The top quark mass from the b quark Energy Peak: first NLO results

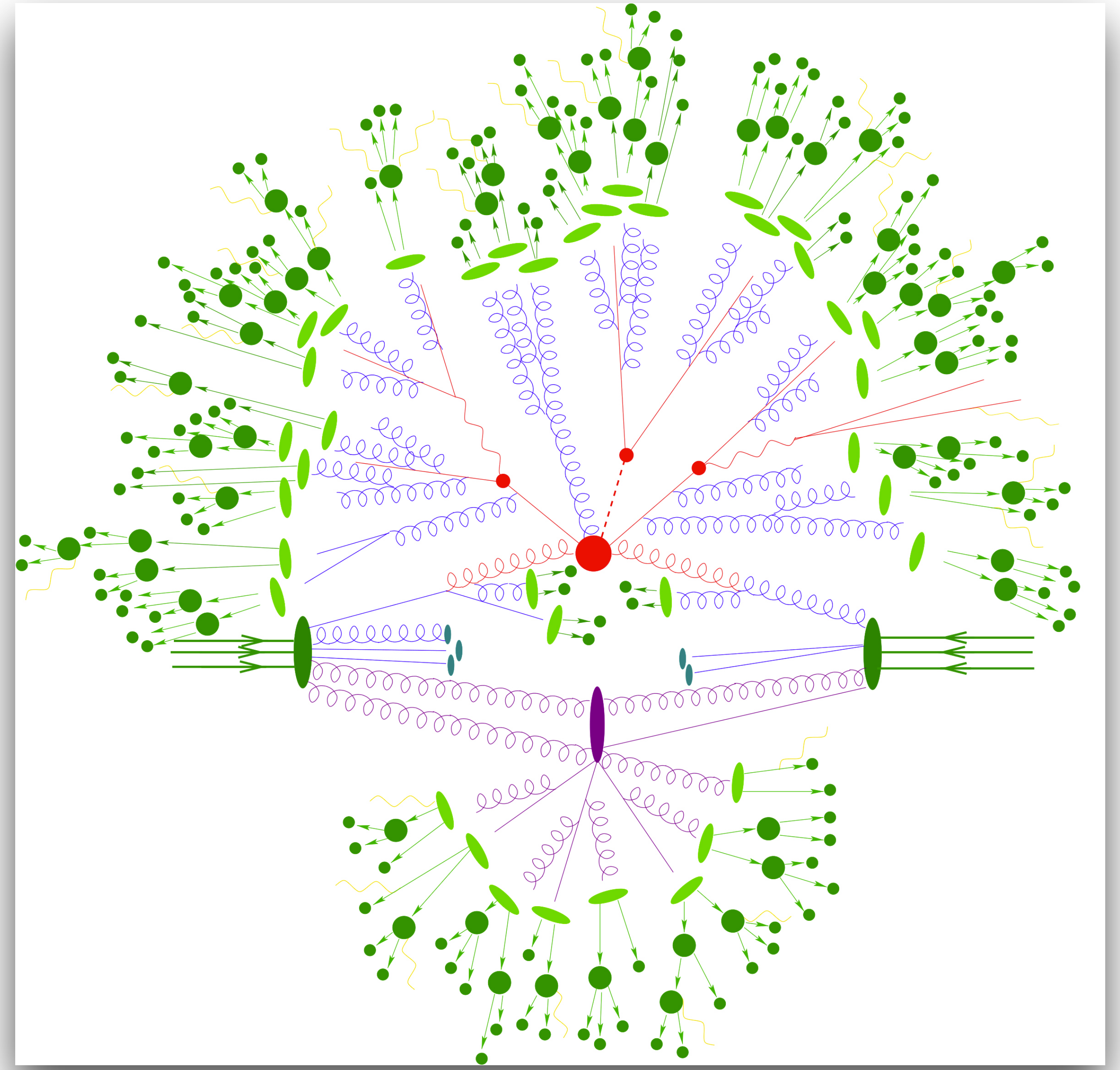
Roberto Franceschini
January 13th 2015

Work in Progress with K. Agashe, D. Kim and M. Schulze

Status

measurement at ≲0.5%! ⇒ *precision* QCD

- precision is systematics limited (JES, …, hadronization)



The strength of the future LHC top mass measurement will build on the **diversity of methods**
⇒ not very useful to talk about "*single best measurement*"

Each methods based on different assumptions/beliefs

- kinematics of the event (going beyond $t\bar{t} \to$ **bWbW**)
- MC *choices* (NLO, scales range & functional form …

  … width treatment, color neutralization, radiation in decays, hadronization)

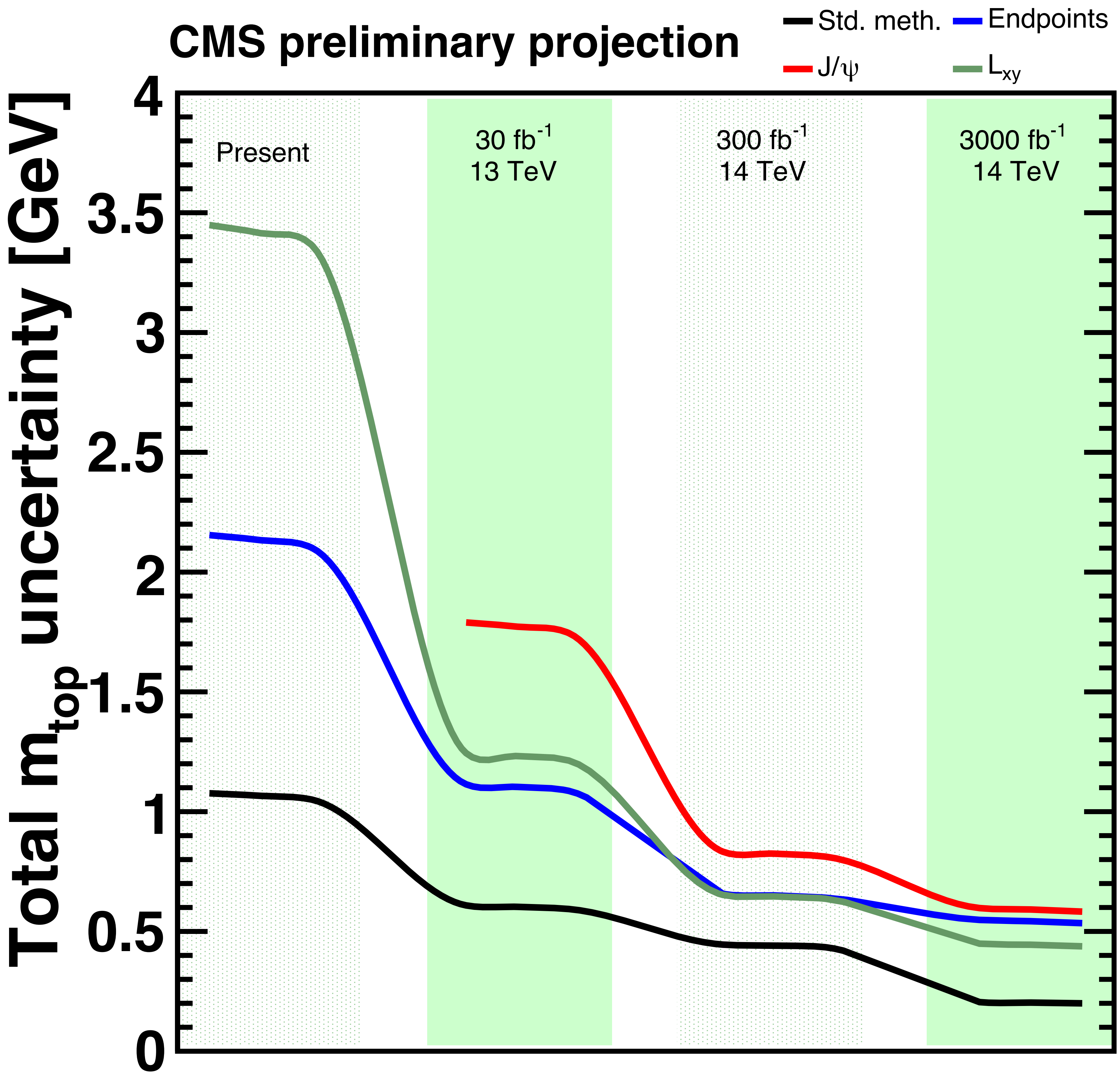
Ideal situation

Have many inherently different methods

possibly based on different experimental objects/quantities

- deal with reconstructed jets
- only-leptons
- only-tracks

Ideal situation



CMS-PAS-FTR-13-017

1310.0799 - Juste, Mantry, Mitov, Penin, Skands, Varnes, Vos, Wimpenny - Determination of the top quark mass circa 2013: methods, subtleties, perspective

Energy Peaks

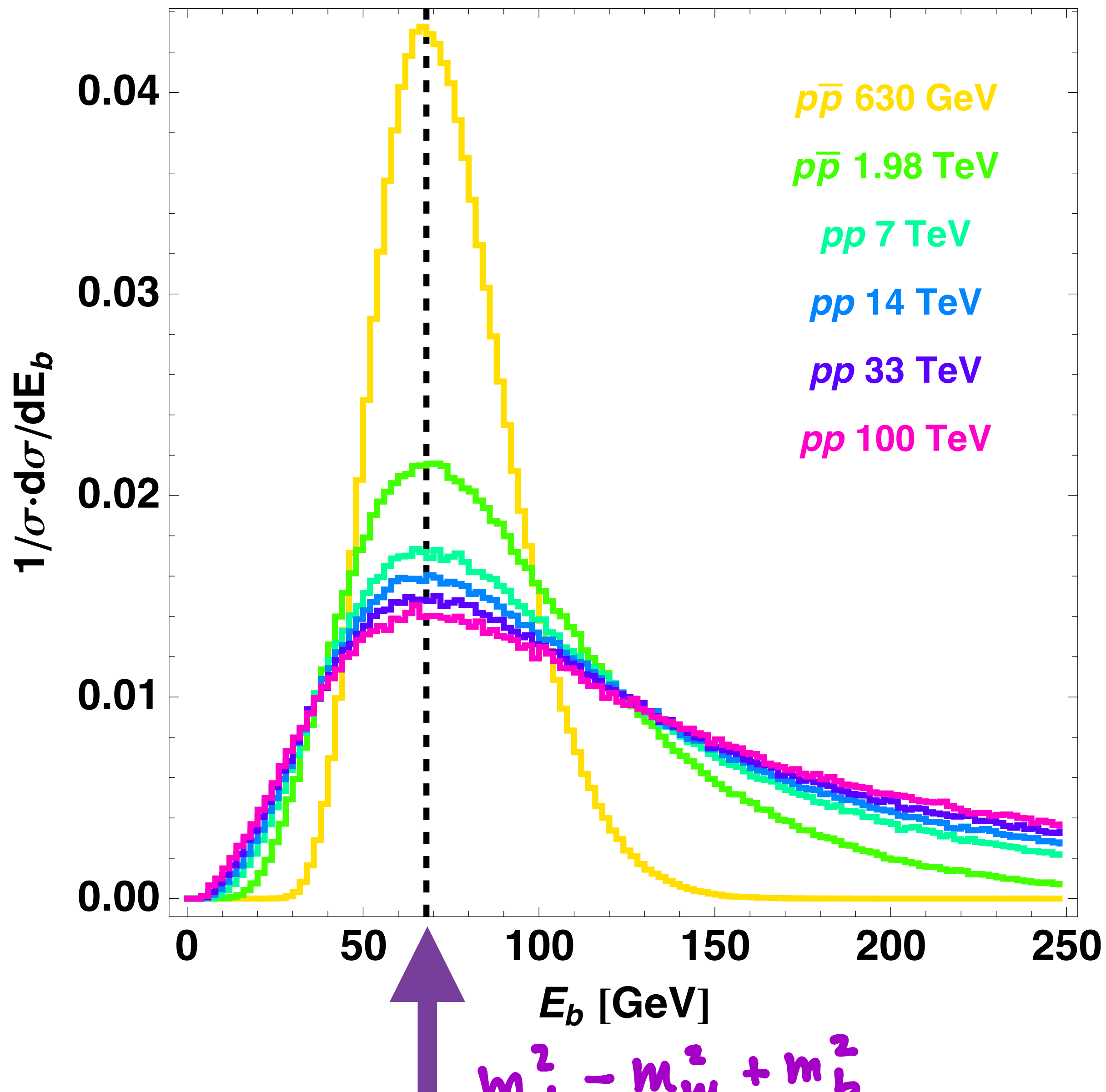
Lorentz *variant* quantities

Given suitable conditions, Lorentz variant quantities can tell us a lot about the invariants

How special is this invariance?

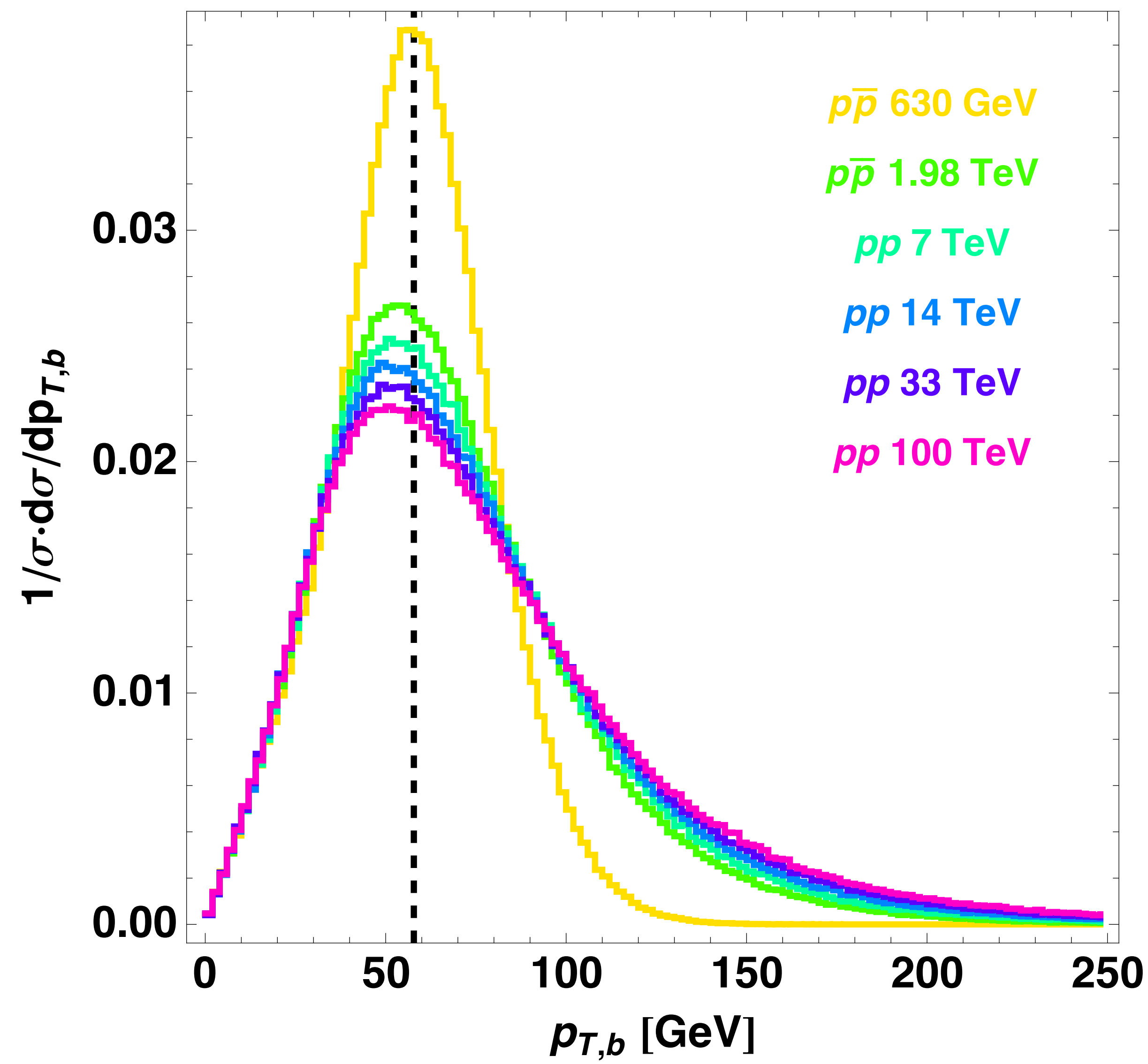
1209.0772 - Agashe, Franceschini and Kim

Shape changes, peak doesn't!



$$E_b^* = \frac{m_t^2 - m_W^2 + m_b^2}{2 m_t}$$

Shape changes, peak does too



The sensitivity to the **boost distribution** is the key

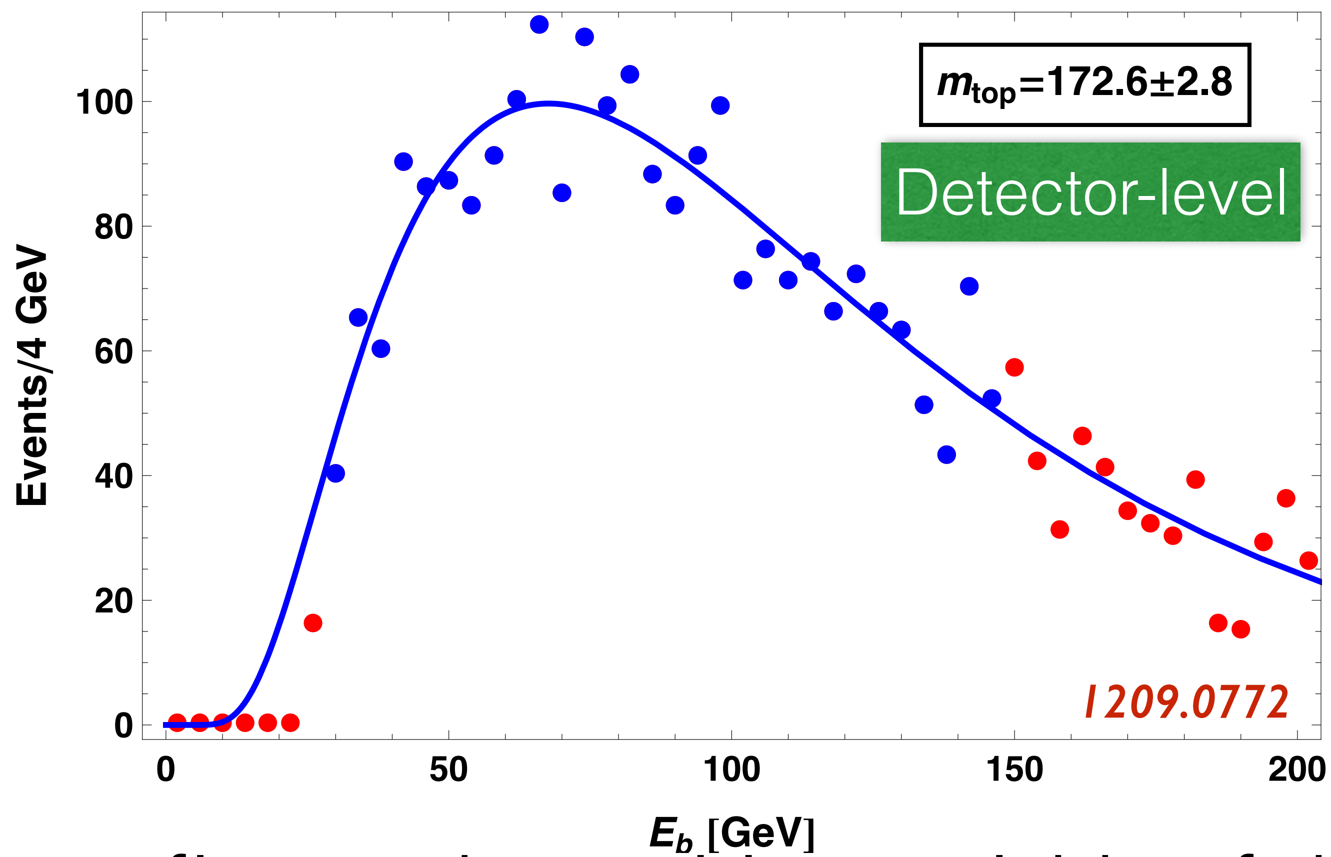
- properties similar to Lorentz invariants
- without the need to form combinations

Useful in practice?

$$E_b^* = \frac{m_t^2 - m_W^2 + m_b^2}{2 m_t}$$

b-**jet** energy (LO+PS)

100 pseudo-experiments from MadGraph5+Pythia6.4+Delphes (**ATLAS-2012-097**)



2-parameters fit: peak position, width of the distribution

Proof of the concept: ***5/fb LHC 7 TeV***

m_{top}=173.1 ± 2.5 GeV (stat)

1209.0772 - Agashe Franceschini and Kim

message: LO effects are well under control → CMS at work!

very encouraging LO result with b-jet energy

after having explored a number of **new physics applications** of this idea

- *1212.5230 - Agashe, RF, Kim, Wardlow*
- *1309.4776 - Agashe, RF, Kim*
- *1403.3399 - Chen, Davoudiasl, Kim*
- *Agashe, RF, Kim, Wardlow - WIP*
- *Agashe, RF, Kim, Hong - WIP*

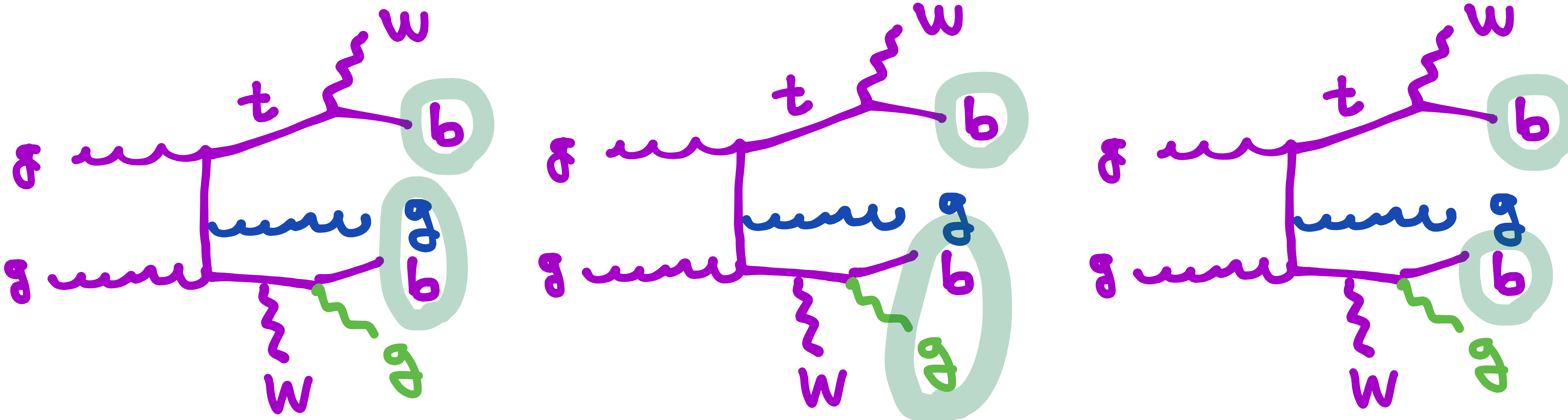
extension to NLO in progress

your inputs are very welcome

NLO: production & decay

(MCFM)

Agashe, Franceschini, Kim, Schulze - in preparation



NLO virtues

Agashe, Franceschini, Kim, Schulze - in preparation

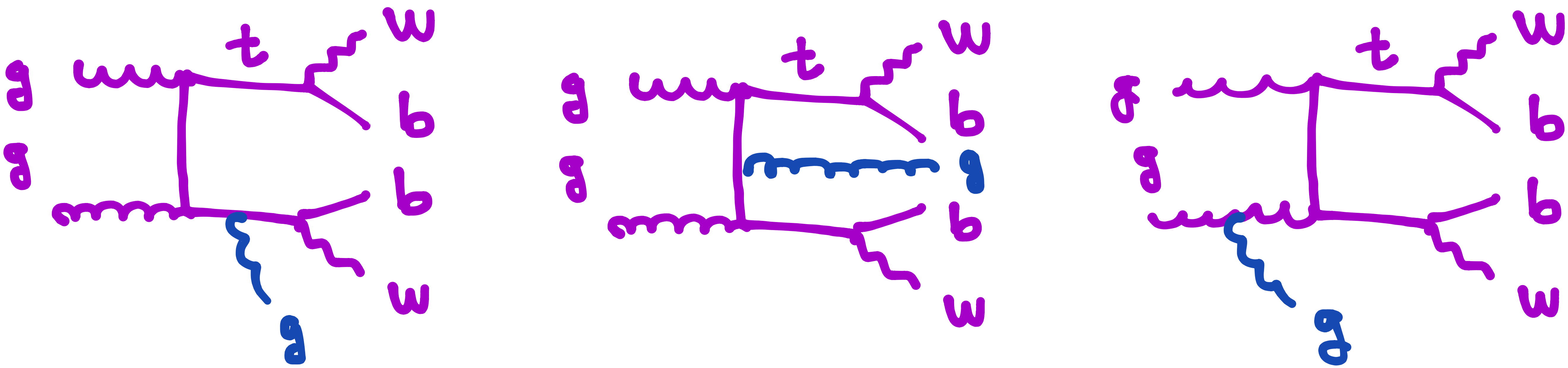
- **Invariance holds for pp→tt @ NLO**
- Not sensitive to Initial State Radiation
- Not sensitive to Parton Distribution Functions
- Not sensitive to the exact energy of the collider

only sensitive to the NLO decay t→bWg

Insensitive to production at NLO

Agashe, Franceschini, Kim, Schulze - in preparation

Production NLO only affects the boost distribution of top



The energy peak position is unchanged

$$E_b^{peak} = \frac{m_t^2 - m_W^2 + m_{b/j}^2}{2m_t} = E_b^*$$

NLO virtues

- Invariance holds for pp→tt @ NLO
- **Not sensitive to Initial State Radiation**
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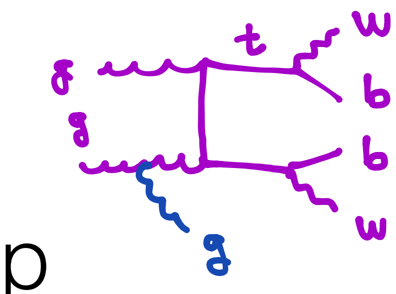
only sensitive to the NLO decay t→bWg

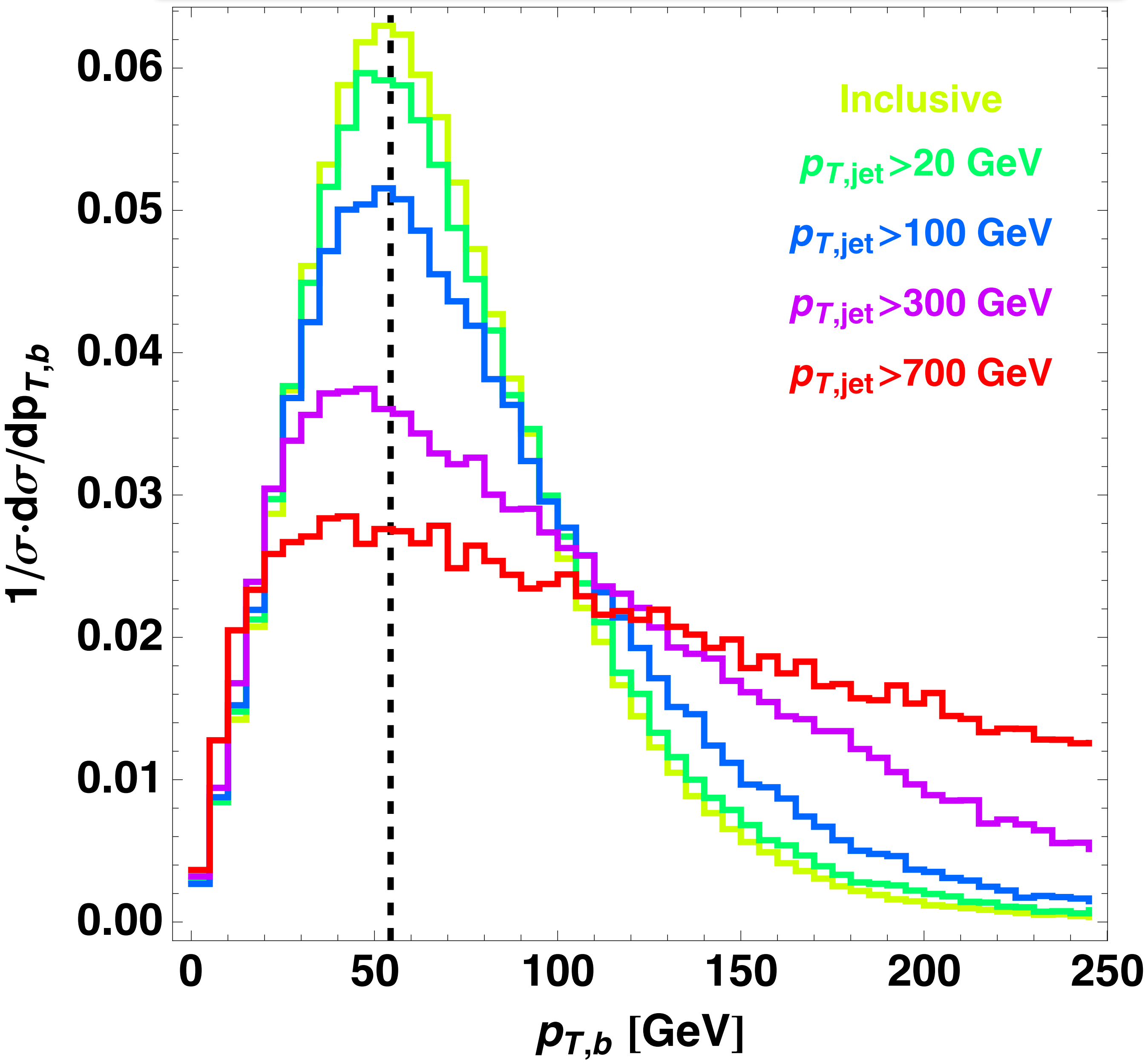
Effect of initial state radiation



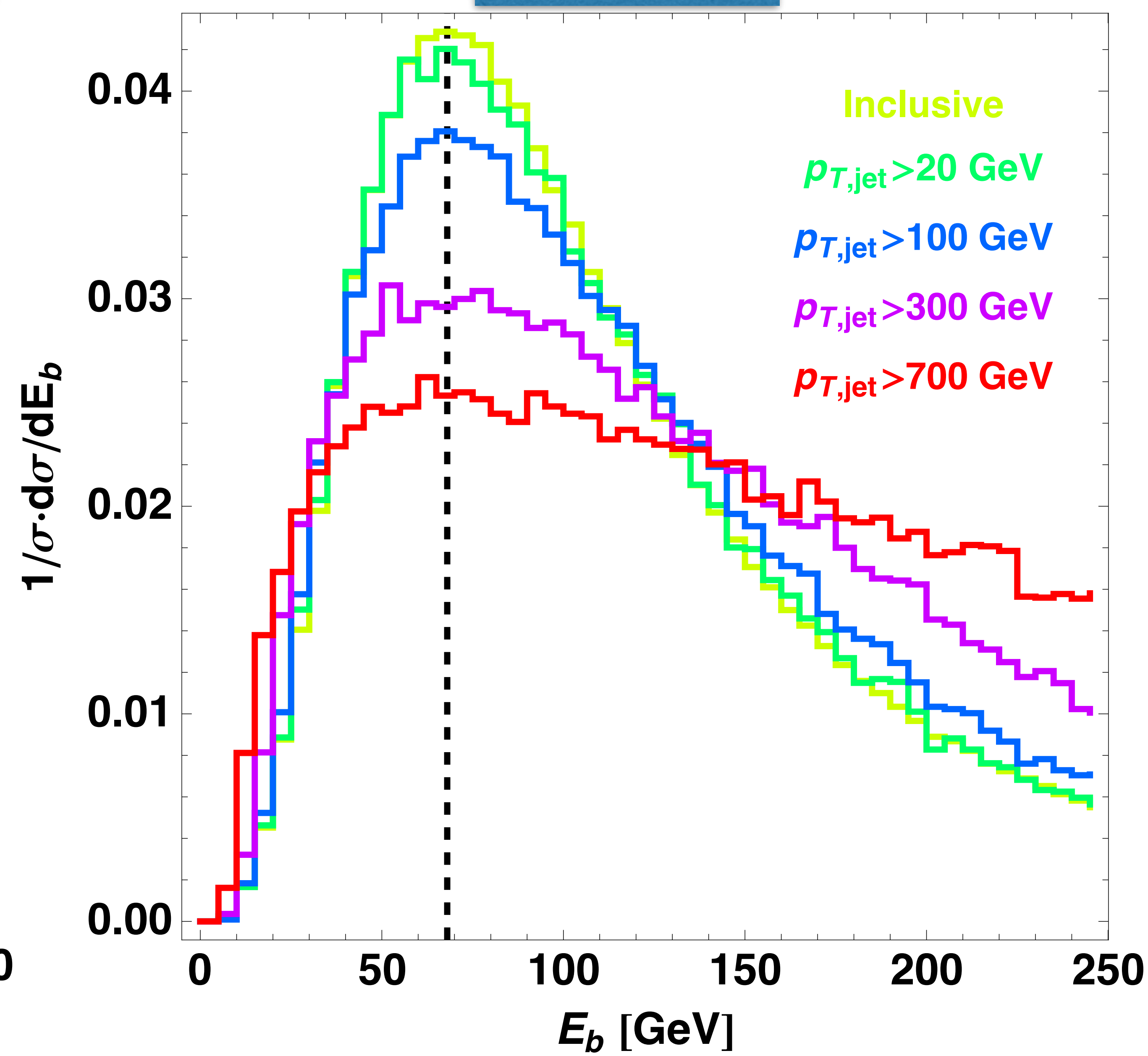
ISR only affects the boost distribution of top

Agashe, Franceschini, Kim, Schulze - in preparation

Transverse Momentum



Energy



peak stability

NLO virtues

- Invariance holds for pp→tt @ NLO
- Not sensitive to Initial State Radiation
- **Not sensitive to Parton Distribution Functions**
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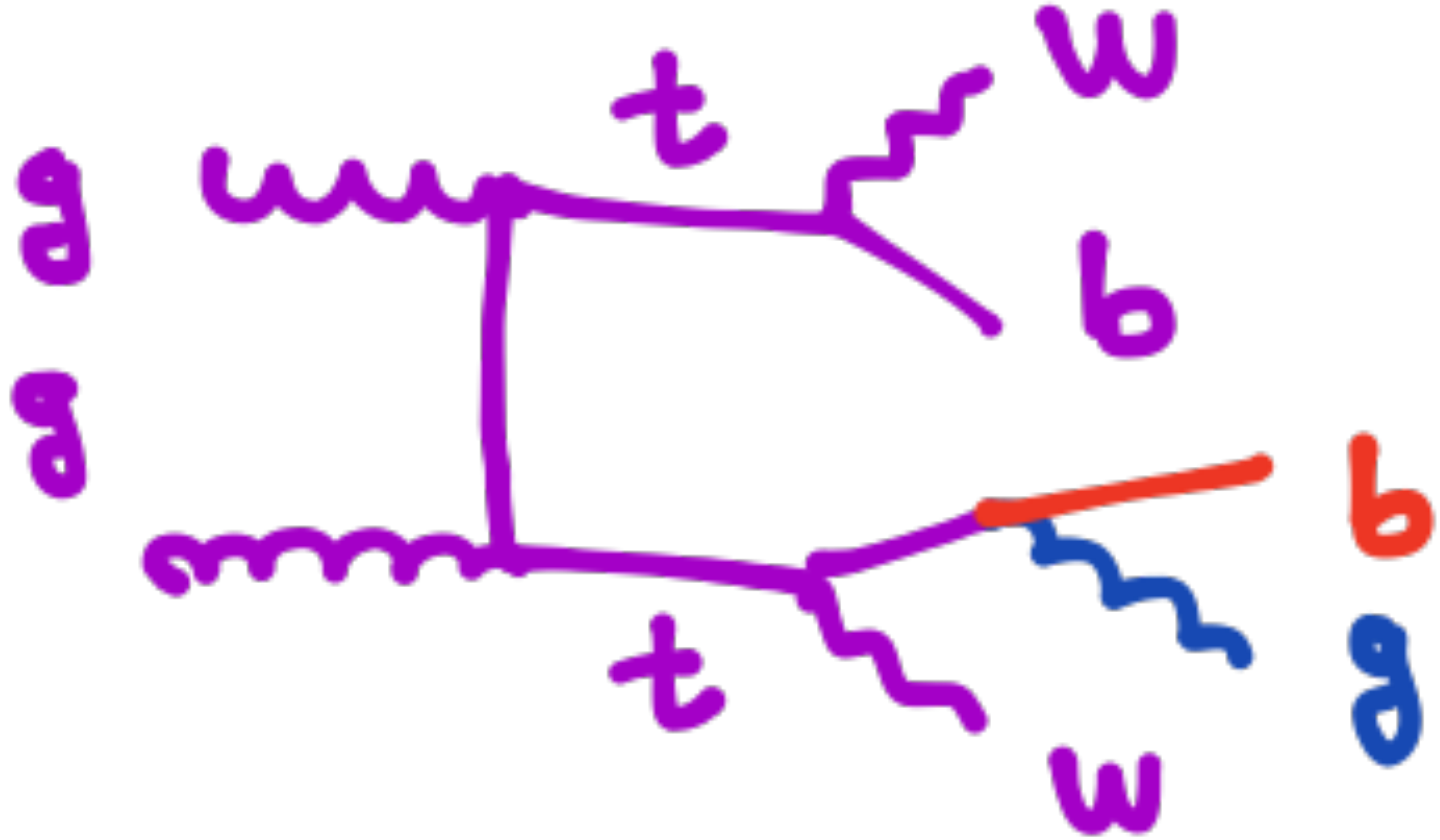
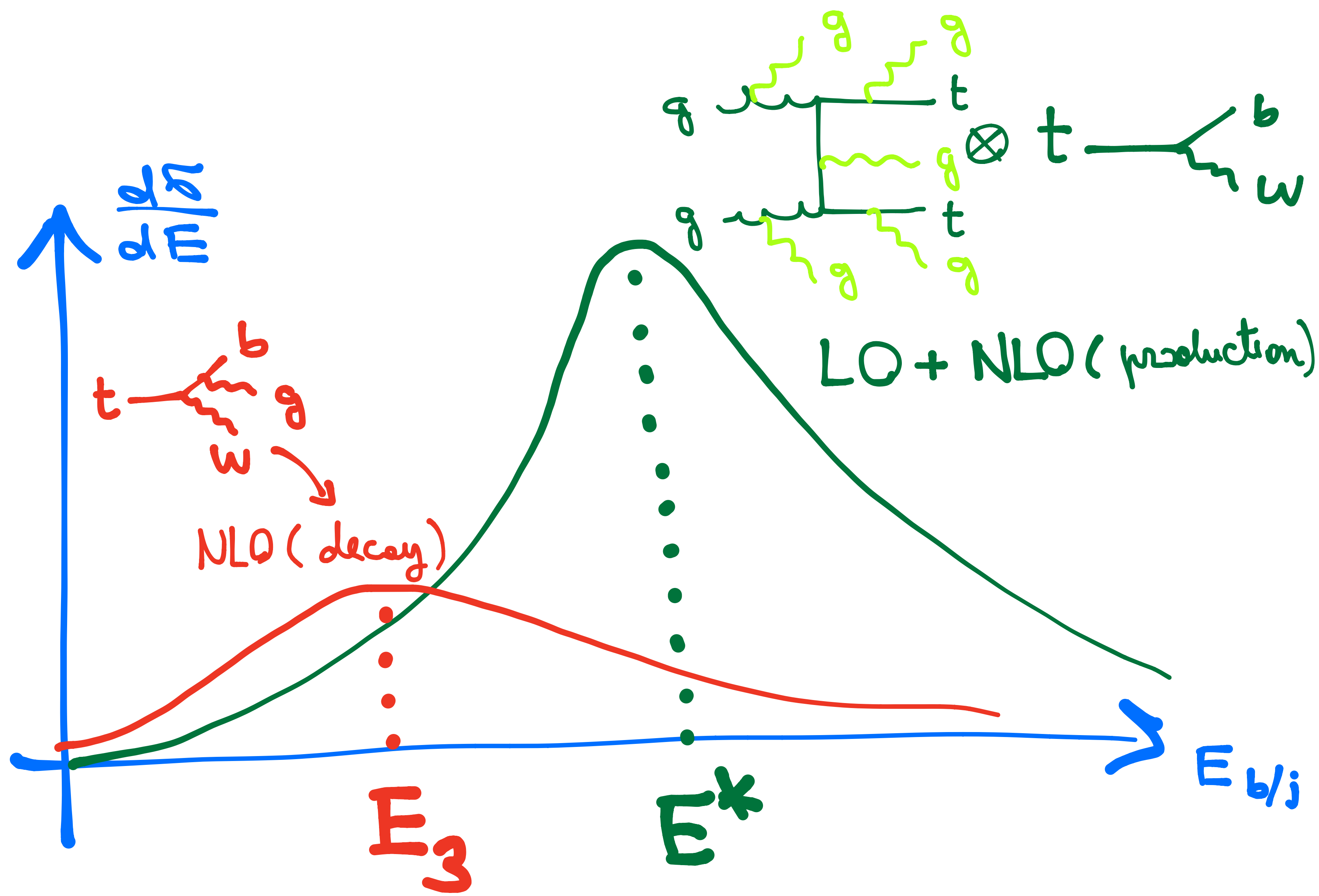
only sensitive to the NLO decay t→bWg

Decay at NLO

Agashe, Franceschini, Kim, Schulze - in preparation

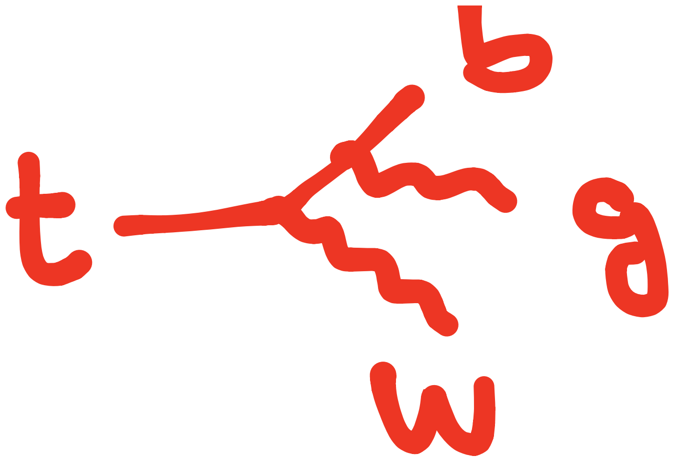


Peak shift at NLO



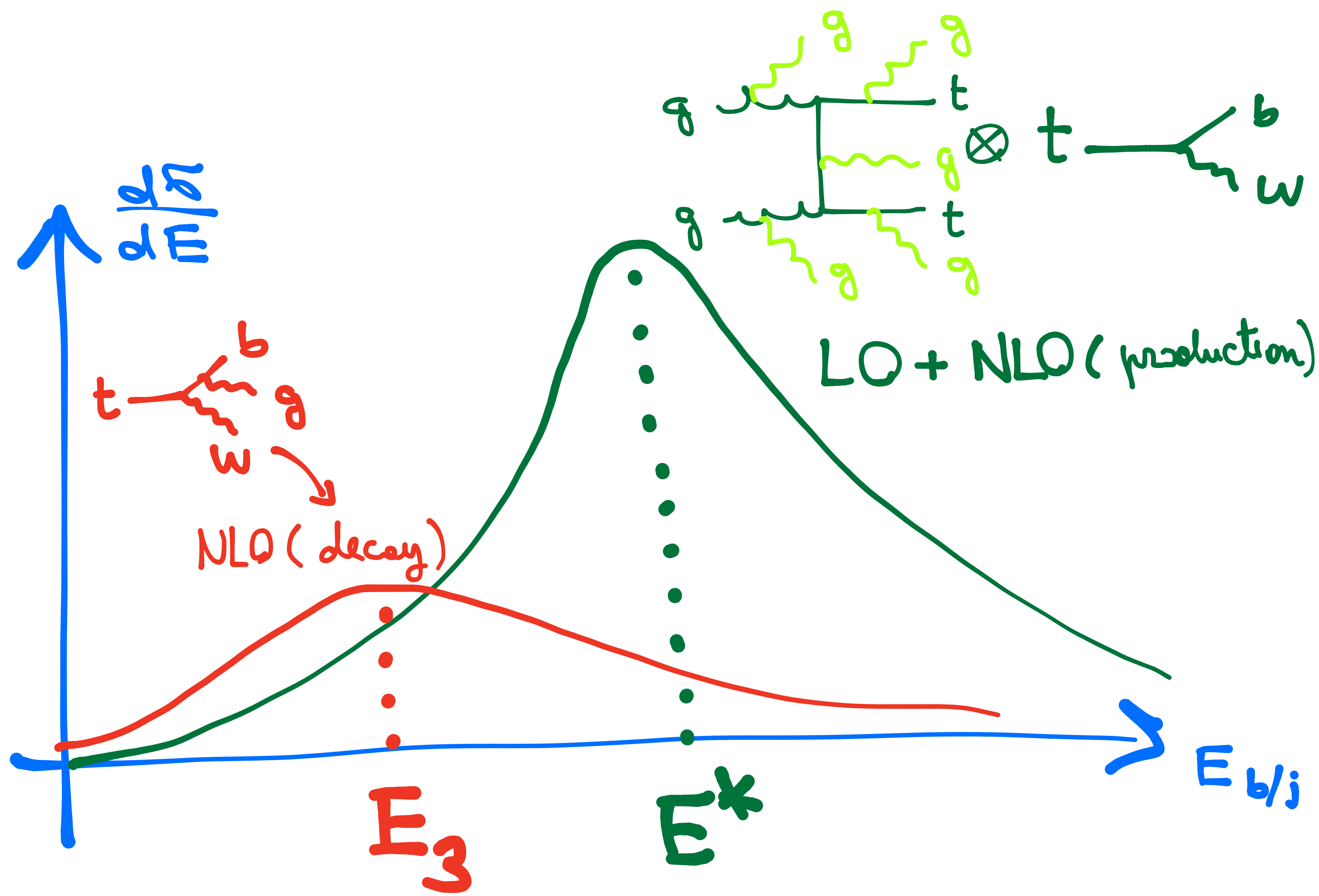
$$E^{peak} = E^* + O(1)\frac{\alpha}{4\pi}E_3$$

Peak shift at NLO



BR(t→bW**g**)
MadGraph5@LO

hard glue	Br
pT>30 GeV dR>0.2	0.061
pT>30 GeV dR>0.4	0.043
pT>20 GeV dR>0.2	0.10
pT>20 GeV dR>0.4	0.074



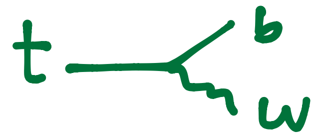
$$E^{peak} = E^{*}(1-\Delta_{TH}) + \Delta_{TH} E_3$$

Δ_{TH}=BR(t→bW**g**)/BR(t→bW)≃0.05

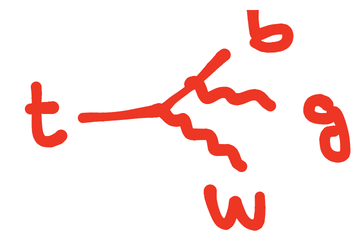
NLO: production & decay

(MCFM)

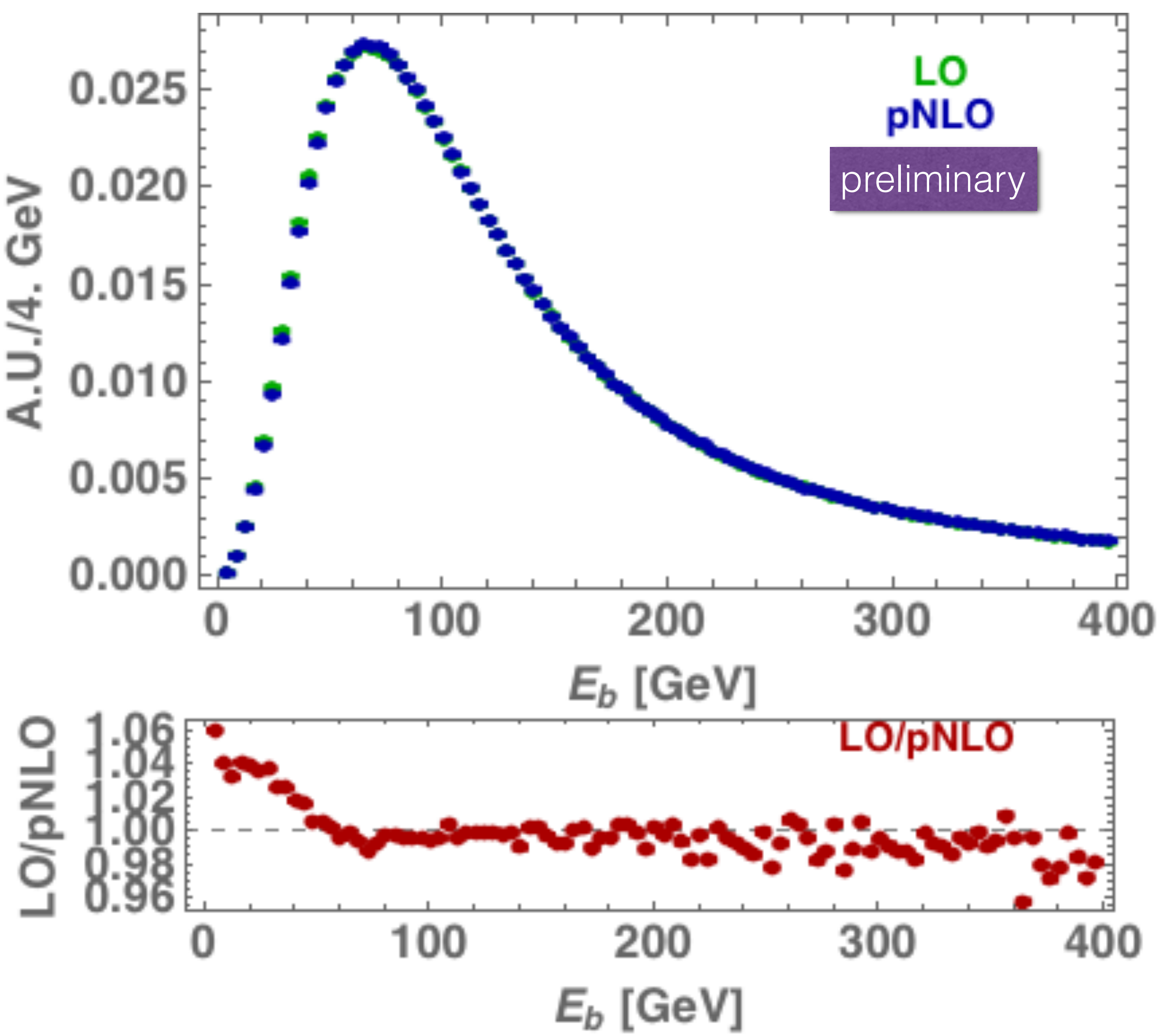
Energy of b

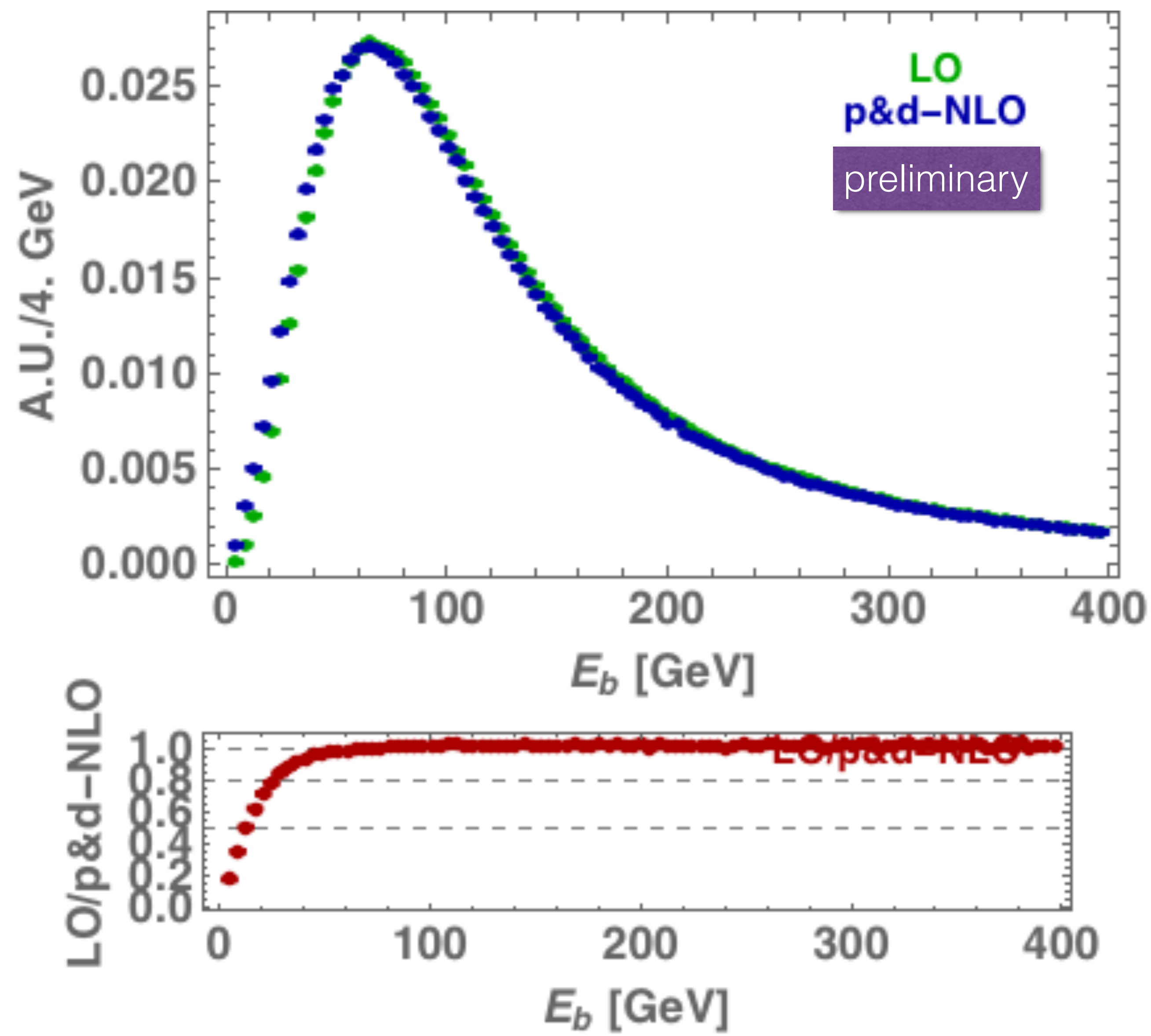


decay at LO



decay at NLO

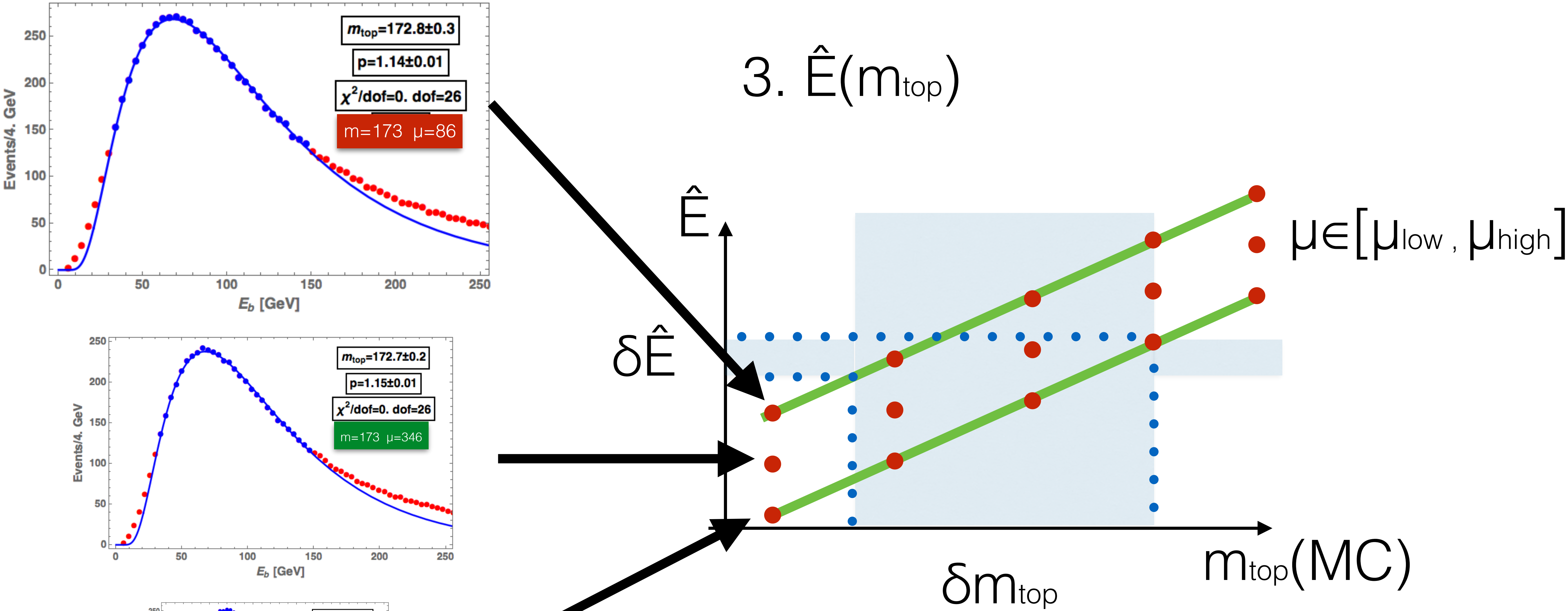


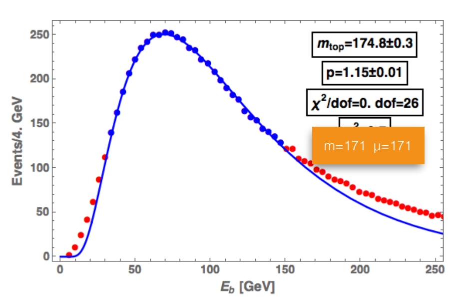


1. energy distribution $d\sigma/dE_b$

2. peak of the distribution $\hat{E}$

3. $\hat{E}(m_{top})$



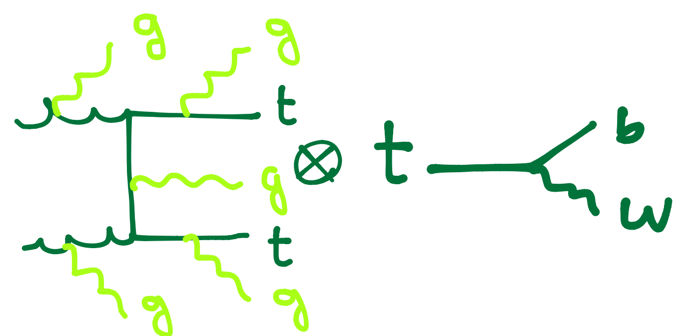


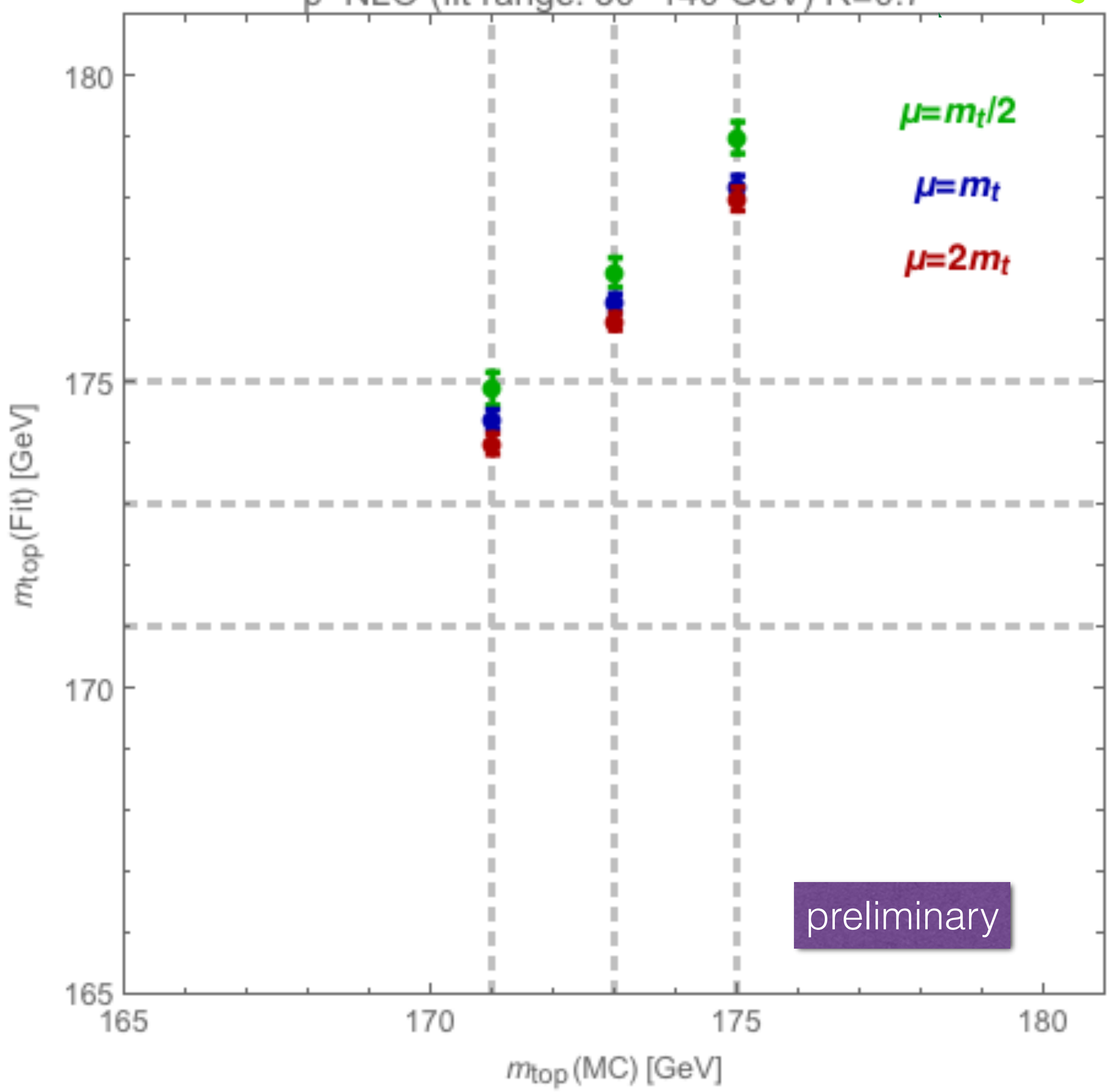
Best:

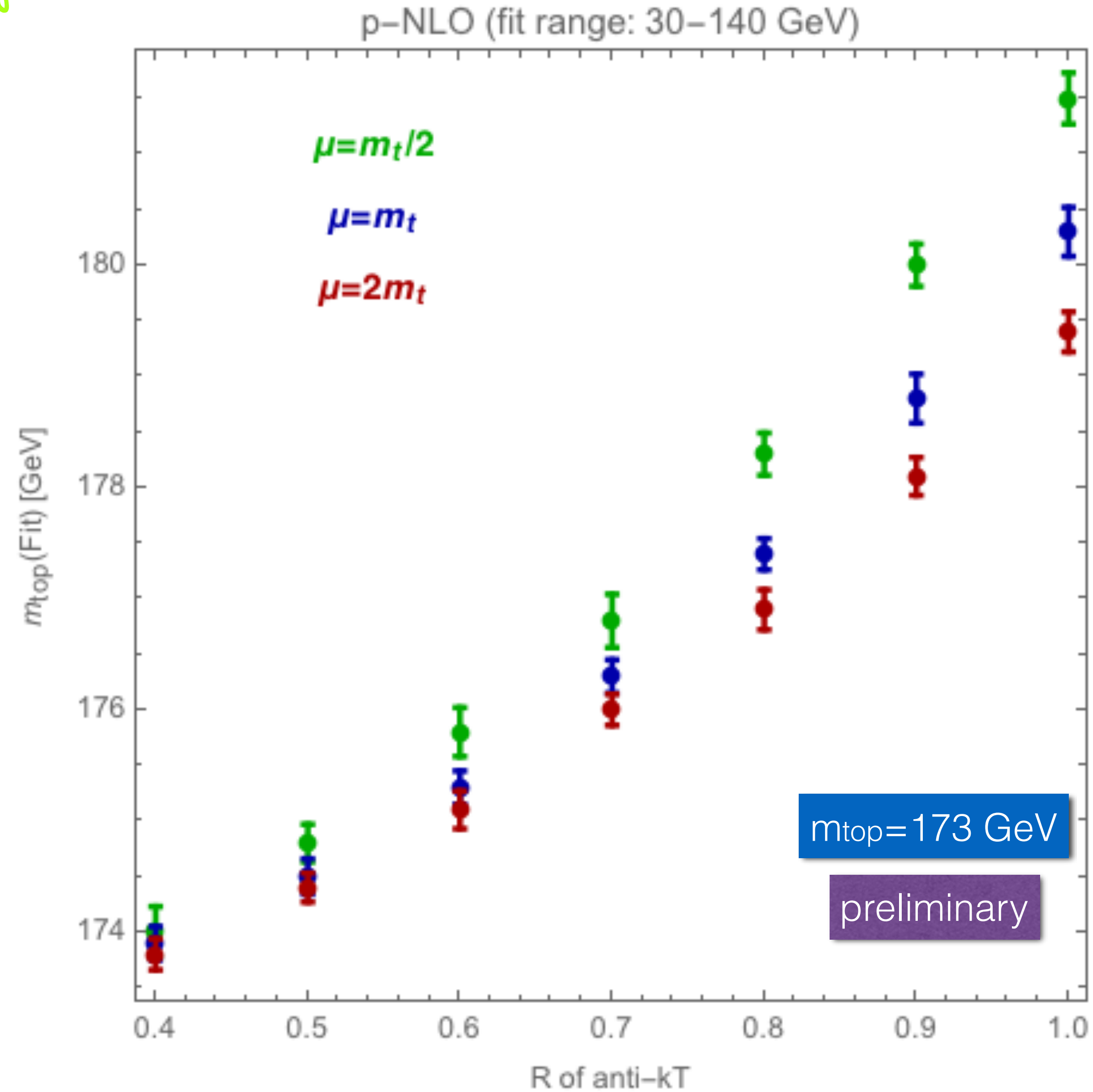
- narrow band between μ_{high} and μ_{low}
- steep E vs. m_{top} $E_b^* = \frac{m_t^2 - m_W^2 + m_b^2}{2 m_t}$

NLO: production

(MCFM)



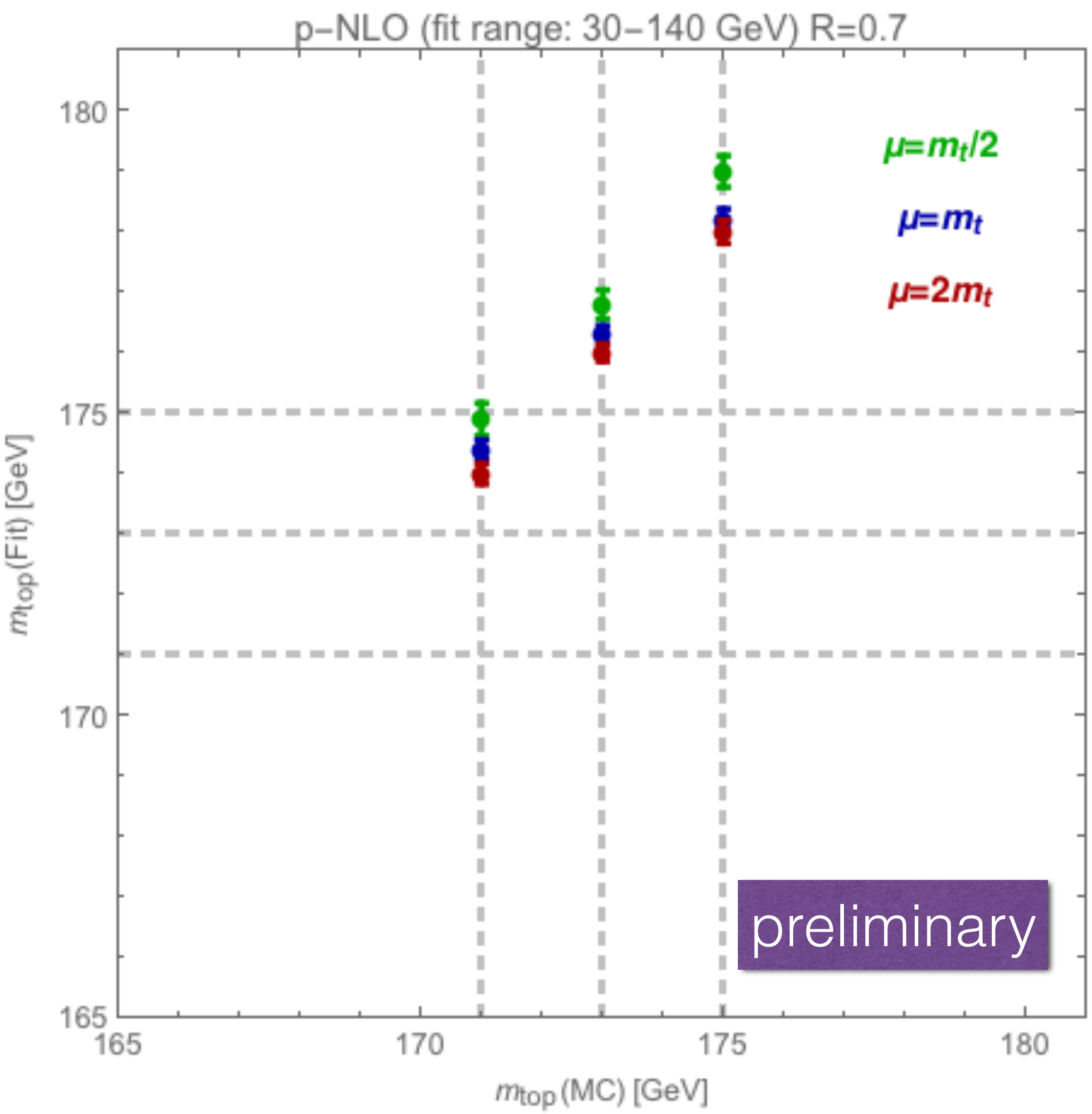


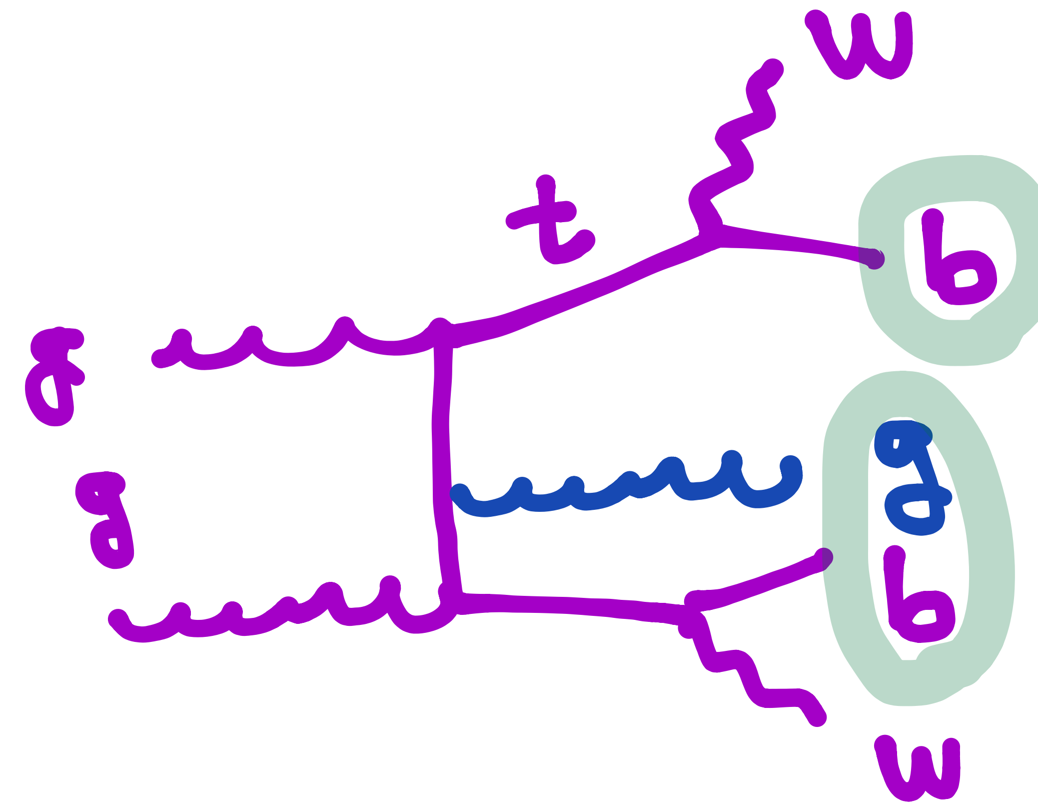


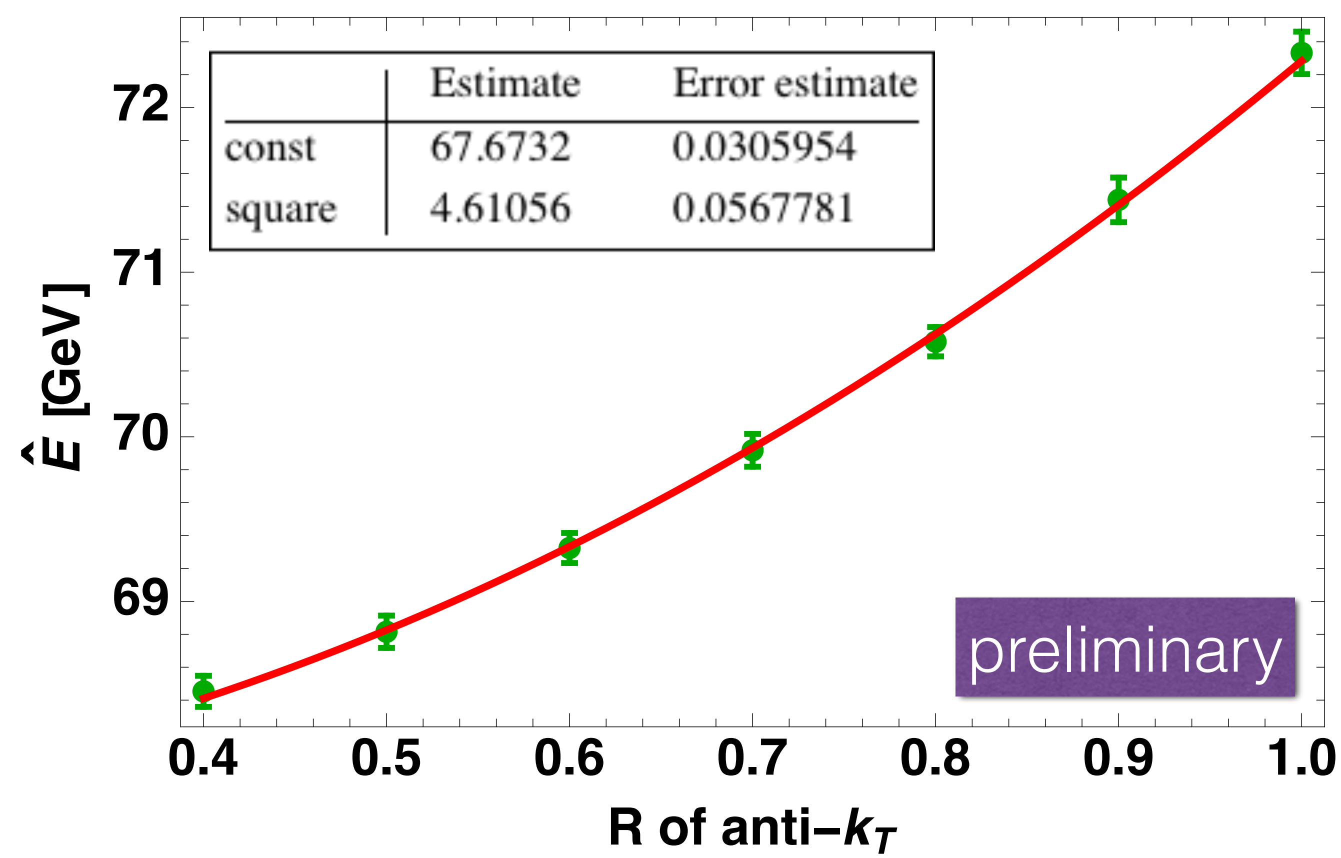
very little sensitive to the scale choice (less than 400 MeV on m_{top})

NLO: production

(MCFM)



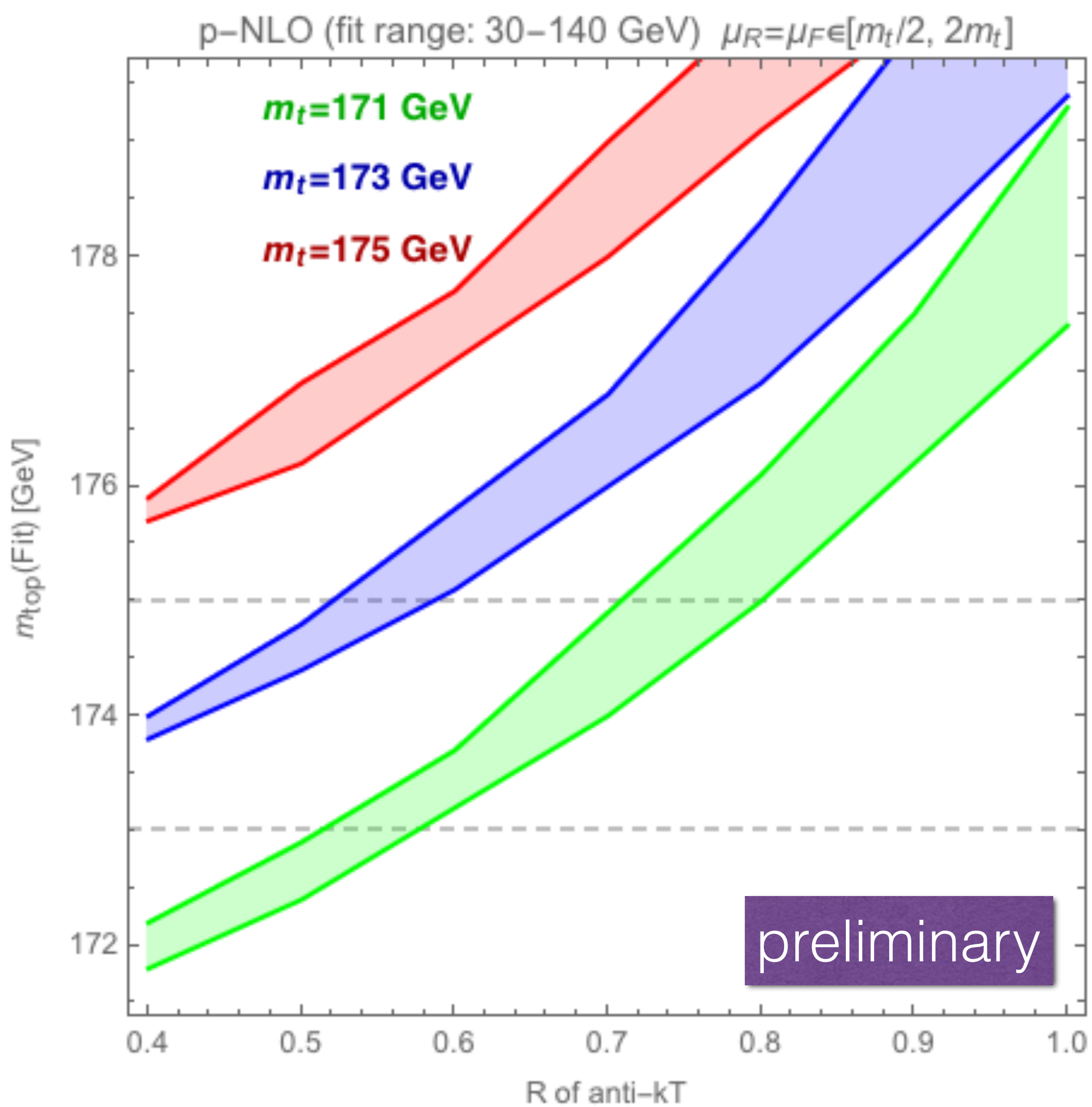


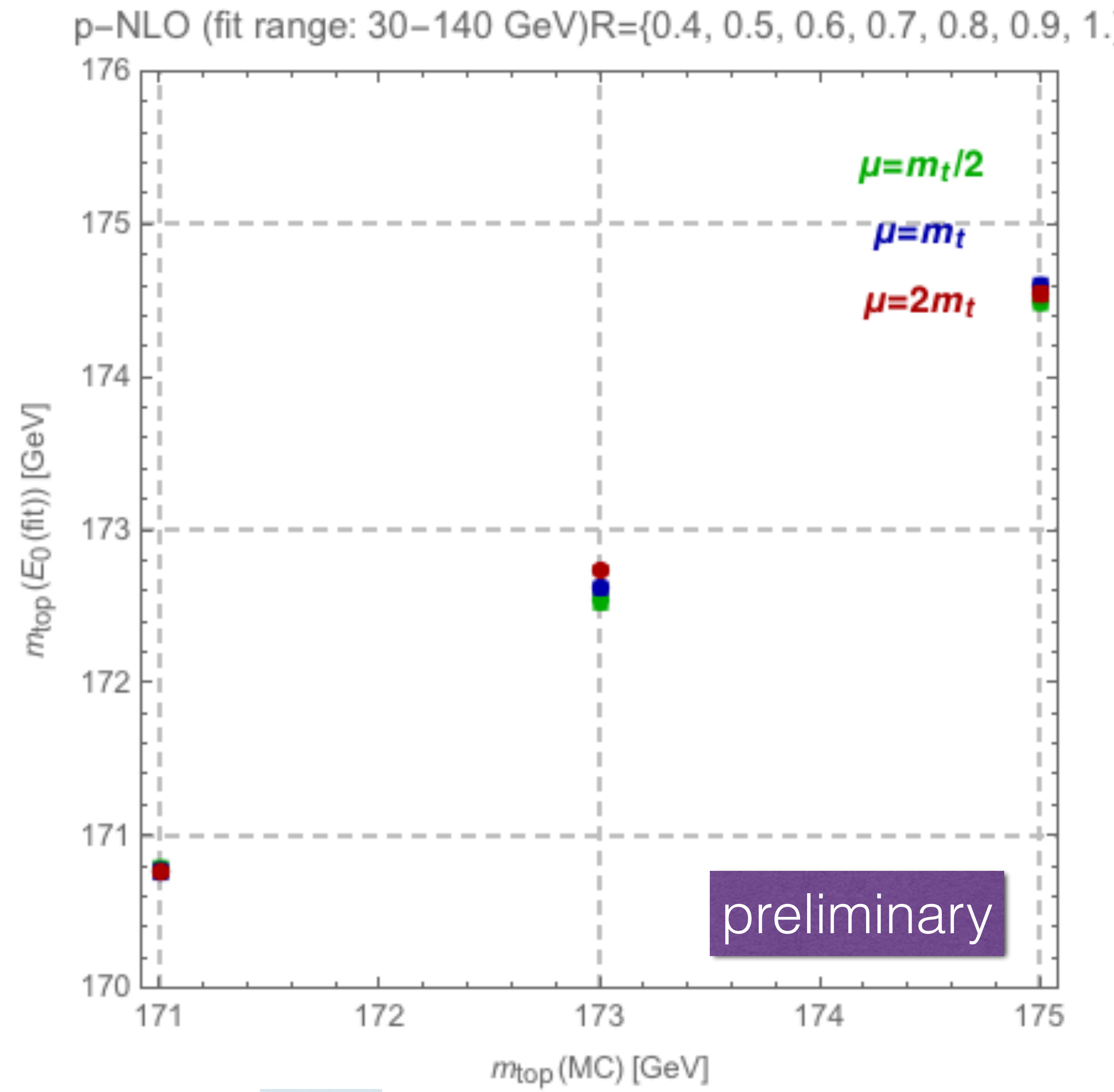


shift ~ R^p (p~2 jet area)
shift ~ 1/μ (real radiation)

NLO: production

(MCFM)





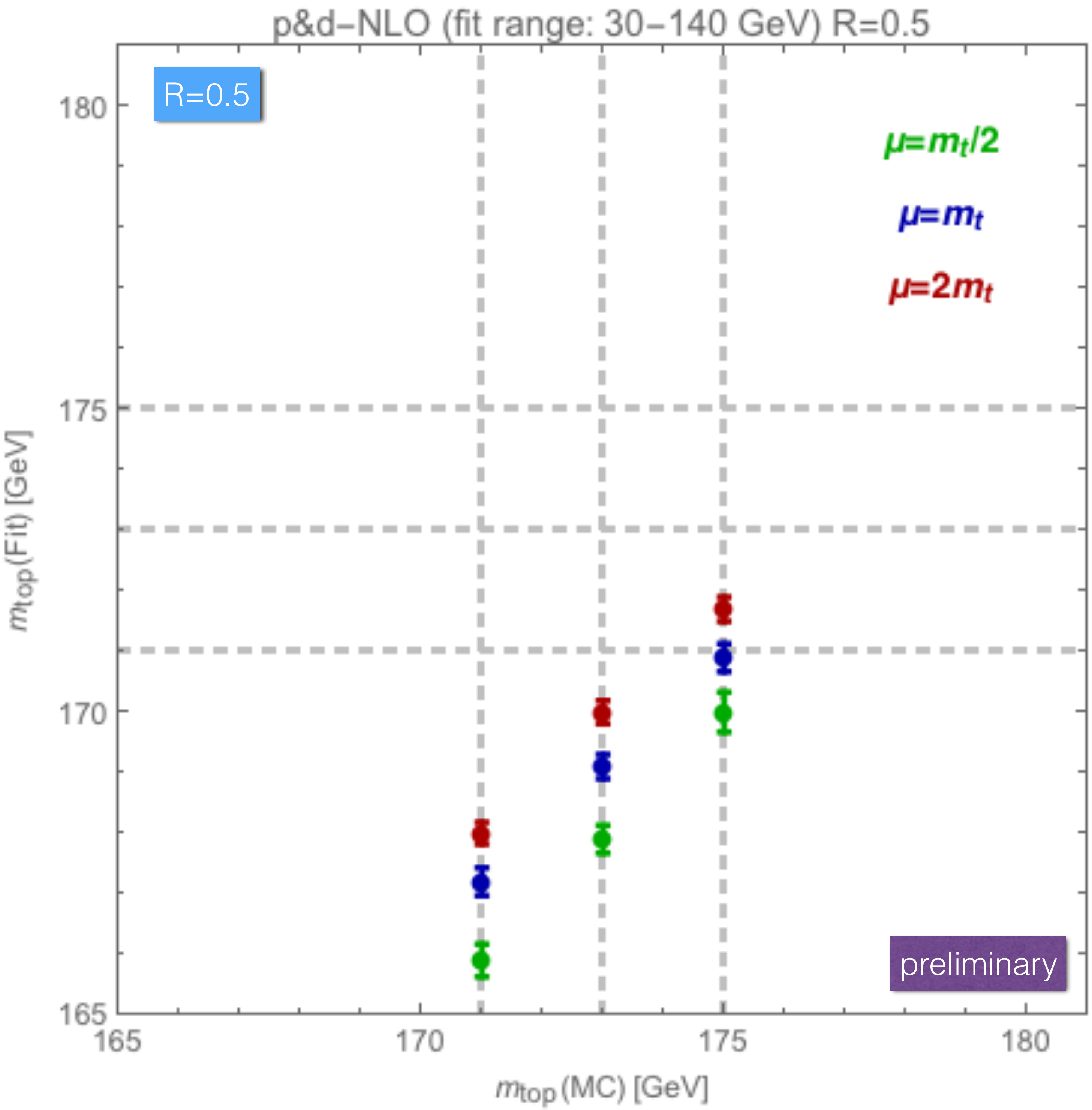
$$\hat{E} = E_0 + \alpha(\mu)\cdot P(\mu)\cdot R^2$$

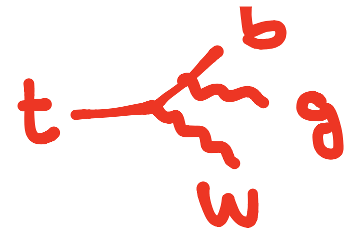
$$E_b^* = \frac{m_t^2 - m_W^2 + m_b^2}{2m_t}$$

shift ~ R^p (p~2 jet area)
shift ~ 1/μ (real radiation)

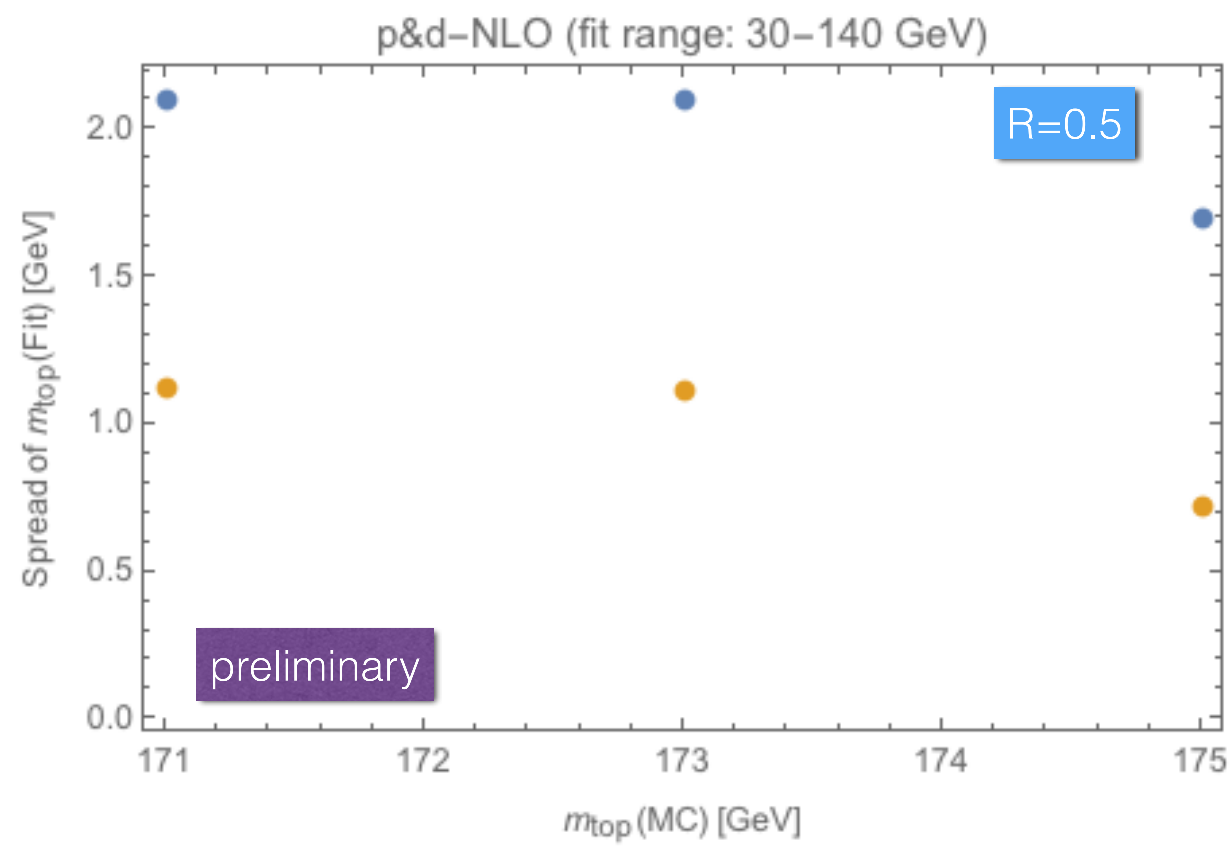
NLO: production & decay R=0.5

(MCFM)





$|\delta| \sim \alpha_3 \sim 1/\mu$

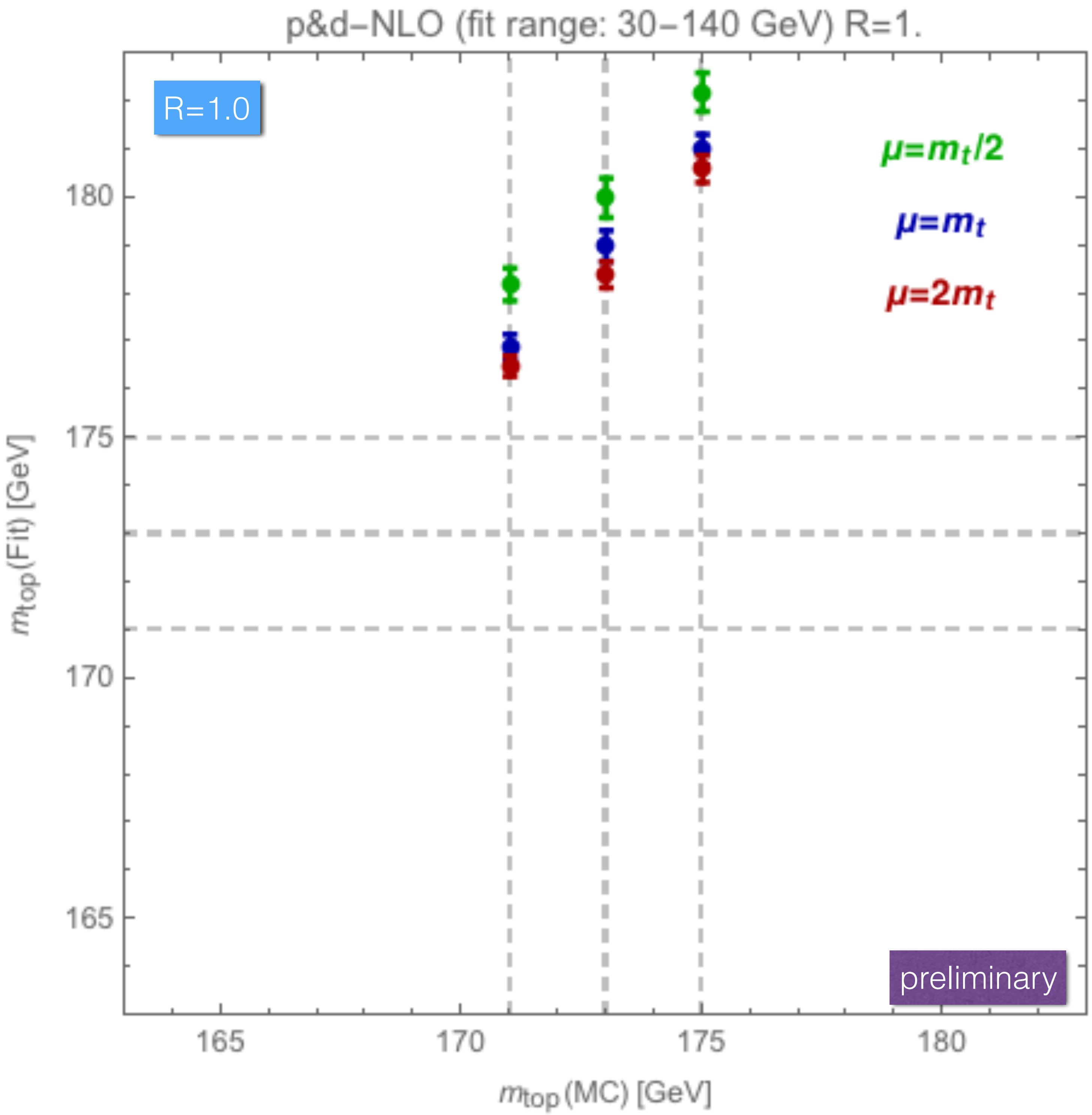


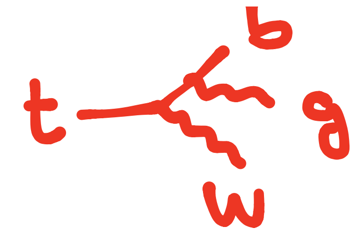
decay NLO sensitive to the scale choice: ±1 GeV on m_{top}

NLO: production & decay

R=1.0

(MCFM)





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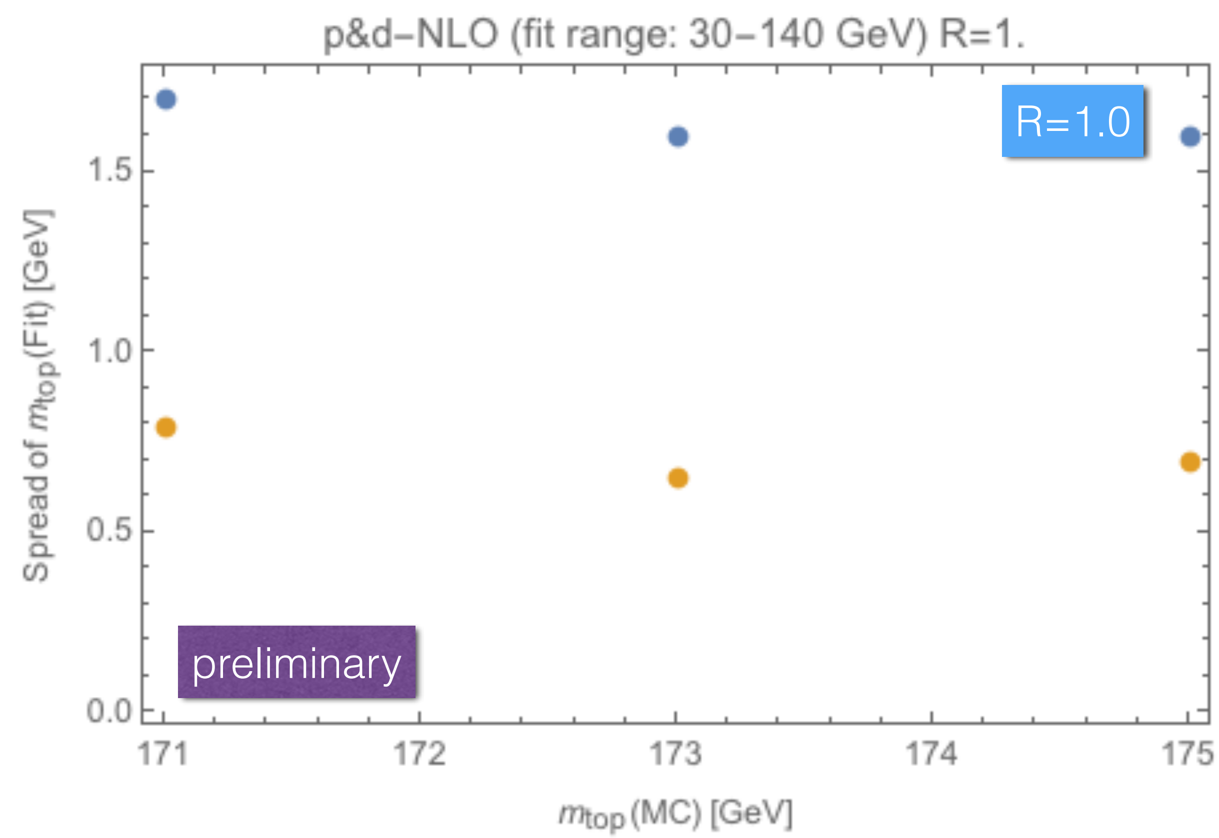
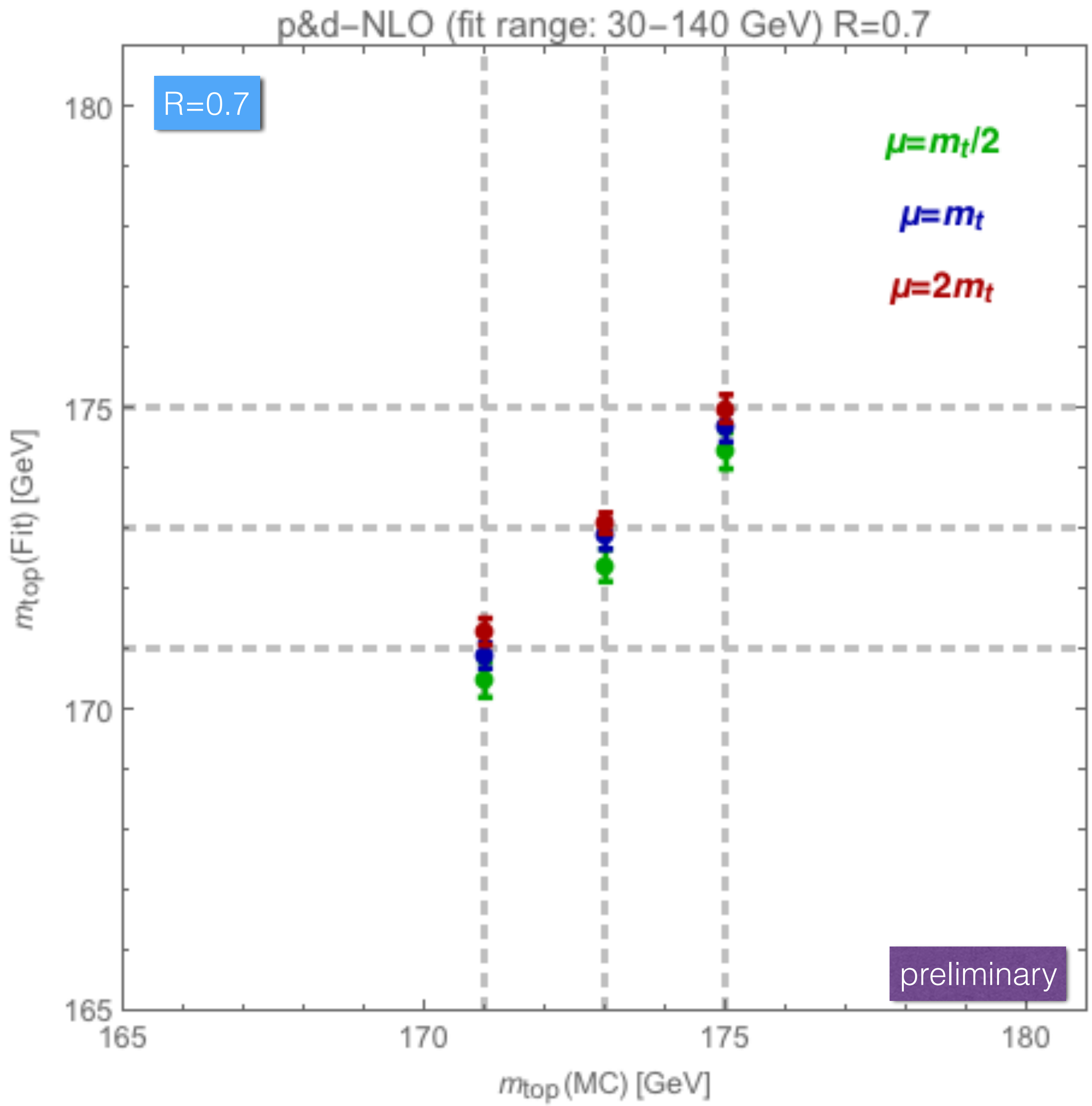


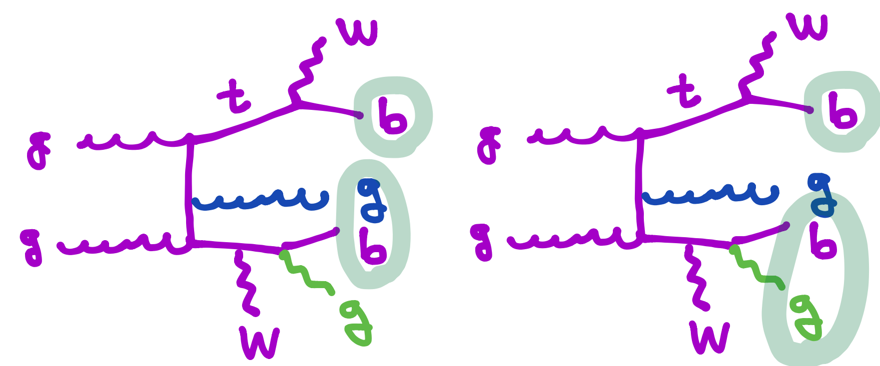
decay NLO sensitive to the scale choice: ±1 GeV on m_{top}

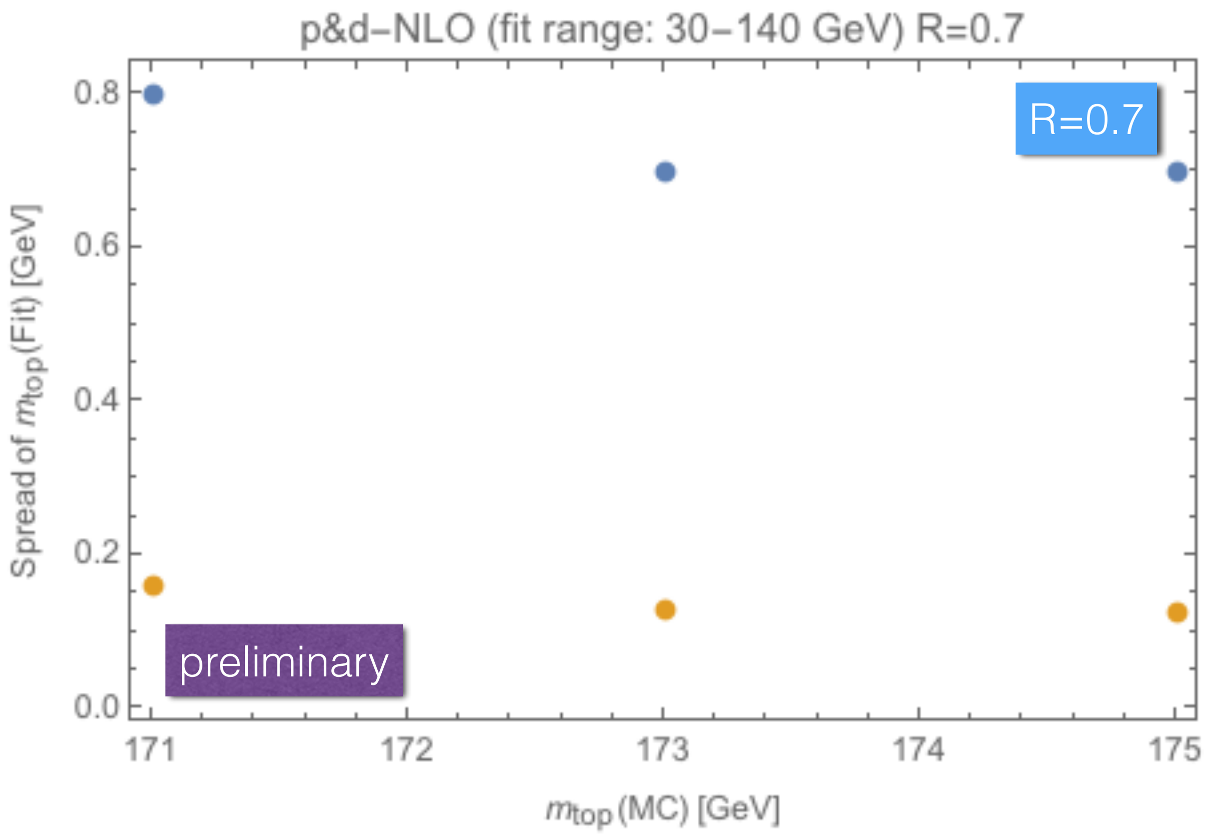
NLO: production & decay

R=0.7

(MCFM)





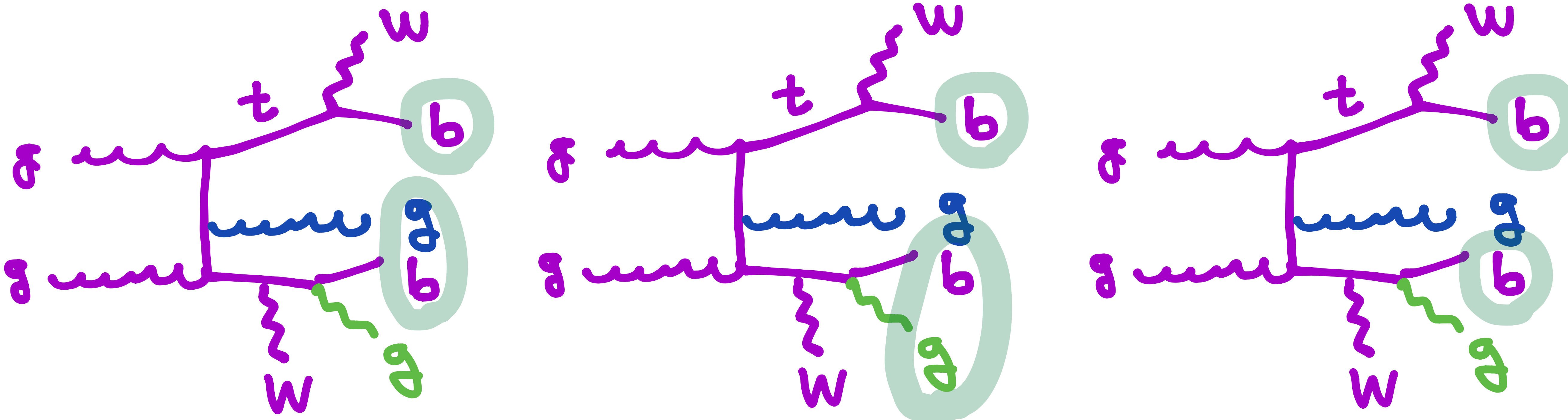


decay NLO sensitive to the scale choice: ±0.5 GeV on m_{top}

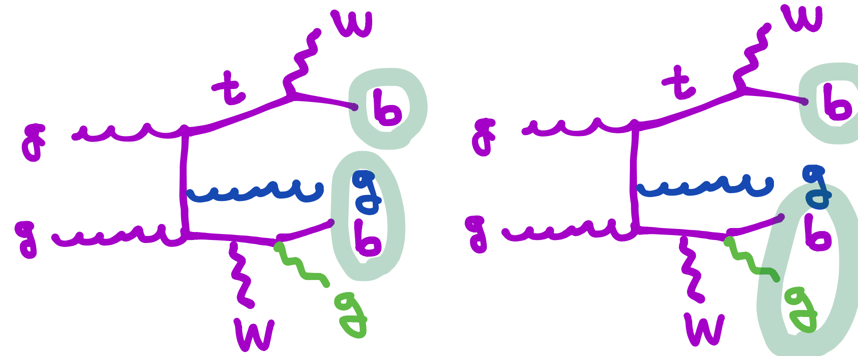
NLO: production & decay

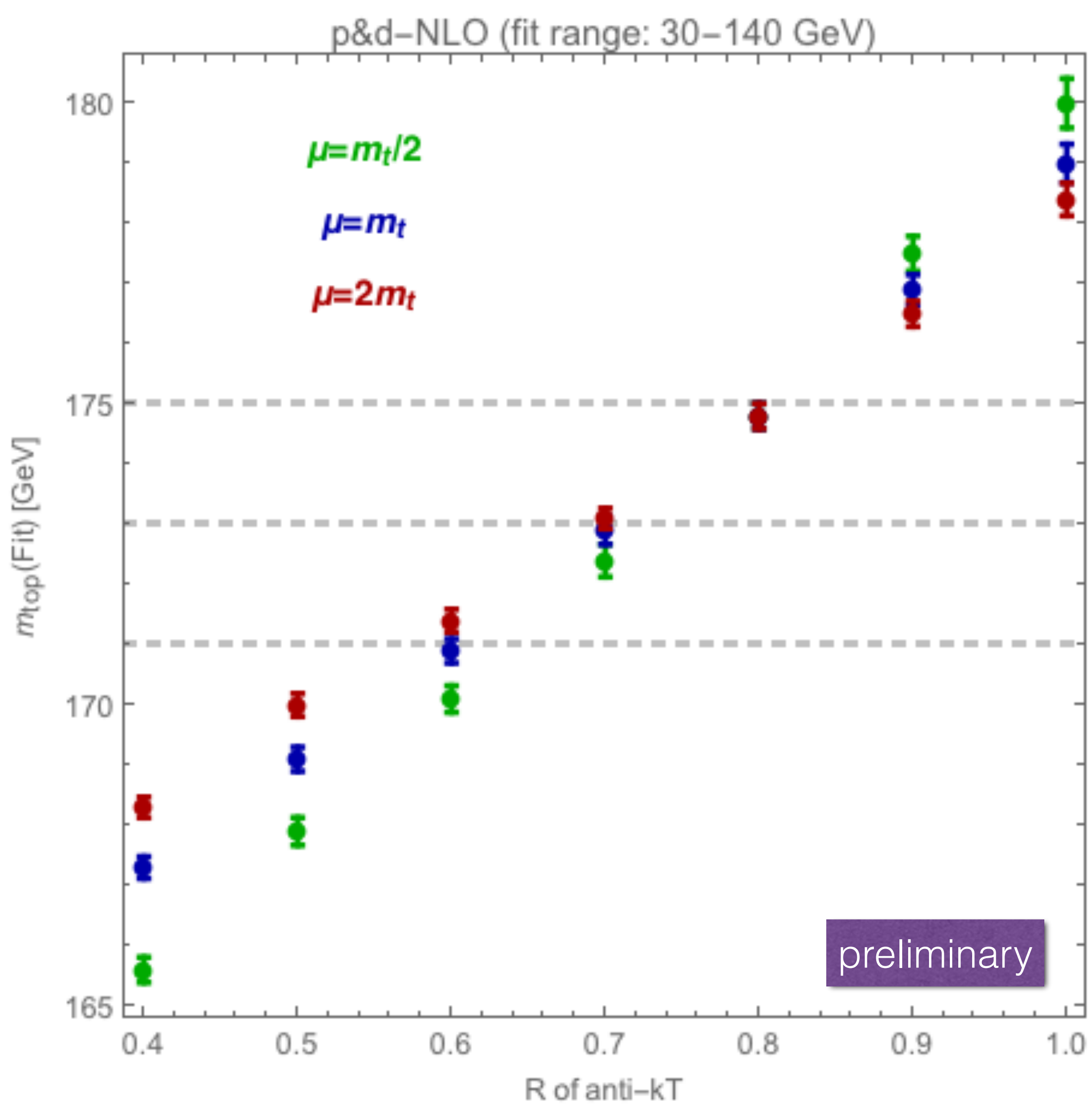
(MCFM)

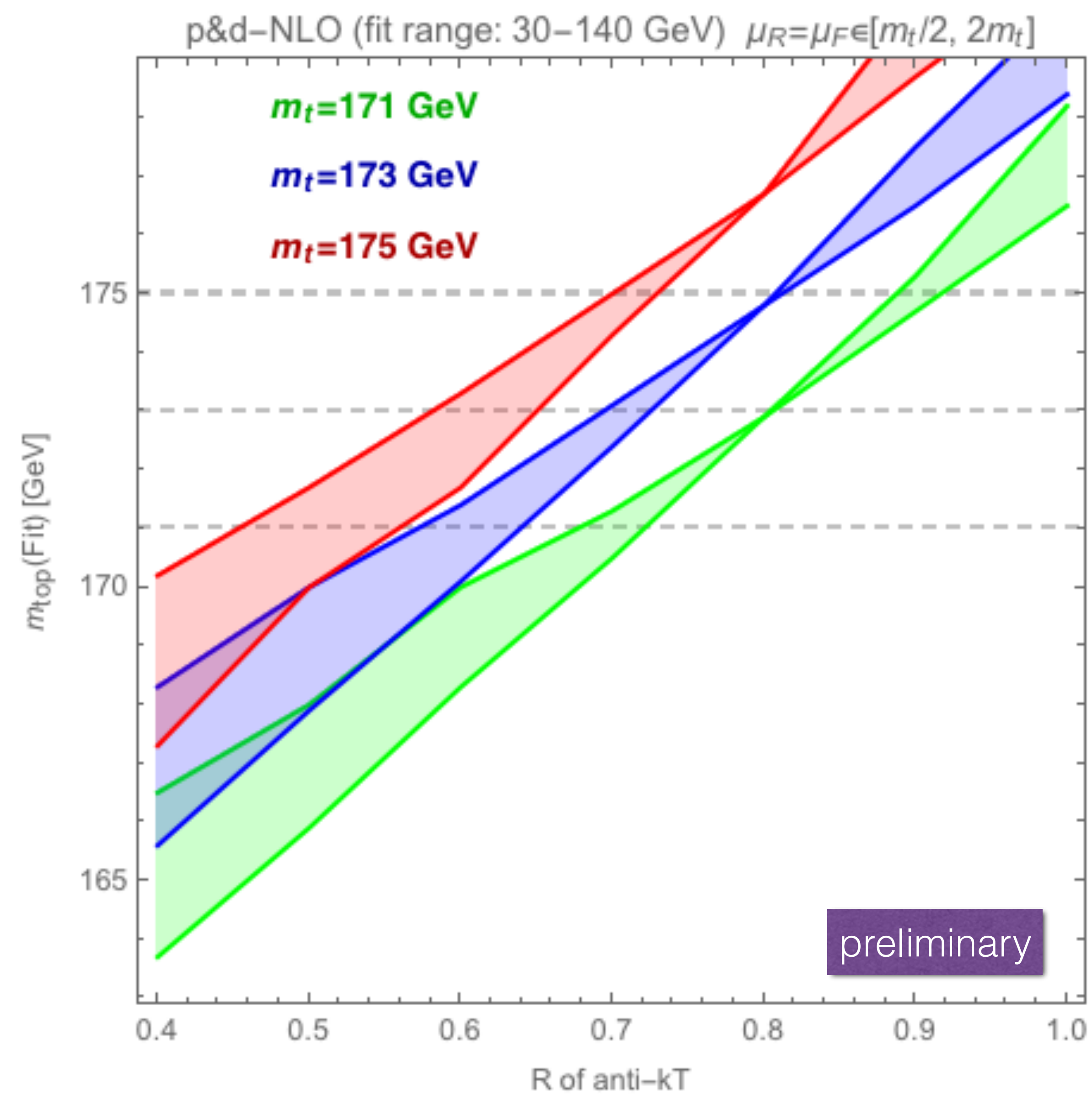
Agashe, Franceschini, Kim, Schulze - in preparation



NLO: production & decay







$$\hat{E} = E_0 + \alpha(\mu)\cdot[\ P(\mu)\cdot R^2 + D(\mu)\cdot \log R\ ] + \ldots$$

decay NLO sensitive to the scale choice: ±1 GeV on m_{top}

Mild corrections from NLO

Agashe, Franceschini, Kim, Schulze - in preparation

$$\hat{E} = E^*_{LO} \cdot \left[1 + f_{pol} + \epsilon_{FSR} \left(C_{bWg} + \underbrace{\delta_{int} + \delta_{PDFs} + \ldots}_{\delta_{prod}} \right) \right]$$

f_{pol}: $\leq 3 \cdot 10^{-3}$ $\quad$ ϵ_{FSR}: ≤ 0.1 $\quad$ C_{bWg}: O(1)

$$O_{NLO} = O_{LO} \cdot \left[1 + \underbrace{\delta_{int} + \delta_{PDFs} + \ldots}_{\delta_{prod}} \right]$$

Conclusions

- **“invariance” holds** when only **NLO production** corrections are considered
- full NLO gives **δm_{top}≃±1 GeV scale sensitivity** for any jet size parameter R
- work in progress to exploit the R dependence to improve results
- chances that a **NNLO <u>decay</u>** description would be enough to make a solid prediction at **δm_{top}≃500 MeV**

To Do (in progress)

- explore minimal sensitivity to scale choice at R~0.82
- check effects of cuts
- compare to moments of $d\sigma/dE_b$
- B-hadron energy

To Do (2)

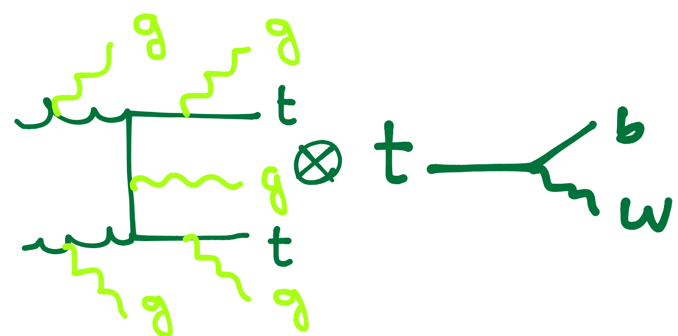
explore:

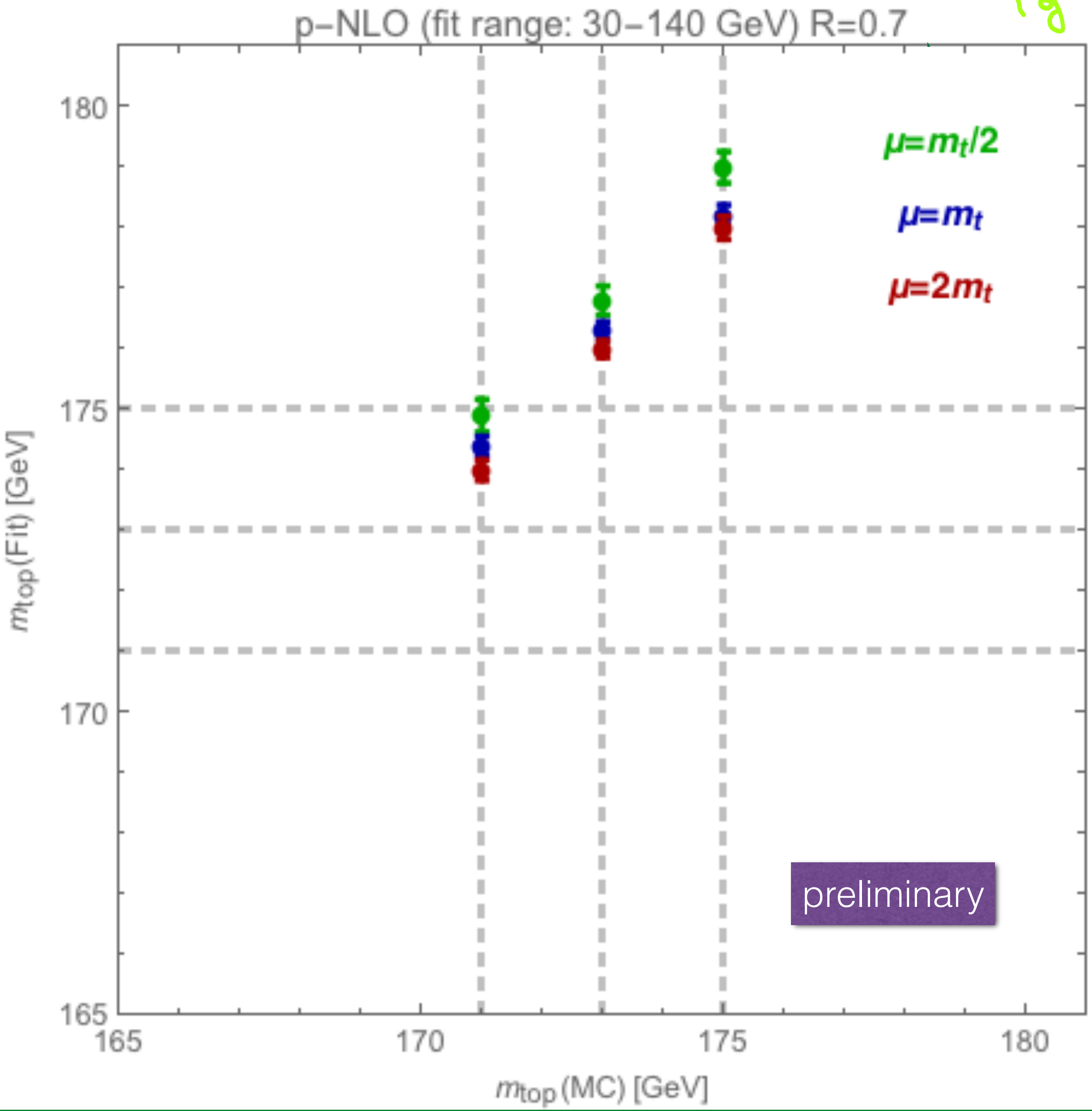
- tt vs. bWbW
- shower effects
- non-perturbative effects

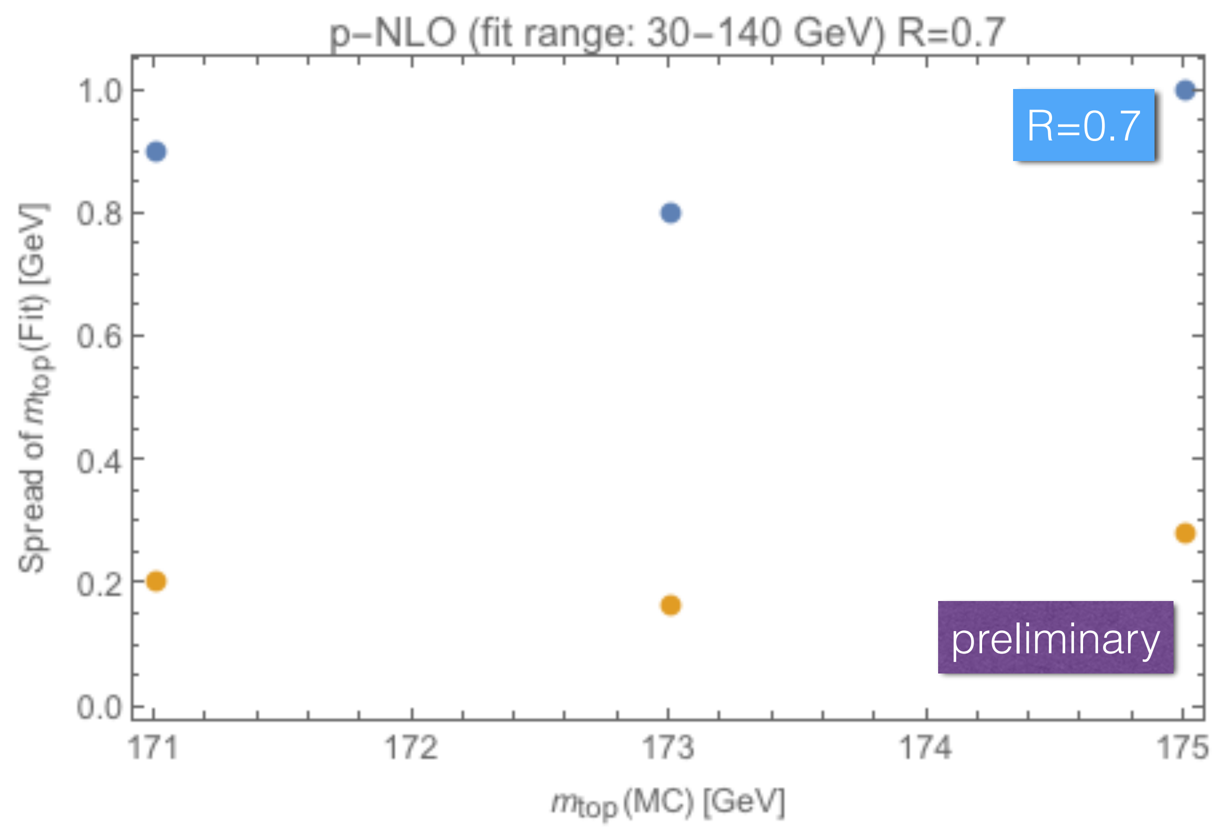
Back-up

NLO: production

(MCFM)







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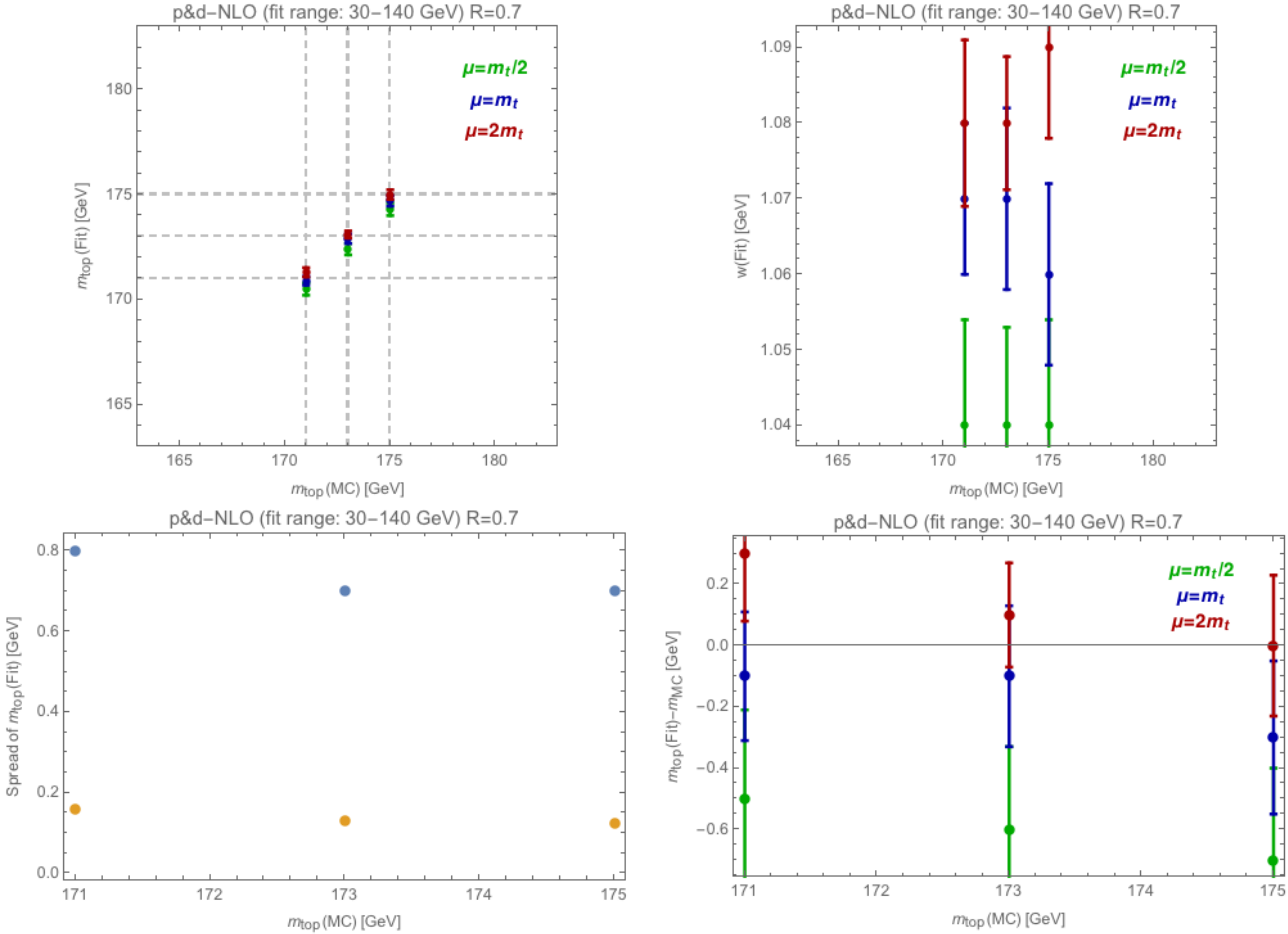
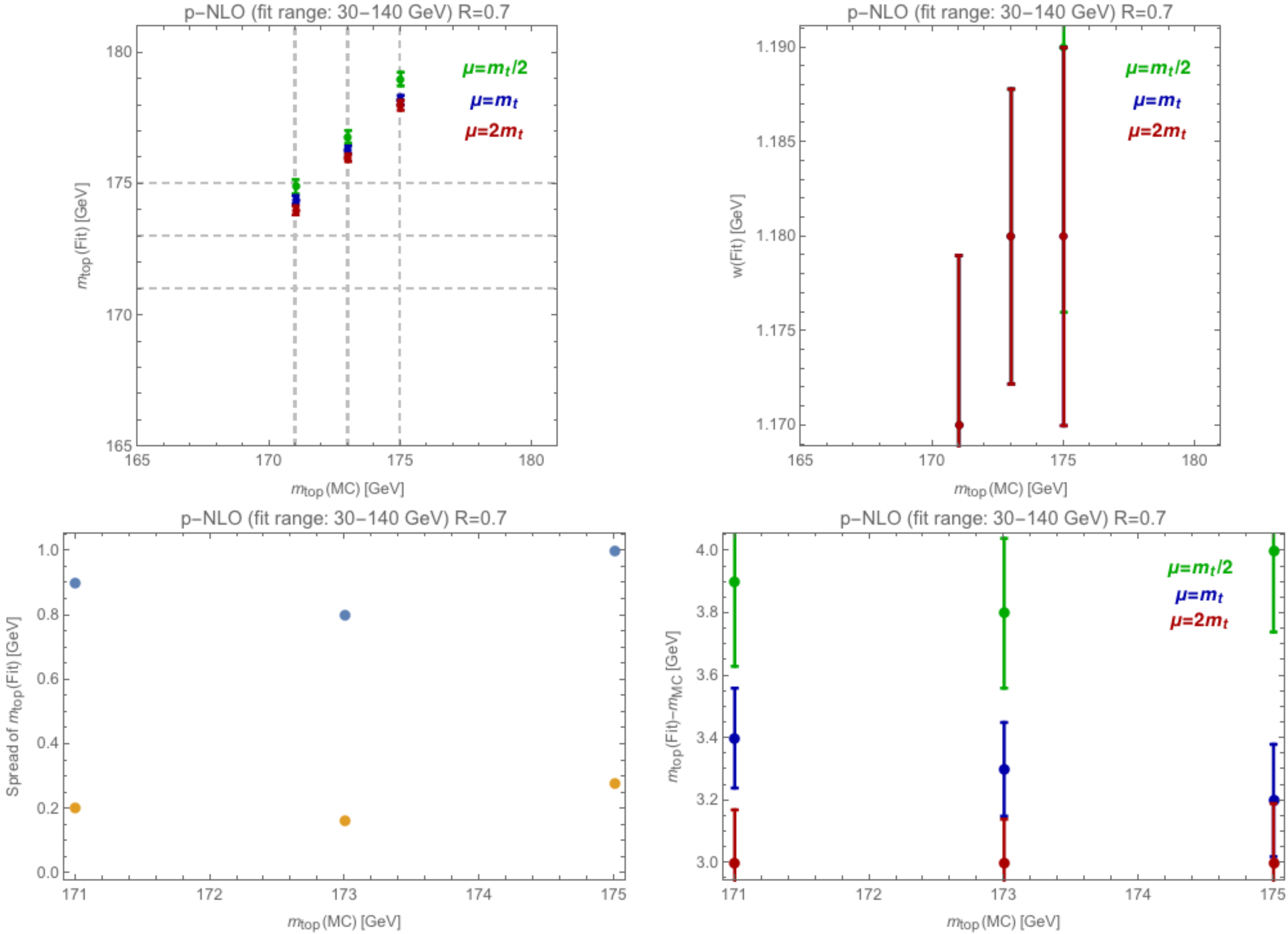


p&d-NLO (fit range: 30-140 GeV) R=0.7
μ=m_t/2
μ=m_t
μ=2m_t
m_top(Fit) [GeV]
m_top(MC) [GeV]
w(Fit) [GeV]
Spread of m_top(Fit) [GeV]
m_top(Fit)-m_MC [GeV]



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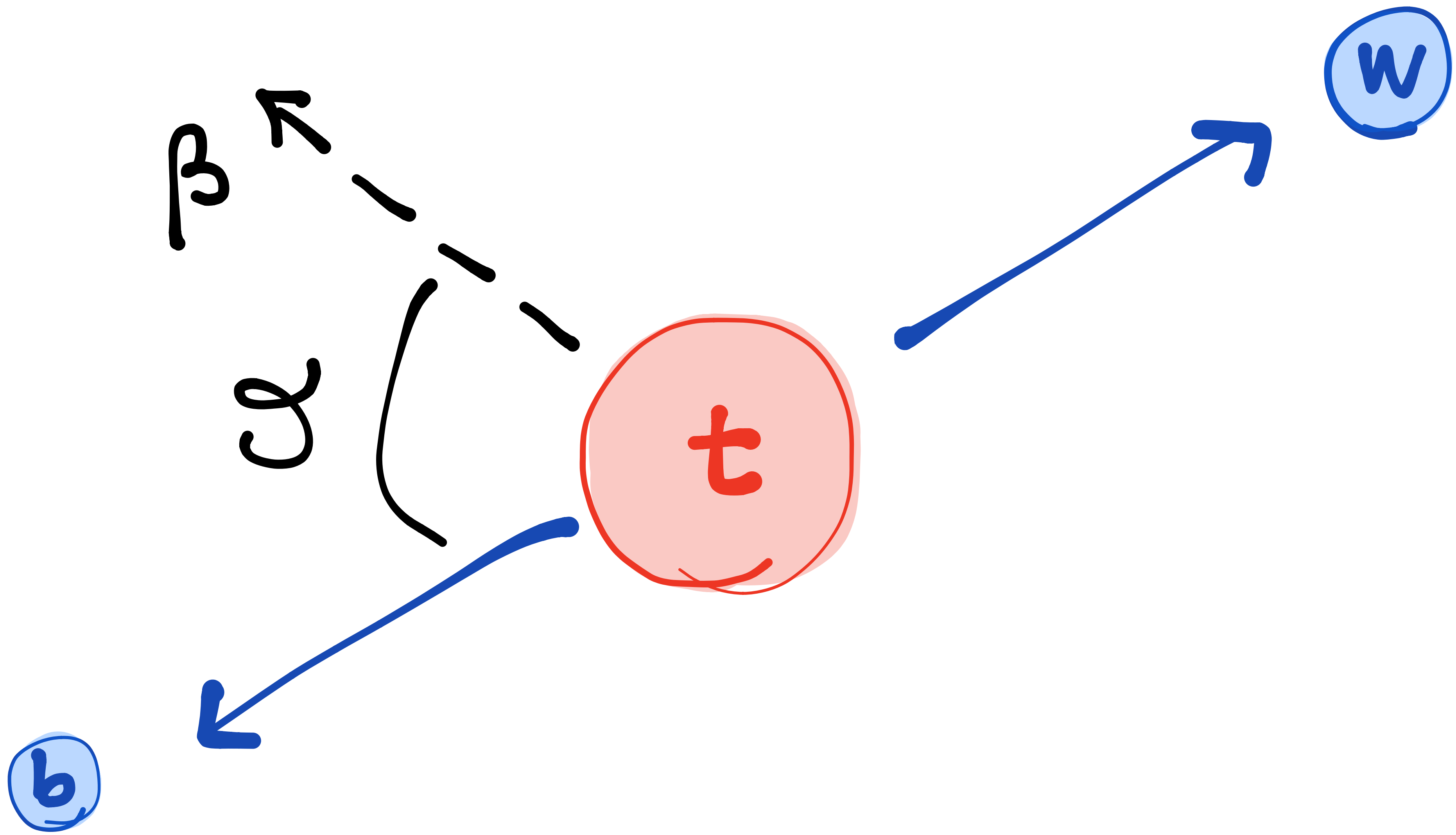
m_top(Fit) [GeV]
m_top(MC) [GeV]
w(Fit) [GeV]
Spread of m_top(Fit) [GeV]
m_top(Fit)–m_MC [GeV]

A simple, yet subtle, invariance of the two body decay

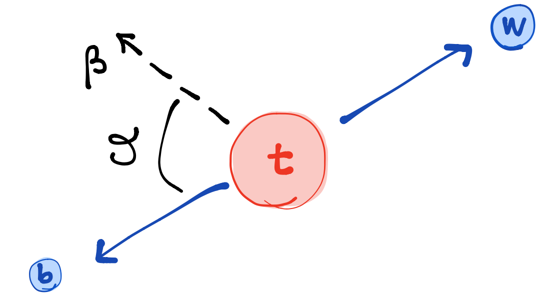
1209.0772 - Agashe, Franceschini and Kim



$$E_{lab,b} = E_b^* \gamma + p_b^* \gamma \beta \cos \vartheta$$

Event-by-event we cannot tell anything

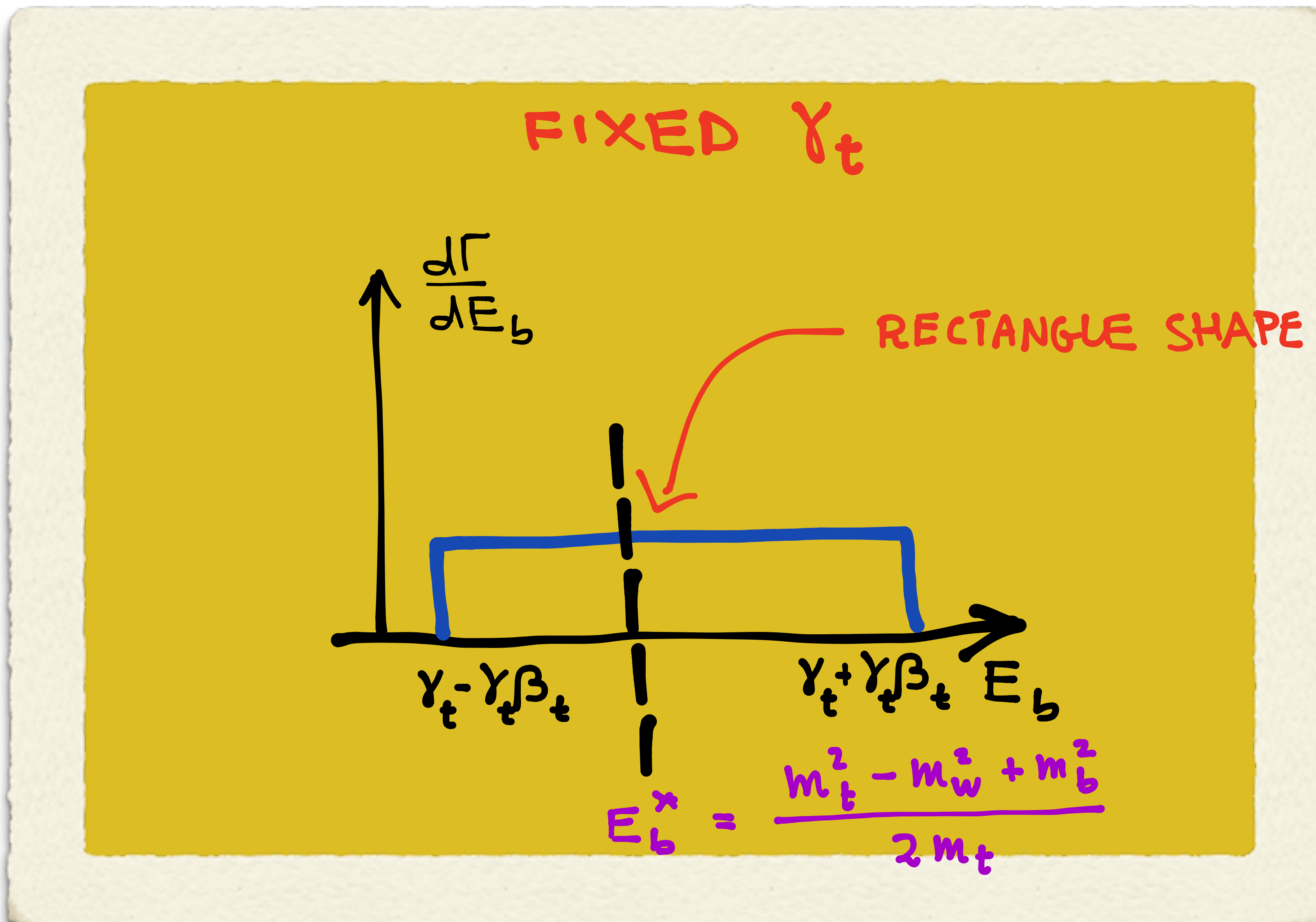
Fixed top boost decay



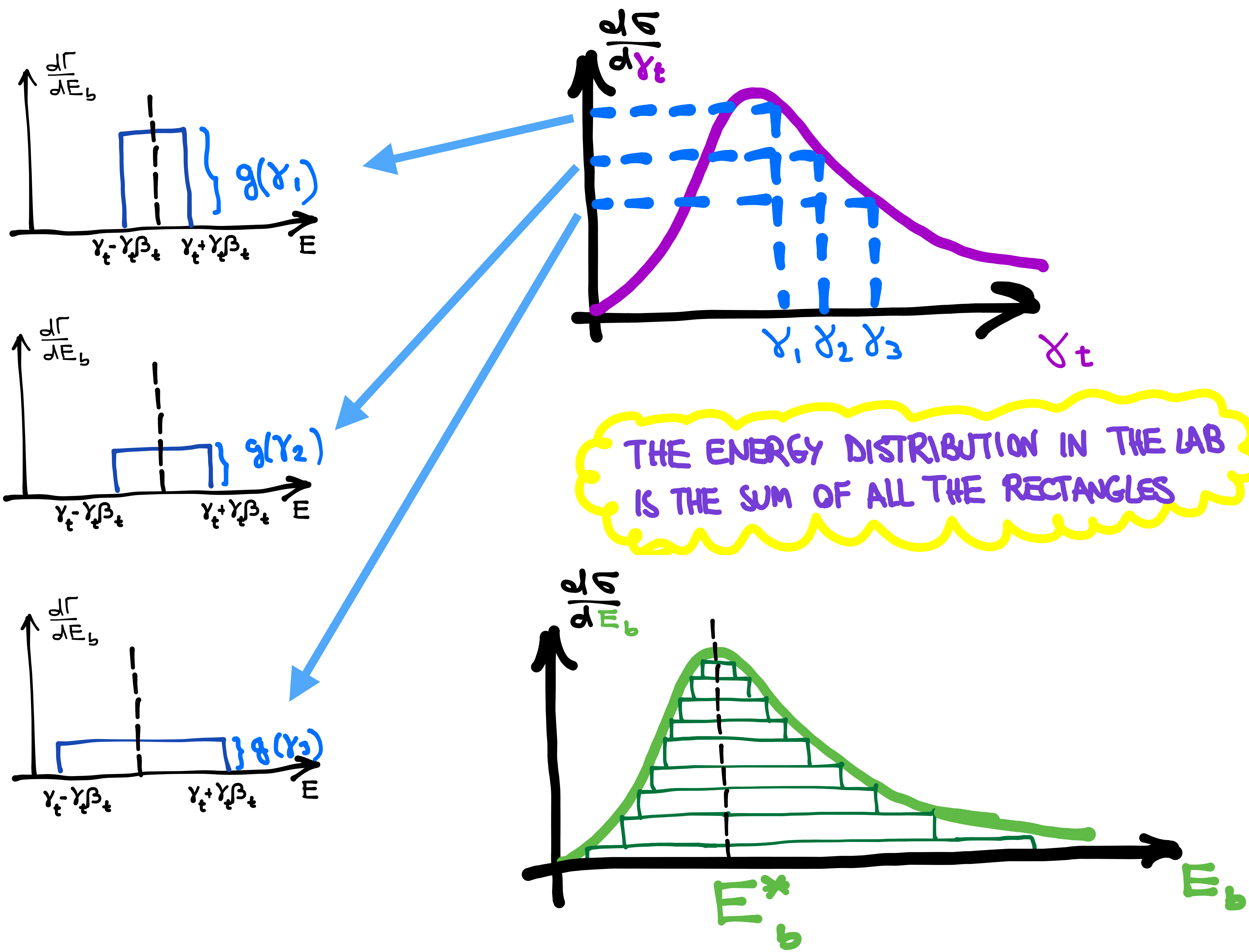
Massless b-quark (for now)

$$E_{lab,b} = E_b^*(\gamma + \gamma\beta\cos\vartheta)$$

unpolarized top sample ⟶ cosθ is flat

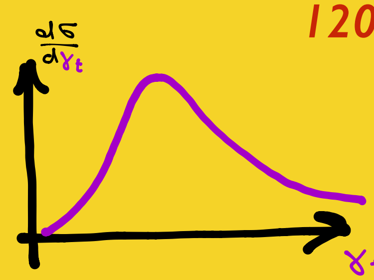


Summing over the top boosts



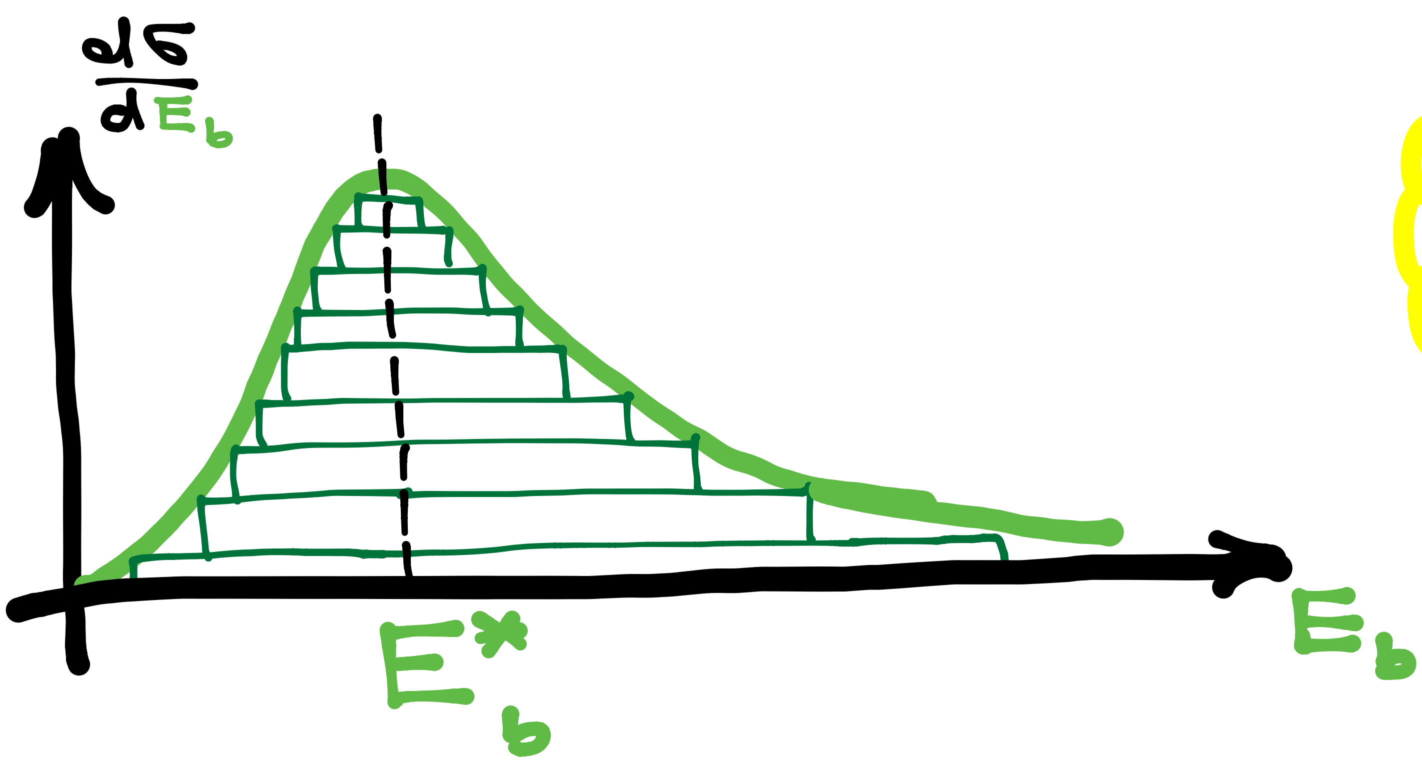
Lab-frame energy distribution

1209.0772 - Agashe, Franceschini and Kim
also Stecker 1971

for any top boost distribution 

the peak:

- is the same as in the rest frame
- encodes invariant $E_b^* = \frac{m_t^2 - m_W^2 + m_b^2}{2 m_t}$

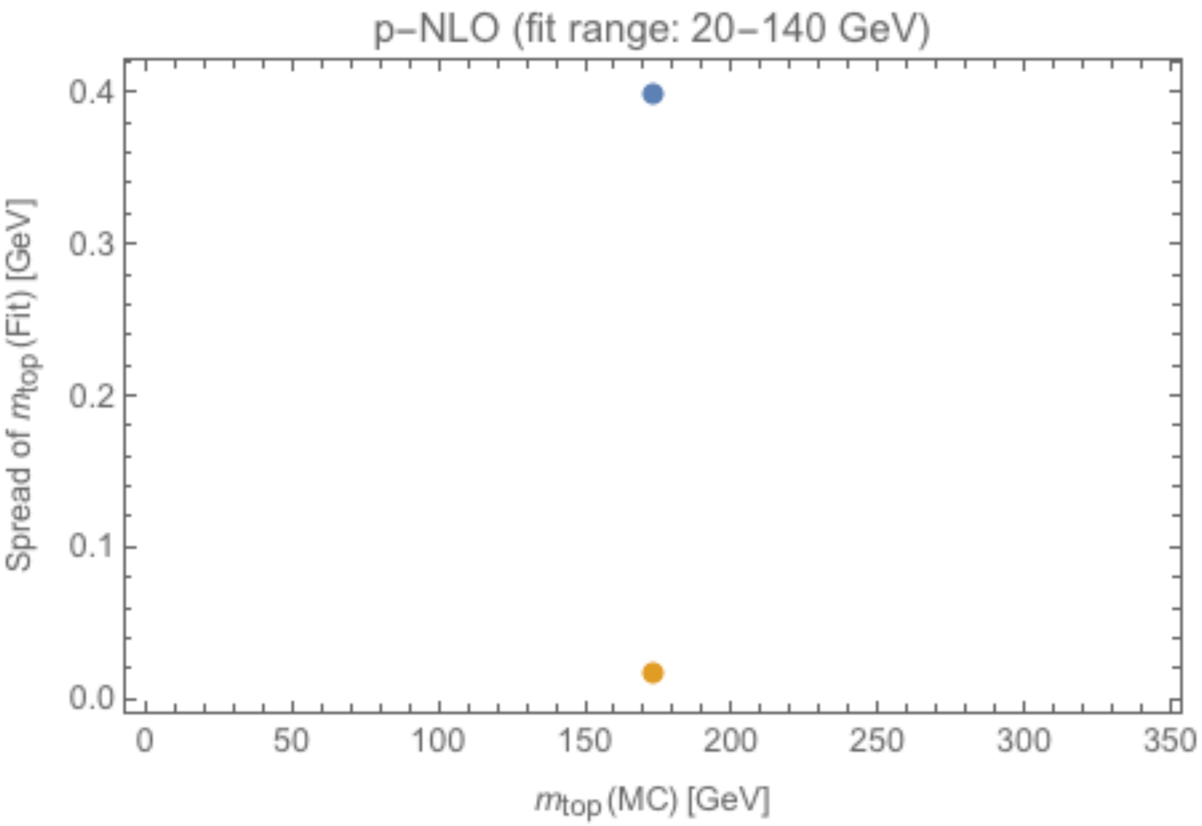


THE FRAME-DEPENDENT ENERGY DISTRIBUTION ENCODES THE INVARIANT E_d^* IN A VERY SIMPLE WAY

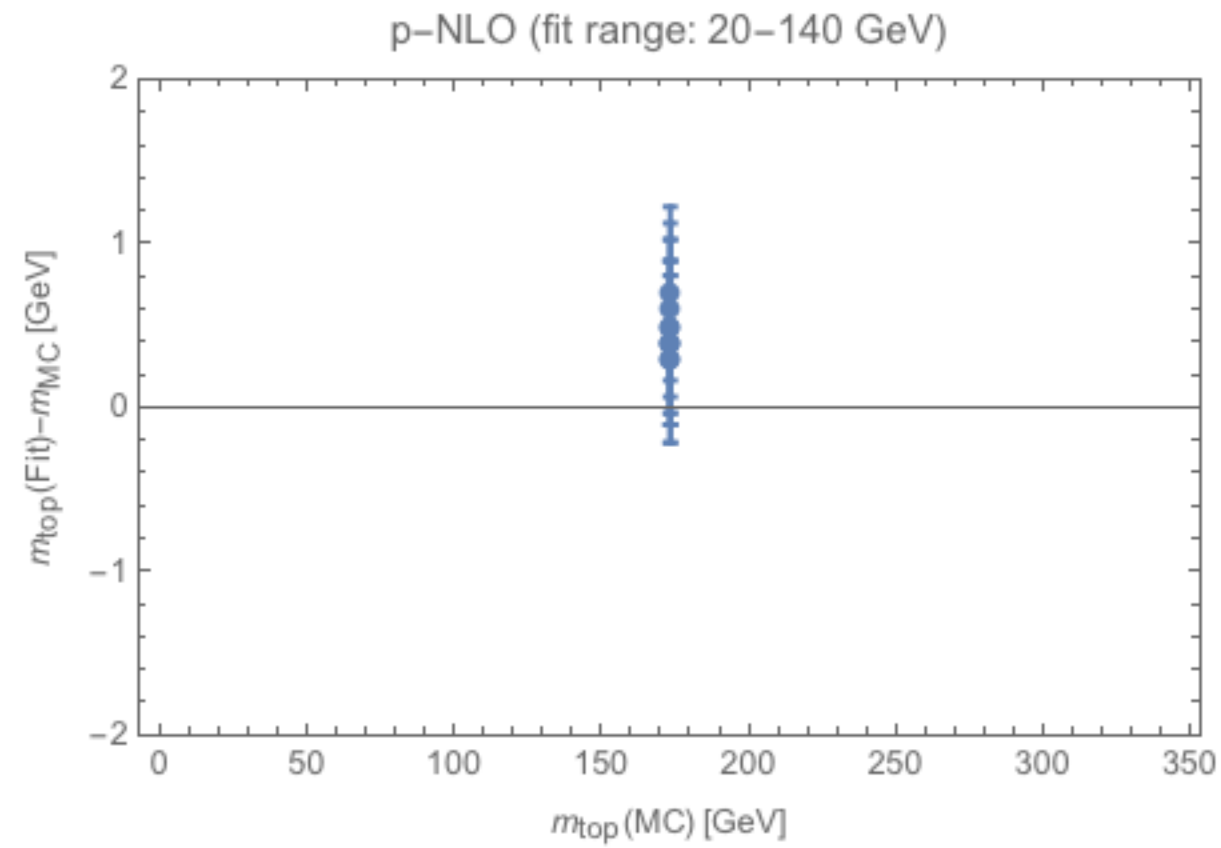
There is no difference when the b-mass is taken into account provided $\gamma_{top} < 500$

back

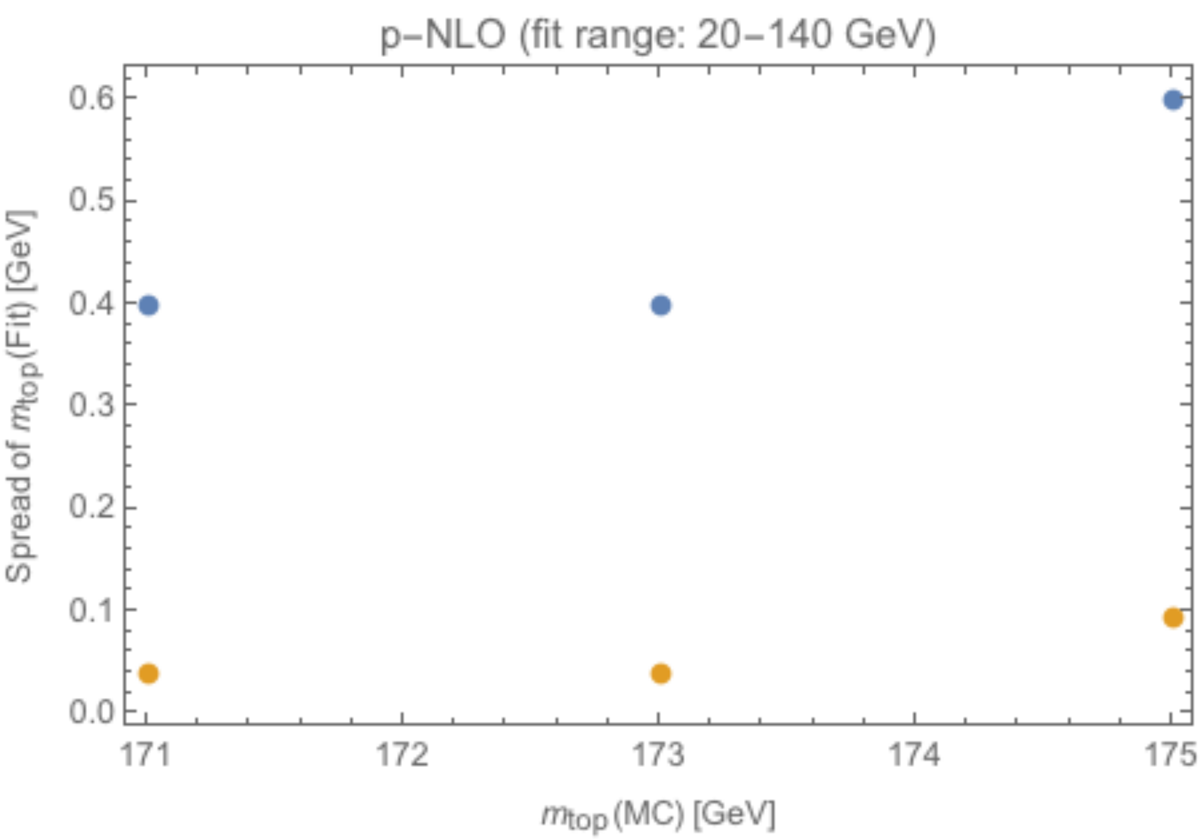
$\mu_F \neq \mu_R$



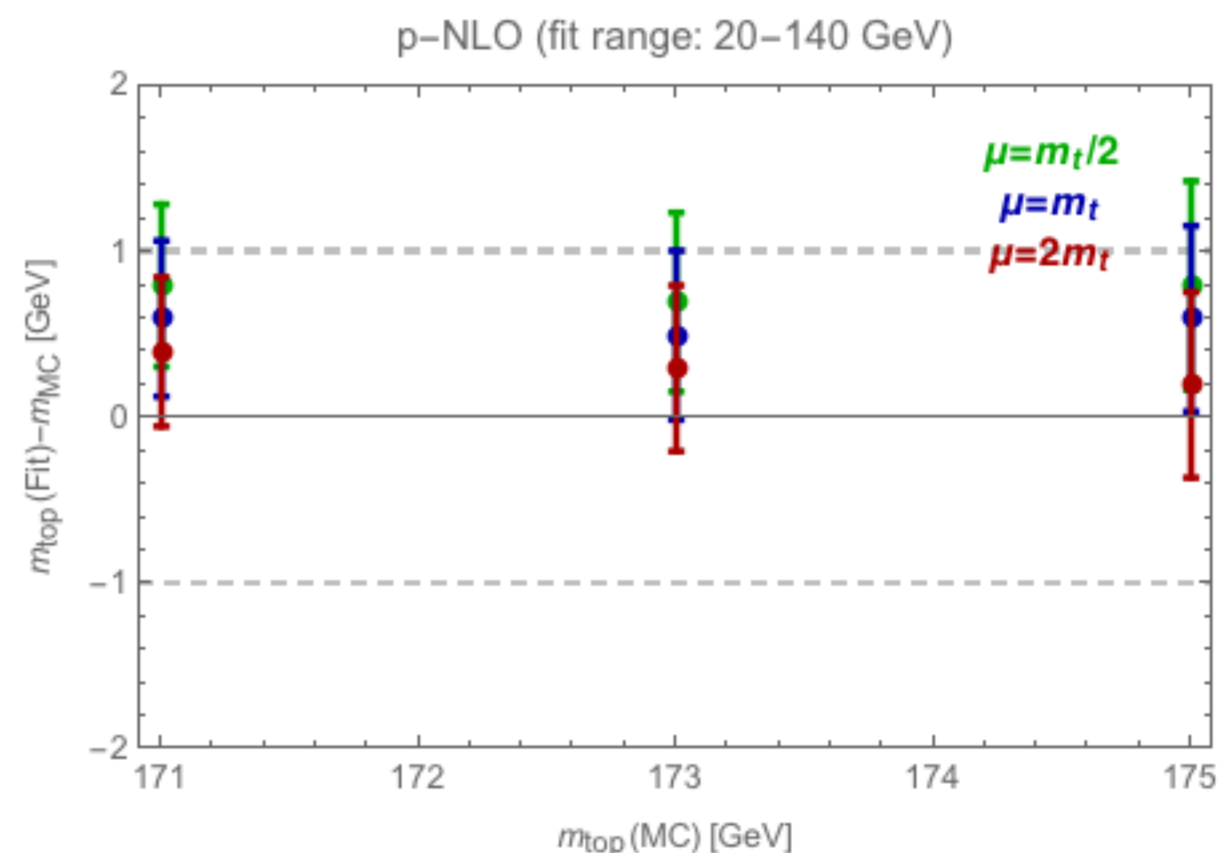
p−NLO (fit range: 20−140 GeV)
Spread of m_{top}(Fit) [GeV]
0.0
0.1
0.2
0.3
0.4
0
50
100
150
200
250
300
350
m_{top}(MC) [GeV]



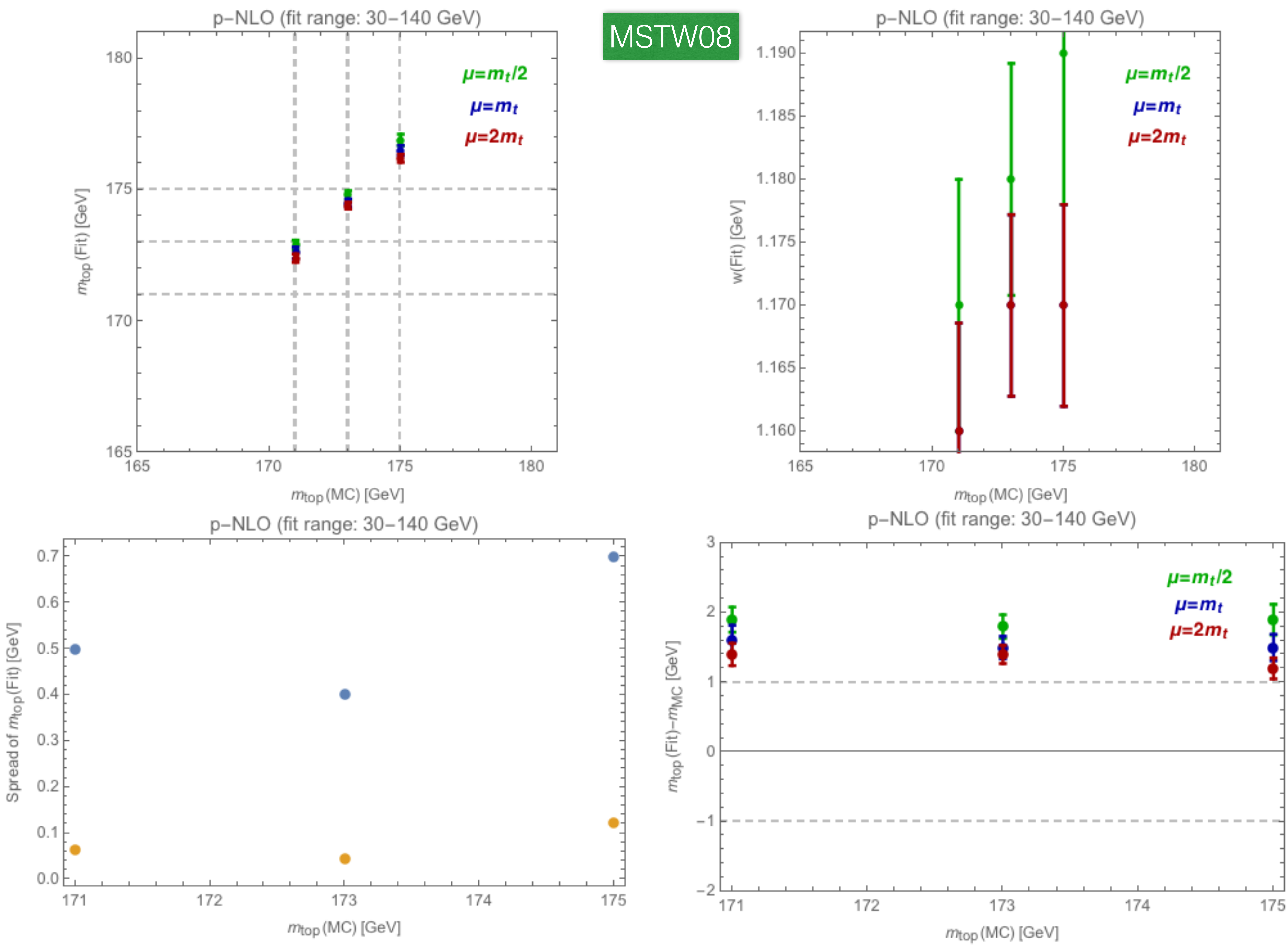
p−NLO (fit range: 20−140 GeV)
m_{top}(Fit)−m_{MC} [GeV]
−2
−1
0
1
2
0
50
100
150
200
250
300
350
m_{top}(MC) [GeV]

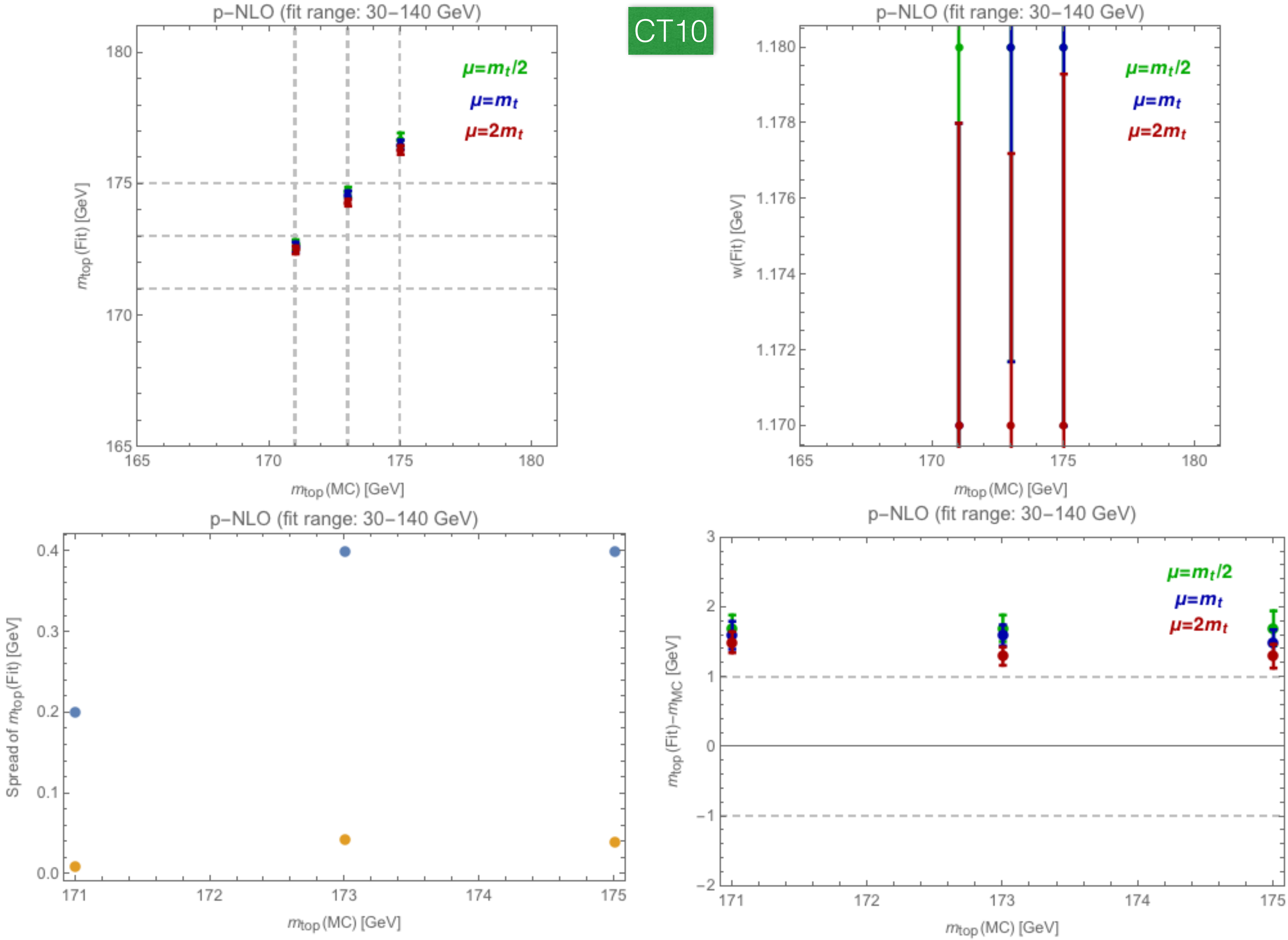


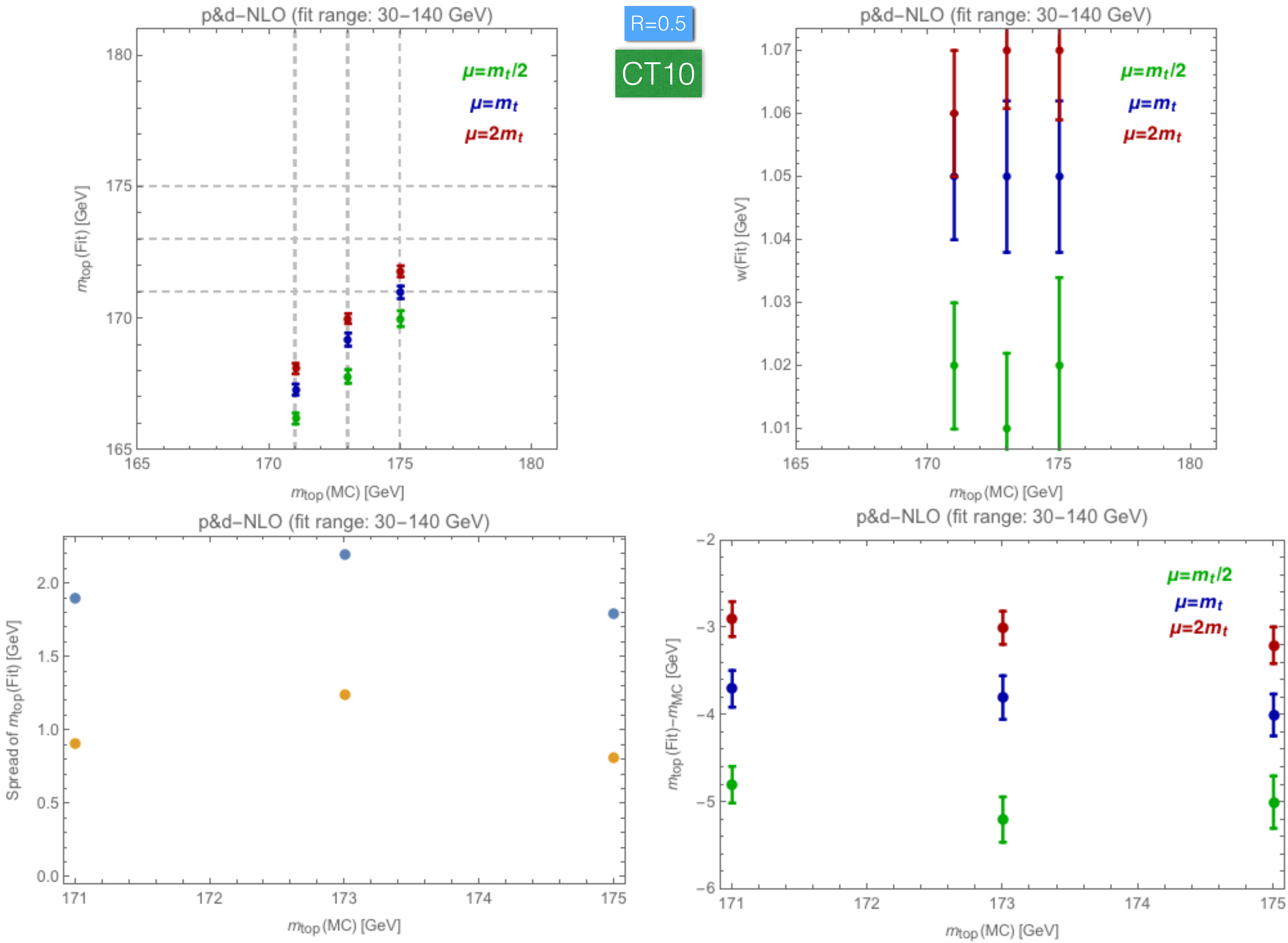
p−NLO (fit range: 20−140 GeV)
Spread of m_{top}(Fit) [GeV]
0.0
0.1
0.2
0.3
0.4
0.5
0.6
171
172
173
174
175
m_{top}(MC) [GeV]

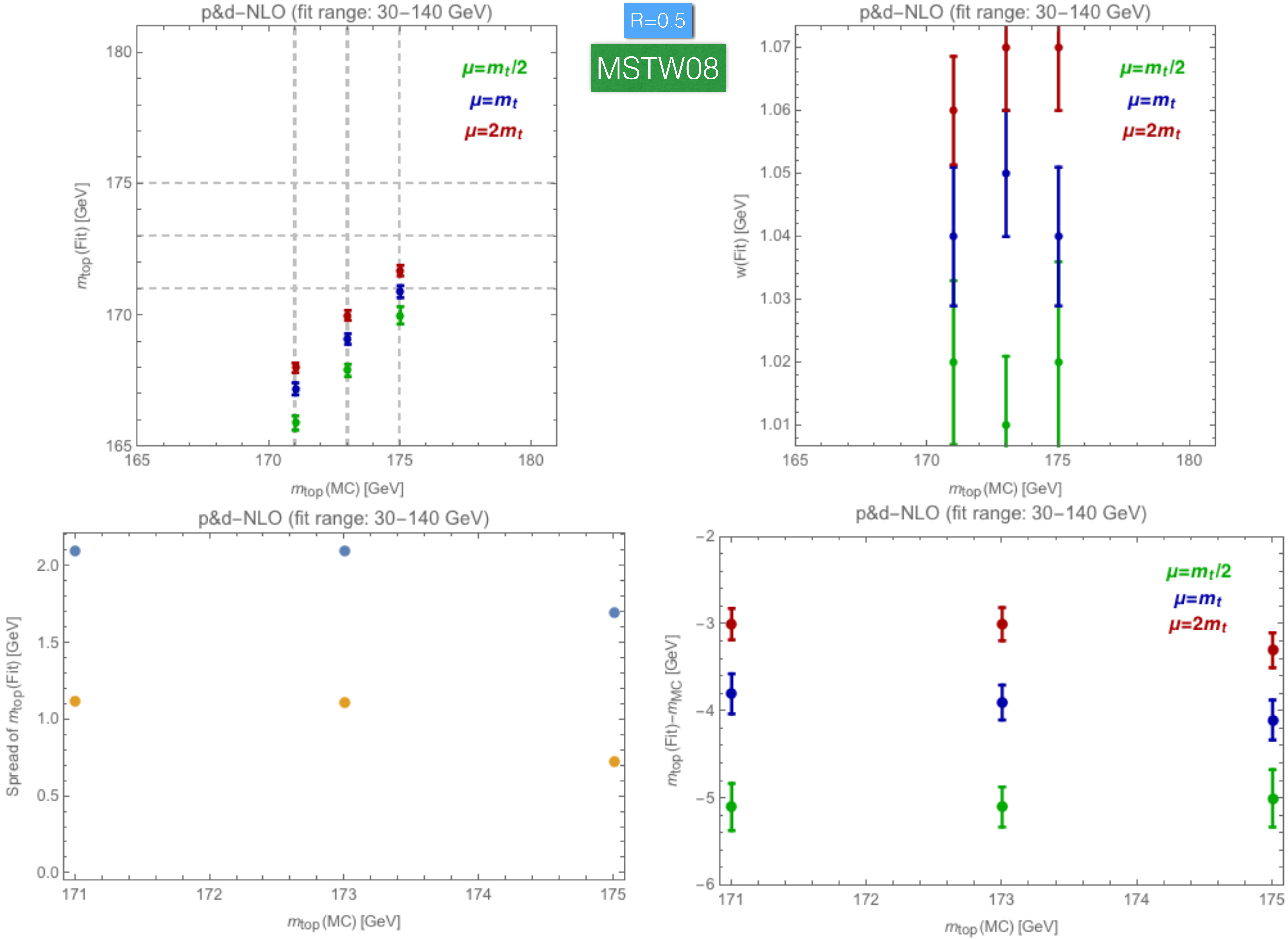


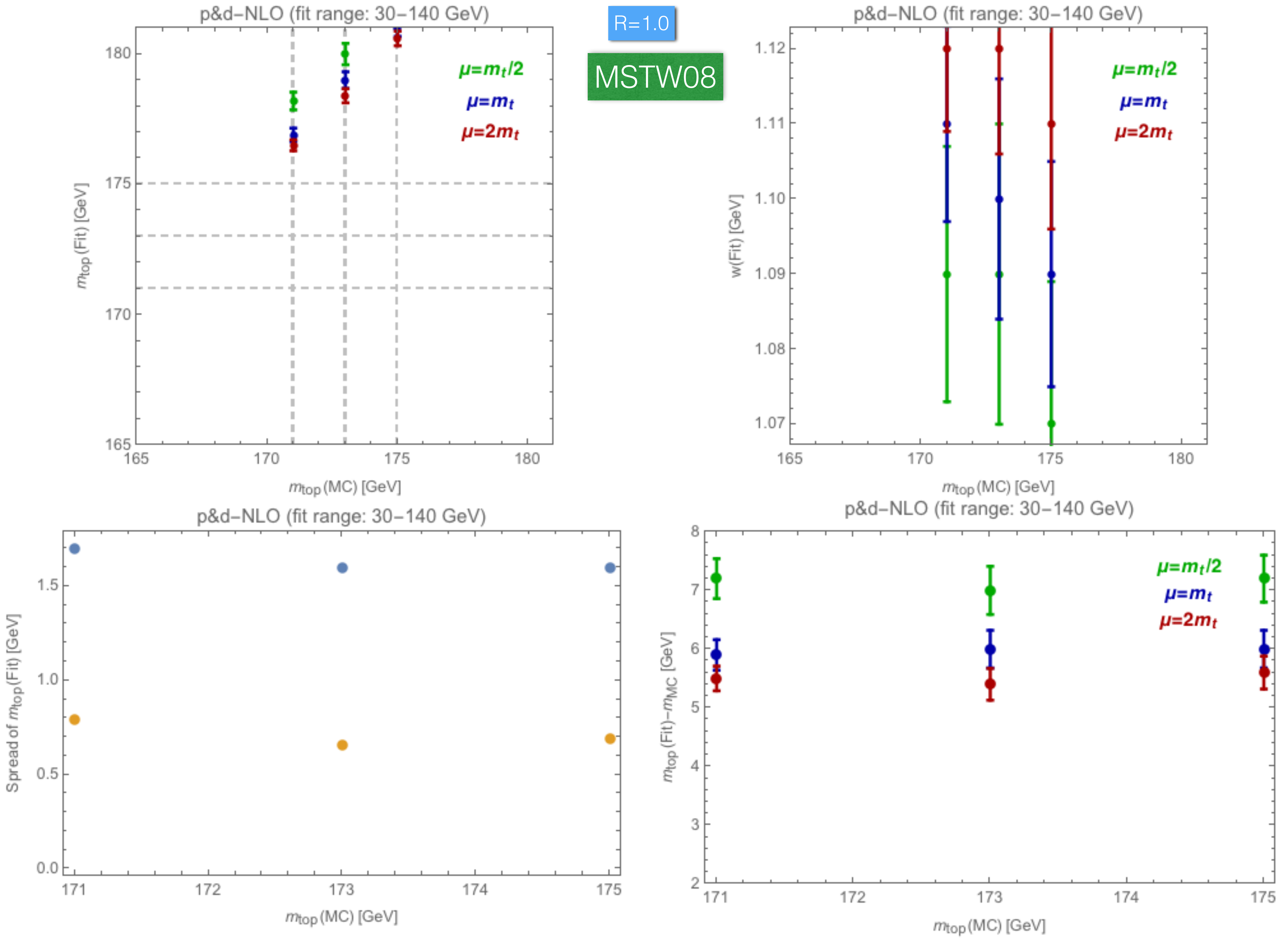
p−NLO (fit range: 20−140 GeV)
$\mu=m_t/2$
$\mu=m_t$
$\mu=2m_t$
m_{top}(Fit)−m_{MC} [GeV]
−2
−1
0
1
2
171
172
173
174
175
m_{top}(MC) [GeV]


MSTW08
p–NLO (fit range: 30–140 GeV)
m_{top}(Fit) [GeV]
m_{top}(MC) [GeV]
μ=m_t/2
μ=m_t
μ=2m_t
w(Fit) [GeV]
Spread of m_{top}(Fit) [GeV]
m_{top}(Fit)−m_{MC} [GeV]

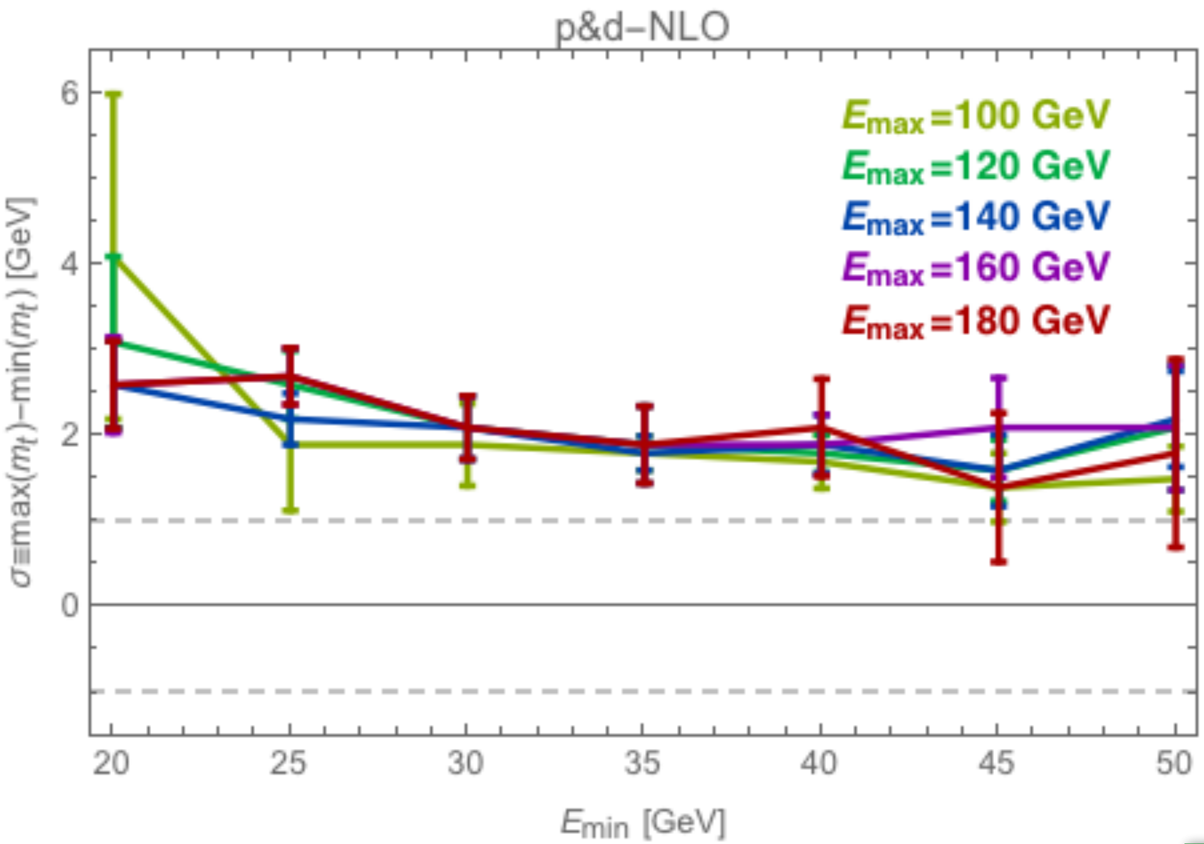

CT10
p–NLO (fit range: 30–140 GeV)
μ=m_t/2
μ=m_t
μ=2m_t
m_top (Fit) [GeV]
m_top (MC) [GeV]
w(Fit) [GeV]
Spread of m_top(Fit) [GeV]
m_top (Fit)–m_MC [GeV]

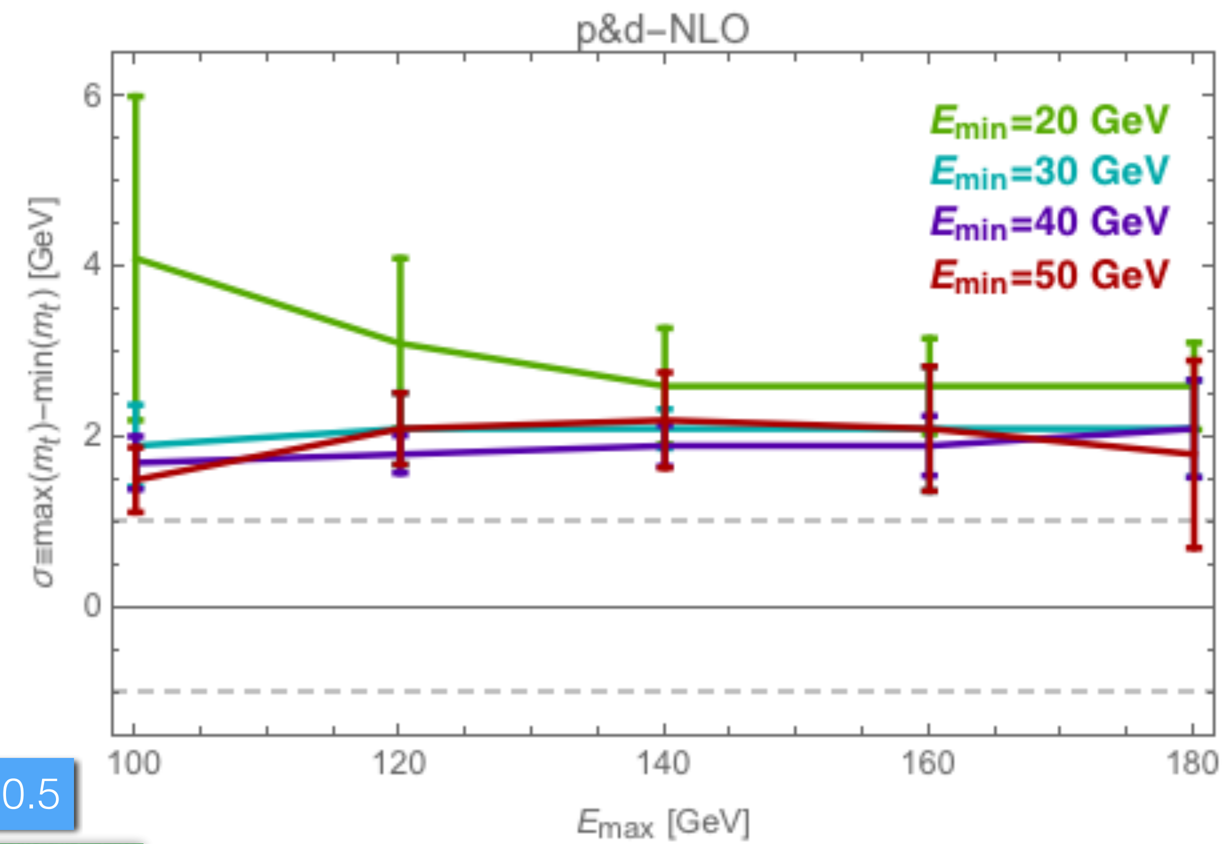

R=0.5
CT10
p&d–NLO (fit range: 30–140 GeV)
μ=m_t/2
μ=m_t
μ=2m_t
m_top(Fit) [GeV]
m_top(MC) [GeV]
w(Fit) [GeV]
Spread of m_top(Fit) [GeV]
m_top(Fit)–m_MC [GeV]


R=0.5
MSTW08
p&d−NLO (fit range: 30−140 GeV)
μ=m_t/2
μ=m_t
μ=2m_t
m_top (Fit) [GeV]
m_top (MC) [GeV]
w(Fit) [GeV]
Spread of m_top (Fit) [GeV]
m_top (Fit)−m_MC [GeV]


R=1.0
MSTW08
p&d−NLO (fit range: 30−140 GeV)
μ=m_t/2
μ=m_t
μ=2m_t
m_top(Fit) [GeV]
w(Fit) [GeV]
m_top(MC) [GeV]
Spread of m_top(Fit) [GeV]
m_top(Fit)−m_MC [GeV]

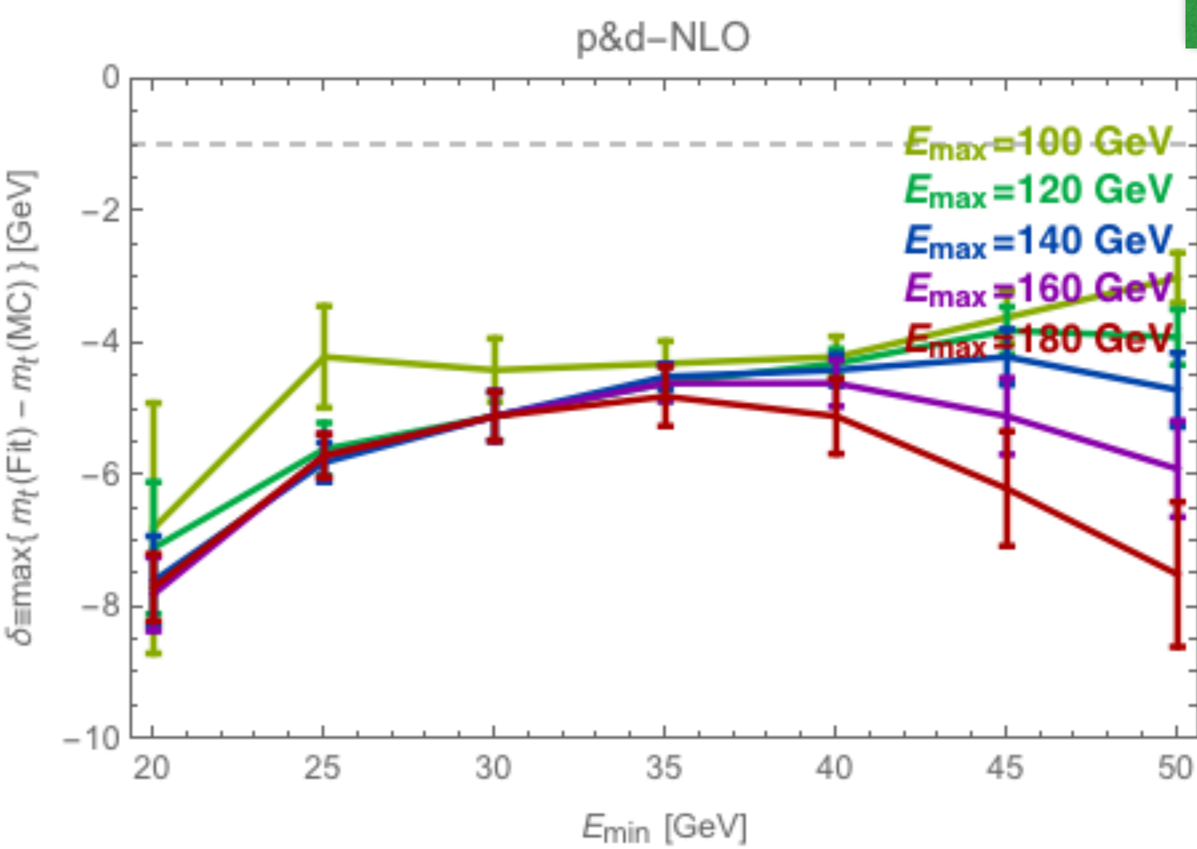
Fit Variations p&d-NLO

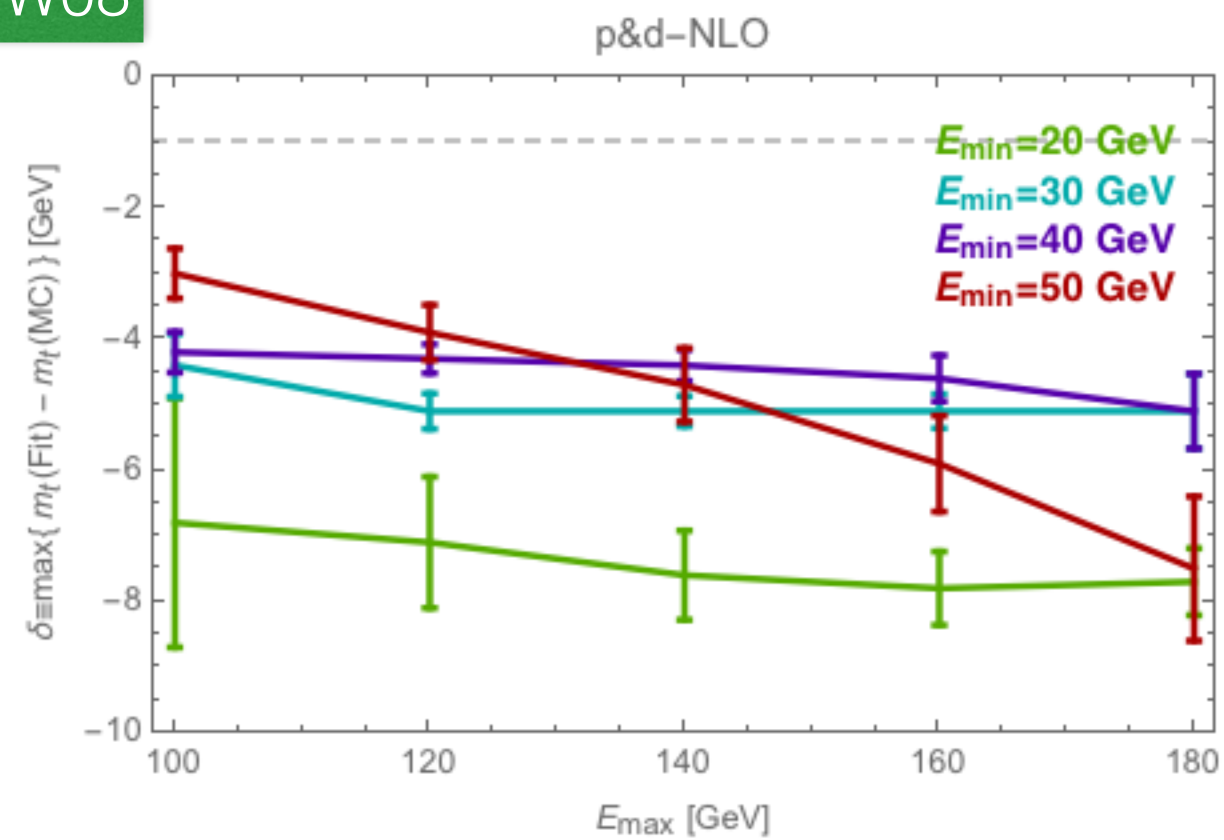




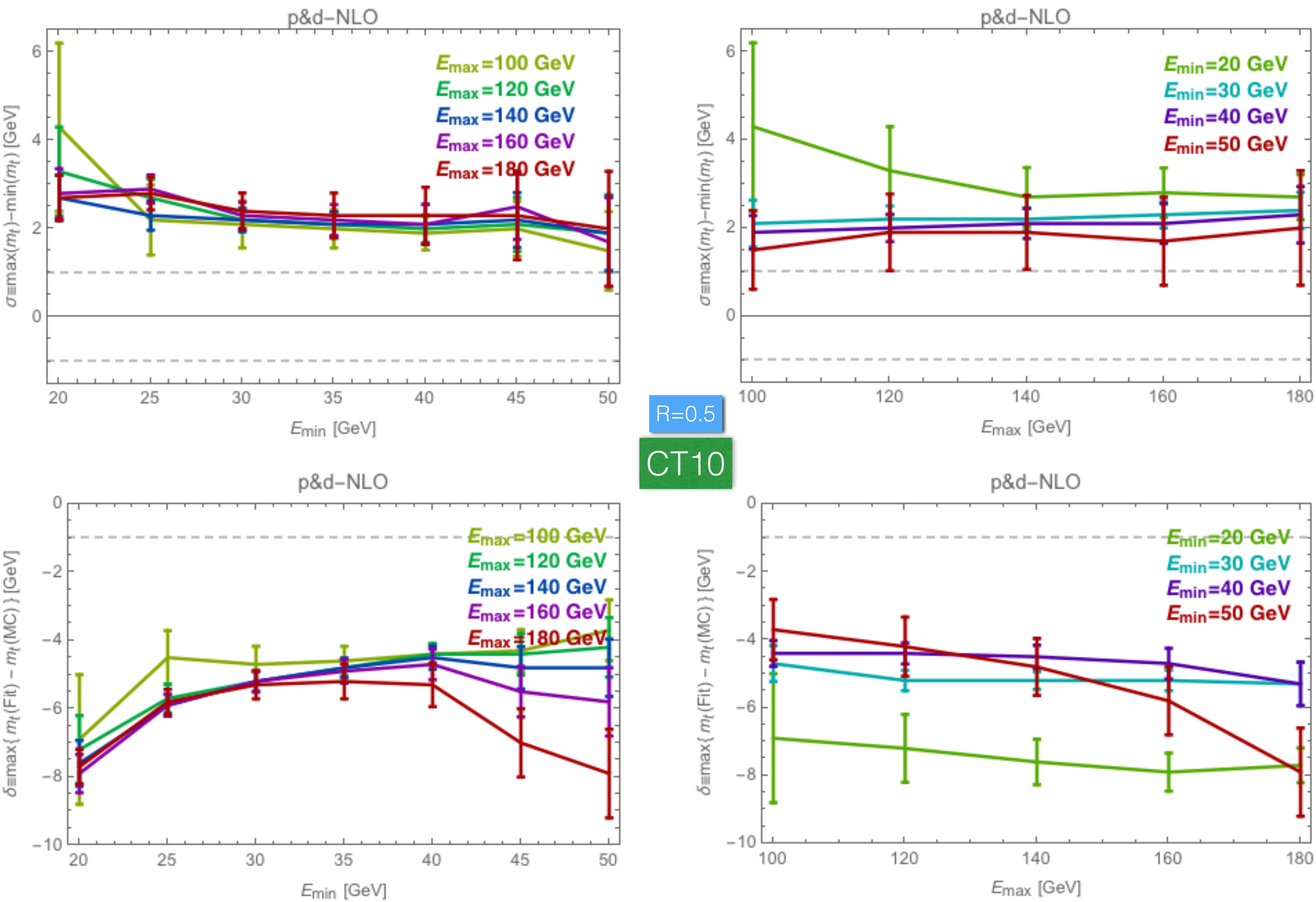
R=0.5

MSTW08



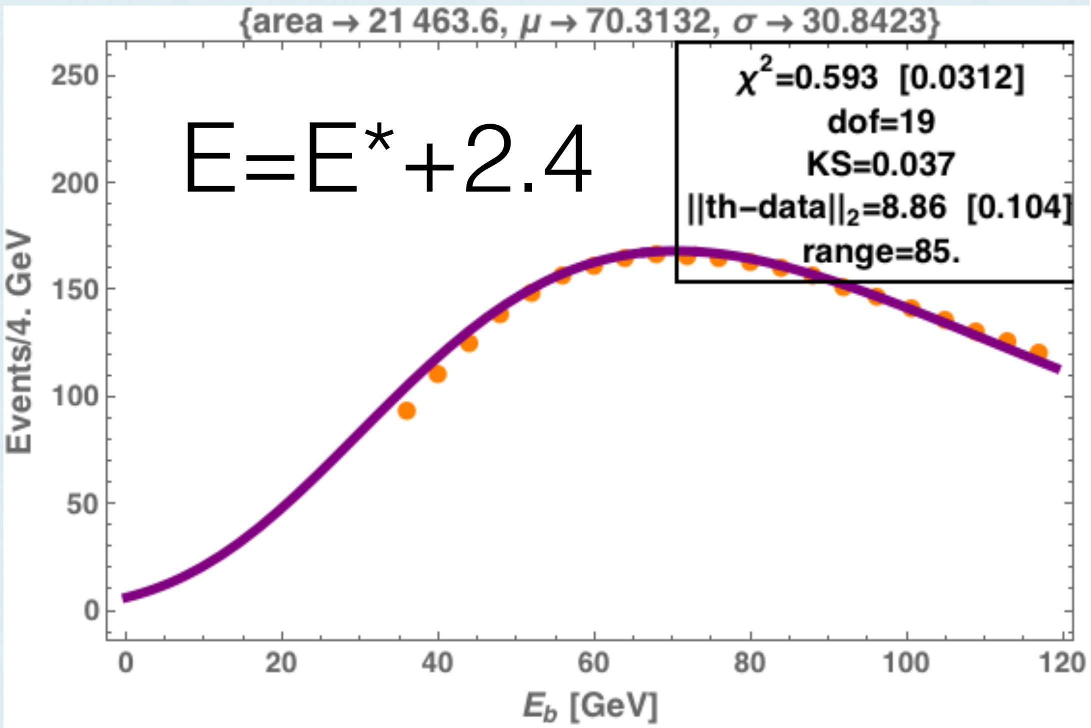


Fit Variations p&d-NLO

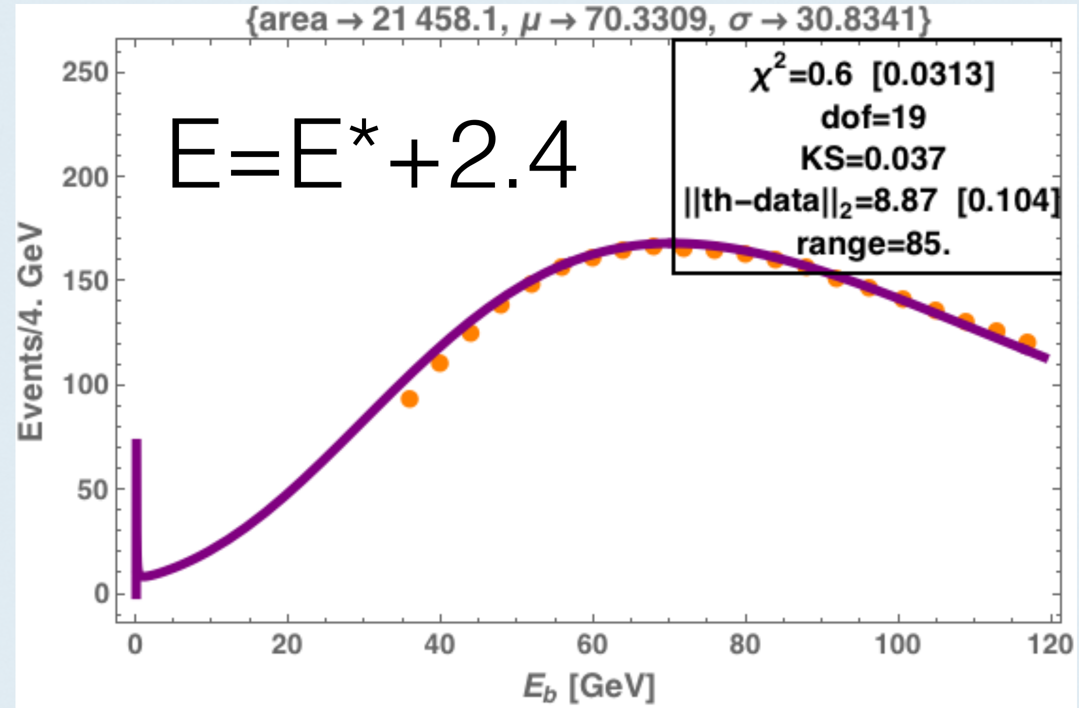


LO MCFM fixed $\mu=m_{top}$ (E=67.9 GeV)

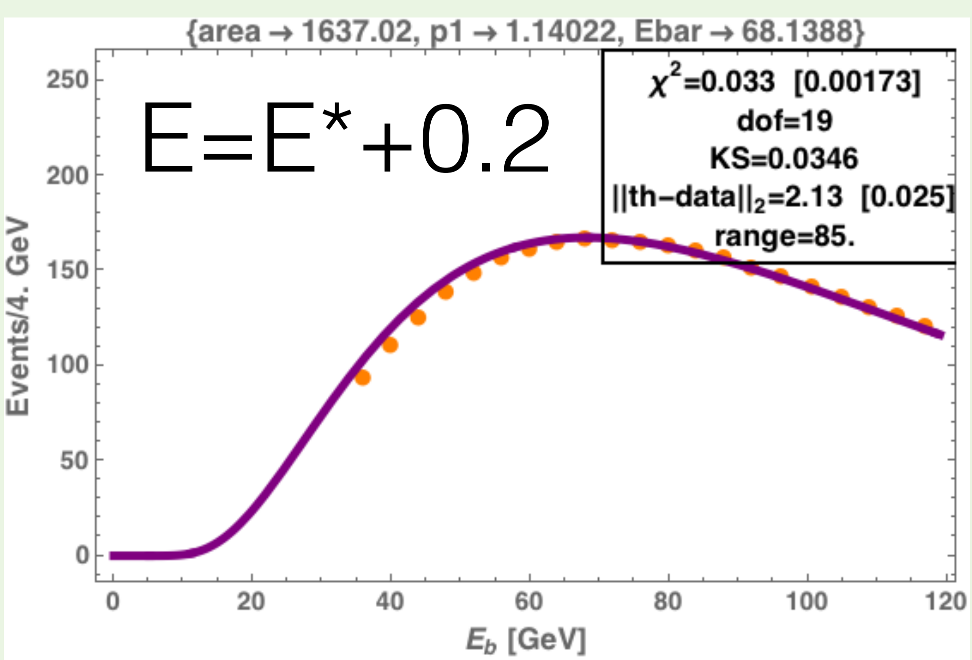
Moyal(x)



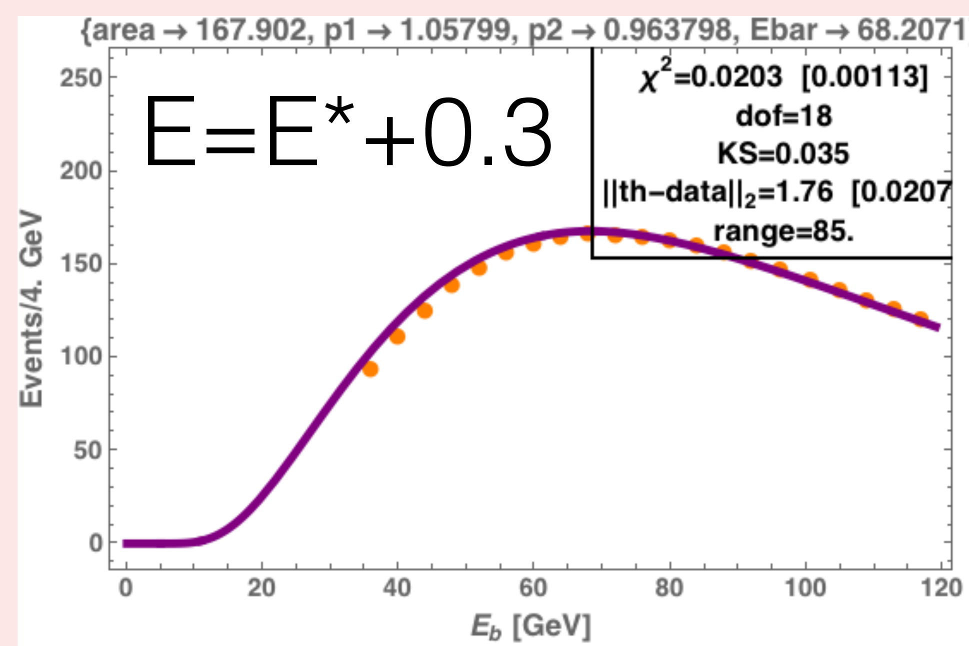
Moyal(1/x+x)



1par Exp(x+1/x)



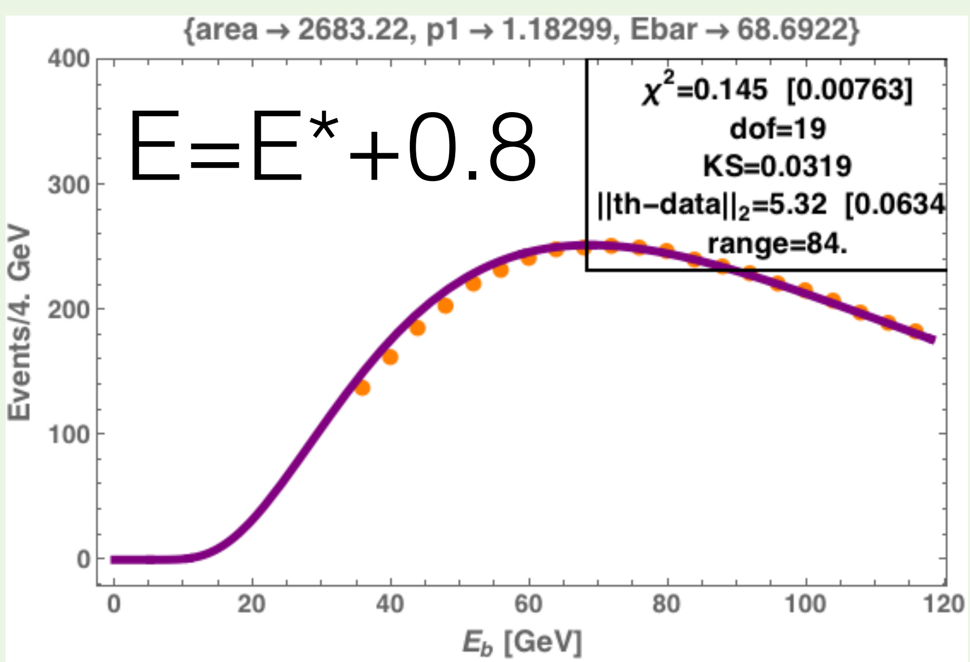
2pars Exp(x+1/x)



pNLO MCFM fixed μ=m$_{top}$ (E=67.9 GeV)

1par Exp(x+1/x)

R=0.5



R=1.0