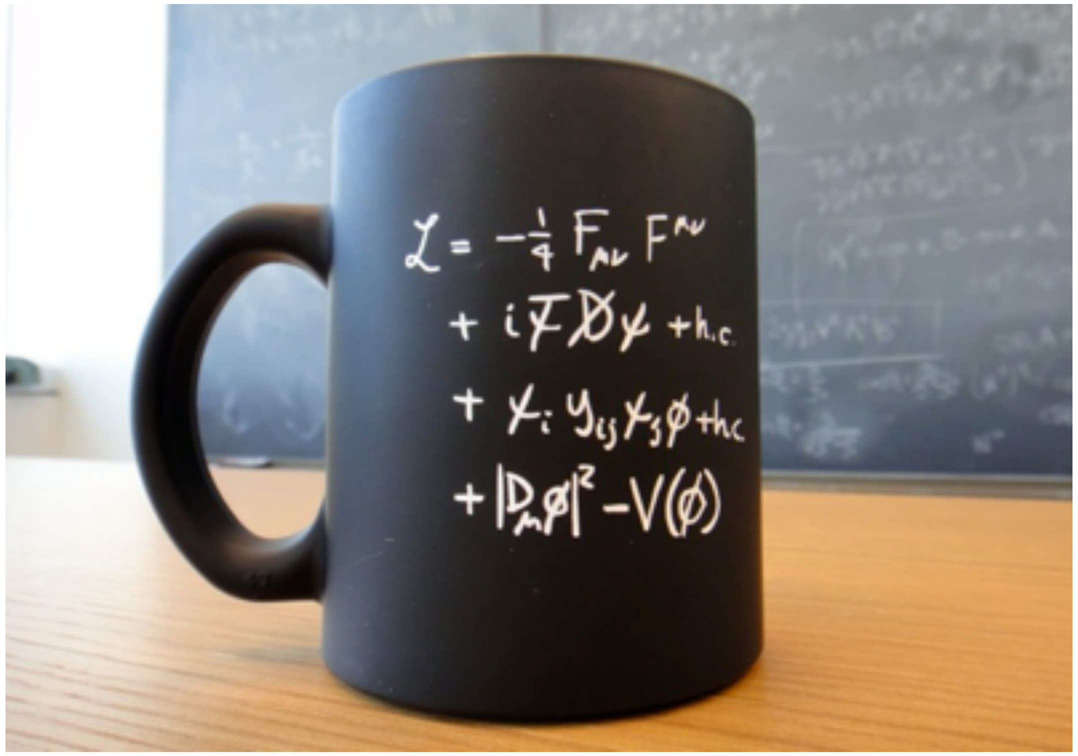
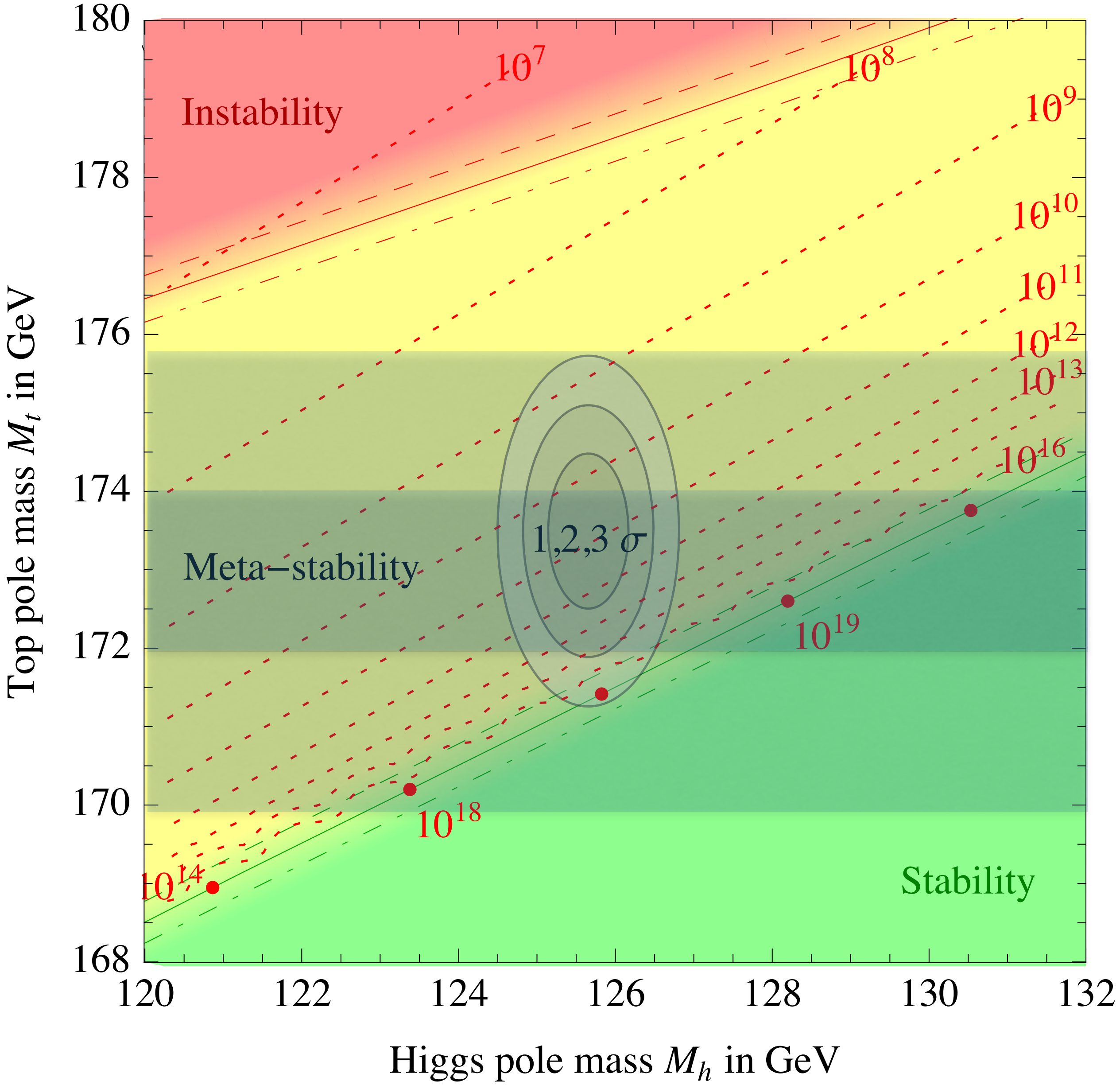
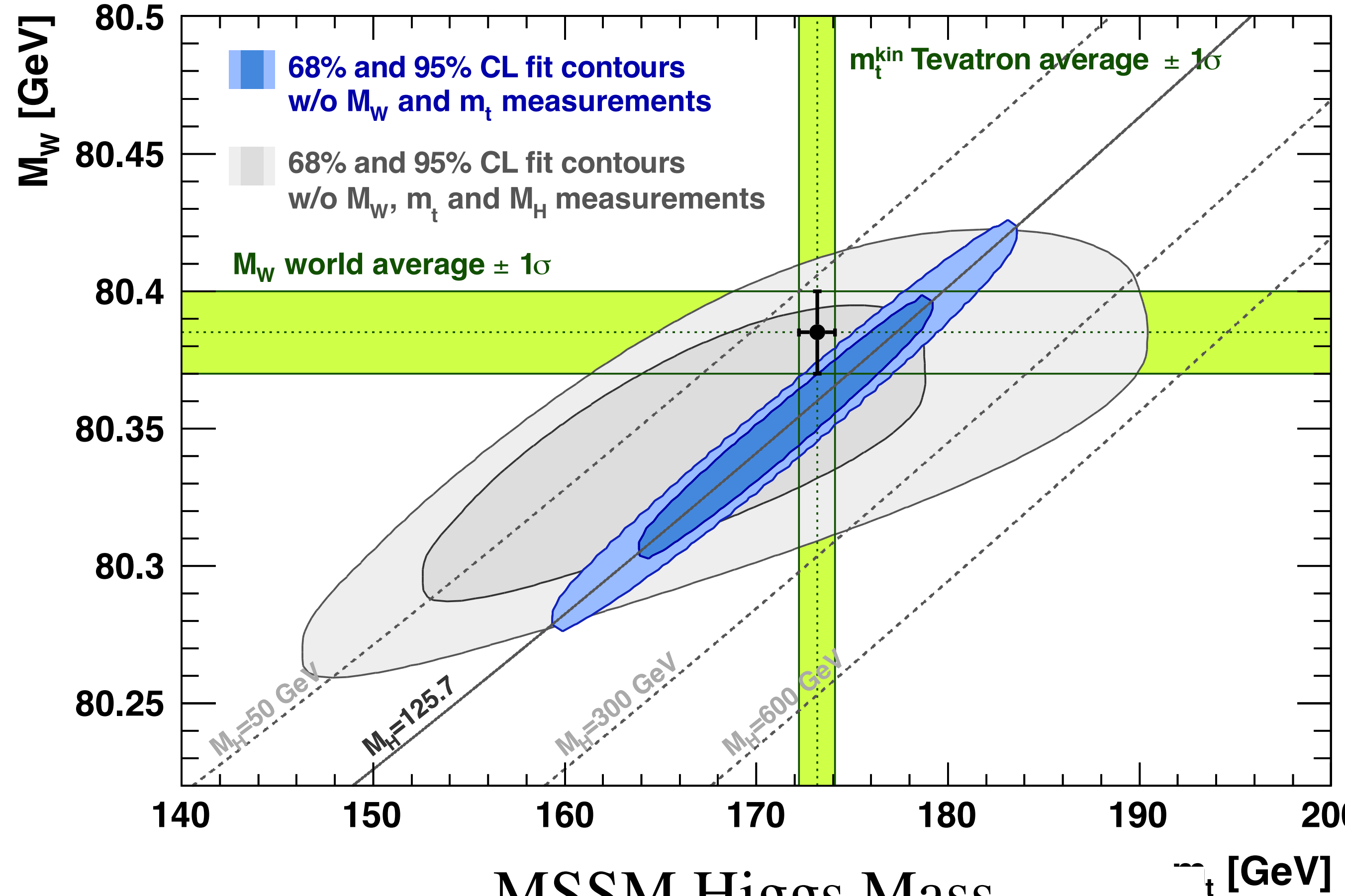
Recent theoretical and experimental results on top quark mass measurements

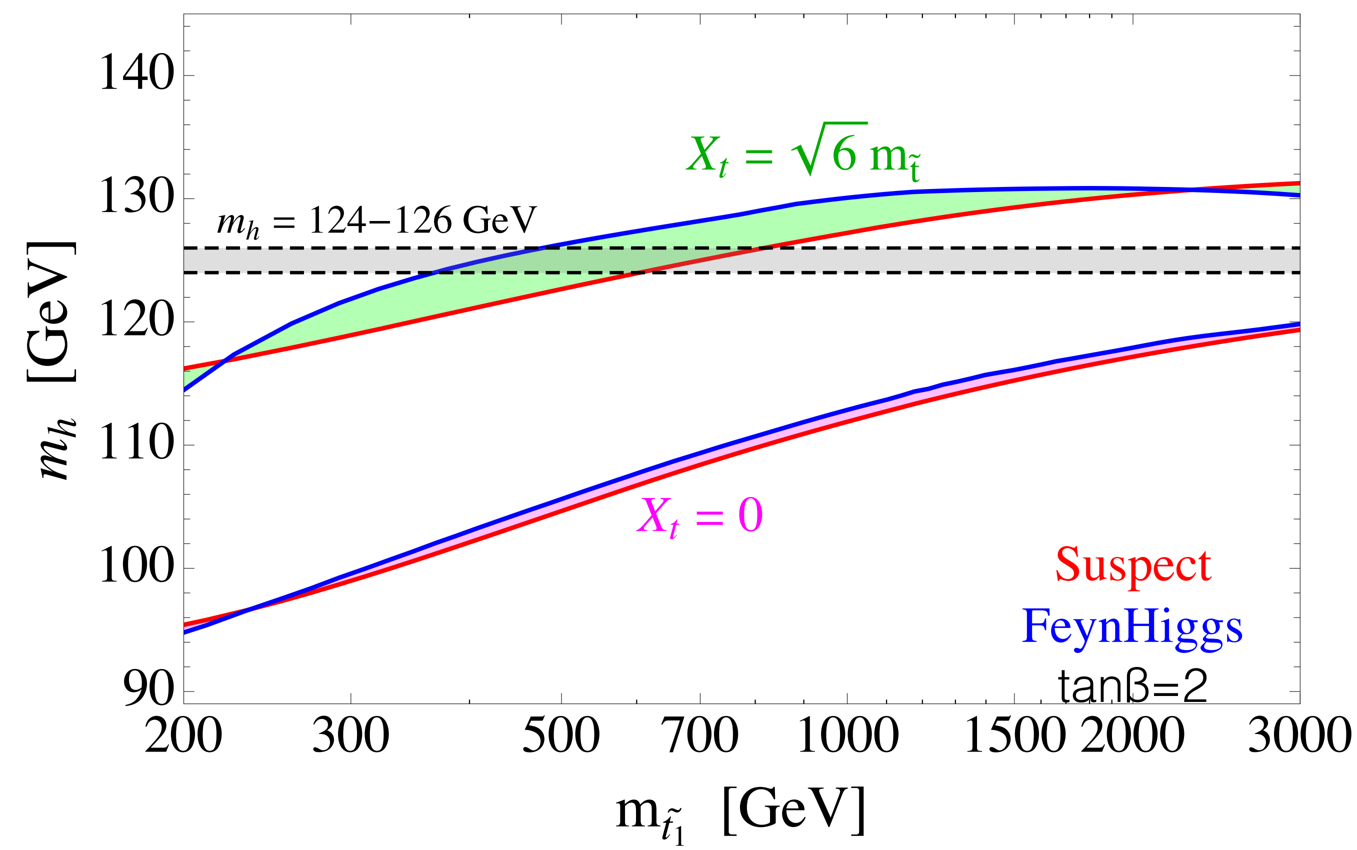
Roberto Franceschini (CERN)
PANIC 2014 - August 25th







MSSM Higgs Mass



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

Top quark: faraway, so close

lots of top quarks produced at TeVatron and LHC, still lots of things to be learned about the top quark

A window on:

- SM vacuum stability
- New physics in the electroweak fit
- Higgs mass in supersymmetry

Top mass combination

1403.4427 - First combination of Tevatron and LHC measurements of the top-quark mass

LHC/Tevatron NOTE

ATLAS-CONF-2014-008
CDF Note 11071
CMS PAS TOP-13-014
D0 Note 6416

March 17, 2014

Experiment	$t\bar{t}$ final state	$\mathcal{L}_{int}$ [fb^{-1}]	m_{top} ± (stat.) ± (syst.) [GeV]	Total uncertainty on m_{top} [GeV] ([%])	Reference
CDF	l+jets	8.7	172.85 ± 0.52 ± 0.99	1.12 (0.65)	[8]
	dilepton	5.6	170.28 ± 1.95 ± 3.13	3.69 (2.17)	[9]
	all jets	5.8	172.47 ± 1.43 ± 1.41	2.01 (1.16)	[10]
	E_T^{miss}+jets	8.7	173.93 ± 1.26 ± 1.36	1.85 (1.07)	[11]
D0	l+jets	3.6	174.94 ± 0.83 ± 1.25	1.50 (0.86)	[12]
	dilepton	5.3	174.00 ± 2.36 ± 1.49	2.79 (1.60)	[13]
ATLAS	l+jets	4.7	172.31 ± 0.23 ± 1.53	1.55 (0.90)	[14]
	dilepton	4.7	173.09 ± 0.64 ± 1.50	1.63 (0.94)	[15]
CMS	l+jets	4.9	173.49 ± 0.27 ± 1.03	1.06 (0.61)	[16]
	dilepton	4.9	172.50 ± 0.43 ± 1.46	1.52 (0.88)	[17]
	all jets	3.5	173.49 ± 0.69 ± 1.23	1.41 (0.81)	[18]

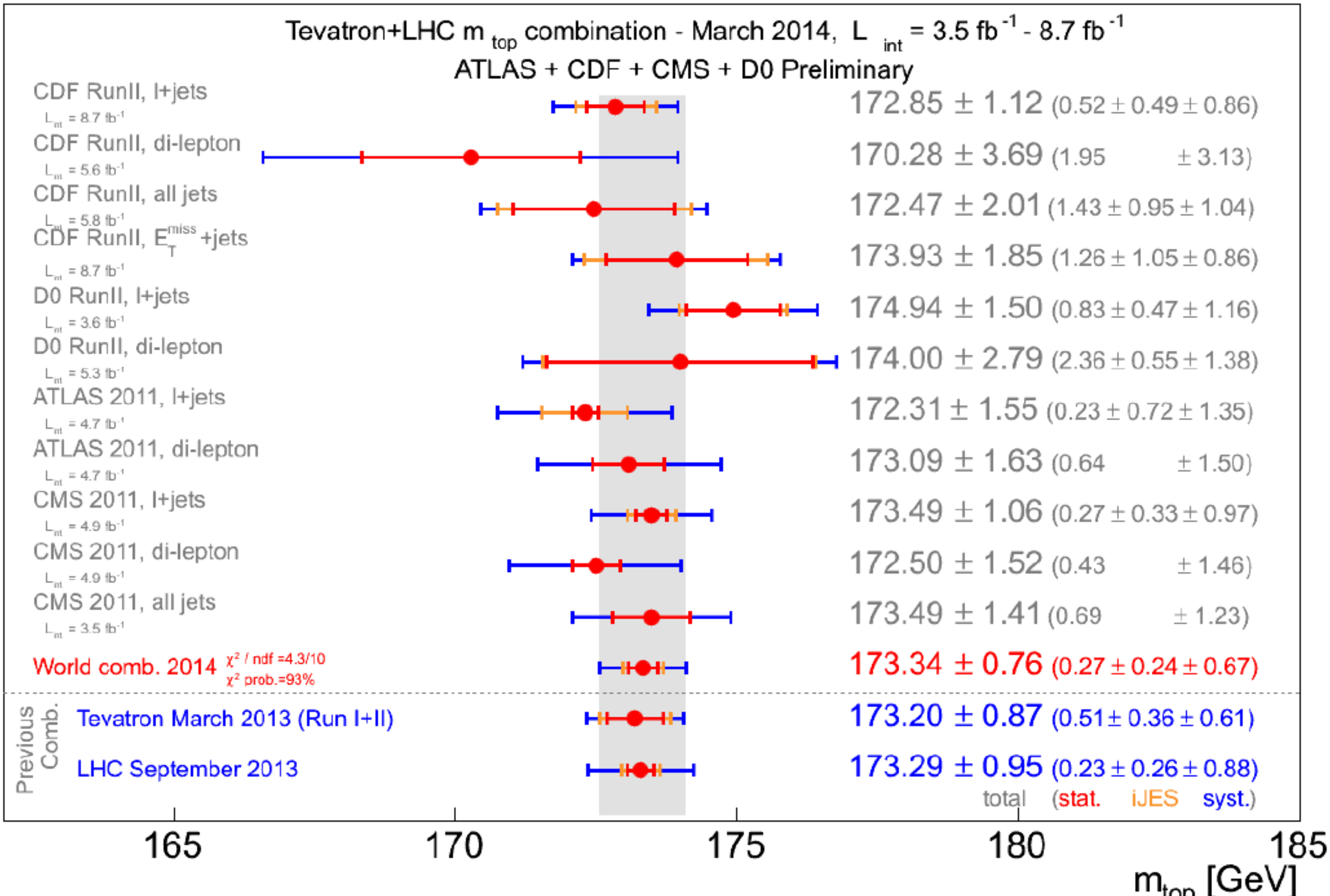
LHC-7 is on par with TeVatron

173.34± 0.27(stat) ± 0.71 (syst) GeV
dominated by systematics

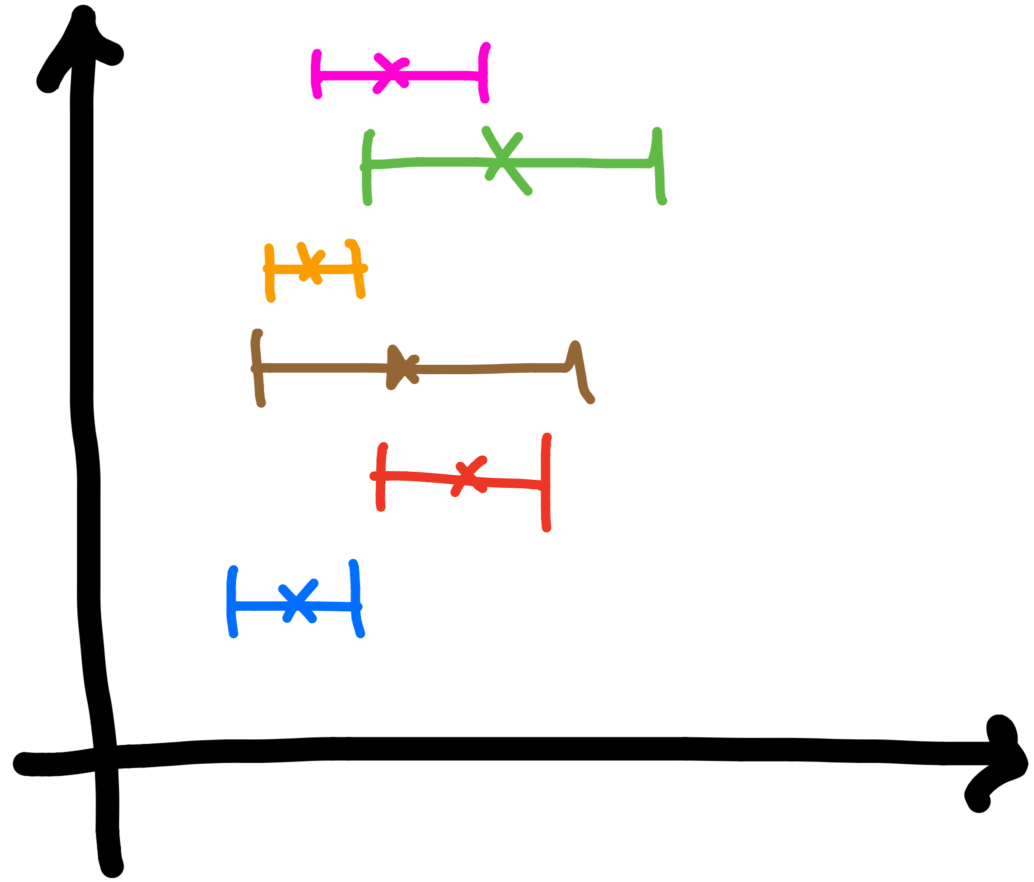
l+jets
dilepton
all jets

sys

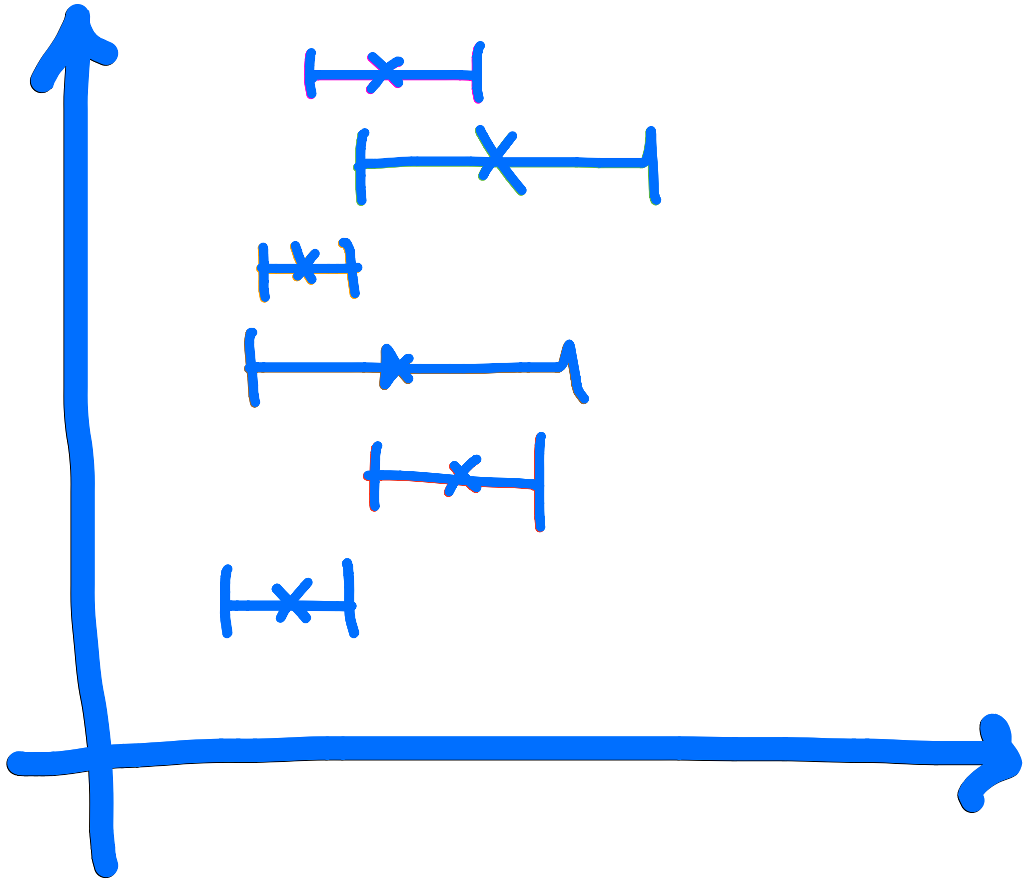
Many measurements



Many measurements?



Many measurements?



Status

measurement at ≲0.5% precision! ⇒ precision QCD

Mostly experimental

- precision is systematics limited (JES, …)
- mixed status w.r.t assessed *theory* systematics

- methods are (somewhat or tightly) tied to MC
- fundamentally based on a Leading Order picture
- mixed status w.r.t. effect of new physics

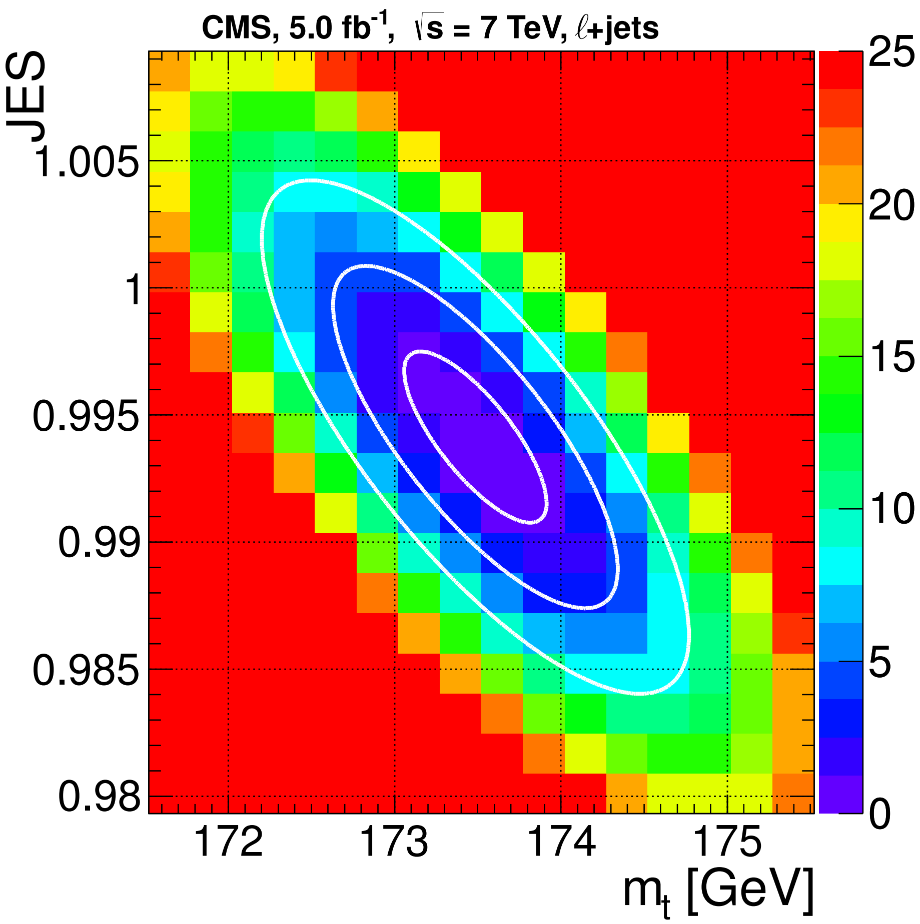
Mostly theoretical

- what top mass**es** we need to measure

CMS 1209.2319

173.49 ± 0.43 (stat.+JES) ± 0.98 (syst.) GeV

Ideogram Method (Kinematic fit)



MG5+Py6

	μ+jets		e+jets		ℓ+jets	
	$\delta^{\mu}_{m_t}$ (GeV)	δ^{μ}_{JES}	$\delta^{e}_{m_t}$ (GeV)	δ^{e}_{JES}	$\delta^{\ell}_{m_t}$ (GeV)	δ^{ℓ}_{JES}
Fit calibration	0.08	0.001	0.09	0.001	0.06	0.001
b-JES	0.60	0.000	0.62	0.000	0.61	0.000
p_T- and η-dependent JES	0.30	0.001	0.28	0.001	0.28	0.001
Lepton energy scale	0.03	0.000	0.04	0.000	0.02	0.000
Missing transverse momentum	0.05	0.000	0.07	0.000	0.06	0.000
Jet energy resolution	0.22	0.004	0.24	0.004	0.23	0.004
b tagging	0.11	0.001	0.15	0.001	0.12	0.001
Pileup	0.07	0.002	0.08	0.001	0.07	0.001
Non-$t\bar{t}$ background	0.10	0.001	0.16	0.000	0.13	0.001
Parton distribution functions	0.07	0.001	0.07	0.001	0.07	0.001
Renormalization and factorization scales	0.23	0.004	0.41	0.005	0.24	0.004
ME-PS matching threshold	0.17	0.000	0.15	0.001	0.18	0.001
Underlying event	0.26	0.002	0.24	0.001	0.15	0.002
Color reconnection effects	0.66	0.004	0.39	0.003	0.54	0.004
Total	1.06	0.008	1.00	0.007	0.98	0.008

ATLAS-CONF-2013-046

m_{top} = 172.31 ± 0.23 (stat) ± 0.27 (JSF) ± 0.67 (bJSF) ± 1.35 (syst) GeV

3D Method (Kinematic Fit)

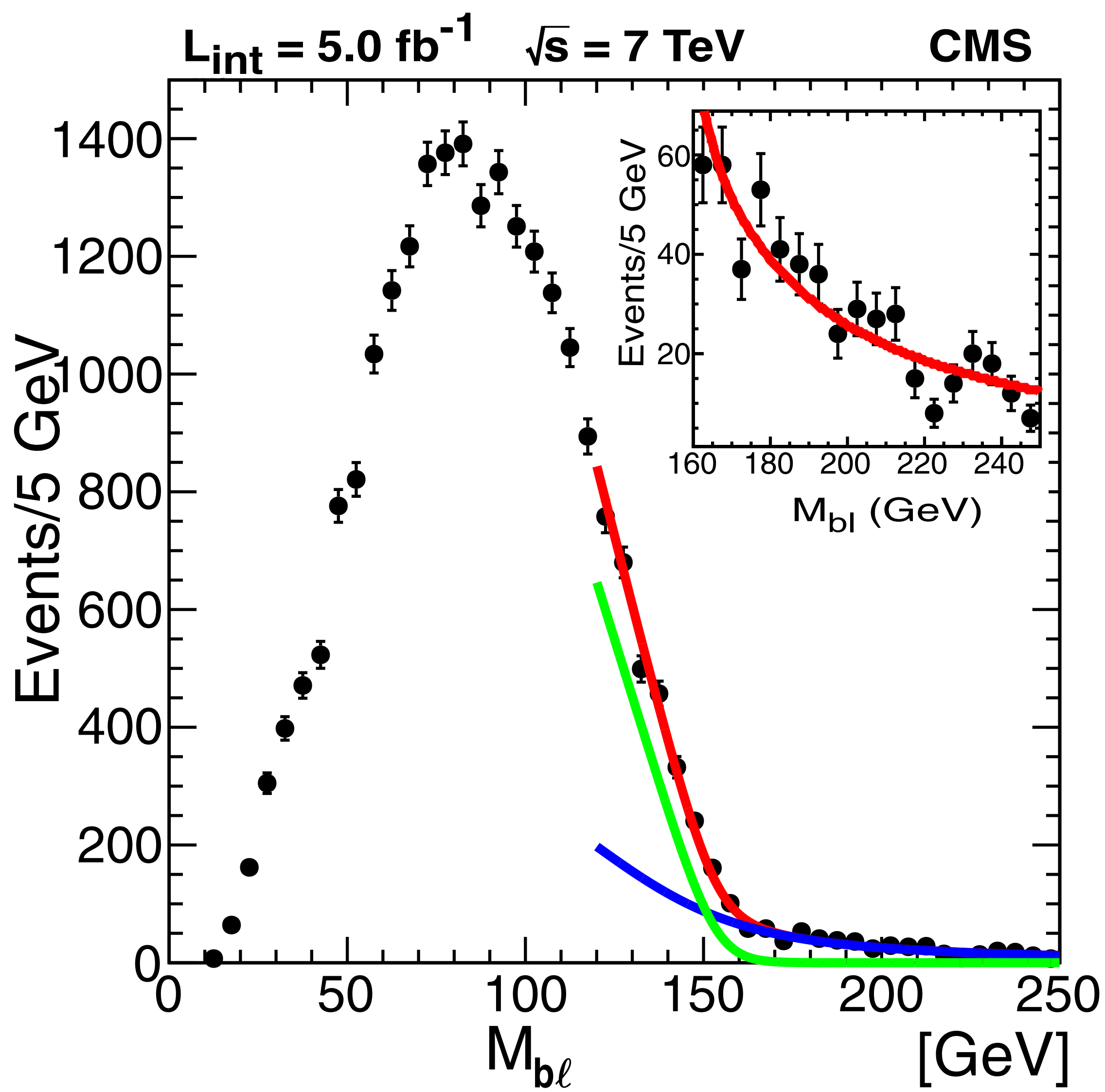
MC@NLO or POWHEG	2d-analysis		3d-analysis		
	m_{top} [GeV]	JSF	m_{top} [GeV]	JSF	bJSF
Measured value	172.80	1.014	172.31	1.014	1.006
Data statistics	0.23	0.003	0.23	0.003	0.008
Jet energy scale factor (stat. comp.)	0.27	n/a	0.27	n/a	n/a
bJet energy scale factor (stat. comp.)	n/a	n/a	0.67	n/a	n/a
Method calibration	0.13	0.002	0.13	0.002	0.003
Signal MC generator	0.36	0.005	0.19	0.005	0.002
Hadronisation	1.30	0.008	0.27	0.008	0.013
Underlying event	0.02	0.001	0.12	0.001	0.002
Colour reconnection	0.03	0.001	0.32	0.001	0.004
ISR and FSR (signal only)	0.96	0.017	0.45	0.017	0.006
Proton PDF	0.09	0.000	0.17	0.000	0.001
single top normalisation	0.00	0.000	0.00	0.000	0.000
W+jets background	0.02	0.000	0.03	0.000	0.000
QCD multijet background	0.04	0.000	0.10	0.000	0.001
Jet energy scale	0.60	0.005	0.79	0.004	0.007
b-jet energy scale	0.92	0.000	0.08	0.000	0.002
Jet energy resolution	0.22	0.006	0.22	0.006	0.000
Jet reconstruction efficiency	0.03	0.000	0.05	0.000	0.000
b-tagging efficiency and mistag rate	0.17	0.001	0.81	0.001	0.011
Lepton energy scale	0.03	0.000	0.04	0.000	0.000
Missing transverse momentum	0.01	0.000	0.03	0.000	0.000
Pile-up	0.03	0.000	0.03	0.000	0.001
Total systematic uncertainty	2.02	0.021	1.35	0.021	0.020
Total uncertainty	2.05	0.021	1.55	0.021	0.022

CMS-TOP-11-027

$$M_t = 173.9 \pm 0.9\,(\text{stat.})^{+1.7}_{-2.1}\,(\text{syst.})\,\text{GeV}$$

m(b,l) end-point

- robust to NLO
- robust to combinatorics
- robust to hadronization



Source	δM_t (GeV)
Jet Energy Scale	$^{+1.3}_{-1.8}$
Jet Energy Resolution	± 0.5
Lepton Energy Scale	$^{+0.3}_{-0.4}$
Fit Range	± 0.6
Background Shape	± 0.5
Jet and Lepton Efficiencies	$^{+0.1}_{-0.2}$
Pileup	<0.1
QCD effects	± 0.6
Total	$^{+1.7}_{-2.1}$

Ideal situation

Have many inherently different methods

Each methods based on different assumptions/beliefs

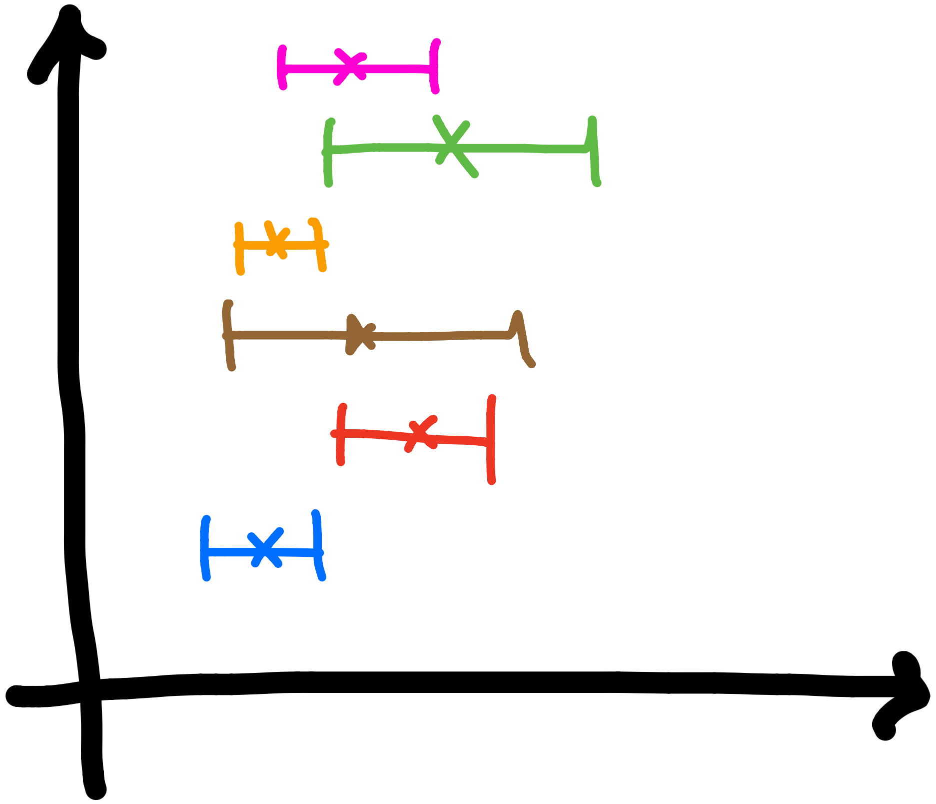
- kinematics of the event (going beyond $t\bar{t} \to bWbW$)
- MC *choices* (NLO, scales range & functional form …

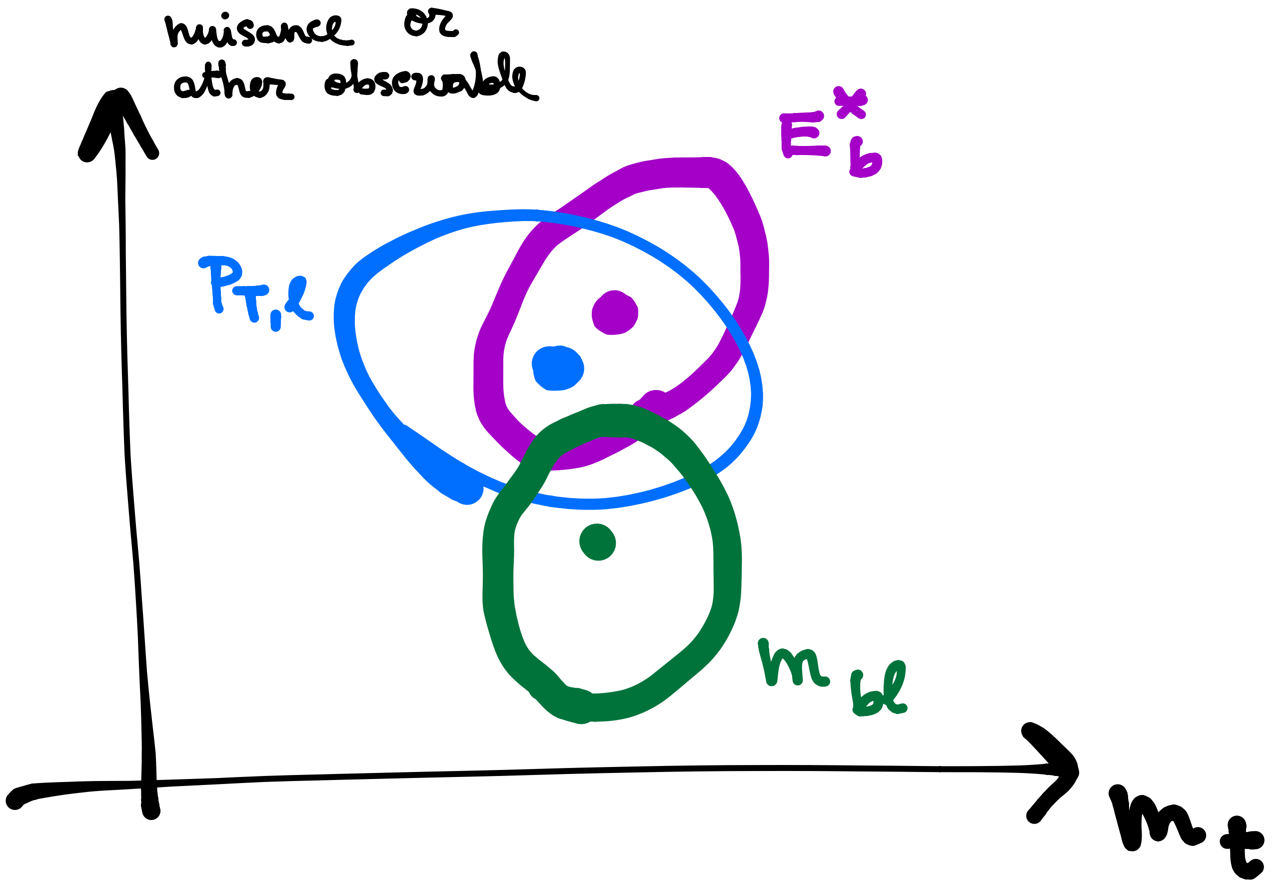
  … width treatment, color neutralization, radiation in decays, hadronization)

and different experimental objects/quantities

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

Many measurements

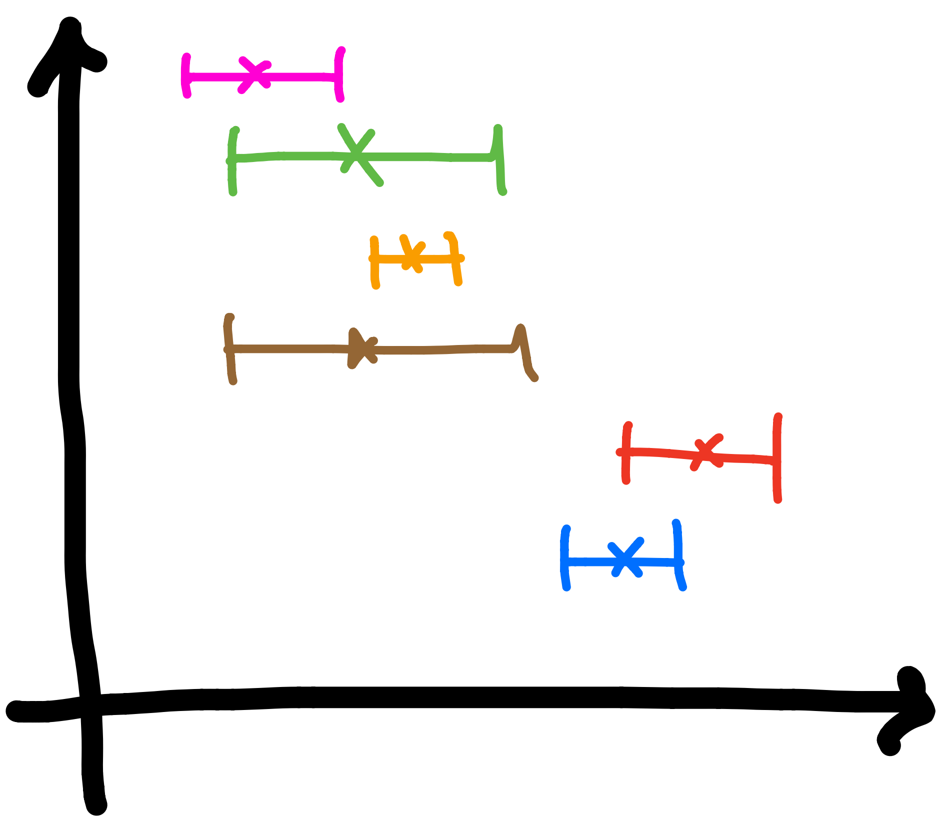


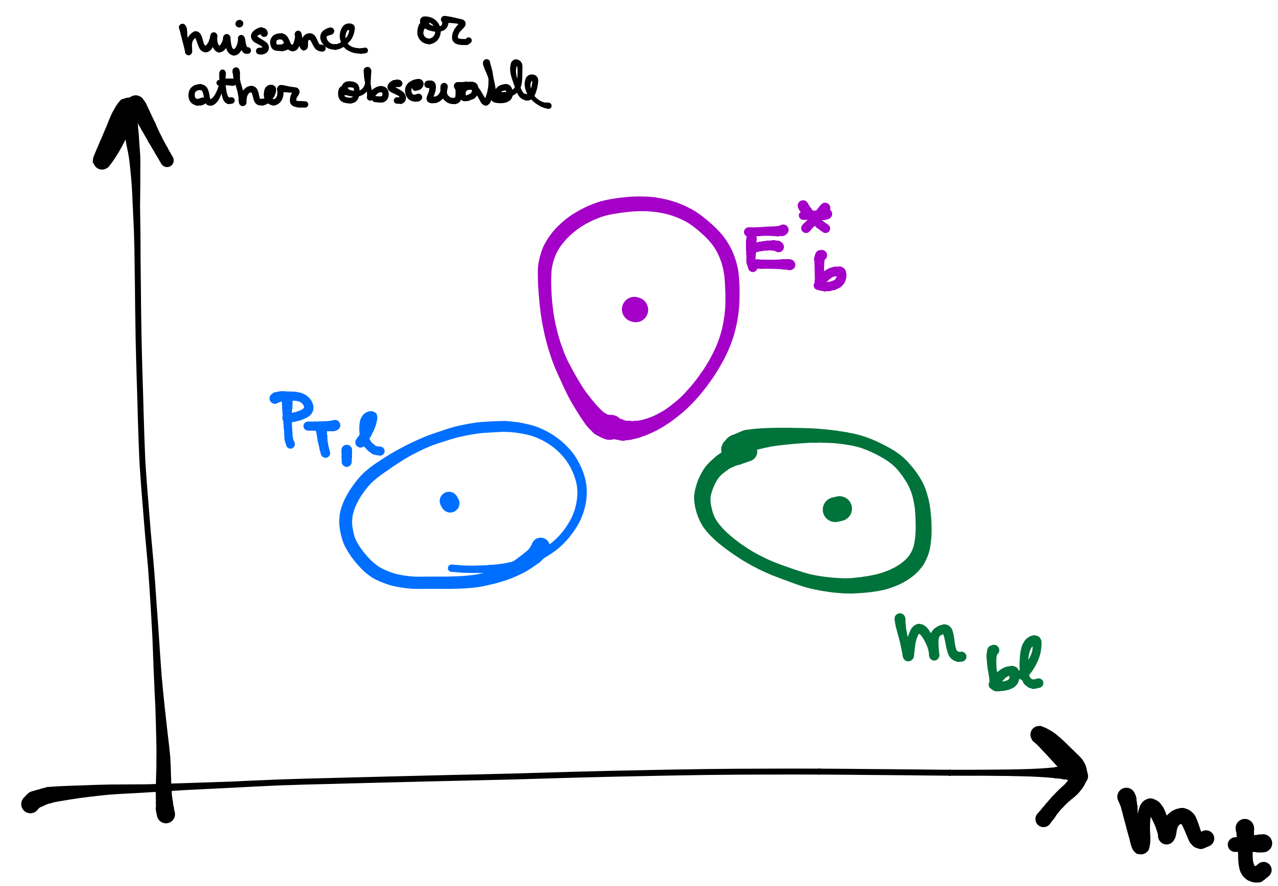


Many measurements

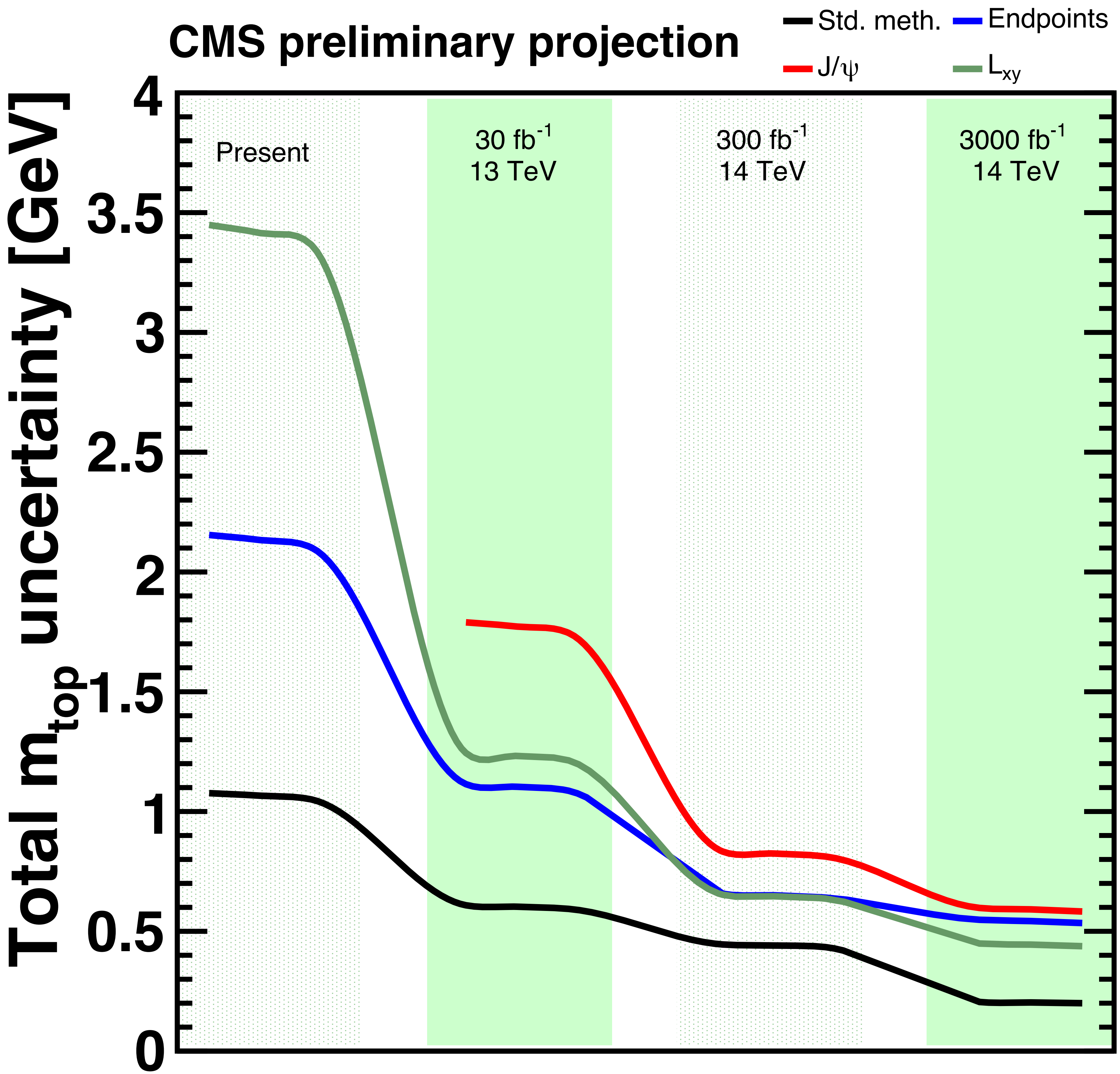
Many measurements

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





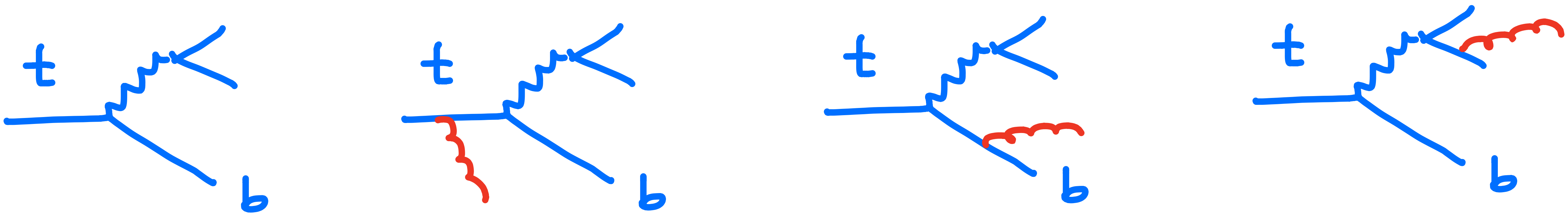
Ideal situation



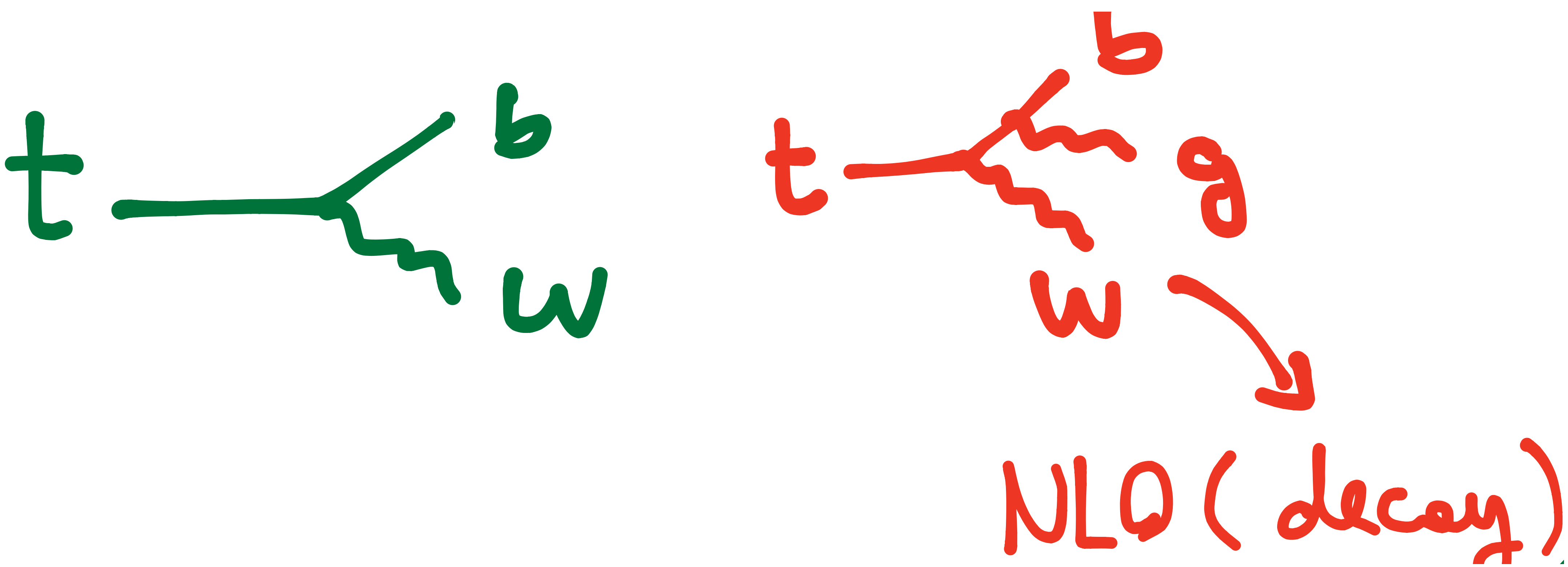
CMS-PAS-FTR-13-017

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

To reconstruct or not to reconstruct?



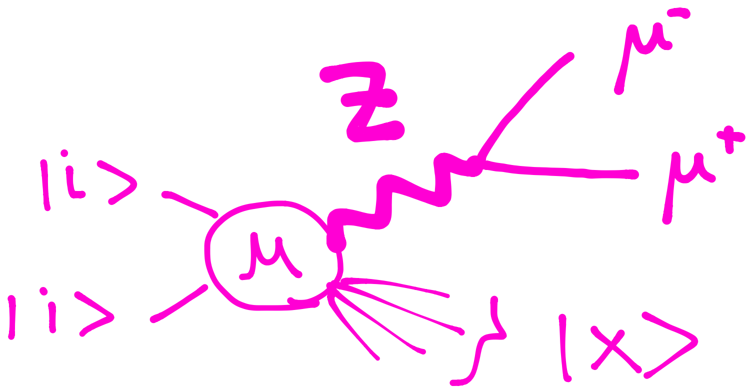
top quark reconstruction is entangled with some picture of the kinematics (fixed order?)

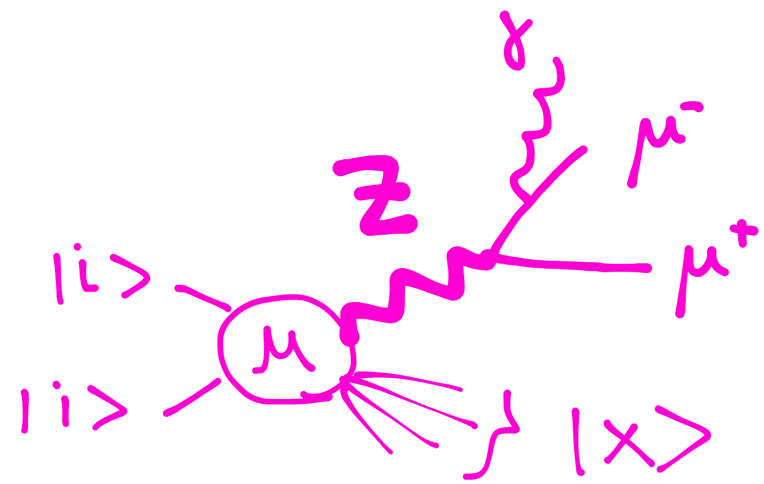


Top decay at NLO not present in current NLO+PS generators

To reconstruct or not to reconstruct?

To reconstruct or not to reconstruct?





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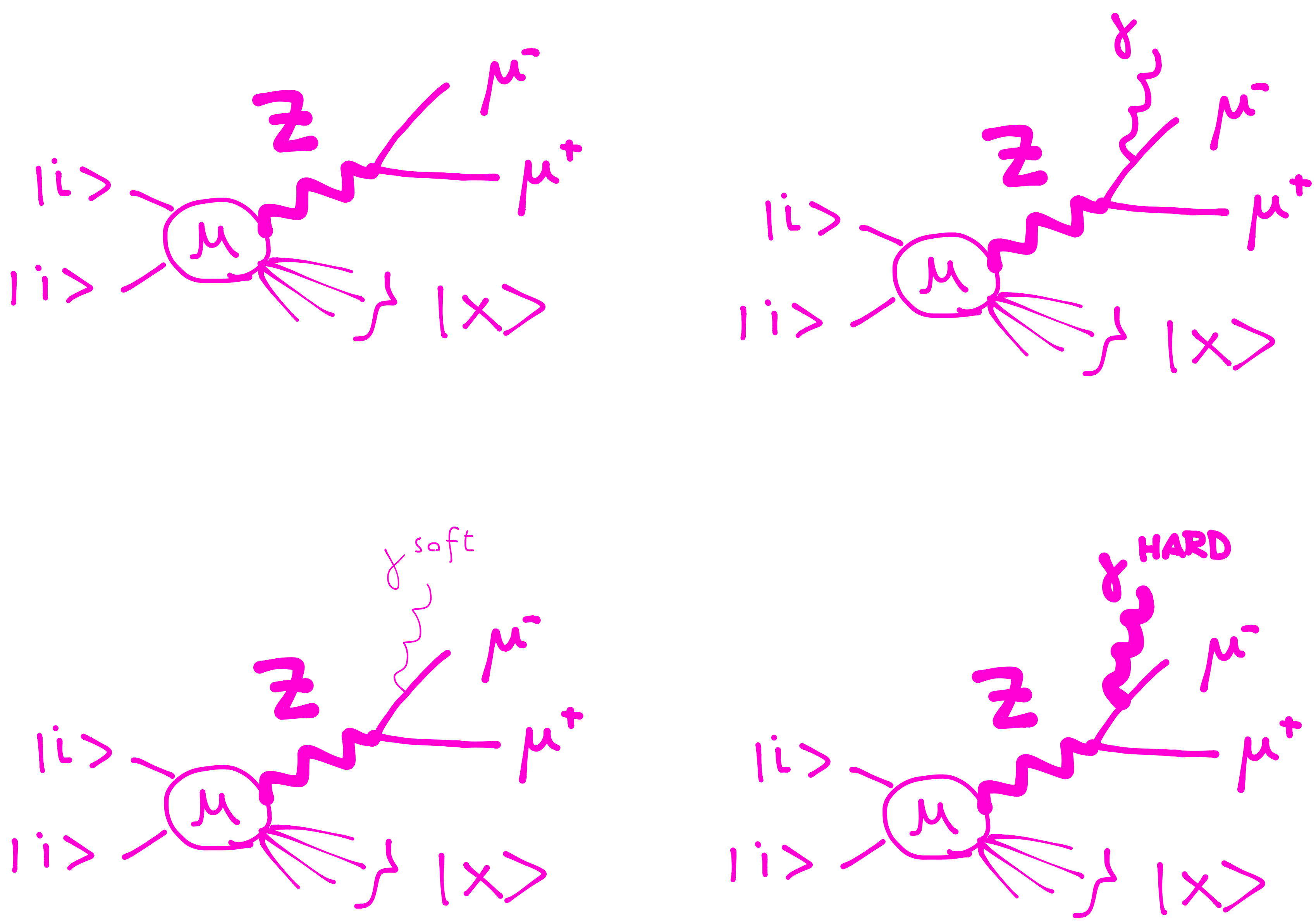

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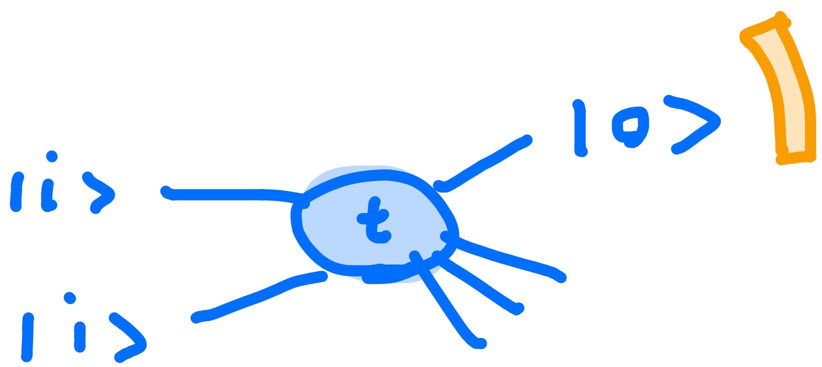
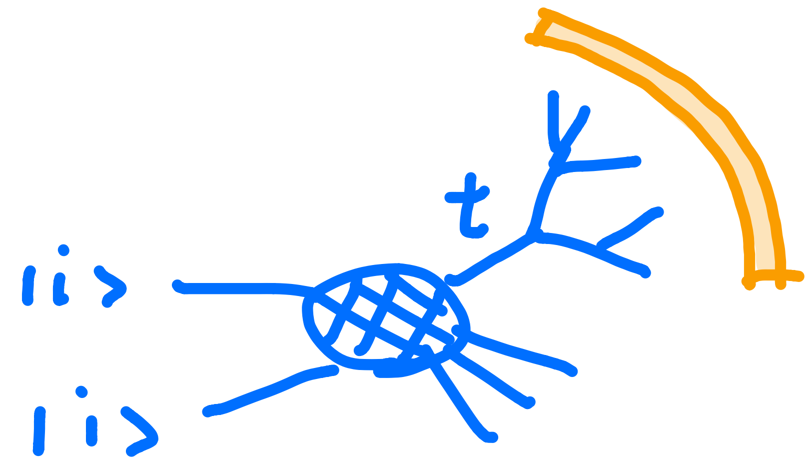




does (not) distinguish where
the final state came from (t, t*, bW, bWg, bqqg)

need (not) to define the top

might (not) depend on the production mechanism

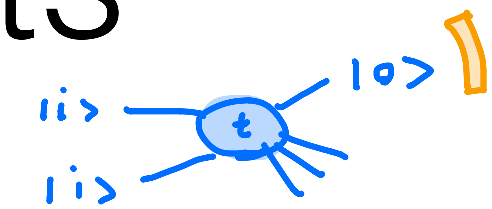
…

New methods

- Leptonic Mellin moments 1407.2763
- Generalized Medians 1405.2395
- Energy Peaks 1209.0772 + WIP

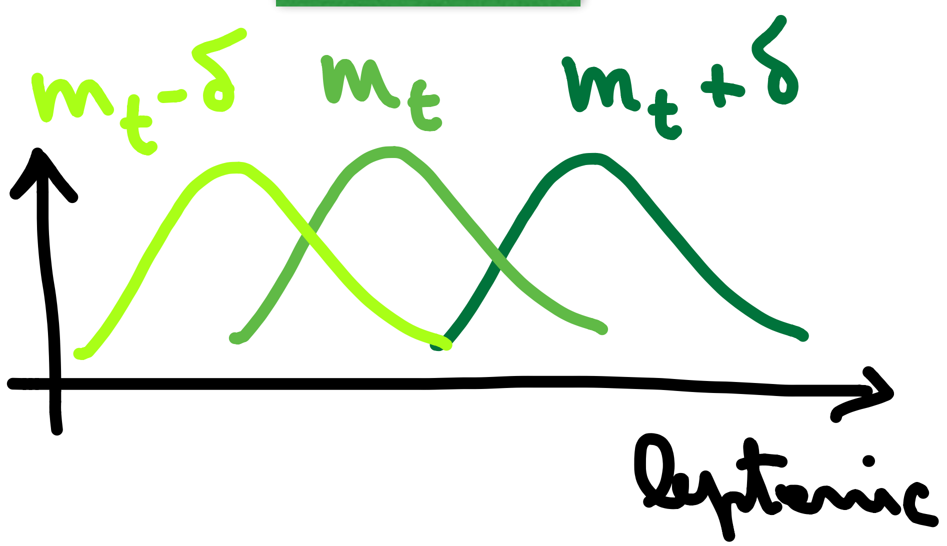
Leptonic Mellin moments

1407.2763



- Take “top like” events
- no explicit reconstruction of the top
- observe the shape of some distribution of the leptons

templates

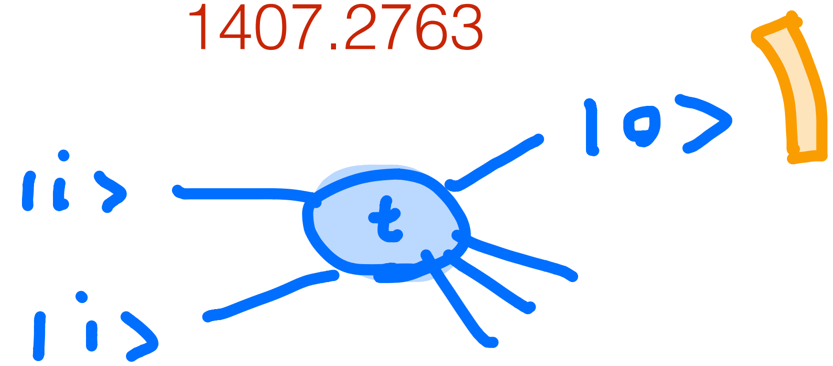


MC: correlate the leptonic shape to *m*top

example: **pT of ℓ⁺** (non-Lorentz invariant)
use Mellin’s moments to parametrize the shape

Leptonic Mellin moments

1407.2763



- no need for an “auxiliary” definition of “top”
- no fixed picture of the kinematics
- naturally an inclusive variable (pp→ ℓ^++tags+X)
- as clean as a lepton (theoretically and experimentally)

- anything that is not simulated might be harmful
- several theoretical subtle effects potentially relevant for *any template method*

Subtleties for *any template method*

1407.2763 - Frixione, S. and Mitov, A. - Determination of the top quark mass from leptonic observables

functional form of fact. scale

m_{top}=174.32 (in the MC)

$$\hat{\mu}^{(1)} = \frac{1}{2}\sum_i m_{T,i}\,, \qquad i \in \{t, \bar{t}\}\,,$$

$$\hat{\mu}^{(2)} = \frac{1}{2}\sum_i m_{T,i}\,, \qquad i \in \text{ final state}\,,$$

$$\hat{\mu}^{(3)} = m_t\,,$$

scale	m_{top} from $p_{T\ell}$
1	$174.73^{+0.80}_{-0.79}\,[0.2]$
2	$174.78^{+0.90}_{-0.90}\,[0.6]$
3	$172.73^{+2.0}_{-1.2}\,[0.5]$
$1 \oplus 2 \oplus 3$	$174.46^{+0.99}_{-0.92}$

1 σ-th bias
σ-th might also change

rate and distributions might feel differently theory variations

Subtleties for *any template method*

1407.2763 - Frixione, S. and Mitov, A. - Determination of the top quark mass from leptonic observables

theory modeling: LO, NLO, LO+PS, NLO+PS (⊗ spin correlations)

- <u>understand the combination</u>
- asses missing effects: NNLO, extra radiation types

effect of shower

obs.	Δ_{PS}@NLO	bias@NLO	Δ_{PS}@LO	bias@LO
$p_{T\bar{\ell}}$	$-0.35^{+1.14}_{-1.16}$	$+0.12$	$-2.17^{+1.50}_{-1.80}$	-0.67
$p_{T\bar{\ell}+\ell}$	$-4.74^{+1.98}_{-3.10}$	$+11.14$	$-9.09^{+0.76}_{-0.71}$	$+14.19$
$M_{\bar{\ell}+\ell}$	$+1.52^{+2.03}_{-1.80}$	-8.61	$+3.79^{+3.30}_{-4.02}$	-6.43
$E_{\bar{\ell}}+E_{\ell}$	$+0.15^{+2.81}_{-2.91}$	-0.23	$-1.79^{+3.08}_{-3.75}$	-1.47
$p_{T\bar{\ell}}+p_{T\ell}$	$-0.30^{+1.09}_{-1.21}$	$+0.03$	$-2.13^{+1.51}_{-1.81}$	-0.67

impact of shower: use of partonic NNLO

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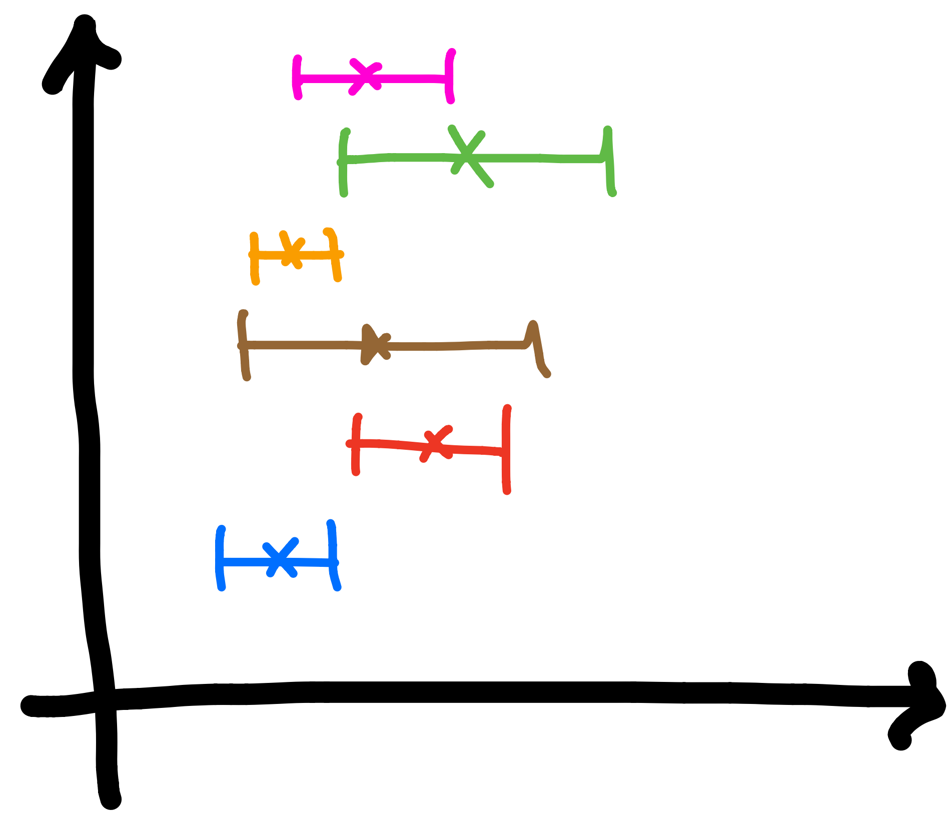
$p_{T\bar{\ell}}$, $E_{\bar{\ell}}+E_{\ell}$, $p_{T\bar{\ell}}+p_{T\ell}$	
LO+PS+MS	$173.61^{+1.10}_{-1.34}$[1.0]
NLO+PS	$174.40^{+0.75}_{-0.81}$[3.5]
LO+PS	$173.68^{+1.08}_{-1.31}$[0.8]
fNLO	$174.73^{+0.72}_{-0.74}$[5.5]
fLO	$175.84^{+0.90}_{-1.05}$[1.2]

$p_{T\bar{\ell}}$, $E_{\bar{\ell}}+E_{\ell}$, $p_{T\bar{\ell}}+p_{T\ell}$, $p_{T\bar{\ell}+\ell}$, $M_{\bar{\ell}+\ell}$	
LO+PS+MS	$175.98^{+0.63}_{-0.69}$[16.9]
NLO+PS	$175.43^{+0.74}_{-0.80}$[29.2]
LO+PS	$187.90^{+0.6}_{-0.6}$[428.3]
fNLO	$174.41^{+0.72}_{-0.73}$[96.6]
fLO	$197.31^{+0.42}_{-0.35}$[2496.1]



discrepancy highlights poor QCD description

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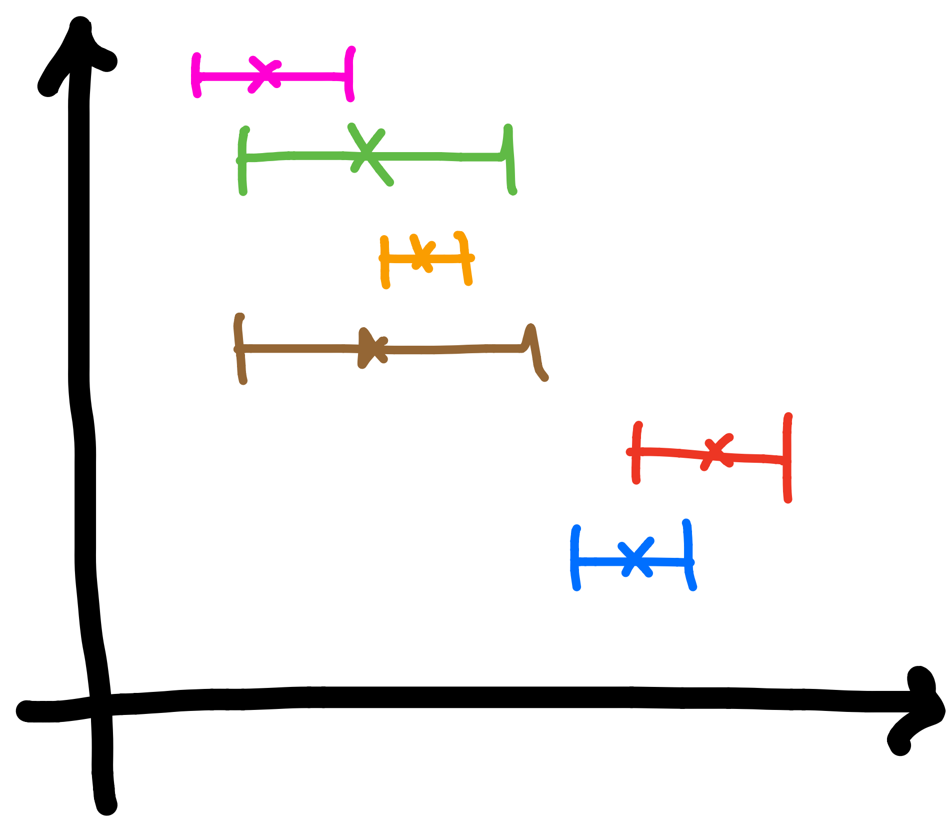
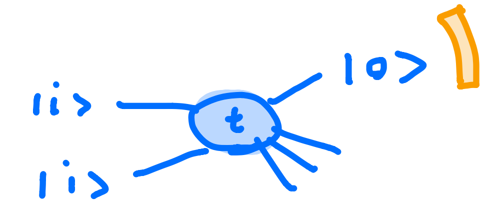


discrepancy highlights poor QCD description

Generalized medians

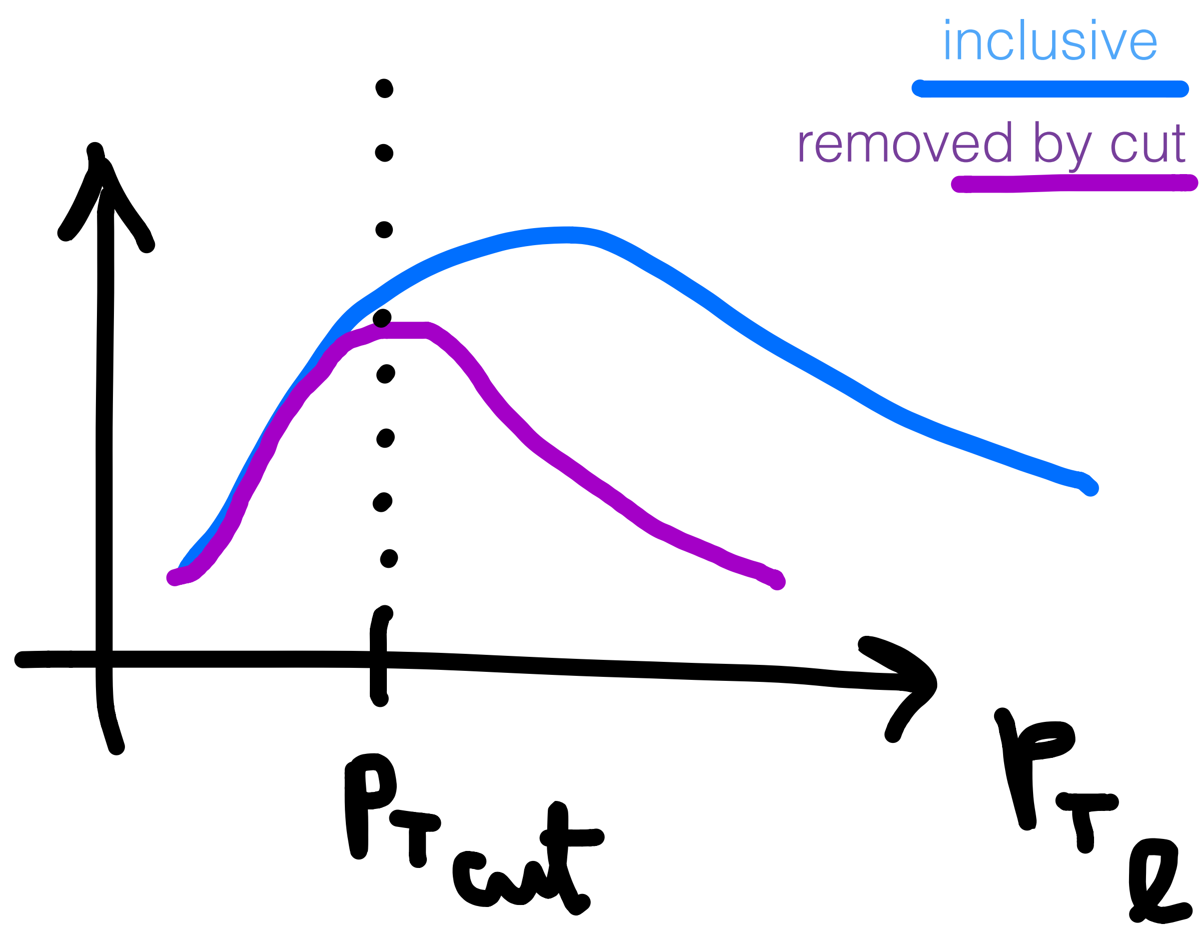


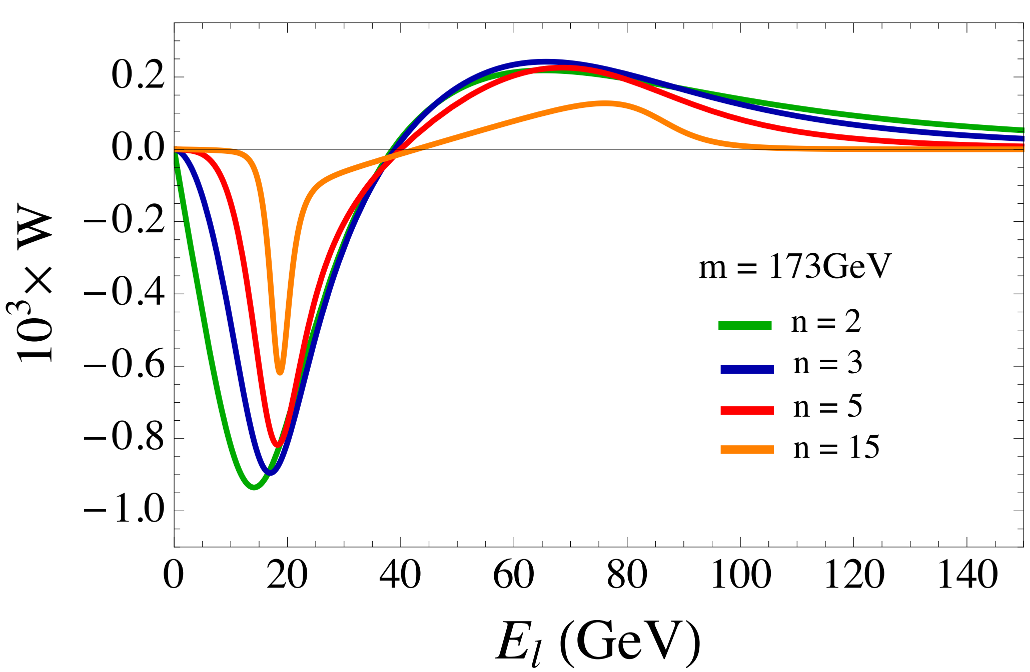
1405.2395

$$I(m)_w = \int dE_\ell \frac{d\Gamma}{dE_\ell} \cdot w(E_\ell, m)$$

inclusive integral over the lab-frame lepton Energy

$$\boxed{I(m=m_t)_w = 0}$$



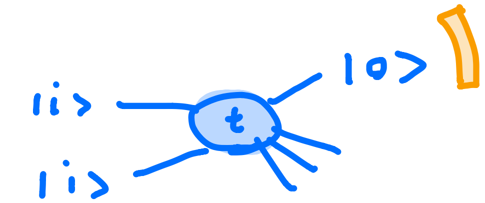


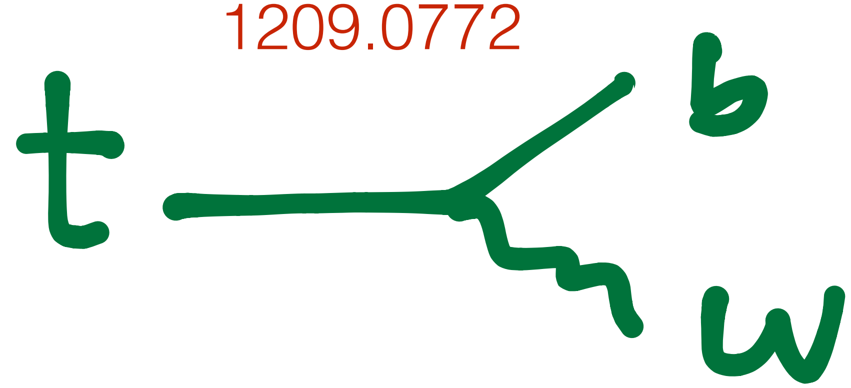
		Signal stat. error	Fac. scale (signal)	JES (signal)	Background stat. error
n	2	0.4	+1.5/−1.6	+0.0/−0.1	0.4
	3	0.4	+1.5/−1.5	+0.1/−0.3	0.4
	5	0.5	+1.4/−1.4	+0.2/−0.4	0.5
	15	0.5	+1.5/−1.3	+0.2/−0.6	0.6

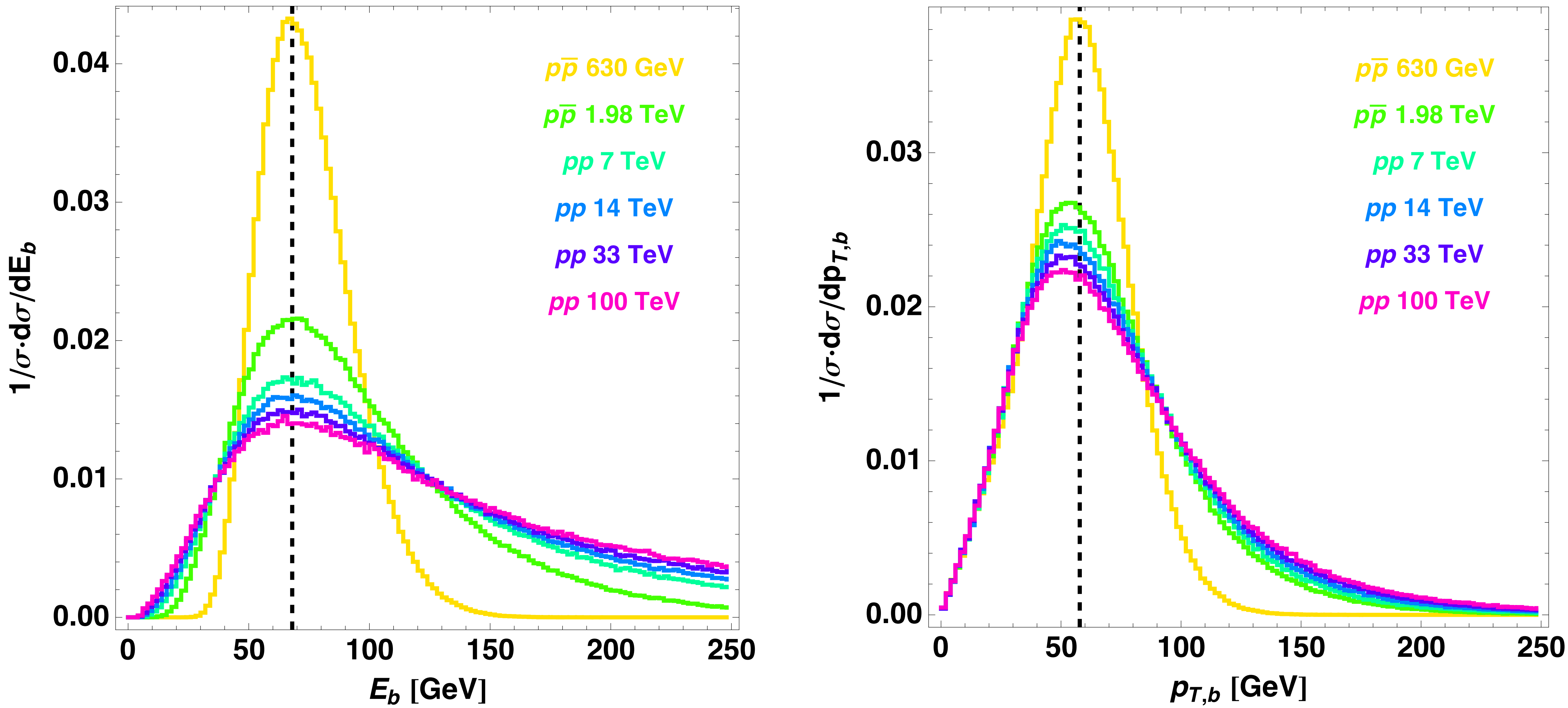
$\Delta_{TH} \sim 1 - \sigma_{exclusive}/\sigma_{inclusive} \sim 1$ - efficiency ~ 0.2

Energy peaks

1209.0772

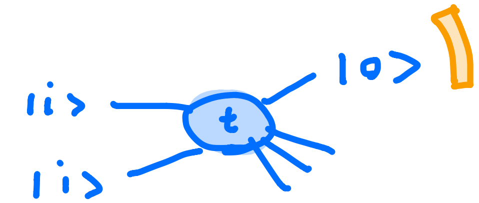






insensitivity to the top **boost distribution** is the key

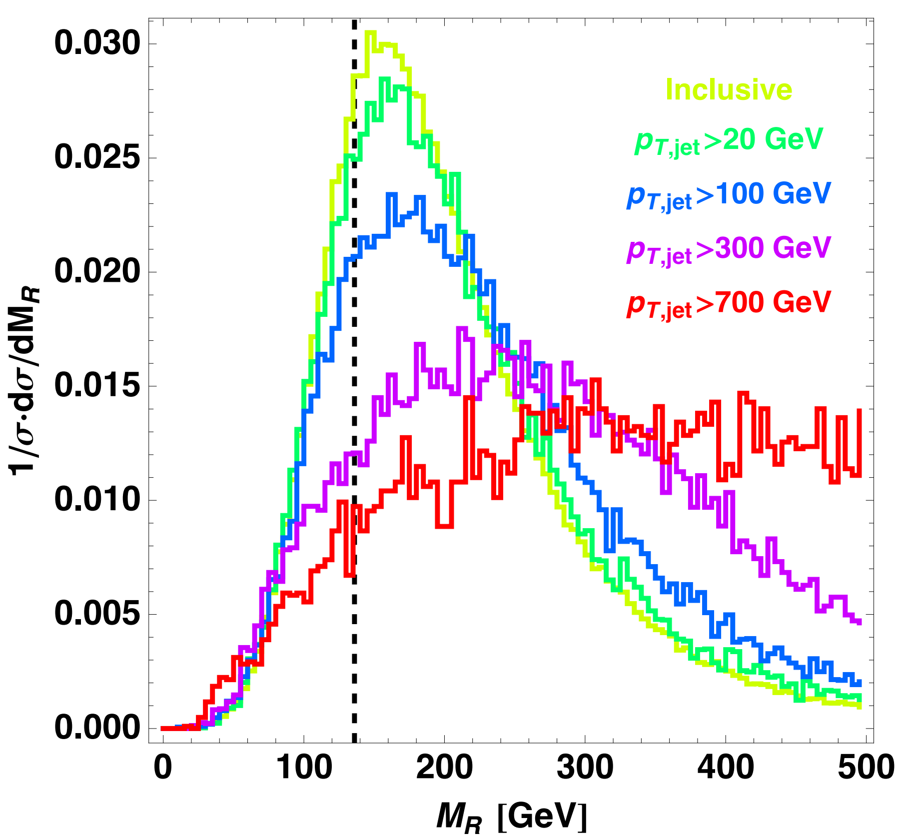
Energy peaks



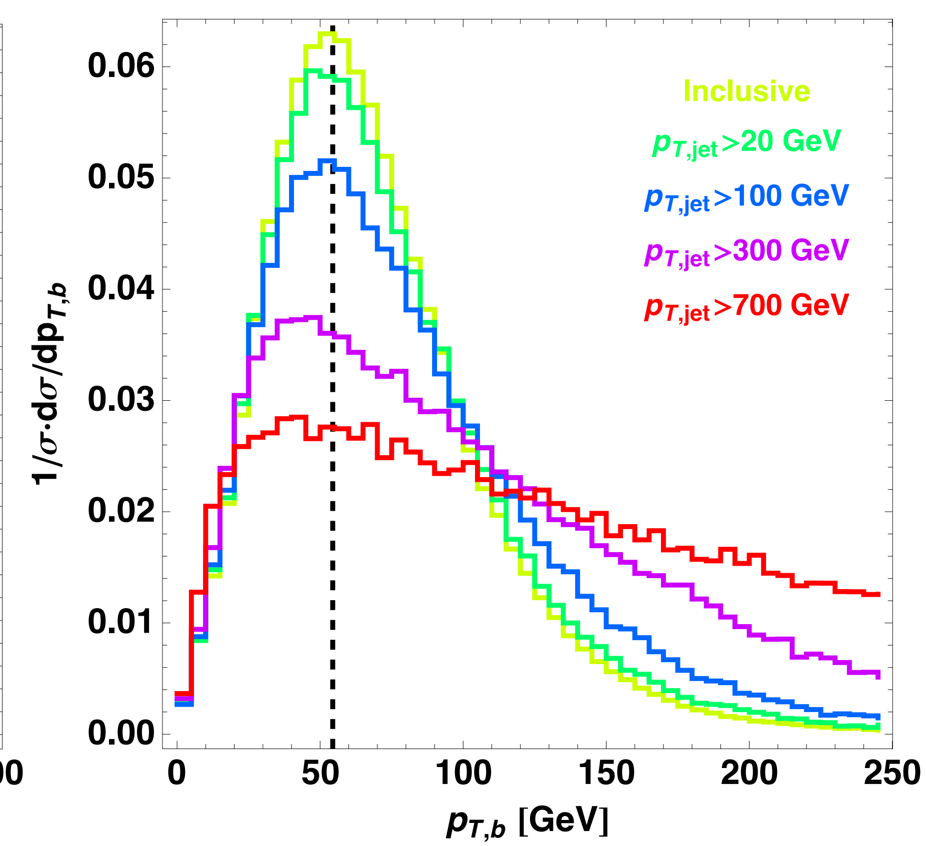
1209.0772

Agashe, Franceschini and Kim - in preparation

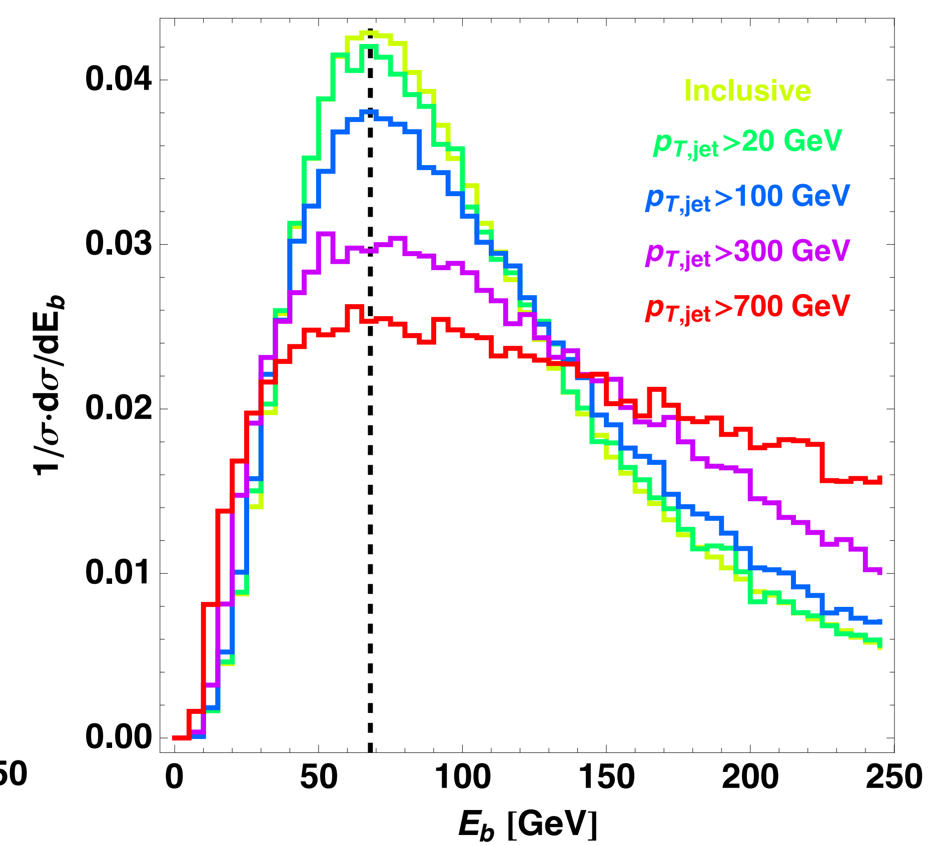
Razor MR



Transverse Momentum



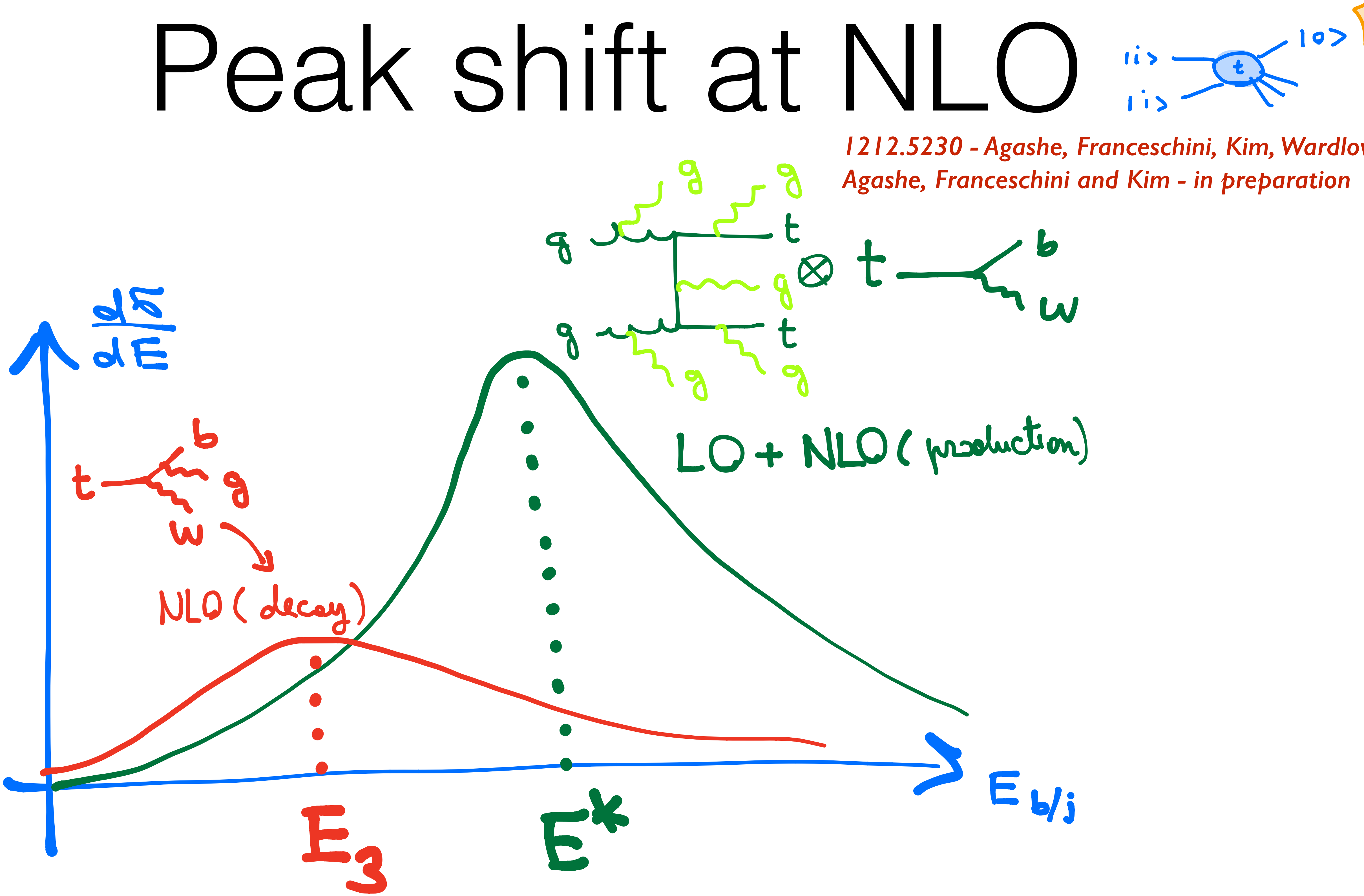
Energy



peak stability

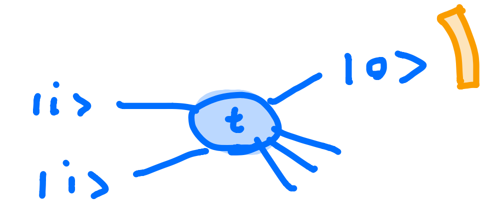
Peak shift at NLO

1212.5230 - Agashe, Franceschini, Kim, Wardlow
Agashe, Franceschini and Kim - in preparation

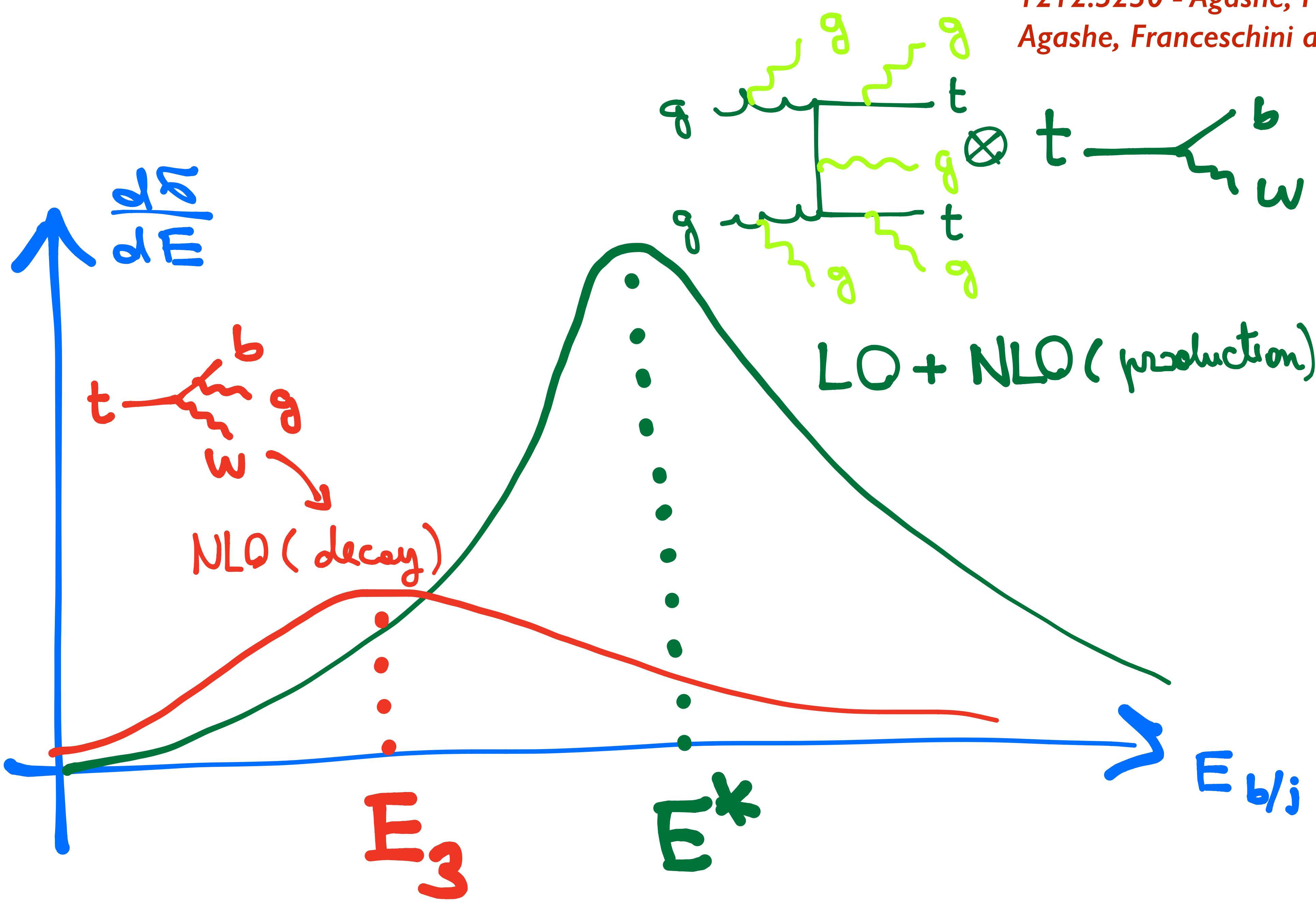


$$E^{peak} = E^{*} + O(1)\frac{\alpha}{4\pi}E_3$$

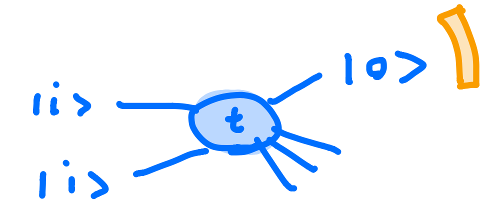
Peak shift at NLO



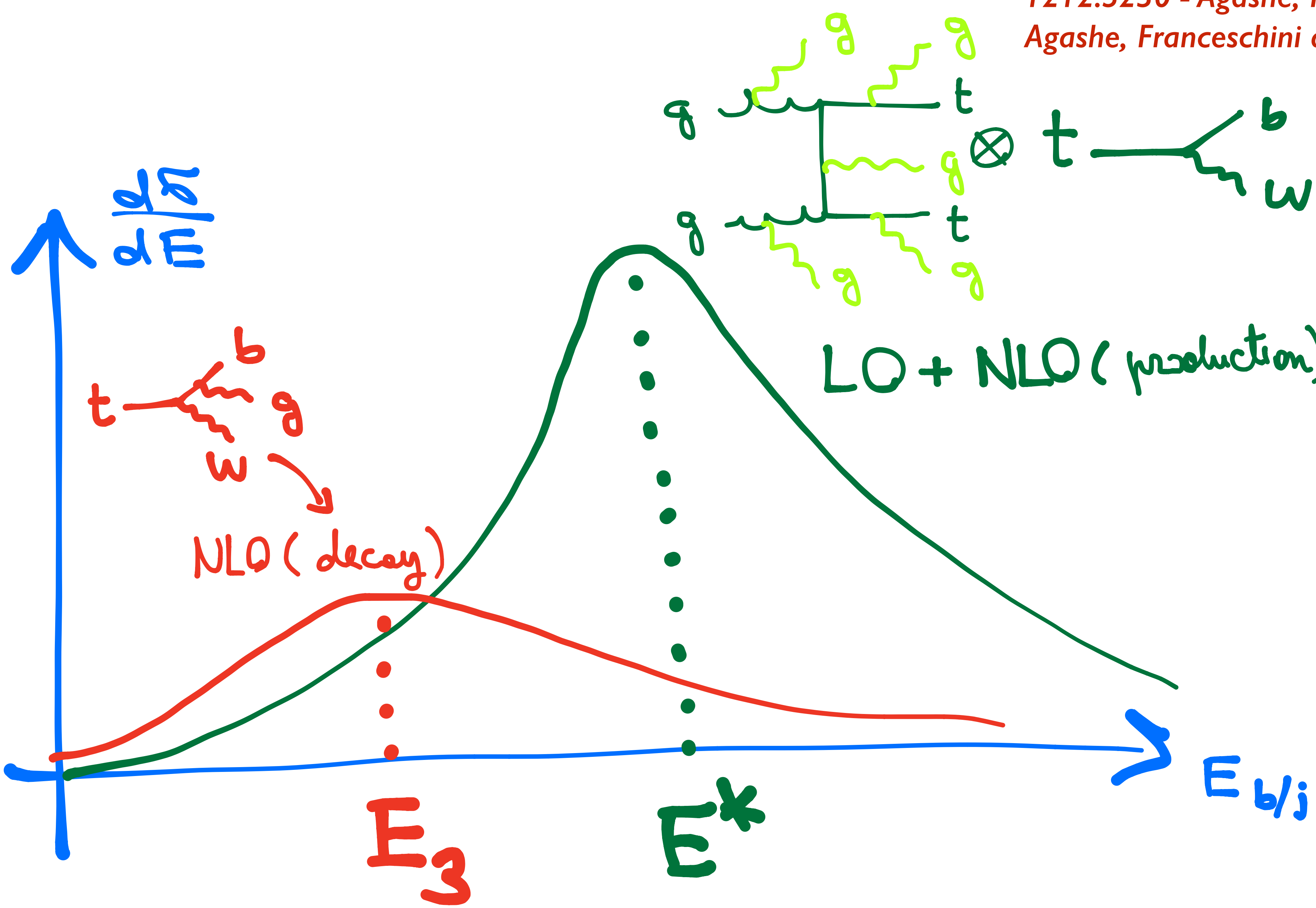
1212.5230 - Agashe, Franceschini, Kim, Wardlow
Agashe, Franceschini and Kim - in preparation



Peak shift at NLO

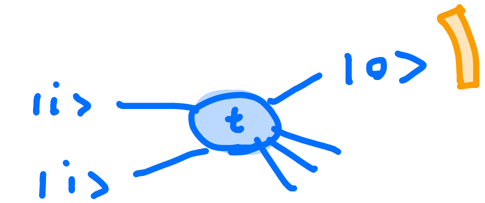


1212.5230 - Agashe, Franceschini, Kim, Wardlow
Agashe, Franceschini and Kim - in preparation

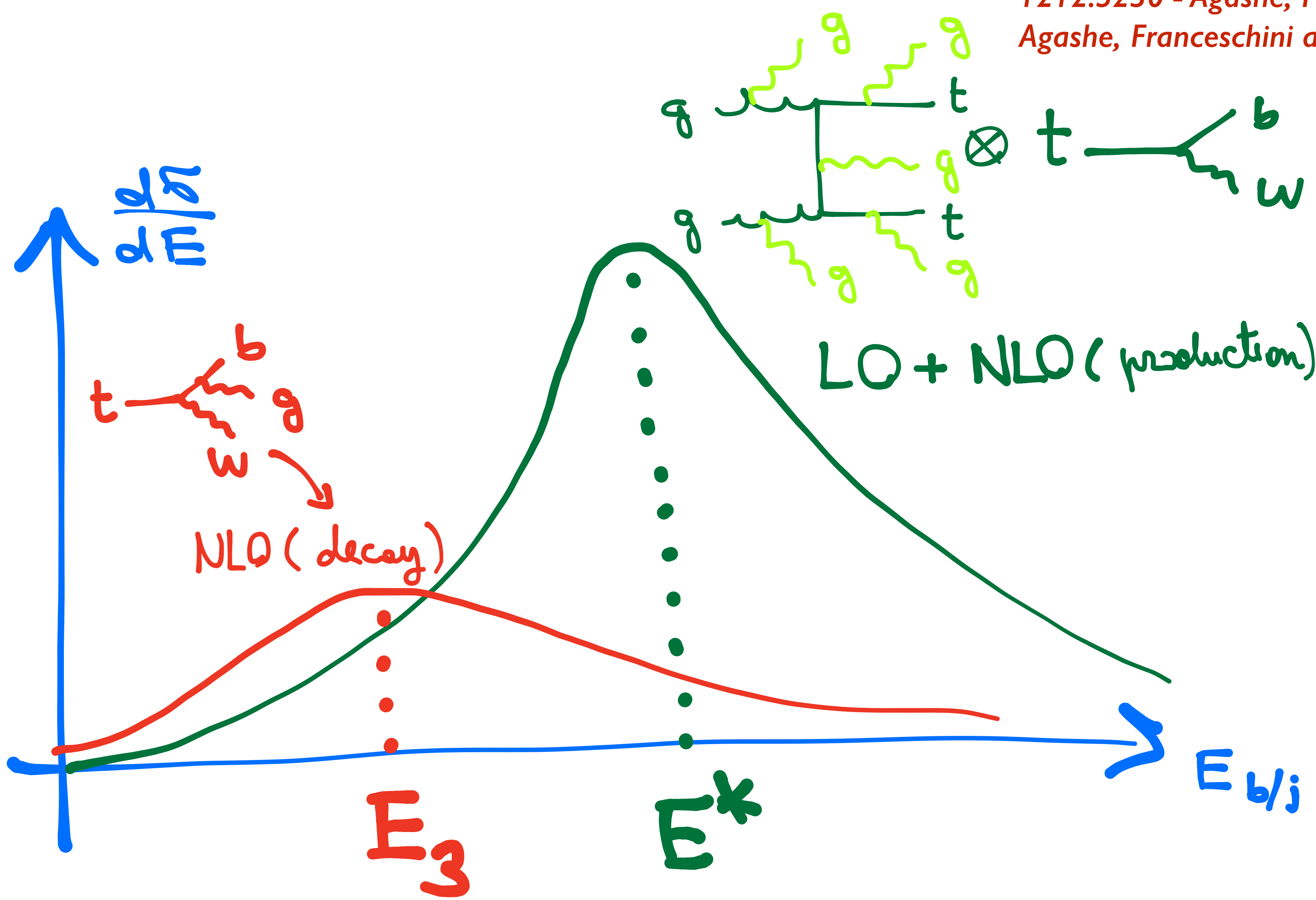


$$E^{peak} = E^{*}(1-\Delta_{TH}) + \Delta_{TH} E_3$$

Peak shift at NLO



1212.5230 - Agashe, Franceschini, Kim, Wardlow
Agashe, Franceschini and Kim - in preparation



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

Δ_{TH}=BR(t→bW**g**)/BR(t→bW)≃0.05

variations around Lorentz Invariance

needs two particles (combinations)

needs just one particle

LI | "pheno"-LI | non-LI

$p_b \cdot p_\ell$ | $\hat{E}_b$ | $p_{T\ell}$

radiation in decays breaks true-LI due to reconstruction

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

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

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

exclusiveness breaks pheno-LI

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

beyond JES …

L_{xy} method *hep-ex/0501043*

J/ψ method *hep-ph/9912320*

More Peaks *Agashe, RF, Kim - in progress*

B **hadron** observables

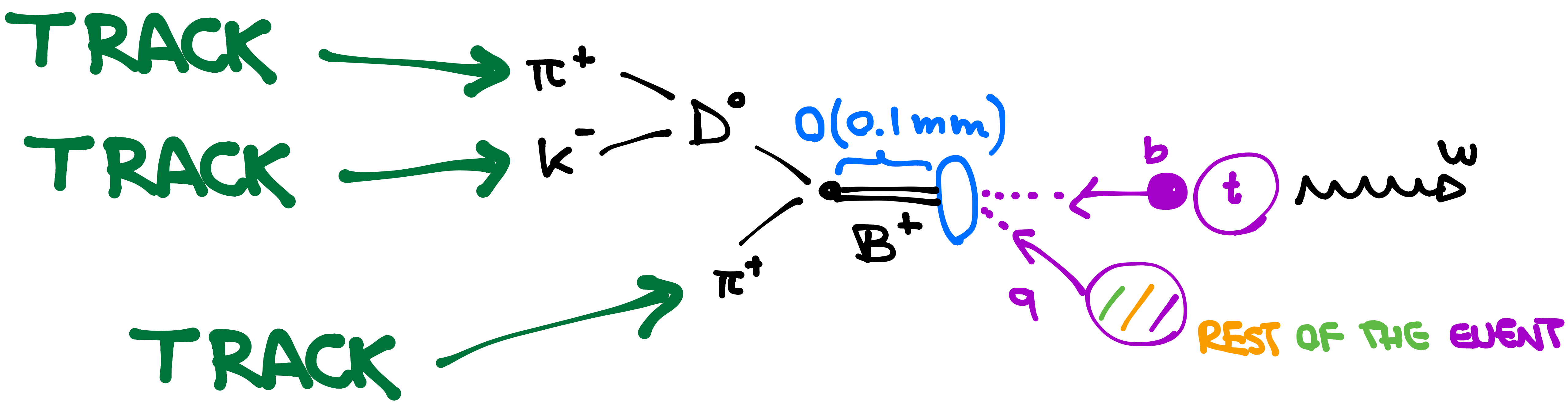
B physics in the top sample

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

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

B hadron
energy peak

get the hadron energy entirely from tracks



$B^+ \rightarrow$ 3 TRACKS

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

$$B^0 \underset{3\cdot10^{-3}}{\longrightarrow} D^-\pi^+ \underset{10^{-2}}{\longrightarrow} K_S^0\pi^-\,\pi^+$$

$$B^0 \underset{3\cdot10^{-3}}{\longrightarrow} D^-\pi^+ \underset{10^{-2}}{\longrightarrow} K^-\pi^+\pi^-\,\pi^+$$

$$B^0 \underset{3\cdot10^{-3}}{\longrightarrow} D^-\pi^+ \underset{3\cdot10^{-2}}{\longrightarrow} K_S^0\pi^+\pi^-\,\pi^+$$

$$B^- \underset{5\cdot10^{-3}}{\longrightarrow} D^0\pi^- \underset{4\cdot10^{-2}}{\longrightarrow} K^-\pi^+\,\pi^-$$

$$B^- \underset{5\cdot10^{-3}}{\longrightarrow} D^0\pi^- \underset{2\cdot10^{-2}}{\longrightarrow} K^{*,-}(892)\pi^+\,\pi^- \to K_S^0\pi^-\,\pi^+\,\pi^-$$

$$B^- \underset{5\cdot10^{-3}}{\longrightarrow} D^0\pi^- \underset{6\cdot10^{-3}}{\longrightarrow} K_S^0\rho^0\,\pi^-$$

$$B^- \underset{5\cdot10^{-3}}{\longrightarrow} D^0\pi^- \underset{5\cdot10^{-3}}{\longrightarrow} K^-\pi^+\rho^0\,\pi^-$$

B <u>hadron</u>
γ boost factor

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

hadron energy peak ⟶ hadron boost peak

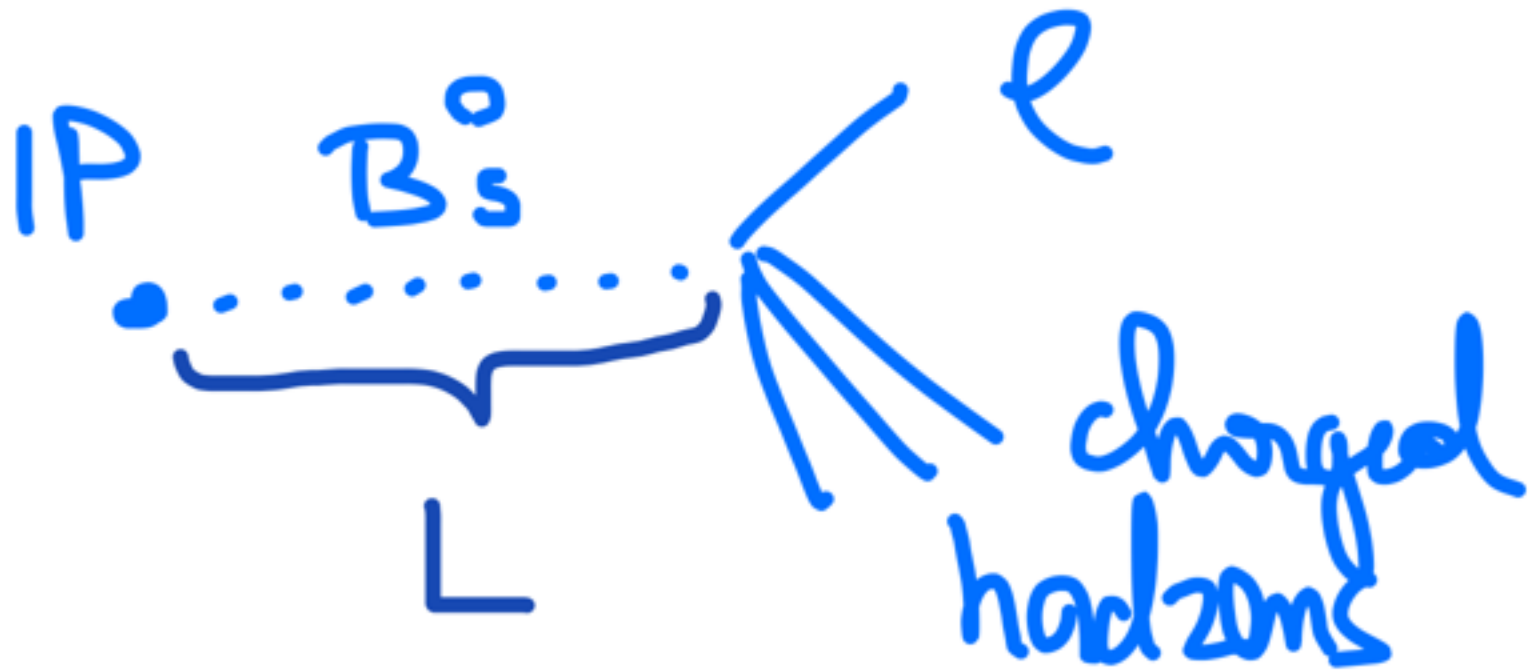
Does the **ratio** $\gamma = E/m$ help to get rid of exp. uncertainties?

3D decay length

discussion with J. Incandela

Time of decays is harder to measure than the position

Experiments measure decay length L



Jet Energy Scale does not affect λ, nor L

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 β=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)

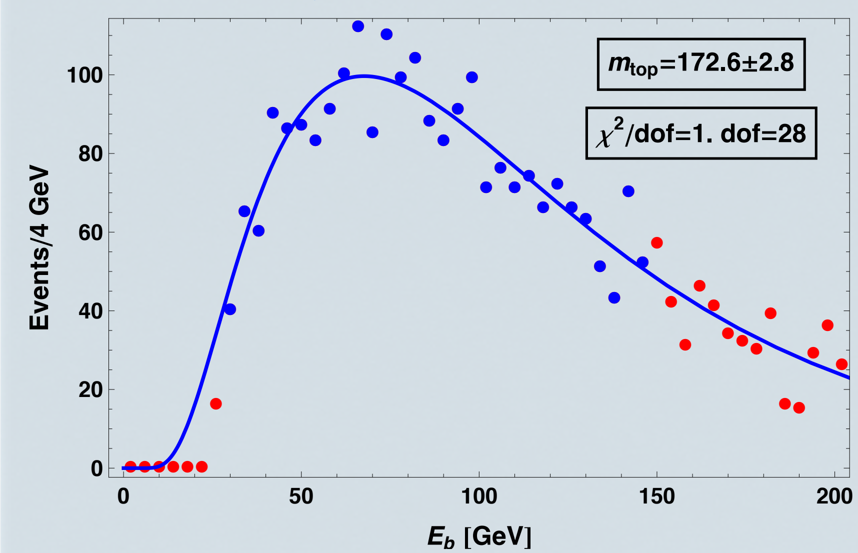
$$\frac{d\sigma}{dE_b} \propto \frac{d\sigma}{d\gamma_b} \propto \frac{d\sigma}{d\lambda}$$

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)

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

Summary

- 0.5% ⇒ precision QCD
- combination of methods ⇒ testing different assumptions
- set a baseline for estimate of uncertainties
- to reconstruct or not?
- Templates for ℓeptonic Mellin's moments
- theory systematics in the template method
- pheno-Lorentz invariance (Energy Peaks & Generalized Medians)
- Beyond JES

Back-up

Subtleties for *any template method*

1407.2763 - Frixione, S. and Mitov, A. - Determination of the top quark mass from leptonic observables

theory modeling: LO, NLO, LO+PS, NLO+PS (⊗ spin correlations)

effect of spin correlation

obs.	Δ_{PS}@NLO	bias@NLO	Δ_{PS}@LO	bias@LO
$p_{T\bar{\ell}}$	$+0.29^{+1.17}_{-1.14}$	$+0.41$	$-0.08^{+1.66}_{-1.96}$	-0.75
$p_{T\bar{\ell}+\ell}$	$-12.32^{+1.62}_{-2.13}$	-1.18	$-12.58^{+0.90}_{-0.94}$	$+1.60$
$M_{\bar{\ell}+\ell}$	$+9.45^{+2.36}_{-2.16}$	$+0.84$	$+8.00^{+3.74}_{-4.26}$	$+1.57$
$E_{\bar{\ell}}+E_{\ell}$	$+0.39^{+2.93}_{-3.16}$	$+0.16$	$-0.11^{+3.42}_{-4.16}$	-1.58
$p_{T\bar{\ell}}+p_{T\ell}$	$+0.22^{+1.12}_{-1.28}$	$+0.25$	$-0.06^{+1.65}_{-2.07}$	-0.73

impact of shower: use of factorized NNLO

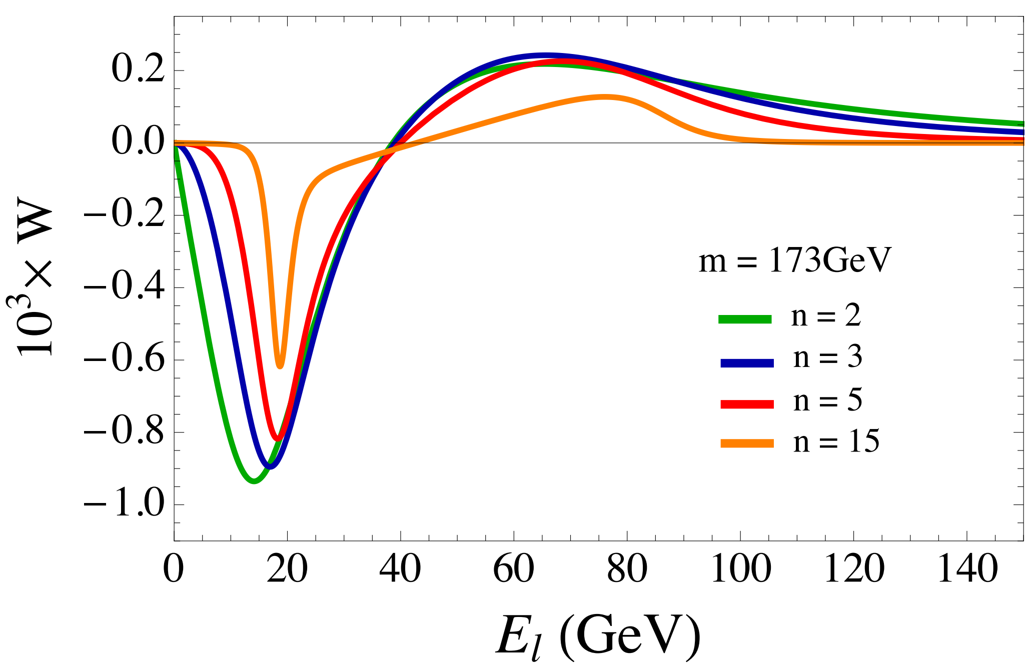
Generalized medians

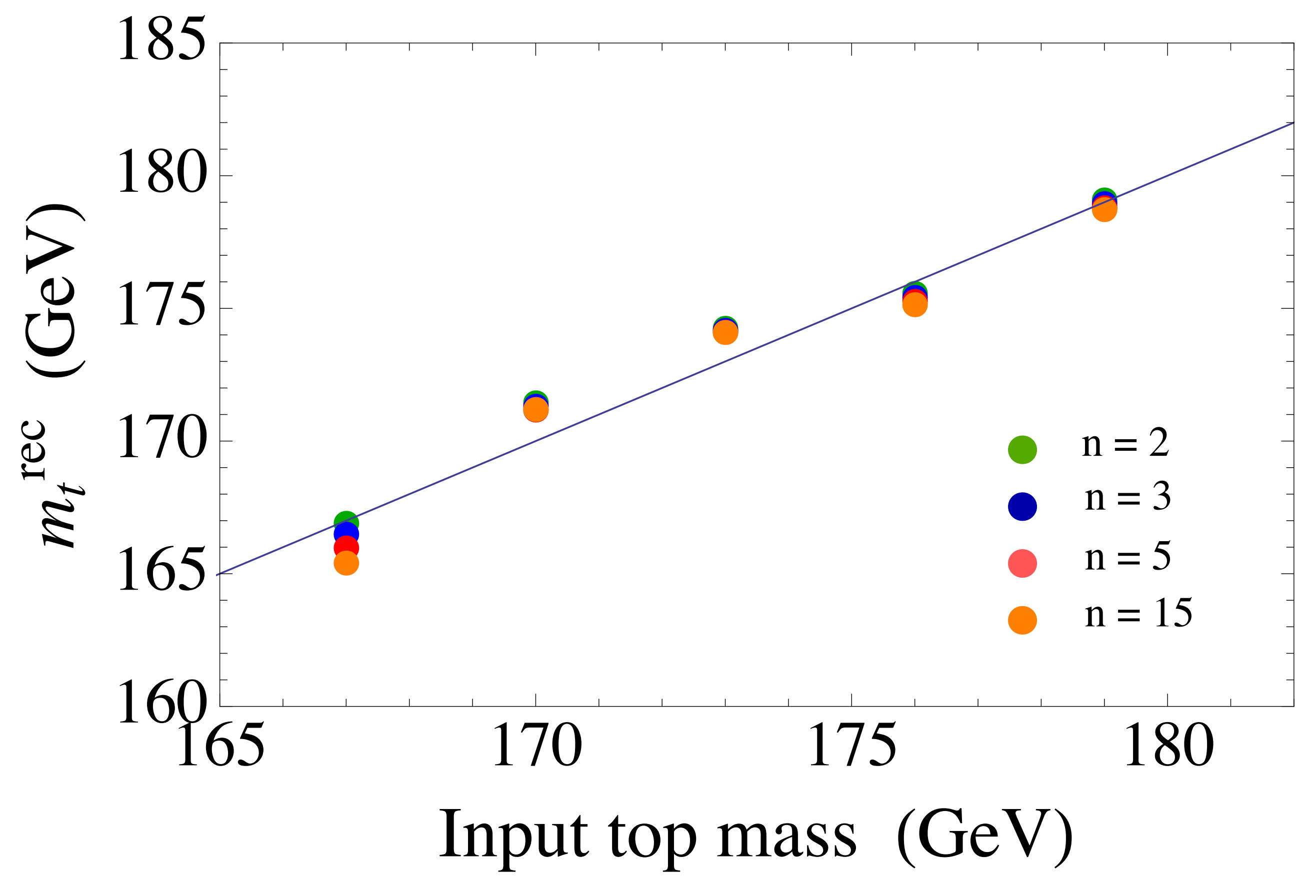
1405.2395

$$I(m)_w = \int dE_\ell \, \frac{d\Gamma}{dE_\ell} \cdot w(E_\ell, m)$$

<u>inclusive</u> integral over the lab-frame lepton Energy

$$\boxed{I(m = m_t)_w = 0}$$





Input top mass(GeV)	167	170	173	176	179
m_t^{rec}(GeV)	166.9	171.4	174.2	175.6	179.1

$\Delta_{TH} \sim 1 - \sigma_{exclusive}/\sigma_{inclusive} \sim 1 -$ efficiency ~ 0.2

BR(t→bW**g**)

mtop/resolvable gluon b->bg	163 GeV	173 GeV	183 GeV
pT>30 GeV dR>0.2	0.052	0.061	0.071
pT>30 GeV dR>0.4	0.037	0.043	0.050
pT>20 GeV dR>0.2	0.091	0.10	0.11
pT>20 GeV dR>0.4	0.066	0.074	0.082
δBR/BR m/δm	1.853		
δBR/BR dR/δdR	0.484		
δBR/BR pT/δpT	1.382		

Top mass combination

LHC/Tevatron NOTE

ATLAS-CONF-2014-008
CDF Note 11071
CMS PAS TOP-13-014
D0 Note 6416

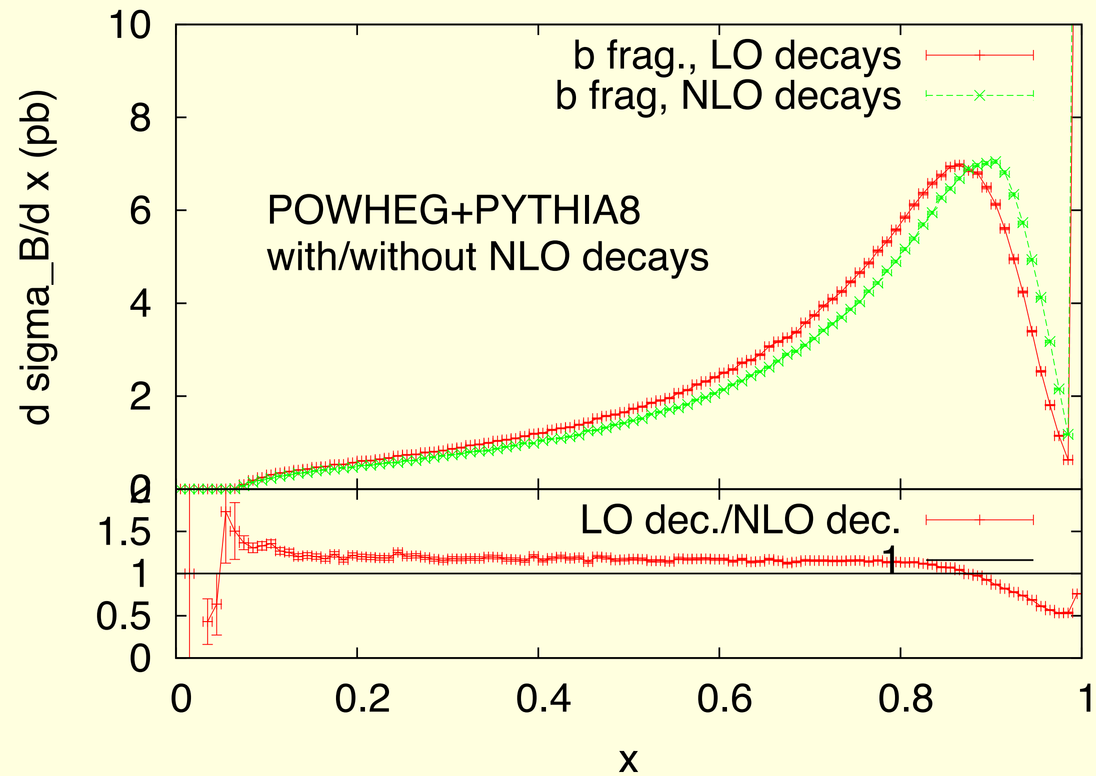
March 17, 2014

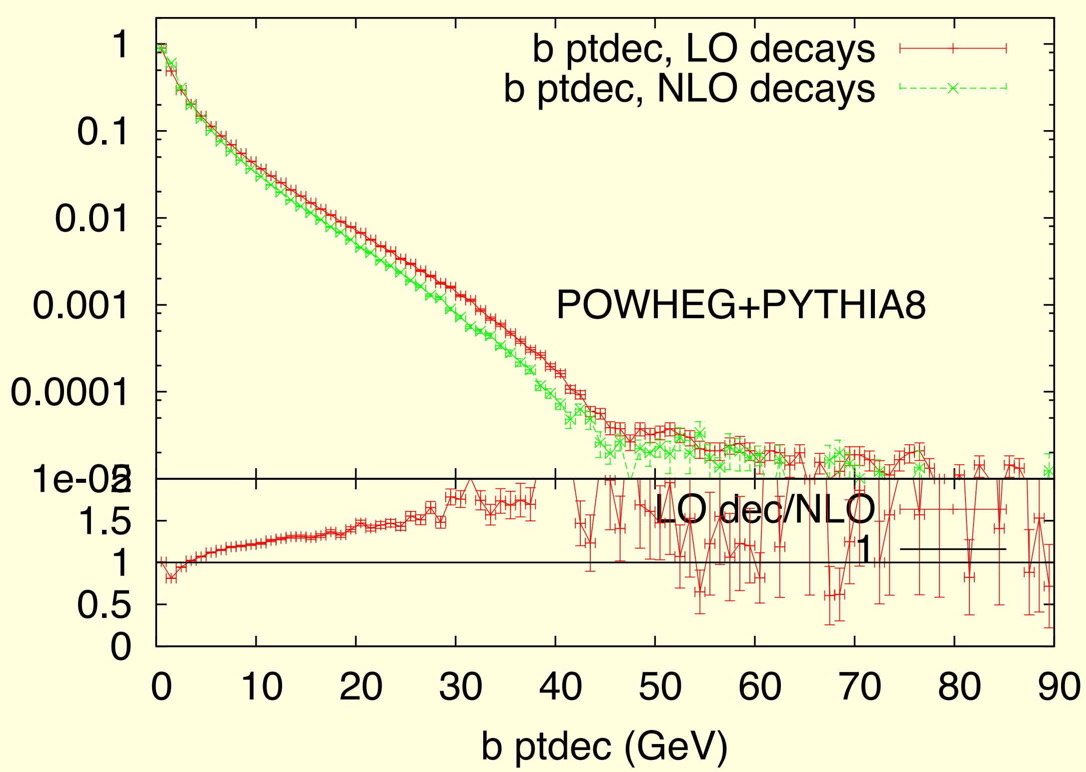
	Input measurements and uncertainties in GeV											
	CDF				D0		ATLAS		CMS			World
Uncertainty	l+jets	di-l	all jets	E_T^{miss}	l+jets	di-l	l+jets	di-l	l+jets	di-l	all jets	Combination
m_{top}	172.85	170.28	172.47	173.93	174.94	174.00	172.31	173.09	173.49	172.50	173.49	173.34
Stat	0.52	1.95	1.43	1.26	0.83	2.36	0.23	0.64	0.27	0.43	0.69	0.27
iJES	0.49	n.a.	0.95	1.05	0.47	0.55	0.72	n.a.	0.33	n.a.	n.a.	0.24
stdJES	0.53	2.99	0.45	0.44	0.63	0.56	0.70	0.89	0.24	0.78	0.78	0.20
flavourJES	0.09	0.14	0.03	0.10	0.26	0.40	0.36	0.02	0.11	0.58	0.58	0.12
bJES	0.16	0.33	0.15	0.17	0.07	0.20	0.08	0.71	0.61	0.76	0.49	0.25
MC	0.56	0.36	0.49	0.48	0.63	0.50	0.35	0.64	0.15	0.06	0.28	0.38
Rad	0.06	0.22	0.10	0.28	0.26	0.30	0.45	0.37	0.30	0.58	0.33	0.21
CR	0.21	0.51	0.32	0.28	0.28	0.55	0.32	0.29	0.54	0.13	0.15	0.31
PDF	0.08	0.31	0.19	0.16	0.21	0.30	0.17	0.12	0.07	0.09	0.06	0.09
DetMod	<0.01	<0.01	<0.01	<0.01	0.36	0.50	0.23	0.22	0.24	0.18	0.28	0.10
b-tag	0.03	n.e.	0.10	n.e.	0.10	<0.01	0.81	0.46	0.12	0.09	0.06	0.11
LepPt	0.03	0.27	n.a.	n.a.	0.18	0.35	0.04	0.12	0.02	0.14	n.a.	0.02
BGMC	0.12	0.24	n.a.	n.a.	0.18	n.a.	n.a.	0.14	0.13	0.05	n.a.	0.10
BGData	0.16	0.14	0.56	0.15	0.21	0.20	0.10	n.a.	n.a.	n.a.	0.13	0.07
Meth	0.05	0.12	0.38	0.21	0.16	0.51	0.13	0.07	0.06	0.40	0.13	0.05
MHI	0.07	0.23	0.08	0.18	0.05	<0.01	0.03	0.01	0.07	0.11	0.06	0.04
Total Syst	0.99	3.13	1.41	1.36	1.25	1.49	1.53	1.50	1.03	1.46	1.23	0.71
Total	1.12	3.69	2.01	1.85	1.50	2.79	1.55	1.63	1.06	1.52	1.41	0.76

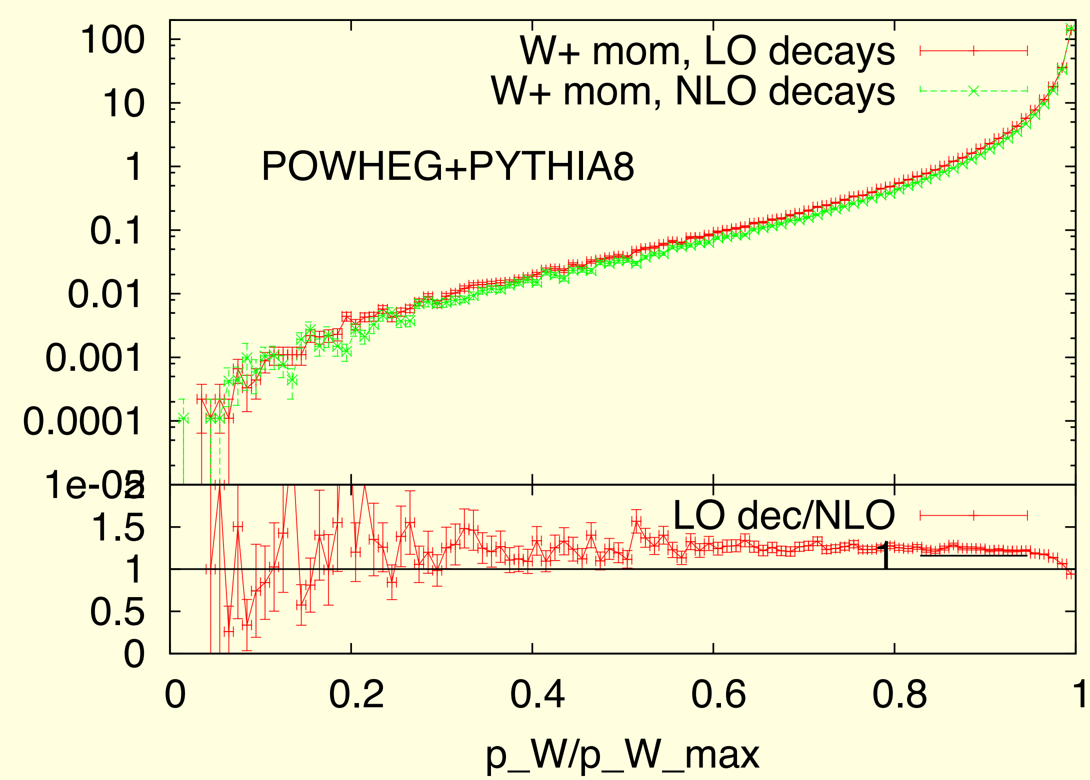
$t \to bW\mathbf{g}$

b fragmentation properties in t decays

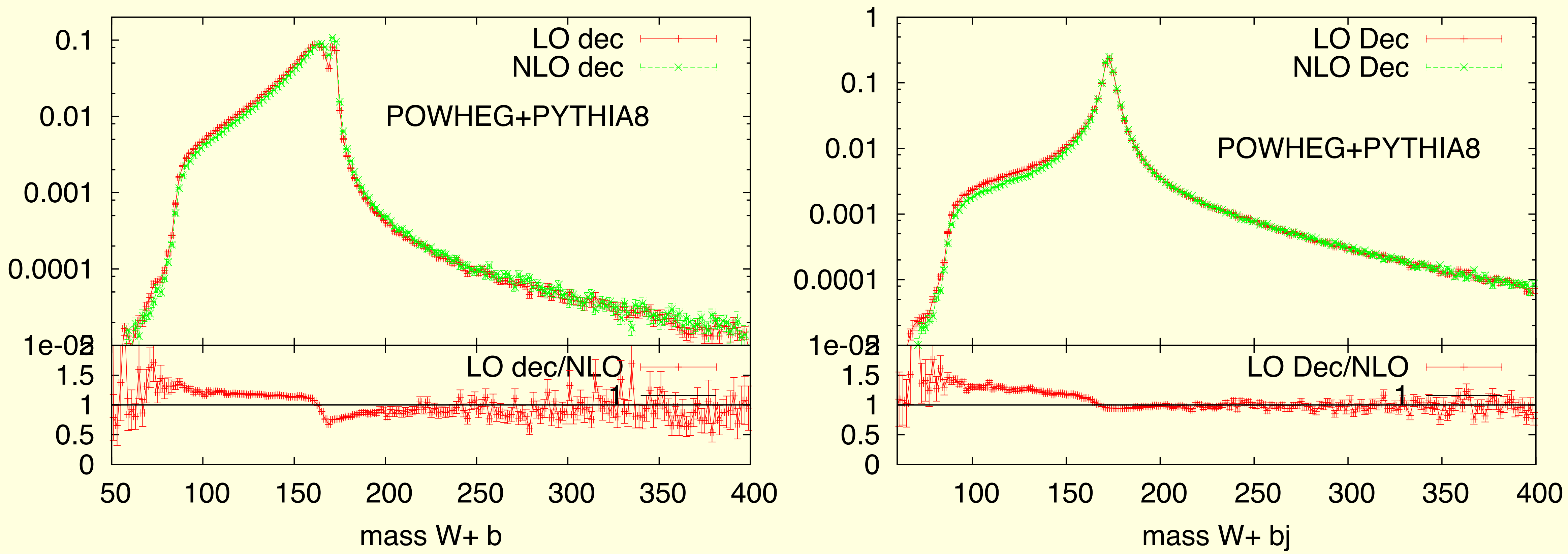
Observables computed in t rest frame.
b stands for hardest b flavoured hadron



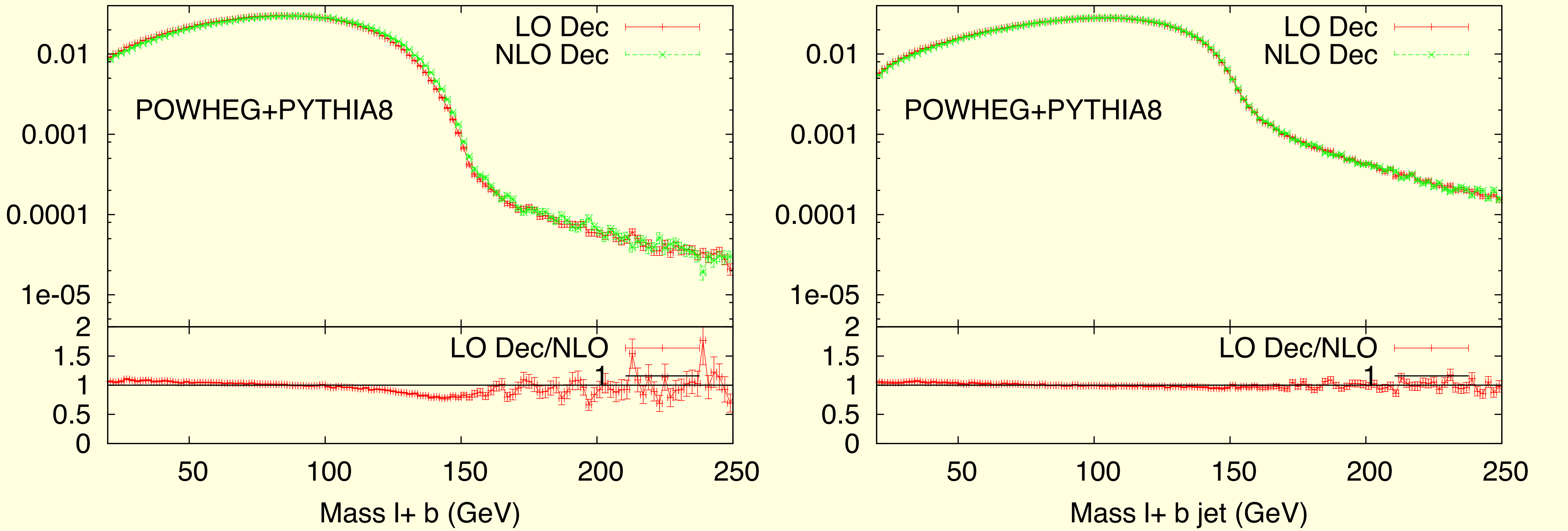




t mass pseudo observables



Notice small peak in $W^{+}b$ plot, due to $x=1$ peak in b fragmentation function.



Effect of different fragmentation behaviour shows up in M_{l+b}, but not in $M_{l+b\,\mathrm{jet}}$.