Universität Zürich[UZH]

Higgs (and top) physics from the theory perspective

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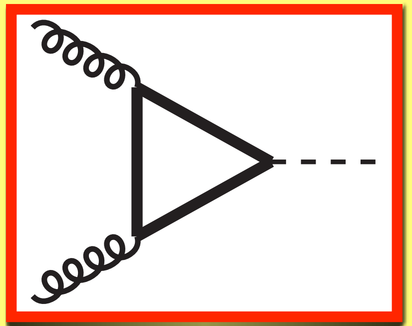
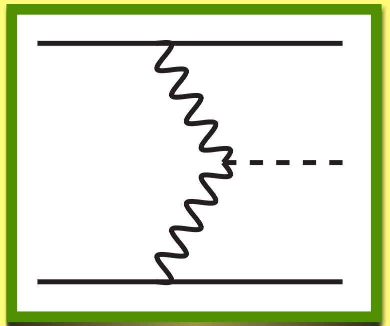
Matter To The Deepest, Ustroń (Poland)

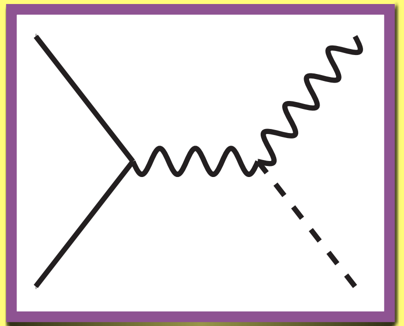
13-18 September, 2015

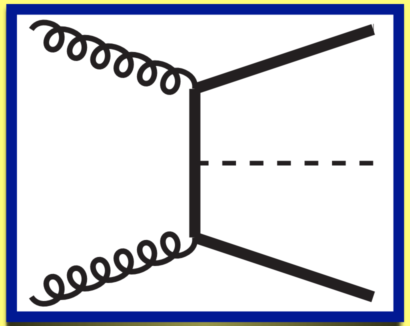
Outline

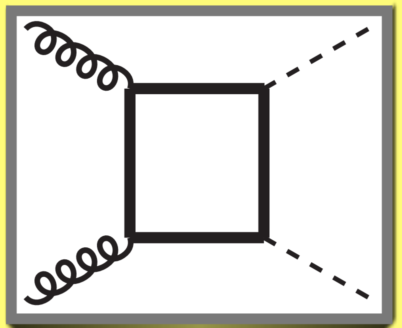
1. Higgs production and decay at the LHC
2. Backgrounds
3. Top physics
4. Inclusive cross section (ggF)
5. Distributions (ggF)
6. State-of-the-art Monte Carlo predictions
7. Other production modes (VBF, VH, ttH, bbH)

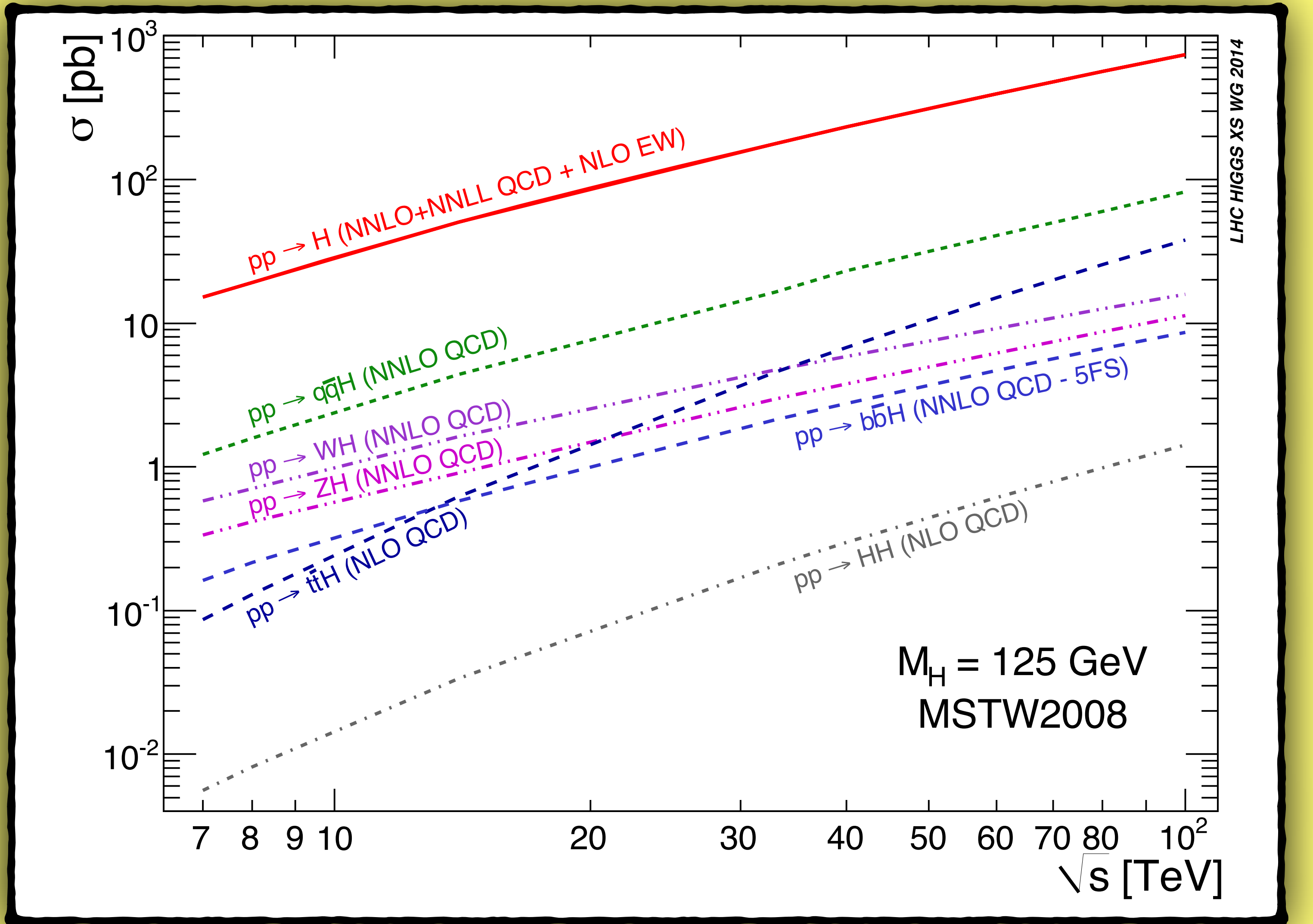




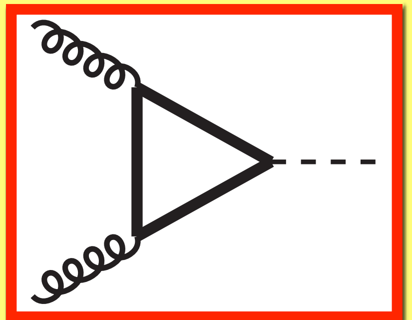


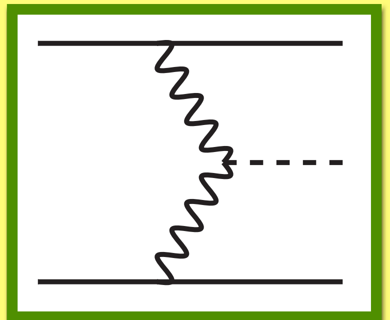


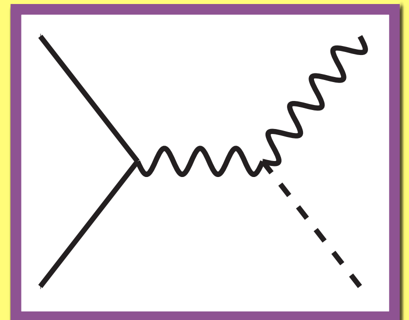


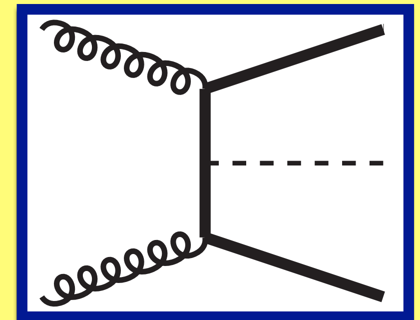


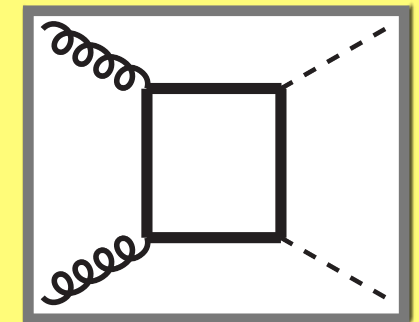
σ [pb]
pp → H (NNLO+NNLL QCD + NLO EW)
pp → qqH (NNLO QCD)
pp → WH (NNLO QCD)
pp → ZH (NNLO QCD)
pp → bbH (NNLO QCD - 5FS)
pp → ttH (NLO QCD)
pp → HH (NLO QCD)
LHC HIGGS XS WG 2014
M_H = 125 GeV
MSTW2008
√s [TeV]

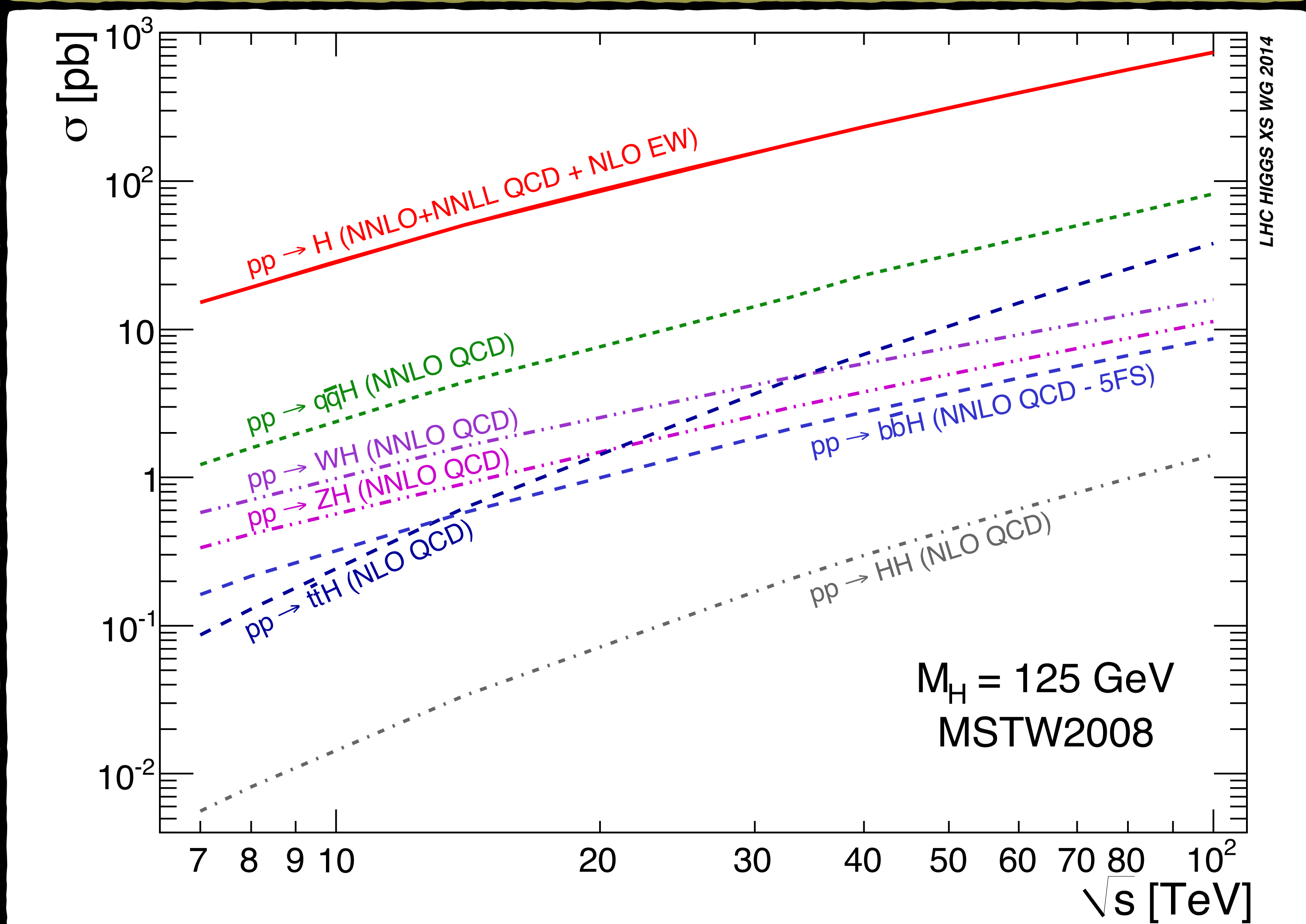












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LHC HIGGS XS WG 2014
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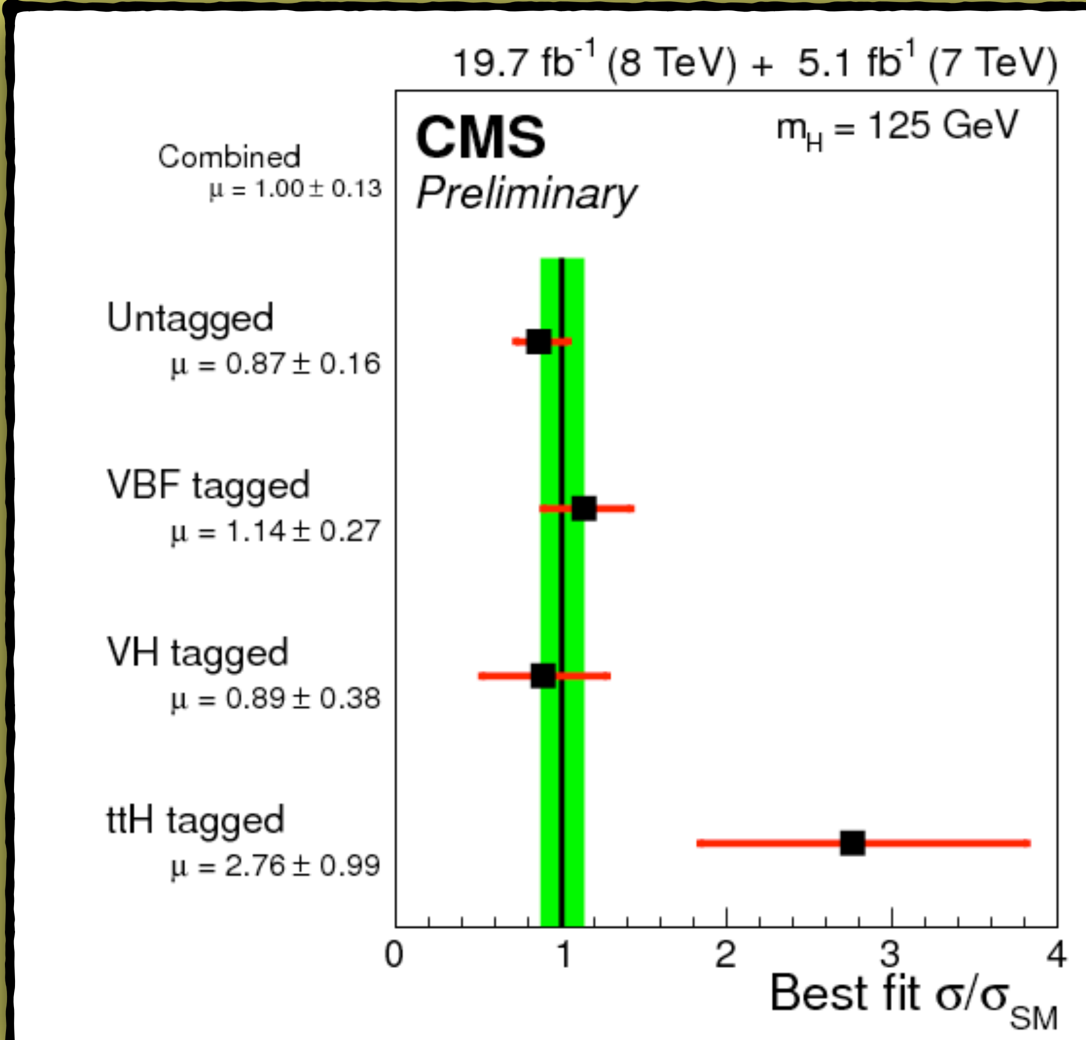

19.7 fb-1 (8 TeV) + 5.1 fb-1 (7 TeV)
CMS
Preliminary
m_H = 125 GeV
Combined
μ = 1.00 ± 0.13
Untagged
μ = 0.87 ± 0.16
VBF tagged
μ = 1.14 ± 0.27
VH tagged
μ = 0.89 ± 0.38
ttH tagged
μ = 2.76 ± 0.99
Best fit σ/σ_SM

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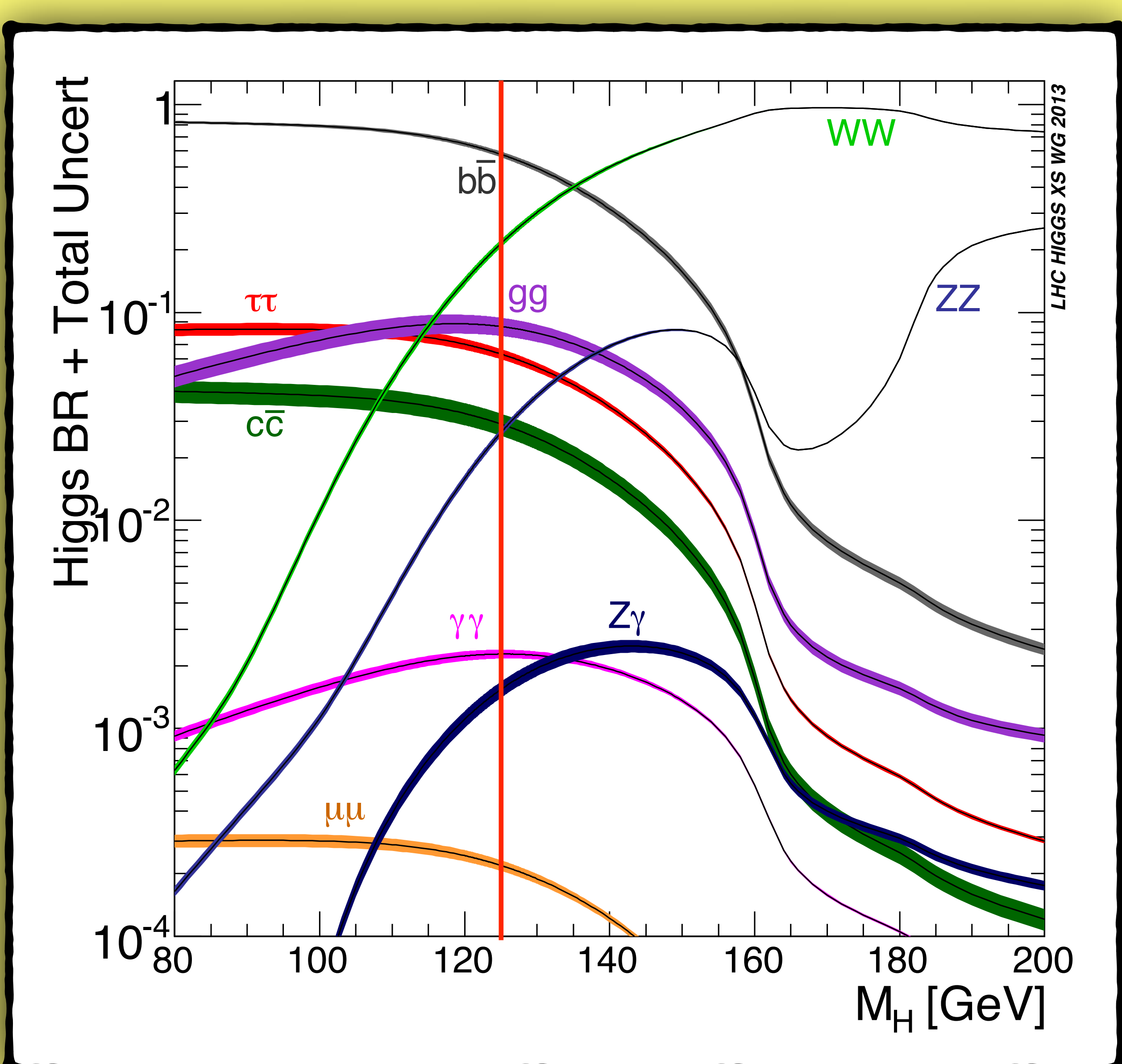
See talk by Z. Troscanyi...



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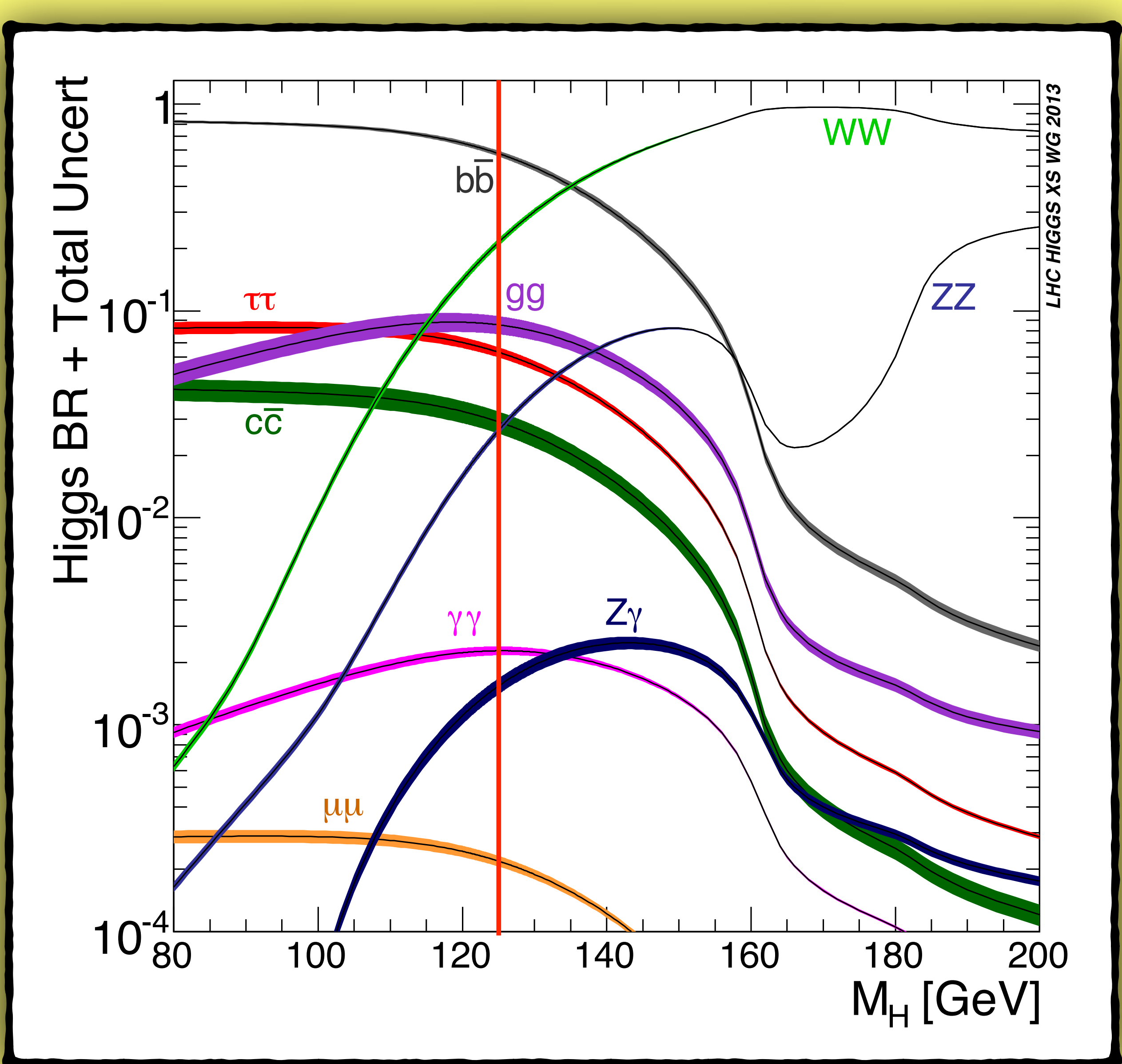
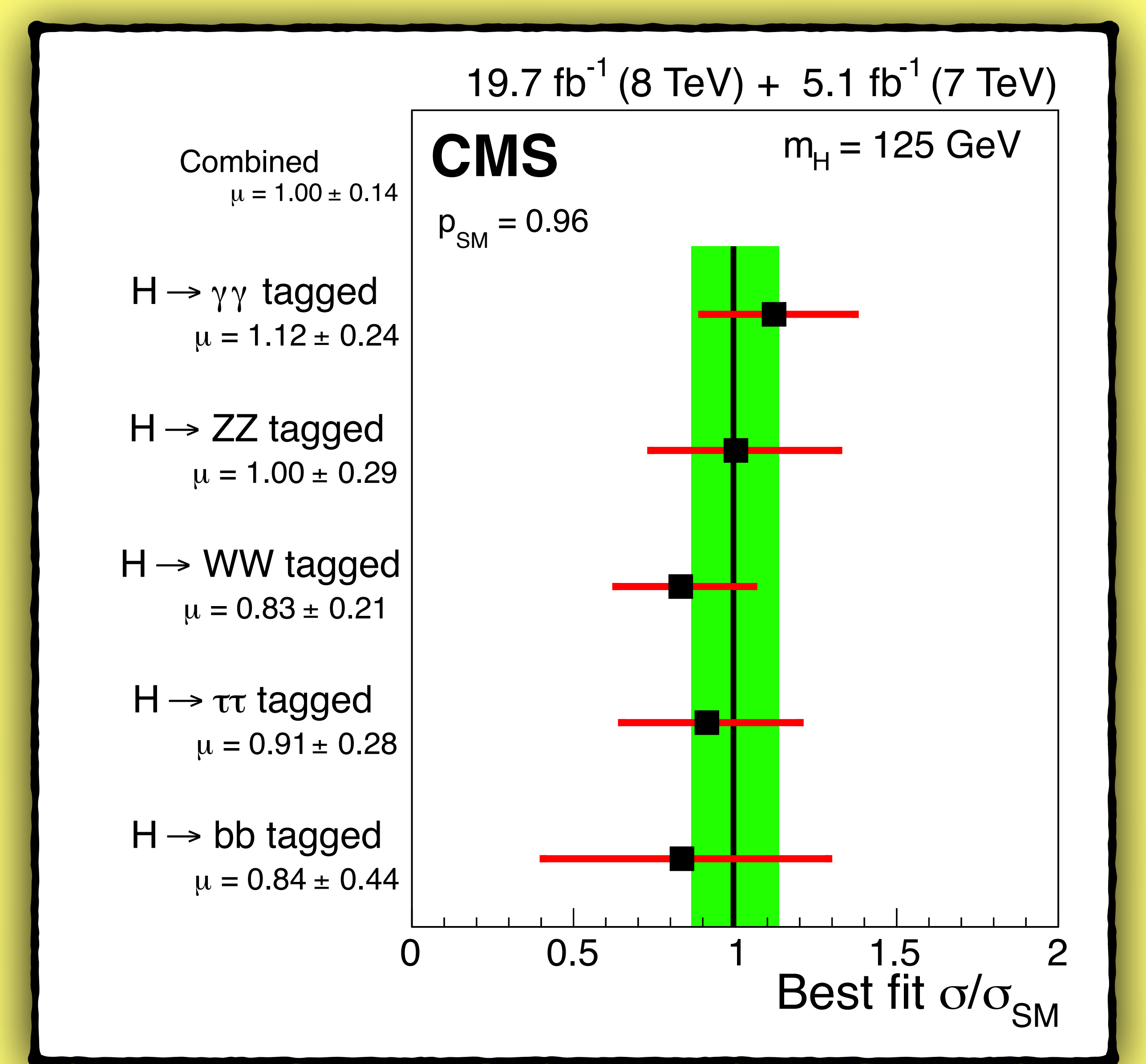




Backgounds (only slide)

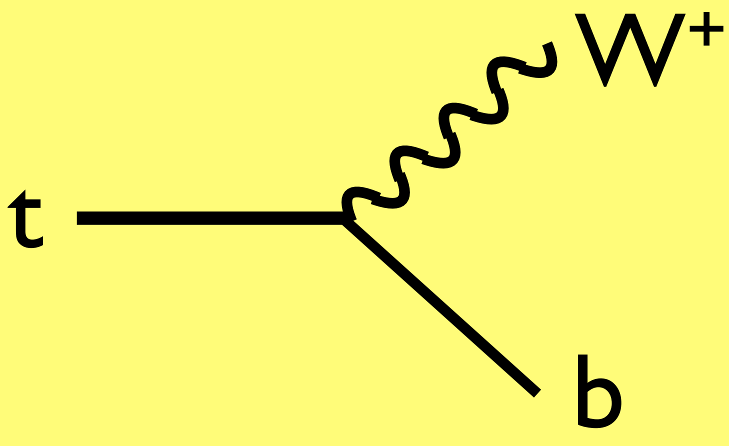
- Automatic NLO tools:
  - MG5_aMC@NLO [Alwall et al. '14]
  - Sherpa [Krauss et al.]
  - POWHEG-BOX [Alioli et al. '10]
  - HELAC-NLO [Czakon et al.]
- NNLO revolution for 2→2 processes:
  - $\gamma\gamma$ [Catani, Cieri, de Florian, Ferrera, Grazzini '11]
  - W/Zγ [Grazzini, Kallweit, Rathlev, Torre '13], [Grazzini, Kallweit, Rathlev '15]
  - ZZ [Cascioli et al. '14], [Grazzini, Kallweit, Rathlev '15]
  - WW [Gehrmann et al. '14]
  - $t\bar{t}$ [Bernreuther, Czakon, Mitov '12], [Czakon, Mitov '13], [Czakon, Fiedler, Mitov '13]
- NEW: NNLO+NNLL p_T resummation:
  - $\gamma\gamma$ [Cieri, Coradeschi, de Florian '15]
  - ZZ/WW [Grazzini, Kallweit, Rathlev, MW '15]

Top-physics from the theory perspective

Top-physics from a Higgs physicist perspective

Top-physics from a Higgs physicist perspective

- top-quark decay (almost to 100%)



- top very unstable (decays before it can form hadrons)

→ Import background from top-pair and Wt production to Higgs physics:

- obvious: ttH
- also: H → WW

ttbar and Wt at NLO

OpenLoops+Sherpa

F.Cascioli, S.Kallweit,
S.Pozzorini,P.Maierhofer (2013);
see also R.Frederix (2013)

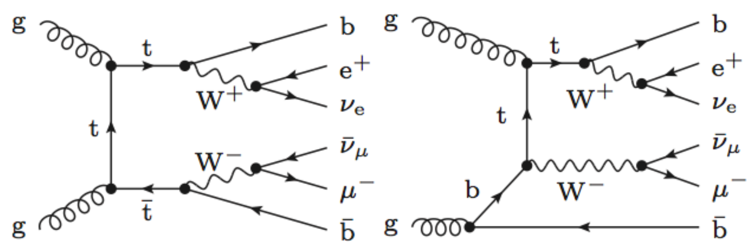


Fig. 1 Representative $t\bar{t}$-like (left) and Wt-like (right) tree diagrams.

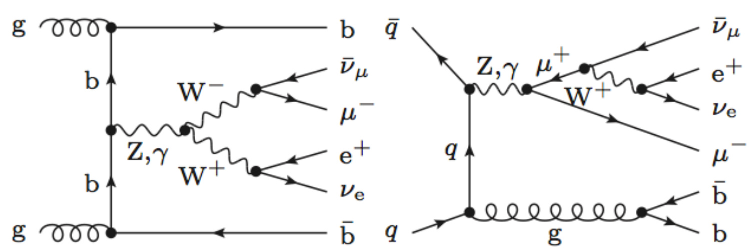
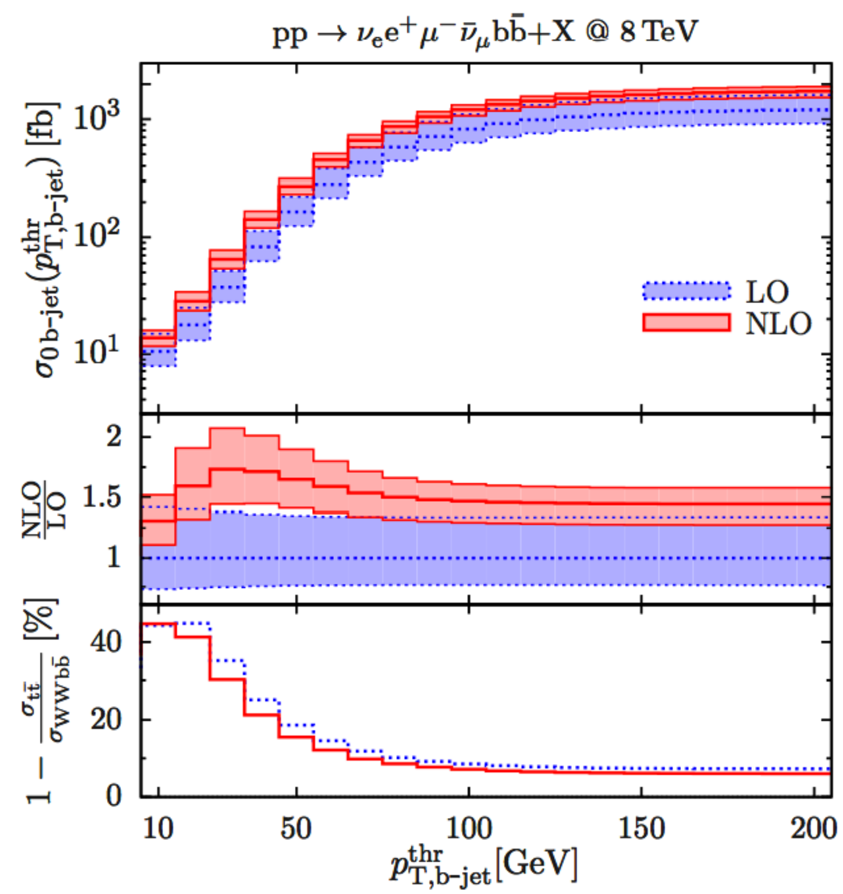


Fig. 2 Representative tree topologies without top resonances and with two (left) or only one (right) resonant W-boson.

The separation of the ttbar and Wt processes is quite subtle

Use of 4F and massive b-quarks allows a unified description of the two processes

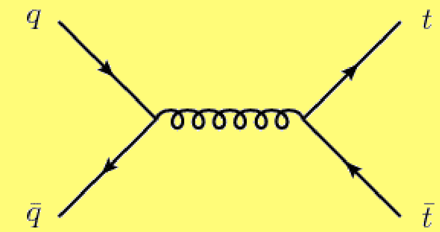


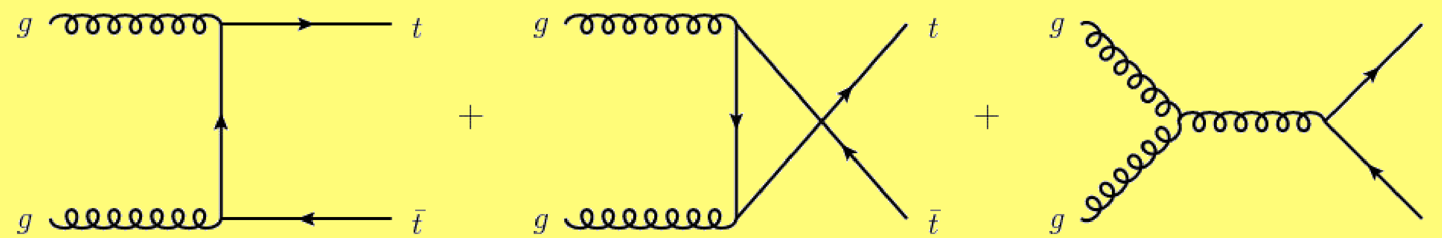
It allows a consistent study of the 0 and 1 jet bin relevant as a background to Higgs production

Finite width effects in the 0-jet bin grow to up to 40% at low p_T threshold

from talk by Massimiliano Grazzini in Warsaw 2014

Top pair production



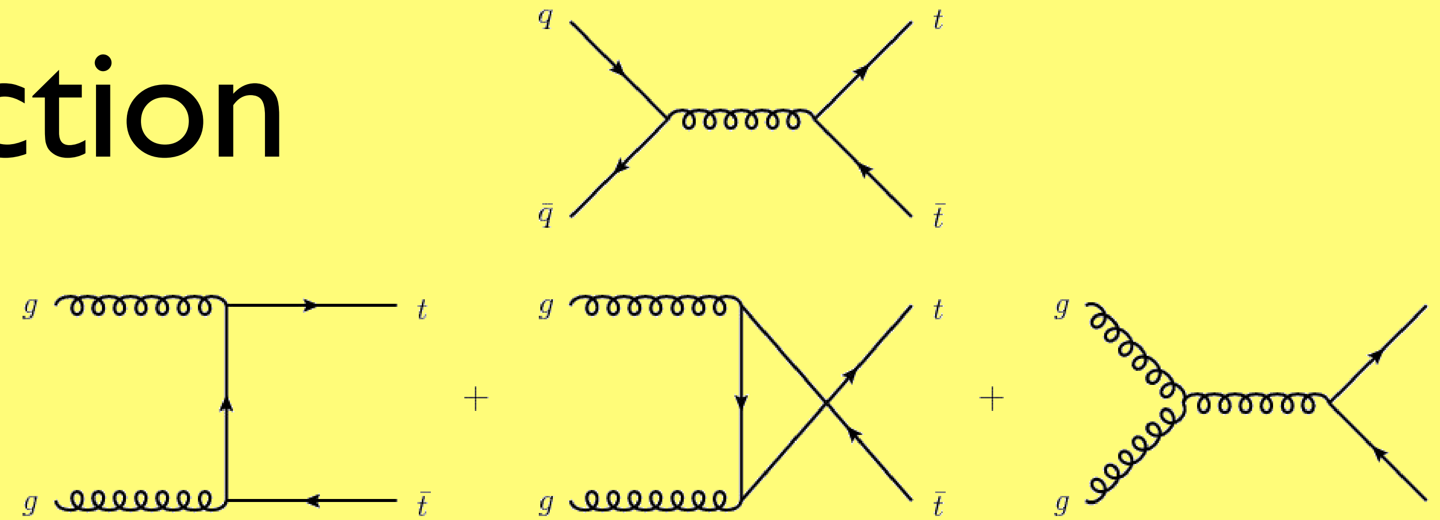


- inclusive cross section at NNLO(+NNLL) [Bernreuther, Czakon, Mitov '12], [Czakon, Mitov '13], [Czakon, Fiedler, Mitov '13]
  - New method: Sector Improved Residue Subtraction Scheme (STRIPPER) [Czakon '10 '11]

- NEW: fully-differential cross section at NNLO
  - STRIPPER [Czakon, Fiedler, Mitov '14]
  - Antenna Subtraction (only qq) [Abelof, Gehrmann-De Ridder, Majer '15]
  - colorful q_T subtraction (only gq) [Catani, Grazzini, Torre, Sargsyan '15]

- transverse momentum resummation for top pair system
  - (N)NLL [Zhu, Li, Li, Shao, Yang '13]
  - method including azimuthal correlations [Catani, Grazzini, Torre '14]

Top pair production



- inclusive cross section at NNLO(+NNLL)

[Bernreuther, Czakon, Mitov '12], [Czakon, Mitov '13], [Czakon, Fiedler, Mitov '13]

- Nev … PPER)

Let's discuss the NNLO(+NNLL) results and their application...

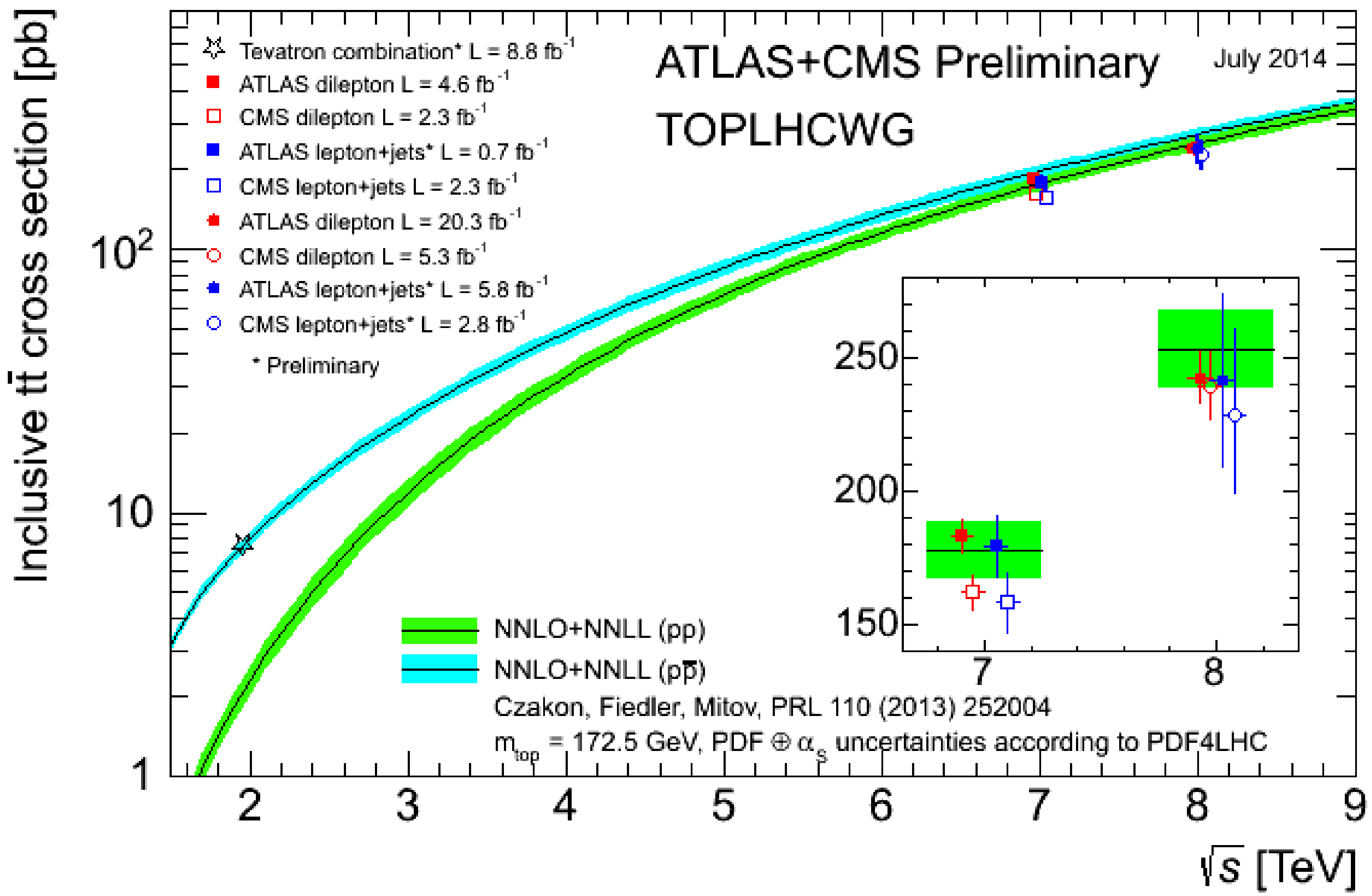
- NEW:
  - STR
  - Ante … '15]
  - colorful q_T subtraction (only gq) [Catani, Grazzini, Torre, Sargsyan '15]

- transverse momentum resummation for top pair system
  - (N)NLL [Zhu, Li, Li, Shao, Yang '13]
  - method including azimuthal correlations [Catani, Grazzini, Torre '14]

Total inclusive cross section at NNLO (+NNLL)

[Czakon, Fiedler, Mitov; 2013]

- Where we are



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from talk by David Heymes at SM@LHC 2014

Summary of combinations of total cross section measurements

- Combining measurements from CDF and DØ gives a Tevatron cross section at 1.96 TeV c-o-m of $7.60 \pm 0.41(5.4\%)$ pb , to be compared with the theoretical calculation (NNLO+NNLL) $7.24^{+0.23}_{-0.27}(3.4\%)$pb (Czakon et. al).

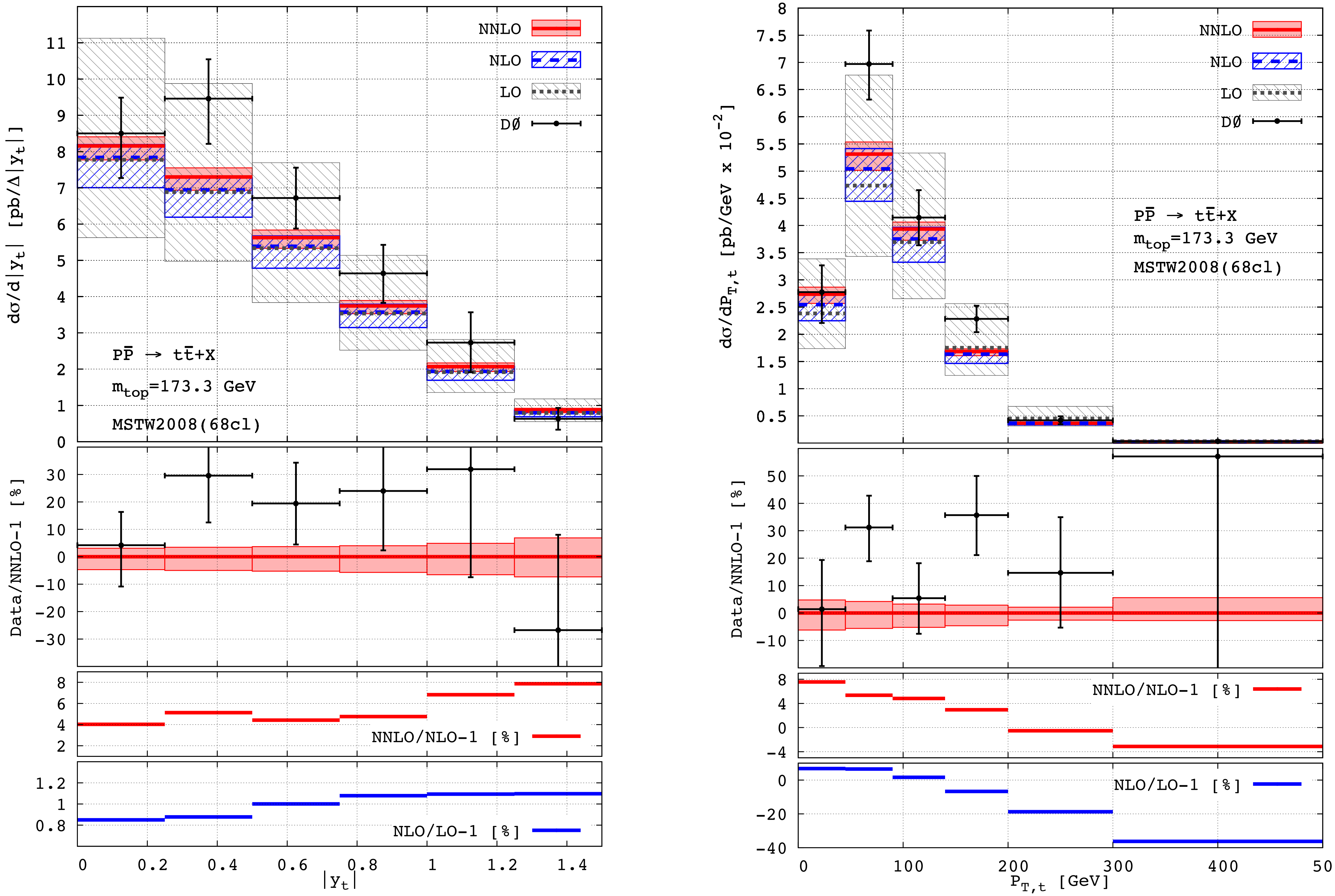
- Combining measurements from ATLAS and CMS gives a LHC cross section at 7 TeV c-o-m of $173 \pm 10(5.8\%)$ pb, to be compared to the theoretical calculation (NNLO+NNLL) of $172.0^{+6.4}_{-7.5}(4.1\%)$ pb.

- The most precise measurements at 8 TeV are from the ATLAS and CMS dilepton channel: $238 \pm 11(4.6\%)$ pb and $227 \pm 15(6.6\%)$ pb.
  The NNLO+NNLL SM prediction is $245.8^{+8.8}_{-10.6}(4.0\%)$ pb.

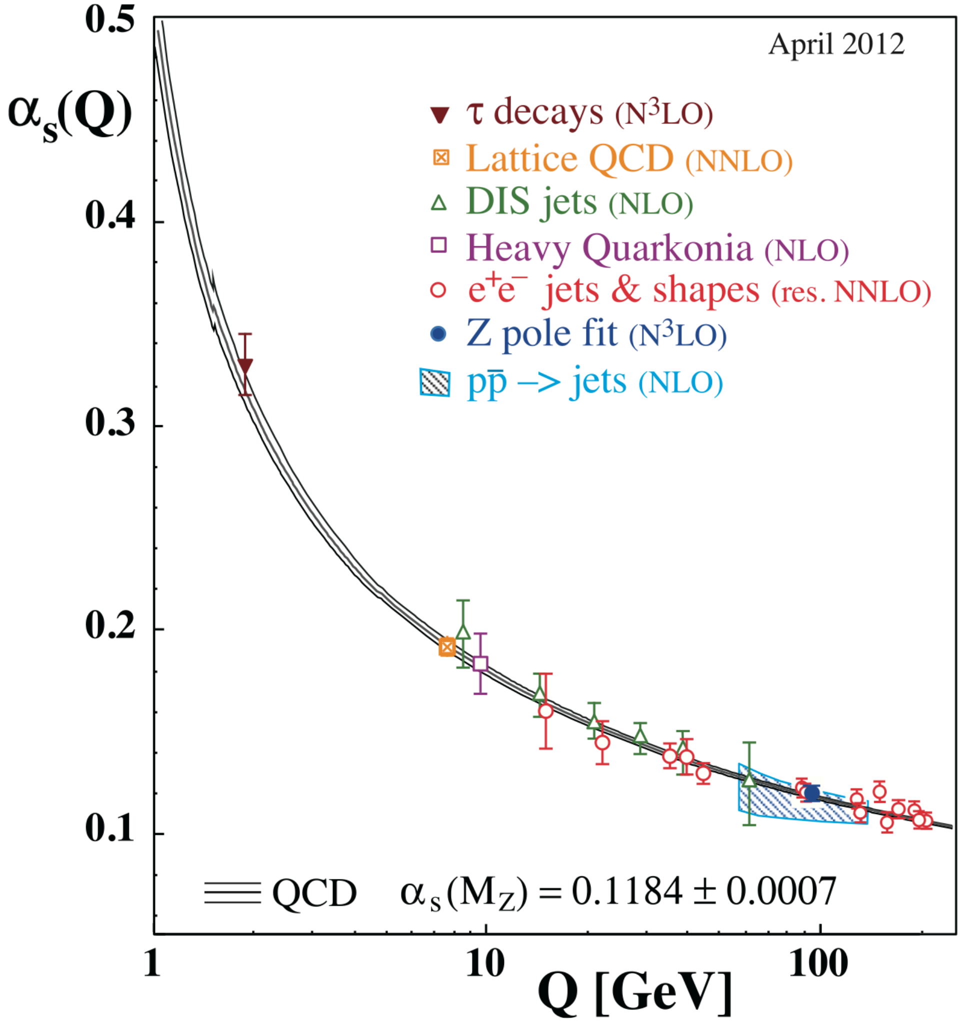
S. Protopopescu, TOP 2013, 15th September 2013

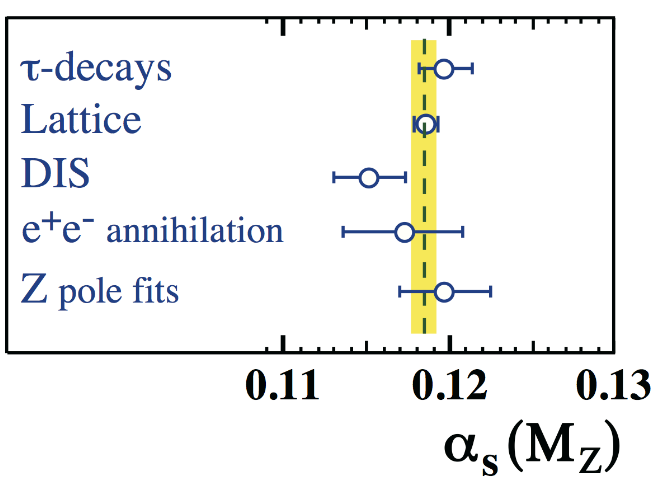
from talk by Michal Czakon at SFB/TR9 Meeting 2014

MC, Fiedler, Mitov, preliminary

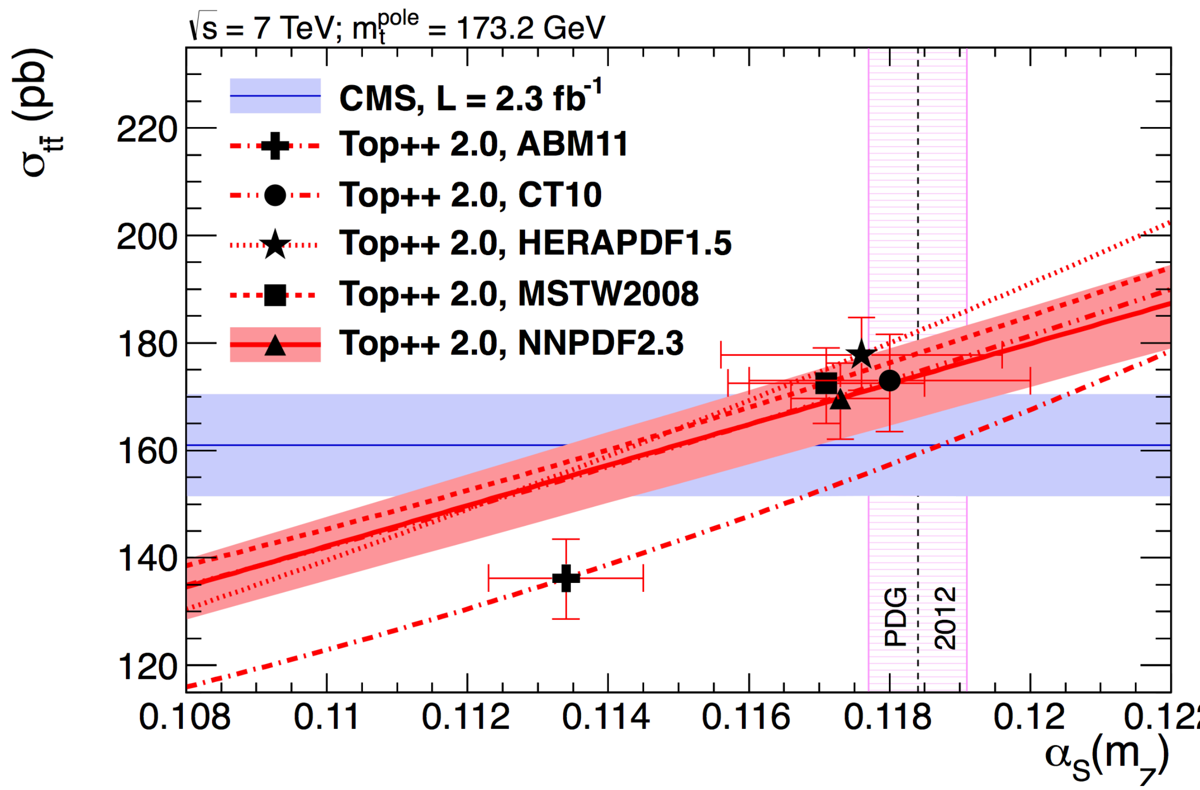


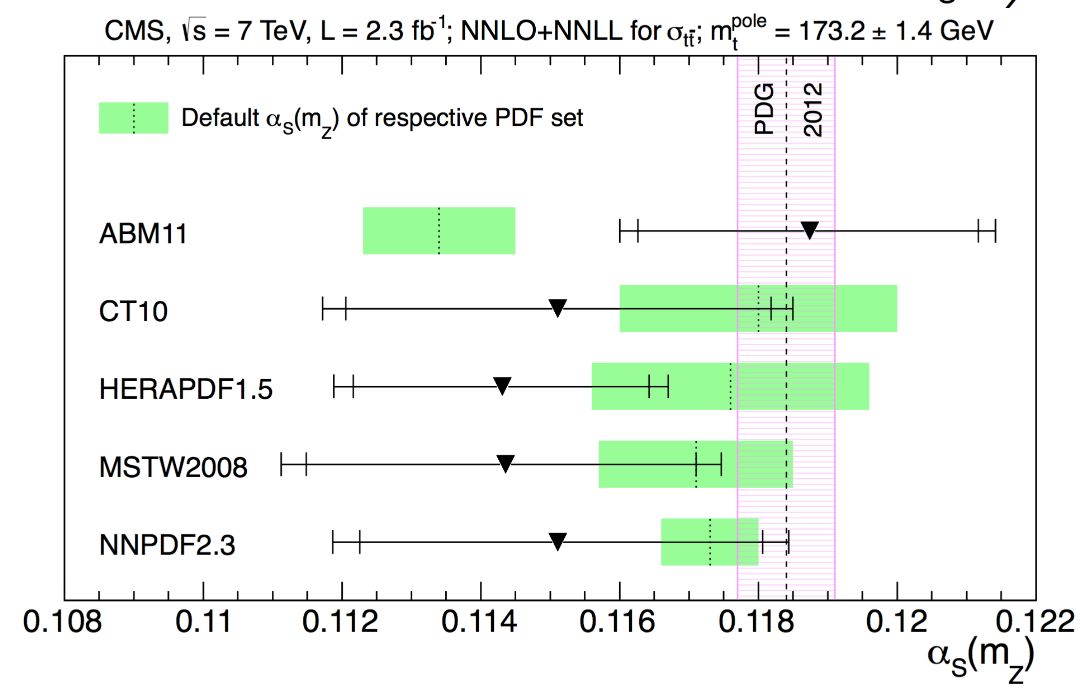
from talk by Michal Czakon at Radcor/Loopfest 2015





arXiv:1307.1907 (CMS-TOP-12-022)





First determination of the strong coupling at NNLO from a hadron collider

Competitive to other collider determinations

With NNPDF: $\alpha_S(m_Z) = 0.1151^{+0.0033}_{-0.0032}$

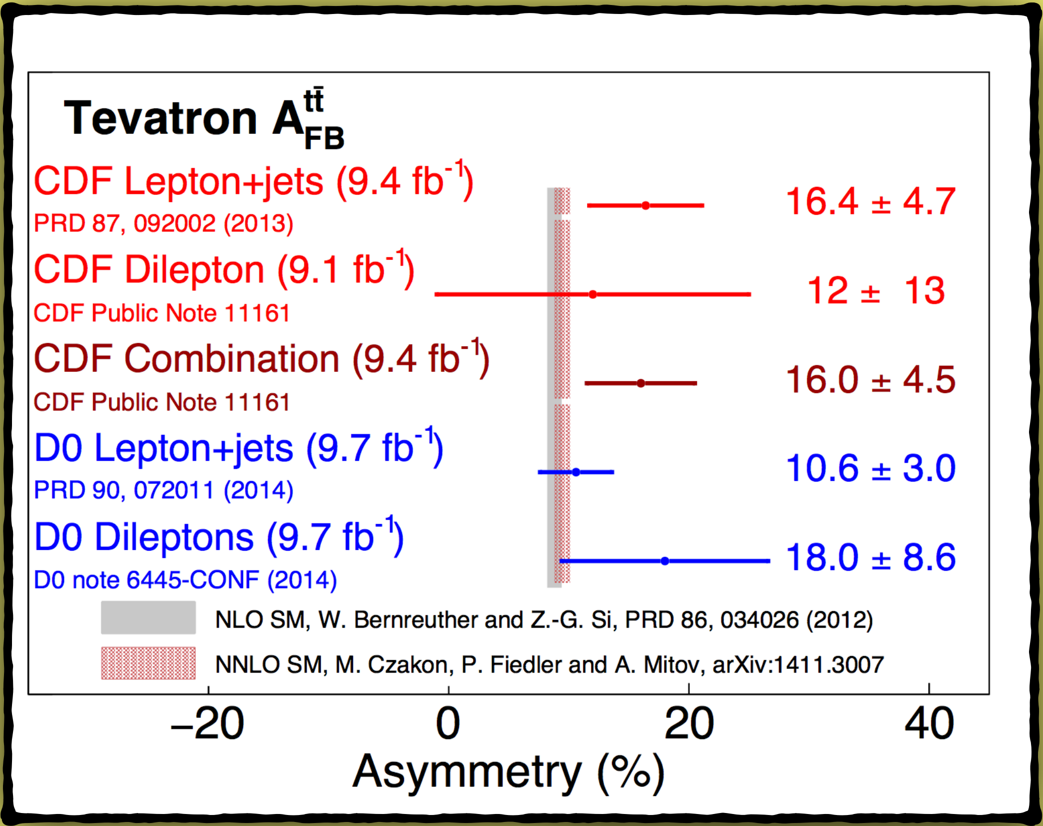
from talk by Michal Czakon at SFB/TR9 Meeting 2014

Forward-Backward Asymmetry

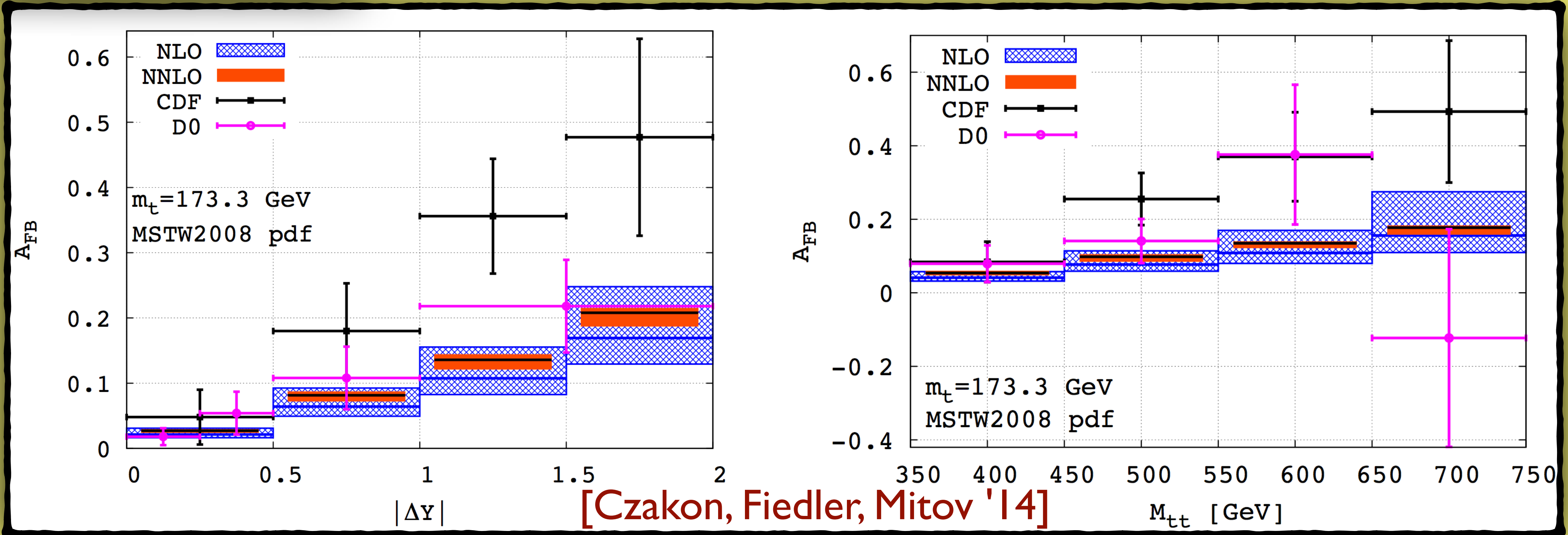
How much more is the top in direction of the Proton than the anti-top?

$$A^{t\bar{t}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

$$\Delta y = y_t - y_{\bar{t}}$$



differential asymmetry (bin wise)



[Czakon, Fiedler, Mitov '14]

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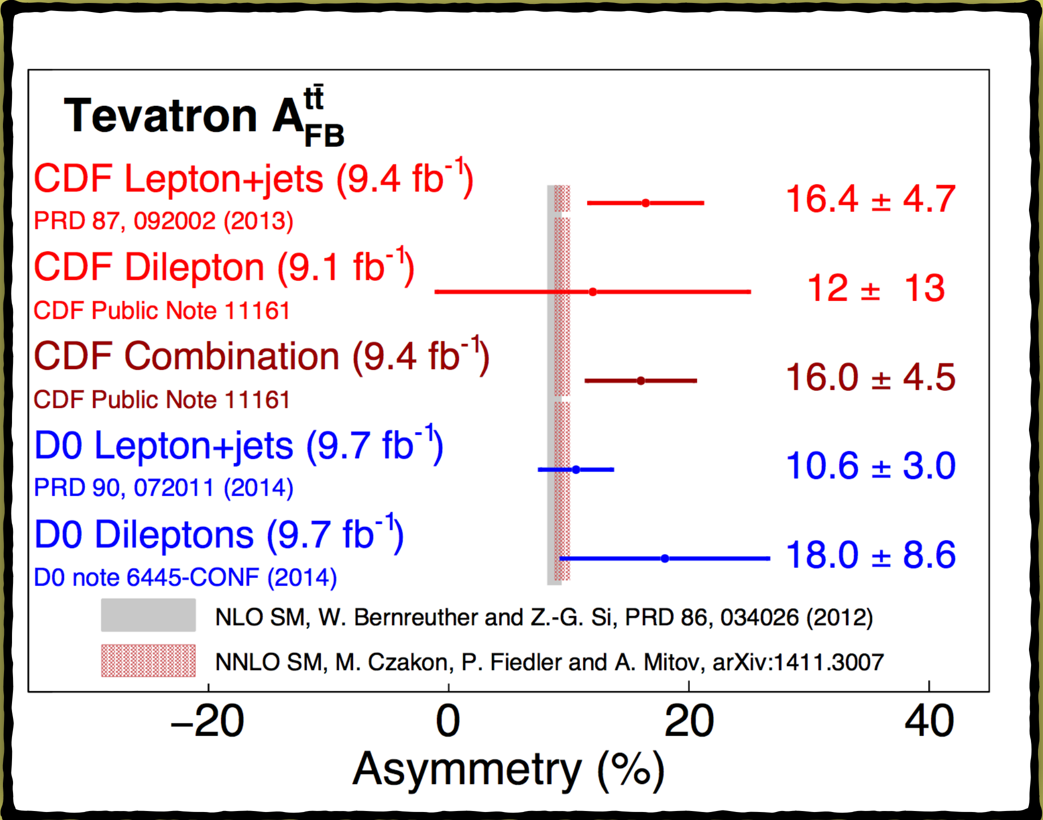
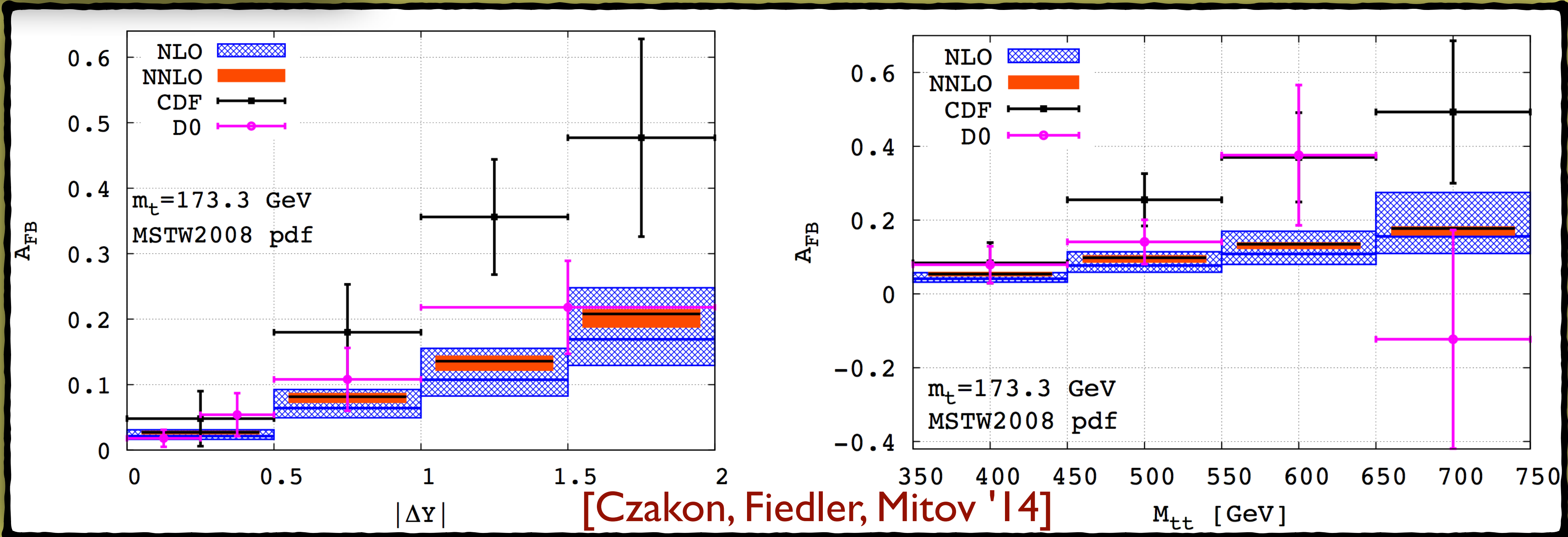


inclusive asymmetry:

D0 compatible with NNLO

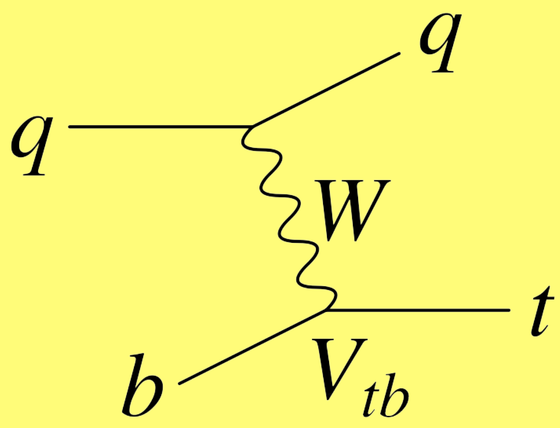
CDF ~1.5σ above NNLO

differential asymmetry (bin wise)

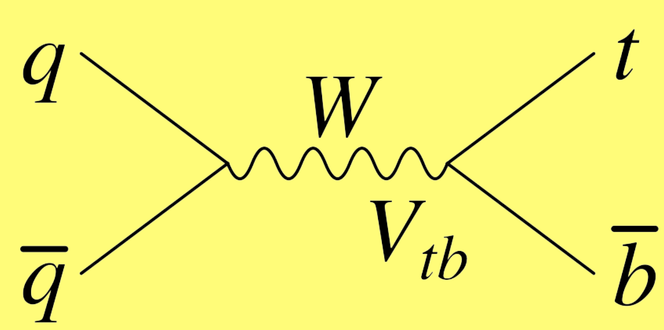


[Czakon, Fiedler, Mitov '14]

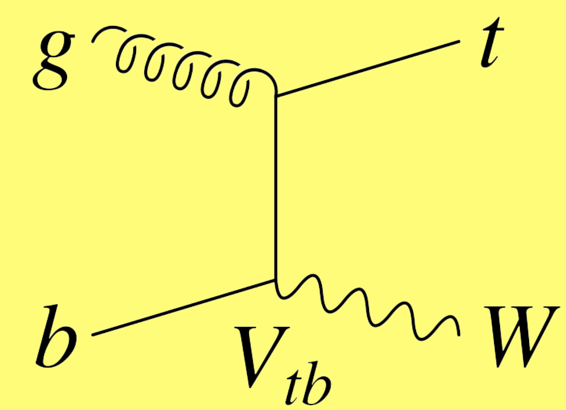
Single-top production



t-channel

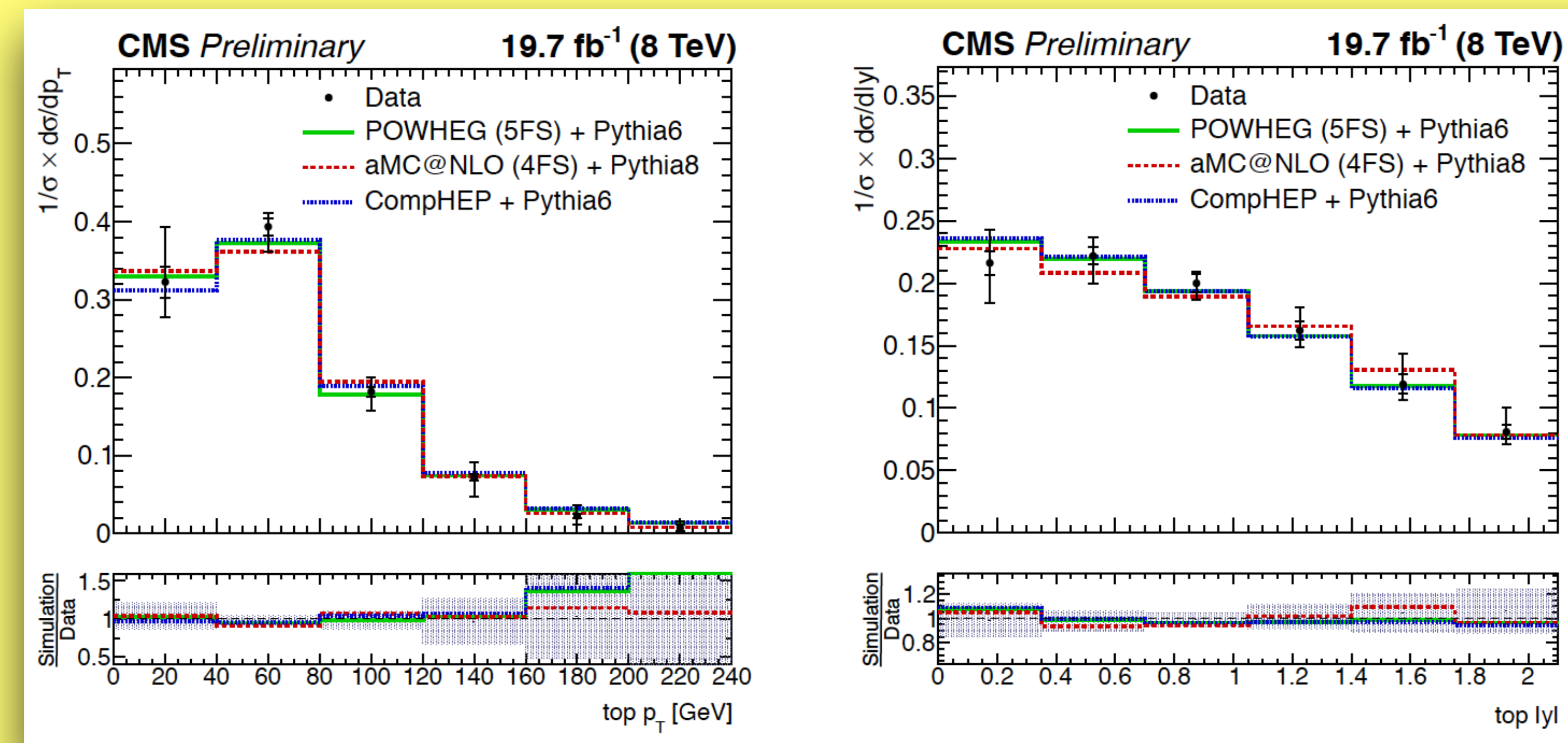


s-channel



Wt-associated

- data in good agreement with Monte Carlos



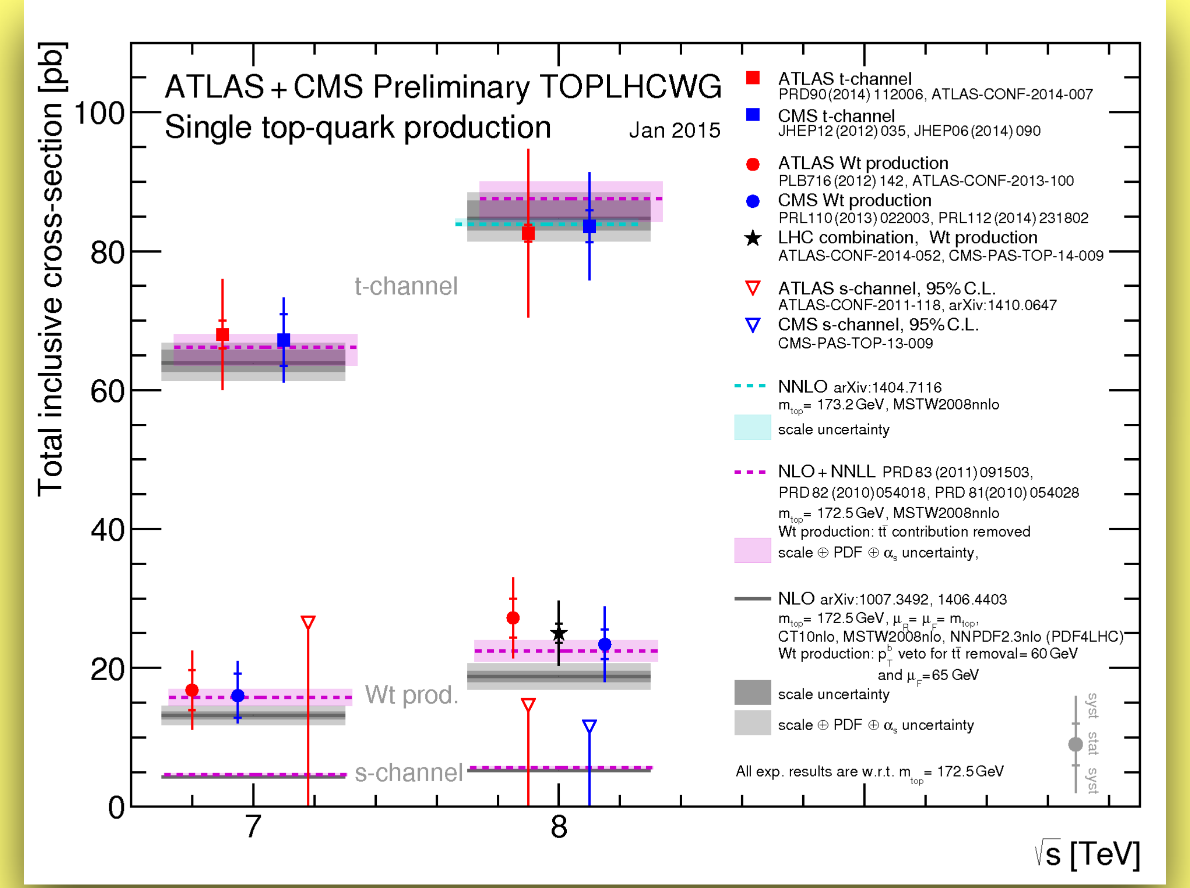
CMS, 8 TeV, 19.7 fb^{-1}
CMS PAS TOP-14-004

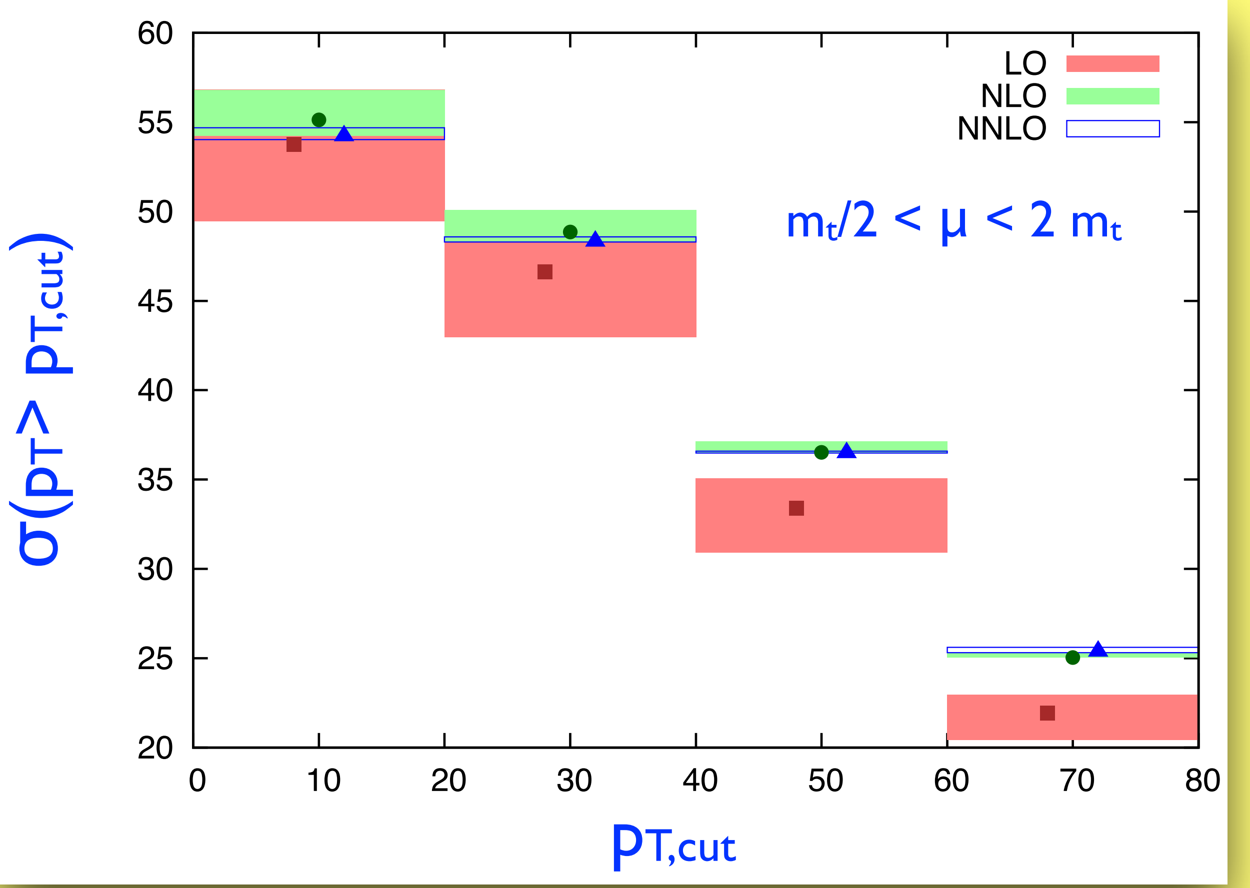
- t-channel: cross section at NNLO [Brucherseifer, Caola, Melnikov '14]

Single-top production

inclusive cross section:

- t-channel: NNLO corrections small ~ 2% [Brucherseifer, Caola, Melnikov '14]
- very good agreement with experiment

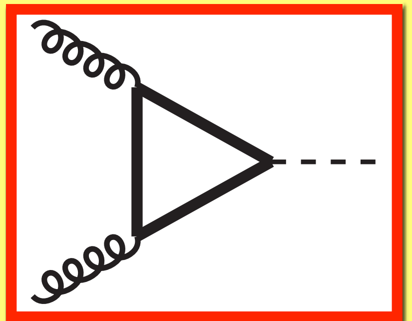


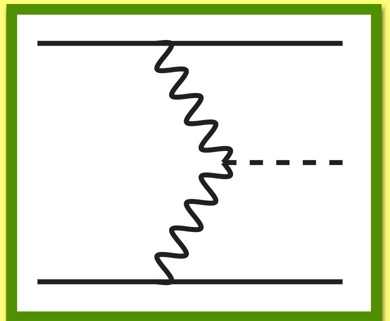


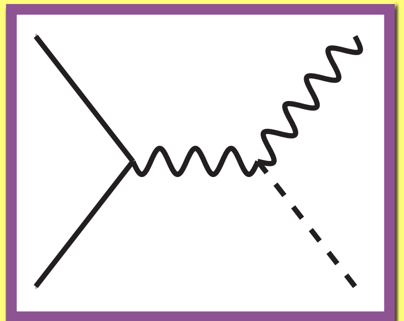
differential cross section:

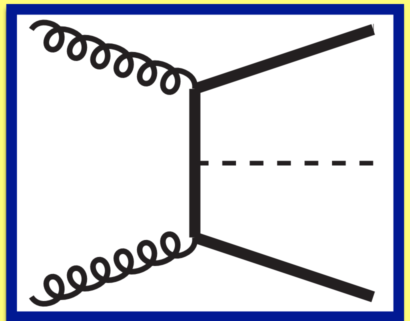
- NNLO corrections still small [Brucherseifer, Caola, Melnikov '14]
- but K-factor not completely flat!

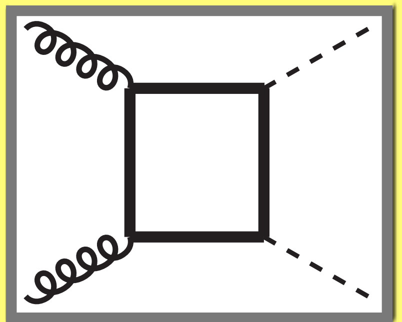
Back to Higgs physics...

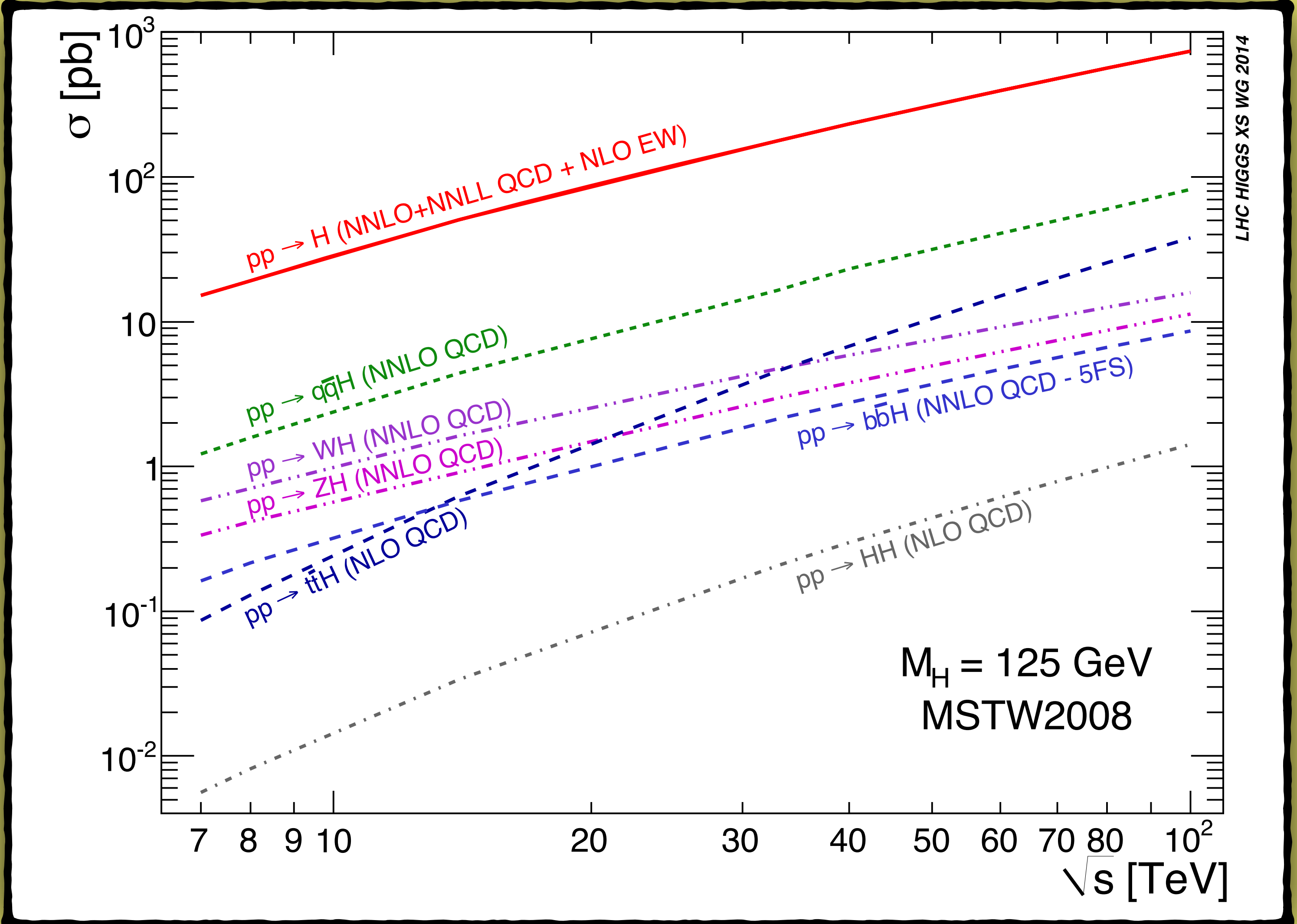


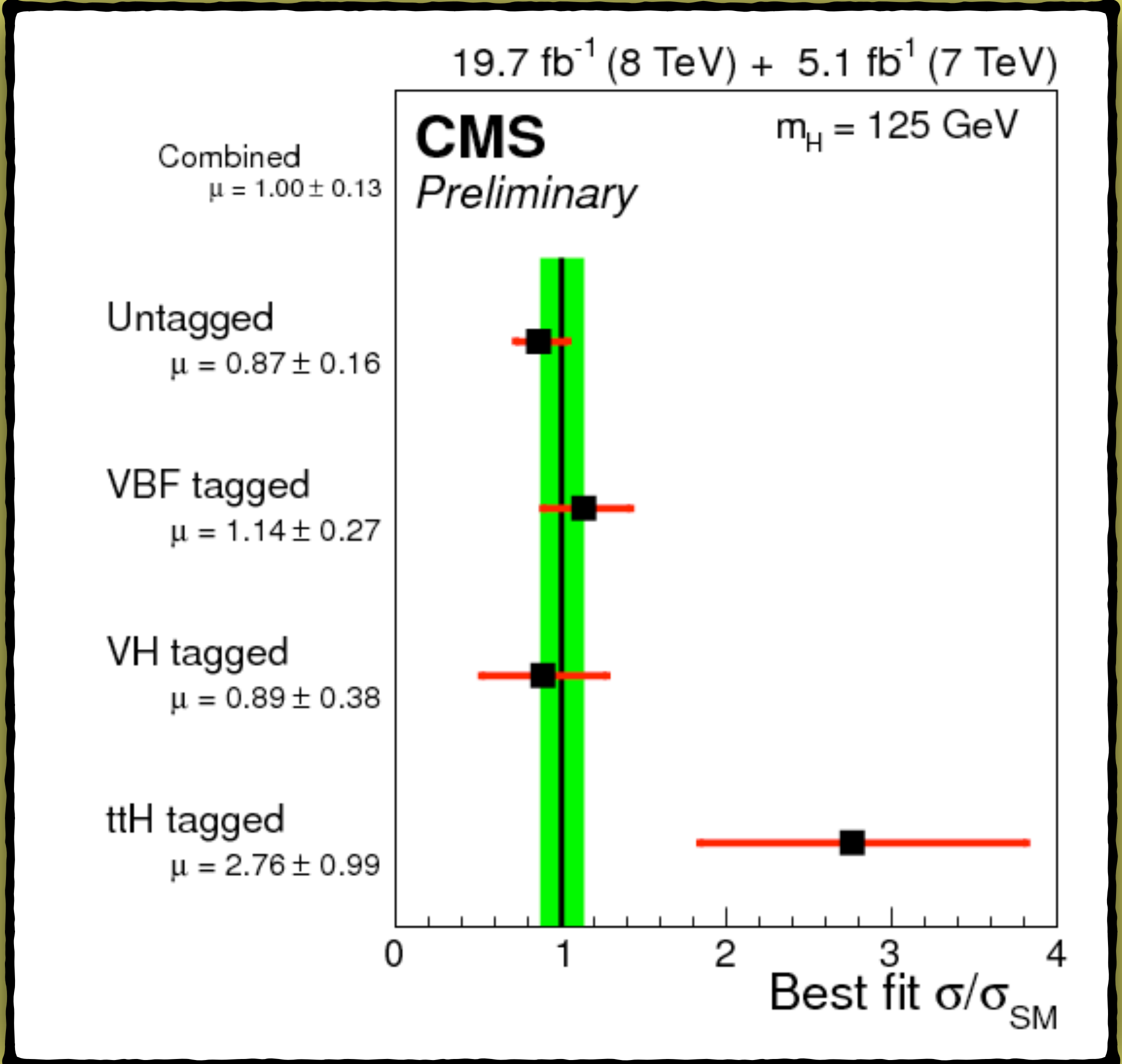






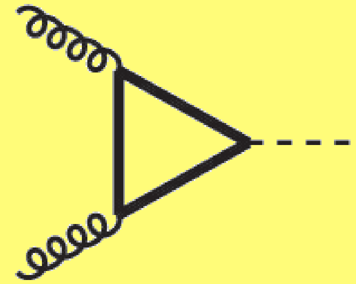






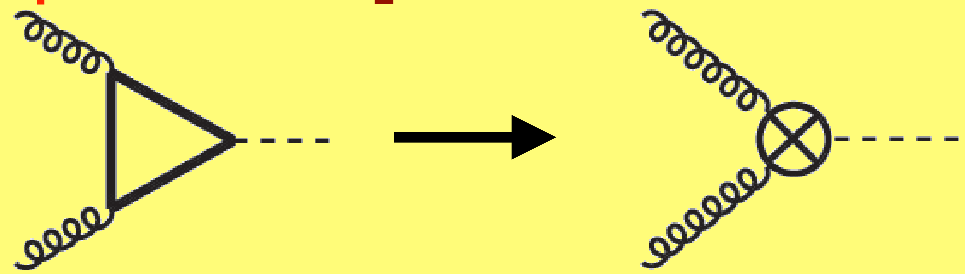
Gluon Fusion

Inclusive cross section

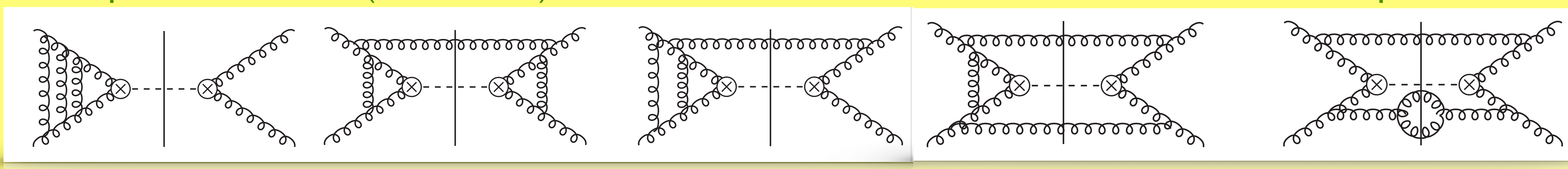


Milestone: First N3LO computation! [Anastasiou, Duhr, Dulat, Mistlberger '15]

- heavy-top limit (htl)



triple virtual (real-virtual)^2 real-double-virtual double-real-virtual triple real

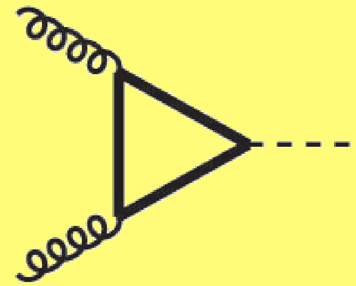


$\hat{s} = m_H^2$ $\qquad$ $m_H^2 \leq \hat{s} \leq S = 13TeV$

- threshold expansion around $z = \dfrac{m_H^2}{\hat{s}} = 1$:

Gluon Fusion

Inclusive cross section



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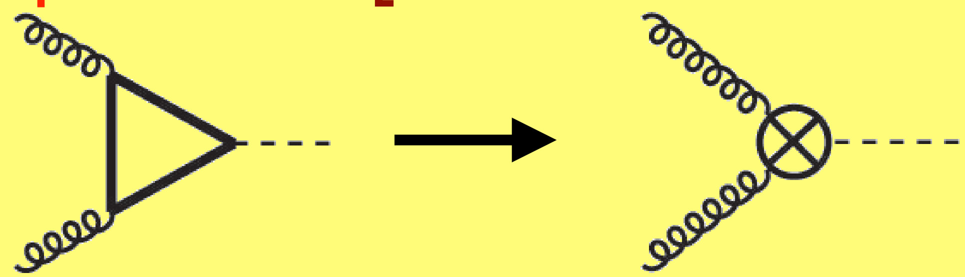
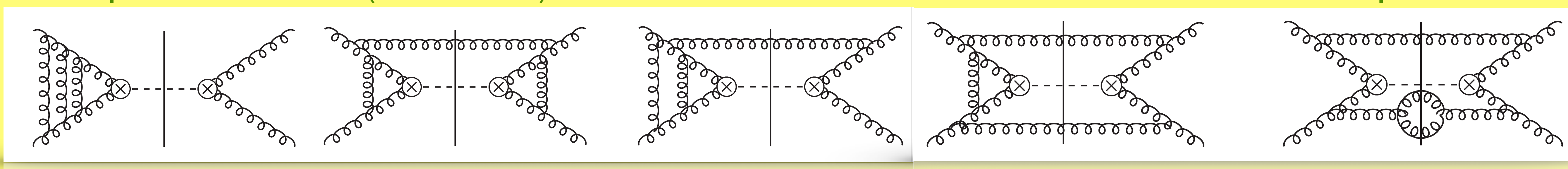


triple virtual | (real-virtual)^2 | real-double-virtual | double-real-virtual | triple real



$\hat{s} = m_H^2$ $\quad\quad$ $m_H^2 \leq \hat{s} \leq S = 13 TeV$

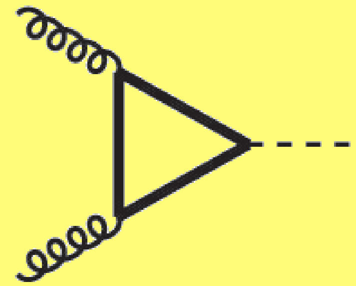
- threshold expansion around $z = \frac{m_H^2}{\hat{s}} = 1$:

$$\sigma \sim \int \frac{dz}{z} \mathcal{L}(\tau/z) \cdot \frac{\hat{\sigma}(z)}{z}, \quad \tau = \frac{m_H^2}{S}$$

$$\frac{\hat{\sigma}(z)}{z} = \hat{\sigma}^{-1}(z) + \sum_{N=0}^{\infty} \sigma^{(N)}(z)\,(1-z)^N$$

Gluon Fusion

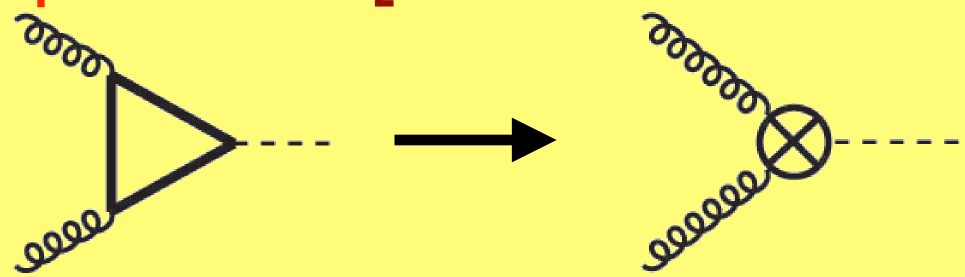
Inclusive cross section



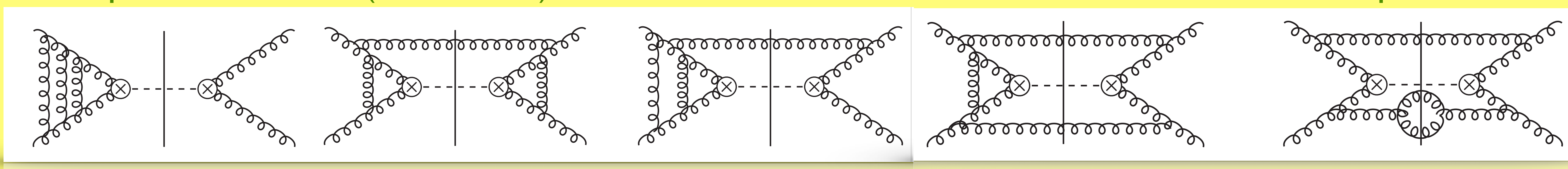
Universität Zürich[UZH]

Milestone: First N3LO computation! [Anastasiou, Duhr, Dulat, Mistlberger '15]

- heavy-top limit (htl)



triple virtual | $(\text{real-virtual})^2$ | real-double-virtual | double-real-virtual | triple real



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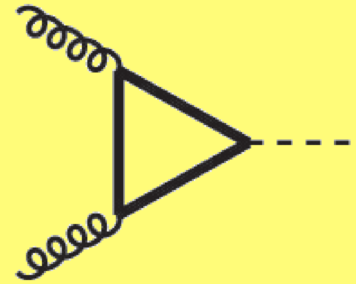
soft term (function of $\delta(1-z)$, $[\log^n(1-z)/(1-z)]_+$)

Gluon Fusion

Inclusive cross section



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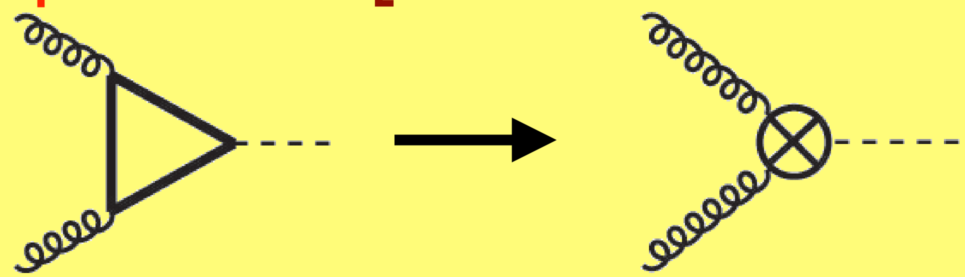
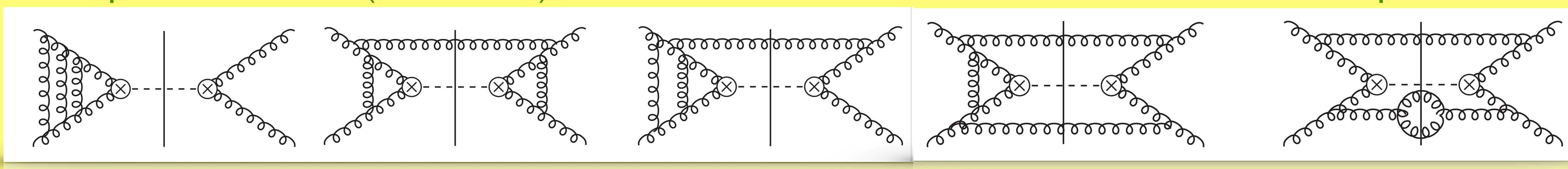


triple virtual (real-virtual)^2 real-double-virtual double-real-virtual triple real



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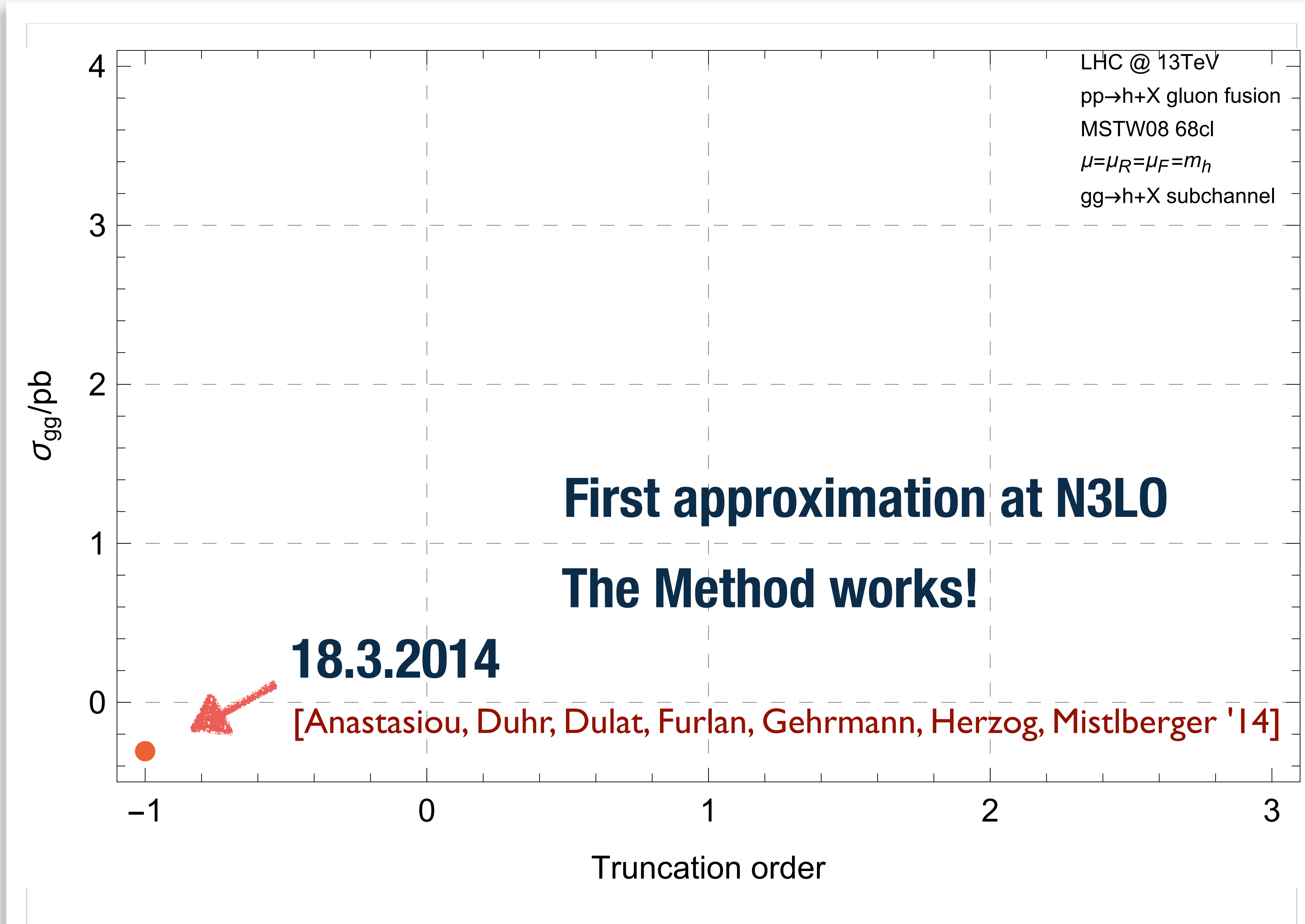
Universität Zürich UZH



from talk by Bernhard Mistlberger at Loopfest/Radcor 2015

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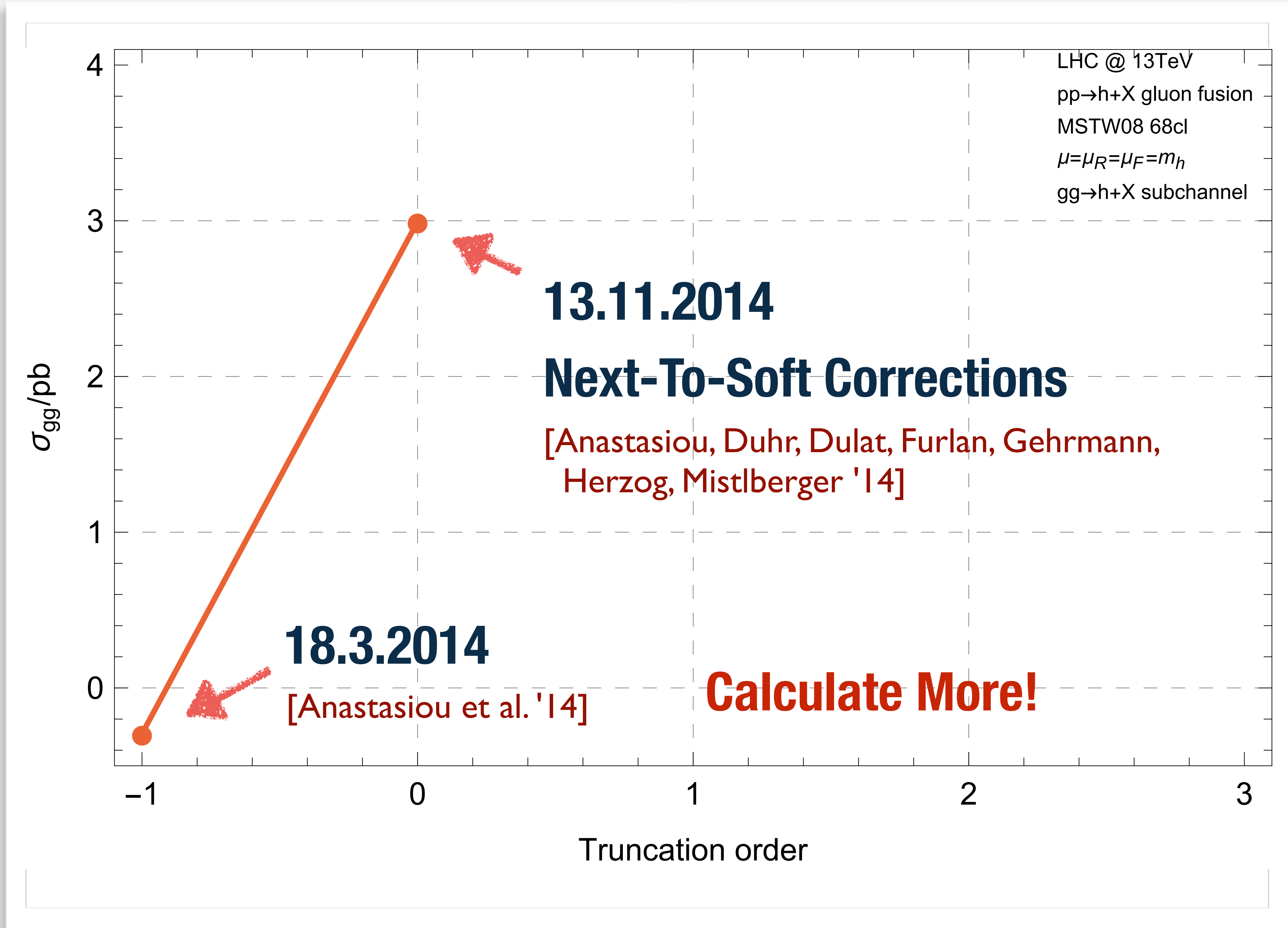
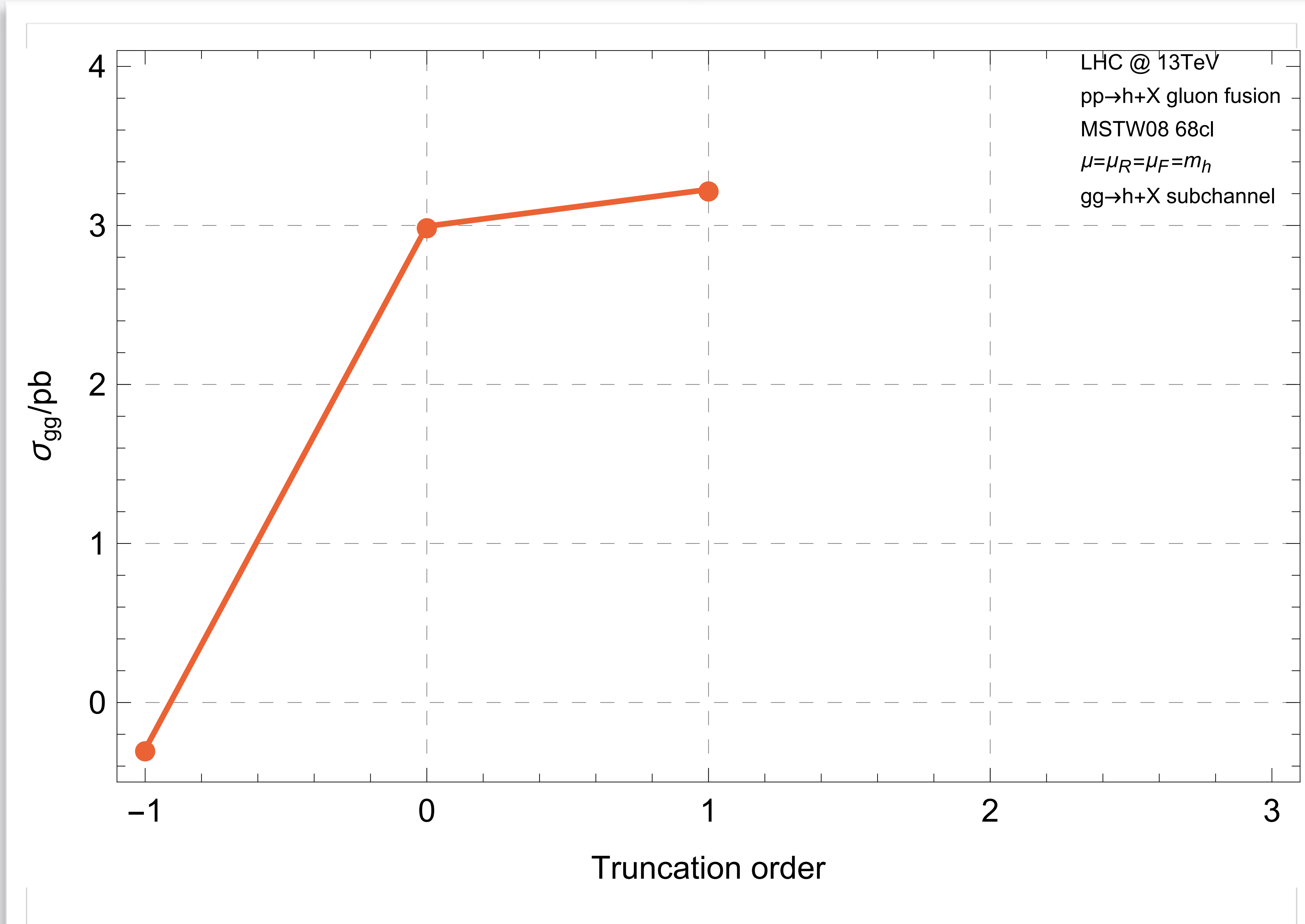
Universität Zürich[UZH]



from talk by Bernhard Mistlberger at Loopfest/Radcor 2015

$$\frac{\hat{\sigma}(z)}{z} = \hat{\sigma}^{-1}(z) + \sum_{N=0,1}^{\infty} \sigma^{(N)}(z)\,(1-z)^N$$

Universität Zürich[UZH]



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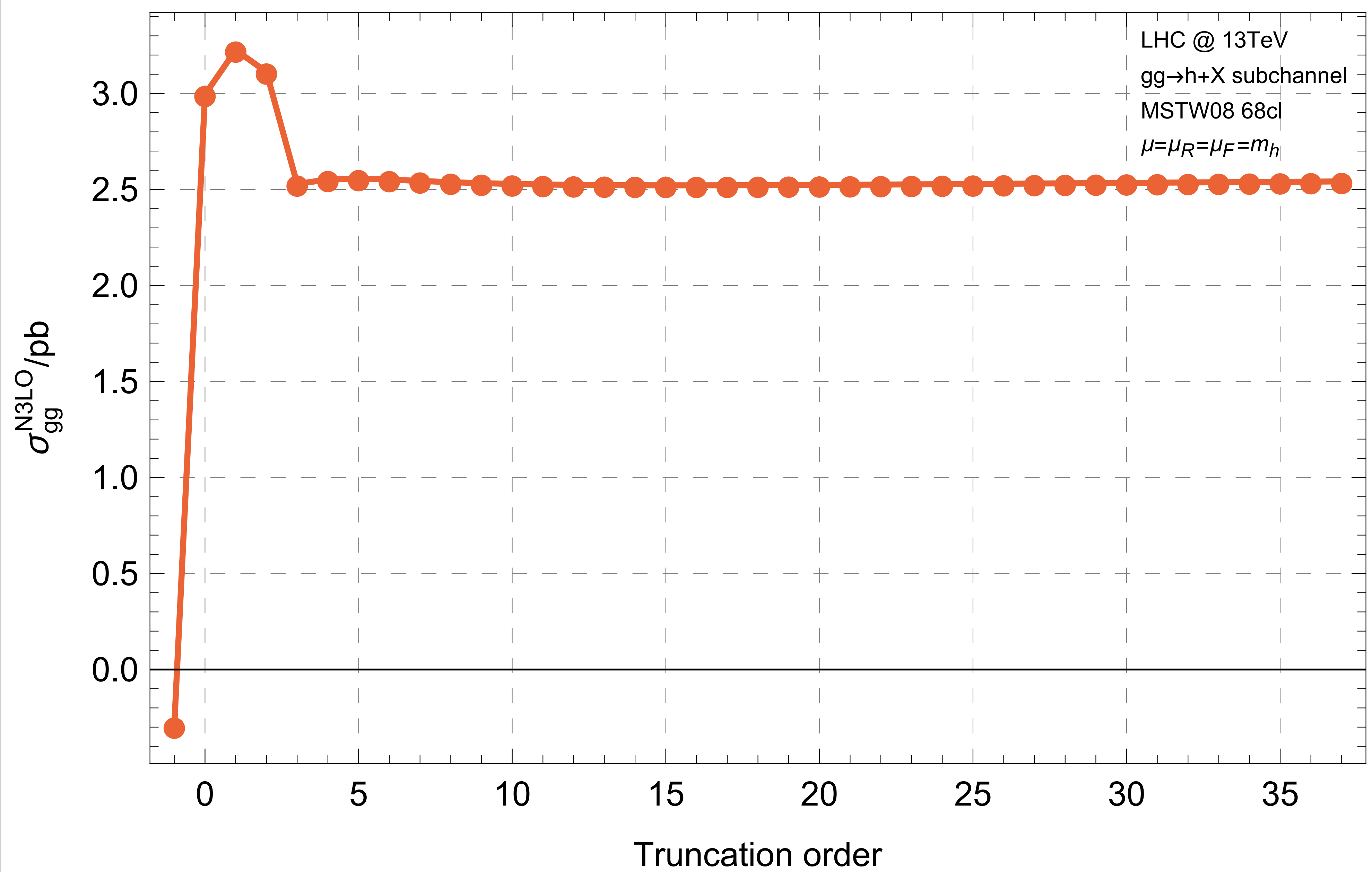
$$\frac{\hat{\sigma}(z)}{z} = \hat{\sigma}^{-1}(z) + \sum_{N=0,1,\ldots,37}^{\infty} \sigma^{(N)}(z)\,(1-z)^N$$

Universität Zürich[UZH]

[Anastasiou, Duhr, Dulat, Mistlberger '15]



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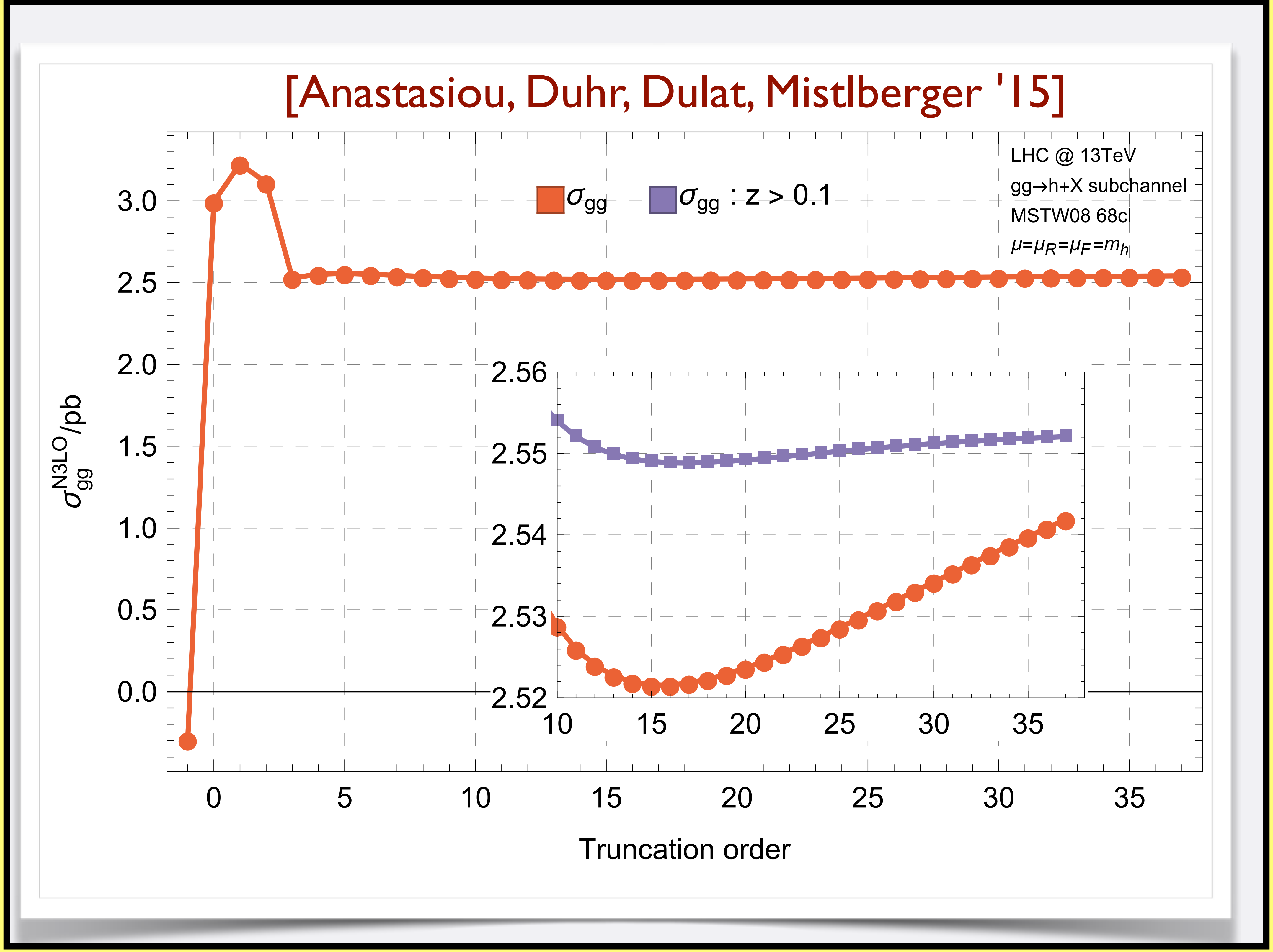

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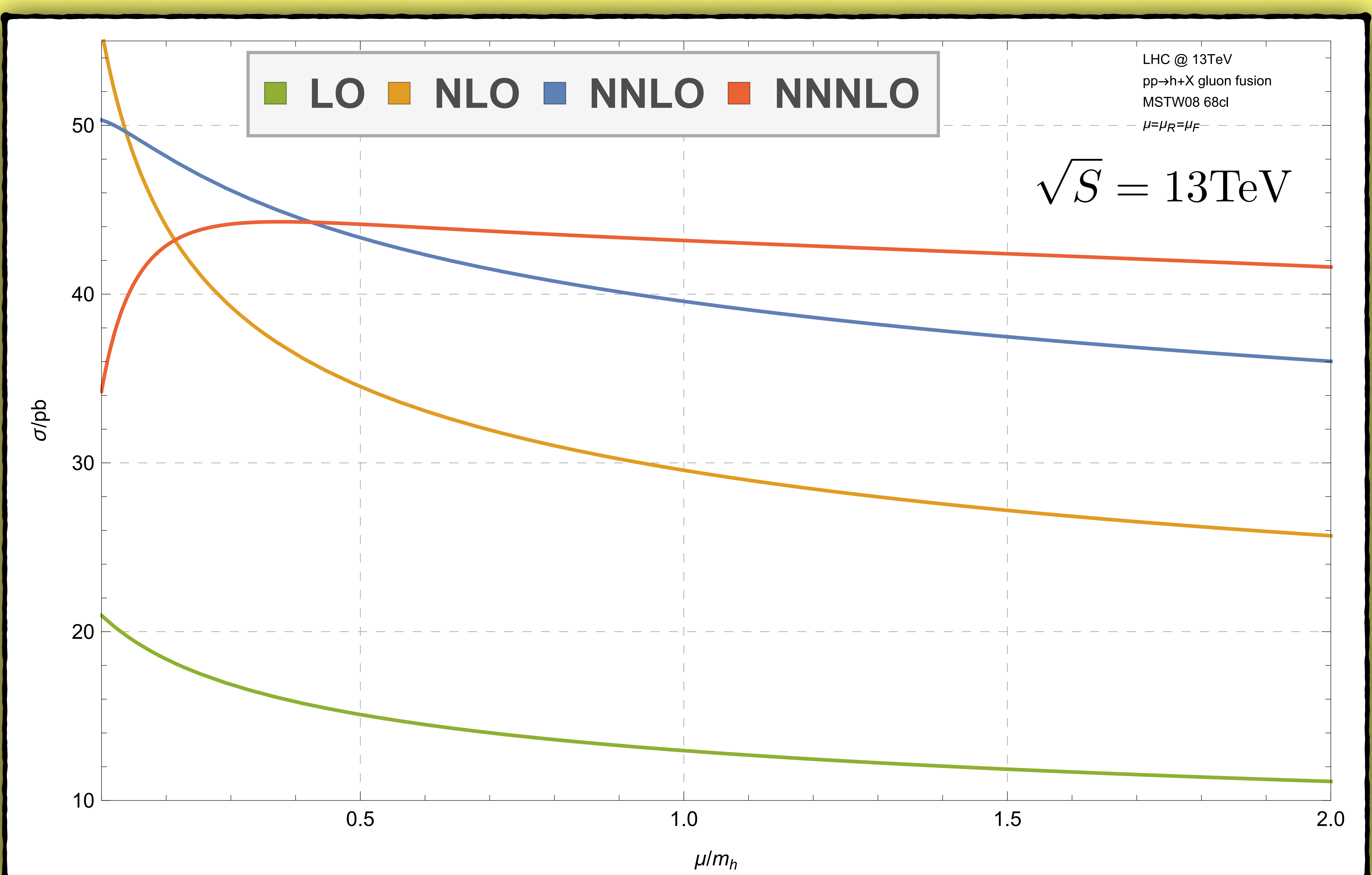
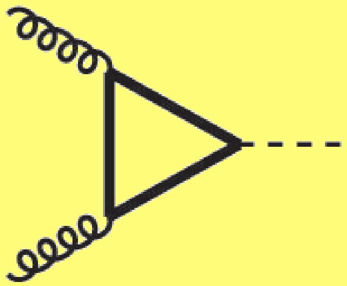


Gluon Fusion

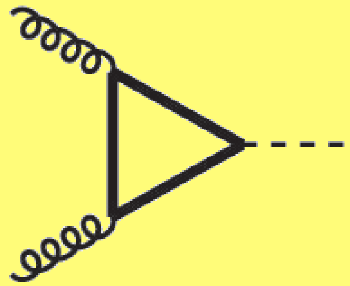
Inclusive cross section



- Conclusion: Radiative corrections in htl under control ~ 2-3% uncertainties
- Other uncertainties?
  - top-mass effects
  - bottom-mass effects
  - EW effects
  - PDFs

Gluon Fusion

Inclusive cross section



- Conclusion: Radiative corrections in htl under control ~ 2-3% uncertainties
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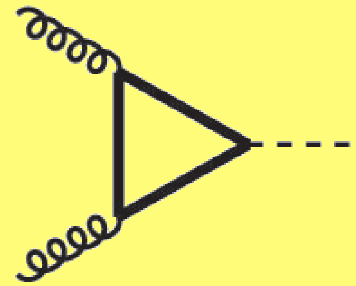
Let's concentrate on mass effects...

Gluon Fusion

Inclusive cross section



- top-mass effects by $1/m_{\text{top}}$ expansion: $$\sigma = \sum_{k=0}^{\infty} \frac{1}{m_{\text{top}}^{2k}}\, \sigma^{(k)}$$

Gluon Fusion

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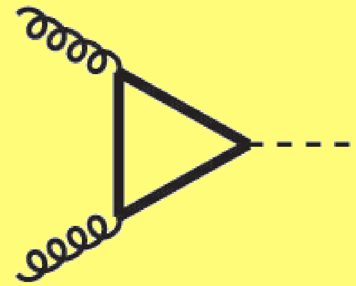

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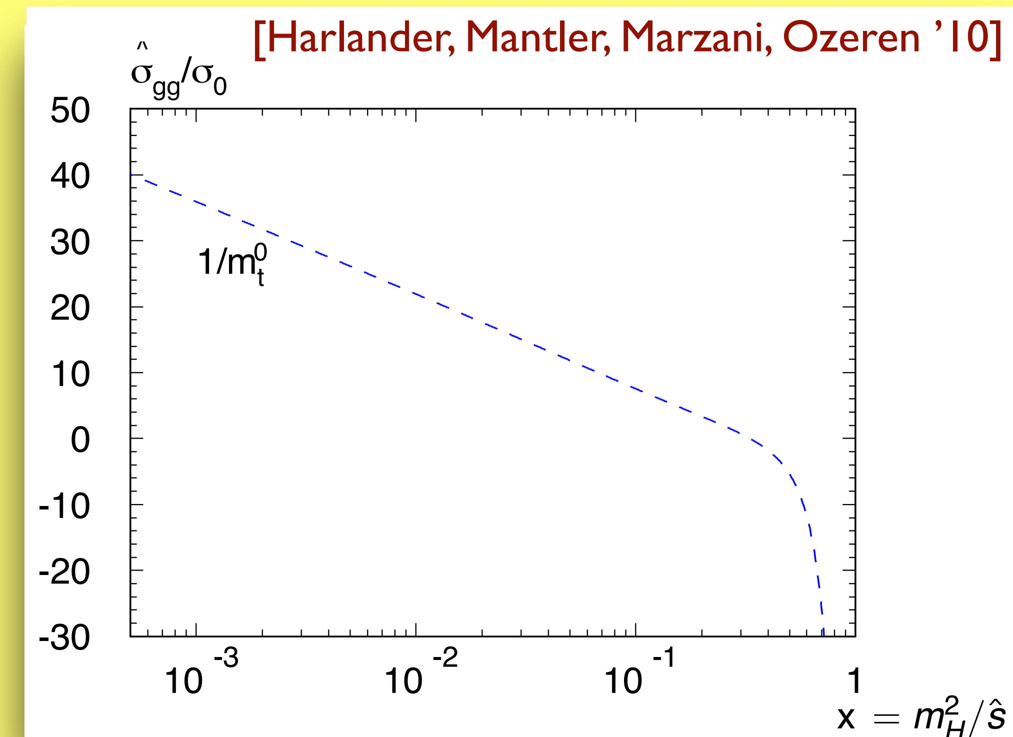
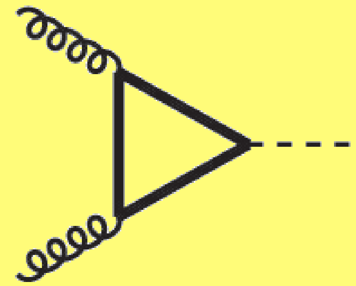


Gluon Fusion

Inclusive cross section



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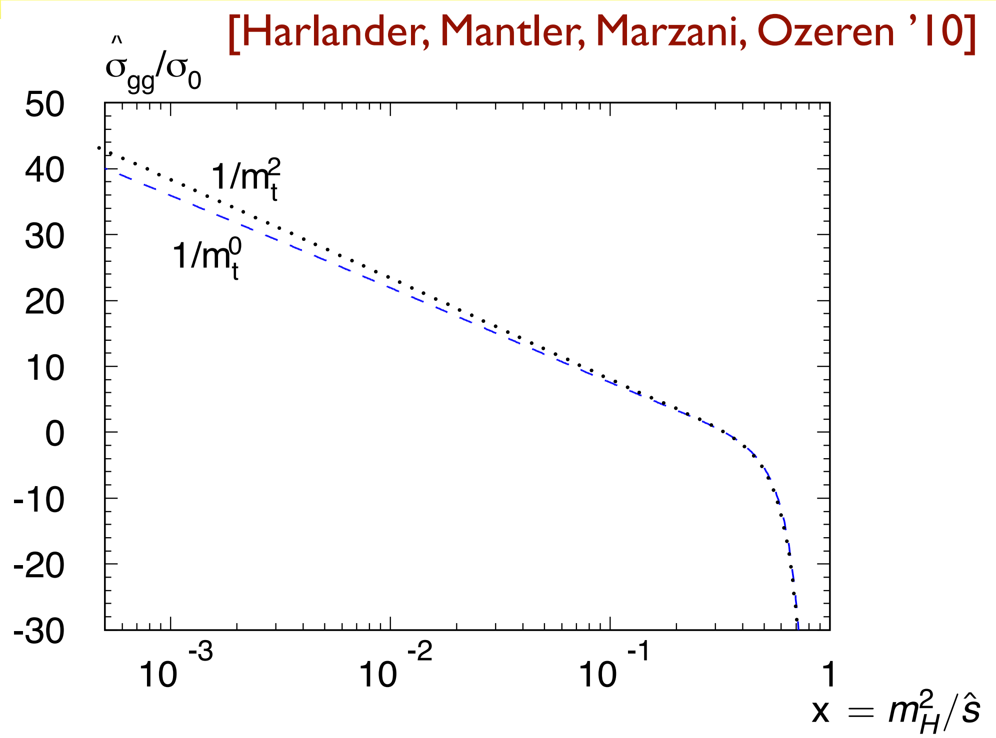

Gluon Fusion

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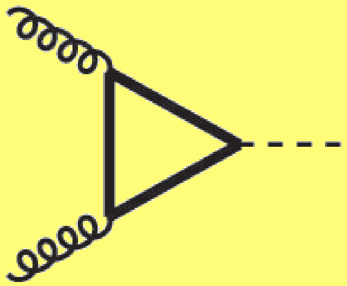

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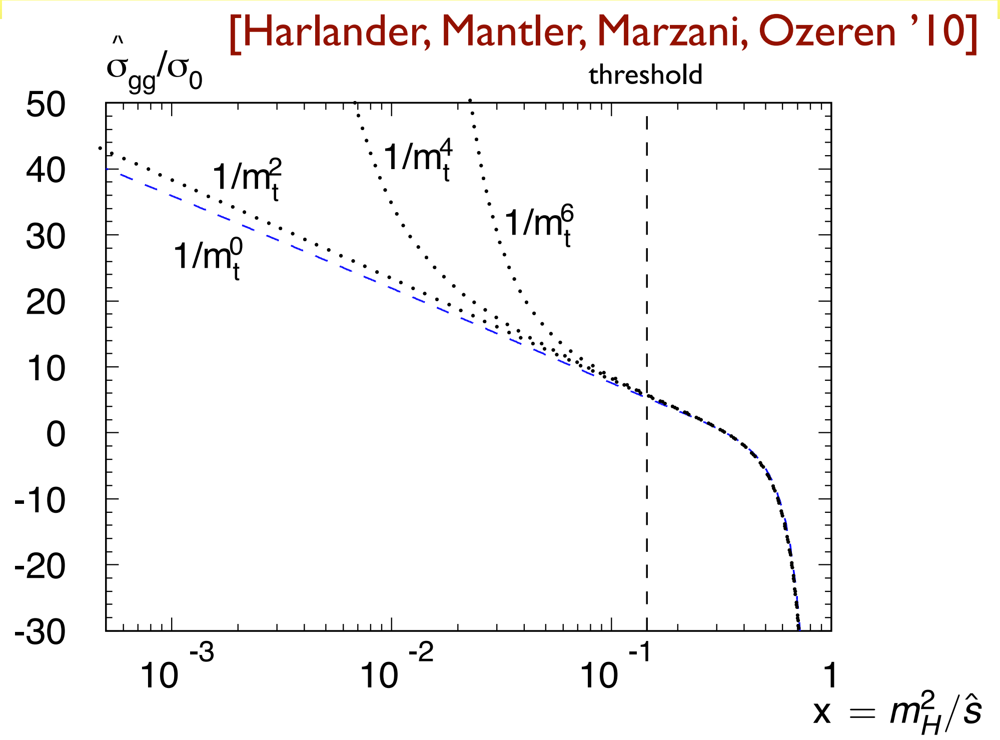

Gluon Fusion

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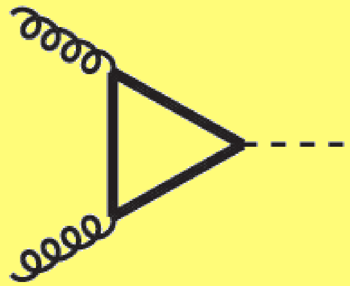

Universität Zürich[UZH]

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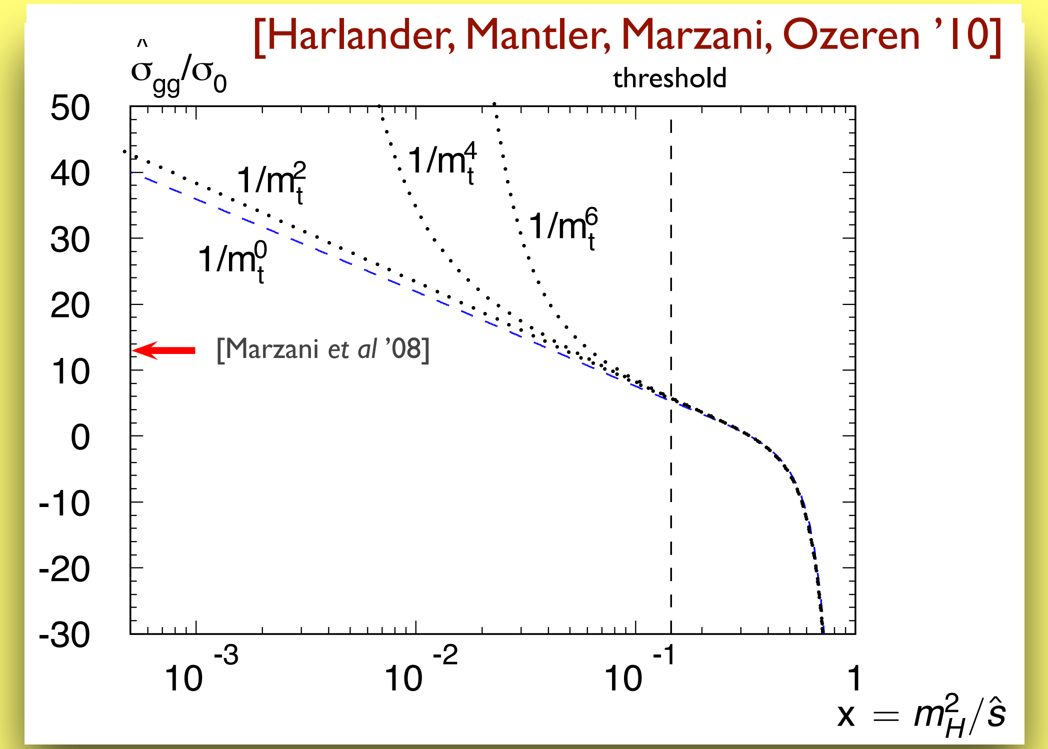

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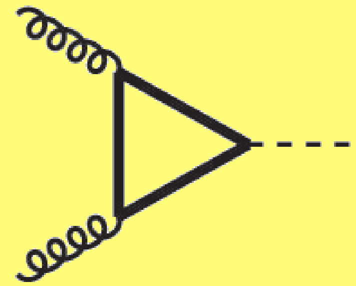

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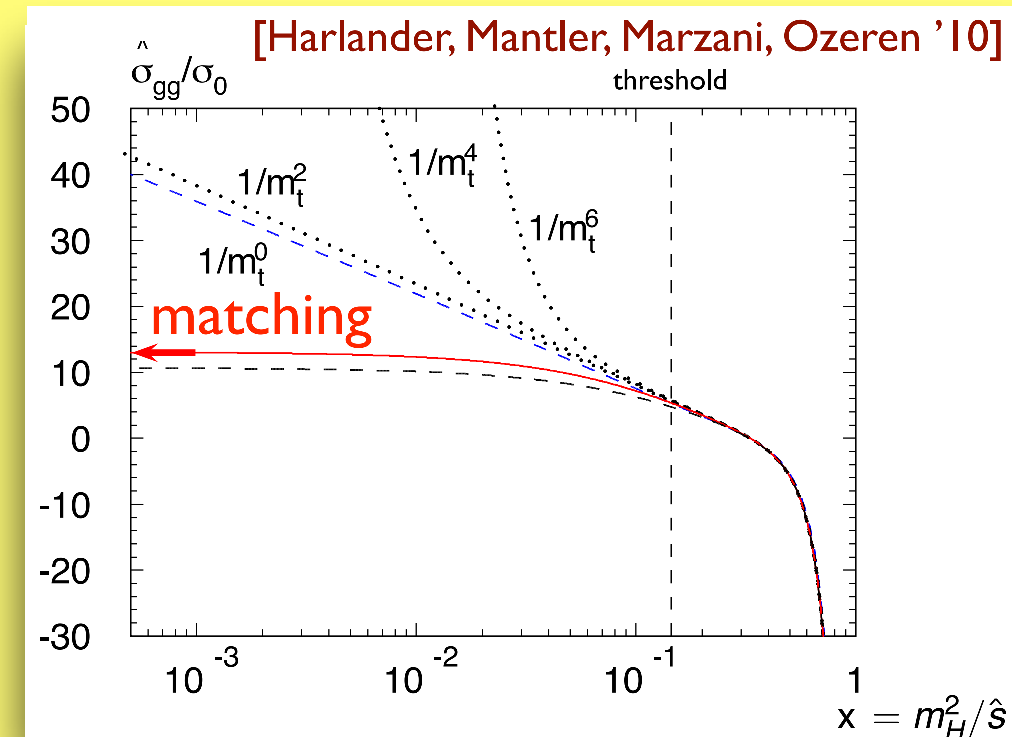

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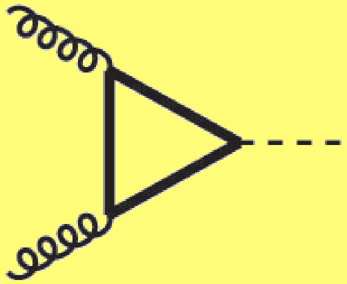

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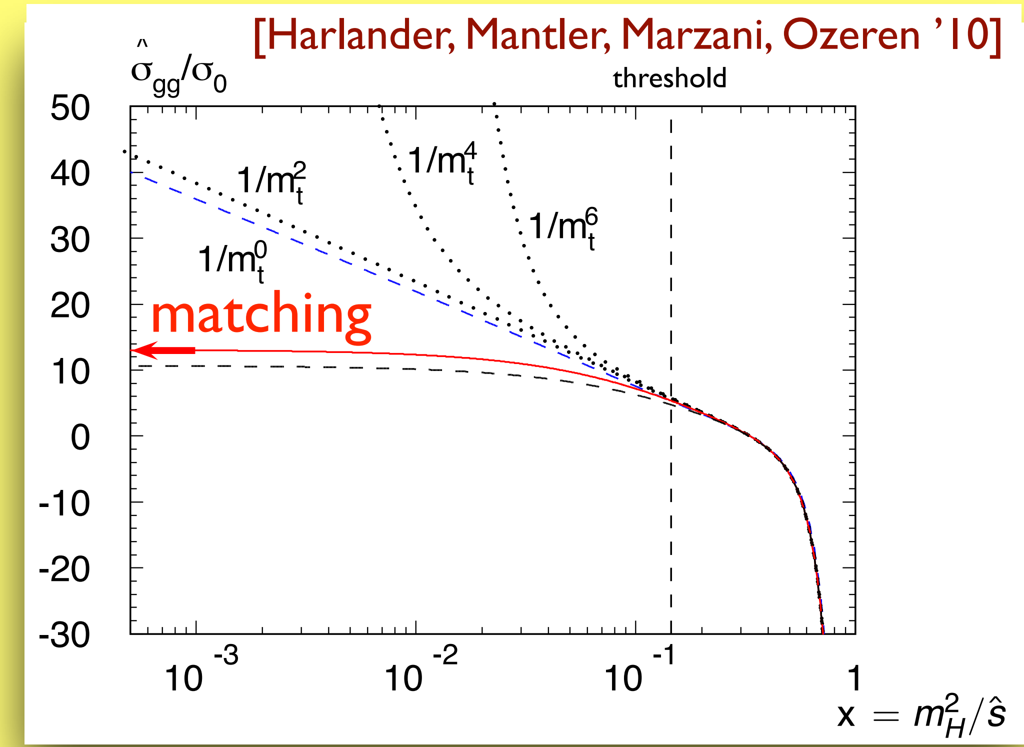
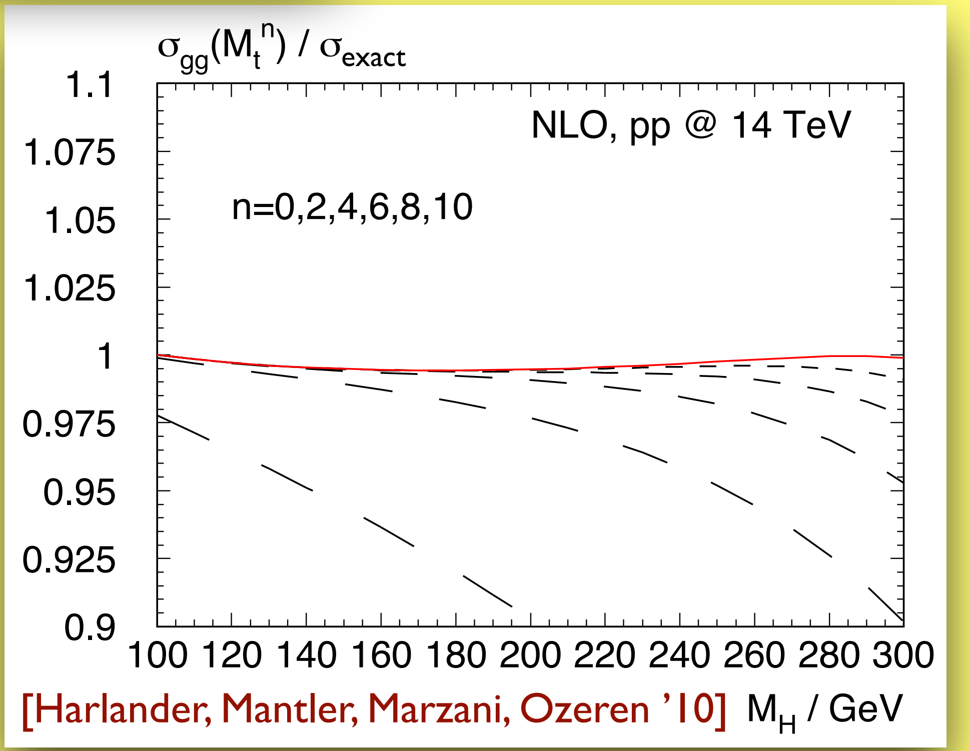
[Harlander, Mantler, Marzani, Ozeren '10]





Gluon Fusion

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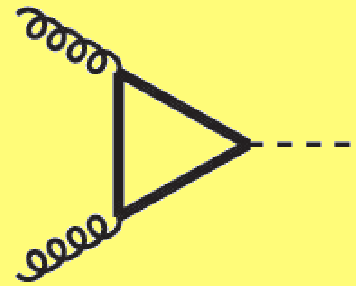

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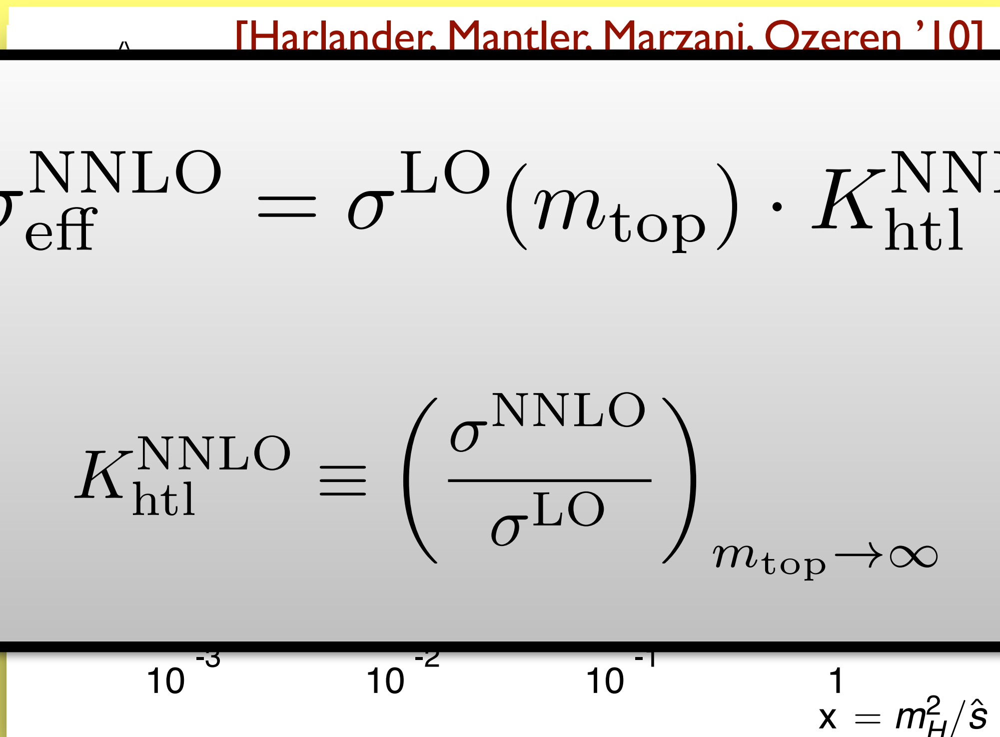
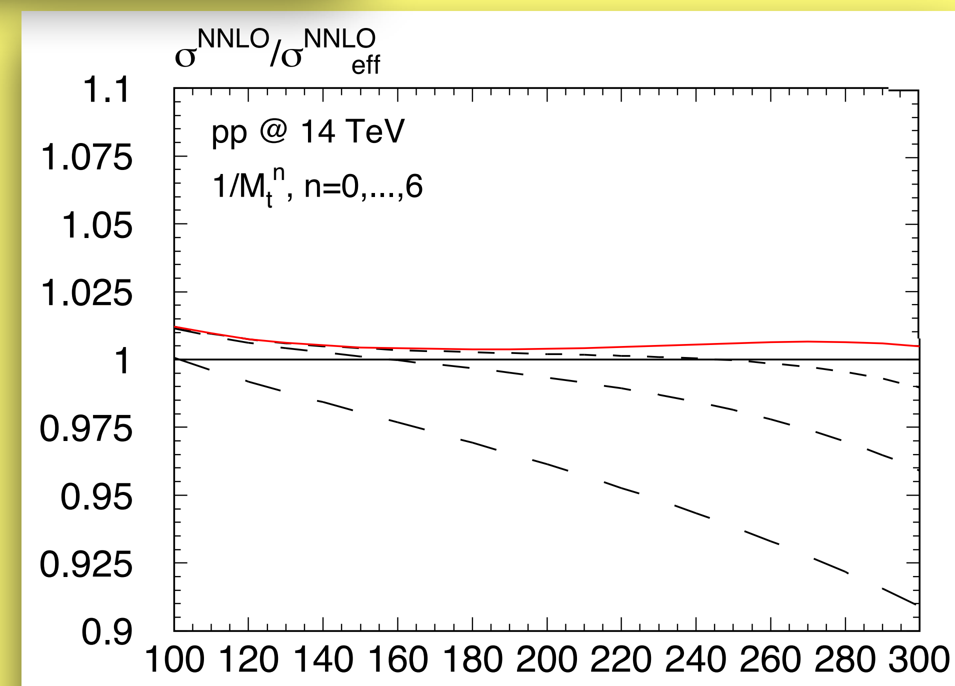


[Harlander, Mantler, Marzani, Ozeren '10]

$$\sigma_{\rm eff}^{\rm NNLO} = \sigma^{\rm LO}(m_{\rm top}) \cdot K_{\rm htl}^{\rm NNLO}$$

$$K_{\rm htl}^{\rm NNLO} \equiv \left(\frac{\sigma^{\rm NNLO}}{\sigma^{\rm LO}}\right)_{m_{\rm top}\to\infty}$$



[Harlander, Mantler, Marzani, Ozeren '10]

Gluon Fusion

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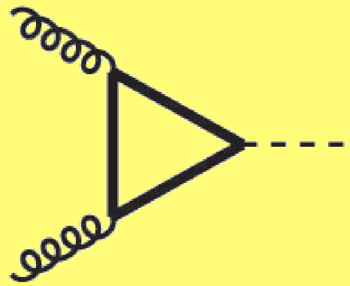

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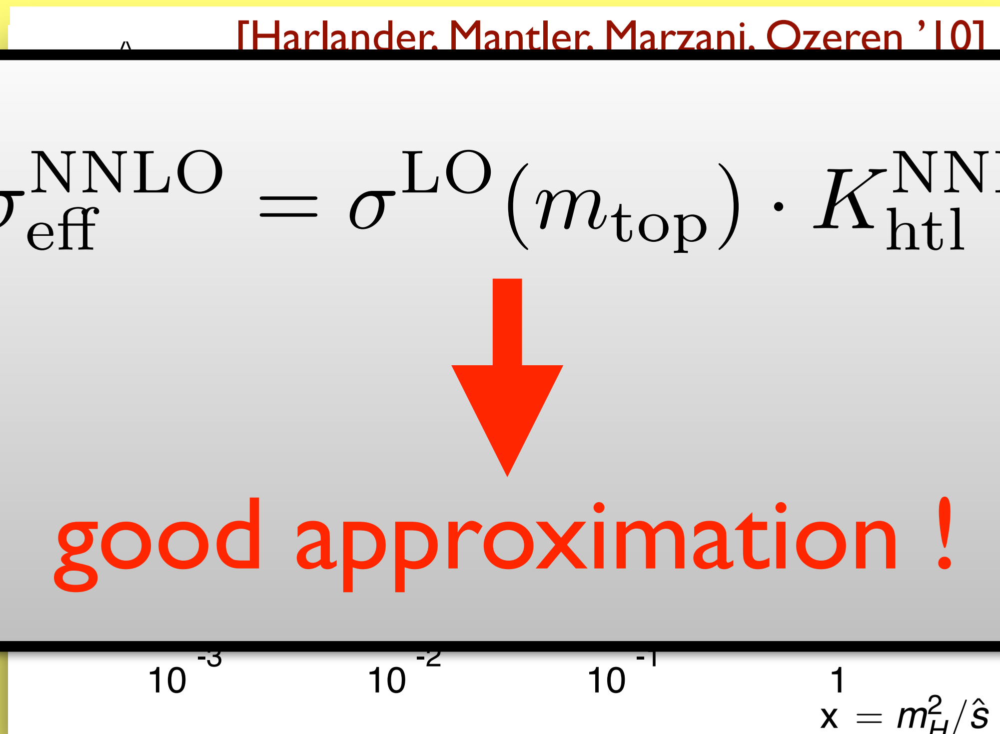
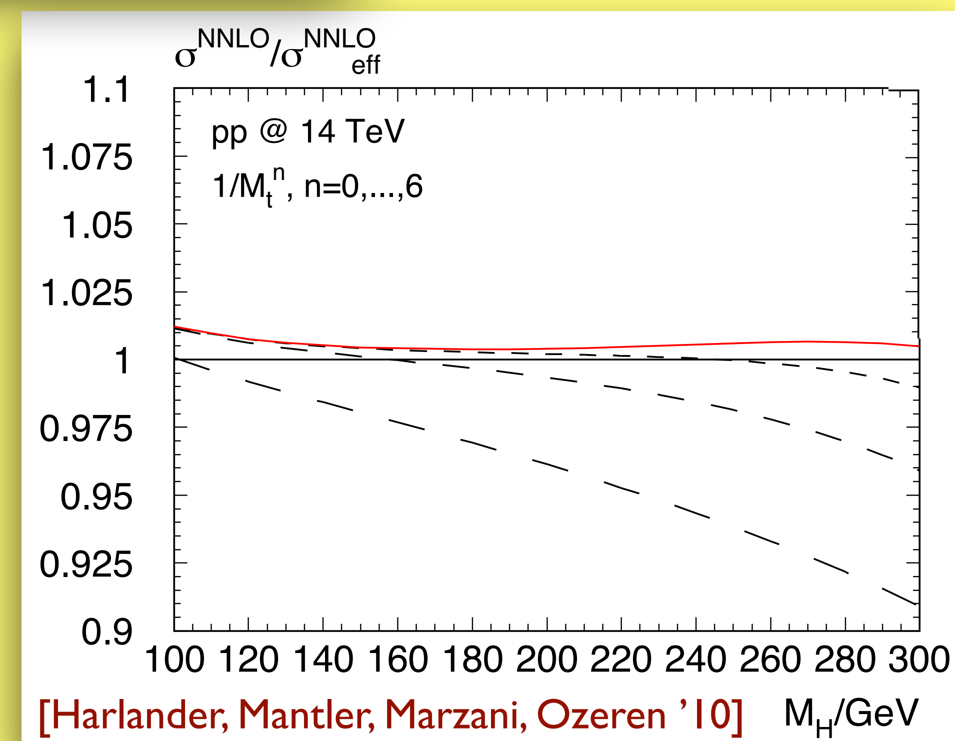


$$\sigma_{\rm eff}^{\rm NNLO} = \sigma^{\rm LO}(m_{\rm top}) \cdot K_{\rm htl}^{\rm NNLO}$$

good approximation !



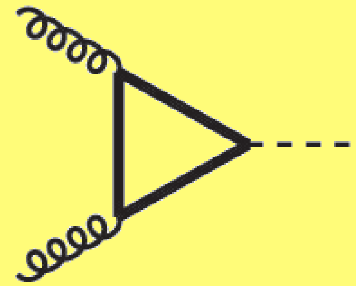
[Harlander, Mantler, Marzani, Ozeren '10]

→ top-mass effects <1%

see also: [Pak, Rogal, Steinhauser '10]

Gluon Fusion

Inclusive cross section



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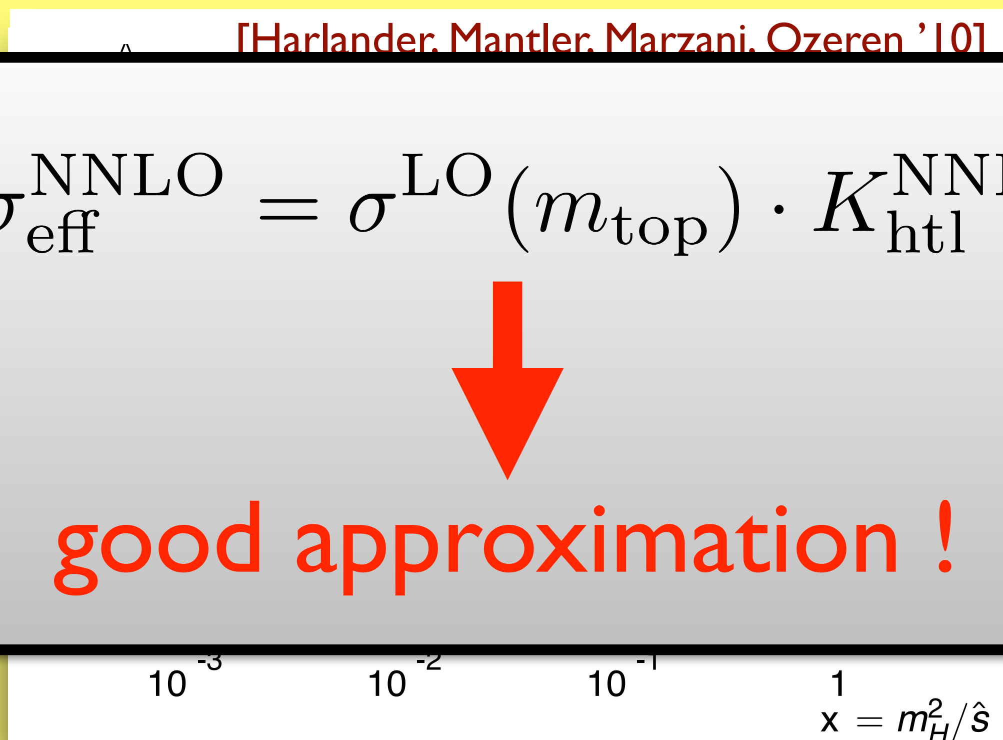
[Harlander, Mantler, Marzani, Ozeren '10]



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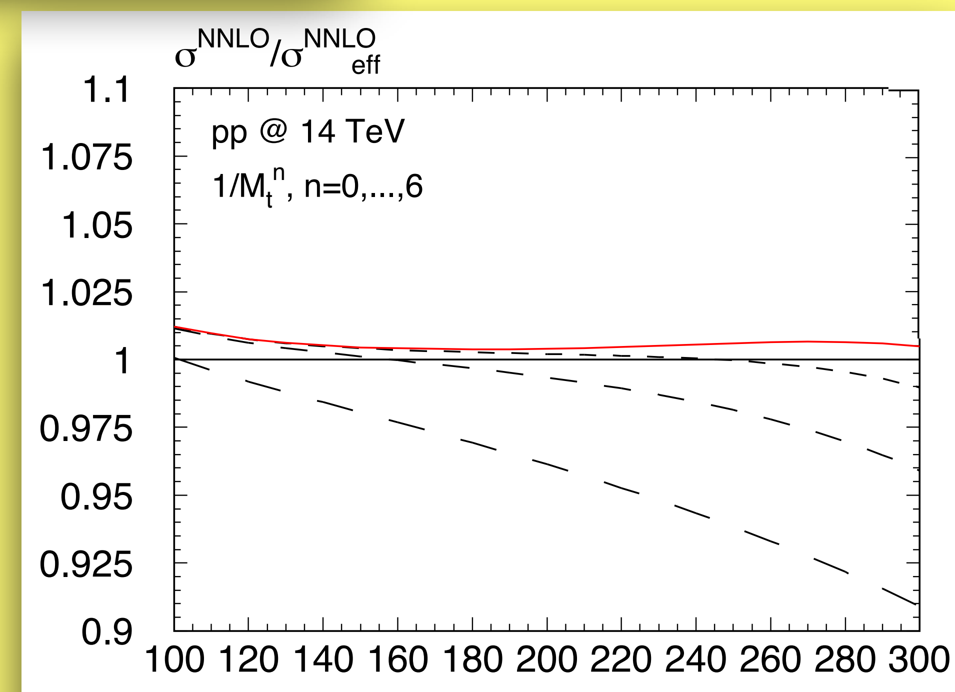
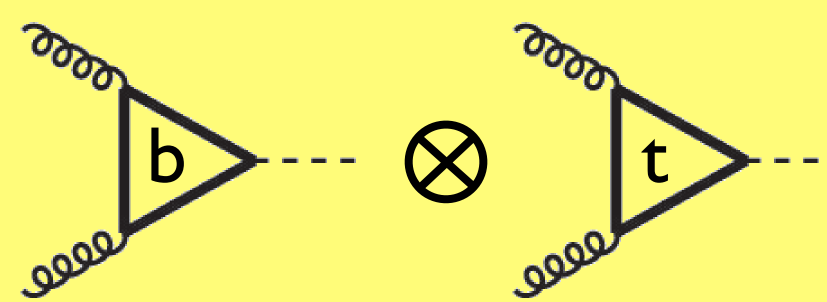


[Harlander, Mantler, Marzani, Ozeren '10]

→ top-mass effects <1%

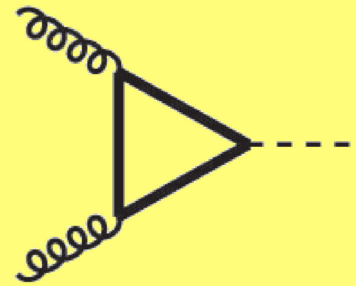
see also: [Pak, Rogal, Steinhauser '10]

- bottom-mass effects:
  - ~7% at NLO, mainly from interference:
  - expected to further decrease (smaller K-factor)
  - assume same K-factor (~1.3) → uncertainty at most +/-2% at N3LO



Gluon Fusion

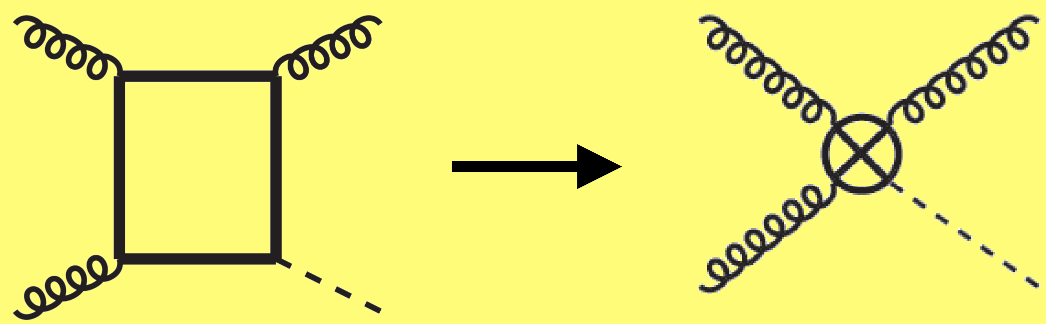
differential cross sections



Universität Zürich[UZH]

NEW: NNLO corrections at large p_T ~20% (H+jet computation)

- heavy-top limit:



- only gluon-gluon channel

[Boughezal, Caola, Melnikov, Petriello, Schulze '13]

[Chen, Gehrmann, Glover, Jaquier '14]

- all channels

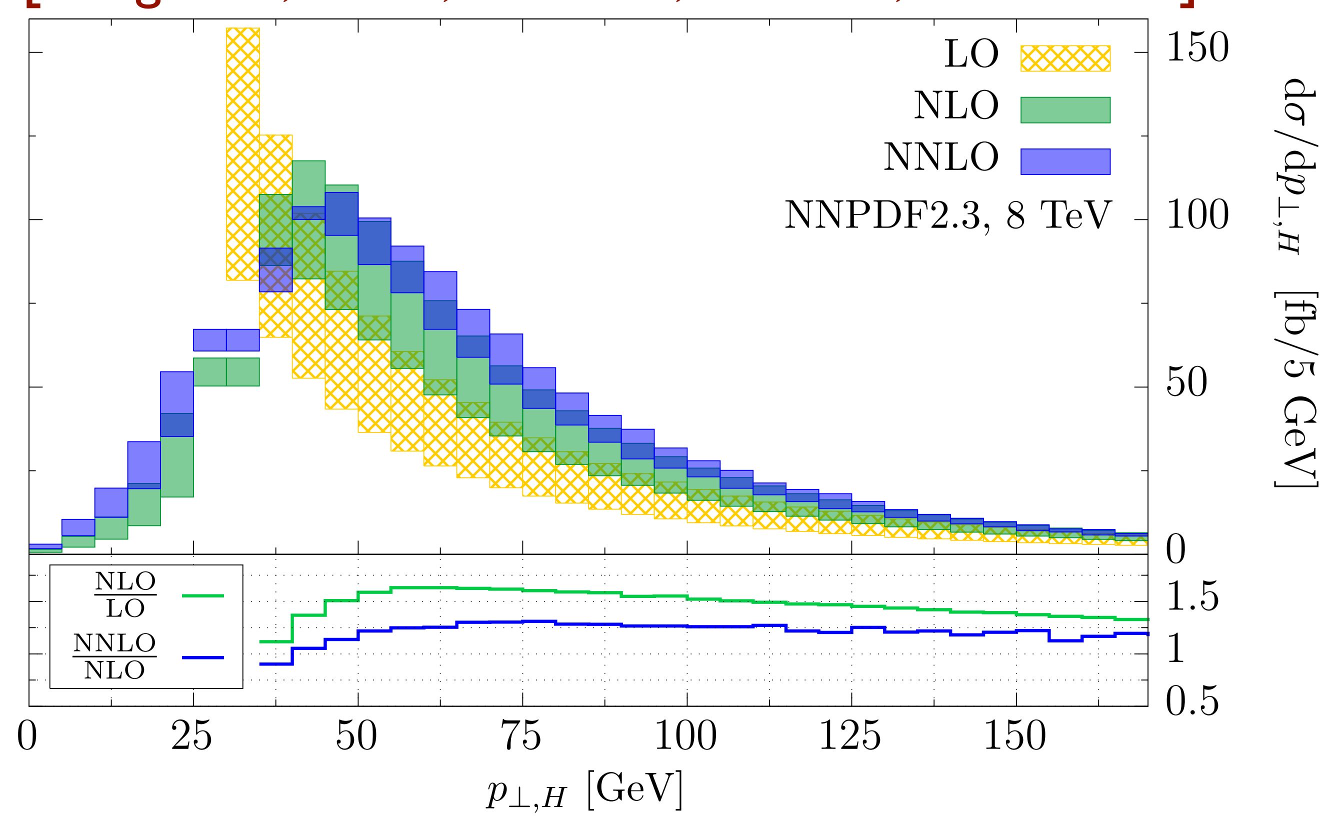
[Boughezal, Caola, Melnikov, Petriello, Schulze '15]

[Boughezal, Focke, Giele, Liu, Petriello '15]

- fiducial cross section

[Caola, Melnikov, Schulze '15]

[Boughezal, Caola, Melnikov, Petriello, Schulze '15]



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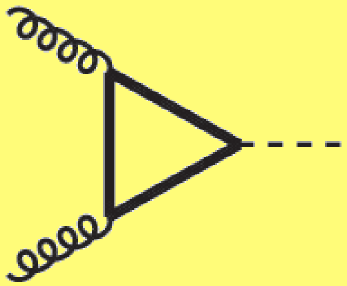
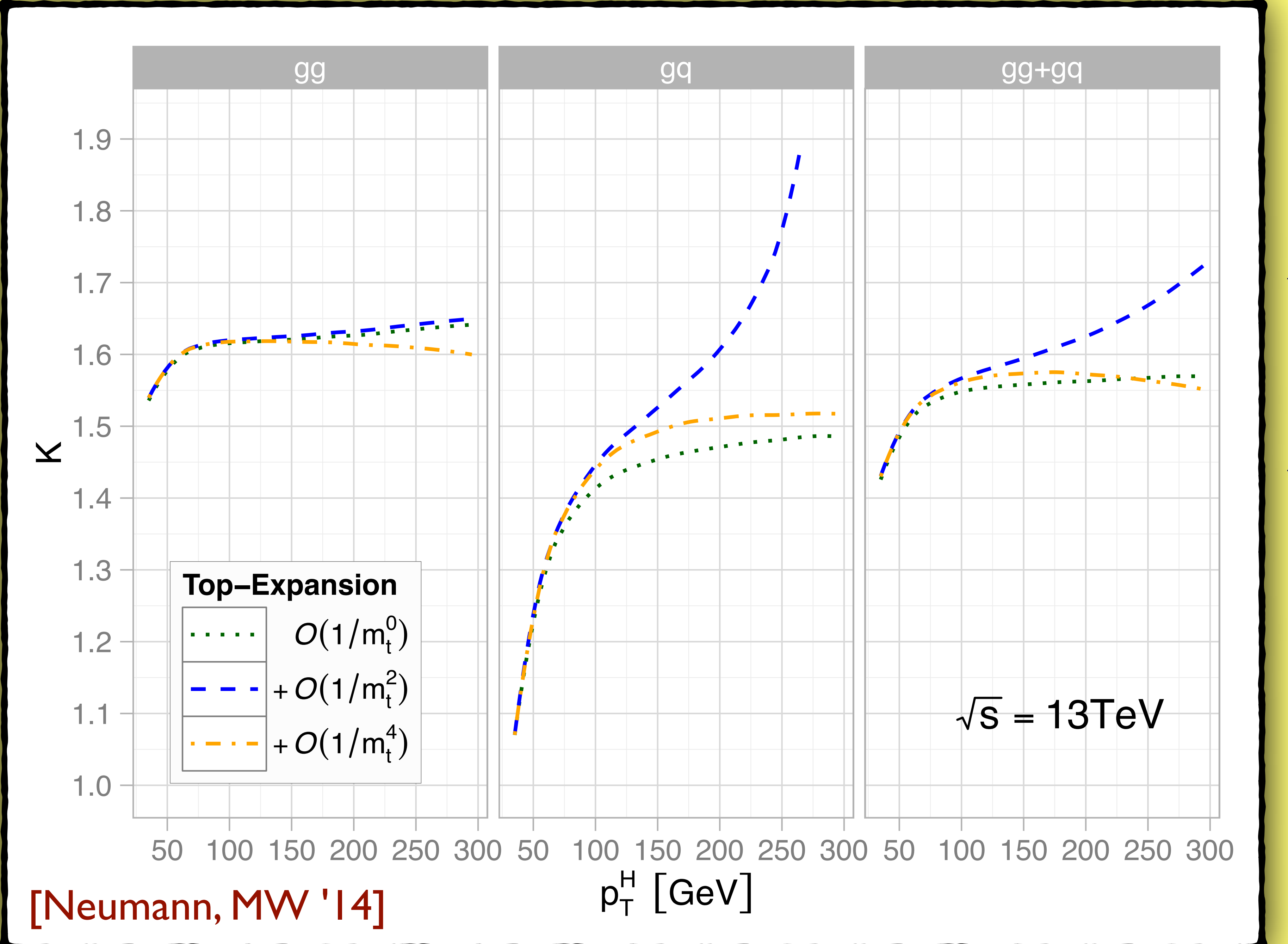


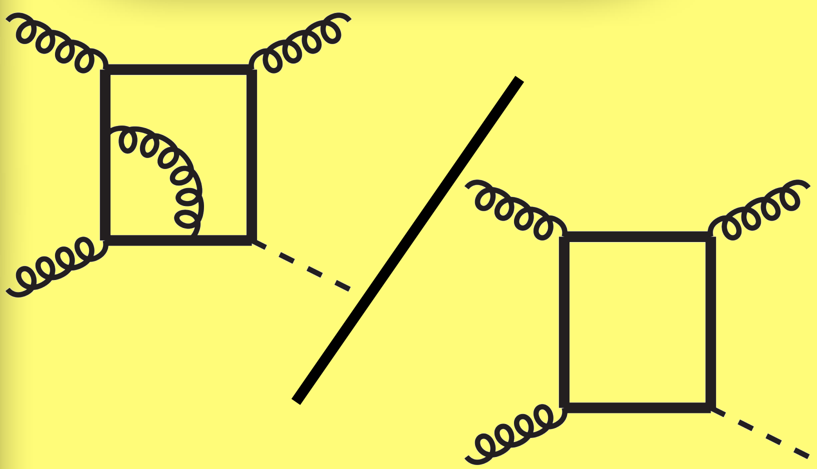
- top-mass effects on NLO corrections at large p_T



[Neumann, MW '14]

$$\sigma = \sum_{k=0}^{\infty} \frac{1}{m_{\text{top}}^{2k}} \sigma^{(k)}$$

$$K = \mathrm{d}\sigma^{\text{NLO}}/\mathrm{d}\sigma^{\text{LO}}$$

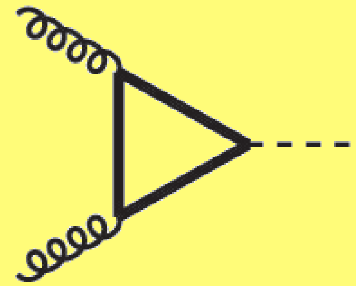


see also:

[Harlander, Neumann, MW '12]

Gluon Fusion

differential cross sections



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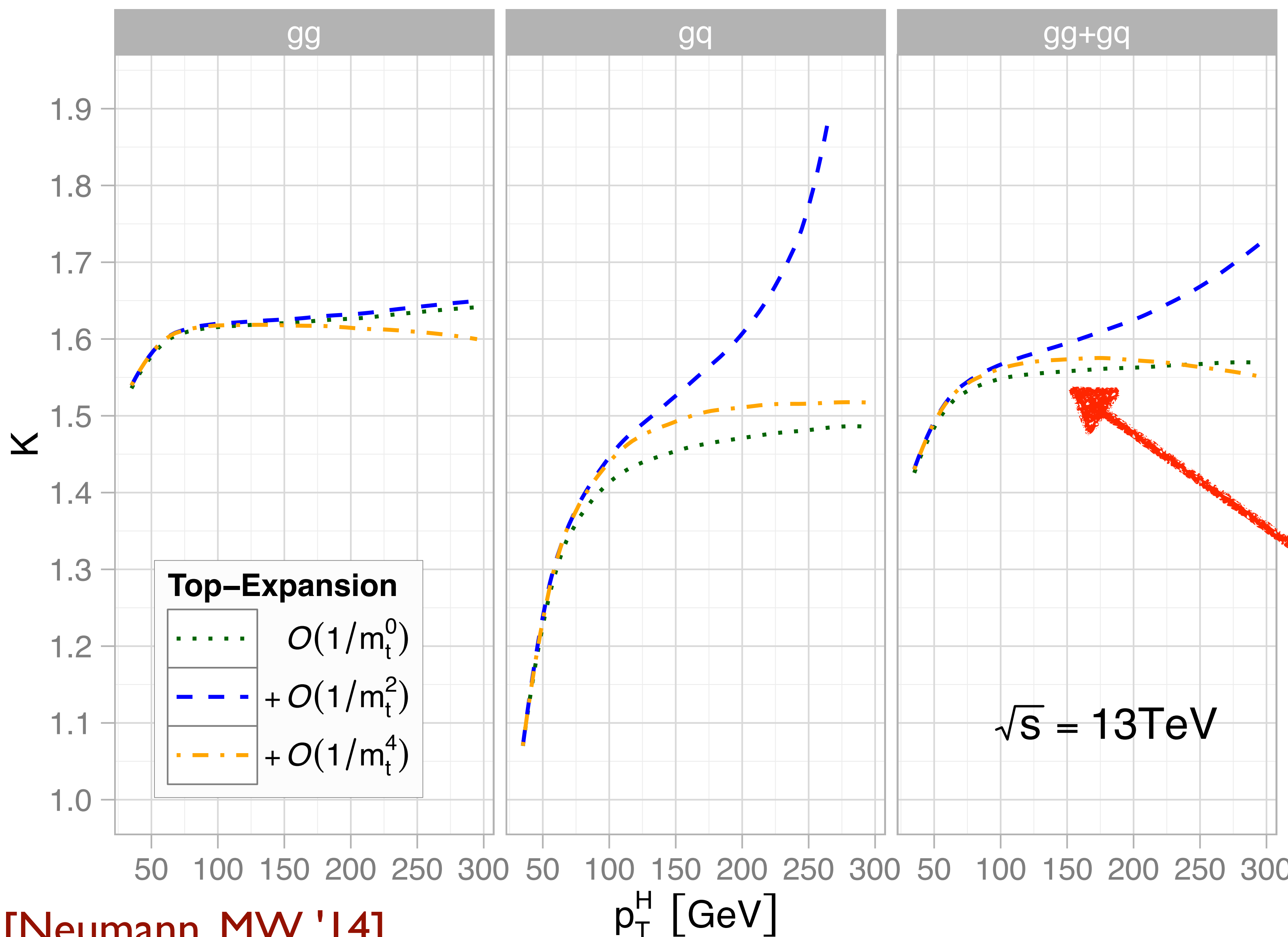

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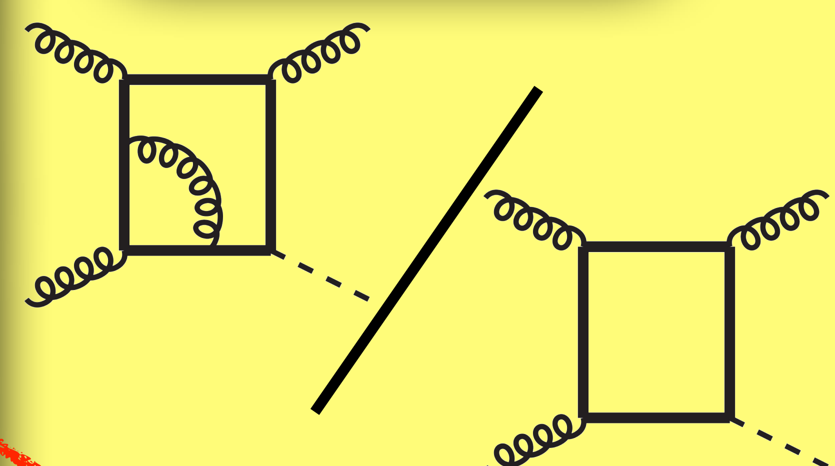


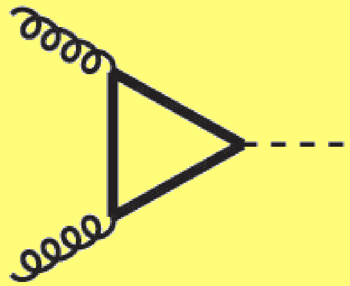
m_{top} effects below ~2% for p_T < 150 GeV

see also:

[Harlander, Neumann, MW '12]

Gluon Fusion

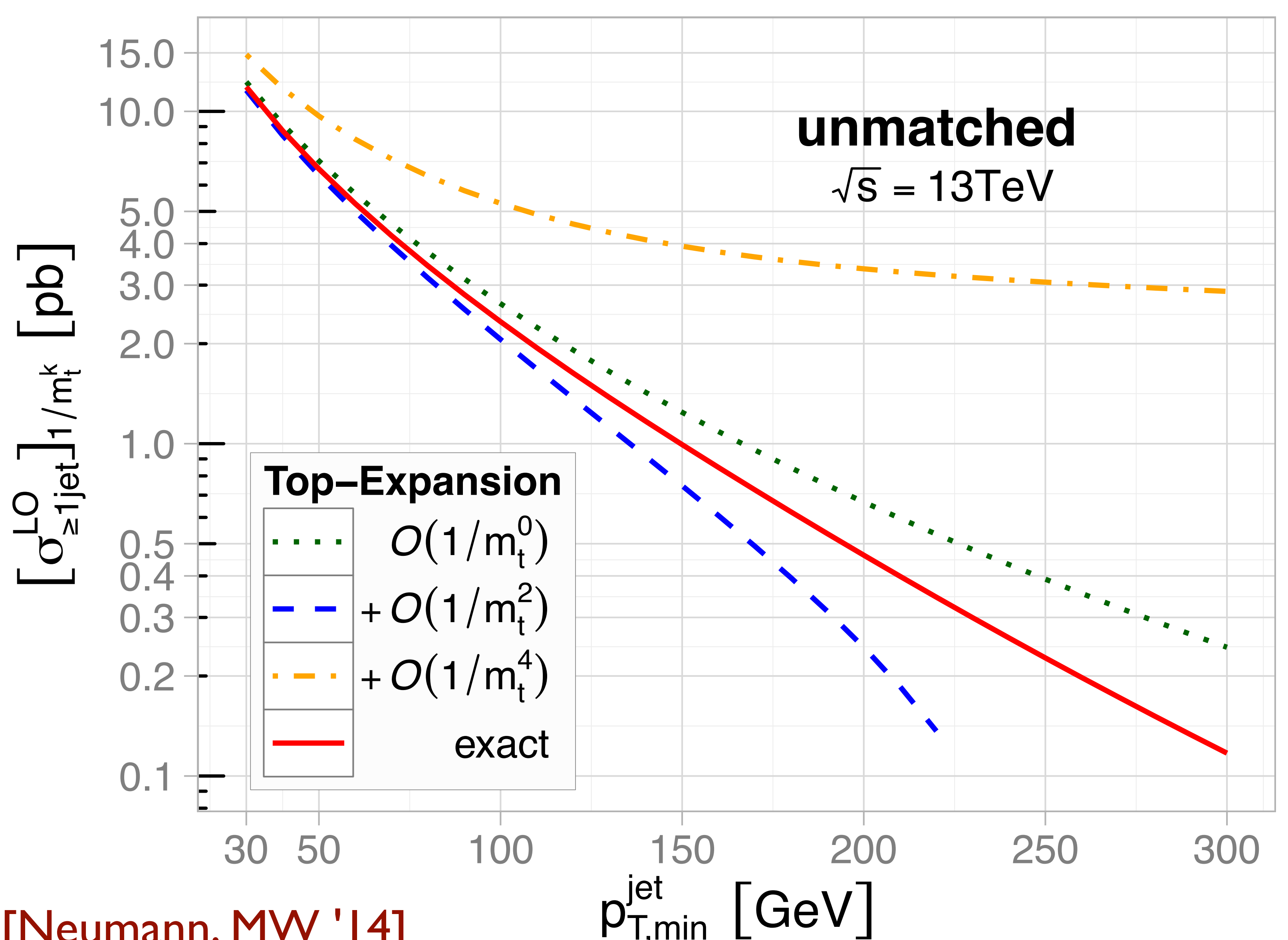
differential cross sections



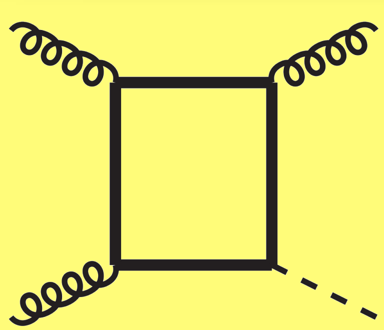
- top-mass effects on H+jet cross section at LO

$$\sigma = \sum_{k=0}^{\infty} \frac{1}{m_{\text{top}}^{2k}} \sigma^{(k)}$$

$$\sigma_{\geq 1\text{jet}} = \int_{p_{\text{T,min}}} \mathrm{d}p_{\text{T}} \frac{\mathrm{d}\sigma}{\mathrm{d}p_{\text{T}}}$$

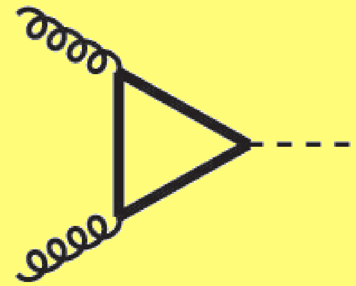


[Neumann, MW '14]



Gluon Fusion

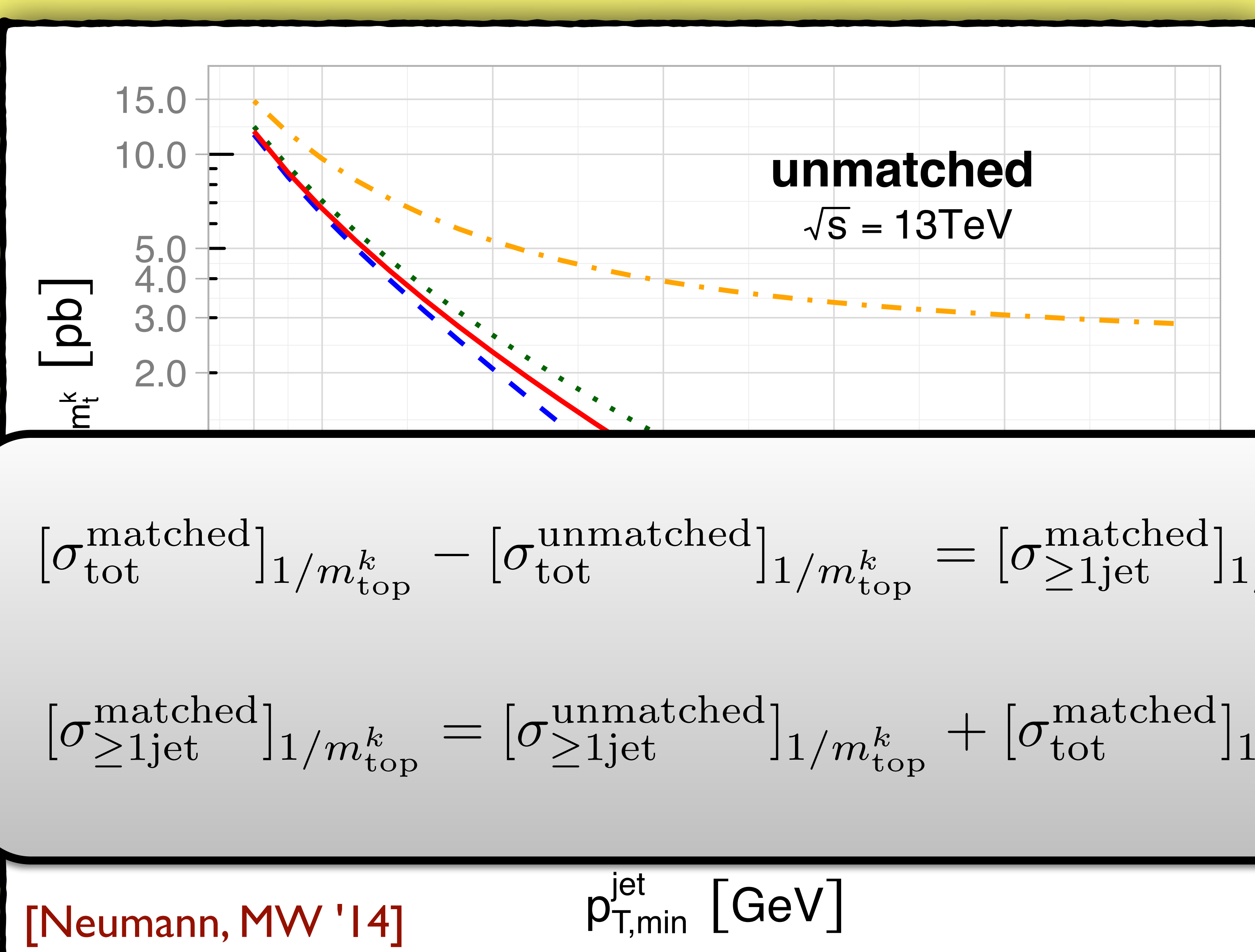
differential cross sections



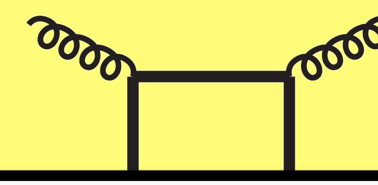
- top-mass effects on H+jet cross section at LO

$$\sigma = \sum_{k=0}^{\infty} \frac{1}{m_{\rm top}^{2k}}\,\sigma^{(k)}$$

$$\sigma_{\geq 1\rm jet} = \int_{p_{\rm T,min}} {\rm d}p_{\rm T}\,\frac{{\rm d}\sigma}{{\rm d}p_{\rm T}}$$



[Neumann, MW '14]

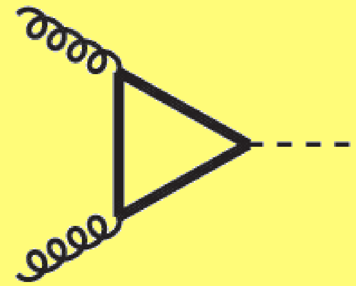


$$[\sigma^{\rm matched}_{\rm tot}]_{1/m^k_{\rm top}} - [\sigma^{\rm unmatched}_{\rm tot}]_{1/m^k_{\rm top}} = [\sigma^{\rm matched}_{\geq 1\rm jet}]_{1/m^k_{\rm top}} - [\sigma^{\rm unmatched}_{\geq 1\rm jet}]_{1/m^k_{\rm top}}$$

$$[\sigma^{\rm matched}_{\geq 1\rm jet}]_{1/m^k_{\rm top}} = [\sigma^{\rm unmatched}_{\geq 1\rm jet}]_{1/m^k_{\rm top}} + [\sigma^{\rm matched}_{\rm tot}]_{1/m^k_{\rm top}} - [\sigma^{\rm unmatched}_{\rm tot}]_{1/m^k_{\rm top}}$$

Gluon Fusion

differential cross sections



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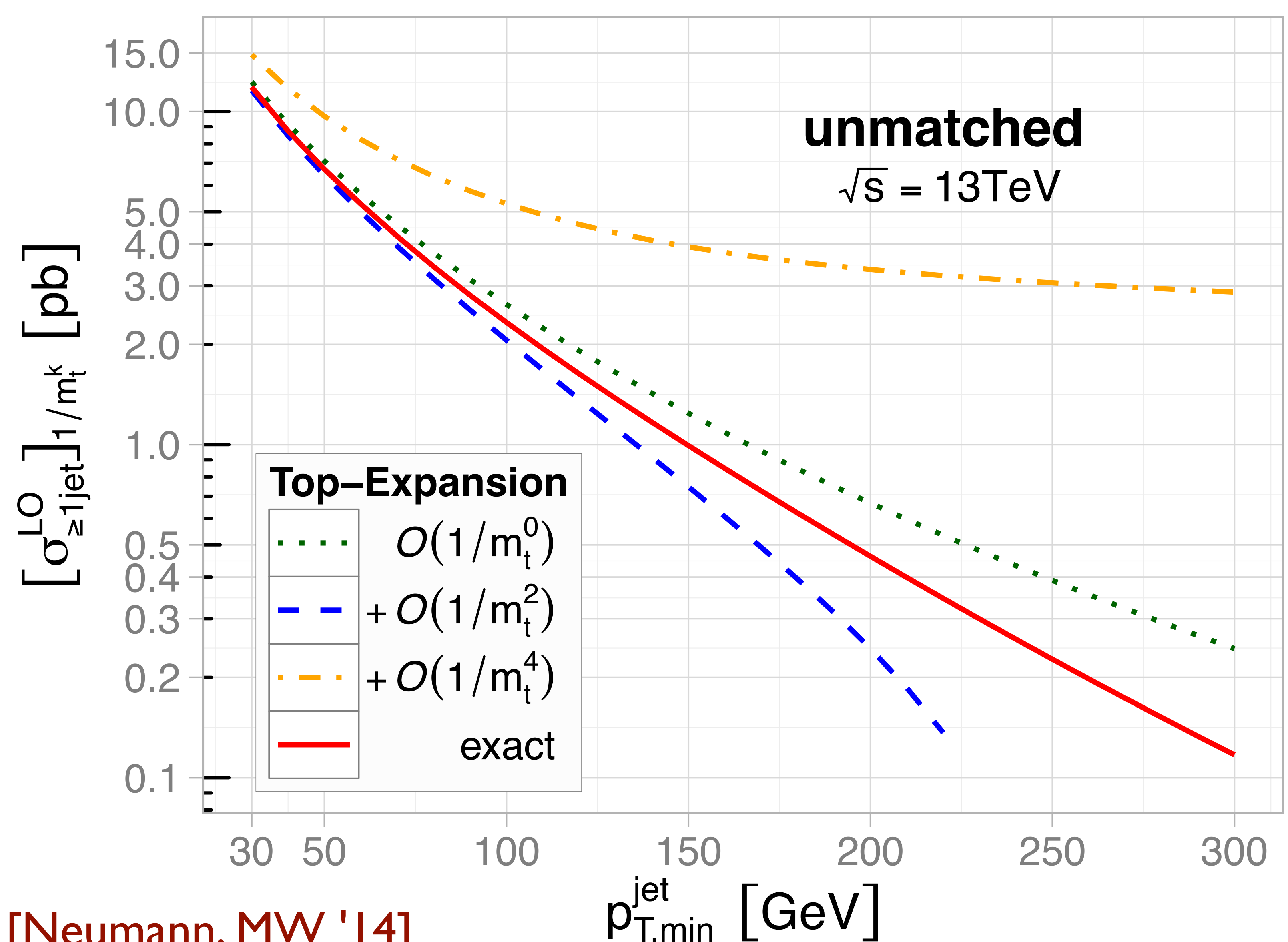

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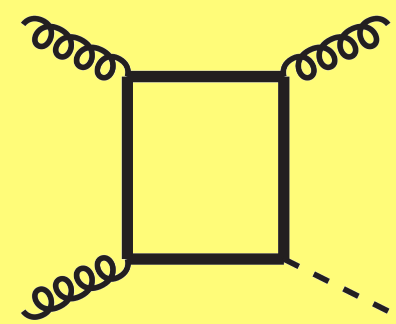
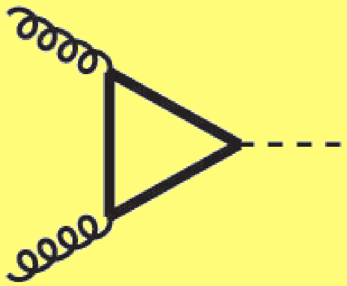


Gluon Fusion

differential cross sections



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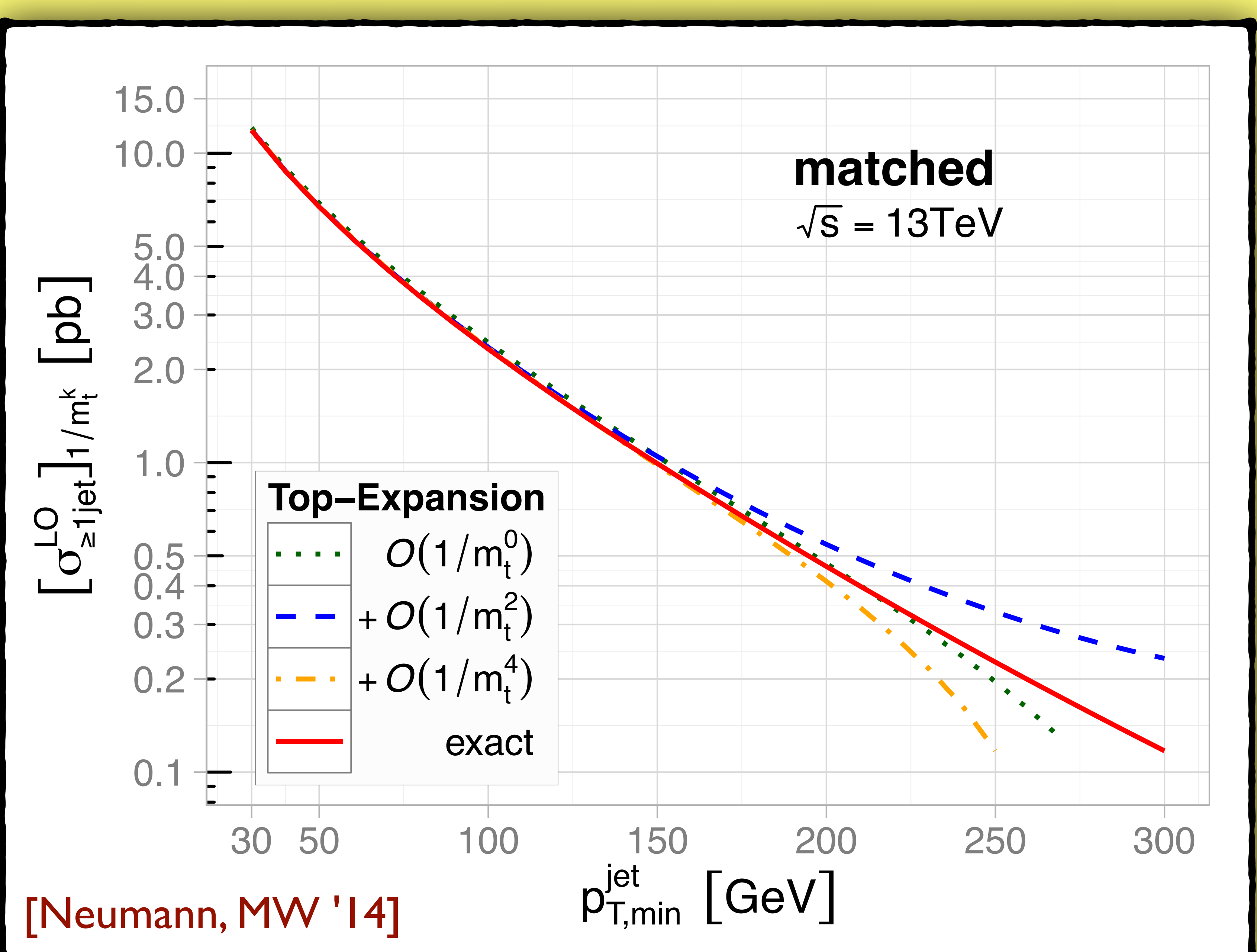

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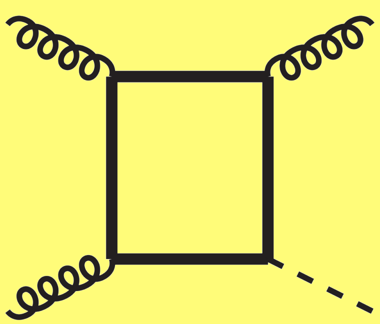
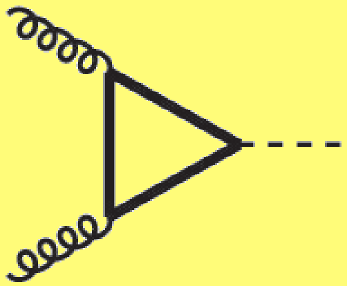


Gluon Fusion

differential cross sections



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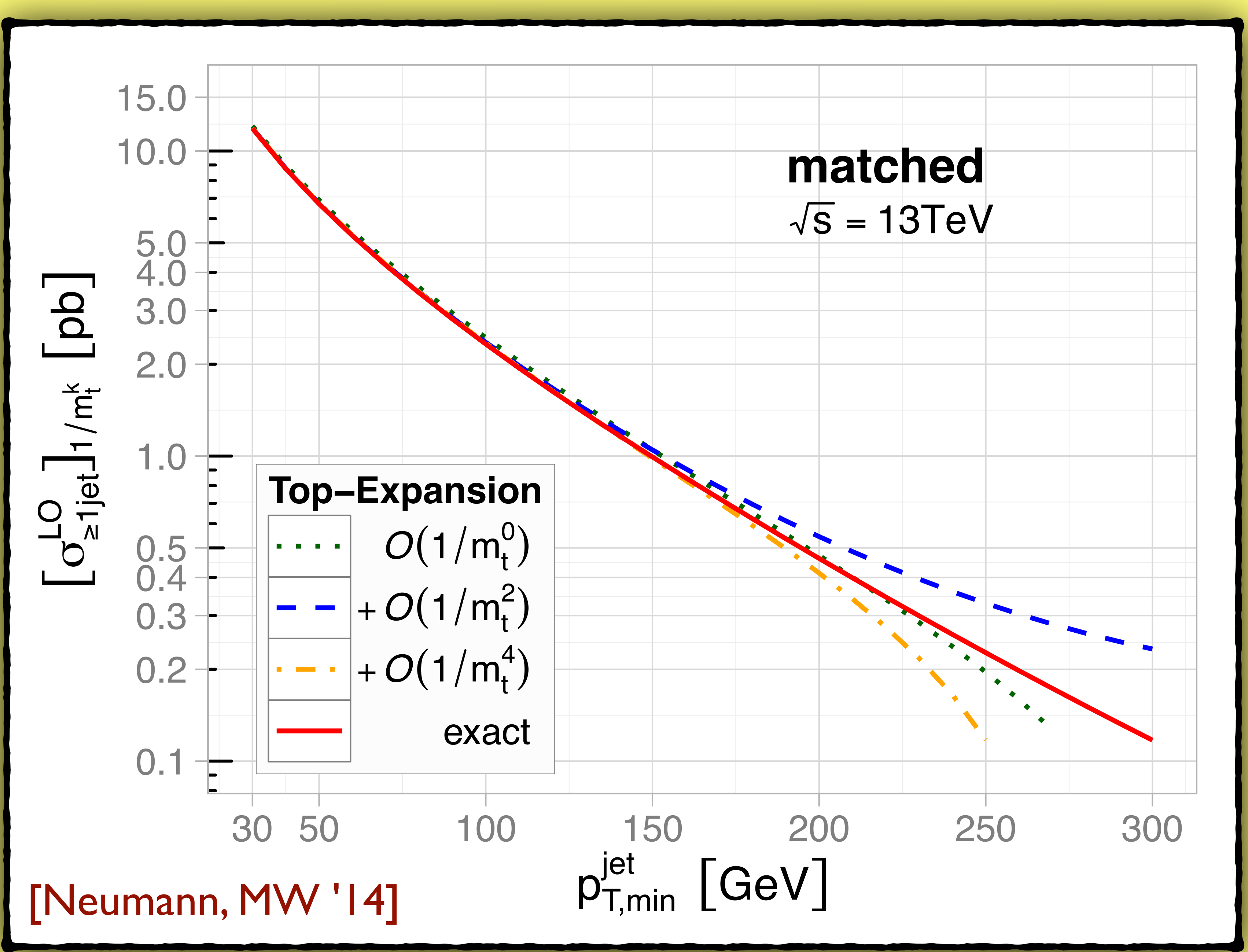

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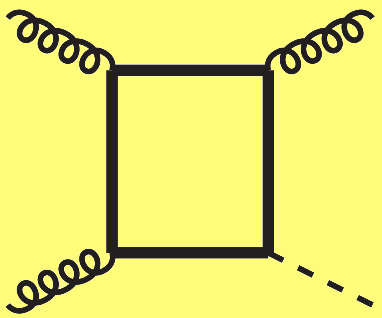
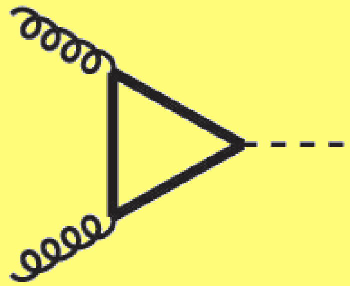


convergence of m_{top} expansion recovered !

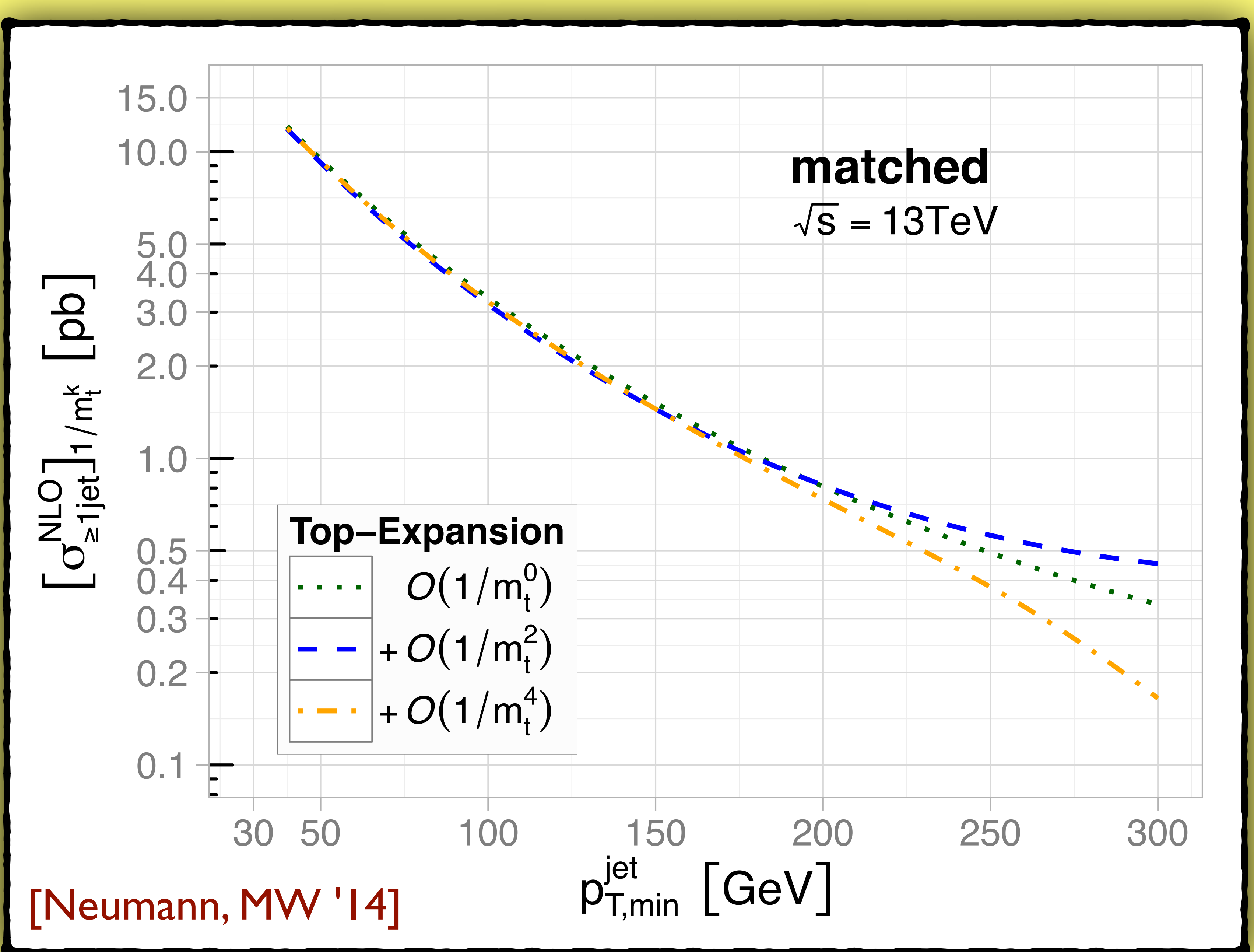
Gluon Fusion

differential cross sections



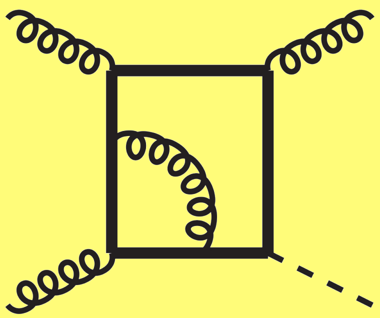
- top-mass effects on H+jet cross section at NLO

$$\sigma = \sum_{k=0}^{\infty} \frac{1}{m_{\text{top}}^{2k}}\, \sigma^{(k)}$$



[Neumann, MW '14]

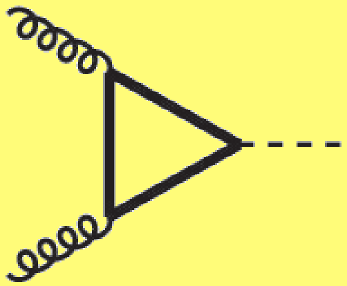
$$\sigma_{\geq 1\mathrm{jet}} = \int_{p_{\mathrm{T,min}}} \mathrm{d}p_{\mathrm{T}}\, \frac{\mathrm{d}\sigma}{\mathrm{d}p_{\mathrm{T}}}$$



matched cross section: reliable NLO prediction

Gluon Fusion

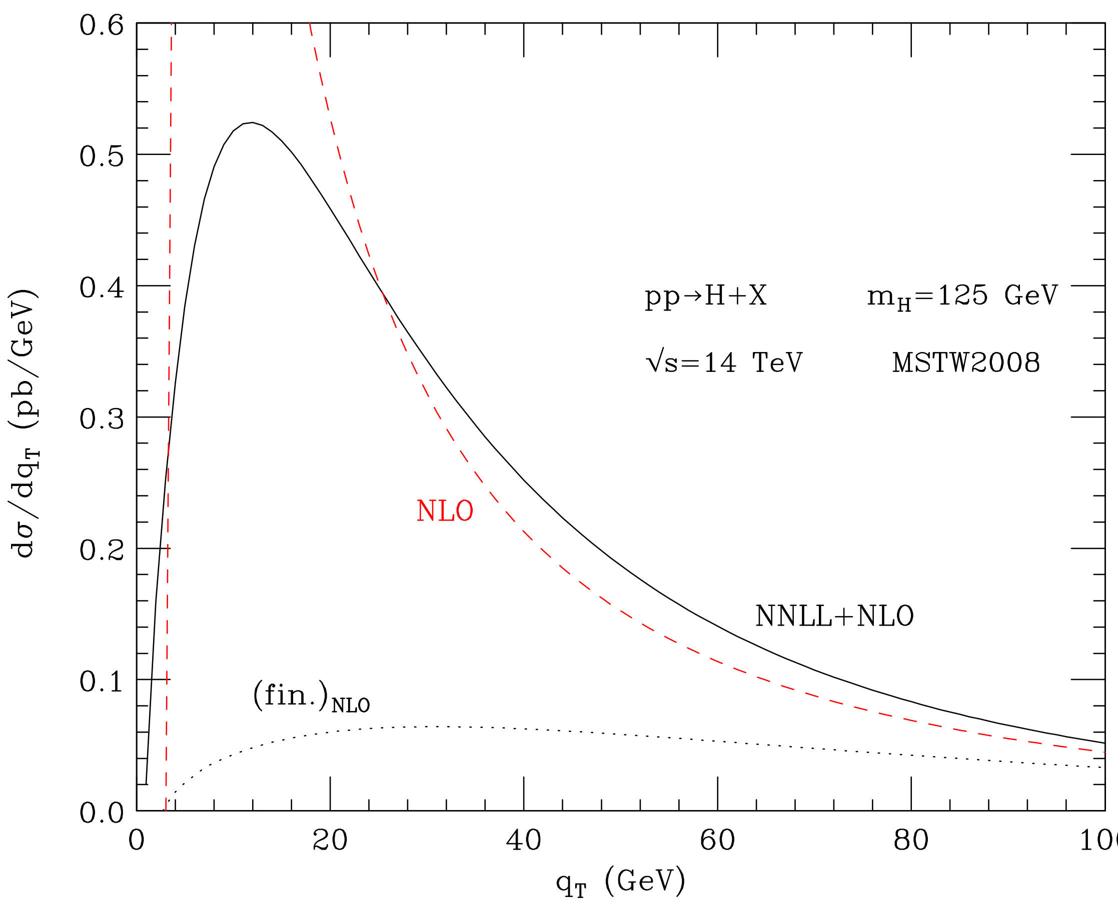
differential cross sections



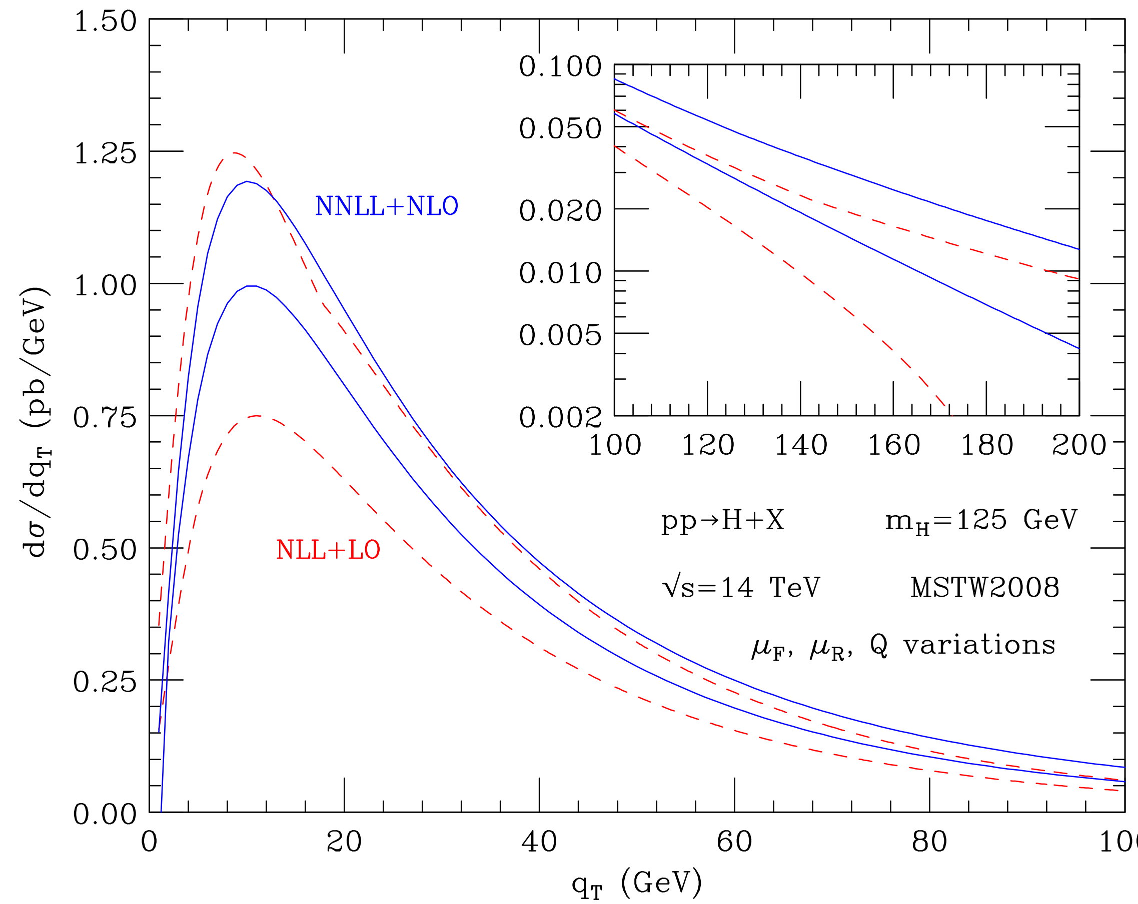
Small Transverse Momenta:

- divergent → requires resummation of $\log(p_T/m_H)$
- state-of-the-art still NNLO+NNLL:
  - HqT [Bozzi, Catani, de Florian, Grazzini '03 '05], [de Florian, Ferrera, Grazzini, Tommasini '11]
  - HRes [de Florian, Ferrera, Grazzini, Tommasini '12], [Grazzini, Sargsyan '13]

[de Florian, Ferrera, Grazzini, Tommasini '11]

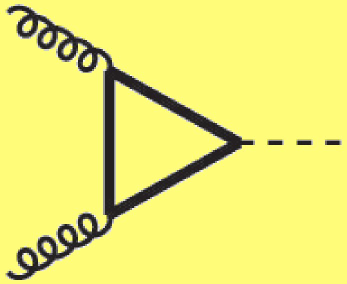


[de Florian, Ferrera, Grazzini, Tommasini '11]



Gluon Fusion

differential cross sections



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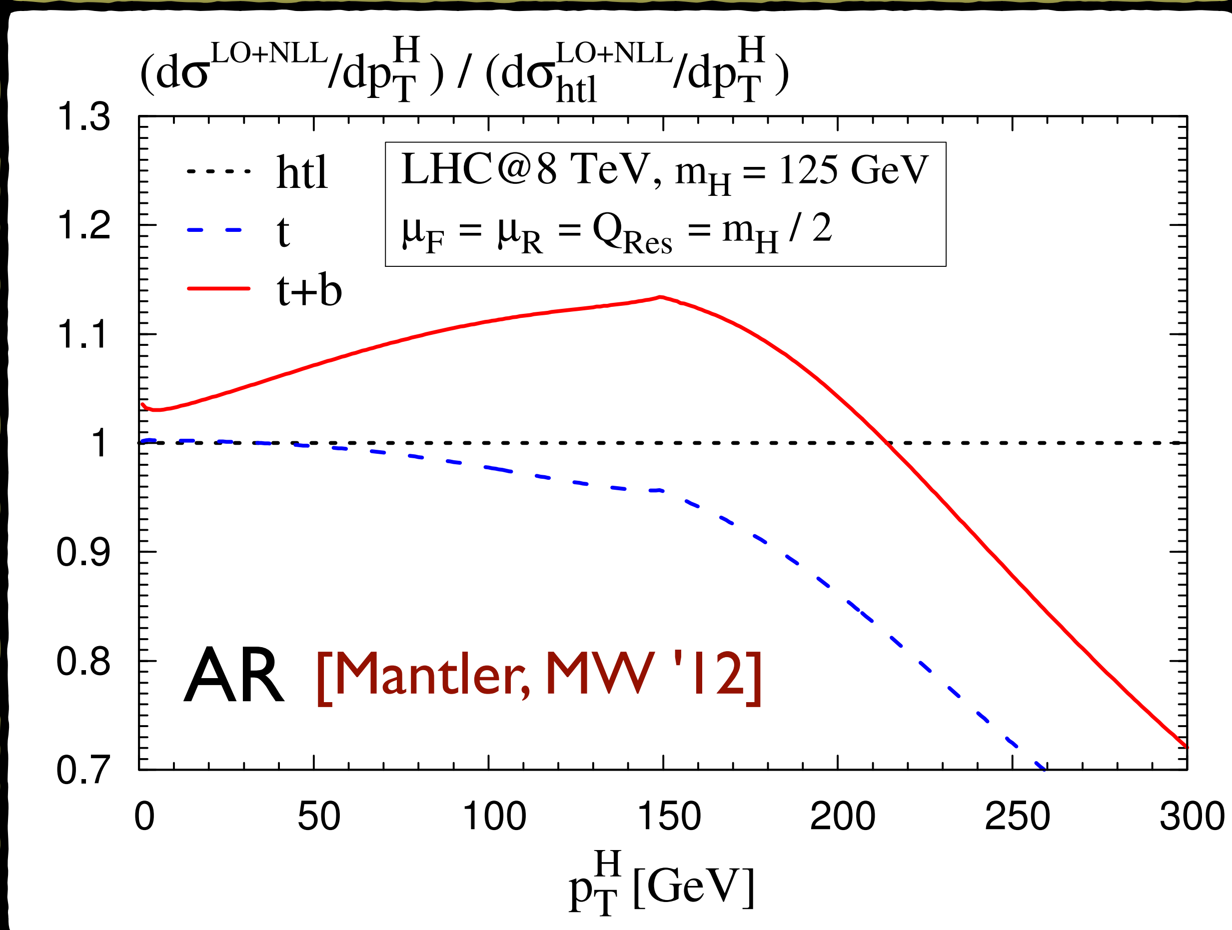
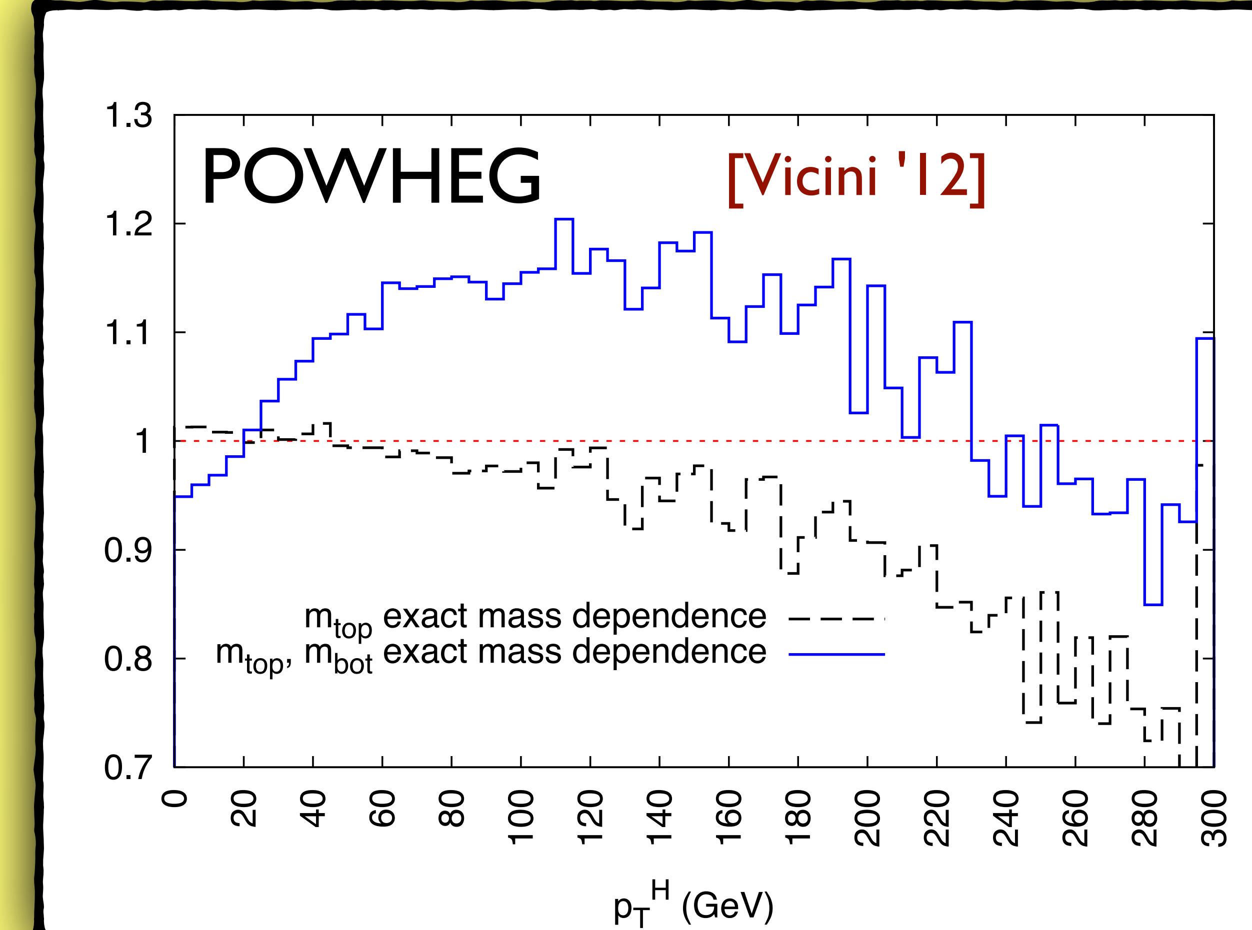
Small Transverse Momenta:

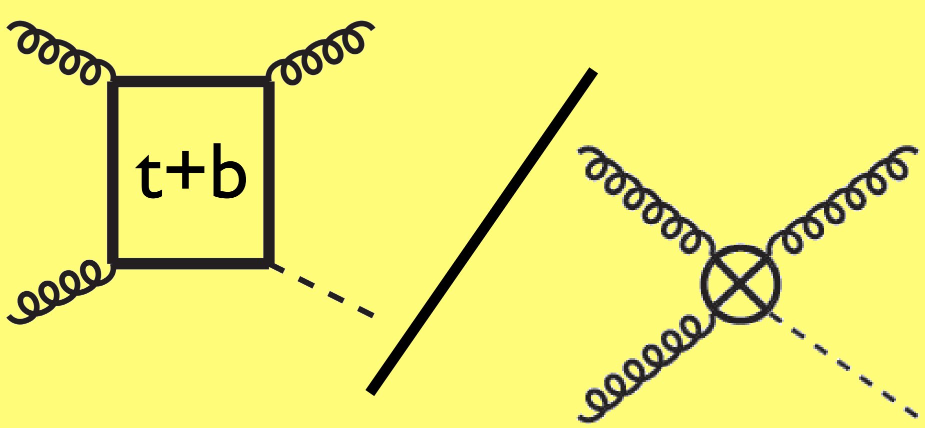
- top-mass effects small
- bottom-mass effects:
  - three scale problem!

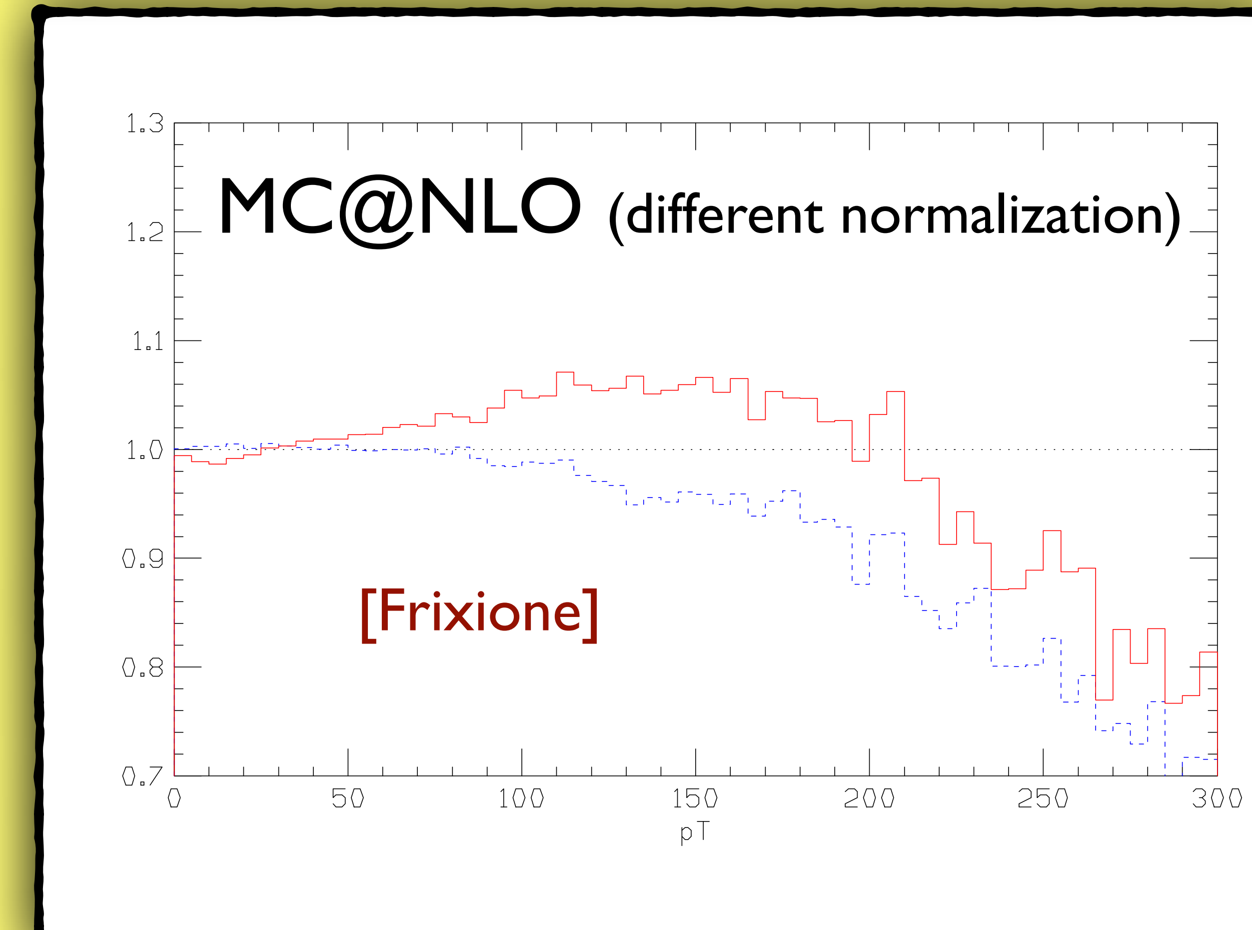
p_T, m_H, m_{bottom} (only two for top loop: p_T, $m_H \sim m_{top}$)

→ difficult choice of hard scale (matching/resummation scale)





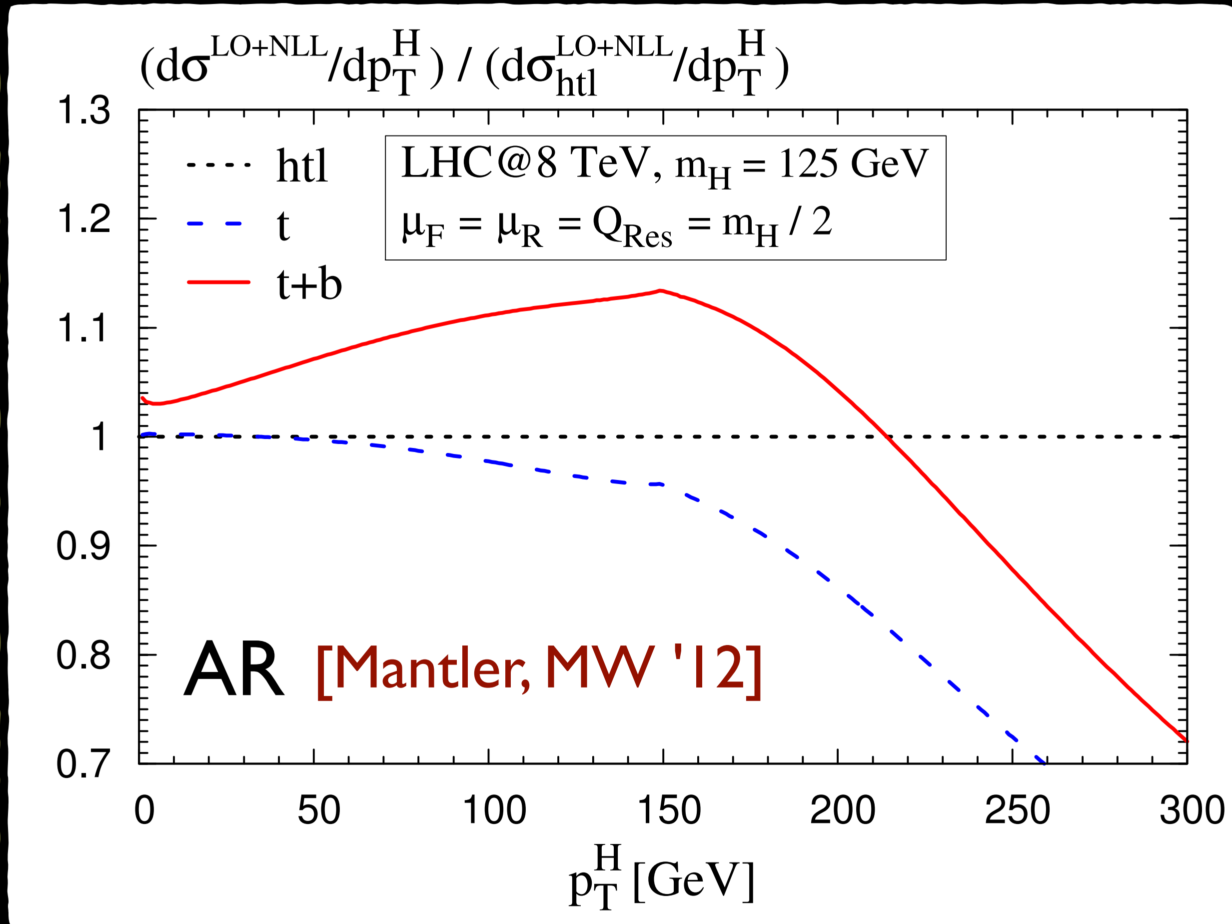


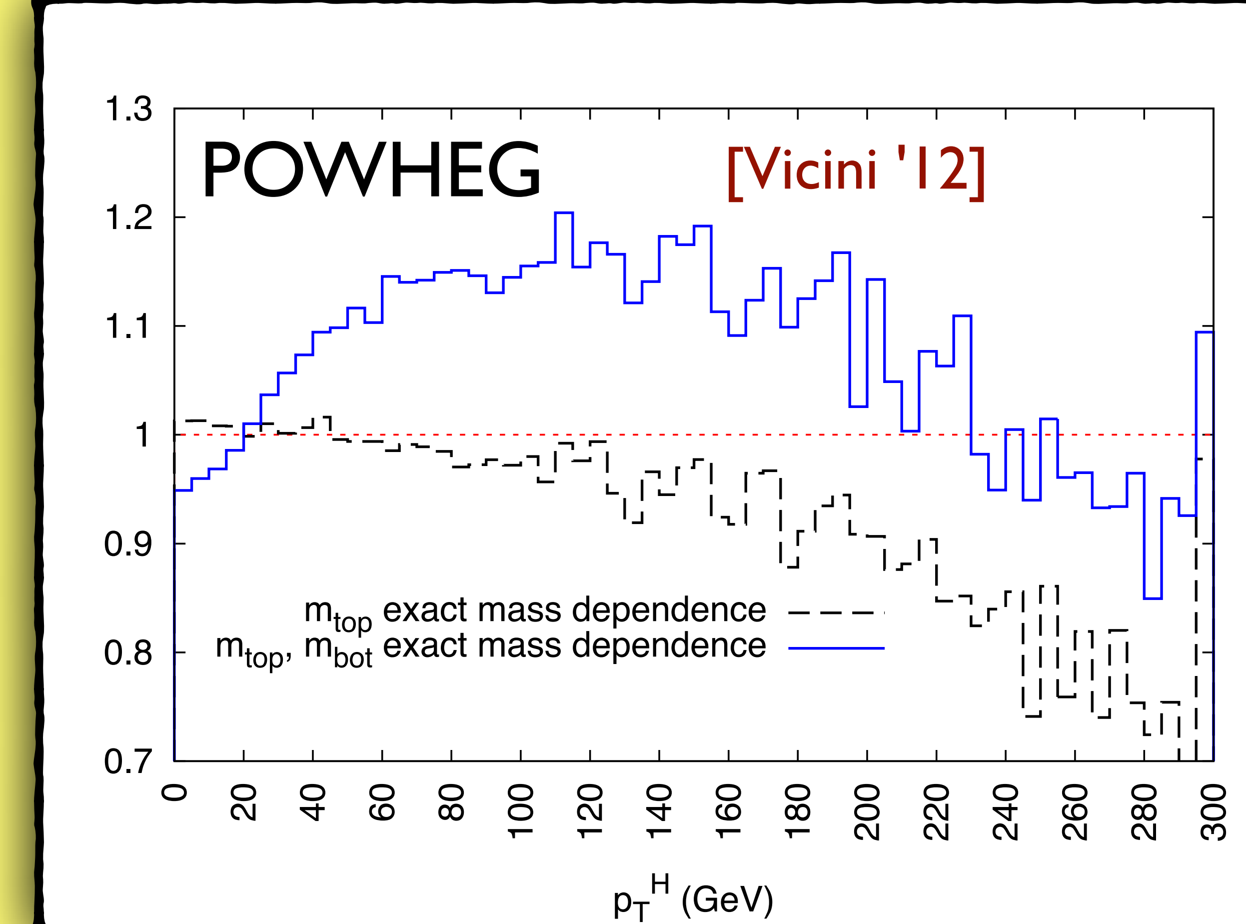


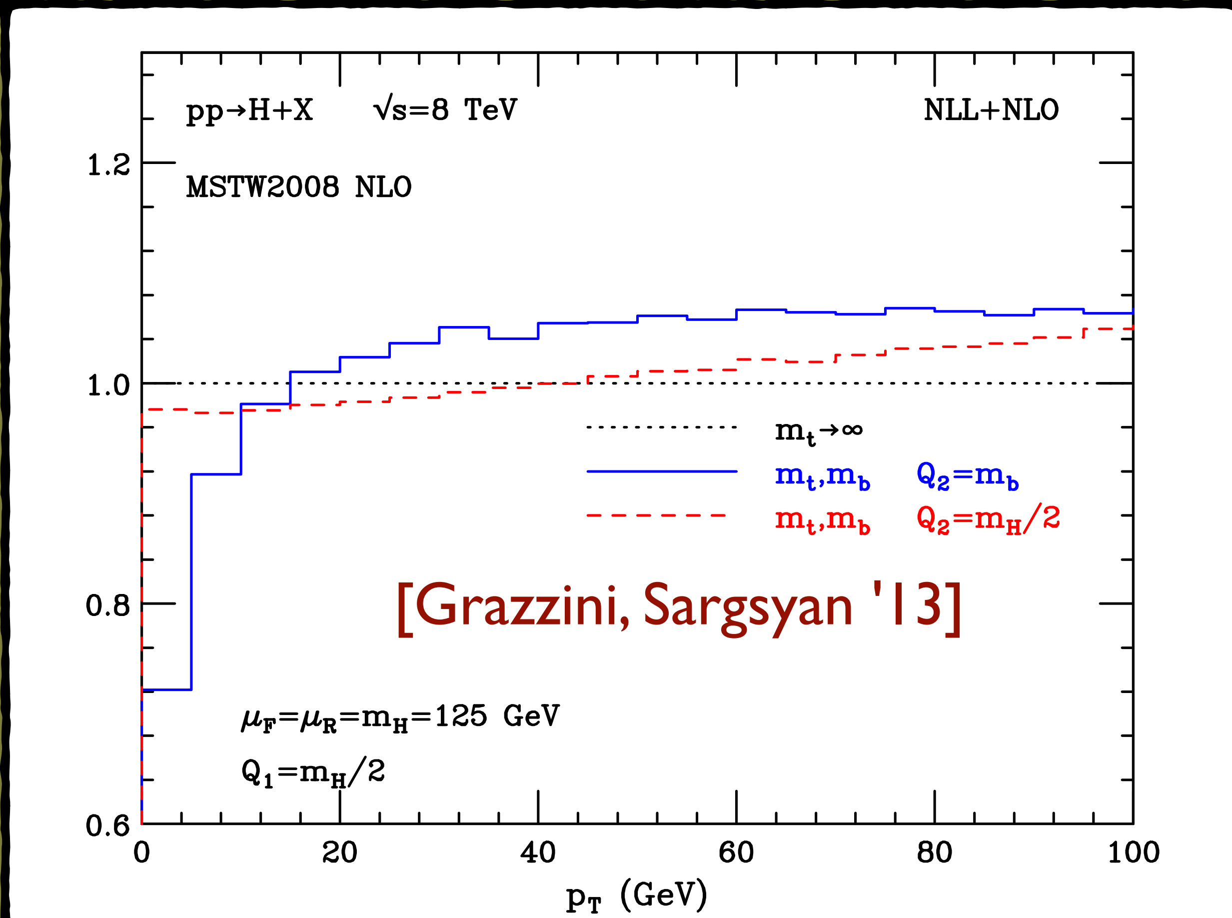
see also:

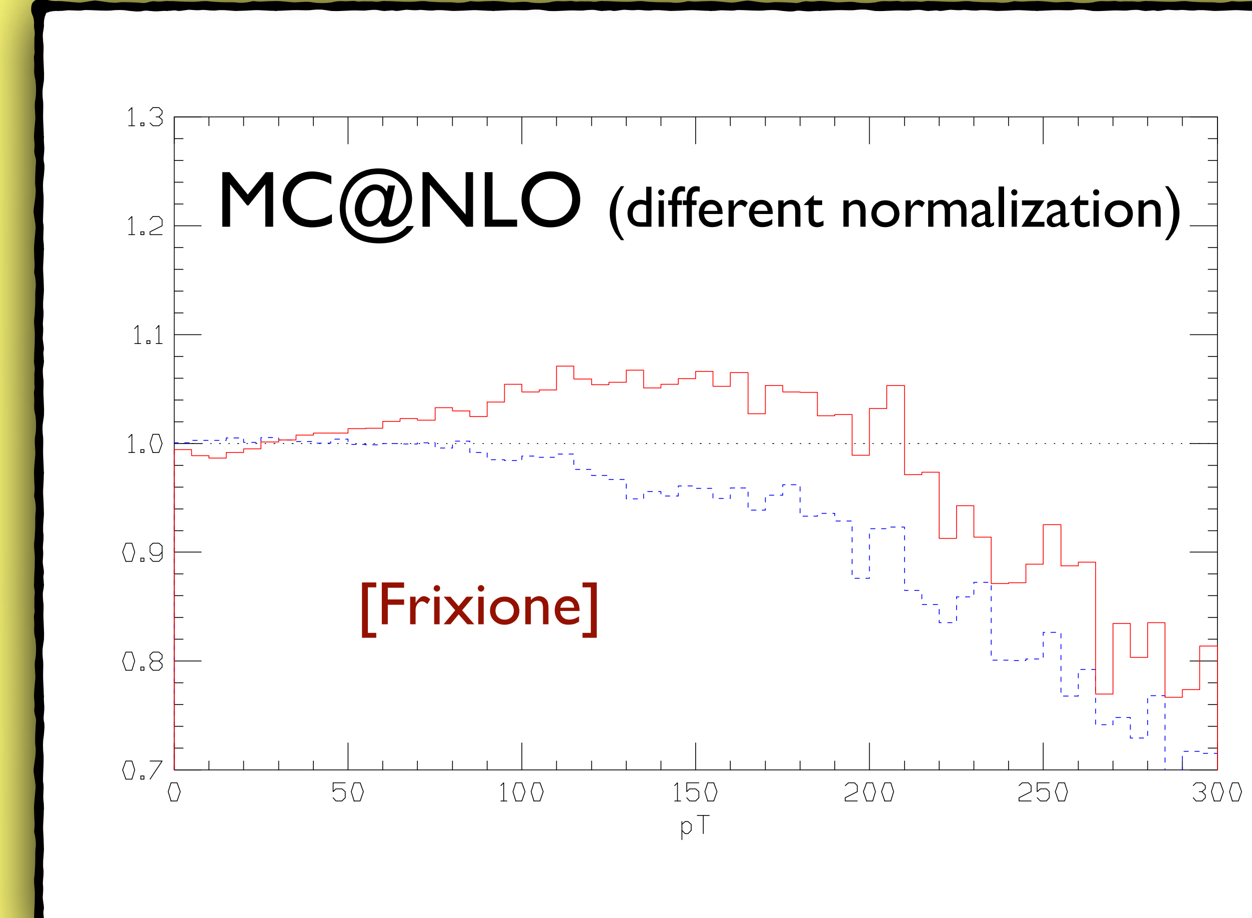
[Banfi, Monni, Zanderighi '13]

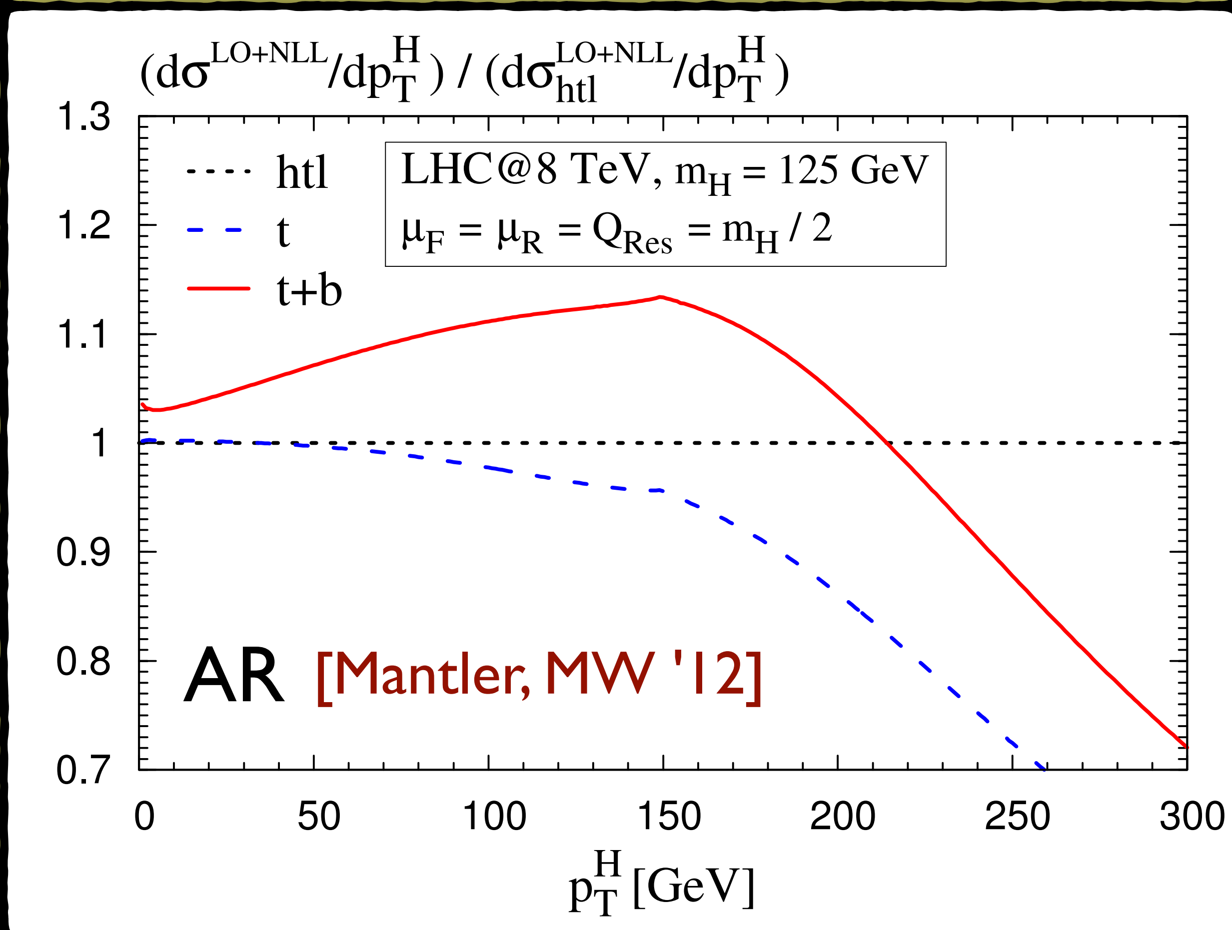
[Hamilton, Nason, Zanderighi '15]


$(d\sigma^{LO+NLL}/dp_T^H) / (d\sigma_{htl}^{LO+NLL}/dp_T^H)$
htl
t
t+b
LHC@8 TeV, m_H = 125 GeV
$\mu_F = \mu_R = Q_{Res} = m_H / 2$
AR [Mantler, MW '12]
p_T^H [GeV]

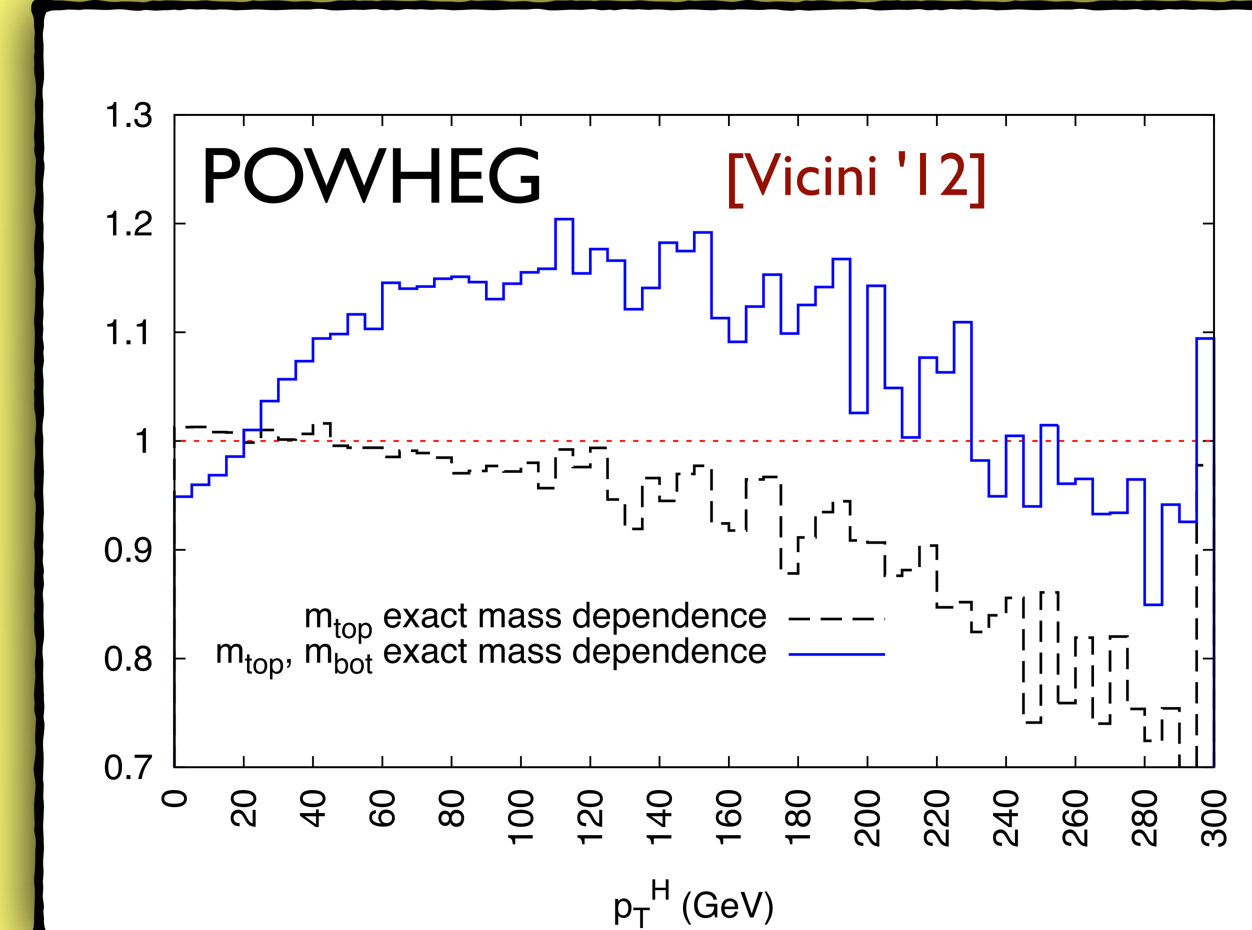

POWHEG
[Vicini '12]
m_{top} exact mass dependence
m_{top}, m_{bot} exact mass dependence
p_T^H (GeV)


pp→H+X √s=8 TeV
NLL+NLO
MSTW2008 NLO
$m_t \to \infty$
m_t, m_b $Q_2 = m_b$
m_t, m_b $Q_2 = m_H/2$
[Grazzini, Sargsyan '13]
$\mu_F = \mu_R = m_H = 125$ GeV
$Q_1 = m_H/2$
p_T (GeV)

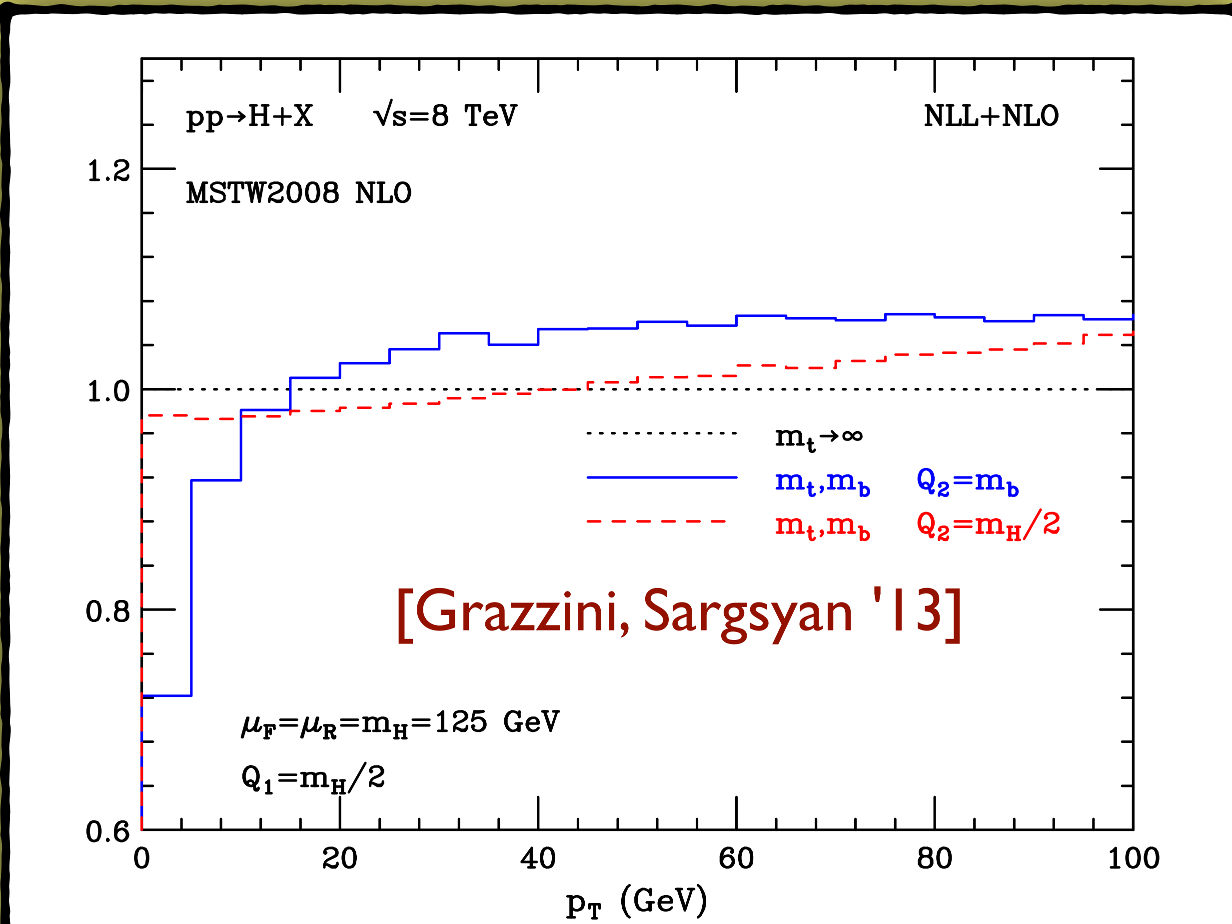

MC@NLO (different normalization)
[Frixione]
pT



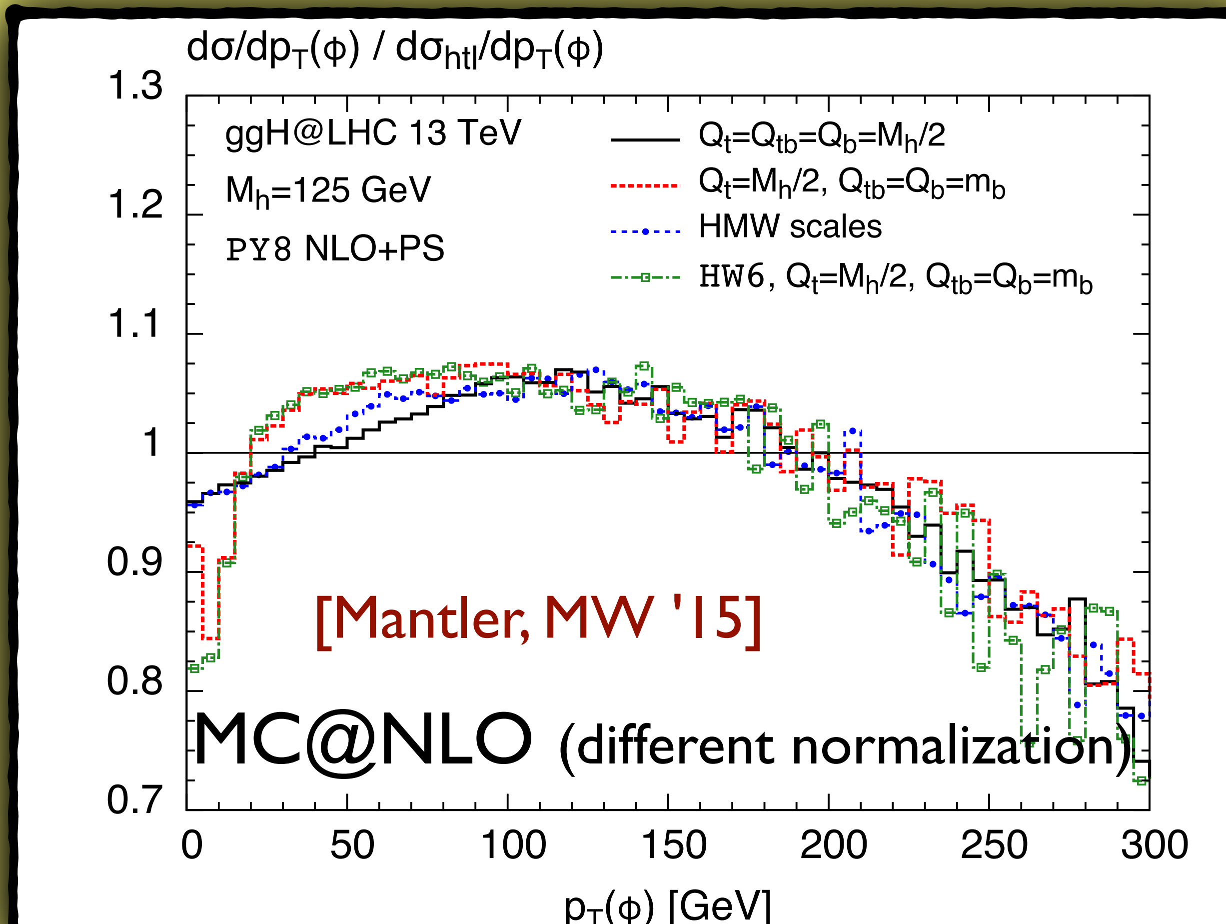
(dσ^LO+NLL/dp_T^H) / (dσ_htl^LO+NLL/dp_T^H)
htl
t
t+b
LHC@8 TeV, m_H = 125 GeV
μ_F = μ_R = Q_Res = m_H / 2
AR [Mantler, MW '12]
p_T^H [GeV]



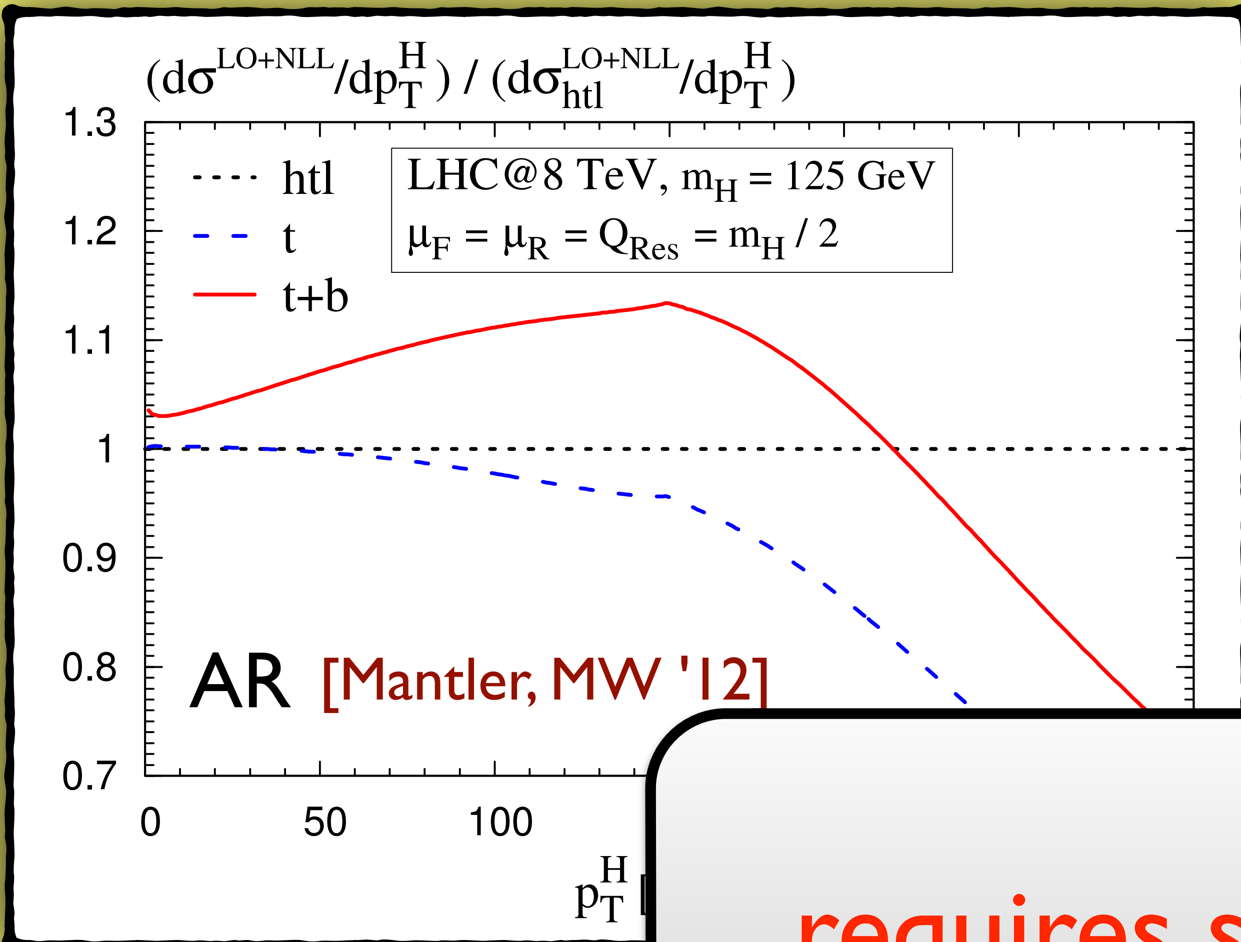
POWHEG
[Vicini '12]
m_top exact mass dependence
m_top, m_bot exact mass dependence
p_T^H (GeV)

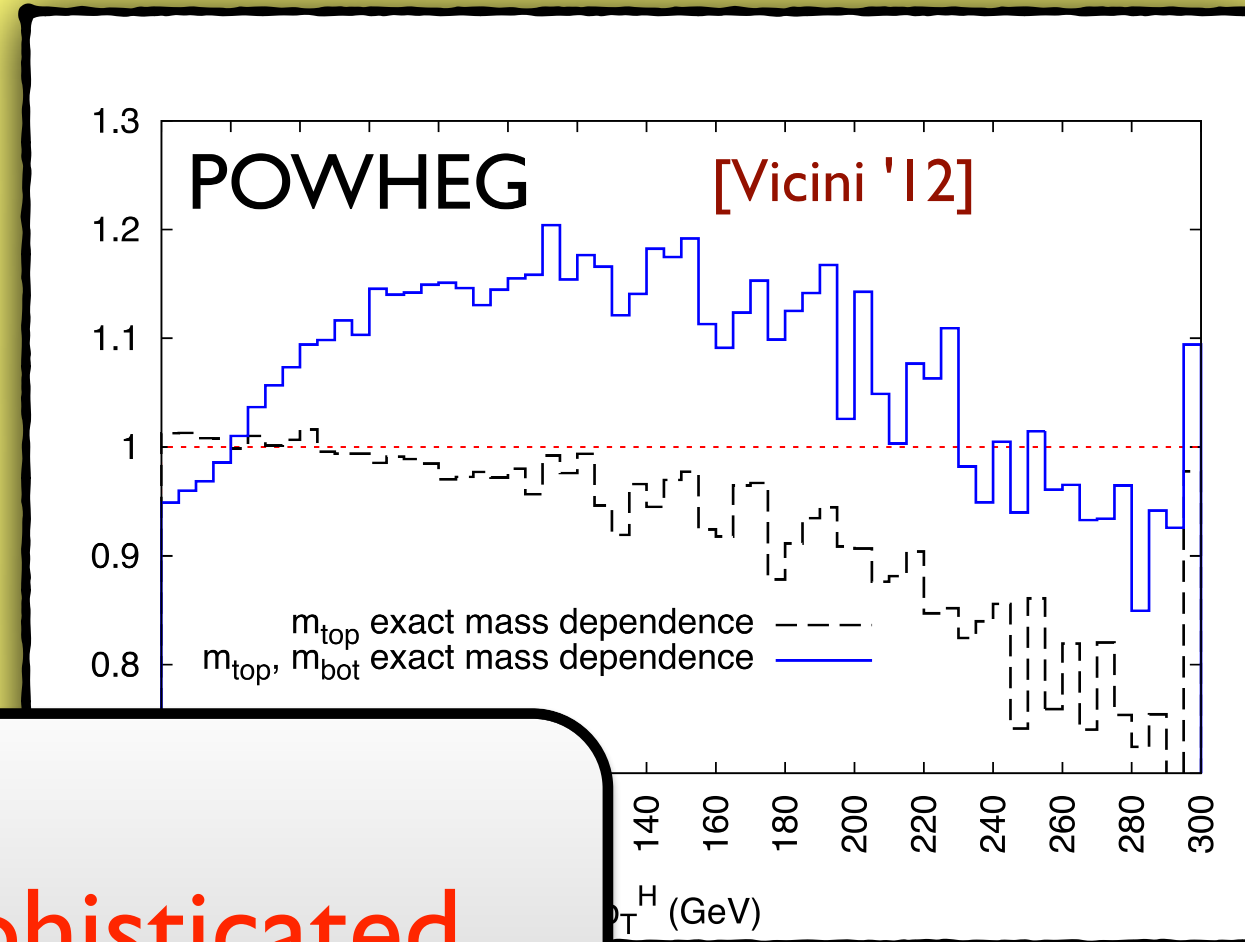


pp→H+X √s=8 TeV
NLL+NLO
MSTW2008 NLO
m_t→∞
m_t,m_b Q_2=m_b
m_t,m_b Q_2=m_H/2
[Grazzini, Sargsyan '13]
μ_F=μ_R=m_H=125 GeV
Q_1=m_H/2
p_T (GeV)

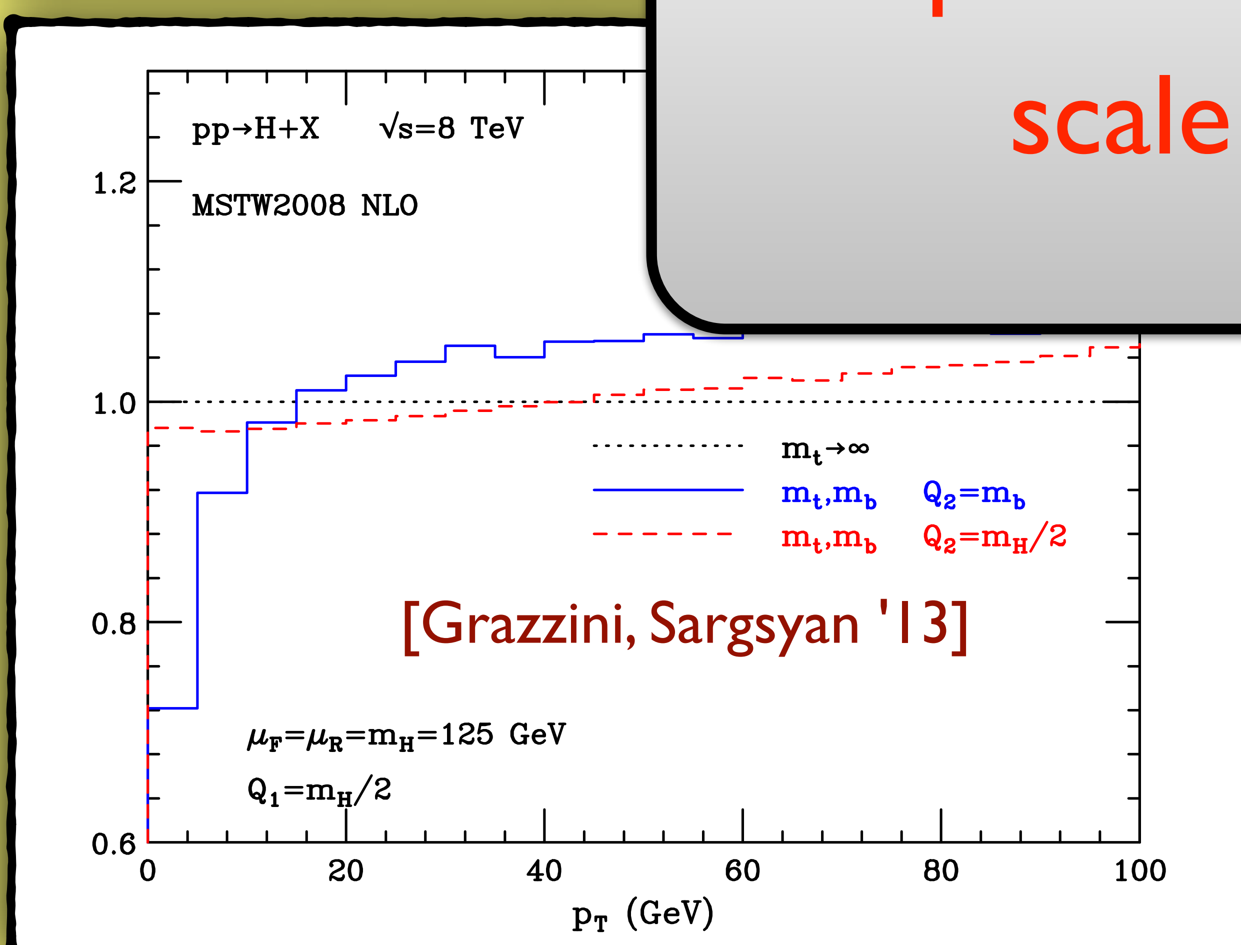


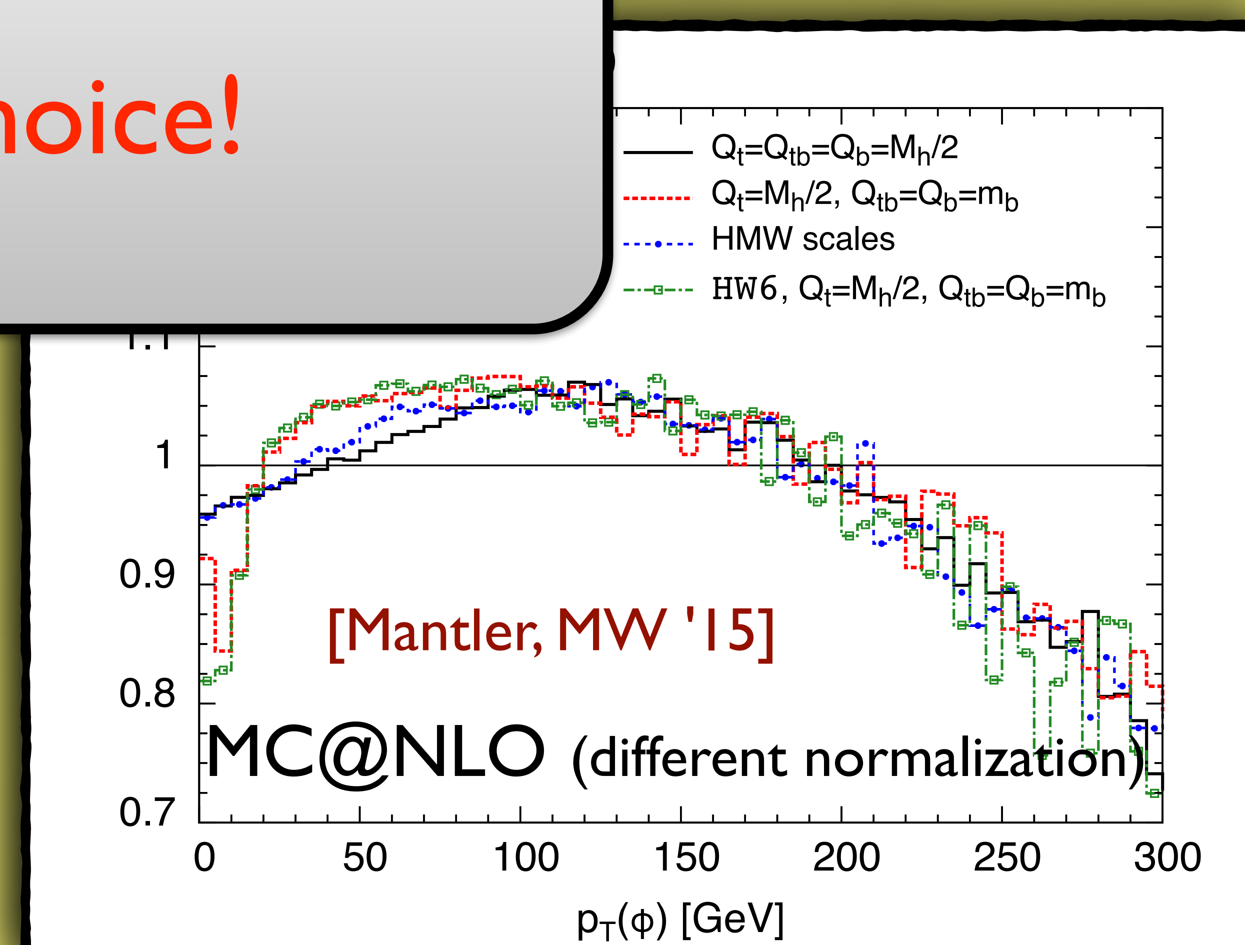
dσ/dp_T(ϕ) / dσ_htl/dp_T(ϕ)
ggH@LHC 13 TeV
M_h=125 GeV
PY8 NLO+PS
Q_t=Q_tb=Q_b=M_h/2
Q_t=M_h/2, Q_tb=Q_b=m_b
HMW scales
HW6, Q_t=M_h/2, Q_tb=Q_b=m_b
[Mantler, MW '15]
MC@NLO (different normalization)
p_T(ϕ) [GeV]





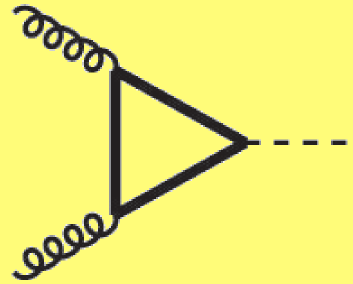
requires sophisticated scale choice!





Gluon Fusion

differential cross sections



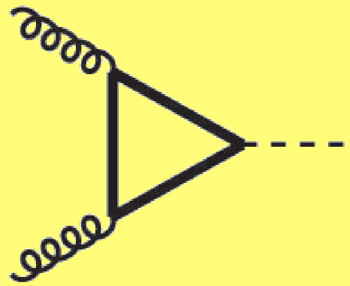
- bottom-mass effects at small p_T: three scale problem! (no complete solution yet)

  → two approaches to choose matching/resummation scale:

[Harlander, Mantler, MW '14]	[Bagnaschi, Vicini '15]
separate scales for top, bottom and top-bottom interference term	
hadron level resummation scales as large as possible, while requiring high-p_T matching	parton level matching scale choosen where collinear approximation fails (by >10%)

Gluon Fusion

differential cross sections



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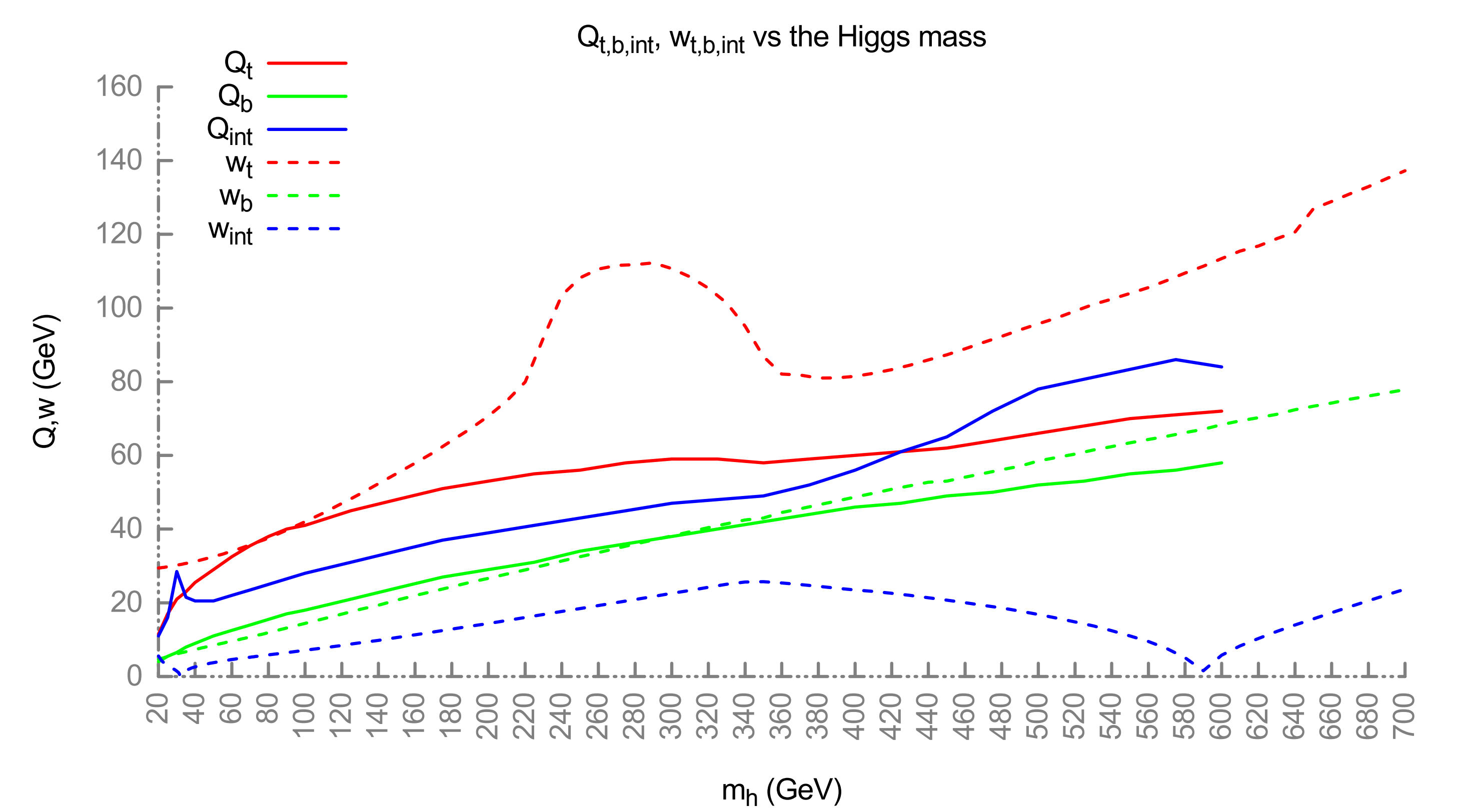
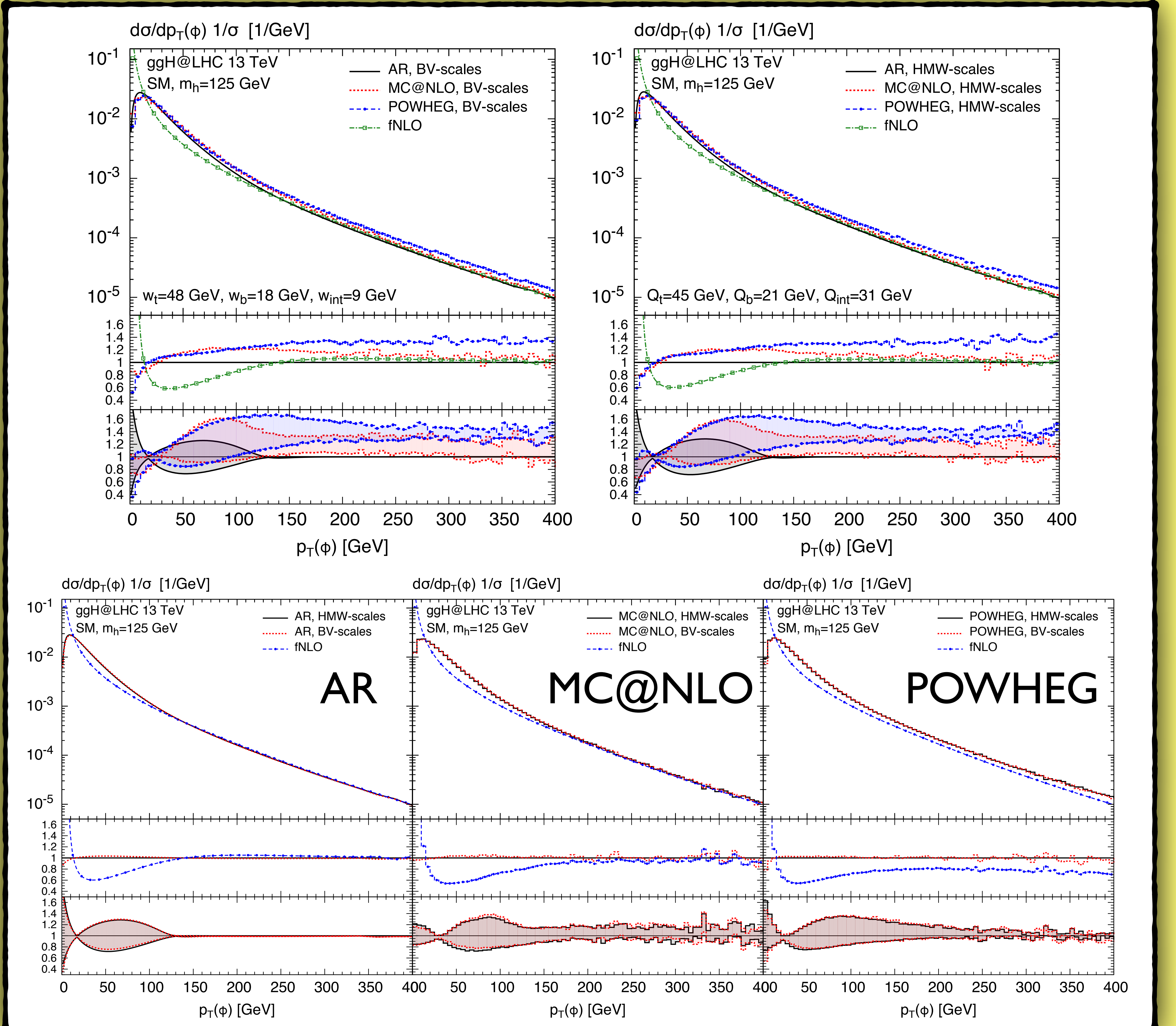


[Bagnaschi, Harlander, Mantler, Vicini, MW]



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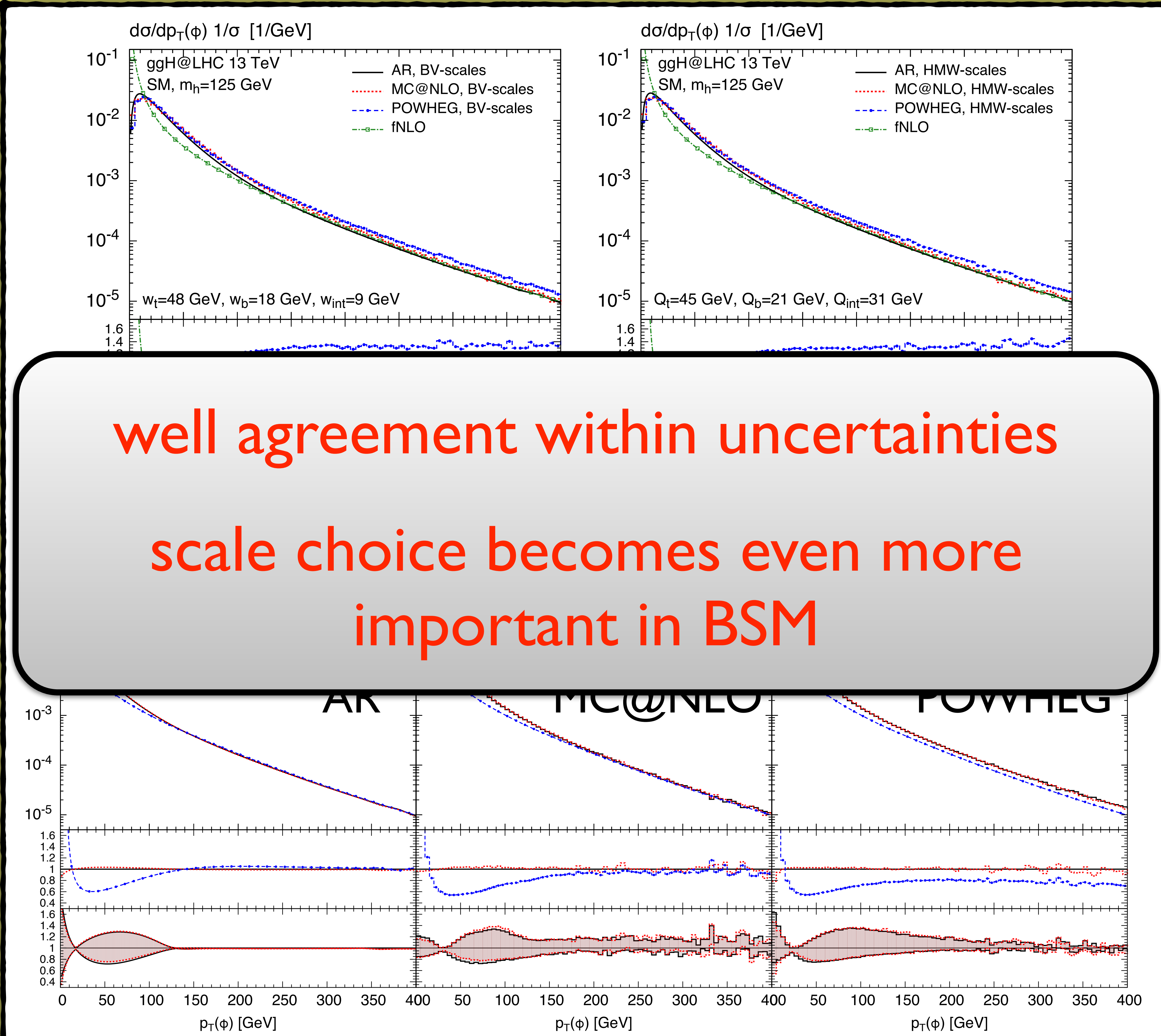
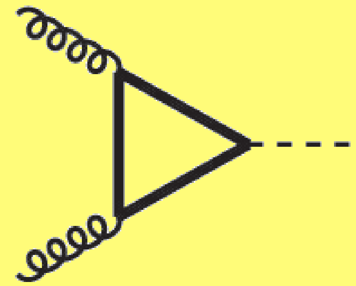


well agreement within uncertainties

scale choice becomes even more important in BSM

Gluon Fusion

differential cross sections



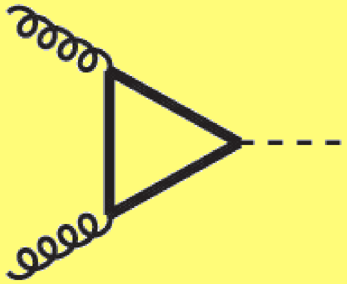
NEW: state-of-the-art shower Monte Carlo predictions (highest perturbative information, quark-mass effects)

- multi-jet merging:

- NNLO+PS

Gluon Fusion

differential cross sections



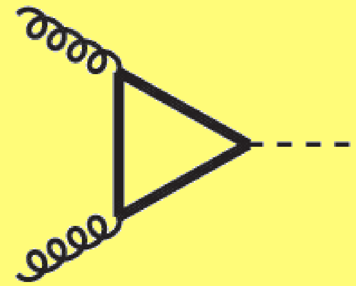
Universität Zürich[UZH]

NEW: state-of-the-art shower Monte Carlo predictions (highest perturbative information, quark-mass effects)

- multi-jet merging:
  - **MG5_aMC@NLO** [Frederix, Frixione, Vryonidou, MW]
    - H+0/1/2-jets @ NLO (FxFx)
    - m_{top} in H+0-jet & 1-loop (borns, reals); H+$\geq$1-jet virtuals (2-loop) reweighted by full (m_{top}) born
    - EFT not valid for m_{bottom} → full m_{bottom} dependence in H+0-jet @ NLO with aMCSusHi [Mantler, MW '15]
  - **Sherpa** [Krauss et al.]
    - H+0/1/2-jets @ NLO (MEPS)
    - m_{top}, m_{bottom} included via reweighting of NLO EFT with LO
- NNLO+PS

Gluon Fusion

differential cross sections



Universität Zürich[UZH]

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    - H+0/1/2-jets @ NLO (MEPS)
    - m_{top}, m_{bottom} included via reweighting of NLO EFT with LO
- NNLO+PS
  - **NNLOPS** [Hamilton, Nason, Zanderighi '14 '15]
    - H+0/1-jets @ NLO (POWHEG-MINLO) + NNLO normalization by reweighting in Higgs-y
    - NLO H+1-jet in EFT reweighted with LO m_{top}, optional: same for m_{bottom} or only at LO H+1-jet
  - **UN^{2}LOPS** [Hoeche, Li, Prestel '14]
    - H+0/1-jets @NLO (S-MC@NLO+UNLOPS) + q_T-slicing with NNLO information below p_T-cut
    - no mass effects yet(?)

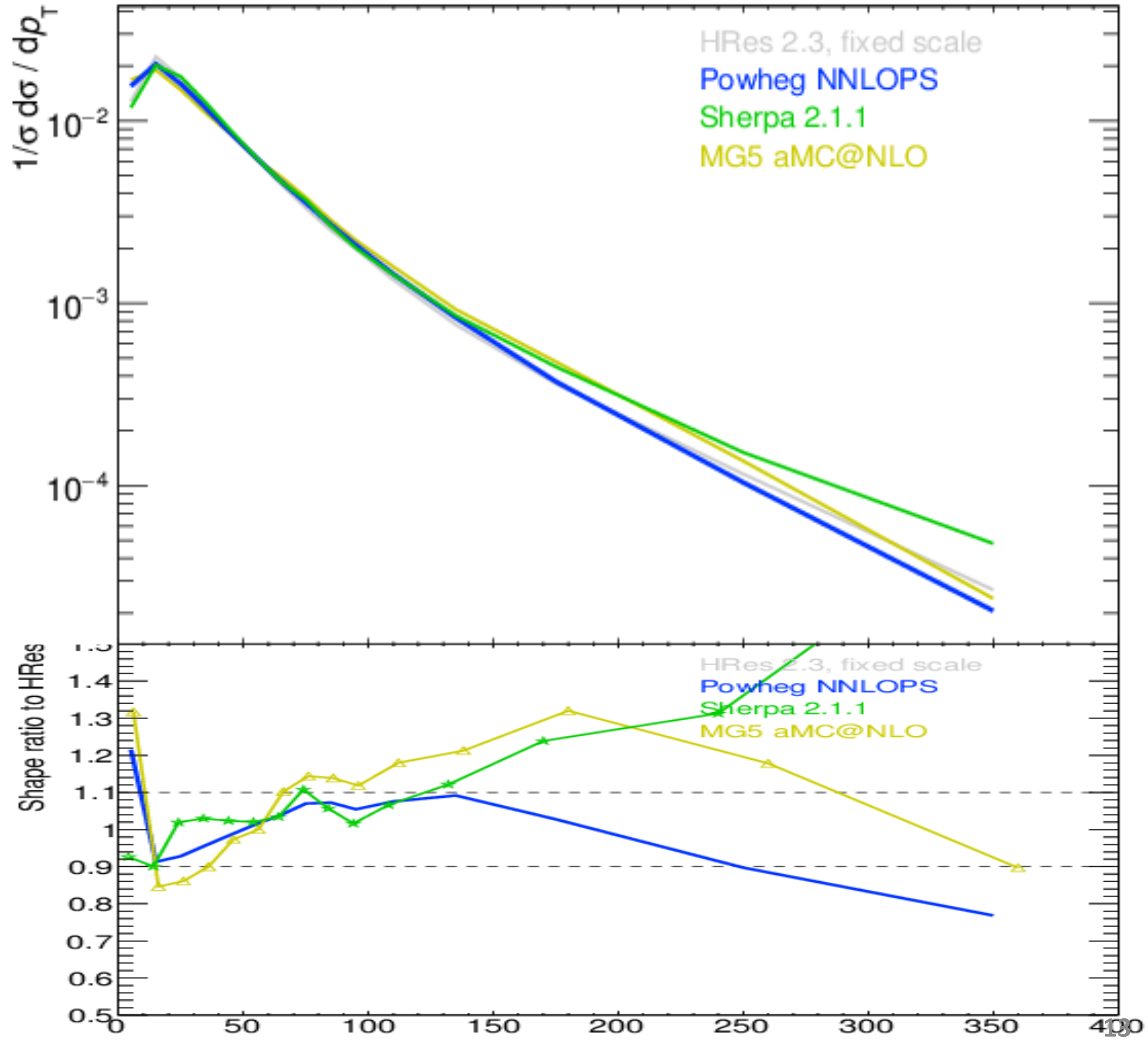
NEW: state-of-the-art shower Monte Carlo predictions

Universität Zürich[UZH]

16/07/15

Higgs p_T shape: MC generators

Comp. of Sherpa, Powheg-NNLOPS, MG5_aMC



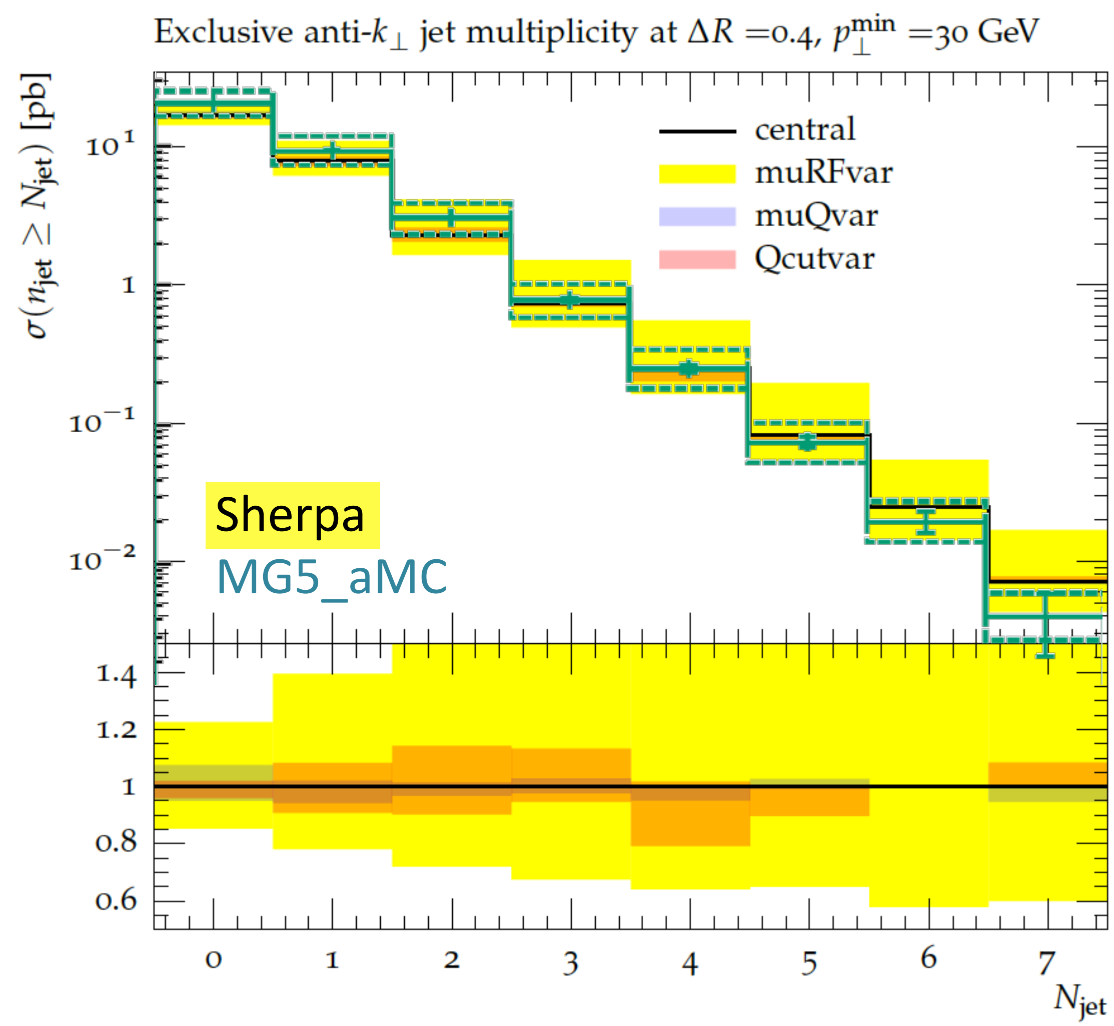
from talk by Giovanni Petrucciani at 10th Workshop of the LHCHXSWG

16/07/15 20

Kinematics: jets

Comparisons of different MC's:

many distributions, received (all very recently), didn't have time to set up a full comparison for today.



from talk by Giovanni Petrucciani at 10th Workshop of the LHCHXSWG

NEW: state-of-the-art shower Monte Carlo predictions

Universität Zürich[UZH]

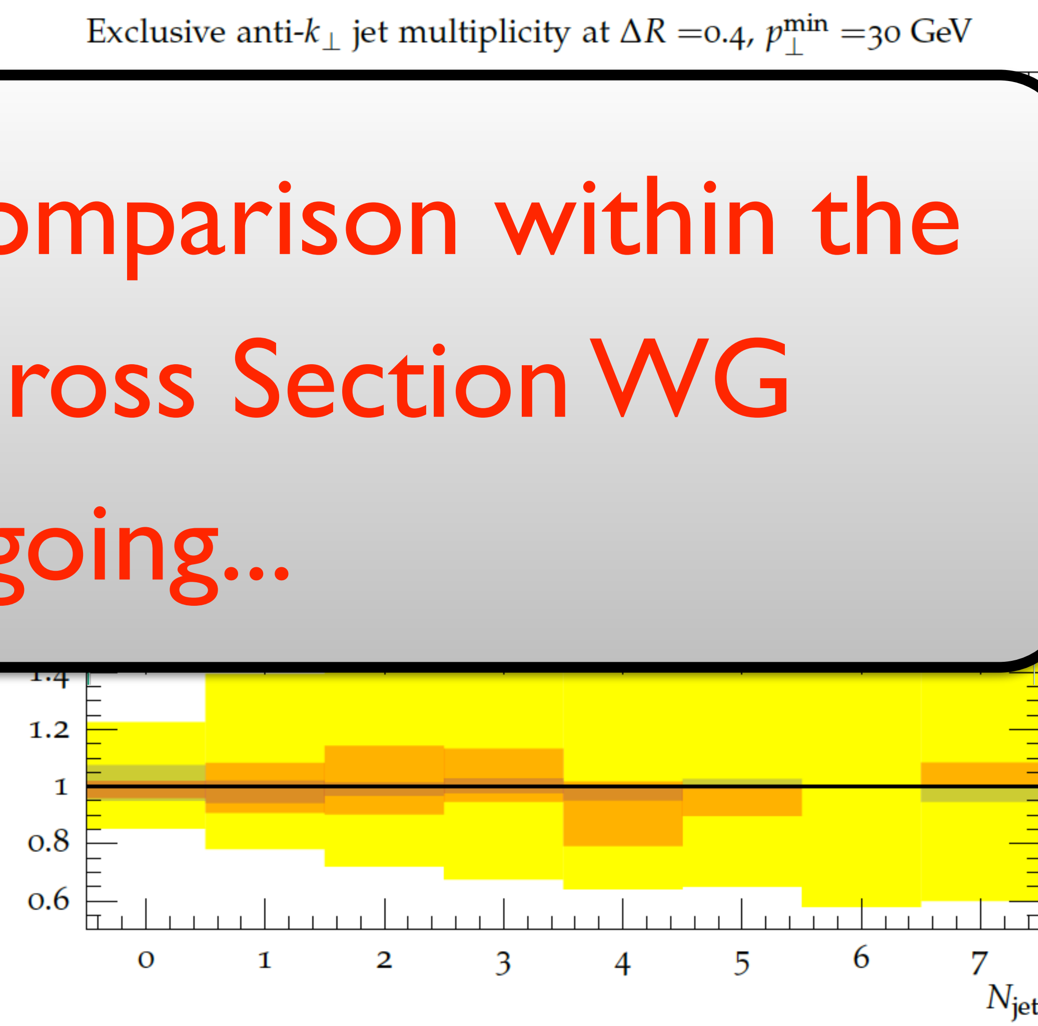
16/07/15 20

Kinematics: jets

Comparisons of

comprehensive comparison within the LHC Higgs Cross Section WG ongoing...

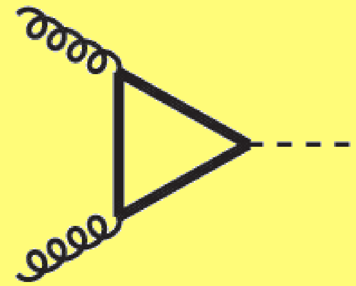
comparison for today.



from talk by Giovanni Petrucciani at 10th Workshop of the LHCHXSWG

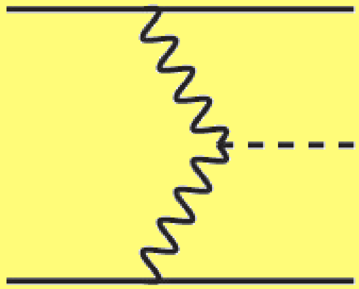
Gluon Fusion

conclusions



- one of the (if not *the*) best studied processes at hadron colliders
- high precision prediction (first N3LO)
- careful assessment of uncertainties (mass effects, resummation, ...)
- New Monte Carlo prediction under way
- ongoing studies in all directions...

VBF



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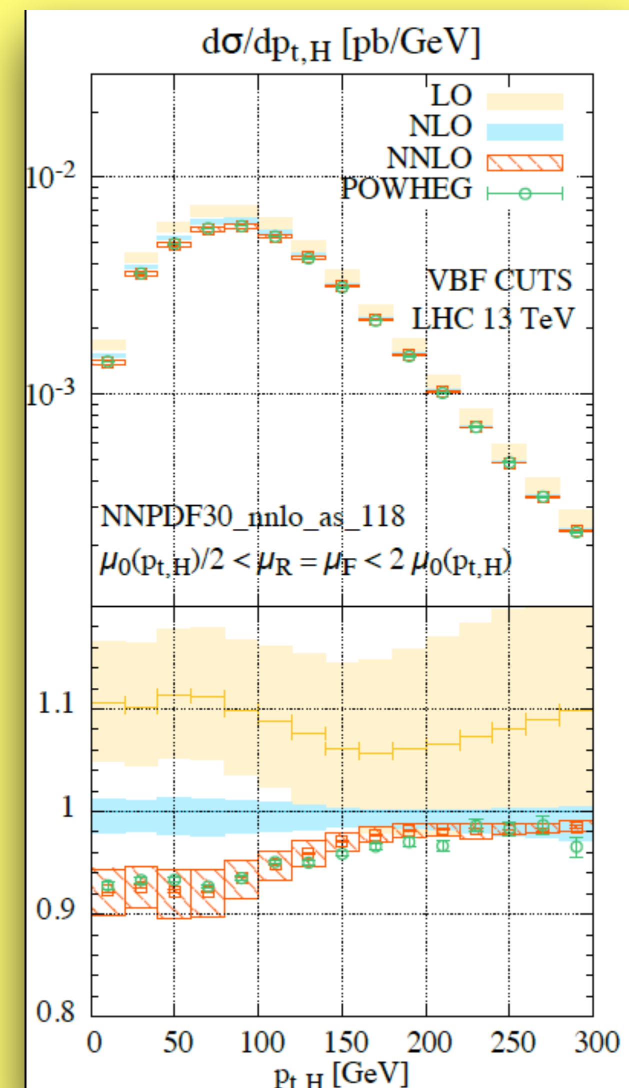
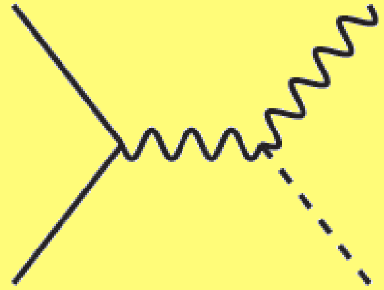
- NLO corrections ~10% [Han, Willenbrock '91], [Figy, Oleari, Zeppenfeld '03], [Campbell, Ellis '03]
- NLO QCD+EW in HAWK (tend to compensate each other) [Ciccolini, Denner, Dittmaier '07]
- NLO+PS VBF-Hjj and VBF-Hjjj in POWHEG [Nason, Oleari '10], [Jäger, Schissler, Zeppenfeld '14] and MG5_aMC@NLO [Frixione, Torrielli, Zaro '13], [Alwall et al. '14]



- Interference effects with gluon fusion negligible [Andersen, Binoth, Heinrich, Smillie '07] [Andersen, Smillie '08] [Bredenstein, Hagiwara, Jäger '08]
- gluon-induced NNLO contributions [Harlander, Vollinga, Weber '08] (well below 1%)
- NNLO with structure function approach (assumption no cross talk):
  - inclusive, NNLO corrections: ~1% [Bolzoni, Maltoni, Moch, Zaro '10]
  - NEW: differential, NNLO corrections with VBF cuts: ~5% [Cacciari, Dreyer, Karlberg, Salam, Zanderighi '15]

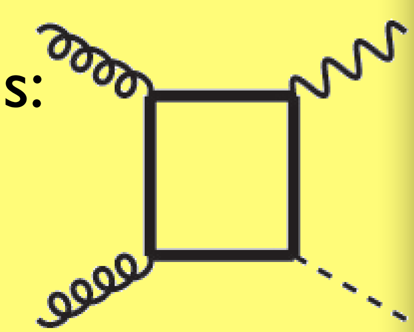
Higgsstrahlung

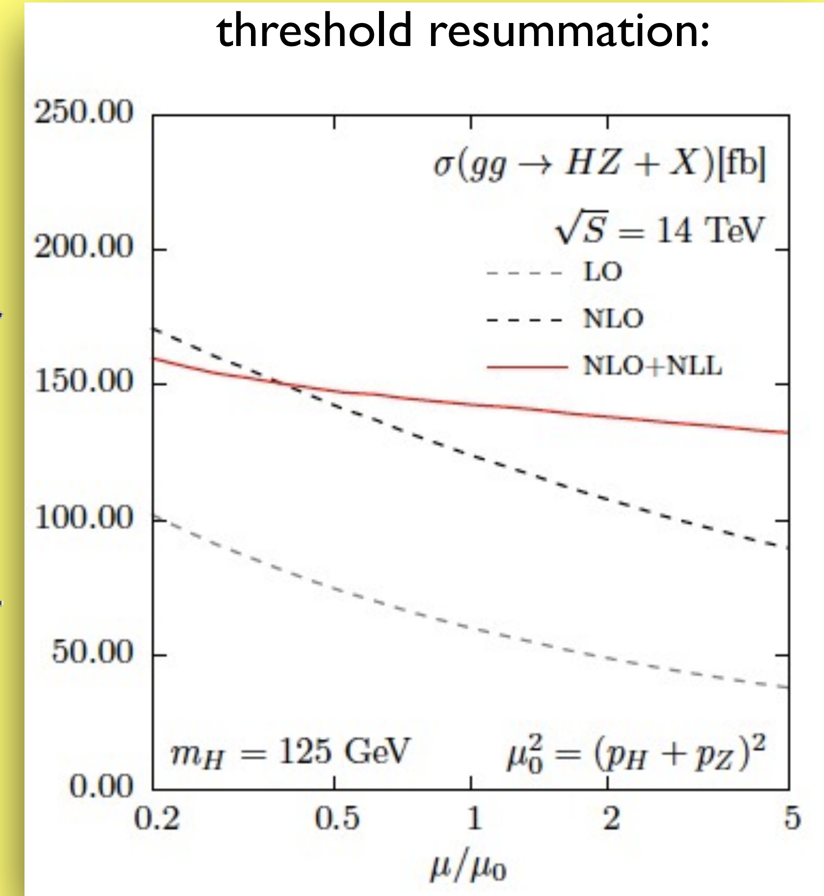


- NNLO [Brein, Harlander, Djouadi '03] mostly by Drell-Yan QCD corrections ~5-10% [Hamberg, Matsuura, Van Neerven '91]
- gluon-induced contributions at NNLO ~10% [Brein, Djouadi, Harlander '03]
- top-quark mediated NNLO contributions ~1-3% [Brein, Harlander, Zirke, MW '11]

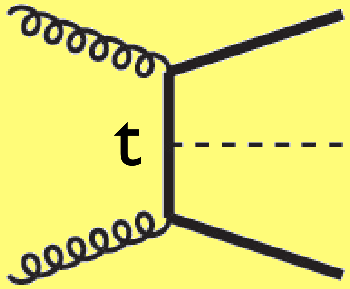
all included in VH@NNLO [Brein, Harlander, Zirke '12]

- differential NNLO [Ferrera, Tramontano, Grazzini '11 '14]
- HAWK: NLO QCD+EW [Denner, Dittmaier, Kallweit, Muck '12]
- NEW: precision for gluon-induced contributions:
  - NLO corrections ($1/m_{top}$ expansion)
  [Altenkamp, Dittmaier, Harlander, Rzehak, Zirke '12]
  - NLL threshold resummation ($1/m_{top}$ expansion)
  [Harlander, Kulesza, Theeuwes, Zirke '14]





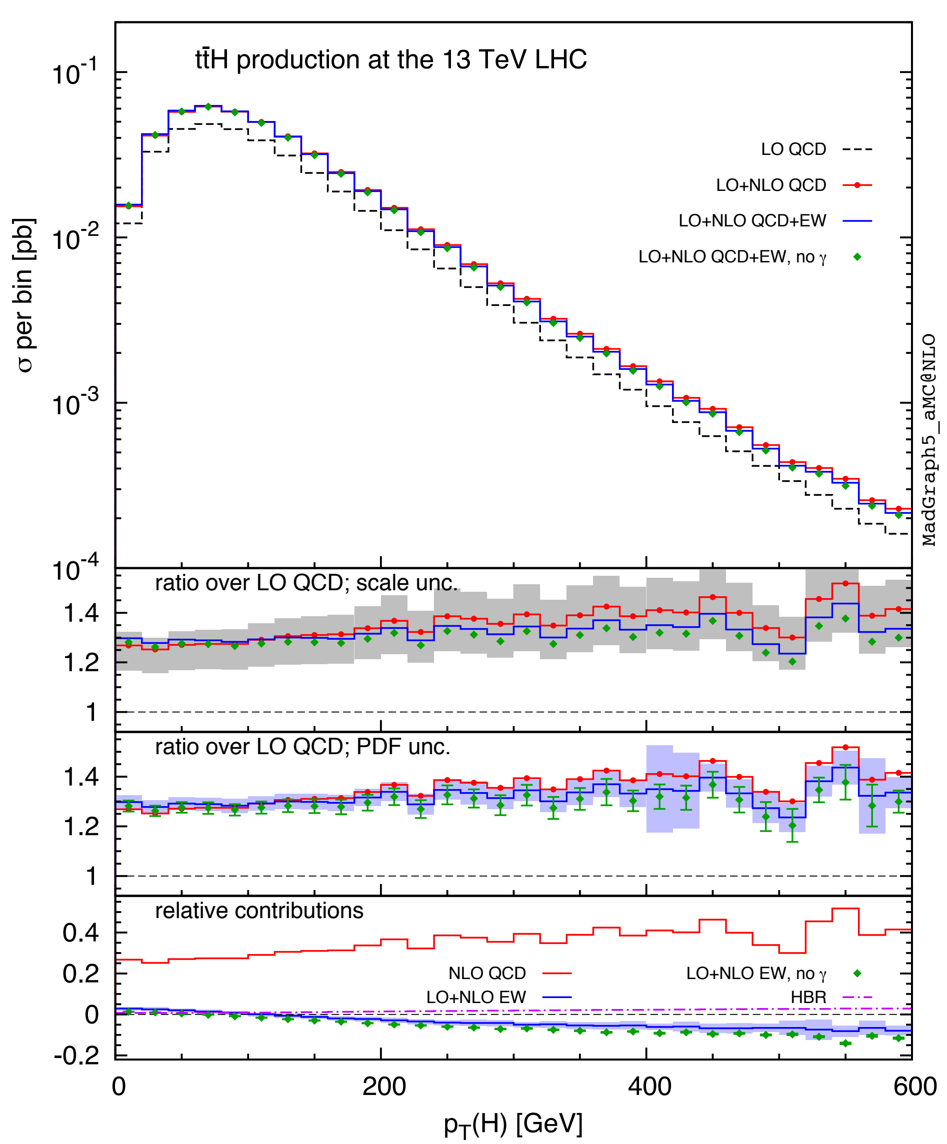
ttH



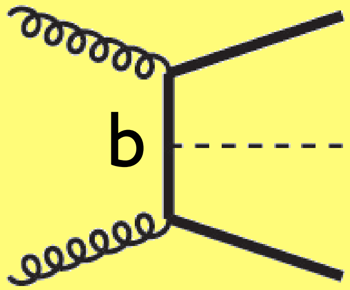
- inclusive cross section at NLO [Beenakker, Dittmaier, Krämer, Plumper, Spira, Zerwas '01], [Dawson, Reina '02]
- NLO+PS:
  - MG5_aMC@NLO [Frederix, Frixione, Hirschi, Maltoni, Pittau, Torrielli '11]
  - POWHEG-BOX [Hartanto, Jäger, Reina, Wackeroth '15]
  - Sherpa
- NEW: EW effects ~10% at large p_T [Frixione, Hirschi, Pagani, Shao, Zaro '14 '15]

→ first important step towards automation of EW effects

see also: Sherpa+OpenLoops [Cascioli, Lindert, Maierhöfer, Pozzorini]



bbH



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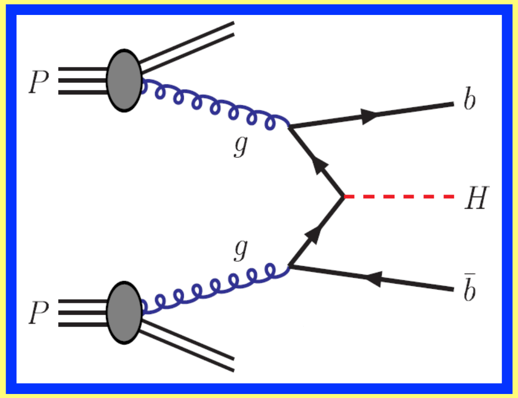
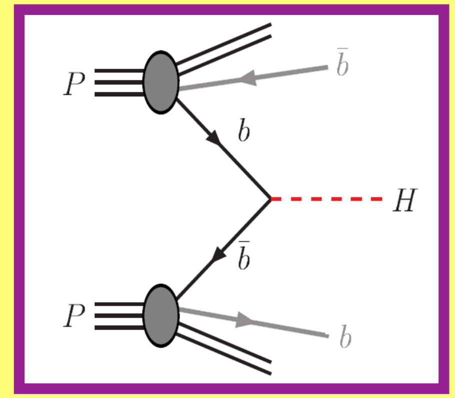
four-flavor scheme (4FS)



- inclusive NLO
  [Dittmaier, Krämer, Spira '04]
  [Dawson, Jackson, Reina, Wackeroth '04]
- exclusive NLO(+PS)
  [MW, Frederix, Frixione, Hirschi, Maltoni, Torrielli '14]

five-flavor scheme (5FS)



- inclusive NNLO
  [Harlander, Kilgore '03]
- towards N3LO
  [Ahmed, Rana, Ravindran '14], [Ahmed, Mandal, Rana, Ravindran '14], [Gehrmann, Kara '14]
- exclusive H+0/1/2-jet at NNLO/NLO/LO
  [Campbell, Ellis, Maltoni, Willenbrock '03], [Harlander, Ozeren, MW '10], [Harlander, MW '11]
- exclusive NNLO
  [Buehler, Herzog, Lazopoulos, Mueller '12]
- p_T resummation at NNLO+NNLL
  [Harlander, Tripathi, MW '14]
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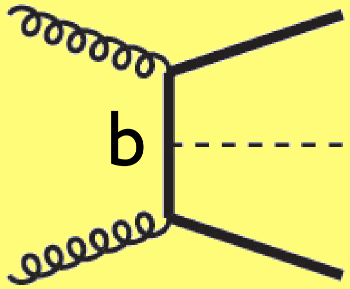
bbH



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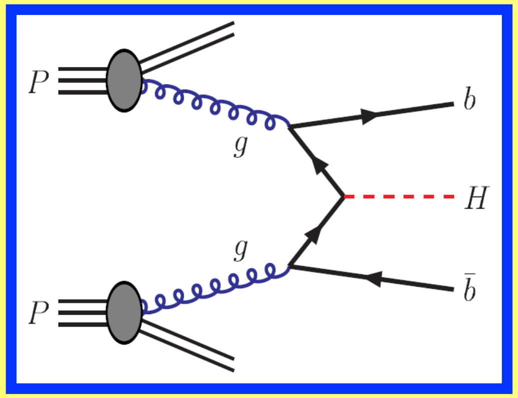

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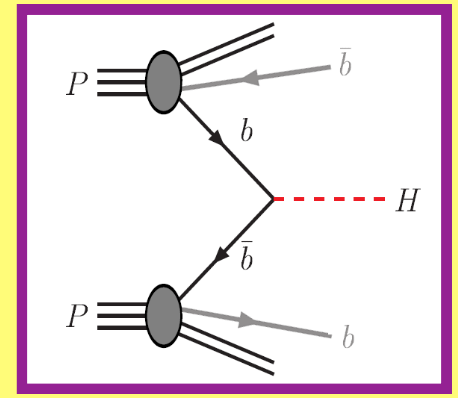

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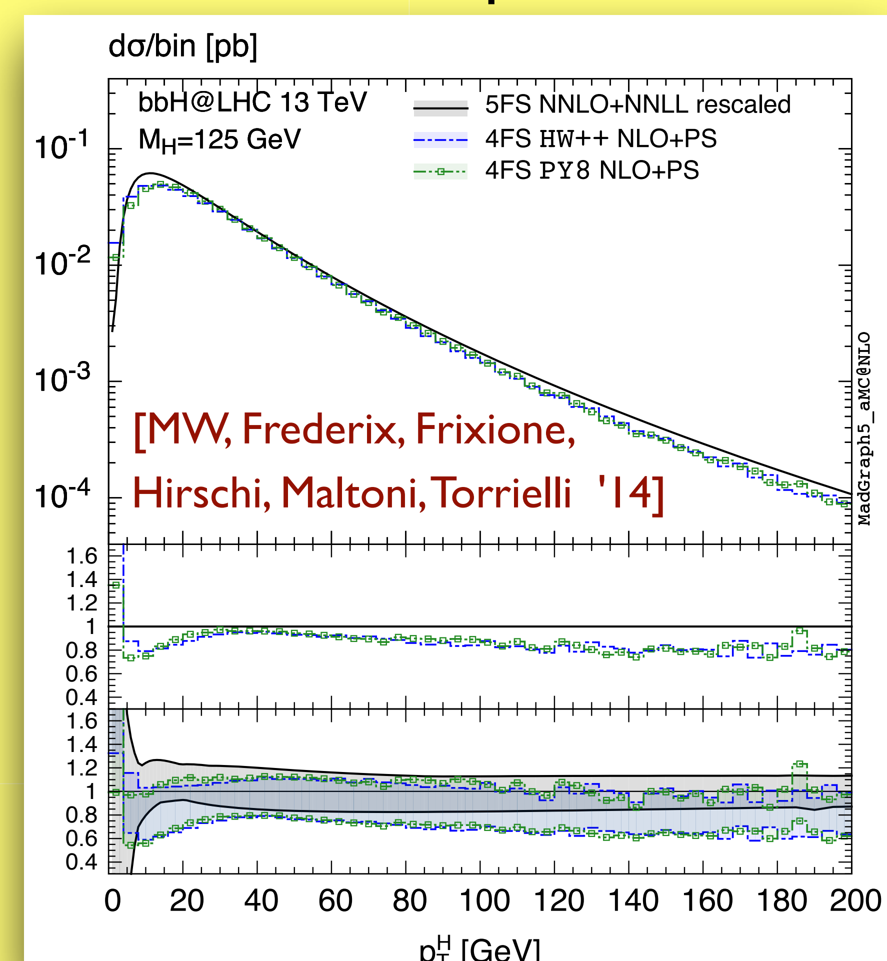
NEW: differential comparison of 4FS and 5FS:



- exclusive H+0/1/2-jet at NNLO/NLO/LO
[Campbell, Ellis, Maltoni, Willenbrock '03], [Harlander, Ozeren, MW '10], [Harlander, MW '11]
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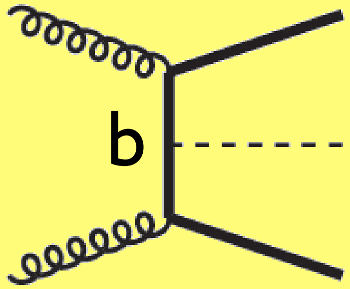

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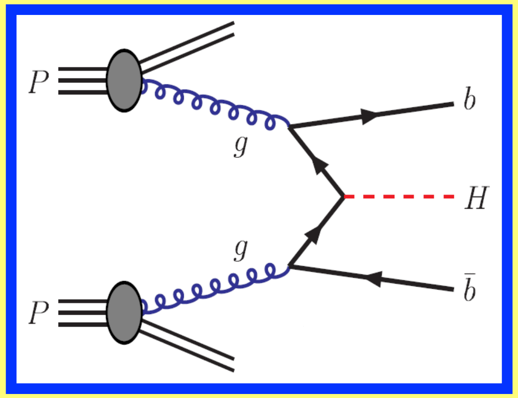

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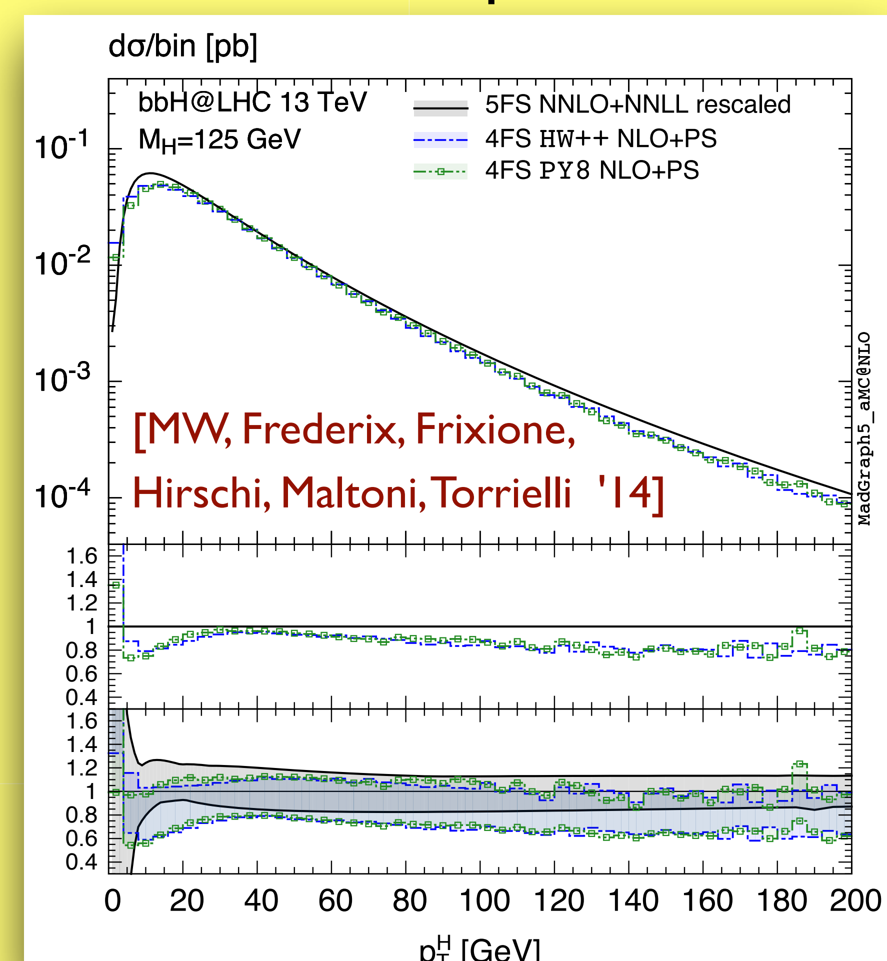

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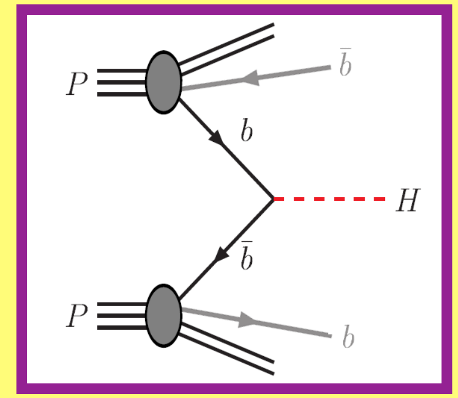

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NEW: approaches to combine inclusive 4FS and 5FS:
[Bonvini, Papanastasiou, Tackmann '15]
[Forte, Napoletano, Ubiali '15]

could not talk about...

- jet-veto resummation in gluon fusion
- decays
- EW effects
- PDFs
- off-shell effects
- double Higgs production
- BSM Higgs physics
- ...

...apologies!

Summary

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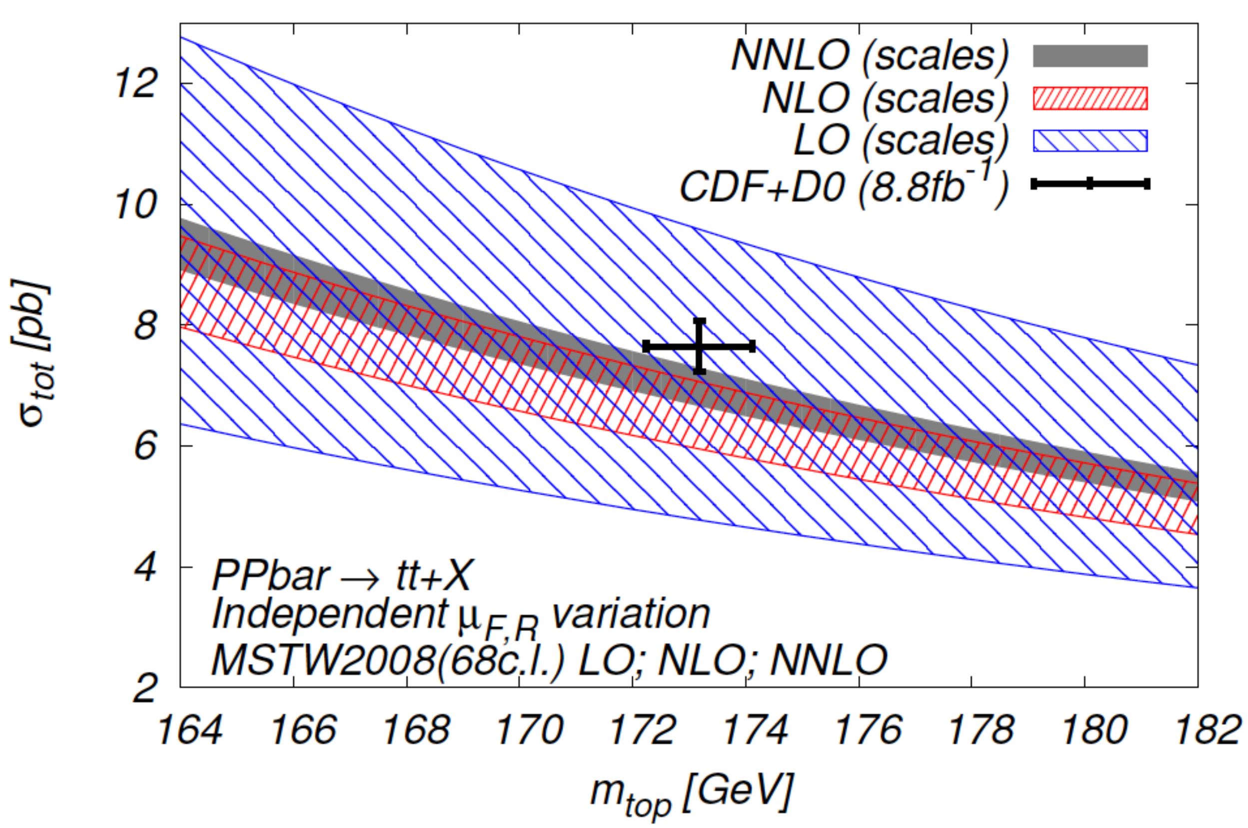
- brief overview of top physics from a Higgs-physicist perspective
- (personal) selection of recent results for gluon fusion:
  - First N3LO compuation at hadron colliders

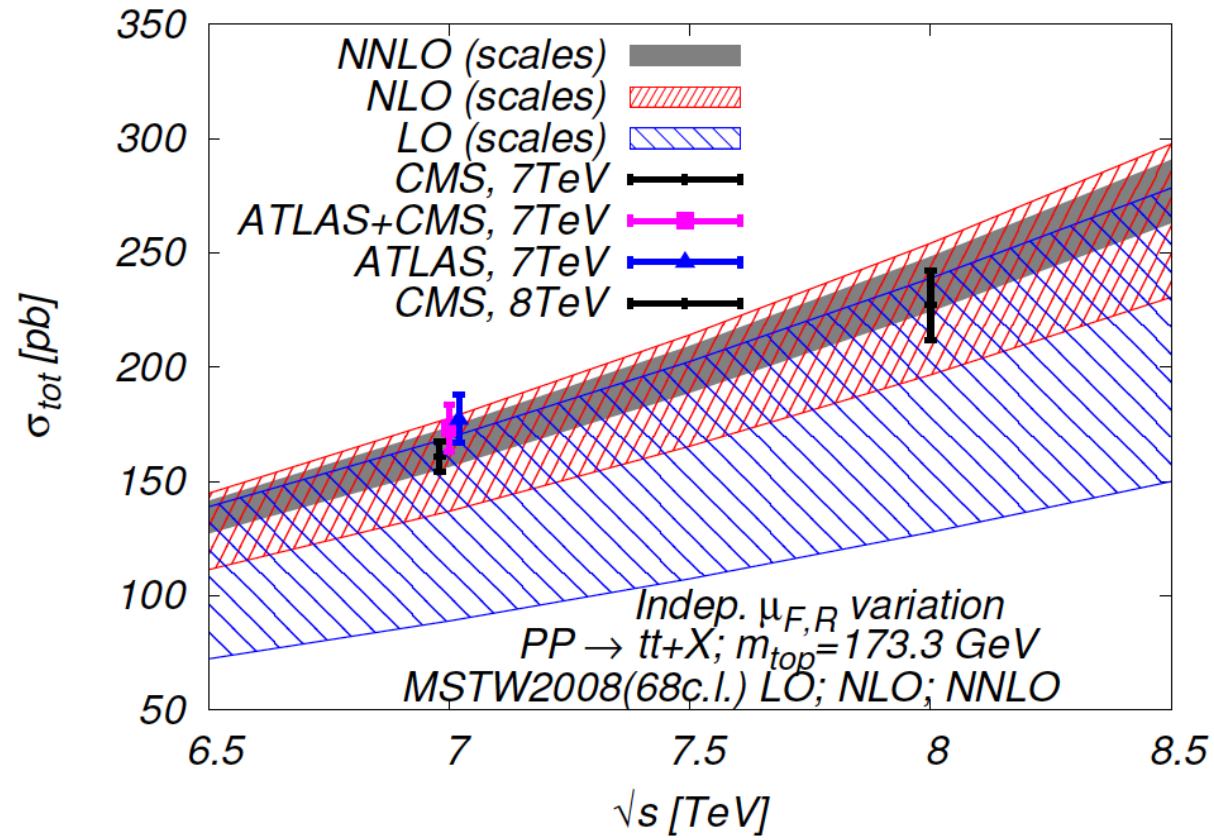
    → radiative corrections under control, small residual uncertainty (~1-3%)
  - need to control other uncertainties
  - top- and bottom-mass small (inclusive cross section)
  - NNLO corrections for H+jet production
  - top-mass effects relevant at large p_T
  - bottom-mass effects relevant at small p_T

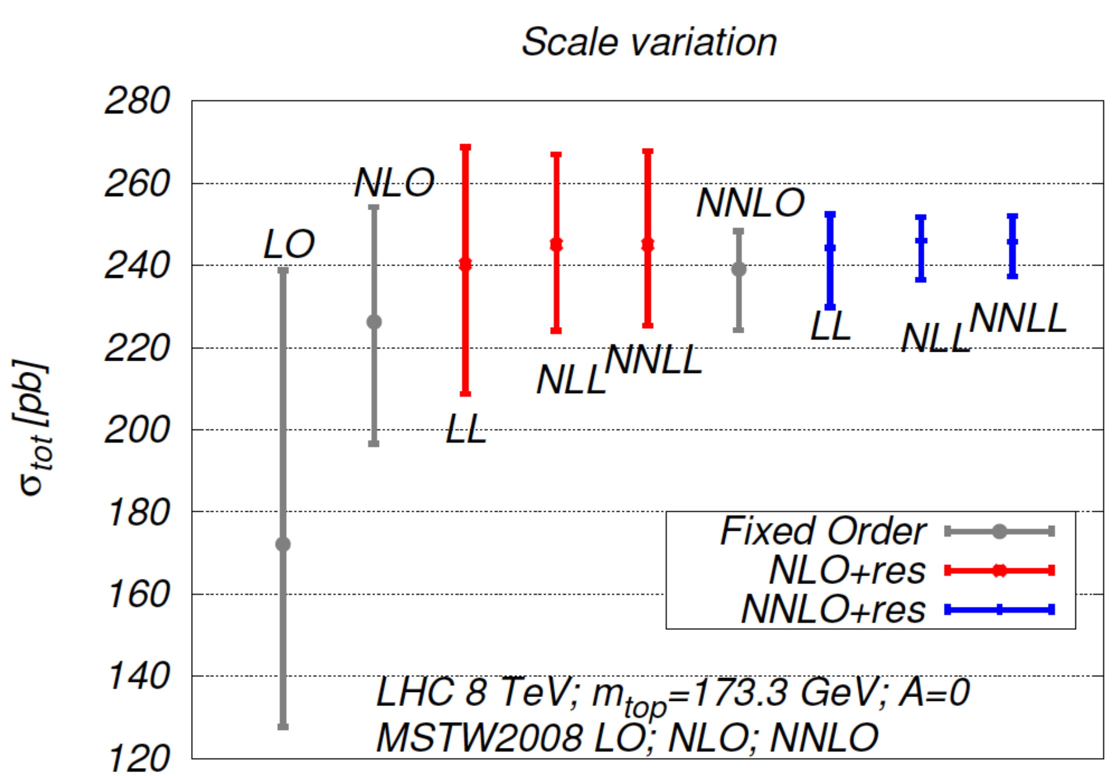
    → requires sophisticated matching/resummation scale choice
  - New generation of Monte Carlo predictions under study
- summarized some relevant results for VBF, VH, ttH, bbH

Thank You !

Back Up







Concurrent uncertainties:

Scales	~ 3%
pdf (at 68%cl)	~ 2-3%
α_S (parametric)	~ 1.5%
m_{top} (parametric)	~ 3%

Soft gluon resummation makes a difference:

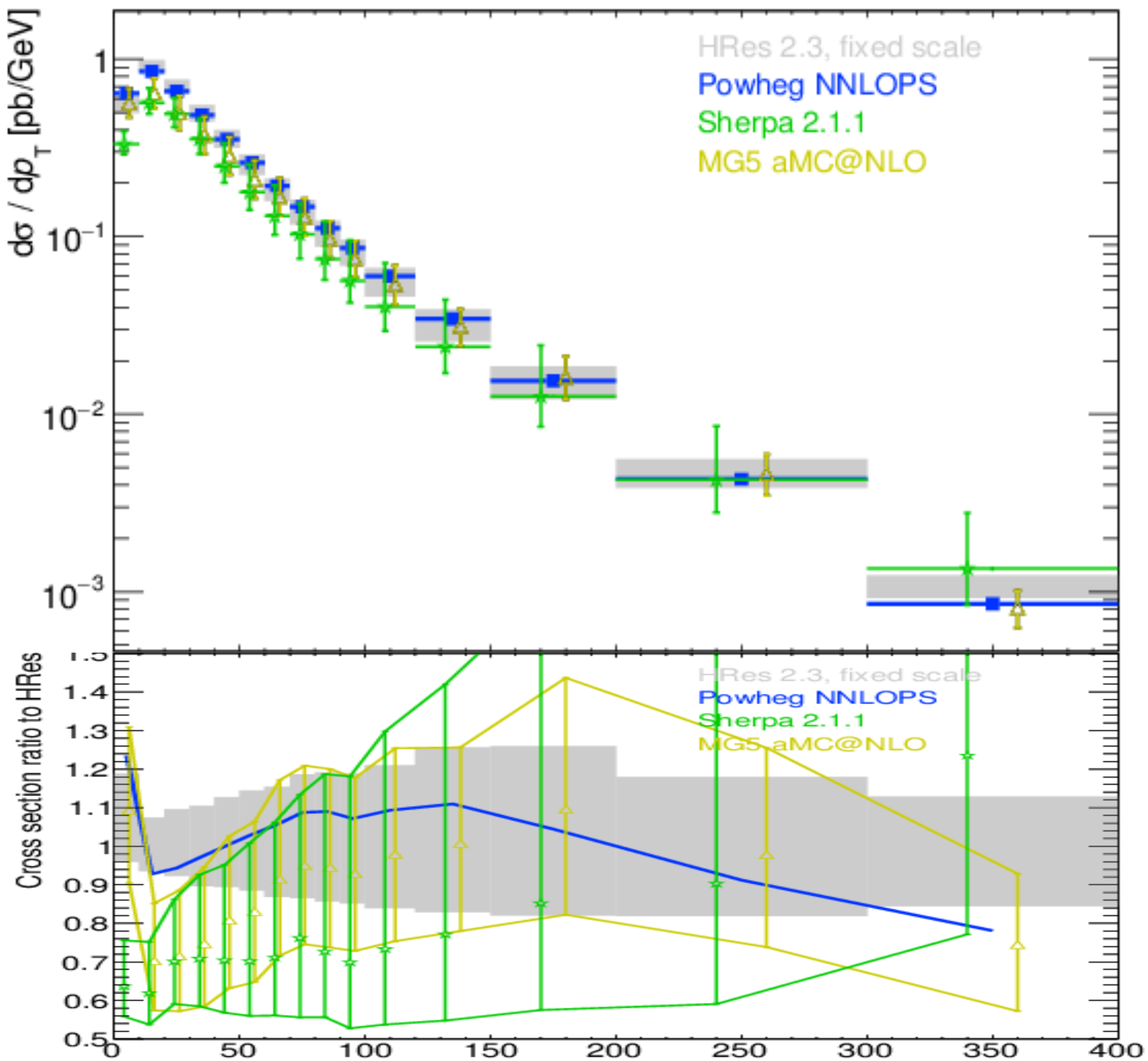
5% -> 3%

from talk by Michal Czakon at SFB/TR9 Meeting 2014

16/07/15

Higgs p_T: MC generators

Comp. of Sherpa, Powheg-NNLOPS, MG5_aMC



from talk by Giovanni Petrucciani at 10th Workshop of the LHCHXSWG

NEW: state-of-the-art shower Monte Carlo predictions

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16/07/15

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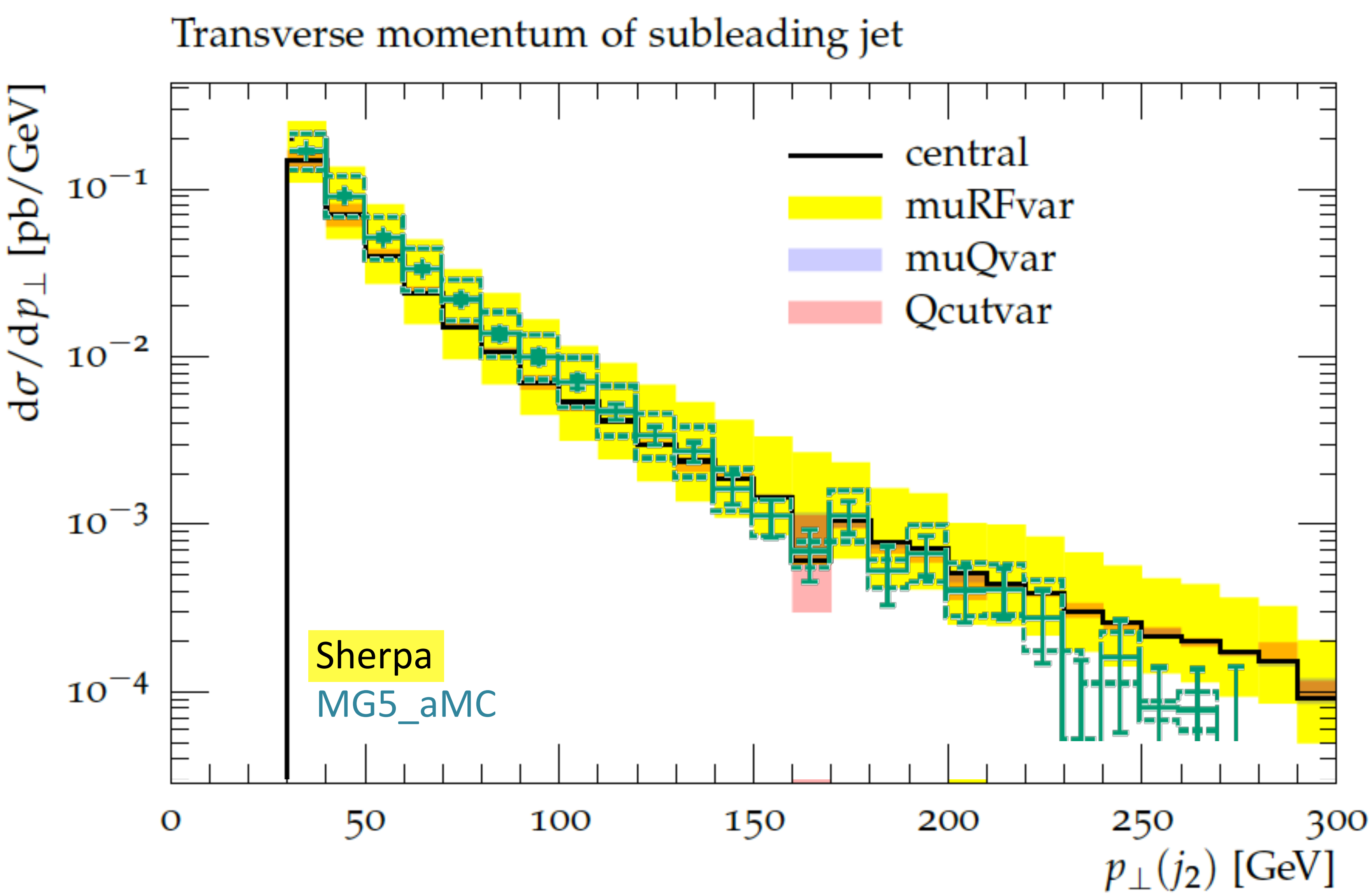
Kinematics: jets



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