Determination of the top-quark mass using jet rates at the LHC

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Outline

1. Introduction
2. Determining the top-quark mass from jet rates
3. Conclusion

How do we measure a quark mass ?

- We don't see free quarks

→ top-quark mass itself is not an observable, mass is *just* a parameter of the underlying theory

Precise value depends on the definition / renormalization scheme (i.e. pole mass, $\overline{\text{MS}}$ mass)

- Determine / fit parameter from comparison of theoretical predictions and measurements

To fix the renormalization scheme at least a NLO calculation is required, at least in theory…

Requirements for a precise quark mass determination

Checklist:

- ❑ Observable should show good sensitivity to m

$$\frac{\Delta O}{O} \leftrightarrow \frac{\Delta m_t}{m_t}$$

- ❑ Observable must be theoretically calculable

- ❑ Theory uncertainties should be small

  small perturbative and non-perturbative corrections

- ❑ Method should employ well defined mass scheme

Top-quark mass from jet-rates ($t\bar{t}$ + 1-jet)

Use $t\bar{t}$+1-jet events

→ Large event rates (~30 % of inclusive tt events)

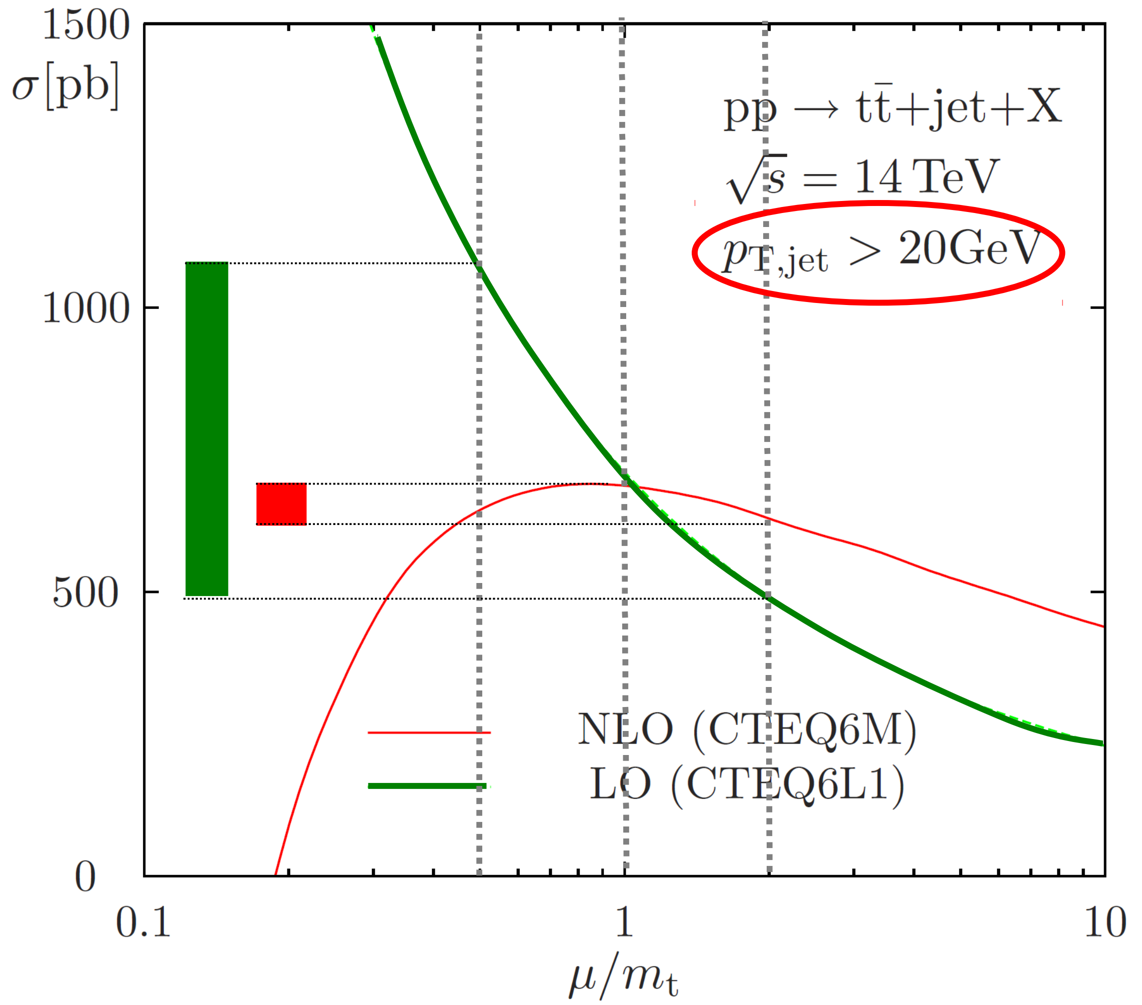
→ NLO corrections available [Dittmaier, PU, Weinzierl ´07,´08, Melnikov, Schulze ’10, Melnikov, Scharf, Schulze ´12]

→ NLO+shower available [Alioli, Moch, PU ´11, Kardos, Papadopoulos, Trocsanyi ‘11]

Additional top-quark mass sensitivity compared to inclusive $t\bar{t}$ due to gluon radiation from top-quarks

Similar to b-quark mass measurement at LEP using 3-jet rates [Bilenky, Fuster, Rodrigo, Santarmaria ‘95]

$t\bar{t}$ + 1-Jet production in NLO QCD



[Dittmaier, PU, Weinzierl ´07,´08]

text book behavior

- small NLO corrections
- small residual scale uncertainty in NLO

$t\bar{t}$ + 1-Jet production in NLO QCD

[Dittmaier, PU, Weinzierl ´07,´08]

$p_{T,\text{jet,cut}}$ [GeV]	$\sigma_{t\bar{t}\text{jet}}$[pb] LO	$\sigma_{t\bar{t}\text{jet}}$[pb] NLO	
20	$710.8(8)^{+358}_{-221}$	$692(3)\ ^{-40}_{-62}$	-3%
50	$326.6(4)^{+168}_{-103}$	$376.2(6)^{+17}_{-48}$	+15%
100	$146.7(2)^{+77}_{-47}$	$175.0(2)^{+10}_{-24}$	+20%
200	$46.67(6)^{+26}_{-15}$	$52.81(8)^{+0.8}_{-6.7}$	+13%

$xy.z(\text{integ. err.})^{\text{shift towards } \mu=m_t/2}_{\text{shift towards } \mu=2m_t}$

- Inclusive tt + 1-Jet production has similar mass sensitivity as total cross section, i.e. $\frac{\Delta\sigma}{\sigma} \approx 5\frac{\Delta m_t}{m_t}$!

Top-quark mass from jet rates

[S. Alioli, P.Fernandez, J.Fuster, A. Irles, S. Moch, PU, M. Vos '13]

To enhance mass sensitivity study:

$$\mathcal{R}(m_{\text{pole}}, \rho_s) = \frac{1}{\sigma_{t\bar{t}+1\text{Jet}}} \frac{d\sigma_{t\bar{t}+1\text{Jet}}}{d\rho_s}(m_{\text{pole}})$$

with $\rho_s = \frac{2m_0}{\sqrt{s_{t\bar{t}+1\text{Jet}}}}, \quad m_0 = O(m)$

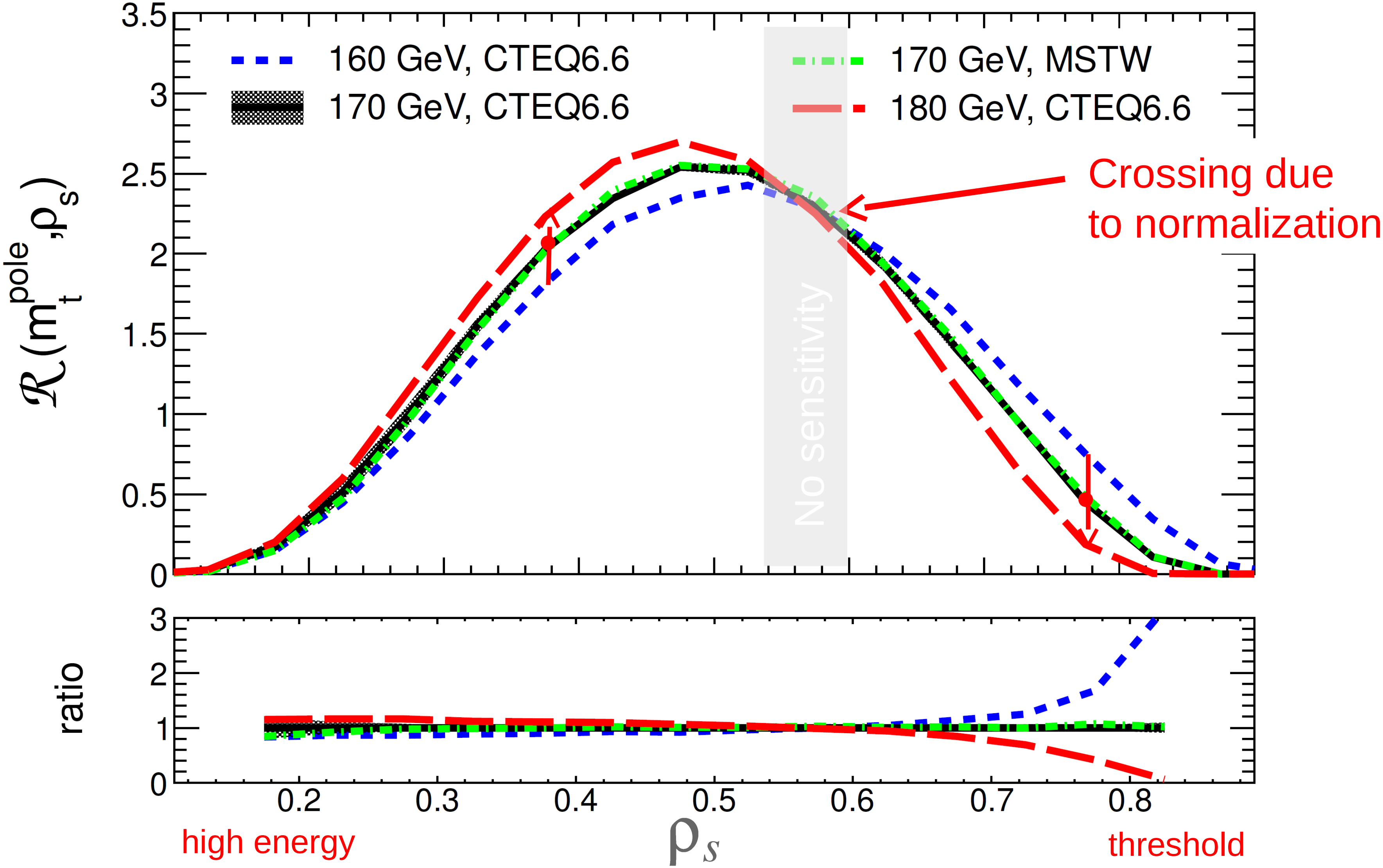
i.e. m_0 = 170 GeV

ρ_s similar to $\rho = \frac{4m_t^2}{s}$ used in incl. $t\bar{t}$ production

many uncertainties cancel in ratio

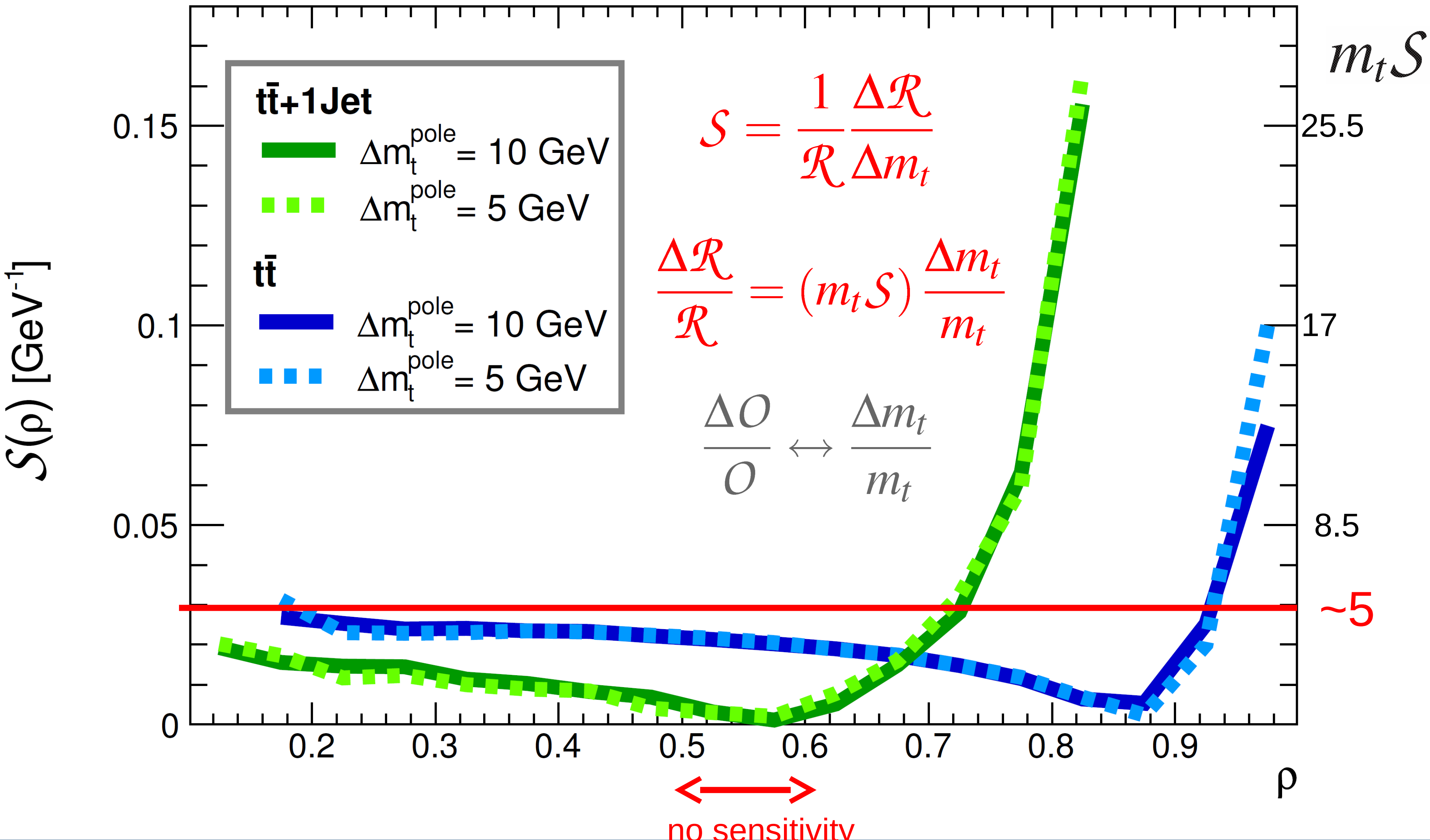
Mass dependence – mass sensitivity

[S. Alioli, P.Fernandez, J.Fuster, A. Irles, S. Moch, PU, M. Vos '13]



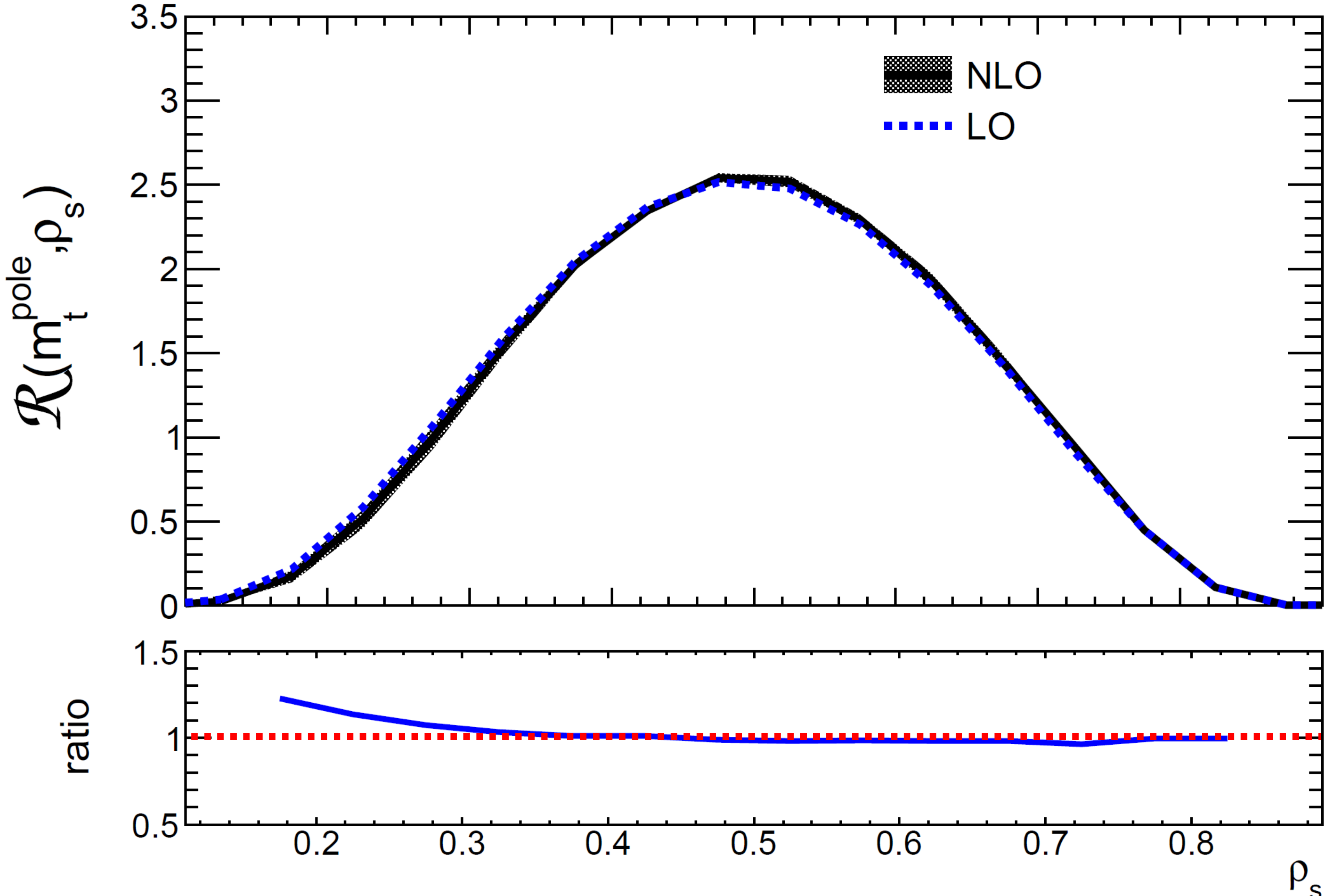
Mass sensitivity

[S. Alioli, P.Fernandez, J.Fuster, A. Irles, S. Moch, PU, M. Vos '13]



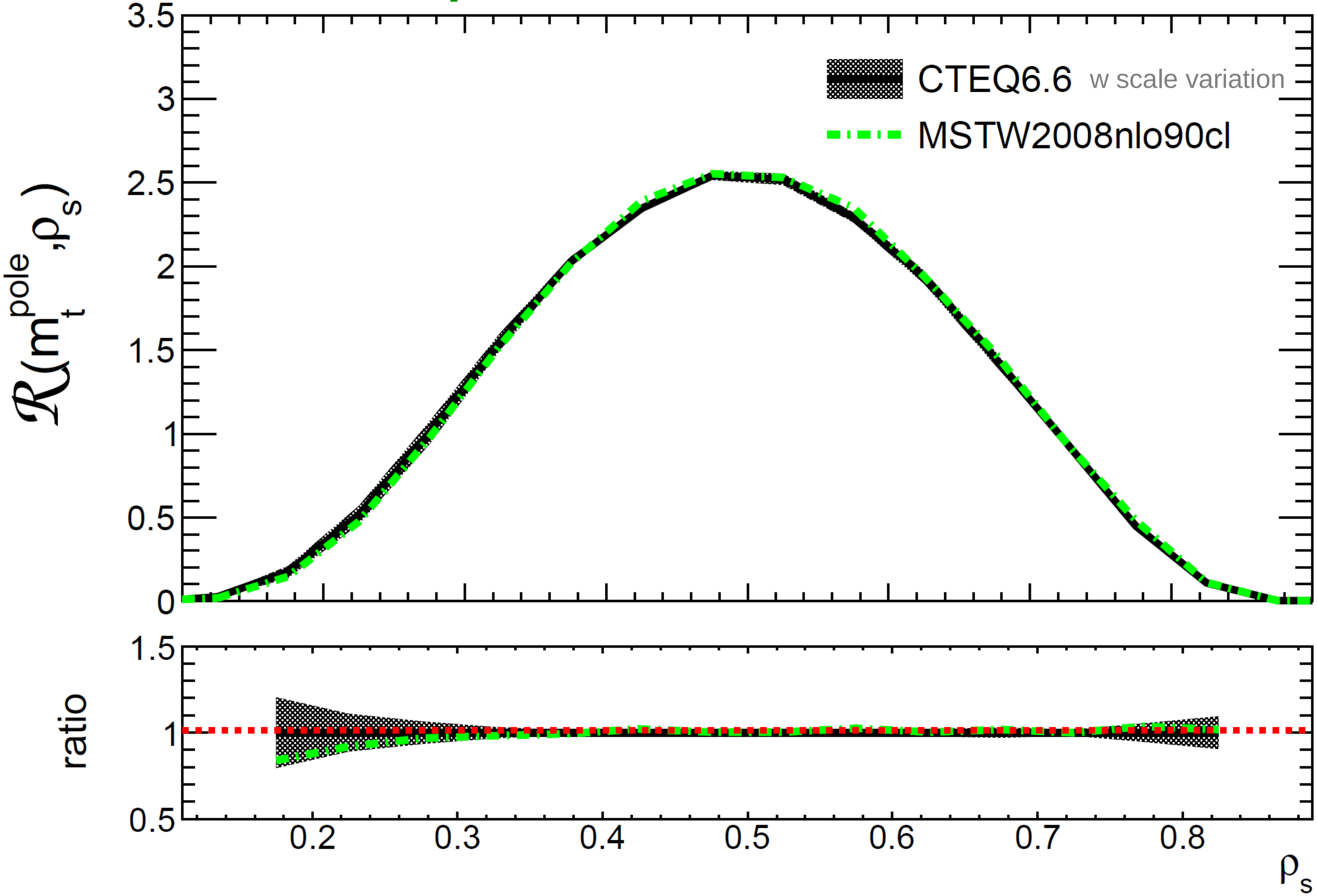
Higher order corrections

[S. Alioli, P.Fernandez, J.Fuster, A. Irles, S. Moch, PU, M. Vos ‘13]



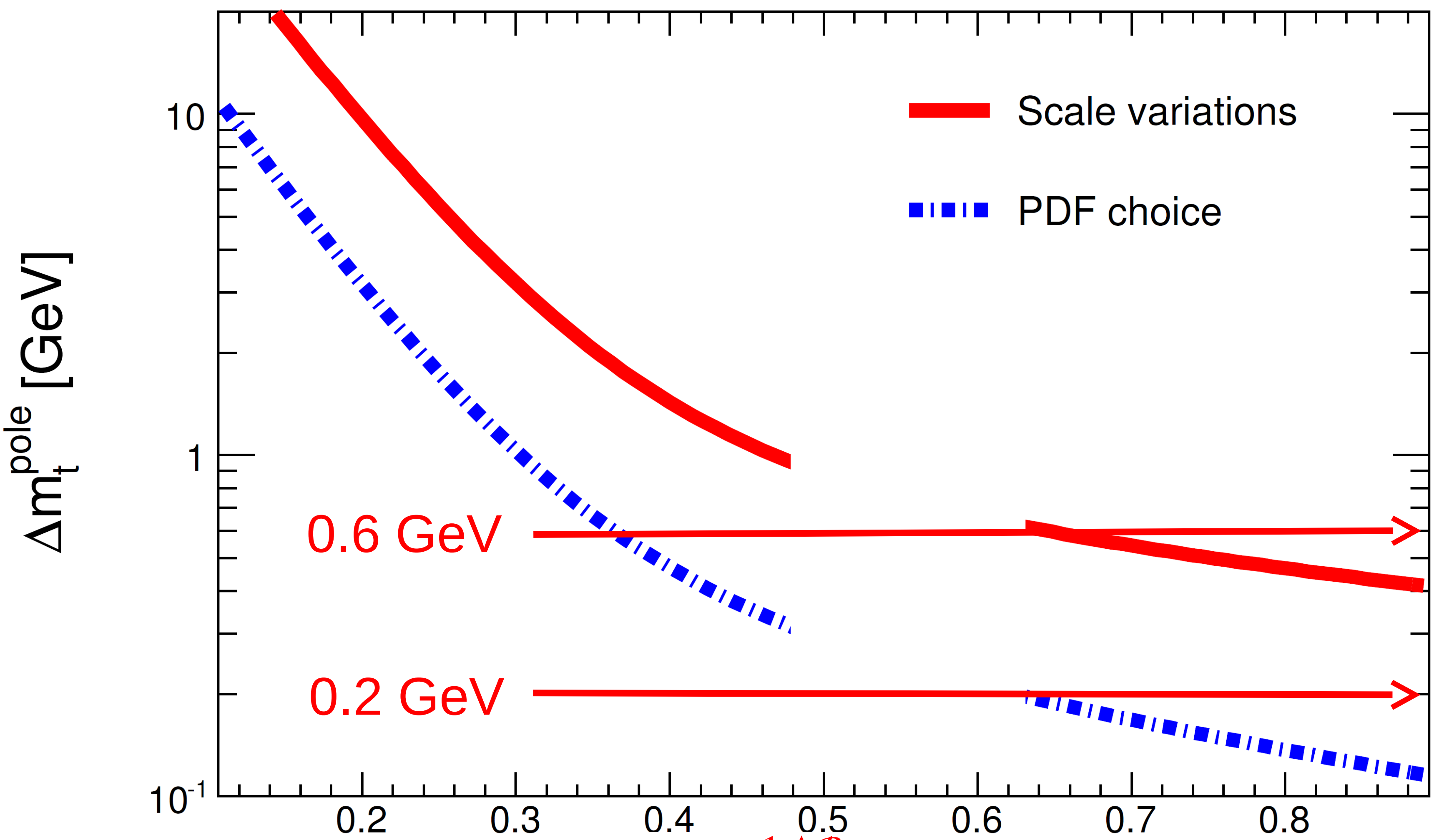
PDF and scale uncertainties

[S. Alioli, P.Fernandez, J.Fuster, A. Irles, S. Moch, PU, M. Vos '13]



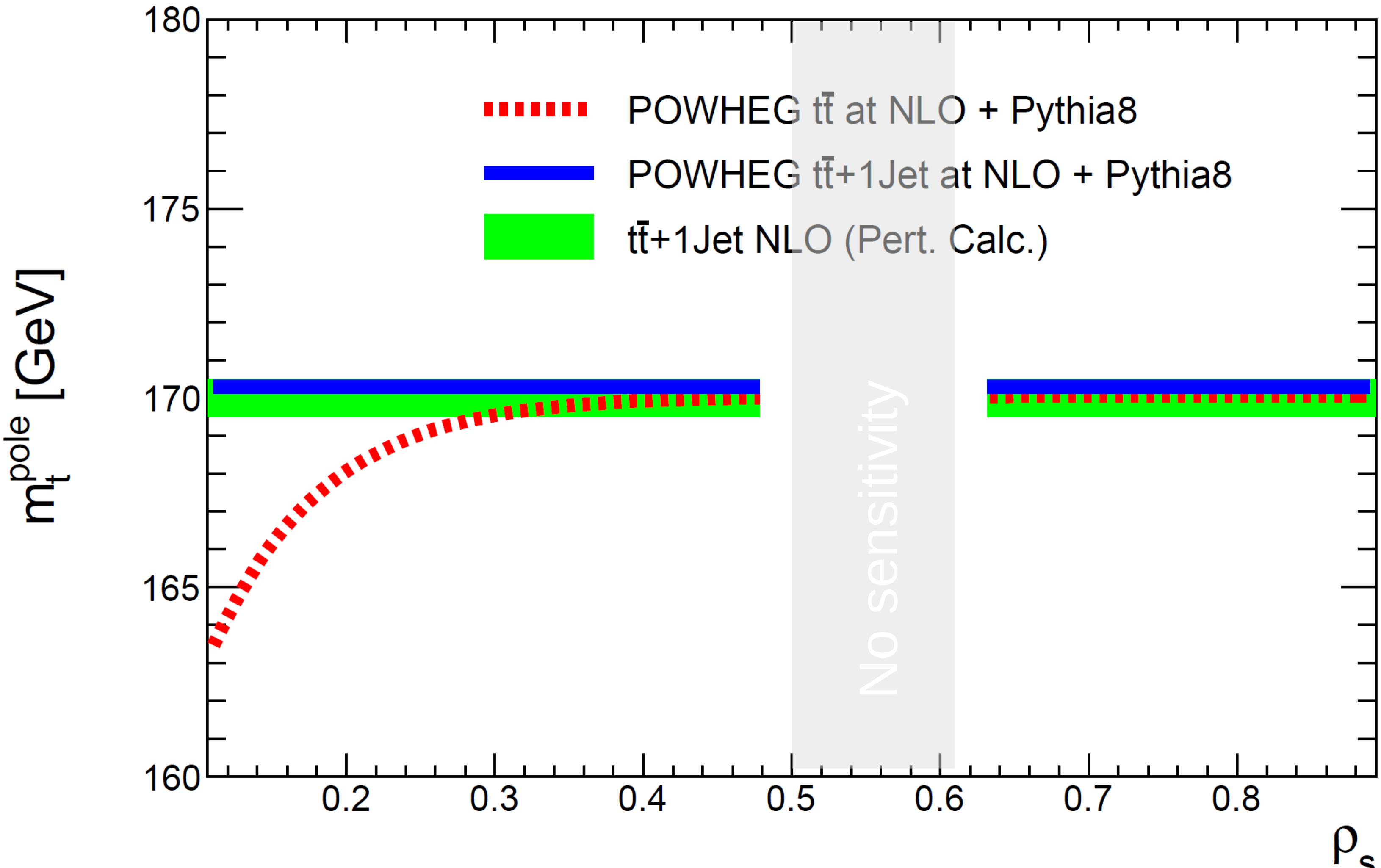
Scale and PDF uncertainties – impact on m_t

[S. Alioli, P.Fernandez, J.Fuster, A. Irles, S. Moch, PU, M. Vos 13]



From $\Delta m_t = \frac{1}{\mathcal{S}} \frac{\Delta \mathcal{R}}{\mathcal{R}}$

Comparison of different approximations

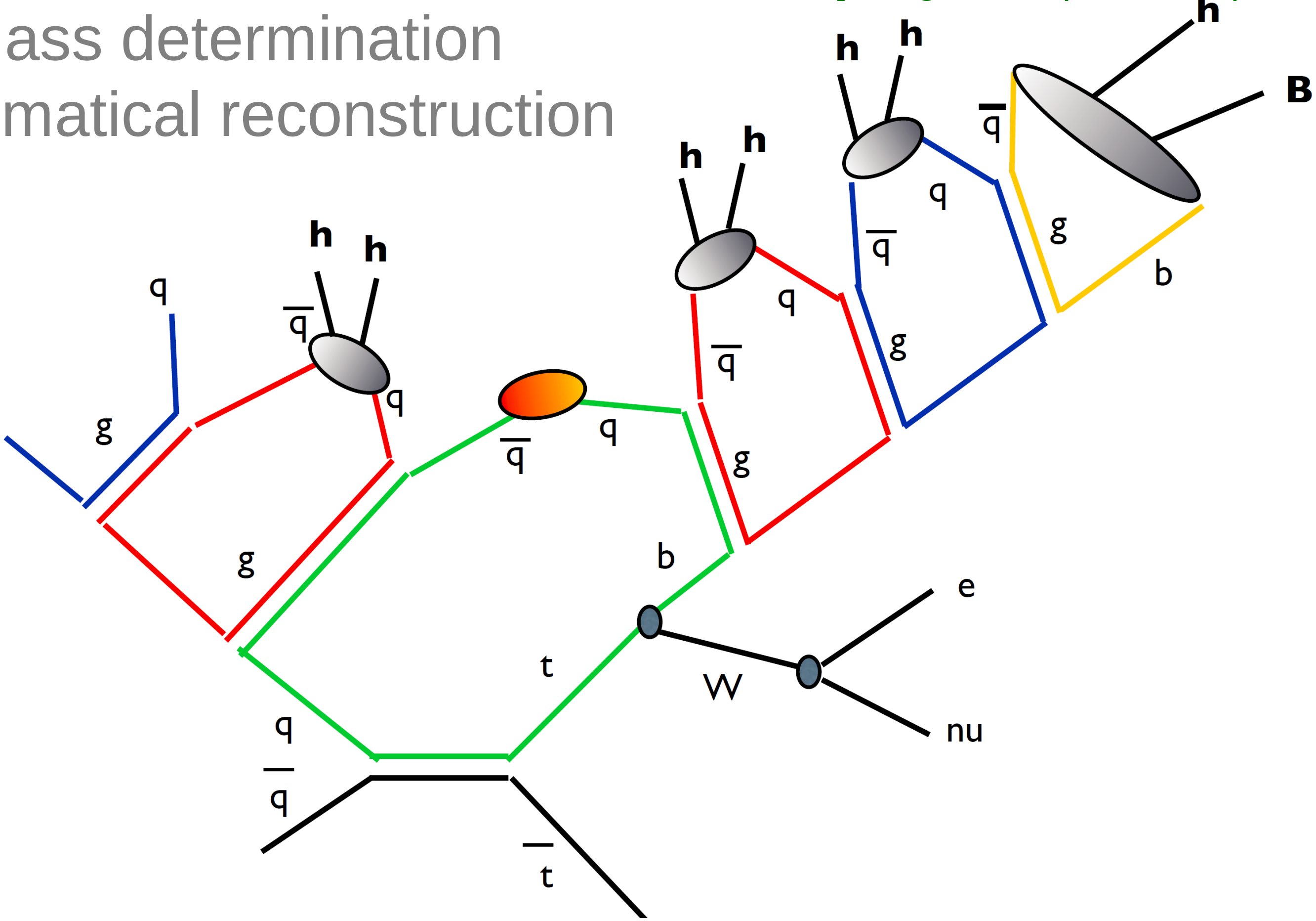


Green band: 170 ± 0.5 GeV

Impact of color reconnection

[Mangano, Top workshop, July 2012, CERN]

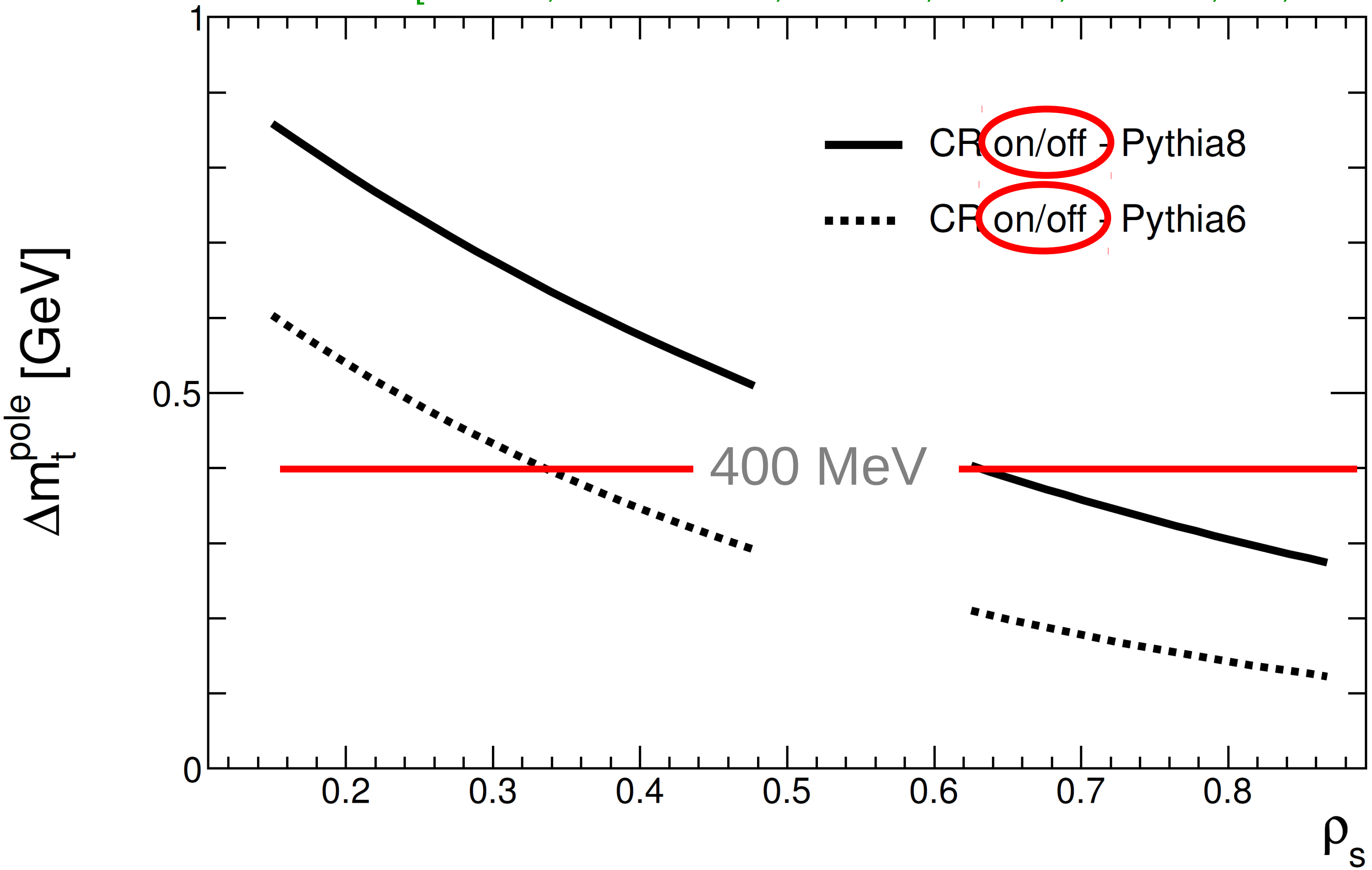
Affects mass determination
from kinematical reconstruction



$$p_t \neq p_W + \sum_i p^i_{\text{had}}$$

Color reconnection – impact on m_t

[S. Alioli, P.Fernandez, J.Fuster, A. Irles, S. Moch, PU, M. Vos '13]



Very conservative estimate, in practice expect smaller effect

Estimate of uncertainties

[S. Alioli, P.Fernandez, J.Fuster, A. Irles, S. Moch, PU, M. Vos '13]

Dominant uncertainties:

- PDF uncertainty: ~0.2 GeV
- Scale uncertainty: ~0.6 GeV
- Color reconnect.: ~0.4 GeV
- JES (+/- 3%): ~0.8 GeV

} 1.2 GeV

Mass independent unfolding possible

→ Promising alternative

ATLAS analysis is underway

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  small perturbative and non-perturbative corrections

- (☑) Method should employ well defined mass scheme

Conclusion

- Method very stable with respect to perturbative corrections (small NLO corrections, small scale uncertainties, different approximations agree well)
- No large uncertainties due to color reconnections
- Many uncertainties cancel due to normalization
- Different renormalization scheme in principle possible
- High sensitivity to top-quark mass

→ Systematic accuracy of 1GeV or even below seems possible