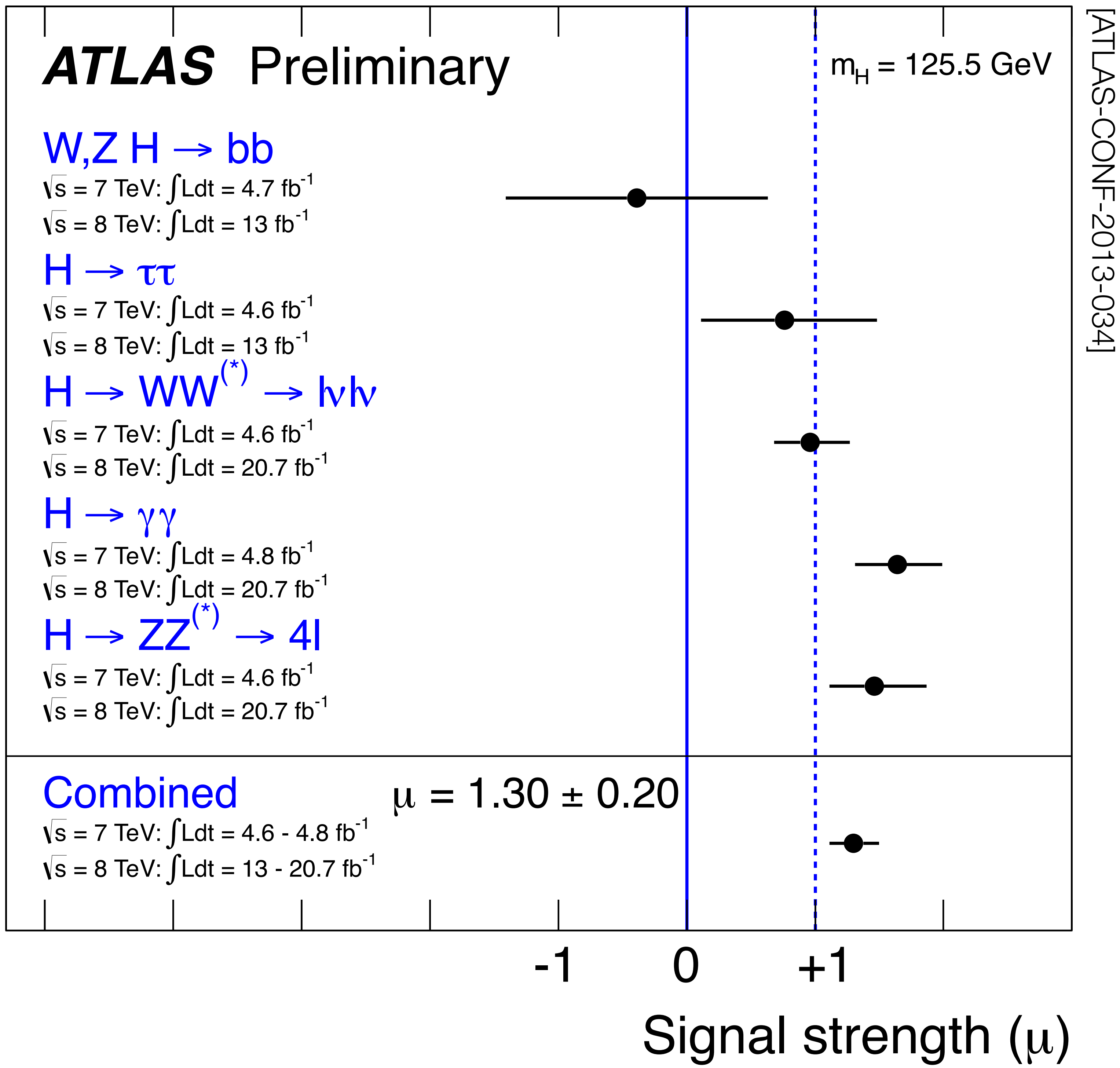
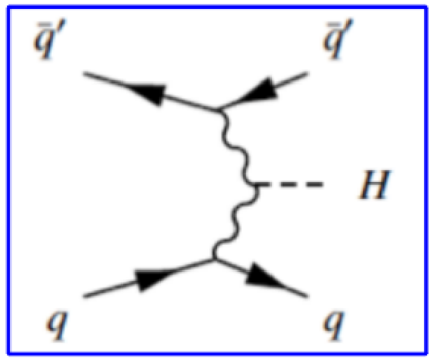
Signal Strength – Summer 2013



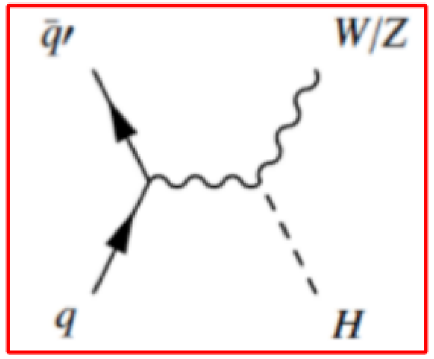
Search for Higgs ➛ bb …

Most sensitive production mode …?

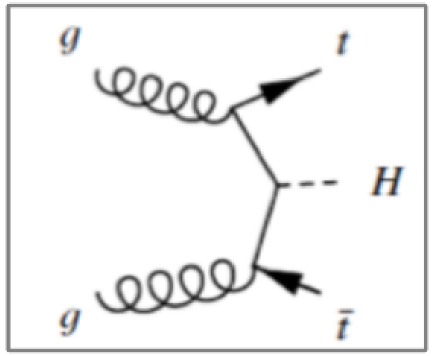
[Gluon fusion excluded]



qqbb final state
high bgk. rate



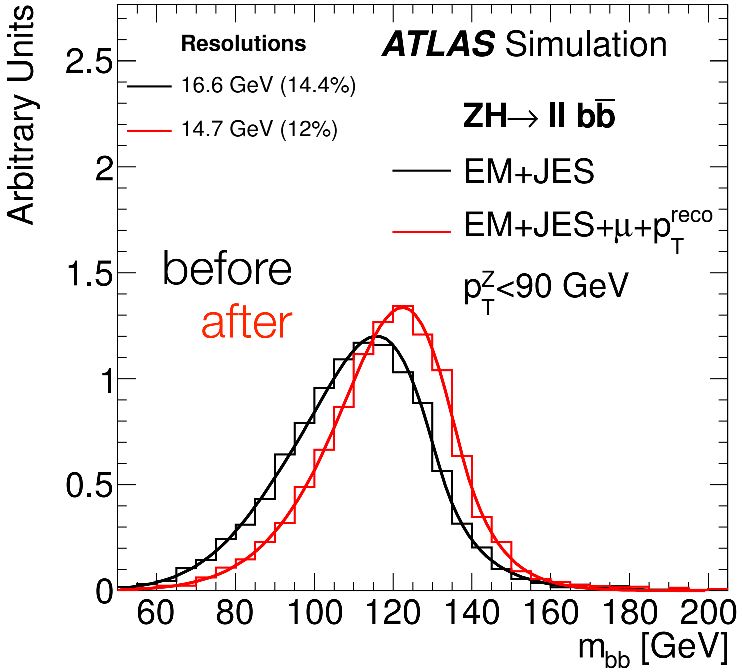
W/Z signature
most sensitive



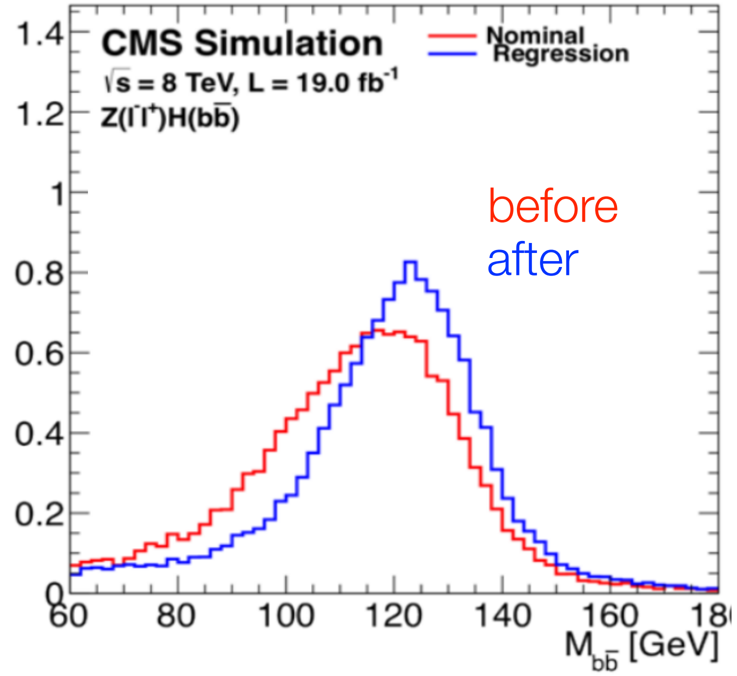
ttH production
dedicated search

Relevant observable: m_{bb} …

ATLAS:
Jet level corrections



CMS:
Multivariate regression

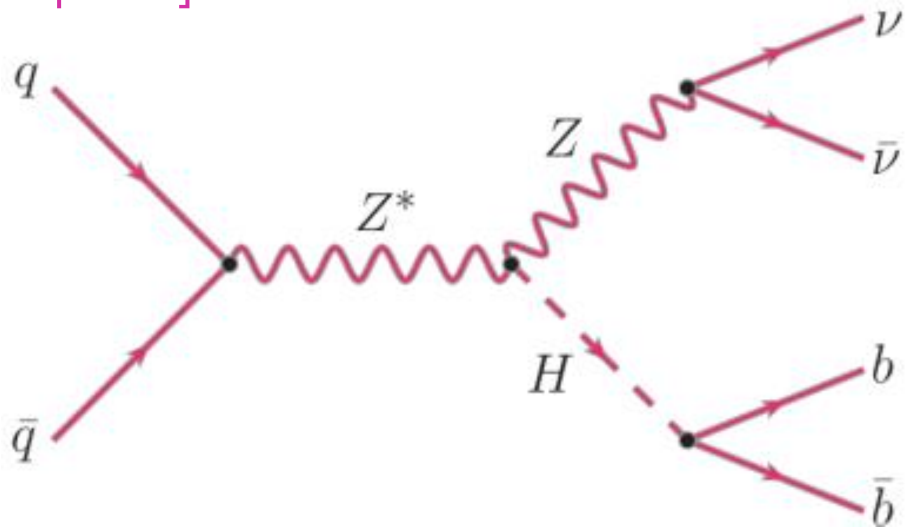


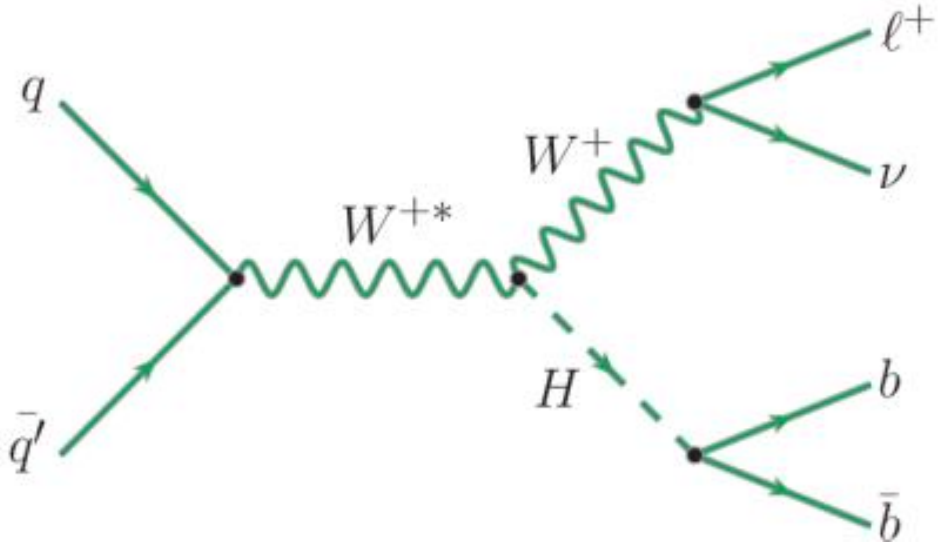
Refined energy scale and resolution for b-jets …

include muon momenta
account for jet properties
…

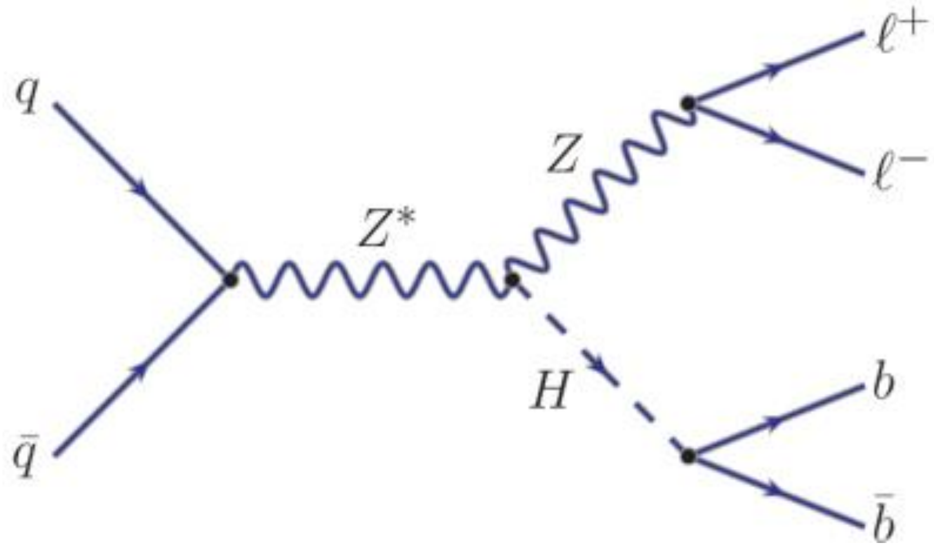
Higgs ➛ bb in Associated Production

$ZH \rightarrow \nu\bar{\nu}b\bar{b}$
[0-lepton]



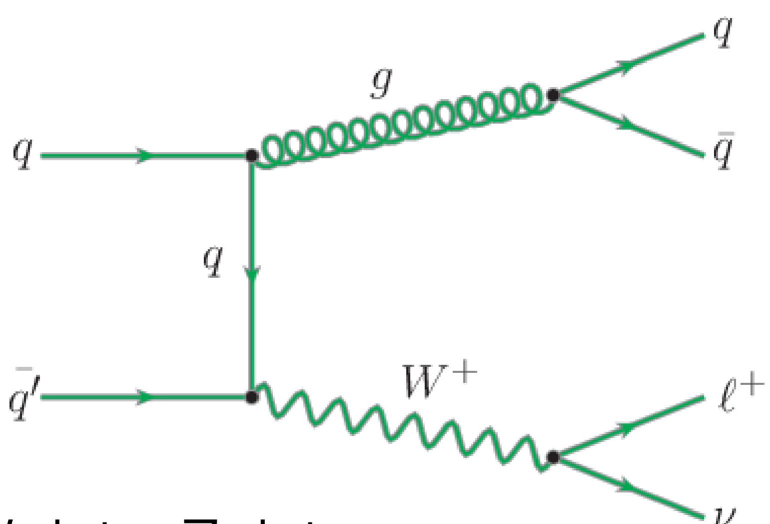


$WH \rightarrow l\nu b\bar{b}$
[1-lepton]

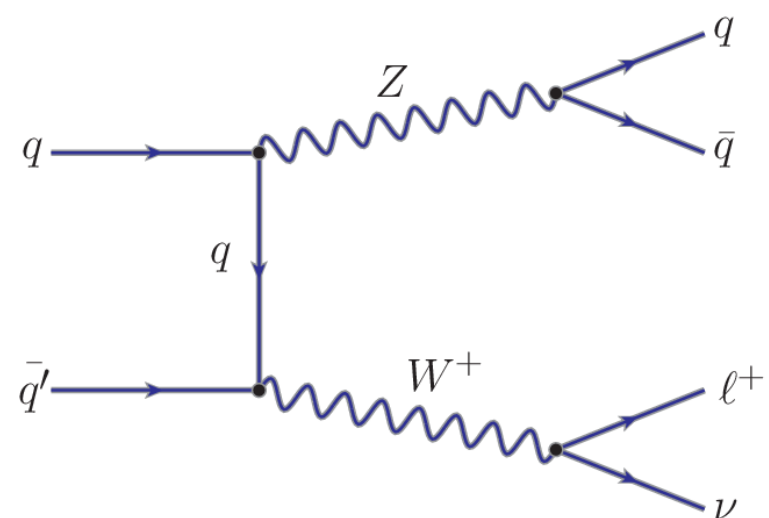


$ZH \rightarrow llb\bar{b}$
[2-lepton]

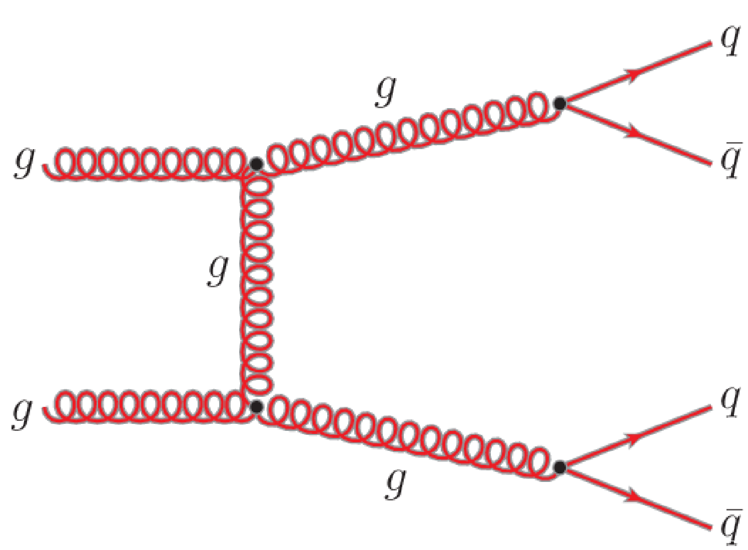
Main Backgrounds



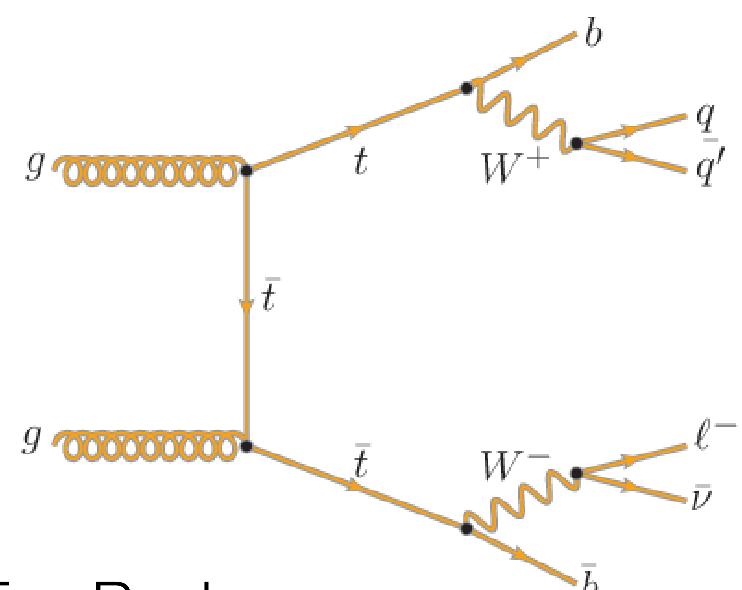
W+jets, Z+jets



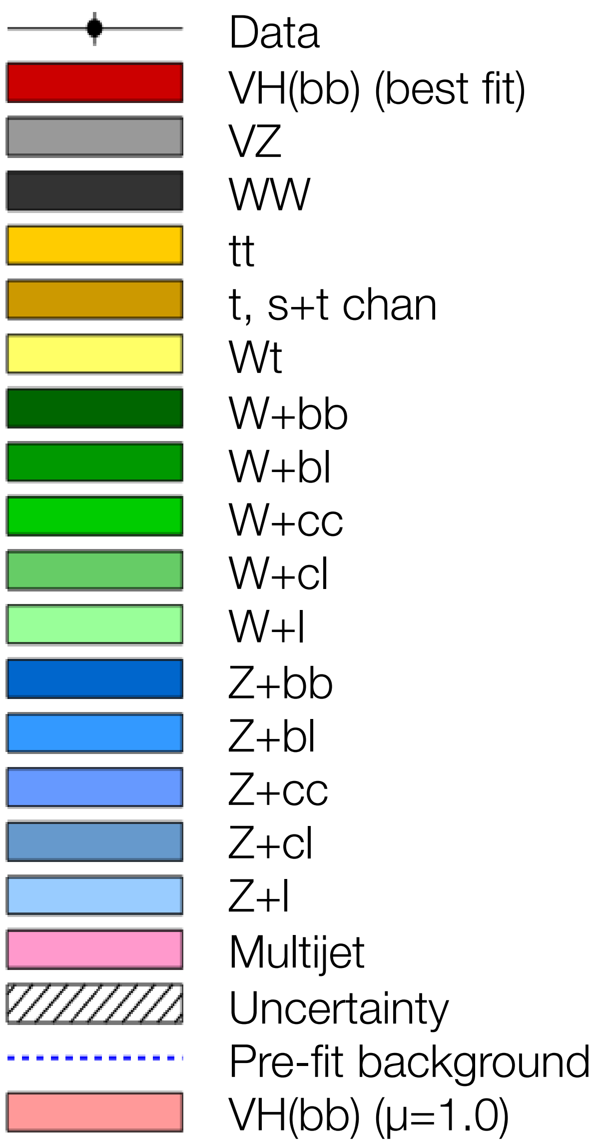
Di-boson Events



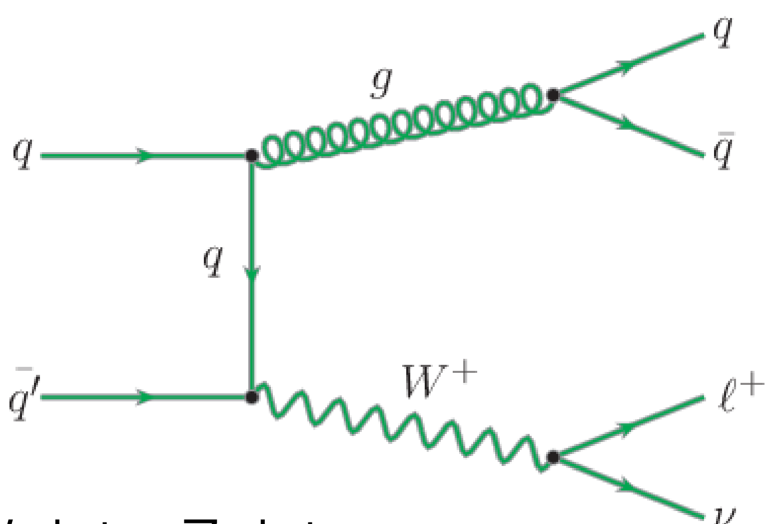
QCD Multijets



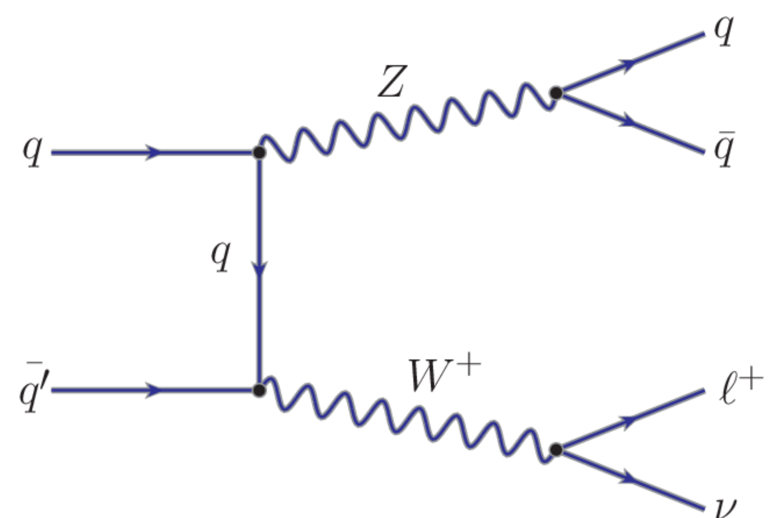
Top Backgr.



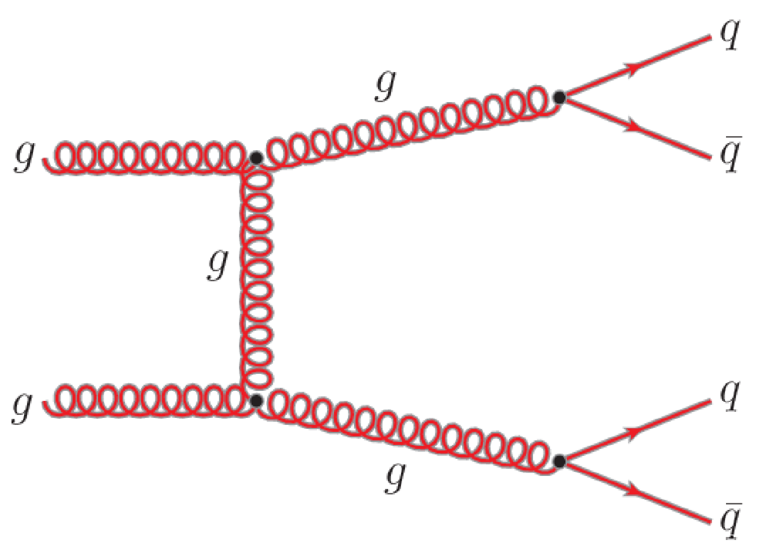
Main Backgrounds



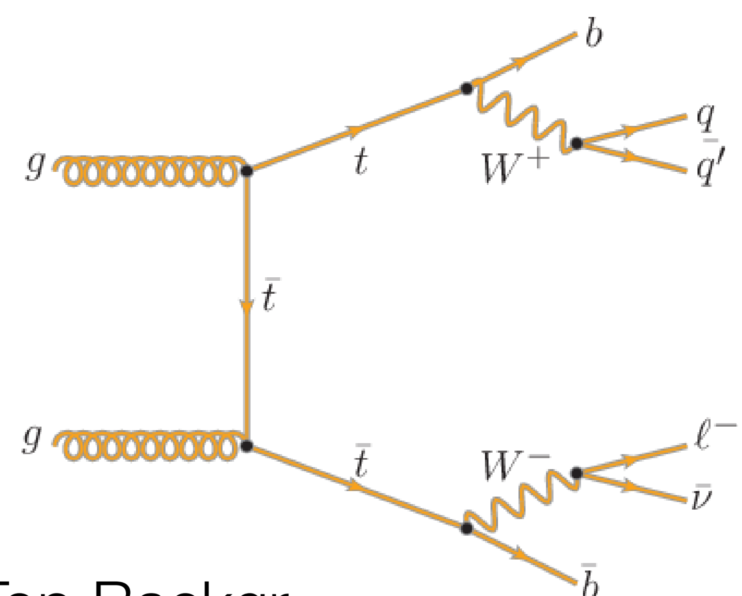
W+jets, Z+jets



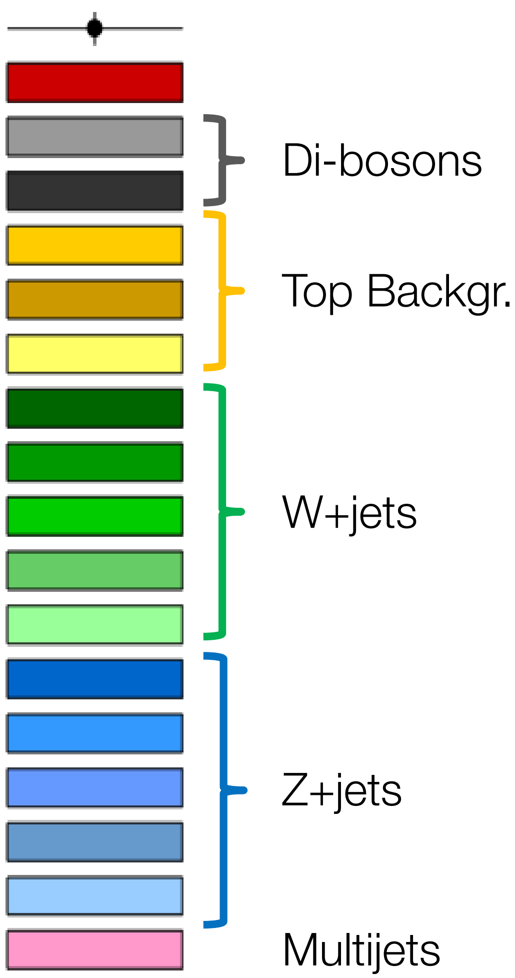
Di-boson Events



QCD Multijets



Top Backgr.



Event Selection – Basics

Common Selection:

at least 2 jets with pt > 45 GeV and pt > 20 GeV; |η| < 2.5 …

the 2 jets with highest momenta are b-tagged, i.e. leading b-jets …

electrons and muons passing loose, medium or tight ID criteria …
[depends on signal categorie]

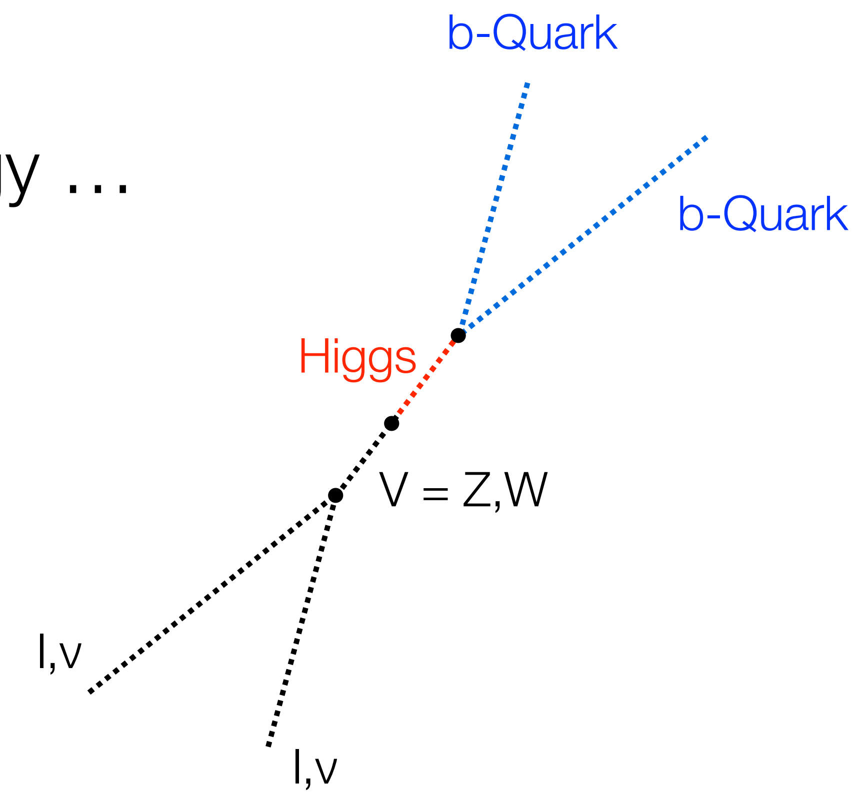
Object	0-lepton	1-lepton	2-lepton
Leptons	0 loose leptons	1 tight lepton + 0 loose leptons	1 medium lepton + 1 loose lepton
Jets	2 b-tags $p_T^{\mathrm{jet}_1} > 45$ GeV $p_T^{\mathrm{jet}_2} > 20$ GeV $+ \leq 1$ extra jets		
Missing E_T	$E_T^{\mathrm{miss}} > 120$ GeV $p_T^{\mathrm{miss}} > 30$ GeV $\Delta\phi(\boldsymbol{E}_T^{\mathrm{miss}}, \boldsymbol{p}_T^{\mathrm{miss}}) < \pi/2$ $\min[\Delta\phi(\boldsymbol{E}_T^{\mathrm{miss}}, \mathrm{jet})] > 1.5$ $\Delta\phi(\boldsymbol{E}_T^{\mathrm{miss}}, b\bar{b}) > 2.8$	$E_T^{\mathrm{miss}} > 25$ Gev	$E_T^{\mathrm{miss}} < 60$ GeV
Vector Boson	-	$m_T^W < 120$ GeV	$83 < m_{\ell\ell} < 99$ GeV

Detailed
selection criteria for
the three signal channels …

… 0-lepton
… 1-lepton
… 2-lepton

Event Selection – Topological Requirements

Background rejection and
sensitivity enhancement using event topology …



Determine transverse momentum p_T of the produced vector boson using …

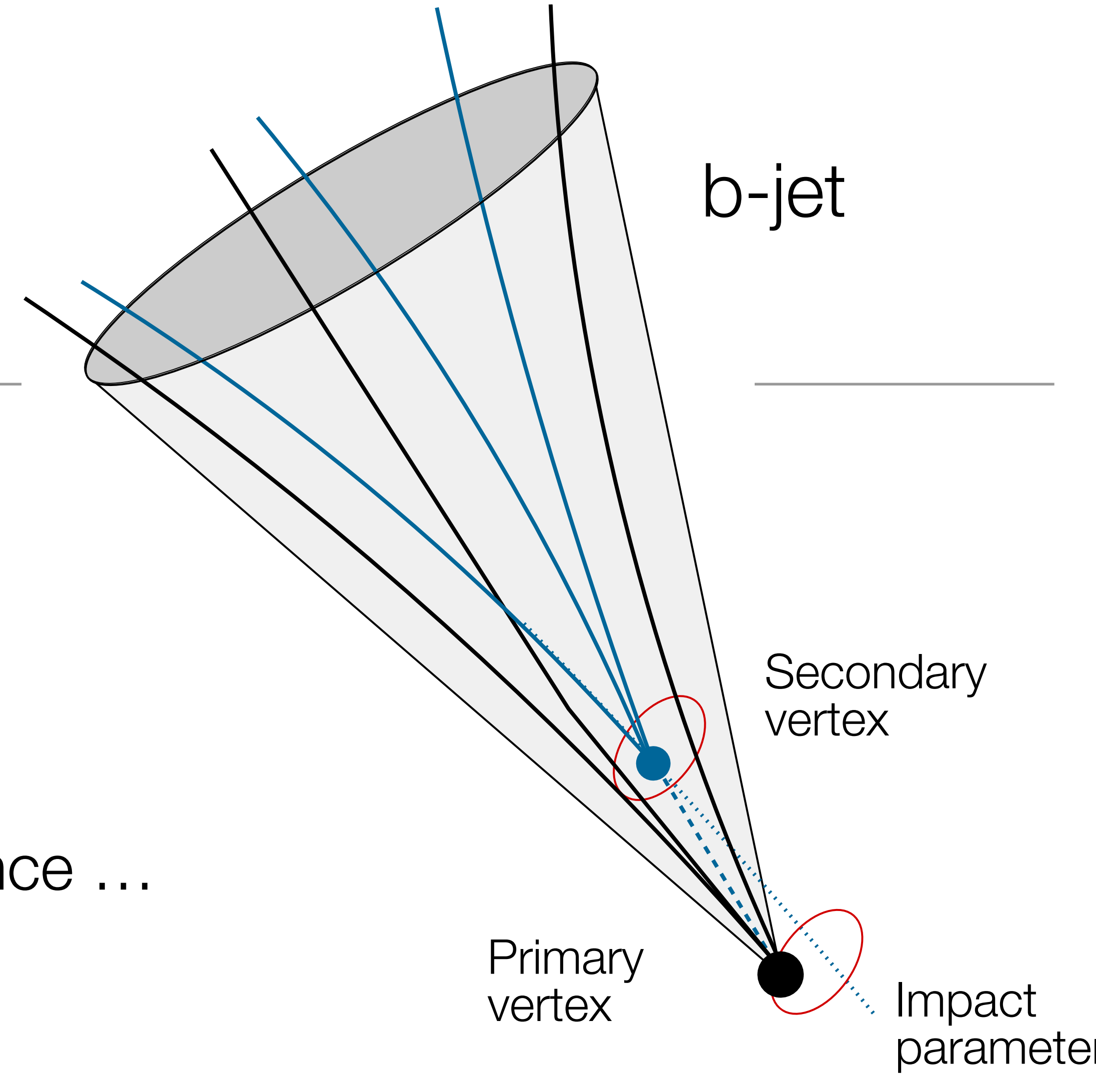
$E_{T,miss}$	0-lepton channel
$E_{T,miss} + p_{T,lep}$	1-lepton channel
$P_{T,Z}$	2-lepton channel

Expectation:
The higher p_T of the Vector Boson the lower the opening angle between Higgs decay products (b-jets) …

	p_T^V [GeV]	0-90	90-120	120-160	160-200	>200
All Channels	$\Delta R(b, \bar{b})$	0.7-3.4	0.7-3.0	0.7-2.3	0.7-1.8	<1.4

Increasing S/B ⟶

B-Quark Tagging in ATLAS



Impact parameter (IP) based …

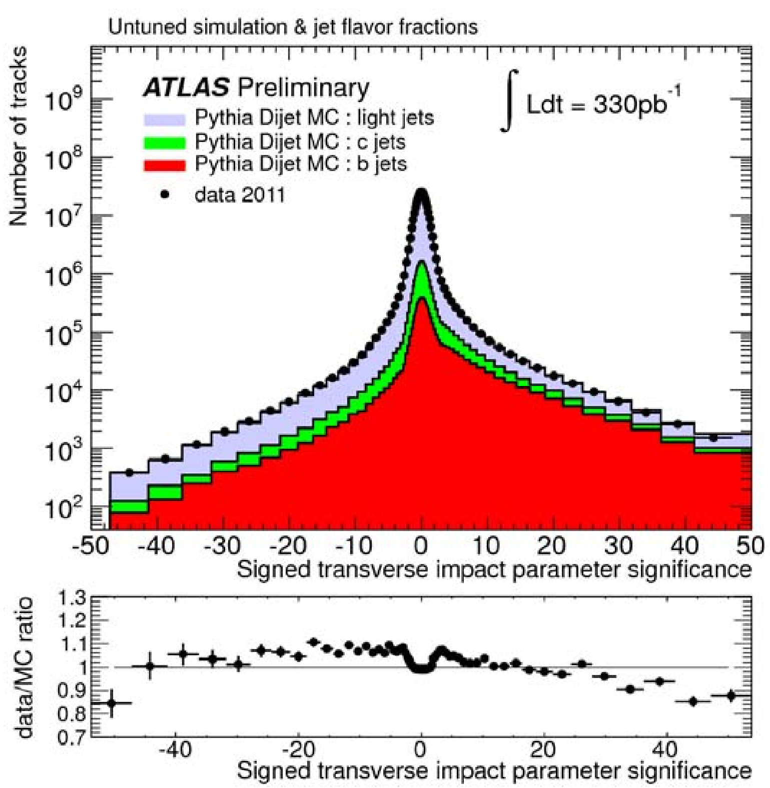
IP3D: Log-likelihood based algorithm …

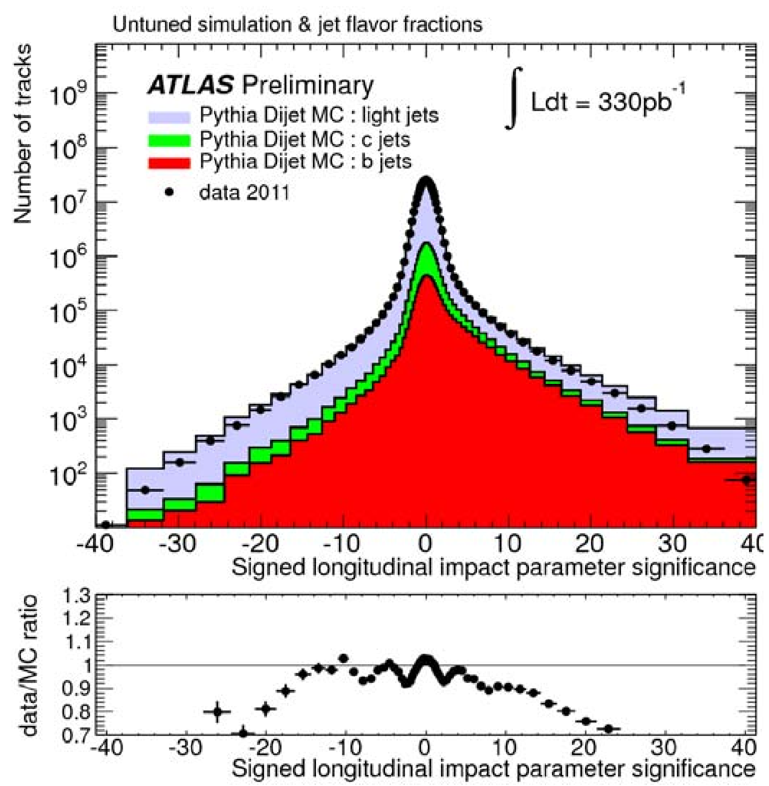
Utilizes PDFs of …

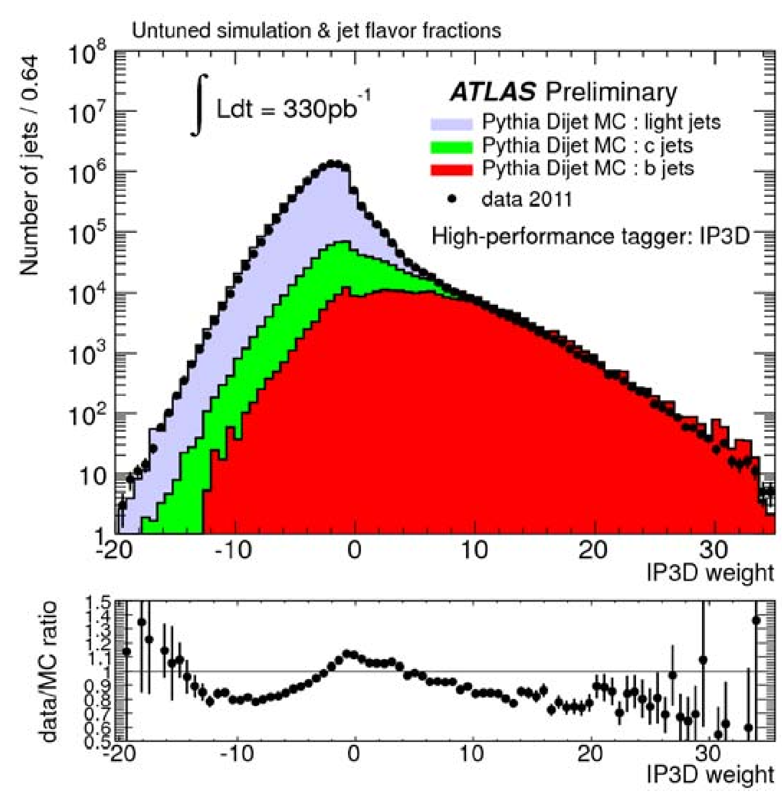
… transverse and longitudinal IP significance …

➛ track weight $w_{track} = P_{b\text{-}jet}/P_{light}$

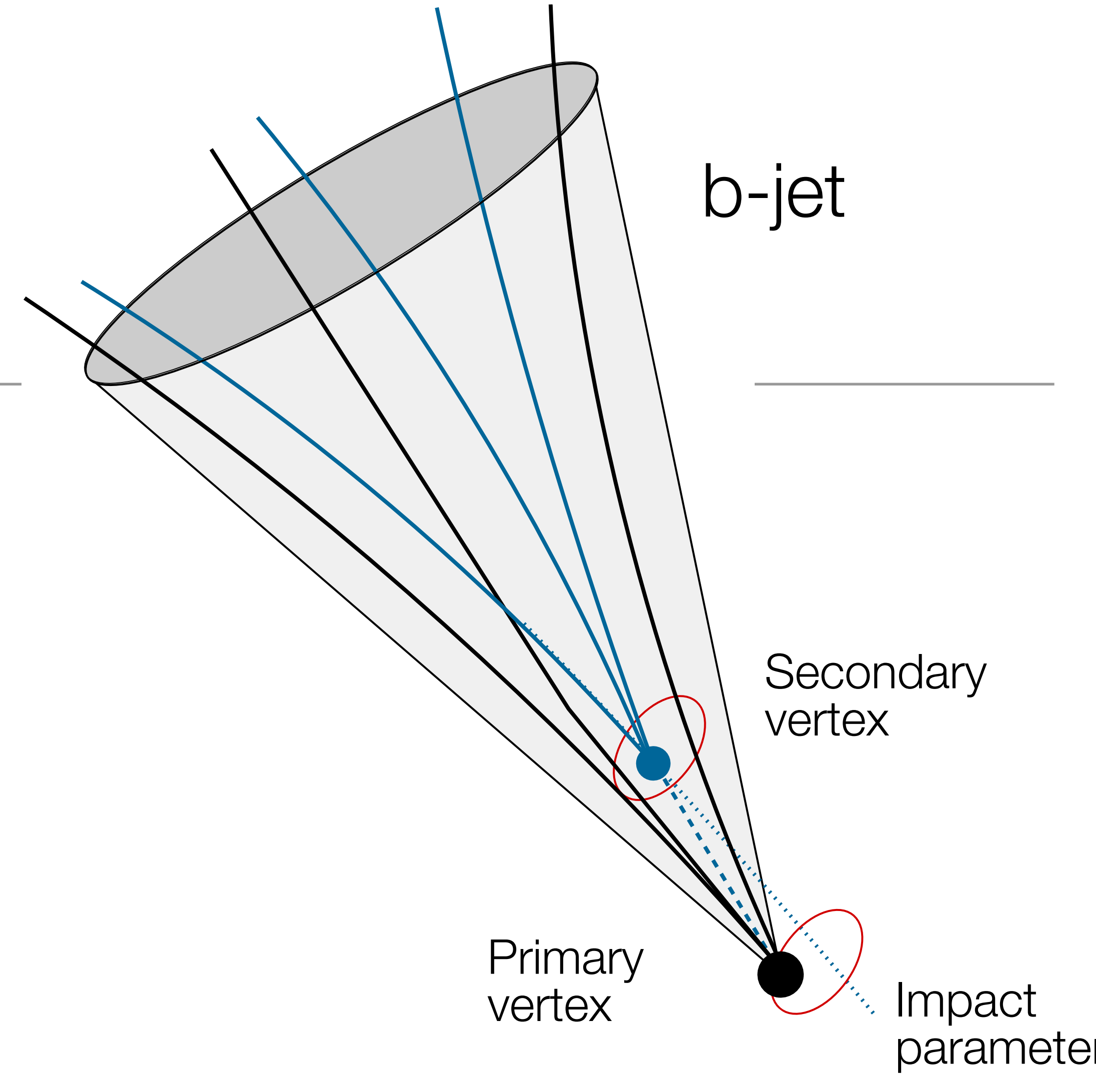
➛ jet weight $w_{tjet} = \sum_{track} \log(w_{track})$







B-Quark Tagging in ATLAS



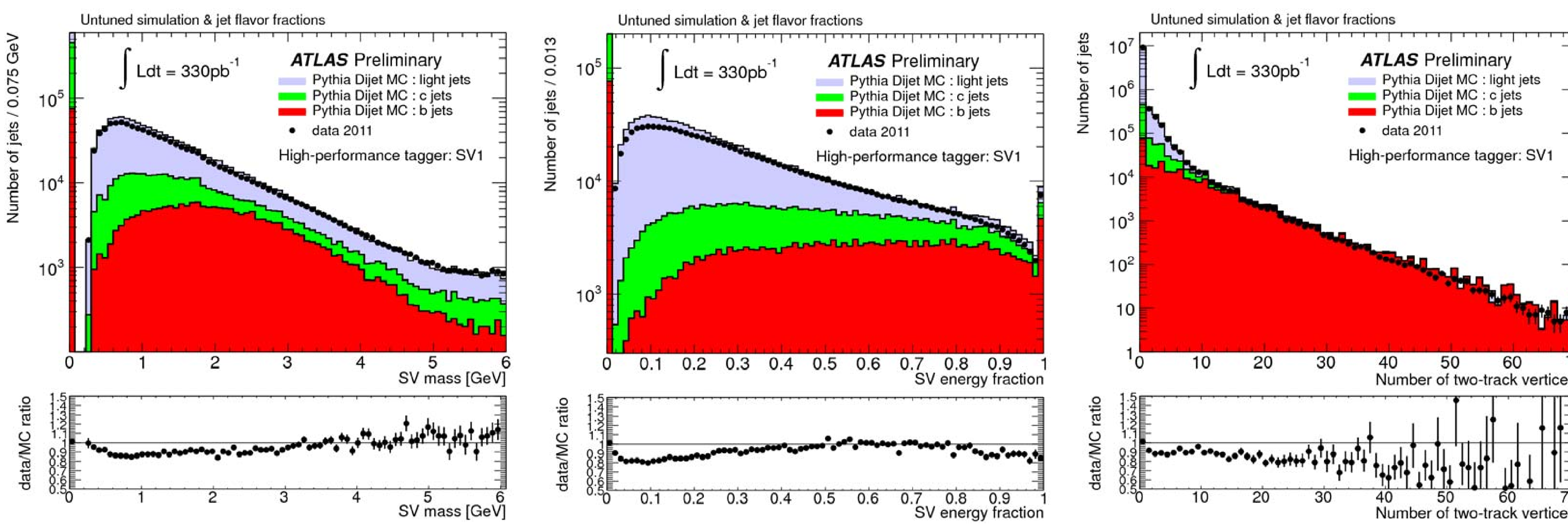
Secondary vertex (SV) based …

SV1: Log-likelihood based algorithm …

Utilizes SV reconstructing …

… 2D and 1D likelihood ratios …

- ➛ 2D: SV mass, $\sum(P_{T,SV})/\sum(P_{T,jet})$ …
- ➛ 1D: number of 2-track vertices …
- ➛ 1D: ΔR(jet, PV-to-SV direction) …



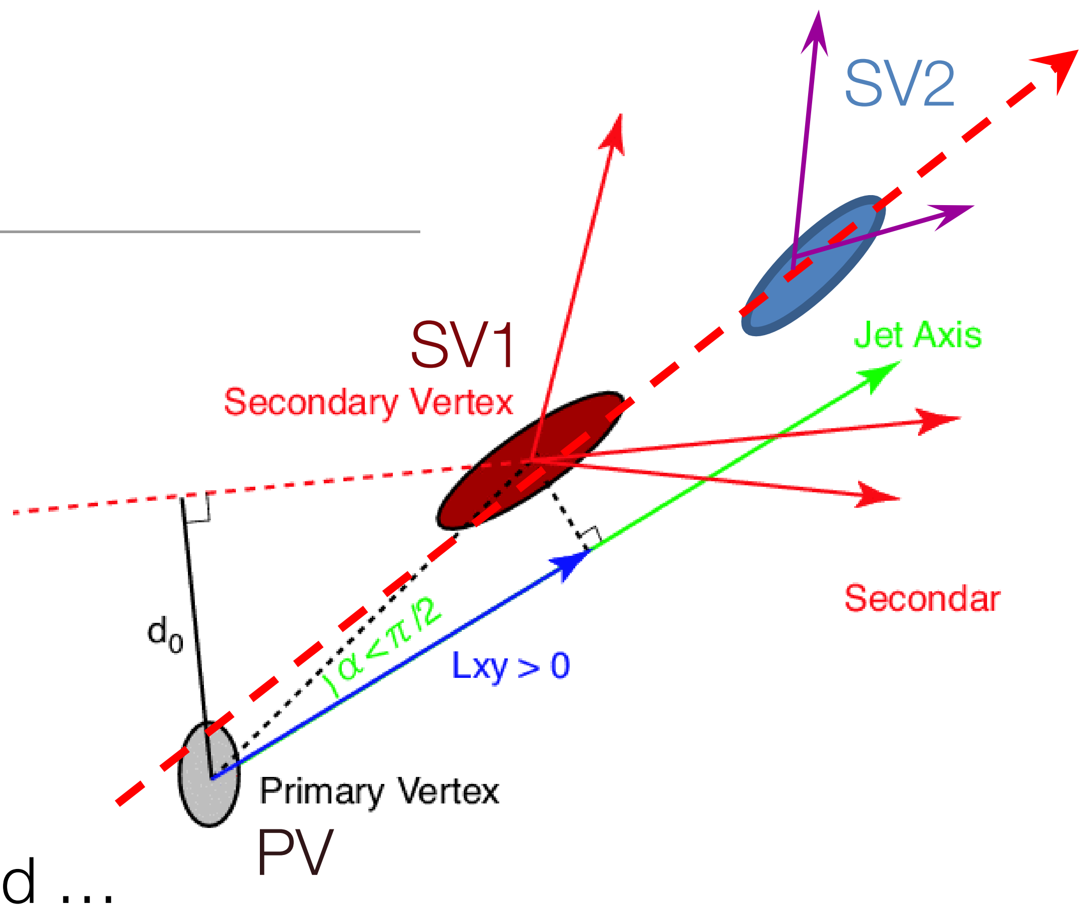
B-Quark Tagging in ATLAS

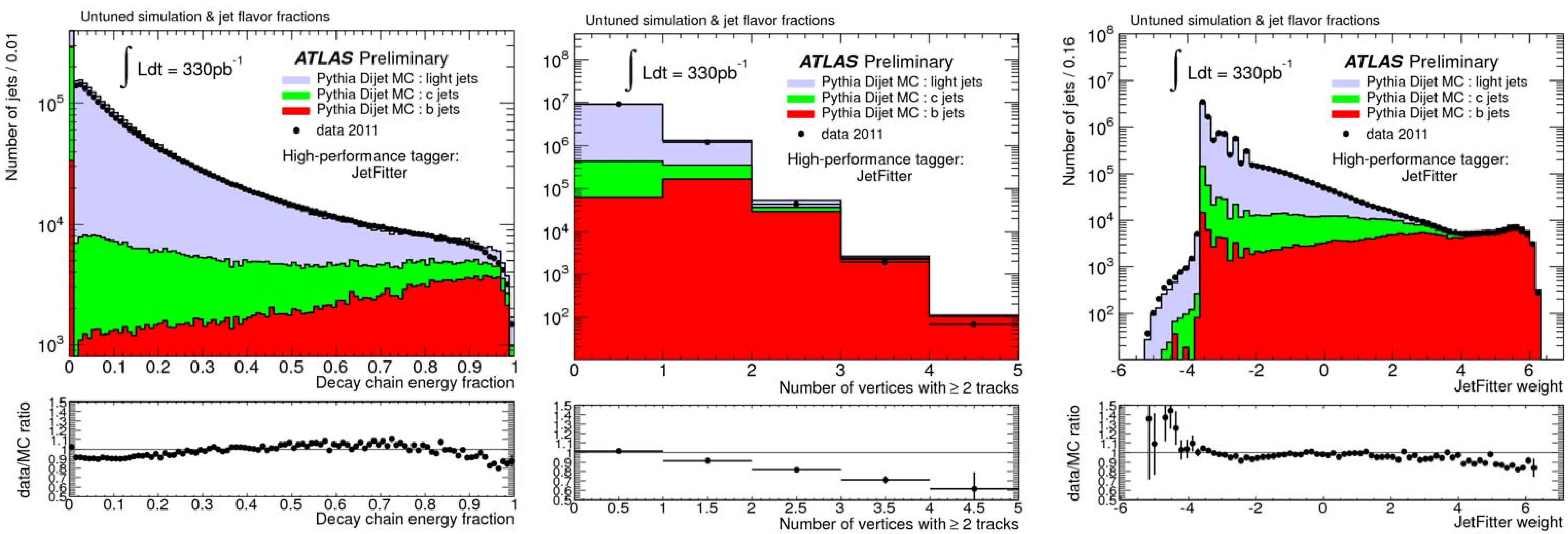
Secondary vertex (SV) based …

JetFitter: Special algorithm …

Exploits topology of weak B/D-hadron decay chain inside jets …

- ➛ reconstruct PV-SV1-SV2 line …
- ➛ use likelihood similar to SV1 method …



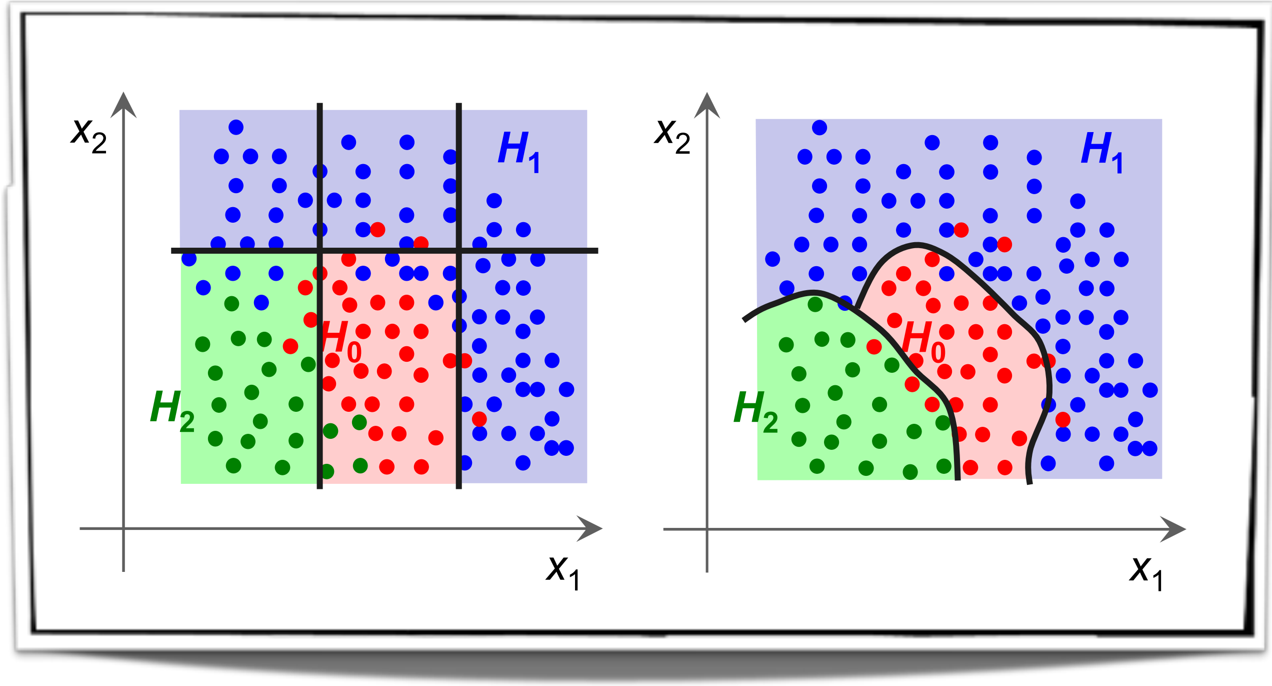


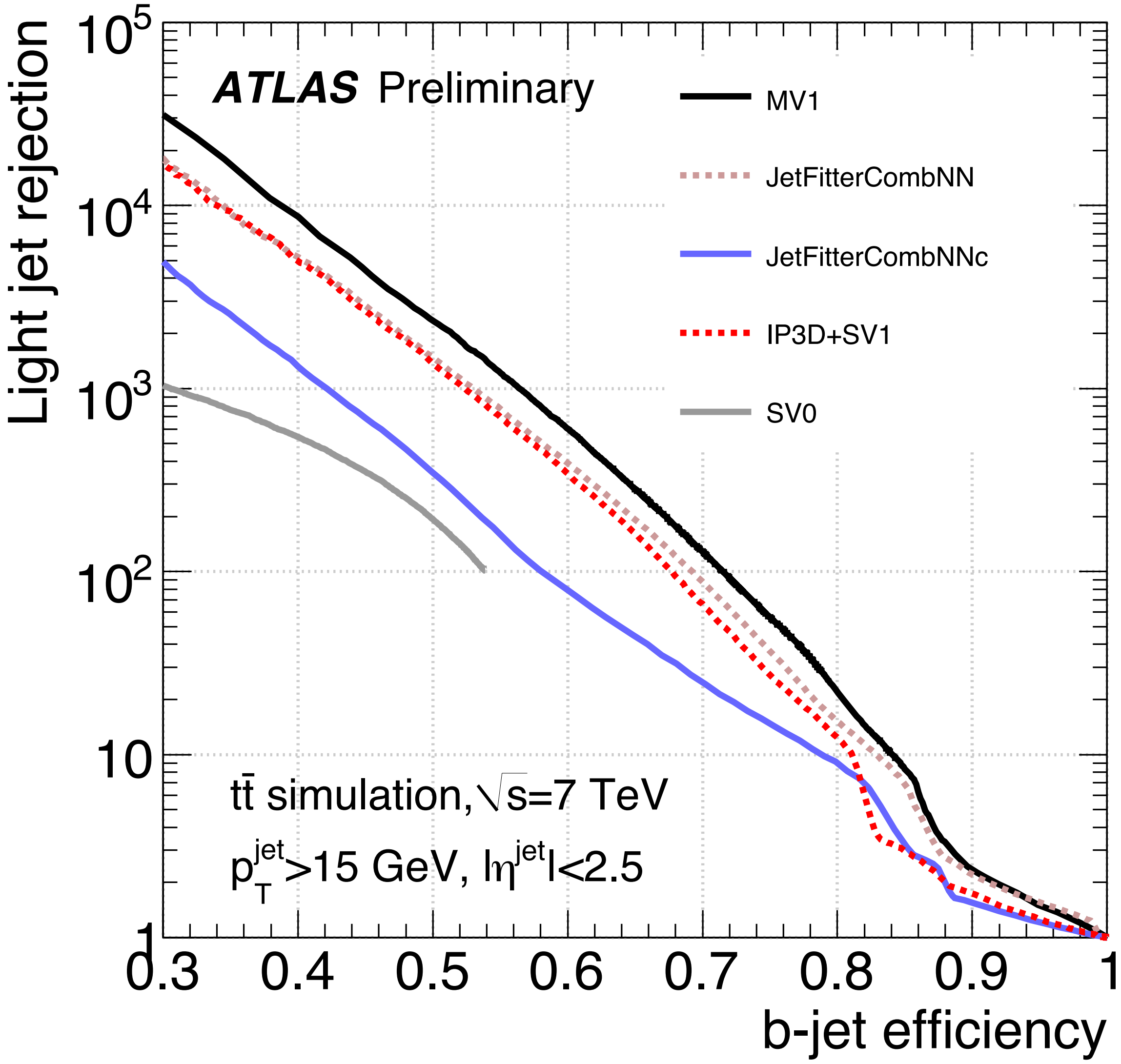
B-Quark Tagging in ATLAS

Advanced
combined algorithm …

MV1: Neural net based …

Combines output weights from IP3D, SV1 and JetFitter in a multivariate method …





MVA: Multivariate Data Analysis

Automatized multi-dimensional classification of different event categories; select optimal classifier [e.g. NN] …

Background Determination

Categories	Signal region: 2 jets 2 tags	Signal region: 3 jets 2 tags	Control region: 2 jets 1 tag	Control region: 3 jets 1 tag	Control region: e-μ 2 tags
0-lepton (x 3 $p_{T,V}$ bins)	Shape	Shape	Norm	Norm	-
1-lepton (x 5 $p_{T,V}$ bins)	Shape	Shape	Norm	Norm	-
2-lepton (x 5 $p_{T,V}$ bins)	Shape	Shape	Norm	Norm	Norm

Total:
26 SR
31 CR

General approach:

Global log-likelihood fit of data in 26 signal and 31 control regions …
Exploit different background and signal compositions in different regions …

- ➛ yields background normalization & shape systematics …
- ➛ allows to account for signal contamination in CRs …
- ➛ includes systematic uncertainties via nuisance parameters …

Higgs ➛ bb
ATLAS

Background Determination

	Signal region		Control region		
	2 jets 2 tags	3 jets 2 tags	2 jets 1 tag	3 jets 1 tag	e-μ 2 tags
0-lepton (x 3 $p_{T,V}$ bins)	Shape	Shape	Norm	Norm	-
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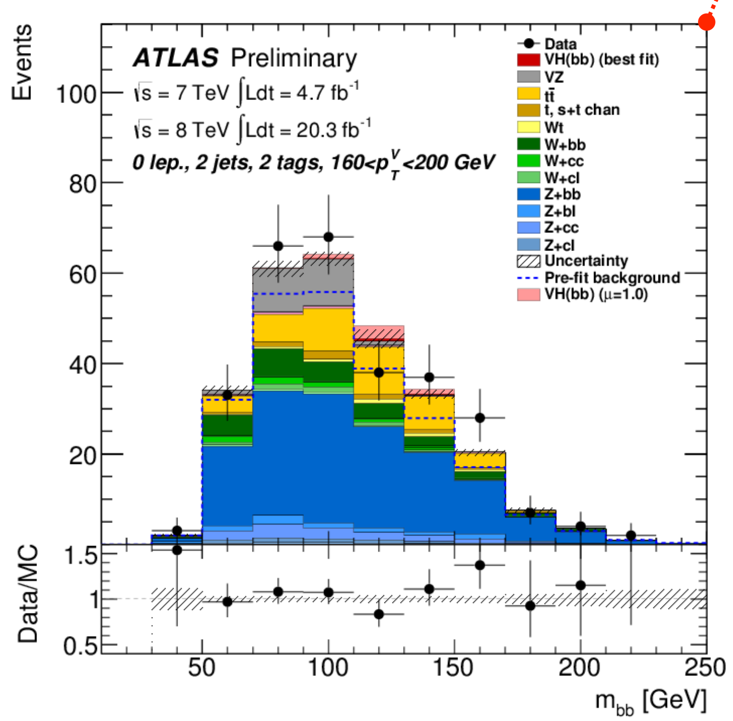
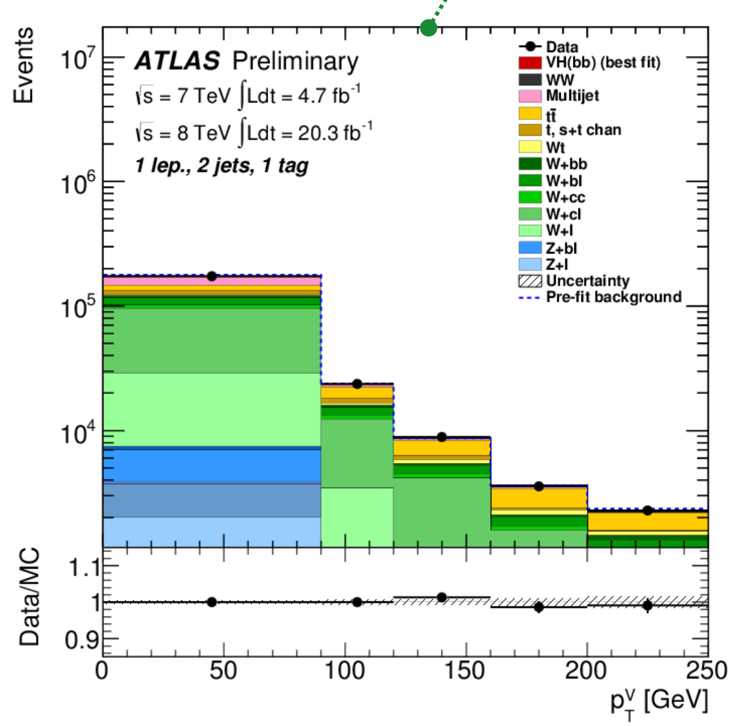
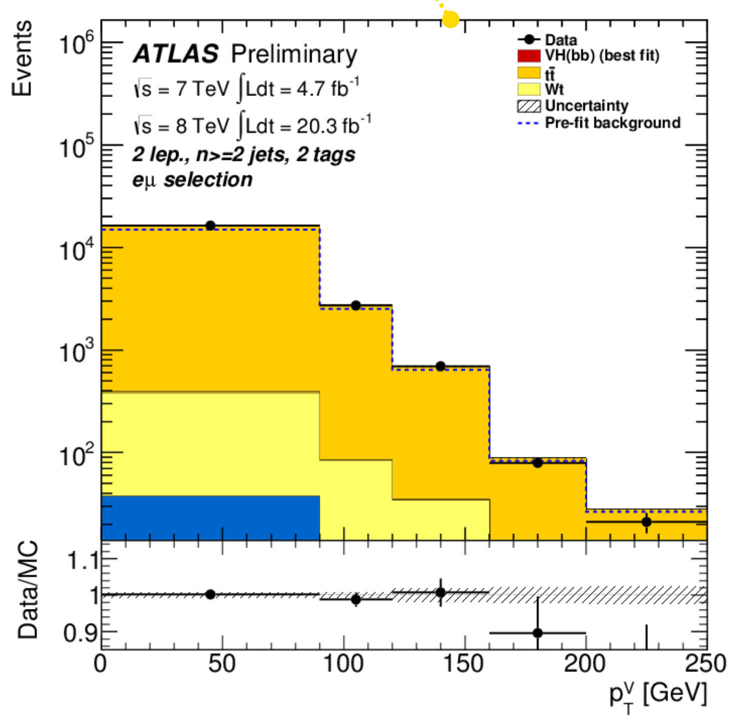
Total:
26 SR
31 CR







Background Determination

	Signal region		Control region		
	2 jets 2 tags	3 jets 2 tags	2 jets 1 tag	3 jets 1 tag	e-μ 2 tags
0-lepton (x 3 $p_{T,V}$ bins)	Shape	Shape	Norm	Norm	-
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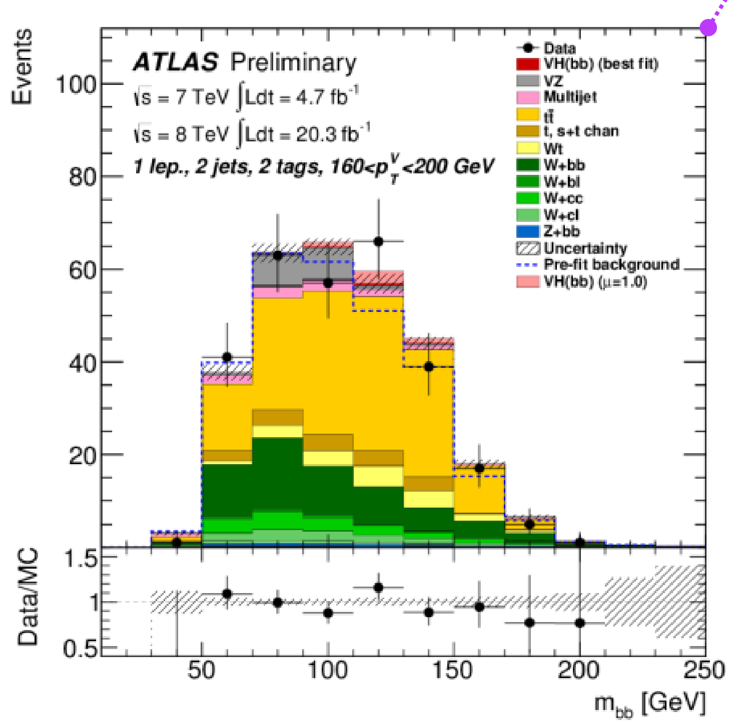
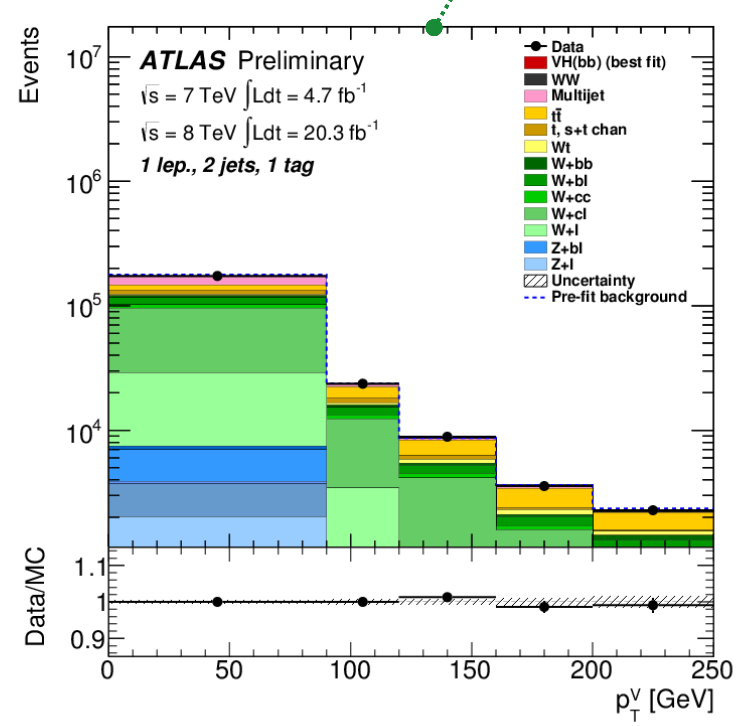
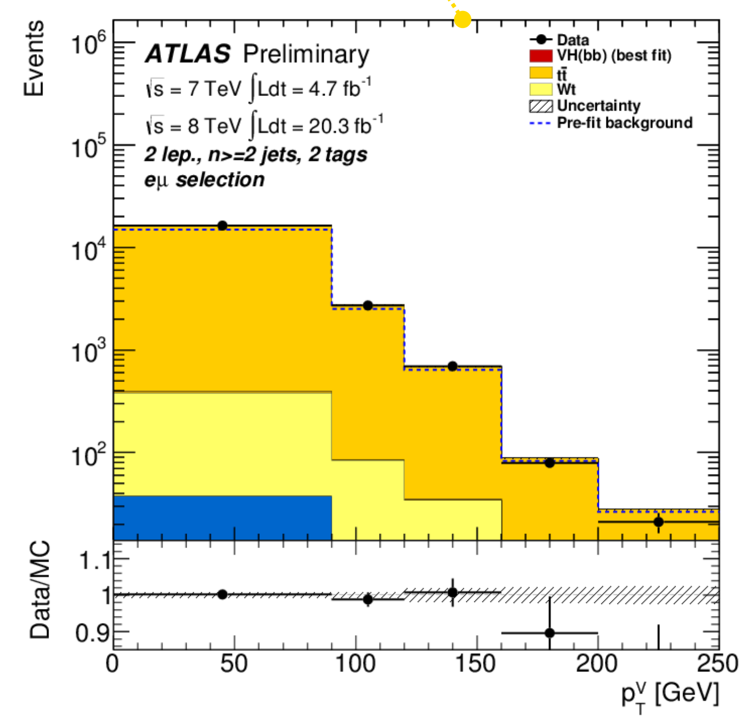
Total:
26 SR
31 CR







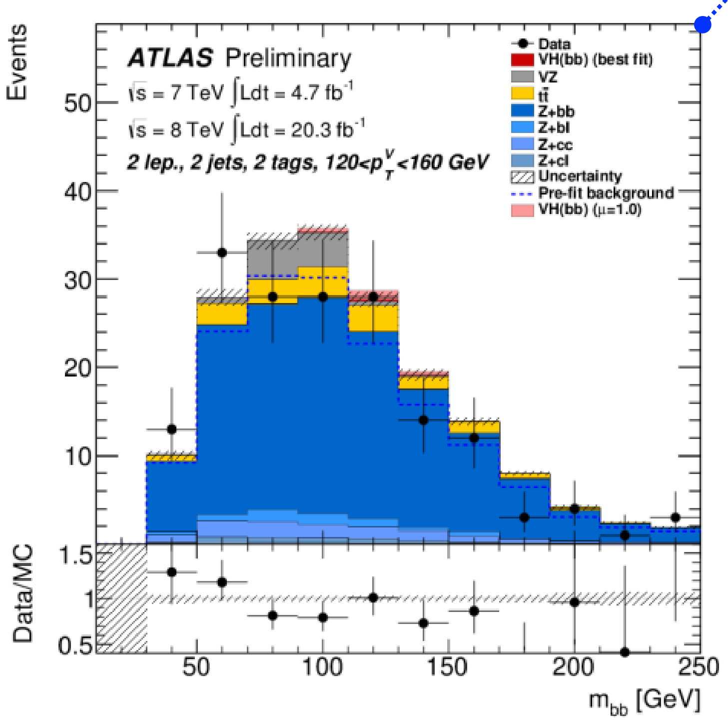
Background Determination

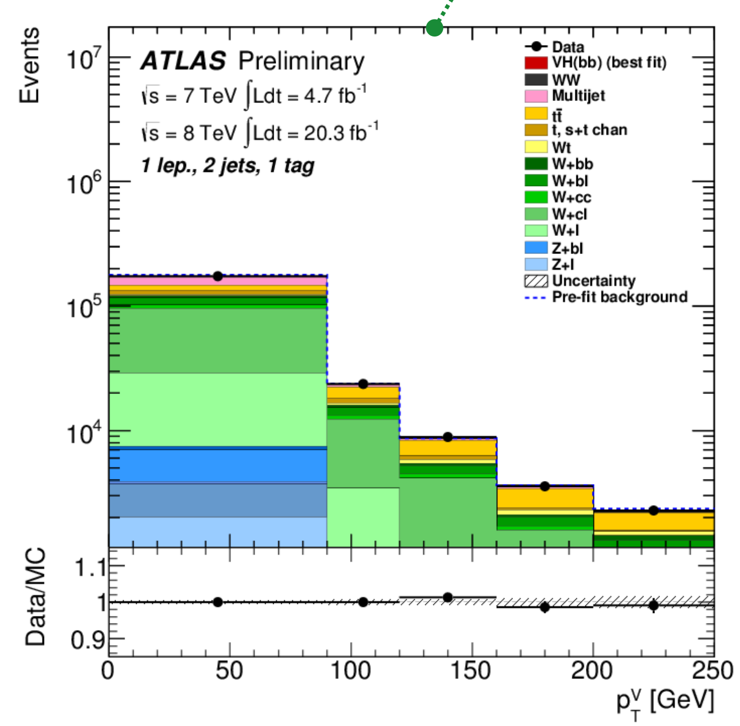
	Signal region		Control region		
	2 jets 2 tags	3 jets 2 tags	2 jets 1 tag	3 jets 1 tag	e-μ 2 tags
0-lepton (x 3 $p_{T,V}$ bins)	Shape	Shape	Norm	Norm	-
1-lepton (x 5 $p_{T,V}$ bins)	Shape	Shape	Norm	Norm	-
2-lepton (x 5 $p_{T,V}$ bins)	Shape	Shape	Norm	Norm	Norm

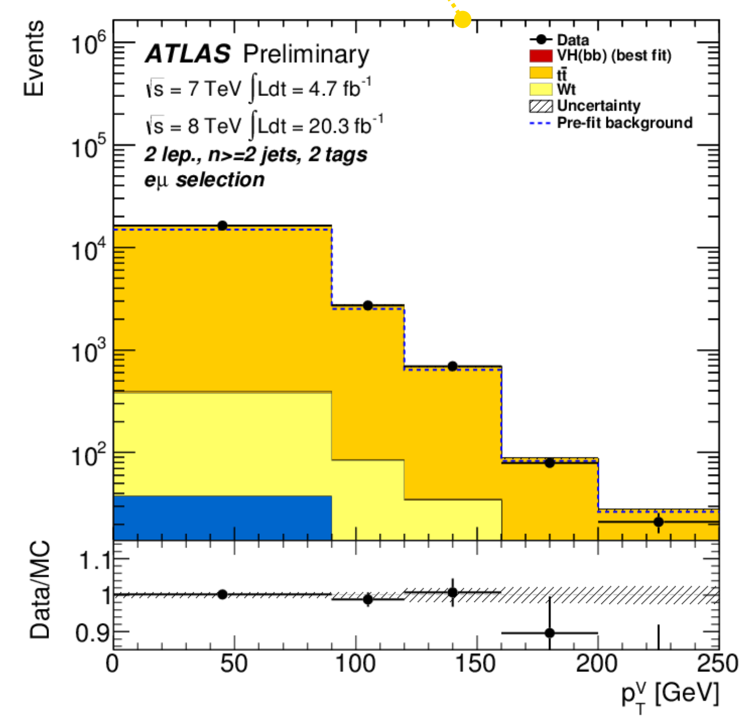
Total:

26 SR

31 CR







Higgs ➛ bb Mass Peak

Background subtracted mass peak …

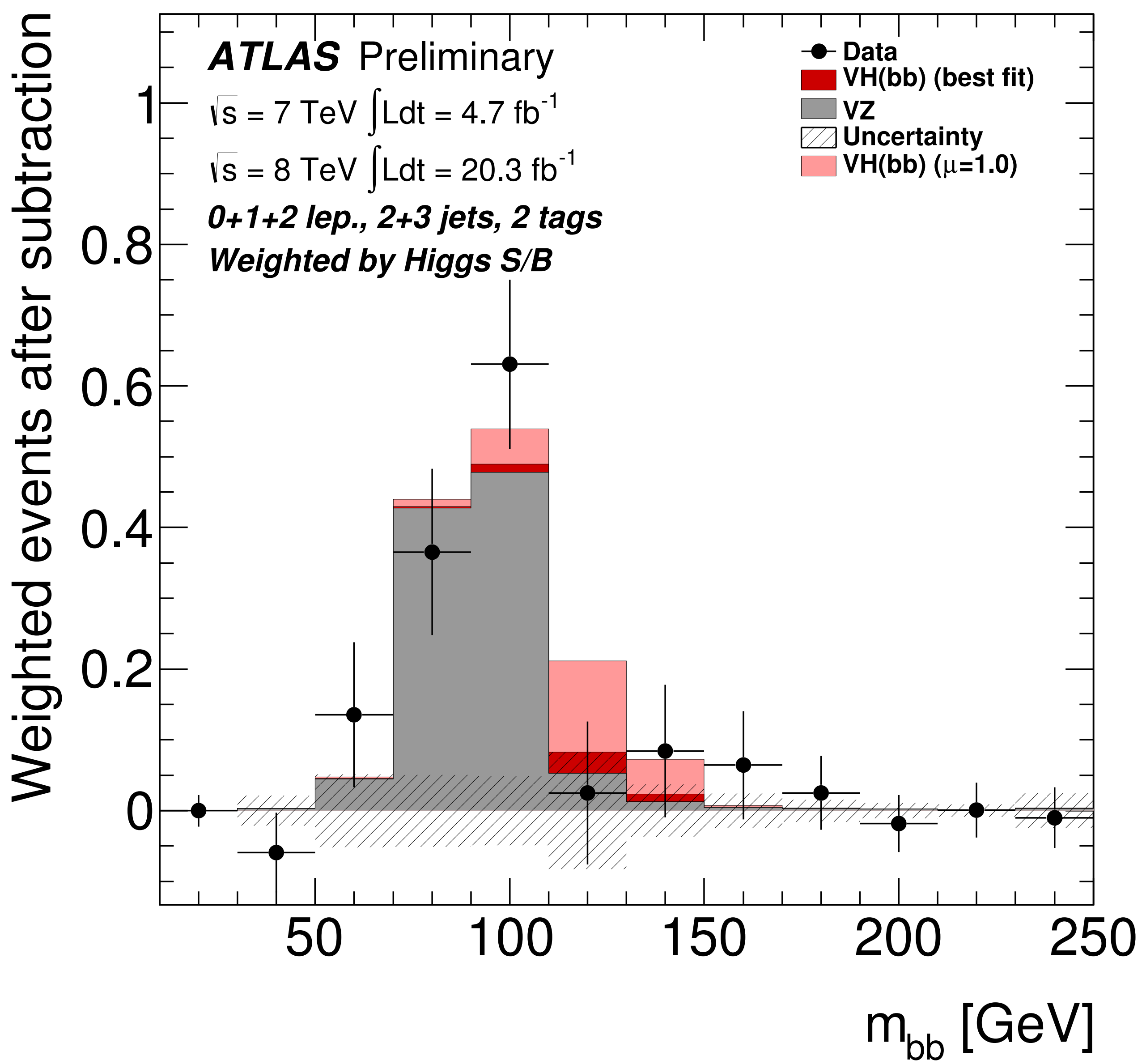
with regions weighted by S/B

Gray: Di-Boson signal

[WZ, ZZ, Z ➛ bb]

Red: Higgs signal

[Dark: fitted; light: SM]



Higgs ➛ bb Signal Strength

$\sqrt{s}$ = 7 TeV:

Substantial deficit …

$\mu = -2.1 \pm 1.4$

$\sqrt{s}$ = 8 TeV:

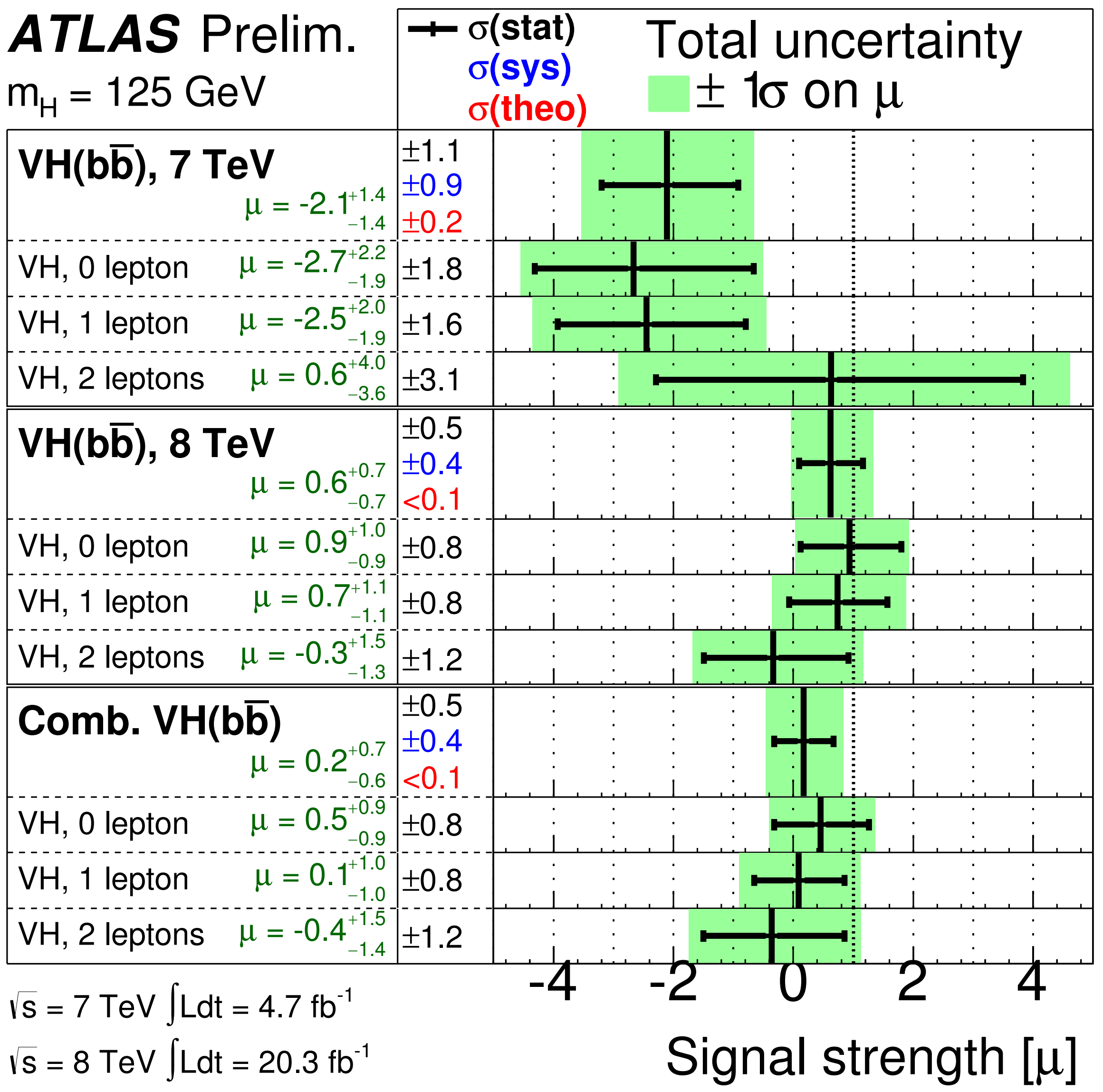
About 1σ excess …

$\mu = 0.6 \pm 0.7$

Combined:

Consistent with μ = 0 or 1…

$\mu = 0.2^{+0.7}_{-0.6}$



Validation of Fit Model

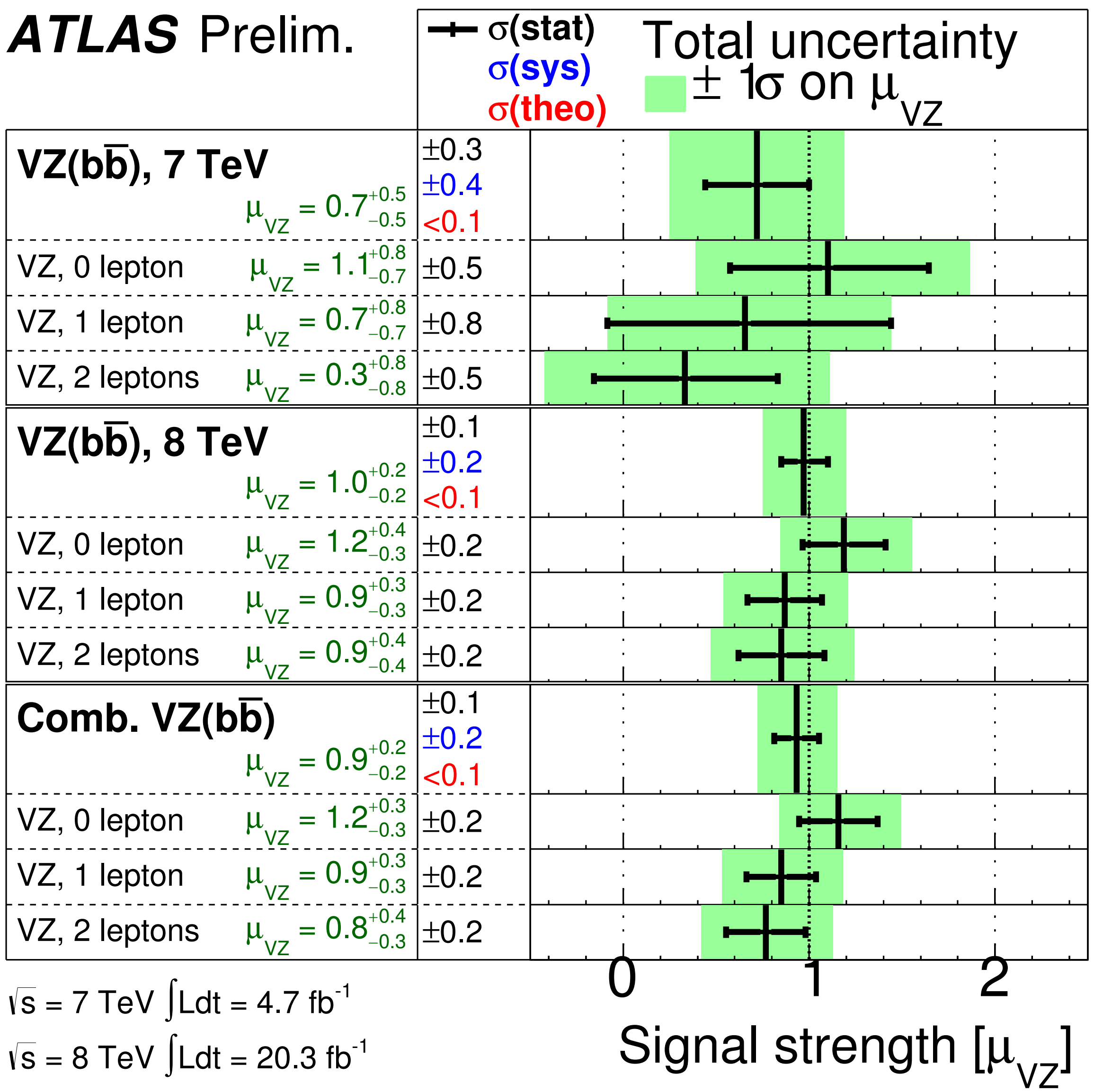
Di-boson fit summary
for each year and channel …

Validation fit done with
Higgs constrained to SM …

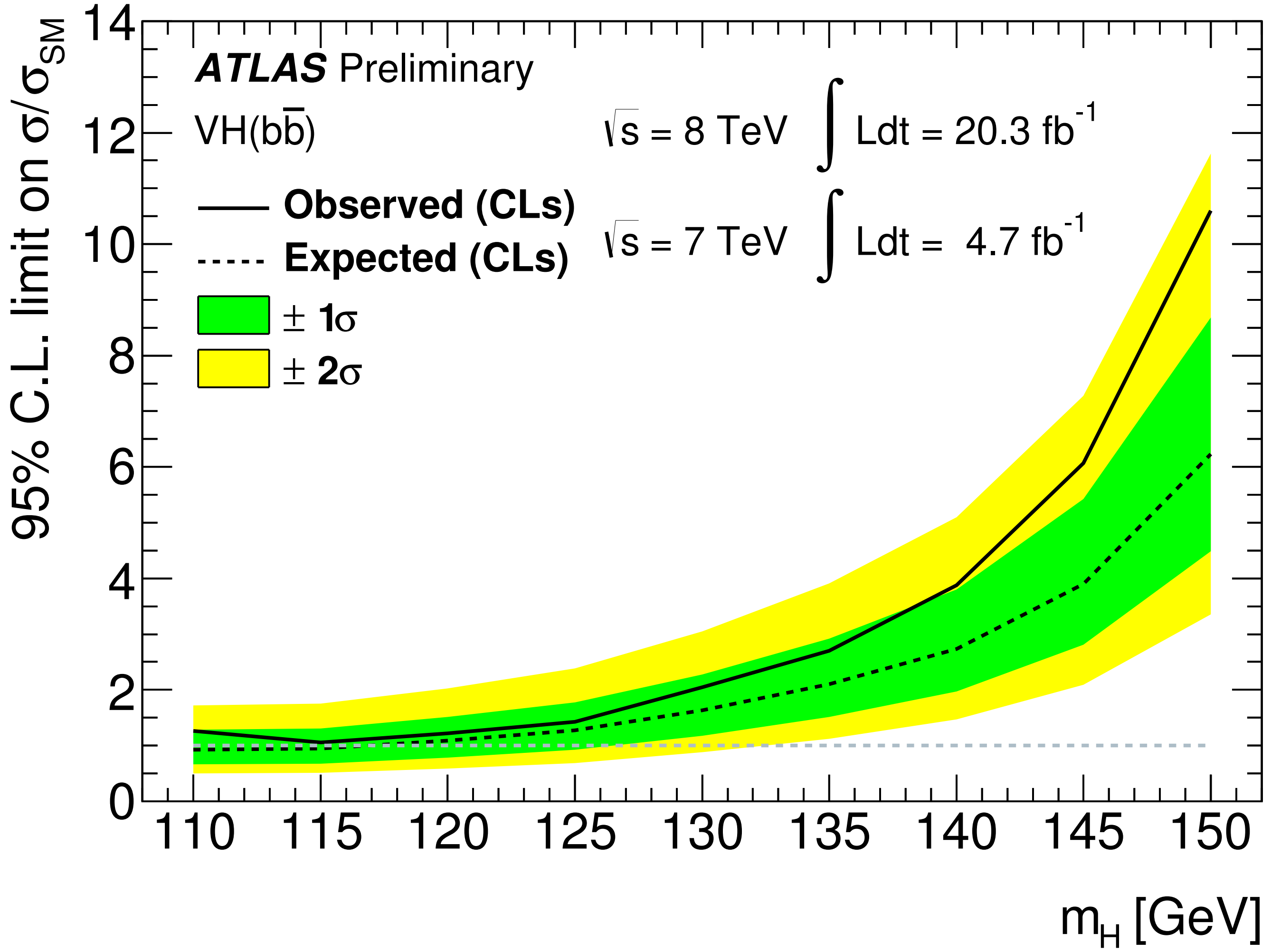
Observed rate:

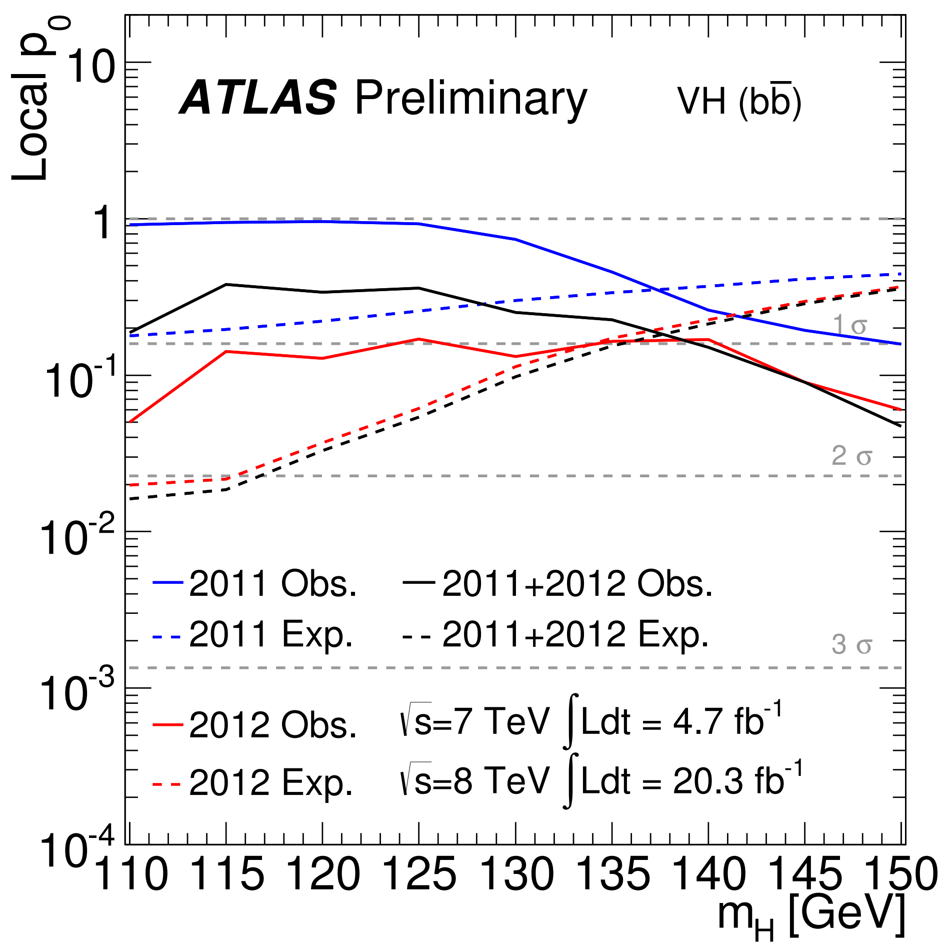
$\mu = 0.9 \pm 0.2$

[Consistent with SM]



Higgs ➛ bb Mass Peak





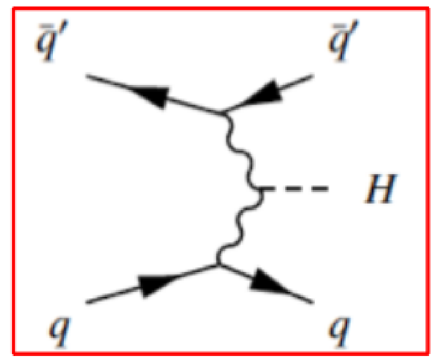
Combined limit at m_H=125 GeV …
σ/σ_{SM} < 1.4 (1.3 expected) @ 95% CL

ATLAS-CONF-2012-160
CMS PAS HIG-13-004
CMS PAS HIG-13-053

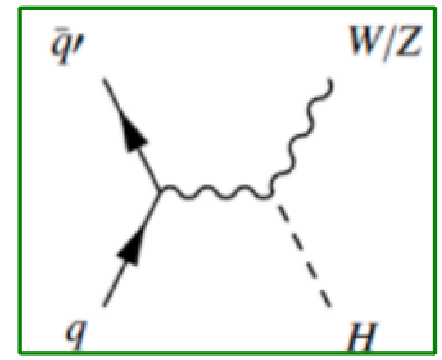
Search for Higgs ➛ ττ

Most sensitive production mode …?

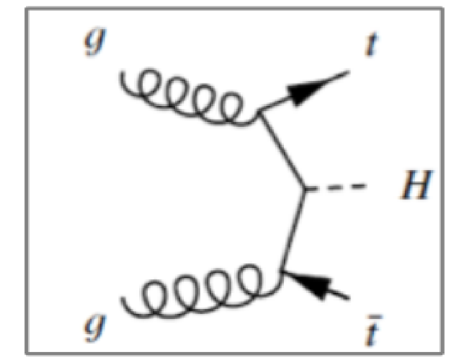
[Gluon fusion only at high p_T]



qqH production
most sensitive



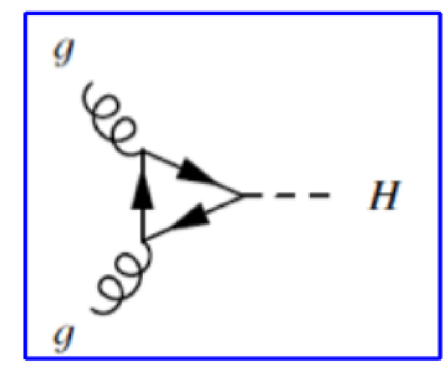
low rate
less sensitive



ttH production
dedicated search

Experimental challenges:

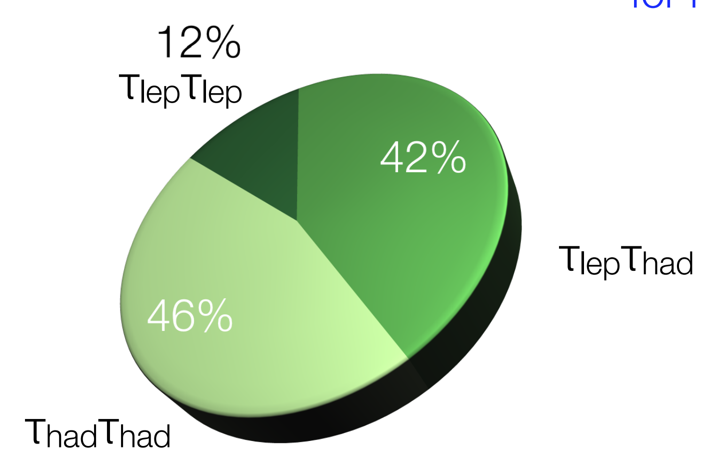
Decay modes lead to 3 different final states …
Invariant mass reconstruction due to missing neutrinos …
Energy scale determination and uncertainty for τ-decays …



mostly sensitive
for high $p_T(\tau,\tau)$

τ-decays:

Leptonic [ca. 35%]: $\tau^{\pm} \rightarrow e^{\pm}\nu_e\nu_\tau$, $\tau^{\pm} \rightarrow \mu^{\pm}\nu_\mu\nu_\tau$
Hadronic [ca. 65%]: $\tau^{\pm} \rightarrow \pi^{\pm}\nu_\tau$, $\tau^{\pm} \rightarrow \pi^{\pm}\pi^{\pm}\pi^{\mp}\nu_\tau$ …



Hadronic
Tau-Reconstruction and Identification

Main Background: QCD jets

Reconstruction

τ_{had}-algorithm seeded from anti-kt R=0.4 jets
[input: noise-suppressed calo-clusters]

track association within a core cone $\delta R < 0.2$

track-vertex association; robust against pile-up

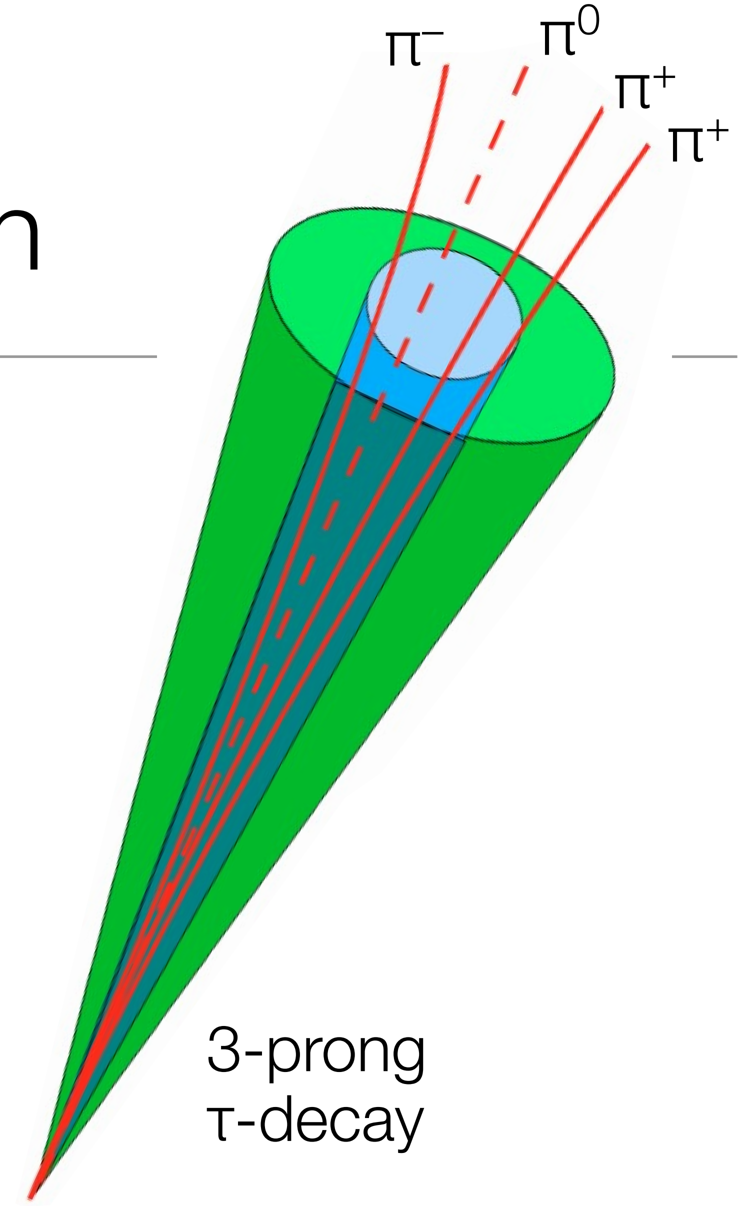
Identification

Boosted decision trees (BDT) or
log-likelihood methods …

Identification variables:

- calorimetric (HAD and EM shower shapes)
- tracking (isolation, momentum, ...)

Veto on electrons and muons …



3-prong
τ-decay

Signature:

Collimated calorimeter clusters …
Low track multiplicity …
Displaced vertex …
Close by tracks …

Tau Identification …

Tau ID input variables …

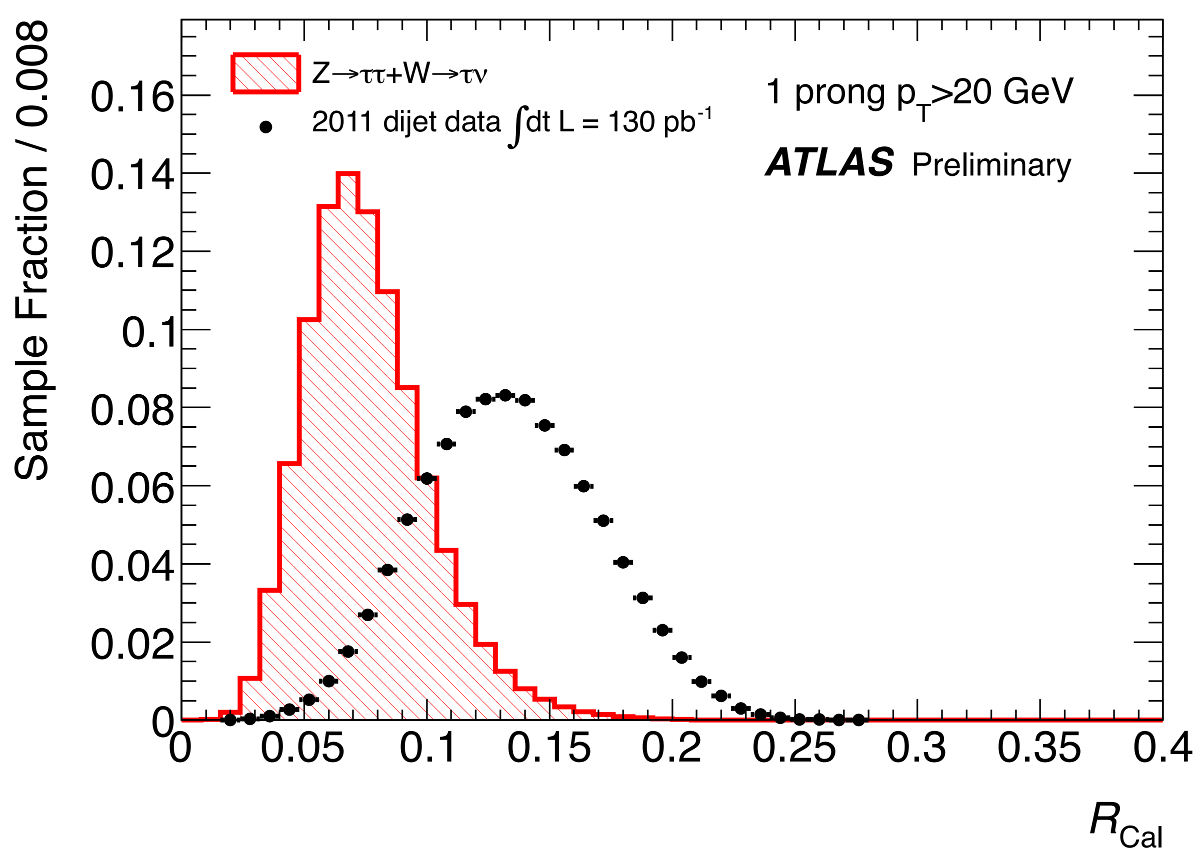
Track radius
Lead core energy fraction
Leading track momentum fraction
Number of isolation tracks
Ring isolation
Cluster mass
Track mass
Transverse flight path significance
Leading track IP significance
First 2(3) leading clusters energy ratio
Maximum ΔR
Electromagnetic fraction
TRT HT fraction
Maximum strip E_T
Hadronic track fraction
Electromagnetic track fraction
Hadronic radius
Corrected cluster isolation energy

Variable	Eqn.	Jet discriminants						Electron discriminants	
		Cut		LLH		BDT		Cut	BDT
		1	m	1	m	1	m	1	1
R_{track}	11	•	•	•	•	•	•		•
f_{track}	12	•	•			•	•		•
f_{core}	13			•	•	•	•		•
$N_{\mathrm{track}}^{\mathrm{iso}}$		•	•	•		•	•		
R_{Cal}	14			•		•	•		
f_{iso}	15								•
$m_{\mathrm{eff.\ clusters}}$	16					•	•		
m_{tracks}	18				•		•		
$S_{\mathrm{T}}^{\mathrm{flight}}$	19		•		•		•		
$S_{\mathrm{lead\ track}}$	20					•	•		
$f_{\mathrm{2\ lead\ clusters}}$				•					
$f_{\mathrm{3\ lead\ clusters}}$						•	•		
ΔR_{max}					•		•		
f_{EM}	21								•
f_{HT}	22							•	•
$f_{\mathrm{Had}}^{\mathrm{track}}$	23							•	•
$E_{\mathrm{T,max}}^{\mathrm{strip}}$								•	•
$f_{\mathrm{EM}}^{\mathrm{track}}$	24							•	
R_{Had}	25								•
$E_{\mathrm{T,corr}}^{\mathrm{iso}}$	26	•	•						

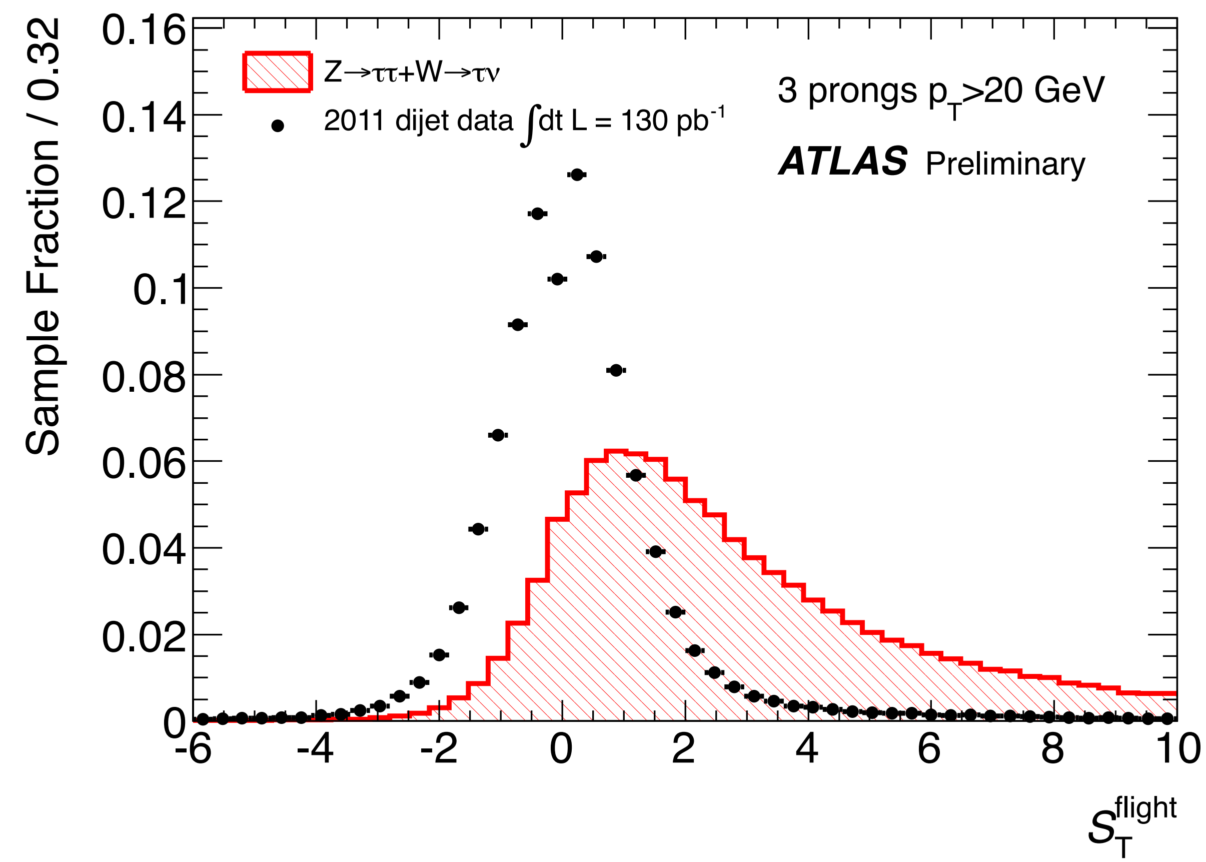
Tau Identification …

Some
sample input variables …

Calorimetric Radius



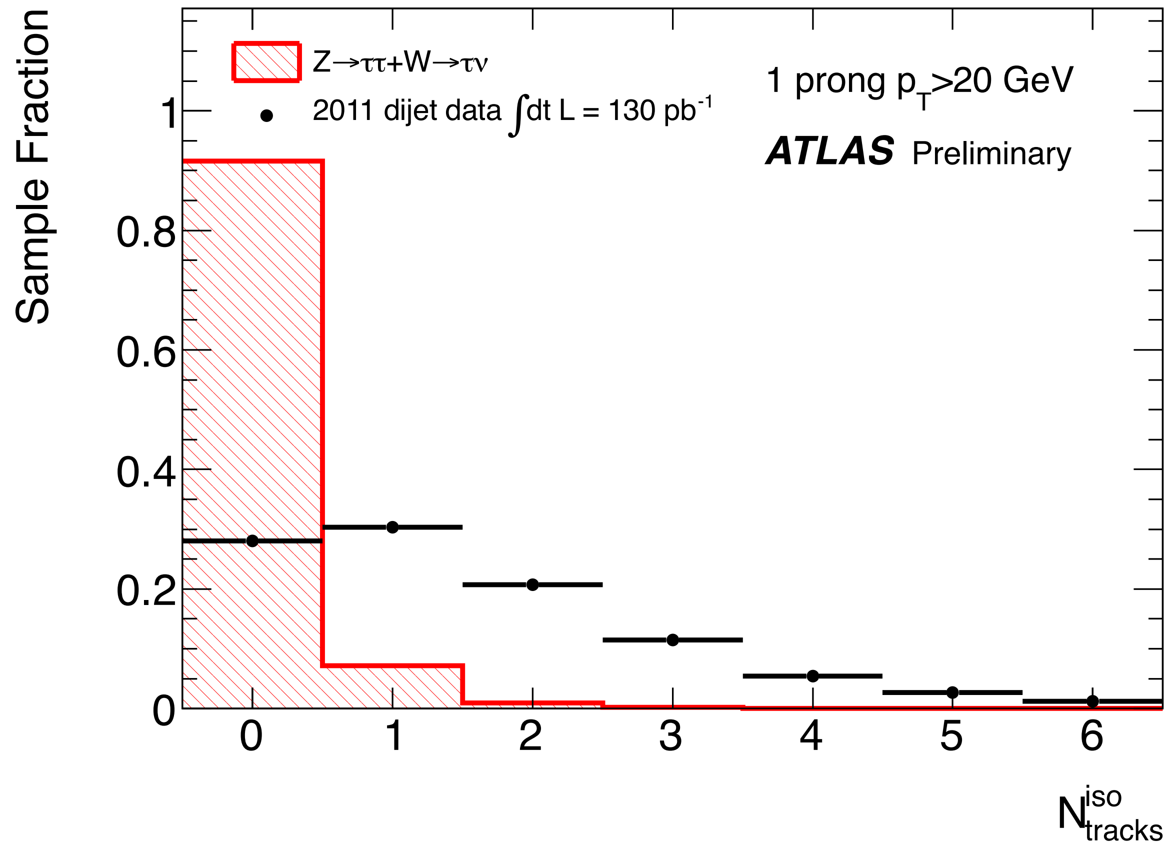
Transverse
flight path significance



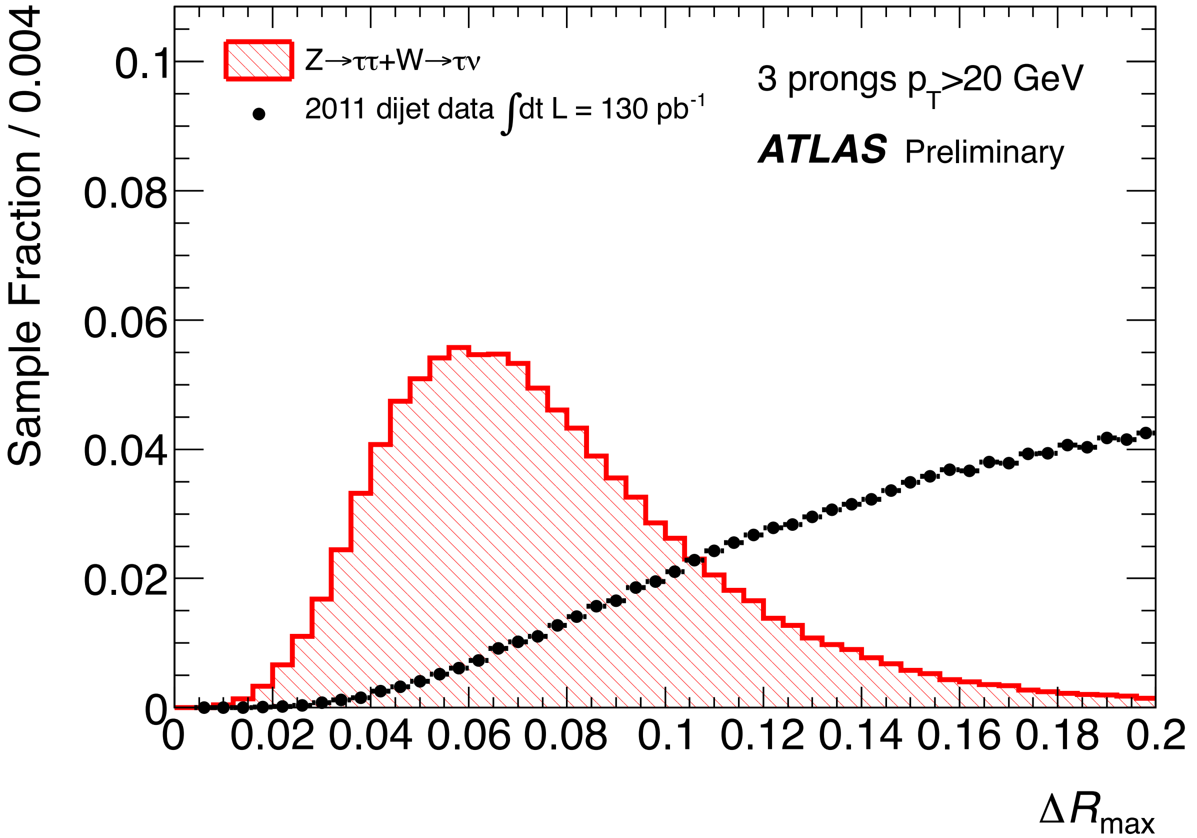
Tau Identification …

Some
sample input variables …

Number of isol. tracks

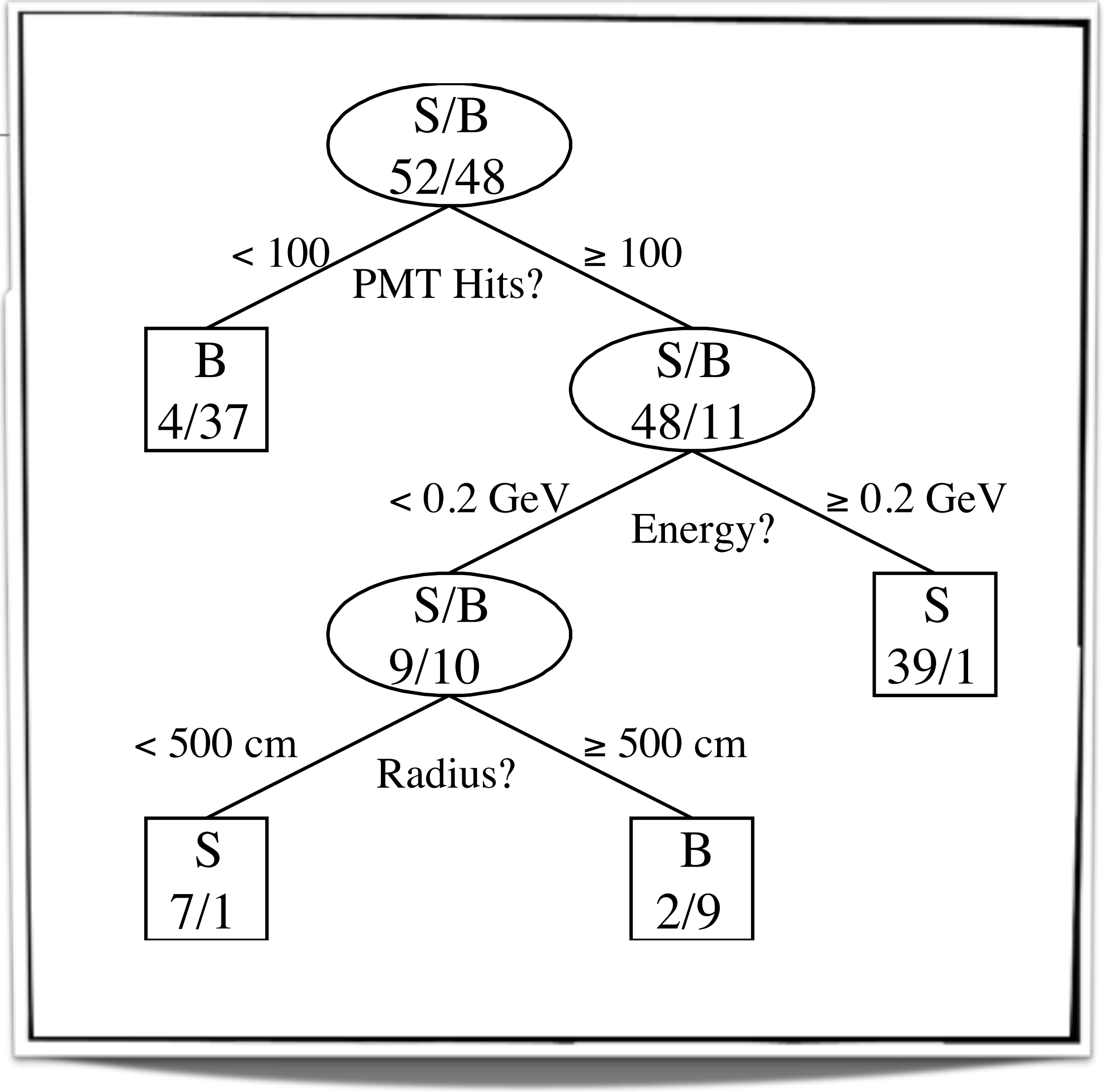


Maximum ΔR between
τ-axis and core track



Boosted Decision Tree

[arXiv:physics/0408124]



Training:

Use a set of simple criteria to categorize events by a decision tree …

Splitting values picked, by optimizing separation of signal and background …

Rebuilt tree by re-weighting events misclassified by the decision tree …

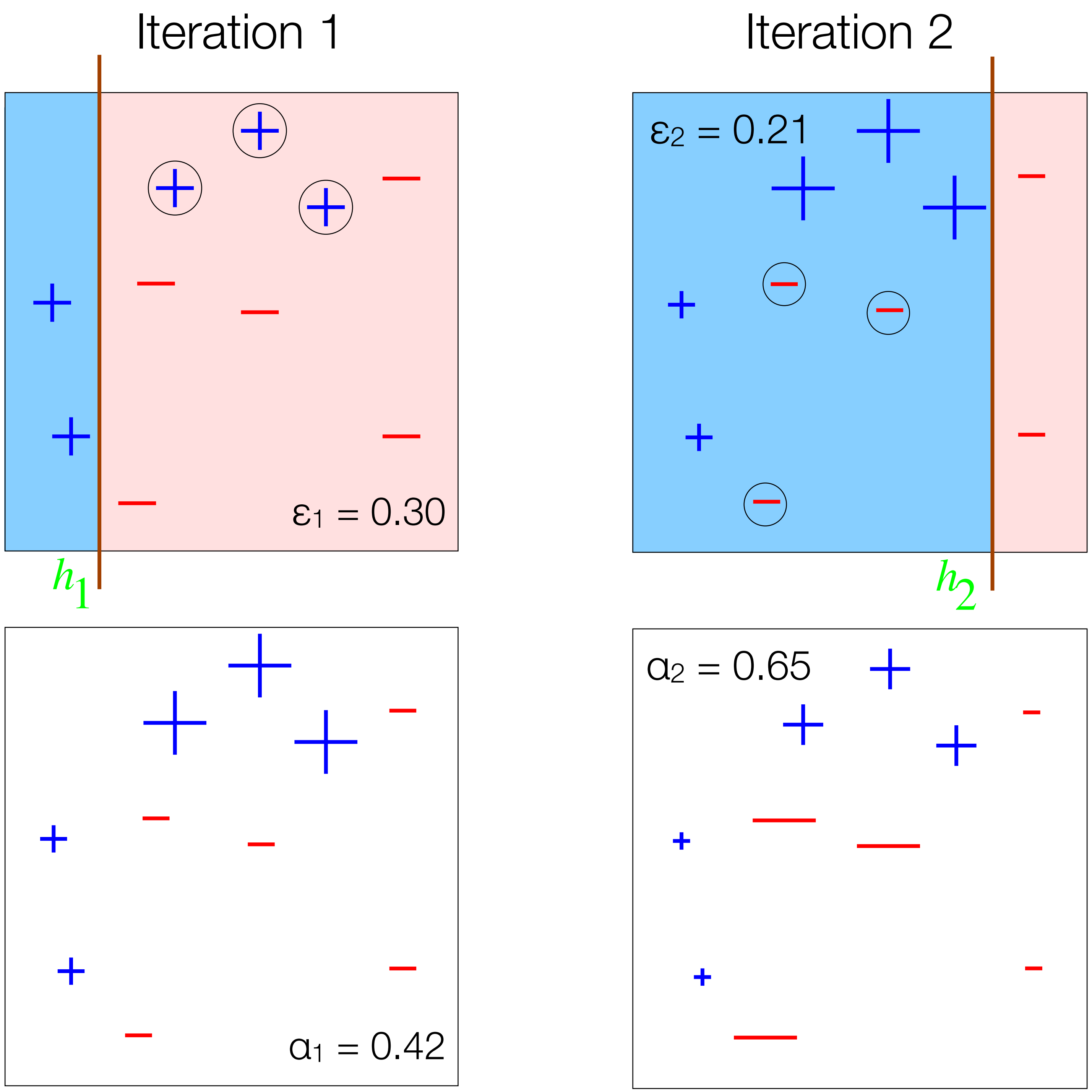
Built many decision trees …

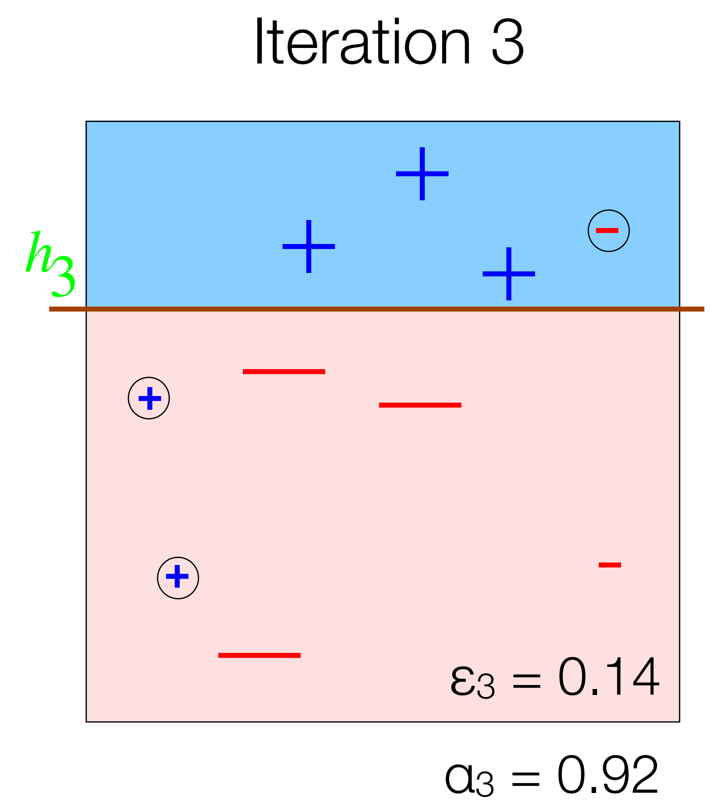
Scoring:

Follow every event through each tree …
Assign "+1" if classified as signal; "–1" otherwise …

Renormalized sum of scores: BDT output.

A Somewhat Intuitive Example

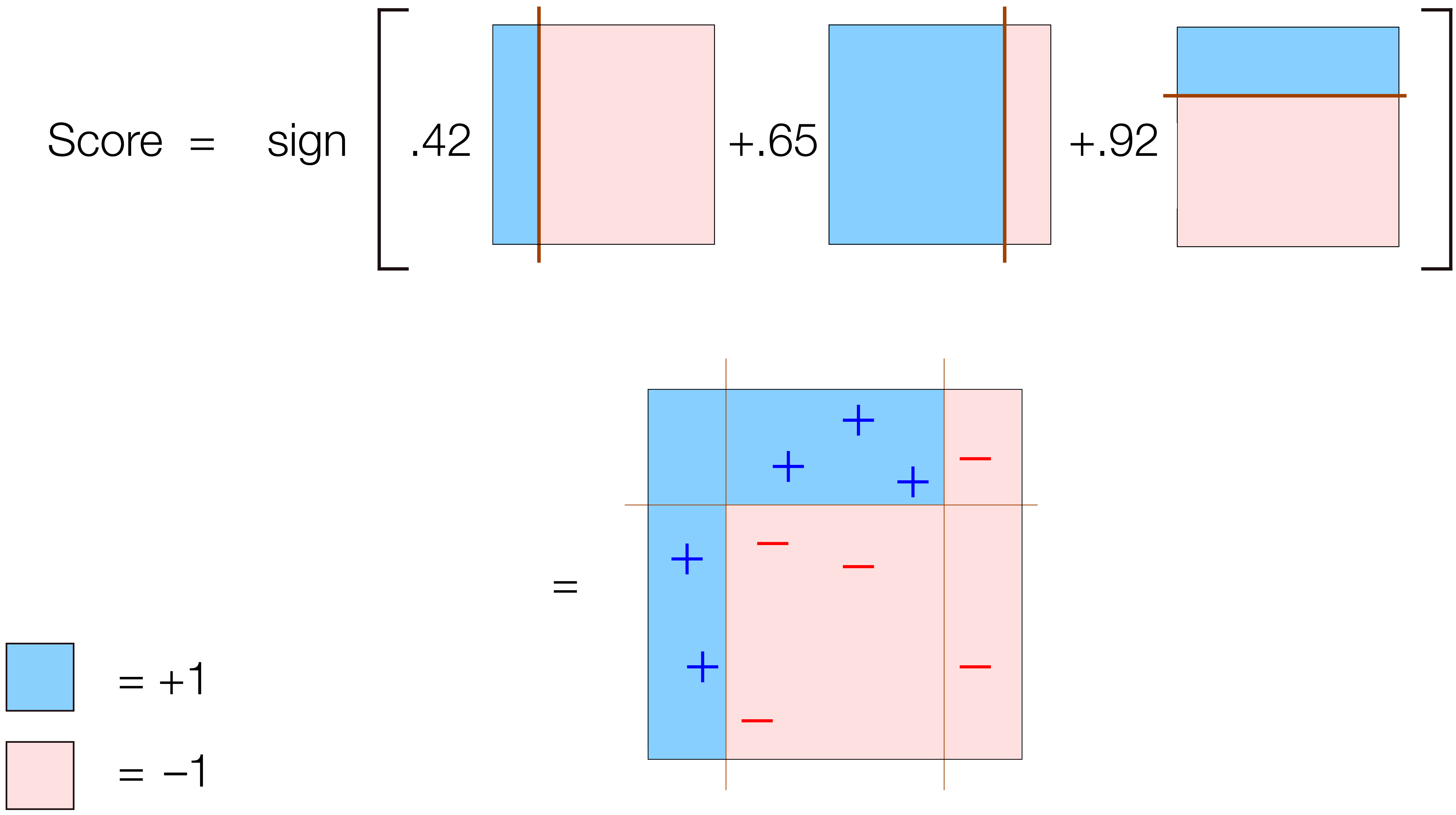




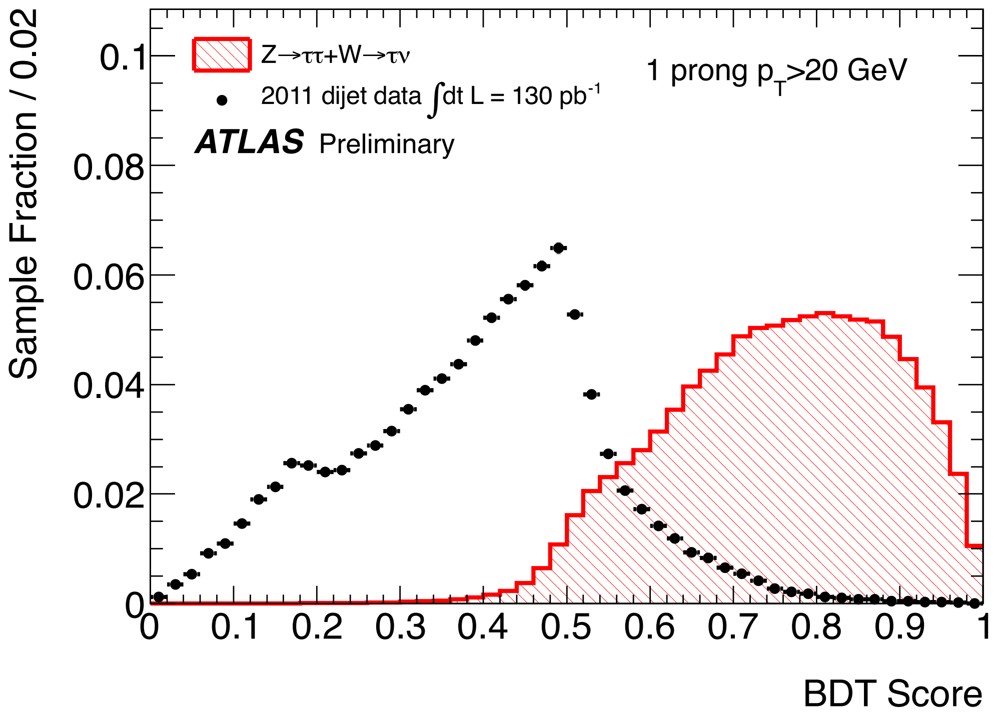
Re-weighting: $\sim e^{\pm\alpha_i}$

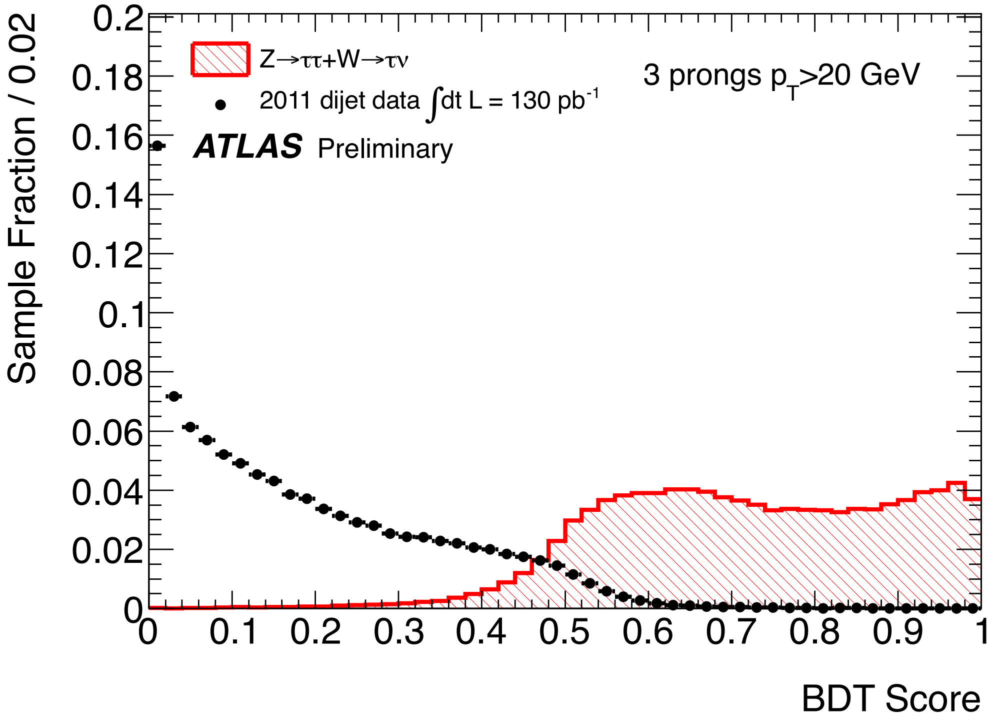
Exponent: $\alpha = \frac{1}{2} \ln (1-\varepsilon_i)/\varepsilon_i$

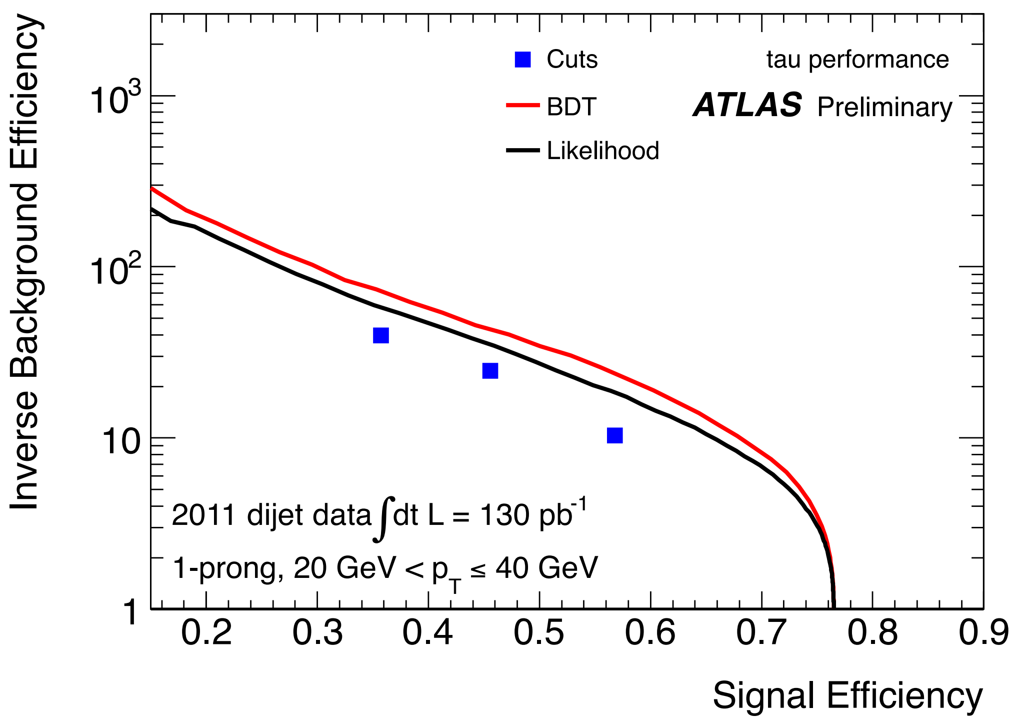
A Somewhat Intuitive Example

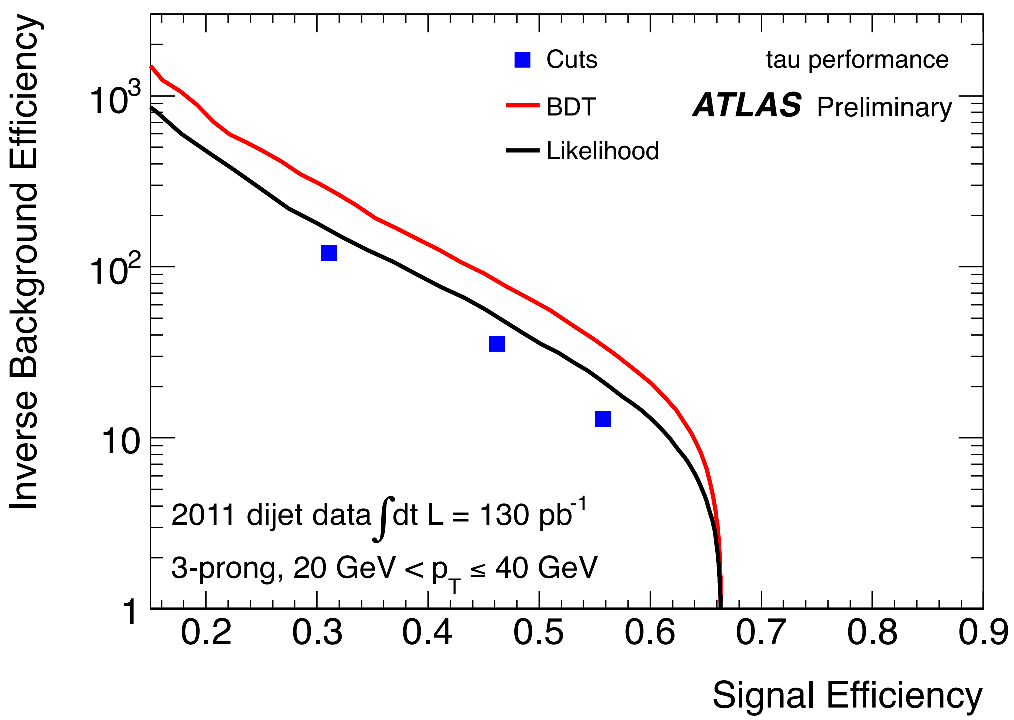


Jet BDT Score and Performance

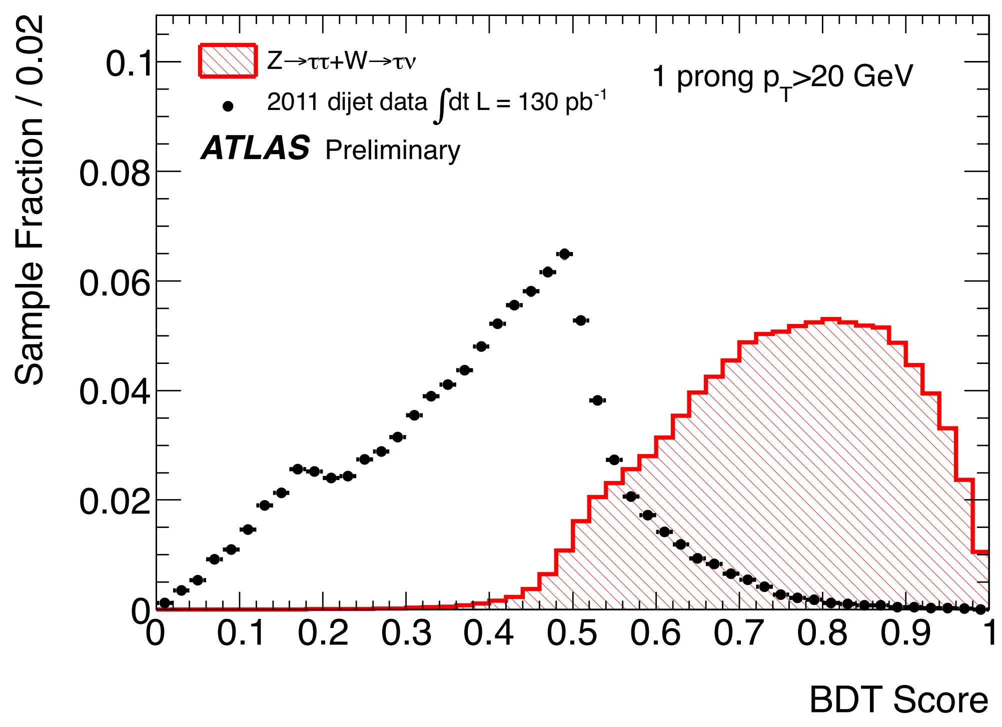


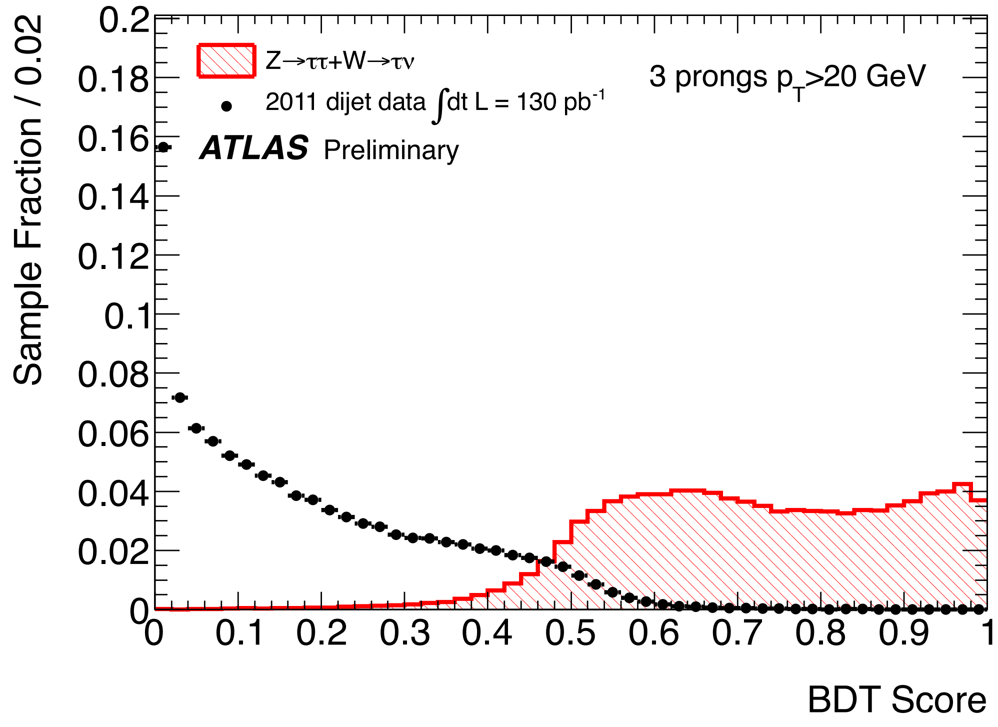


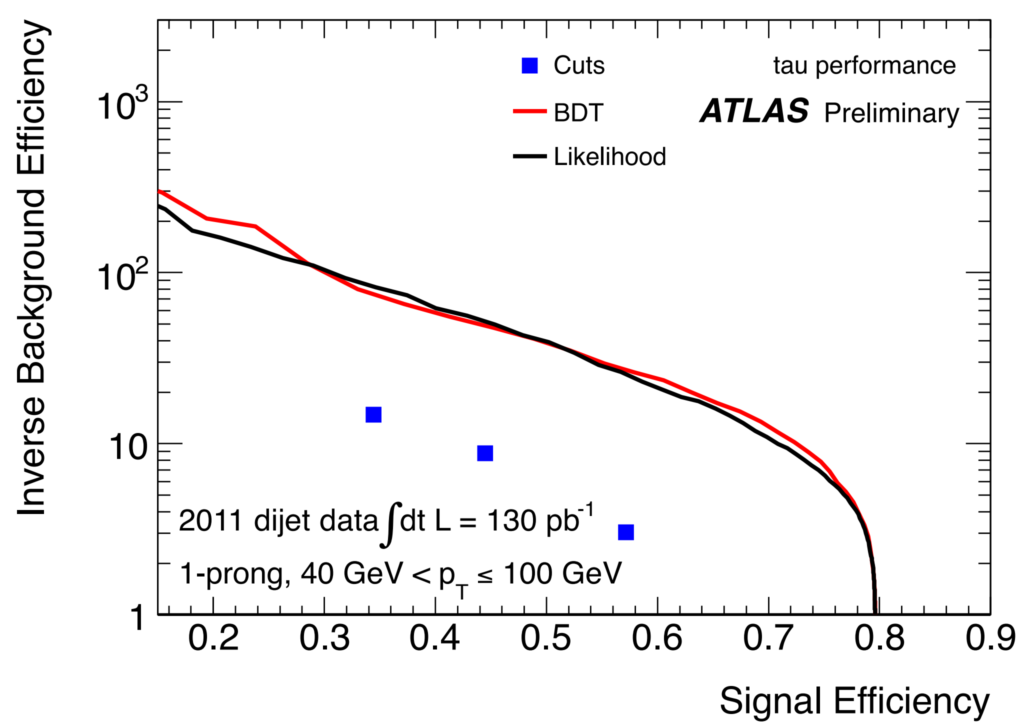


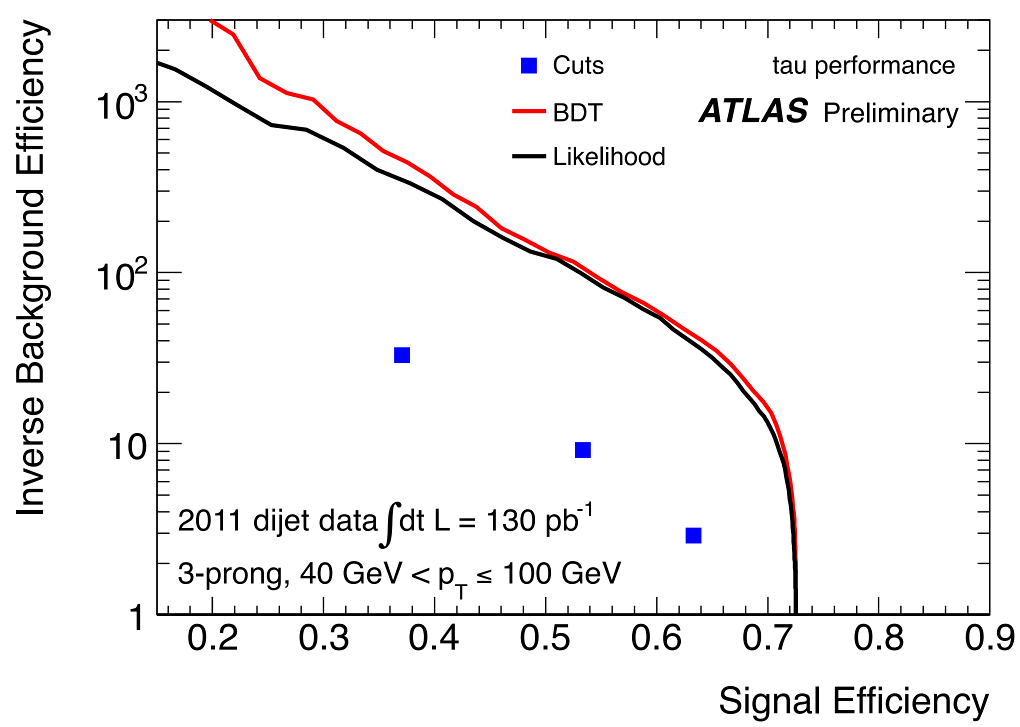


Jet BDT Score and Performance

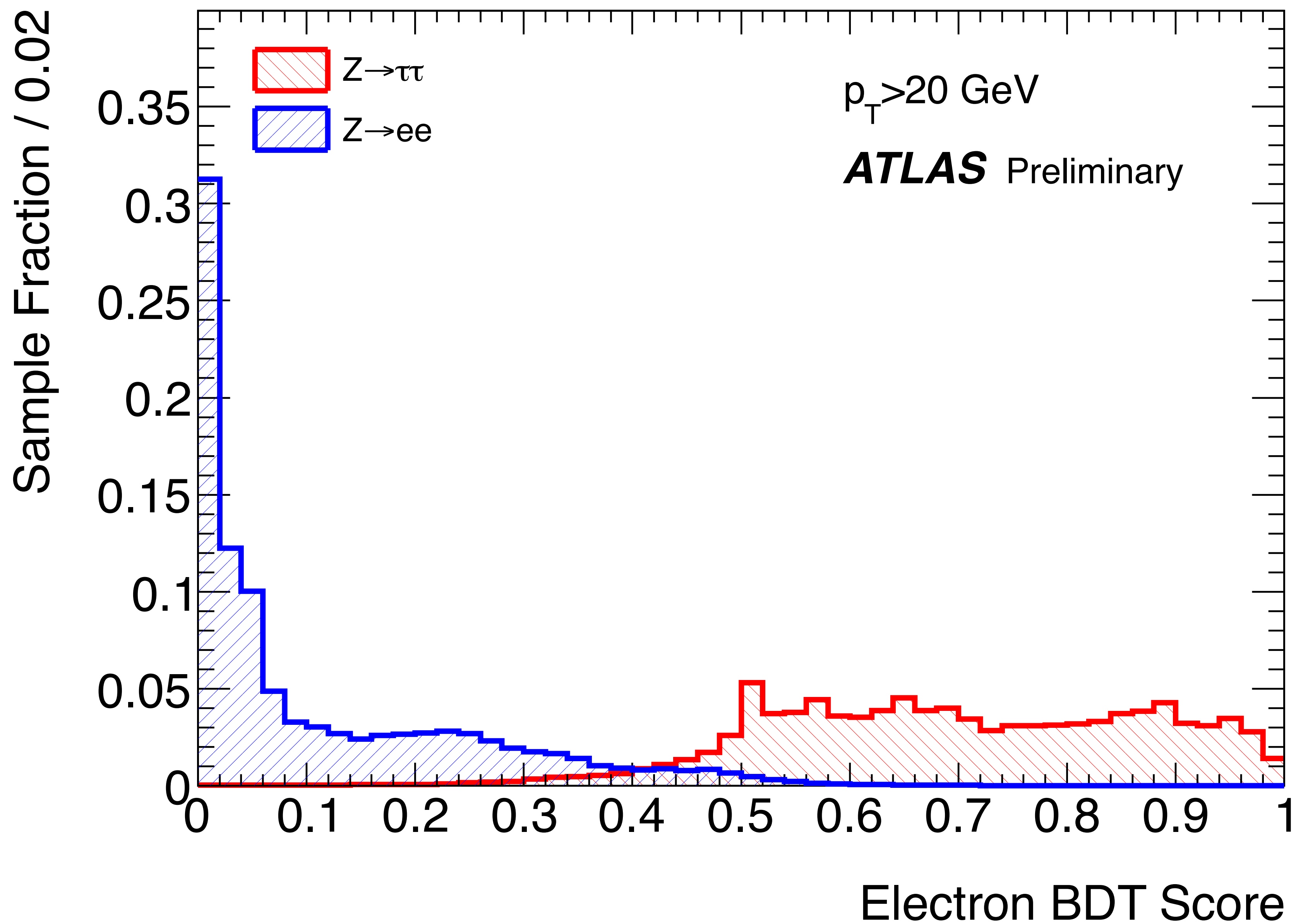




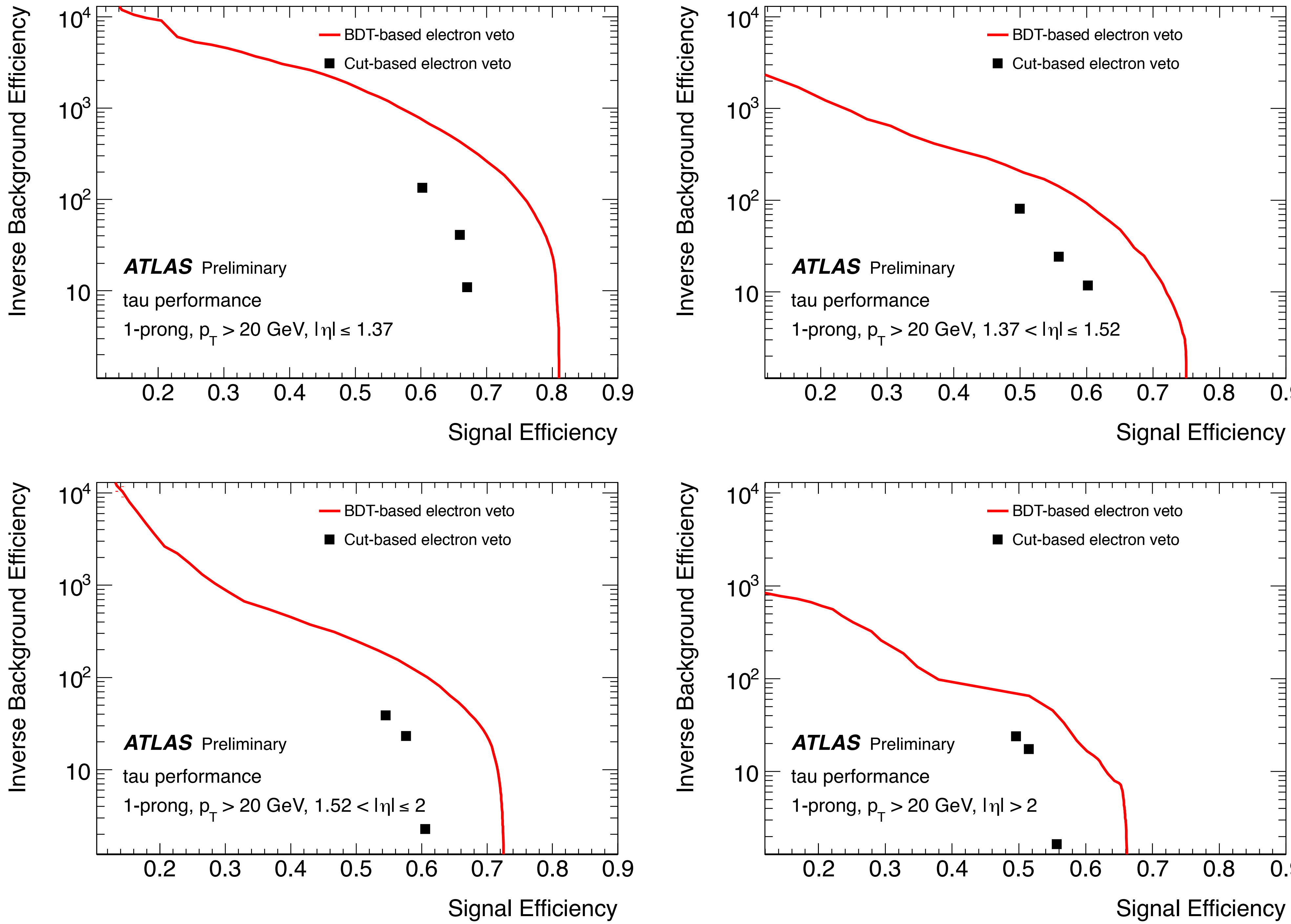




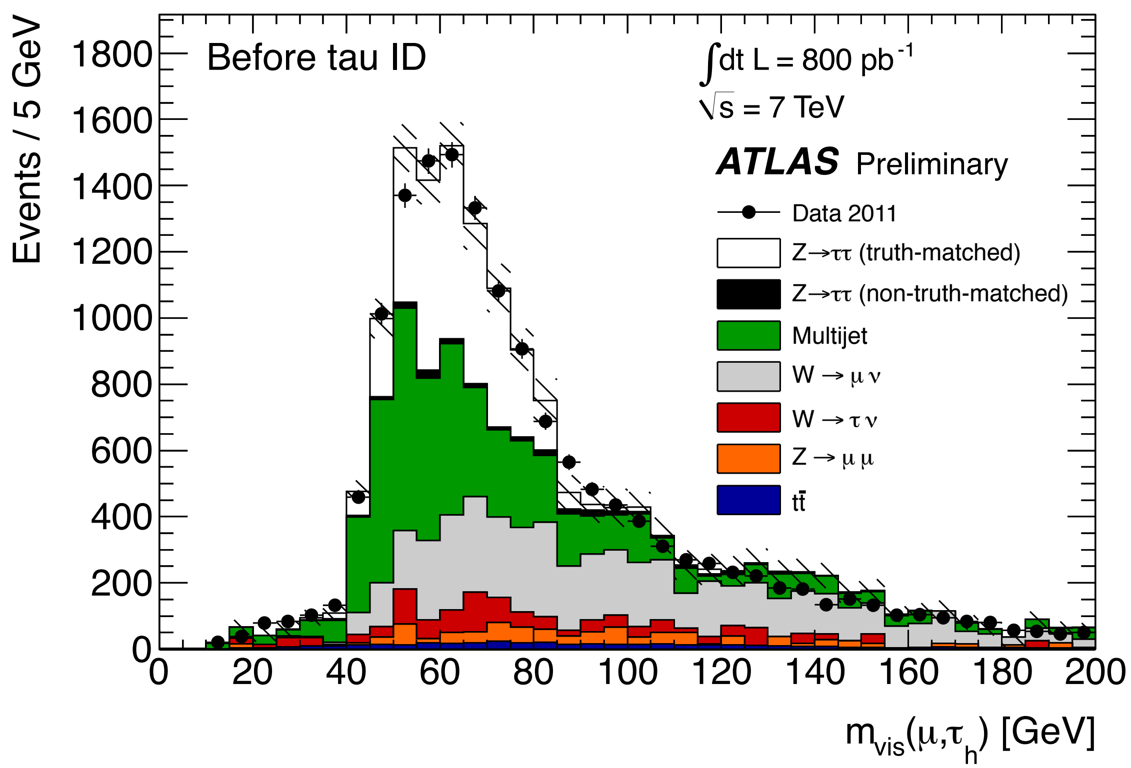
Electron BDT Score

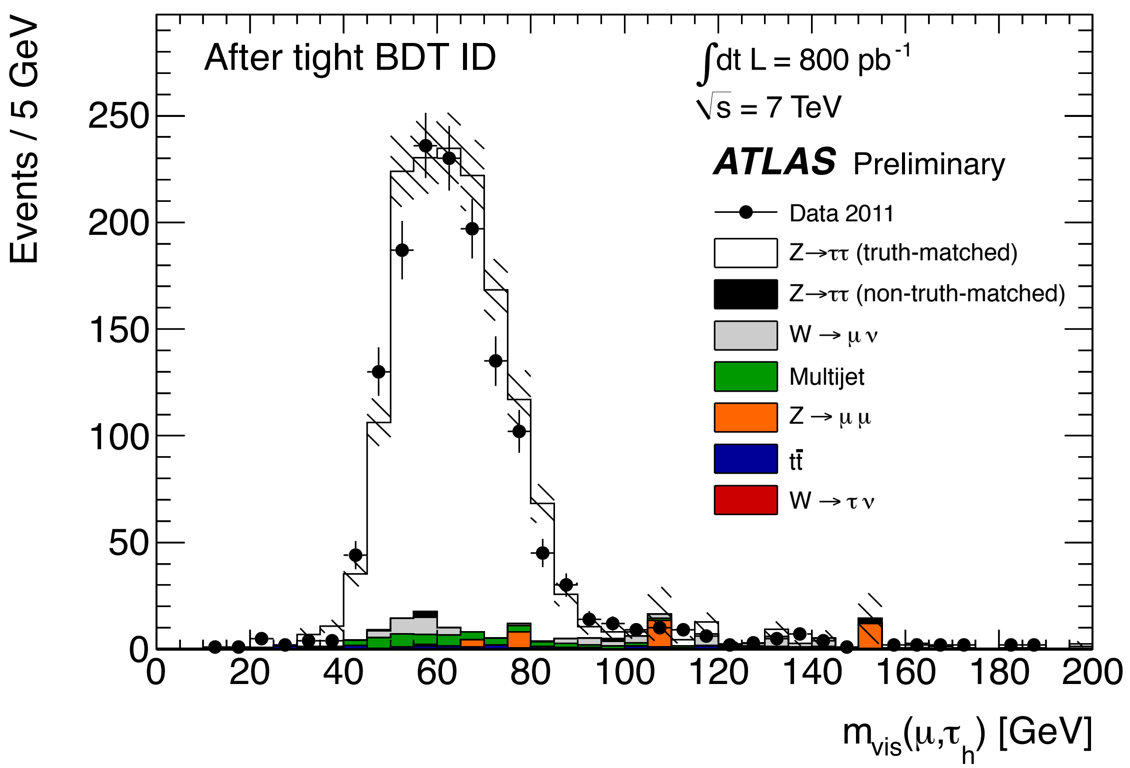


Electron BDT Performance



Tau Identification …

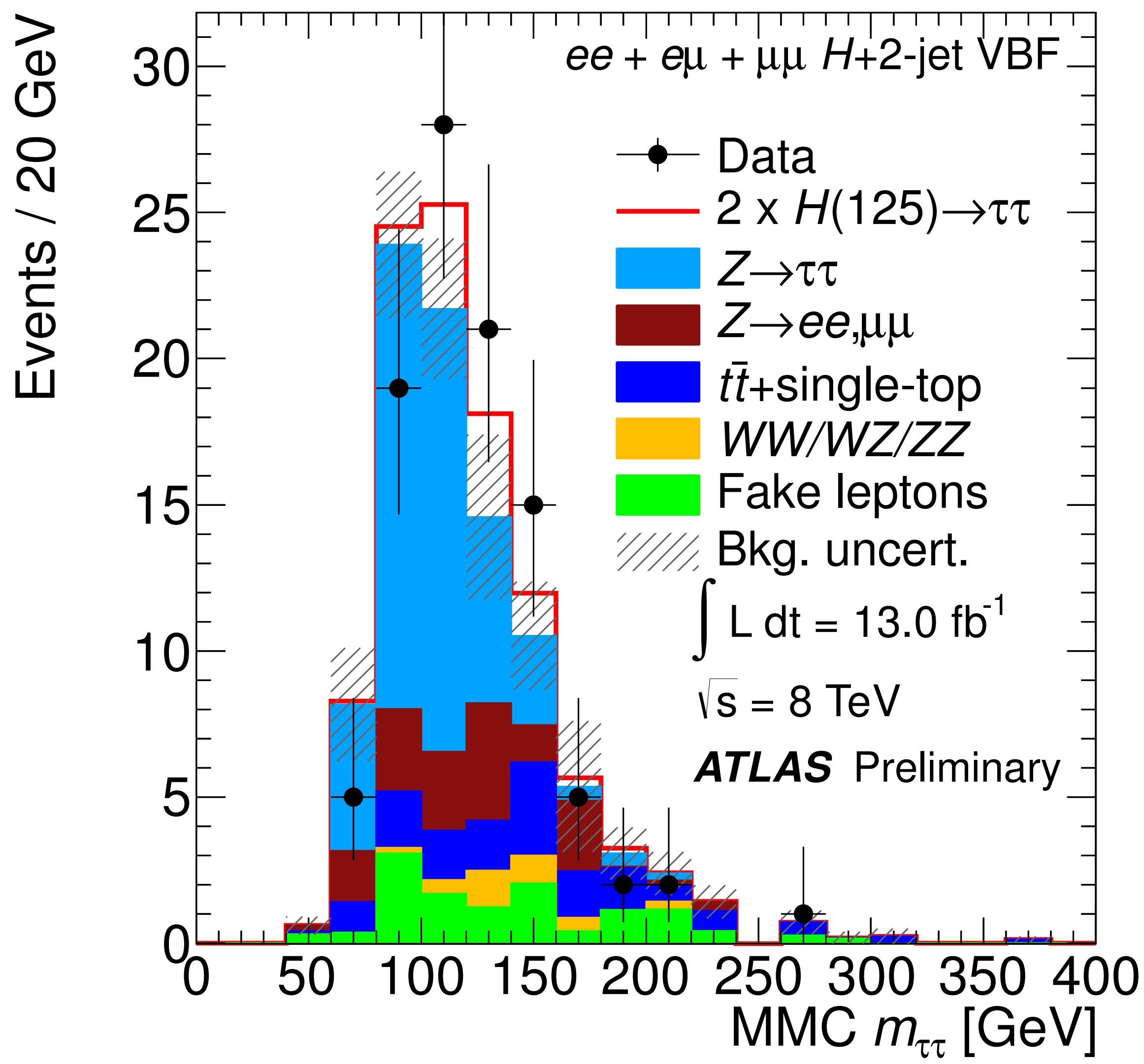


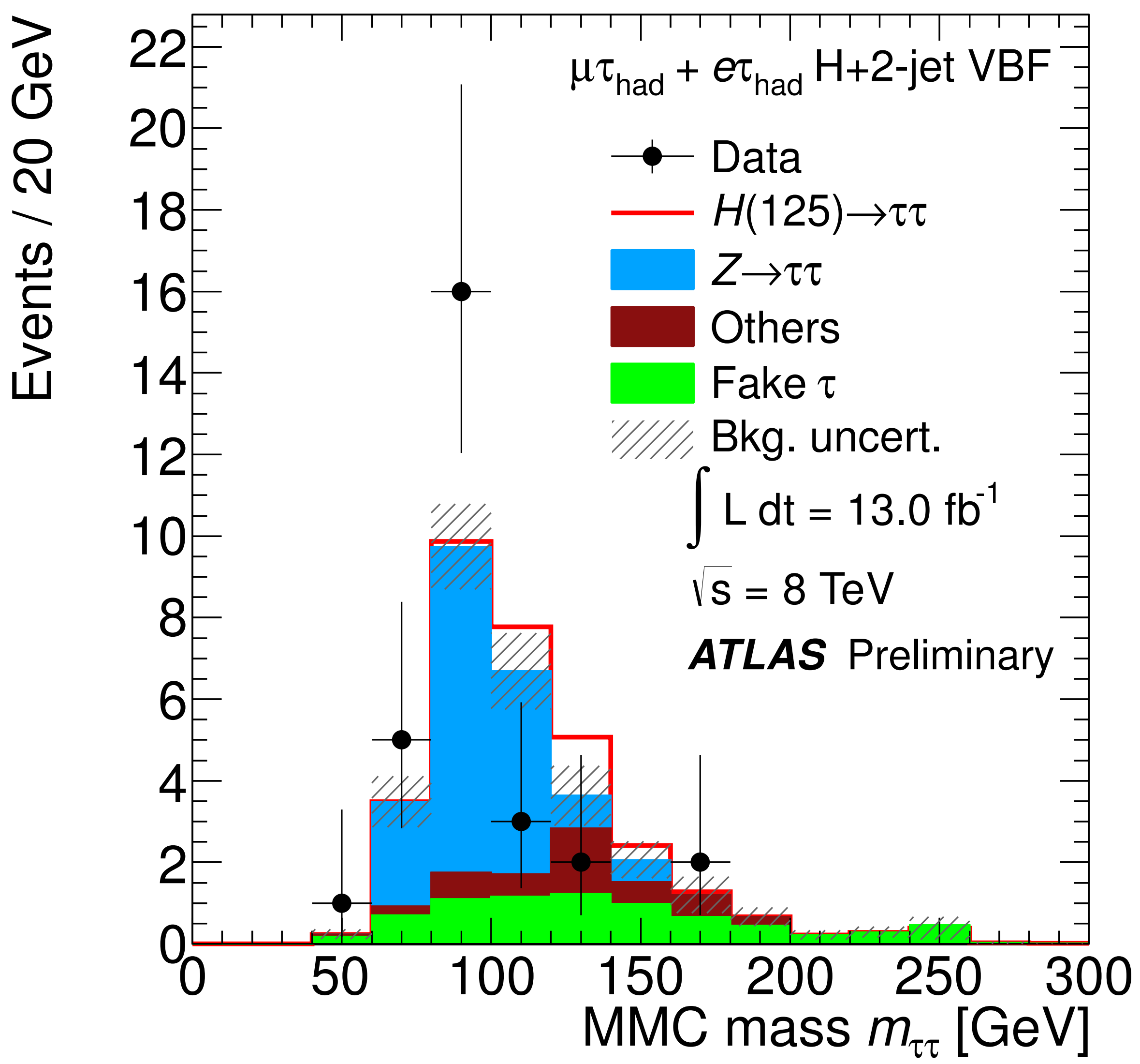


Visible Z ➤ ττ mass distributions after full event selection before and after tight BDT identification

H ➛ ττ Analysis Results

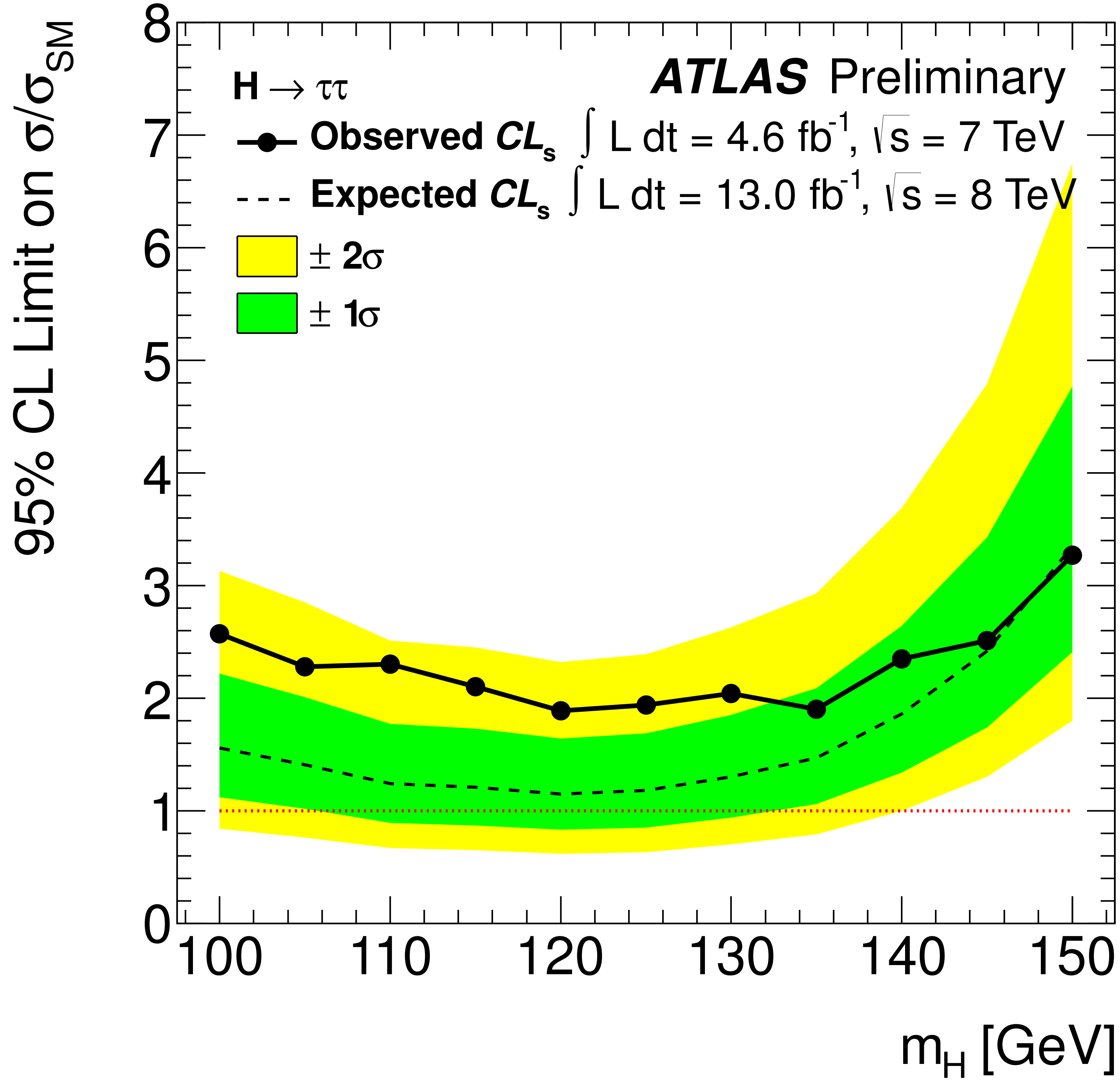
[Example Plots]





H ➛ ττ Analysis Results

[Example Plots]



Nov. 2012

H ➛ ττ Analysis Results

Run Number: 209109, Event Number: 86250372

Date: 2012-08-24 07:59:04 UTC

ATLAS EXPERIMENT