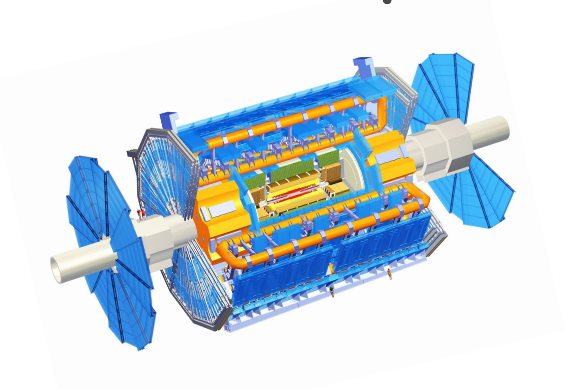
Monte Carlo reweighting

Signal interpolation for ATLAS Dark Matter searches

Spåtind 2020 - Nordic conference on Particle Physics
5 January, 2020



Kristian Bjørke

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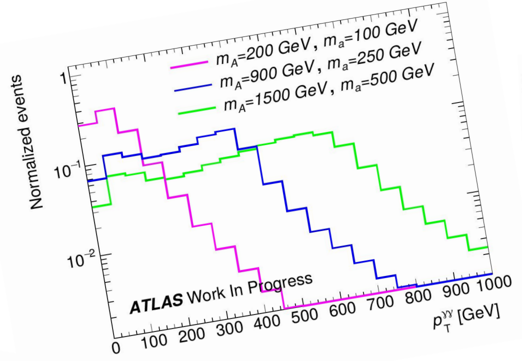

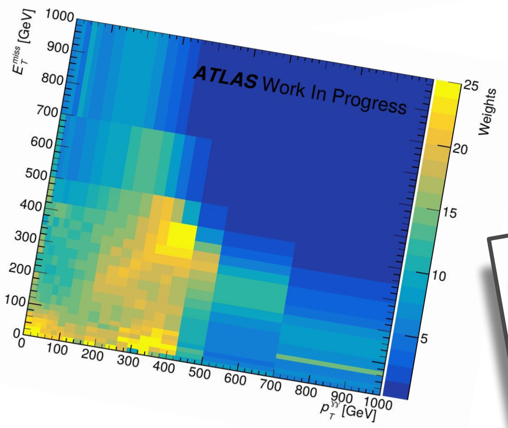

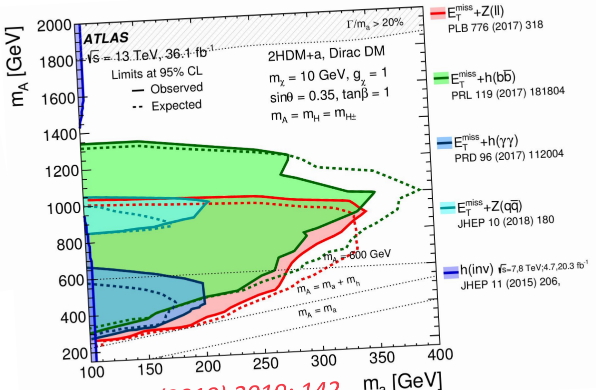

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What?

PHYSICAL REVIEW D **96**, 112004 (2017)

Search for dark matter in association with a Higgs boson decaying to two photons at $\sqrt{s} = 13$ TeV with the ATLAS detector

M. Aaboud *et al.**
(ATLAS Collaboration)

PRD 96, 112004 (2017)

December 8, 2017

Why?

Constraints on mediator-based dark matter and scalar dark energy models using $\sqrt{s} = 13$ TeV pp collision data collected by the ATLAS detector

ATLAS EXPERIMENT

The ATLAS collaboration

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May 23, 2019

New EPIC Dark Matter results from Higgs decaying to two photons!
(or something more scientific...)
ATLAS collaboration

2020

DM at colliders:

What does it look like?

DM at colliders:

What does it look like?

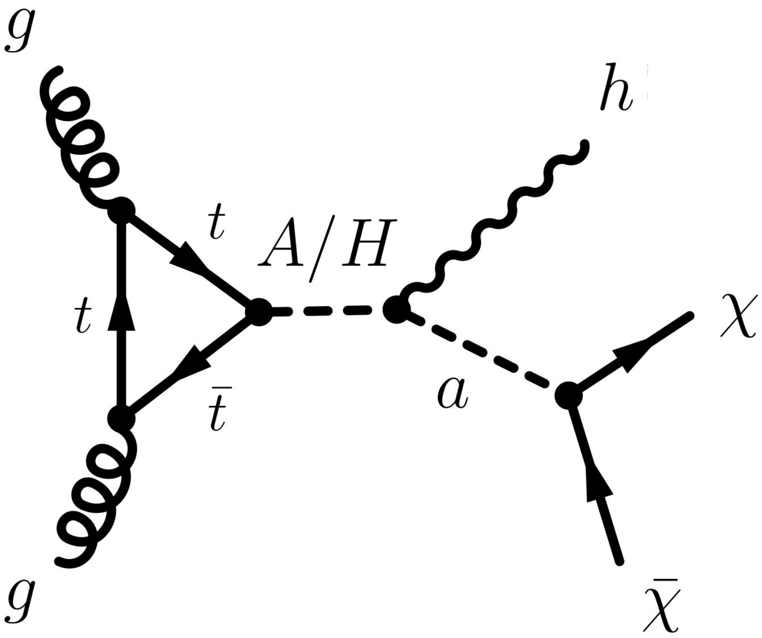
BSM models

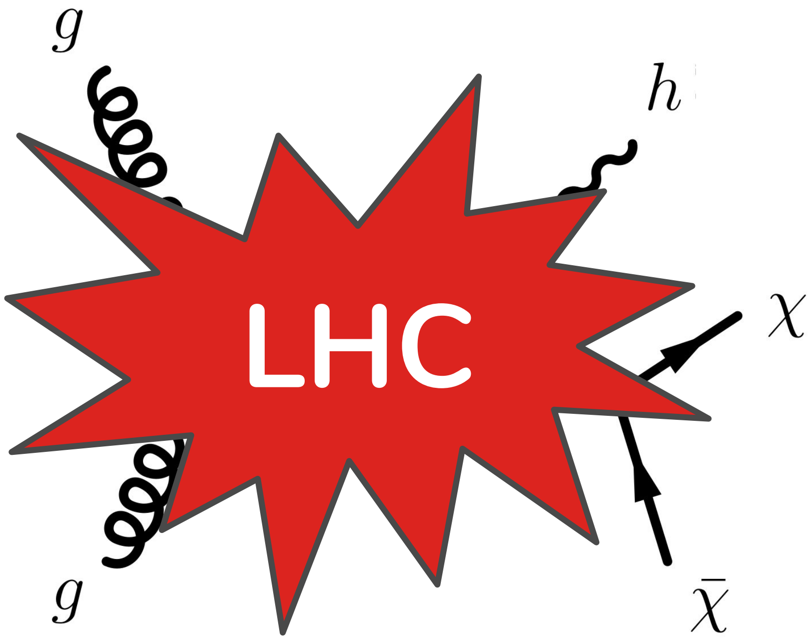
f.ex. 2HDM+a

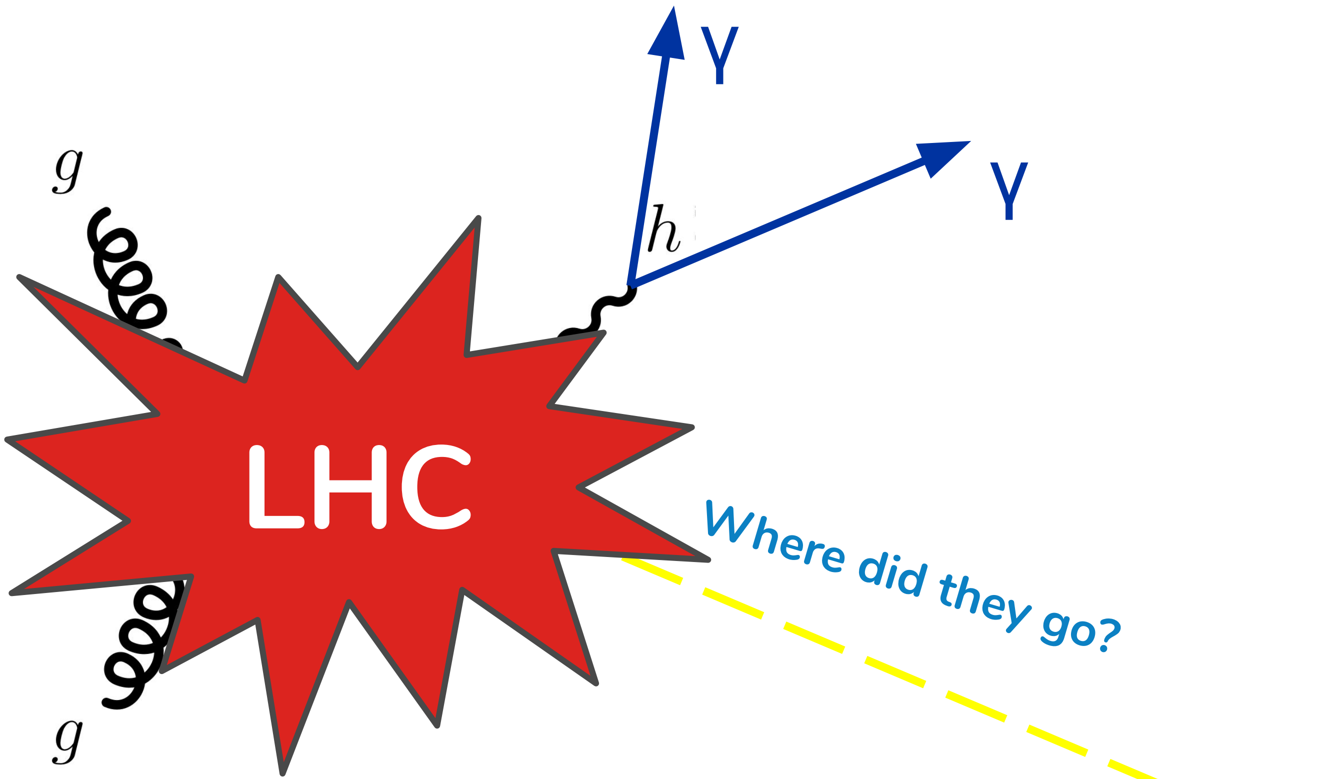
Bauer et al. HEP (2017) 2017: 138

$h \quad H^{\pm} \quad H \quad A \quad \chi \quad a$

$m_A \quad m_H \quad \lambda_{P1} \quad \lambda_{P2} \quad m_\chi \quad m_{H^\pm} \quad \lambda_3 \quad m_a \quad y_\chi \quad m_h \quad \alpha \quad v \quad \tan\beta \quad \theta$


g
h
t
A/H
t
χ
a
$\bar{t}$
g
$\bar{\chi}$


g
h
LHC
χ
g
$\bar{\chi}$



g
LHC
h
γ
γ
Where did they go?
g

Analysis cut variables

Two photons!

To ensure high energetic photon pair:

Two leading photons with

- ➢ $p_{\mathrm{T}} > 25$ GeV
- ➢ $p_{\mathrm{T}}(\gamma\gamma) > 90$ GeV

$E_{\mathrm{T}}^{\mathrm{miss}}$

To ensure possibility for dark matter production:

Require sufficient missing transvere momentum

- ➢ $E_{\mathrm{T}}^{\mathrm{miss}} / \sqrt{\sum E_{\mathrm{T}}} > 7\ \mathrm{GeV}^{\frac{1}{2}}$

$m_{\gamma\gamma}$

To ensure diphotons decaying from a Higgs:

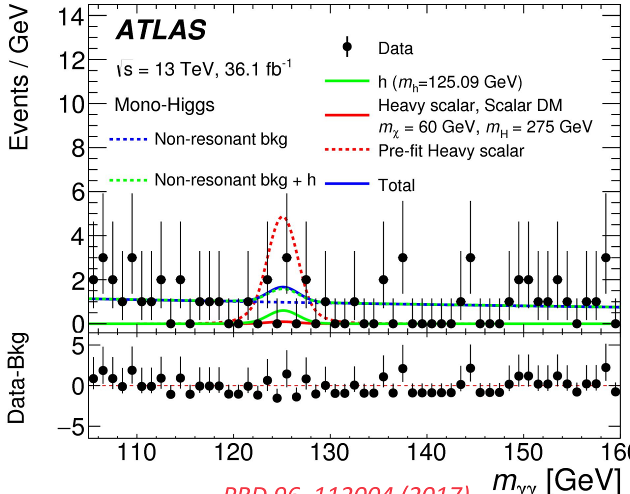
Restriction on invariant mass of diphotons

- ➢ $105\ \mathrm{GeV} < m_{\gamma\gamma} < 160\ \mathrm{GeV}$

Analysis results

Discovery signature

Look for excess of data in signal region with respect to background.

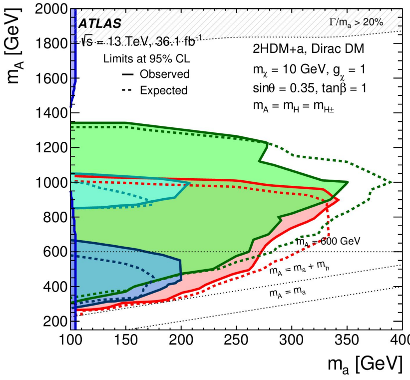


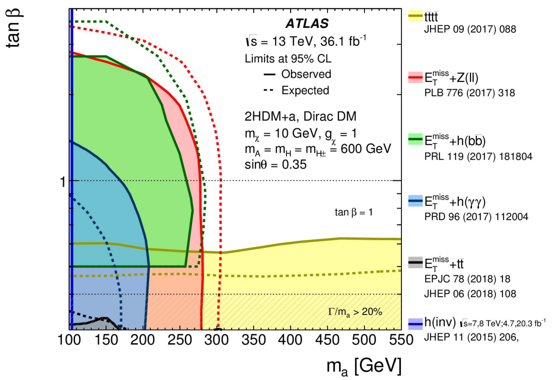
[PRD 96, 112004 (2017)]

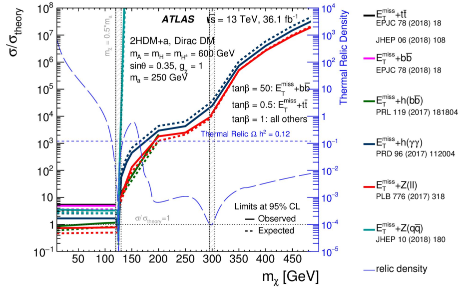
Exclusion

No significant excess!

Upper limit on visible cross section based on profile likelihood ratio and C.L.s formalism.







[JHES (2019) 2019: 142]

Signal prediction

How does it appear in the experiment?

Model/Pheno paper

- Detailed description of theoretical model.
- Rough estimate of detector signature.

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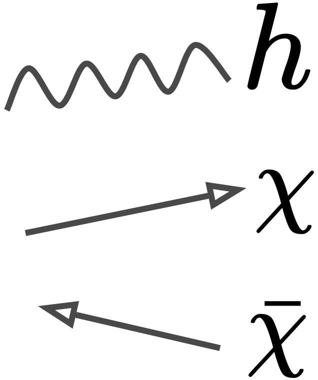
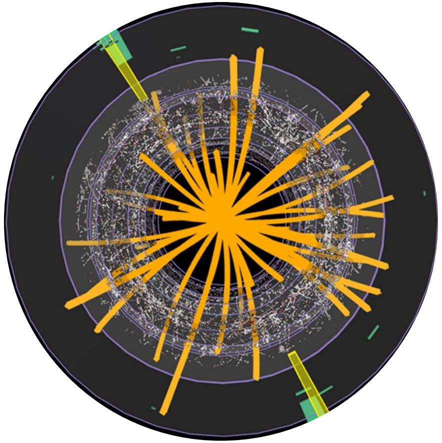
ATLAS analysis

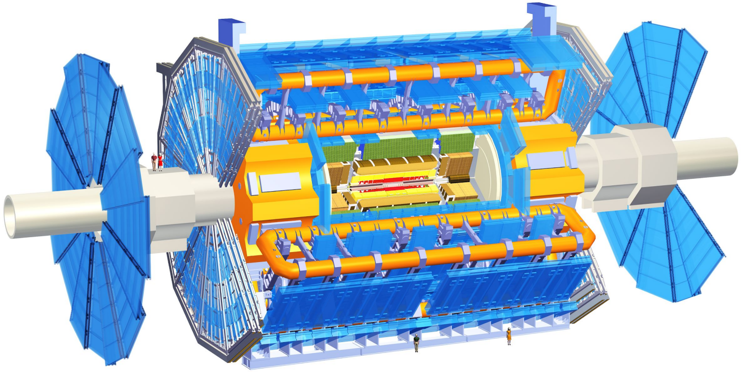
- Based on theoretical model.
- Detailed estimation of experimental signal.
  - ➢ Detector and material interactions.

Simulation steps

- Generation
- Hadronization
- Detector level



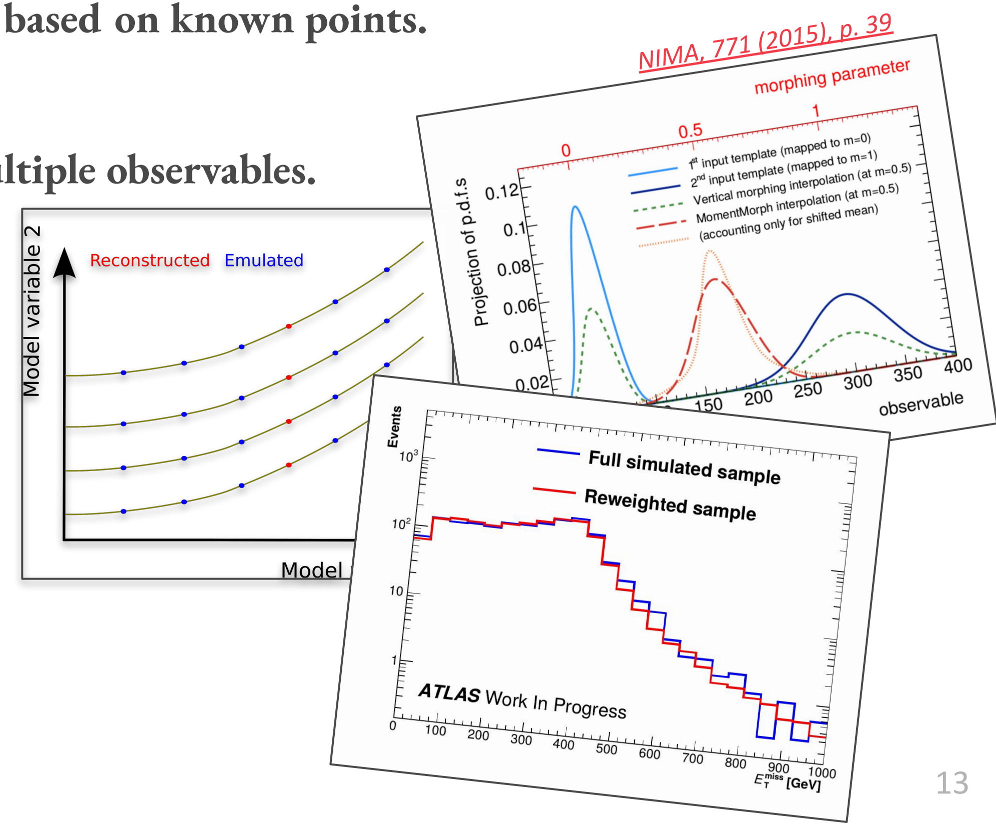




Signal interpolation

- Estimate signals for new models point based on known points.
- Based on knowledge of BSM models.
- Analysis might require accuracy in multiple observables.

Different signal interpolation methods in use in the ATLAS collaboration.



MC reweighting

Gainer et al. JHES (2014) 2014: 78

Model

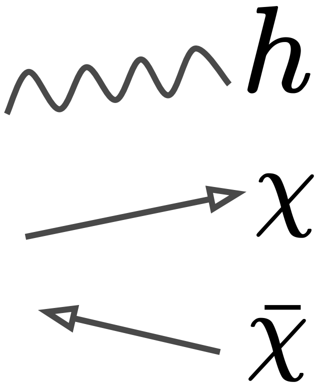
$$\mathcal{M}(\underbrace{\mathbf{p_h}, \mathbf{p}_{\chi}, \mathbf{p}_{\bar{\chi}}}_{\text{Event}}; \vec{\theta})$$

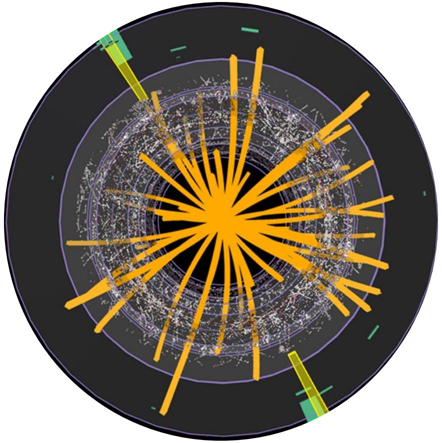
Event

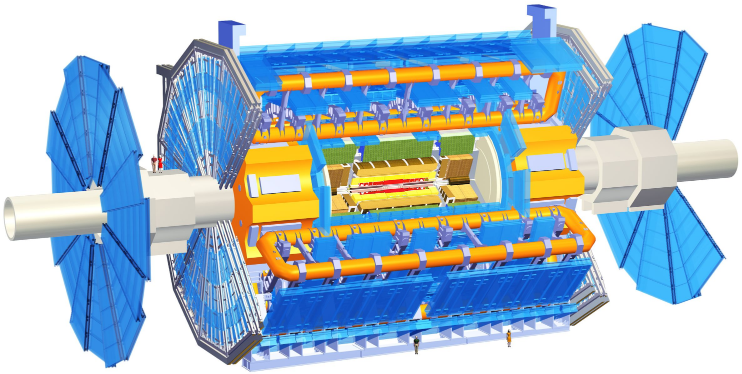
$$\mathrm{P}\left(\mathbf{p_h}, \mathbf{p}_{\chi}, \mathbf{p}_{\bar{\chi}}\right)$$

Detector response

$$\mathrm{dr}\left(\mathbf{p_h}, \mathbf{p}_{\chi}, \mathbf{p}_{\bar{\chi}}\right)$$







MC reweighting

Gainer et al. JHES (2014) 2014: 78

Model

$$\mathcal{M}(\mathbf{p_h}, \mathbf{p}_\chi, \mathbf{p}_{\bar\chi}; \vec{\theta}) \qquad \mathrm{P}\left(\mathbf{p_h}, \mathbf{p}_\chi, \mathbf{p}_{\bar\chi}\right) \qquad \mathrm{dr}\left(\mathbf{p_h}, \mathbf{p}_\chi, \mathbf{p}_{\bar\chi}\right)$$

Event

Detector response

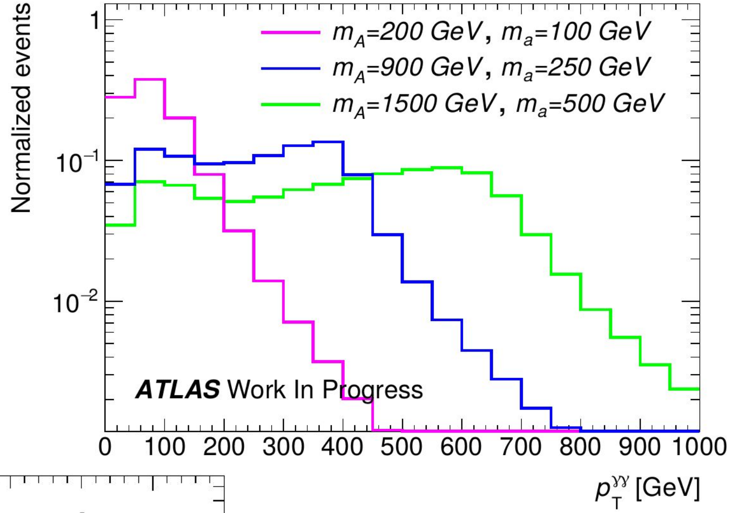
- Simulate many events to get total $\mathrm{DR}(\vec{\theta})$ for one model point.
- For new model points $\hat{\vec{\theta}}$, each events has “weight” $\hat{\mathcal{M}}(\mathbf{p_h}, \mathbf{p}_\chi, \mathbf{p}_{\bar\chi}; \hat{\vec{\theta}})$.
- Reweight each event: $\mathrm{dr}(\mathbf{p_h}, \mathbf{p}_\chi, \mathbf{p}_{\bar\chi}; \hat{\vec{\theta}}) = \frac{\hat{\mathcal{M}}}{\mathcal{M}} \mathrm{dr}(\mathbf{p_h}, \mathbf{p}_\chi, \mathbf{p}_{\bar\chi}; \vec{\theta})$
- Combine all events to get $\mathrm{DR}(\hat{\vec{\theta}})$.

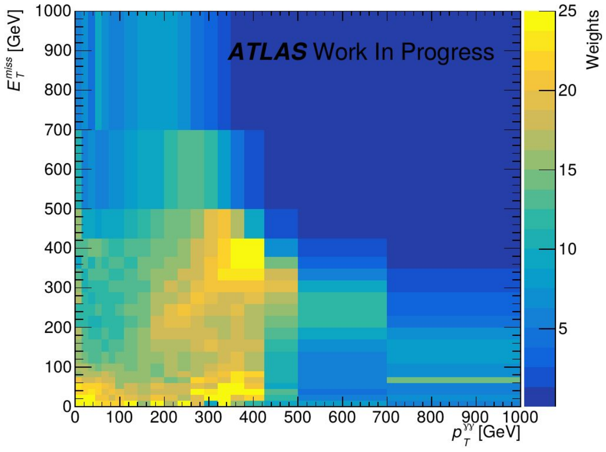
Mono-H($\gamma\gamma$) approach:

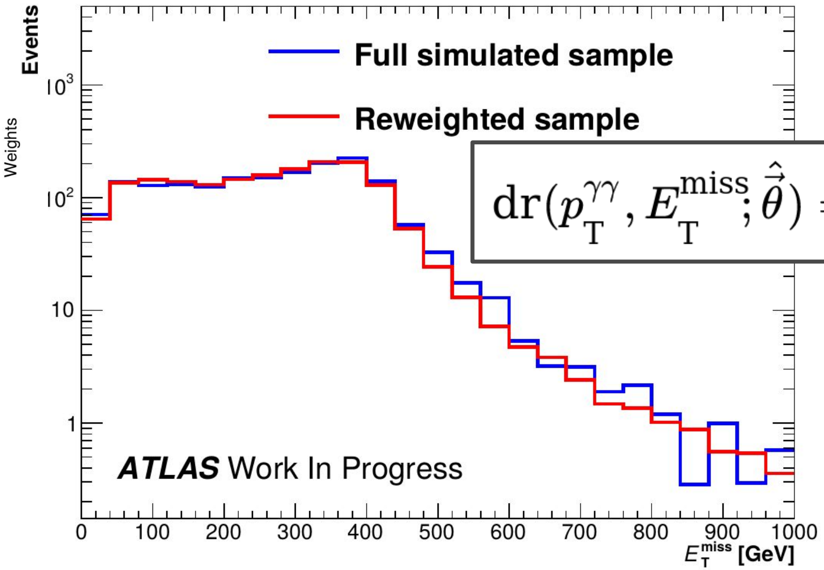
Weight

$$\#\mathrm{Evt}\,(p_{\mathrm{T}}^{\gamma\gamma}, E_{\mathrm{T}}^{\mathrm{miss}}; \vec{\theta})$$

$$p_{\mathrm{T}}^{\gamma\gamma} \in [x, x+h]$$
$$E_{\mathrm{T}}^{\mathrm{miss}} \in [y, y+k]$$







$$\mathrm{dr}(p_{\mathrm{T}}^{\gamma\gamma}, E_{\mathrm{T}}^{\mathrm{miss}}; \hat{\vec{\theta}}) = \frac{\hat{\#\mathrm{Evt}}}{\#\mathrm{Evt}}\,\mathrm{dr}(p_{\mathrm{T}}^{\gamma\gamma}, E_{\mathrm{T}}^{\mathrm{miss}}; \vec{\theta})$$

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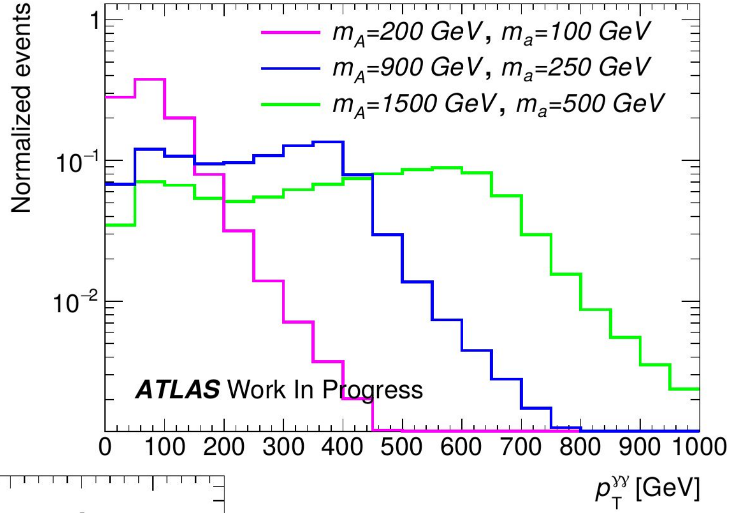
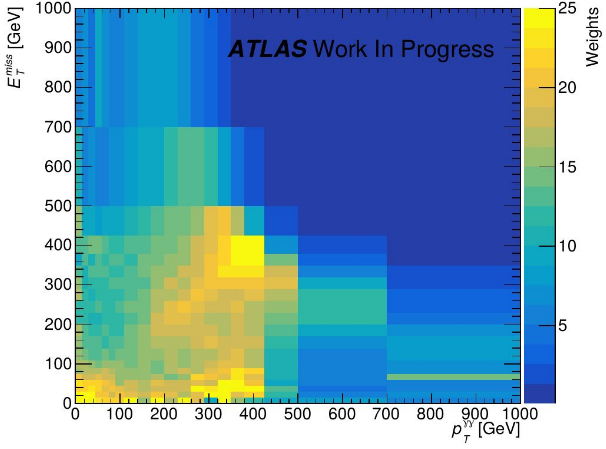
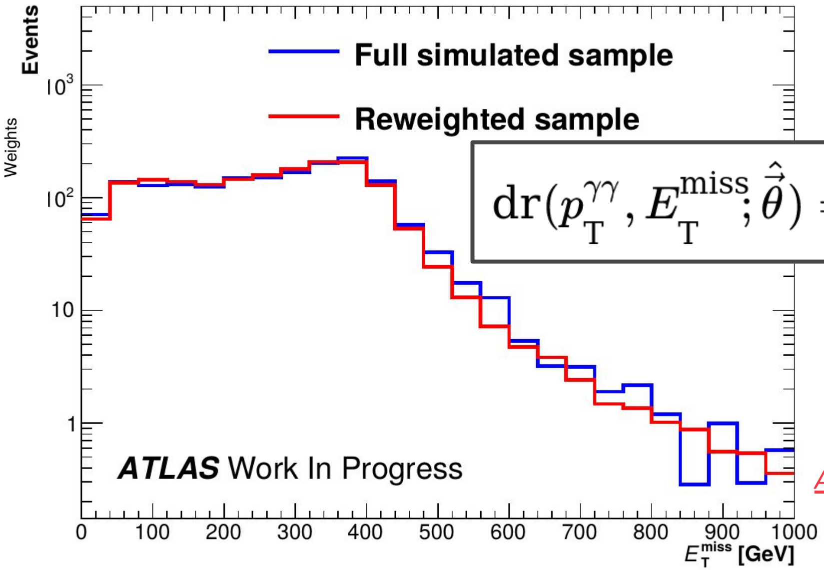




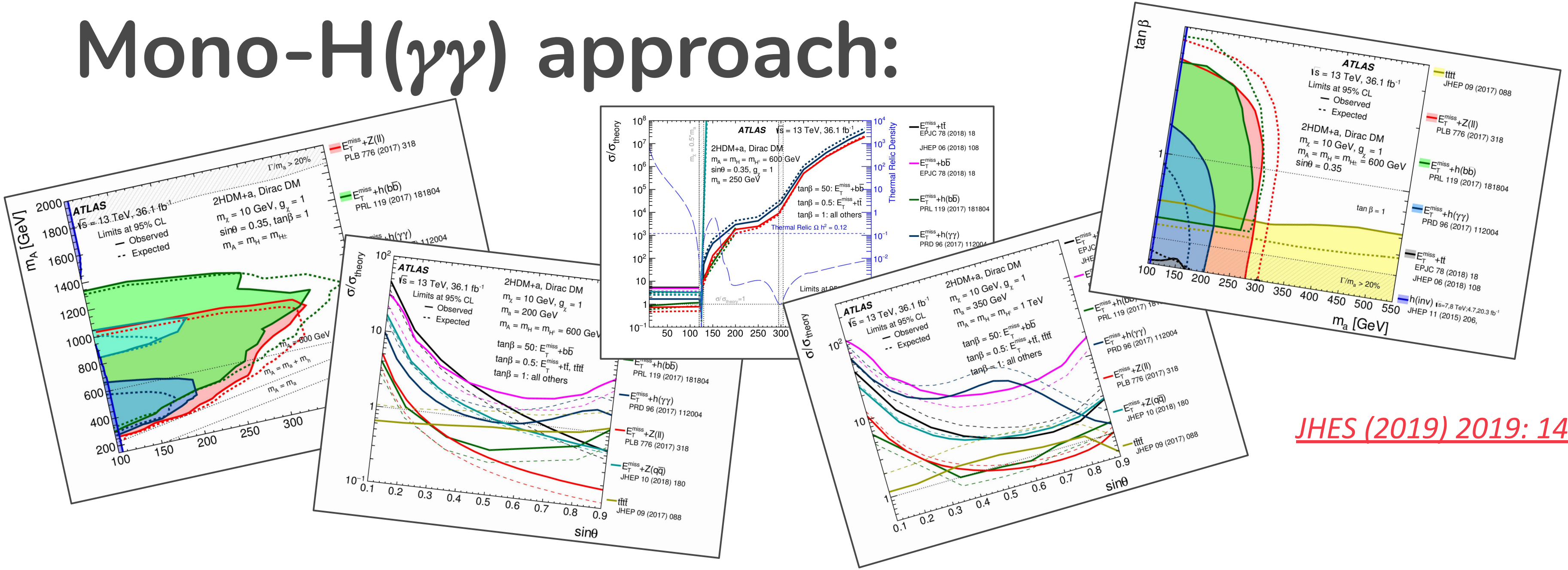


$$\mathrm{dr}(p_{\mathrm{T}}^{\gamma\gamma}, E_{\mathrm{T}}^{\mathrm{miss}}; \hat{\vec{\theta}}) = \frac{\#\hat{\mathrm{Evt}}}{\#\mathrm{Evt}}\,\mathrm{dr}(p_{\mathrm{T}}^{\gamma\gamma}, E_{\mathrm{T}}^{\mathrm{miss}}; \vec{\theta})$$

BTD reweighting?

A. Rogozhnikov, JPCS 762 (2016) 012036

Mono-H($\gamma\gamma$) approach:



[JHES (2019) 2019: 142]

	Reweighted	Full simulation
Number of sample points	284	1
Number of simulated events	56.8 M	200 k

Summary - MC reweighting

- Improved coverage for BSM/DM searches in the ATLAS experiment.
- Reduced number of full detector level simulations needed.
- Simplified approach used in mono-H($\gamma\gamma$) analysis, easy to apply.