NLO precise top mass from the b-jet energy peak

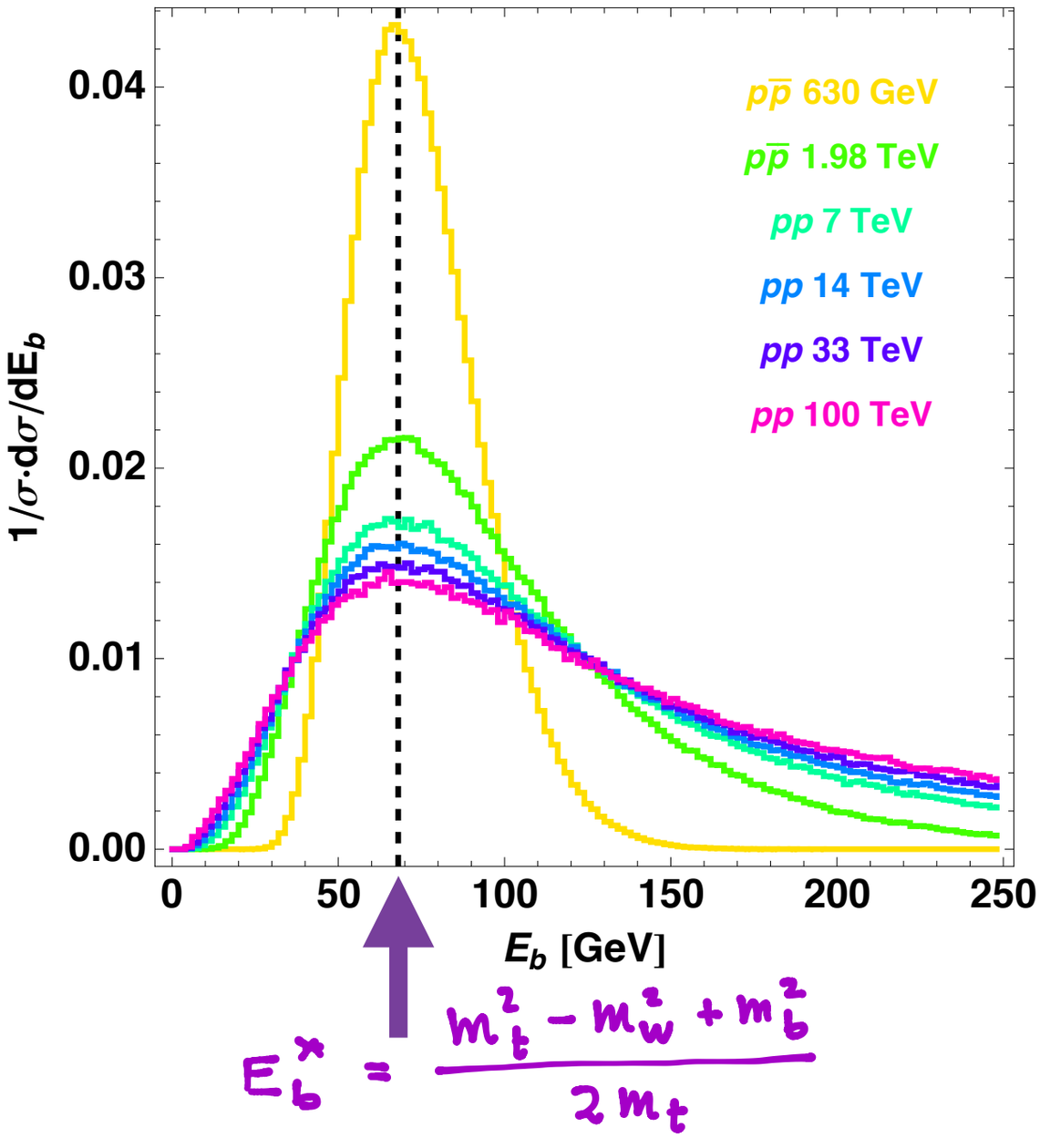
Roberto Franceschini (CERN)
November 17th 2015

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

Energy peak invariance

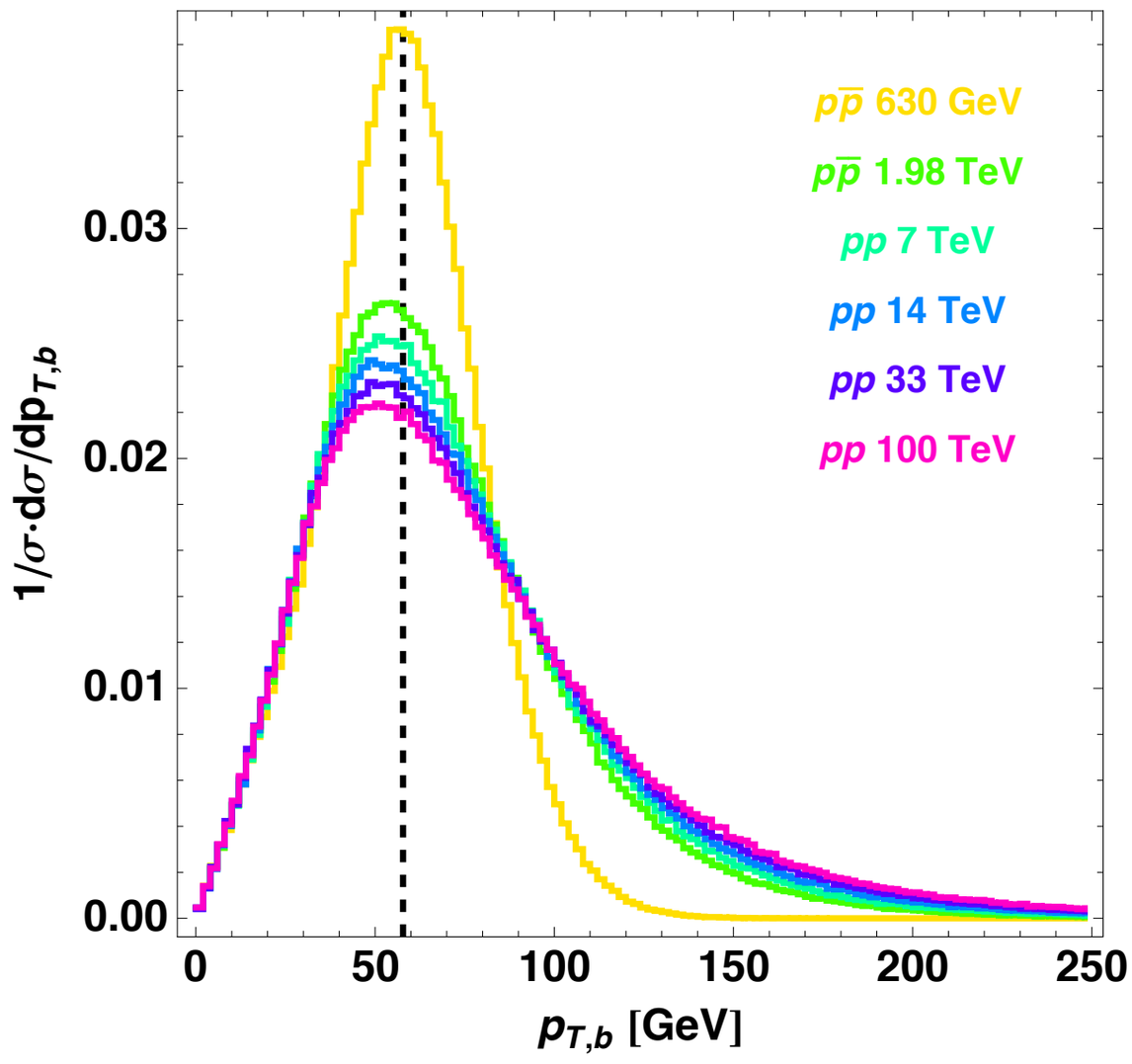
1209.0772 - Agashe, RF and Kim

Shape changes, peak doesn't!



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

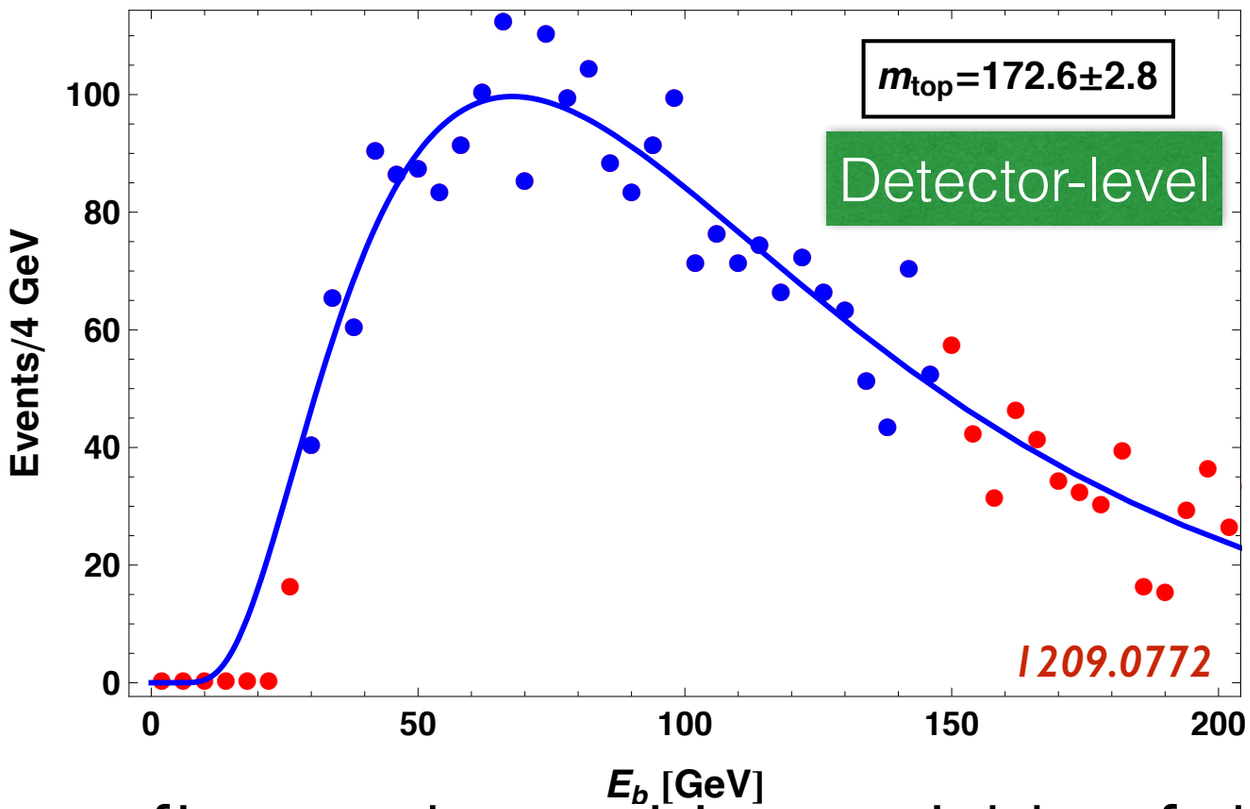
Shape changes, peak does too



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

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)

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

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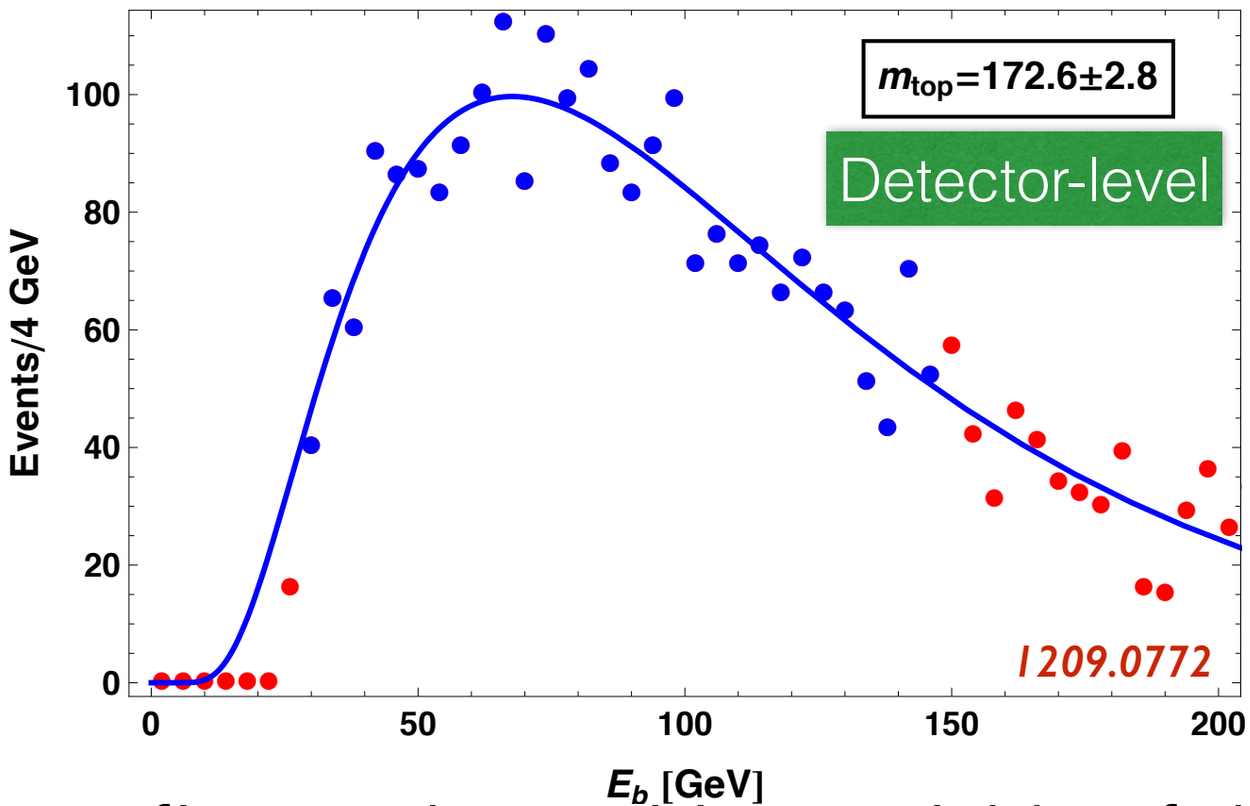

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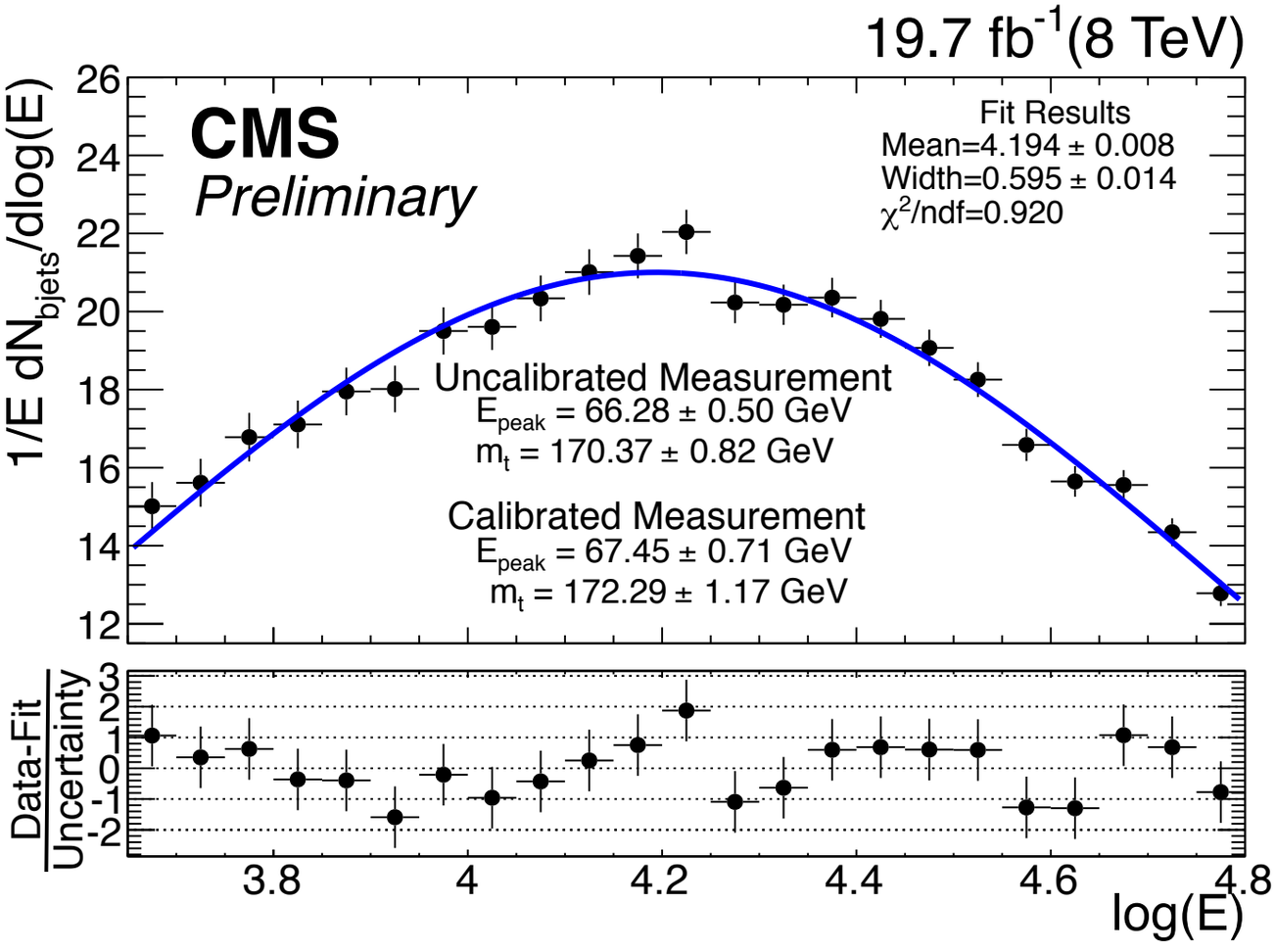
CMS PAS TOP-15-002

m_t = 172.29 ± 1.17 (stat.) ± 2.66 (syst.) GeV

Just released !!!



Source of uncertainty	δE_{peak} (GeV)	δm_t (GeV)
Experimental uncertainties		
Jet energy scale	0.74	1.23
b jet energy scale	0.14	0.22
Jet energy resolution	0.18	0.30
Pile-up	0.01	0.02
b-tagging efficiency	0.12	0.20
Lepton efficiency	0.02	0.03
Fit calibration	0.14	0.24
Backgrounds	0.21	0.34
Modeling of hard scattering process		
Generator modeling	0.91	1.50
Renormalization and factorization scales	0.13	0.22
ME-PS matching threshold	0.24	0.39
Top p_T reweighting	0.90	1.49
PDFs	0.13	0.22
Modeling of non-perturbative QCD		
Underlying event	0.22	0.35
Color reconnection	0.38	0.62
Total	1.62	2.66

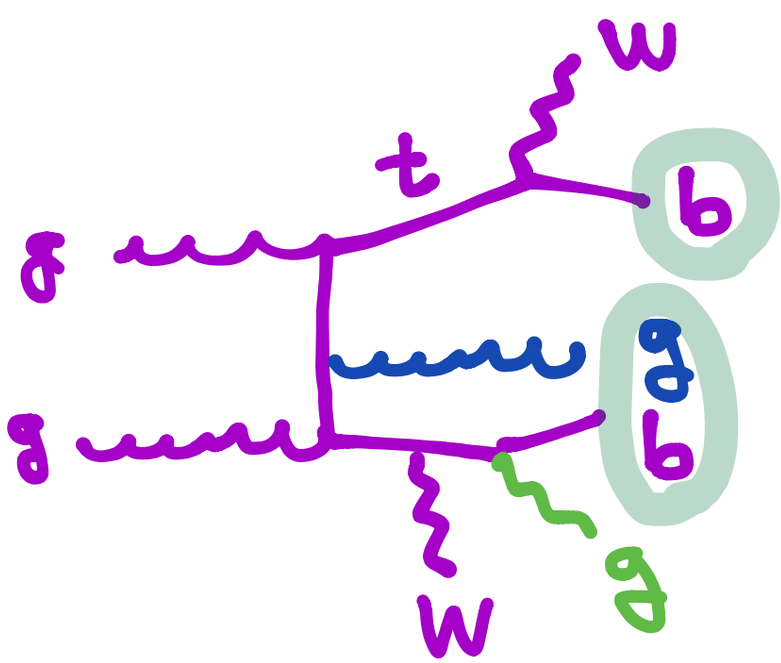
leading uncertainty from theory can be reduced

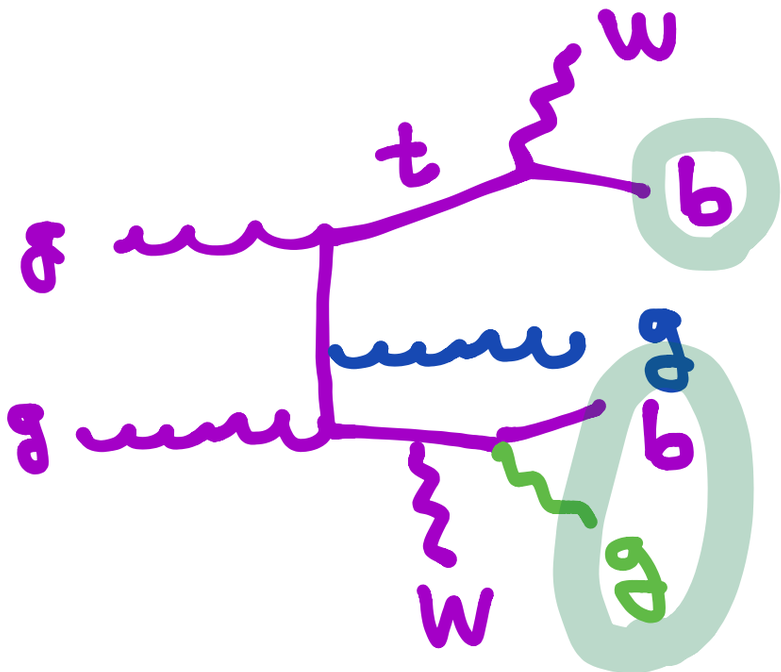
pT(top) reweighting smaller than other methods (Lxy, pTℓ …)

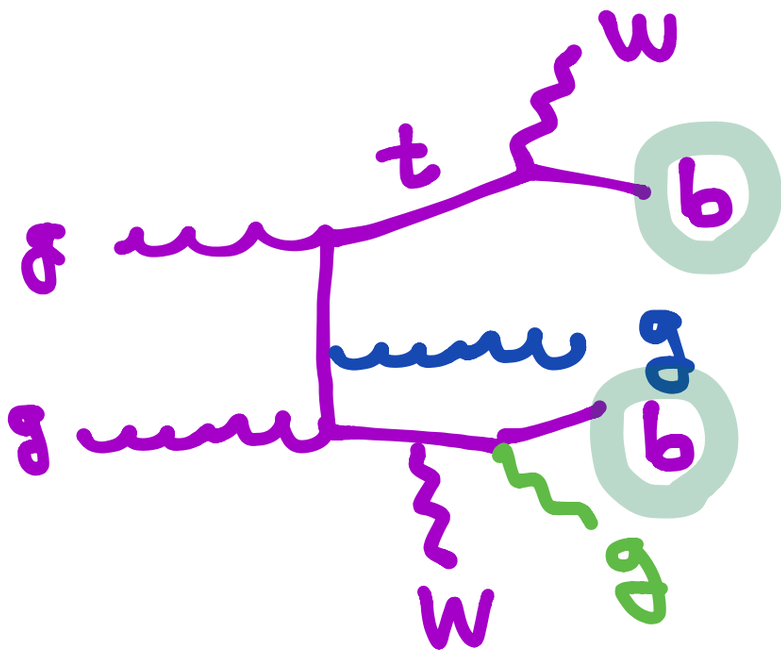
NLO: production & decay

(MCFM)

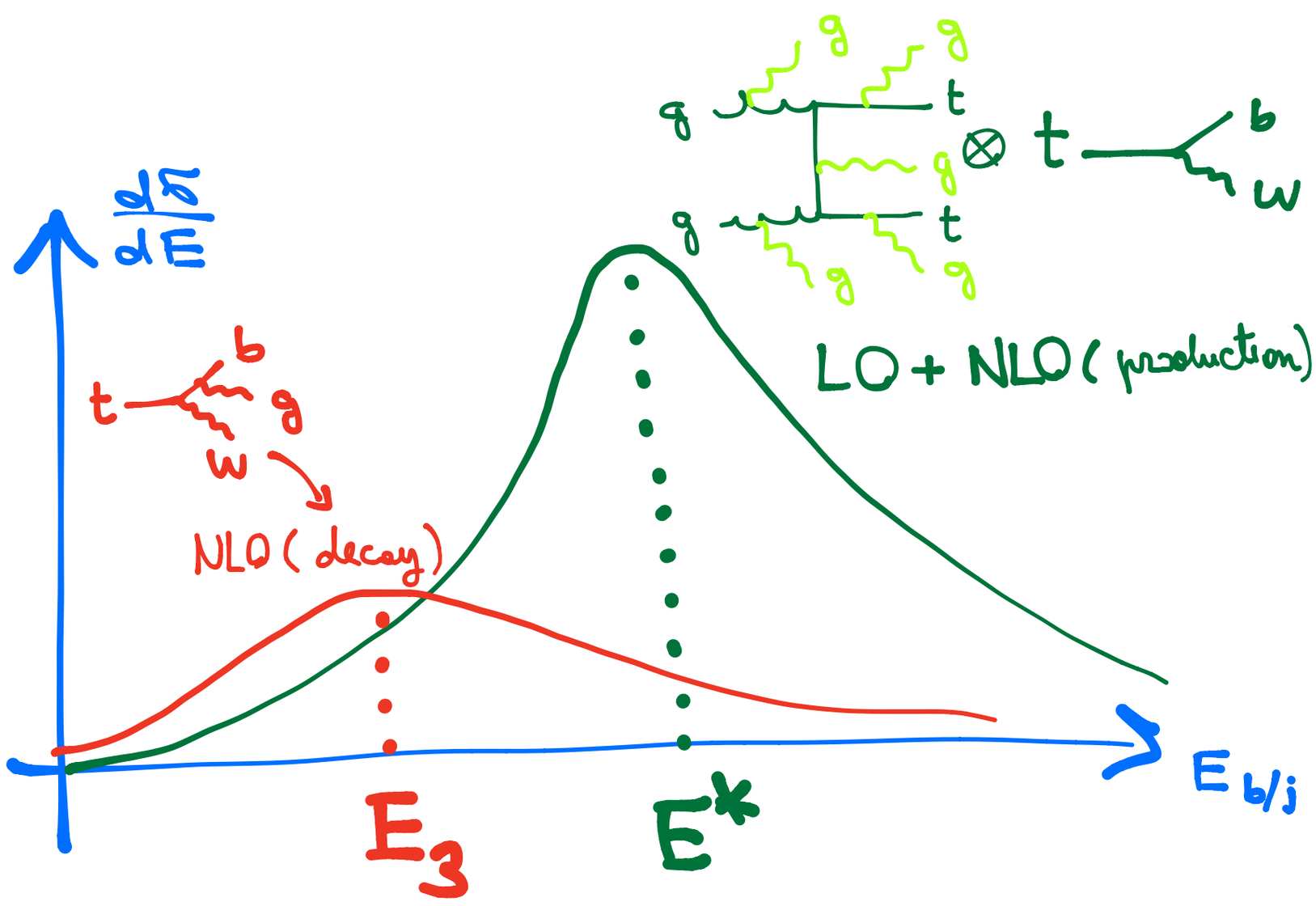
Agashe, Franceschini, Kim, Schulze - in preparation





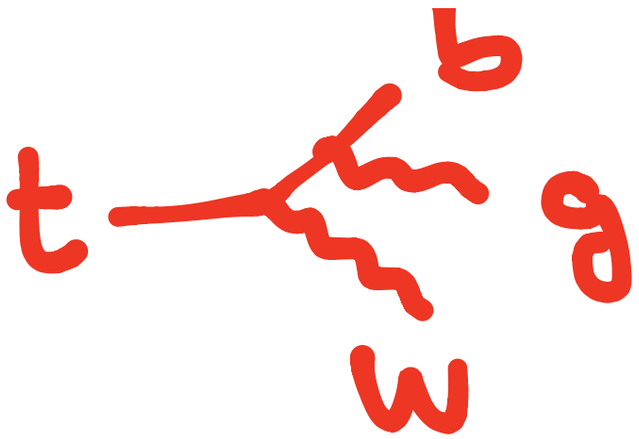


Peak shift at NLO



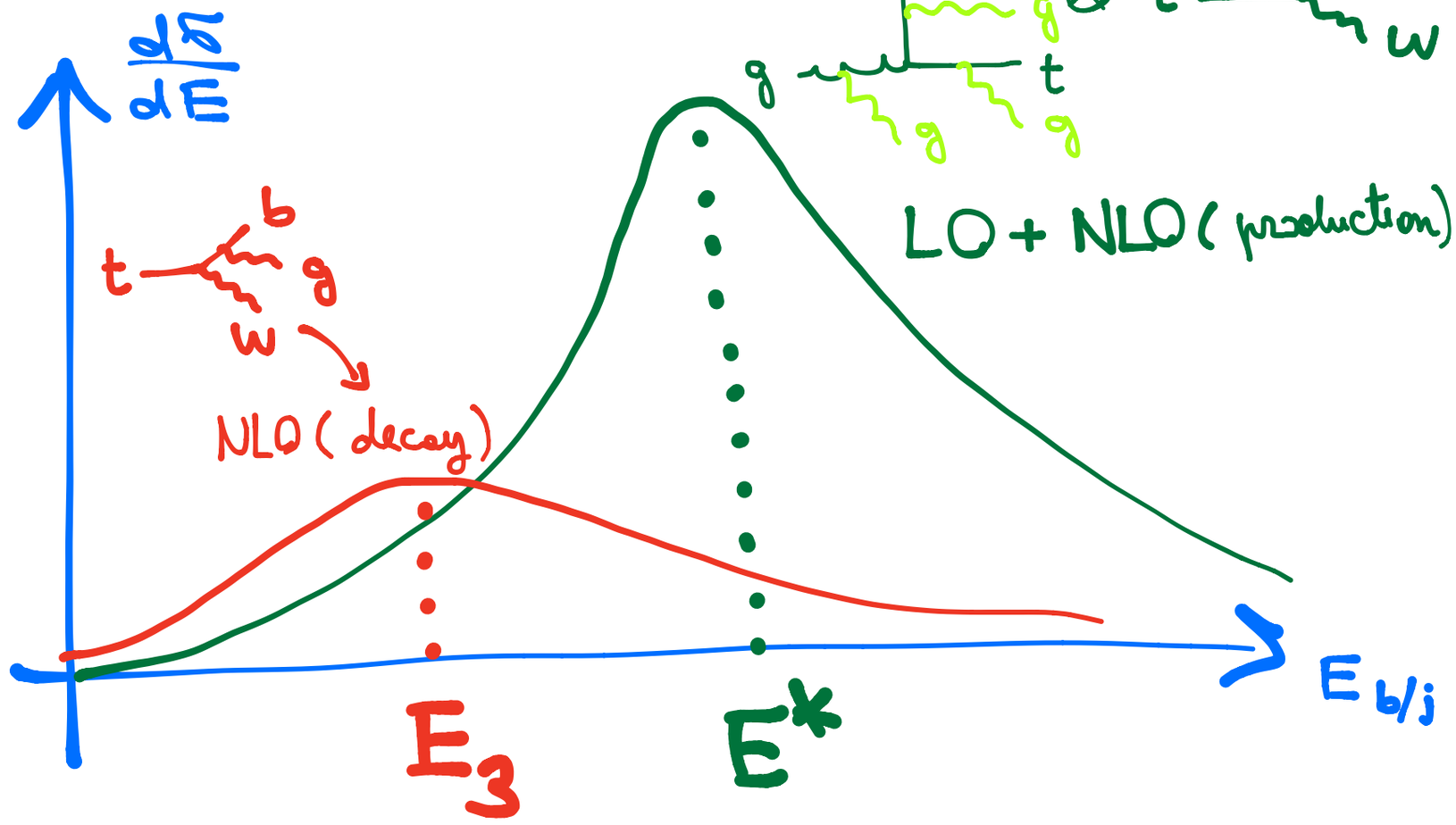
$$E^{peak} = E^* + O(1)\,\frac{\alpha}{4\pi}\,E_3$$

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

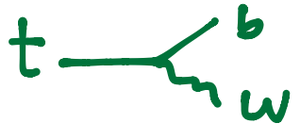


$$E^{peak} = E^{*}(1-\Delta_{TH}) + \Delta_{TH} E_3$$

Δ_{TH}=BR(t→bW**g**)/BR(t→bW)≃0.05

NLO: production & decay

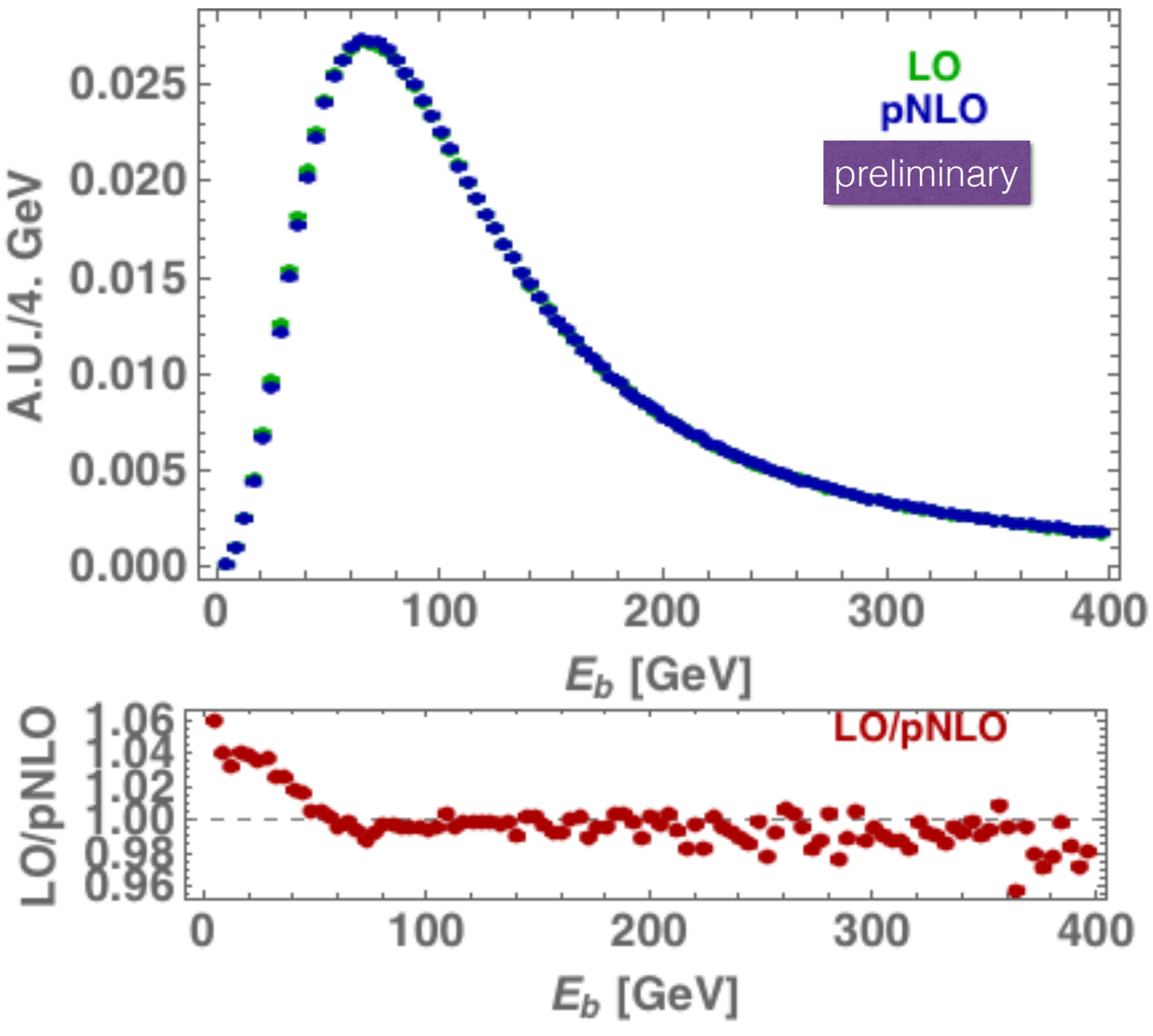
(MCFM)

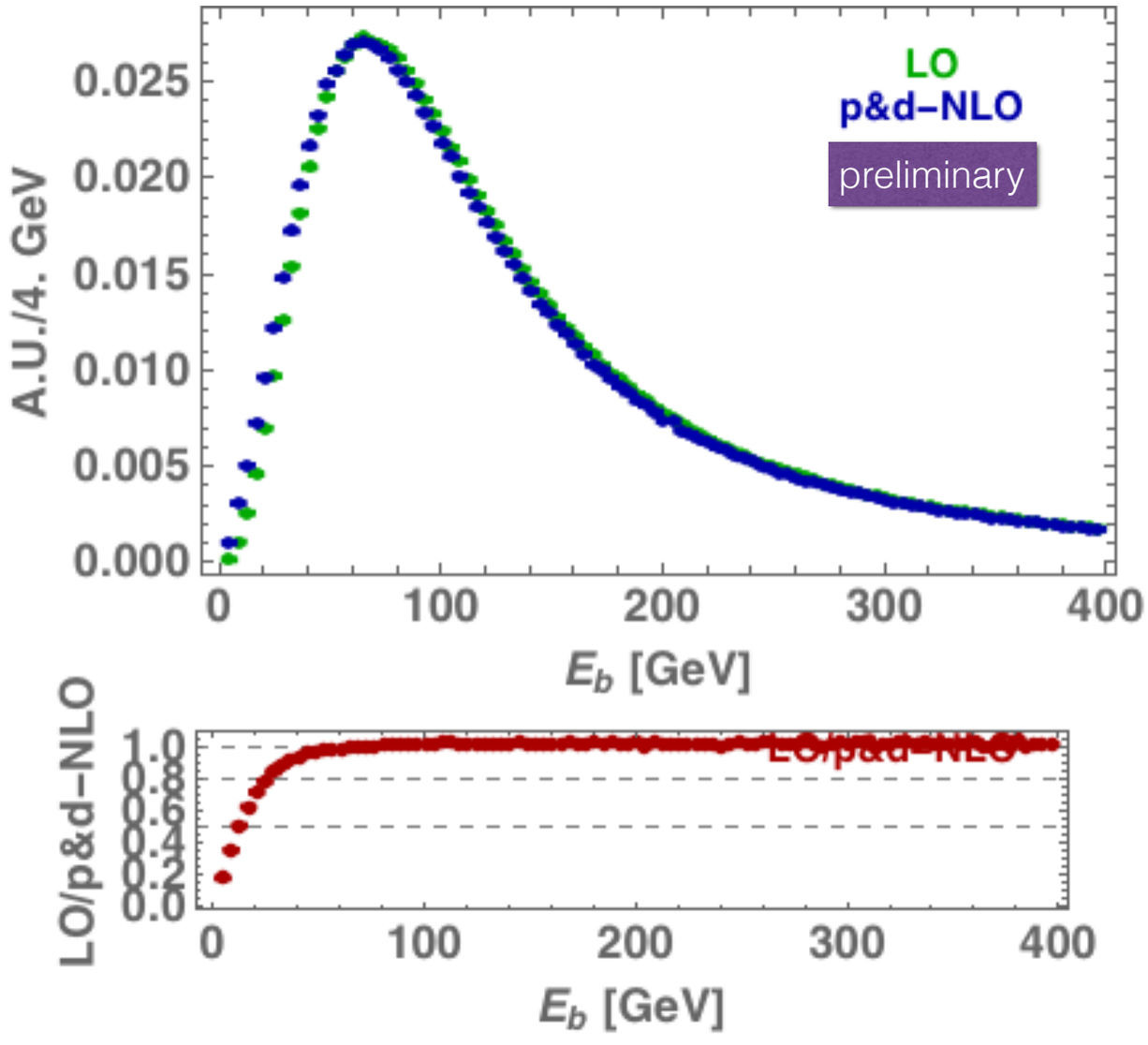


decay at LO

Energy of b

decay at NLO

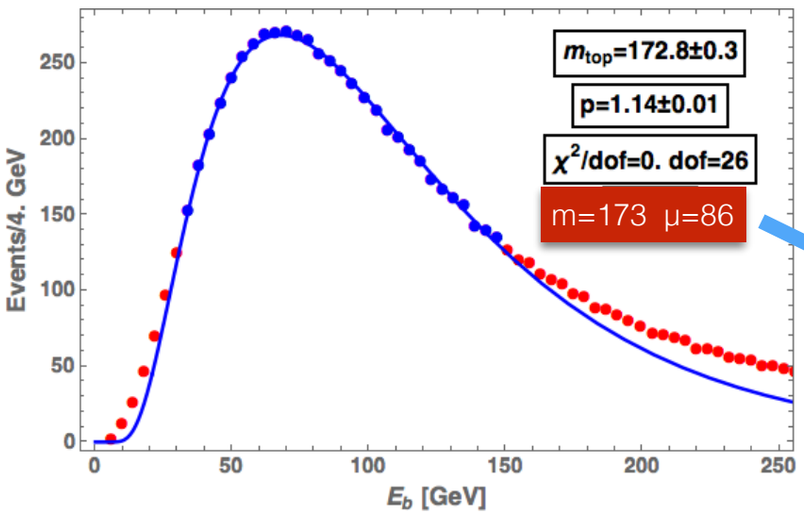


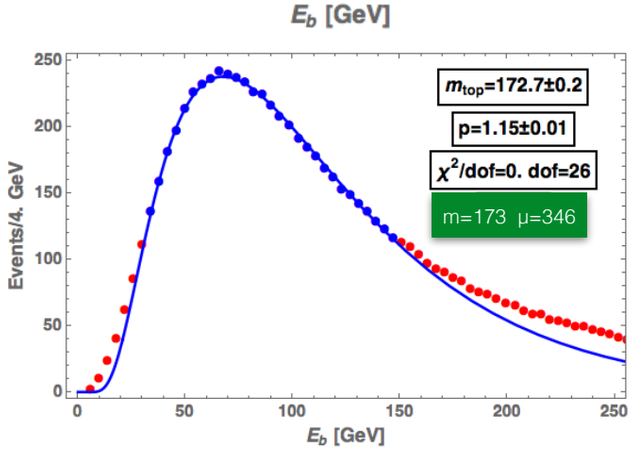


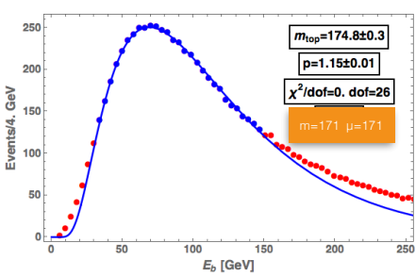
pQCD prediction: Ê(mtop)

1. pick top pole mass
2. pick ren./fact. scales
3. energy distribution dσ/dEb
4. peak of the distribution Ê
5. Ê(mtop)

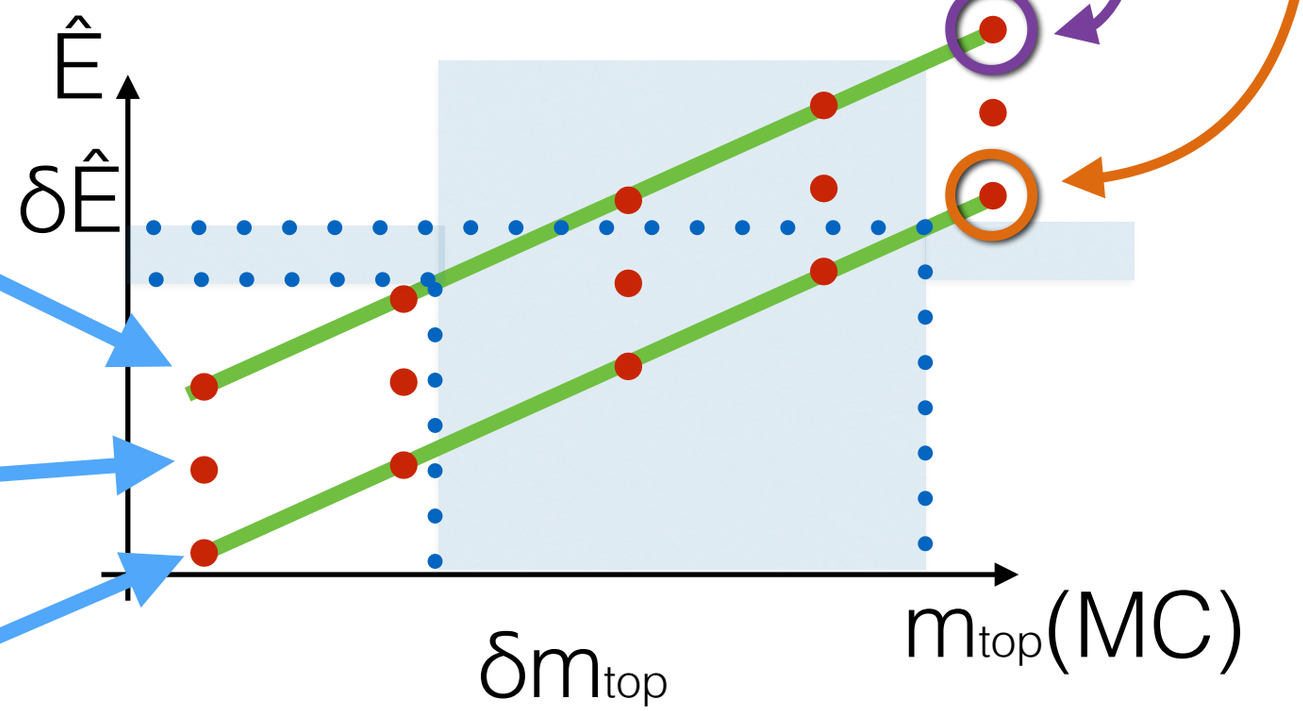
pQCD







energy peaks



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 $E^*(m_{top})$

Agashe, RF, Kim, Schulze - in preparation

pT_j>30 GeV, η_j<2.4, $pT\ell$>20 GeV, $\eta\ell$<2.4

NLO E*(m_{top})

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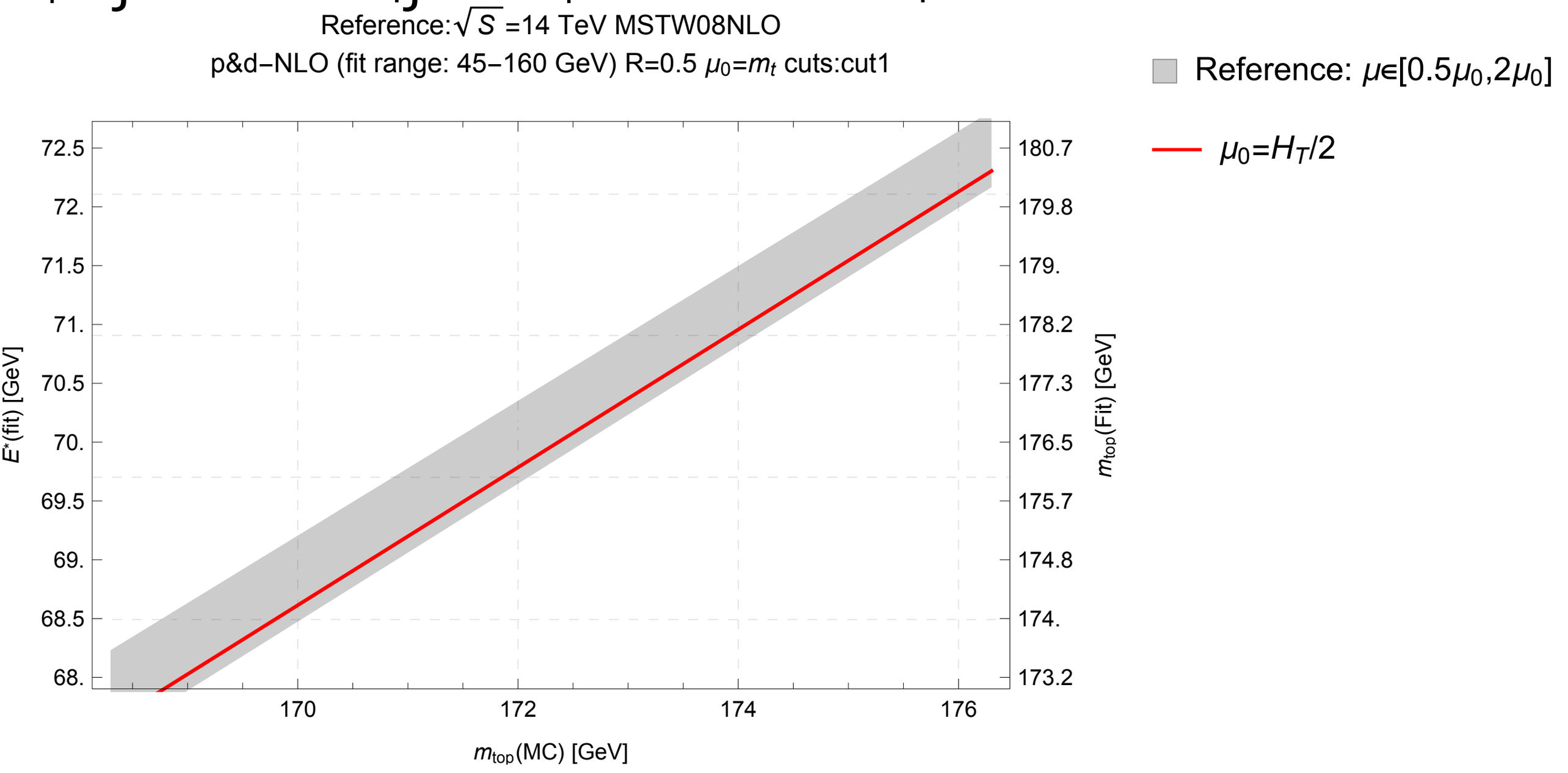

NLO sensitive to the scale choice: ±1 GeV on m_{top}

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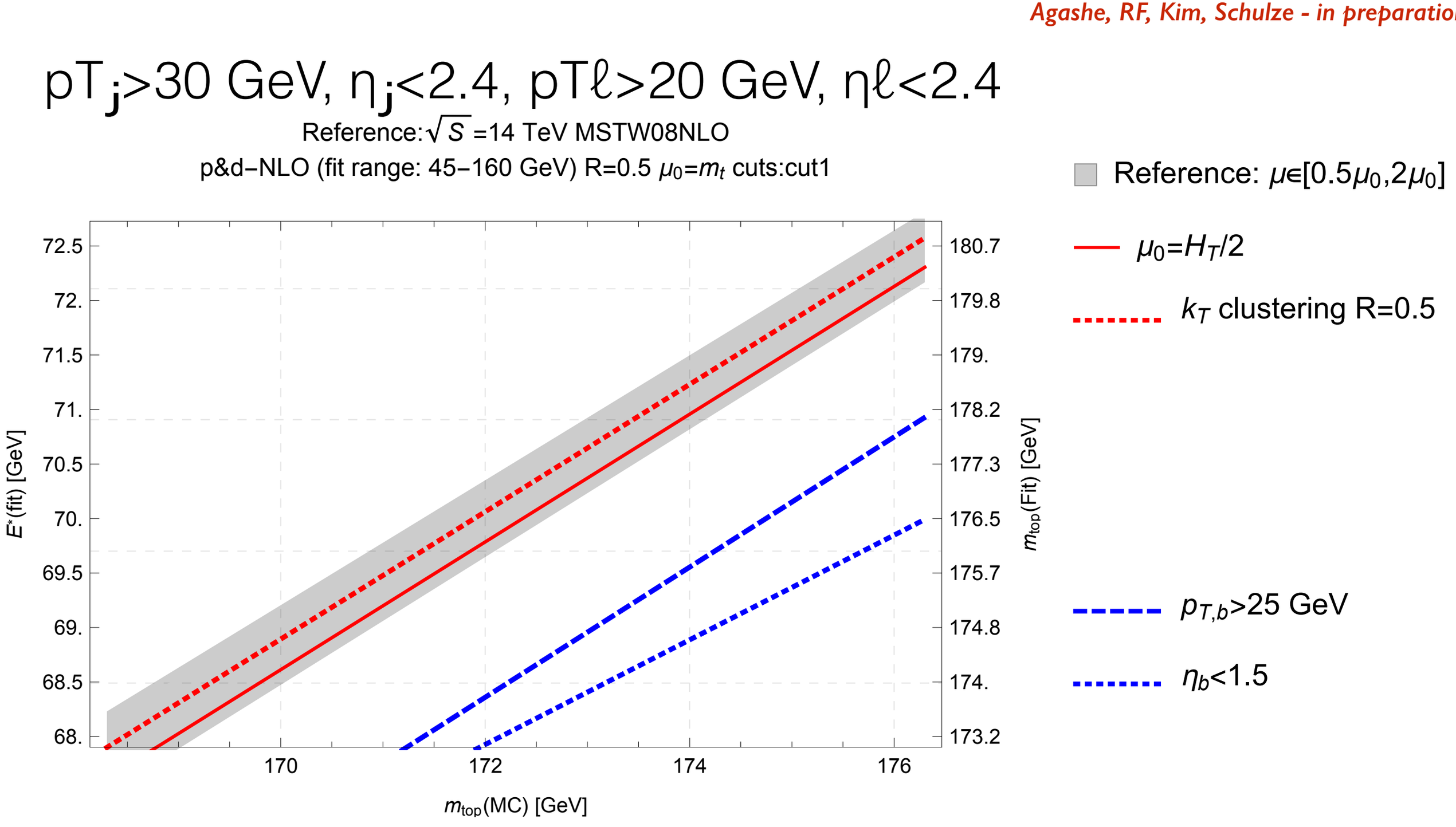

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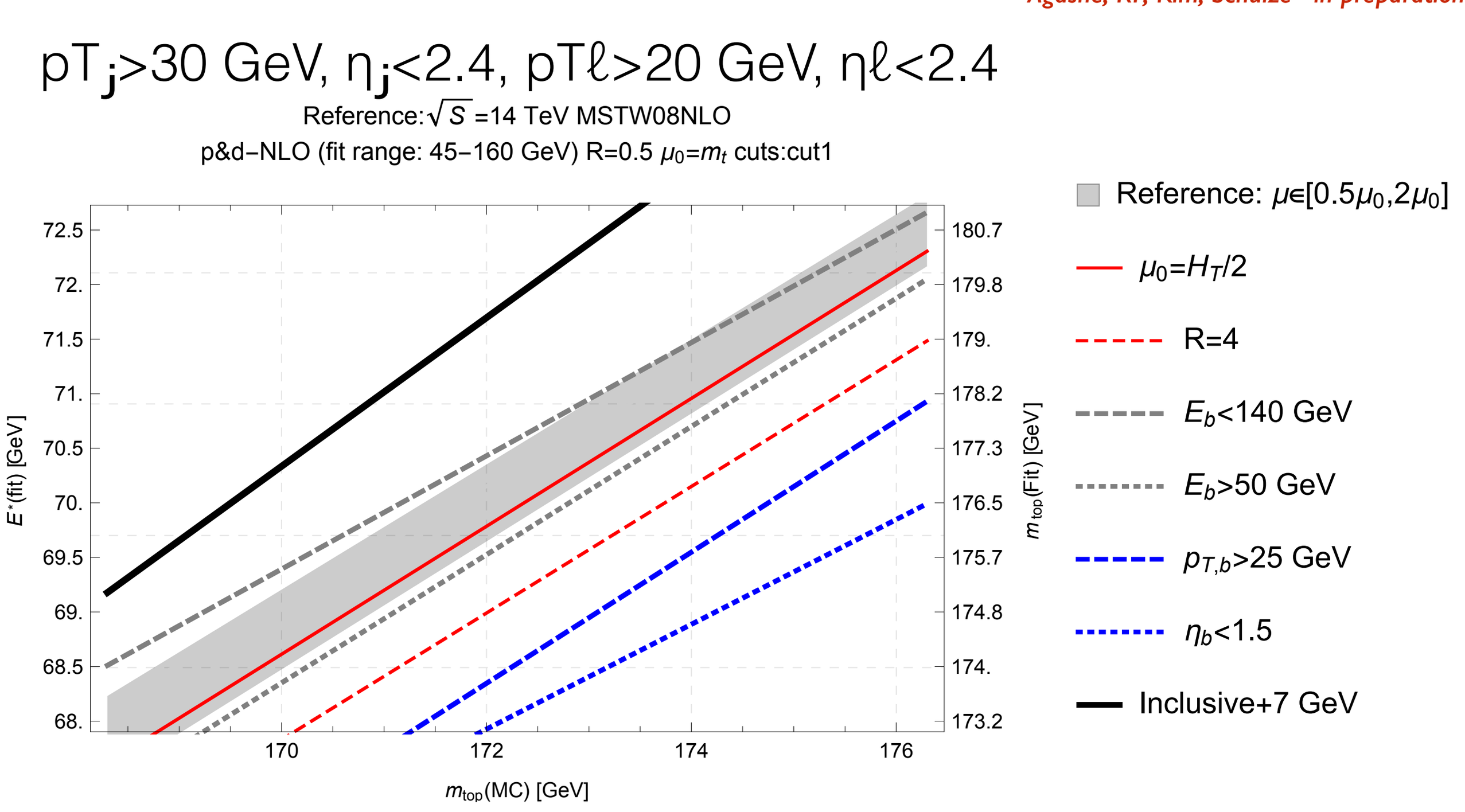

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Parton shower uncertainties

Sensitivity to shower parameters

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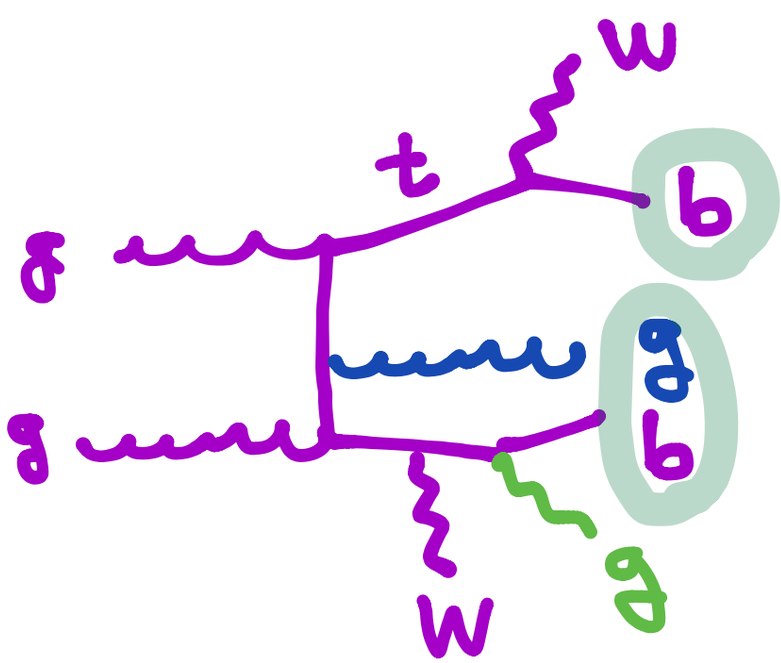

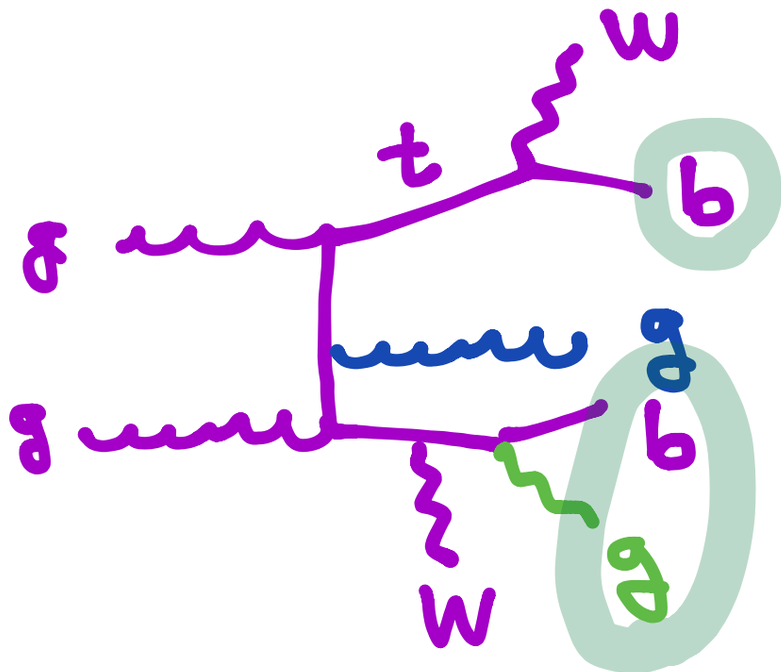

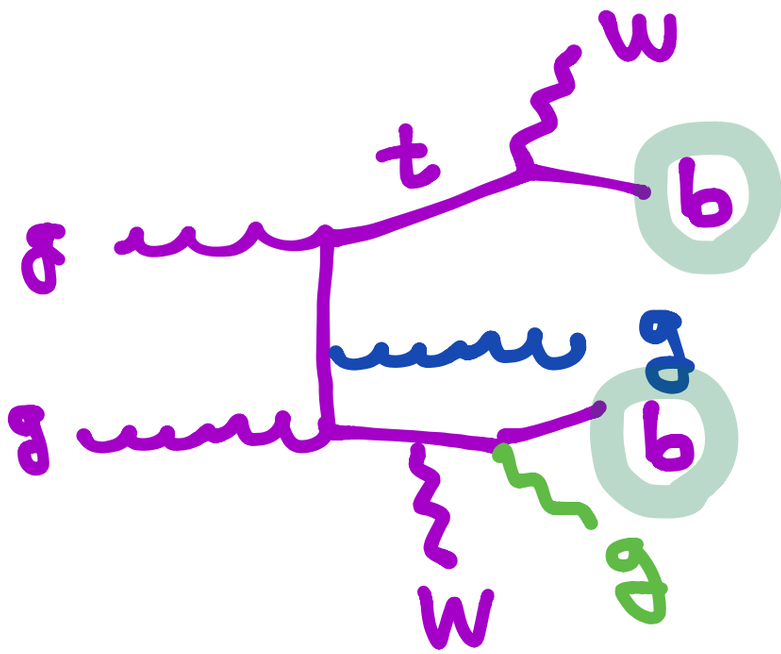

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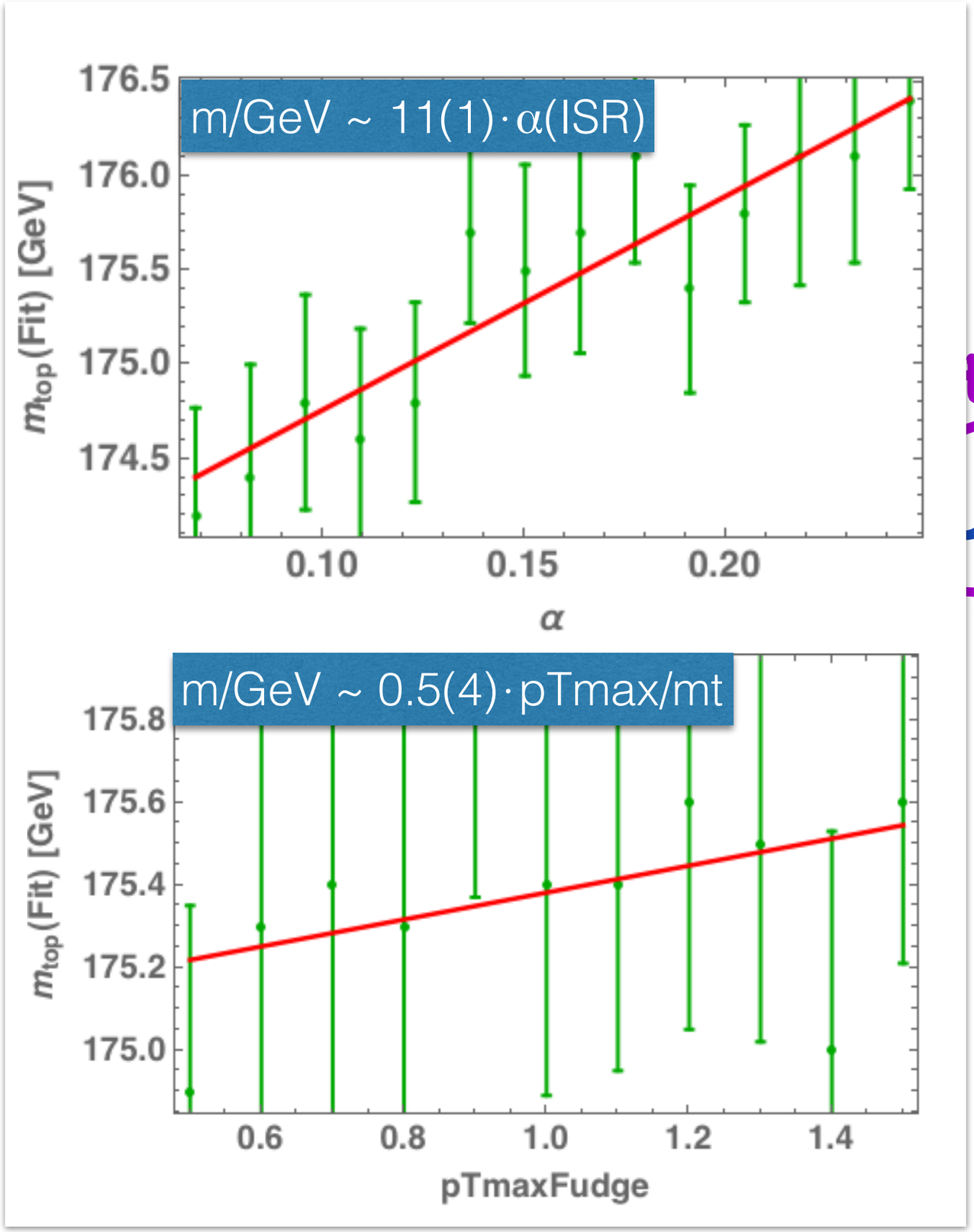

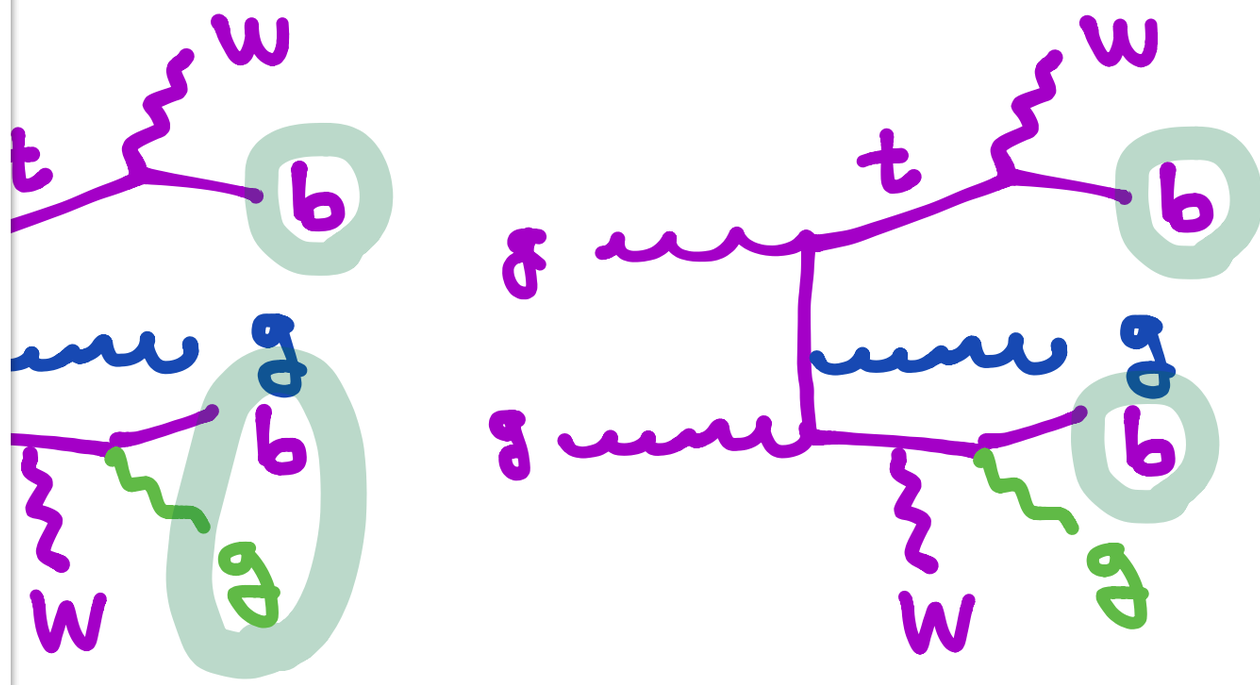

Parton shower uncertainties

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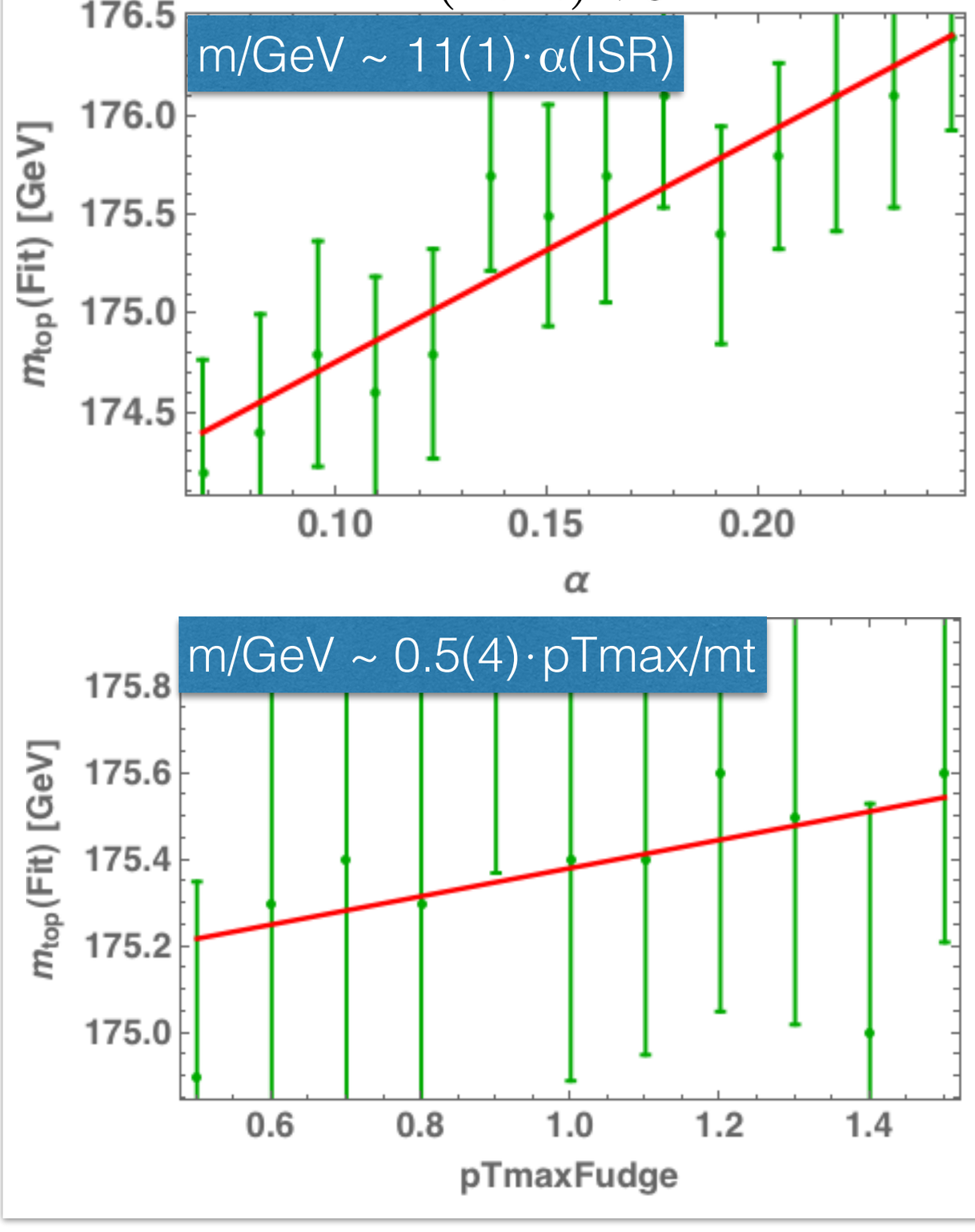
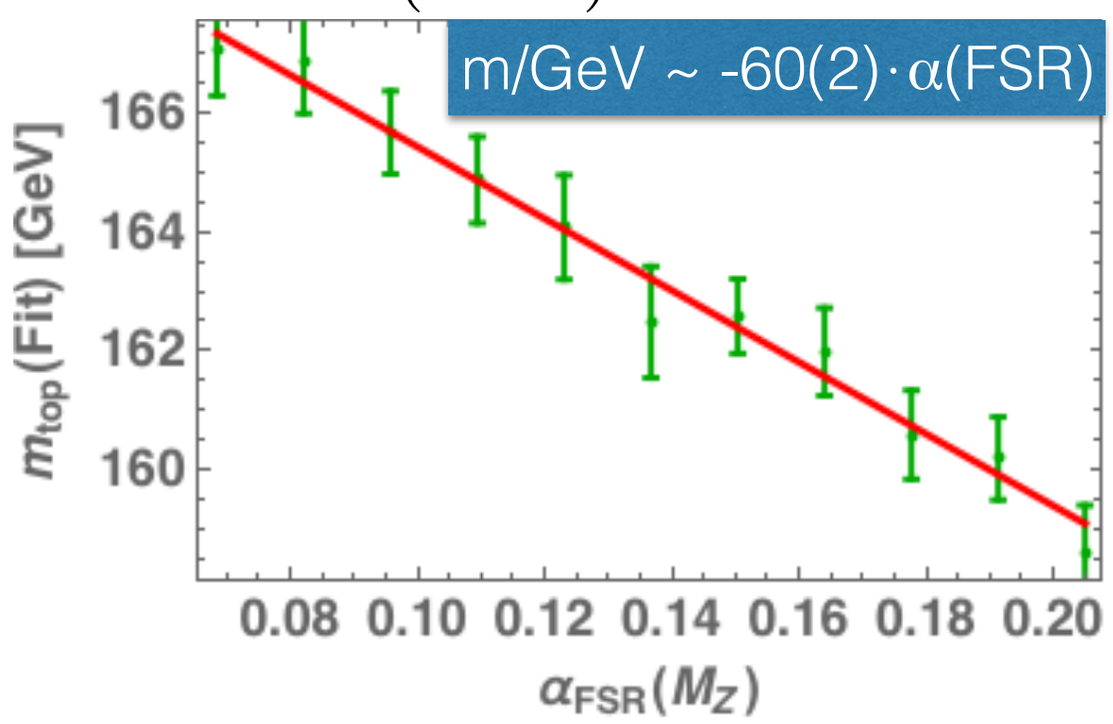
$\Delta_{\alpha(ISR)} \lesssim 0.01$



$\Delta_{\alpha(FSR)} = -0.05$



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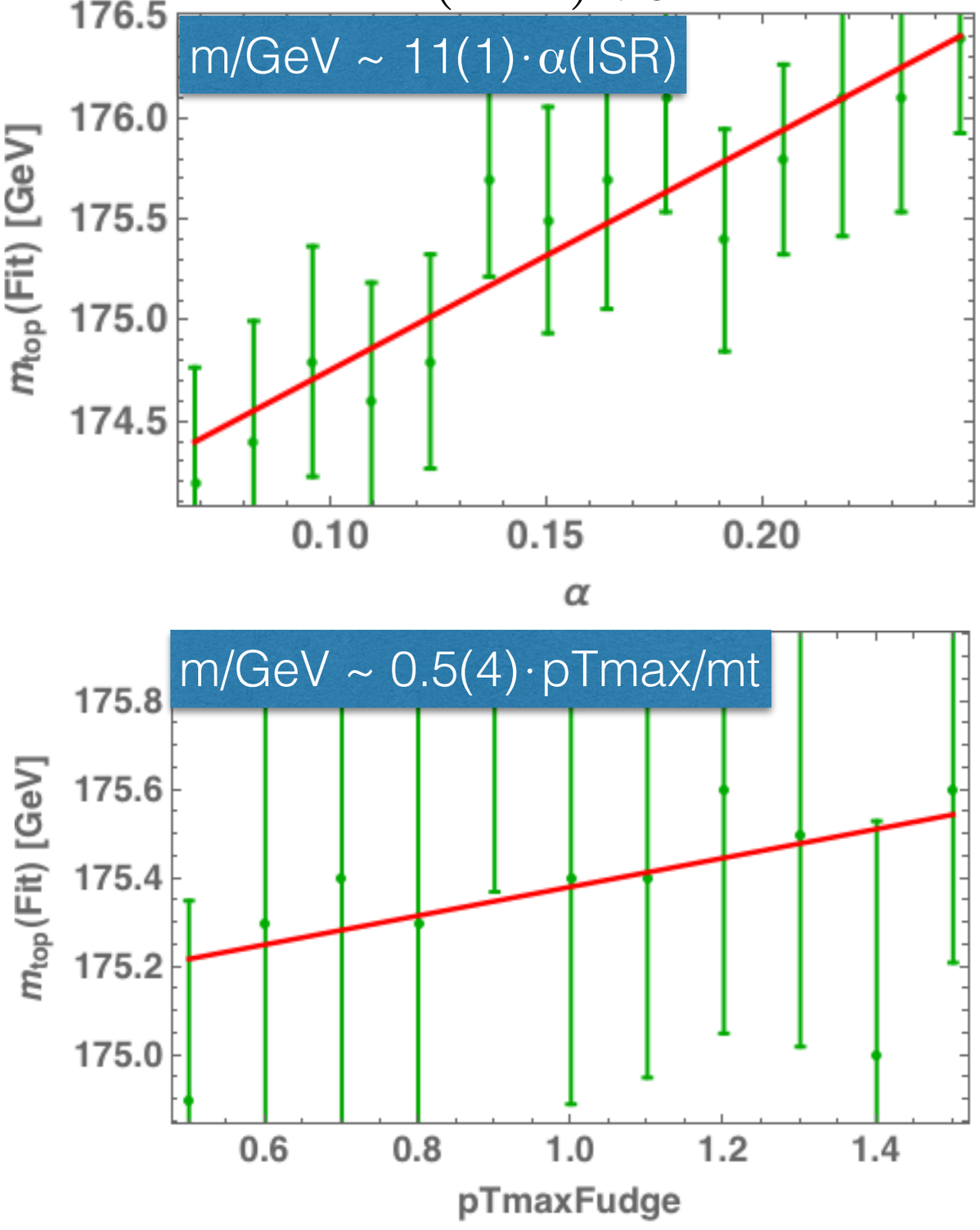

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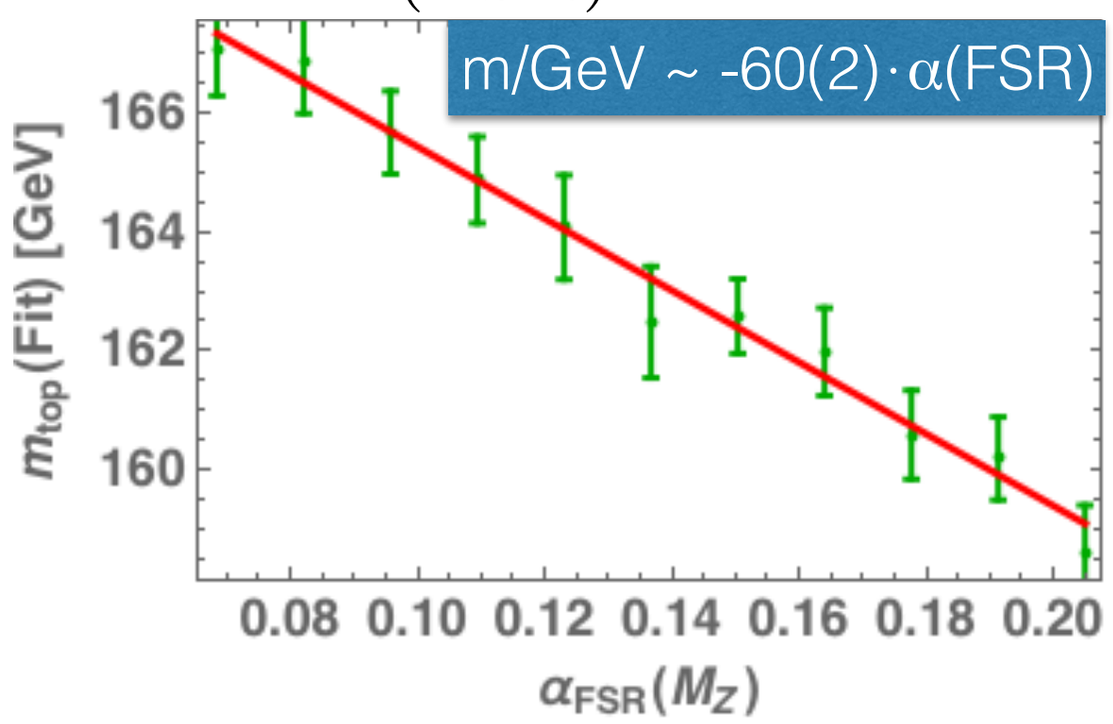

my take:

definitively ok to quote uncertainty from missing shower (well) below 1 GeV

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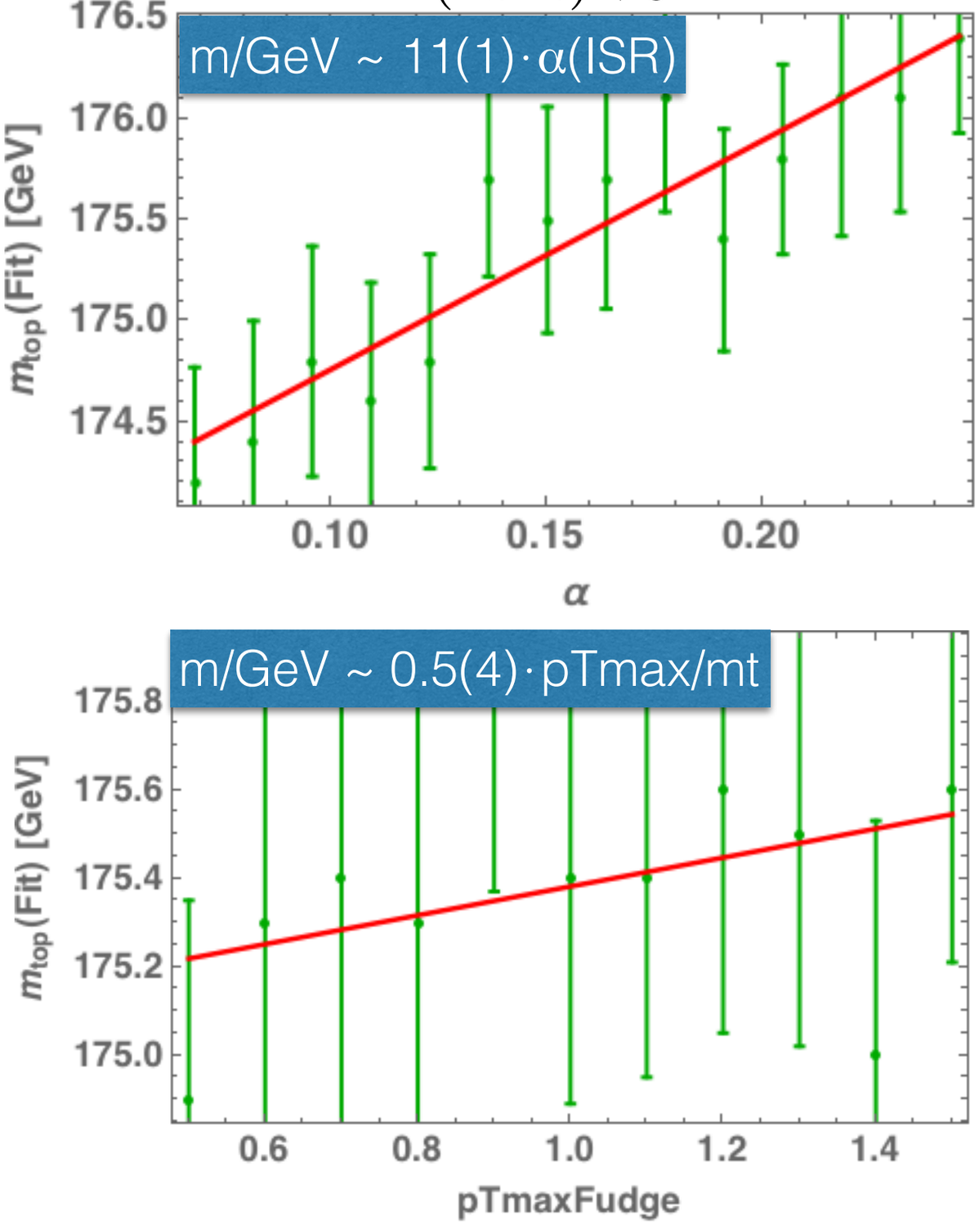

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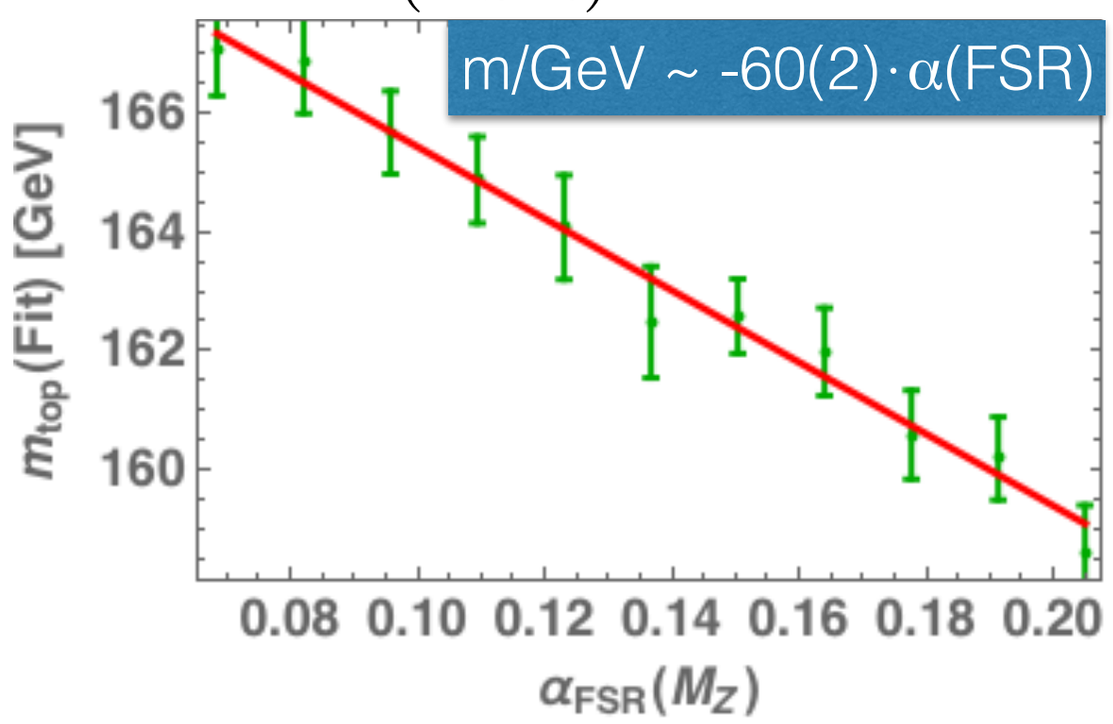

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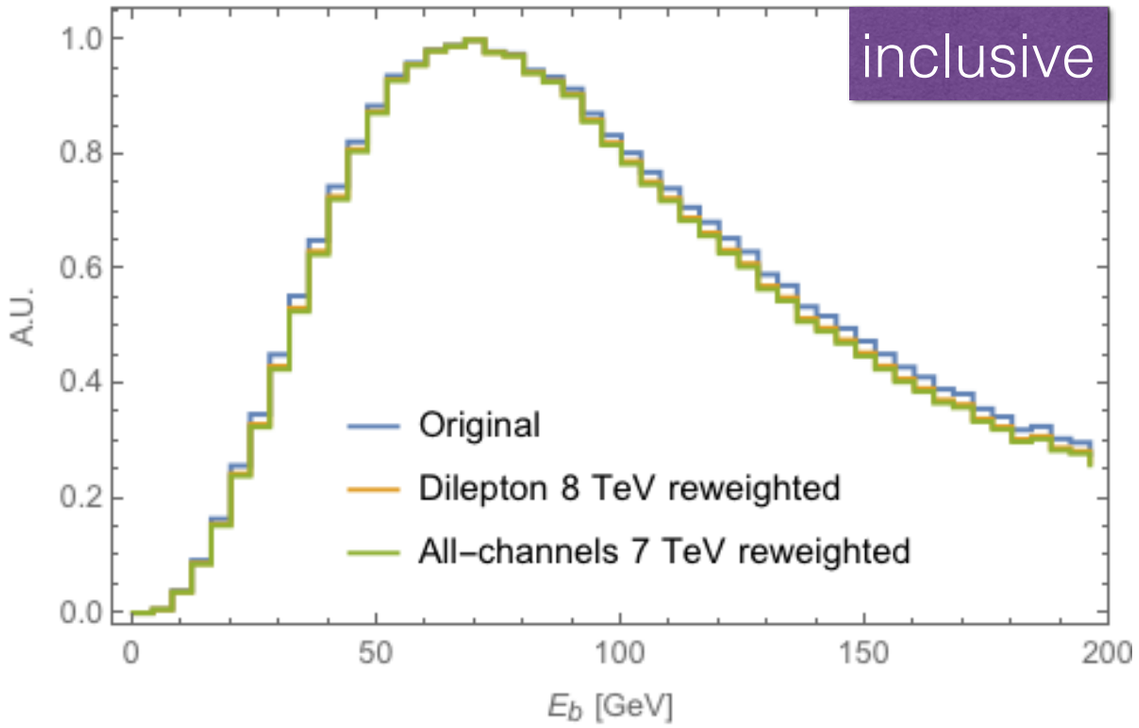
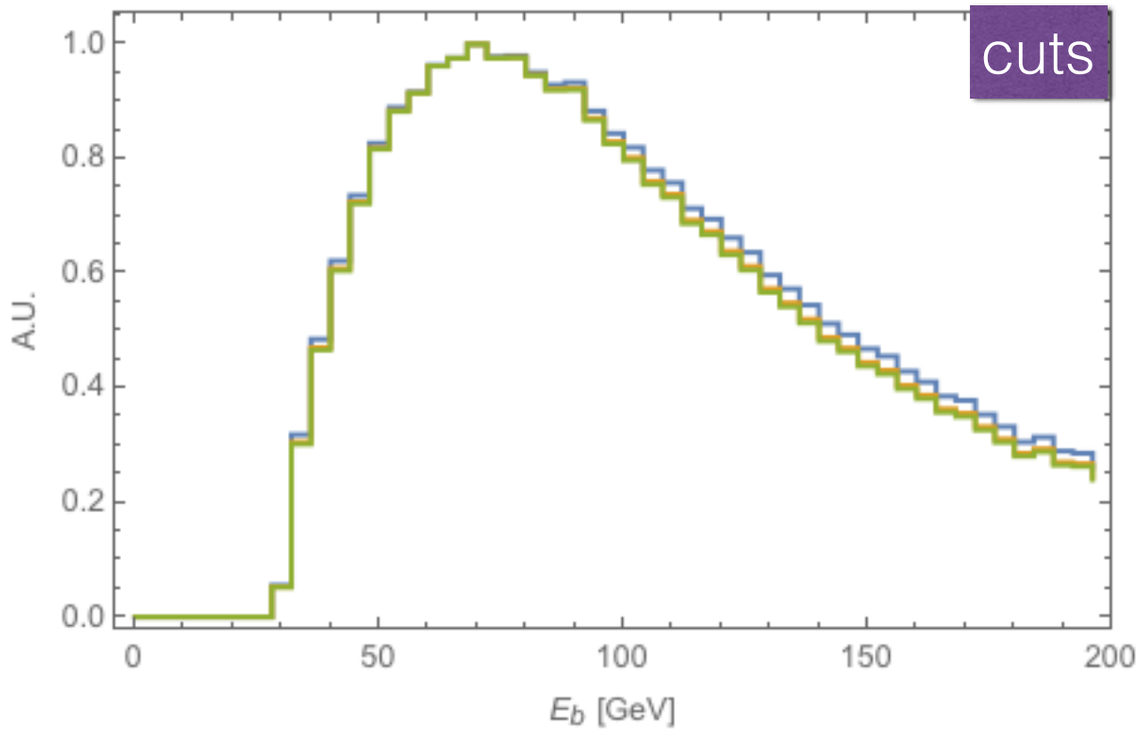
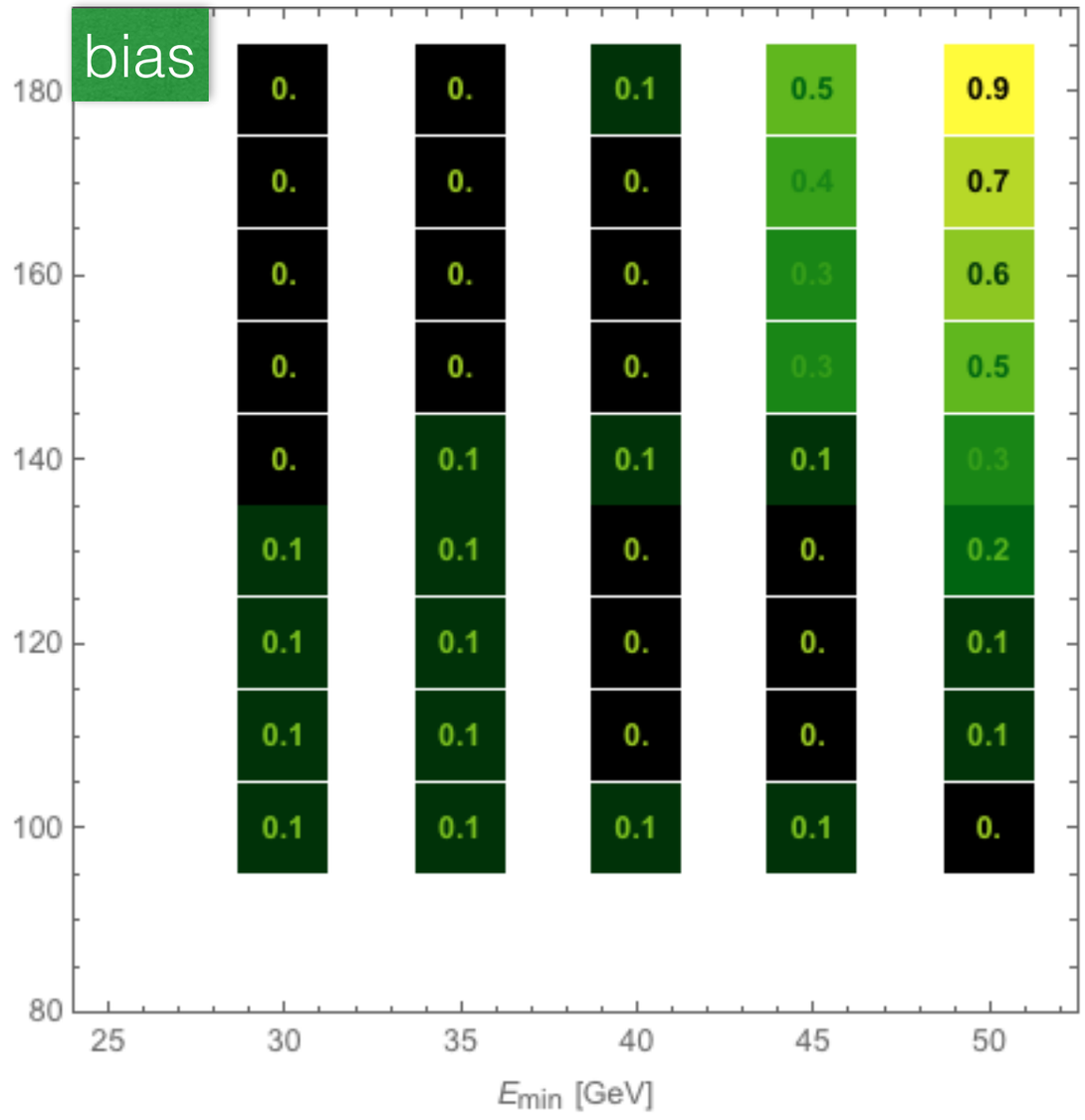
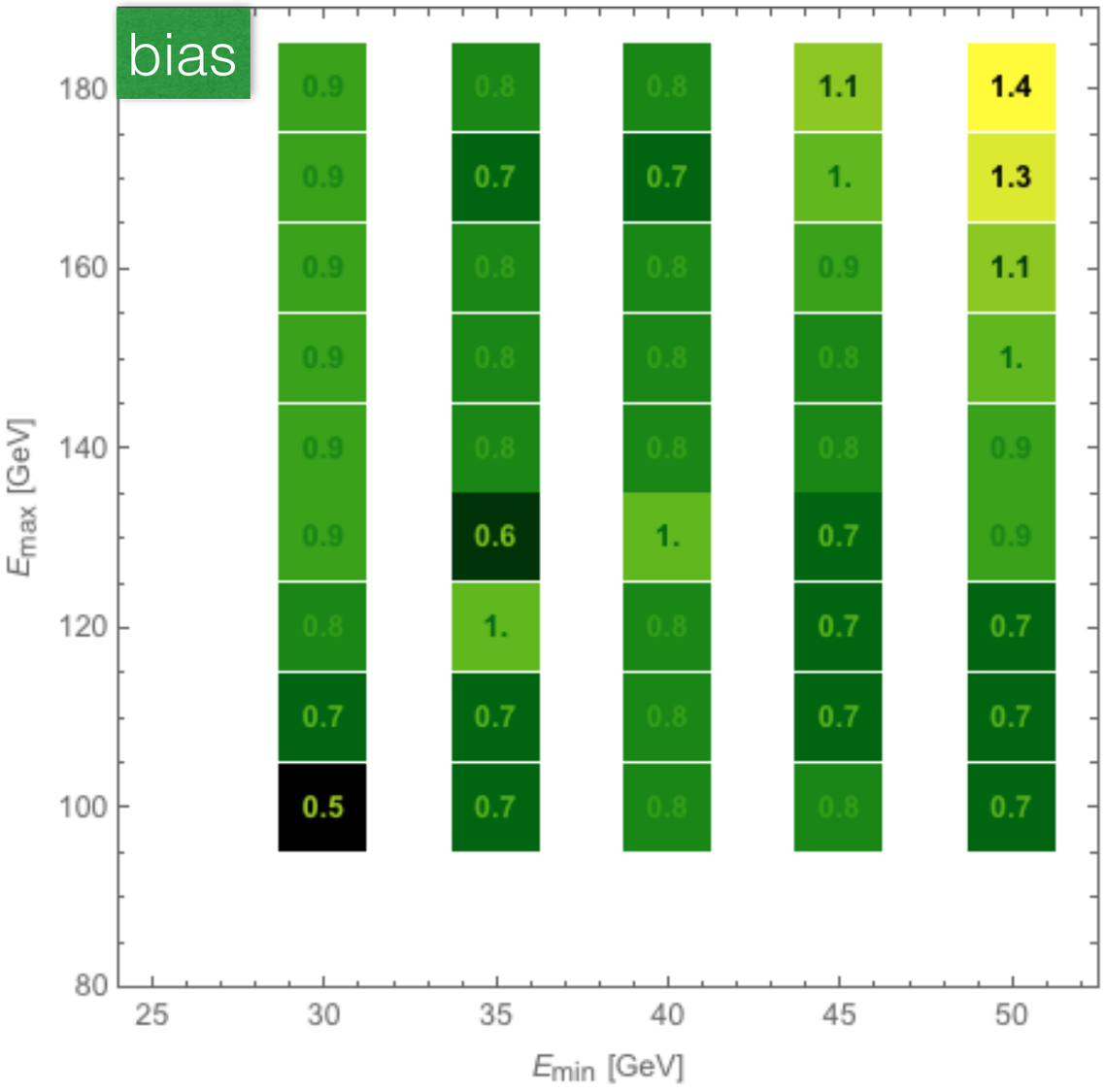
m(pole) up to FSR variations?

pT(top) reweighting









What next?

ATLAS?

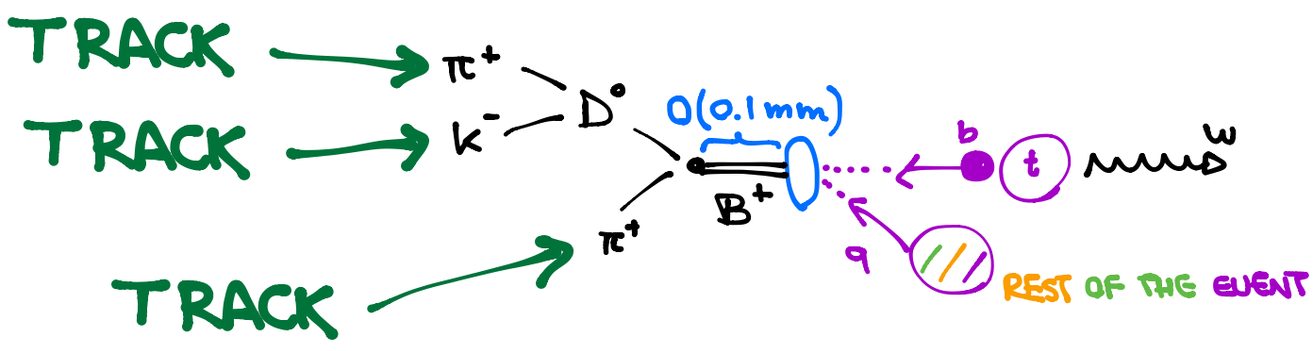
More (B hadron) peak observables

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*"

$$\frac{d\sigma}{dE_b} \propto \frac{d\sigma}{d\gamma_b} \propto \frac{d\sigma}{d\lambda}$$

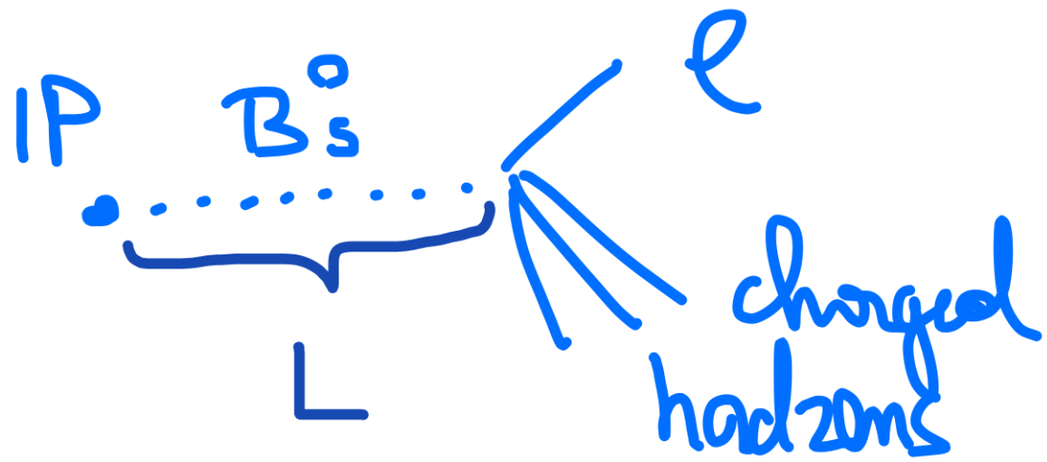
hadron energy peak

get the hadron energy entirely from tracks



COMING SOON

mean decay path peak



Exclusive Decay

(Fully reconstructible with tracks)

J/psi modes

$$b \underset{few\cdot 10^{-3}}{\longrightarrow} J/\psi + X \underset{10^{-1}}{\longrightarrow} \ell\bar{\ell} + X$$

$B_s^0 \to J/\psi\,\phi \to \mu^-\mu^+K^+K^-$ *1106.4048*

$B^0 \to J/\psi\,K_S^0 \to \mu^-\mu^+\pi^+\pi^-$ *1104.2892*

$B^+ \to J/\psi\,K^+ \to \mu^+\mu^-K^+$ *1101.0131 1309.6920*

$\Lambda_b \to J/\psi\,\Lambda \to \mu^+\mu^-p\pi^-$ *1205.0594*

$$B^+ \to J/\psi\,K^+(1270) \to J/\psi\,\rho^0K^+ \to J/\psi\,\pi^+\pi^-K^+$$

D modes

$$B^0 \underset{3\cdot 10^{-3}}{\longrightarrow} D^-\pi^+ \underset{10^{-2}}{\longrightarrow} K_S^0\pi^-\,\pi^+$$
$$B^0 \underset{3\cdot 10^{-3}}{\longrightarrow} D^-\pi^+ \underset{10^{-2}}{\longrightarrow} K^-\pi^+\pi^-\,\pi^+$$
$$B^0 \underset{3\cdot 10^{-3}}{\longrightarrow} D^-\pi^+ \underset{3\cdot 10^{-2}}{\longrightarrow} K_S^0\pi^+\pi^-\,\pi^+$$

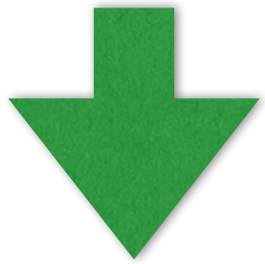
$$B^- \underset{5\cdot 10^{-3}}{\longrightarrow} D^0\pi^- \underset{4\cdot 10^{-2}}{\longrightarrow} K^-\pi^+\,\pi^-$$
$$B^- \underset{5\cdot 10^{-3}}{\longrightarrow} D^0\pi^- \underset{2\cdot 10^{-2}}{\longrightarrow} K^{*,-}(892)\pi^+\,\pi^- \to K_S^0\pi^-\,\pi^+\,\pi^-$$
$$B^- \underset{5\cdot 10^{-3}}{\longrightarrow} D^0\pi^- \underset{6\cdot 10^{-3}}{\longrightarrow} K_S^0\rho^0\,\pi^-$$
$$B^- \underset{5\cdot 10^{-3}}{\longrightarrow} D^0\pi^- \underset{5\cdot 10^{-3}}{\longrightarrow} K^-\pi^+\rho^0\,\pi^-$$

What next to next?

Precision Observable Programme on the TOP

M_{top} related observables

Distributions used for top mass should be well under control



Suitable to look for subtle effects

my guess for $\tilde{t} \rightarrow t\chi^0$

- $\max(m_{b\ell,min})$ (truly?) unaffected
- m_{T2} larger end-point
- E_b affected by top polarization (maybe small)
- $p_{T\ell}$, L_{xy},s(ttj), affected by top boost (maybe small)

To know the answer we need to see signal injections

New physics effect on $m_{b\ell}$ and E_b

with G. Polesello

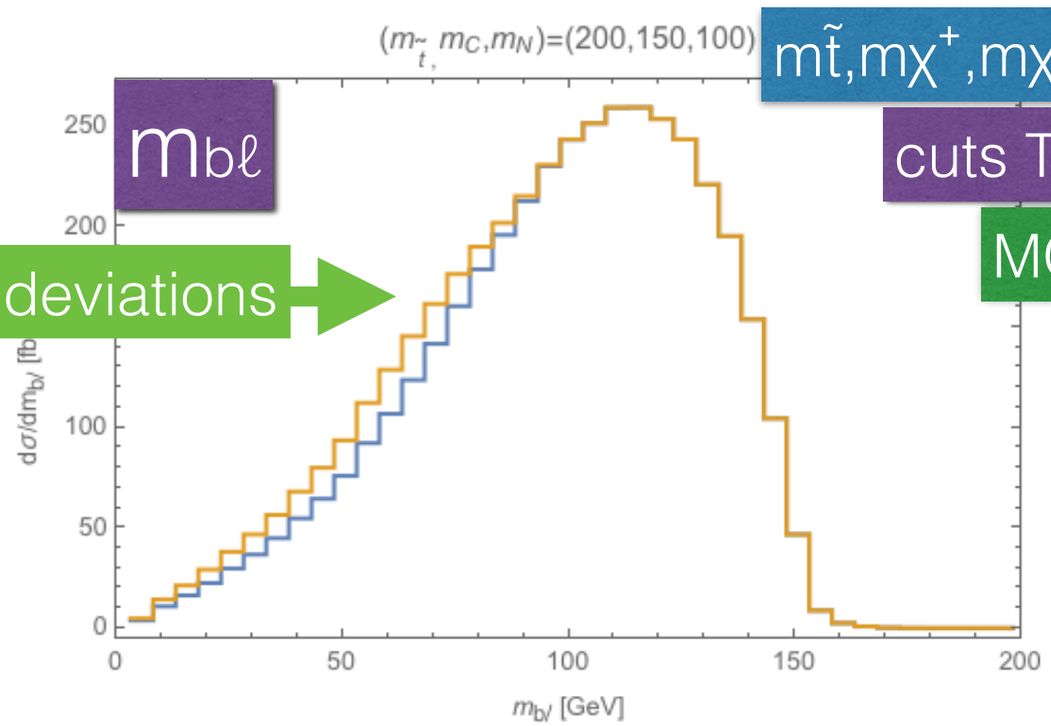
$m\tilde{t}, m\chi^+, m\chi = (200, 150, 100)$

cuts TOP-14-014

MG5@LO

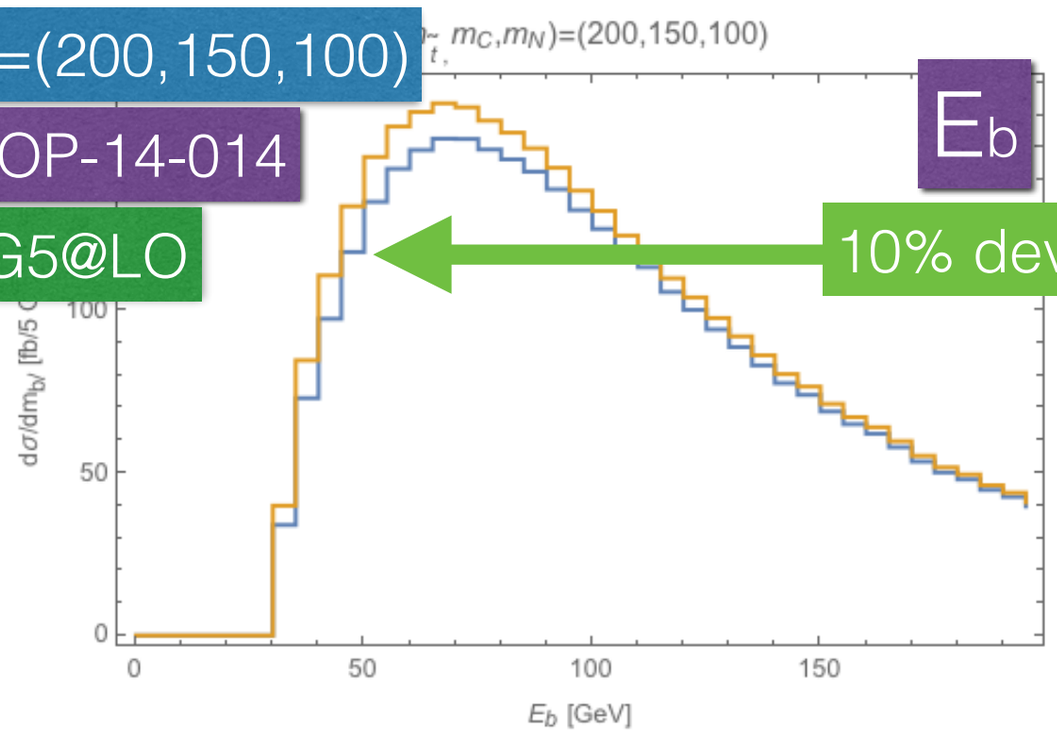
$m_{b\ell}$

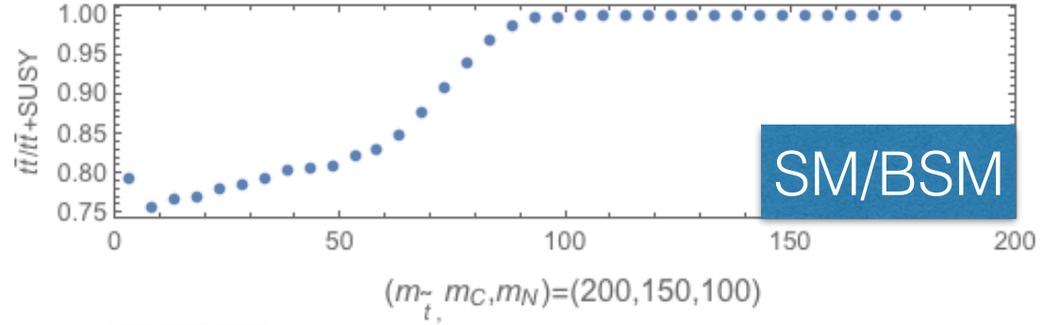
15% deviations

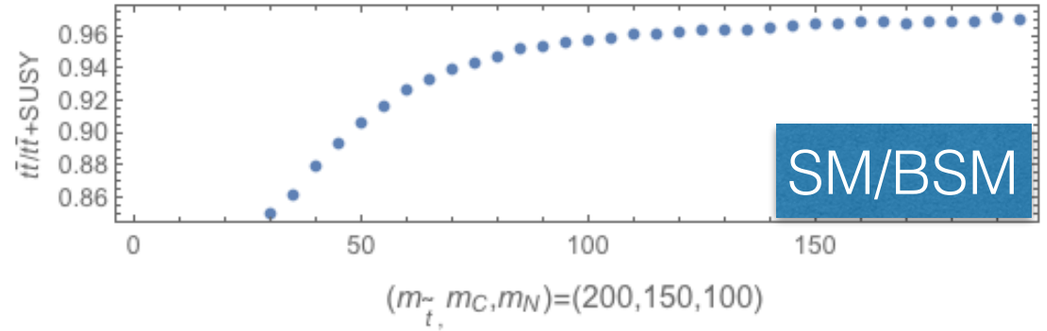


E_b

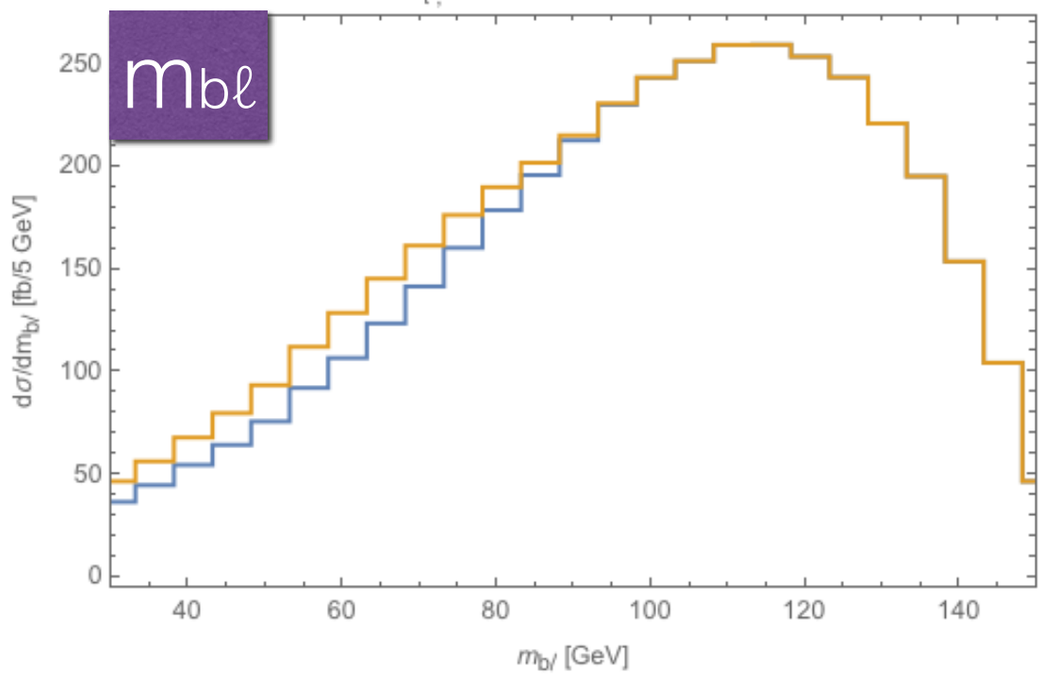
10% deviations



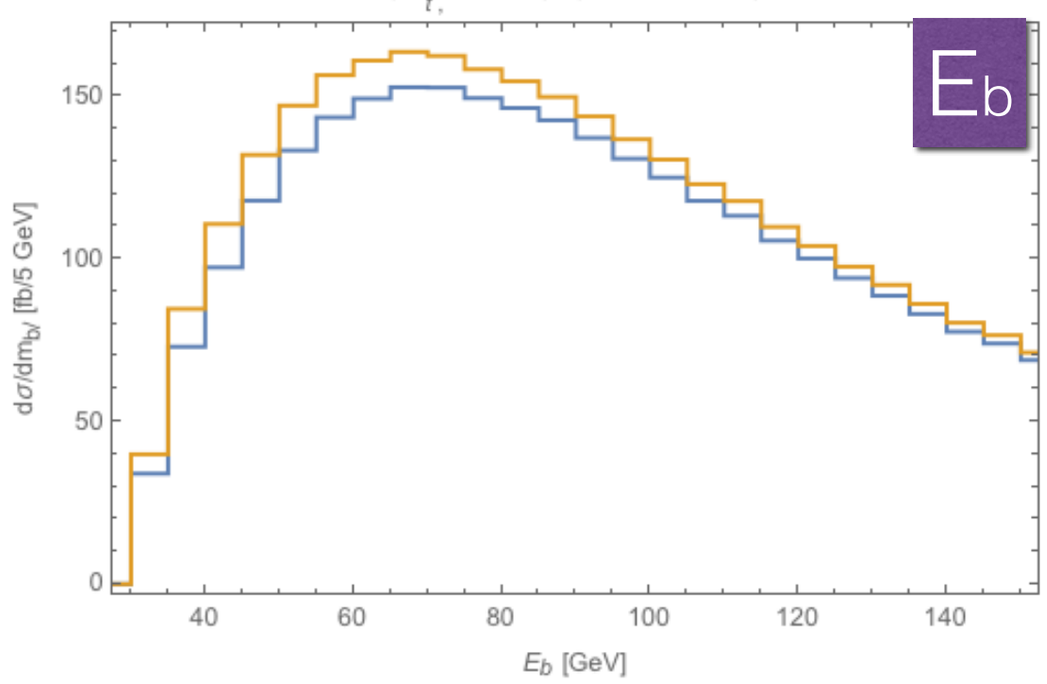




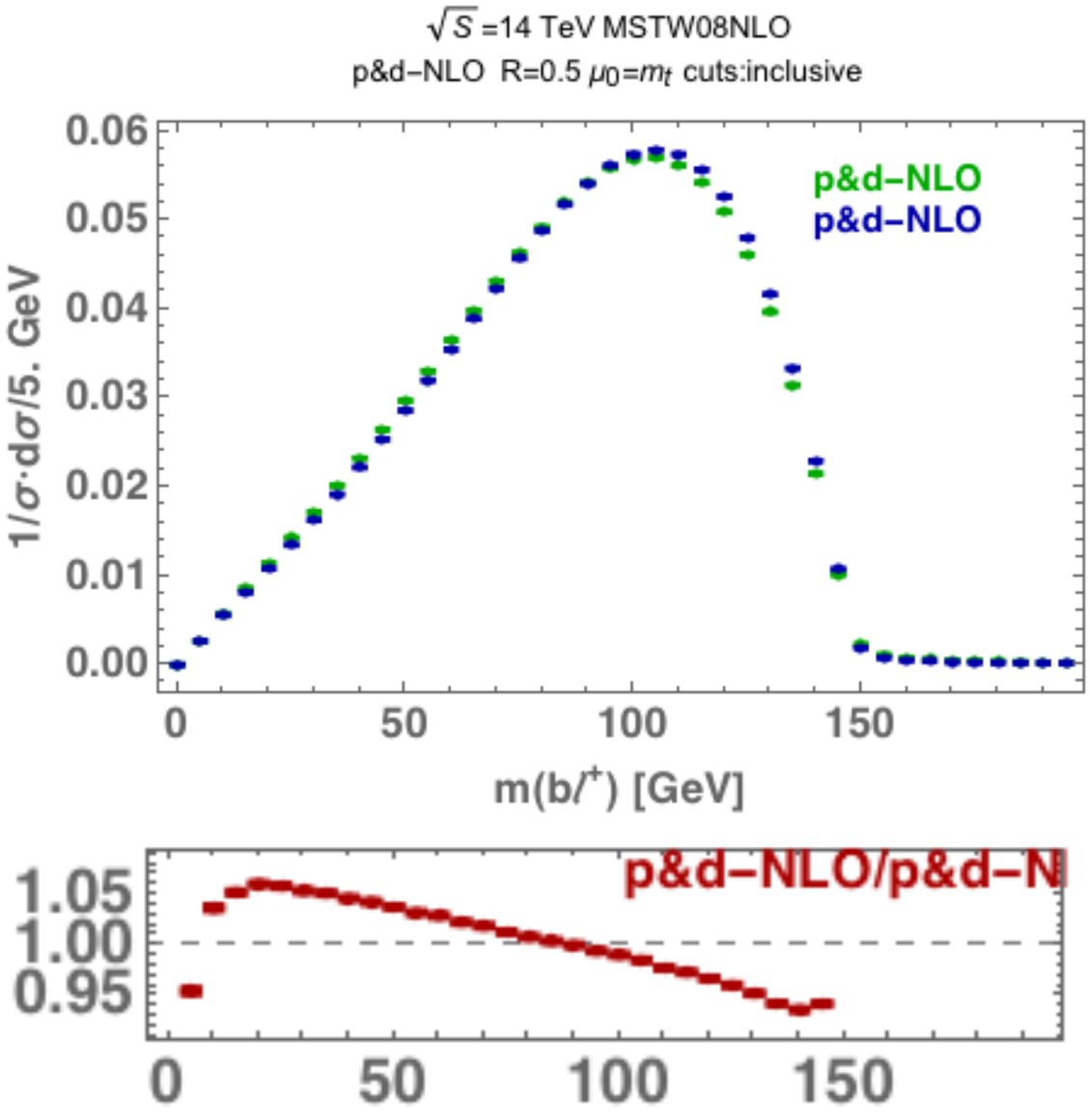
$m_{b\ell}$

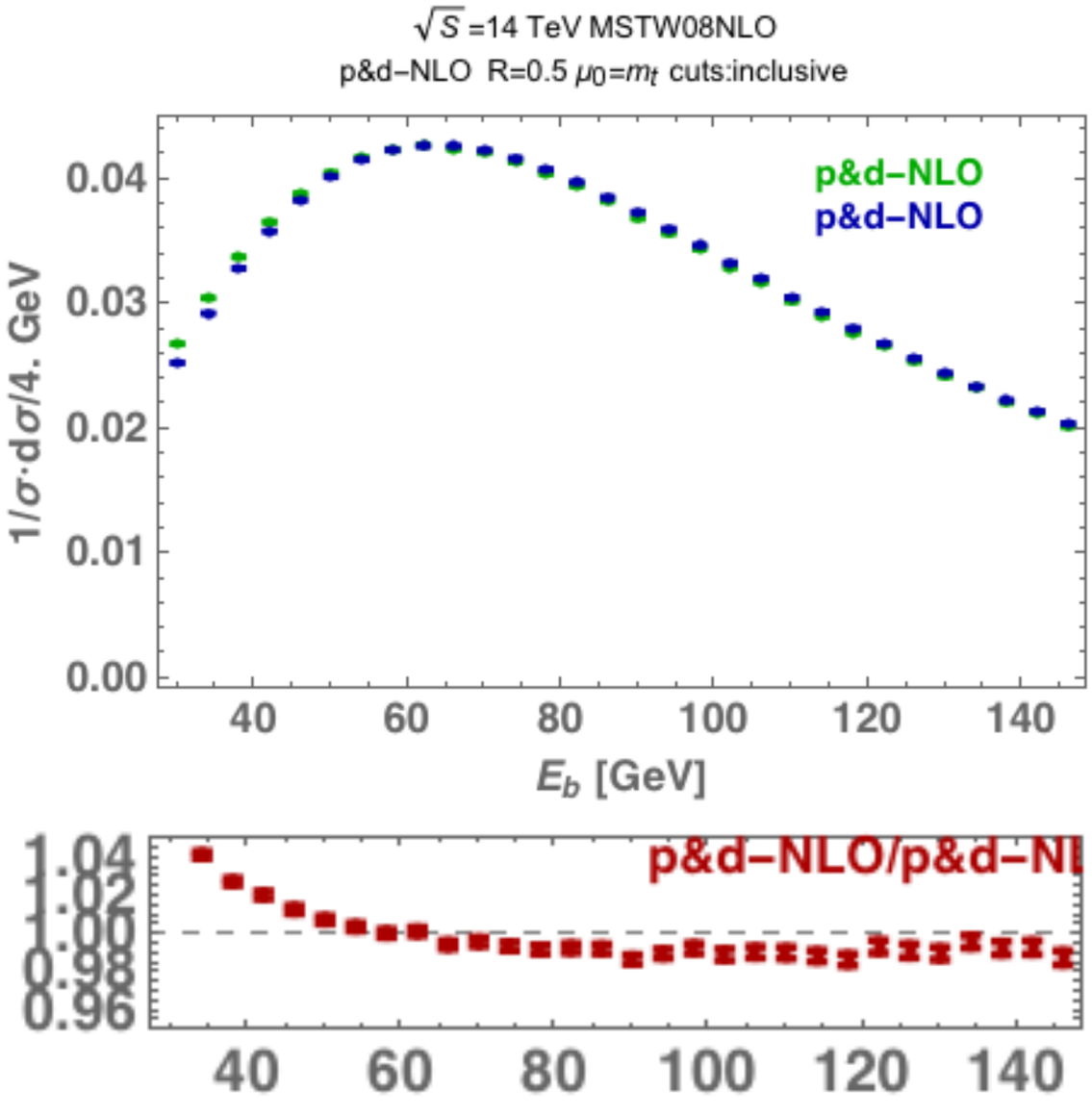


E_b

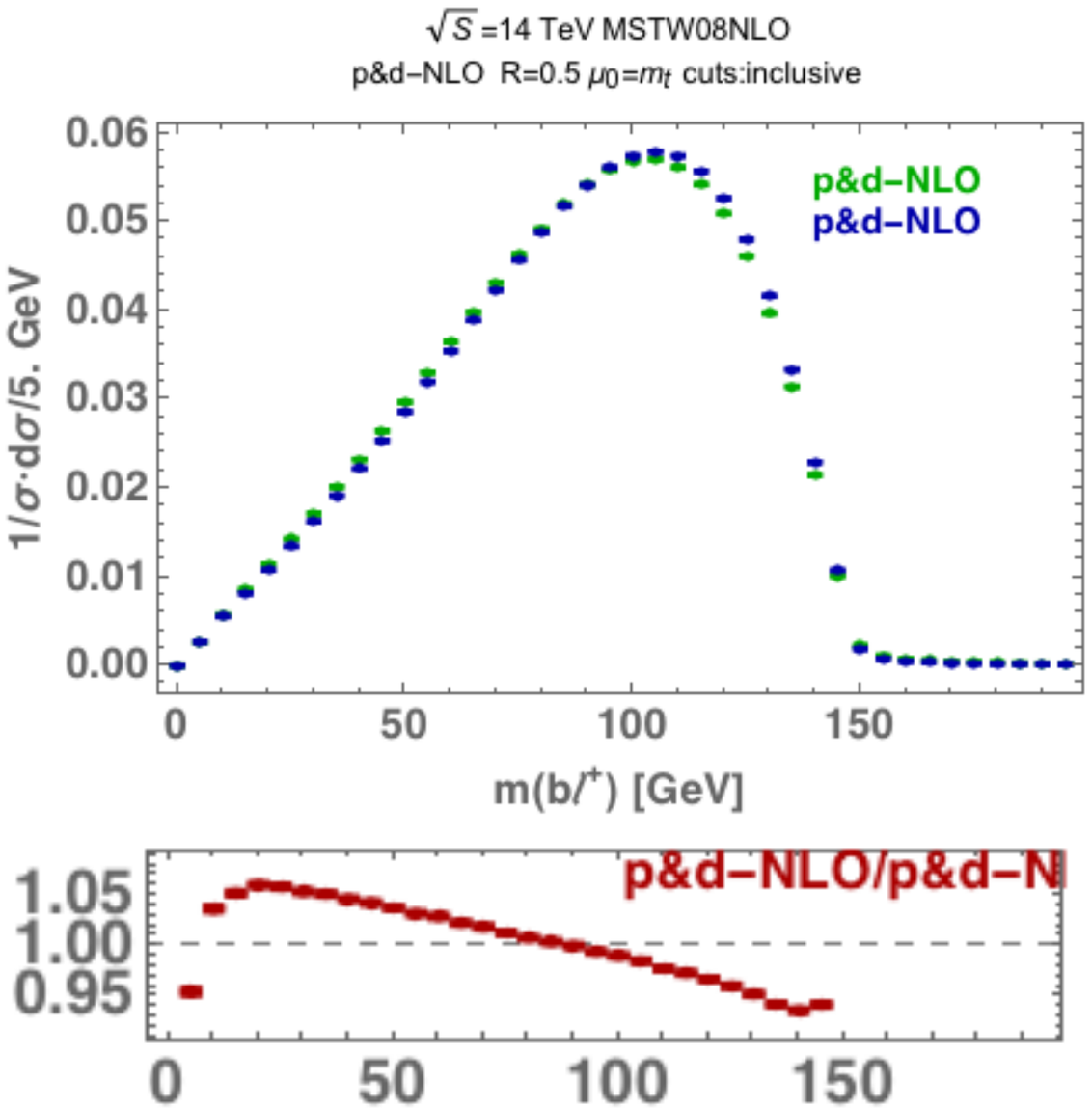


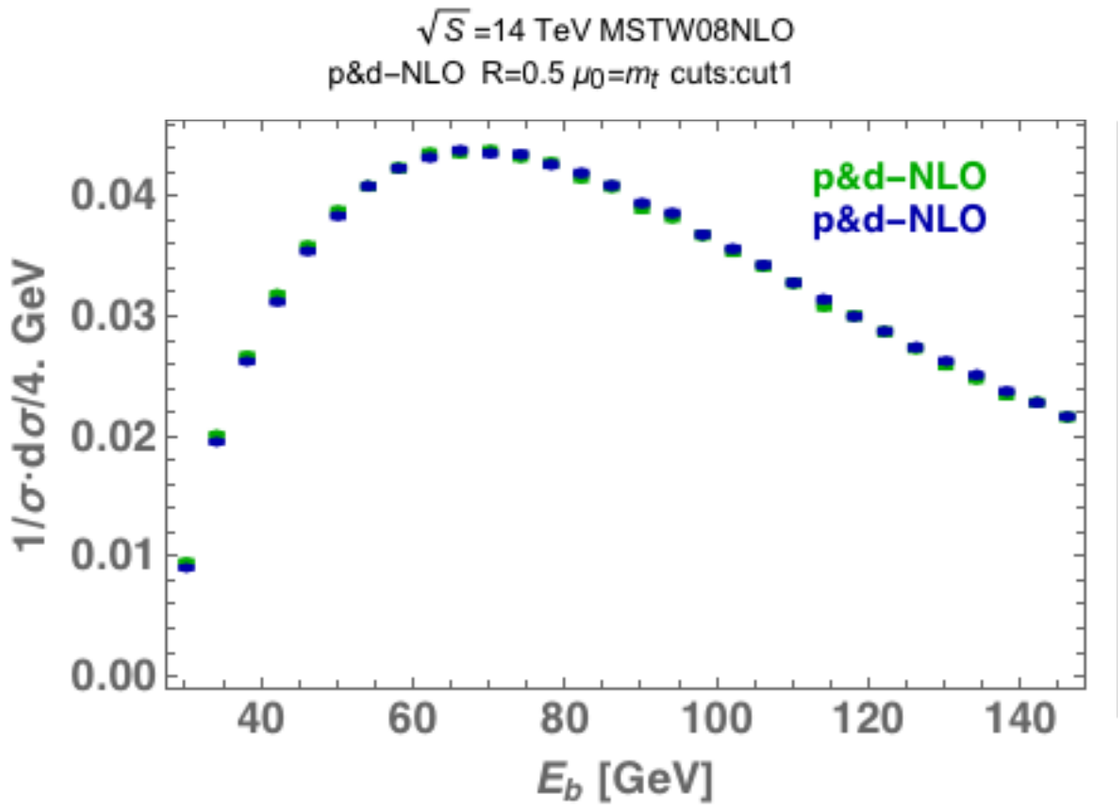
A first look at scale uncertainties

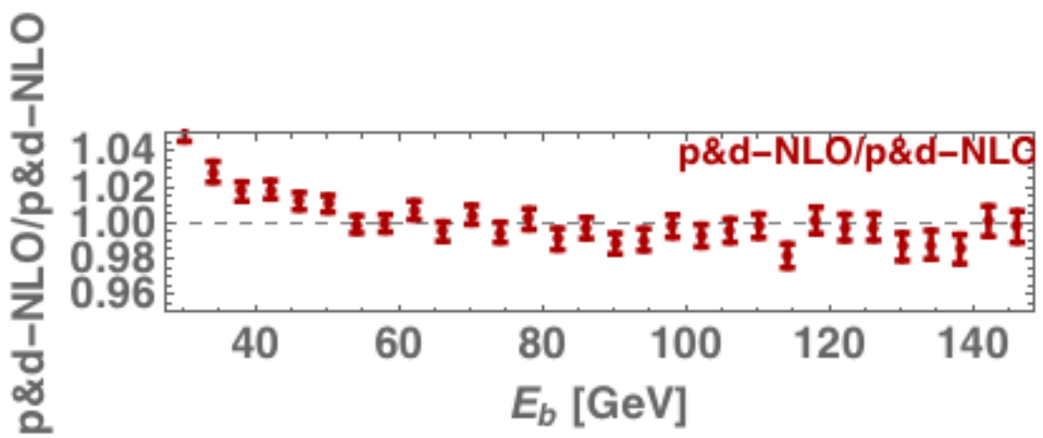




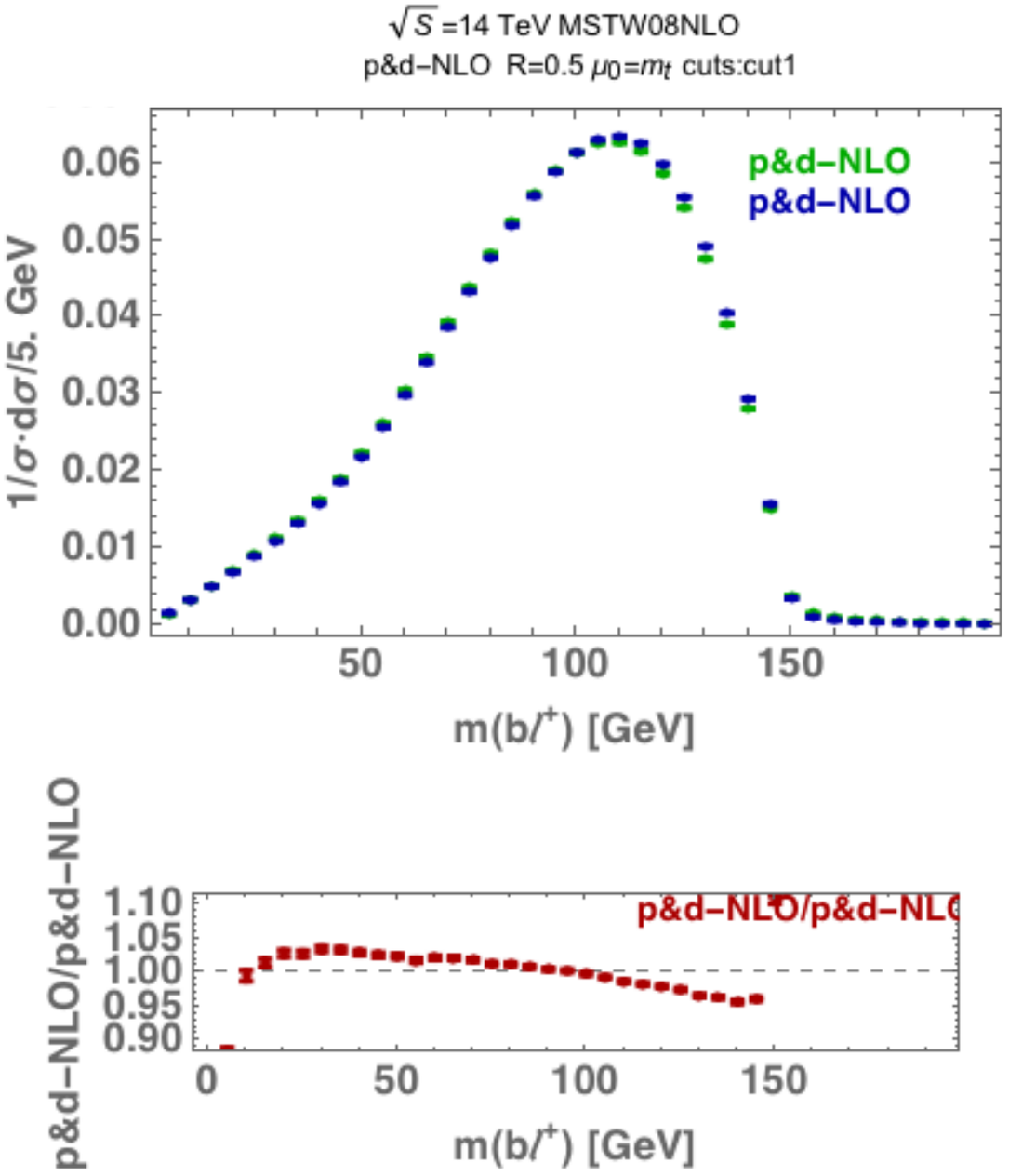
A first look at scale uncertainties

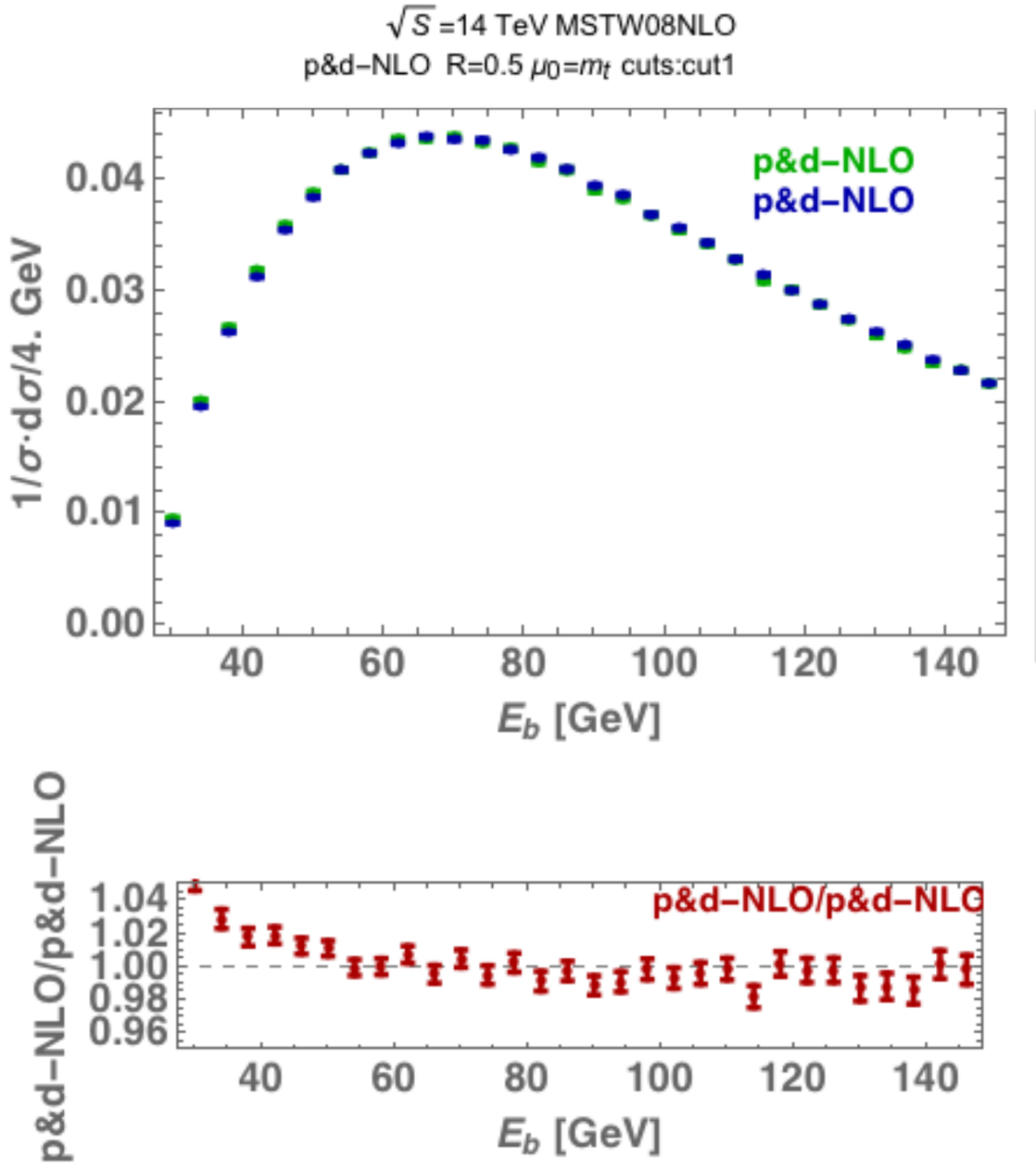






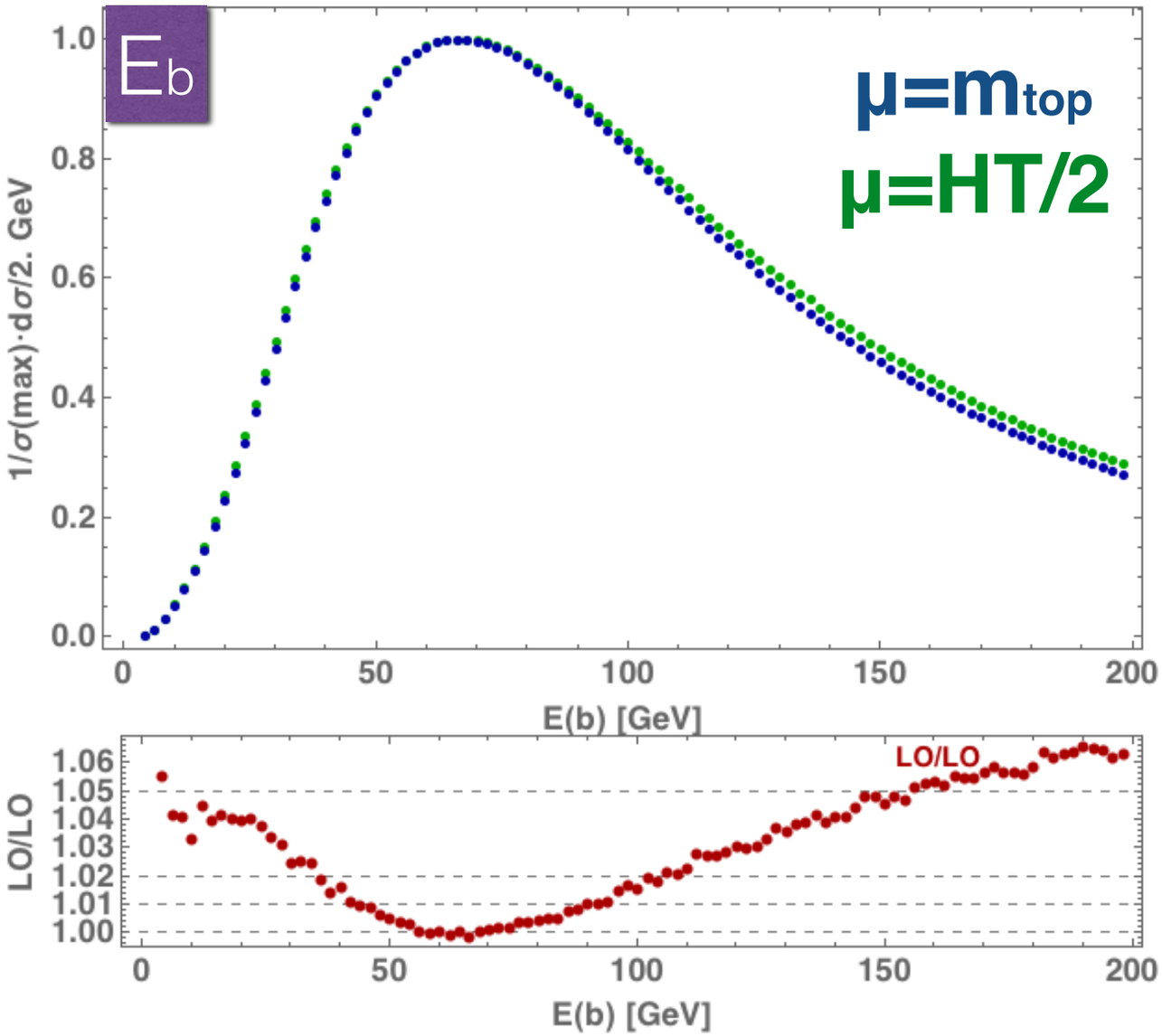
A first look at scale uncertainties





Subtleties of the subtle effects

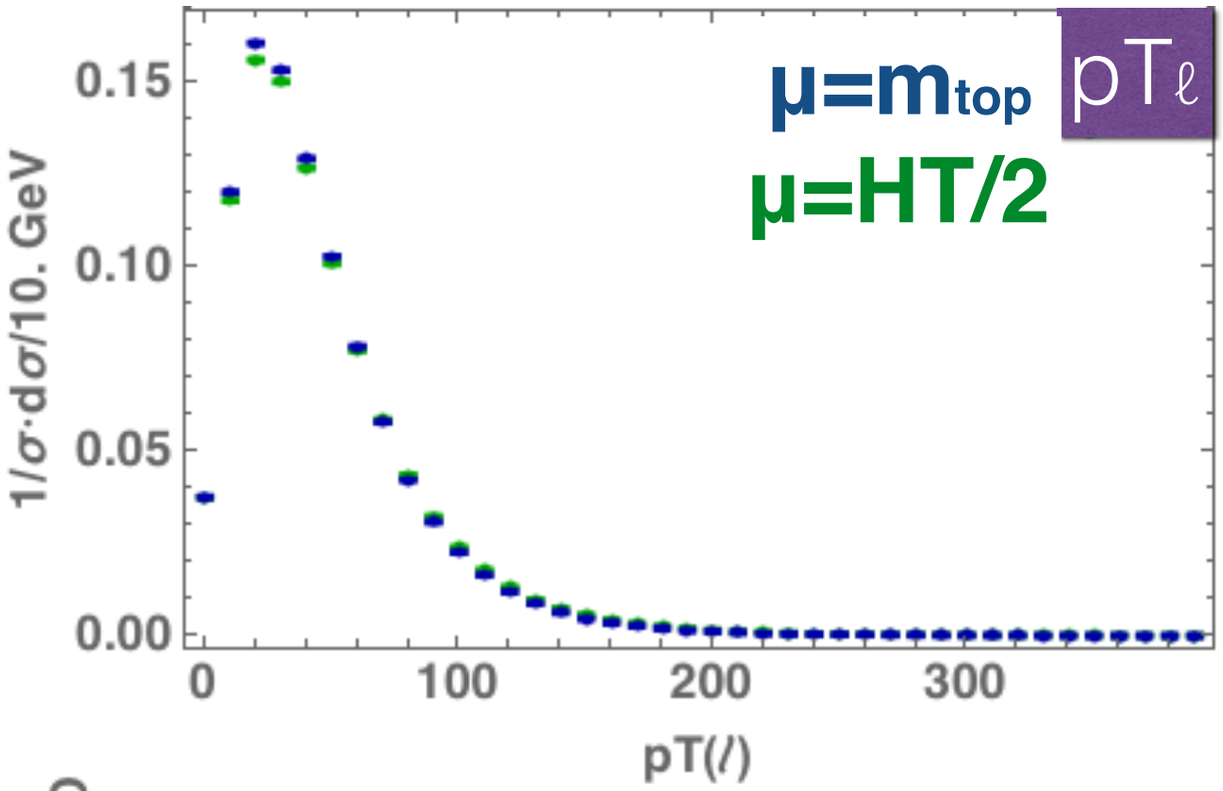
$\Delta m_{top} \lesssim 300$ MeV despite 5% deviations in the tails

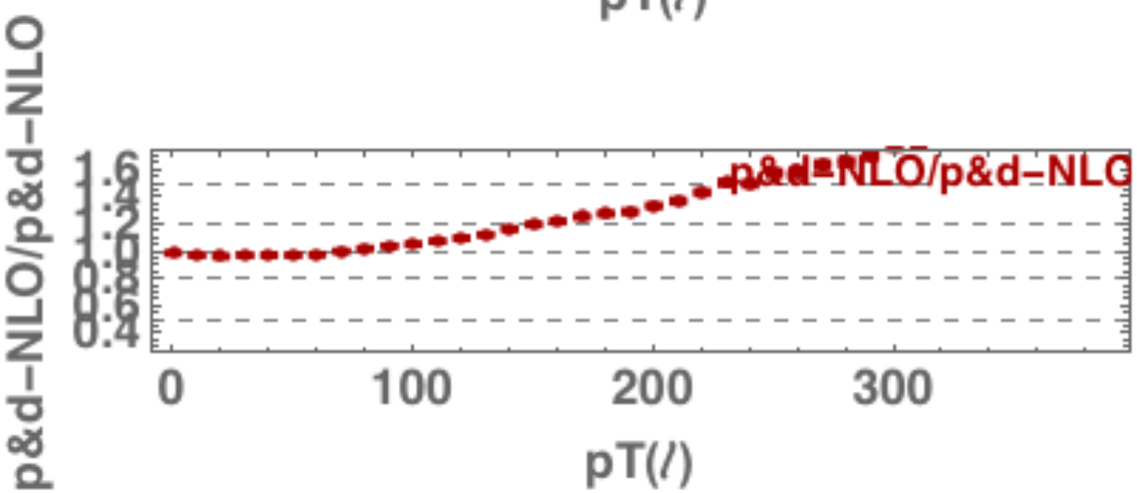


- despite “large” difference in the tails, m_{top} is unaffected
- good for m_{top}
- would be terrible if this was the effect of new physics sough for in m_{top}

Subtleties of the subtle effects

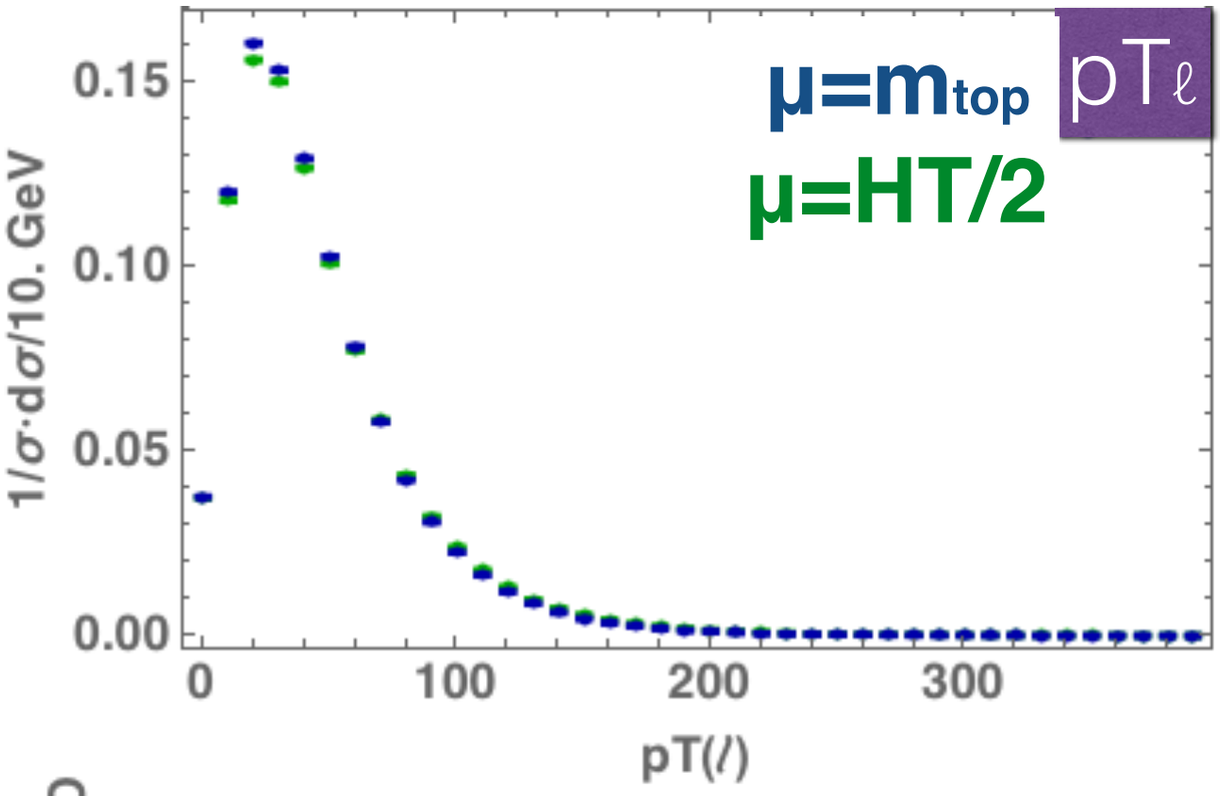
$\Delta m_{top} \lesssim 1$ GeV and large deviations in the tails

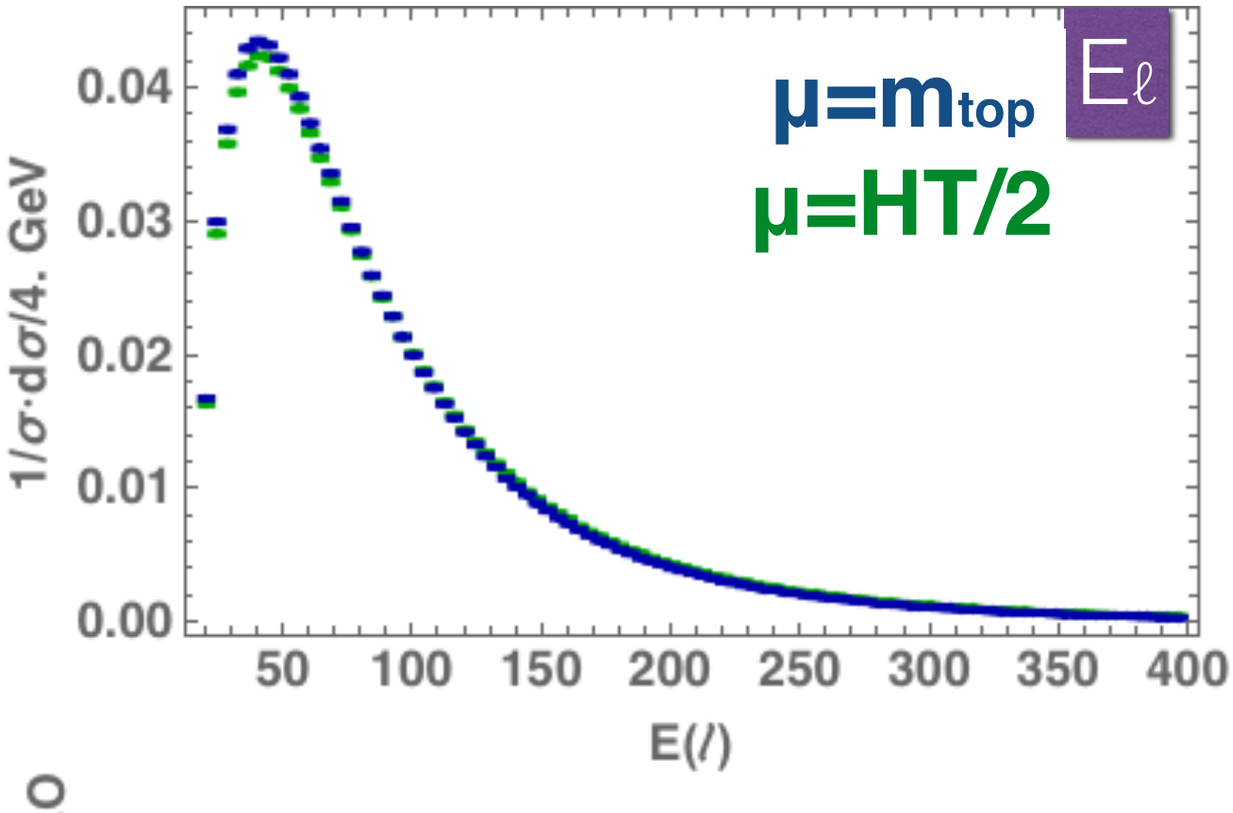


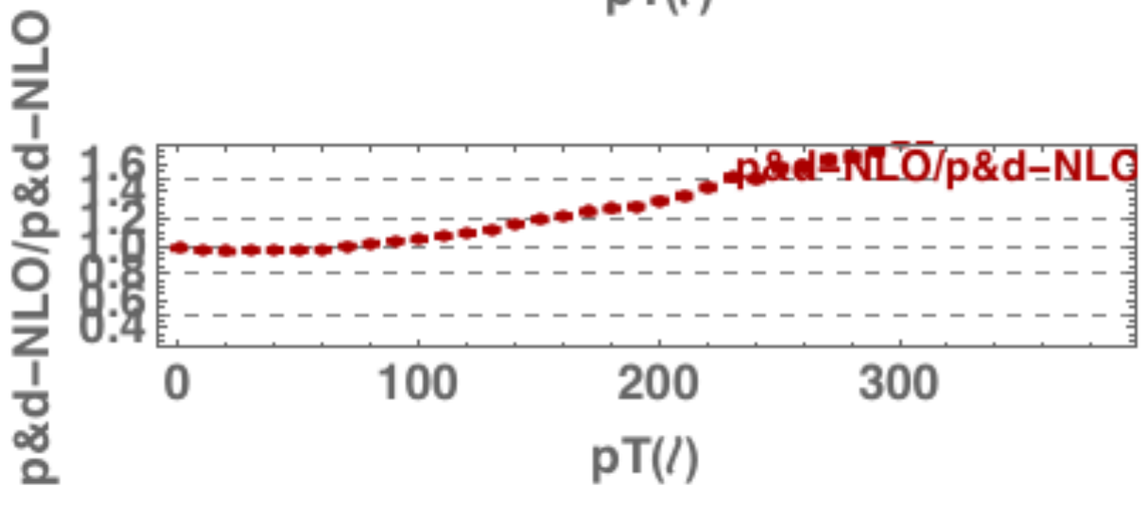


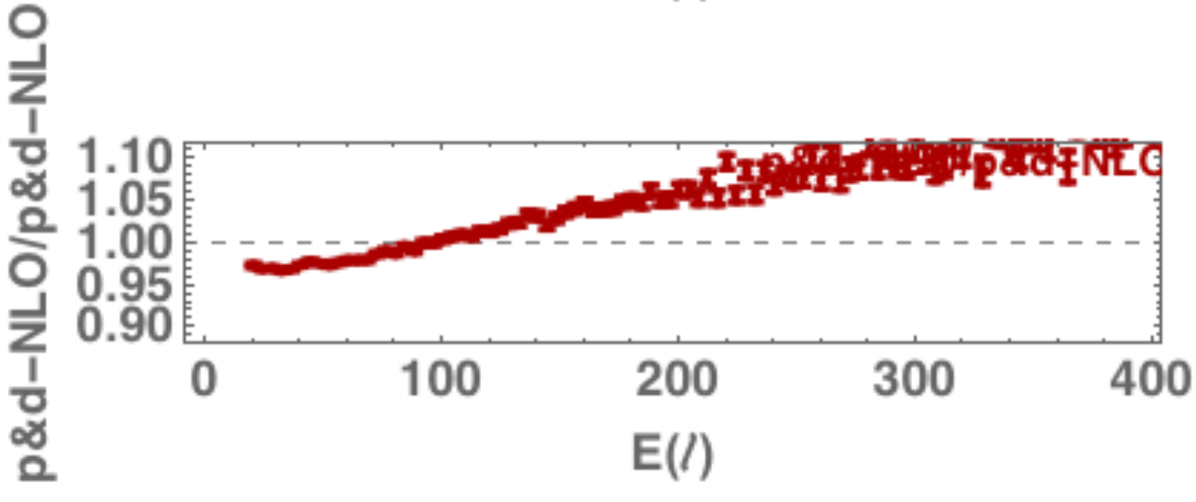
- "large" difference in the tails, m_{top} is affected
- not too bad for m_{top} (1407.2763)
- would be terrible if this was the effect of new physics sough for in these tails

Subtleties of the subtle effects





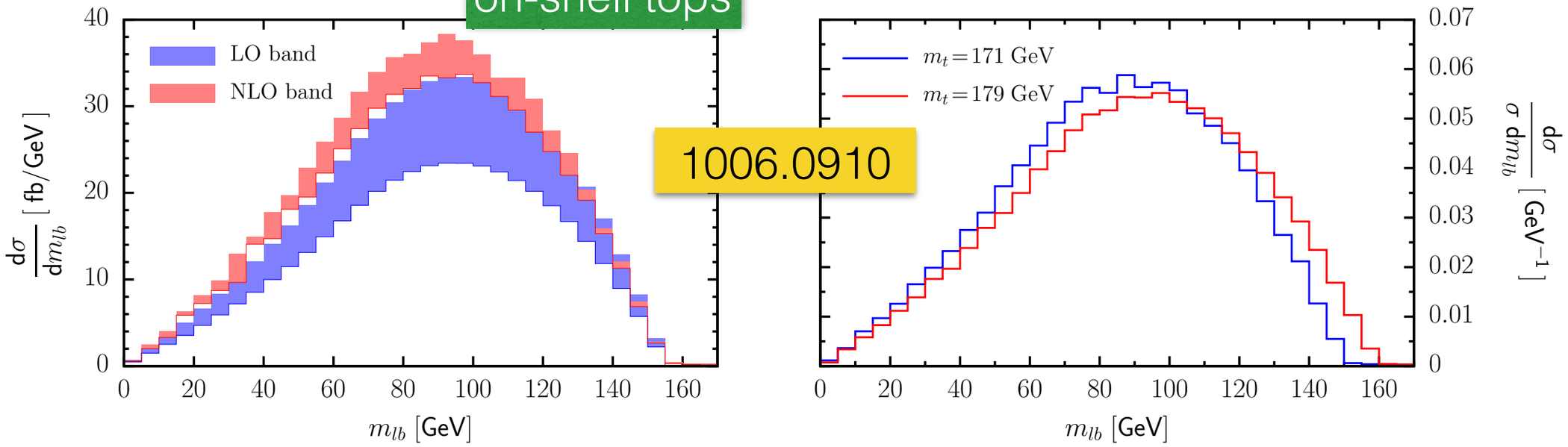




Thank you

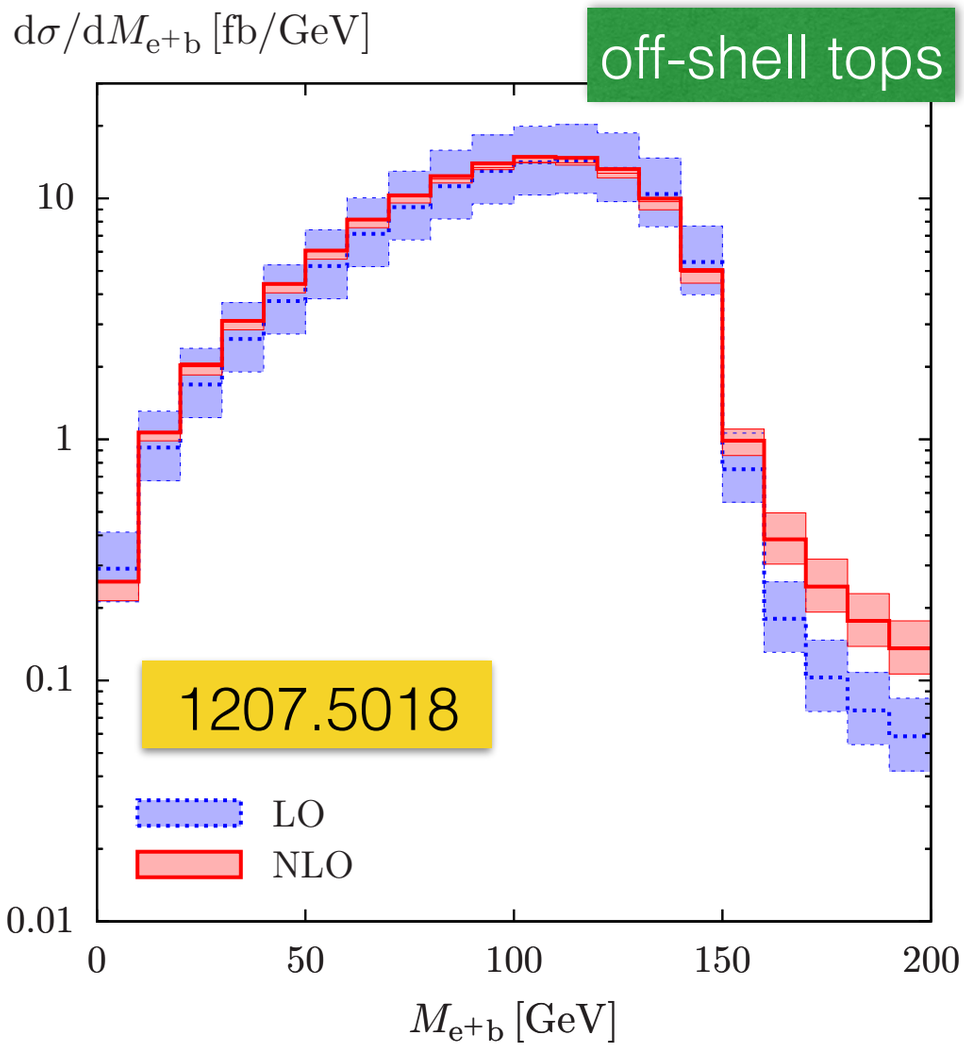
$m_{b\ell}$ at NLO

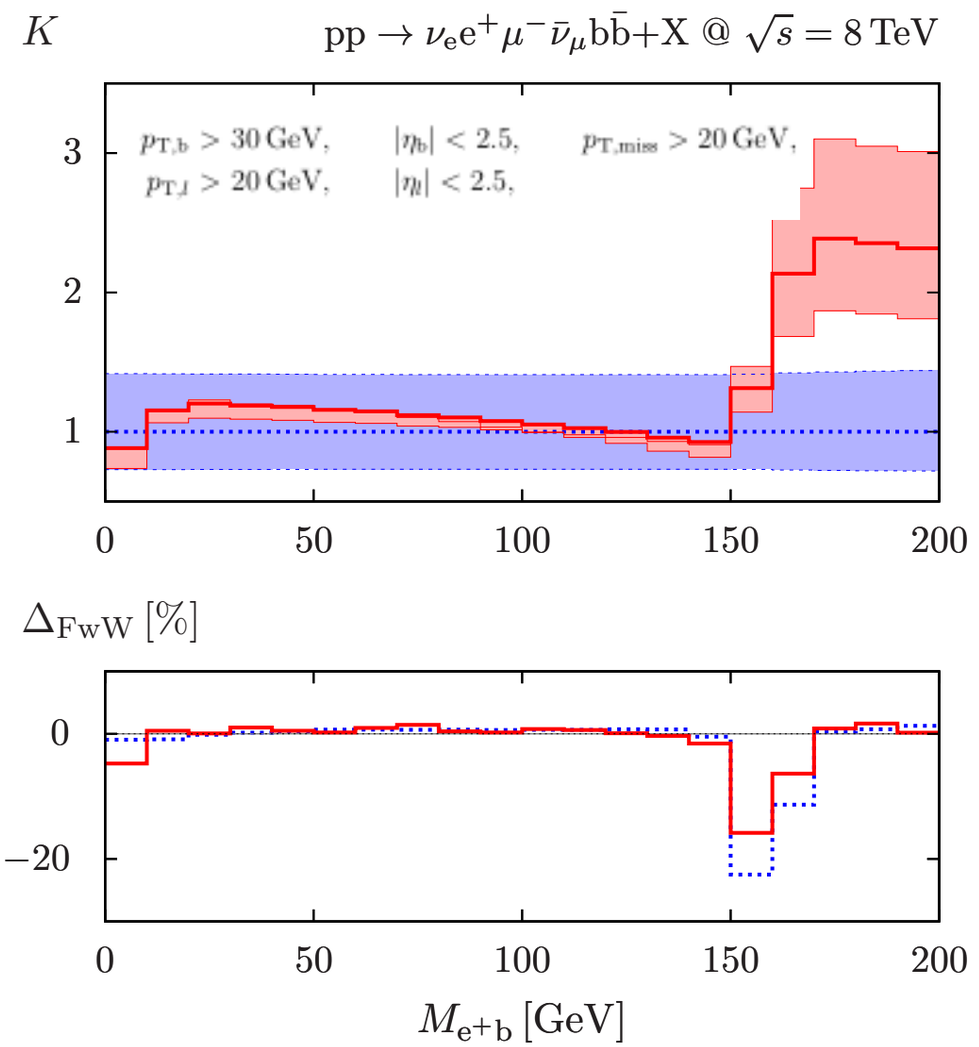
on-shell tops



1006.0910

off-shell tops



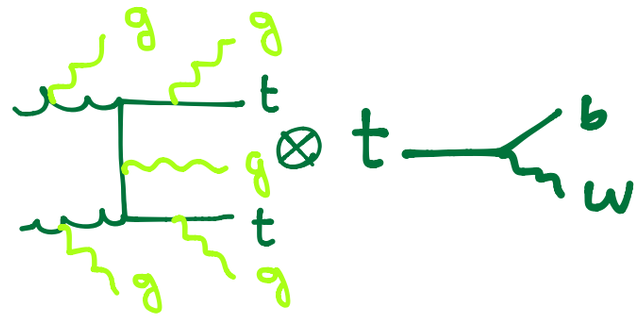


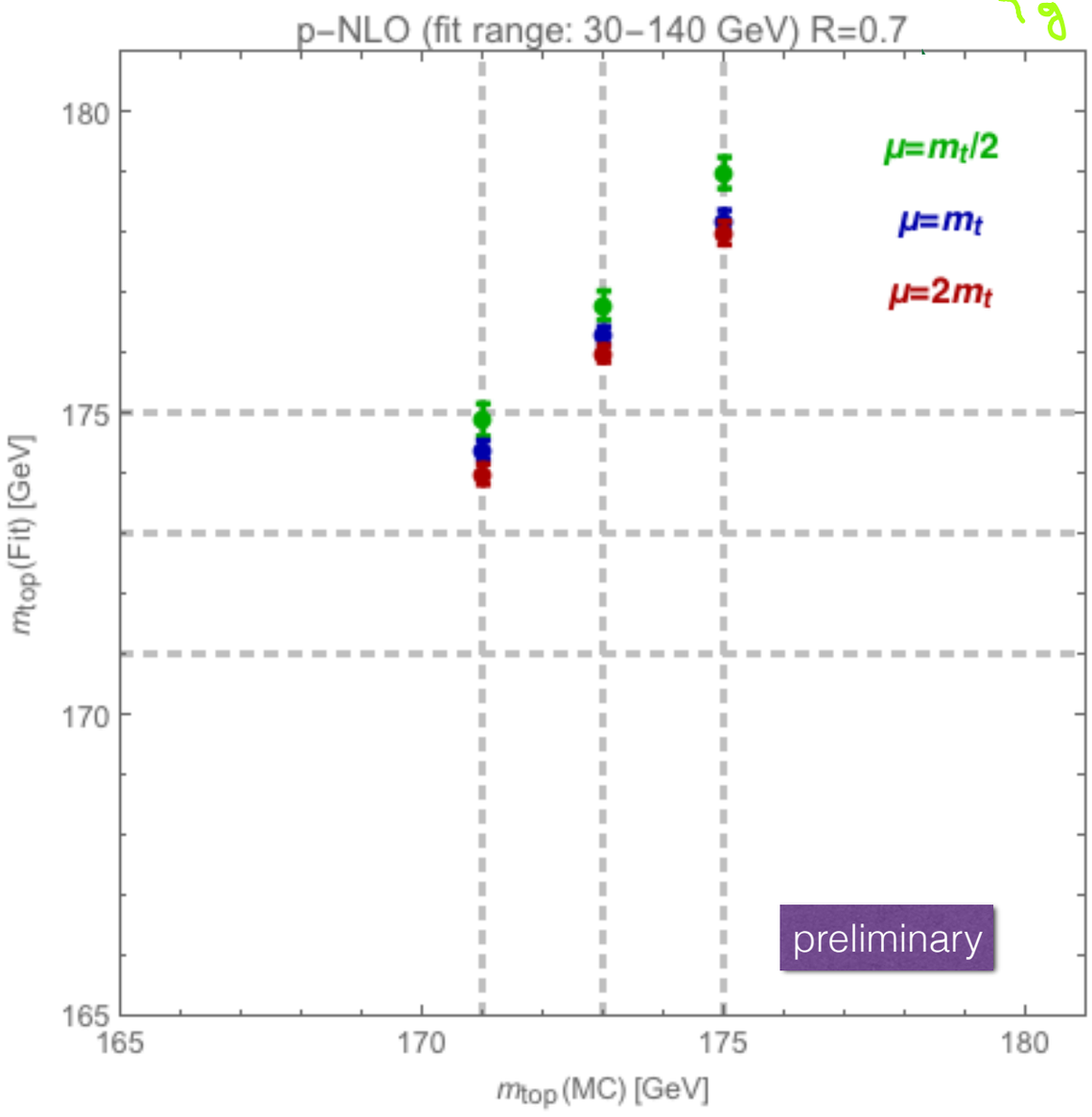
	pdNLO	pNLO	LO
$2\mu_0$	$-3.$	0.4	-0.2
μ_0	-4.1	0.7	$0.$
$0.5\mu_0$	-5.3	0.8	-0.2

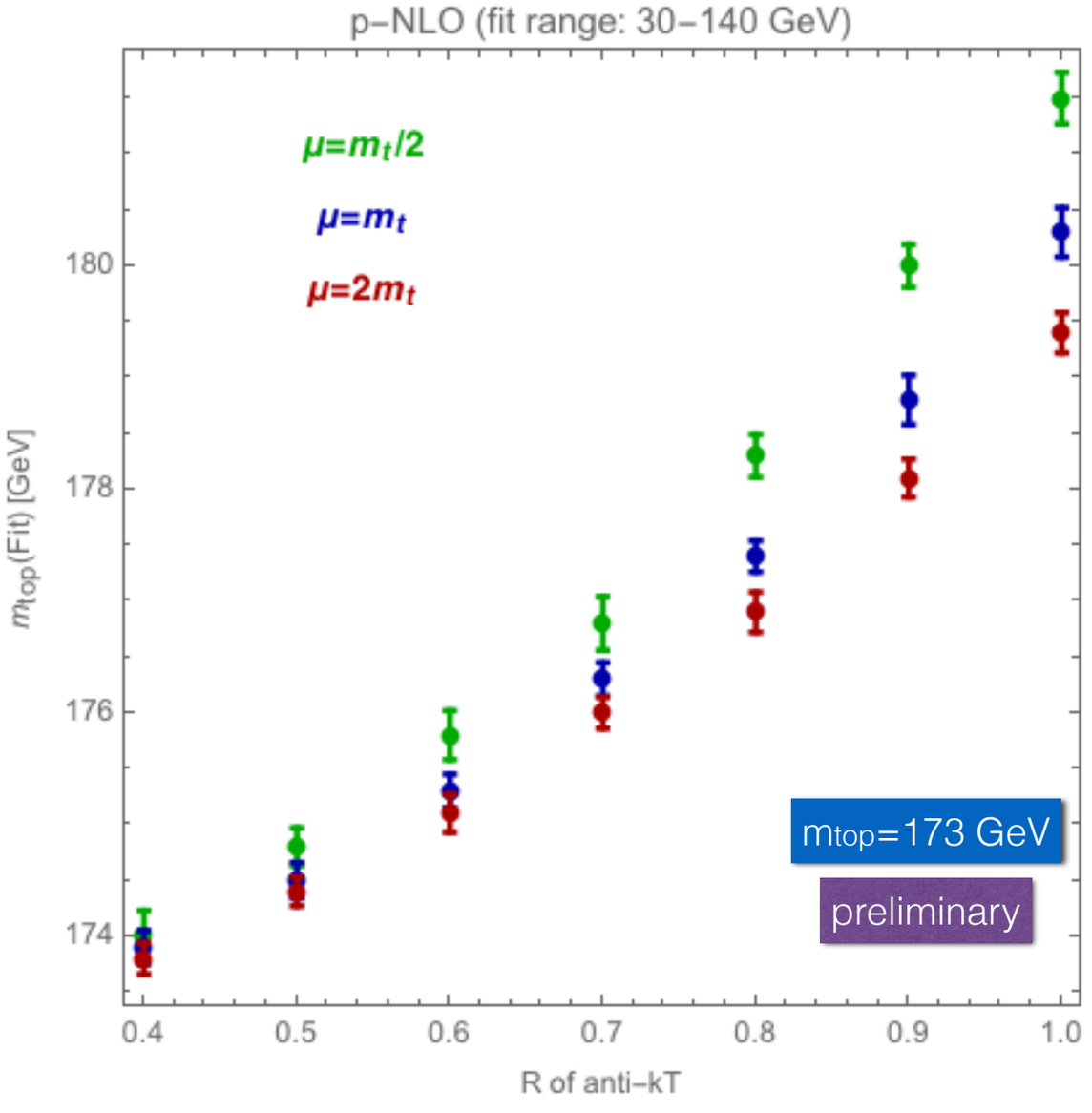
	pdNLO	pNLO	LO
$2\mu_0$	$5.$	7.4	$7.$
μ_0	4.7	7.5	7.2
$0.5\mu_0$	3.9	7.6	7.3

NLO: production

(MCFM)



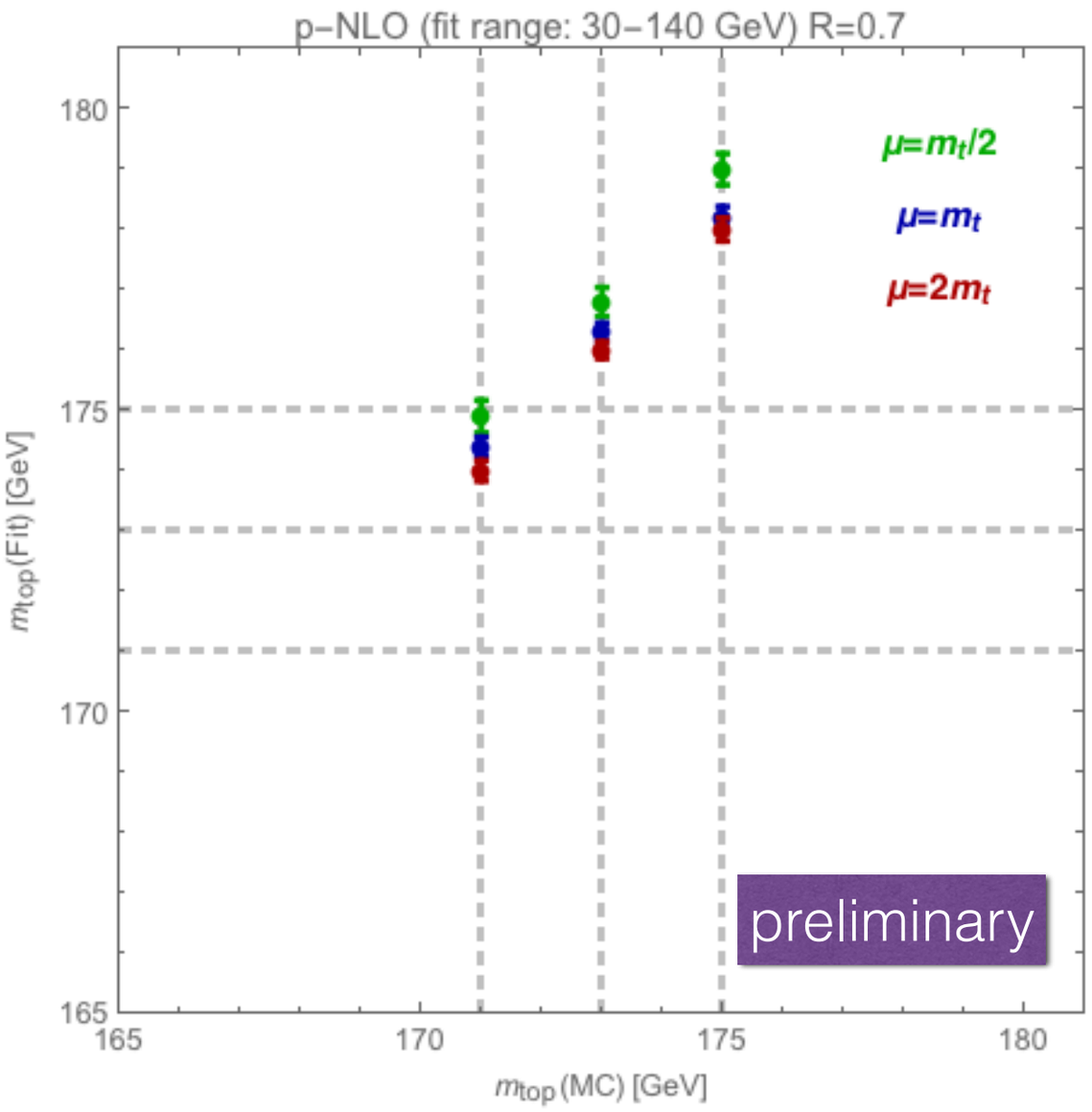


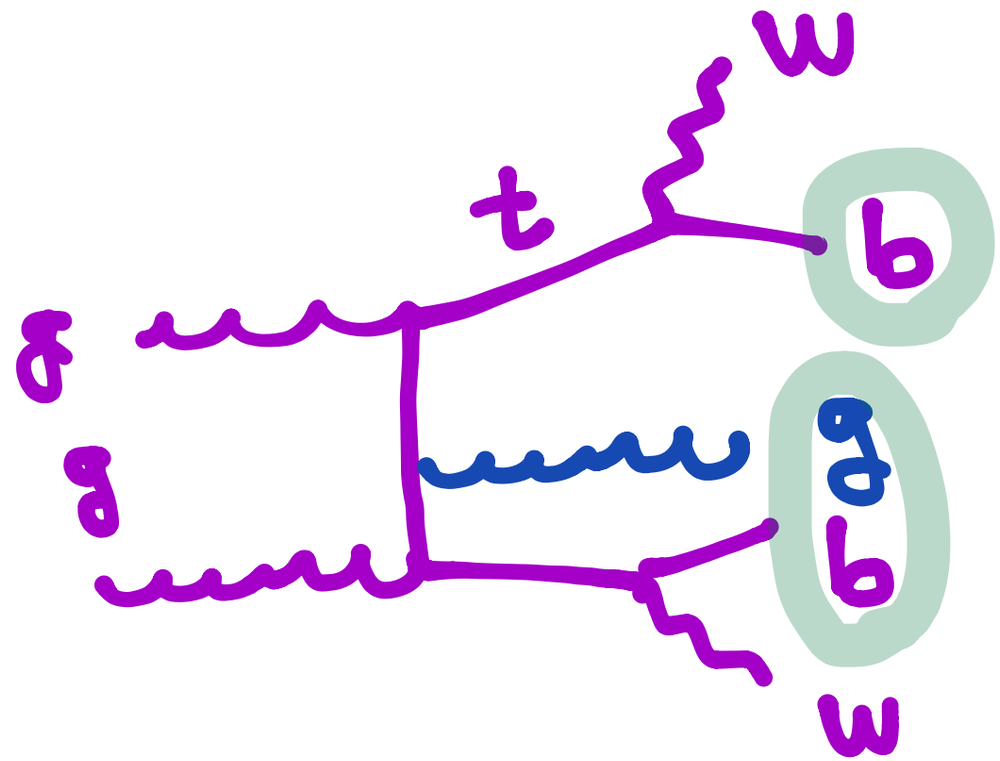


very little sensitive to the scale choice (less than 400 MeV on m_{top})

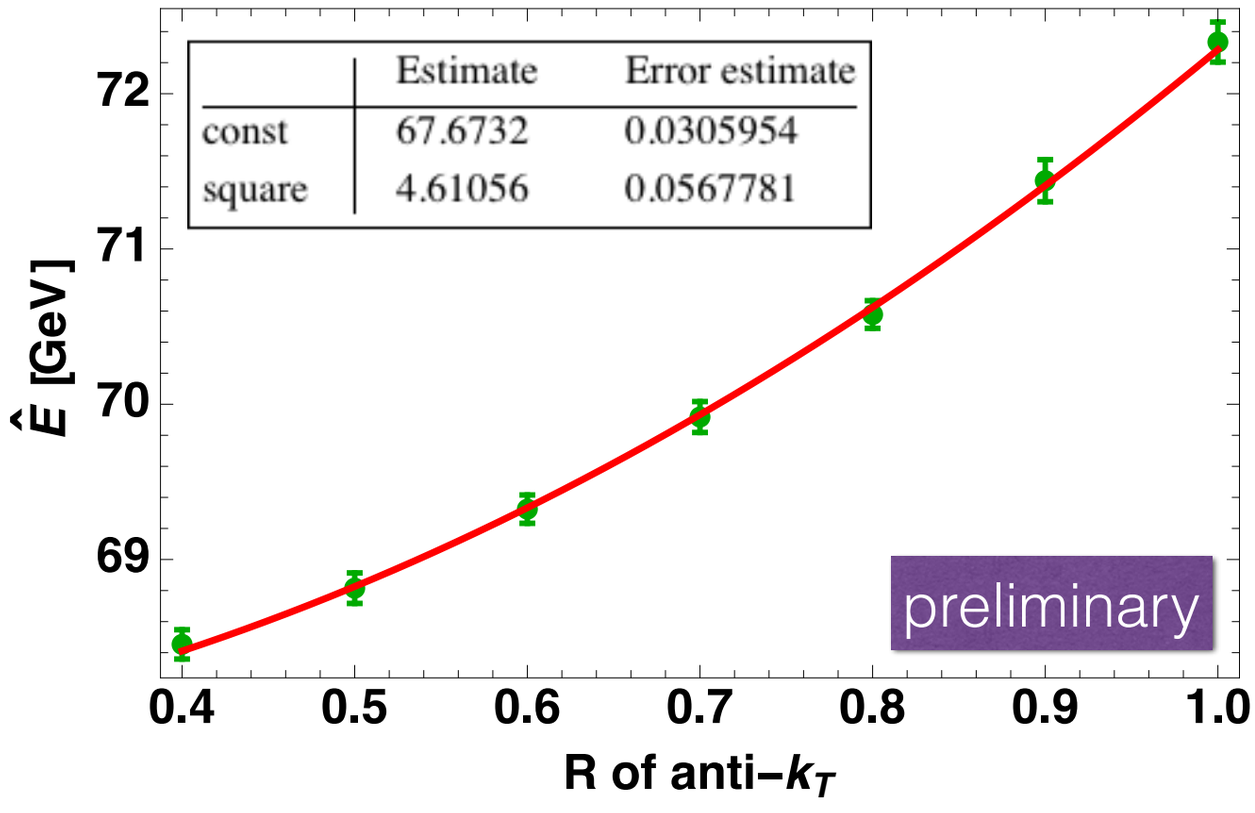
NLO: production

(MCFM)



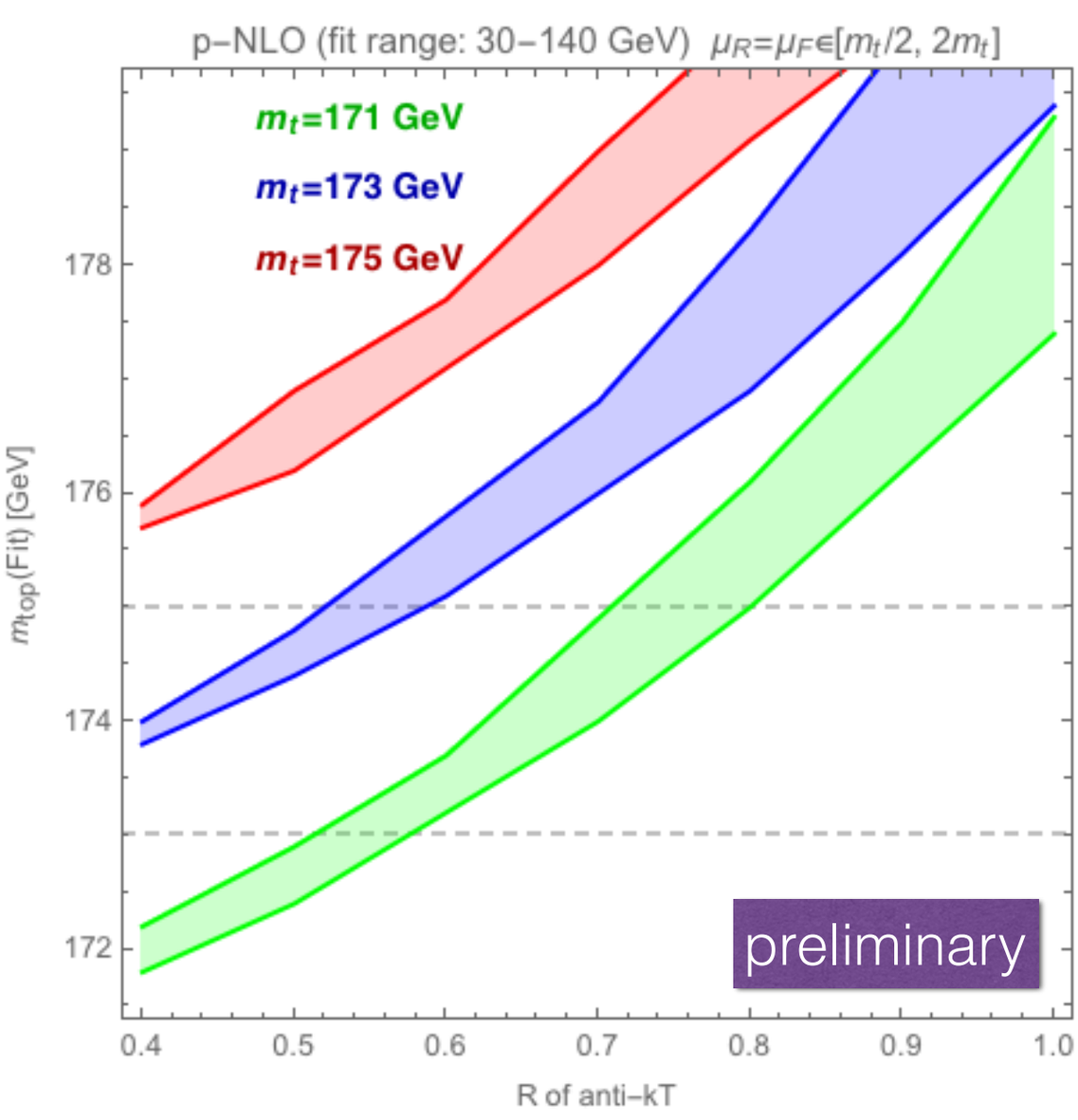


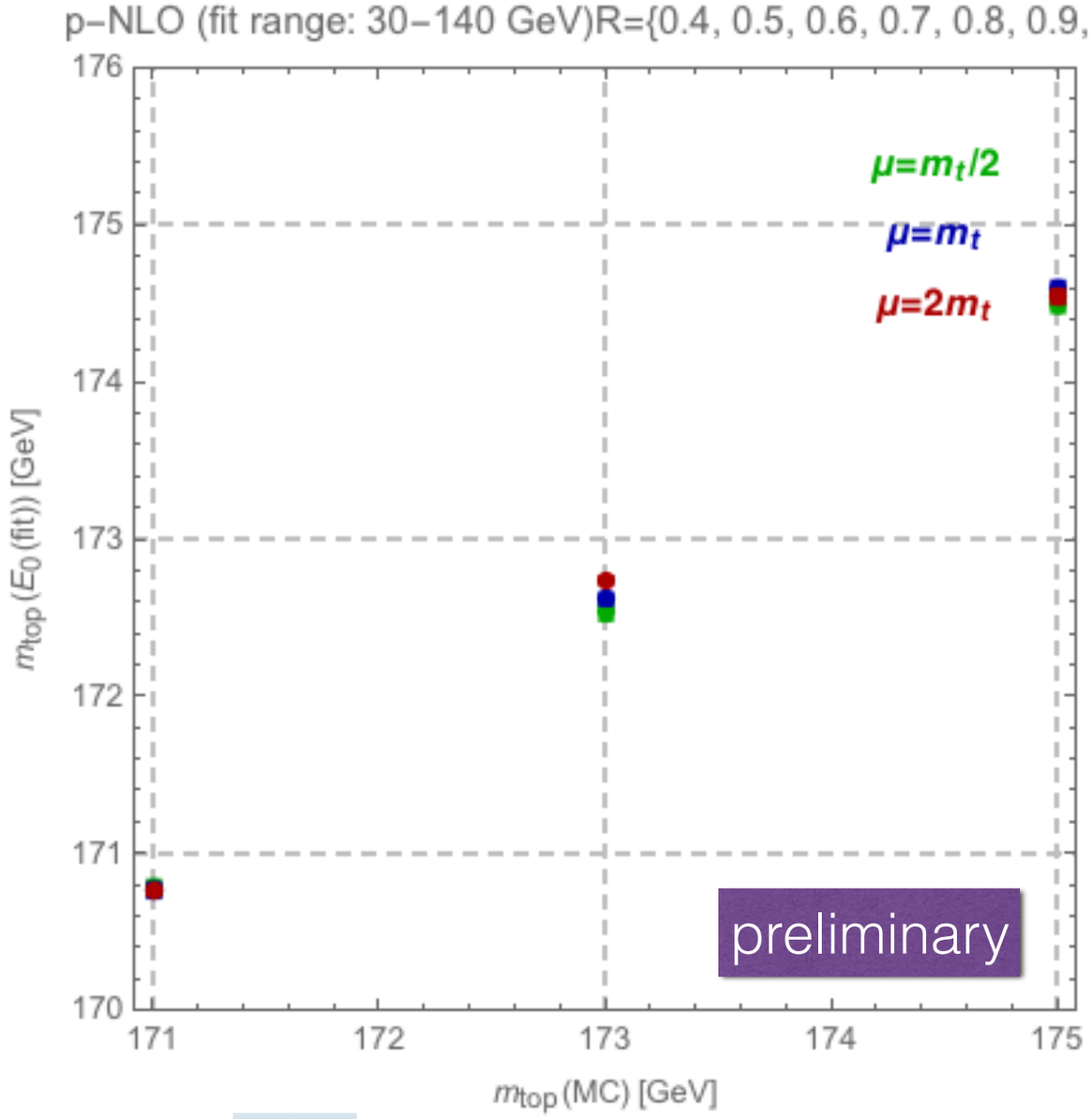
shift ~ R^p (p~2 jet area)
shift ~ 1/μ (real radiation)



NLO: production

(MCFM)



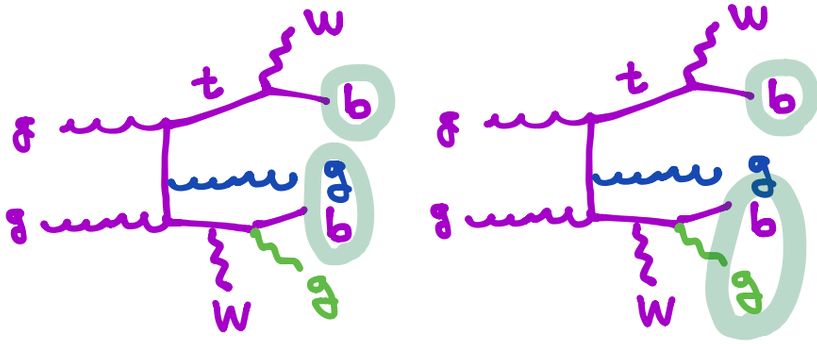


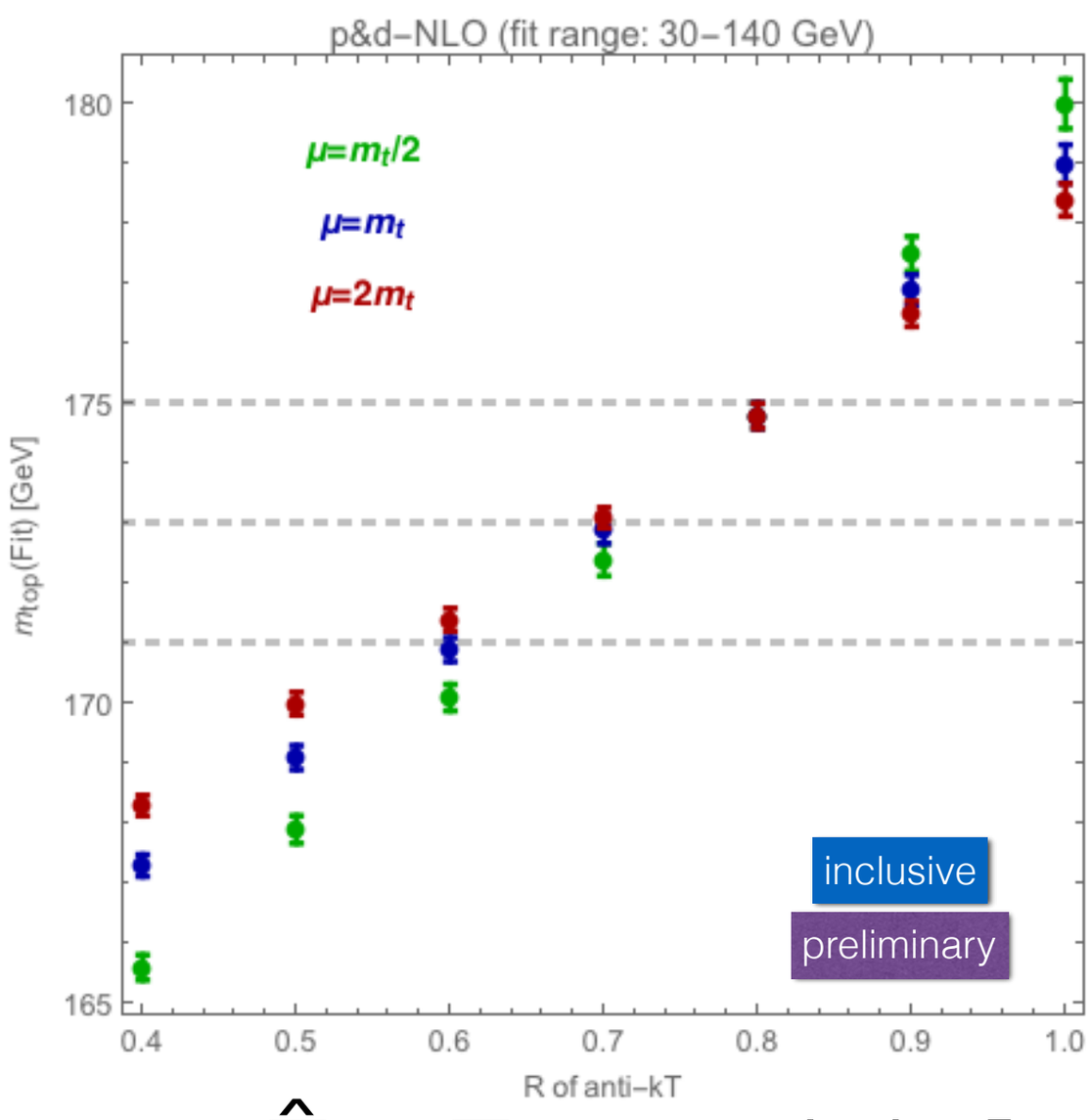
shift ~ R^p (p~2 jet area)
shift ~ 1/μ (real radiation)

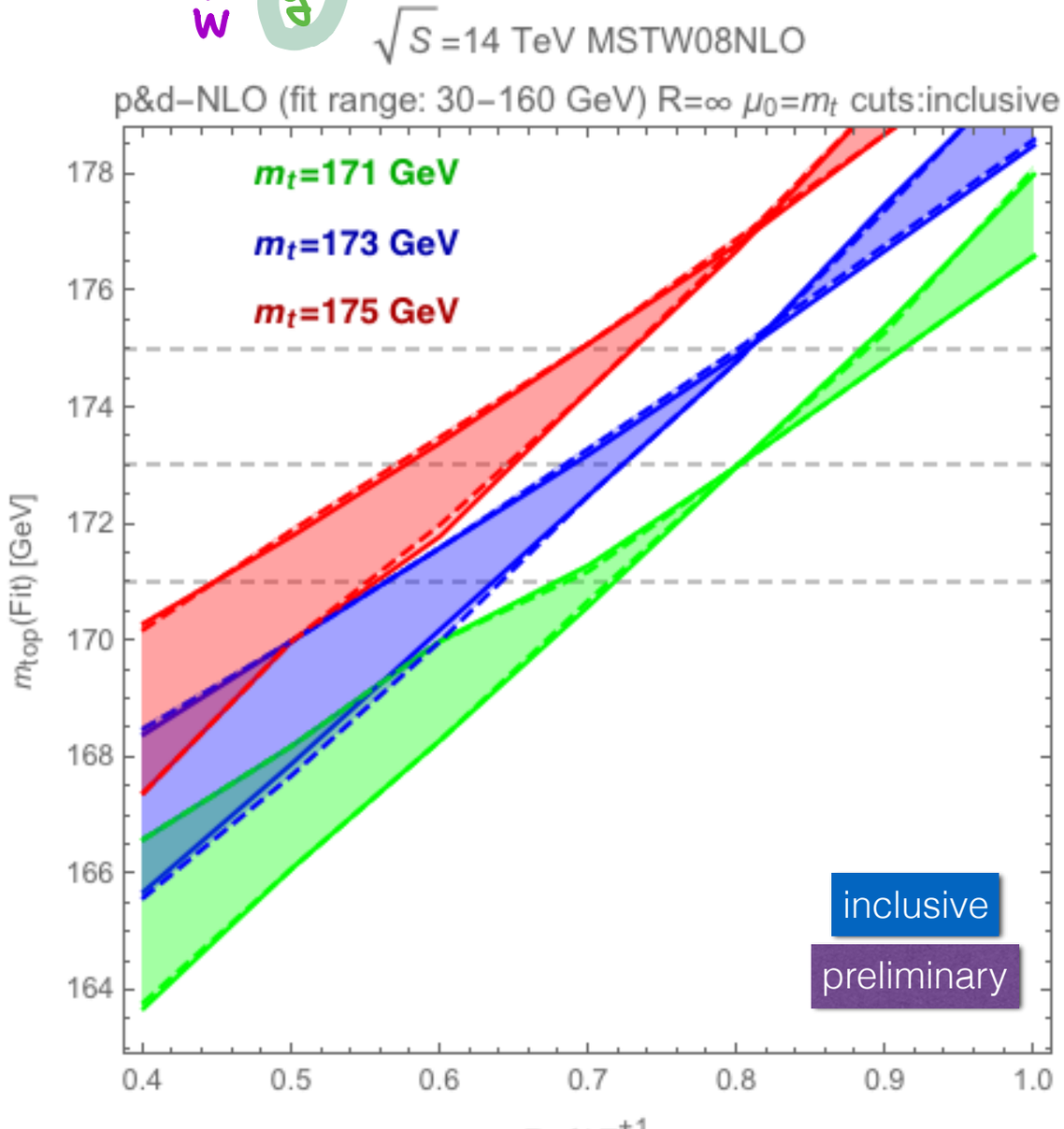
$$\hat{E}=E_0+\alpha(\mu)\cdot p\cdot R^2+\ \ldots$$

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

NLO: production & decay



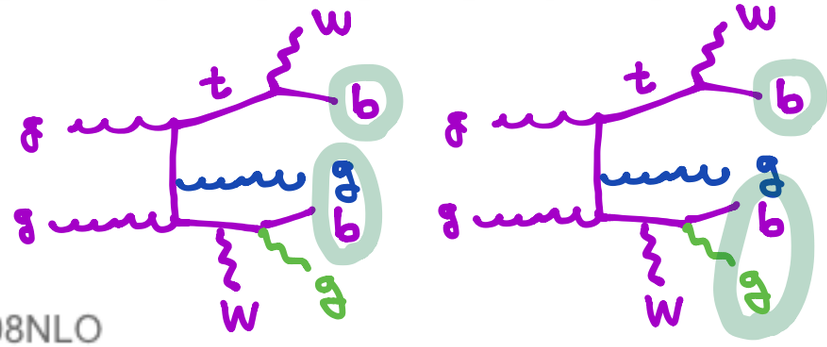


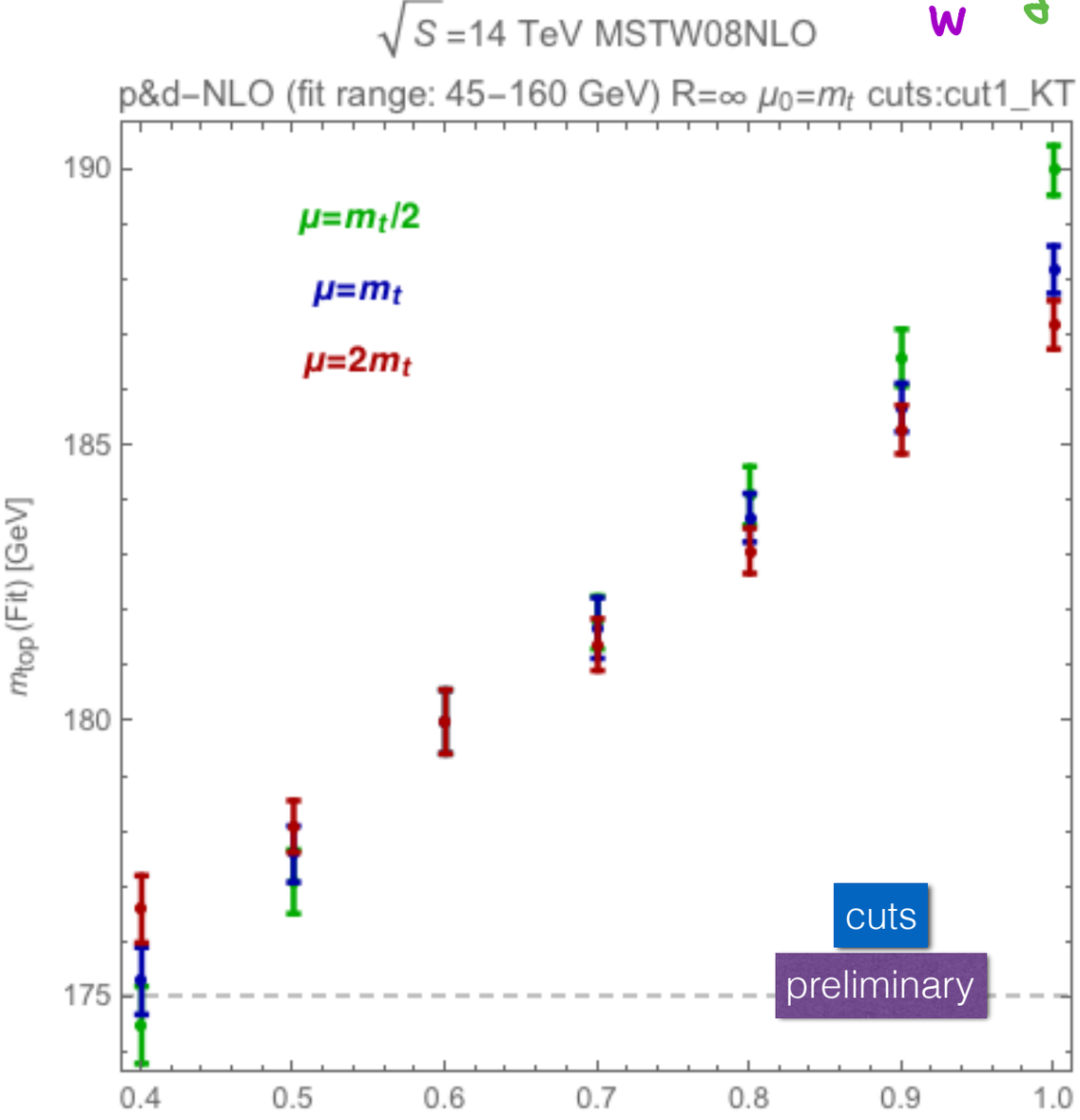


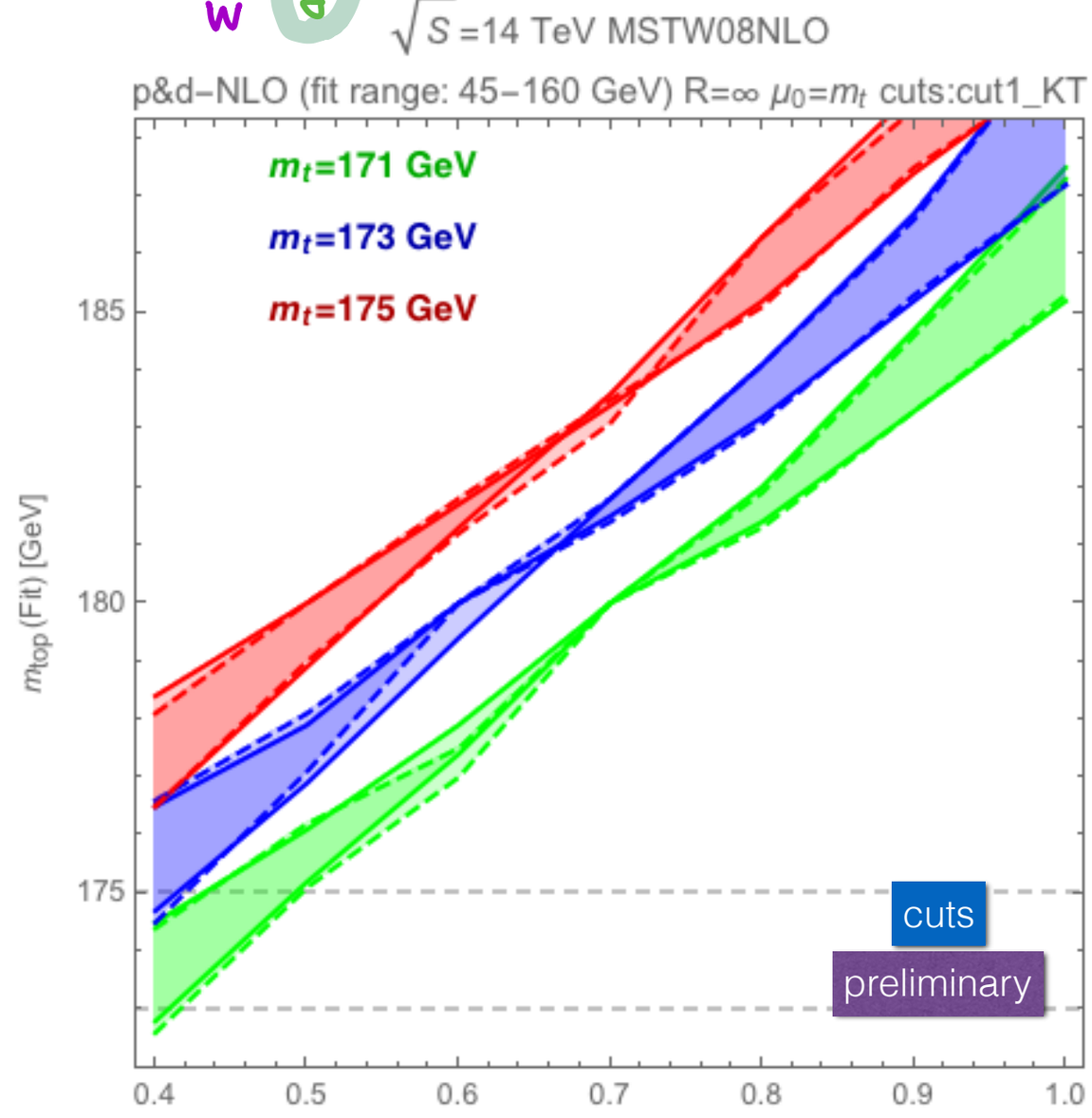
$$\hat{E} = E_0 + \alpha(\mu)\cdot[\, p\cdot R^2 + p\cdot \log R\,] + \ldots$$

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

NLO: production & decay





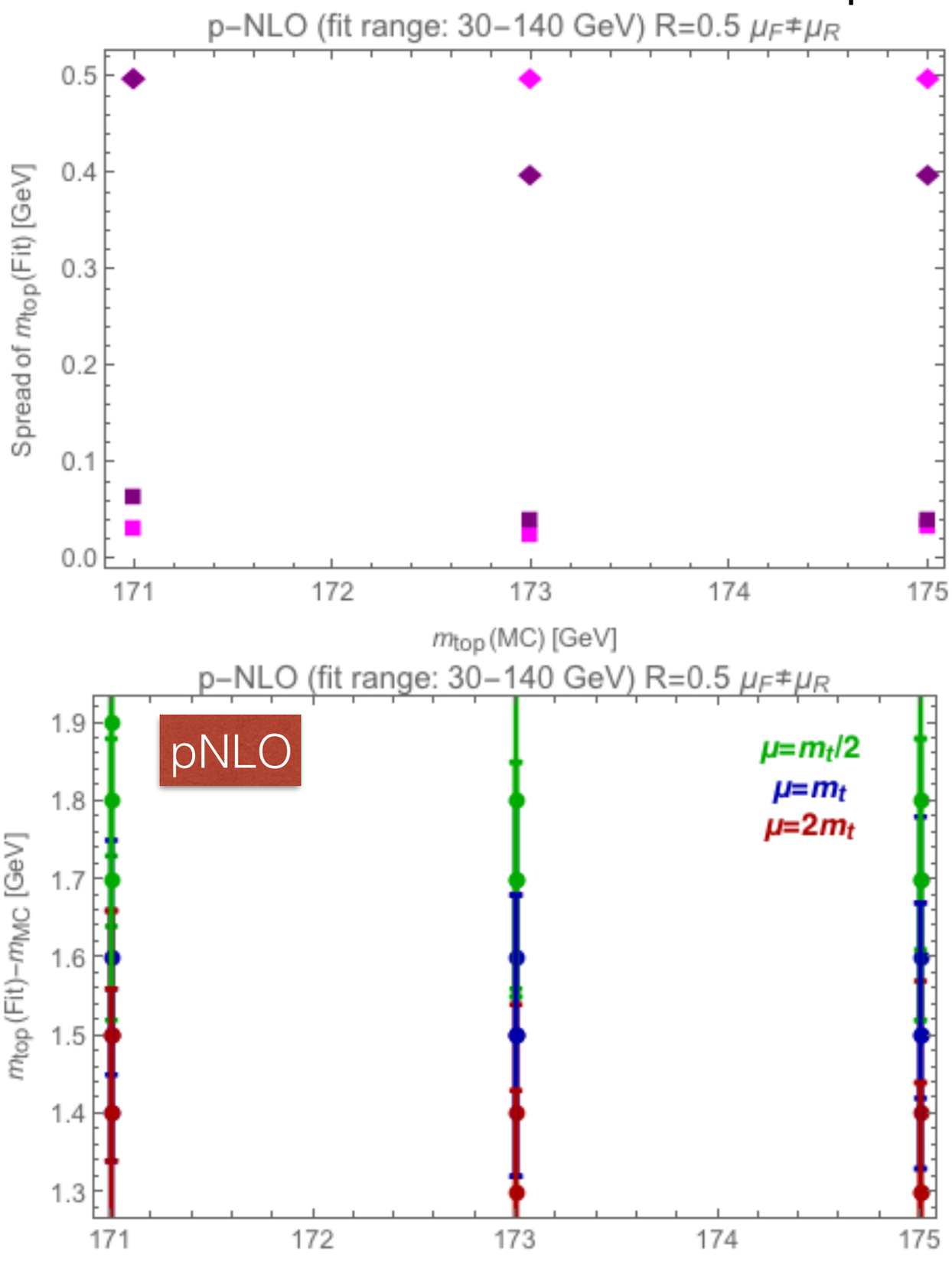


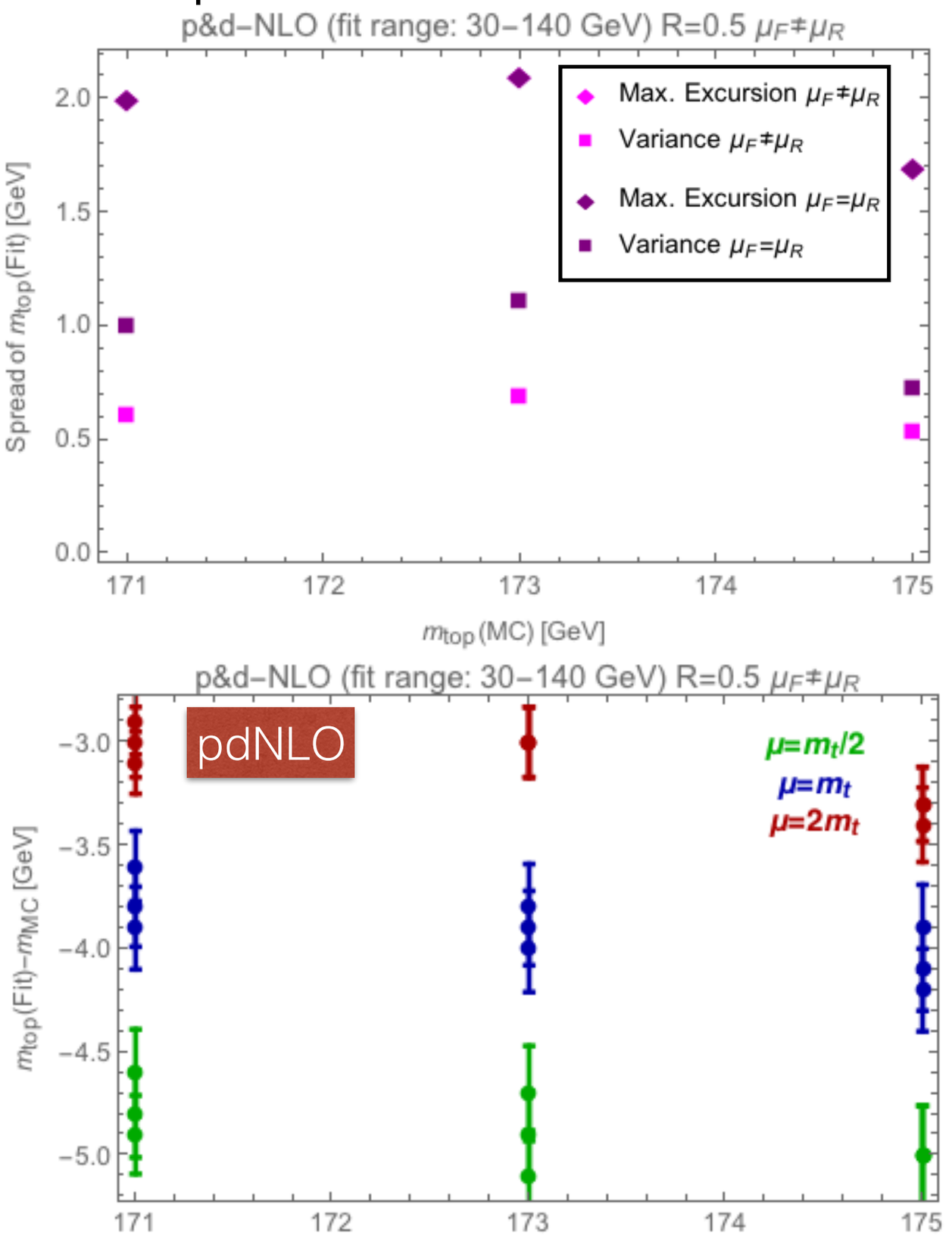
$$\hat{E} = E_0 + \alpha(\mu)\cdot[\, p\cdot R^2 + p\cdot \log R\,] + \ldots$$

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

Dependence on the scales

R=0.5 pNLO vs. pdNLO

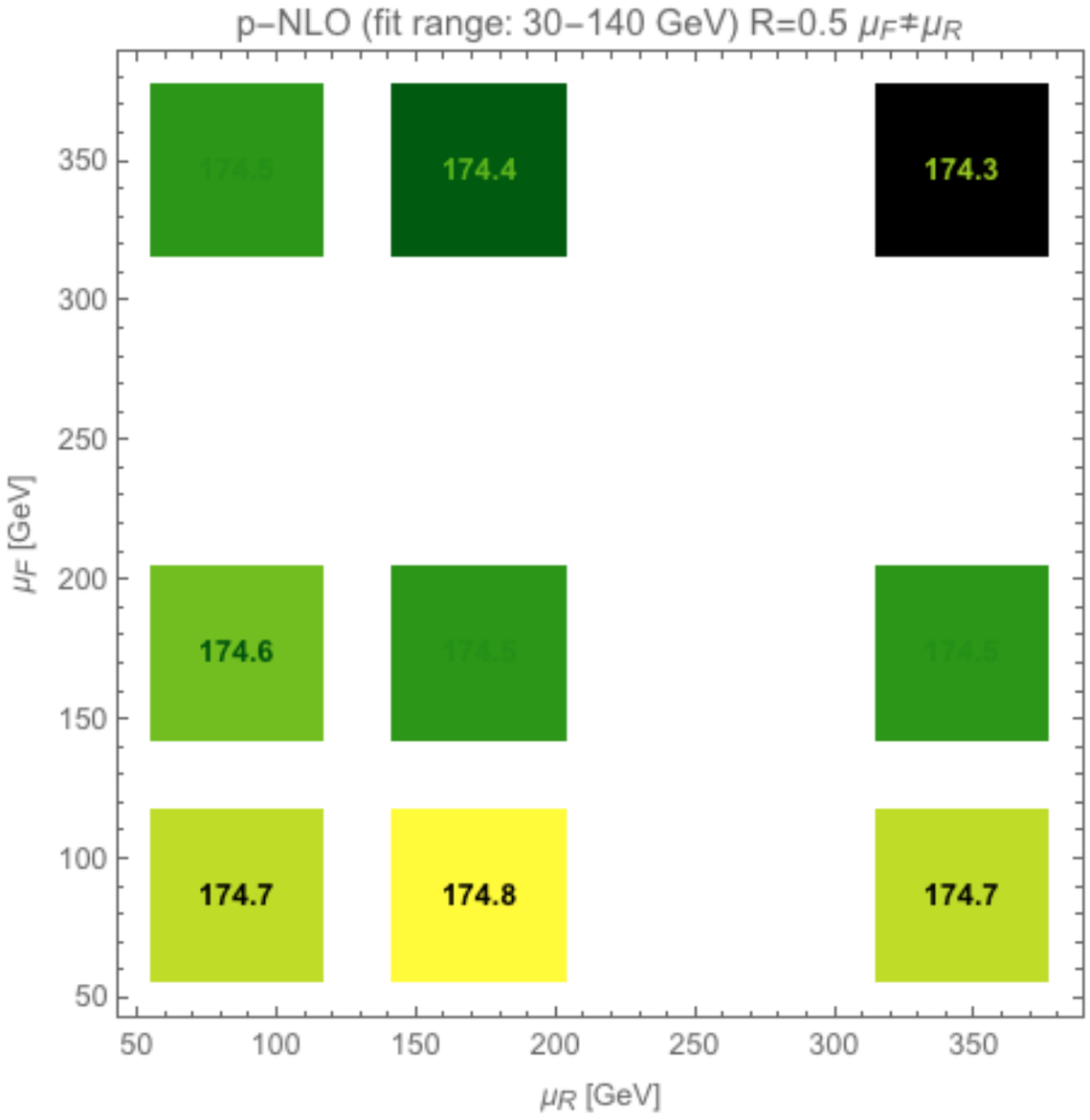




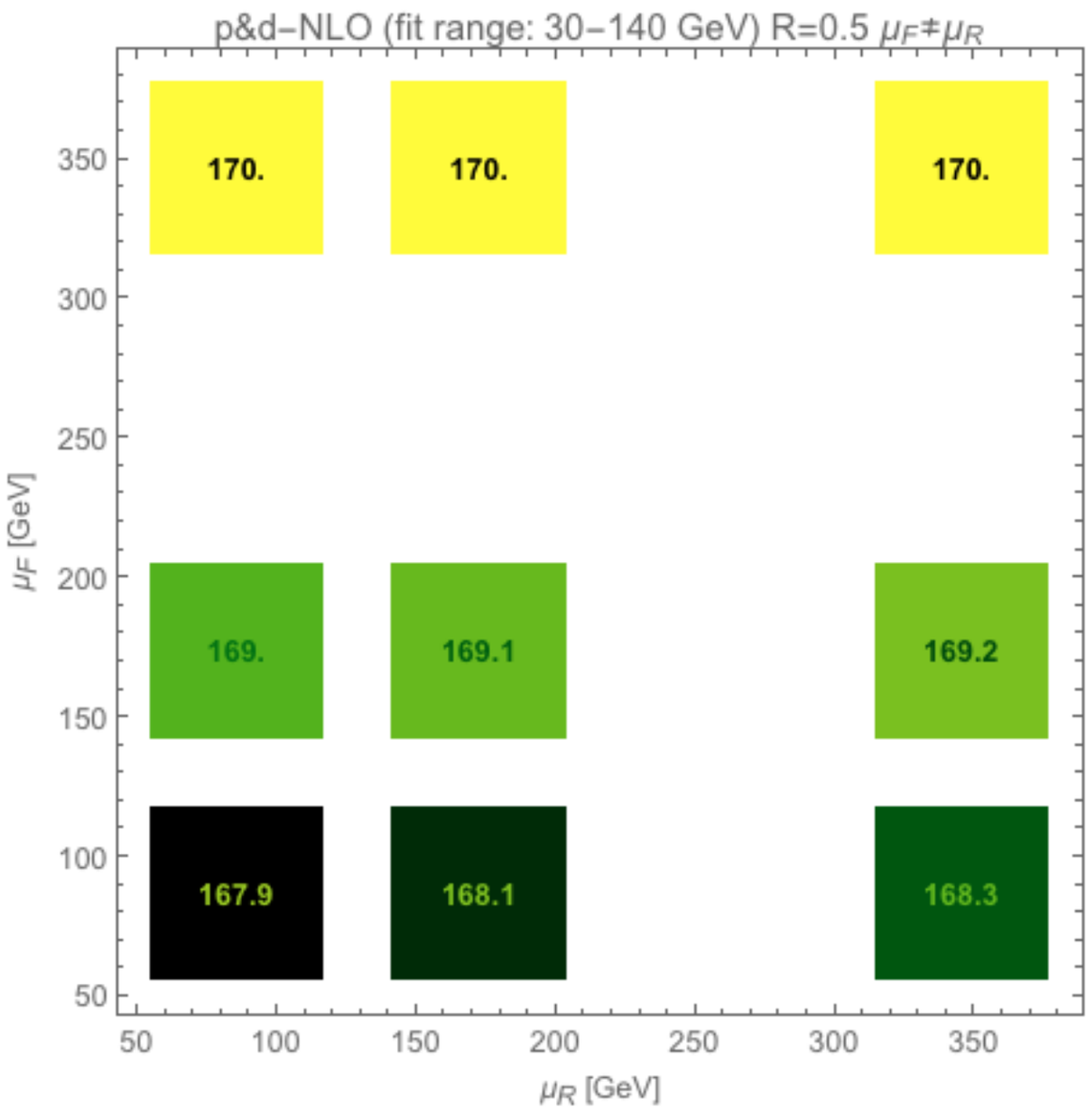
Dependence on the scales

R=0.5 pNLO vs. pdNLO

pNLO

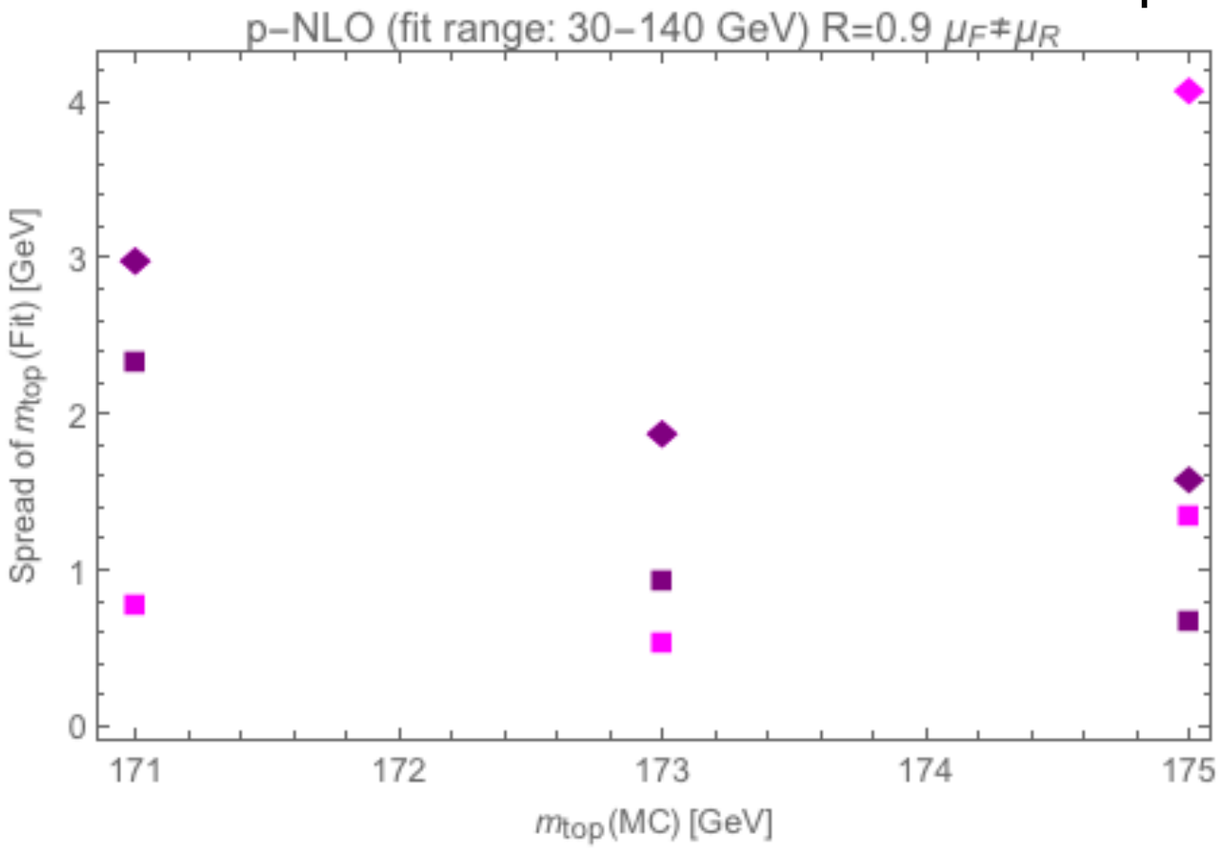


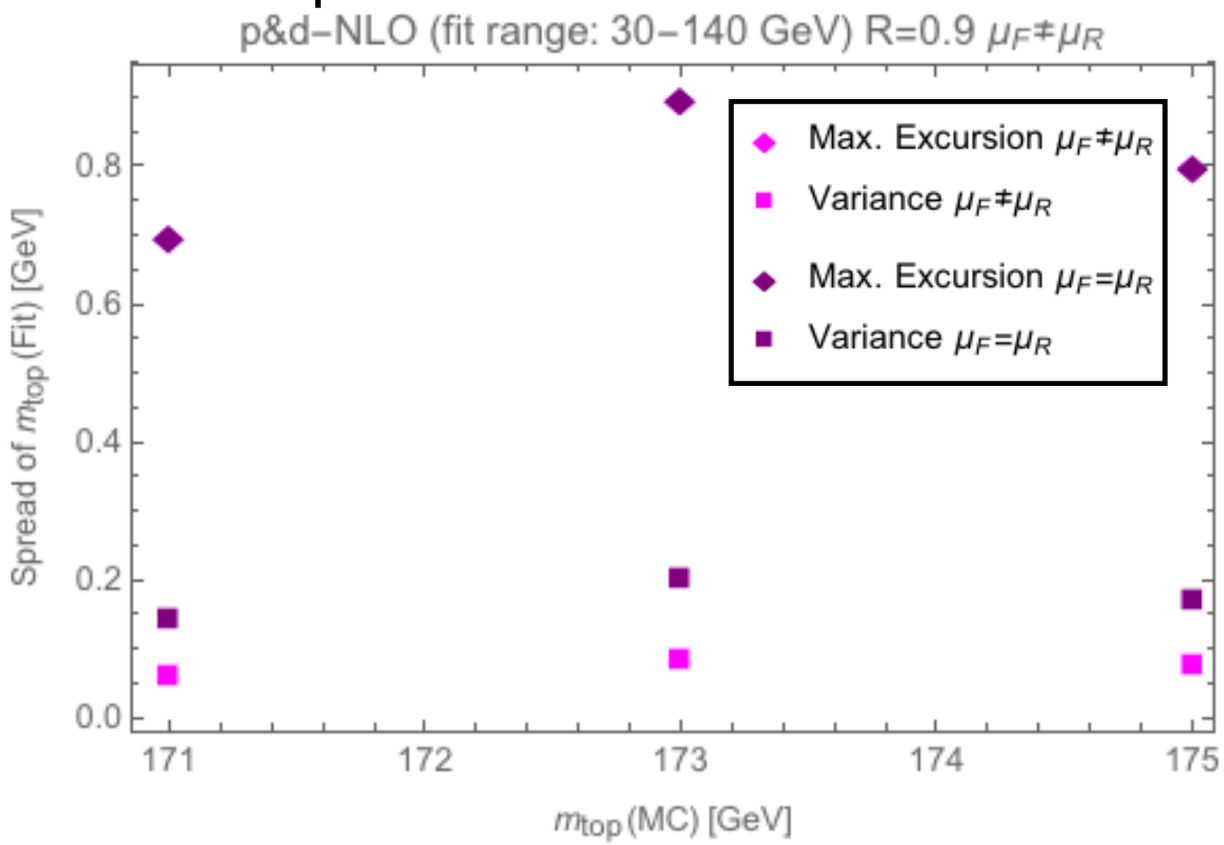
pdNLO

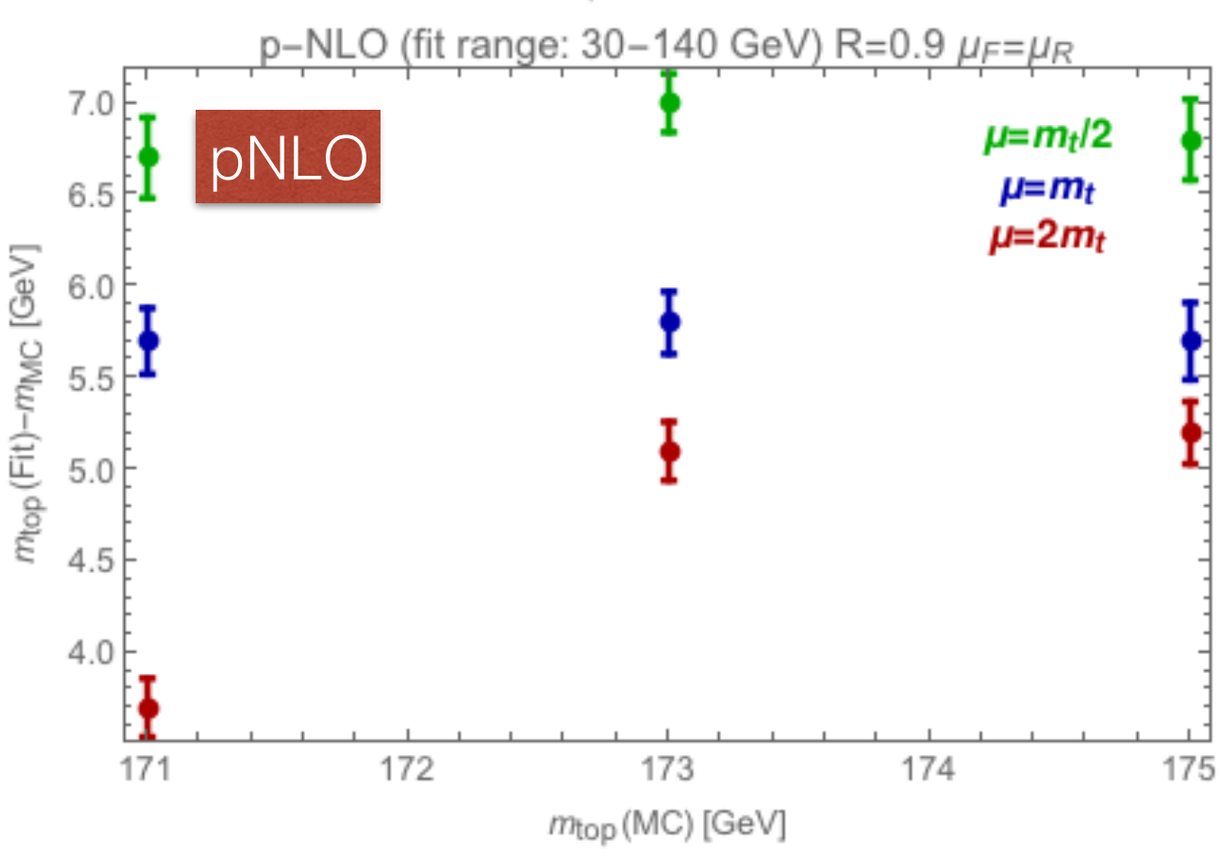


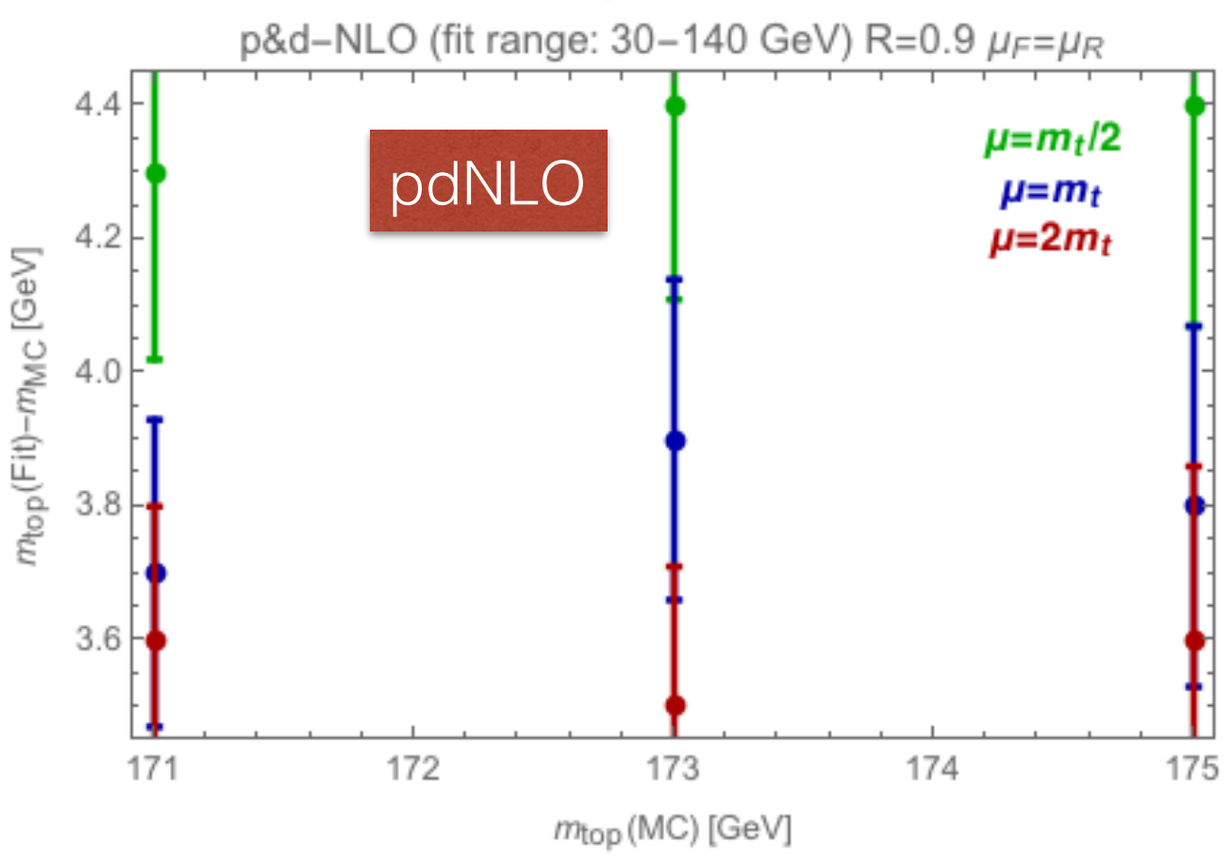
Dependence on the scales

R=0.9 pNLO vs. pdNLO





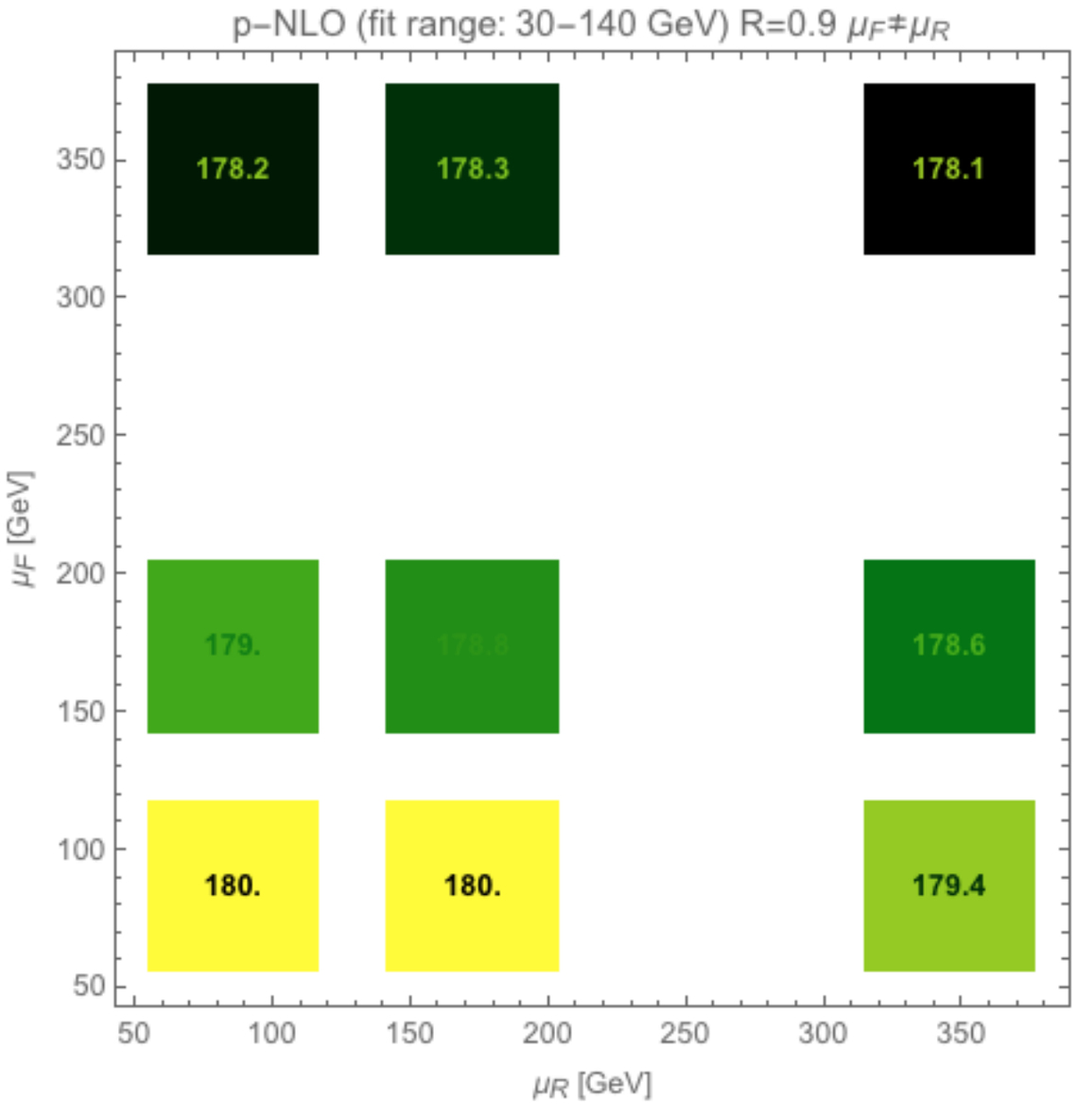




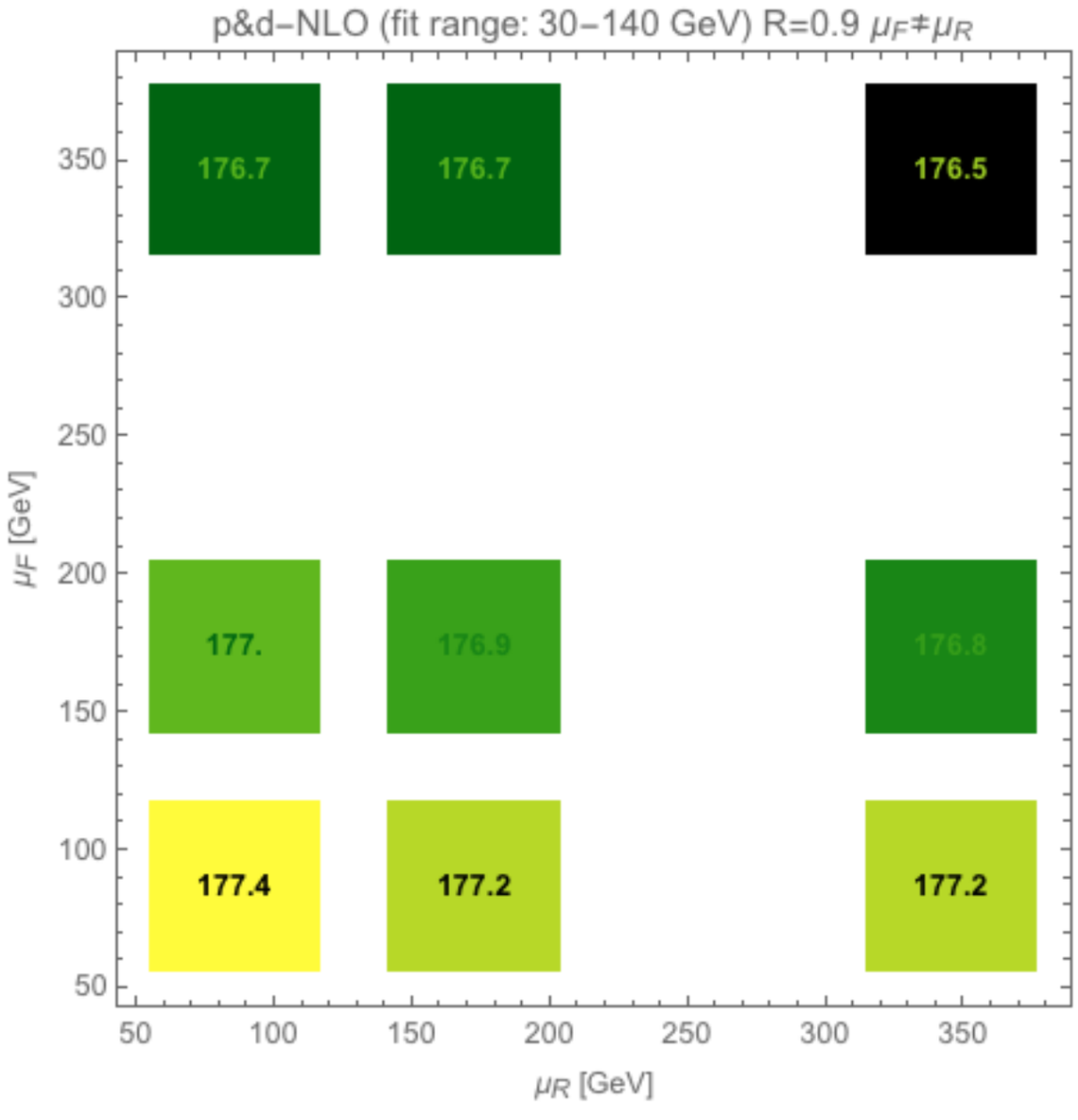
Dependence on the scales

R=0.9 pNLO vs. pdNLO

pNLO

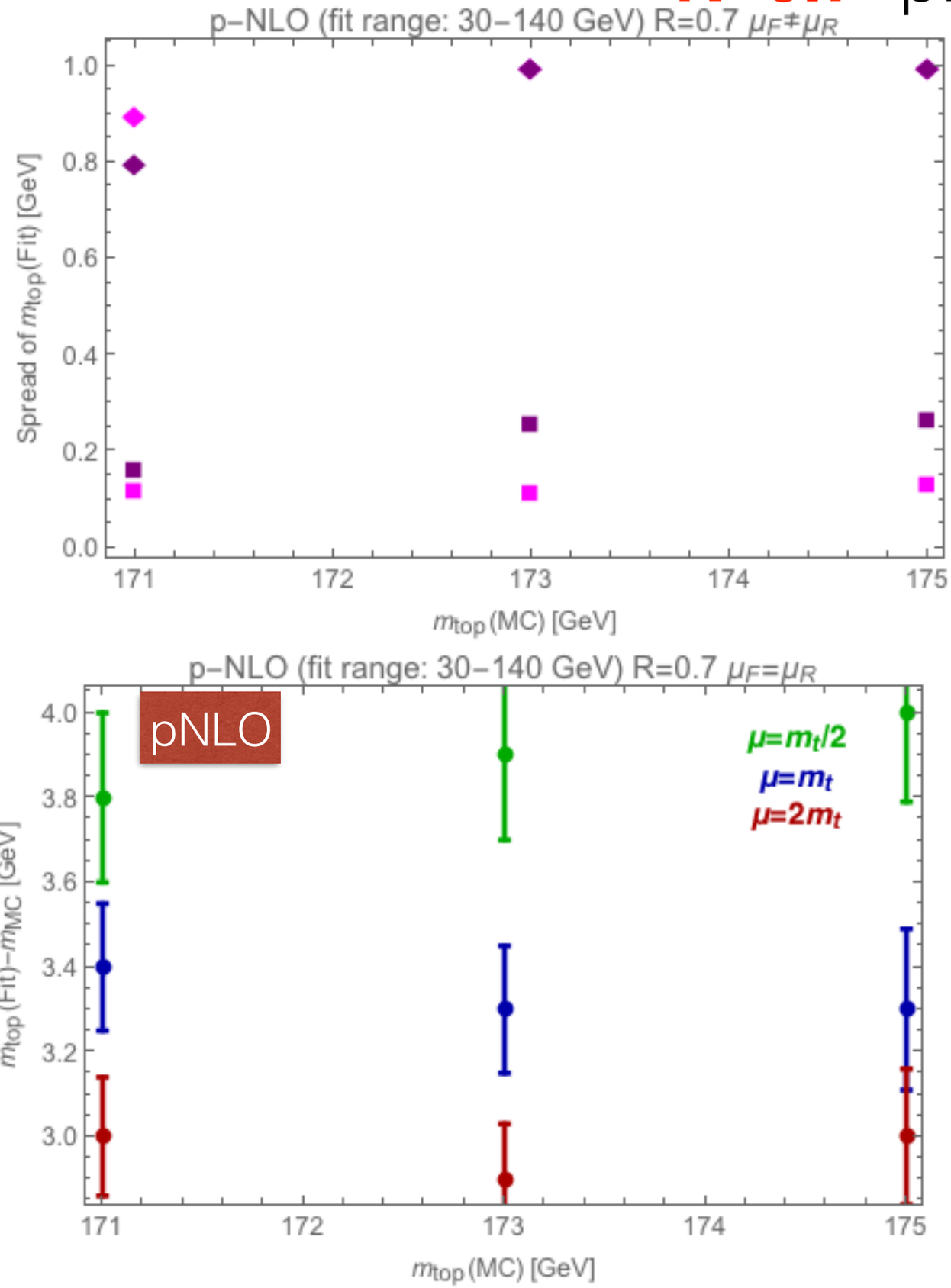


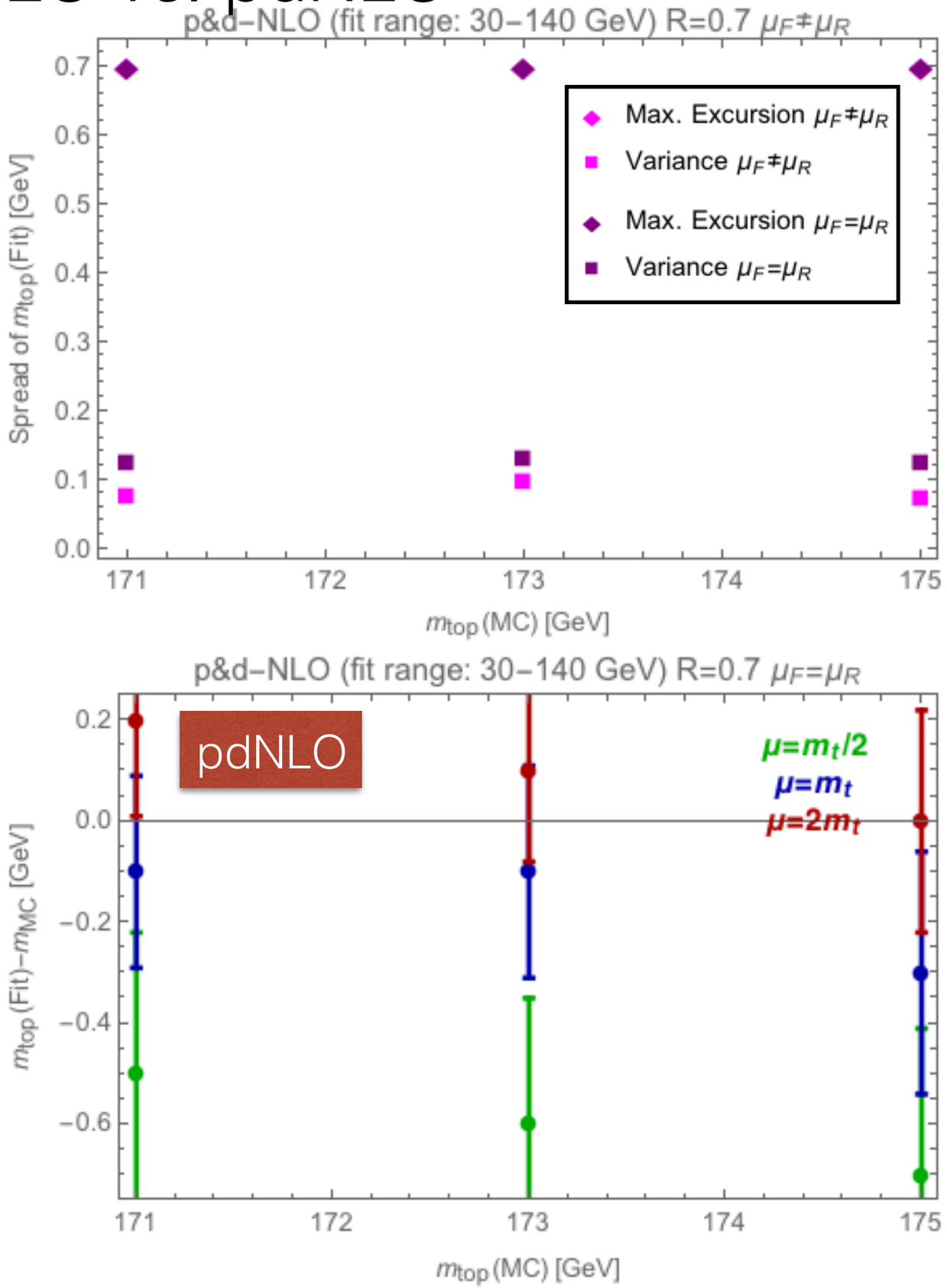
pdNLO



Dependence on the scales

R=0.7 pNLO vs. pdNLO

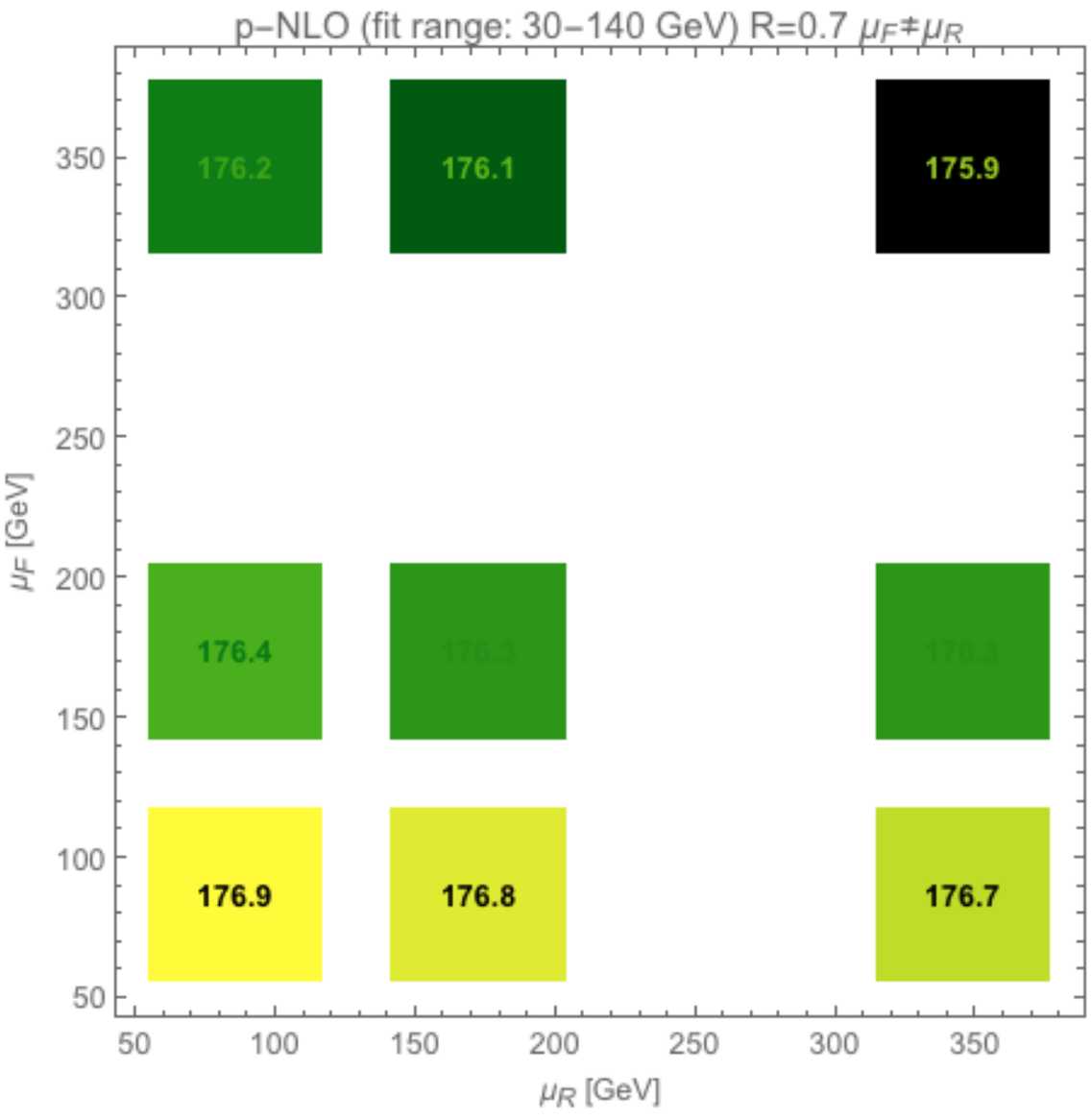




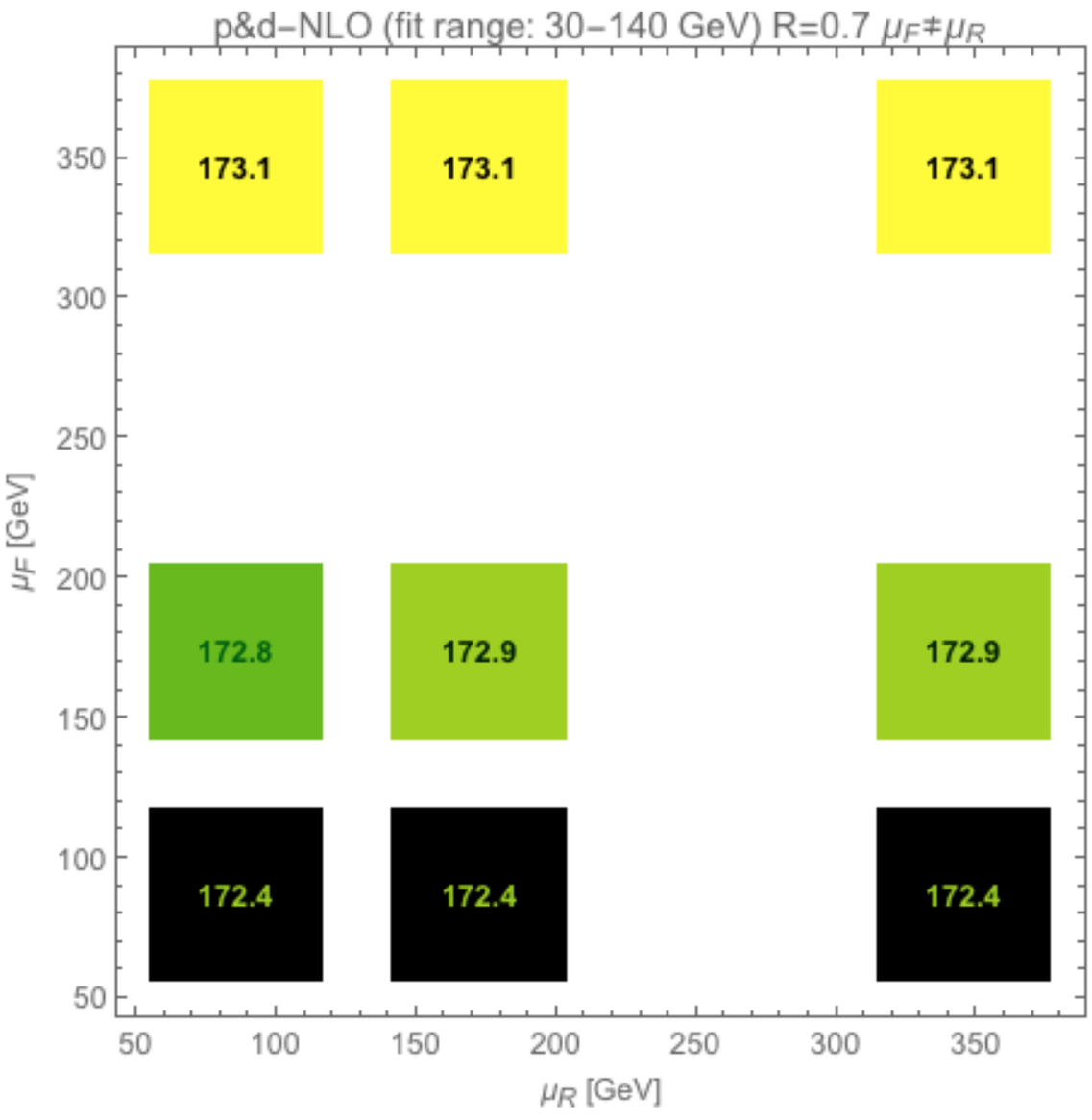
Dependence on the scales

R=0.7 pNLO vs. pdNLO

pNLO

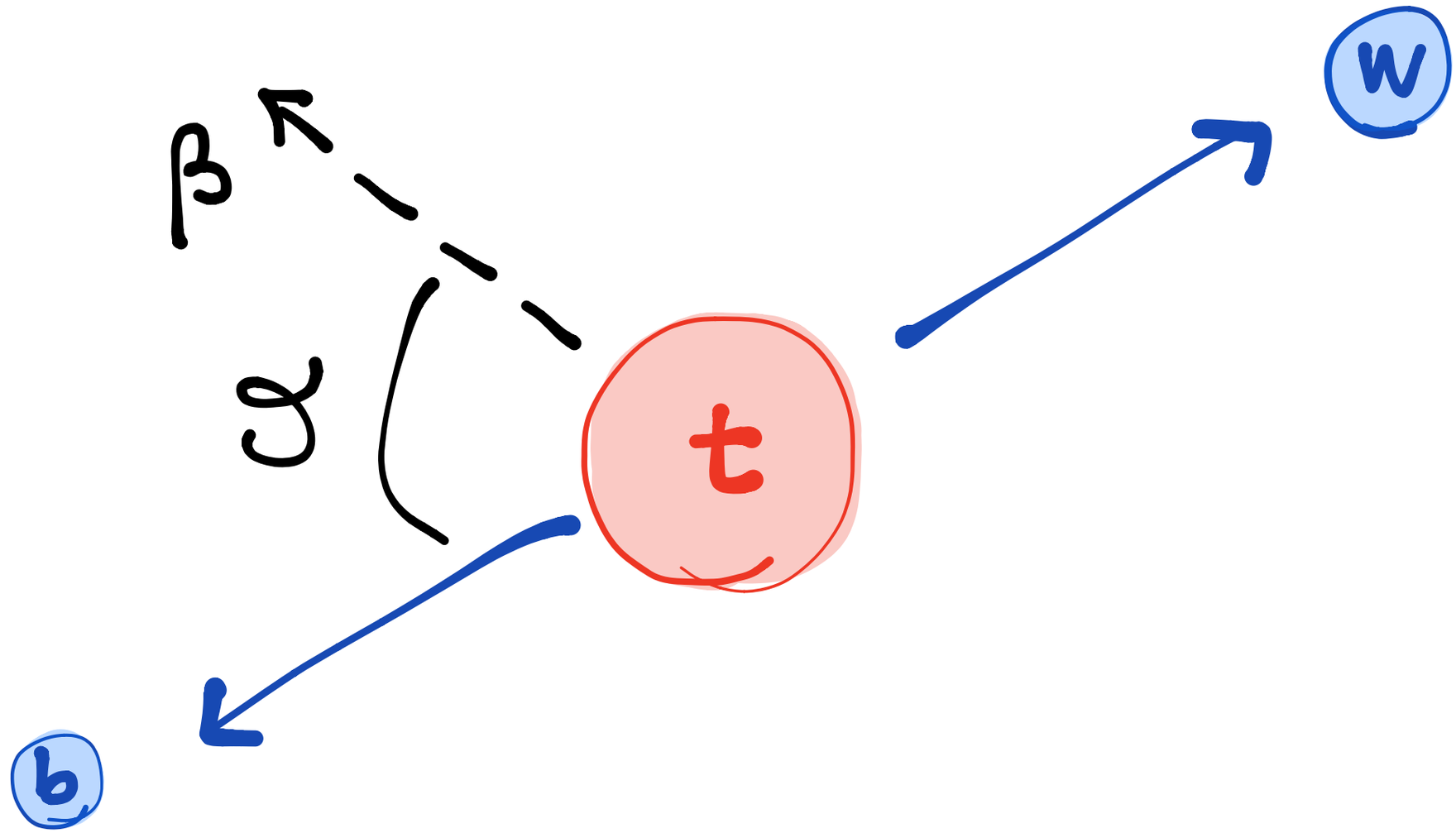


pdNLO



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

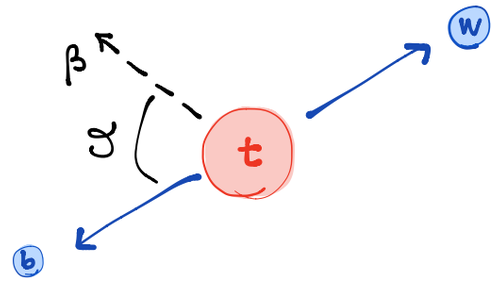
1209.0772 - Agashe, Franceschini and Kim



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

Event-by-event we cannot tell anything

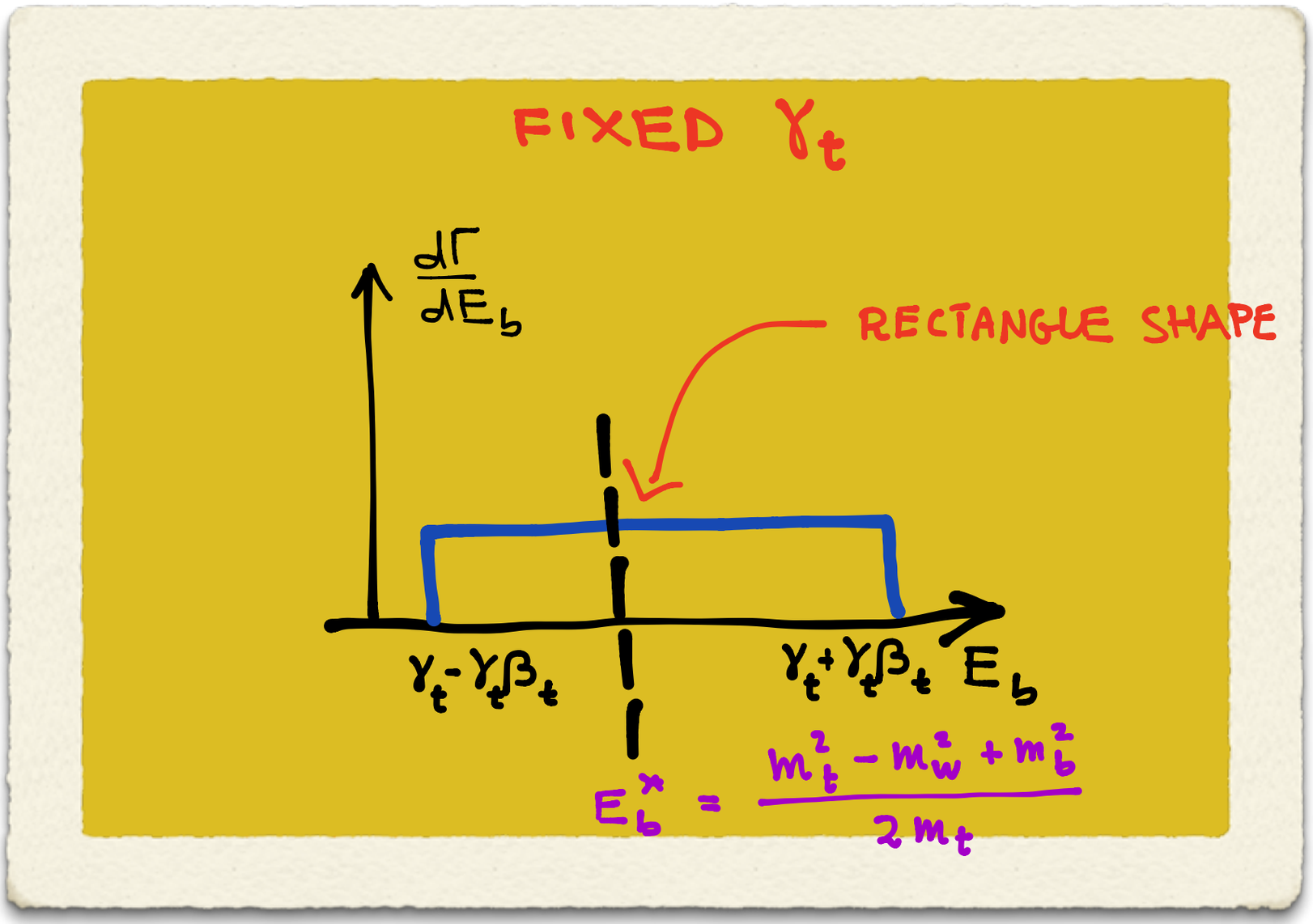
Fixed top boost decay



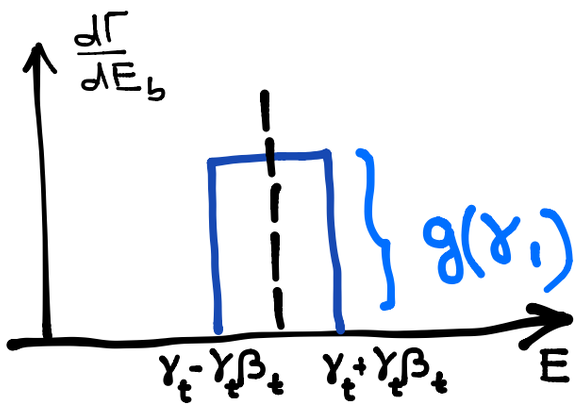
Massless b-quark (for now)

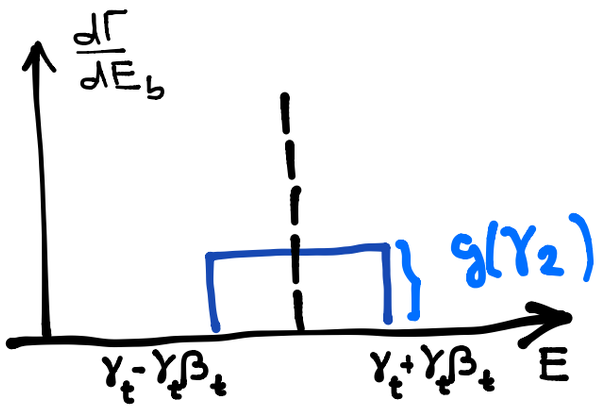
$$E_{lab,b} = E_b^* \left(\gamma + \gamma\beta \cos\vartheta \right)$$

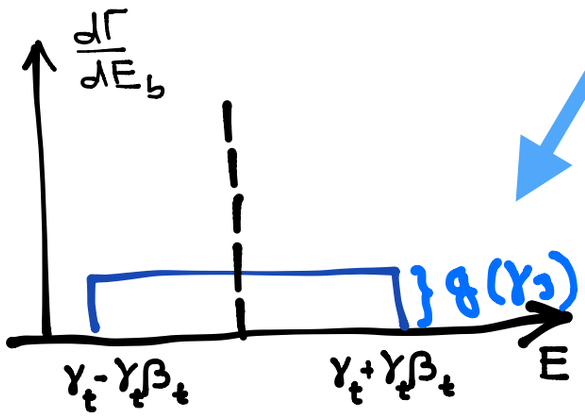
unpolarized top sample ⟶ cosθ is flat

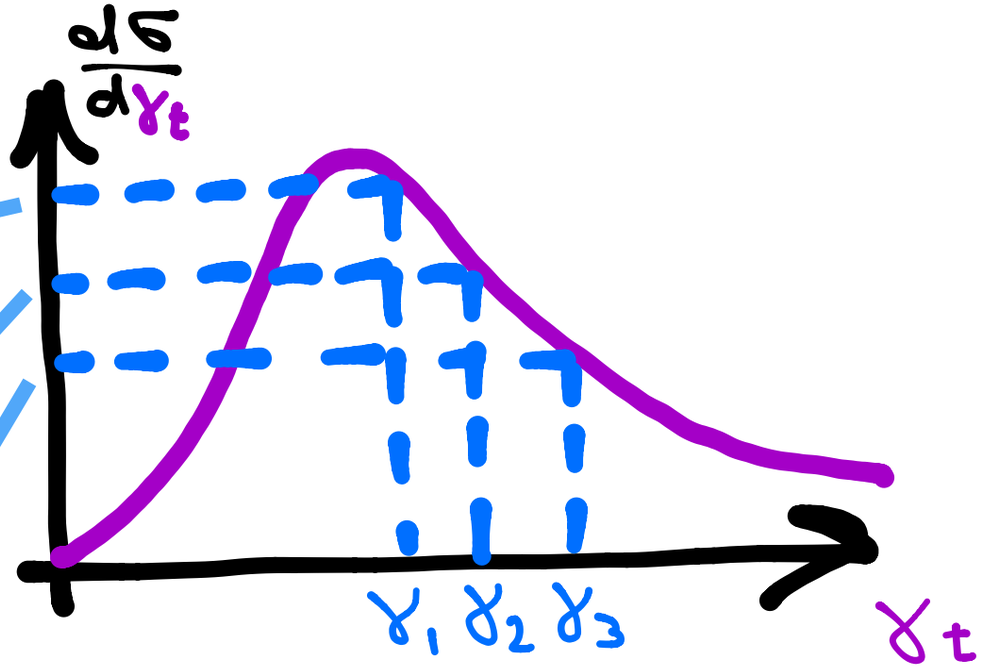


Summing over the top boosts

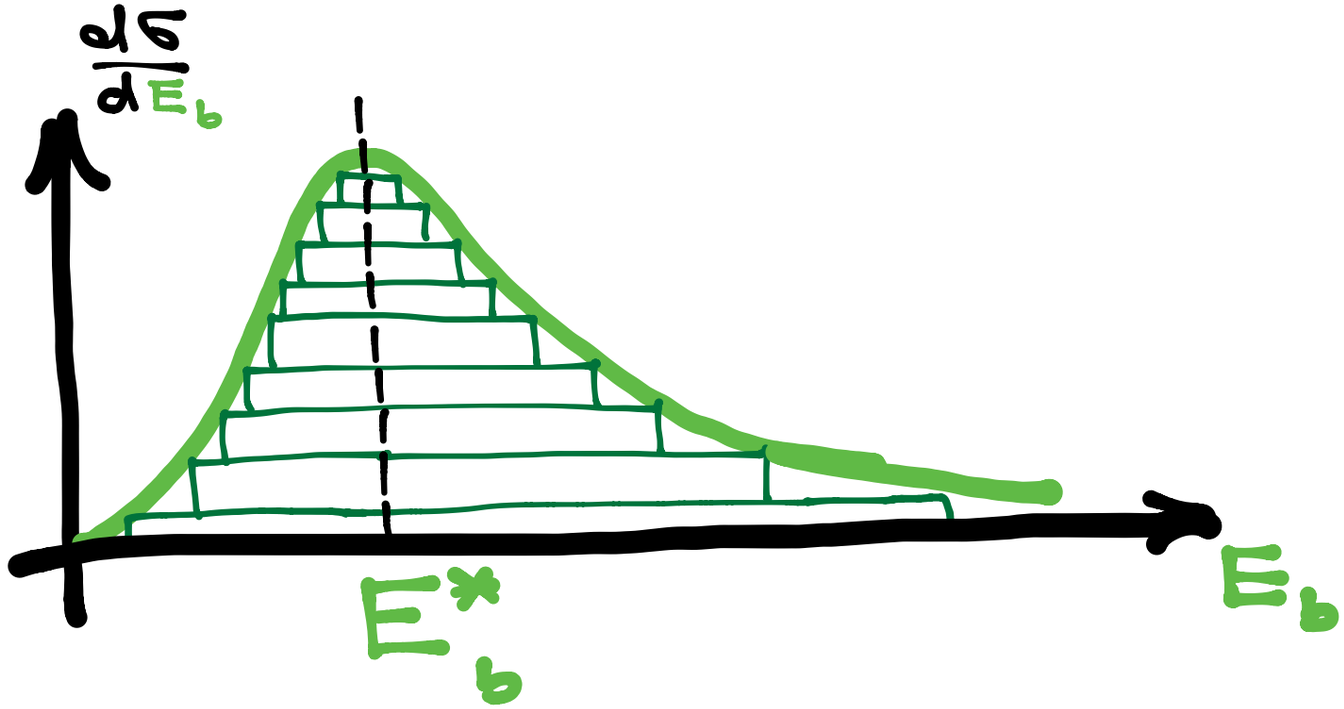








THE ENERGY DISTRIBUTION IN THE LAB IS THE SUM OF ALL THE RECTANGLES



Lab-frame energy distribution

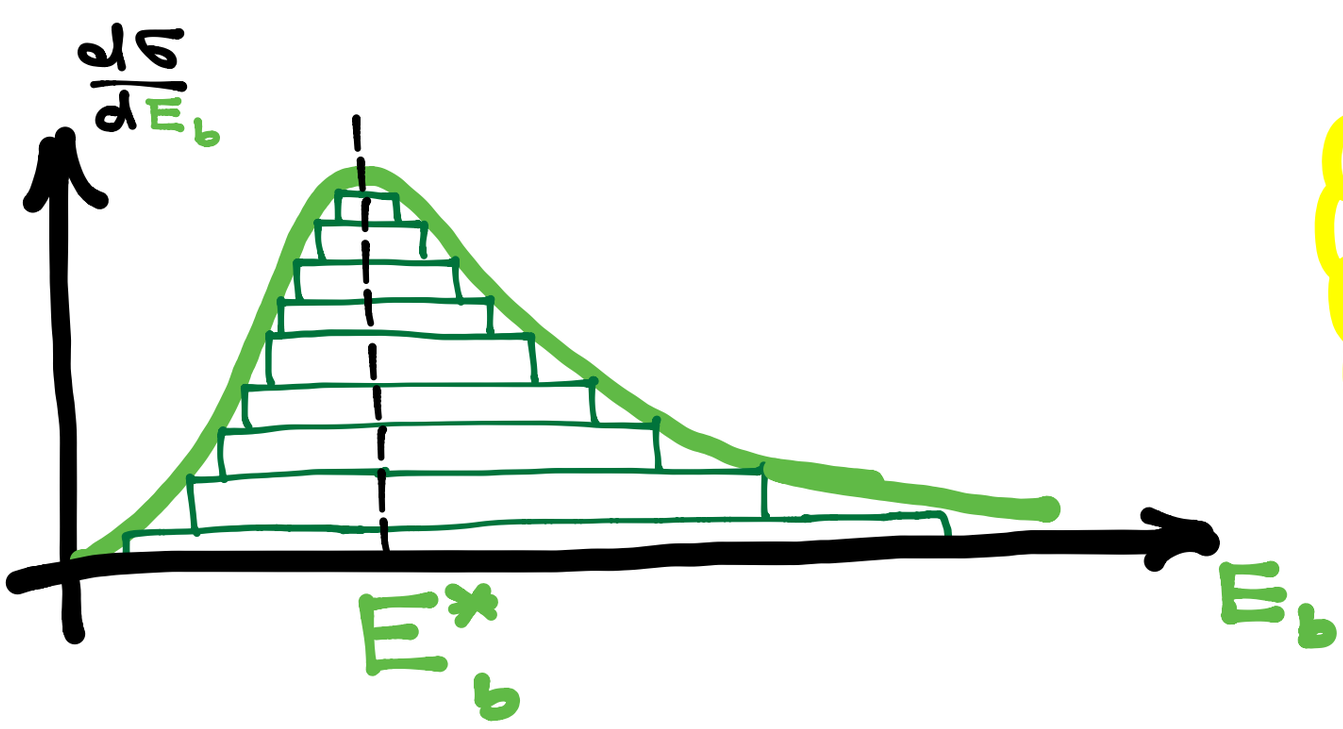
1209.0772 - Agashe, Franceschini and Kim

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_j^* IN A VERY SIMPLE WAY

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

back