...with BSM on top

Roberto Franceschini (CERN)
GGI Florence, October 15th 2015

Precision physics with BSM on top

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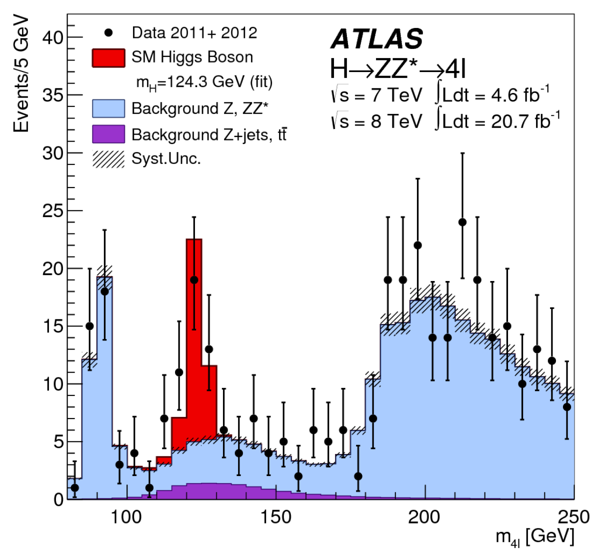
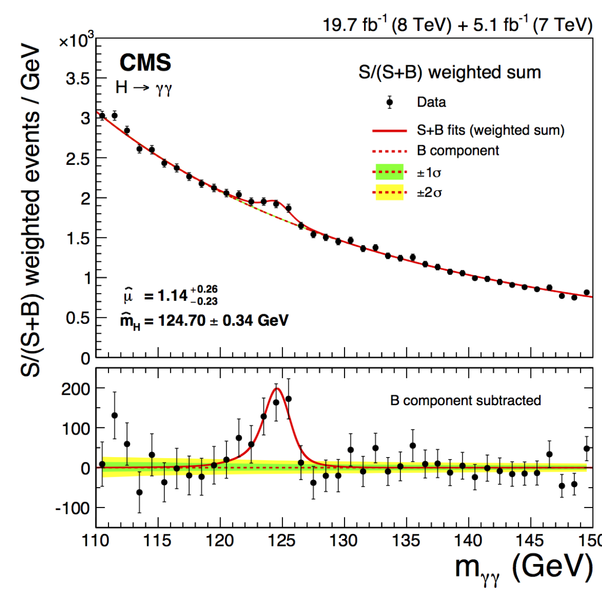
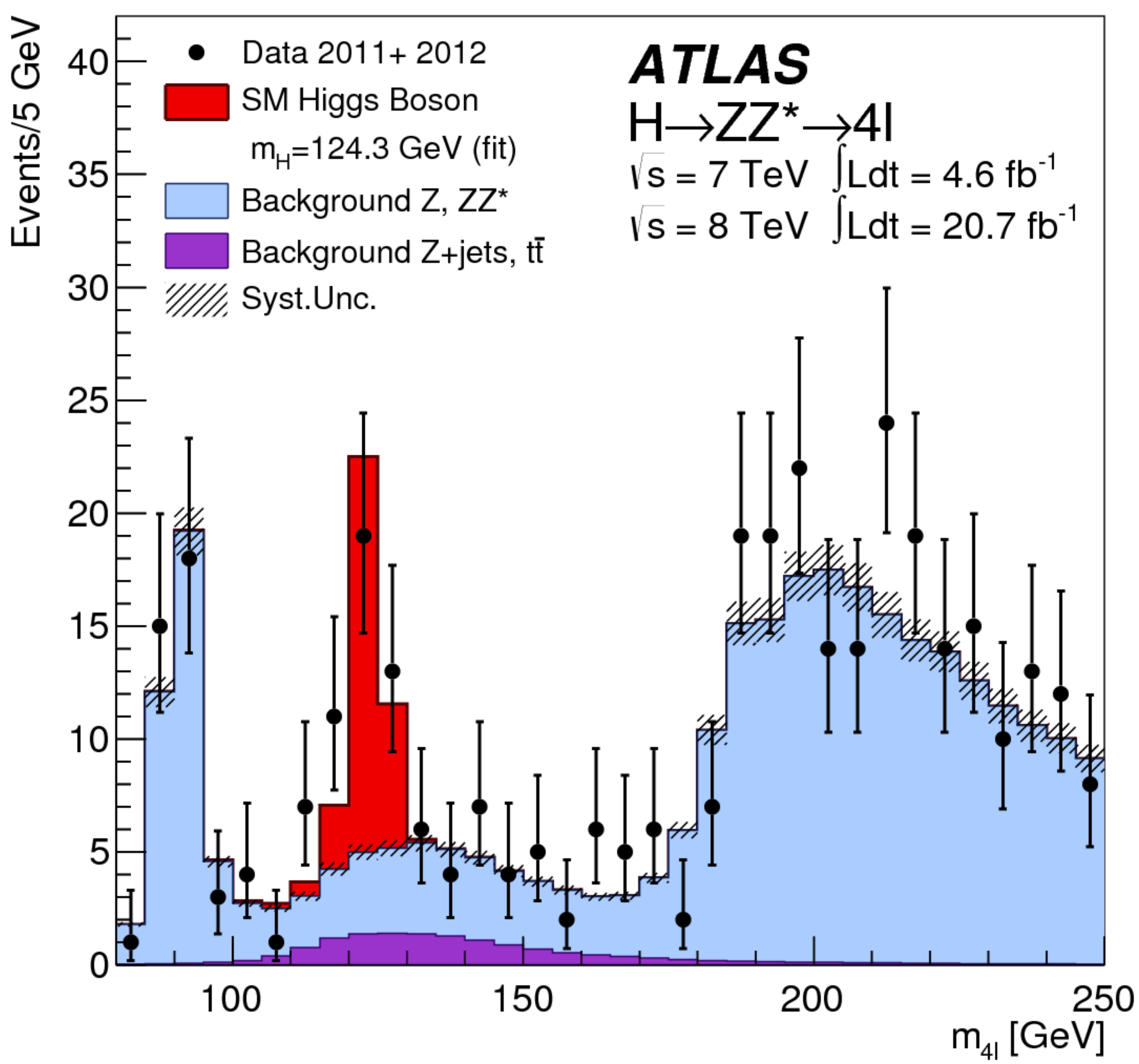
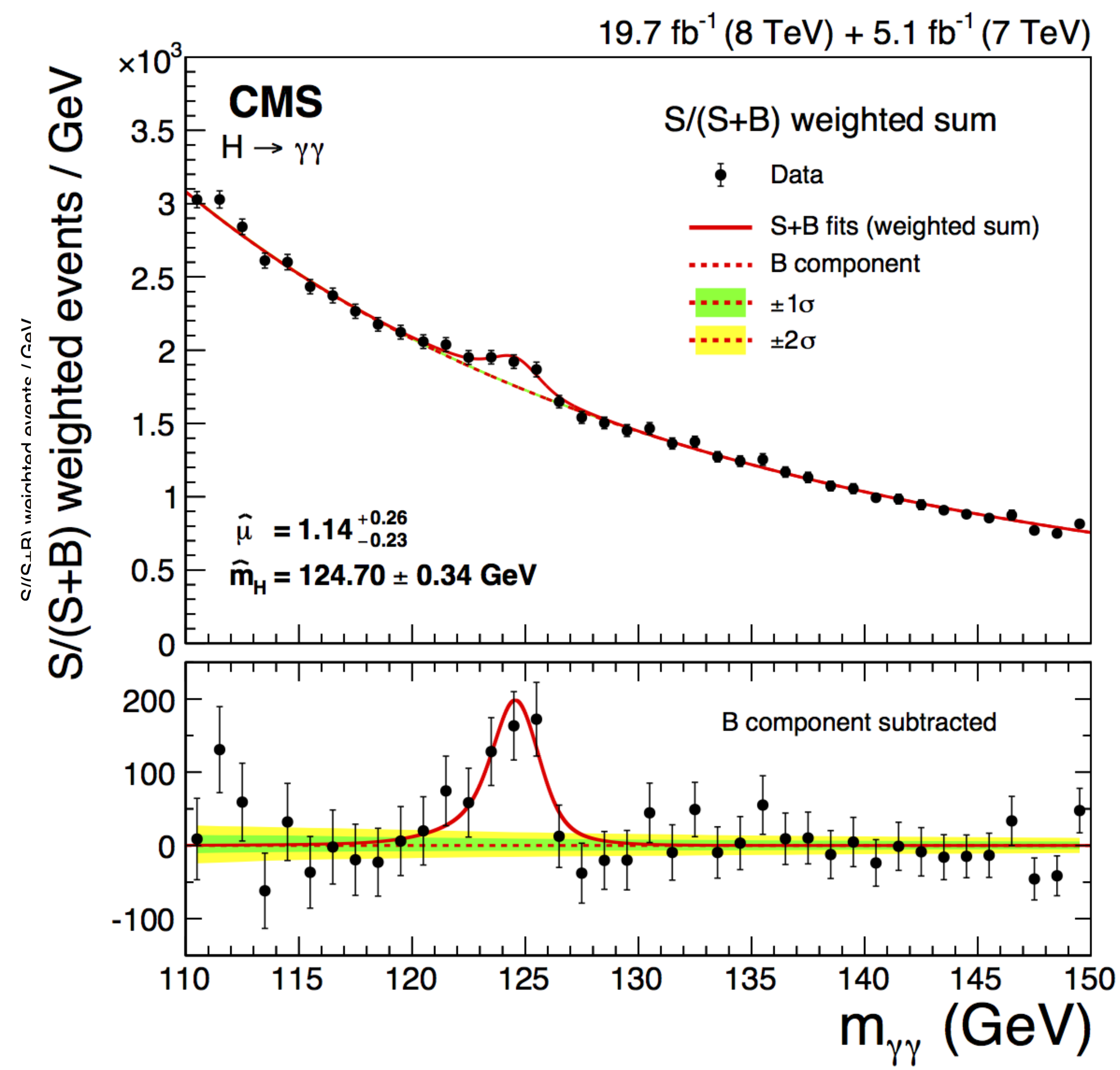
The “Spectacular” Paradigm





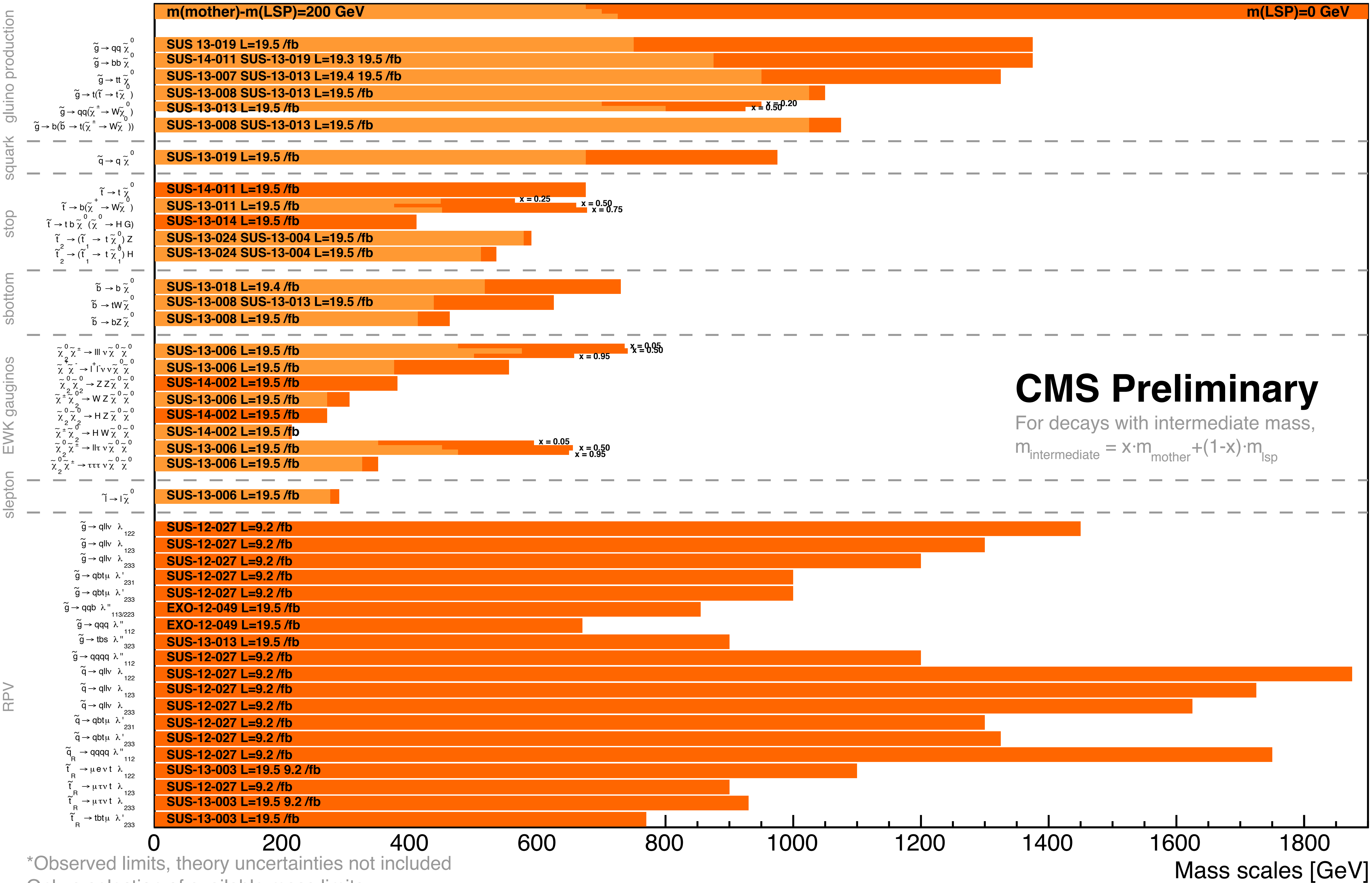
The “Spectacular” Paradigm





Summary of CMS SUSY Results* in SMS framework

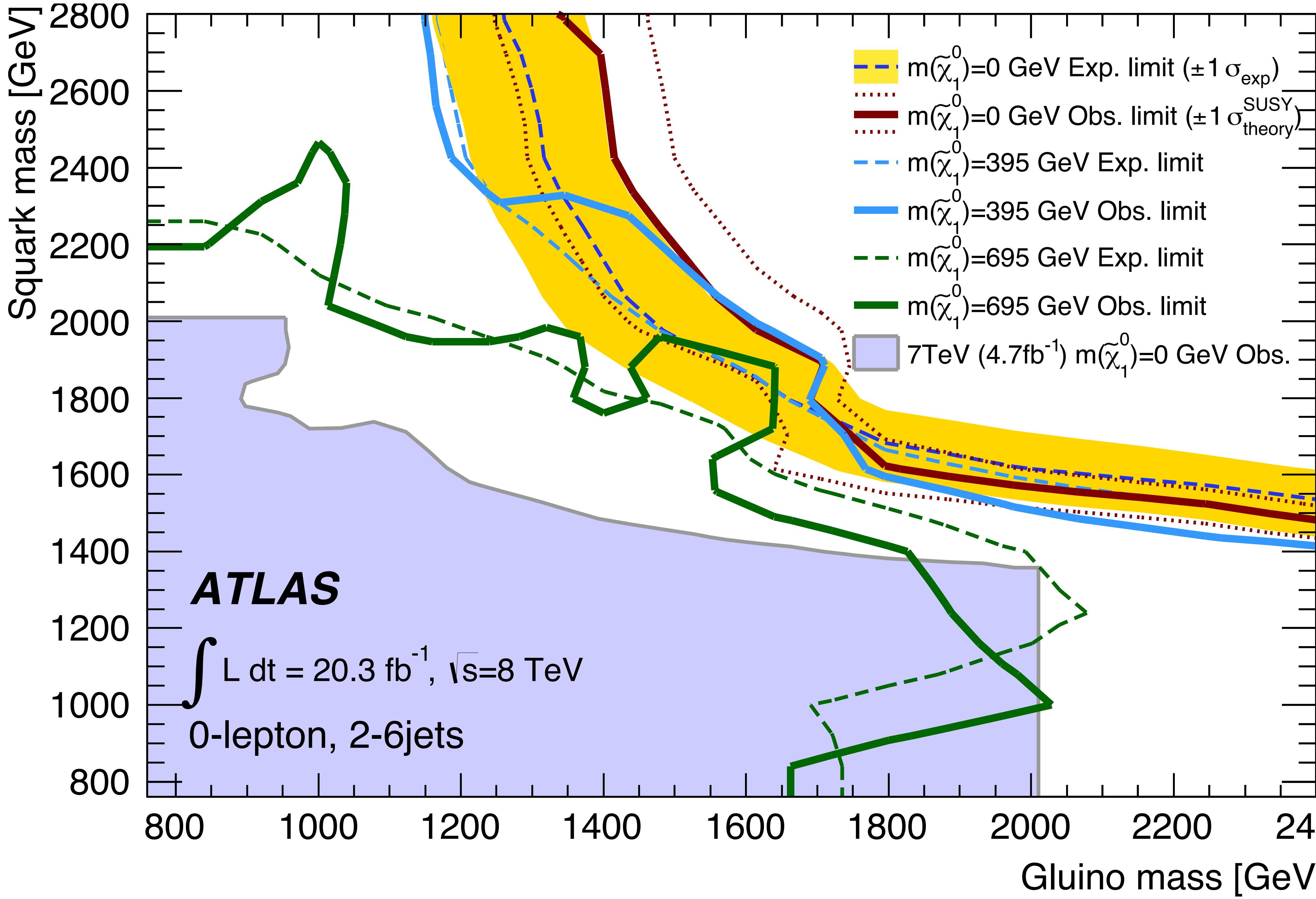
ICHEP 2014



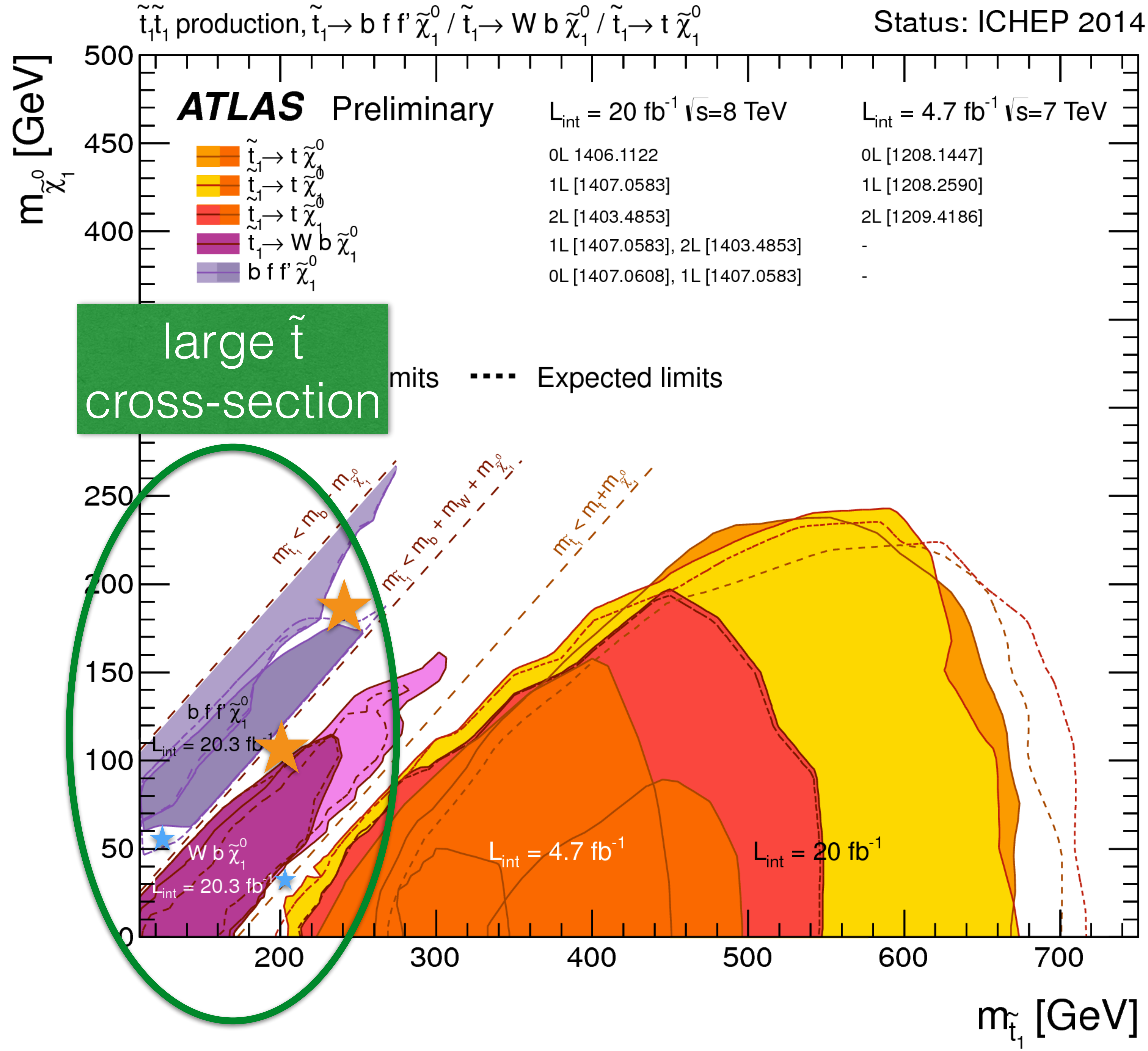
*Observed limits, theory uncertainties not included
Only a selection of available mass limits
Probe *up to* the quoted mass limit

No signs of new physics yet

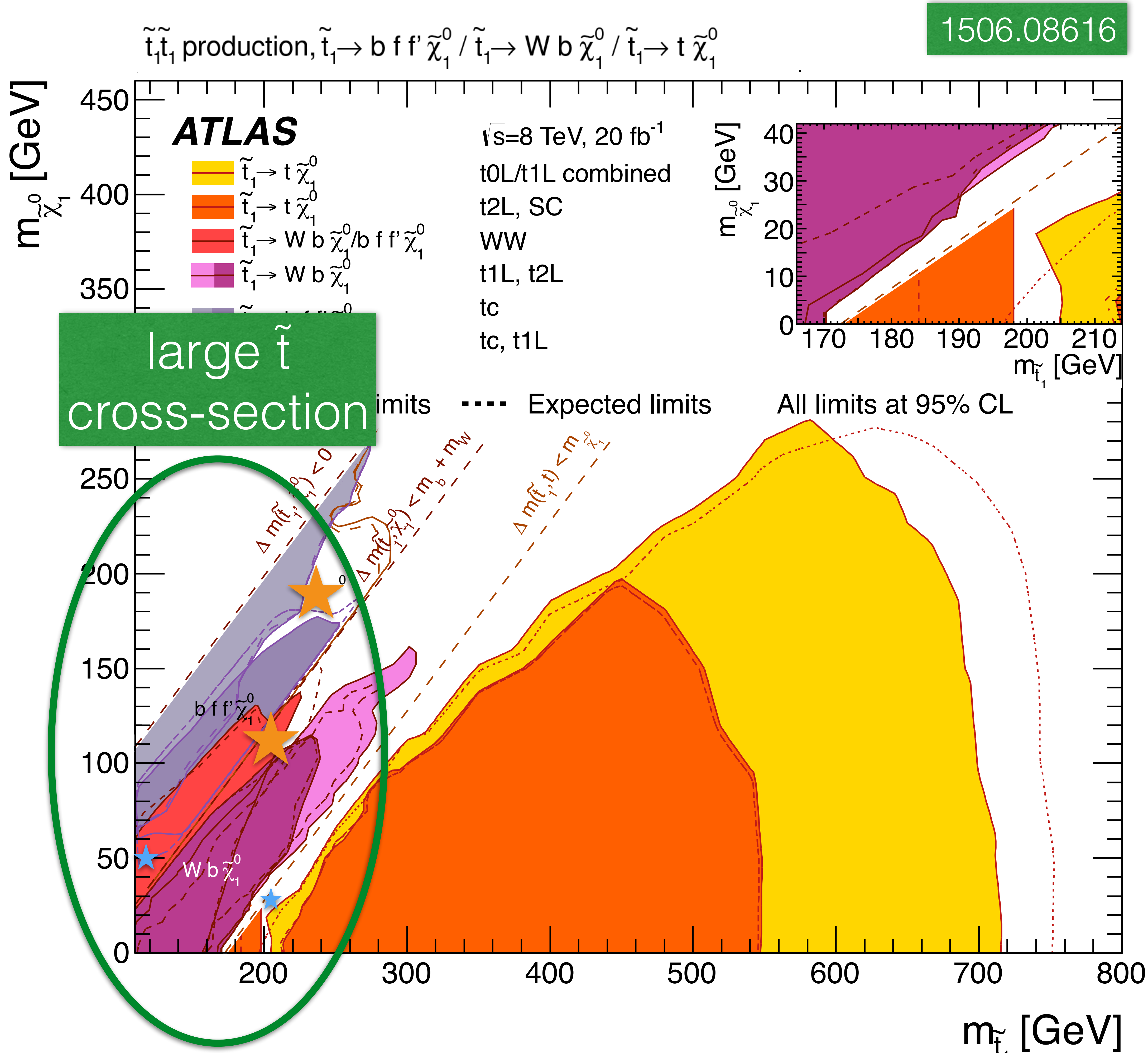
pp→ jets + leptons + photons + **mET**



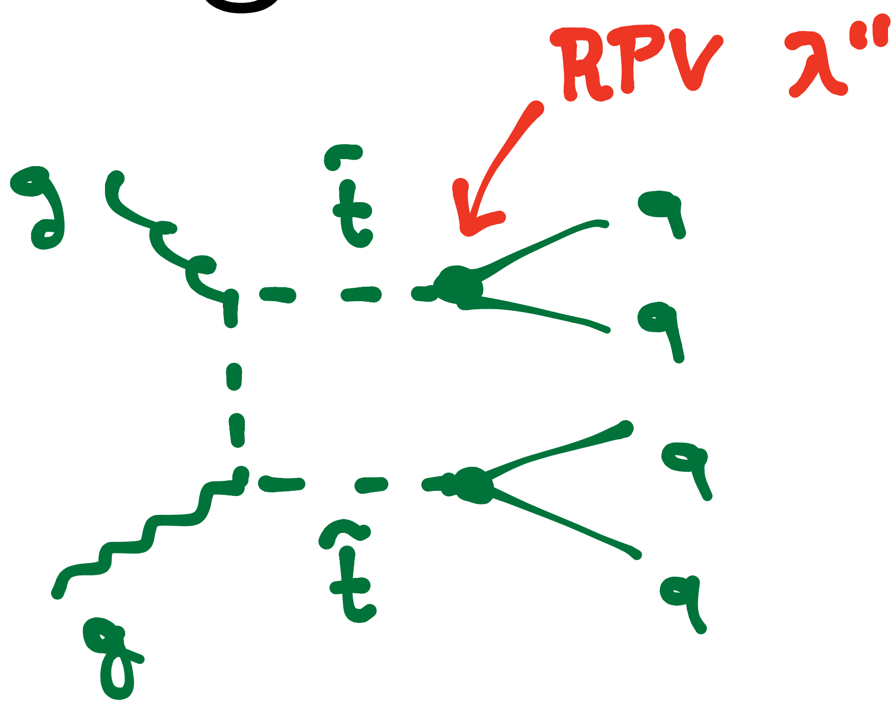
direct limits: M_{SUSY} > 1 TeV



t̃₁t̃₁ production, t̃₁→ b f f' χ̃⁰₁ / t̃₁→ W b χ̃⁰₁ / t̃₁→ t χ̃⁰₁
Status: ICHEP 2014
ATLAS Preliminary
L_{int} = 20 fb⁻¹ √s=8 TeV
L_{int} = 4.7 fb⁻¹ √s=7 TeV
t̃₁→ t χ̃⁰₁ 0L 1406.1122 0L [1208.1447]
t̃₁→ t χ̃⁰₁ 1L [1407.0583] 1L [1208.2590]
t̃₁→ t χ̃⁰₁ 2L [1403.4853] 2L [1209.4186]
t̃₁→ W b χ̃⁰₁ 1L [1407.0583], 2L [1403.4853] -
b f f' χ̃⁰₁ 0L [1407.0608], 1L [1407.0583] -
large t̃ cross-section
Expected limits
b f f' χ̃⁰₁
L_{int} = 20.3 fb⁻¹
W b χ̃⁰₁
L_{int} = 20.3 fb⁻¹
L_{int} = 4.7 fb⁻¹
L_{int} = 20 fb⁻¹
m_χ̃⁰₁ [GeV]
m_t̃₁ [GeV]


1506.08616
t̃₁t̃₁ production, t̃₁→ b f f' χ̃₁⁰ / t̃₁→ W b χ̃₁⁰ / t̃₁→ t χ̃₁⁰
ATLAS
√s=8 TeV, 20 fb⁻¹
t̃₁→ t χ̃₁⁰ t0L/t1L combined
t̃₁→ t χ̃₁⁰ t2L, SC
t̃₁→ W b χ̃₁⁰/b f f' χ̃₁⁰ WW
t̃₁→ W b χ̃₁⁰ t1L, t2L
tc
tc, t1L
large t̃
cross-section
Expected limits
All limits at 95% CL
Δ m(t̃₁,t) < m χ̃₁⁰
b f f' χ̃₁⁰
W b χ̃₁⁰
m χ̃₁⁰ [GeV]
m t̃₁ [GeV]

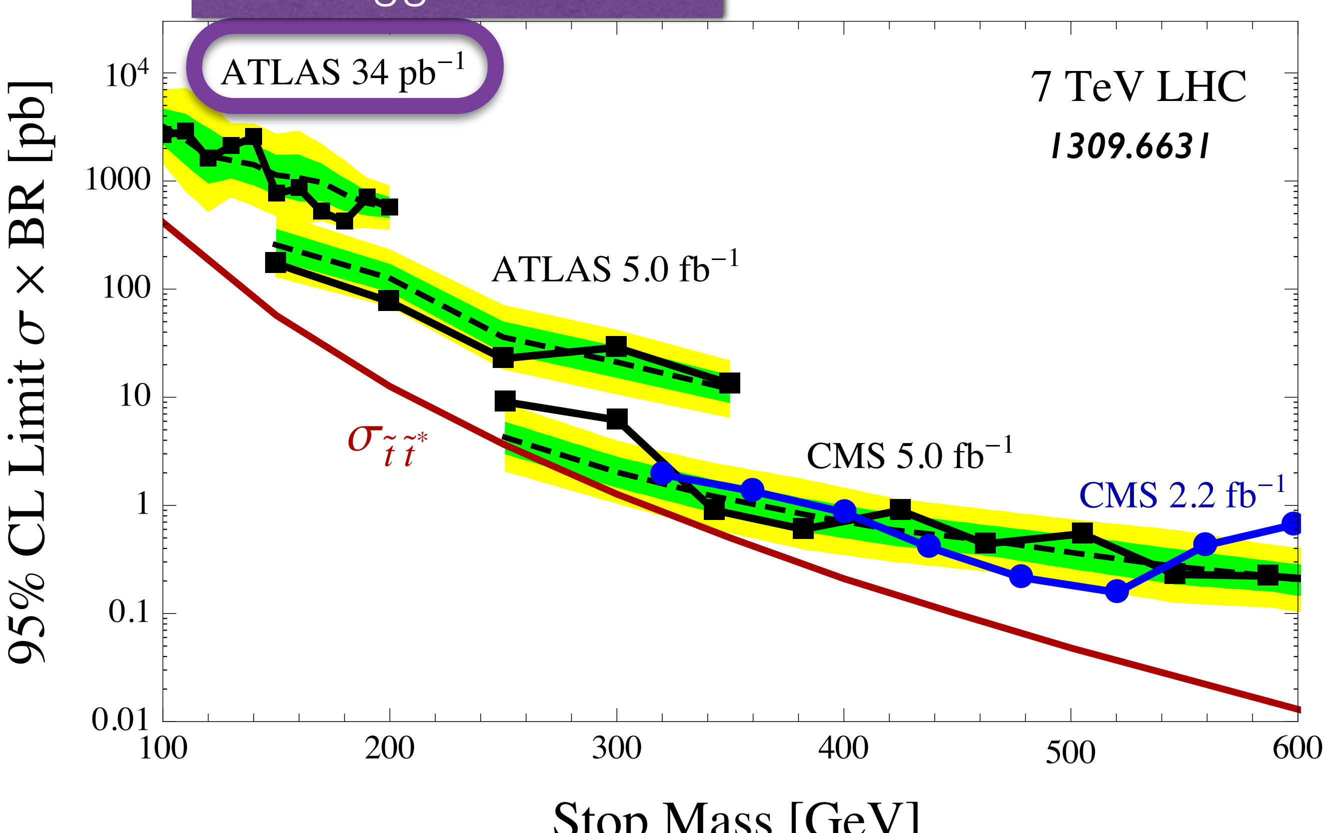
Light bumps are difficult

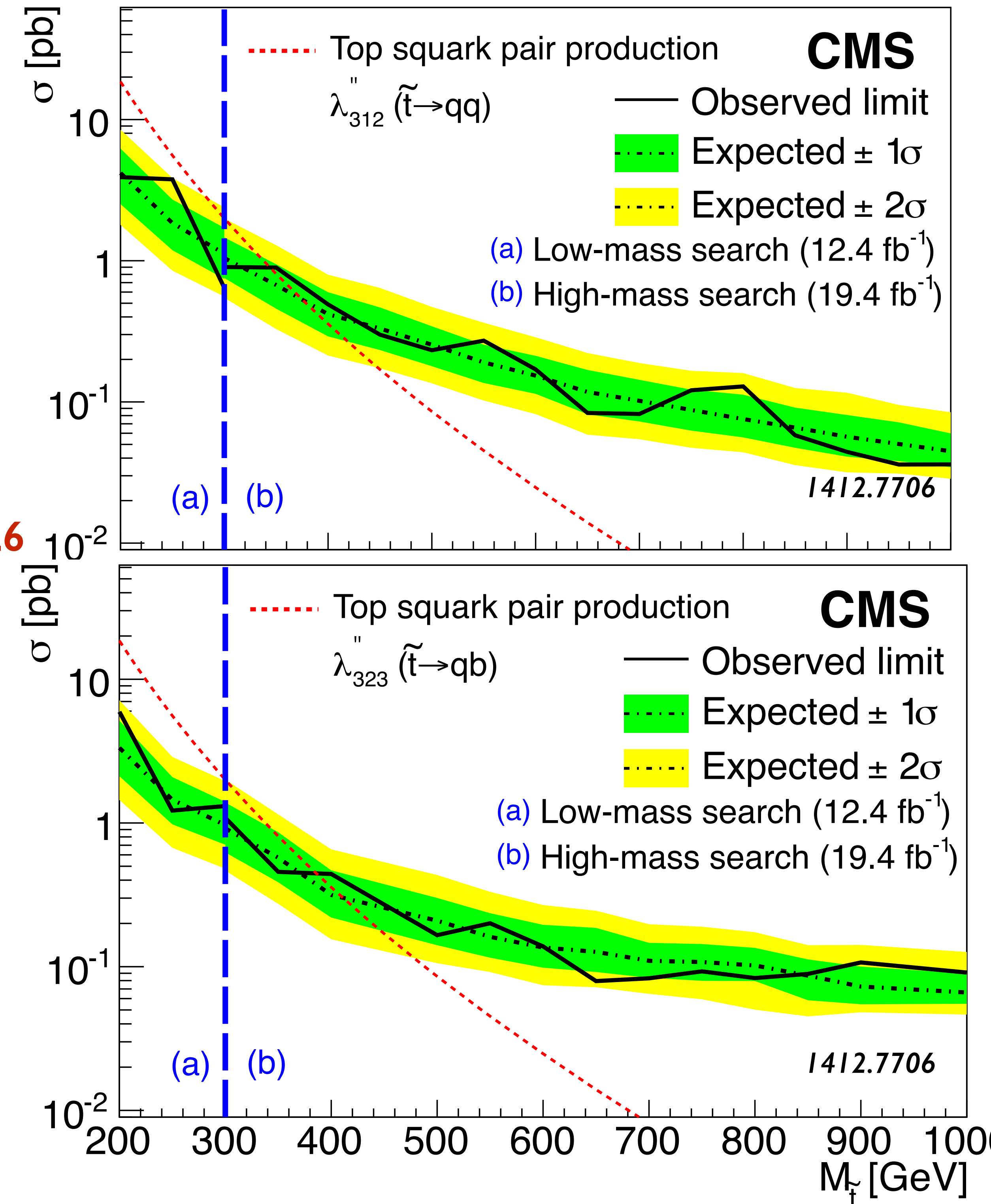


trigger is a killer at low mass

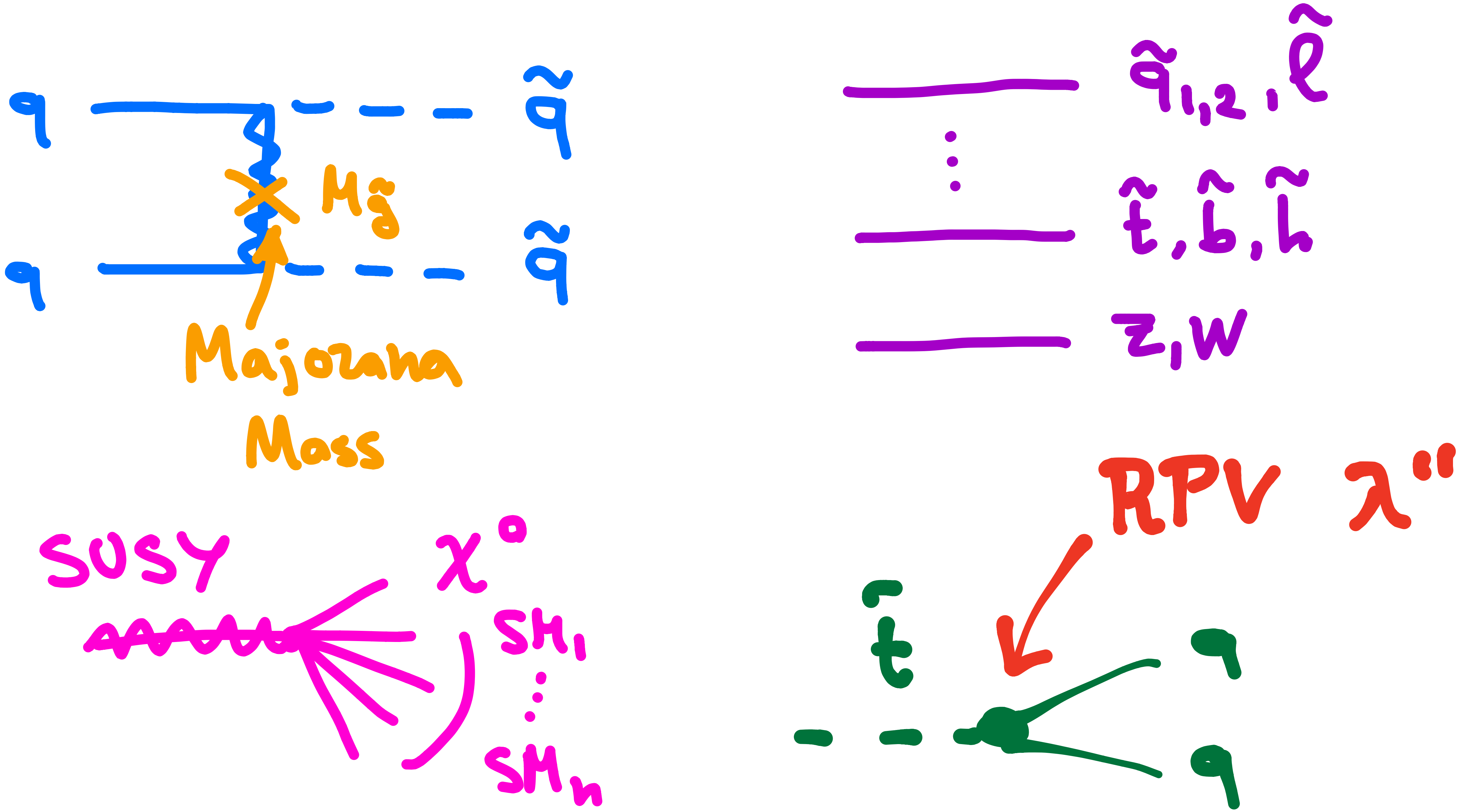
cut&count w/sub-structure in ATLAS-CONF-2015-026

lower trigger thresholds





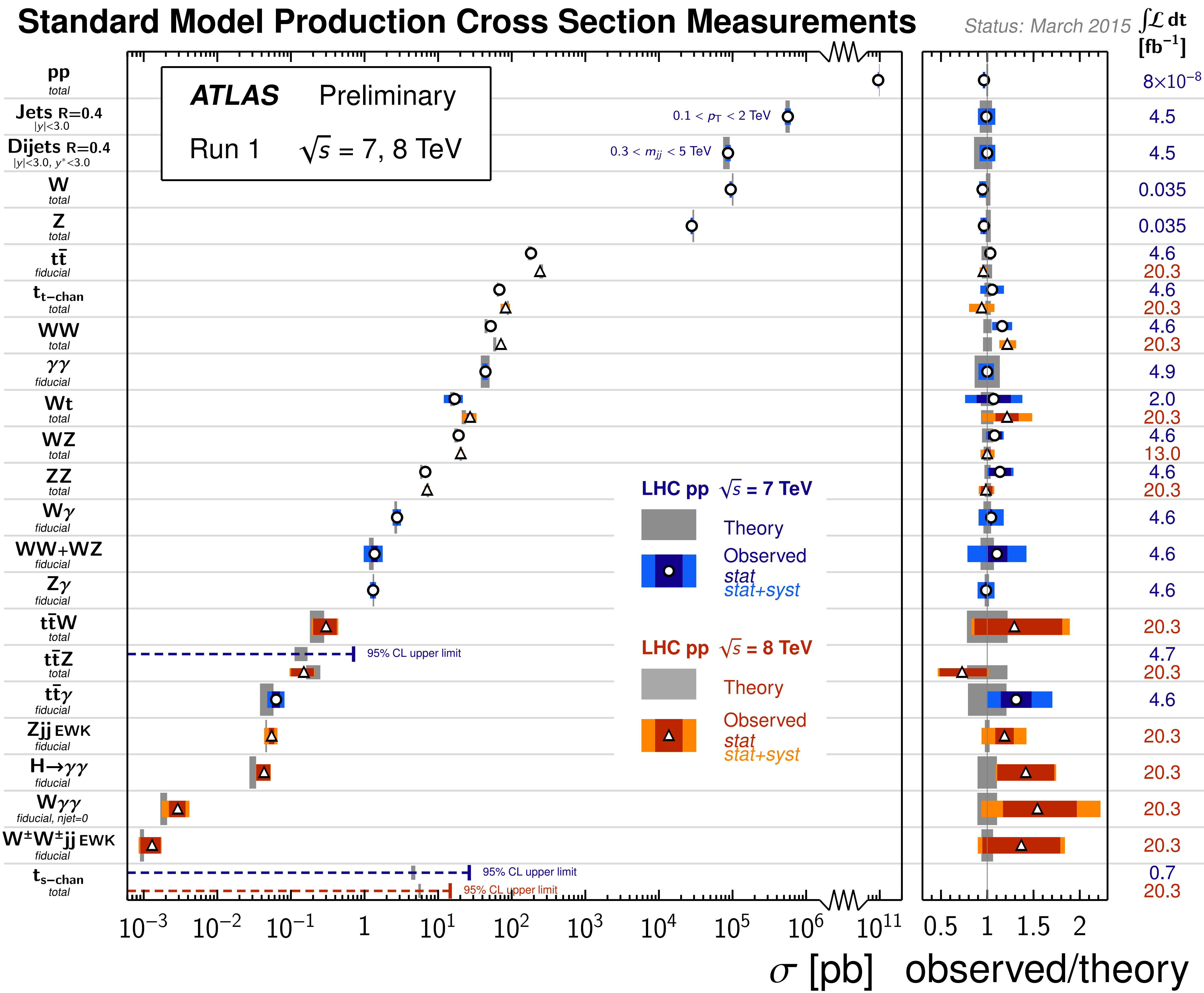
Theory Options



more subtle signals ⇒ precision

Run2 $\simeq$ Subtle New Physics

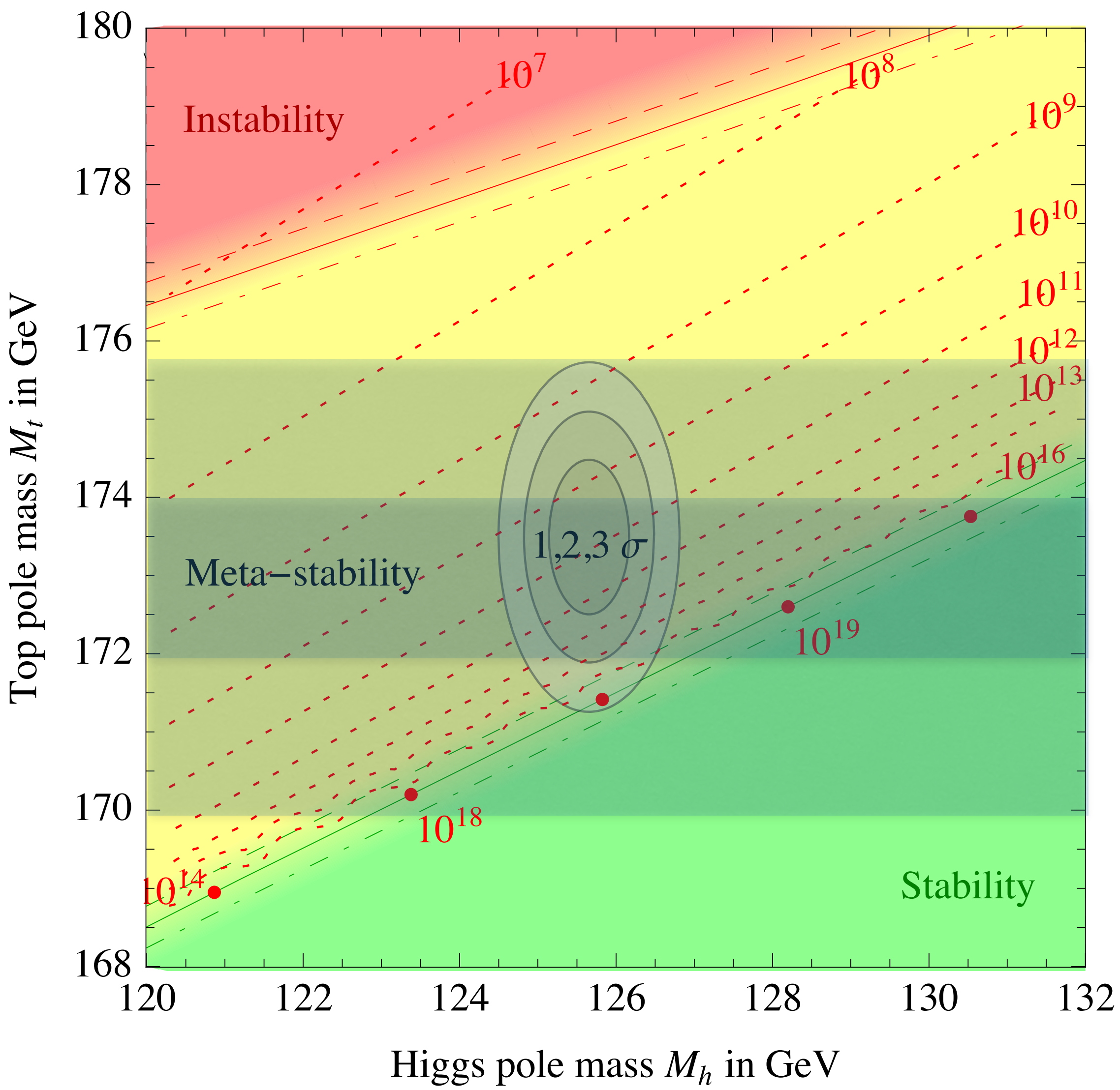
Run2 → Precision Physics

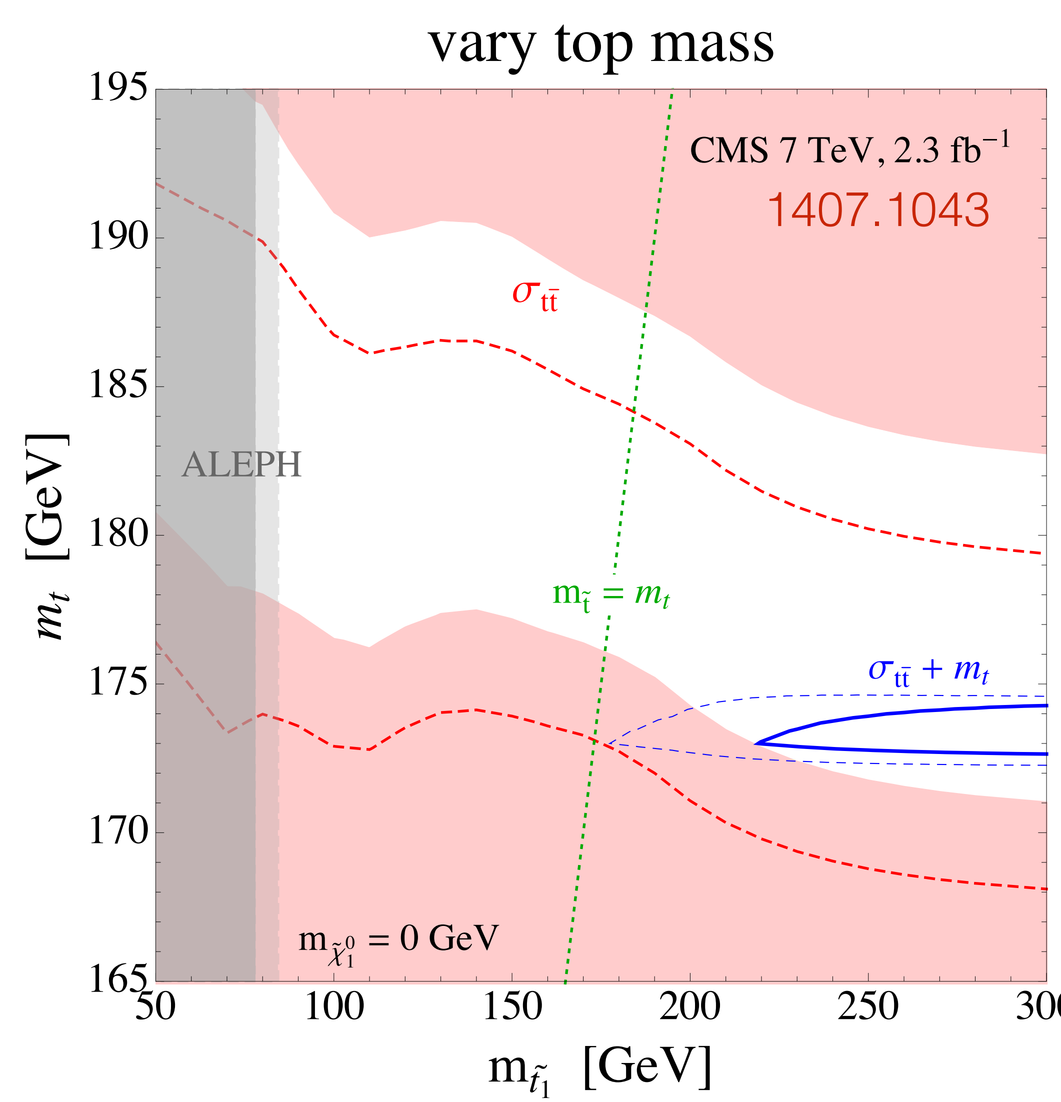


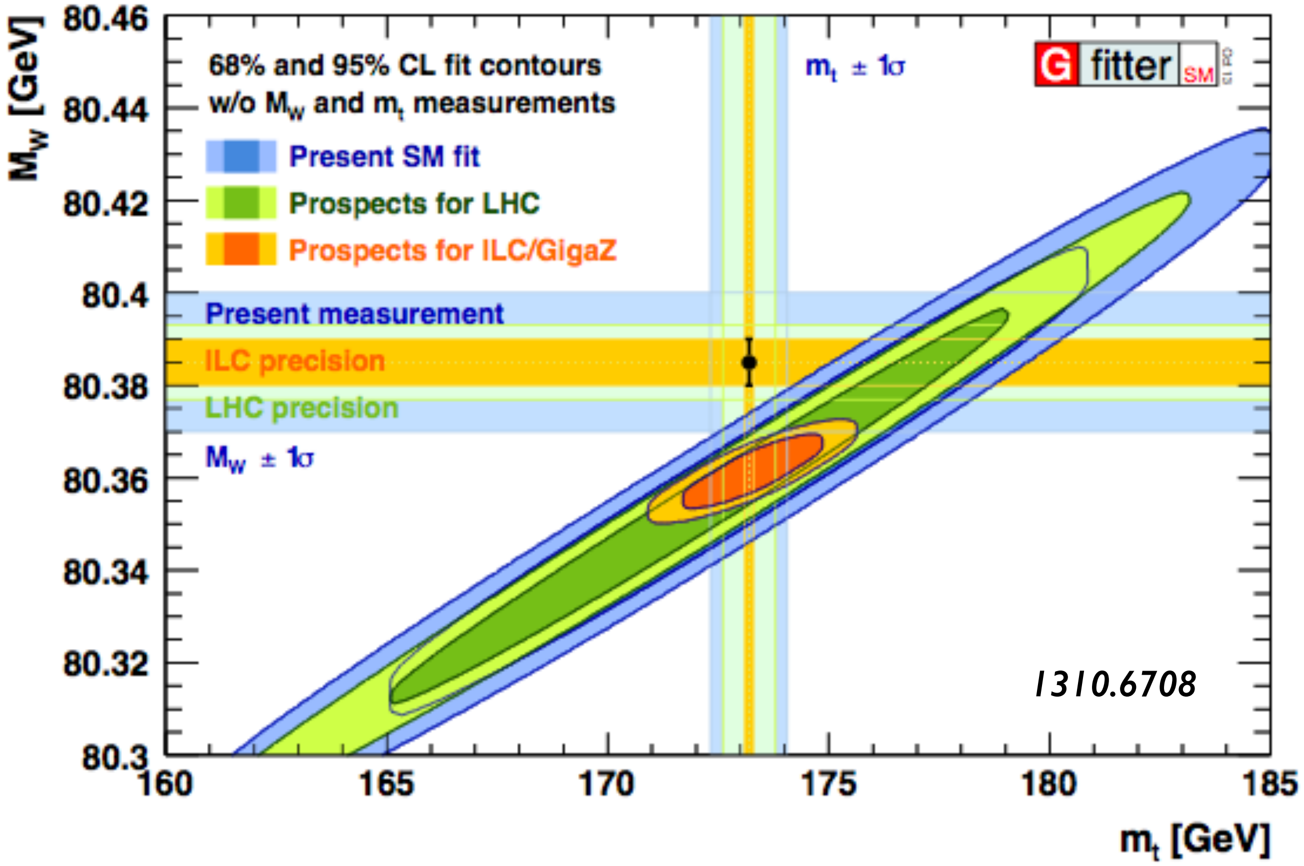
Standard Model Production Cross Section Measurements
Status: March 2015
∫ℒ dt [fb⁻¹]
ATLAS Preliminary
Run 1 √s = 7, 8 TeV
pp total
Jets R=0.4 |y|<3.0
Dijets R=0.4 |y|<3.0, y*<3.0
W total
Z total
tt̄ fiducial
t t-chan total
WW total
γγ fiducial
Wt total
WZ total
ZZ total
Wγ fiducial
WW+WZ fiducial
Zγ fiducial
tt̄W total
tt̄Z total
tt̄γ fiducial
Zjj EWK fiducial
H→γγ fiducial
Wγγ fiducial, njet=0
W±W±jj EWK fiducial
t s-chan total
0.1 < pT < 2 TeV
0.3 < mjj < 5 TeV
95% CL upper limit
LHC pp √s = 7 TeV
Theory
Observed
stat
stat+syst
LHC pp √s = 8 TeV
Theory
Observed
stat
stat+syst
8×10⁻⁸
4.5
4.5
0.035
0.035
4.6
20.3
4.6
20.3
4.6
20.3
4.9
2.0
20.3
4.6
13.0
4.6
20.3
4.6
4.6
4.6
20.3
4.7
20.3
4.6
20.3
20.3
20.3
20.3
0.7
20.3
10⁻³ 10⁻² 10⁻¹ 1 10¹ 10² 10³ 10⁴ 10⁵ 10⁶ 10¹¹
0.5 1 1.5 2
σ [pb]
observed/theory

Outline

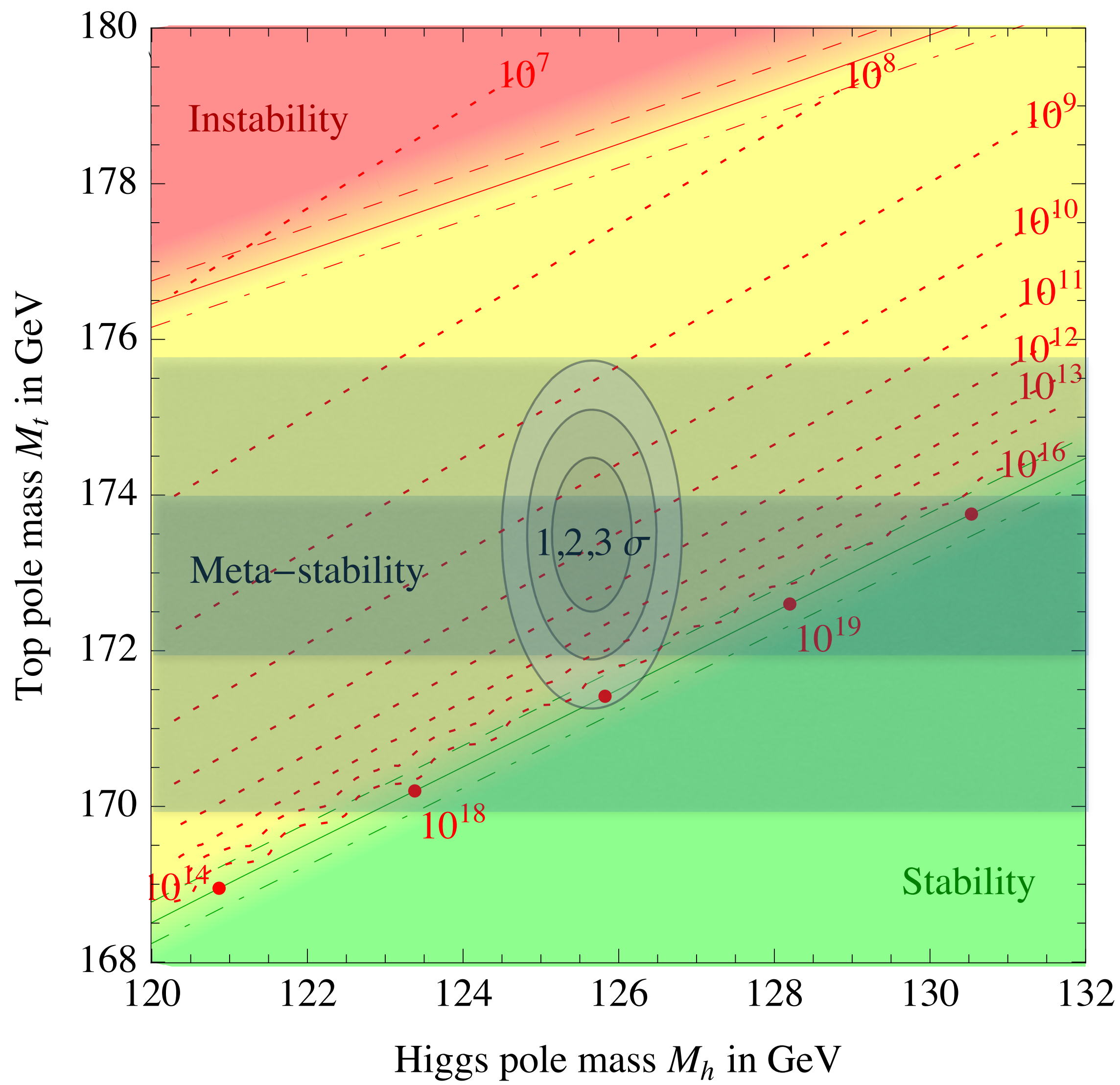
- Top quark mass from energy spectra
- Precision top observables and SUSY blind-spots


Top pole mass M_t in GeV
Higgs pole mass M_h in GeV
Instability
Meta−stability
Stability
1,2,3 σ
10^7
10^8
10^9
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}
10^{16}
10^{18}
10^{19}
180
178
176
174
172
170
168
120
122
124
126
128
130
132


vary top mass
CMS 7 TeV, 2.3 fb^{-1}
1407.1043
$\sigma_{t\bar{t}}$
ALEPH
$m_{\tilde{t}} = m_t$
$\sigma_{t\bar{t}} + m_t$
$m_{\tilde{\chi}_1^0} = 0$ GeV
m_t [GeV]
$m_{\tilde{t}_1}$ [GeV]
195
190
185
180
175
170
165
50
100
150
200
250
300



68% and 95% CL fit contours
w/o M_W and m_t measurements
Present SM fit
Prospects for LHC
Prospects for ILC/GigaZ
Present measurement
ILC precision
LHC precision
$M_W \pm 1\sigma$
$m_t \pm 1\sigma$
G fitter SM
1310.6708
M_W [GeV]
m_t [GeV]



Instability
Meta−stability
Stability
1,2,3 σ
10^7
10^8
10^9
10^{10}
10^{11}
10^{12}
10^{13}
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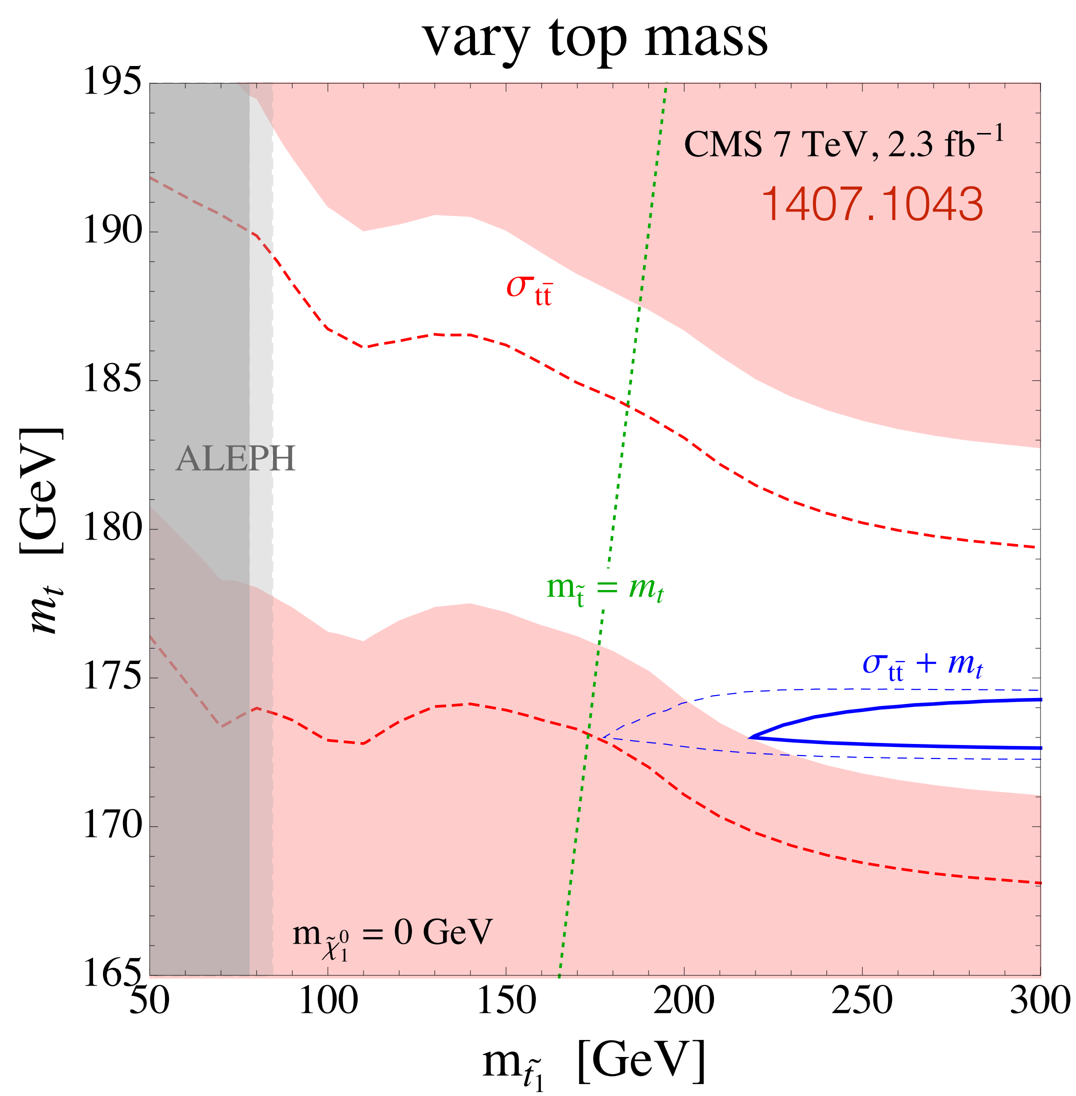
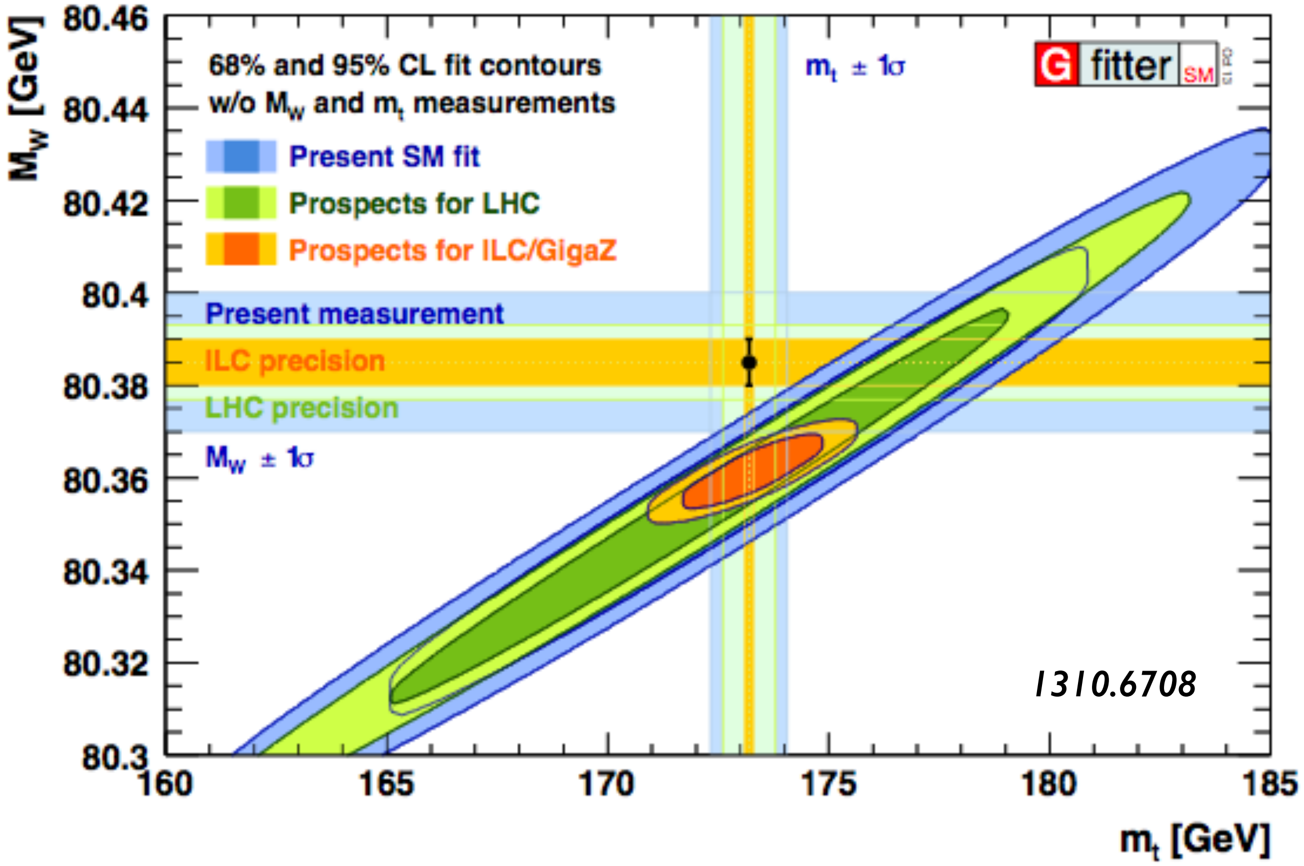
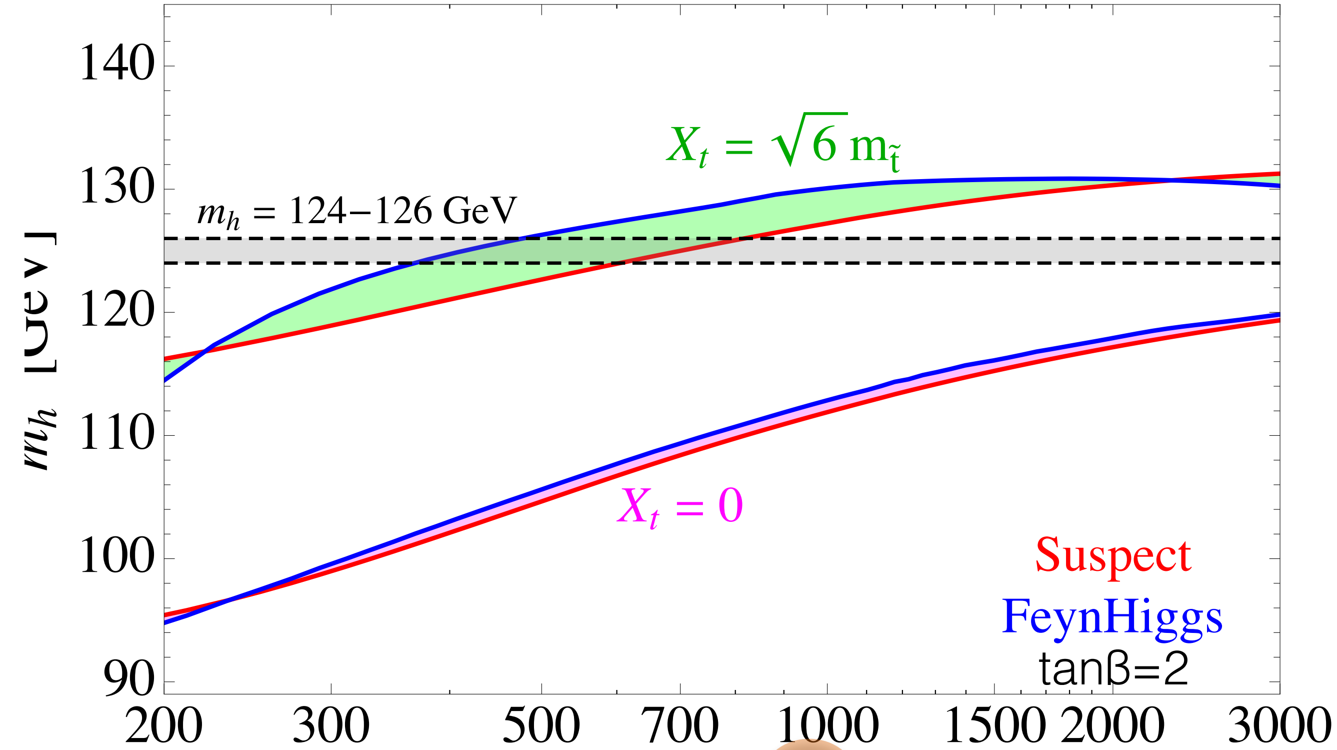
Higgs pole mass M_h in GeV

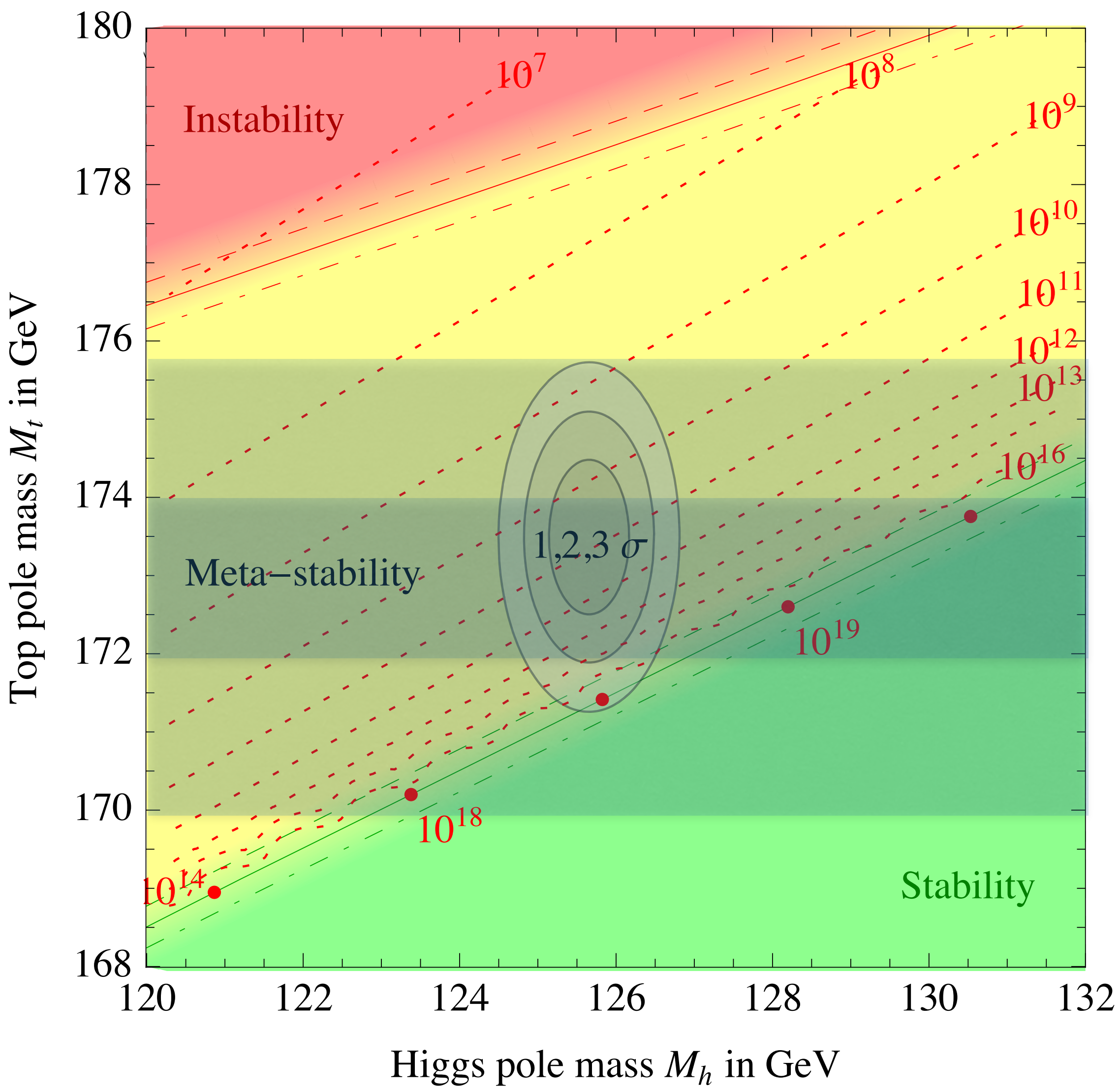


vary top mass
CMS 7 TeV, 2.3 fb^{-1}
1407.1043
ALEPH
$\sigma_{t\bar{t}}$
$m_{\tilde{t}} = m_t$
$\sigma_{t\bar{t}} + m_t$
$m_{\tilde{\chi}_1^0} = 0$ GeV
m_t [GeV]
$m_{\tilde{t}_1}$ [GeV]

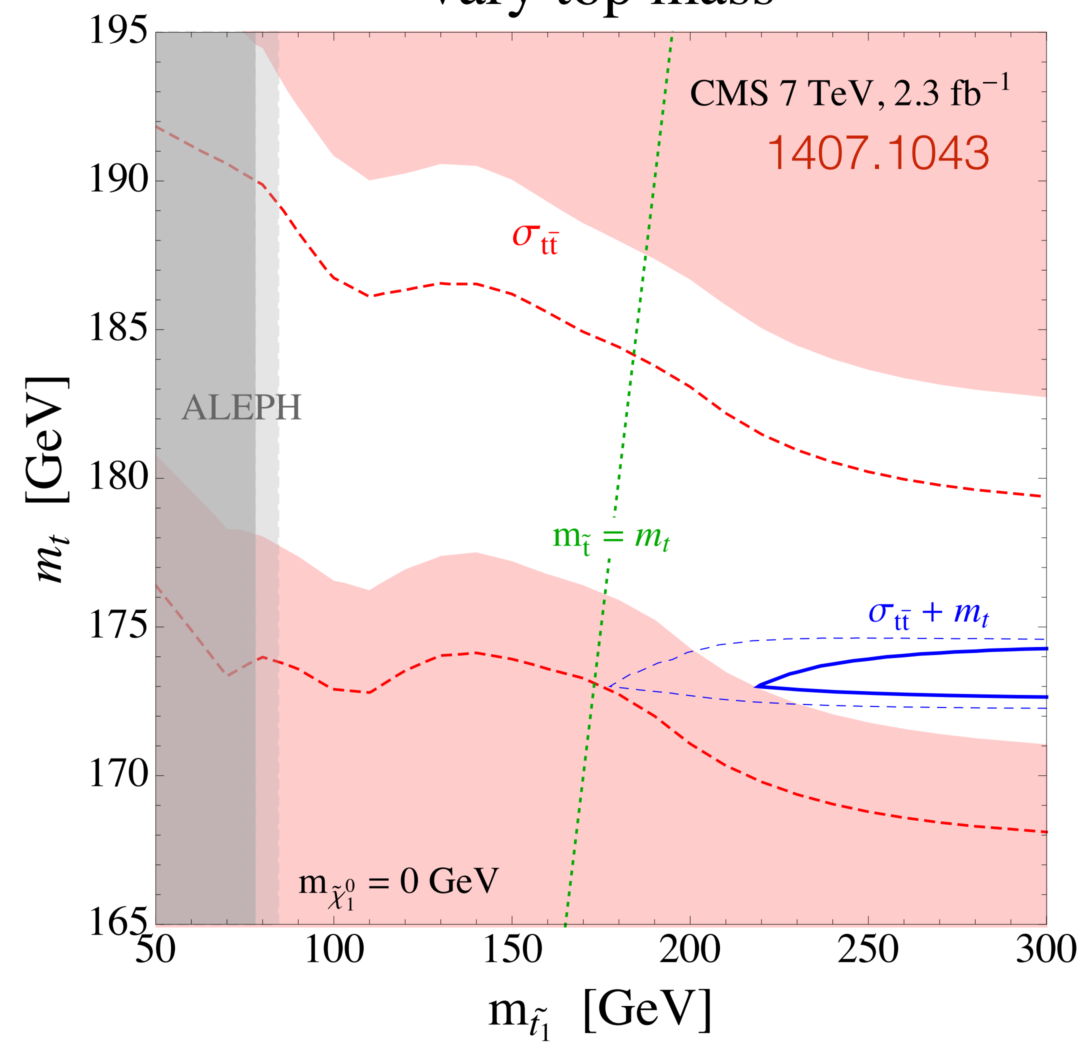




$$m_h^2 \approx m_Z^2 \cos^2 2\beta + \frac{3}{(4\pi)^2}\frac{m_t^4}{v^2}\left[\ln\frac{m_{\tilde{t}}^2}{m_t^2} + \frac{X_t^2}{m_{\tilde{t}}^2}\left(1 - \frac{X_t^2}{12 m_{\tilde{t}}^2}\right)\right]$$



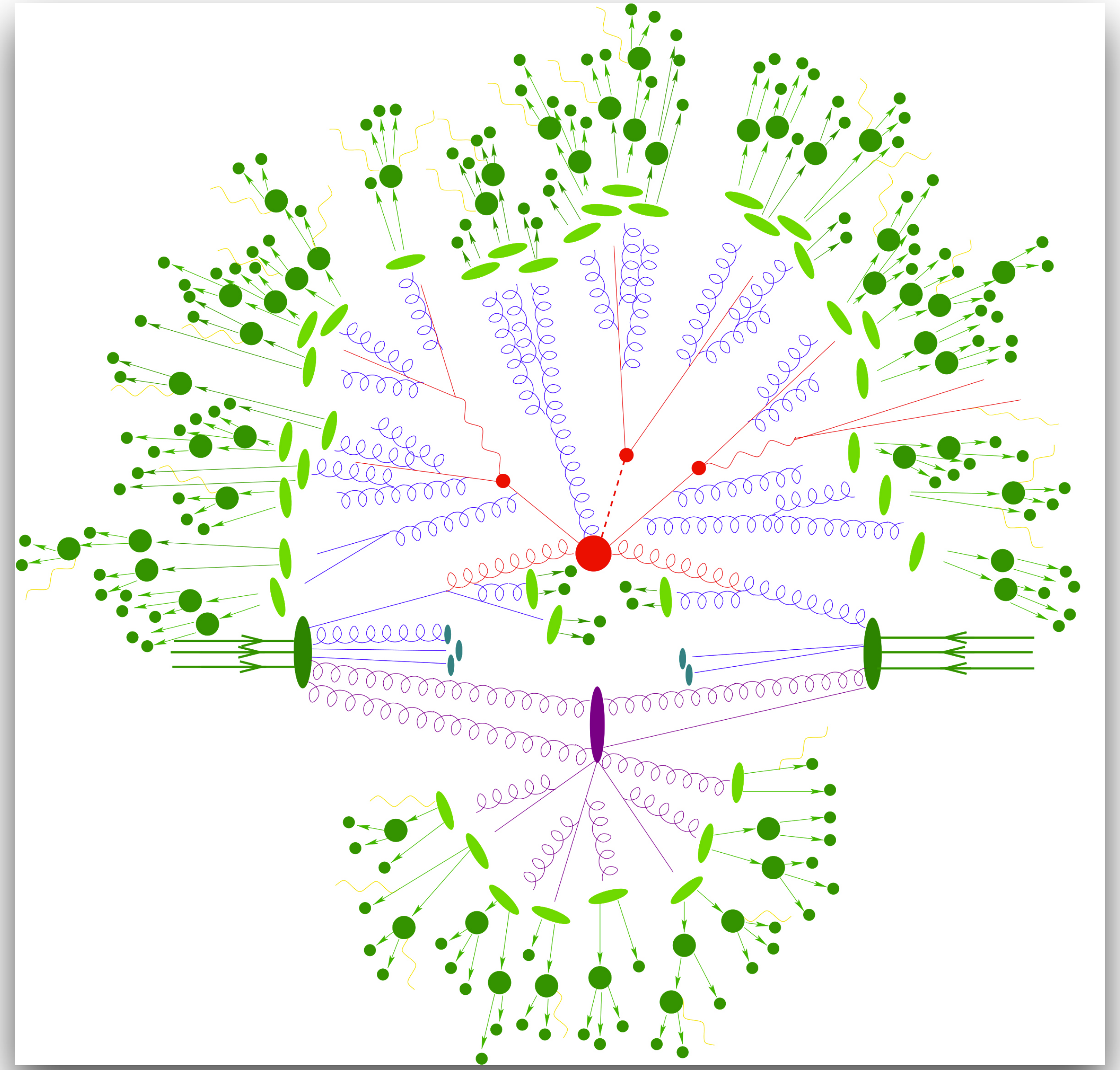
vary top mass



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

Many measurements

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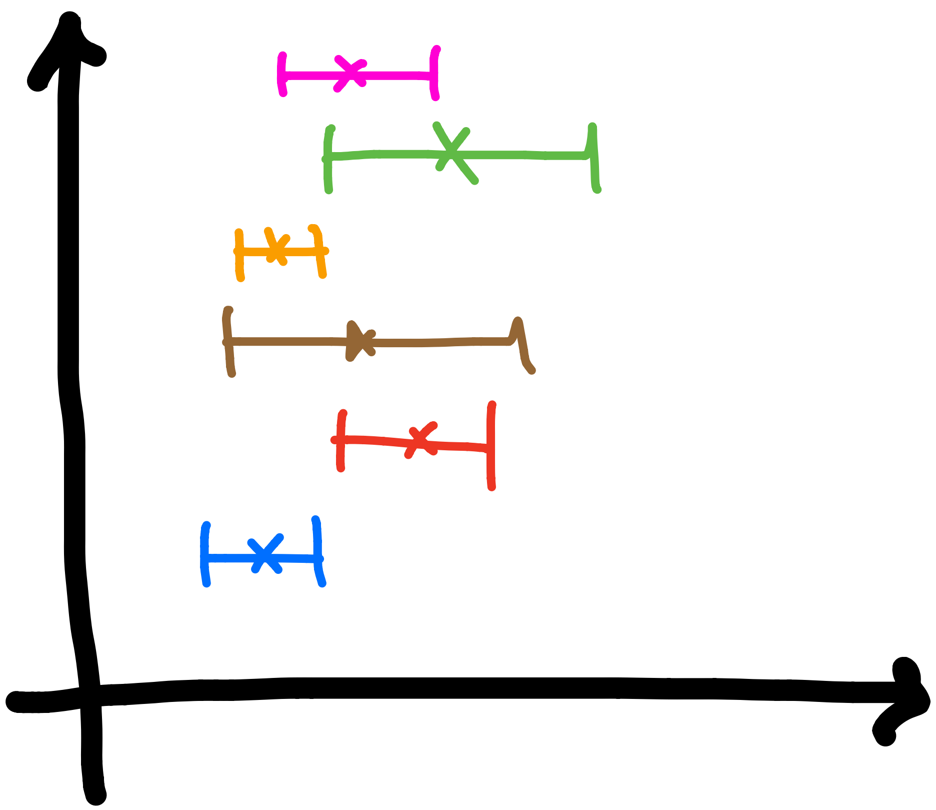
Many measurements



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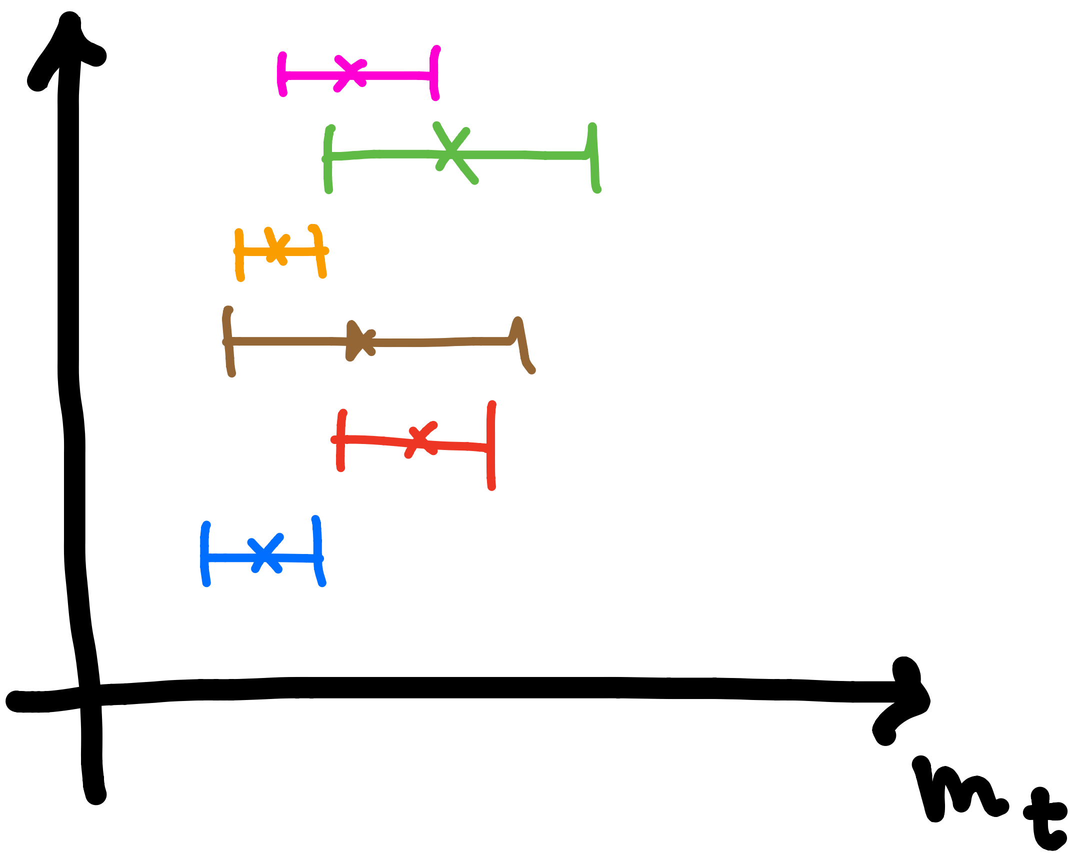
Many measurements



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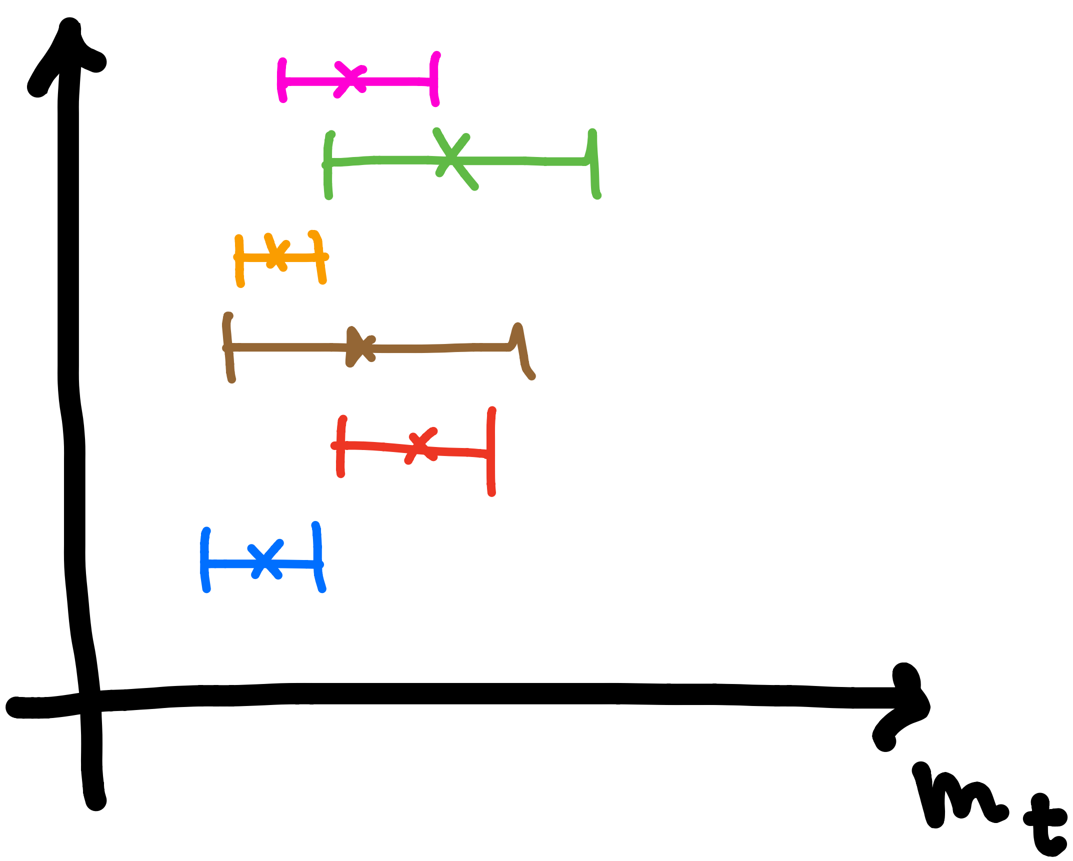
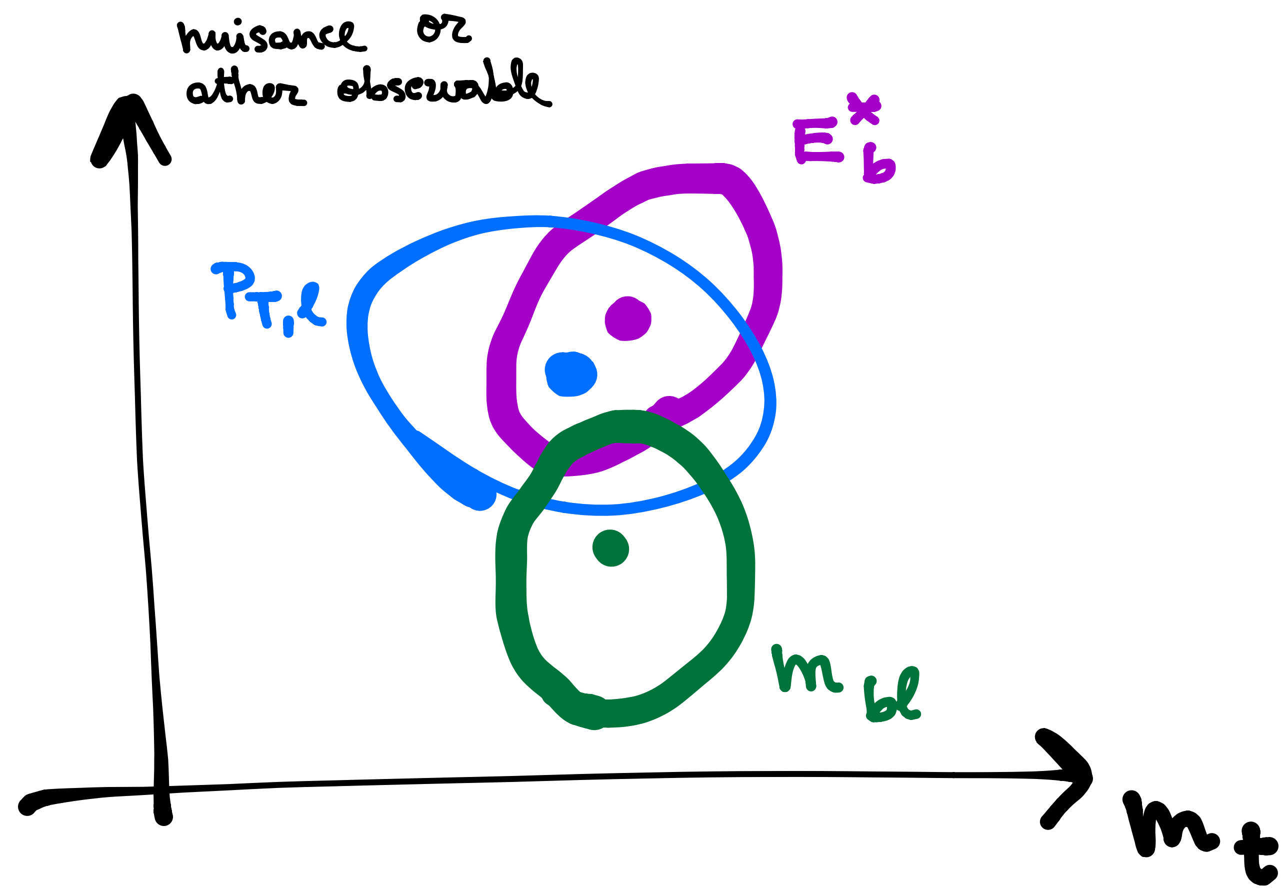
Many measurements





The strength of the future LHC top mass measurement will build on the **diversity of methods**
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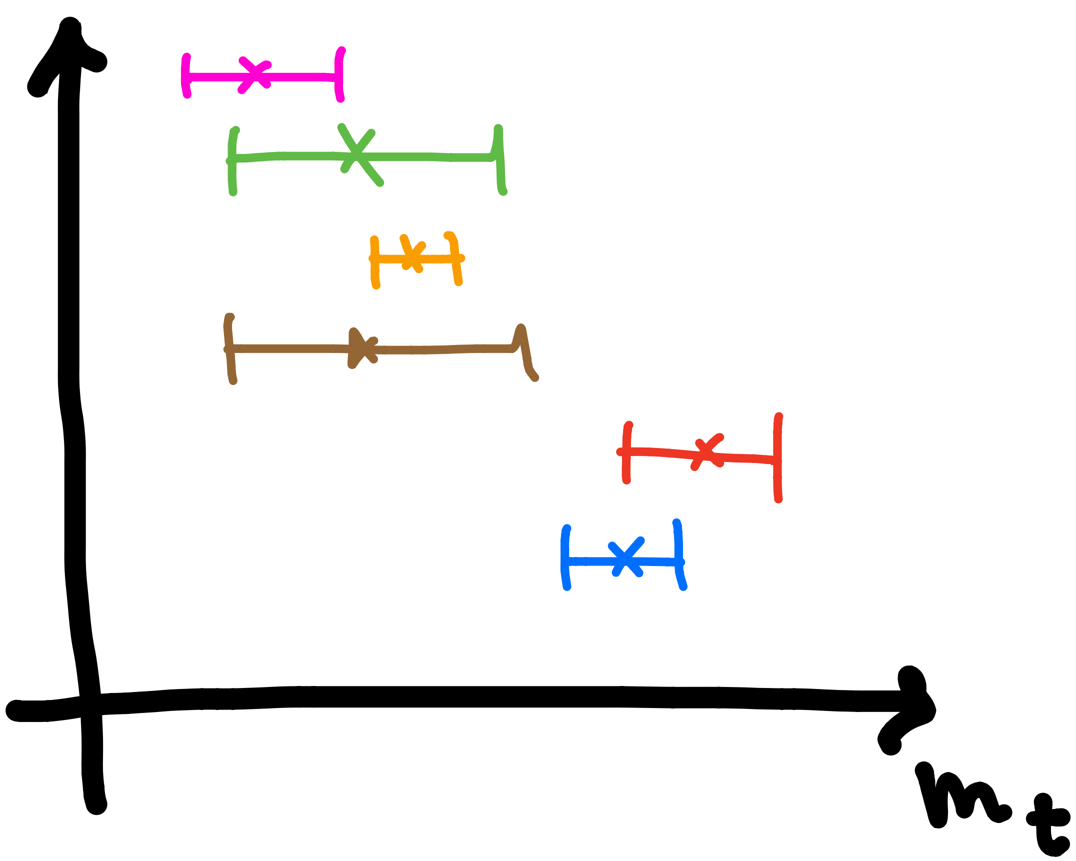
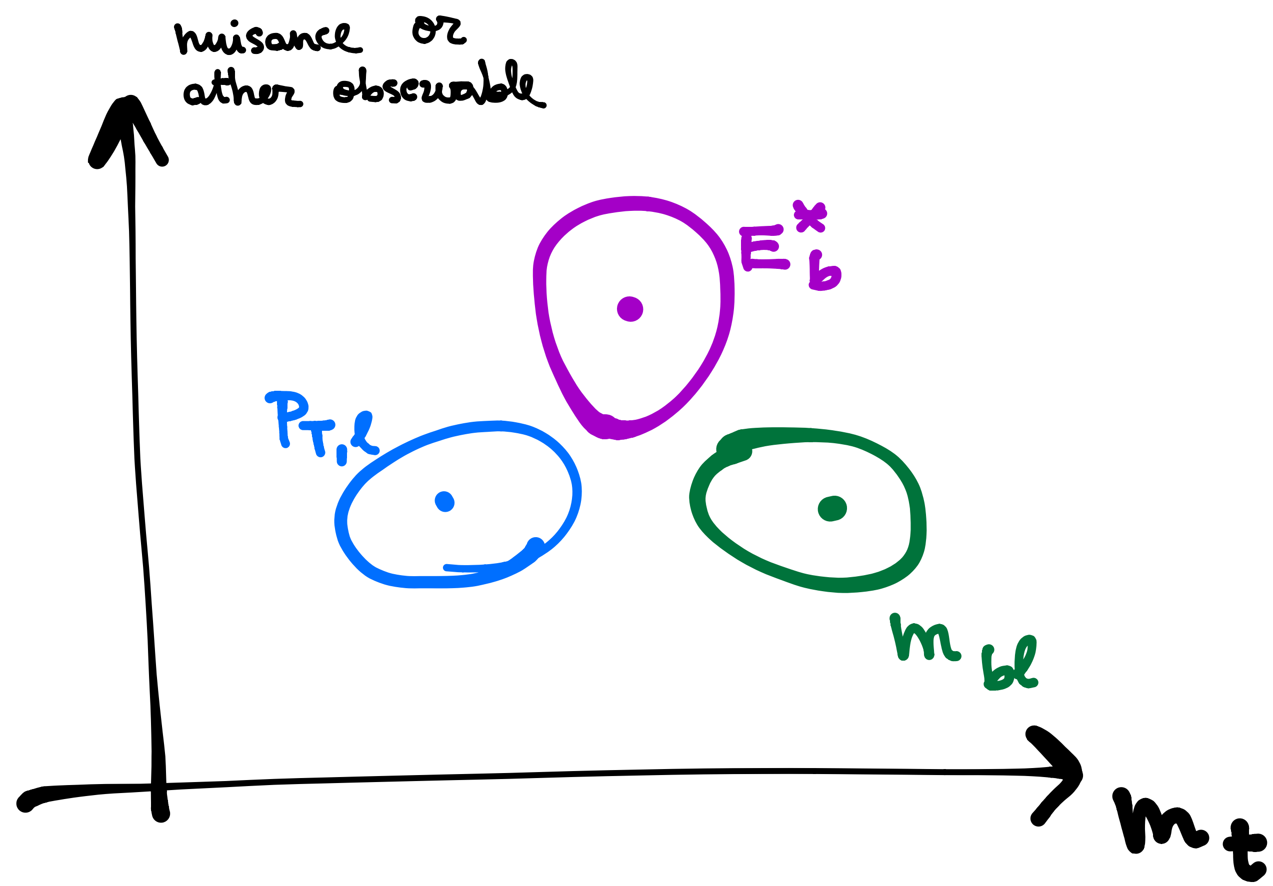
Many measurements

due to different hypothesis, different mass measurement methods can result in significantly disagreeing measurements: **QCD or new physics effect?**





The strength of the future LHC top mass measurement will build on the **diversity of methods**
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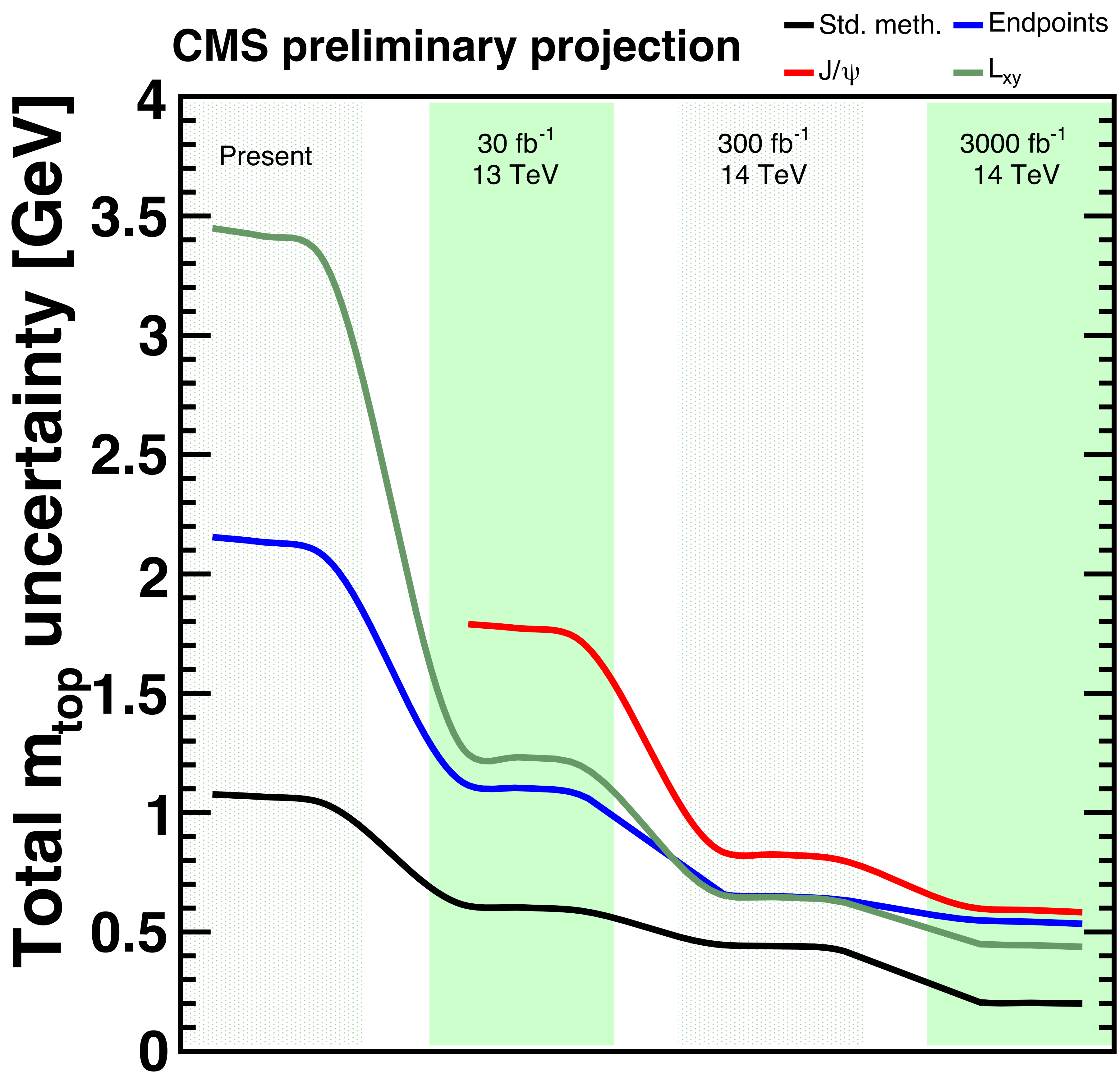
Ideal situation



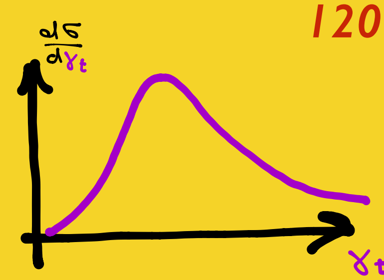
CMS-PAS-FTR-13-017

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

Lab-frame energy distribution

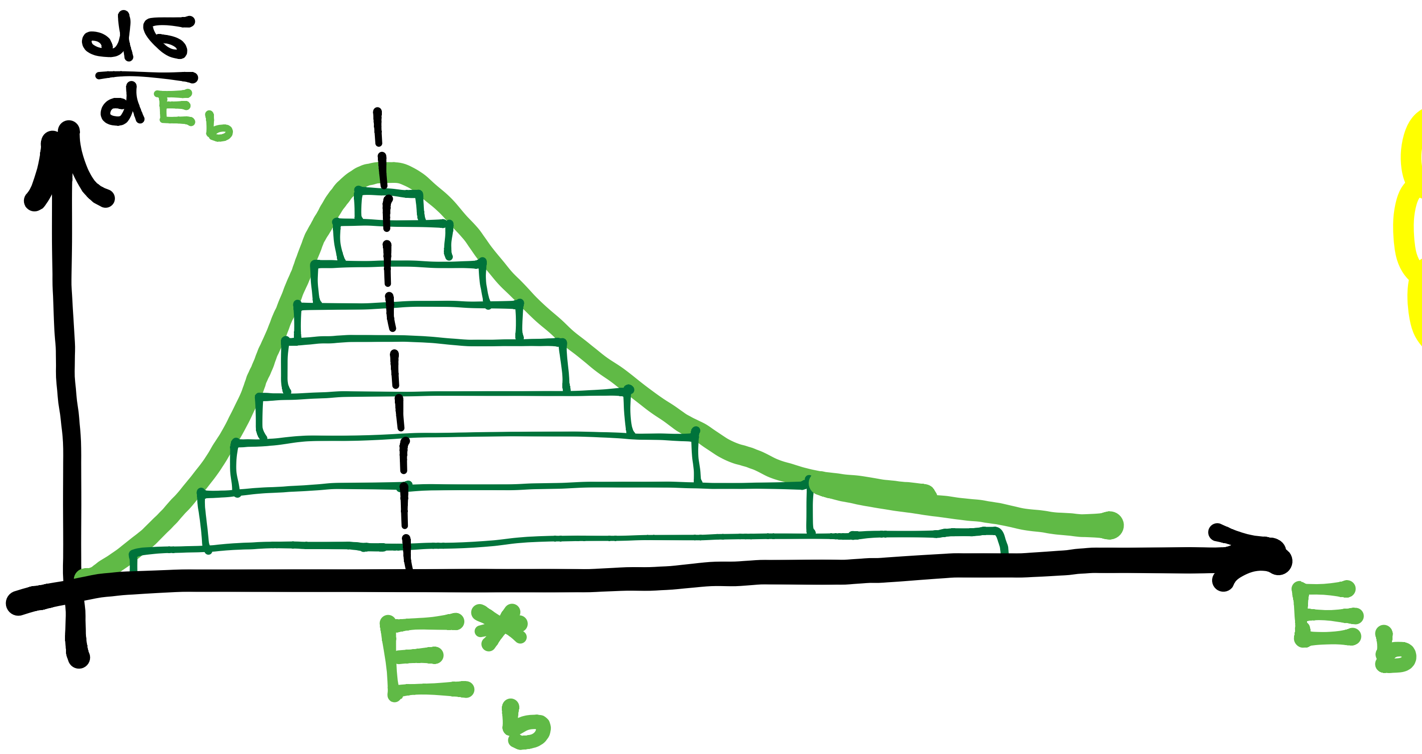
1209.0772 - Agashe, Franceschini and Kim

also Stecker 1971

for any top boost distribution 

the peak:

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



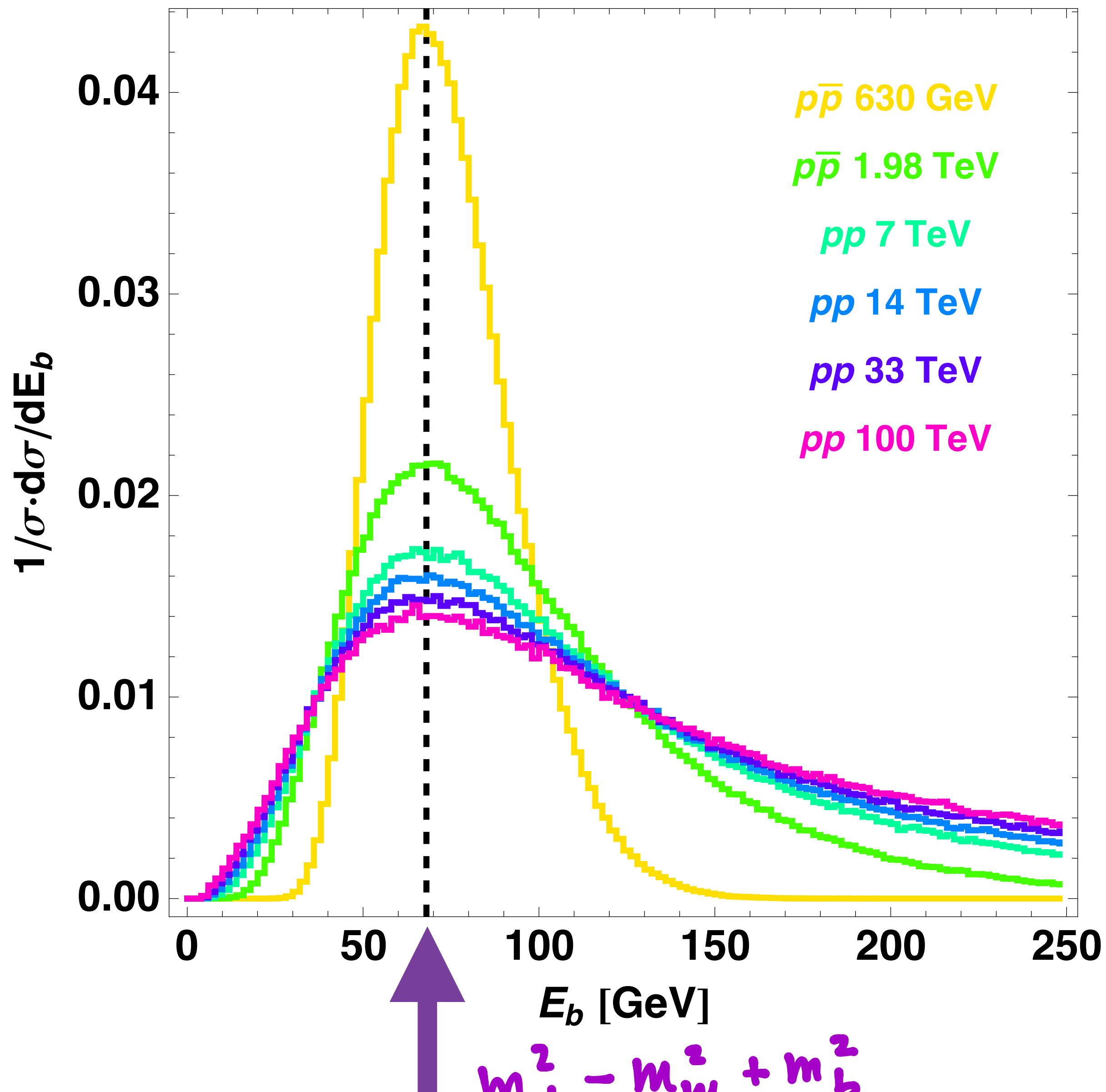
THE FRAME-DEPENDENT ENERGY DISTRIBUTION ENCODES THE INVARIANT E^*_b IN A VERY SIMPLE WAY

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

How special is this invariance?

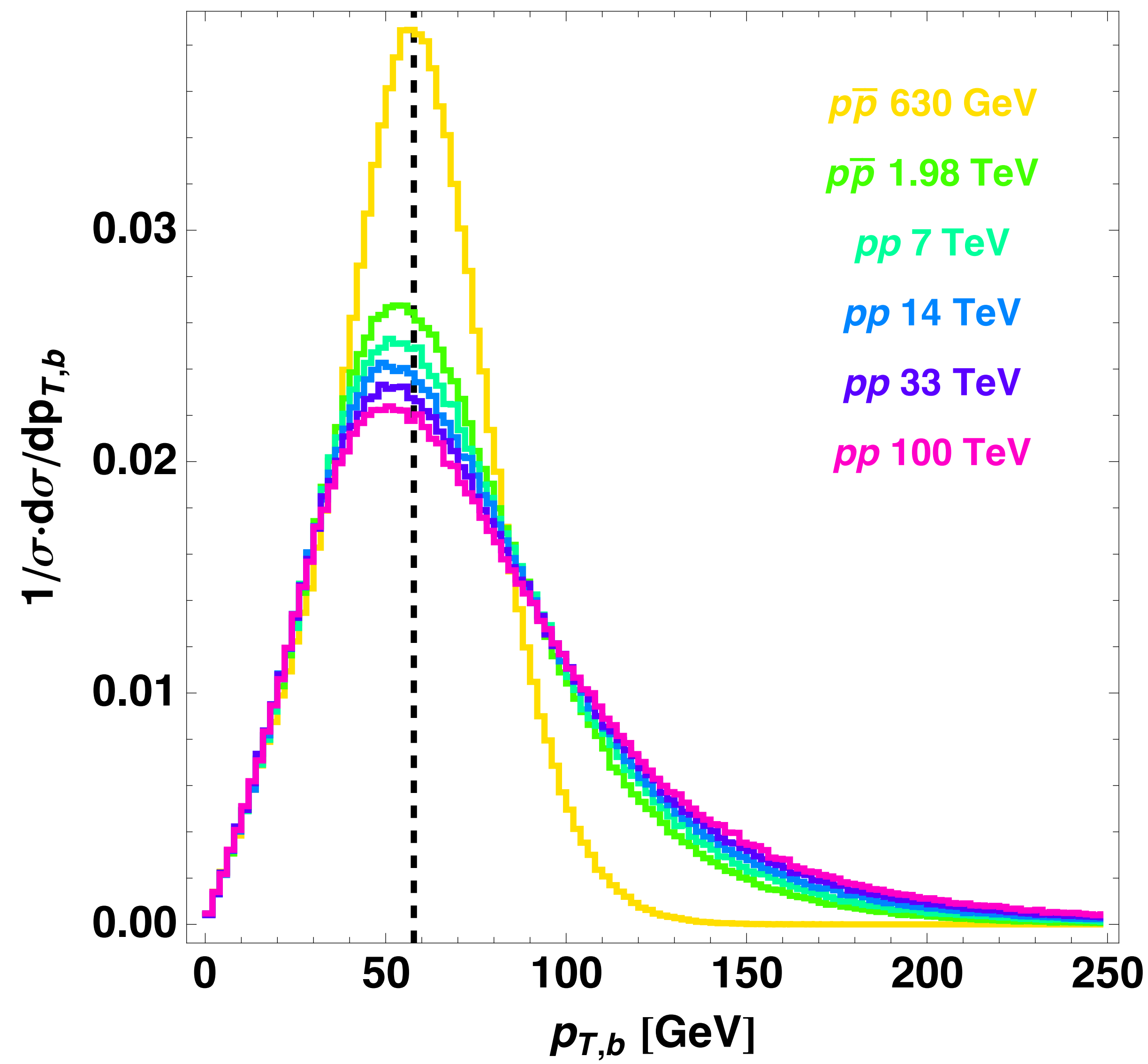
1209.0772 - Agashe, Franceschini and Kim

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

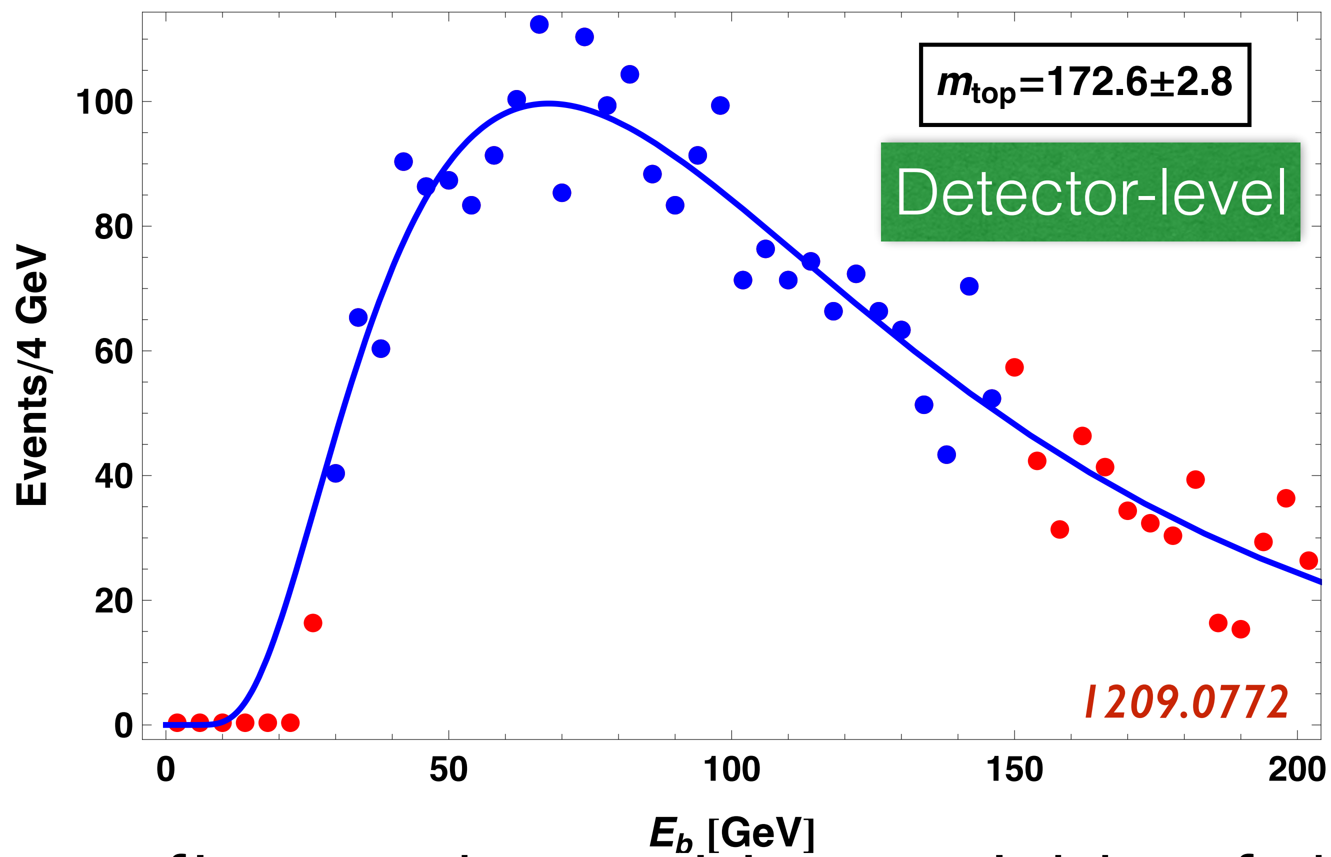
- properties similar to Lorentz invariants

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!

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

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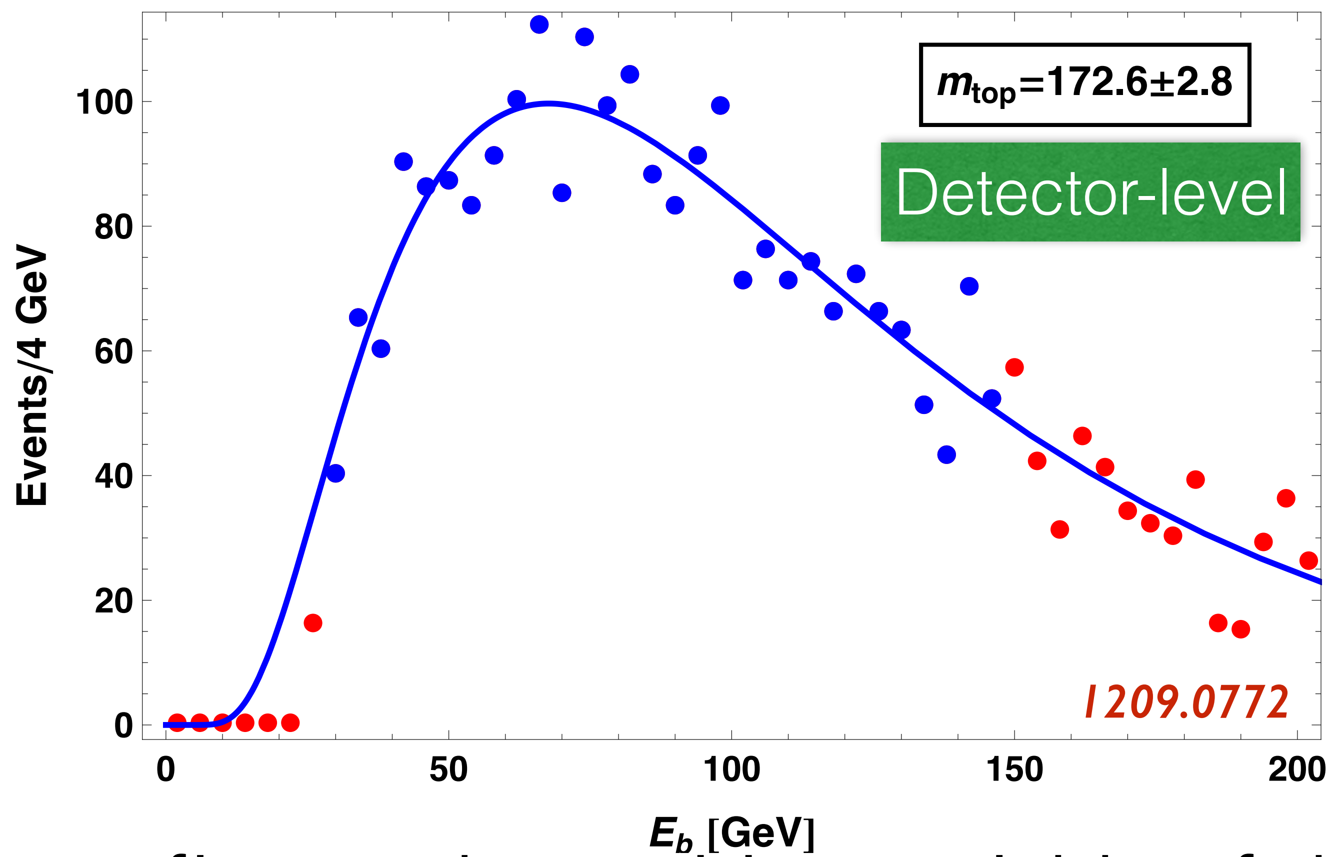


2-parameters fit: peak position, width of the distribution

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

m_{top}=173.1(1±α/π)± 2.5 GeV (stat)

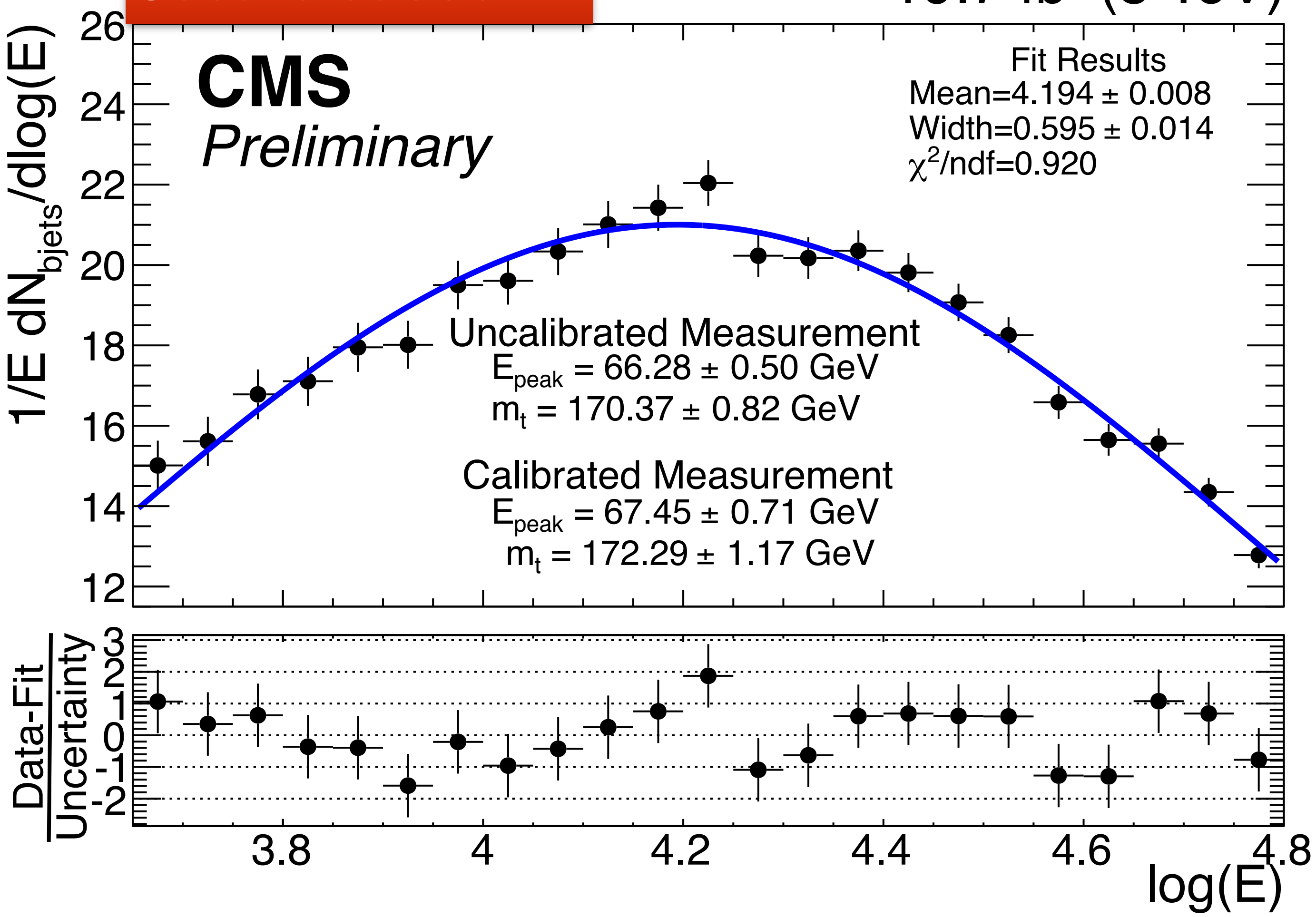
1209.0772 - Agashe Franceschini and Kim

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

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

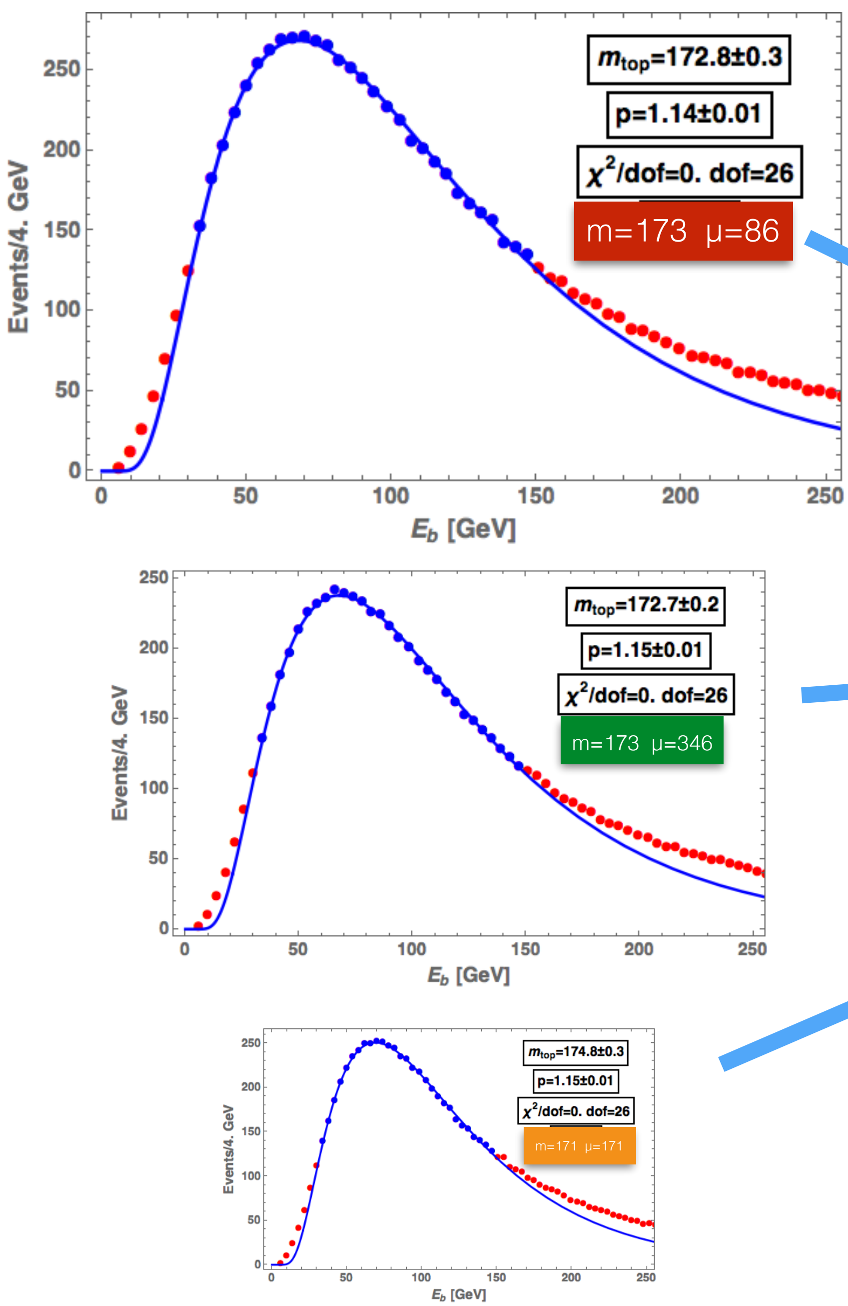
leading uncertainty from theory can be reduced

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

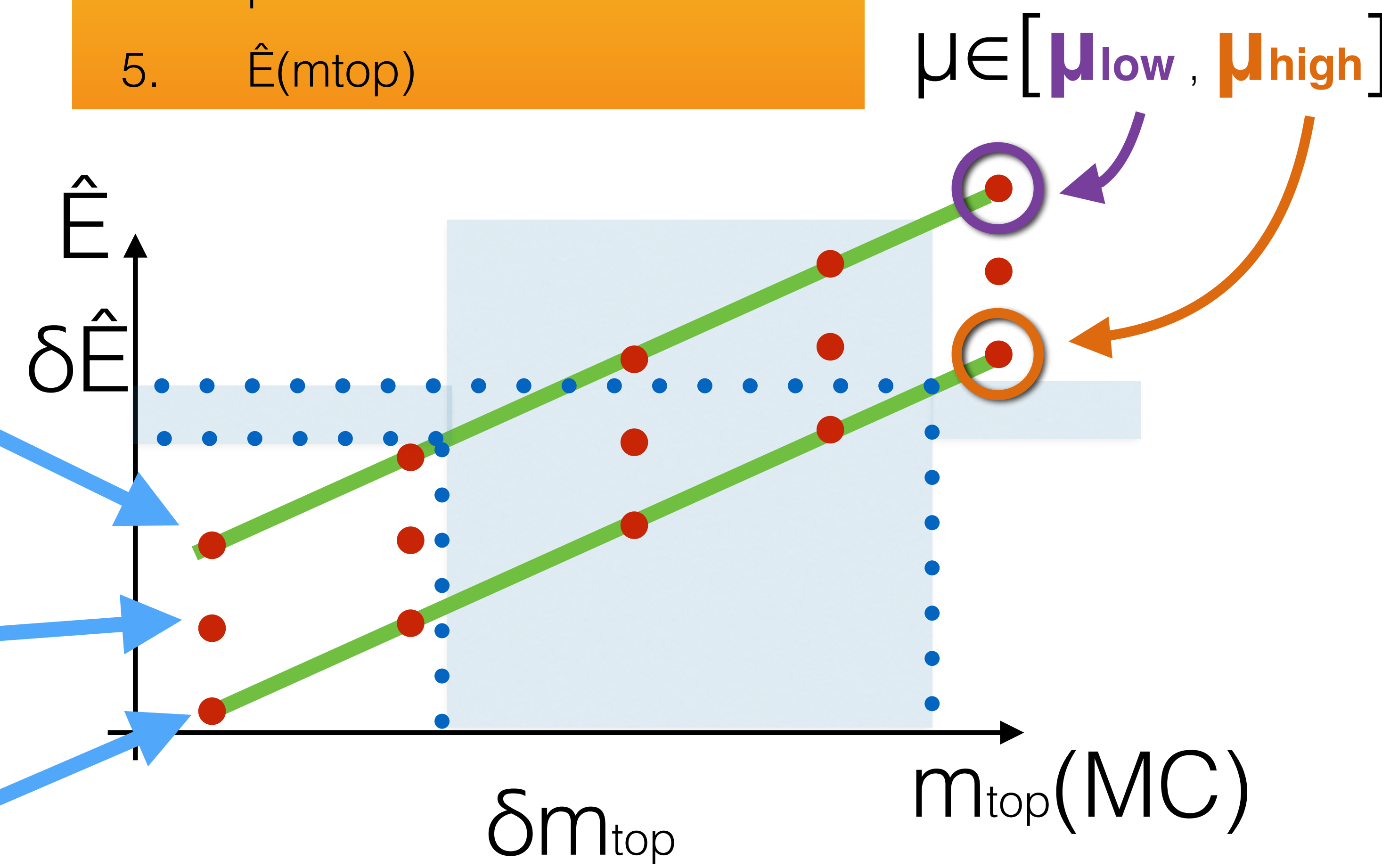
pQCD

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)



energy peaks



Best:

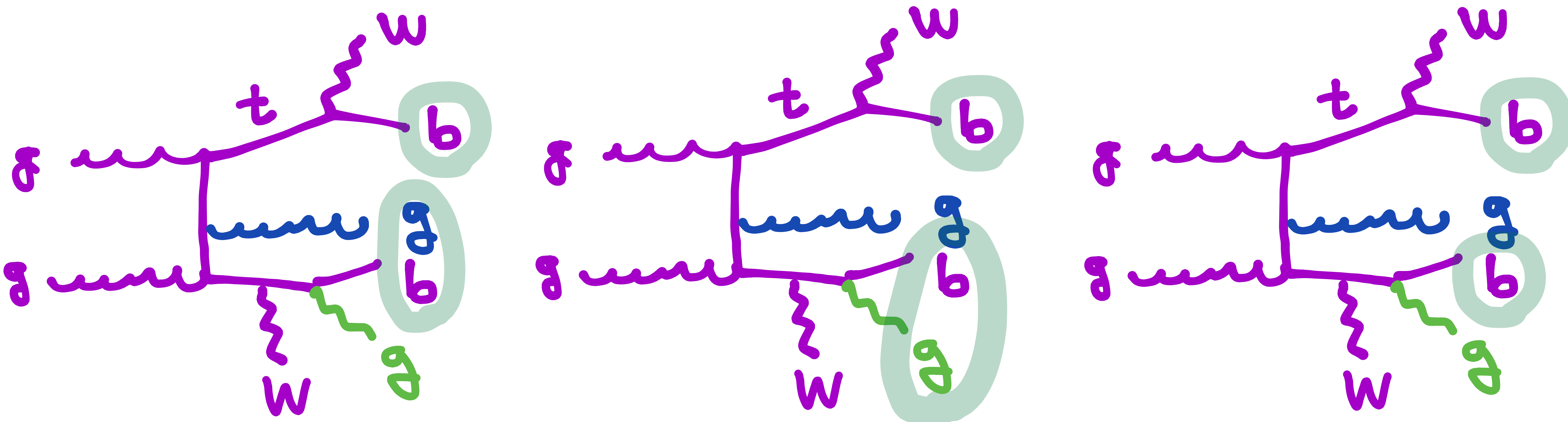
- narrow band between μ_{high} and μ_{low}
- steep E vs. m_{top}

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

NLO: production & decay

(MCFM)

Agashe, RF, Kim, Schulze - in preparation



NLO $E^*(m_{top})$

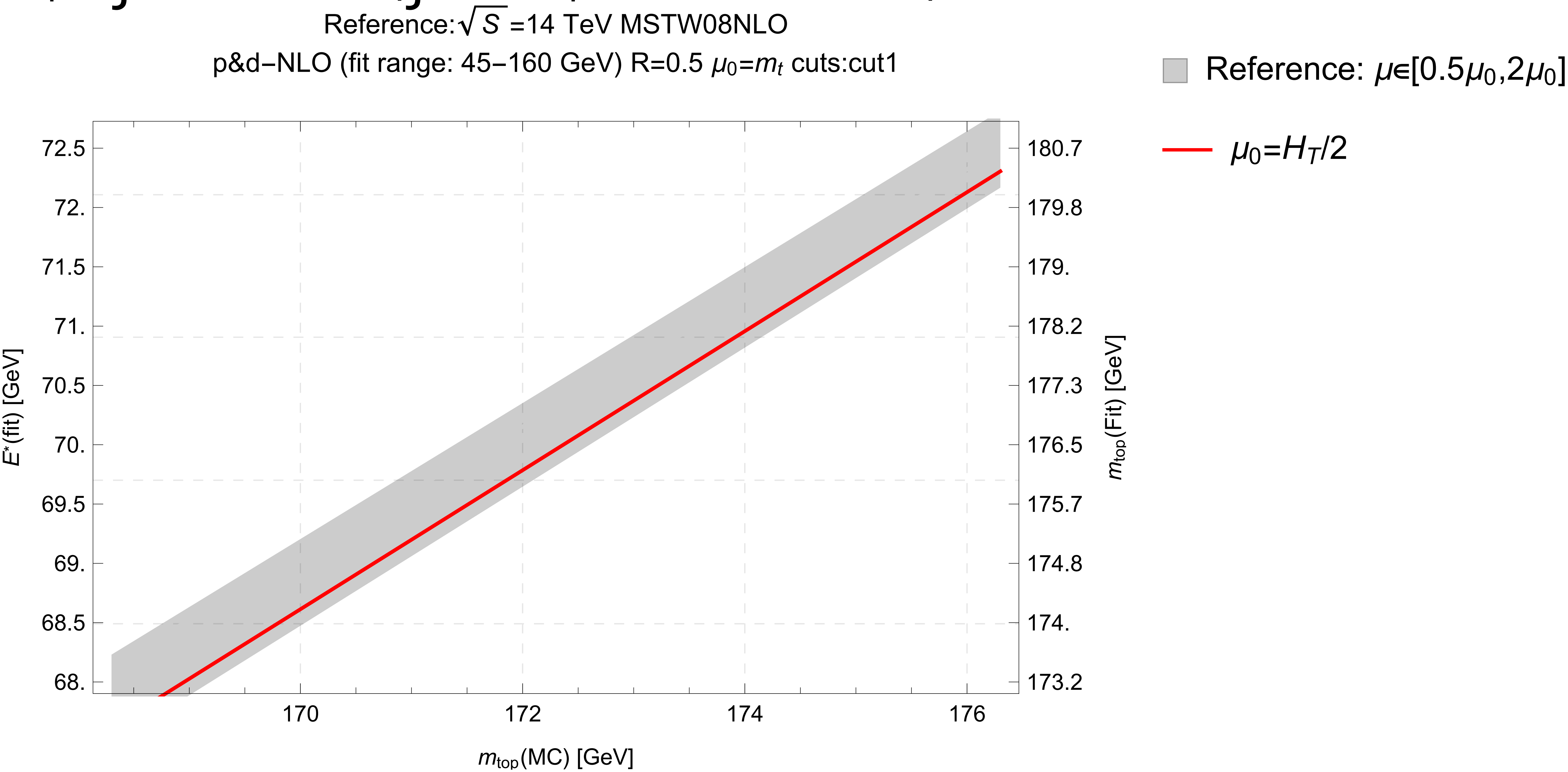
Agashe, RF, Kim, Schulze - in preparation

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

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

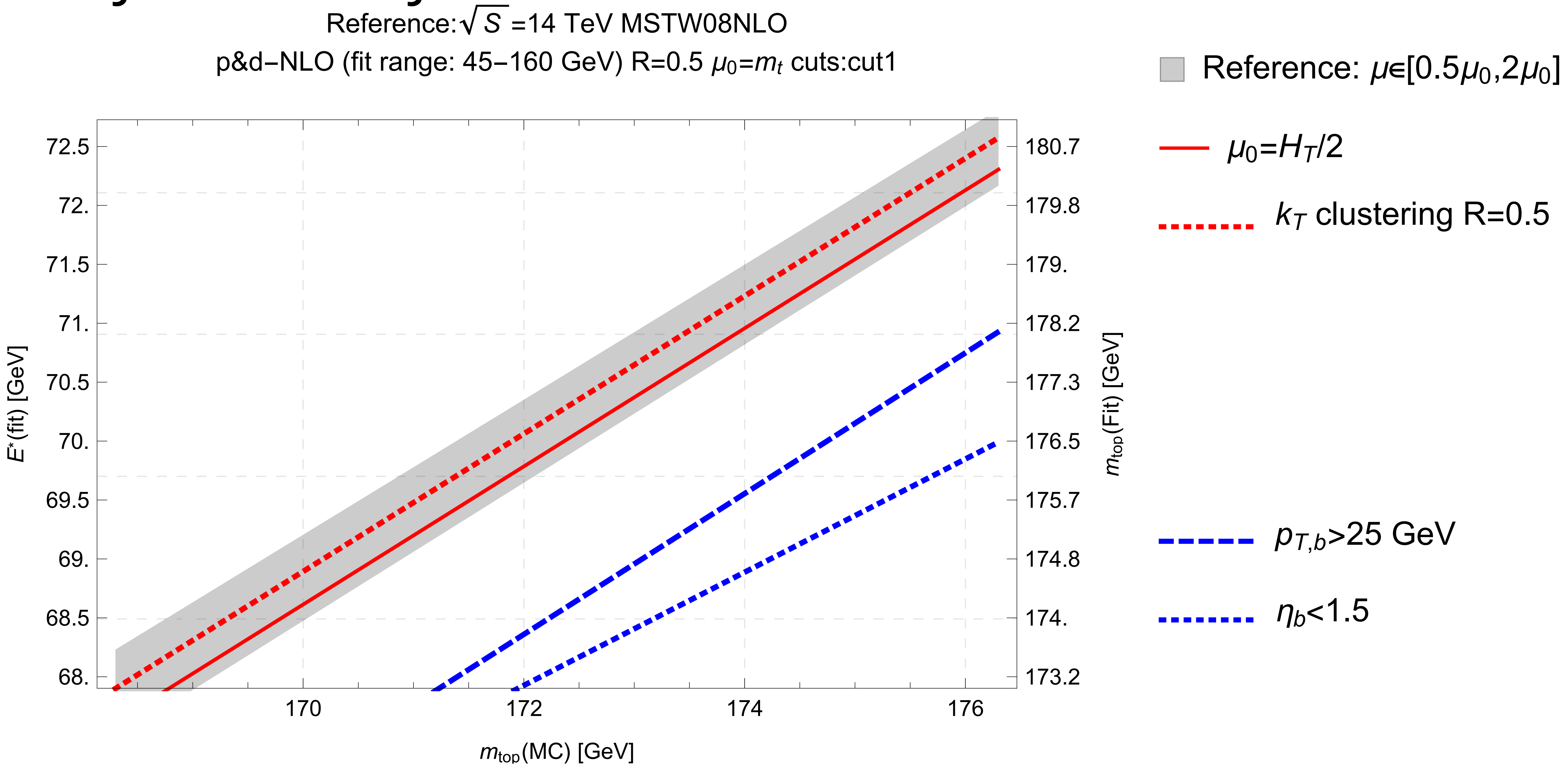


NLO sensitive to the scale choice: ±1 GeV on m_{top}

NLO $E^*(m_{top})$

Agashe, RF, Kim, Schulze - in preparation

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

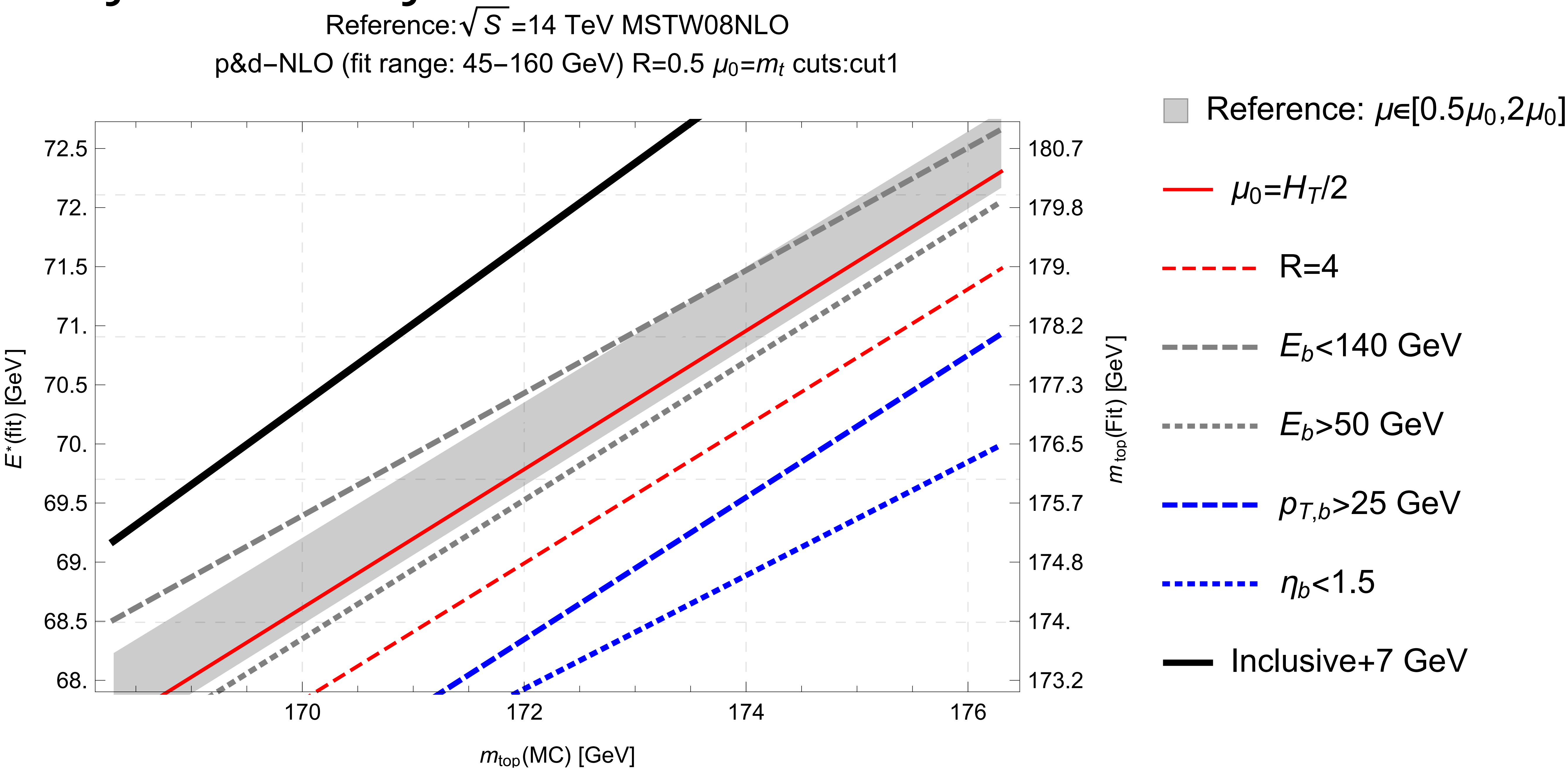


NLO sensitive to the scale choice: ±1 GeV on m_{top}

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

M_{top} related observables

Distributions used for top mass should be well under control

Suitable to look for subtle effects

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

- $\max(m_{b\ell,min})$ (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

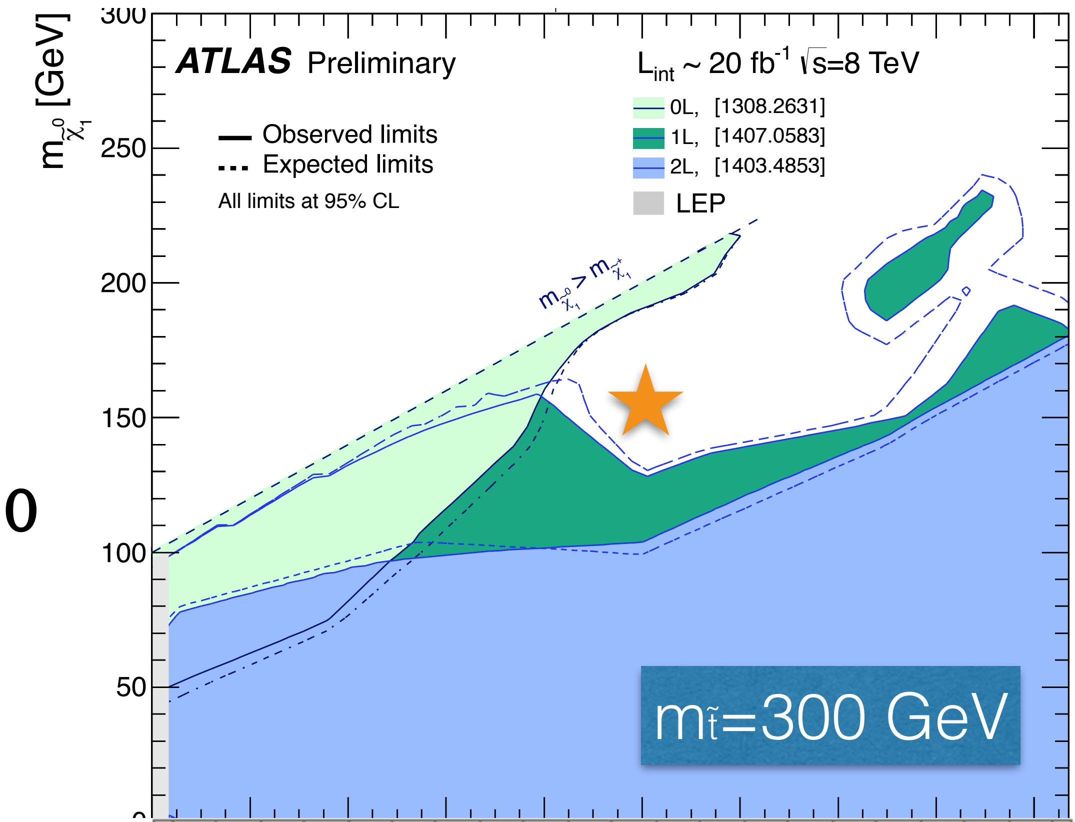
E_b and $m_{b\ell}$ behave differently

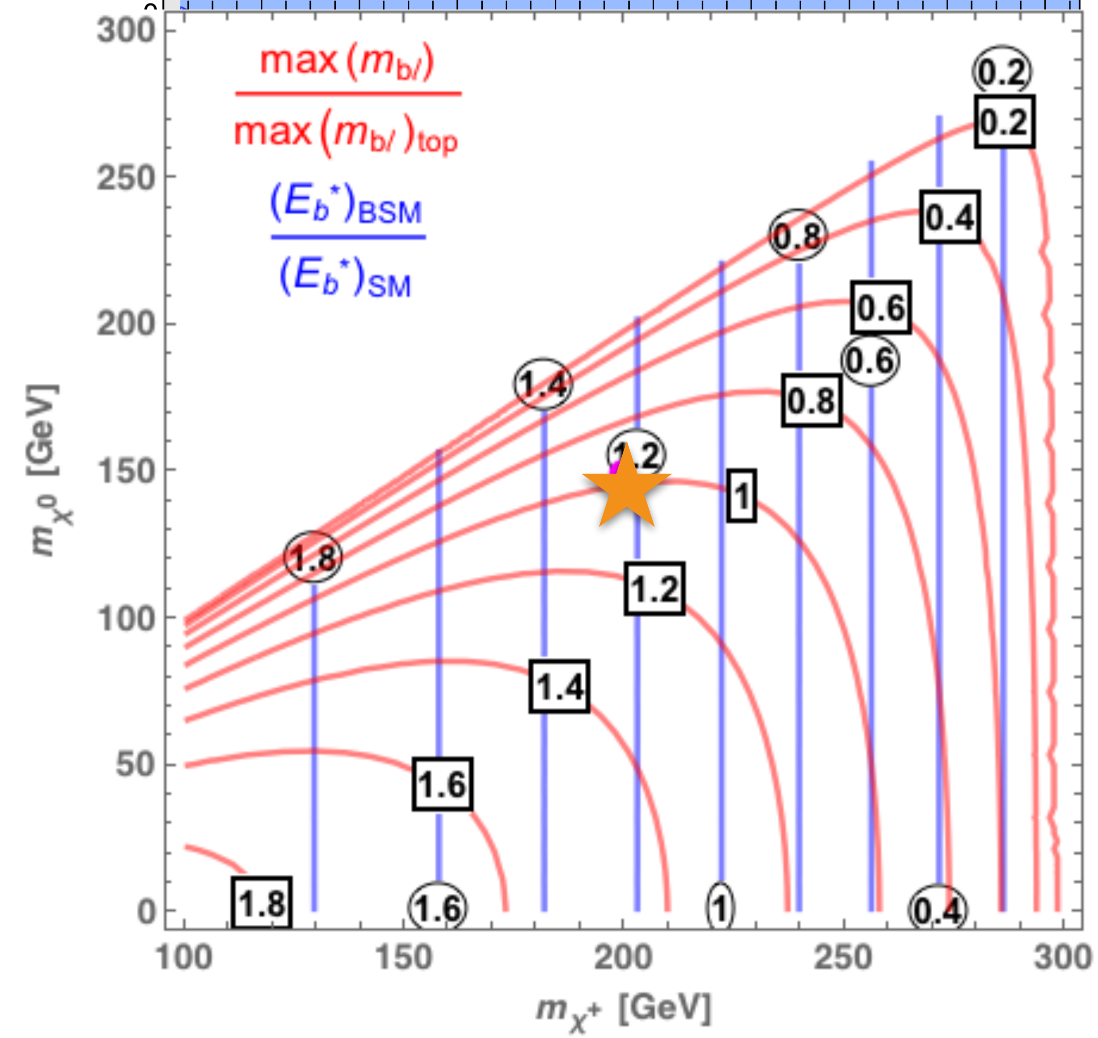
$t \to bW \to b\ell\nu$ ➡ $\tilde{t} \to b\,\chi^+ \to b\ell\nu\chi^0$

$$m_{b\ell}^{max}\Big|_{m_b=0} = \sqrt{\frac{(m_{\tilde{t}}^2 - m_{\chi^+}^2)(m_{\chi^+}^2 - m_{\chi^0}^2)}{m_\chi}}$$

$$E_b^* = \frac{m_{\tilde{t}}^2 - m_{\chi^+}^2}{2\, m_{\tilde{t}}}$$

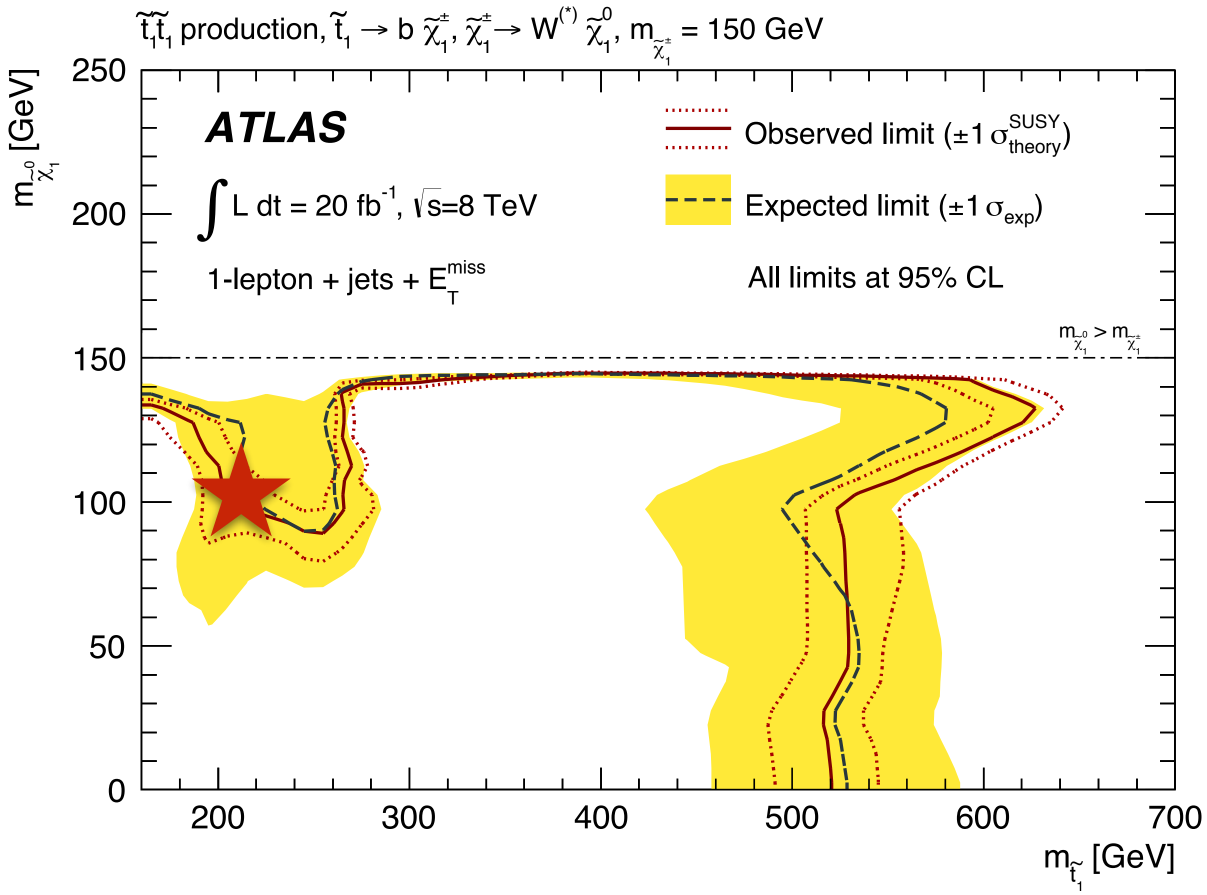
★ Harder E_b, softer $m_{b\ell}$

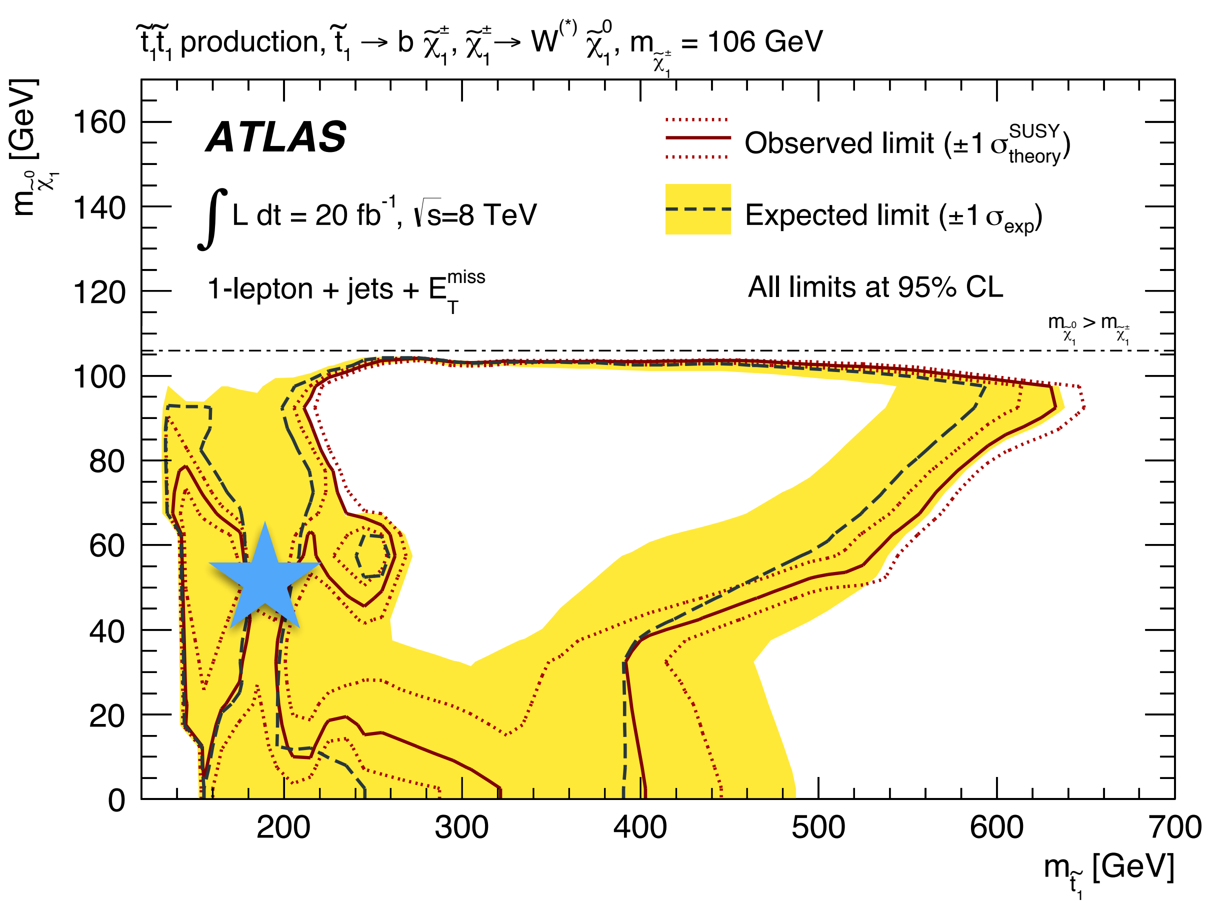


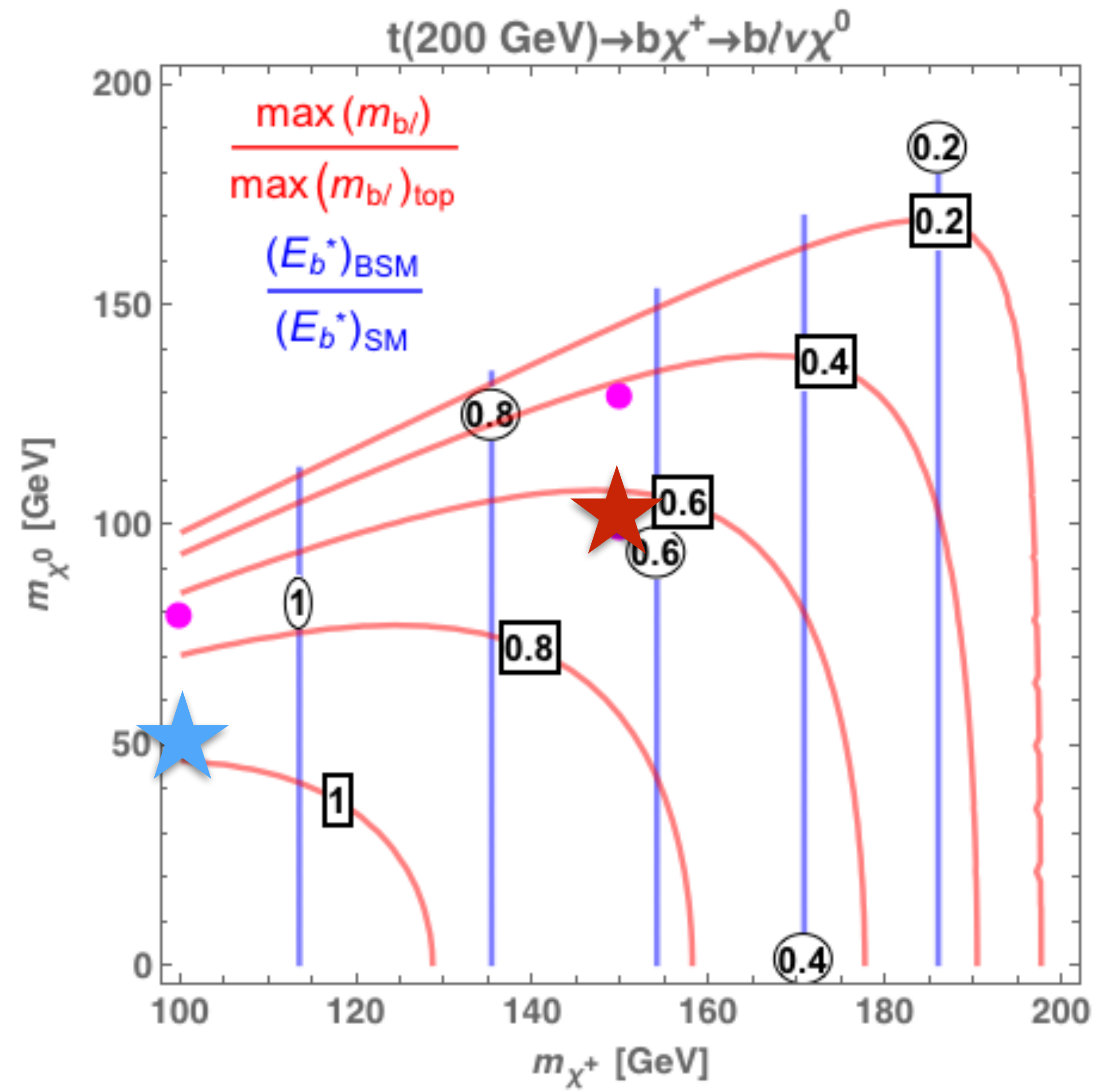


New physics effect on $m_{b\ell}$ and E_b

with G. Polesello





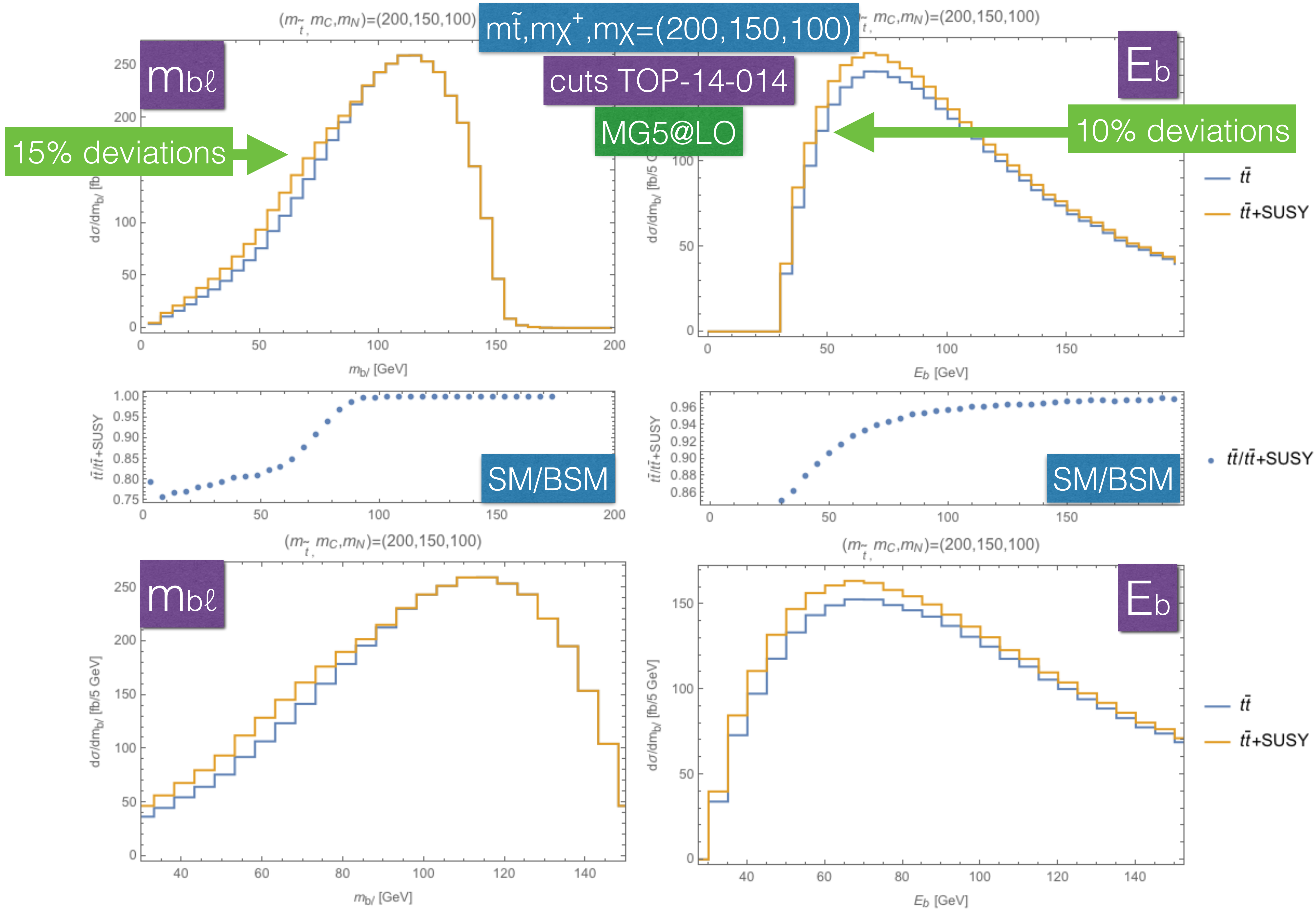


★ harder E_b, softer $m_{b\ell}$

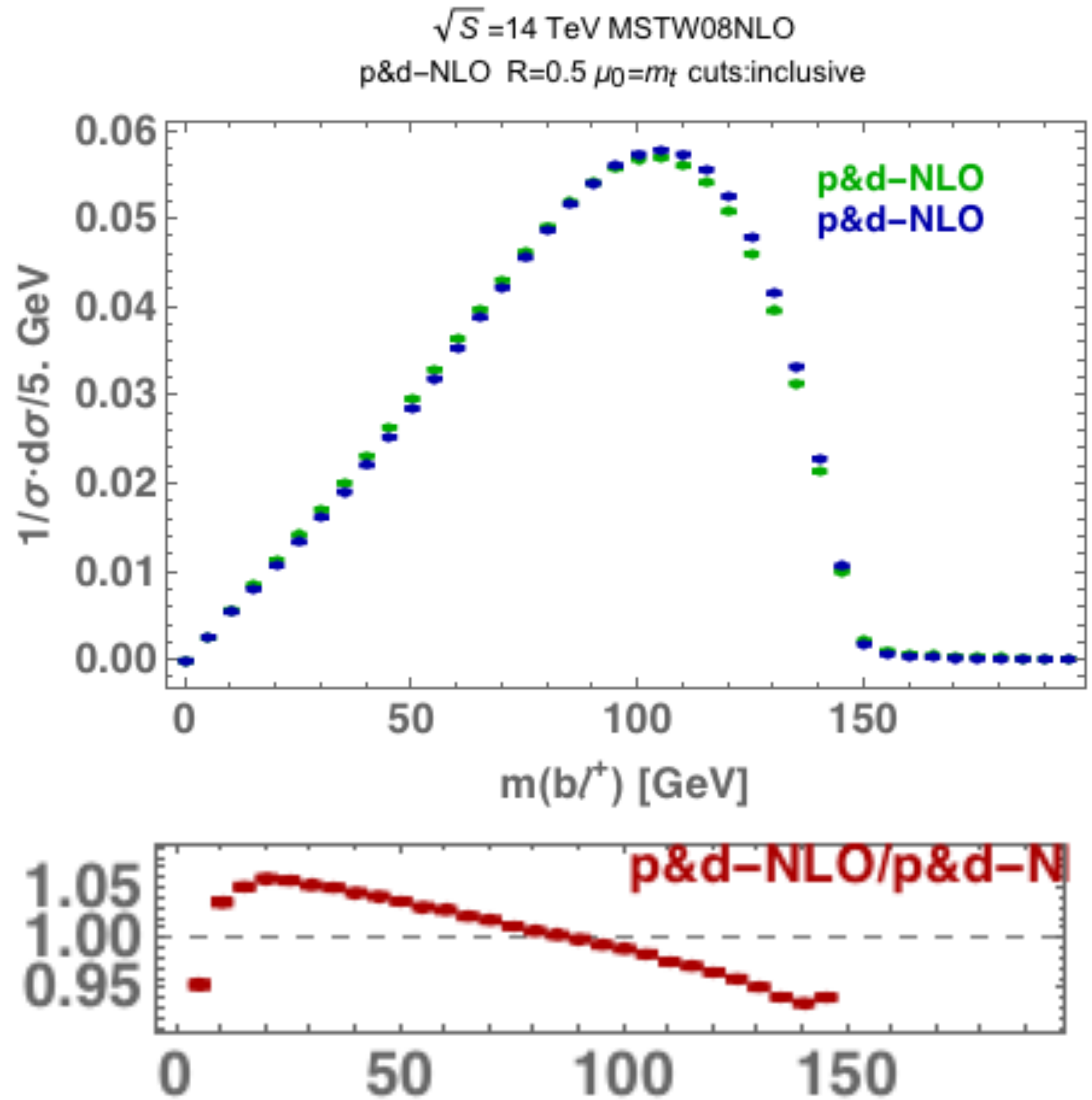
★ softer E_b, softer $m_{b\ell}$

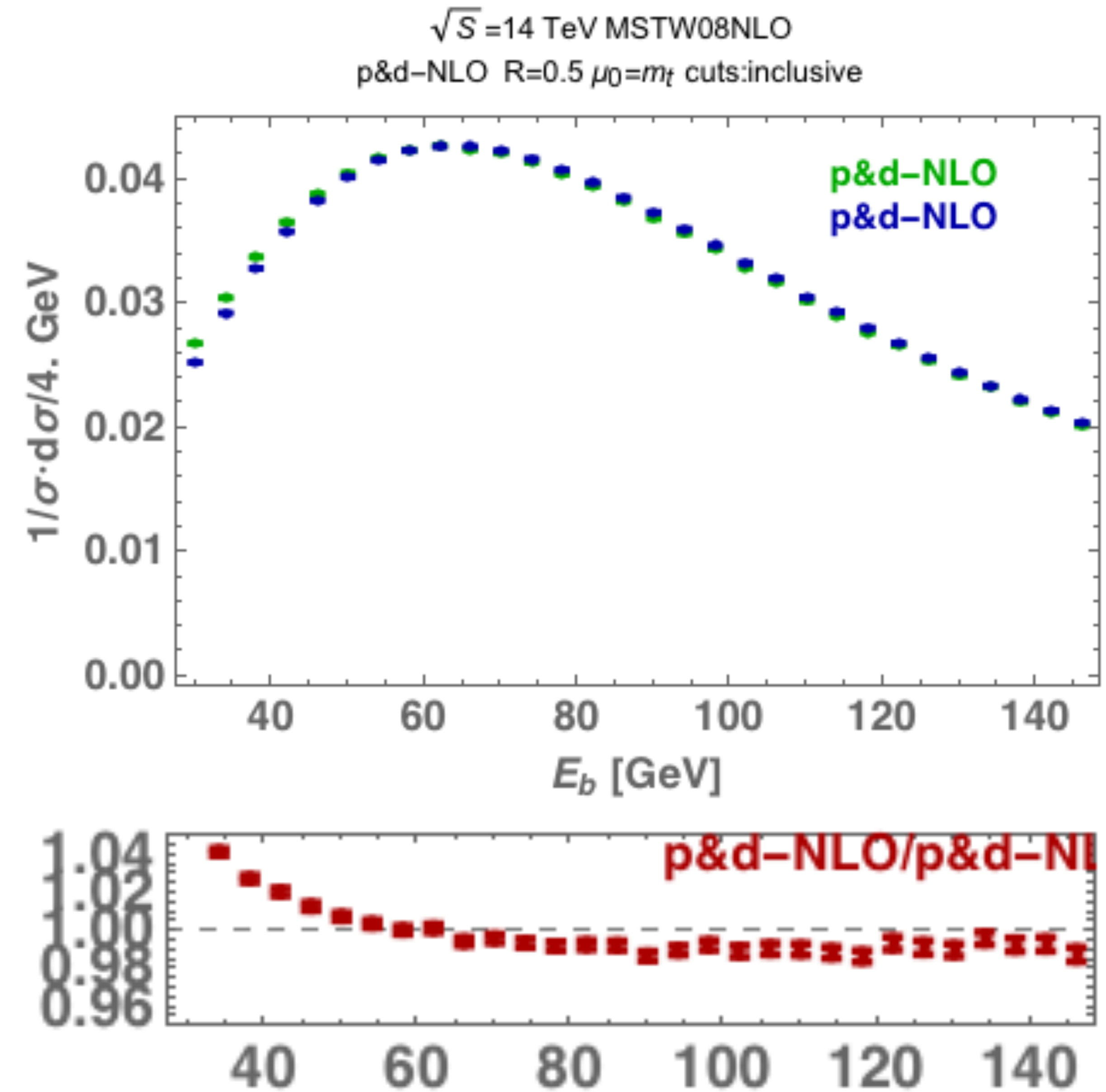
New physics effect on $m_{b\ell}$ and E_b

with G. Polesello

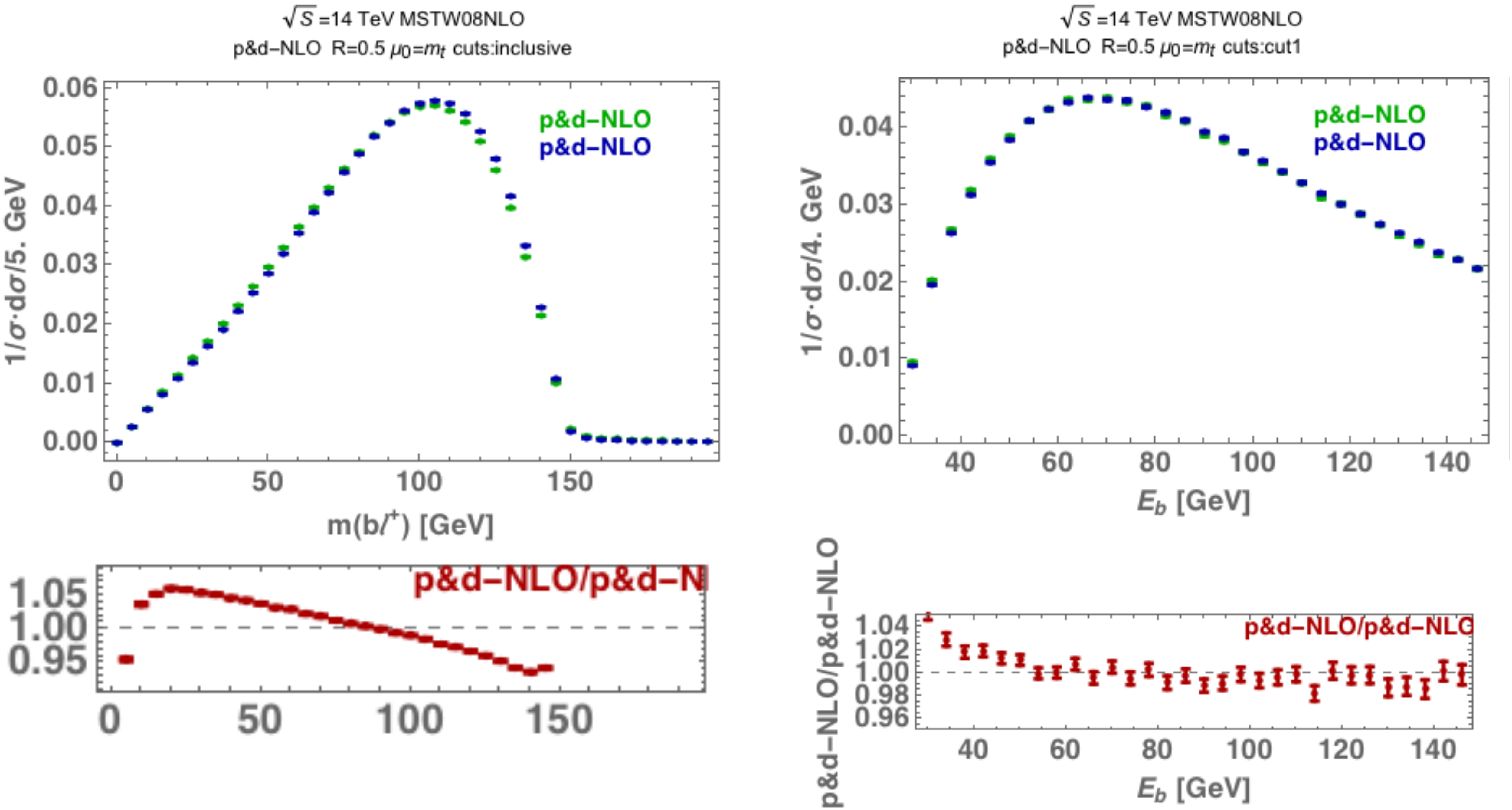


A first look at scale uncertainties

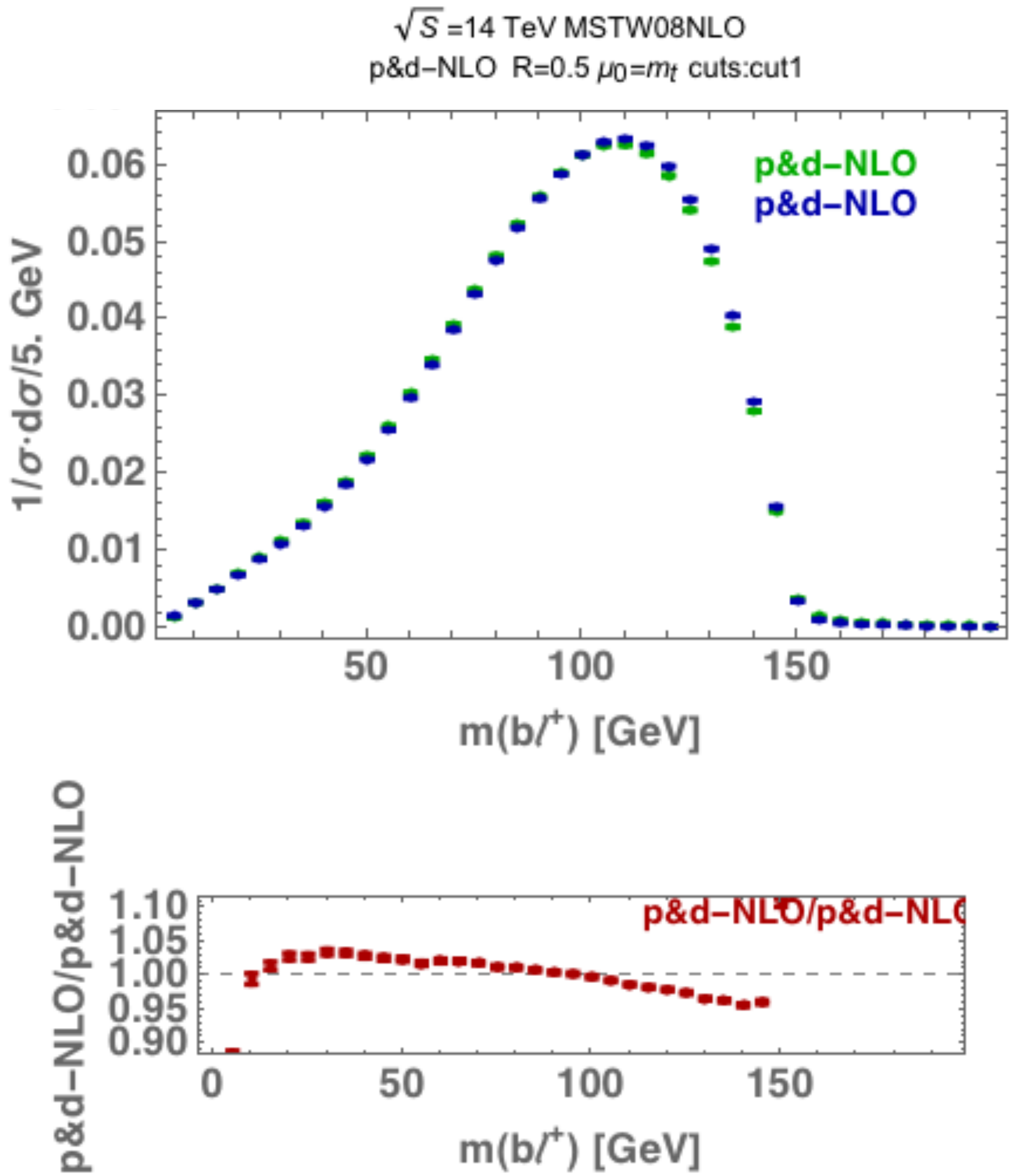


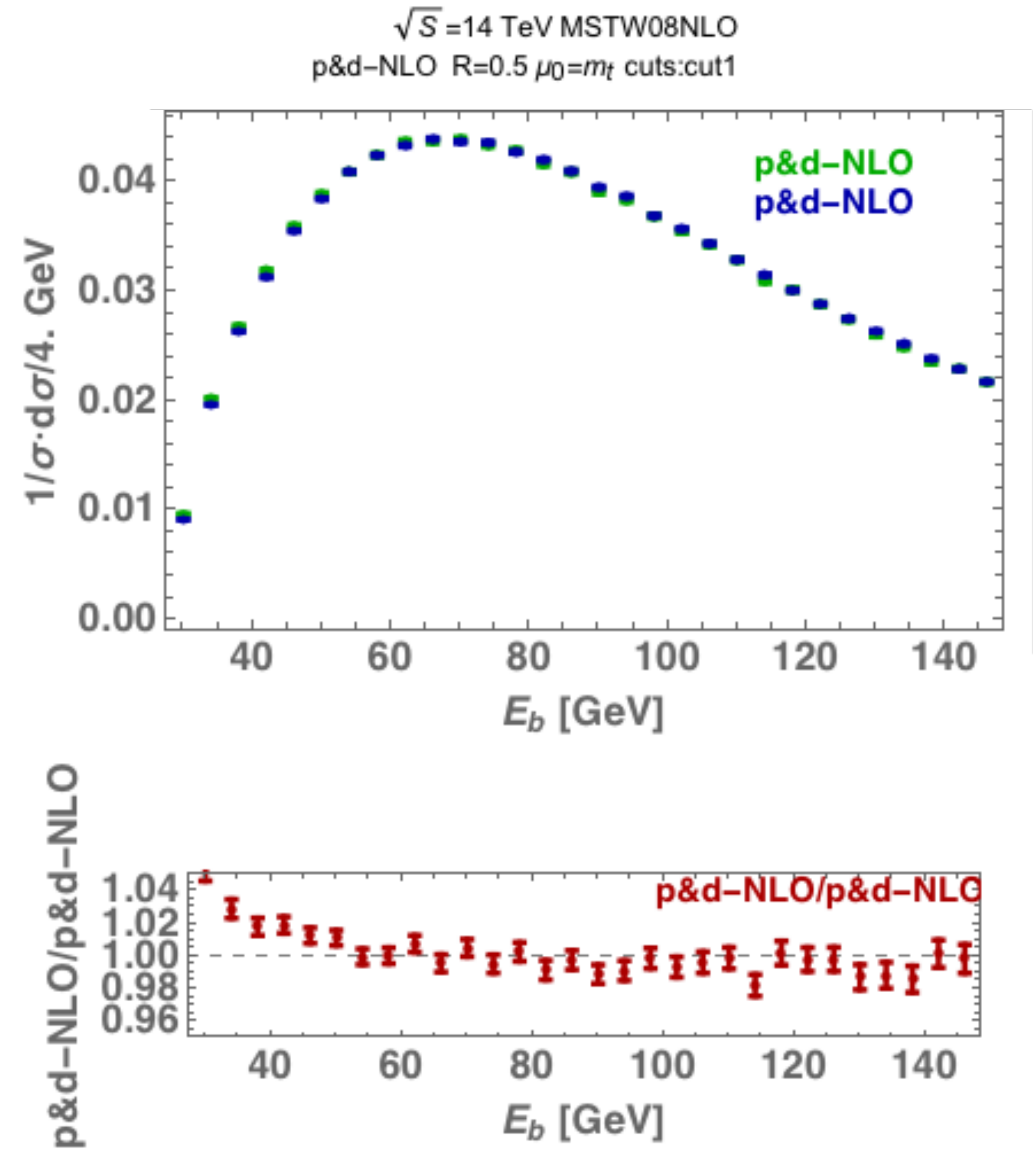


A first look at scale uncertainties

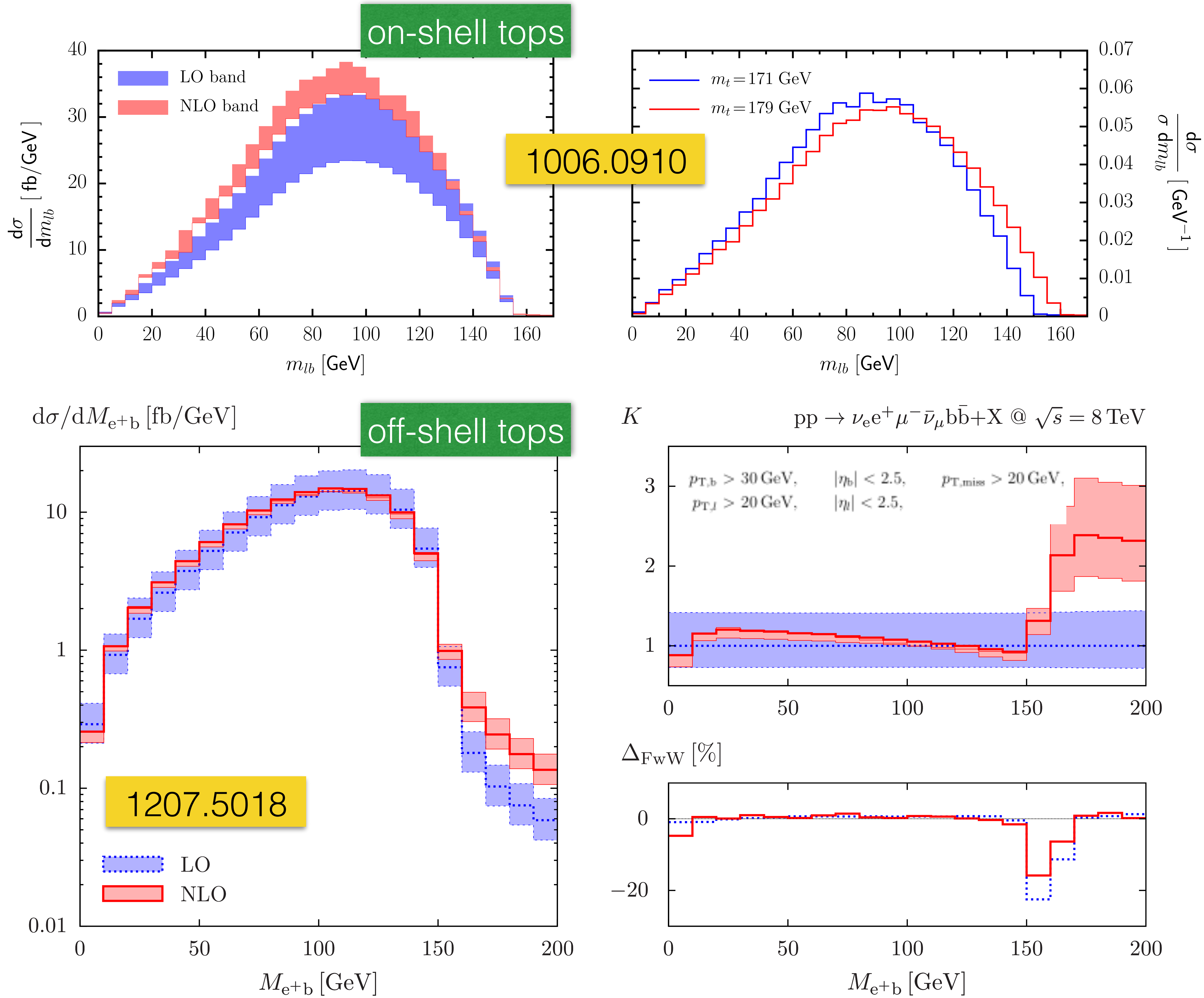


A first look at scale uncertainties





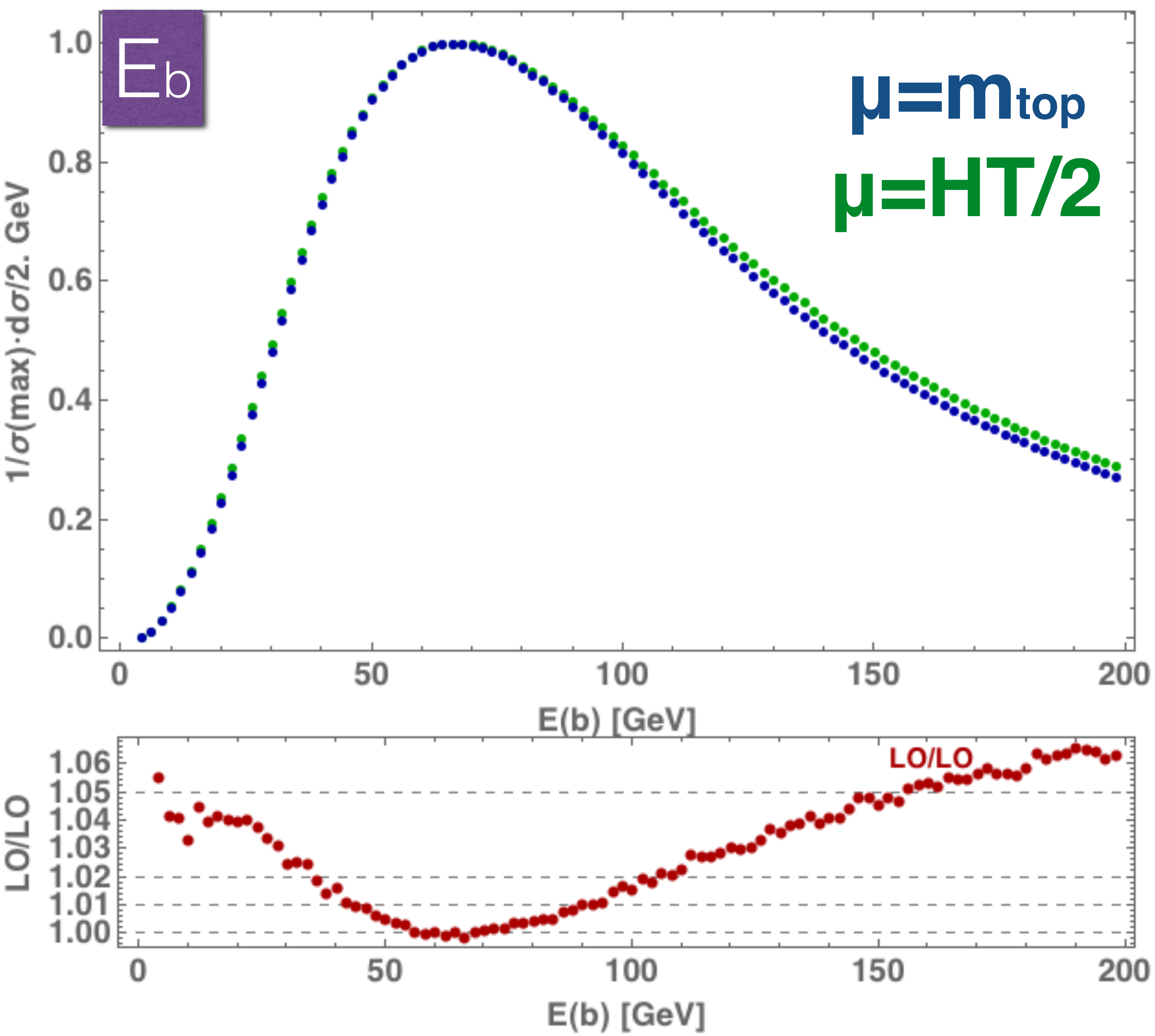
$m_{b\ell}$ at NLO



on-shell tops
1006.0910
LO band
NLO band
$\frac{d\sigma}{dm_{lb}}$ [fb/GeV]
m_{lb} [GeV]
$m_t = 171$ GeV
$m_t = 179$ GeV
$\frac{d\sigma}{\sigma\, dm_{lb}}$ [GeV^{-1}]
off-shell tops
$d\sigma/dM_{e^+b}$ [fb/GeV]
1207.5018
LO
NLO
M_{e^+b} [GeV]
K
$pp \to \nu_e e^+ \mu^- \bar{\nu}_\mu b\bar{b} + X$ @ $\sqrt{s} = 8$ TeV
$p_{T,b} > 30$ GeV, $|\eta_b| < 2.5$, $p_{T,miss} > 20$ GeV,
$p_{T,l} > 20$ GeV, $|\eta_l| < 2.5$,
Δ_{FwW} [%]

Subtleties of the subtle effects

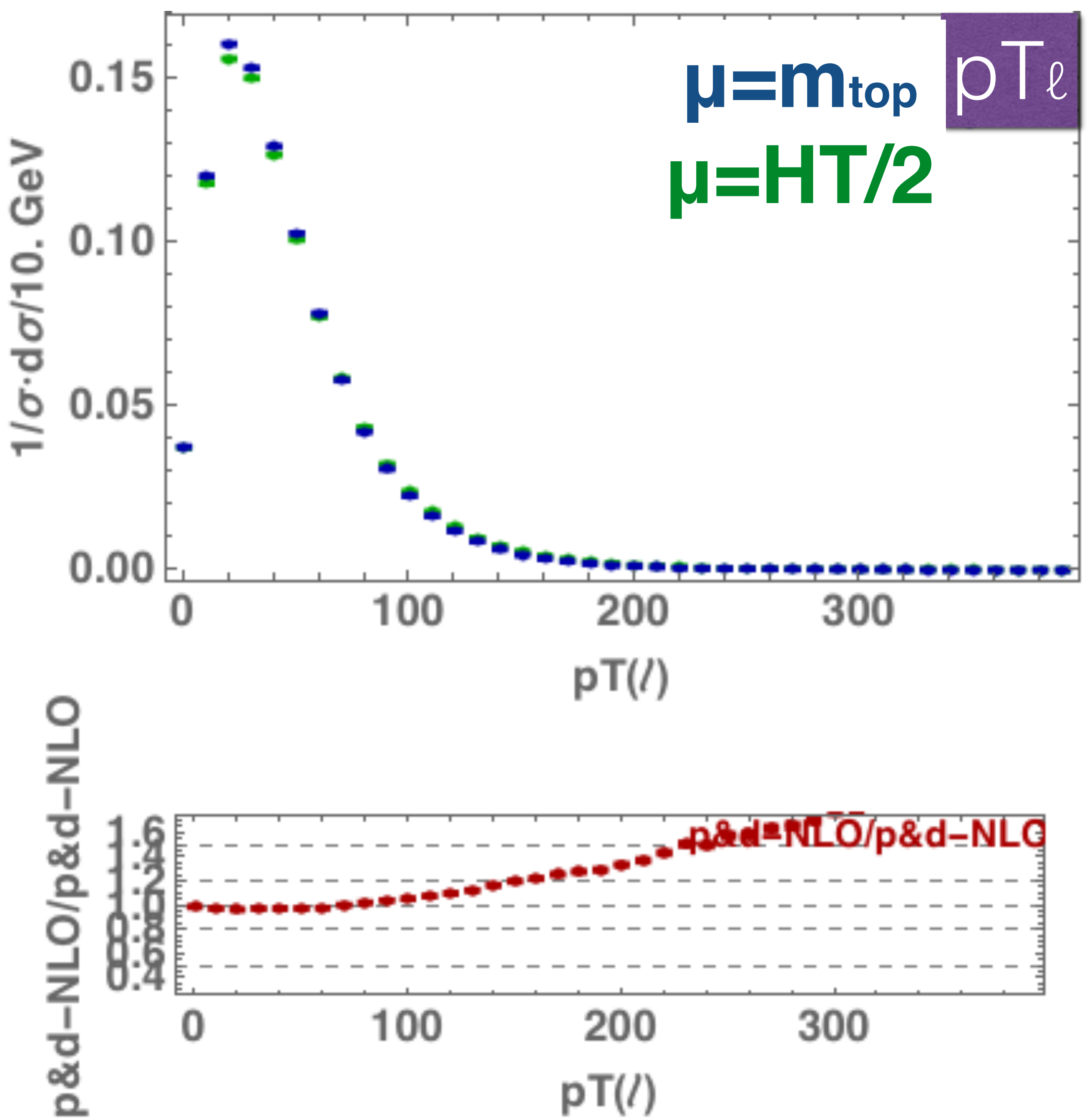
$\Delta m_{top} \lesssim 300$ MeV despite 5% deviations in the tails



- 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}

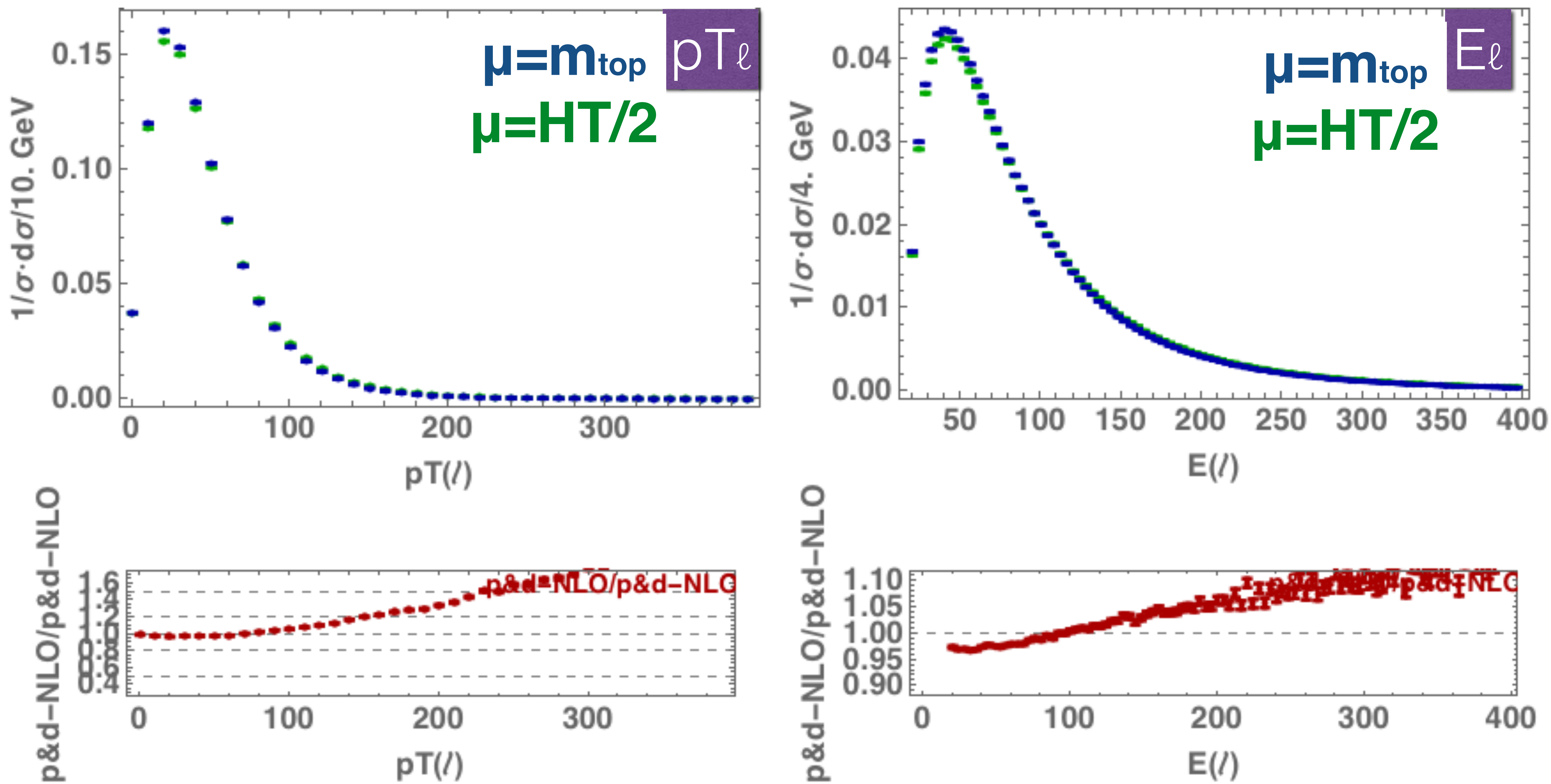
Subtleties of the subtle effects

$\Delta m_{top} \lesssim 1$ 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



t $\quad t \to \tilde{t}\chi$

Br($t \to \tilde{t}\chi$) can be 5% for χ=Bino

$\tilde{t}$ $\quad \tilde{t} \to b\, ff'\chi$

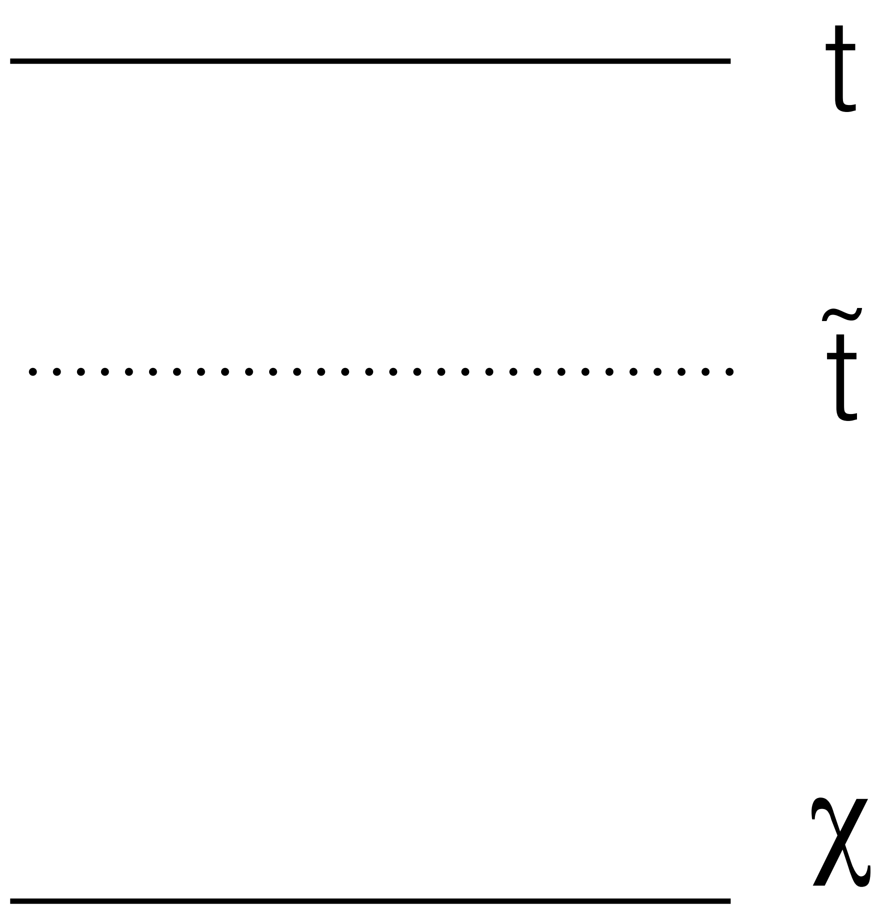
χ $\quad$ stable LSP

softer visible products

$$t \to \tilde{t}\chi \to b\, ff'\, \chi\chi$$

soft challenge

$$t \to \tilde{t}\chi \to b\ ff'\ \chi\chi$$



$t \to \tilde{t}\chi$

Br($t \to \tilde{t}\chi$) can be 5% for χ=Bino

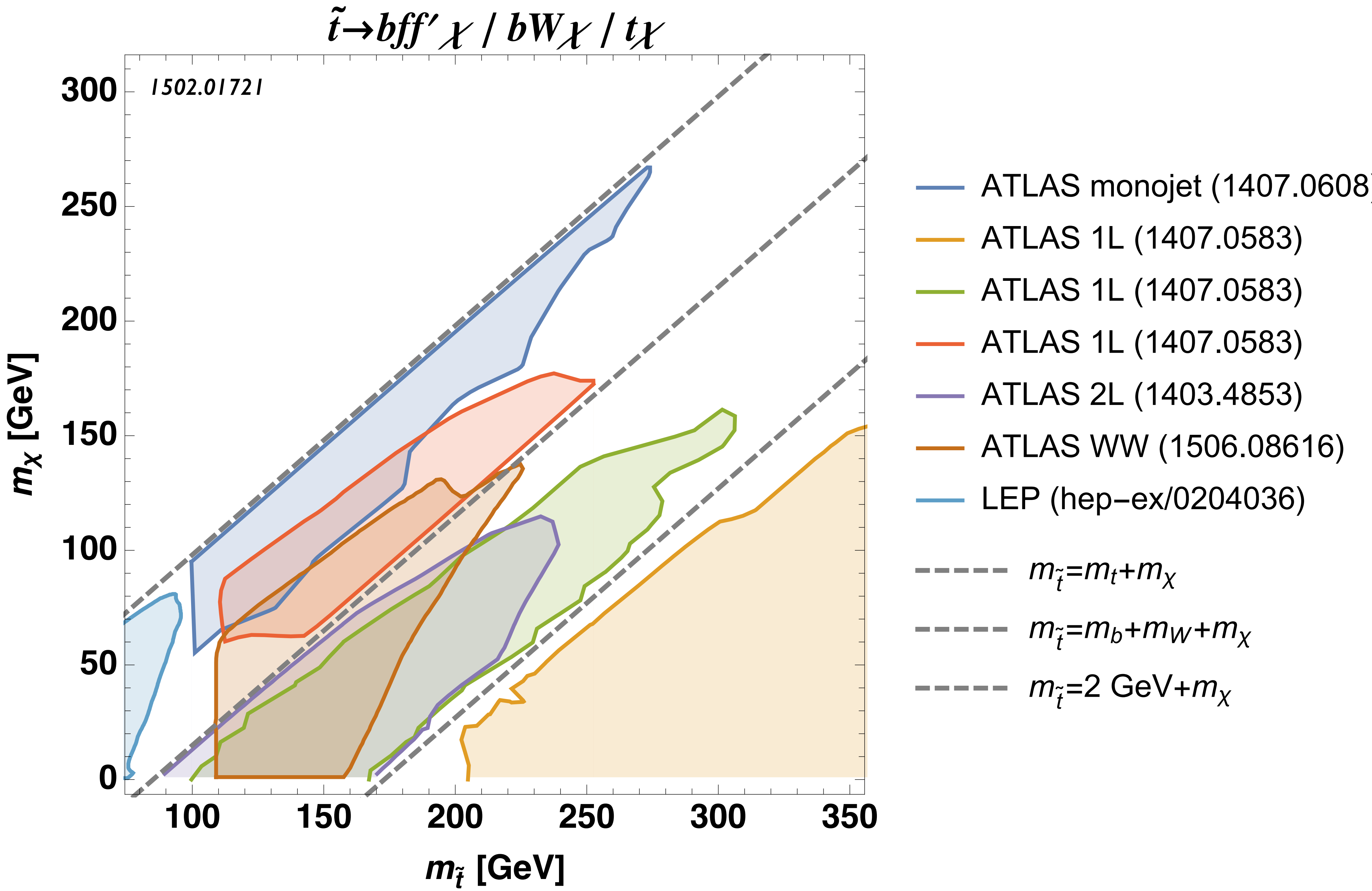
$\tilde{t} \to b\ ff'\chi$

stable LSP

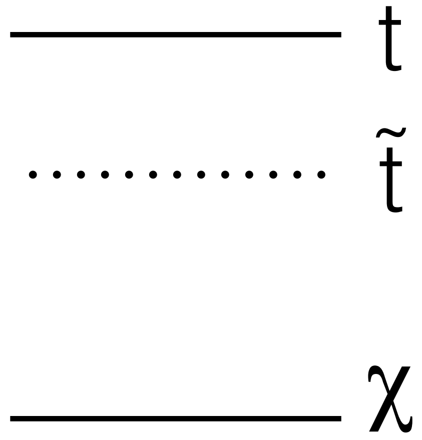
softer visible products

$$t \to \tilde{t}\chi \to b\ ff'\ \chi\chi$$

soft challenge

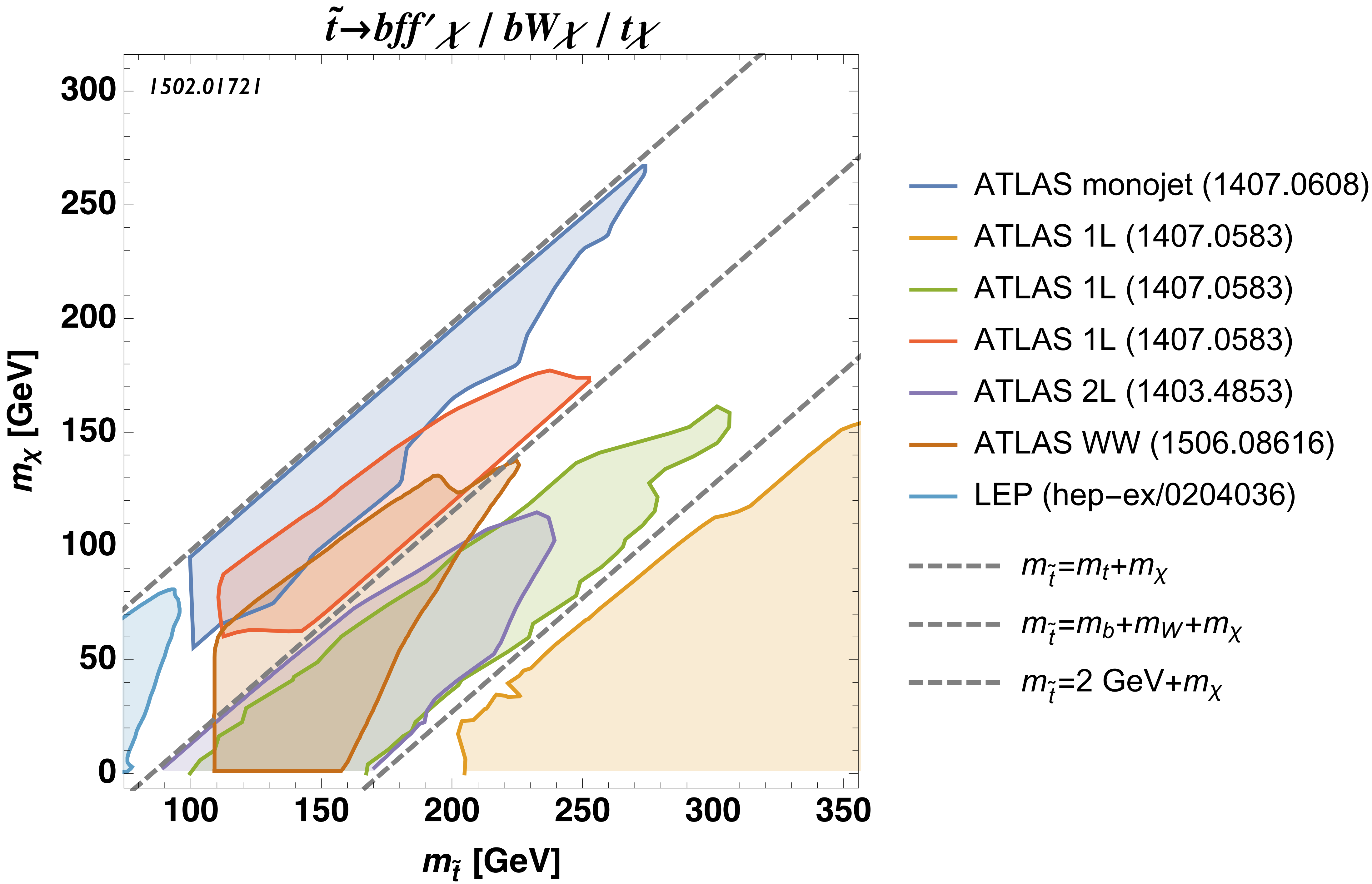


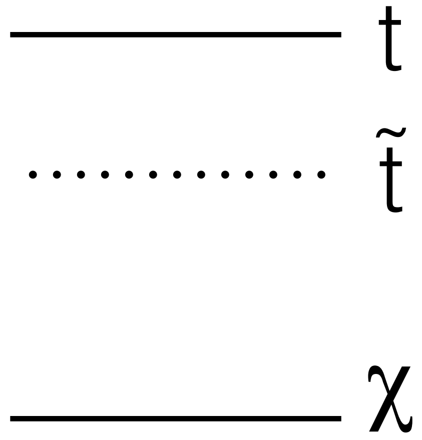
$\tilde{t}\to bff'\chi$ / $bW\chi$ / $t\chi$
1502.01721
300
250
200
150
100
50
0
m_χ [GeV]
100
150
200
250
300
350
$m_{\tilde{t}}$ [GeV]
ATLAS monojet (1407.0608)
ATLAS 1L (1407.0583)
ATLAS 1L (1407.0583)
ATLAS 1L (1407.0583)
ATLAS 2L (1403.4853)
ATLAS WW (1506.08616)
LEP (hep-ex/0204036)
$m_{\tilde{t}}=m_t+m_\chi$
$m_{\tilde{t}}=m_b+m_W+m_\chi$
$m_{\tilde{t}}=2$ GeV$+m_\chi$



$t \to \tilde{t}\chi \to b\ ff'\ \chi\chi$

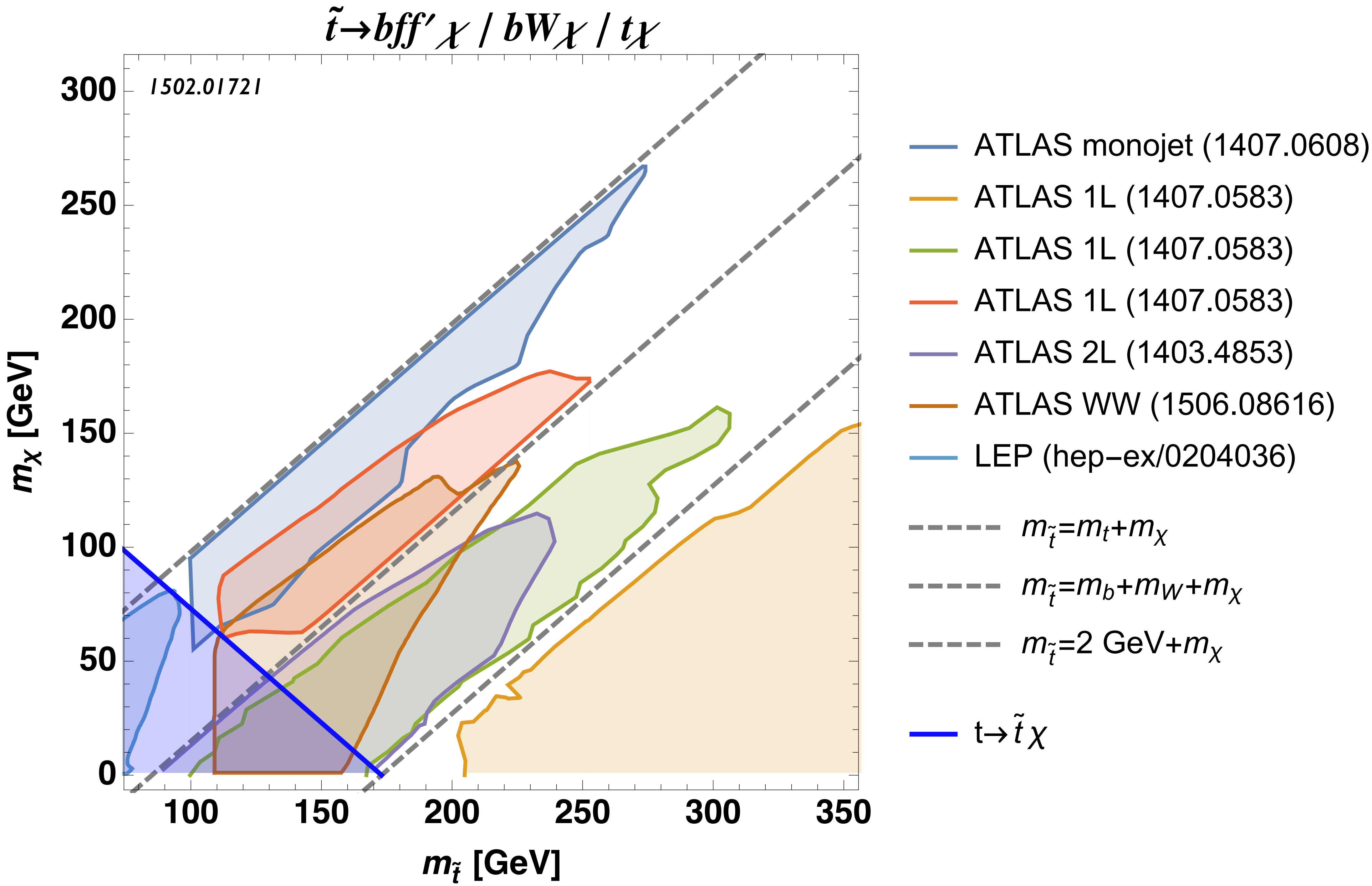
An orthogonal playground





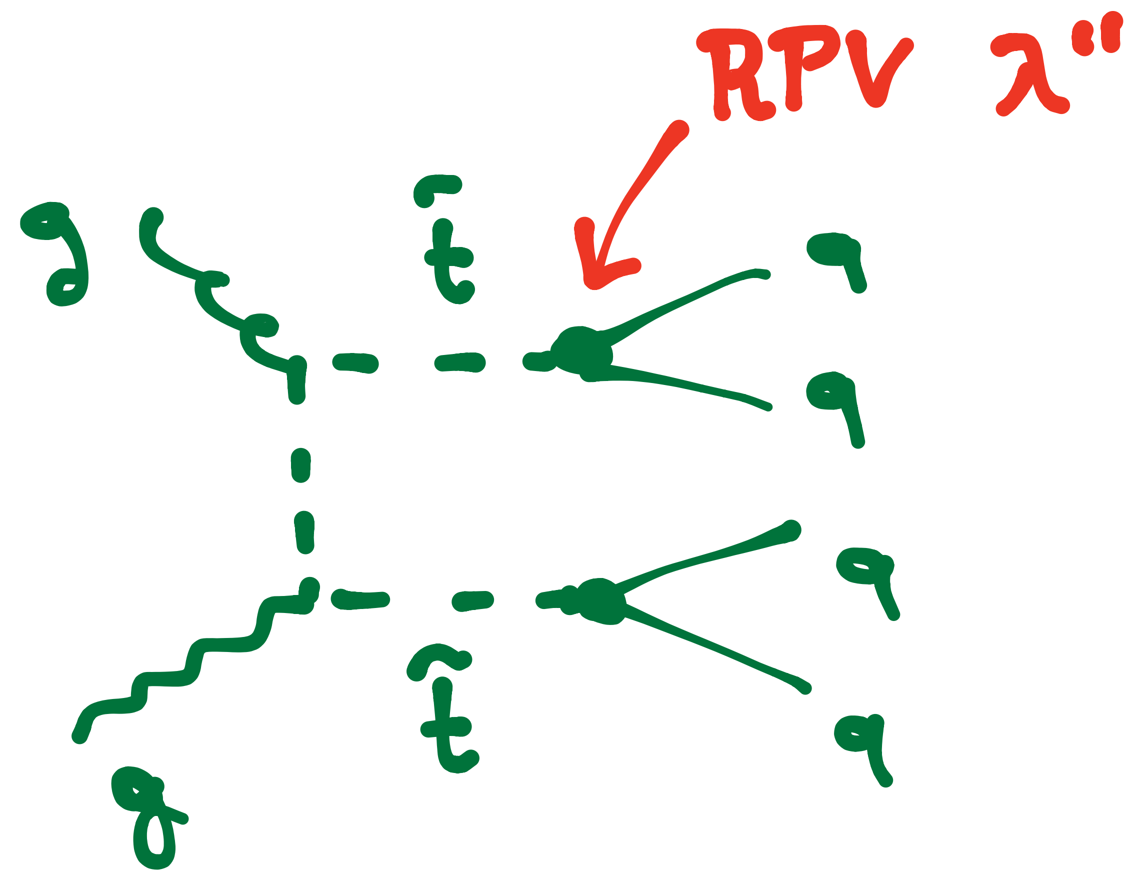
$t \rightarrow \tilde{t}\chi \rightarrow b\, ff'\, \chi\chi$

An orthogonal playground



Top as a trigger

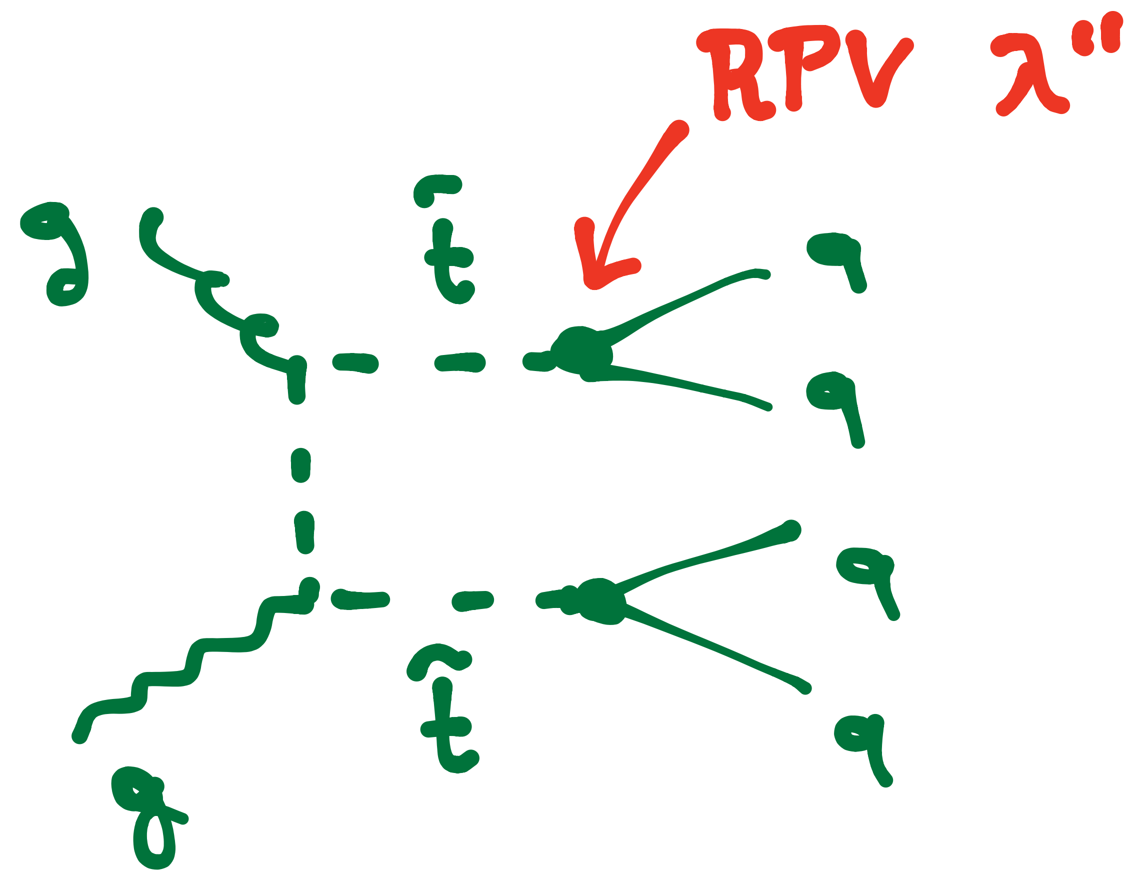
hadronic stops in RPV SUSY



large QCD cross-section for direct production

Top as a trigger

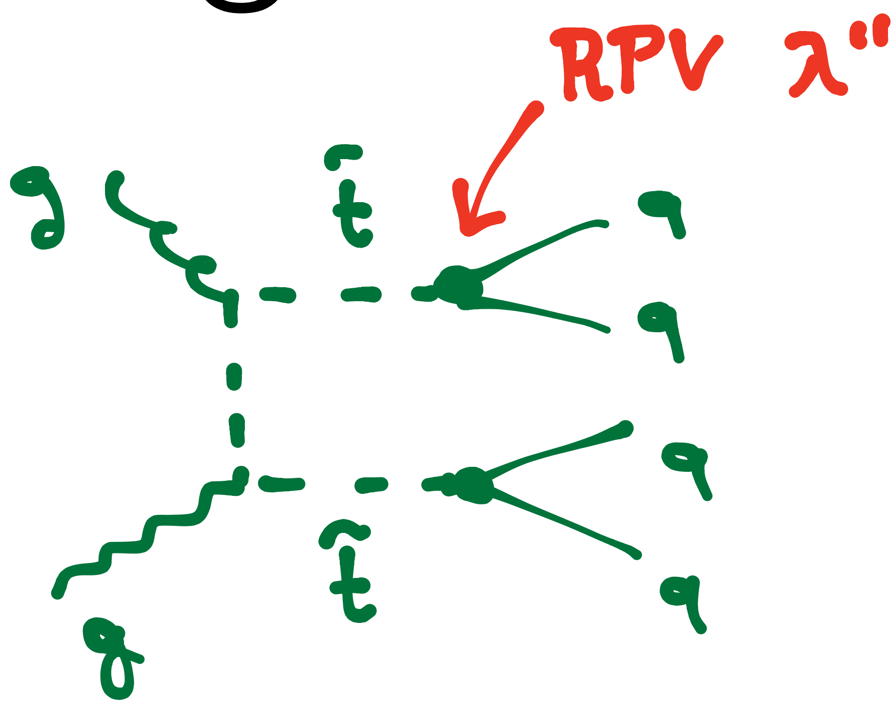
hadronic stops in RPV SUSY



large QCD cross-section for direct production

larger QCD background!

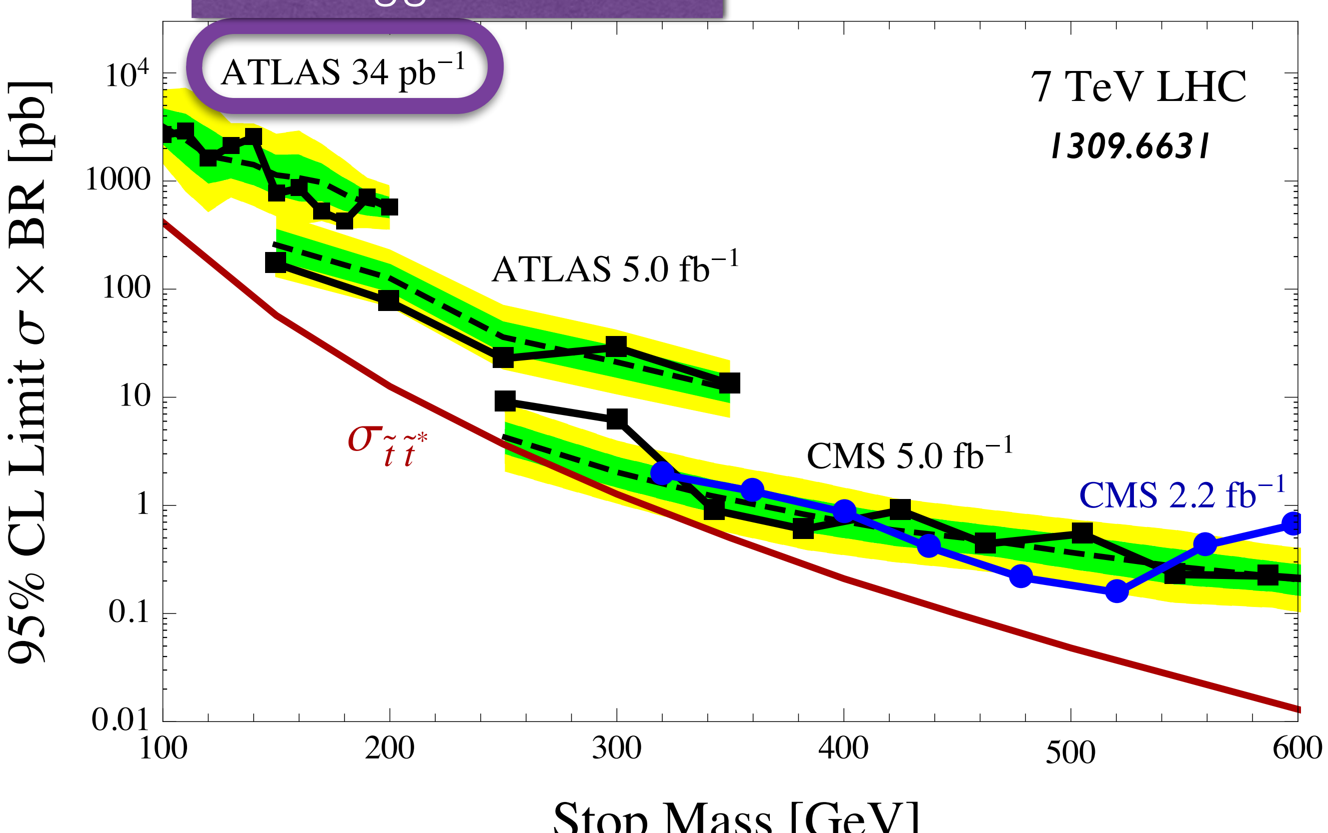
Light bumps are difficult

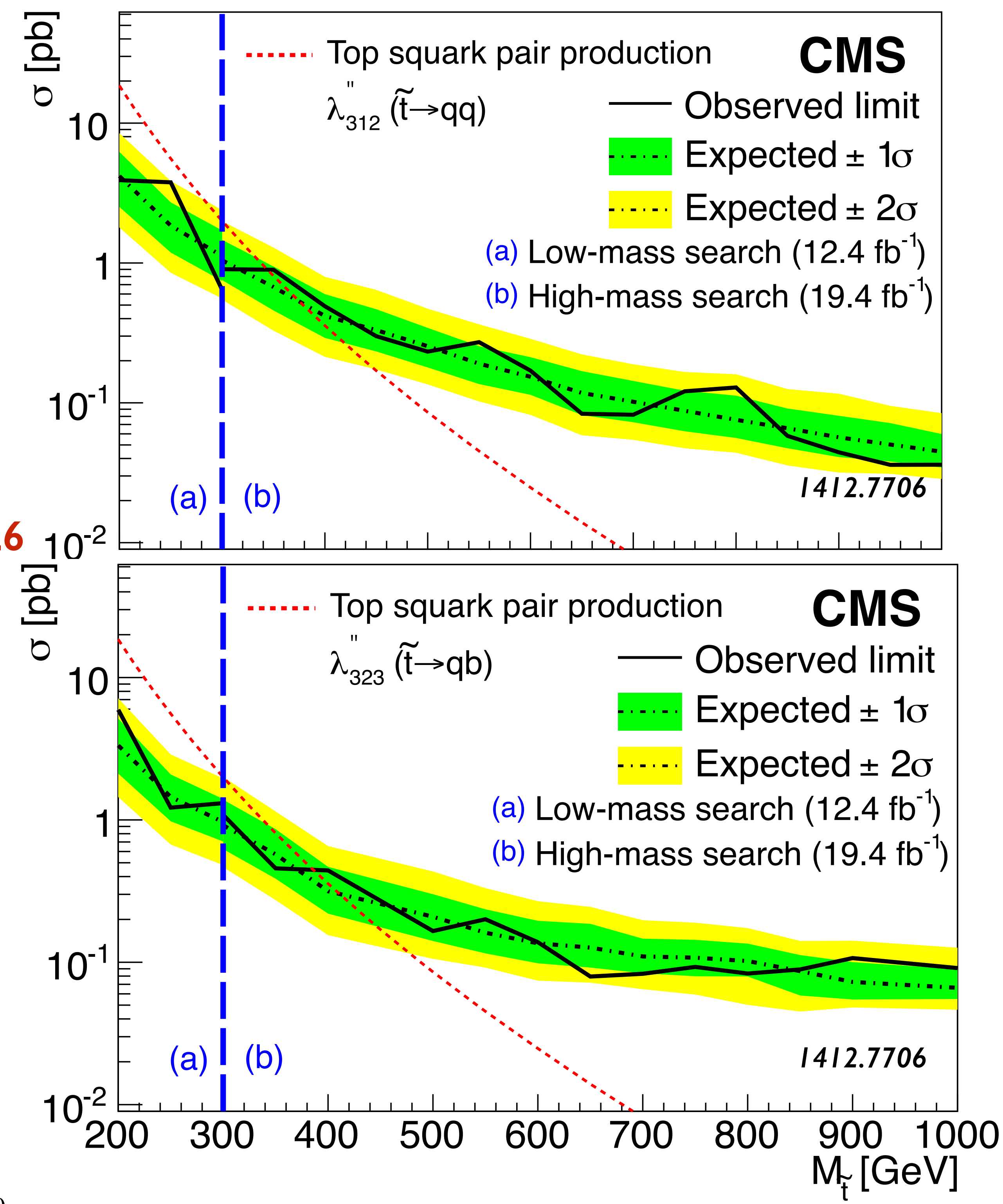


trigger is a killer at low mass

cut&count w/sub-structure in ATLAS-CONF-2015-026

lower trigger thresholds

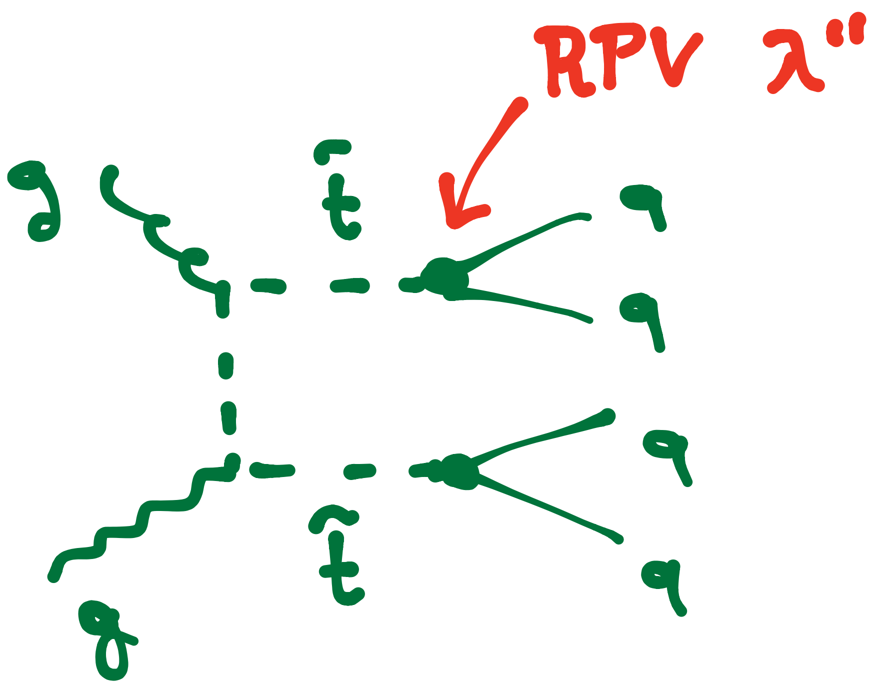




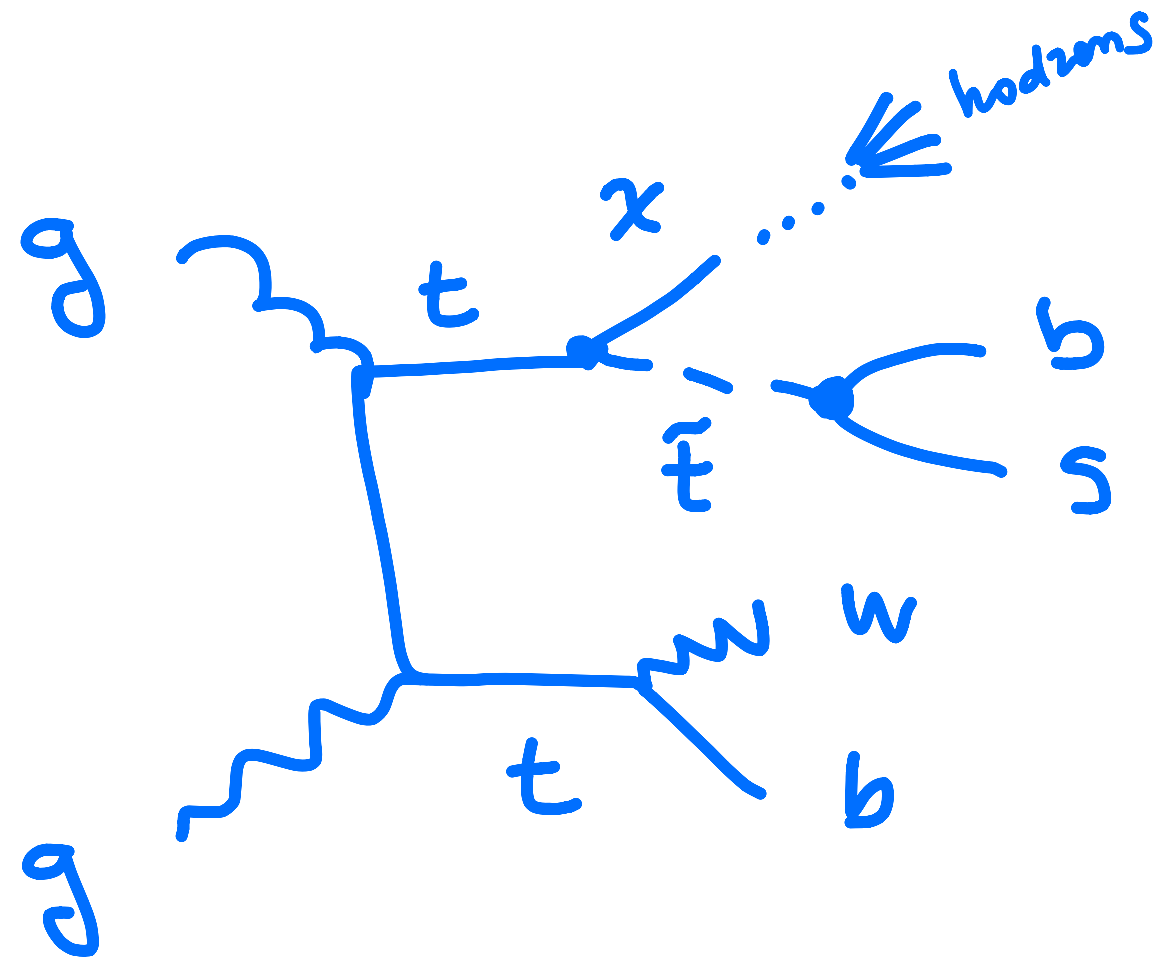
Top as a trigger

Ferretti, RF, Petersson, Torre, in progress

hadronic stops in RPV SUSY



stops from top in RPV SUSY



Top as a trigger

Ferretti, RF, Petersson, Torre, in progress

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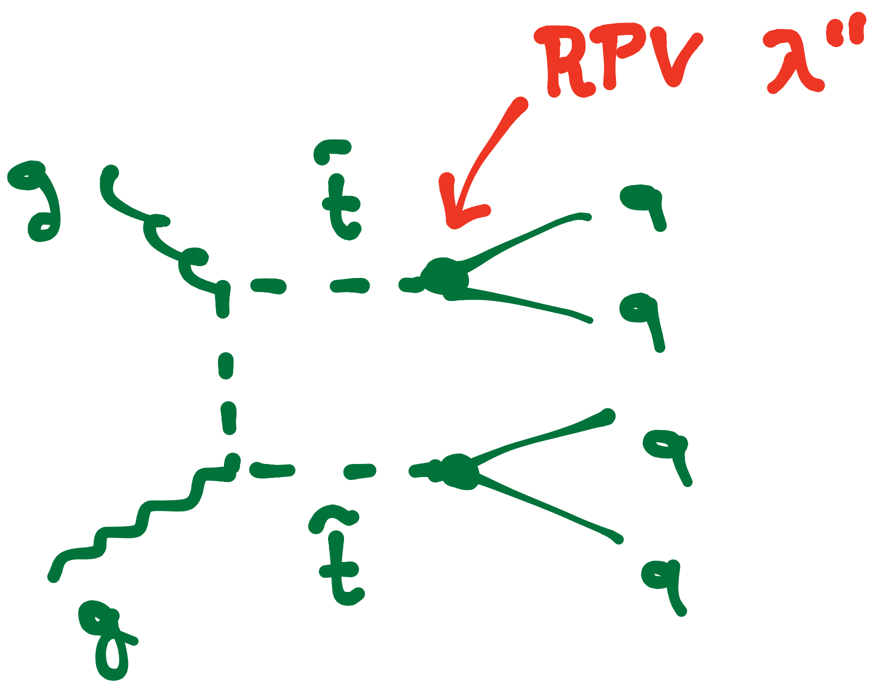
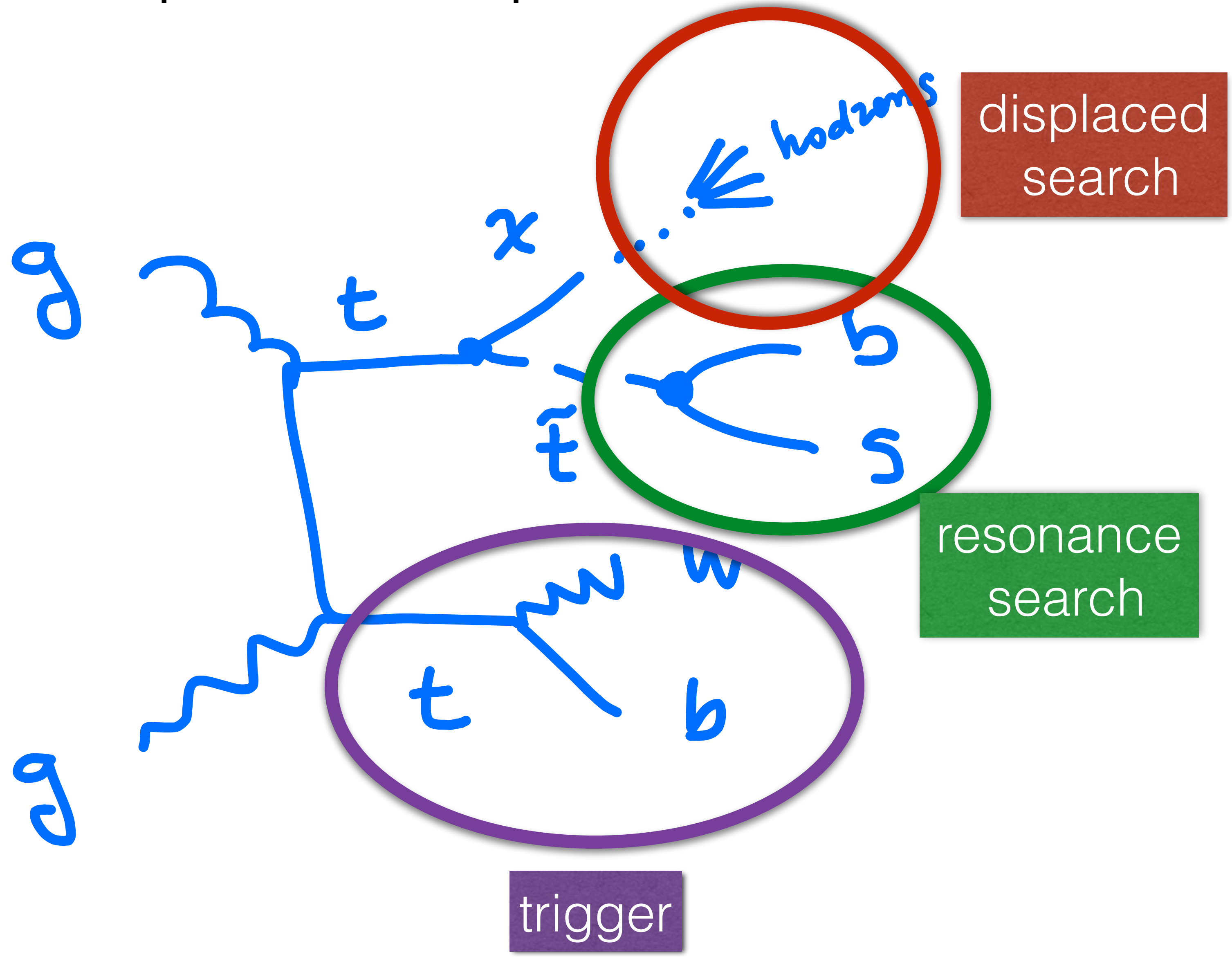


stops from top in RPV SUSY

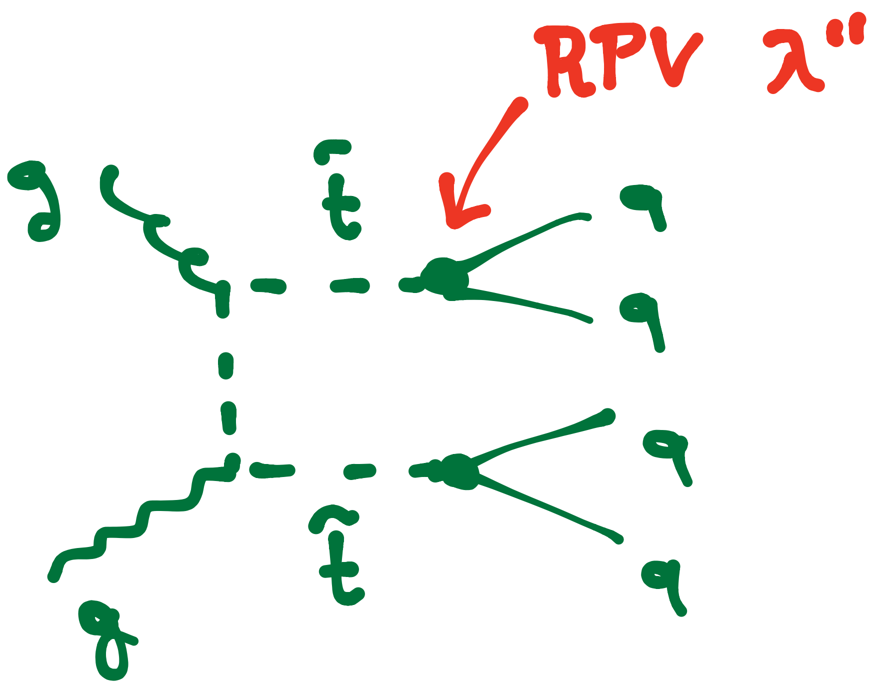


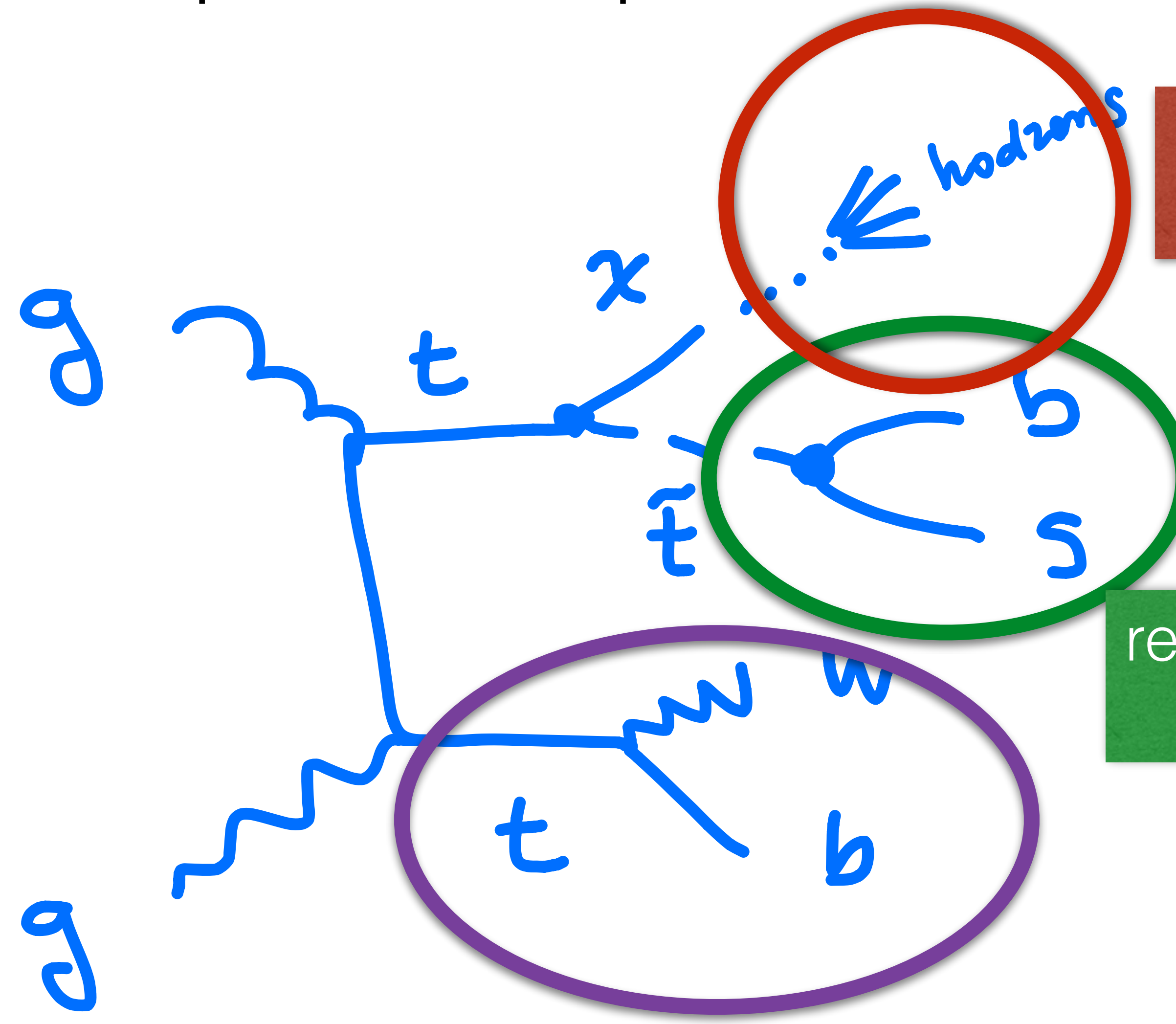
Top as a trigger

Ferretti, RF, Petersson, Torre, in progress

stops from top in RPV SUSY

hadronic stops in RPV SUSY





displaced search

resonance search

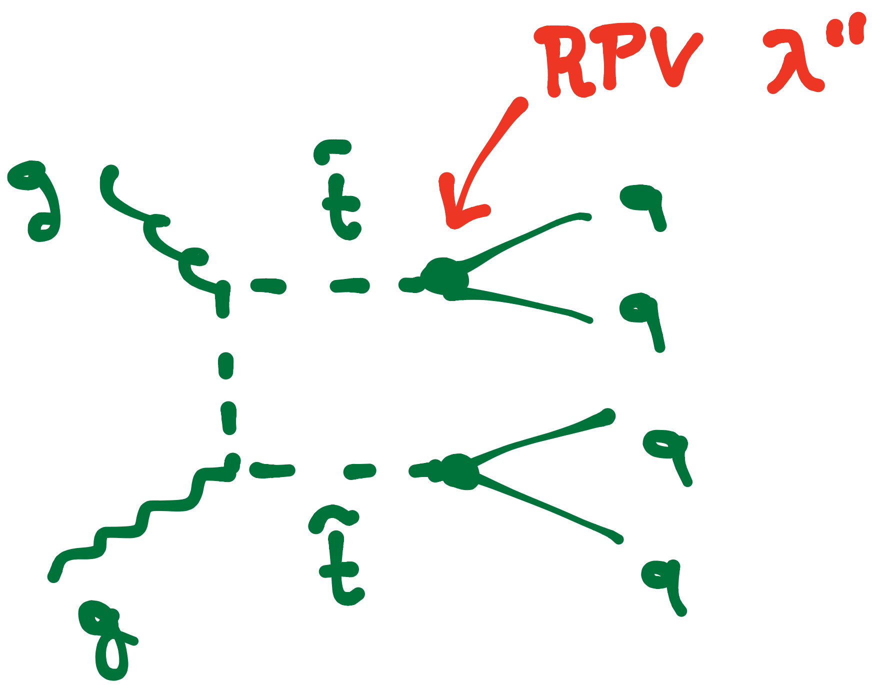
trigger

would appear in top properties measurements

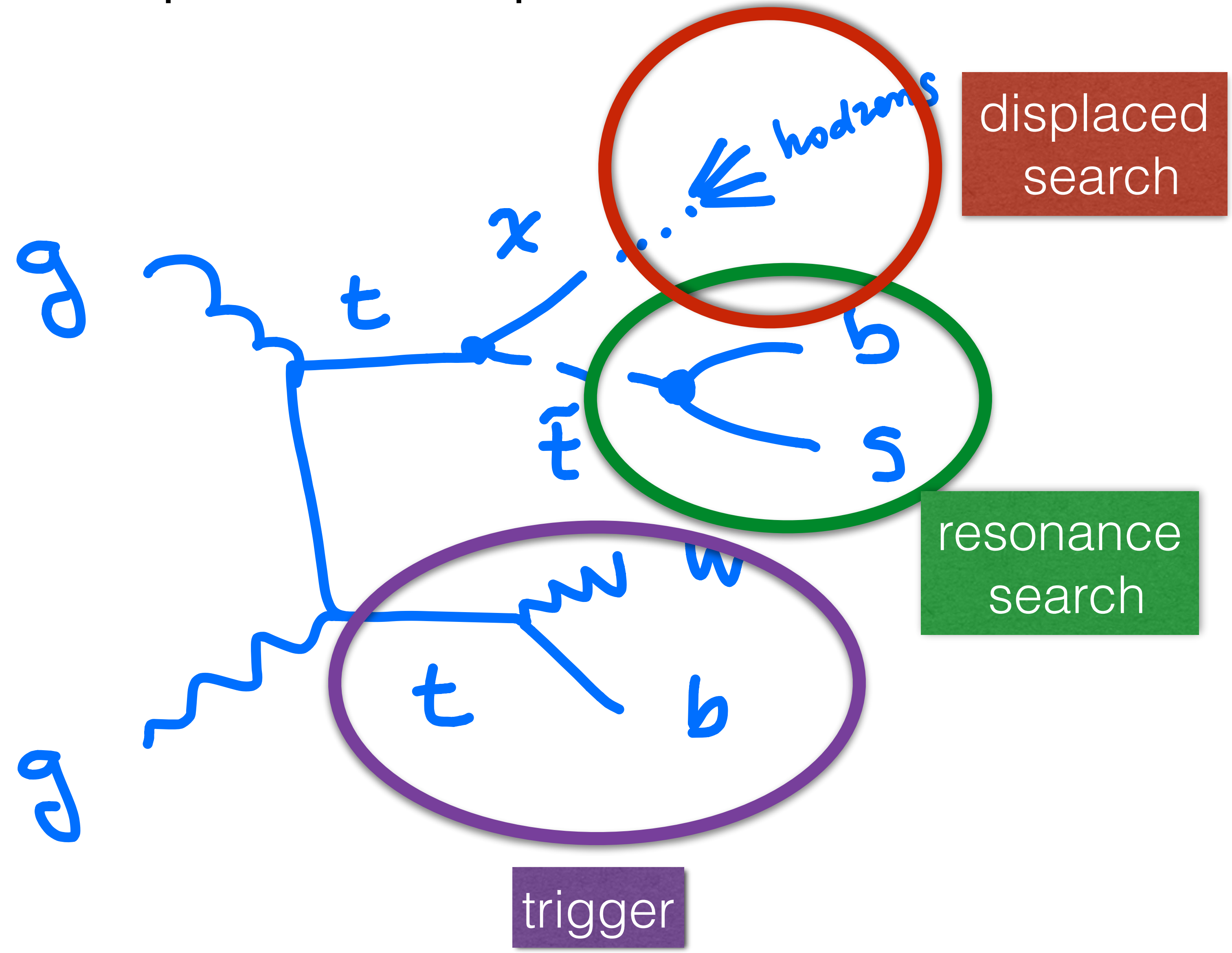
Top as a trigger

Ferretti, RF, Petersson, Torre, in progress

hadronic stops in RPV SUSY



stops from top in RPV SUSY



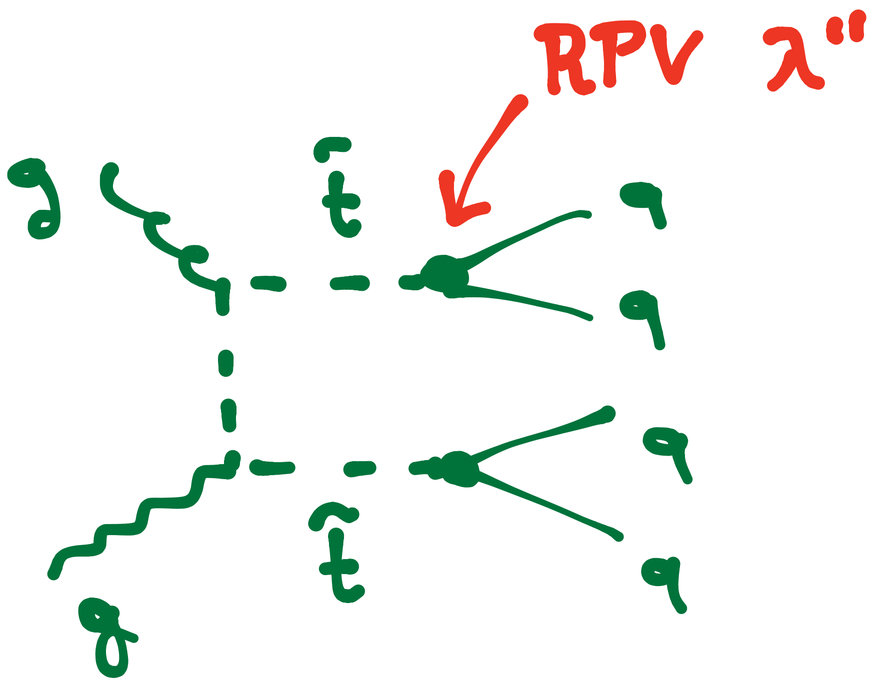
would appear in top properties measurements

CMS "BR" measurement 1506.05074
CMS "V_{tb}" measurement 1404.2292

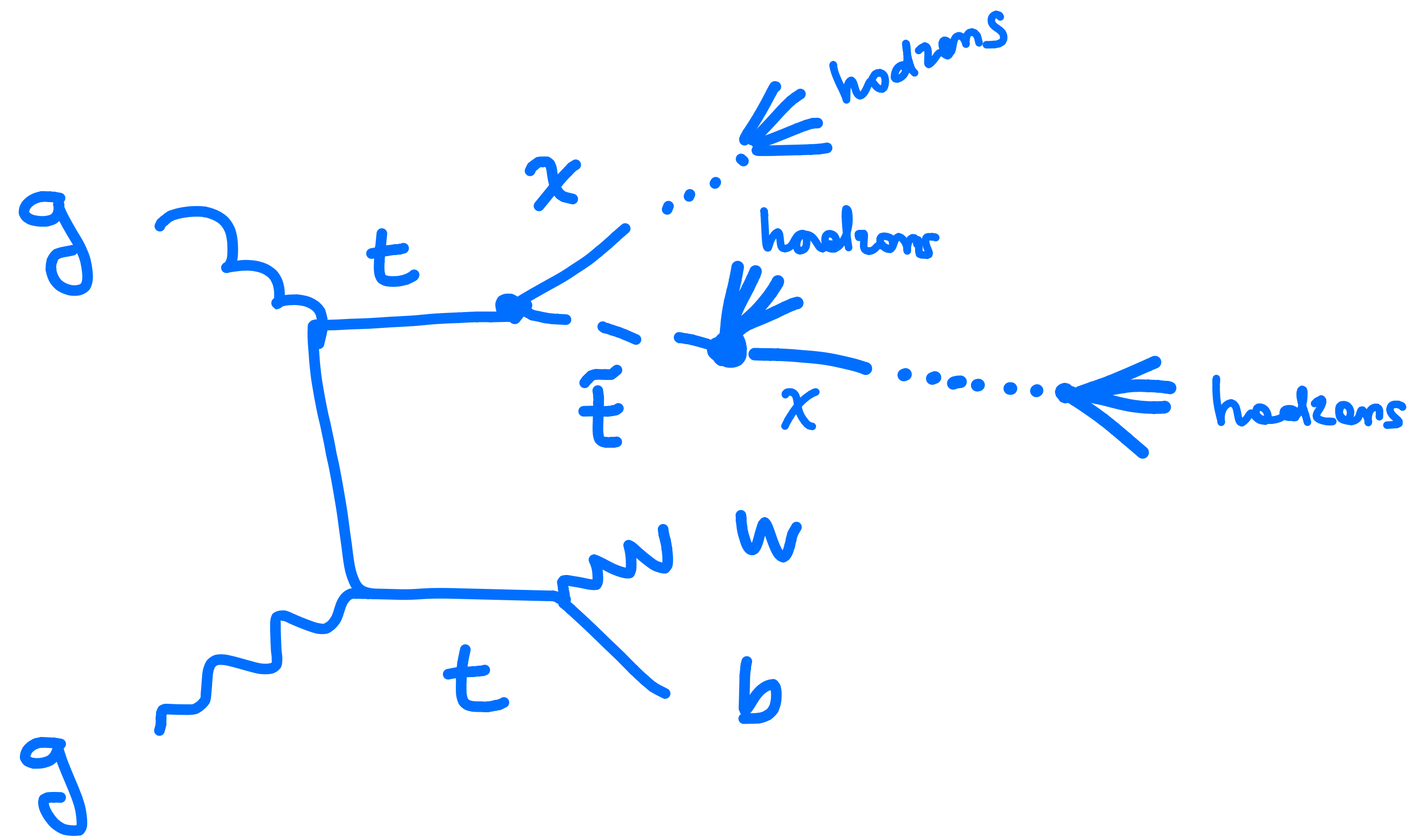
Top as a trigger

Ferretti, RF, Petersson, Torre, in progress

hadronic stops in RPV SUSY



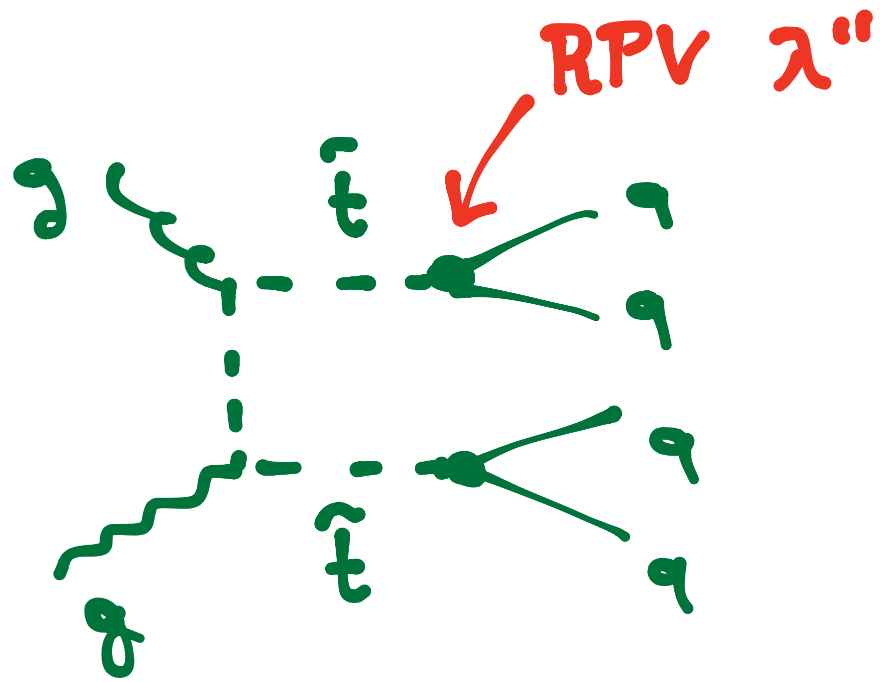
stops from top in RPV SUSY



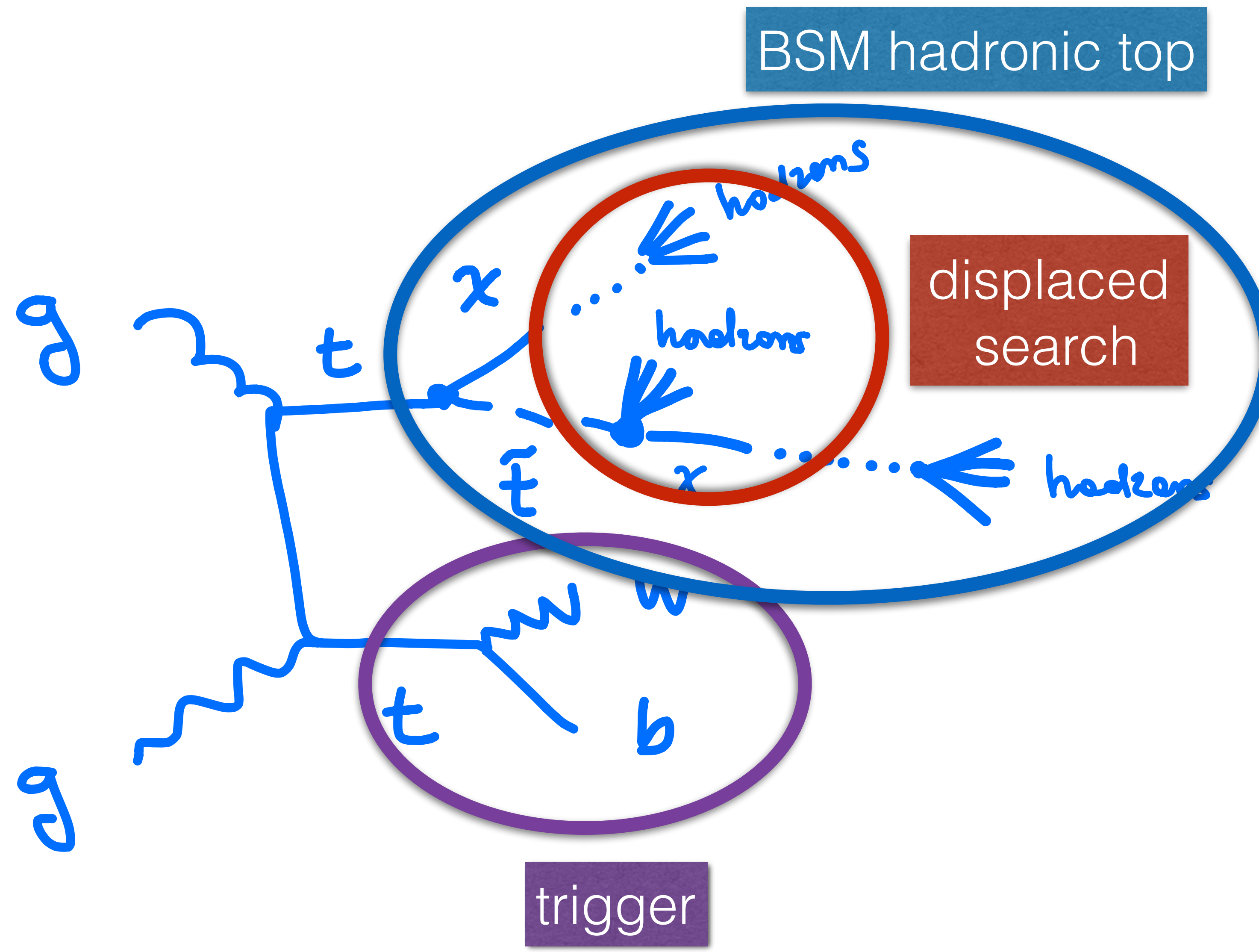
Top as a trigger

Ferretti, RF, Petersson, Torre, in progress

hadronic stops in RPV SUSY



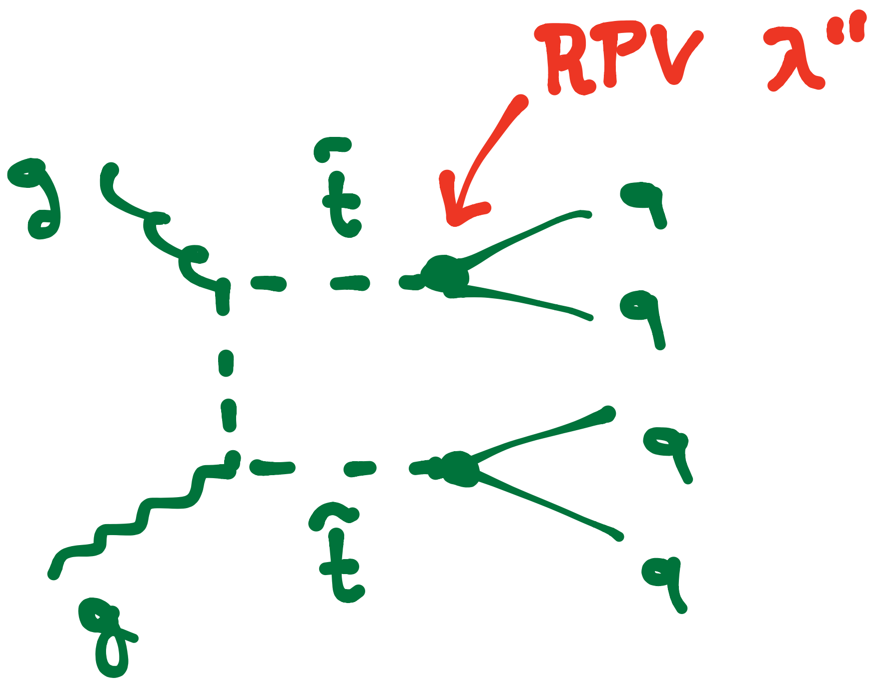
stops from top in RPV SUSY



Top as a trigger

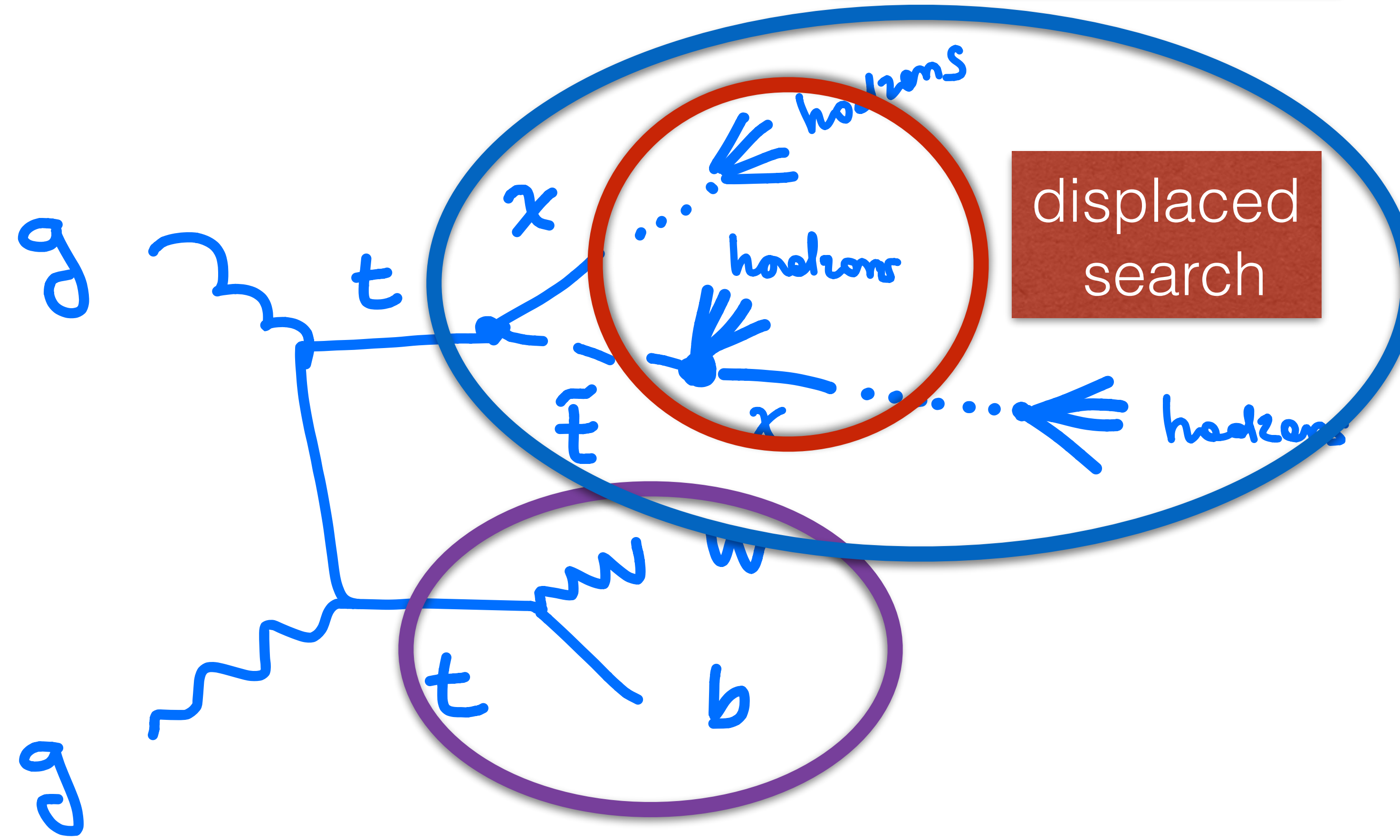
Ferretti, RF, Petersson, Torre, in progress

hadronic stops in RPV SUSY



stops from top in RPV SUSY

BSM hadronic top



displaced search

trigger

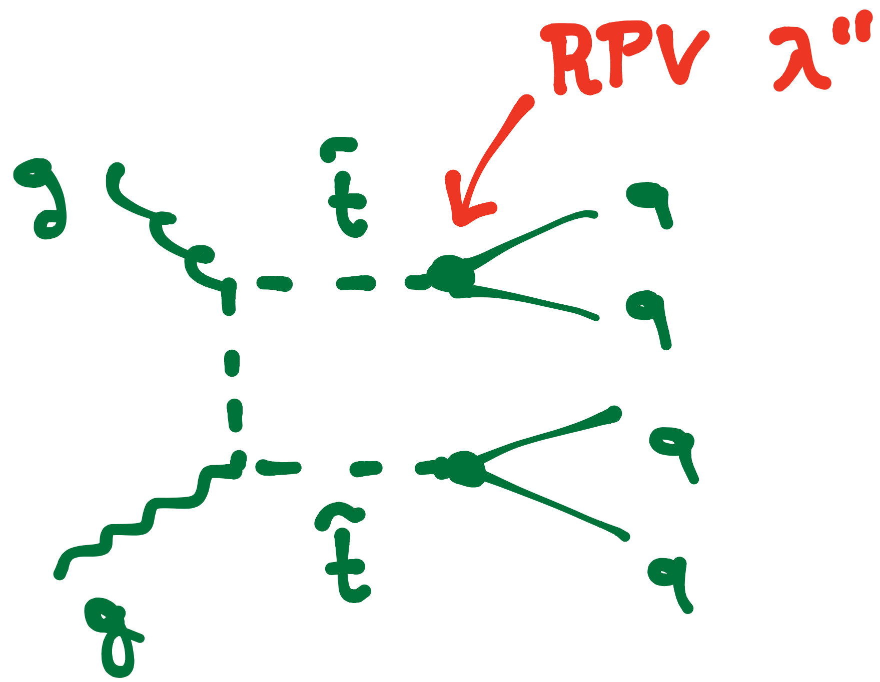
would appear in top properties measurements

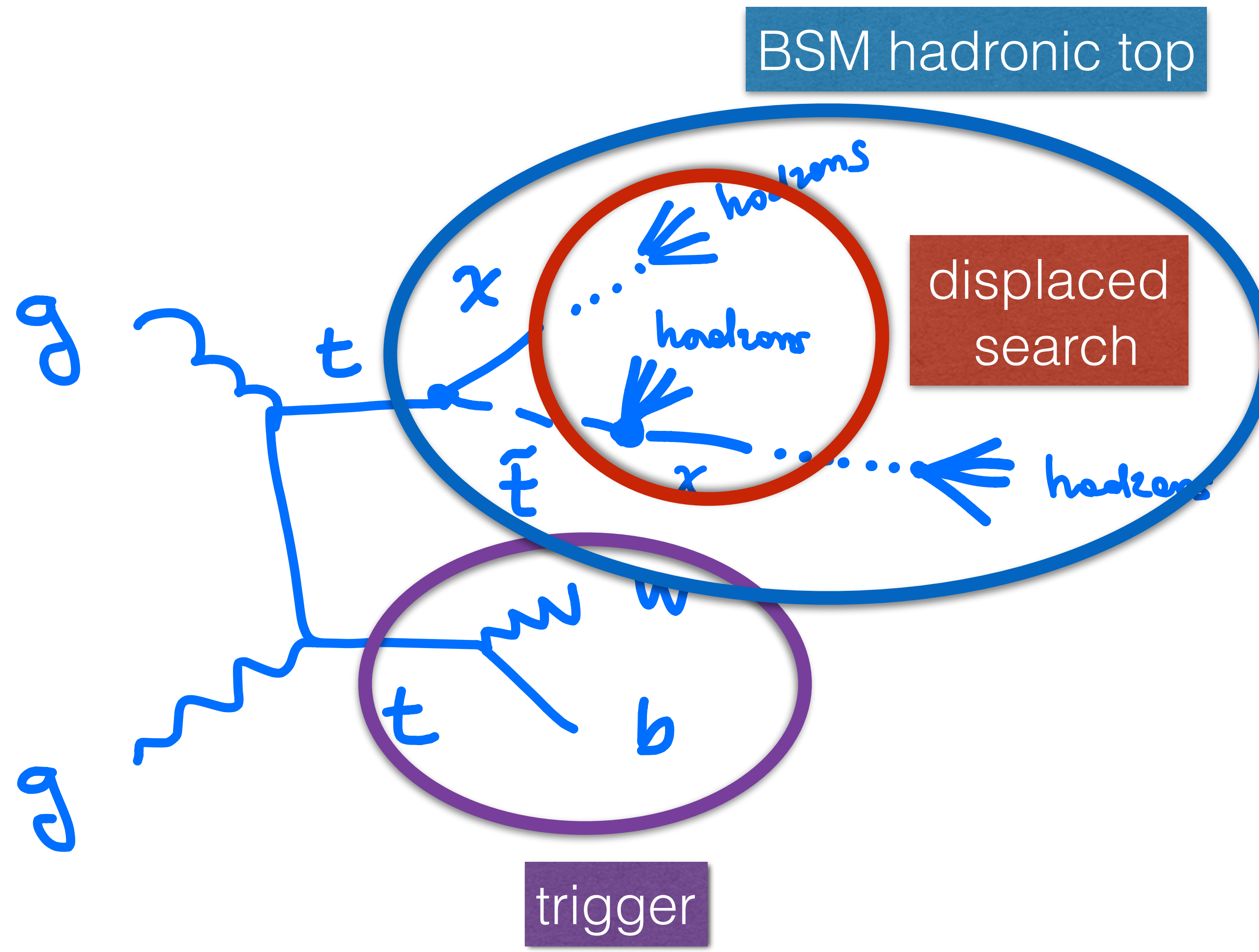
Top as a trigger

Ferretti, RF, Petersson, Torre, in progress

stops from top in RPV SUSY

hadronic stops in RPV SUSY





would appear in top properties measurements

CMS “BR” measurement 1506.05074
CMS “Vtb” measurement 1404.2292

Conclusions

- Run2: more emphasis on precision in SM and BSM
- Many new observables for precision SM measurements (exciting new results from CMS *TOP-PAS-15-002*)
- Rich playground for precision studies to uncover direct effects of new physics
- Indirect effects can be probed as well

More to discuss ...

Thank you!

B **hadron** observables

B physics in the top sample

Fragmentation: the b quark energy peak is translated into a (broader) B hadron energy peak

- more exclusive final states
- non-JES uncertainties
- hadronization uncertainties

More (B <u>hadron</u>) peak observables

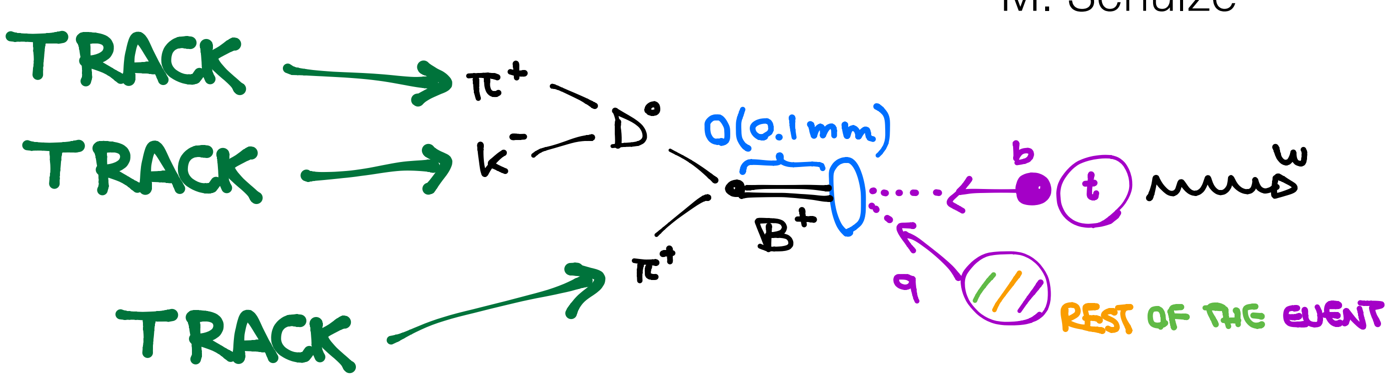
The strength of the future LHC top mass measurement will build on the **diversity of methods**
⇒ not very useful to talk about "*single best measurement*"

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

hadron energy peak

get the hadron energy entirely from tracks

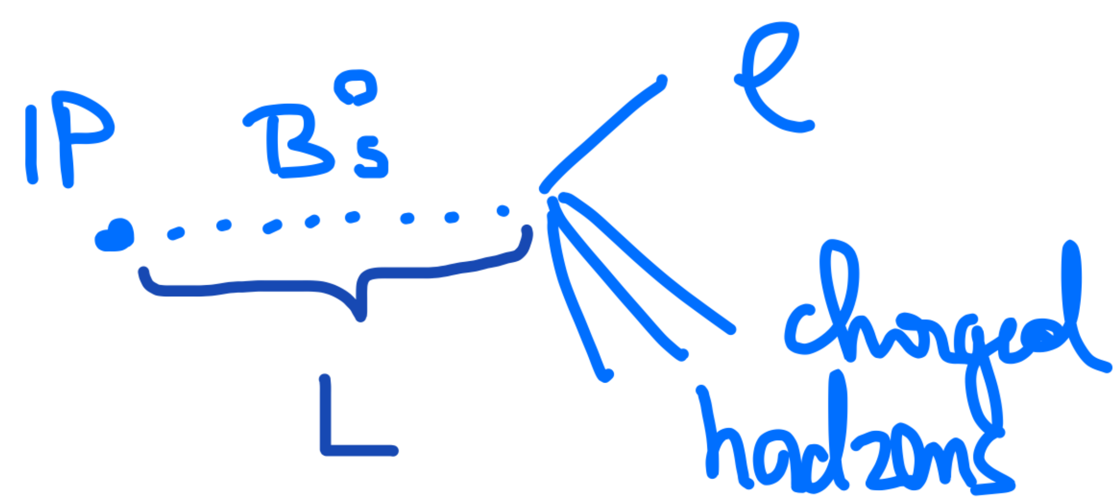
collaboration with
M. Schulze



exclusive B decays in the top sample

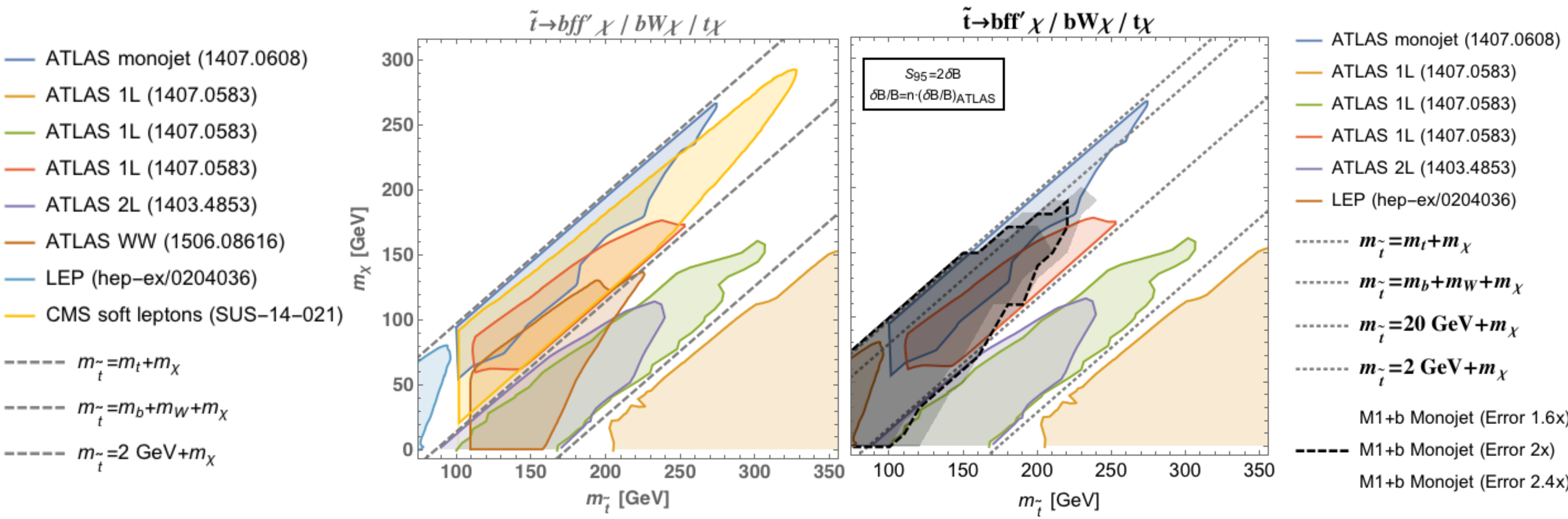
<u>mean</u> decay path peak

discussions with
J. Incandela

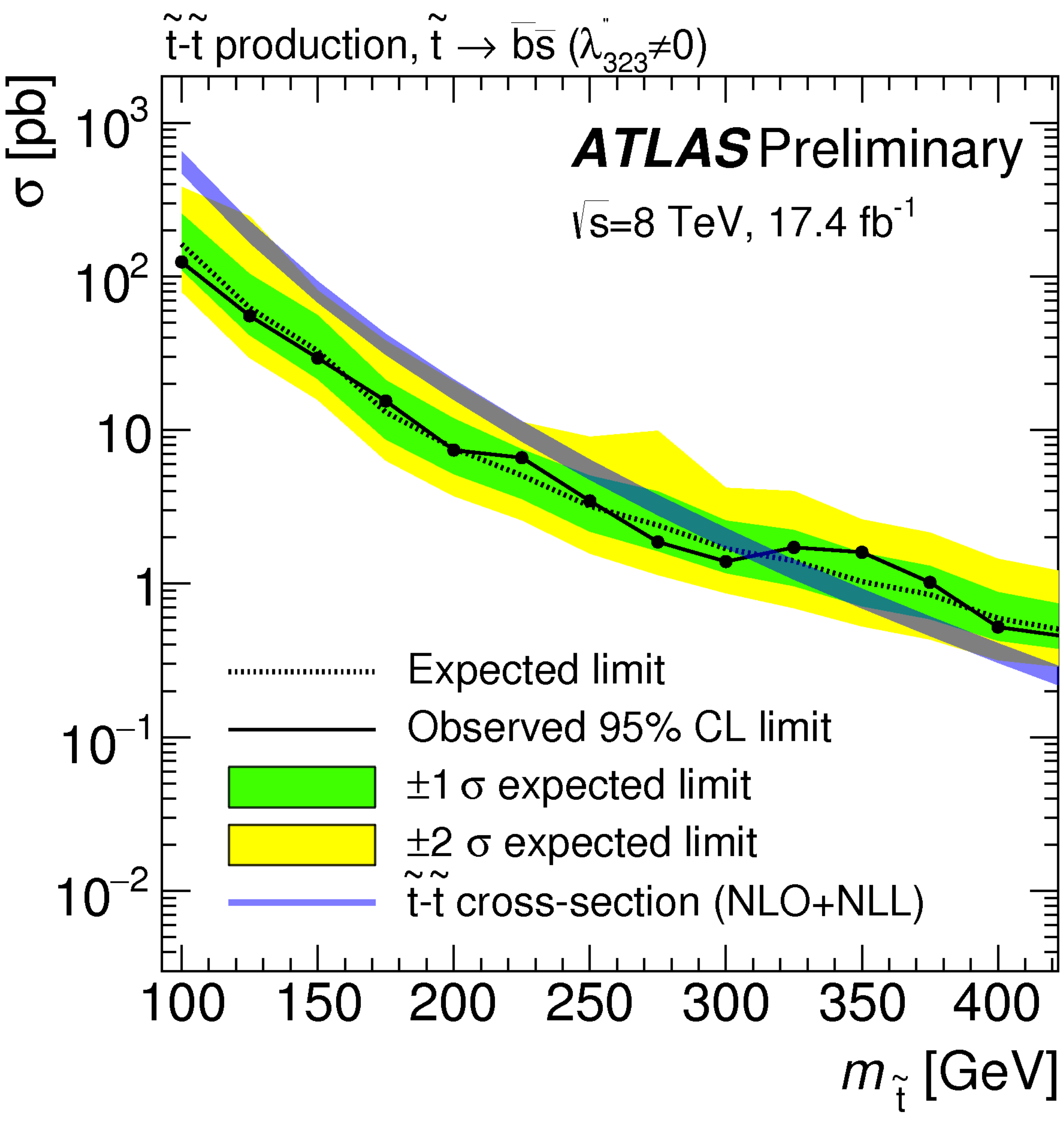


Thank you! (again)

ATLAS+CMS $\tilde{t}$-χ

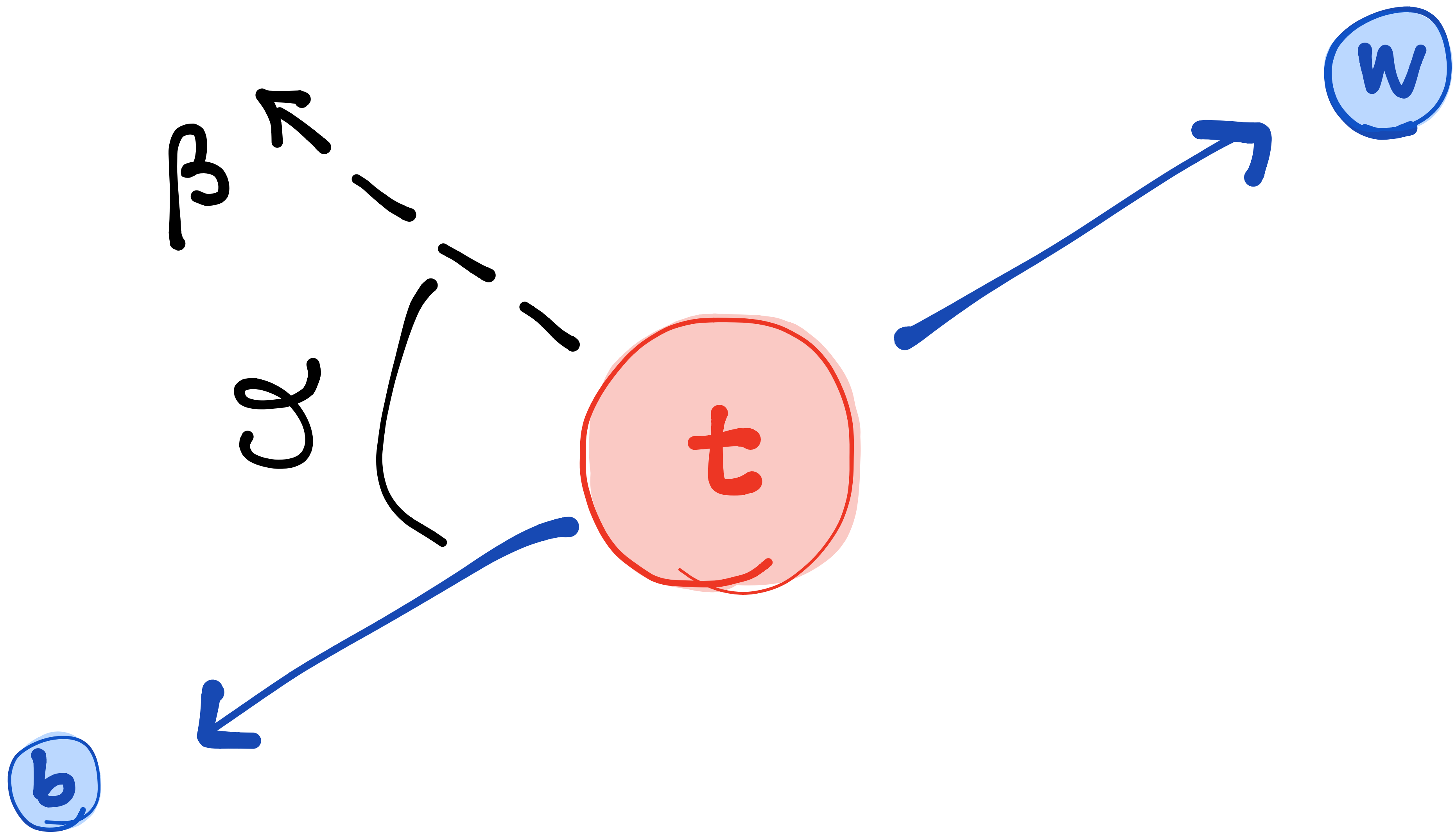


ATLAS-CONF-2015-026



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

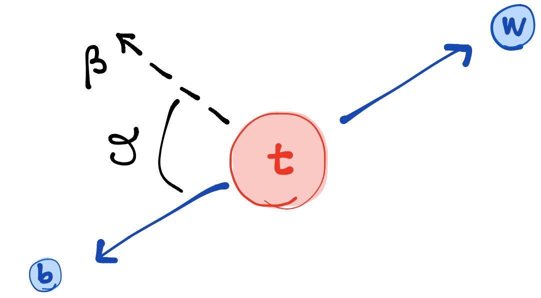
1209.0772 - Agashe, Franceschini and Kim



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

Event-by-event we cannot tell anything

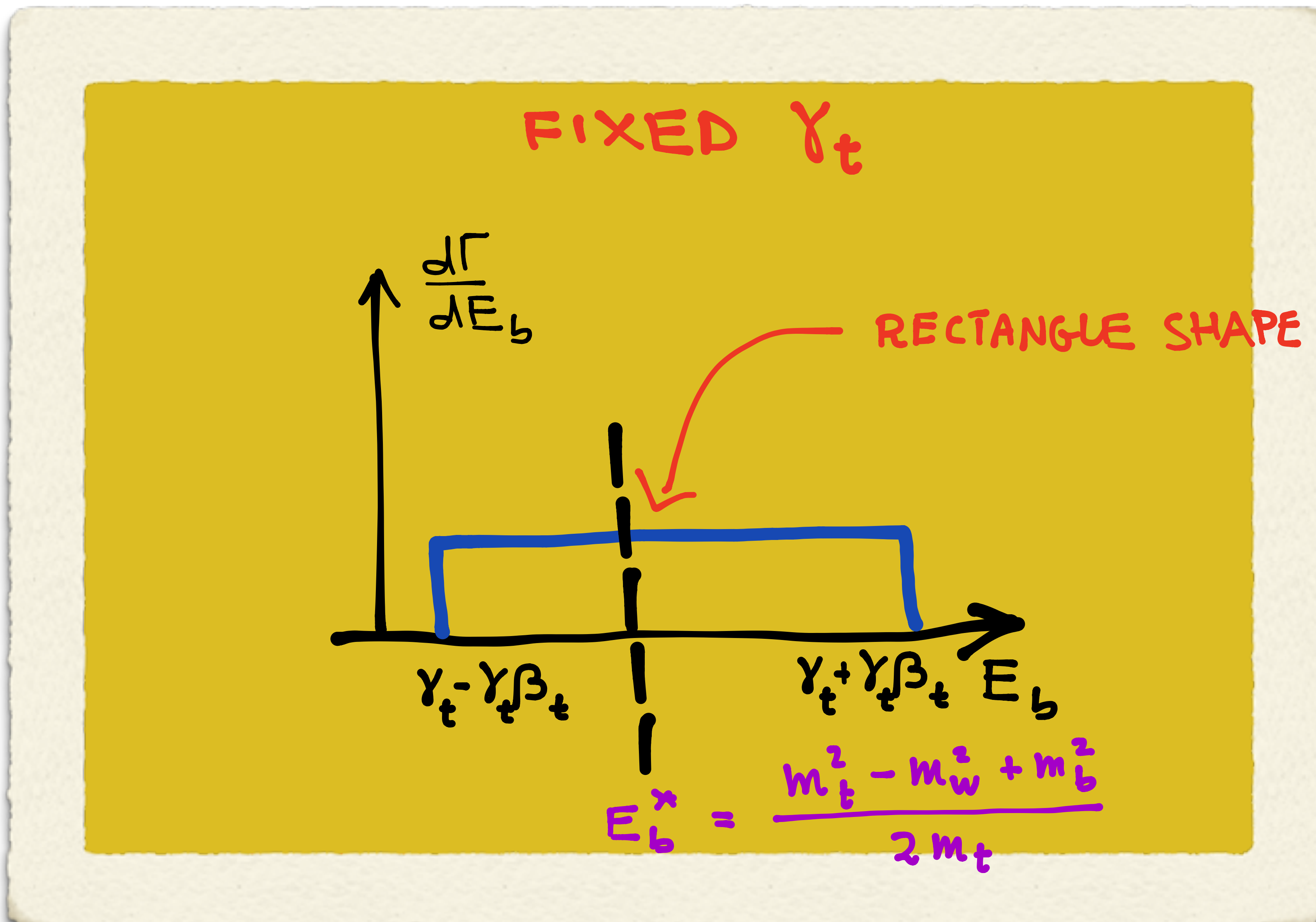
Fixed top boost decay



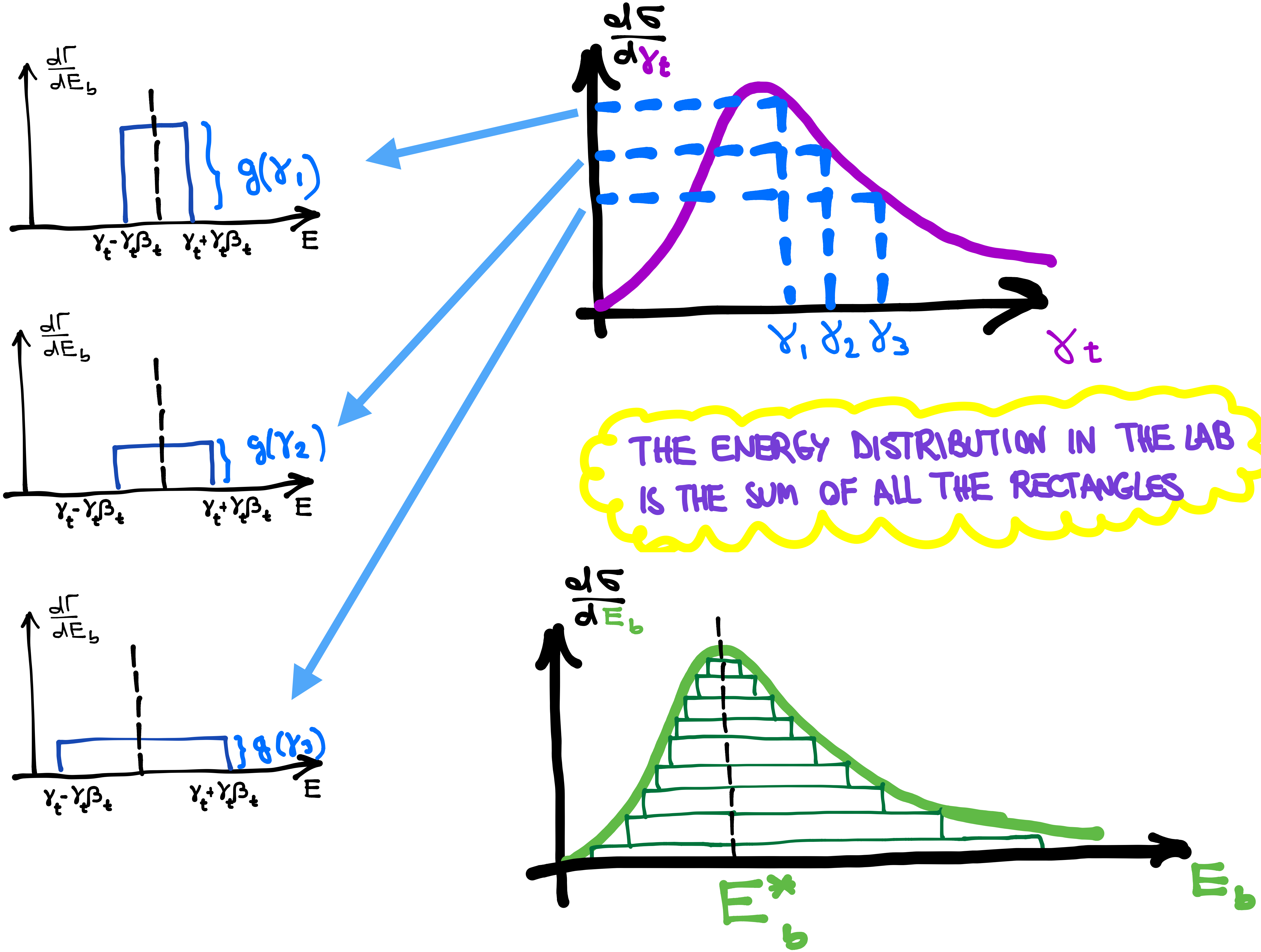
Massless b-quark (for now)

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

unpolarized top sample ⟶ cosθ is flat

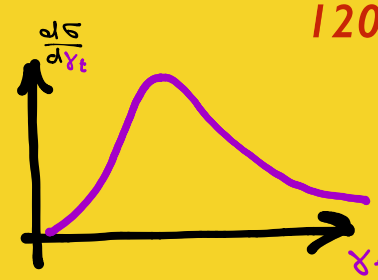


Summing over the top boosts

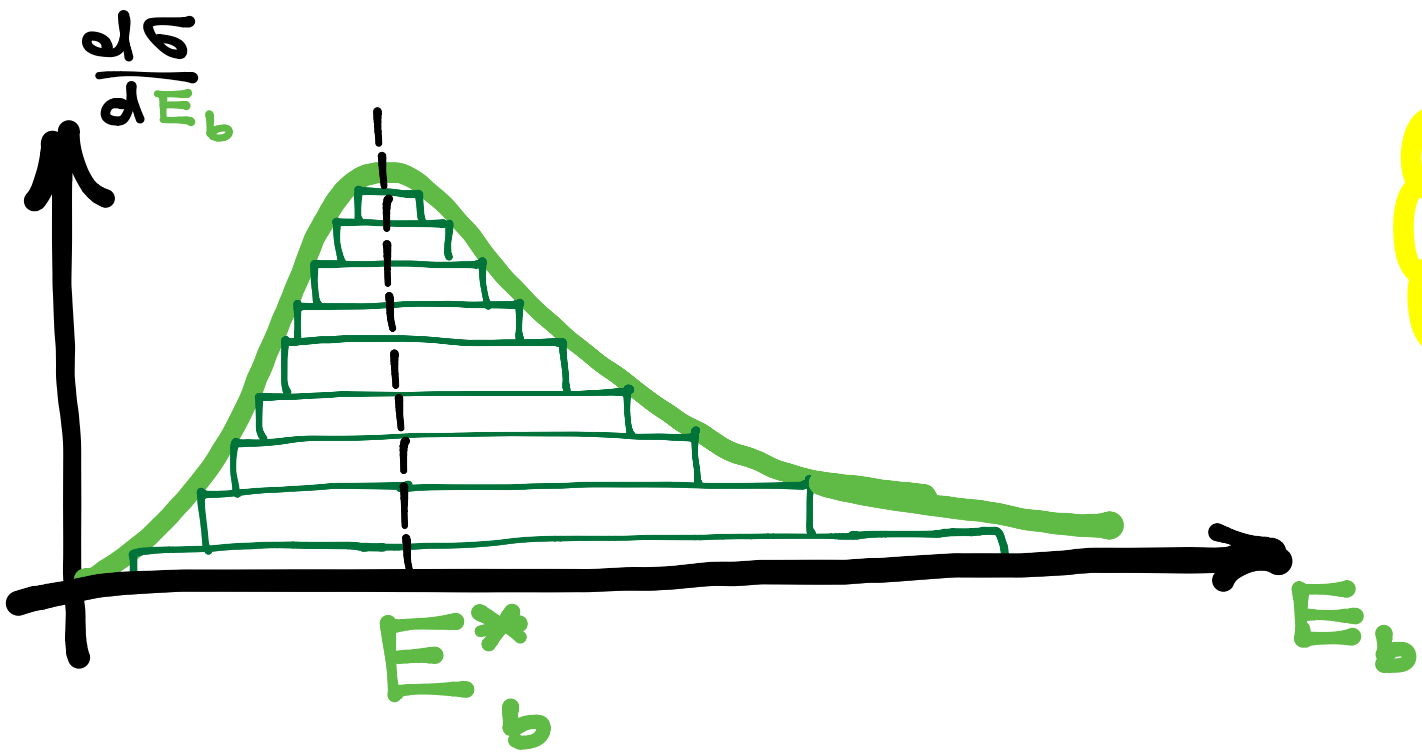


Lab-frame energy distribution

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

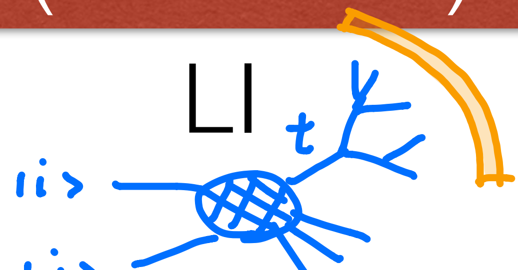
There is no difference when the b-mass is taken into account provided $\gamma_{top} < 500$

variations around Lorentz Invariance

needs two particles (combinations)

needs just one particle

LI

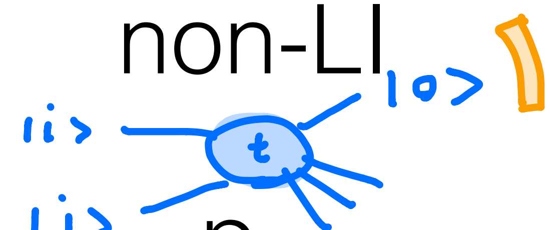


$p_b \cdot p_\ell$

"pheno"-LI

$\hat{E}_b$

non-LI



$p_{T\ell}$

radiation in decays breaks true-LI due to reconstruction

radiation in decays breaks pheno-LI due to 3-body

end-point is safe w.r.t radiation in decay

exclusiveness breaks pheno-LI

in practice we need the tail, which is sensitive to radiation

what is the "small parameter" Δ_{TH} that "breaks" (true or effective) LI?

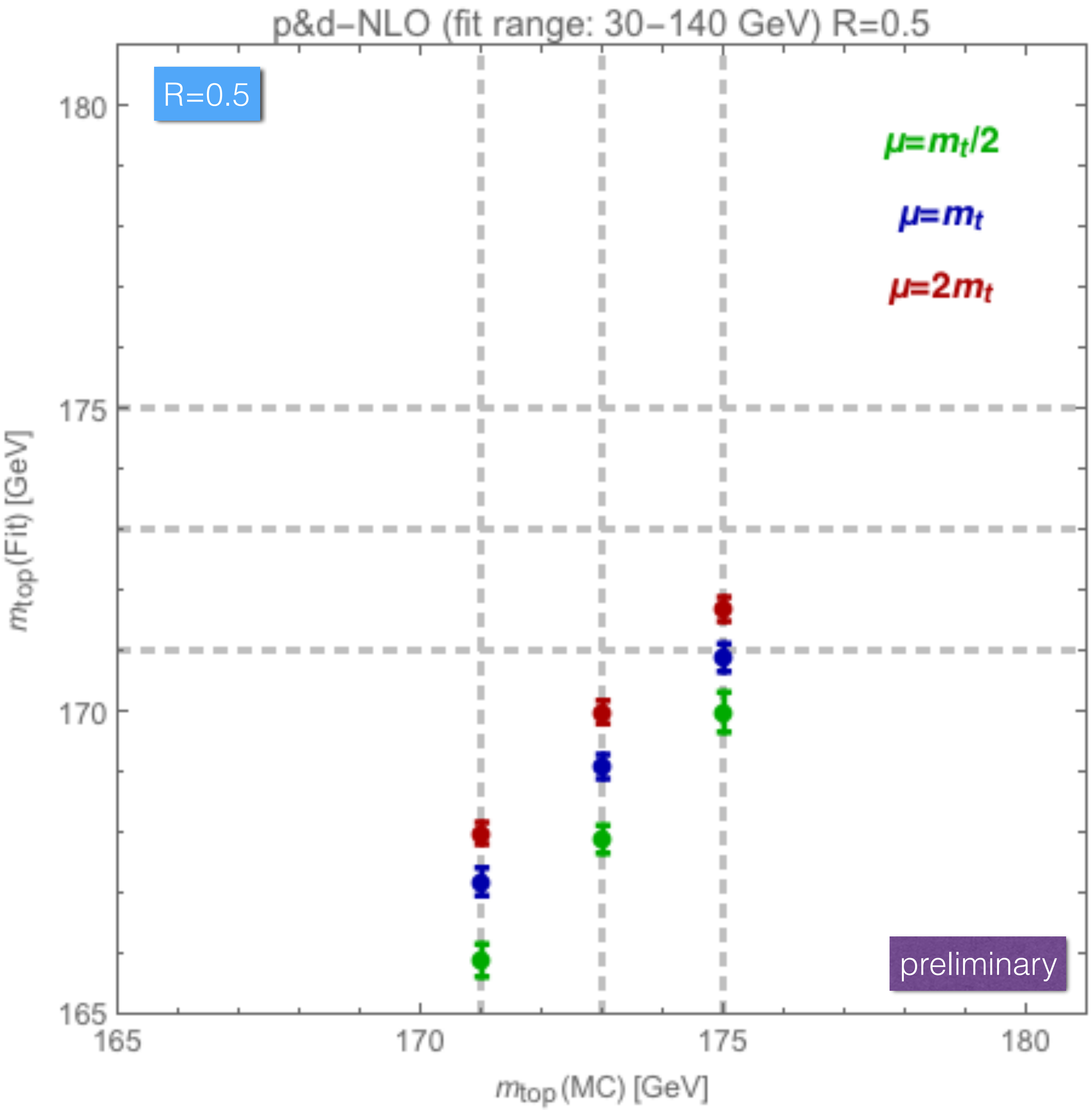
	pdNLO	pNLO	LO
$2\mu_0$	170.	173.4	172.8
	178.	180.4	180.
μ_0	168.9	173.7	173.
	177.7	180.5	180.2
$0.5\mu_0$	167.7	173.8	172.8
	176.9	180.6	180.3

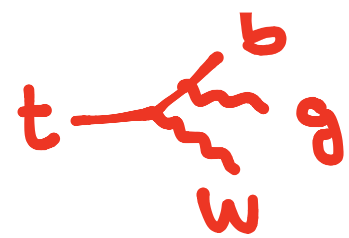
	pdNLO	pNLO	LO
$2\mu_0$	−3.	0.4	−0.2
	5.	7.4	7.
μ_0	−4.1	0.7	0.
	4.7	7.5	7.2
$0.5\mu_0$	−5.3	0.8	−0.2
	3.9	7.6	7.3

NLO: production & decay

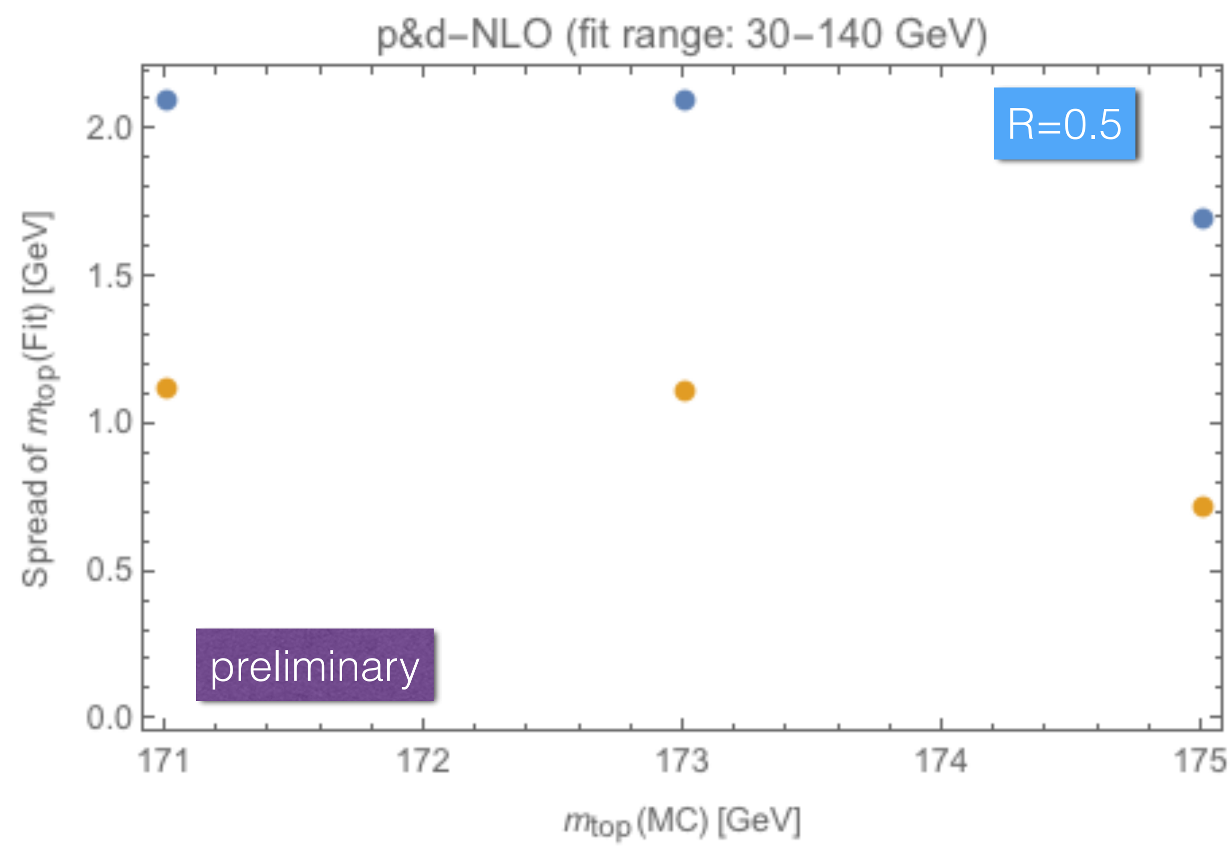
R=0.5

(MCFM)





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

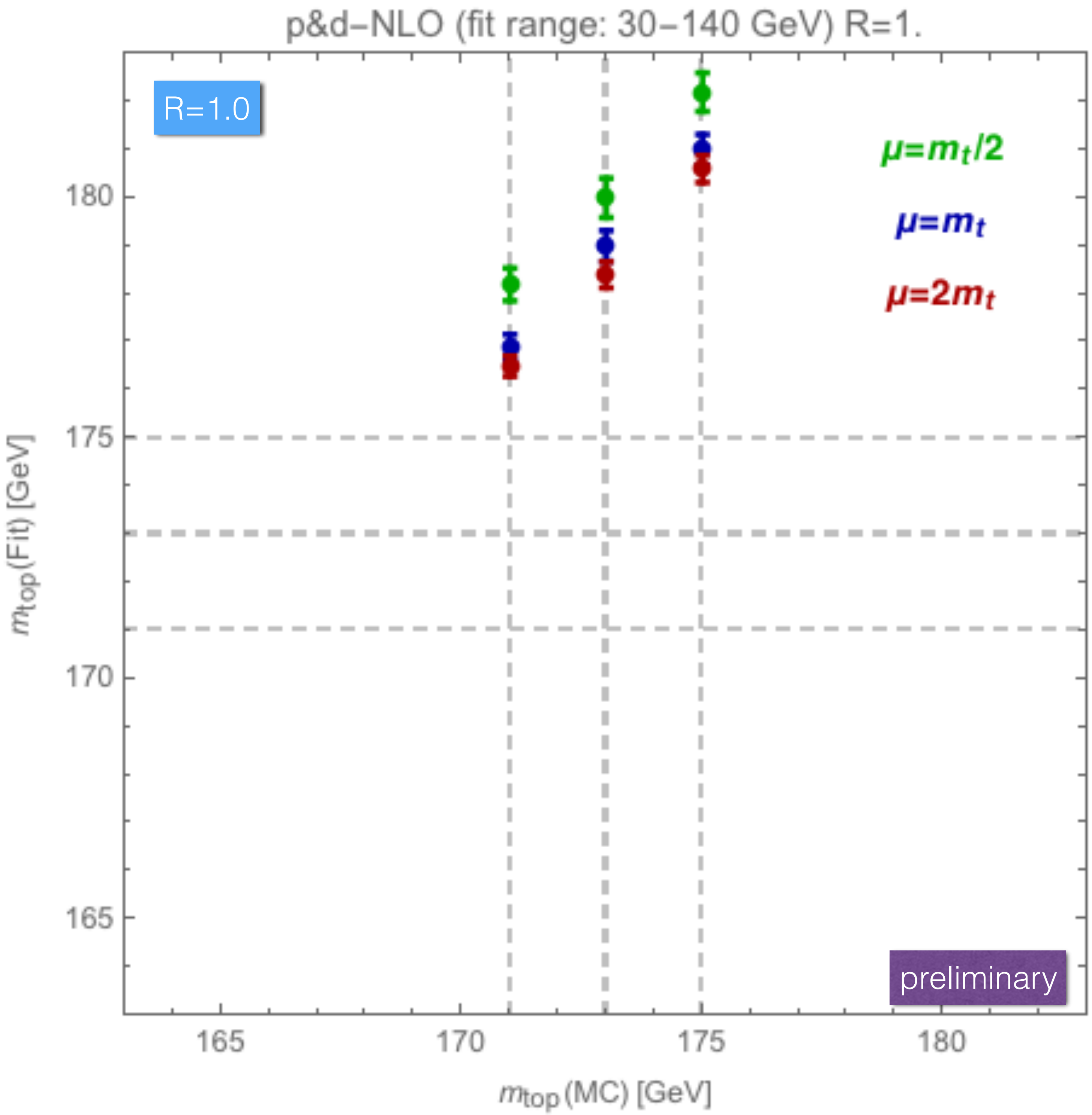


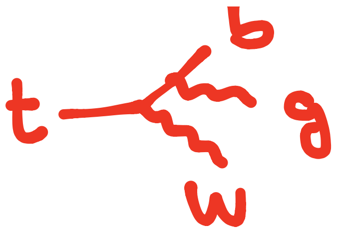
decay NLO sensitive to the scale choice: ±1 GeV on m_{top}

NLO: production & decay

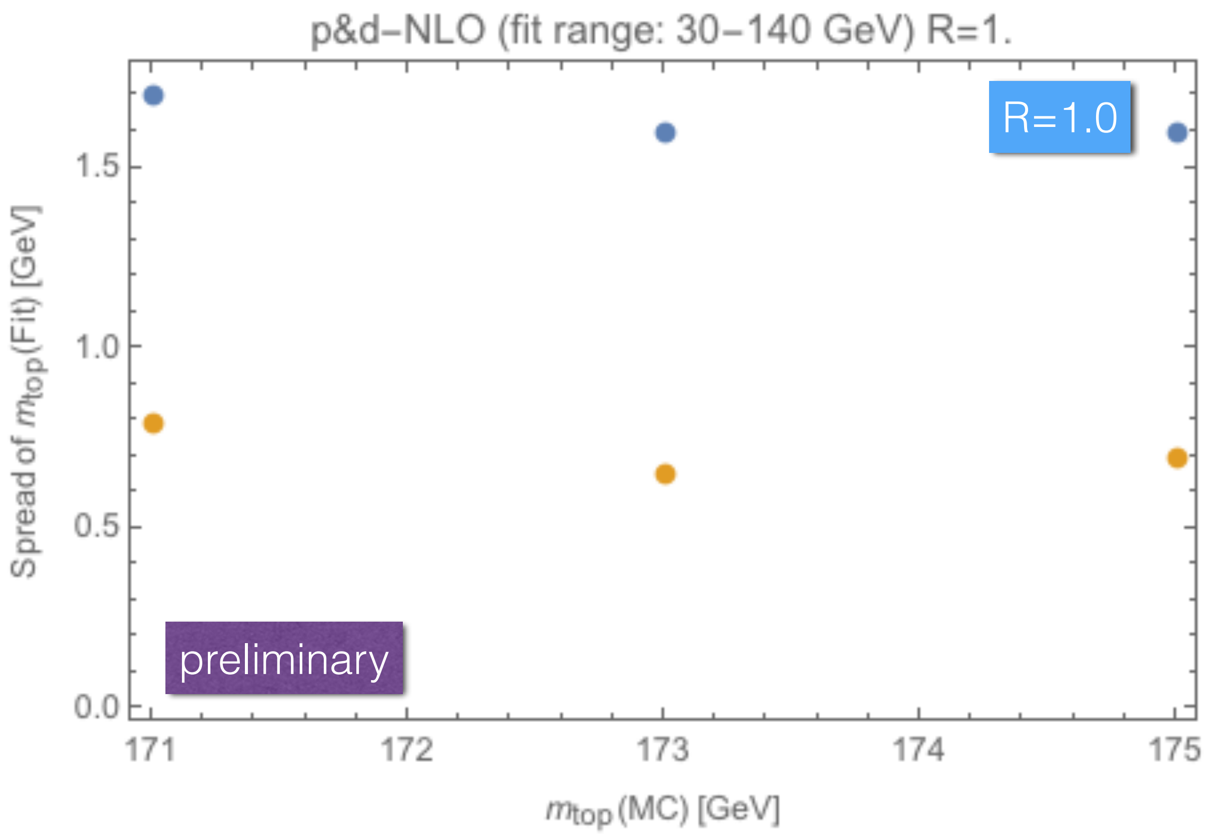
R=1.0

(MCFM)





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

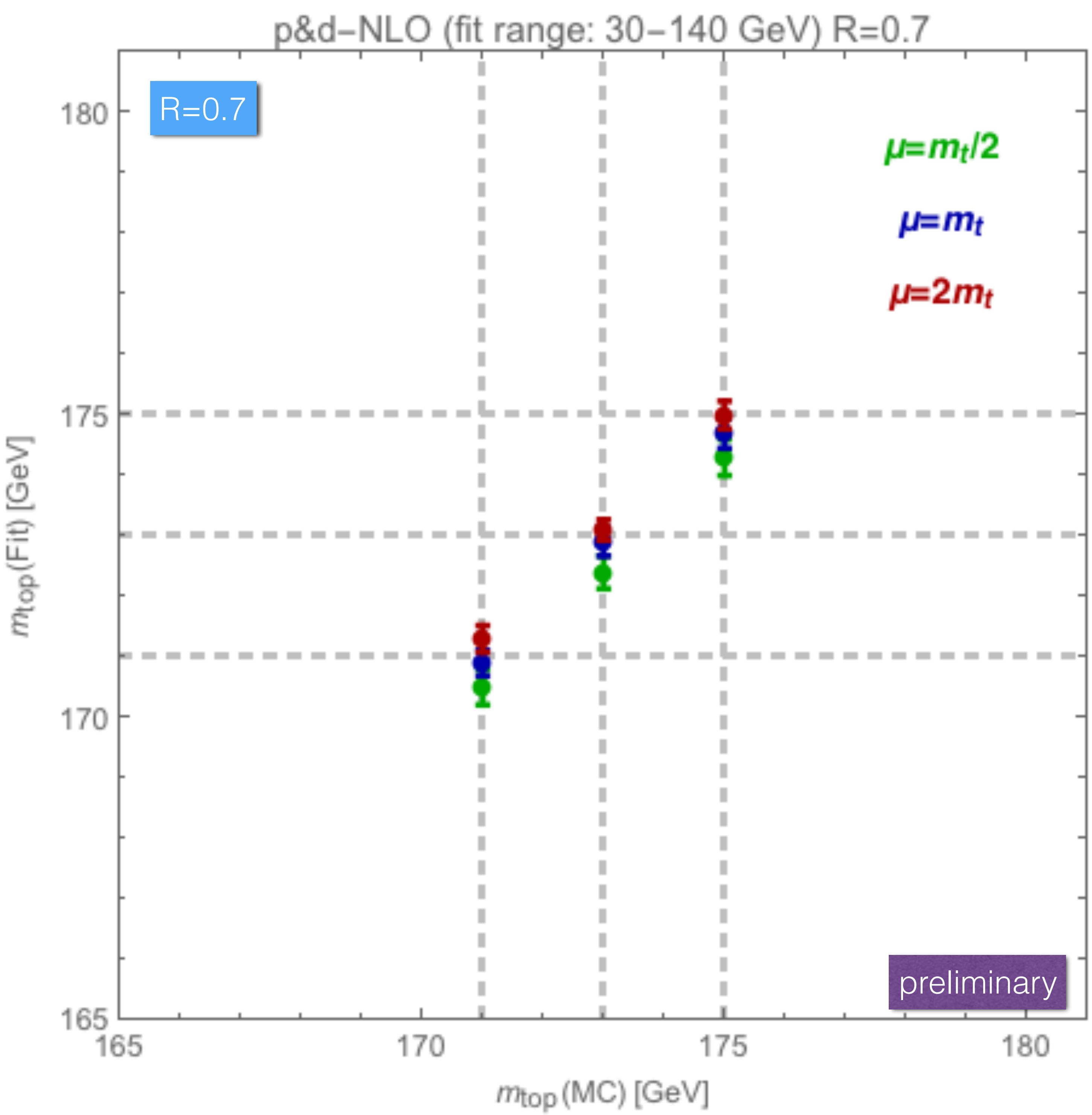


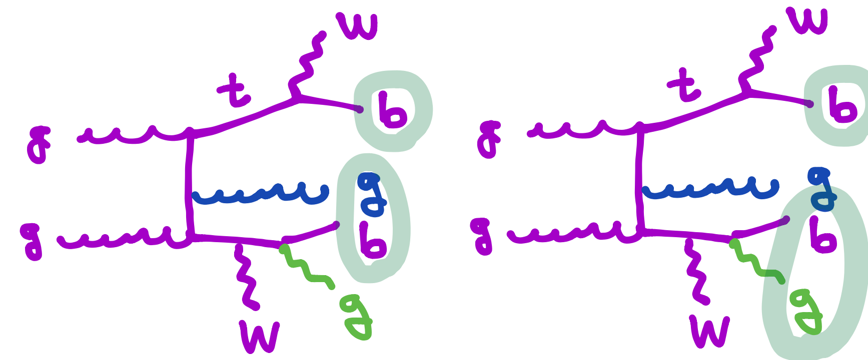
decay NLO sensitive to the scale choice: ±1 GeV on m_{top}

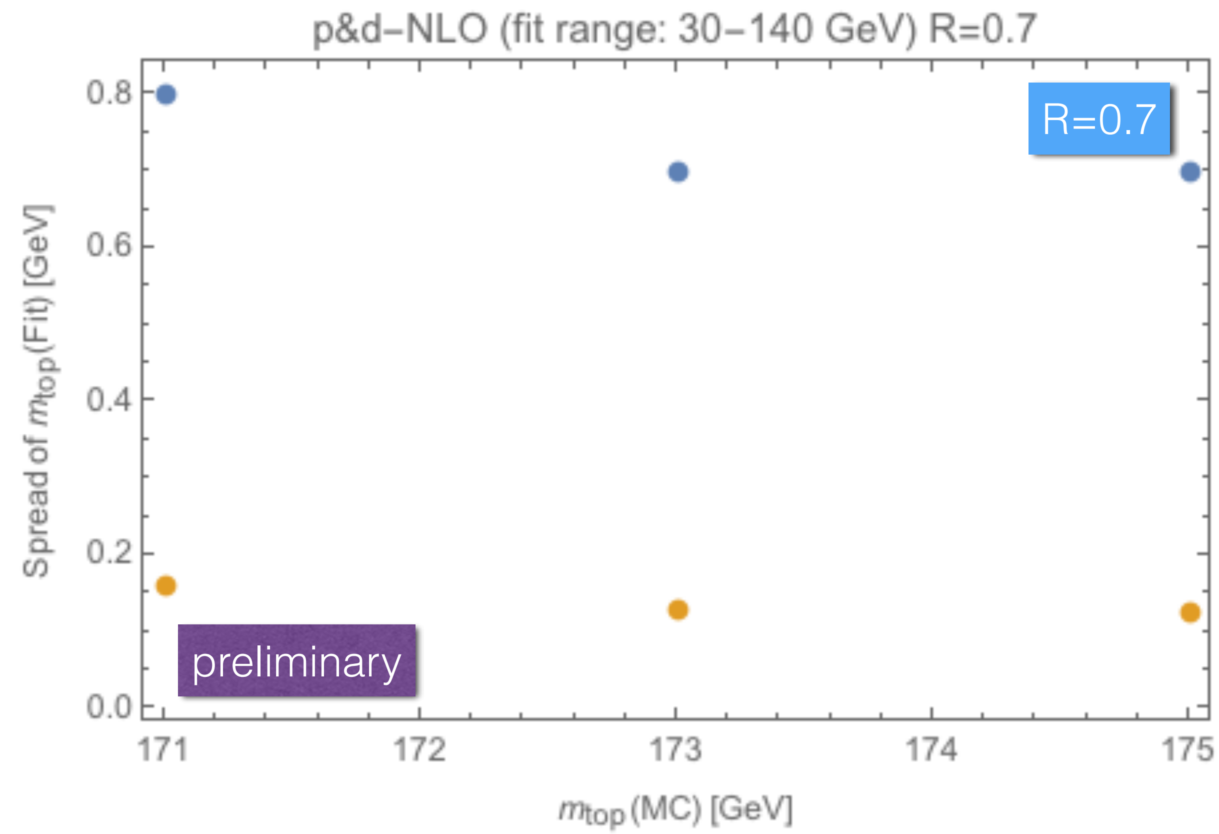
NLO: production & decay

R=0.7

(MCFM)



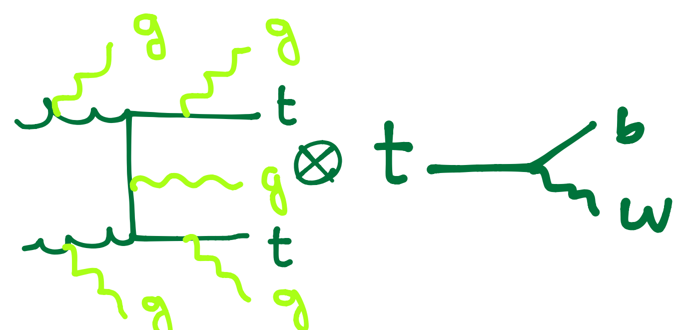


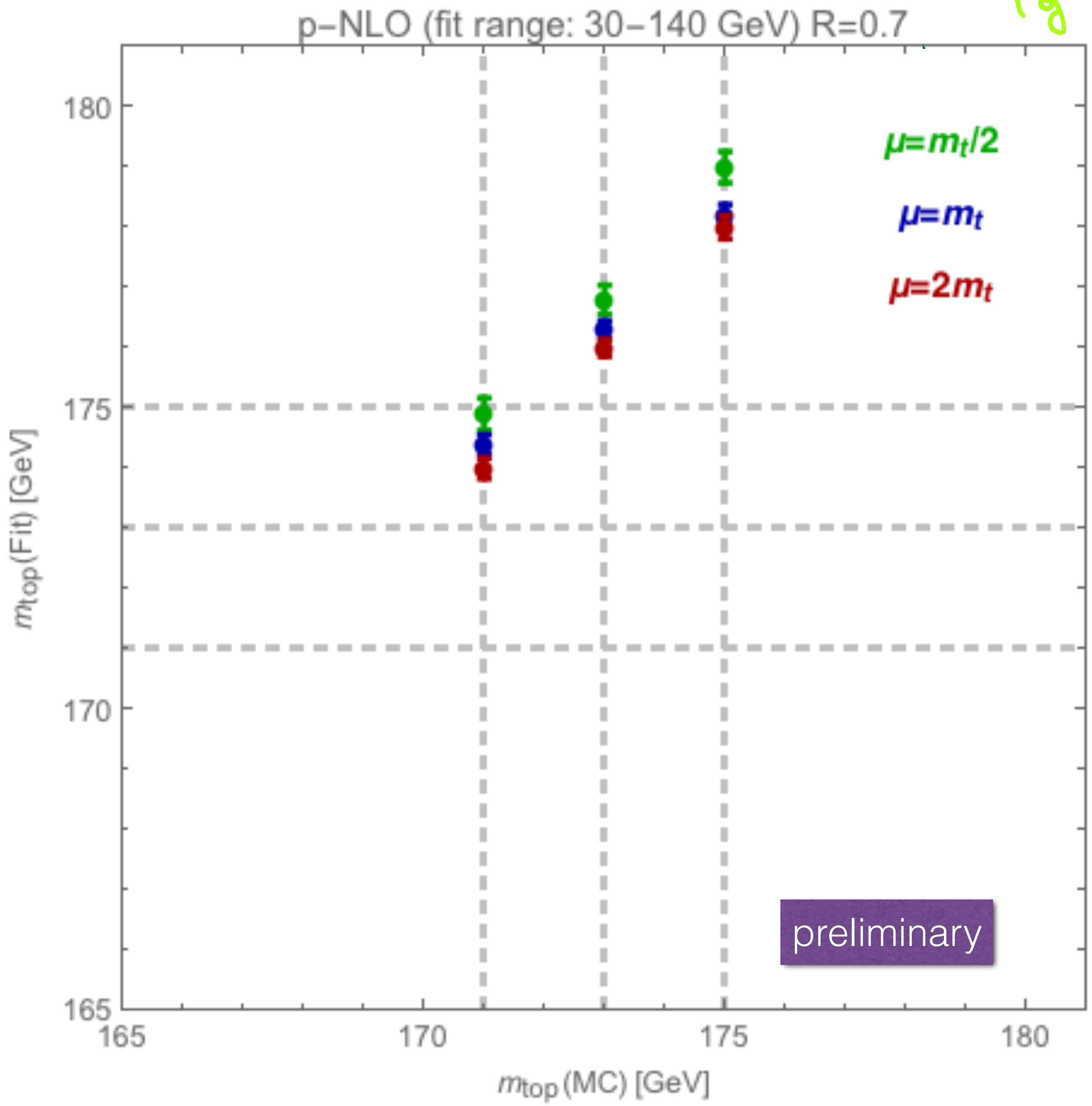


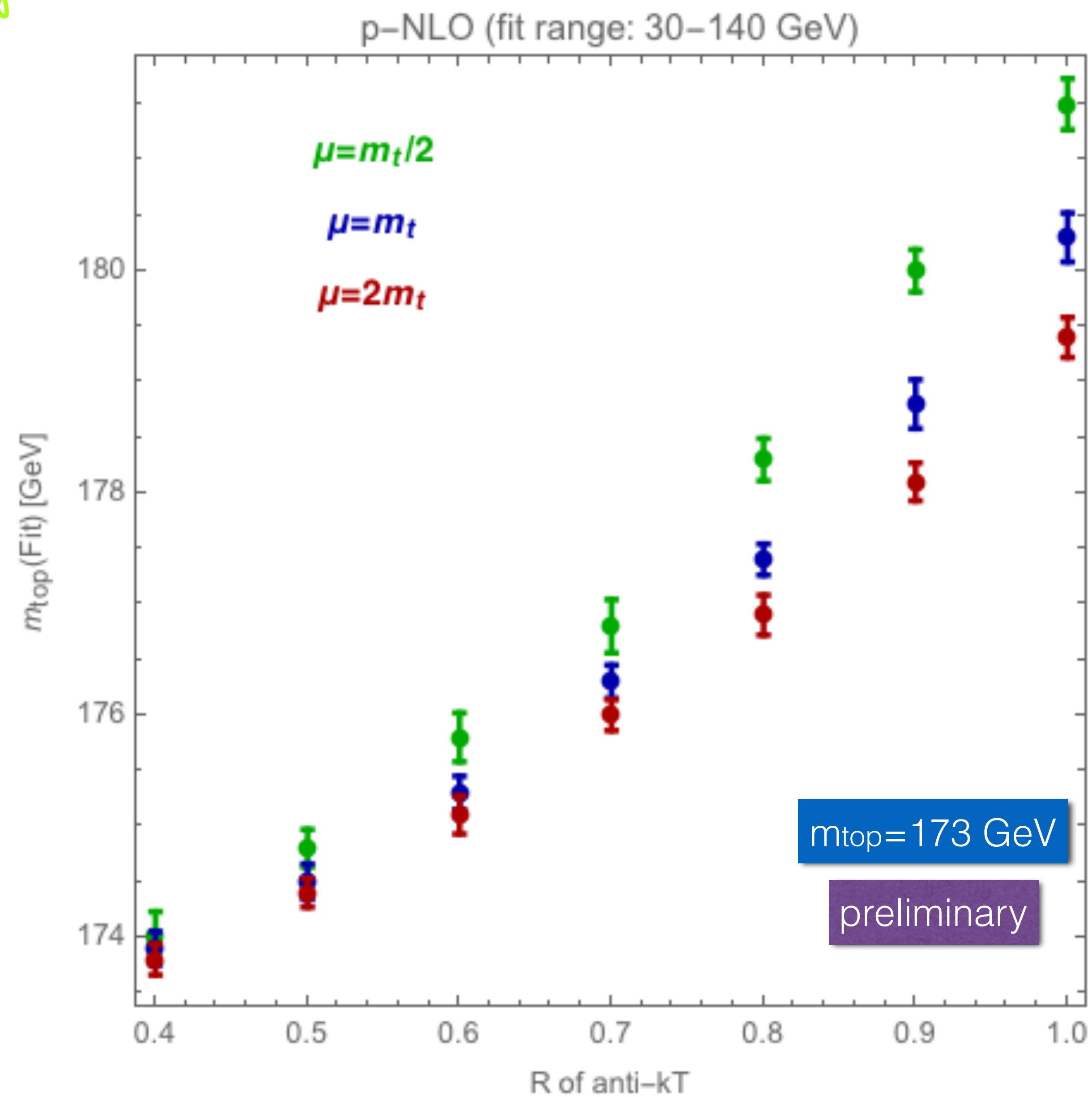
decay NLO sensitive to the scale choice: ±0.5 GeV on m_{top}

NLO: production

(MCFM)



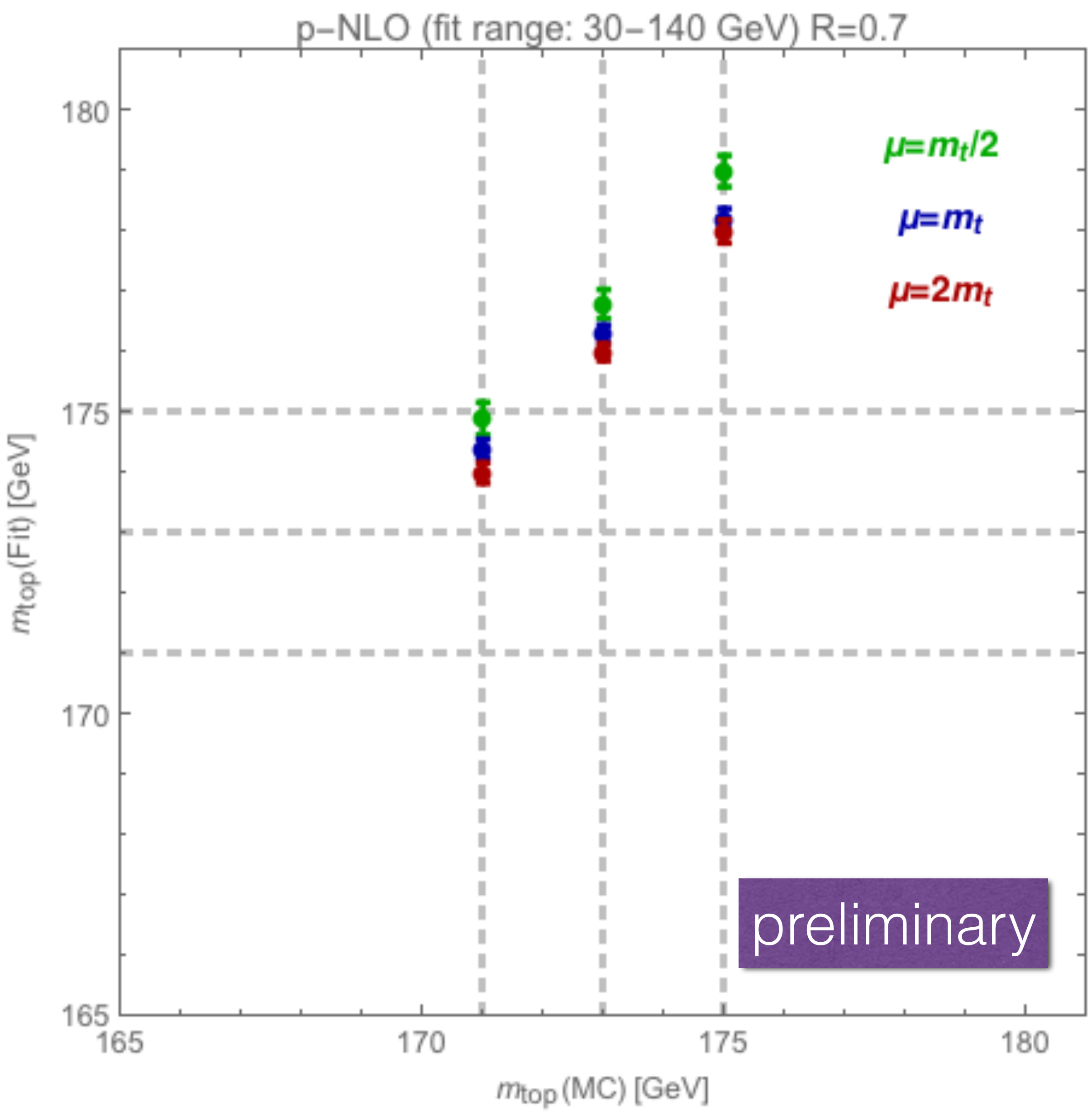


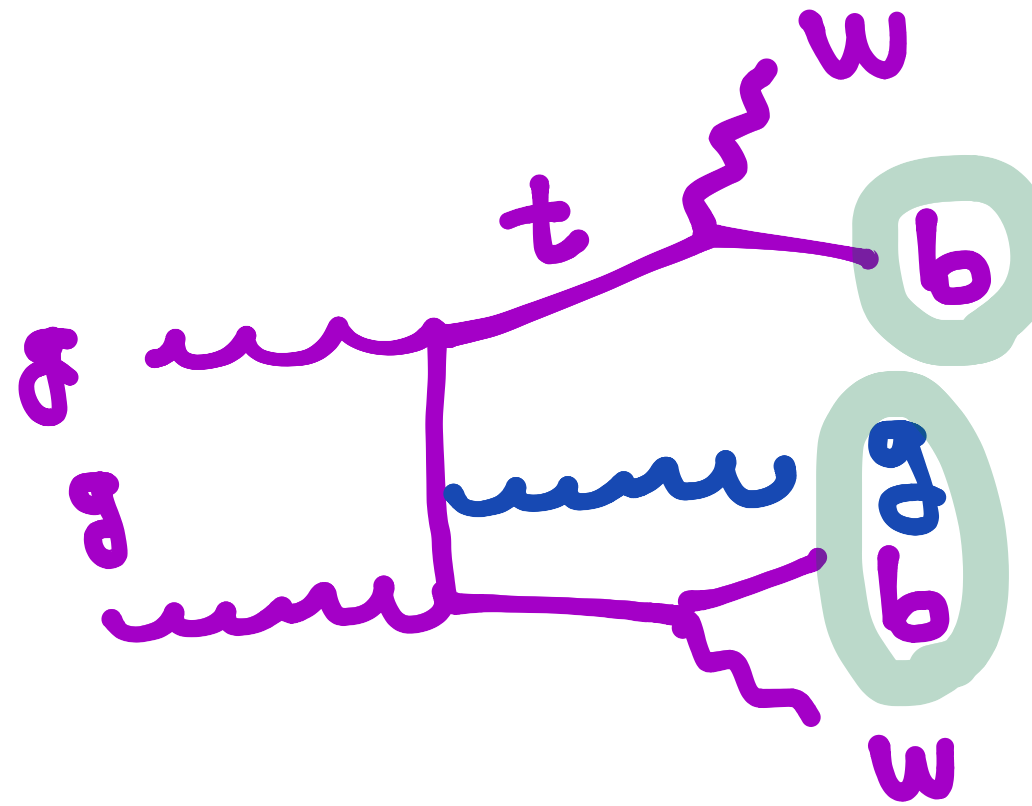


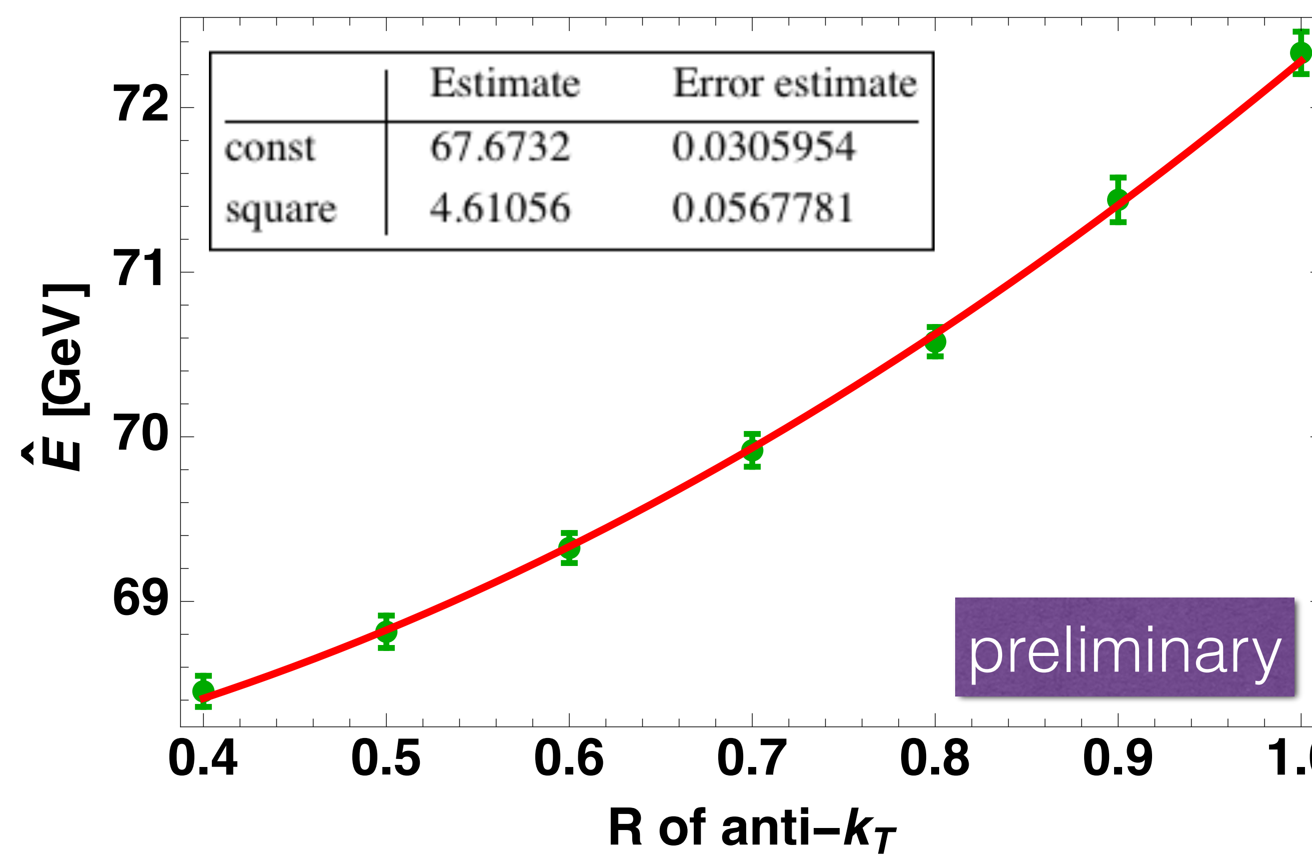
very little sensitive to the scale choice (less than 400 MeV on m_{top})

NLO: production

(MCFM)



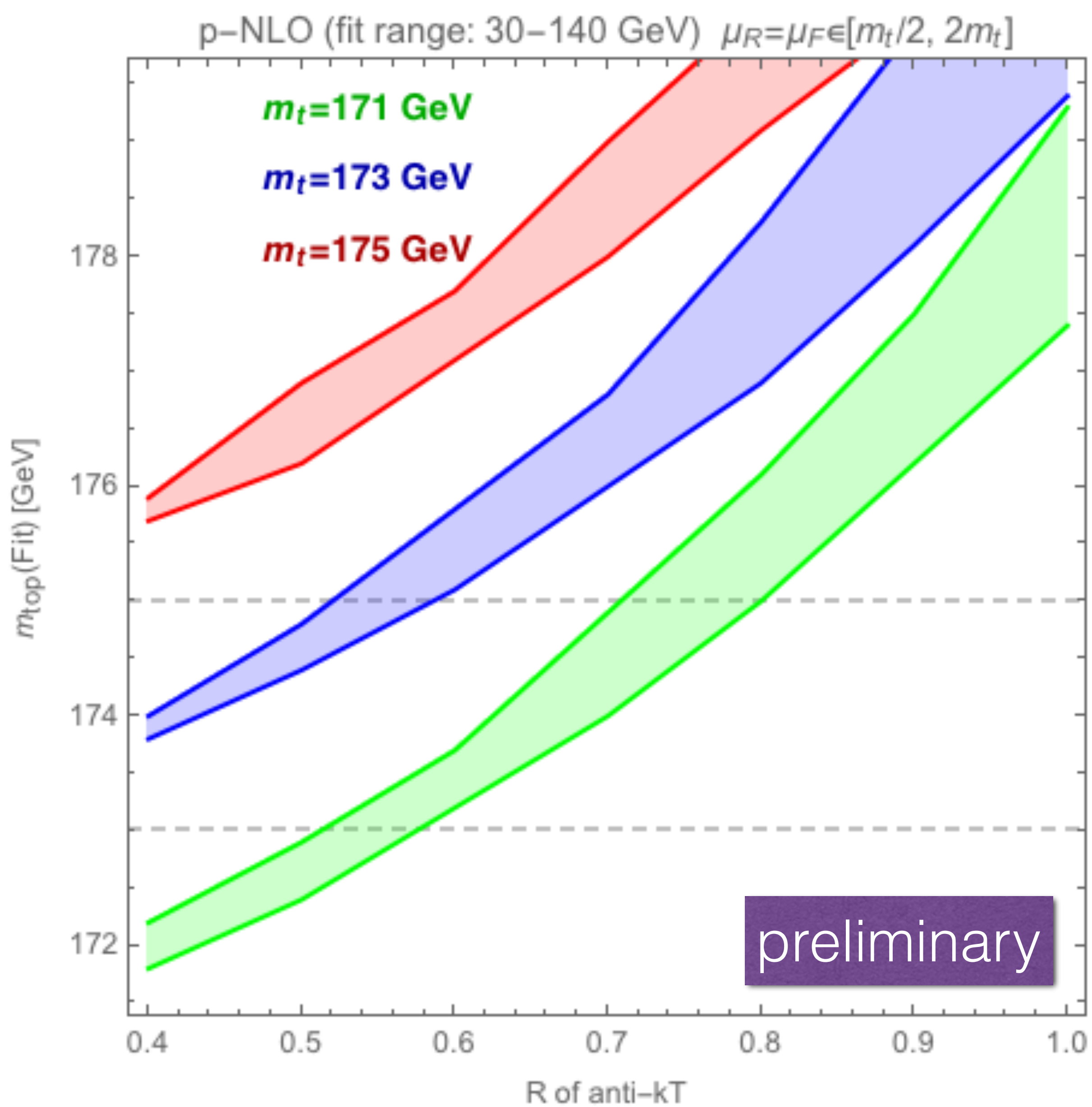


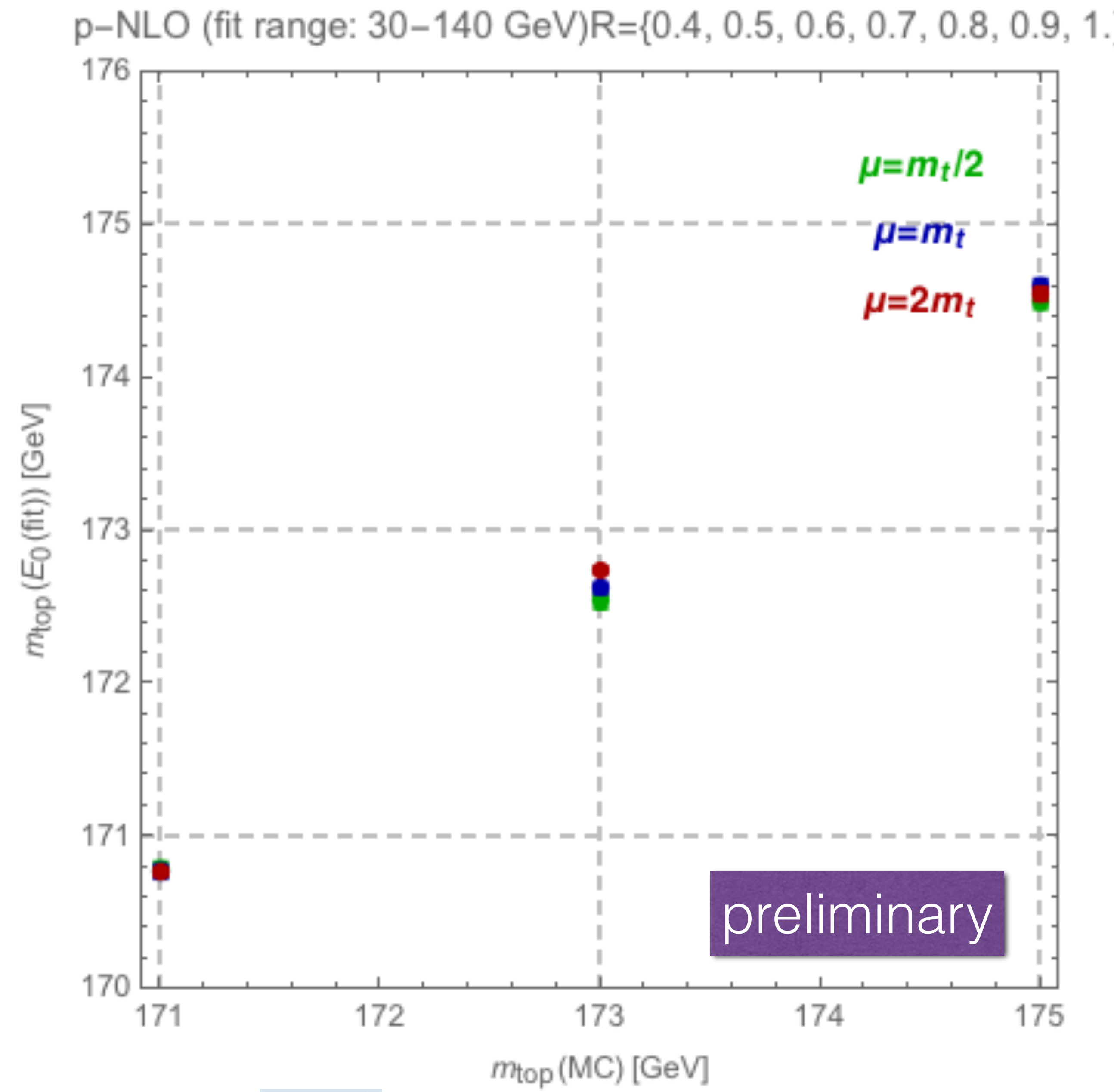


shift ~ R^p (p~2 jet area)
shift ~ 1/μ (real radiation)

NLO: production

(MCFM)





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

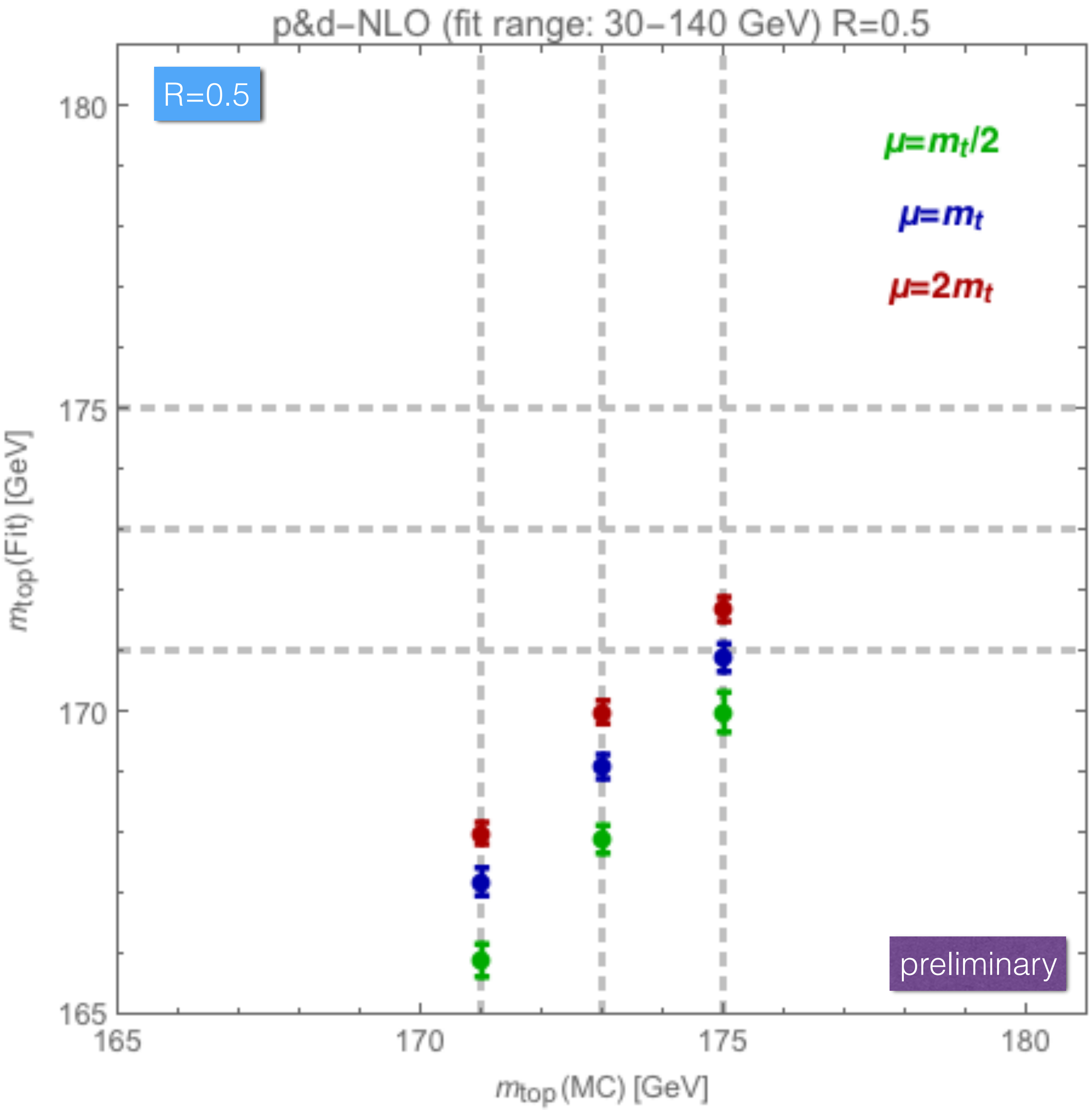
$$E_b^* = \frac{m_t^2 - m_w^2 + m_b^2}{2 m_t}$$

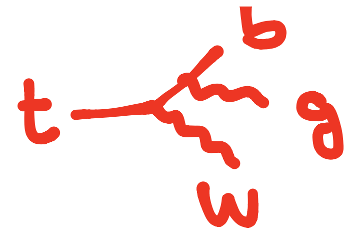
shift ~ R^p (p~2 jet area)
shift ~ 1/μ (real radiation)

NLO: production & decay

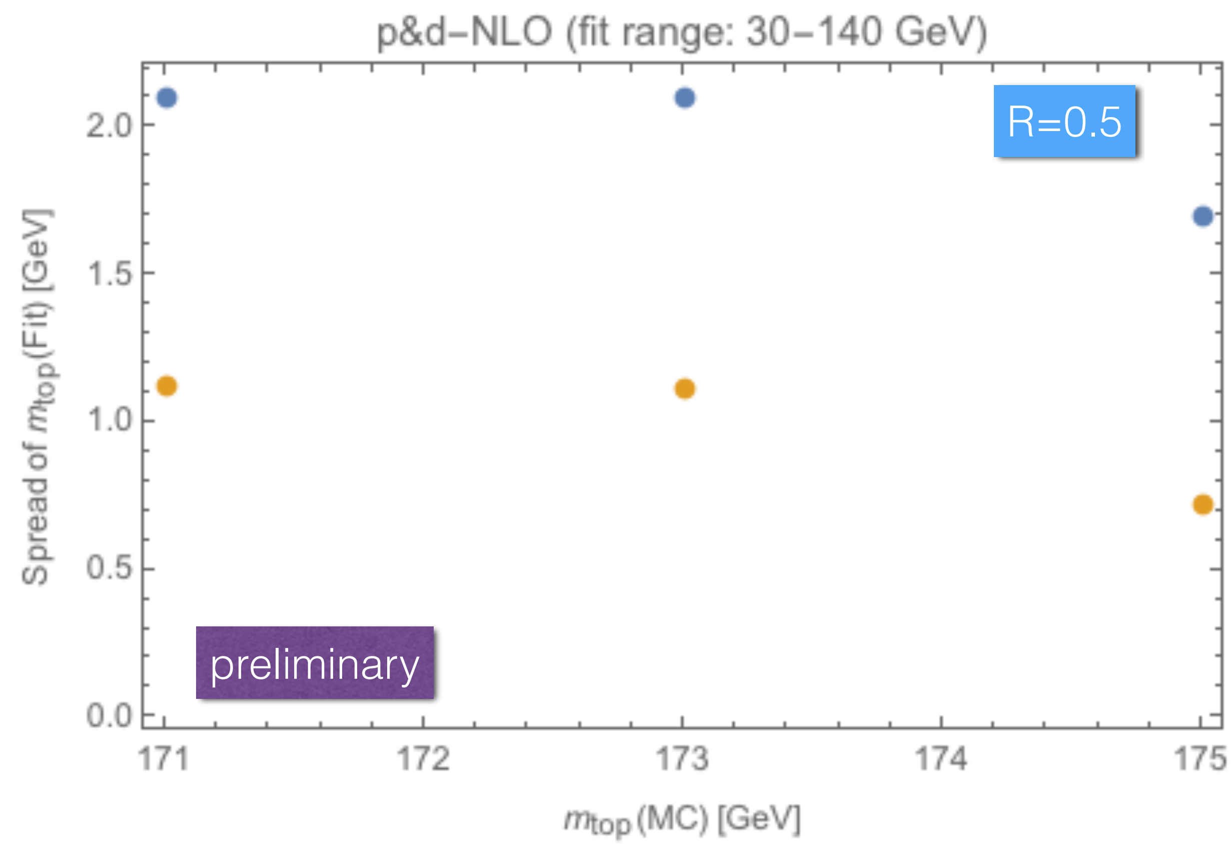
R=0.5

(MCFM)





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

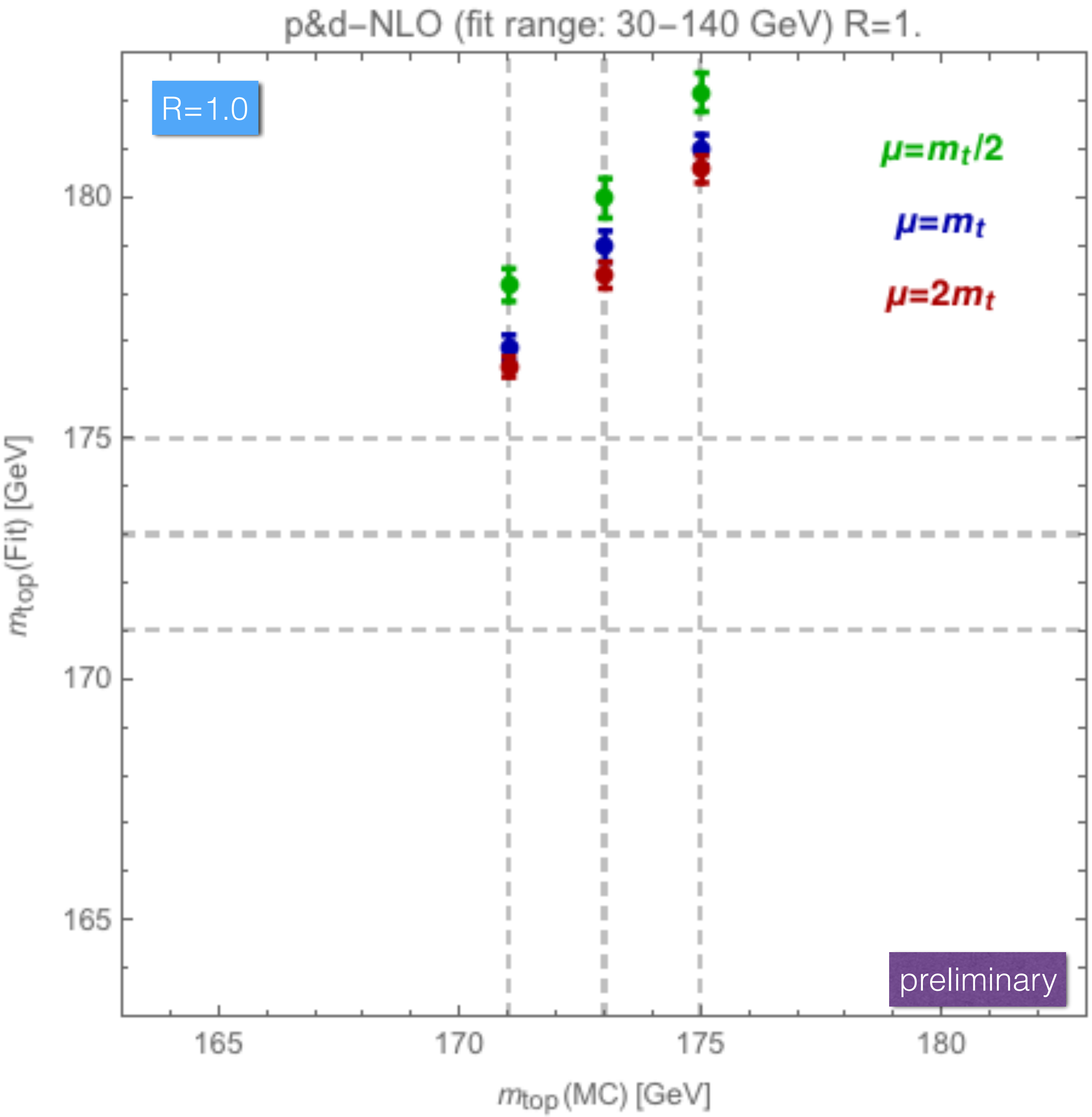


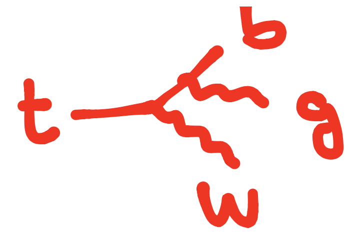
decay NLO sensitive to the scale choice: ±1 GeV on m_{top}

NLO: production & decay

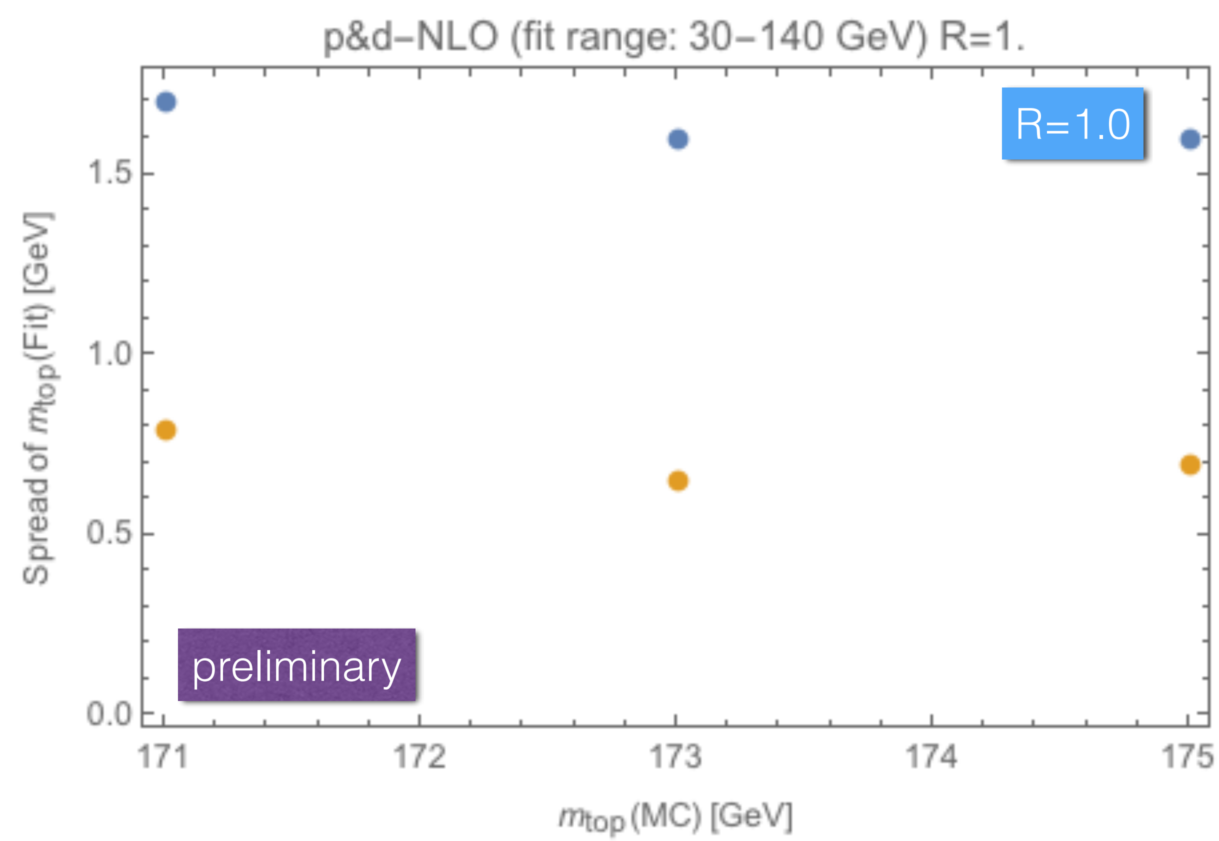
R=1.0

(MCFM)





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

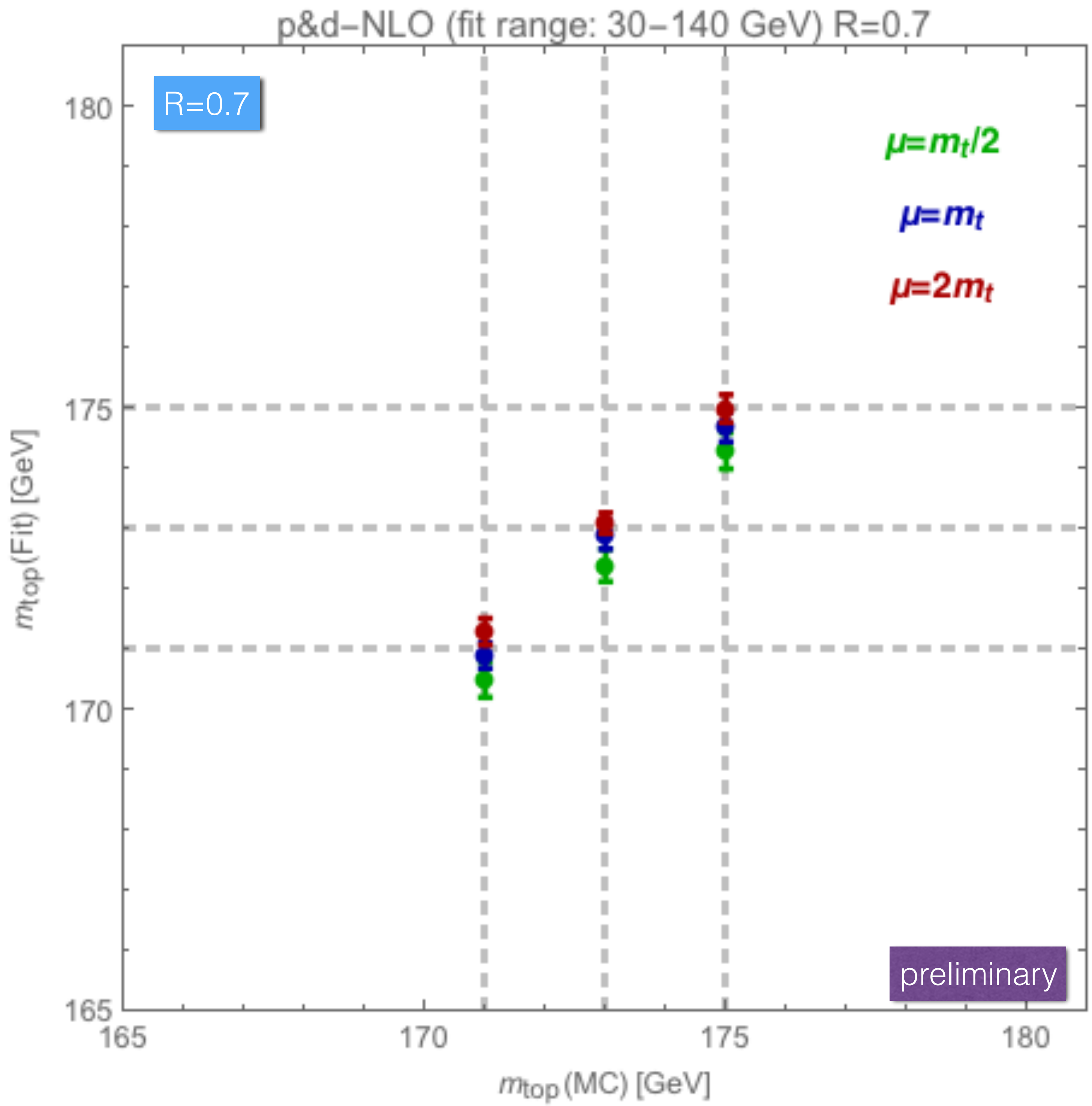


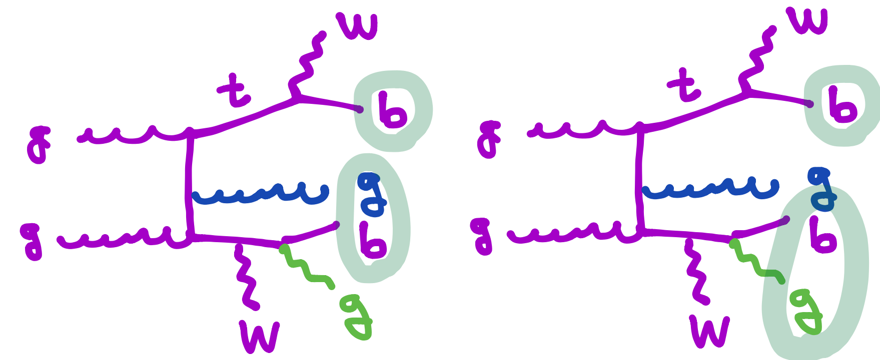
decay NLO sensitive to the scale choice: ±1 GeV on m_{top}

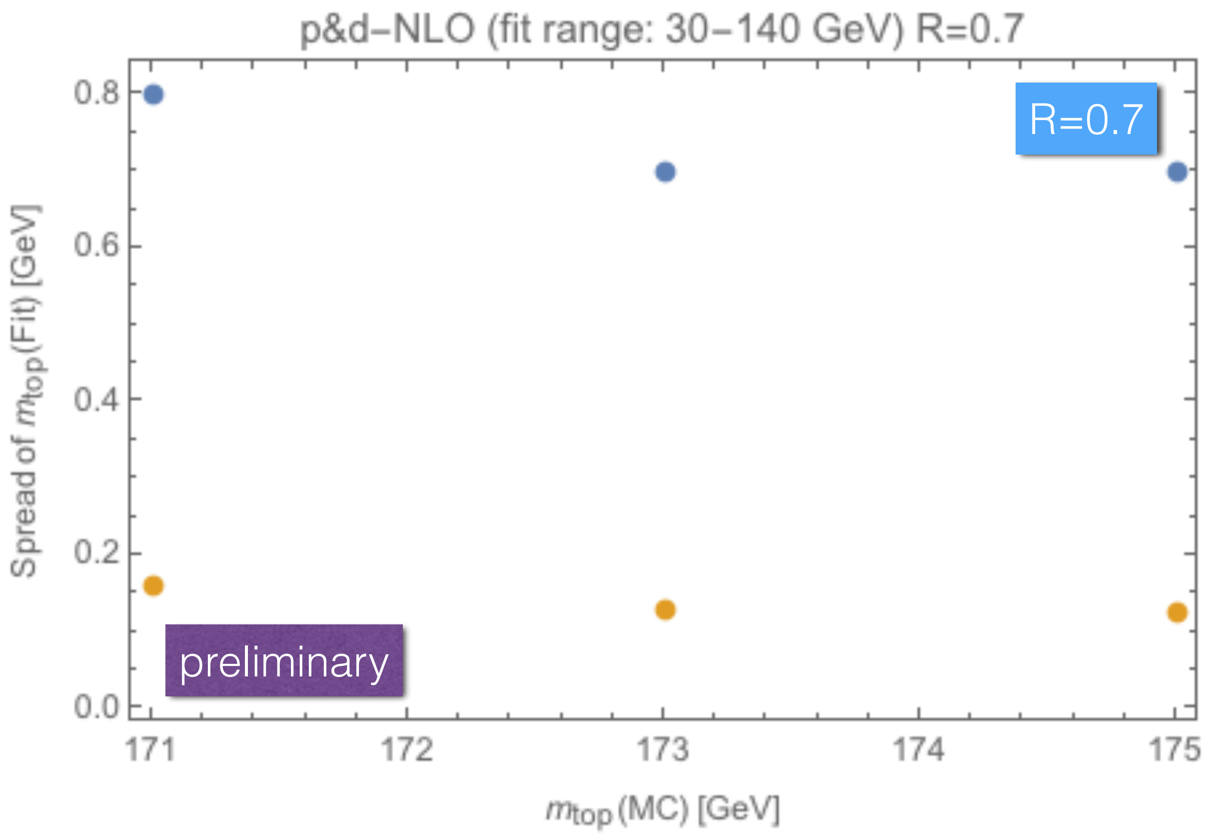
NLO: production & decay

R=0.7

(MCFM)





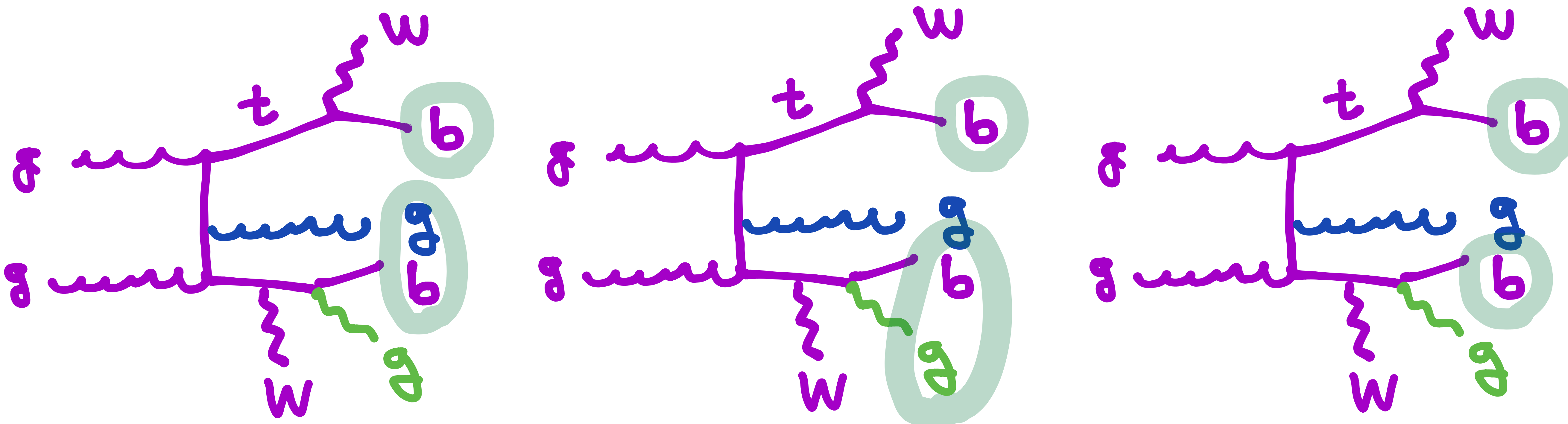


decay NLO sensitive to the scale choice: ±0.5 GeV on m_{top}

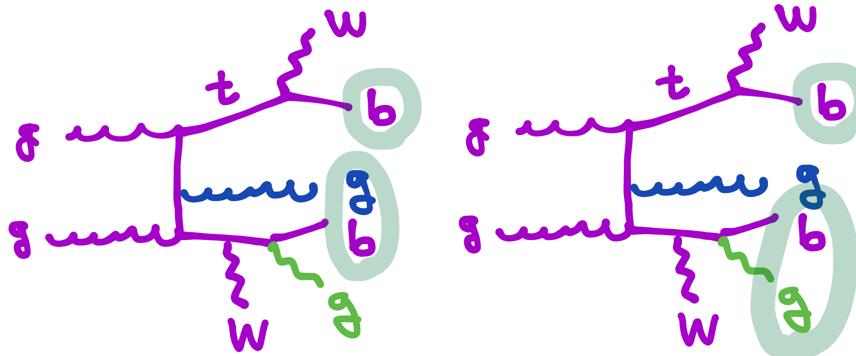
NLO: production & decay

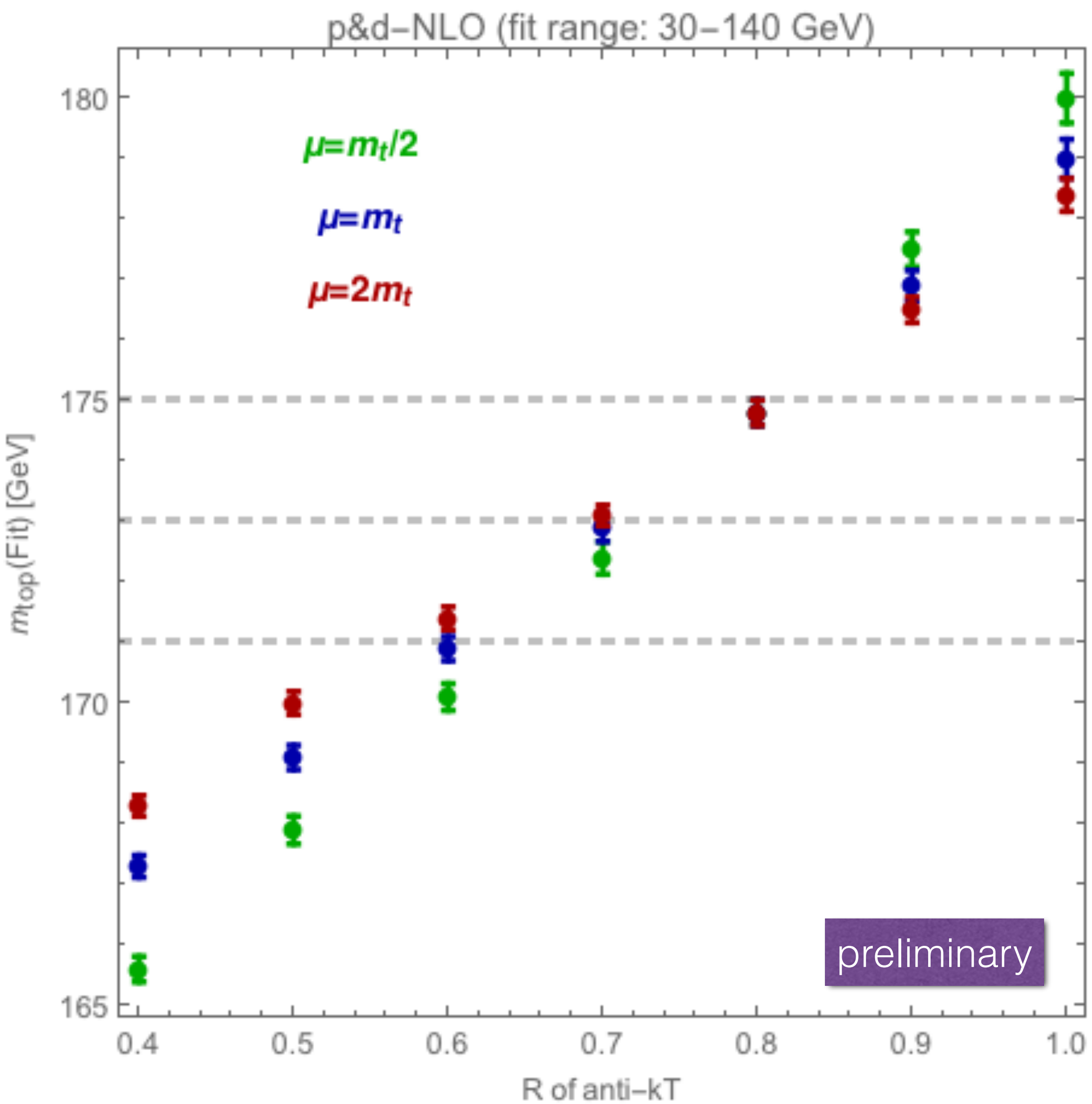
(MCFM)

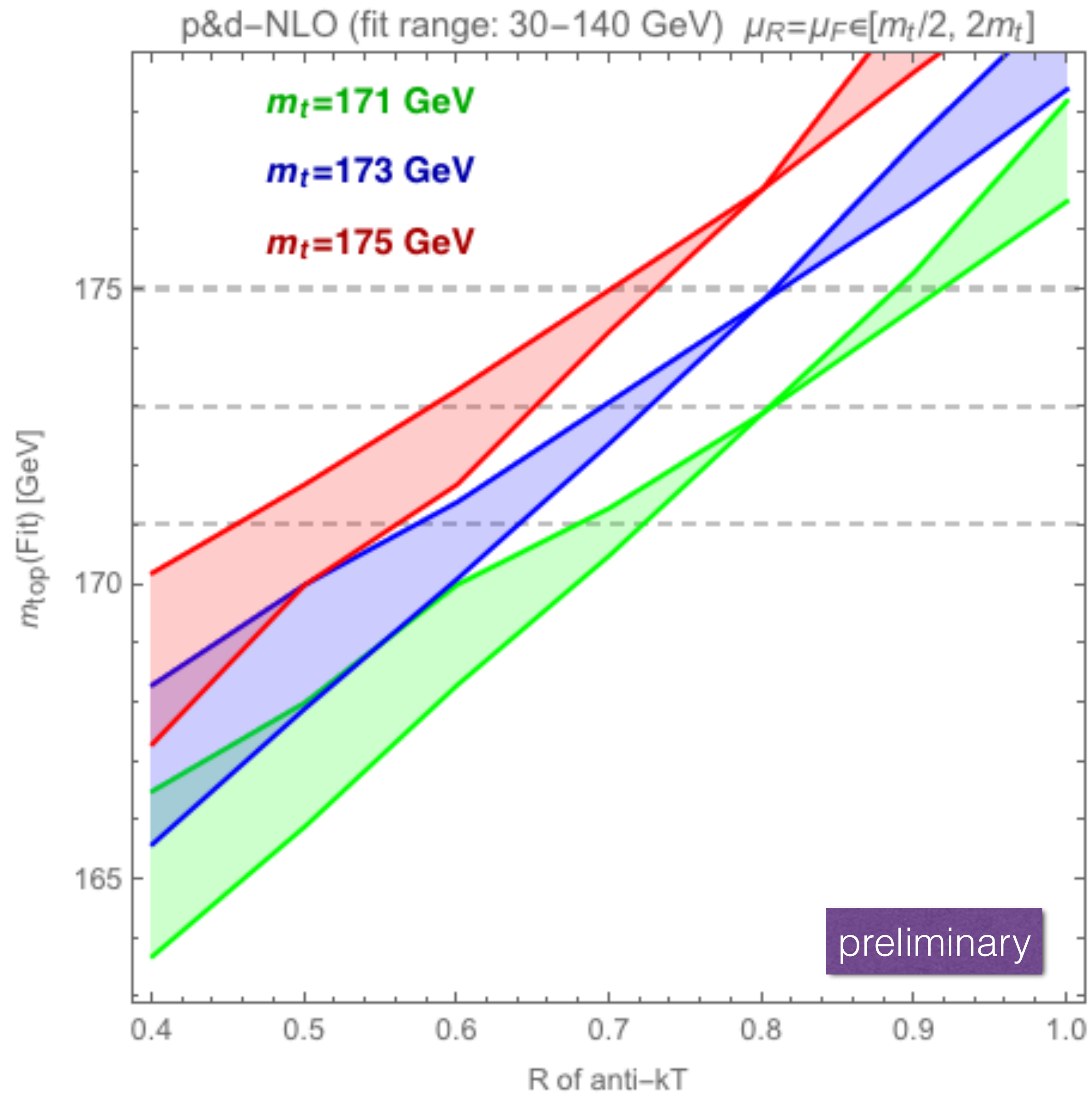
Agashe, Franceschini, Kim, Schulze - in preparation



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

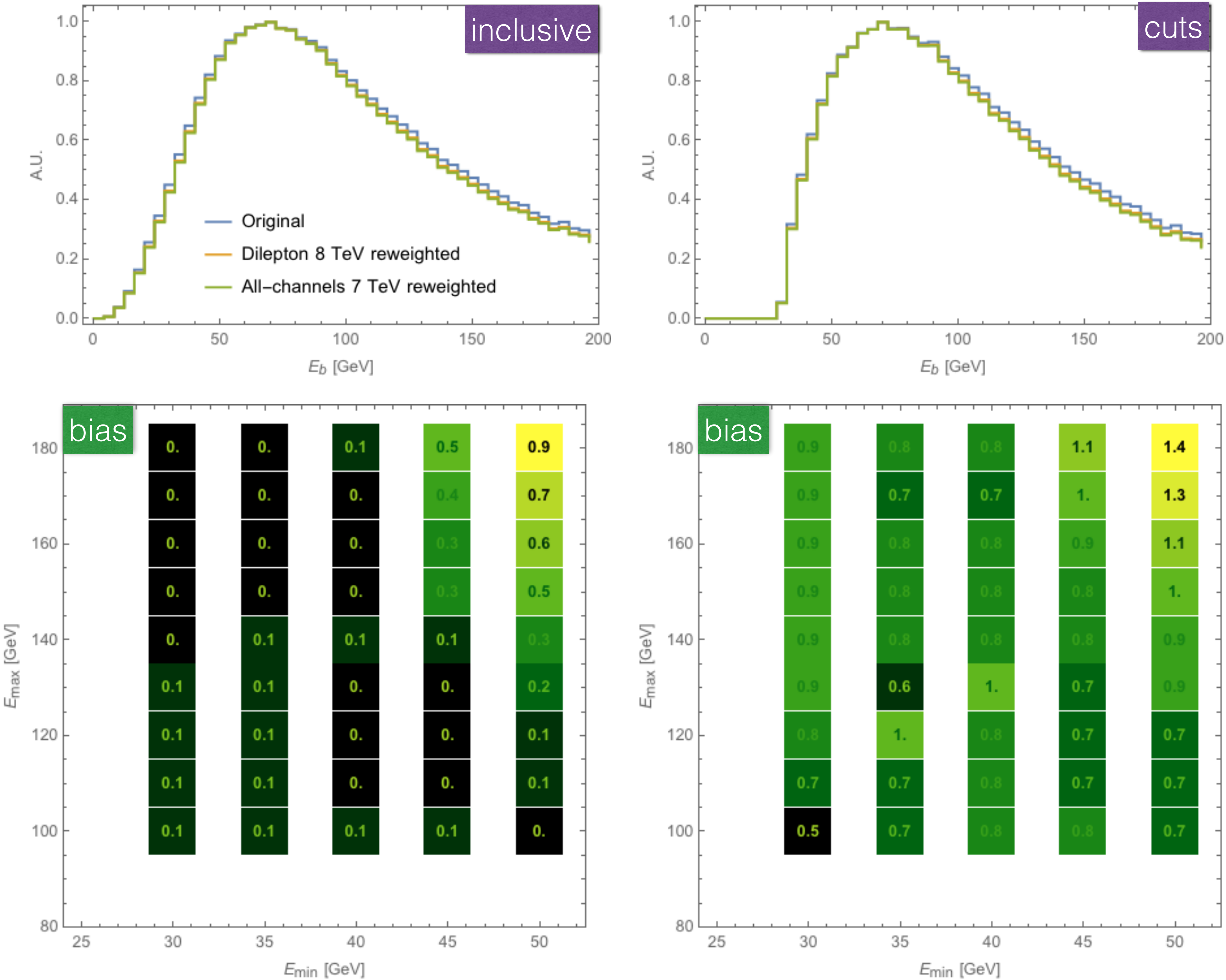
Agashe, Franceschini, Kim, Schulze - in preparation

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

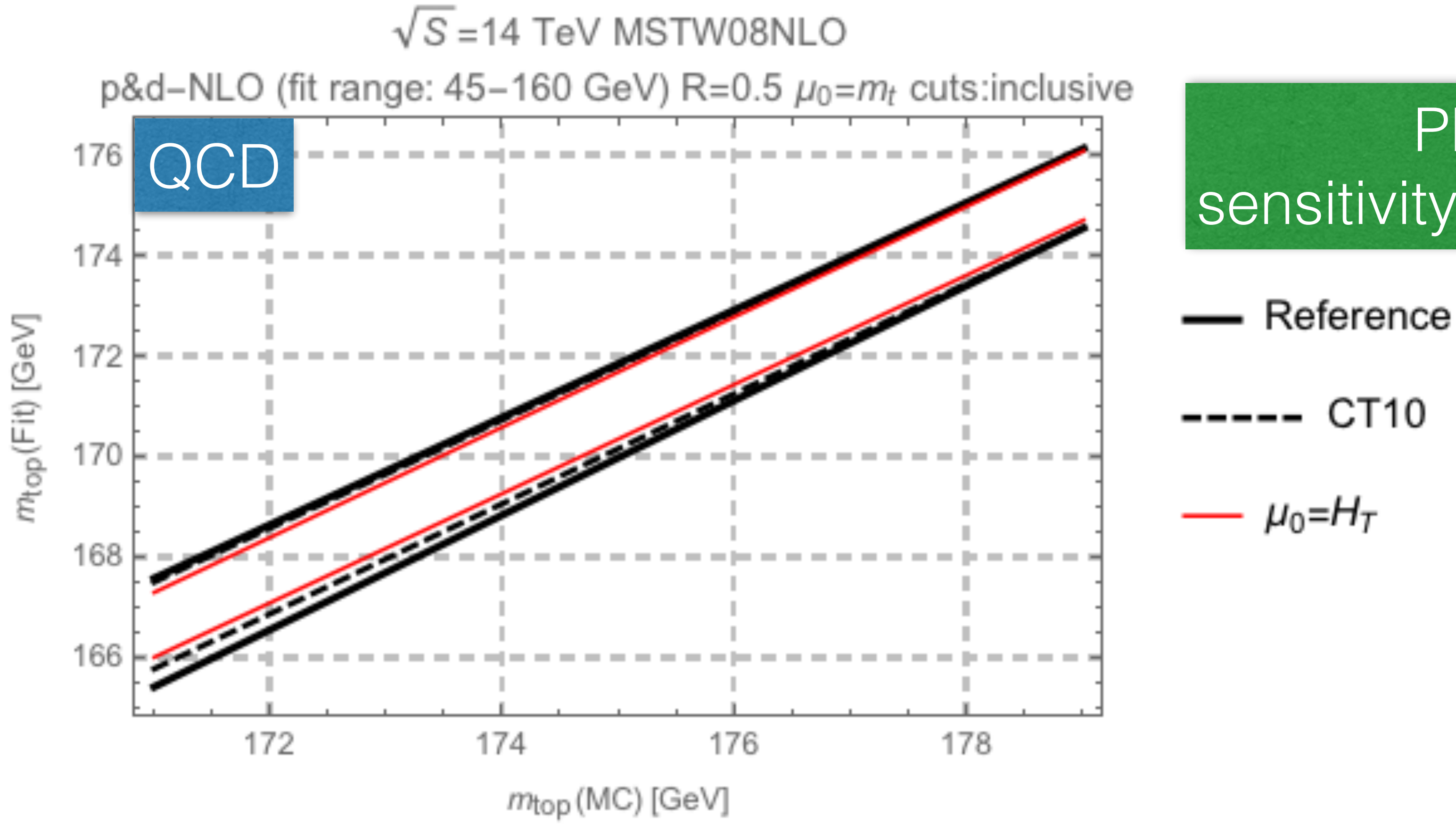
f_{pol}: $\leq 3 \cdot 10^{-3}$; ϵ_{FSR}: ≤ 0.1 ; C_{bWg}: O(1)

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

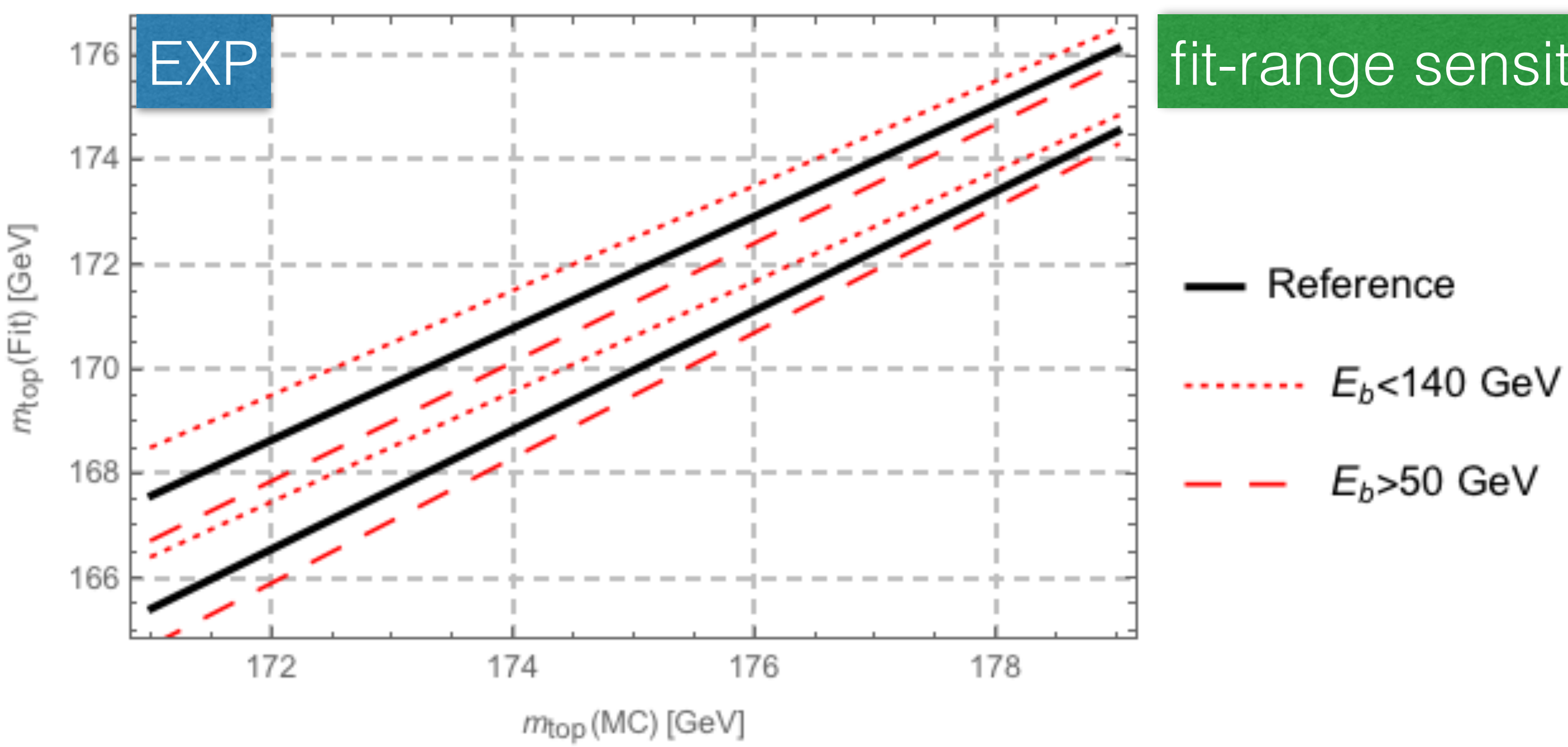
pT(top) reweighting



Inclusive MSTW08



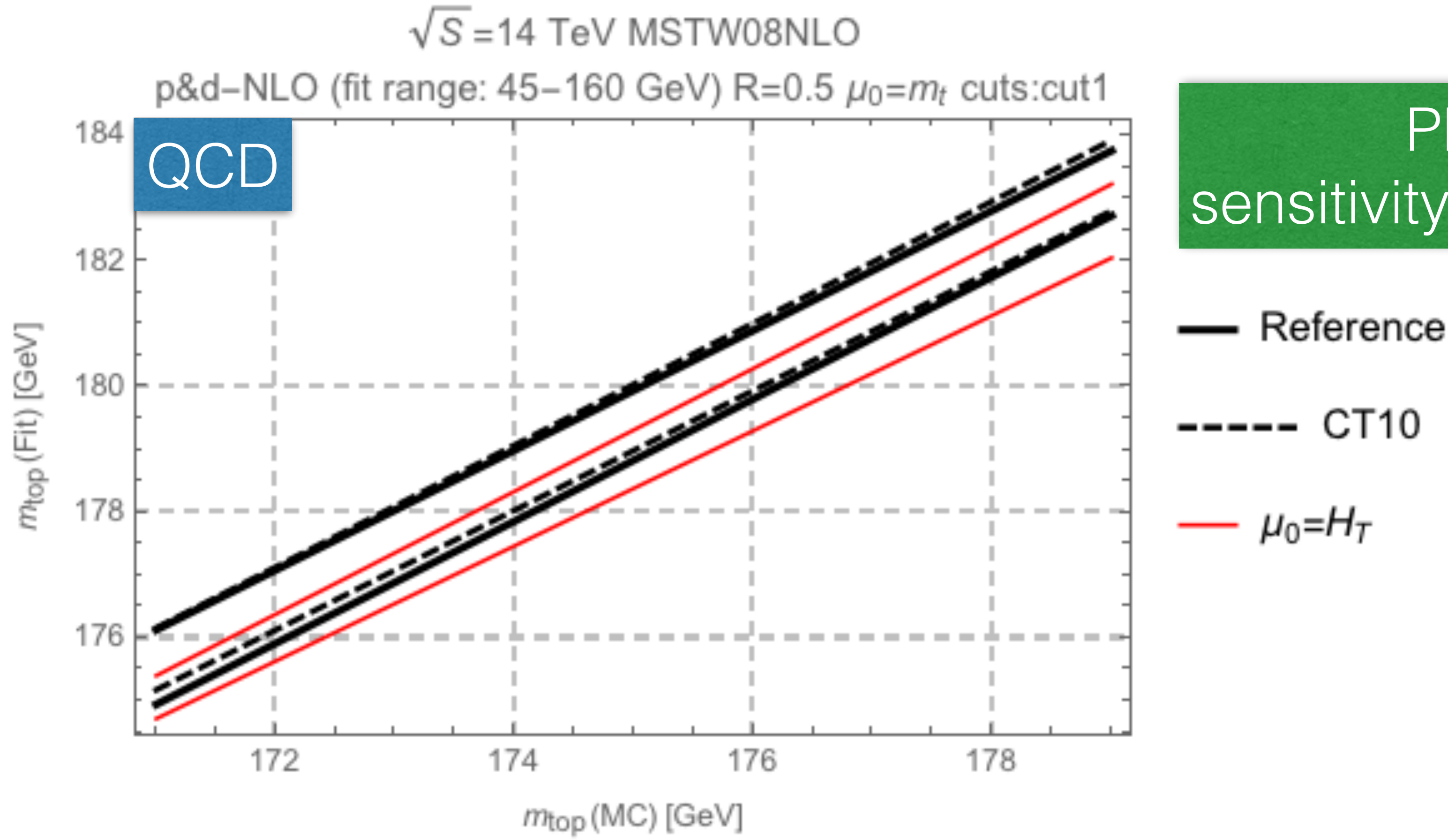
PDF set and scale function sensitivity subdominant w.r.t scale variation



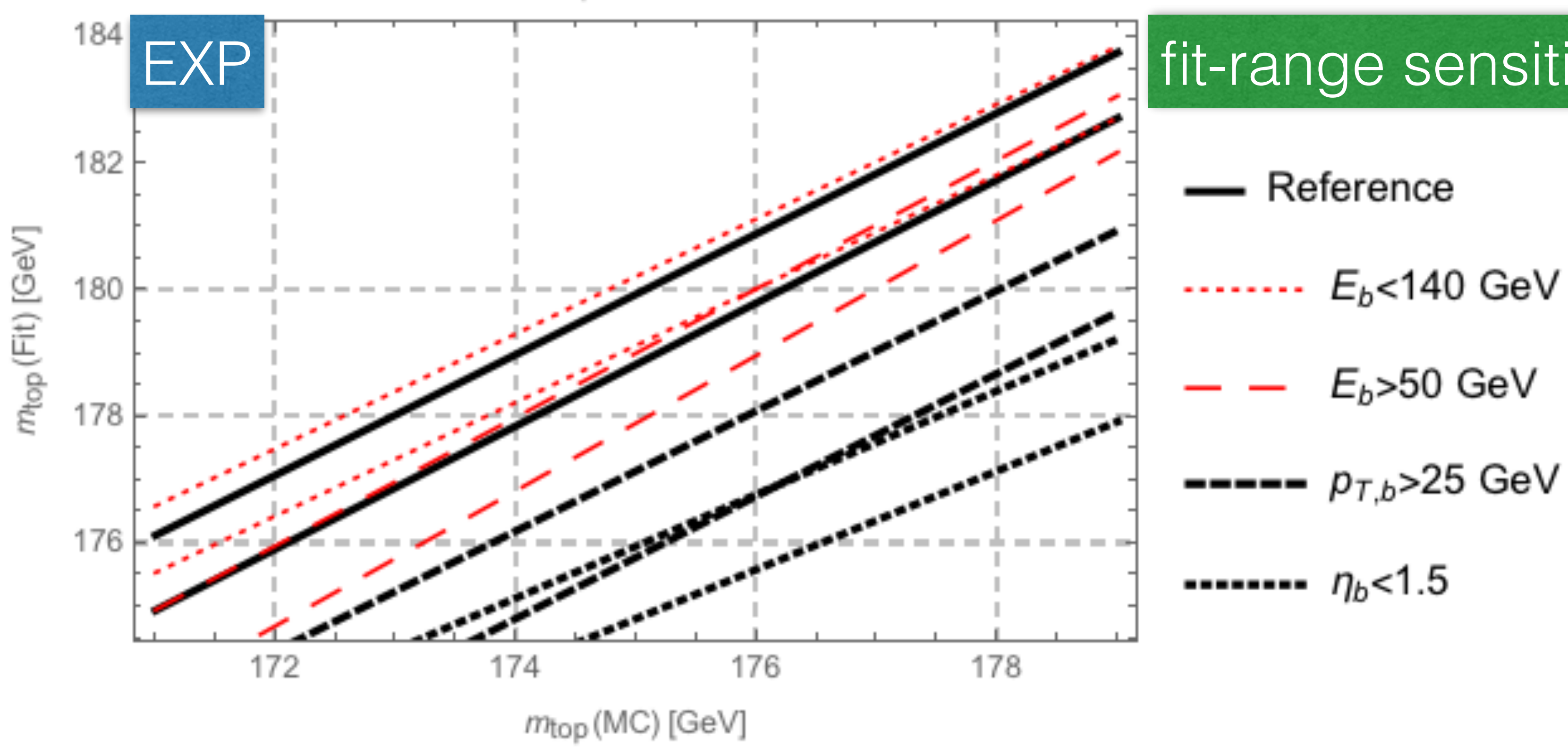
fit-range sensitivity comparable to scale variation

Cuts MSTW08

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

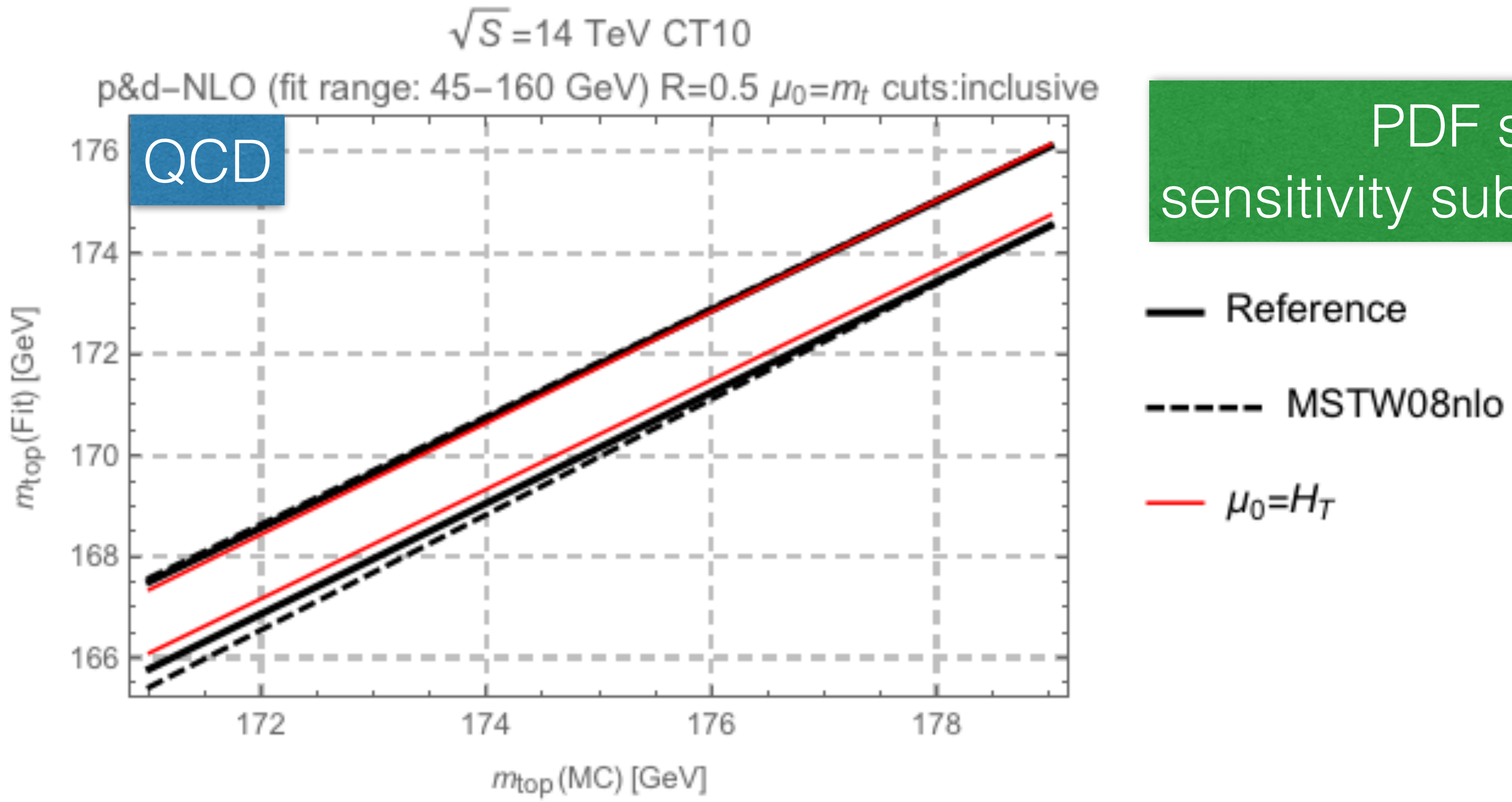


PDF set and scale function sensitivity subdominant w.r.t scale variation

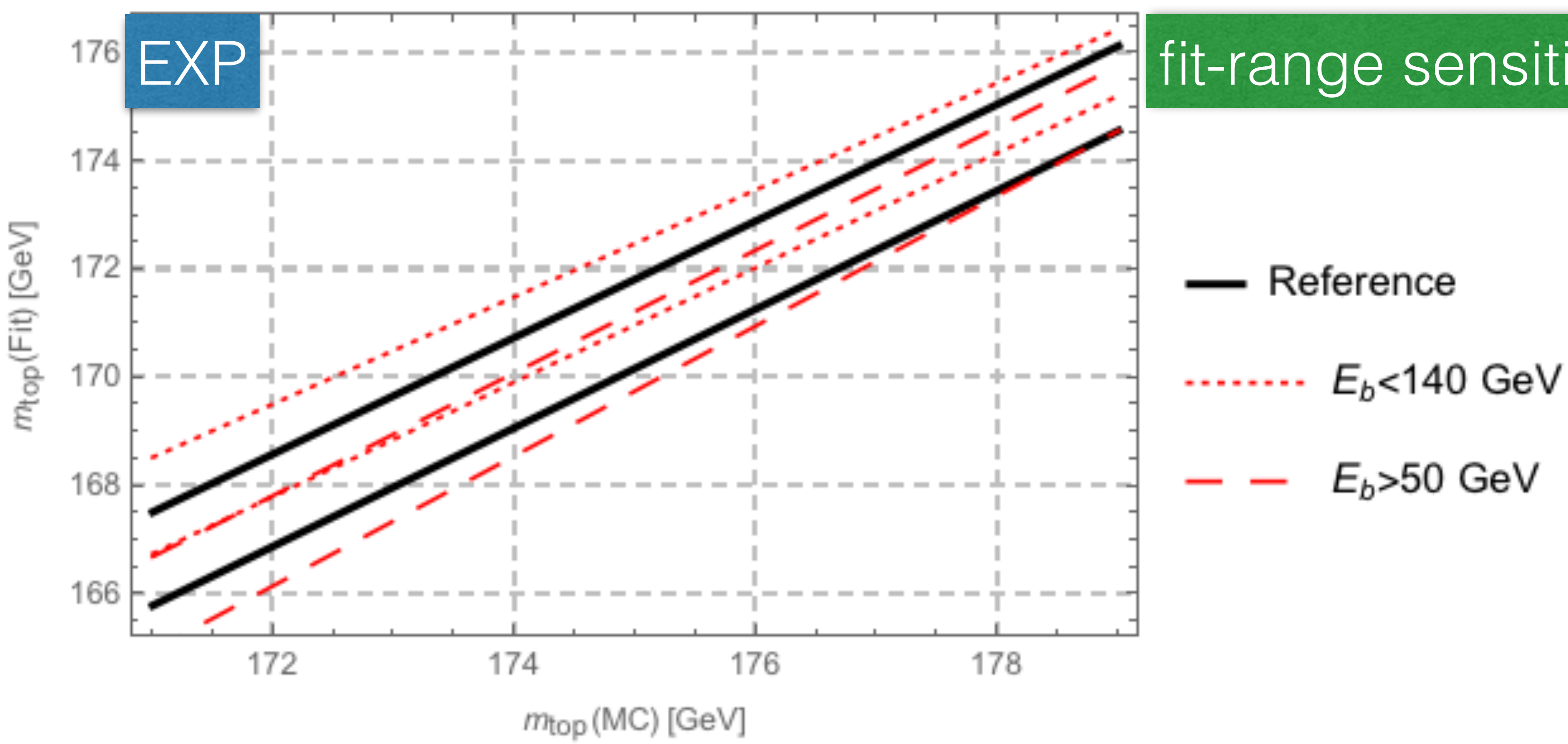


fit-range sensitivity comparable to scale variation

Inclusive CT10



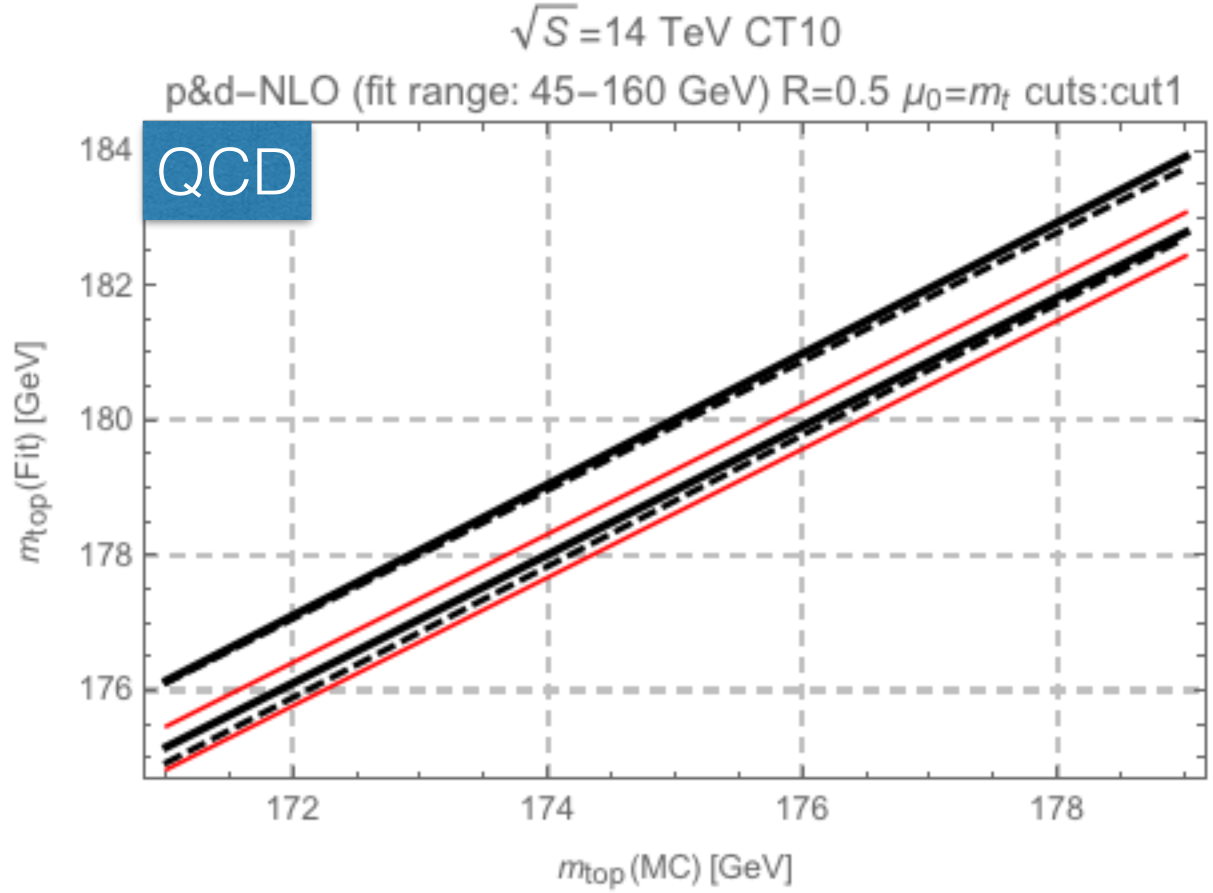
PDF set and scale function sensitivity subdominant w.r.t scale variation



fit-range sensitivity comparable to scale variation

Cuts CT10

pT$_j$>30 GeV, η$_j$<2.4, pTℓ>20 GeV, ηℓ<2.4

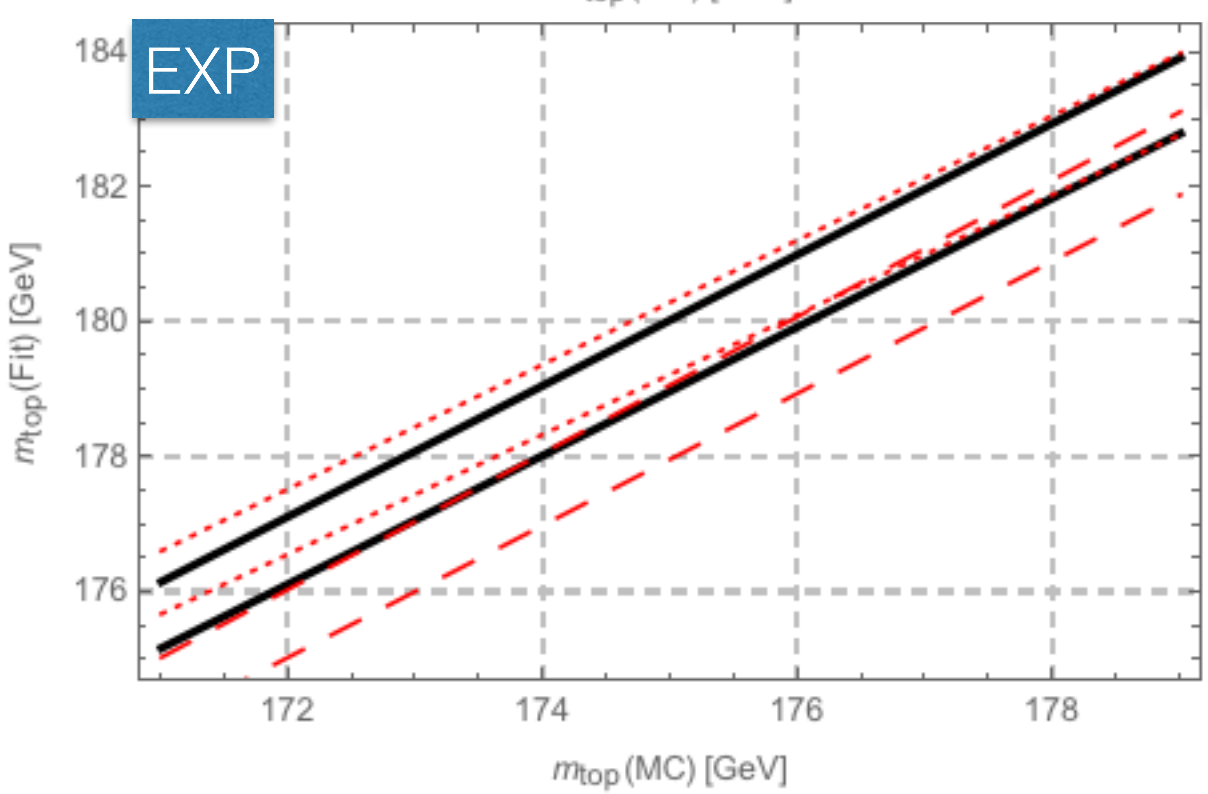


PDF set and scale function sensitivity subdominant w.r.t scale variation

Reference

MSTW08

$\mu_0=H_T$



fit-range sensitivity comparable to scale variation

Reference

E_b<140 GeV

E_b>50 GeV

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

J/psi but no need to require leptonic W decay

D modes

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

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

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

$$B^- \underset{5\cdot 10^{-3}}{\longrightarrow} D^0\pi^- \underset{4\cdot 10^{-2}}{\longrightarrow} K^-\pi^+\,\pi^-$$

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

$$B^- \underset{5\cdot 10^{-3}}{\longrightarrow} D^0\pi^- \underset{6\cdot 10^{-3}}{\longrightarrow} K_S^0\rho^0\,\pi^-$$

$$B^- \underset{5\cdot 10^{-3}}{\longrightarrow} D^0\pi^- \underset{5\cdot 10^{-3}}{\longrightarrow} K^-\pi^+\rho^0\,\pi^-$$

Mean decay length invariance

$$\gamma = E/m$$

- A peak in the energy distribution of the b quark implies a peak in the boost factor distribution

- Not so interesting because the boost is not measured directly

However ...

For $\beta=1$ is

$$\tau'(\text{lab})=\gamma\tau$$

$$\lambda=c\beta\tau'(\text{lab})=c\tau\, E/m$$

E and λ distributions are the same up to a rescaling

up to m^2/E^2 effects the *mean* decay length of the *b* quark has a peak at the top rest frame value

How to get the distribution of λ from the observed L?

$$\frac{d\sigma}{dL} = \int e^{-L/\lambda} \otimes \mathrm{pdf}(\lambda)\, d\lambda$$

For now we just predicted the mode of pdf(λ)

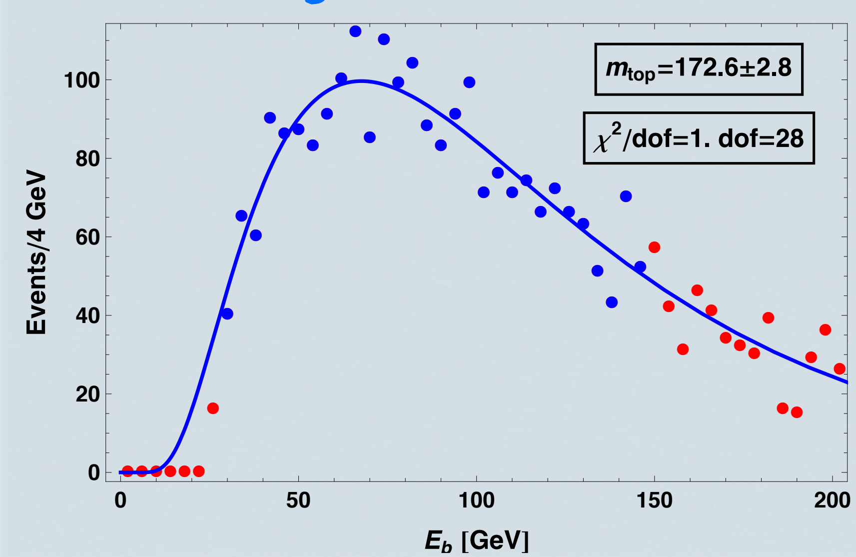
$$\frac{d\sigma}{dE_b} \propto \frac{d\sigma}{d\gamma_b} \propto \frac{d\sigma}{d\lambda}$$

1209.0772 - Agashe, Franceschini and Kim

from MC:

exponential ansatz work well

$$\frac{d\sigma}{dE_b} \propto e^{-w\left(\frac{E_b}{E^*} + \frac{E^*}{E_b}\right)}$$



How to get the distribution of λ from the observed L?

$$\frac{d\sigma}{dL} = \int e^{-L/\lambda} \otimes \mathrm{pdf}(\lambda)\, d\lambda$$

For now we just predicted the mode of pdf(λ)

$$\mathrm{pdf}(\lambda) = e^{-w\left(\frac{\lambda}{\lambda_0} + \frac{\lambda_0}{\lambda}\right)} \ ?$$

Global picture of top decay

1506.05074

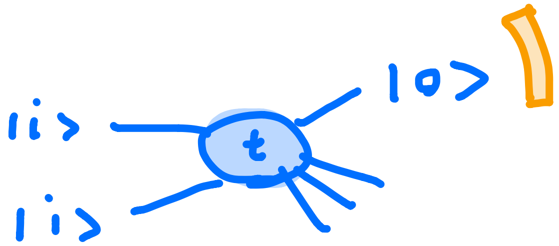
(BR measurement)

	Measured (top quark)	SM	LEP (W)
$\sigma_{t\bar{t}}$	178 ± 3 (stat.) ± 16 (syst.) ± 3 (lumi.) pb	$177.3 \pm 9.0^{+4.6}_{-6.0}$ pb	
B_j	66.5 ± 0.4 (stat.) ± 1.3 (syst.)	67.51±0.07	67.48±0.28
B_e	13.3 ± 0.4 (stat.) ± 0.5 (syst.)	12.72±0.01	12.70±0.20
B_μ	13.4 ± 0.3 (stat.) ± 0.5 (syst.)	12.72±0.01	12.60±0.18
B_τ	7.0 ± 0.3 (stat.) ± 0.5 (syst.)	7.05±0.01	7.20±0.13

precise test of **SM**

clearly a test for **BSM (*e.g.* t→ b τ mET)**

interesting to see interpretation in new physics scenarios
(t→ b τ mET, t → c mET, t → bff' mET, …)



Lxy decay length CMS-PAS-TOP-12-030

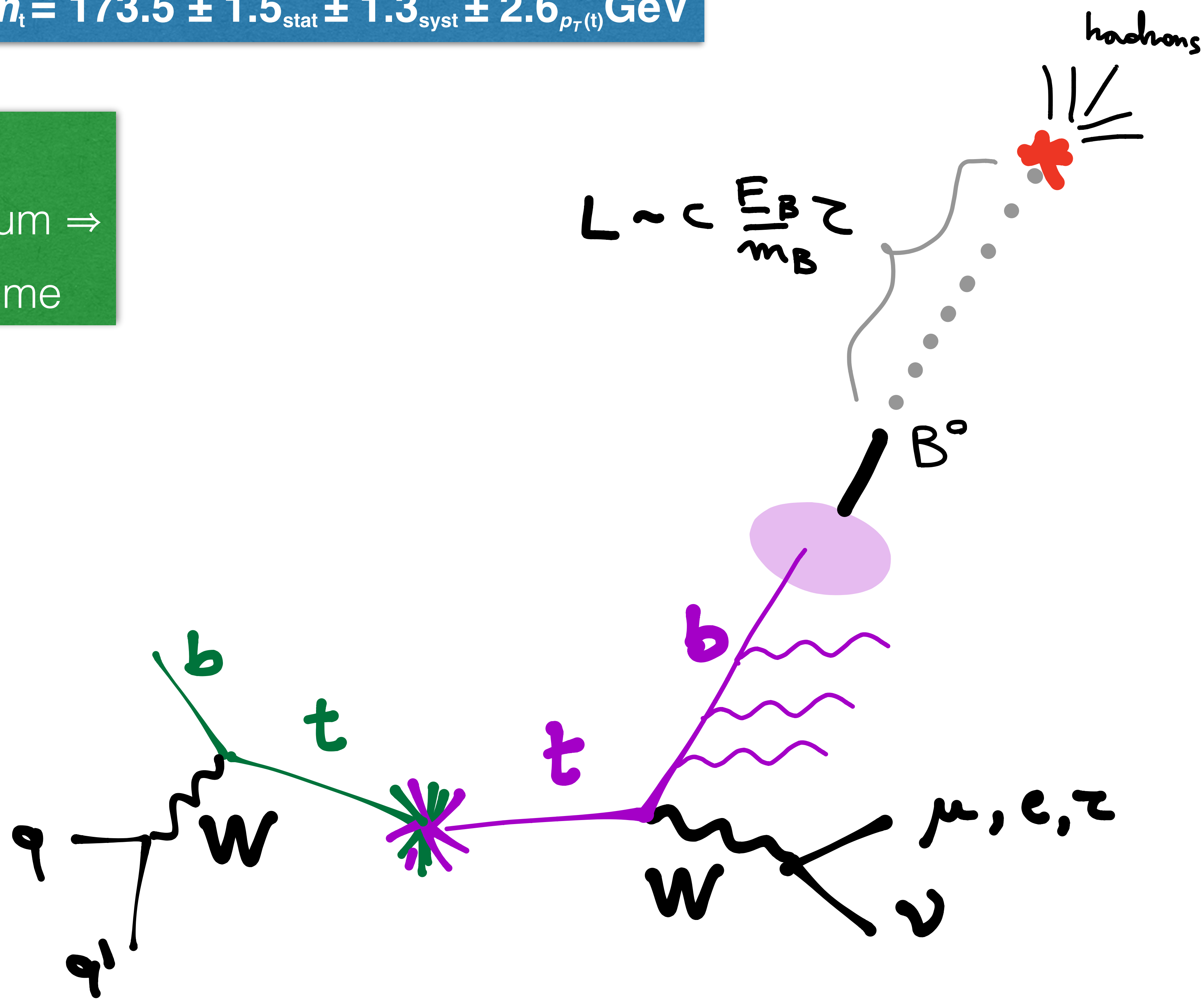
- B-hadron life-time - Lxy hep-ex/0501043

$m_t = 173.5 \pm 1.5_{stat} \pm 1.3_{syst} \pm 2.6_{p_T(t)}$ GeV

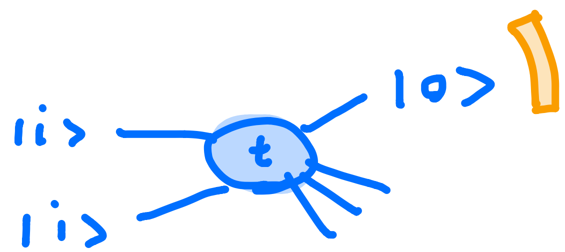
larger top **mass** ⇒

⇒ large B hadron momentum ⇒

⇒ larger lab-frame life-time



dependence on the dynamics (e.g. production of top at LHC)



Lxy decay length CMS-PAS-TOP-12-030

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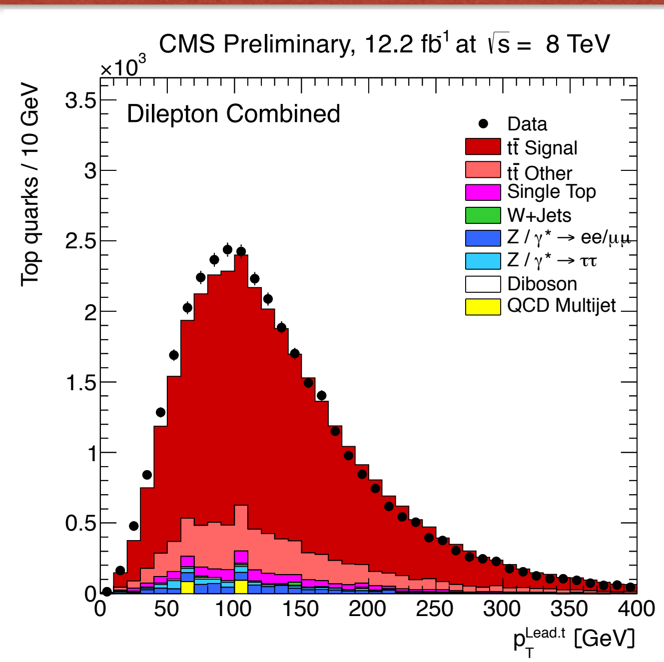
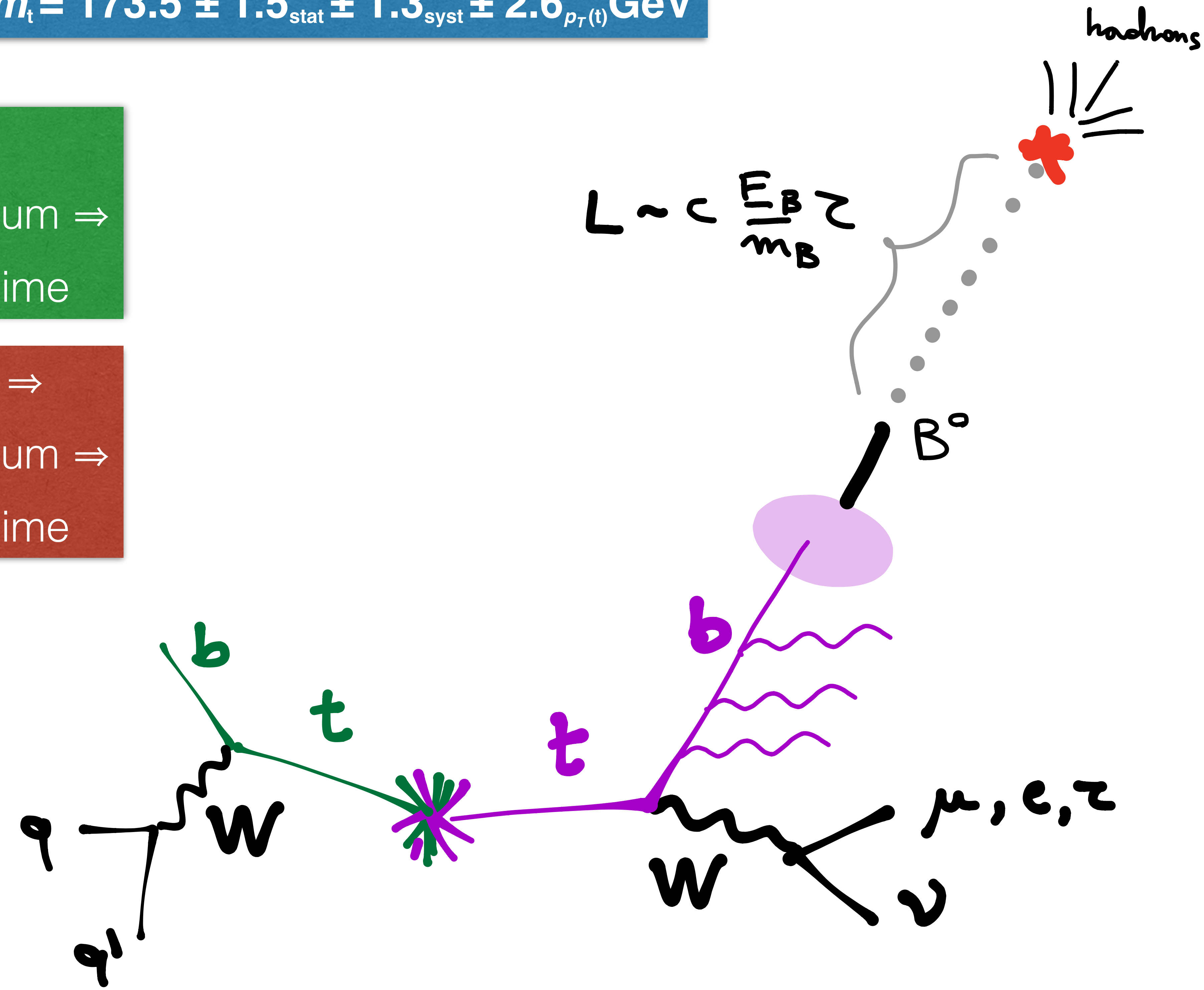
$m_t = 173.5 \pm 1.5_{stat} \pm 1.3_{syst} \pm 2.6_{p_T(t)}$ GeV

larger top **mass** ⇒
⇒ large B hadron momentum ⇒
⇒ larger lab-frame life-time

larger top **momentum** ⇒
⇒ large B hadron momentum ⇒
⇒ larger lab-frame life-time



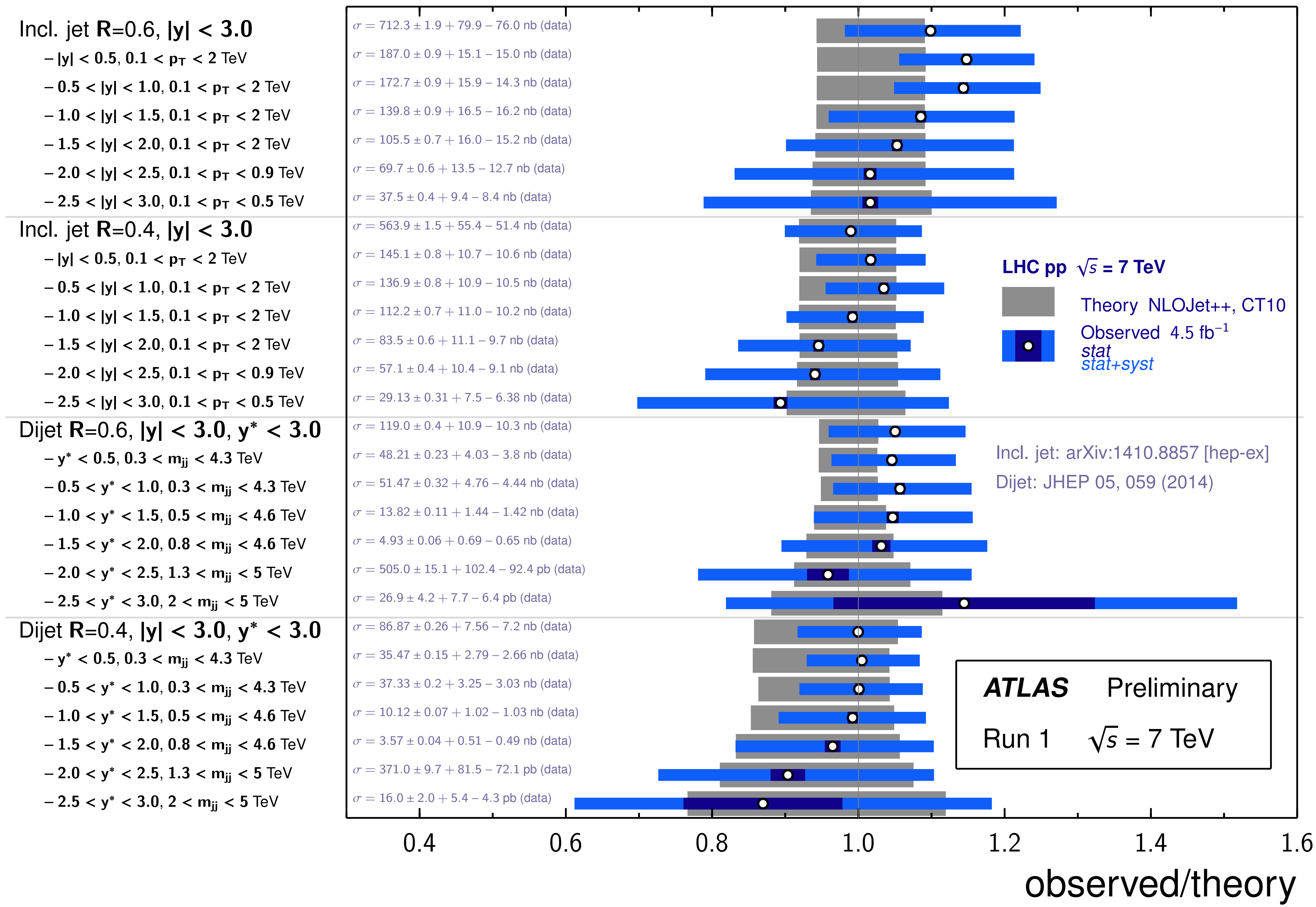


dependence on the dynamics (e.g. production of top at LHC)

	δ m_t [GeV]				
	$P_t(l^+)$	$P_t(l^+l^-)$	$M(l^+l^-)$	$E(l^+)+E(l^-)$	$P_t(l^+)+P_t(l^-)$
QCD Scale Up	-1.05 ± 0.54	-1.70 ± 0.42	-0.44 ± 0.77	-0.35 ± 0.74	-1.14 ± 0.37
Down	1.09 ± 0.58	2.85 ± 0.24	2.82 ± 1.68	2.29 ± 2.02	1.35 ± 0.37
ME/PS Up	0.55 ± 0.66	-0.87 ± 0.6	0.81 ± 1.06	0.22 ± 0.68	-0.94 ± 0.47
Down	2.01 ± 1.02	2.26 ± 0.96	3.32 ± 1.16	2.42 ± 2.71	1.98 ± 1.03
Pile Up	0.30	0.14	0.35	0.15	0.26
Down	-0.23	-0.14	-0.32	-0.18	-0.23
Lepton Sel. Up	-0.04	-0.02	-0.05	-0.33	-0.03
Down	0.04	0.03	0.05	0.34	0.04
Top Pt	-5.09	-0.67	-8.53	-5.55	-4.79
LES Up	0.12	0.47	0.70	0.54	0.39
Down	-0.21	-0.45	-0.71	-0.55	-0.38
Total syst.	+2.37	+3.67	+5.60	+3.40	+2.44
	−5.21	−2.08	−4.50	−8.57	−5.03

Inclusive Jet Cross Section Measurements

Status: March 2015



Cosmic peaks (Stecker 1971)