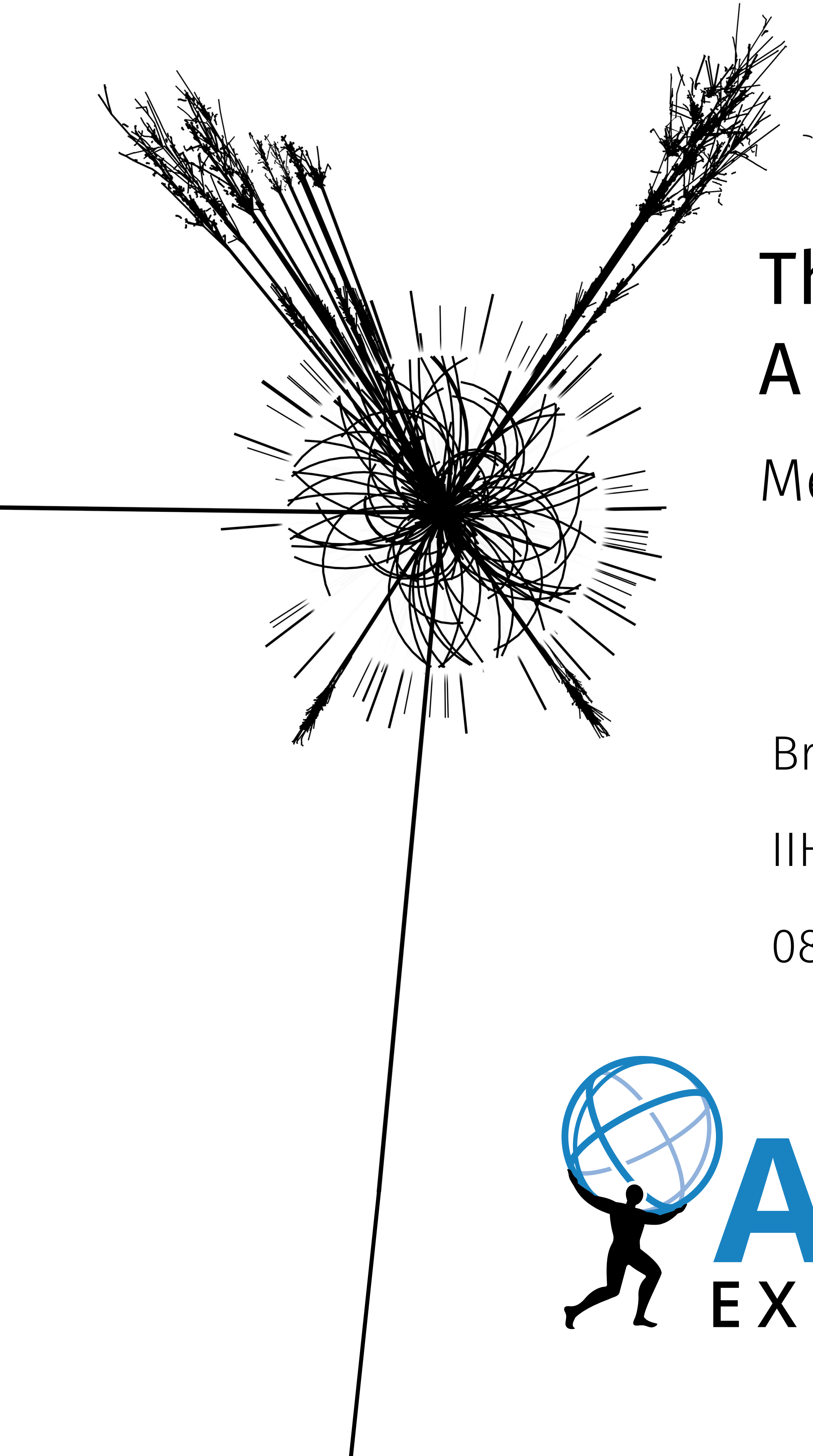


The Beauty and the Boost: A Higgs boson tale

Measuring boosted VH, H—>bb with ATLAS

ATLAS-CONF-2020-007

Brian Moser (Nikhef)

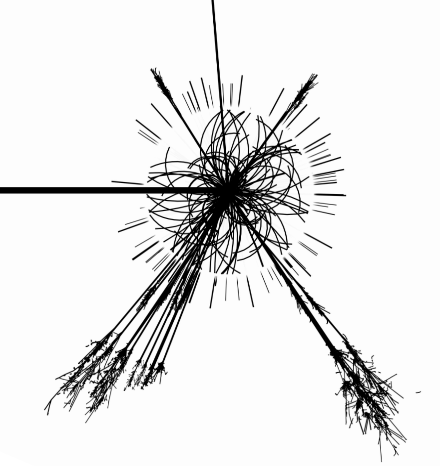
IIHE Seminar Brussels

08/05/2020

ATLAS EXPERIMENT

Nikhef

The Standard Model of particle physics (SM)



$$\mathcal{L}_{\rm SM} = -\frac{1}{4}F^a_{\mu\nu}F_a^{\mu\nu}$$ → Gauge terms

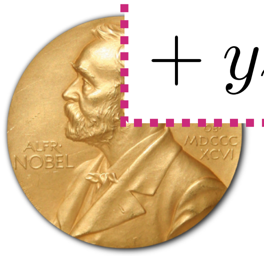
$$+ i\bar{\psi}\not{D}\psi$$ → Fermion kinematics and interactions with bosons

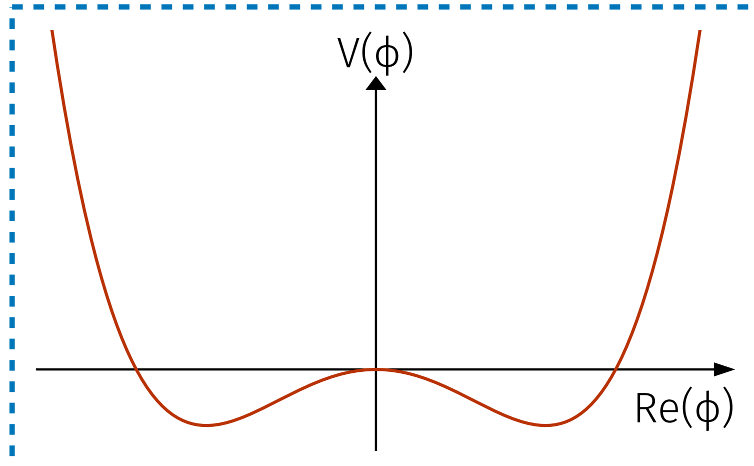
$$+ |D_\mu\phi|^2 - \mu^2(\phi^\dagger\phi) - \lambda(\phi^\dagger\phi)^2$$ → B.E.H. mechanism

$$+ y_{ij}\psi_i\phi\psi_j + \text{h.c.}$$ → Yukawa terms

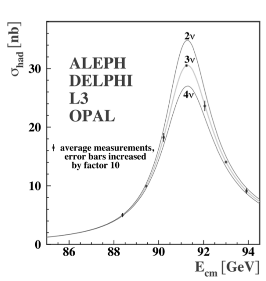
2012

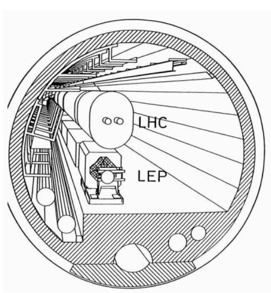
Higgs interactions

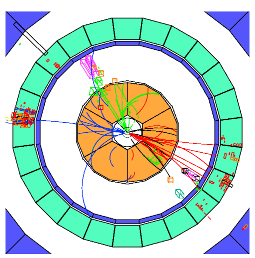




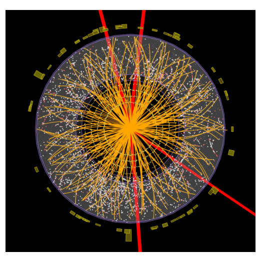
A long story of discoveries...

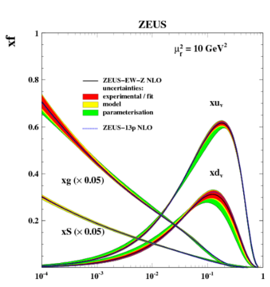


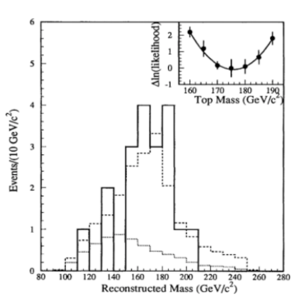




... precision measurements ...





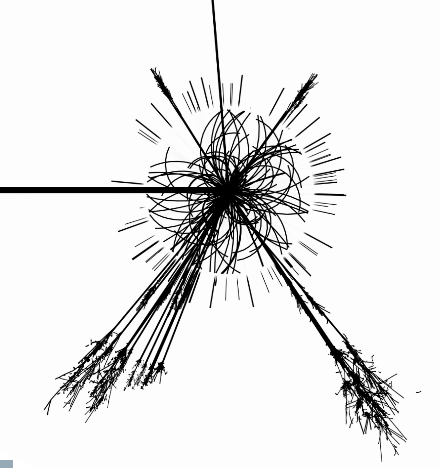


... and more discoveries

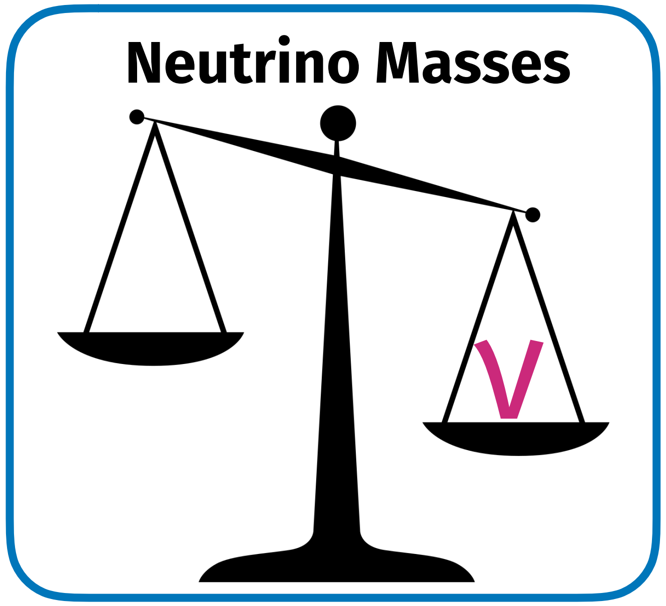
m_H = 125.38 GeV [± 0.14 GeV]

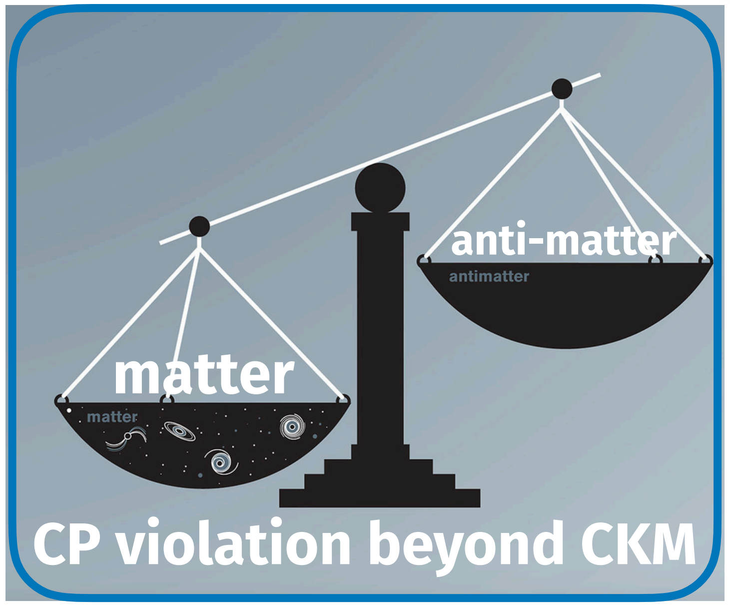
With the measurement of the Higgs mass, the last free parameter of the SM has been measured!

The need for physics beyond the SM



- Several experimental observations imply physics beyond what the SM can explain





+ ...

- Galactic rotation curves
- Grav. lensing
- Bullet cluster
- Hot gas clusters

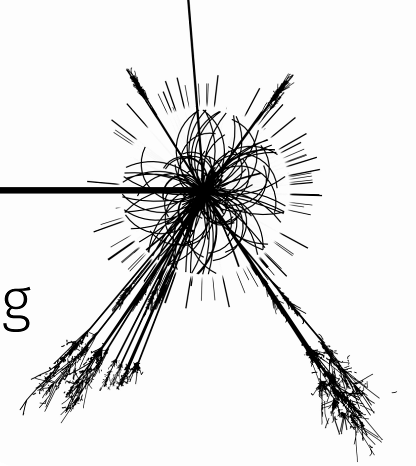
- Neutrino oscillations

- Additionally, there are theoretical considerations such as the quantization of gravity, the hierarchy of mass scales, ...

Yet, in controlled collider environments things seem to point at the SM only*

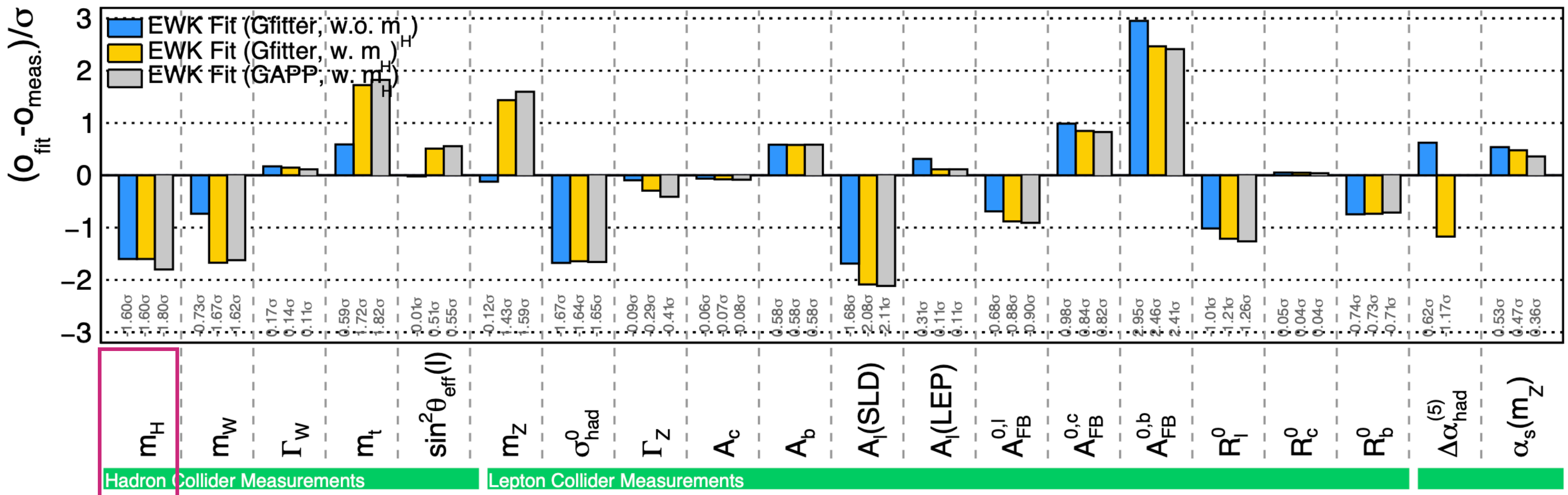
* not interpreting tensions below the observation threshold as new physics

Where to look for new physics (at colliders)?



- Testing the self-consistency of the Standard Model yields some tensions but nothing above the statistical significant threshold

[arXiv:1902.05142]

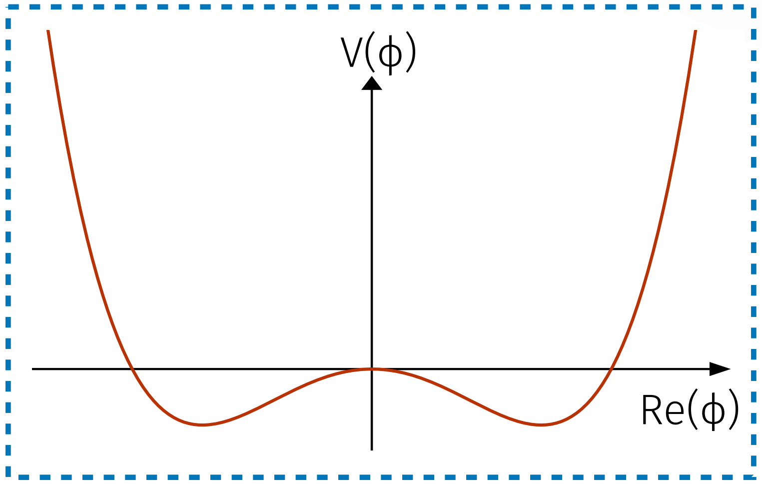


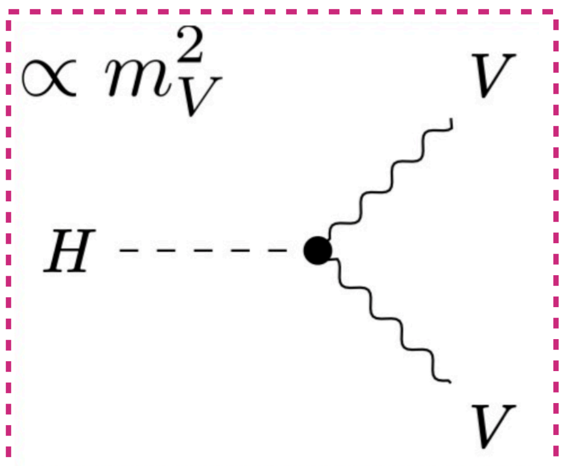
→ **Pragmatic approach:**

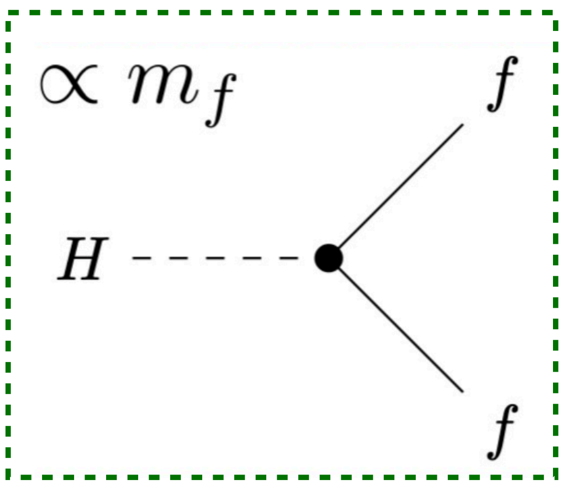
- This is the newest part of the SM, we have direct evidence of it since 2012
- What do we really know about it?
- Is there room for BSM physics?

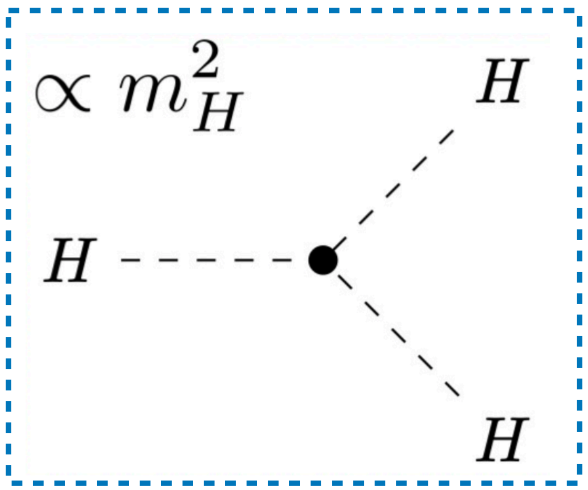
Deciphering the Higgs sector

$$
\begin{aligned}
\mathcal{L}_{\mathrm{SM}} = &-\frac{1}{4}F^a_{\mu\nu}F_a^{\mu\nu} \\
&+ i\bar{\psi}\not{D}\psi \\
&+ |D_\mu\phi|^2 - \mu^2(\phi^\dagger\phi) - \lambda(\phi^\dagger\phi)^2 \\
&+ y_{ij}\psi_i\phi\psi_j + \mathrm{h.c.}
\end{aligned}
$$

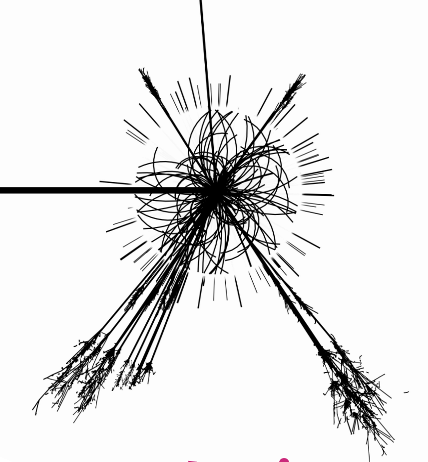








Deciphering the Higgs sector

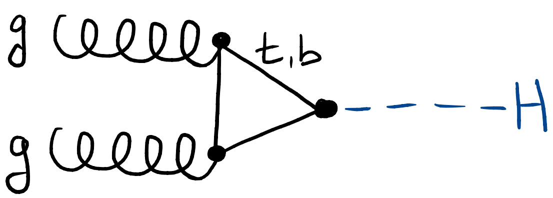


- Using the allowed couplings, the main production modes and decay channels are:

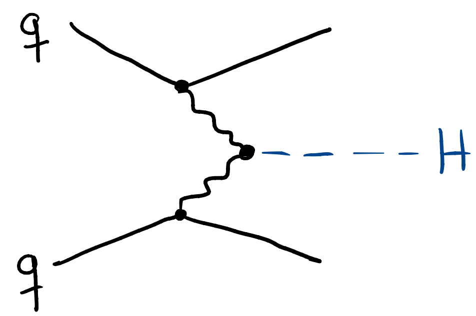
[arXiv:1610.07922]

production

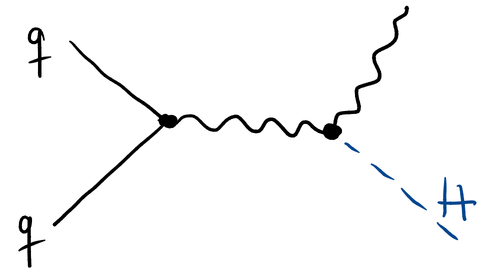
gluon-gluon fusion [ggF]



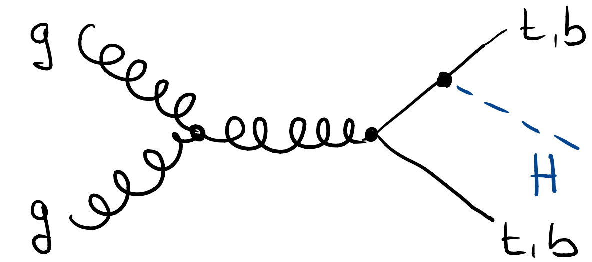
vector-boson fusion [VBF]



Higgs-Strahlung [VH]



t-/b-assoc. prod. [ttH/bbH]

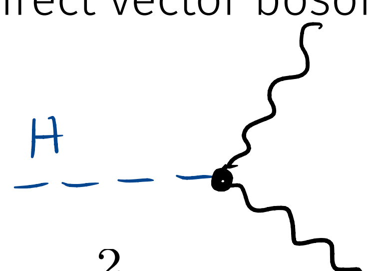


	ggF	VBF	VH	ttH/bbH
inclusive cross-section	48.7 pb	3.77 pb	2.25 pb	0.51 pb (each)
Run 2 yield:	**6.7 million**	**520 000**	**310 000**	**71 000 (each)**

✘ [narrow width]

decay

direct vector boson

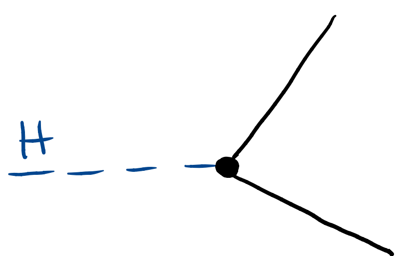


WW*

ZZ*

$\propto m_V^2$

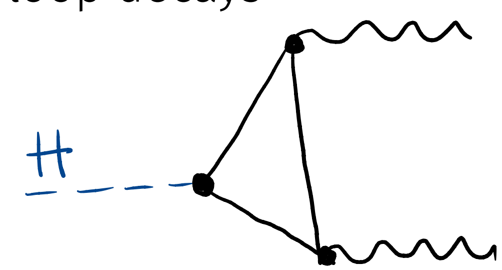
direct fermion



$\propto m_f$

u	c	
d	s	b
e	μ	τ

loop decays



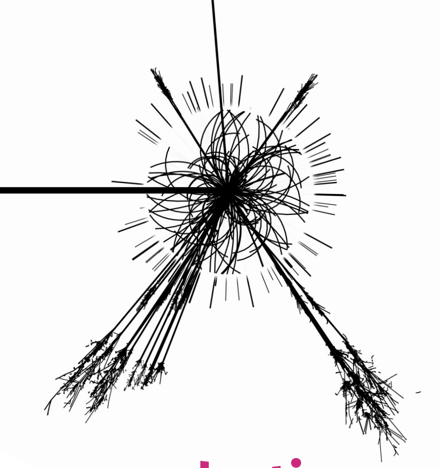
γγ

gg

Zγ

BR

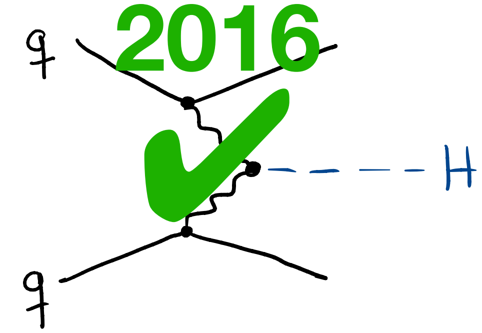
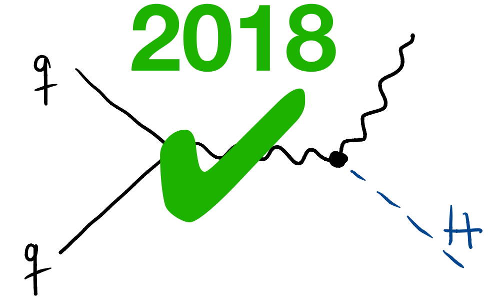
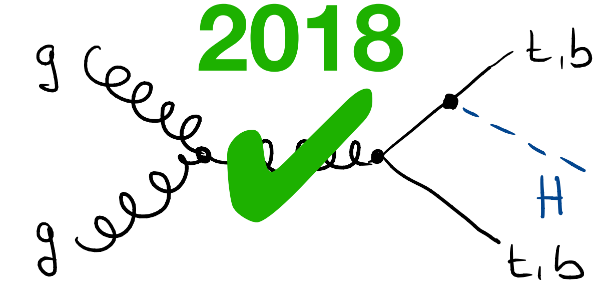
Deciphering the Higgs sector



- Using the allowed couplings, the main production modes and decay channels are:

[arXiv:1610.07922]

production

gluon-gluon fusion [ggF]	vector-boson fusion [VBF]	Higgs-Strahlung [VH]	t-/b-assoc. prod. [ttH/bbH]
2012	**2016**	**2018**	**2018**
			
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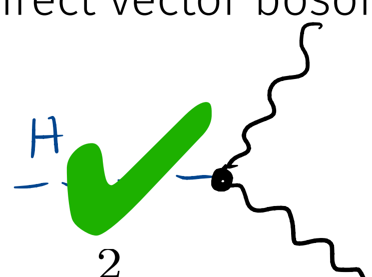
✘ [narrow width]

decay

direct vector boson

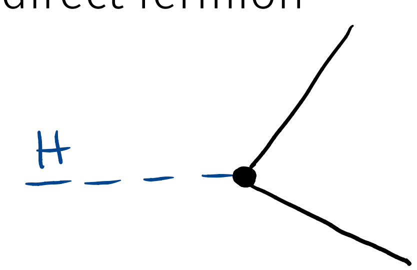


2014 WW*

ZZ* **2014**

$\propto m_V^2$

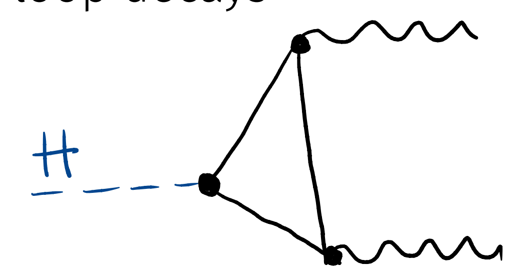
direct fermion



$\propto m_f$

u	c	
d	s	b ✔ **2018**
e	μ	τ ✔ **2016**

loop decays



2014 γγ ✔

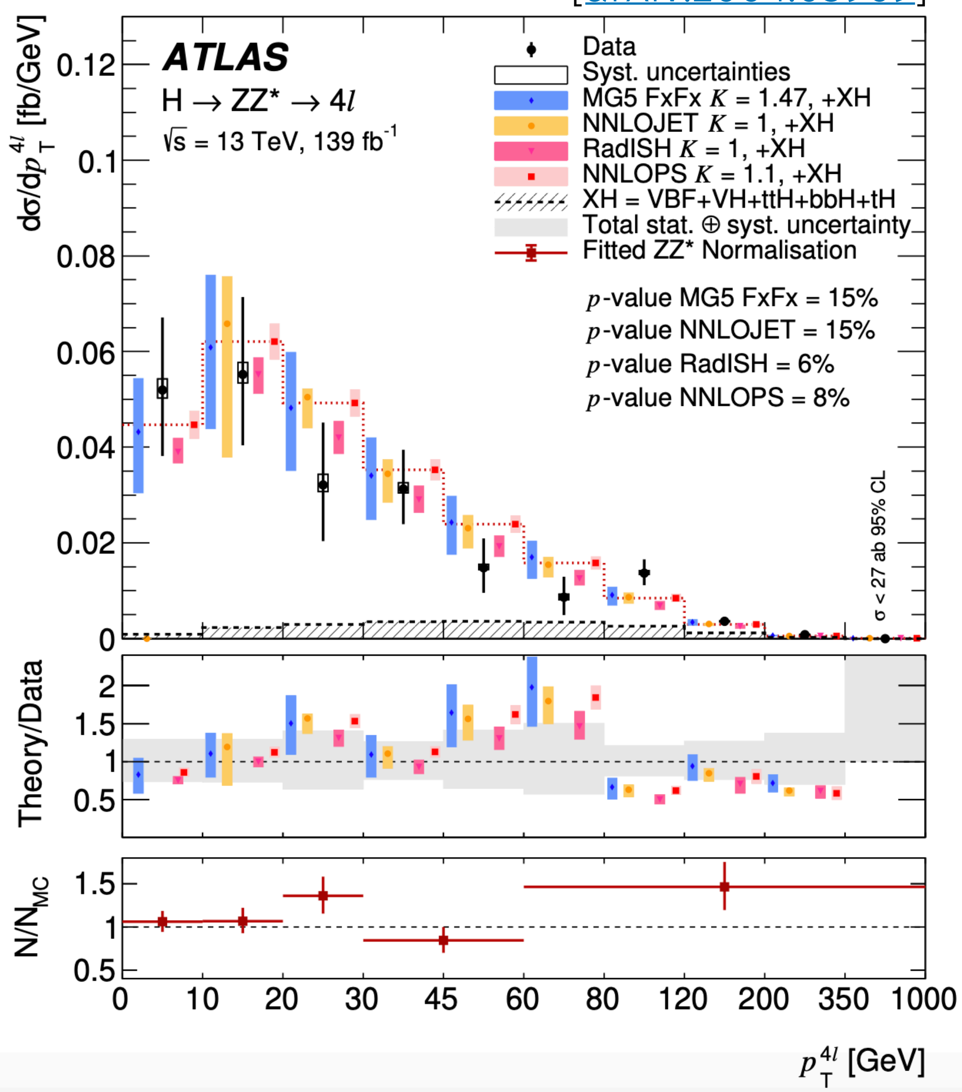
gg

Zγ

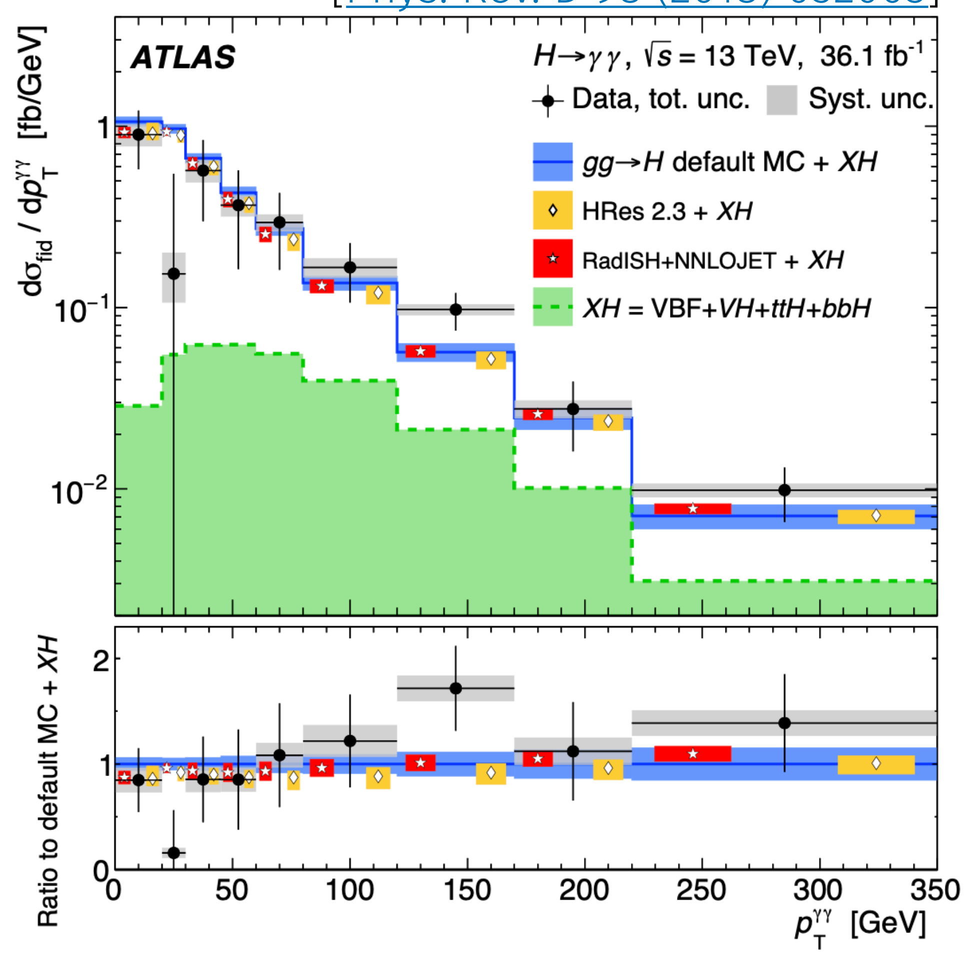
What do we know beyond signal strengths?

- Slowly going beyond inclusive quantities …

[arXiv:2004.03969]



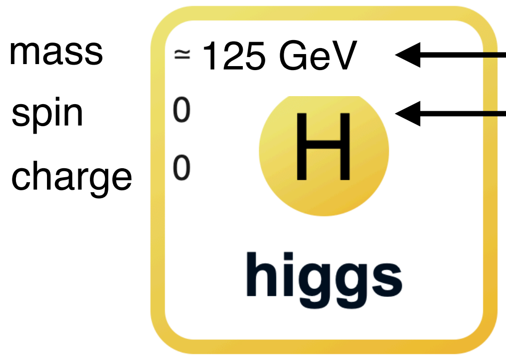
[Phys. Rev. D 98 (2018) 052005]



„Higgs boson“ transverse momentum

… but quite limited in energy reach with the golden channels

Puzzles in the Higgs sector



The (bare) Higgs mass is sensitive to higher mass scales

The Higgs boson is the only fundamental scalar particle

$+|D_\mu \phi|^2$ Are the structure/values of the couplings with the vector bosons as predicted by the SM? ⟶ Within ~ 10% precision, yes

$+y_{ij}\psi_i \phi \psi_j + \text{h.c.}$ Are the structure/values of the couplings with the fermions as predicted by the SM? ⟶ Within ~ 20% precision, yes for b and t

Does the Higgs boson also couple to second/first generation fermions?

$-\mu^2(\phi^\dagger \phi) - \lambda(\phi^\dagger \phi)^2$ Is there a deeper reason for the shape of the Higgs potential?

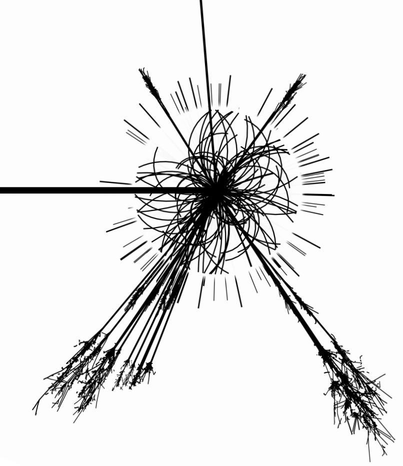
What is the exact shape?

How stable is the electroweak vacuum?

Is there only one Higgs boson?

\+ ...

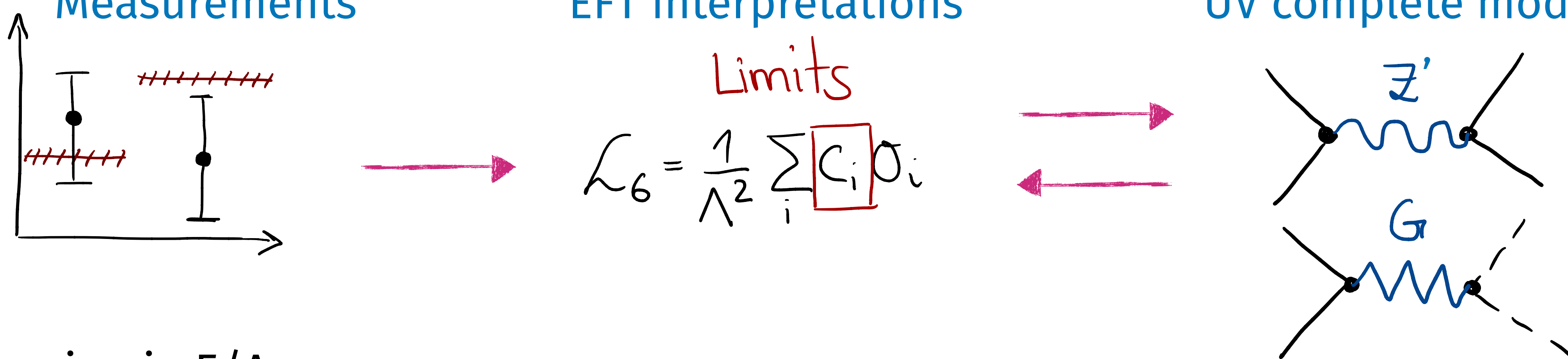
Generalized BSM searches with EFTs



- **Two fundamental assumptions:**
  - Scale of new physics Λ enters is **nearly decoupled** w.r.t. what we probe a.t.m.
  - At our accessible scale **only** the light d.o.f. (**SM fields + symmetries**) contribute

→ Allows a **systematic classification of BSM effects** without knowledge of the actual UV model

Measurements | EFT interpretations | UV complete models



Taylor expansion in E/Λ:

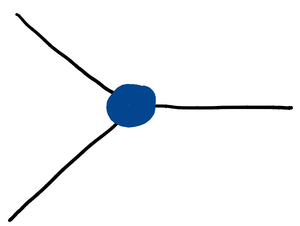
$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \frac{1}{\Lambda}\mathcal{L}_5 + \frac{1}{\Lambda^2}\mathcal{L}_6 + \frac{1}{\Lambda^3}\mathcal{L}_7 + \frac{1}{\Lambda^4}\mathcal{L}_8 + \ldots$$

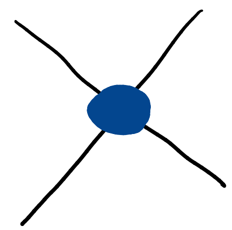
	$\mathcal{L}_5$	$\mathcal{L}_6$	$\mathcal{L}_7$	$\mathcal{L}_8$	
# operators:	12	2499	948	36971	[N_f = 3]
	(2)	(79)	(22)	(895)	[N_f = 1]

The case for higher energy reach

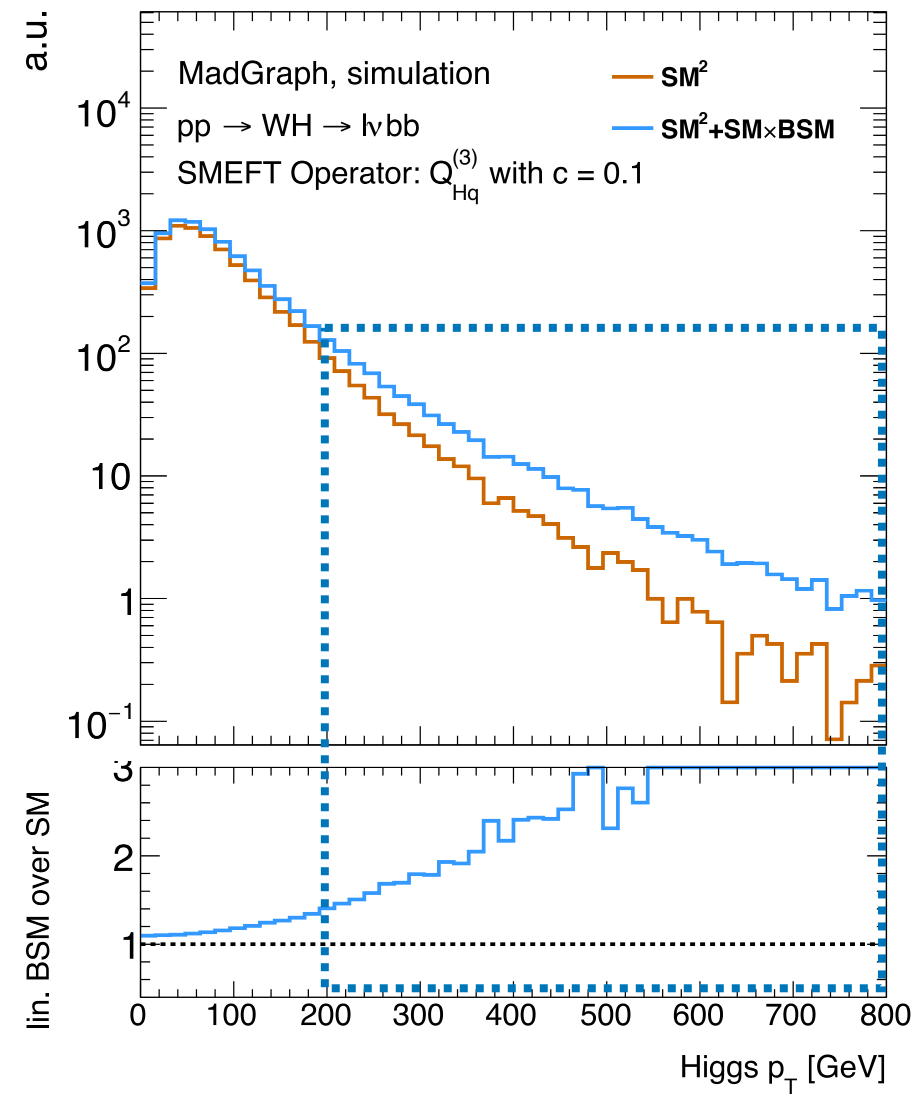
- Using the general SMEFT approach to look for BSM, two ingredients play a key role:

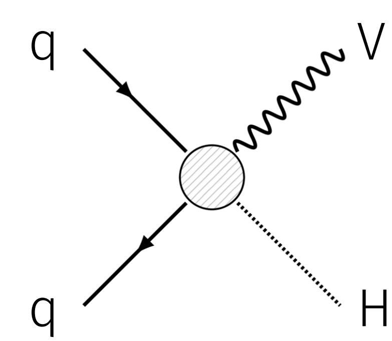
Precision vs. **Energy**





tight constraints in the electroweak sector from LEP





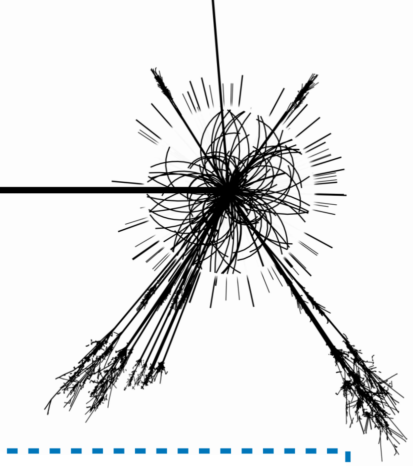
Consider a E² dependent deviation from SM

$$0.3\% \ @ \ 100\,\text{GeV} \quad \sim \quad 30\% \ @ \ 1\,\text{TeV}$$

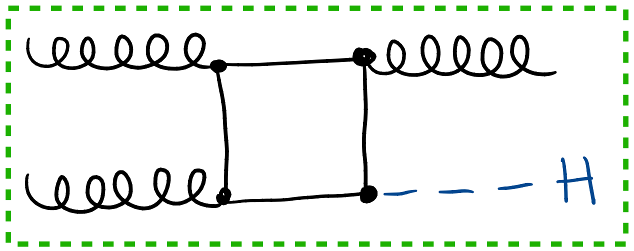
We can use the energy growth of BSM to probe regimes comparable to the ones accessible with precision machines

This talk: Focus on the Higgs sector, the least known part of the SM with a lot of puzzling (yet-to-be understood) features

How to reach high momentum Higgs bosons?



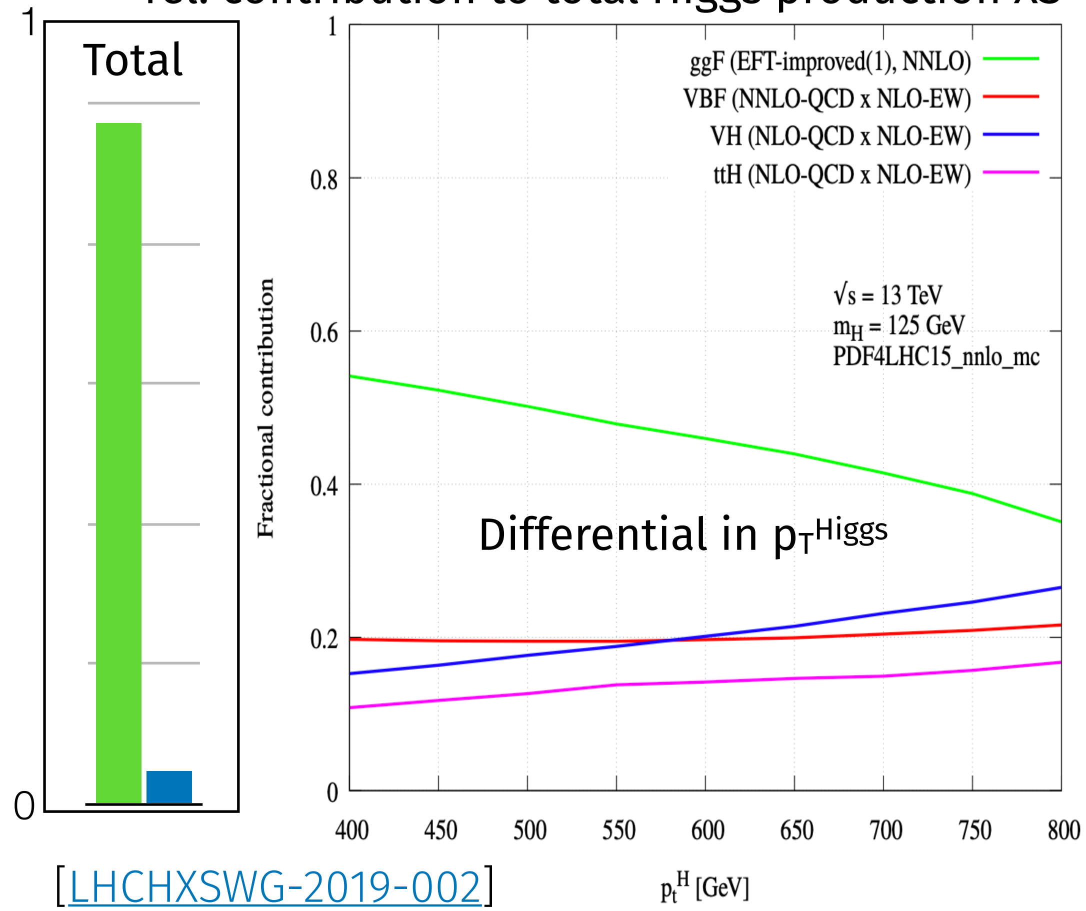
- Focus on $H \rightarrow bb$ decay as it has the largest BR of ~ 58%
- Which production channel?



Gluon-**G**luon **F**usion:

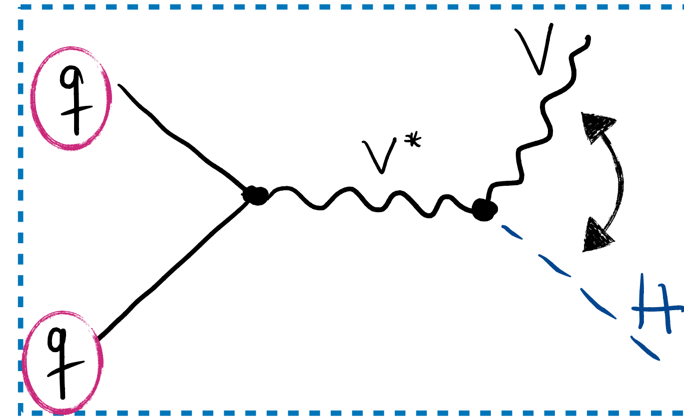
- Huge cross-section
- Huge multi-jet background
- Triggering on high p_T jets possible
- Interesting full Run-2 result by CMS with 2.5 σ sensitivity + excess at high jet p_T

[CMS-PAS-HIG-19-003]



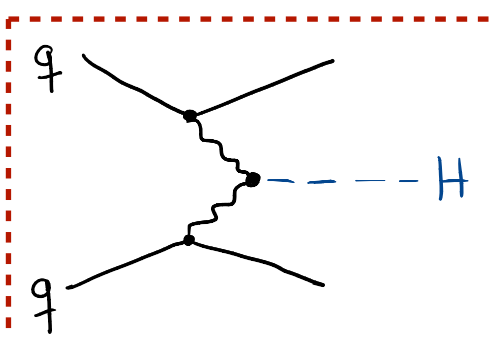
[LHCHXSWG-2019-002]

this talk



Higgs Strahlung (**VH**):

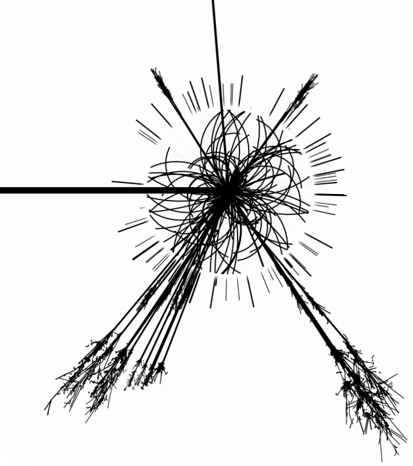
- Lower overall cross-section
- Exploit leptonic V decays to trigger and improve S/B
- The main Hbb search channel
- $p_T^H > 0$ at LO already, only limited by PDF suppression
- Harder p_T^H spectrum than Σ bkgs

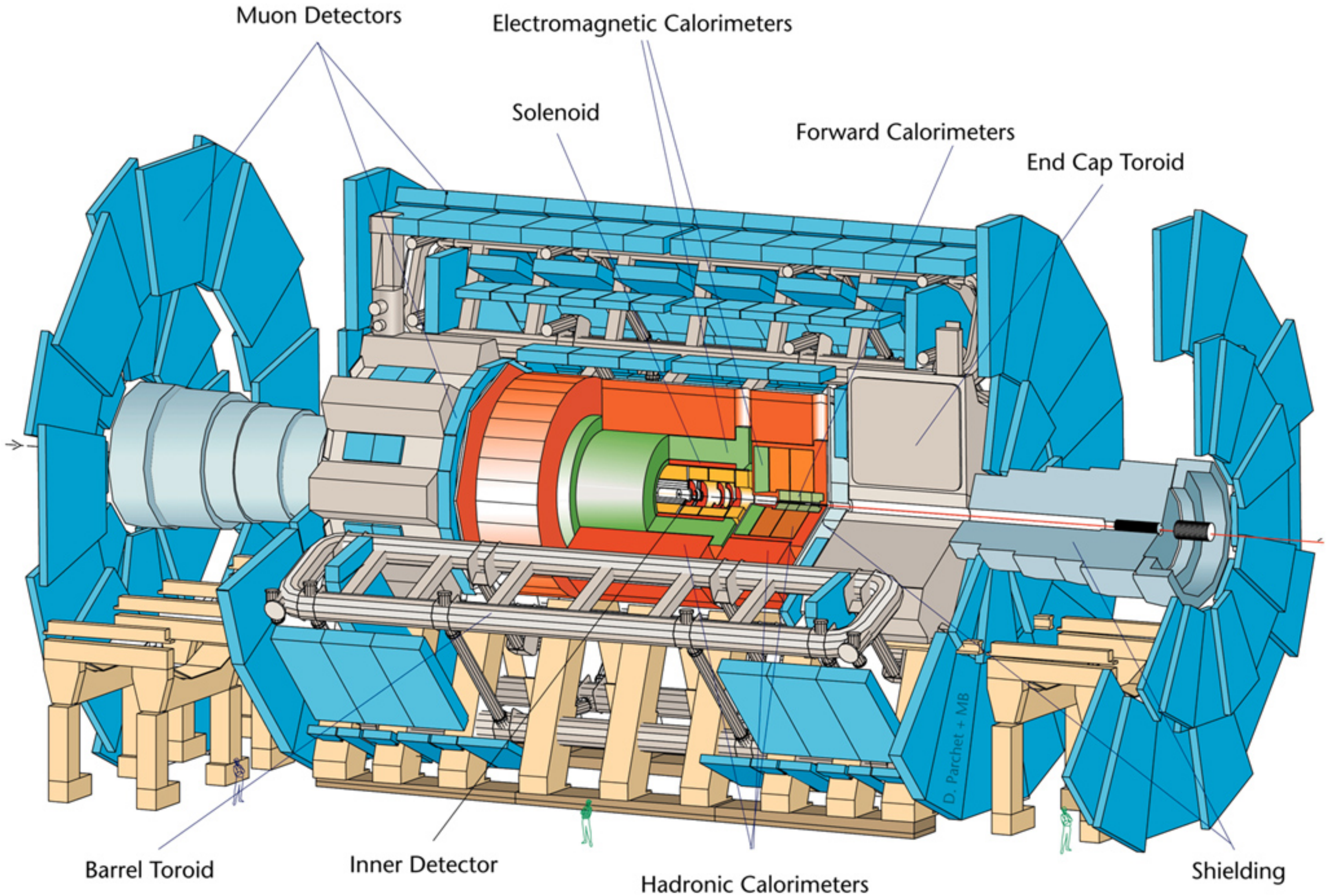


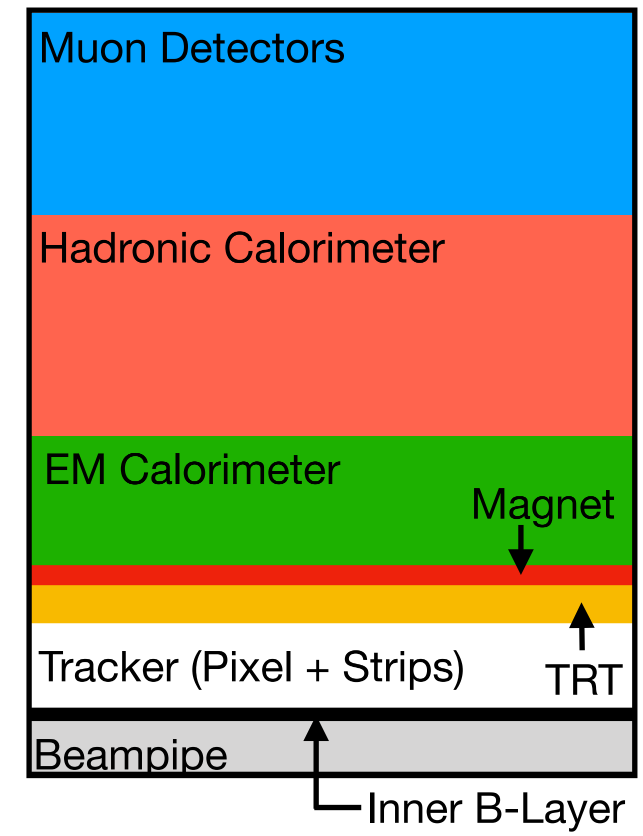
Vector **B**oson **F**usion:

- Large cross-section
- Large multi-jet background
- Fully hadronic final state

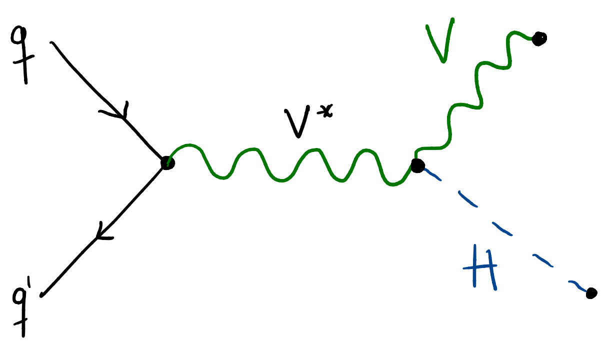
The ATLAS detector



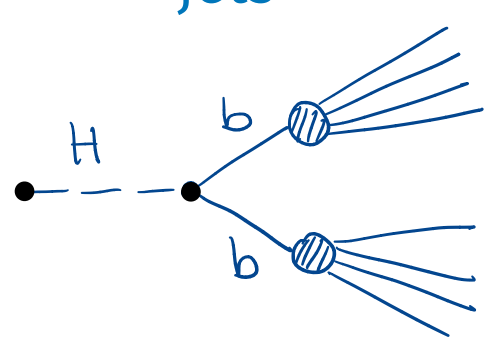




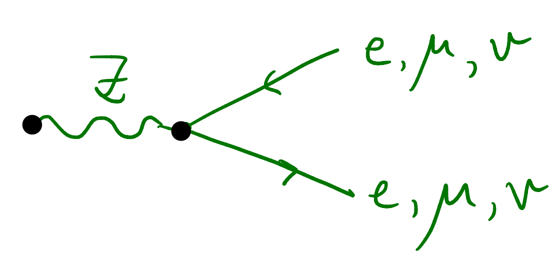
Signal signatures:

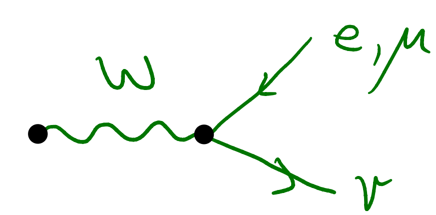


jets



electrons, muons, neutrinos





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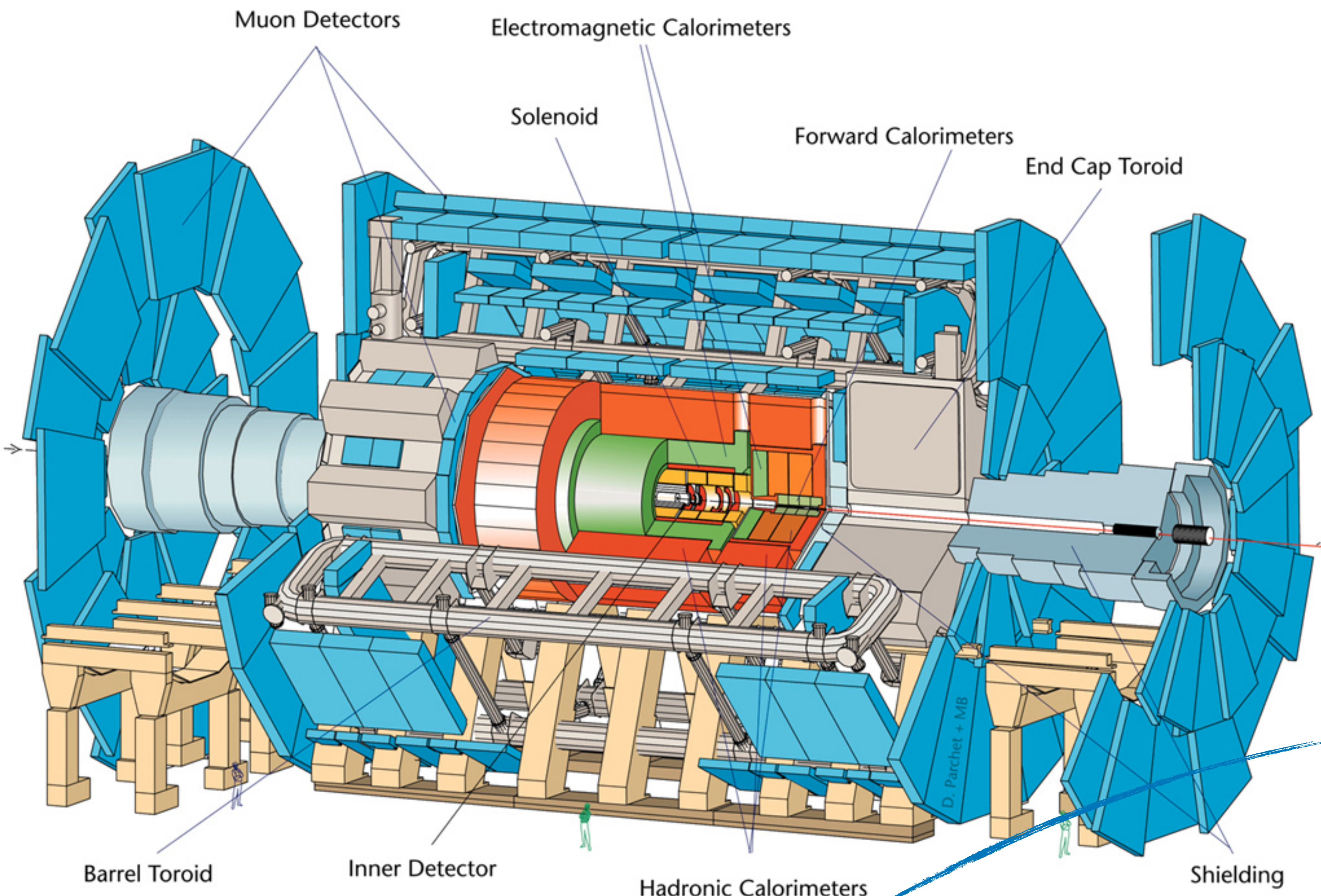
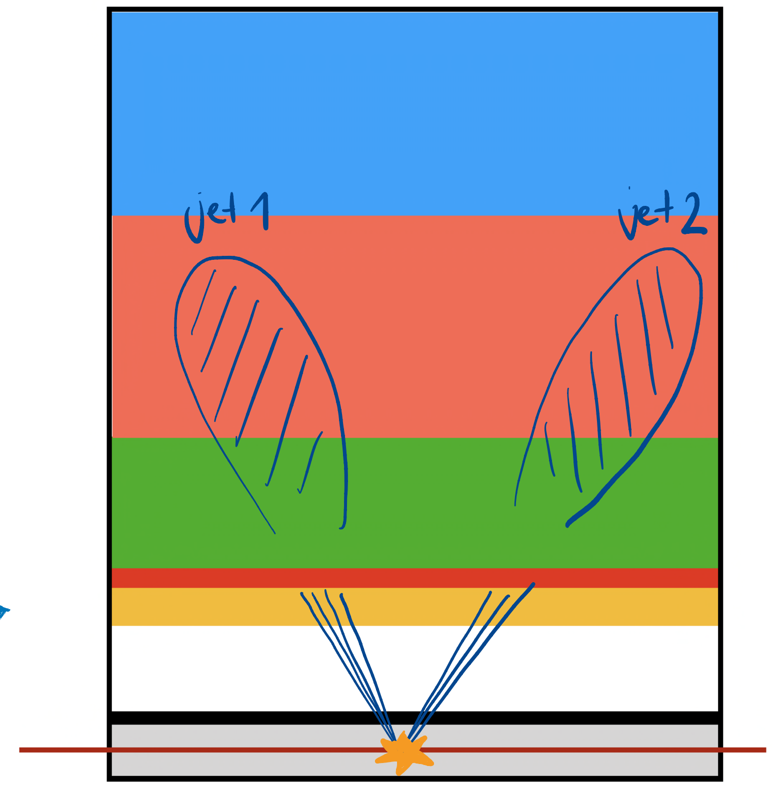
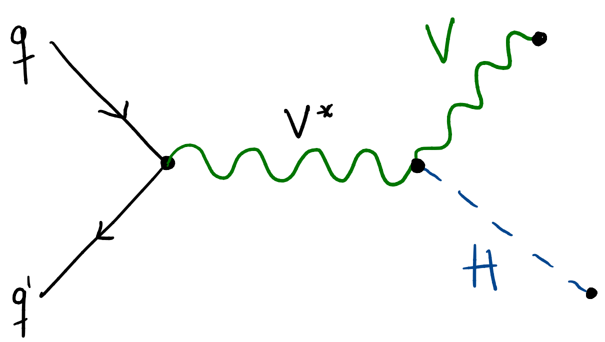
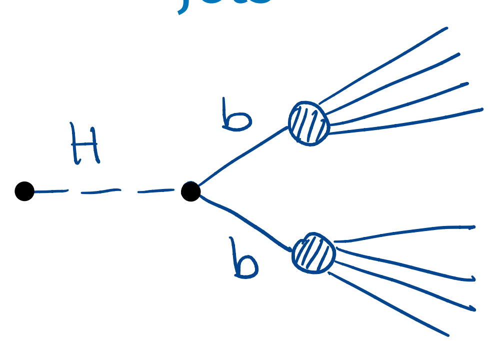




Signal signatures:

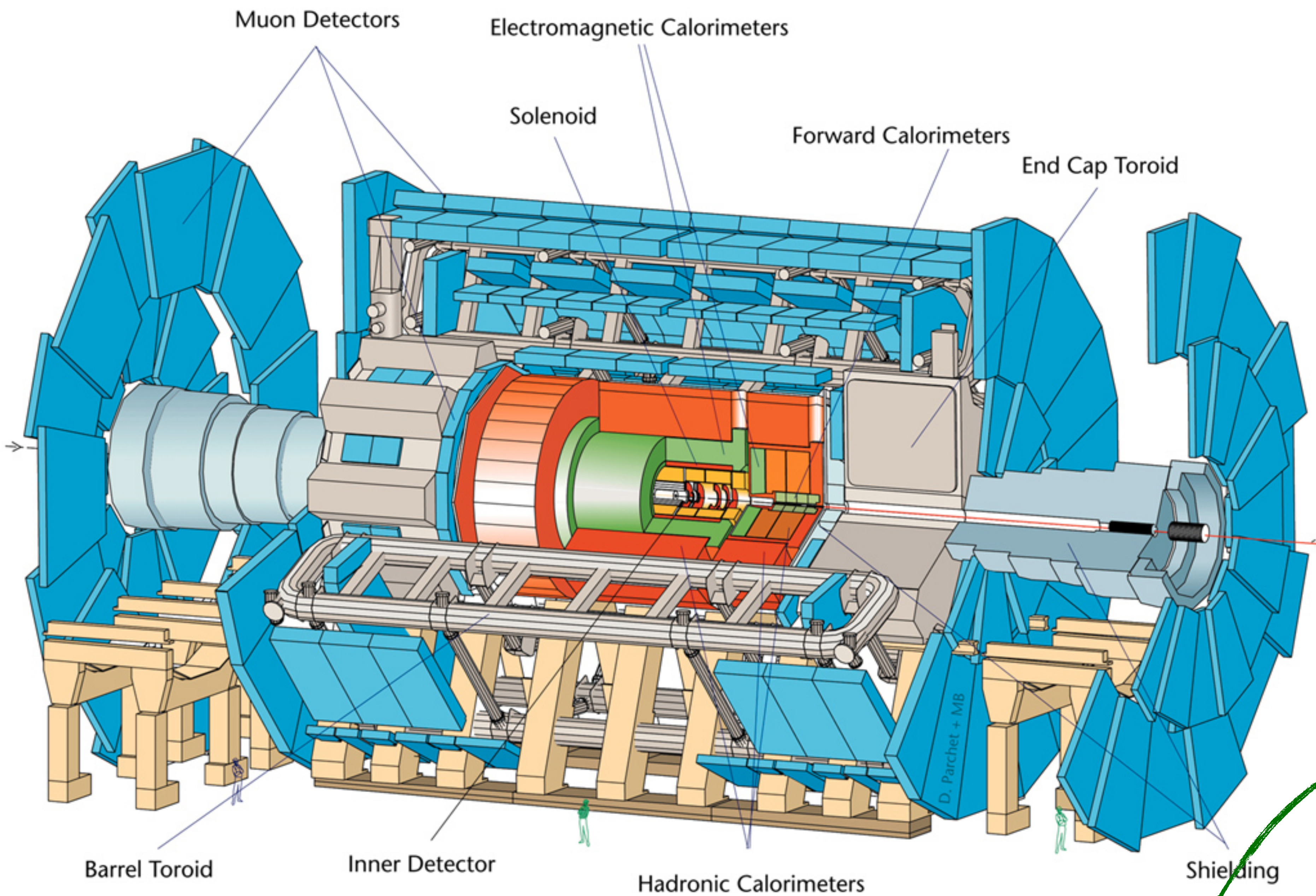


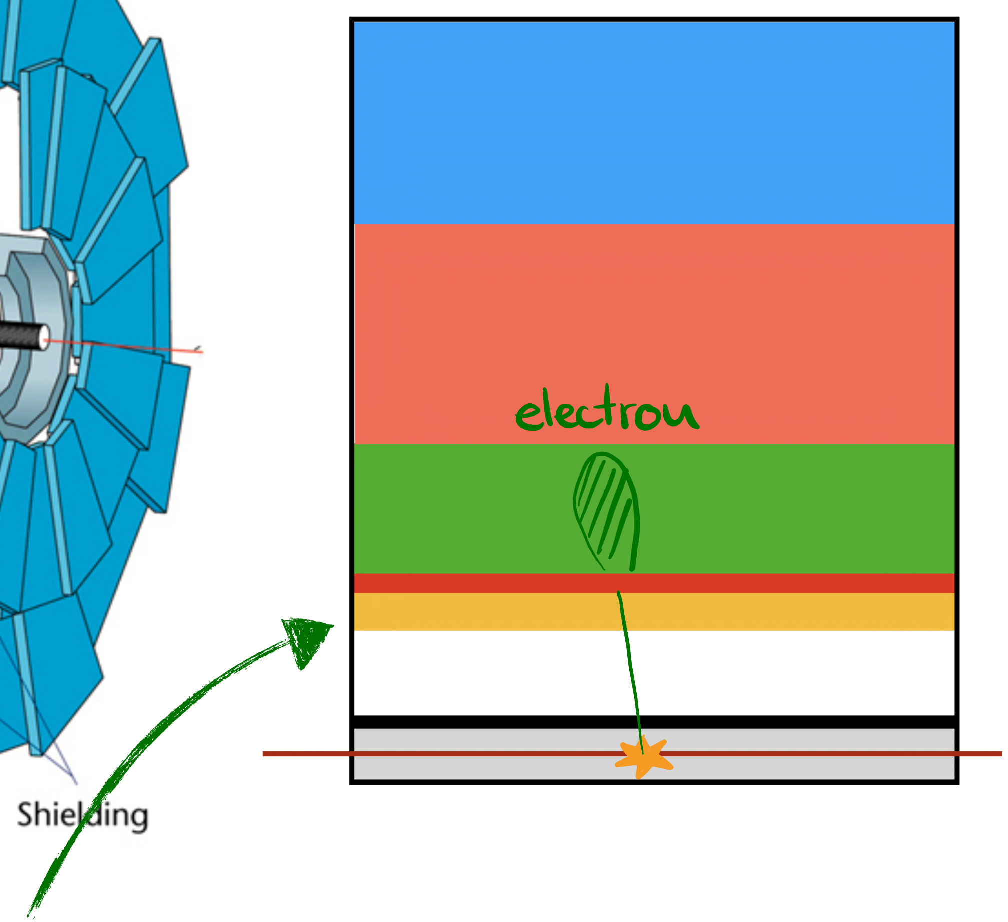
jets



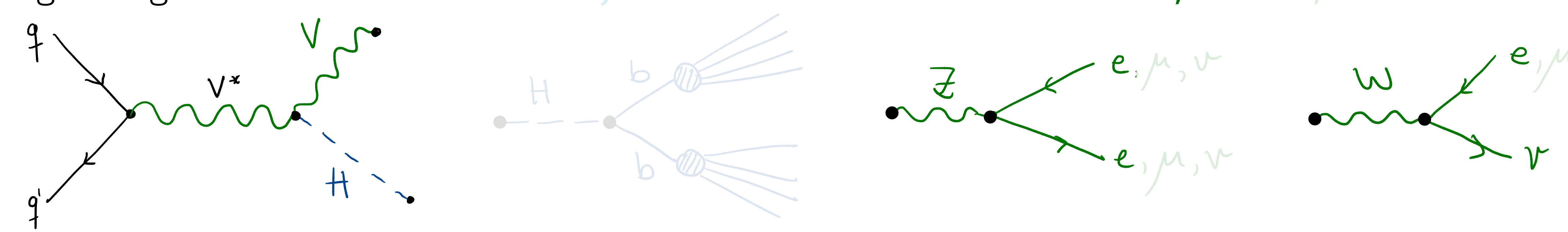
electrons, muons, neutrinos

The ATLAS detector

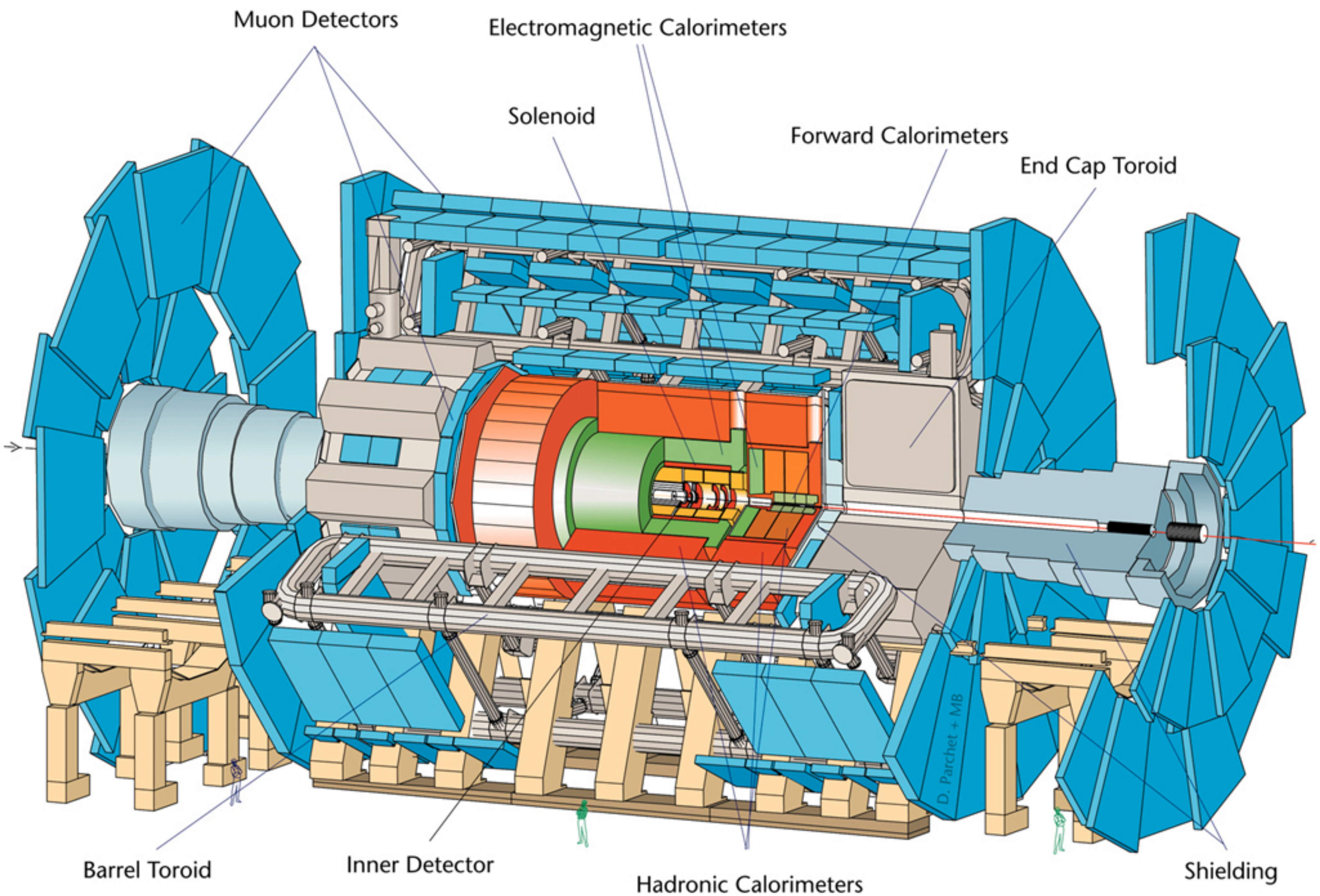


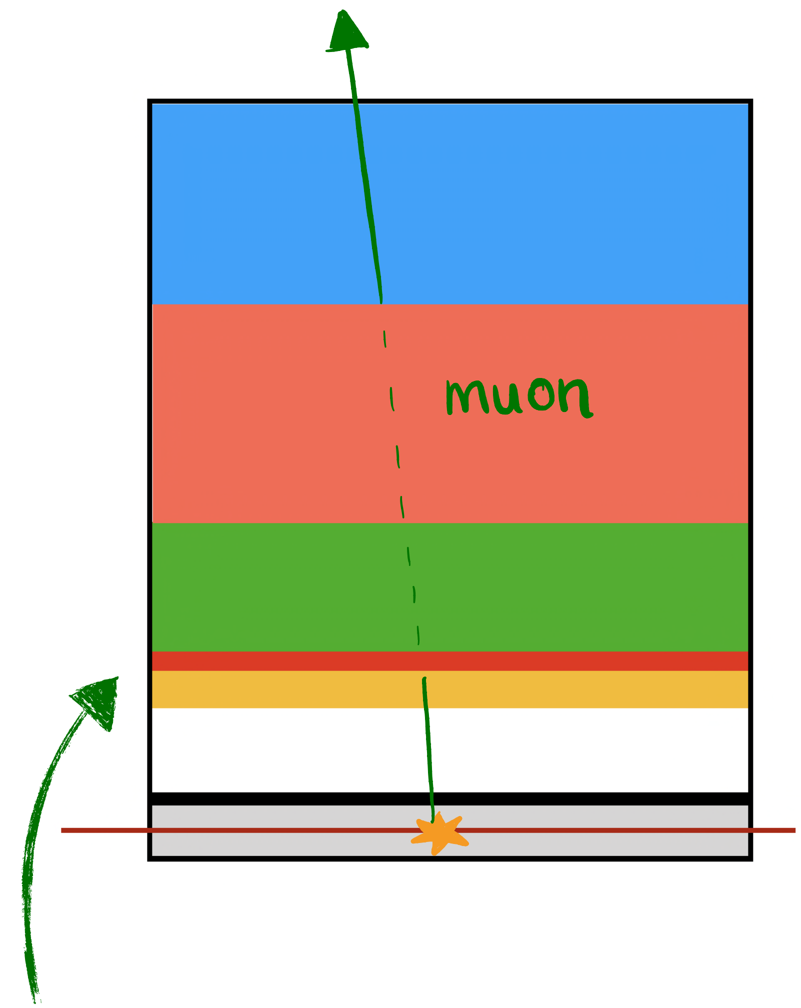


Signal signatures: jets electrons, muons, neutrinos

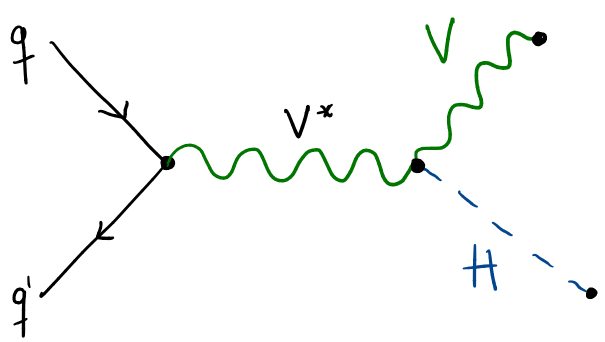


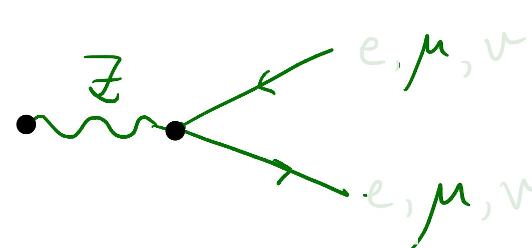
The ATLAS detector

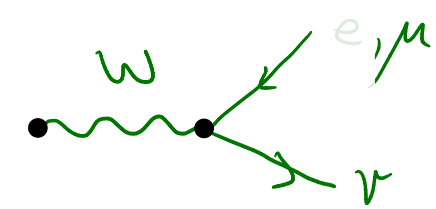




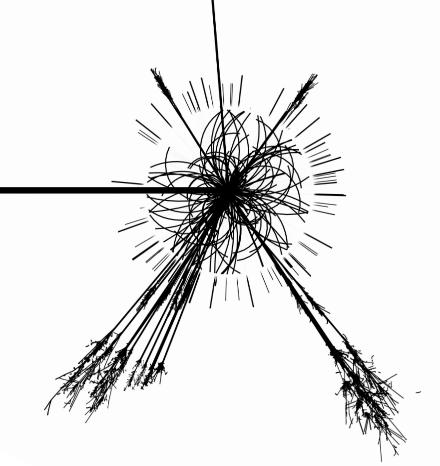
Signal signatures: jets electrons, **muons,** neutrinos

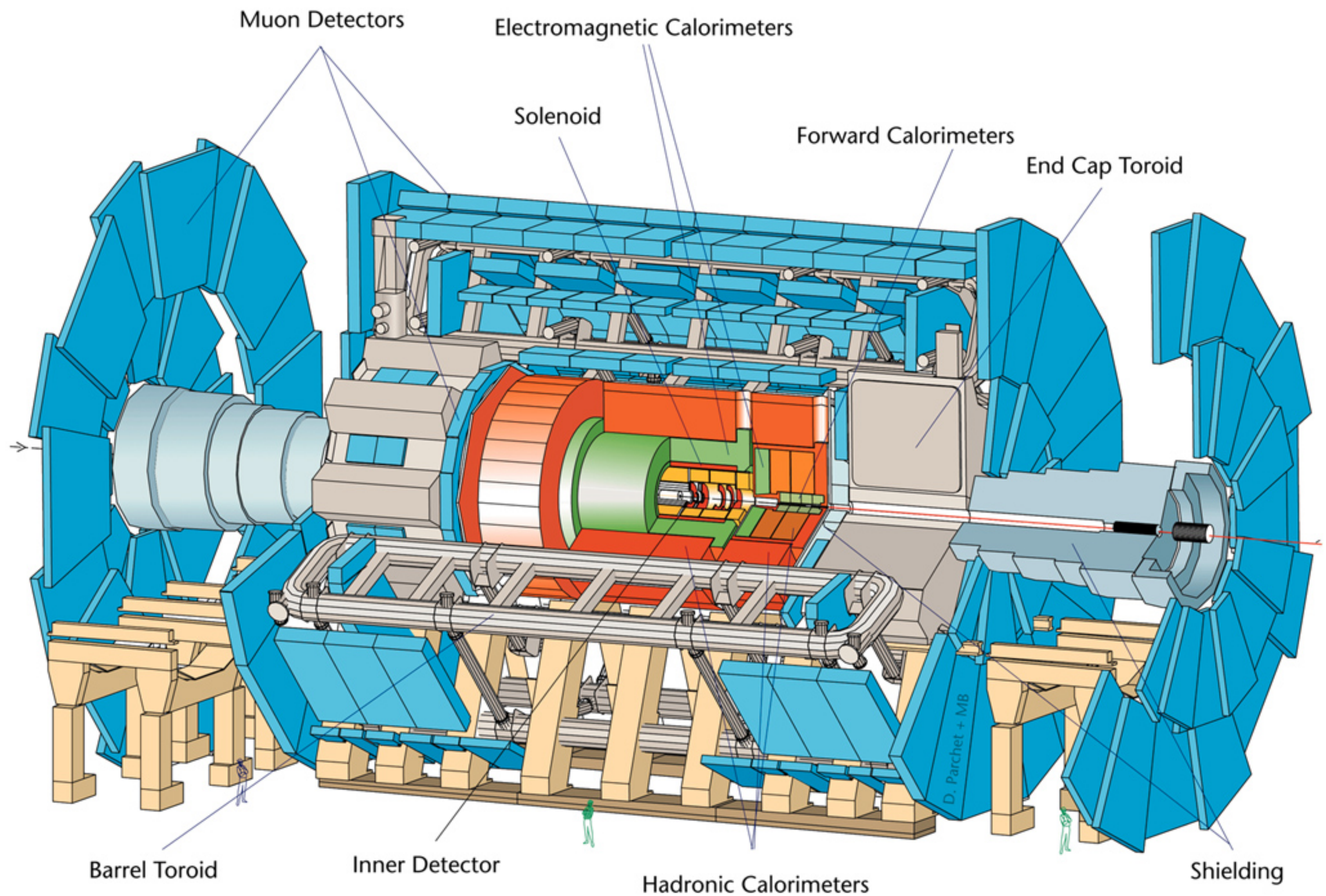


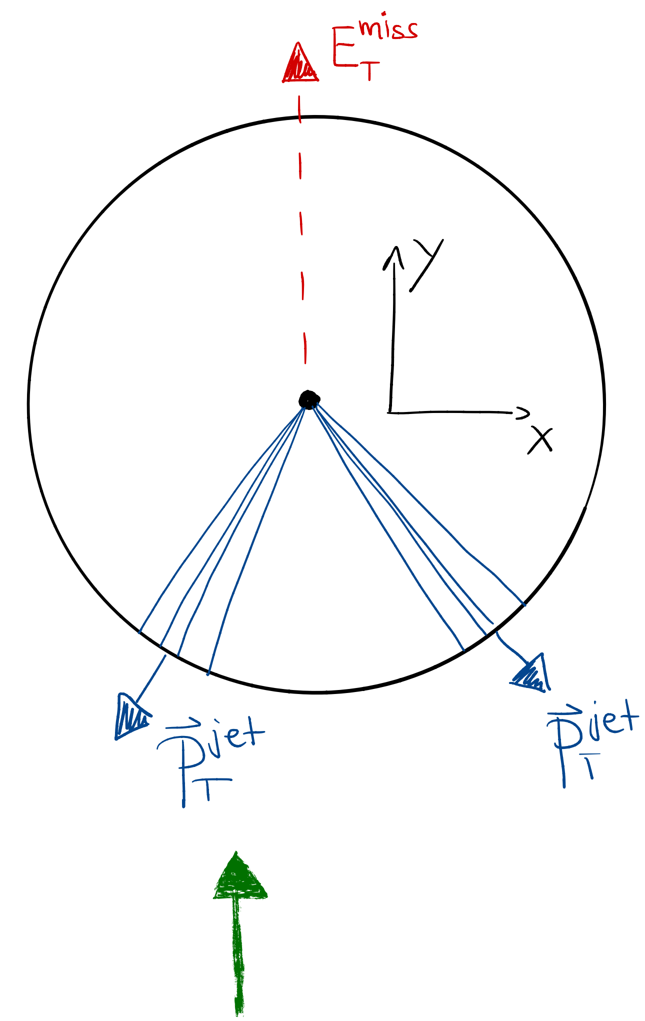




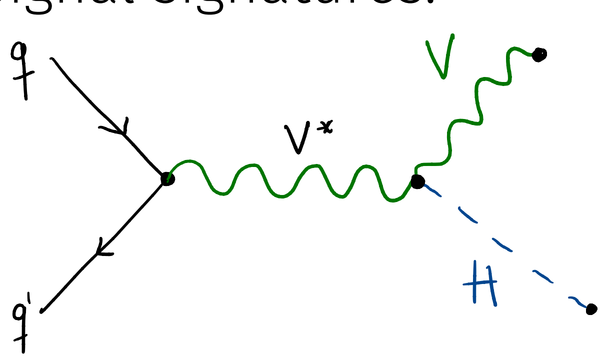
The ATLAS detector

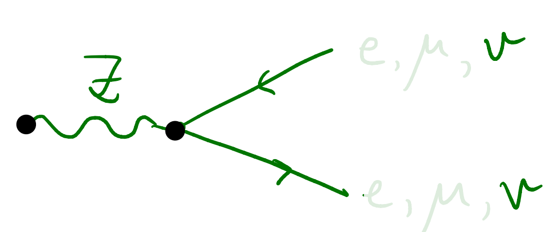


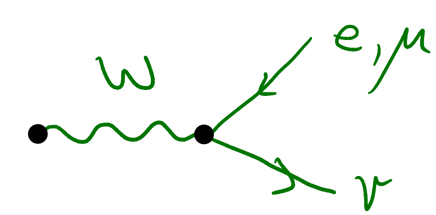




Signal signatures: jets electrons, muons, **neutrinos**

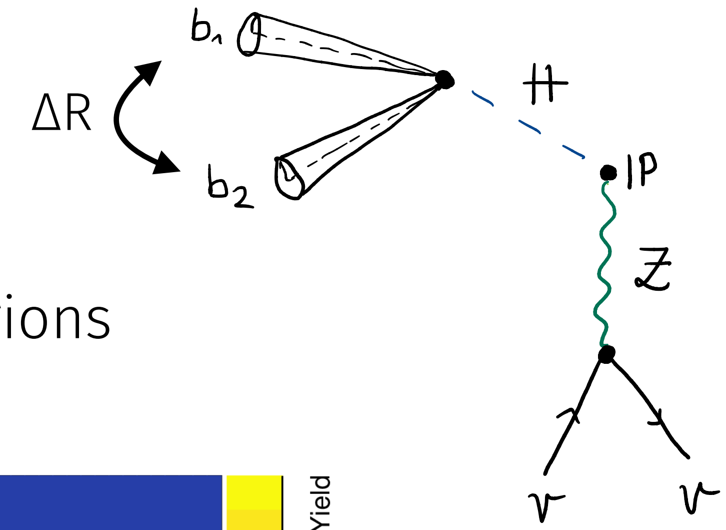




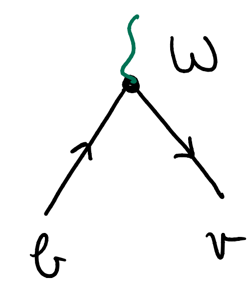


The „resolved“ VHbb analysis in a nutshell (1/2)

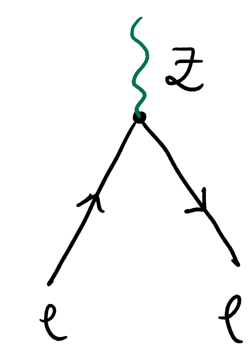
- Classify the events according to the charged lepton multiplicity
- Categorize in regions of p_T^V (signal harder than sum of all bkgs)
  (75-150 GeV) 150-250 GeV >250 GeV
- Use jet angular separation $\Delta R(b_1, b_2)$ to define signal and control regions



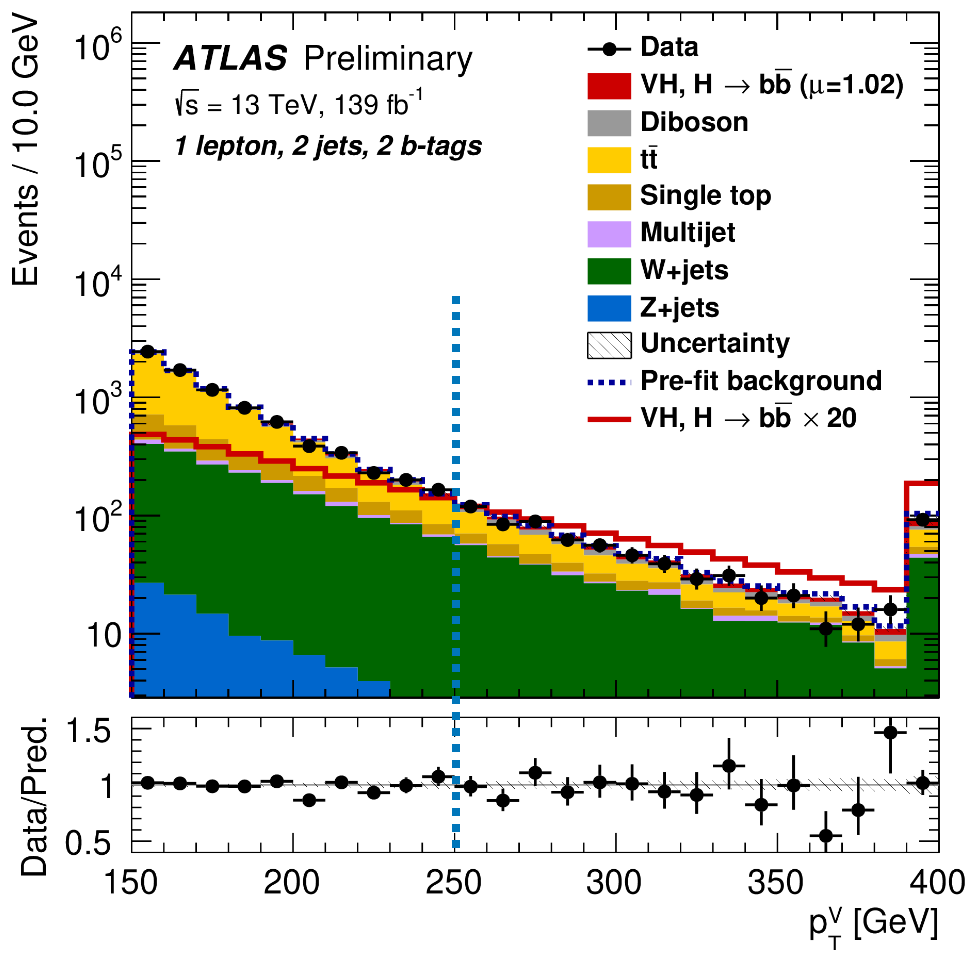
0-lepton



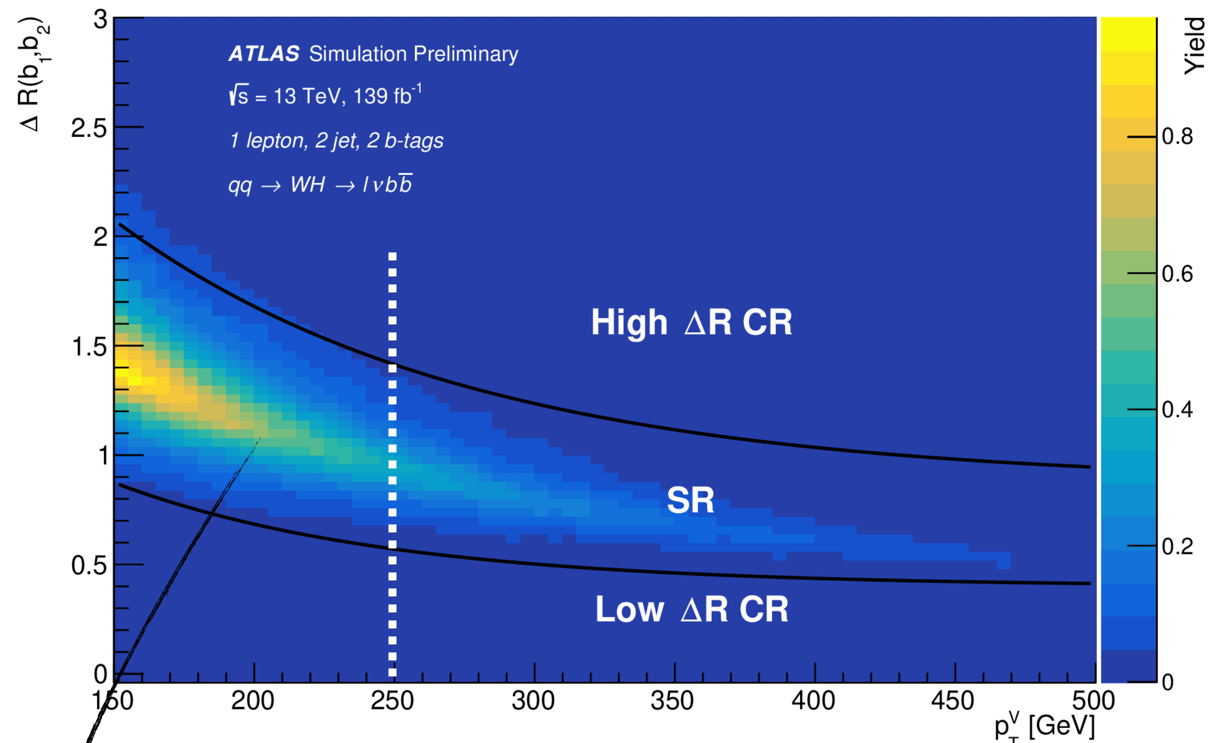
1-lepton



2-lepton



[additional split in jet multiplicity]



- High ΔR CR: enriched in tt background
- Low ΔR CR: enriched in V+bb

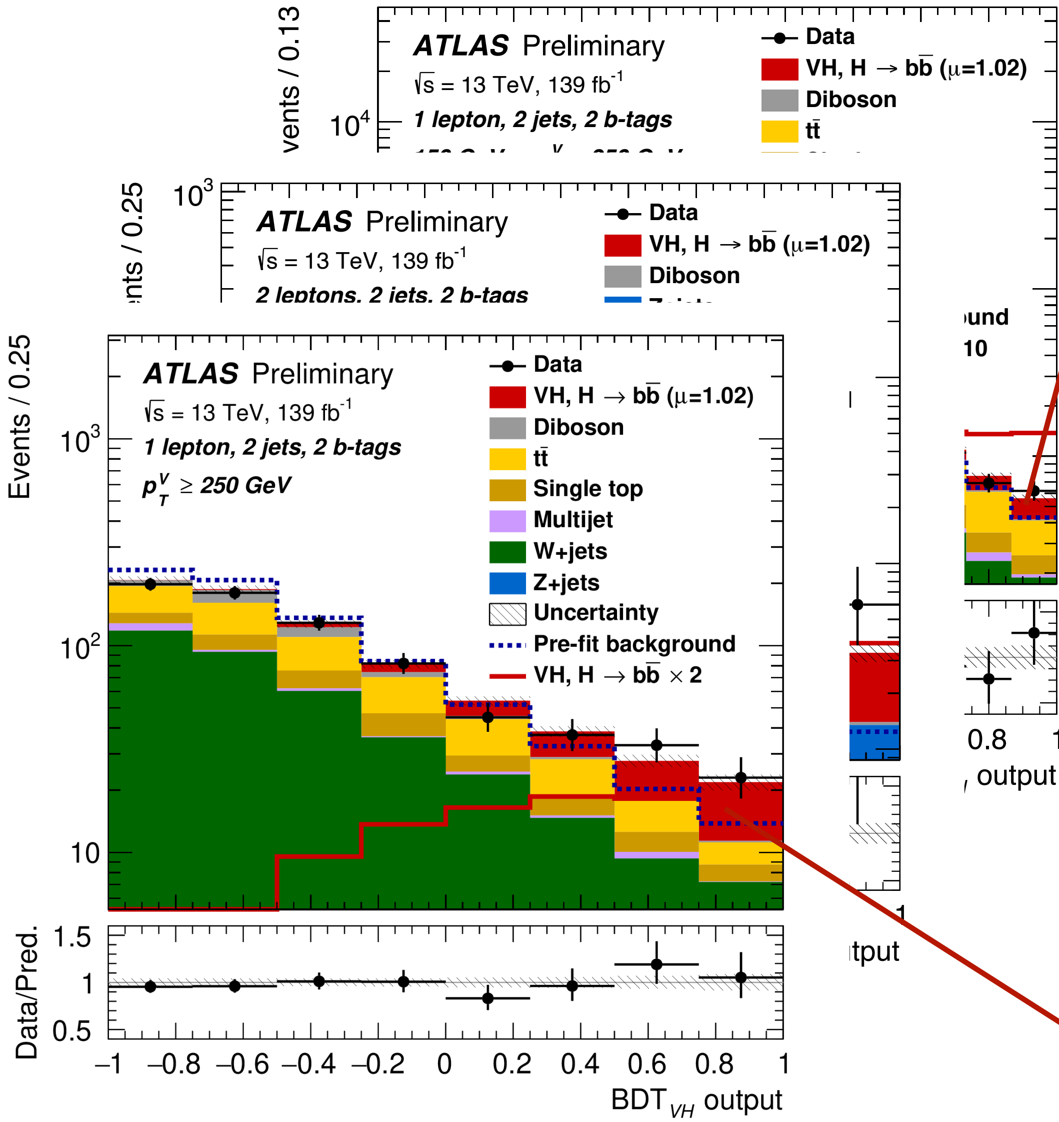
contains > 80-90% of the signal (1-lepton)

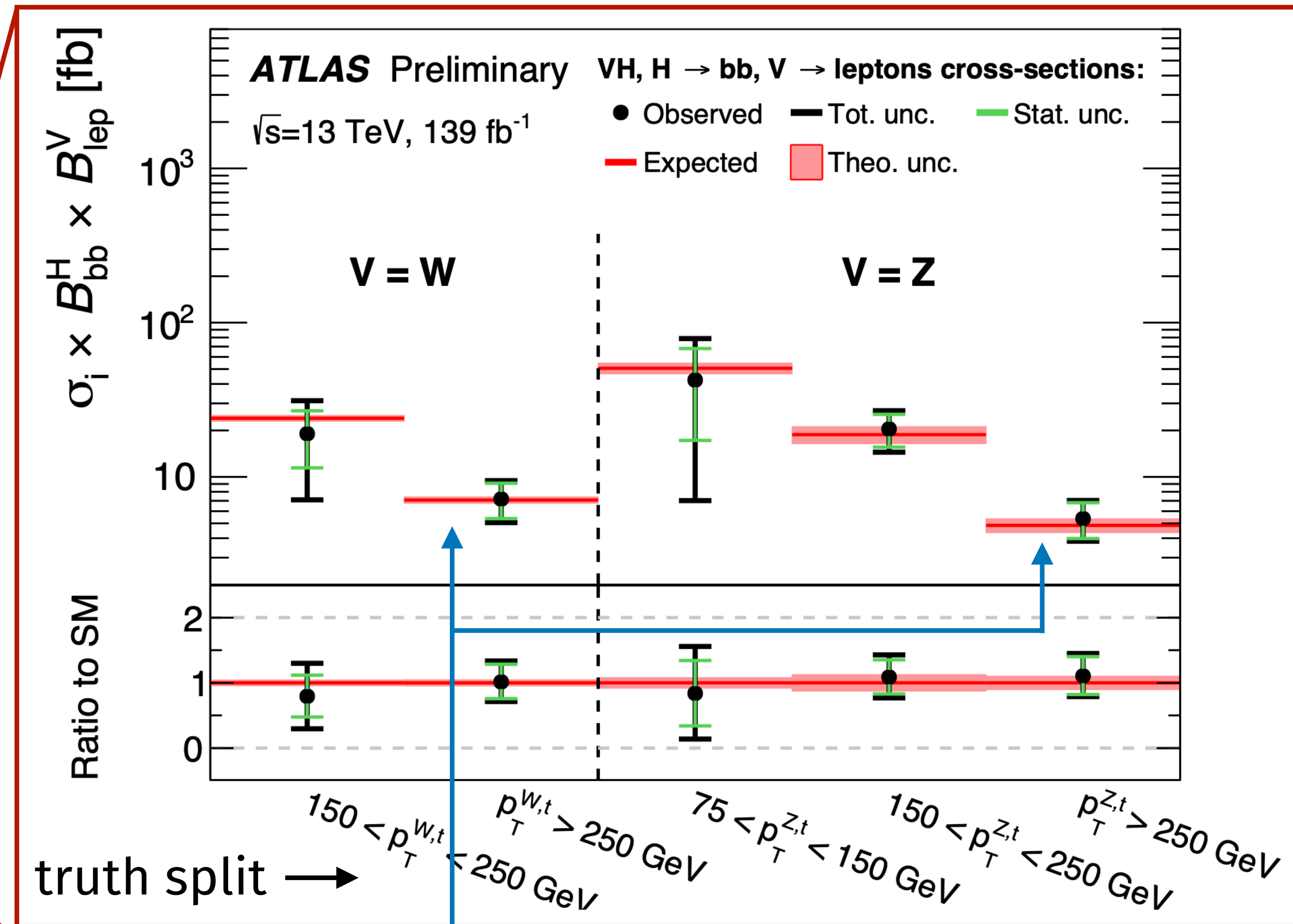
As expected, signal moves to lower ΔR with higher p_T^V

[ATLAS-CONF-2020-006]

The „resolved“ VHbb analysis in a nutshell (2/2)

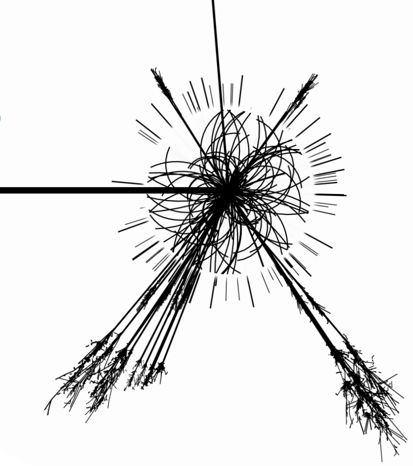
- A BDT is trained to discriminate signal from background, combining O(10) input variables
- The BDT score is fit simultaneously in each region to extract the signal





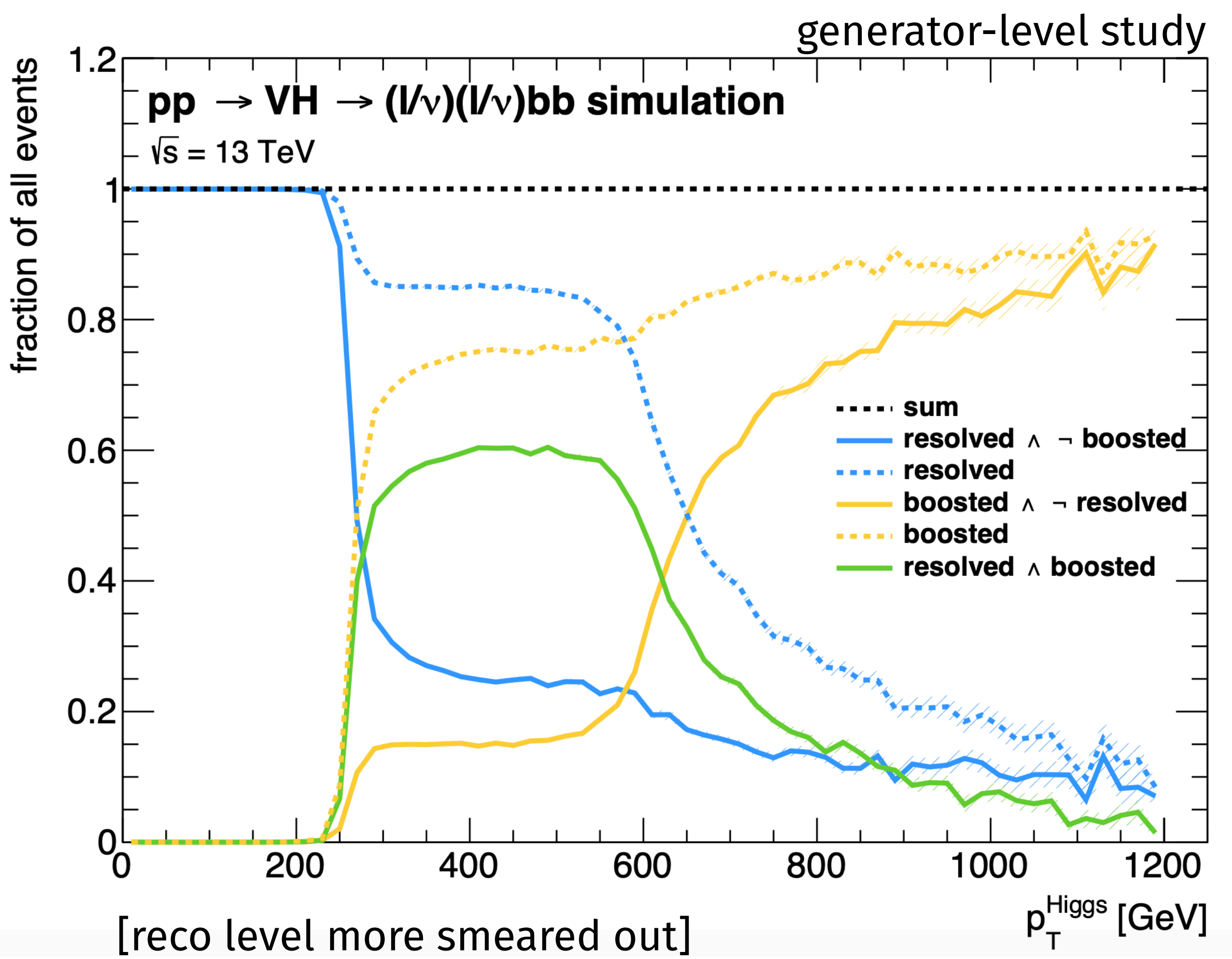
What is happening in the regime beyond?

[ATLAS-CONF-2020-006]

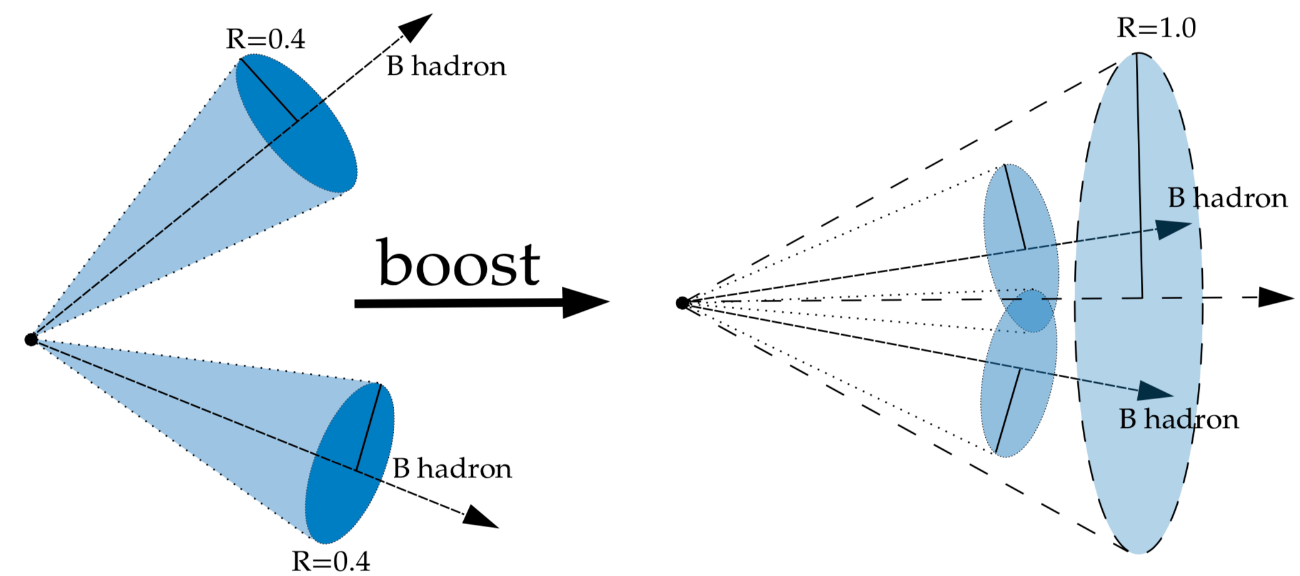


- H→bb is a simple 1→2 decay: In LO defined by m^{Higgs} and p_T^{Higgs}
- Rule of thumb: $\Delta R(b_1, b_2) \sim \frac{2m^{\text{Higgs}}}{p_T^{\text{Higgs}}}$
- Reconstructing the Higgs system with **two anti-k_T (R=0.4) jets** gets less efficient at p_T^{Higgs} ~ 550 GeV

⟶ **New paradigm:** Reconstruct the Higgs decay by using a single anti-k_T (R=1.0) jet



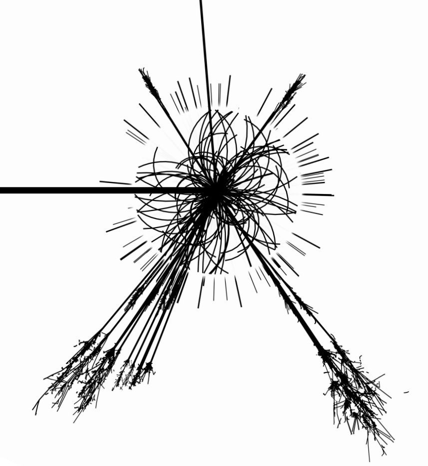
[reco level more smeared out]



The event is reconstructable:

- resolved and not boosted
- both resolved and boosted
- boosted and not resolved

p_T limitations and the need for new techniques



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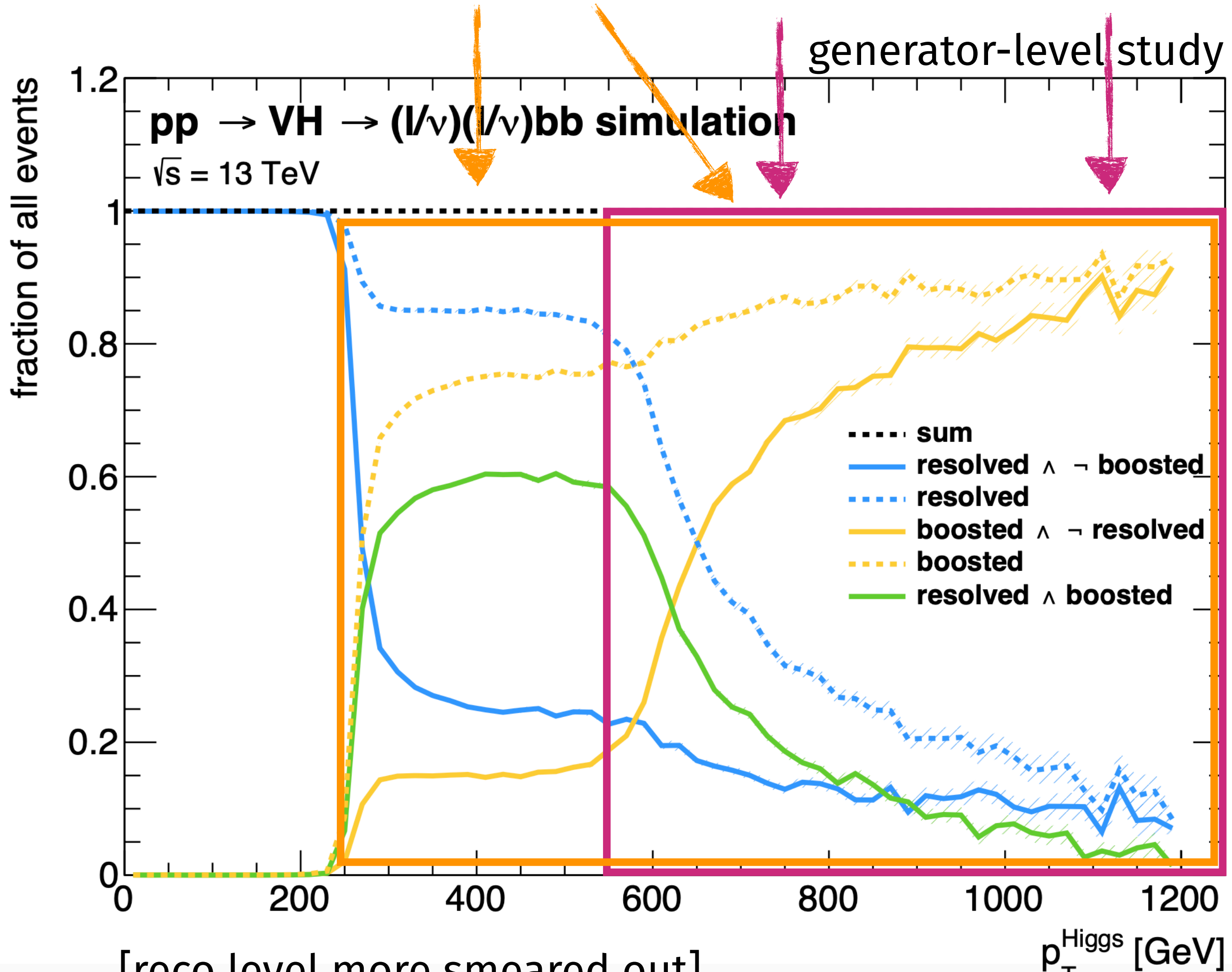
⟶ **New paradigm:** Reconstruct the Higgs decay by using a single anti-k_T (R=1.0) jet

This is where we test it **This is where we absolutely need it**



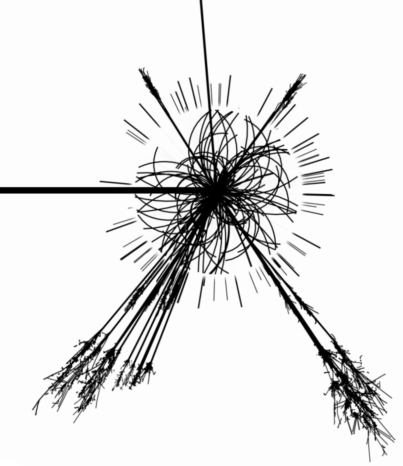
[reco level more smeared out]

- Robust analysis, proof of principle: **„we can do a Higgs measurement using boosted techniques“**
- Do not remove the overlap with resolved VHbb analysis

The event is reconstructable:

- resolved and not boosted
- both resolved and boosted
- boosted and not resolved

From first ideas to the first measurement



Jet substructure as a new Higgs search channel at the LHC **2008**

Jonathan M. Butterworth, Adam R. Davison
Department of Physics & Astronomy, University College London.

Mathieu Rubin, Gavin P. Salam
LPTHE; UPMC Univ. Paris 6; Univ. Denis Diderot; CNRS UMR 7589; Paris, France.

It is widely considered that, for Higgs boson searches at the Large Hadron Collider, WH and ZH production where the Higgs boson decays to $b\bar{b}$ are poor search channels due to large backgrounds. We show that at high transverse momenta, employing state-of-the-art jet reconstruction and decomposition techniques, these processes can be recovered as promising search channels for the standard model Higgs boson around 120 GeV in mass.

ATLAS PUBLIC NOTE

August 19, 2009 **2009**

ATLAS Sensitivity to the Standard Model Higgs in the HW and HZ Channels at High Transverse Momenta

Boosted Higgs $\to b\bar{b}$ in vector-boson associated production at 14 TeV **2015**

Jonathan M. Butterworth, Inês Ochoa, Tim Scanlon
Department of Physics and Astronomy, University College London,
Gower St., London, WC1E 6BT, UK

[ATLAS-CONF-2020-007]

ATLAS CONF Note
ATLAS-CONF-2020-007
11th April 2020

Measurement of the associated production of a Higgs boson decaying to b quarks with a vector boson at high transverse momentum in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

The ATLAS Collaboration

The associated production of a Higgs boson with a W or Z boson decaying to leptons and where the Higgs boson decays to a $b\bar{b}$ pair is measured in the high vector boson transverse momentum regime, above 250 GeV, with the ATLAS detector. The analysed data, corresponding to an integrated luminosity of 139 fb^{-1}, were collected in proton–proton collisions at the Large Hadron Collider between 2015 and 2018 at a centre-of-mass energy of $\sqrt{s}$ = 13 TeV. The measured signal strength, defined as the ratio of the measured signal yield to that predicted by the Standard Model, is $0.72^{+0.39}_{-0.36}$ corresponding to an observed (expected) significance of 2.1 (2.7) standard deviations. Fiducial cross-sections are measured in two ranges of gauge boson transverse momentum, 250 – 400 GeV and above 400 GeV, according to region definitions of the simplified template cross-section framework.

ATLAS-CONF-2020-007
11 April 2020

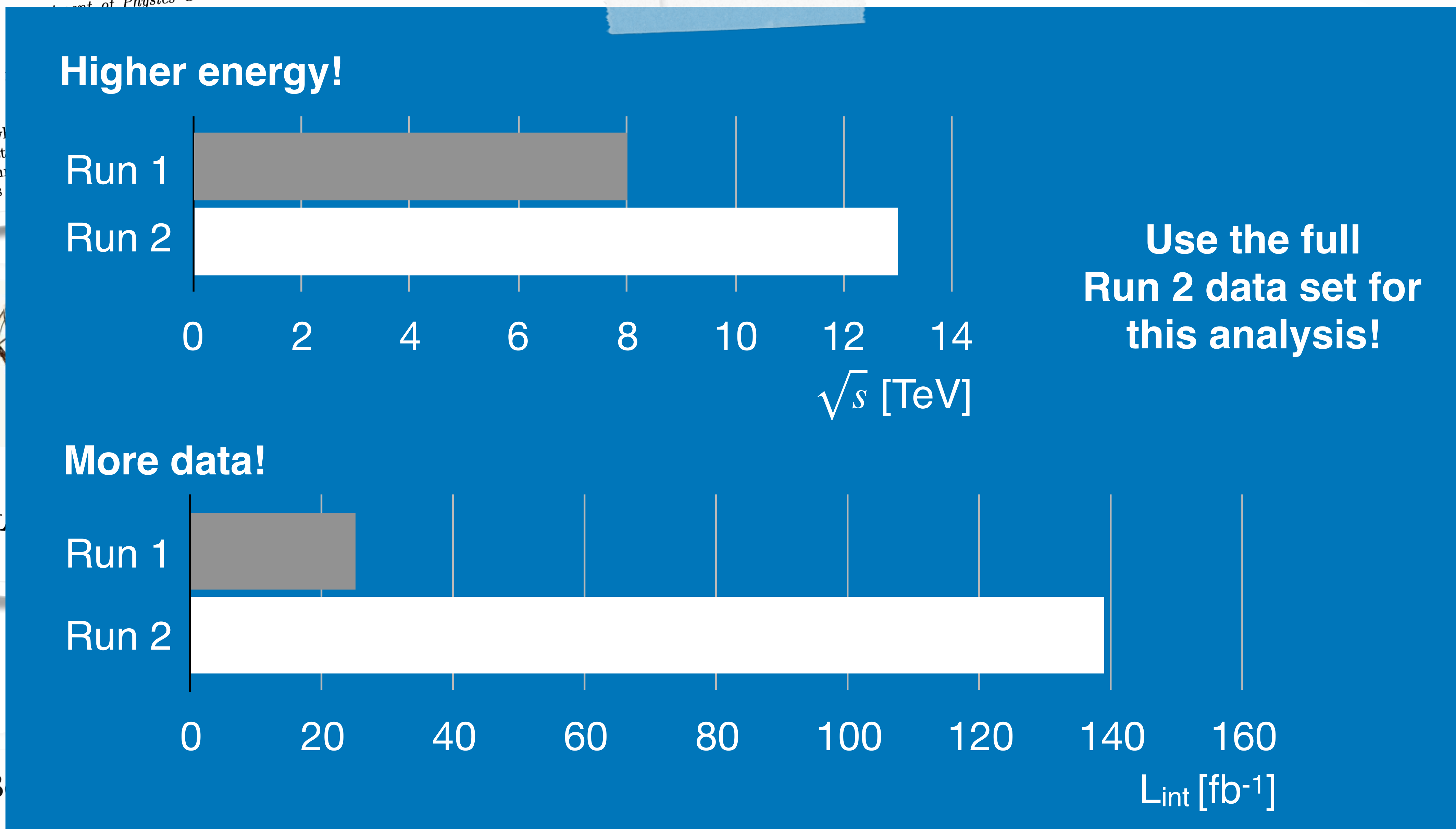
From first ideas to the first measurement

Jet substructure as a new Higgs search channel at the LHC
Jonathan M. Butterworth, Adam R. Davison
University College London.
LPTHE;
CERN
Jonathan M. Butterworth, Inês Ochoa, Tim Scanlon
Department of Physics and Astronomy, University College London,
Gower St., London, WC1E 6BT, UK

2008

With the increasing LHC data set…

-2020-007]

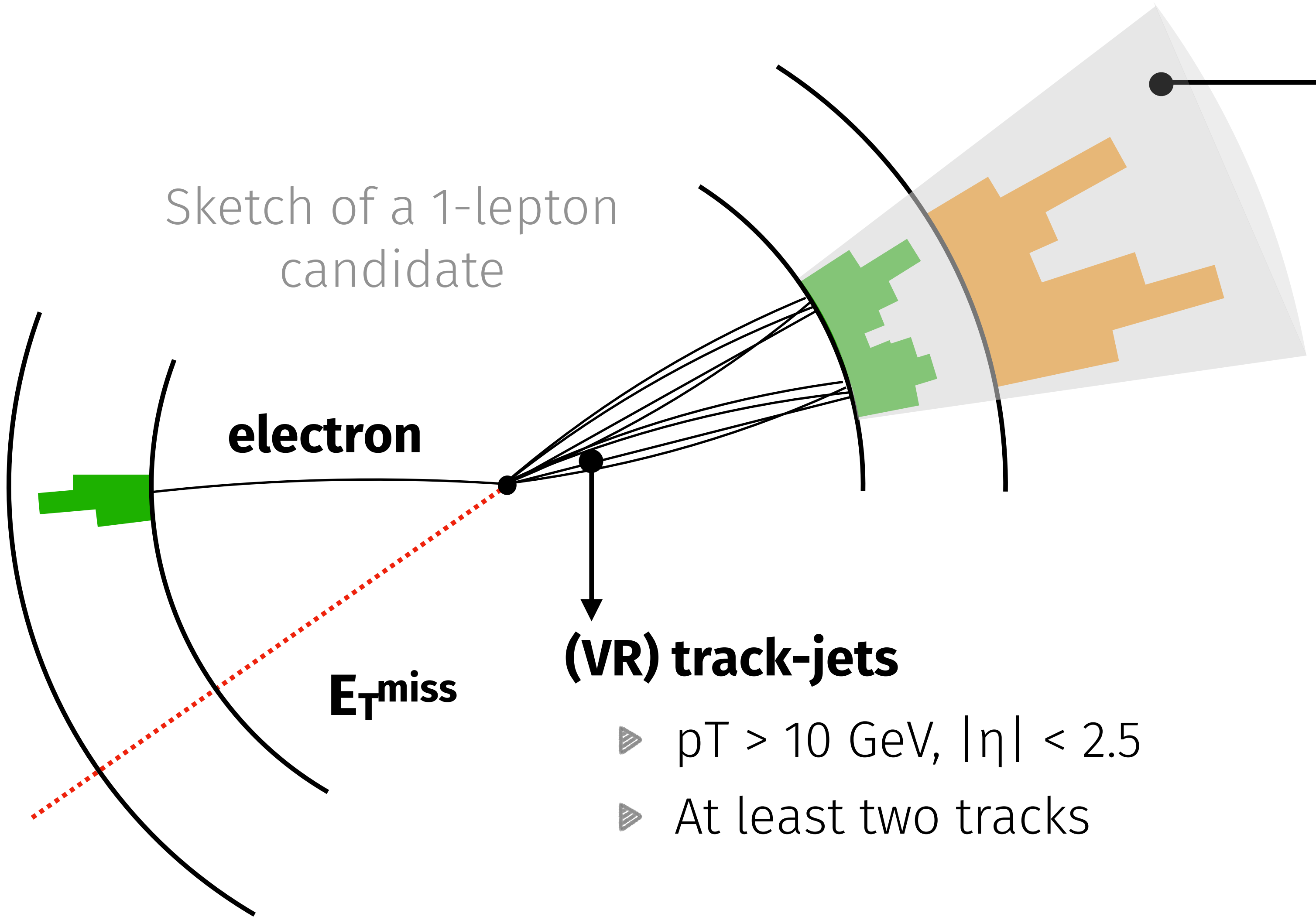


…these topologies finally start to become accessible

The targeted event topology: an overview

- Categorize according to the charged lepton multiplicity in the final state:
  Z $\rightarrow \nu\nu$: 0-lepton   W $\rightarrow \ell\nu$: 1-lepton   Z $\rightarrow \ell\ell$: 2-lepton $(\ell \in \{e, \mu\})$
- Boosted Higgs candidate selection chosen commonly between all three channels
  - Higgs candidate: leading (highest p_T) large-R (R=1.0) calorimeter jet in the event
  - b-tagging done on the two leading variable-R track-jets ghost-associated to it

Sketch of a 1-lepton candidate



large-R (calorimeter) jet

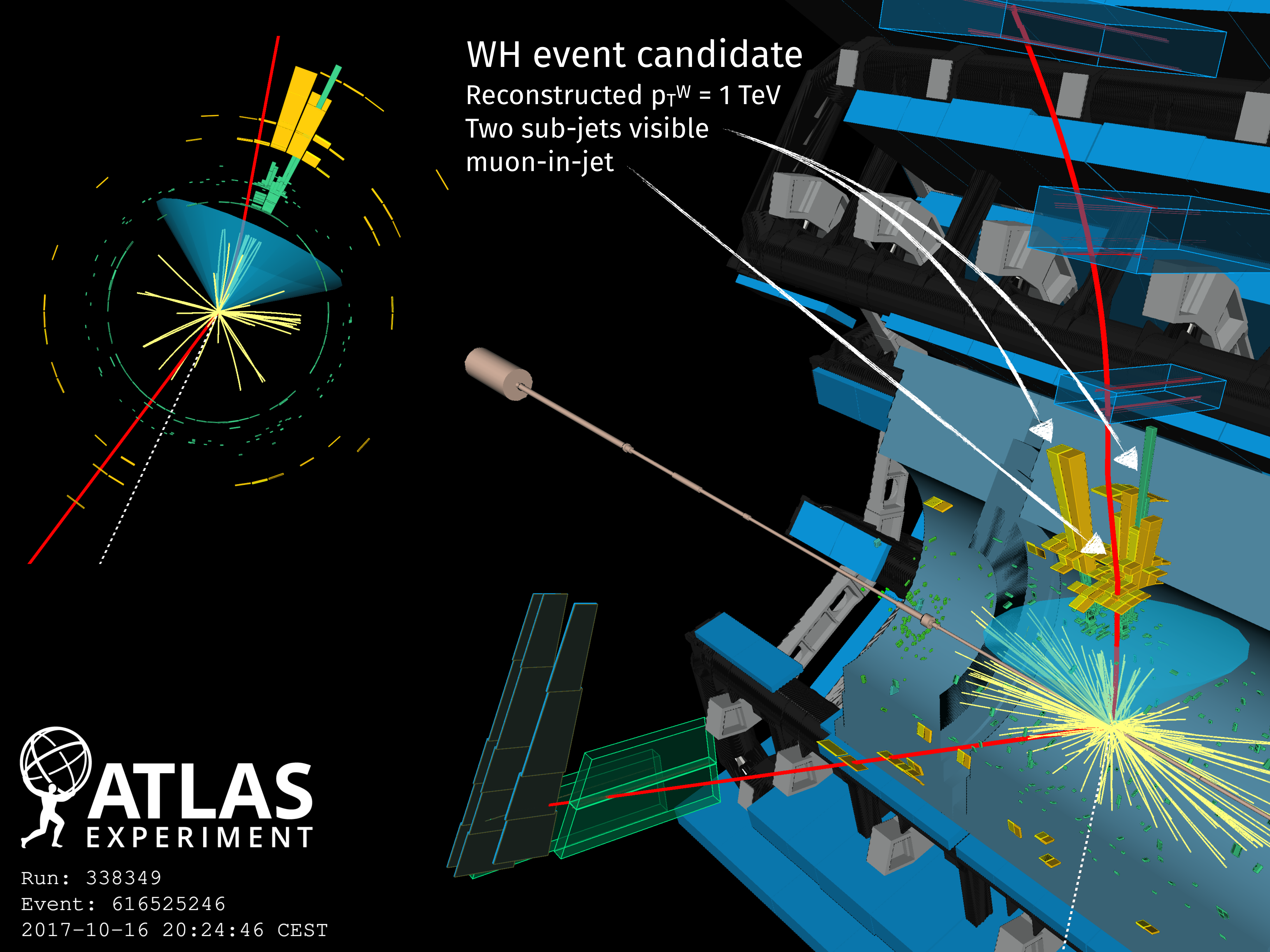
- p_T > 250 GeV, |η| < 2.0 (central)
- **m_J is final discriminant**
- Dedicated energy corrections

(VR) track-jets

- pT > 10 GeV, |η| < 2.5
- At least two tracks

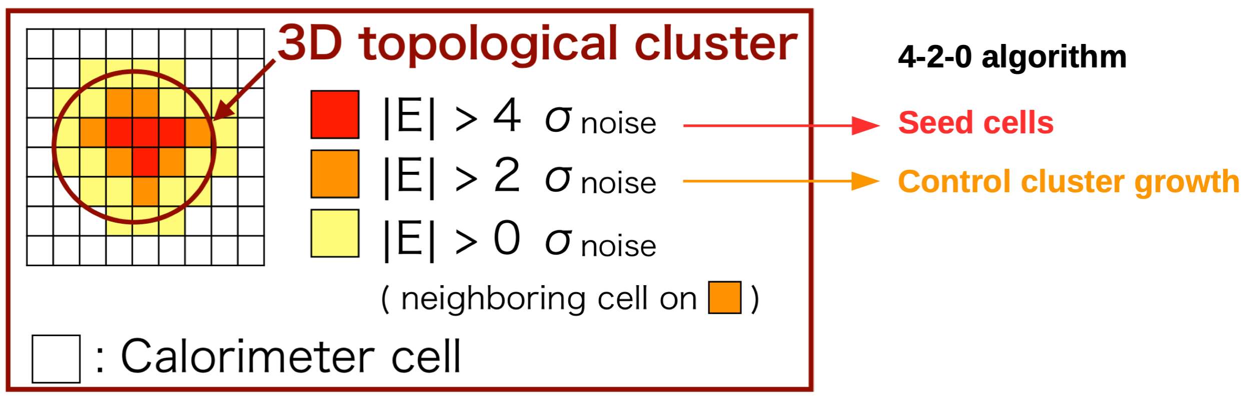
Require 2 b-tags using a 70% single-tag WP

+ small-R (R=0.4) calo jets for event categorization (later)


WH event candidate
Reconstructed p_T^W = 1 TeV
Two sub-jets visible
muon-in-jet
ATLAS
EXPERIMENT
Run: 338349
Event: 616525246
2017-10-16 20:24:46 CEST

Jet Inputs → **Clustering** → Grooming → Calibration

1. Use 3-dim. **topological calorimeter clusters** as inputs using **Local Cell Weighting**



[CERN-PH-EP-2015-304]

↓

use the cluster's properties to assign a probability to be originated from an EM or HAD interaction

apply a weight to each cell

$$E^{\mathrm{LCW}}_{\mathrm{clus}} = \sum_{i \in \mathrm{cluster}} w^{\mathrm{LCW}}_{\mathrm{cell},i} \, E^{\mathrm{EM}}_{\mathrm{cell},i}$$

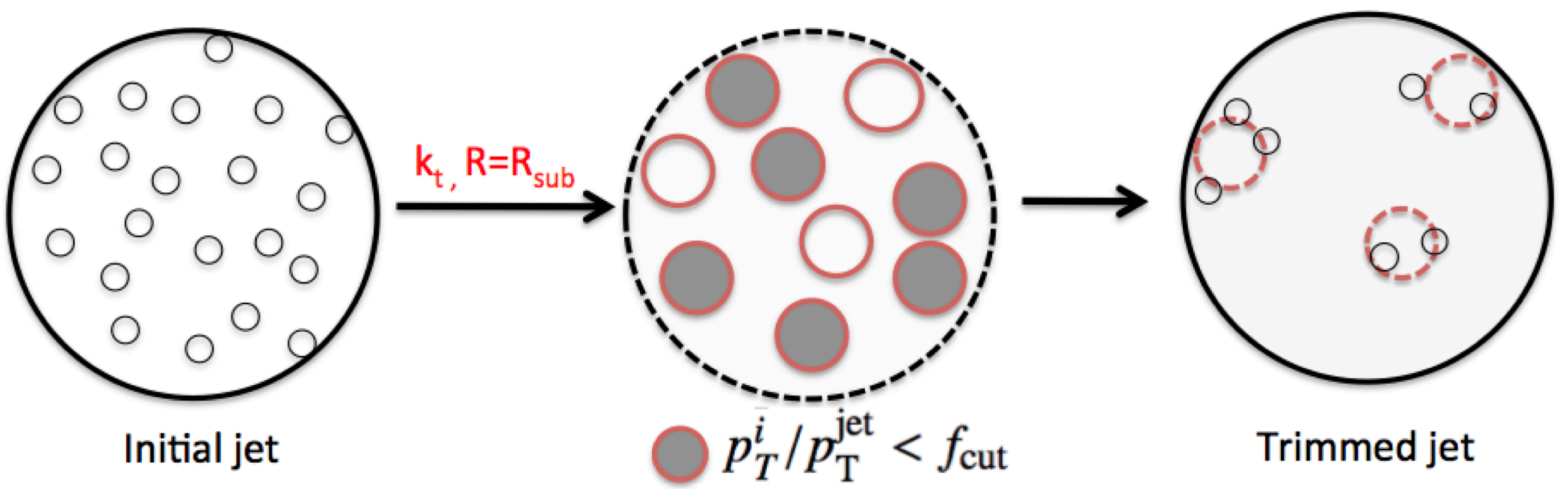
apply pile-up suppression

2. Cluster using **anti-kt with R=1.0**

Boosted VHbb from bottom-up: Large-R jets (2)

Jet Inputs → Clustering → **Grooming** → Calibration

Trimming used as grooming procedure: [CERN-PH-EP-2013-069]



- Contamination from pile-up, initial state radiation, multiple parton interactions often much softer than outgoing patrons and their FSR

1. Create k_t sub-jets of size R = 0.2 from the large-R jet constituents
2. Remove them if their p_T fraction is less than 5% of the large-R jet

Boosted VHbb from bottom-up: Large-R jets (3)

Jet Inputs	Clustering	Grooming	Calibration
LCTopo	anti-kt R = 1.0	trimmed R_{sub} = 0.2 f = 5%	

Optimized for performance on boosted W bosons in Run 1
[e.g. to minimize the QCD-jet rejection and pile-up dependence of <m_{Jet}>]

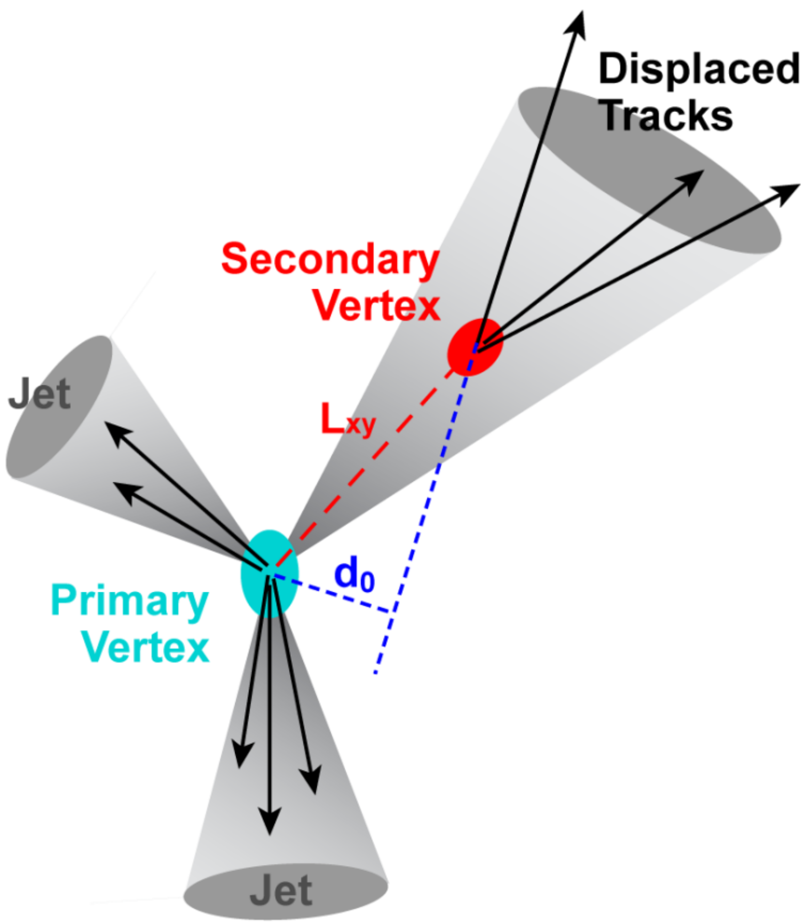
[CERN-PH-EP-2015-204]

These choices are currently under re-optimization with promising improvements

[ATL-PHYS-PUB-2019-027]

Boosted VHbb from bottom-up: b-tagging

- Identifying (sub-) jets originating from B-hadrons (b-tagging) crucial for this analysis
- Making use of physics properties of B-hadrons:



B-hadron carries most of the initial b-quark energy (~80%)

High mass of B-hadrons of ~ 5 GeV

High decay multiplicity (~ 5 charged particles)

CKM suppressed lifetime τ ~ 1.5 ps (cτ ~ 450 μm)

20% semi-leptonic decays with muons

Weak decays mostly into C-hadrons

3 classes of algorithms:

Impact parameter based

Secondary Vertex Finder

Decay Chain Fitter

→ **MVA combining all information (trained on simulation, calibrated on data)**

Higgs candidate tagging on VR track-jets

- Use the leading two VR track-jets that are ghost-associated to the leading large-R jet for (single) b-tagging

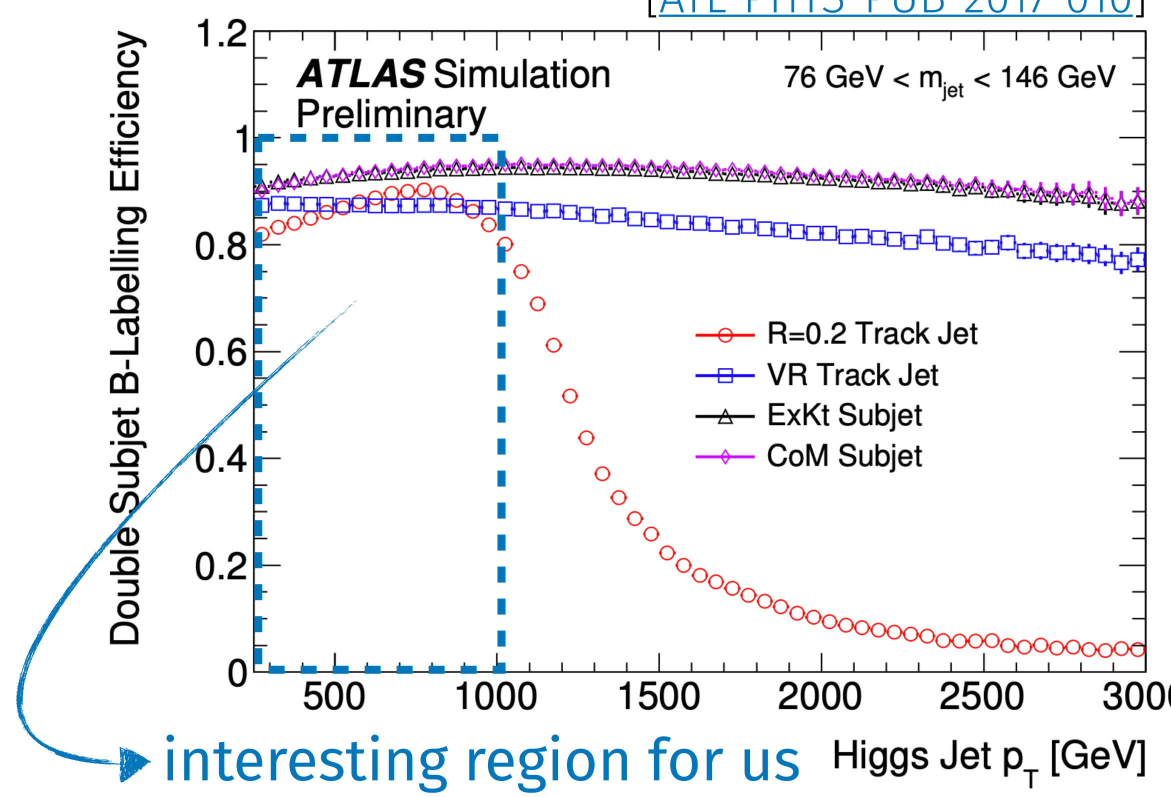
Pros of track-jets:

- High granularity
  → tiny R possible
- Pile-up insensitive
- Independent of large-R jet (no grooming, indep. calib.)

Cons of track-jets:

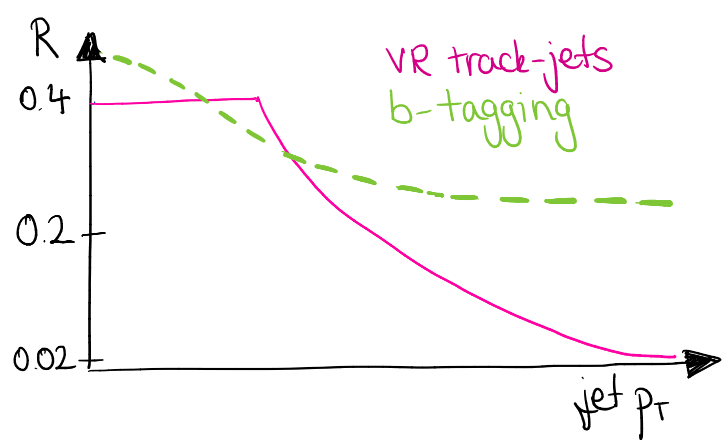
- Missing neutrals

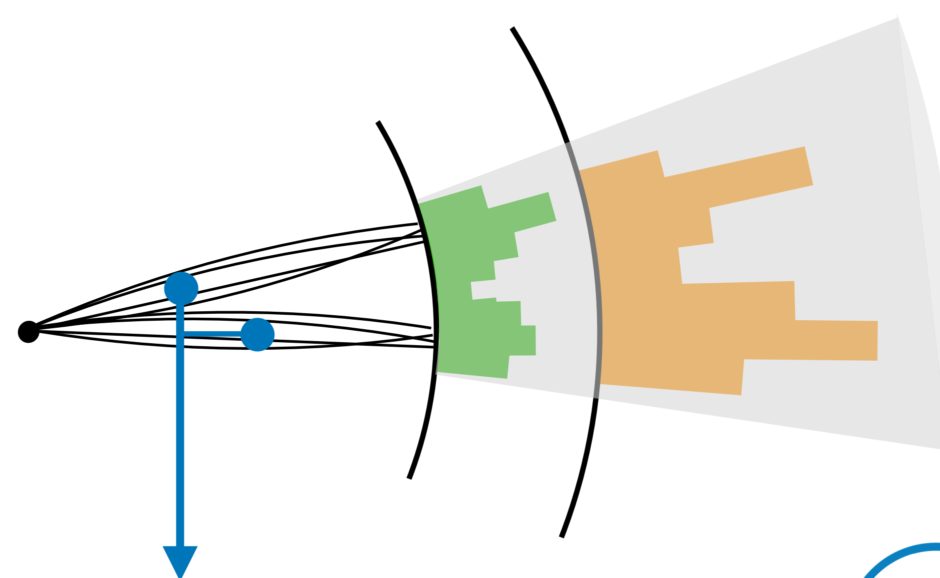
[ATL-PHYS-PUB-2017-010]



Variable-R:

$$R_{\text{eff.}} = \frac{30\ \text{GeV}}{p_T}$$





(VR) track-jets

- MV2c10 algorithm used at 70% single-tag efficiency
  - light-jet rejection: 304
  - c-jet rejection: 9

Large-R jet mass resolution

- Use the **combined mass*** (weighted sum of calorimeter and tracker mass)

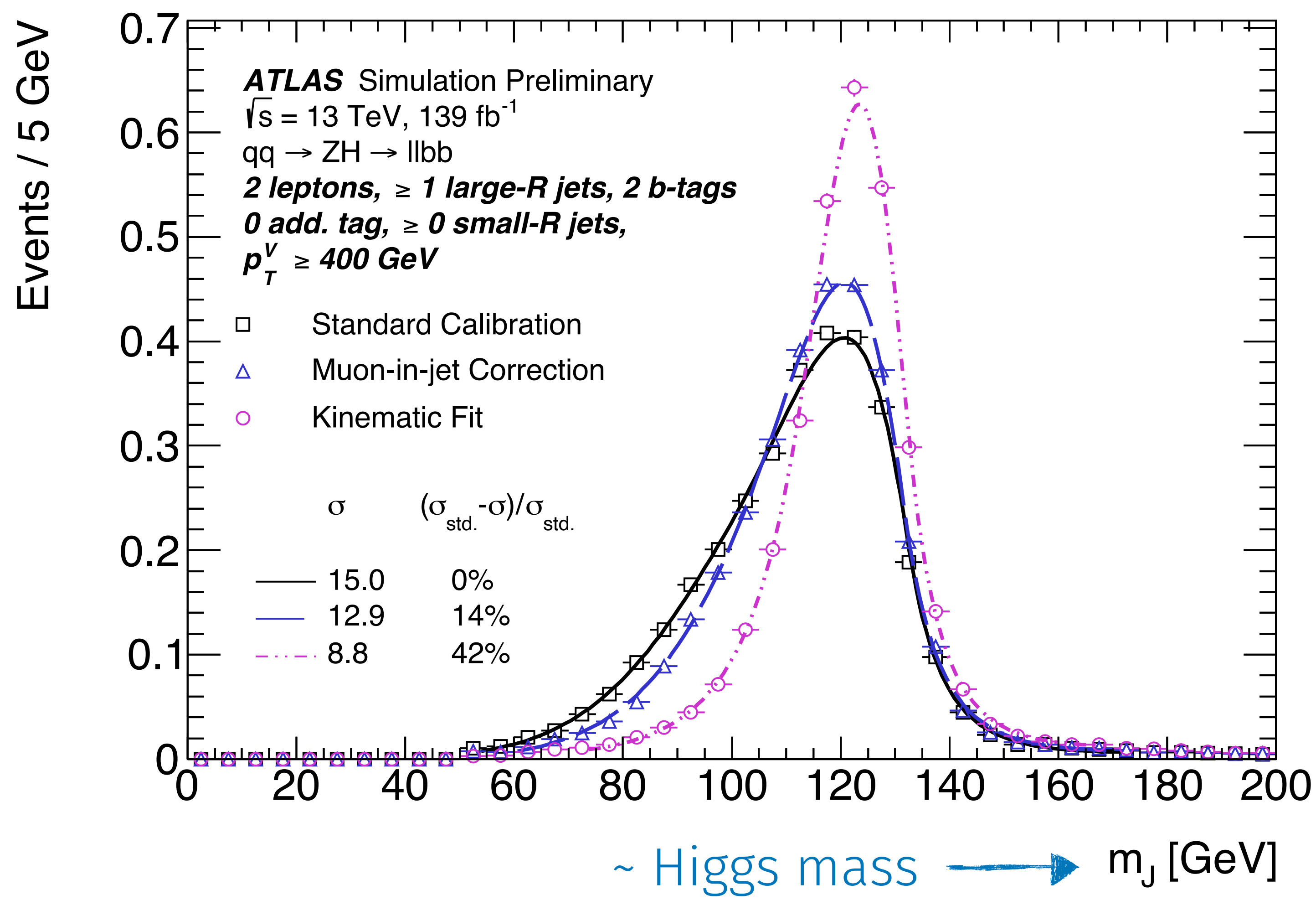
$$m_{\text{comb}} = w_{\text{calo}} \times m_{\text{calo}} + w_{\text{TA}} \times m_{\text{tracker}} \frac{p_T^{\text{calo}}}{p_T^{\text{tracker}}}$$

- Mass resolution: ~ 15%

Improving the resolution:

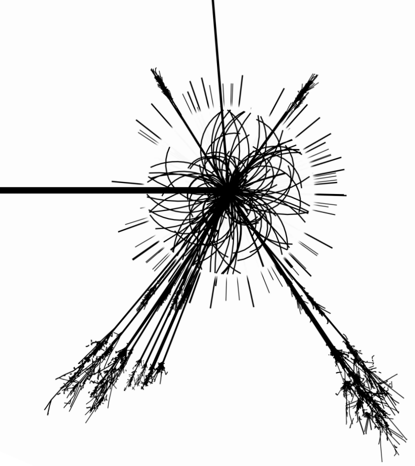
1. Muon-in-jet correction
   correcting for muons created in heavy hadron decays that exit the calorimeter
   → 6%-14% improvement w.r.t. m_{comb}

2. Kinematic Fit in 2-lepton channel
   exploiting the kinematic balance of the di-lepton system (1% resolution) with the jet system
   → 30%-40% improvement w.r.t. m_{comb}



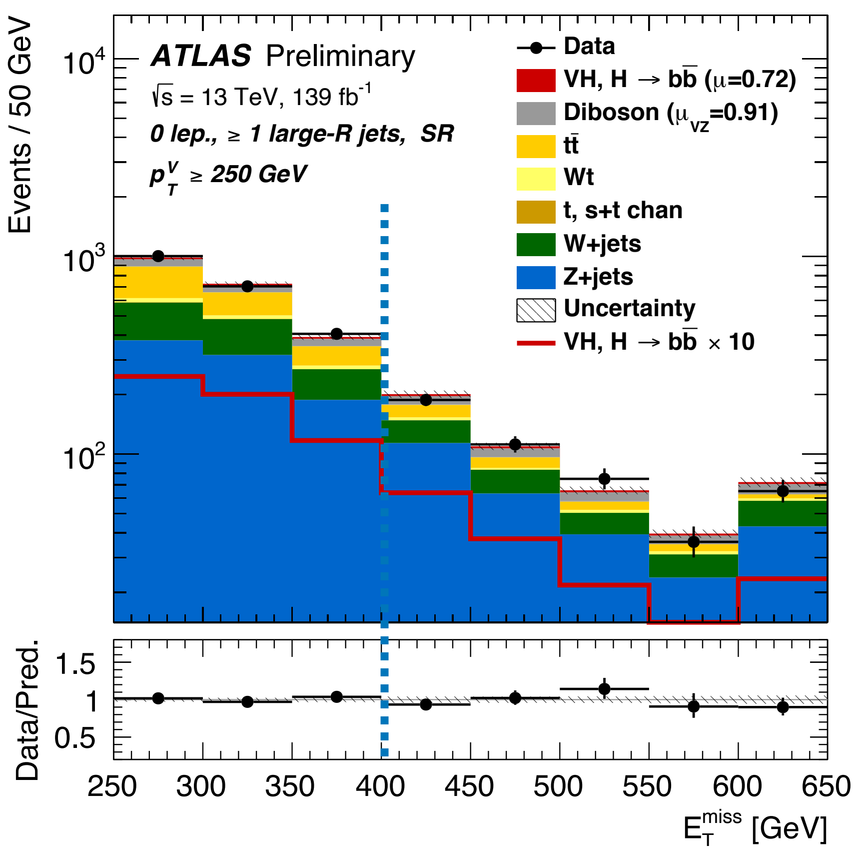
* outperforms pure calorimeter mass jet from p_T ~ 500 GeV upwards, see [ATLAS-CONF-2016-035]

Binning in vector boson p_T

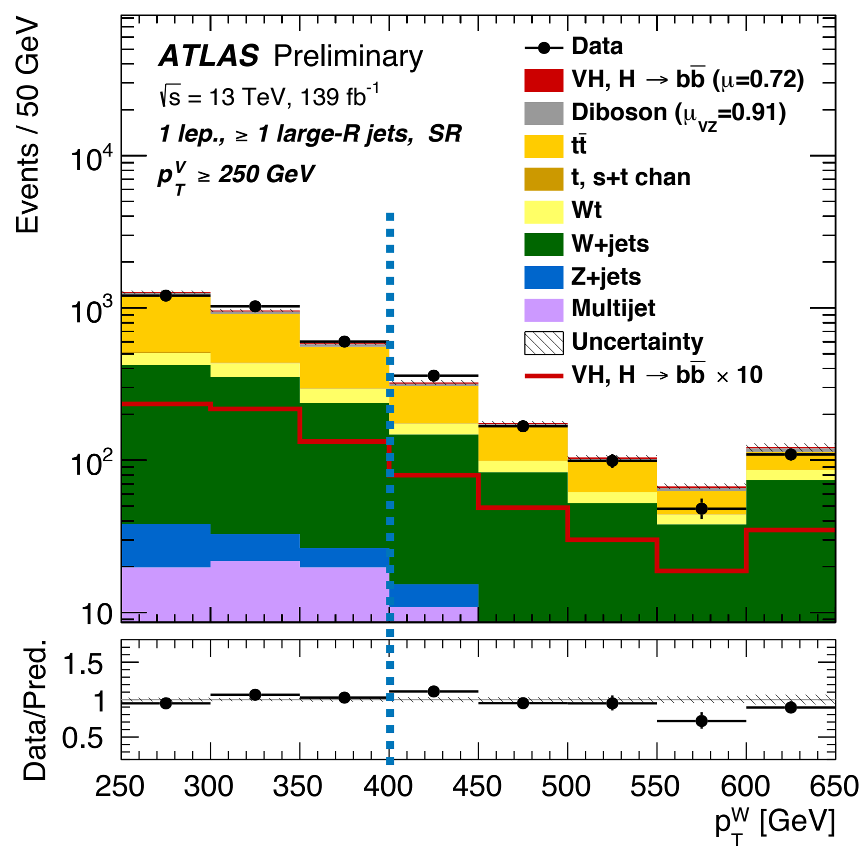


- Since $p_T^H \sim p_T^V$, require at least p_T^V = 250 GeV
- 2 regions exploited: **[250, 400[GeV and [400, ∞[GeV**
  → this matches per design the extended STXS stage 1++ binning

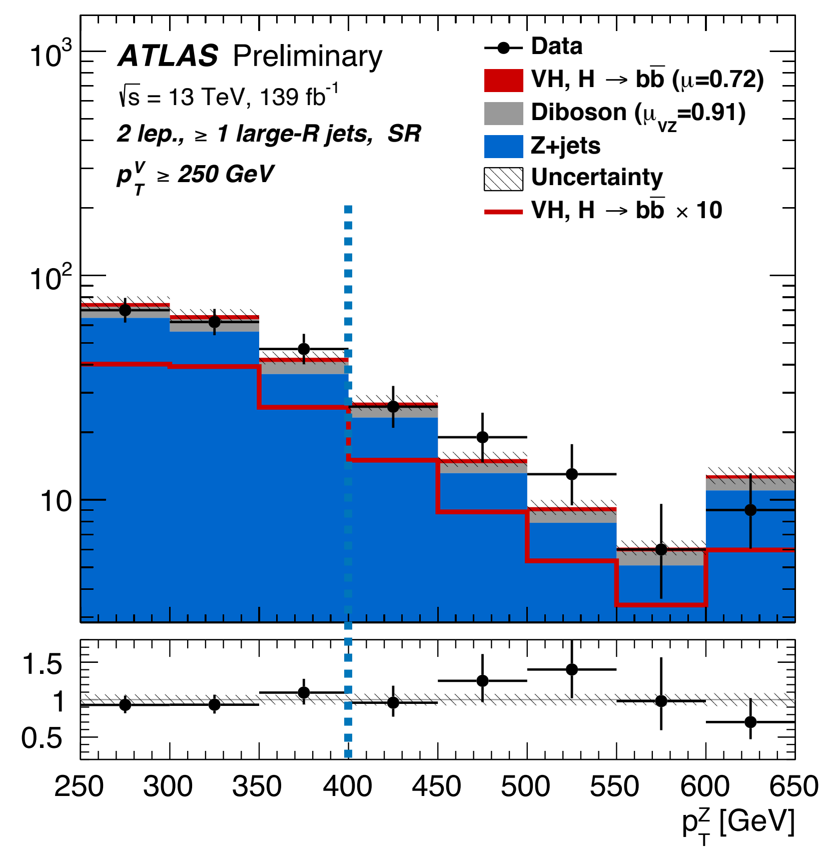
0-lepton



1-lepton



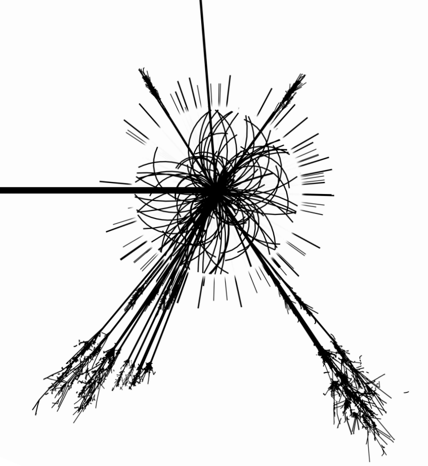
2-lepton



Main backgrounds:

- 0-lepton: **ttbar**, **W+jets**, **Z+jets**
- 1-lepton: **ttbar**, **W+jets**, **single top**
- 2-lepton: **Z+jets**, **diboson**

Signal- and Control Regions (SRs + CRs)

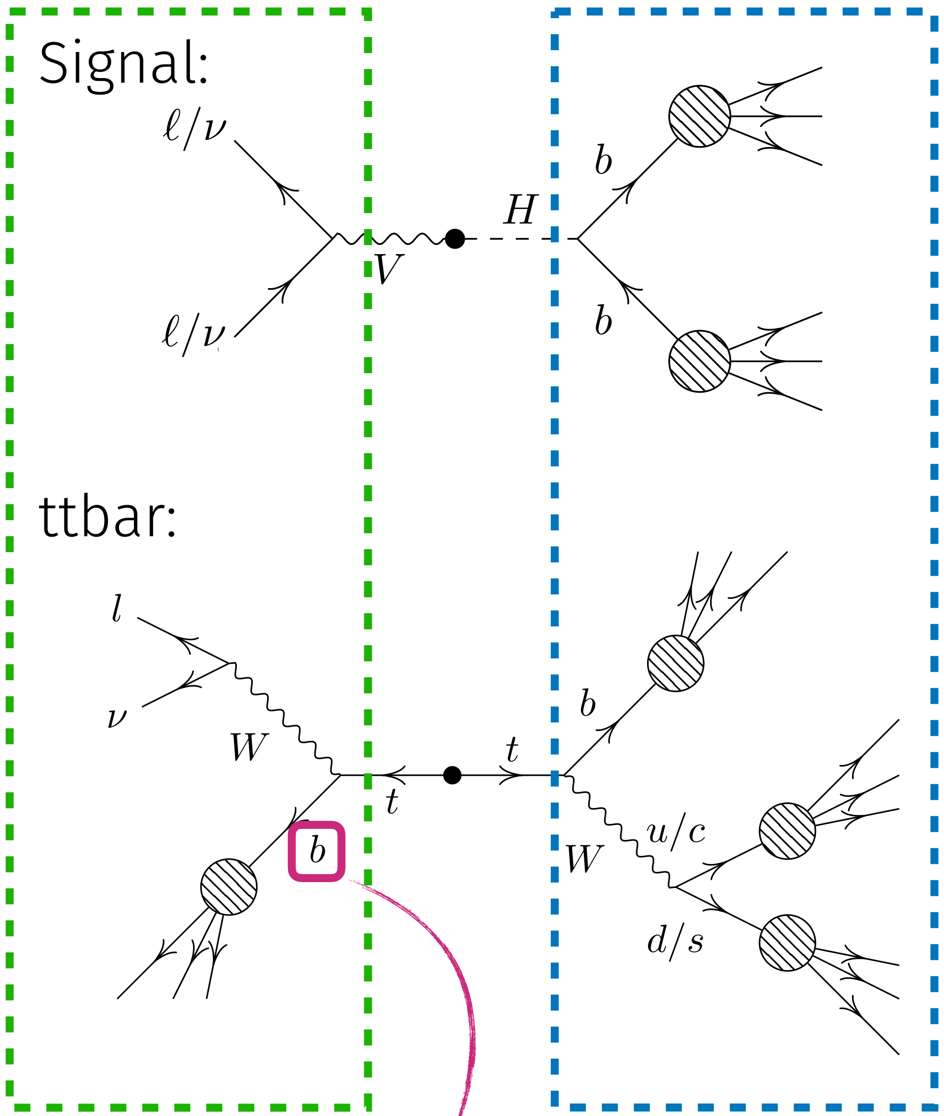


The signal region:

- In LO, **no add. b-jet** outside the large-R jet
- Veto on additional b-tags

The ttbar control region:

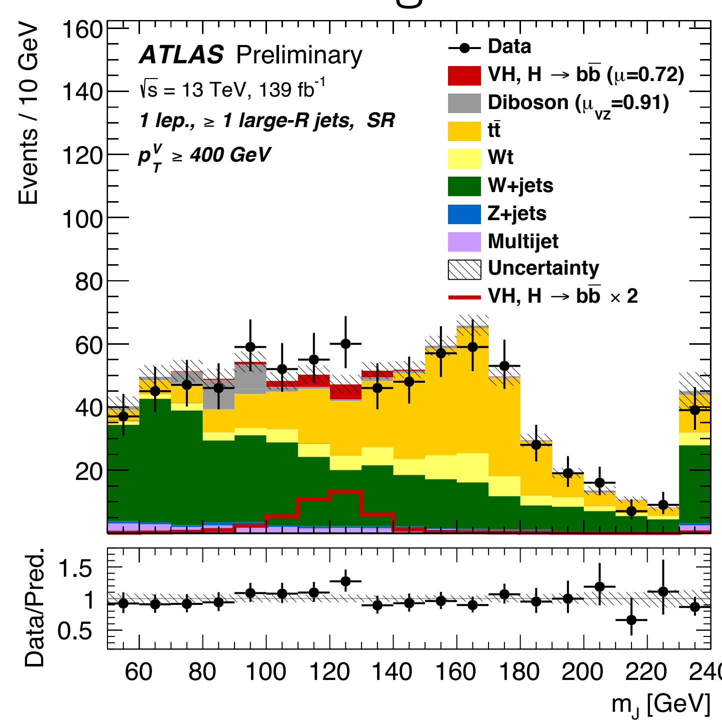
- Higgs candidate most-likely built from boosted (had.) top
- b-jet from the lept. top-quark decay still somewhere
- Obtain a ttbar CR in 0L and 1L by requiring additional b-tags outside the large-R jet

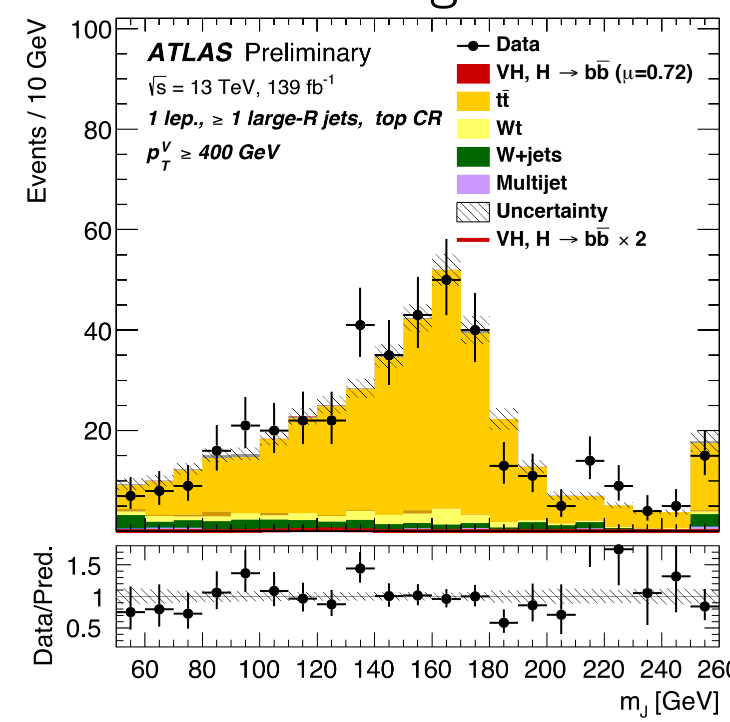


(different levels of containment)

additional b

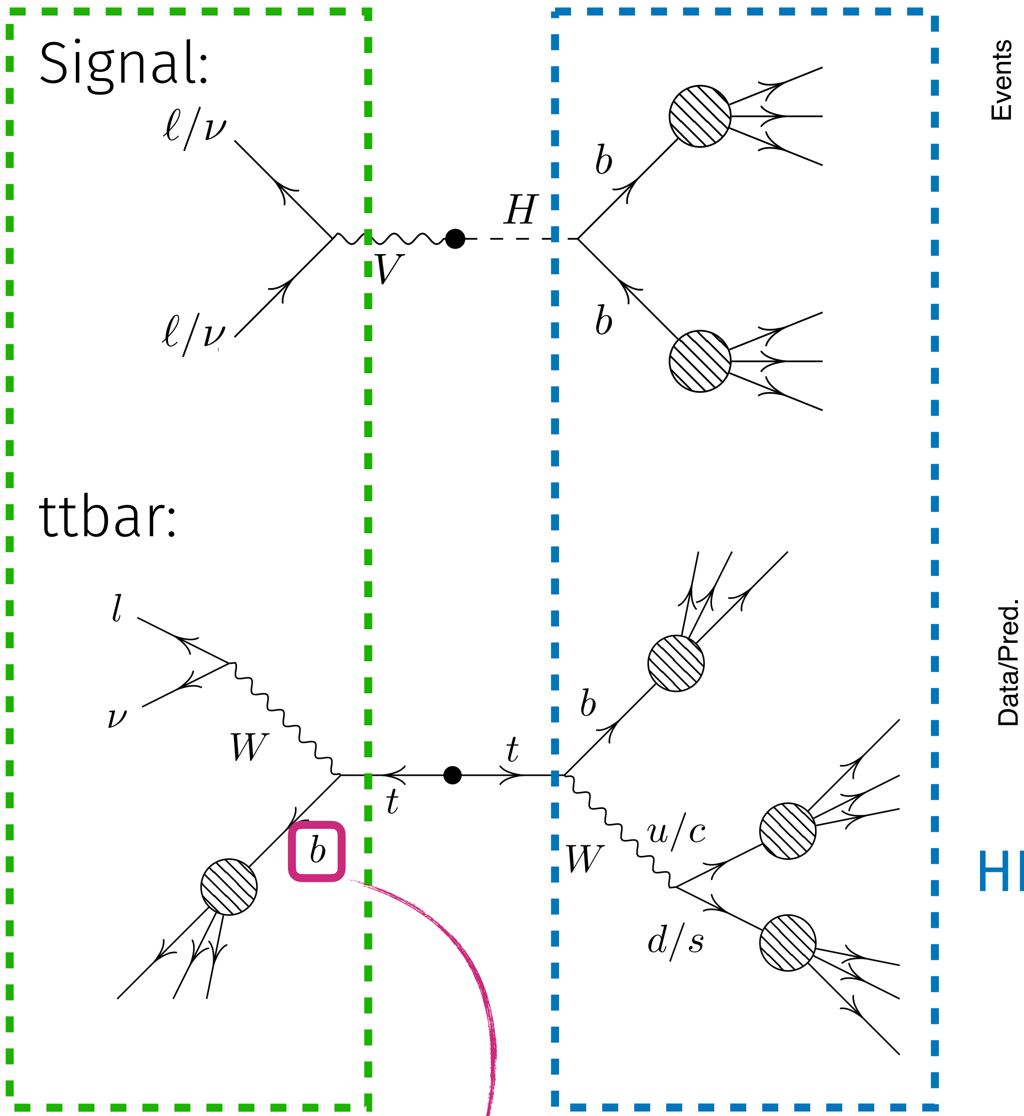
0 add. b-tags **SR** → 1+ add. b-tags **CR**





High purity (HP) and low purity (LP) SRs

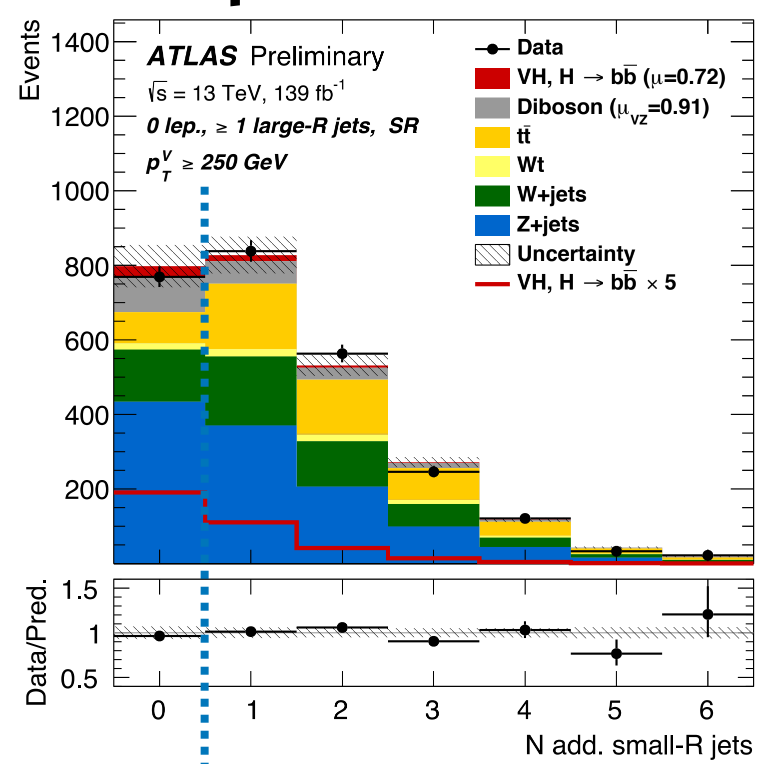
- In the 0-lepton and 1-lepton channels the signal region is further split into a high purity and low purity SR



(different levels of containment)

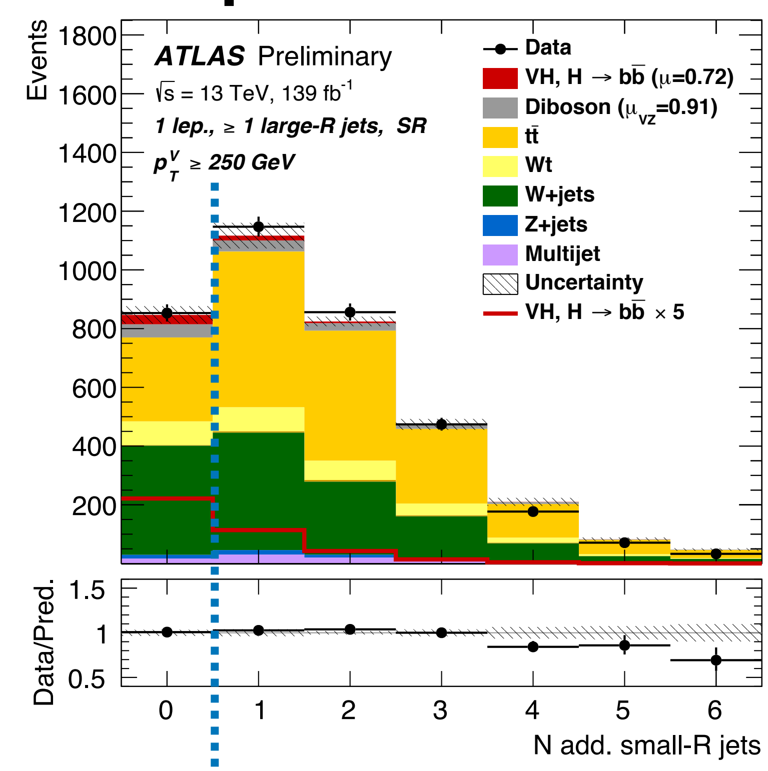
un-identified b (and/or additional radiation)

0-lepton



HP SR ⟷ LP SR

1-lepton



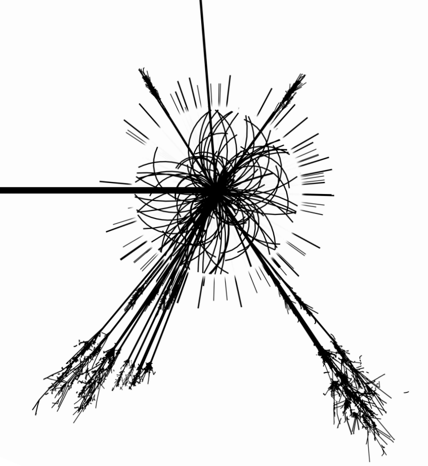
HP SR ⟷ LP SR

Split according to small-R (calo) jet multiplicity:

- high: 0 small-R jets outside of the leading large-R jet
- low: ≧ 1 small-R jet outside of the leading large-R jet

[p_T > 30 GeV, $|\eta|$ < 4.5 as in STXS jet definition]

To summarize: the analysis regions and the fit



- 10 signal regions
- 4 control regions

} 14 regions distributed over 3 lepton channels

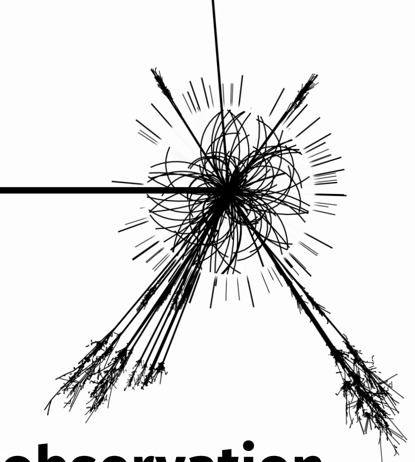
Channel	Categories					
	$250 < p_T^V < 400$ GeV			$p_T^V > 400$ GeV		
	0 add. b-track-jets		≥ 1 add. $b-$track-jets	0 add. b-track-jets		≥ 1 add. b-track-jets
	0 add. small-R jets	$\geq$ 1add. small-R jets		0 add. small-R jets	$\geq$ 1add. small-R jets	
0-lepton	SR	SR	CR	SR	SR	CR
1-lepton	SR	SR	CR	SR	SR	CR
2-lepton	SR			SR		

- Perform a **binned profile likelihood fit** in m_{comb} to the 14 regions to **extract the signal strengths** μ_{VH} **and** μ_{VZ} **simultaneously**

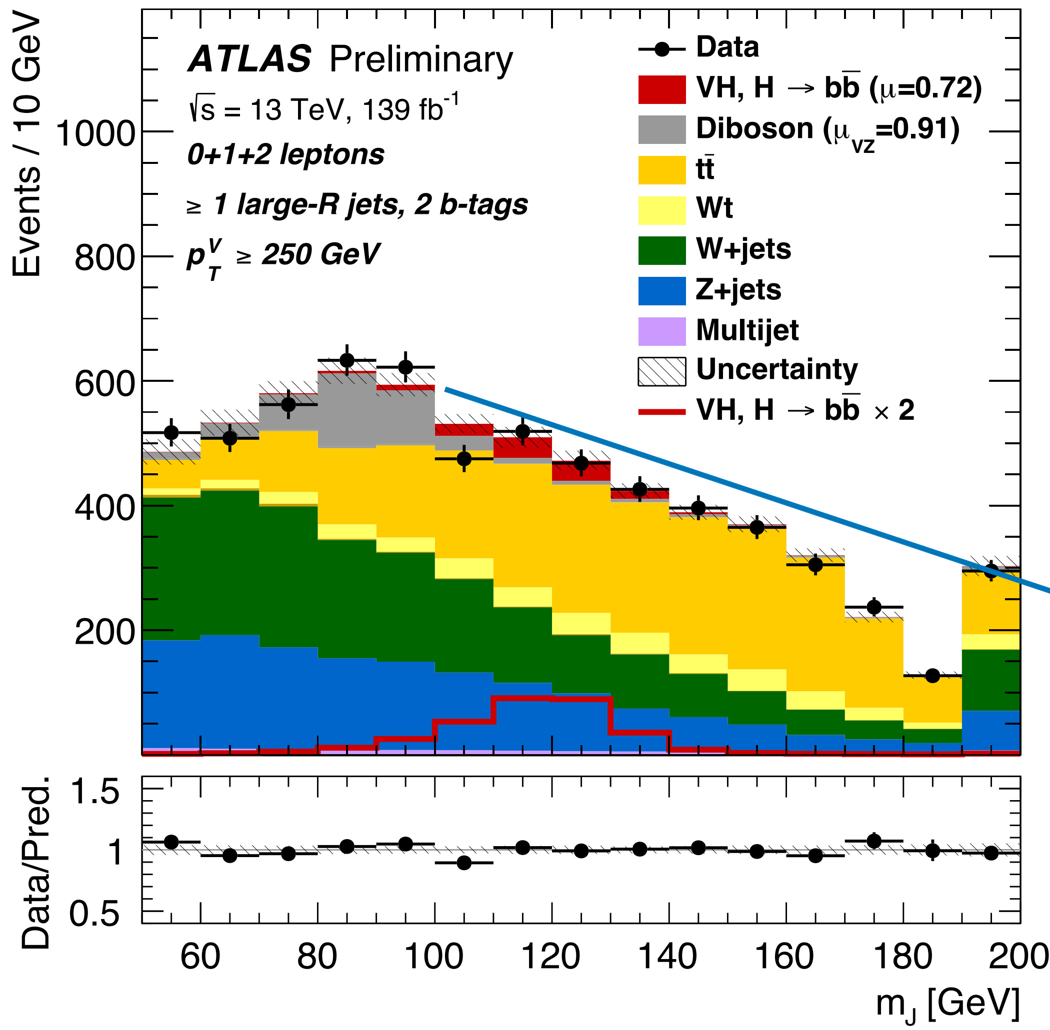
Fit setup and systematics:

- Normalizations of „V+heavy flavor“ and „ttbar" left unconstrained in the fit
- Systematic uncertainties included as nuisance parameters:
  - Experimental: **large-R jet JMS/JMR**, JES/JER; small-R jets, MET, leptons, b-tagging, ...
  - Modelling: Acceptance, containment and flavor uncertainties, sub-dom. norms, ...
  - MC statistics

Unblinded results



- VH signal: Observed (expected) significance: Z = 2.1 (2.7) [σ]
- VZ signal: Observed (expected) significance: Z = 5.2 (5.7) [σ] ⟵ **Boosted V(->lep)Z(->bb) observation**



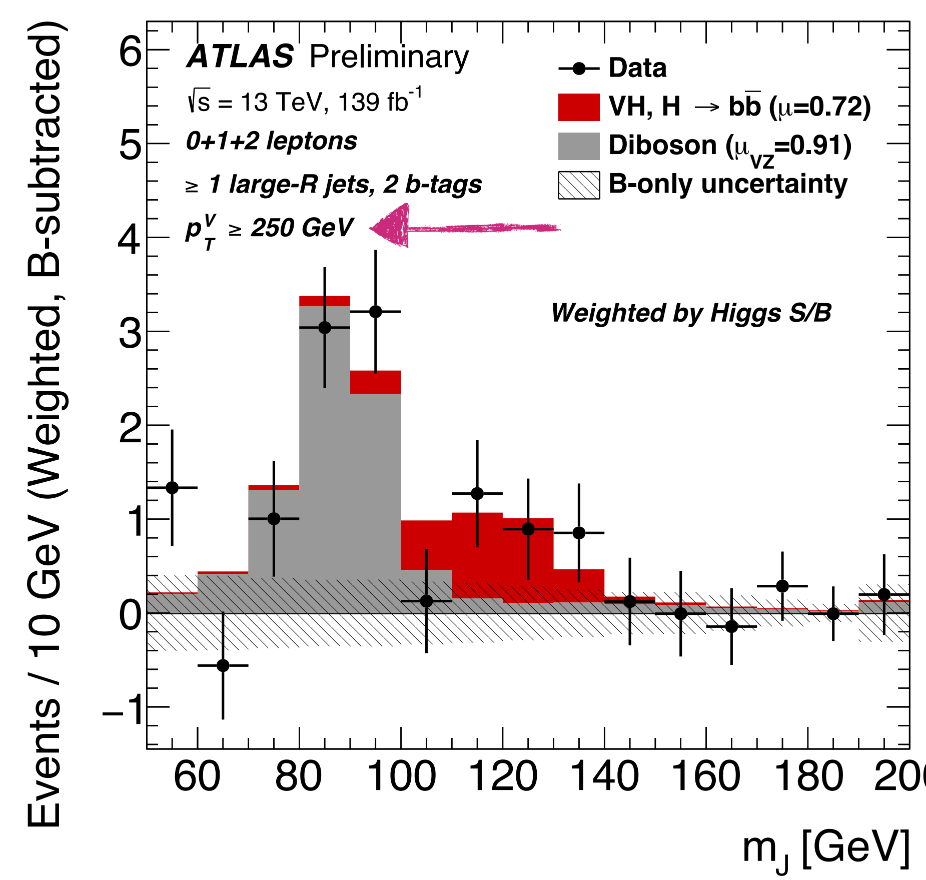
VH signal strength:

$$\mu_{VH}^{bb} = 0.72^{+0.39}_{-0.36} = 0.72^{+0.29}_{-0.28}(\text{stat.})^{+0.26}_{-0.22}(\text{syst.})$$

VZ signal strength:

$$\mu_{VZ}^{bb} = 0.91^{+0.29}_{-0.23} = 0.91 \pm 0.15(\text{stat.})^{+0.25}_{-0.17}(\text{syst.})$$

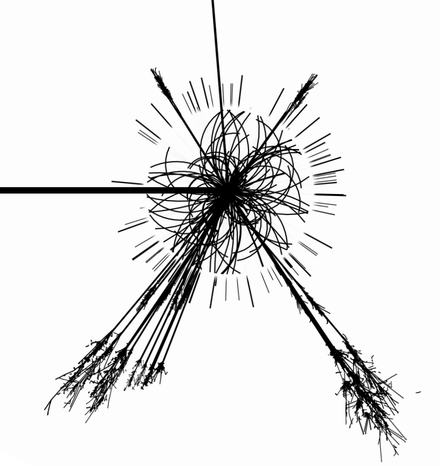
weighting regions by Higgs S/B before adding them; bkg subtracted



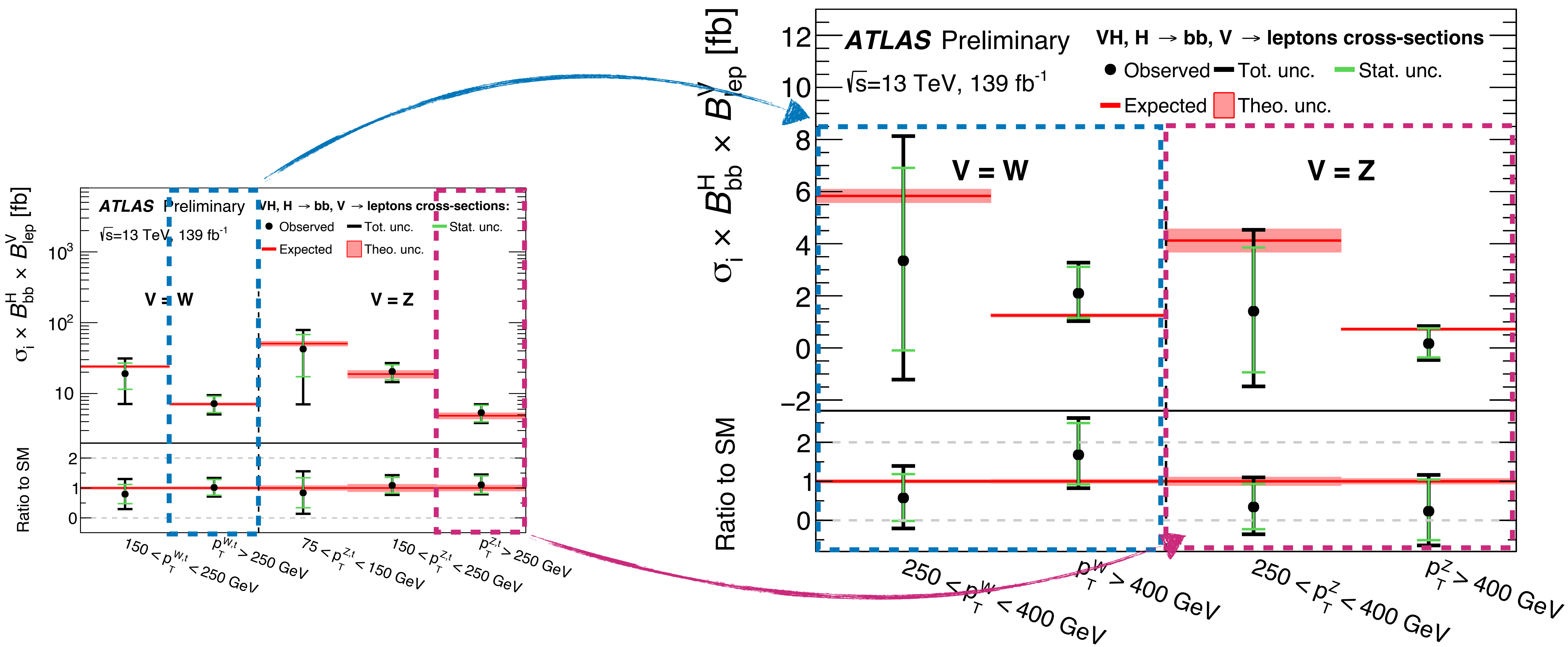
Limiting factors:

1. Data statistics
2. Large-R jet mass scale + resolution
3. Background modelling

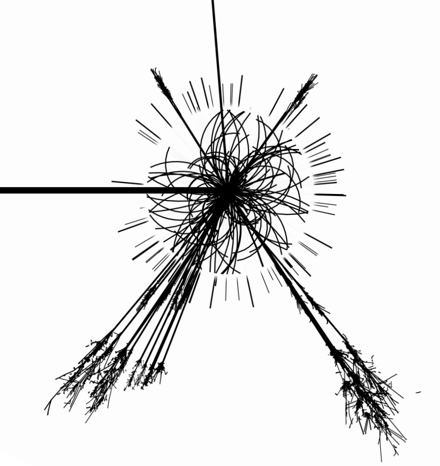
Increasing granularity: STXS results



- **First measurement of Higgsstrahlung σ x BR for p_T^V (truth) > 400 GeV !**
- Still rather larger uncertainties ~70-90% but more data will come…
- Results so far in good agreement with the SM



Conclusion

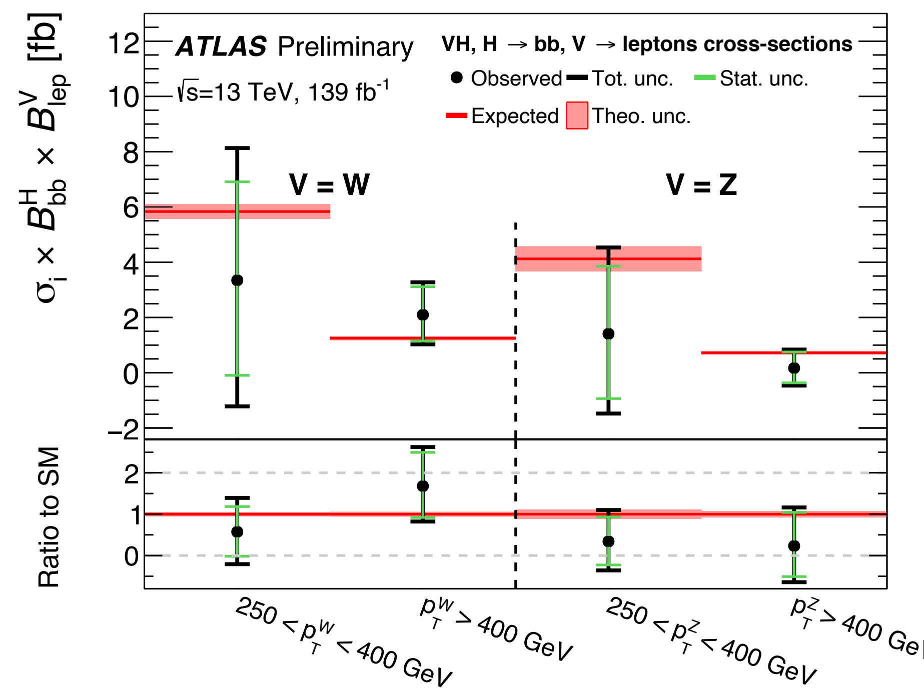


- Measurement of high-energetic VH production using **boosted jet techniques**

The analysis works well and we get nice sensitivity to high Higgs p_T!

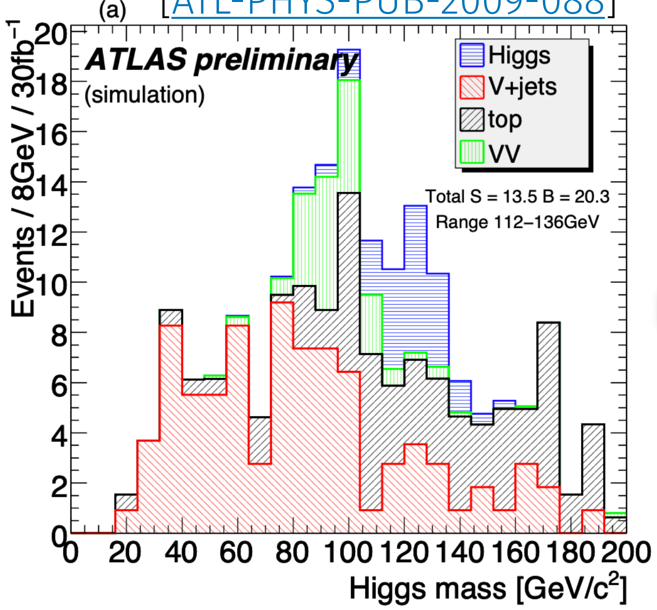
⟶ First direct measurement for p_T^V > 400 GeV

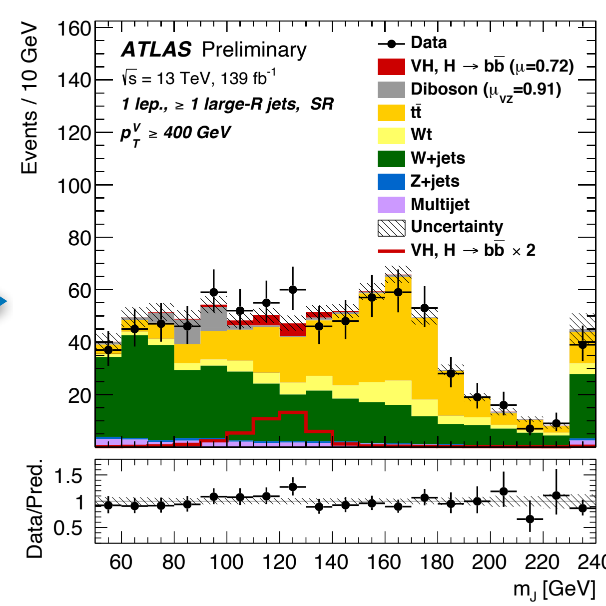
⟶ Boosted V(->lep)Z(->bb) observation

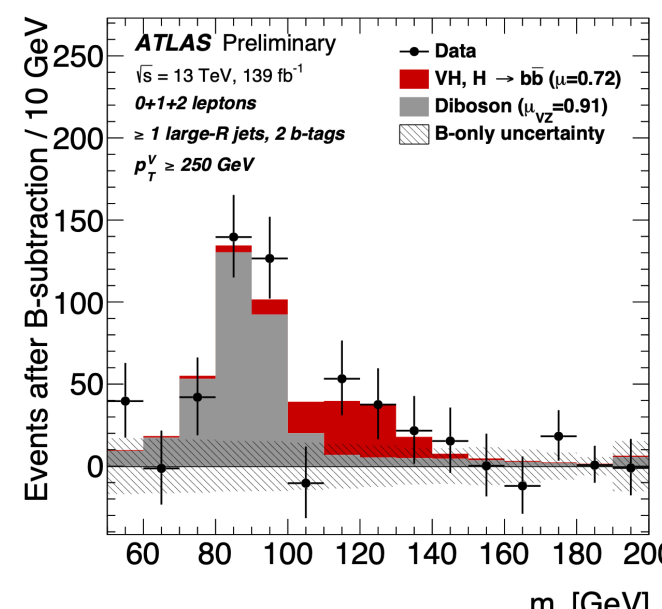


Boosted is **the** path to exploit the full energy reach of the LHC in a data rich future

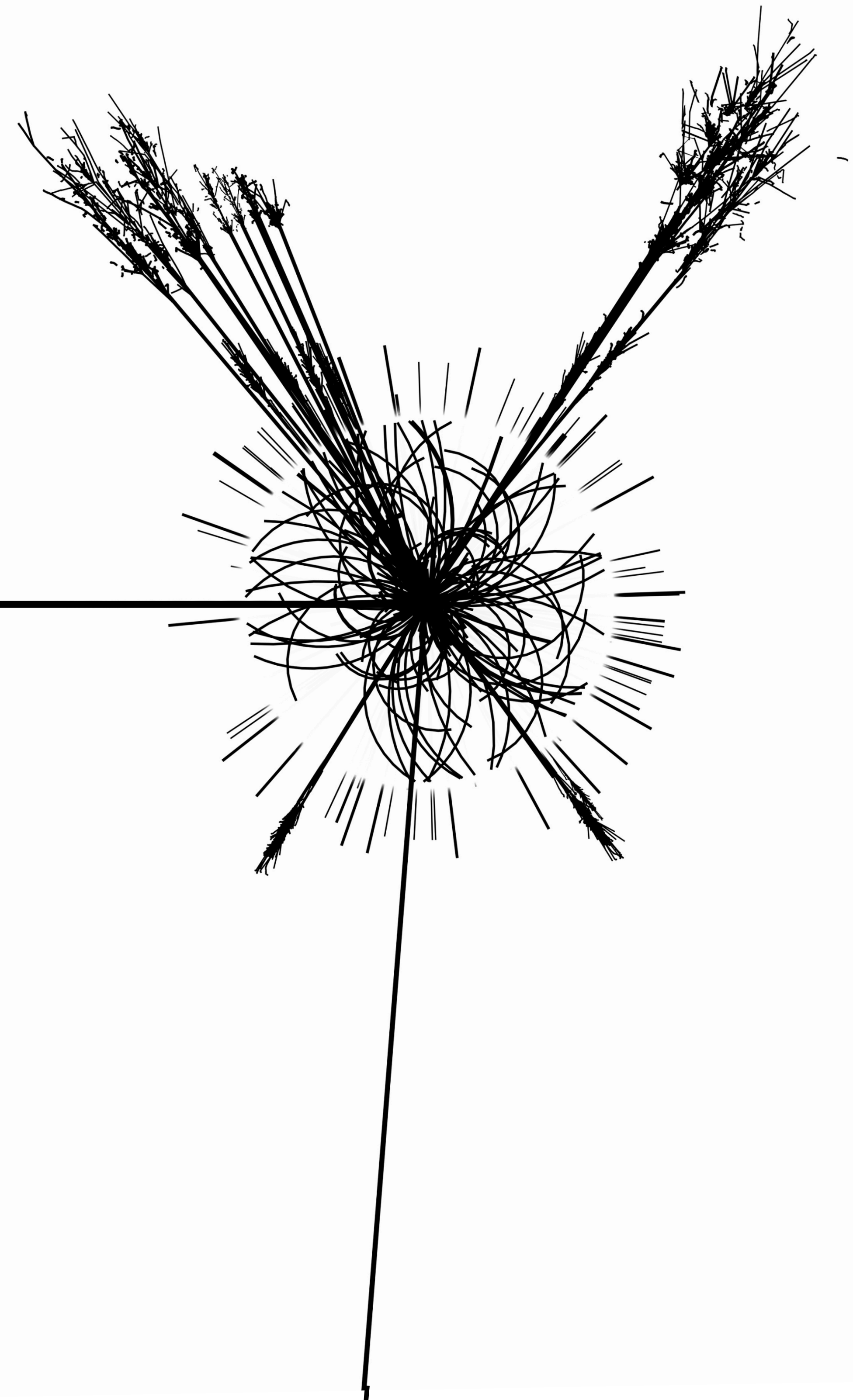
[ATL-PHYS-PUB-2009-088]







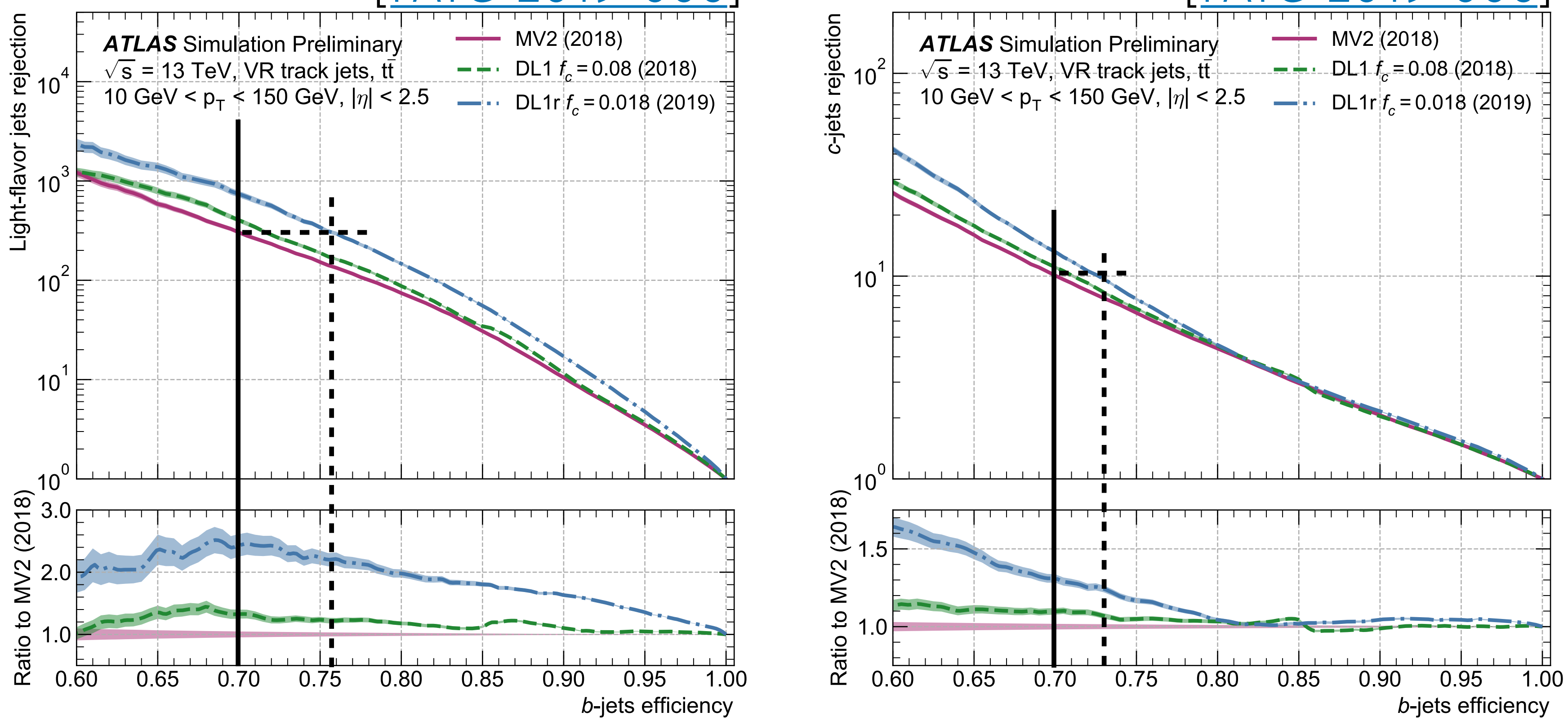
Backup.



Potential improvements

- Lots of refinements with promising potential ready to be tested

[FATG-2019-006] [FATG-2019-006]



Single b-tagging algorithm improvements

Revisiting the jet inputs, clustering algorithms, grooming procedures, ... [ATL-PHYS-PUB-2019-027]

together with refinements on the analysis itself!

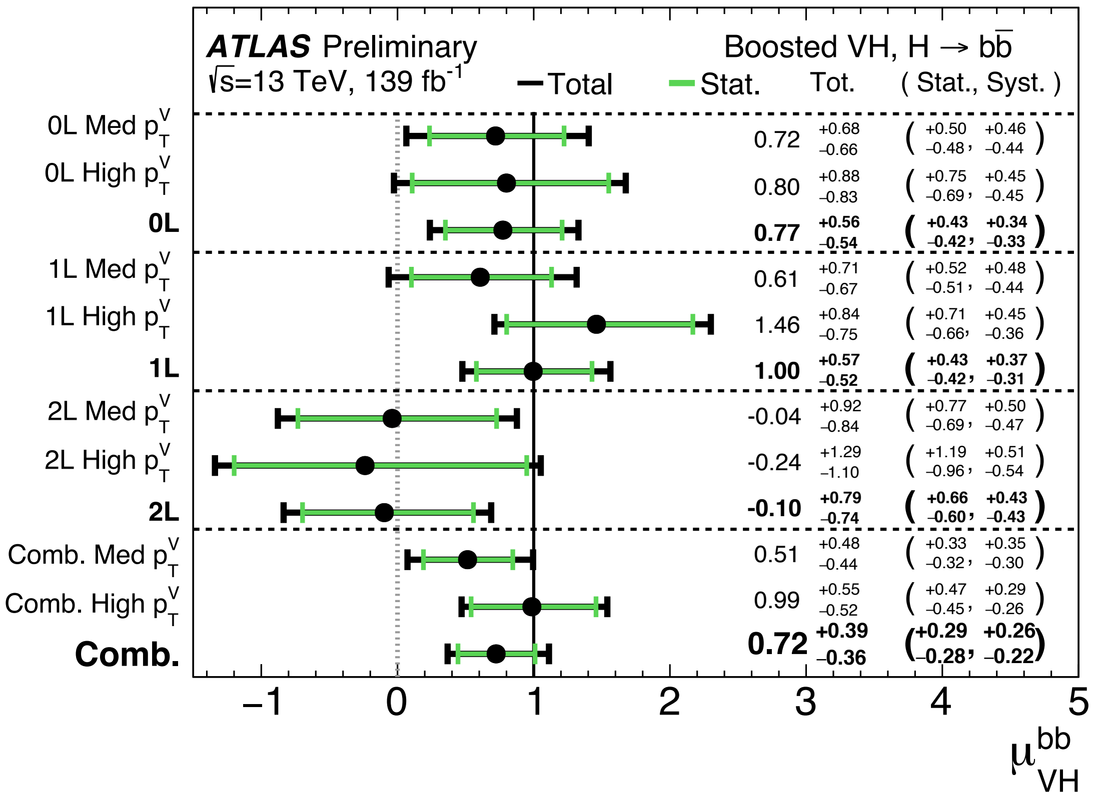
The used generators

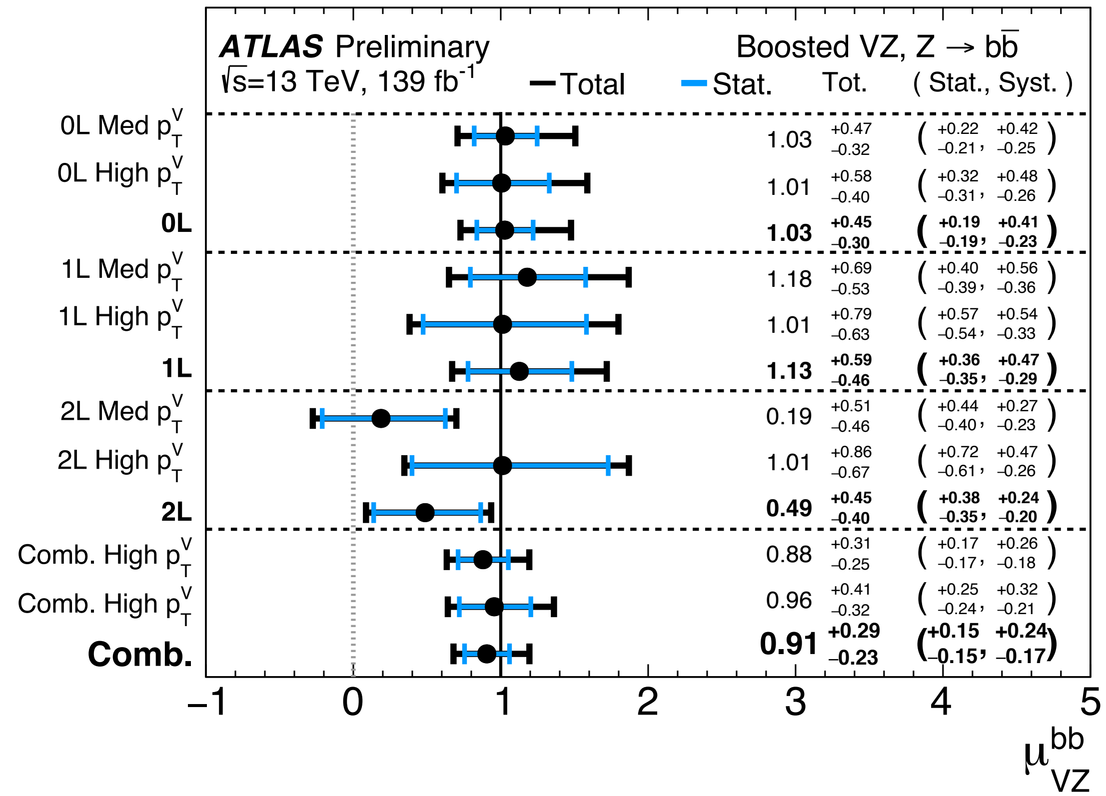
Process	ME generator	ME PDF	PS and Hadronisation	UE model tune	Cross-section order
Signal ($m_H = 125$ GeV and $b\bar{b}$ branching fraction set to 58%)					
$qq \to WH \to \ell\nu b\bar{b}$	Powheg-Box v2 + GoSam + MiNLO	NNPDF3.0NLO$^{(\star)}$	Pythia 8.212	AZNLO	NNLO(QCD)+ NLO(EW)
$qq \to ZH \to \nu\nu b\bar{b}/\ell\ell b\bar{b}$	Powheg-Box v2 + GoSam + MiNLO	NNPDF3.0NLO$^{(\star)}$	Pythia 8.212	AZNLO	NNLO(QCD)$^{(\dagger)}$+ NLO(EW)
$gg \to ZH \to \nu\nu b\bar{b}/\ell\ell b\bar{b}$	Powheg-Box v2	NNPDF3.0NLO$^{(\star)}$	Pythia 8.212	AZNLO	NLO+ NLL
Top quark ($m_t = 172.5$ GeV)					
$t\bar{t}$	Powheg-Box v2	NNPDF3.0NLO	Pythia 8.230	A14	NNLO+NNLL
s-channel	Powheg-Box v2	NNPDF3.0NLO	Pythia 8.230	A14	NLO
t-channel	Powheg-Box v2	NNPDF3.0NLO	Pythia 8.230	A14	NLO
Wt	Powheg-Box v2	NNPDF3.0NLO	Pythia 8.230	A14	Approximate NNLO
Vector boson + jets					
$W \to \ell\nu$	Sherpa 2.2.1	NNPDF3.0NNLO	Sherpa 2.2.1	Default	NNLO
$Z/\gamma^* \to \ell\ell$	Sherpa 2.2.1	NNPDF3.0NNLO	Sherpa 2.2.1	Default	NNLO
$Z \to \nu\nu$	Sherpa 2.2.1	NNPDF3.0NNLO	Sherpa 2.2.1	Default	NNLO
Diboson					
$qq \to WW$	Sherpa 2.2.1	NNPDF3.0NNLO	Sherpa 2.2.1	Default	NLO
$qq \to WZ$	Sherpa 2.2.1	NNPDF3.0NNLO	Sherpa 2.2.1	Default	NLO
$qq \to ZZ$	Sherpa 2.2.1	NNPDF3.0NNLO	Sherpa 2.2.1	Default	NLO
$gg \to VV$	Sherpa 2.2.2	NNPDF3.0NNLO	Sherpa 2.2.2	Default	NLO

The event selection

Selection	0 lepton channel	1 lepton channel		2 leptons channel	
		e sub-channel	μ sub-channel	e sub-channel	μ sub-channel
Trigger	$E_{\mathrm{T}}^{\mathrm{miss}}$	Single electron	$E_{\mathrm{T}}^{\mathrm{miss}}$	Single electron	$E_{\mathrm{T}}^{\mathrm{miss}}$
Leptons	0 *baseline* leptons	1 *signal* lepton $p_{\mathrm{T}} > 27$ GeV no second *baseline* lepton	1 *signal* lepton $p_{\mathrm{T}} > 25$ GeV no second *baseline* lepton	2 *baseline* leptons among which ≥ 1 *signal* lepton, $p_{\mathrm{T}} > 27$ GeV both leptons of the same flavour -	2 *baseline* leptons among which ≥ 1 *signal* lepton, $p_{\mathrm{T}} > 27$ GeV both leptons of the same flavour opposite sign muons
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 250GeV	> 50 GeV	-	-	
p_{T}^{V}	$p_{\mathrm{T}}^{V} > 250$ GeV				
Large-R jets	at least one large-R jet, $p_{\mathrm{T}} > 250$ GeV, $\lvert\eta\rvert < 2.0$				
Track-jets	at least two track-jets, $p_{\mathrm{T}} > 10$ GeV, $\lvert\eta\rvert < 2.5$, associated to the leading large-R jet				
b-jets	leading two track-jets associated to the leading large-R must be b-tagged (MV2c10, 70%)				
m_{J}	> 50 GeV				
min[$\Delta\phi(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}$, small-$R$ jets)]	$> 30°$	-			
$\Delta\phi(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, H_{\mathrm{cand}})$	$> 120°$	-			
$\Delta\phi\ (\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \vec{E}_{\mathrm{T,\ trk}}^{\mathrm{miss}})$	$< 90°$	-			
$\Delta y(V, H_{\mathrm{cand}})$	-	$\lvert\Delta y(V, H_{\mathrm{cand}})\rvert < 1.4$			
$m_{\ell\ell}$	-			66 GeV $< m_{\ell\ell} <$ 116 GeV	
Lepton p_{T} imbalance	-			$(p_{\mathrm{T}}^{\ell_1} - p_{\mathrm{T}}^{\ell_2})/p_{\mathrm{T}}^{Z} < 0.8$	

Compatibility tests





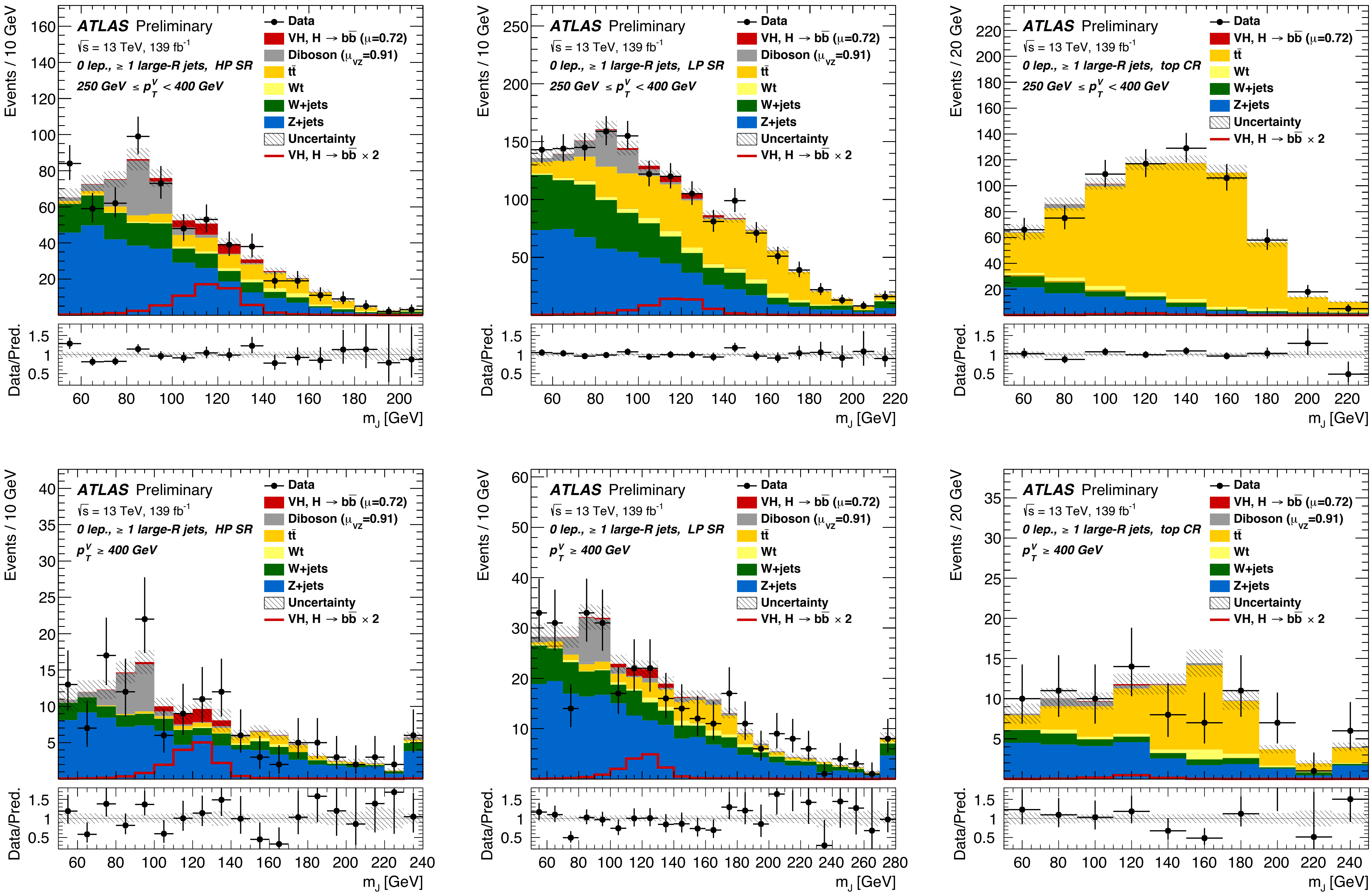
Measured STXS cross-sections

Measurement region ($\lvert y_H \rvert < 2.5, H \to b\bar{b}$)	SM prediction [fb]	Result [fb]	Stat. unc. [fb]	Syst. unc. [fb]
$W \to \ell\nu;\ p_T^W \in [250, 400[\,\text{GeV}$	5.83 ± 0.26	$3.3\ ^{+4.8}_{-4.6}$	$^{+3.6}_{-3.4}$	$^{+3.2}_{-3.0}$
$W \to \ell\nu;\ p_T^W \in [400, \infty[\,\text{GeV}$	1.25 ± 0.06	$2.1\ ^{+1.2}_{-1.1}$	$^{+1.0}_{-0.9}$	$^{+0.6}_{-0.5}$
$Z \to \ell\ell, \nu\nu;\ p_T^Z \in [250, 400[\,\text{GeV}$	4.12 ± 0.45	$1.4\ ^{+3.1}_{-2.9}$	$^{+2.4}_{-2.3}$	$^{+1.9}_{-1.7}$
$Z \to \ell\ell, \nu\nu;\ p_T^Z \in [400, \infty[\,\text{GeV}$	0.72 ± 0.05	$0.2\ ^{+0.7}_{-0.6}$	$^{+0.6}_{-0.5}$	$^{+0.3}_{-0.3}$

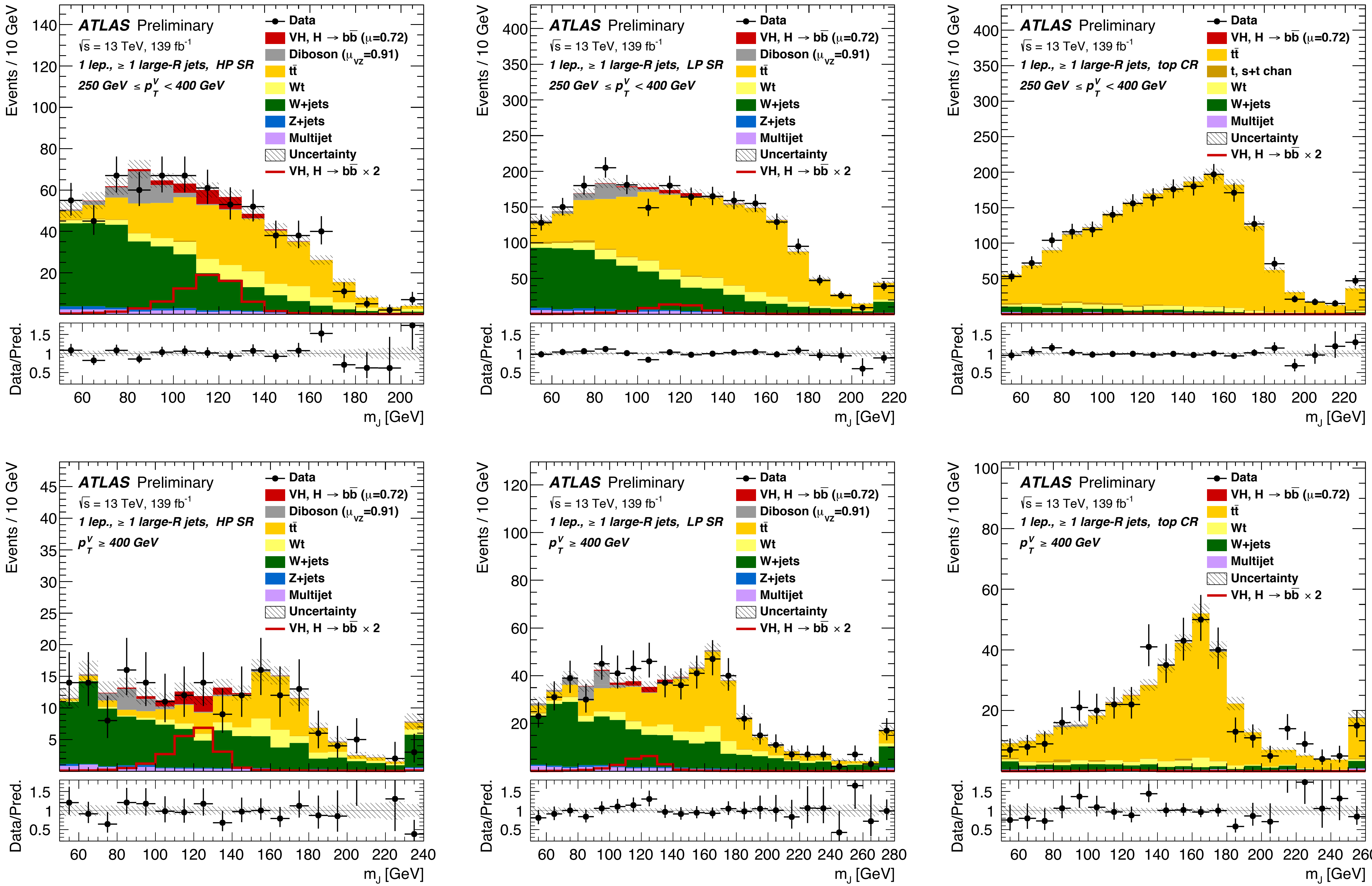
Uncertainty breakdown

Source of uncertainty		Avg. impact
Total		0.372
Statistical		0.283
Systematic		0.240
Experimental uncertainties		
small-R jets		0.038
large-R jets		0.133
E_T^{miss}		0.007
Leptons		0.010
b-tagging	b-jets	0.016
	c-jets	0.011
	light-flavour jets	0.008
	extrapolation	0.004
Pile-up		0.001
Luminosity		0.013
Theoretical and modelling uncertainties		
Signal		0.038
Backgrounds		0.100
$\hookrightarrow$ Z + jets		0.048
$\hookrightarrow$ W + jets		0.058
$\hookrightarrow$ $t\bar{t}$		0.035
$\hookrightarrow$ Single top quark		0.027
$\hookrightarrow$ Diboson		0.032
$\hookrightarrow$ Multijet		0.009
MC statistical		0.092

Post-fit plots: 0-lepton



Post-fit plots: 1-lepton



Post-fit plots: 2-lepton