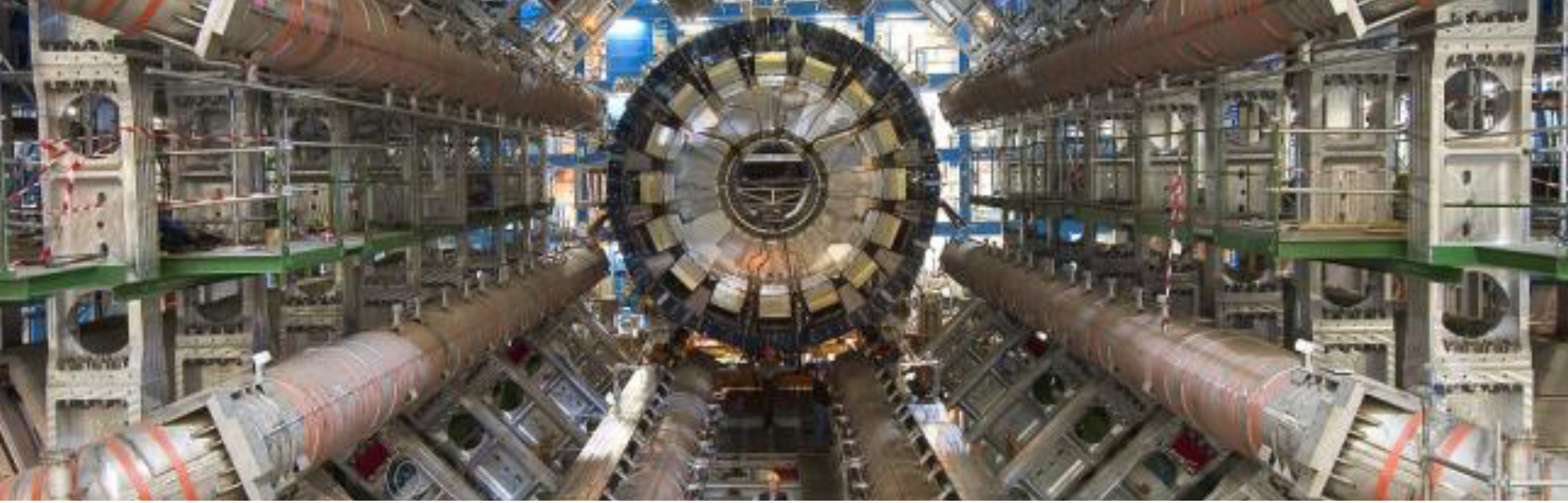

Search for heavy charged Higgs Bosons at ATLAS

FSP 103 ATLAS

ATLAS EXPERIMENT

GRADUIERTEN KOLLEG Masse-Spektrum-Symmetrie

HUMBOLDT-UNIVERSITÄT ZU BERLIN

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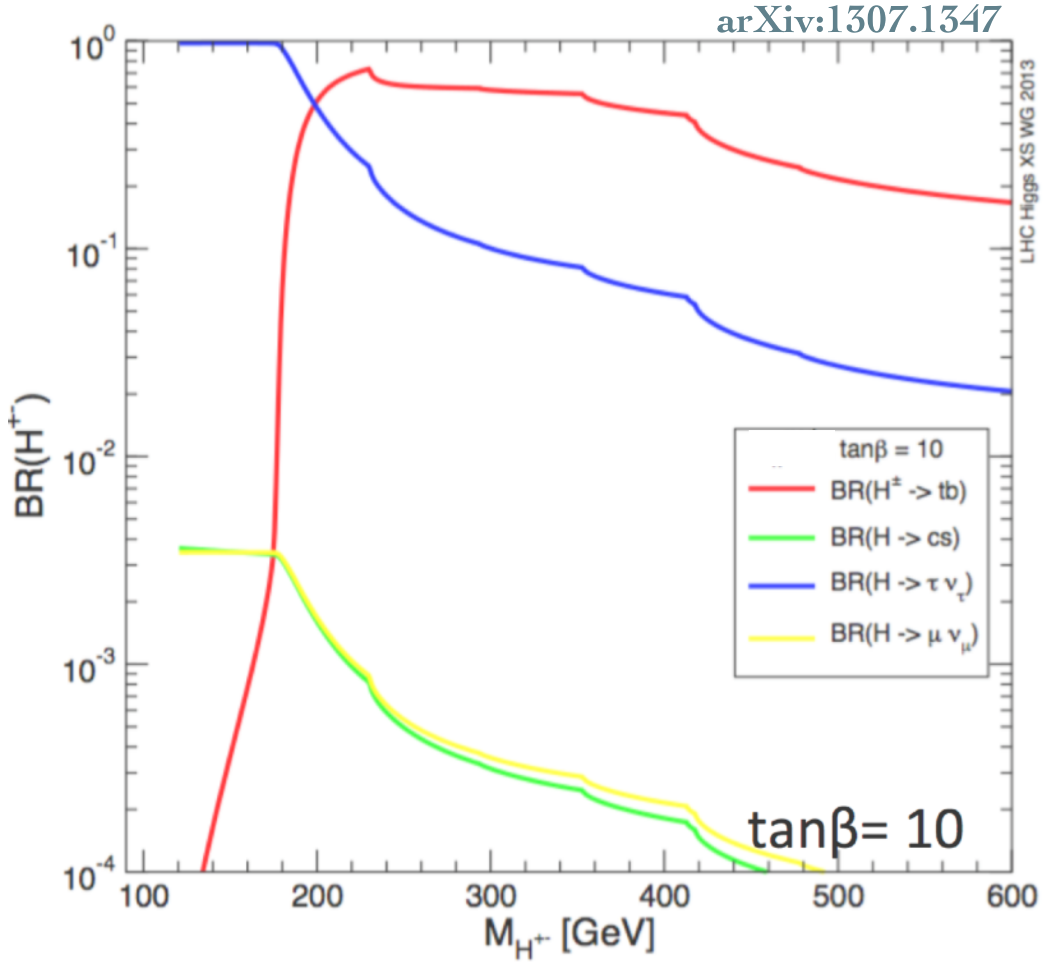
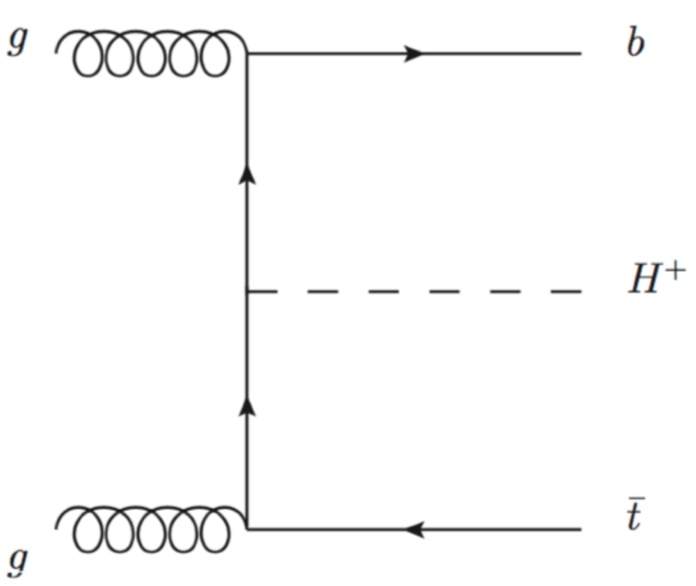
Introduction

- Charged Higgs Boson predicted by several BSM models
- MSSM, 2HDM: 5 detectable Higgs h, H, A, H+, H-
- $H^{\pm}$ Production and decay depend on:
  - Mass of the bosons $M(H^{\pm})$
  - Mixing angles between doublets: α, β
- When $M(H^{\pm}) > M(t)+M(b)$: $pp \to tbH^{\pm}$, $H^{\pm} \to tb$ dominant

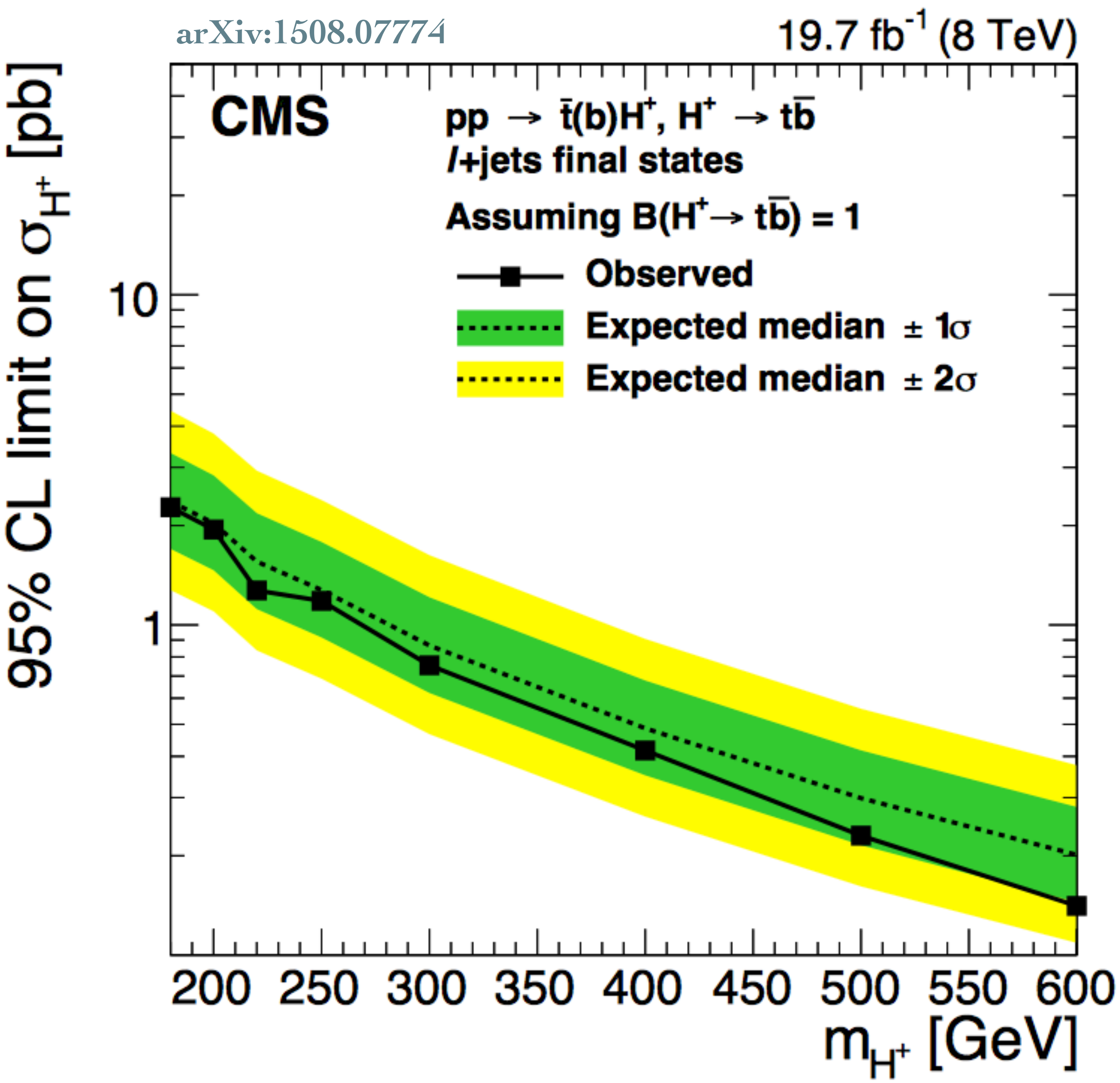
arXiv:1307.1347



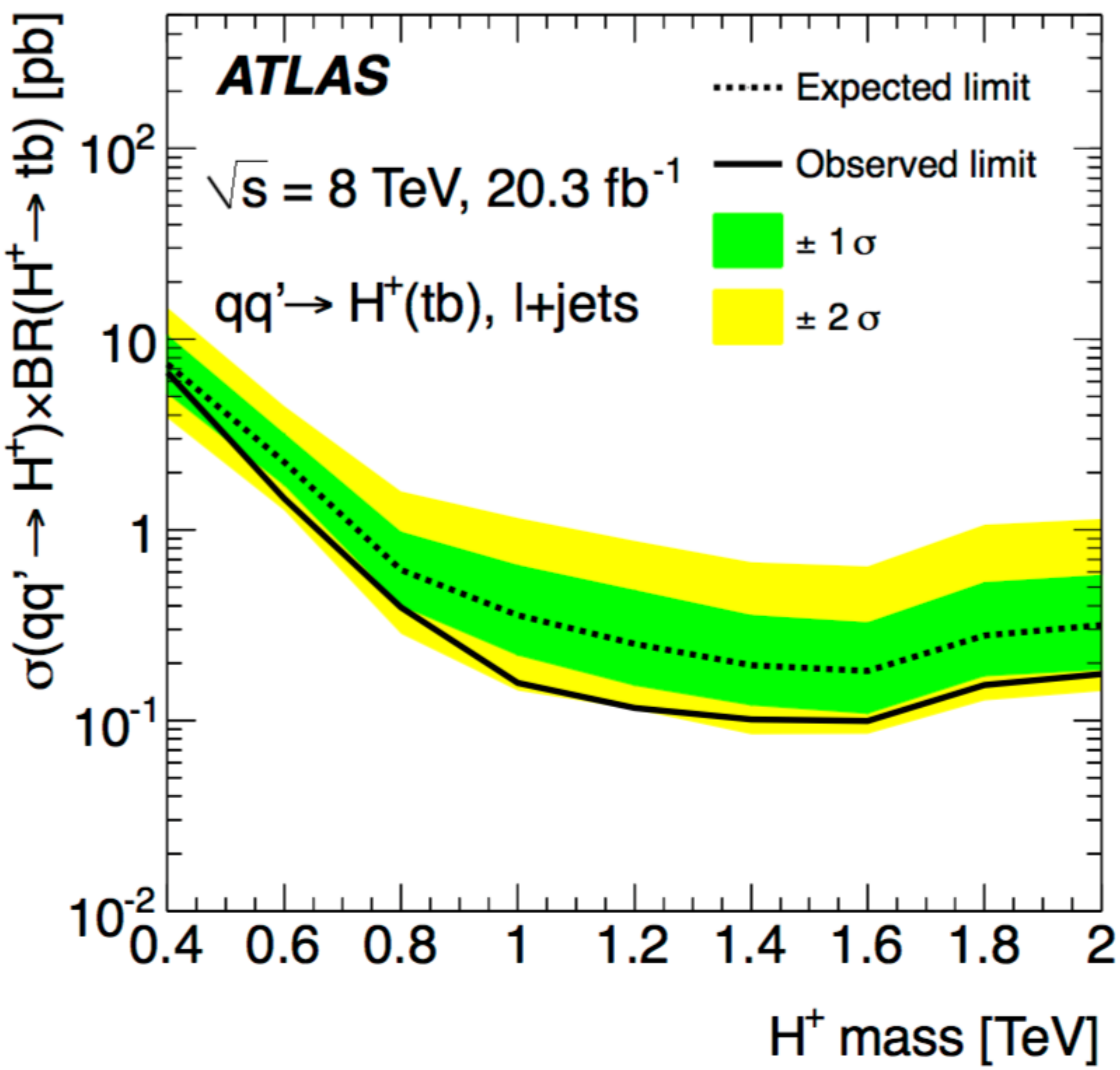


Results at 8 TeV

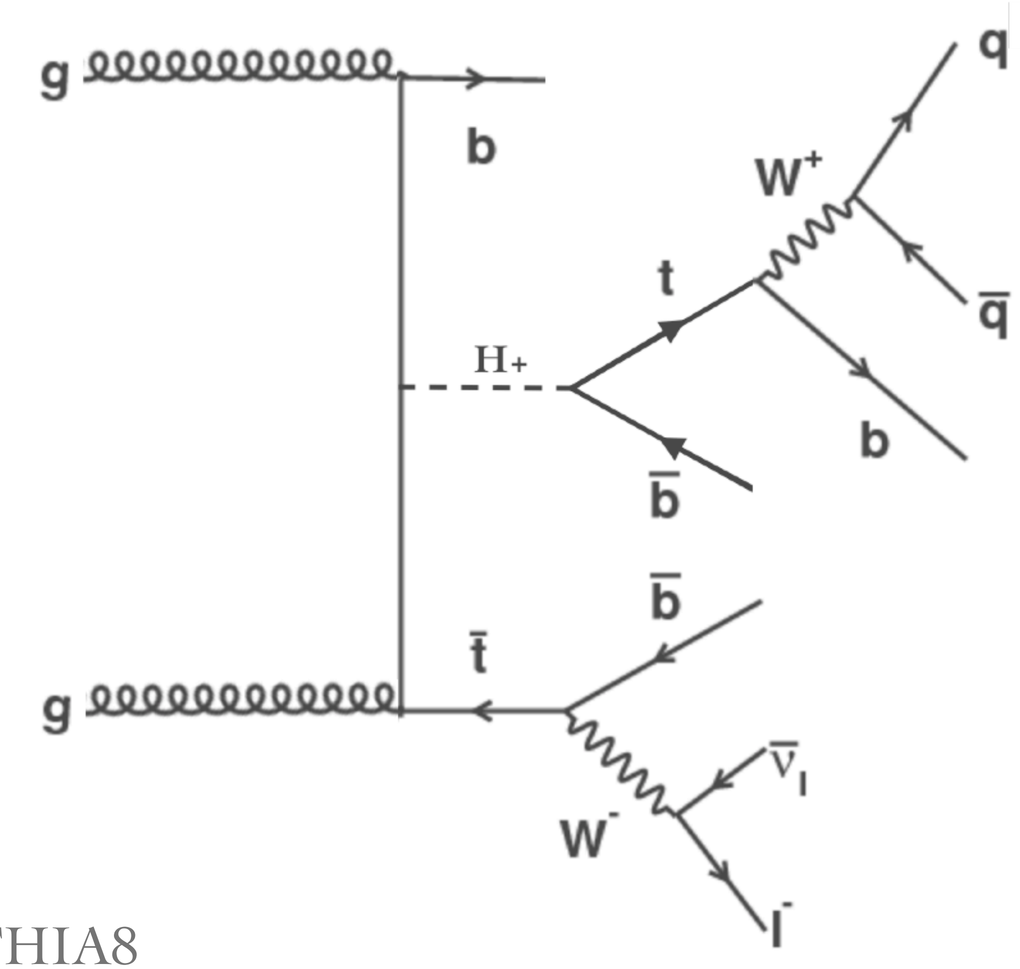
arXiv:1508.07774



arXiv:1512.03704



$H^{\pm}$ ->tb Analysis Setup



- LHC 13.2 fb^{-1} pp collisions at 13 TeV (2015+2016 data)
- **Single lepton** trigger (e,μ) events
- 4 Signal Regions (SR) and 4 Control Regions (CR):
  - SR: 5j3b, 5j≥4b, ≥6j3b, ≥6j≥4b
  - CR: 4j2b (4 jets - 2 bjets), 5j2b, ≥6j2b, 4j≥3b
  - Jet (antikt04pt) and lepton $p_T \geq 25$ GeV
- Signal modelling:
  - tb$H^{\pm}$ process modelled with MG5_aMC@NLO (4FS) + PYTHIA8
  - 9 $H^{\pm}$ mass points: $300 \leq M_H \leq 1000$ GeV
- Background modelling:
  - tt (+light, +heavy flavour) background: POWHEG-BOX + PYTHIA6 (NLO - ATLAS FullSim)
  - Additional backgrounds: single top, *W*/*Z*+jets, diboson, ttX, fakes

H± ->tb Analysis Setup - PreFit

- Boosted Decision Tree (BDT) is trained separately per each mass point and signal region
- M(H±) < 600 GeV, BDT trained against tt+≥1b only
- M(H±) ≥ 600 GeV, BDT trained against tt+light,≥1c, ≥1b

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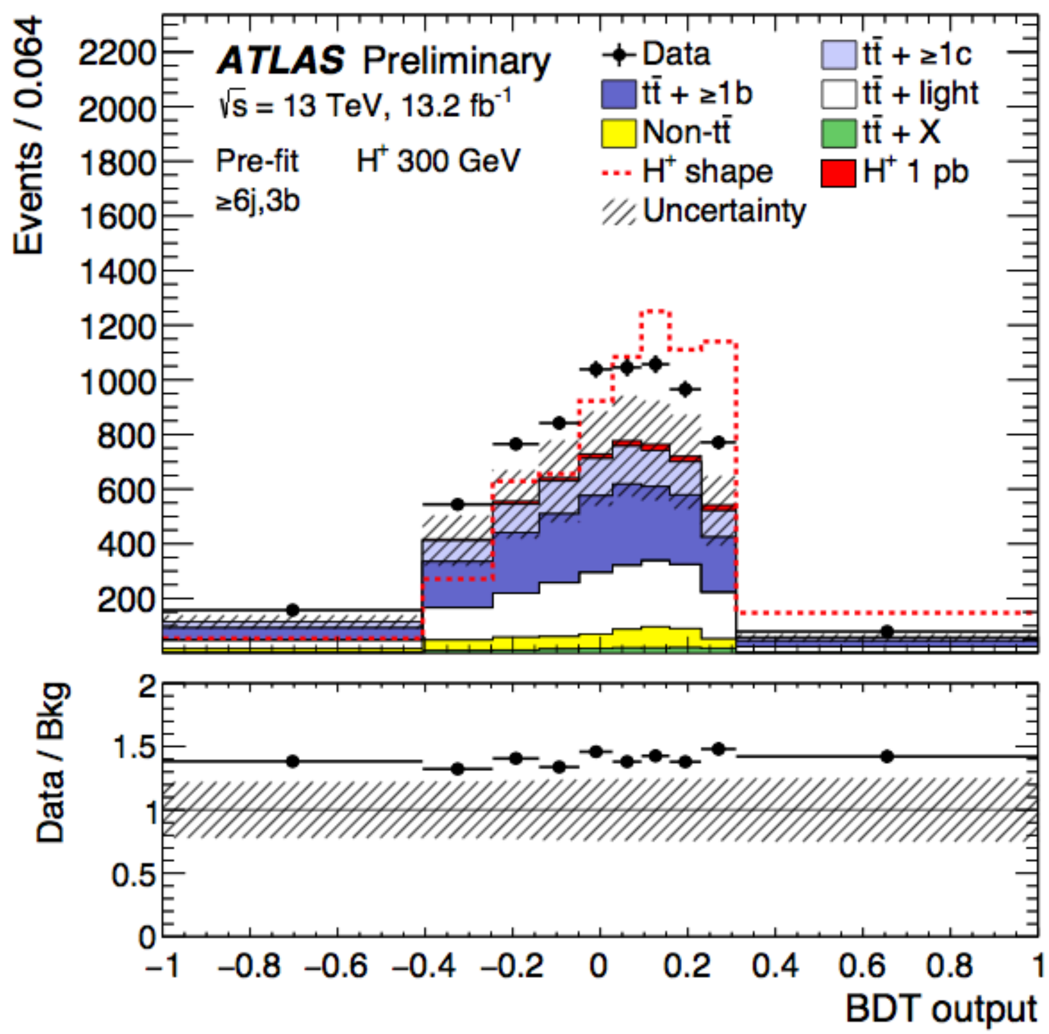

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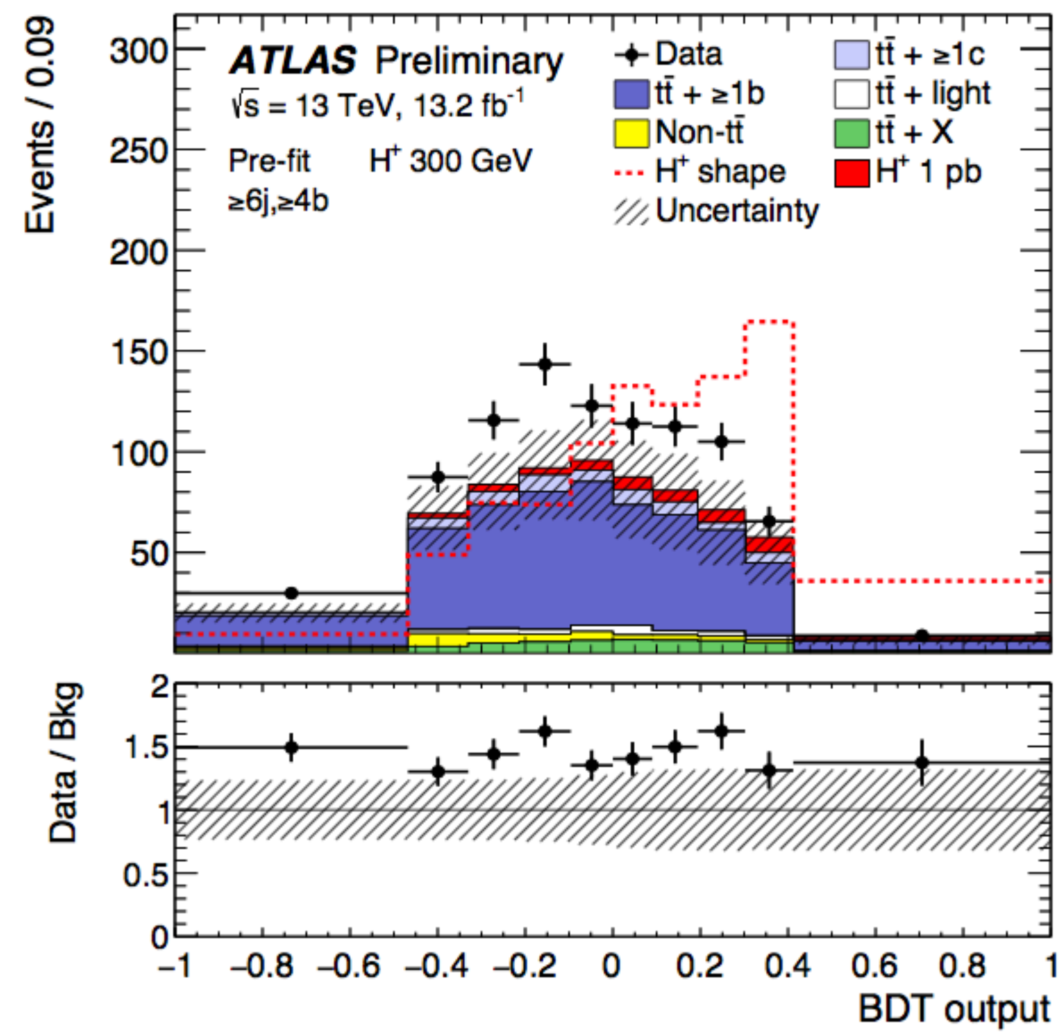

H± ->tb Analysis Setup - PreFit

- Good Data/MC agreement in low bjets multiplicity regions
- Data exceed expected BGKs when ≥3 bjets (poor modelling of tt+≥1c, tt+≥1b)
- Solution: tt+≥1c, tt+≥1b normalisations free floating parameters in the fit

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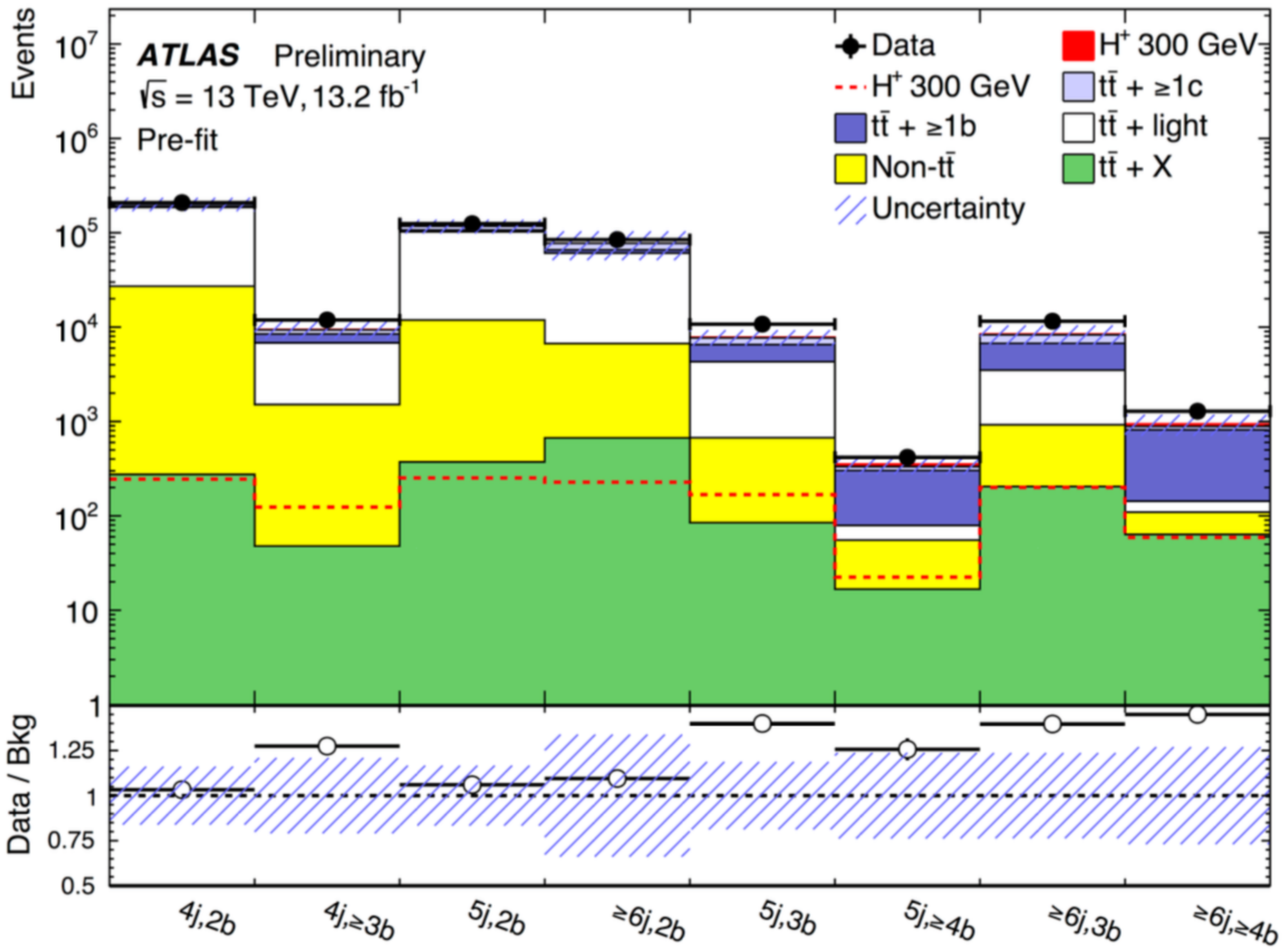

Results - PostFit

- Binned maximum-likelihood fit to the data performed per each mass point
- Inputs to the fit: $H_T^{had} = \Sigma p_T^{jets}$ in CR, BDT output in SR

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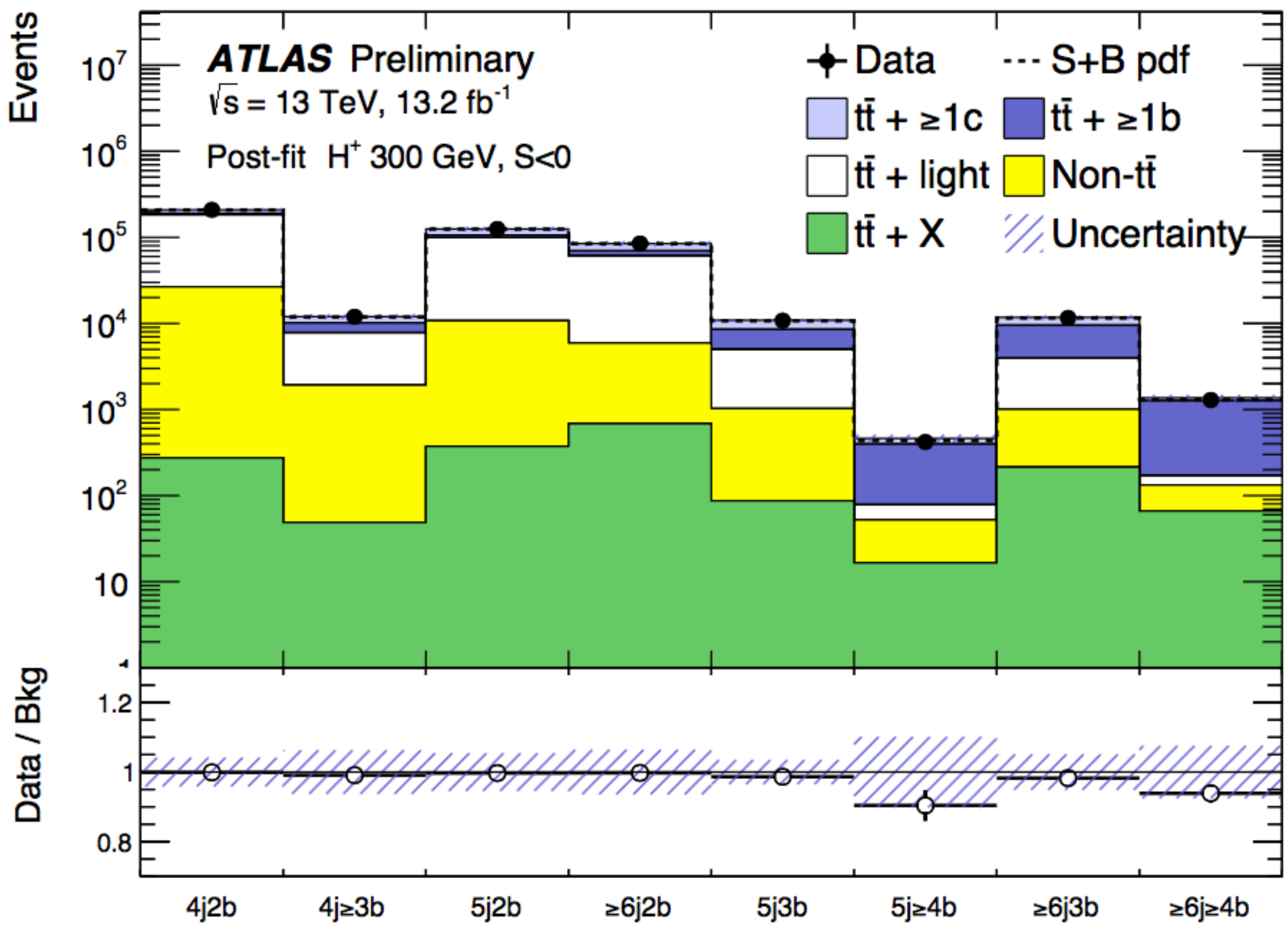

Results

- No relevant excess above SM background
- Observed limit ranges from σ×BR=1.09 pb to σ×BR=0.18 pb
- tanβ<0.5 excluded for M_H<800 GeV
- First exclusion of high tanβ (>66) for M_H<350 GeV

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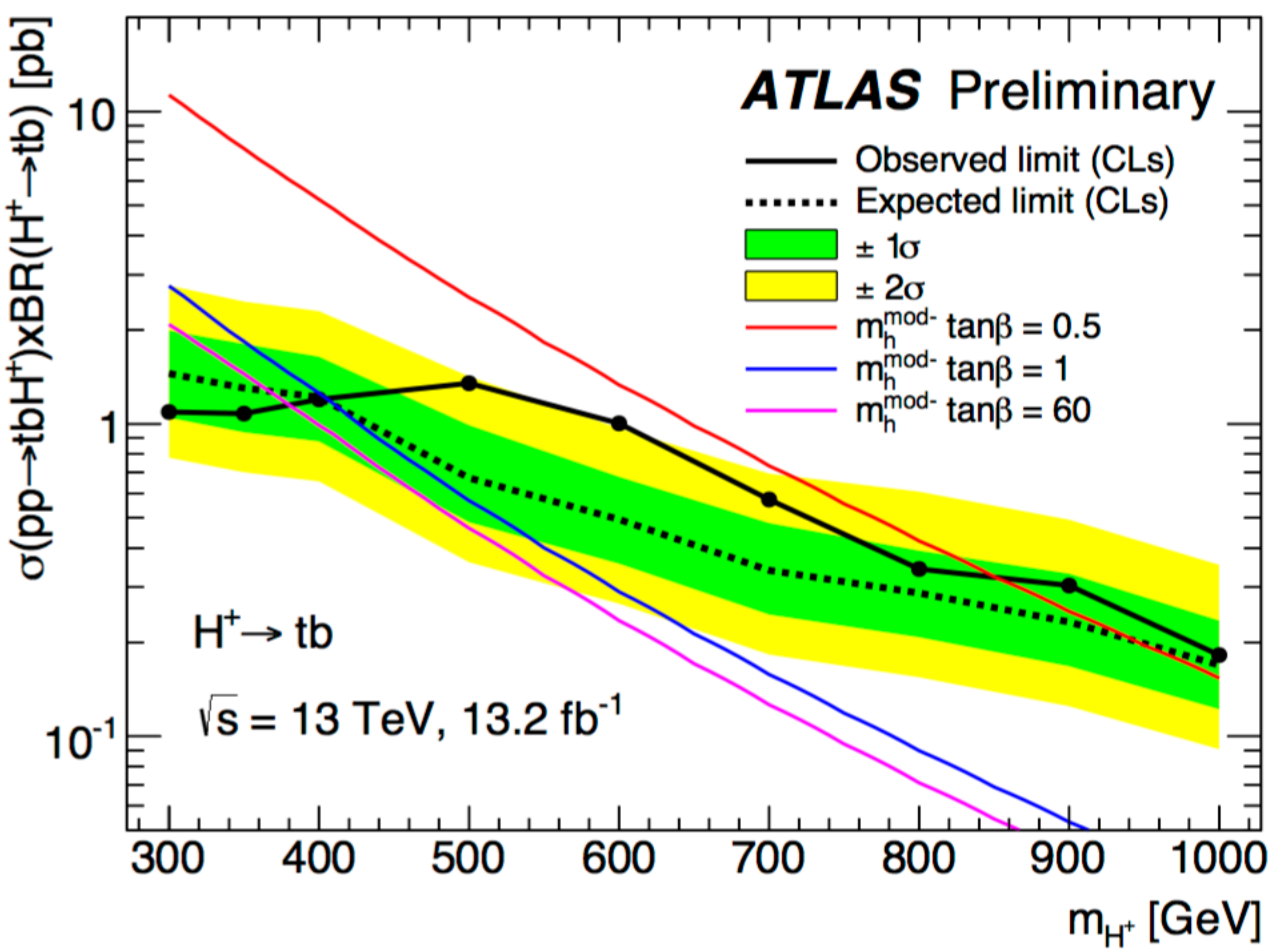

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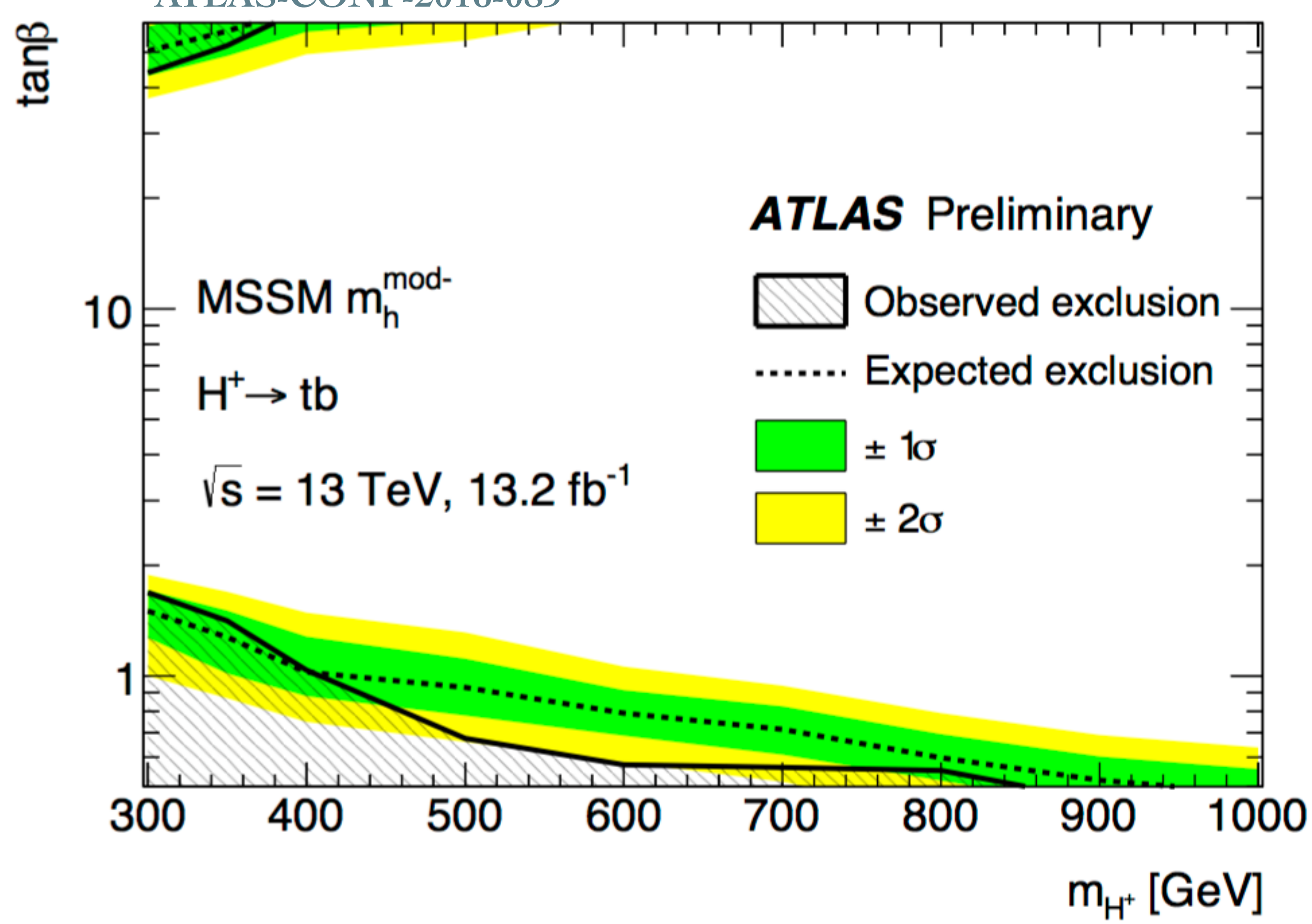

Conclusions

- Search for $H^{\pm}$ using 13.2 fb^{-1} in the $300 \leq M_H \leq 1000$ GeV mass range
- No significant excess observed with respect to SM predictions
- Results presented at ICHEP: ATLAS-CONF-2016-089

- Full 2016 data available now
- Many studies ongoing:
  - New ttbar (POWHEG+P8) sample and modelling systematics
  - Working on improving the BDTs
  - Fit optimisation
  - Testing modern machine learning libraries (Keras and Theano)

Thank you for the attention!

Backup 1 - Higgs models

- 2HDM: we introduce a new Higgs doublet, replication of the first one:

$$\Phi_1 = \begin{pmatrix} \phi_1^+ \\ \phi_1^0 \end{pmatrix} \; ; \; \Phi_2 = \begin{pmatrix} \phi_2^+ \\ \phi_2^0 \end{pmatrix}$$

- Both doublets could acquire VEV:

$$\langle \Phi_1 \rangle = \frac{v_1}{\sqrt{2}} \quad ; \quad \langle \Phi_2 \rangle = \frac{v_2}{\sqrt{2}} e^{i\theta}$$

- Redefining the states as:

$$\Phi_1 = \begin{pmatrix} \phi_1^+ \\ \frac{h_1 + v_1 + i g_1}{\sqrt{2}} \end{pmatrix} \; ; \; \Phi_2 = \begin{pmatrix} \phi_2^+ \\ \frac{h_2 + v_2 e^{i\theta} + i g_2}{\sqrt{2}} \end{pmatrix}$$

- Then β, α are:

$$\begin{pmatrix} \cos\beta & \sin\beta \\ -\sin\beta & \cos\beta \end{pmatrix} \begin{pmatrix} \phi_1^+ \\ \phi_2^+ \end{pmatrix} = \begin{pmatrix} G^+ \\ H^+ \end{pmatrix}$$

$$\begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} h_1 \\ h_2 \end{pmatrix} = \begin{pmatrix} H^0 \\ h^0 \end{pmatrix}$$

$$\begin{pmatrix} \cos\beta & \sin\beta \\ -\sin\beta & \cos\beta \end{pmatrix} \begin{pmatrix} g_1 \\ g_2 \end{pmatrix} = \begin{pmatrix} G^0 \\ A^0 \end{pmatrix}$$

- tan(β)=v1/v2;
- α= mixing angle between CP-even Higgs bosons

Backup 2 - BDT Variables

- The leading jet p_T.
- The mass of the bb pair with smallest ΔR.
- The p_T of the fifth jet, with the jets ordered by transverse momentum with the b-tagged jets first and then the non-b-tagged jets.
- The second Fox-Wolfram moment calculated using all jets and leptons.
- The average ΔR of all bb pairs.
- The ΔR of the lepton and the bb pair with smallest ΔR.
- The mass of the untagged jet pair with smallest ΔR.
- The scalar sum of E_T calculated using all jets.
- The mass of the bb pair with largest p_T.
- The mass of the bb pair with largest mass.
- The mass of the jet triplet with largest p_T.
- The centrality, defined as the ratio of the scalar sum of the p_T of all jets and leptons over the total visible energy.

Backup 3 PreFit CR M_H=300 GeV

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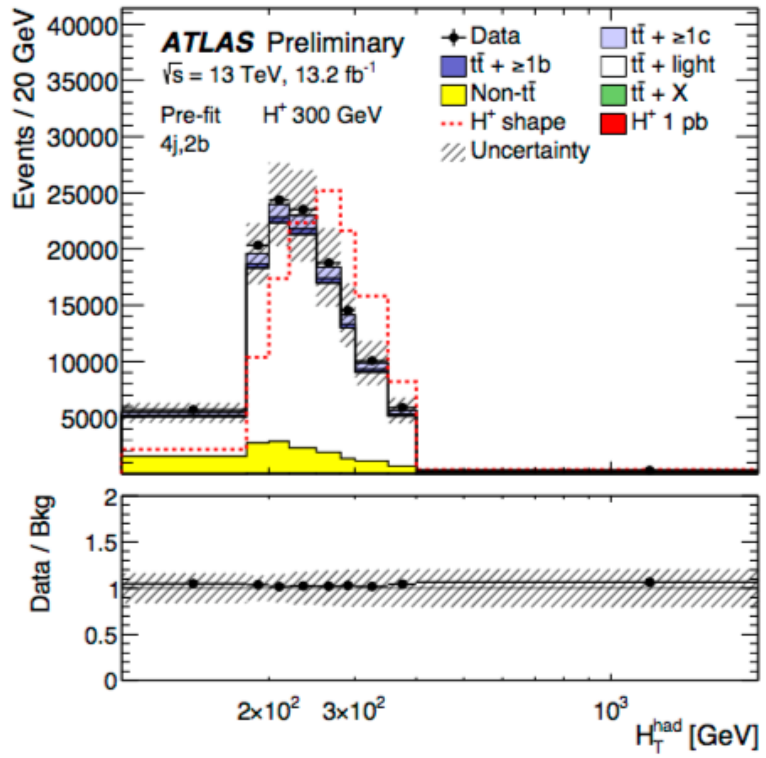

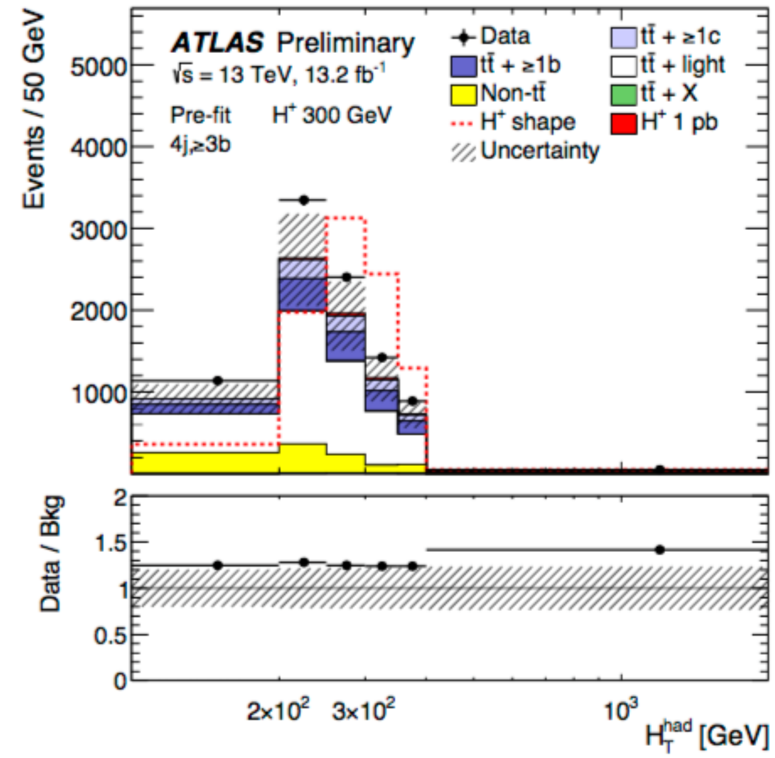

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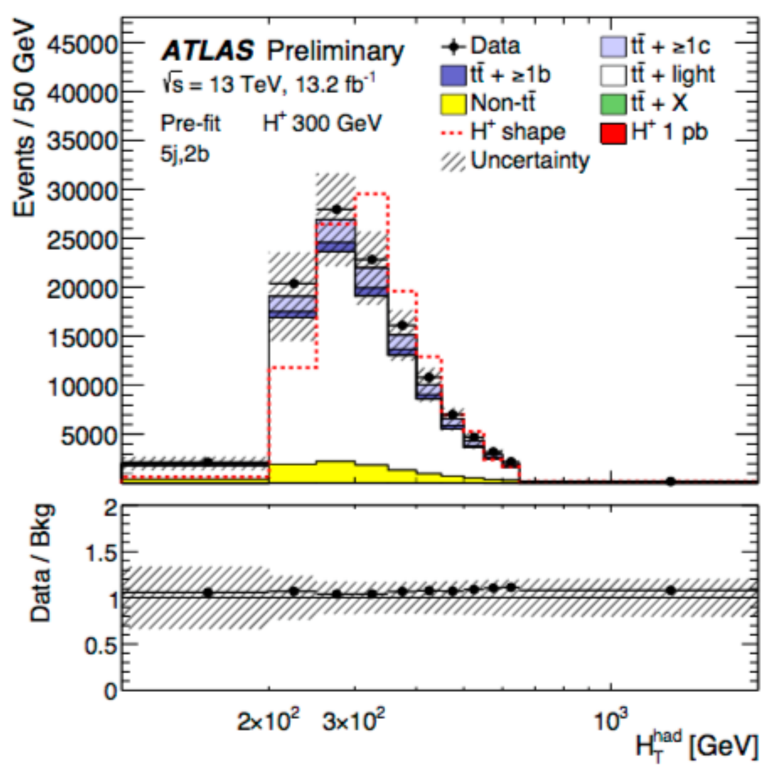

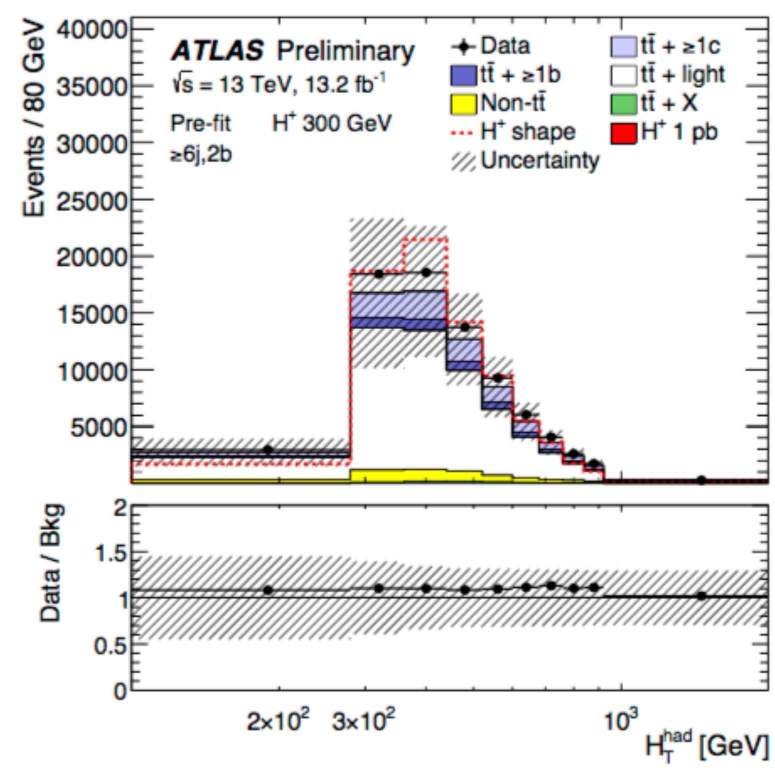

Backup 4 PreFit SR M_H=300 GeV

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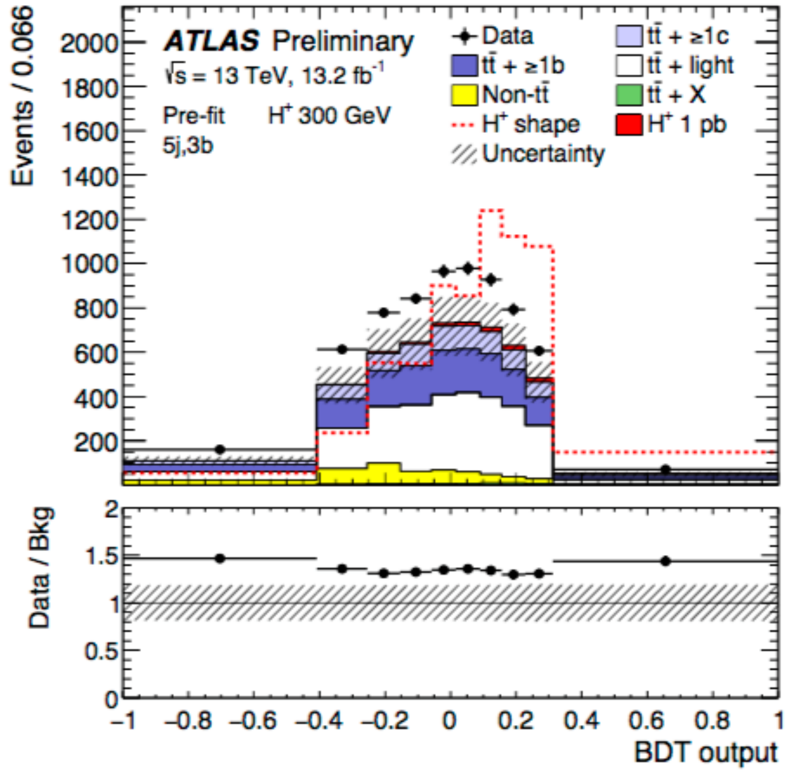

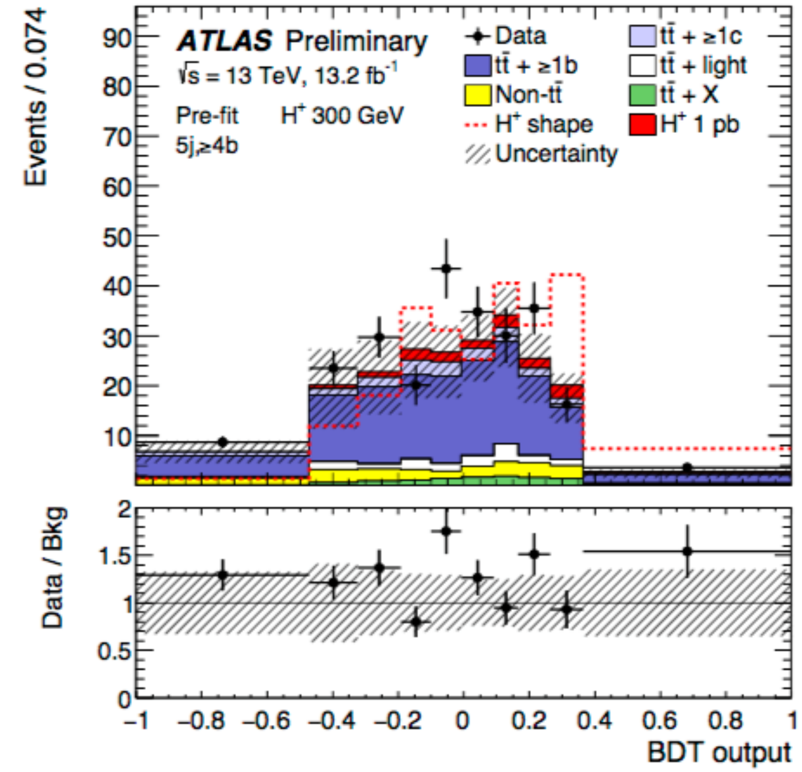

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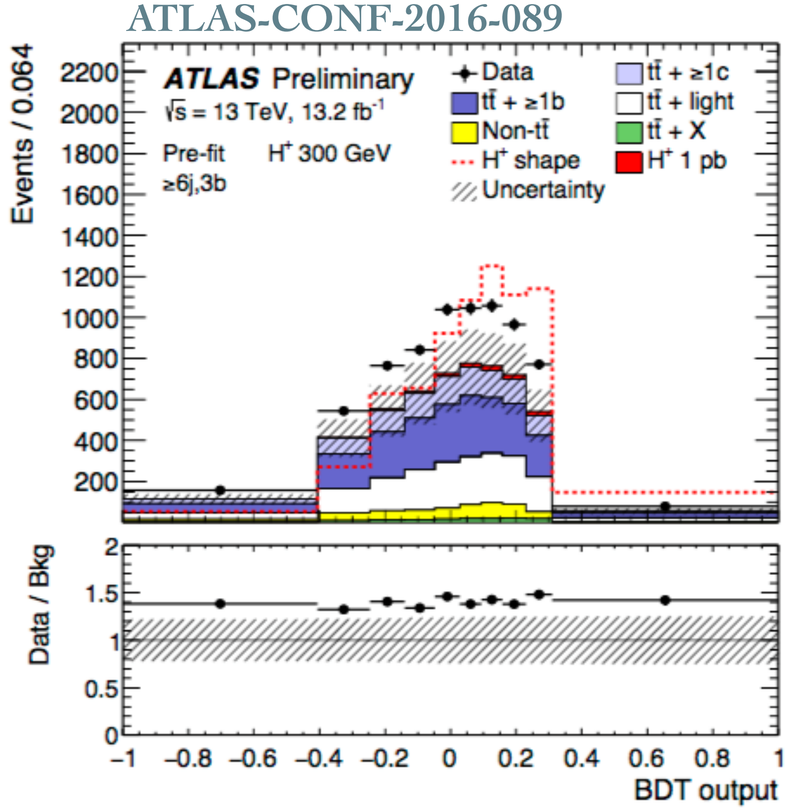

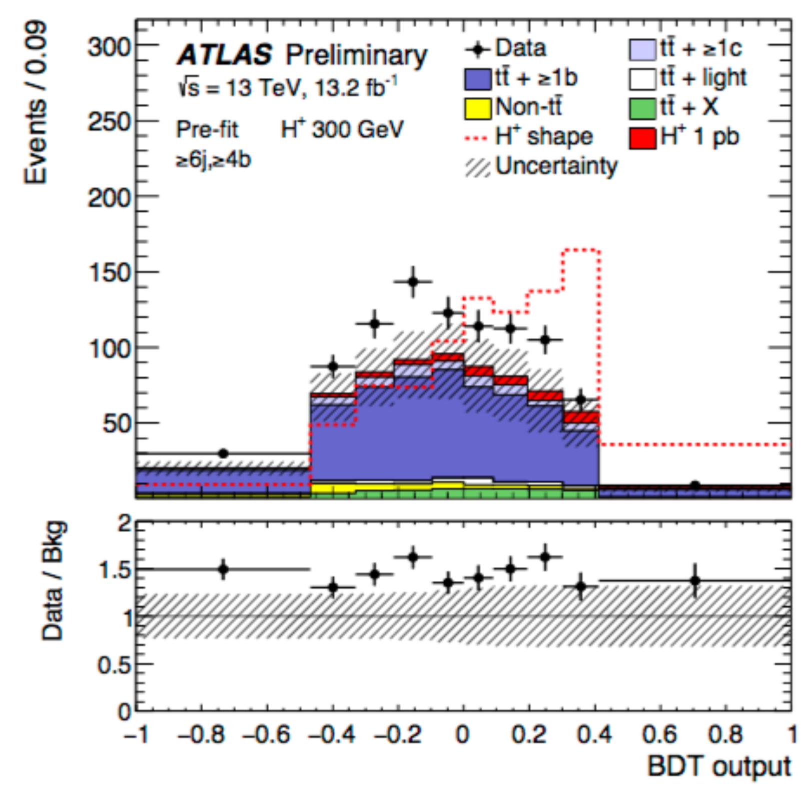

Backup 5 $H^{\pm}$ ->tb PostFit CR M_H=300 GeV

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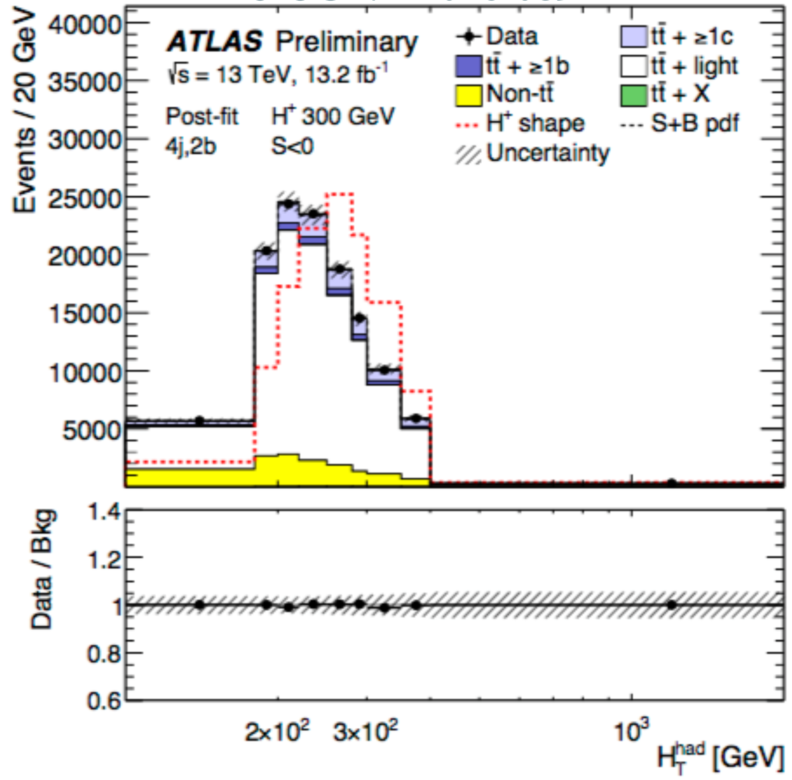

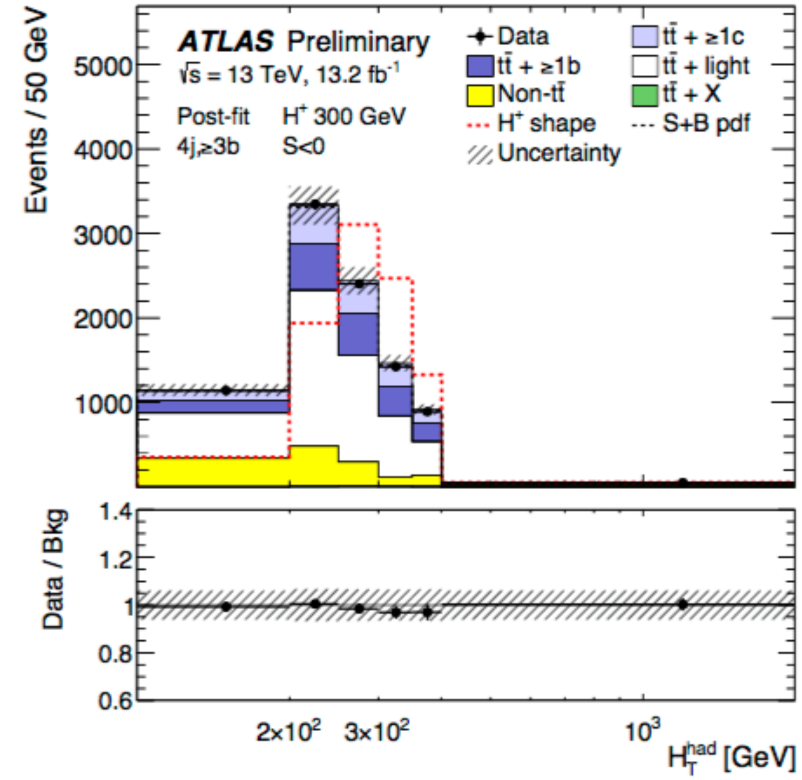

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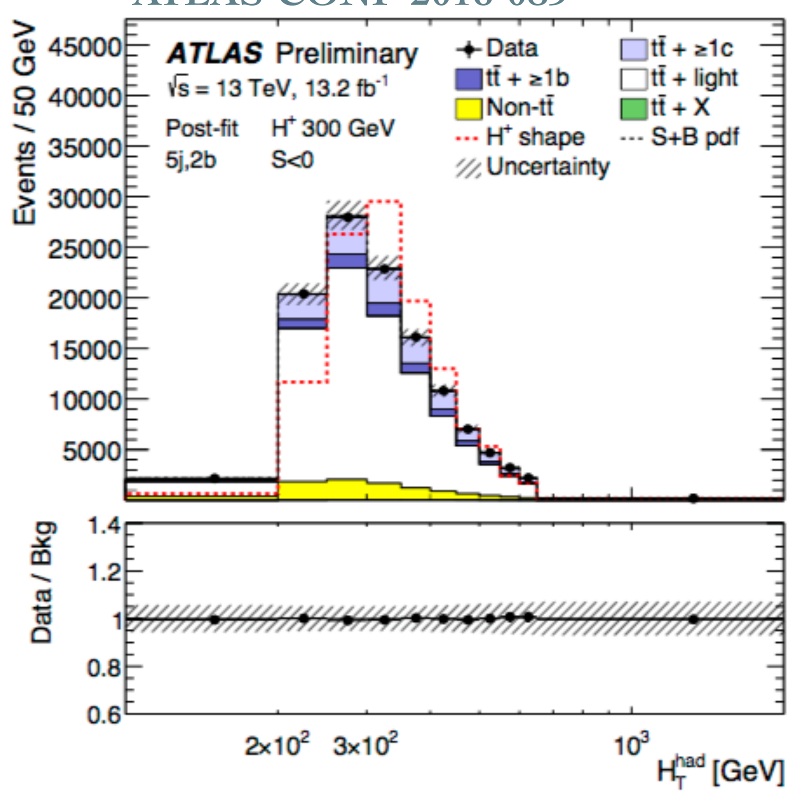

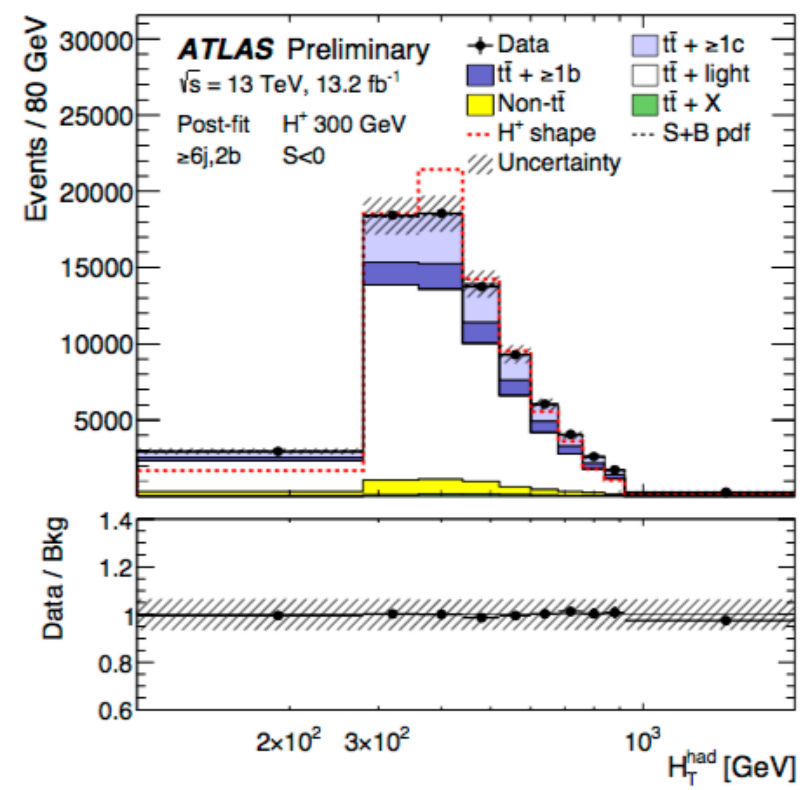

Backup 6 $H^{\pm}$ ->tb PostFit SR M_H=300 GeV

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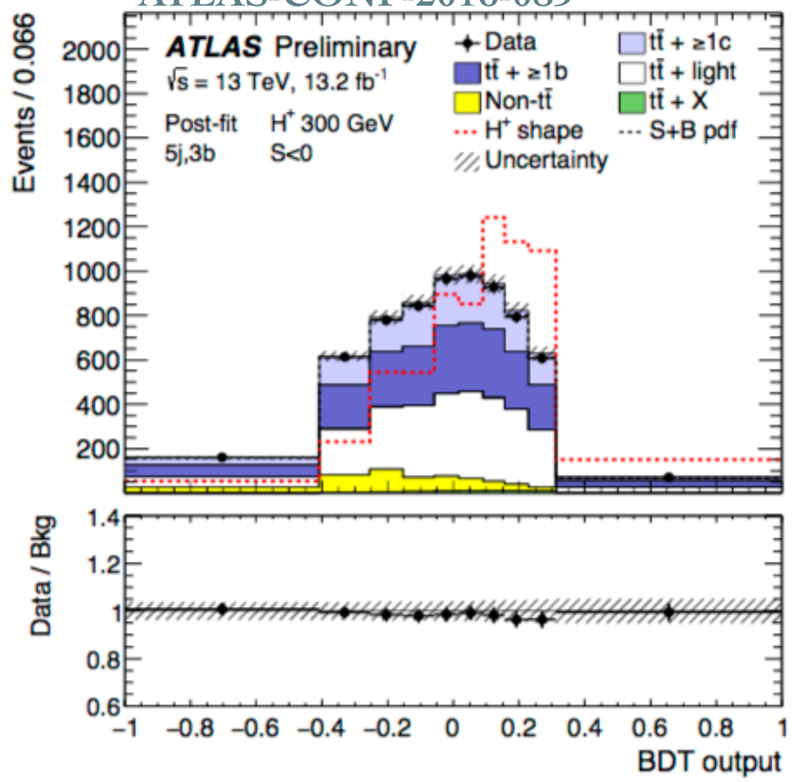

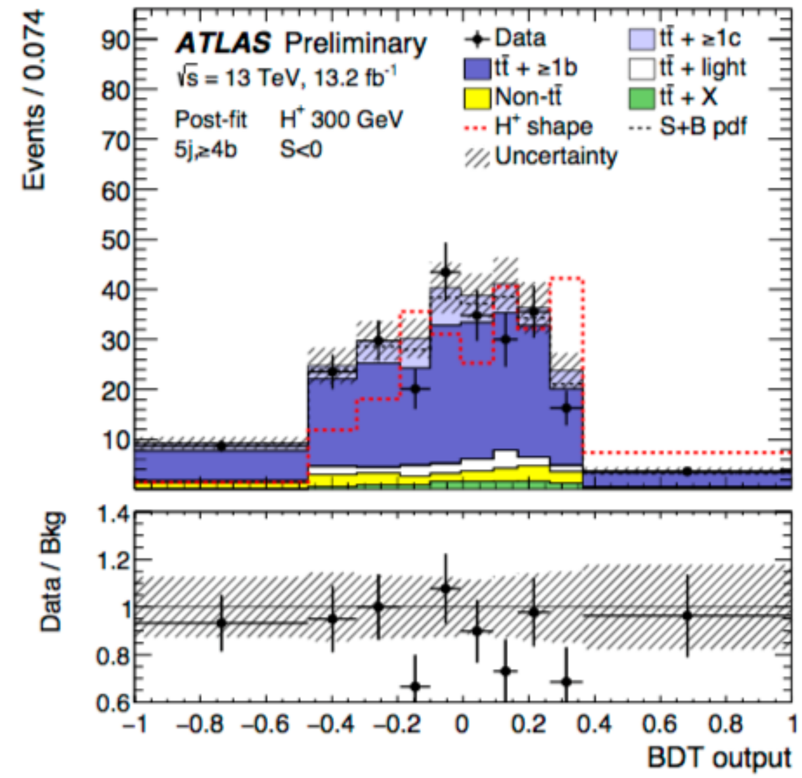

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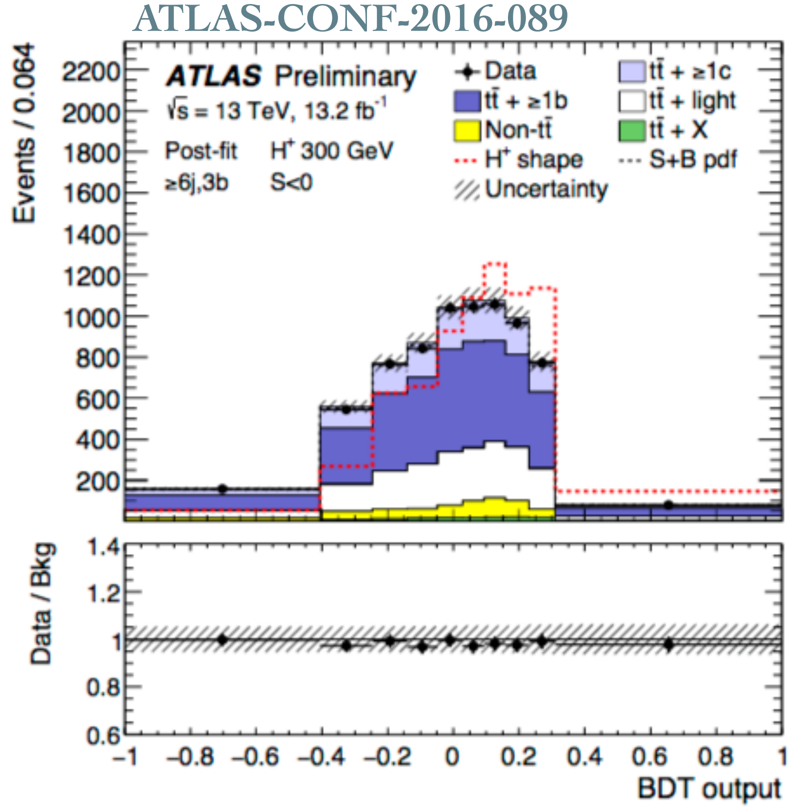

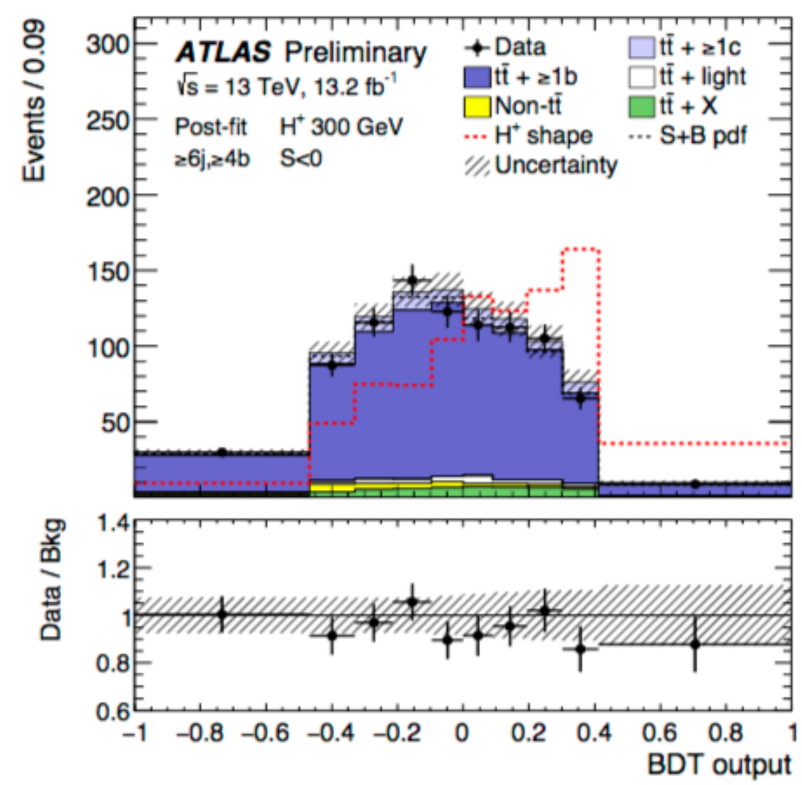

Backup 7 - Systematic Uncertainties

- Many sources of systematic uncertainty:
  - luminosity and pileup measurement
  - reconstruction of physics objects
  - signal or background modelling
- Uncertainties can affect both the normalisation of the samples and the shape of the final discriminants.

Uncertainty Source	$\Delta\mu(H^+_{300})$		$\Delta\mu(H^+_{800})$	
$t\bar{t}+\geq 1b$ modelling	+0.53	−0.53	+0.07	−0.07
Jet flavour tagging	+0.30	−0.29	+0.07	−0.07
$t\bar{t}+\geq 1c$ modelling	+0.23	−0.22	+0.03	−0.03
Background model statistics	+0.19	−0.19	+0.05	−0.05
Jet energy scale and resolution	+0.18	−0.17	+0.03	−0.03
$t\bar{t}$+light modelling	+0.16	−0.16	+0.03	−0.03
Other background modelling	+0.15	−0.14	+0.03	−0.03
Jet-vertex association, pileup modelling	+0.12	−0.11	+0.01	−0.01
Luminosity	+0.12	−0.12	+0.01	−0.01
Light lepton (e, μ) ID, isolation, trigger	+0.01	−0.01	$< +0.01$	< -0.01
Total systematic uncertainty	+0.72	−0.79	+0.13	−0.11
$t\bar{t}+\geq 1b$ normalisation	+0.36	−0.36	+0.03	−0.03
$t\bar{t}+\geq 1c$ normalisation	+0.15	−0.14	+0.02	−0.02
Total statistical uncertainty	+0.44	−0.43	+0.08	−0.08
Total	+0.84	−0.90	+0.15	−0.13

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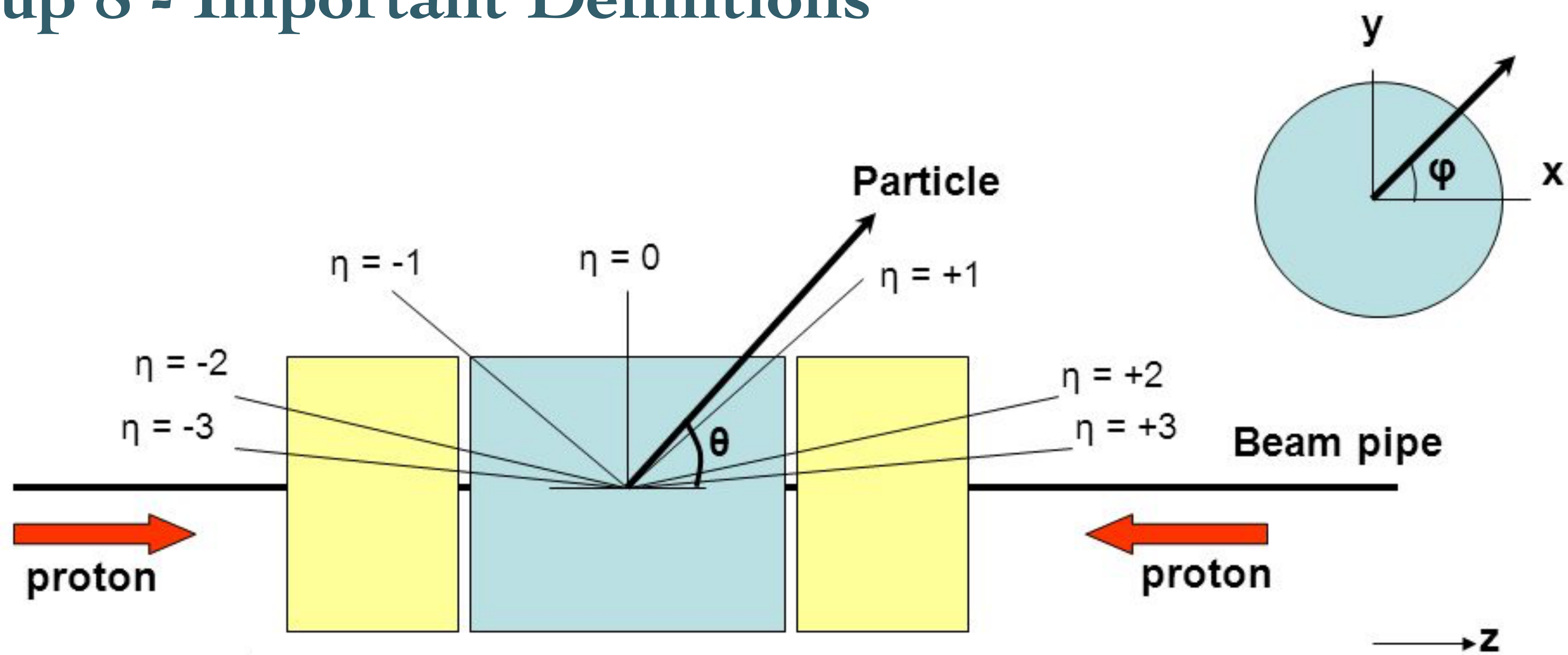
Backup 8 - Important Definitions



Rapidity:	$y = \frac{1}{2}\log\frac{E+p_z}{E-p_z}$	**Differences in rapidity are conserved under Lorentz boosts in the z-direction**
Pseudorapidity:	$\eta = -\ln[\tan(\theta/2)]$	**Good approximation to rapidity if E>>m**
"Transverse"	$\mathbf{p}_T = (p_x, p_y)$	$\lvert\mathbf{p}_T\rvert = \sqrt{(p_x^2, p_y^2)}$

Backup 9 - Production cross section