Higgs differential cross sections at the LHC

HL/HE LHC Meeting

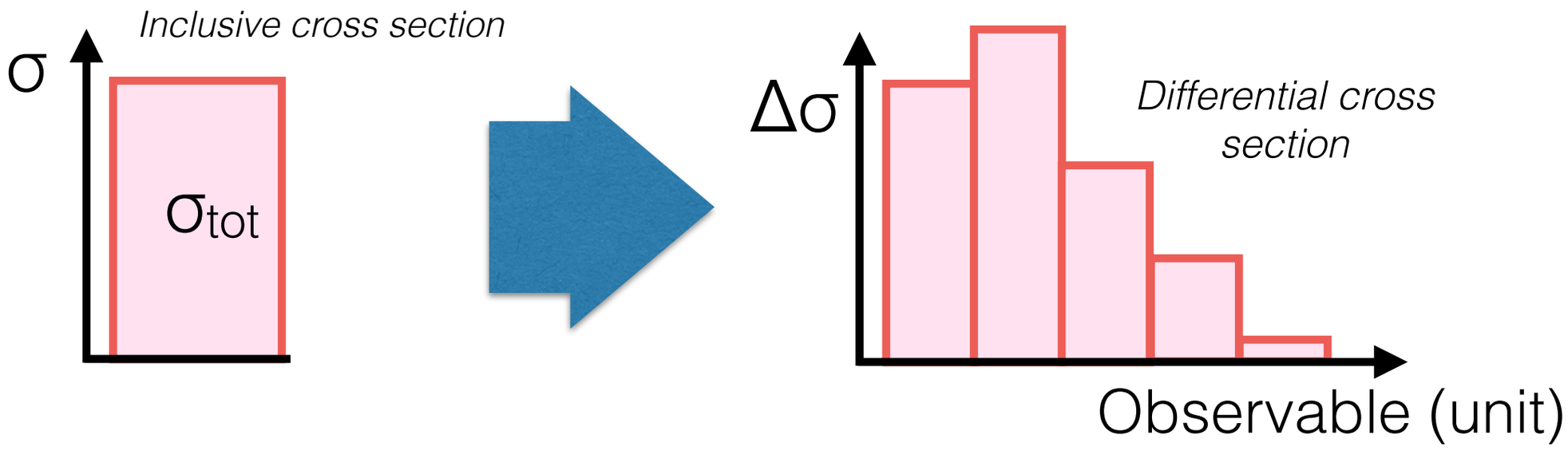
Fermilab, 5th of April 2018

Thomas Klijnsma

On behalf of the ATLAS and CMS collaborations

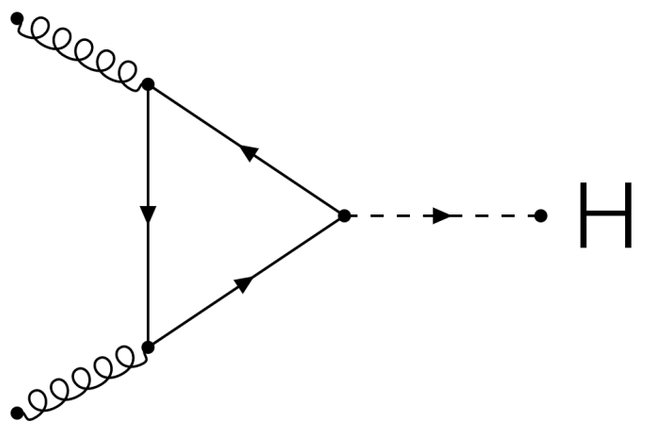
ETH zürich

Introduction: Differential cross sections



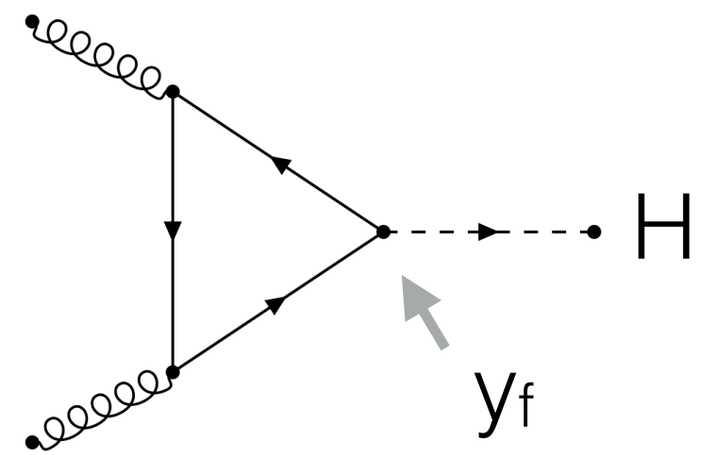
- What is so interesting about **differential cross sections**?
  - The **inclusive cross section** may agree perfectly well with the SM, but the **shape** can still deviate

- Of particular interest: **gluon fusion**, all sorts of interesting effects in the loop



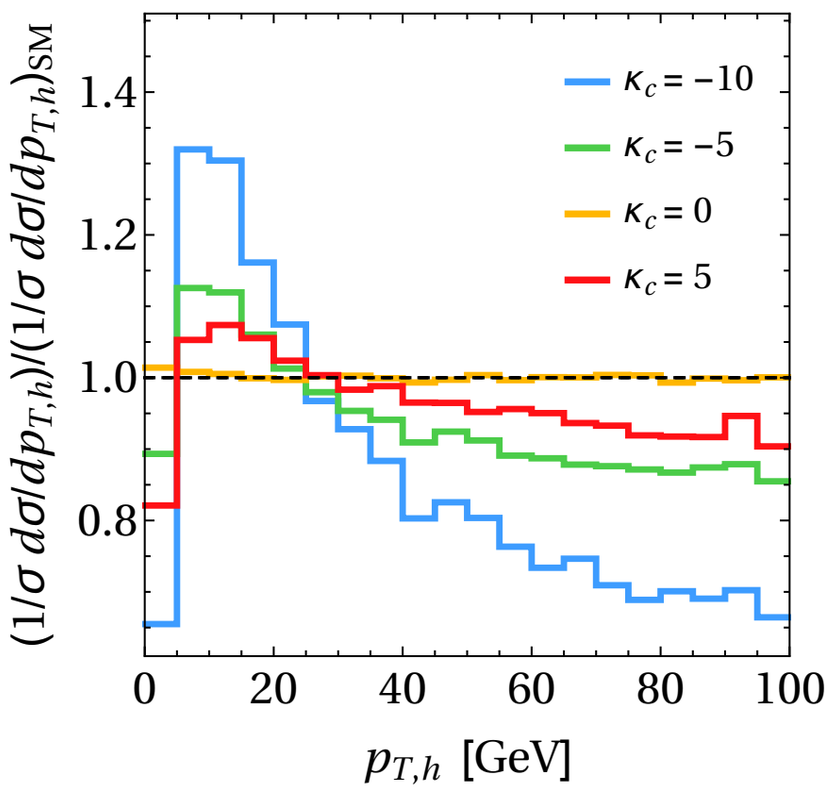
Introduction: Differential cross sections

- **Transverse momentum p_T^H**
  - Sensitivity to modifications of effective **Higgs Yukawa couplings**
  - Sensitivity to **finite top mass effects**

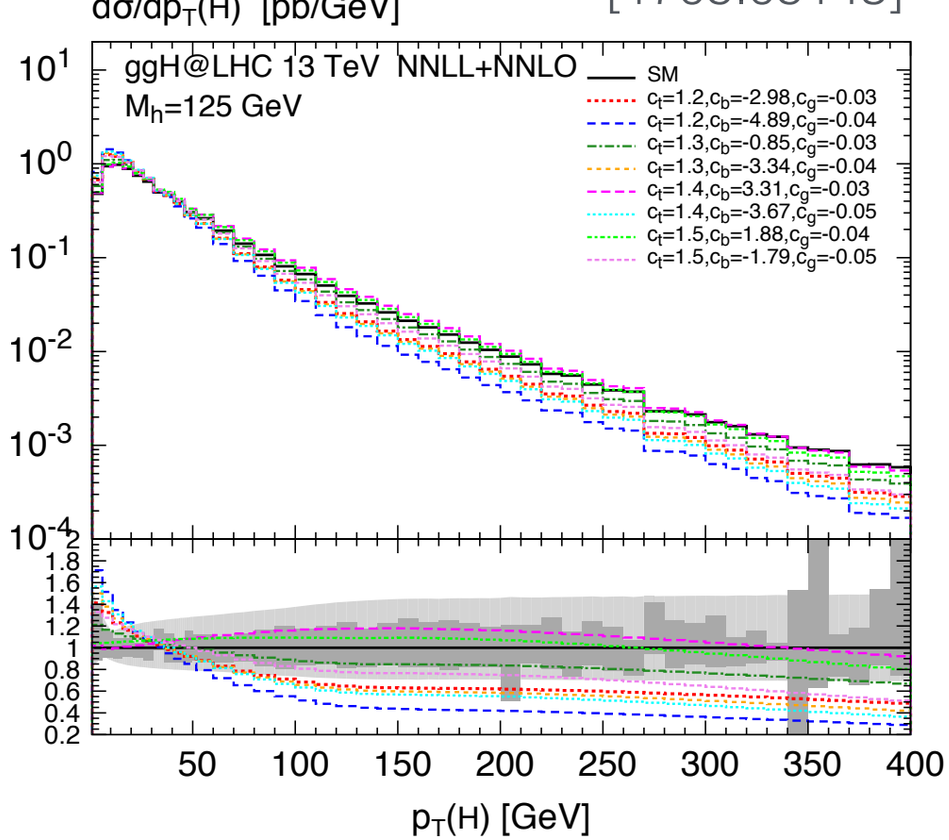


$$y_f = \kappa_f \cdot y_f^{SM}$$

Bishara, Haisch, Monni, Re (2016) [1606.09253]

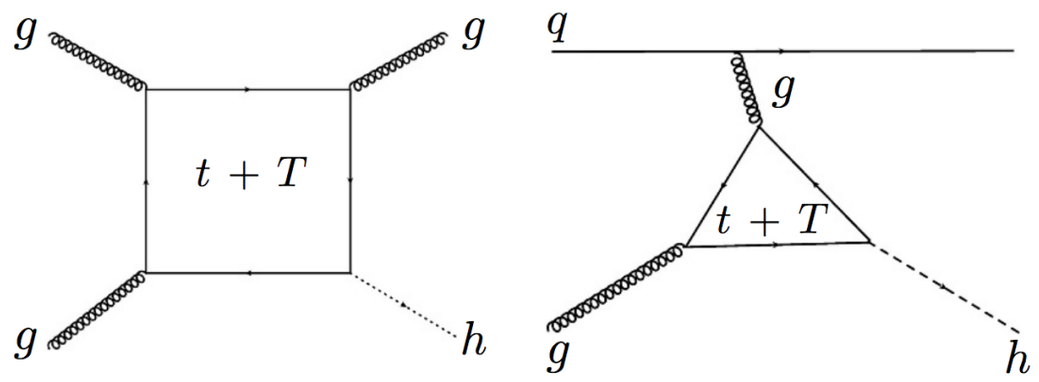


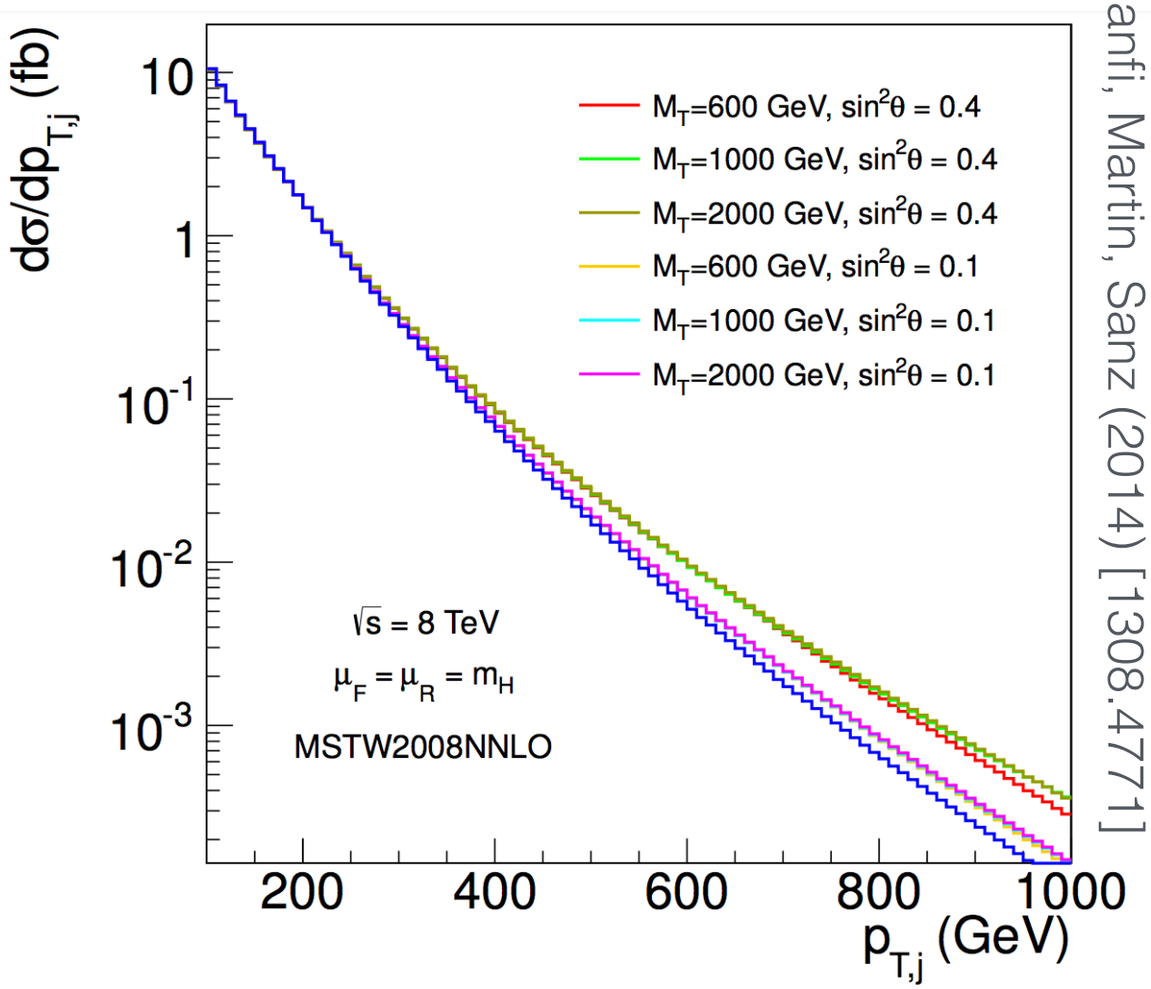
Grazzini, Ilnicka, Spira, Wiesemann (2017) [1705.05143]



Introduction: Differential cross sections

- **Jet multiplicity N_{jets} & p_T of the first jet p^T_{jet1}**
  - New physics in the loop, sensitivity at high p_T
- **Rapidity $|y^H|$**
  - Theory distribution mostly determined by the **gluon PDF**; possible test





Banfi, Martin, Sanz (2014) [1308.4771]

The current state

- Primary measurements of differential cross sections from **H to 2 photons** and **H to 4 leptons**

- Current state for **13 TeV**:

	ATLAS	CMS
H→γγ	p_T^H, N_{jets}, p^T_{jet1}, $\lvert y^H \rvert$ [1802.04146]	p_T^H, N_{jets} [CMS-PAS-HIG-17-015]
H→ZZ	p_T^H, N_{jets} [1712.02304]	p_T^H, N_{jets}, p^T_{jet1} [JHEP 1711 (2017) 047]
Combination	✓ [ATLAS-CONF-2018-002]	⟳

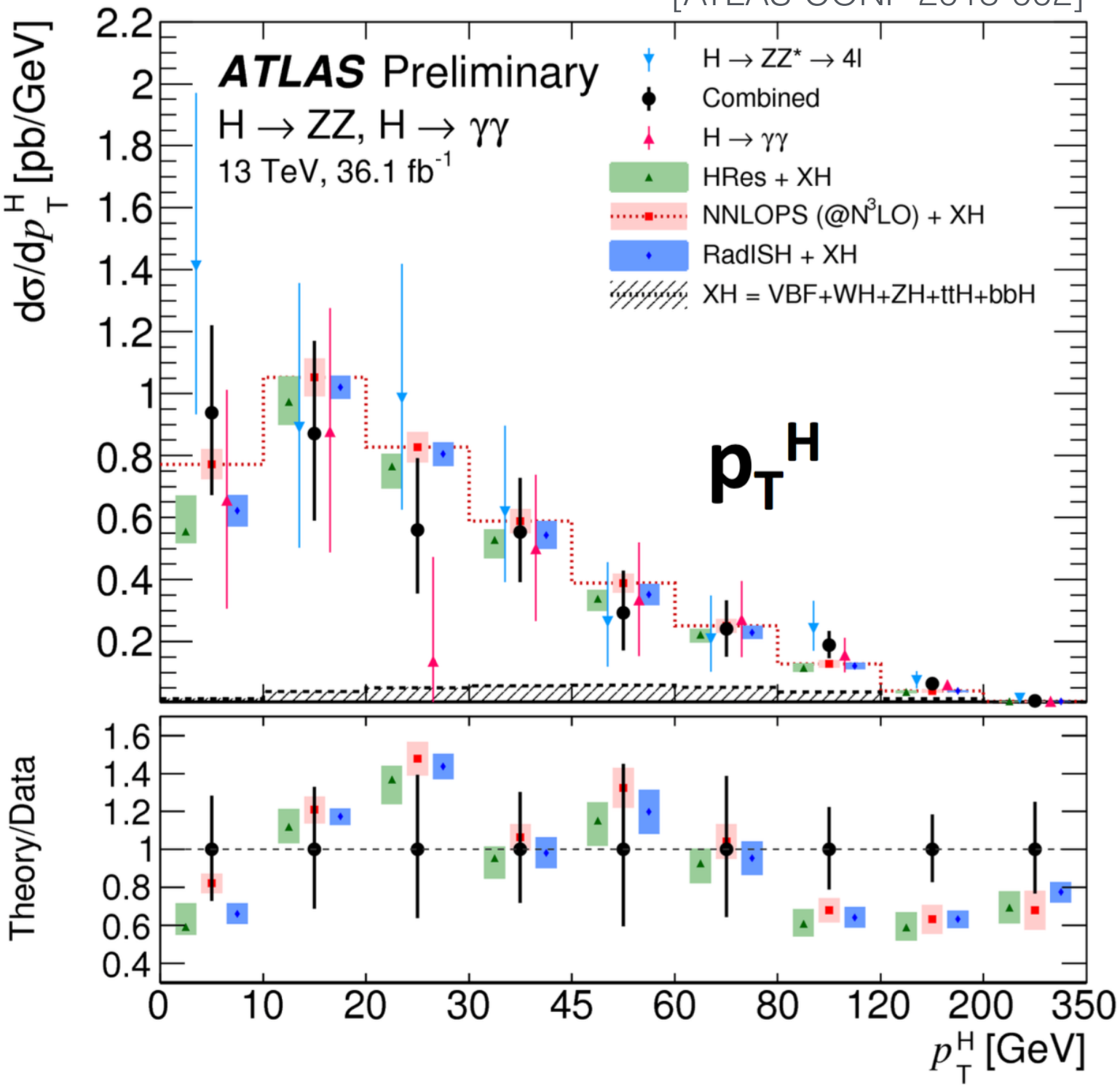
Outline

- Considering what we have now, **what can we expect at 3000 fb^{-1}?**
  - **p_T^H:** Basic CMS ‘combination’, assuming **no correlations** and uncertainties to be **statistically dominated**
- What can we do with these differential cross sections?
  - Higgs coupling modifiers using p_T^H

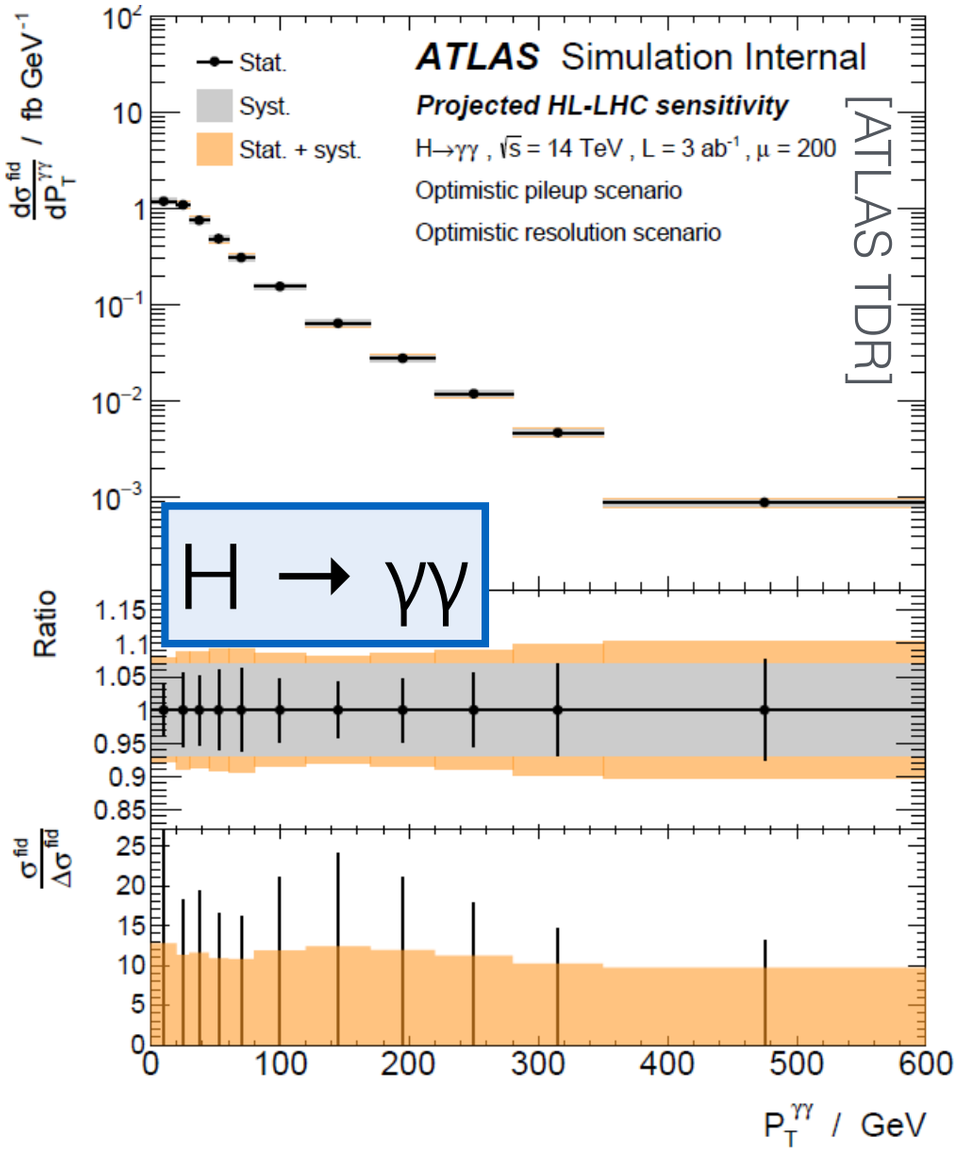
p_T^H: ATLAS

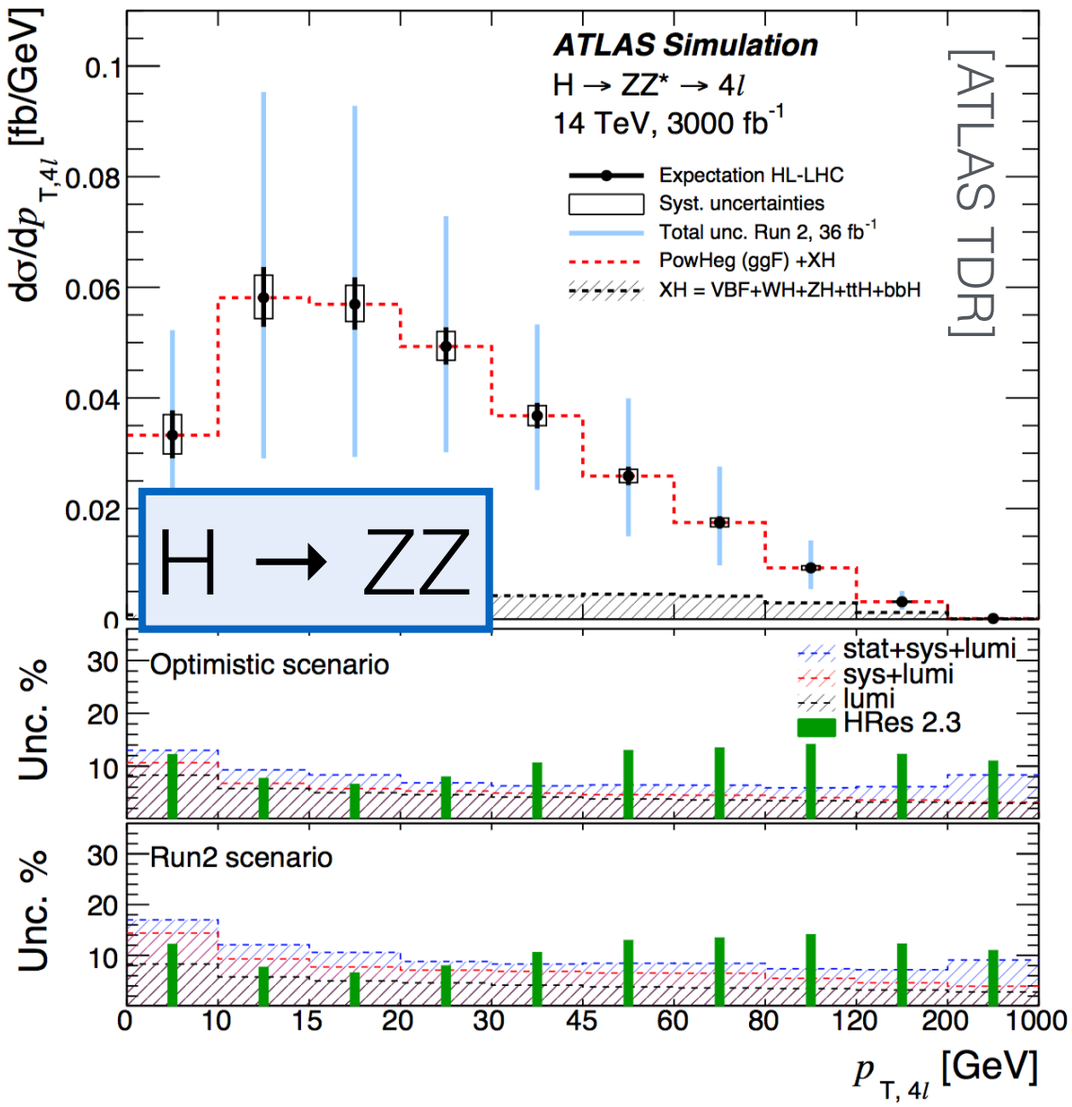
- Fleshed out combination from ATLAS
- Particular improvement in the low p_T region
- 20%-40% uncertainties, mostly statistically dominated

[ATLAS-CONF-2018-002]



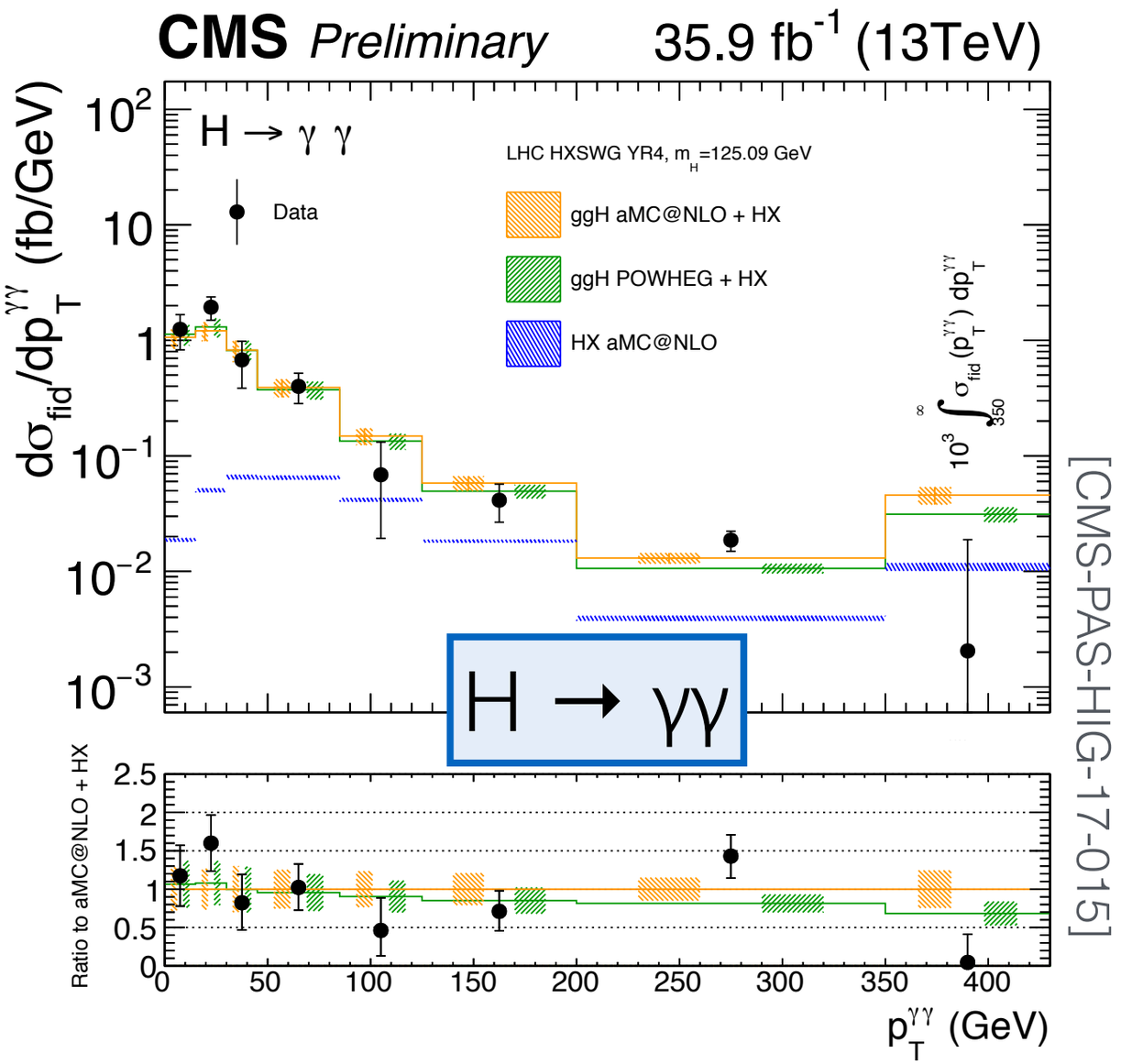
p_T^H: Projections from ATLAS

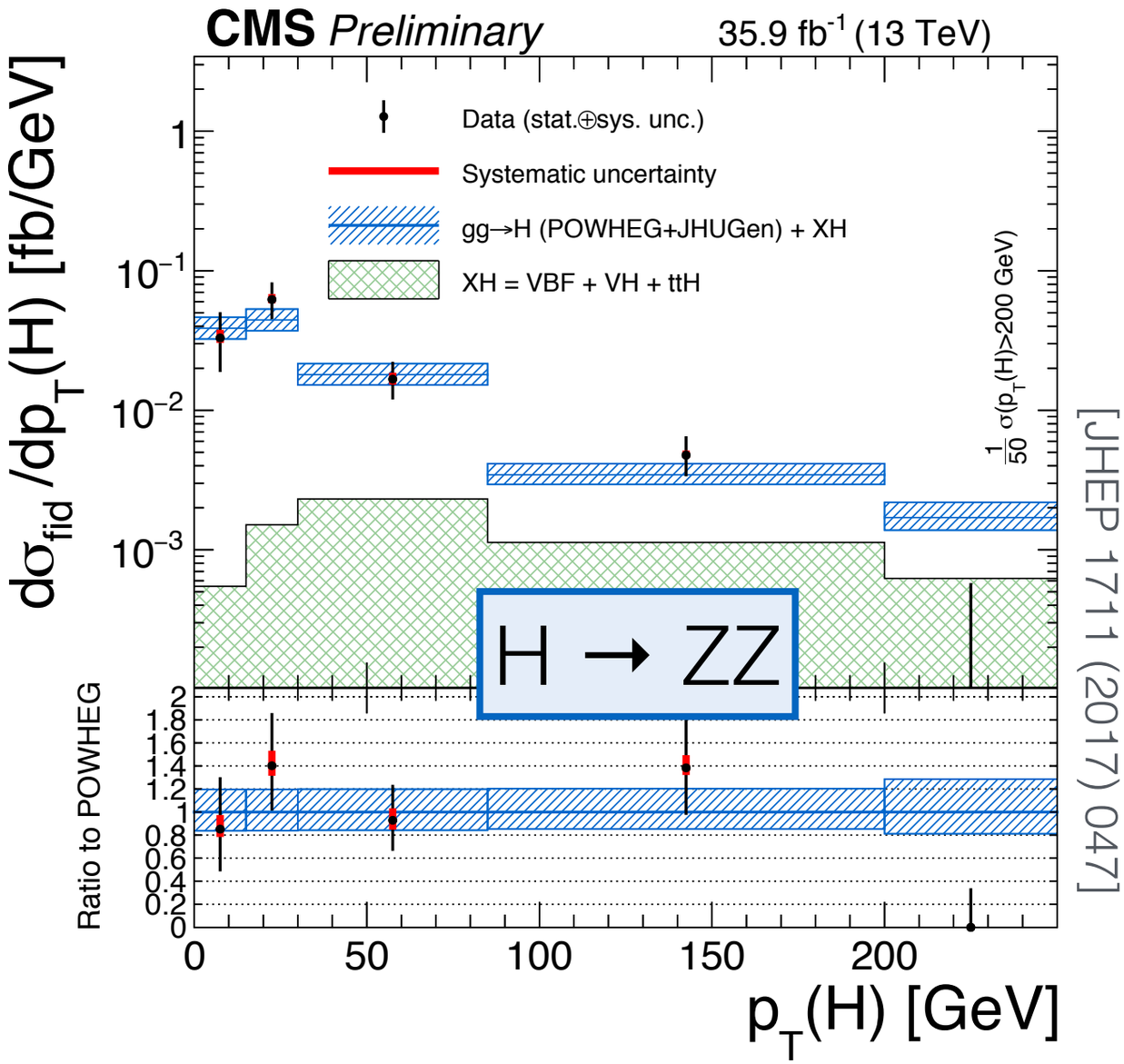




- ~5% uncertainties for H → γγ, between 5-10% for H → ZZ
- For H → γγ, Improvement by a factor of ~8-9,
  really close to $\sqrt{3000/36} \simeq 9$ (scaling only stat., assuming same syst.)
- **<5%** uncertainty achievable with a combination

p_T^H: CMS



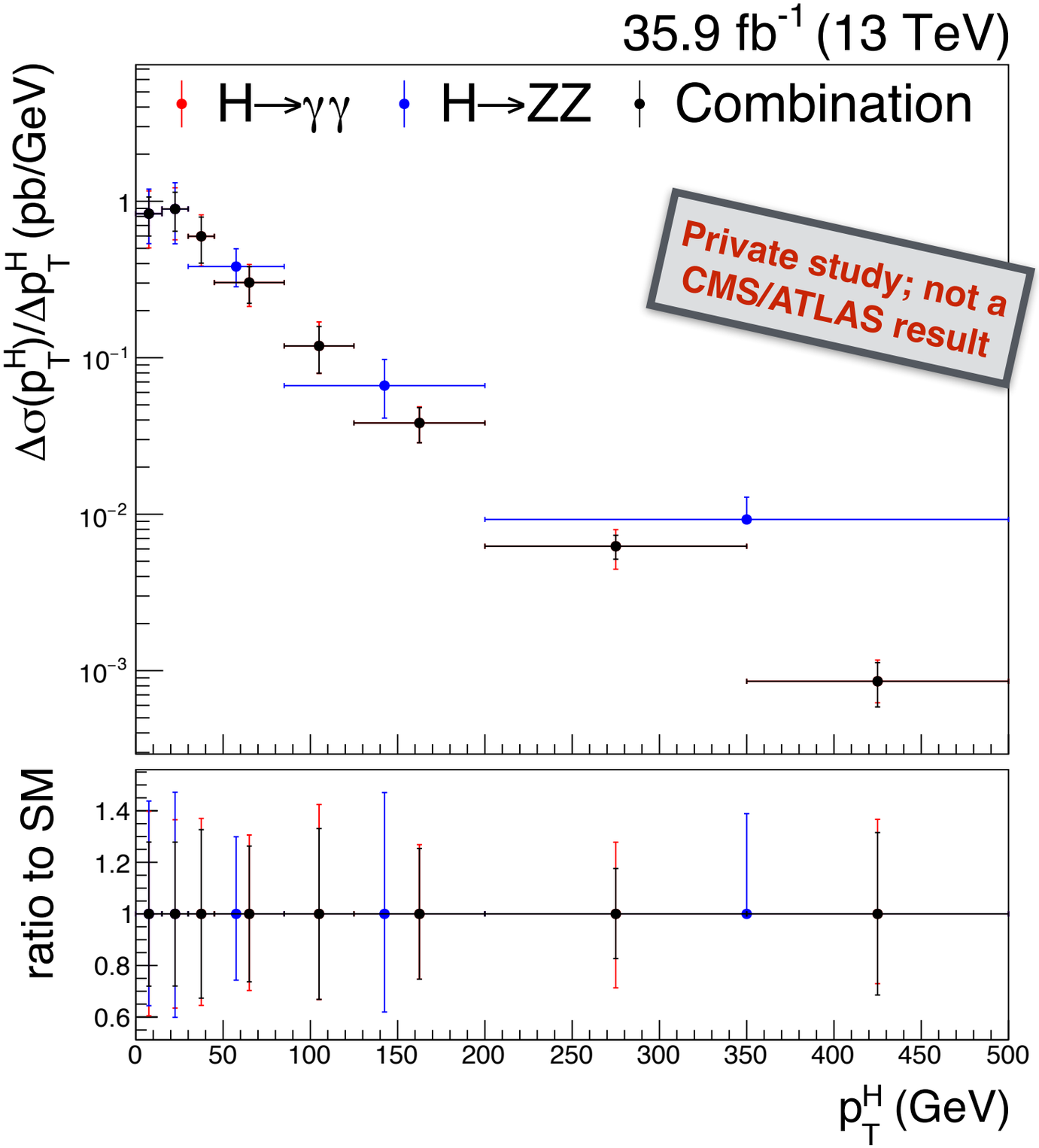


- Proper combination ongoing, but we can make an attempt:
  - Assume no correlations, and no bin-to-bin migrations

p_T^H: CMS

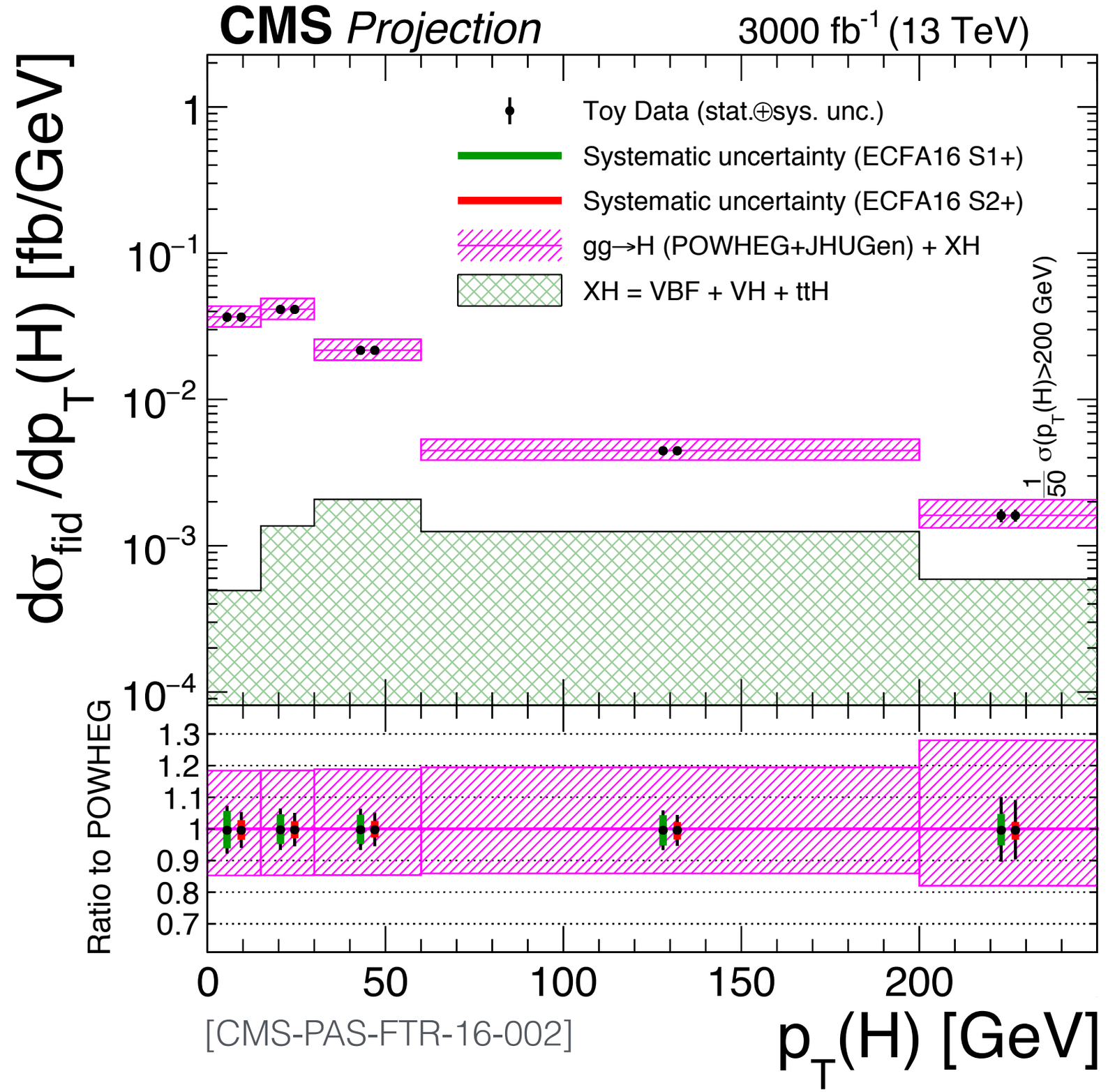
DISCLAIMER: NOT A PROPER COMBINATION; BALLPARK ESTIMATE

- Doing a very basic combination
  - No bin-to-bin correlations/migrations
  - Simple χ2 fit (entries weighted by uncertainty)
- This is **not** a proper combination and **not** a CMS result
- This study indicates a similar pattern to ATLAS: **20-30% statistically dominated uncertainties**



p_T^H: Projections from CMS

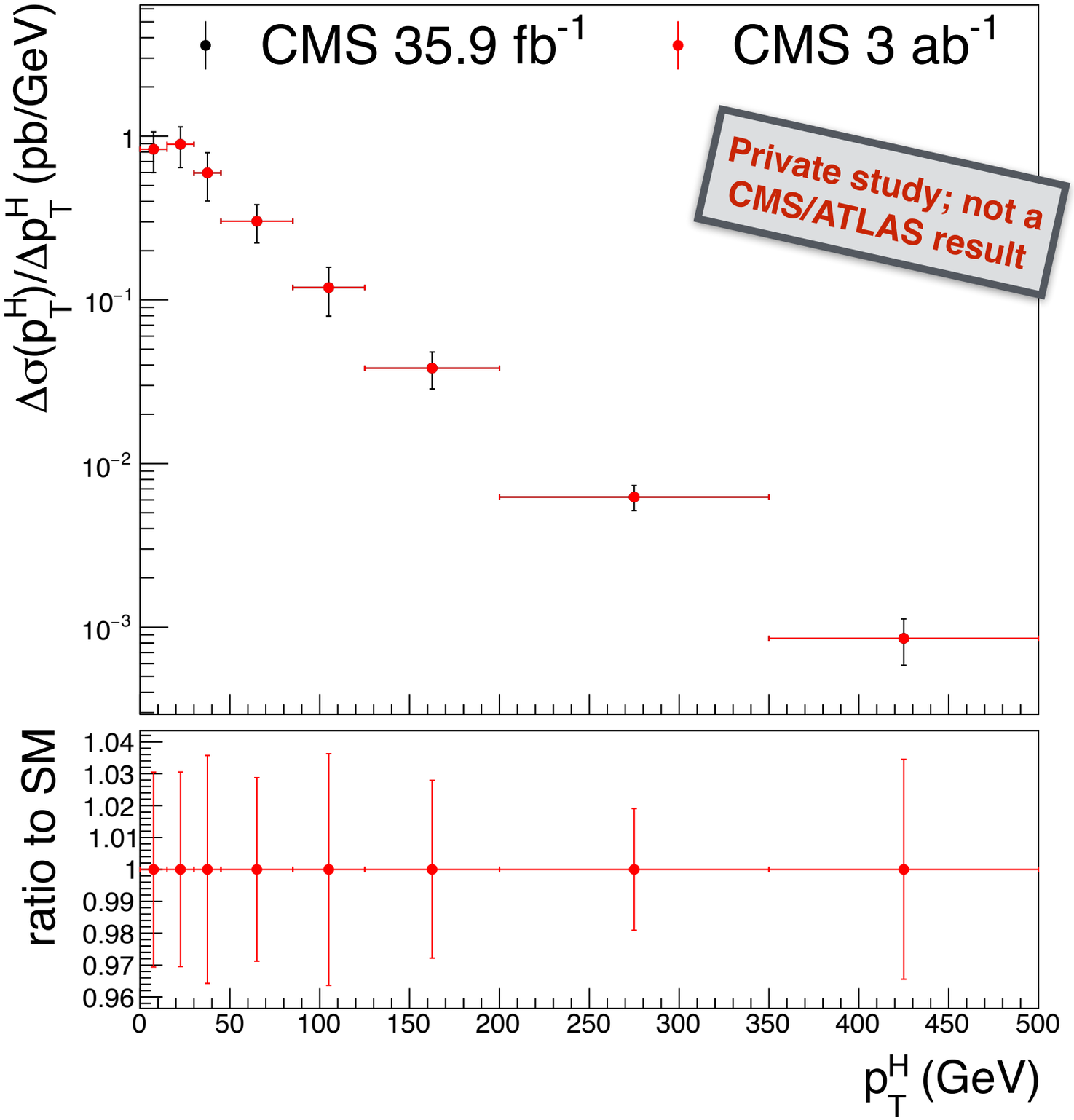
- Projection available for **H → ZZ**
- 5-10% uncertainties, comparable to ATLAS H → ZZ



[CMS-PAS-FTR-16-002]

p_T^H: Projections from CMS

- No proper projection for the **combination** yet, but simply scaling observed uncertainties by $\sqrt{35.9/3000}$
- Moved central values to SM expectation
- Yields **~3%** uncertainties (a bit by construction of course), comparable to the ATLAS projections



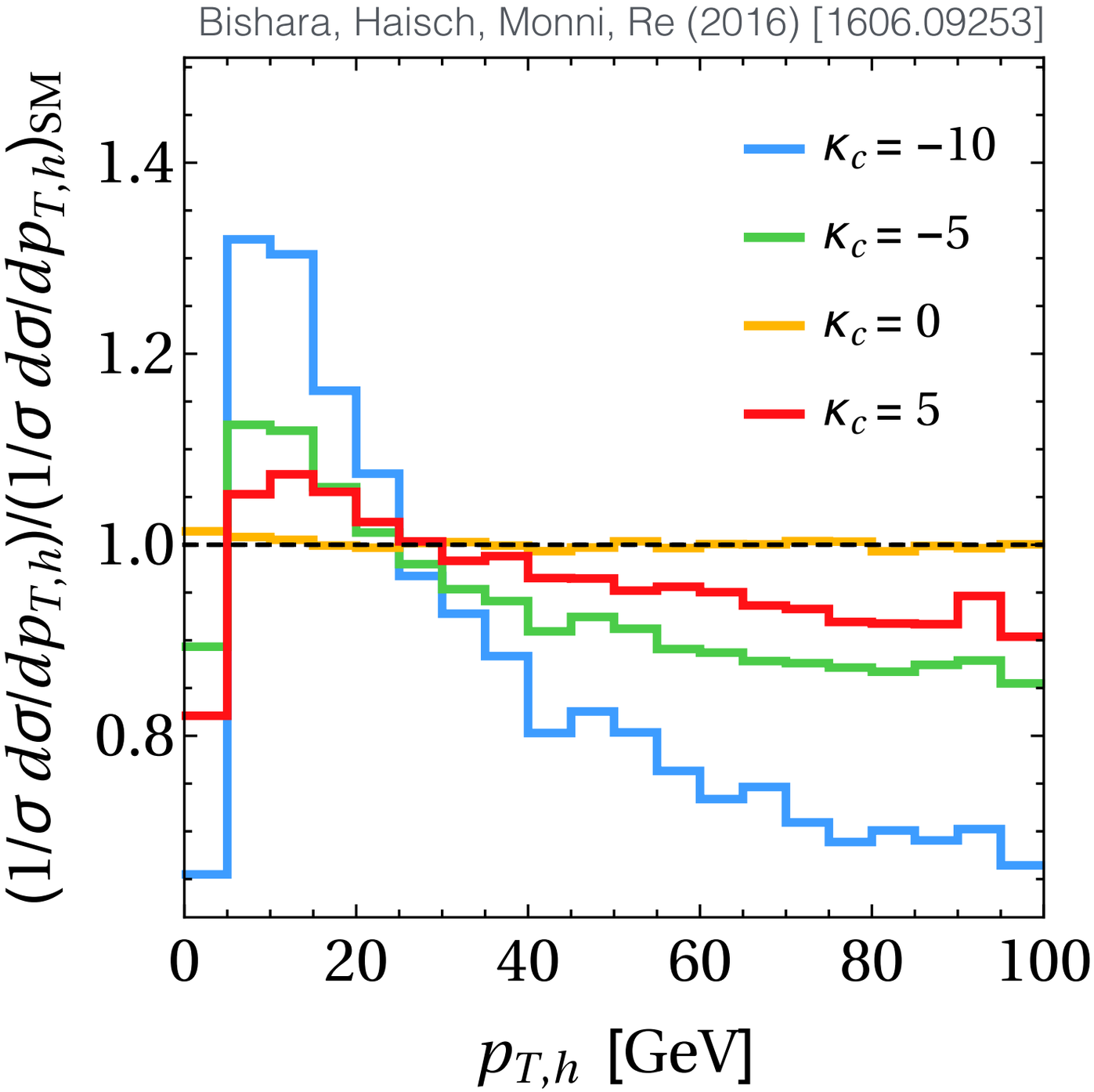
Remarks on p_T^H

- Uncertainties of the **order of a few percent** seem achievable for HL-LHC, with $\mathcal{O}(10)$ bins up to p_T 350 GeV
- Currently, uncertainties are very **statistically dominated**
    - Differentials are not hit as hard by the '*systematics wall*'
        - Good motivation to combine results from both experiments
- Possibility to improve further by including more decay channels in the combination: H → WW, VH → bb (planned by ATLAS), (boosted) H → bb, etc.

Couplings: κ_b vs. κ_c

- Can use the p_T spectra to fit κ_b vs. κ_c
  - Simply vary κ_b vs. κ_c until the spectrum matches the observed spectrum the best
- What can we do with this at 3 ab^{-1}?

Bishara, Haisch, Monni, Re (2016) [1606.09253]



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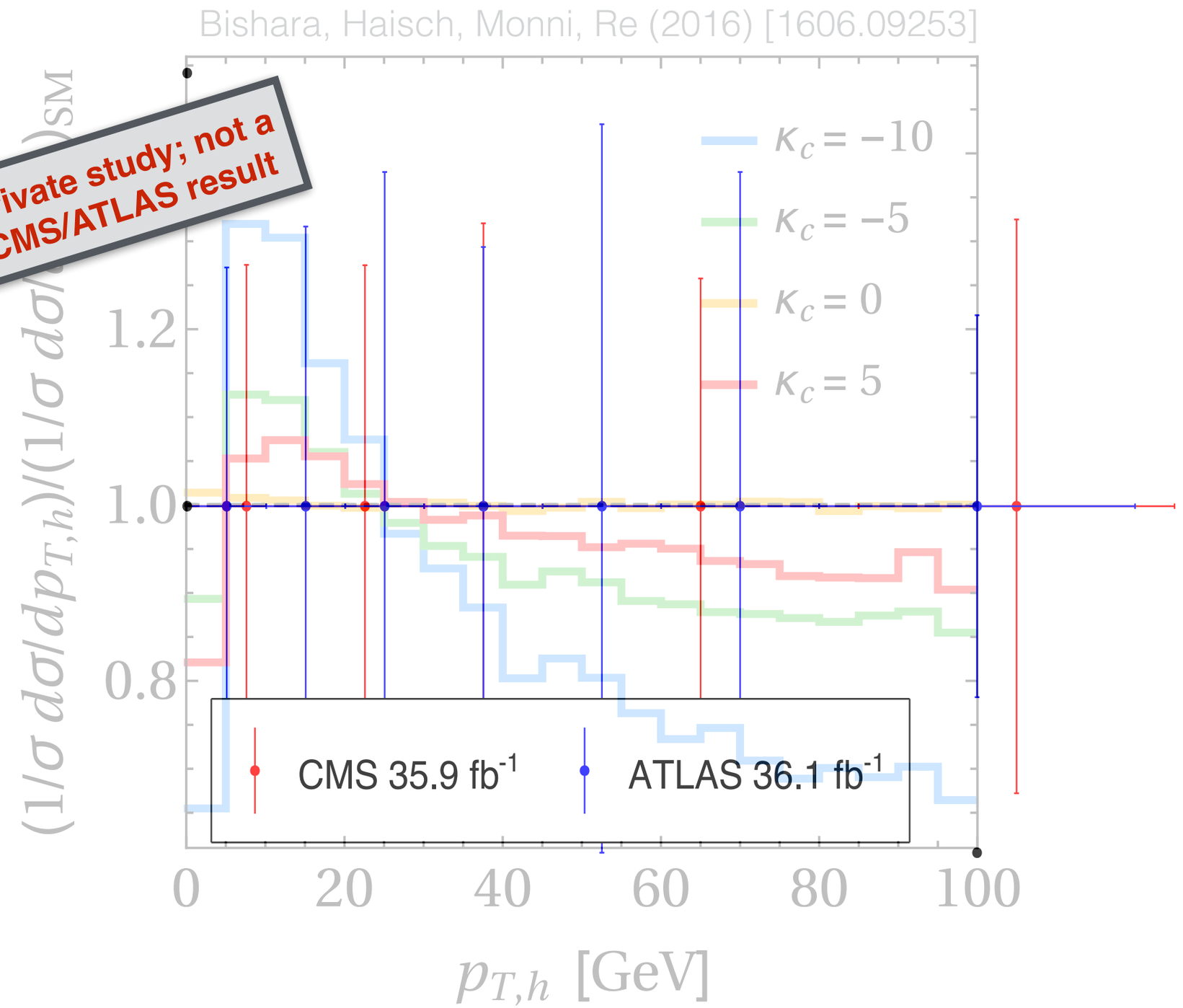

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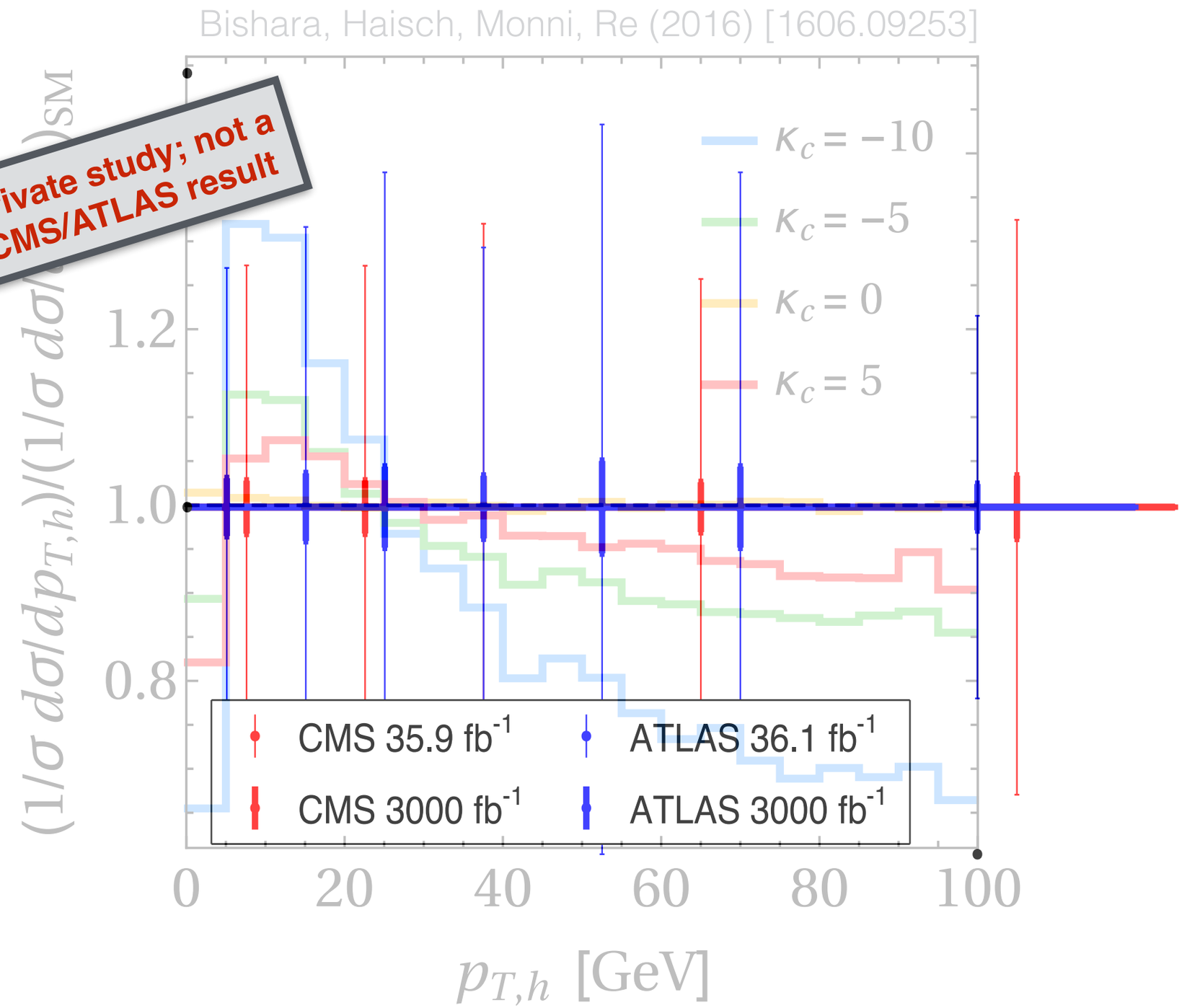
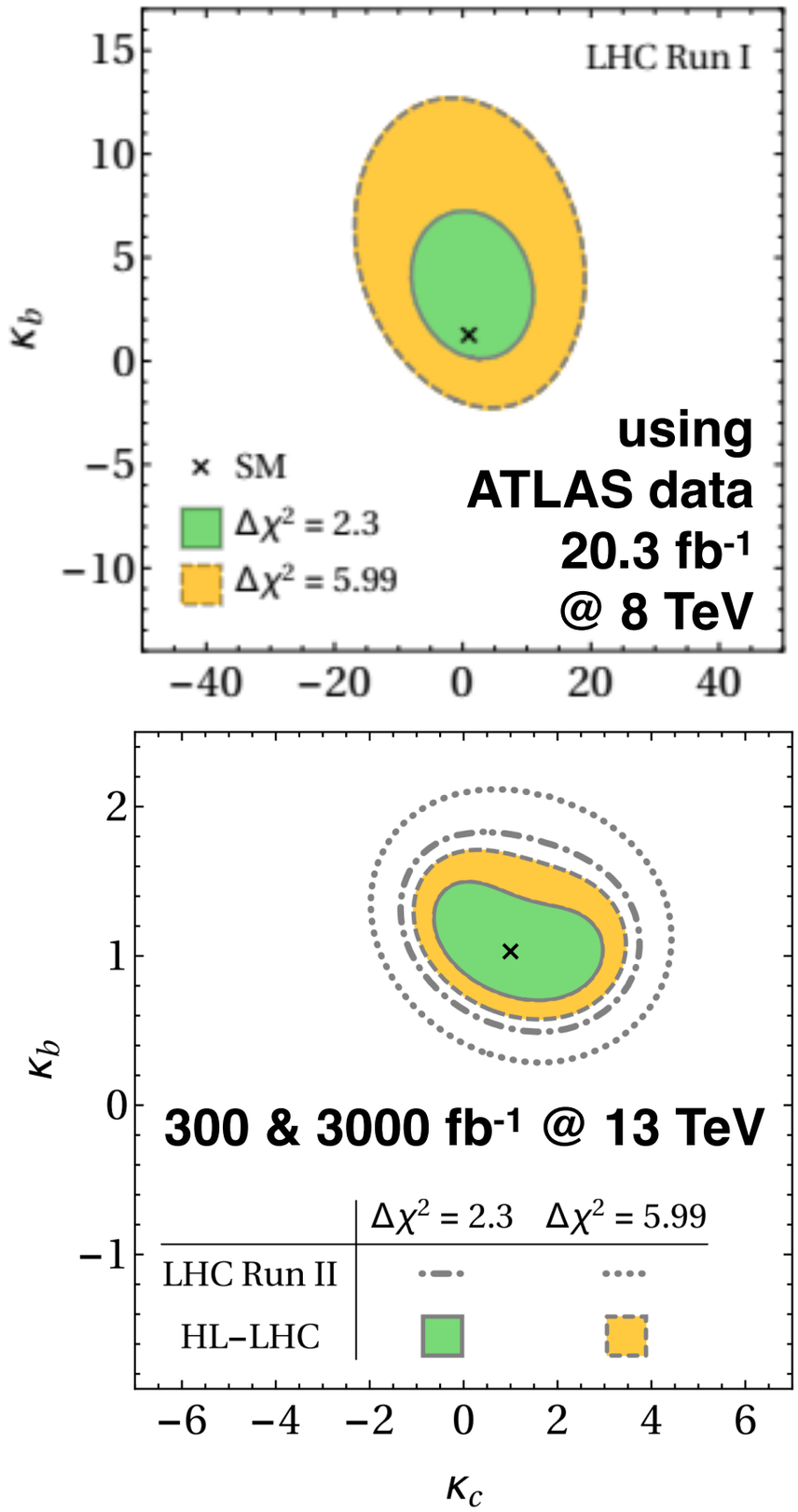


Couplings: κ_b vs. κ_c

- Theorist fit on ATLAS combined pT-specturm indicates κ_c sensitivity of order [-10, 10] @ 68% CL
- Projections*:
  - ~[-1.5 , 4.0] @ 300 fb^{-1}
  - ~[-0.5 , 3.0] @ 3000 fb^{-1}

*: Some side notes:

- Optimistic projections for theory uncertainties
- Assuming also H → WW
- Correlations taken from 8 TeV case



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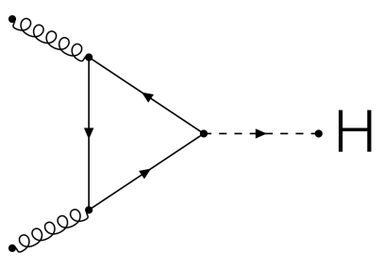
Couplings: κ_t vs. c_g

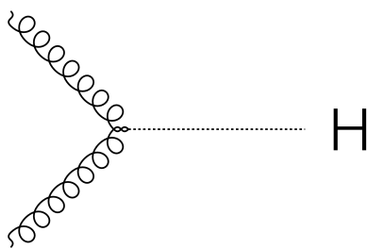
- Similar thing can be done for **κ_t vs. c_g**
  - Modify Lagrangian:

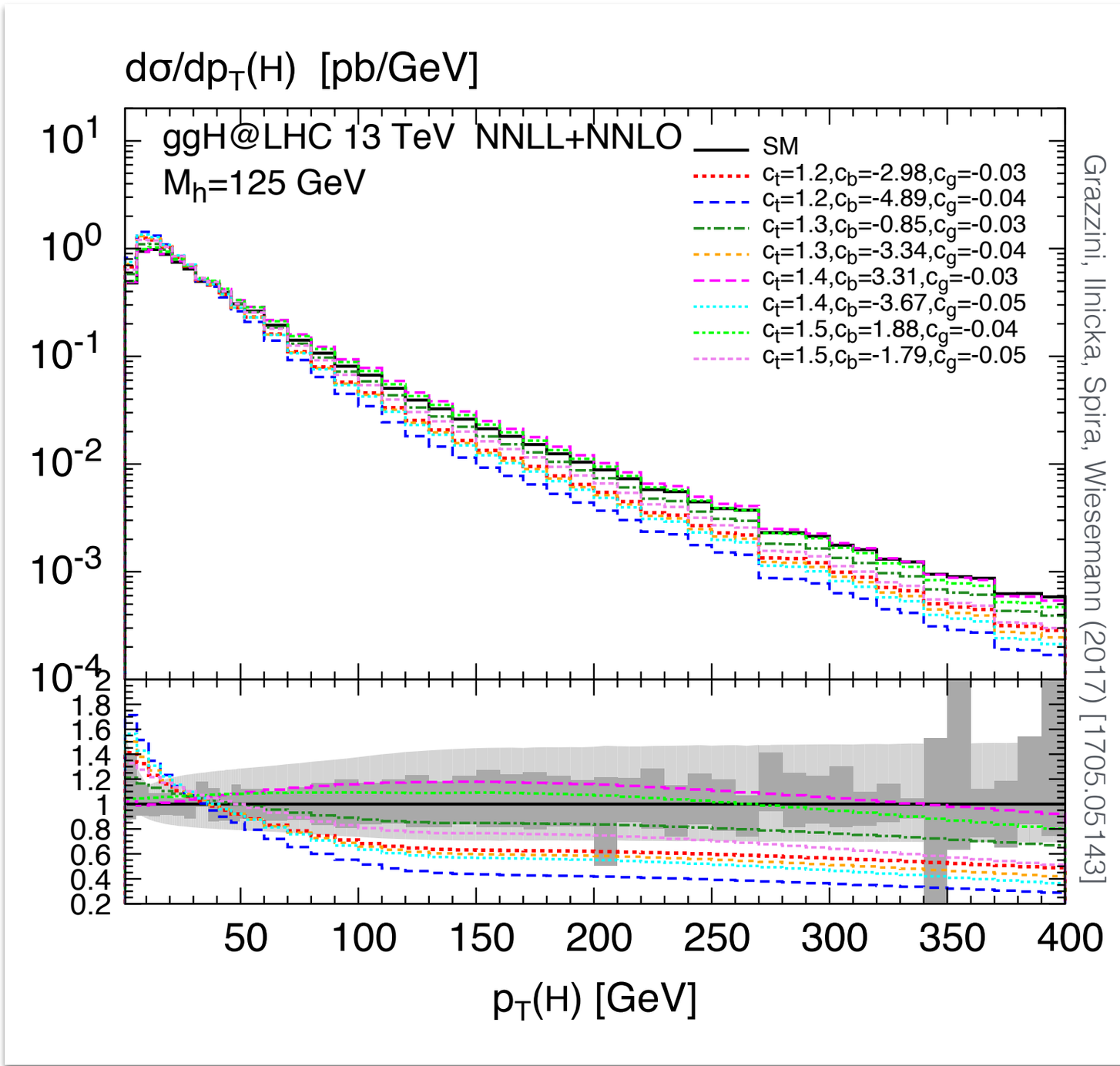
$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} + \frac{\alpha_S}{\pi v} c_g h G^a_{\mu\nu} G^{a,\mu\nu}$$

($\kappa_t = 1$, $c_g = 0$) ~ SM,



($\kappa_t = 0$, $c_g = 0.007$) ~ point-like coupling of the Higgs to gluons





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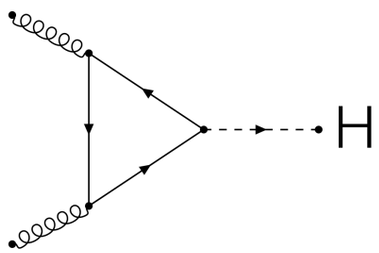

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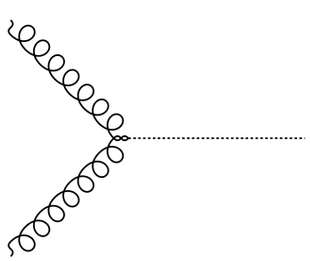

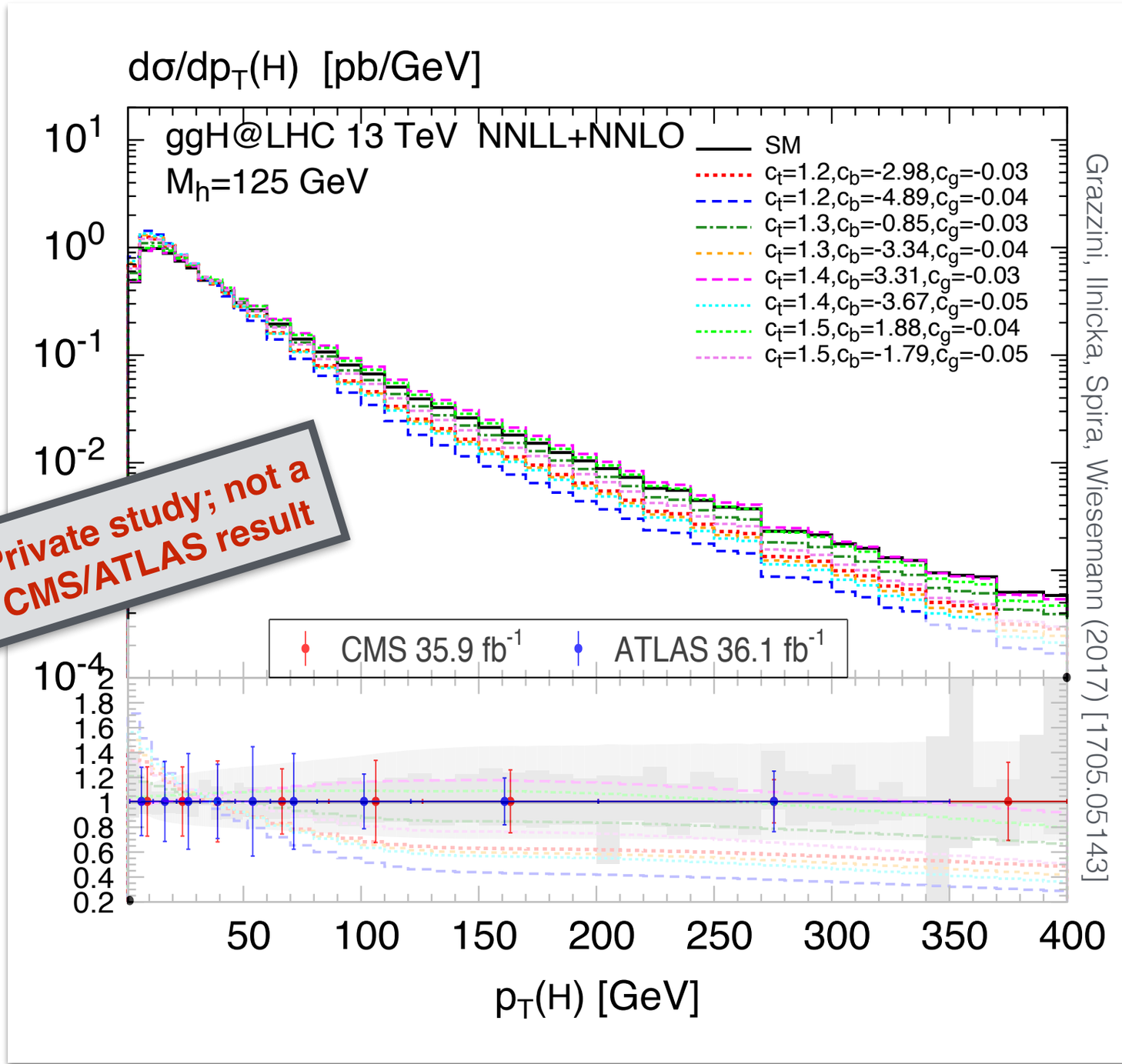

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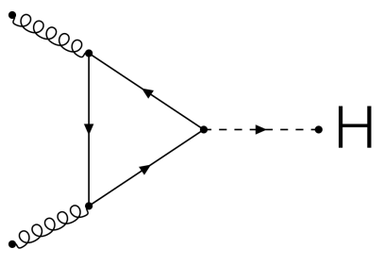

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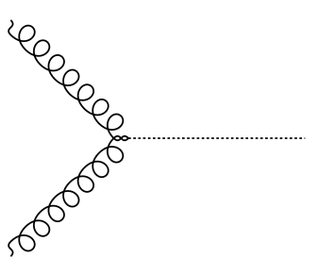

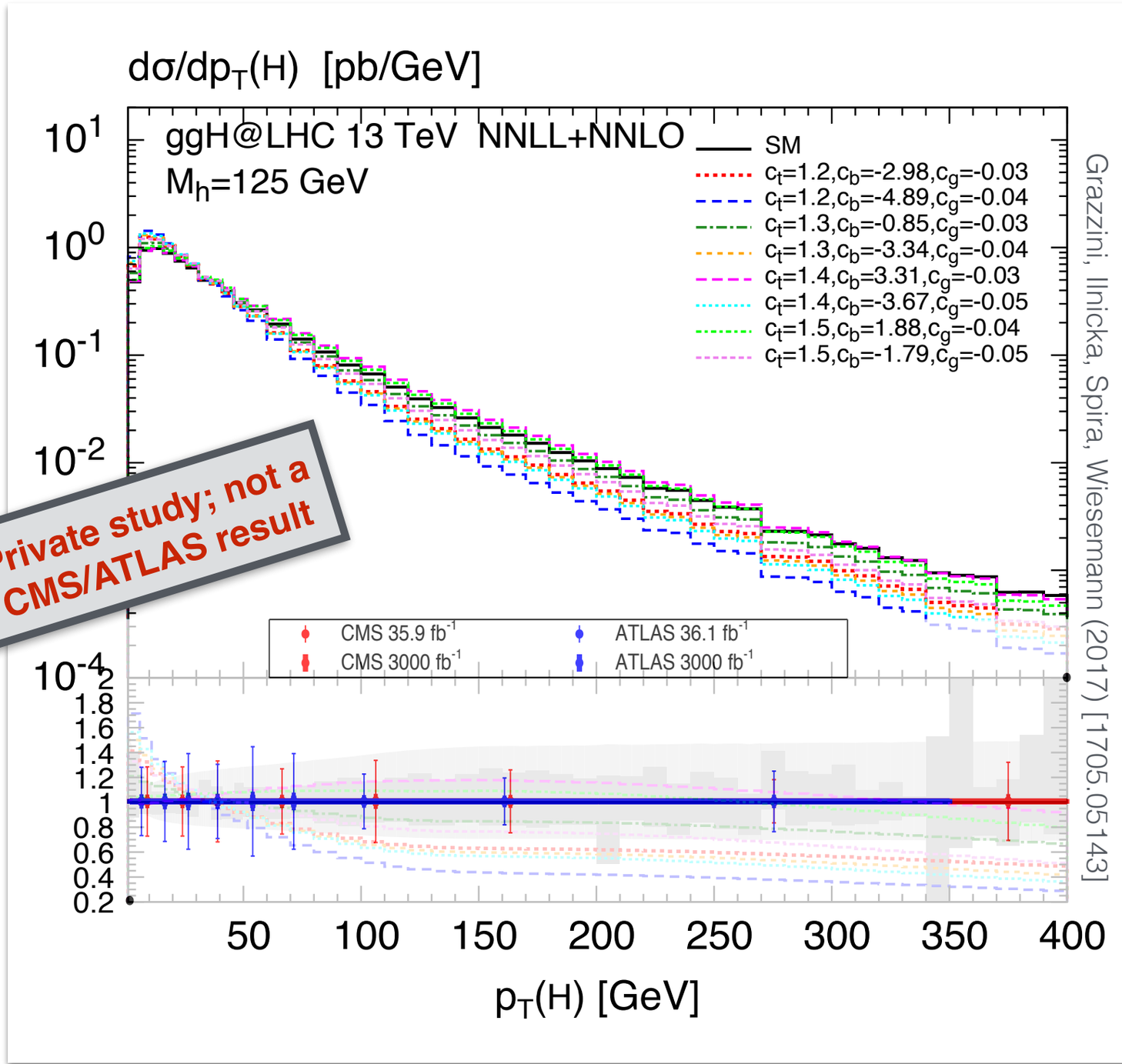

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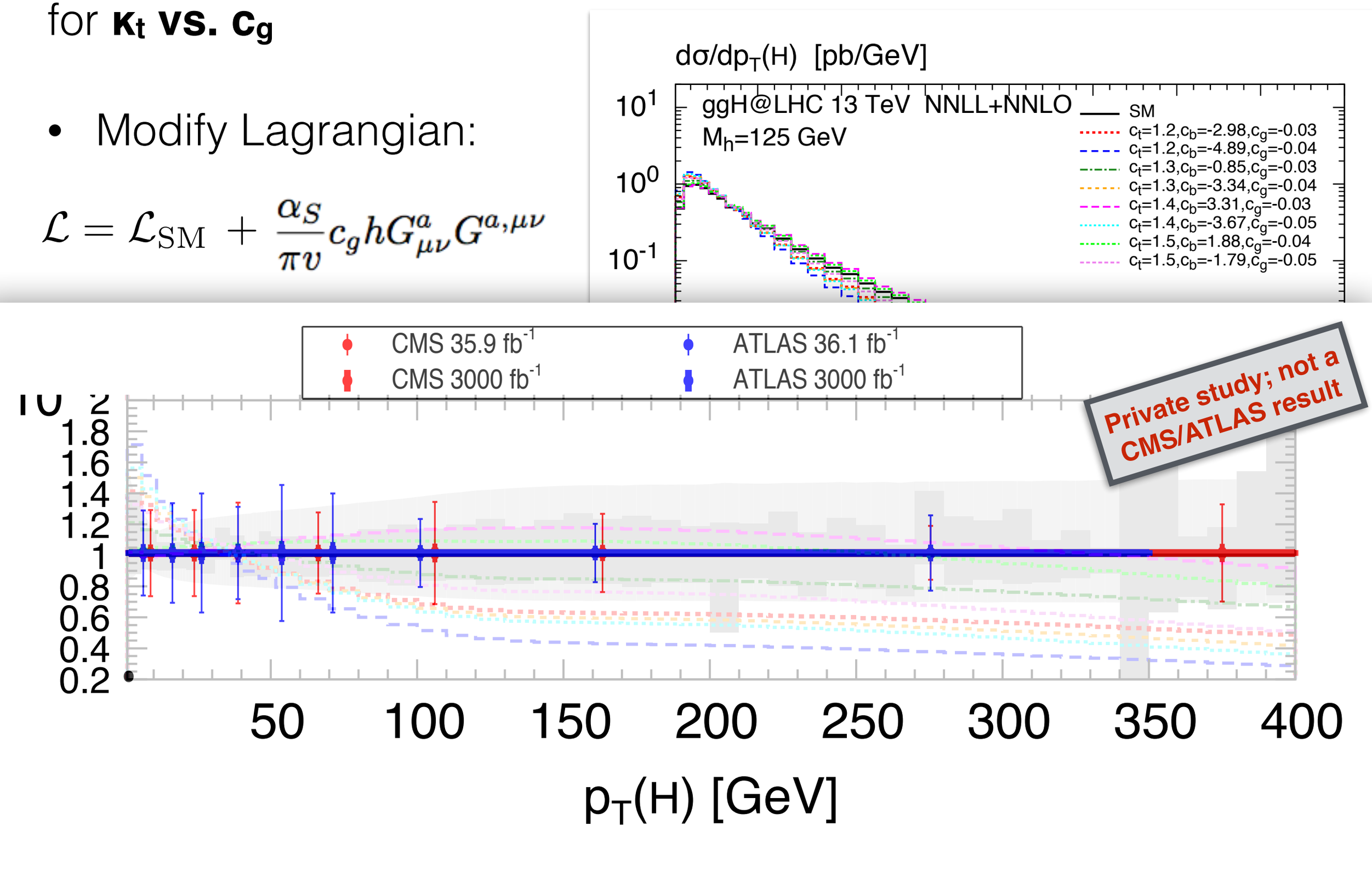

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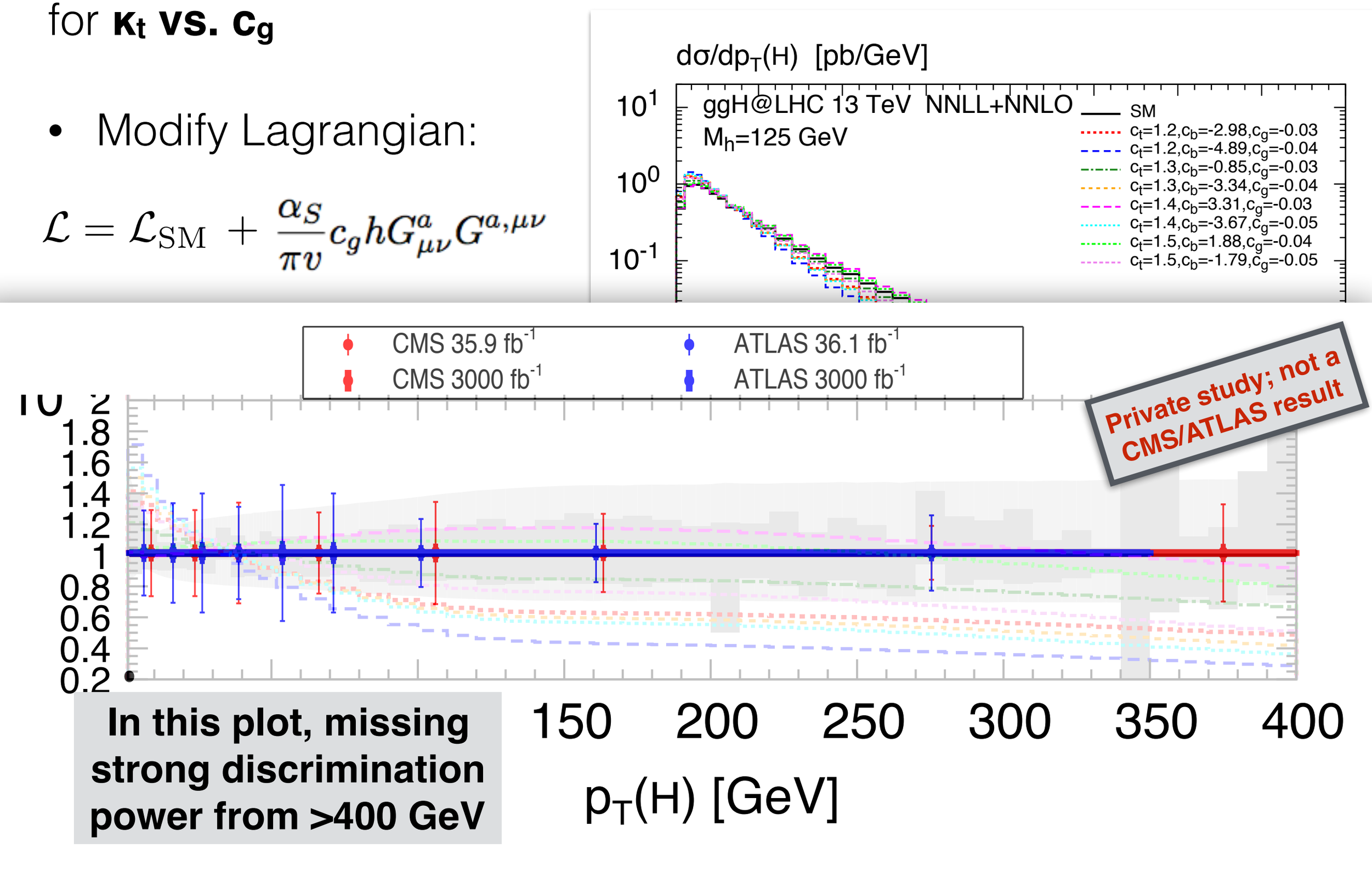

In this plot, missing strong discrimination power from >400 GeV

Conclusion

- Differential cross sections provide an interesting portal to a number of physical observables

- Currently the interpretation of differential cross sections is limited by statistics

  - 3 ab^{-1} of data opens up possibilities for new measurements, and would provide competitive limits on Higgs couplings

Back up