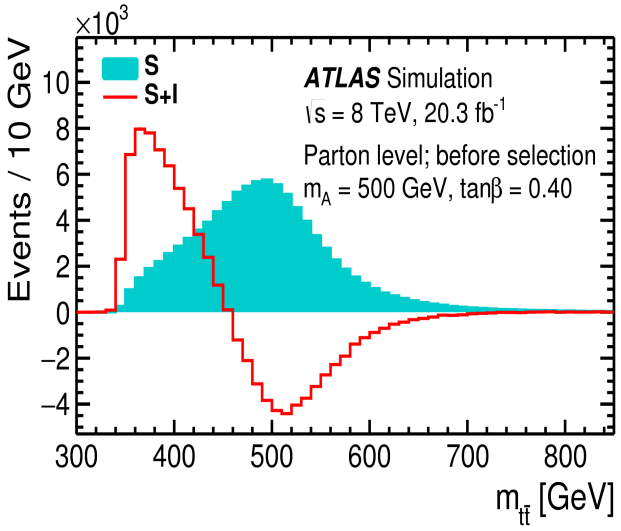
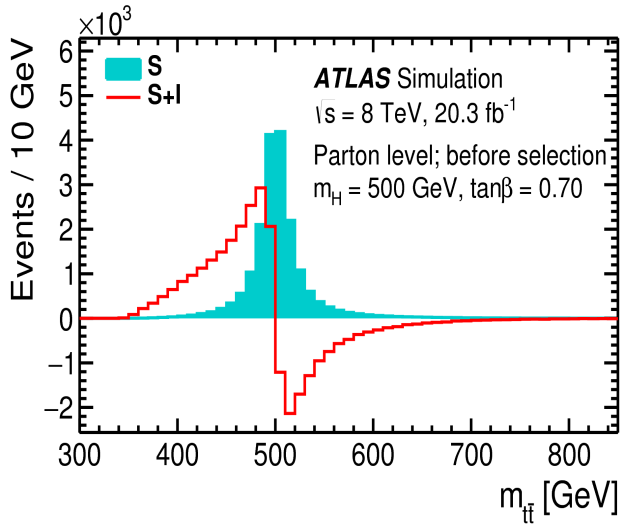
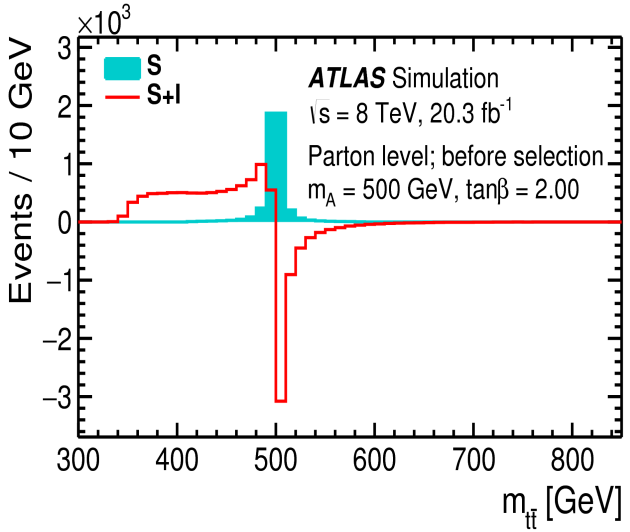
Search for A/H → ttbar @ ATLAS

LHC Physics Discussions
18 November 2019

Katharina Behr







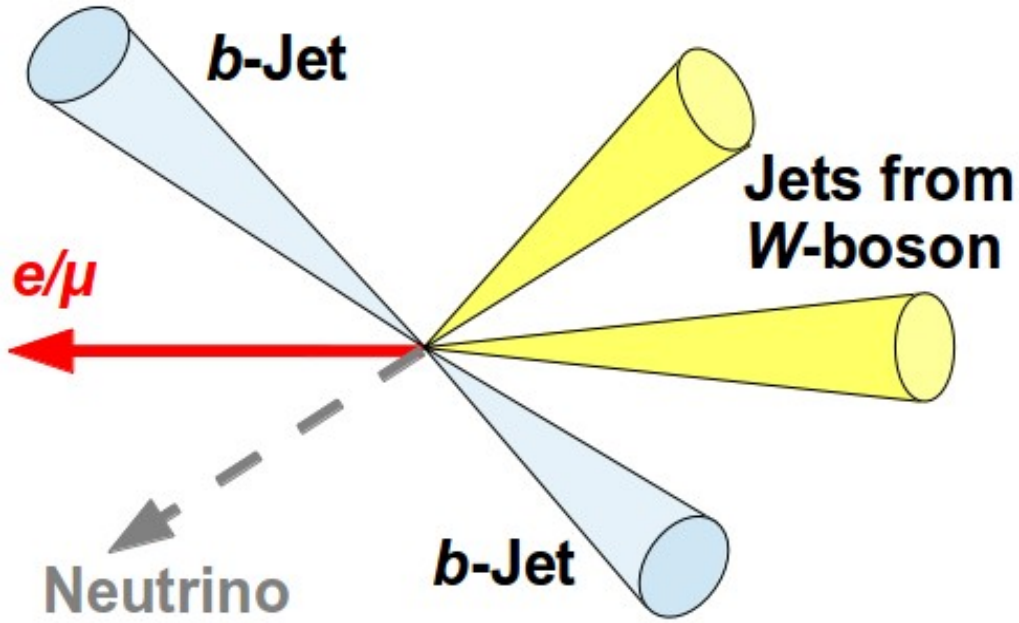
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

ATLAS EXPERIMENT

DESY.

In a nutshell

- First and (so far) only ATLAS result [Phys. Rev. Lett. 119 (2017) 191803]
  - Using 20.3 ifb of 8 TeV data
- Piggy-backing on earlier ATLAS ttbar resonance search @ 8 TeV [JHEP08(2015)148]
  - 1-lepton channel
  - Used only resolved-topology selection, targetting resonance masses < ~700 GeV



In a nutshell

- First and (so far) only ATLAS result [Phys. Rev. Lett. 119 (2017) 191803]
  - Using 20.3 ifb of 8 TeV data
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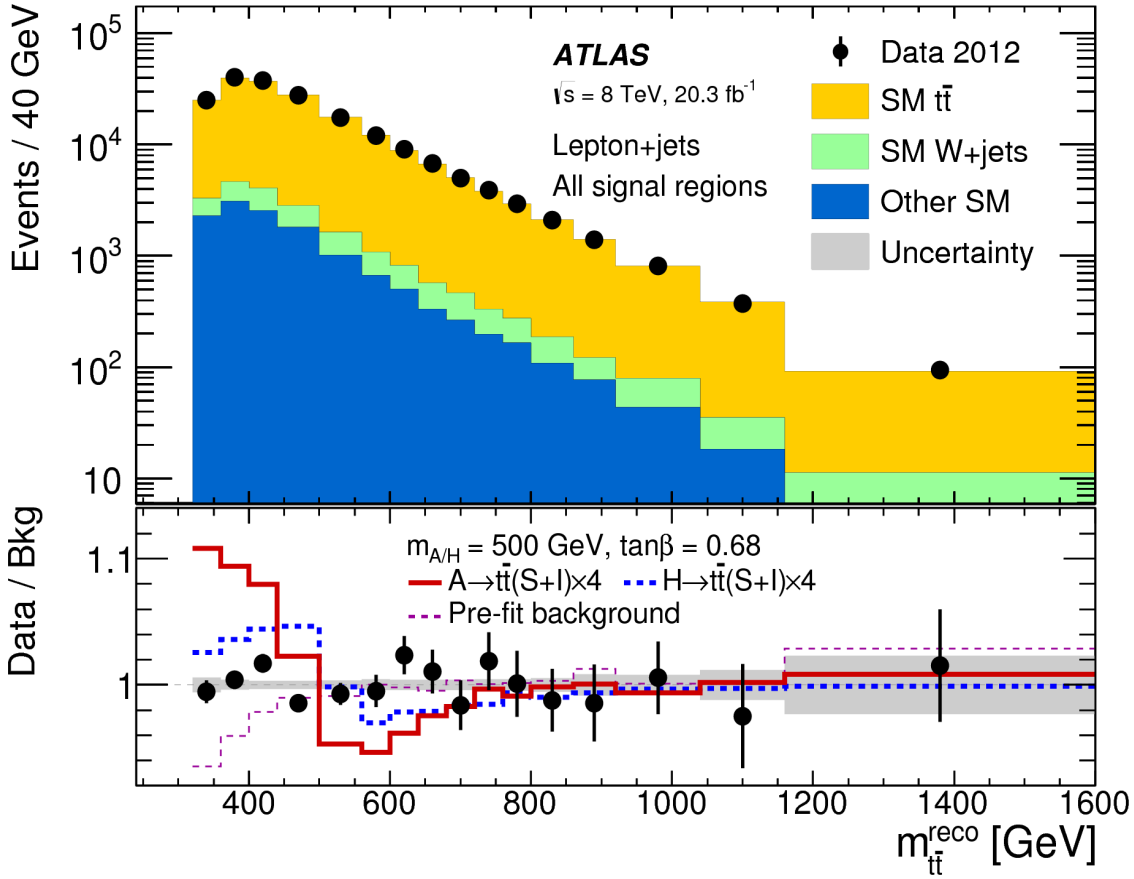
  - 1-lepton channel
  - Used only resolved-topology selection, targetting resonance masses < ~700 GeV
  - Search in m(ttbar) spectrum
    - Main background: SM ttbar production
    - Powheg+Pythia8 @ NLO
  - Remove bins with m(ttbar) < 320 GeV to avoid turn-on region where higher-order background effects become important



Systematic uncertainties

- Extra uncertainties compared to Z' search
  - Top-quark mass uncertainty
  - Interference modelling: difference between diagram-subtraction and diagram removal scheme
  - Reweighting uncertainty
  - Signal MC scales
    - Flat 7.3% variation
    - Additional variation with bins at low-/high-end of spectrum anti-correlated

Systematic uncertainties [%]	Total bkg	S	$S+I$
Luminosity [55]	1.7	1.9	1.9
PDF	2.5	2.1	12
$t\bar{t}$ initial-/final-state radiation	3.2	–	–
$t\bar{t}$ parton shower + fragmentation	4.9	–	–
$t\bar{t}$ normalization	5.7	–	–
$t\bar{t}$ event generator	0.5	–	–
Top quark mass	0.5	2.2	13
Jet energy scale	6.4	4.9	9.3
Jet energy resolution	1.3	1.6	1.7
b-tagging: b-jet efficiency	1.5	1.3	1.1
b-tagging: c-jet efficiency	0.2	0.2	0.8
Electron efficiency	0.3	0.4	0.7
Muon efficiency	0.9	1.0	1.0
Signal MC scales	–	7.3	7.3
Reweighting	–	–	5.0
MC statistical uncertainty	0.5	2.4	11
Total uncertainty	11	10	25

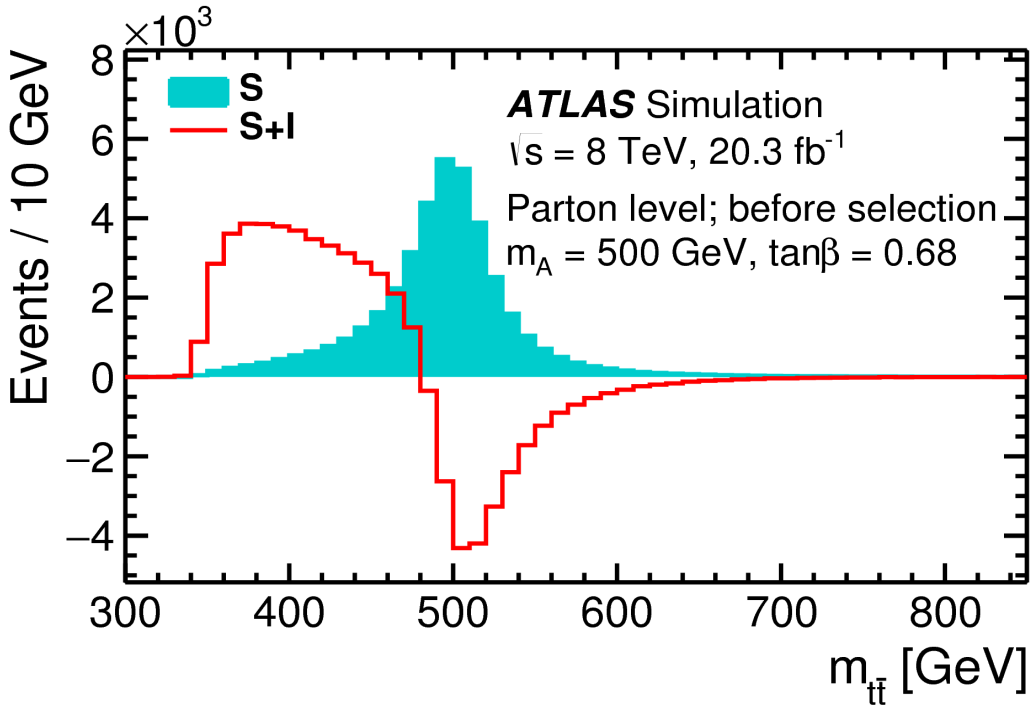
Limit setting

> Based on modified likelihood function

$$\mu \cdot S + \sqrt{\mu} \cdot I + B = (\mu - \sqrt{\mu}) \cdot S + \sqrt{\mu} \cdot (S + I) + B$$

> Implemented by hand in RooFit+RooStats+HistFactory setup

> Requires **S** and **S+I** samples for each model point



Signal Interpolation

> Reweighting to produce **S+I** from (broad) pure **S** samples

– Event weights = from matrix-element ratios

Event-by-event basis

Weights = matrix elements ratios calculated in MADGRAPH5

$$\mathcal{W}_{\text{new}}(\{s_i\}_{\text{new}}, \{p_j\}) = \frac{|\text{ME}(\{s_i\}_{\text{new}}, \{p_j\})|^2}{|\text{ME}(\{s_i\}_{\text{old}}, \{p_j\})|^2} \times \mathcal{W}_{\text{old}}(\{s_i\}_{\text{old}}, \{p_j\})$$

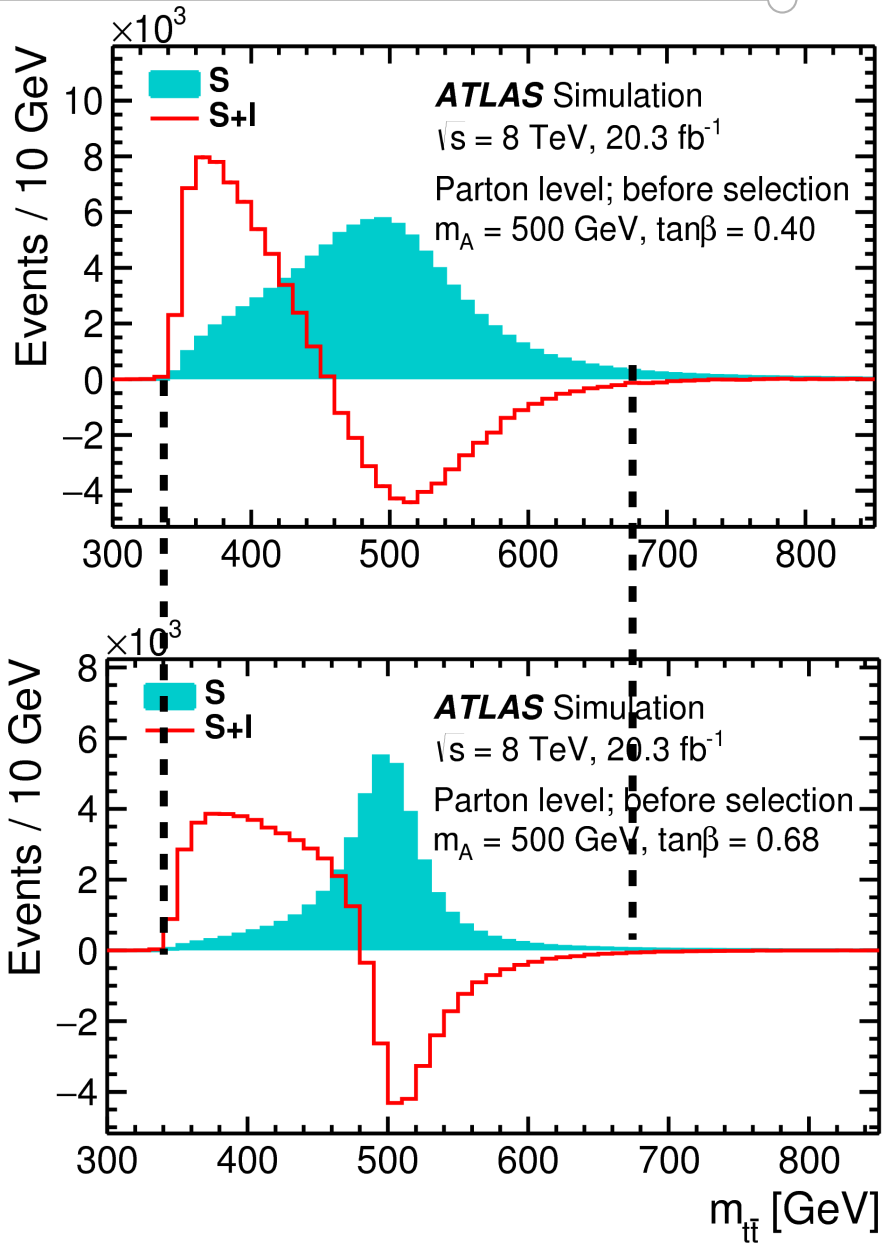
Weights depend on

- 4-momenta of incoming and outgoing partons $\{p_j\}$
- Initial and target signal parameters $\{m_{A/H}, \tan\beta, \cos(\beta-\alpha)\} = \{s_i\}_{\text{new,old}}$

Signal Interpolation

- Reweighting to produce **S+I** from pure **S** samples
  - Event weights = from matrix-element ratios

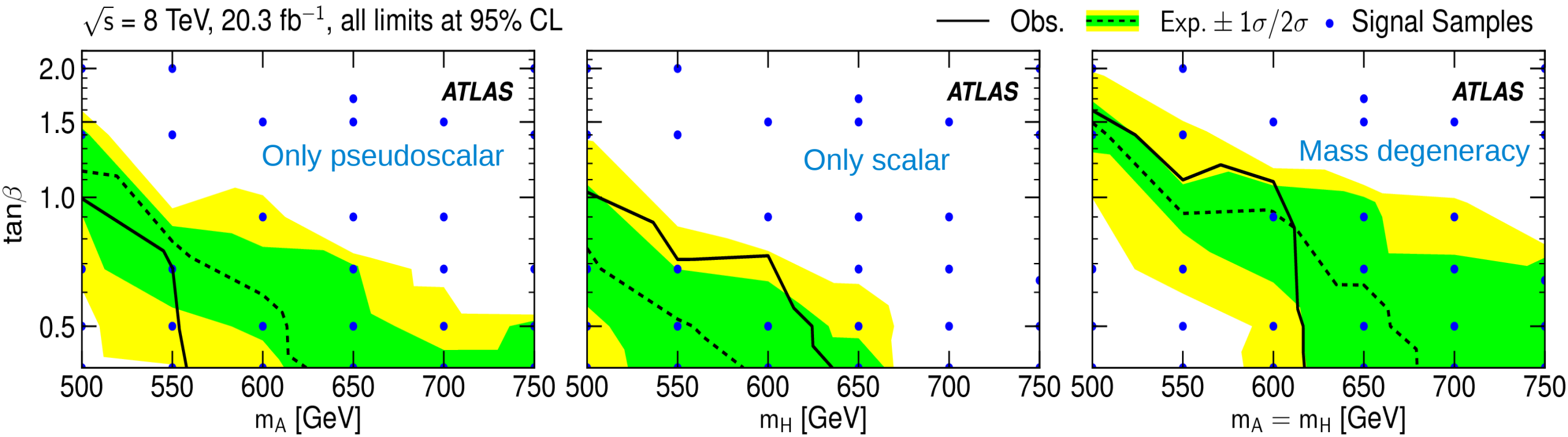
- Input: broad (low tanb) pure signal samples **S**
- Targets:
  - Larger tanb values
  - Slightly different mass values, Δm = 50 GeV



Results

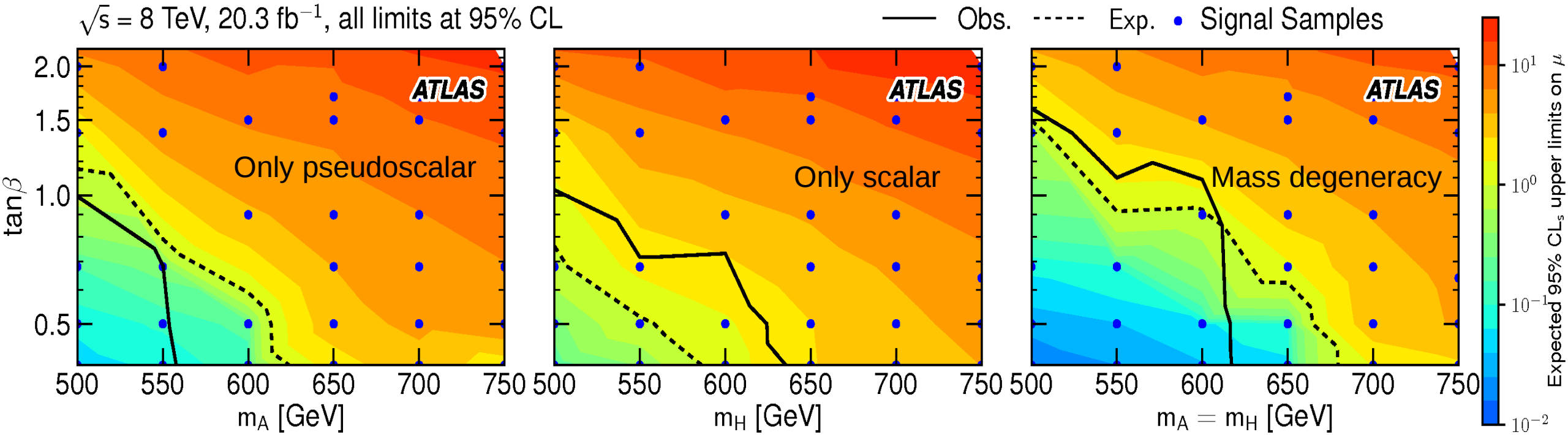
> Benchmark: generic type-II 2HDM in the alignment limit

– A and H do not interfere with each other →can simply add their interference patterns



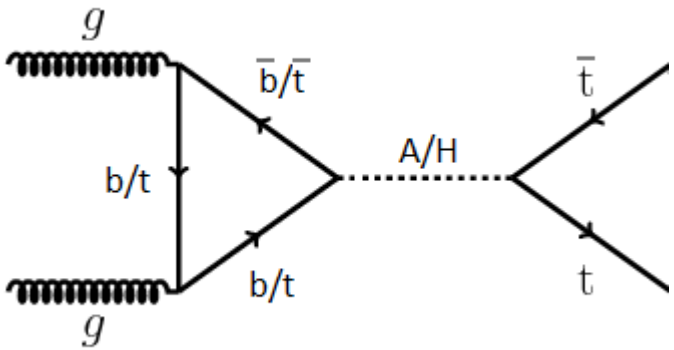
Results

- Benchmark: generic type-II 2HDM in the alignment limit
  - A and H do not interfere with each other → can simply add their interference patterns
- Triangular interpolation between signal points
  - Checked that interpolation is sane = no complete cancellation of peak and dip



Higher-order corrections (current approach)

- Signal + interference modelled with leading-order UFO
- Signal cross-section available at NLO
  - $K_S = \sigma_{NLO}/\sigma_{LO}$
- Interference cross-section at approximate NLO
  - $K_I = \sqrt{K_S} * K_B$
  - $(S + I)_{corr} = [(S + I) - S] \cdot K_I + S \cdot K_S$
- Irreducible background from SM ttbar production
  - Powheg+Pythia8 @ NLO
  - Cross-section corrected to NNLO+NNLL
    - $K_B = \sigma_{NNLO+NNLL}/\sigma_{NLO}$



Higher-order corrections (plans + ideas)

> Higher-order corrections worth investigating, in particular in the **turn-on region**
  - UFO for gg→A/H→ttbar at (approximate) NLO available [here]
  - Alternative approaches exist [arxiv:1611.08119]

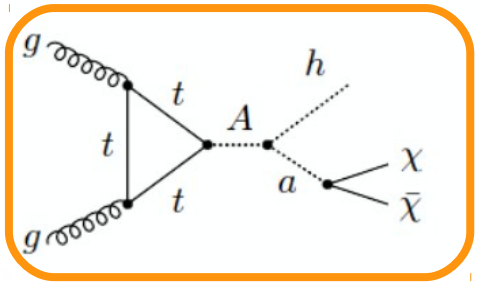
> Cooperation among ATLAS, CMS, and theory sensible to make sure results are comparable

> Background modelling in the turn-on region?

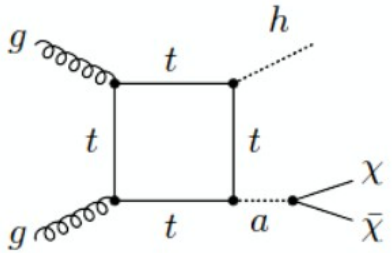
A possible dark matter interpretation

> New LHC benchmark model for dark matter searches: **2HDM + pseudoscalar mediator** [JHEP 1705 (2017) 138]
  - Joint effort from ATLAS + CMS + Theory [LHC DMWG whitepaper]

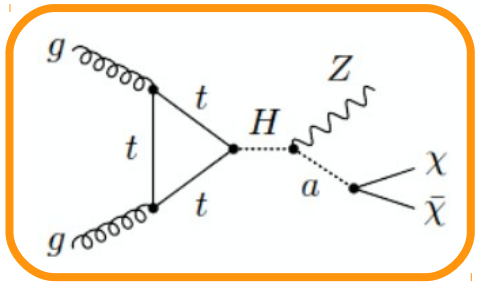
> Rich collider phenomenology



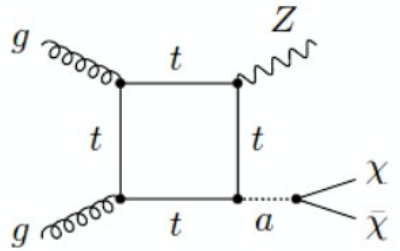
Mono-Higgs

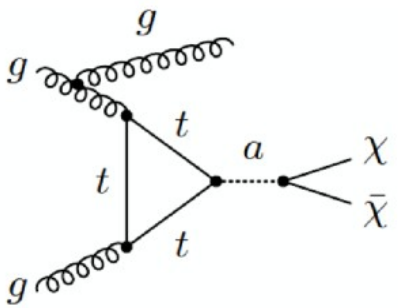


Resonant production!

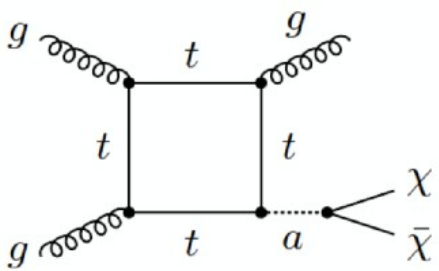


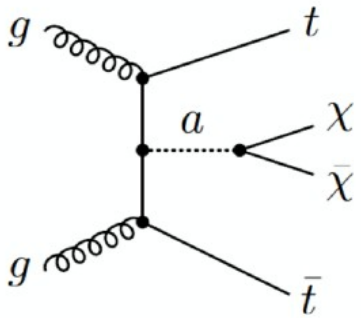
Mono-Z

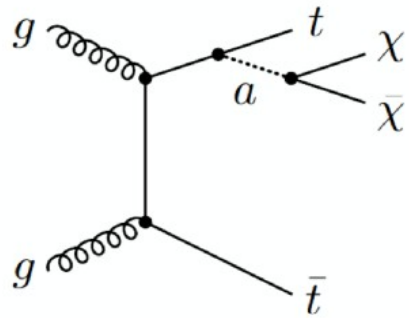




Mono-jet



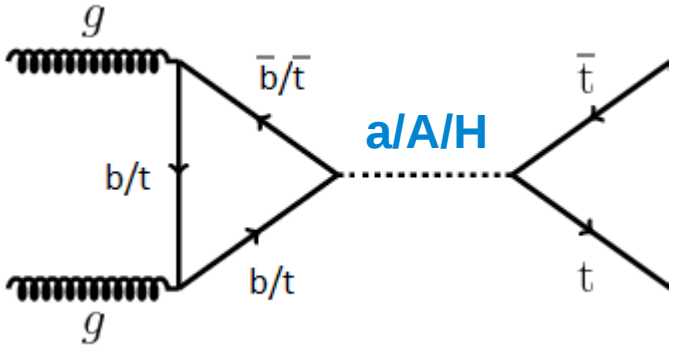




DM+tops

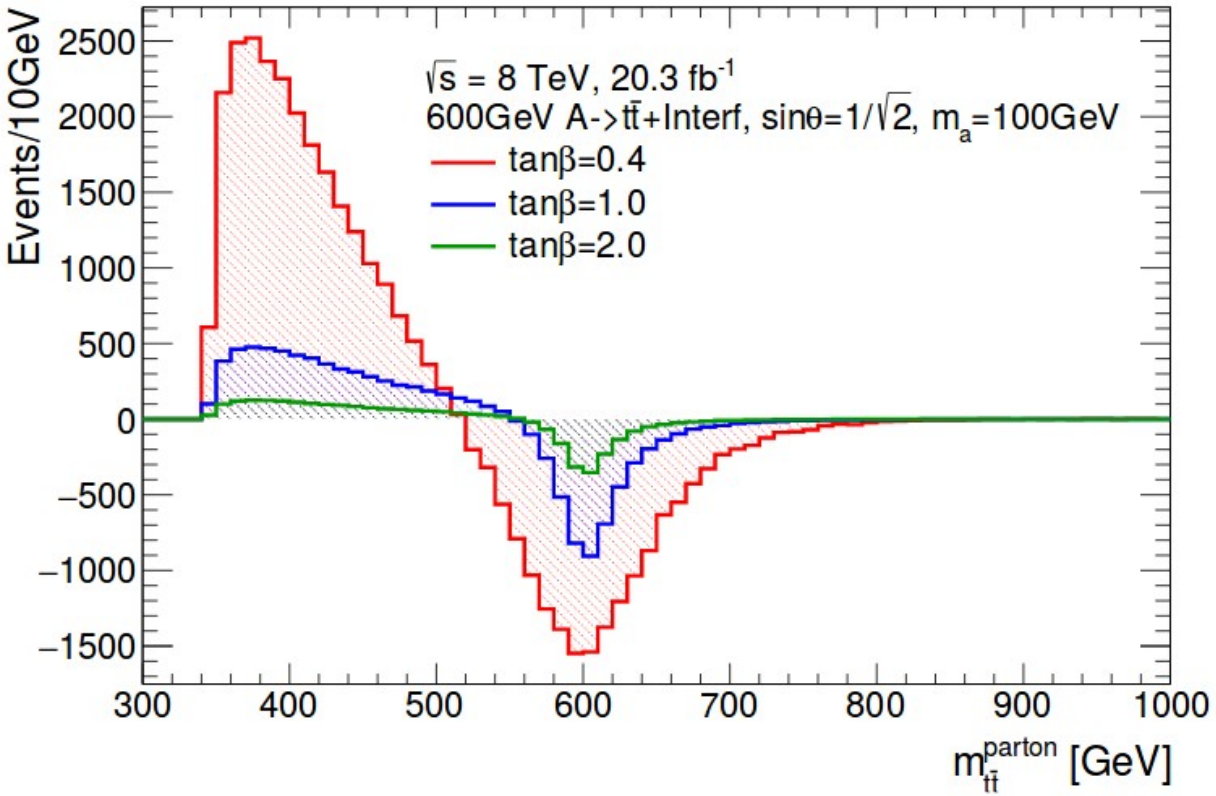
A possible dark matter interpretation

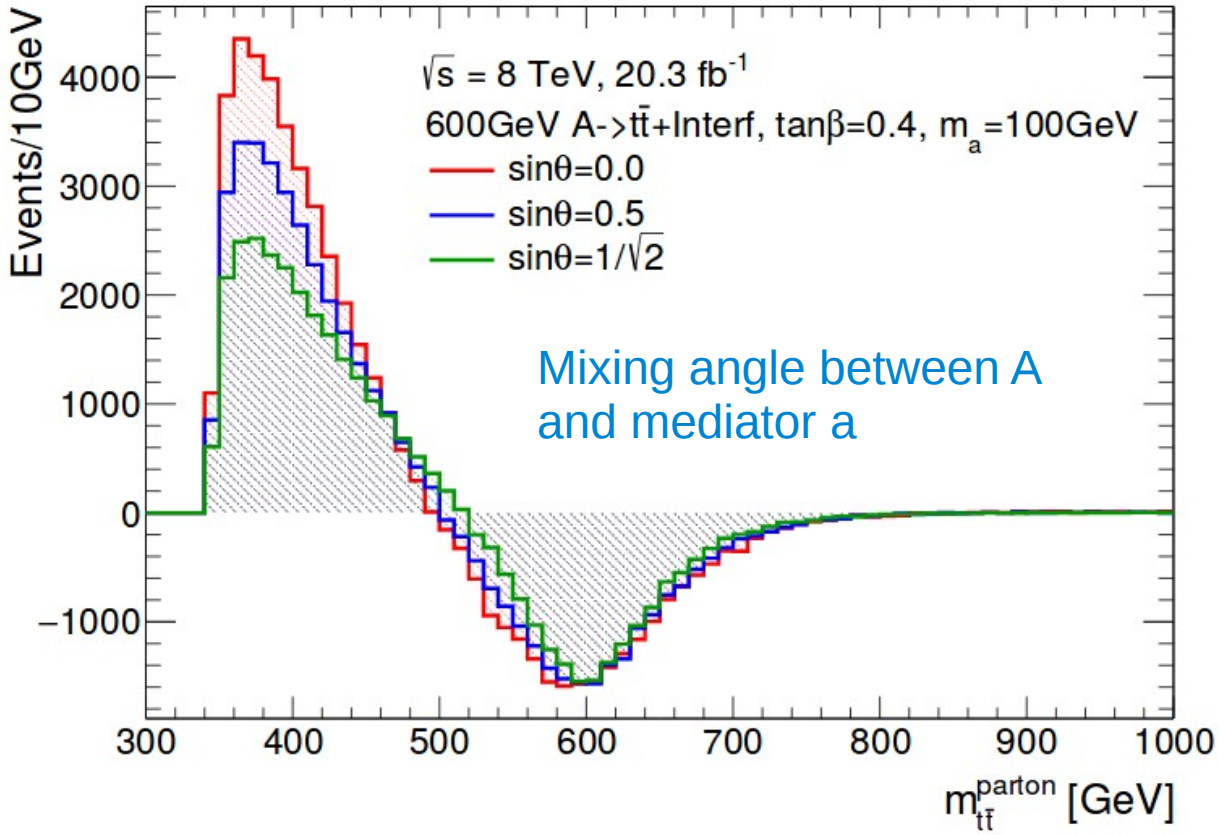
> Interference pattern highly model parameter dependent



Yu-Heng Chen (DESY)

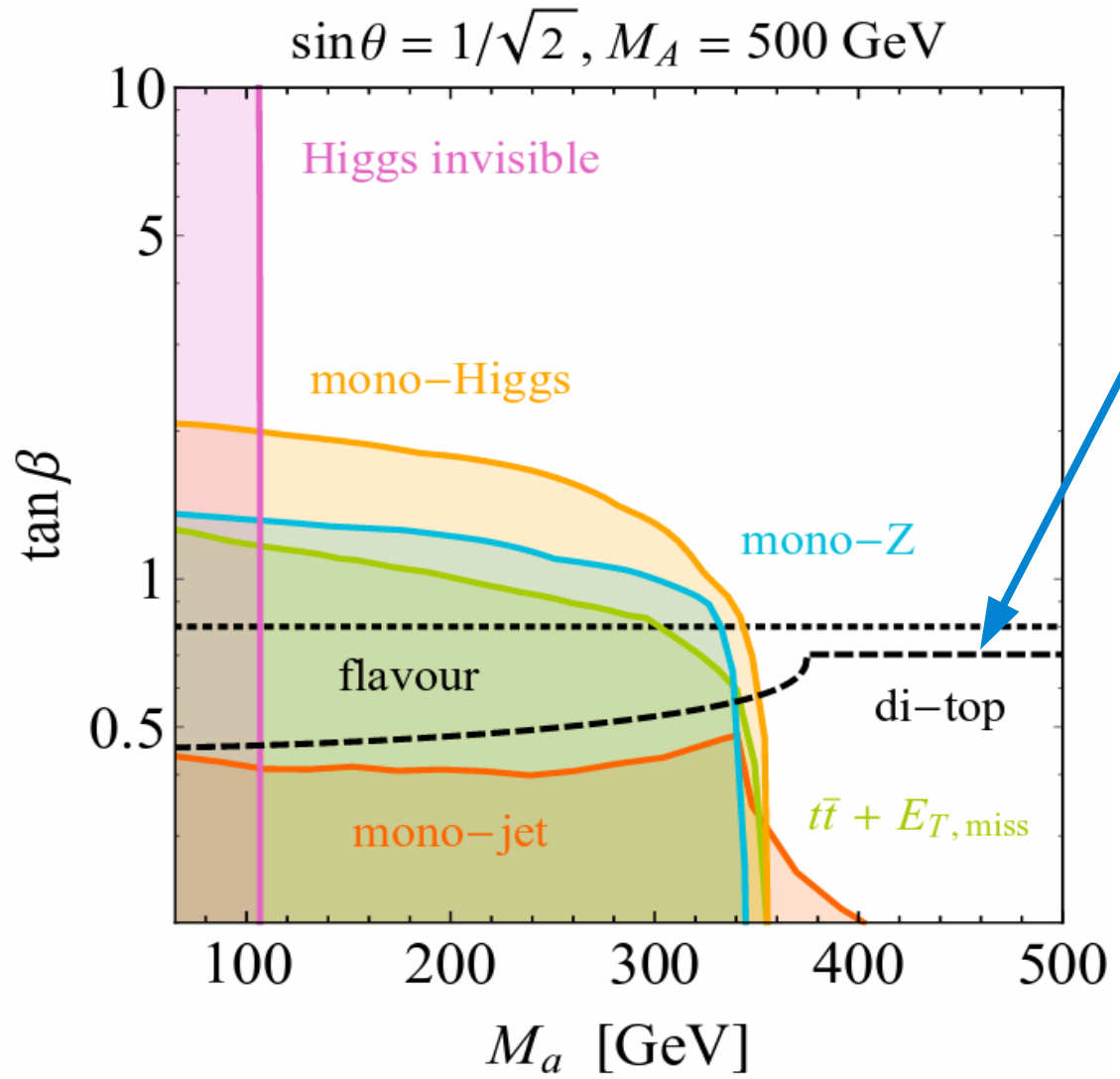
[LHC DMWG whitepaper]





A possible dark matter interpretation

> Existing and projected constraints [JHEP 1705 (2017) 138]



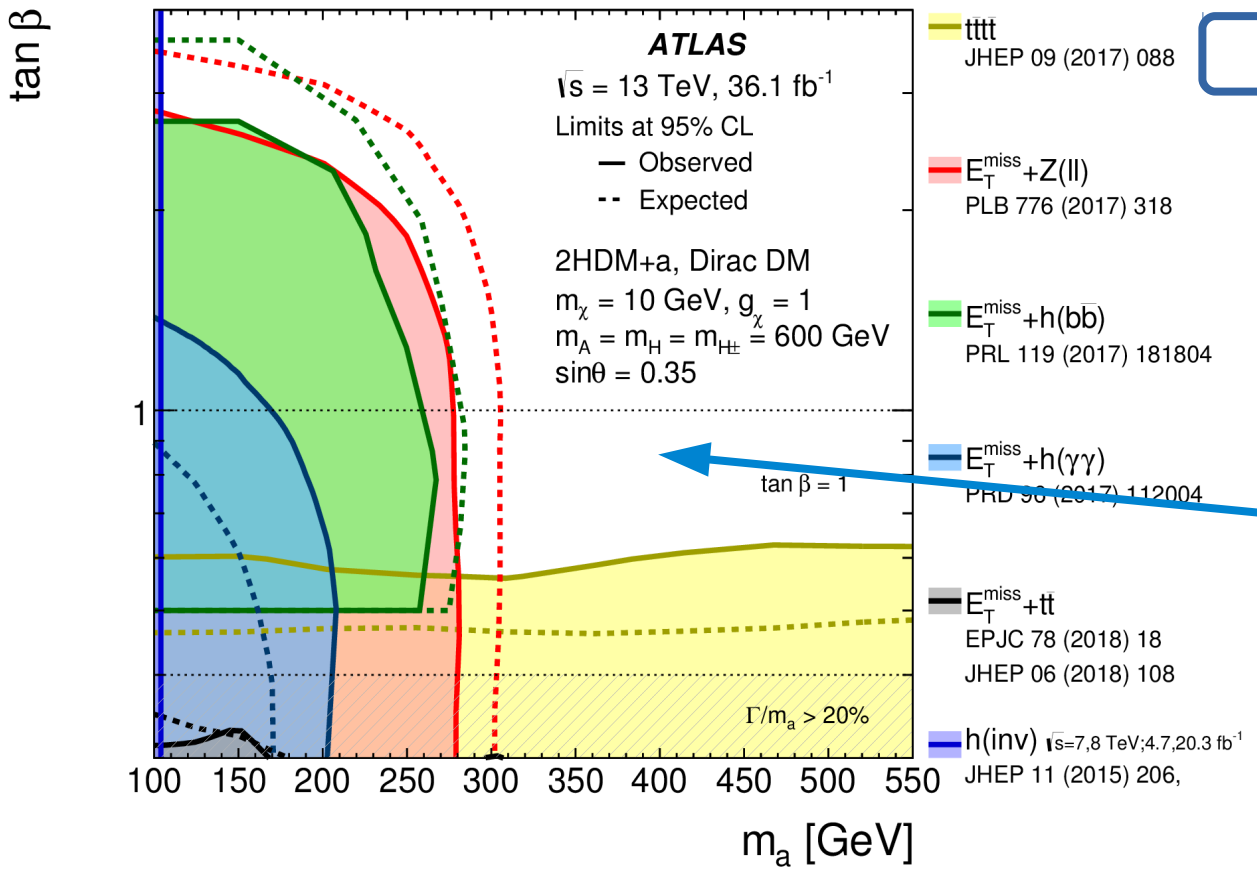
> Re-interpretation of preliminary 8 TeV ATLAS result [ATLAS-CONF-2016-073]

> Rough estimate of constraints via simple cross-section rescaling

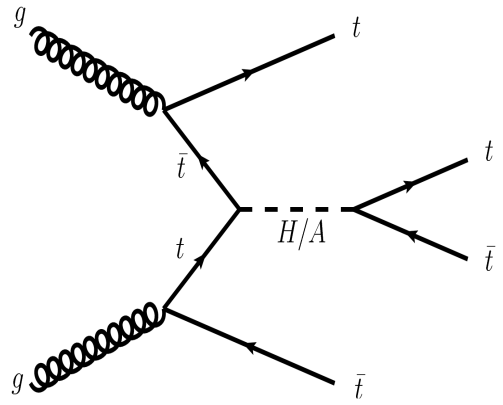
> Not accurate as width/shape differences in the interference pattern neglected

A possible dark matter interpretation

> Latest constraints from ATLAS [JHEP 05 (2019) 142]



4-top production



Interference search should do much better than 4-tops here!

Conclusion

- Initial ATLAS result on Run 1 data for generic type-II 2HDM with $m_A = m_H$
- Model dependence of interference renders signal interpolation crucial

- **Next steps:**
  - Higher-order corrections are needed
    - Signal at (approximate) NLO
    - Background modelling in turn-on region
  - Other benchmarks are interesting, e.g. for dark matter, CP-violation, ...

Dialog between CMS and ATLAS and theory groups on benchmarks would be useful!