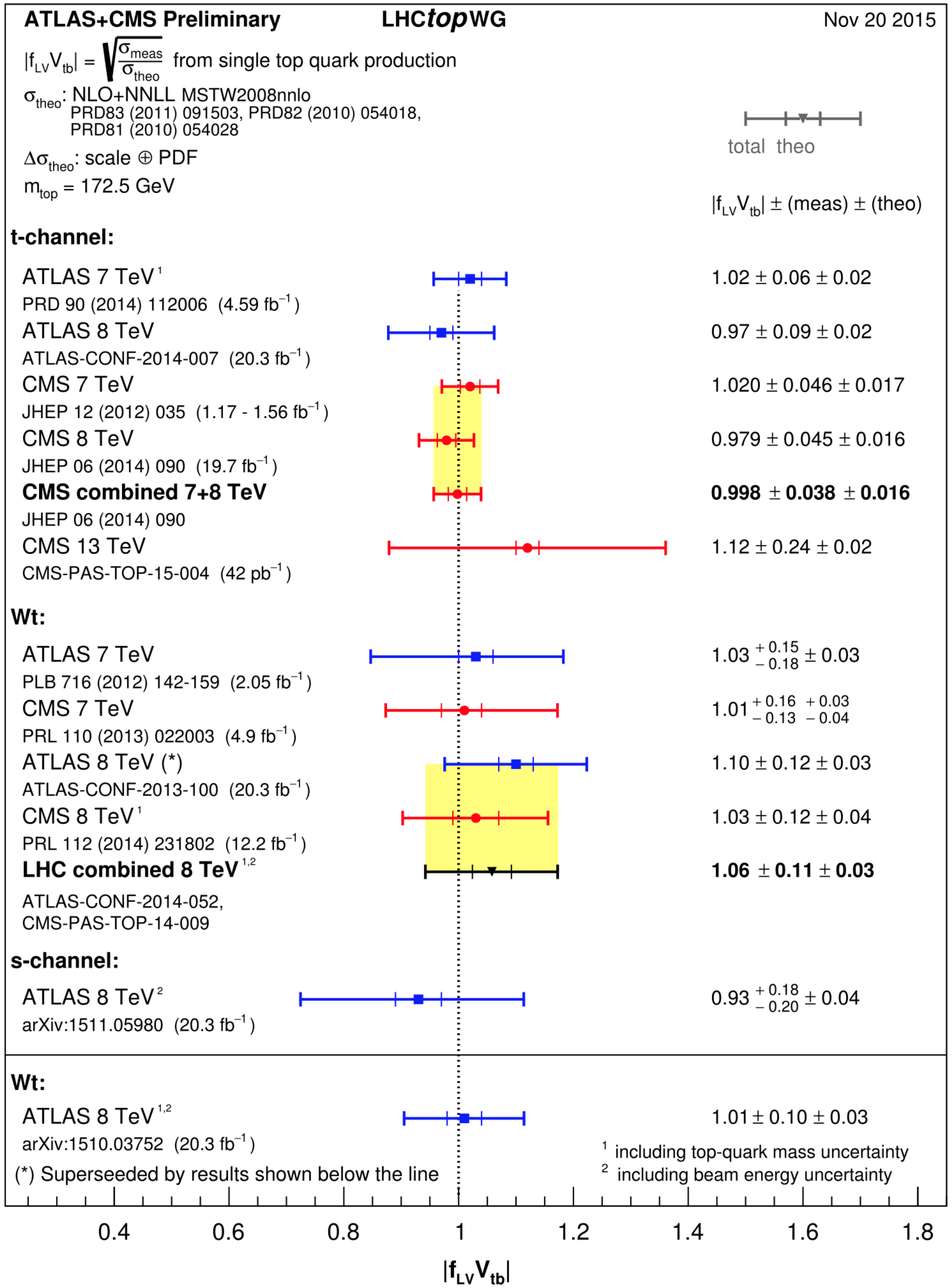
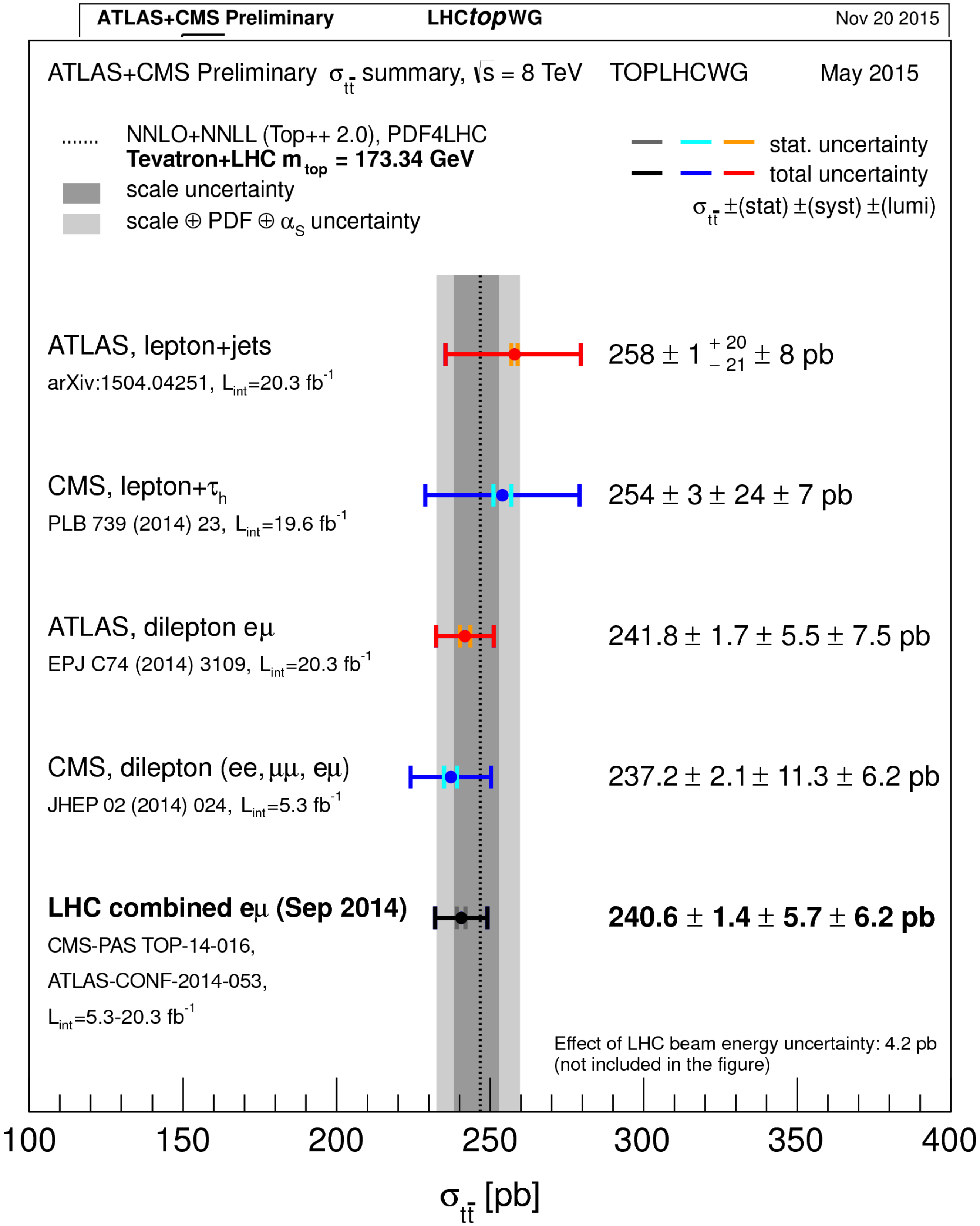
Top quark physics (for BSM)

Roberto Franceschini (CERN TH)
March 10th 2016 - La Thuile 2016

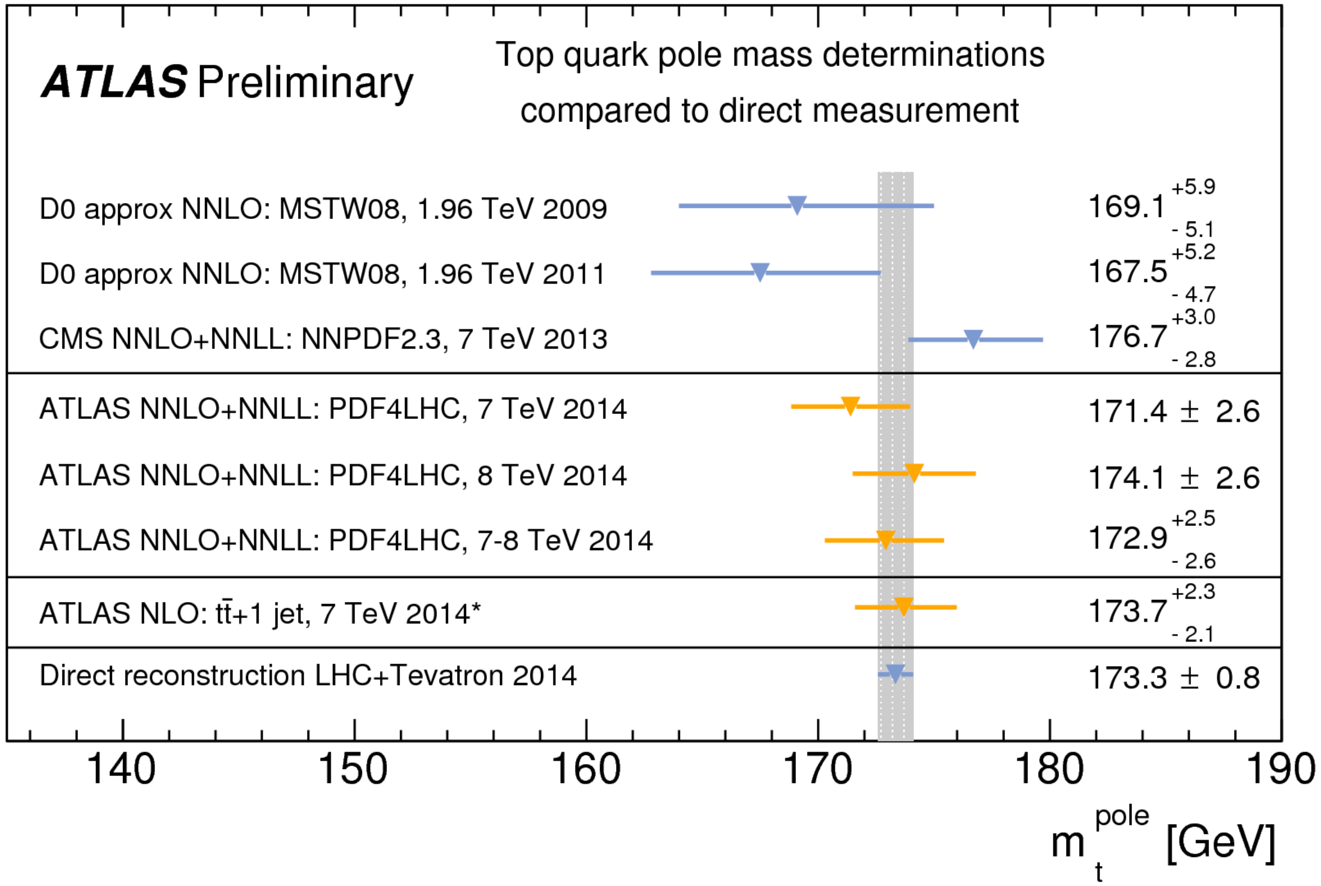
The luminous side of LHC...



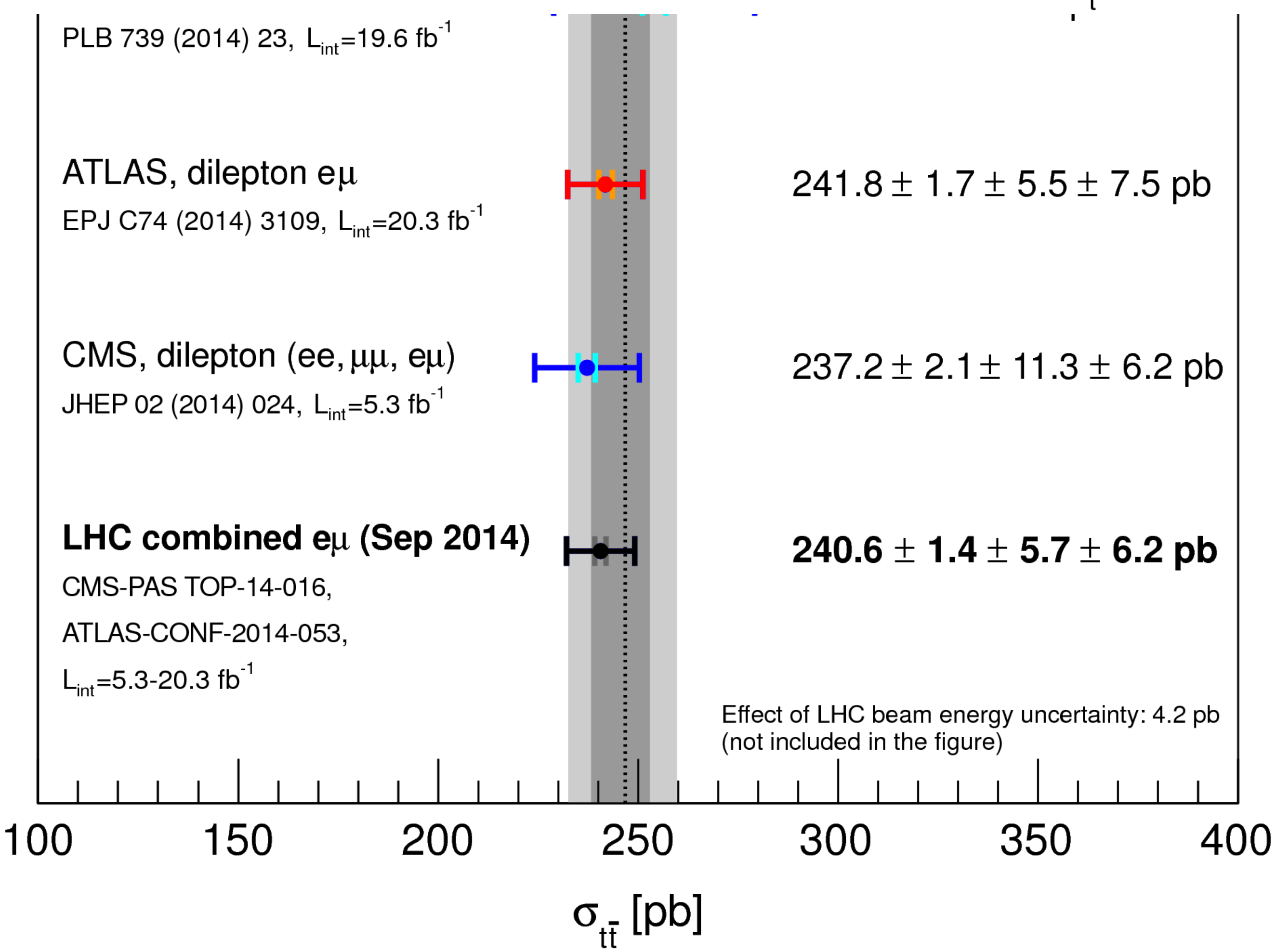
ATLAS+CMS Preliminary
LHCtopWG
Nov 20 2015
$|f_{LV}V_{tb}| = \sqrt{\frac{\sigma_{meas}}{\sigma_{theo}}}$ from single top quark production
σ_{theo}: NLO+NNLL MSTW2008nnlo
PRD83 (2011) 091503, PRD82 (2010) 054018, PRD81 (2010) 054028
$\Delta\sigma_{theo}$: scale ⊕ PDF
m_{top} = 172.5 GeV
total theo
$|f_{LV}V_{tb}|$ ± (meas) ± (theo)
t-channel:
ATLAS 7 TeV [1]
PRD 90 (2014) 112006 (4.59 fb^{-1})
1.02 ± 0.06 ± 0.02
ATLAS 8 TeV
ATLAS-CONF-2014-007 (20.3 fb^{-1})
0.97 ± 0.09 ± 0.02
CMS 7 TeV
JHEP 12 (2012) 035 (1.17 - 1.56 fb^{-1})
1.020 ± 0.046 ± 0.017
CMS 8 TeV
JHEP 06 (2014) 090 (19.7 fb^{-1})
0.979 ± 0.045 ± 0.016
CMS combined 7+8 TeV
JHEP 06 (2014) 090
0.998 ± 0.038 ± 0.016
CMS 13 TeV
CMS-PAS-TOP-15-004 (42 pb^{-1})
1.12 ± 0.24 ± 0.02
Wt:
ATLAS 7 TeV
PLB 716 (2012) 142-159 (2.05 fb^{-1})
$1.03\,^{+0.15}_{-0.18} \pm 0.03$
CMS 7 TeV
PRL 110 (2013) 022003 (4.9 fb^{-1})
$1.01\,^{+0.16}_{-0.13}\,^{+0.03}_{-0.04}$
ATLAS 8 TeV (*)
ATLAS-CONF-2013-100 (20.3 fb^{-1})
1.10 ± 0.12 ± 0.03
CMS 8 TeV [1]
PRL 112 (2014) 231802 (12.2 fb^{-1})
1.03 ± 0.12 ± 0.04
LHC combined 8 TeV [1,2]
ATLAS-CONF-2014-052, CMS-PAS-TOP-14-009
1.06 ± 0.11 ± 0.03
s-channel:
ATLAS 8 TeV [2]
arXiv:1511.05980 (20.3 fb^{-1})
$0.93\,^{+0.18}_{-0.20} \pm 0.04$
Wt:
ATLAS 8 TeV [1,2]
arXiv:1510.03752 (20.3 fb^{-1})
1.01 ± 0.10 ± 0.03
(*) Superseeded by results shown below the line
[1] including top-quark mass uncertainty
[2] including beam energy uncertainty
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
$|f_{LV}V_{tb}|$



ATLAS+CMS Preliminary
LHCtopWG
Nov 20 2015
ATLAS+CMS Preliminary $\sigma_{t\bar{t}}$ summary, $\sqrt{s}$ = 8 TeV
TOPLHCWG
May 2015
NNLO+NNLL (Top++ 2.0), PDF4LHC
Tevatron+LHC m_{top} = 173.34 GeV
scale uncertainty
scale ⊕ PDF ⊕ α_S uncertainty
stat. uncertainty
total uncertainty
$\sigma_{t\bar{t}}$ ±(stat) ±(syst) ±(lumi)
ATLAS, lepton+jets
arXiv:1504.04251, L_{int}=20.3 fb^{-1}
$258 \pm 1 ^{+20}_{-21} \pm 8$ pb
CMS, lepton+τ_h
PLB 739 (2014) 23, L_{int}=19.6 fb^{-1}
254 ± 3 ± 24 ± 7 pb
ATLAS, dilepton eμ
EPJ C74 (2014) 3109, L_{int}=20.3 fb^{-1}
241.8 ± 1.7 ± 5.5 ± 7.5 pb
CMS, dilepton (ee, μμ, eμ)
JHEP 02 (2014) 024, L_{int}=5.3 fb^{-1}
237.2 ± 2.1 ± 11.3 ± 6.2 pb
LHC combined eμ (Sep 2014)
CMS-PAS TOP-14-016,
ATLAS-CONF-2014-053,
L_{int}=5.3-20.3 fb^{-1}
240.6 ± 1.4 ± 5.7 ± 6.2 pb
Effect of LHC beam energy uncertainty: 4.2 pb
(not included in the figure)
100
150
200
250
300
350
400
$\sigma_{t\bar{t}}$ [pb]



ATLAS Preliminary
Top quark pole mass determinations
compared to direct measurement
D0 approx NNLO: MSTW08, 1.96 TeV 2009
169.1 +5.9 - 5.1
D0 approx NNLO: MSTW08, 1.96 TeV 2011
167.5 +5.2 - 4.7
CMS NNLO+NNLL: NNPDF2.3, 7 TeV 2013
176.7 +3.0 - 2.8
ATLAS NNLO+NNLL: PDF4LHC, 7 TeV 2014
171.4 ± 2.6
ATLAS NNLO+NNLL: PDF4LHC, 8 TeV 2014
174.1 ± 2.6
ATLAS NNLO+NNLL: PDF4LHC, 7-8 TeV 2014
172.9 +2.5 - 2.6
ATLAS NLO: tt̄+1 jet, 7 TeV 2014*
173.7 +2.3 - 2.1
Direct reconstruction LHC+Tevatron 2014
173.3 ± 0.8
140
150
160
170
180
190
m_t^pole [GeV]



PLB 739 (2014) 23, L_int=19.6 fb^-1
ATLAS, dilepton eμ
EPJ C74 (2014) 3109, L_int=20.3 fb^-1
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LHC combined eμ (Sep 2014)
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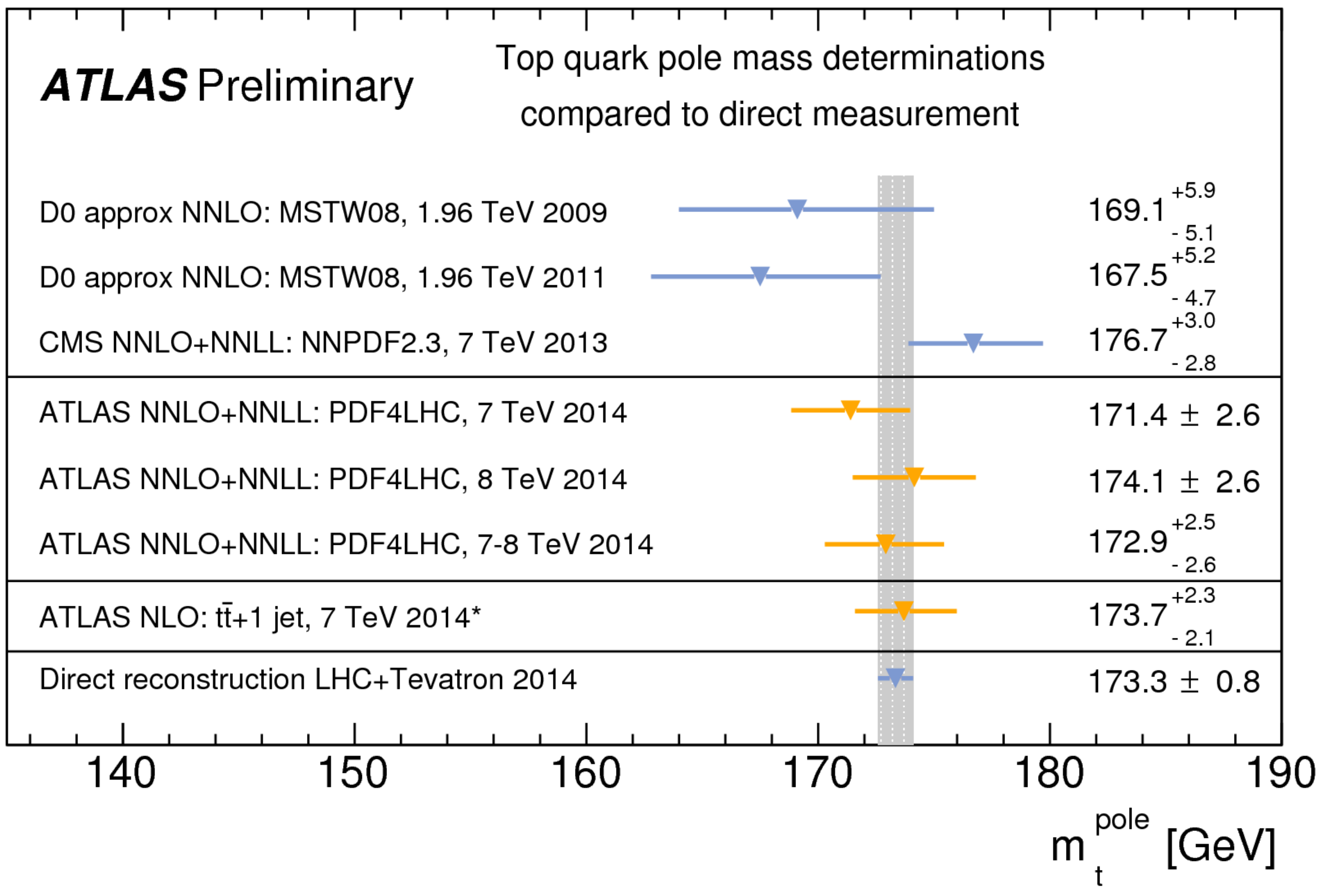
Effect of LHC beam energy uncertainty: 4.2 pb
(not included in the figure)
100
150
200
250
300
350
400
σ_tt̄ [pb]


ATLAS Preliminary
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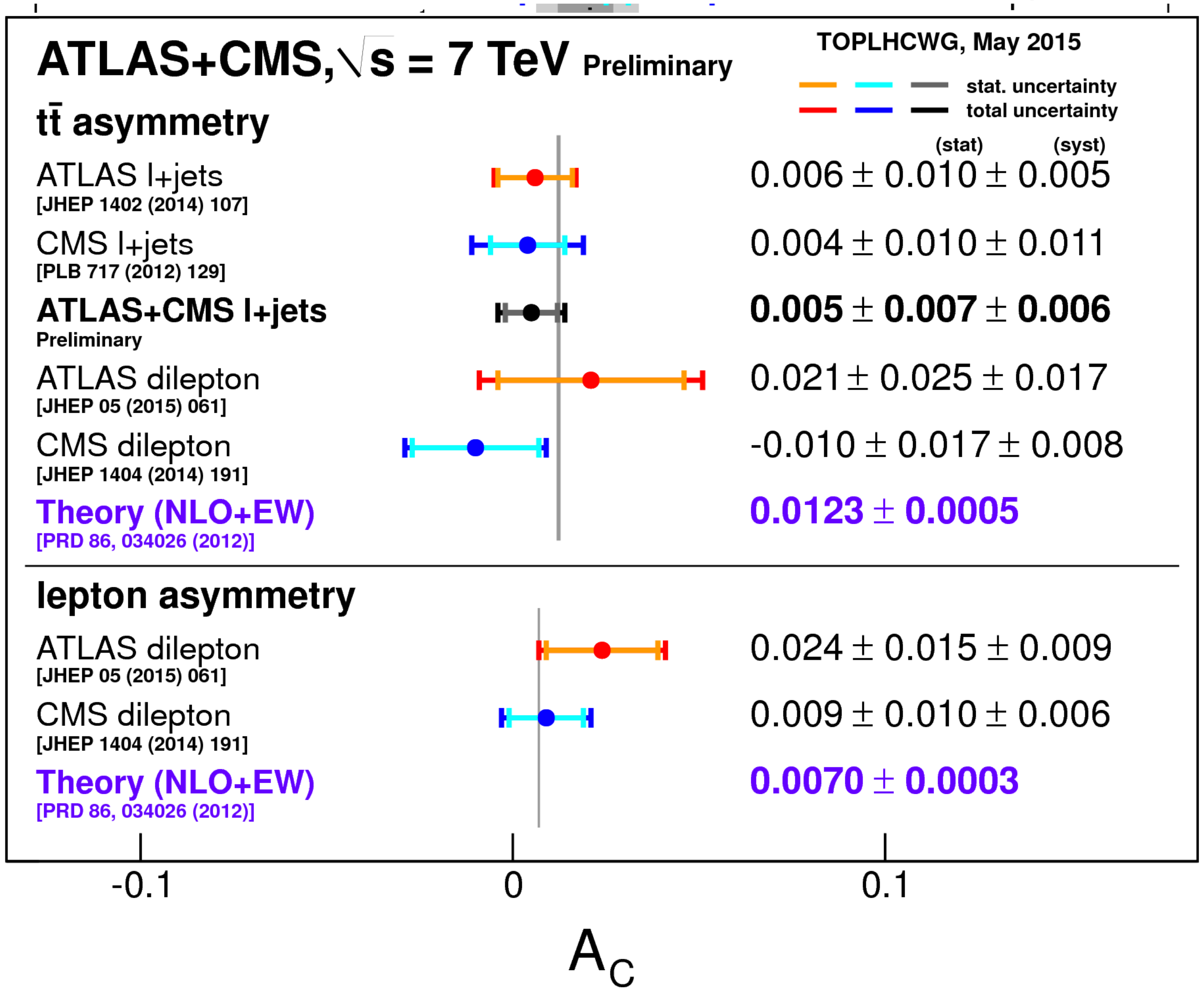
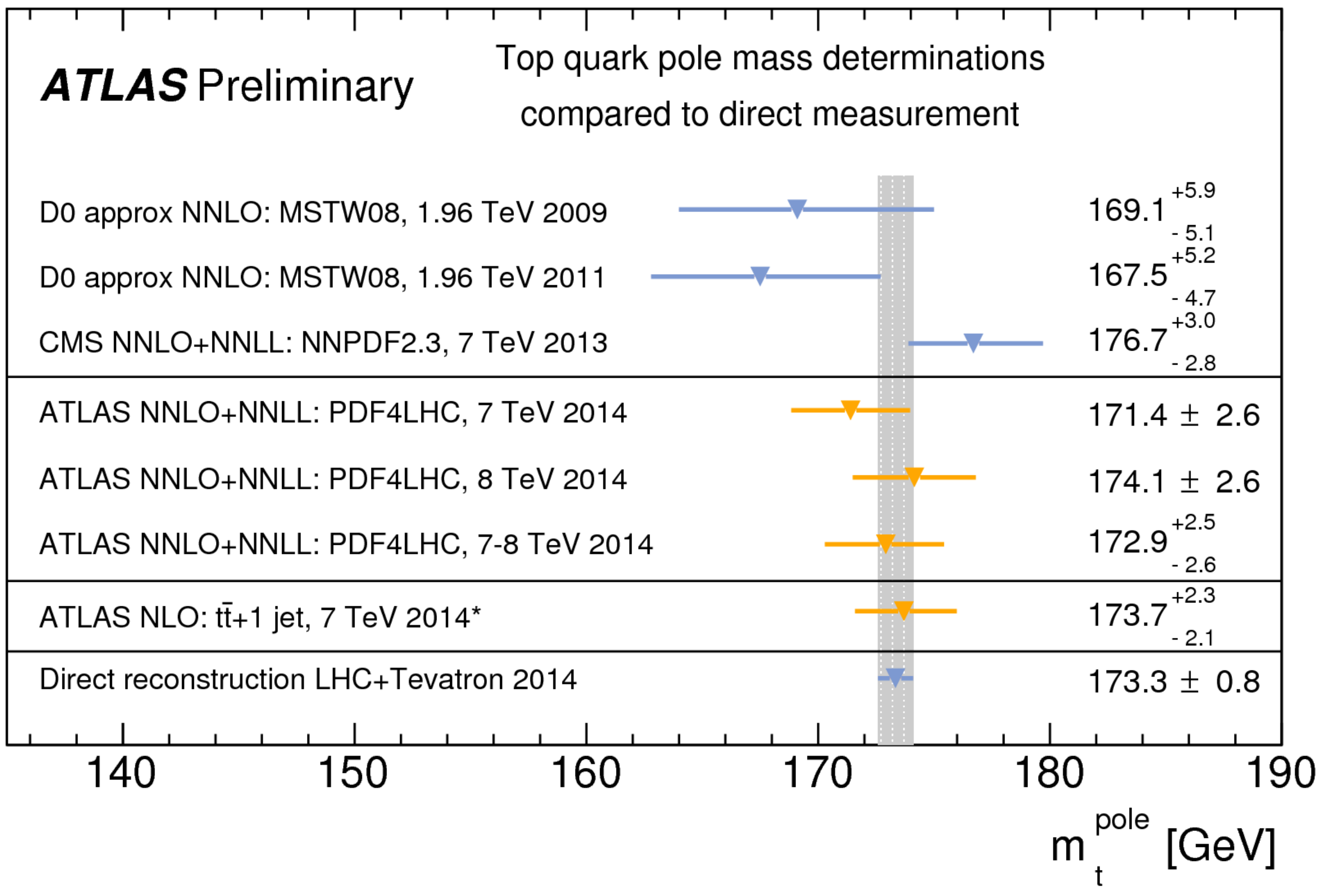
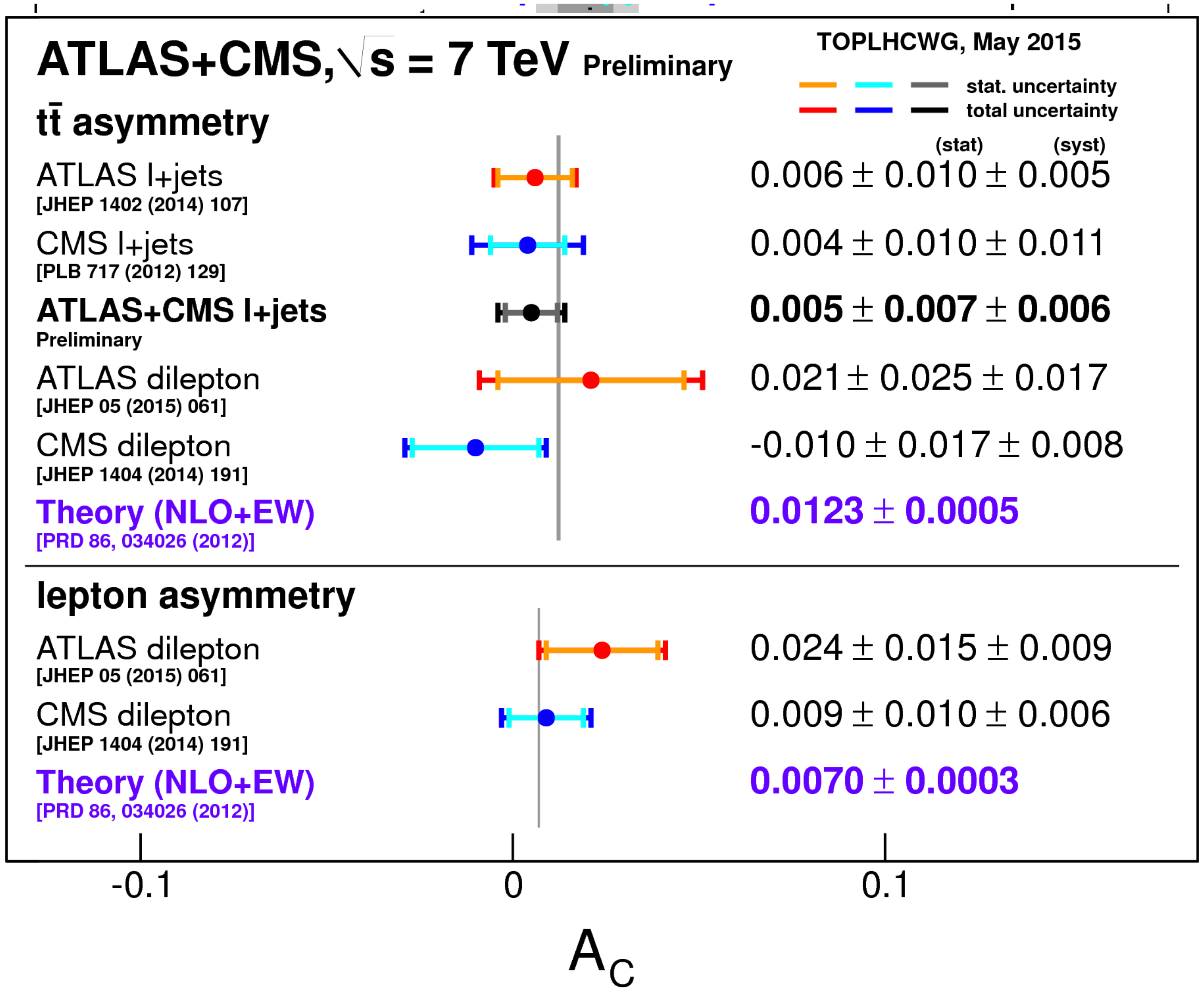
Direct reconstruction LHC+Tevatron 2014
173.3 ± 0.8
140
150
160
170
180
190
m_t^pole [GeV]


ATLAS+CMS, √s = 7 TeV Preliminary
TOPLHCWG, May 2015
stat. uncertainty
total uncertainty
tt̄ asymmetry
(stat)
(syst)
ATLAS l+jets
[JHEP 1402 (2014) 107]
0.006 ± 0.010 ± 0.005
CMS l+jets
[PLB 717 (2012) 129]
0.004 ± 0.010 ± 0.011
ATLAS+CMS l+jets
Preliminary
0.005 ± 0.007 ± 0.006
ATLAS dilepton
[JHEP 05 (2015) 061]
0.021 ± 0.025 ± 0.017
CMS dilepton
[JHEP 1404 (2014) 191]
-0.010 ± 0.017 ± 0.008
Theory (NLO+EW)
[PRD 86, 034026 (2012)]
0.0123 ± 0.0005
lepton asymmetry
ATLAS dilepton
[JHEP 05 (2015) 061]
0.024 ± 0.015 ± 0.009
CMS dilepton
[JHEP 1404 (2014) 191]
0.009 ± 0.010 ± 0.006
Theory (NLO+EW)
[PRD 86, 034026 (2012)]
0.0070 ± 0.0003
-0.1
0
0.1
A_C





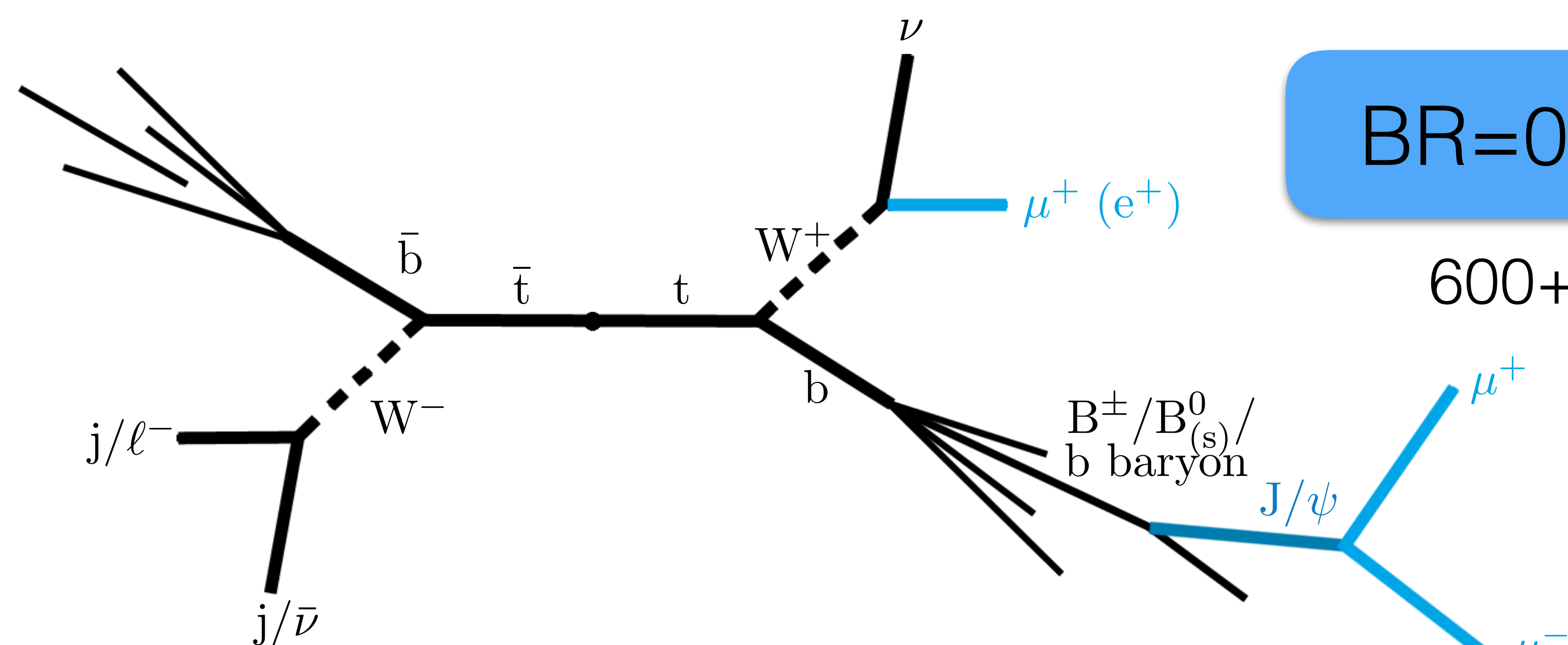
Large amount of top quarks in the 13 TeV run

Better precision

Rare phenomena

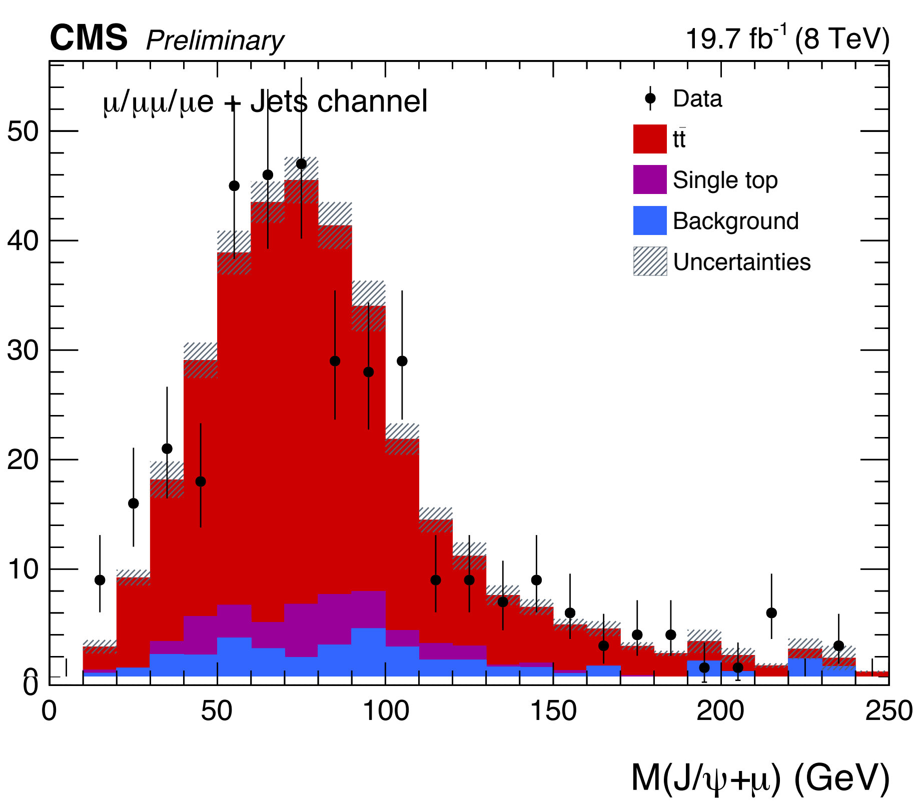
CMS-PAS-TOP-15-014

2016/03/04



BR=0.00032

600+ events!



M_t = 173.5 ± 3.0 (stat.) ± 0.9 (syst.) GeV.

No jet energy scale

The other side of LHC ...

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: Moriond 2014

ATLAS Preliminary

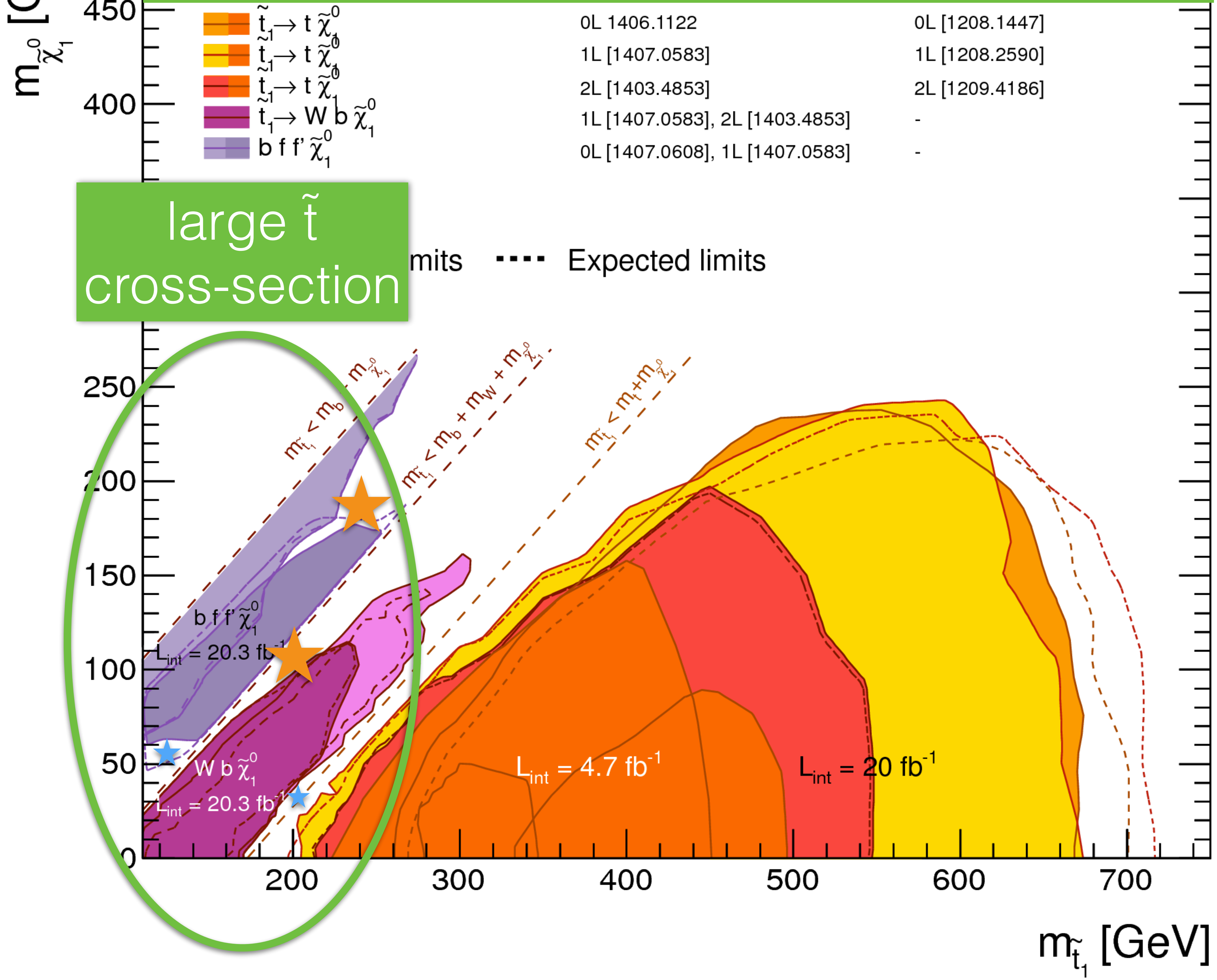
$\int \mathcal{L}\, dt = (4.6 - 22.9)\ \mathrm{fb}^{-1}$ $\sqrt{s} = 7, 8$ TeV

	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	$\tan\beta$<15	1208.4688
	GMSB ($\tilde{\tau}$ NLSP)	1-2 τ	0-2 jets	Yes	20.7	$\tilde{g}$	1.4 TeV	$\tan\beta$ >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, $\tau(\tilde{\chi}_1^\pm)$=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<$\tau(\tilde{g})$<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<$\tan\beta$<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<$\tau(\tilde{\chi}_1^0)$<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	$m(\chi)$<80 GeV, limit of<687 GeV for D8	ATLAS-CONF-2012-147

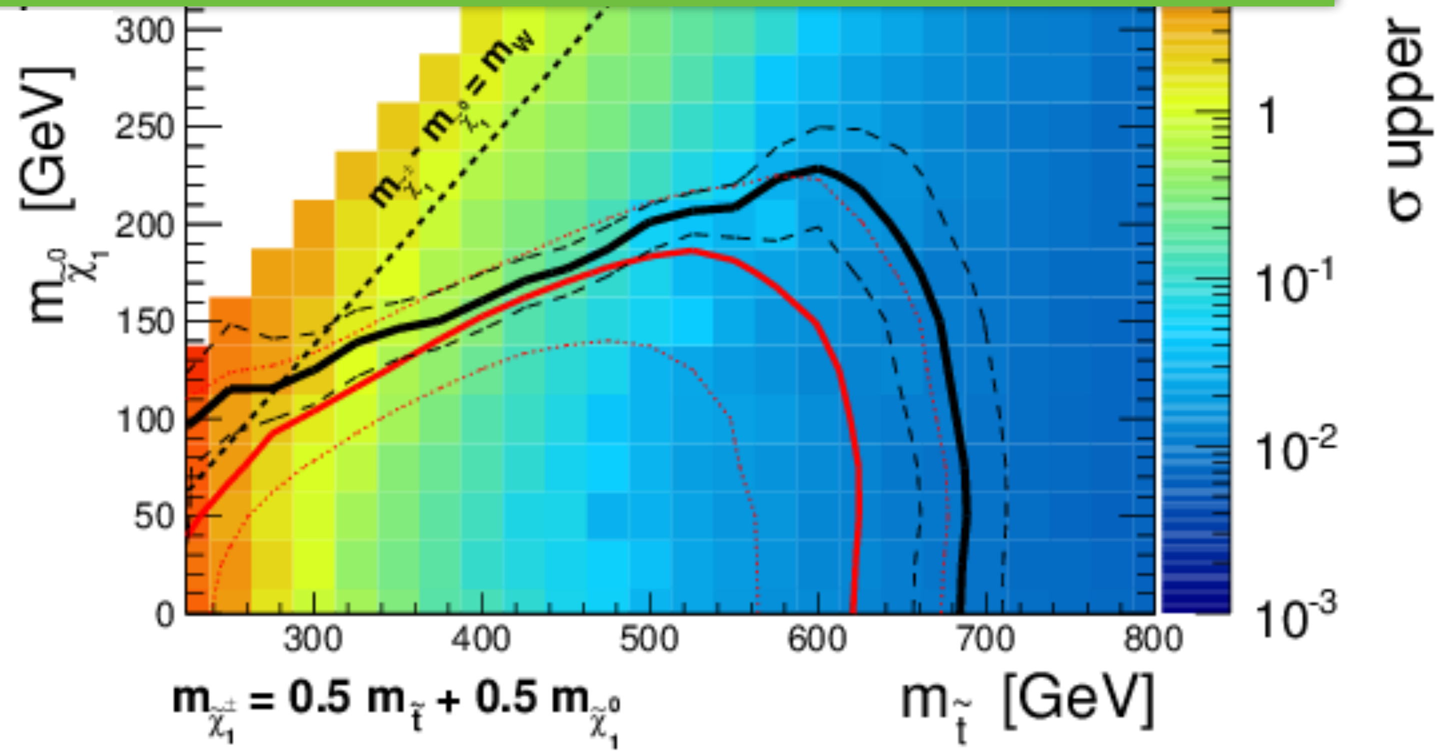
10^{-1} 1 Mass scale [TeV]

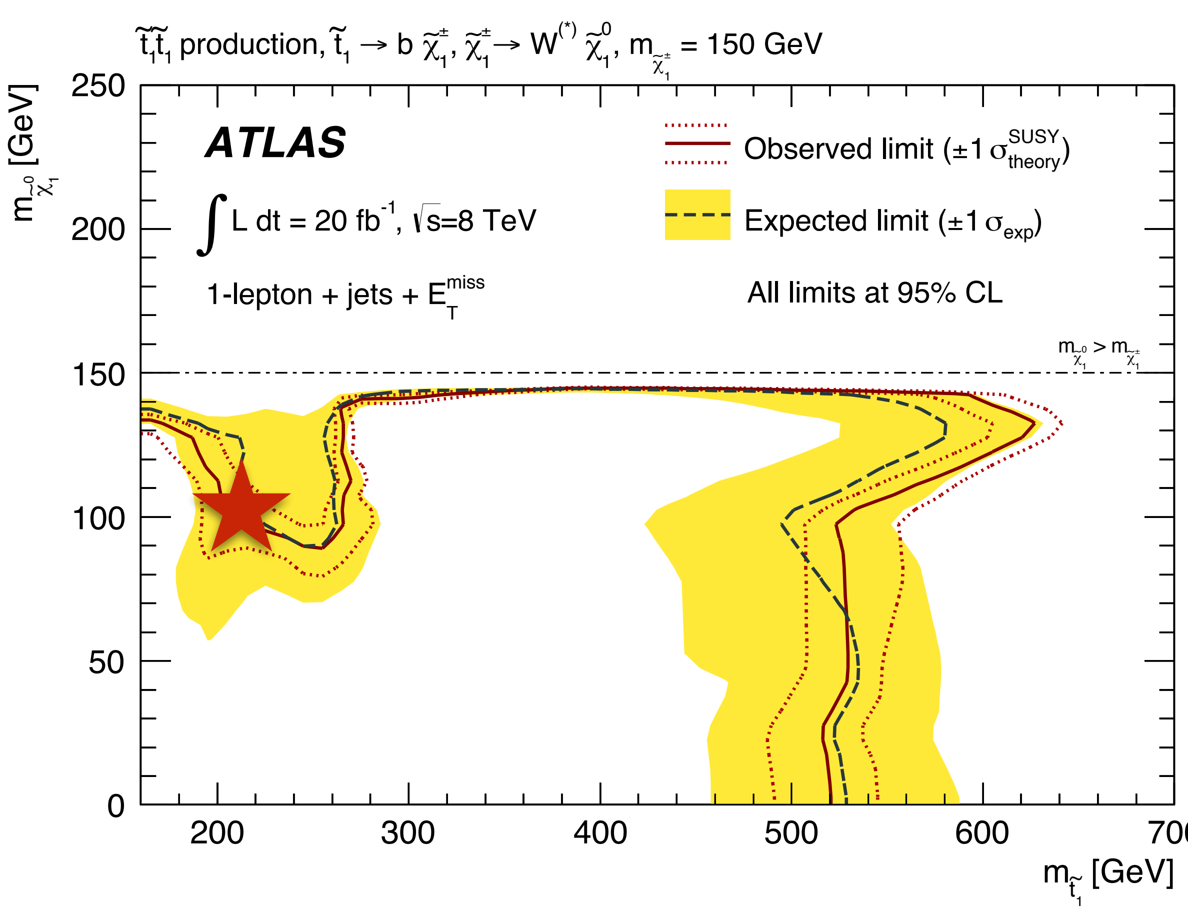
$\sqrt{s}$ = 7 TeV full data | $\sqrt{s}$ = 8 TeV partial data | $\sqrt{s}$ = 8 TeV full data

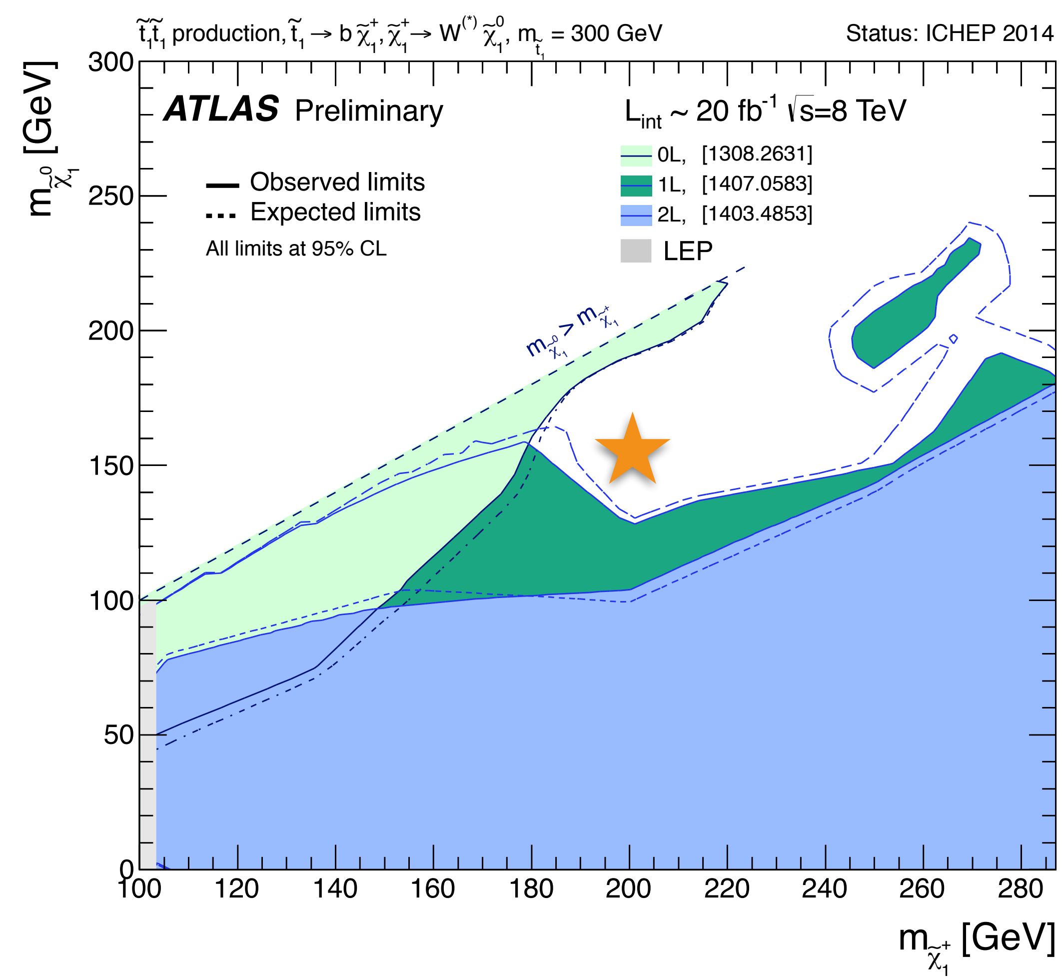
$\tilde{t} \rightarrow t\,\chi^0$



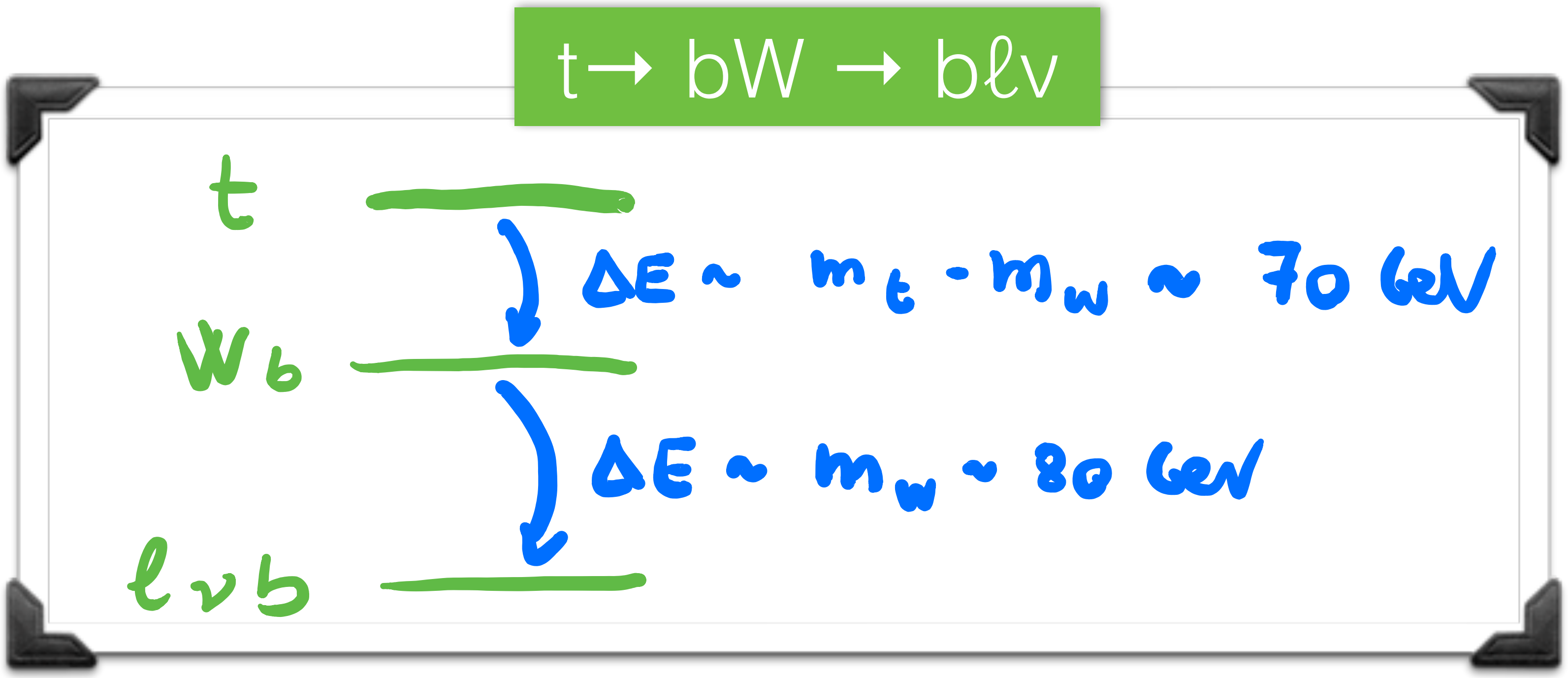
$\tilde{t} \rightarrow b\,\chi^{+} \rightarrow b\ell\nu\chi^{0}$

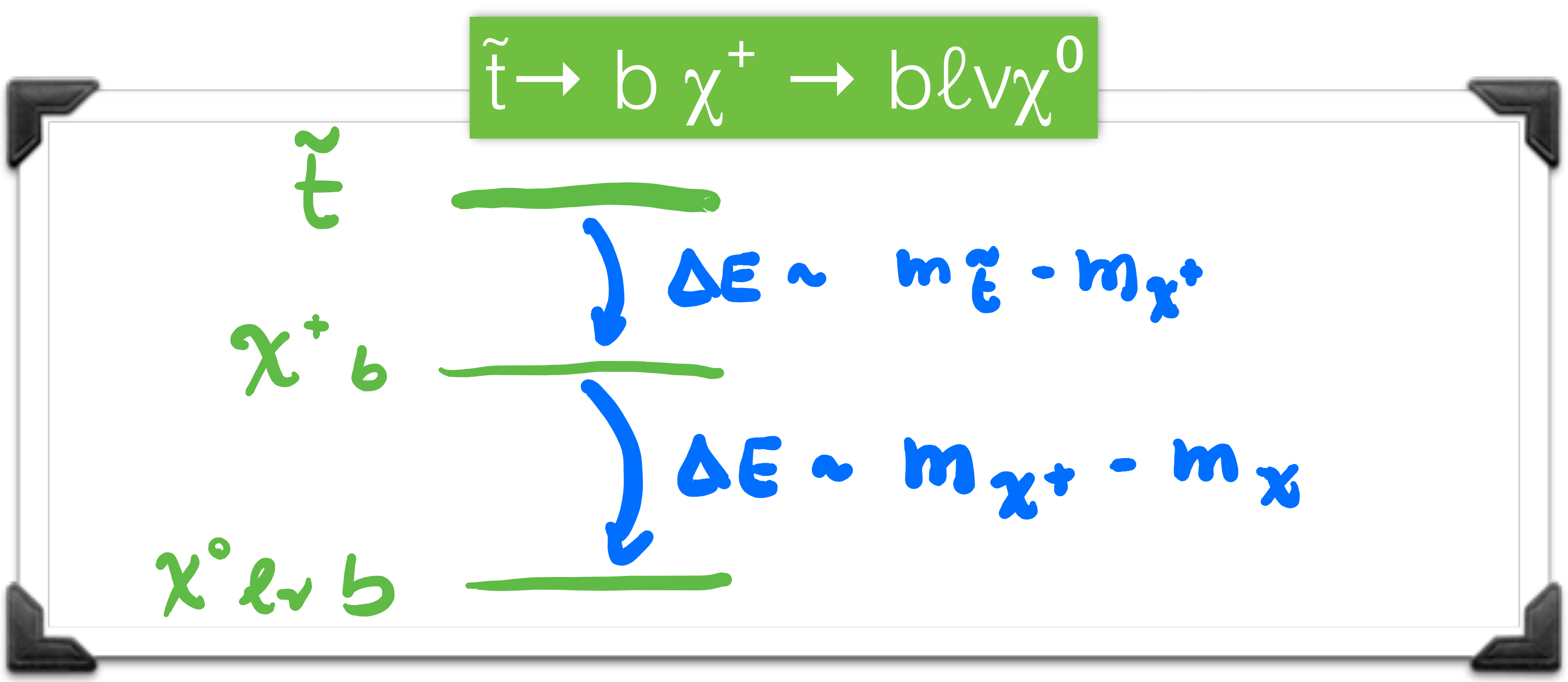






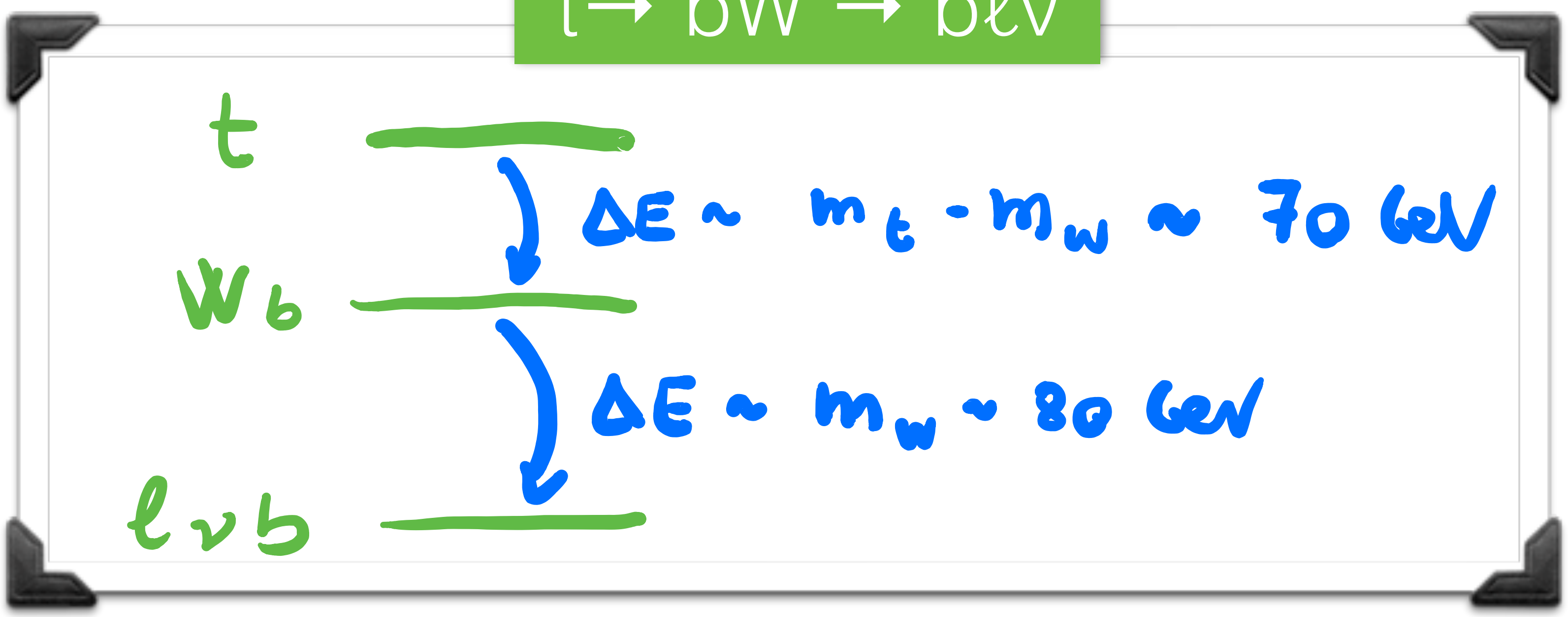
Soft is hard


$t \to bW \to b\ell\nu$
t
$W\,b$
$\Delta E \sim m_t - m_W \sim 70$ GeV
$\Delta E \sim m_W \sim 80$ GeV
$\ell\,\nu\,b$

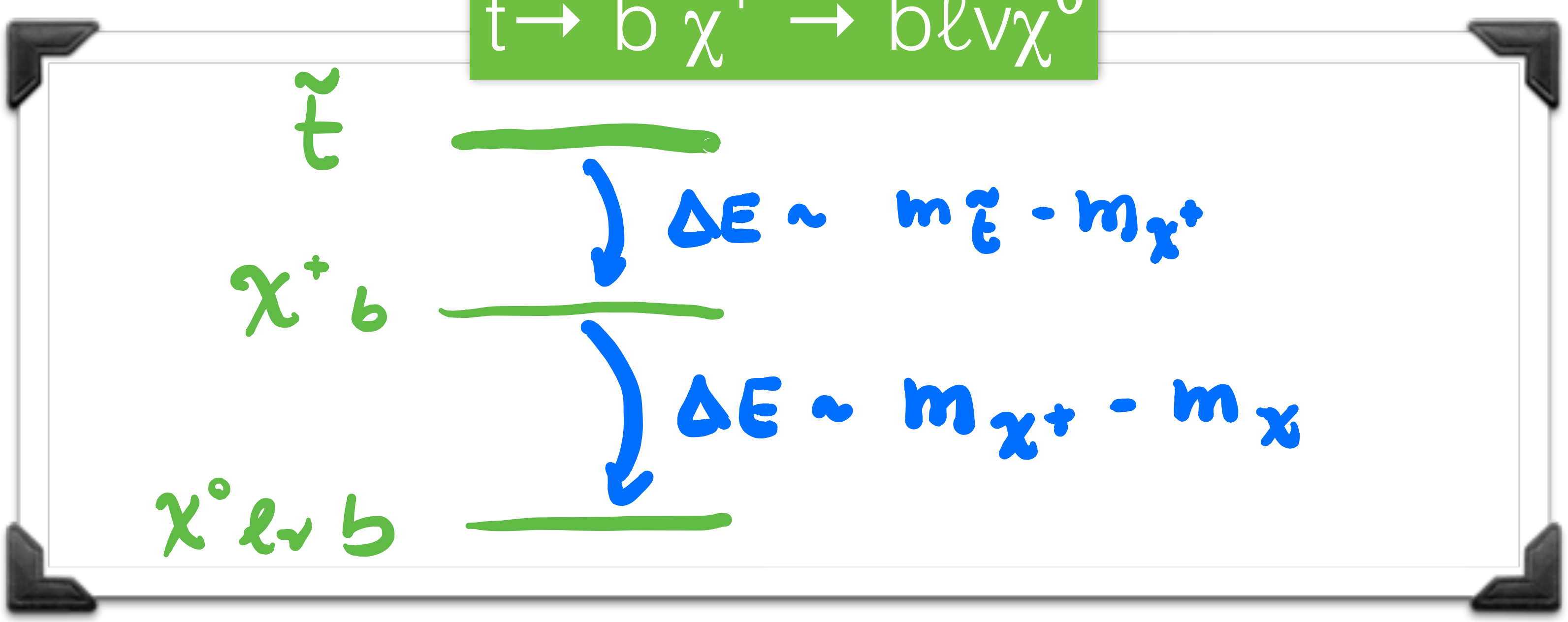

$\tilde{t} \to b\,\chi^+ \to b\ell\nu\chi^0$
$\tilde{t}$
$\chi^+\,b$
$\Delta E \sim m_{\tilde{t}} - m_{\chi^+}$
$\Delta E \sim m_{\chi^+} - m_{\chi^0}$
$\chi^0\,\ell\,\nu\,b$

Soft is hard

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



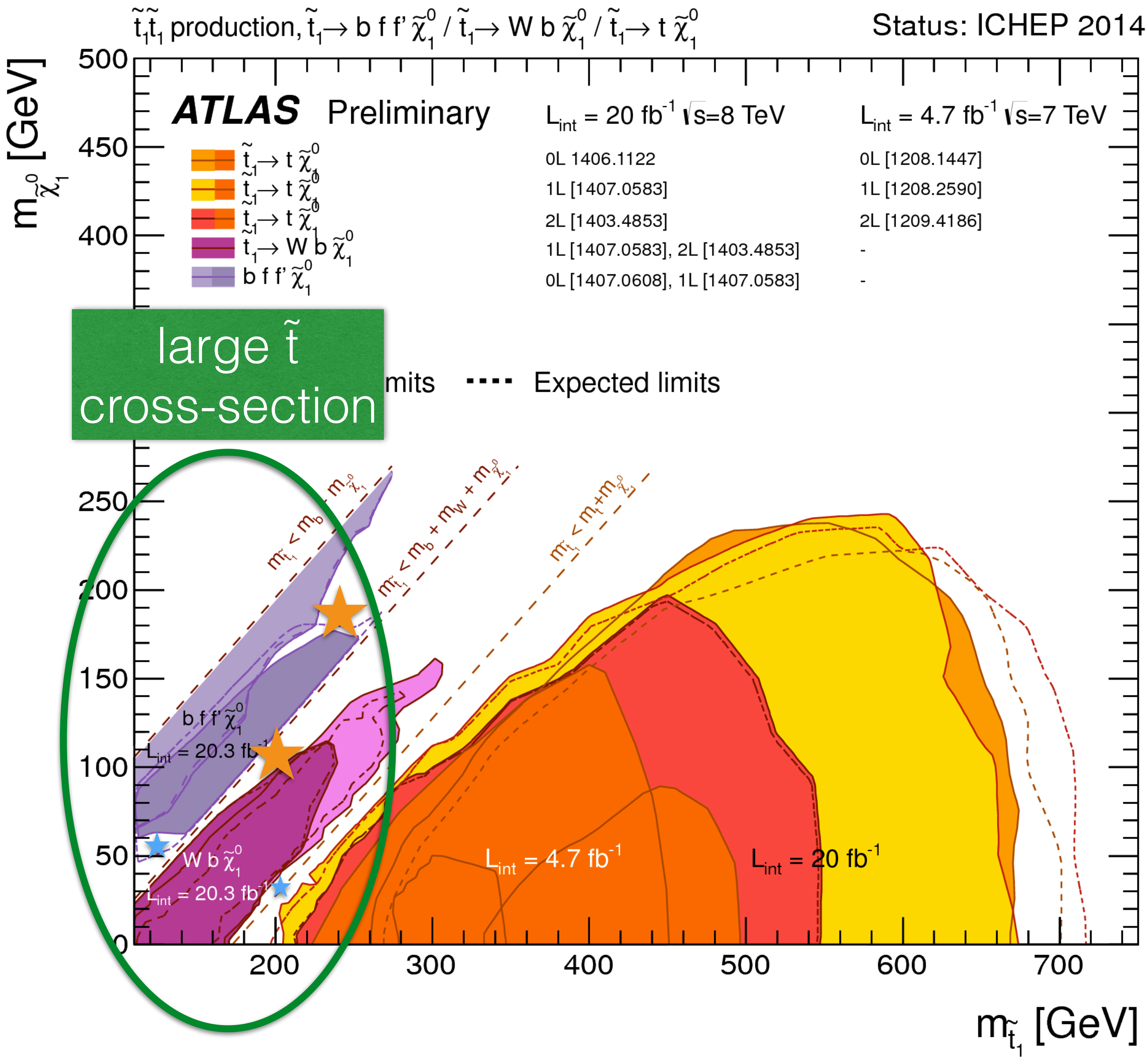
$\tilde{t} \to b\,\chi^+ \to b\ell\nu\chi^0$



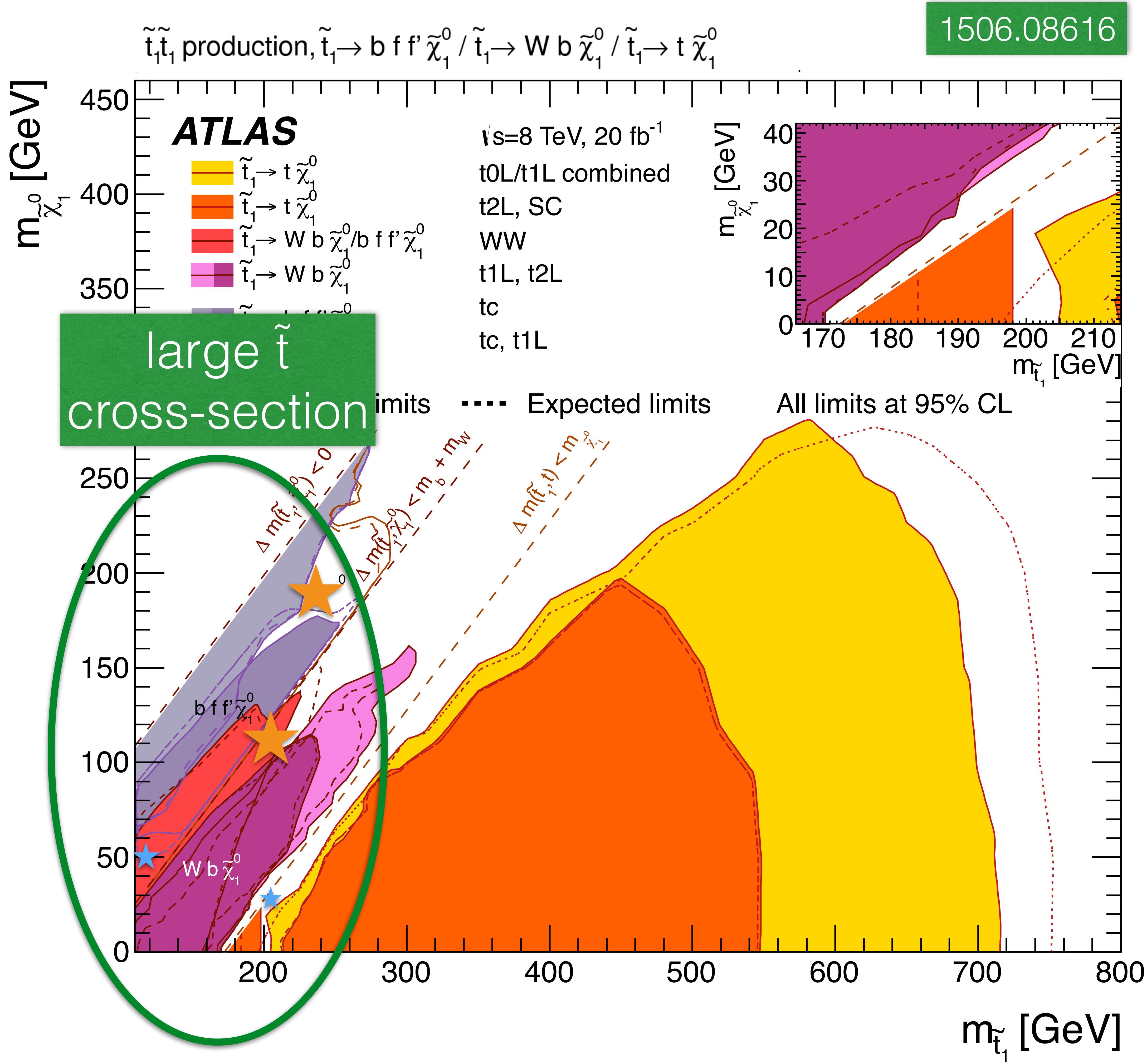
New physics is SM-like

Better precision

Rare phenomena



$\tilde{t}_1\tilde{t}_1$ production, $\tilde{t}_1 \rightarrow b f f' \tilde{\chi}_1^0$ / $\tilde{t}_1 \rightarrow W b \tilde{\chi}_1^0$ / $\tilde{t}_1 \rightarrow t \tilde{\chi}_1^0$
Status: ICHEP 2014
ATLAS Preliminary
L_{int} = 20 fb^{-1} $\sqrt{s}$=8 TeV
L_{int} = 4.7 fb^{-1} $\sqrt{s}$=7 TeV
$\tilde{t}_1 \rightarrow t \tilde{\chi}_1^0$ 0L 1406.1122 0L [1208.1447]
$\tilde{t}_1 \rightarrow t \tilde{\chi}_1^0$ 1L [1407.0583] 1L [1208.2590]
$\tilde{t}_1 \rightarrow t \tilde{\chi}_1^0$ 2L [1403.4853] 2L [1209.4186]
$\tilde{t}_1 \rightarrow W b \tilde{\chi}_1^0$ 1L [1407.0583], 2L [1403.4853] -
$b f f' \tilde{\chi}_1^0$ 0L [1407.0608], 1L [1407.0583] -
large $\tilde{t}$ cross-section
mits
Expected limits
$m_{\tilde{t}_1} < m_b + m_{\tilde{\chi}_1^0}$
$m_{\tilde{t}_1} < m_b + m_W + m_{\tilde{\chi}_1^0}$
$m_{\tilde{t}_1} < m_t + m_{\tilde{\chi}_1^0}$
$b f f' \tilde{\chi}_1^0$
L_{int} = 20.3 fb^{-1}
$W b \tilde{\chi}_1^0$
L_{int} = 20.3 fb^{-1}
L_{int} = 4.7 fb^{-1}
L_{int} = 20 fb^{-1}
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{t}_1}$ [GeV]

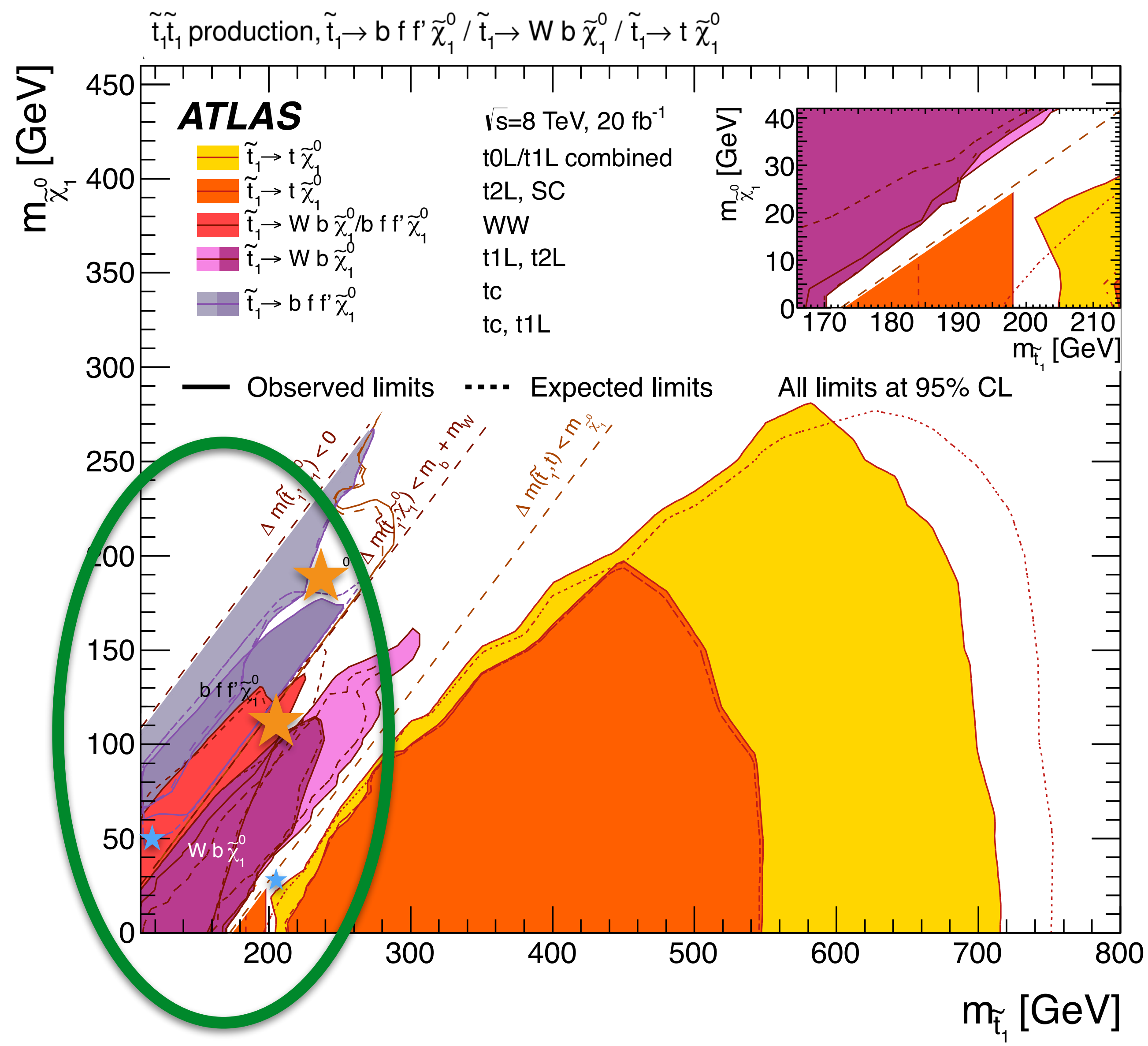

1506.08616
$\tilde{t}_1\tilde{t}_1$ production, $\tilde{t}_1 \to b f f' \tilde{\chi}_1^0$ / $\tilde{t}_1 \to W b \tilde{\chi}_1^0$ / $\tilde{t}_1 \to t \tilde{\chi}_1^0$
ATLAS
$\sqrt{s}$=8 TeV, 20 fb^{-1}
$\tilde{t}_1 \to t \tilde{\chi}_1^0$ t0L/t1L combined
$\tilde{t}_1 \to t \tilde{\chi}_1^0$ t2L, SC
$\tilde{t}_1 \to W b \tilde{\chi}_1^0 / b f f' \tilde{\chi}_1^0$ WW
$\tilde{t}_1 \to W b \tilde{\chi}_1^0$ t1L, t2L
tc
tc, t1L
large $\tilde{t}$ cross-section
Expected limits
All limits at 95% CL
$\Delta m(\tilde{t}_1,\tilde{\chi}_1^0) < 0$
$\Delta m(\tilde{t}_1,\tilde{\chi}_1^0) < m_b + m_W$
$\Delta m(\tilde{t}_1,t) < m_{\tilde{\chi}_1^0}$
$b f f' \tilde{\chi}_1^0$
$W b \tilde{\chi}_1^0$
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{t}_1}$ [GeV]

Soft is hard

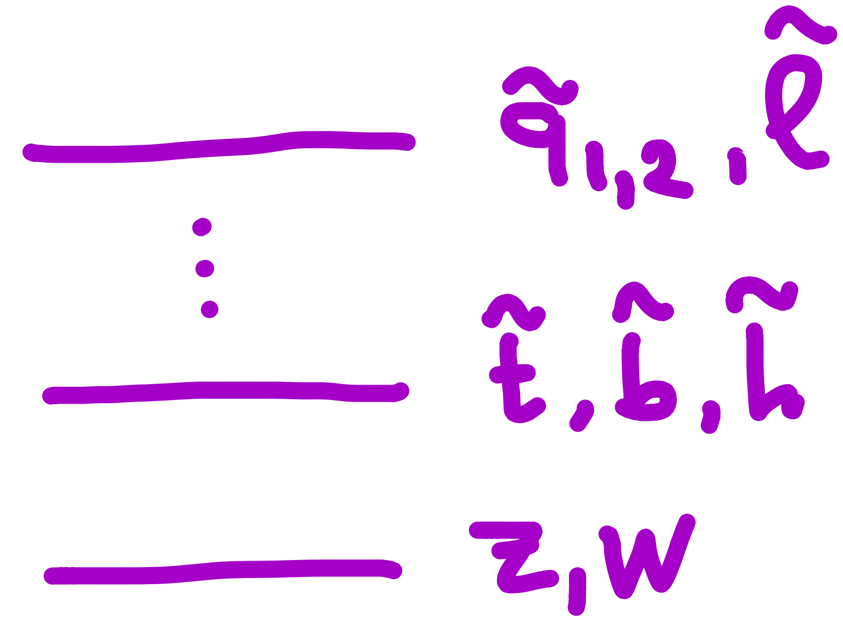
Generic
issue of new physics searches

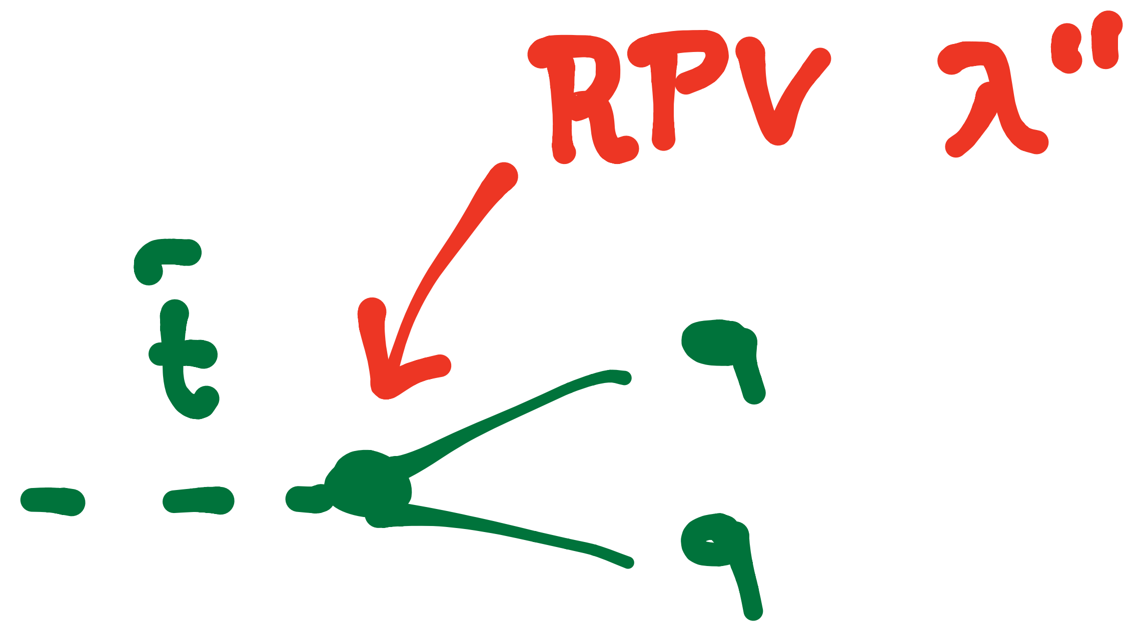
SUSY as proxy to many other
scenario fo new physics

Likely to persist at 13 TeV



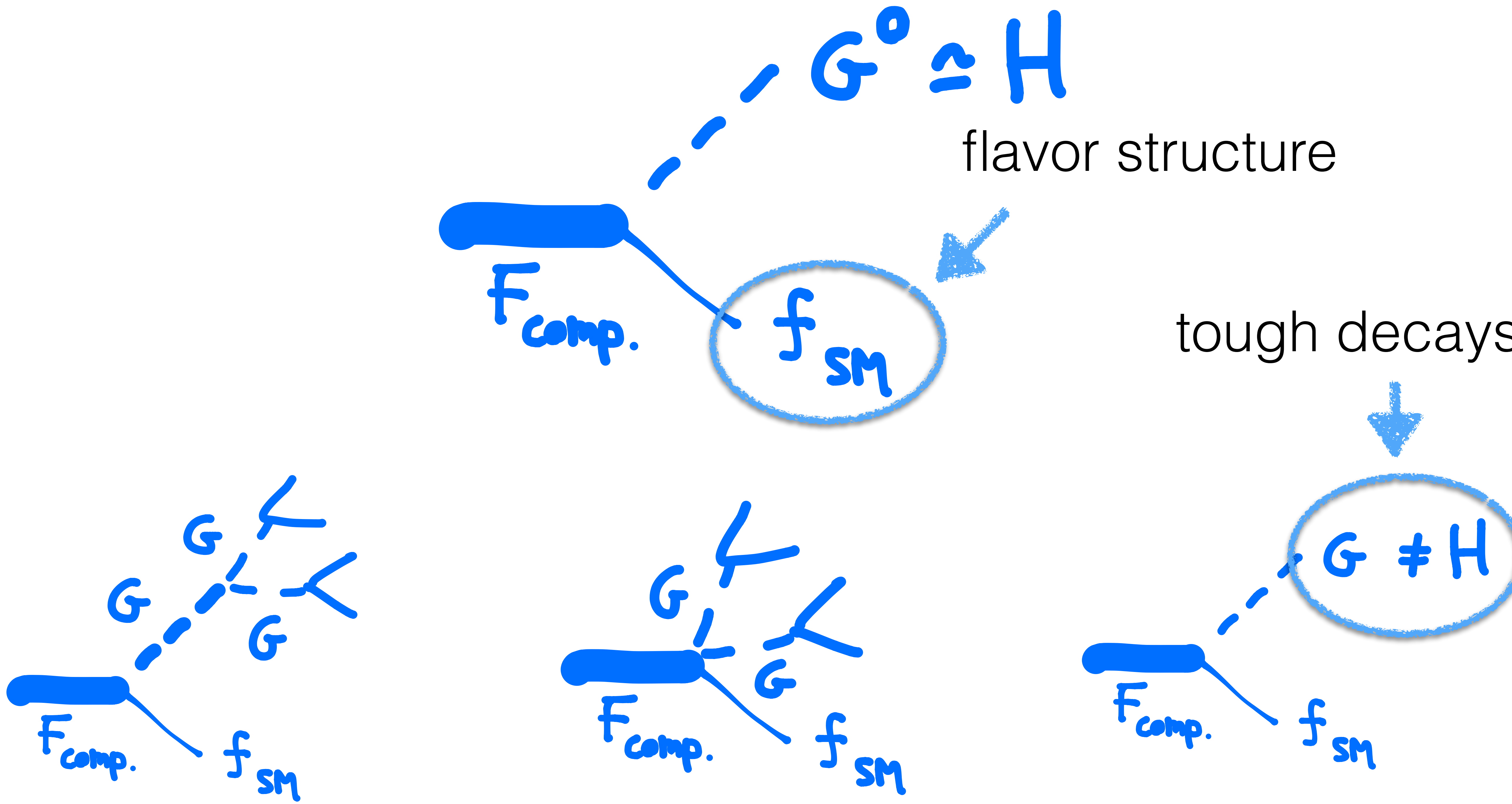
Theory Options ~SUSY





more subtle signals ⇒ precision

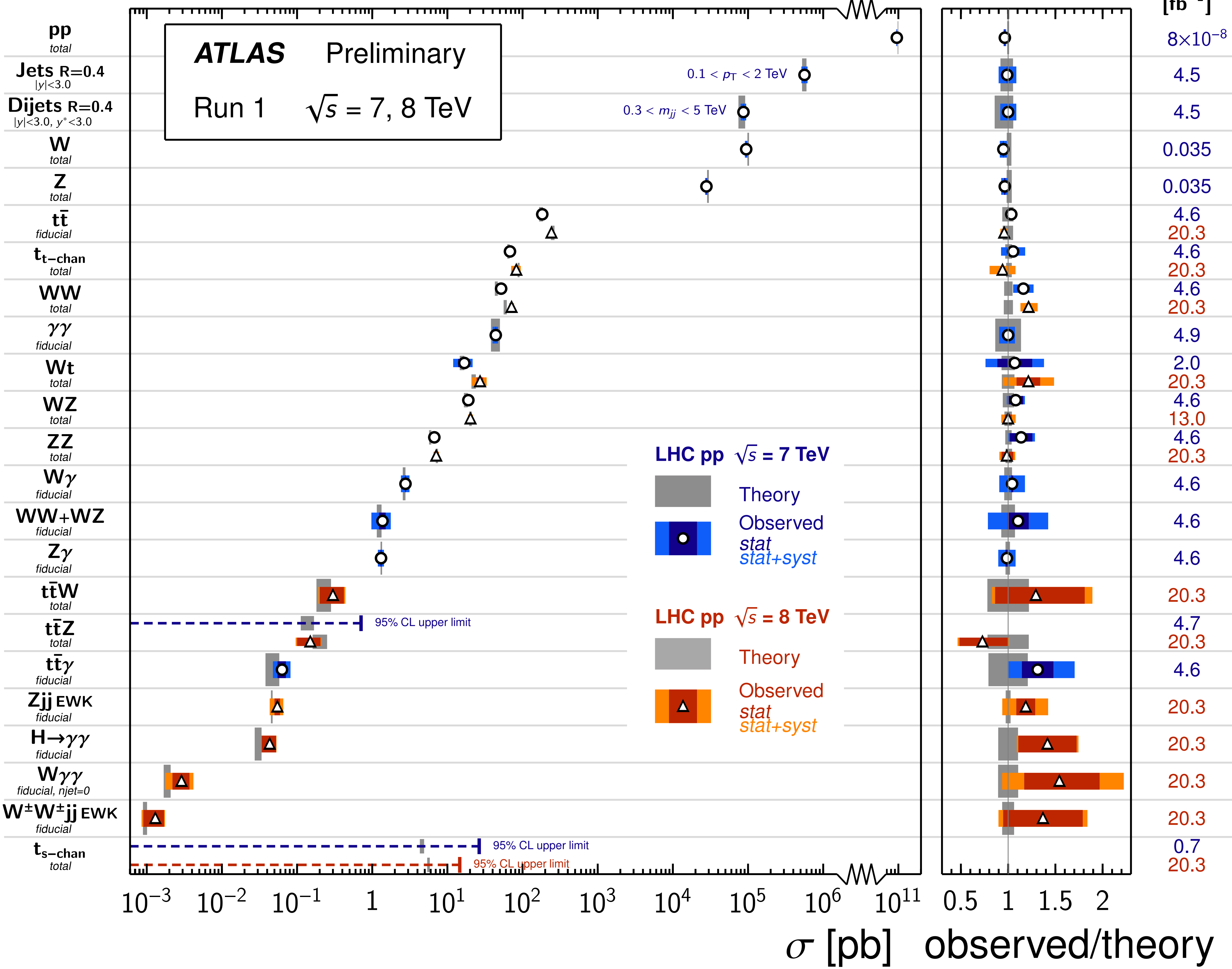
Theory Options ~non-SUSY



more subtle signals ⇒ precision

Run2 $\simeq$ Subtle New Physics

Standard Model Production Cross Section Measurements



Will not cover

“closed” games

- $\tilde{g} \rightarrow tt\chi$

(well known) indirect limits

- A_FB, A_c (e.g. review 1506.02800)
- ttZ, $tt\gamma$, …
- $G_{\mu\nu}\, t\sigma_{\mu\nu}t$ ($\sigma(tt)$ 1210.2570, CMS-TOP-14-005 $\Delta\phi(\ell\ell)$, boosted 1412.6654)
- $G_{\mu\nu}\, T'\sigma_{\mu\nu}t$ (CMS-PAS-B2G-12-014 and alike)
- …

Will cover

- Top as a background
- Top as a source
- Top as a trigger

Will cover

- Top as a background for subtle new physics
- Top as a source of subtle new physics
- Top as a trigger for subtle new physics

Will cover

- Top as a background for subtle new physics
- Top as a source of subtle new physics
- Top as a trigger for subtle new physics

↓

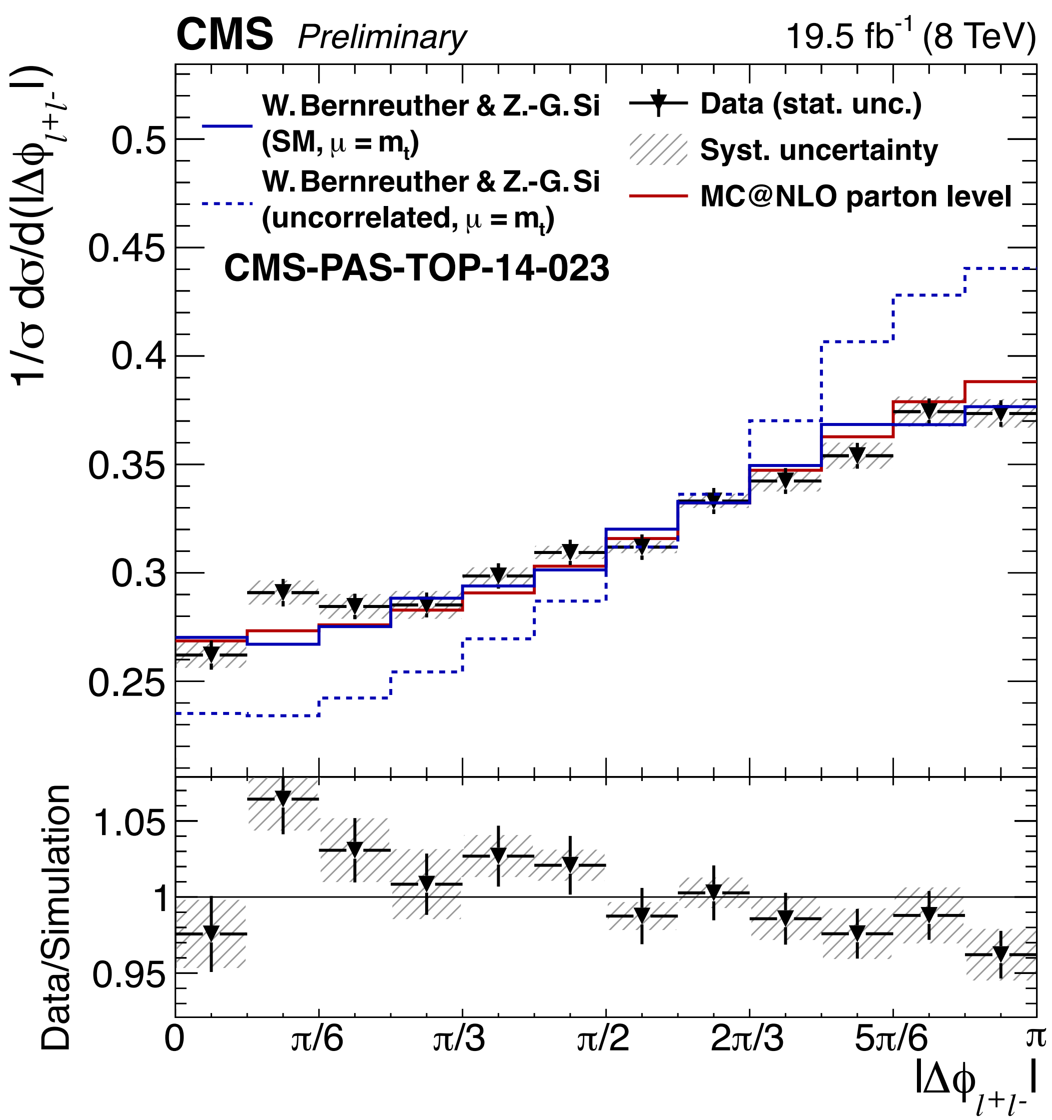
BSM in *precision* hadronic scattering

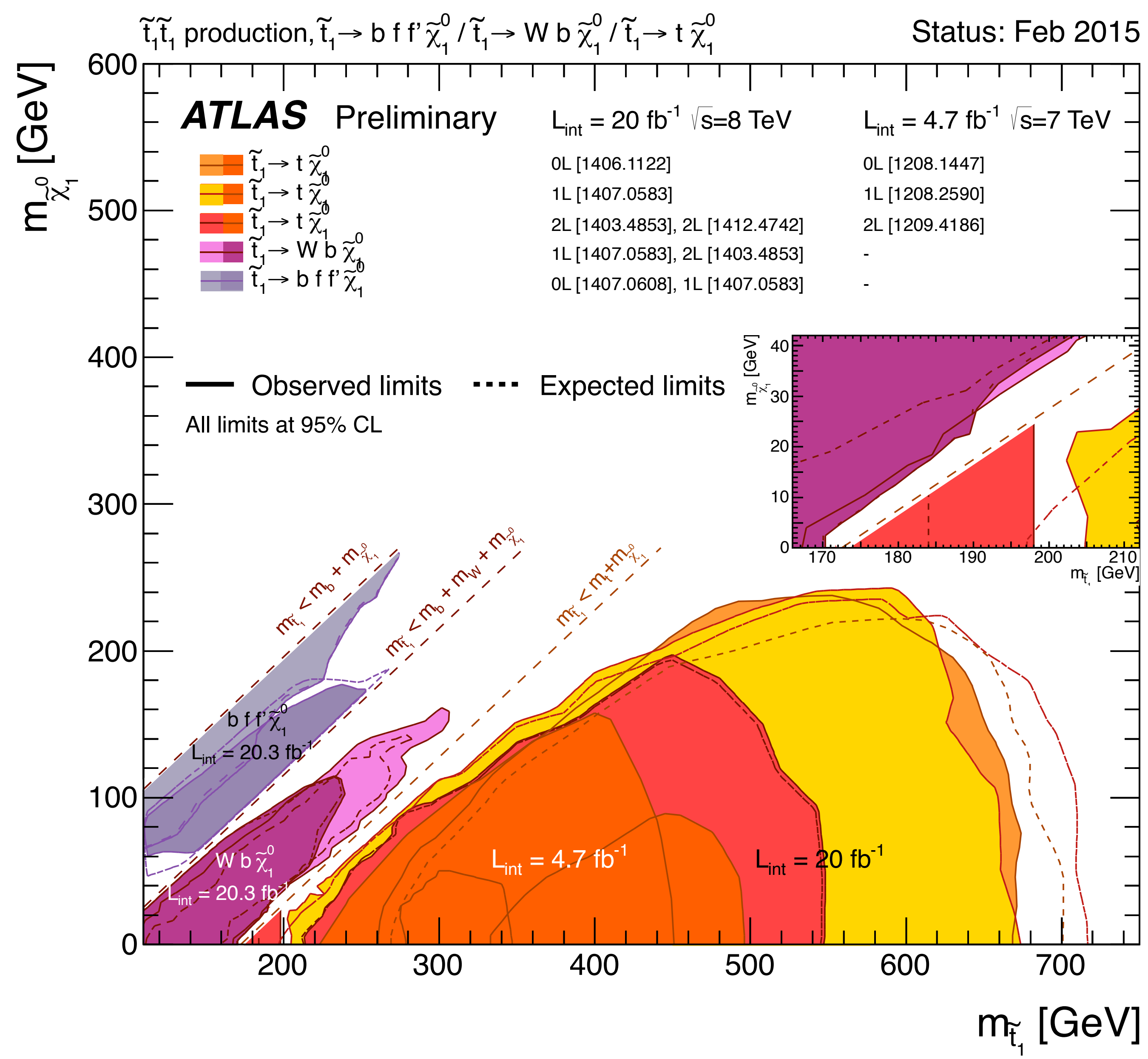
Top as a background

$\Delta\phi(\ell\ell)$

1205.5808 1412.4742+ATLAS-CONF-2014-056

$$\mathcal{L}_{eff} = -\frac{\widetilde{\mu}_t}{2}\bar{t}\sigma^{\mu\nu}T^a t G^a_{\mu\nu} - \frac{\widetilde{d}_t}{2}\bar{t}i\sigma^{\mu\nu}\gamma_5 T^a t G^a_{\mu\nu},$$

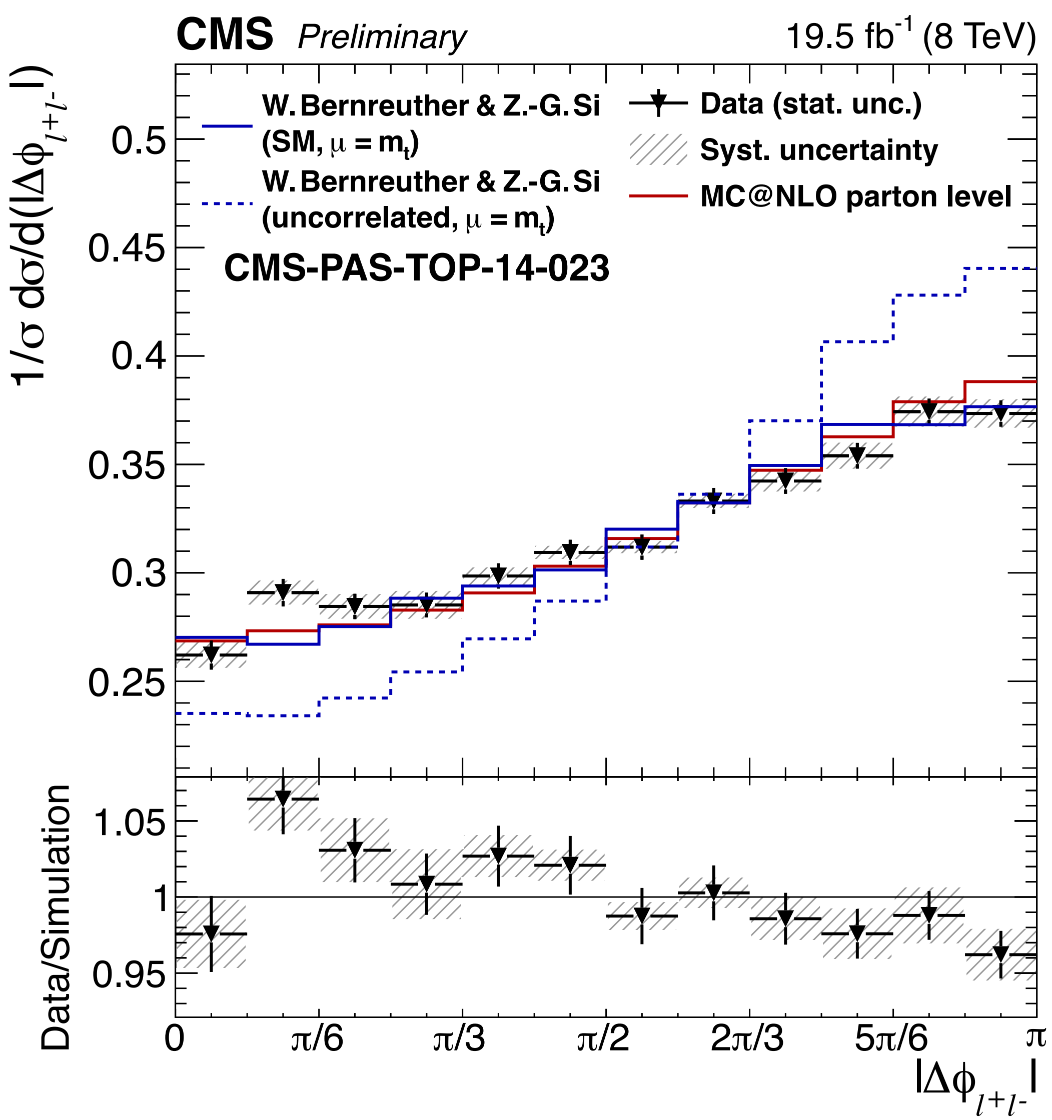


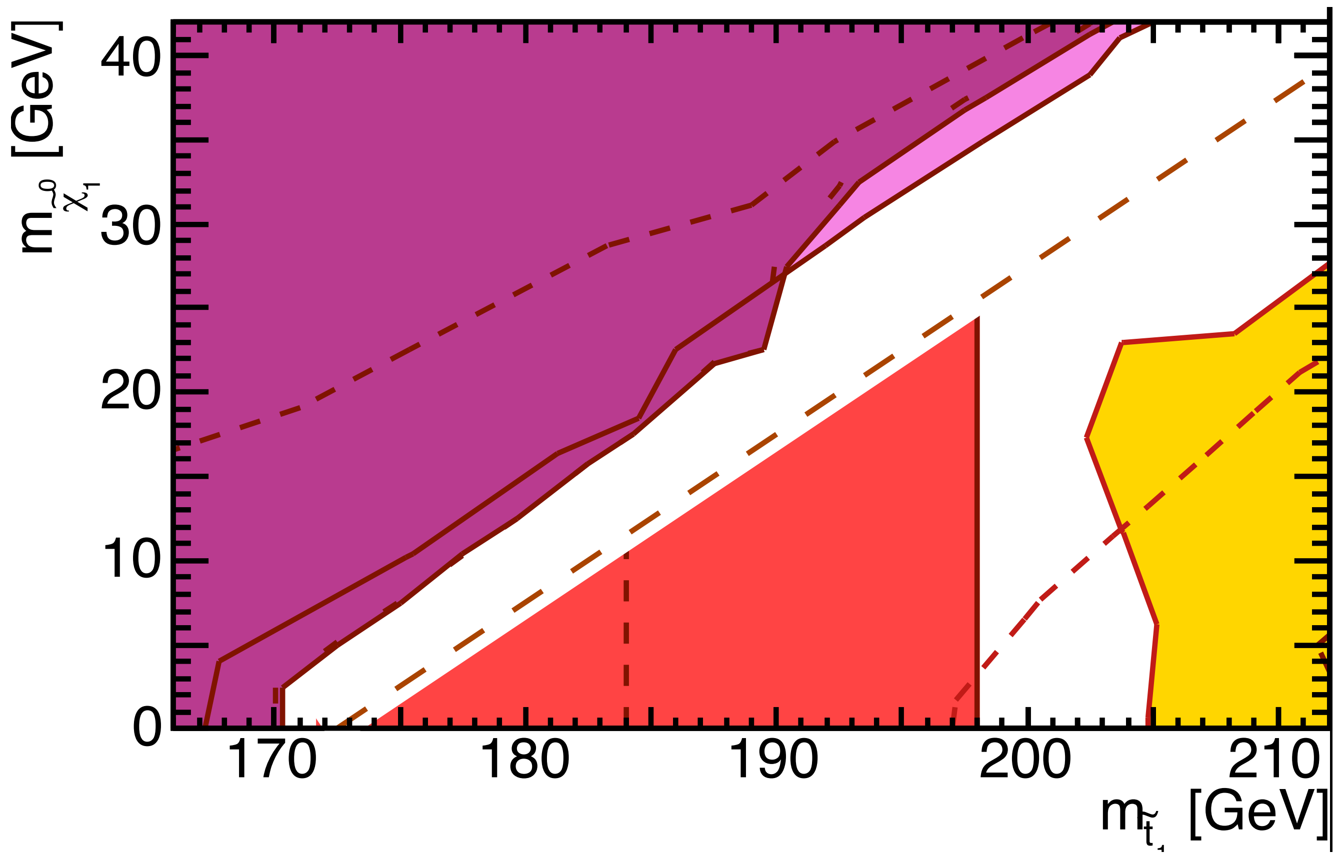


$\Delta\phi(\ell\ell)$

1205.5808 1412.4742+ATLAS-CONF-2014-056

$$\mathcal{L}_{eff} = -\frac{\widetilde{\mu}_t}{2}\bar{t}\sigma^{\mu\nu}T^a t G^a_{\mu\nu} - \frac{\widetilde{d}_t}{2} i\sigma^{\mu\nu}\gamma_5 T^a t G^a_{\mu\nu},$$

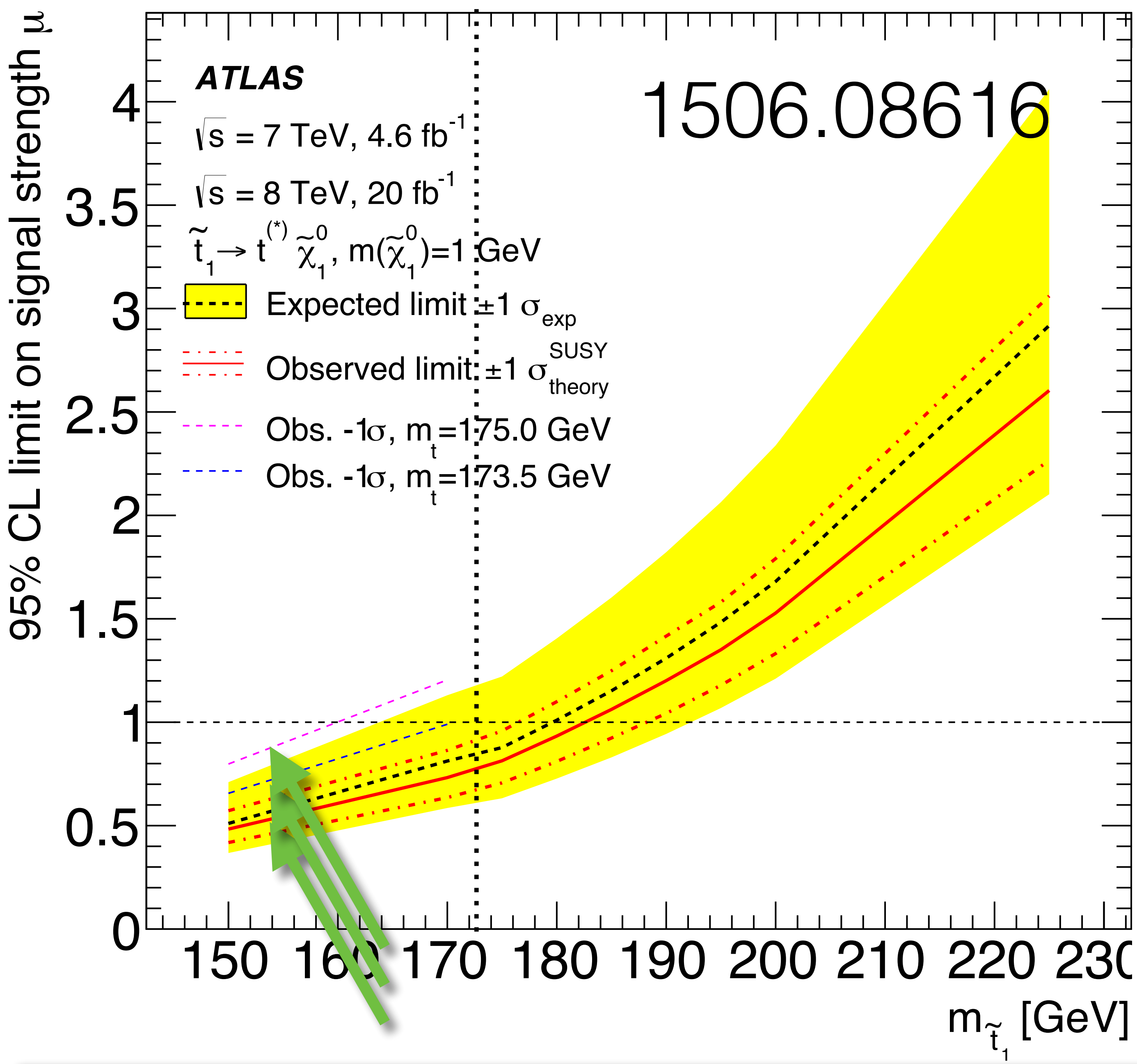




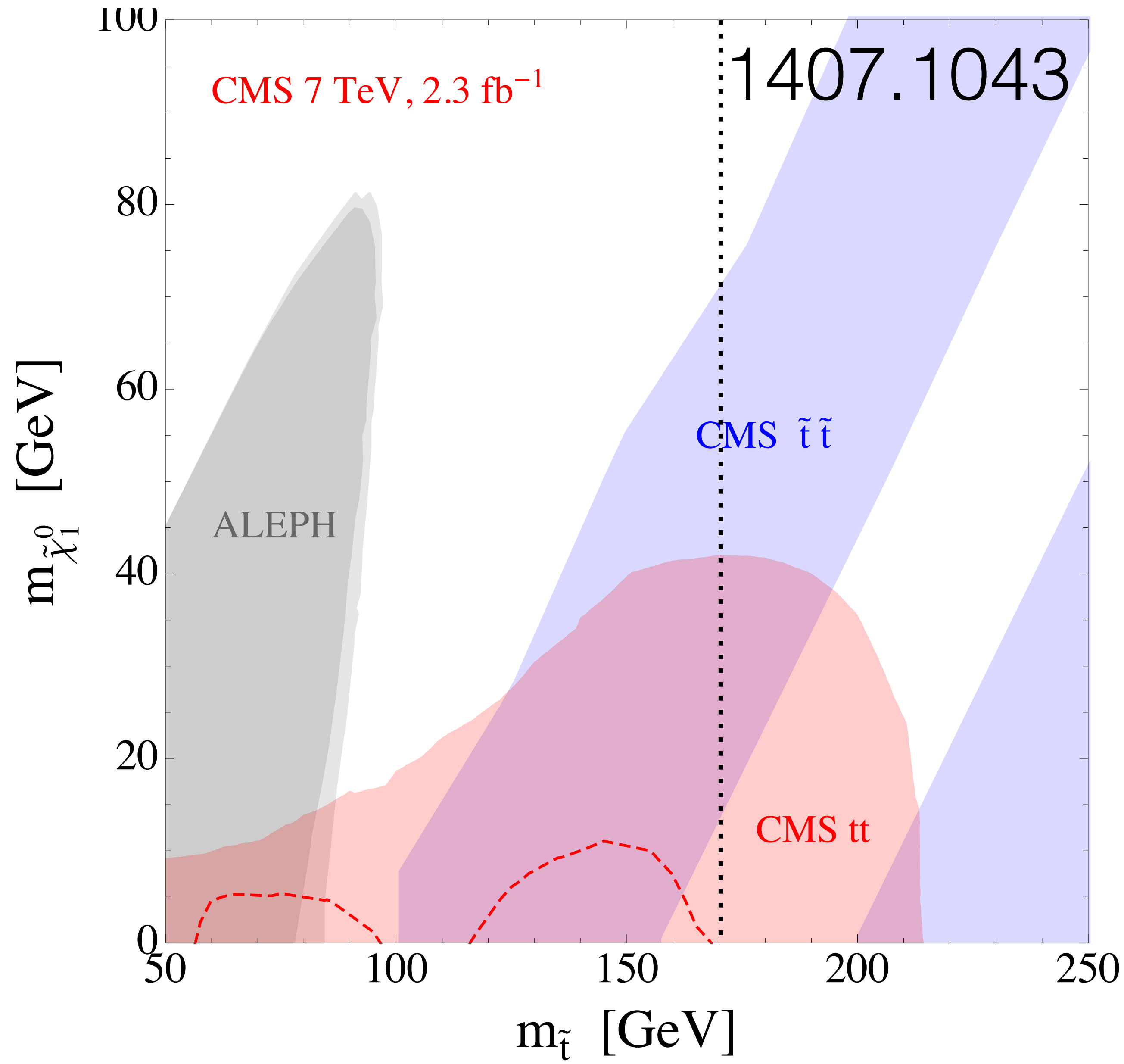
$\sigma(t\bar{t})$

1407.1043 + 1406.5375 + 1506.08616

light stop effects on top cross-section



mχ ≠ 1 GeV



variations of m_{top} reflected on σ(tt)

BSM in precision hadronic scattering

top quark physics is well under control

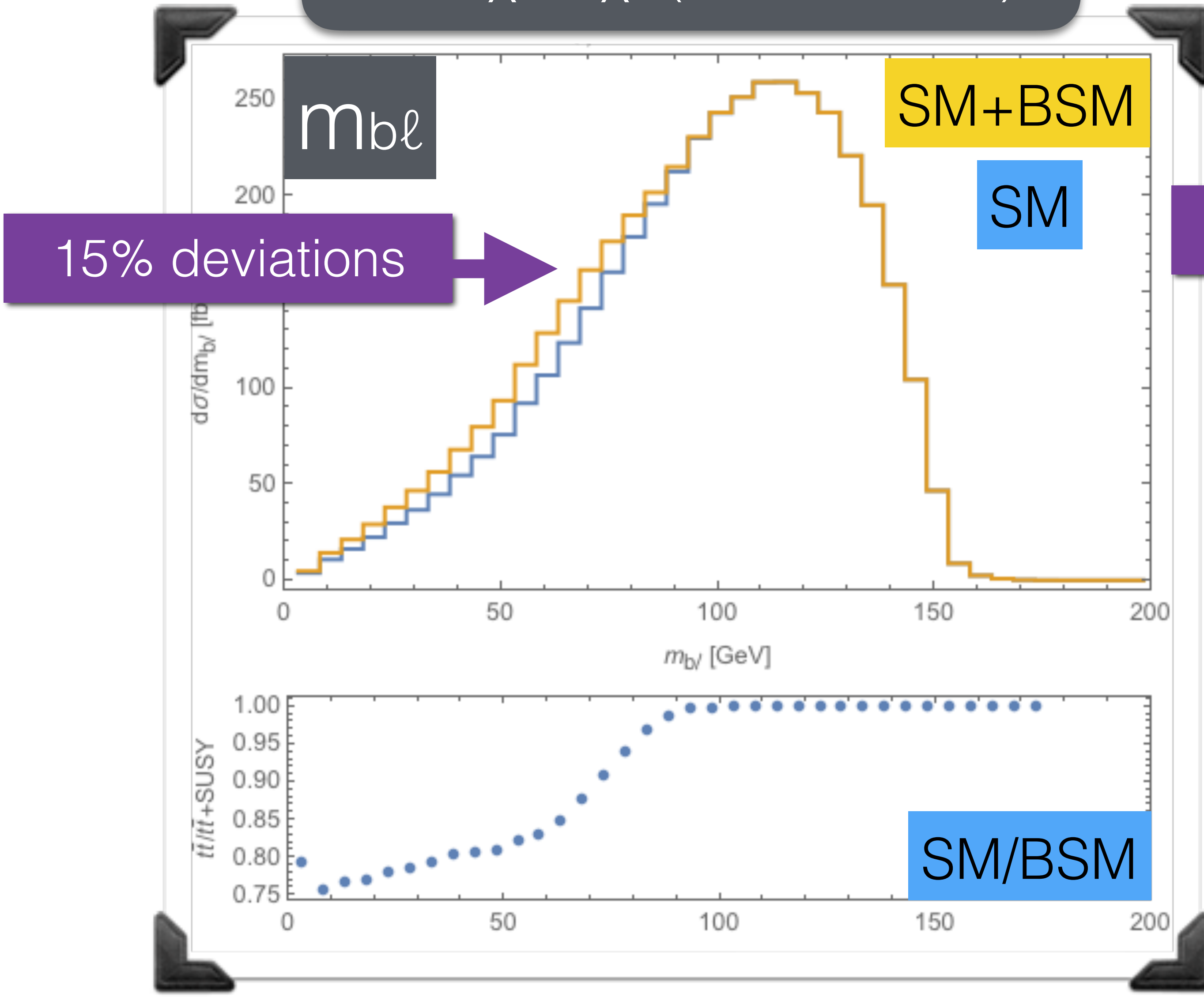
mass measurement at ≲0.5%! ⇒ *precision* QCD

suitable to look for subtle effects

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

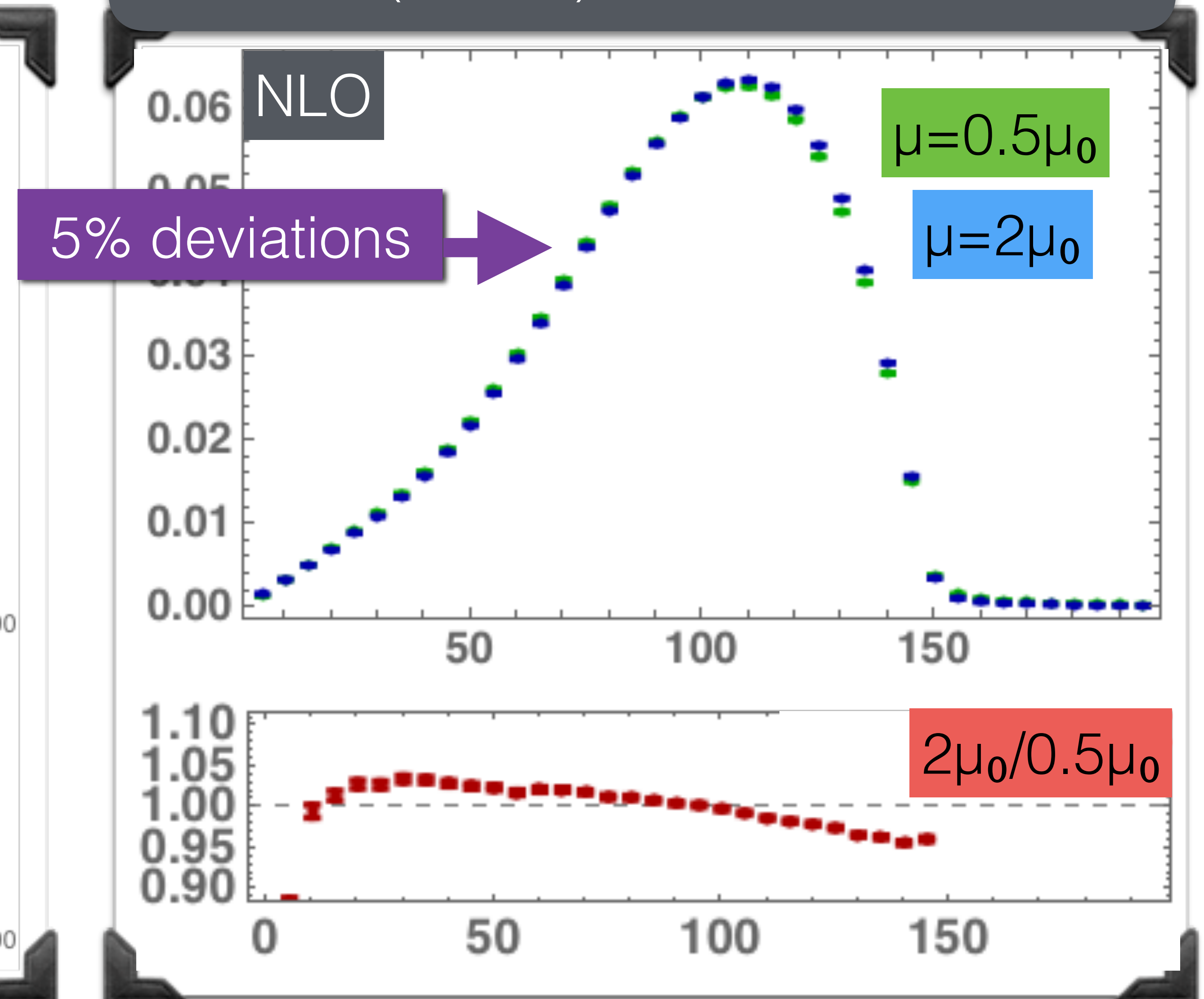
RF - 1601.02684

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



RF - in preparation

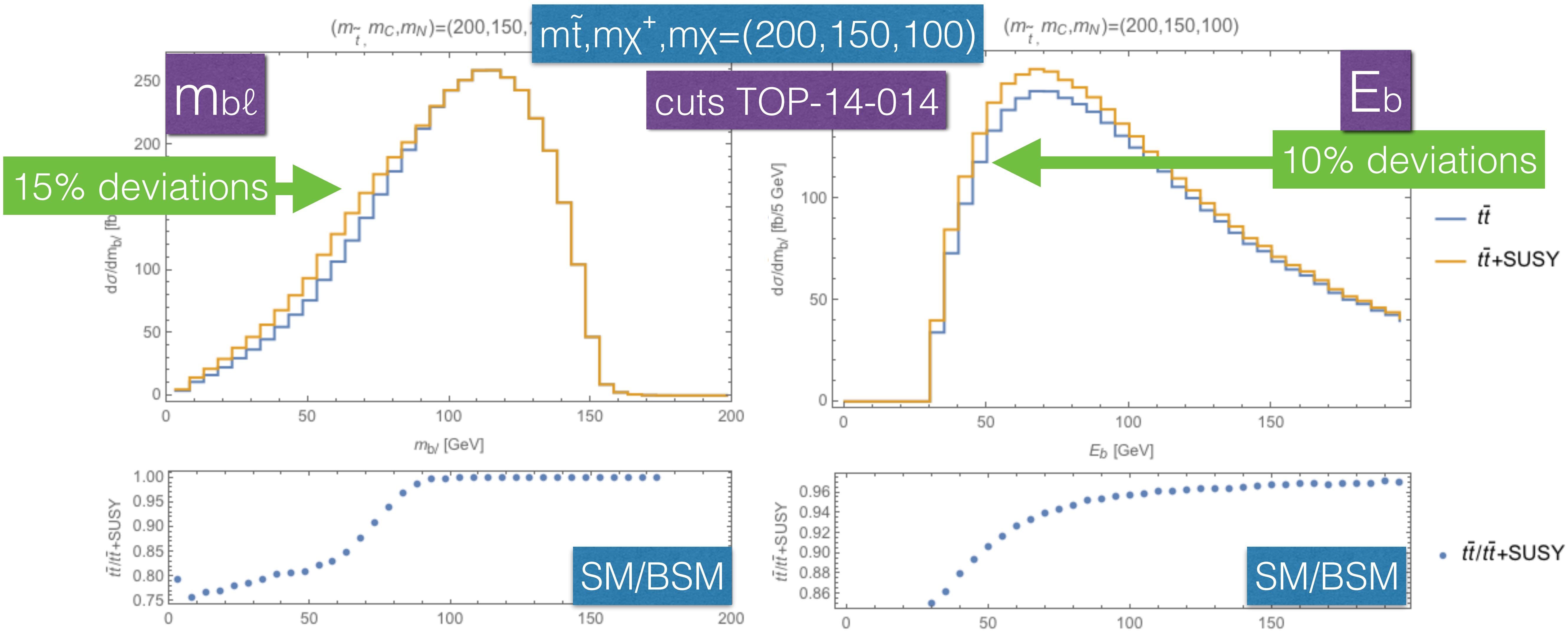
SM $t\bar{t}$ (MCFM) as in TOP-14-014



Theory uncertainty is critical

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

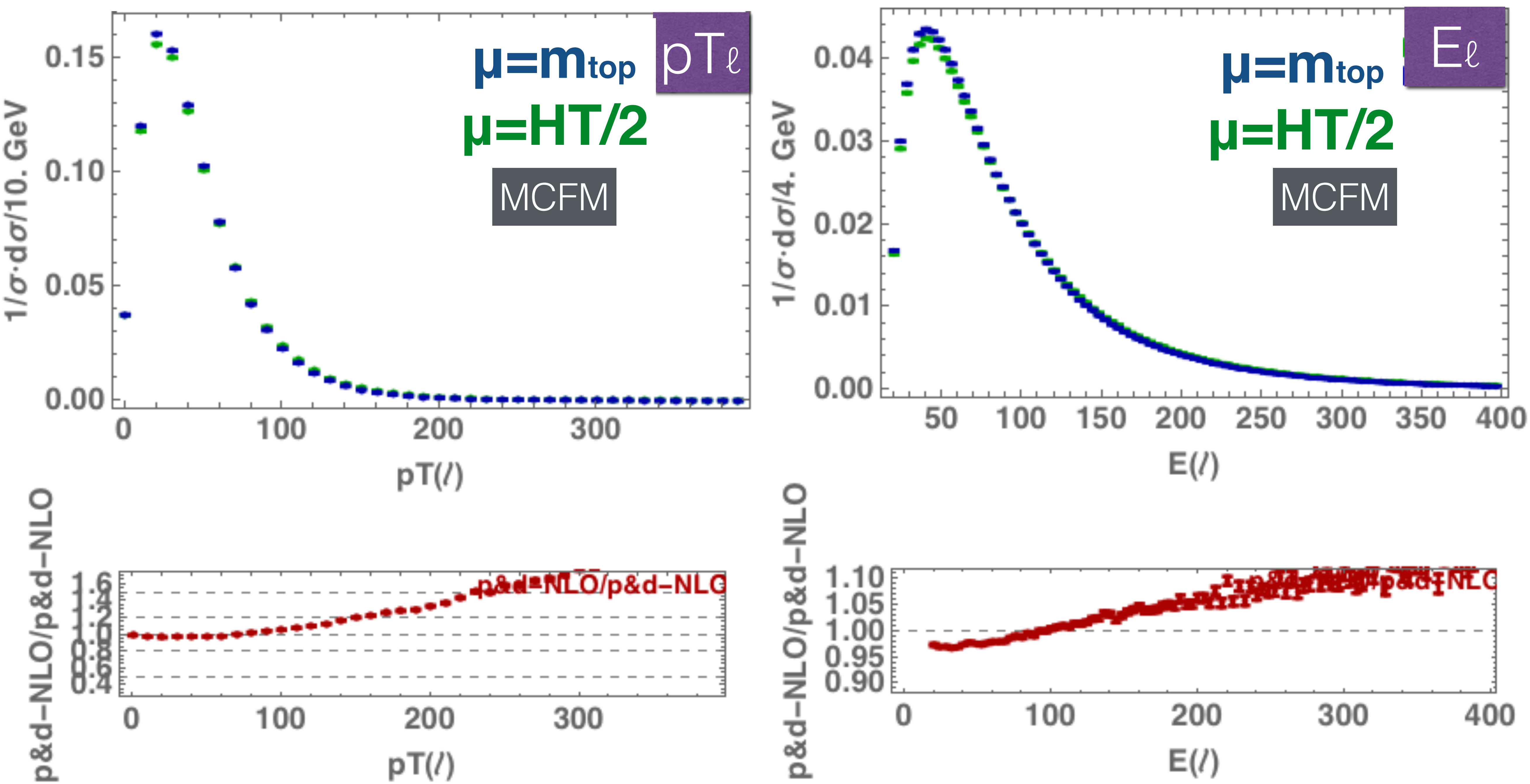
RF - in preparation



Theory uncertainty is critical

Adding more variables

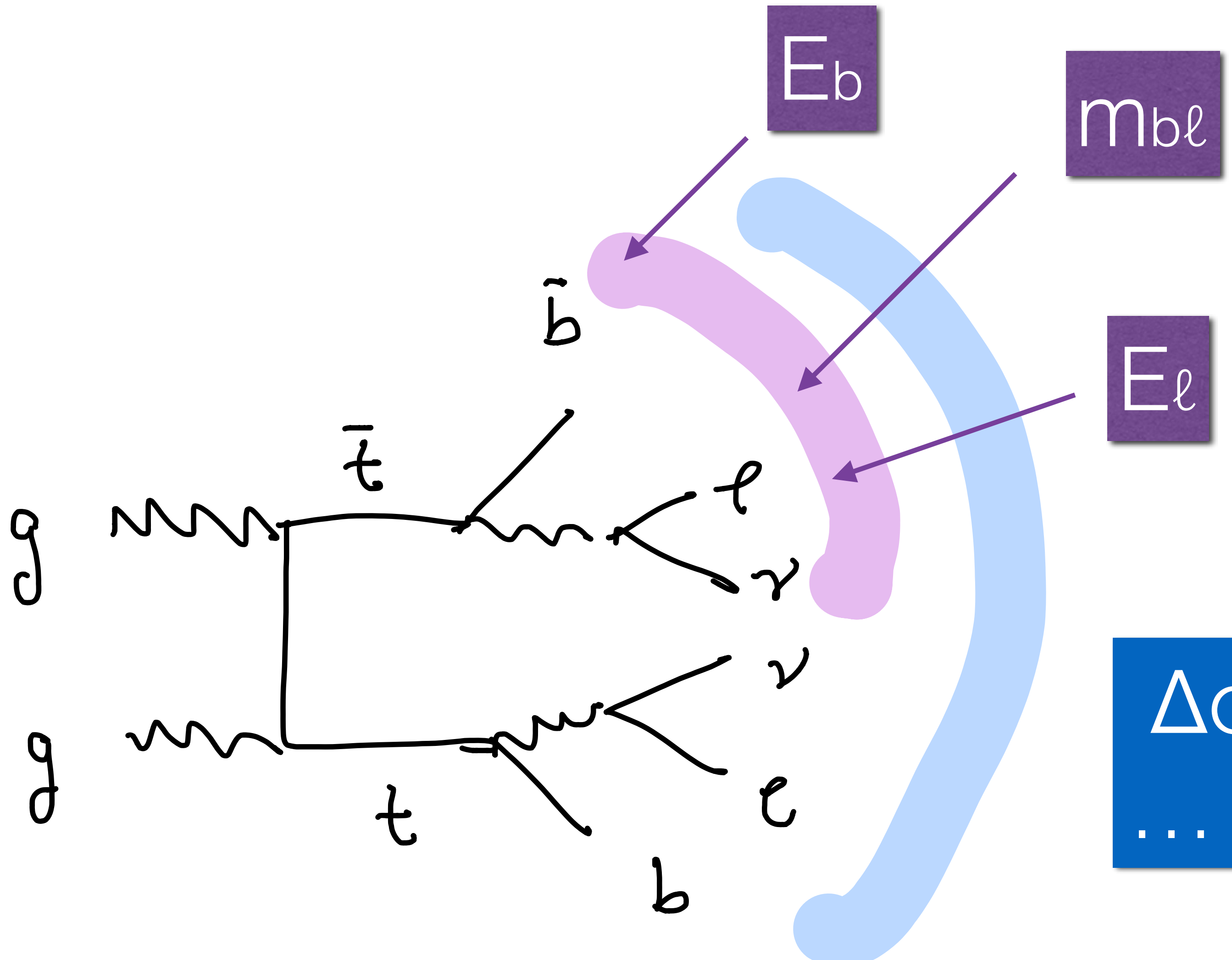
RF - in preparation



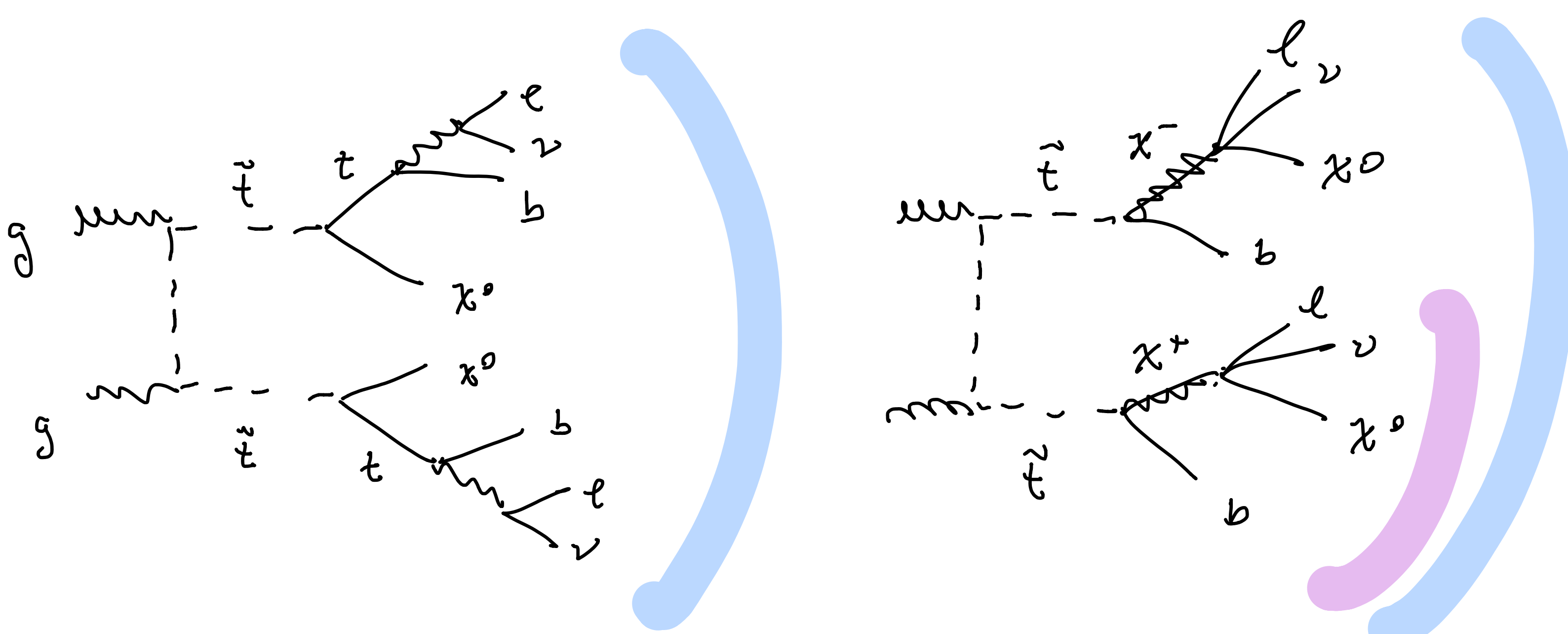
Theory uncertainty is critical

N-dim global analysis

RF - in preparation



$\Delta\phi(\ell\ell)$, $m(\mathbf{t\bar{t}})$,
… mT2(Subsystems)



Top as a source

Top as a source

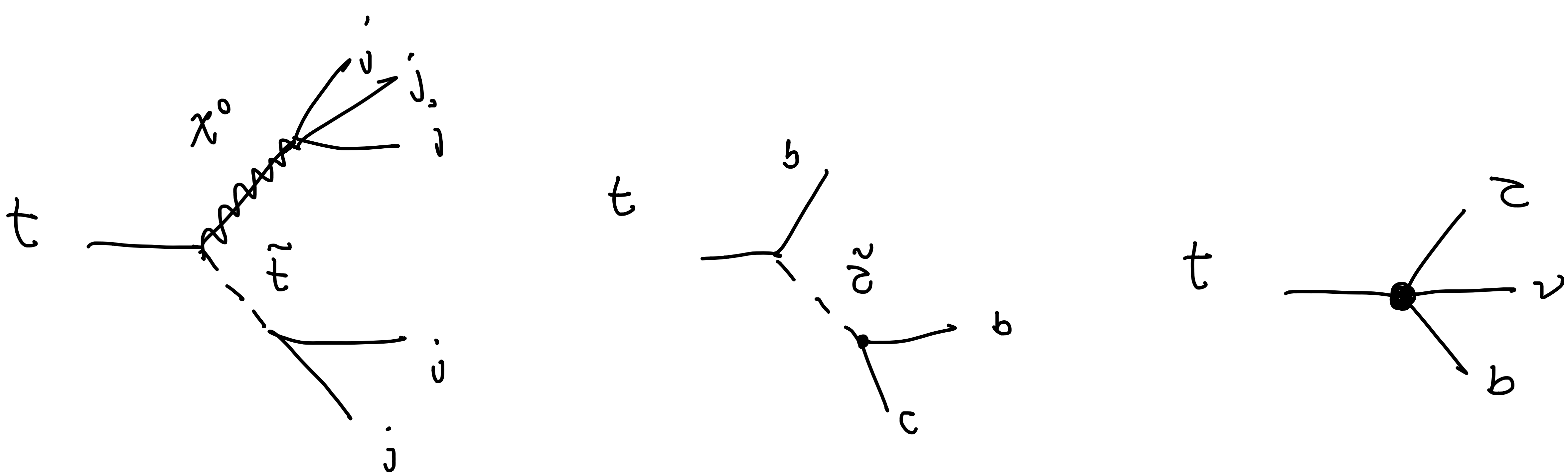
Top as a trigger

Direct production of light states

despite being light, new physics can have

- low cross-section (EW states)
- subtle signatures (hadronic states)

pp→tt̄ becomes a **trigger** and a **source** for new physics



top decays to BSM

top as a "portal"

Direct production of light new physics:

- $t \to bH^{+} \to b\tau\nu$ (CMS-PAS-HIG-12-052)
- $t \to \tilde{t}\,\chi$ (few % BR in the MSSM)
- $t \to \tilde{\tau}\, b \to b\, b\, c$ (RPV λ')

Indirect test through higher dimensional operators:

- $t \to cZ, cH$ (and c→q, 1508.05796, 1312.4194, PAS-TOP-14-020)
- $t \to bc\ell$ (BNV 1107.3805, 1310.1618)
- $t \to qe\mu$ (1507.07163)
- $t \to qW$ (1404.2292)
- $t \to bbc$ (1407.1724,1407.1725)

- Generic (SM is tiny)
- can be done → need to be done
- indirect test, but some models in the reach (e.g. *cZ, cH*)

lots of dedicated searches, worth considering also BR measurement 1506.05074

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

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

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

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

χ $\quad$ stable LSP

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

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

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

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

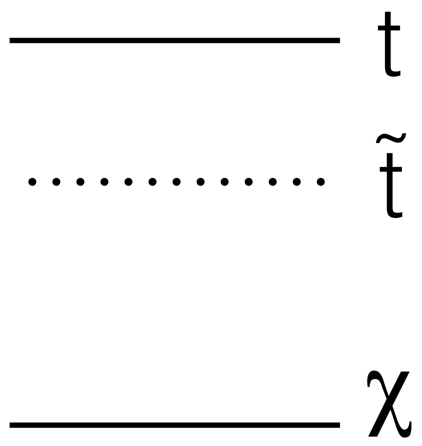
$\tilde{t}$ $\quad \tilde{t} \rightarrow b\, ff'\chi$

χ stable LSP

softer visible products

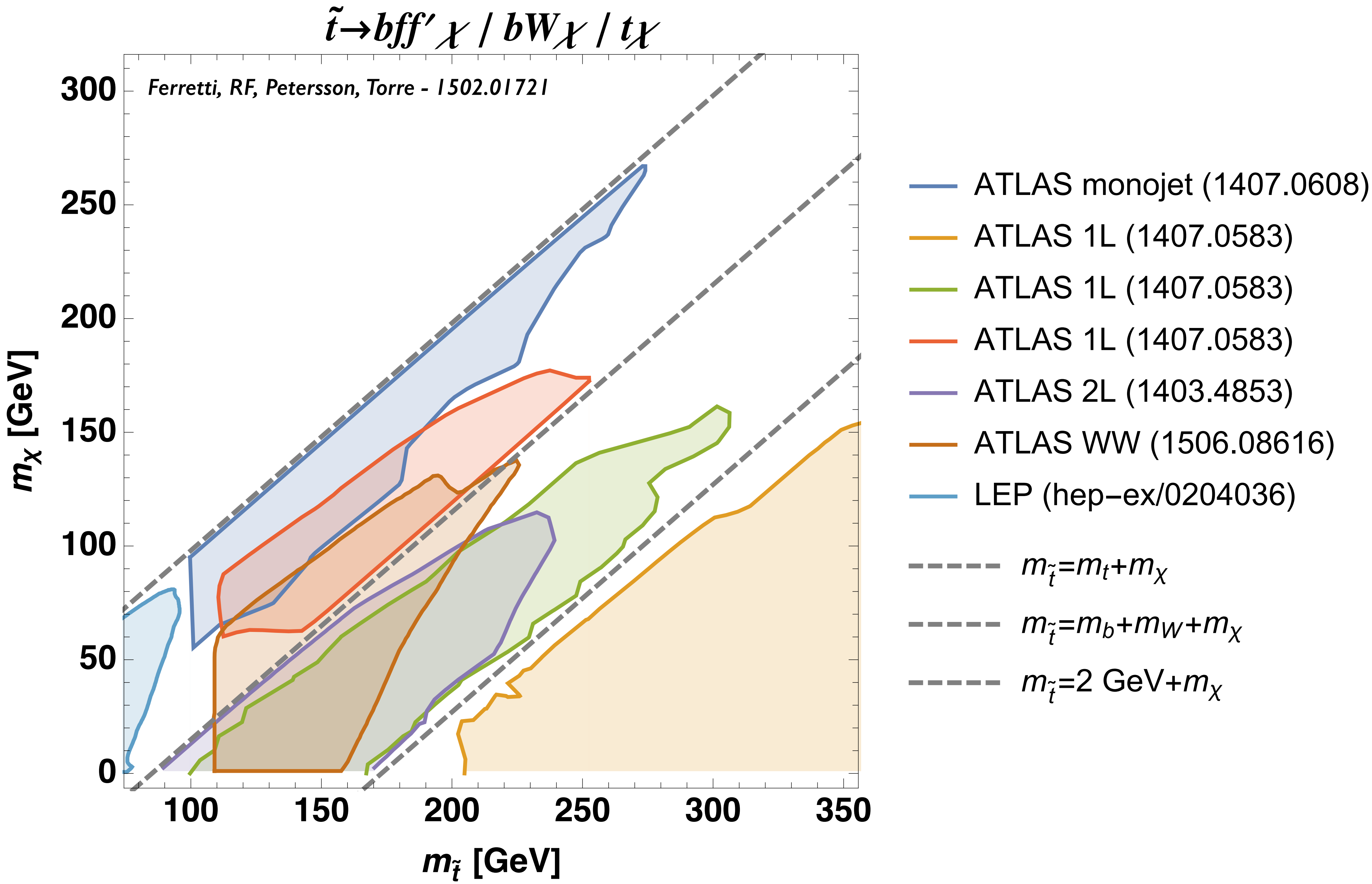
$$t \rightarrow \tilde{t}\chi \rightarrow b\, ff'\, \chi\chi$$

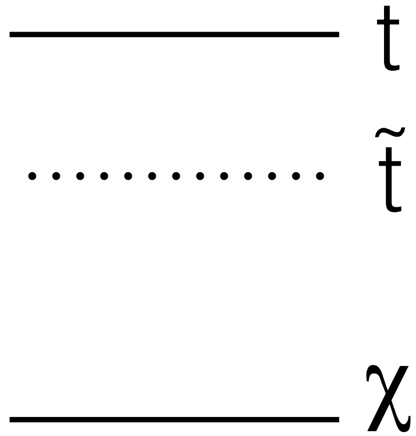
soft challenge



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

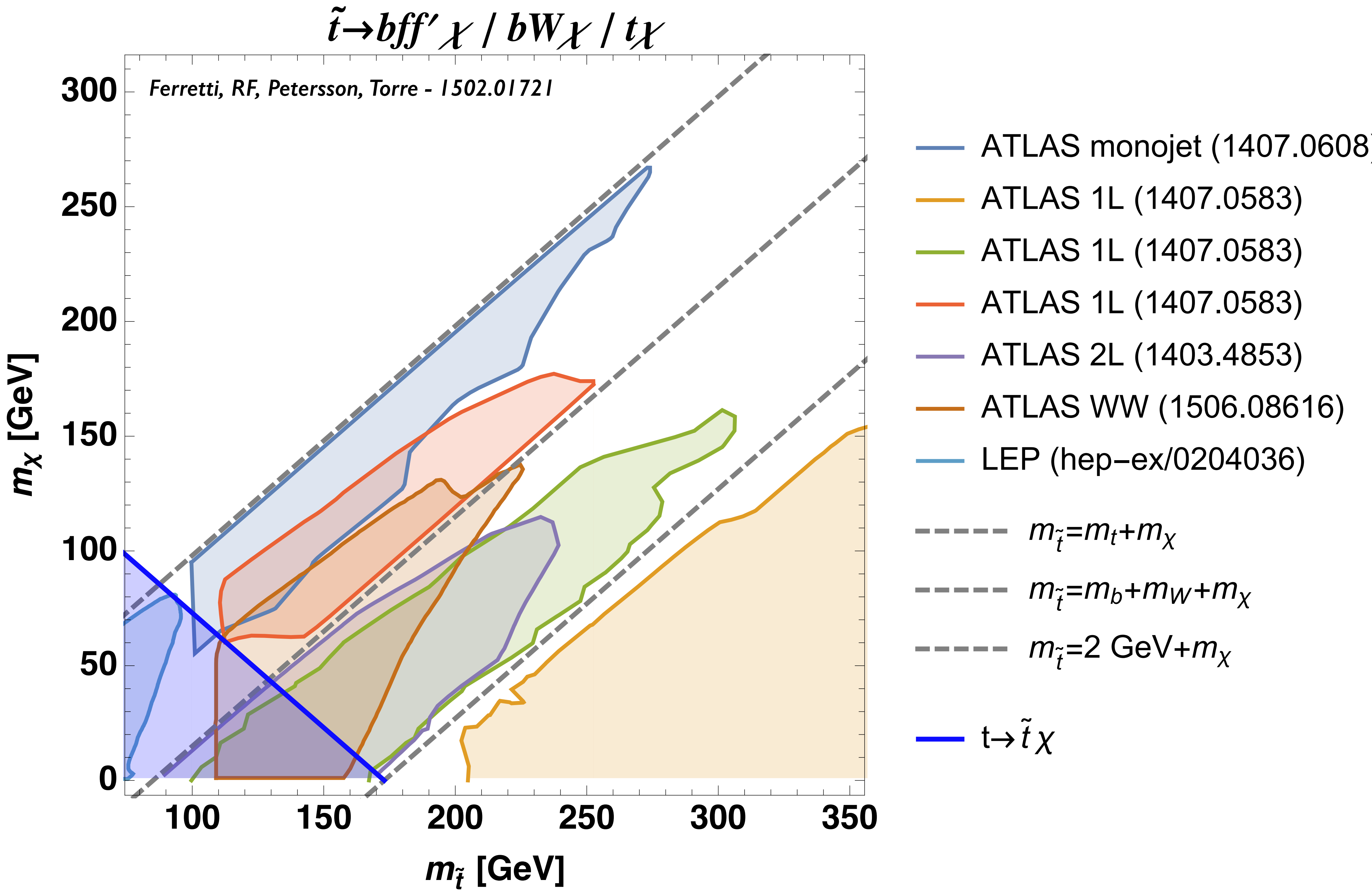
An orthogonal playground





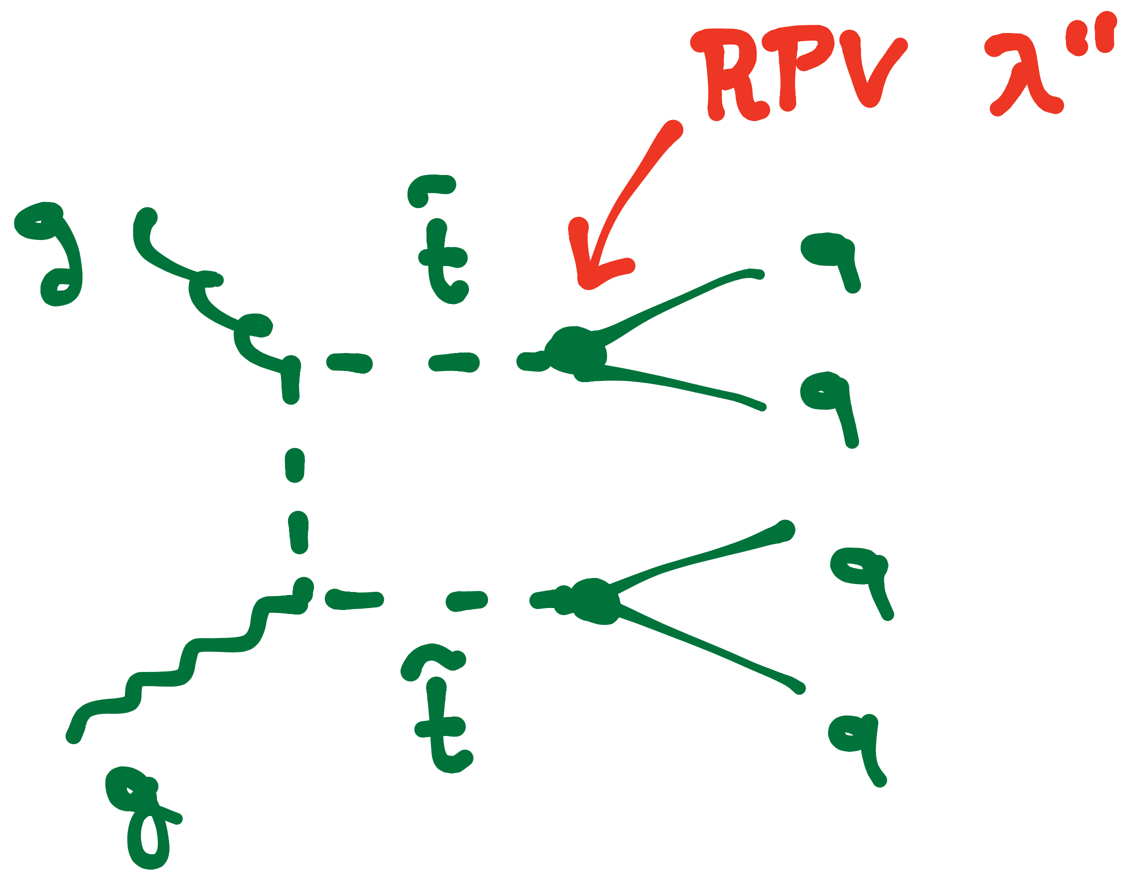
$t \to \tilde{t}\chi \to b\, ff'\, \chi\chi$

An orthogonal playground



Top as a trigger

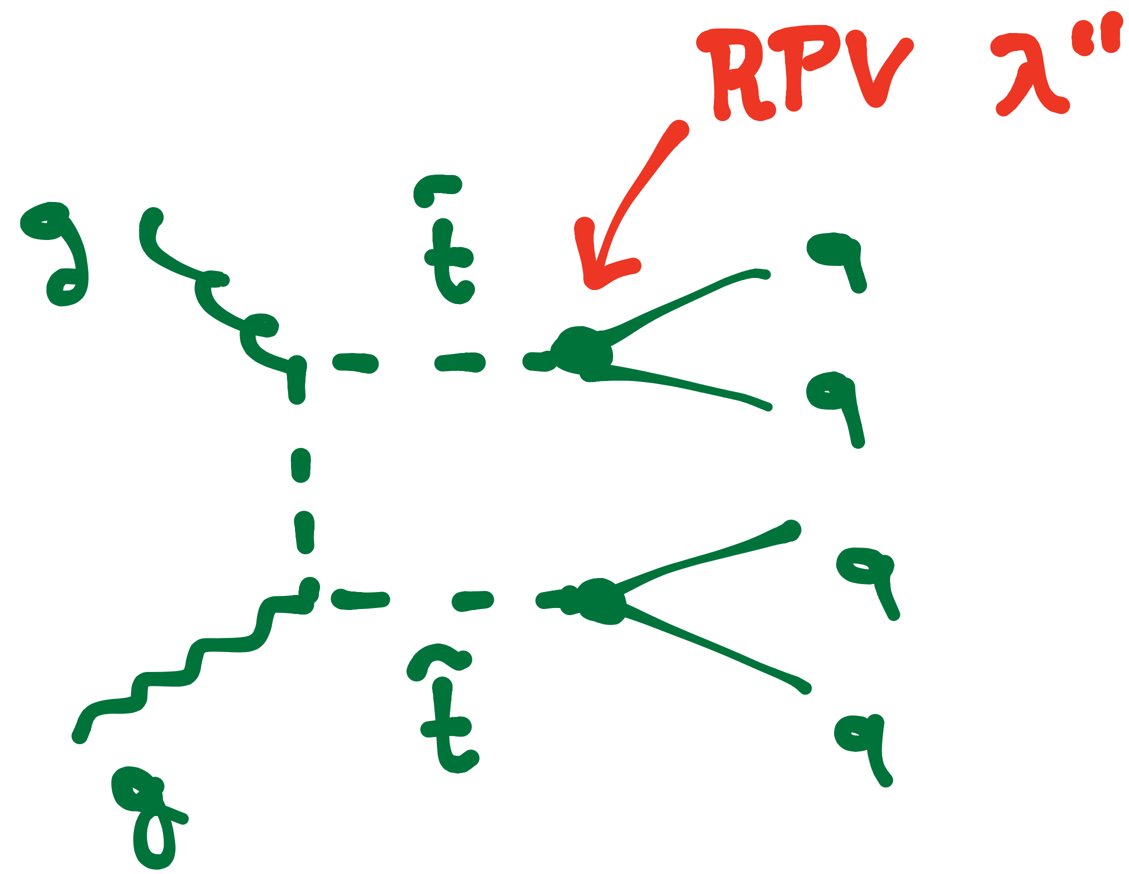
hadronic stops in RPV SUSY



large QCD cross-section for direct production

Top as a trigger

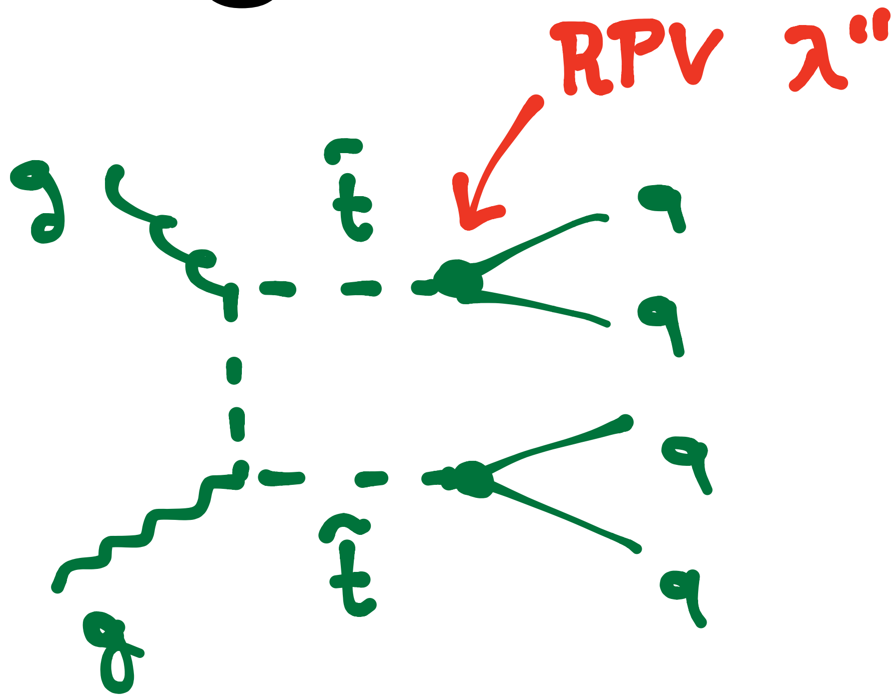
hadronic stops in RPV SUSY



large QCD cross-section for direct production

larger QCD background!

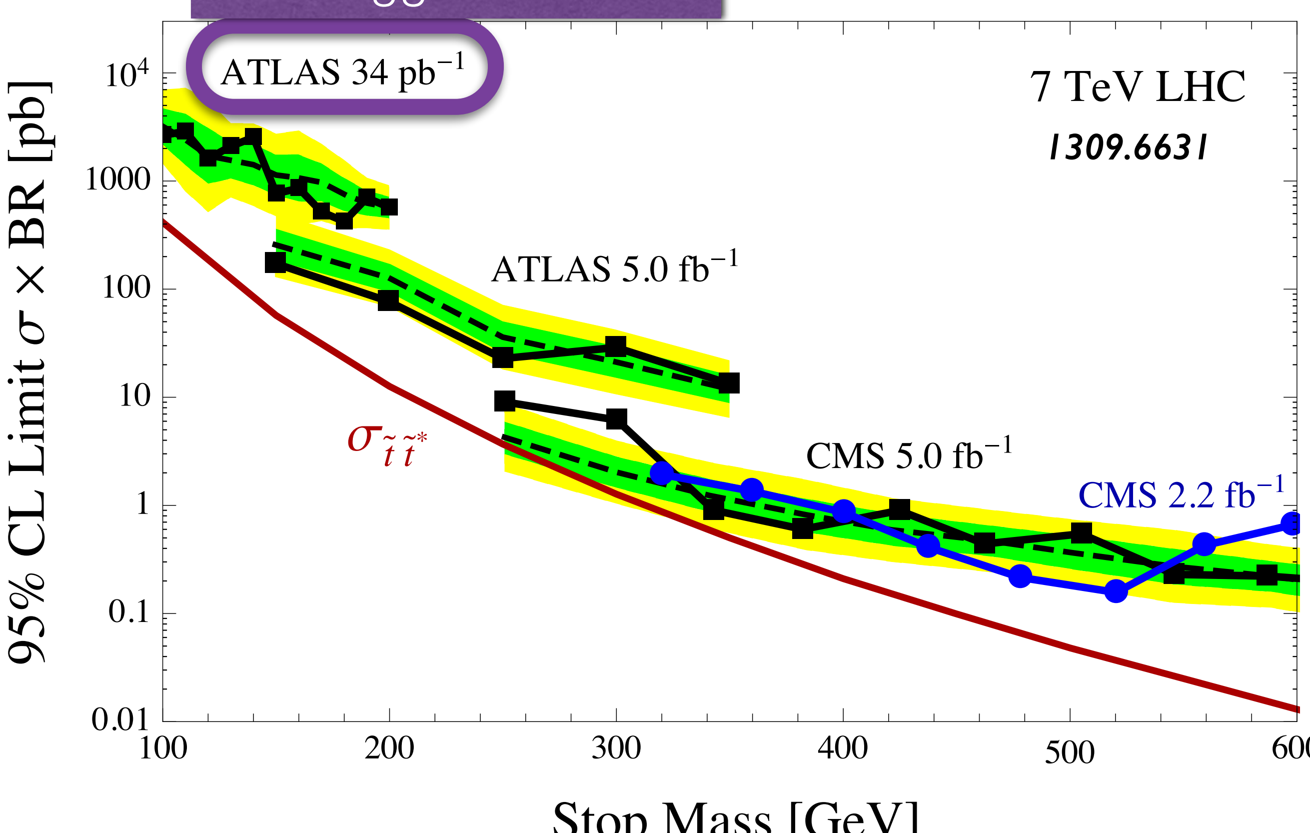
Light bumps are difficult

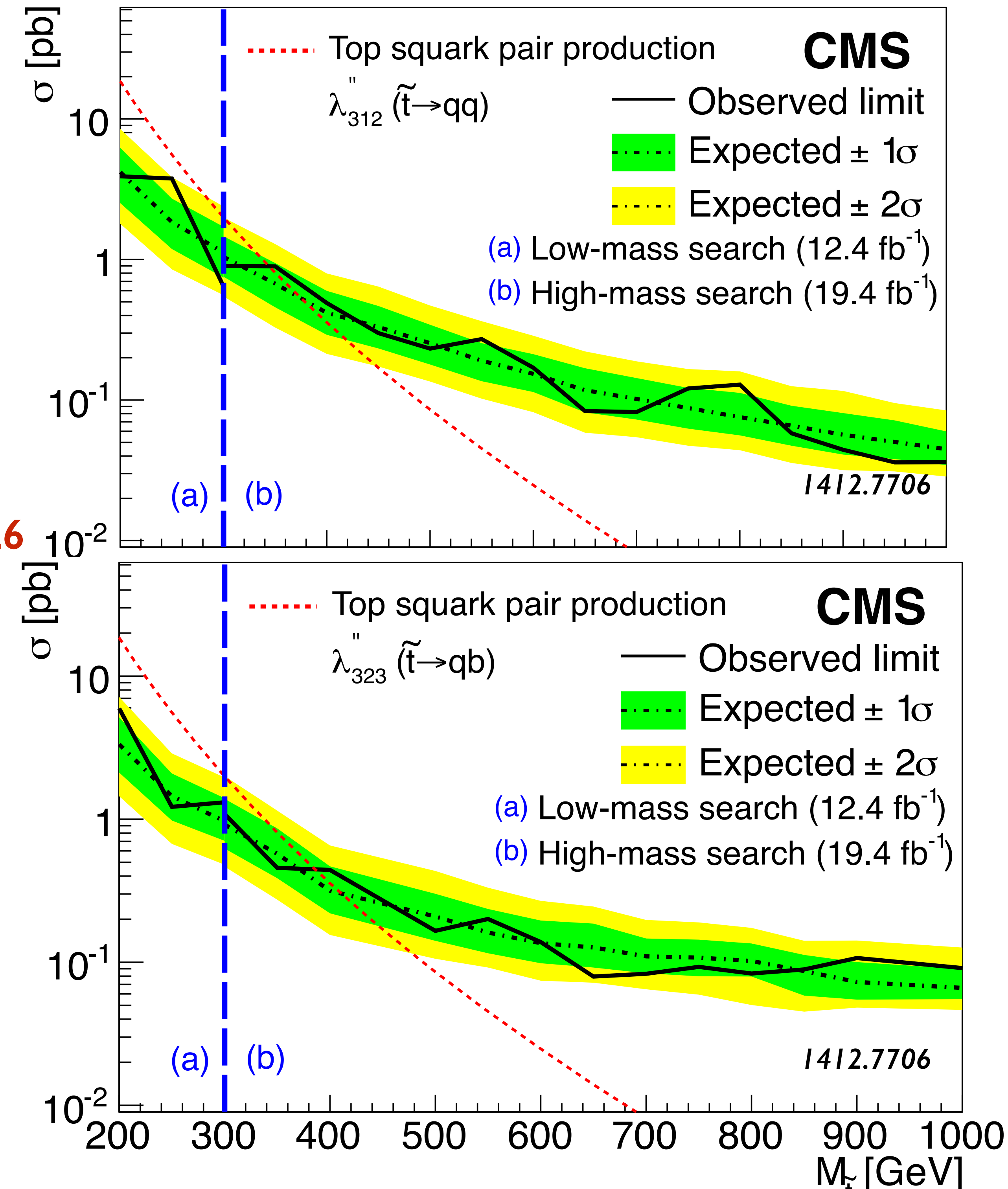


trigger is a killer at low mass

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

lower trigger thresholds

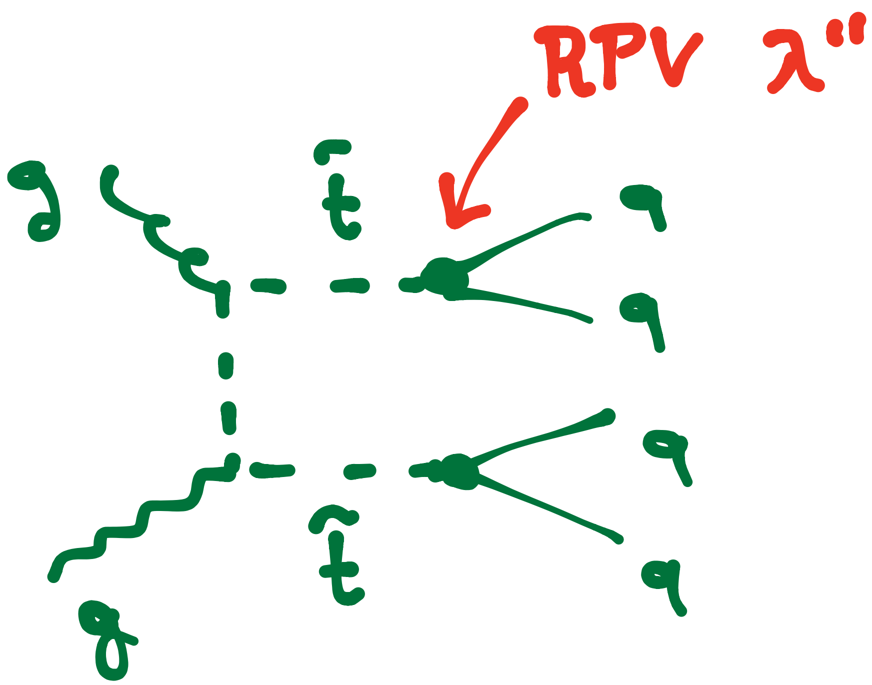


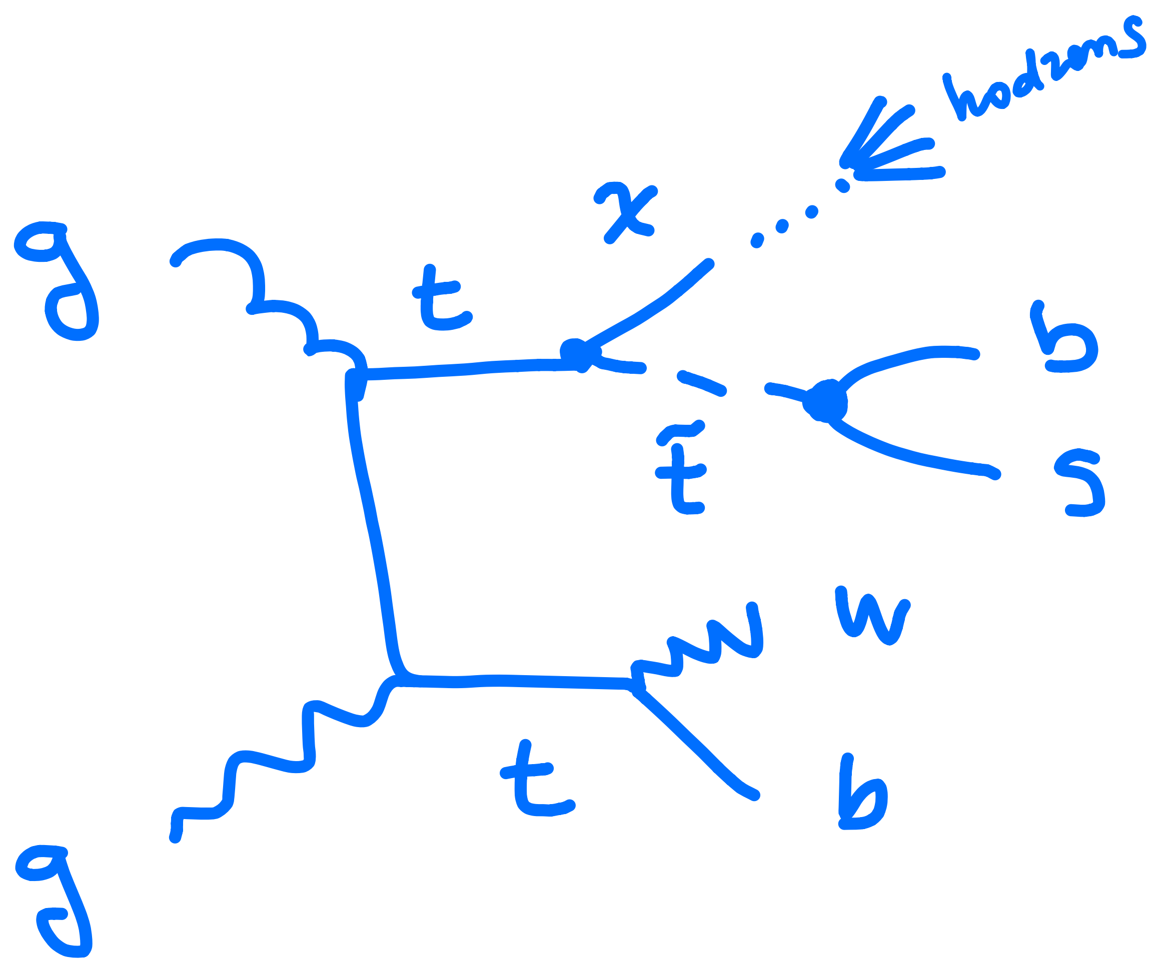


Top as a trigger

stops from top in RPV SUSY

hadronic stops in RPV SUSY

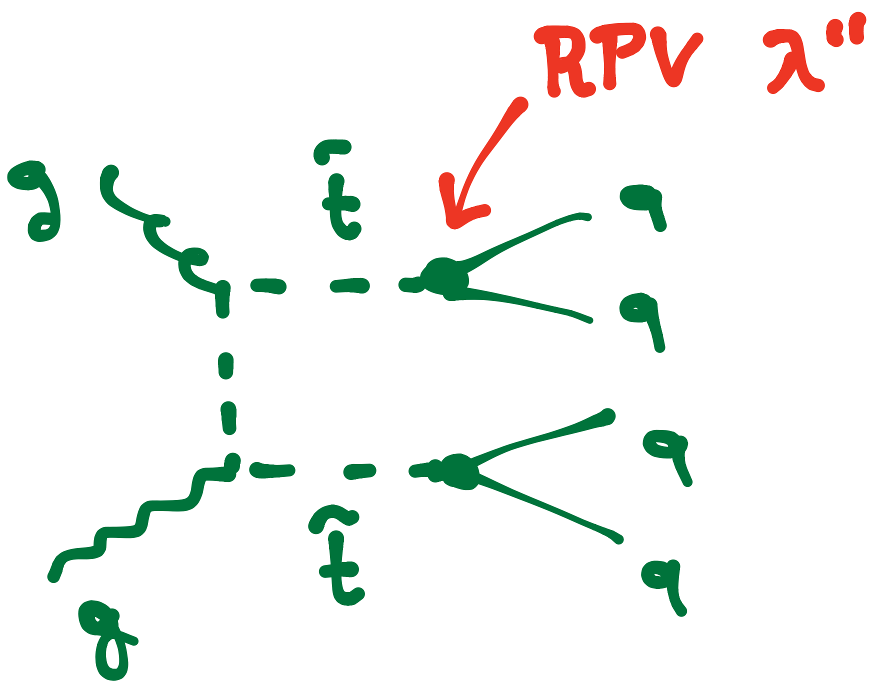


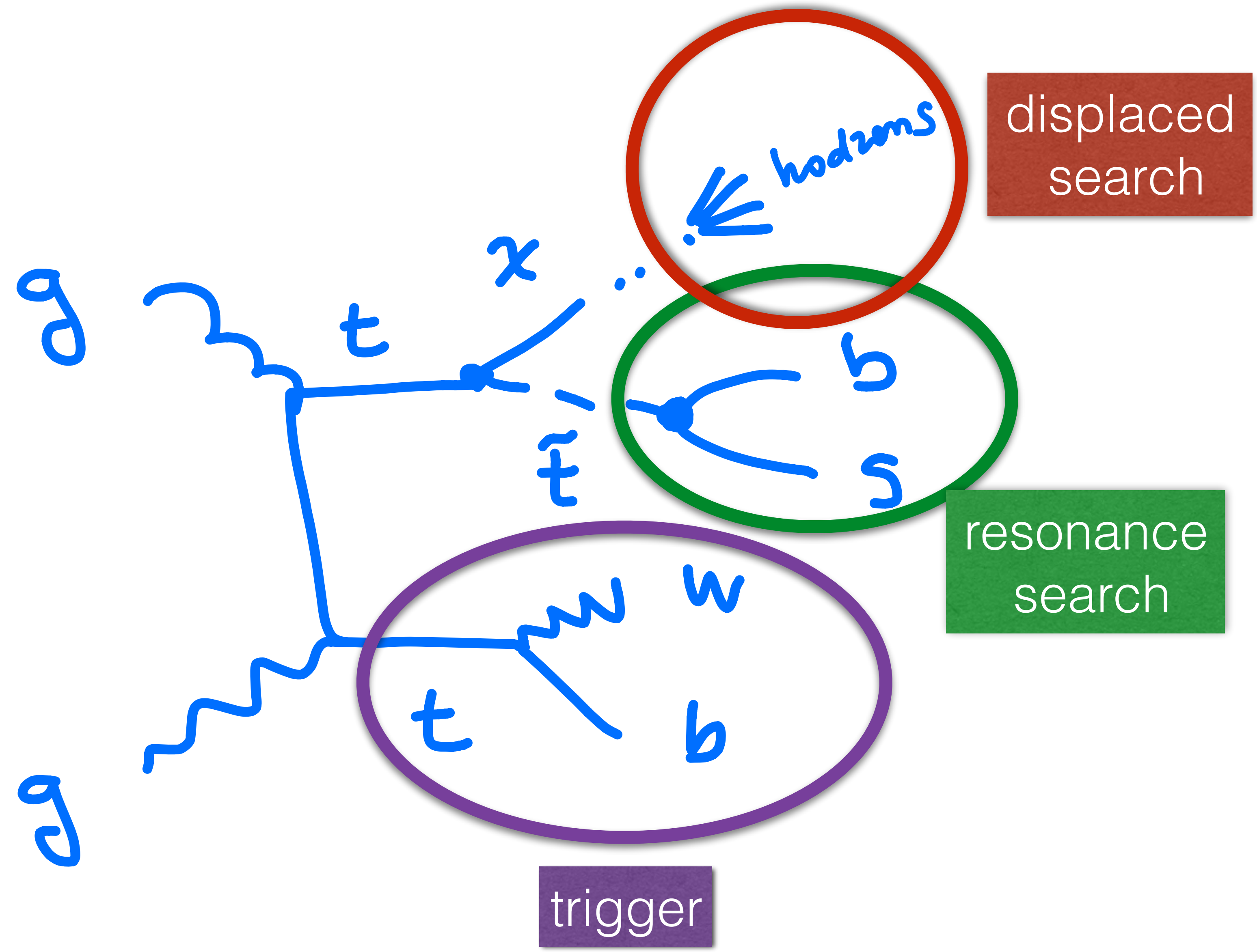


Top as a trigger

stops from top in RPV SUSY

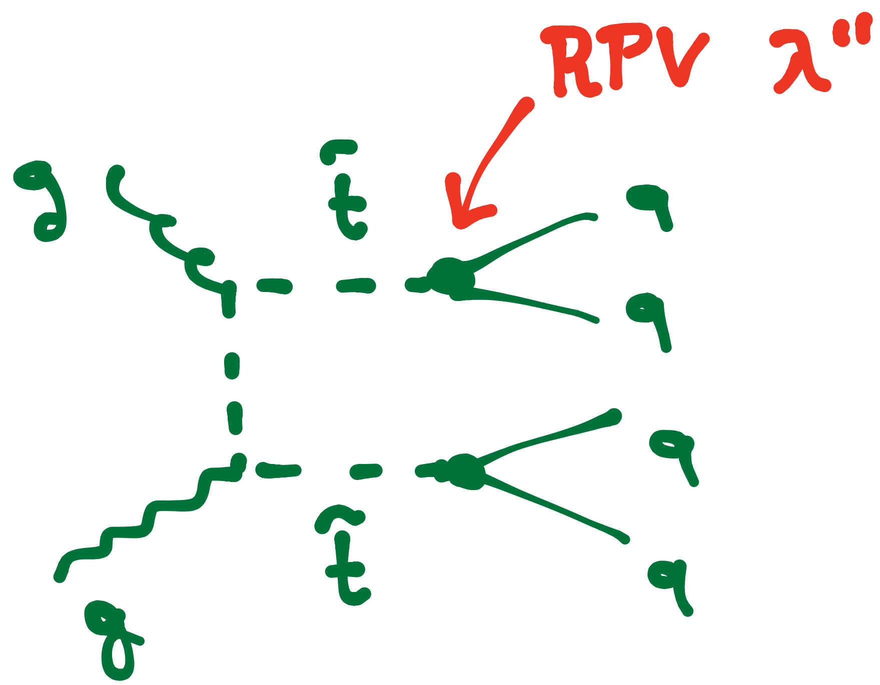
hadronic stops in RPV SUSY



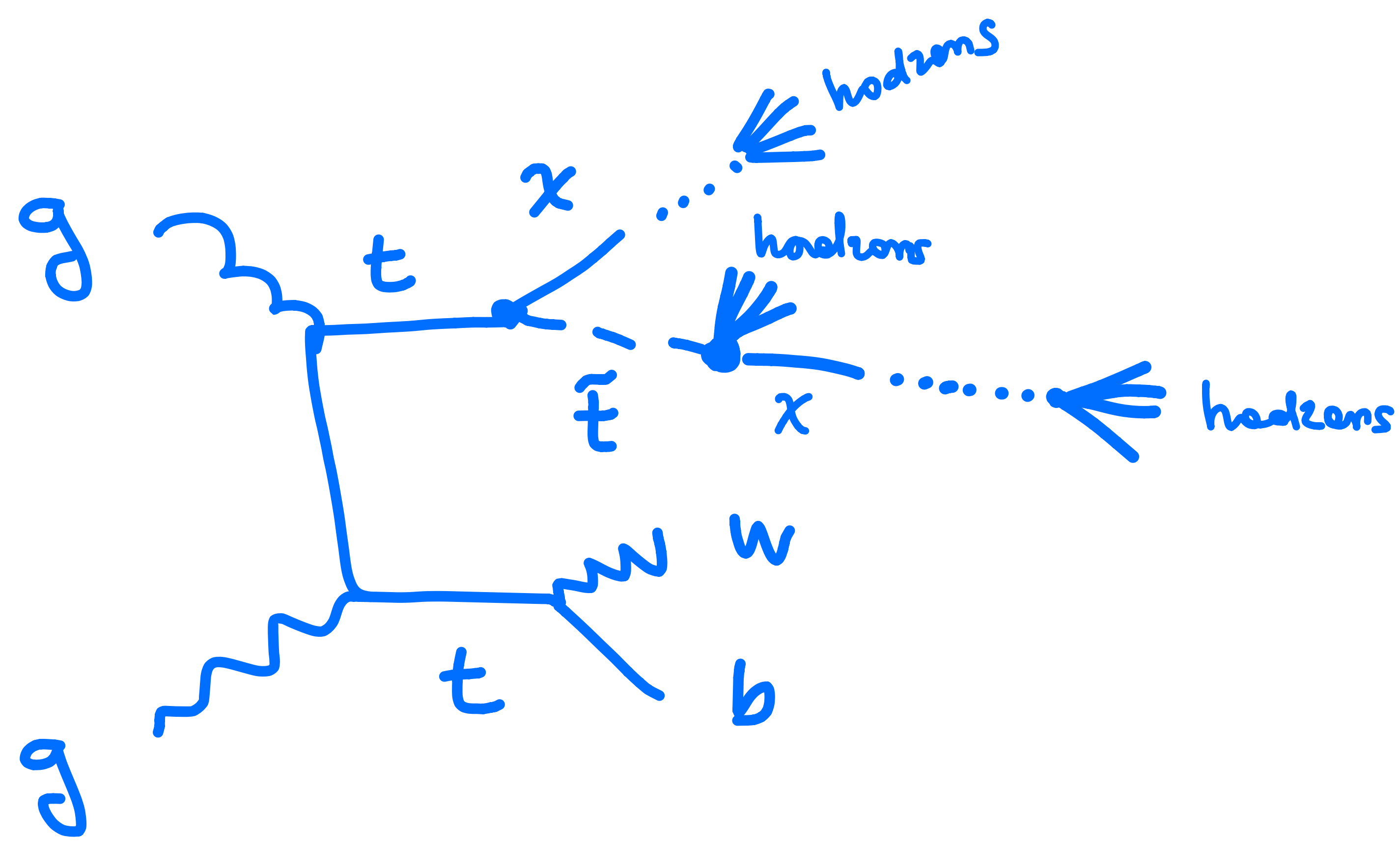


Top as a trigger

hadronic stops in RPV SUSY

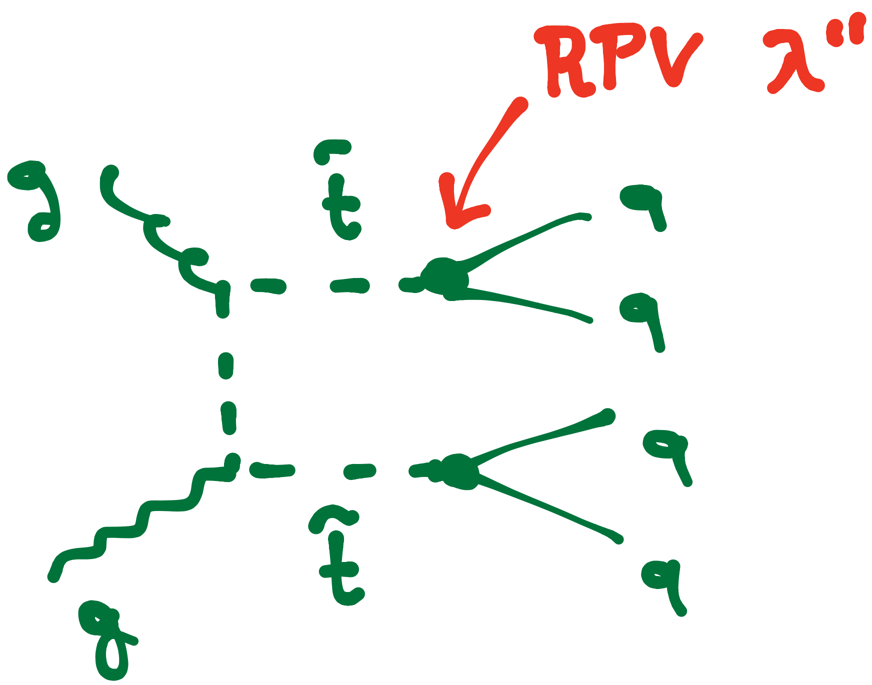


stops from top in RPV SUSY

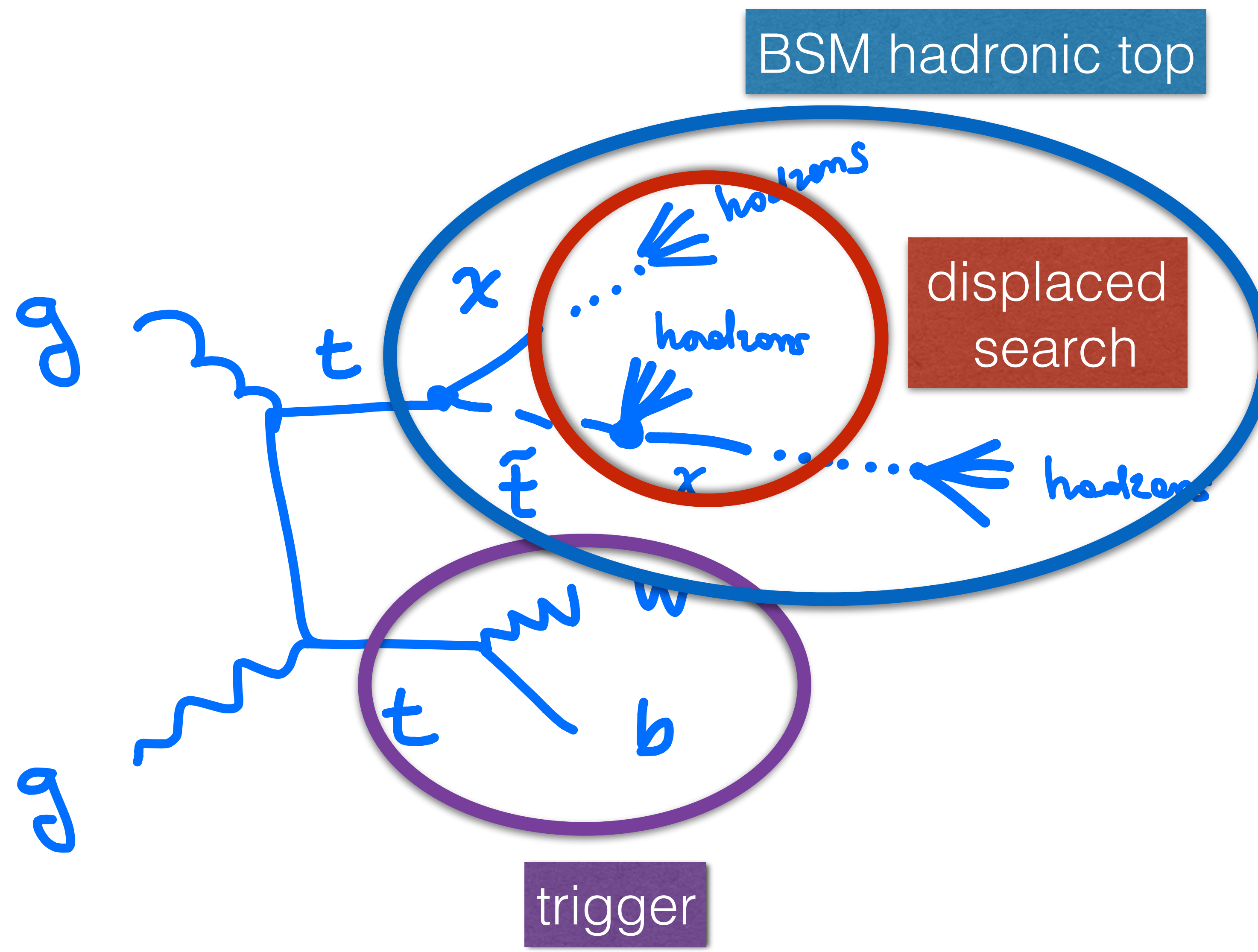


Top as a trigger

hadronic stops in RPV SUSY



stops from top in RPV SUSY



1506.05074

Global picture of top decay fractions

(BR measurement)

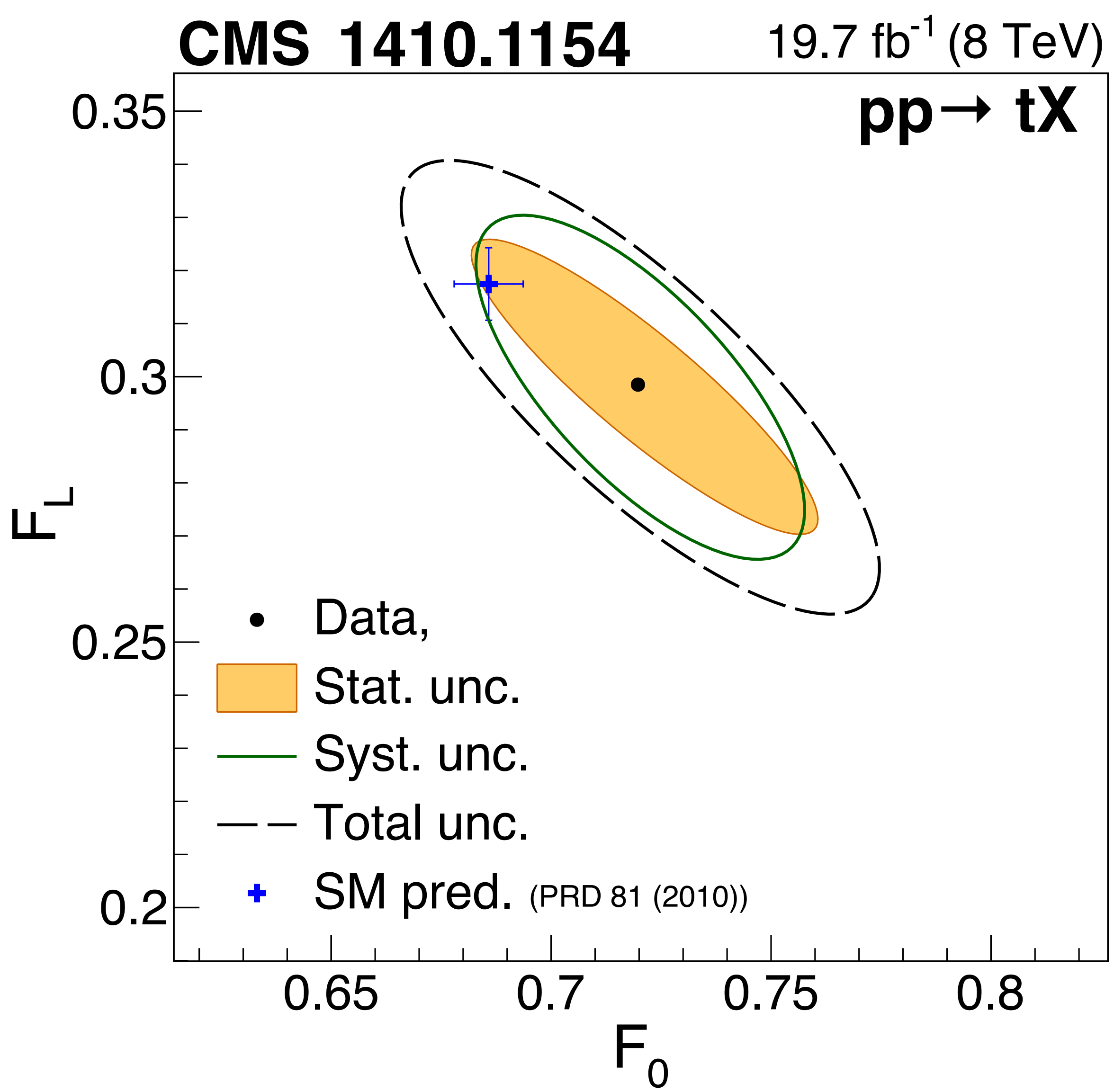
	Measured (top quark)	SM	LEP (W)
$\sigma_{t\bar{t}}$	178 ± 3 (stat.) ± 16 (syst.) ± 3 (lumi.) pb	$177.3 \pm 9.0^{+4.6}_{-6.0}$ pb	
B_j	66.5 ± 0.4 (stat.) ± 1.3 (syst.)	67.51±0.07	67.48±0.28
B_e	13.3 ± 0.4 (stat.) ± 0.5 (syst.)	12.72±0.01	12.70±0.20
B_μ	13.4 ± 0.3 (stat.) ± 0.5 (syst.)	12.72±0.01	12.60±0.18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

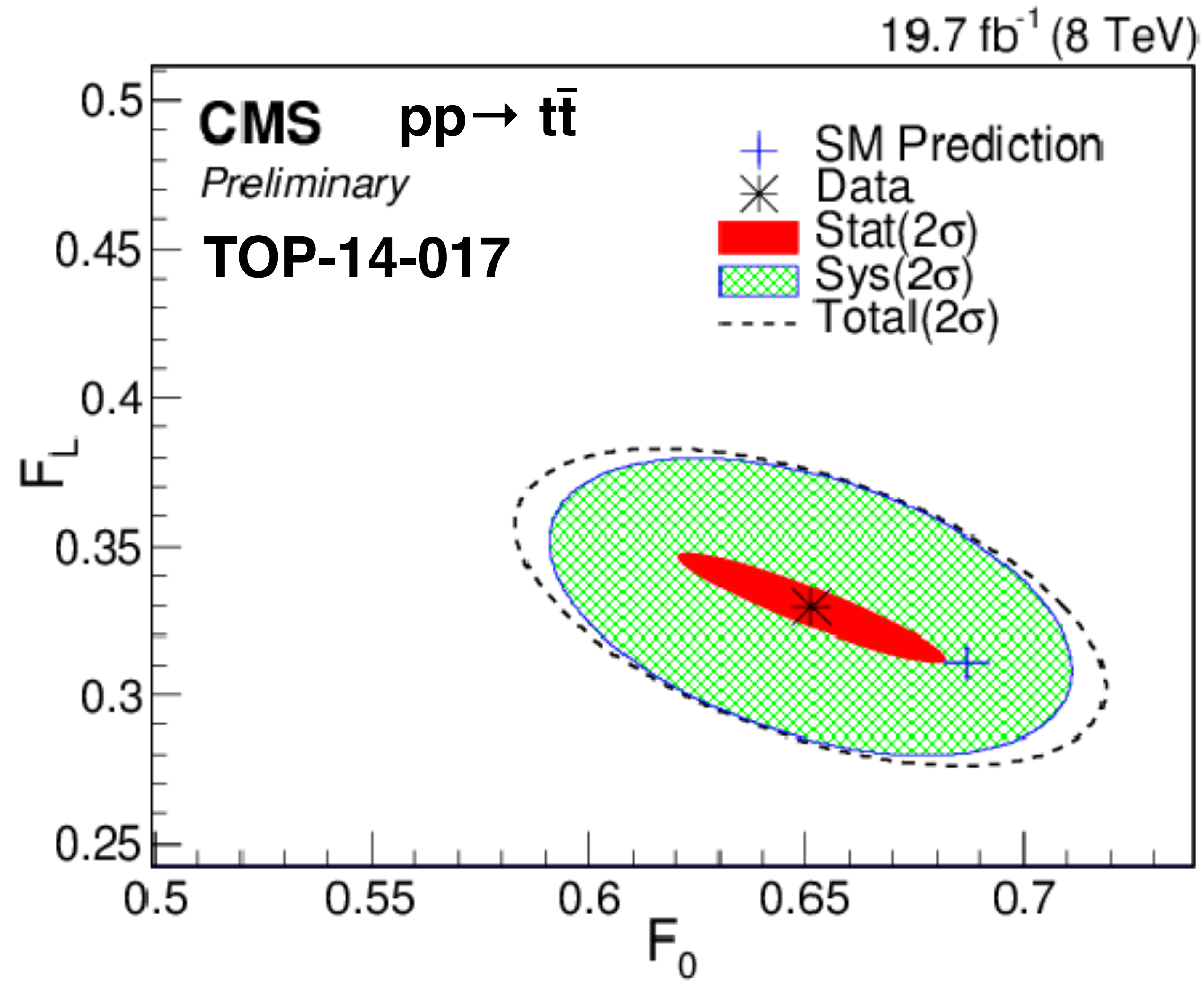
precise test of **SM**

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, …)

W helicity fractions





interesting to see interpretation in new physics scenarios
($t \to b\,\tau$ mET, $t \to c$ mET, $t \to bff'$ mET, …)

Conclusions

large number of tops → better understanding of top

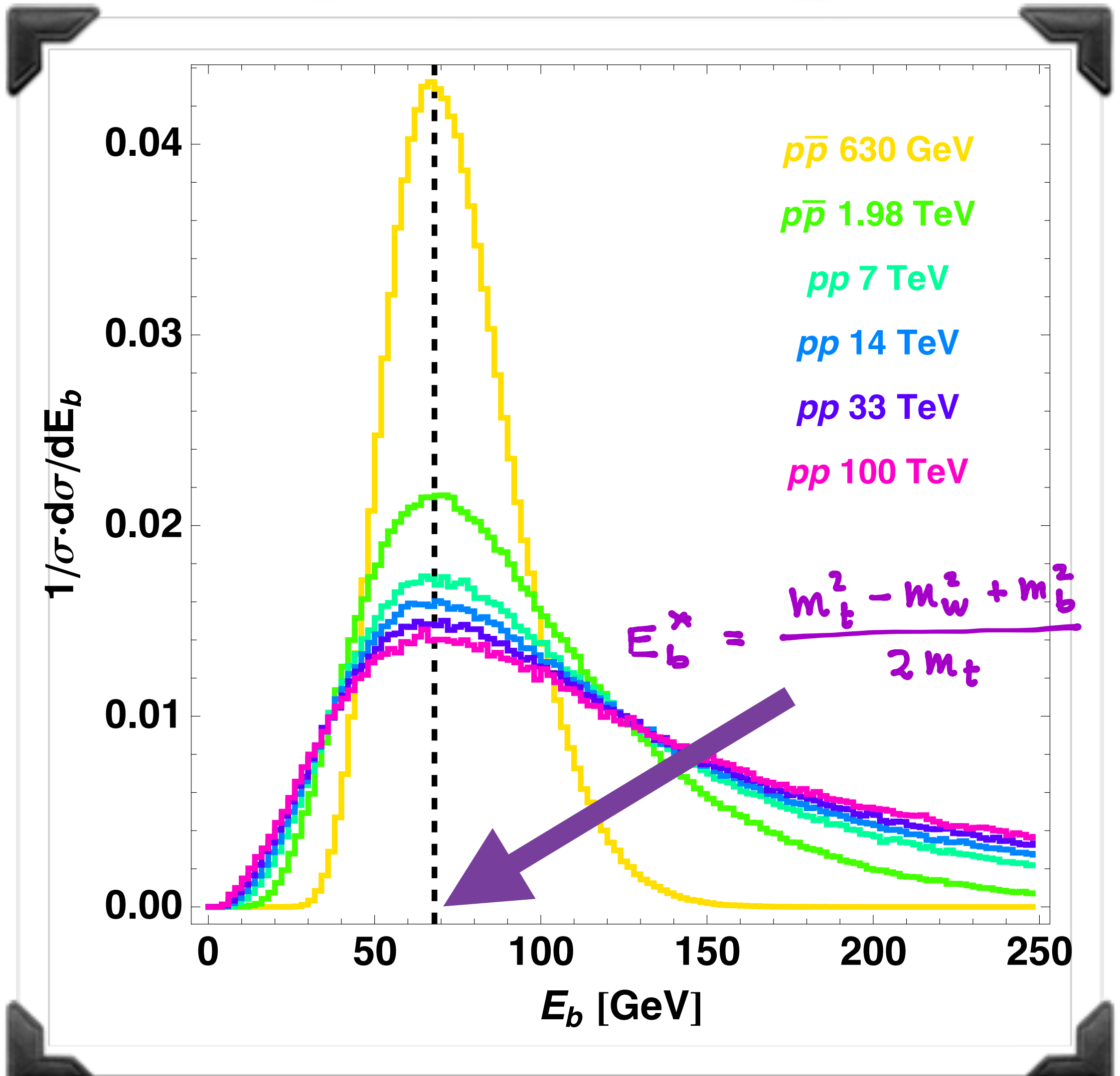
- top in association with other states
- high precision study of top decay (including studies on hadrons)

precision is an asset, can be “inherited” for BSM interpretations

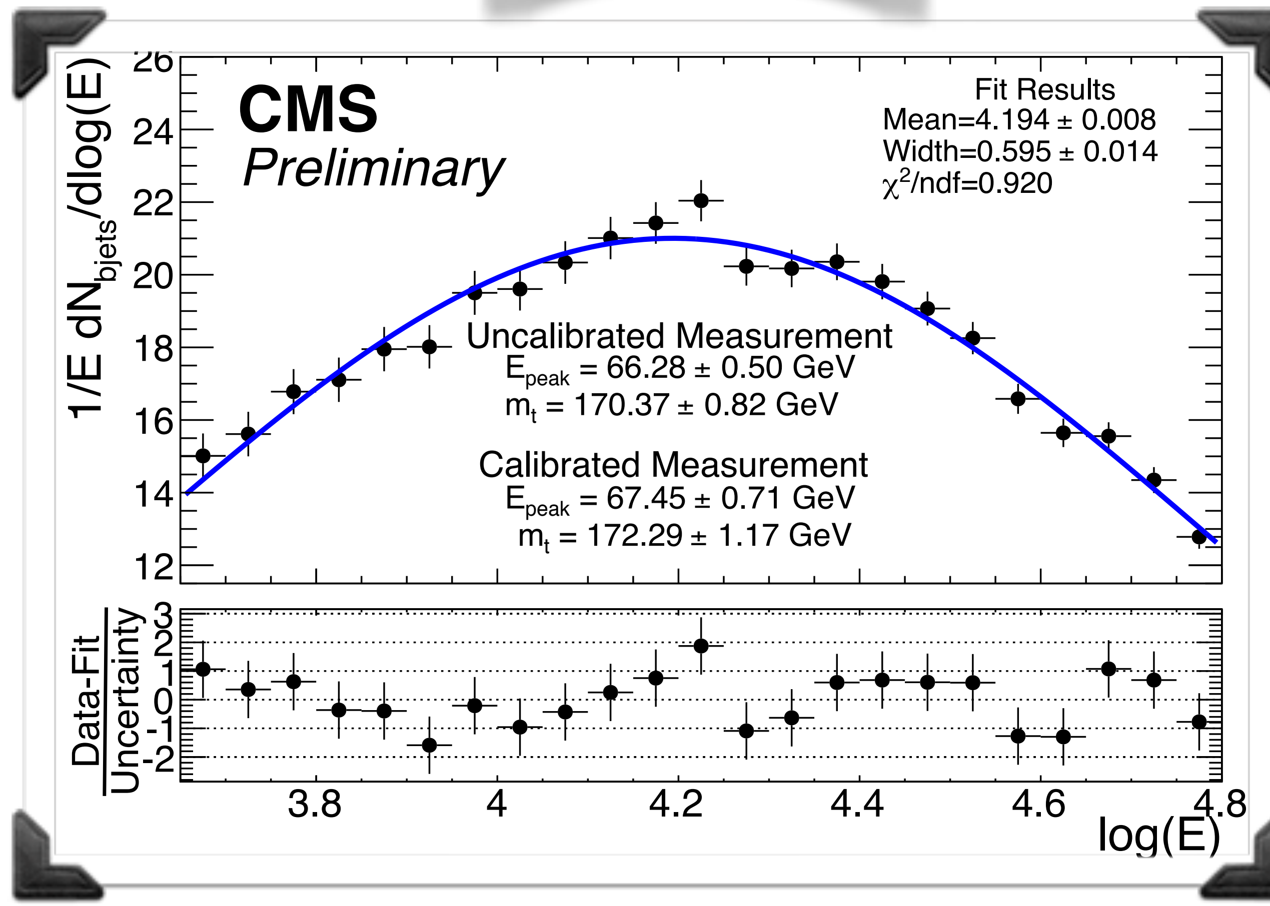
- **“soft” new physics (mass~m_{top})** may be hard for searches
  - BSM **signals** in precision top obs. (σ_{tt}, $\Delta\phi(\ell\ell)$, $\mathbf{m_{b\ell}}$, $\mathbf{E_b}$, …)
  - **N-dim strategy** to isolate multiple small coherent signals
  - $m_{\tilde{t}} < m_t$ and $m_{\tilde{t}} < m_t - m_\chi$ very worth looking at
- **global picture of top decay**, including BSM decays
  - several examples (light $\tilde{t}$, 4-fermions operators, …)
- **top as a source** of new physics, also **trigger**
  - rare or soft BSM decays of W and b into $\mathbf{t\bar{t}}$ sample
  - rare or soft BSM associated to $\mathbf{t\bar{t}}$

Thank you!

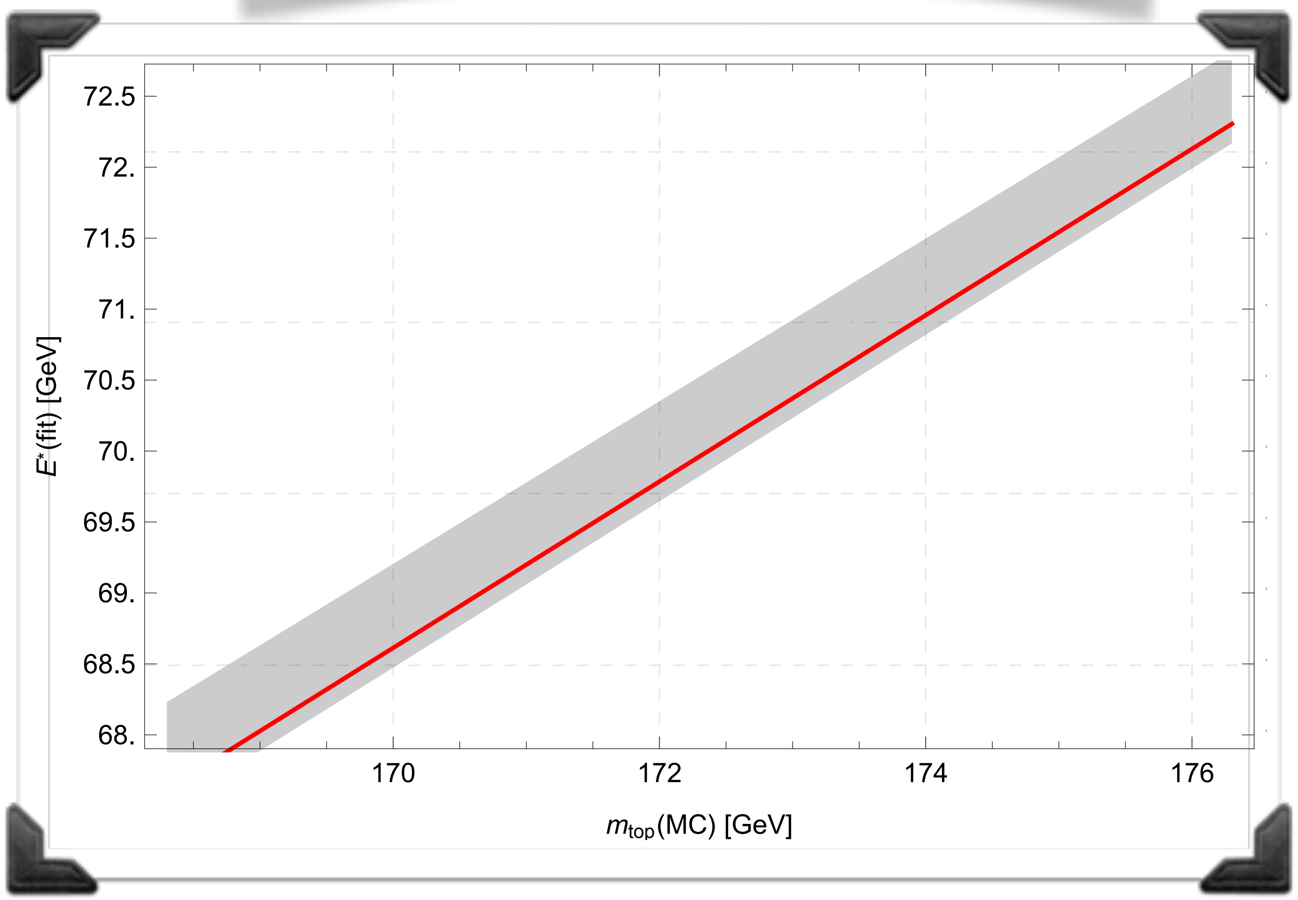
Agashe, RF, Kim 1209.0772



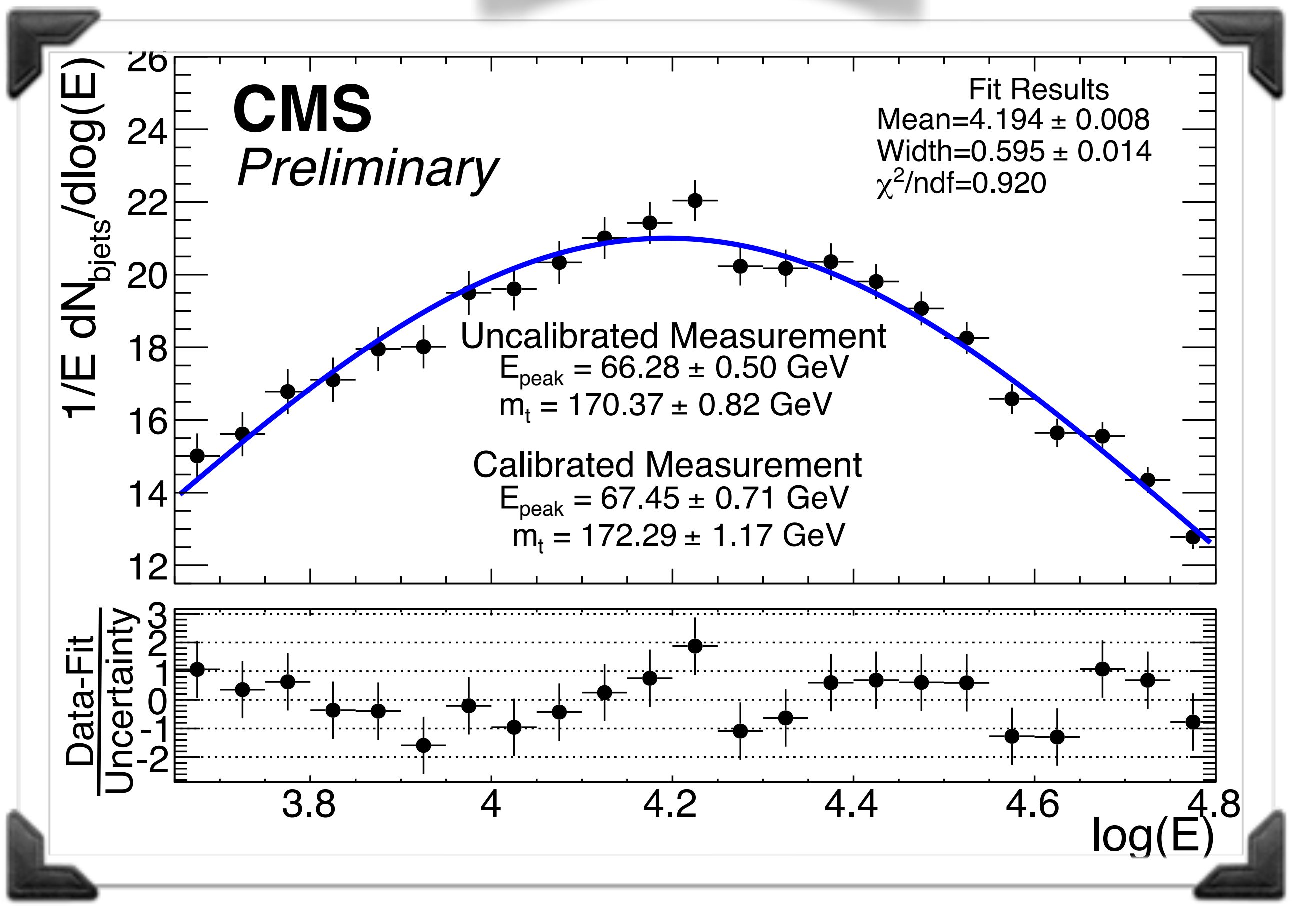
CMS PAS TOP-15-002



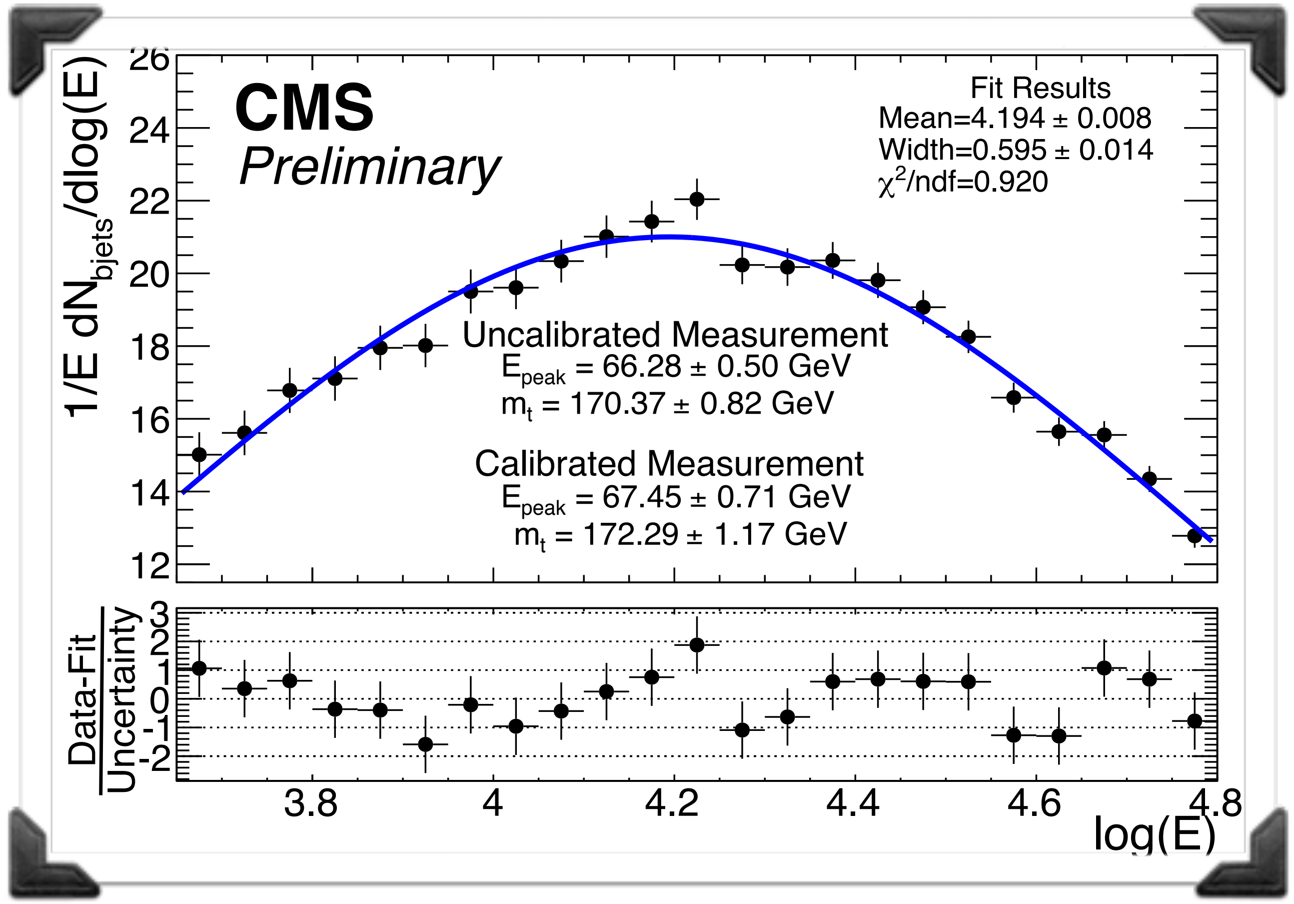
Agashe, RF, Kim, Schulze - in preparation

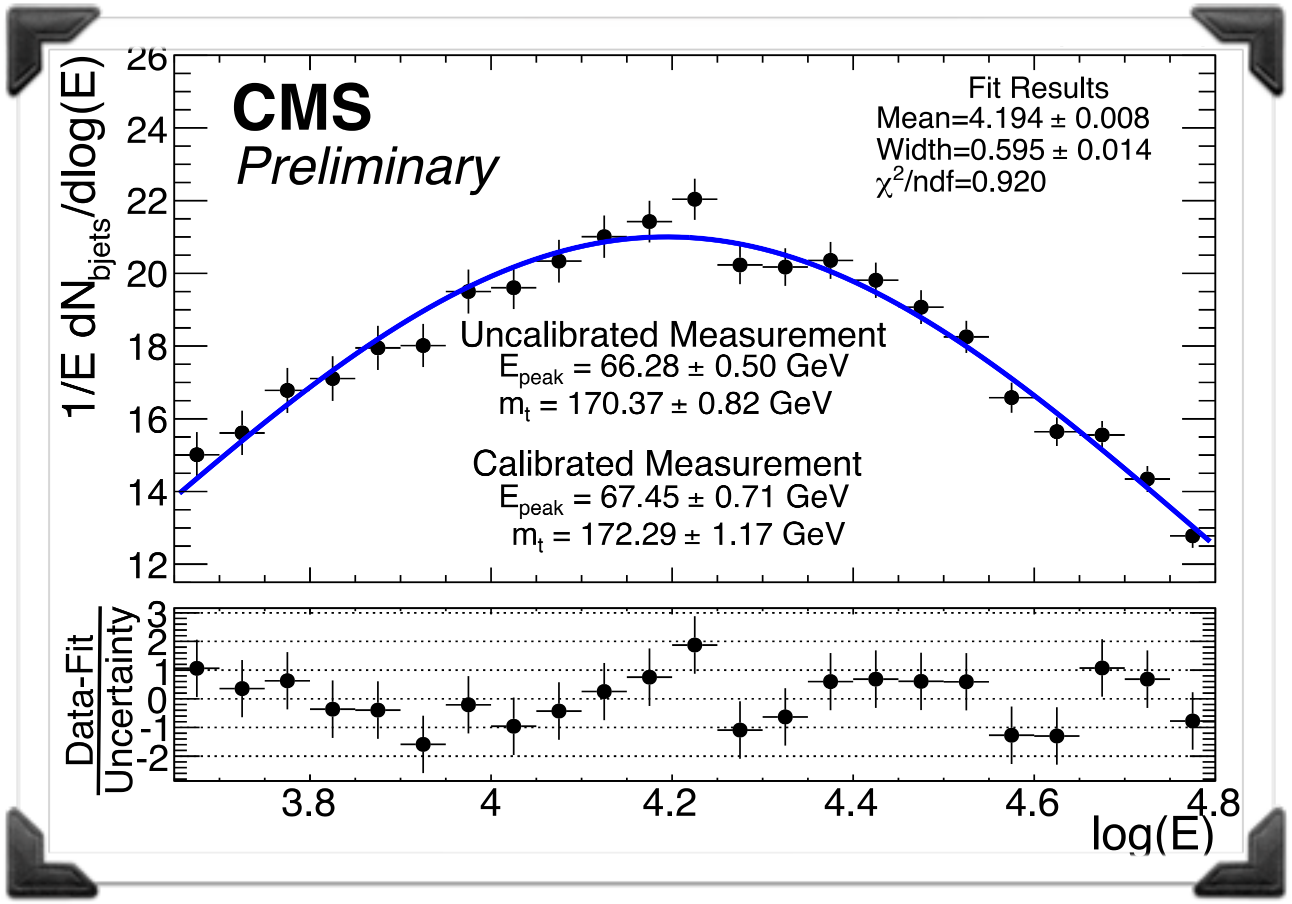


CMS PAS TOP-15-002

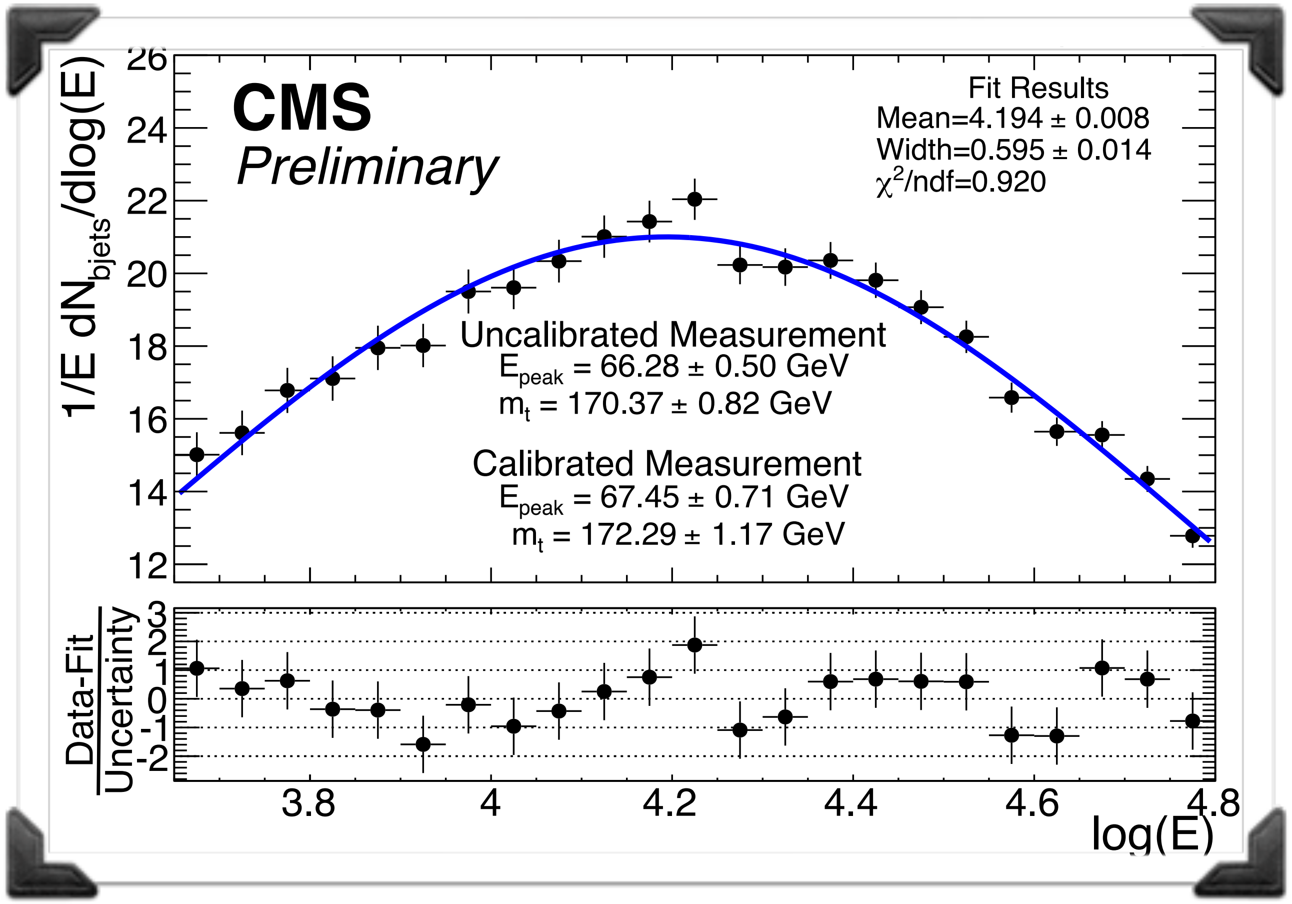


$\delta m_{top} = \pm(\ 1.2(\mathrm{exp}) + 0.6(\mathrm{th})\ )$ GeV


CMS
Preliminary
Fit Results
Mean=4.194 ± 0.008
Width=0.595 ± 0.014
χ^2/ndf=0.920
Uncalibrated Measurement
E_{peak} = 66.28 ± 0.50 GeV
m_t = 170.37 ± 0.82 GeV
Calibrated Measurement
E_{peak} = 67.45 ± 0.71 GeV
m_t = 172.29 ± 1.17 GeV
1/E dN_{bjets}/dlog(E)
Data-Fit / Uncertainty
log(E)

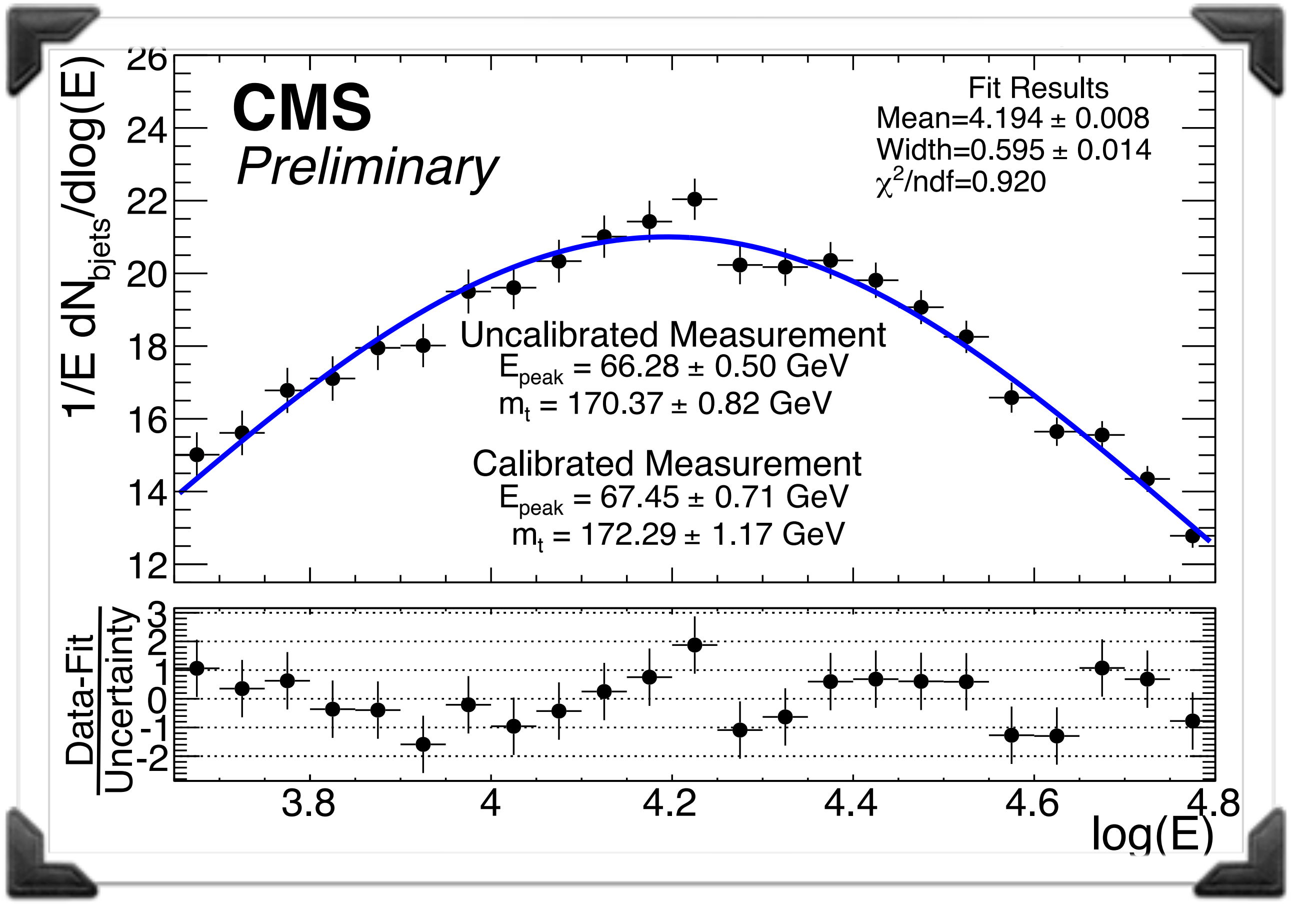


First mass measurement to this type at colliders



First mass measurement to this type at colliders

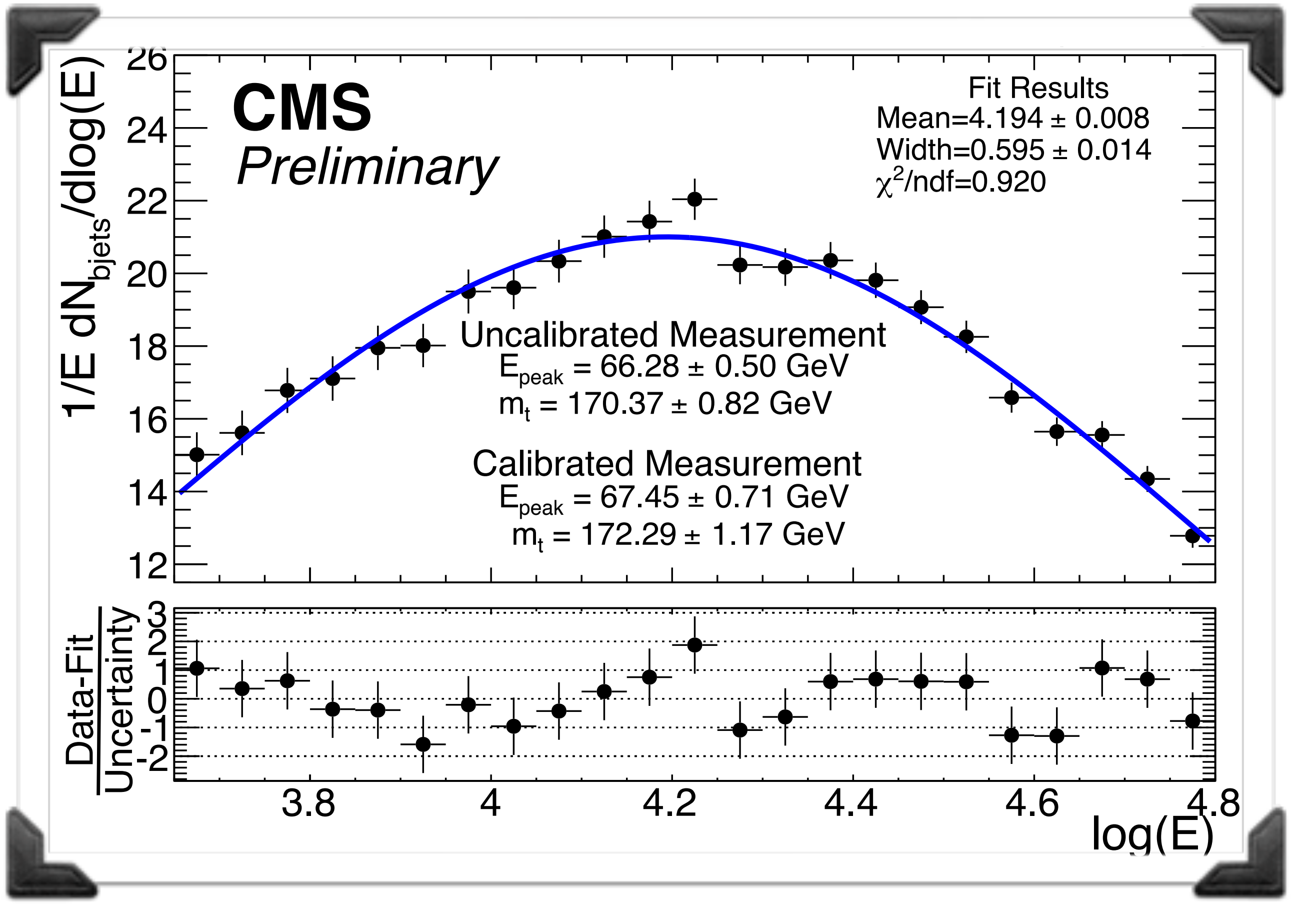
Reduced sensitivity to possible new physics



First mass measurement to this type at colliders

Reduced sensitivity to possible new physics

Reduced sensitivity to QCD production corrections



First mass measurement to this type at colliders

Reduced sensitivity to possible new physics

Reduced sensitivity to QCD production corrections

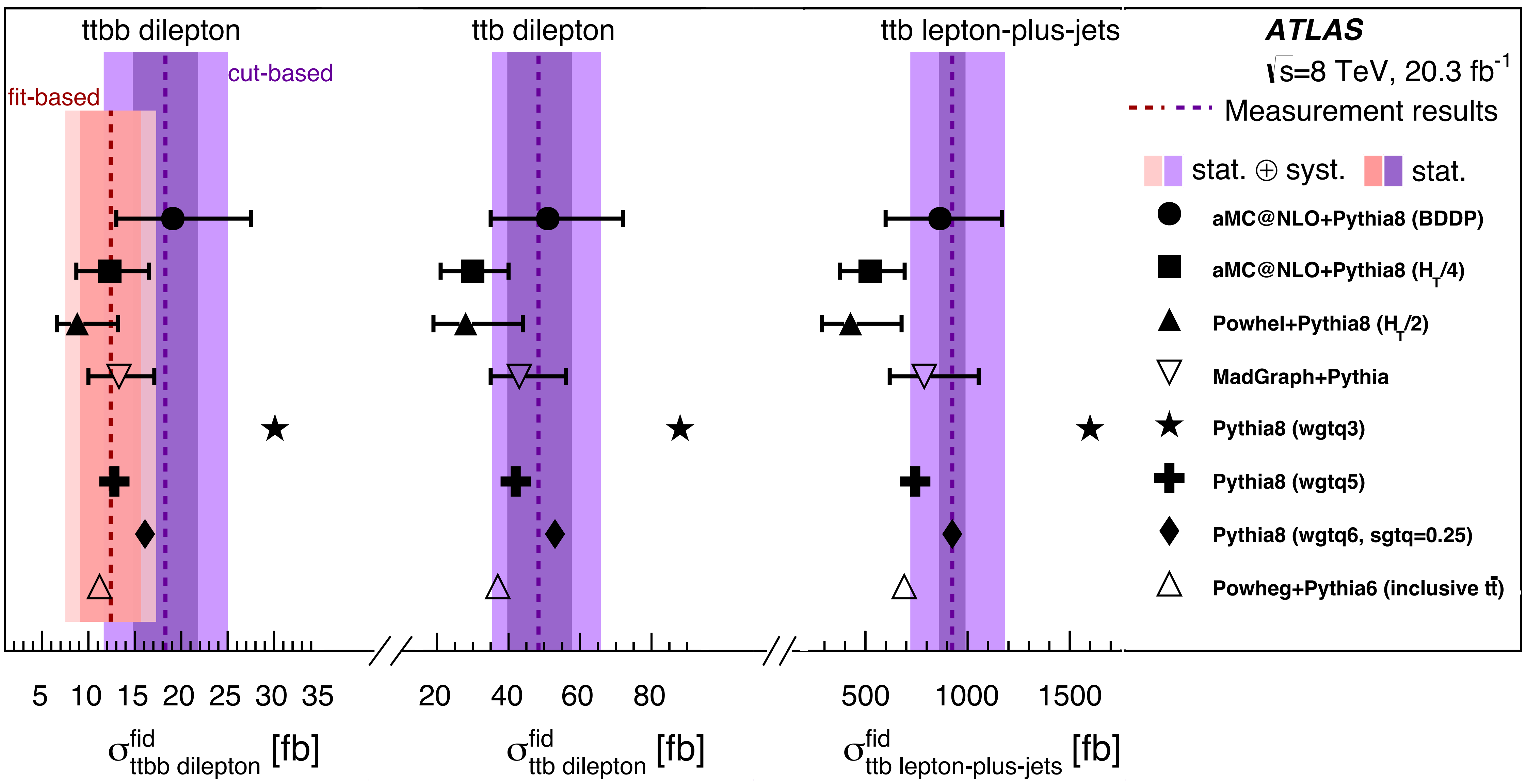
Improved by calculation at NLO ± 1.2 (syst.) ± 0.6 (th.)

ttbb 1508.06868

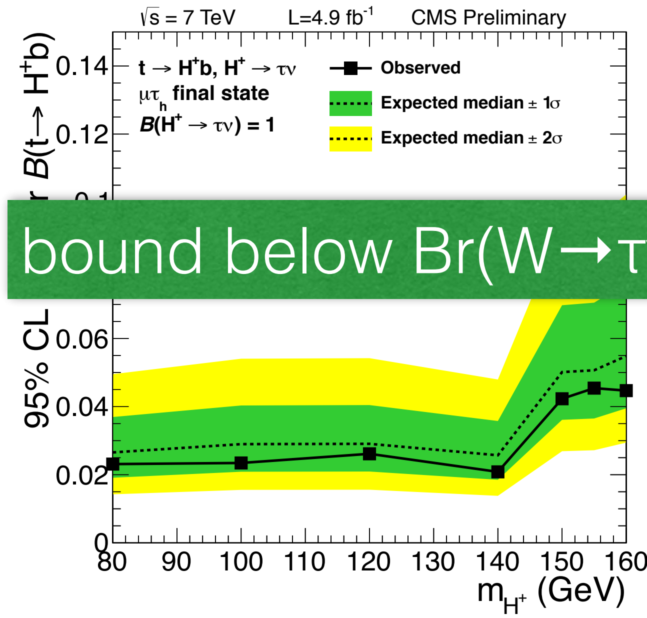
large **multiplicity** → challenge for (precise) predictions

background for **BSM** searches

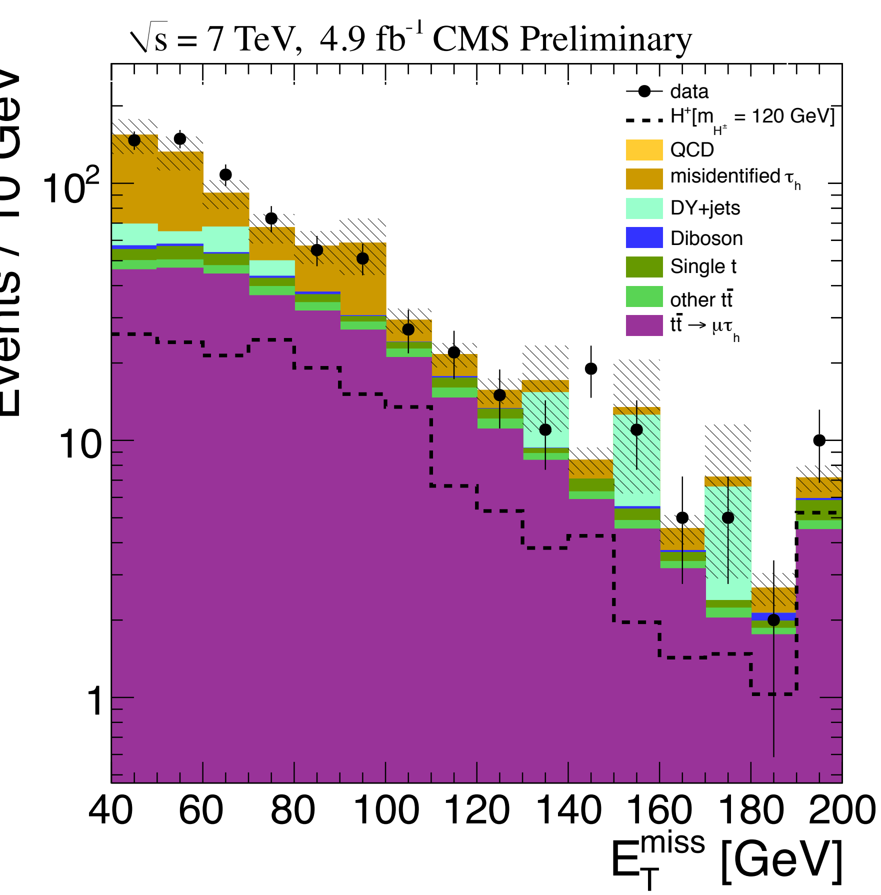
test of radiation of ***b*** associated to top

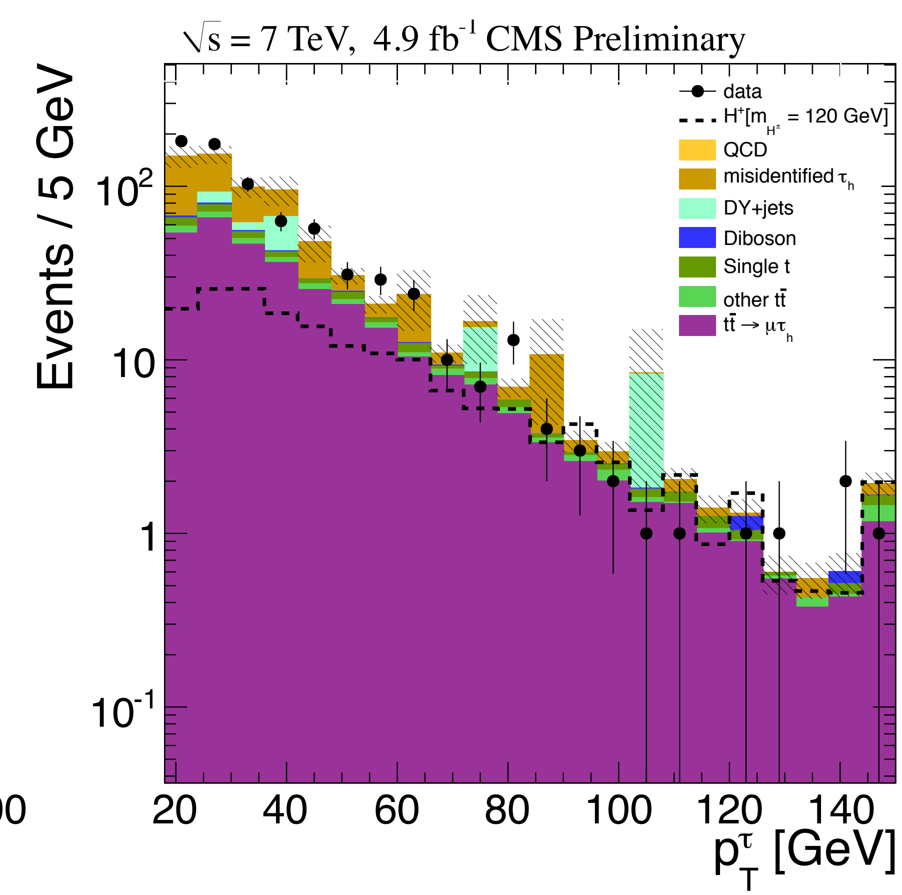


$t \to bH^+ \to b\tau\nu$ (CMS-PAS-HIG-12-052)

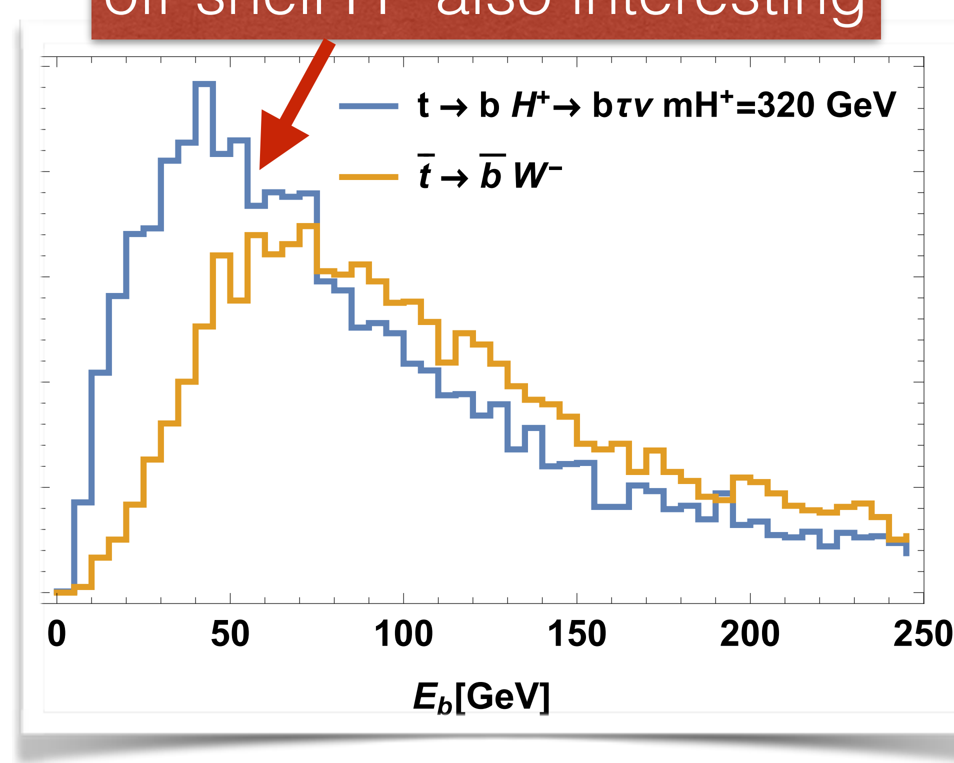


bound below Br(W→τν)





off-shell H^+ also interesting



insist on well understood distributions to **test SM and BSM**

$t \to bc\ell$ 1310.1618

"exclusive" selections

$\varepsilon(\text{basic} \to \text{tight}) \sim 0.05$

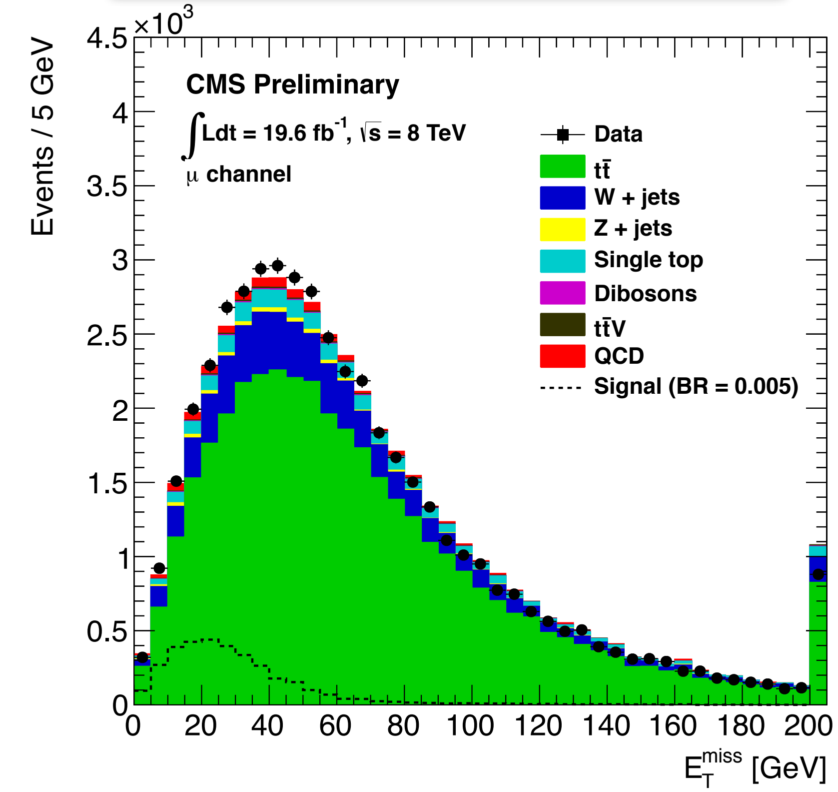
bound $Br \lesssim 0.002$
much below $Br(W \to \tau\nu)$

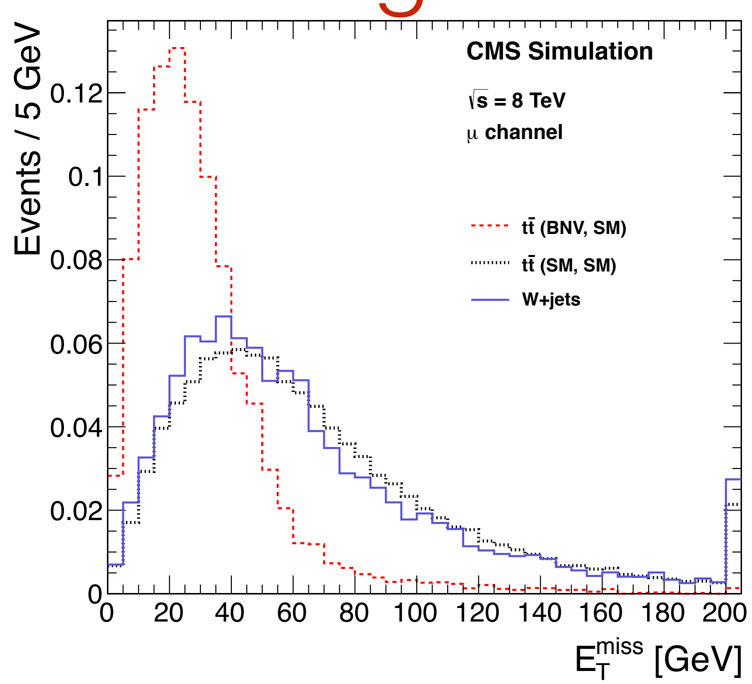
basic

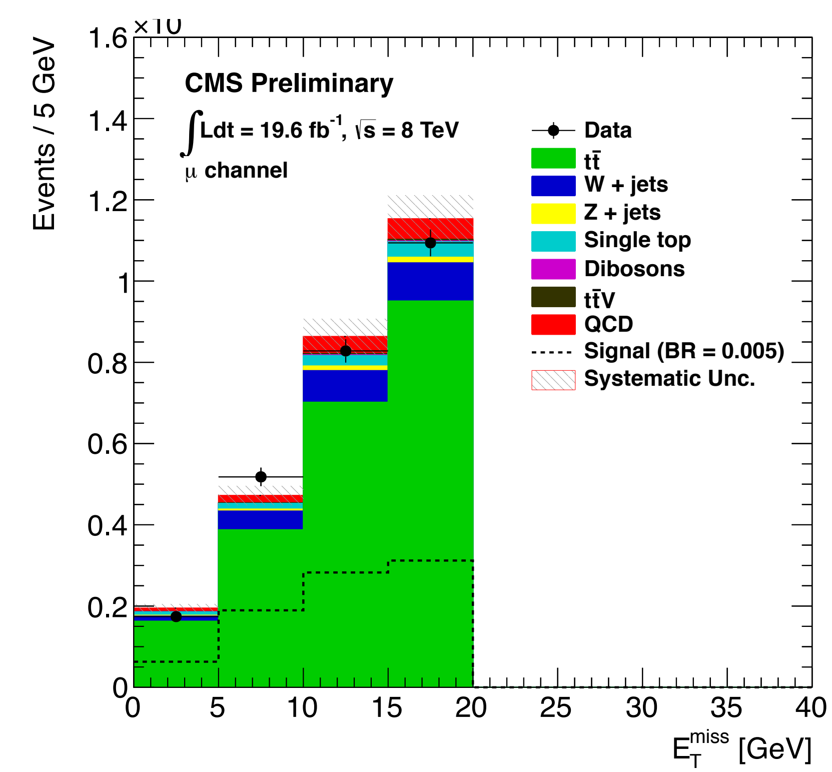
- μ: $p_T > 25$ GeV $\eta < 2.1$
- jet: $p_T > 70,55,40,30,30$ GeV $\eta < 2.4$
- $n_b \geq 1$

tight

- mET<20 GeV
- kinematic goodness-of-fit



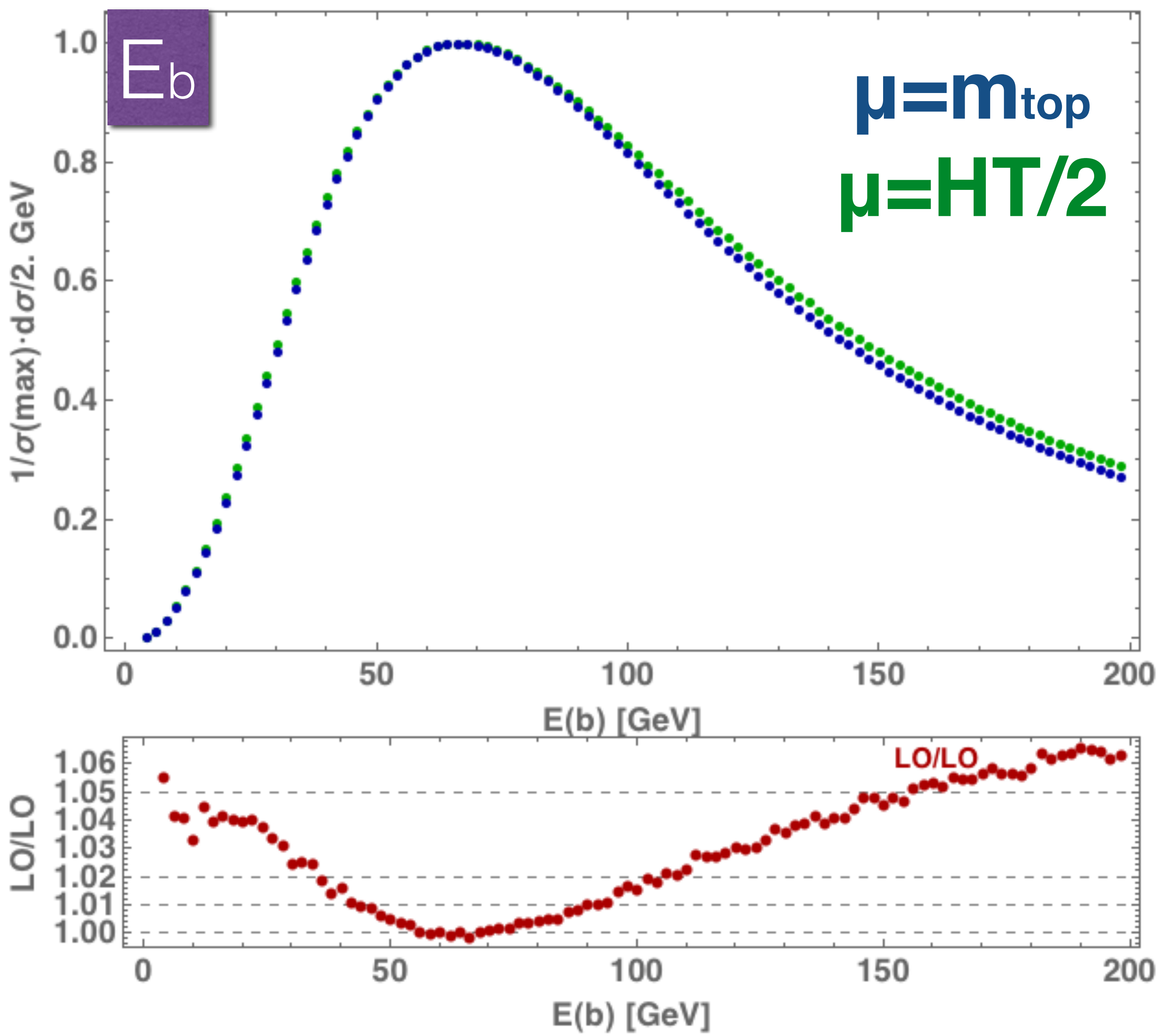




insist on well understood distributions to test SM and BSM

Subtleties of the subtle effects

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

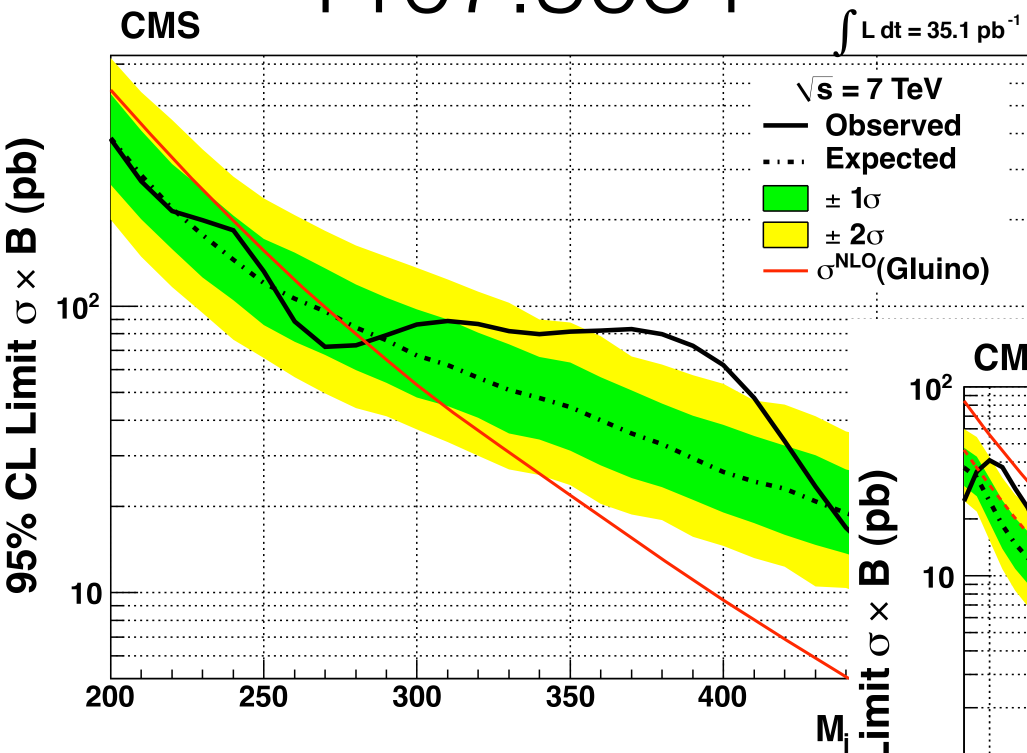


- despite "large" difference in the tails, m_{top} is unaffected
- good for m_{top}
- would be terrible if this was the effect of new physics sough for in m_{top}

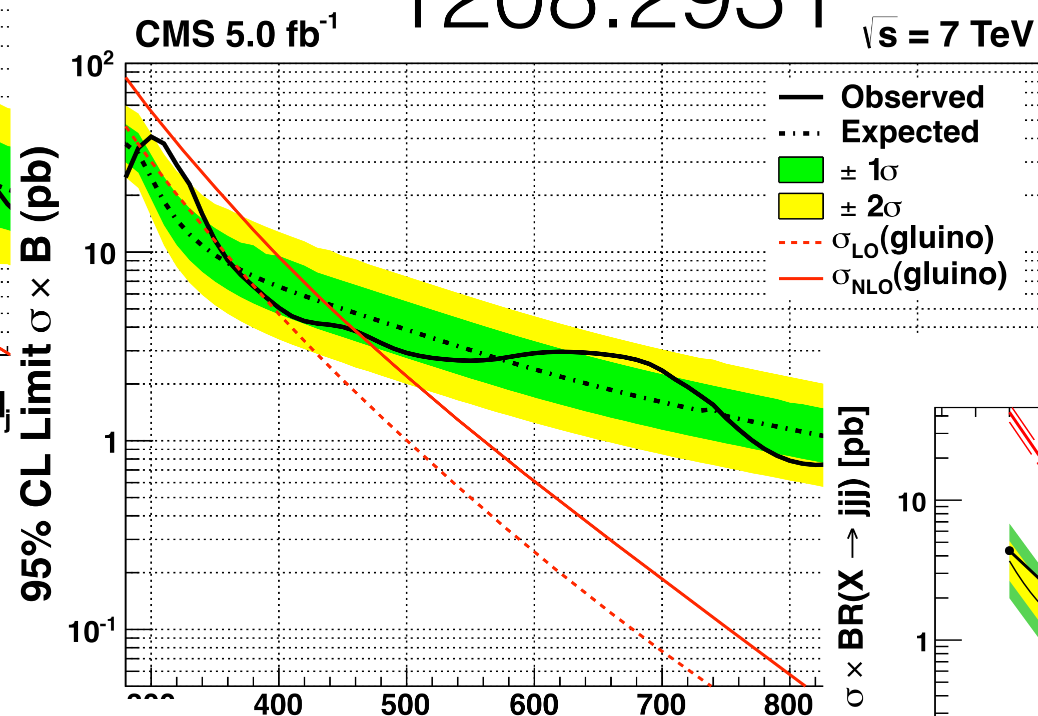
Light bumps are difficult

$\tilde{g} \rightarrow jjj$

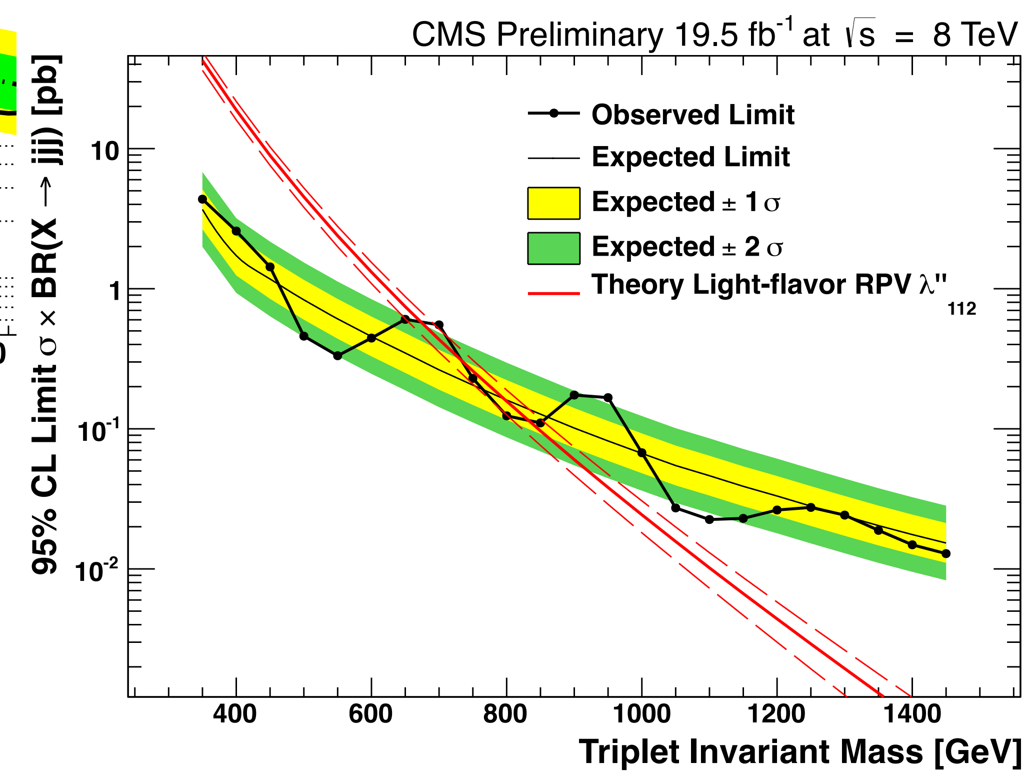
1107.3084

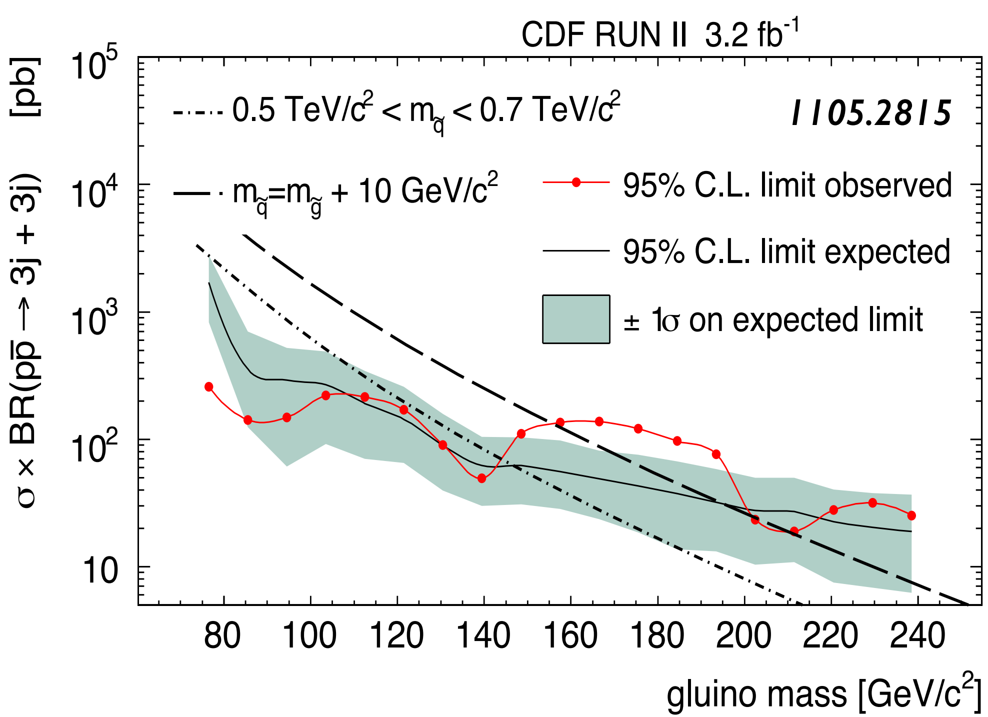


1208.2931



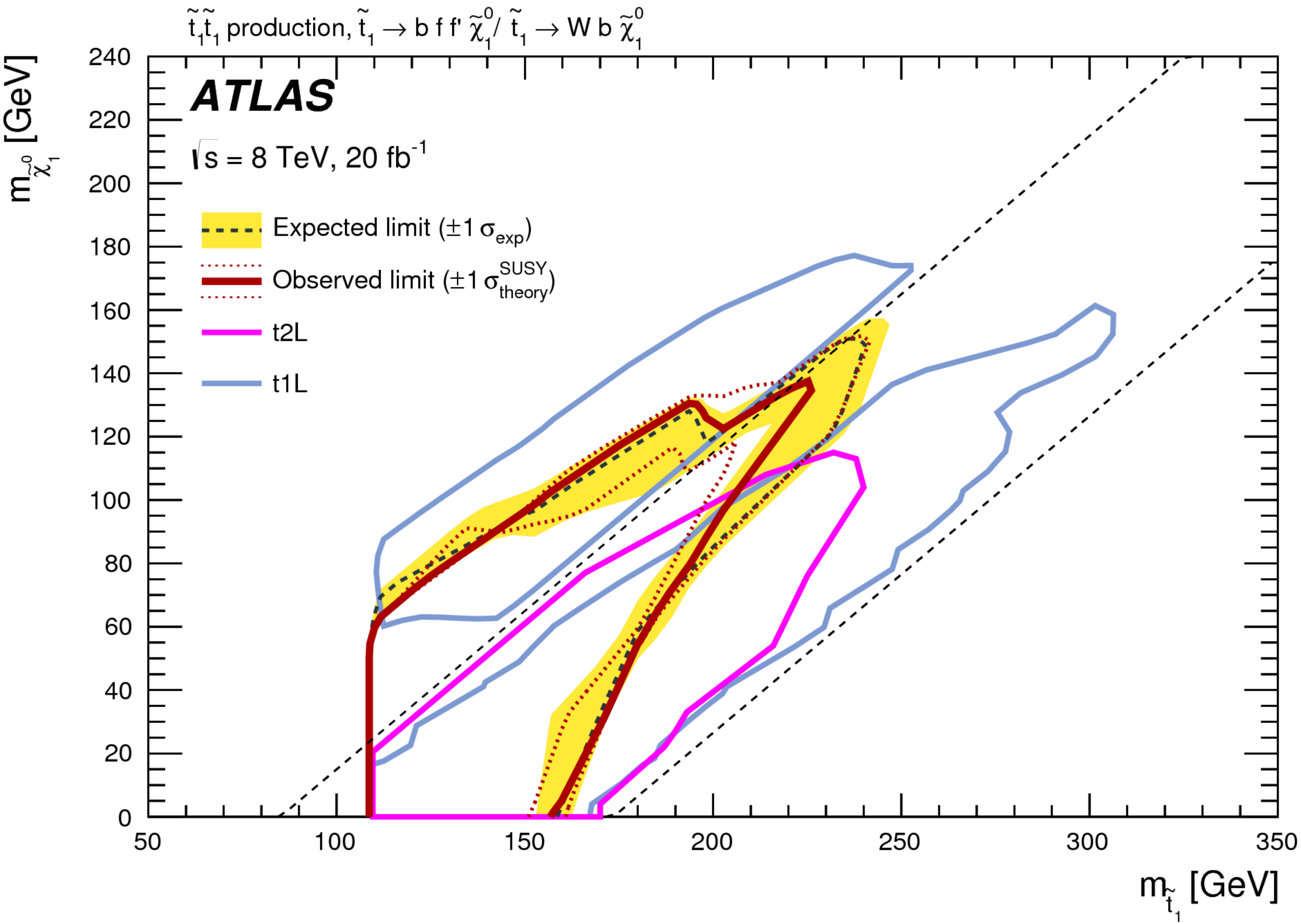
EXO-12-049





trigger is a killer at low mass

cut&count search 1210.4813

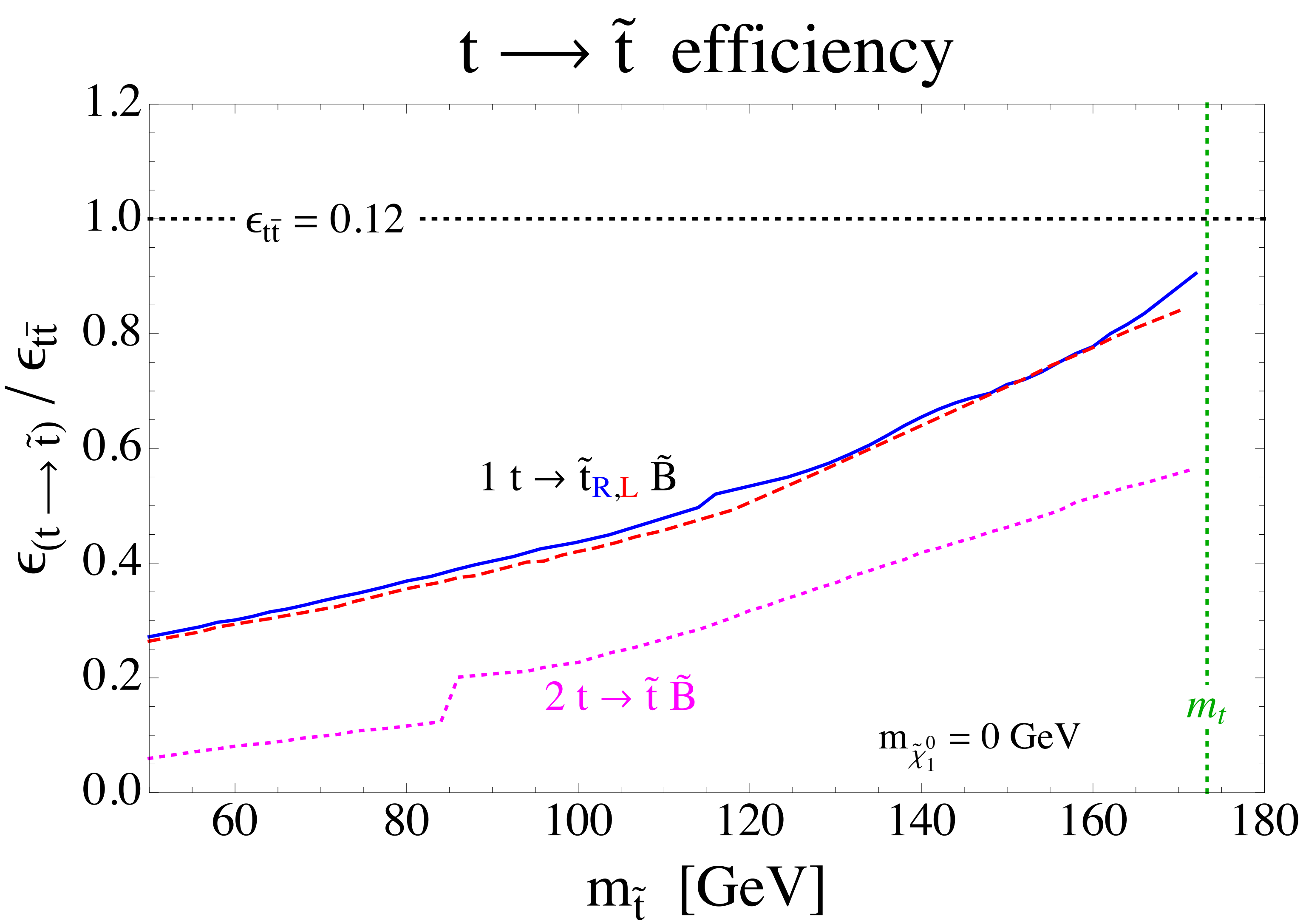


$\tilde{t}_1\tilde{t}_1$ production, $\tilde{t}_1 \to b f f' \tilde{\chi}^0_1$ / $\tilde{t}_1 \to W b \tilde{\chi}^0_1$
ATLAS
$\sqrt{s}$ = 8 TeV, 20 fb^{-1}
Expected limit ($\pm 1\ \sigma_{exp}$)
Observed limit ($\pm 1\ \sigma^{SUSY}_{theory}$)
t2L
t1L
$m_{\tilde{\chi}^0_1}$ [GeV]
$m_{\tilde{t}_1}$ [GeV]
0
20
40
60
80
100
120
140
160
180
200
220
240
50
100
150
200
250
300
350

$\sigma(t\bar{t})$: $m_{\tilde{t}}+m_{\chi}<m_t$

1407.1043 + hep-ph/9605340

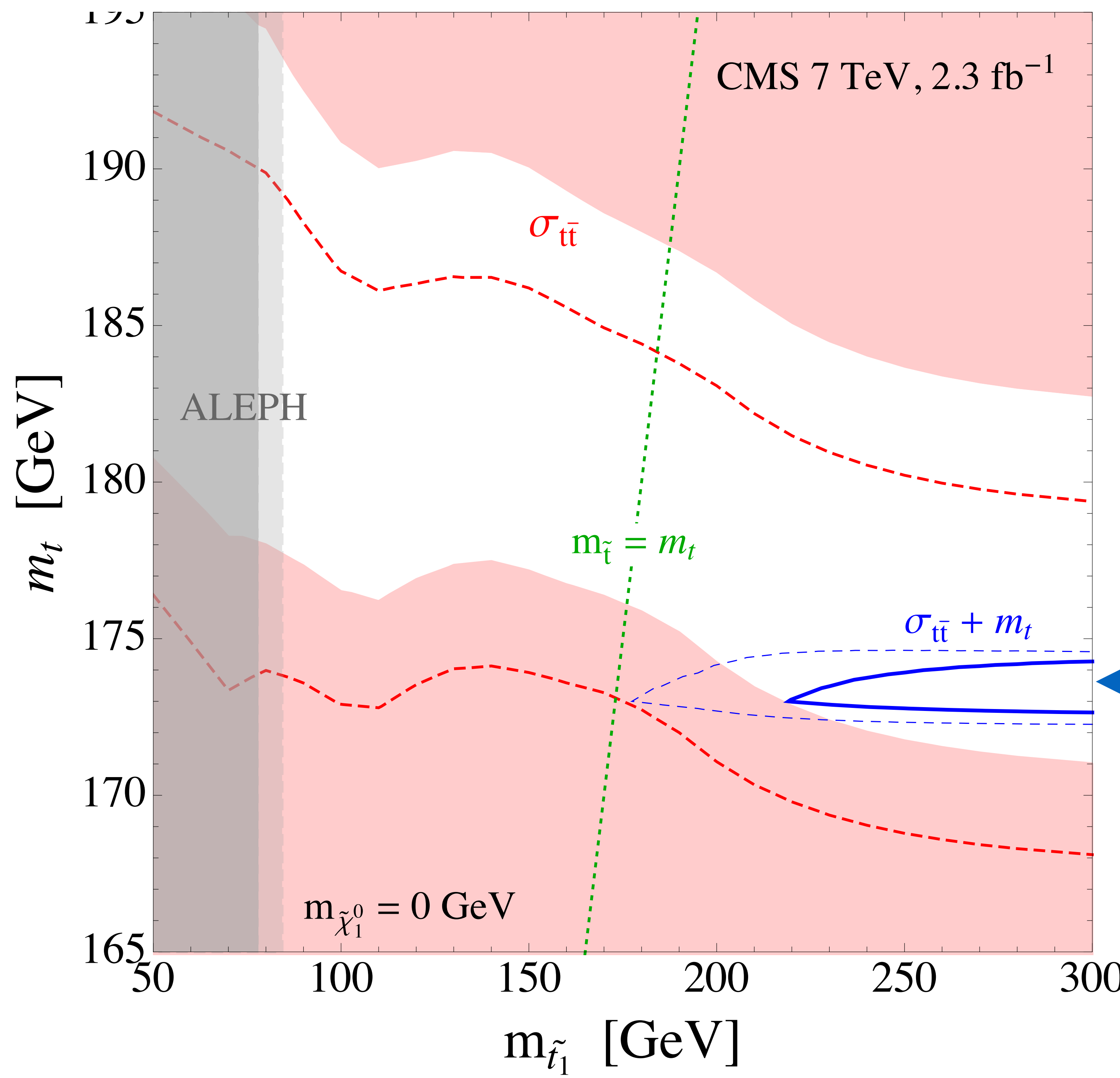
B(t→ $\tilde{t}\chi$) can be sizable

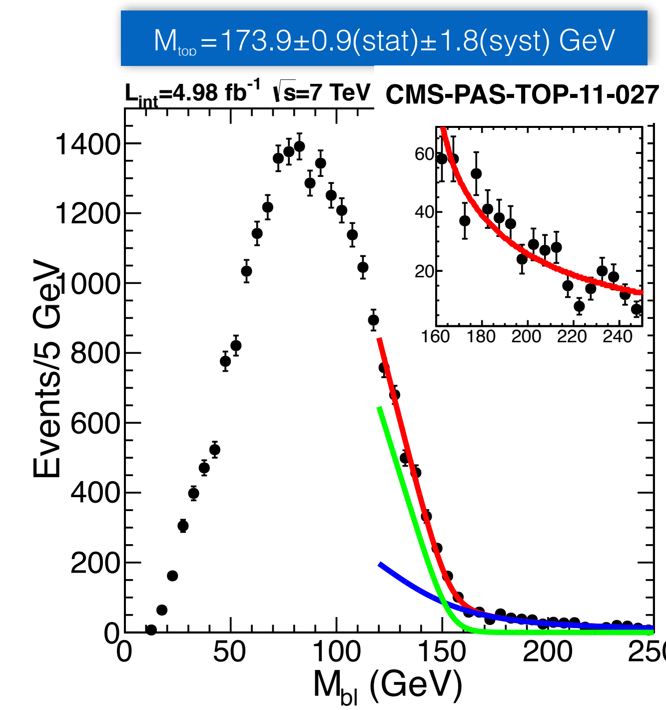


more on distributions later …

$\sigma(t\bar{t})$

1407.1043





from end-point
1304.5783

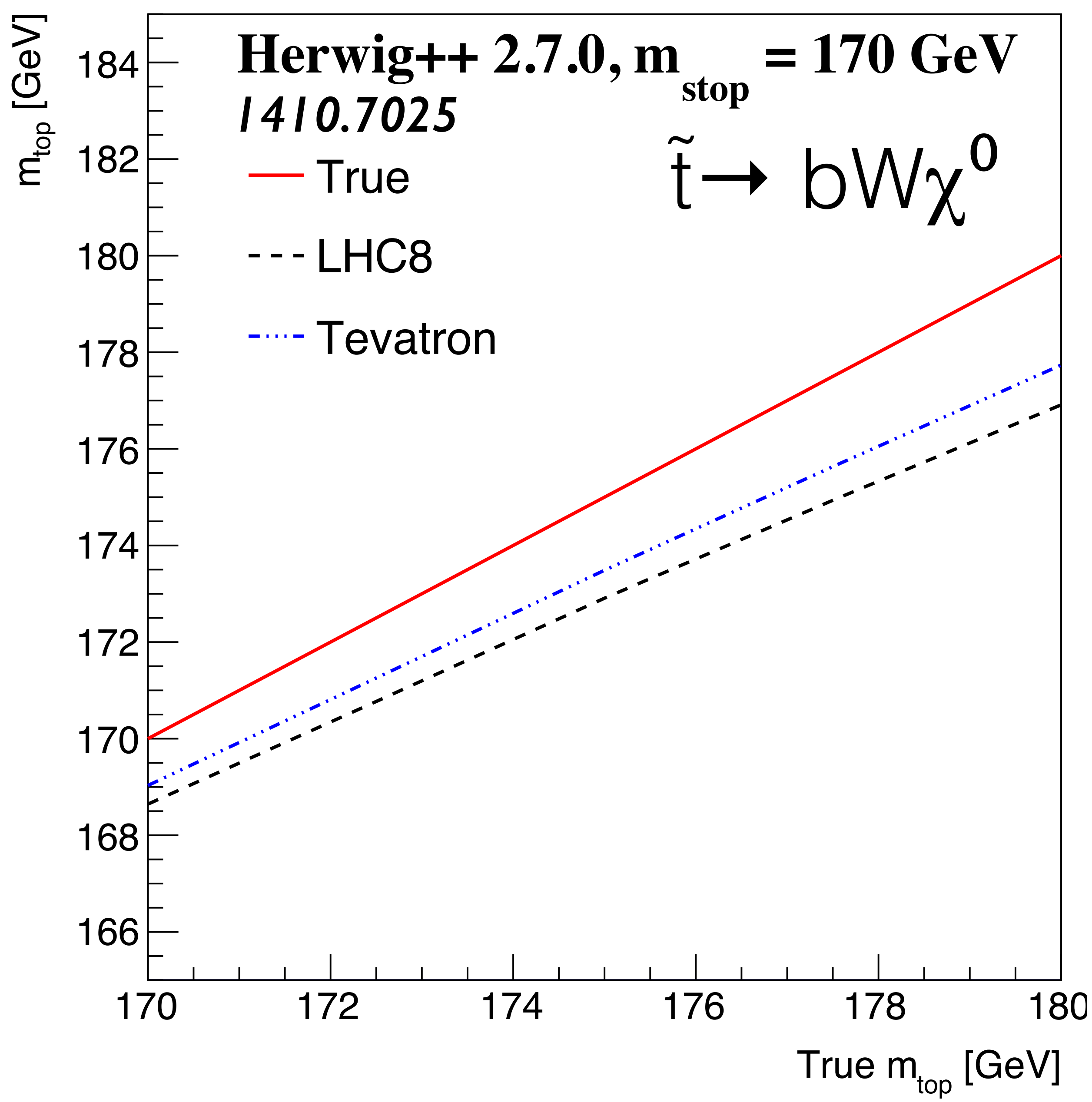
interplay with top mass measurement

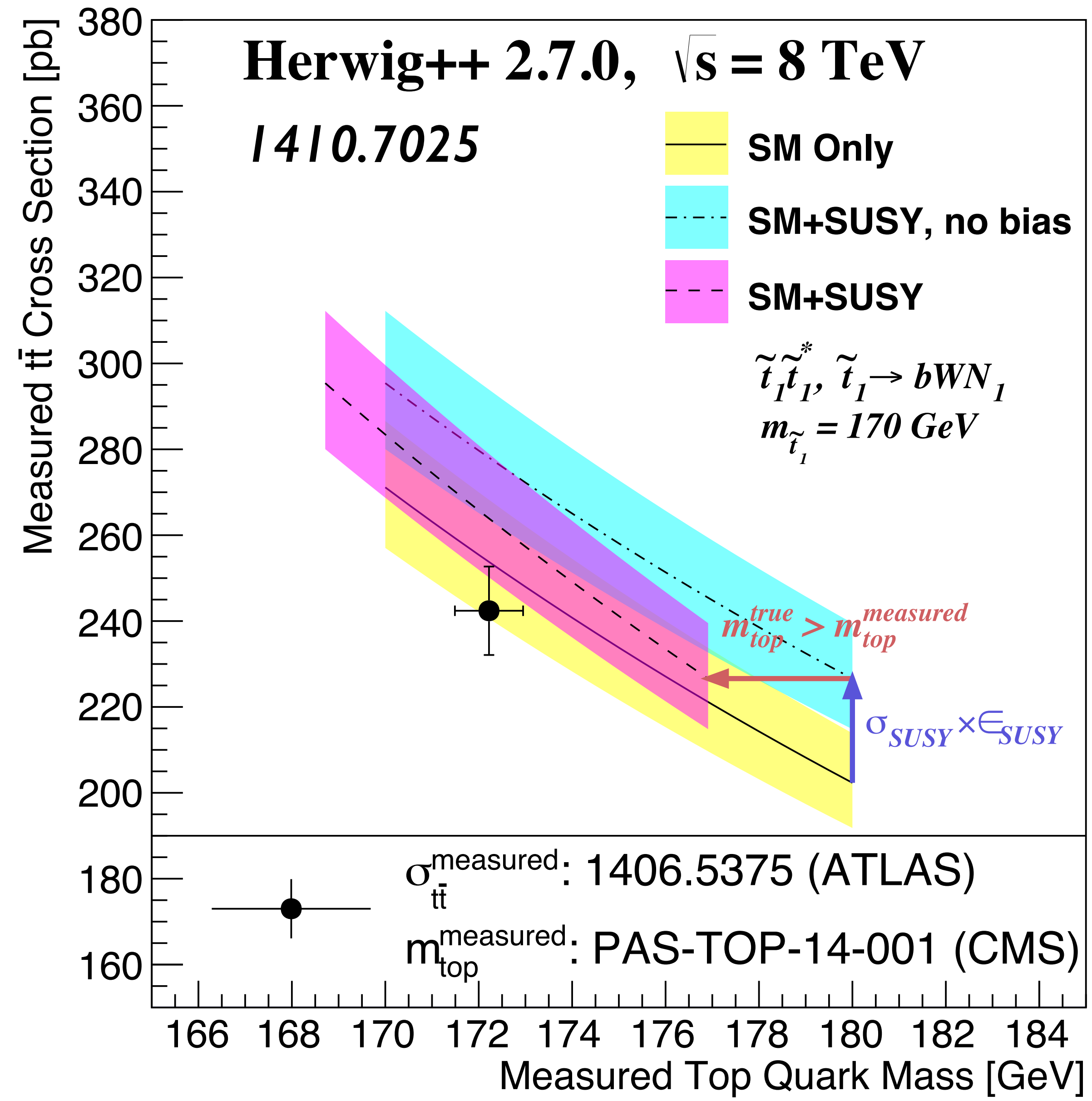
Top mass affected by BSM?

1410.7025

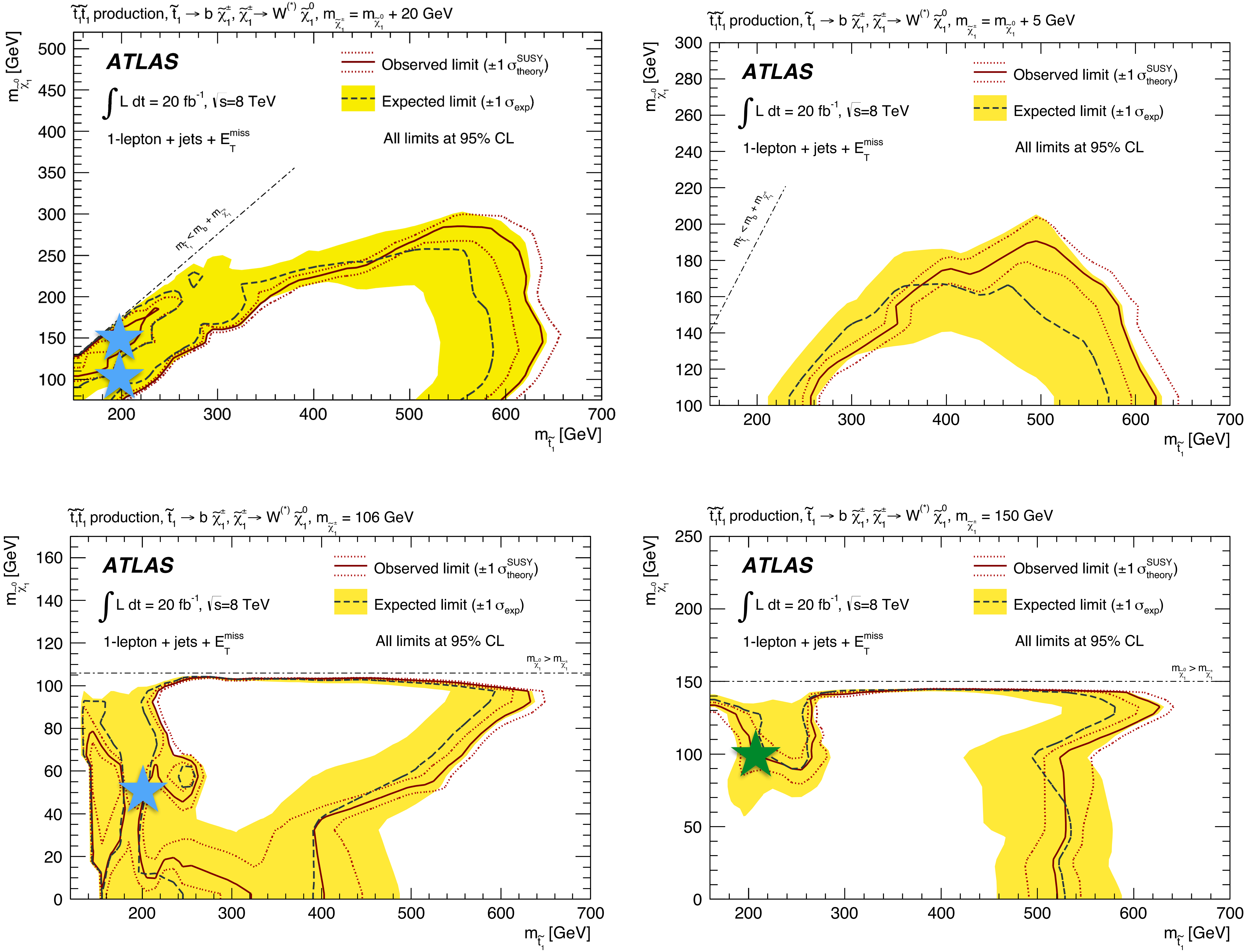
"proxy" for the kinematic fit used in the present "best" measurements

m_{top} from m_{bjj} that minimizes $$\chi^2 = \frac{(m_{j_1 j_2 b_1} - m_{b_2 l\nu})^2}{(20\ \mathrm{GeV})^2} + \frac{(m_{j_1 j_2} - m_W)^2}{(10\ \mathrm{GeV})^2},$$





mass potentially shifted by ~1 GeV



t̃₁t̃₁ production, t̃₁ → b χ̃±₁, χ̃±₁ → W(*) χ̃⁰₁, m χ̃±₁ = m χ̃⁰₁ + 20 GeV
ATLAS
∫L dt = 20 fb⁻¹, √s=8 TeV
1-lepton + jets + E_T^miss
Observed limit (±1 σ_theory^SUSY)
Expected limit (±1 σ_exp)
All limits at 95% CL
m t̃₁ < m_b + m χ̃±₁
m χ̃⁰₁ [GeV]
m t̃₁ [GeV]
t̃₁t̃₁ production, t̃₁ → b χ̃±₁, χ̃±₁ → W(*) χ̃⁰₁, m χ̃±₁ = m χ̃⁰₁ + 5 GeV
t̃₁t̃₁ production, t̃₁ → b χ̃±₁, χ̃±₁ → W(*) χ̃⁰₁, m χ̃±₁ = 106 GeV
m χ̃⁰₁ > m χ̃±₁
t̃₁t̃₁ production, t̃₁ → b χ̃±₁, χ̃±₁ → W(*) χ̃⁰₁, m χ̃±₁ = 150 GeV

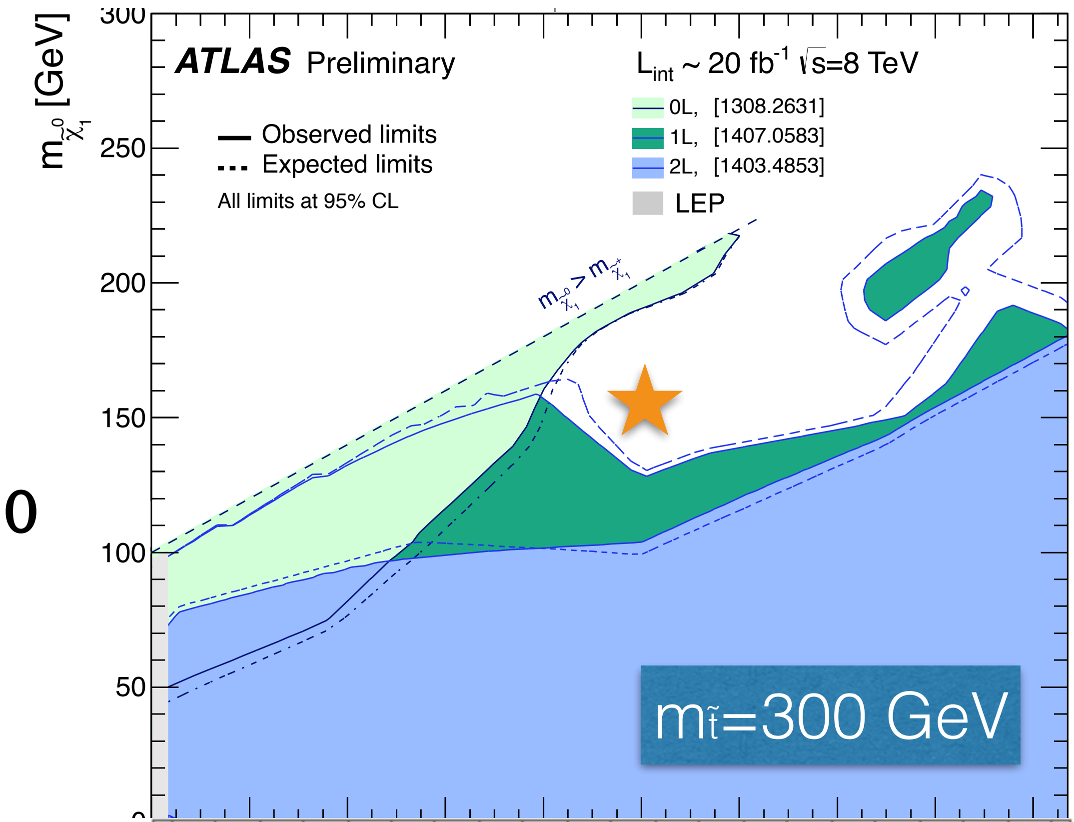
New physics effect on $m_{b\ell}$ and E_b

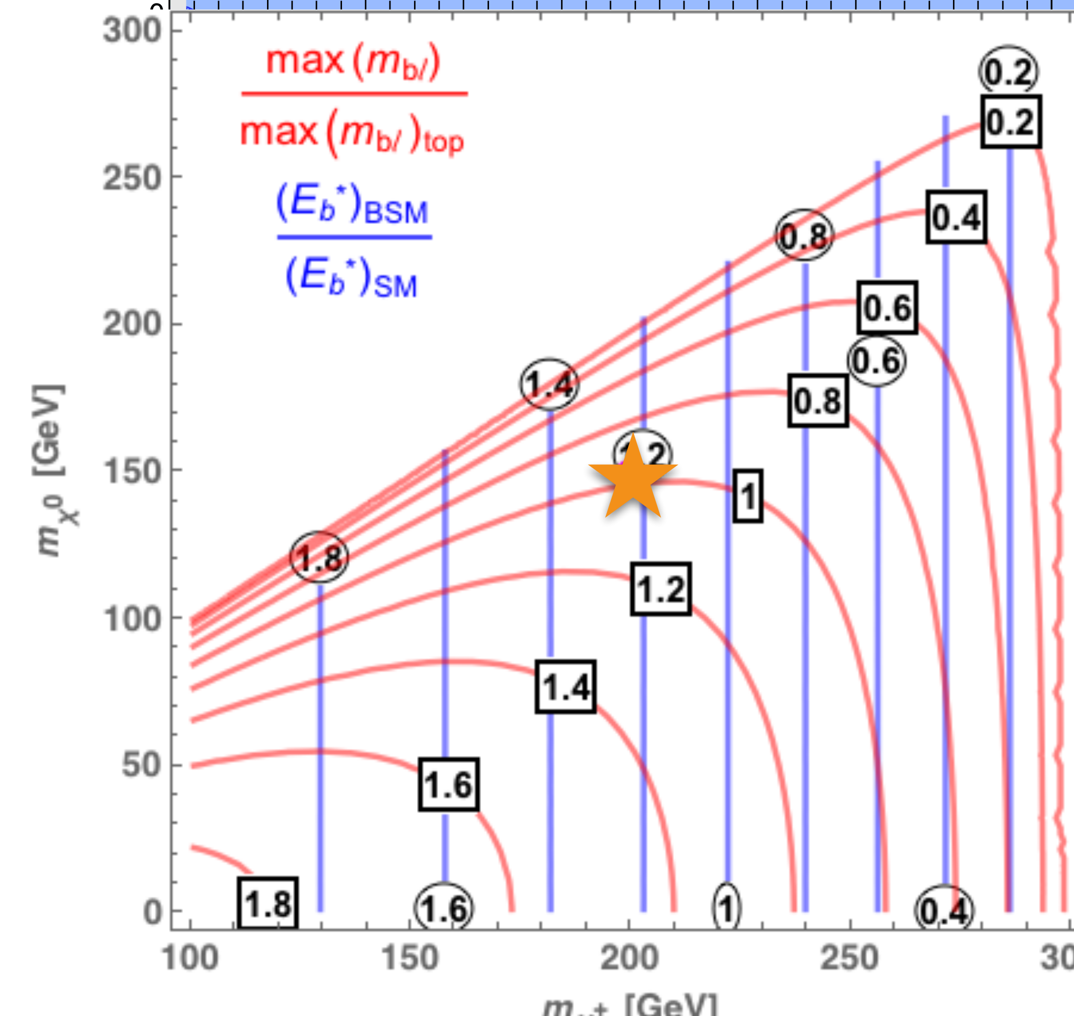
E_b and $m_{b\ell}$ behave differently

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

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

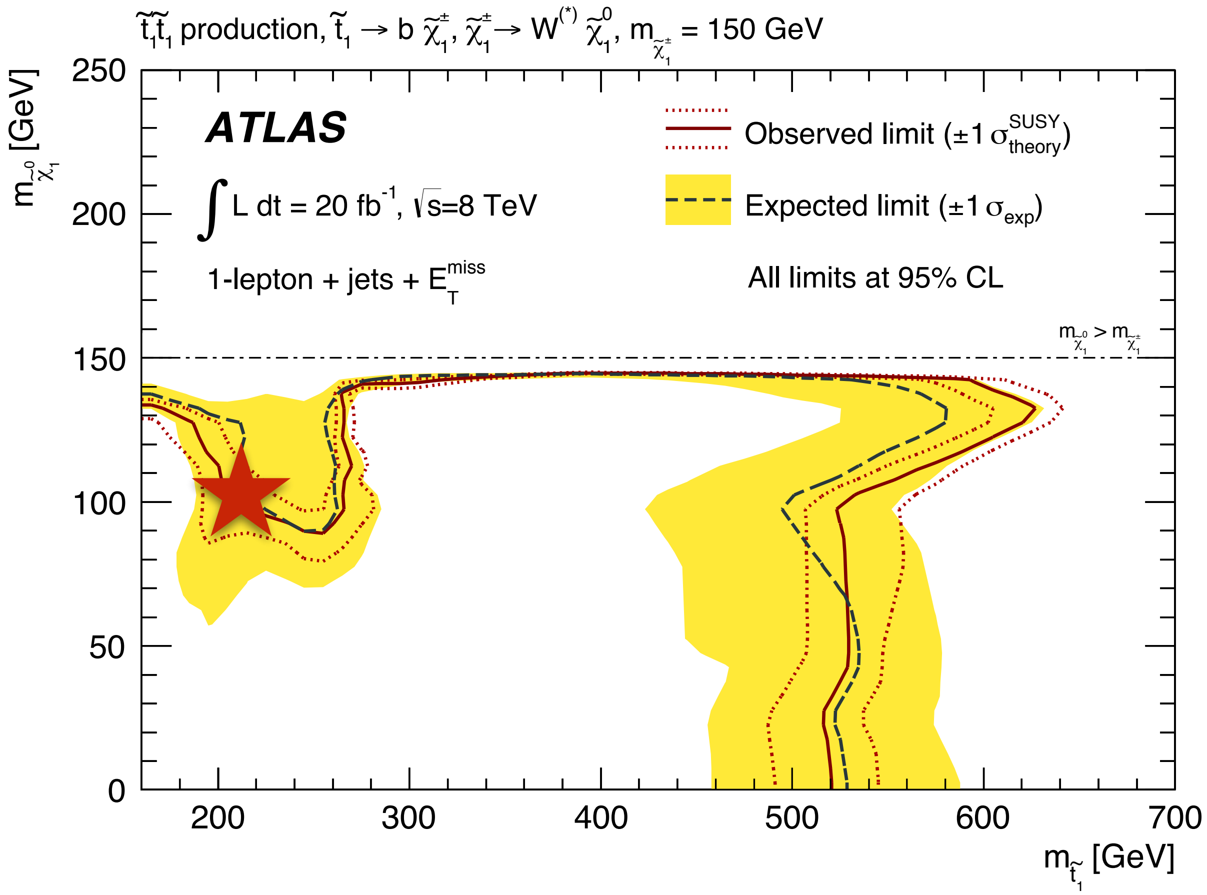
$$E_b^* = \frac{m_{\tilde{t}}^2 - m_{\chi^+}^2}{2\,m_{\tilde{t}}}$$

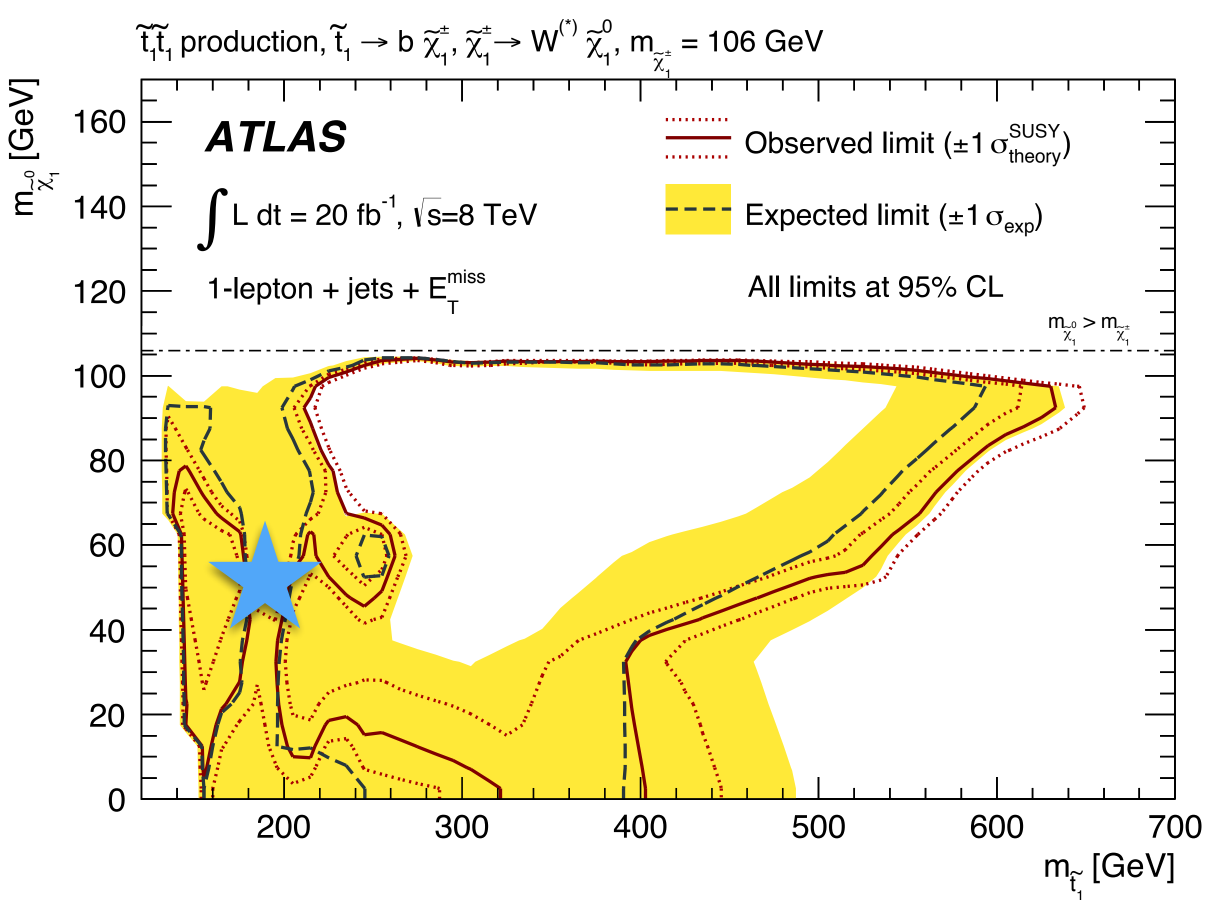


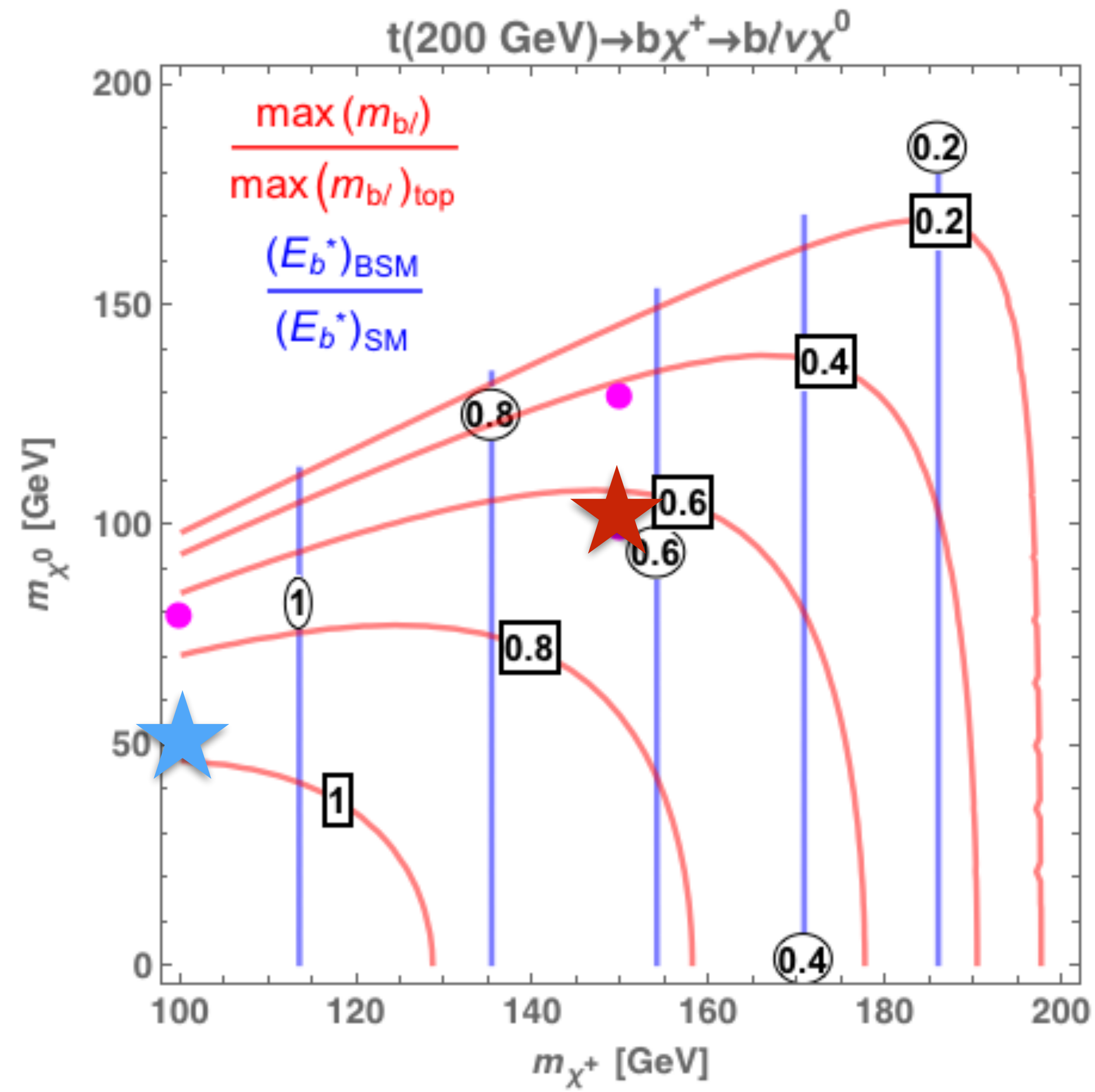


★ **Harder E_b, softer $m_{b\ell}$**

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



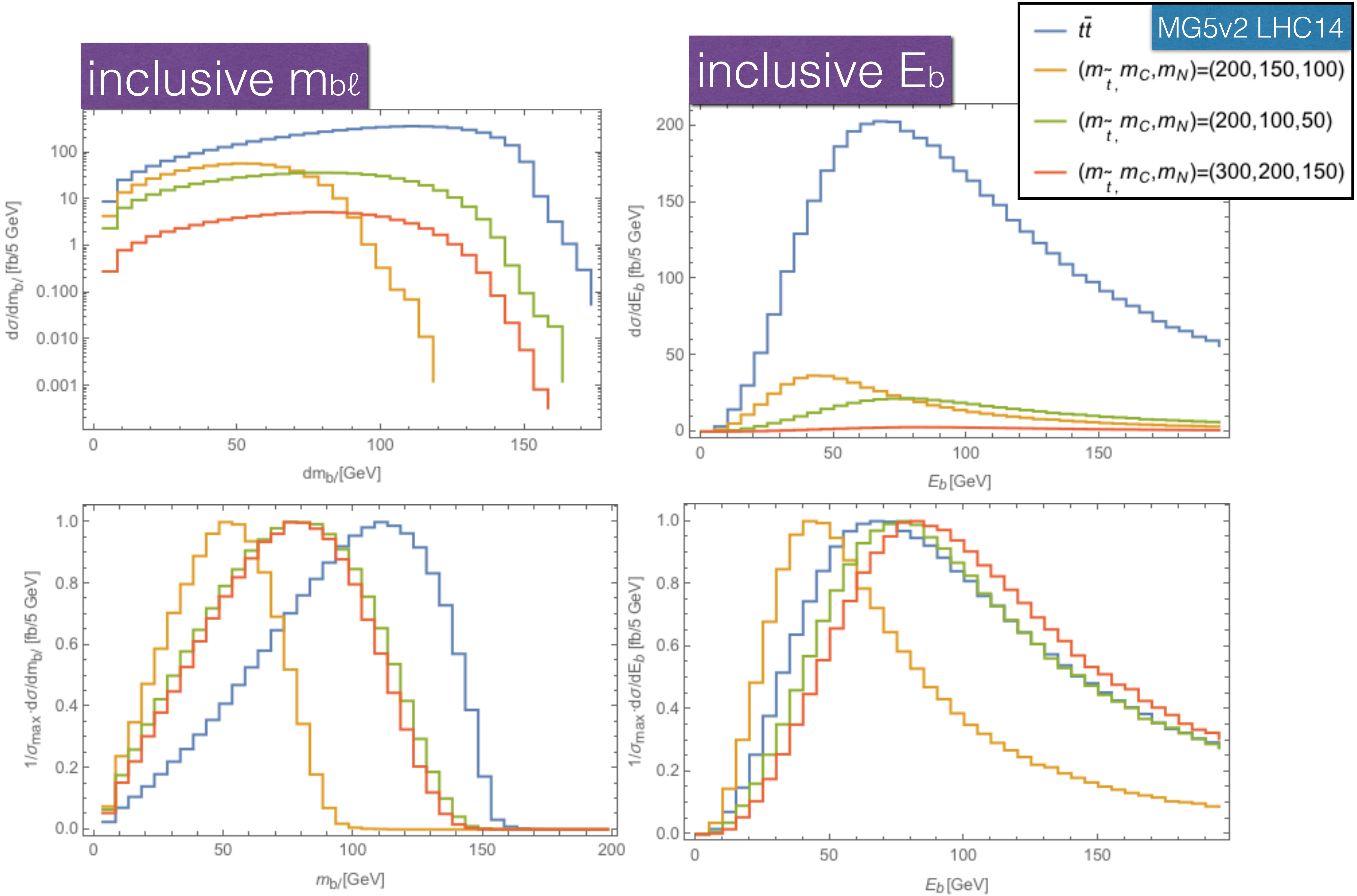




★ harder E_b, softer $m_{b\ell}$

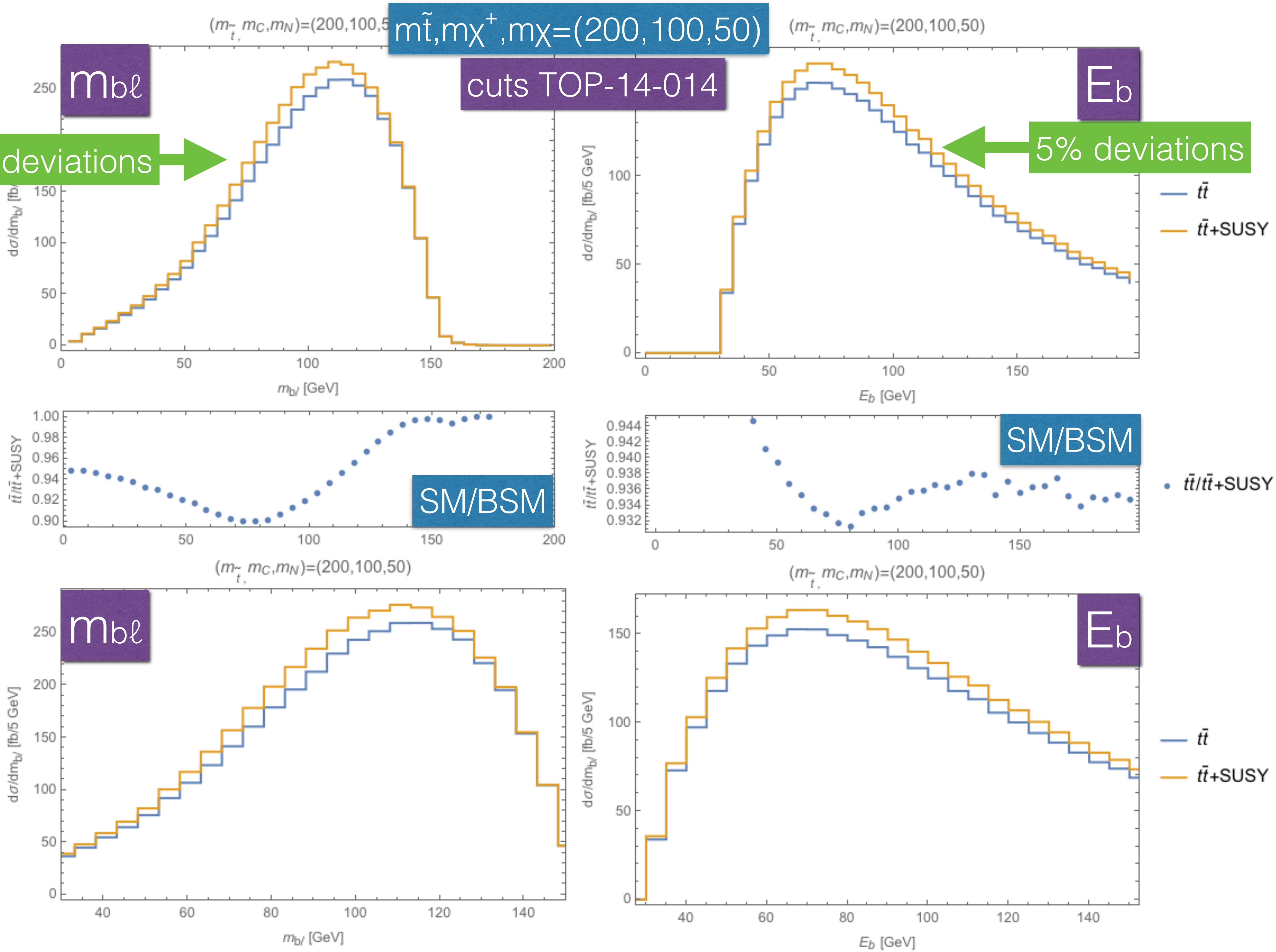
★ softer E_b, softer $m_{b\ell}$

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



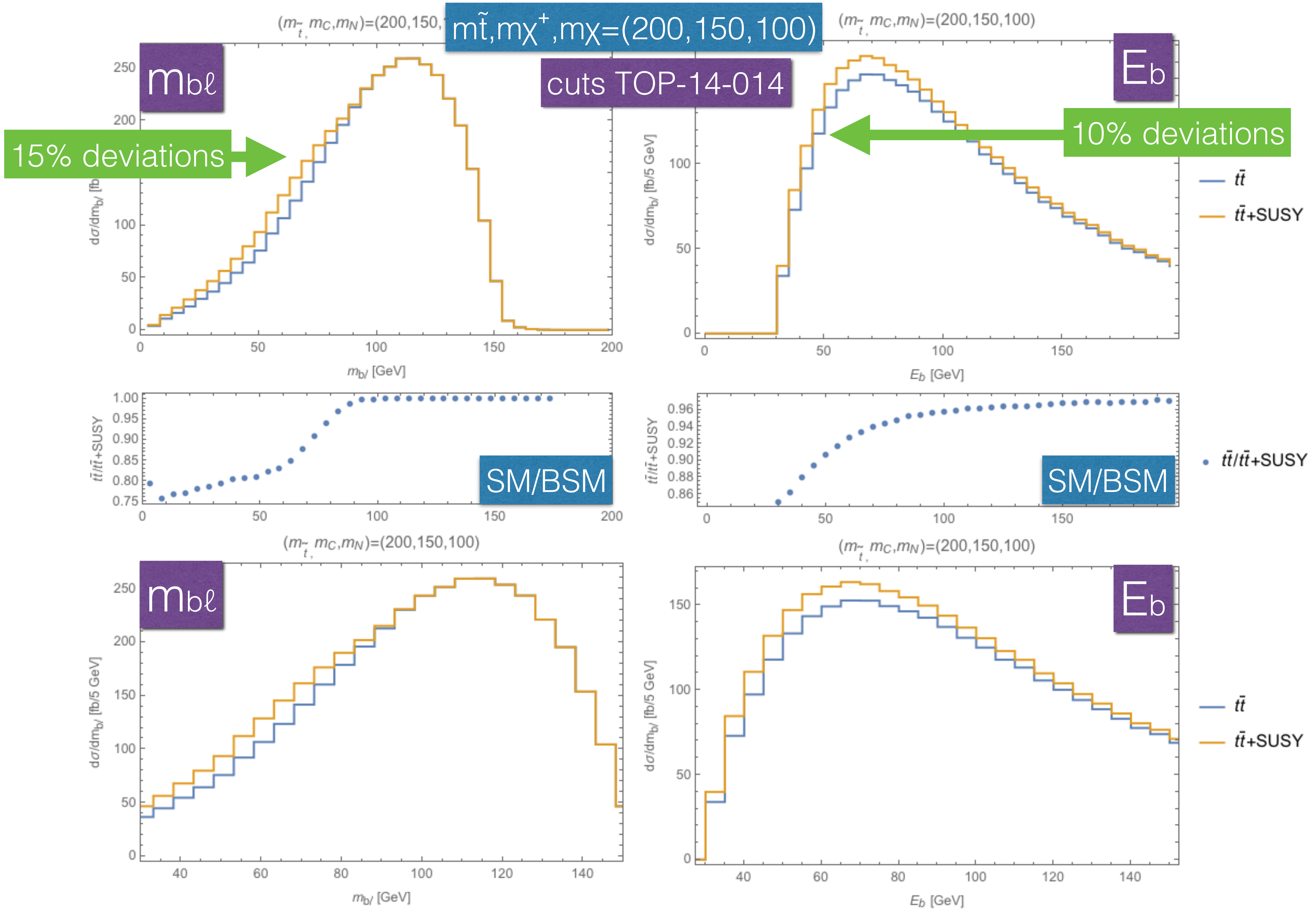
New physics effect on $m_{b\ell}$ and E_b

discussion with G. Polesello



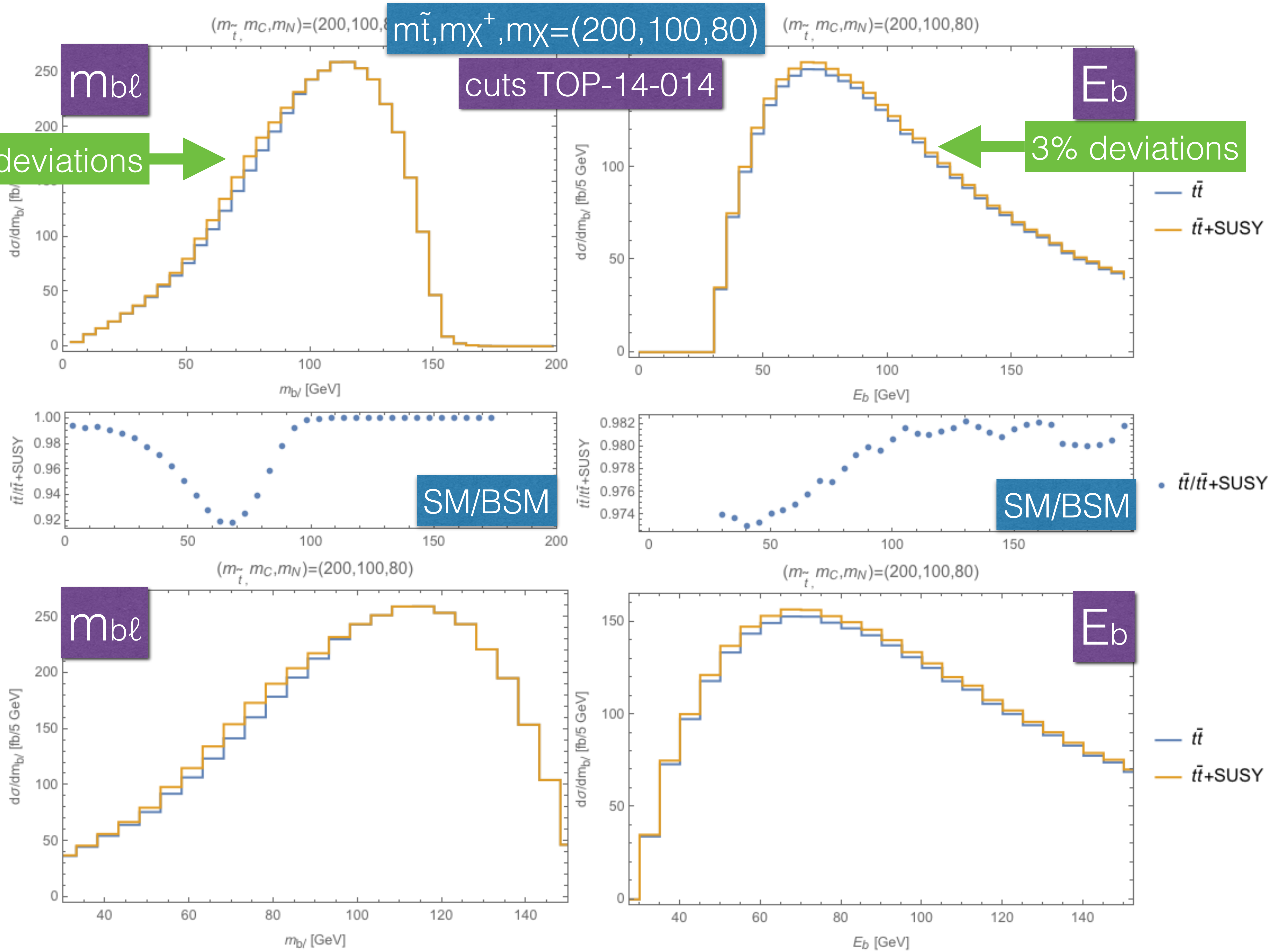
New physics effect on $m_{b\ell}$ and E_b

discussion with G. Polesello



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

discussion with G. Polesello

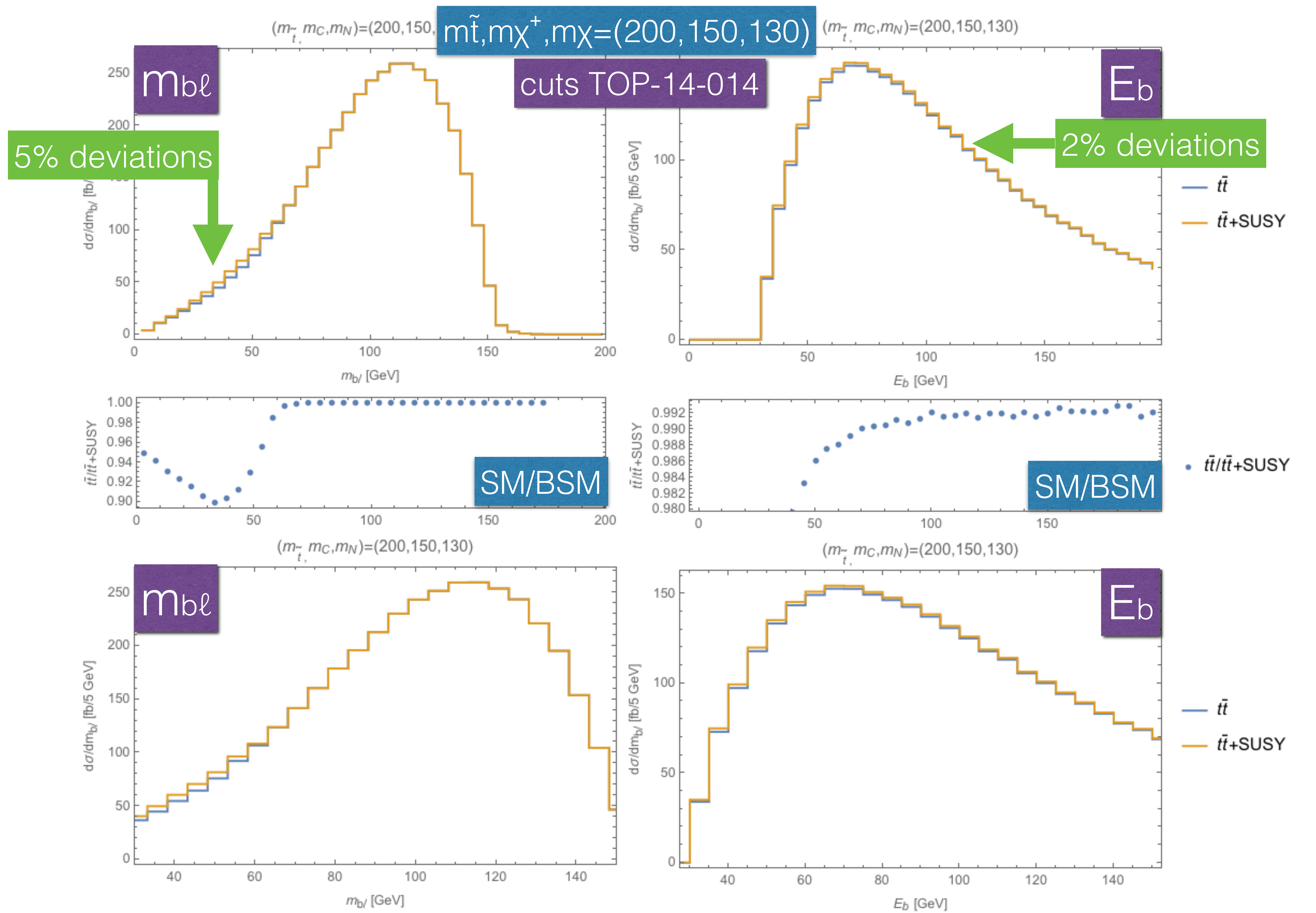


New physics effect on $m_{b\ell}$ and E_b

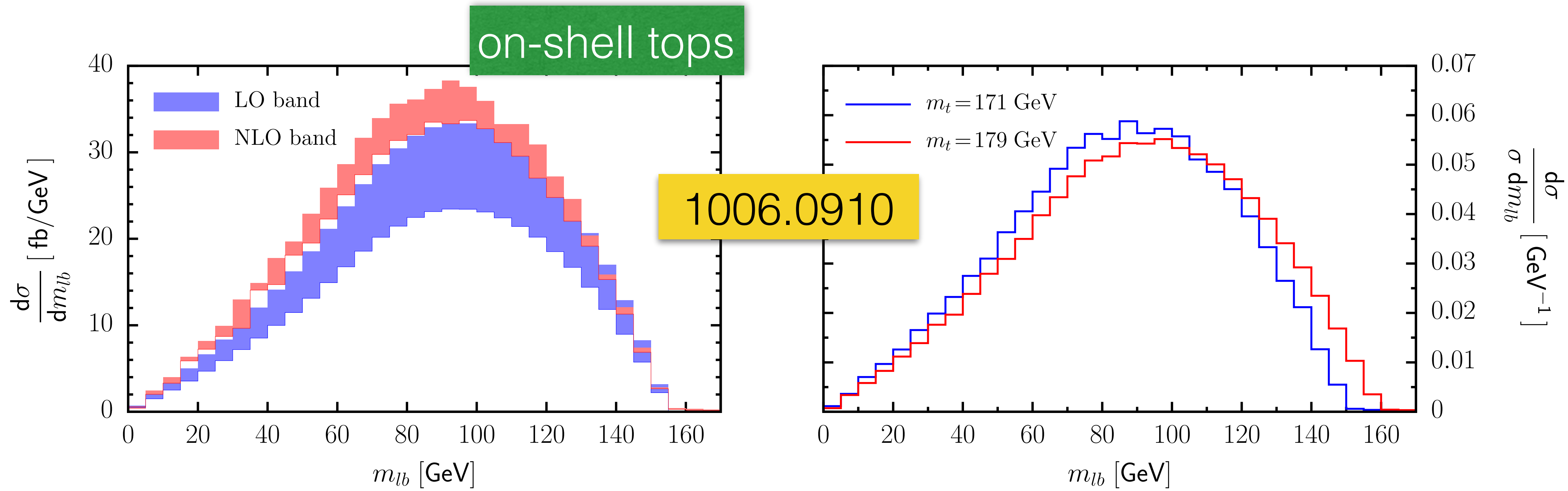
discussion with G. Polesello

$m_{\tilde{t}}, m_{\chi^+}, m_{\chi} = (200, 150, 130)$

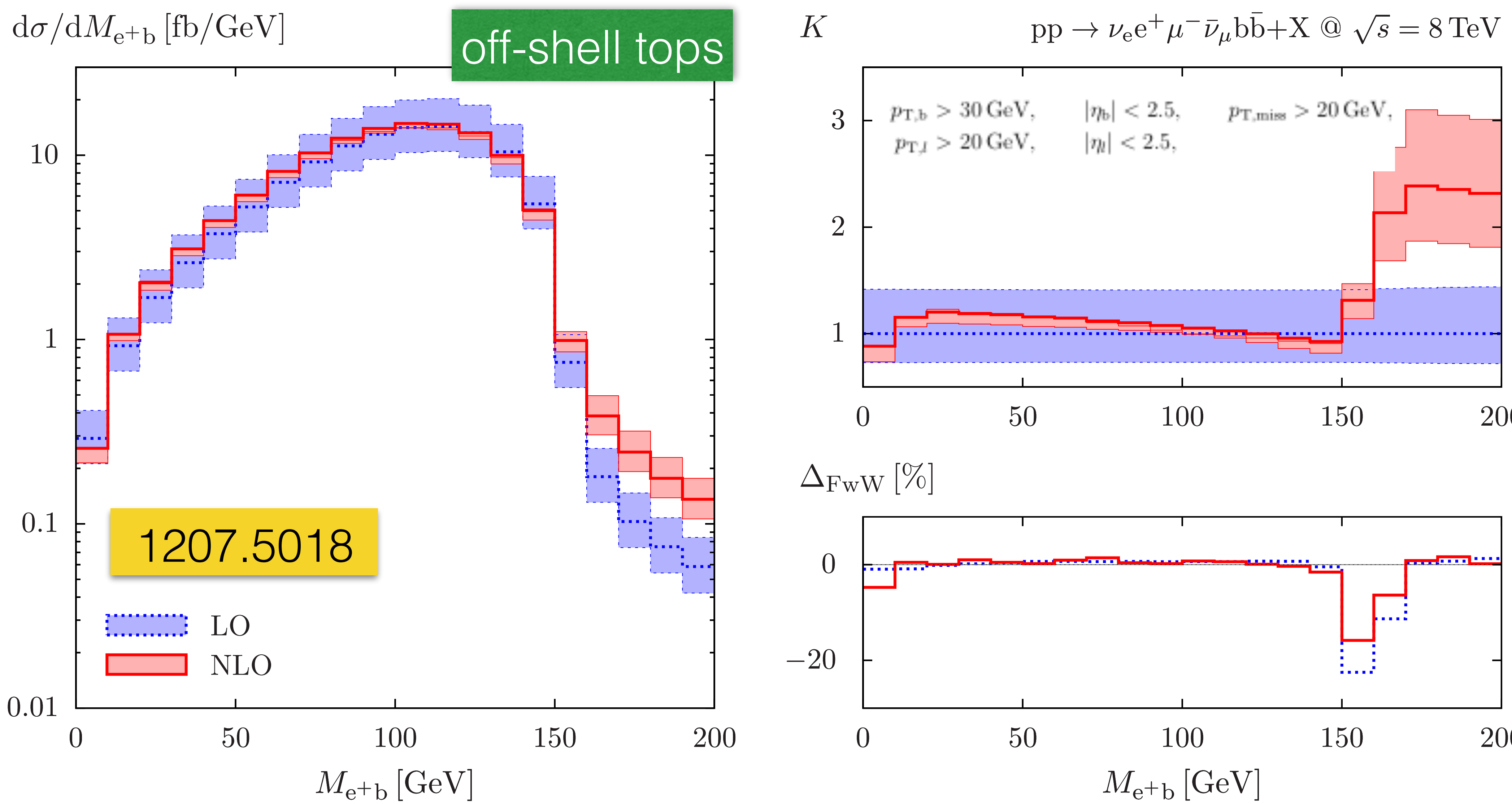
cuts TOP-14-014



$m_{b\ell}$ at NLO

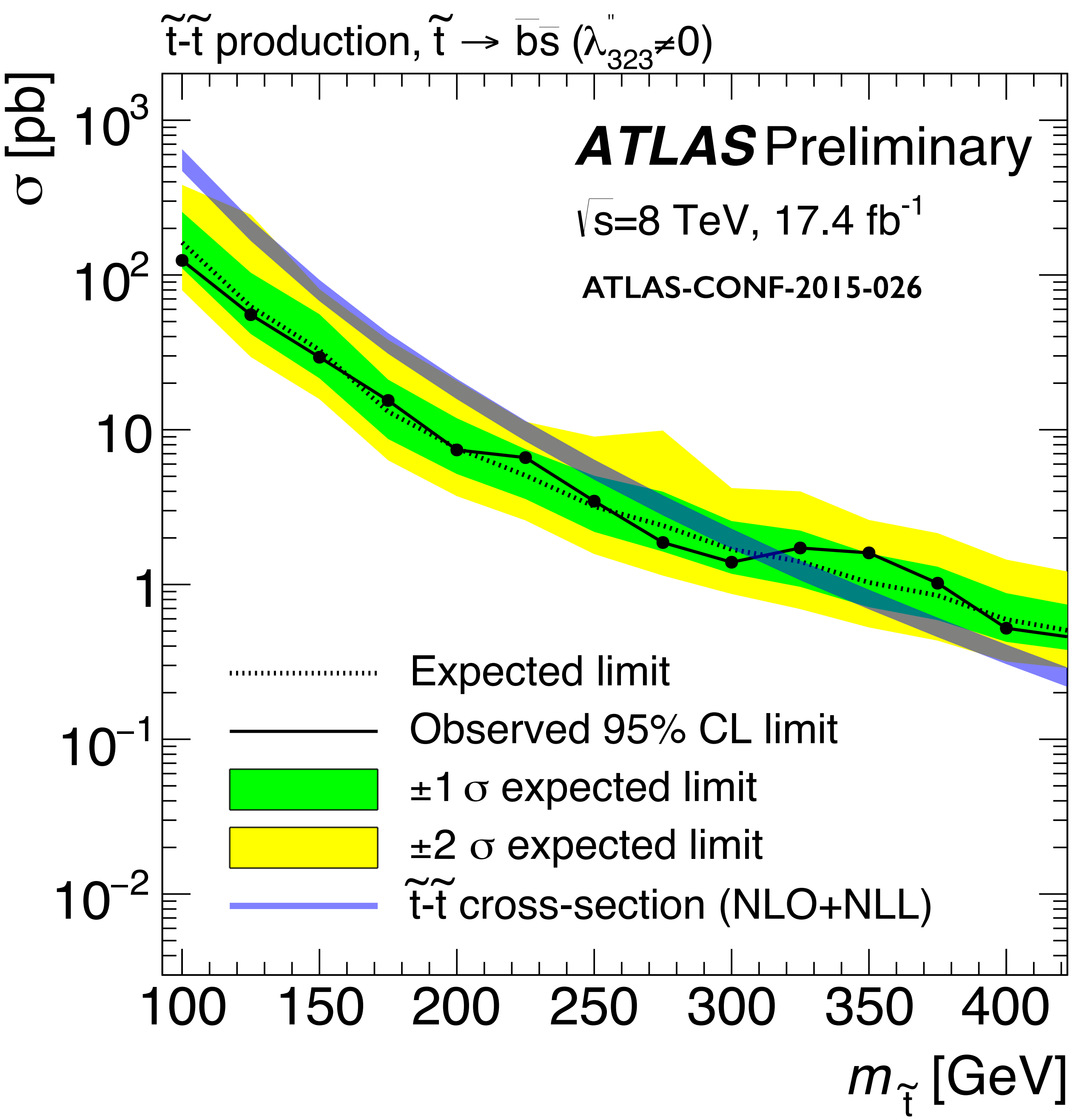


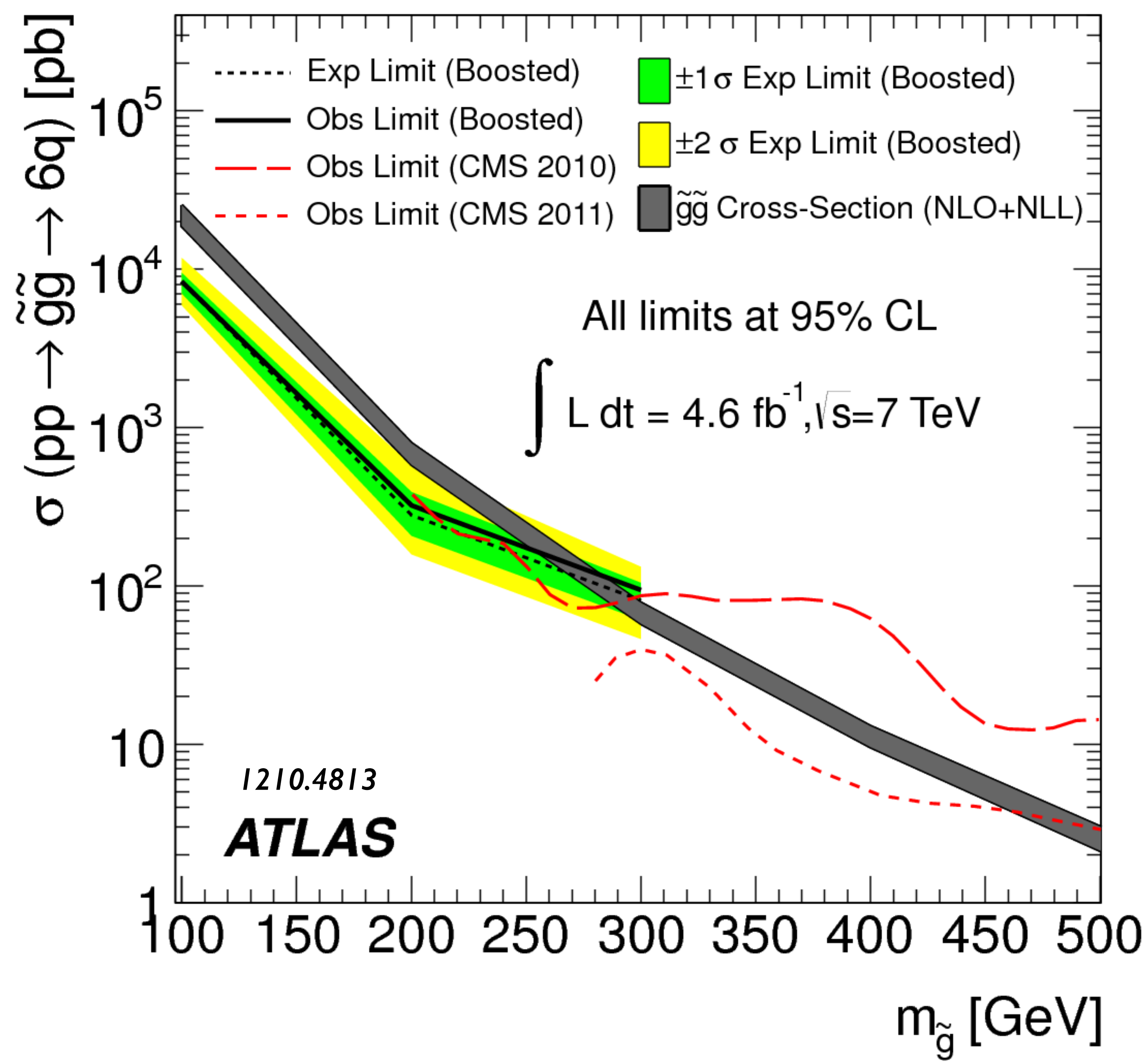
on-shell tops
1006.0910
LO band
NLO band
$m_t = 171$ GeV
$m_t = 179$ GeV
$\frac{d\sigma}{dm_{lb}}$ [fb/GeV]
$\frac{d\sigma}{\sigma\, dm_{lb}}$ [GeV^{-1}]
m_{lb} [GeV]



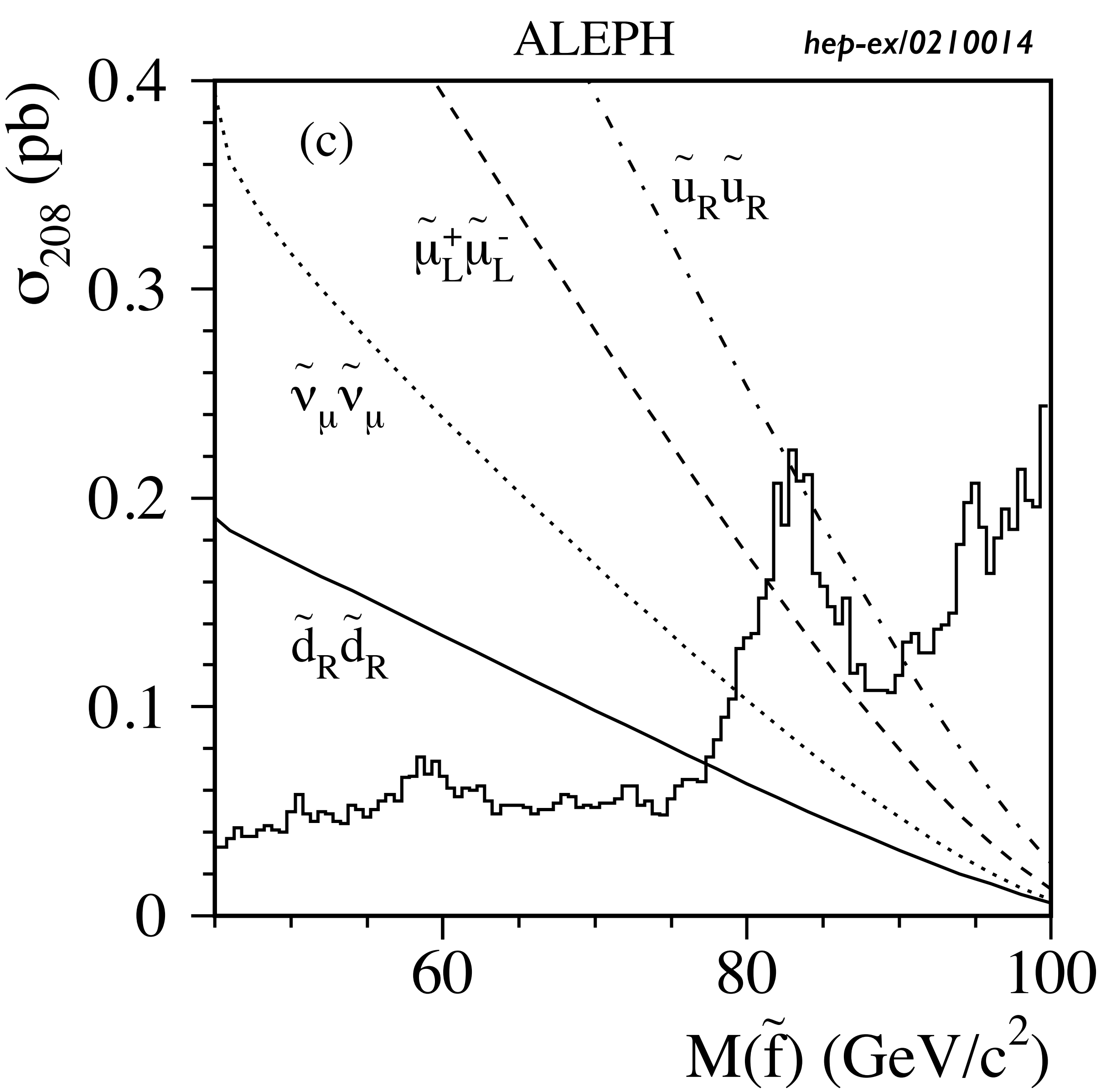
off-shell tops
1207.5018
$d\sigma/dM_{e^+b}$ [fb/GeV]
K
$pp \to \nu_e e^+ \mu^- \bar{\nu}_\mu b\bar{b} + X$ @ $\sqrt{s} = 8$ TeV
$p_{T,b} > 30$ GeV, $|\eta_b| < 2.5$, $p_{T,miss} > 20$ GeV,
$p_{T,l} > 20$ GeV, $|\eta_l| < 2.5$,
LO
NLO
Δ_{FwW} [%]
M_{e^+b} [GeV]

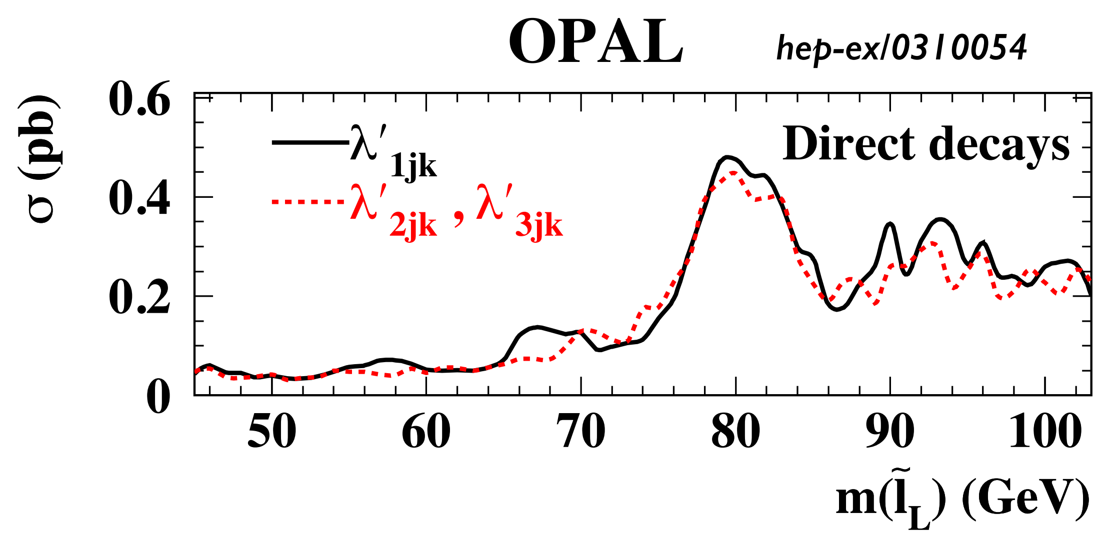
Merged jet resonances

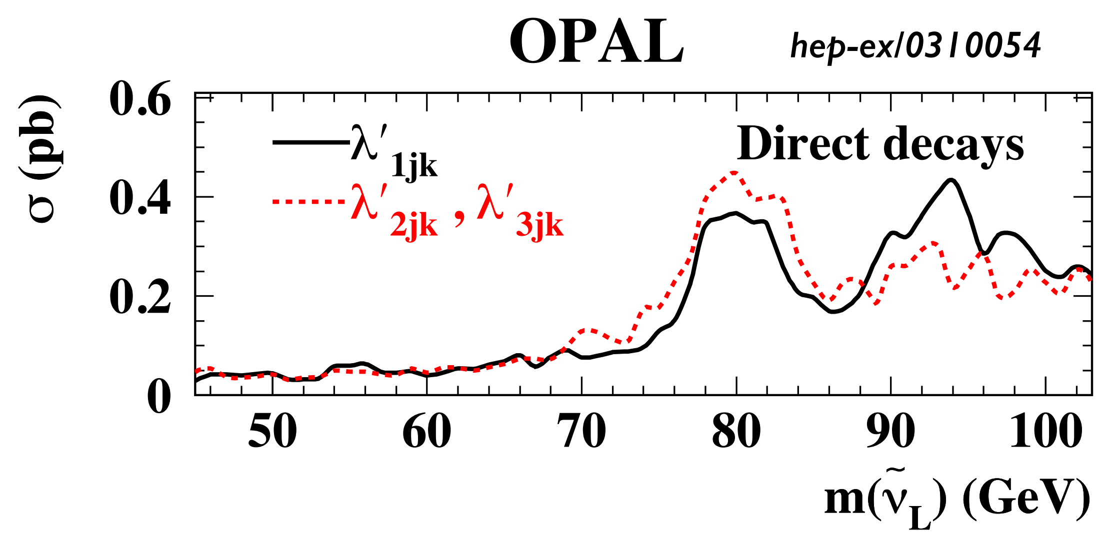


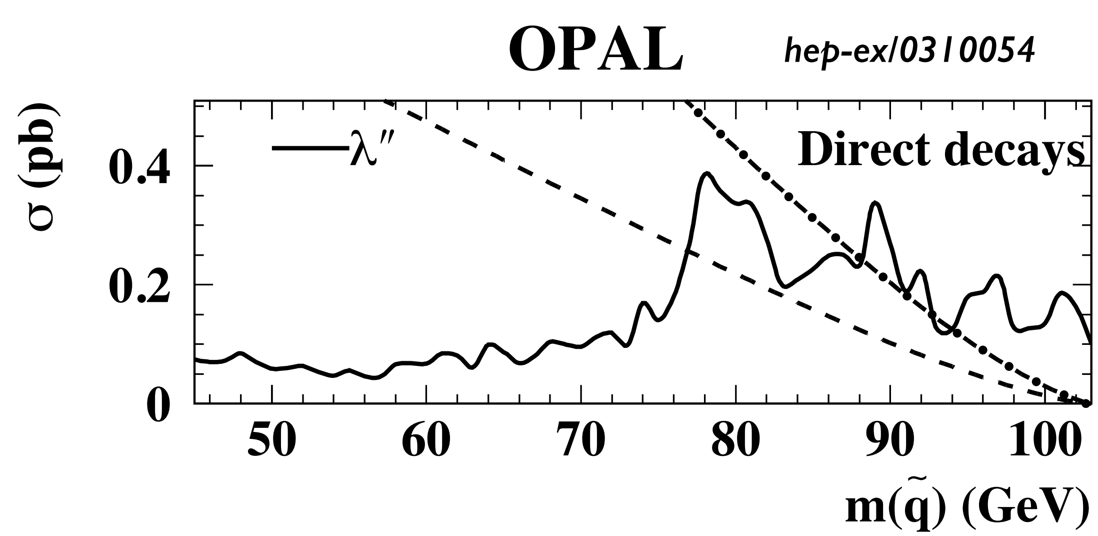


$e^+e^- \to 4j$ limits







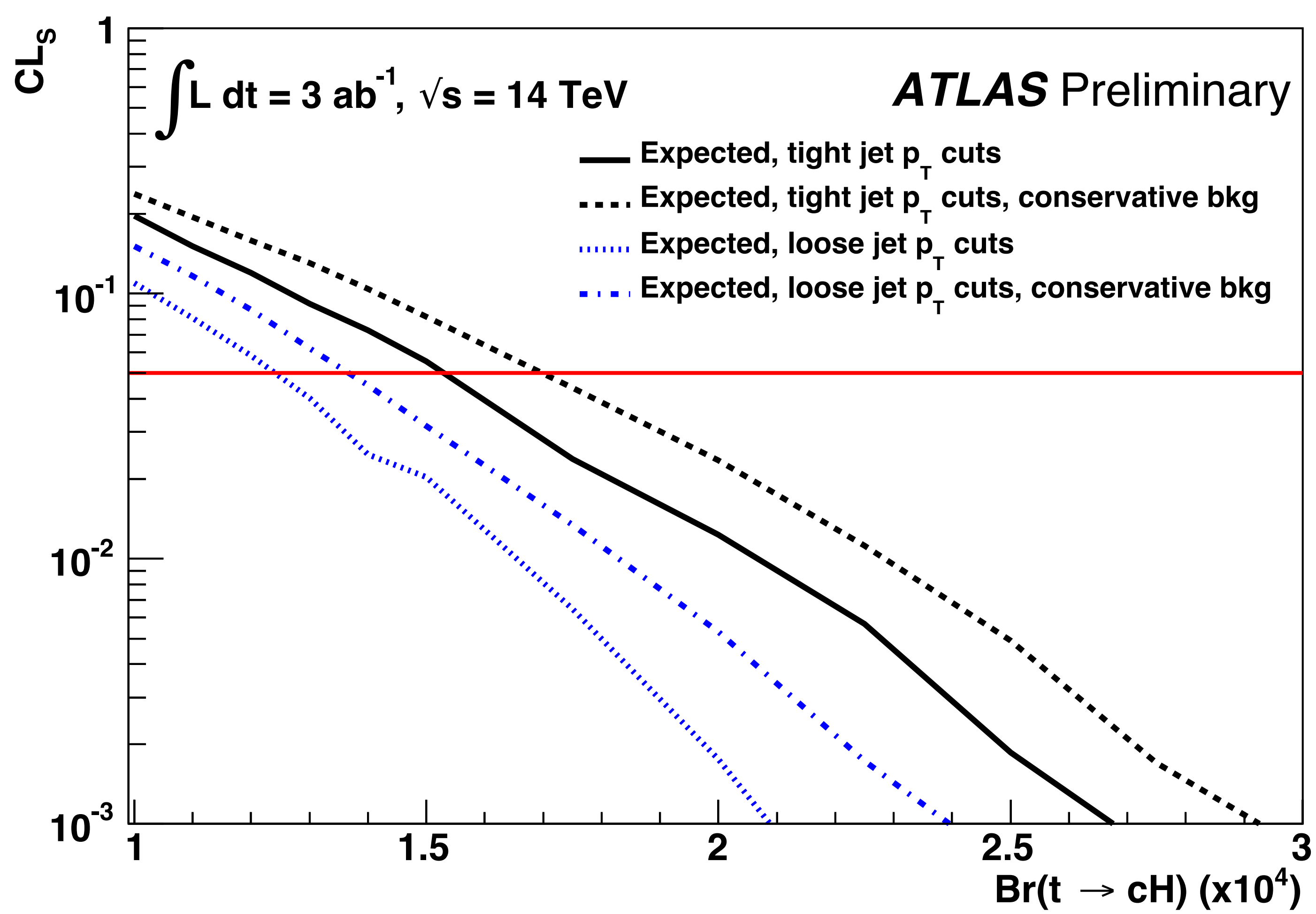


BSM Top FCNC overview

1311.2028, ATL-PHYS-PUB-2013-012, CMS-PAS-FTR-13-016

Process	SM	2HDM(FV)	2HDM(FC)	MSSM	RPV	RS
$t \to Zu$	7×10^{-17}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	–
$t \to Zc$	1×10^{-14}	$\leq 10^{-6}$	$\leq 10^{-10}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-5}$
$t \to gu$	4×10^{-14}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	–
$t \to gc$	5×10^{-12}	$\leq 10^{-4}$	$\leq 10^{-8}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-10}$
$t \to \gamma u$	4×10^{-16}	–	–	$\leq 10^{-8}$	$\leq 10^{-9}$	–
$t \to \gamma c$	5×10^{-14}	$\leq 10^{-7}$	$\leq 10^{-9}$	$\leq 10^{-8}$	$\leq 10^{-9}$	$\leq 10^{-9}$
$t \to hu$	2×10^{-17}	6×10^{-6}	–	$\leq 10^{-5}$	$\leq 10^{-9}$	–
$t \to hc$	3×10^{-15}	2×10^{-3}	$\leq 10^{-5}$	$\leq 10^{-5}$	$\leq 10^{-9}$	$\leq 10^{-4}$

$t \to cH \to \gamma\gamma$



RPV $\tilde{t}\,\chi^+\chi^0$ simplified model