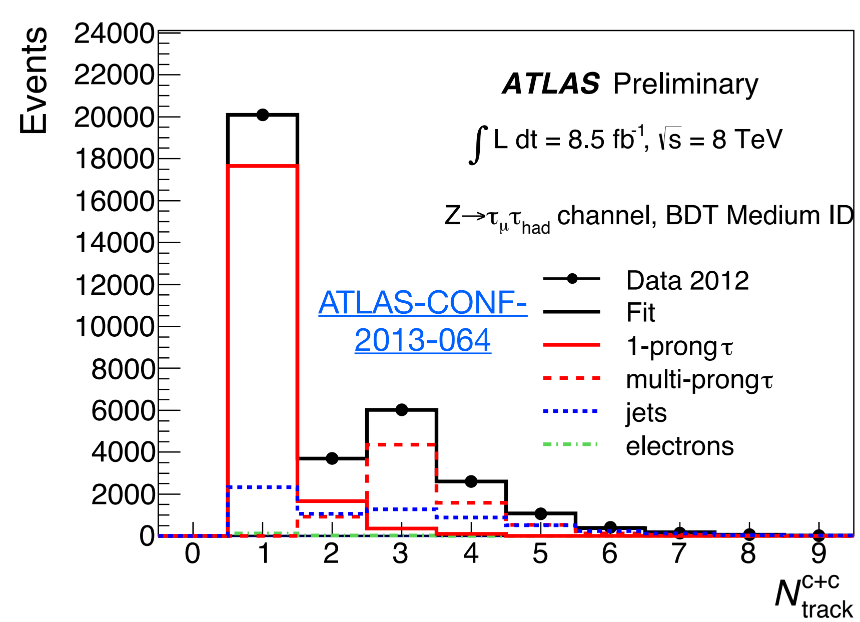
τ_h tend to have 1 or 3 tracks, narrow calorimeter showers, and a displaced vertex.

τ_h identification efficiency can be measured in data with $Z \rightarrow \tau_\mu \tau_h$ tag-and-probe.









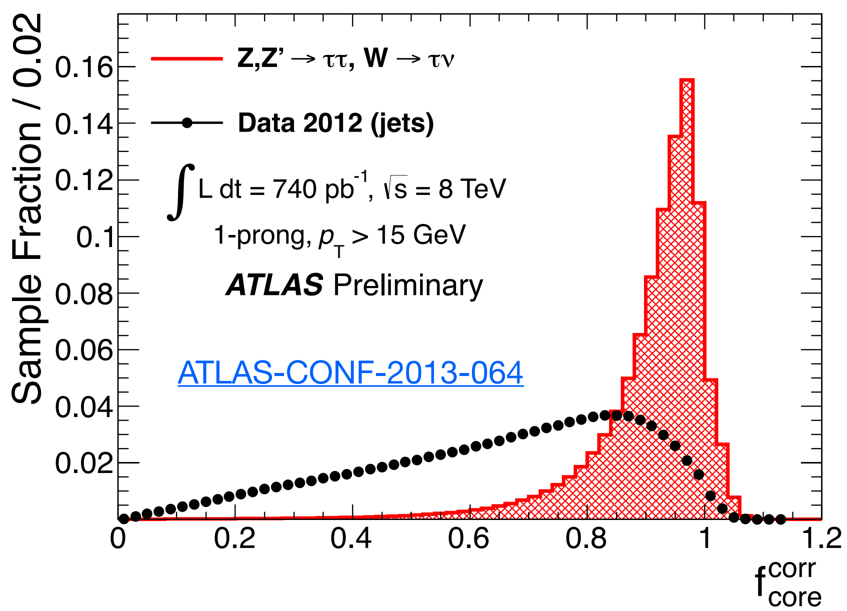
τ_h @ ATLAS

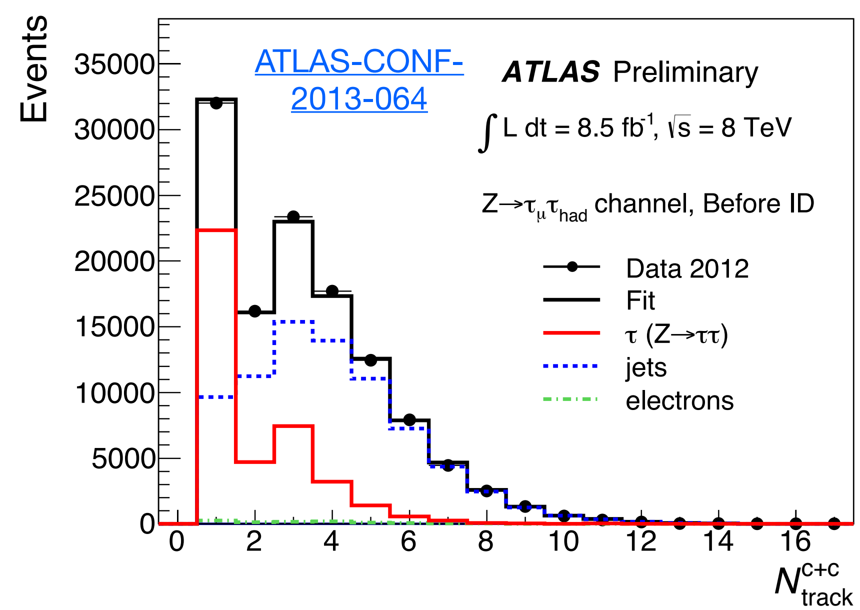
τ_h candidates are seeded by calorimeter clusters and tracks are associated to the candidates.

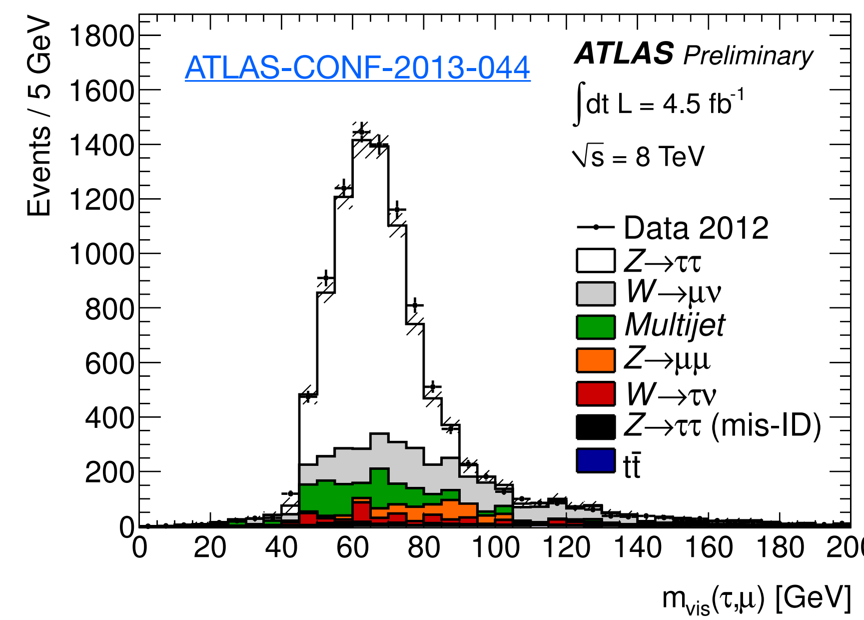
τ_h tend to have 1 or 3 tracks, narrow calorimeter showers, and a displaced vertex.

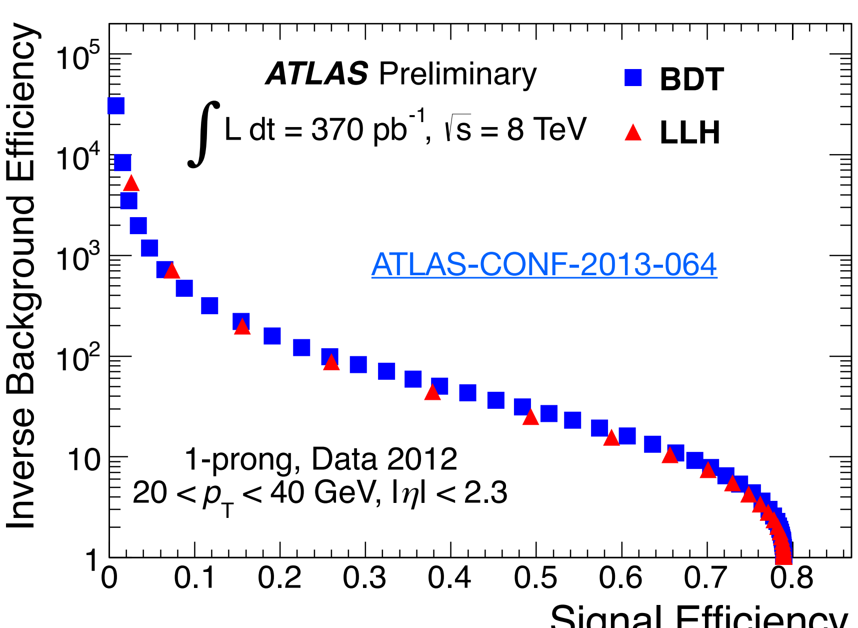
τ_h identification efficiency can be measured in data with $Z \rightarrow \tau_\mu \tau_h$ tag-and-probe.

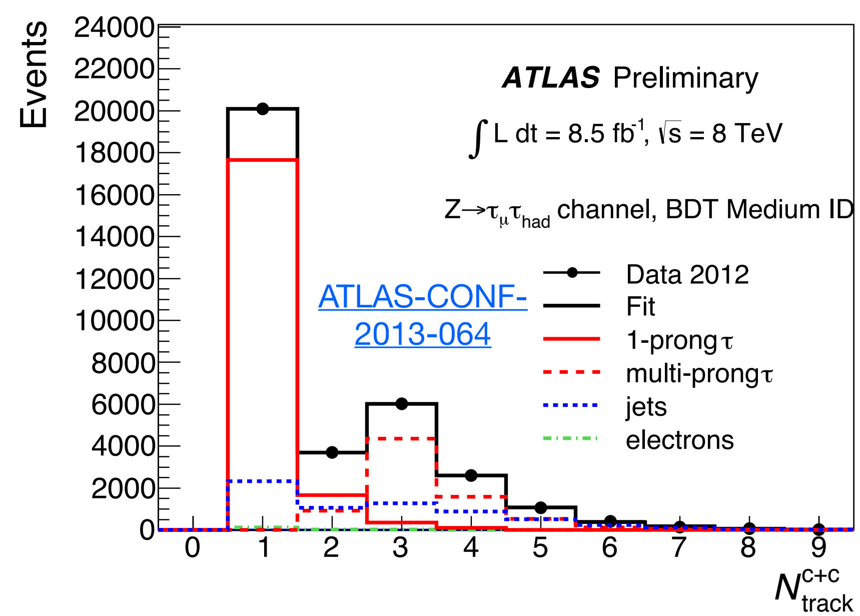
The τ_h energy scale (TES) can be corrected with MC and CTB data and also measured with $Z \rightarrow \tau_\mu \tau_h$ T&P.

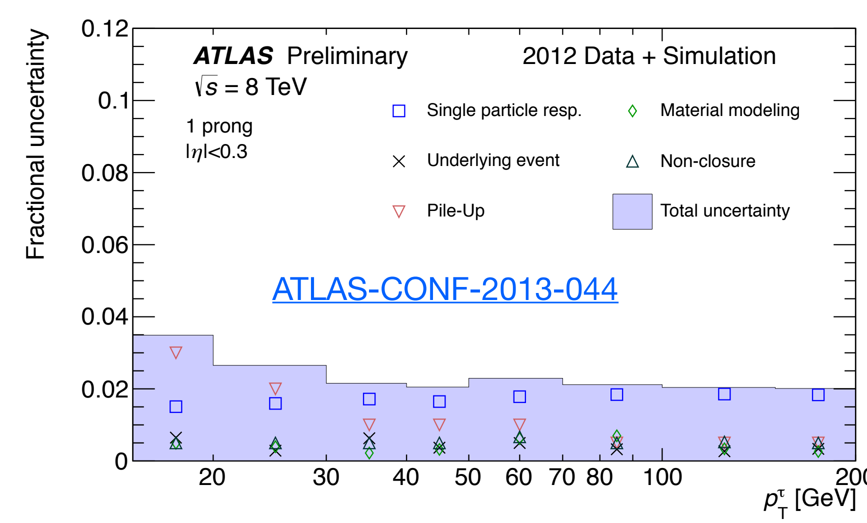




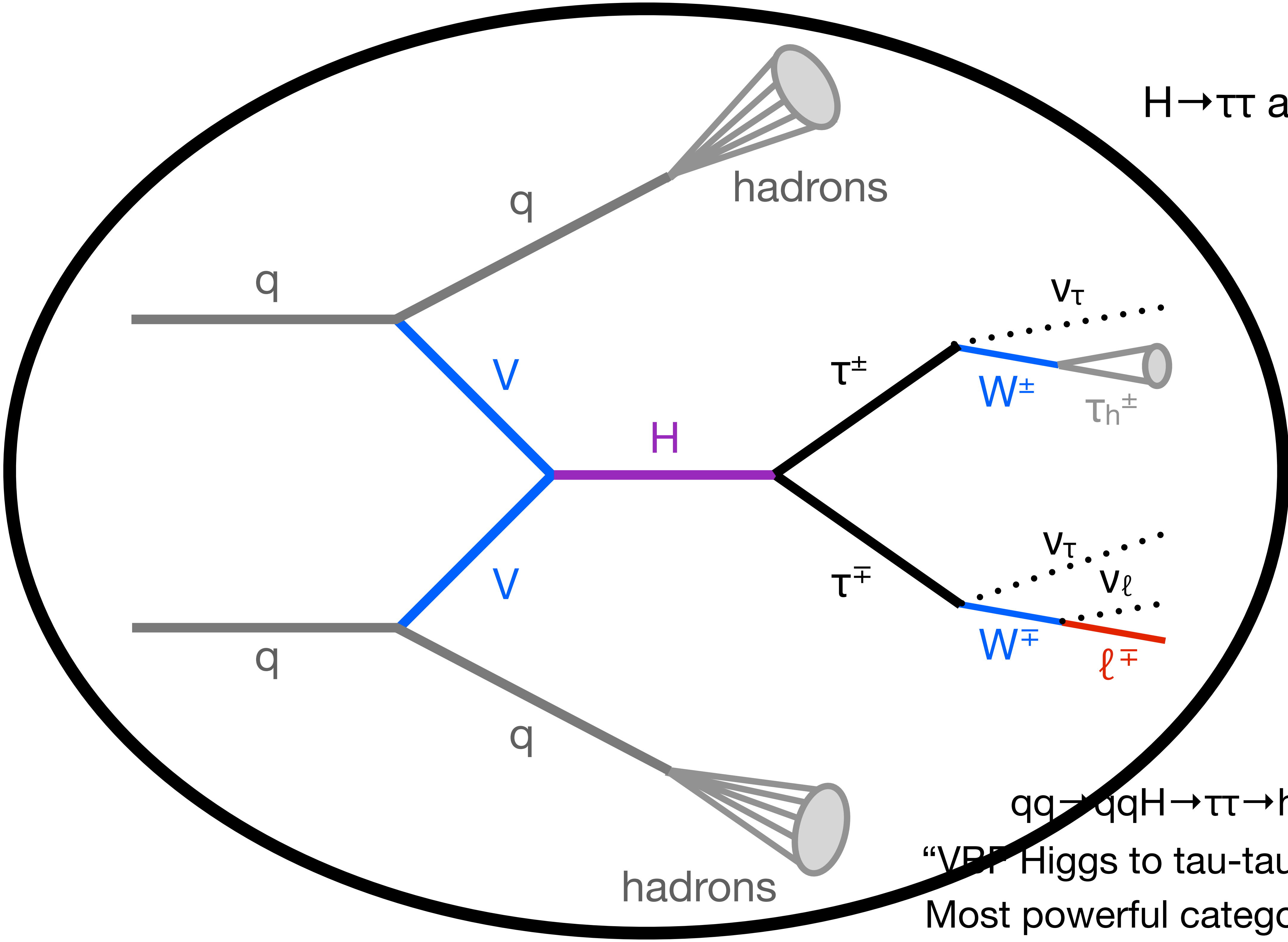








Picture of the analysis



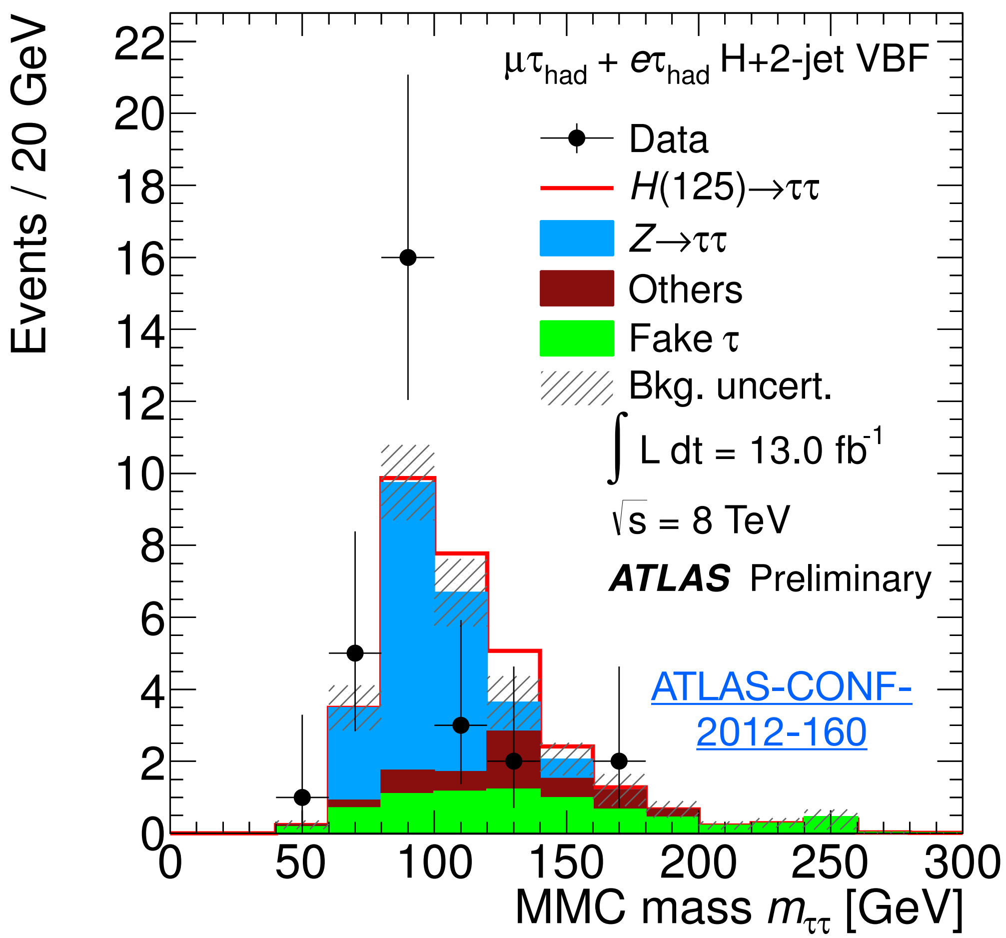
H→ττ at ATLAS!

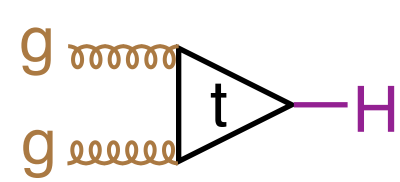
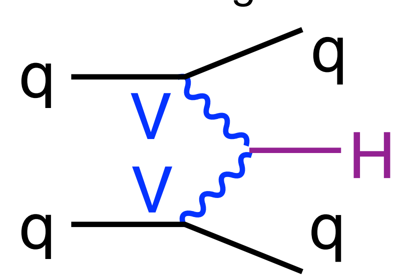
qq→qqH→ττ→hνττℓνℓντ

"VBF Higgs to tau-tau to lep-had"

Most powerful category for H→ττ

$H \to \tau\tau$ strategy



	$H\to\tau_\ell\tau_h$	$H\to\tau_h\tau_h$	$H\to\tau_\ell\tau_\ell$
Nickname	"lep-had"	"had-had"	"lep-lep"
Trigger	single ℓ $\ell+\tau_h$	di-τ_h	single ℓ di-ℓ
ggF categories 	0 jet 1 jet boosted H	boosted H	0 jet 1 jet boosted H
VBF categories 	2-jet VBF	2-jet VBF	2-jet VBF

Select events with well-identified τ_h, ℓ, and categorize the events by jet multiplicity and $p_T(H)$.

Add topological cuts to reduce background contamination.

Extract signal with maximum likelihood fit of $m(\tau\tau)$.

Common issue: Z→ττ

Issue

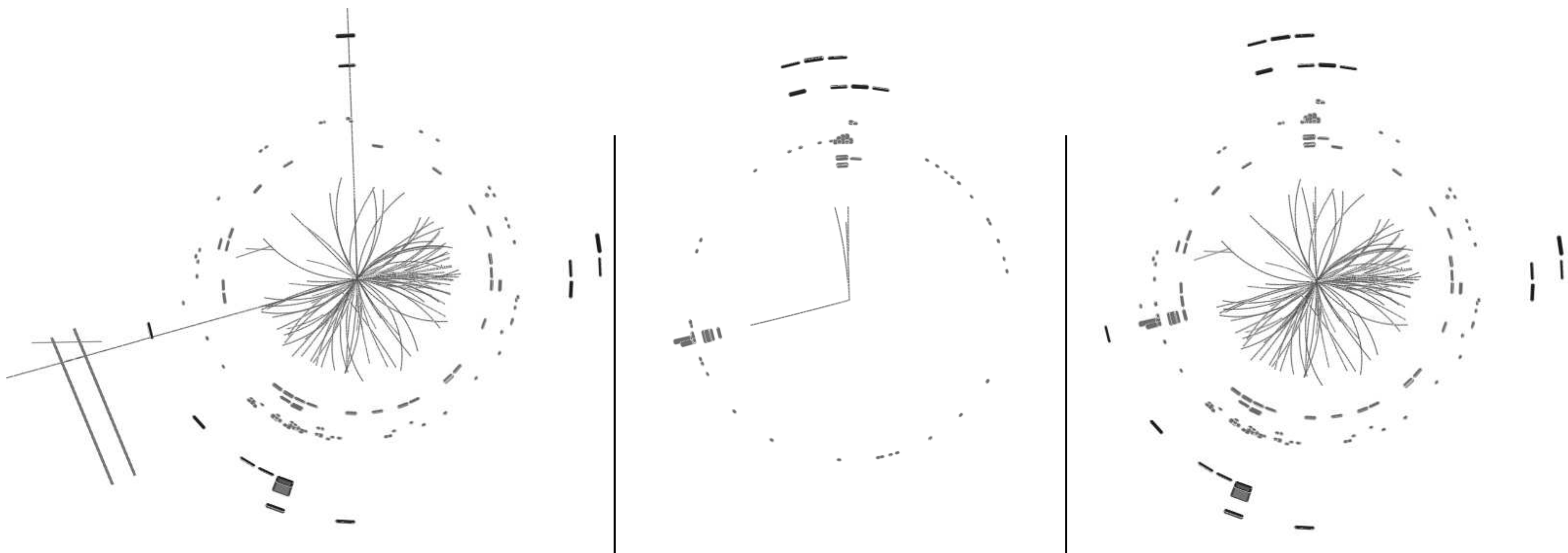
Difficult to find CR for largely irreducible $Z/\gamma^* \to \tau\tau$

Dominant background in all final states

Idea

Embed simulated τ decays in Z→μμ data

Z→ ττ “embedding”



Z→μμ in data	τ decays in MC	Embedded Z→ττ

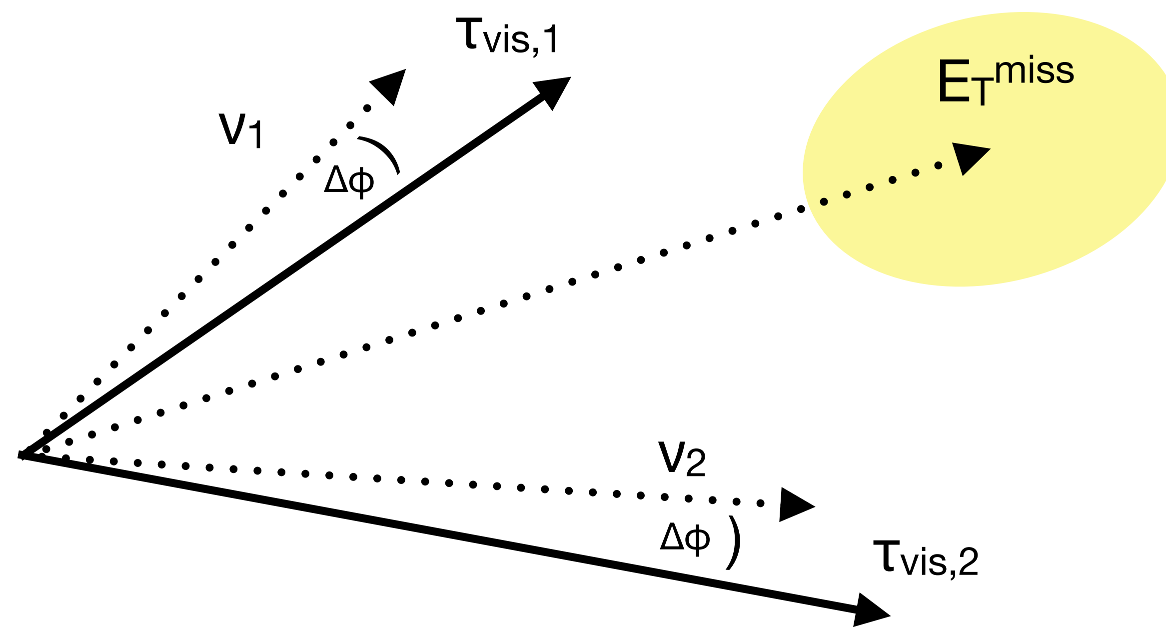
Replace μ	Simulate τ decay	Benefits
Tracks	TAUOLA for polarization and spin correlations	Jets, underlying event, and pileup effects from data
Calorimeter cells	Full ATLAS simulation, digitization, reconstruction	Significantly reduced systematics uncertainties

Common issue: m(ττ)

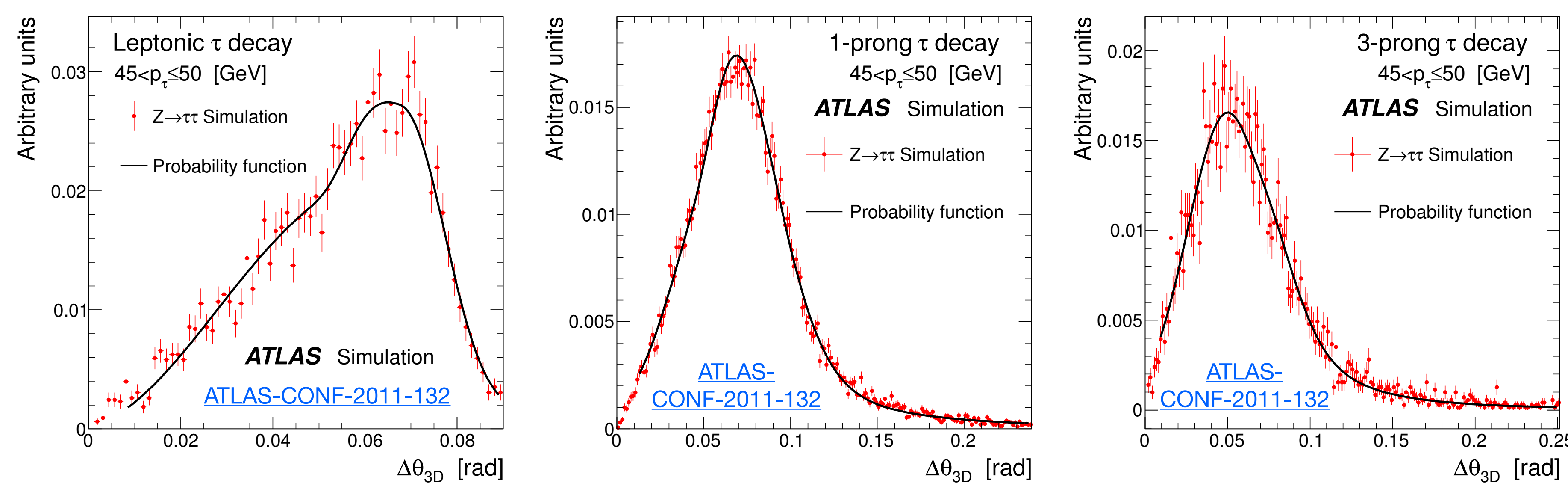
Accurate mass reconstruction is challenging because there are 2 ($\tau_h\tau_h$), 3 ($\tau_h\tau_\ell$), or 4 ($\tau_\ell\tau_\ell$) neutrinos in the ττ decay. The Missing Mass Calculator (MMC) helps here.

Unknowns:	6-8	$p(\nu_1)$, $p(\nu_2)$
Constraints:	4	E_x^{miss}, E_y^{miss}, $m(\tau_1)$, $m(\tau_2)$
Scans:	2-4	$\Delta\phi(\tau_{vis,1},\nu_1)$, $\Delta\phi(\tau_{vis,2},\nu_2)$, $m(\nu_1)$, $m(\nu_2)$

ν_i refers to neutrino system of *i*th tau lepton decay



m(ττ) is built for each scan point and weighted by the $\Delta\theta_{3D}(\tau_{vis,i},\nu_i)$ probabilities. The maximally-probable m(ττ) is chosen.



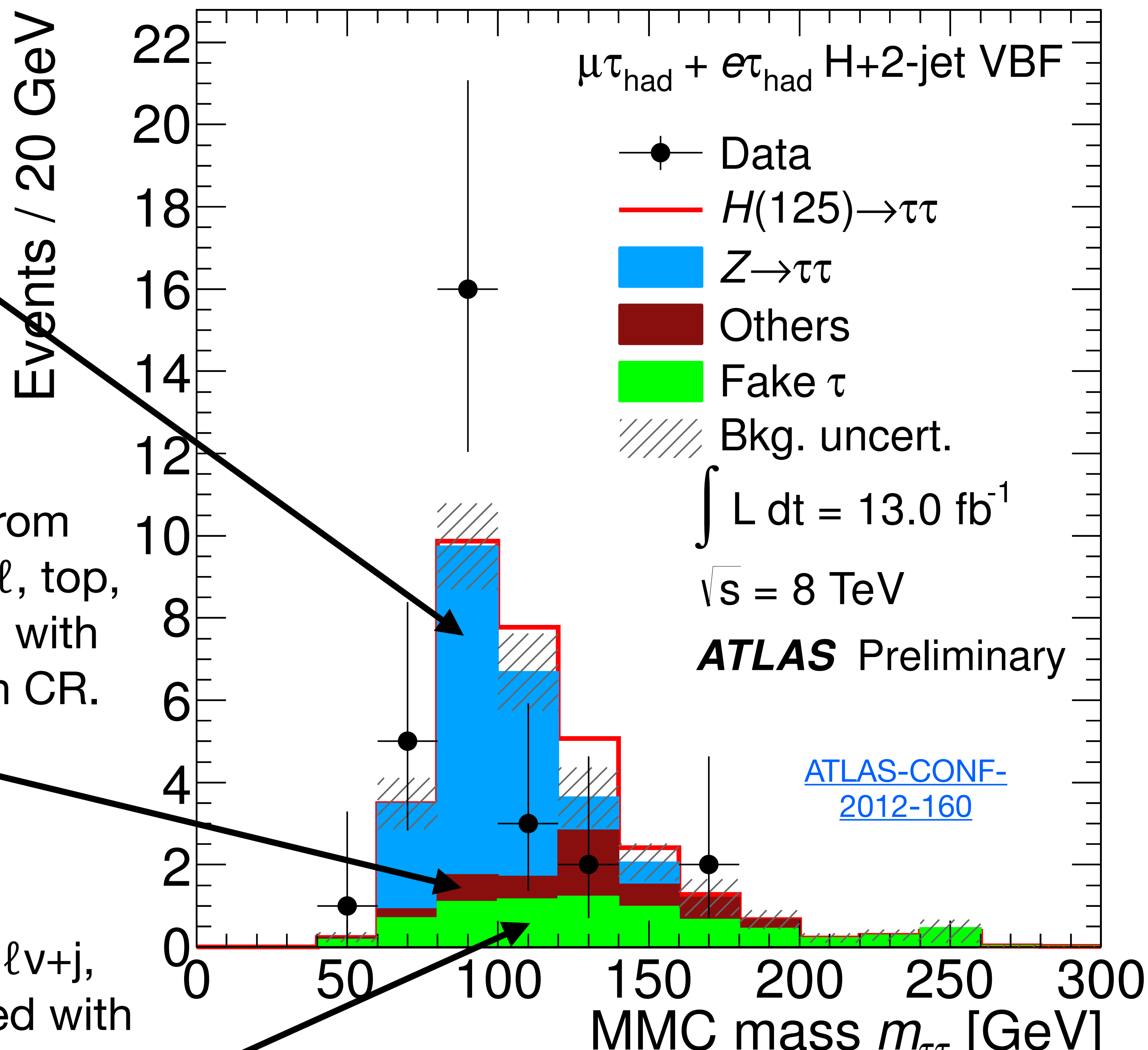
$\Delta\theta_{3D}(\tau_{vis,i},\nu_i)$ PDFs for three possible tau lepton decays.

$H \to \tau_\ell \tau_h$

$Z \to \tau_\ell \tau_h$ is estimated with embedding (non-VBF) and VBF-filtered MC (VBF).

Small contribution from other processes ($Z \to \ell\ell$, top, diboson) is estimated with MC and normalized in CR.

Jets-faking-τ_h ($W \to \ell\nu$+j, multi-jet) are estimated with SS data (non-VBF) and "fake factor" method (VBF) on τ_h PID



Categories

(ranked by sensitivity)

VBF
Boosted H
1-jet
0-jet

Selected systematic uncertainties (signal)

JES	3-9%
TES	2-9%
TID	4-5%
TH	18-23%

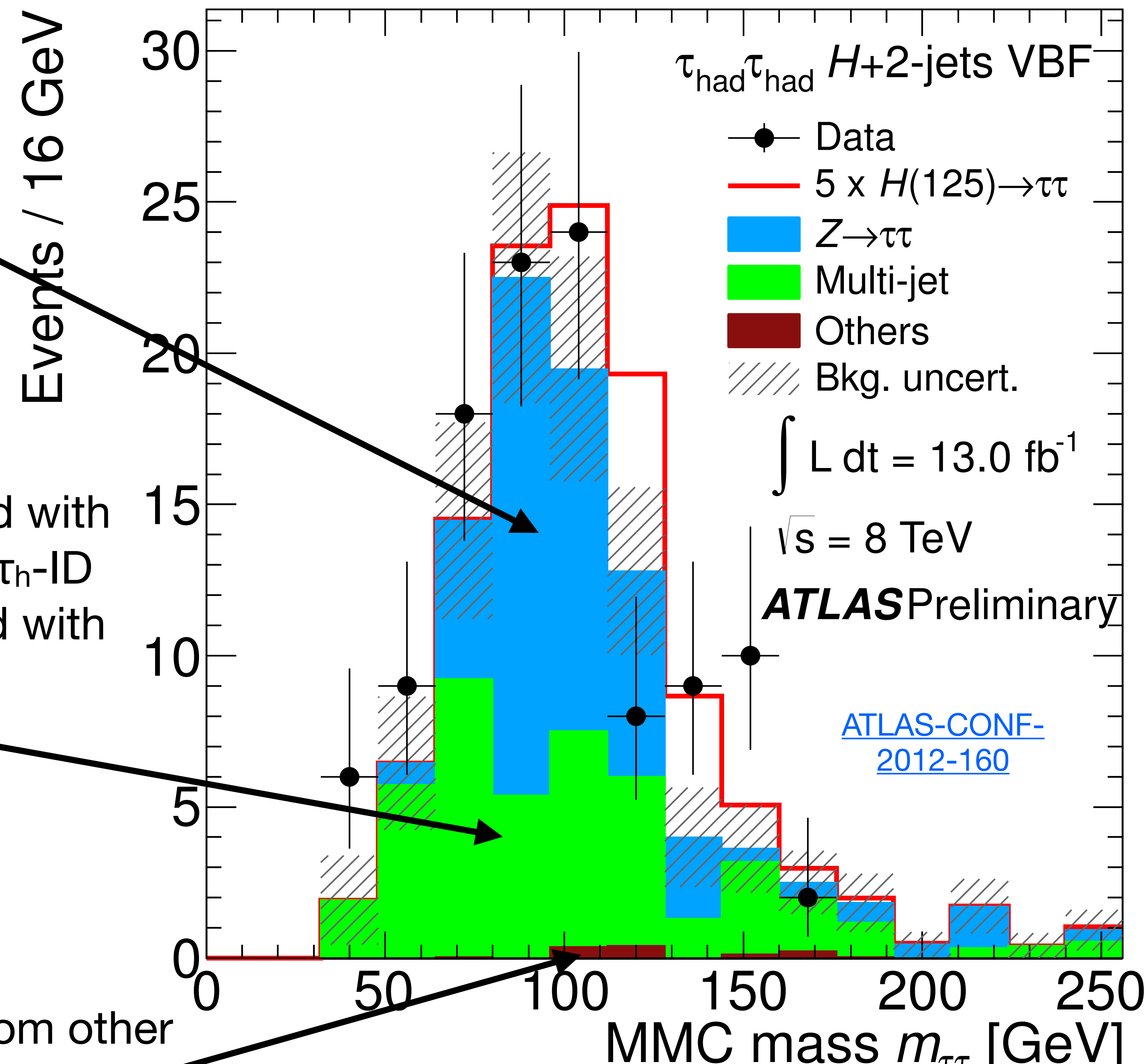
Selected systematic uncertainties (backg. est.)

FF	50%

$H \to \tau_h \tau_h$

$Z \to \tau_h \tau_h$ is estimated with embedding and normalized with 2D τ_h-track fit.

Multi-jet is estimated with SS, not-OS, or fail-τ_h-ID data and normalized with 2D τ_h-track fit.



Small contribution from other processes ($W \to \tau\nu$+j, top, diboson) are estimated with MC

Categories
(ranked by sensitivity)

VBF
Boosted H

Selected systematic uncertainties (signal)

JES	2-4%
TES	4-6%
TID	10%
TH	3-20%

Selected systematic uncertainties (backg. est.)

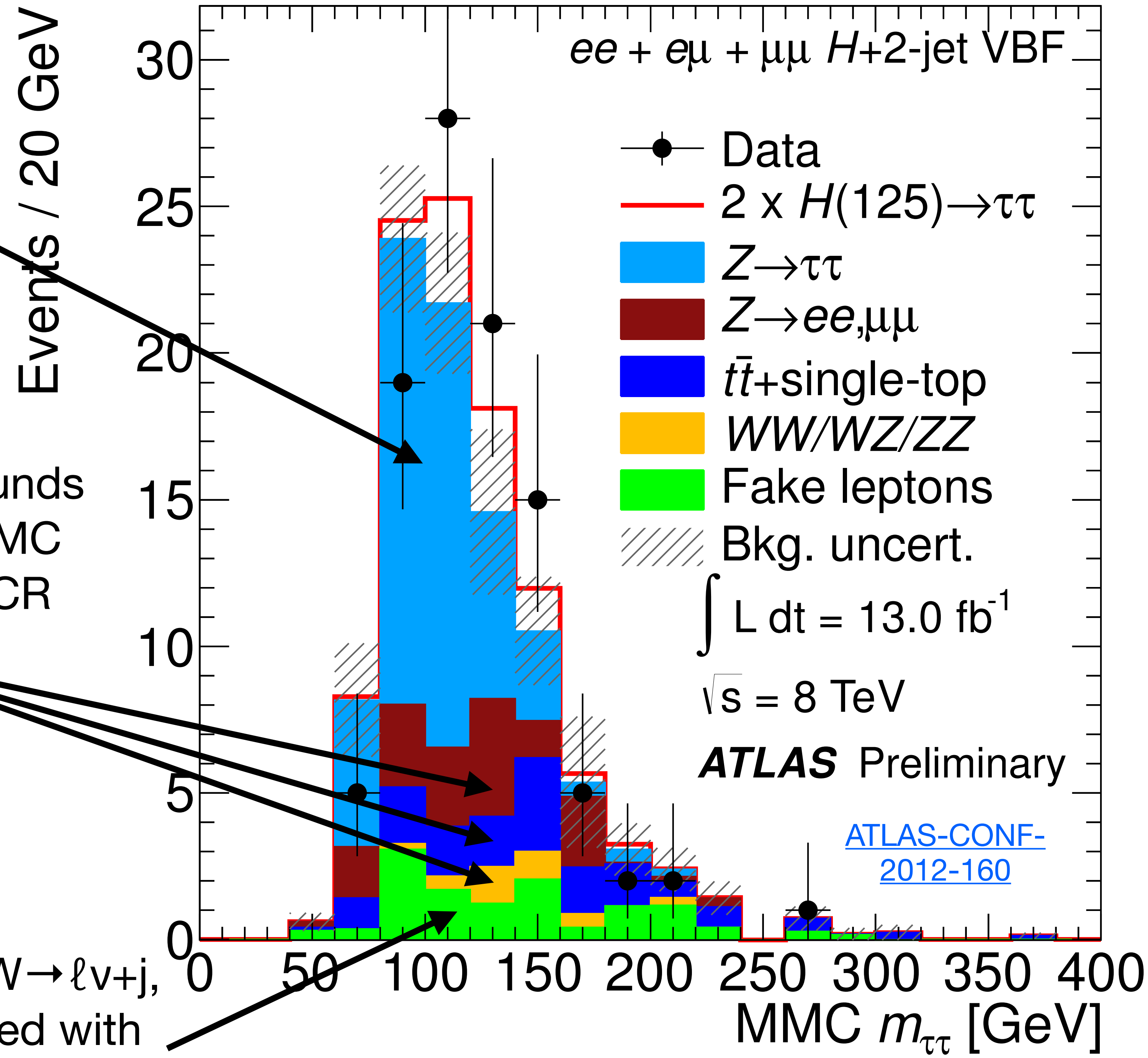
$Z \to \tau\tau$ (VBF)	11%
multi-j (VBF)	10%

$H\to\tau_\ell\tau_\ell$

$Z\to\tau_\ell\tau_\ell$ is estimated with embedding and normalized to $Z\to\tau_\ell\tau_\ell$ MC.

Non-ττ EW backgrounds are estimated with MC and normalized in CR

Jets-faking-leptons ($W\to\ell\nu$+j, multi-jet) are estimated with non-isolated leptons and sublead lepton p_T template



Categories

(ranked by sensitivity)

VBF

Boosted H

1-jet

VH

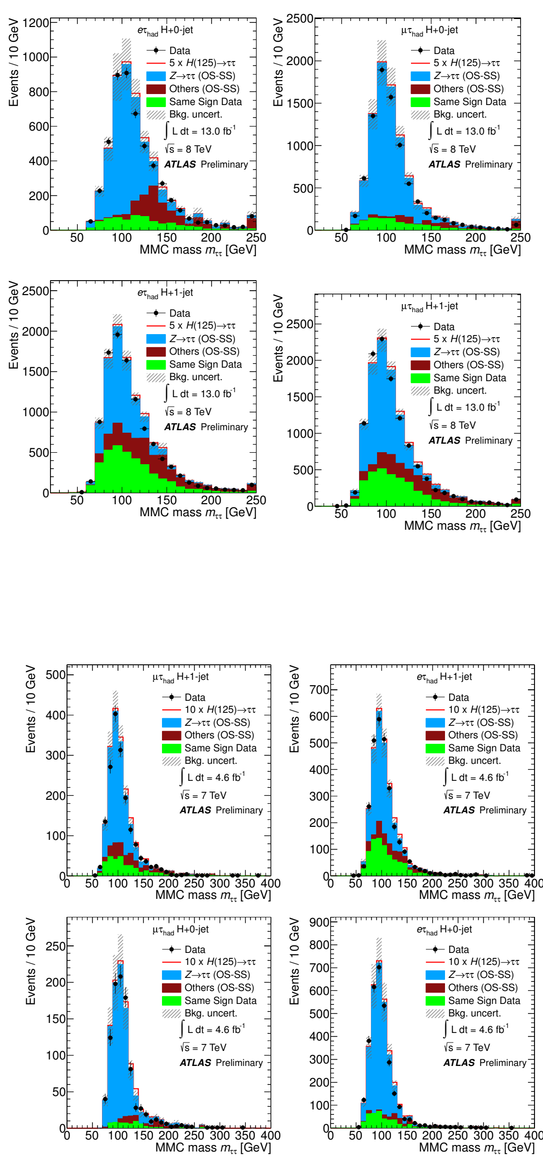
0-jet

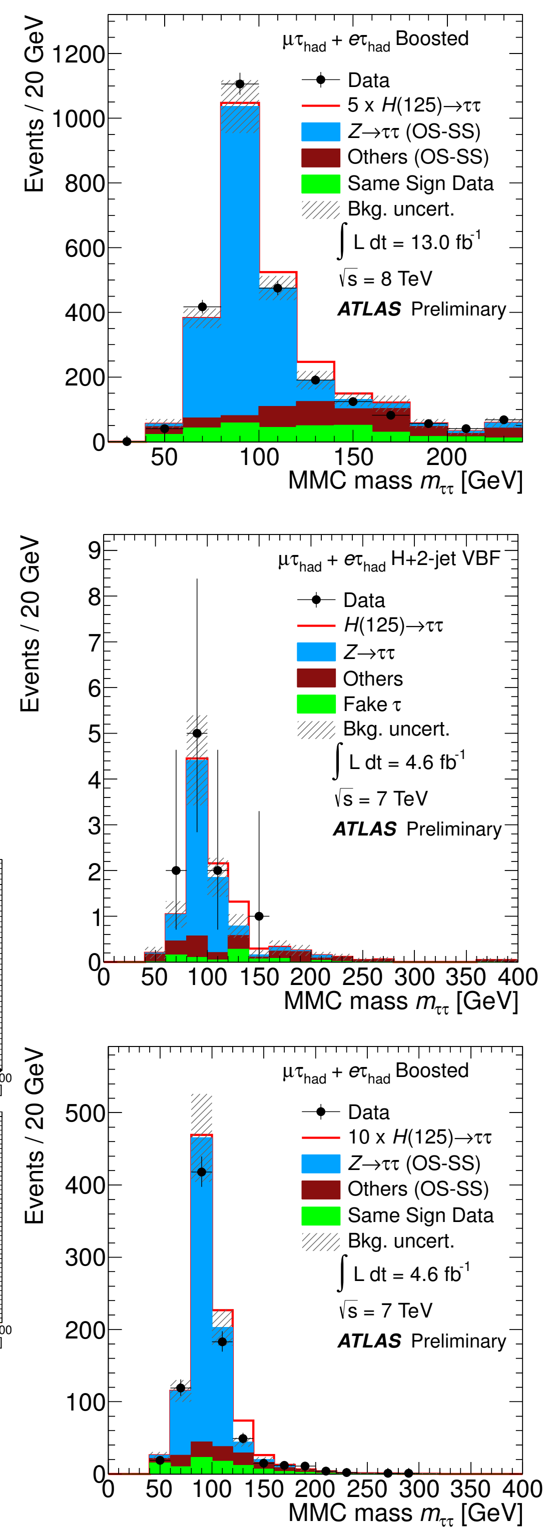
Selected systematic uncertainties (signal)	
JES	1-5%
TH	8-28%

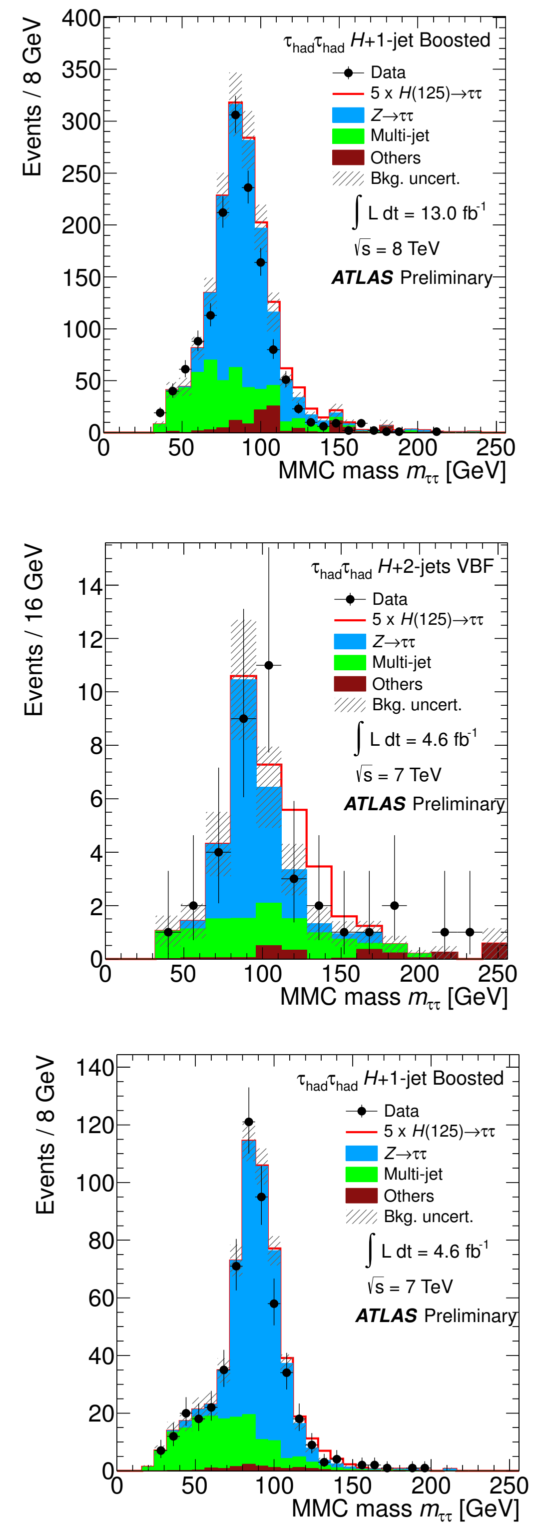
Selected systematic uncertainties (backg. est.)	
Fake ℓ	20-40%

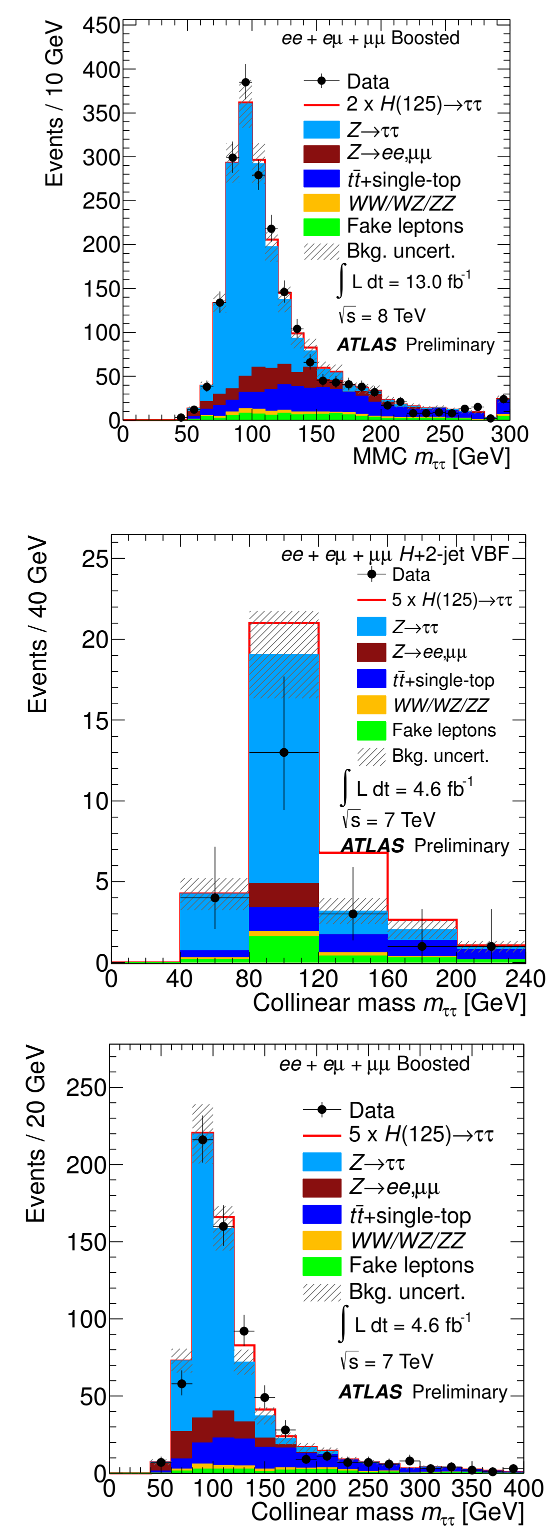
Other categories

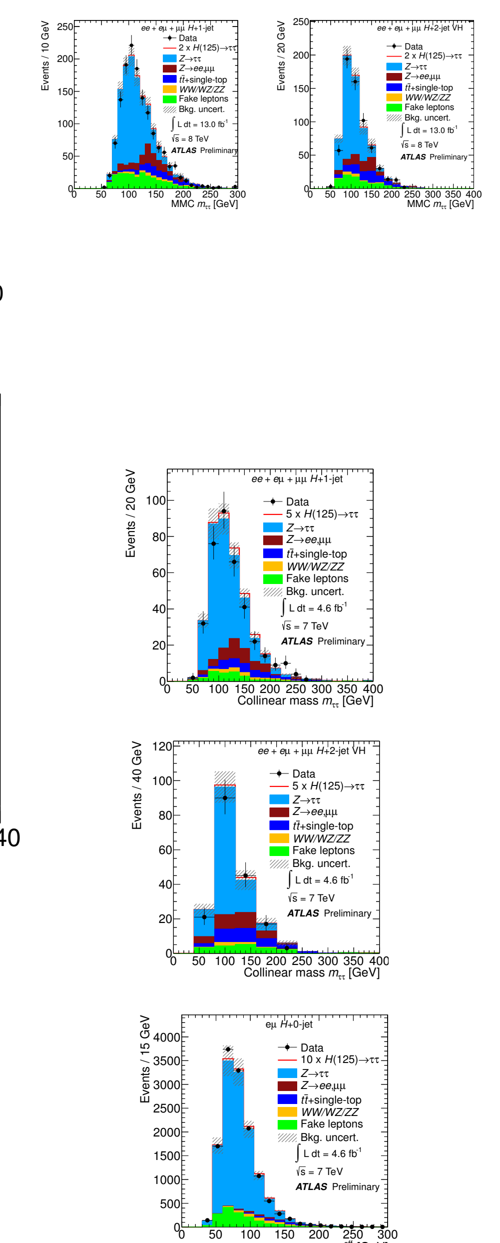
τℓτh	τhτh	τℓτℓ







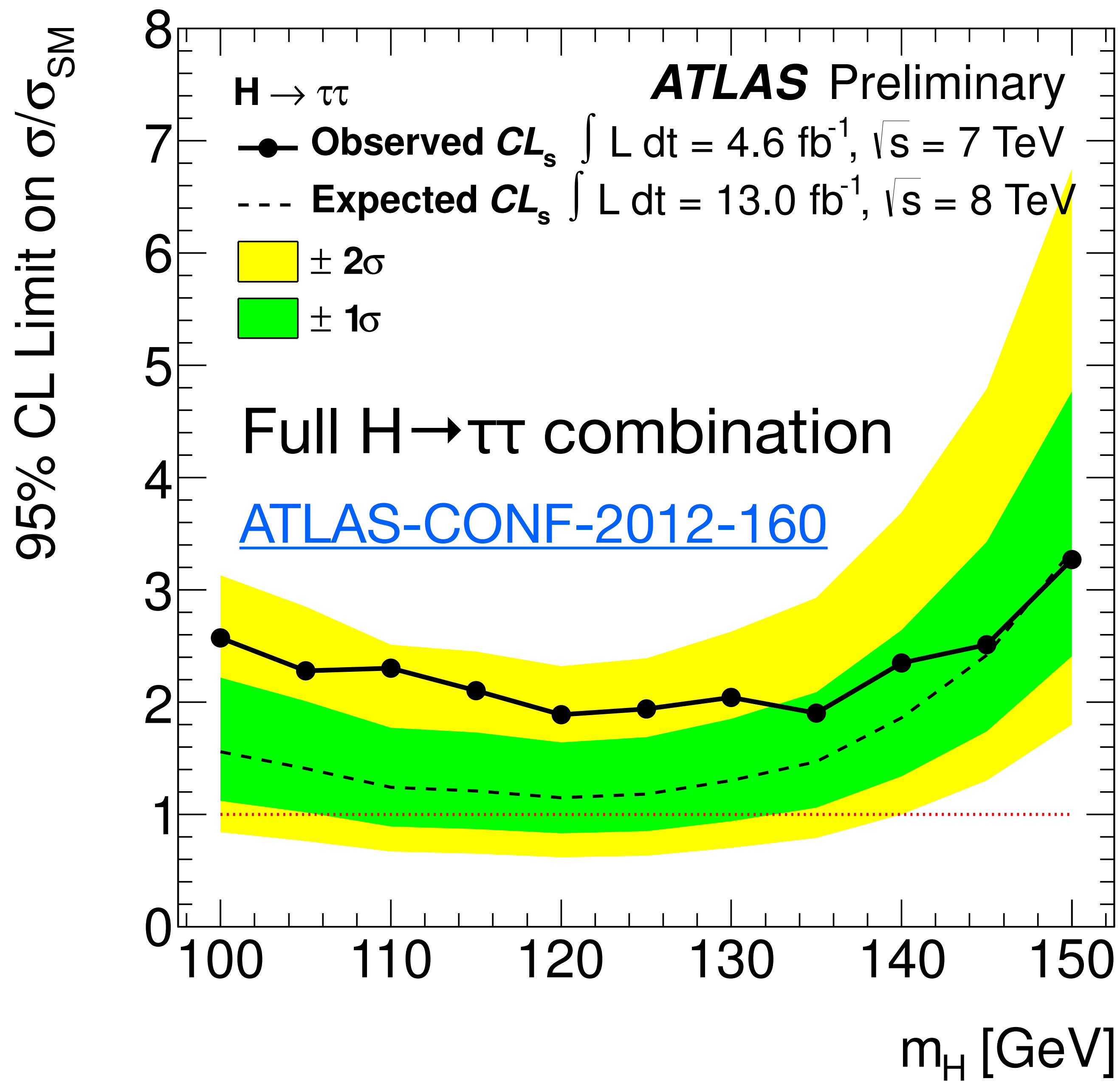


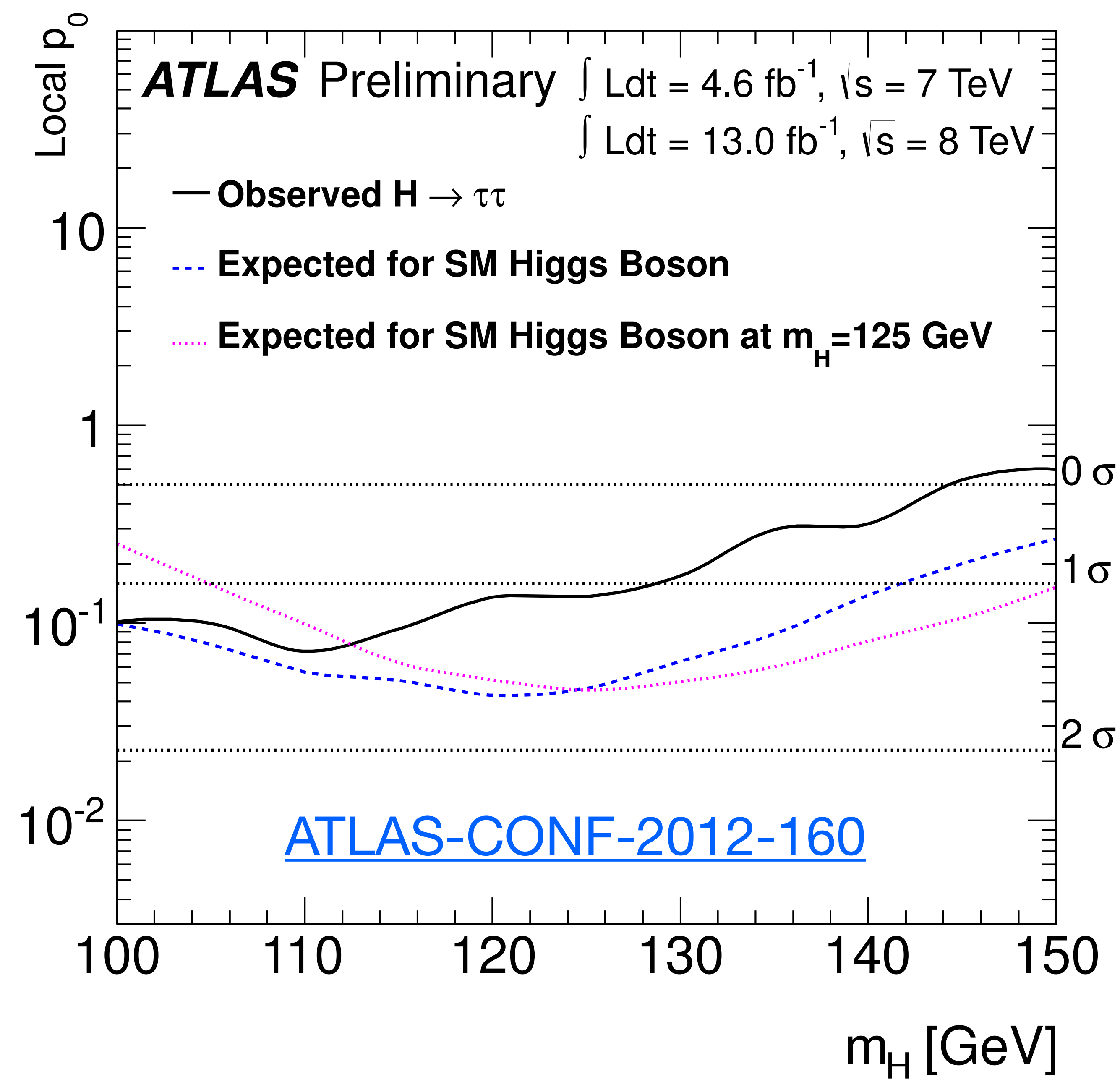


Results

Number of categories (25 total)

	$\tau_\ell\tau_h$	$\tau_h\tau_h$	$\tau_\ell\tau_\ell$
2011	6	2	5
2012	6	2	4





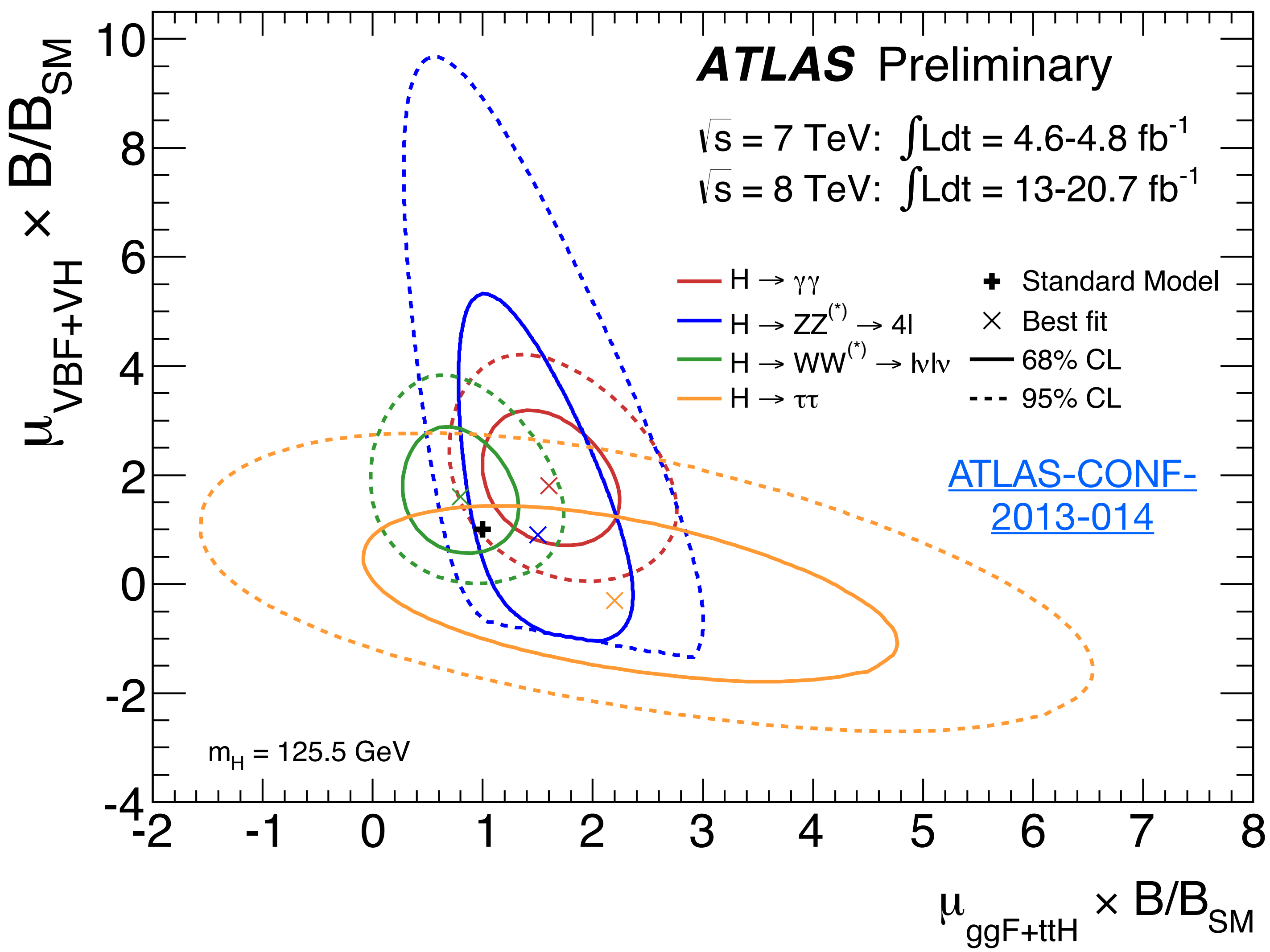
1.2×SM expected, 1.9×SM observed

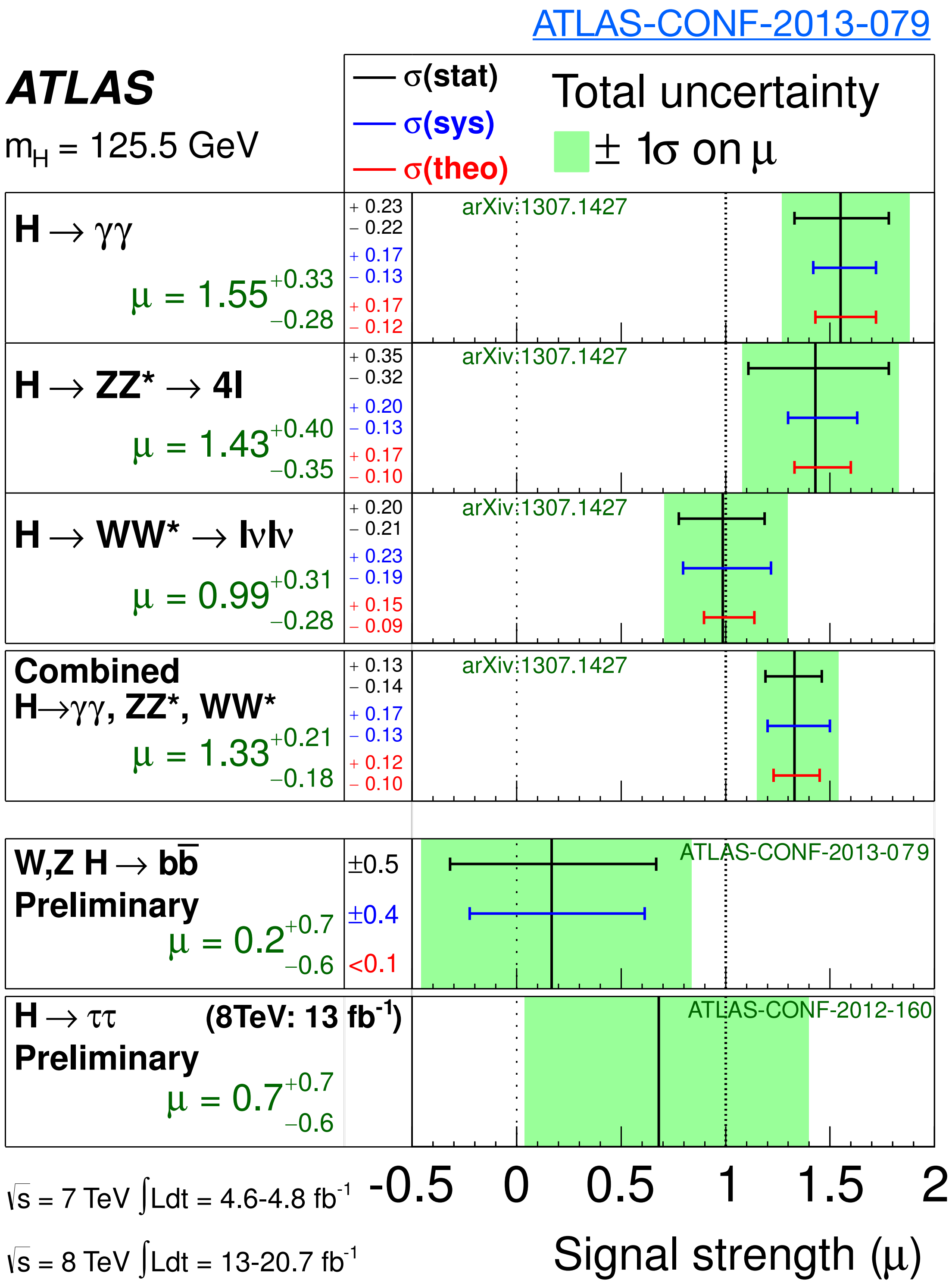
95% CL limit for m_H = 125 GeV

1.7σ expected, 1.1σ observed

local significance for m_H = 125 GeV

Results





Best fit signal strength parameter (μ) is 0.7 ± ~0.7.

Combined H→ττ search is compatible with μ=0 and μ=1.

Future of $H \rightarrow \tau\tau$ @ ATLAS?

The analysis has many improvements planned for the near future.

Full 2012 dataset	MVA event selection
Better objects (τ_h, ℓ, E_T^{miss})	Better background estimates
Channel harmonization	More CRs in the fit

The analysis faces many challenges for 2015.

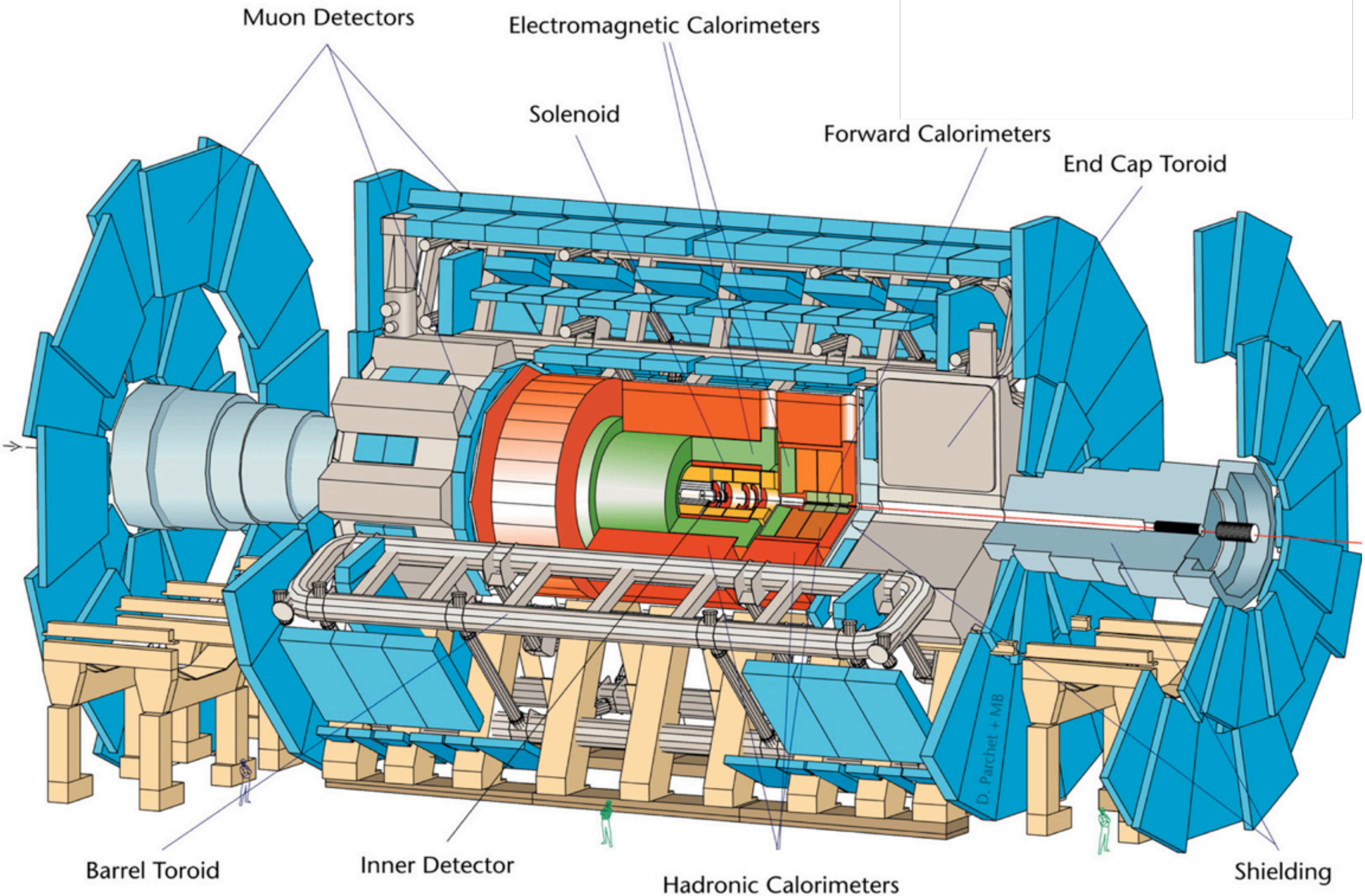
Much tougher to trigger	Increased pileup

τ_h identification in dense environment

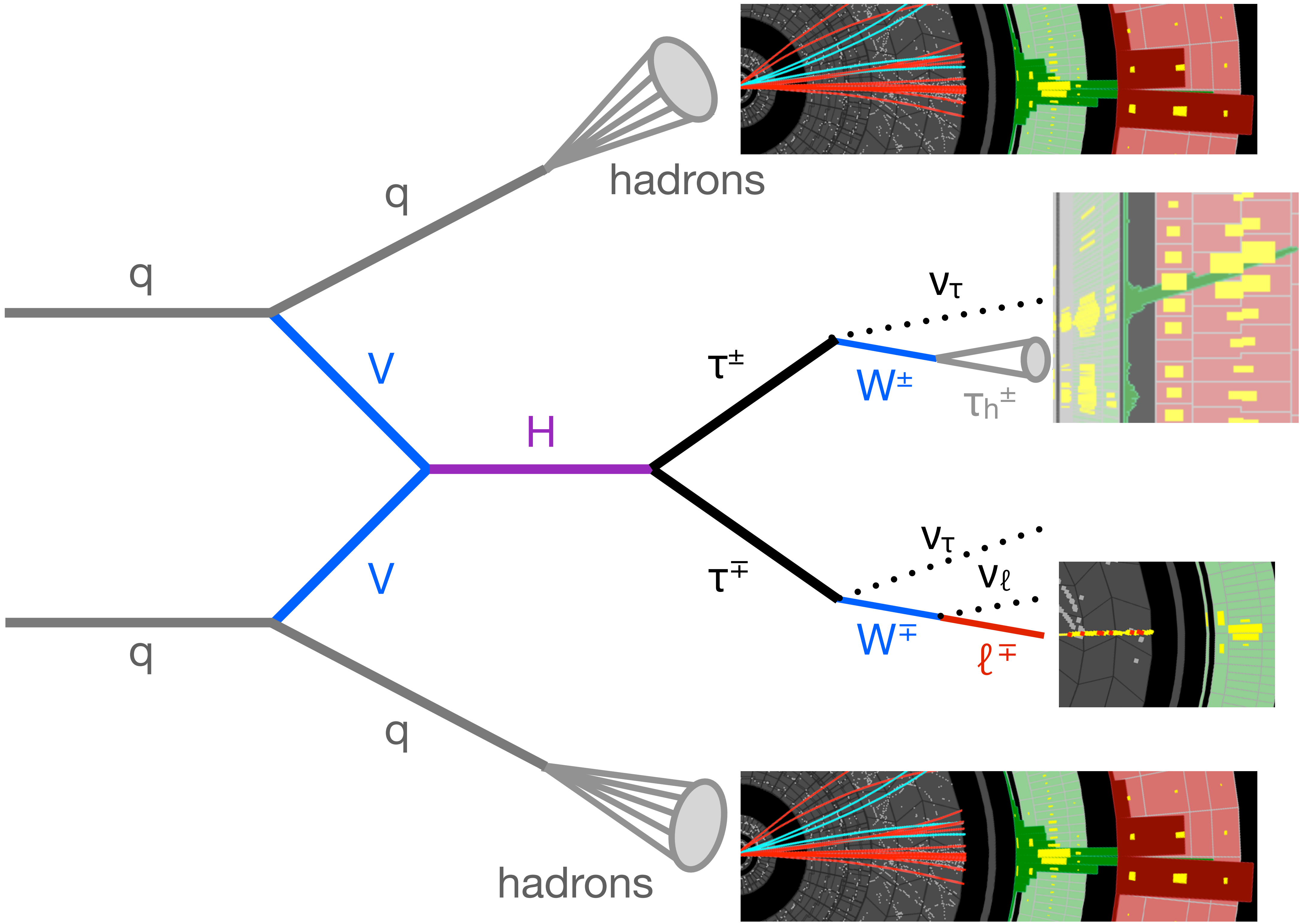
Great time to be doing Higgs physics with taus.

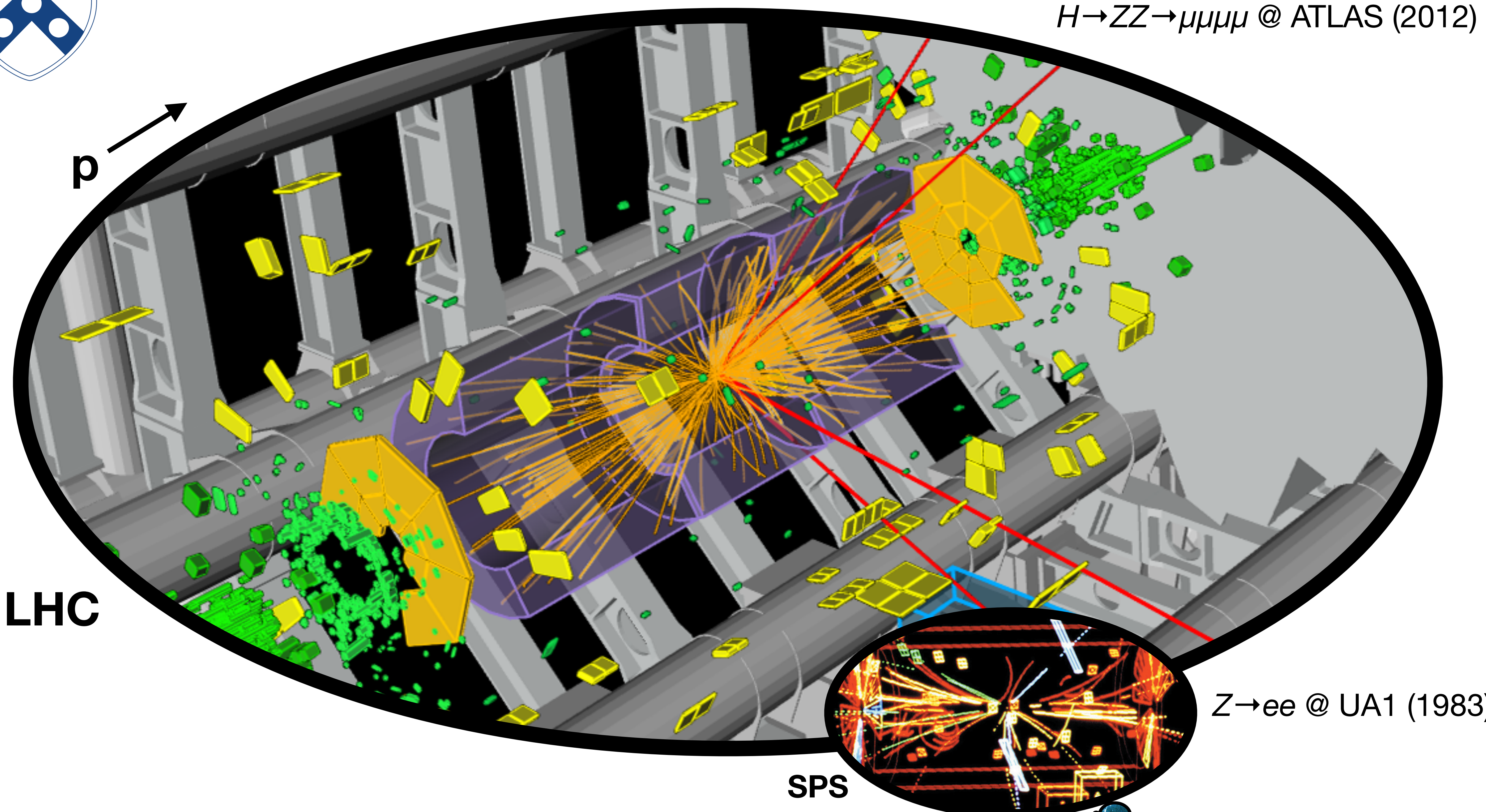
Thanks for listening!

ATLAS and the LHC

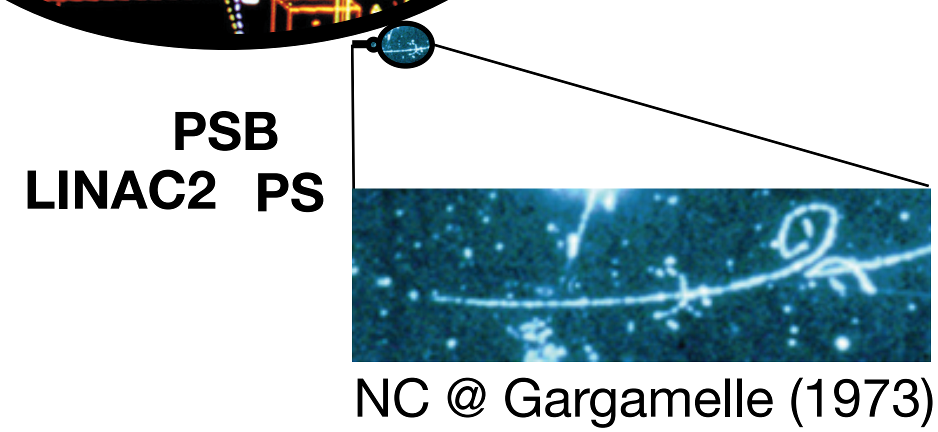


Picture of the analysis



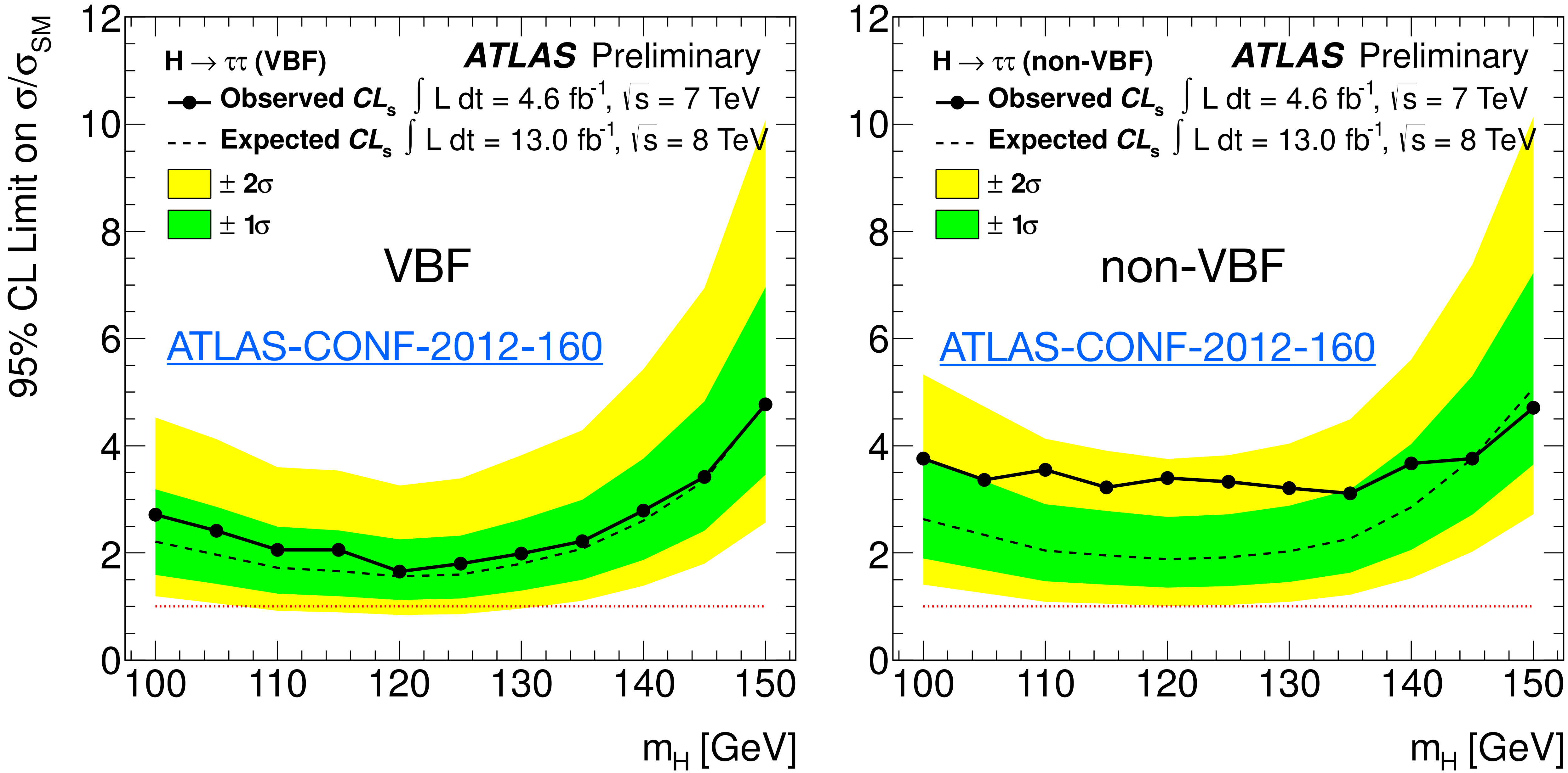


CERN accelerator complex



x-axis to scale (9.5 m/px)

VBF vs. non-VBF



Statistical analysis

Likelihood function: $\mathcal{L}(\mu,\theta) = \prod_{\text{category}} \left[\prod_{\text{bin } j} \text{Poisson}(N_j|\mu \cdot s_j + b_j) \prod_{\theta} \text{Gaussian}(t|\theta,1) \right]$

Test statistic: $q_\mu = -2\ln\left(\mathcal{L}(\mu,\hat{\theta}_\mu)/\mathcal{L}(\hat{\mu},\hat{\theta})\right)$ Binned variable: $m_{\tau\tau}$