Modelling BSM effects on the Higgs pT spectrum in an EFT approach

Agnieszka Ilnicka

based on [1511.08059], *work in progress*,
in collaboration with:
M.Grazzini, M.Spira, M.Wiesemann

Why BSM?
Why Effective Field Theory?
Why Higgs pT spectra?

Cosmological phenomena which need explanation:
Baryogenesis
Dark Matter

Hierarchy problem

Neutrino masses,
some anomalies from
flavour physics

Why BSM?
Why Effective Field Theory?
Why Higgs pT spectra?

Many, many models
proposed to explain all
or some of this problems

…but no new particles seen so far!
Maybe they will not be in reach of LHC

Theory consistent

Model independent

Allows for systematic improvements from theoretical side

Well suited to parametrise small deviations from SM

Why BSM?

Why Effective Field Theory?

Why Higgs pT spectra?

Complementary to direct searches

Can be used to store what LHC measured

Proved to work in flavour physics

Can link many measurements

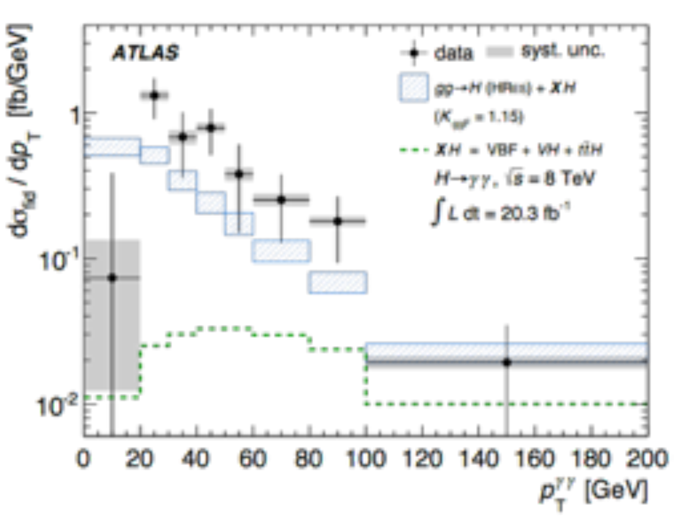
More information than single number:
Shape
Normalisation
Maximum position

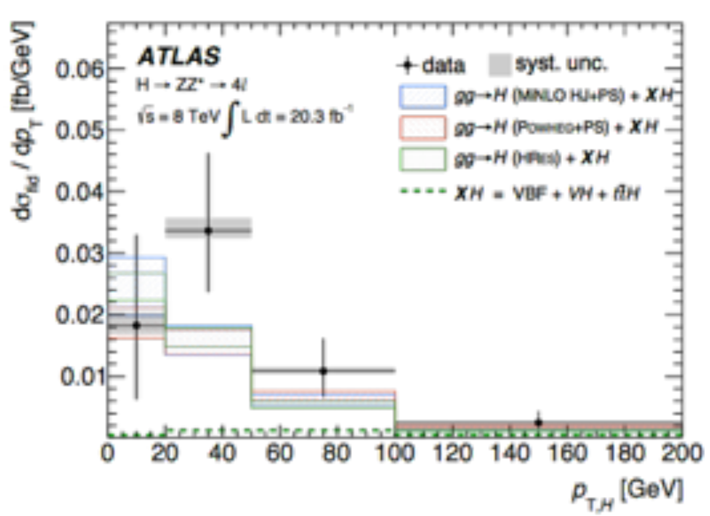
Enable to disentangle properties hidden in total rates: eg. Higgs-gluon coupling

For the scalar particle production and decay factorise

Why BSM?
Why Effective Field Theory?
Why Higgs pT spectra?

First data from ATLAS & CMS available

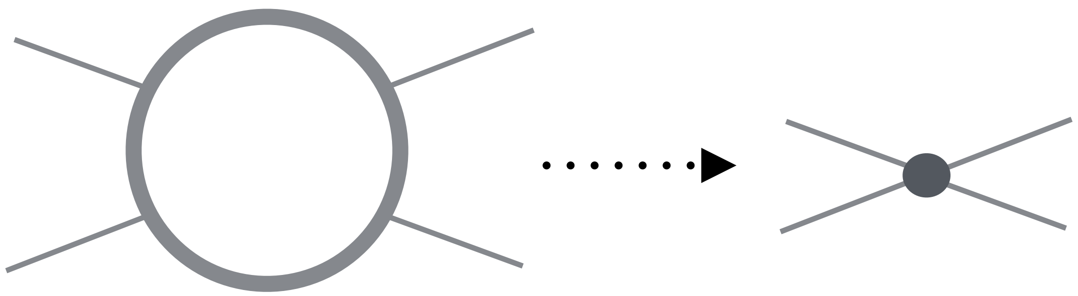




Should be significantly improved in Run 2 and HL

What is Effective Field Theory?

Top-down:



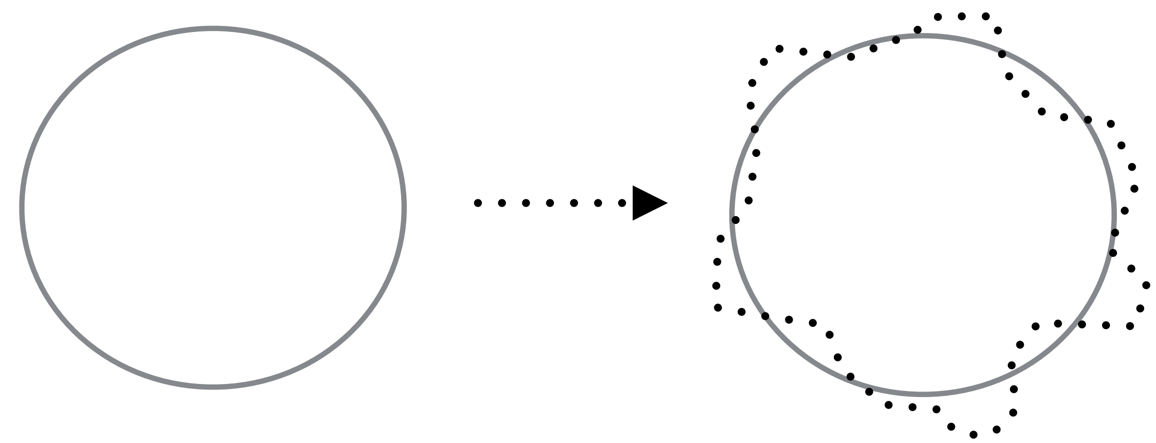
From UV complete model heavy degrees of freedom are integrated out.

$$\mathcal{L} = \mathcal{L}_{low} + \mathcal{L}_{high} + \mathcal{L}^{int}$$

As a consequence an infinite ladder of new operators build from light fields will appear.

$$\mathcal{L} = \mathcal{L}^{(4)}_{low} + \sum_{k=4}^{\infty} \sum_{i} \frac{\bar{c}_i^{(k)}}{\Lambda^{(k-4)}} \mathcal{O}_i^{(k)}$$

Bottom-up:



We take the renormalizable theory (e.g. SM).
From its fields we build the operators of higher dimensions obeying the Lorentz and gauge invariance to account for the small deviations from the theory.

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{c^{(5)}}{\Lambda}\mathcal{O}^{(5)} + \sum_{i} \frac{c_i^{(6)}}{\Lambda}\mathcal{O}_i^{(6)} + \dots$$

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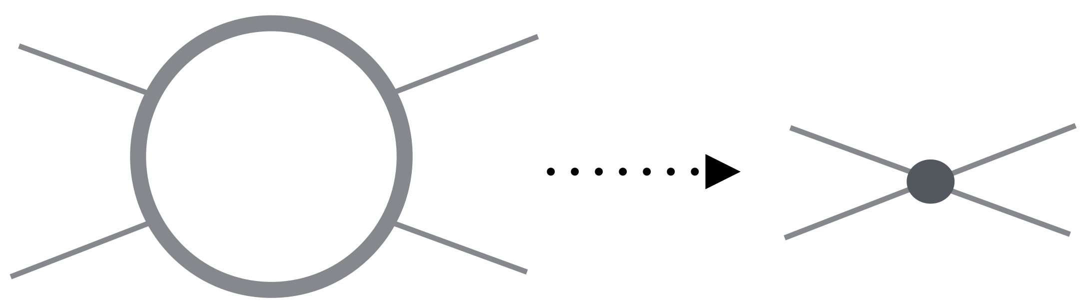

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Explicit integrating out of heavy states:

Gorbahn et al ‘15
Chiang et al ‘15
Boggia et al ‘16

Covariant Derivative Expansion:

Henning et al ’14-‘16
Drozd et al ‘15
del Aguila et al ‘16
Zhang ‘16

How analysis differs: explicit model vs eft

Drozd et al ‘15

What is Effective Field Theory?

Dimension 5, 6, 7, … operators:

Weinberg '80
Buchmuller et al '86
Grzadkowski '10
Lehman '14

Different basis of dim 6:

Contino et al '13
Falkowski et al '15

2HDMEFT:

Crivellin et al '16

Radiative corrections and renormalisation:

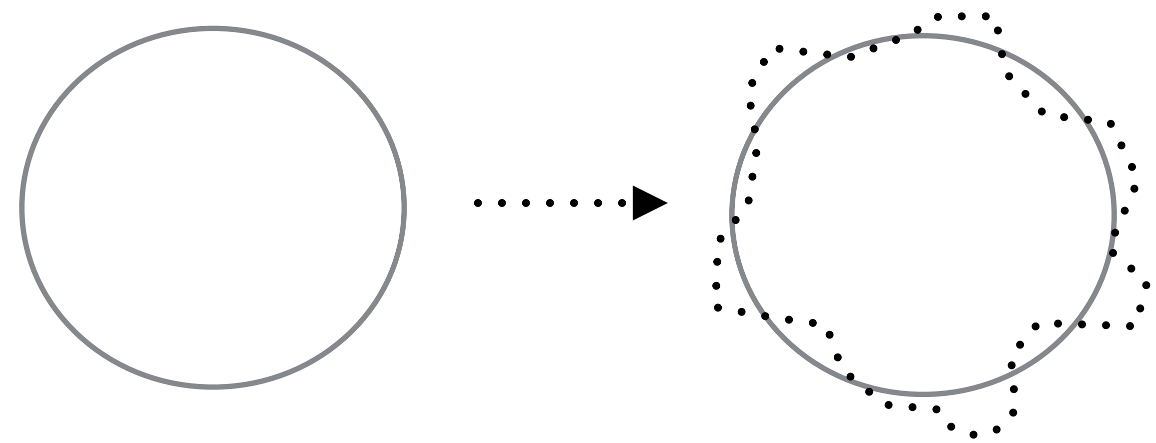
Passarino et al '12-16
Jenkins et al '13-'14

How to use it in LHC:

HXSWG Yellow Report 4: Section 2 (and 3.1)

Inclusion in the observables, Fits to the available data…

Bottom-up:



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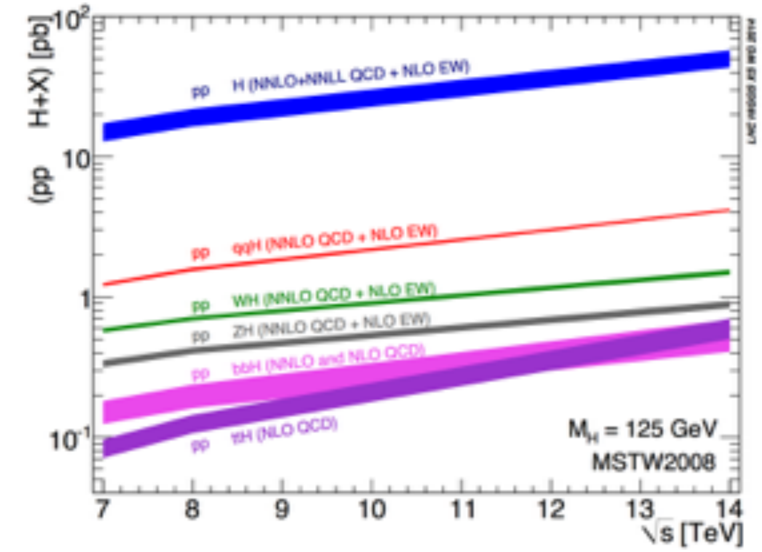
How to get Higgs boson in LHC?

Gluon fusion is the most efficient Higgs boson production channel in LHC

Due to the dominance of gluon pdf



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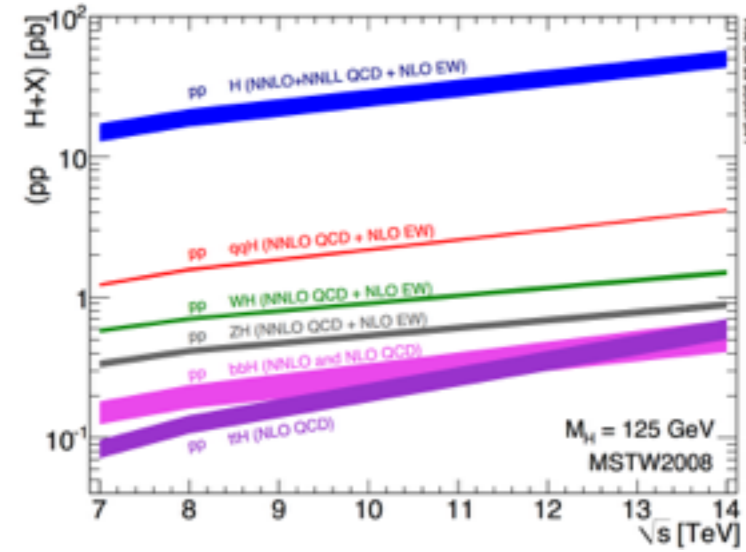

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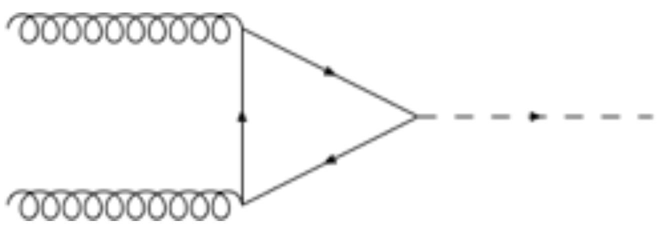

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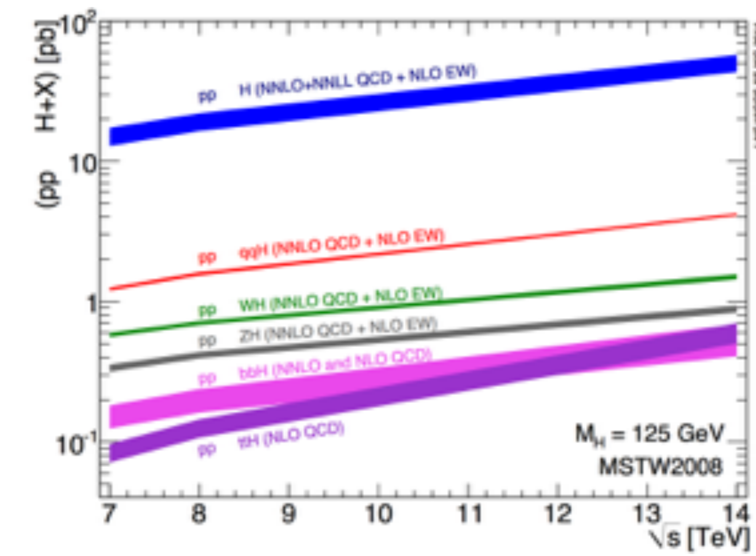

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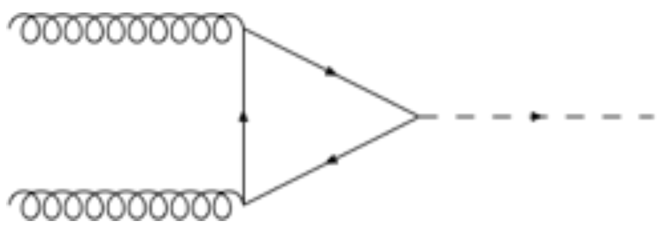

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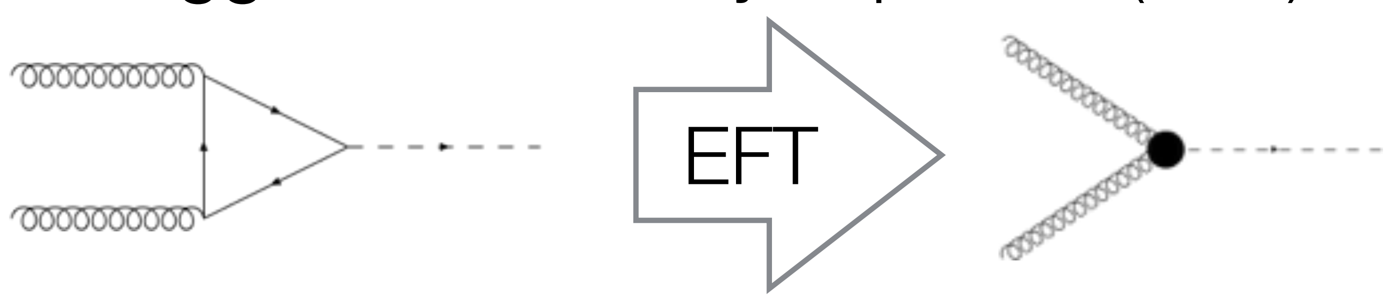
Top mass > Higgs mass: Heavy Top Limit (HTL) trick in calculations:



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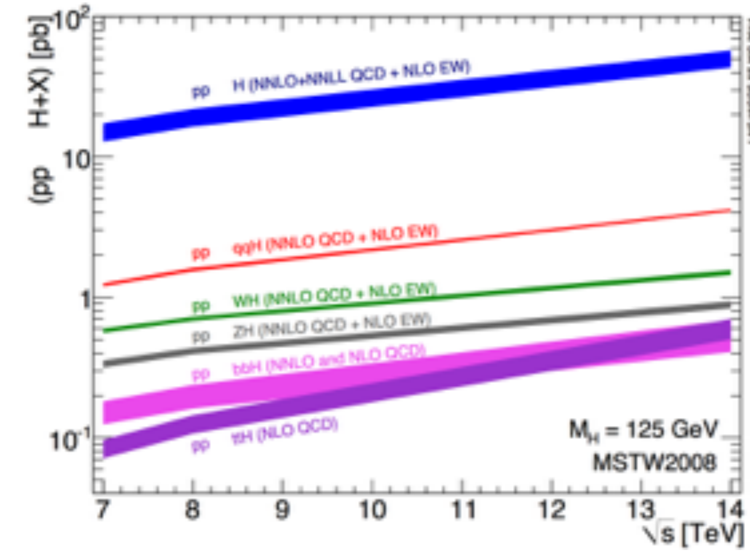

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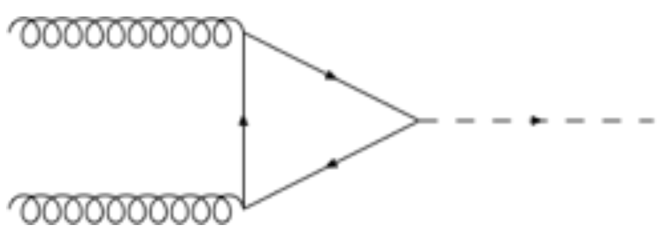

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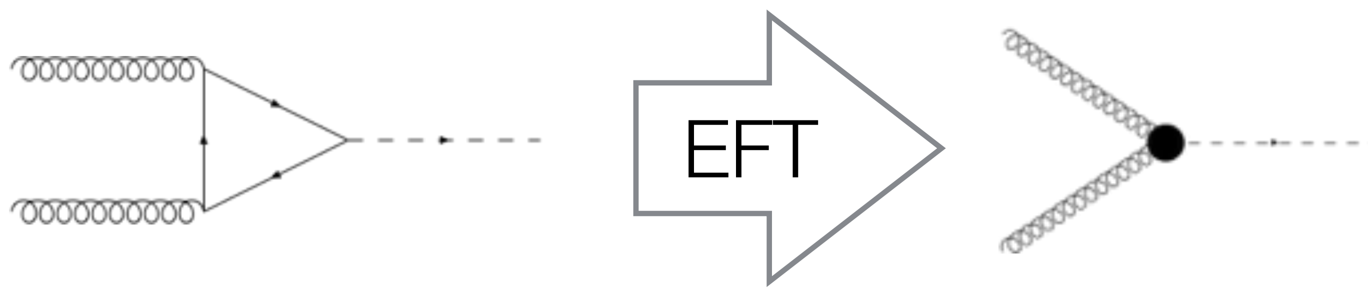

Known up to NLO QCD

Ellis, Hinchliffe et al.'88; Baur, Glover '90; Spira et al.'91, '95; Dawson '91

and NLO EW corrections

Aglietti et al.'04; Degrassi, Maltoni '04; Passarino et al '08

Known up to N3LO QCD

Anastasiou, Duhr, Mistlberger et al.'13-'15

and NNLO QCD

Harlander, Kilgore '02; Anastasiou, Melnikov '02; Ravindran, Smith, Van Neerven '03

with approximate top mass effects

Marzani et al.'08; Harlander et al.'09,'10; Steinhauser et al.'09

Why and how we care about Higgs pT?

All Higgs bosons measured in LHC have nonzero pT!

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We need additional parton to recoil Higgs

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NLO first partial results:

Bonciani '16

NNLO results:

Boughezal et al.'13; Chen et al'14

NLO known:

de Florian, Grazzini, Kunszt '99; Glosser, Schmidt '02; Ravindran, Smith, Van Neerven '02

with approximate top mass effects:

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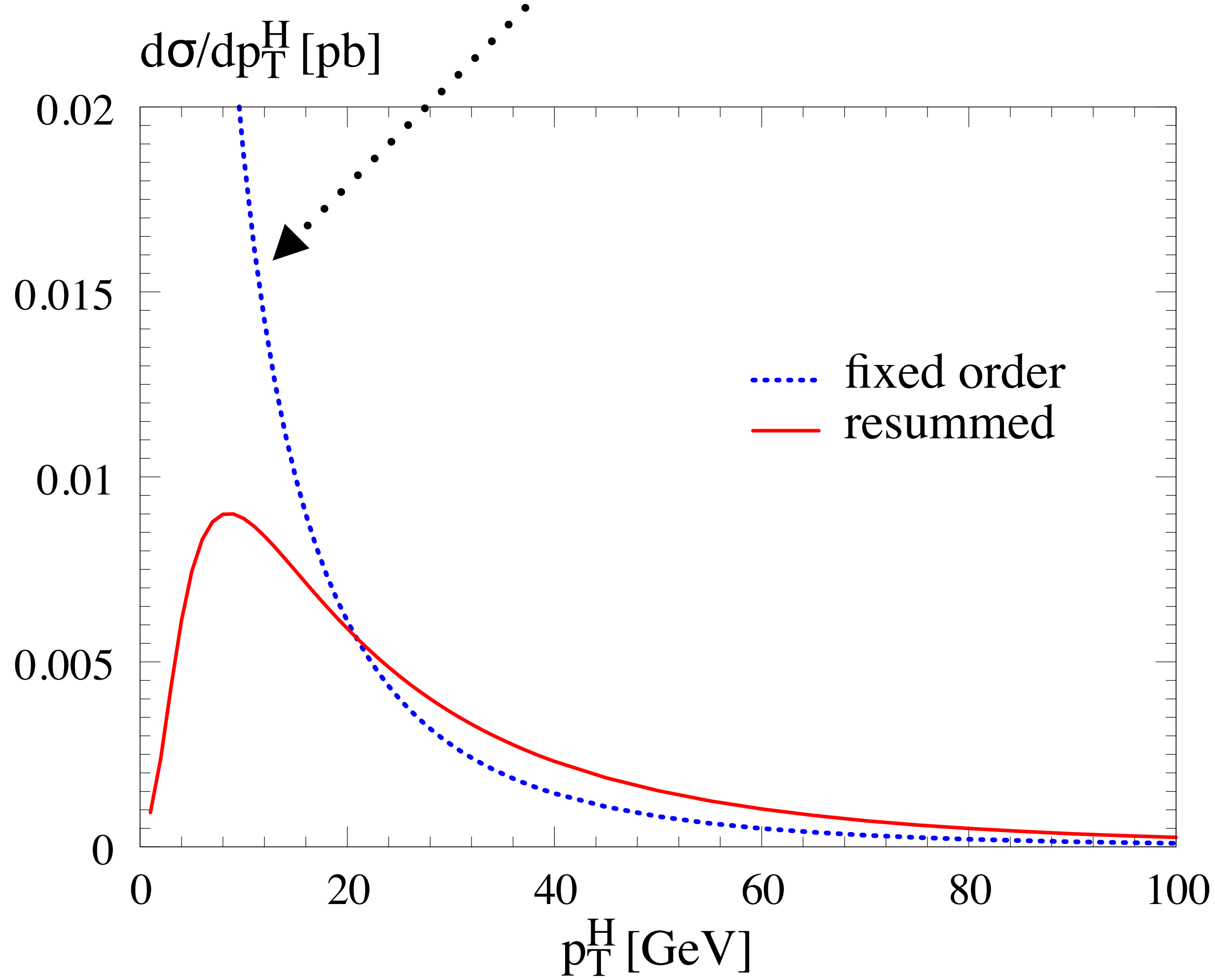
"New Physics sits in the tails of distributions"

but there is a problem at low pT…

Problems at low pT? Resummation!

Singular behaviour at pT<mH



See Hayk's talk in few minutes!

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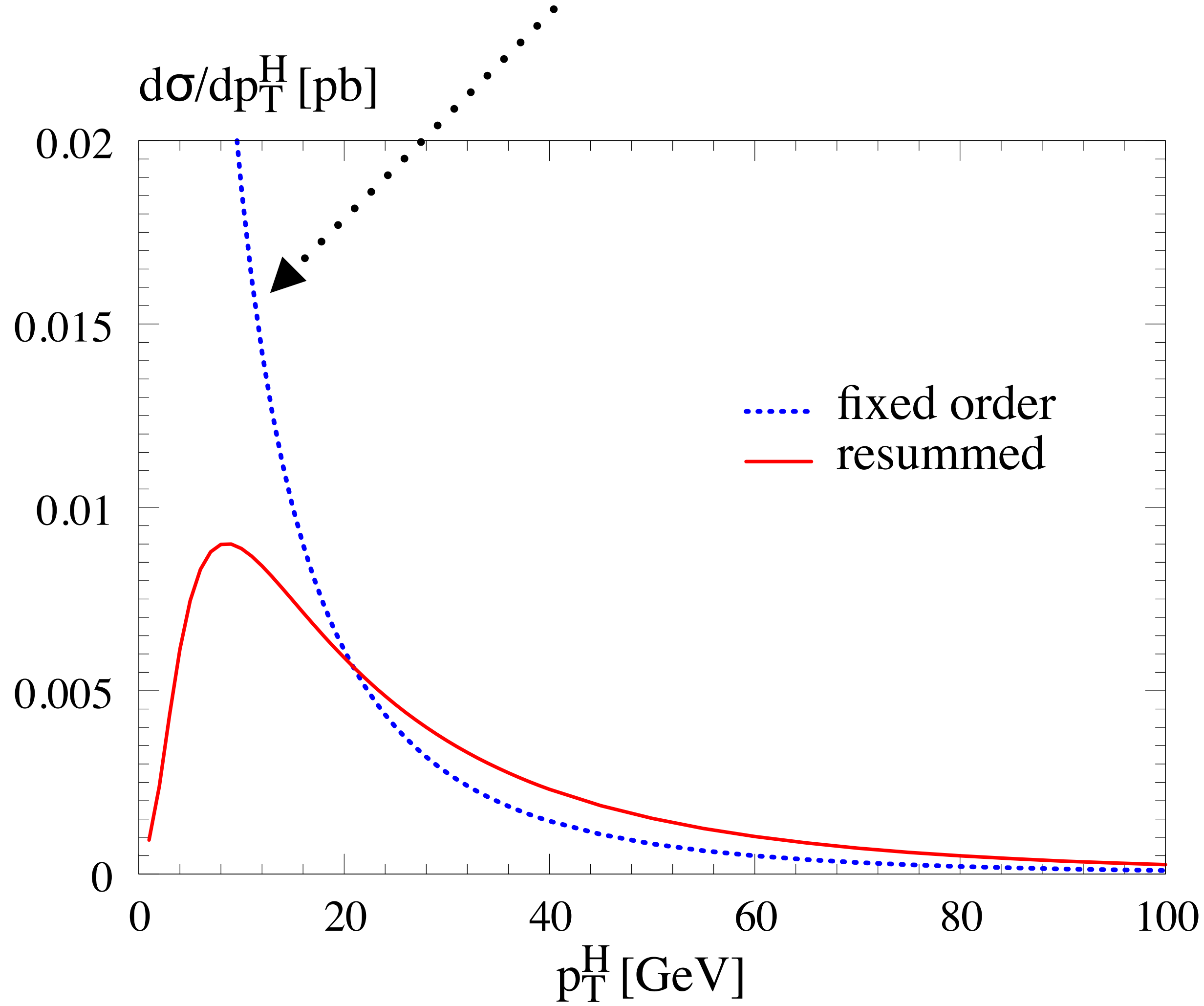

Technically, the perturbative expansion is affected by large logarithms of a form $ln^n(\frac{m_H^2}{p_T^2})$

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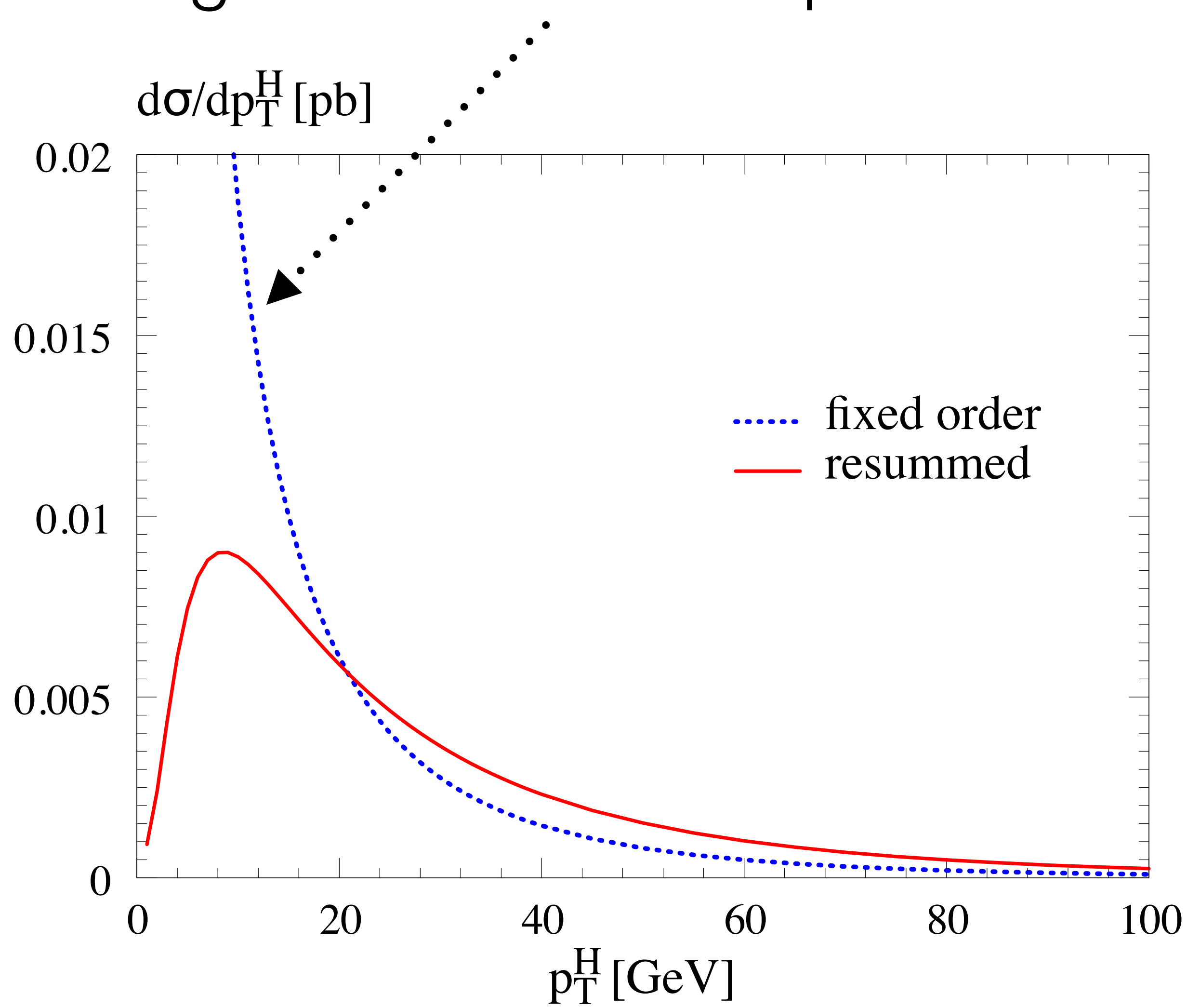

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They can be systematically resummed working in the impact parameter *b* space to all orders

Collins, Soper,Sterman '85

Then the resummed and fixed order spectra need to be properly matched at intermediate pT

Bozzi, Catani, de Florian, Grazzini '05

$$\left[\frac{d\sigma}{dp_T^2}\right]_{f.o.+a.o.} = \left[\frac{d\sigma}{dp_T^2}\right]_{f.o.} - \left[\frac{d\sigma^{(res)}}{dp_T^2}\right]_{f.o.} + \left[\frac{d\sigma^{(res)}}{dp_T^2}\right]_{.a.o.}$$

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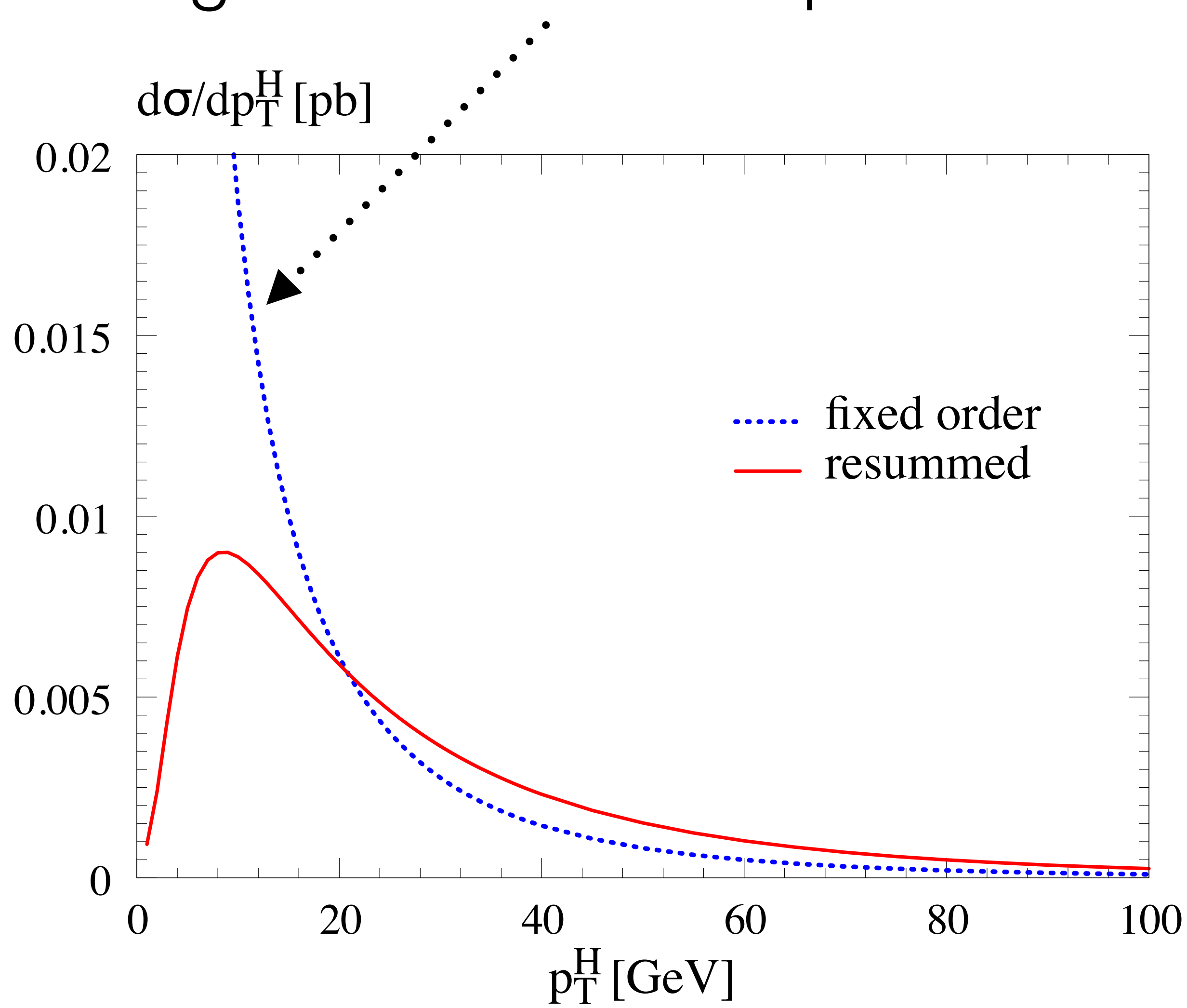

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The matched spectrum satisfies the unitarity condition:
area below graph corresponds to the total cross section

See Hayk's talk in few minutes!

Our setup for Higgs production and pT spectrum including EFT effects

Our SMEFT operators

$$\mathcal{O}_1 = |H|^2 G^a_{\mu\nu} G^{a,\mu\nu}$$
$$\mathcal{O}_2 = |H|^2 \bar{Q}_L H^c u_R + h.c.$$
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$$\frac{\alpha_S}{\pi v} c_g h G^a_{\mu\nu} G^{a,\mu\nu}$$ ← as HTL in SM

$$\frac{m_t}{v} c_t h \bar{t} t$$
$$\frac{m_b}{v} c_b h \bar{b} b$$
← modified top/bottom Yukawa coupling

$$c_{tg} \frac{g_S m_t}{2 v^3} (v+h) G^a_{\mu\nu} (\bar{t}_L \sigma^{\mu\nu} T^a t_R + h.c)$$

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c_b: can be bounded from the h->bb decay (and *bbh* production)

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c_{tg} → can be bounded from the *tt* production

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c_g: Easiest to bound from the Higgs pT spectrum

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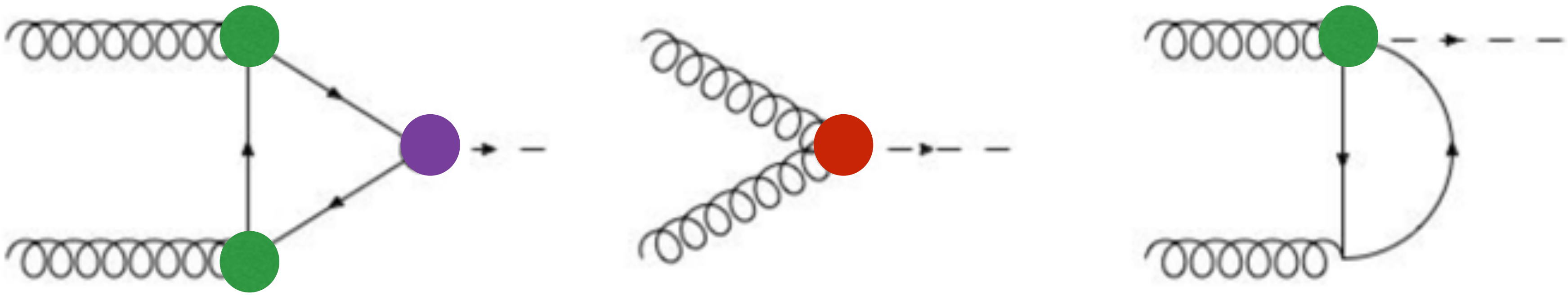
Previous studies including dimension 6 and dimension 8 operators

Grojean, Salvioni et al.'13;
Azatov, Paul '13,
Langenegger, Spira et al.'15
Maltoni, Vryonidou, Zhang '16

Harlander, Neumann'13,
Dawson, Lewis, Zeng'14

- (mostly) did not include chromomagnetic operator
- (mostly) only valid for high pT - no resummation included

Higgs production at LO



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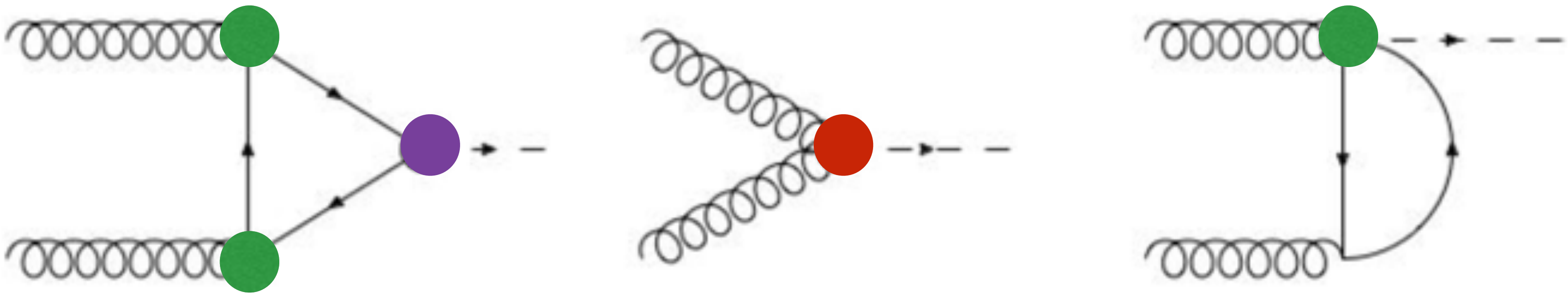

$$\mathcal{M}\left(g(p_1)+g(p_2)\to H\right)=i\frac{\alpha_S}{3\pi v}\epsilon_{1\mu}\epsilon_{2\nu}\left[p_1^\nu p_2^\mu-(p_1p_2)g^{\mu\nu}\right]F(\tau)$$

$$F(\tau)=c_t F_1(\tau)+c_g(\mu_R)F_2(\tau)+Re(c_{tg})\frac{m_t^2}{v^2}F_3(\tau)$$

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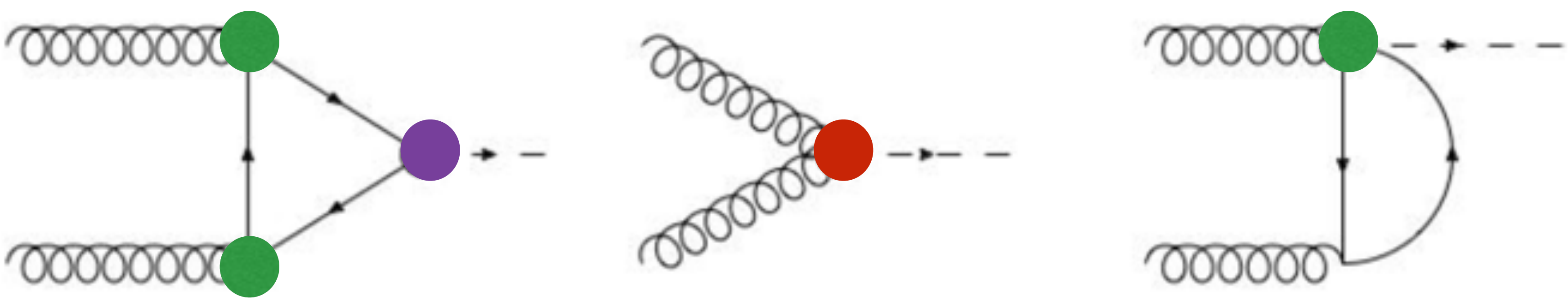

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$$F_1(\tau) = \frac{3}{2}\tau\left[1+(1-\tau)f(\tau)\right],$$

$$F_2(\tau) = 12,$$

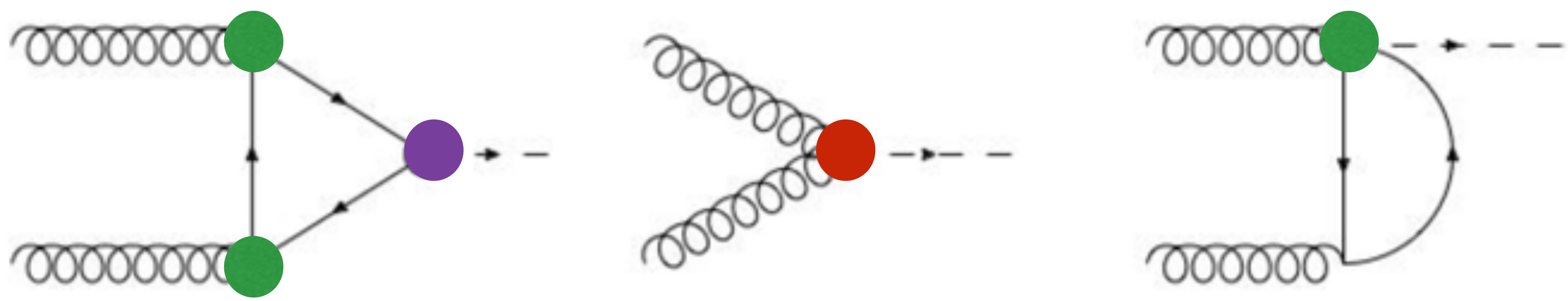
$$F_3(\tau) = 3\left(1-\tau f(\tau)-2g(\tau)+2\ln\frac{\mu_R^2}{m_t^2}\right)$$

$$g(\tau) = \begin{cases} \sqrt{\tau-1}\arcsin\frac{1}{\sqrt{\tau}} & \tau\geq 1 \\ \sqrt{1-\tau}\left[\ln\frac{1+\sqrt{1-\tau}}{1-\sqrt{1-\tau}}-i\pi\right] & \tau<1 \end{cases}$$

$$f(\tau) = \begin{cases} \arcsin^2\frac{1}{\sqrt{\tau}} & \tau\geq 1 \\ -\frac{1}{4}\left[\ln\frac{1+\sqrt{1-\tau}}{1-\sqrt{1-\tau}}-i\pi\right]^2 & \tau<1 \end{cases}$$

HTL: $F_1(\tau)\to 1,\qquad F_2(\tau)\to 12,\qquad F_3(\tau)\to 6\left(\ln\frac{\mu_R^2}{m_t^2}-1\right)$

Higgs production at LO



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Calculations published with contradictory results
Choudhury et al ’12
Degrande et al ’12

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Formally higher order of yt

$$g(\tau) = \begin{cases} \sqrt{\tau-1}\arcsin\frac{1}{\sqrt{\tau}} & \tau\geq 1 \\ \sqrt{1-\tau}\left[\ln\frac{1+\sqrt{1-\tau}}{1-\sqrt{1-\tau}}-i\pi\right] & \tau<1 \end{cases}$$

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HTL: $F_1(\tau)\to 1,\quad F_2(\tau)\to 12,\quad F_3(\tau)\to 6\left(\ln\frac{\mu_R^2}{m_t^2}-1\right)$

Higgs transverse momentum spectrum

Based on the *HqT* programme, cross-checked for f.o. part with *HNNLO* and *HIGLU* programmes

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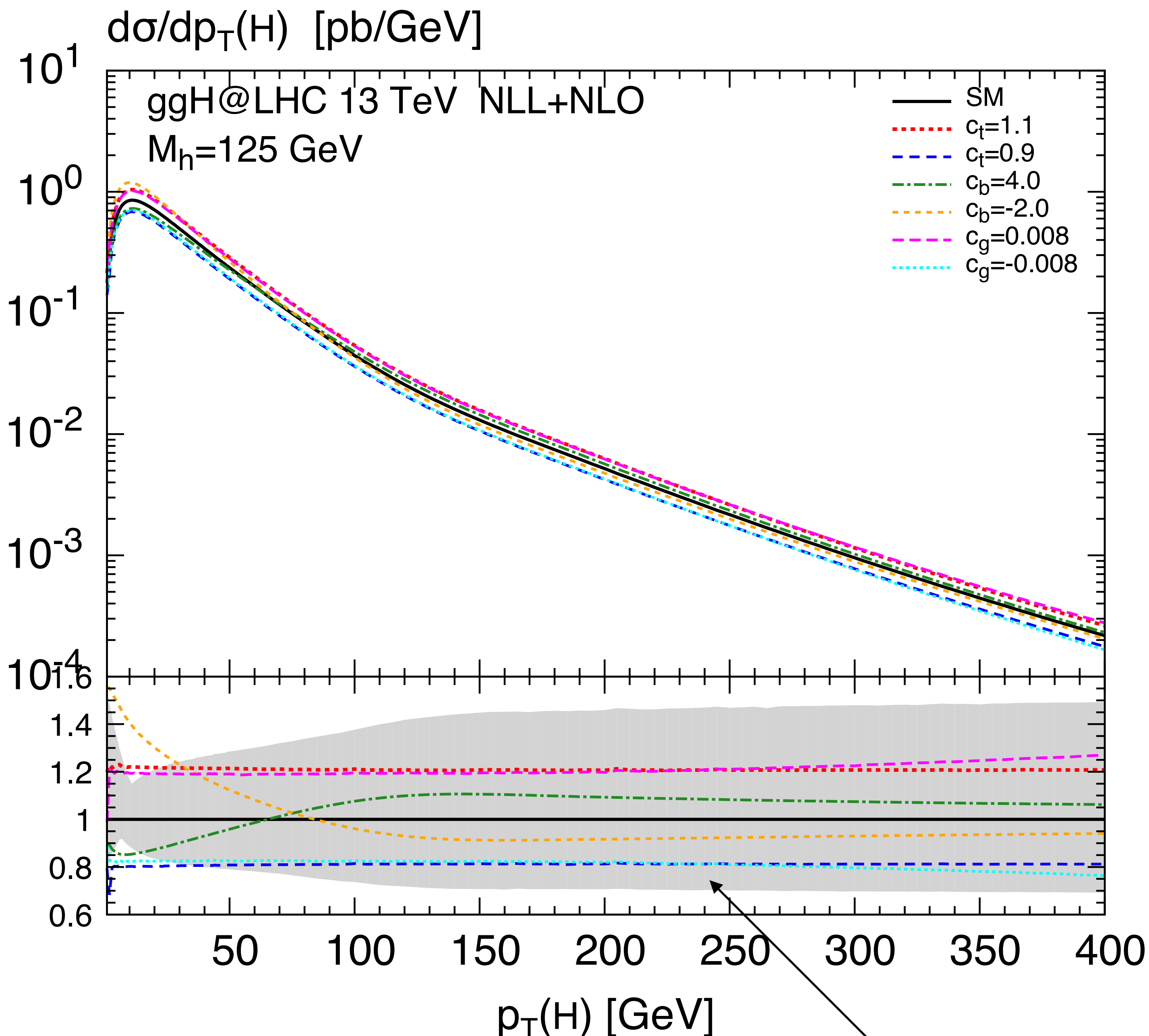
Renormalisation and factorisation scales: $\mu_R = \mu_F = \mu_0 = \sqrt{p_T^2 + m_H^2}/2$

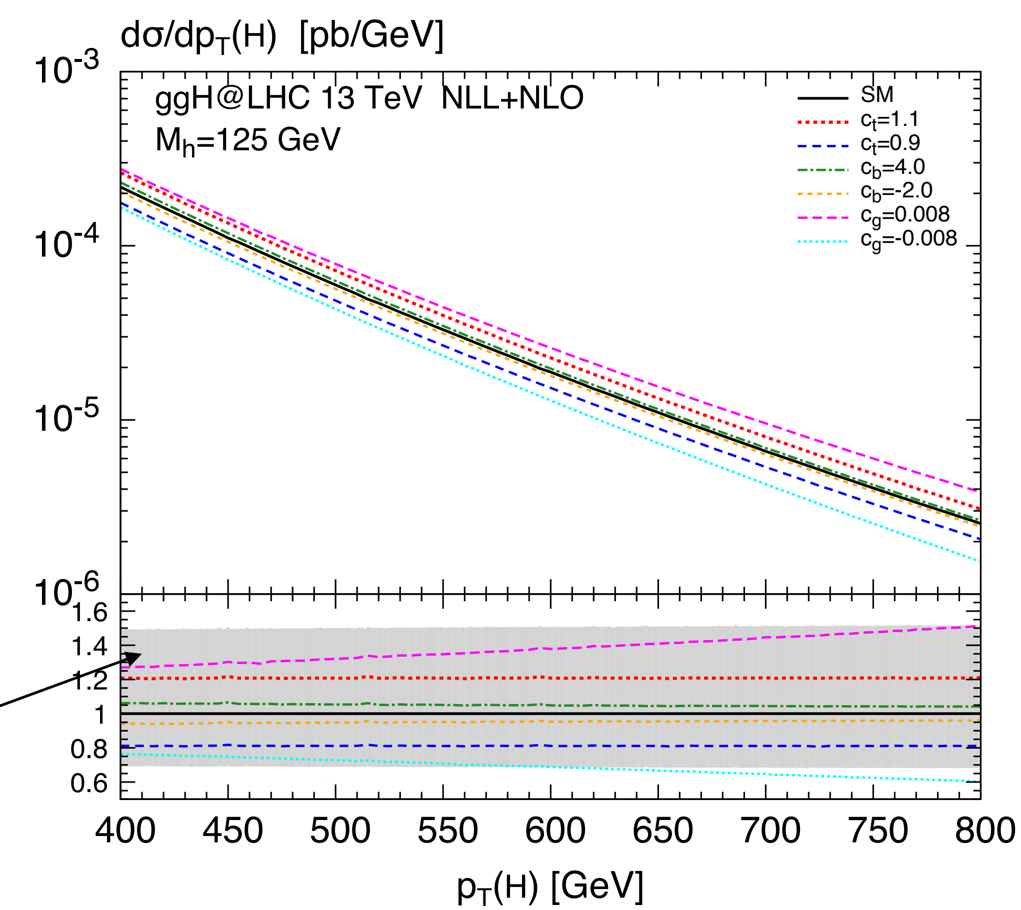
Three scales of resummation: $Q_t = m_H/2 \quad Q_b = 4\,m_b \quad Q_{\text{int}} = \sqrt{Q_t\,Q_b}$

Parton distribution functions: NLO set from PDF4LHC2015

Separate contributions of dim 6 operators

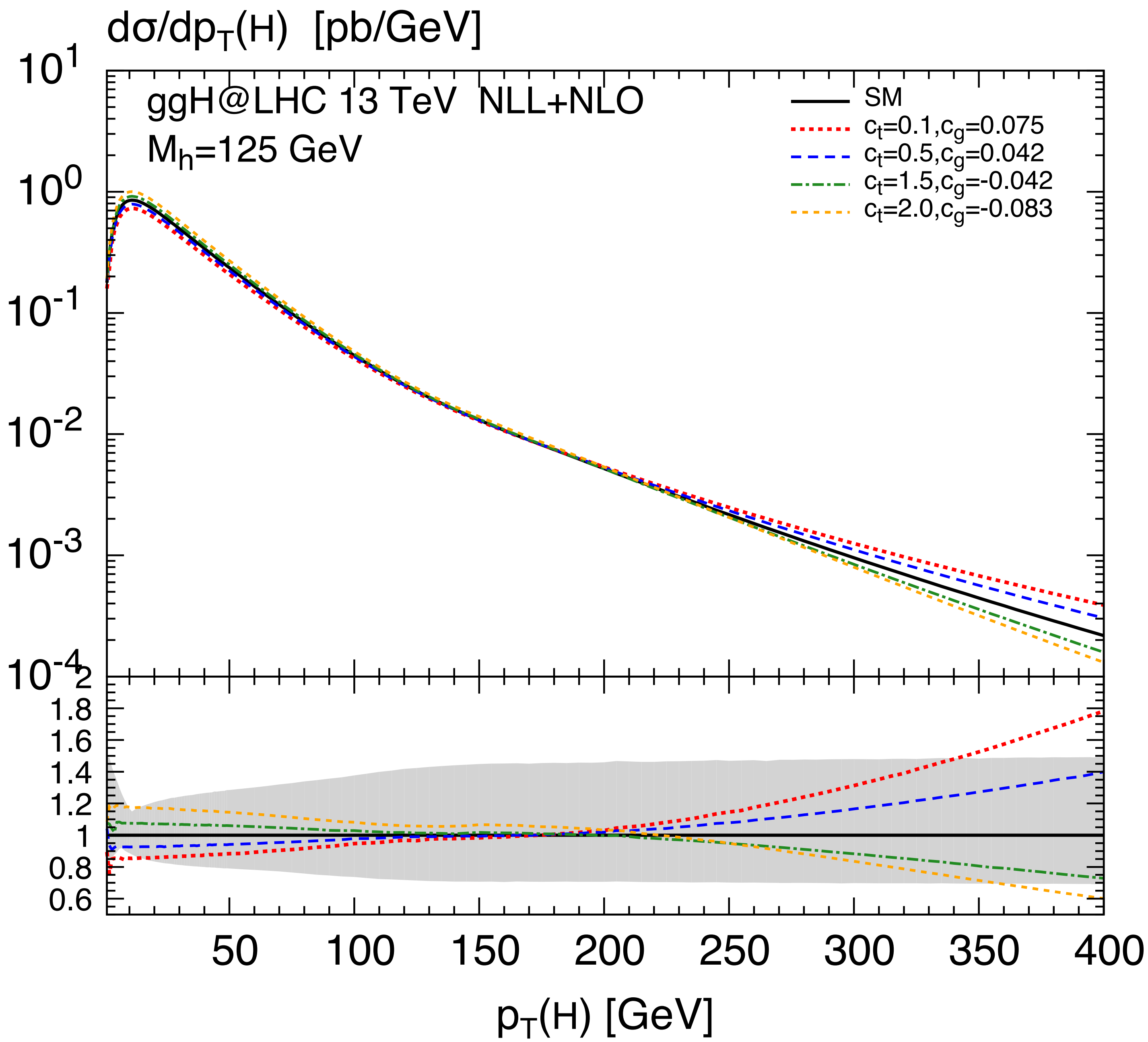


- Kept within 20% from SM total cross section
- Not exceeding (much) the SM uncertainty
- Effects in different regions of the spectrum



SM scale variation

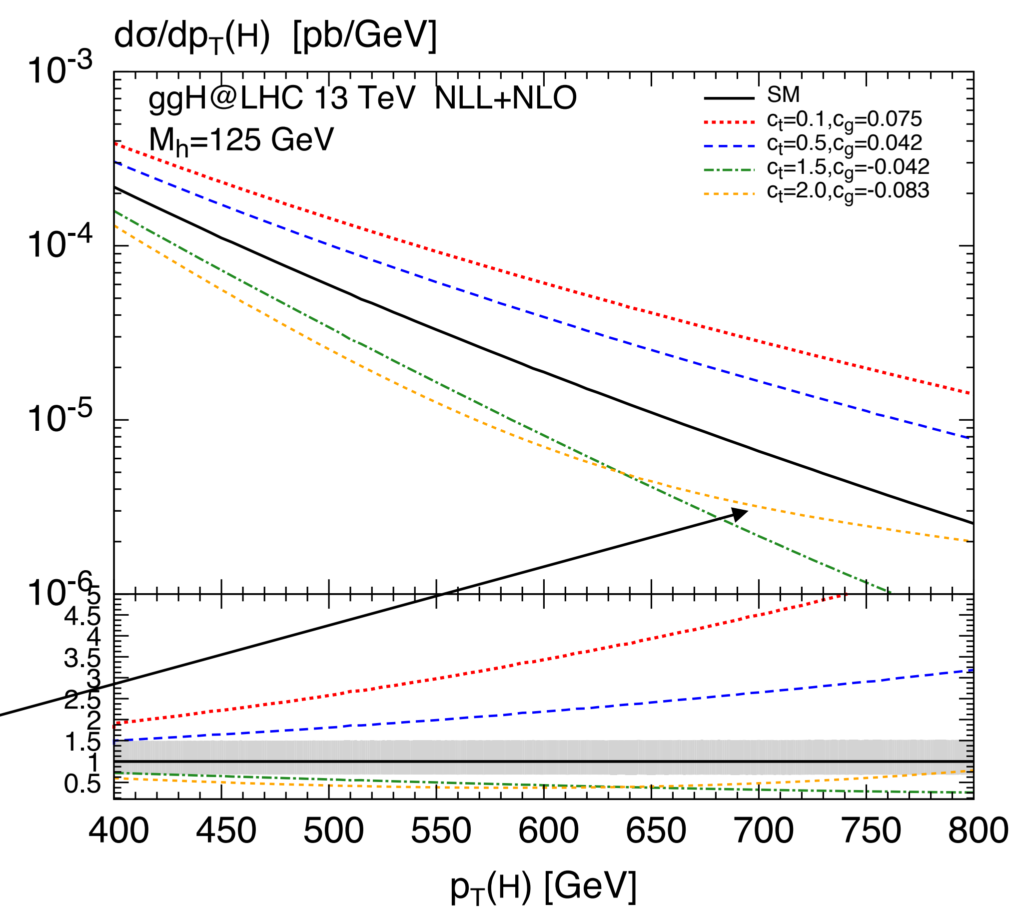
Mixed contributions of ct and cg



- More dramatic shape effects with same total rate

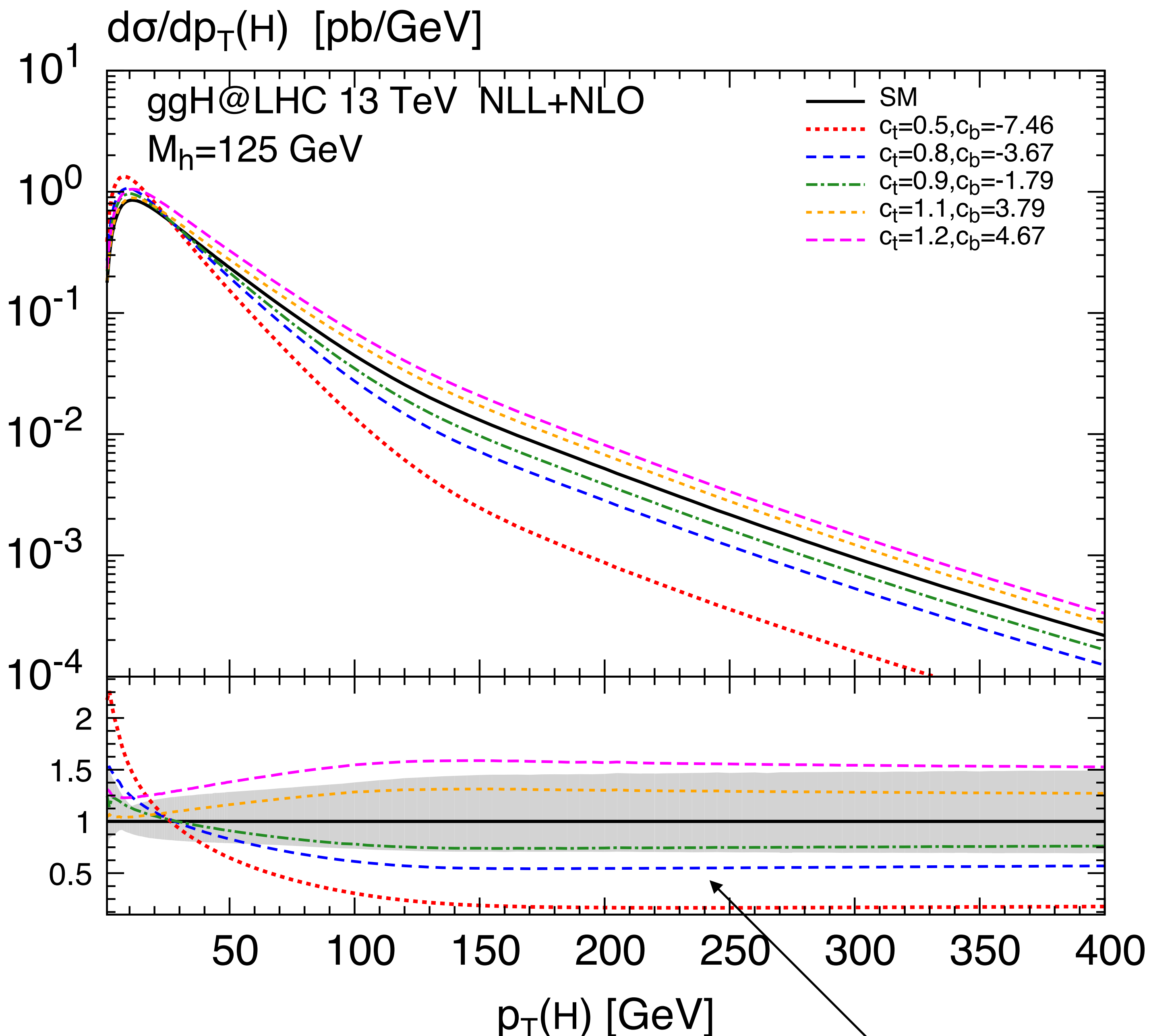
$$\sigma \approx |12c_g + c_t|^2 \sigma_{SM}$$

- At high pT clearly visible effect of point-like coupling

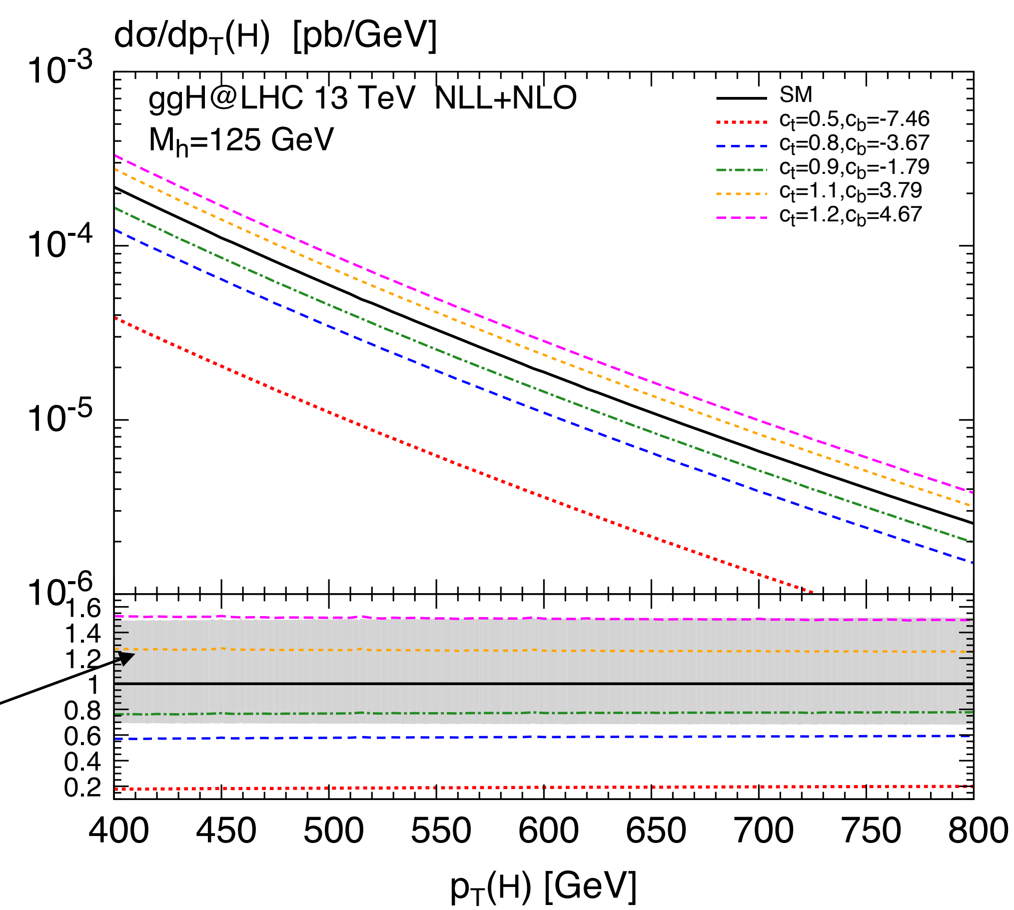


effect caused by dominance of cg2

Mixed contributions of ct and cb

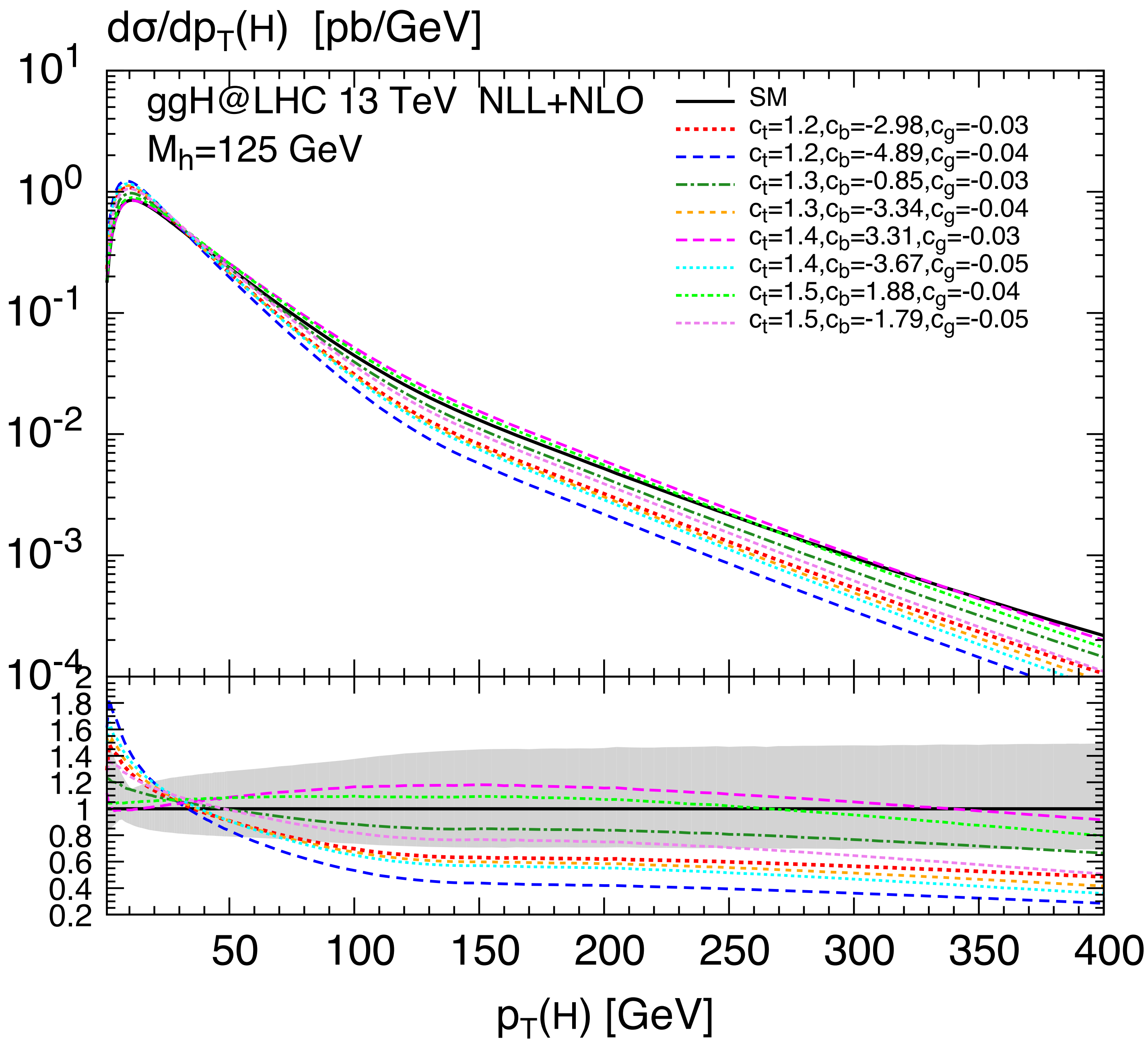


- For ct >1 hard to balance with real cb
- At low pT clearly visible effect of modification of bottom Yukawa
- For pT>150 GeV governed by the ct modification

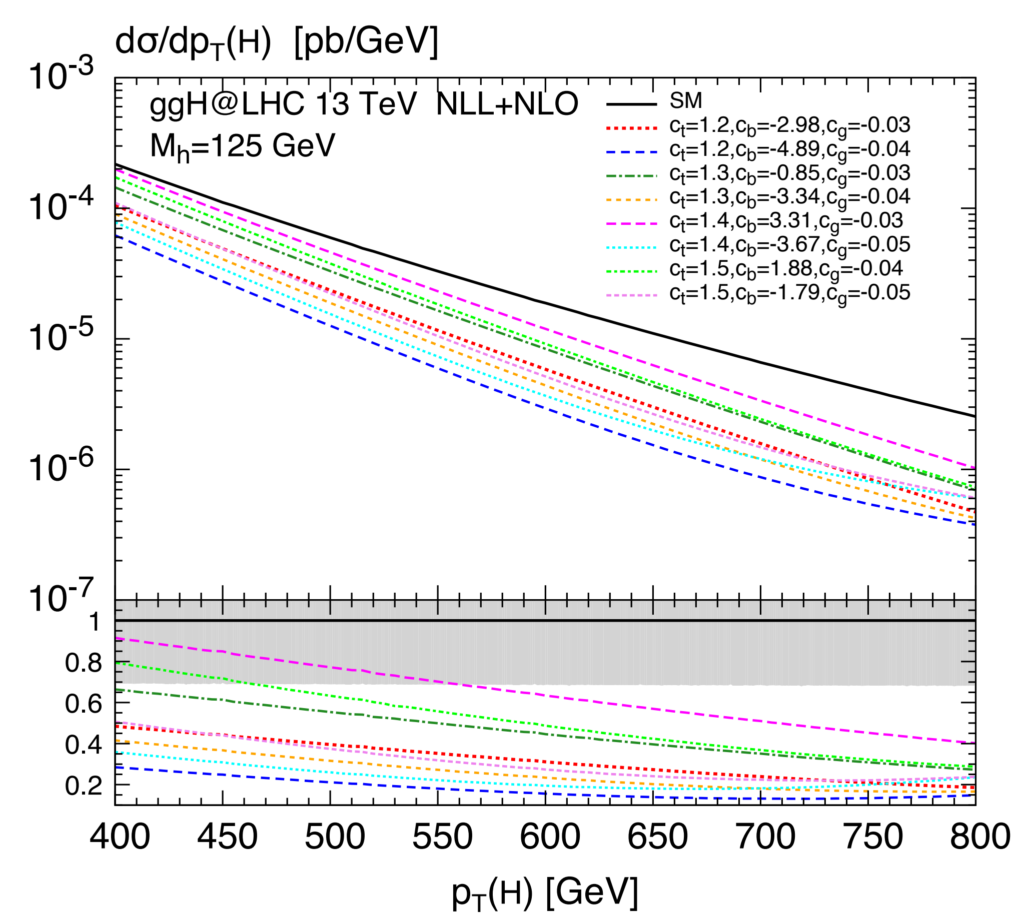


No shape distortion compared to SM
top loop dominance

Mixed contributions of all three operators



- Scenario with top Yukawa enhanced, inspired by the higher than SM rate of ttH in first CMS and ATLAS results
- Leads to the softer spectrum
- Combination of all previous effects



Outlook

Combine our results with state-of-art SM: NNLL+NNLO (in HTL)

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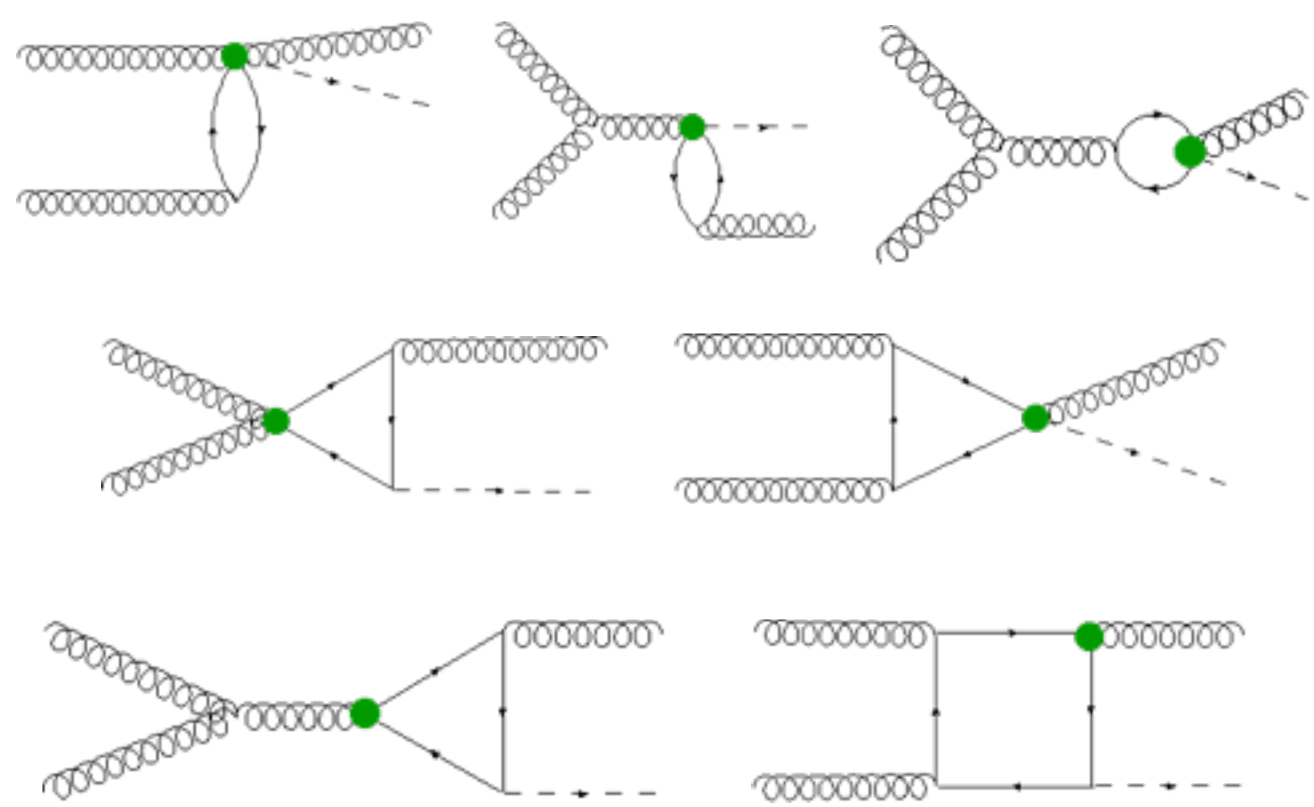
Calculate the NLO with the chromomagnetic operator to include also in the transverse momentum spectrum

- 39 diagrams a priori for gggh case
- different tensor structure of operator than the SM
- work in progress…



Summary

Bottom-up Effective Field Theory for Standard Model (SMEFT) is a model independent framework to study high scale BSM physics and also to store LHC precision measurements

Measurement of Higgs transverse momentum spectrum would be useful in determining its properties

We studied the impact of set of relevant SMEFT operators on the Higgs production and its pT spectrum

The effect of different operators is manifested in different regions of spectrum: cg at high and cb at low pT

Calculations are available on NLL+NLO level, i.e. allowing access to low pT region

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Thank you for the attention!