Higgs physics study with fermion

Lei Zhang

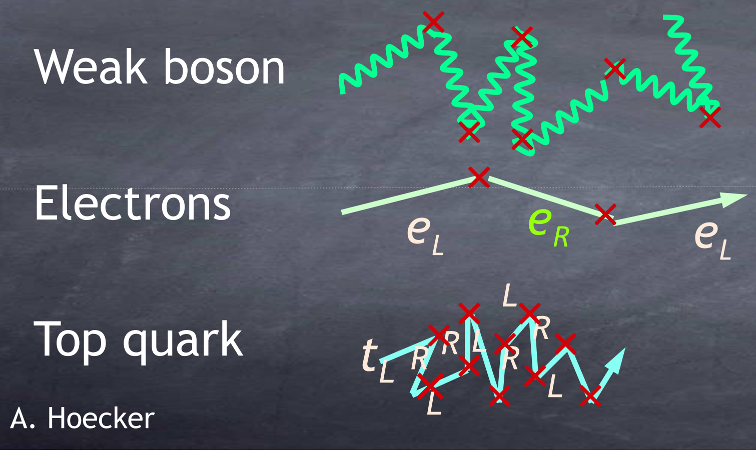
CPS-HEP, Shanghai, 19-24 June 2018

Higgs and Fermions interaction

LHC Run 1 legacy

- Higgs boson mass and spin-CP well constrained by bosonics channels $H \to \gamma\gamma$, $H \to ZZ \to 4\ell$ and $H \to WW^*$

Higgs and Fermions interaction



- Fermion to Higgs interaction proportional to mass and alters chirality of massive Dirac fermion
- Huge mass difference (10^{11}) among fermions

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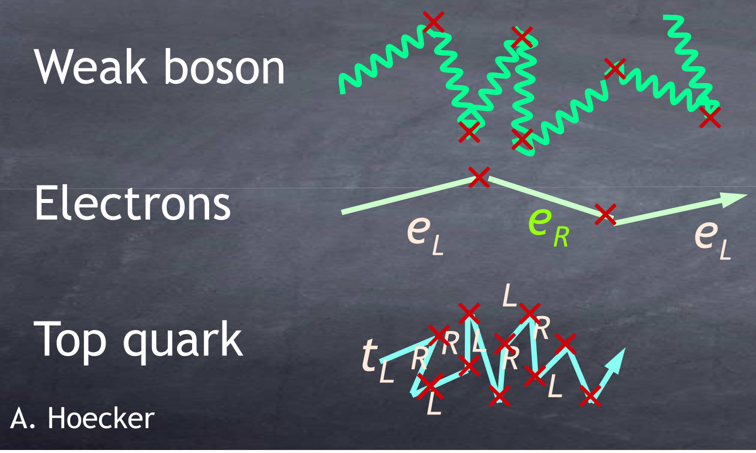

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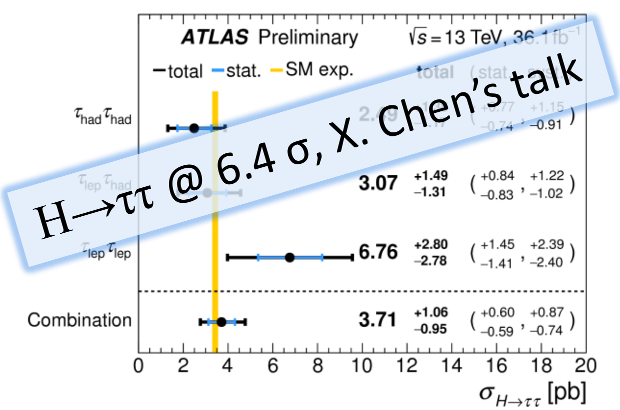
Run 2: Good news from Fermions



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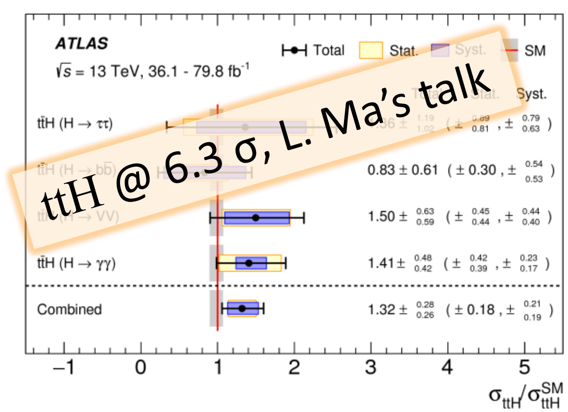
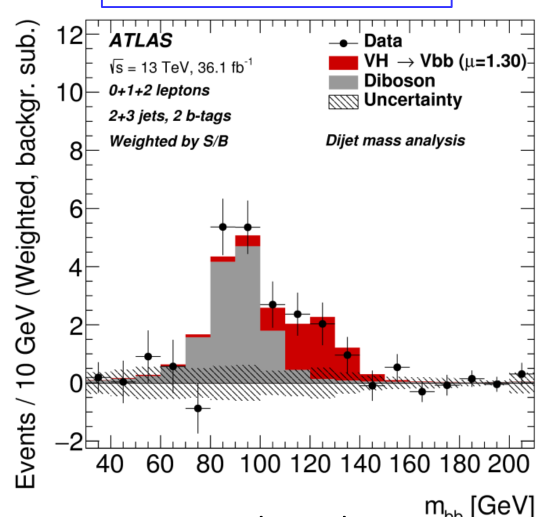


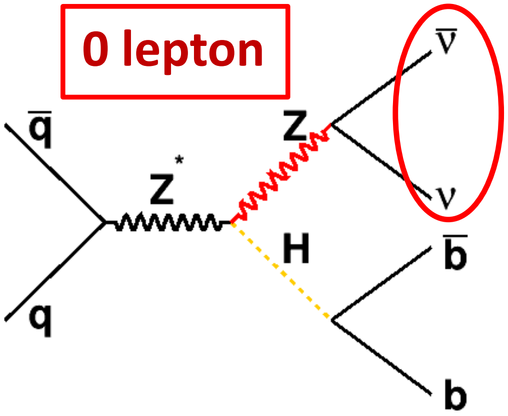
arXiv:1806.00425

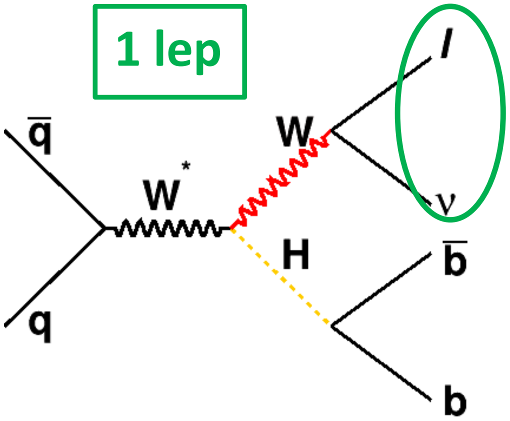
H→bb, this talk

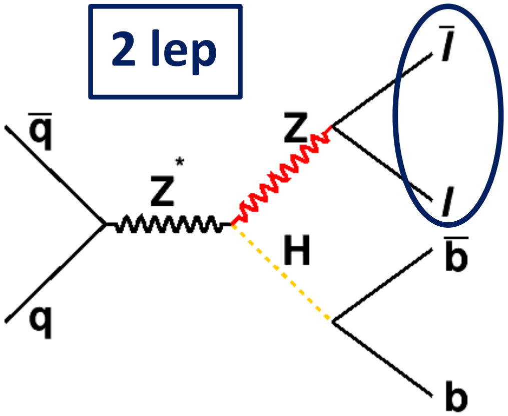


JHEP 12 (2017) 024

H⟶bb analysis strategy







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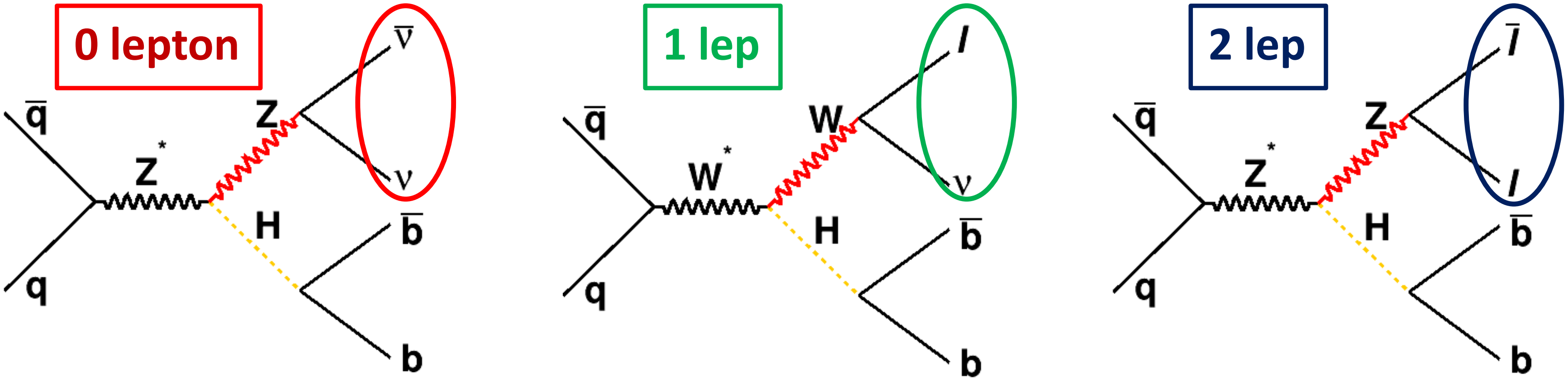
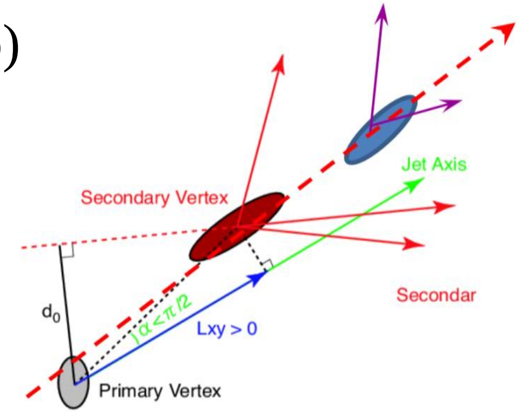


- p_T^V **>150 GeV** (extra category 75-150 GeV for 2-lep)
  - $p_T^V = |E_T^{miss}|$, $p_T(W \rightarrow l\nu)$, $p_T(Z \rightarrow ll)$
- All leptonic channels require **2 b-tagged jets**



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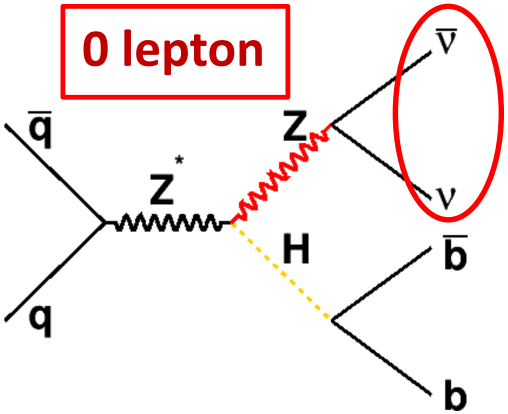

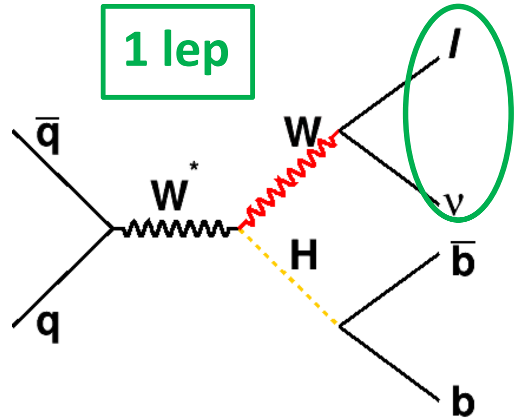

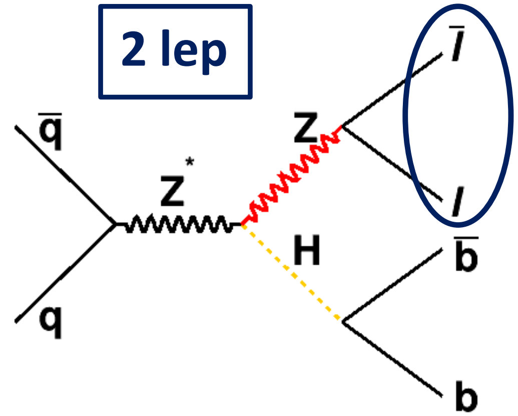

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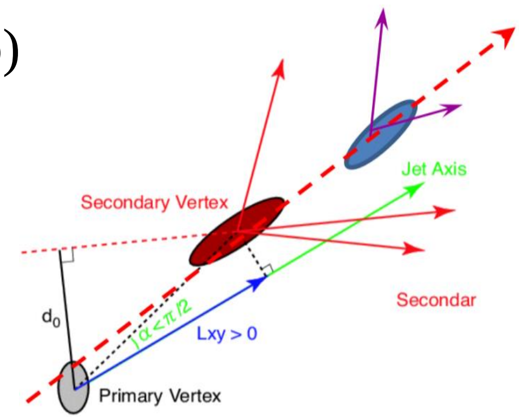
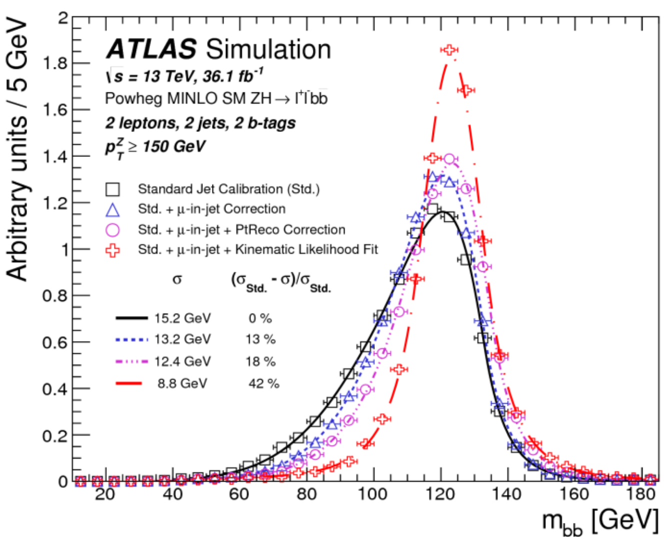
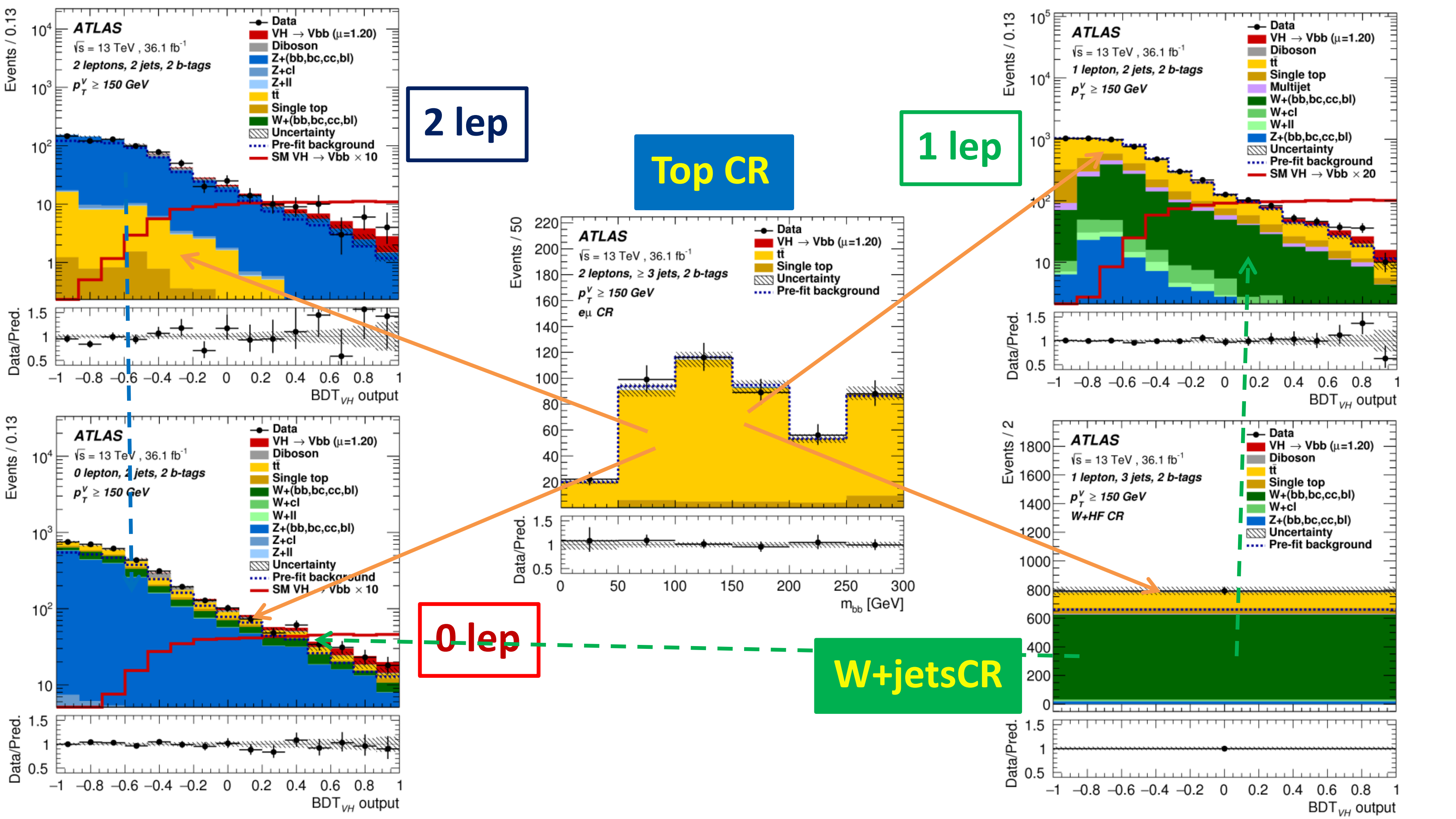




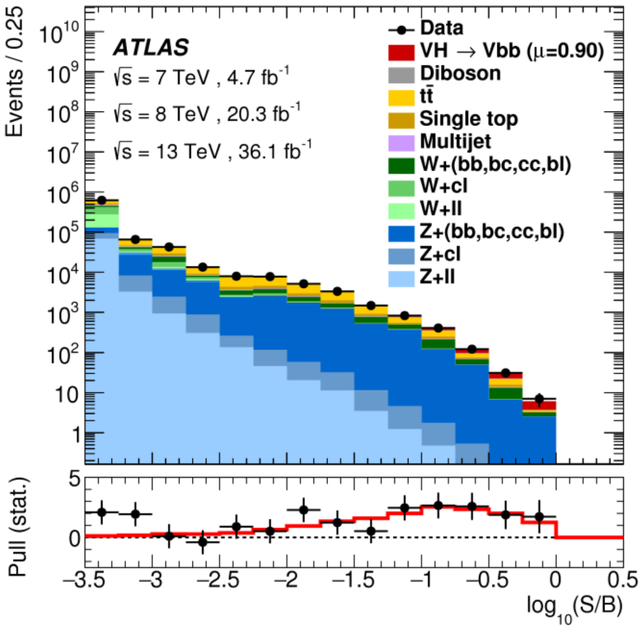
- **m_{bb} correction**
  - μ-in-jet, b-jet energy response cor., kinematic likelihood fit
- **MVA**: main search technique
  - Validation: m(bb) main discriminant

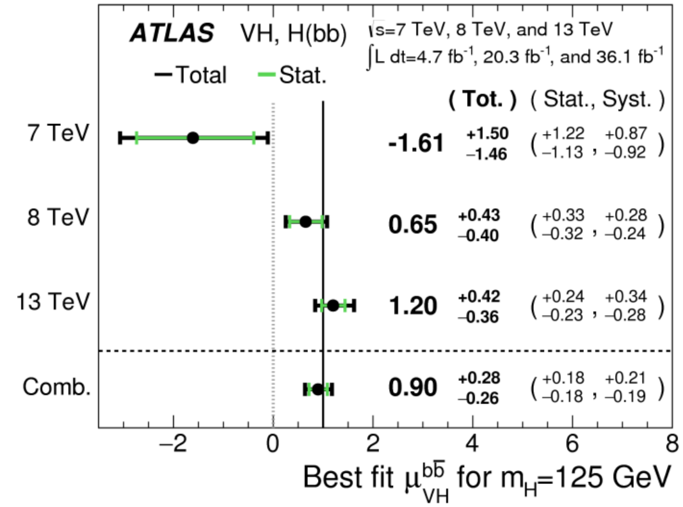
VHbb: background estimation

- Main backgrounds modeled with MC simulation
  - Corrected to data by simultaneous fit with various categories



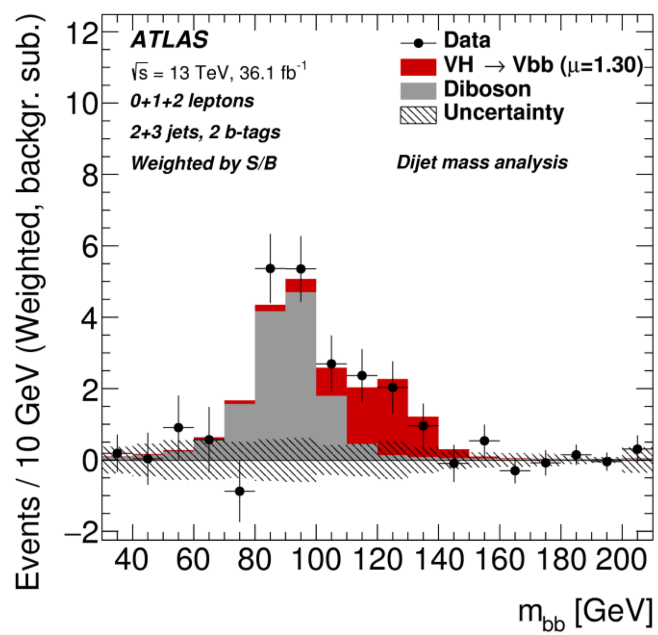
Evidence for VH, H→bb





Results:

- Evidence of H→bb at 3.5σ (3.0σ exp.)
- Dominant uncertainties: signal modeling, MC statistics, b-tagging



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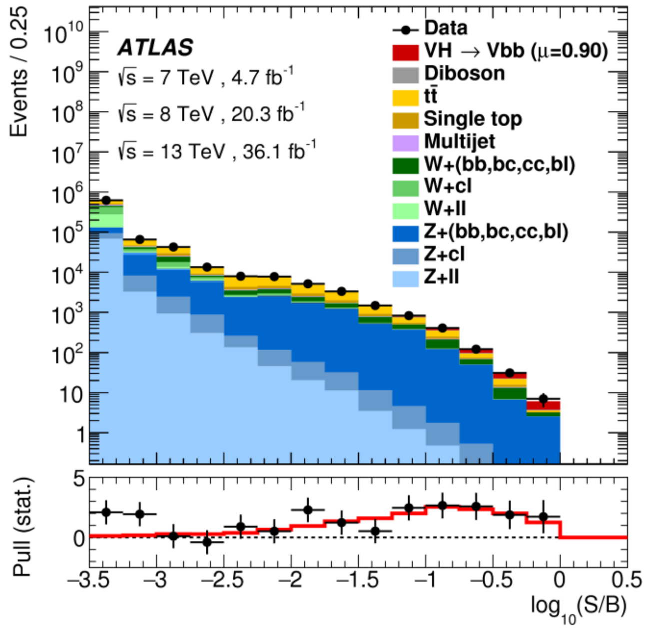
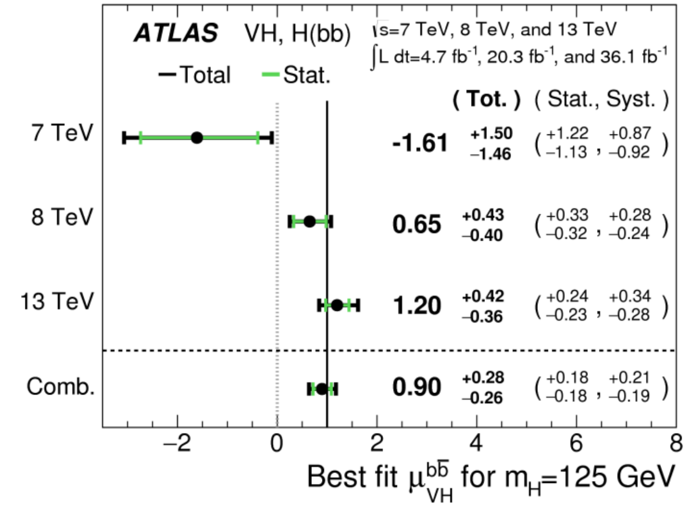
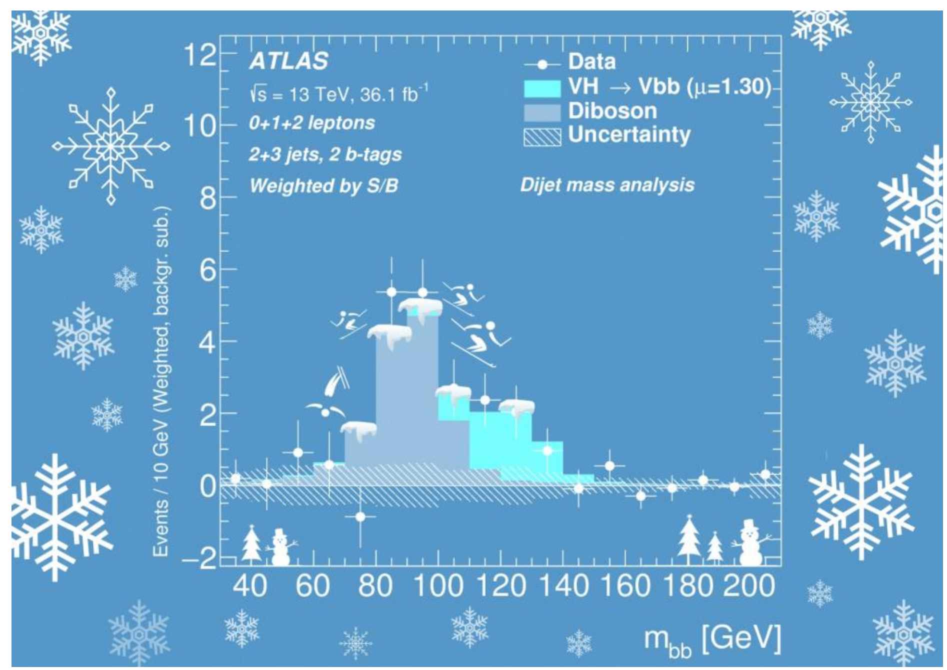


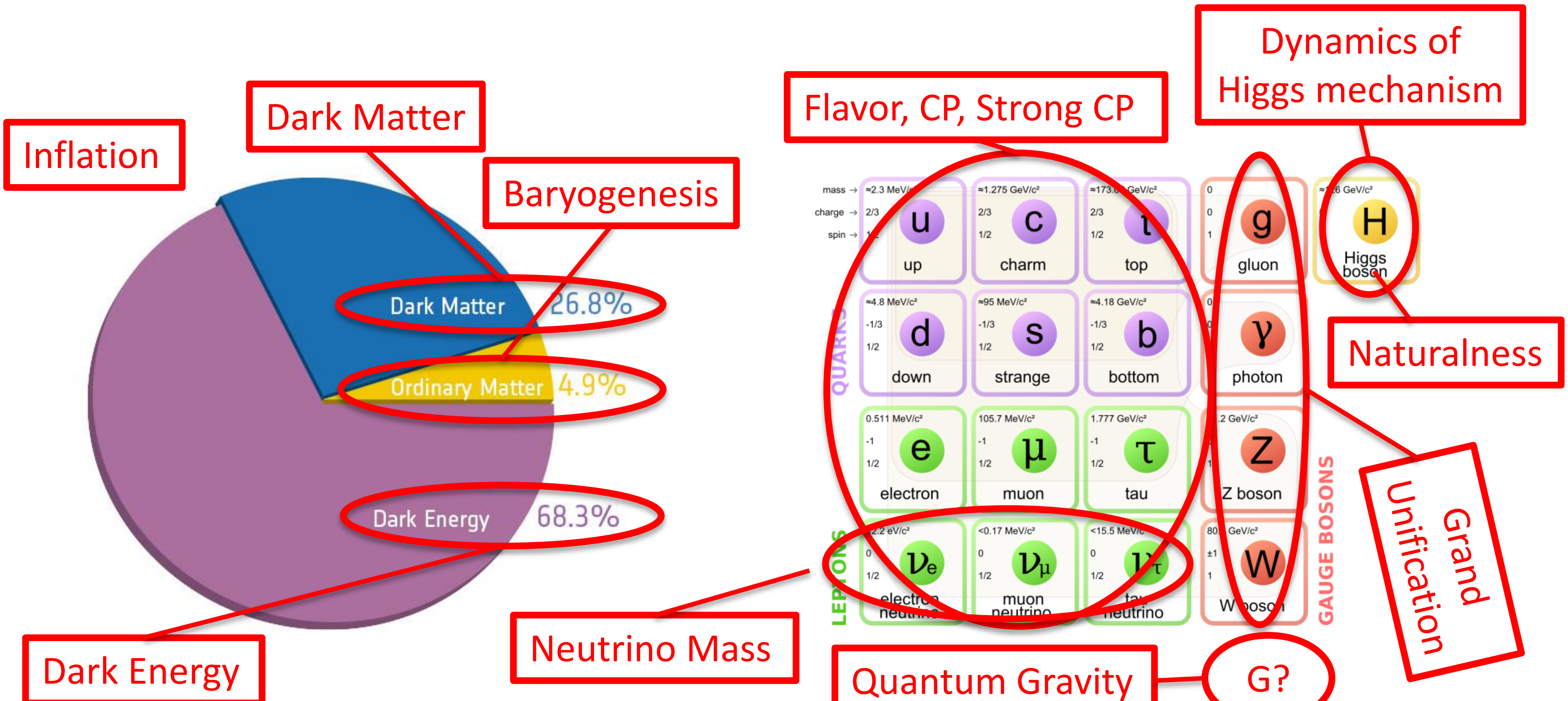


ATLAS End of Year (2017) greeting card



Known Unknowns

- Discovery of Higgs prove Standard Model successful
  - Dynamics of Higgs mechanism is unknown
- Many phenomena could not be explained by SM
  - Dark matter, naturalness, etc.



Picture modified from Jonathan Feng at 2017 ICFA Seminar

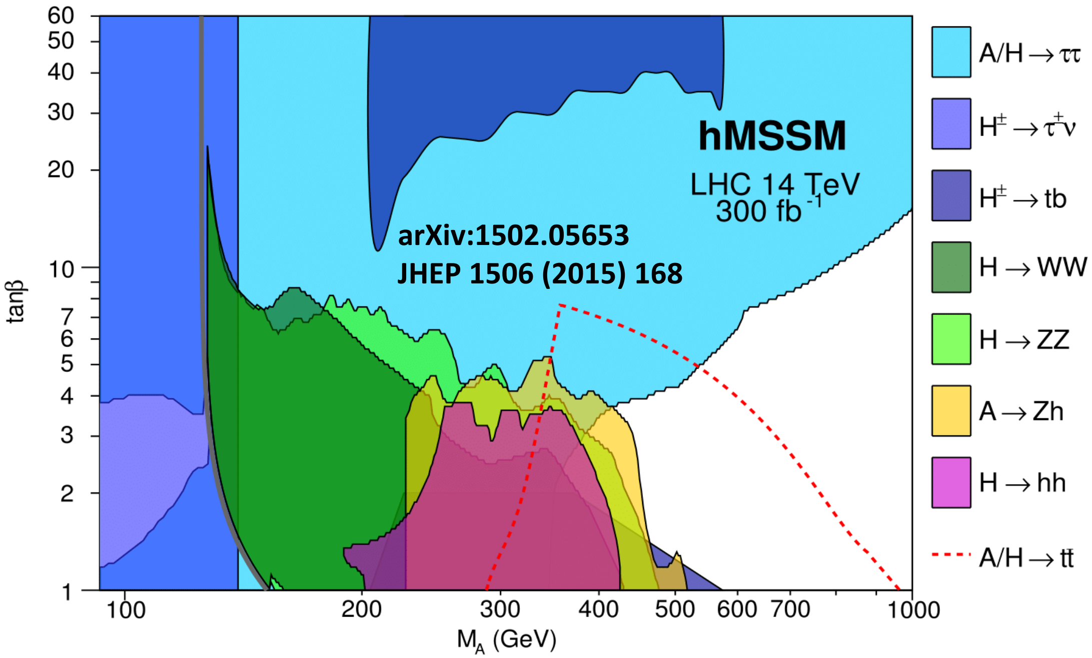
Extended Higgs sector

Two-Higgs Doublets Model (2HDM)

- Minimum extension of Higgs sector, requested by MSSM
- Predicts 5 Higgs bosons: $H^{+/-}$, A, H, h

MSSM as bench mark model

- Two free parameters at tree level: m_A, $\tan\beta = v_u/v_d$

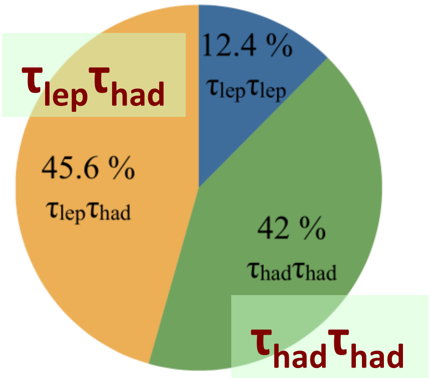


Fermion matters

- A/H→ττ
- A/H→tt
- $H^{+/-}$→τν
- $H^{+/-}$→tb

MSSM Higgs decay to di-τ

Di-τ event selections ($\tau_{lep}\tau_{had}$ and $\tau_{had}\tau_{had}$)



- Opposite charge sign, τ_{lep}/τ_{had} and τ_{had} back-to-back
- Regions: b-veto (b-tag) with 0 (≥1) b-jet

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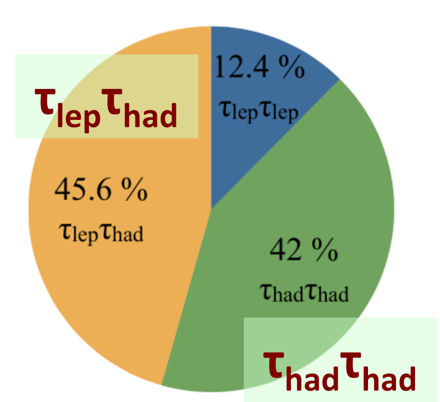
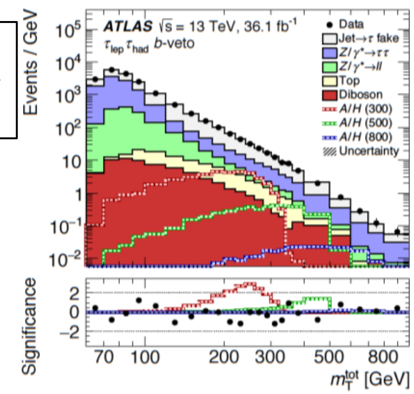


Final discriminant: total transverse mass

$$m_{\mathrm{T}}^{\mathrm{tot}} \equiv \sqrt{(p_{\mathrm{T}}^{\tau_1} + p_{\mathrm{T}}^{\tau_2} + E_{\mathrm{T}}^{\mathrm{miss}})^2 - (\mathbf{p}_{\mathrm{T}}^{\tau_1} + \mathbf{p}_{\mathrm{T}}^{\tau_2} + \mathbf{E}_{\mathrm{T}}^{\mathrm{miss}})^2}$$

$\tau_{e/\mu}\tau_{had}$ bveto



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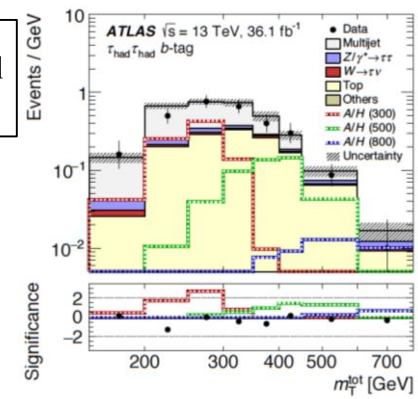

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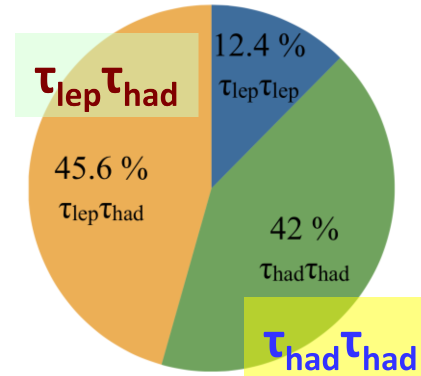

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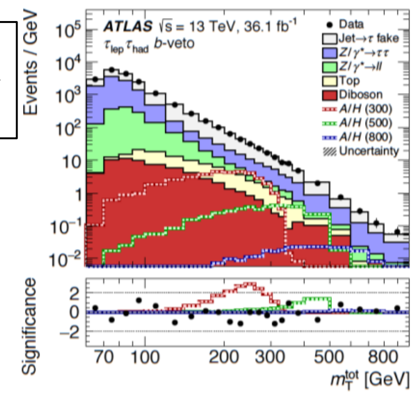
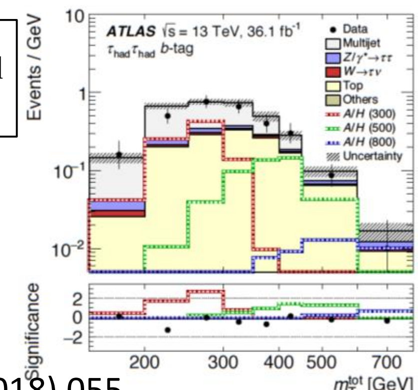


Background modeling

Process	τ_{had} cand.	Modeling
• Z→ee • Z→ττ • top	Real lepton (e, μ, τ)	→ Simulation with data-driven cor.
• W+jets • Multi-jet	Jet→τ fake	→ Data-driven

$\tau_{had}\tau_{had}$ btag



JHEP 01 (2018) 055

Jet fake τ_{had} estimation

- Simulation not suitable: bad modeling and sample size
- Fake Factor: $FF(n_{track}, p_T) = N_{pass}/N_{fail}$

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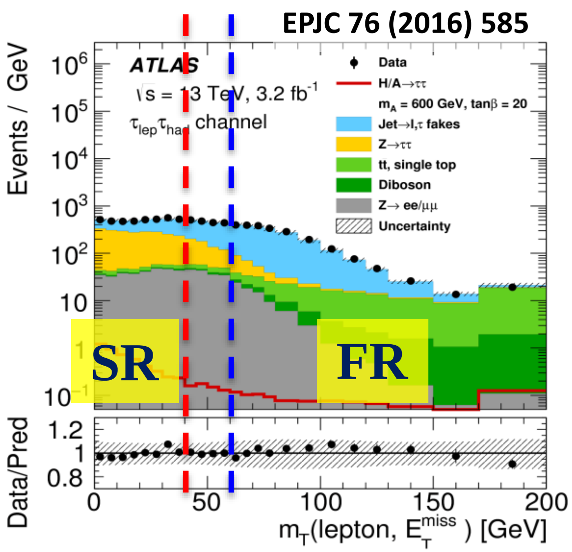
EPJC 76 (2016) 585



- Measured in top, W+jets, Multi-jet enriched regions

bveto→FR_{W+jets}

btag →FR_{Top}

FR_{MJ}

$\tau_{lep}\tau_{had}$: lepton fail isolation

$\tau_{had}\tau_{had}$: leading tau fail ID

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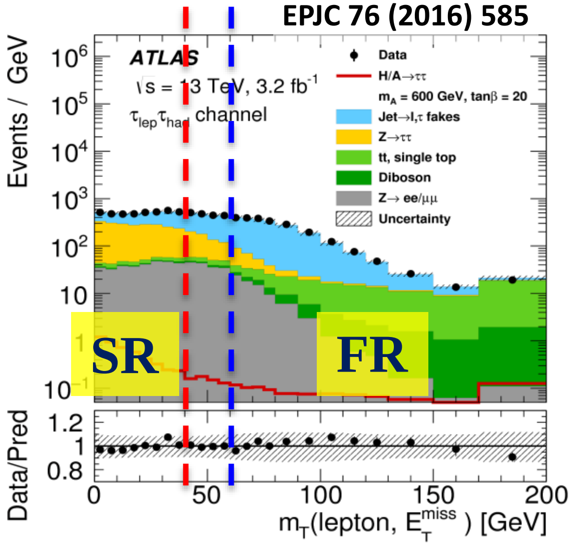

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btag →FR_{Top}

FR_{MJ}
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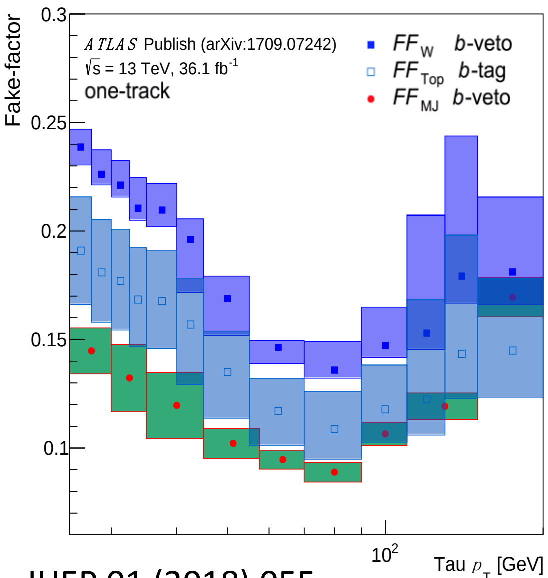
$$FF = \sum_i w_i \cdot FF_i$$ *i*: W+jets, MJ, Top



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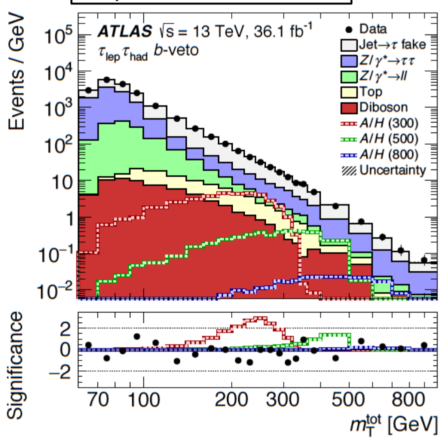
- Application: $N_{bkg} = CR_{fail\text{-}ID} \times FF$;
  - $CR_{fail\text{-}ID}$: Failed tau-ID control region
  - w_i: composition estimated by simulation ($\tau_{had}\tau_{had}$) or data-driven ($\tau_{lep}\tau_{had}$)

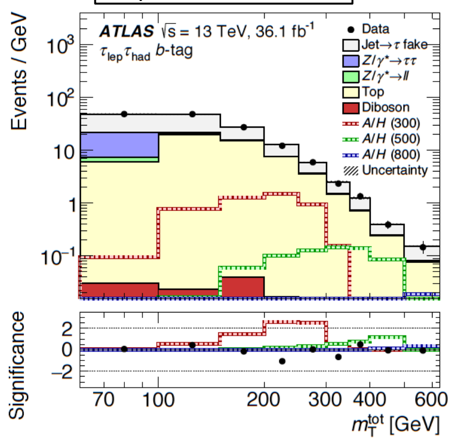
Di-tau results

$\tau_{e/\mu}\tau_{had}$, bveto



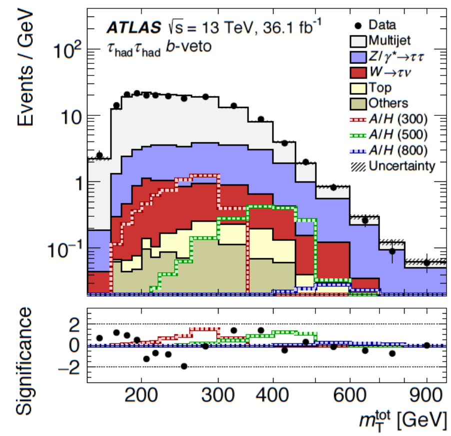
(a) $\tau_{lep}\tau_{had}$ b-veto category

$\tau_{e/\mu}\tau_{had}$, btag



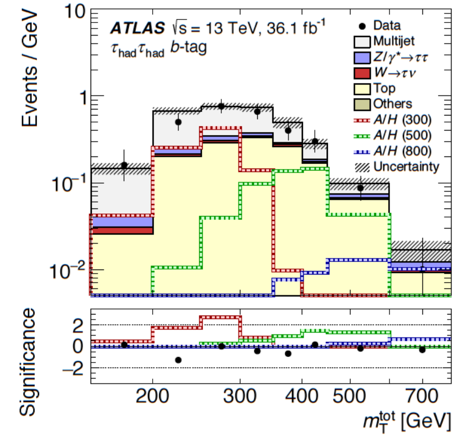
(b) $\tau_{lep}\tau_{had}$ b-tag category

$\tau_{had}\tau_{had}$, bveto



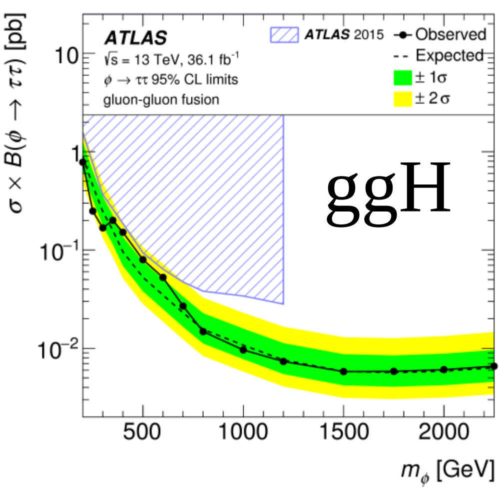
(c) $\tau_{had}\tau_{had}$ b-veto category

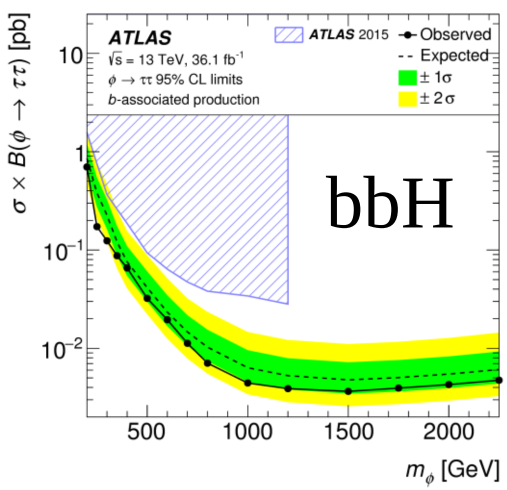
$\tau_{had}\tau_{had}$, btag



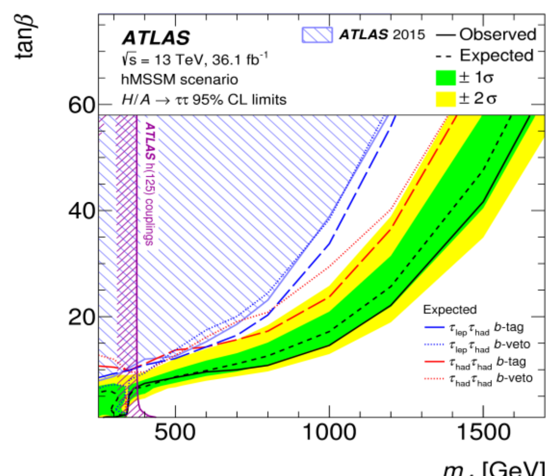
(d) $\tau_{had}\tau_{had}$ b-tag category

- Exclusion limit





hMSSM

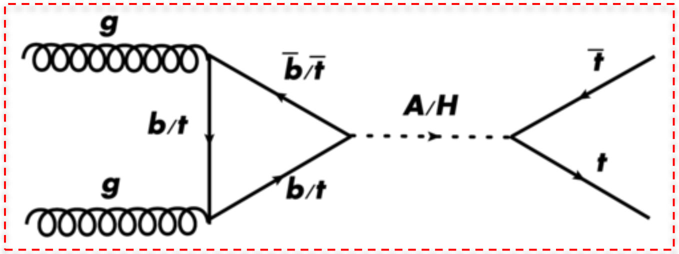


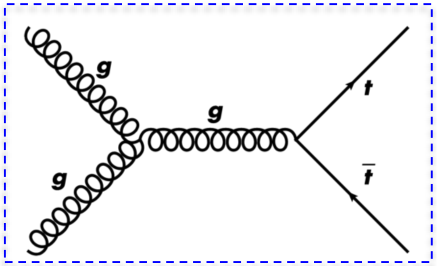
JHEP 01 (2018) 055

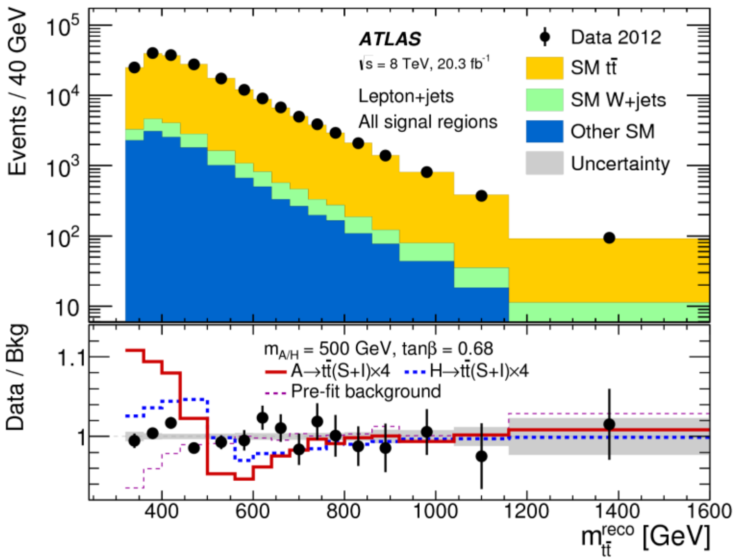
A/H→$t\bar{t}$ signal modeling

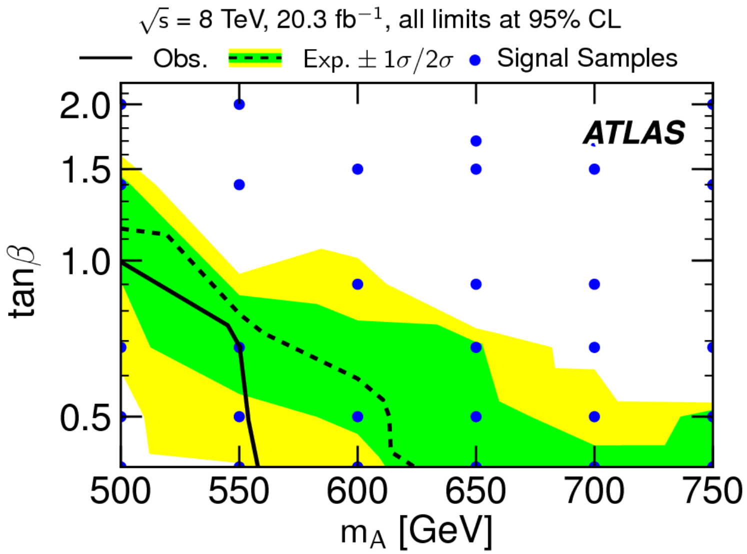
EXOT-2016-04

- Reinterprete ATLAS Run1 ttbar resonance search: *JHEP 08 (2015) 148*
- Model: Signal+Inter.+BKG (S+I+B)

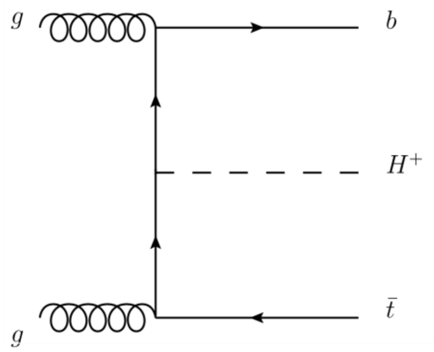








$H^+ \rightarrow \tau\nu$ search

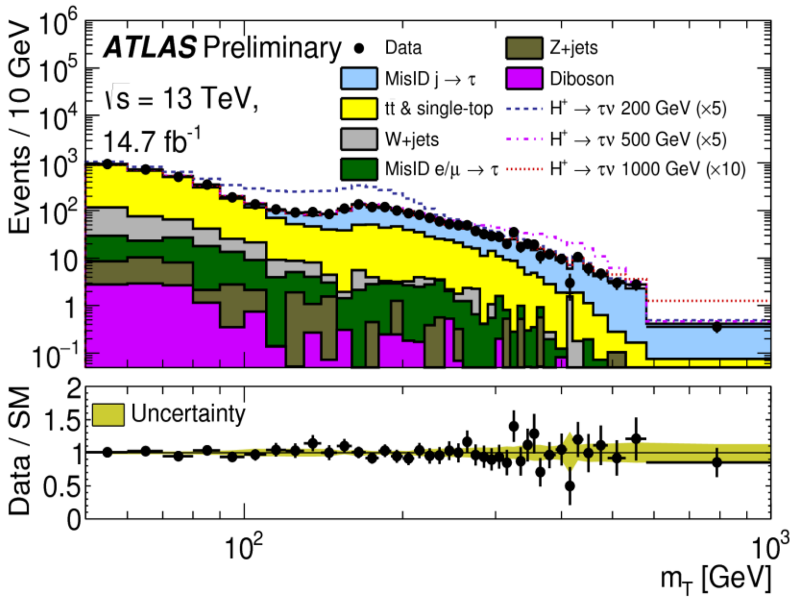


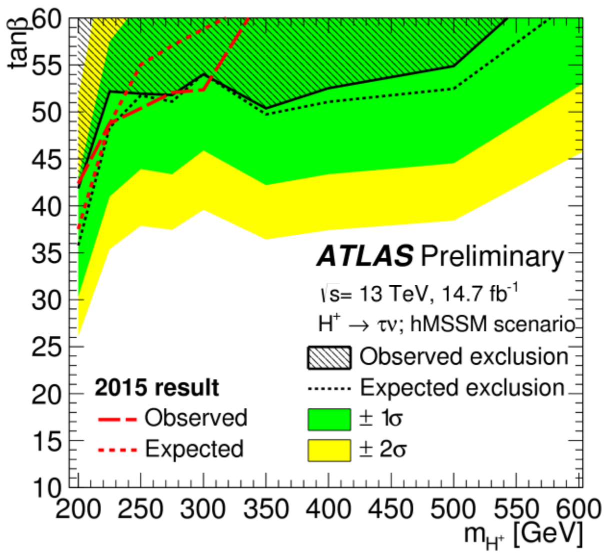
Event selection

- 1 τ_{had} and large E^T_{miss} (> 150 GeV)
- 3 jets (at least 1 b-jet)

Backgrounds

- Fake τ_{had} modeled with data-driven





Final Discriminant:

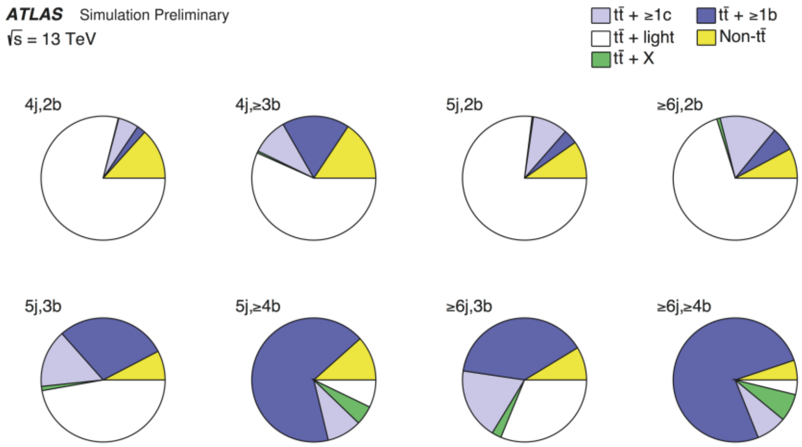
$$m_T = \sqrt{2p_T^\tau E_T^{miss}(1 - \cos\Delta\phi_{\tau,E_T^{miss}})}$$

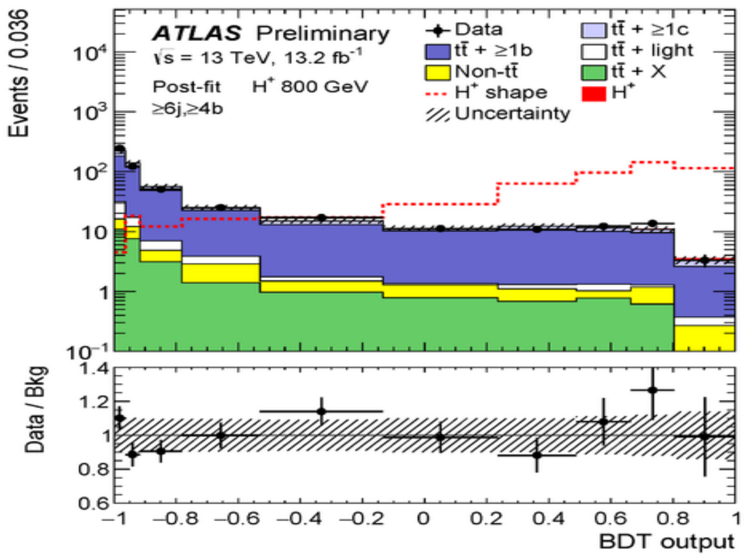
ATLAS-CONF-2016-088

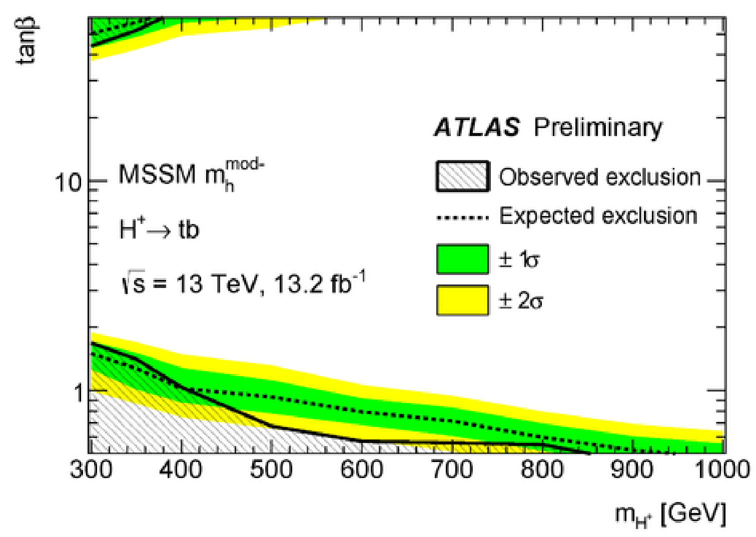
H⁺→tb estimation

Event Selection

- lepton+jets final state (lep=e,μ)
- Using MVA technique with 12 variables







Main backgrounds (ttbar+jets)

- Modeled with MC simulation, corrected to data by simultaneous fit

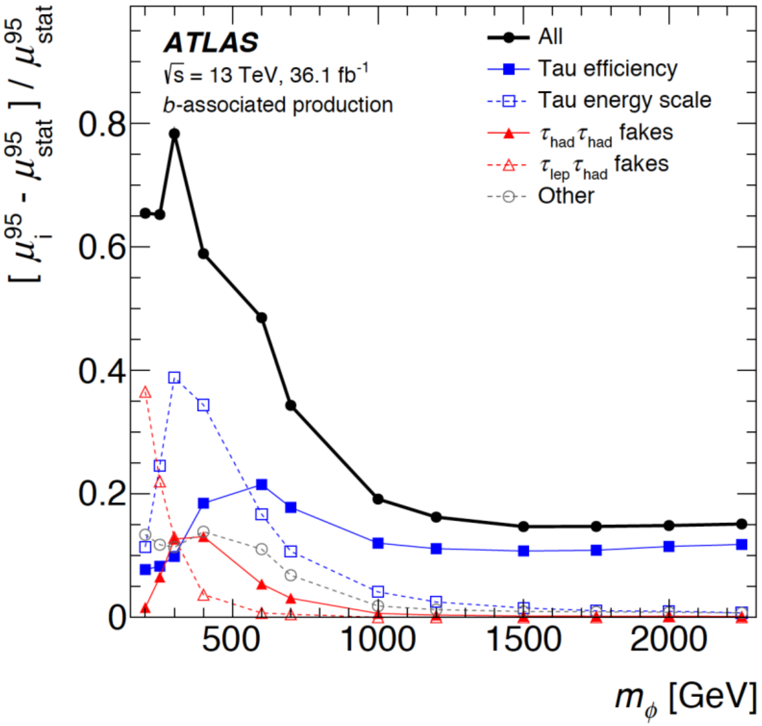
ATLAS-CONF-2016-089

Summary

- Higgs to fermions Yukawa coupling established in Run 2, which is important to understand the Higgs mechanism
- Fermionic channels particularly important to explore the BSM Higgs sectors.
- Extra Higgs bosons are extensively searched at ATLAS
- With the coming more data, Higgs to fermion Yukawa coupling can be studied in further, e.g. Differential X-sec, CP violation, etc.

Backup

Systematic uncertainties



- Major Systematics
  – Tau ID, energy scale, jet fake
  – Tau sys. dominant at the high mass regime