Precision And New Physics After LHC Run2

ROBERTO FRANCESCHINI

PLANCK 2017, WARSAW, MAY 25TH 2017

ROMA TRE
UNIVERSITÀ DEGLI STUDI

Rita
Levi
Montalcini

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: Moriond 2014

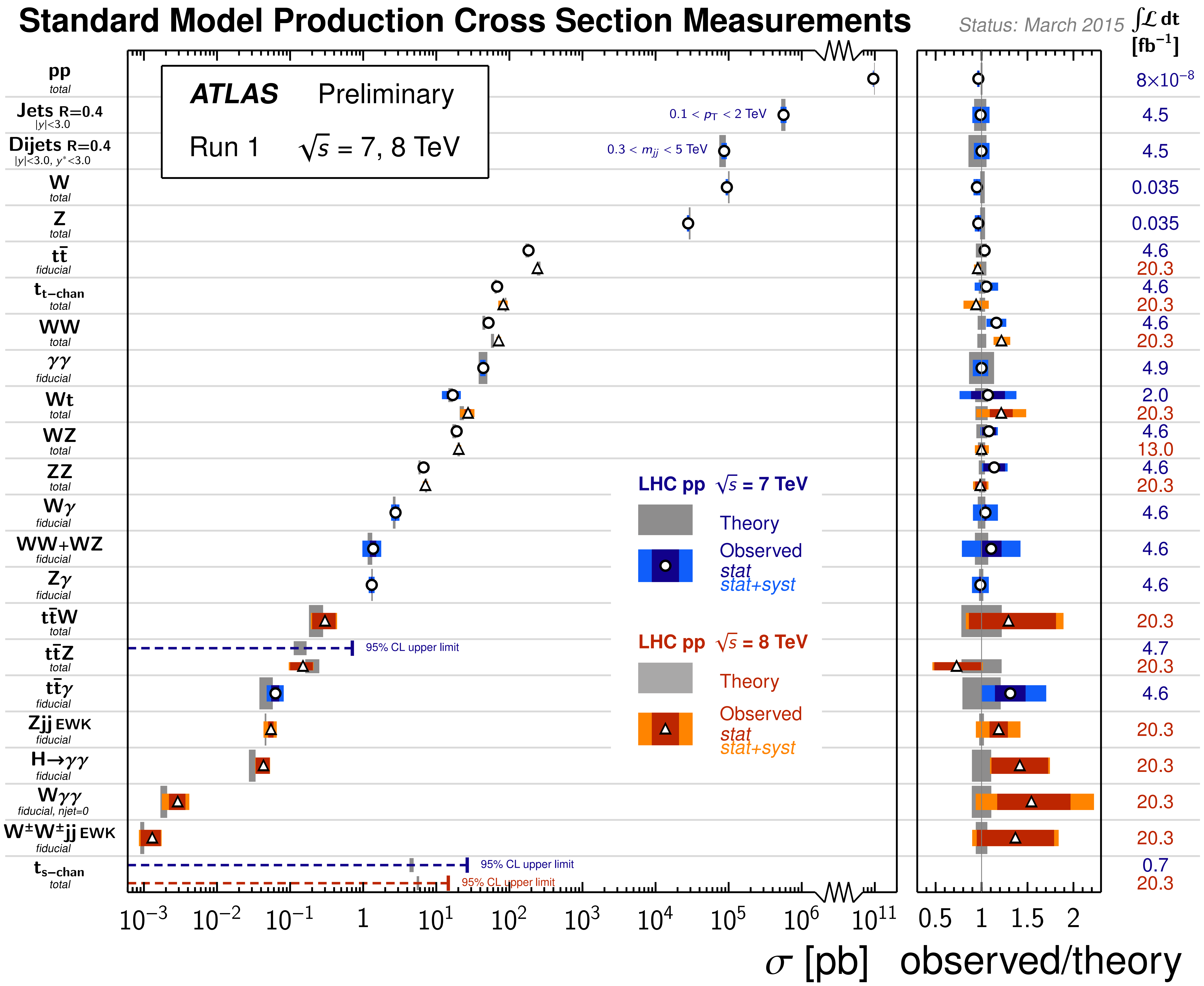
ATLAS Preliminary

$\int \mathcal{L}\,dt = (4.6 - 22.9)\ \mathrm{fb}^{-1}$ $\sqrt{s}$ = 7, 8 TeV

	Model	e,μ,τ,γ	Jets	E_T^{miss}	$\int \mathcal{L}\,dt[\mathrm{fb}^{-1}]$	Mass limit			Reference
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$\tilde{q},\tilde{g}$	1.7 TeV	m($\tilde{q}$)=m($\tilde{g}$)	ATLAS-CONF-2013-047
	MSUGRA/CMSSM	1 e,μ	3-6 jets	Yes	20.3	$\tilde{g}$	1.2 TeV	any m($\tilde{q}$)	ATLAS-CONF-2013-062
	MSUGRA/CMSSM	0	7-10 jets	Yes	20.3	$\tilde{g}$	1.1 TeV	any m($\tilde{q}$)	1308.1841
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$	740 GeV	m($\tilde{\chi}_1^0$)=0 GeV	ATLAS-CONF-2013-047
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$	1.3 TeV	m($\tilde{\chi}_1^0$)=0 GeV	ATLAS-CONF-2013-047
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}_1^\pm\to qqW^\pm\tilde{\chi}_1^0$	1 e,μ	3-6 jets	Yes	20.3	$\tilde{g}$	1.18 TeV	m($\tilde{\chi}_1^0$)<200 GeV, m($\tilde{\chi}^\pm$)=0.5(m($\tilde{\chi}_1^0$)+m($\tilde{g}$))	ATLAS-CONF-2013-062
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 e,μ	0-3 jets	-	20.3	$\tilde{g}$	1.12 TeV	m($\tilde{\chi}_1^0$)=0 GeV	ATLAS-CONF-2013-089
	GMSB ($\tilde{\ell}$ NLSP)	2 e,μ	2-4 jets	Yes	4.7	$\tilde{g}$	1.24 TeV	tanβ<15	1208.4688
	GMSB ($\tilde{\tau}$ NLSP)	1-2 τ	0-2 jets	Yes	20.7	$\tilde{g}$	1.4 TeV	tanβ >18	ATLAS-CONF-2013-026
	GGM (bino NLSP)	2 γ	-	Yes	20.3	$\tilde{g}$	1.28 TeV	m($\tilde{\chi}_1^0$)>50 GeV	ATLAS-CONF-2014-001
	GGM (wino NLSP)	1 $e,\mu+\gamma$	-	Yes	4.8	$\tilde{g}$	619 GeV	m($\tilde{\chi}_1^0$)>50 GeV	ATLAS-CONF-2012-144
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	4.8	$\tilde{g}$	900 GeV	m($\tilde{\chi}_1^0$)>220 GeV	1211.1167
	GGM (higgsino NLSP)	2 e,μ (Z)	0-3 jets	Yes	5.8	$\tilde{g}$	690 GeV	m($\tilde{H}$)>200 GeV	ATLAS-CONF-2012-152
	Gravitino LSP	0	mono-jet	Yes	10.5	$F^{1/2}$ scale	645 GeV	m($\tilde{G}$)>10^{-4} eV	ATLAS-CONF-2012-147
3^{rd} gen. $\tilde{g}$ med.	$\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	20.1	$\tilde{g}$	1.2 TeV	m($\tilde{\chi}_1^0$)<600 GeV	ATLAS-CONF-2013-061
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$	1.1 TeV	m($\tilde{\chi}_1^0$) <350 GeV	1308.1841
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$	1.34 TeV	m($\tilde{\chi}_1^0$)<400 GeV	ATLAS-CONF-2013-061
	$\tilde{g}\to b\bar{t}\tilde{\chi}_1^+$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$	1.3 TeV	m($\tilde{\chi}_1^0$)<300 GeV	ATLAS-CONF-2013-061
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{b}_1$	100-620 GeV	m($\tilde{\chi}_1^0$)<90 GeV	1308.2631
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to t\tilde{\chi}_1^\pm$	2 e,μ (SS)	0-3 b	Yes	20.7	$\tilde{b}_1$	275-430 GeV	m($\tilde{\chi}_1^\pm$)=2 m($\tilde{\chi}_1^0$)	ATLAS-CONF-2013-007
	$\tilde{t}_1\tilde{t}_1$(light), $\tilde{t}_1\to b\tilde{\chi}_1^\pm$	1-2 e,μ	1-2 b	Yes	4.7	$\tilde{t}_1$	110-167 GeV	m($\tilde{\chi}_1^0$)=55 GeV	1208.4305, 1209.2102
	$\tilde{t}_1\tilde{t}_1$(light), $\tilde{t}_1\to Wb\tilde{\chi}_1^0$	2 e,μ	0-2 jets	Yes	20.3	$\tilde{t}_1$	130-210 GeV	m($\tilde{\chi}_1^0$) =m($\tilde{t}_1$)-m(W)-50 GeV, m($\tilde{t}_1$)<<m($\tilde{\chi}_1^\pm$)	1403.4853
	$\tilde{t}_1\tilde{t}_1$(medium), $\tilde{t}_1\to t\tilde{\chi}_1^0$	2 e,μ	2 jets	Yes	20.3	$\tilde{t}_1$	215-530 GeV	m($\tilde{\chi}_1^0$)=1 GeV	1403.4853
	$\tilde{t}_1\tilde{t}_1$(medium), $\tilde{t}_1\to b\tilde{\chi}_1^\pm$	0	2 b	Yes	20.1	$\tilde{t}_1$	150-580 GeV	m($\tilde{\chi}_1^0$)<200 GeV, m($\tilde{\chi}_1^\pm$)-m($\tilde{\chi}_1^0$)=5 GeV	1308.2631
	$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$	1 e,μ	1 b	Yes	20.7	$\tilde{t}_1$	200-610 GeV	m($\tilde{\chi}_1^0$)=0 GeV	ATLAS-CONF-2013-037
	$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$	0	2 b	Yes	20.5	$\tilde{t}_1$	320-660 GeV	m($\tilde{\chi}_1^0$)=0 GeV	ATLAS-CONF-2013-024
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$	90-200 GeV	m($\tilde{t}_1$)-m($\tilde{\chi}_1^0$)<85 GeV	ATLAS-CONF-2013-068
	$\tilde{t}_1\tilde{t}_1$(natural GMSB)	2 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$	150-580 GeV	m($\tilde{\chi}_1^0$)>150 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+Z$	3 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_2$	290-600 GeV	m($\tilde{\chi}_1^0$)<200 GeV	1403.5222
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}$, $\tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e,μ	0	Yes	20.3	$\tilde{\ell}$	90-325 GeV	m($\tilde{\chi}_1^0$)=0 GeV	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e,μ	0	Yes	20.3	$\tilde{\chi}_1^\pm$	140-465 GeV	m($\tilde{\chi}_1^0$)=0 GeV, m($\tilde{\ell},\tilde{\nu}$)=0.5(m($\tilde{\chi}_1^\pm$)+m($\tilde{\chi}_1^0$))	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.7	$\tilde{\chi}_1^\pm$	180-330 GeV	m($\tilde{\chi}_1^0$)=0 GeV, m($\tilde{\tau},\tilde{\nu}$)=0.5(m($\tilde{\chi}_1^\pm$)+m($\tilde{\chi}_1^0$))	ATLAS-CONF-2013-028
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu)$, $\ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e,μ	0	Yes	20.3	$\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$	700 GeV	m($\tilde{\chi}_1^\pm$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, m($\tilde{\ell},\tilde{\nu}$)=0.5(m($\tilde{\chi}_1^\pm$)+m($\tilde{\chi}_1^0$))	1402.7029
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	2-3 e,μ	0	Yes	20.3	$\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$	420 GeV	m($\tilde{\chi}_1^\pm$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, sleptons decoupled	1403.5294, 1402.7029
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 h\tilde{\chi}_1^0$	1 e,μ	2 b	Yes	20.3	$\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$	285 GeV	m($\tilde{\chi}_1^\pm$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, sleptons decoupled	ATLAS-CONF-2013-093
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}_1^\pm$	270 GeV	m($\tilde{\chi}_1^\pm$)-m($\tilde{\chi}_1^0$)=160 MeV, τ($\tilde{\chi}_1^\pm$)=0.2 ns	ATLAS-CONF-2013-069
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	22.9	$\tilde{g}$	832 GeV	m($\tilde{\chi}_1^0$)=100 GeV, 10 μs<τ($\tilde{g}$)<1000 s	ATLAS-CONF-2013-057
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	15.9	$\tilde{\chi}_1^0$	475 GeV	10<tanβ<50	ATLAS-CONF-2013-058
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	4.7	$\tilde{\chi}_1^0$	230 GeV	0.4<τ($\tilde{\chi}_1^0$)<2 ns	1304.6310
	$\tilde{q}\tilde{q}$, $\tilde{\chi}_1^0\to qq\mu$ (RPV)	1 μ, displ. vtx	-	-	20.3	$\tilde{q}$	1.0 TeV	1.5 <$c\tau$<156 mm, BR(μ)=1, m($\tilde{\chi}_1^0$)=108 GeV	ATLAS-CONF-2013-092
RPV	LFV $pp\to\tilde{\nu}_\tau+X$, $\tilde{\nu}_\tau\to e+\mu$	2 e,μ	-	-	4.6	$\tilde{\nu}_\tau$	1.61 TeV	λ'_{311}=0.10, λ_{132}=0.05	1212.1272
	LFV $pp\to\tilde{\nu}_\tau+X$, $\tilde{\nu}_\tau\to e(\mu)+\tau$	1 $e,\mu+\tau$	-	-	4.6	$\tilde{\nu}_\tau$	1.1 TeV	λ'_{311}=0.10, $\lambda_{1(2)33}$=0.05	1212.1272
	Bilinear RPV CMSSM	1 e,μ	7 jets	Yes	4.7	$\tilde{q},\tilde{g}$	1.2 TeV	m($\tilde{q}$)=m($\tilde{g}$), $c\tau_{LSP}$<1 mm	ATLAS-CONF-2012-140
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e,μ	-	Yes	20.7	$\tilde{\chi}_1^\pm$	760 GeV	m($\tilde{\chi}_1^0$)>300 GeV, λ_{121}>0	ATLAS-CONF-2013-036
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 $e,\mu+\tau$	-	Yes	20.7	$\tilde{\chi}_1^\pm$	350 GeV	m($\tilde{\chi}_1^0$)>80 GeV, λ_{133}>0	ATLAS-CONF-2013-036
	$\tilde{g}\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$	916 GeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2013-091
	$\tilde{g}\to\tilde{t}_1 t$, $\tilde{t}_1\to bs$	2 e,μ (SS)	0-3 b	Yes	20.7	$\tilde{g}$	880 GeV		ATLAS-CONF-2013-007
Other	Scalar gluon pair, sgluon$\to q\bar{q}$	0	4 jets	-	4.6	sgluon	100-287 GeV	incl. limit from 1110.2693	1210.4826
	Scalar gluon pair, sgluon$\to t\bar{t}$	2 e,μ (SS)	2 b	Yes	14.3	sgluon	350-800 GeV		ATLAS-CONF-2013-051
	WIMP interaction (D5, Dirac χ)	0	mono-jet	Yes	10.5	M* scale	704 GeV	m(χ)<80 GeV, limit of<687 GeV for D8	ATLAS-CONF-2012-147

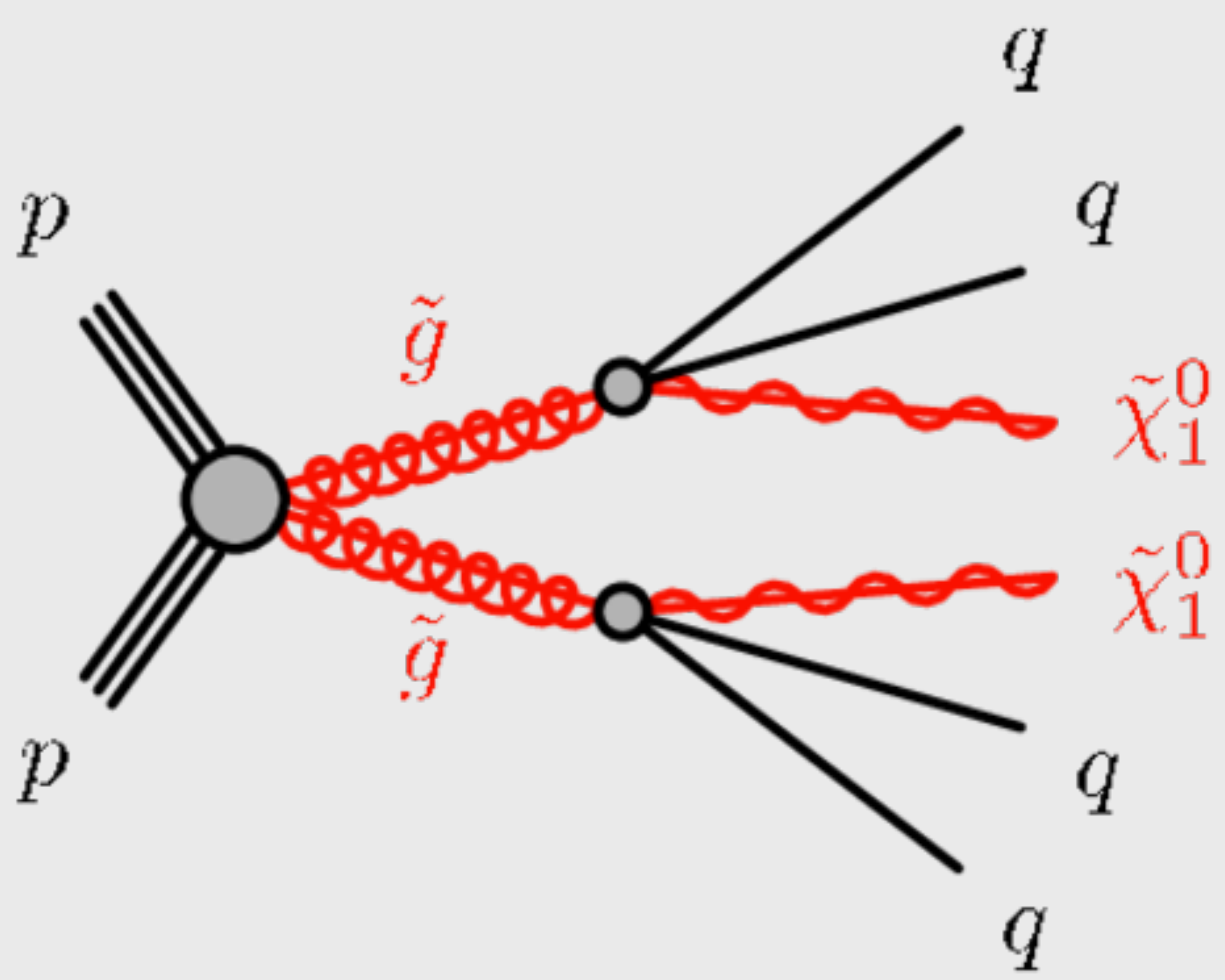
10^{-1} 1 **Mass scale [TeV]**

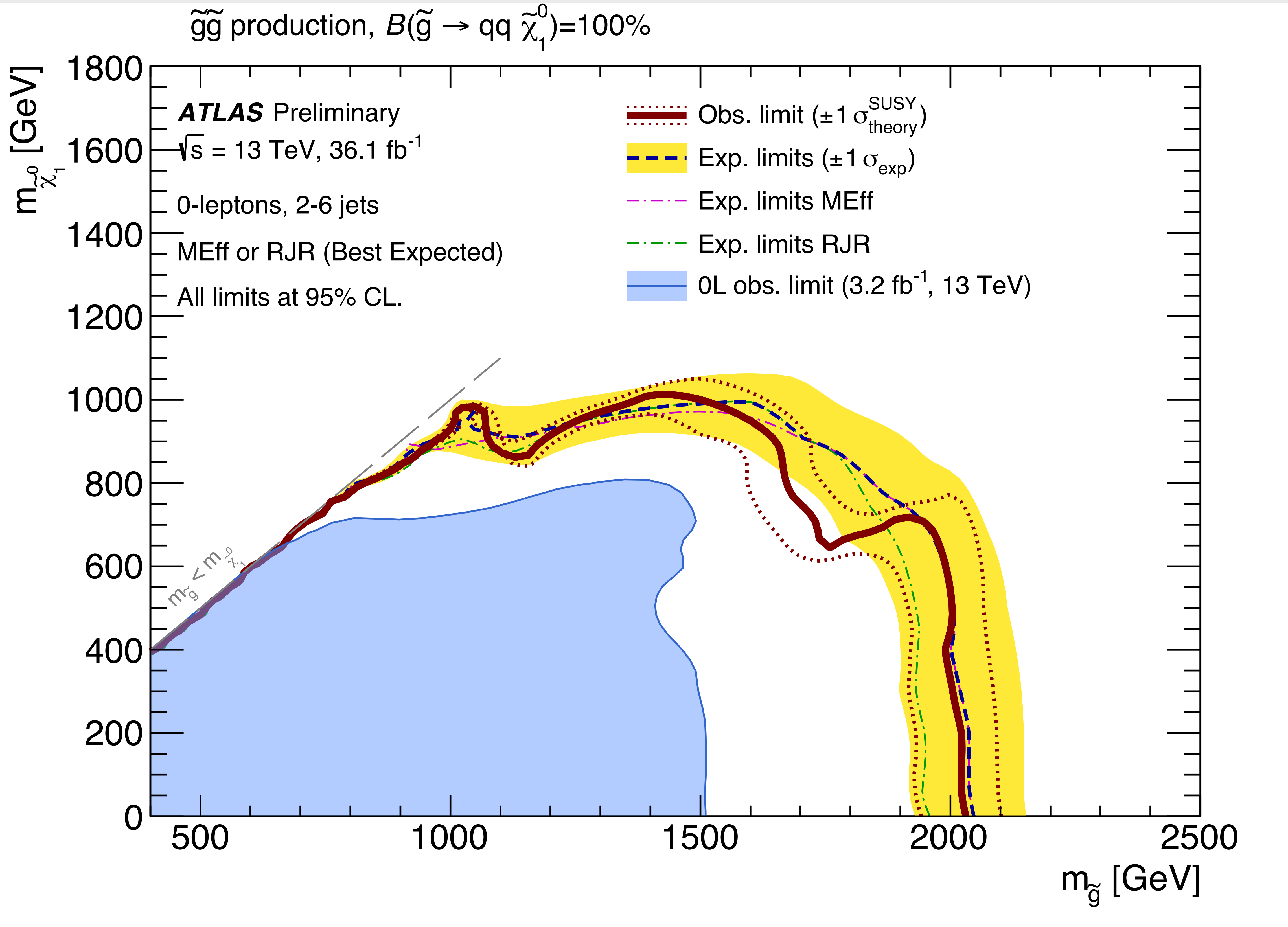
$\sqrt{s}$ = 7 TeV full data | $\sqrt{s}$ = 8 TeV partial data | $\sqrt{s}$ = 8 TeV full data


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
95% CL upper limit
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
σ [pb]
0.5 1 1.5 2
observed/theory

No Signals Of Susy

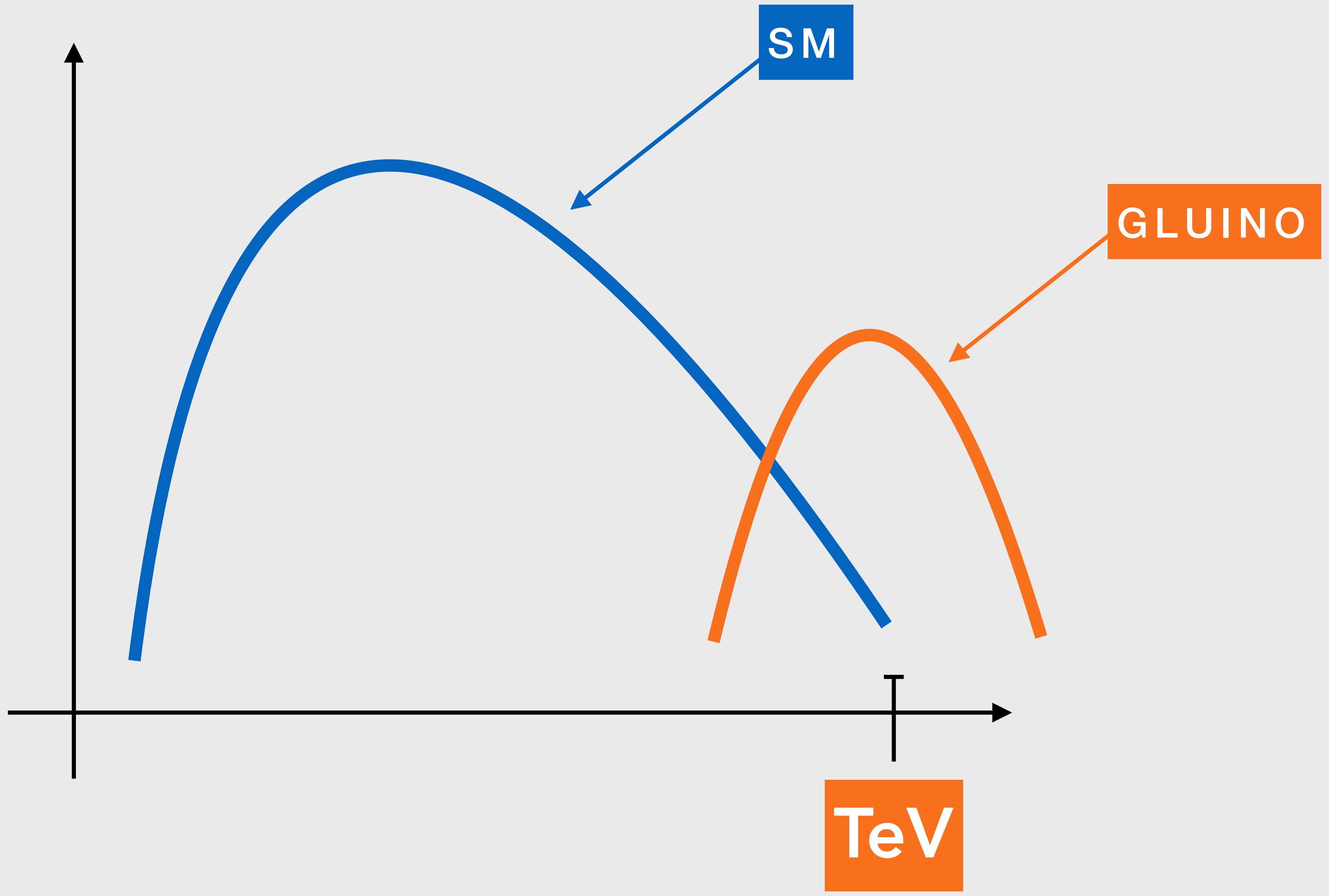
SEARCHES IN FINAL STATES : HARD LEPTONS+PHOTONS+JETS+MET

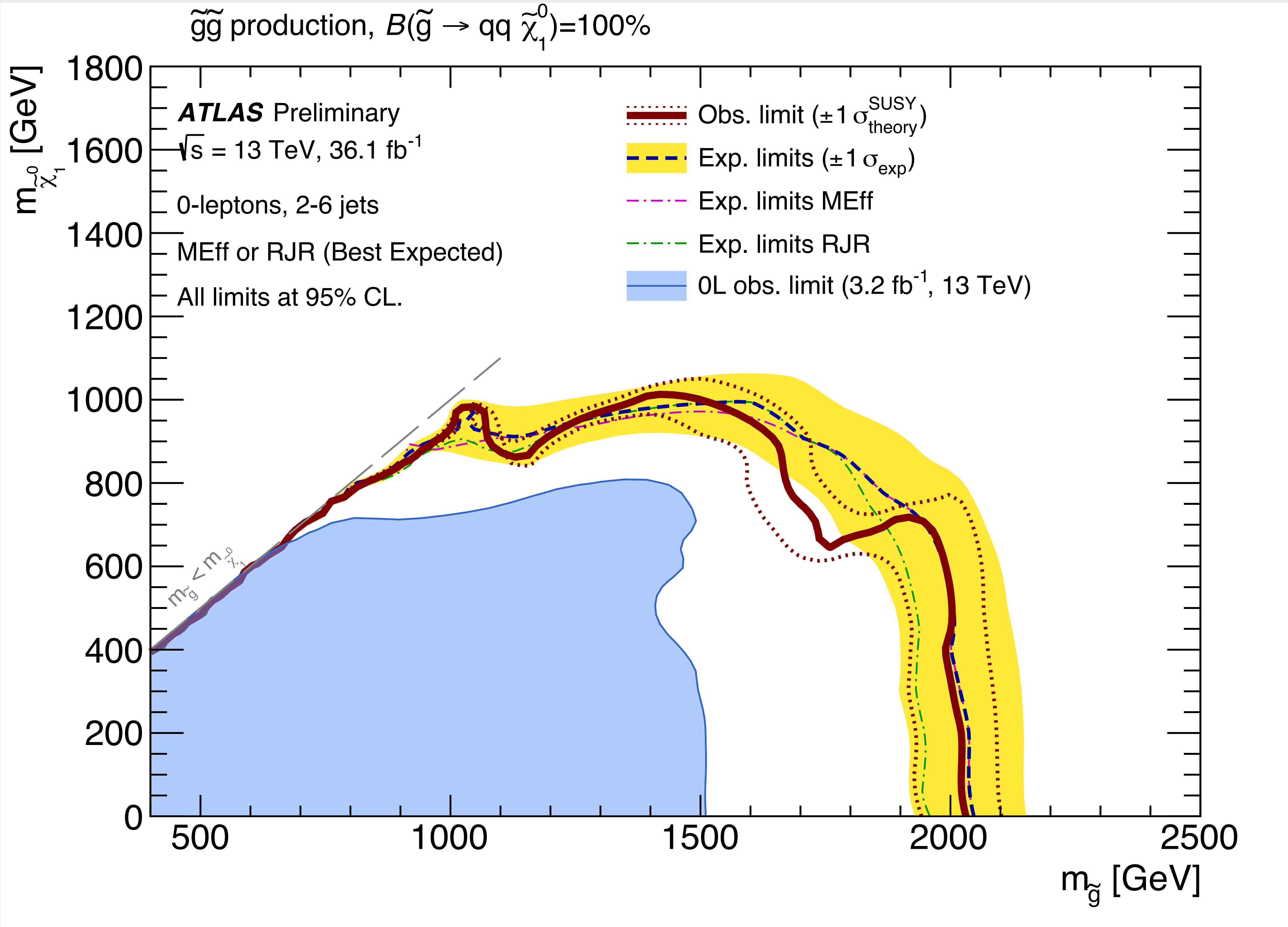




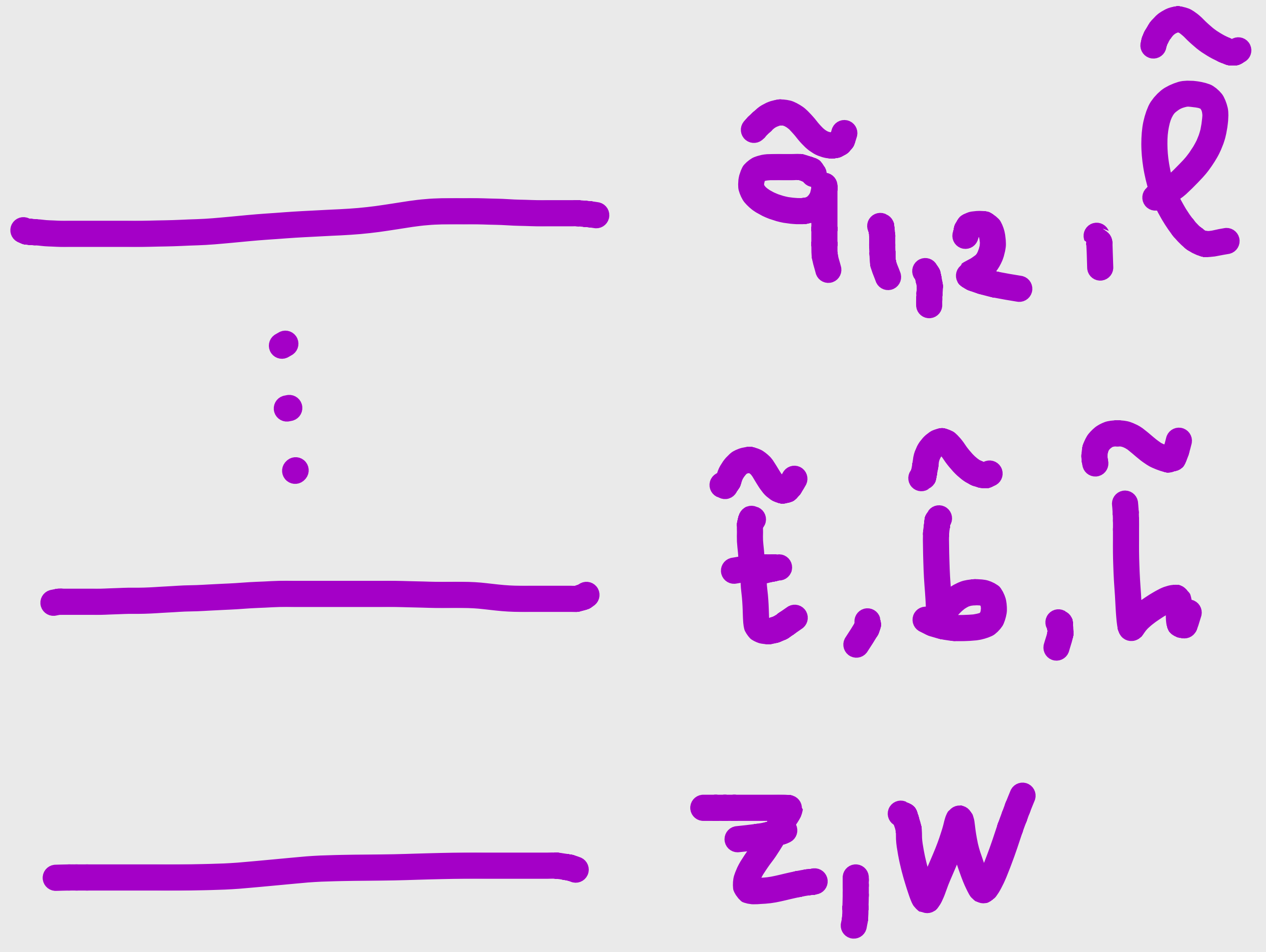
No Signals Of Susy

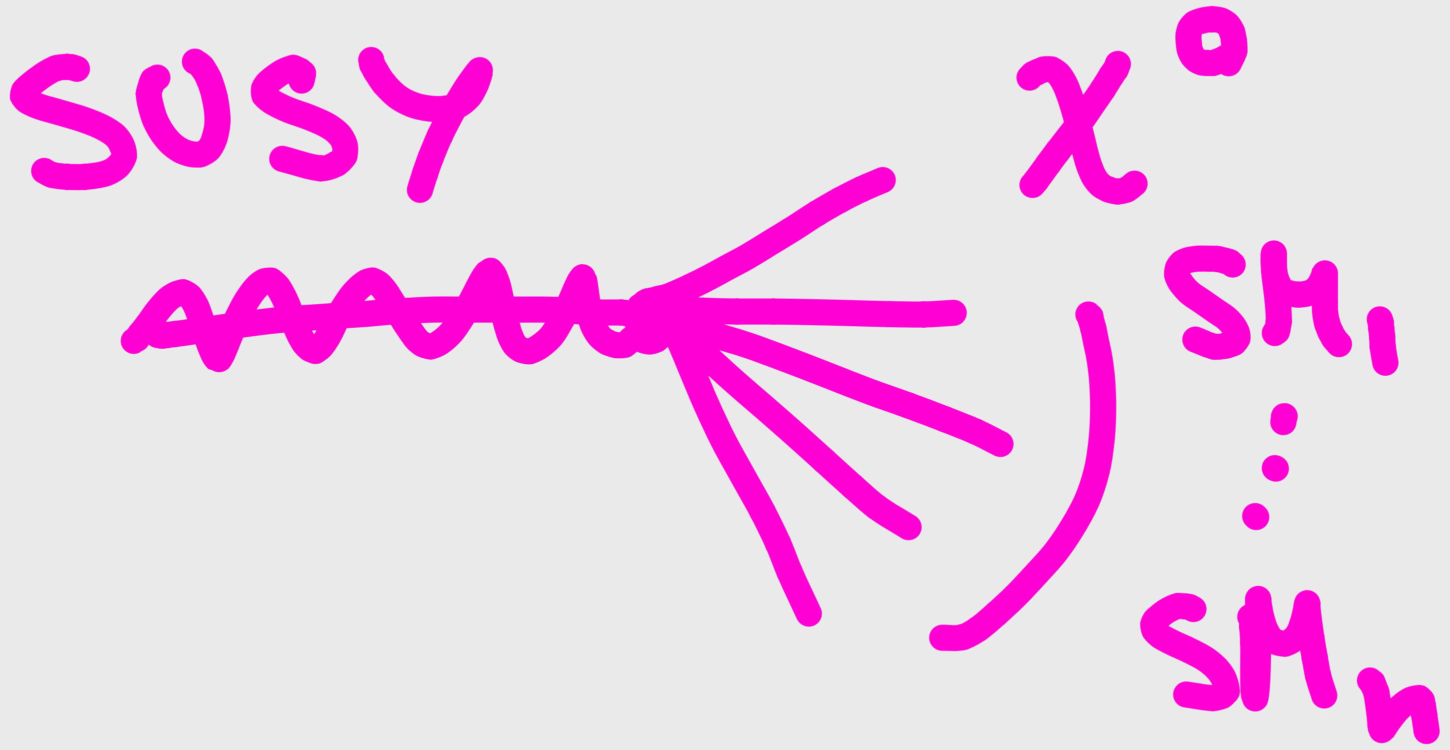
SEARCHES IN FINAL STATES : HARD LEPTONS+PHOTONS+JETS+MET

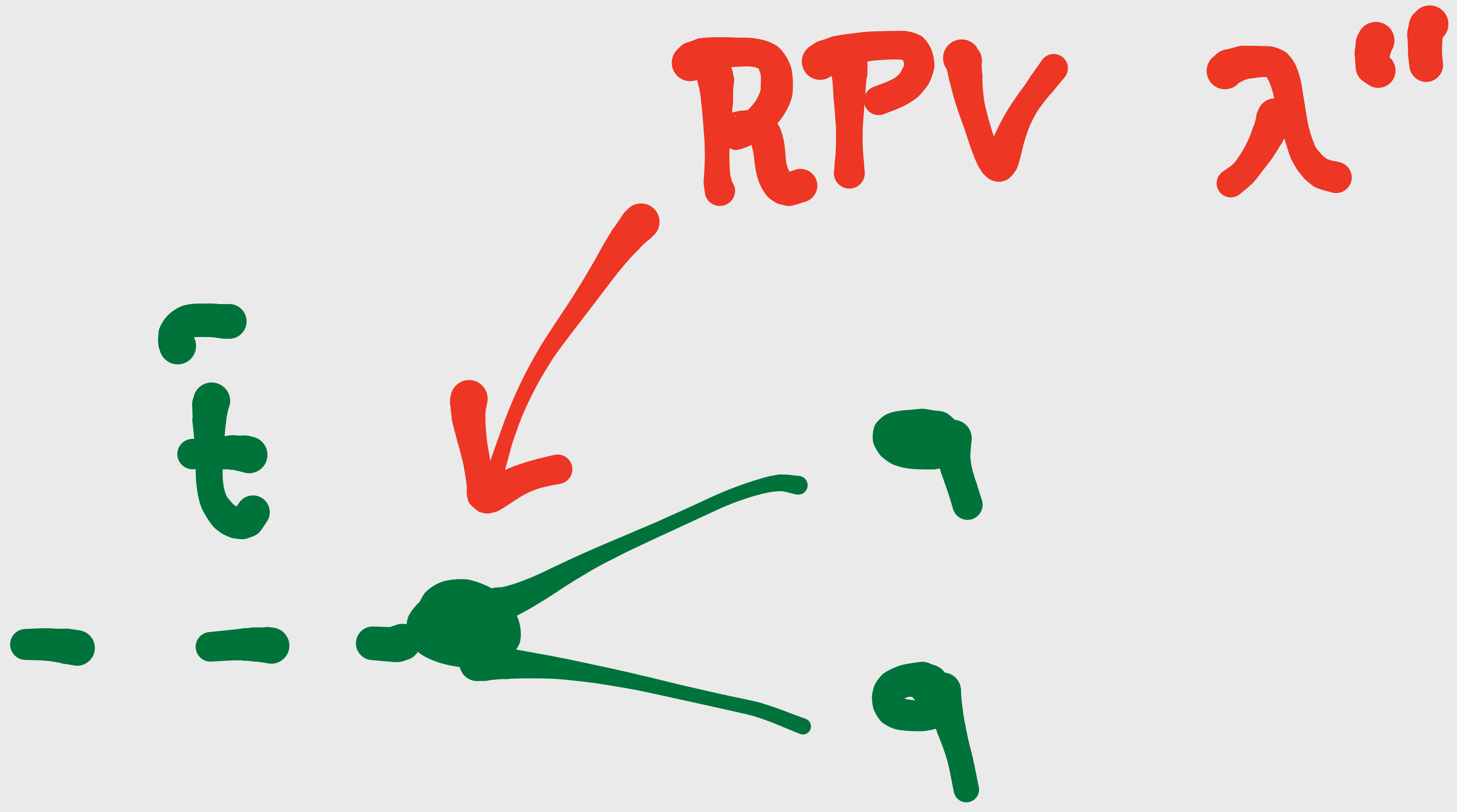




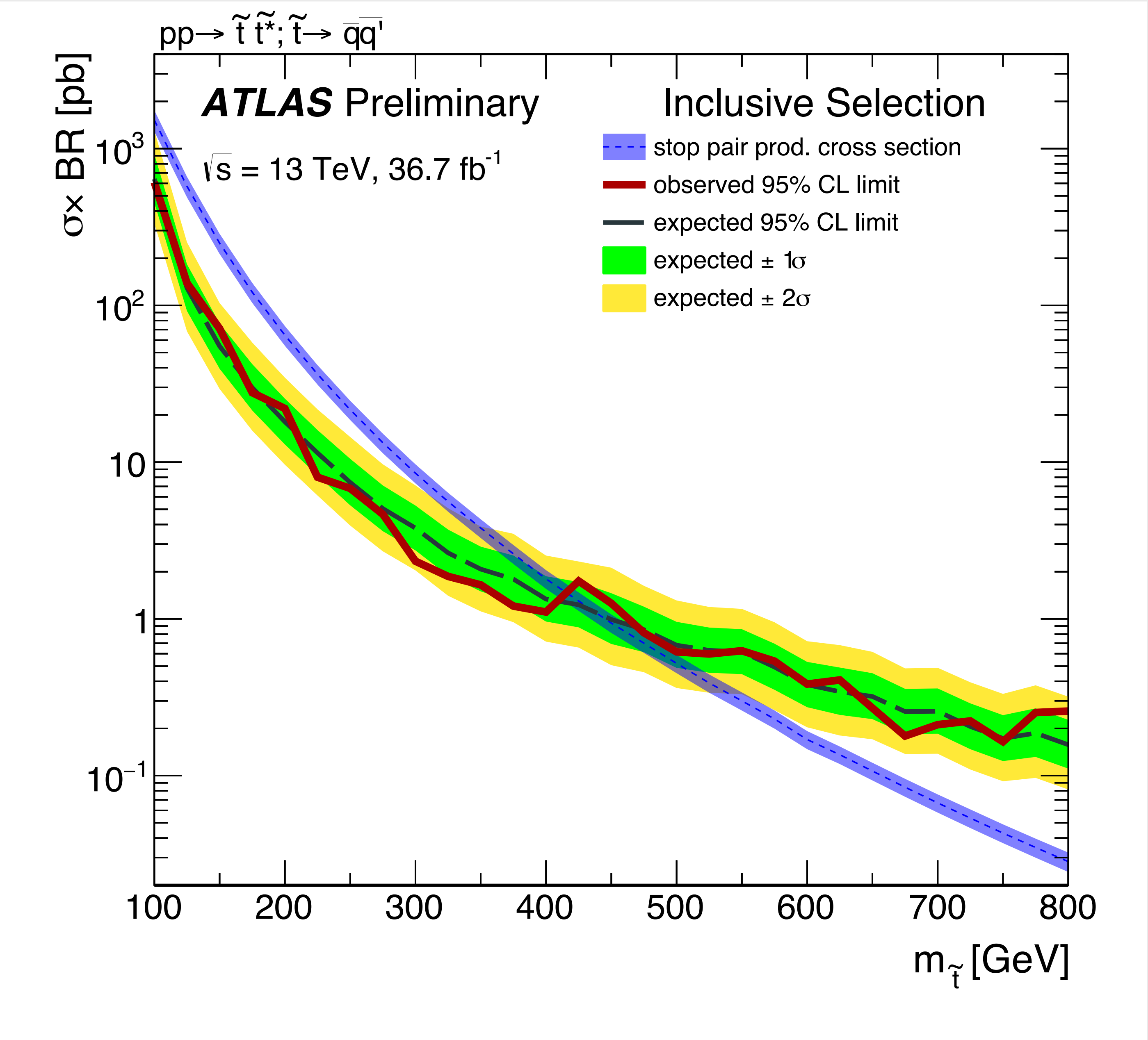
Theory Options (~Susy)

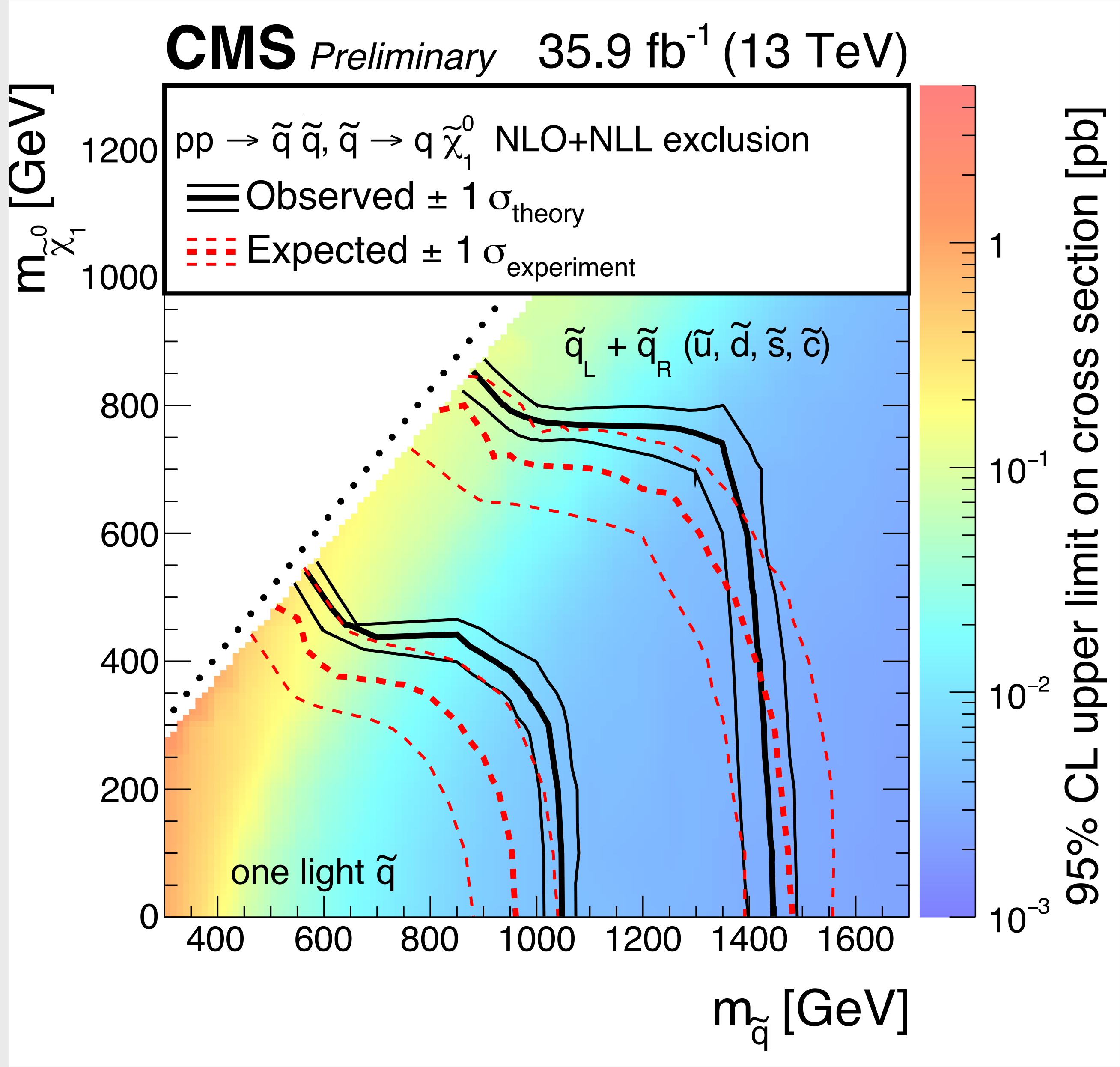


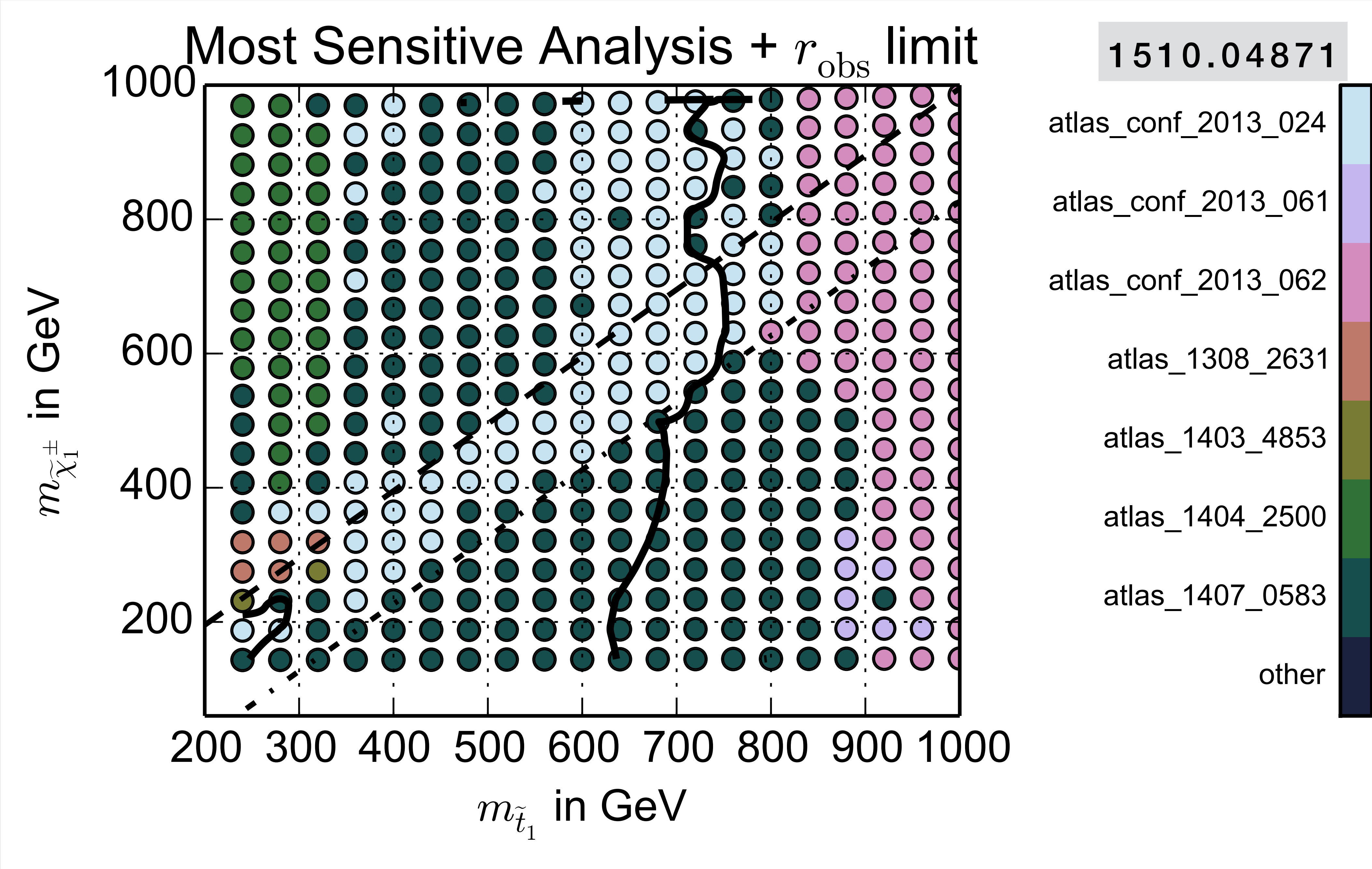




After Run2 ...

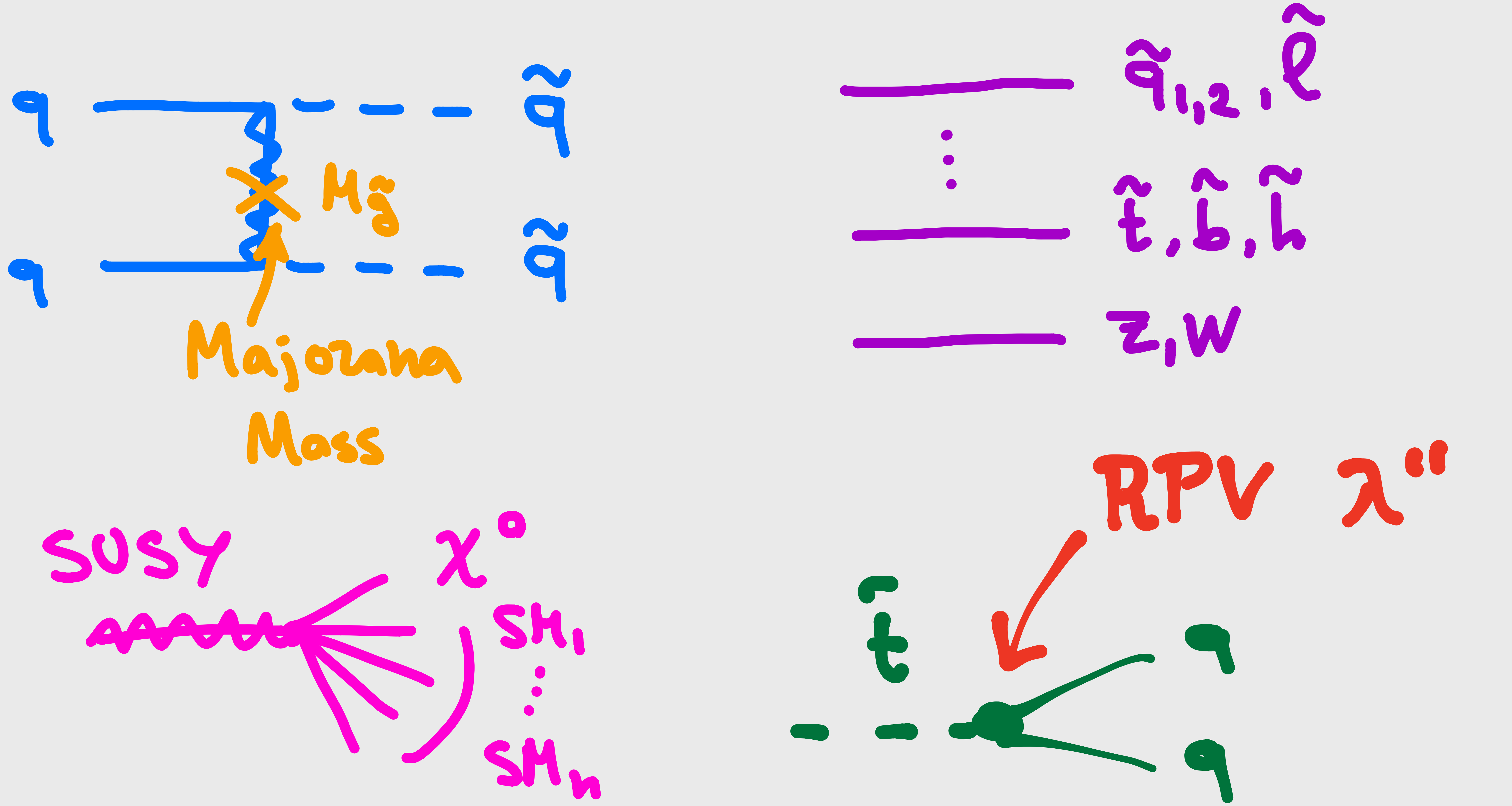






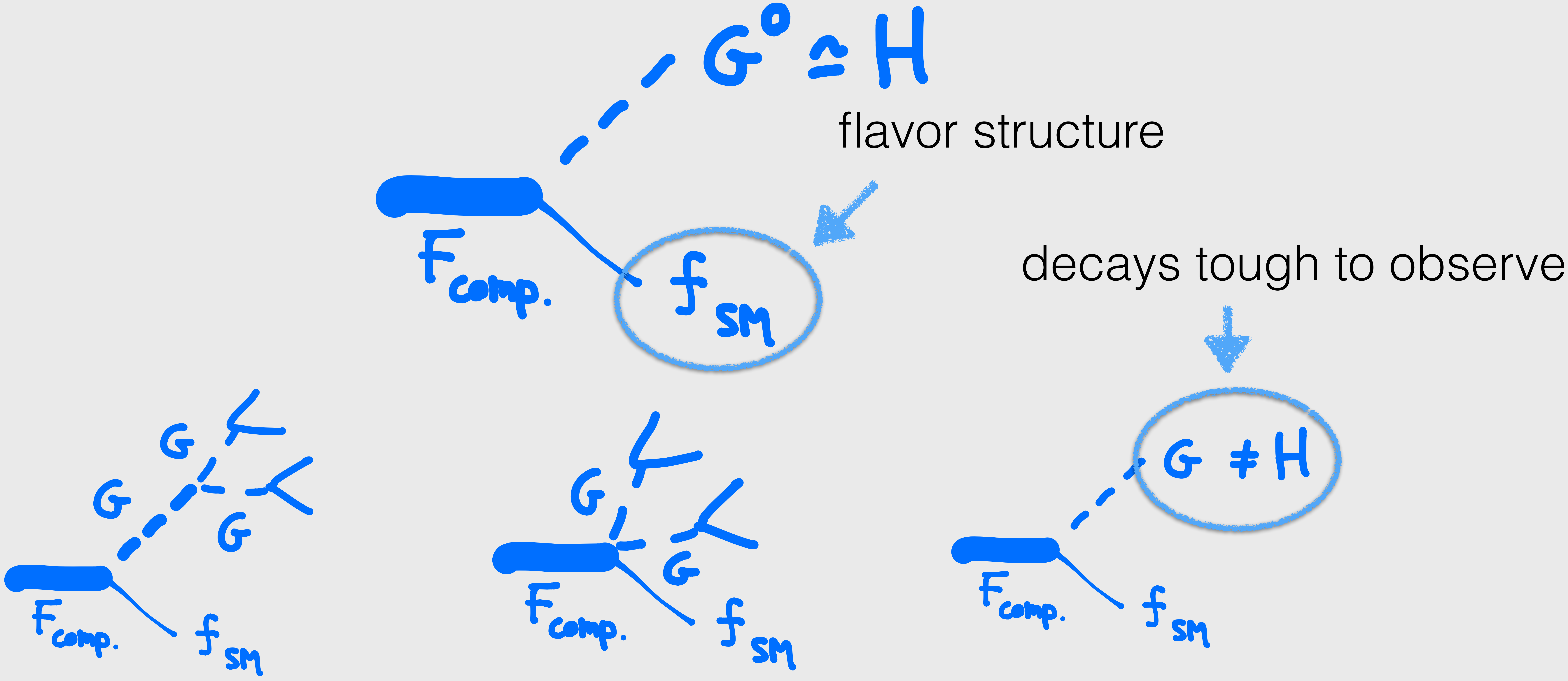
even in non-standard scenarios $m_{susy} > 500$ GeV

Theory Options (~Susy)



MORE SUBTLE SIGNALS ⇒ **PRECISION**

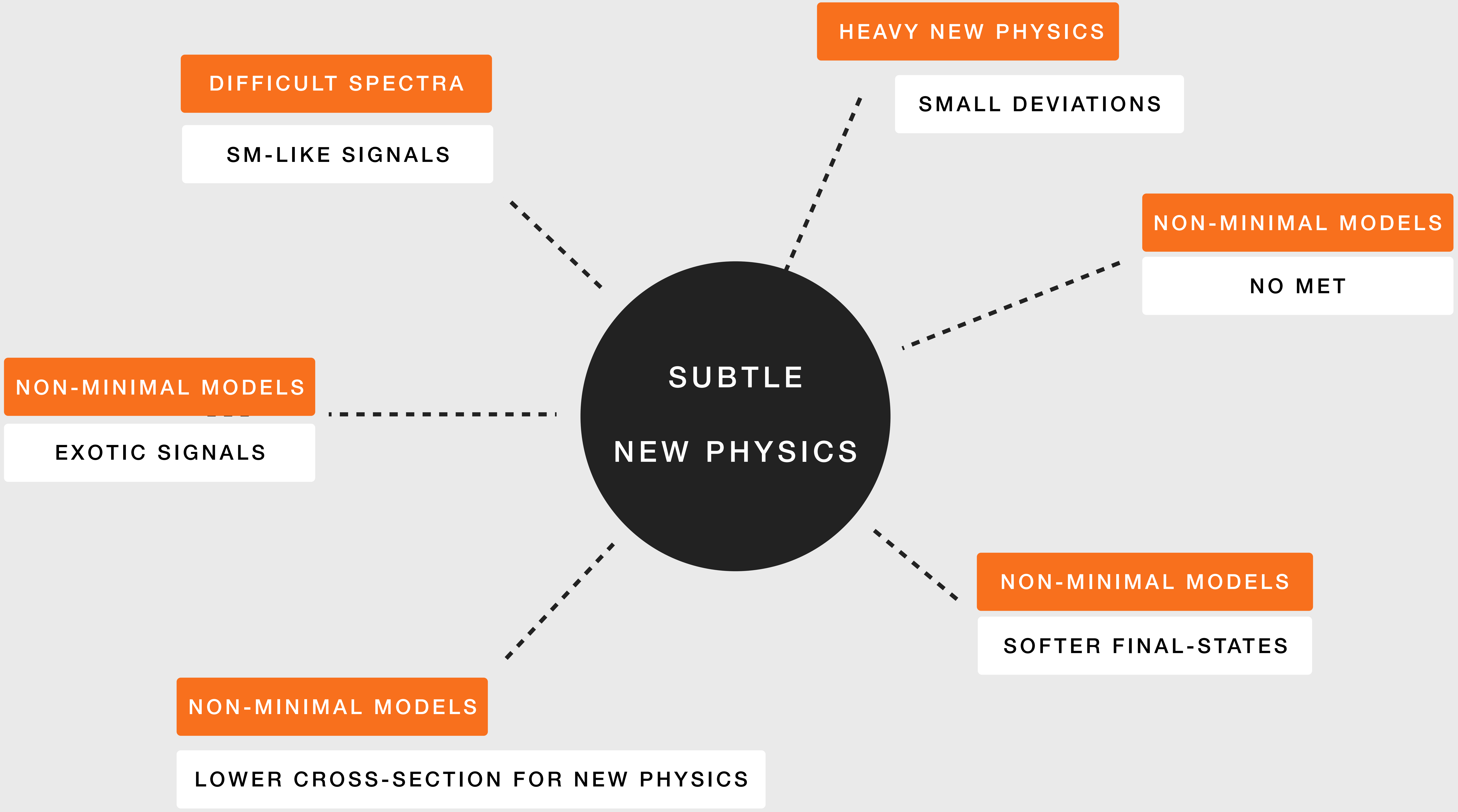
Theory Options (~Non-Susy)

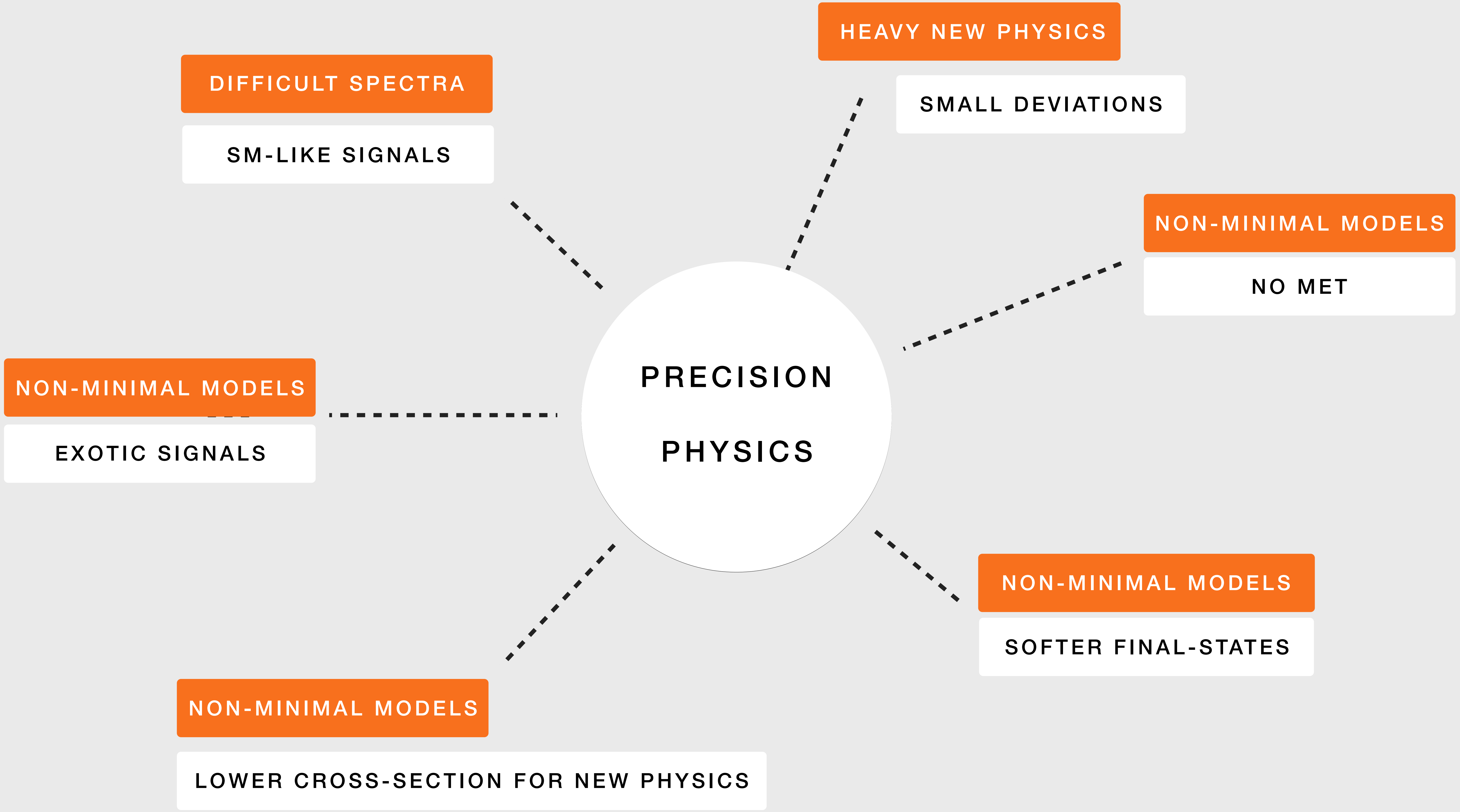


MORE SUBTLE SIGNALS ⇒ **PRECISION**

Run2 $\simeq$ Subtle New Physics

Run2 → Precision Physics


SUBTLE
NEW PHYSICS
DIFFICULT SPECTRA
SM-LIKE SIGNALS
HEAVY NEW PHYSICS
SMALL DEVIATIONS
NON-MINIMAL MODELS
NO MET
NON-MINIMAL MODELS
EXOTIC SIGNALS
NON-MINIMAL MODELS
SOFTER FINAL-STATES
NON-MINIMAL MODELS
LOWER CROSS-SECTION FOR NEW PHYSICS


PRECISION PHYSICS
DIFFICULT SPECTRA
SM-LIKE SIGNALS
HEAVY NEW PHYSICS
SMALL DEVIATIONS
NON-MINIMAL MODELS
NO MET
NON-MINIMAL MODELS
EXOTIC SIGNALS
NON-MINIMAL MODELS
SOFTER FINAL-STATES
NON-MINIMAL MODELS
LOWER CROSS-SECTION FOR NEW PHYSICS

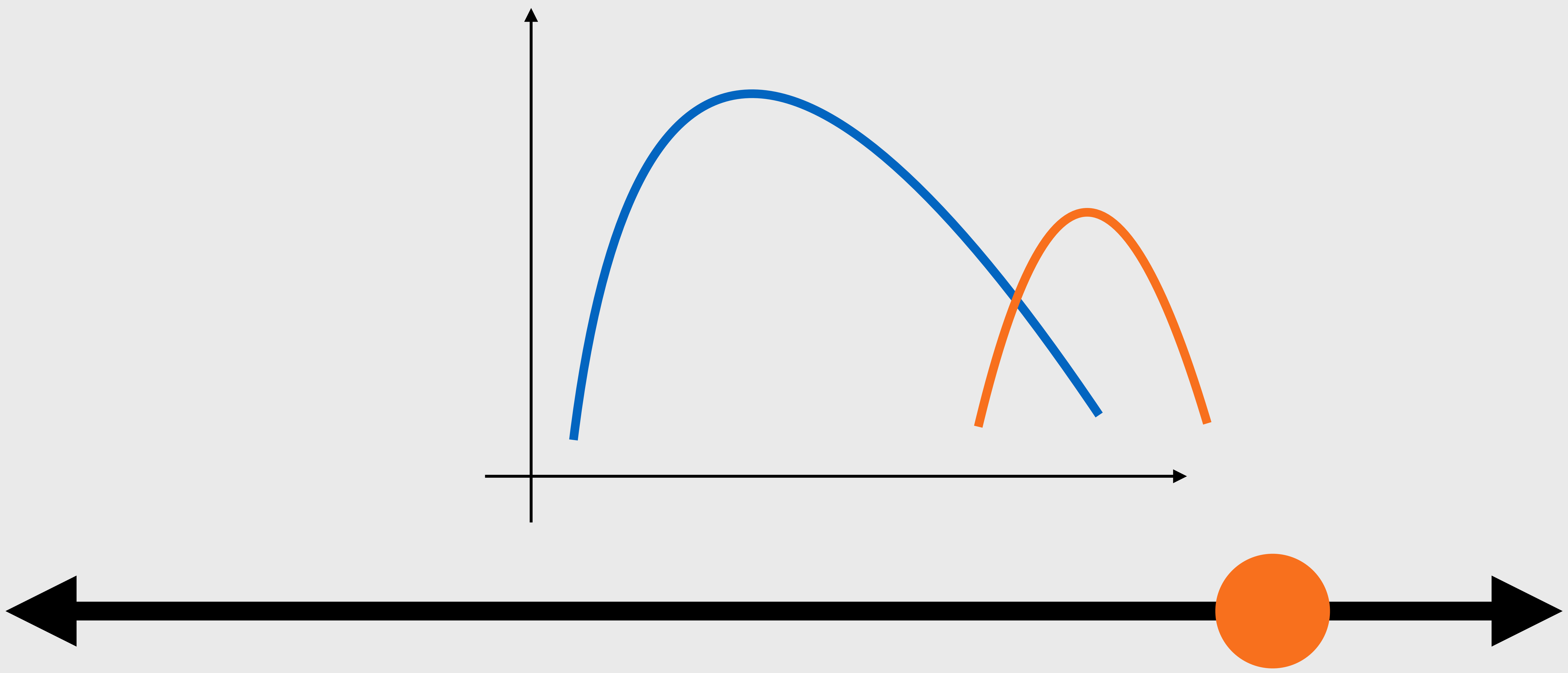
New Physics In The "Top Quark Sample"

RF - in preparation

Why Top Quarks?

- Motivated in many BSM scenarios (hierarchy problem)
- NLO+PS and NNLO precision recently achieved for differential distributions *
- Blindspots of SUSY due to top quark background

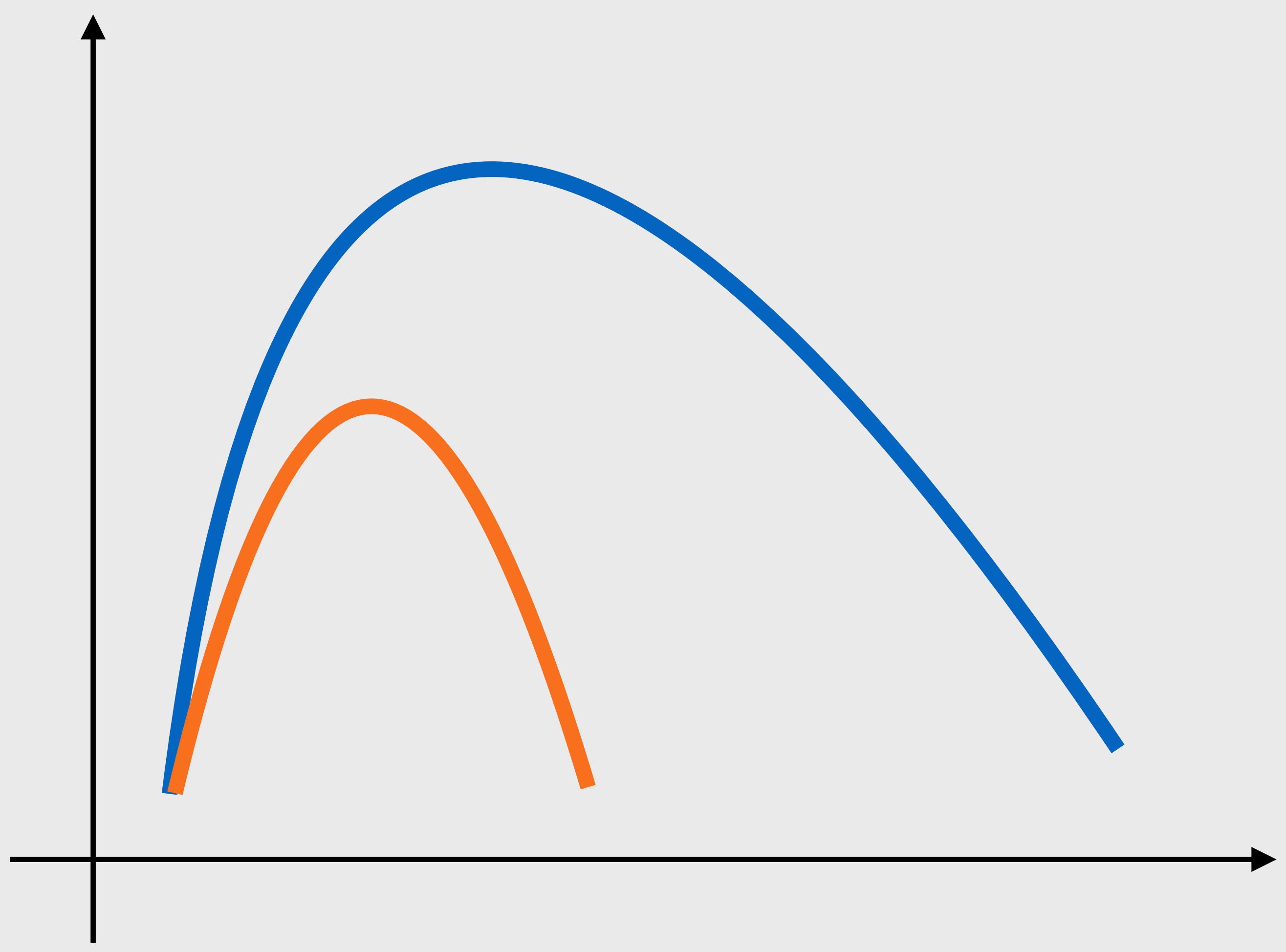
Search Approach



S/B

S≫B

Search Approach



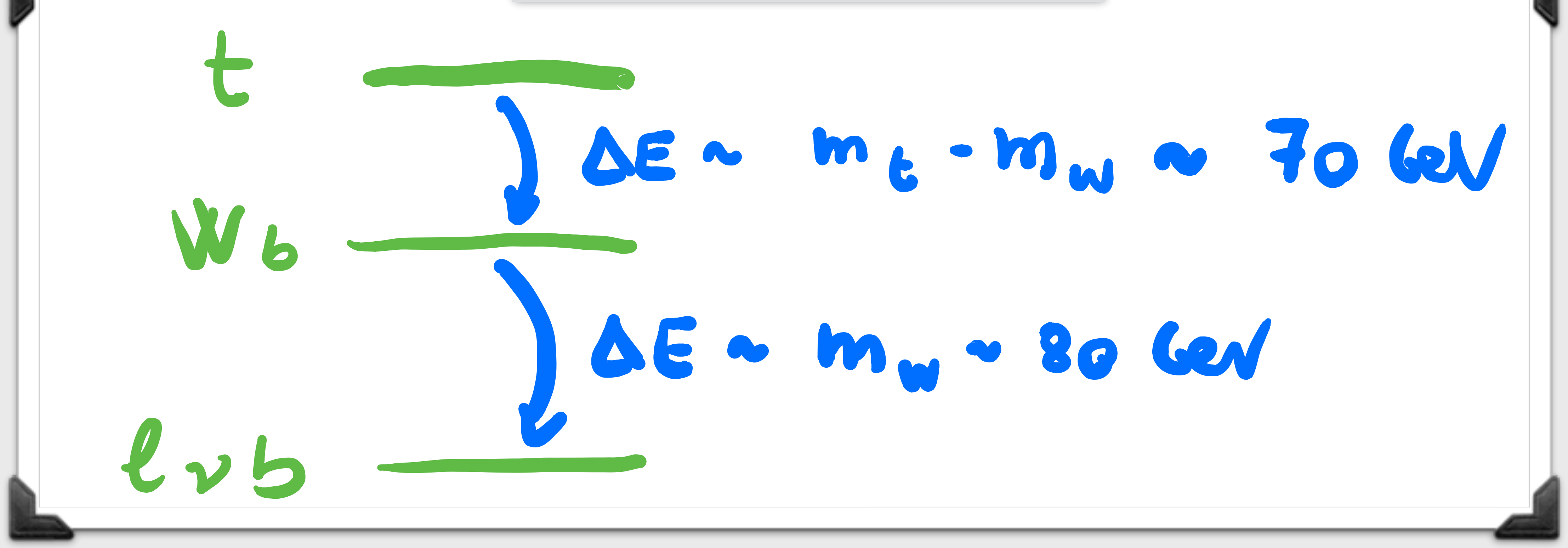
S/B

S≲B

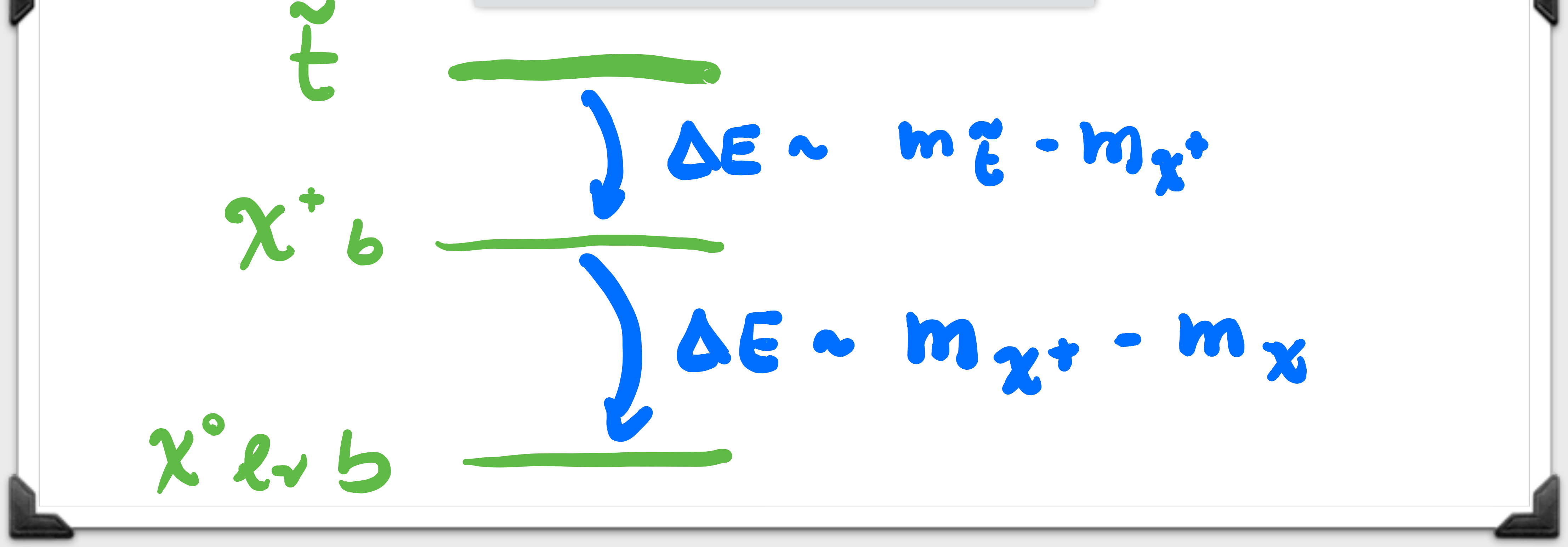
The $\{\tilde{t}, \tilde{\chi}^{+}, \tilde{\chi}^{0}\} = \{200, 150, 100\}$ GeV blindspot

Soft Is Hard

$t \to bW \to b\ell\nu$

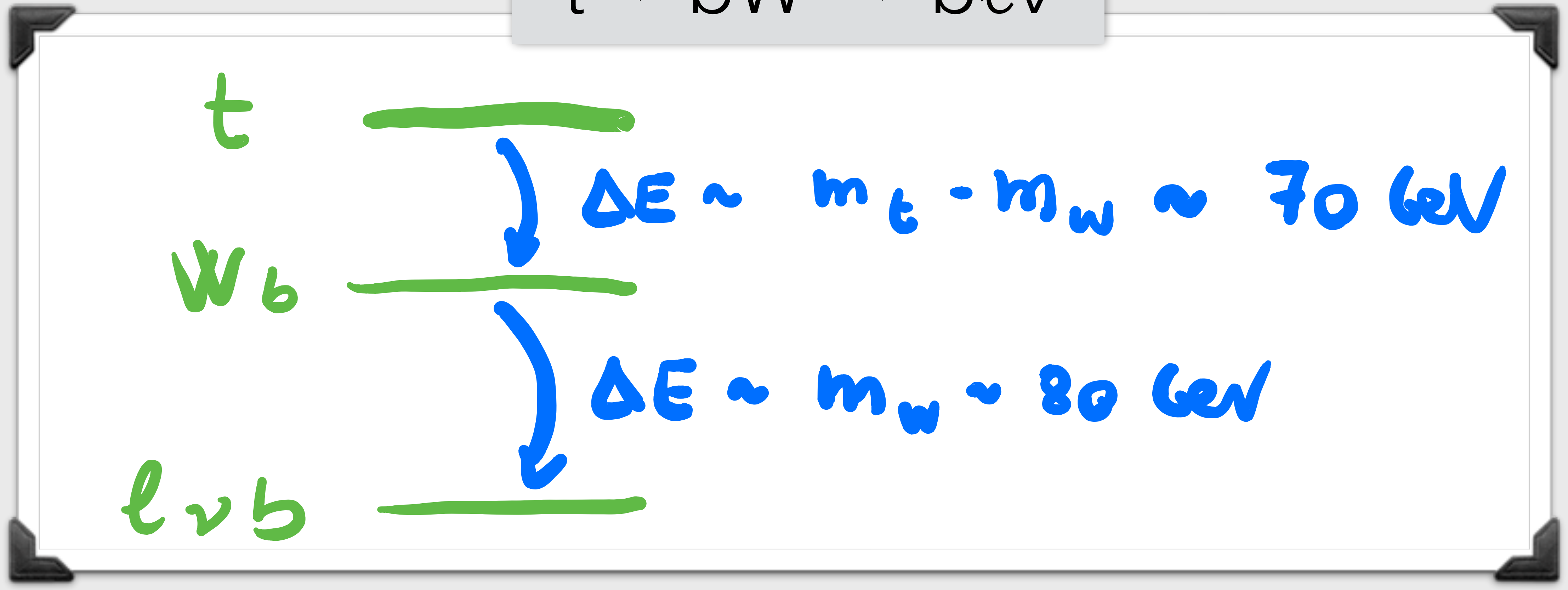


$\tilde{t} \to b\,\chi^+ \to b\ell\nu\chi^0$

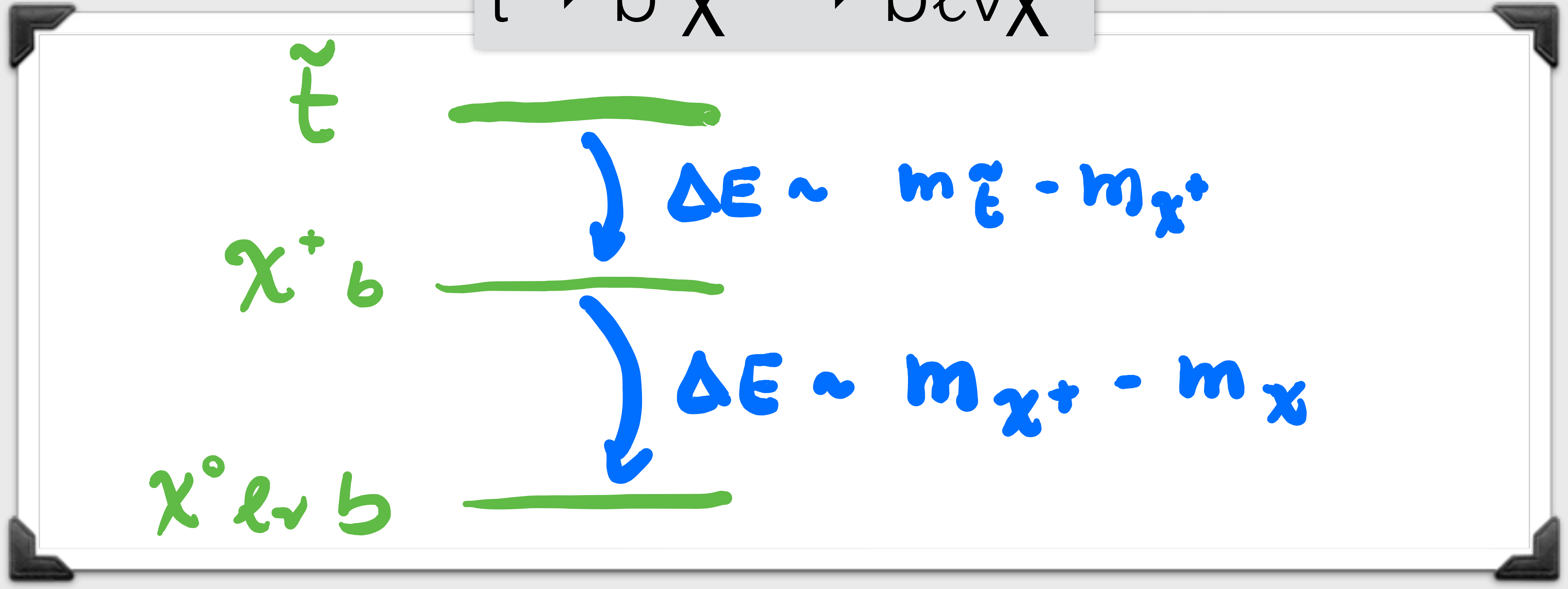


Soft Is Hard

$t \rightarrow bW \rightarrow b\ell\nu$



$\tilde{t} \rightarrow b\,\chi^{+} \rightarrow b\ell\nu\chi^{0}$

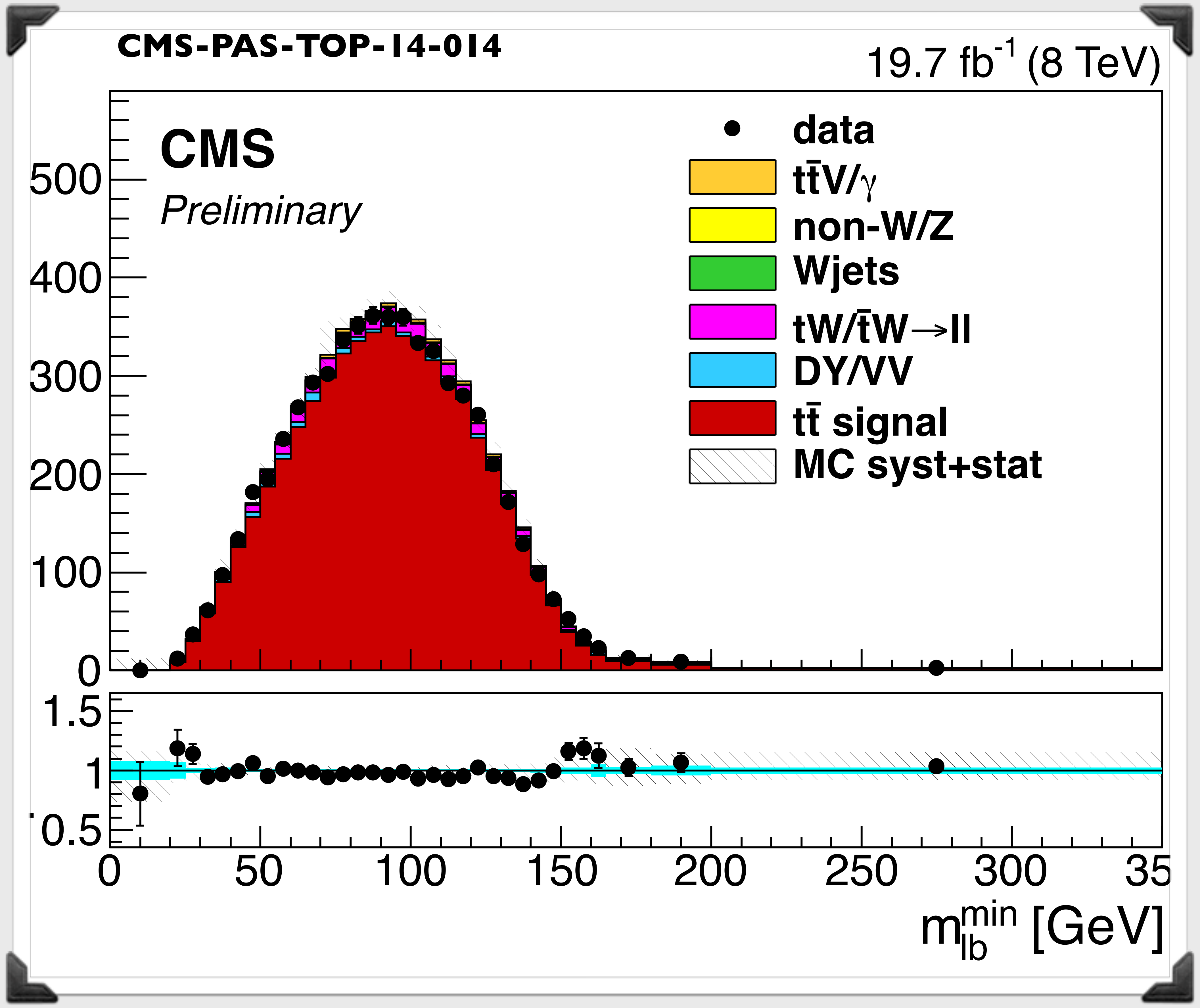


NEW PHYSICS IS SM-LIKE

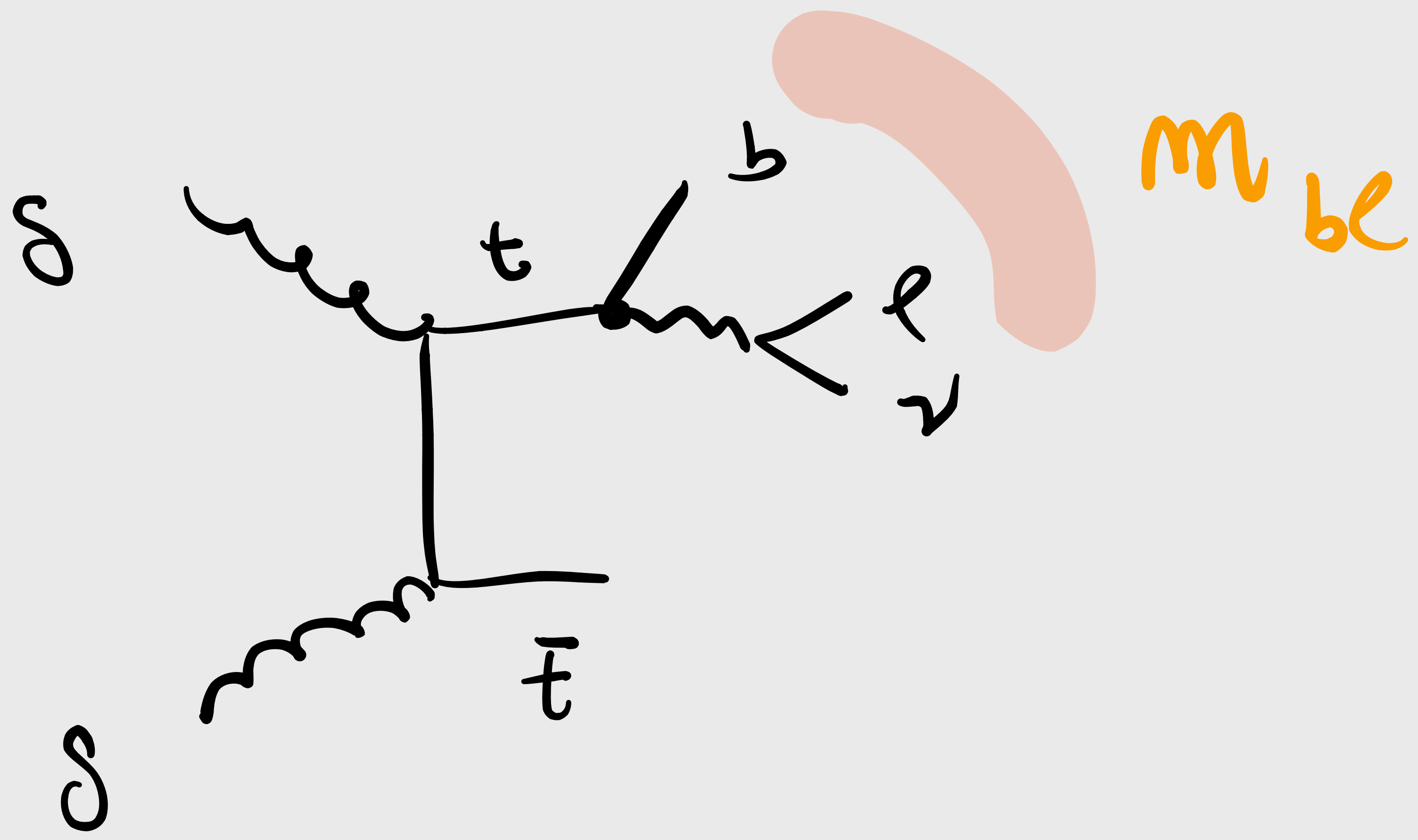
BETTER PRECISION

Resolution

PRECISION AT THE LHC



- NLO and NNLO precision top quark physics is a reality
- SM precision predictions for many observables
- Useful *per se*
- Can show deviations from SM in subtle features

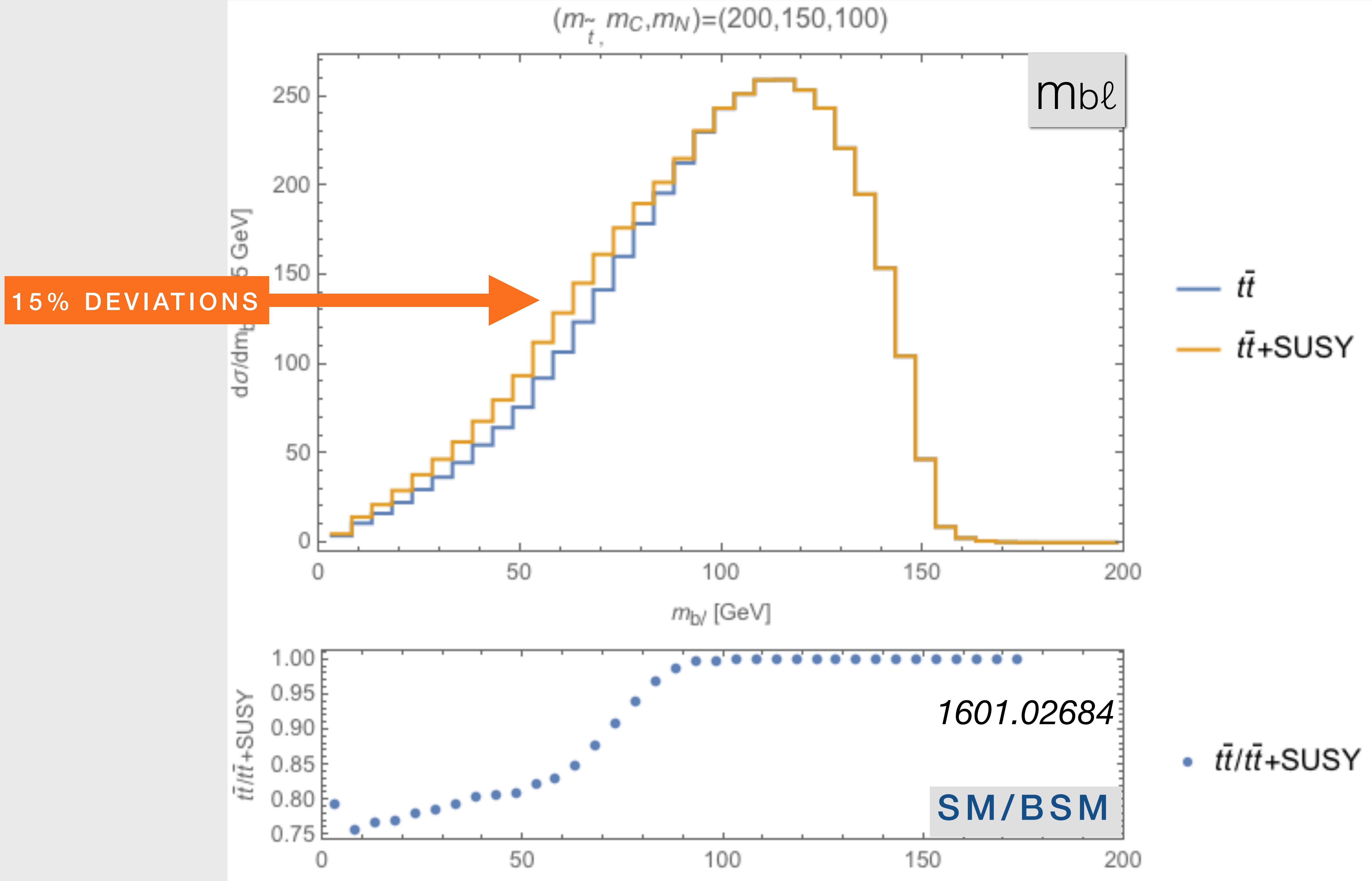


New Physics Effect On $m_{b\ell}$

MG5@LO

cuts TOP-14-014

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



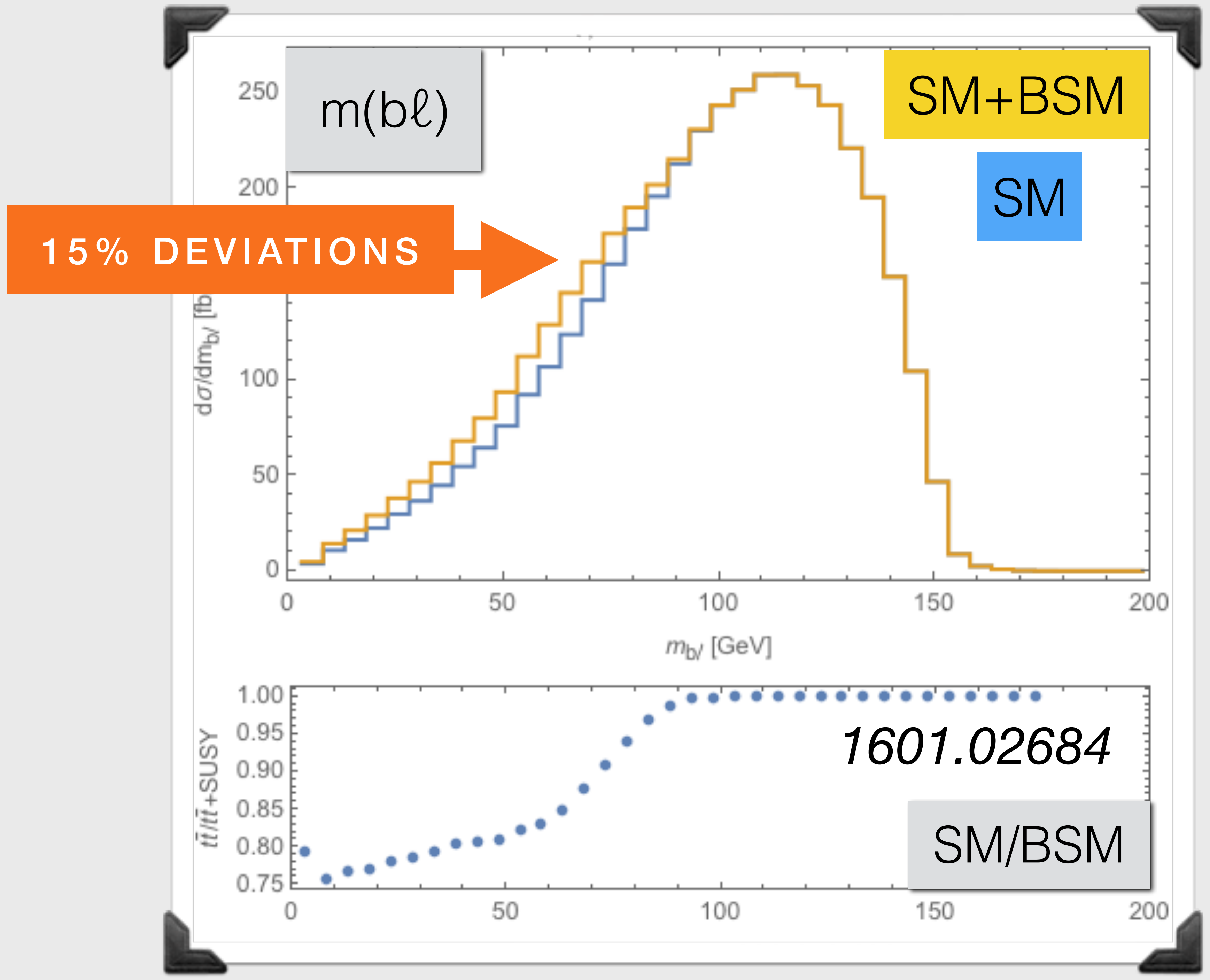
10-15% Deviation In A Distribution, Is It Enough To Claim New Physics/Put A Bound?

THEORY UNCERTAINTIES

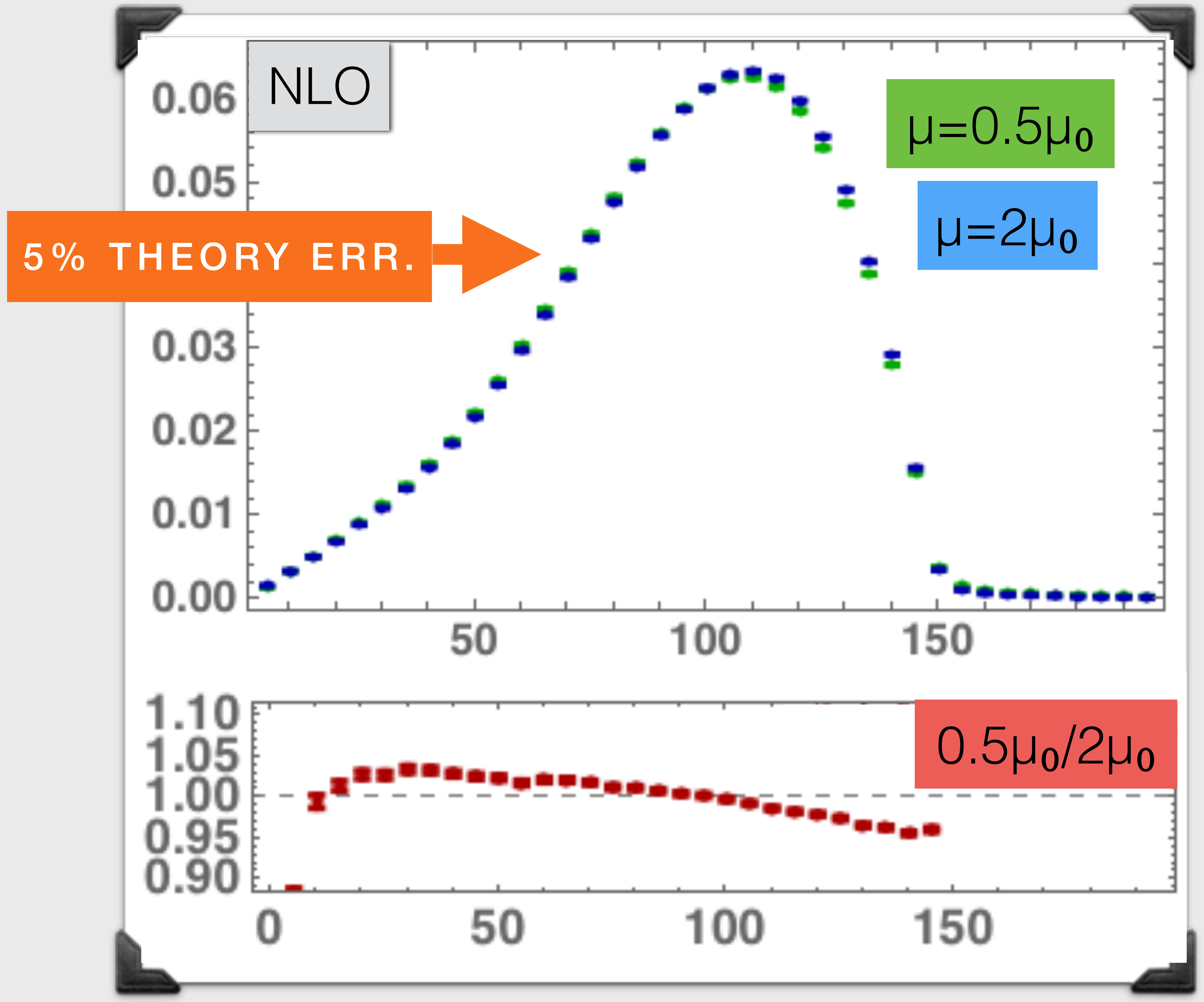
Resolution

PRECISION AT THE LHC

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

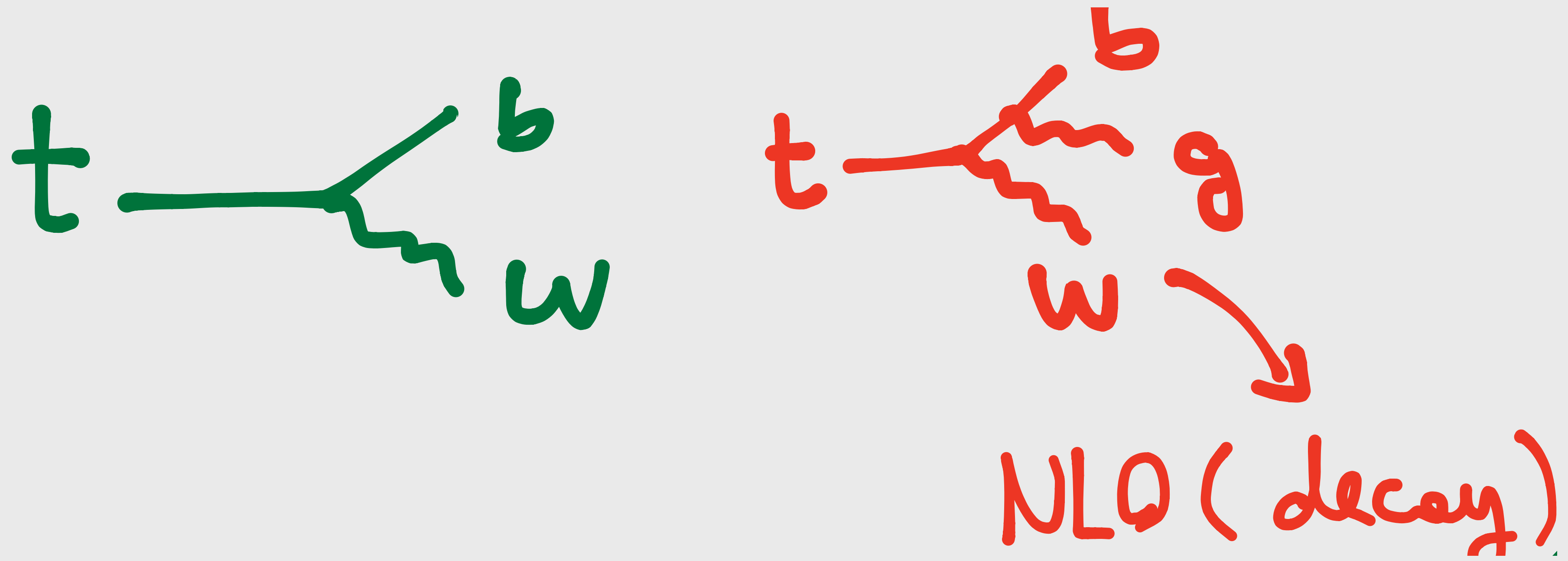


SM $t\bar{t}$ (MCFM) as in TOP-14-014

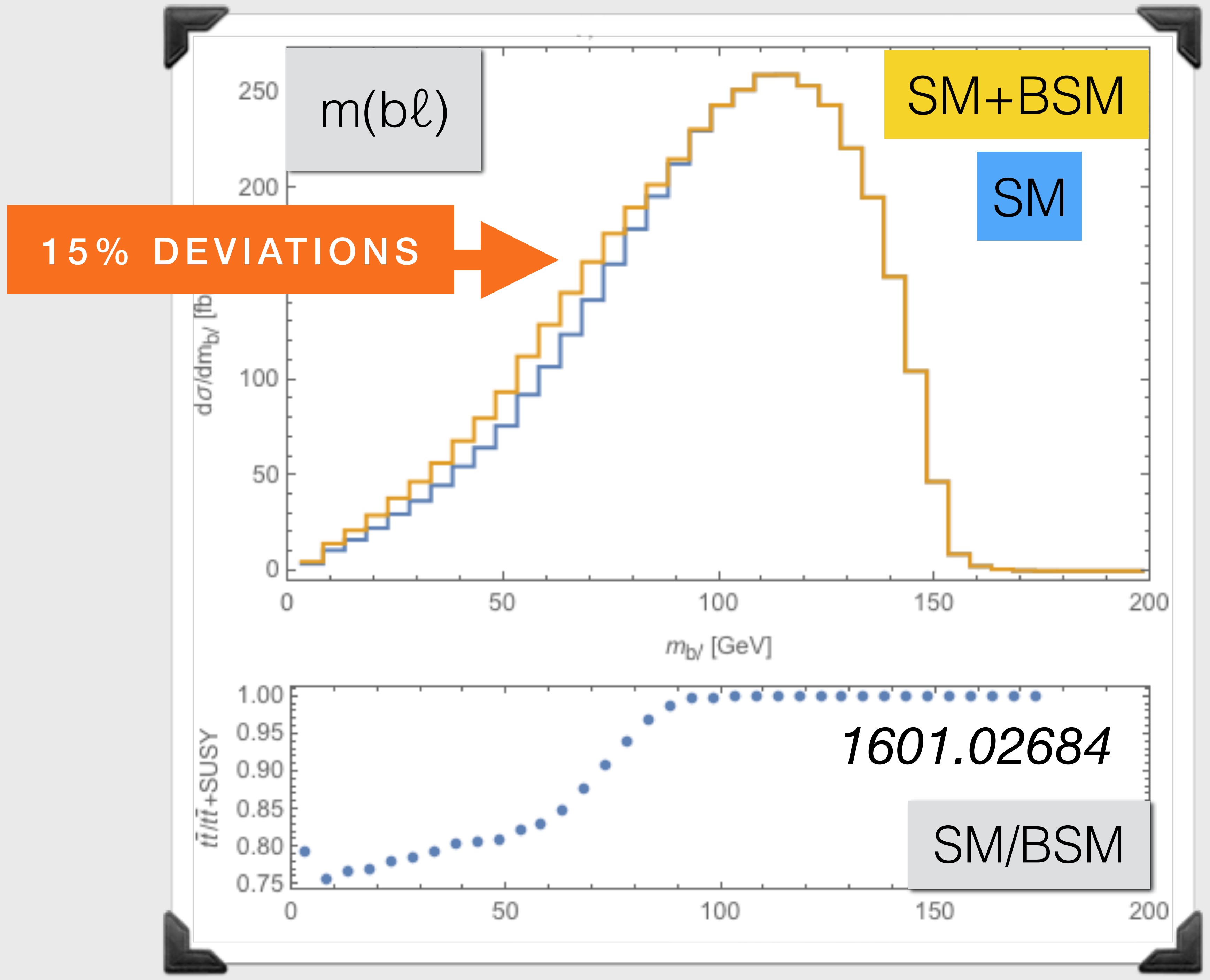


Resolution

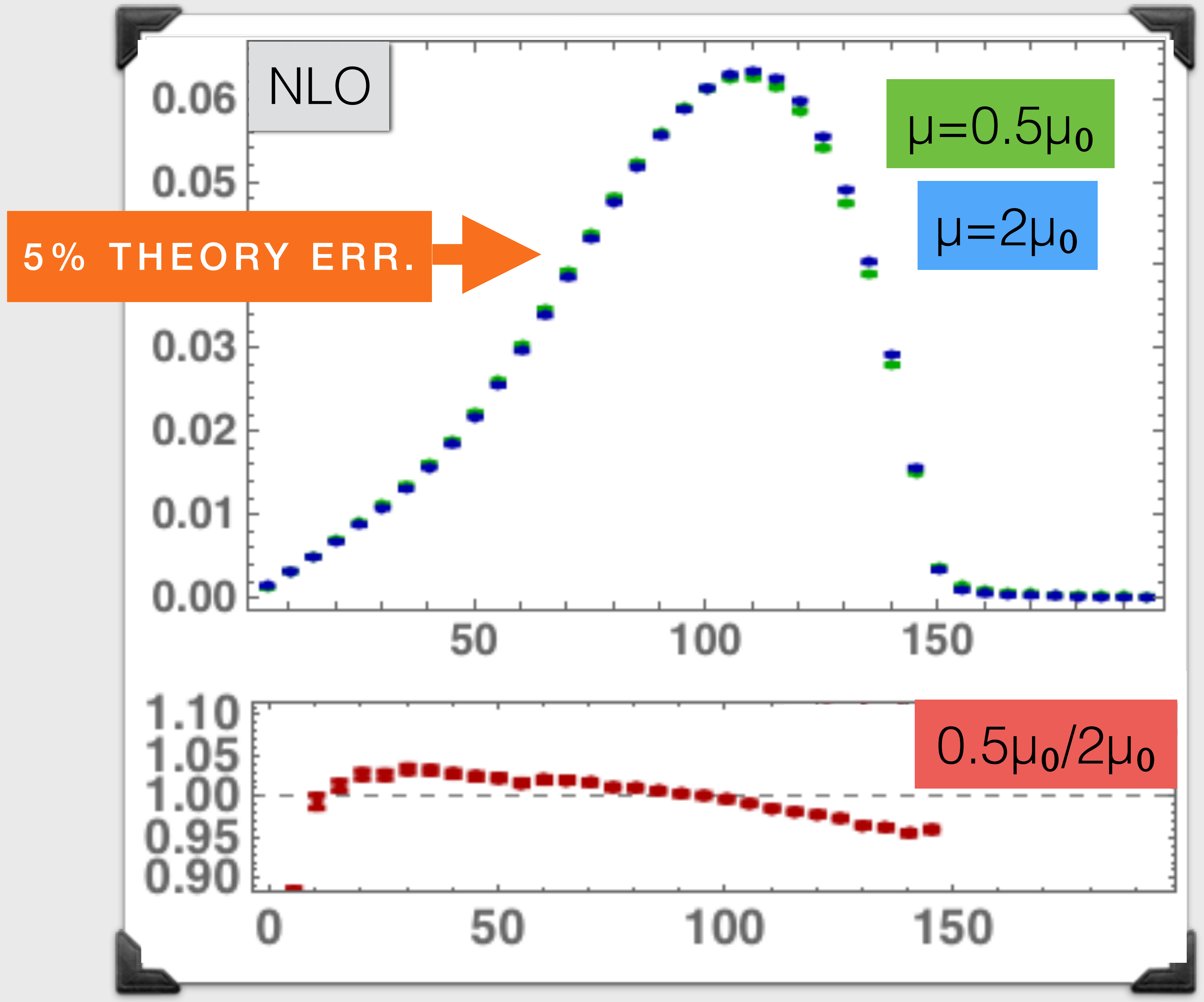
PRECISION AT THE LHC



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

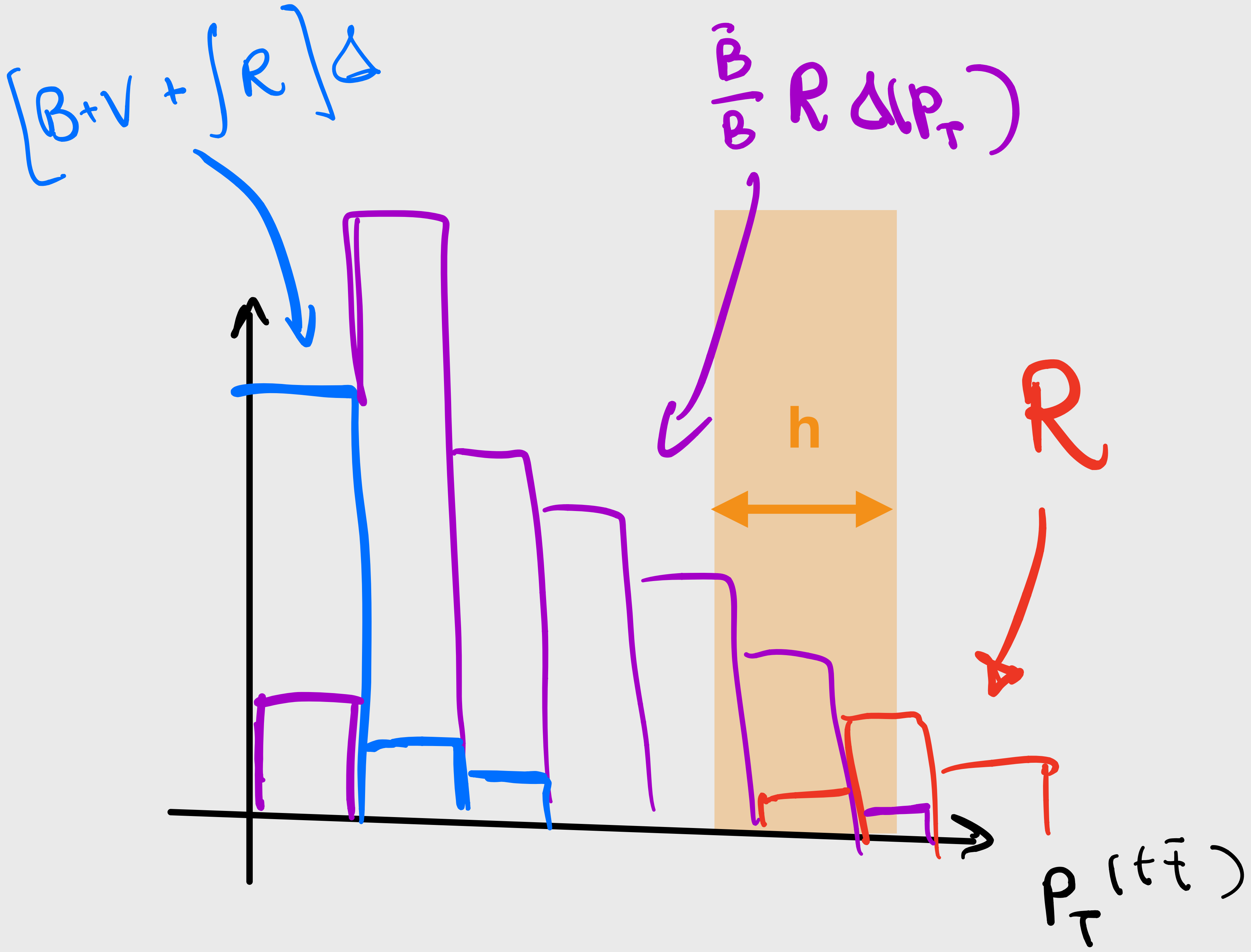


SM $t\bar{t}$ (MCFM) as in TOP-14-014



A Closer Look At Scale Uncertainties

NLO + PARTON SHOWER (1202.1251) | POWHEG V2 (1412.1828) | POWHEG-RES (1607.04538)



$$\bar{B} \cdot \left[\Delta(Q_0) + \frac{R}{B} \Delta(p_T)\, d\Phi_{\mathrm{rad}} \right] d\Phi_B$$

$$\bar{B} \cdot \left[\Delta(Q_0) + \frac{R}{B} \Delta(p_T)\, d\Phi_{\mathrm{rad}}\, H \right] d\Phi_B + R\, d\Phi_R\, (1-H)$$

$H=h^2/(h^2+p_T^2)$

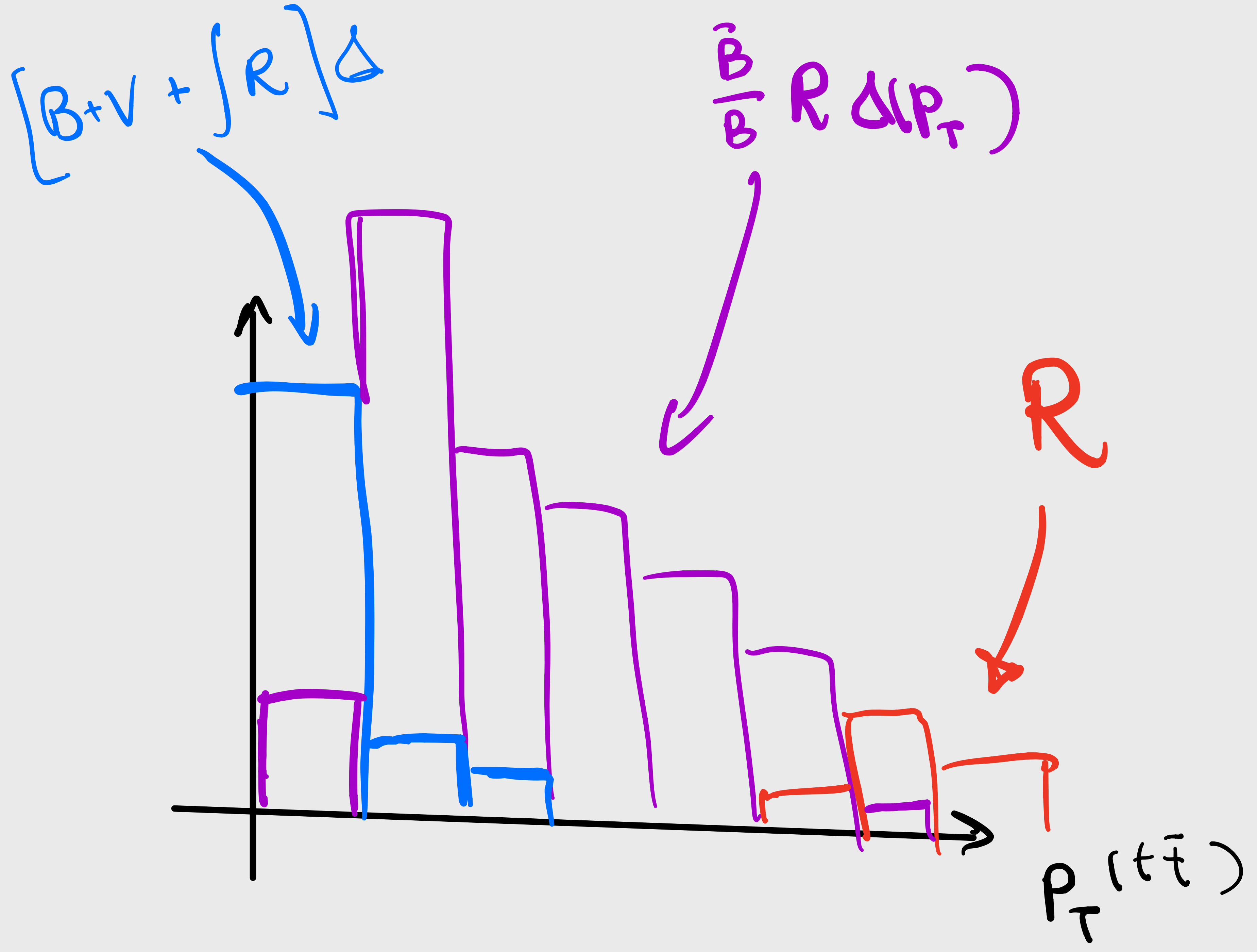
$h \to 0$ Fixed Order

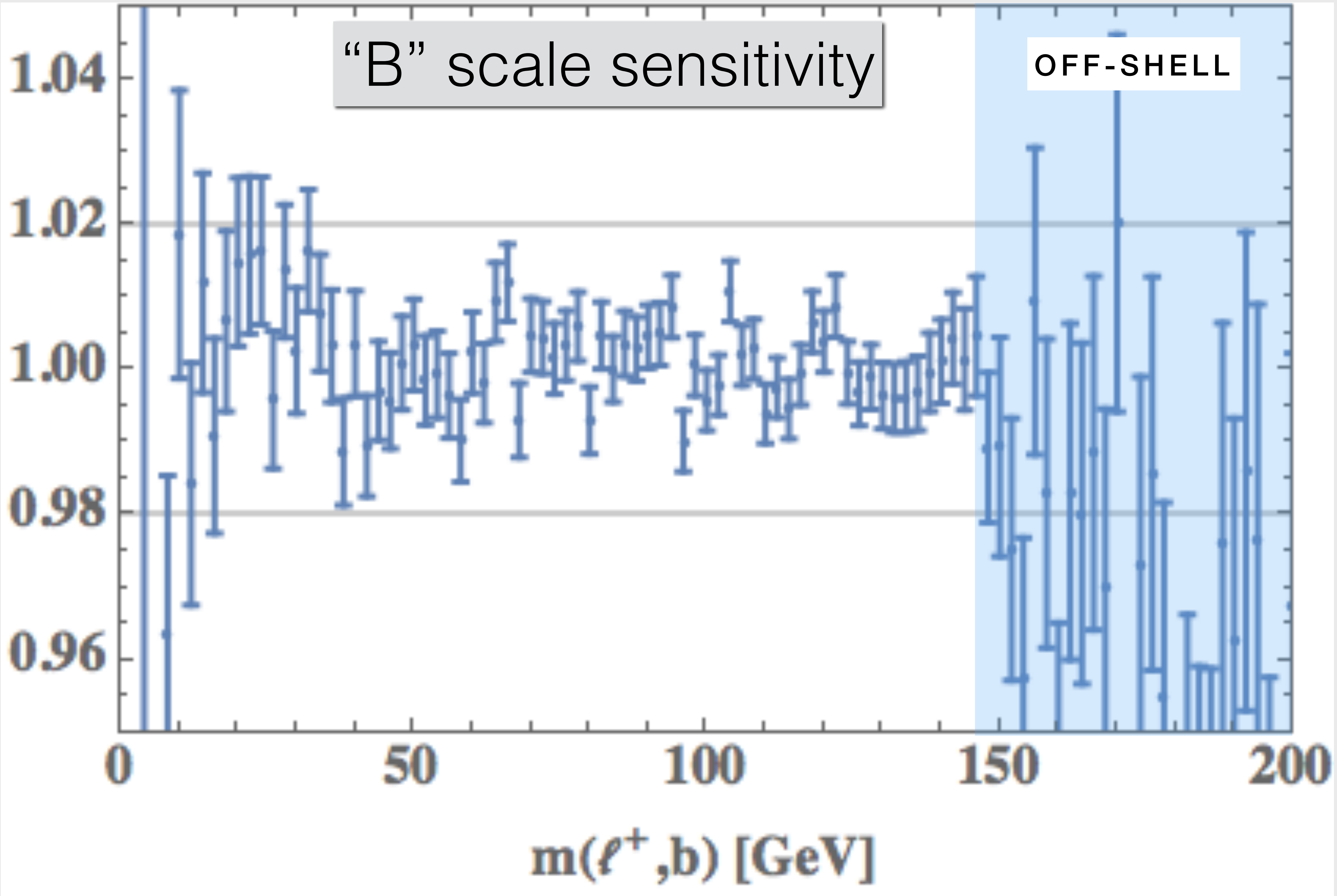
$h \to \infty$ Parton Shower + Matrix Element

A Closer Look At Scale Uncertainties

POWHEG-V2

$$\bar{B} \cdot \left[\Delta(Q_0) + \frac{R}{B} \Delta(p_T) d\phi_{rad} H \right] d\phi_B + R \, d\phi_R \, (1-H)$$

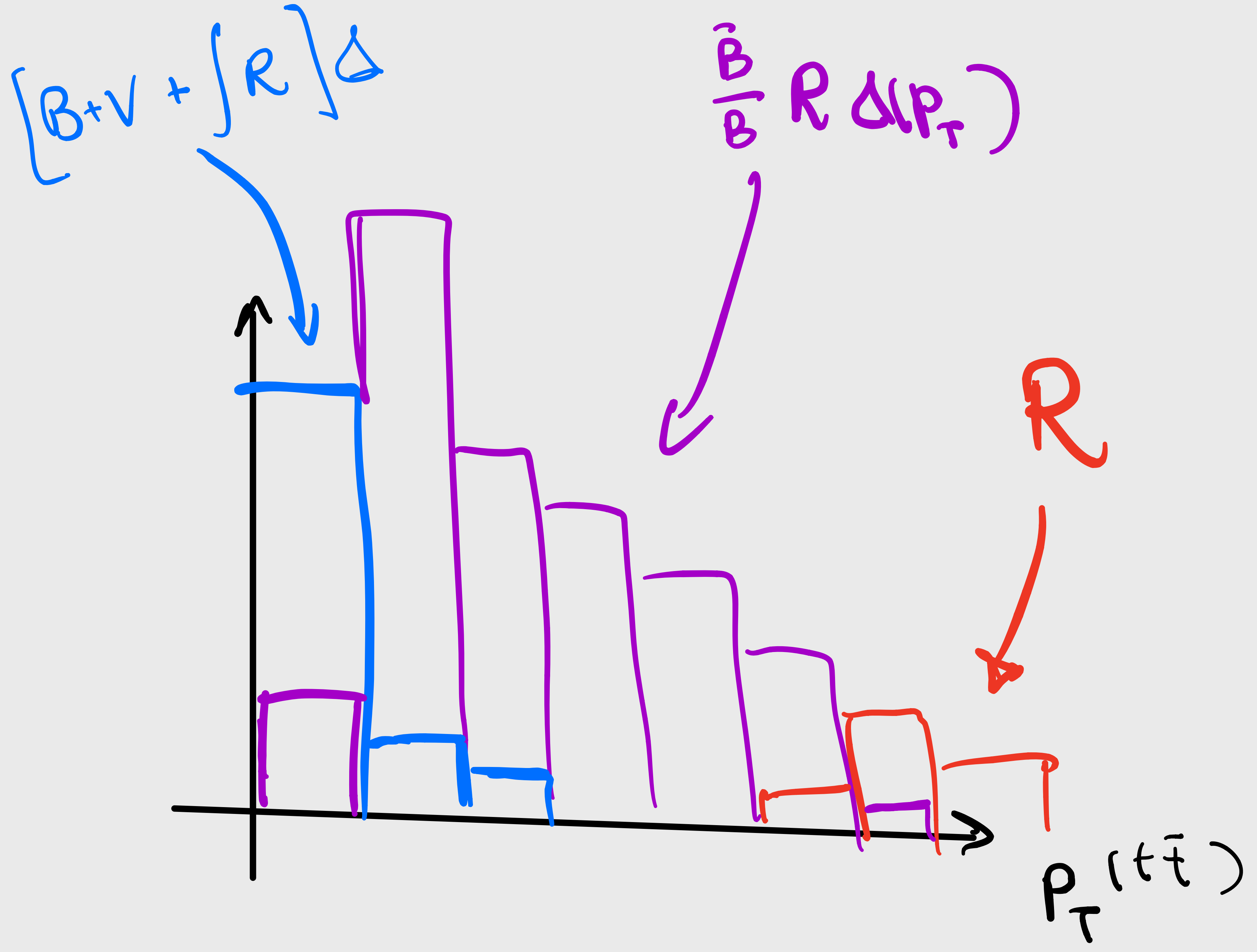


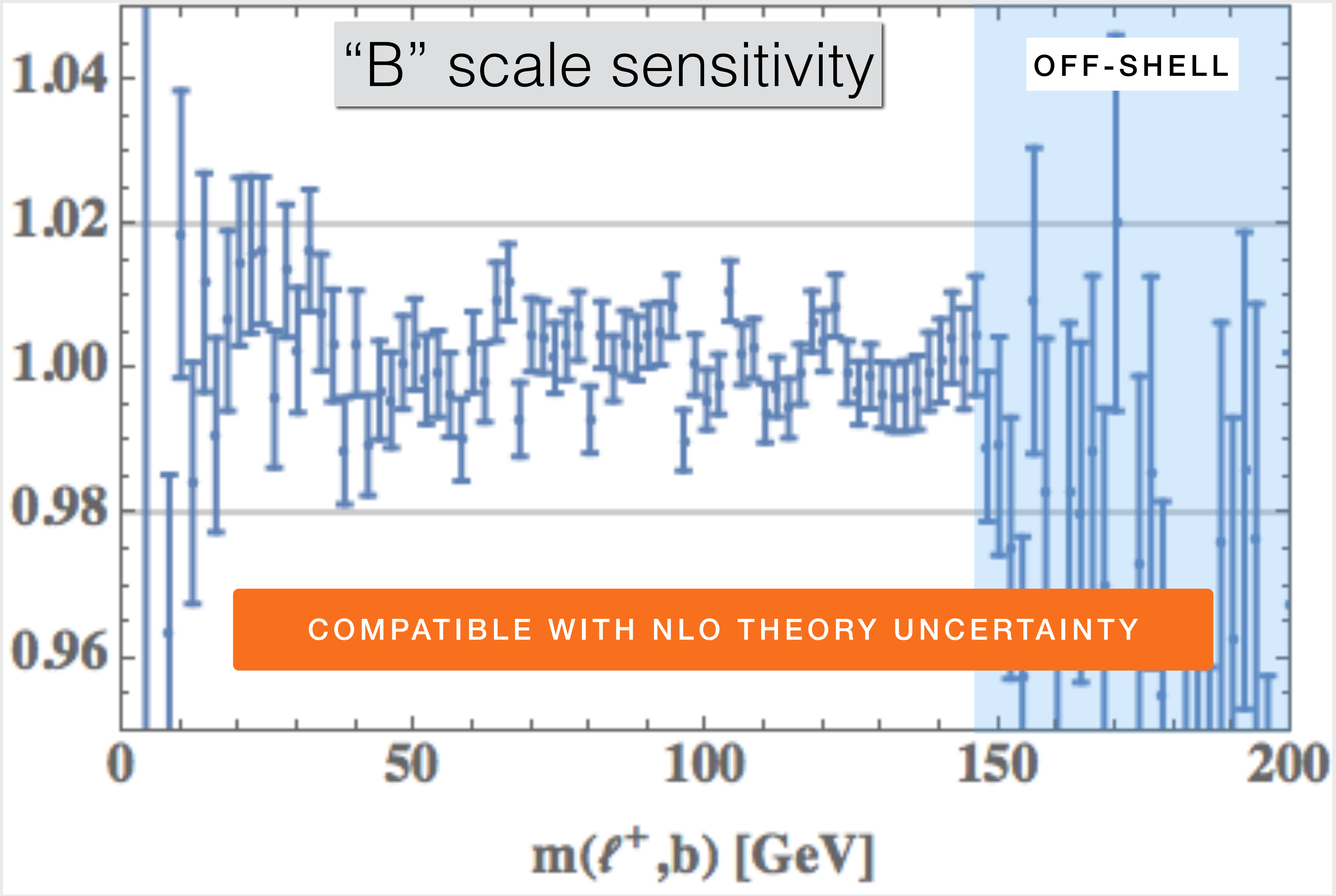


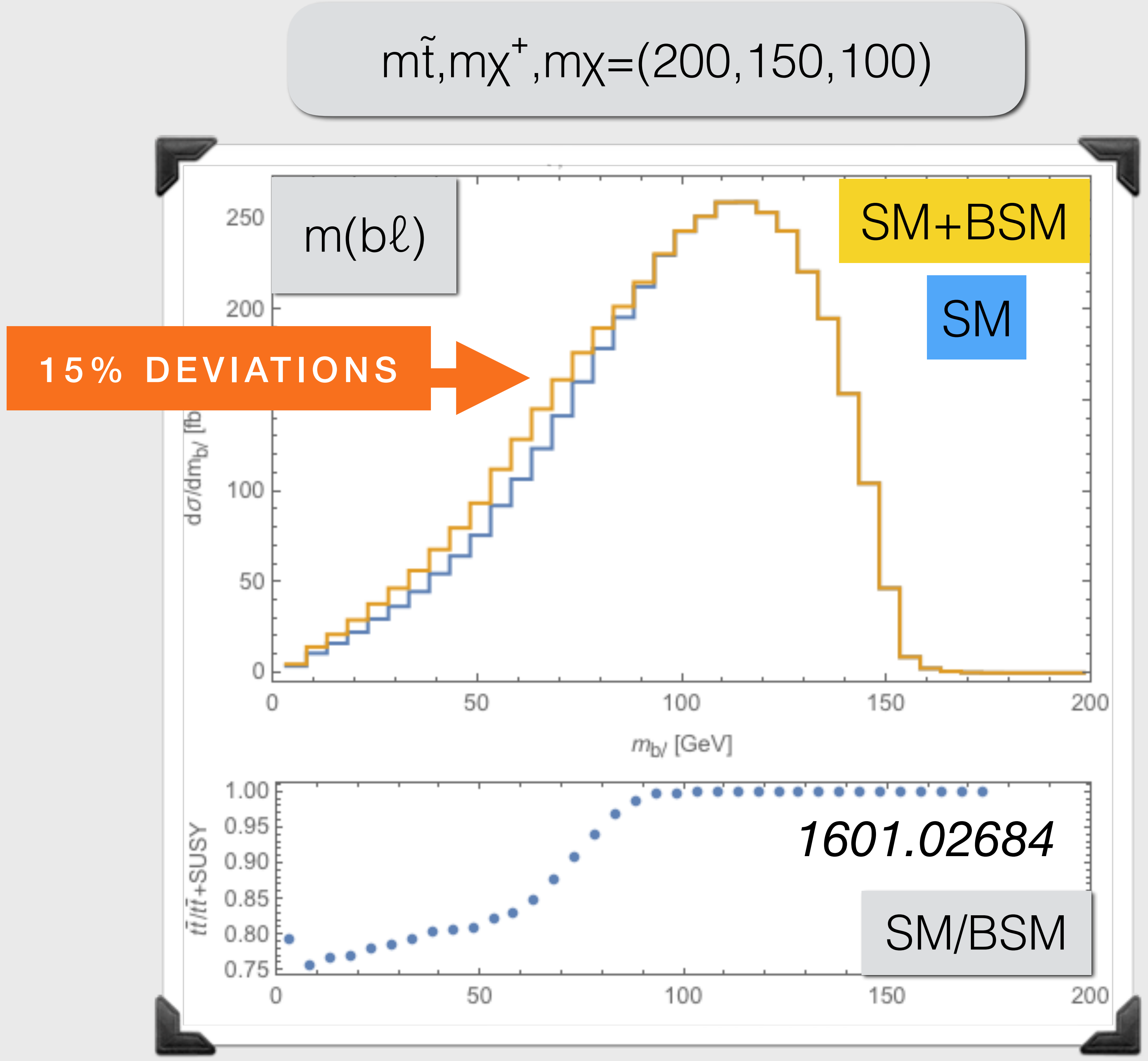
A Closer Look At Scale Uncertainties

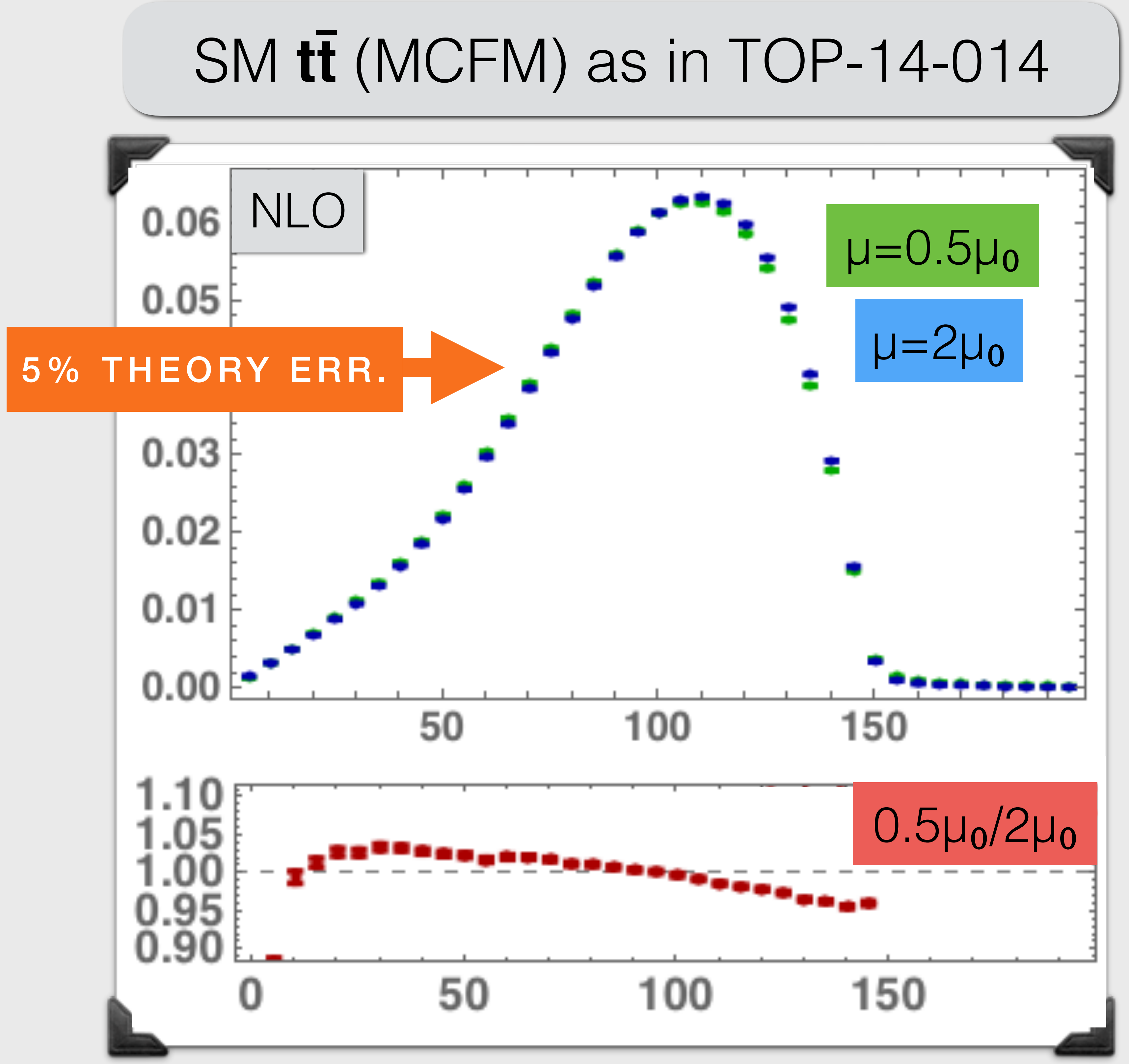
POWHEG-V2

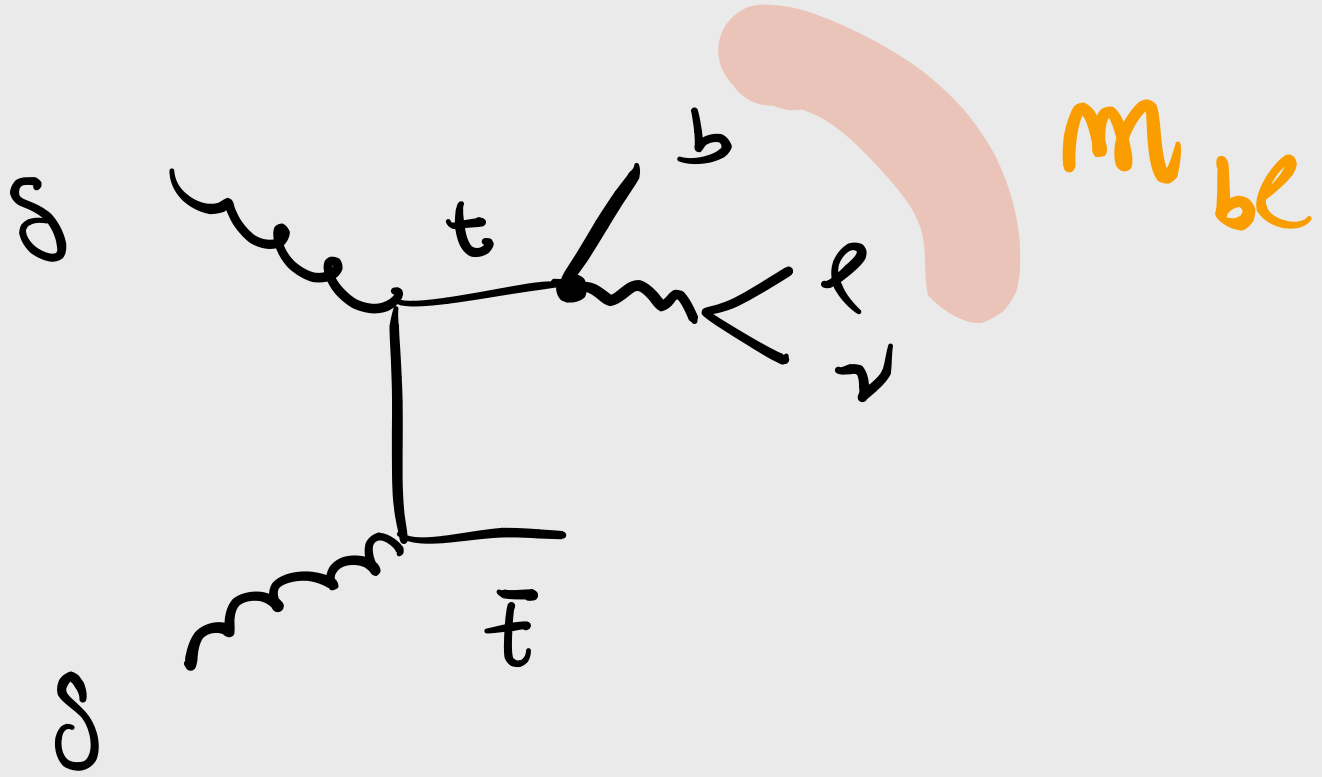
$$\bar{B} \cdot \left[\Delta(Q_0) + \frac{R}{B} \Delta(p_T) d\phi_{rad} H \right] d\phi_B + R\, d\phi_R (1-H)$$









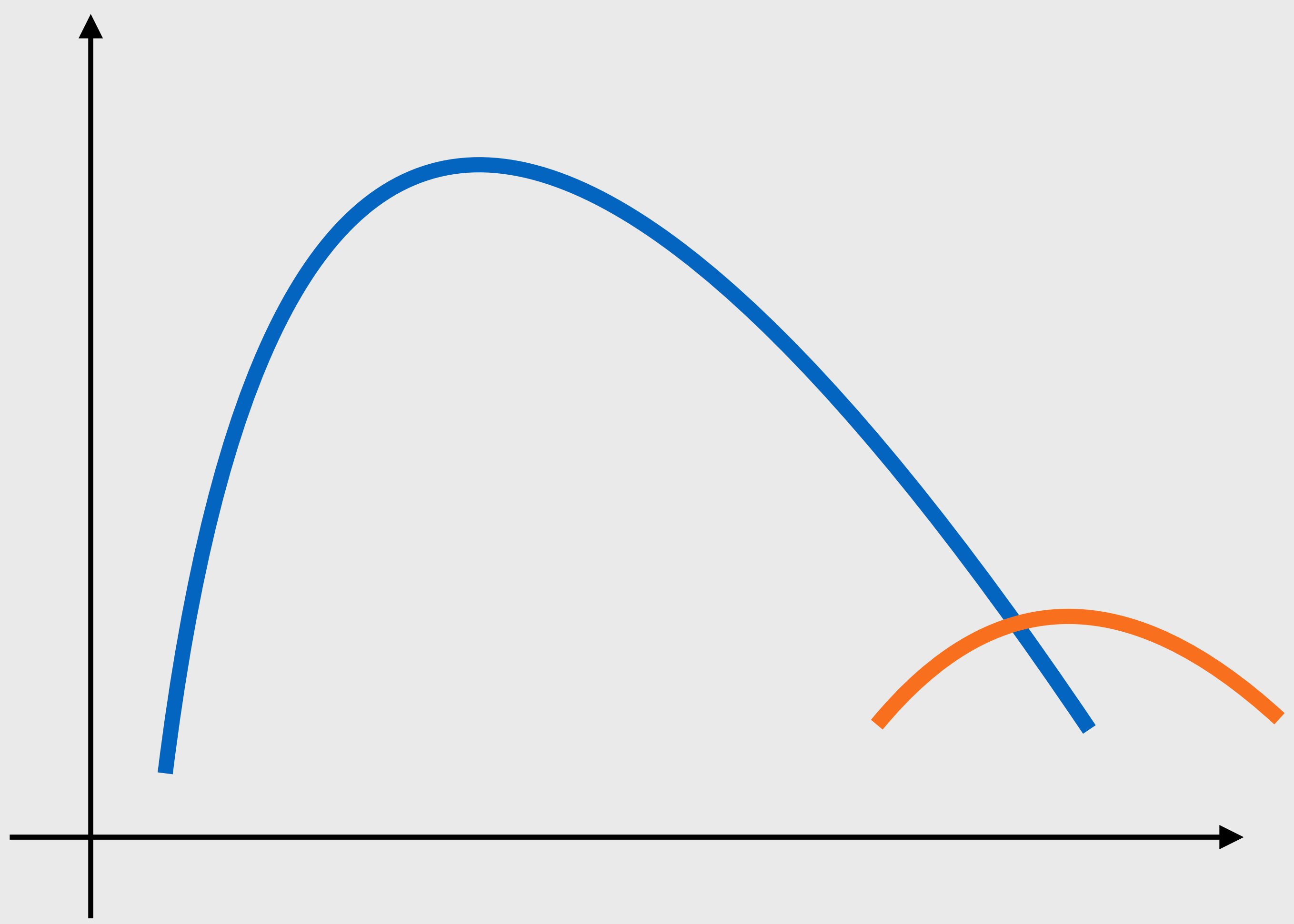


m(bℓ) **and other observables used in precision top quark physics can <u>probe still uncovered new physics scenarios</u>**

Precision Di-Bosons At The Hi-Lumi LHC

RF, Panico, Pomarol, Riva, Wulzer - in preparation

Search Approach



S/B

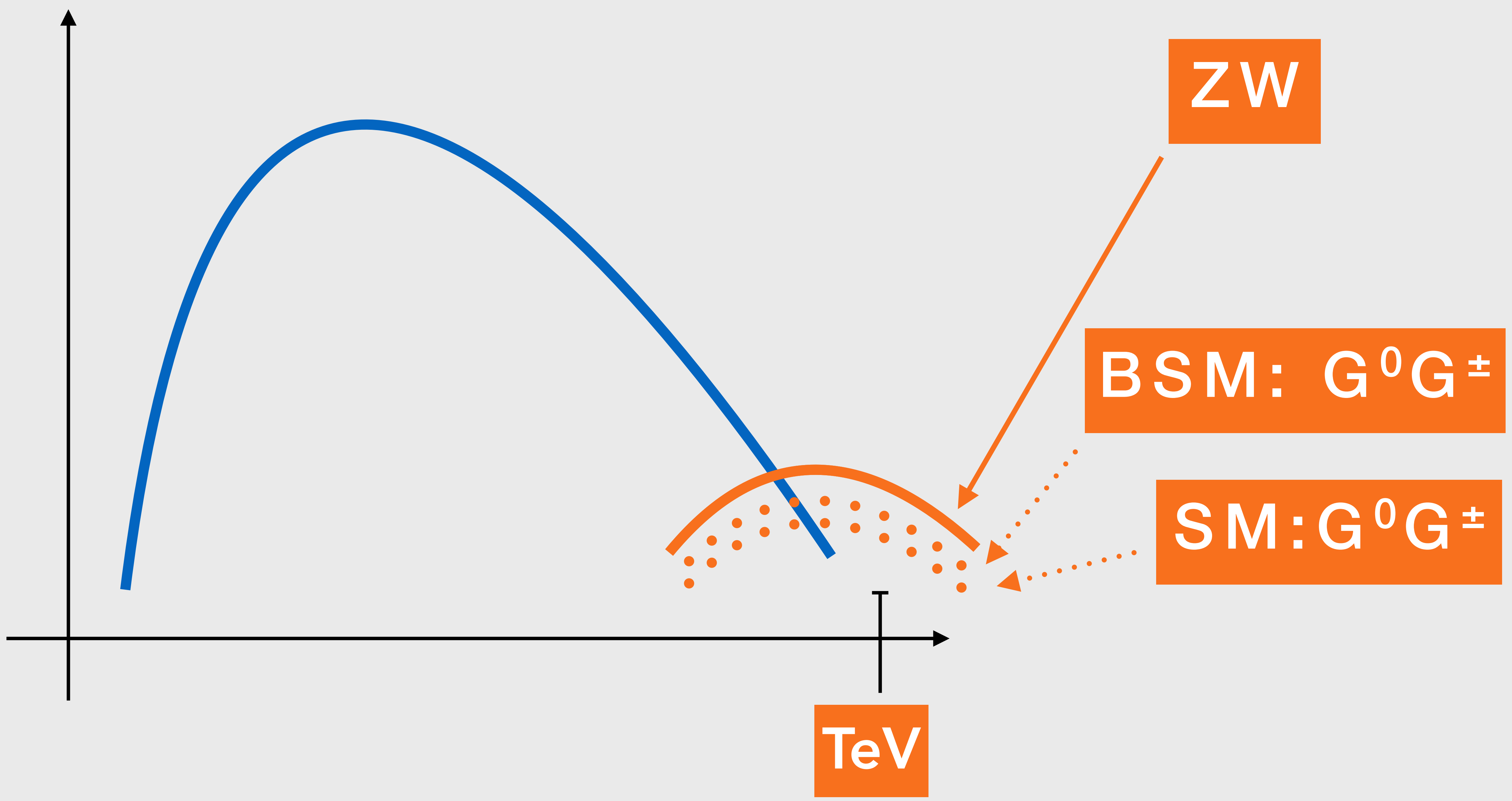
$S \lesssim B$

pp→ Goldstones

- directly relevant for EWSB
- new physics can show-up at high-energy (e.g. $O_{Hq} \sim (q_L \sigma^a \gamma^\mu q_L)(H D_{\mu,a} H)$ grows with E)
- $G \subset V \Rightarrow$ never large S/B (unless strong coupling)
- precision SM di-bosons distributions (NNLO)

$pp \to G^{\pm 0} G^{\pm 0}$

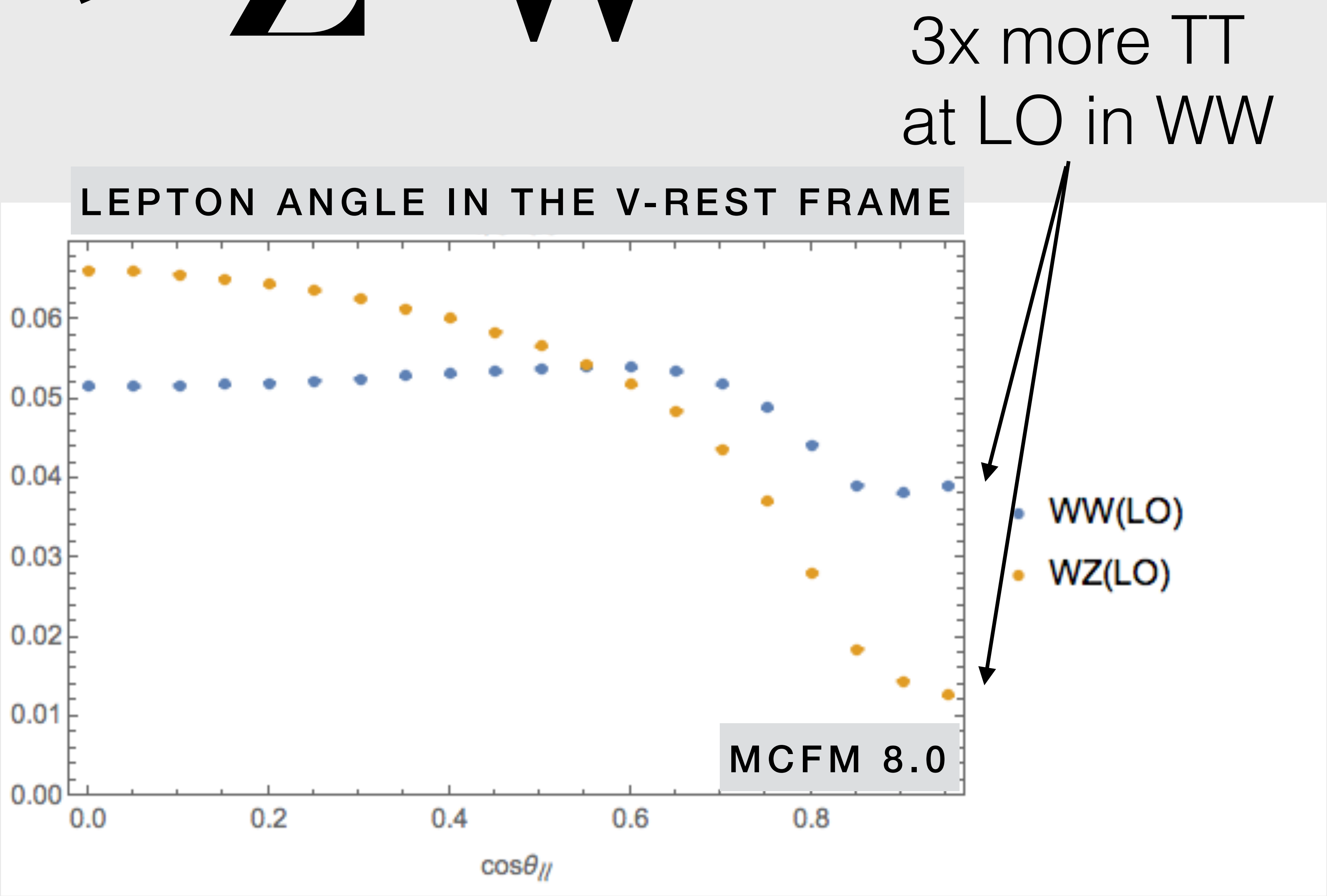
- pp → WW, ZW, ZZ, ZH, WH all potentially interesting
- however most processes have large background from other processes (e.g. tt fakes WW, V+jets fakes VH, …)
- ZW stands out because can give a fully leptonic final state, hence S>B. Only then the chase for Gold starts…

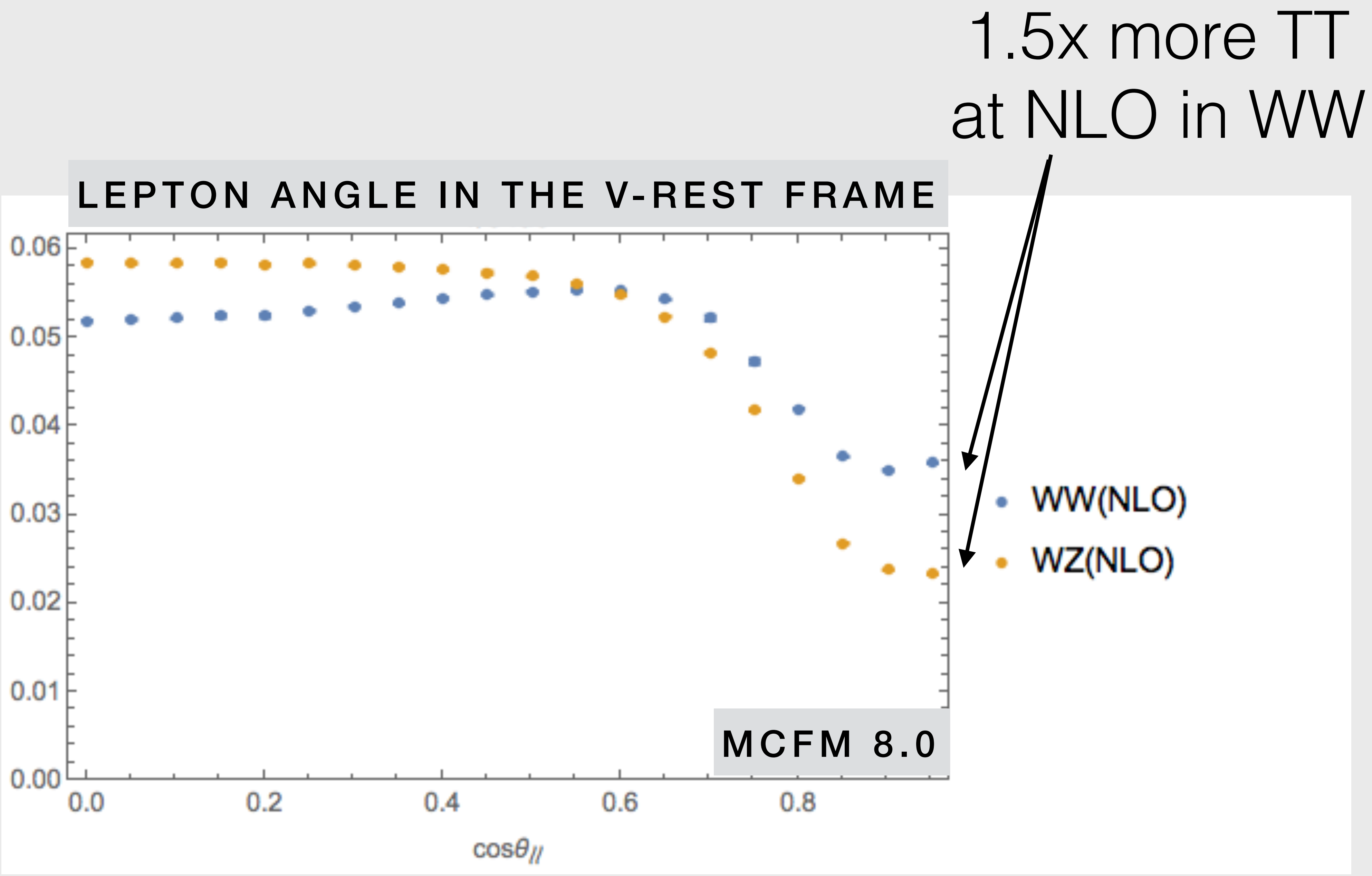


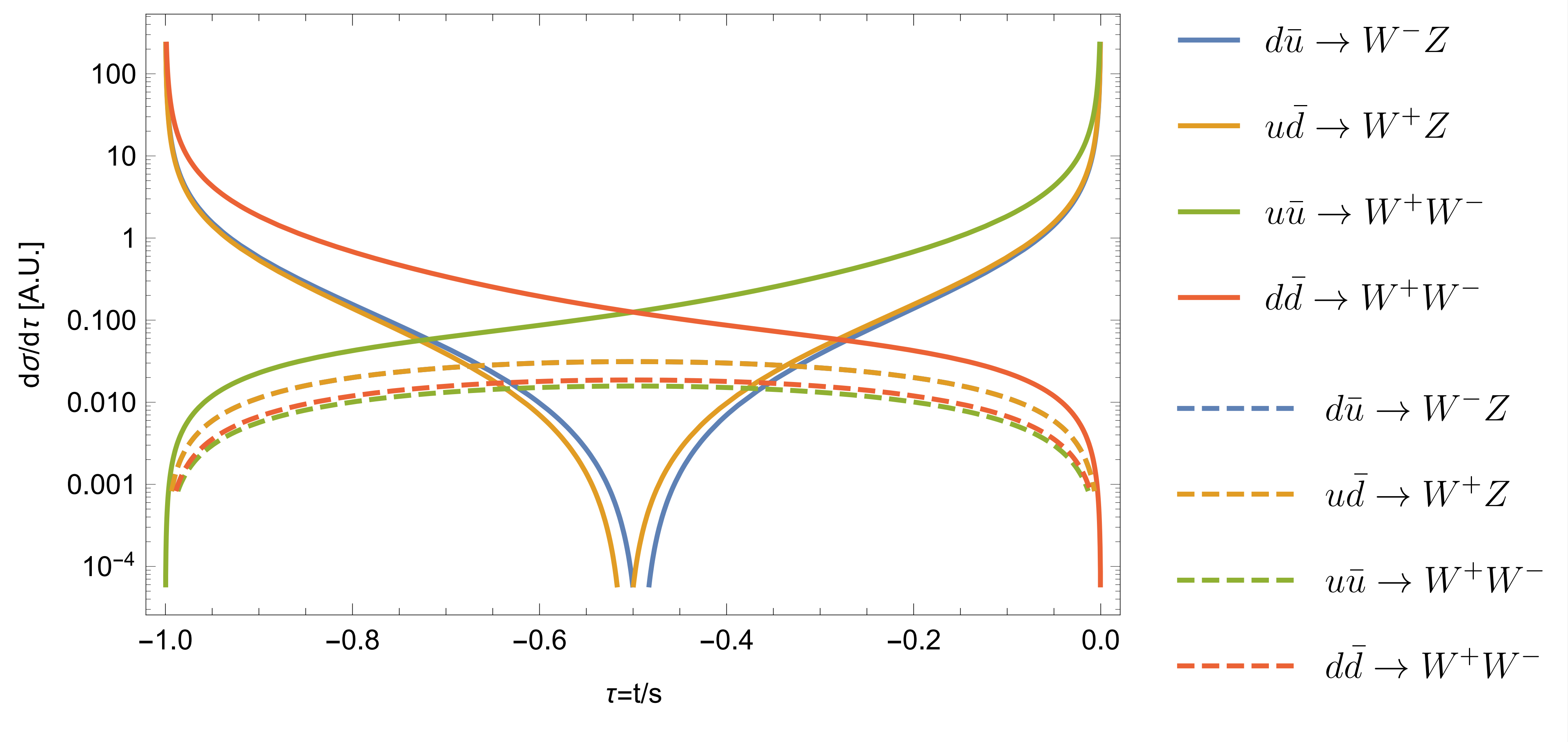
E^2 ENHANCEMENT OF BSM

10% accuracy at 1 TeV should compare to 0.1% at 100 GeV

pp→ $Z^0W^{\pm}$



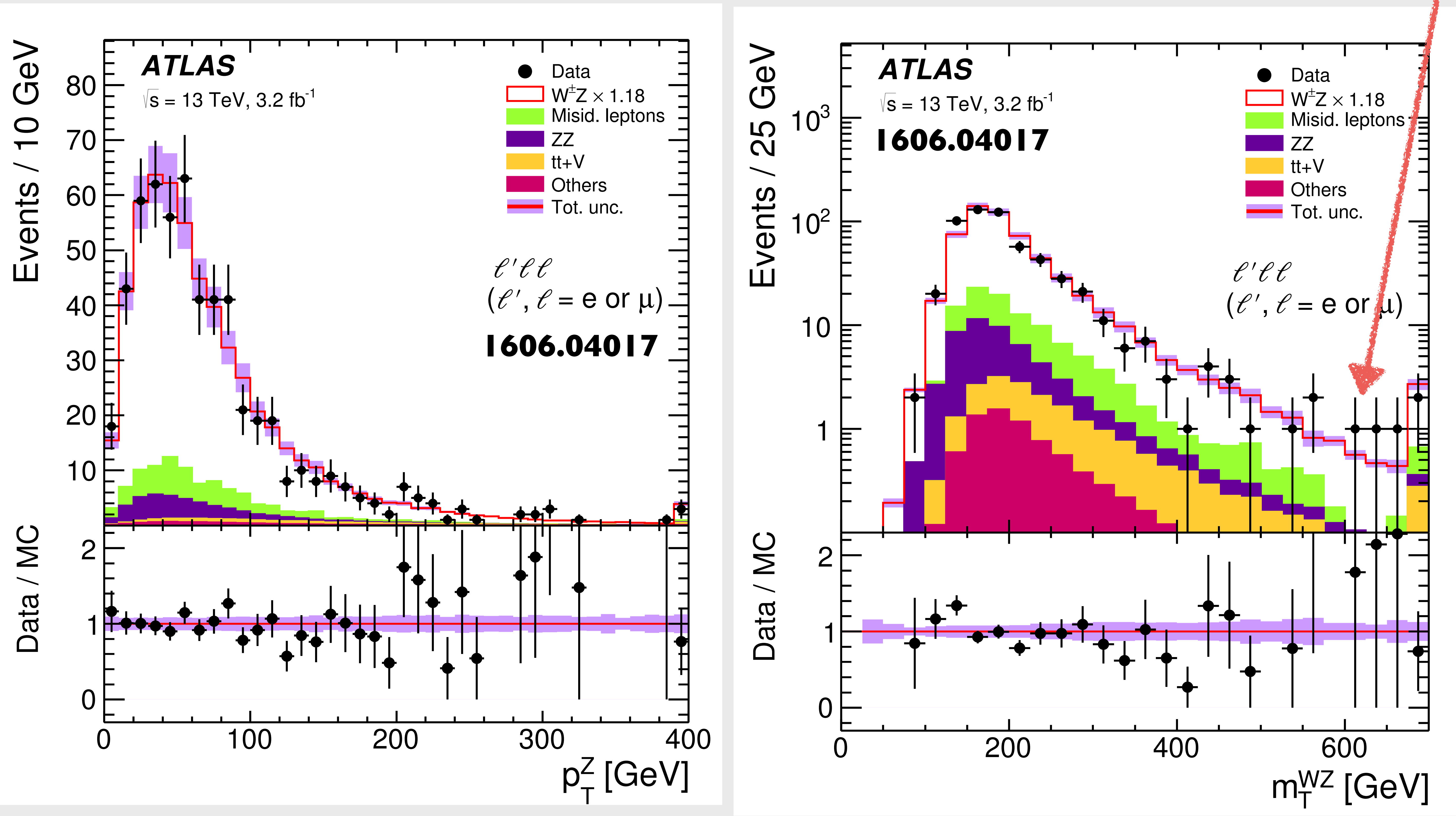




- at LO qq → V V is **3**⊕**1** of SU(2)
- antisymmetry of **3** at ***t=u*** makes qq → ZW be suppressed in the central region
- NLO corrections are important, but the LO effect is still noticeable

pp→ $Z^0W^{\pm}$

FAST-DROPPING RATE!

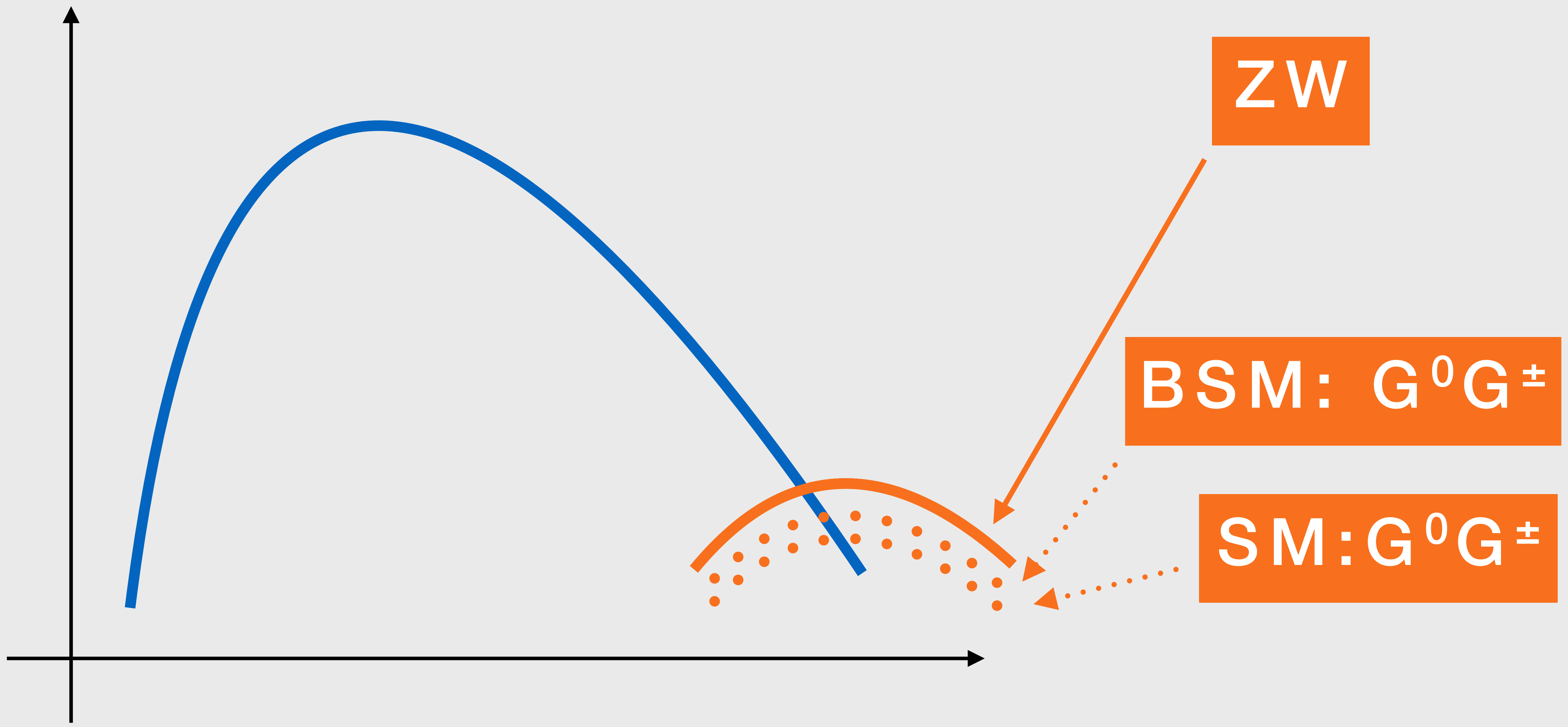


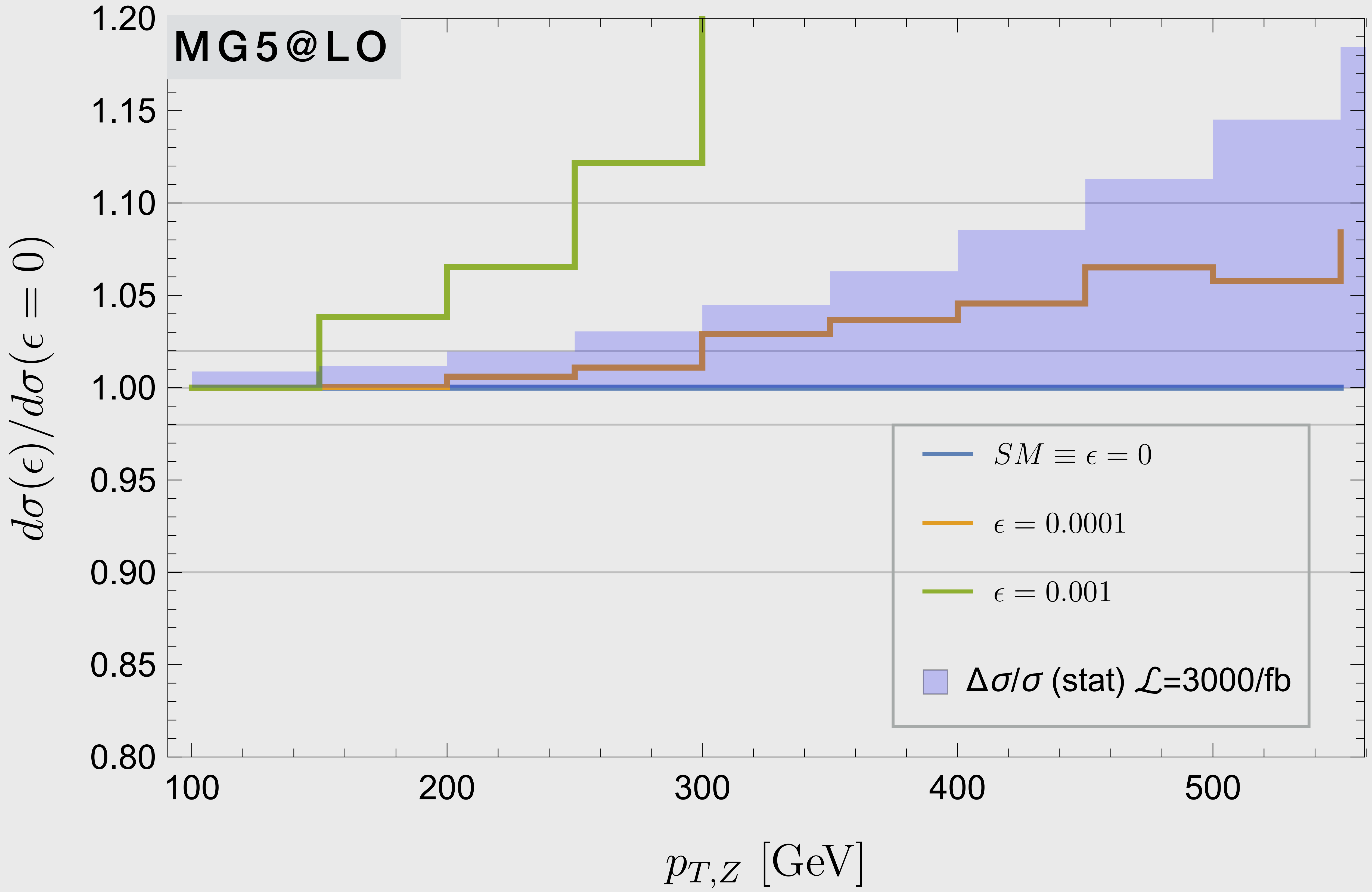
- $|\cos\theta^*_{WZ}| < 0.5$
- $\sigma \sim 0.1$ fb for $p_{TZ} > 200$ GeV

High Luminosity LHC

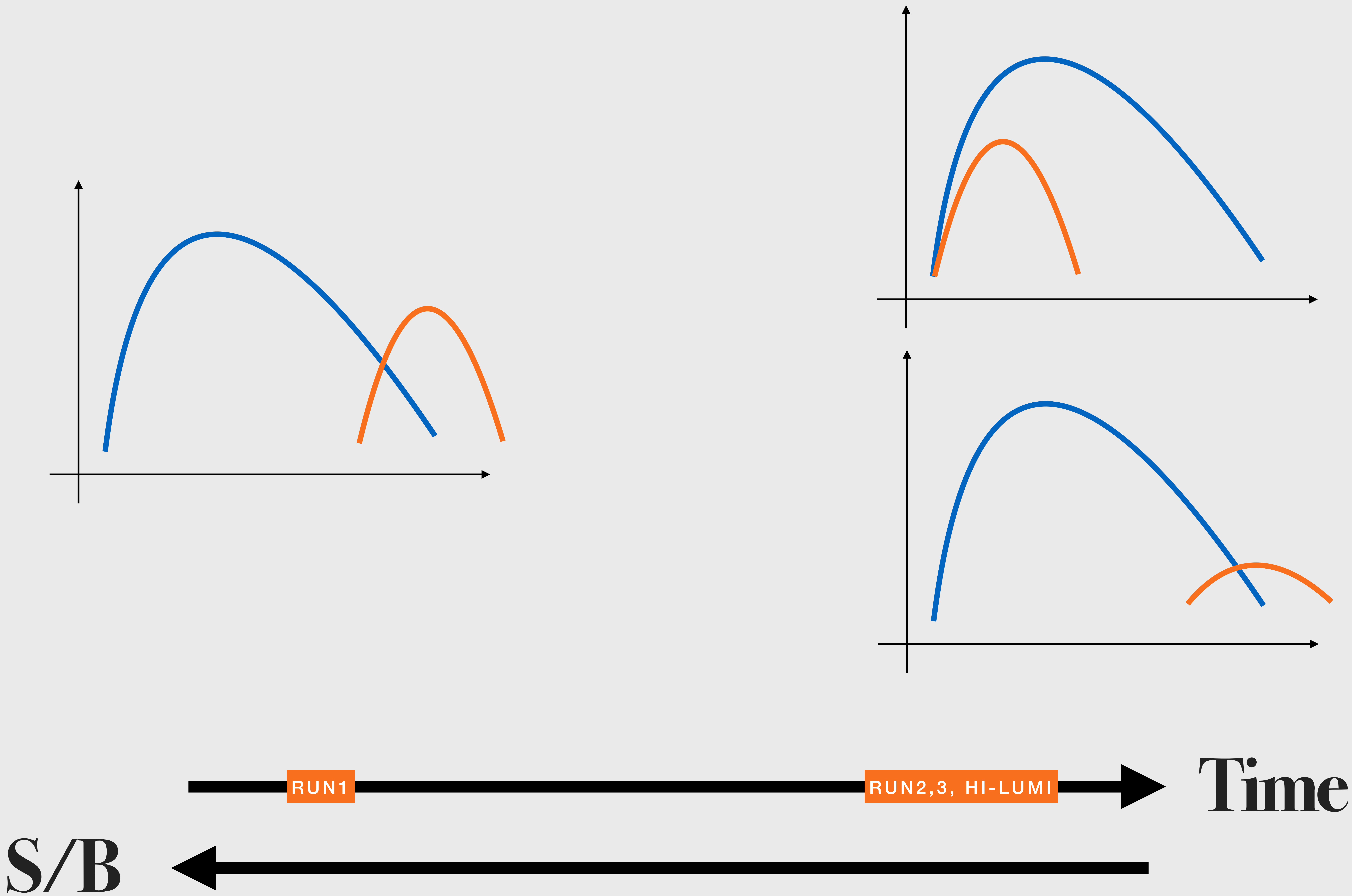
$pp \to Z^0W^\pm$

- $(c_{Hq} / \Lambda^2)\ (q_L \gamma^\mu \sigma^a q_L)(HD_{\mu,a}H)$
- $\varepsilon \sim v^2/\Lambda^2$





LHC, thanks to energy and large lumi, can catch O(10%) effects in TeV tails: a probe of new physics in EWSB at LEP-level.


RUN1
RUN2,3, HI-LUMI
Time
S/B

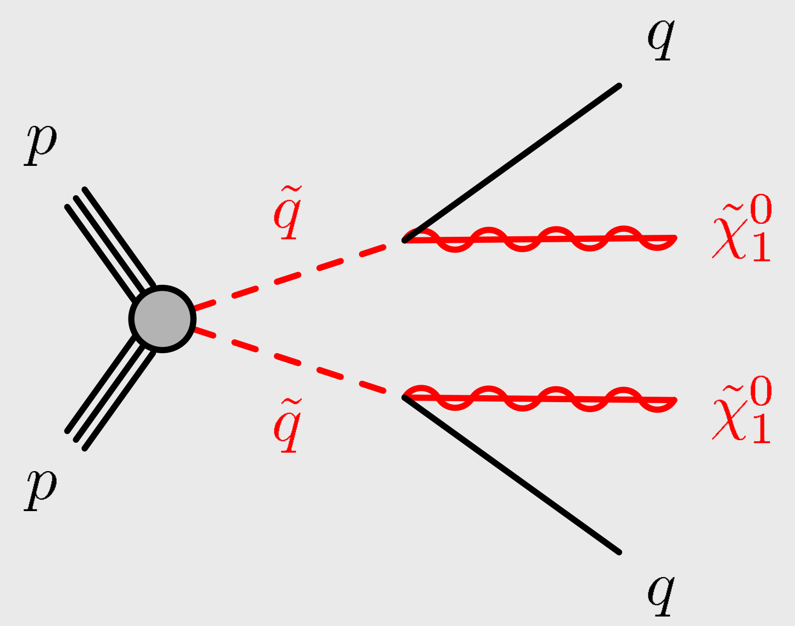
Conclusions

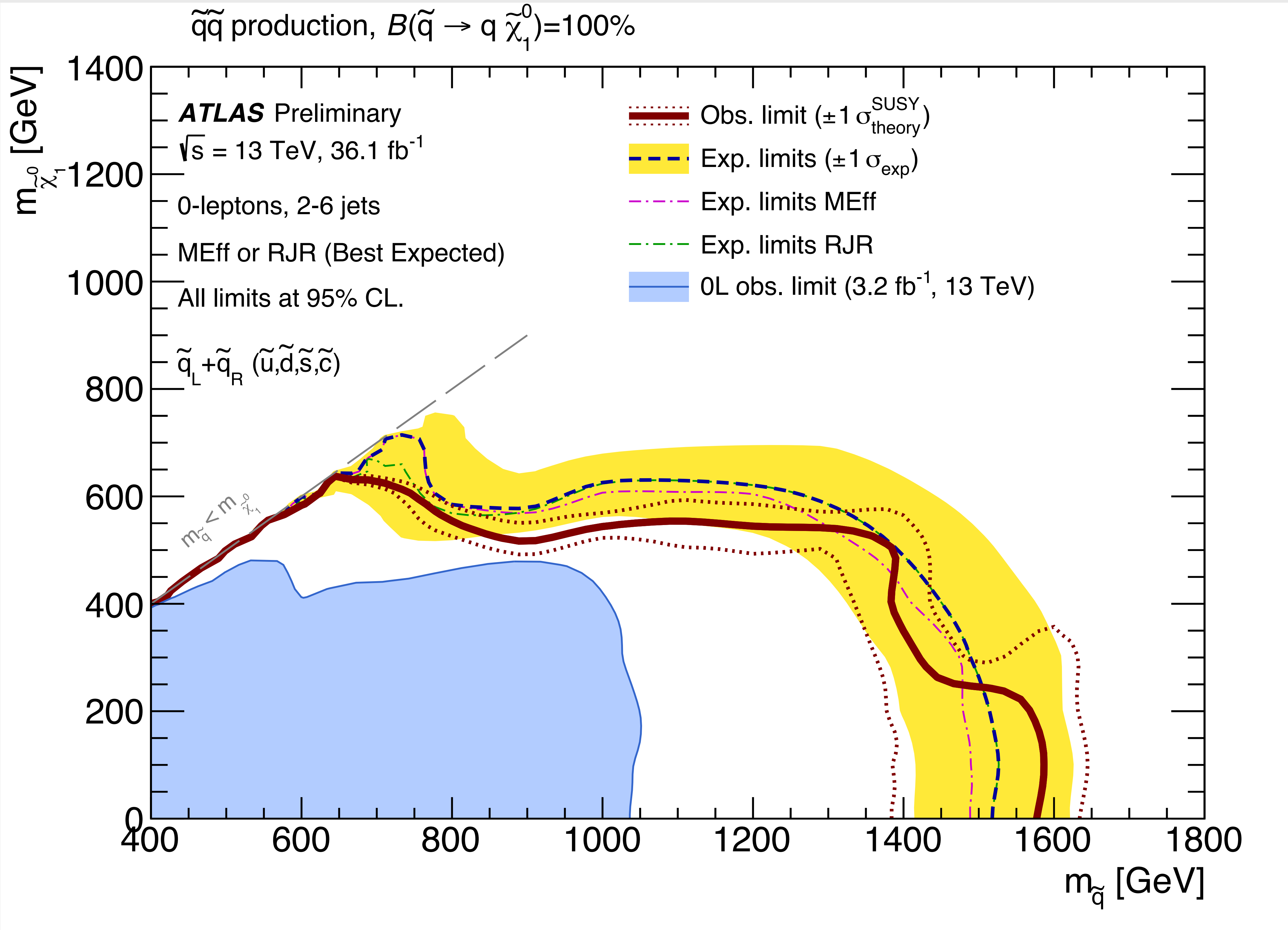
- in the NNLO QCD epoch, SM differential distribution are powerful probes of BSM
- top quark precision is sweet-spot for BSM motivation and QCD precision
- results for $\mathbf{m_{b\ell}}$ distribution are very promising for $\tilde{t},\chi^+,\chi^0$ SUSY spectra
- di-boson precision at high-energy sensitive probe of Goldstone bosons
- pp$\rightarrow$ **ZW** might deliver limits at HL-LHC that can reach LEP on weakly coupled BSM

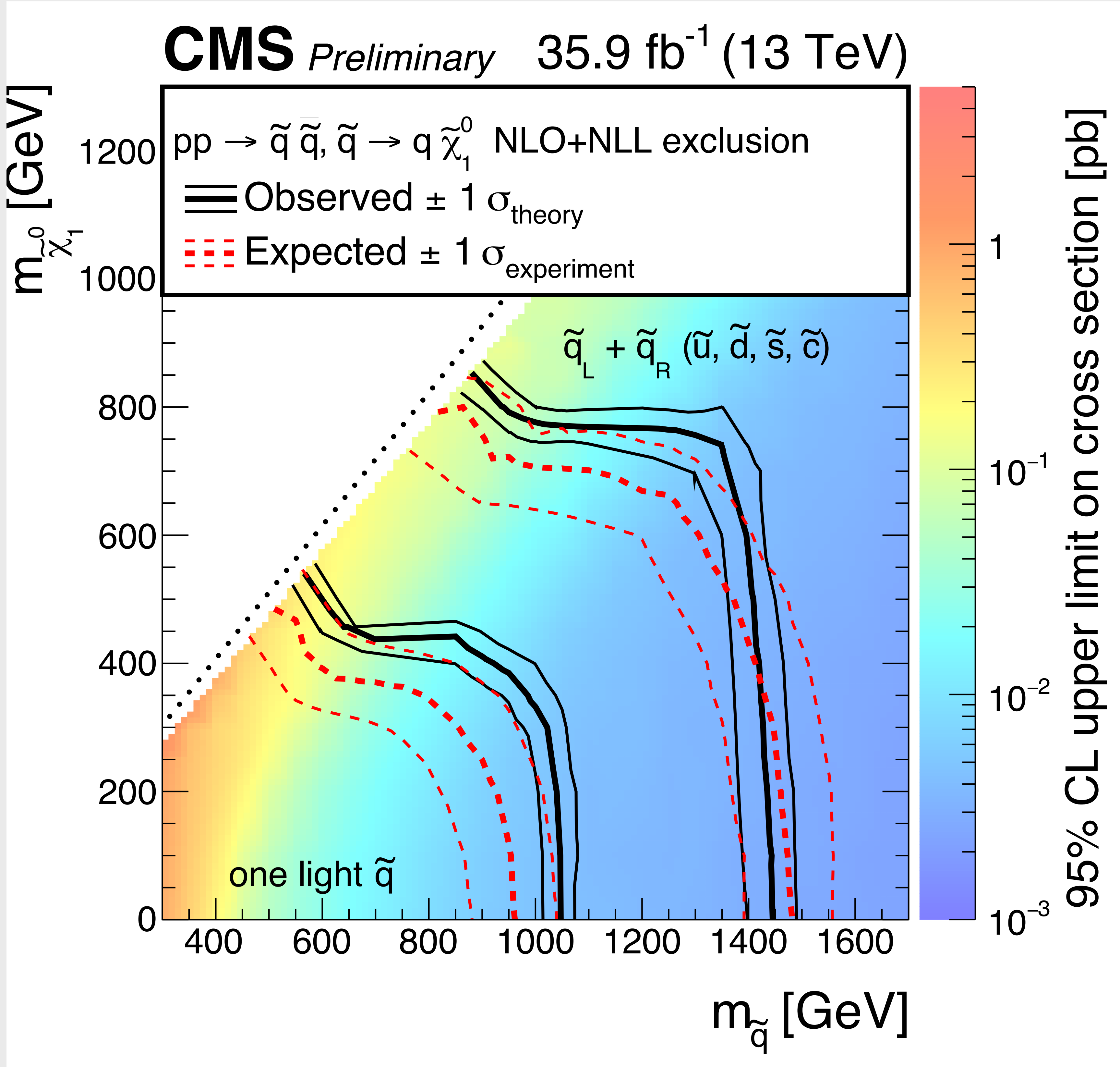
Thank You!

Standard Signatures

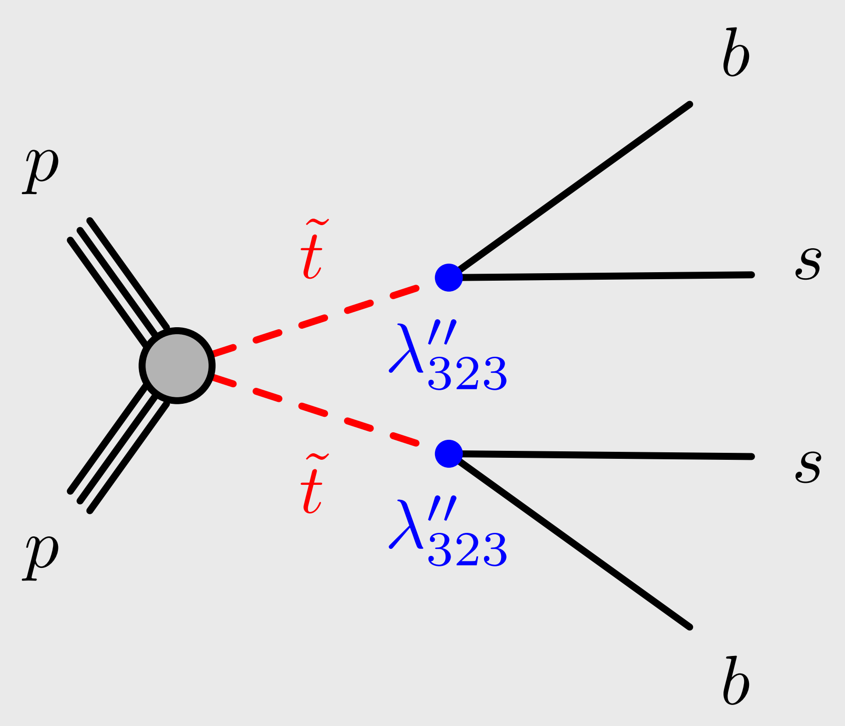
APPLIES TO DIRAC GAUGINOS

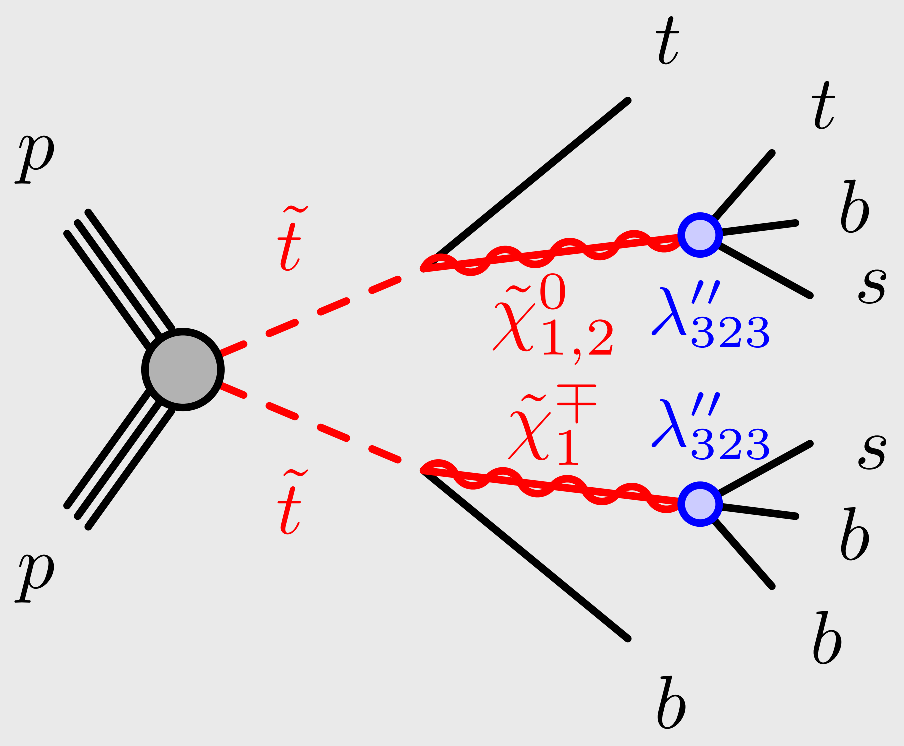


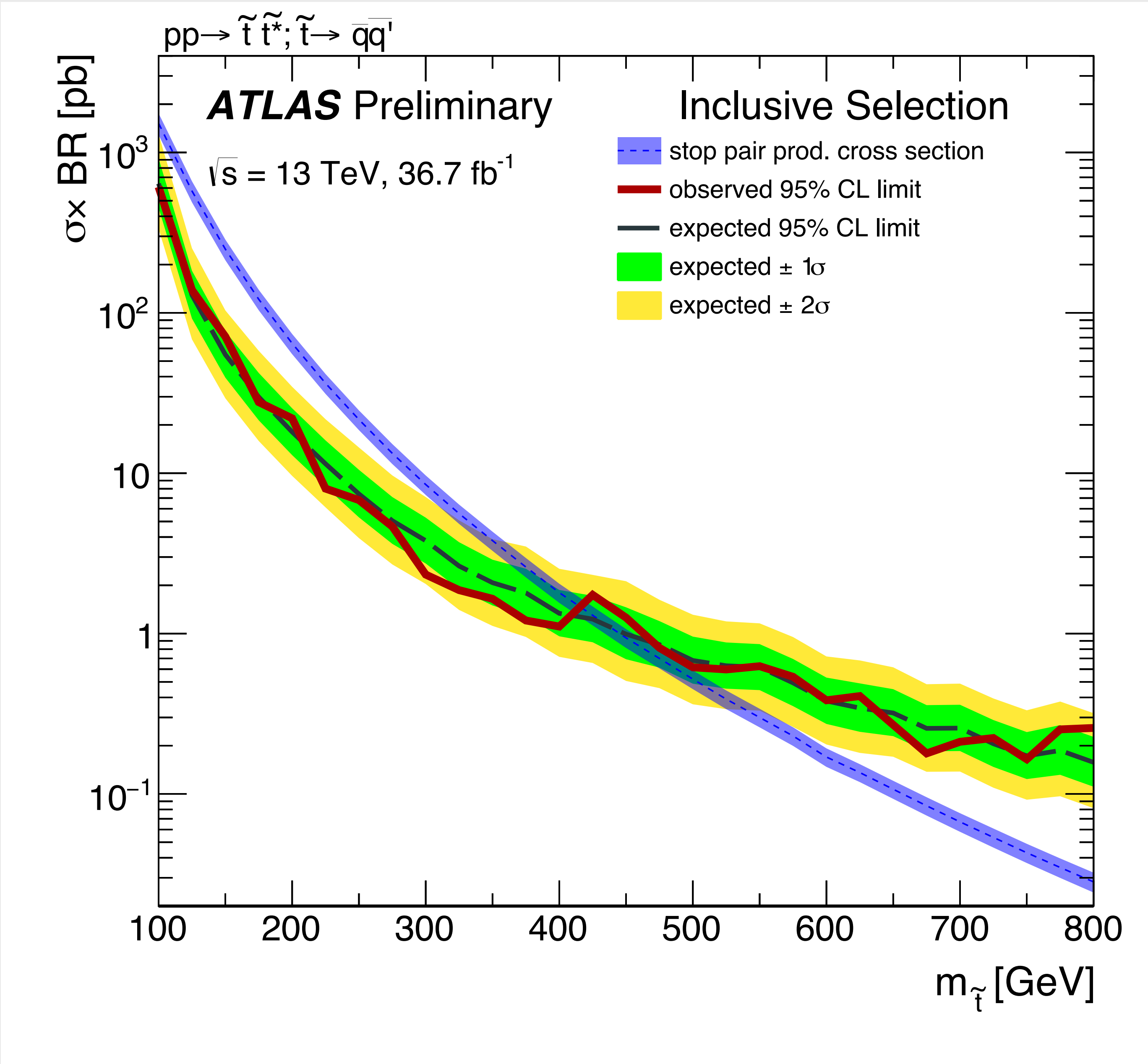


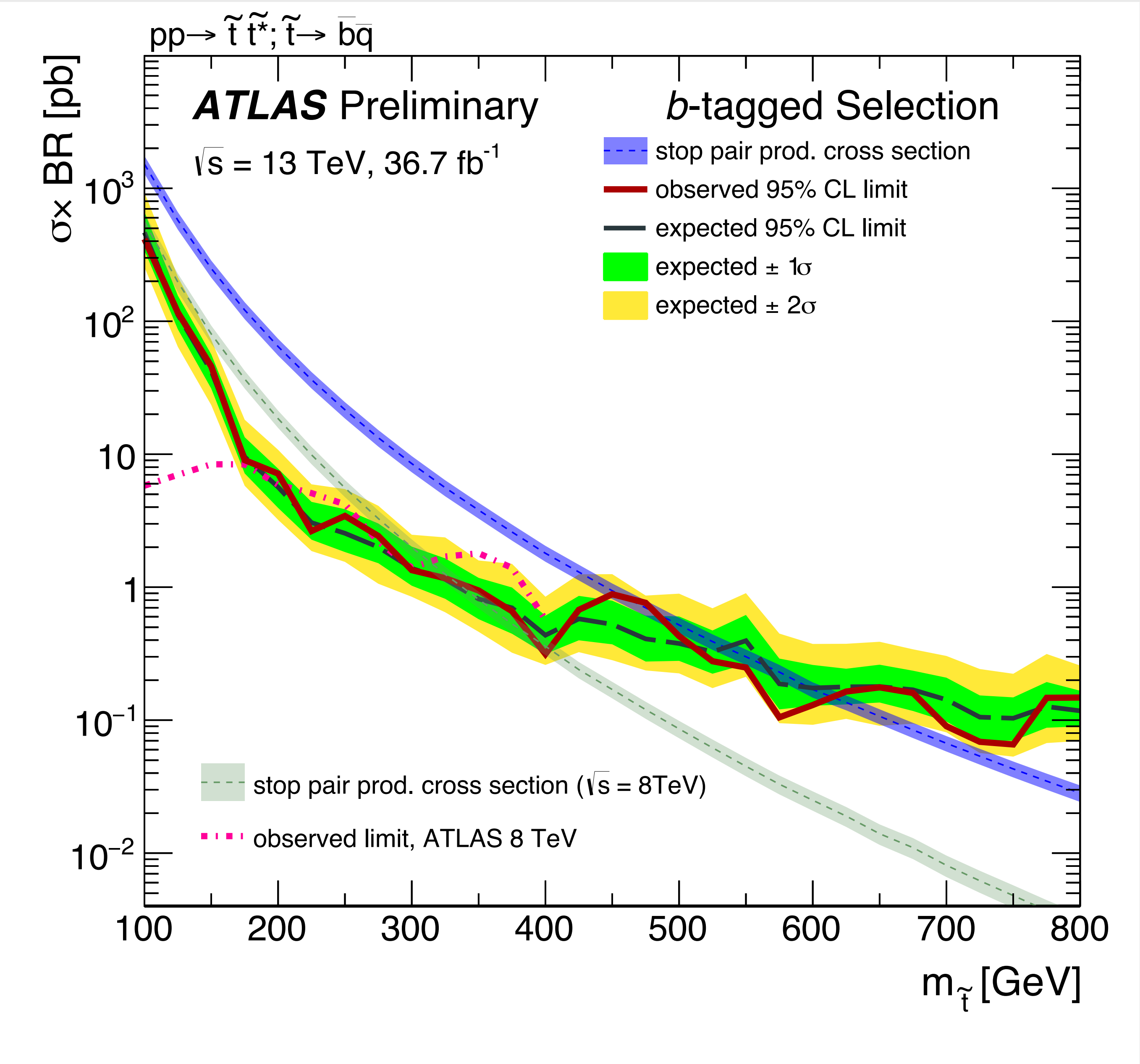


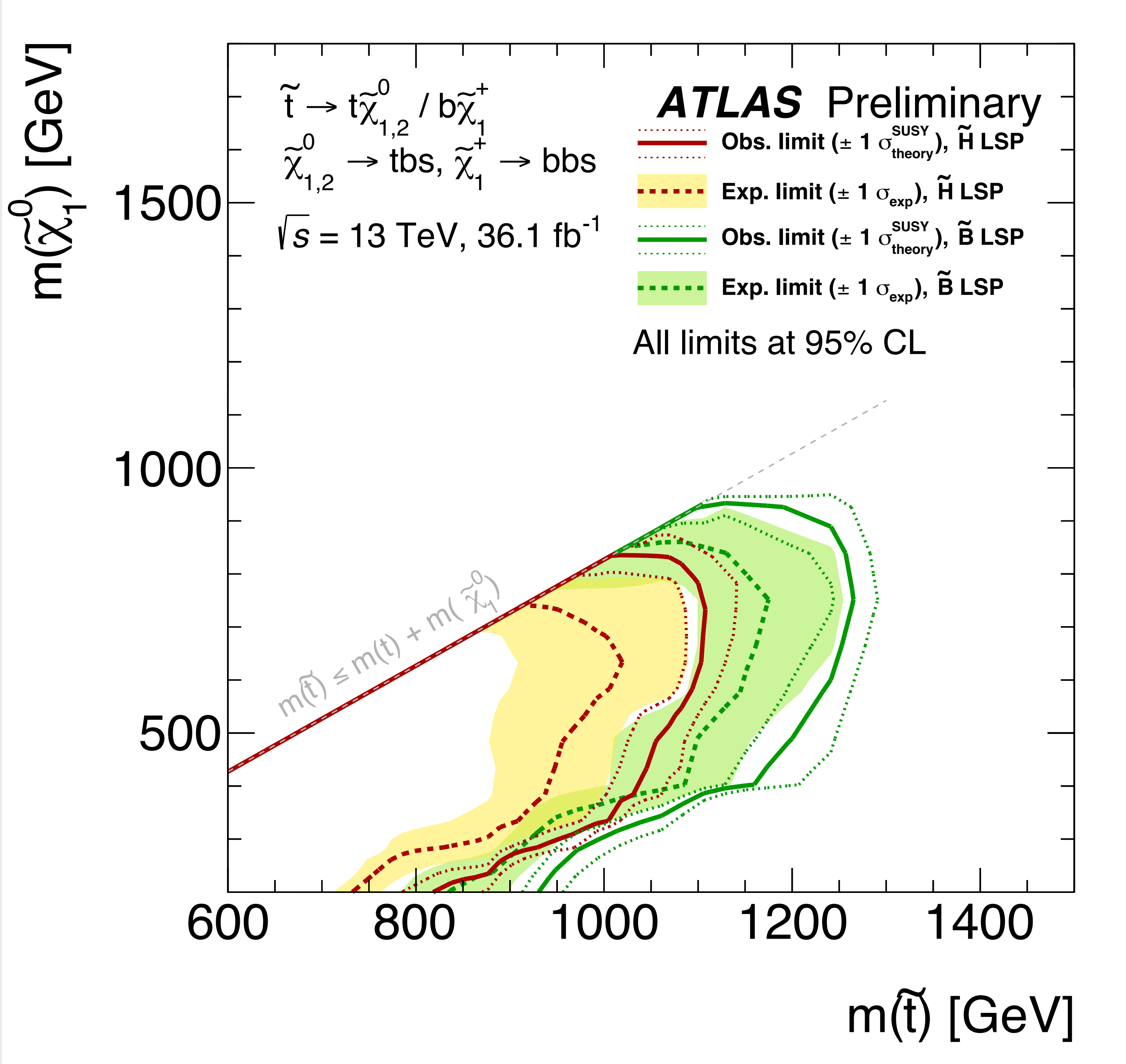
R-Parity Violation







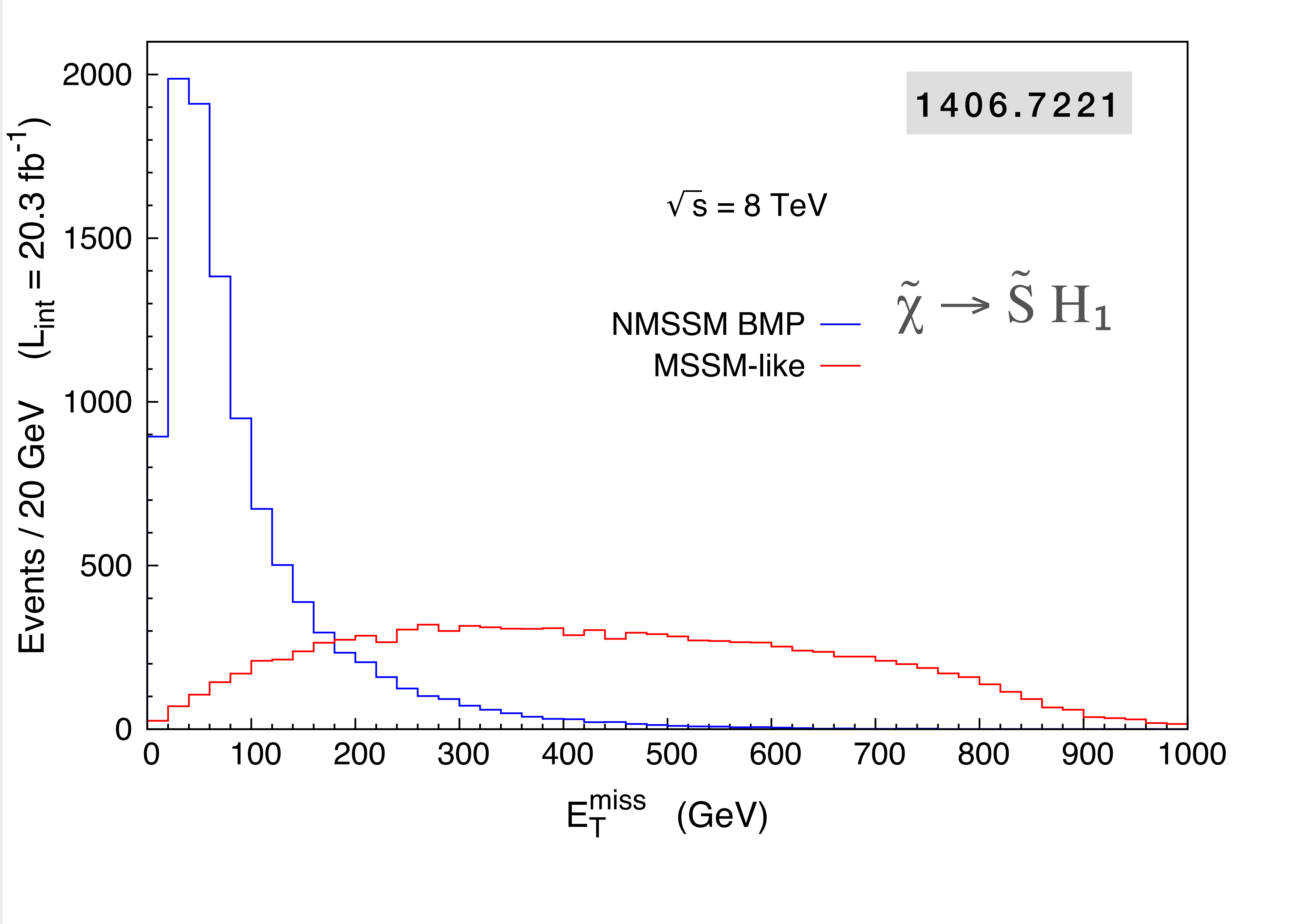


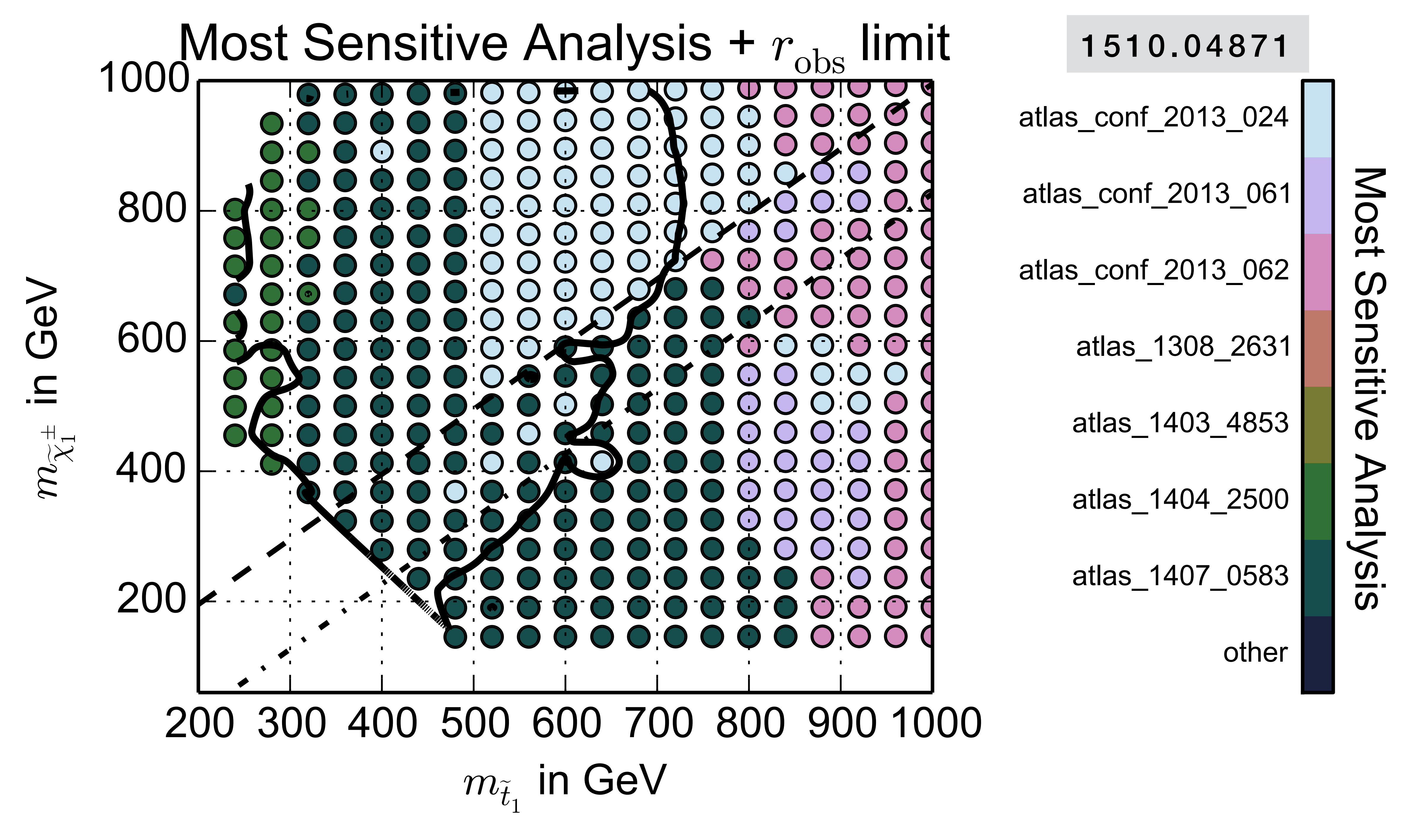


Softer

EACH MODIFICATION MAY NEED NEW AD-HOC SEARCHES

e.g. NMSSM light Singlino: extra bb-resonance in a generic SUSY search

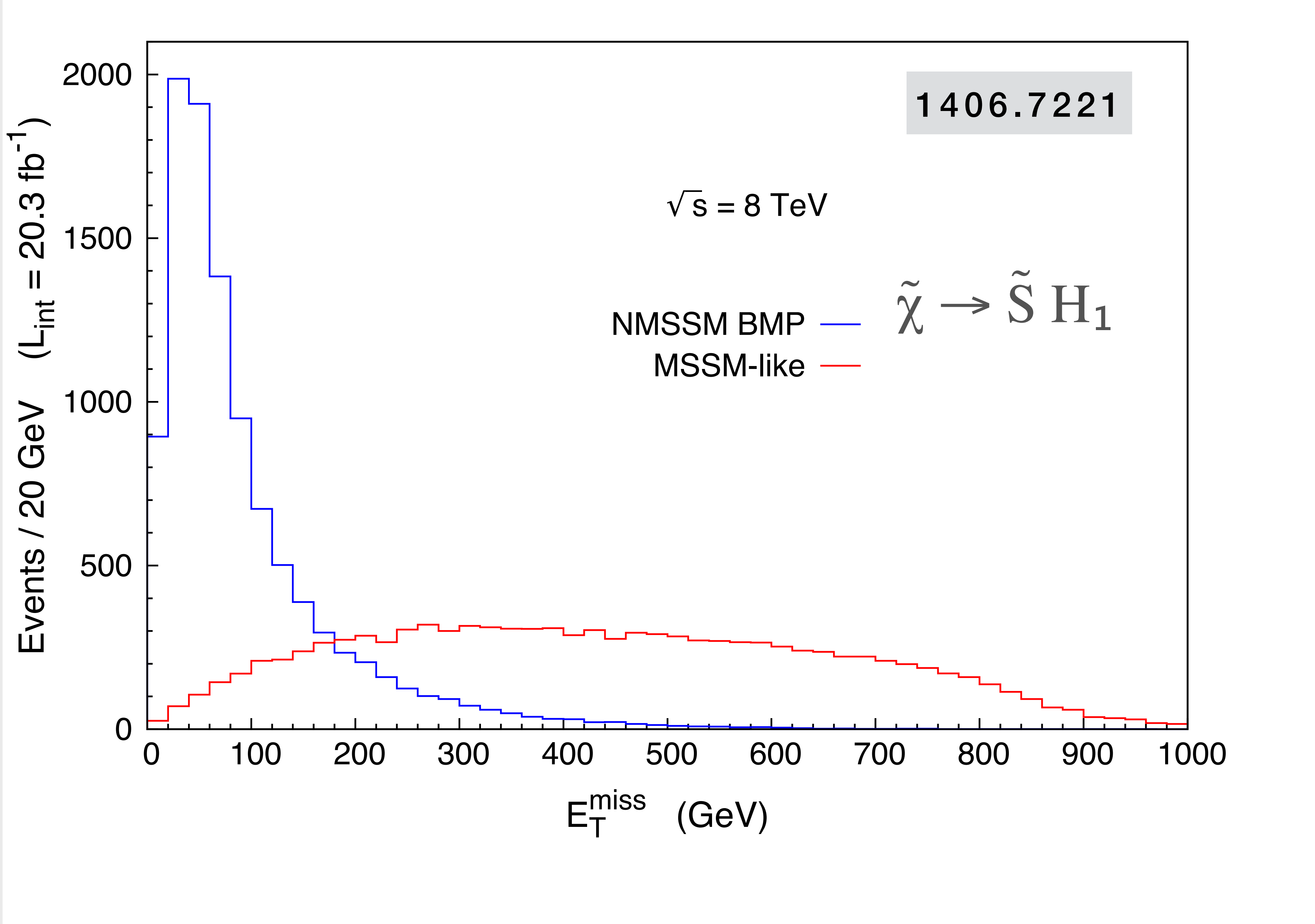


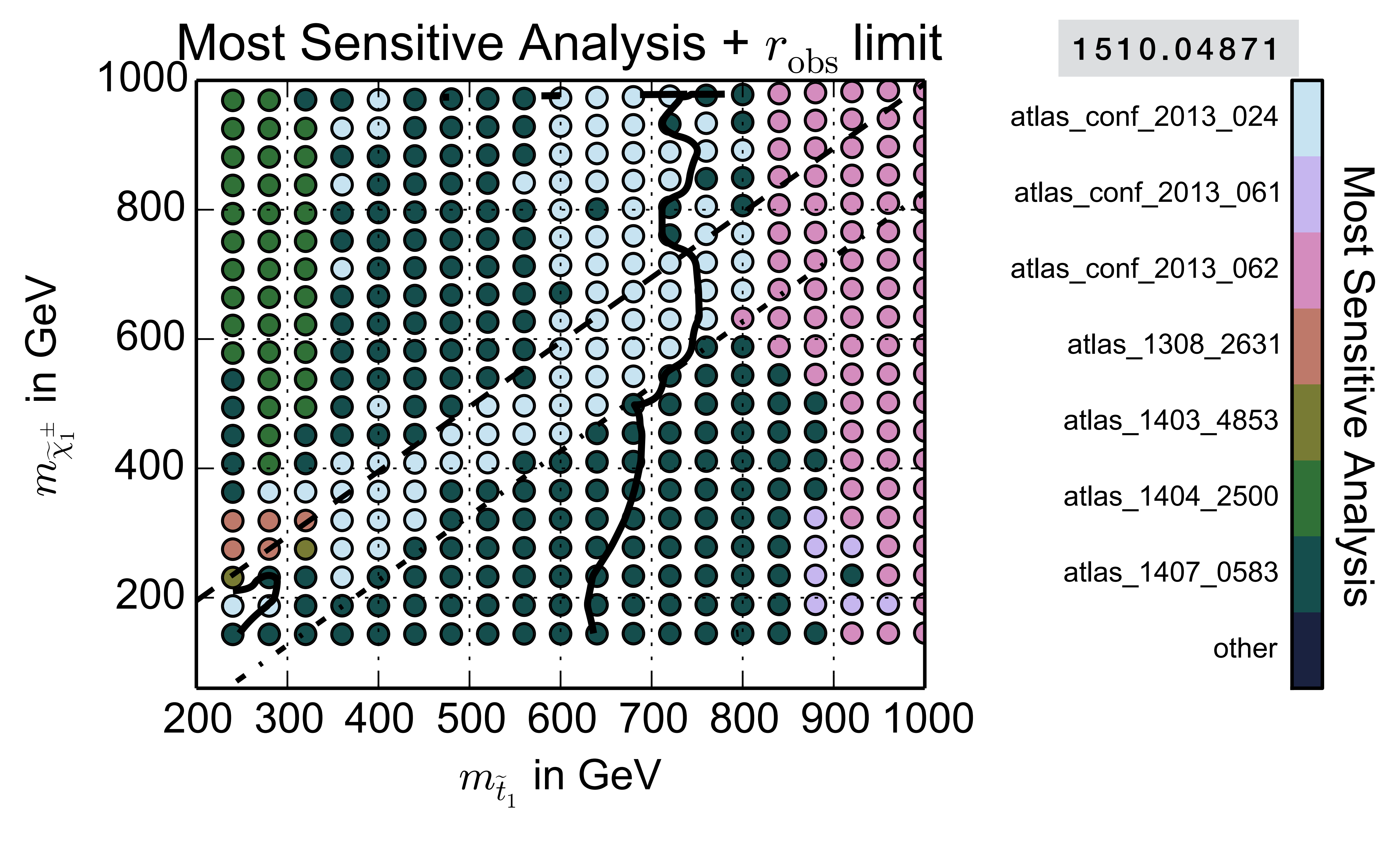


Softer

EACH MODIFICATION MAY NEED NEW AD-HOC SEARCHES

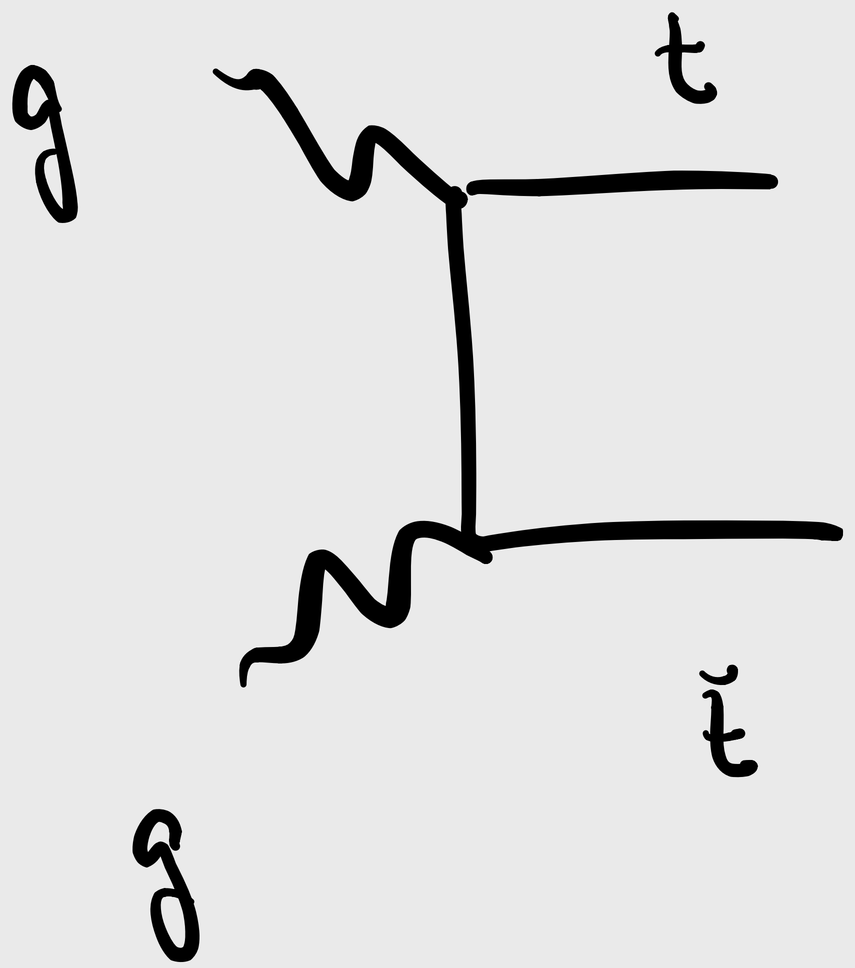
e.g. NMSSM light Singlino: extra bb-resonance in a generic SUSY search

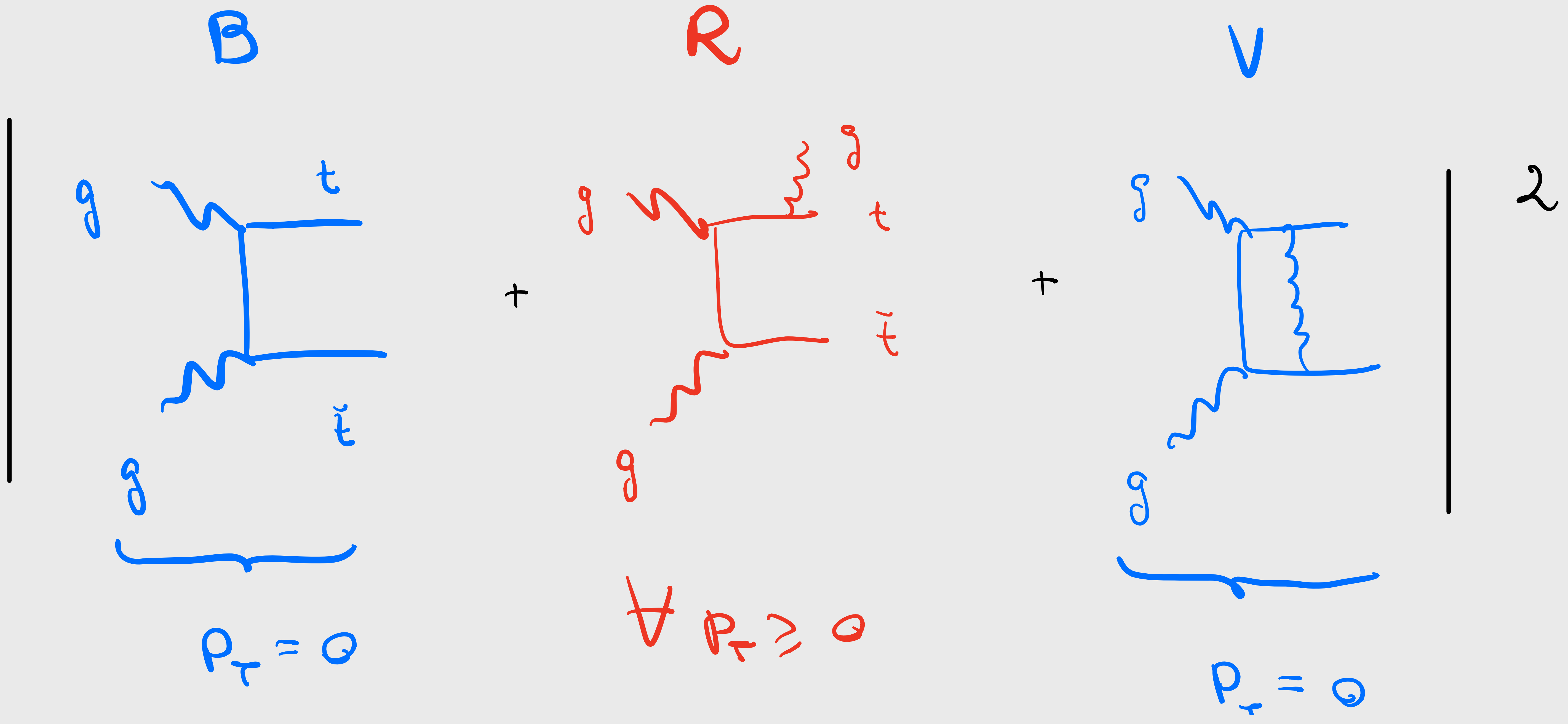




A Closer Look At Scale Uncertainties

NLO + PARTON SHOWER | POWHEG V2 | POWHEG-RES



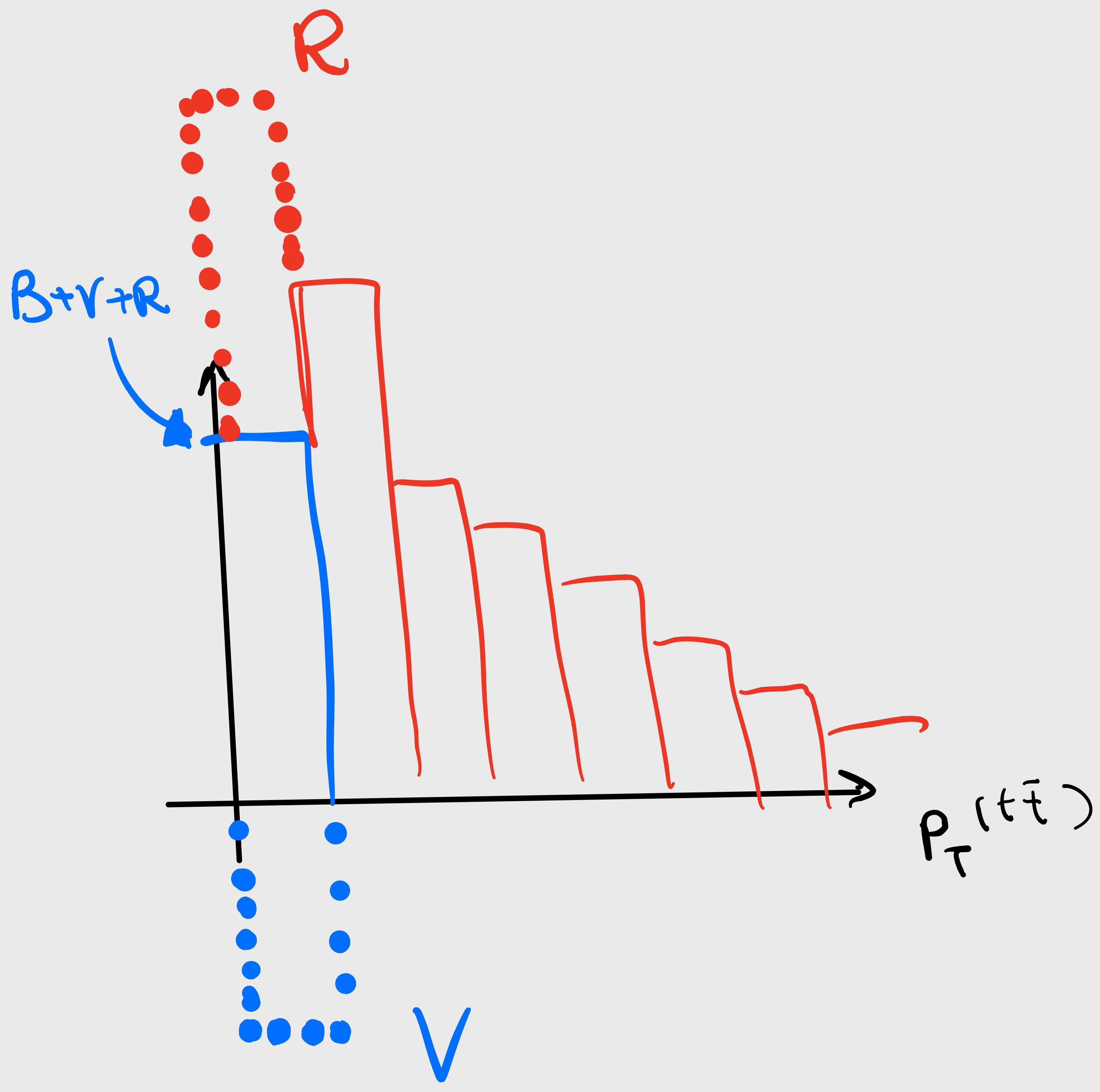


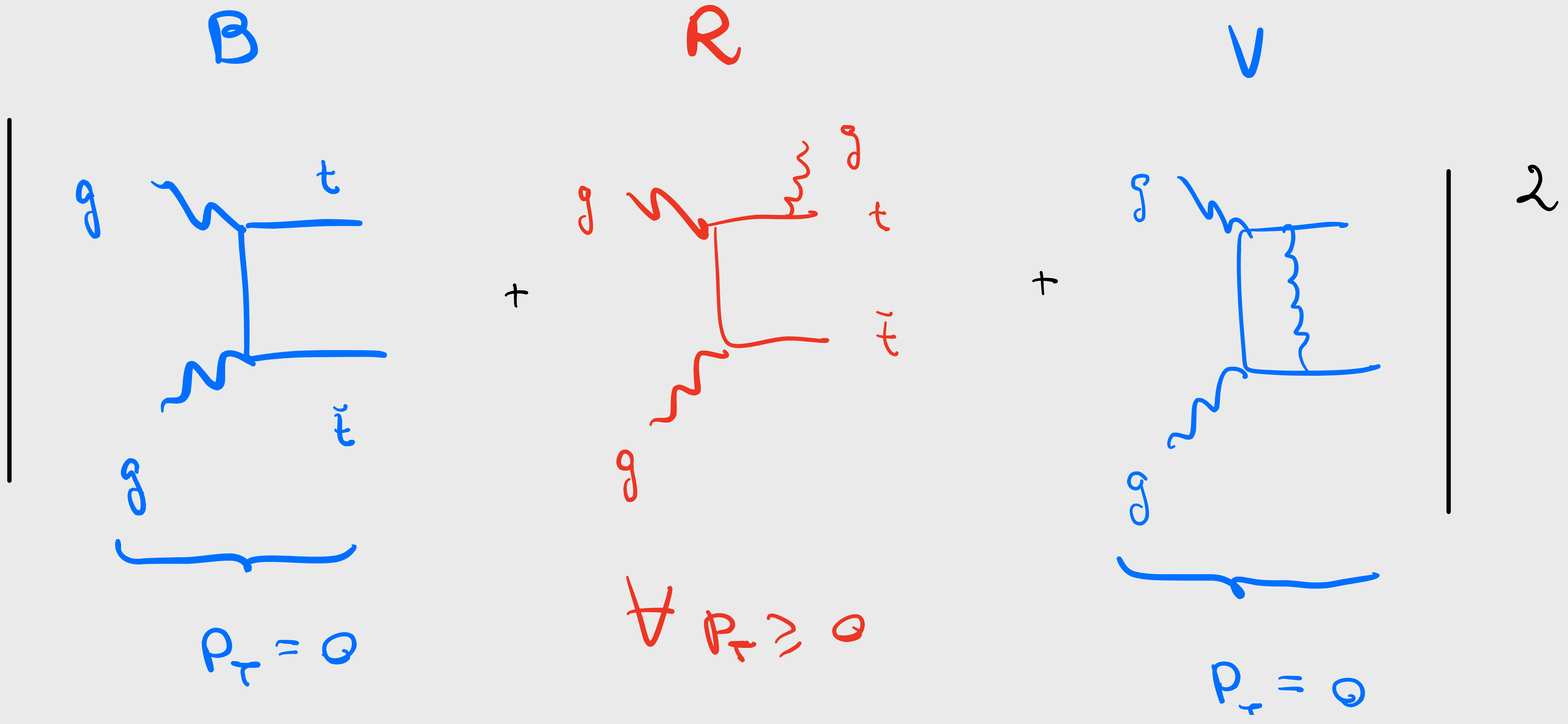
A Closer Look At Scale Uncertainties

NLO + PARTON SHOWER

POWHEG V2

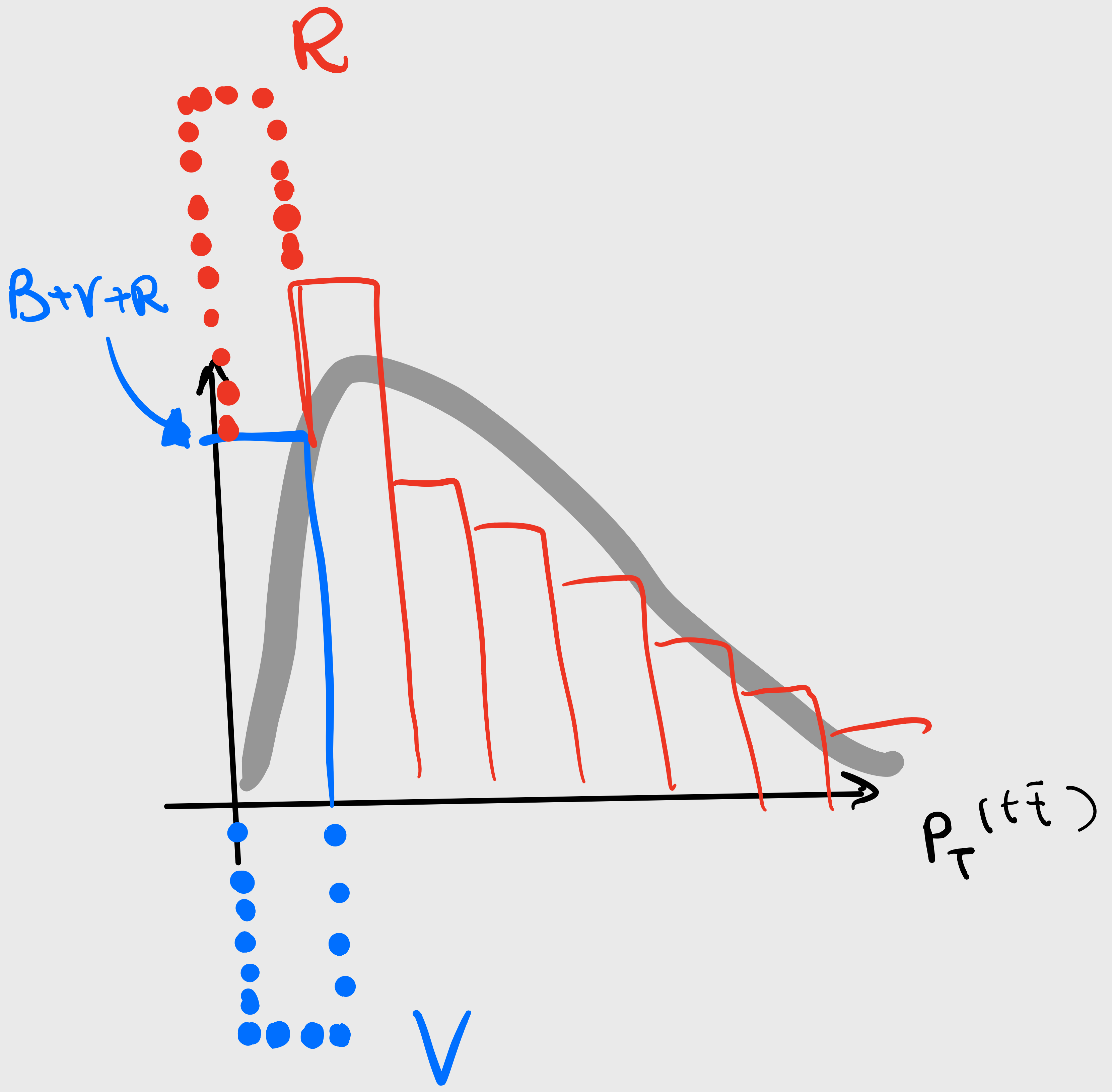
POWHEG-RES

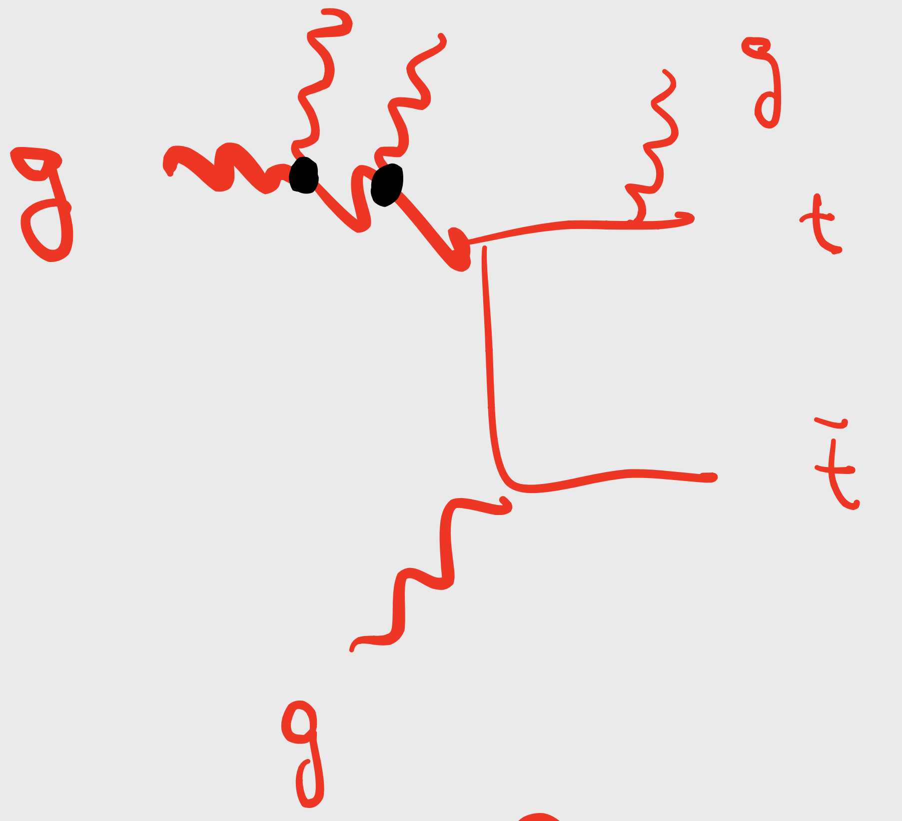


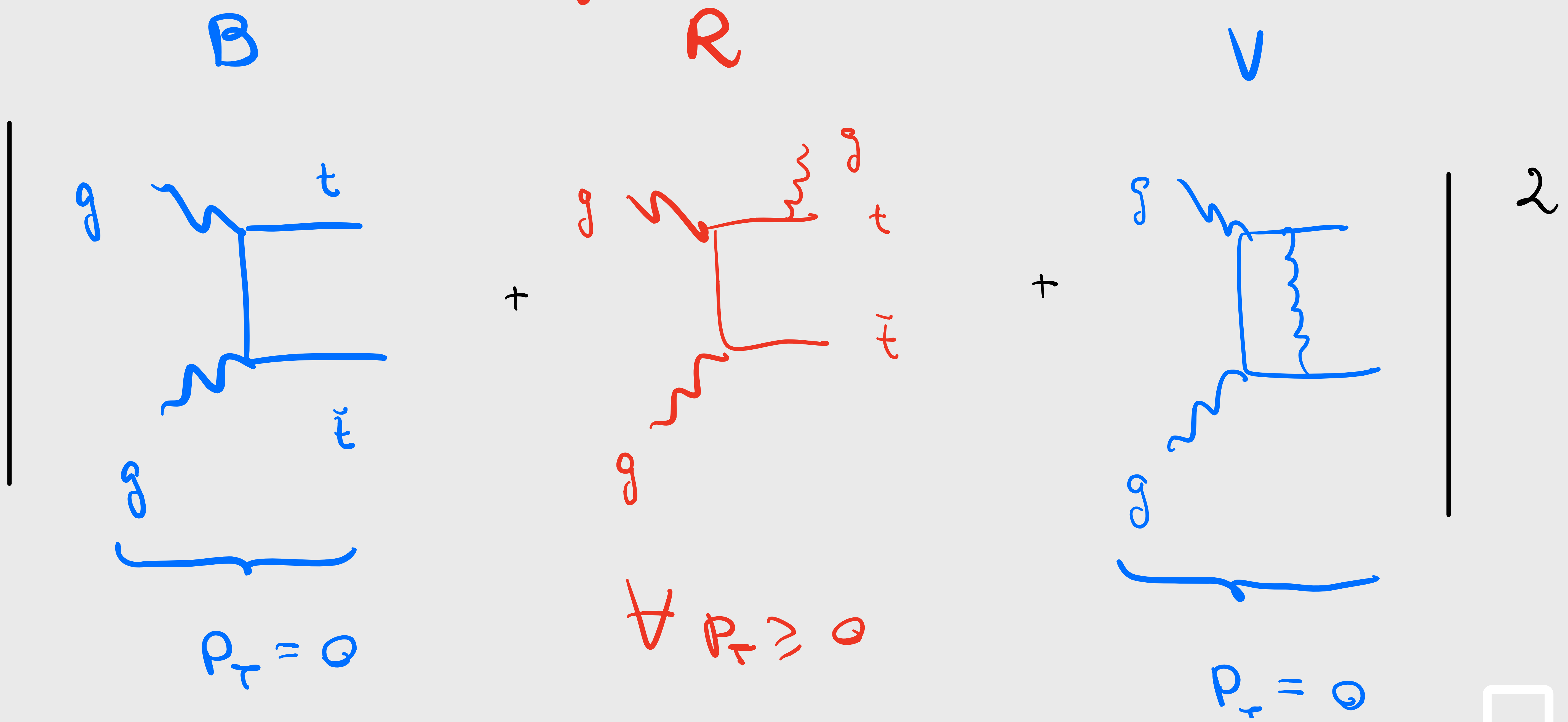


A Closer Look At Scale Uncertainties

NLO + PARTON SHOWER | POWHEG V2 | POWHEG-RES



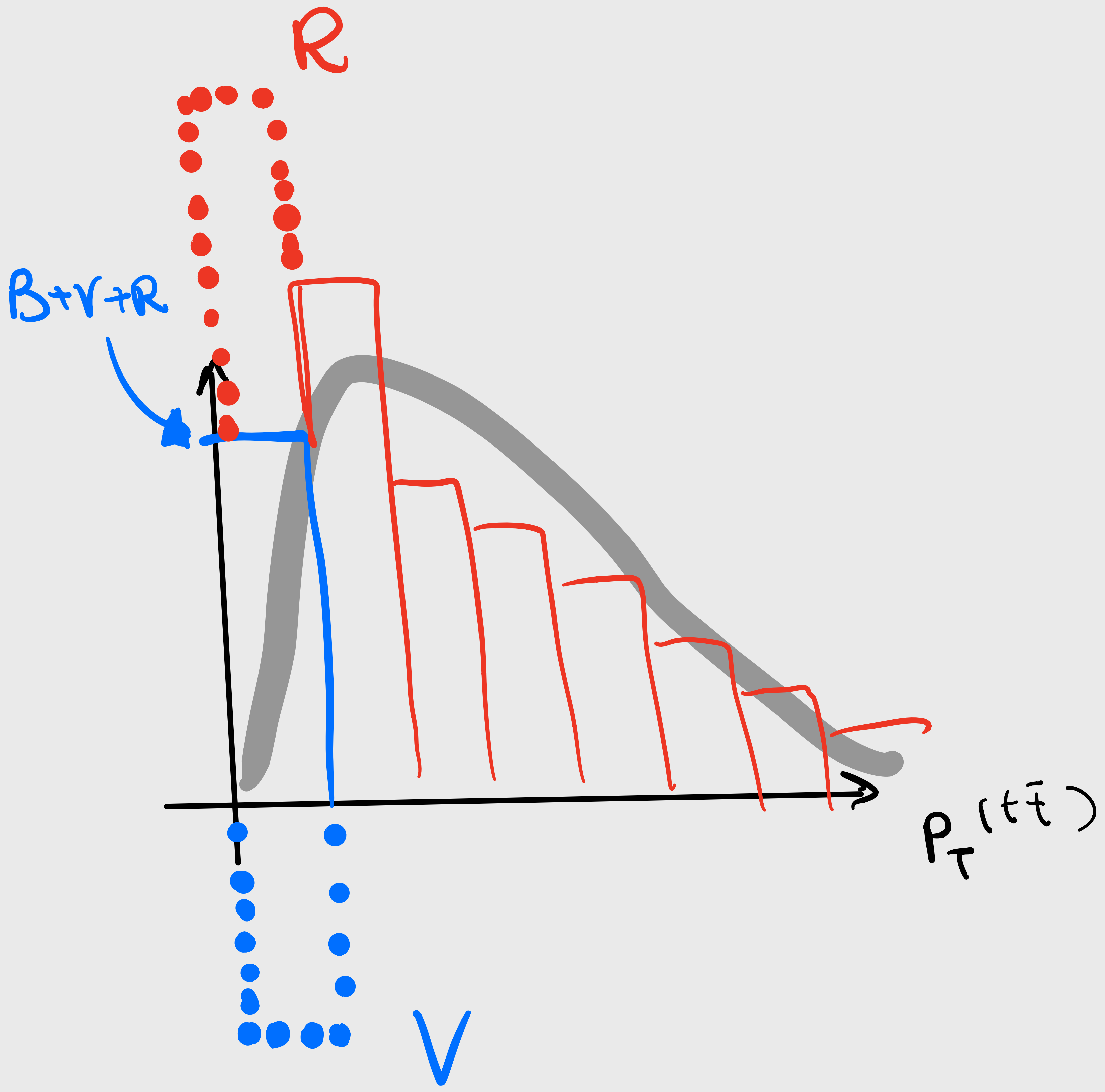




$$\sigma = B\left[1 + \frac{\alpha_s}{\pi}\log^2\left(\frac{p_T^2}{Q^2}\right) + \dots\right]$$

A Closer Look At Scale Uncertainties

NLO + PARTON SHOWER | POWHEG V2 | POWHEG-RES

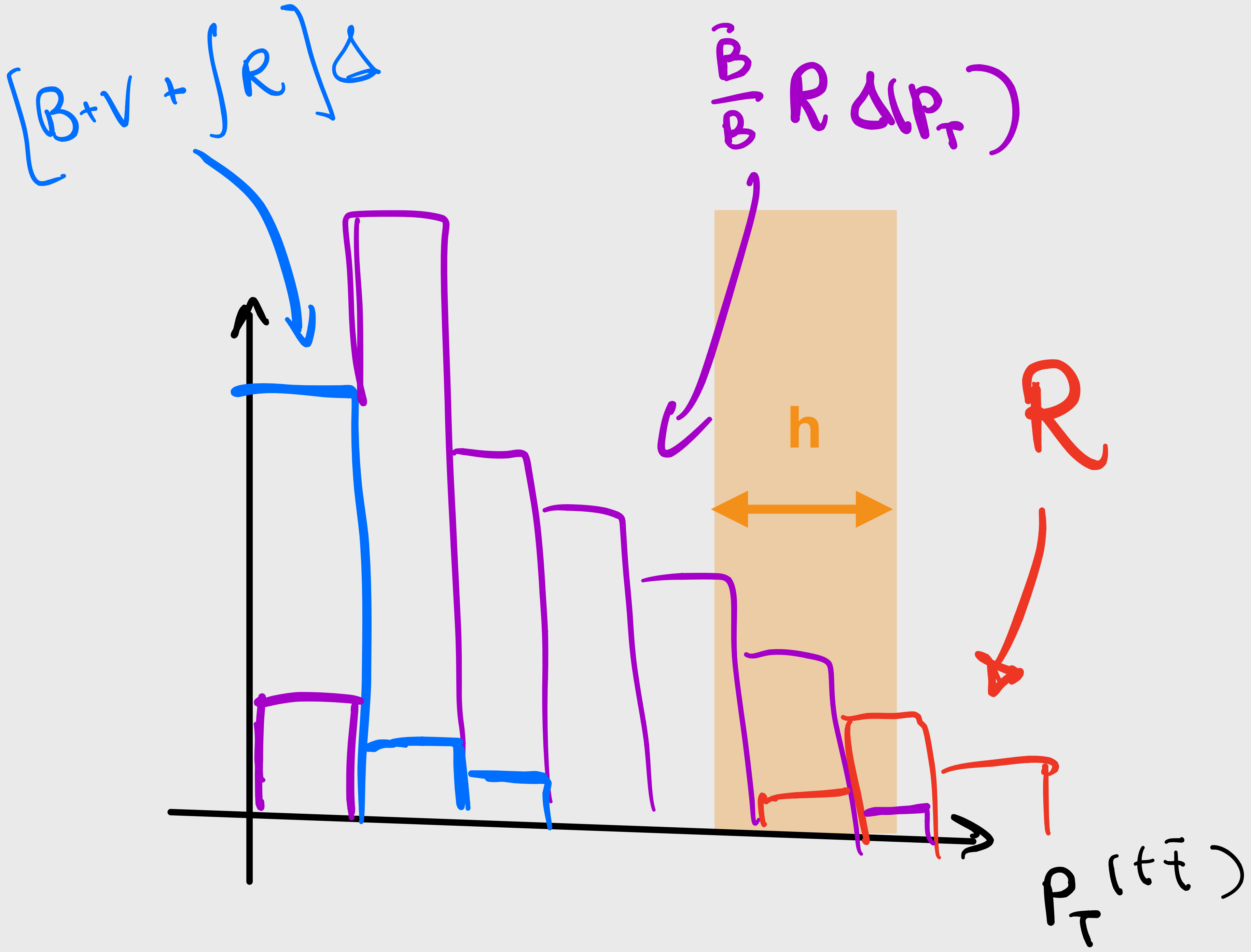


$$B\,d\phi_B + V\,d\phi_B + \int_0^{\epsilon} R\,d\phi_R$$

$$\underbrace{\left[B\,d\phi_B + V\,d\phi_B + \int_0^{\infty} R\,d\phi_R\right]}_{\bar{B}\,d\phi_B}\,\Delta(Q^0)$$

A Closer Look At Scale Uncertainties

NLO + PARTON SHOWER (1202.1251) | POWHEG V2 (1412.1828) | POWHEG-RES (1607.04538)

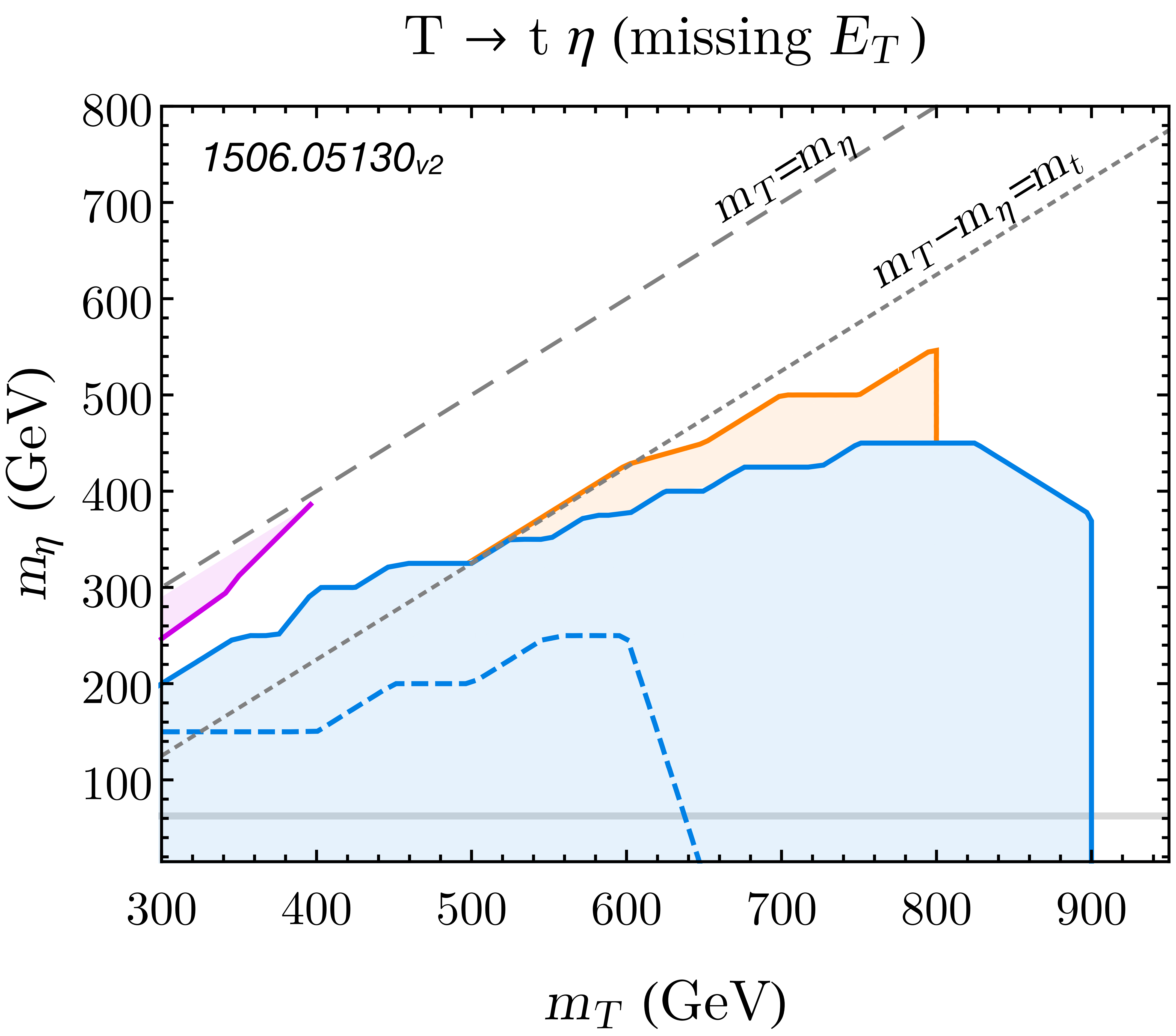


$$\bar{B}\cdot\left[\Delta(Q_0) + \frac{R}{B}\Delta(p_T)\,d\phi_{2nd}\right] d\phi_B$$

$$\bar{B}\cdot\left[\Delta(Q_0) + \frac{R}{B}\Delta(p_T)\,d\phi_{2nd}\,H\right] d\phi_B + R\,d\phi_R\,(1-H)$$

$H=h^2/(h^2+p_T^2)$ | $h\to 0$ Fixed Order | $h\to\infty$ Parton Shower + Matrix Element

Non Standard Top Partners Decay

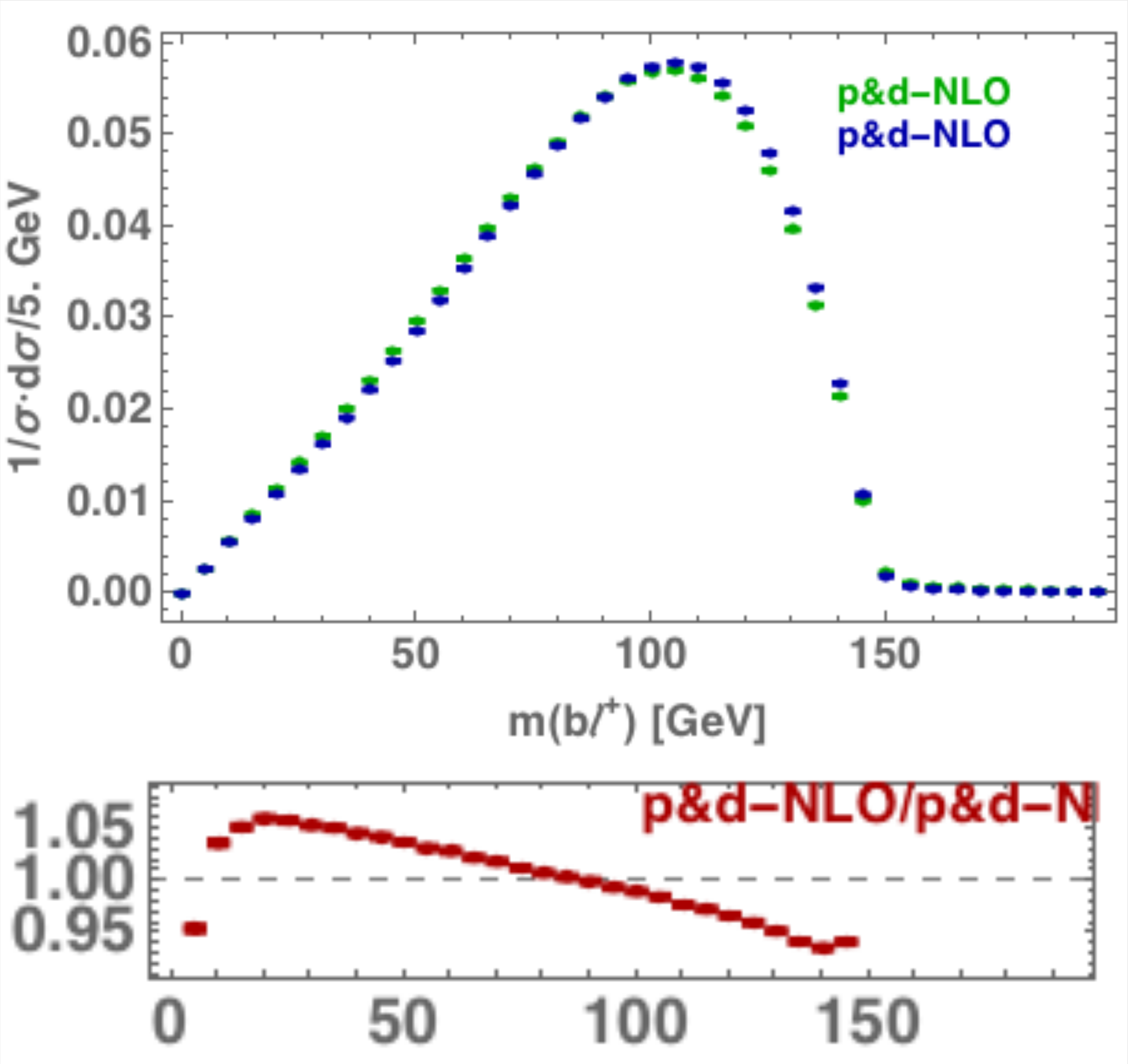


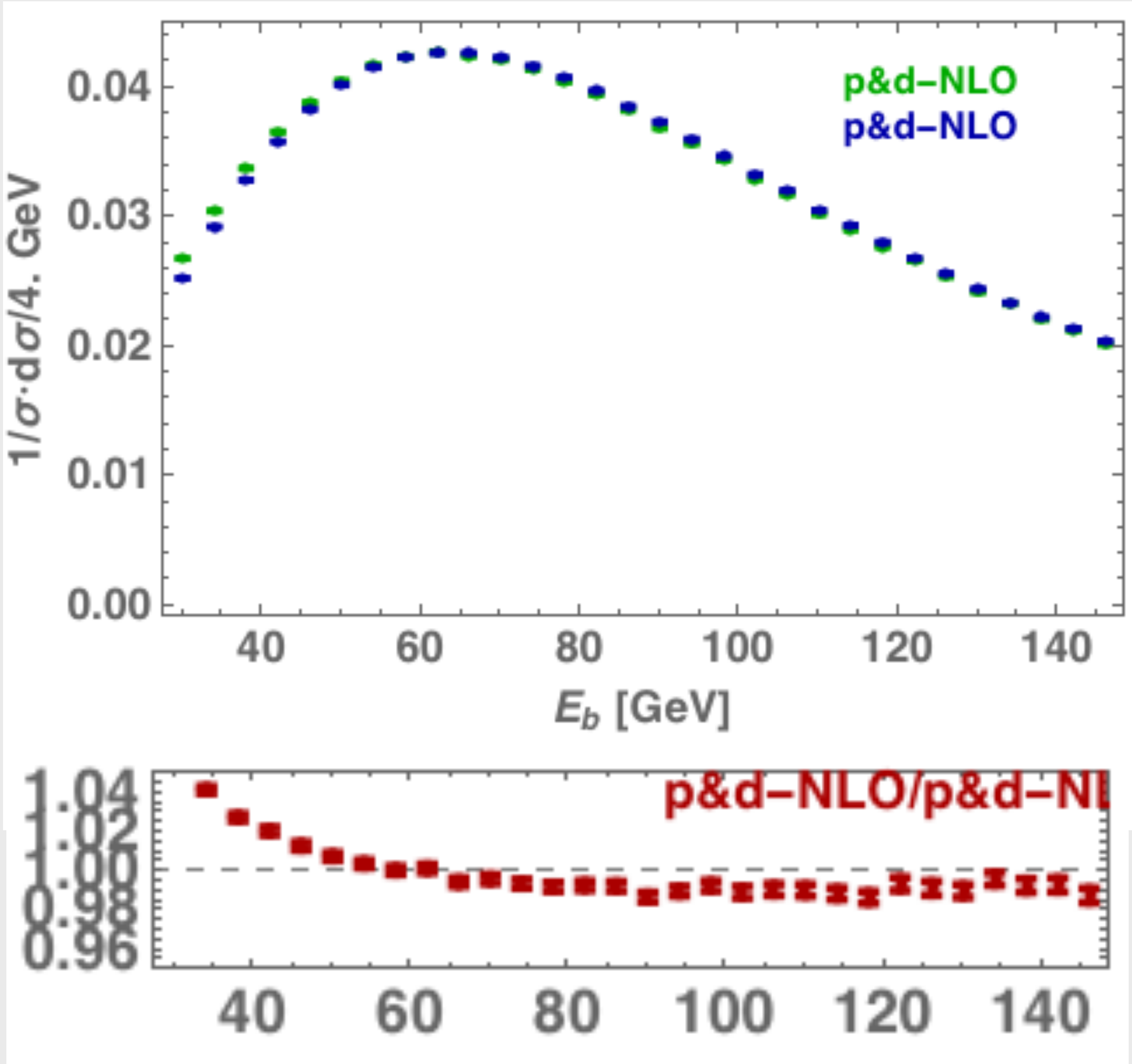
1506.05130

A First Look At Scale Uncertainties

NLO FIXED ORDER

MCFM 6.8

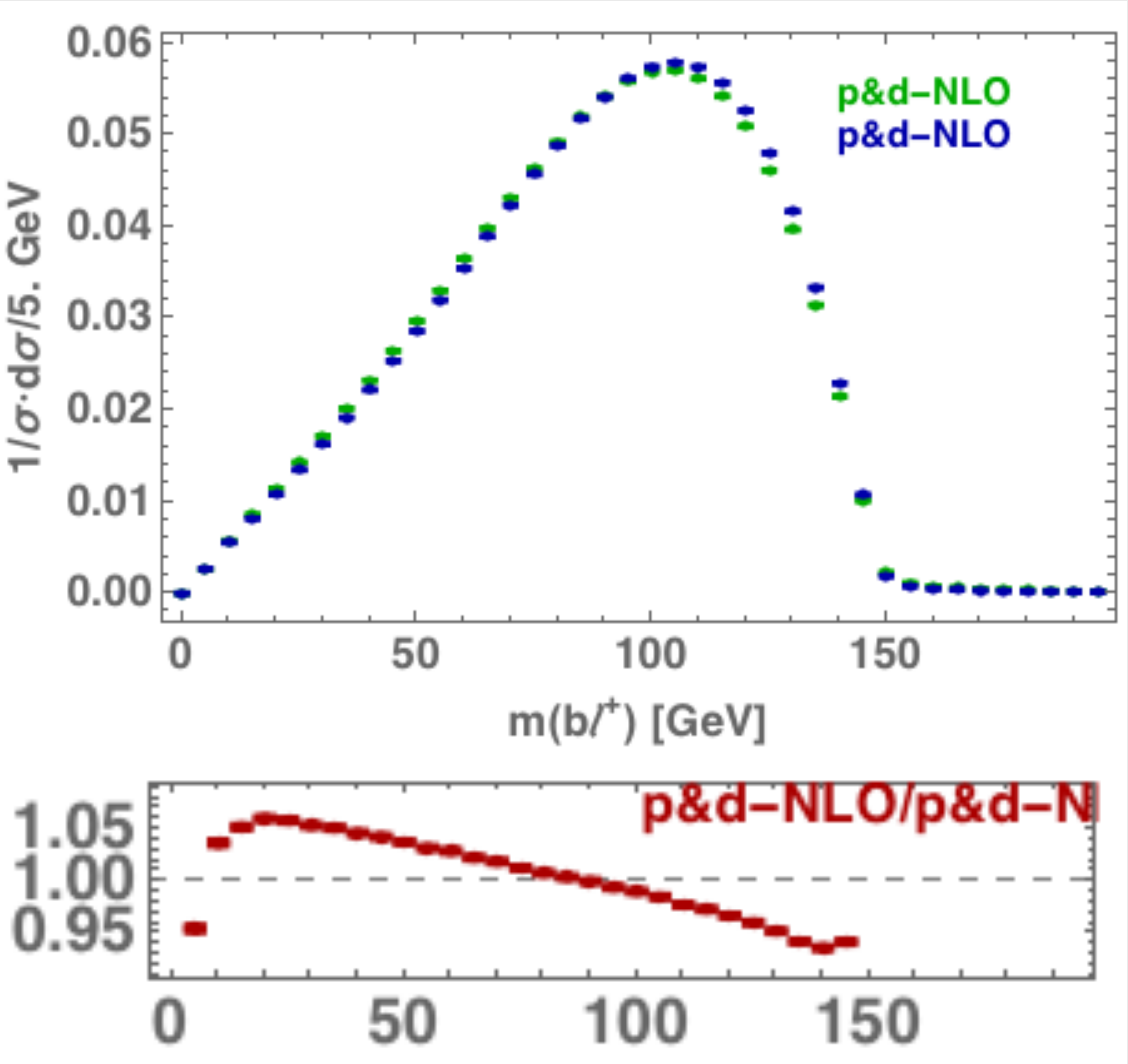


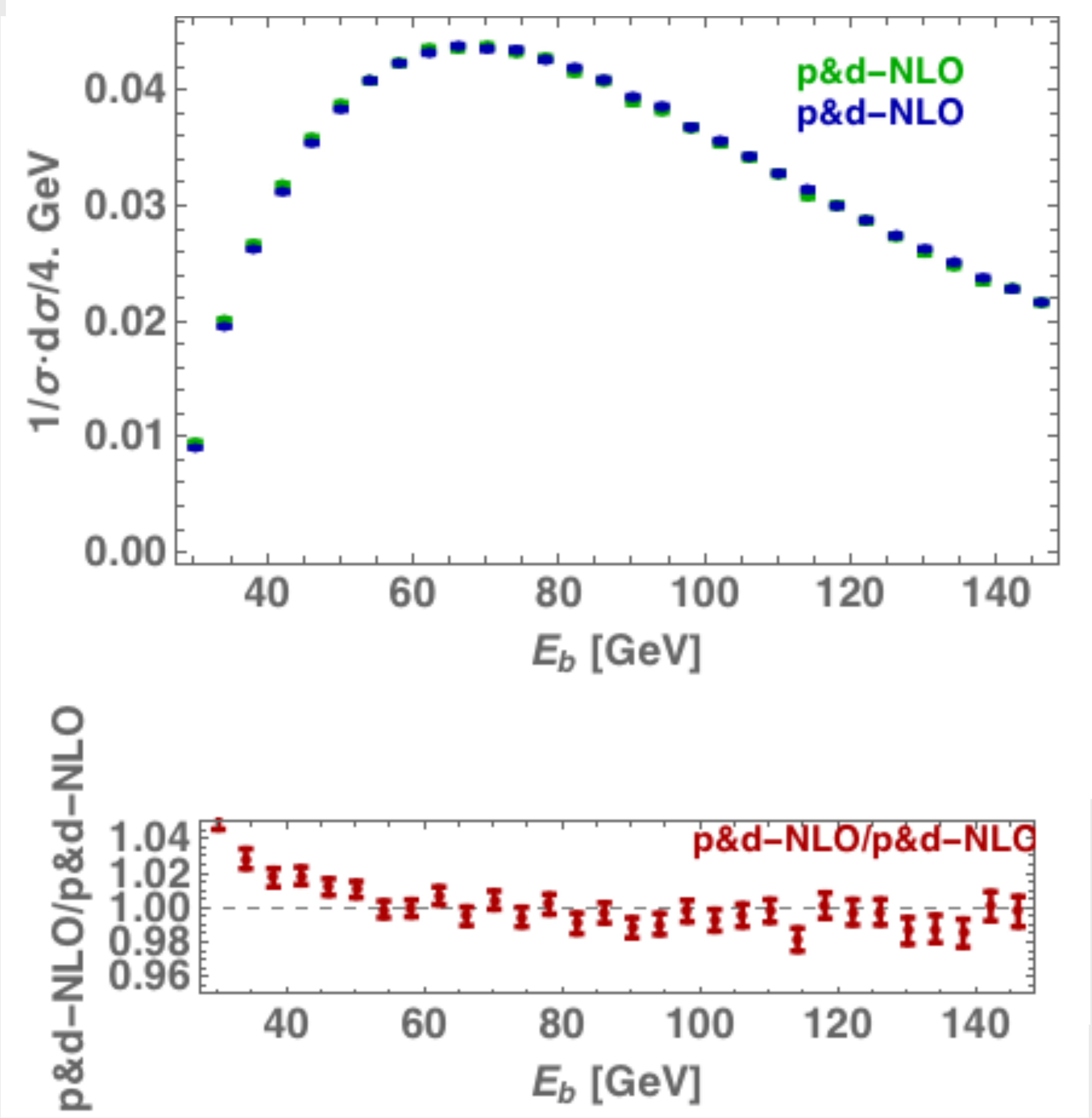


A First Look At Scale Uncertainties

NLO FIXED ORDER

MCFM 6.8

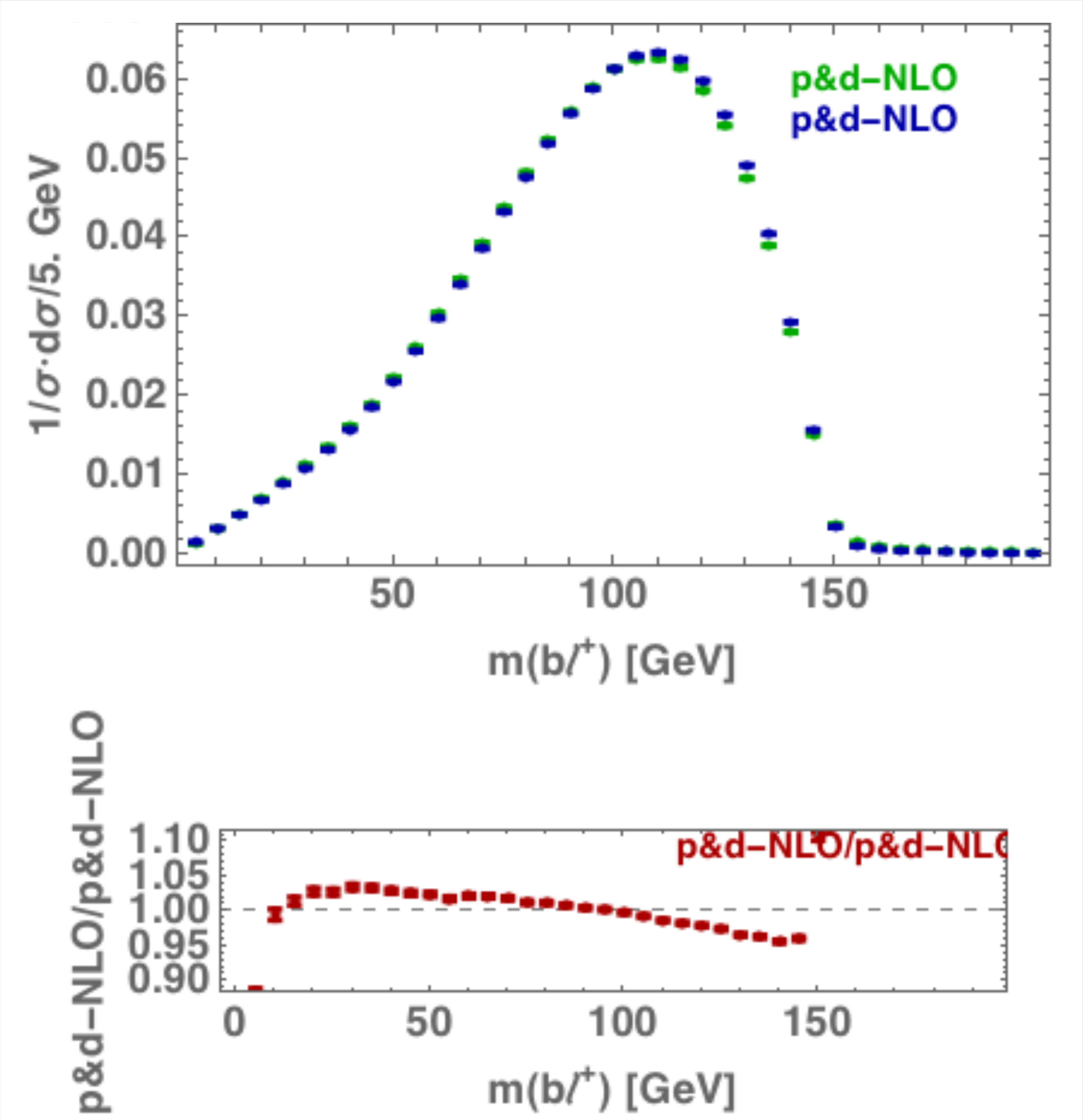


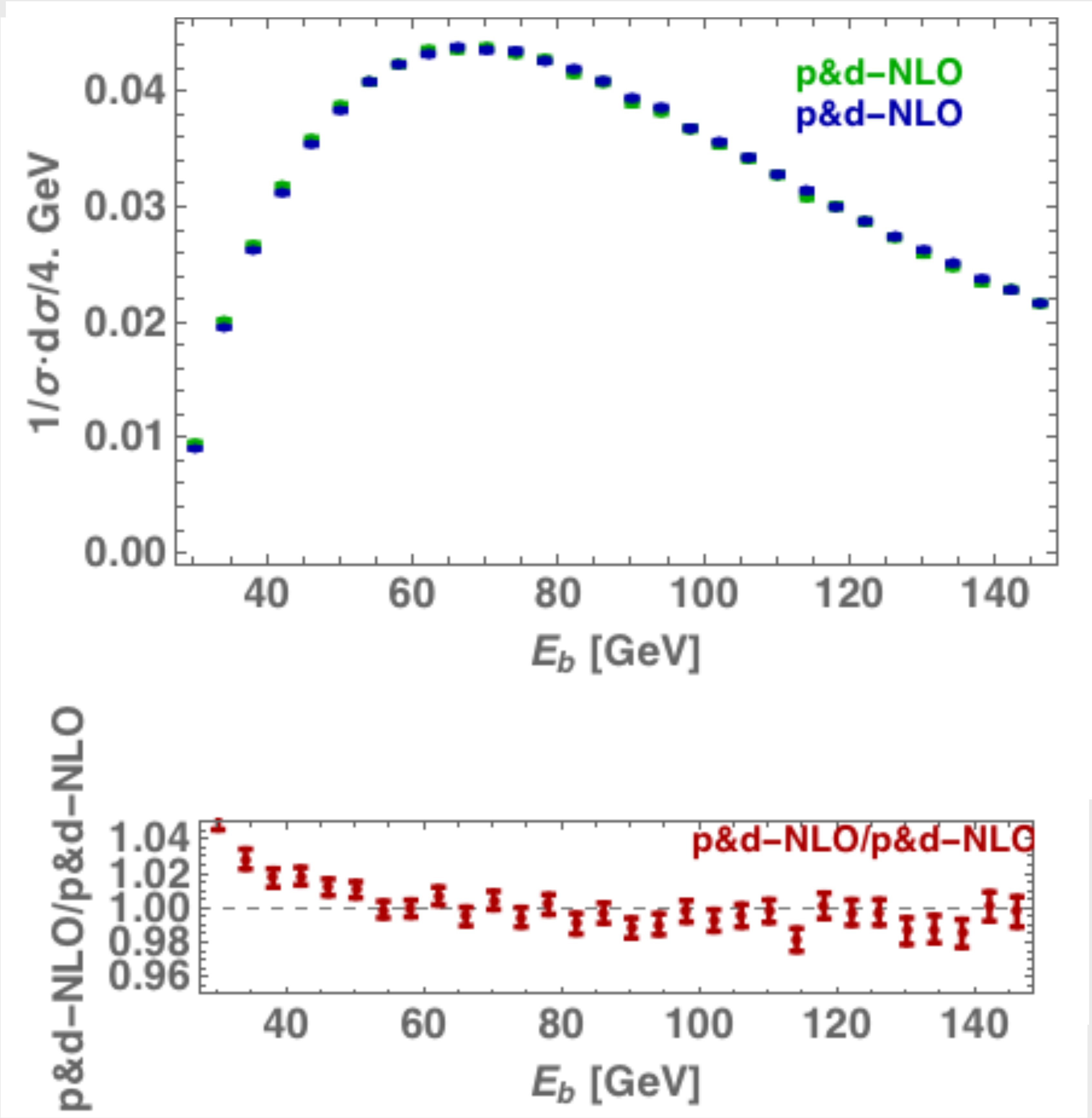


A First Look At Scale Uncertainties

NLO FIXED ORDER

MCFM 6.8

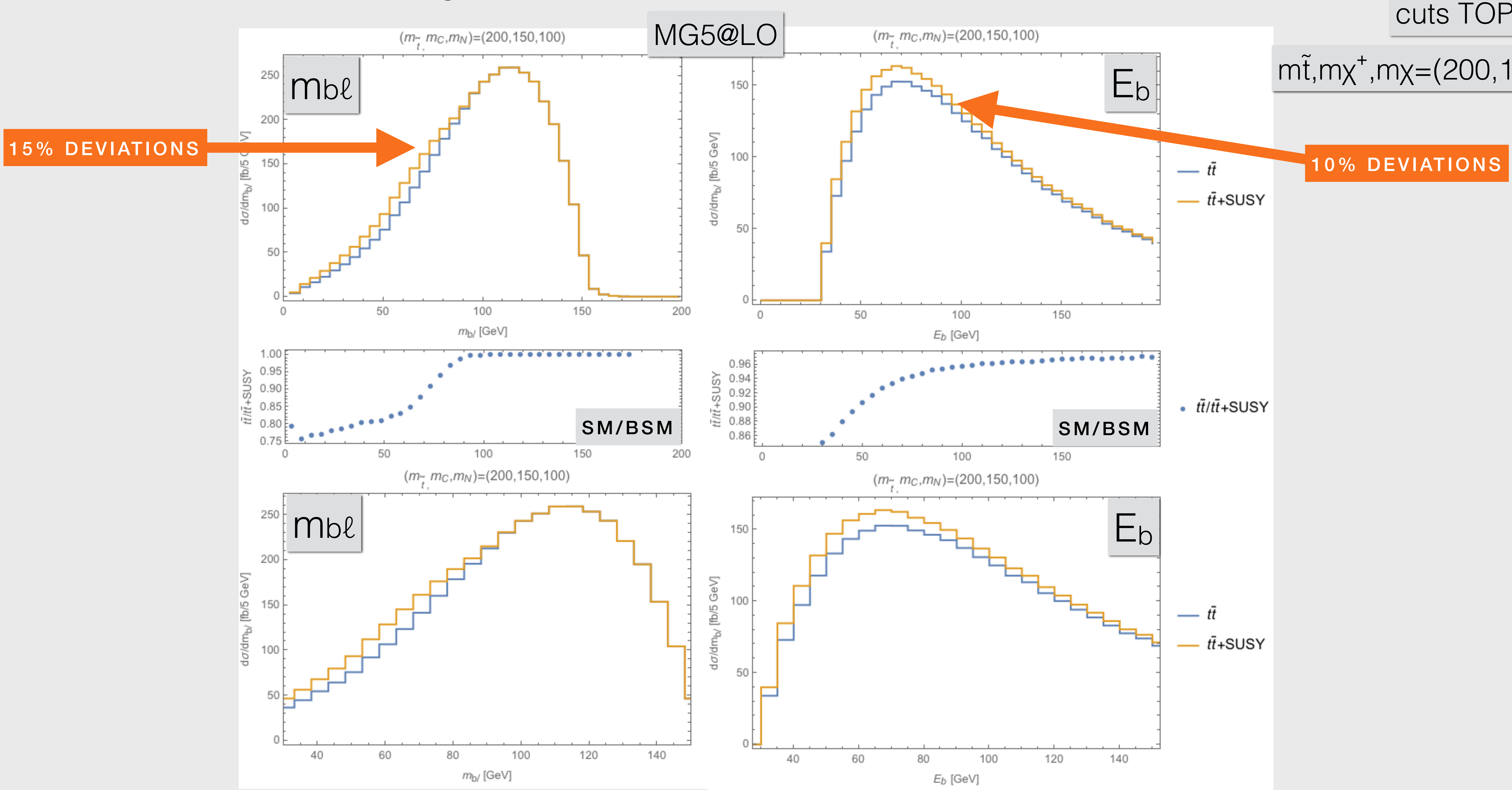




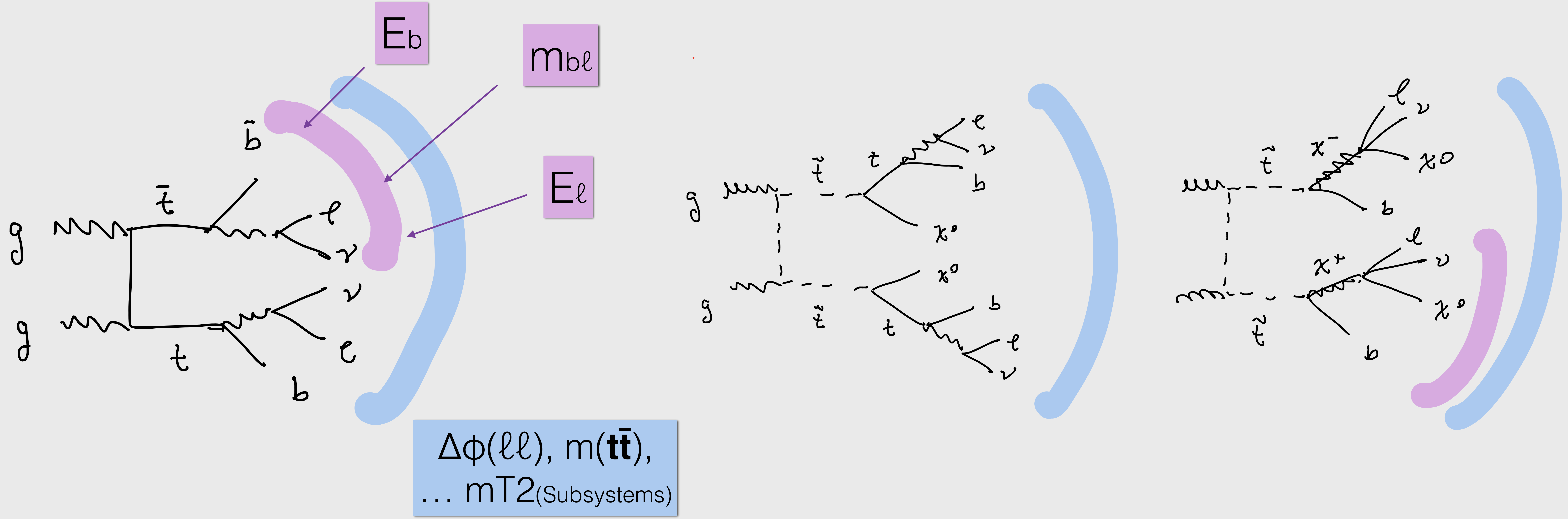
New Physics Effect On $m_{b\ell}$ and E_b

cuts TOP-14-014

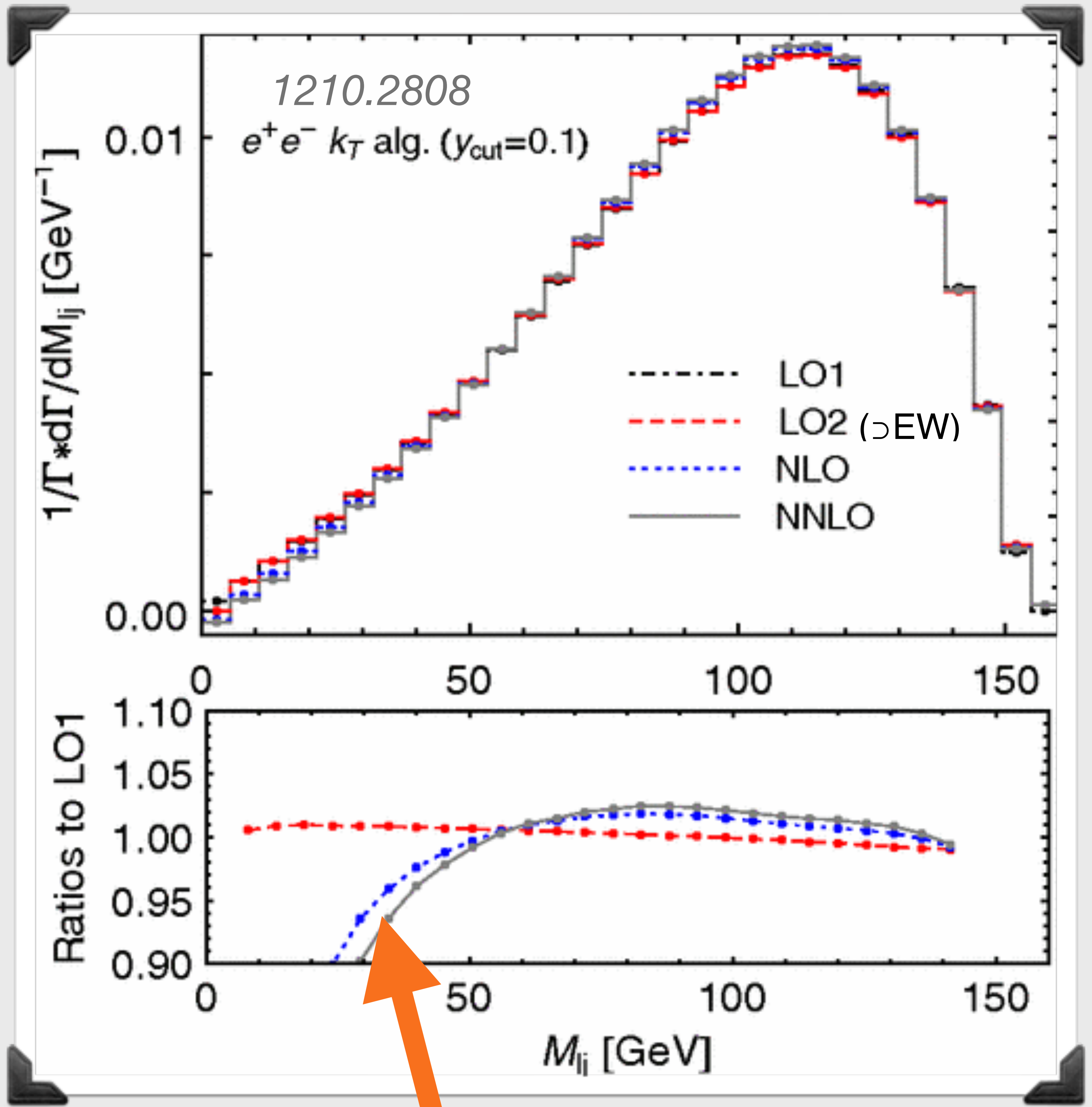
$m_{\tilde{t}}, m_{\chi^+}, m_{\chi} = (200,150,100)$



N-Dim Global Analysis



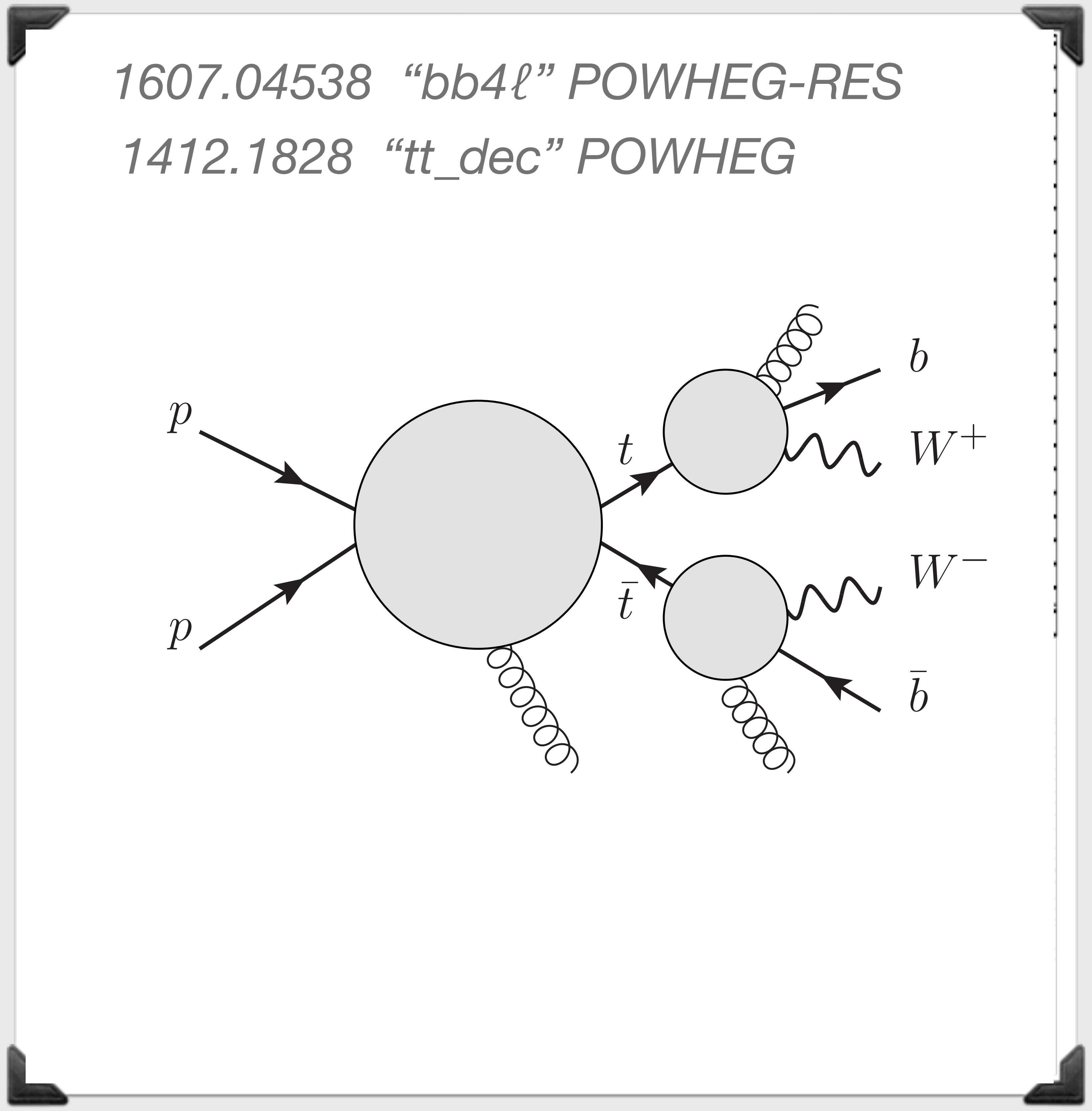
NNLO top decay



2% NNLO CORRECTION

ALSO 1301.7133 NNLO TOP DECAY

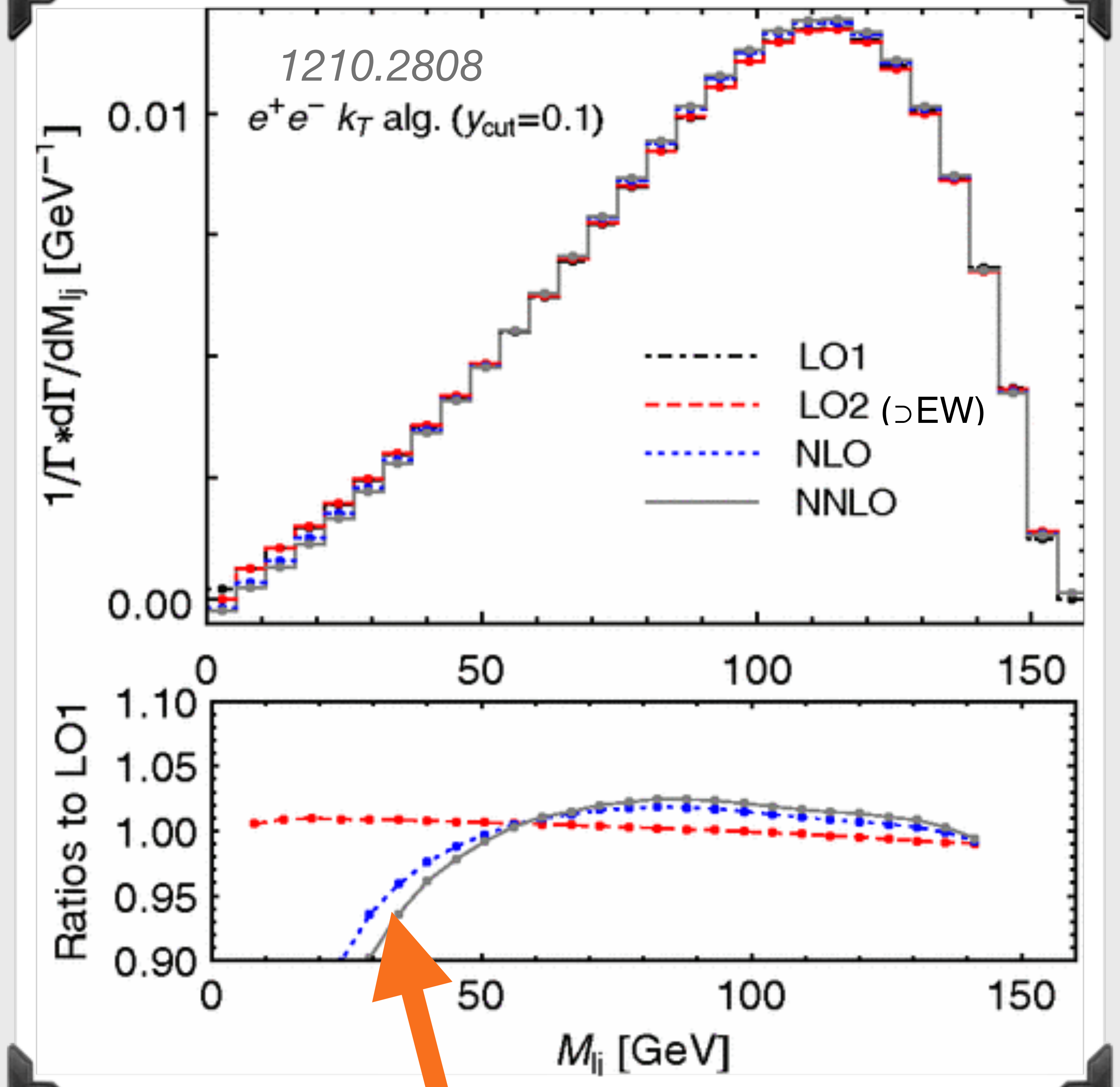
NLO+PS w/top decay



encouraging results form "*tt_dec*"

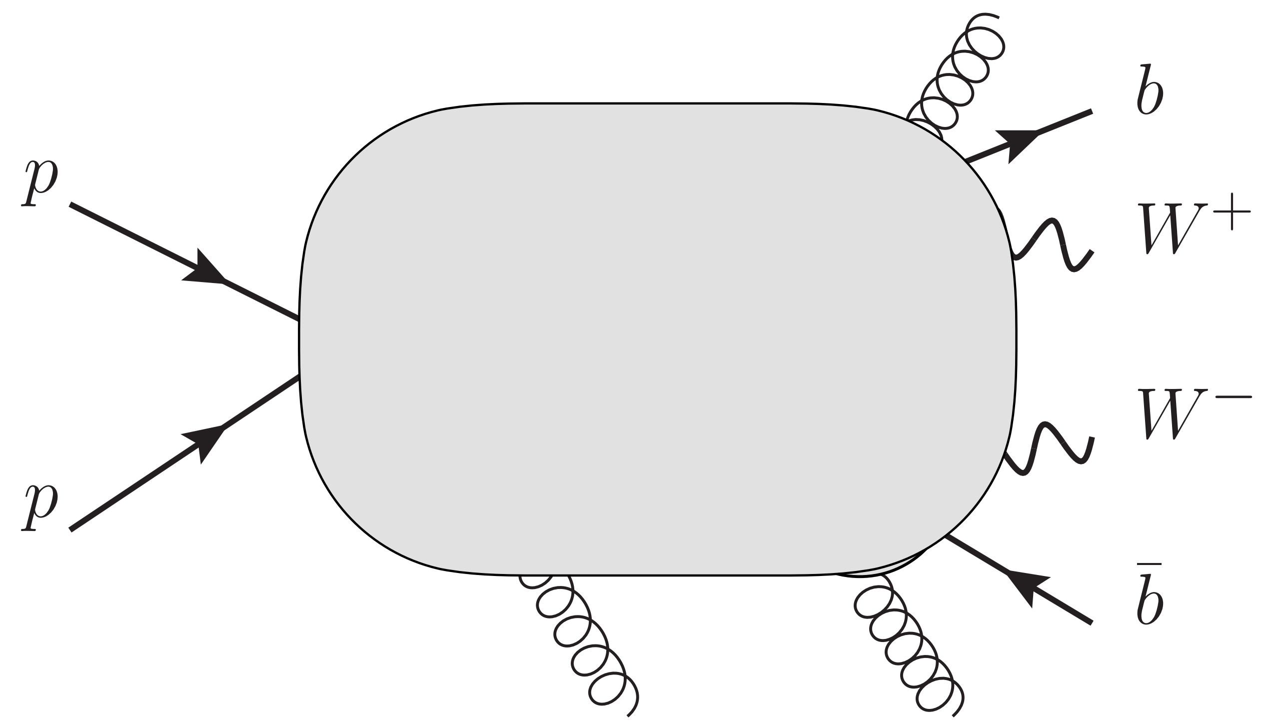
NNLO top decay

NLO+PS w/top decay



1607.04538 "bb4ℓ" POWHEG-RES

1412.1828 "tt_dec" POWHEG



2% NNLO CORRECTION

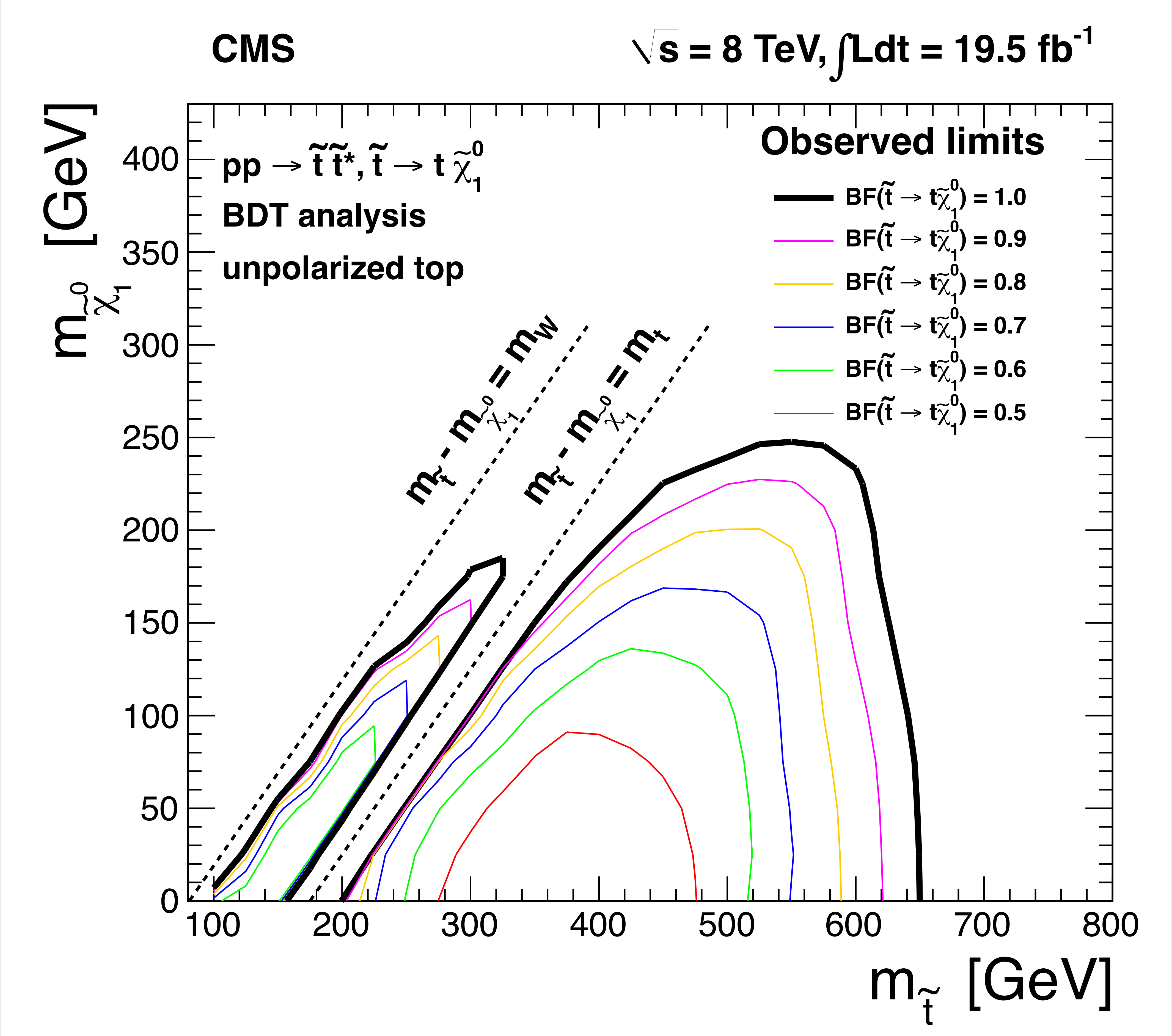
ALSO 1301.7133 NNLO TOP DECAY

encouraging results form "*tt_dec*"

Challenges

- compressed ⇒ little visible energy
- diluted
- delayed

Dilution

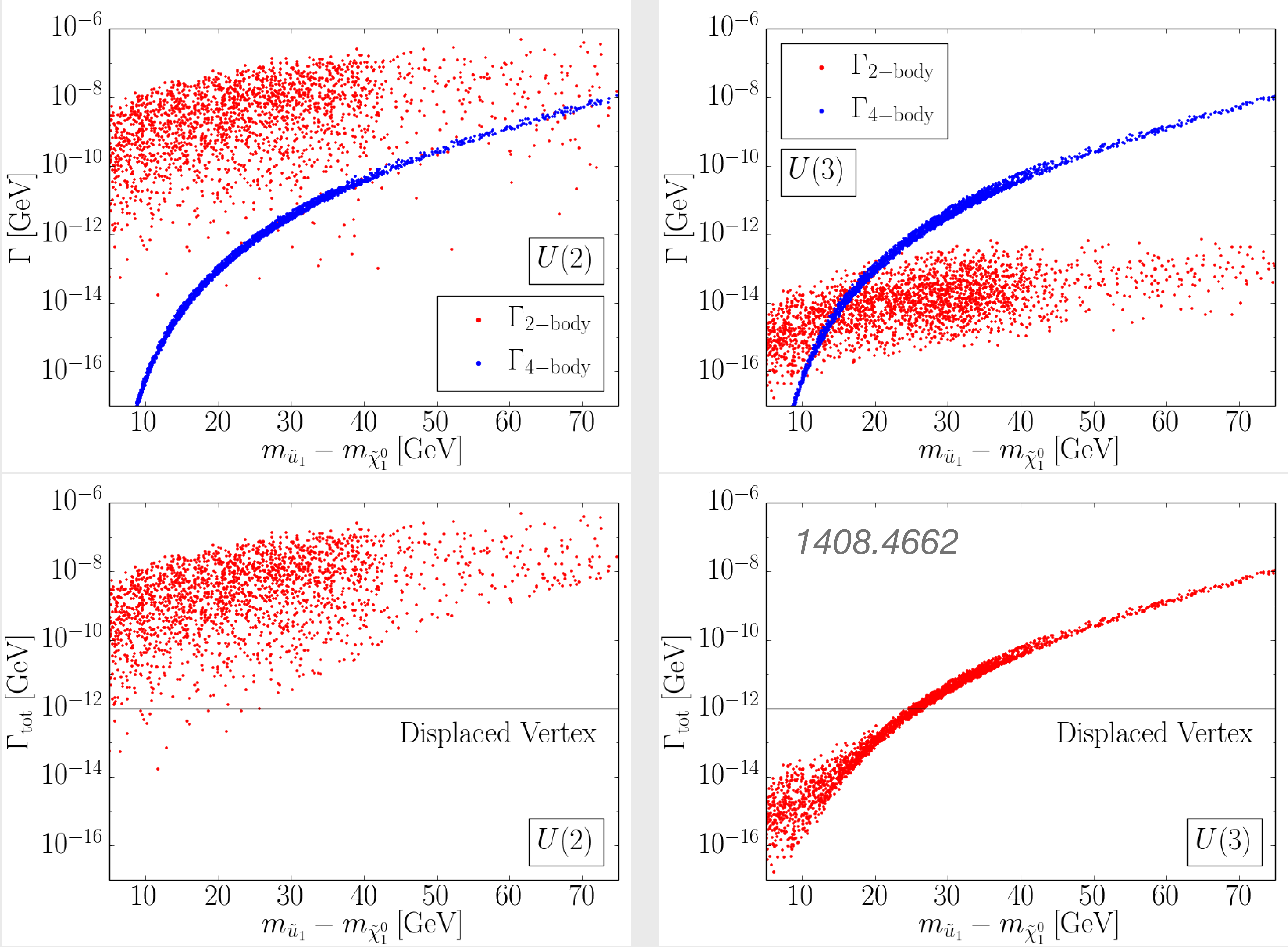

CMS
$\sqrt{s}$ = 8 TeV, $\int$Ldt = 19.5 fb^{-1}
$pp \to \tilde{t}\tilde{t}^*, \tilde{t} \to t\,\tilde{\chi}_1^0$
BDT analysis
unpolarized top
Observed limits
BF($\tilde{t} \to t\tilde{\chi}_1^0$) = 1.0
BF($\tilde{t} \to t\tilde{\chi}_1^0$) = 0.9
BF($\tilde{t} \to t\tilde{\chi}_1^0$) = 0.8
BF($\tilde{t} \to t\tilde{\chi}_1^0$) = 0.7
BF($\tilde{t} \to t\tilde{\chi}_1^0$) = 0.6
BF($\tilde{t} \to t\tilde{\chi}_1^0$) = 0.5
$m_{\tilde{t}} - m_{\tilde{\chi}_1^0} = m_W$
$m_{\tilde{t}} - m_{\tilde{\chi}_1^0} = m_t$
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{t}}$ [GeV]
0
50
100
150
200
250
300
350
400
100
200
300
400
500
600
700
800

Challenges

- compressed ⇒ little visible energy
- diluted ⇒ spread on many channels
- delayed

Wait…

$\tilde{t} \rightarrow b\, ff'\chi^0 + c\, \chi^0$

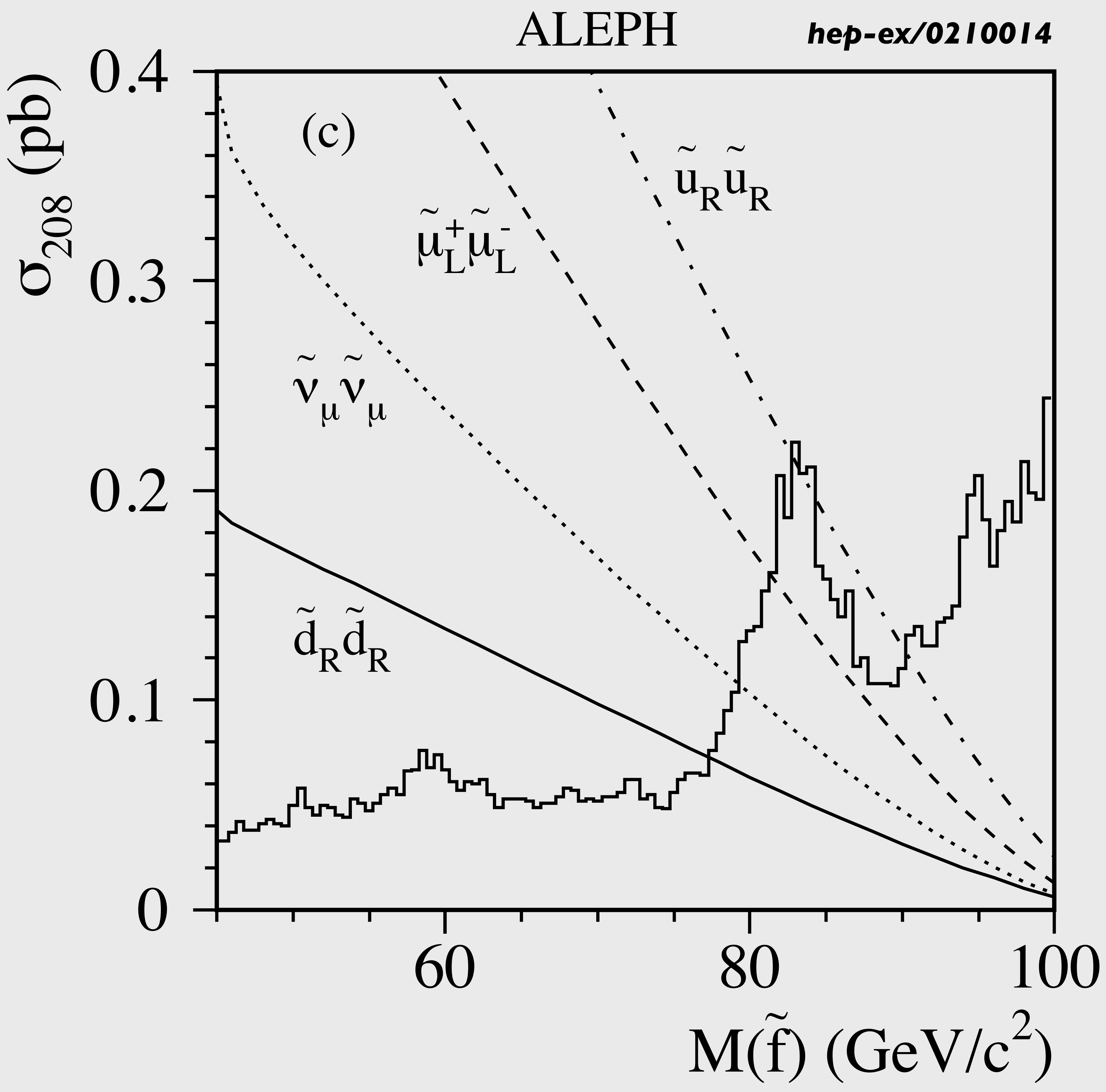


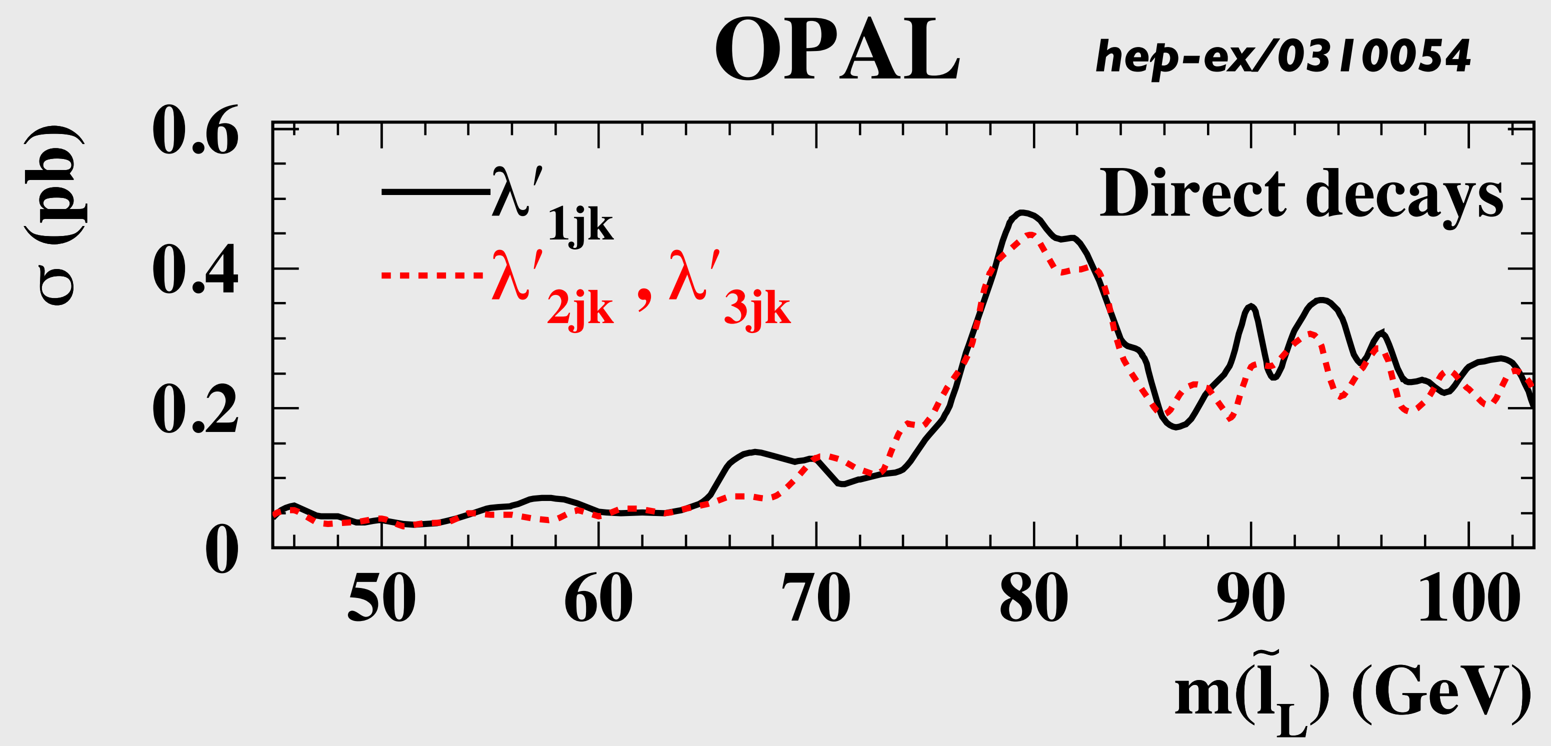
Challenges

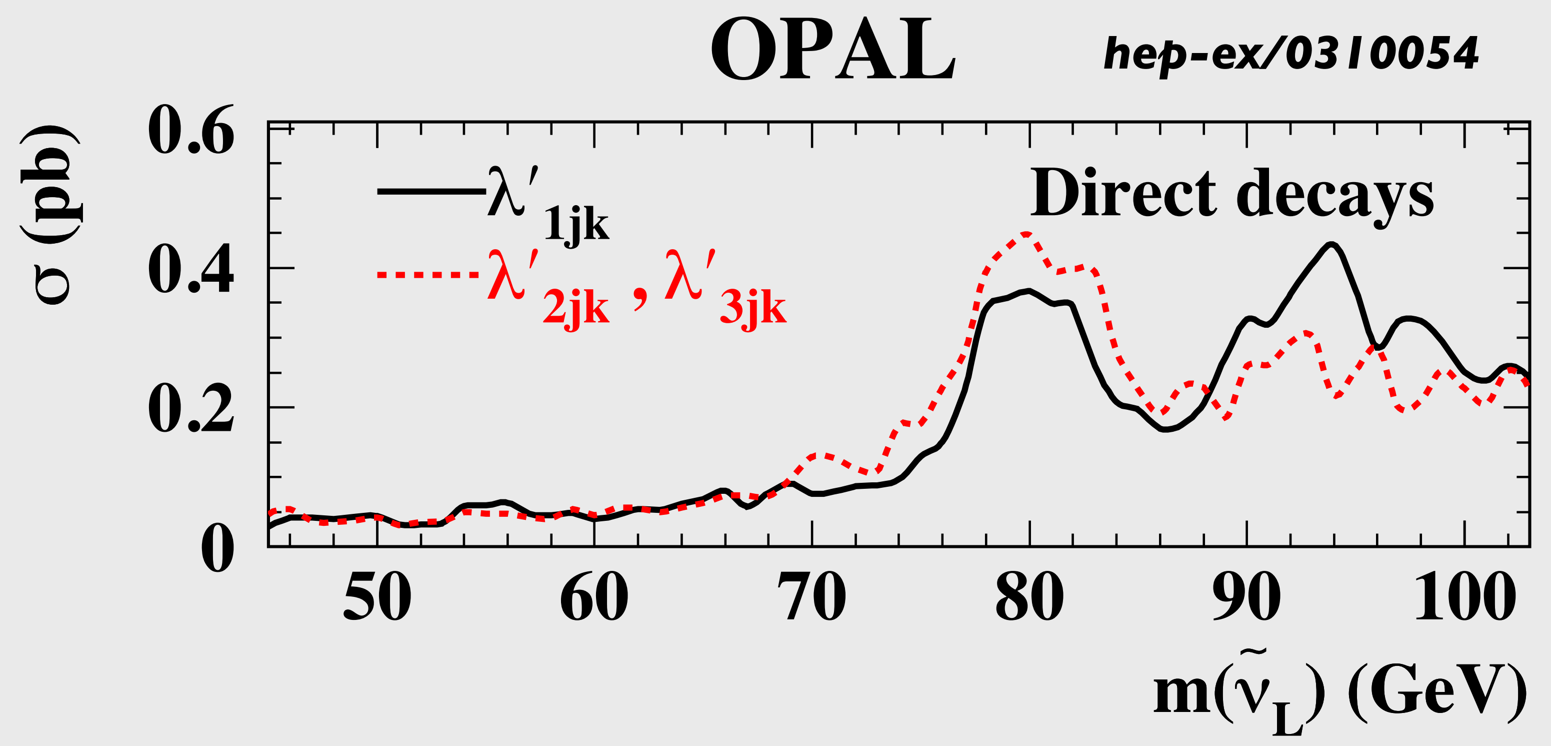
- compressed ⇒ little visible energy
- diluted ⇒ spread on many channels
- delayed ⇒ flavor tags may not work, signal is different than what originally thought

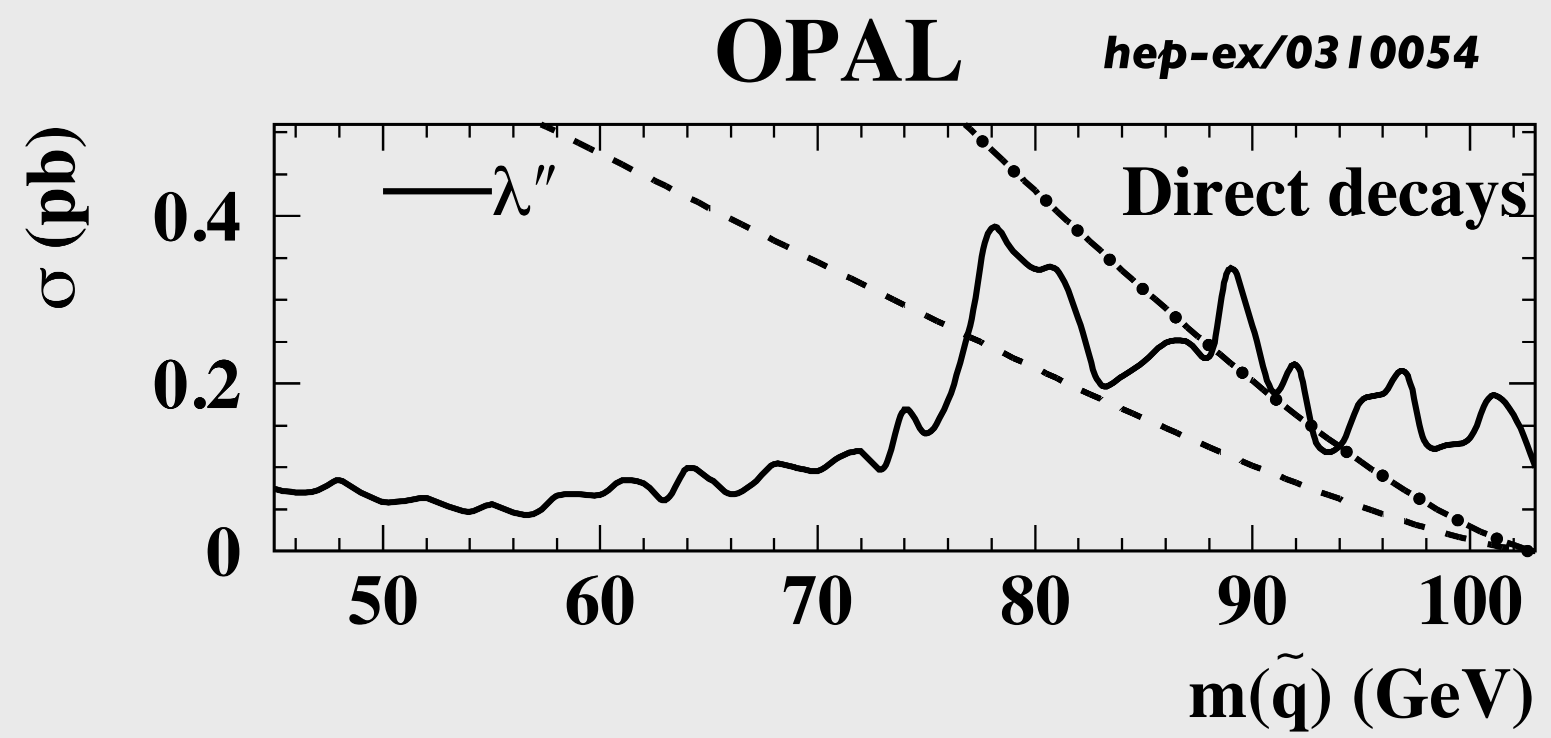
$e^+e^- \to 4j$ limits

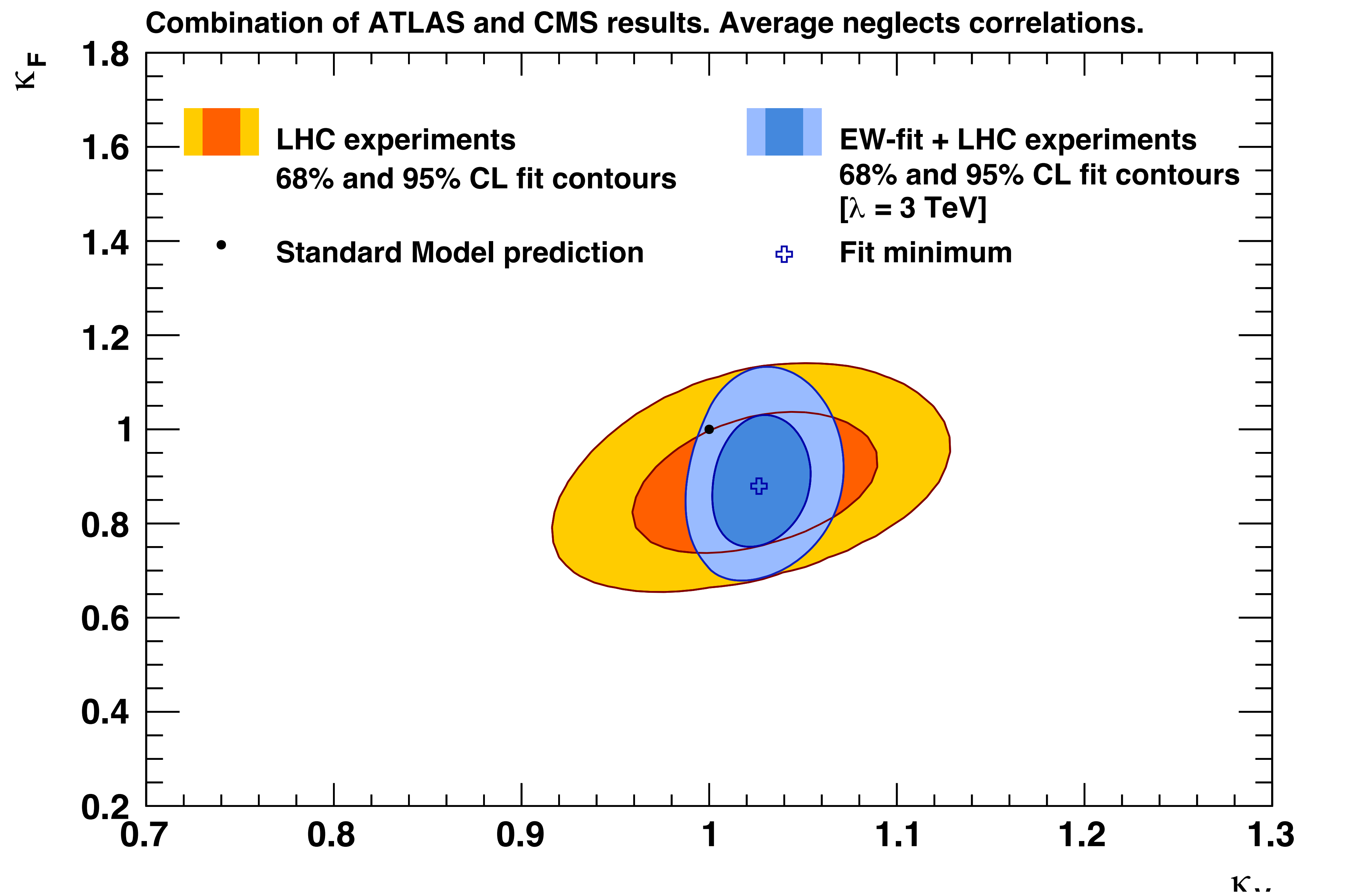
HISTORY

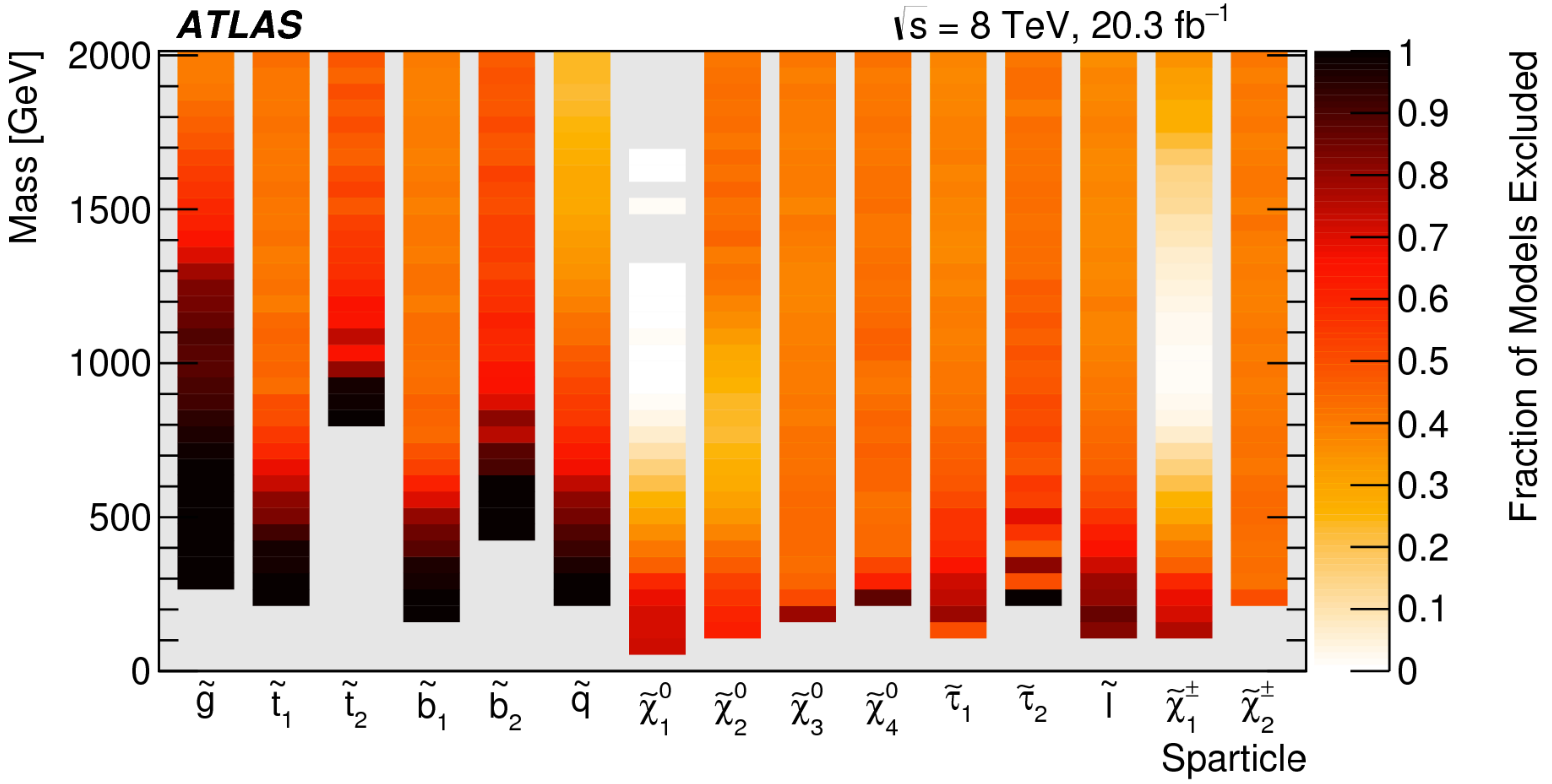









Combination of ATLAS and CMS results. Average neglects correlations.
κ_F
LHC experiments
68% and 95% CL fit contours
EW-fit + LHC experiments
68% and 95% CL fit contours
[λ = 3 TeV]
Standard Model prediction
Fit minimum
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0.7
0.8
0.9
1
1.1
1.2
1.3


ATLAS
√s = 8 TeV, 20.3 fb⁻¹
Mass [GeV]
2000
1500
1000
500
0
Fraction of Models Excluded
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Sparticle